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Invited talk.

Cherenkov light imaging in particle and nuclear physics experiments

Initial performance of Aerogel RICH detector in Belle II experiment

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The Belle II experiment is a new generation B factory experiment at the SuperKEKB electron-positron collider. The main purpose of the experiment is to search for new physics with a huge sample of B meson decays. The proximity-focusing Aerogel Ring-Imaging Cherenkov detector (ARICH) has been designed to identify kaons and pions in the forward end-cap of the Belle II spectrometer. Using aerogel as radiators with a specialized photon sensor called HAPD, the K/π separation is expected to reach more than 4 σ in the momentum range of 0.5 to 4.0 GeV/c.
ARICH was constructed in summer 2017 and was installed in the Belle II spectrometer in the beam line of SuperKEKB collider. The test of ARICH is performed using both cosmic rays and the beam collision during the accelerator commissioning. We observe Cherenkov rings in ARICH associated with charged tracks detected by the tracking system.
Different ARICH parameters including the number of Cherenkov photons per charged track and Cherenkov angle distribution of detected photons are evaluated for both data sets and compared to expected values obtained by simulation. Preliminary results of the cosmic ray data analysis showed good agreement with the expected values and the results for all the data collected during commissioning of the detector will be presented. We also discuss detector parameters that are a part of the data quality monitoring system evaluating the detector performance during data-taking.
Particle identification capability based on likelihood calculation was also studied with the beam data and compared with the simulation for each particle species, especially for kaons and pions to evaluate K/π separation of ARICH. The results of this study will also be reported.

Cherenkov light imaging in particle and nuclear physics experiments

The TOP counter of Belle II: status and first results

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High-efficiency and high-purity particle identification are fundamental requirements for the success of the Belle II experiment, whose main goal is to explore the new-physics scenarios in the CP-violating decays of the B mesons. To achieve the required PID performances, the Time-of-propagation counter (TOP) has been installed in the central barrel region. This unique device consists in 16 bars of fused silica that act simultaneously as radiator and as light guide for the Cerenkov light. Unlike in the DIRC detectors, the PID information is mostly extracted measuring the time of propagation of the Cherenkov light in the radiator rather than its purely geometrical patterns.
We will present here a general overview of the status of the TOP counter, including the estimation of the time resolution, the calibration strategies and performances, and the first result obtained in the commissioning phase, both using cosmic rays and e+e- collision events collected during the "Phase II" pilot run of the Belle II experiment. These are the first measurements of the particle identification performances of a time-of-propagation detector in a full HEP experimental setup.

Cherenkov light imaging in particle and nuclear physics experiments

The LHCb RICH detectors: operations and performance

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The LHCb experiment has collected an unprecedented data sample to investigate beauty and charm hadrons decays. One of its key detector components is the RICH system providing excellent particle identification (PID) over a wide momentum range (2-100 GeV). Last year for the first time the RICH detectors have been operated in the automatic LHCb online alignment framework that, together with the well established calibration system, provided an excellent performance. The operations and performance of the RICH system during Run II are presented together with the activities performed during the winter shutdown to prepare for the last running period of the current RICH detectors before the LHCb upgrade.

Cherenkov light imaging in particle and nuclear physics experiments

The Hybrid MPGD-based photon detectors of COMPASS RICH-1

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COMPASS RICH-1 has been upgraded in 2016 with Hybrid MPGD-based photon detectors, covering a total active area of 1.4 square meters. The detector architecture consists of two layers of THGEMs, the first of which also acts as a reflective photocathode and a bulk Micromegas on a pad-segmented anode; the signals are read-out via capacitive coupling by analog F-E based on the APV-25 chip. The detectors have been commissioned in 2016 and during the 2017 COMPASS physics run they provided stable and efficient operation.
The main aspects of the COMPASS RICH-1 Photon Detectors upgrade are presented together with the problems encountered during the commissioning phase and the adopted solutions. The response

of the hybrid detectors is illustrated and their performance is presented. The combination and comparison of the three photon detector technologies (MAPMTs, MWPCs and MPGDs) in COMPASS RICH-1 are discussed. The perspectives for further developments and applications of these novel detectors will be addressed.
The talk is on behalf of the COMPASS RICH group.

Cherenkov light imaging in particle and nuclear physics experiments

The Large-area Hybrid-optics CLAS12 RICH: Assembling, Commissioning and First Data-taking

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The CLAS12 experiment at the upgraded 12 GeV continuous electron beam accelerator facility of Jefferson Lab will offer unique possibilities to study the 3D nucleon structure in the yet poorly explored valence region by deep-inelastic scattering, and to perform precision measurements in hadron spectroscopy.
A large area Ring-Imaging Cherenkov detector has been designed to provide clean hadron identification capability in the momentum range from 3 to 8 GeV/c. The detector will exploit a novel hybrid-optics configuration, in which the Cherenkov photons will either be detected directly for forward particles or after two mirror reflections for large-angle tracks. The detector comprises a three squared meters layer of aerogel as photon radiator, made of large-area tiles of cutting edge transmittance at n=1.05, a system of glass-skin planar and composite spherical mirrors of unprecedent lightness and, for the first time, an array of 391 Hamamatsu H8500 and H12700 Multi-Anode Photomultiplier Tubes as photodetectors. The readout of the 25000 electronic channels is provided by a compact system made by an ASIC front-end card based on the MAROC3 chip configured and controlled by an FPGA card.
The first RICH module was assembled during the second half of 2017 and successfully installed at the beginning of January 2018, in time for the start of the first CLAS12 experiments with an unpolarized liquid Hydrogen targets. A second RICH sector is in construction for the beginning of the operation of CLAS12 with transversely polarized target.
In the presentation, the quality assurance tests, the assembling operations and the alignment procedures of the components will be reviewed. The RICH commissioning performed with cosmic muons and with the CEBAF electron beam during the CLAS engineering run will be discussed. The detector performance during the first months of data-taking will be reported.

Cherenkov light imaging in particle and nuclear physics experiments

The RICH detector of the NA62 experiment at CERN

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NA62 is the last generation kaon experiment at the CERN SPS aiming to study the ultra-rare $K^+ \to \pi^+\nu\overline{\nu}$ decay. According to the Standard Model (SM) prediction, the decay branching ratio (BR) is of O(10^{-10}) with very small uncertainty. The main goal of the NA62 experiment is the measurement of this BR with 10% accuracy. This is achieved by collecting about 100 $K^+ \to \pi^+\nu\overline{\nu}$ events assuming a 10% signal acceptance.
The challenging aspect of NA62 is the suppression of background decay channels with BR up to 10 orders of magnitude higher than the signal and with similar experimental signature, such as $K^+ \to \mu^+\nu$. To this purpose, the NA62 experimental strategy requires, among other conditions, good particle identification (PID) capability and rejection power of the kinematic selection.
A key element of PID in NA62 is the Ring-Imaging Cherenkov (RICH) detector, exploiting neon gas at atmospheric pressure as radiator medium. According to the NA62 requirements, the RICH identifies μ^+ and π^+ in the momentum range between 15 and 35 GeV/c with a muon rejection factor of 10^{-2}, leaving a muon contamination of about 1% in the pion sample. It also measures the arrival time of charged particles with a precision better than 100 ps, needed to correctly associate the π^+ with the parent K^+ at a kaon decay rate of about 5 MHz, and is one of the main components of the NA62 trigger system.
NA62 has recently presented the result of the 2016 data analysis: one clear $K^+ \to \pi^+\nu\overline{\nu}$ event has been detected, compatible with the SM within the errors. The 2017 data analysis is in progress and a long data taking period is in program in 2018, which will greatly improve the present result. The RICH detector has been successfully operated during the 2016 and 2017 data taking periods and it is ready to be exploited in the 2018 run. The main design aspects and operational characteristics of the detector will be described in detail and the general performance, measured with the data collected in the last NA62 running periods, will be summarized.

Cherenkov detectors in astroparticle physics

Cherenkov light imaging in Astroparticle Physics

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Invited talk.

Cherenkov detectors in astroparticle physics

The AMS-02 RICH detector: status and physics results

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The Alpha Magnetic Spectrometer (AMS-02) is a high-energy particle physics magnetic spectrometer installed on the International Space Station since May 2011, and operating continuously since then. Thanks to the large acceptance, long exposure time and particle identification capabilities, AMS-02 measures cosmic rays fluxes in the kinetic energy range between a fraction of GeV/n to multi-TeV/n with unprecedented precision.
The AMS-02 Ring Imaging Cherenkov counter (RICH) detector provides a precise measurement of the particle velocity and charge. The detector has shown stable and nominal response during the past 7 years of continuous data taking without showing significant degradation. With the additional use of the Silicon Tracker momentum measurement, the RICH is able to measure the isotopic composition of the light elements (up to charge Z=5) in the kinetic energy range from few GeV/n to about 10 GeV/n.
In particular this contribution will focus on the separation of cosmic rays species with |Z|=1. For positive rigidities (Z=+1), the measurement of individual p and D fluxes and their ratio are important for the understanding of CRs propagation in our galaxy, being the D an almost entirely secondary product of the interaction of cosmic rays with the interstellar matter, while p is mainly produced by

astrophysical sources. The negative rigidity sample (Z=-1) is promising for indirect search of Dark Matter, looking at the p-bar and at d-bar components. These species are rare secondary products of CRs propagation and therefore an excess due to new physics could be more significantly seen on top of their faint expected flux. AntiDeuterons in particular have never been observed so far in CRs. The current status of this work will be presented.

Cherenkov detectors in astroparticle physics

Status and Prospects for the IceCube Neutrino Observatory

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The IceCube Neutrino Observatory is located at the geographic South Pole and consists of over 5000 optical sensors embedded in the Antarctic ice along with 81 cosmic ray detector and veto stations on the surface. IceCube was designed to detect high energy neutrinos from extreme astrophysical environments which are potential cosmic ray acceleration sites, such as active galactic nuclei, gamma ray bursts and supernova remnants. The discovery of astrophysical neutrinos by IceCube in 2013 heralded the beginning of neutrino astronomy, and we continue to collect data and explore the properties and potential sources of these neutrinos. An expanded successor called IceCube-Gen2 is in development, with updated optical sensors and calibration devices, and an expanded surface veto. The IceCube-Gen2 detector will search for the sources of cosmic neutrinos and will also include an infill component which will investigate fundamental neutrino physics using atmospheric neutrinos. I will discuss the latest results from IceCube, and the status of IceCube-Gen2.

Cherenkov detectors in astroparticle physics

Neutrino astronomy and oscillation research in the Mediterranean: ANTARES and KM3NeT

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ANTARES, the largest underwater neutrino telescope in the Northern Hemisphere, has been continuously operating since 2007 in the Mediterranean Sea. The transparency of the water allows for a very good angular resolution in the reconstruction of signatures of interactions from neutrinos of all flavors. This results in unprecedented sensitivity for neutrino source searches in the Southern Sky at TeV energies, so that valuable constraints can be set on the origin of the cosmic neutrino flux discovered by the IceCube detector.
Building on the successful experience of ANTARES the next generation KM3NeT neutrino telescope is now under construction in the Mediterranean Sea to significantly boost the sensitivity. Two detectors with the same technology but different granularity are under construction at two sites and will focus on high energy cosmic neutrinos (ARCA with Gton instrumented volume, offshore Capo Passero, Italy) and on atmospheric neutrinos at low energies down to a GeV to address atmospheric neutrino oscillations (ORCA with Mtons instrumented volume, offshore Toulon, France). The basic KM3NeT detection element, the Digital Optical Module (DOM), houses 31 three-inch PMTs inside a 17 inch glass sphere. This multi-PMT concept yields significant allows for an accurate measurement of the light intensity (photon counting) and offers directional information with an almost isotropic field of view, at a reduced cost.
The presentation will provide an overview on the newest results from Antares and an outlook towards the construction plan and exciting science potential of KM3NeT.

Cherenkov detectors in astroparticle physics

Extending the Observation Limits of Imaging Air Cherenkov Telescopes Toward Horizon

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Abstract. Here we want to report on significantly increased observation limits of imaging air Cherenkov telescopes. Typically these telescopes observe sources until the zenith angle 60°. There exist some observational results when sources were observed till the zenith angle 70°, but these suffer from systematic errors. One of the main problems with large zenith angle observation is related to the transparency of the atmosphere. At larger zenith angle observations the atmosphere is becoming significantly "thicker". Thus, compared to small zenith angles, light that passes through the "thicker" atmosphere is stronger attenuated due to the scattering and absorption processes. Because of absence of reliable calibration of the atmospheric transmission, the Cherenkov light spectrum from air showers, measured at large zenith angles observations, suffers from uncertainties. This situation is becoming progressively more severe with increase of the observation zenith angle. We plan to report on observations of sources performed with the MAGIC imaging air Cherenkov telescope, extended till the zenith angle of 80°. This is a significant improvement compared to earlier observations. It provides longer measuring time for a given source and due to more than one order of magnitude increased collection area for air showers, improved statistics at the highest energies. The latter is a key issue for studying the highest energy gamma-ray emission from sources, especially from the so-called galactic PeVatron candidates. Such observations of MAGIC are supported by two methods for calibrating the transmission of the atmospheric. We plan to report on both methods.

Cherenkov detectors in astroparticle physics

Cherenkov water detector NEVOD and its further development

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NEVOD - the first in the world Cherenkov water detector (CWD) at the Earth's surface equipped with a spatial lattice of quasi-spherical measuring modules for the investigations of all basic components of cosmic rays including neutrinos is considered. A large dynamic diapason and close location of quasispherical modules allows use this detector as a Cherenkov water calorimeter for cascade shower investigations and measurements of the energy deposit of muon bundles. Its further development is connected with the widening of the CWD both existing modules and new quasispherical modules consisting of 14 PMTs. Additionally, it is planned to place new optical modules of IceCube, KM3NET and GVD (Baikal) in CWD NEVOD for their common calibration. To sharply increase the accuracy of measurements of energy of various events (cascade showers, muon bundles, EAS cores. etc.) it is proposed to cover inner walls of the water reservoir with optical modules which are now used in the ANTARES experiment.

Cherenkov detectors in astroparticle physics

Cherenkov EAS arrays in Tunka Astophysical Center: from Tunka-133 to TAIGA gamma- and cosmic-ray Hybrid Installation

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One of the most informative methods of cosmic ray studies is the detection of Cherenkov light from extensive air showers (EAS). The primary energy reconstruction is possible by using the Earth's atmosphere as a huge calorimeter. The EAS Cherenkov light array Tunka-133, with ˜ 3 km2 geometrical area, is taking data since 2009. Tunka-133 is located in Tunka Astophysical Center at -˜50 km to the West from the Lake Baikal. This array allows us to perform a detailed study of the energy spectrum and the mass composition in the energy range from 5 • 1015 eV to 1018 eV.
Most of the ongoing efforts are focused on the construction of the first stage of the TAIGA (Tunka Advanced Instrument for cosmic ray physics and Gamma Astronomy) installation. The latter is designed for the study of gamma-rays and charged cosmic- rays in the energy range of 1013 eV - 1018 eV. The TAIGA prototype will consist of ˜100 wide angle timing Cherenkov stations (TAIGA-HiSCORE) and three IACTs deployed over an area of ˜1 km2. The installation of the array is planned to be finished in 2019 while the data-taking can start already during the commissioning phase. The joint reconstruction of energy, direction, and core position of the imaging and non-imaging detectors shall allow us to increase the distance between the IACTs up to 800-1000 m, therefore providing a low-cost, highly sensitive installation.
The relatively low investments together with the high sensitivity for energies ≥ 30-50 TeV make this pioneering technique very attractive for exploring the galactic PeVatrons and cosmic rays.
In addition to the Cherenkov light detectors we intend to deploy a surface and underground muon detectors over an area of 1 km2 with a total area of about 1000 m2.
The results of the first season of coincident operation of the first ˜4m diameter IACT with an aperture of ˜10° with 40 stations of TAIGA-HiSCORE will be presented.

Cherenkov detectors in astroparticle physics

Status of the Large Size Telescopes and Medium Size Telescopes for the Cherenkov Telescope Array Observatory

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The Cherenkov Telescope Array (CTA) is the next generation of ground-based observatory in the Very High Energy (VHE) gamma-ray domain. The observatory, operating in an open, all-sky mode, will consist of two sites, one in the Northern Hemisphere, at Observatorio Roque de los Muchachos (La Palma, Spain), and another in the Southern Hemisphere. CTA will implement Imaging Atmospheric Cherenkov Telescopes (IACTs) of large, medium and small size, mapping the VHE sky with an unprecedented sensitivity in an extended energy range. In its baseline design, 4 Large Size Telescopes (LSTs) will operate in coincidence in each site, dominating the CTA sensitivity in the 20 GeV - 150 GeV gamma-ray band, while the CTA core energy range, from 150 GeV to 5000 GeV, will be best covered by Medium Size Telescopes (MSTs), 25 in CTA-South and 15 in CTA-North.
Each LST will be based on a 23 m diameter segmented, light-weight reflector, incorporating an active mirror control system, and a fast Photo-Multiplier Tube (PMT) camera. These features will allow CTA to observe extragalactic sources up to redshifts larger than two and to improve the sensitivity in observing gamma-ray transients. A prototype LST is currently under construction at the CTA-North site. A commissioning and validation phase will follow, which will mark the beginning for the construction of the rest of the LSTs of CTA-North and CTA-South.
The MSTs, with an aperture of 10-12 m, are being explored in two different design options. One is based on the traditional IACT Davies-Cotton optical system and PMT-based cameras (FlashCAM and NectarCAM), which is perfected after the experience from current HESS, MAGIC and VERITAS observatories. An alternative approach, based on the novel Schwarzschild-Couder optical system and Silicon-Photo-Multiplier-based camera, is also being developed to improve angular resolution.
In this contribution, we will review the status of the prototypes of the LST and both MST for CTA.

Cherenkov detectors in astroparticle physics

Very High Energy Astrophysics with the SHALON Cherenkov Telescopes

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Cherenkov light emission is widely used in numerous astroparticle physics experiments where the success was reached with the detection technique using the imaging atmospheric Cherenkov telescopes. The base of such experiments is that the Cherenkov light emitted from the particles of extensive air shower created by the primary gamma-ray is collected by a mirror reflector and then detected by a pixelized PMT camera.
SHALON are the imaging atmospheric Cherenkov telescopes creating in the P.N. Lebedev Physical Institute for gamma-ray astronomy at the energies of 800 GeV to 100 TeV. It is located in the Tien-Shan mountains at the altitude of 3340 m a.s.l. The idea of enhancement of angular resolution and sensitivity to the gamma-rays was realized in SHALON telescopes by the number of technical solutions presented here, including the construction the widest field of view in the world of $> 8^\circ$. It allows to enlarge the experiment effective area $> 10^5 m^2$, then to detect the weak gamma-ray fluxes $\leq 10^{-13} cm^{-2} s^{-1}$ due to the high 99.93% rejection of background of cosmic rays and to reconstruct the source structure on the scales $\sim 20''$ as a result of the better determination of the gamma-ray arrival direction. The main technical characteristics of SHALON telescopes are starting to reproduce in the astroparticle projects to reach the high sensitivity and enlarge the energy rage up to 100 TeV. SHALON experiment has been operating since 1992 and covers the wide astroparticle physics topics including an acceleration and origin of cosmic rays in supernova remnants, the physics of relativistic flaring objects like a black holes and active galactic nuclei as well as the long-term studies of the different type objects. SHALON has discovered of more than 30% of TeV energy gamma-ray sources in Northern Hemisphere and continues to produce the results on very high energy astrophysics.

Cherenkov detectors in astroparticle physics

Status and perspectives of the Small Size Telescopes for the Cherenkov Telescope Array southern Observatory

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The Cherenkov Telescope Array project is the next generation of ground-based very high energy gamma-ray instrument. It will serve as an open observatory for a wide astrophysics community and will provide a deep insight into the non-thermal high-energy universe. The array for the southern observatory will consist of about 4 large, 25 medium and 70 small size telescopes.
The small size telescopes (SSTs) will provide the sensitivity to the highest energies between a few TeV and 300 TeV. Three concepts of telescopes have been proposed to be part of the SST sub-array. If they differ by their design and some of the technological choices, they all propose to use silicon photo-multiplier sensors for their camera. Two of them will use a Schwarzschild-Couder optics with two mirrors dishes, ASTRI and GCT, while one will use a single dish Davies-Cotton optics, SST-1M. The contribution will focus on the design and performance of the existing prototypes inferred from laboratory measurements and observation campaigns. An insight on the expected physics performance based on Monte Carlo simulation will be presented too.

Cherenkov detectors in astroparticle physics

Cherenkov detection at the Pierre Auger Observatory

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Pierre Auger Observatory is the largest detector ever built for measuring the air-showers produced by ultra high energy cosmic rays. It combines a surface detector of 1600 water Cherenkov detectors spread over 3000 km2 with 27 telescopes. Currently the Pierre Auger collaboration is deploying an upgrade of the surface detector, AugerPrime. The surface detectors are being equipped with scintillators. We present the performances of the current surface detector and we describe the advantages on distinguishing the muonic from the electromagnetic components of the air-showers using AugerPrime. The performances of a detector for which the optical volume of has been separated in two are briefly described. A recent reconstruction of the properties of the air-showers for which a large fraction of the Cherenkov light has reached the telescopes will be also presented.

Cherenkov detectors in astroparticle physics

Recent results and future prospects of Super-Kamiokande

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Super-Kamiokande (SK) is a water Cherenkov detector located 1,000 m underground in Kamioka Observatory, ICRR, University of Tokyo in Japan. It consists from a cylindrical stainless steel tank, 50,000 ton of purified water, and 11,000 of 20-inch PMTs, as shown in Fig. 1. The fiducial volume of the SK detector is 22.5 kton. The experiment was started in April 1996, and currently phase IV (SK-IV) is running (Fig. 2). SK has been the world largest water Cherenkov detector with purified water in underground since 1996. SK has a variety of measurement or physics targets, namely, solar neutrinos, atmospheric neutrinos, supernova neutrinos, neutrinos produced by the accelerator in J-PARC (as T2K experiment), and search for nucleon decay.
In near future, we are going to move to the next phase, that is SK-Gd. In the SK-Gd phase, we are planning to add 0.1% of gadolinium to the current SK detector in order to enhance neutron tagging efficiency, and then try to achieve the first observation of supernova relic neutrinos (SRN) (or diffuse supernova neutrino background (DSNB)). The initial work in this upgrade project will be started in June 2018.
In this presentation, a brief summary of the SK experiment, recent solar neutrino results, and recent atmospheric neutrino results will be reported as the current status (Fig. 3). As a future plan, the purpose of SK-Gd and status of the upgrade work will be reported.

Photon detection for Cherenkov counters

Status and perspective of gaseous photon detectors

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Gaseous photomultipliers are strongly benefiting from the tremendous developments that micropatterned gaseous detectors have gone through in the last years. These developments triggered different possibilities of combining photocatodes and electron multipliers, leading to gaseous photomultipliers with impressive performances even when large detection areas are considered. Advances and future prospects on the technological issues and developed strategies in order to achieve high performance in many aspects, such as gain, ion- and photon-feedback, time resolution, sealed operation, and the important challenge of efficiently detect visible light, are presented. These new capabilities also lead to new possibilities of applications to fields ranging from particle and nuclear physics and astrophysics to societal challenges, which are also addressed.

Poster Session - Board: 14

Analog-to-digital converter and DAQ system intellectual controller for PMT used very high energy astrophysics experiments

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Modern tasks of very high energy gamma-ray astronomy and astrophysics require the effective and secure record of PMT signals from EAS Cherenkov lighting in the wide energy range from hundred GeV up to some hundred TeV, thus the more than 1000 dynamic range and low noise electronics are required for these purposes. Here we present the modern multi-channel analog-to-digital converter BPA-8 developed on the base of a low power, high speed, 16-bit analog device with high amplitude resolution. The developed and created converters BPA-8 together with data acquisition system managed with intellectual crate-controller K-167 which controls the equipment, using all control and measuring modules allow to record PMT signals with high accuracy and efficiency for the further precise analysis and reliable extraction of weak gamma-ray emission from astrophysical objects.

Poster Session - Board: 11

Charged particle identification with the liquid Xenon calorimeter of the CMD-3 detector

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The talk is devoted to the currently being developed procedure of charged particle identification with the multilayer liquid Xenon calorimeter of the CMD-3 detector. The procedure uses the boosted decision trees classification method with specific energy losses of charged particles as input variables. The efficiency of the procedure is illustrated by an example of the selection of the events of e+e−⟶K+K− process in the center-of-mass energy range from 1.6 to 2.0 GeV. Special attention is paid to the detector responce simulation and calibration issues.

Poster Session - Board: 5

Development of medium and small size photomultipliers for Cherenkov and scintillation detectors in astroparticle physics experiments

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A number of small-size photomultipliers have been developed by collaboration of INR RAS and MELZ-FEU for large-scale astroparticle physics experiments in particular for neutrino, gamma-astronomy and cosmic ray physics experiments. The developed photomultipliers are of different sizes and optimized for use in Cherenkov and scintillation detectors. The photomultipliers are of different sizes and shapes. The largest photomultipliers have 3 inches photocathodes – hemispherical and flat. We present also results of extensive studies of parameters of developed photomultipliers.

Poster Session - Board: 17

Front end electronics of the Belle II Aerogel Ring Imaging detector

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In the forward end-cap of the Belle II spectrometer, the proximity focusing RICH with aerogel radiator will be used for charged particle identification. The detector, consisting of 4˜cm aerogel radiator, 16˜cm expansion volume and a photon detector plane with 420 Hybrid Avalanche Photo Detectors is mounted in a very confined space between central drift chamber and electromagnetic calorimeter, leaving only 5˜cm space for the readout electronics. A low power front end read-out board is mounted at the back side of each of the photosensor. The digitized signals from up to six front-end boards are collected by merger boards mounted approximately 4˜cm above the front end boards. In between the 30˜m long service, cables are installed, connecting the sensors end boards with power supplies and common readout electronics outside of spectrometer.
Prior to installation, the sensor components have been tested on the bench. The detector was installed in 2016 and 2017 by carefully routing the cables through the available space and finally mounted in the Belle II spectrometer. During the commissioning phase, parts of the detector were

tested and connected to the power supplies.
In the presentation, the electronics of the Belle II aerogel RICH will be reviewed. We will focus on the first experience, low voltage power supply control system, calibration and the temperature control of the detector.

Poster Session - Board: 22

Pinhole camera for study of atmospheric UV flashes and background at high altitud

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The near UV background level at the atmosphere has several sources. In order to evaluate the possibility to detect ultra high energy cosmic ray fluorescence signals, it is necessary to measure and monitor this UV background level. Study of space-time development of UV background level and events presented is suggested by Garipov-Khrenov in 1994-1995. By that, we construct a new fast imaging detector, a pinhole camera with the multi anode photomultiplier tuve MaPMT. In this work we present the design and construction of the pinhole camera prototype to be installed in a mountain. Also present the calibration and characterization of the MaPMT procedures used. The electronic design includes an automatic gain control to protect the MaPMT of very bright events. Finally, we present some results of events recorded in the Sierra Negra Volcano near Puebla, Mexico, located at 4300 meters above sea level.

Poster Session - Board: 2

Cascade showers in the Cherenkov light in water

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The basis of Experimental complex NEVOD located in MEPhI is the Cherenkov water detector NEVOD with volume of 2000 m^3 equipped with a dense spatial lattice of quasi-spherical modules (QSMs, 91 in total). Each module consists of six FEU-200 PMTs with flat photocathodes directed along the axes of the orthogonal coordinate system. Cascade showers with energies of 100 - 500 GeV were generated by near-horizontal muons of cosmic rays. Tracks of muons were reconstructed with a high angular (better than 1 degree) and spatial (about 1 cm) accuracy using the coordinate-tracking detector DECOR that is deployed around NEVOD.
The dependence of the intensity of Cherenkov radiation on the depth of the cascade shower development at various distances from its axis has been measured with the step of detalization about 0.5 m. Experimental results are compared with calculations of distribution of Cherenkov radiation for different models of cascade electron scattering.
On the basis of the obtained dependence, a technique of reconstruction of cascade parameters (energy, generation point, and axis direction) has been developed and tested by means of comparison with Geant4 simulation. Angular and energy accuracy of the technique are presented.

Poster Session - Board: 9

Cherenkov Detectors Fast Simulations Using Neural Networks

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New runs of the Large Hadron Collider and next generation of colliding experiments with increased luminosity will require an unprecedented amount of simulated events to be produced. This would bring an extreme challenge to the computing resources. Thus new approaches to events generation and simulation of detector responses are needed. Cherenkov detectors, being relatively slow to simulate, are well suited for applying recent approaches to fast simulations using neural networks. We propose a way to simulate cherenkov detector response using a generative neural network to bypass low level details. This network is trained to reproduce high level features of the simulated detector events based on input observables of incident particle. This allows the dramatic increase of simulation speed. We demonstrate that this approach provides simulation precision which is consistent with the baseline and discuss possible implication of these results.

Poster Session - Board: 19

Fully digital readout and trigger for fast Cherenkov counters

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Fully integrated digital readout, pulse analysis, extraction of time and charge, signal alignment, multiplicity analysis and trigger generation electronics have been developed for the new Cherenkov-based Fast Interaction Trigger (FIT) for the upgrade of the ALICE detector at LHC,CERN. FIT will also serve as the main luminometer, collision time, multiplicity, centrality, and reaction plane detector for the ALICE experiment during Runs 3 and 4. The main sensor will be Planacon XP85012/FIT-Q – a modified MCP-PMT with a pore size 25 um. Among the many challenges of this project are a high dynamic range (1:500), requirement to operate with the sustained bunch crossing of 25 ns, provide time resolution below 50 ps, complete the entire signal processing and trigger generation within 205 ns, etc. To ensure proper operation over the required running time, a very low output amplitude of 10 mV/MIP at the detector output will be used, requiring special cabling and low-noise fast electronics. Event time will be evaluated by a CFD and then digitized with an accuracy better than 50 ps over the entire dynamic range. The input charge will be integrated and measured by an ADC. The digitized event data will be sent to the Common Readout Unit (CRU) by 4.8 Gbps optical links. Trigger data processing will be done in the two-level FPGA processor, based on the Kintex-7 Xilinx FPGAs with a 320 MHz main processing clock and a 600 MHz timing input clock. In total, FIT electronics will be processing 256 independent channels in parallel. The project has already completed and passed the Engineering Design Review. The prototype testing has been completed and the 205 ns total processing time was confirmed. The first prototype of the sensor and the front-end electronics have been installed inside of the ALICE magnet and were used to collect data from LHC collisions since 2016.

Poster Session - Board: 13

Optimization of electromagnetic and hadronic extensive air showers identification using muon detectors of TAIGA experiment

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The Taiga experiment at Tunka valley near Baikal is heading with new scintillation detector stations named Taiga-Muon, for advanced study of astroparticle. The realistic model of experiment was created by using GEANT4 software package. The Monte Carlo simulation of experiment is done with Corsika and Geant4, with the help additional libraries FLUKA, COAST. The extensive air showers of primary gamma-quanta and protons with energies 100, 300, 1000, 3000 TeV and having theta angle 0, 30, 45 degrees are created with Corsika. Coast library is used to select the particle within the area of interest. The programming language C++ is mainly used to simulate the experiment, final data analysis is done using ROOT package. The trigger efficiency is calculated with simulated results. The trigger efficiency for both Tunka-Grande and Taiga-Muon were calculated. The Geant4 data is analyzed by changing the depth of soil to optimize its thickness. The suppression factor of electromagnetic showers from hadronic showers is studied. This study leads us to find the optimum depth of soil in the case of Taiga-Muon detector stations. Data on the detection efficiency for primary gamma-quanta and proton events are presented as well as suppression factor.

Poster Session - Board: 26

The production of the large scale aerogel radiators for use in the Ring-imaging Cherenkov detectors

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Aerogel for different types of Cherenkov detectors is produced by a collaboration of Budker Institute of Nuclear Physics and Boreskov Institute of Catalysis during more than two decades. Until recently, only the production of two sizes was possible in large numbers: 50x50 and 115x115 mm^2.
This work is devoted to the development of the production technology of large scale aerogel radiators for use in the Ring-imaging Cherenkov detectors.
These detectors requires additional parameters to be controlled for each aerogel tile during production. Procedures of measurement of the aerogel tiles refractive index, the light scattering length, the upper surface flatness and the tile dimensions are described. The new precise cutting machine was developed and produced for aerogel tile processing. More than one hundred aerogel tiles with thicknesses of 20 and 30 mm and size 200x200 mm^2 were produced for the CLAS12 RICH detector. The actual data on the measurement results of controlled parameters are presented.

Poster Session - Board: 28

Preparing the ALICE-HMPID for the High-Luminosity LHC period 2021-2023

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Approaching the end of the LHC Run 2 period (2015-2018), the ALICE High Momentum Particle IDentification (HMPID) detector, based on RICH counters, is on hold for operating at the High Luminosity LHC Run 3 period (HL-LHC 20120-2023) when the collider will provide up to 50 kHz of Pb-Pb collision rate at $\sqrt{s_{NN}}$ = 5.5 TeV.
The upgraded ALICE detector will be able to read out all interactions and it will exploit the full scientific potential of the HL-LHC to study the properties of the quark-gluon plasma (QGP), using proton-proton, nucleus-nucleus and proton-nucleus collisions at high energies.
The stable particle identification performance of the HMPID, the proved linearity of the MWPC's during the high luminosity test runs in ALICE using pp collisions, the still not critical charge dose so far integrated on the CsI photocathodes and the ongoing upgrading activities, enable the use of the detector in the ALICE scientific program defined for the HL-LHC period.
In this paper we present the HMPID status and the activities under way to integrate the detector in the new ALICE computing and trigger environments.

Poster Session - Board: 24

Silica aerogel radiator for the Belle II ARICH system

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The Aerogel Ring-Imaging Cherenkov detector (ARICH) was developed to provide a particle identification in the forward endcap of Belle II detector at a SuperKEKB electron–positron collider at the High Energy Accelerator Research Organization (KEK), Japan. It is used to identify charged π and K mesons at momenta between 0.5 and 4.0 GeV/c. The ARICH system is a proximity-focusing RICH counter with an expansion length of 20 cm that uses silica aerogels as radiators and hybrid avalanche photo-detectors as position-sensitive photo-sensors, which was installed in the Belle II spectrometer in late 2017. The design objective is a π/K separation capability exceeding 4σ at a momentum of 4 GeV/c.
To detect more photons without degrading the Cherenkov angle resolution, we introduced a double layer aerogel radiator in a novel focusing configuration. It consists of 2 layers of 2 cm thick aerogel tiles with different refractive indices of 1.045 and 1.055. It is important to reduce the number of the aerogel tiles used to cover the large radiator area (˜3.3 m^2) because particles cannot be clearly identified in these gaps. Therefore, large, crack-free aerogel tiles are preferred. Installing the tiles

onto the module by trimming them with a water-jet cutter and avoiding optical degradation of the aerogels via moisture adsorption during long-term experiments should ultimately result in highly hydrophobic conditions.
Approximately 450 large-area (18 × 18 × 2 cm) aerogel tiles were manufactured, and their optical characteristics (refractive index and transmission length) were confirmed to meet the ARICH design requirements. Each tile was cut into wedge shapes using a water-jet cutter to fit the cylindrical support structure. A total of 248 aerogel tiles were successfully installed in the 124 segmented containers of the support structure. Here, results from the development of the dual-layer aerogel radiator module for the Belle II ARICH system are presented.

Poster Session - Board: 20

Neutron detection capabilities of Water Cherenkov Detectors

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In this work we show the neutron detection capabilities of a water Cherenkov detector (WCD). The experiments presented here were performed using a simple WCD with a single photomultiplier tube (PMT) and a ^{252}Cf neutron source. We compared the use of pure water and water with non contaminant additives as the detection volume, while explore different neutron moderators and shield configurations.
We show that fast neutrons from the ^{252}Cf source, as well as, thermal neutrons coming from neutron moderators and exhibiting different spectral characteristics, can be clearly detected and identified over the flux of atmospheric particles background. Our first estimation for the neutron detection efficiency is at the level of (19)\% for pure water and (44)\% for the water with the additive. In this work we also present the simulation of the response of the WCD to neutrons of different energies, ranging for meV to GeV. To do this, a detailed model of the WCD and of the neutron source spectra have been implemented. The results of our simulations show the detailed mechanism for the detection of neutral massive particles using WCD and support the experimental evidences presented. We compared the expected results from different WCD sizes, different active volumes and shields, and calculated the expected efficiency for each configuration. The sensitivity of WCD obtained in our simulations in the wide neutron energy range explored is a relevant result for cosmic rays and space weather studies.
Being both the active volume and the additive, cheap, non-toxic and easily accessible materials, the results obtained are of interest for the development of large neutron detectors for different applications. Of special importance are those related with space weather phenomena as well as those for the detection of special nuclear materials. We conclude that WCD used as neutron detectors can be a complementary tool for standard neutron monitors based on He^3.

Poster Session - Board: 25

Strategy and Automation of the Quality Assurance Testing of MaPMTs for the LHCb RICH Upgrade

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The LHCb RICH system will undergo major modifications for the LHCb Upgrade during the Long Shutdown 2 of the LHC, and the current photon detectors will be replaced by Multi Anode PMTs. The operating conditions of the upgraded experiment puts forth significant requirements onto the MaPMTs in terms of their performance, durability & reliability. Presented is an overview of the testing facilities designed and used to vet 3100 units of Hamamatsu 1-inch R13742 and 450 units of Hamamatsu 2-inch R13743 during the short 2 year testing period. Furthermore, discussed are the hardware architecture, the different read-out, power and control components, as well as the novel extensible software framework to steer the procedure. Finally, the operation of four automated stations, that have been deployed in two separate labs, is reported, with each station capable of fully characterising 16 MaMPTs per day.

Poster Session - Board: 8

Single-photon imaging tube with sub-100ps time and sub-10 microns position resolutions

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We present the concept of a single-photon imager capable of detecting up to 10^9 photons per second with simultaneous measurement of position ($<10\mu$m resolution) and time (few tens of picosecond resolution) for each individual photon over an active area of 7 cm^2. The detector is based on a "hybrid" concept: a vacuum tube, with a transparent input window on which a suitable photocathode material is deposited, a micro-channel plate (MCP) and a pixelated read-out anode based on the Timepix4 ASIC (65nm CMOS technology) designed in the frame of the Medipix4 collaboration. A MCP with <10 μm pore diameter will be used, operated at low gain (a few 10^4) and treated with atomic layer deposition, allowing a lifetime increase to >10 C/cm^2 accumulated charge. This detector will allow to fully exploit all the excellent intrinsic characteristics of a MCP, using a front-end electronics ASIC encapsulated in the tube with unprecedented performance. Timepix4 is an array of 512x448 pixels, 55μmx55μm each, with an active area of 28mmx25mm. It features 50-70 e- equivalent noise charge, a maximum rate of 1.2 Ghits/s, and allows to time-stamp leading-edge time and measure Time-over-Threshold (ToT) for each individual pixel. A weighted average of the cluster pixels position can be calculated using their ToT information, which allows to reach 5-10 μm position resolution. The ToT information can also be used to correct for the leading-edge time-walk in each pixel, and a timing resolution of few tens of picosecond is expected. The detector will be highly compact: the front-end electronics is encapsulated in the vacuum tube and allows local processing of the detector information, which are sent out of the tube in digital form. The Timepix4 architecture is data driven, producing 64 bits for each pixel hit, corresponding to a maximum data rate of 80 Gbps for 1.2 Ghits/s. A flexible design is conceived, with electro-optical transceivers linking the ASIC to a FPGA-based board, placed far from the detector, for the exchange of configuration and the collection of event data. The FPGA will perform serial decoding and send the data directly to a PC for storage using fast serial data links.
A Ring Imaging Cherenkov detector equipped with such a device could deliver unprecedented information and allow efficient particle identification in high particle multiplicity environments: the high granularity and rate capabilities are crucial in applications with large detector occupancies; few microns resolution allows to reduce the pixel size contribution to the Cherenkov angle resolution to a negligible level; few tens of picosecond timing resolution per single photon will greatly simplify pattern recognition exploiting time-association of the individual photons; small dark count rate at room temperature (~10^2 Hz/cm^2) allows to have negligible detector-related background; MCP and tube geometry guarantees robustness against magnetic fields.

Poster Session - Board: 29

Prospects for future upgrade of the LHCb RICH system

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The LHCb experiment has collected data corresponding to 6.9 fb-1 of integrated luminosity since 2010 and the two RICH detectors have been essential for most of the LHCb physics programme. Preparations are underway to install an upgraded RICH detector so that from 2021 onwards LHCb can collect data corresponding to 5 fb-1 of integrated luminosity per year in order to improve the statistical precision of the physics measurements and to search for very rare B-decays and D-decays. For this, the current Level 0 hardware trigger running at 1 MHz will be removed so that detectors can be read out at at the full collision rate of 40 MHz.
The long term physics goals of LHCb calls for a further upgrade of the detector system for collecting data corresponding 50 fb-1 of integrated luminosity by 2029 and 300 fb-1 afterwards. The first set of such upgrades are envisaged for the run starting in 2026 where the luminosity in LHCb continues to be 2X1033 cm-2s-1 as in the preceeding years. For the run from 2030 onwards the luminosity in LHCb is planned to be 2X1034 cm-2s-1 and this will result in about 35 interactions per LHC bunch crossing. Hence the detectors would require a major upgrade to cope with the high occupancies resulting from the increased particle multiplicity.
Feasibility studies are underway for recording the time of arrival of the RICH hits in addition to their spatial coordinates on the detector plane. The complexity of the event can be reduced by removing hits outside the signal time window and by separating out the hits created by tracks which originated in different primary vertices. Incorporating the RICH hit time information can also improve the performance of the particle identification algorithm.This requires using photon detectors with fast readout. The feasibility of this is expected to be tested using prototypes. Using a photon detector with increased quantum efficiency in the green, like a SiPM(silicon photomultiplier), one can help to improve the chromatic error without reducing the photon yield. Measures to improve the optical configuration of the RICH detectors and to improve their pixel granularity are being investigated. Extending the momentum range to improve the performance in the 1-10 GeV/c range and in the range above 70 GeV/c is also explored. One option for this is to develop novel radiators based on photonic crystals.
An overview of all these developments will be presented. This will include the expected performances and the status of the feasibility studies from simulations and prototype testing.

Poster Session - Board: 1

Measurement of the p-terphenyl decay constant using WLS coated H12700 MAPMTs and the fast FPGA based CBM/HADES readout electronics*

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The HADES and CBM experiment both employ gaseous RICH detectors for high performance electron identification. Currently, the HADES RICH detector is undergoing an upgrade of its photodetector in order to improve the performance for future measurements at SIS 18 and SIS 100 at GSI/ FAIR. Both RICH detectors will share the same H12700 MAPMTs from Hamamatsu and will use the same FPGA based readout electronics. Before mass production the readout electronics has been finally qualified in a proton testbeam at the COSY accelerator in November 2017. The time precision of the combined system of MAPMT and readout electronics has been measured to 260 ps, dominated by the precision of the MAPMTs. In order to enhance the UV sensitivity of the MAPMTs, WLS coatings with p-terphenyl have been investigated in detail, so far focusing on the increase of the quantum efficiency for wavelength > 200 nm. With the new fast readout electronics the decay constant of

p-terphenyl was now determined to 2.4 ns comparing results from MAPMTs with and without WLS coating. These results compare well with time-resolved fluorescence measurements. This poster will present results from the COSY testbeam analysis focusing on the time precision and comparing results with and without WLS coating.

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Poster Session - Board: 12

Lage Area Thin Scinitillating Counters as Charge Particles Identification Detector

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This work presents performance and characteristics for detectors based on developed in NRC «Kurchatov Institute – IHEP» photomultipliers with distant photocathode (FEU-KS) and polystyrene-based scintillators with 0.5 – 1 mm thickness and up to 200 mm width.
Photomultiplier FEU-KS is a tubular glass envelope 40 mm diameter and be-alkaline photocathode 15⊠200 mm2 size, 200 mm length dynodes and one or two anodes (length 200 mm or 100 mm respectively). The length of the detector is limited by light attenuation length in scintillator and is about 300 mm in our case. The typical light output of the detector is about 150 ph.e./MeV that provides efficiency of registration of charged particles more than 98%. The detector of this type provide a high ratio of suppression of the gamma-quants counting rate. For the energy in area 1 MeV this ratio of e/γ counts is not worth than 104. The maximum counting-rate in the detector is not less than 107 pulses/s.
These detectors are using in the experiments «OKA» and «GIPERON» on the IHEP proton synchrotron U-70 in order to significantly reduce the scattering of beam particles. The set measurements for low energies was done also and it shows the efficiency of such type detectors for identification of charged low-energy particles, for example, in the control systems for radiation beta pollution

Poster Session - Board: 4

Measuring the Cherenkov light yield from cosmic ray muon bundles in the water detector

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An experiment on the measurements of the Cherenkov light yield of inclined cosmic ray muon bundles in water is being conducted at the Experimental complex NEVOD (MEPhI). The total number of Cherenkov photons is nearly proportional to the muon energy deposit (including secondary particles and cascades from them) within the detector volume. Since in the muon energy range above a hundred GeV the energy loss is linearly related to the energy of muons (dE/dX ˜ a + bE), the average energy loss of the bundles carries the information about the mean muon energy in such events. The complex includes the Cherenkov water calorimeter NEVOD with a volume of 2000 cub. m and the coordinate-tracking detector DECOR (total area of 70 sq. m). The DECOR data are used to determine the local muon densities in the bundle events and their arrival directions, while the energy deposits are evaluated from the Cherenkov calorimeter response. The detection of the bundles in a wide range of muon multiplicities and zenith angles gives the opportunity to explore the energy range of primary cosmic ray particles from about 10 PeV to 1000 PeV in frames of a single experiment. Experimental results on the dependence of the muon bundle energy deposit on the zenith angle and the local muon density will be presented and compared with expectations based on simulations of the EAS muon component by means of the CORSIKA code and of the response of the Cherenkov calorimeter with the Geant4 toolkit.

Poster Session - Board: 10

Development of alignment algorithm for Belle II Aerogel RICH counter

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The Aerogel Ring Imaging CHerenkov (ARICH) counter provides particle identification of charged kaons and pions at the endcap of the Belle II detector at the SuperKEKB the asymmetric electron-positron collider in KEK. ARICH consists of silica aerogel radiators, an expansion volume and Hybrid Avalanche Photo-Detectors (HAPD) as photodetectors. Cherenkov photons are radiated when a charged particle passes through a silica aerogel. The detected photons are observed as a ring image on HAPDs. The particle identification is performed based on the difference in radius of Cherenkov light ring image that is originated from the difference in mass of charged particles. Since we perform particle identification based on the position information of Cherenkov light, the mis-alignment needs to be measured and taken into account to ensure the efficient performance of the ARICH detector.
ARICH was installed into Belle II detector in September 2017. The commissioning of Belle II with positron and electron beams started in April 2018. We report the study of the alignment of the ARICH detector. The position of the ARICH is aligned using e + e - ⟶ μ + μ − events in the beam collision.
In this study, we develop the alignment method using Monte Carlo simulation of e + e - ⟶ μ + μ - events. In order to quantify how the installed position of ARICH differs from the ideal position, translational or rotational misalignment of the ARICH relative to the entire Belle II detector is added to the Monte Carlo simulation. We compare the distributions of the Cherenkov angle with respect to the azimuthal angle (phi) for different mis-alignment. In the ideal position, Cherenkov angle is constant with regards to phi, but when the ARICH position is shifted from the ideal place, it has cosine-dependence on phi. From the shape of Cherenkov angle dependency on phi, we can calculate the combination of translations and rotations.
In this presentation, we report on development of alignment method. We also report the result of alignment using the real data of beam collision.

Poster Session - Board: 7

Novel NanoDiamond based photocathodes for gaseous detectors

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Gaseous radiators are required for high momenta hadron PID, where limited length of the radiator compatible with a collider experiment is the key challenge. Selecting photon wavelength in far UltraViolet (UV) domain, around 120 nm, is an effective option to increase number of detectable photons: here the Cherenkov photon rate is higher. In this domain, gaseous photodetectors with Cesium Iodide (CsI) photocathode are ideal sensors. Limited material budget, operation ability in magnetic field, cheapest option for large surfaces are additional key features of these sensors. A concrete example is by the MicroPattern Gaseous Detectors (MPGD) based PhotoDetectors (PD) used in 2016 to upgrade COMPASS RICH.
Their characteristics suggest that these photodetectors are particularly suited for the needs of high momentum hadron PID at future EIC. We aim further developments: among them the use of fully innovative photoconverters (PC) based on hydrogenated NanoDiamond(ND) crystals, being presently developed. These novel and robust photocathodes do not require production at high temperatures or in vacuum; therefore they can replace the standard PCs in window-less RICHes. Moreover, they are of interest also in sectors beyond particle physics.
All the developments are performed by detector design supported by propaedeutic studies, prototype realization and tests. These studies are in an initial stage and we report about the first R&D steps.

Poster Session - Board: 15

Characterization of SiPMs for Cherenkov light detection

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Silicon photomultipliers are an interesting alternative sensor of single photons. One of their biggest disadvantages is their huge background and sensitivity to neutron irradiation. The first one can be overcome by using a narrow time window in an analysis or during data acquisition. To maximize their signal to the noise a light collection system can be used which collects the photons from a larger area. By using this technique also the sensitivity to neutrons can be minimized.Several studies have been performed with the use of silicon photomultipliers for detection of multiple photons. In the present contribution, we will present a study of the impact of different neutron radiation fluences to the ability of silicon photomultipliers for detection of single photons.
We will show the I-V characteristics, waveform, pulse height and timing analysis of samples from several different producers irradiated to different neutron fluences.

Poster Session - Board: 18

Front end Electronics of the Compact High Energy Camera (CHEC)

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The Compact High Energy Camera (CHEC) is a focal plane camera designed for two mirror Schwarzschild-Couder design Imaging Air Cherenkov Telescopes (IACT) such as the SST-2M variants on the Cherenkov Telescope Array (CTA). It utilises a 2048 pixel array of silicon photomultipliers (SiPM) arranged in thirty-two 8 x 8 pixel tiles. Each detector tile is instrumented with a front-end electronics (FEE) module designed to provide single photon counting with sub-nanosecond timing, full waveform digitisation and event triggering capabilities.
The FEE module has 64 identical channels each comprising an analogue shaper to optimise the pulse characteristics for the high speed digitiser, and a slow readout of pixel photon count rate to enable star tracking for telescope pointing determination. Conditioned event pulses are fed to the TARGET chipset which consists of a high speed 1GS/s 12-bit digitiser in parallel with a comparator, acting on summed groups of 2 x 2 channels known as superpixels. The latter provides a first level over-threshold trigger which is processed by pattern-matching algorithm to generate a camera trigger for a validate event. Valid event determination results in a full readout of the camera, each of the 32 FEE modules providing 64 digitised waveforms of typically 96 ns duration.
We describe the optimisations undertaken for the latest FEE module designed for CHEC. Analogue and digital functionality have been physically separated to minimise crosstalk by optimisation of PCB layout, use of the latest TARGET chipset in which trigger and digitiser functionality are separated onto two chips, and electromagnetic shielding. Power conditioning for the FEE and SiPM array has been moved to a separate PCB which also houses the housekeeping monitoring.
We present results of FEE performance including noise, crosstalk, linearity, and dynamic range both from initial bench tests and from full camera testing in the laboratory. We discuss the fundamental advantages of full waveform capture provided by the FEE for the CHEC camera and its application to the IACT arrays.

Poster Session - Board: 16

Developments of a mirror supporting frame, mounting scheme and alignment monitoring system of the CBM RICH detector

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The Compressed Baryonic Matter (CBM) experiment at the future FAIR complex will investigate the phase diagram of strongly interacting matter at high baryon density and moderate temperatures in A+A collisions from 2-11 AGeV at the SIS 100 accelerator setup. One of the key detector components foreseen to cope with the CBM physics program is the RICH detector, providing efficient and clean electron identification and pion suppression (up to 8 GeV/c momentum). It will be made of a CO2 gaseous radiator, Multi-Anode Photo-Multipliers for photon detection and about 80 trapezoidal glass mirror tiles, equally distributed in two half-spheres and used as focusing elements with spectral reflectivity down to the UV range. In CBM the RICH detector and a muon detector system (MuCh) will be exchanged on a (bi-)yearly basis. This requires to carefully design a stable mirror system which also allows (bi-)yearly crane operations.
To guarantee a rigid and stable mirror system of the RICH detector even if being craned in and out of the measuring position, a mirror supporting frame reinforced with channel bars and mounting scheme were designed. To reduce the material budget, a lightweight version of the mirror supporting frame was designed in aluminium. A full scale prototype was produced and its key components were tested. Tests on latest mirror supporting frames and pillars will be shown.
For careful monitoring of the mirror positions, an alignment control system is being developed which goes together with software routines for misalignment corrections. To that extent, a developed correction cycle employs two complementary methods, the CLAM method developed by the COMPASS experiment and a technique inspired from the HERA-B experiment. The correction cycle aims at the automatic detection of misalignments and includes them to correct collected data. Results from an automated correction routine and the correction impacts on the matching efficiency of the RICH detector will be presented.

Poster Session - Board: 21

Operational status of the Belle II Time-Of-Propagation counter readout and data acquisition system

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The Time-Of-Propagation counter is a new particle identification (PID) device which was introduced by the Belle II experiment, an upgrade of the Belle experiment. The counter is based on a novel idea of extracting Cherenkov ring information using precise timing information. This feature enables significant improvement of PID performance and a compact detector system, allowing more space for tracking. To realize this concept, it is necessary to detect each single Cherenkov photon with timing resolution of better than 100 ps. Therefore, high-speed electronics is a key point for this detector.
We developed dedicated front-end electronics, which can perform fast waveform sampling and online data processing. Thanks to these features, an excellent timing resolution of 50 ps for single photon detection is achieved and data taking with an input trigger rate of up to 30 kHz is possible. The entire TOP readout system consists of 64 subdetector readout modules (SRM), where each SRM contains 128 readout channels with 8,192 channels in total. All the SRMs are installed in the detector and operational. Firmware development for online data processing for the real detector was started from a simple and robust algorithm, but with limited readout performance. This firmware has been evolving to complicated and high-performance version. We are now finalizing and verifying this readout scheme for the coming first collisions in the Belle II experiment.
In this presentation, the current performance of the readout system for the installed TOP counter is reported and an overview of the hardware is given.

Poster Session - Board: 3

Development of a web monitor for the water Cherenkov detectors array of the LAGO project

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The Latin American Giant Observatory (LAGO) is composed by a network of water Cherenkov detectors installed in the Andean region at various latitudes, from Sierra Negra in M\'exico 18° 59' N to the Antarctic Peninsula 64° 14'S 56° 38' O and altitudes from Lima, Peru at 20 m a.s.l. to Chacaltaya, Bolivia at 5400 m a s.l. The detectors of the network are built on the basis of commercial water tanks, so they have several geometries (cylindrical in general) and different methods of water purification. LAGO's network of detectors also spans over a wide range of geomagnetic rigidity cut offs and atmospheric absorption depths. This, together with its manufacturing differences, generates different structures in the atmospheric radiation spectra measured by our detectors.
One of the main scientific goals of LAGO is to measure the temporal evolution of the flow of secondary particles at ground. This atmospheric flux is produced by the interaction of cosmic rays with the atmosphere at different sites to study the solar modulation of galactic cosmic rays. So, to integrate, monitor and share the data of the detectors, a web monitor is being developed, which is based

on a novel semi-analytical method that combines simulations of the total cosmic ray spectrum and the detectors response to estimate the signals left by secondary particles at the detector.
In the present work we give details of the detector calibration method, applied on four detectors of the network and including the one operated in the Base Machu Picchu, ($62°05'S58°28'O$) during the last Peruvian scientific campaign to Antarctica (January 2018). We also review some candidates for Forbush decrease measured in the detectors under this calibration and present the functionalities of the web monitor.

Poster Session - Board: 27

Tests of Cherenkov Electromagnetic Calorimeter for the HADES experiment

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Cherenkov electromagnetic calorimeter (ECAL)is being developed to complement the dilepton spectrometer HADES currently operating at SIS18 accelerator (GSI Darmstadt, Germany). Later itwill be used at HADES@FAIR experiments. Neutral meson production in heavy ion collisions and detection of photons from strange resonances in elementary and heavy ion reactionswill be measured with this calorimeter with energy resolution about $(5-6)\%/\sqrt{(E(GeV))}$at the beam energy range of 1-10 A GeV. The calorimeter will also improve the electron-hadron separation.
ECALwill cover forward polar angles 16°<Θ< 45° and almost full azimuthal angle of the HADES acceptance and consist of 978 modules divided into 6 sectors. Each module consists of a lead glass Cherenkov counter with light readout by photomultiplier. A dedicated LED based system will be usedto monitor the stability of the calorimeter during beamtime.
Details of ECAL construction and cosmic tests results of ECAL modules in the lab and in-situ at the HADES are discussed.

Poster Session - Board: 30

To Discovery

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The article contains interesting details of the design and implementation of the experiment at significant stages, allowing to more accurately represent the research character of the young graduate student PA. Cherenkov, contribution to the experimental work of its leader, SI. Vavilov, the creative atmosphere of the FIAN of that time. A short history of awarding the Nobel Prize for "discovering and interpreting the Cherenkov effect" is given.

Poster Session - Board: 23

Quasi-spherical modules for Cherenkov water detectors

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Problems of registration of Cherenkov radiation using photomultiplier tubes (PMTs) with flat and hemispherical photocathodes are considered. Configurations of several PMTs with flat photocathodes allow to design a module that has the properties of spherical PMT. Besides the independence of its response on the direction of incident Cherenkov radiation, such quasi-spherical module (QSM) allows to estimate this direction.
The module with six PMTs oriented along the axes of an orthogonal coordinate system – the simplest configuration of quasi-spherical module – was proposed for the first time in 1979 by the MEPhI group and was used in practice in the Cherenkov water detector (CWD) NEVOD.
Common principles of designing the quasi-spherical modules are considered. The properties of isotropy of the response of QSM depending on the distance to a track of charged particle and on the number of PMTs in QSM are discussed. The relevance of the problem of studying the properties of quasi-spherical modules is confirmed by the decisions to use multi-PMT QSMs in modern large-scale projects such as KM3NeT and next generation of IceCube.

Poster Session - Board: 6

Fast LED based imitators of Cherenkov and scintillation light pulses

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We developed a number of LED drivers based on fast blue and UV LEDs. The drivers are inexpensive, robust and simple in operation. They can imitate well Cherenkov and scintillation light pulses. The drivers can be used for calibration purposes in Cherenkov and scintillation detectors. For Cherenkov detectors the fastest LED drivers are used, their light pulses width is less than 1 ns (fwhm) and light yields can be adjusted in a wide range with maximum close to 10ˆ9 photons per pulse. They can imitate single passage of single relativistic particles and/or showers. In case of scintillation detectors, special drivers were developed with their light pulses shapes imitating well light pulses of plastic, liquid and even inorganic scintillation detectors. Moreover it is possible to select drivers which can repeat well pulses of any particular scintillation detectors. It is believed that the developed drivers will be useful for tuning, control and calibration of experiments using Cherenkov and scintillation detectors.

Photon detection for Cherenkov counters

Photosensors and Front-end Electronics for the Hyper-Kamiokande Experiment

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Hyper-Kamiokande is the next generation Water Cherenkov detector that is being developed by an international collaboration as a leading worldwide experiment based in Japan. It will address the biggest unsolved questions in physics through a multi-decade physics program that will start in the middle of the next decade. The Hyper-Kamiokande detector will be the largest underground water Cherenkov detector in the world. It will be hosted in the Tochibora mine, about 295 km away from the J-PARC proton accelerator research complex in Tokai, Japan.
A summary of an extensive R&D program will be presented, which covers two crucial aspects of the planned detector - photosensors and associated front-end electronics. Results of studies for various

candidate photosensors will be presented, both for inner and outer detector volume. Tested sensors include a 50 cm Hamamatsu R12860-HQE photomultiplier tube (current baseline for inner detector), a 50 cm Hamamatsu R12850-HQE hybrid photodetector, a 50 cm MCP-PMT from NVT, multi-PMT module, 3” PMTs for both multi-PMT and one of the variants of the outer detector. In addition, a summary of current status of protective cover design will be provided. Finally, a short overview of various R&D activities related to front-end electronics design will be shown.

Photon detection for Cherenkov counters

Study on the double micro-mesh (DMM) gaseous structure as a photon detector

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Application of micro-pattern gaseous detectors to photon detection has been widely investigated over the past decades. In this talk, I will present a double micro-mesh (DMM) gaseous structure developed with a thermal bonding technique for this application. A detector prototype has been built with this structure and showed excellent performance for detecting single photons in various tests with X-rays and UV laser light. The gain of the gaseous structure can reach up to 10ˆ6 for single electrons while maintaining a very low ion-backflow ratio down to 0.05%. The structure can maintain a stable gain of > 7×10ˆ4 with a good energy resolution of 19% (FWHM) for 5.9 keV X-rays. The DMM has good potential to serve as photon detector in Cherenkov light detection, as well as for other applications, e.g. TPC readout, that require a very low level of ion backflow. The thermal bonding technique used in the development of DMM, including its advantages over conventional Micromegas fabrication methods, will also be briefly introduced.

Photon detection for Cherenkov counters

Performance and commissioning of HAPDs in the Aerogel RICH counter

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The Aerogel Ring Imaging Cherenkov (ARICH) counter is a particle identification device located in the endcap region of the Belle II detector. The main components of the ARICH counter are 248 silica aerogel tiles built into the Cherenkov radiator and 420 Hybrid Avalanche Photo Detectors (HAPDs) making up the photon detector. Angular distribution of Cherenkov photons emitted from silica aerogel and detected by HAPDs is used to identify charged particles. Therefore, HAPD performance is essential for the ARICH counter.
The HAPD is a vacuum tube made of ceramic body, quartz window with semitransparent photocathode and 4 segmented Avalanche Photo Diode (APD) chips. APD chips consist of 36 pixels covering $4.9 \times 4.9\, mm^2$ each. Multiplication in an HAPD is a combination of impact ionization of a photoelectron accelerated by the high voltage applied between photocathode and APD, bombardment gain, and APD avalanche process, avalanche gain.
All the HAPDs were tested before the installation into ARICH detector. One of the issues of HAPDs is a very large signal observed when operated inside the magnetic field therefore each HAPD was also tested in the magnetic field. Final results of the tests before the installation will be reported.
Installation of HAPDs to the ARICH detector finished in July 2017, and the ARICH was installed in the Belle II detector at the end of 2017. The commissioning of the ARICH counter was performed in the spring 2018 with cosmic rays and beam collision events. Although all HAPDs passed several tests before the assembly, few of them suffered issues as frequent large signals and inability to apply bias voltage properly. The behavior of these HAPDs will also be discussed. Performance of HAPDs based on the number of detected Cherenkov photons and Cherenkov angle distributions was evaluated and the results will be reported.

Photon detection for Cherenkov counters

Optimized MPGD-based photon detectors for high momentum particle identification at the Electron-Ion Collider

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Particle identification is a central requirement of the experiments at the future Electron-Ion Collider (EIC) recommended by the U.S. Nuclear Science Advisory Committee Long Range Plan. In particular, hadron identification at high momenta by RICH techniques requires the use of low density gaseous radiators, where the challenge is the limited length of the radiator region available at a collider experiment. A concrete option to increase the number of detectable photons is by selecting a photon wavelength range in the far UV domain, around 120 nm, where the Cherenkov photon rate is higher. Ideal sensors in this domain are gaseous PDs with CsI photocathode, where the status of the art is represented by the MicroPattern Gaseous Detectors (MPGD) with sensitivity in the UV range in operation at COMPASS RICH. Detector optimization is required for the application at EIC.
Here we report about a dedicated prototype where the sensor pad-size has been reduced to preserve the angular resolution in a more compressed architecture. A new DAQ system based on the SRS read-out electronics that has been developed for the laboratory and test beam studies of the prototype.

Photon detection for Cherenkov counters

Single photon detection with the multi-anode CLAS12 RICH detector

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A large area Ring-Imaging Cherenkov detector has been designed to provide clean hadron identification capability in the momentum range from 3 GeV/c up to 8 GeV/c for the CLAS12 experiment. The adopted solution foresees a novel hybrid optics design based on aerogel radiator, composite mirrors and high-packed and high-segmented photon detector.
The photon detector must efficiently detect single photons in the visible light region, provide a fast response for background rejection and pattern recognition, have a spatial resolution of less than 1 cm covering an area of about 1 m2. A first sector has been recently put into operation using for the first time the well known Hamamatsu H8500 MAPMT and the new single photon dedicated H12700, for a total of 400 MA-PMTs and about 25000 pixels.
Spatial, thermal and low noise requirements led to design a modular front-end electronics capable of local signal processing and data buffering, optically linked to the central acquisition node. Each readout unit is composed by a group of MA-PMTs (2 or 3) and a stack of three electronic boards with specific tasks. The core of the readout is composed by the Multi Anode Read Out Chip (MAROC), able to discriminate the 64 signals from one MA-PMT and to produce 64 corresponding binary outputs with 100% efficiency starting at 50 fC injected charge level, and by the FPGA board that provides 1 ns TDC capability with 8 us maximum latency and acts as a controller and DAQ board. The system is designed to be almost dead-time free at the foreseen 20 kHz CLAS12 trigger rate.
Each unit has been validated and characterized for single-photon detection using external light sources (laser stand and online LED system), the on-board charge injector, thermal dark counts and real data from the CLAS12 engineering run. A cosmic stand has been realised to study the global performance of the detector before installation. The best working conditions, the optical and electronic cross-talk, time walk correction, channel-by-channel timing and equalization, dark count and noise level have been studied at laser stands and with the electron beam data. The detector started the physics data taking at the beginning of February 2018. A report of the photon detector preparation, commissioning and operation will be presented.

Photon detection for Cherenkov counters

Status and perspectives of solid state photon detectors

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Development of solid state photon detectors is a mature field of engineering and technology based on well-established grounds of solid state physics, and, in the same time, a frontier area of research and innovations faced with dramatic challenges.
The ultimate challenge for the modern developments is a detection of any optical signal at a quantum level – resolving arrival time and spatial location of individual photons – to realize a formula "every photon counts". To succeed, the developments are focused on improvements in three directions: threshold sensitivity and photon number resolution, fast timing and time resolution, and fine granularity imaging with fast readout. There are many inherent trade-offs to be resolved in each direction.
Development of Silicon Photomultiplier (SiPM) is considered as one of the most promising innovations toward "near ideal" photon detector. The SiPM concept was originated from basic research of avalanche breakdown processes with negative feedback in heterostructures carried out in the P.N. Lebedev Physical Institute in the 1970s–1980s. SiPMs of various designs have been developed in the 1990s – 2000s in Russia (LPI, INR, JINR, CPTA, MEPhI), and their unique performance in the photon number and time resolution has been demonstrated and recognized. Now SiPMs are widely implemented in nuclear medicine, high energy physics, astrophysics, and Cherenkov light detection.
However, developers of Geiger Mode APD or SPAD arrays based on active quenching also found new opportunities for considerable improvements using modern CMOS technology, namely: reduction of a dead space occupied by electronics (Digital SiPM, Philips), multiplexing readout architecture (TU Delft, EPFL), backside illumination (MISPIA), 3D integration of photosensor and electronic layers (3D SiPM, Sherbrook university) and others.
Detection of Cherenkov light is one of the most challenging applications for photodetectors. Superior photon number resolution starting from single photons, picosecond-scale time resolution, and large-area imaging are typical requirements, and many applications demand all these capabilities.
This report presents overview and analysis of the state-of-art in the modern solid state photon detectors as well as their potential and perspectives to meet the quantum imaging challenge.

Photon detection for Cherenkov counters

Performance of Planacon MCP-PMT photosensors under extreme working conditions

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The new Fast Interaction Trigger (FIT) detector has been designed to serve as the main luminometer, collision time, multiplicity, centrality, and reaction plane detector for the upgraded ALICE experiment during Run 3 and 4 at LHC, CERN. FIT will consist of a large scintillator ring and 52 Cherenkov modules combined in two arrays. Each module is based on Cherenkov radiators with four-fold segmentation, optically coupled to a photosensor. Traditional vacuum or solid-state photosensors were not able to fulfil the stringent requirements imposed by the limited space, 0.5 T magnetic field, hadron fluence in excess of 3x10^11 1-MeV-neq per cm2 and expected performance during more than 6 years of service life.
The sensor chosen for FIT is Planacon XP85012/A1-Q microchannel plate-based PMT, which was modified by our group and transformed to the XP85002/FIT-Q-version. With the modified Planacons we were able to achieve time resolution below 20 ps, eliminate the crosstalk problem, and reduce the total length of the sensor. This presentation gives an overview of the extensive in-beam measurements and the outcome of dedicated ageing and magnetic field tests, as well as the description of the implemented PMT modifications

Photon detection for Cherenkov counters

The R&D, Mass Production of the 20 inch MCP-PMT for neutrino detector

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Researchers at IHEP have conceived a new concept of MCP-PMT several years ago. The small MCP units replace the bulky Dynode chain in the large PMTs. In addition the transmission and reflection photocathode in the same glass bulb to enhance the efficiency of photoelectron conversion. After three years R&D, a number of 8 inch prototypes were produced in 2013. The 20 inch prototypes were followed in 2014, and its' performance were improving a lot in 2015. This type of PMT has large sensitive area, high QE, and large P/V for good single photoelectron detection. Compensating the PMT performances, cost, radioactivity, the JUNO ordered 15000 pic 20-inch MCP-PMT from the NNVT in Dec.2015. The MCP-PMT collaboration group finished to build the mass production line in Nanjing, and finished the batch test system in the same place in 2016. From 2017 to 2019, all the 20-inch PMTs will be produced and tested one by one in NNVT for JUNO. This presentation will talk about the R&D, the mass production and batch test result of the 5K pieces of MCP-PMT prototypes for JUNO.

Photon detection for Cherenkov counters

Recent Progress with Microchannel-Plate PMTs

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PANDA is a hadron physics experiment at the FAIR facility at GSI which will employ a high intensity antiproton beam of up to 15 GeV/c to do high precision studies of, among others, objectives like charmonium spectroscopy and search for gluonic excitations. The measurements require a robust and compact PID system placed inside a magnetic field of >1 Tesla with the main components being two DIRC detectors for pion/kaon separation.
Due to the boundary conditions in the focal plane vicinity of the PANDA DIRC detectors microchannel-plate (MCP) PMTs were identified as the only suitable photon sensors. As the long-standing lifetime problem of these devices was overcome recently by employing an atomic layer deposition (ALD) technique to coat the MCP pores, we have investigated further improved and lifetime-enhanced 2-inch MCP-PMTs from PHOTONIS and Hamamatsu. The currently best performing tube is a PHOTONIS XP85112 with two ALD-layers which meanwhile has accumulated close to 20 C/cm^2 intergrated anode charge (IAC) without any sign of aging. The best of the new Hamamatsu 2-inch MCP-PMT prototypes has reached >5 C/cm^2 without aging.
In addition to the current status of our ongoing lifetime measurements in this talk we will present performance results of the latest hiQE MCP-PMTs with high collection efficiency from PHOTONIS and a new Hamamatsu ALD-coated MCP-PMT without protection film. These are the most advanced commercial MCP-PMTs to date.
We will also present first measurement results obtained with a new quality assurance setup for mass production MCP-PMTs which shall be used to screen all tubes before being installed in the PANDA DIRCs. This setup consists of a 3D-stepper with a PiLas laser and a high performance PADIWA/TRB data aquisition system to measure the response of all anode pixels simultaneously. Among other things this system will allow us to study otherwise difficult to measure background parameters like position dependent dark count rates and ion afterpulsing. Also temporal and spacial distributions of recoil electrons as well as electronic and charge-sharing crosstalk among the anode pixels can be investigated.

Photon detection for Cherenkov counters

Another step in photodetection innovation: the 1-inch VSiPMT prototype

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The VSiPMT (Vacuum Silicon PhotoMultiplier Tube) is an original design for an innovative light detector we proposed with the aim to create new scientific instrumentation for future missions of exploration and observation of the universe. The idea behind this device is to replace the classical dynode chain of a photomultiplier tube with a silicon photomultiplier, the latter acting as an electron detector and amplifier. In this way we obtain a large area photodetector with an excellent photon counting, proper of the SiPMs, but with the dark noise of only one SiPM (1-inch is equivalent to $\sim$ 54 SiPM 3x3 mm2). From this point of view, the VSiPMT offers very attractive features and unprecedented performance in large area detection, such as: negligible power consumption, excellent SPE resolution, easy low-voltage-based stabilization and very good time performance. Hamamatsu

realized for our group a 1-inch prototype. We present the results of the full characterization of the device.

Pattern recognition and data analysis

NA62 RICH performance: measurement and optimization

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The main goal of the NA62 experiment is to measure the branching ratio of the K+ ⟶ π+ ν ν̄ decay with ~10% precision. The NA62 RICH is crucial for the identification of charged particles from kaon and pion decays. In particular, the detector should perform well enough to provide a muon suppression factor of at least 100 for the pion sample in the momentum range between 15 and 35 GeV/c while keeping a reasonably high efficiency for the pion selection.
The RICH performance is traditionally described in terms of parameters like ring radius resolution, single hit resolution and the average number of hits per event which are evaluated for electron tracks in order to avoid the momentum dependence. One of the most important factors for the performance improvement is the precise mirror alignment.
In the first part of the talk the mirror alignment procedure is described in detail. The procedure was accomplished for the first time in 2016 and allowed to improve the relative mirror misalignment from ~500 to ~30 µrad in terms of the mirror orientation. Given the focal length of mirrors equal to 17 m, the latter value corresponds to ~1 mm residual misalignment in terms of the Cherenkov ring centre position in the mirror focal plane.
The second part of the talk is dedicated to the measurement of the basic performance using electron tracks: ring radius resolution, ring centre resolution, single hit resolution and mean number of hits. The main constituents of the single hit resolution are discussed. The contribution of the residual mirror misalignment to the performance is evaluated.

Pattern recognition and data analysis

The role of the NA62 RICH in the BR($K^+ \to \pi^+\nu\bar{\nu}$) measurement

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The NA62 experiment aims to measure the $BR(K+ \to \pi^+\nu\bar{\nu})$ with a 10% precision. One of the main backgrounds comes from the decay $K^+ \to \mu^+\nu$, therefore a highly powerful pion/muon separation is needed. The NA62 RICH, together with the calorimeter system, provides an accurate particle identification. The first results of the NA62 $K^+ \to \pi^+\nu\bar{\nu}$ analysis, based on 2016 data, have been recently presented, showing one candidate event selected as a $K^+ \to \pi^+\nu\bar{\nu}$ decay.
Despite that the analyzed data are only a small part of the collected data, the results demonstrate that the new "in-flight decay" approach works as expected. This outcome has been possible also thanks to the very good RICH performance. Two different algorithms have been exploited: (i) the "standalone" ring reconstruction, which makes use exclusively of information from the RICH hits and (ii) the "Likelihood" algorithm, which employs the NA62 Spectrometer measurement of the tracks. In the $K^+ \to \pi^+\nu\bar{\nu}$ analysis these two approaches have been used in combination, getting a pion reconstruction and identification efficiency of 75%, with a muon suppression factor of about 500, in the momentum range 15-35 GeV/c.
In this work we present the way the RICH detector has been employed to get this first important NA62 result and the performances of the RICH detector obtained for $K^+ \to \pi^+\nu\bar{\nu}$ dedicated selection.

Pattern recognition and data analysis

PID performance of the High Momentum Particle IDentification (HMPID) detector during LHC-RUN2

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The ALICE apparatus is devoted to collect pp, p-A and A-A collisions data provided by the LHC, to study the properties of strongly interacting matter under extremely high temperature and energy density conditions. In ALICE, the tracks momentum is evaluated exploiting a solenoid magnetic field of 0.5 T. Among the ALICE PID detectors, the HMPID (High Momentum Particle Identification Detector) is devoted to the identification of charged hadrons. It consists of seven identical RICH (Ring Imaging Cherenkov) counters, with liquid C_6F_{14} as Cherenkov radiator (n $\approx$ 1.298 at λ_{ph} = 175 nm). Cherenkov photons and charged particles are detected by a MWPC, coupled with a pads segmented CsI coated photo-cathode. The HMPID provides 3σ K-π and p-K separation up to p_{T} = 3 and 5 GeV/c, respectively. The detector performance depends on the experimental conditions, such as the event multiplicity and the intensity of the solenoid magnetic field. During the LHC RUN2 period (2015-2017), the HMPID collected data coming from pp, p-Pb, Pb-Pb and Xe-Xe collisions. pp data with B = 0.2 T have been also recorded. A review of the detector PID performance during LHC RUN2 period is shown. The contribution given, so far, by the HMPID to the ALICE physics measurements, performed with LHC RUN2 data, is also presented.

Pattern recognition and data analysis

Calibration of the Belle II Aerogel Ring Imaging detector

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To efficiently separate hadrons in the forward end-cap of the Belle II spectrometer, an aerogel proximity focusing Ring Imaging Detector is installed in the high magnetic field between the central drift chamber and electromagnetic calorimeter. Cherenkov photons, emitted in the double layer aerogel radiator are expanded in the 16 cm empty space and detected on the photon detector comprising by 420 Hybrid avalanche photo diodes. Photons at the outer edge of the detector, which would not be detected, are reflected back towards the photo sensors. The readout electronics working in a threshold mode will record hit patterns created during beam collisions. A particle identification algorithm based on the two dimensional extended maximum likelihood technique will be used to assign probabilities for different particle hypotheses of tracks traversing the aerogel RICH detector. The likelihood function combines the probabilities for different photon emission and path hypotheses

To tune and to determine detector performance, we will use particles, unambiguously identified by other subsystems or only by tracking system.

In the presentation, the particle identification algorithm will be presented together with the expected simulated performance. We will present the strategy to determine a kaon identification efficiency by using $D^{\pm *}$ decays. Data from first beam collisions will also be shown.

Alternative PID techniques

PID methods other than RICH

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Invited talk.

Alternative PID techniques

The Panda Barrel Time-of-Flight Detector

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The barrel-Time-of-Flight detector is one of the outer layers of the multi-layer design of the PANDA target spectrometer, covering an angle of $22 < \theta_{lab} < 150$. PANDA, which is being built at the FAIR facility, will use cooled antiprotons on a fixed Hydrogen or nuclei target, to study broad topics in hadron physics.
The detector is a scintillating tile hodoscope with an SiPM readout. A single unit consists of a $90 \times 30 \times 5$ mm^3 fast plastic scintillator tile and 3×3 mm^2 SiPM photosensors on both ends. Four SiPMs are conected in series to overcome the limited sensor size of a single SiPM sensor and to improve the time resolution darastically (˜100 ps to 50 ps).
While the PANDA experiment is equipped with DIRC detectors for PID of faster particles, the barrel TOF complements the setup by providing additional PID information up to ˜1.4 GeV/c and a π/K separation of ˜5 sigma up to the Cherenkov threshold.
In this contribution we will also review recent topics on SiPMs and compare them to MCP-PMTs.

Alternative PID techniques

Particle detection efficiency of the KEDR detector ASHIPH system

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The particle identification system ASHIPH (Aerogel SHifter PHotomultiplier) has been working in the KEDR experiment at VEPP-4M collider since 2014. The system consists of 160 counters arranged in two layer and covers the 96% of the solid angle. Two layer system permits to use different approaches for pi/K-separation. Three such approaches are described. The status of the system is presented. Main system parameters such as BhaBha suppression factor, pi/K-separation power, relativistic particle detection efficiency were measured with help of cosmic particles and experimental data collected at the peak of J/psi-meson. Dependences of these parameters on time are evaluated. Monte-Carlo simulation procedures are described and its results are presented as well.

Remembering Pavel Cherenkov

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Invited talk.

Remembering Pavel Cherenkov

P.A. Cherenkov in the mirror of world science

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Invited talk.

Remembering Pavel Cherenkov

Cherenkov detectors with aerogel radiators

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This review discusses the application of the aerogel as radiator in Cherenkov detectors. The talk gives the view on the history of use of aerogel in detectors for particle physics experiments. Physical principles of such detectors construction and operation are described. Data on threshold Cherenkov counters with direct light collection and on those using wavelength shifters are presented. Also presented are data on Ring Image Cherenkov detectors with single and multilayer focusing aerogel radiators.

Alternative PID techniques

Development of the TORCH time-of-flight detector

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The TORCH time-of-flight detector, designed to provide particle identification over the momentum range 2–10 GeV/c over large areas, is under development. The detector exploits prompt Cherenkov light produced by charge particles traversing a 10 mm thick quartz plate. The photons propagate via total-internal reflection and are focussed onto a detector plane comprising position-sensitive micro-channel plate (MCP) detectors. The goal is to achieve a resolution of 15 ps per particle by combining the information from around 30 detected photons, given a single-photon resolution of 70 ps. The MCP-PMT detectors have been developed with a commercial partner (Photek), leading to the delivery of a square 53 by 53mm tube, with 8 by 128 pixels equivalent, capable of withstanding a large integrated charge on its anode (5 Ccm^{-2}). A small-scale demonstrator of TORCH has been verified in beam tests at the CERN PS with custom readout electronics and a data-driven calibration. Preliminary results indicate a single photon-resolution better than 100 ps can achieved. Progress towards a larger-scale system with a 10 MCP-PMTs will be presented.

Alternative PID techniques

Ten years of operation of the MRPC TOF detector of ALICE: results and perspectives

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The ALICE Time Of Flight (TOF) detector is based on 1638 Multigap strip RPCs, for a total active area of 140 m^2 and more than 150000 readout channels. After ten years of operations the detector performance remains excellent, with no observable degradation in stability of operation nor in efficiency of particle detection. A new calibration has brought to a significant improvement in the time resolution - down to 60 ps - very close to the value observed in beam test measurements. A new algorithm allowed a better event collision time determination, while more powerful methods to separate particles have been developed for the different LHC colliding systems (pp, p-Pb and Pb-Pb). These improvements allowed an extension of the particle identification(PID) capacities of TOF in the intermediate momentum range, achieving a separation better than 3σ, up to a particle momentum of p $\sim$ 2.5 GeV/c and p $\sim$ 4 GeV/c for π/K and K/p, respectively. Few examples of PID application to physics analysis will be described. Finally, the TOF upgrade program will be briefly discussed: this will allow the TOF detector to become a detector with a continuous readout during the next LHC Run3 data taking period.

Alternative PID techniques

Development a picosecond MCP based particle detector

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Measurement of a particle detection time with accuracy better $30\,ps$ could help to separate particles from different vertexes in future experiments at hadron colliders with high Luminosity (for instance at LHC Phase III L˜$10^{35}cm^{-2}\cdot s^{-1}$). From other hand measurement of Time-of-Flight with such accuracy could sufficiently improve power of particle identification technique in various colliding beam experiments. Now the MCP based charge particle detector with a high intrinsic time resolution of about $10\,ps$ is being developed in BINP. The device must also has a high count rate, long lifetime in hard radiation conditions, large area of the sensitive surface and operate in magnetic field up to $4\,T$. The suggested device consists of a Cherenkov light radiator (MgF_2), ultraviolet CsI-semitransparent photocathode and electronic amplifier based on MCPs. The production in vacuum installation of a semitransparent CsI-photocathode with deposition its at radiator from MgF_2 was mastered at BINP. The prototype has been developed and tested on test beam at BINP.

Technological aspects and applications of Cherenkov detectors

Status and perspectives of high quality aerogel

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Invited talk.

Technological aspects and applications of Cherenkov detectors

Photon detectors and front-end electronics for RICH detectors in high particle density environments

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Next generation ring imaging Cerenkov detectors at high luminosity accelerators, like HL-LHC, have to provide particle identification in increasingly challenging conditions. The photon detectors will have to cope with high track densities, leading to hit rates up to $10\ \mathrm{Mhits\,s^{-1}\ mm^{-2}}$, and with high radiation levels, namely a total dose up to a few Mrad and neutron fluence up to $10^{14}\ \mathrm{n_{eq}\ cm^{-2}}$. For this purpose, high segmentation, fast and radiation tolerant photon detectors operating in single photon regime are required. Silicon photomultipliers (SiPMs) and micro-channel plates photomultiplier tubes (MCP-PMT) are among the most promising devices that could be adopted.
In this contribution I will present the work carried out for the performance evaluation of the latest models of SiPMs and MCP-PMTs available by Hamamatsu and SensL, with timing measurements in single photon regime, dark count rate measurements on new and irradiated devices, also as a function of bias voltage and operating temperature. These new photon detectors will require tailored front-end electronics in order to exploit the better timing characteristics and to implement other functionalities to reduce occupancy, like multiple photon detection. Studies for the realization of the upgraded version of the CLARO chip, an ASIC developed by our group for the readout of multi-anode PMTs, will also be presented.

Technological aspects and applications of Cherenkov detectors

Nanostructured Organosilicon Luminophores as effective wavelength shifters for Cherenkov light and elementary particles detectors

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We report on recent developments of Nanostructured Organosilicon Luminophores (NOLs) and their application as highly efficient and fast wavelength shifters (WLS) in various types of elementary particles photodetectors. NOL consists of two types of covalently bonded via Si atoms organic luminophores with efficient Förster resonance energy transfer between them. NOLs combine the best properties of organic luminophores and inorganic quantum dots: high absorption cross-section and photoluminescence quantum yield (PLQY), low self-absorption, fast luminescence decay time, good solubility and processability, as well as low toxicity. A variety of organic luminophores allowed us to design and synthesize a library of NOLs, absorbing from 150 to 550 nm and emitting at the desired wavelengths from 390 to 650 nm. The luminescence decay time of NOLs can be as short as 0.8 ns at 90% PLQY.
NOLs were applied as highly efficient vacuum UV WLS for PMT and SiPM used in liquid argon detectors. WLS based on NOL covered on PMT allowed to increase the efficiency of Cherenkov light detection on 15%. Plastic scintillators containing NOLs were 50% more efficient and 40% faster as the standard ones. Fast and efficient NOL-based scintillating fibers (SciFi) emitting in blue and green regions with the decay time of 1.18 – 1.34 ns that is 2-5 times faster than the standard Kuraray SciFi were developed. NOL-containing WLS plates were used for efficient conversion of UV photons into visible light in fast pure CsI scintillators coupled with avalanche photodiodes. That allowed to rise 2-3 times the scintillation light output for upgrade of the end cap electromagnetic calorimeter of Belle II detector.
This work was supported by Federal Agency of Scientific Organizations and made in the framework of leading science school NSh-5698.2018.3.

Technological aspects and applications of Cherenkov detectors

Silica aerogel radiator for the HELIX RICH system

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We have been developing silica aerogels for use as RICH radiators used in the HELIX (High-Energy Light Isotope eXperiment) spectrometer. The HELIX program is a balloon-borne cosmic-ray experiment designed to measure the mass of light cosmic-ray isotopes (in particular, those of beryllium). The main objective is to explore the propagation mechanism of cosmic rays by measuring the relative abundances of key light cosmic-ray isotopes. The first flight is scheduled during NASA's 2019/20 Antarctic long-duration balloon campaign.
The HELIX instrument consists of a 1-T superconducting magnet, a gas drift chamber, time-of-flight counters, and an aerogel RICH system. The HELIX RICH is used for measuring the velocity of cosmic-ray isotopes in an energy range from 1 to 3 GeV/nuc. The system is a proximity-focusing RICH with an expansion length of 50 cm, and a focal-plane composed of a silicon-photomultiplier module array with a pixel size of 6 mm. Hydrophobic aerogels with a refractive index, n of 1.15 were chosen as the radiators. The requirements for the aerogels include tile dimensions of $10 \times 10 \times 1$ cm and refractive index and thickness uniformities of ~1% across the tile for the precise determination of the particle velocity. The dimensions of the radiator module are 60×60 cm; thus, a total of 36 tiles are needed. Developing highly transparent aerogels with an ultrahigh index exceeding 1.10 without cracking is a serious challenge. In late 2016, we began the experimental fabrication of aerogels specific for HELIX. We determined that the production of n = 1.15 tiles is feasible using the pin-drying technology. In early 2018, we succeeded in prototyping highly transparent (a transmittance of ~73% for 400-nm wavelength) aerogels close to the flight-qualified radiators. We have begun the mass production of 92 tiles as candidates for the flight aerogels at the end of March 2018. Here, progress in the development and mass production of high optical quality aerogels is presented.

Technological aspects and applications of Cherenkov detectors

Optical elements for RICH detectors

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Invited talk.

Technological aspects and applications of Cherenkov detectors

Efficiency of a Cherenkov based PET module with an array of SiPMs

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The detectors in positron emission tomography (PET) can be based on detection of Cherenkov light instead of the traditional approach of using scintillation light. This enables excellent time resolution that can be used in time-of-flight (TOF) PET, but it proved difficult to achieve efficiency in detection of annihilation gammas comparable to traditional methods. The Cherenkov method however has another advantage - low cost of the most suitable conversion material (lead fluoride) compared to the most commonly used scintillators. Especially when incorporating silicon photomultiplier (SiPM) photodetectors, such PET detectors could be realized at a very competitive price. In this work the performance of such PET module is presented, with an emphasis on the efficiency of detection. Two modules consisting of 4x4 lead fluoride Cherenkov radiator arrays coupled to Hamamatsu 4x4 SiPM arrays were assembled and their performance was tested using annihilation gammas from a sodium source.

Technological aspects and applications of Cherenkov detectors

The Cherenkov optics qualification facilities at INAF-OAB laboratories

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In the last decade the Osservatorio Astronomico di Brera of the Italian Institute for Astrophysics, INAF, got deeply involved in Cherenkov optics manufacturing and testing contributing to the realization of mirrors for MAGIC and CTA projects. In this paper we would like to review the characterization facilities that INAF-OAB developed to qualify Cherenkov mirrors performance. The design of these facilities was driven by the general Cherenkov optics configuration, which is realised with a large number of mirrors with arc-minutes resolution. The capability to obtain arc-minutes resolution characterization in a short measuring time is hence a driving concept for an efficient Cherenkov mirror qualification facility. The first facility implemented by INAF-OAB for Cherenkov optics is an outdoor 2f optical bench equipped with a large area CCD detector. This facility is very advantageous for the Cherenkov spherical mirrors qualification allowing both radius of curvature and focal spot measurements. Nevertheless, as any 2f facility, this facility has the capability to manage exclusively focusing optics. On the other hand, the introduction of novel optical design for Cherenkov telescopes, like the Schwarzschild-Couder design, creates the necessity to qualify free-form non-focusing optics. For these reason the INAF-OAB developed a flexible deflectometry setup capable to qualify any kind of Cherenkov optics. This system, based on an inverse Ronchi test working in synergy with specific software, allows precise simulation of the focal spot at telescope focal plane. In this contribution we will describe these facilities, present some measurement results and discuss the wide range of possible application they offer.

Novel Cherenkov imaging techniques for future experiments

The Upgrade of LHCb RICH Detectors

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The LHCb Ring-Imaging Cherenkov (RICH) detector system has been operated with very high availability in the LHCb experiment since 2009, performing charged hadron identification in a wide momentum range with high efficiency and providing crucial information for most physics analyses.
The LHCb experiment will undergo a major upgrade during the second LHC long shutdown (2019-2020), improving the performance of many of its detector systems in order to sustain the planned five-fold increase in instantaneous luminosity (up to 2×10^{33} cm^{-2}s^{-1}) compared to the current running conditions. In particular, a substantial change in the LHCb trigger and read-out schemes will be implemented to allow 40 MHz continuous data taking.
The RICH detectors will be upgraded by installing new single-photon detectors (multi-anode photomultiplier tubes in place of hybrid photo-detectors) read out by 40 MHz capable electronics, and by modifying the upstream RICH optics and mechanics.
An overview of the RICH upgrade program will be presented, including a summary of the expected performances and the result of the latest tests of the complete photo-electronics chain in laboratory and test-beams.

Novel Cherenkov imaging techniques for future experiments

Status of the CBM- and HADES RICH projects at GSI/FAIR

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The HADES RICH detector at GSI/FAIR is currently being upgraded using Hamamatsu H12700 photomultipliers for Cherenkov photon detection. The same sensors will be also used by the CBM RICH detector, which is being built at FAIR-SIS100. A total of 1100 already delivered MAPMTs have been individually measured with respect to sensitivity, gain, dark current, and afterpulsing. The test data prove the constant production quality, and allow to group the sensors into readout modules of 6 PMTs each.
A new FPGA-TDC based electronic readout chain has been developed and provides excellent timing precision and high rate capability. Core element is the 32ch DIRICH front-end module, combining discrimination, digitization, and data handling on a single FPGA. The new readout chain has been characterized in detail during a test beam at COSY, FZ Jülich, using a small Cherenkov prototype detector. Based on these results, the mass production of all eletronic modules for the HADES upgrade has started and is presently ongoing.

In the presentation, we give an overview on the upgrade status of the HADES RICH detector, and show the progress of the ongoing CBM RICH detector development.

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Novel Cherenkov imaging techniques for future experiments

RICH counter development for the Electron Ion Collider experiment

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In the proposed Electron-Ion Collider (EIC) experiments, particle identification (PID) of the final state hadrons in the semi-inclusive deep inelastic scattering allows the measurement of flavor-dependent gluon and quark distributions inside nucleons and nuclei. The EIC PID consortium (eRD14 Collaboration) has been formed for identifying and developing PID detectors using ring imaging Cherenkov

(RICH) and the ultra-fast time-of-flight (TOF) techniques for the EIC experiments with broad kinematics coverage. A modular ring imaging Cherenkov (mRICH) detector has been designed for particle identification in the momentum coverage from 3 GeV/c to 10 GeV/c. The mRICH detector consists of an aerogel radiator block, a Fresnel lens, a mirror-wall and a photosensor plane. The first prototype of this detector was successfully tested at Fermi National Accelerator Laboratory in April 2016 for verifying the detector working principles. This talk will highlight the first mRICH beam test results and show the preliminary results from the second beam test in late June of 2018. An implementation of the mRICH detector array in the Forward Angle sPHENIX spectrometer at BNL will also be described in this talk.

Novel Cherenkov imaging techniques for future experiments

Development of the PANDA Forward RICH with aerogel radiator

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The PANDA detector at the international accelerator Facility for Antiproton and Ion Research in Europe (FAIR) in Darmstadt (Germany) will address fundamental questions of hadron physics in high-energy antiproton collisions with fixed hydrogen and nuclear targets.
The PANDA Forward RICH (FRICH) is intended for identification of charged particles with forward polar angles below 5°–10° and momenta from 3 to 15 GeV/c. FRICH will have a multilayer focusing aerogel radiator to achieve the required resolution on Cherenkov angle. A set of precisely aligned flat mirrors will collect light on the multi-anode photomultipliers which are located outside of the detector's effective aperture. The PANDA Forward RICH R&D relies on experience of other modern RICH detectors. A baseline design of the PANDA Forward RICH is presented including results of the full Monte-Carlo simulation, optical measurements and prototype beam tests.

Novel Cherenkov imaging techniques for future experiments

The PANDA DIRC Detectors

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The PANDA experiment at the international accelerator Facility for Antiproton and Ion Research in Europe (FAIR), under construction near GSI, Darmstadt, Germany, will address fundamental questions of hadron physics. Excellent Particle Identification (PID) over a large range of solid angles and particle momenta will be essential to meet the objectives of the rich physics program. Charged PID for the PANDA target spectrometer will be provided by two innovative RICH counters using the DIRC (Detection of Internally Reflected Cherenkov light) technology.
The Barrel DIRC will cover the polar angle range of 22-140 degrees and cleanly separate charged pions from kaons for momenta between 0.5 GeV/c and 3.5 GeV/c with a separation power of at least 3 standard deviations (s.d.). The design is based on the successful BABAR DIRC and the SuperB FDIRC R&D with several important improvements to optimize the performance for PANDA, such as wider and shorter radiator bars, a spherical focusing lens system, fast timing, a compact fused silica prism as expansion region, and lifetime-enhanced Microchannel-Plate PMTs (MCP-PMTs) for photon detection.
The Endcap Disc DIRC (EDD) will separate pions from kaons with momenta up to 4 GeV/c and polar angles between 5 and 22 degrees with a separation power of 3 s.d. or more. The EDD consists of four optically isolated quadrants, each comprising a synthetic fused silica radiator plate of 2 cm thickness,

focusing optics along the outer edge to convert the angle information into a position information, and a compact readout region. The intrinsic contribution of a chromatic error is reduced by an optical filter and an adapted photocathode. High-resolution MCP-PMTs will be used in connection with a fast ASIC-based readout to record events.
We will discuss the technical design of the two PANDA DIRC detectors and the results of the design validation using prototypes in hadronic particle beams at DESY and at CERN.

Novel Cherenkov imaging techniques for future experiments

Status of the GlueX DIRC

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This year we start assembling the DIRC detector to upgrade the particle identification capabilities in the forward region of the GlueX detector in Hall D at Jefferson Lab. The main components of the GlueX DIRC are the four radiator boxes (reused from the decommissioned BaBar DIRC) and two photon cameras, which were designed based on the prototype for the SuperB FDIRC. The first radiator box has already arrived to JLab from SLAC, where the delicate BaBar radiator boxes have been stored for the last 10 years. It will be attached to the newly built photon camera and installed in the Hall D already for the 2018 fall run. We present the status of the GlueX DIRC project including the ongoing R&D and the plan for the future.

Novel Cherenkov imaging techniques for future experiments

PID system based on Focusing Aerogel RICH for the Super C-Tau Factory

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The excellent PID system is needed for successful execution of the broad experimental program at future Super C-τ Factory in Novosibirsk. The main requirements for PID system are following: good π/K-separation in whole operational momentum range and good μ/π-separation in momentum range from 0.4 up to 1.2 GeV/c. The RICH detector based on focusing aerogel (FARICH) suits for all these requirements. The method FARICH is described and beam test results are presented. The scheme of the FARICH system for the universal detector of Super C-τ Factory project is given. Limits for multilayer aerogel production uncertainties are formulated. Most promising position sensitive photodetectors are considered.

Novel Cherenkov imaging techniques for future experiments

Photonic crystals as novel radiators for Cherenkov detectors

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In a Cherenkov detector, the refractive index of the conventional radiator sets a fundamental limit to the momentum coverage and sensitivity, for particle identification. For example for particles above 10 GeV/c, RICH detectors use large gas radiators. There is a dearth of materials to cover the full 1-10 GeV/c range. A new mechanism based on constructive interference of resonance transition radiation from photonic crystals is proposed to overcome this fundamental limit.
Photonic crystals can be designed from transparent dielectric materials to have the desired effective refractive index. They can produce forward and backward effective Cherenkov radiation in the optical and UV wavelengths. The typical overall thickness is a few millimetres.
Simulations based on FDTD (Finite Difference Time Domain) technique have shown that they can be configured for particle identification in different momentum ranges. However, they could potentially have chromatic error coming from the periodic structure. R&D to verify the performance using prototypes have started.
The results of simulations and potential for photonic crystals for particle identification are presented. The strategies to reduce the effect of the Chromatic error and to optimize the yield are discussed. The prospects for prototype testing are also presented.