Status of the CBM- and HADES RICH projects at FAIR
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for the CBM RICH and HADES collaboration

Contents:

Status of the FAIR facility
The CBM RICH detector
The HADES RICH upgrade

R&D work
  - Hamamatsu H12700 MAPMT series testing
  - DiRICH readout chain for MAPMTs
  - Test beam results for DiRICH

Summary

CBM RICH:
Giessen University, Germany
Wuppertal University, Germany
Petersburg Nuclear Physics Institute (PNPI), Russia
Institute for Theoretical and Exp. Physics (ITEP), Russia
Joint Institute for Nuclear Research (JINRLIT), Russia

HADES RICH upgrade:
Technical University Munich, Germany
Giessen + Wuppertal University
GSI Darmstadt, Germany
TRB collaboration
Present status of FAIR - Facility for Anti-Proton and Ion Research

- FAIR civil construction started 4th of July 2017
- Much progress during last year!
- This summer: beam back in GSI SIS18 (after 4 year shutdown for upgrades)
- HADES physics run autumn this year
The CBM RICH detector

**Facts:**
- **Dimensions:** 2m x 5.14m x 3.93m (length x height x width)
- **Acceptance:** 0-35° / 0-25° (horizontal / vertical)

- **CO₂ gas radiator**
  - Pion threshold 4.5 GeV/c
  - UV cutoff <190 nm
  - 35 m³ radiator gas volume, 1.7m radiator length

- 13m² segmented glass mirror, 80 tiles 40x40 cm², focal length 1.5m
- **MAPMT readout:** ~1000x Hamamatsu H12700, 64k channels

**Challenges:**
- High rate (up to 100 kHz photon rate per pixel)
- Magnetic stray field from CBM magnet (shielding box)
- RICH downstream of tracking system
- Free-streaming readout
- Moveable by crane

**Updated CBM timeline:**
- 2014 Technical Design Report approved
- 2019 Conceptual Design Review
- 2019 Production of first components
- 2022/23 Installation in the cave
- 2024 First beam

See Poster #16 for more details:
"Development of a mirror supporting frame, mounting scheme and alignment monitoring system for CBM RICH"
The HADES RICH detector

HADES: High Acceptance DiElectron Spectrometer
- Installed at GSI SIS 18, in operation since 2001
- Studying baryonic matter in light and heavy systems
- Part of FAIR – phase 0 program
- Will later move to CBM cave at SIS 100

→ extensive detector upgrade program

“Old” HADES RICH:
\[ C_4F_{10} \] radiator
Low material budget, carbon mirror
Hadron blind detector
Electron id \( 15 \text{ MeV/c} < p_e < 1.5 \text{ GeV/c} \)

Reflective CsI cathode
Deep-UV, 145nm – 210 nm
MWPC readout
**Photon detector upgrade of HADES RICH**

**Motivation:**
- Ensure stable RICH operation for future FAIR program, - 2025 and beyond
- Improve close-pair dielectron reconstruction (essential for future physics program)

**Concept:**
- Share MAPMTs and readout chain development with CBM RICH
- 428pc H12700 MAPMTs on new photon detector flange
- PMT module backplane serves as gas- and light tight seal of PMT camera volume
- Keep CaF window to enclose $\text{C}_4\text{F}_{10}$ radiator volume

- Center part of photon detector 10 cm elevated (→ better match focal plane)

**Validated in detailed Monte Carlo simulations**
New photon detector with MAPMTs mounted

New photon detector flange after installation of PMT backplanes

HADES RICH mirror with CaF window in front

... and after installation of the first 396 MAPMTs

Close-up of MAPMTs mounted on backplanes

photos by G. Otto, GSI
New photon detector readout electronics

Backside of photon detector with readout modules installed

Total power dissipation: 2.5 kW,
present cooling concept: enforced air cooling
Selected simulation results – single electrons

- **Typical single event**
  - blue: all photons
  - red: detected photo-electrons

- **Cherenkov ring radius**
  - as function of scattering angle

- **Number of detected photons**
  - as function of scattering angle

- 11 – 16 detected photons per ring expected
- Photon yield increasing with scattering angle due to effective radiator path length
- Ring radius matches roughly size of single PMT
- Gap in photon yield / radius due to 10 cm shift of inner part of detection plane
Selected simulation results - dilepton pairs

- Reconstruction efficiency for dilepton pairs with small opening angle drastically improved by the upgrade

Reconstruction efficiency for dilepton pairs with small opening angle (4°)

\[ d\phi = 4^\circ \]
MAPMT procurement and testing

1100 Hamamatsu H12700 MAPMTs ordered
- 428 to be used by HADES starting 2018
- All to be used by CBM-RICH starting ~2023

Delivery of MAPMTs: Autumn 2015 - November 2017

Extensive series testing of each MAPMT
- Quality control
- Characterization of each MAPMT (->gain grouping)
- Rejection of MAPMTs out of specs

Test stand for spatially resolved single-photon scans:
- Pulsed laser light source, ca 0.1 photons / pulse
- XY-table for point illumination (spot size < 1 mm)
- Self-triggered, free-streaming readout, ADC + TDC
- 3 PMTs (+1 reference PMT) per scan (8 hr)

From single scan:
- Single-photon detection efficiency (xy-resolved)
- Single-photon amplitude spectrum (per pixel)
- Gain
- Dark rate
- Gain dependence on HV
- Afterpulsing
- Crosstalk
- ...

+ dedicated measurement of quantum efficiency for selected PMTs
PMT overview plot for each MAPMT
"Efficiency index":
- measure of the relative single photon detection efficiency (@405nm),
- averaged over active area
- in relation to (average) reference PMTs
  ("1.0" = same efficiency as ref. PMT)

- Fairly constant over production time, variation ~ +/- 10%
- 30% improved efficiency compared to old H8500 MAPMTs
**MAPMT dark rate over time**

PMT total dark rate (sum of 64 pixel), 25°C
- threshold ~ 30% of SEP peak
- measured after ~7 hr operation in total darkness
- Dark rate corrected for PMT temperature

- Dark rate is important criterium for CBM-RICH (self-triggered readout)
- First H12700 MAPMT significantly higher dark rate compared to H8500 (→high qe cathode)
  - usually only few pixel contribute very strongly, often corner / border pixel

- **Significant improvement over production period!**
H12700 darkrate temperature dependence

\[ NR(T) = NR(T_0) \cdot e^{\lambda(T-T_0)} \]

with \( \lambda \sim 0.12 \text{ K}^{-1} \)

PMT darkrate as function of temperature for 3 different threshold values (~ 20% ... 40% single photon peak)

- \( \lambda \) parameter from fit to 5 MAMTS: fairly constant for all tested H12700 MAPMTs
- Allows to extrapolate measured dark rates to 25° “standard” temperature
- Strong increase in dark rate seen already at ~40° (due to exponential temperature dependance) → important for cooling design
"skewness" number over time

"Skewness" factor:
average efficiency index left half / right half

- Skewness not observed for H8500 MAPMTs
- "Skewness" improved over time (after feedback to Hamamatsu)
The **DIRICH readout chain**

Based on TRB development by M. Traxler, C. Uğur, J. Michel et al (TRB collaboration)

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**DIRICH-Power module**
(LV + HV supply, DCDC)

**32ch DIRICH frontend module**

**3x2 MAPMT backplane**
(with few modules equipped)

**DIRICH-Combiner module**
DIRICH frontend module

- 32ch analog amplification, discrimination, leading+trailing edge TDC, digital control all implemented on single FPGA with few discrete elements only

- **Galvanically isolated inputs** to minimize noise and ground loops
- Single-stage transistor amplifier, amplitude **gain ~30, high band width (4 GHz)** amplifier: **only 10 mW per channel** (1.1V Vcc)
- Signal shaping to optimize time measurement

- **Leading+Trailing edge time measurement** on same channel using stretcher
- No signal integration: pure “amplitude measurement” (no charge measurement as on nXYter)
- Accurate **Time-Over-Threshold measurement** (for amplitude, walk corr.)

- Up to 50 MHz hit rate (burst)
DIRICH timing precision in the lab - with pulse generator

Excellent timing precision down to 1 mV pulse amplitude
PMT TransitTimeSpread will be the limiting factor
Effect of cut on Pulsewidth

<table>
<thead>
<tr>
<th>Signal threshold:</th>
<th>Cut on threshold only</th>
<th>Additional cut on PulseWidth: 2ns &lt; PW &lt; 10ns</th>
<th>Amplitude spectrum w / wo cut</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 mV</td>
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<td>75 mV</td>
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<td>100 mV</td>
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PMT single photon response after DIRICH-preamplifier and shaping (derived from scope signal traces)
**RICH@COSY prototype**

- Final test of readout chain before production
- COSY accelerator, FZ-Juelich
- Proton beam, 1.8 GeV/c

- Two different setups:
  - Proximity focussing setup
    - 3mm quartz glass radiator
  - Focussing setup, borosilicate lens as radiator and focussing mirror (idea borrowed from LHCb)
Photon detection efficiency

Lense setup:
$E_{\text{kin},p} = 1730$ MeV
(with wrong threshold polarity)

Proximity focussing:
$E_{\text{kin},p} = 600$ MeV

Number of detected photons vs Threshold
3 different HV values

Full Monte Carlo simulation
assuming 90% collection efficiency: **14.8 hits/ring**

Timing precision single photon: ~ 300-400ps
(MAPMT TTS: 290 ps)

More details: poster #1
"Measurement of […] and the fast FPGA based CBM/HADES readout electronics"
Summary and outlook

- Construction of FAIR facility now in full swing
  - First beam in SIS100 CBM/HADES cave expected for 2024
  - FAIR Phase0 with HADES@SIS18 starting this year

- Design of CBM RICH detector far advanced
  - Conceptual Design Report in 2019

- HADES photon detector upgraded using H12700 MAPMTs

- Detailed series testing of 1100pc H12700 MAPMTs for CBM and HADES
  - Several improvements (darkrate, uniformity) during massproduction

- New FPGA-TDC readout chain DiRICH
  - For MAPMTS: CBM- and HADES RICH
  - For MCPs: PANDA
  - Promising in-beam test of DiRICH readout chain at COSY

- HADES physics run with new RICH still this year !

Thank you for your attention
spares
Effect of WLS on efficiency

- Both HADES and CBM will use gaseous radiator: C4F10 / CO2
  - Most Cherenkov photons expected in UV range
  - Cherenkov photon yield usually THE critical parameter when building a RICH

- WLS coating of PMT glass window to enhance UV sensitivity
- WLS gain can only be realistically tested with real Cherenkov spectrum → test beam

Measurement during COSY test beam:
- Initially, all PMTs were WLS coated
- WLS layer removed in two consecutive steps
- Allows for precise determination of Cherenkov photon yield
- Also allows to study influence of WLS on photon timing
choice of radiator gas (CO$_2$) motivated by low fluorescence

Abbildung A.8: Relativer spektraler Verlauf des Szintillationslichts von CO$_2$ bei einem Druck von $p = 970$ hPa und Anregung durch einen Schwefelstrahl.

Korbinian Schmidt-Sommerfeld
master thesis TU Munich (Jürgen Friese)
Alternative cooling concept

- Problem of “conventional“ air cooling:
  Air blown from outside, **into** the electronics

- Highest temperatures at backplane, closest to PMT

- Alternative idea: Use “compressed air” (~200 mbar)
  special “distribution masks” between backplane and DiRICH distribute air between modules

  Cool air blown inside electronics, pushing warm air out of setup
  lowest temperatures close to backplane

- Promising first tests, but need larger air pump (~ 2 m³ / min, 200 mbar)
- Distribution masks already installed
Selected results: gain @ 1000V

PMT Gain @ 1000V
- as derived from fit to single photon amplitude spectrum and charge calibration of ADC 
  (measured in center of each pixel)

- Average gain: \( \sim 2.5 \times 10^6 \), maximum \( \sim 5 \times 10^6 \)
- gain specification: \( > 0.8 \times 10^6 \)