Status of the CBM- and HADES RICH projects at FAIR

C. Pauly, Wuppertal University
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

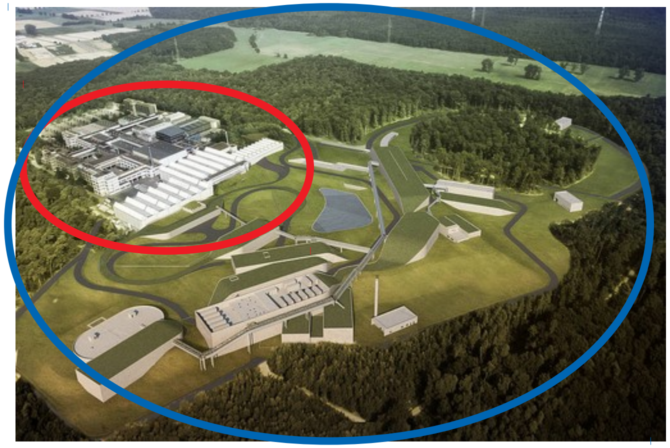
Summary

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

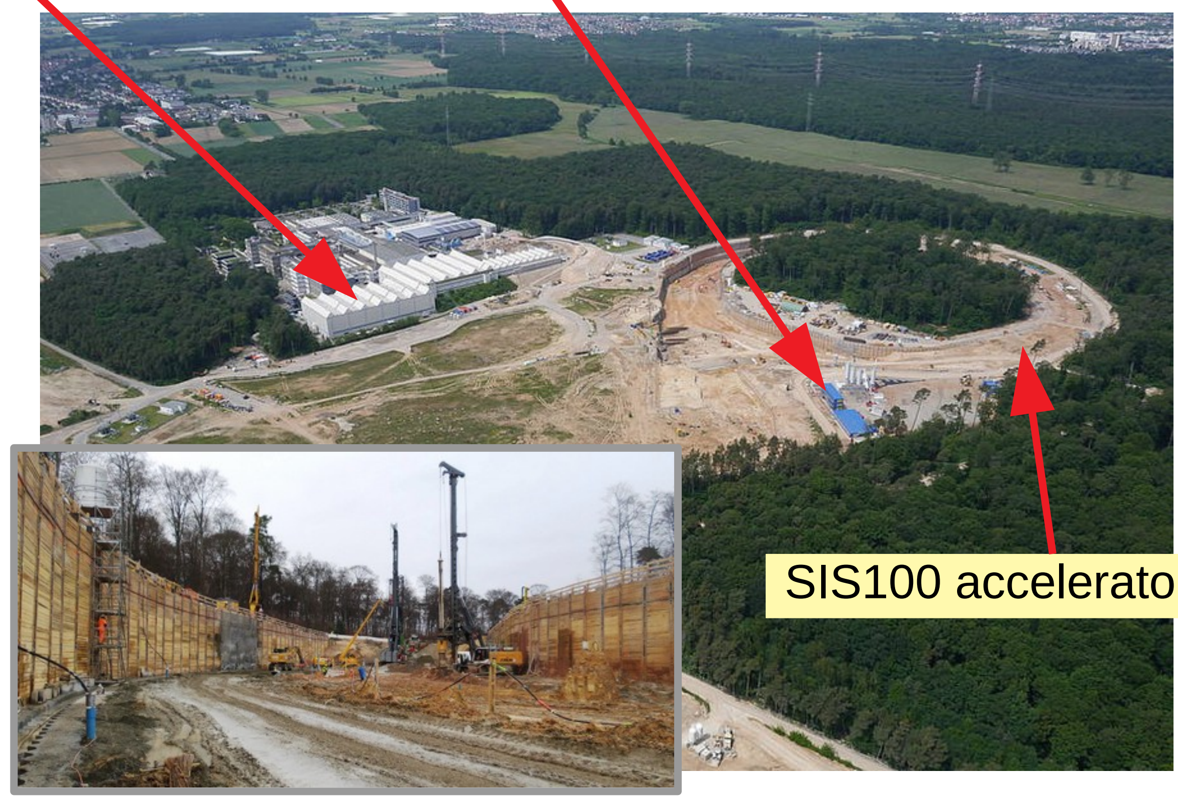
HADES RICH upgrade:
Technical University Munich, Germany
Giessen + Wuppertal University
GSI Darmstadt, Germany
TRB collaboration

Present status of FAIR - Facility for Anti-Proton and Ion Research



Artist view of the future FAIR facility

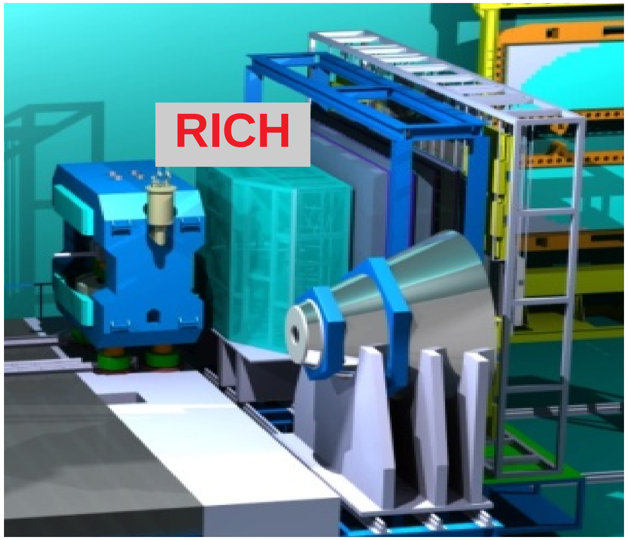
- FAIR civil construction started 4th of July 2017
- Much progress during last year !
- This summer:
  beam back in GSI SIS18
  (after 4 year shutdown for upgrades)
- **HADES physics run autumn this year**

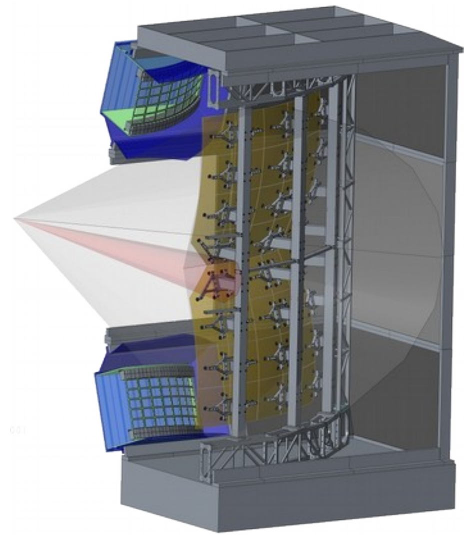


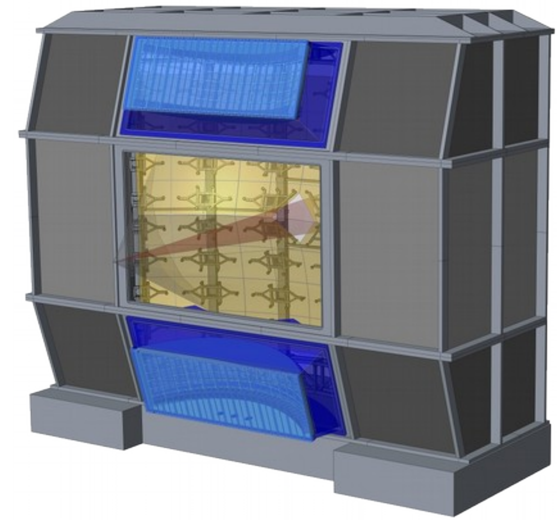
The FAIR construction site as it looks today

Bilder: GSI Helmholtzzentrum für Schwerionenforschung

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)

- **CO_2 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

Updated CBM timeline:

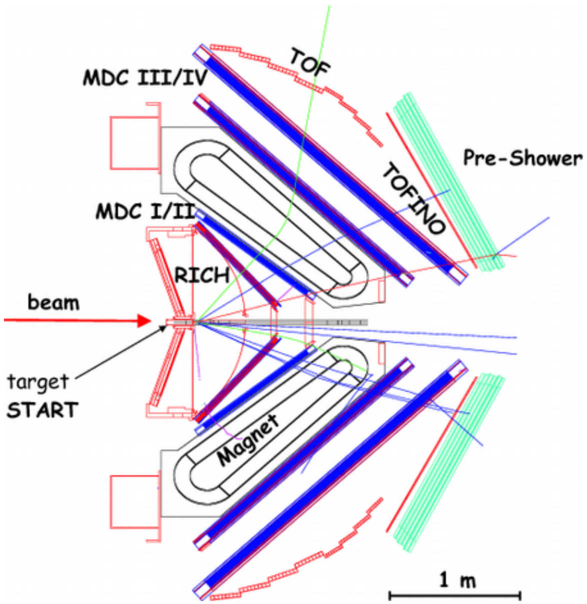
2014	Technical Design Report approved
2019	Conceptual Design Review
2019	Production of first components
2022/23	**Installation in the cave**
2024	First beam

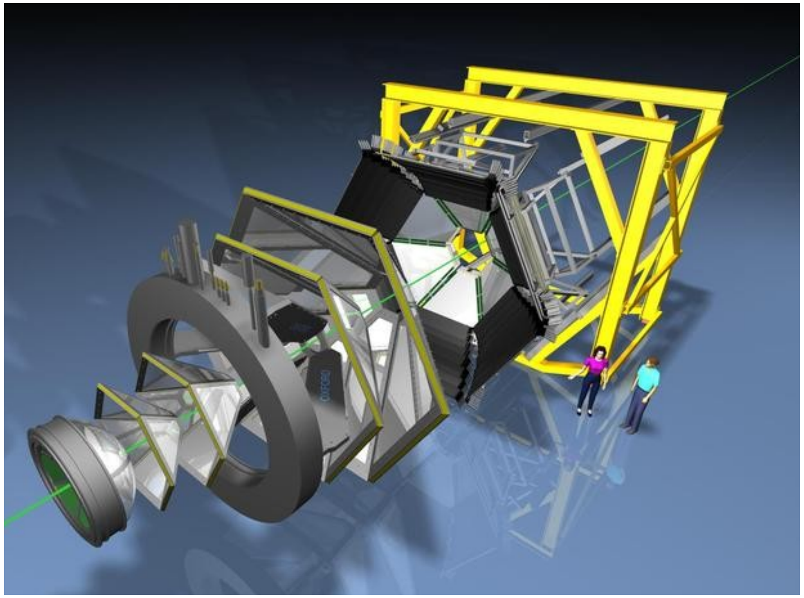
Challenges:

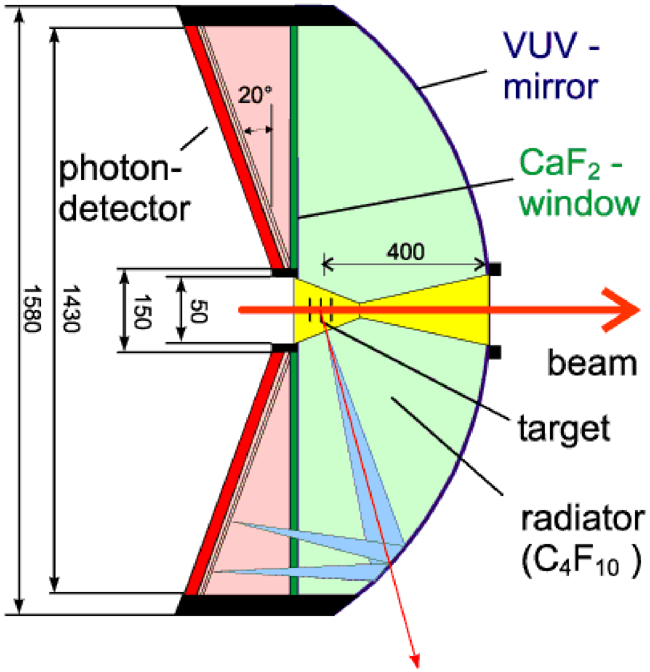
- High rate (up to 100 kHz photon rate per pixel)
- Magnetic stray field from CBM magnet (shielding box)
- RICH downstream of tracking system
- Free-streaming readout
- Moveable by crane

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

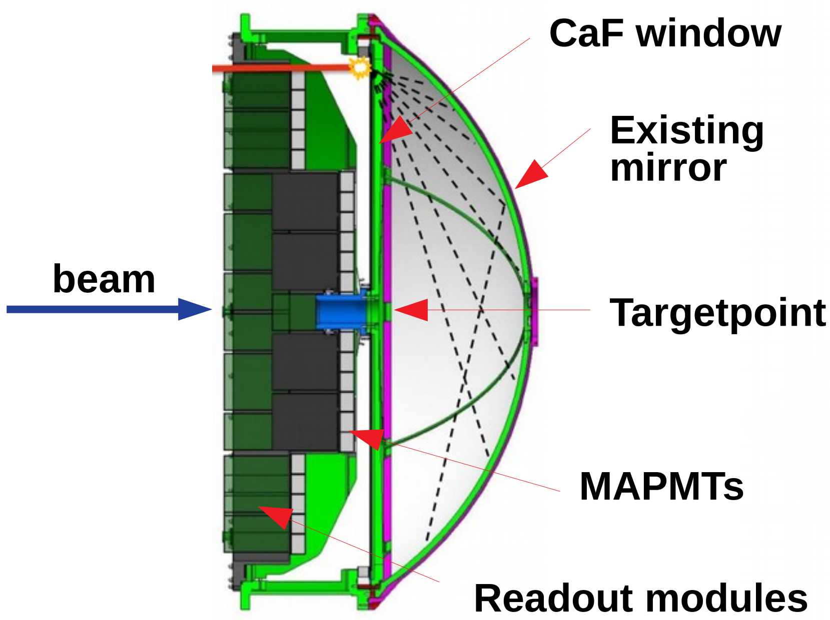
→ **extensive detector upgrade program**

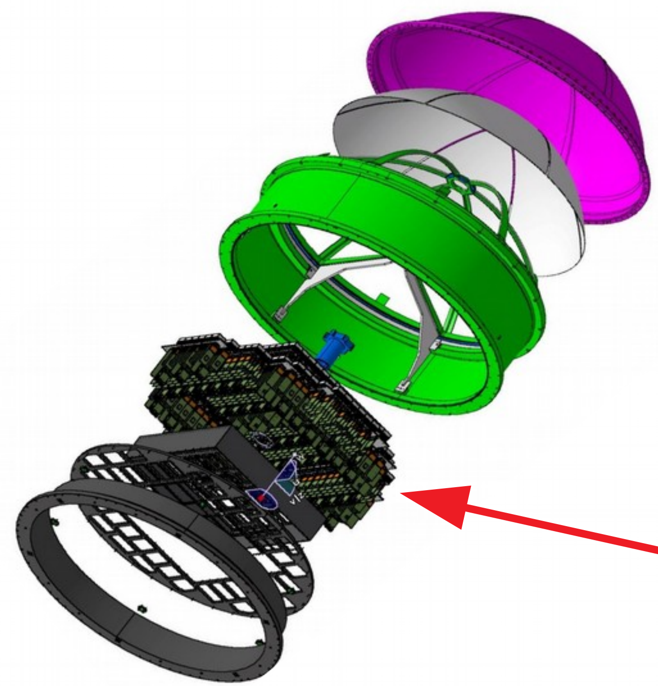
"Old" HADES RICH:

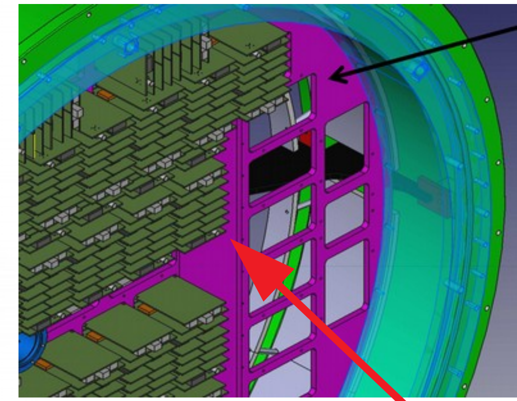
C_4F_{10} radiator
Low material budget, carbon mirror
Hadron blind detector
Electron id 15 MeV/c < p_e < 1.5 GeV/c

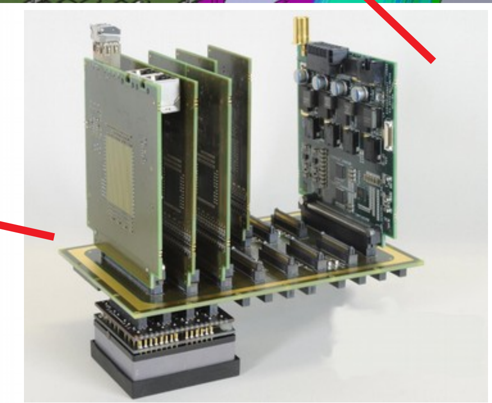
Reflective **CsI cathode**
Deep-UV, 145nm – 210 nm
MWPC readout

Photon detector upgrade of HADES RICH









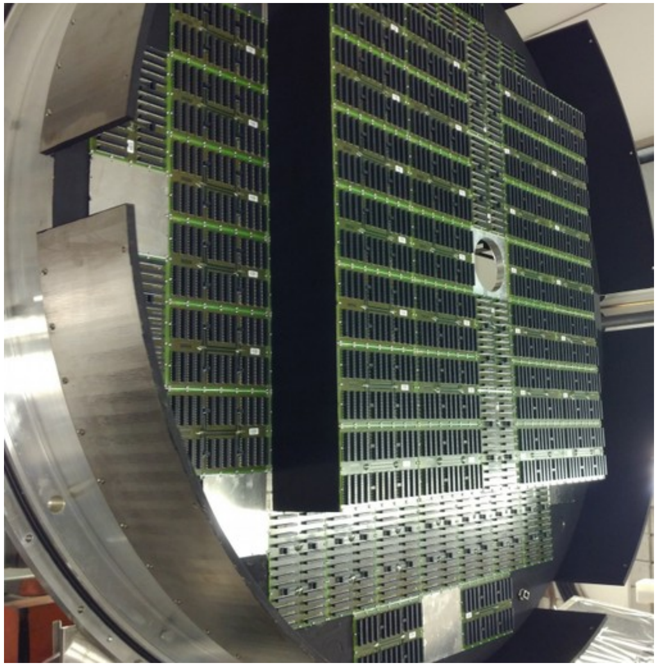
Motivation:
- Ensure stable RICH operation for future FAIR program, - 2025 and beyond
- Improve close-pair dielectron reconstruction (essential for future physics program)

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 C_4F_{10} radiator volume

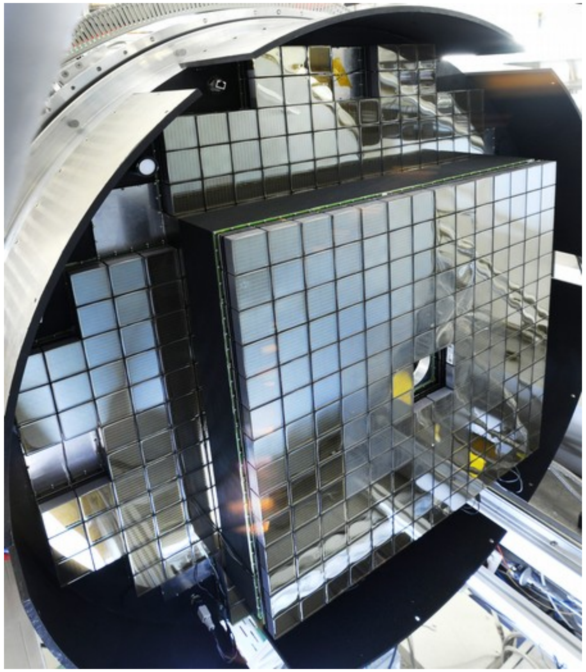
- Center part of photon detector 10 cm elevated (→better match focal plane)

Validated in detailed Monte Carlo simulations

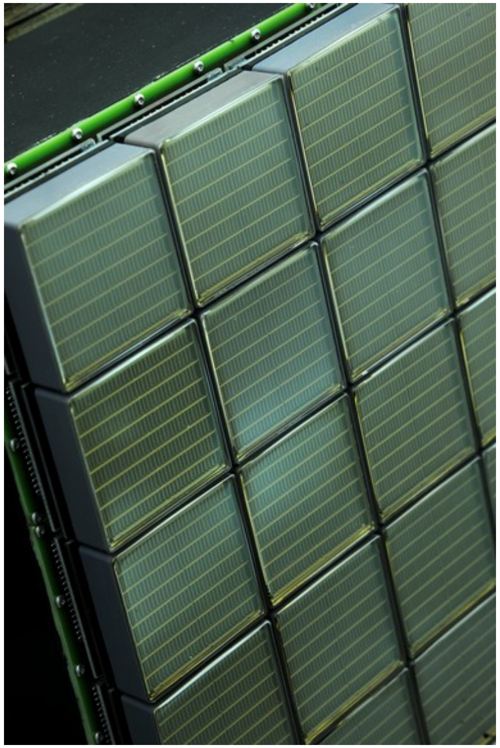
New photon detector with MAPMTs mounted



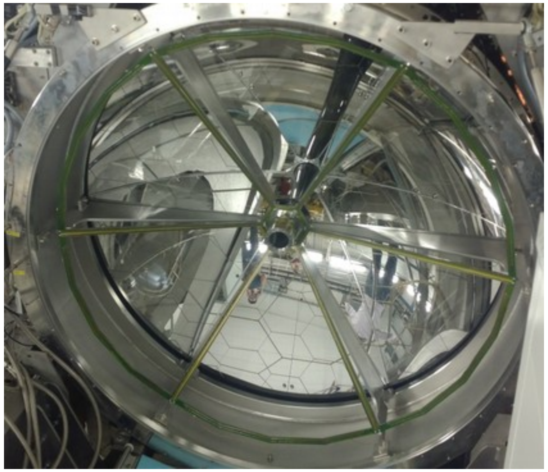
New photon detector flange
after installation of PMT backplanes



… and after installation of the
first 396 MAPMTs



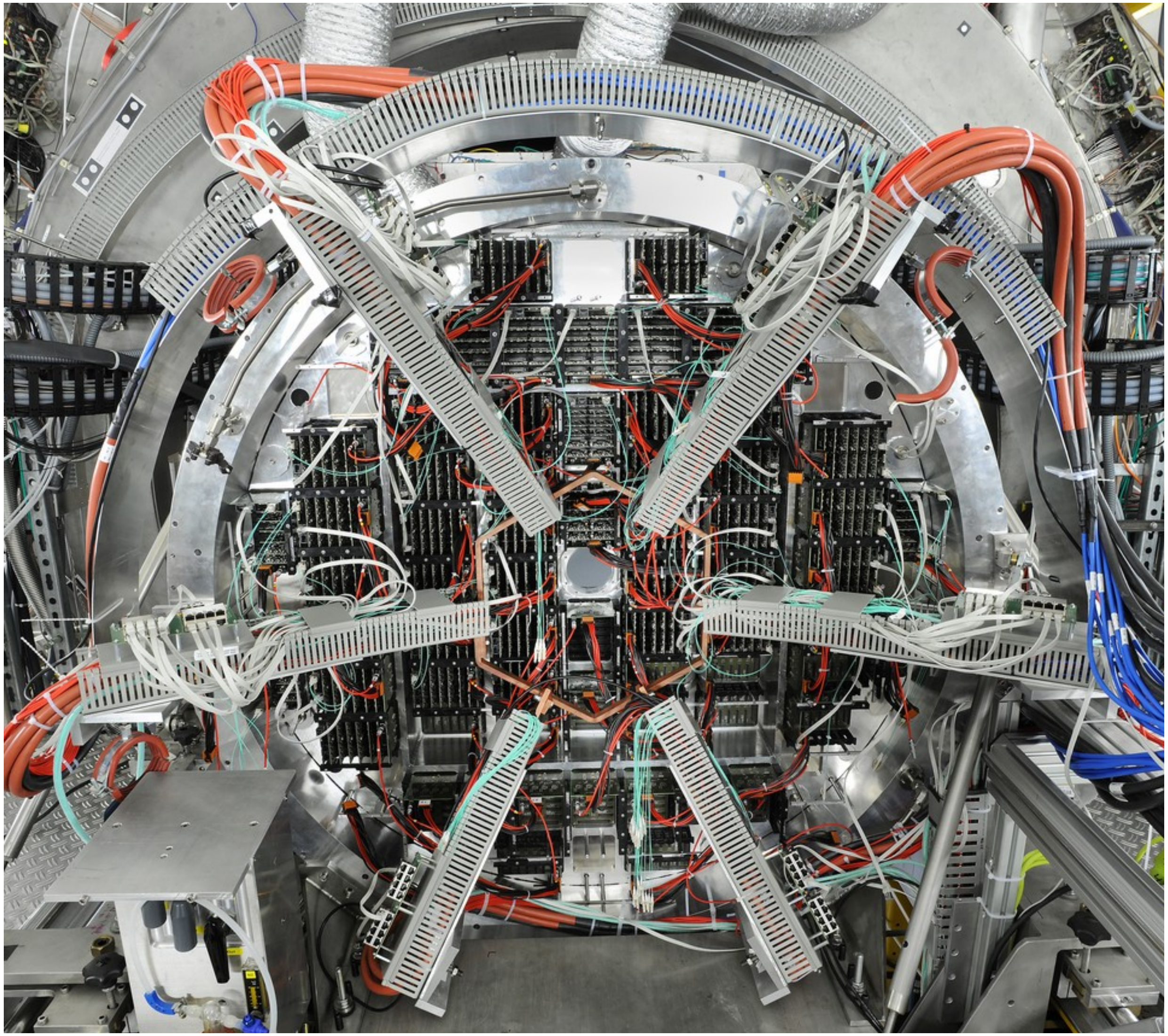
Close-up of MAPMTs
mounted on backplanes



HADES RICH mirror with
CaF window in front

photos by G. Otto, GSI

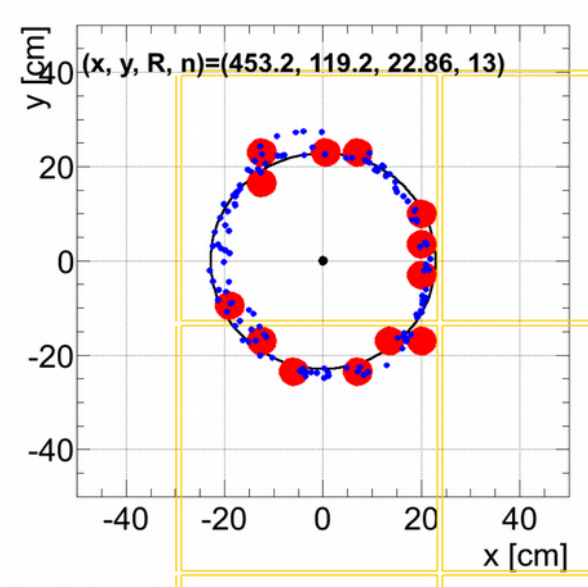
New photon detector readout electronics



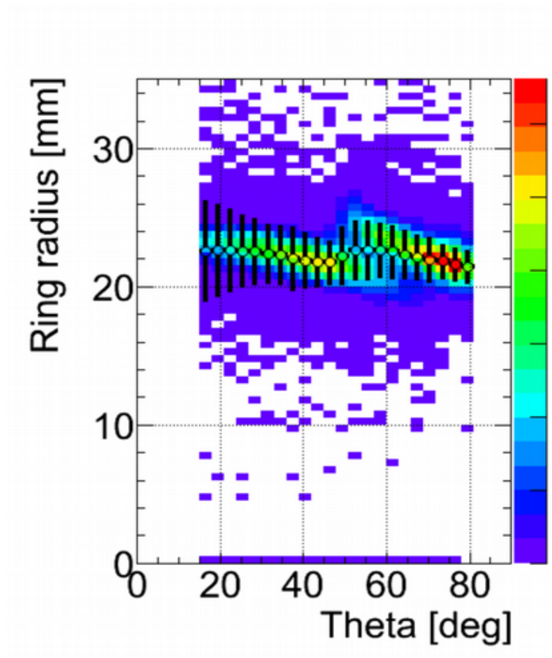
Backside of photon detector with readout modules installed

Total power dissipation: 2.5 kW,
present cooling concept: enforced air cooling

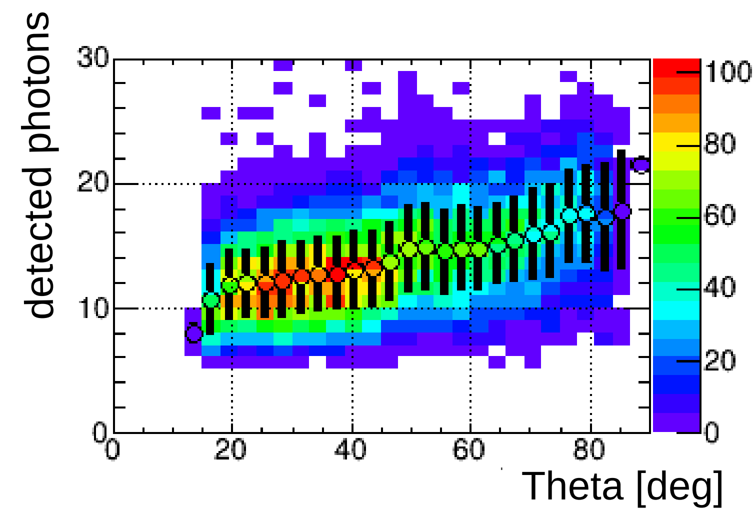
Selected simulation results – single electrons



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



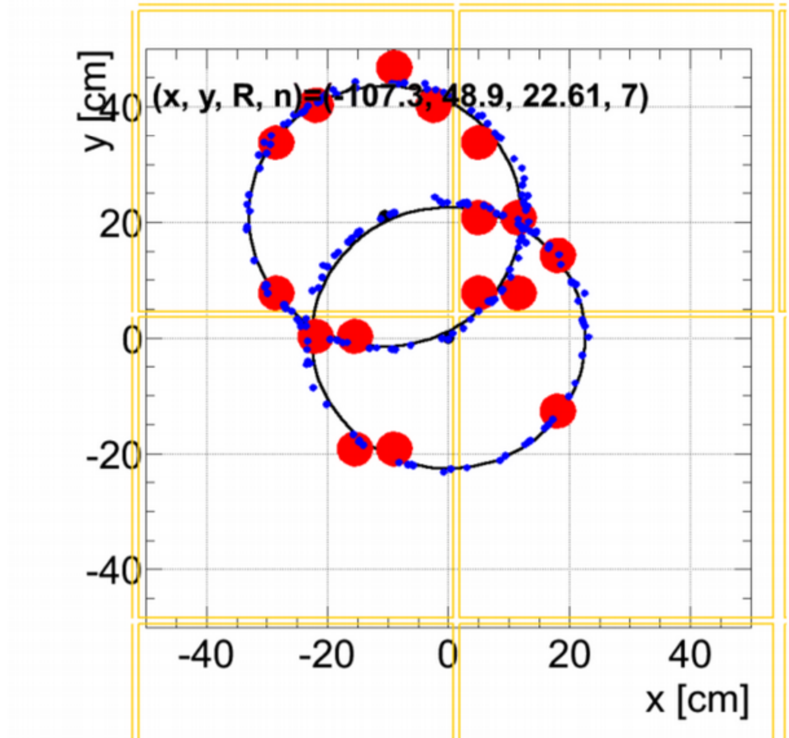
Cherenkov ring radius
as function of scattering angle

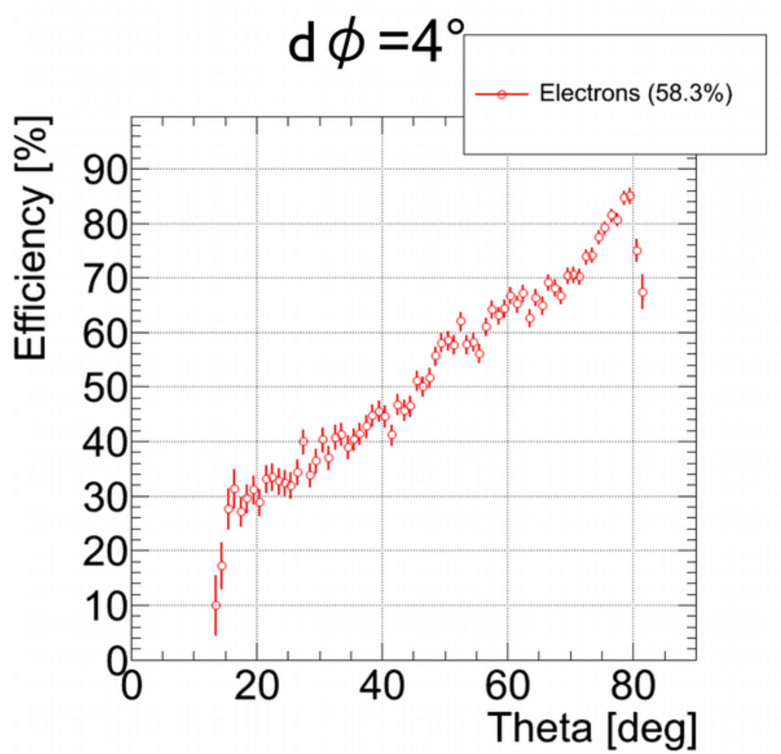


Number of detected photons
as function of scattering angle

- **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





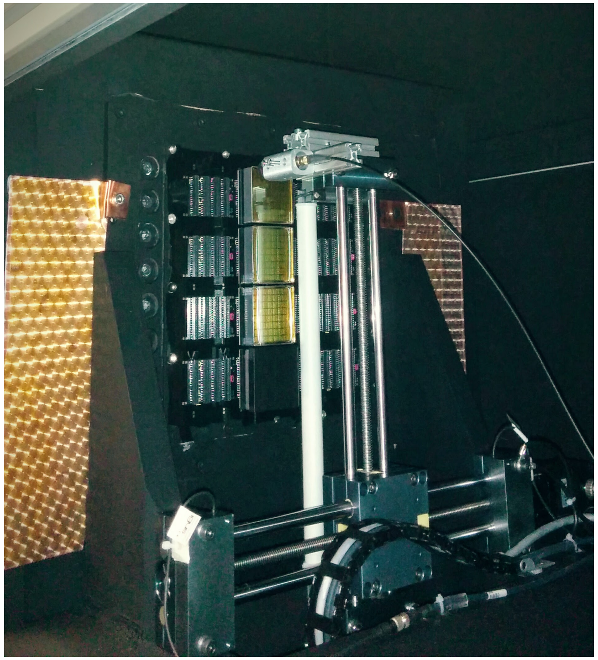
Reconstruction efficiency for dilepton pairs with small opening angle (4°)

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

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

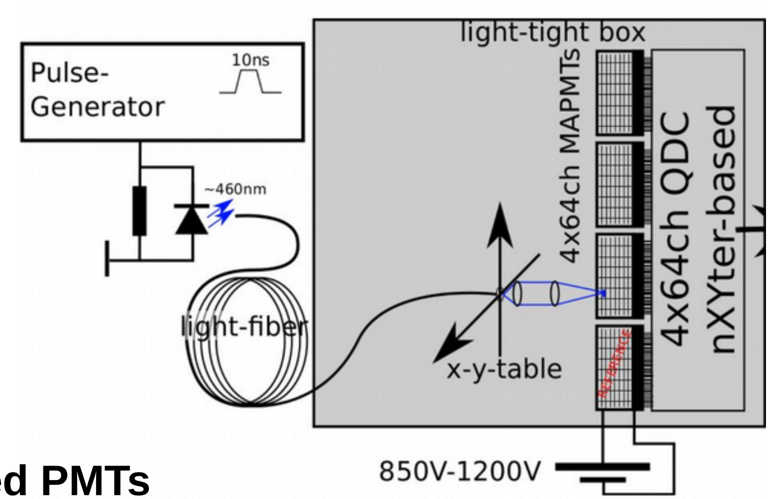
Delivery of MAPMTs: Autumn 2015 - November 2017



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

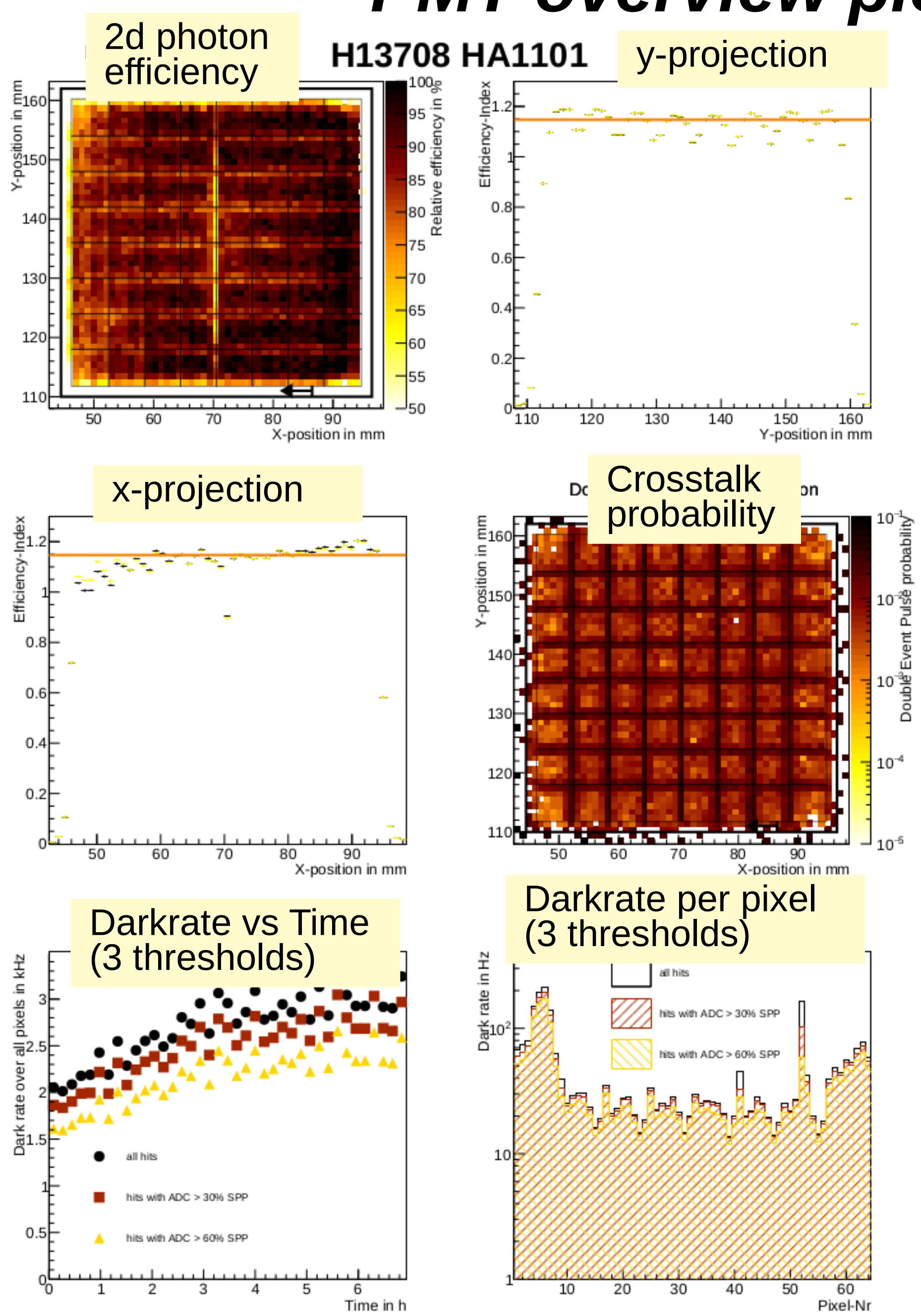
Test stand for spatially resolved single-photon scans:
- Pulsed laser light source, ca 0.1 photons / pulse
- XY-table for point illumination (spot size < 1 mm)
- Self-triggered, free-streaming readout, ADC + TDC
- 3 PMTs (+1 reference PMT) per scan (8 hr)

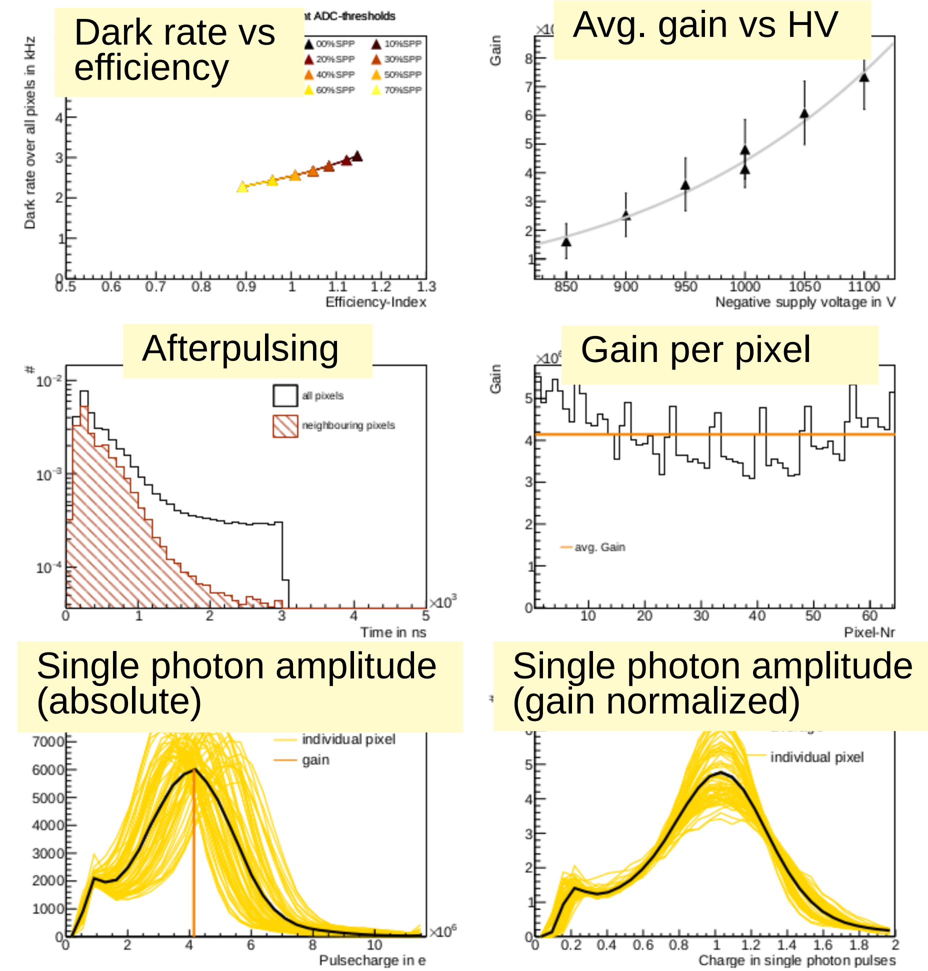
From single scan:
- Single-photon detection efficiency (xy-resolved)
- Single-photon amplitude spectrum (per pixel)
- Gain
- Dark rate
- Gain dependence on HV
- Afterpulsing
- Crosstalk
- ...



+ dedicated measurement of quantum efficiency for selected PMTs

PMT overview plot for each MAPMT





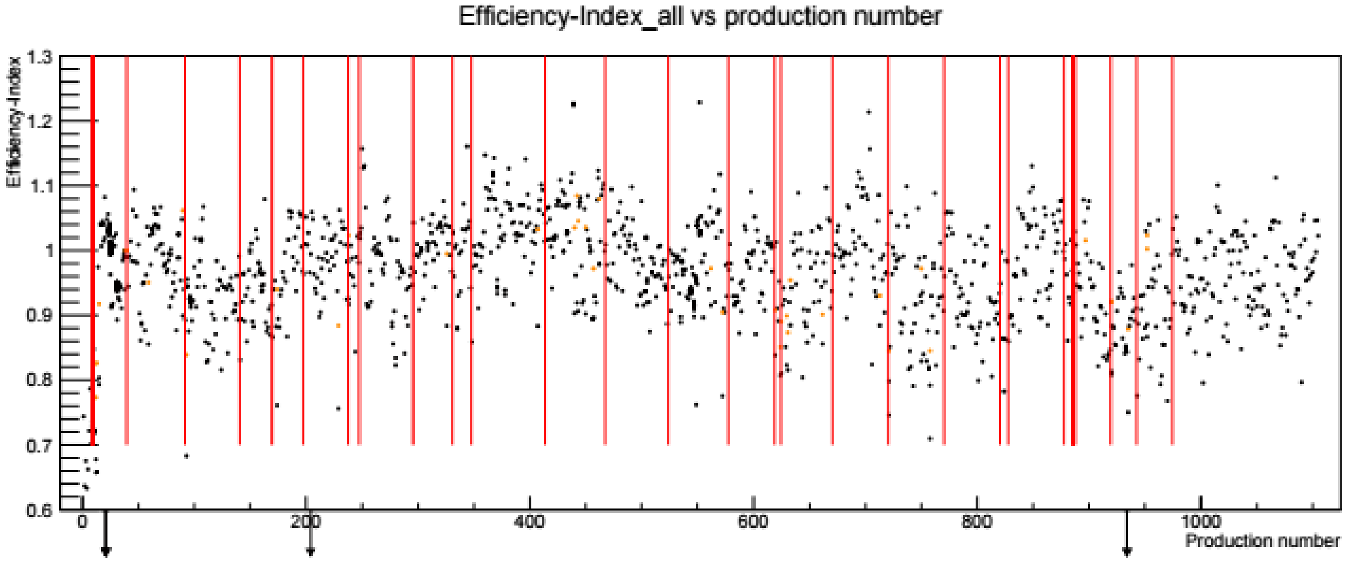
H13708 HA1101 / meas.-date: 160713_0846 / meas. -pos: 3 / extrapolated meas.-points: 0

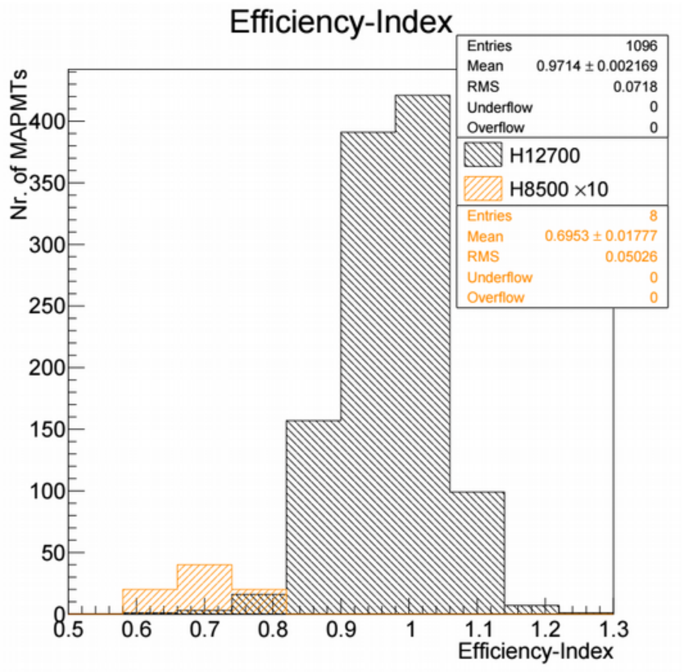
Efficiency-Index:	1.147
Effective Area: Area w.(rel. Eff.>60% / Eff.-I.>0.8):	85.37%/84.92%
Efficiency Skewness in X-direction:	0.949
Afterpulse Probability (w/wo-noise):	2.183%/2.013%(neighb.px)3.786%/2.576%(all-px)
Average Double-Event-Signal Probability:	1.119%/0.605%(corrected for light-intensity)
Average Gain at -1000 V over all pixels:	4.143E+06 (ADC-shift:155.70/107.27)
Extrapolated Gain at -1000V:	4.413E+06
Temperatrure during/late scan, electronics	30.14 deg.C/30.72 deg.C, 21.95 deg.C(FEB)
Dark noise of all pixels:	3.045 kHz, 1.533 kHz @25 deg.C
Highest Darknoise in one pixel:	214.924 Hz, 108.249 Hz @25 deg.C

Efficiency index over time

"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)

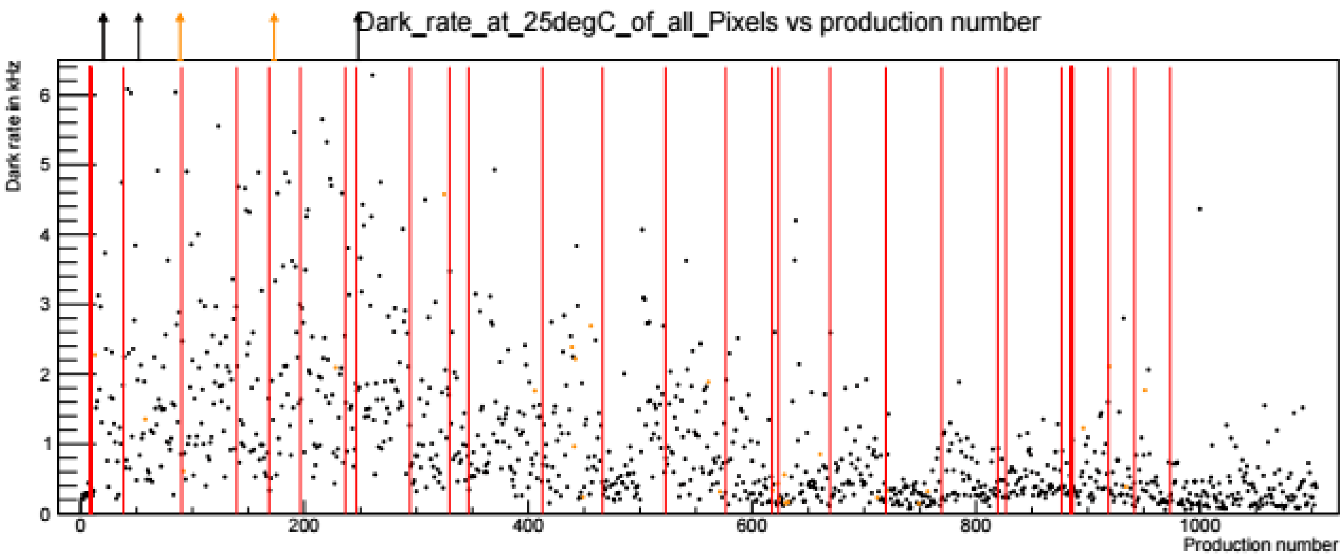


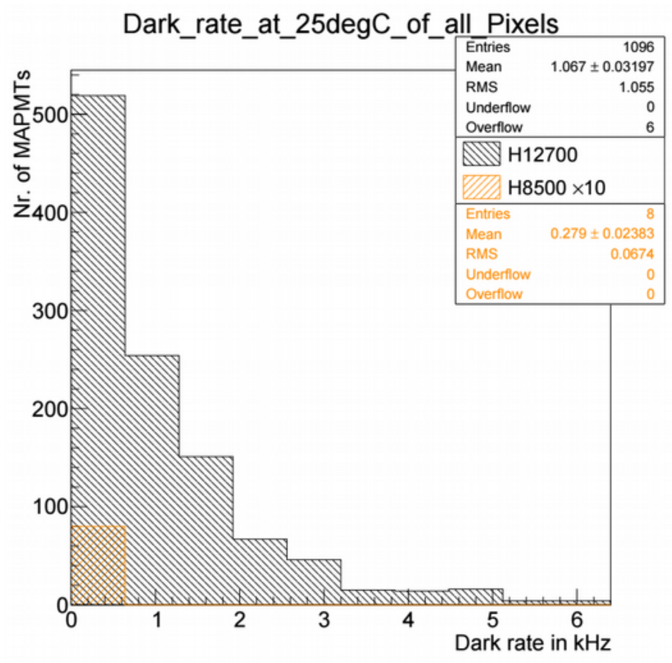


- Fairly constant over production time, variation ~ +- 10%
- 30% improved efficiency compared to old H8500 MAPMTs

MAPMT dark rate over time

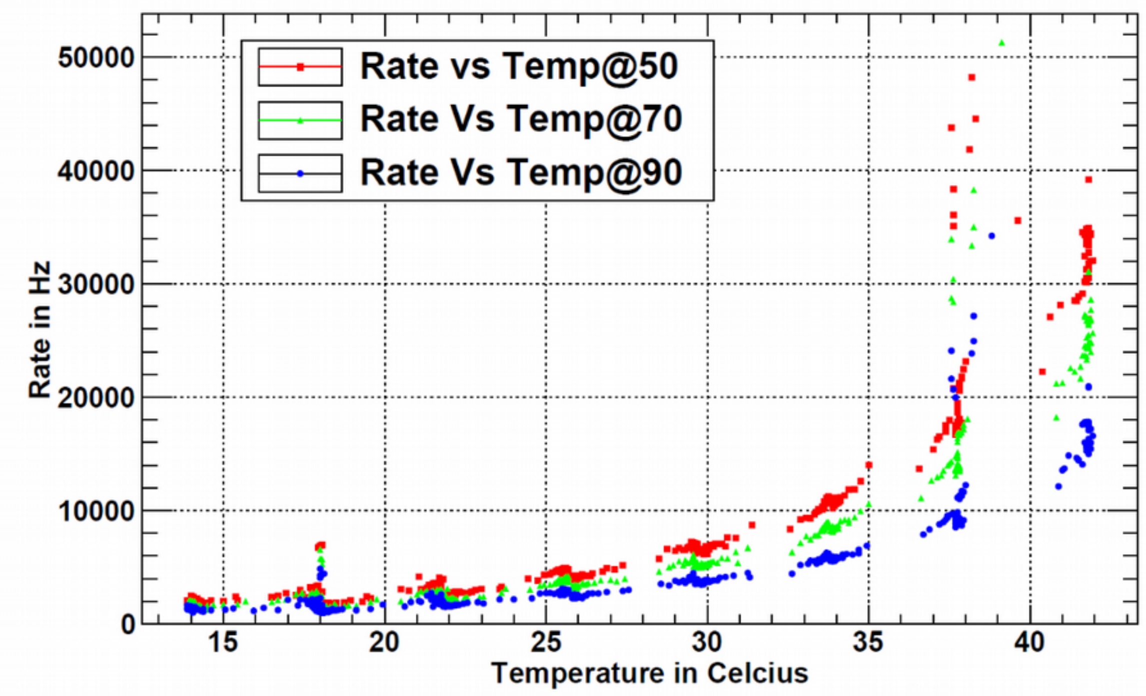
PMT total dark rate (sum of 64 pixel), 25°C
- threshold ~ 30% of SEP peak
- measured after ~7 hr operation in total darkness
- Dark rate corrected for PMT temperature





- 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



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

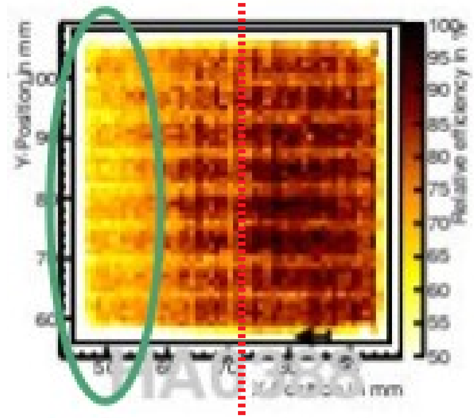
with **λ ~ 0.12 K^{-1}**

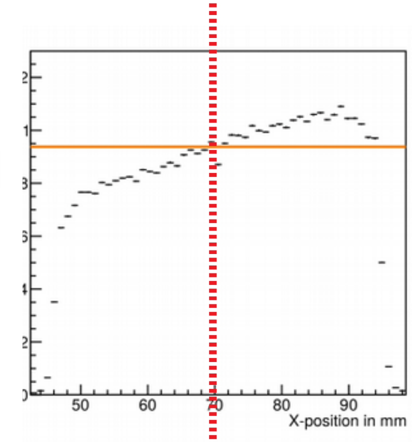
PMT darkrate as function of temperature for 3 different threshold values
(~ 20% … 40% single photon peak)

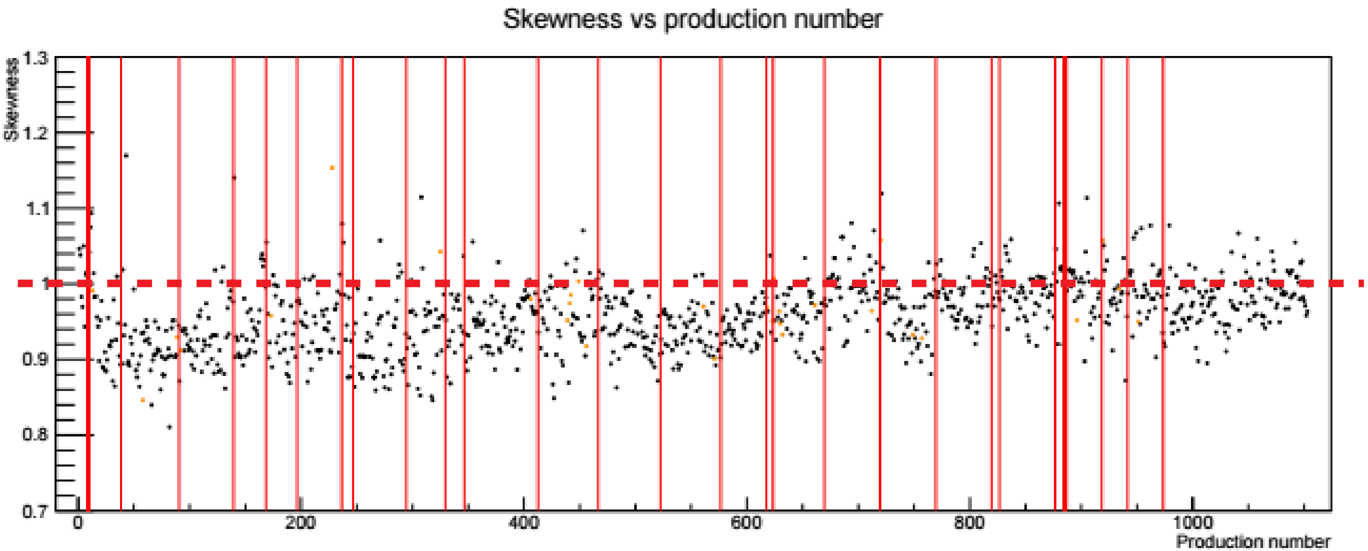
- λ parameter from fit to 5 MAMTS:
  fairly constant for all tested H12700 MAPMTs
- Allows to extrapolate measured dark rates to 25° “standard” temperature
- Strong increase in dark rate seen already at ~40° (due to exponential temperature dependance)
  → important for cooling design

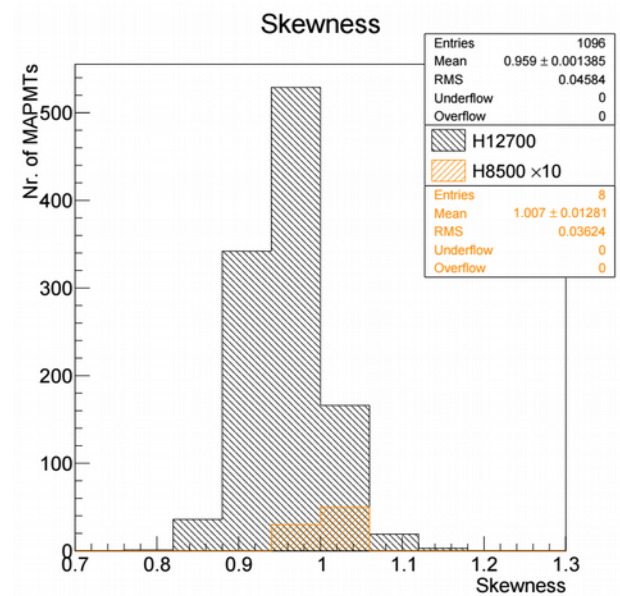
”skewness” number over time

“Skewness” factor:
average efficiency index left half / right half







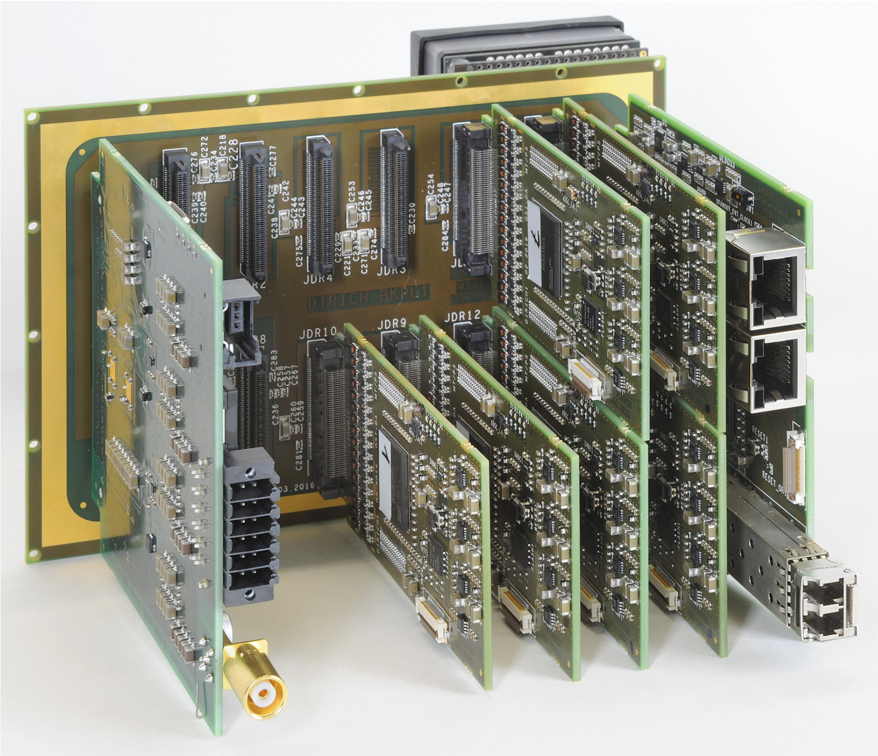


- Skewness not observed for H8500 MAPMTs
- “Skewness” improved over time (after feedback to Hamamatsu)

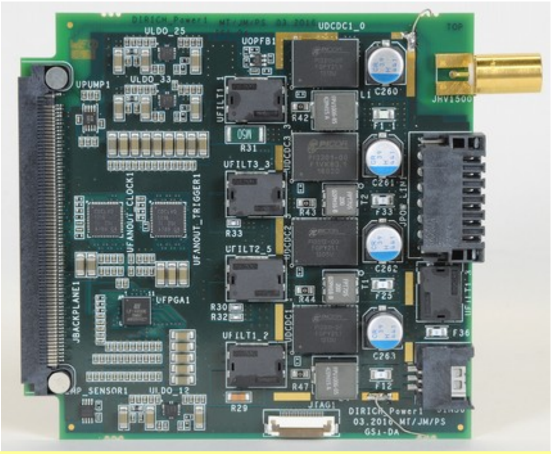
The DIRICH readout chain

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

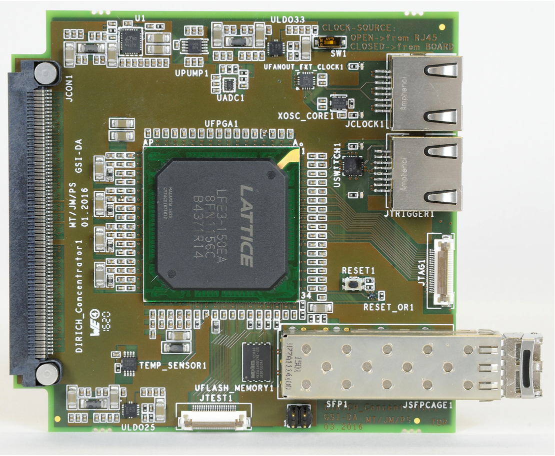
32ch DIRICH
frontend module



3x2 MAPMT backplane
(with few modules equipped)

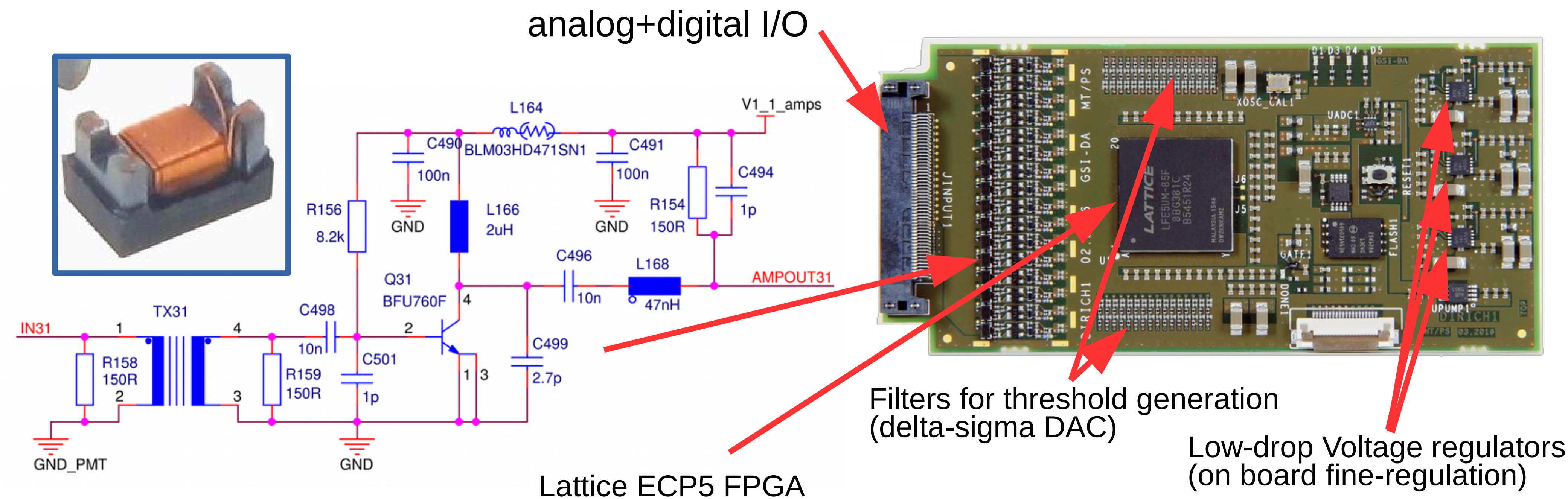


DIRICH-Power module
(LV + HV supply, DCDC)



DIRICH-Combiner module

DIRICH frontend module



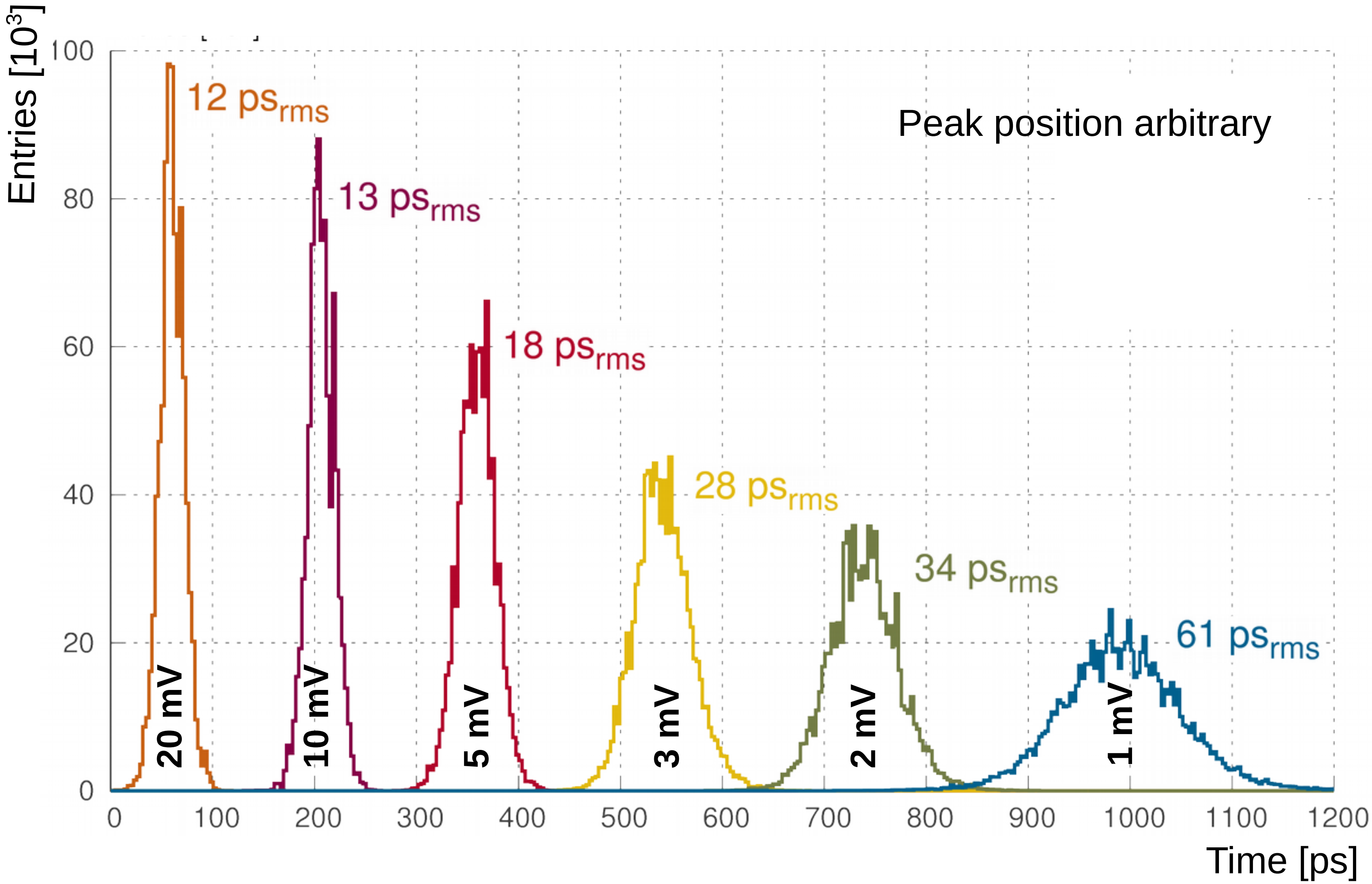
- 32ch analog amplification, discrimination, leading+trailing edge TDC, digital control all implemented on single FPGA with few discrete elements only

- **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



Time difference between two DiRICH channels with same analog input signal

Excellent timing precision down to 1 mV pulse amplitude

PMT **T**ransit**T**ime**S**pread will be the limiting factor

Effect of cut on Pulsewidth

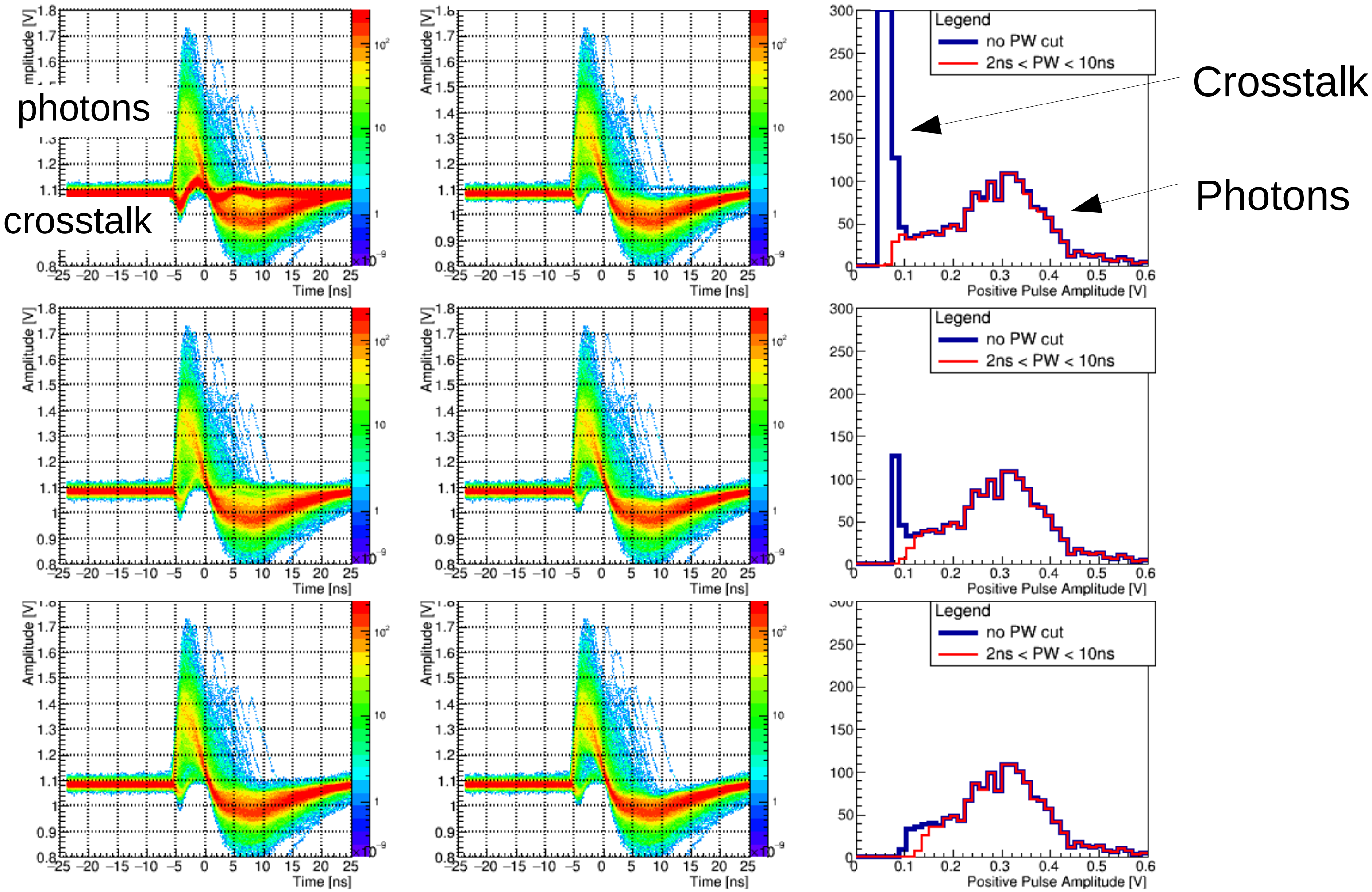
Cut on threshold only | **Additional cut on PulseWidth: 2ns < PW < 10ns** | **Amplitude spectrum w / wo cut**

Signal threshold:

50 mV

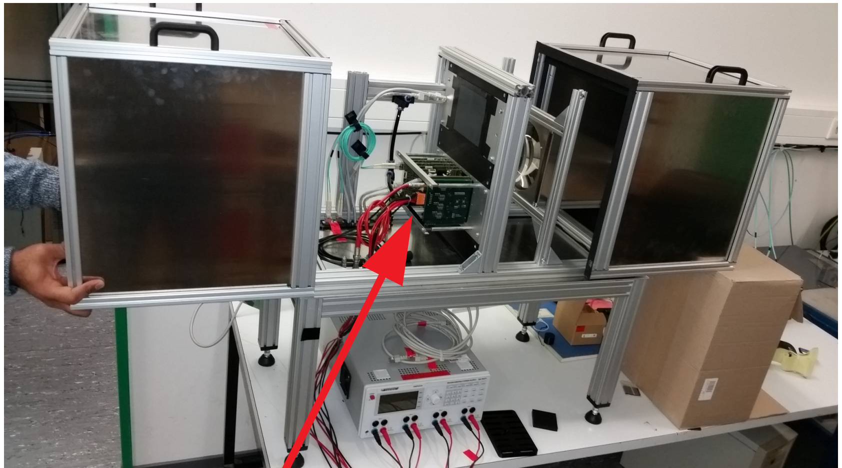
75 mV

100 mV



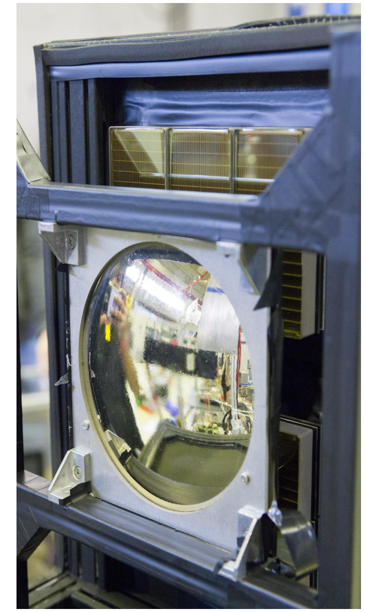
PMT single photon response after DIRICH-preamplifier and shaping
(derived from scope signal traces)

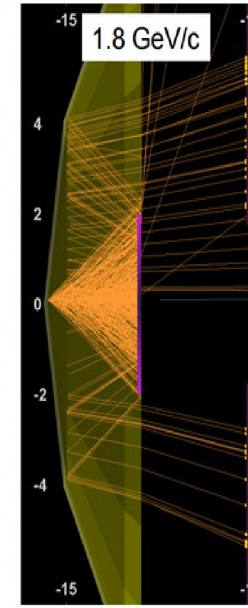
RICH@COSY prototype



2pc 3x2 readout modules,
24 (-2) DiRICH modules,
12 MAPMTs

setup 1:
Proximity focussing setup
3mm quartz glass radiator

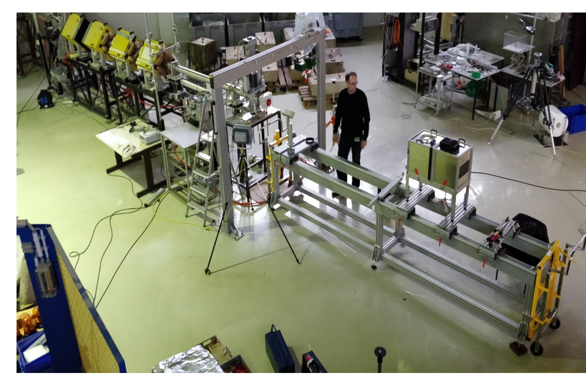




setup 2:
Focussing setup, borosilicate lense
as radiator and focussing mirror
(idea borrowed from LHCb)

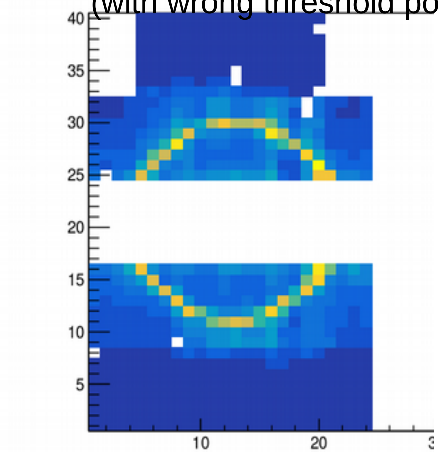
- Final test of readout chain before production
- COSY accelerator, FZ-Juelich
- Proton beam, 1.8 GeV/c

- Two different setups:
  proximity focussing / lense focussing setup

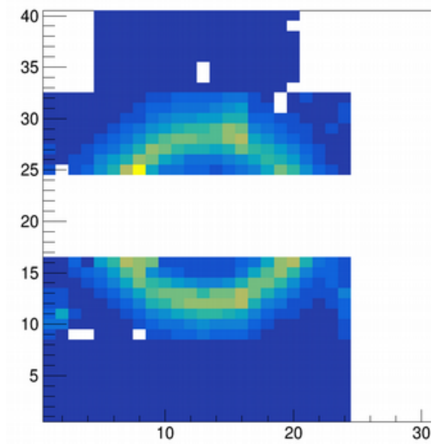


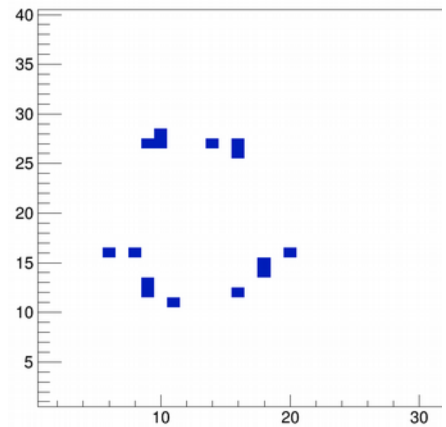
Photon detection efficiency

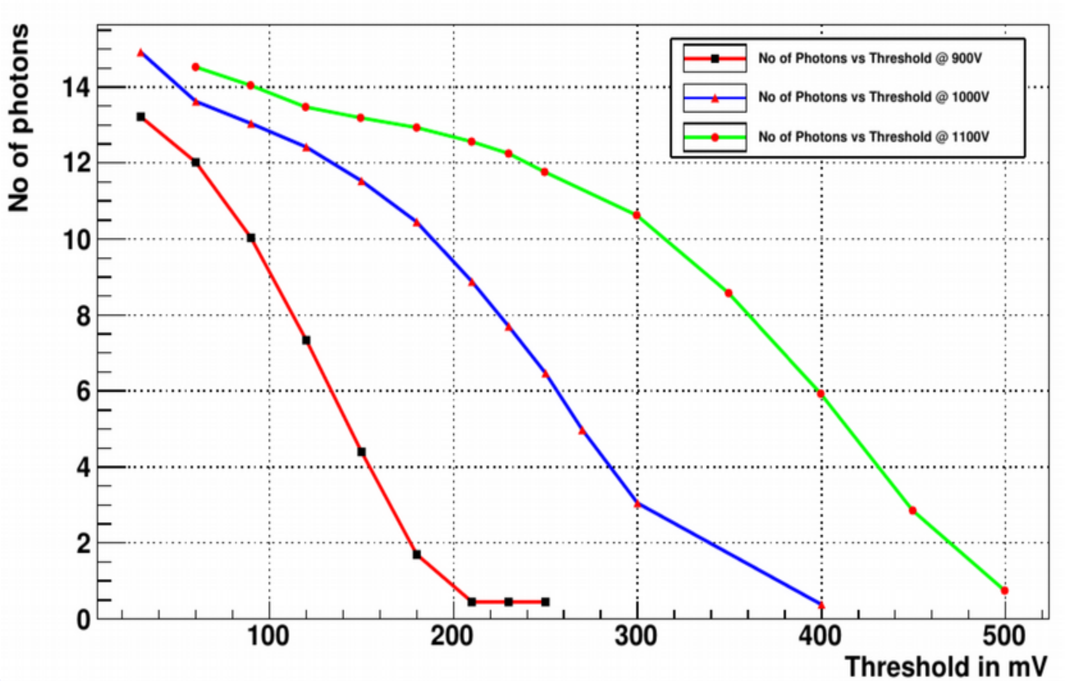
Lense setup:
$E_{kin,p}$=1730 MeV
(with wrong threshold polarity)



Proximity focussing:
$E_{kin,p}$=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

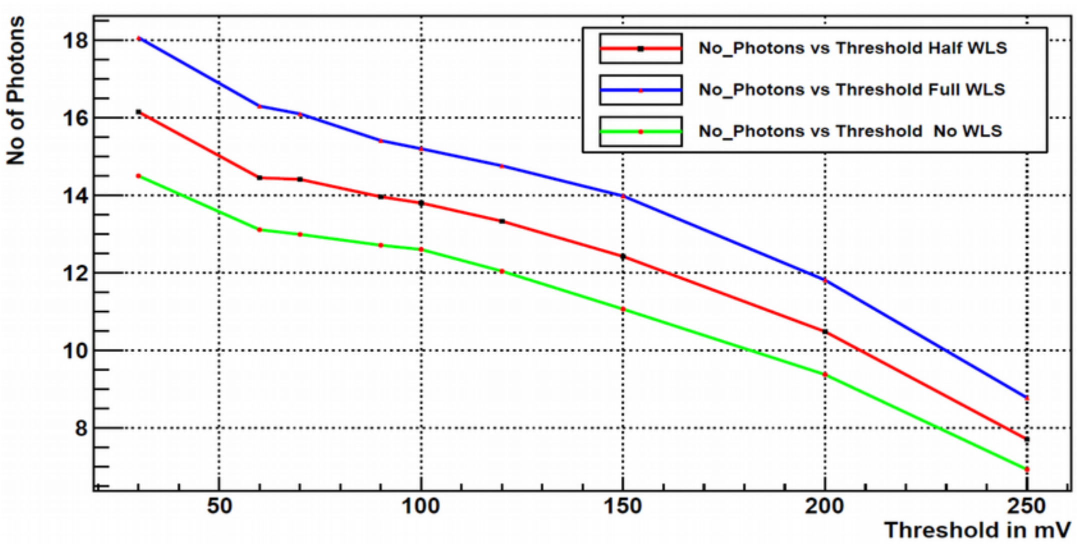
Effect of WLS on efficiency

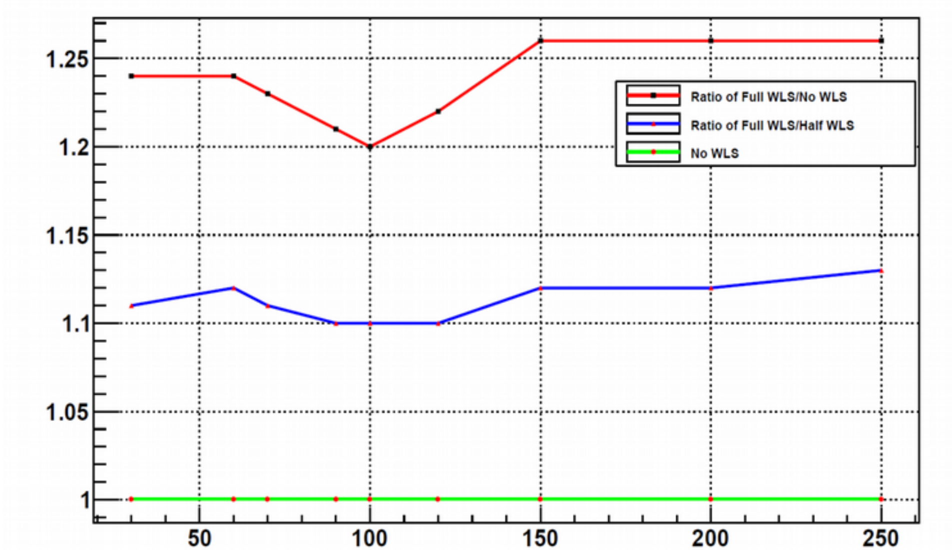
- Both HADES and CBM will use gaseous radiator : C4F10 / CO2
  → most Cherenkov photons expected in UV range
  → Cherenkov photon yield usually THE critical parameter when building a RICH

- 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

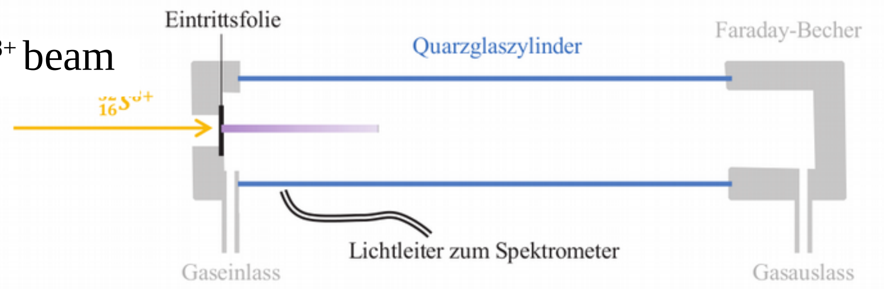




Ratio of different multiplcity vs Threshold in mV

choice of radiator gas (CO_2) motivated by low fluorescence

$_{16}S^{8+}$ beam



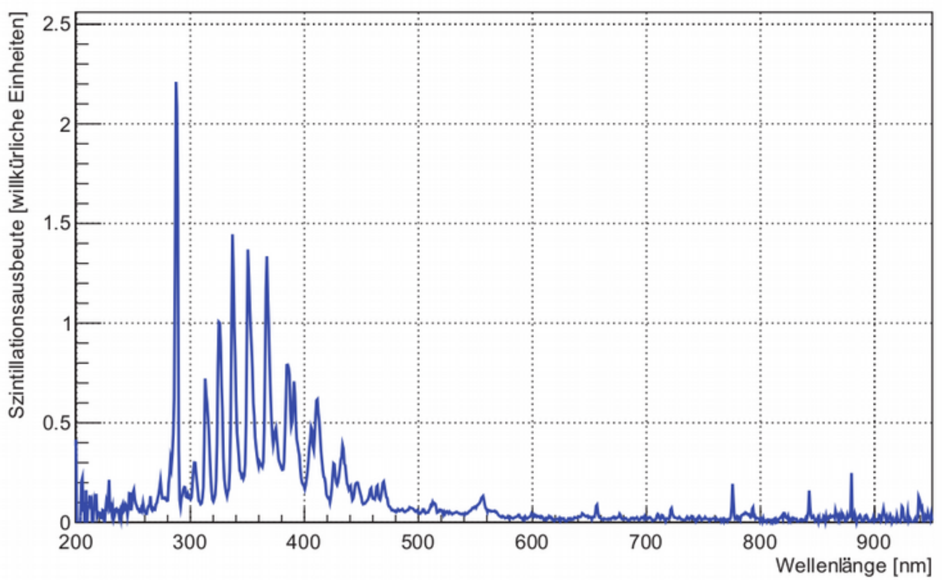


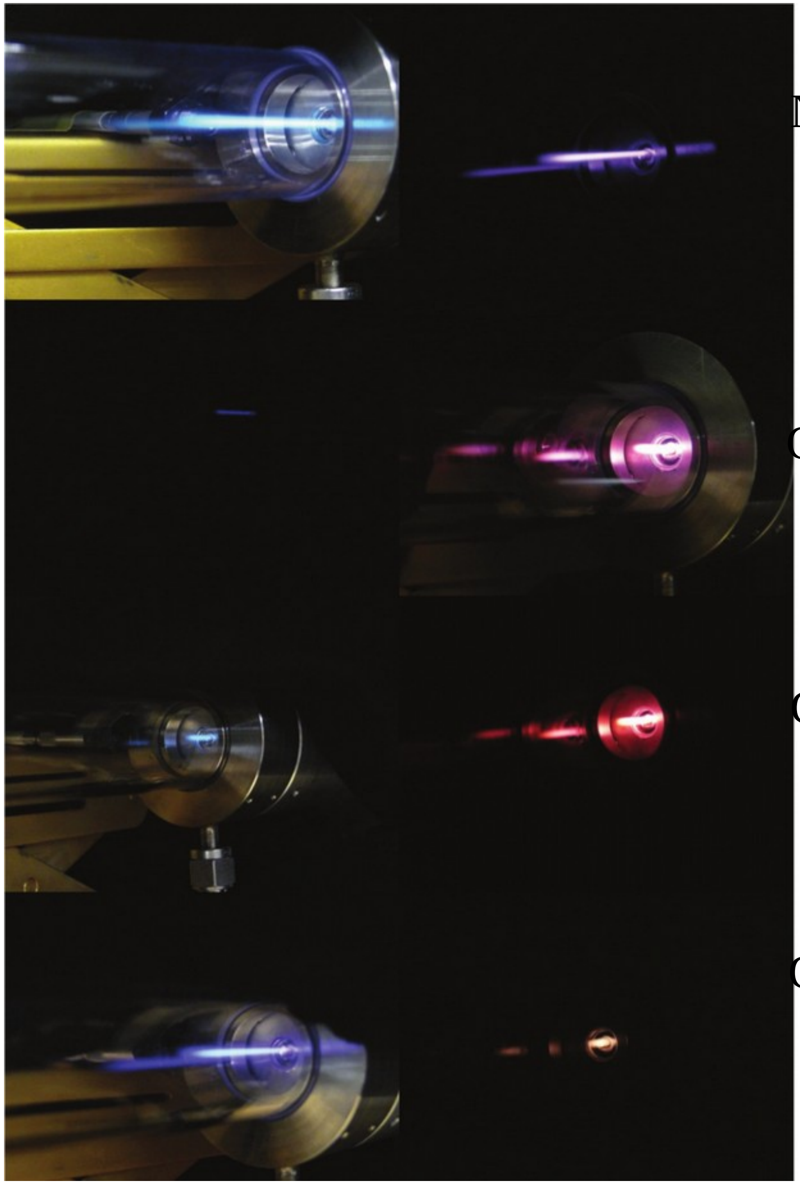
Abbildung A.8: Relativer spektraler Verlauf des Szintillationslichts von CO_2 bei einem Druck von $p = 970$hPa und Anregung durch einen Schwefelstrahl.

Ar

CO_2

CH_4

C_4F_{10}



N_2

CF_4

C_3F_8

C_4H_{10}

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 m^3 / min, 200 mbar)
- Distribution masks already installed

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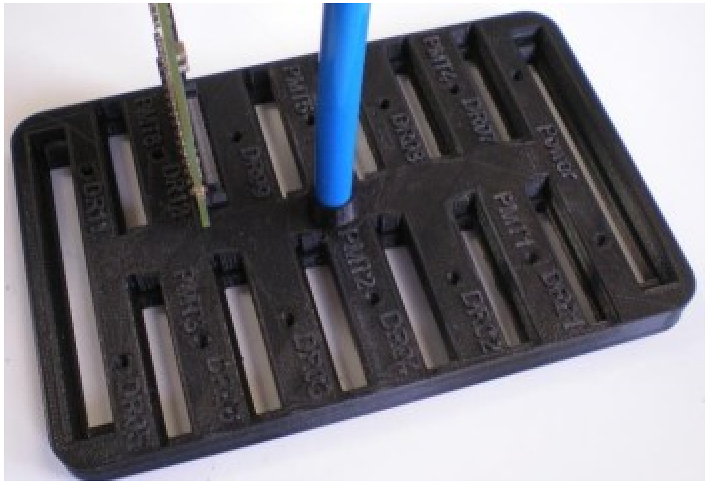

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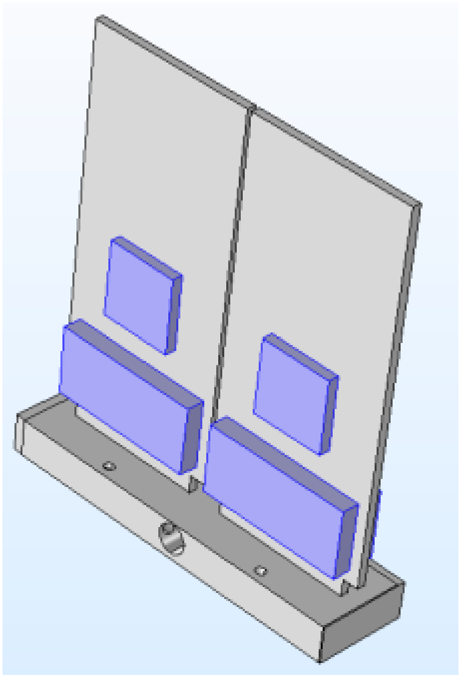
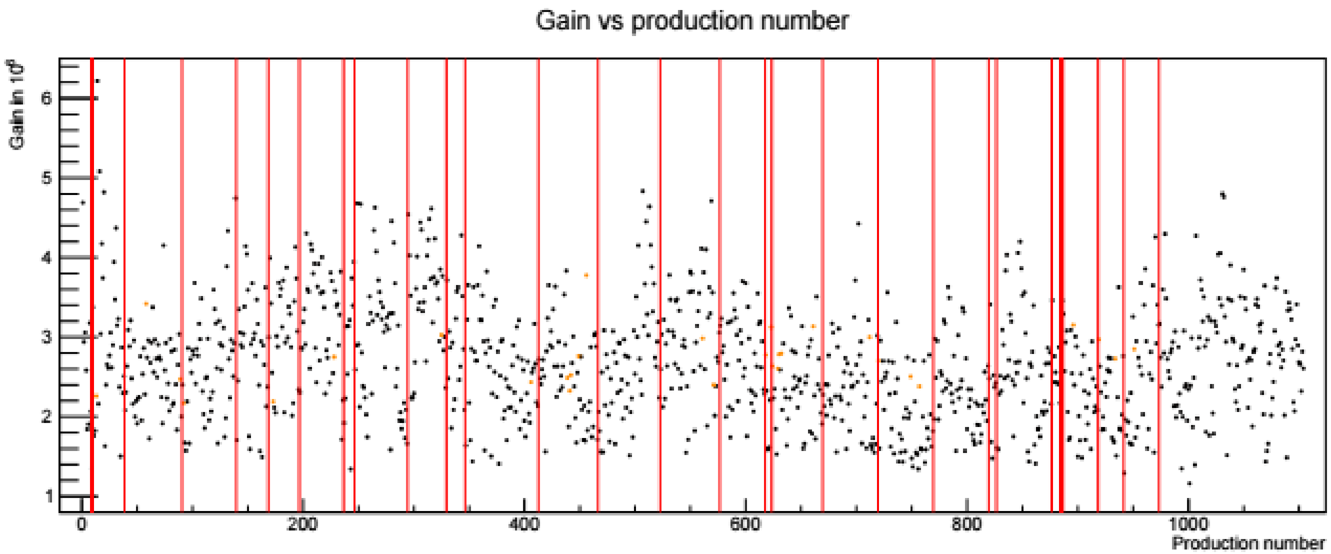
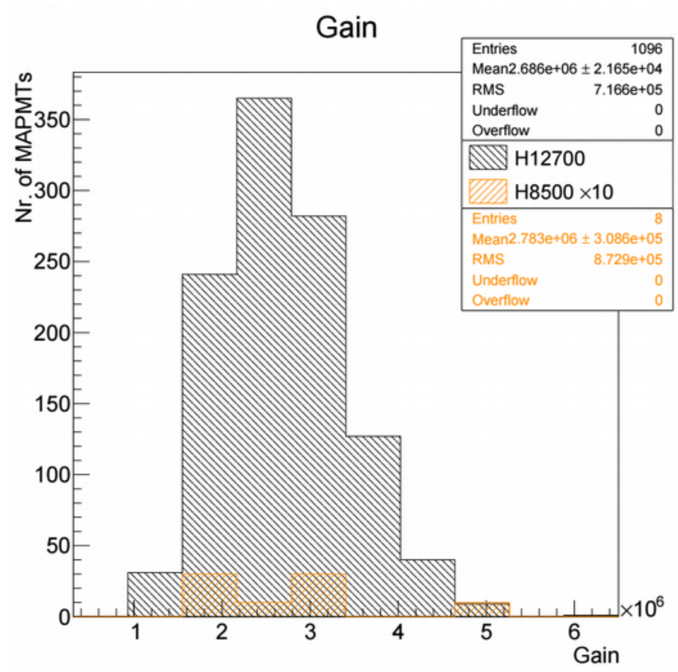


Selected results: gain @ 1000V

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: ~2.5×10^6, maximum ~ 5×10^6
- gain specification: > 0.8×10^6