JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

The Innovative Design of the Endcap Disc DIRC for PANDA at FAIR

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on behalf of the PANDA Cherenkov group

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HIC for FAIR
Helmholtz International Center

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HGS-HIRe for FAIR
Helmholtz Graduate School for Hadron and Ion Research

$\bar{\text{P}}$ANDA Spectrometer

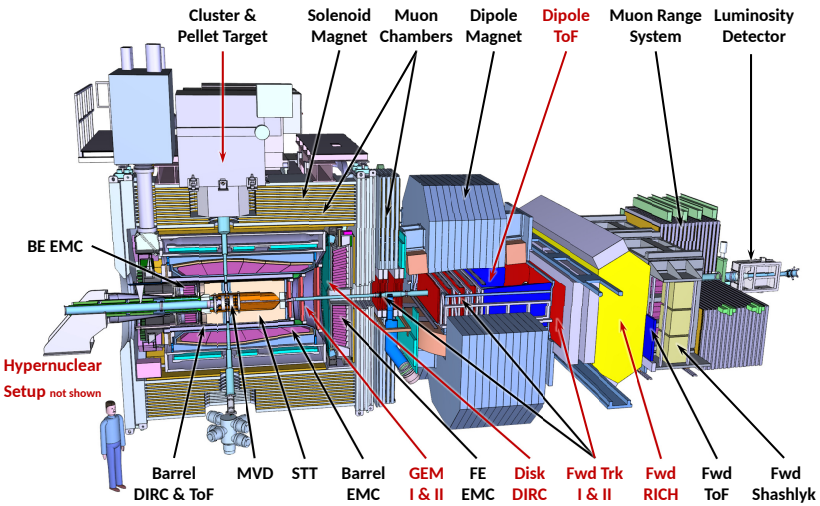
FAIR

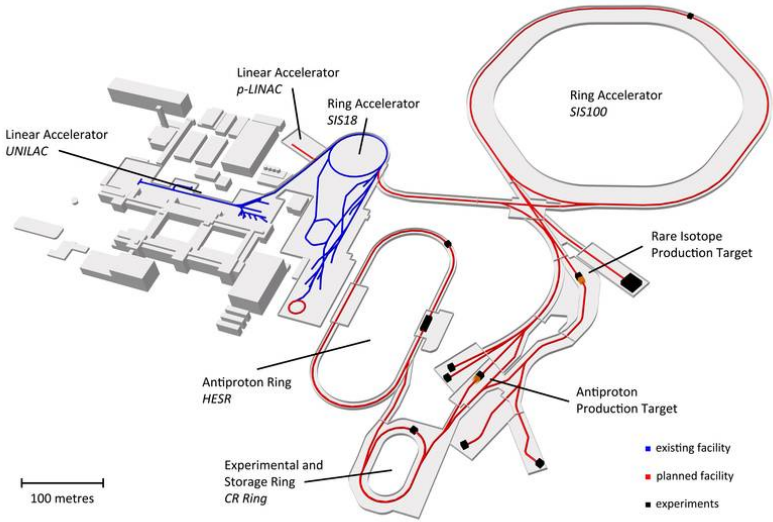
- Antiprotons $\bar{p}$ from HESR
- High luminosity mode:

$$\mathcal{L} = 2 \cdot 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$$

- Average interaction rate:

$$\dot{N} = 2 \cdot 10^{7}\,\mathrm{s}^{-1}$$





PANDA

- $\bar{p}p$ collisions with hydrogen target
- Created particles with forward boost in z-direction
- Excellent PID necessary to fulfill physics program goals

FAIR Construction

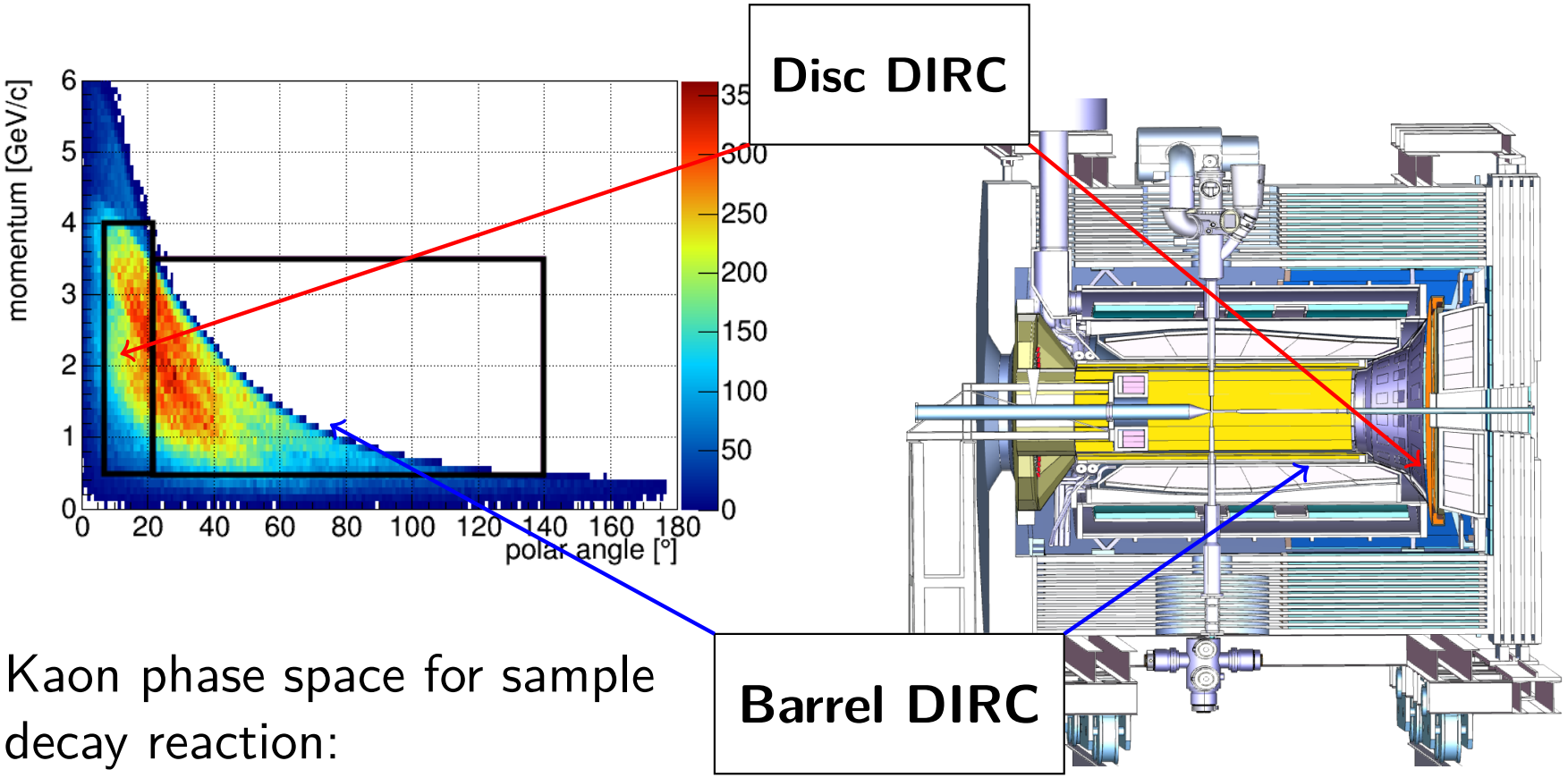
Construction site view taken from drone video (March 2019)

Particle Identification

No hadronic calorimeter in PANDA

Two DIRC detectors for PID in target spectrometer

DIRC: Detection of Internally Reflected Cherenkov Light



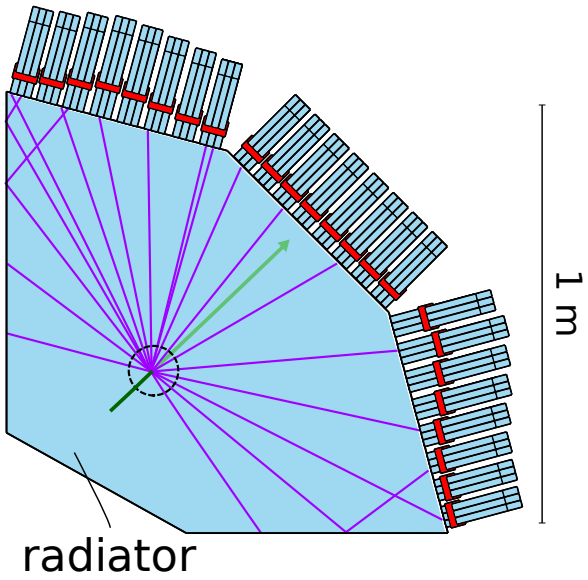
Kaon phase space for sample decay reaction:
$J/\Psi \rightarrow K^+K^-\gamma$ @ 6.5 GeV/c

Detector Overview

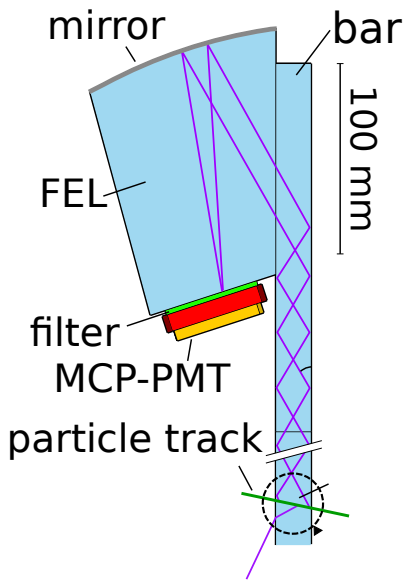
Disc DIRC Design Parameters:

- Separation of π/K
- Momentum range: $0.5\,\mathrm{GeV/c} \leq p < 4\,\mathrm{GeV/c}$
- Polar angle range: $5^\circ \leq \theta \leq 22^\circ$
- Performance goal: $\geq 3\,\mathrm{s.d.}$ separation over full phase space
  $\Rightarrow$ Average detector resolution $\leq 1.7\,\mathrm{mrad}$ required

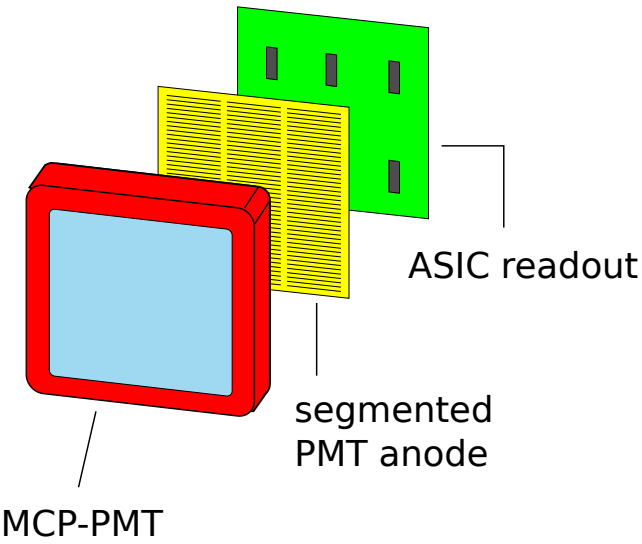
Quadrant (upstream view)



ROM (side view)

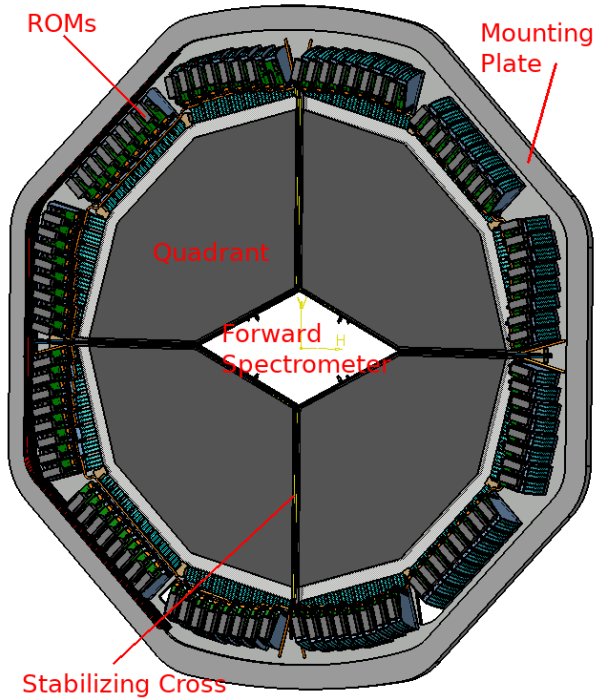


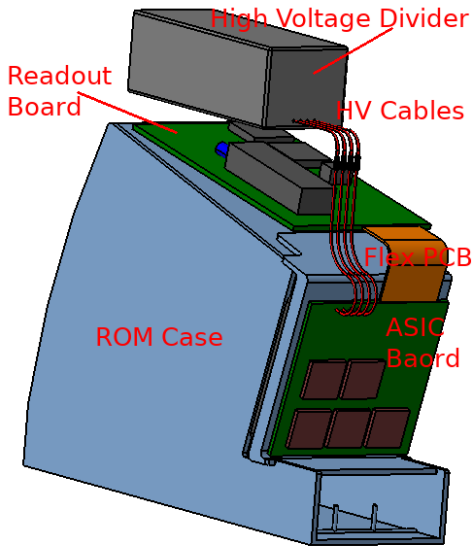
Photon detector



Technical Specifications

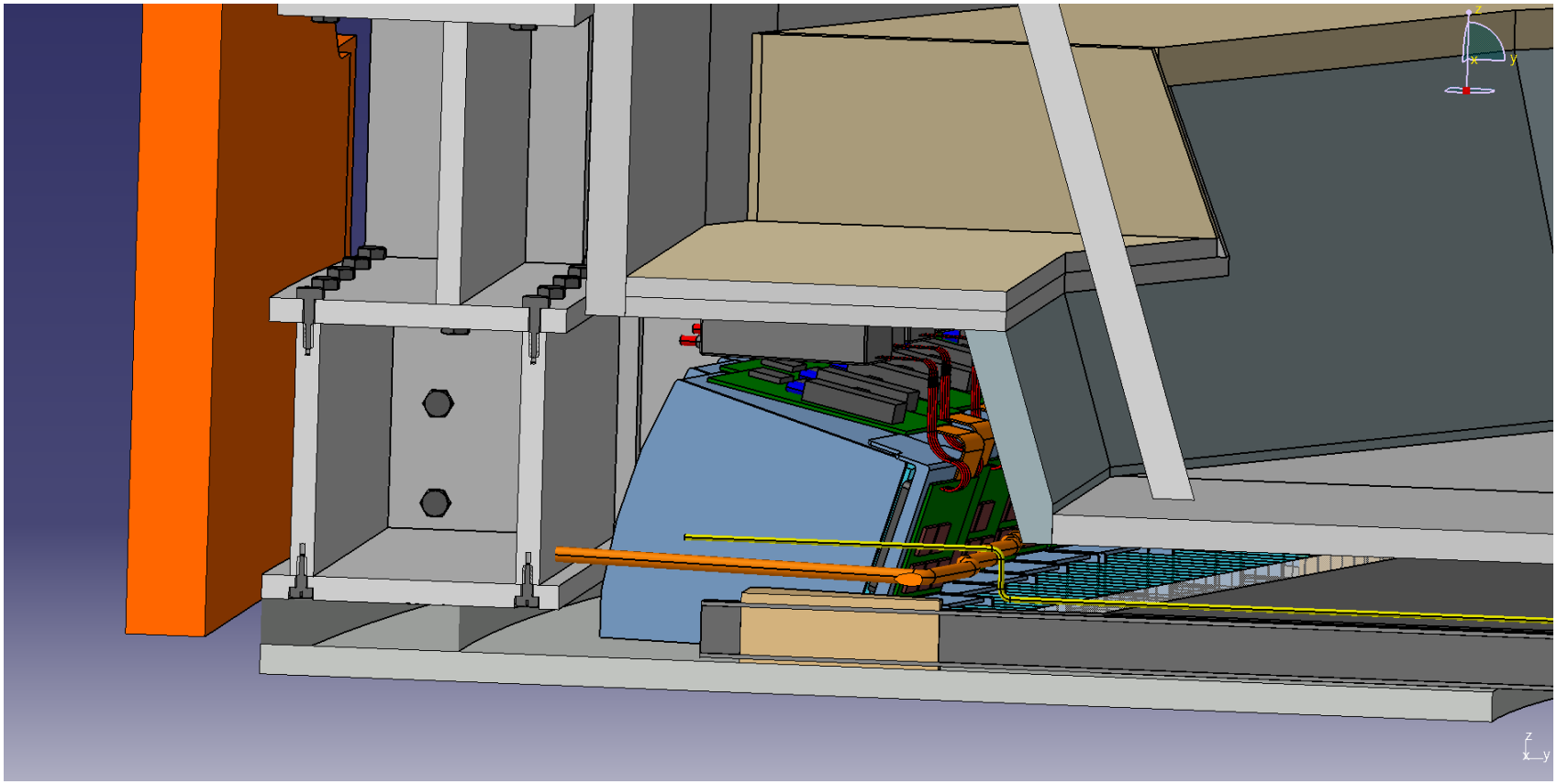
- 8 Readout Modules (ROMs) per side $\Rightarrow$ 96 ROMs in total
- Readout: PETsys TOFPET ASICs with 30 ps LSB
- 5 ASICs with 64 channels per ROM
- 300 pixels per MCP-PMTs $\Rightarrow$ 28,800 readout channels
- Approx. 1 charged track per collision (22 photon hits per track)
- Hit frequency per channel: 60 kHz in high luminosity mode
- Connection to PANDA DAQ system
- Using SODAnet for time synchronisation





EDD Mechanics

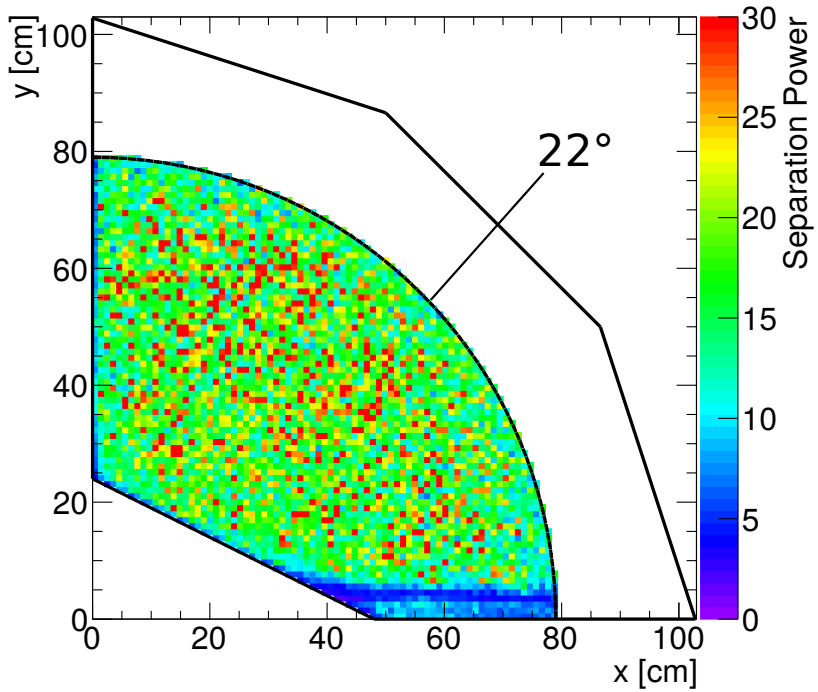
- Insulation of Endcap EMC limits in z direction
- Light tightness with extra volume around FELs
- Required cables: High voltage, low voltage, optical fiber and cooling pipes
- High voltage divider for each ROM individually



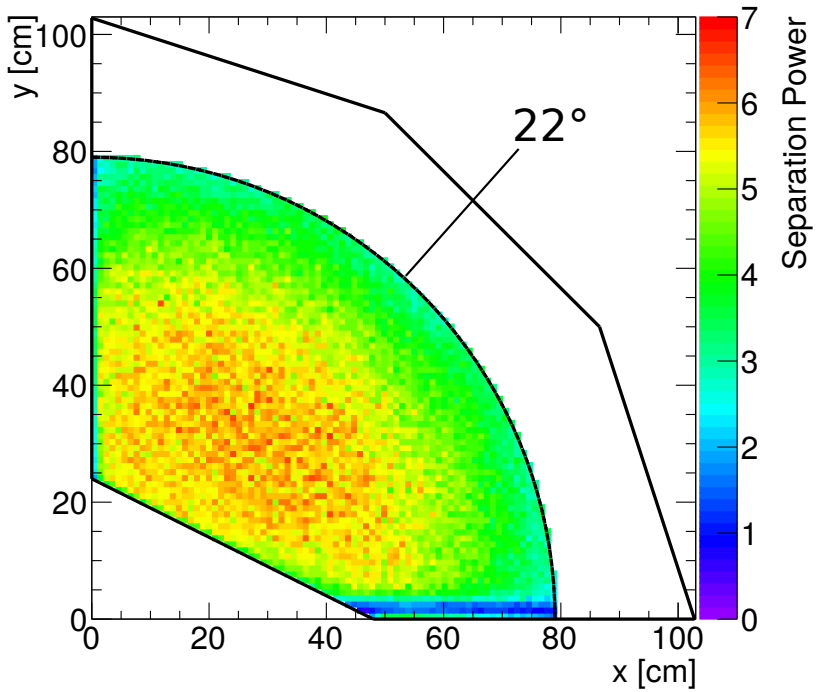
High Resolution Simulations

Simulatiated scan with high resolution for π^+/K^+ for full radiator quadrant including solenoid field of target spectrometer:

Momentum 2 GeV/c



Momentum 4 GeV/c



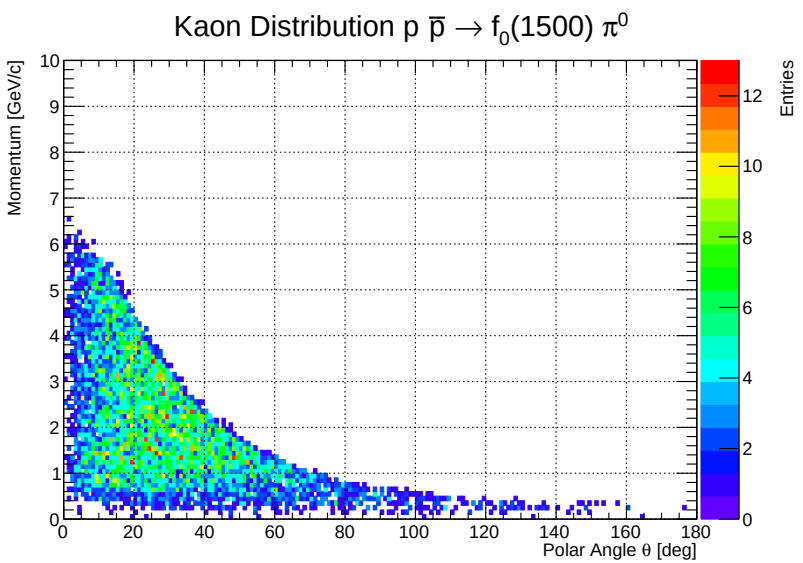
- Overlapping of hit patterns (drop of separation power)
- *Inefficient area* shifting as function of momentum

Benchmark Channel Analysis

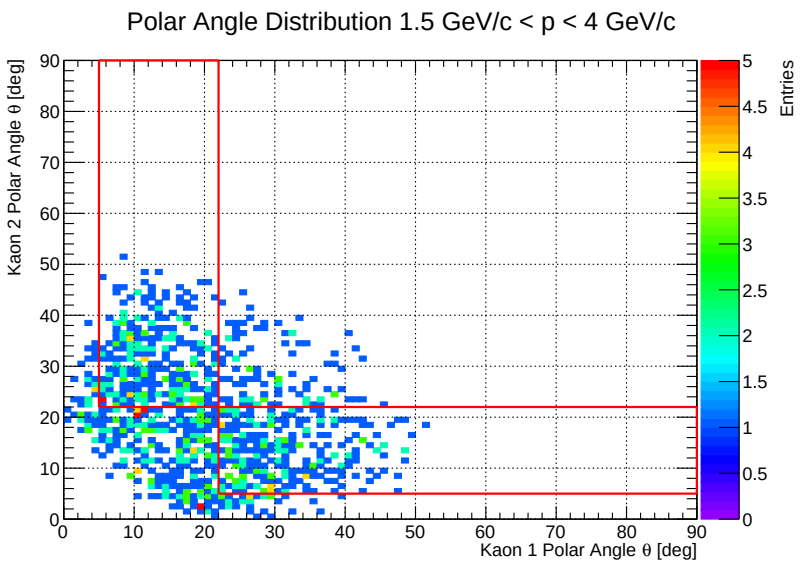
Glueball candidate $f_0(1500)$ decay analysis with $J^{PC} = 0^{++}$ using all subdetectors of P

$$p\bar{p} \rightarrow f_0\pi^0 \quad \rightarrow \quad K^+K^-\pi^0 \ (\approx 4.2\%)$$
$$\hookrightarrow \quad \pi^+\pi^-\pi^0 \ (\approx 82.5\%)$$
(One possible background channel)

Kaon phase space



Polar angle distribution



Particle Identification

- Bayesian Approach:

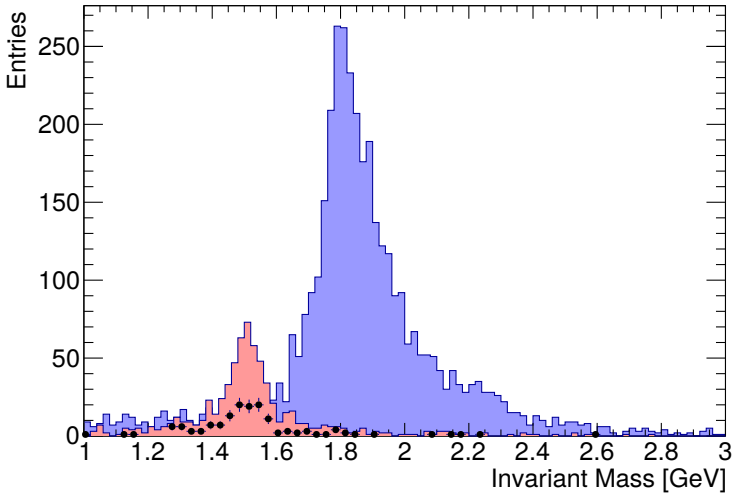
$$p(\theta|x) = \frac{\mathcal{L}(\theta|x)\pi(\theta)}{\int \mathcal{L}(\theta'|x)\pi(\theta')d\theta'}$$

- Probability for N subdetectors and $j = \pi, K$ particle hypotheses:

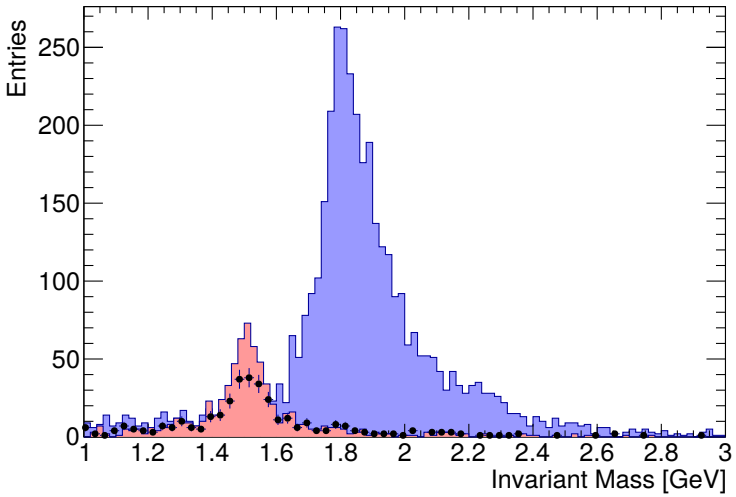
$$p(k) = \frac{\prod_i \mathcal{L}_i(k)}{\sum_j \prod_i \mathcal{L}_i(j)}$$

- PID cut at 90% for every particle
- PID results:
  Increase of signal to background ratio: 53 %

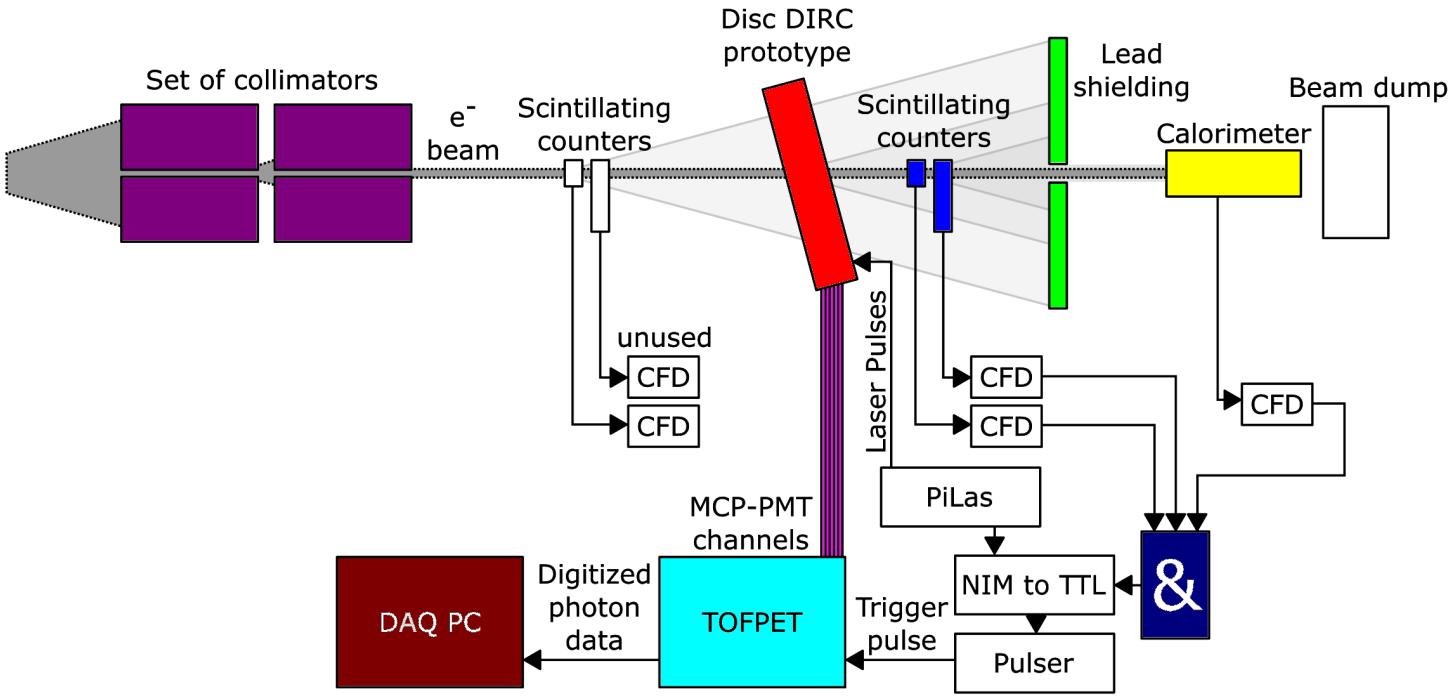
PID without Disc DIRC



PID with Disc DIRC



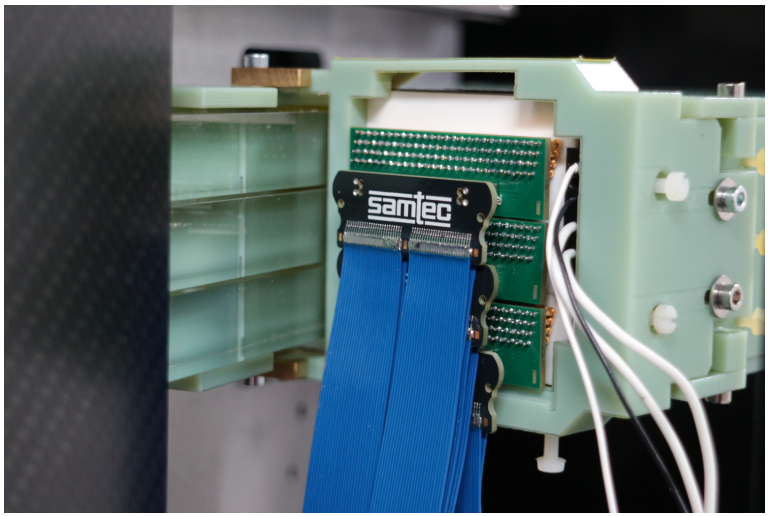
DESY Testbeam 2016



- DESY testbeam with electrons at $p = 3\,\mathrm{GeV/c}$
- Installed prototype with different shape ($50 \times 50\,\mathrm{cm}^2$)
- Free-running readout system (TOFPET) with 50 ps resolution
- Using scintillation counters and calorimeter as software trigger
- Trigger signal discrimination with Constant Fraction Discriminator (CFD) NIM module to reduce time-walk effects

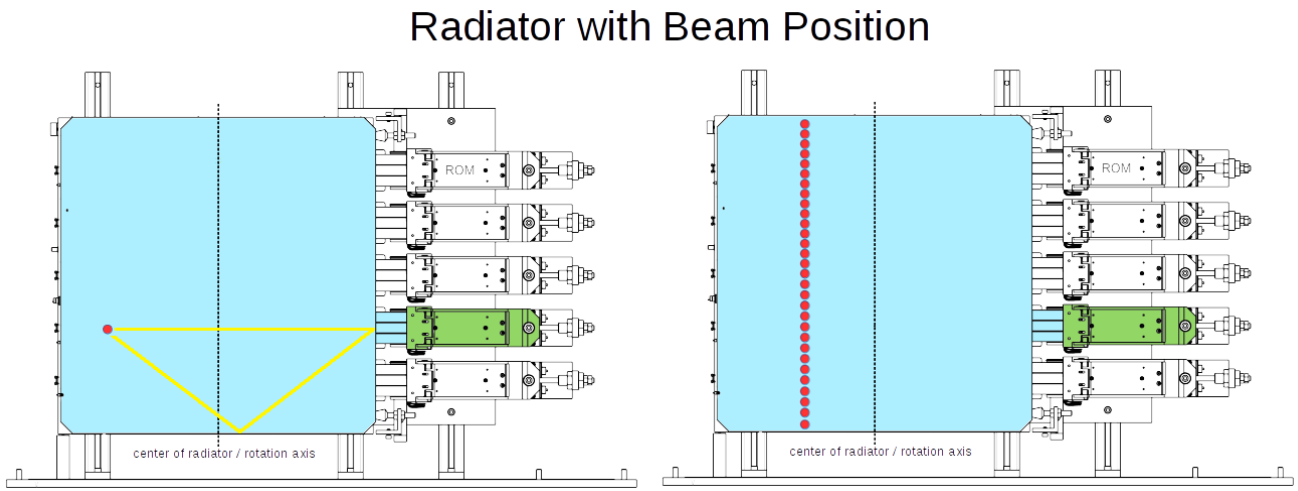
Testbeam Setup 2016

DESY testbeam photos in T24/1 testbeam hall:

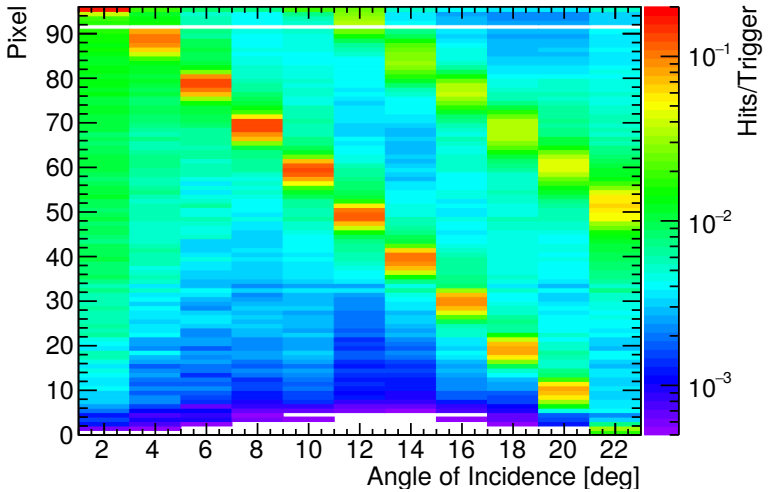


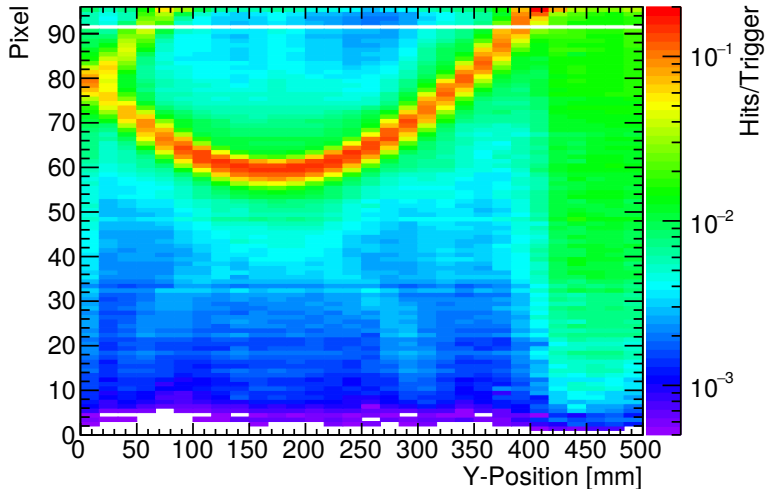
Testbeam Scans 2016

Hit patterns including vertical position and angle scan

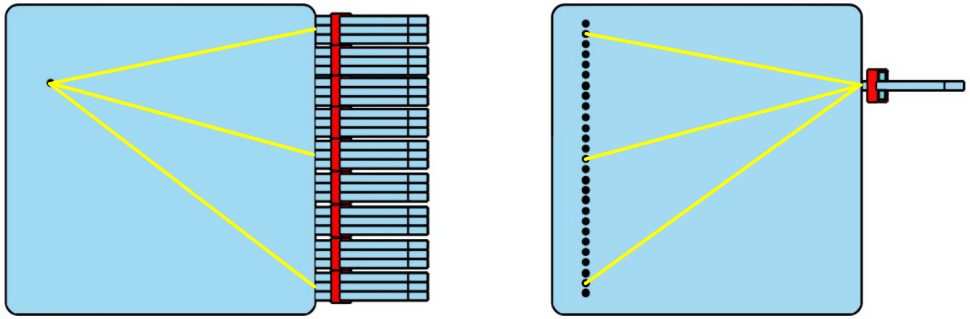


Hit pattern from the central FEL inside highlighted ROM



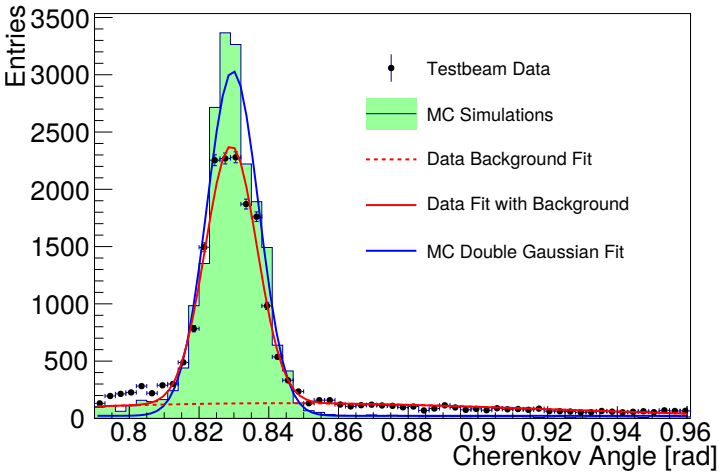


Event Combination 2016

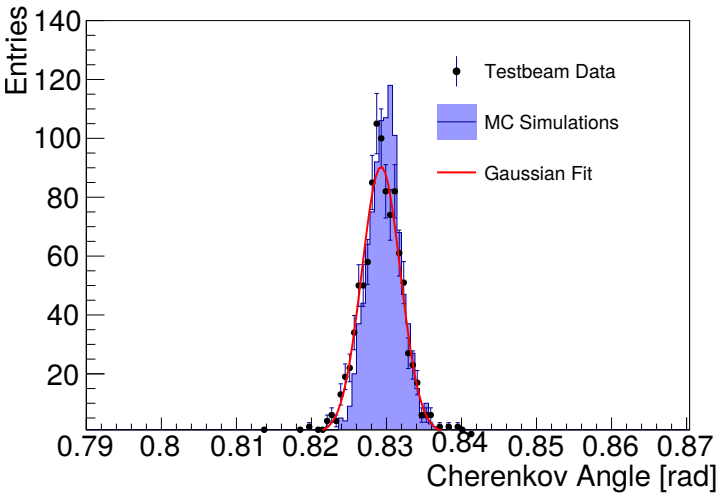


- Combining each event from every position to one new event
- Making a coarse time cut according to photon propagation time
- Reduction of background with truncated mean of pixel hits
- Obtained resolutions:
  $\sigma_\theta = 7.4\,\text{mrad}$ (single photon)
  $\sigma_{\bar{\theta}} = 2.5\,\text{mrad}$ (average)

Single Photon Distribution

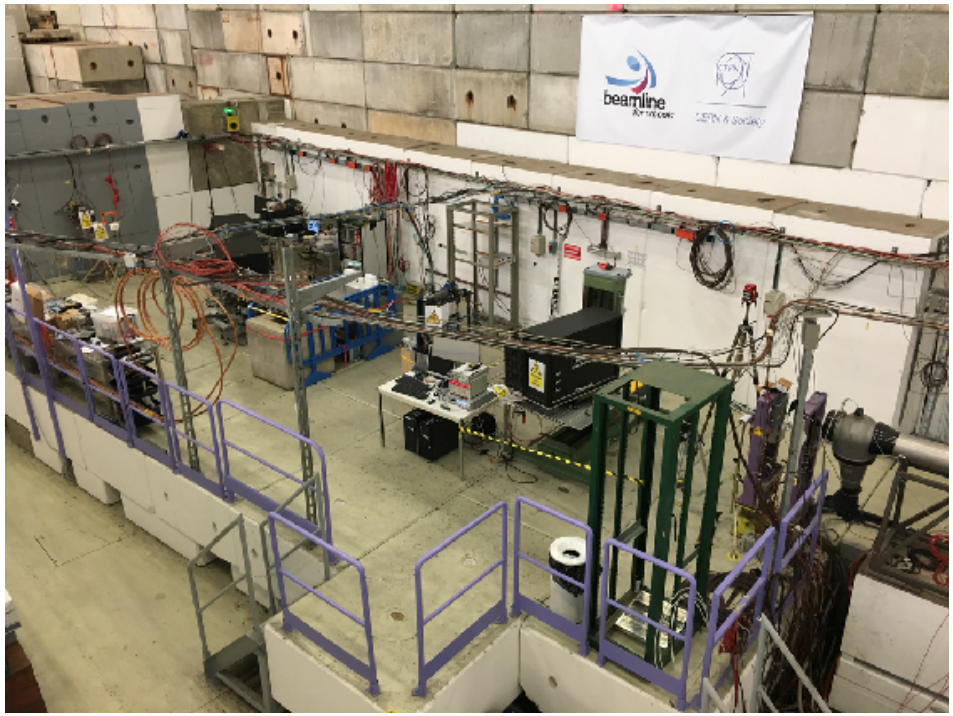


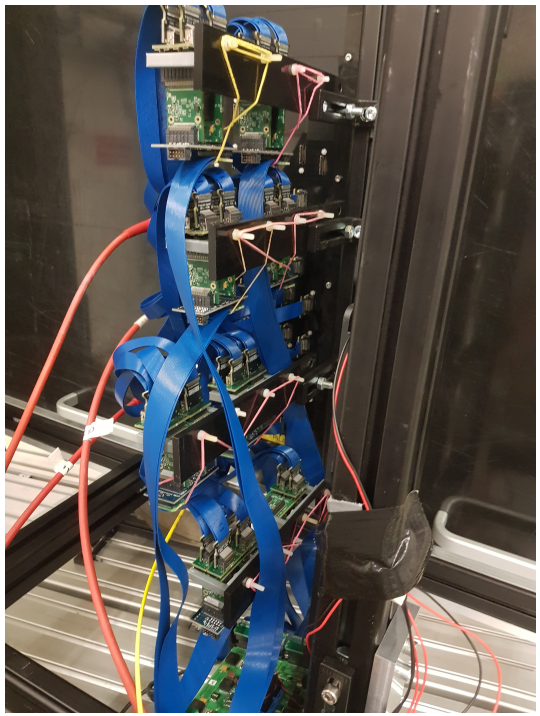
Event Mean Distribution



CERN Testbeam 2018

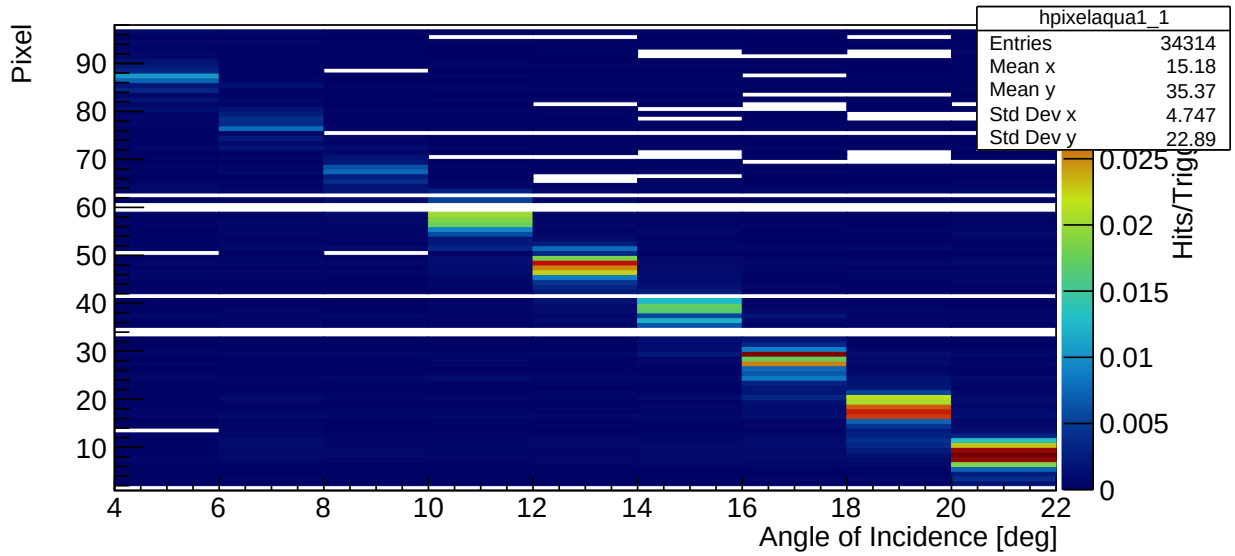
- New testbeam campaign in July/August 2018 at CERN
- Using new TOFPET 2 ASICs with 3 different MCP-PMTs
- Analysis still ongoing



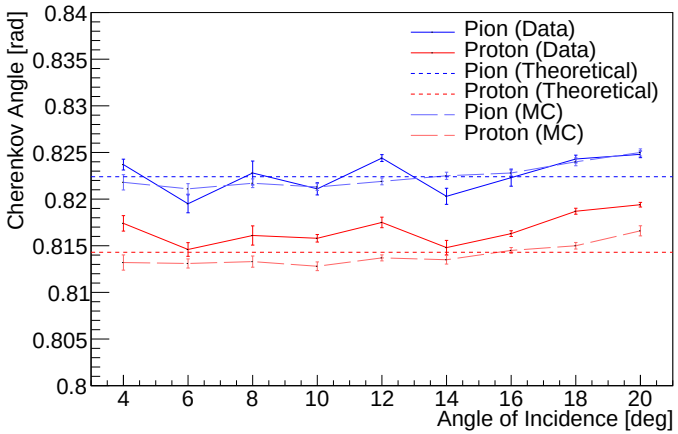


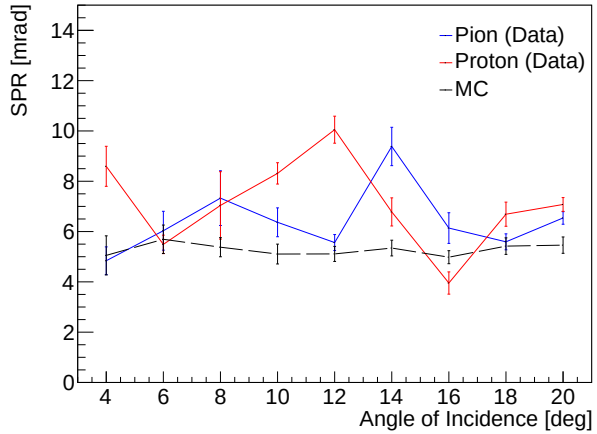
Testbeam Results

Hit pattern for 7 GeV/c pion/proton beam (pion cut)



Reconstructed Cherenkov angle and single photon resolution





Summary & Outlook

Summary:

- Full detector simulations in dedicated framework (PandaRoot)
- Updated detector design based on simulation results
- Successful prototype testbeams matching well with Monte-Carlo simulations

Outlook:

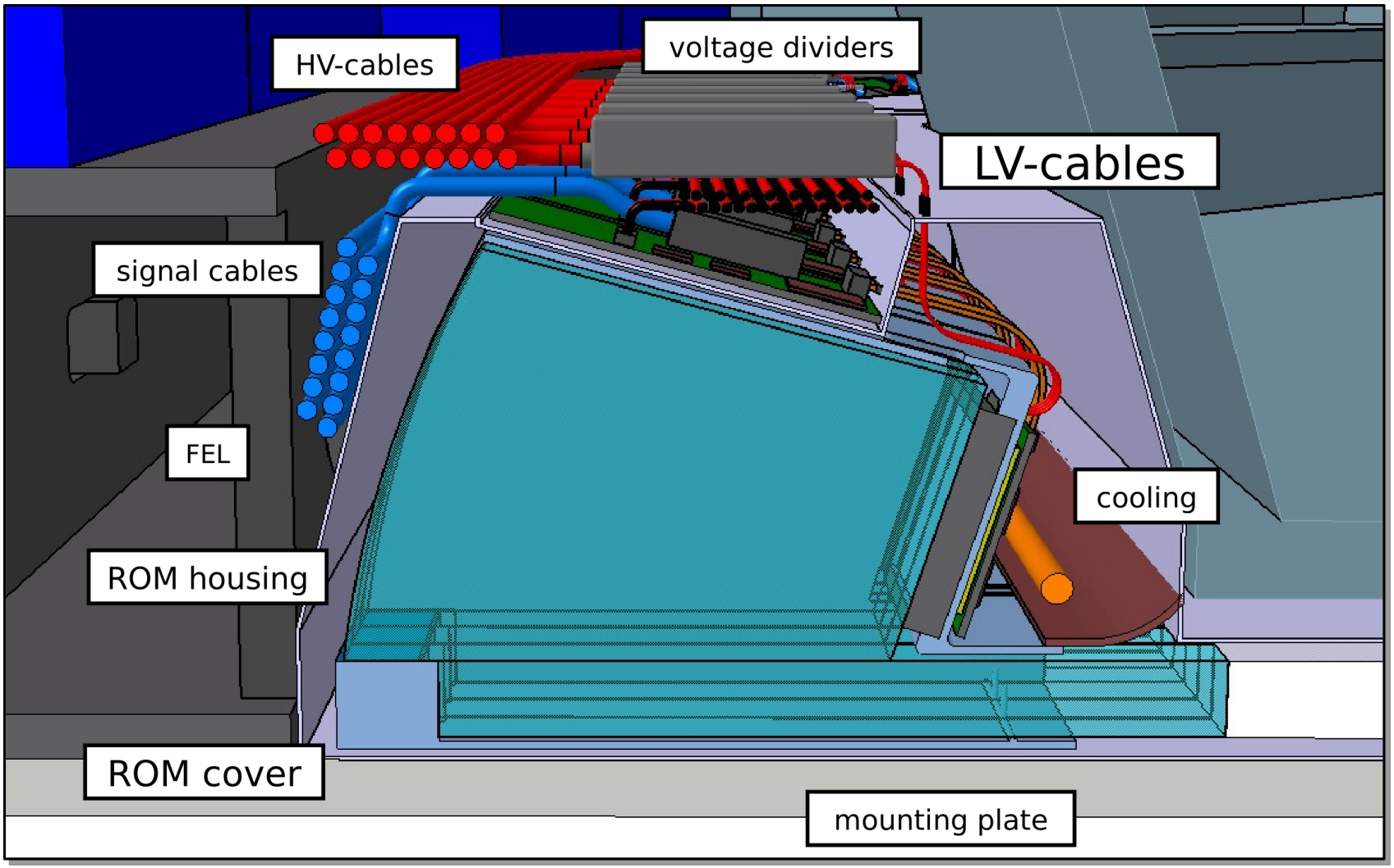
- Finishing analysis of the last testbeam (CERN 2018)
- Finalizing design of readout boards in cooperation with PETsys
- Construction and implementation of a *first-of-series* DIRC quadrant in PANDA in 2026

Thank you very much for your attention!

Backup Slides

Electronics in Final Detector

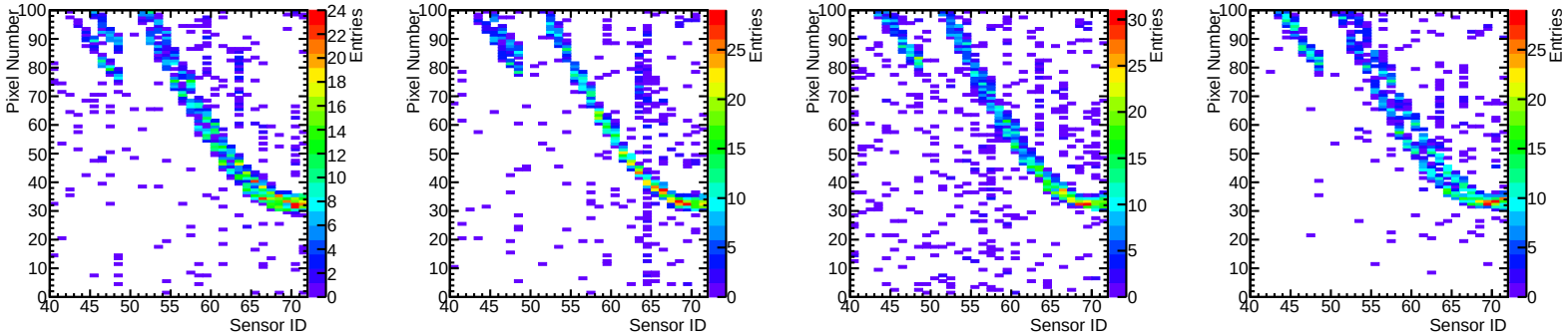
TOFPET ASICS attached to MCP-PMTs



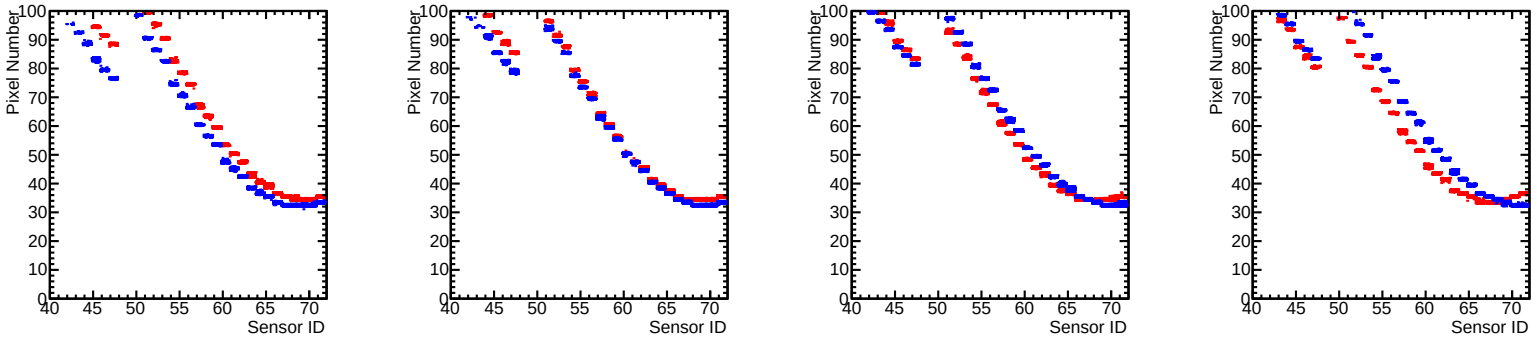
Overlapping Hitpattern

Hitpattern overlap due to reflections at outer rim

Simulated hitpattern



Calculated hitpattern



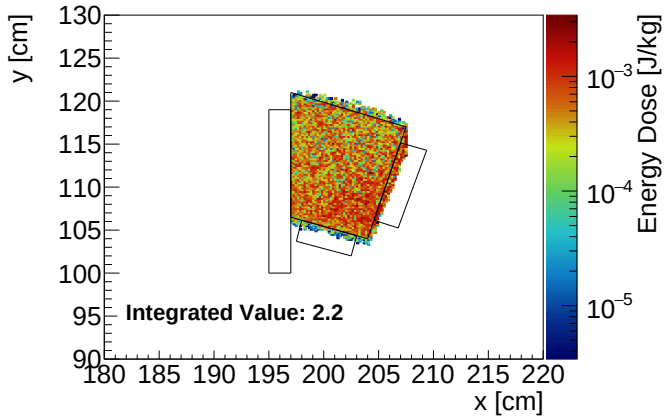
- Simulated hitpatterns are shifting as function of azimuth angle
- Full overlap cannot be observed due to bending inside magnetic field

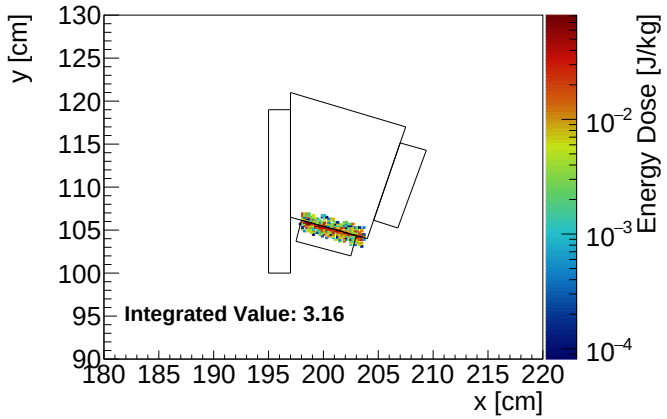
Online Reconstruction

- Requirement: Usable with 20 MHz reaction frequency
- SiTCP package developed at KEK for gigabit ethernet communication
- Prototype working with ML403 board and Xilinx Virtex 4 chip
- Available block RAM: 648 kB
- Clock frequency: 130 MHz
- Sending data in 8 bit blocks per clock cycle into FIFO buffer
- Small self-written C++ client sending simulation data to FPGA card

Radiation Hardness

Simulated Radiation Dose for MCP-PMTs and Filter





0% – 3.5% @ 3 Gy and 0.5% – 4.5% @ 30 Gy depending on filter

Simulated Charged Hadron Rate for MCP-PMTs and PCBs