The Forward RICH detector at PANDA

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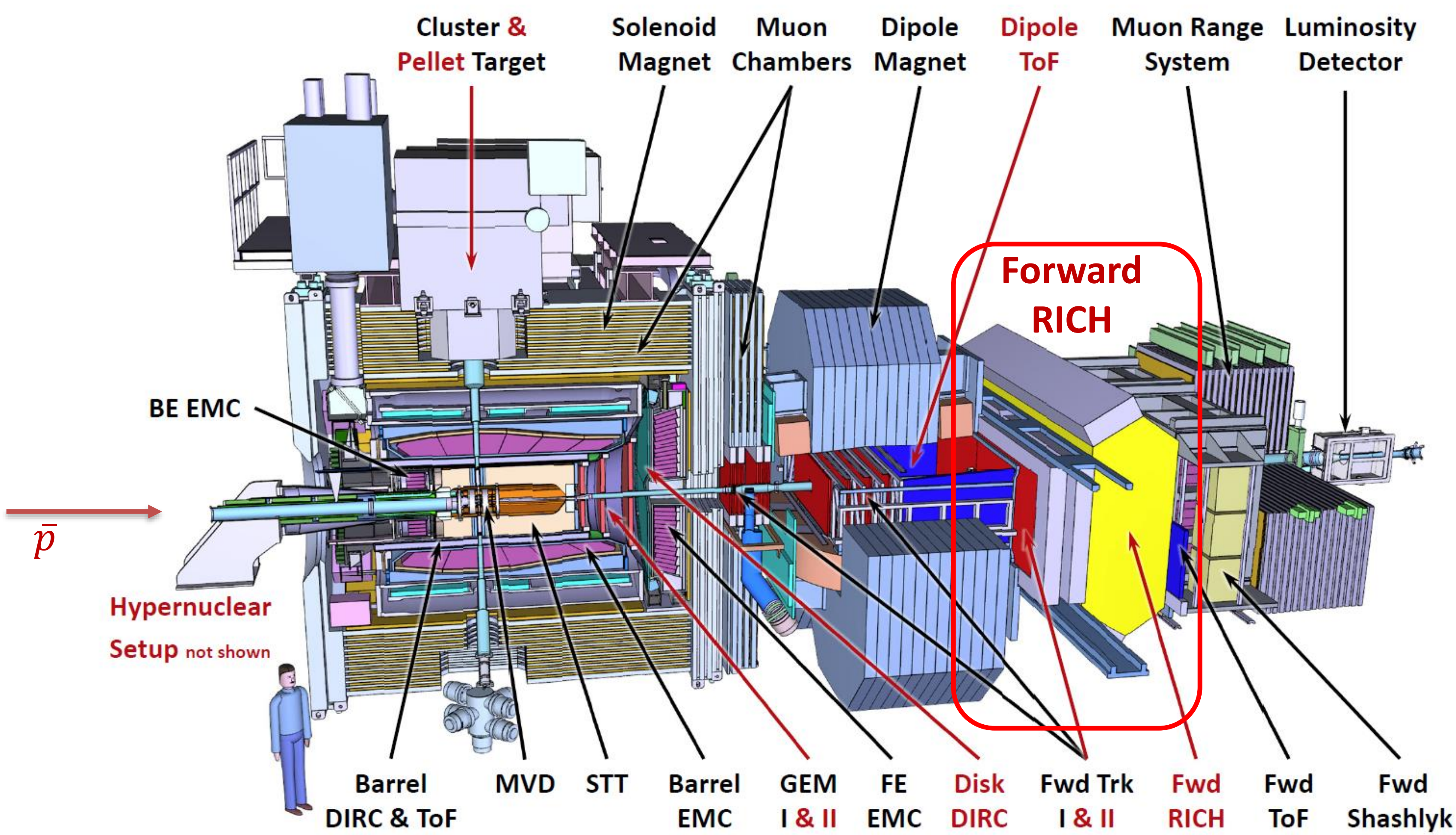
Talk outline

- Focusing Aerogel RICH concept
- PANDA Forward RICH design
- MC simulated performance
- Optical measurements
- Test beam 2019 results
- Conclusion & outlook

PANDA Detector

Day-1 & Full setups



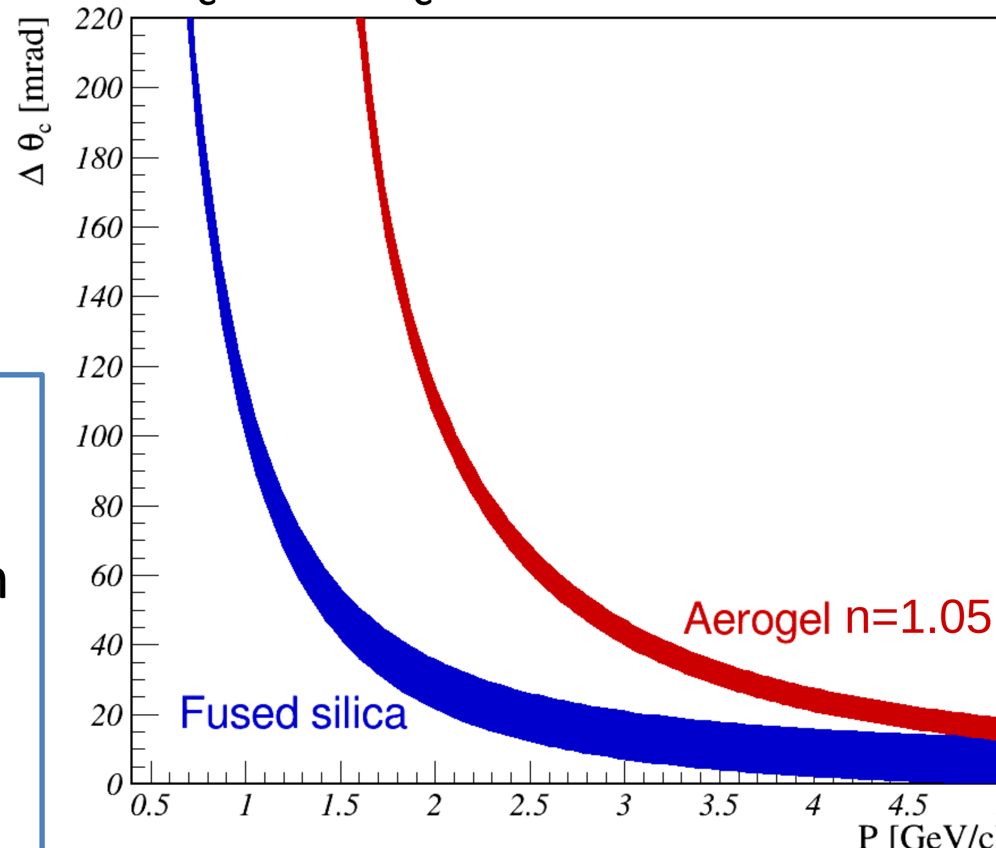
Parameters of the PANDA Forward RICH

- **Purpose:** Charged PID in the Forward Spectrometer
- **Acceptance:** $|\theta_X| < 10°$, $|\theta_Y| < 5°$
- **Dimensions:** 3m (X) x 1m (Y) x 0.8m (Z)
- **Expected material budget:** $\leq 10\% \ X_0$
- **Expected PID performance:**
  - 3 s.d. π/K separation: P = 2÷10 GeV/c
  - 3 s.d. μ/π separation: P = 0.5÷2 GeV/c (complementing the Muon System)
- **Physics cases:** processes with high charged hadrons multiplicity in the final states for high beam momenta

Quartz vs Aerogel as Cherenkov Radiator in a RICH detector

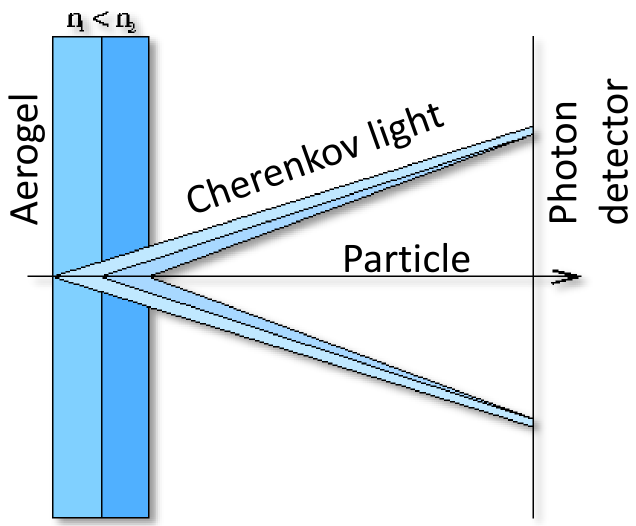
Band width correspond to the chromatic dispersion of refractive index in the 350-700 nm wavelength range

$\theta_c(K) - \theta_c(\pi)$ vs momentum



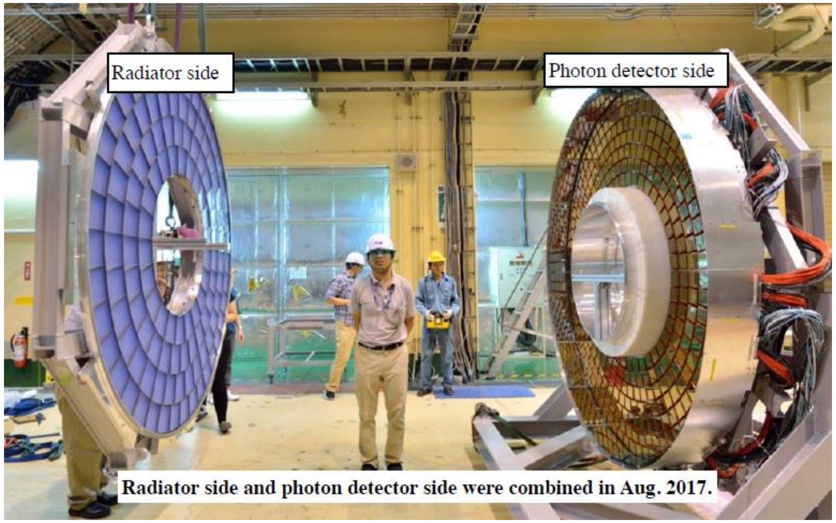
Aerogel has much larger Cherenkov angle difference and less chromatic dispersion than Fused silica. This results in PID capability for higher momenta.

Focusing Aerogel RICH (FARICH)



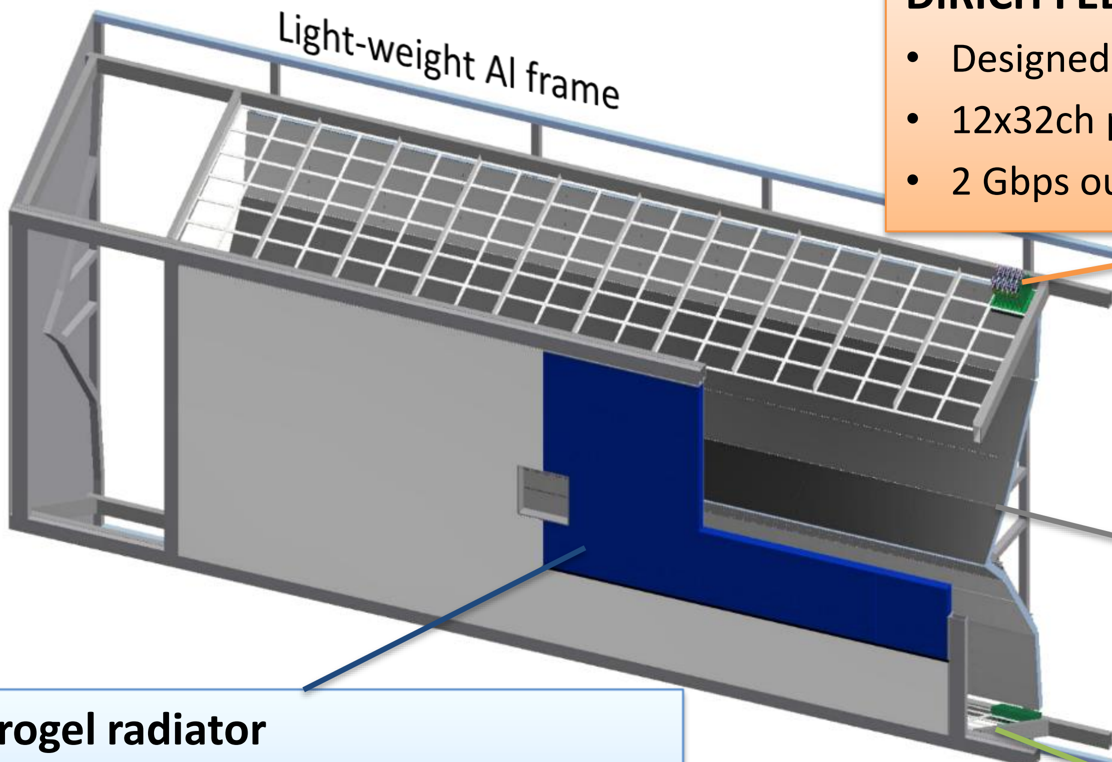
T.Iijima et al., NIM A548 (2005) 383
A.Yu.Barnyakov et al., NIM A553 (2005) 70

First real-life application in Belle2 ARICH



Focusing aerogel improves proximity focusing design by reducing the contribution of radiator thickness into the Cherenkov angle resolution

Forward RICH baseline design



DiRICH FEE (GSI)

- Designed for H12700 readout
- 12x32ch preamp+disc+TDC
- 2 Gbps output link

Mirrors

- Flat
- 2 mm float glass
- Al+SiO_2 coating

Aerogel radiator

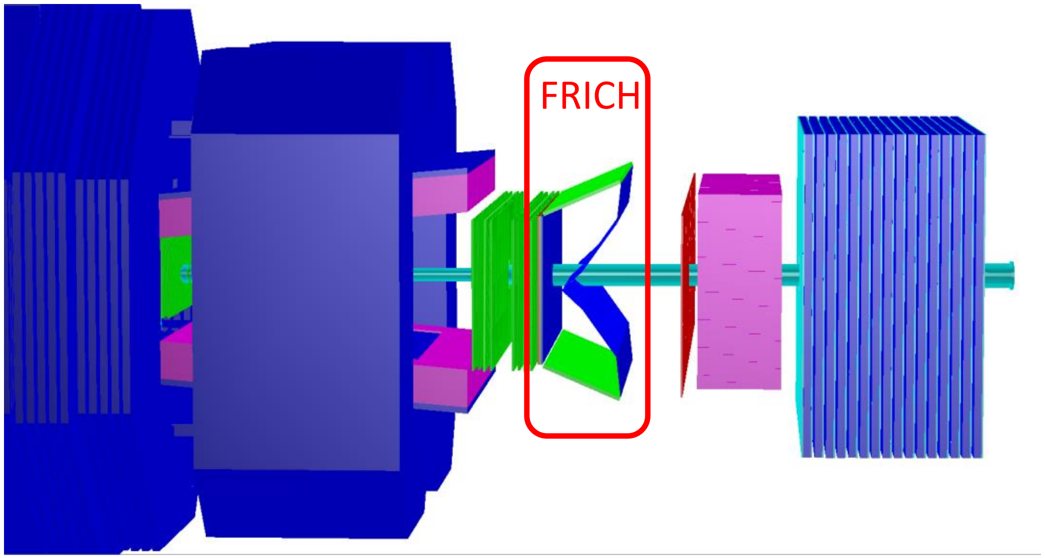
- Focusing 2- or 3-layer aerogel
- n≈1.05
- 3 x 1 m^2 area
- 40 mm thickness

Photon Detector

H12700 MaPMTs (Hamamatsu), 1400 pcs

- flat panel
- 87% active/total area ratio
- 8x8 anode pixels of 6mm size

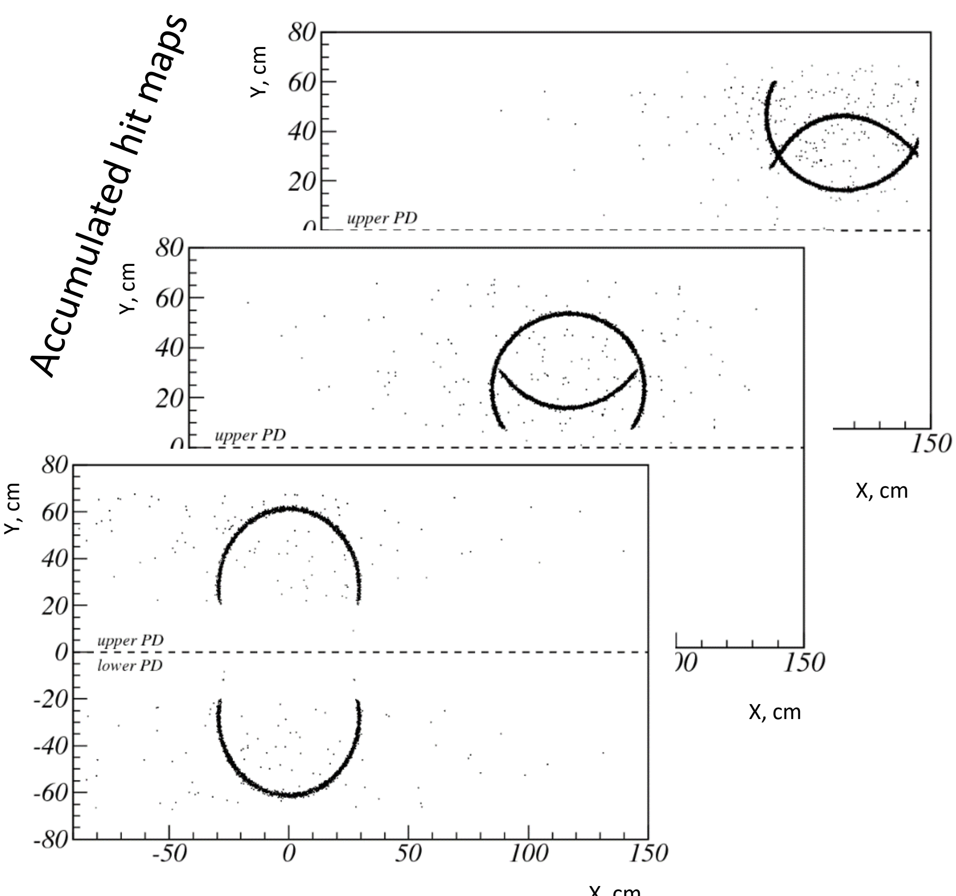
PANDA Forward RICH simulation

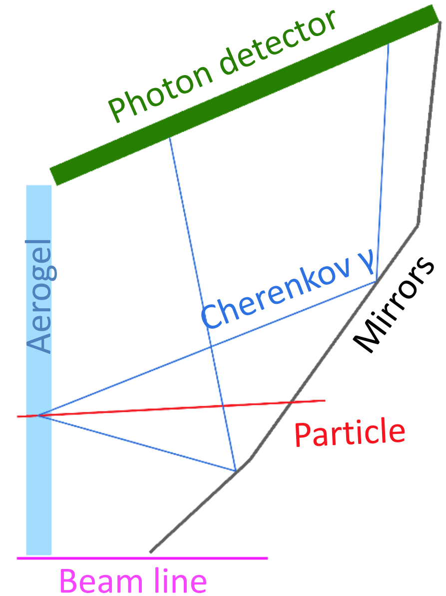


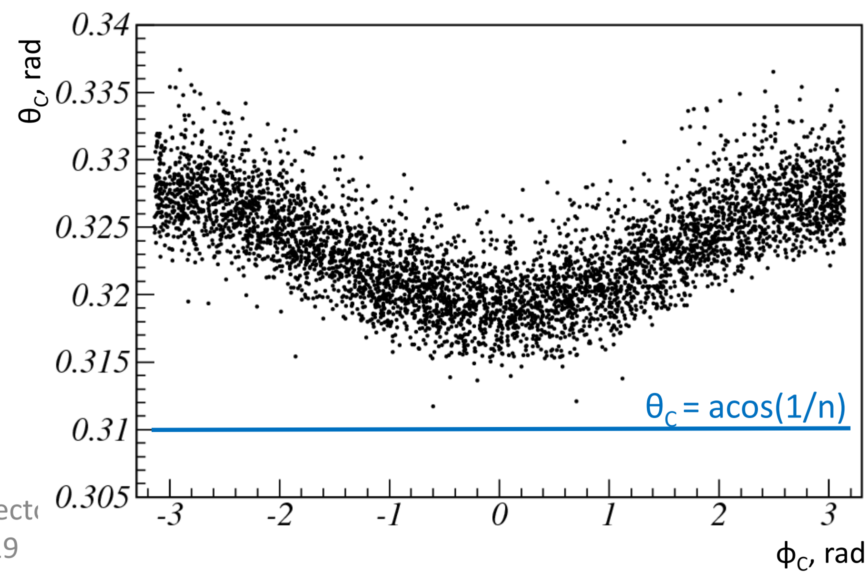
Full MC simulation is implemented in PandaRoot

1. Physics (Geant4)
   - ✓ Electromagnetic processes
   - ✓ Multiple scattering
   - ✓ Hadron interactions
   - ✓ Optical processes (aerogel, mirror, PD)
2. Digitization
   - ✓ PD pixelization
   - ✓ PDE
   - ✓ PD dark counting
   - ✓ Dead time
   - ✓ Timing resolution
3. Reconstruction
   - ✓ Hit preselection
   - ✓ Fit $\theta_c(\phi_c)$ dependence
4. Calibration of beta resolution for fast simulation
5. PID
   - ✓ Probabilities calculation

Hit reconstruction



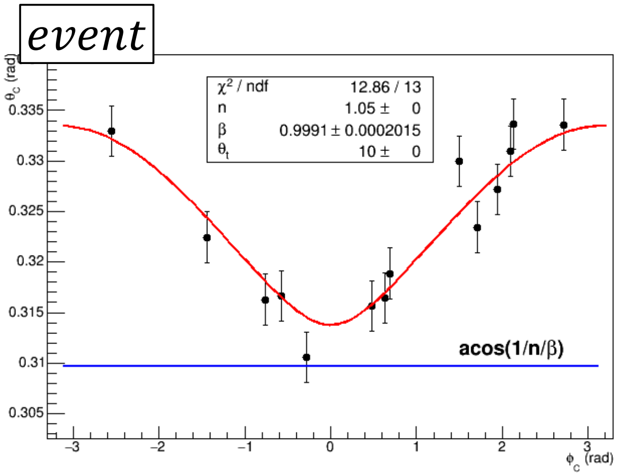


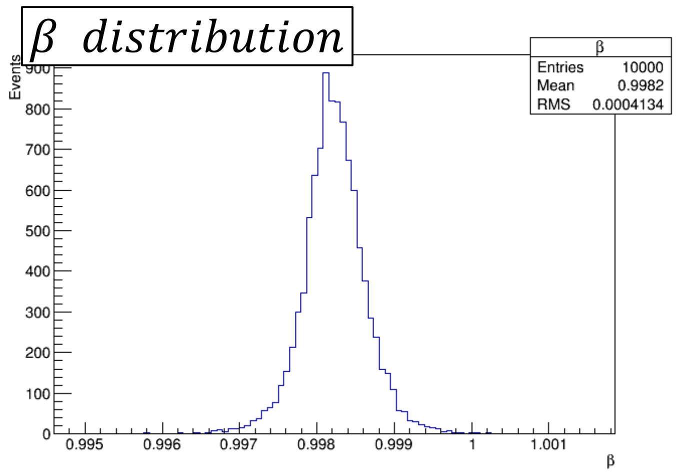


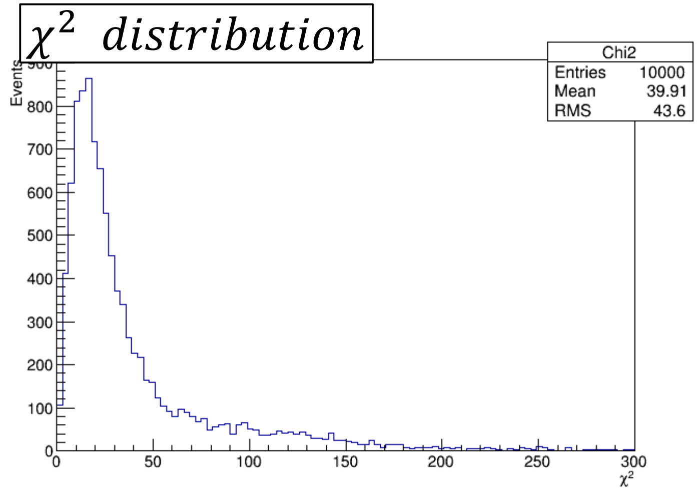
Track-based reco

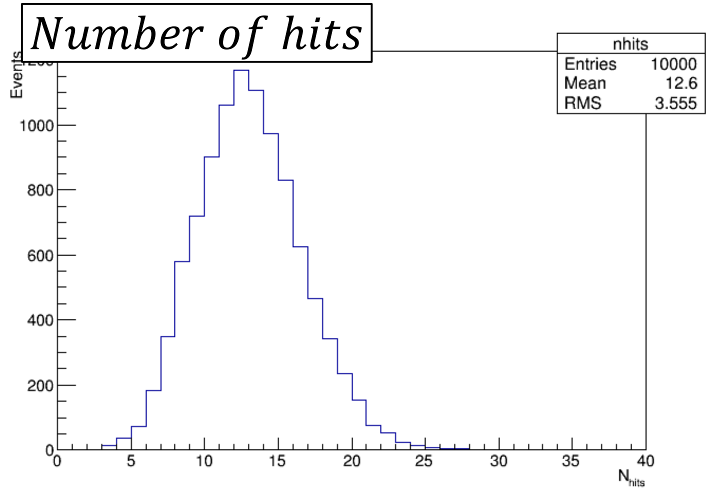
Trace back a PD hit position (X,Y) to the midpoint of a track segment in the radiator and find (θ_c, φ_c)

Event reconstruction



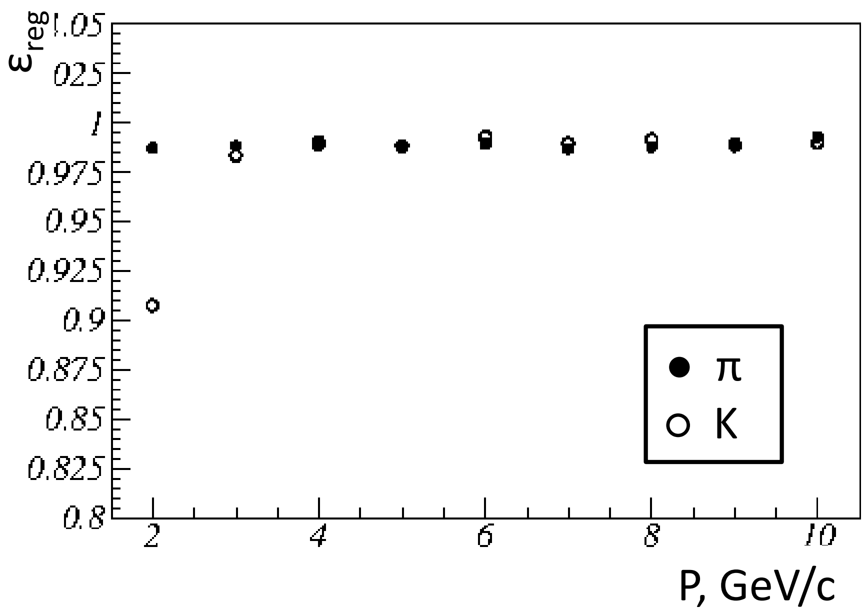




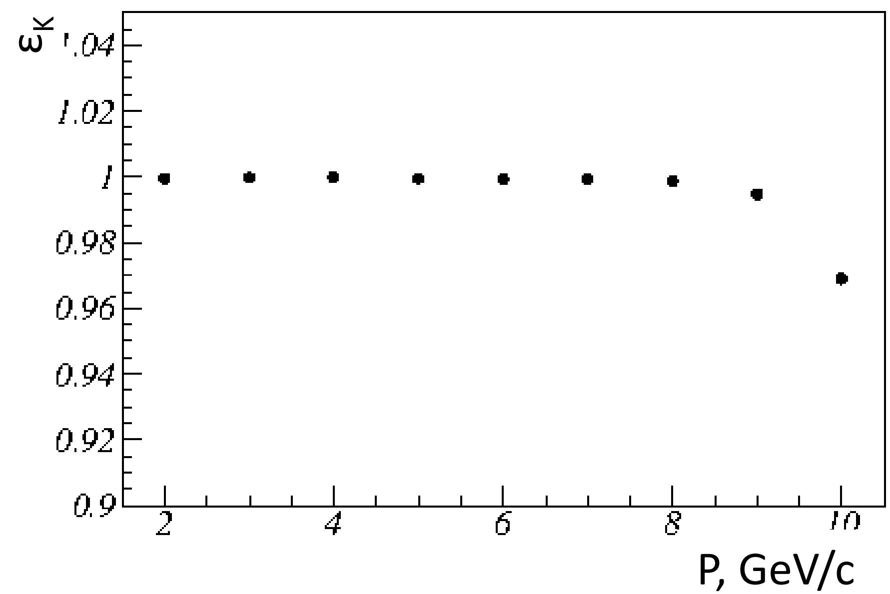


MC FRICH PID vs momentum
H12700 photon detector, 3 layers

Reconstruction efficiency
(reconstructed β is within ±3σ of expected)



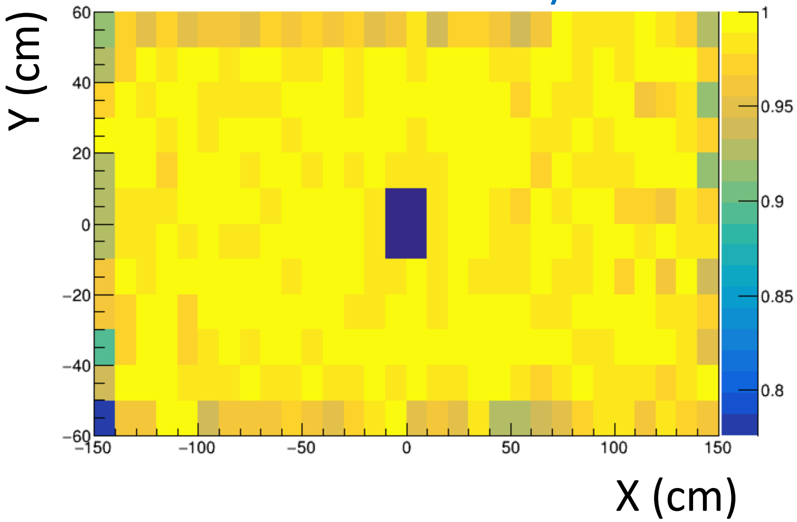
K identification efficiency
at 1% π misidentification



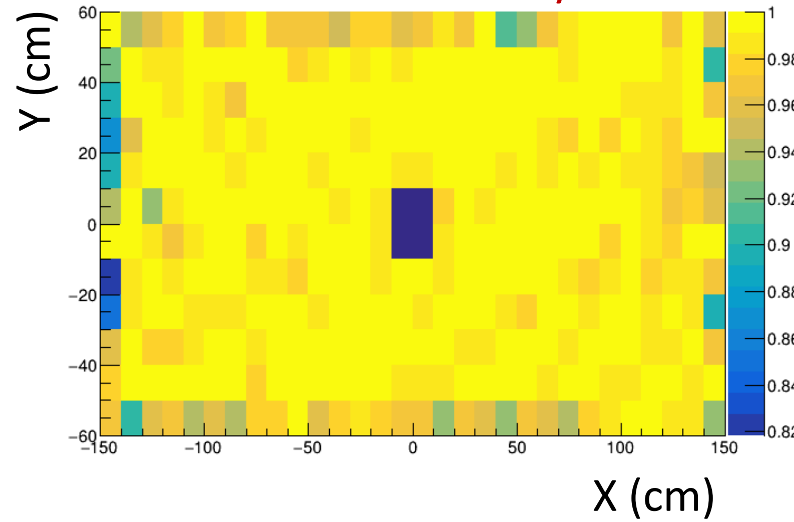
MC FRICH PID uniformity

H12700 PD, 3 layers, p^{-} beam@ 10 GeV/c

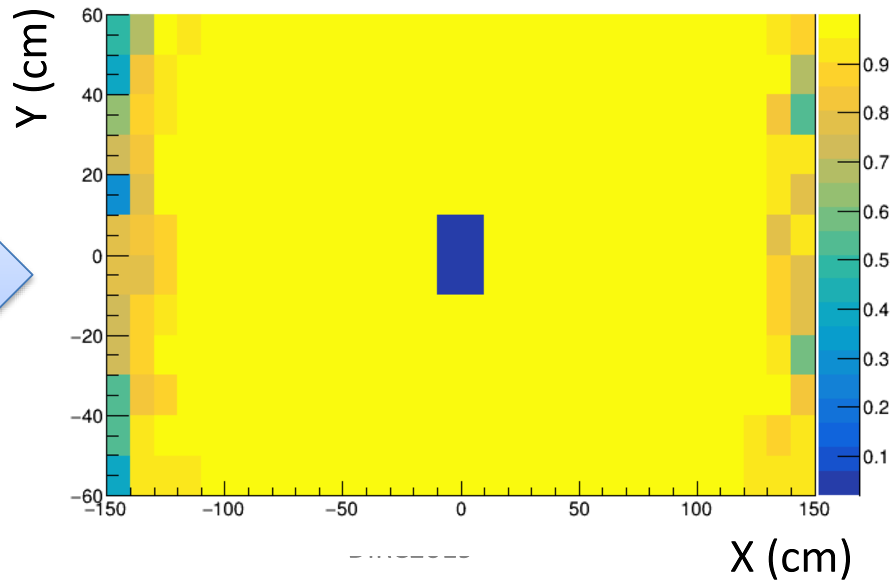
π reco efficiency



K reco efficiency

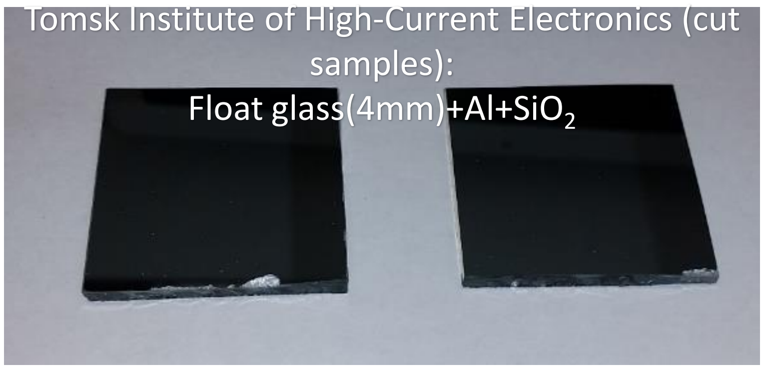


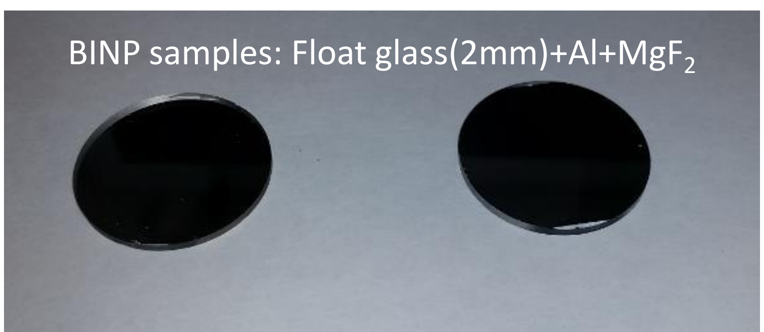
K identification efficiency at 2% π misidentification



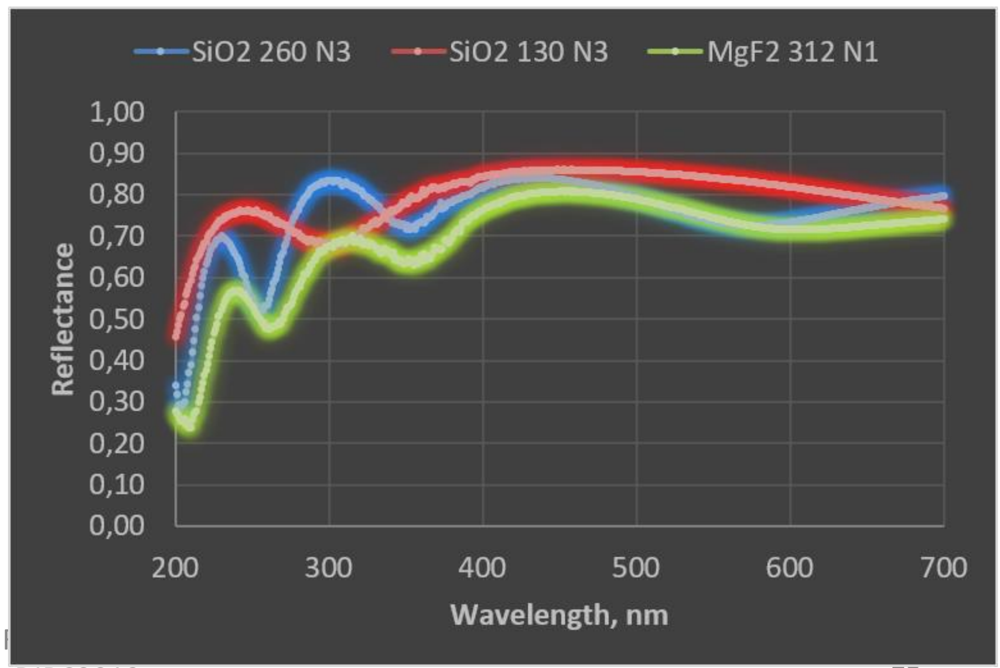
Mirror study

- Main option chosen after review of technologies: float glass with Al & SiO_2 coating. Pieces of 300x420 mm^2 can be produced in Tomsk
- A few µm flatness – quite good
- Reflectance is measured for several samples as a function of wavelength and angle of incidence





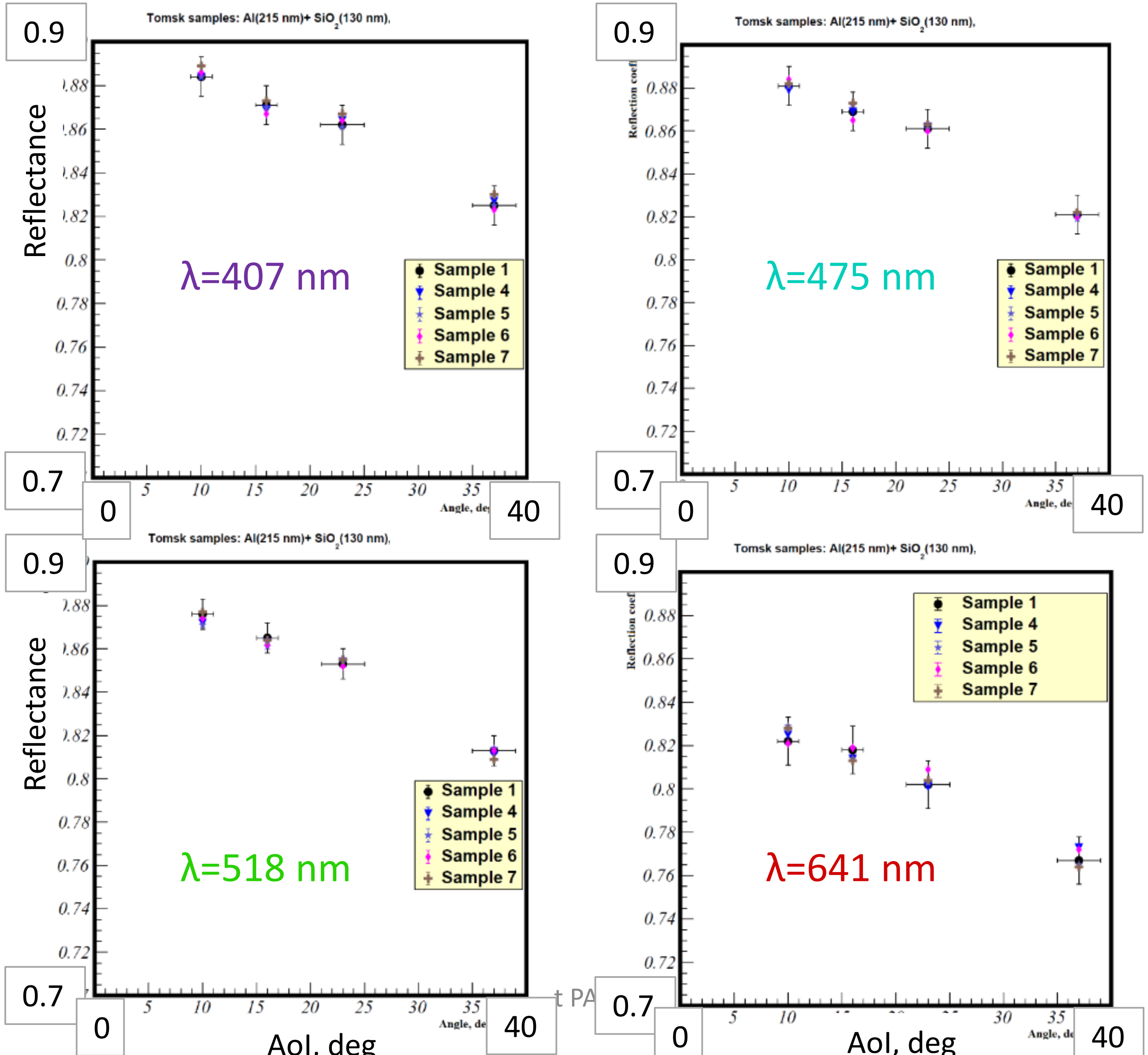
Абсолютный коэффициент отражения зеркал измеренный с помощью монохроматора и приставки



Reflectance as function of AoI

Laser measurements

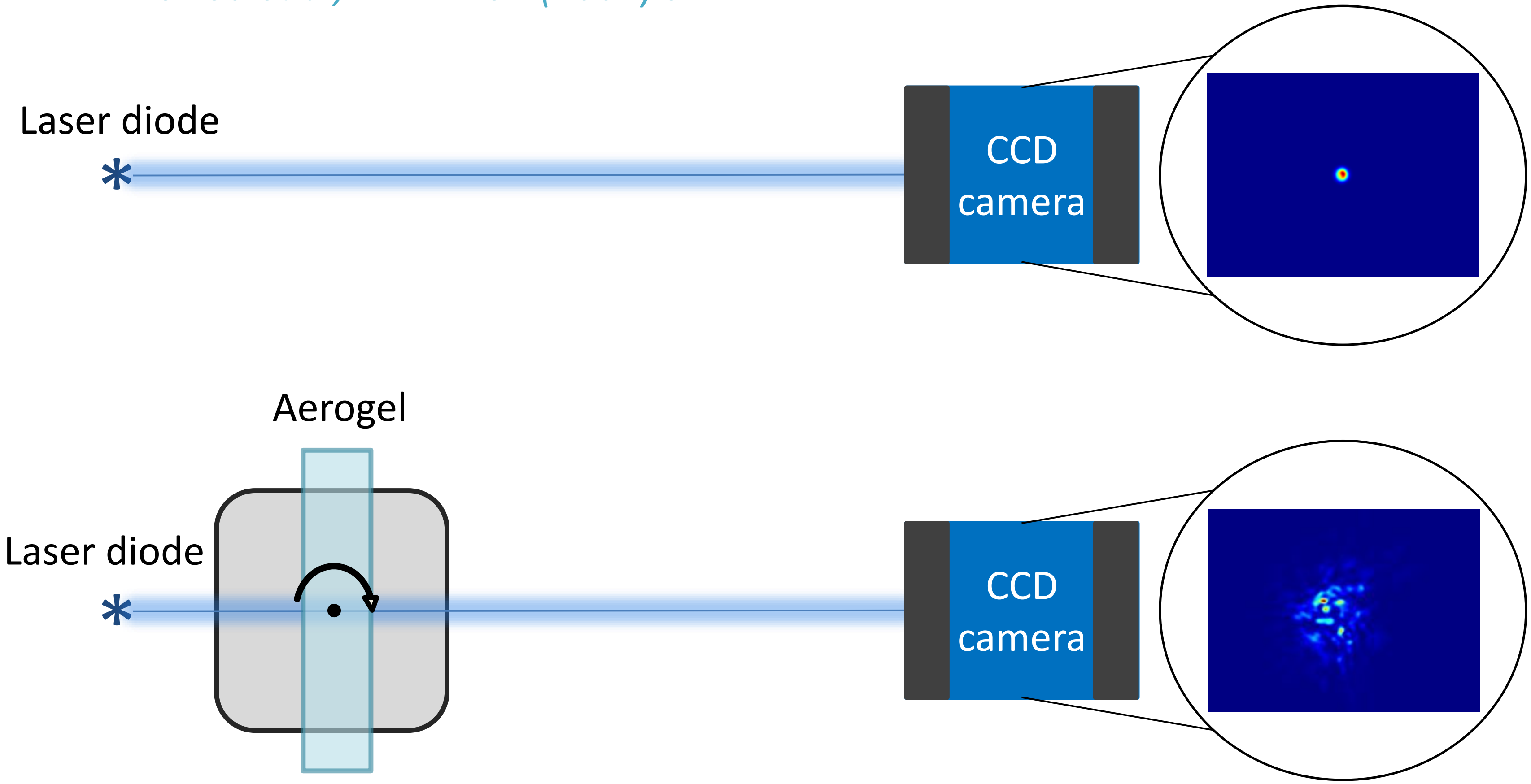
Tomsk sample
Float glass +
Al (215 nm) +
SiO_2 (130 nm)



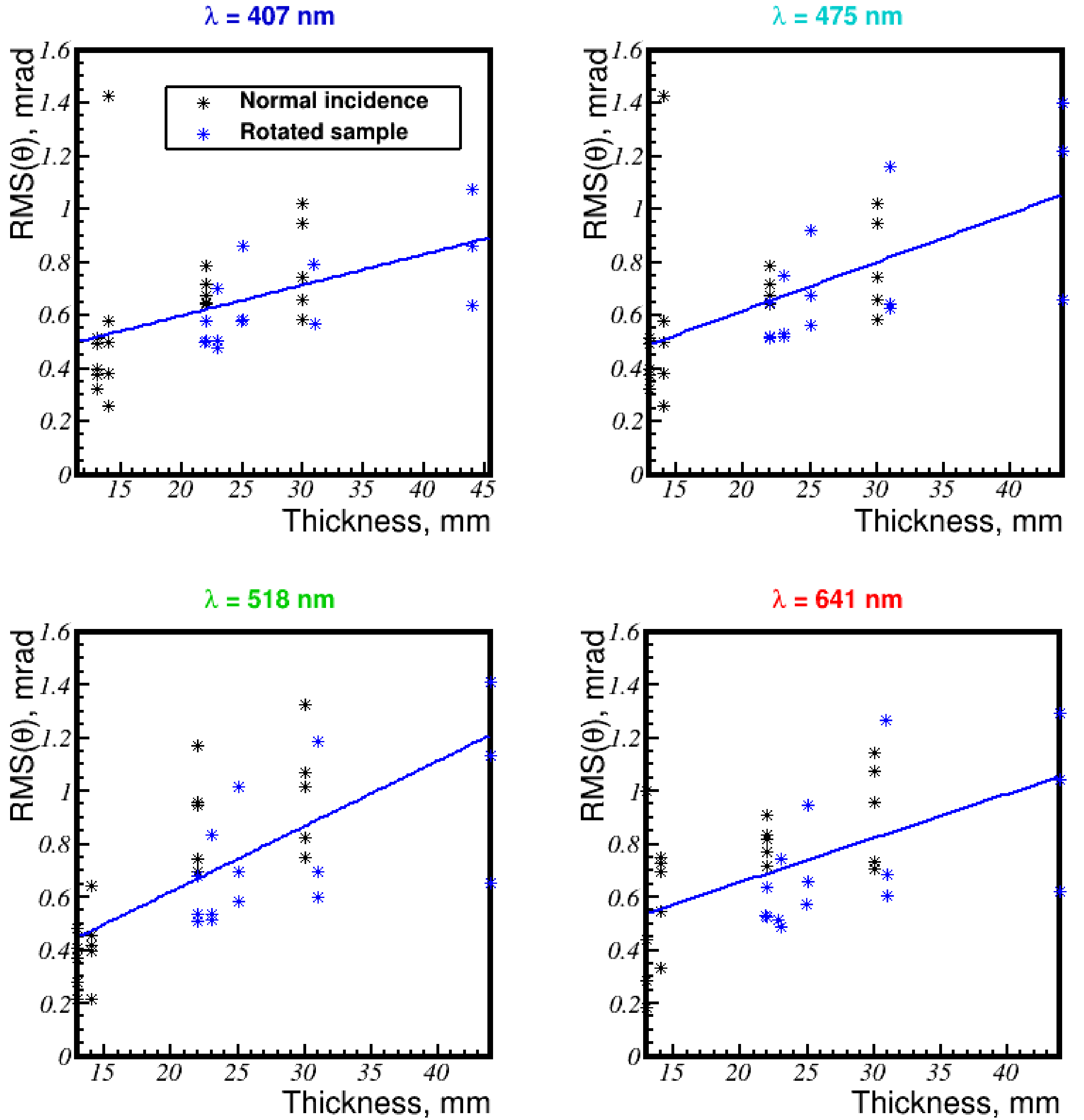
Light forward scattering in aerogel (1)

Forward scattering is known to contribute to the Cherenkov angle resolution in an aerogel RICH

R. De Leo et al, NIMA 457 (2001) 52

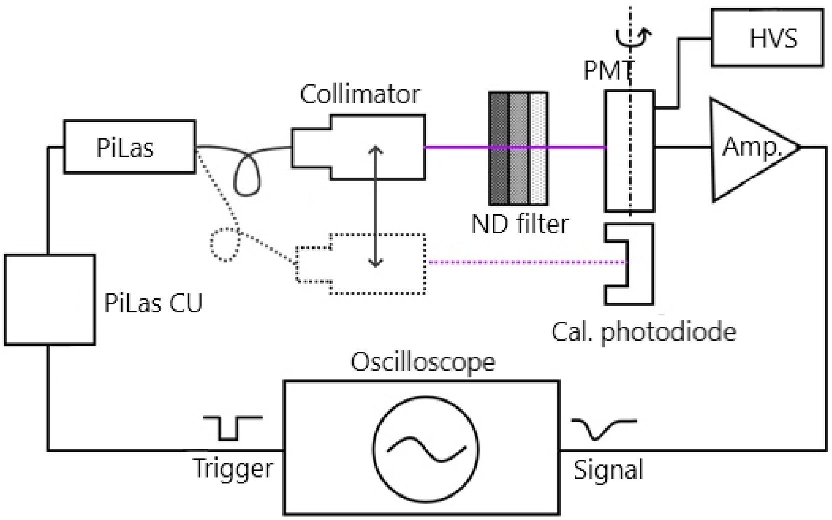


RMS scattering angle vs light path in aerogel



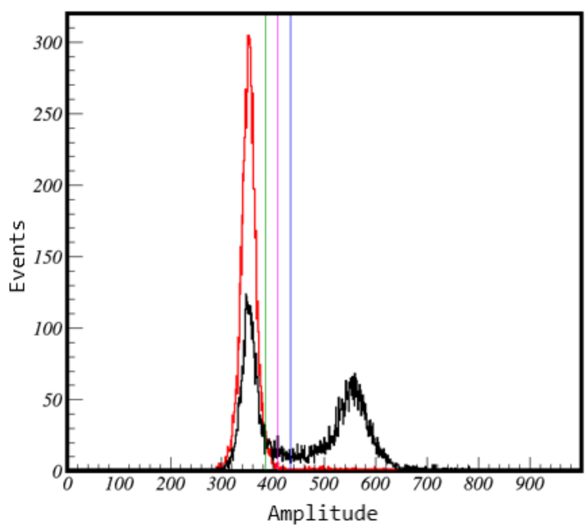
FS RMS(θ) ≈ 1mrad for 40 mm path length. To be compared with 4.8mrad of SPR → **effect is negligible**

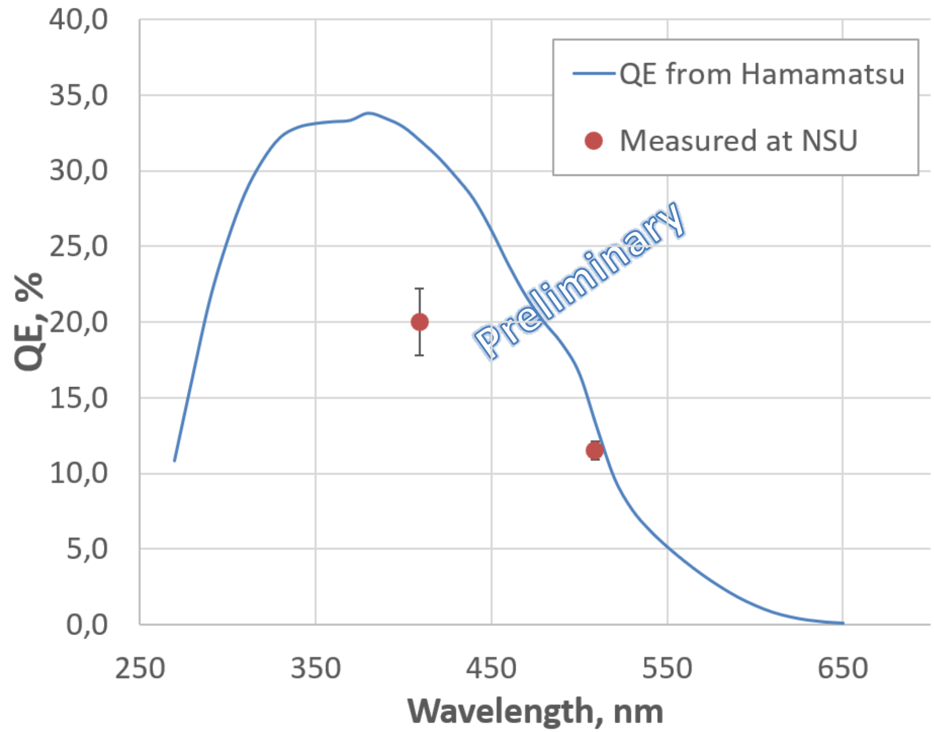
Absolute QE of MaPMT H12700



$$QE = \frac{N_{\text{p.e.}}}{N_{\gamma}} \qquad N_{\text{p.e.}} = -\ln \frac{N_0^{signal}}{N_0^{noise}}$$

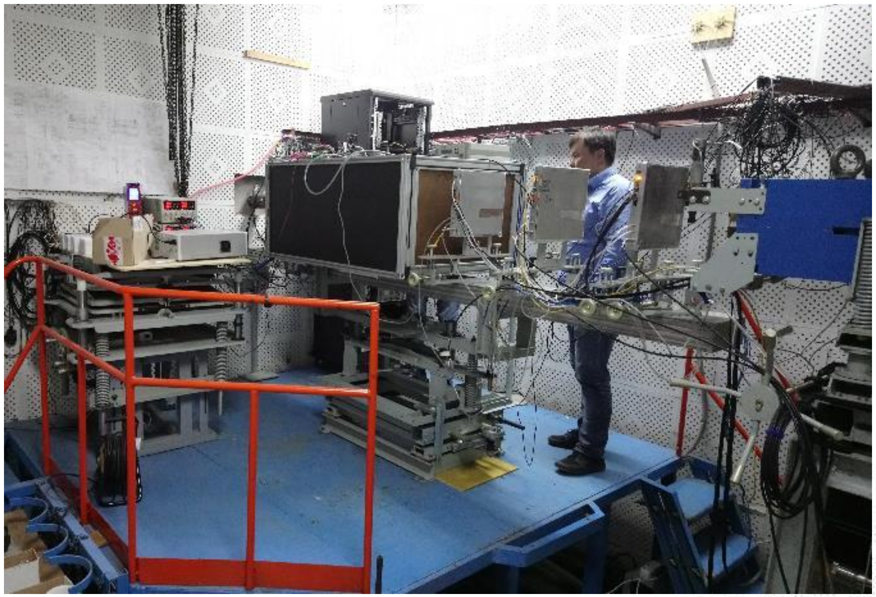
Charge amplitude spectrum





To do: MaPMT QE is to be scanned on wavelength and area

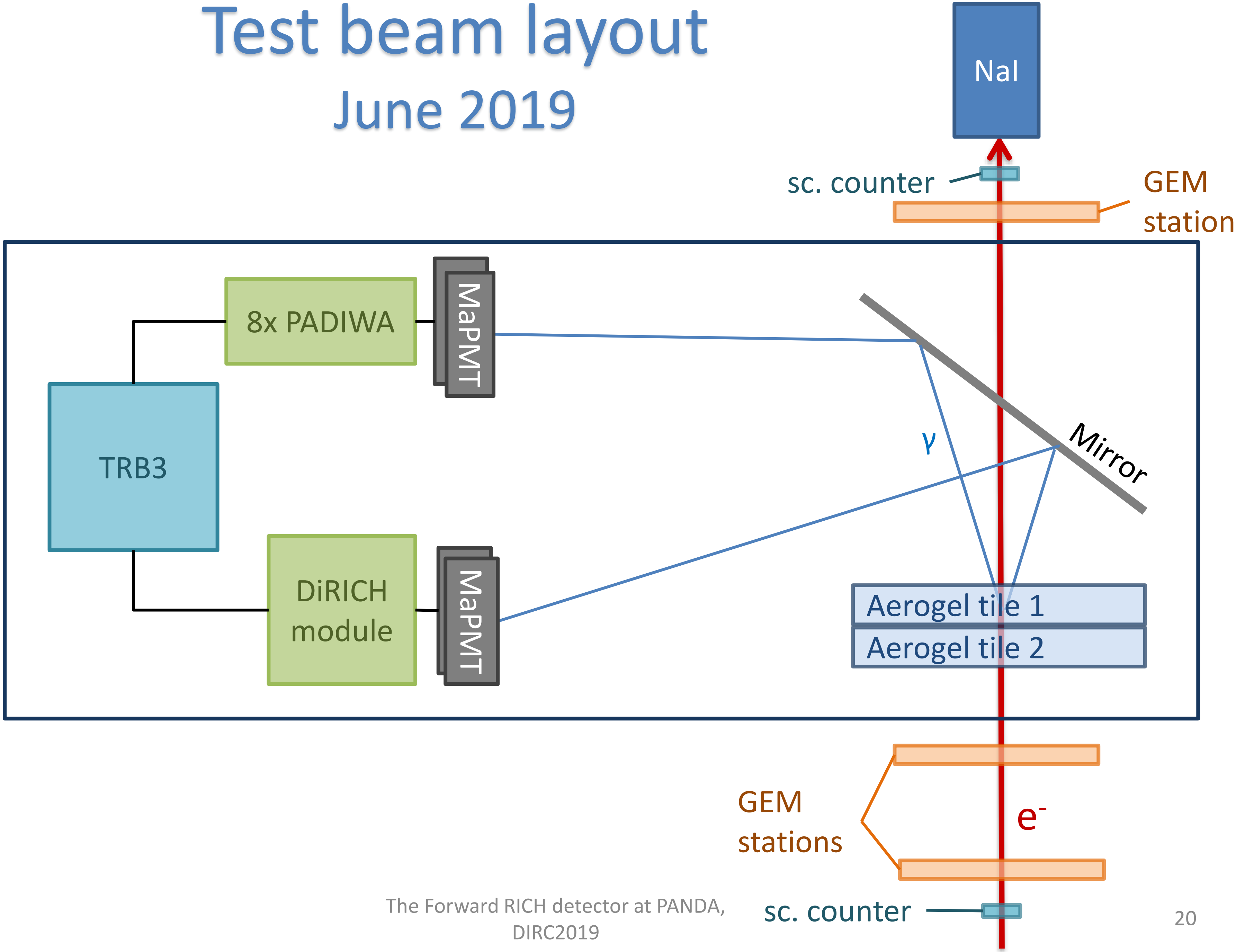
Test beam in June 2019



Electron and gamma test beam facility at the BINP VEPP-4M accelerator

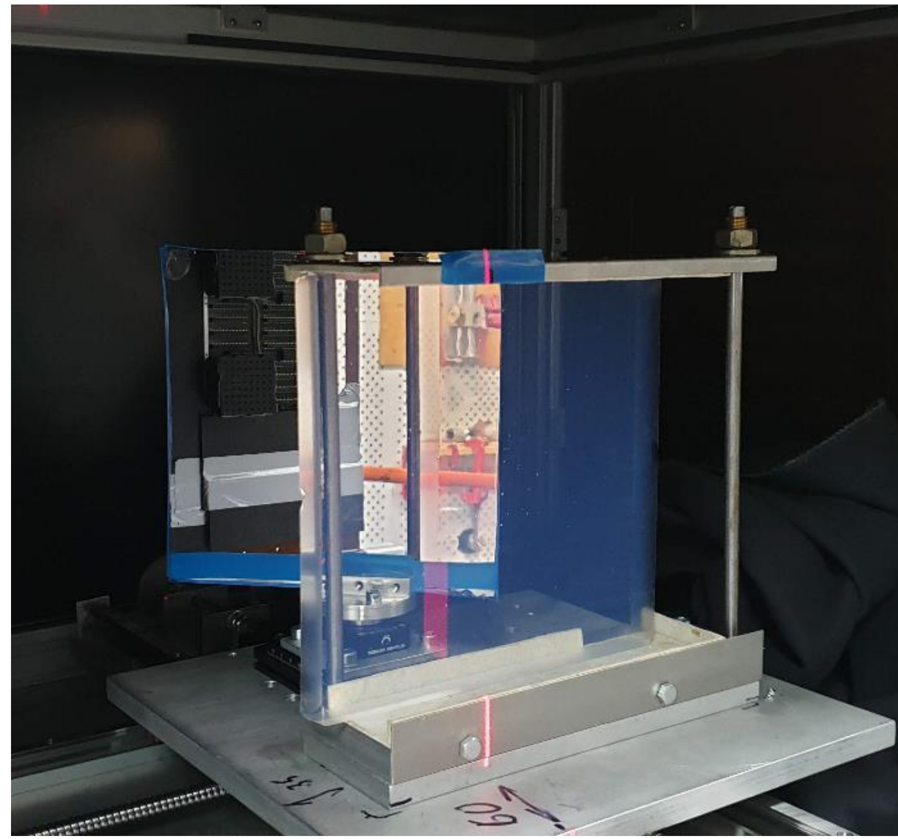
- 3 GeV electrons
- 3 scintillation counters in coincidence for triggering
- 3 GEM with strip readout tracker stations with 70-200 μm resolution
- NaI calorimeter

Test beam layout
June 2019



Forward RICH prototype
June 2019

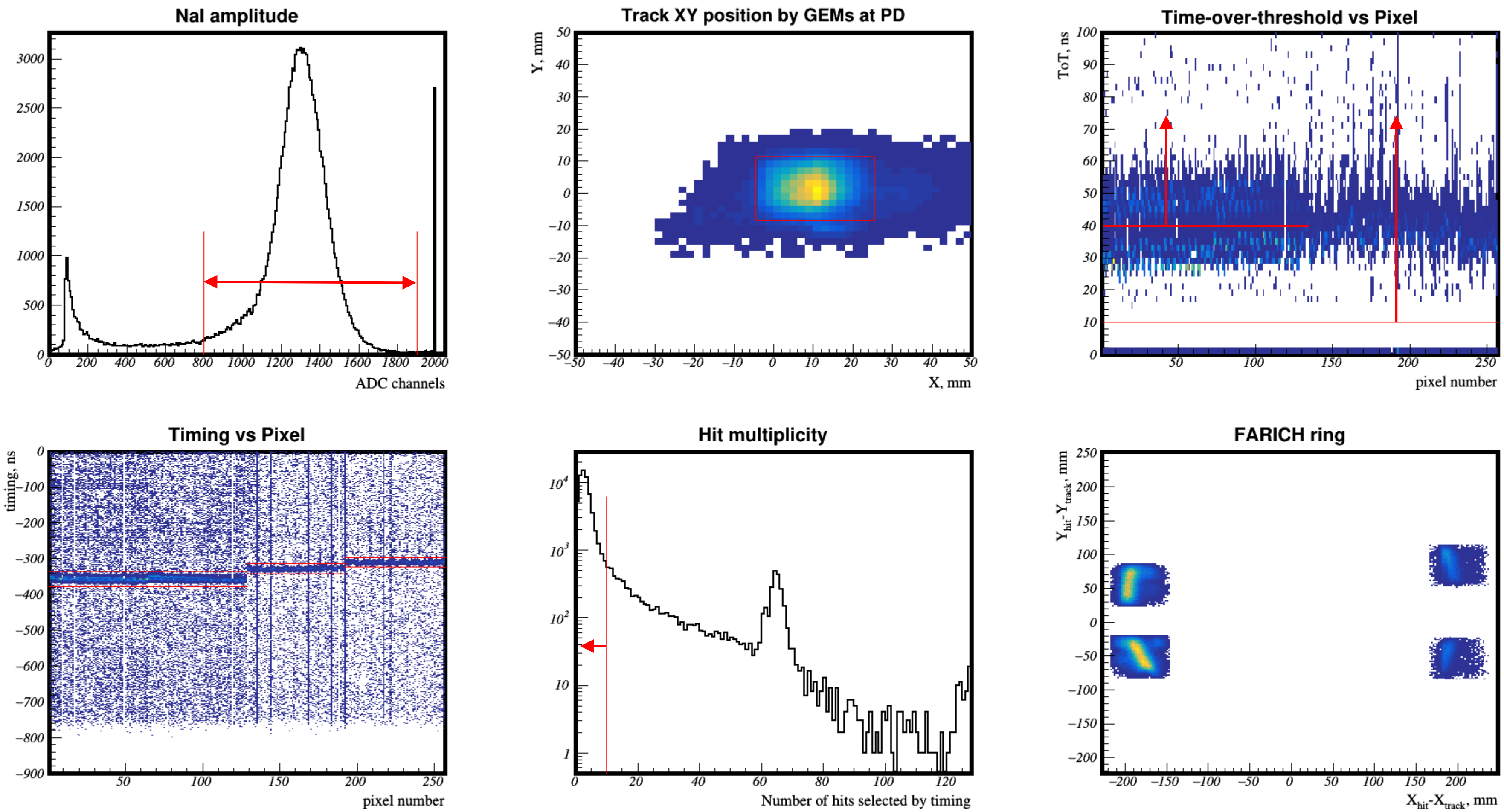
4 MaPMTs readout in half by PADIWA (128 ch) and DiRICH (128 ch)



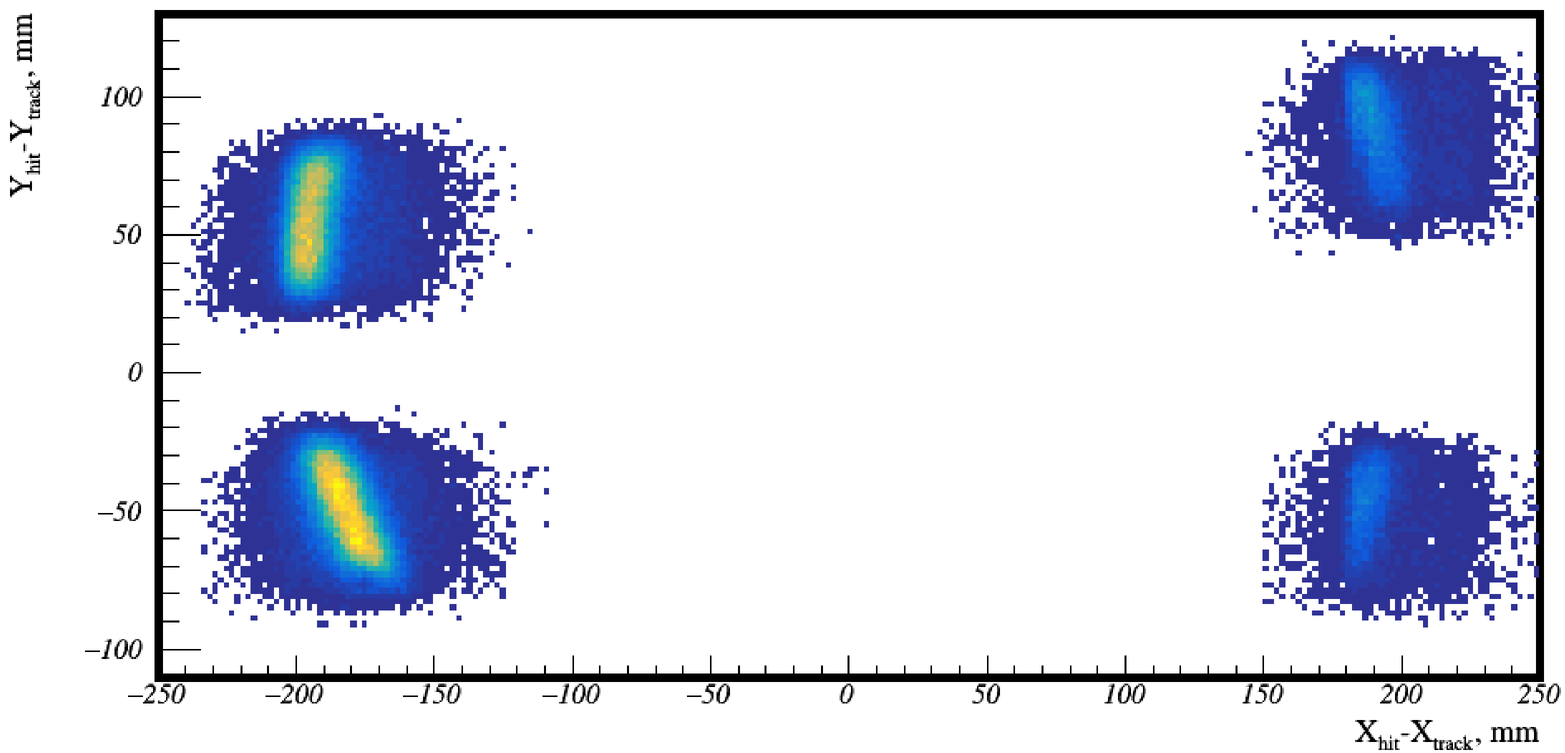
Aerogel sample with a flat mirror installed at 45° w.r.t. the PD and aerogel.

Event and hit selection

June 2019



Track adjusted hit map – Cherenkov ring
June 2019

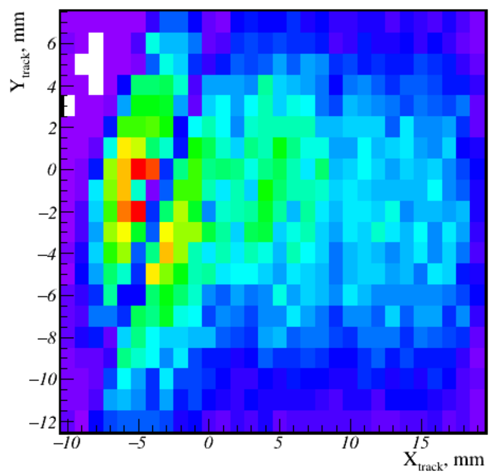


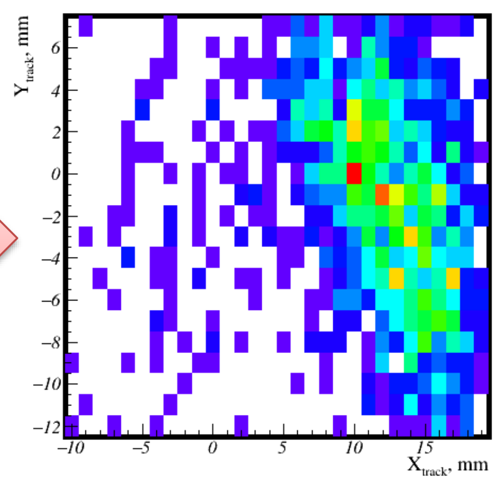
Evaluation of the F-RICH prototype performance

All tracks

Tracks with pixel #20 hit

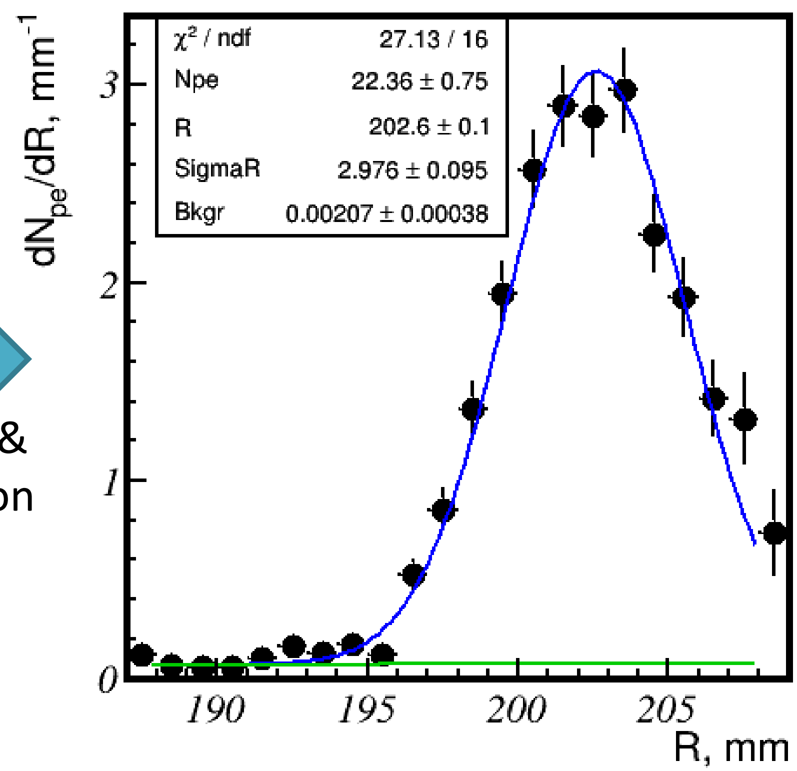
Track position XY distribution





division & projection

Photoelectron density distribution on radius for pixel #20 fitted by gaussian + linear background

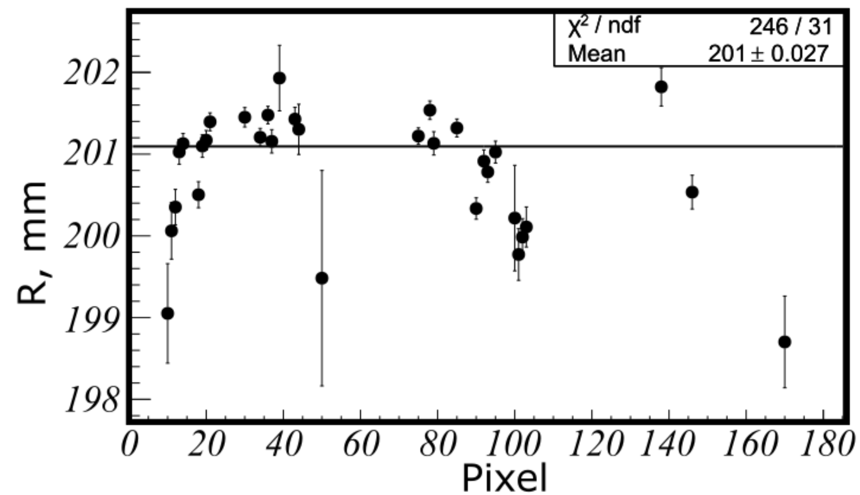


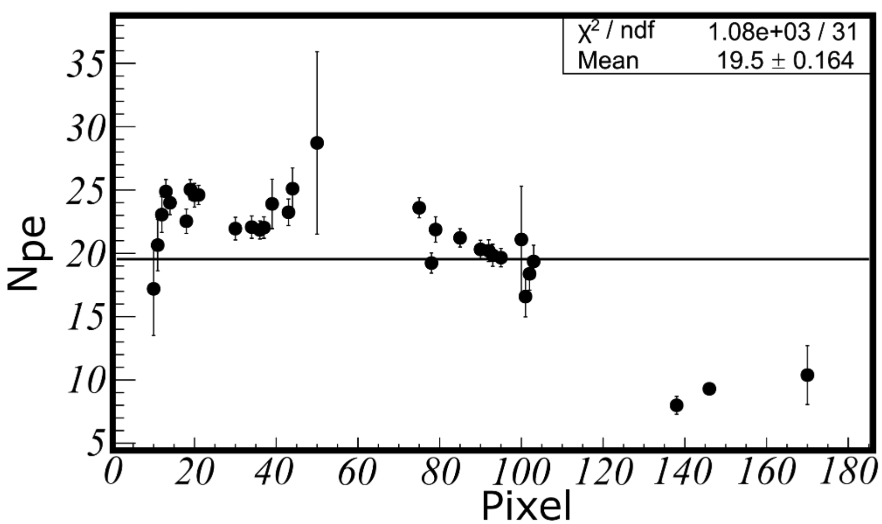
Test beam 2019 results (1)

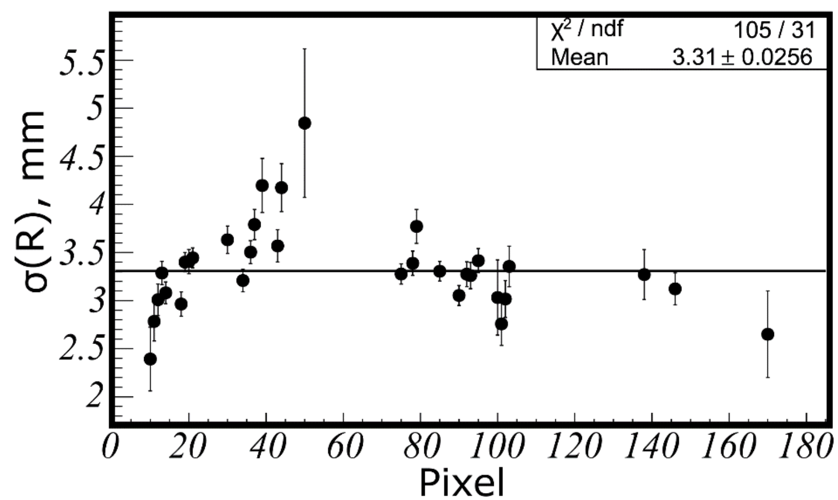
Radiator configuration

1-st layer: n=1.0526, t=2cm

2-nd layer: n=1.0500, t=2cm







Test beam 2019 results (2)

Performance averaged on the DiRICH channels only

Radiator	Parameter	Test beam 2019	Calculation
Stack of 2 layers 2 cm, n=1.0526 + 2 cm, n=1.0500	N_{pe}	22	39
	R, mm	201	199
	$\sigma_{1pe}(R)$, mm	3.31	3.08
Stack of 2 layers 2 cm, n=1.0538 + 2 cm, n=1.0511	N_{pe}	21	40
	R, mm	203	201
	$\sigma_{1p.e.}(R)$, mm	3.25	3.11
Single layer 2 cm, n=1.0538	N_{pe}	15	26
	R, mm	204	201
	$\sigma_{1pe}(R)$, mm	3.24	3.17

1.8 times less

$\sqrt{3.3^2 - 3.1^2} \cong 1\text{ mm}$

Effects in the calculation: aerogel chromaticity, Rayleigh scattering, radiator thickness, pixel size, 80% efficiency factor (reflectance, light loss at aerogel surface).

Effects left out of the calculation: tracking resolution, multiple scattering, anode charge sharing, aerogel inhomogeneity, FEE efficiency, non-gaussian shape of dN_{pe}/dR.

Conclusion and outlook

- PANDA Forward RICH design is described.
- Different mirror samples were studied. Tomsk mirrors are chosen.
- Preliminary measurement of the absolute QE for H12700 showed . To be studied in more detail and negotiated with the producer.
- Light forward scattering in aerogel is studied. Effect is negligible for the PANDA F-RICH
- Results of the test beam in 2019 are presented. Single photon radius resolution agrees quite well with the calculation. Discrepancy in the photoelectrons is observed (probably due to low DQE).
- TDR will be drafted in 2019-2020. F-RICH is to be ready for installation by 2026.