The Forward RICH Detector for the $\bar{\text{P}}$ANDA Experiment

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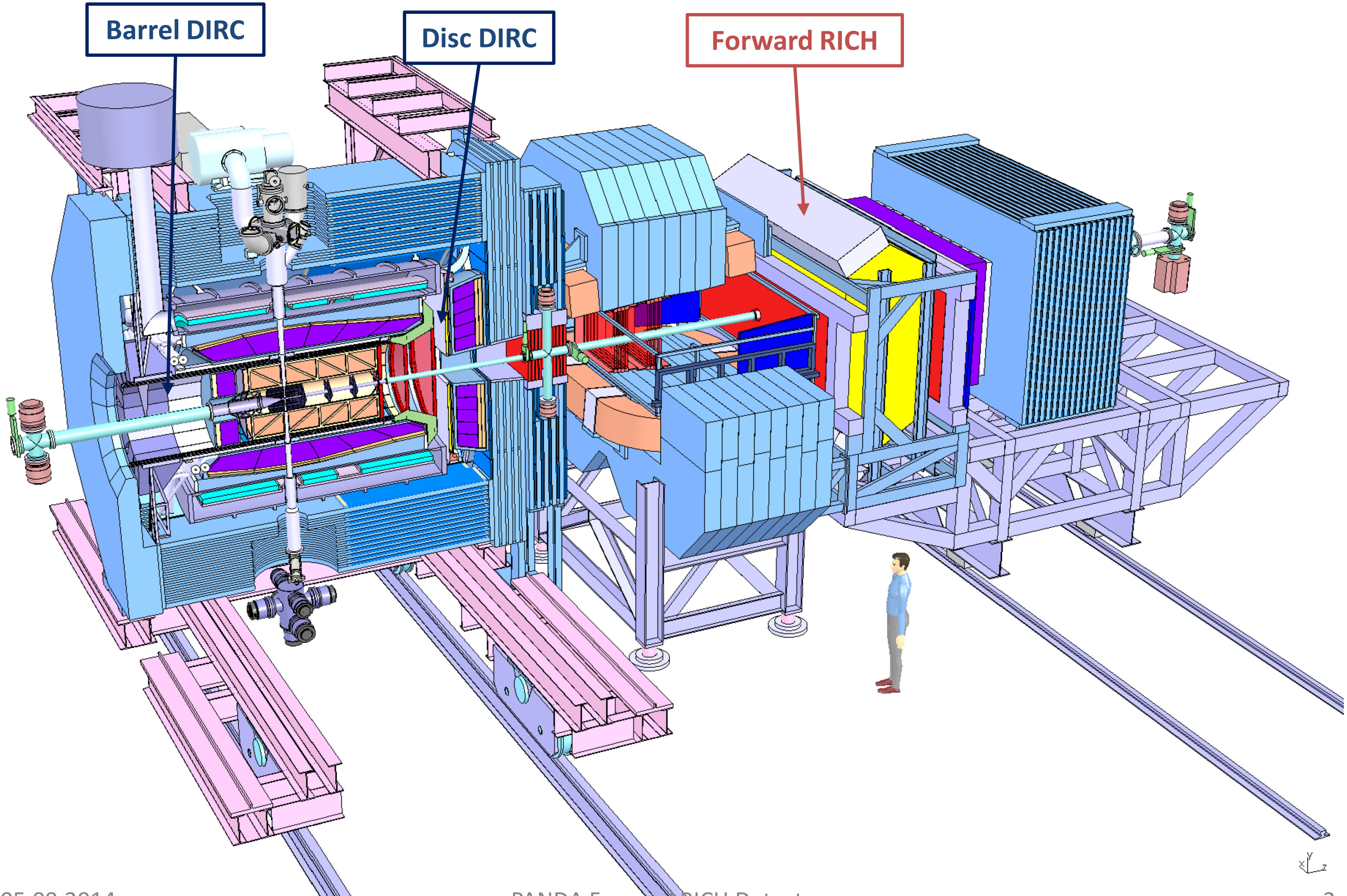
P̄ANDA detector PID

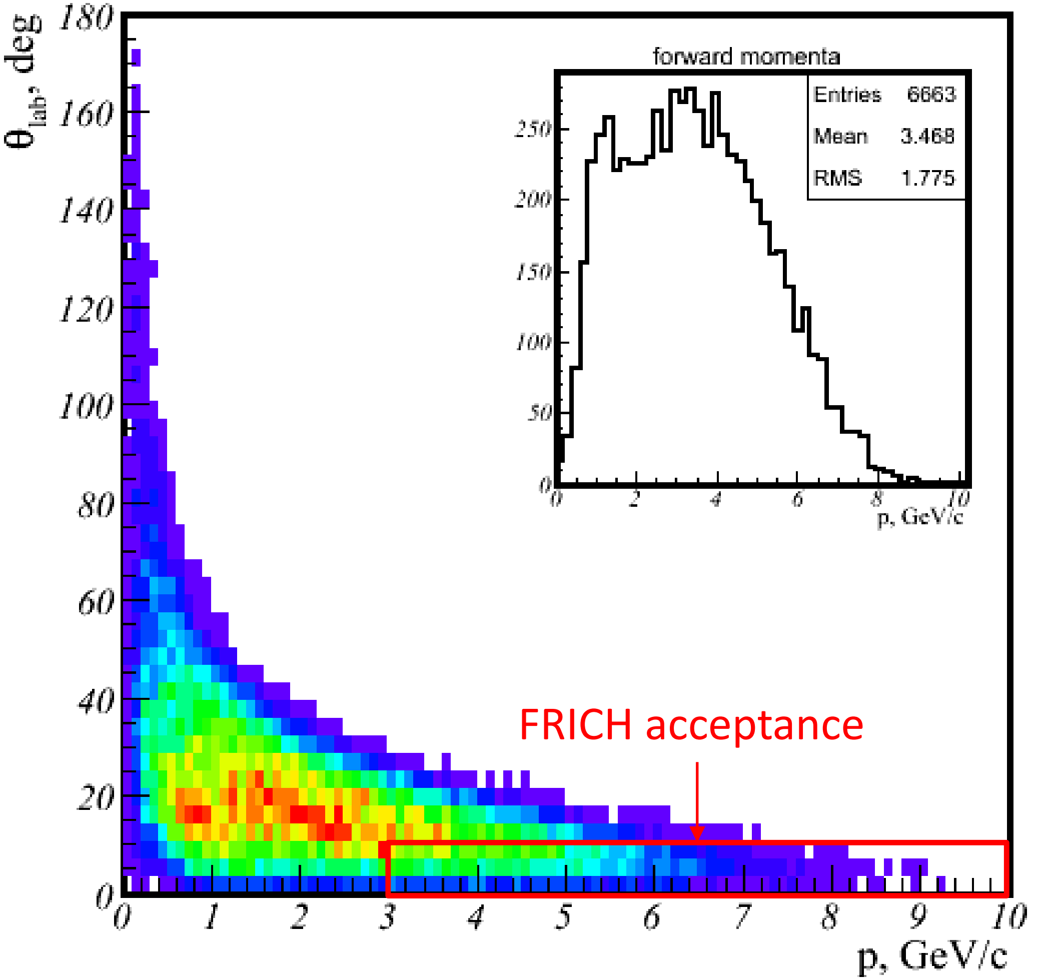


Requirements for PANDA Forward RICH

- Charged PID in the Forward Spectrometer
- $|\theta x| < 10°$, $|\theta y| < 5°$
- 3 m^2 transverse acceptance
- Working momentum range for 3σ separation
  - π /K: 2÷10 GeV/c
  - μ/π: 0.5÷2 GeV/c
- Low material before the PANDA EMC

A physics case

π, K from $p\bar{p} \to D^0 \overline{D}^{*0} \eta$



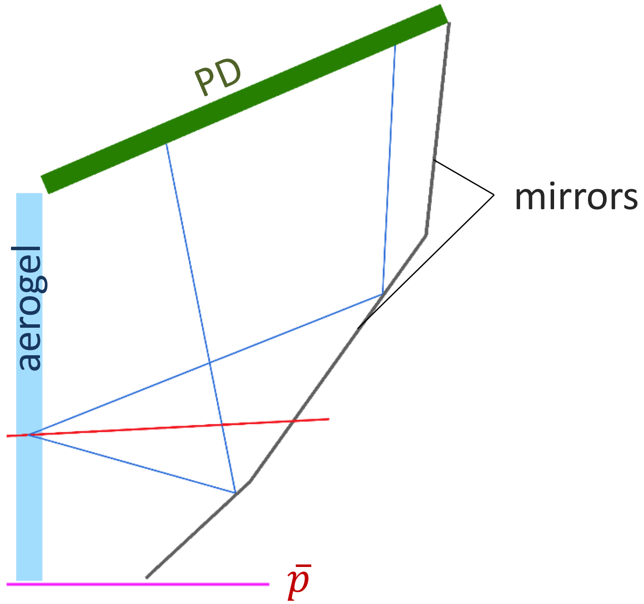
Hybrid $\tilde{\eta}_{c1}(c\bar{c}g)$ search at 15 GeV/c

$$p\bar{p} \to \tilde{\eta}_{c1}\eta \to D^0\overline{D}^{*0}\eta + c.c.$$
$$\to 2K\ 2\pi\ 6\gamma$$

FastSim: 46% of events are reconstructed only due to the FRICH

Processes at high beam momentum with a large multiplicity are likely to give particles in the Forward RICH.

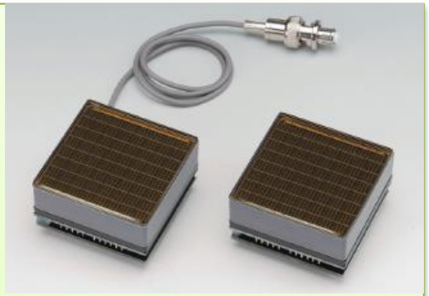
Baseline conceptual design



Mirrors

- Flat segments
- Float glass substrate 2 mm thick
- $Al+SiO_2$ coating, $R \geq 90\%$
- Light-weight Al or carbon fiber support
- Simplicity of production and positioning

Photon Detector



Hamamatsu H12700 MaPMT

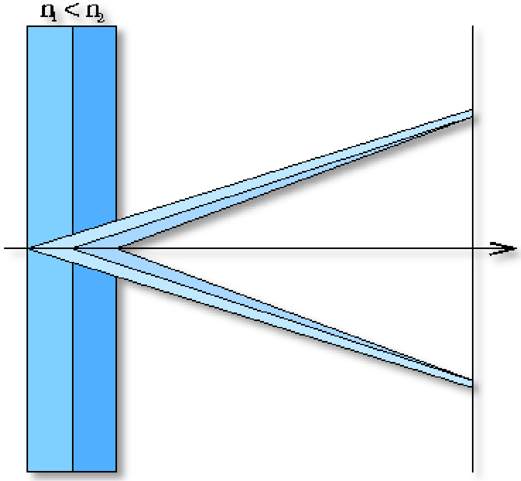
- flat panel,
- 8x8 anode pixels of 6mm size
- 87% active area ratio
- Bialkali photocathode
- Gain: $1.5 \cdot 10^6$
- Good single p.e. amp resolution
- Robust
- Long lifetime
- Works in the mag. field 25G (stray field of the dipole)

Radiator

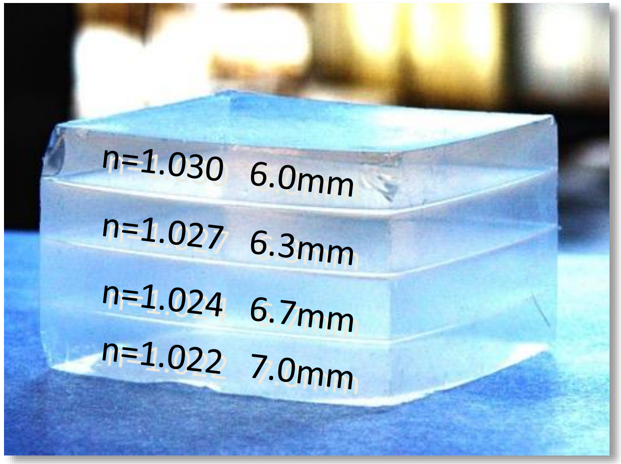
- Focusing 2- or 3-layer aerogel
- 40 mm thick
- No gaseous radiator

Focusing Aerogel RICH (FARICH)

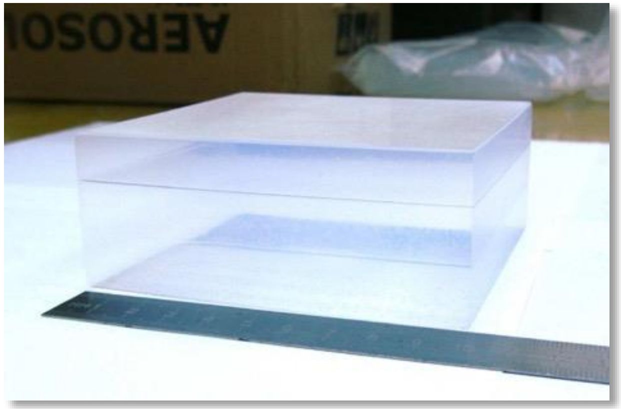
Single ring option



First sample of 4-layer aerogel



3-layer aerogel 115x115x41 mm^3



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

Multi-layer monolith aerogels have been being produced by the Boreskov Institute of Catalysis in cooperation with the Budker INP since 2004.

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

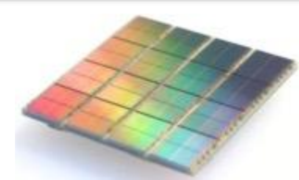
Readout options

MaPMT H12700B → FEE PADIWA3 → TDC TRBv3

Baseline option
H12700B (~1400 pcs in total)

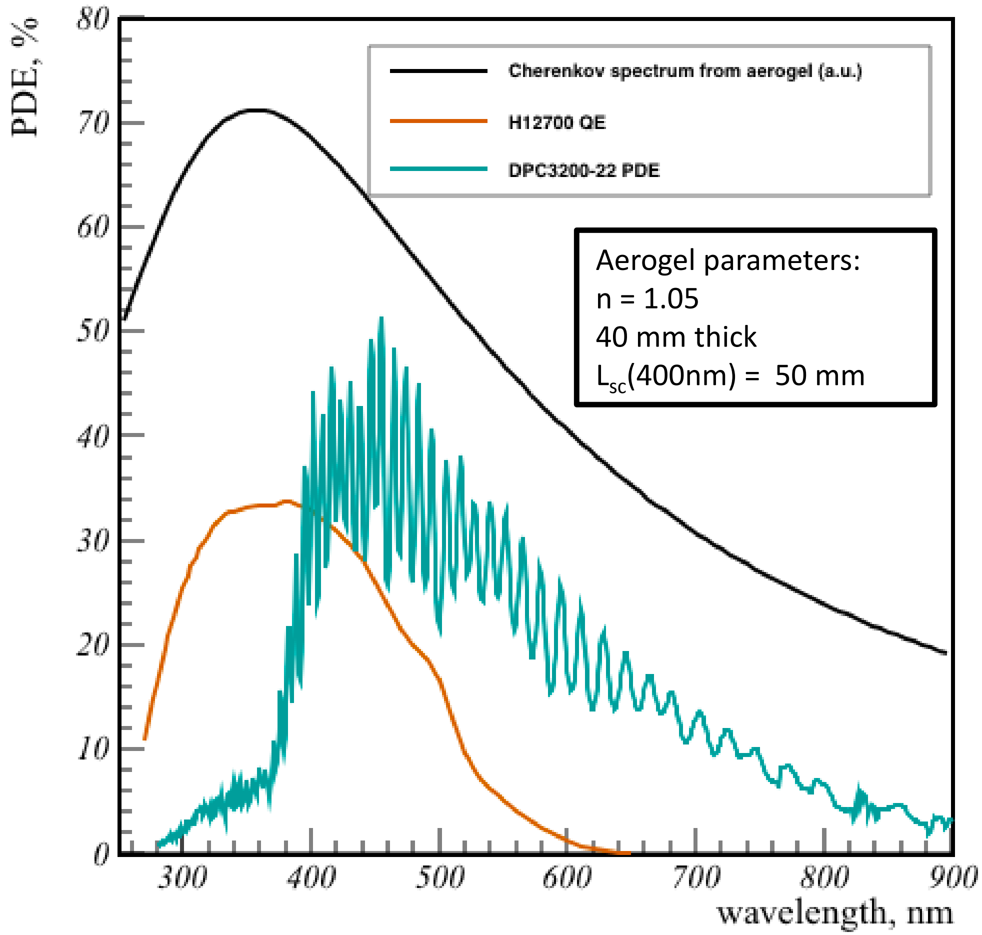
DPC 3200-22-44 → Tile FPGA → Module FPGA → Data concentrator

Secondary option
DPC modules (~ 800 pcs In total)
720 ns sensor dead time
Needs cooling
Not radiation hard (lifetime ~1 year in PANDA FRICH w/o neutron shielding)



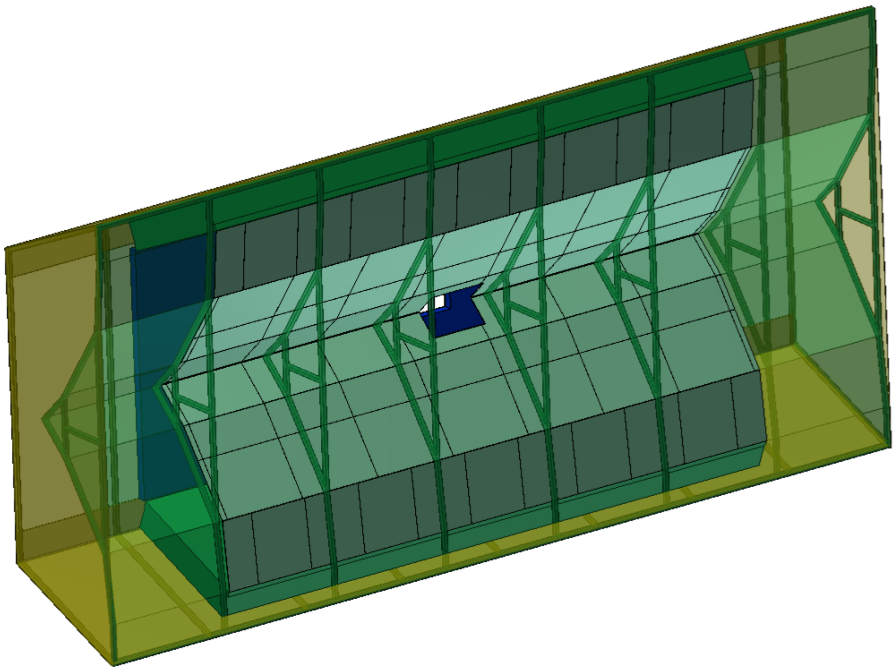
H12700 QE / DPC3200-22-44 PDE

producers' data

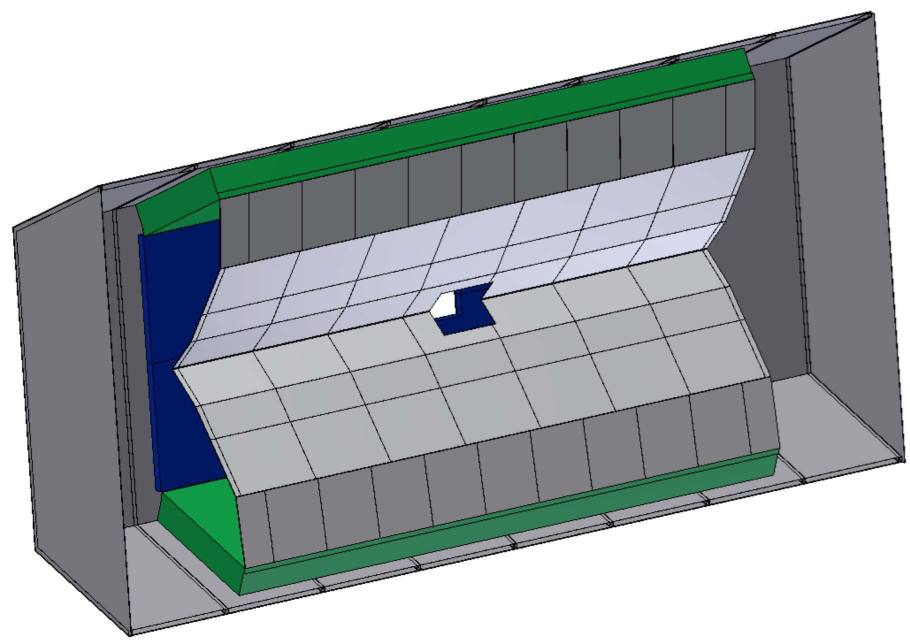


DPC PDE is actually about 1.7 times lower as was shown by the beam test [A.Yu.Barnyakov et al., NIMA 732 (2013) 352] and our PDE direct measurements

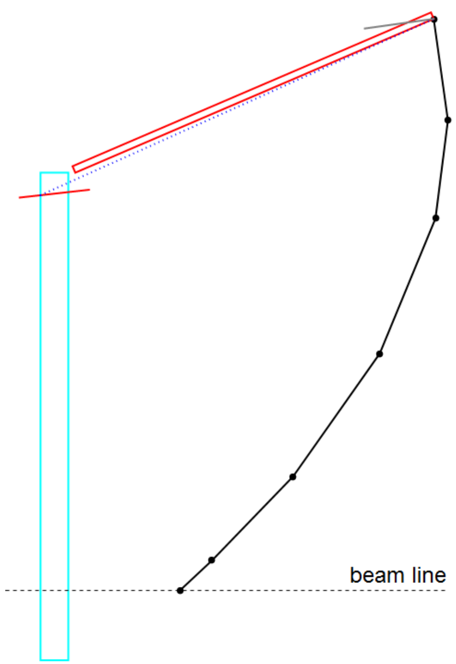
Conceptual mechanical design



- Light-weight Al support
- 0.5mm windows for particles
- Total material budget about 10% X_0



Mirror layout optimization in 2D



Six segments flat mirror
(as an example)

I. **100% photon acceptance**

(there are never too many Cherenkov photons)

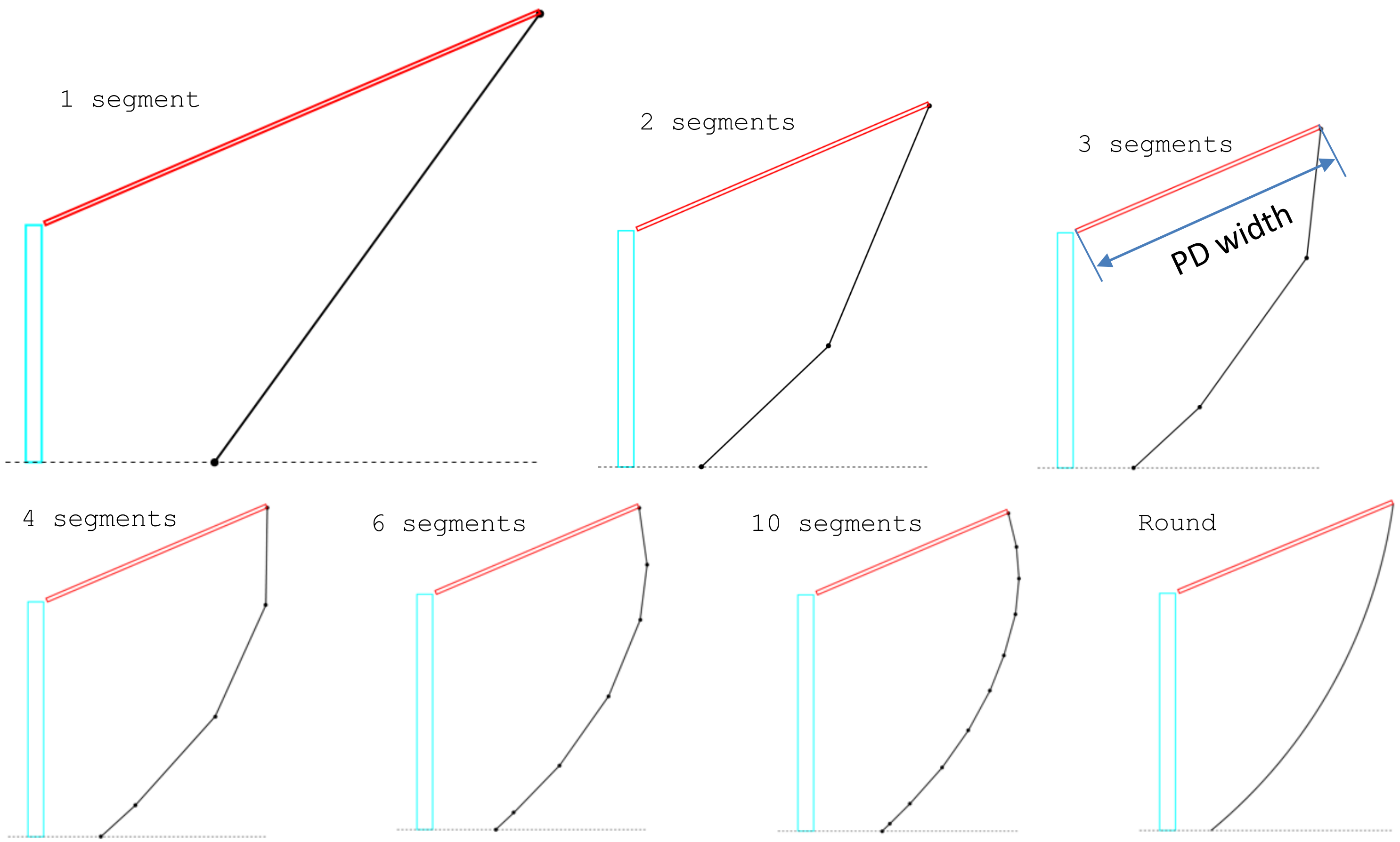
- Lower Č photon hits PD
- Upper Č photon hits PD
- All other Č photons automatically do the same

II. **Photo detector area minimization**

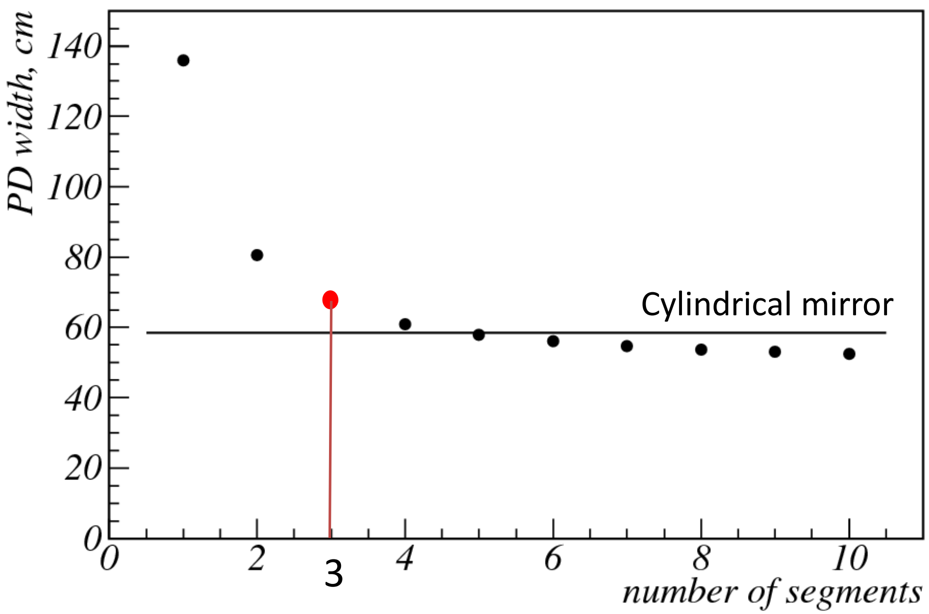
$w(z, l_1, l_2, l_3, \dots) \rightarrow w_{min}$

First (lower) segment has major influence on PD size!

Possible mirror configurations



Mirrors: flat vs cylindrical



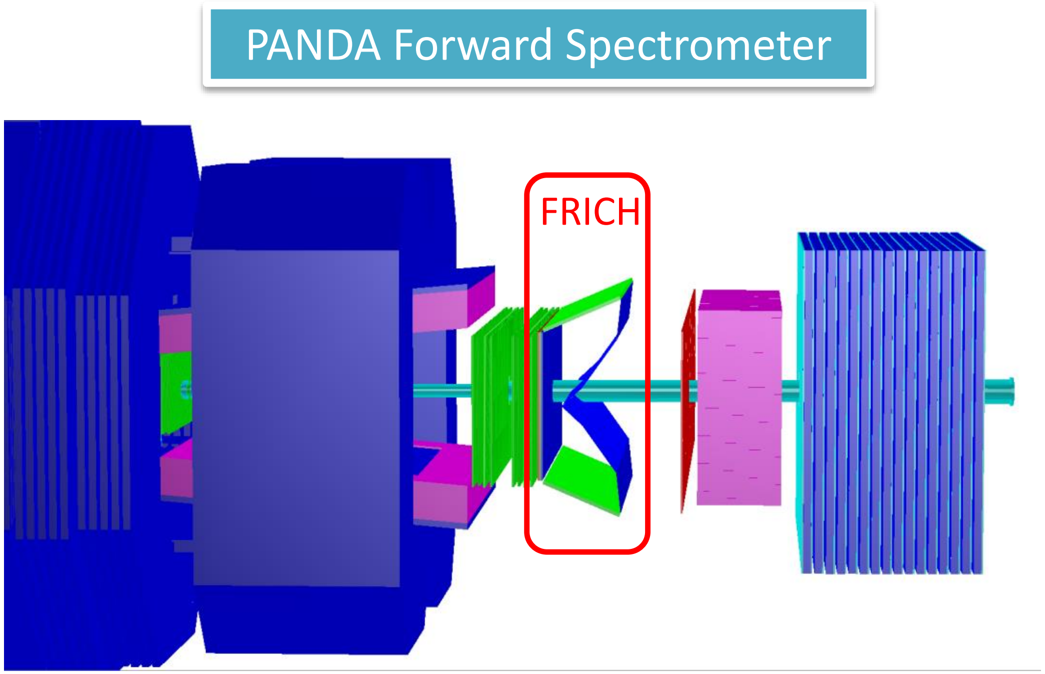
Feature	3 segments	Cylindrical
PD width*, cm	67.5	58.5
Mirror focusing	no	yes
Aerogel focusing	yes	no
Combinatorial background	yes	no
Cherenkov image shape on PD surface	broken elliptical	complicated

* Size of the PD side projection. Aerogel plate half-size is 60 cm.

Mirror bent in 3-rd dimension does not give much reduction of PD area but substantially cuts the photon acceptance

3-segment mirror was chosen as a baseline option

PANDA Forward RICH simulation

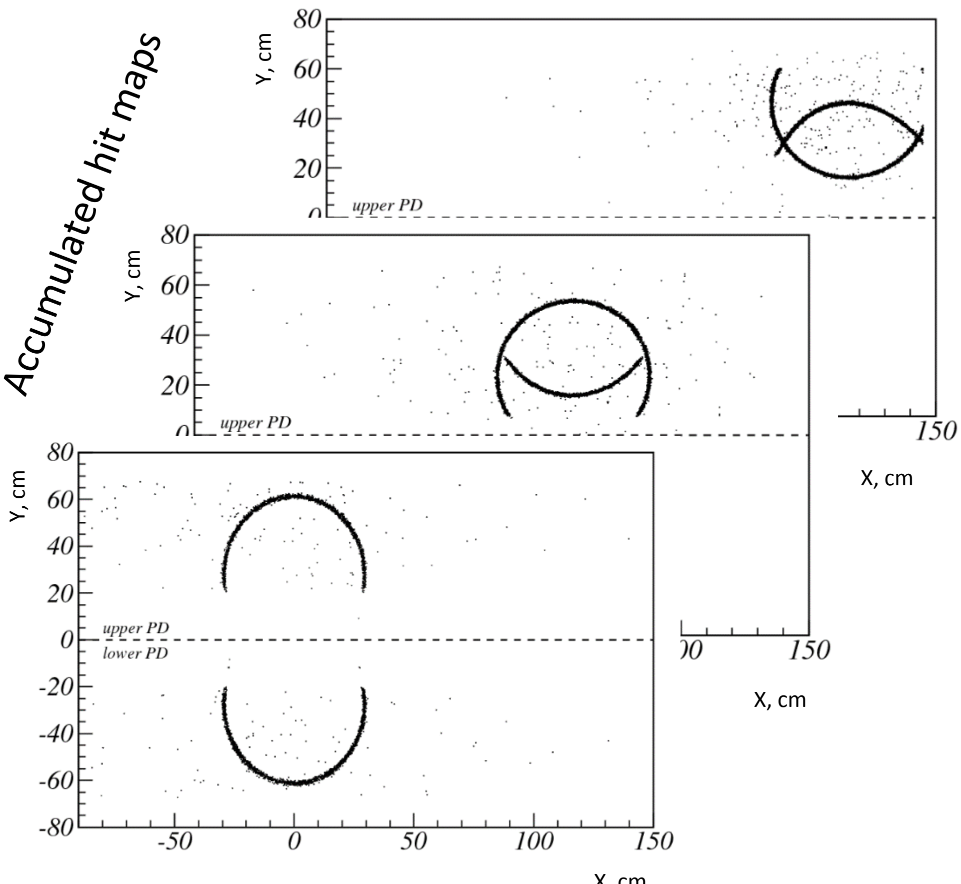


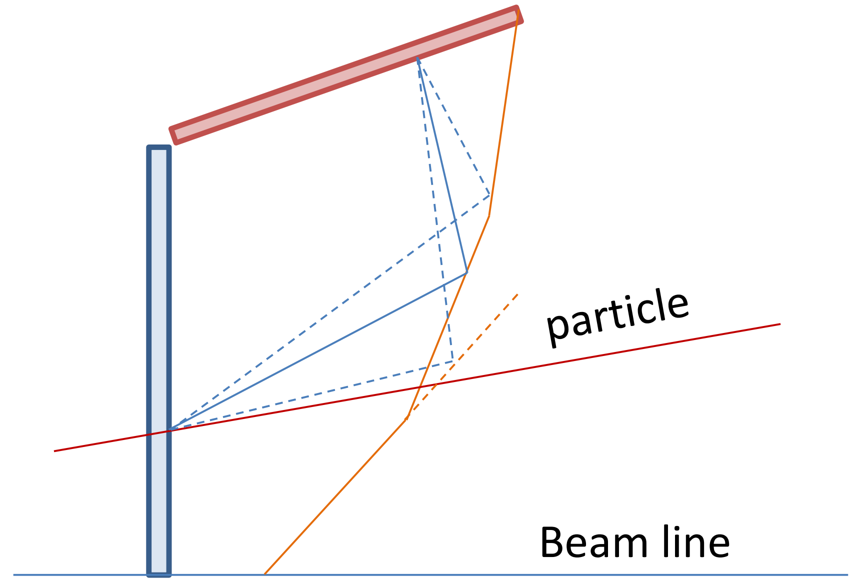
Radiator	focusing aerogel with n~1.05
Photon detector	Philips DPC 3200-22
Radiator thickness	4 cm

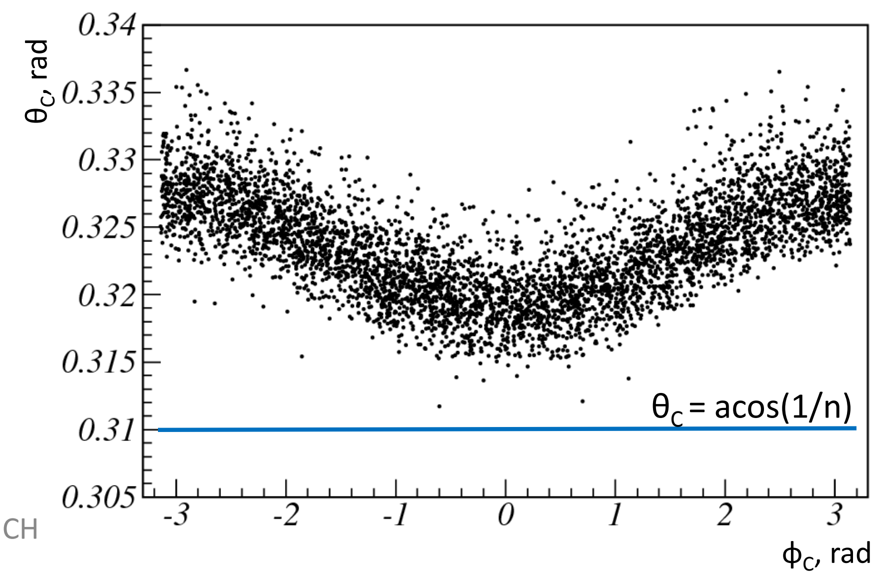
Sim done by K. Beloborodov using PandaRoot

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
   - ✓ Crosstalks (to do)
3. Reconstruction
   - ✓ Hit preselection
   - ✓ Fit $\theta_c(\phi_c)$ dependence
4. Calibration of beta resolution for fast simulation
5. PID
   - ✓ Probabilities calculation

Hit reconstruction



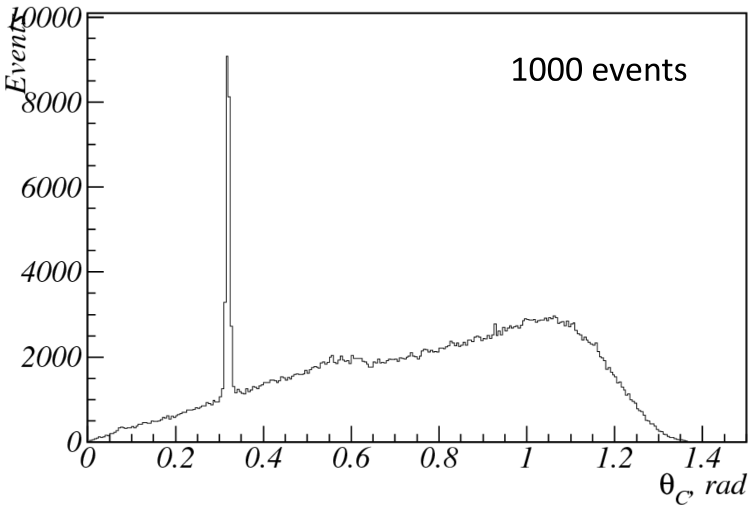


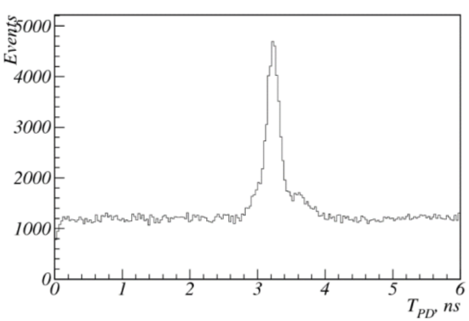


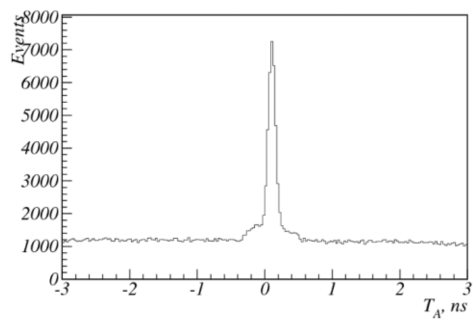
Track-based reco

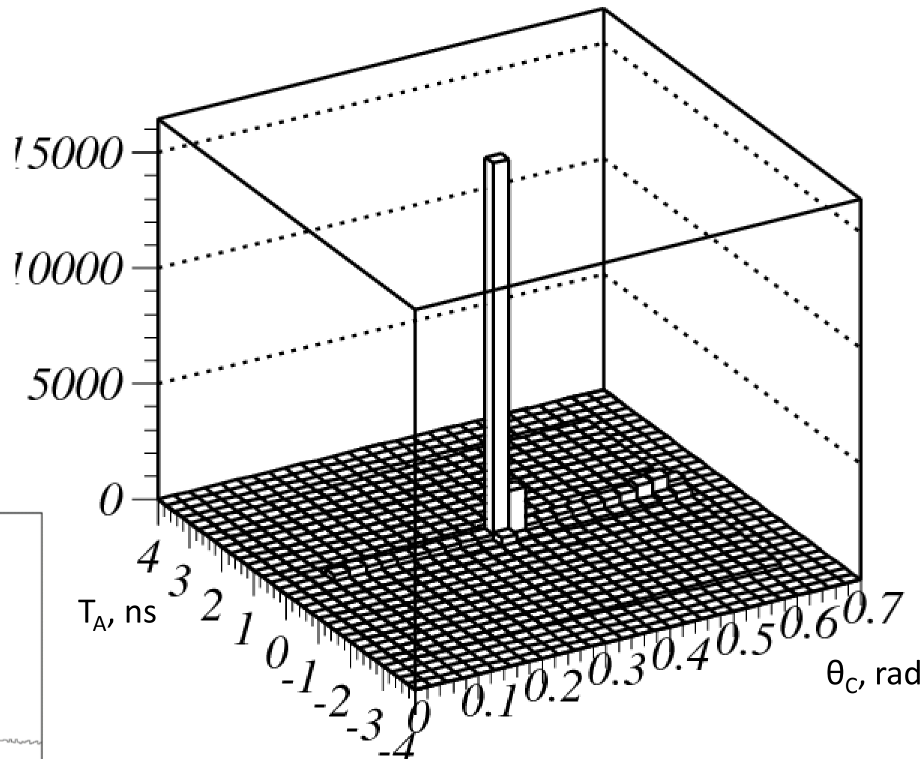
Trace back a PD hit position (X,Y) to the midpoint of a track segment in the radiator and find (θ_c, φ_c)

Hit pre-selection

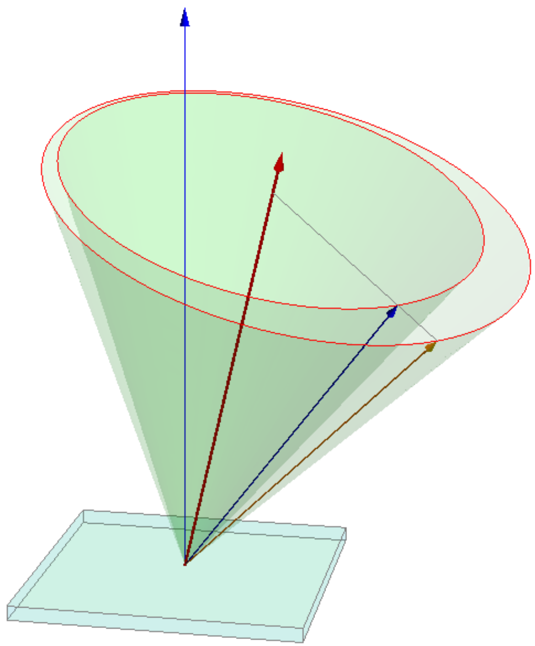


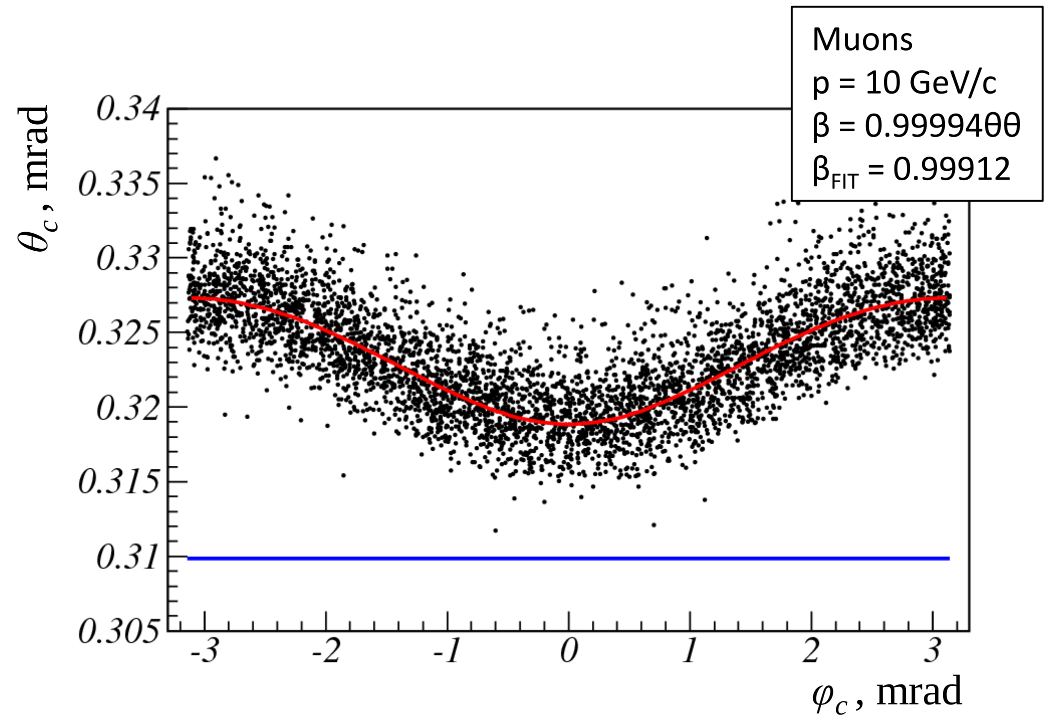






Ring fitting





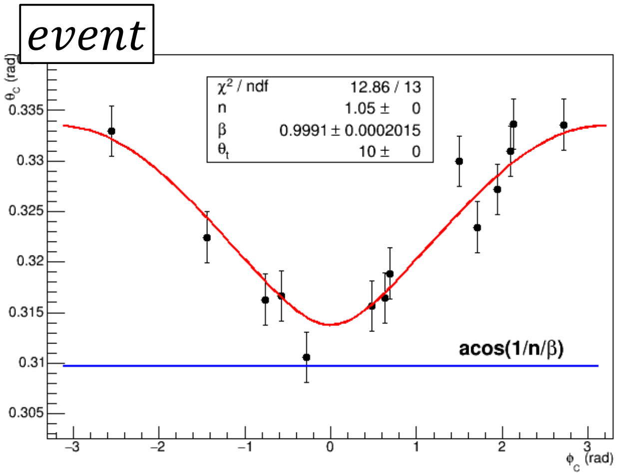
$$\theta_c(\varphi_c;\beta,n,\theta_t) = \mathrm{acos}\left(\frac{1}{n\beta}\right) + \mathrm{acos}\left(n\left(1-(\vec{n}_0\vec{n}_\gamma)^2\right) + (\vec{n}_0\vec{n}_\gamma)\sqrt{1-n^2\left(1-(\vec{n}_0\vec{n}_\gamma)^2\right)}\right)$$

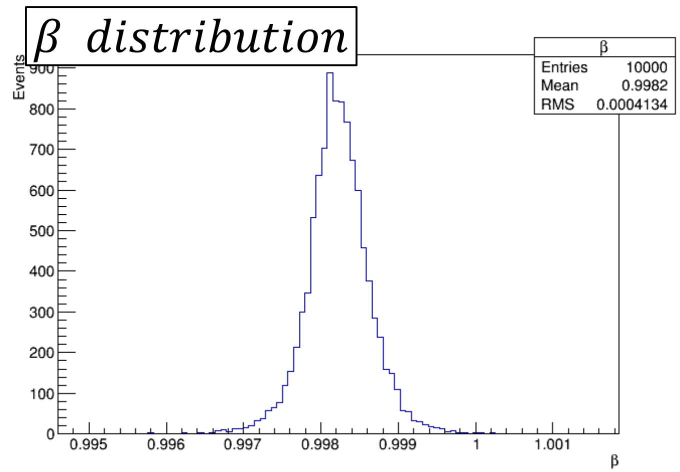
$$(\vec{n}_0\vec{n}_\gamma) = \frac{\cos\theta_t}{n\beta} + \cos\varphi_c \sin\theta_t \sqrt{1-\frac{1}{(n\beta)^2}}$$

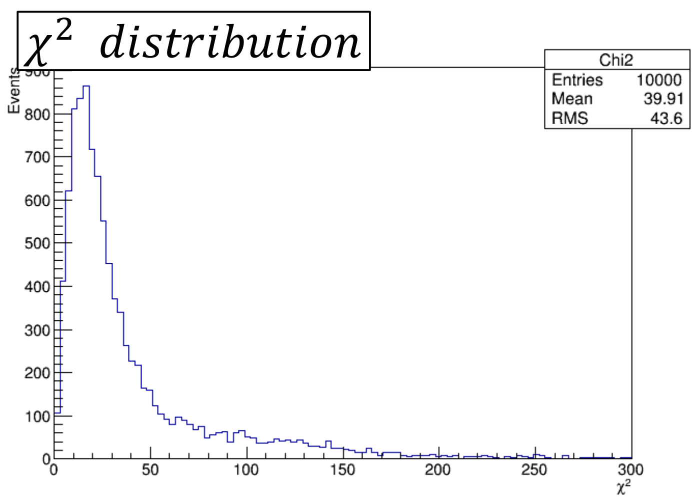
Fit $\theta_c(\varphi_c)$ dependence for each event and get particle's velocity β

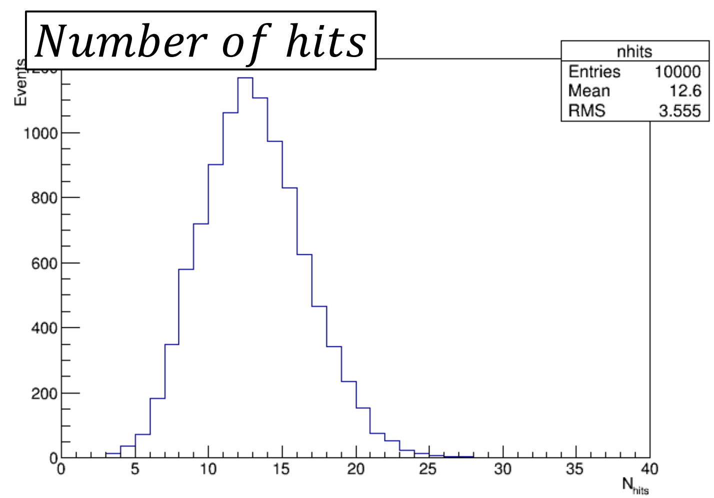
- θ_c – polar angle of Cherenkov photon
- ϕ_c – azimuthal angle of Cherenkov photon
- β – velocity of the charged particle
- n – refraction index of the aerogel
- θ_t – polar angle of the charged particle

Event reconstruction

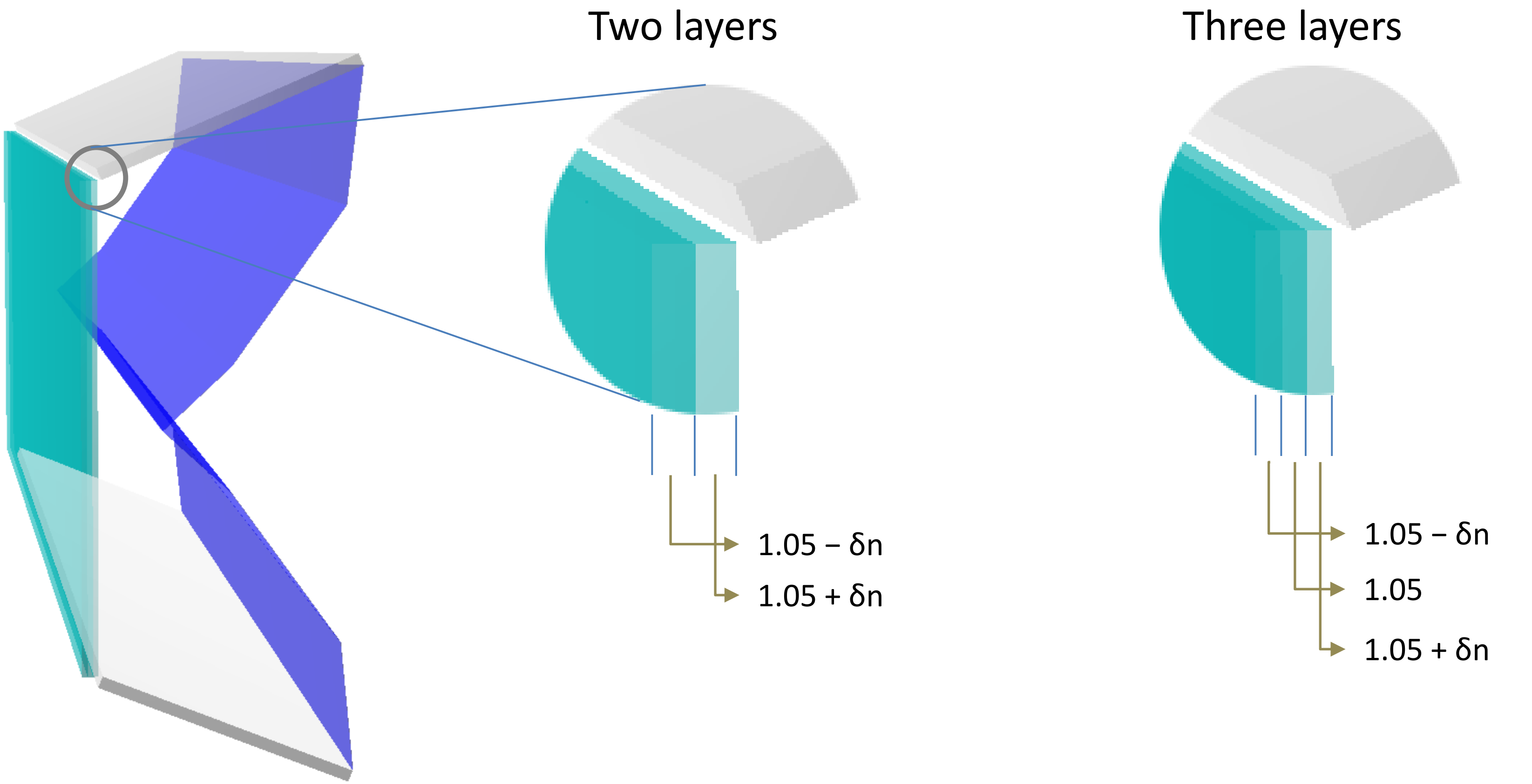






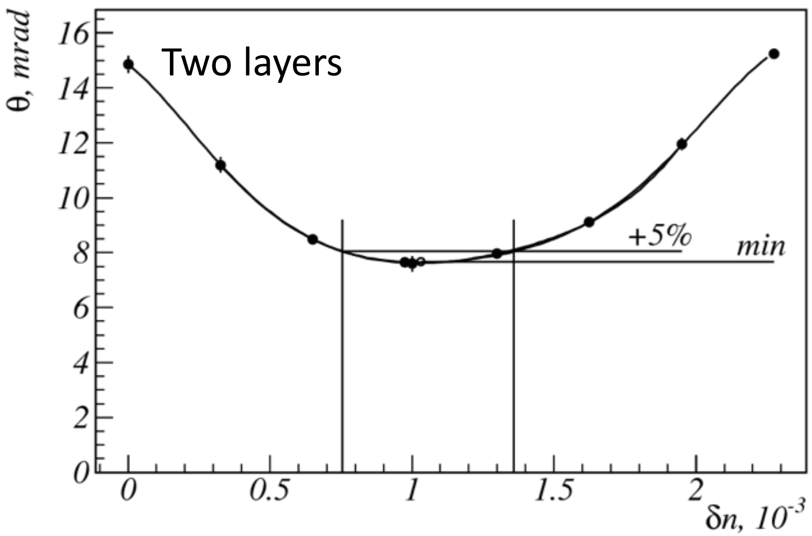


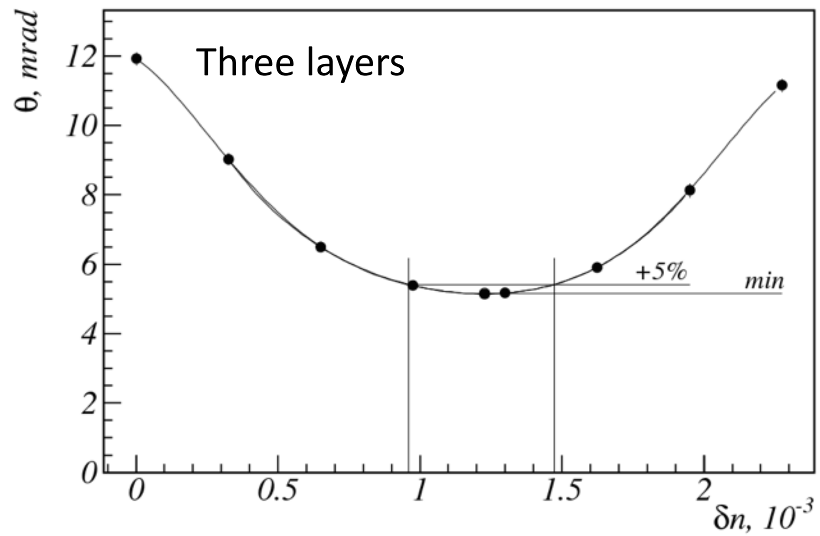
Focusing aerogel optimization



Optimize Cherenkov angle resolution by varying δn

Focusing aerogel optimization



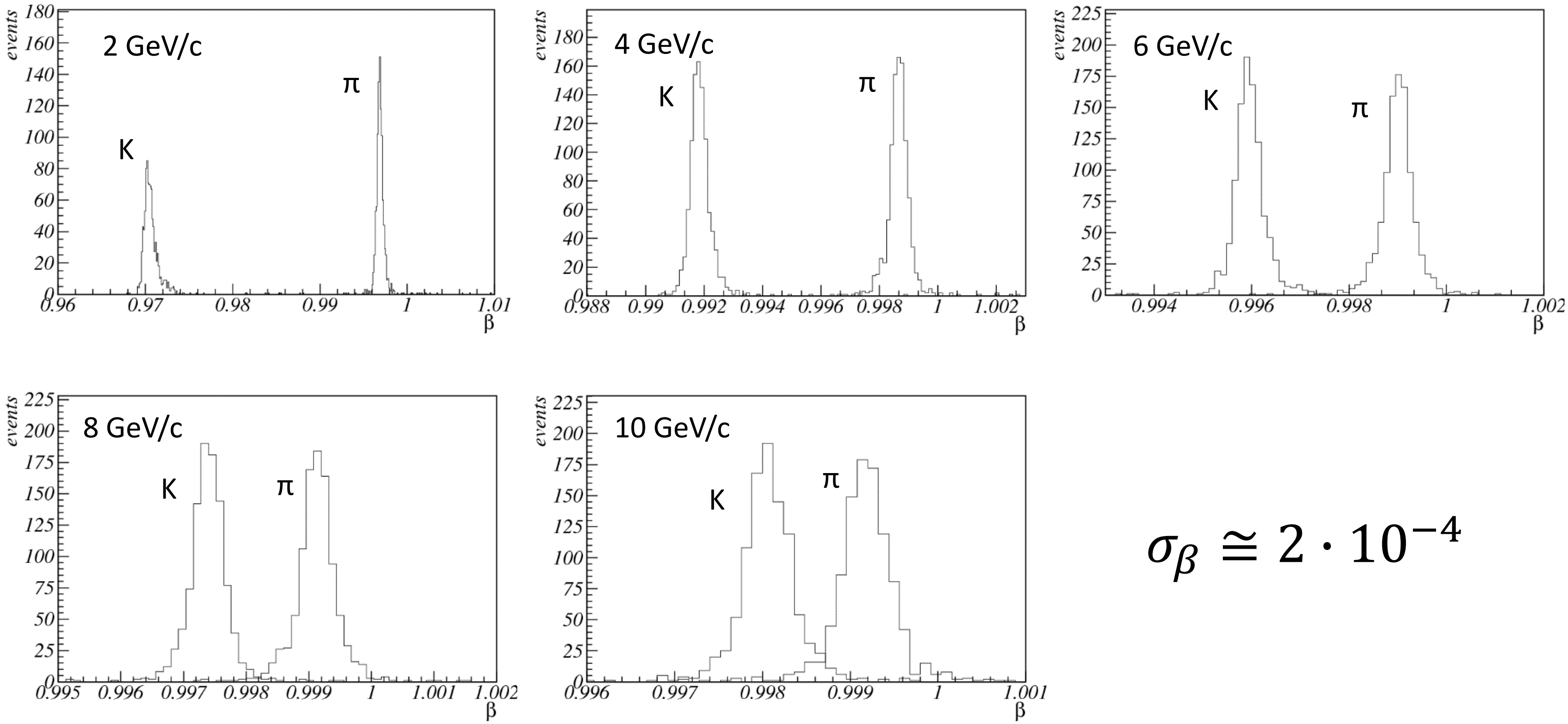


Optimal values:
$\delta n = 1.03^{+0.33}_{-0.27} \cdot 10^{-3}$
$\sigma_\theta = 7.7$ mrad

Optimal values:
$\delta n = 1.23^{+0.24}_{-0.27} \cdot 10^{-3}$
$\sigma_\theta = 5.2$ mrad

3-layer aerogel was chosen for the following sim

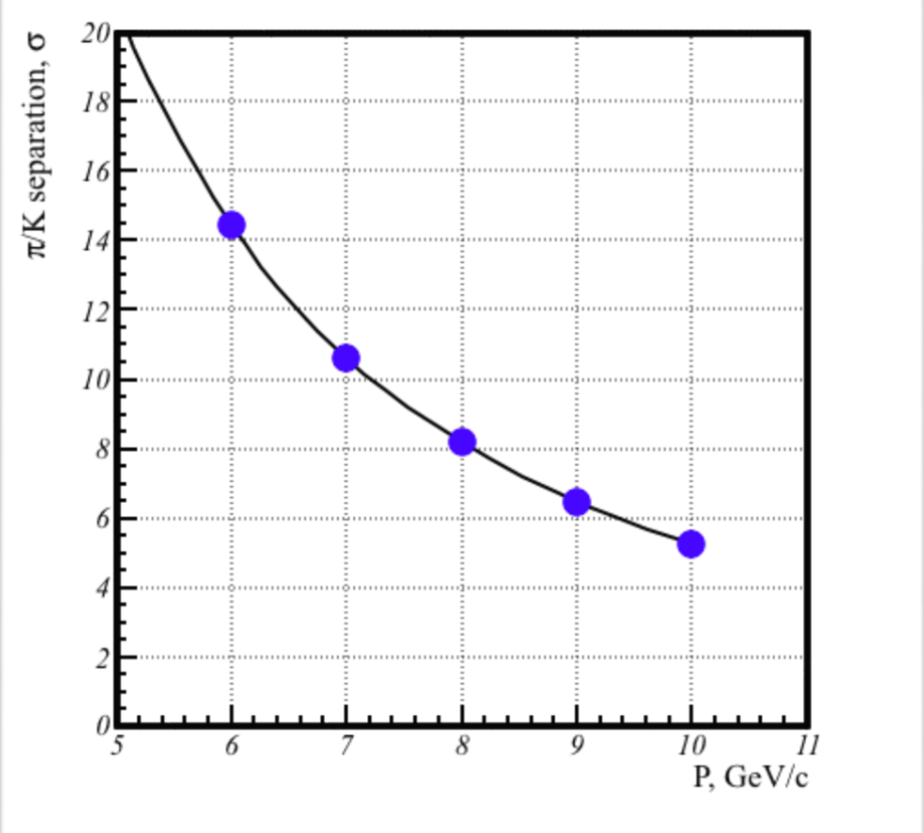
π-K separation

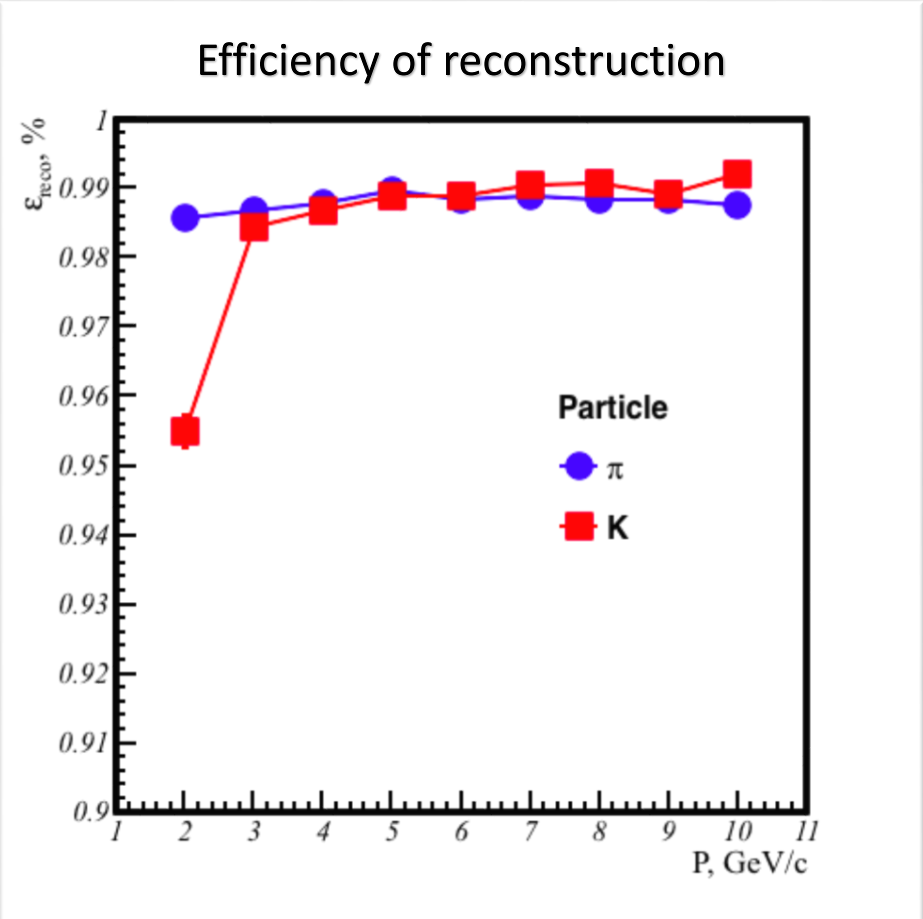


$$\sigma_\beta \cong 2 \cdot 10^{-4}$$

PANDA FRICH performance

$$S(\pi/K) = 2\frac{\beta_\pi - \beta_K}{\sigma_\pi + \sigma_K}$$





Conclusion and outlook

- PANDA FRICH conceptual design is described
- Realistic full simulation of PANDA FRICH is realized in PandaRoot/Geant4
- PANDA FRICH (with DPC) PID capacity is confirmed by simulation

Plans

- H12700 & PADIWA & TRB3 tests
- Mirror samples production and measurements
- Detailed mechanical design
- Focusing aerogel production technique improvement
- …

Thank you for your attention!

History of FARICH R&D in Novosibirsk

2003: Outlook for an Aerogel RICH at BaBar/SuperB

2004: FARICH idea and first pubs by Belle coll. and Novosibirsk

2004-2011: MC sim studies of FARICH at SuperB, ALICE, PANDA

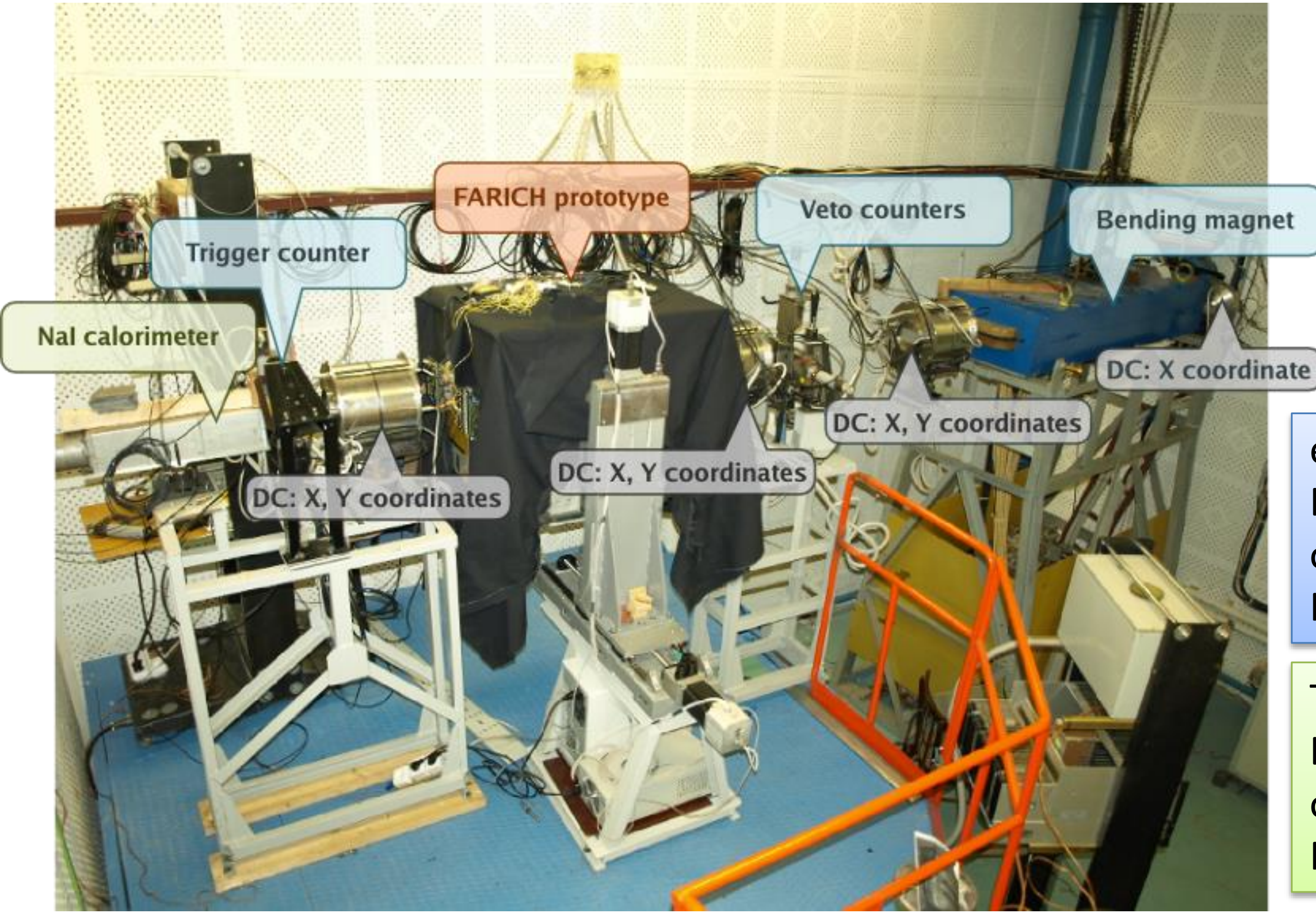
2010: FARICH proposal for Super Charm-Tau Factory

2011: First beam test of FARICH prototype at the BINP electron beam facility

2012: FARICH prototype with Digital Photon Counter PD was tested at CERN. First continuous gradient aerogel samples were produced

2014: PANDA Forward RICH R&D project started

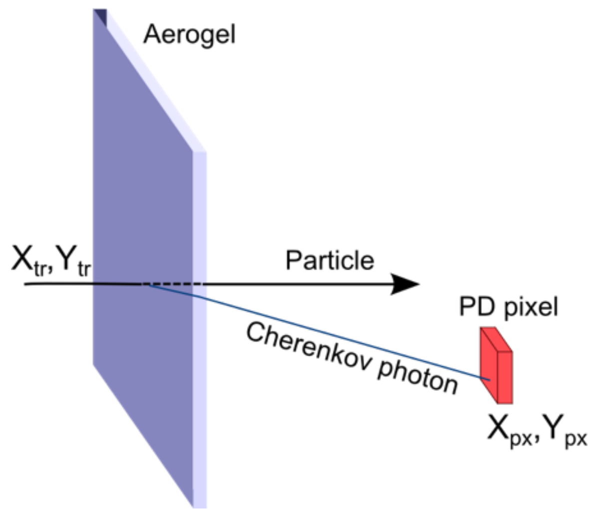
e and γ beam test facility at BINP VEPP-4M

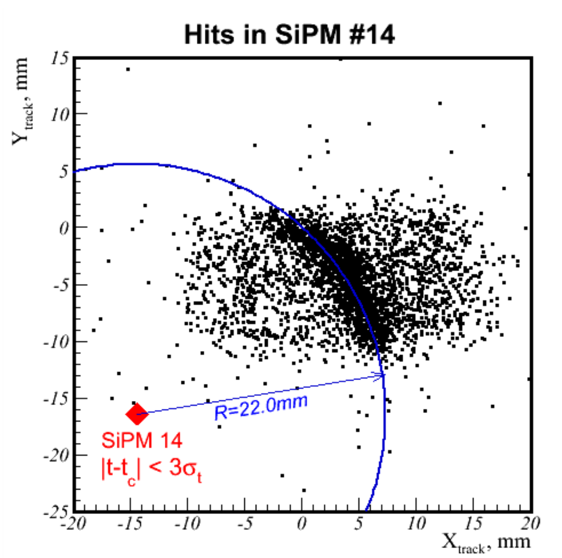


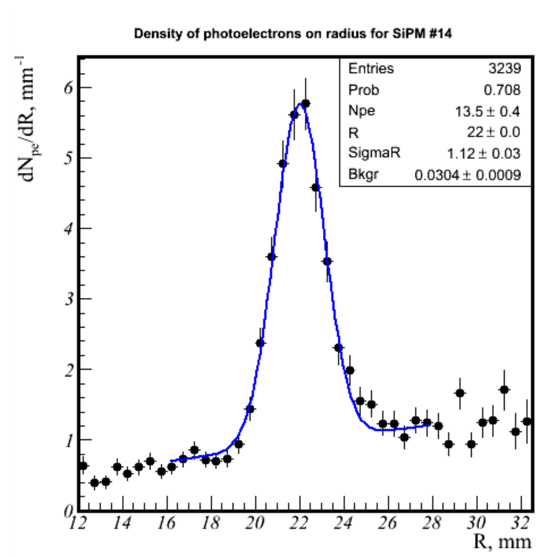
e^- beam
$E_e = 0.06 \div 3$ GeV
$\sigma_E/E = 2\%$ @ 1 GeV
Rate up to 100 s^{-1}

Tagged γ beam
$E_\gamma = 0.05 \div 1.5$ GeV
$\sigma_E/E = 0.5\%$ @ 1.5 GeV
Rate up to 10^3 s^{-1}

Single pixel approach for aerogel characterization at the beam

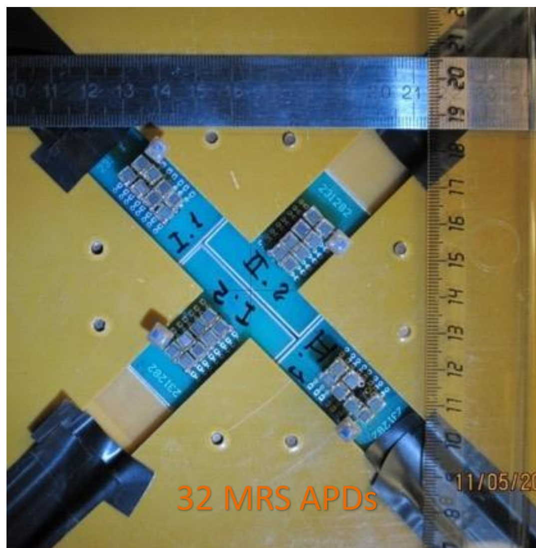






Given a tracking system and enough particle statistics, a single PD pixel is enough to build the distribution of Cherenkov photons on R_{ch} (θ_{ch}).

Many pixels are combined to improve accuracy and align the tracking system with PD



Sum of all pixels w.r.t. track position