The Aerogel Forward RICH detector for PANDA

Presented by Sergey Kononov

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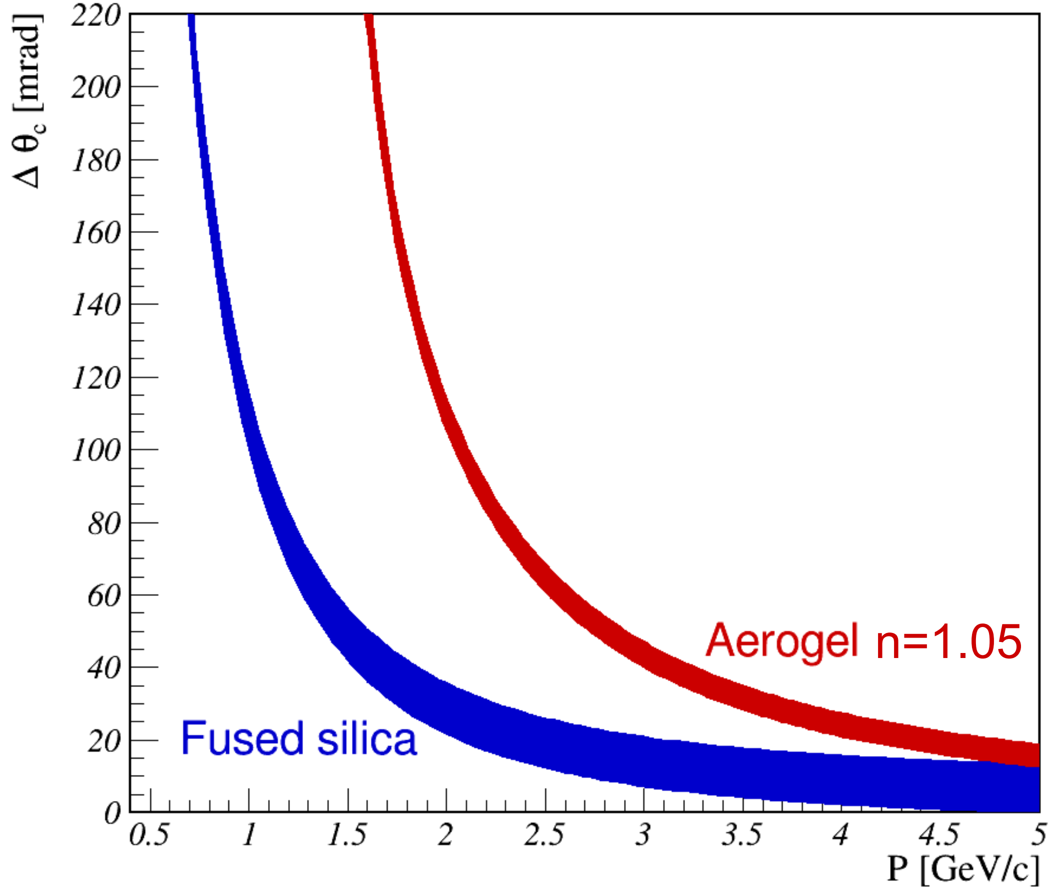
DIRC2017: Workshop on fast Cherenkov detectors

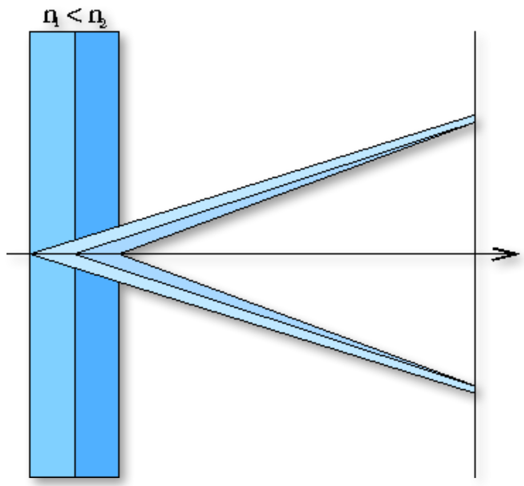
8.August.2017

Quartz vs Aerogel radiators

Difference in Cherenkov angle θ_c for π and K
Bands – chromatic dispersion in 350-700 nm



Focusing Aerogel RICH (FARICH)

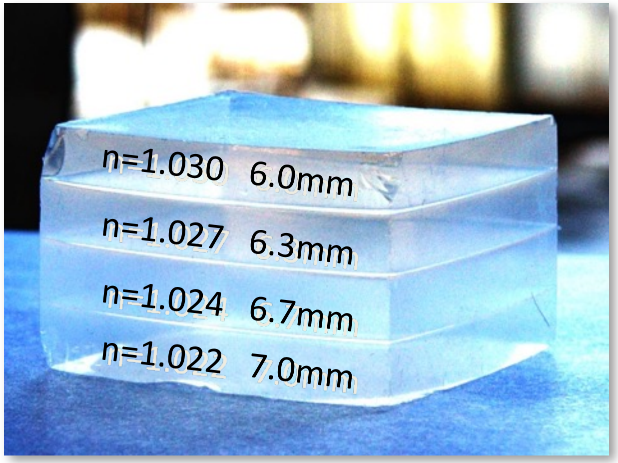


T.Iijima et al., NIM A548 (2005) 383
A.Yu.Barnyakov et al., NIM A553 (2005) 70

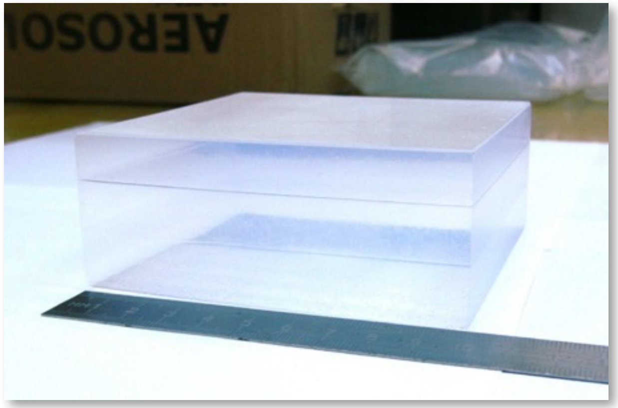
Focusing aerogel improves proximity focusing design by reducing the contribution of radiator thickness into the Cherenkov angle resolution

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

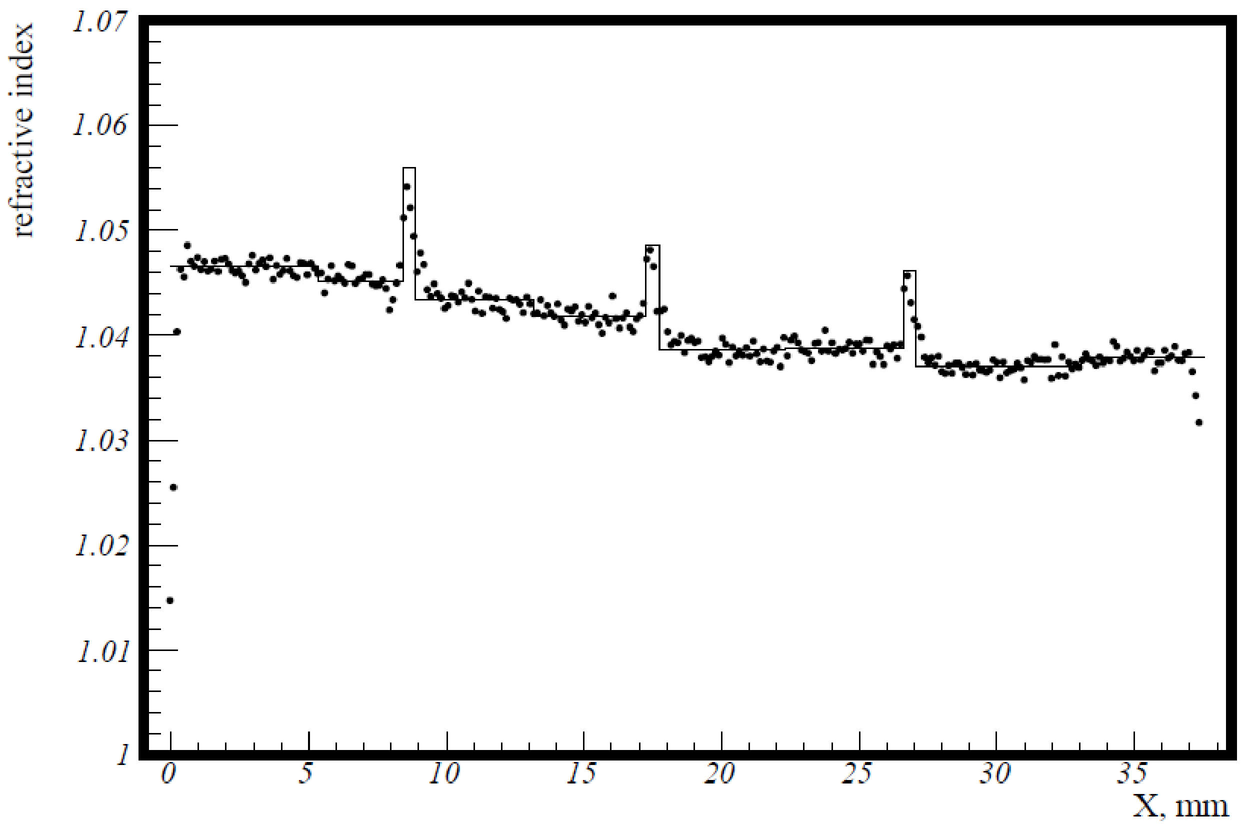
First sample of 4-layer aerogel



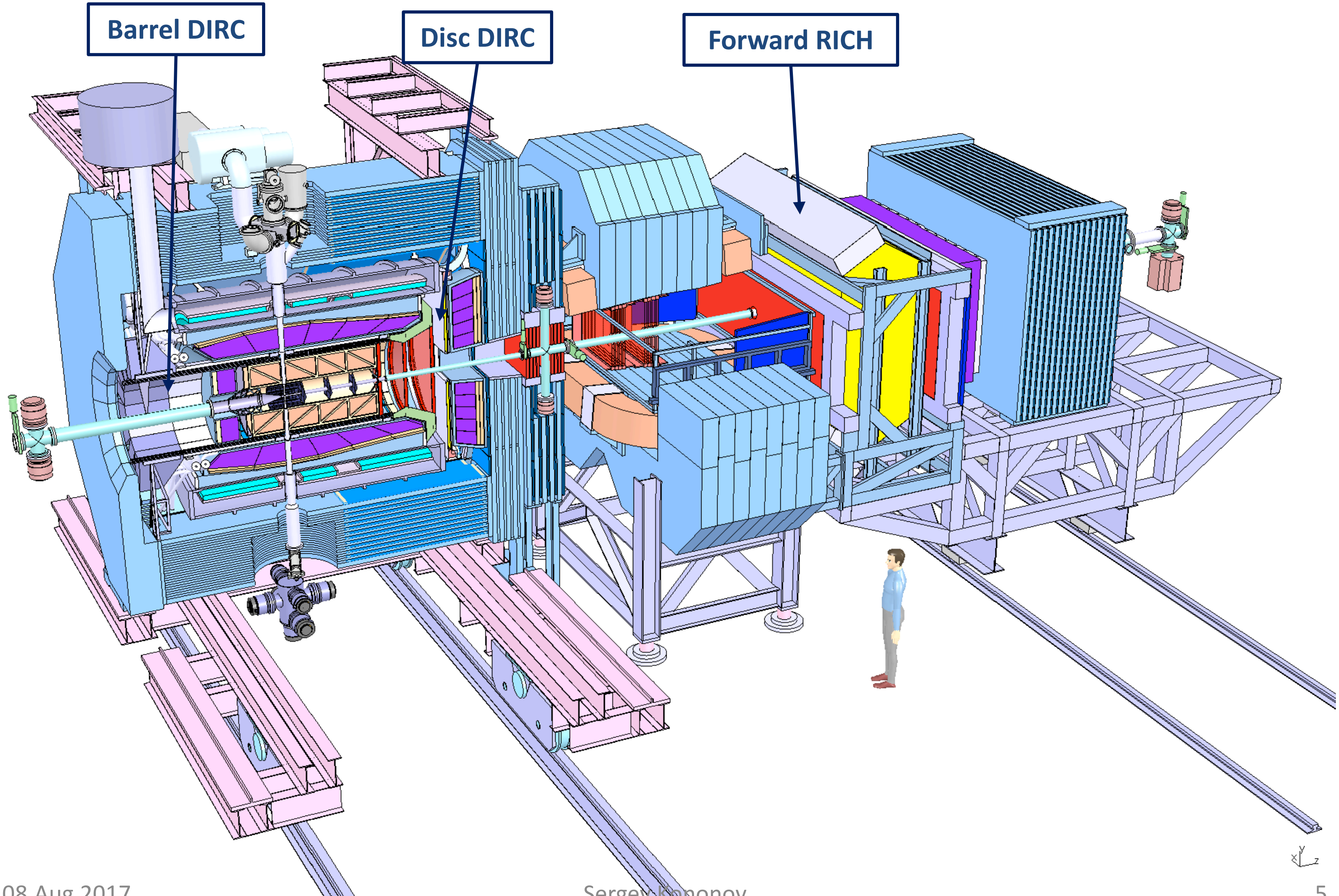
3-layer aerogel 115x115x41 mm^3



Refractive index of 4-layer aerogel
measured by X-ray scanning setup



PANDA detector PID



Requirements for PANDA Forward RICH

- Charged PID in the Forward Spectrometer
- $|\theta x| < 10°$, $|\theta y| < 5°$
- 1 m space along the beam
- approximately 3 x 1 m transverse active size
- Working momentum range for 3σ separation
  - π /K: 2÷10 GeV/c
  - μ/π: 0.5÷2 GeV/c possible
- Physics cases: processes with high charged hadrons multiplicity in the final states for high beam momenta

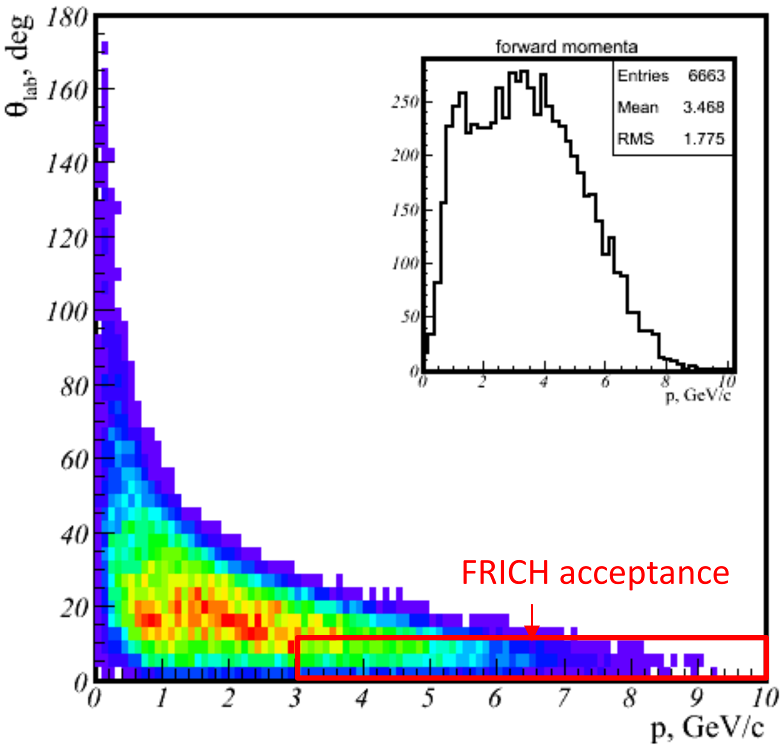
Use cases of PANDA Forward RICH (2010)

Example from Physics Performance Report (2009): hybrid $\tilde{\eta}_{c1}(c\bar{c}g)$ search at **15 GeV/c**

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

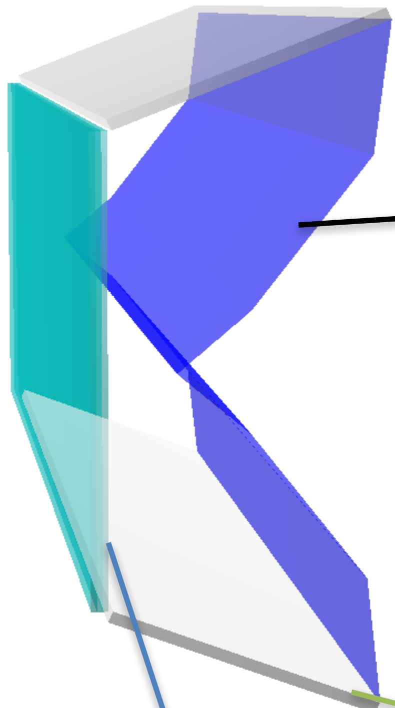
FastSim: 46% of events are reconstructed only due to the RICH. That means **86%** statistics gain due to the RICH.

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



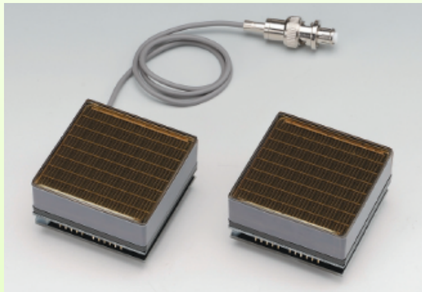
In spite of the small covered solid angle production processes at high beam momentum with a large multiplicity are likely to give particles in the Forward RICH.

Baseline conceptual design



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

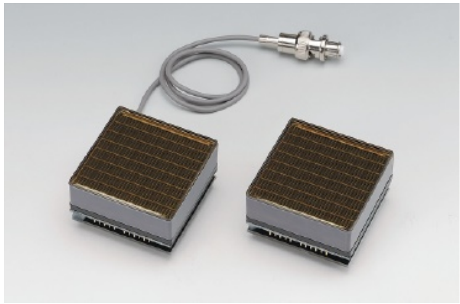
Photon Detector



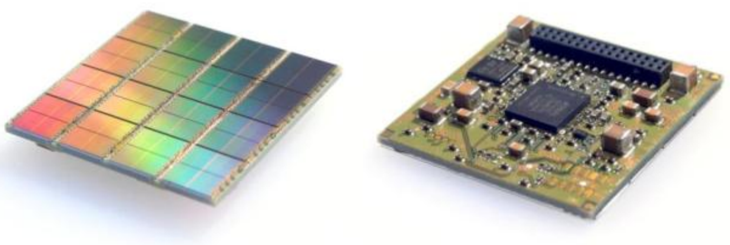
Hamamatsu H12700 MaPMT
- flat panel,
- 8x8 anode pixels of 6mm size
- 87% active area ratio
- Bialkali photocathode
- Gain: $1.5 \cdot 10^6$
- Good single p.e. amp resolution
- Robust
- Long lifetime
- Works in the mag. field 25G (stray field of the dipole)

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

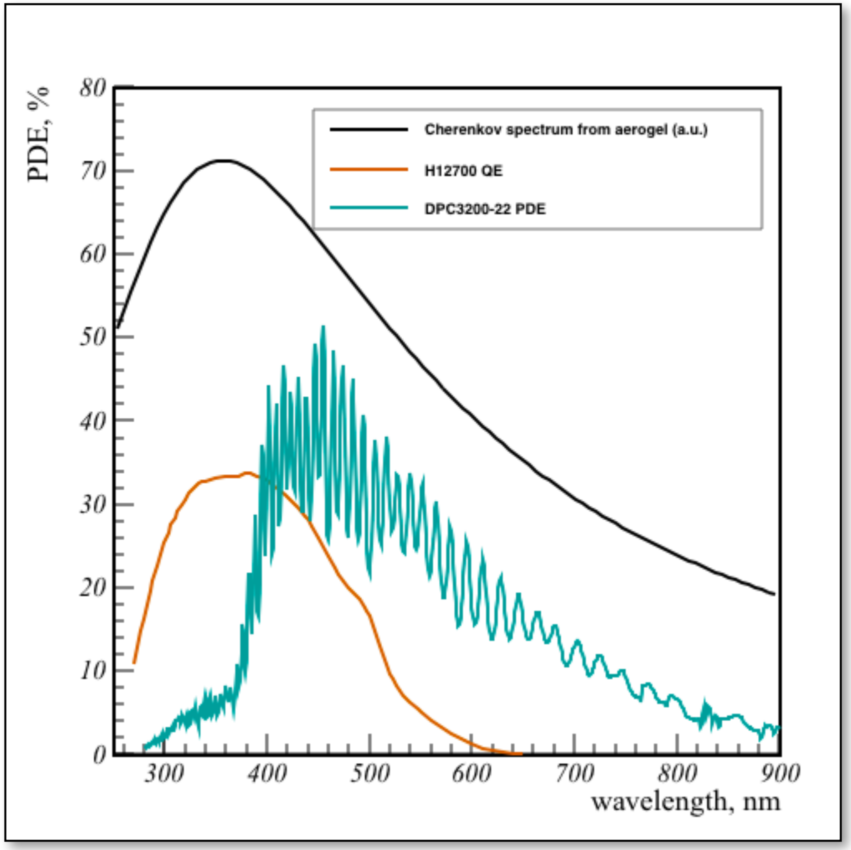
Readout options for PANDA FRICH



Hamamatsu H12700B
DiRICH (GSI) electronics

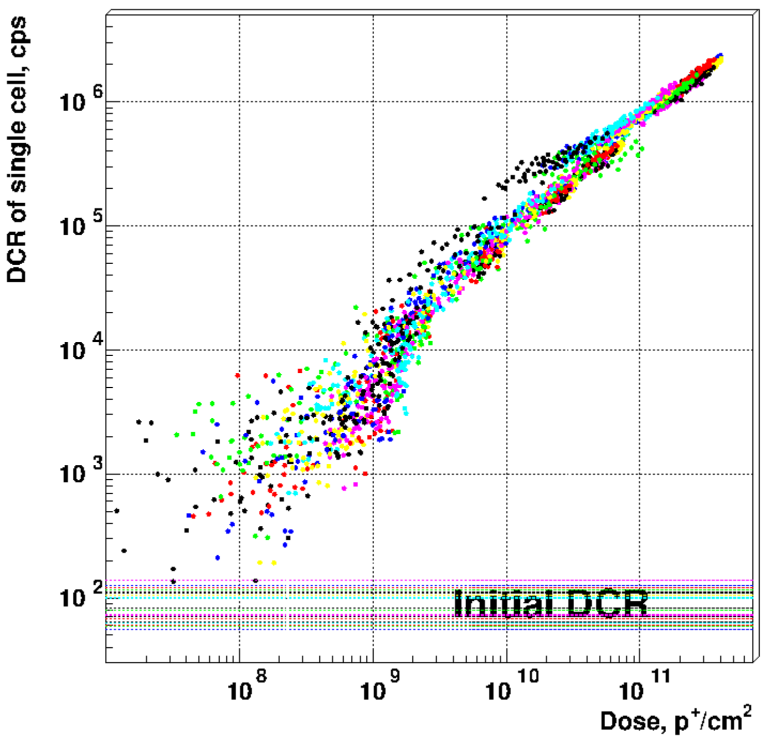


Digital Photon Counter
720 ns sensor dead time
Needs cooling
Not radiation hard (lifetime ~1 year in PANDA FRICH w/o neutron shielding)

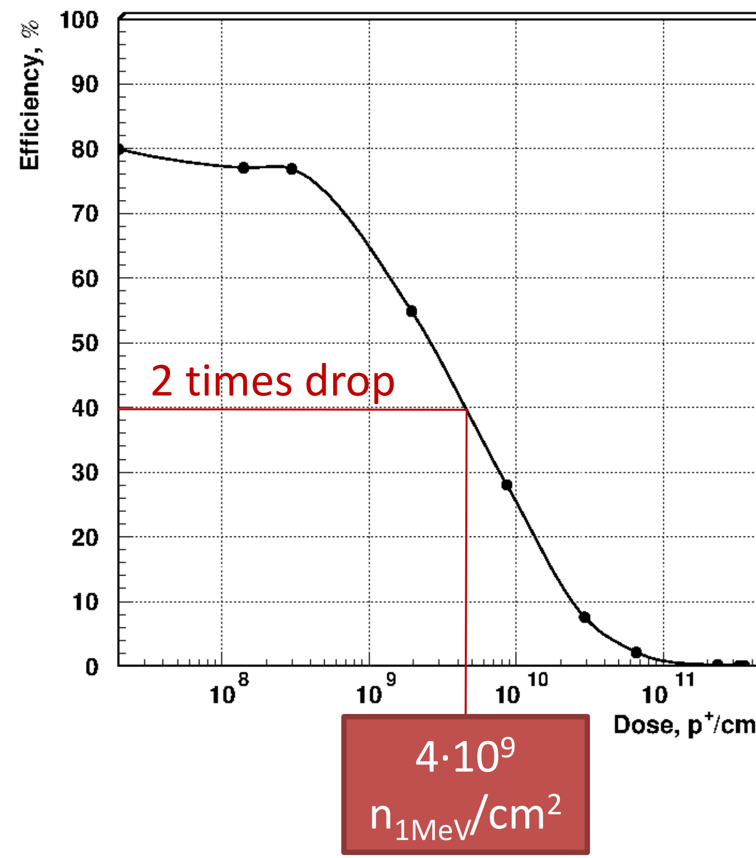


DPC radiation hardness study
p beam (800 Mev/c) at COSY PS in FZ Jülich

Effect of radiative damage on DCR



PDE degradation due to DCR increase



DPC tiles cooled to −18°C

Max fluence accumulated $4 \cdot 10^{11}$ p/cm^2

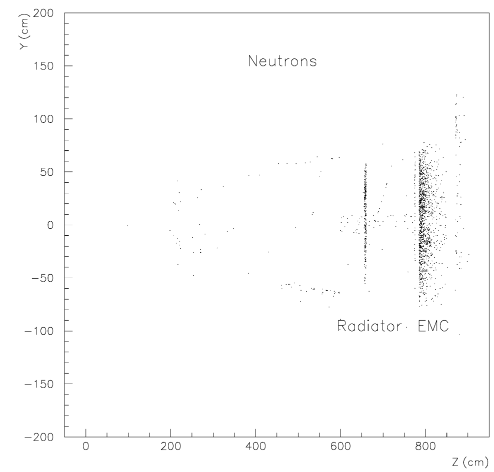
Evaluation of radiative background in PANDA and DPC lifetime

Simulation conditions in PandaRoot

- DPM generator
- 10 GeV/c beam momentum
- Geant4 sim. engine
- 4 geometry options considered
- Particle fluxes are scaled to 1MeV neutron equivalent fluence for damage in silicon
- Simplified detector description w/o frames, support, etc.
- High neutron generation threshold (>1 MeV) in PandaRoot

Results

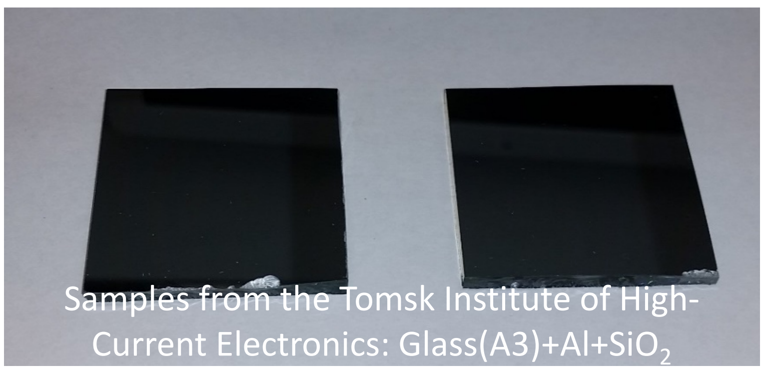
- $1.5 \cdot 10^{-5}\ n_{1\mathrm{MeV}}/\mathrm{cm}^2$ per $\bar{p}p$ interaction at the PD
- Highest contribution come from neutrons produced in FS EMC



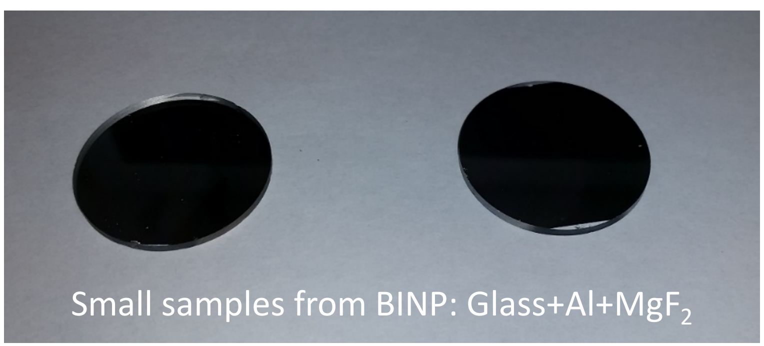
- Less than 1 year DPC lifetime at the interaction rate $2 \cdot 10^7 \mathrm{s}^{-1}$ (PANDA HL mode) and 6 years in the PANDA HR mode.

Mirrors for Forward RICH

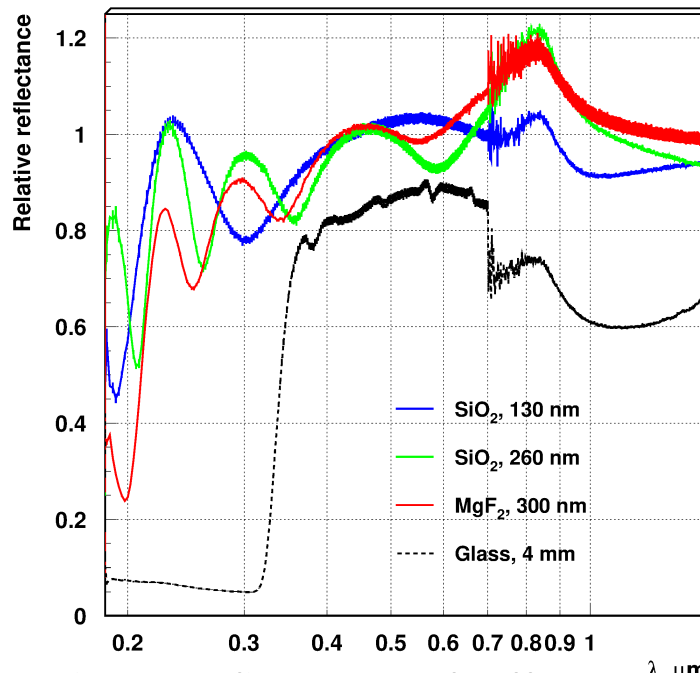
- Float glass + Al + SiO_2 in A3 (300x420 mm^2) size
- Requirements on flatness for float glass (few µm) are met. Mirror samples from two producers were obtained and compared by reflectivity.
- Absolute reflectivity measurements to be done
- Light scattering due to surface roughness to be measured



Samples from the Tomsk Institute of High-Current Electronics: Glass(A3)+Al+SiO_2

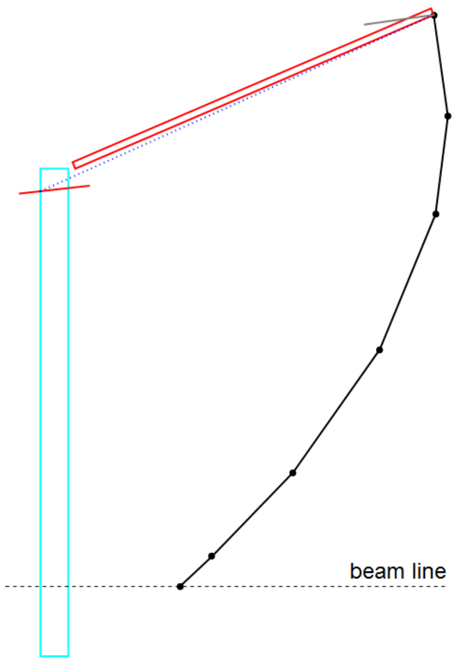


Small samples from BINP: Glass+Al+MgF_2



Relative reflectance of different samples

Mirror layout optimization in 2D

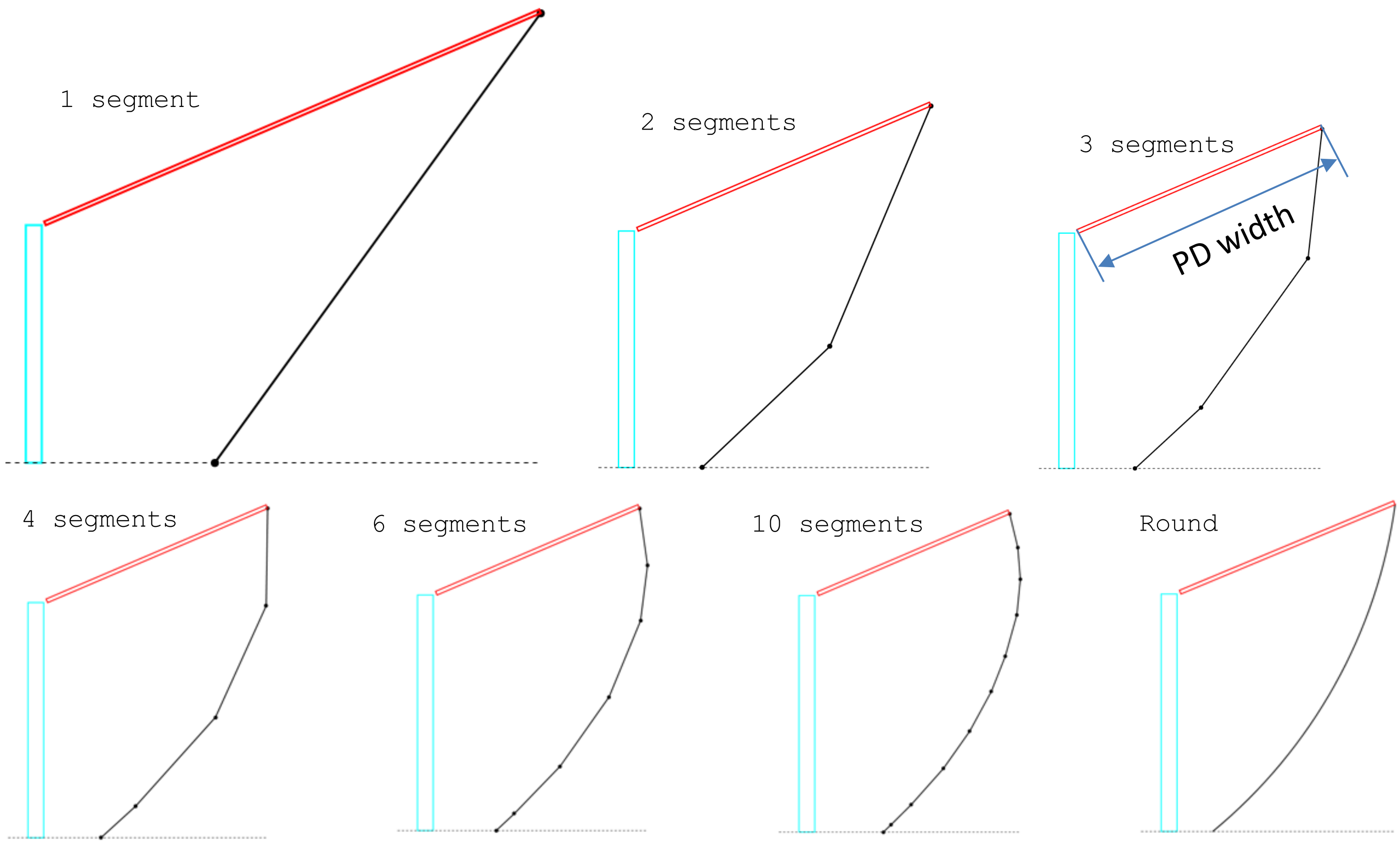


Six segments flat mirror
(as an example)

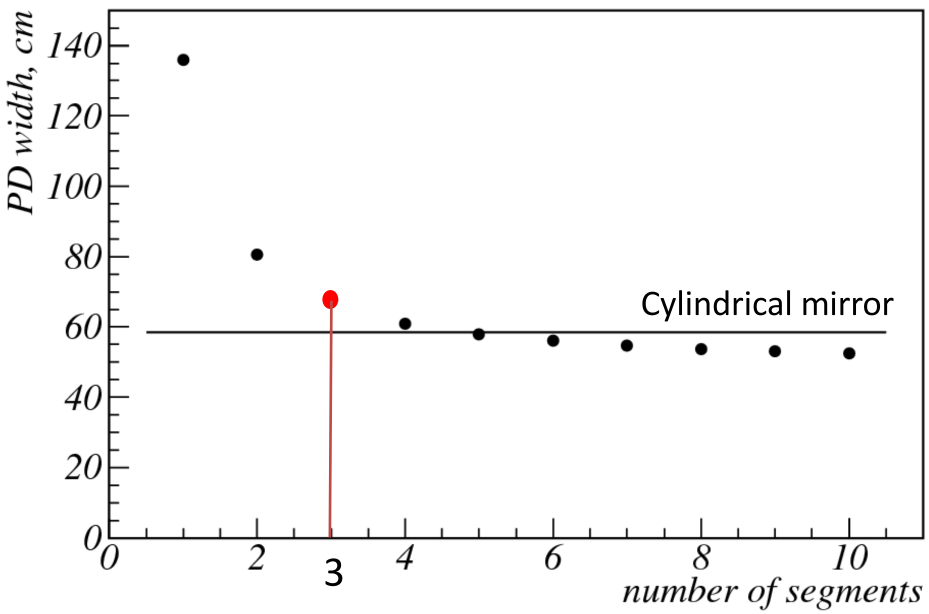
I. **100% photon acceptance**
(there are never too many Cherenkov photons)
- Lower Č photon hits PD
- Upper Č photon hits PD
- All other Č photons automatically do the same

II. **Photo detector area minimization**
$w(z, l_1, l_2, l_3, \ldots) \rightarrow w_{min}$
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

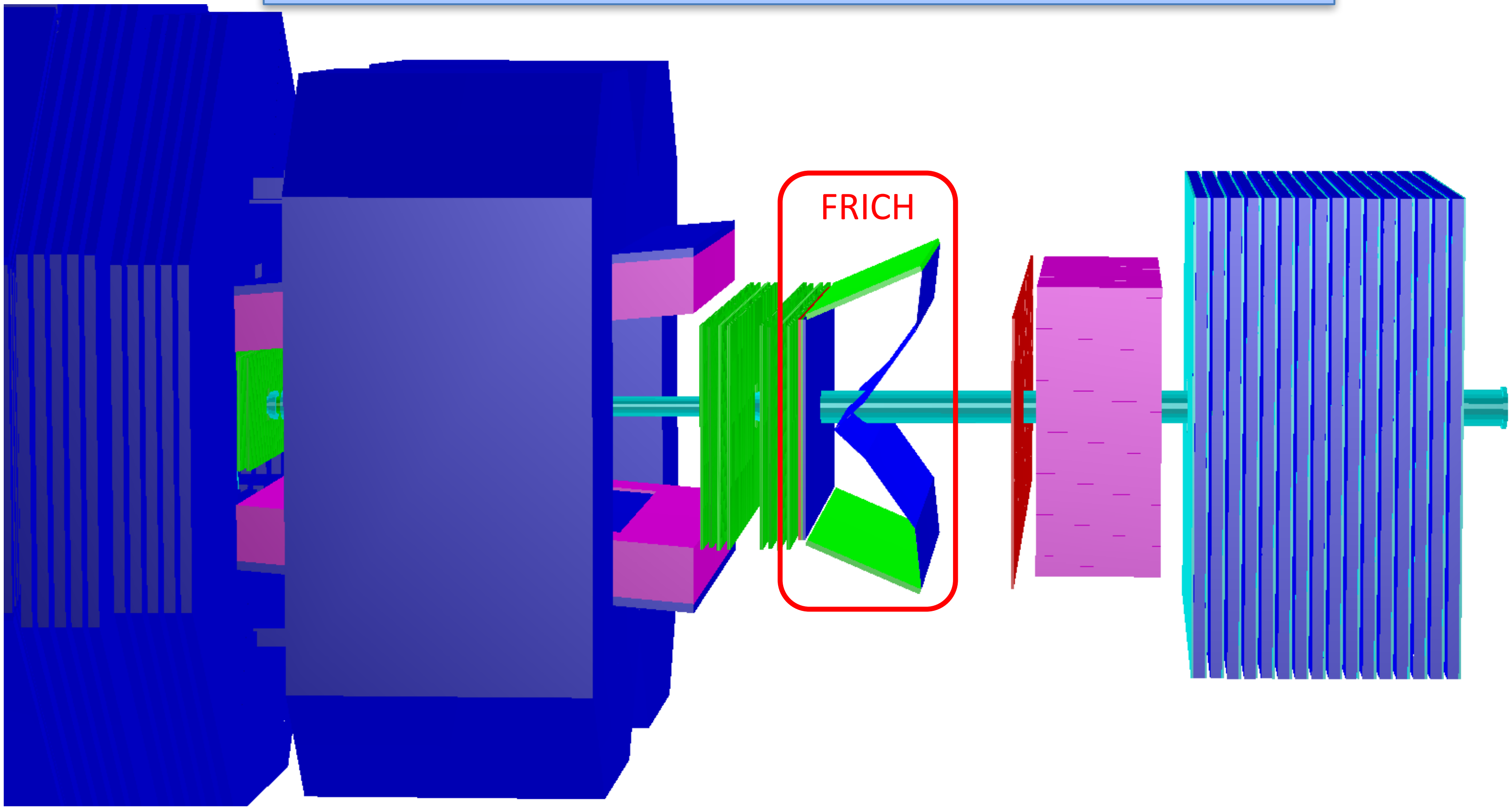
* Size of the PD side projection. Aerogel plate half-size is 60 cm.

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

MC simulation of the PANDA Forward RICH

PANDA Forward Spectrometer geometry in PandaRoot

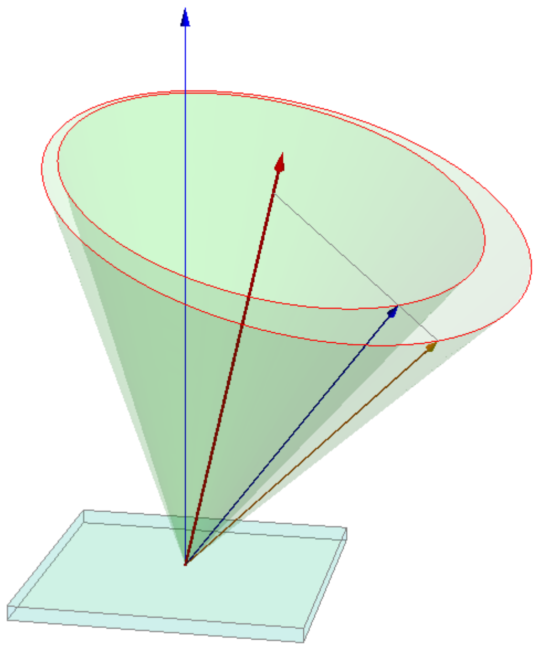


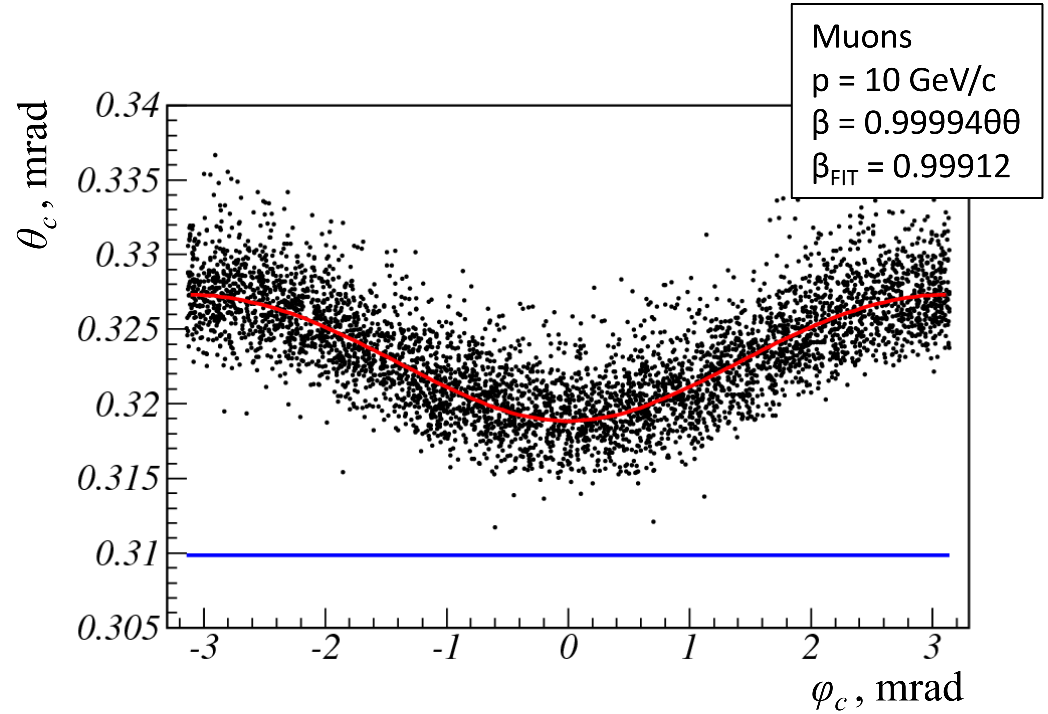
Simulation code variants

Processes described in two simulation variants

FULL	FAST
Passage of particles through matter	
Optical processes	-
Digitization	-
Tracking	
Full event reconstruction	Calibration based event reconstruction
PID	

Ring fitting





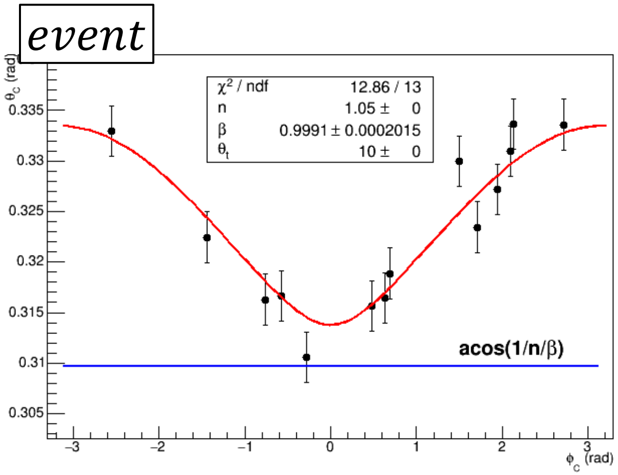
$$\theta_c(\varphi_c;\beta,n,\theta_t) = \mathrm{acos}\left(\frac{1}{n\beta}\right) + \mathrm{acos}\left(n\left(1-(\vec{n}_0\vec{n}_\gamma)^2\right) + (\vec{n}_0\vec{n}_\gamma)\sqrt{1-n^2\left(1-(\vec{n}_0\vec{n}_\gamma)^2\right)}\right)$$

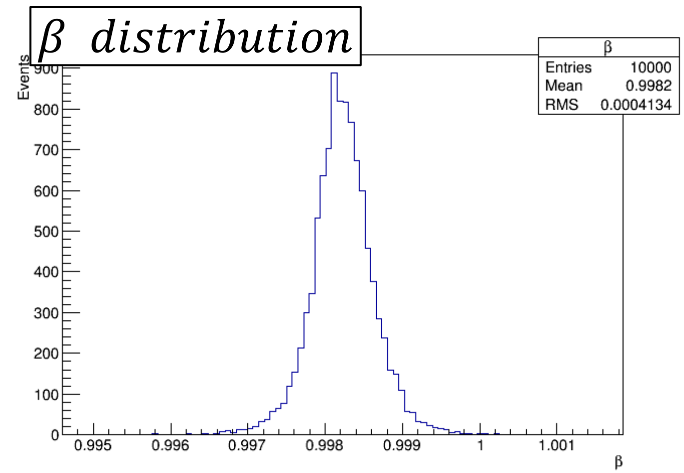
$$(\vec{n}_0\vec{n}_\gamma) = \frac{\cos\theta_t}{n\beta} + \cos\varphi_c \sin\theta_t \sqrt{1-\frac{1}{(n\beta)^2}}$$

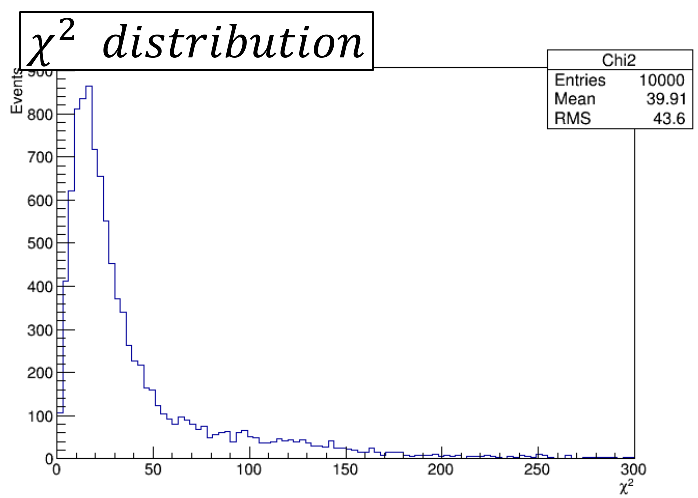
Fit $\theta_c(\varphi_c)$ dependence for each event and get particle's velocity β

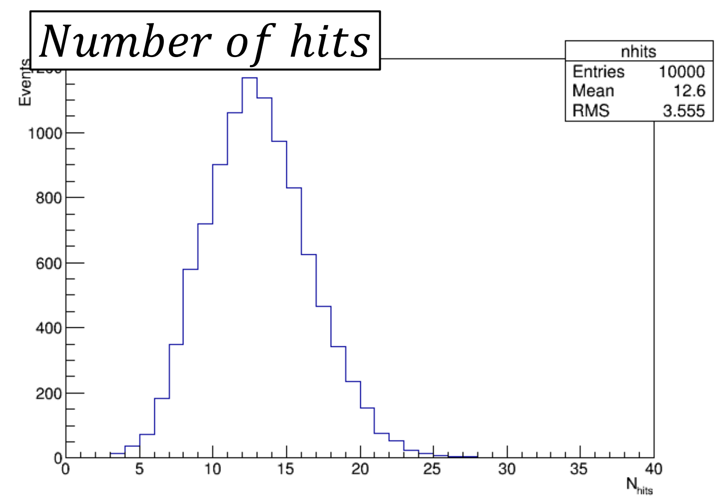
- θ_c – polar angle of Cherenkov photon
- ϕ_c – azimuthal angle of Cherenkov photon
- β – velocity of the charged particle
- n – refraction index of the aerogel
- θ_t – polar angle of the charged particle

Event reconstruction in simulation

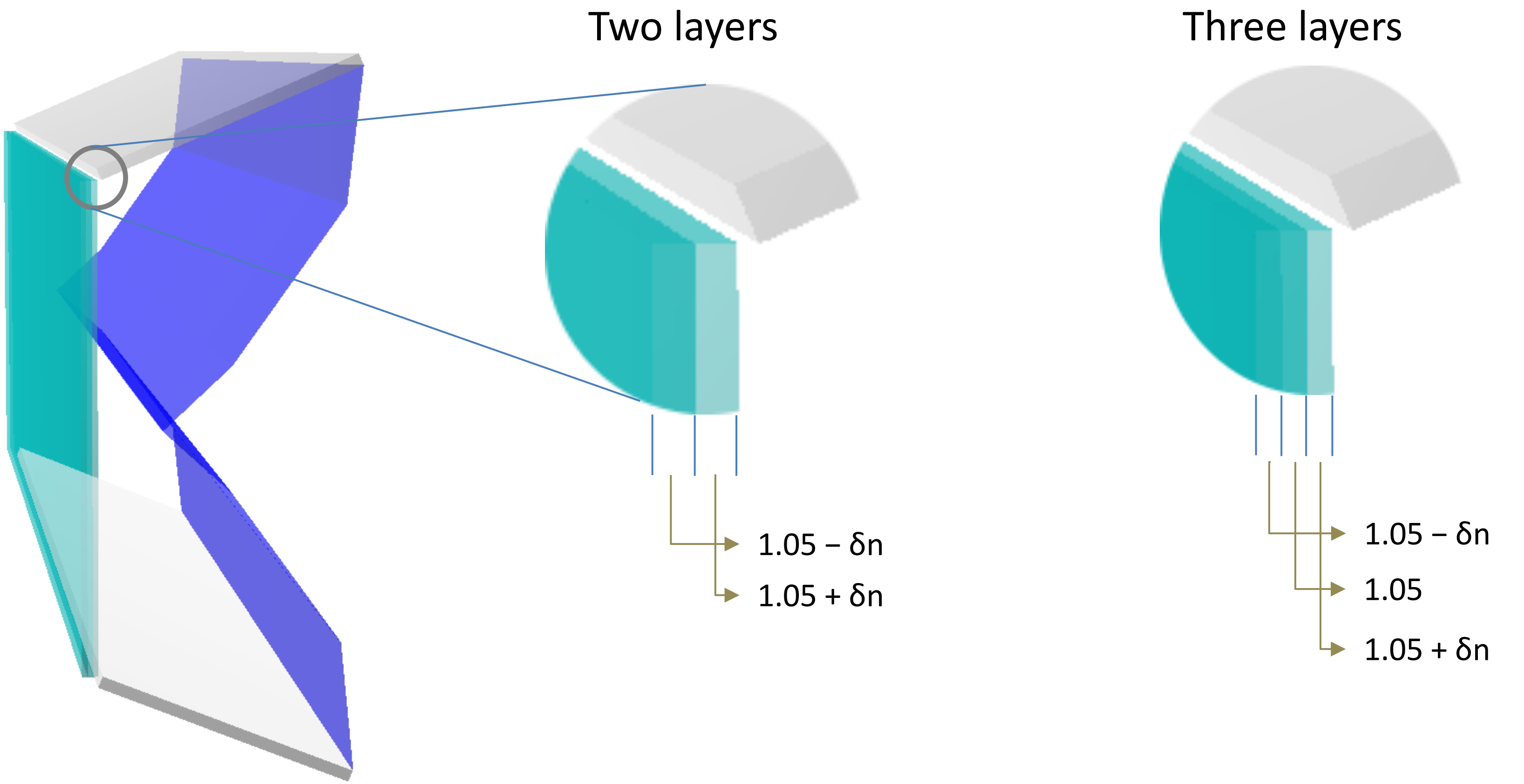








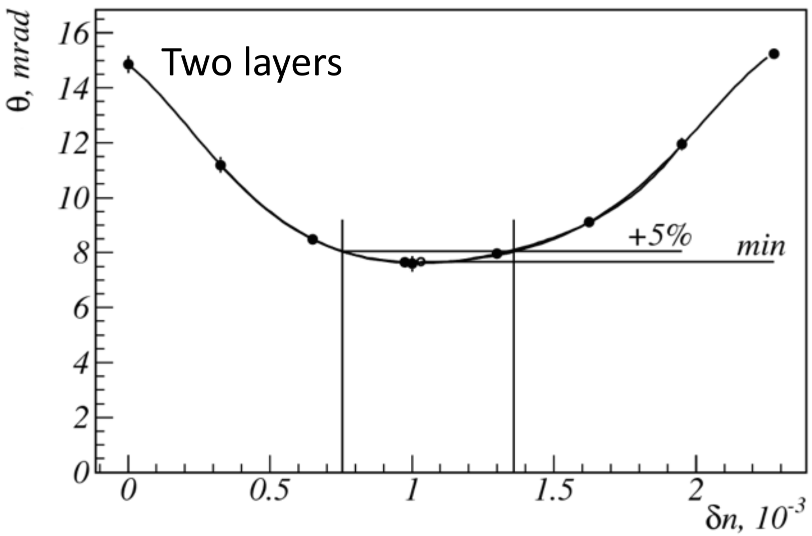
Focusing aerogel optimization (1)

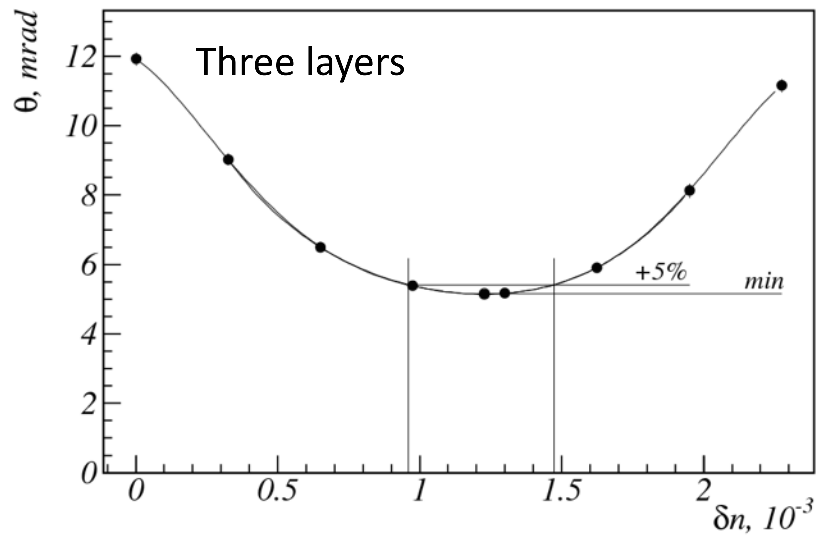


Optimize Cherenkov angle resolution by varying δn

Focusing aerogel optimization (2)

DPC photon detector



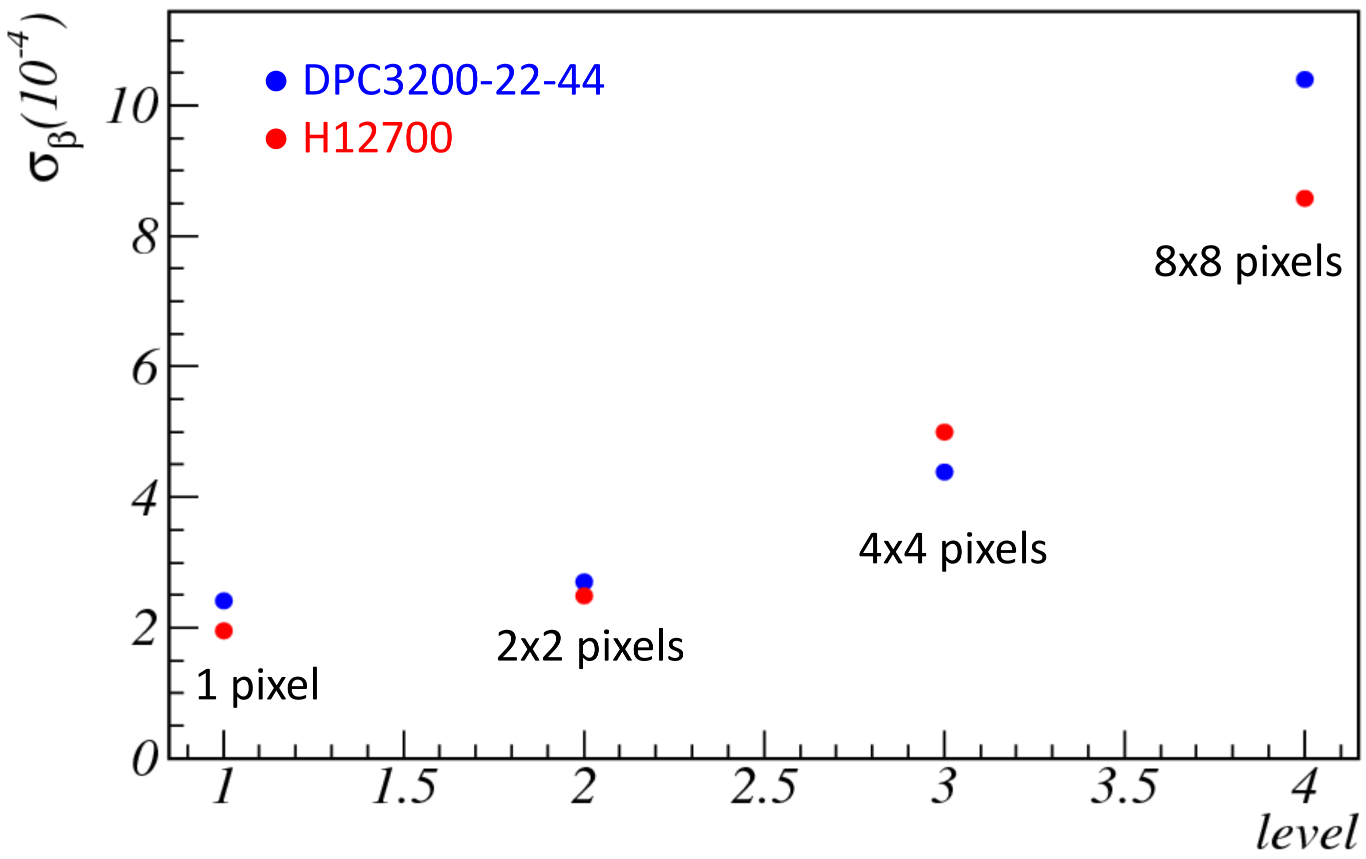


Optimal values:
$\delta n = 1.03^{+0.33}_{-0.27} \cdot 10^{-3}$
$\sigma_\theta = 7.7$ mrad

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

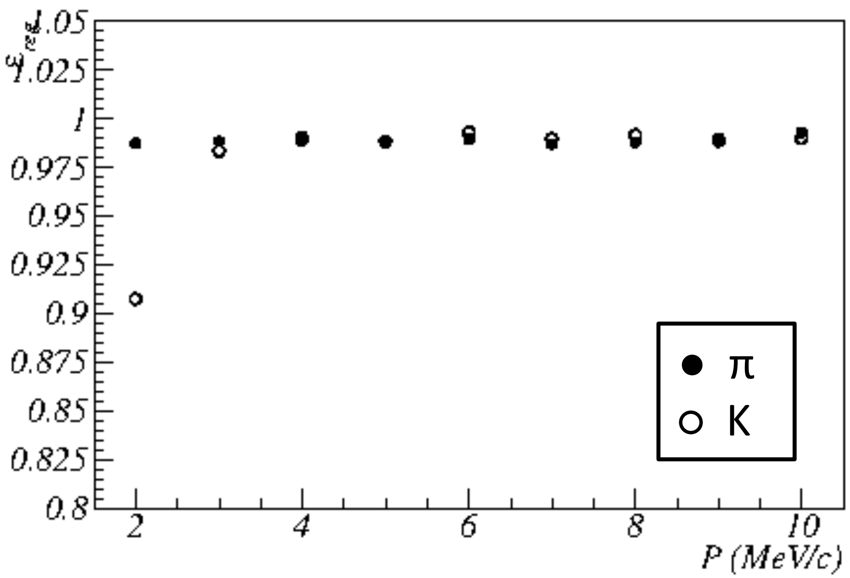
Comparison of velocity resolution in FRICH for DPC and MaPMT H12700



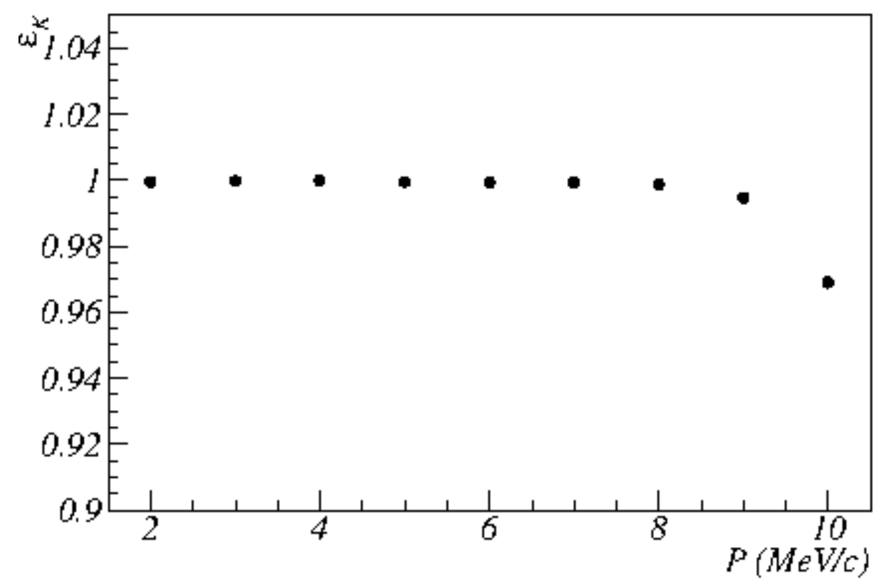
MC FRICH PID vs momentum

H12700 photon detector

Reconstruction efficiency

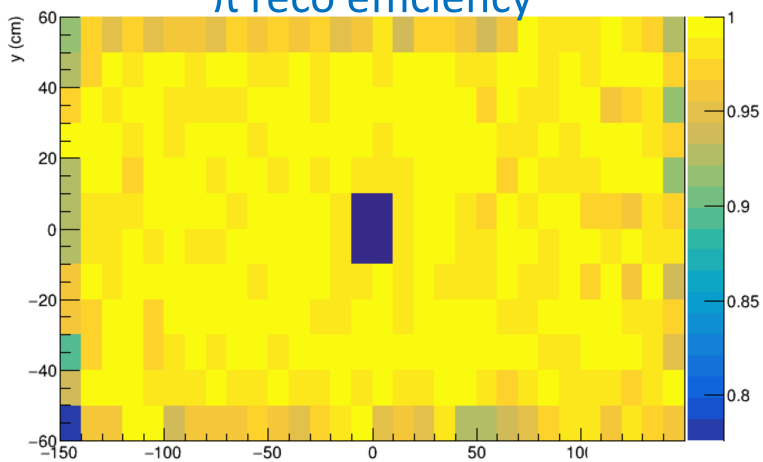


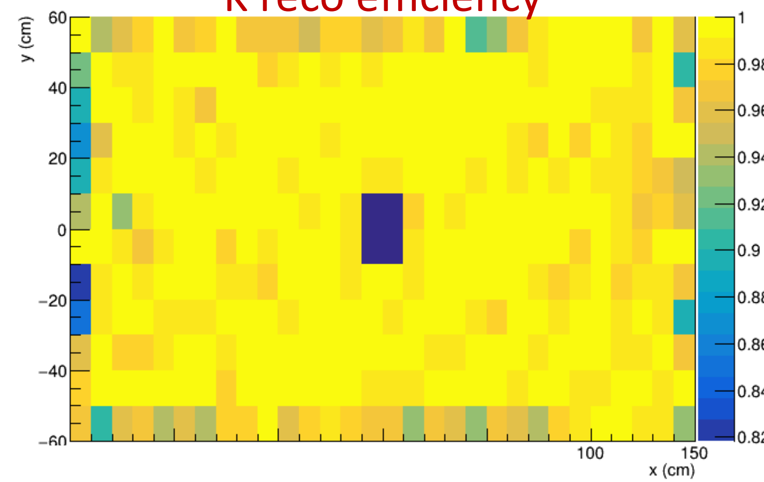
K identification efficiency
at 1% π misidentification



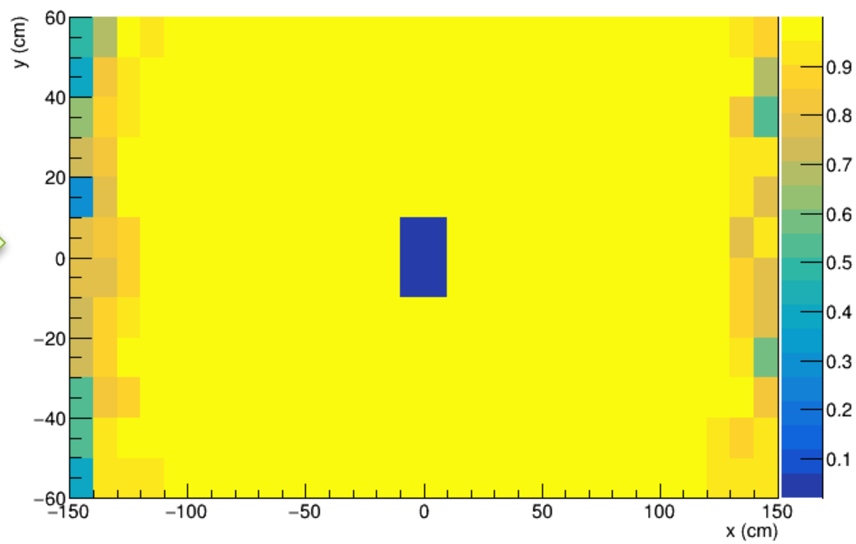
MC FRICH PID uniformity

H12700 PD, p⁻ beam@ 10 GeV/c

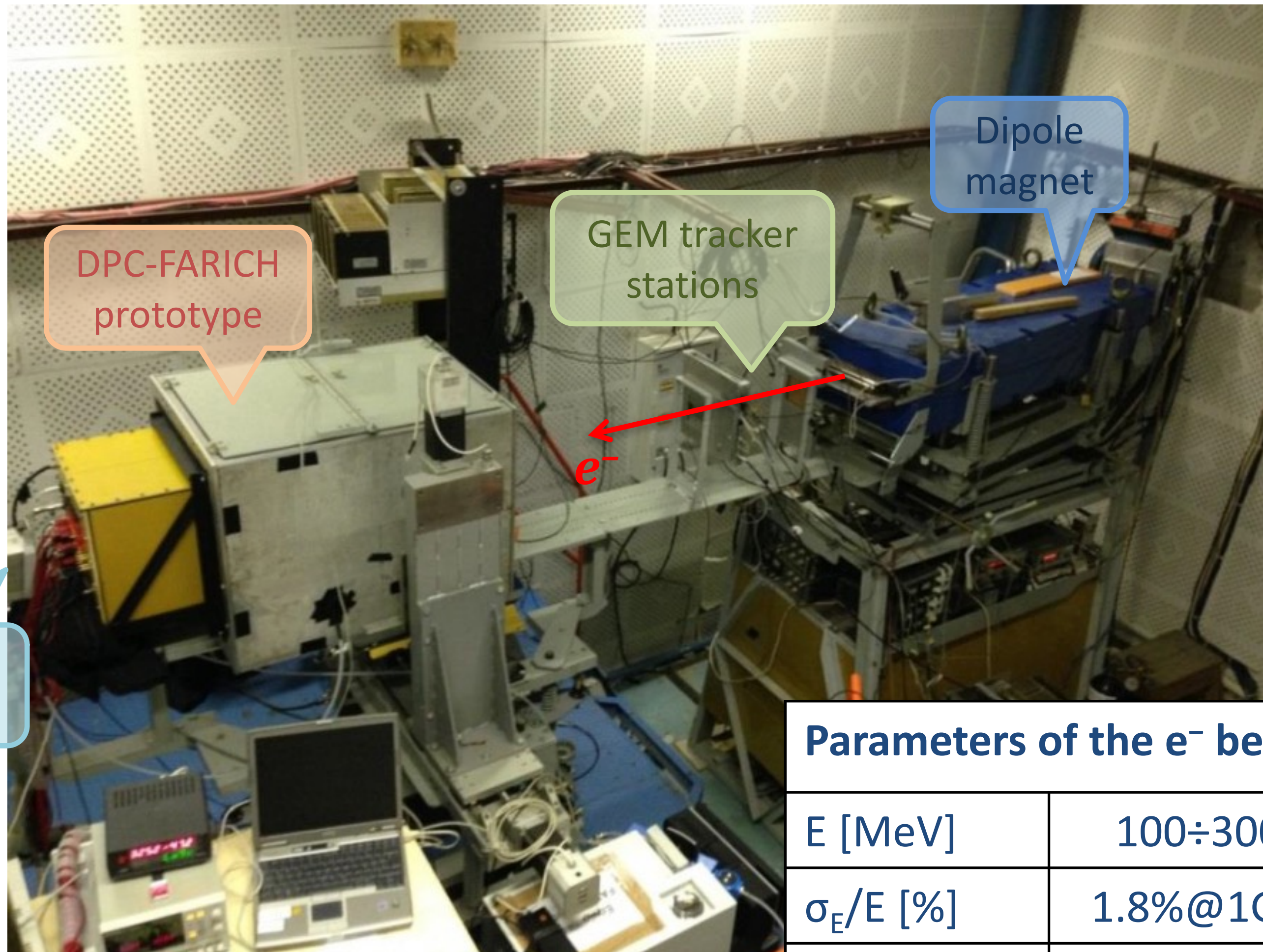




K identification efficiency at 2% π misidentification



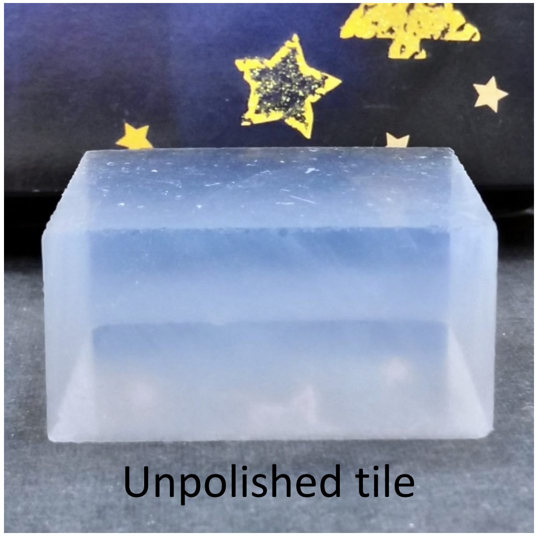
Electron beam line of the VEPP-4M acc. at BINP

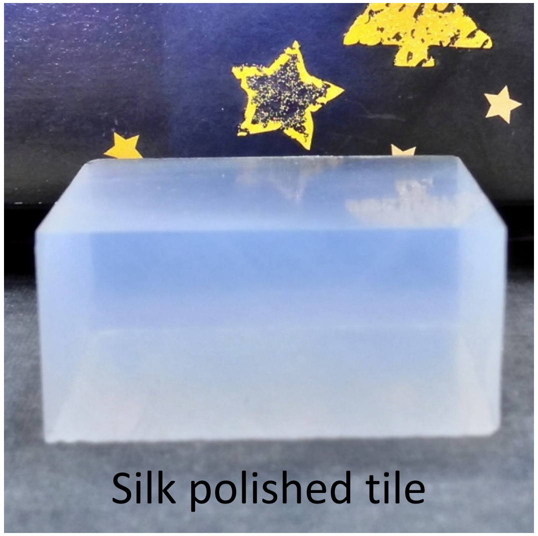


Parameters of the e^- beam	
E [MeV]	100÷3000
σ_E/E [%]	1.8%@1GeV
Rate [s^{-1}]	50

Aerogel polishing effect study

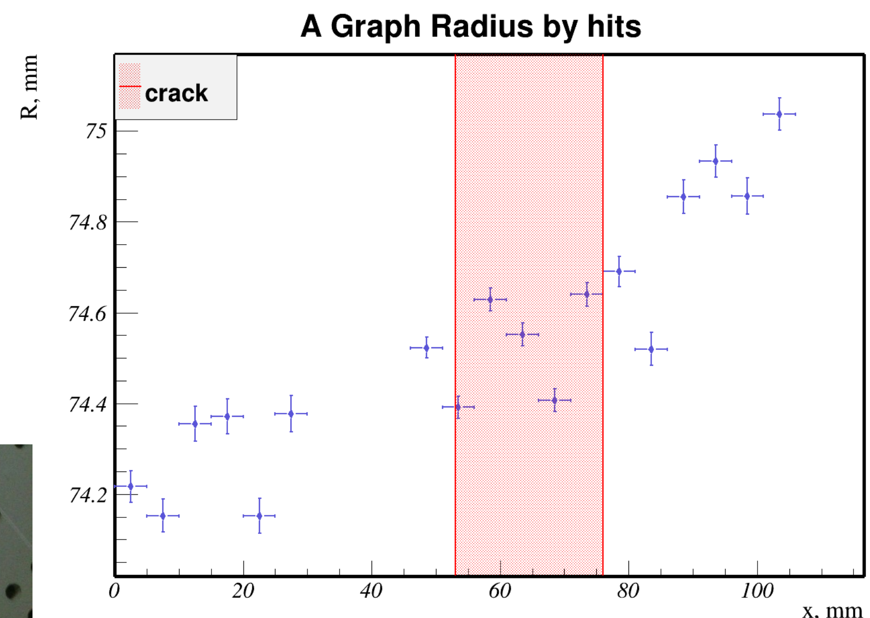
e⁻ beam @ VEPP-4M, DPC detector

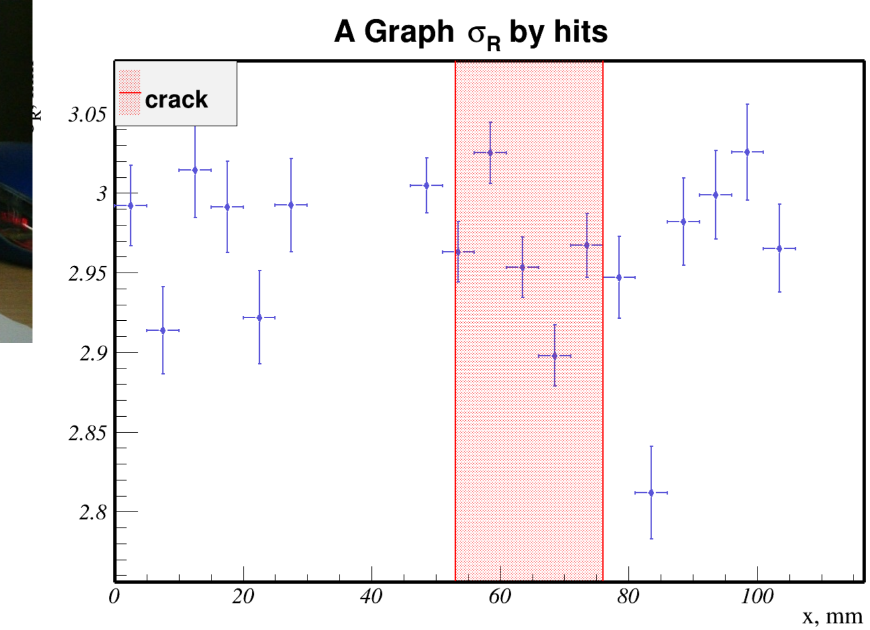




		R, mm	σ_R, mm	Npe
#1	clean	69.33±0.05	1.18±0.03	13.3±0.1
#1	silk	69.01±0.05	1.83±0.06 (+55%)	12.7±0.1
#2	clean	69.78±0.05	1.22±0.03	12.6±0.1
#2	abrasive	68.01±0.05	2.67±0.09 (+119%)	12.0±0.1
#3	clean	70.95±0.05	1.08±0.04	13.3±0.1
#3	bottom	71.27±0.05	1.39±0.06 (+29%)	13.3±0.1

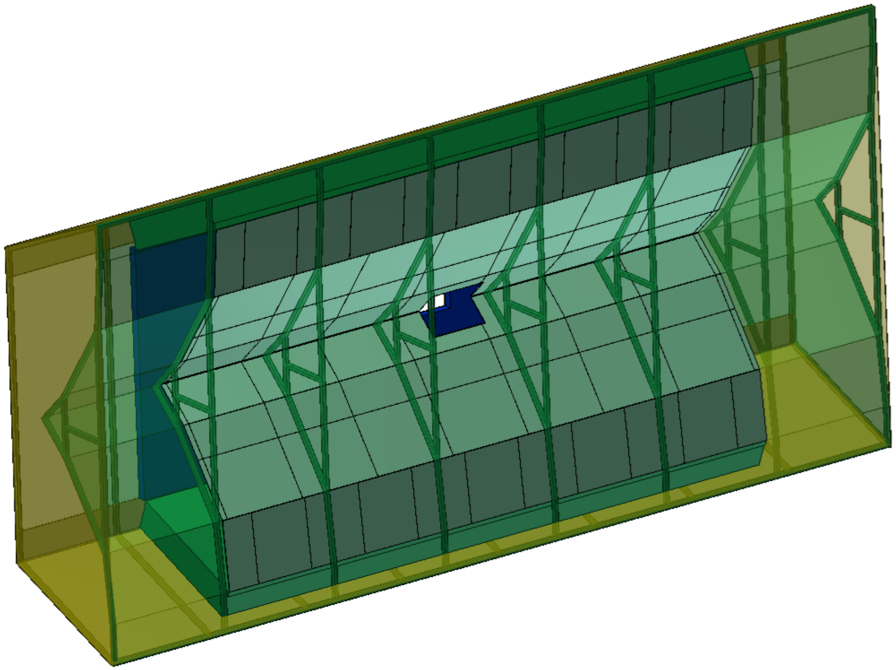
Study of aerogel cracks with e⁻ beam



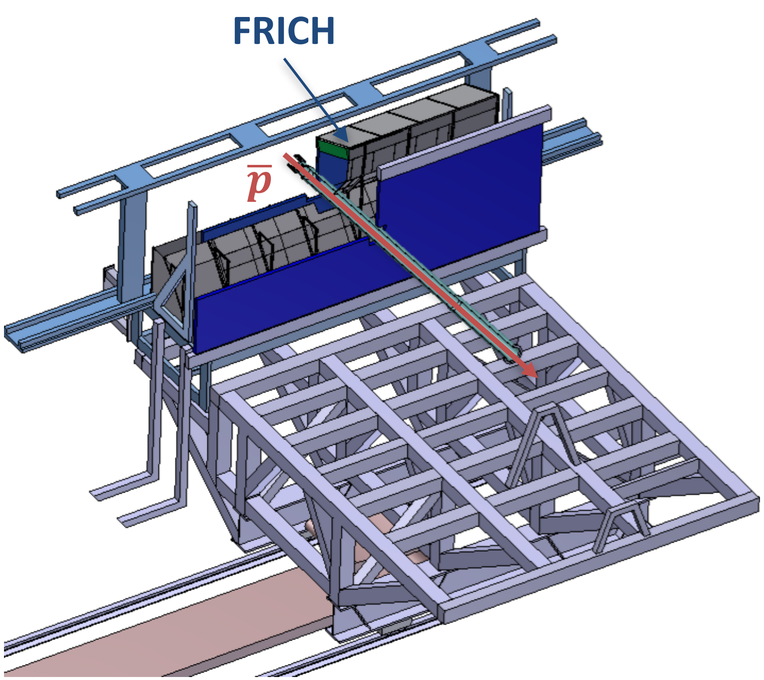


No considerable effect of crack on ring radius, width or Npe

Mechanical design draft v1



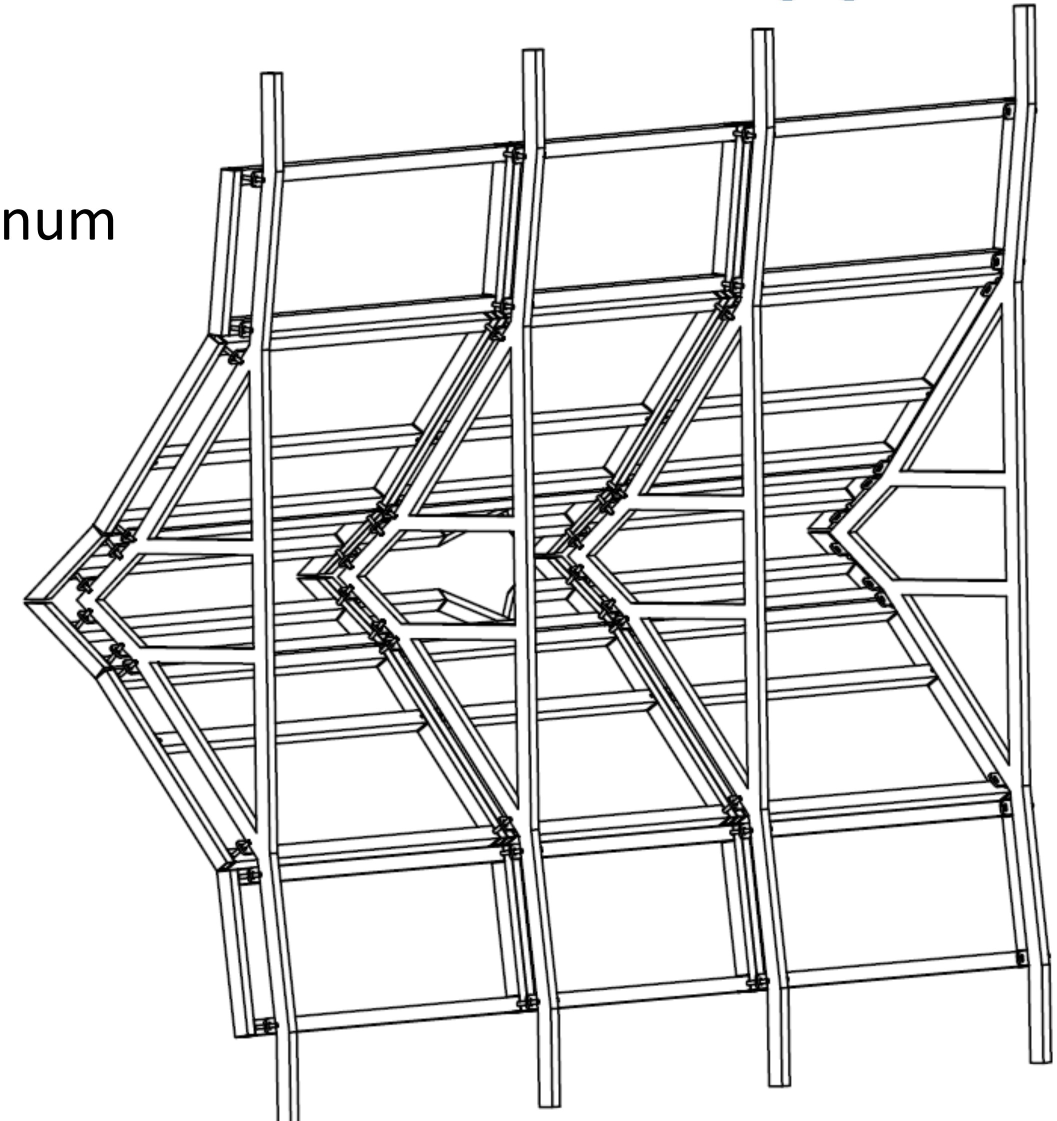
- Light-weight Al support
- 0.5mm windows for particles
- Total material budget about 10% X_0



Forward RICH on the Forward Spectrometer platform

Mirror support v2

Aluminum
77 kg



Carbon fiber support is being considered as a light weight alternative

Conclusion

- R&D of the PANDA Forward RICH based on focusing aerogel is described
- Latest MC simulation of the PANDA Forward RICH results are demonstrated
- R&D is focused on aerogel with a desired refractive index profile
- TDR for PANDA Forward RICH is to be written in 2018

Thank you for your attention!