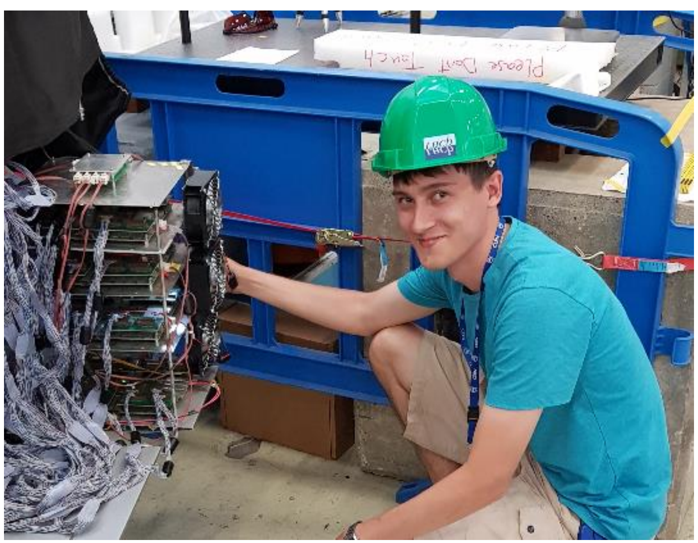
Development of the PANDA Forward RICH with an aerogel radiator

Sergey Kononov[ab]
on behalf of the PANDA Forward RICH group
[a] *Budker Institute of Nuclear Physics, Novosibirsk, Russia*
[b] *Novosibirsk State University, Novosibirsk, Russia*

10th International Workshop on Ring Imaging Cherenkov Detectors (RICH2018)
03.August.2018



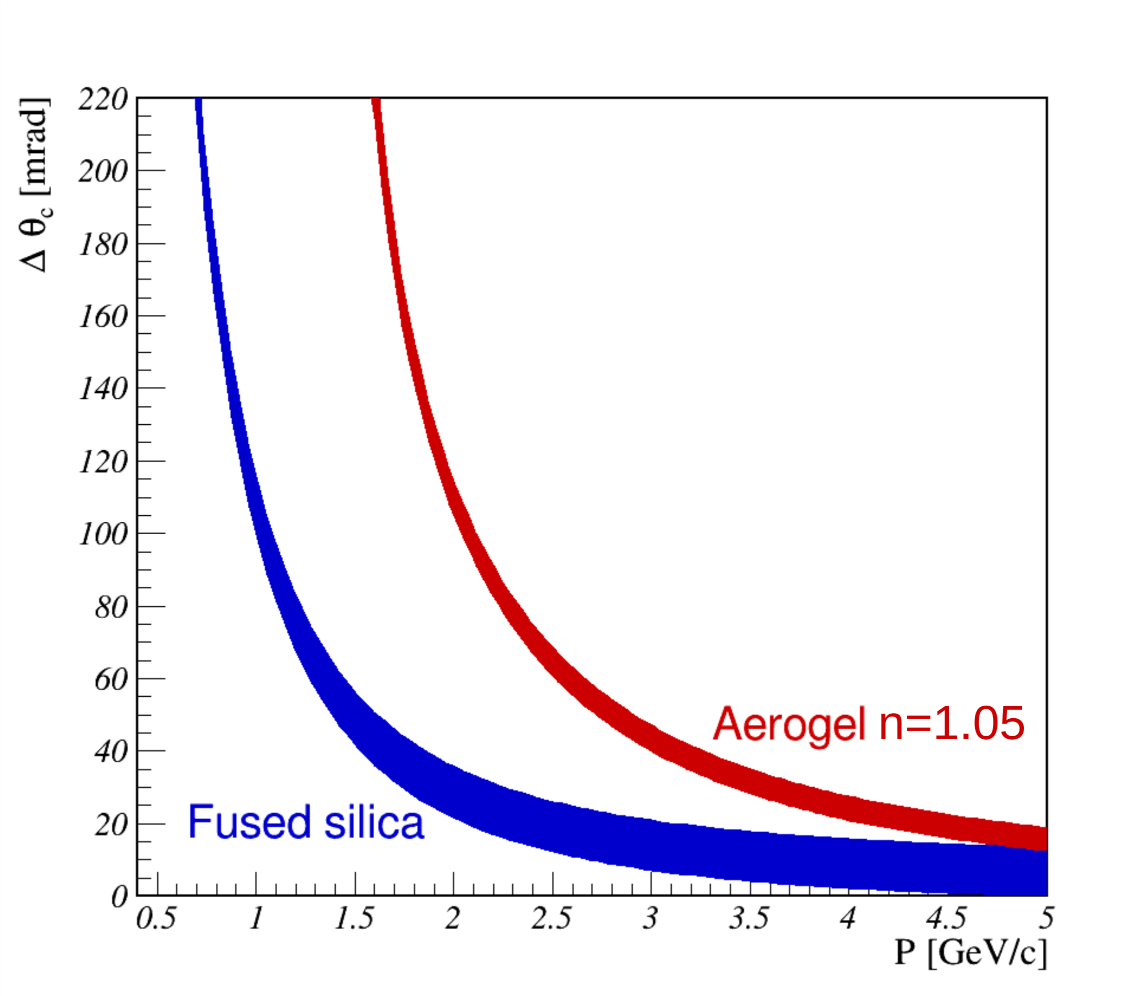
Outline

- Introduction
- PANDA Forward RICH design
- Simulation
- Mirror samples measurements
- Preliminary beam test results
- Conclusion

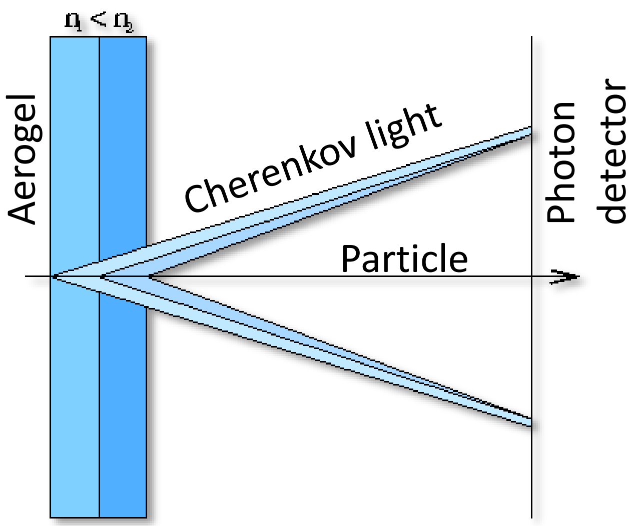
Quartz vs Aerogel radiators

Difference in Cherenkov angle θ_c for π and K

Bands – chromatic dispersion in the wavelength range 350-700 nm



Focusing Aerogel RICH (FARICH)

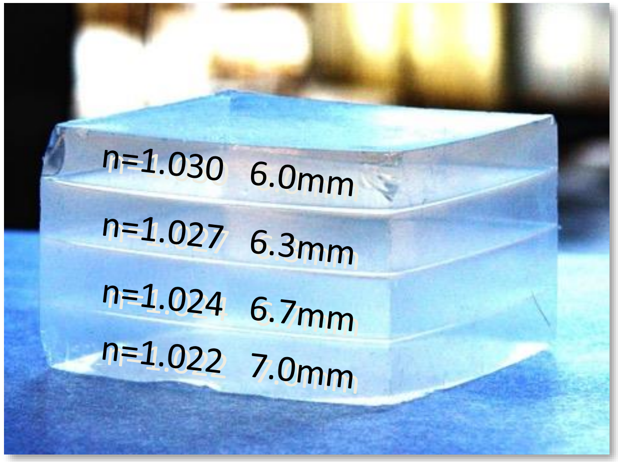


T.Iijima et al., NIM A548 (2005) 383
A.Yu.Barnyakov et al., NIM A553 (2005) 70

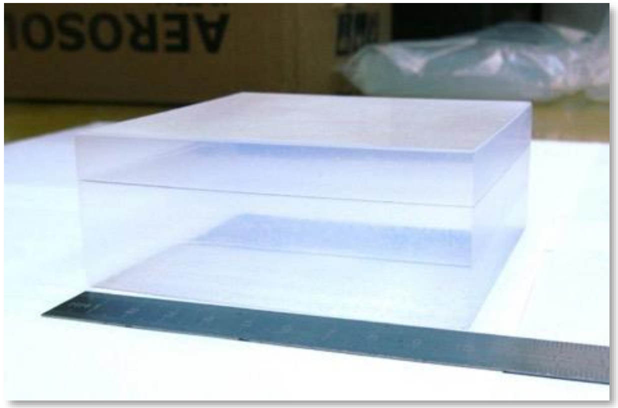
Focusing aerogel improves proximity focusing design by reducing the contribution of radiator thickness into the Cherenkov angle resolution

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

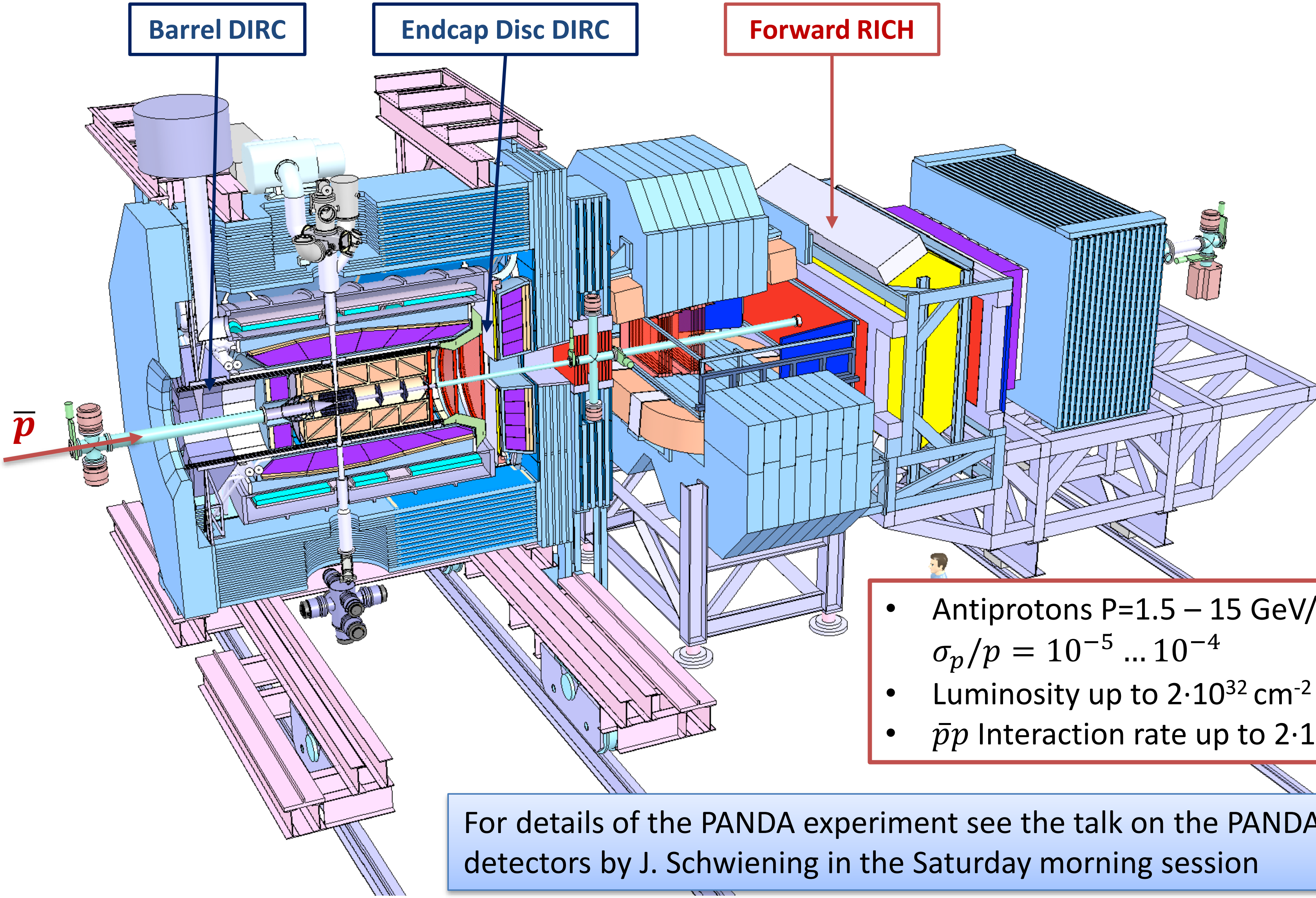
First sample of 4-layer aerogel



3-layer aerogel 115x115x41 mm^3



PANDA detector



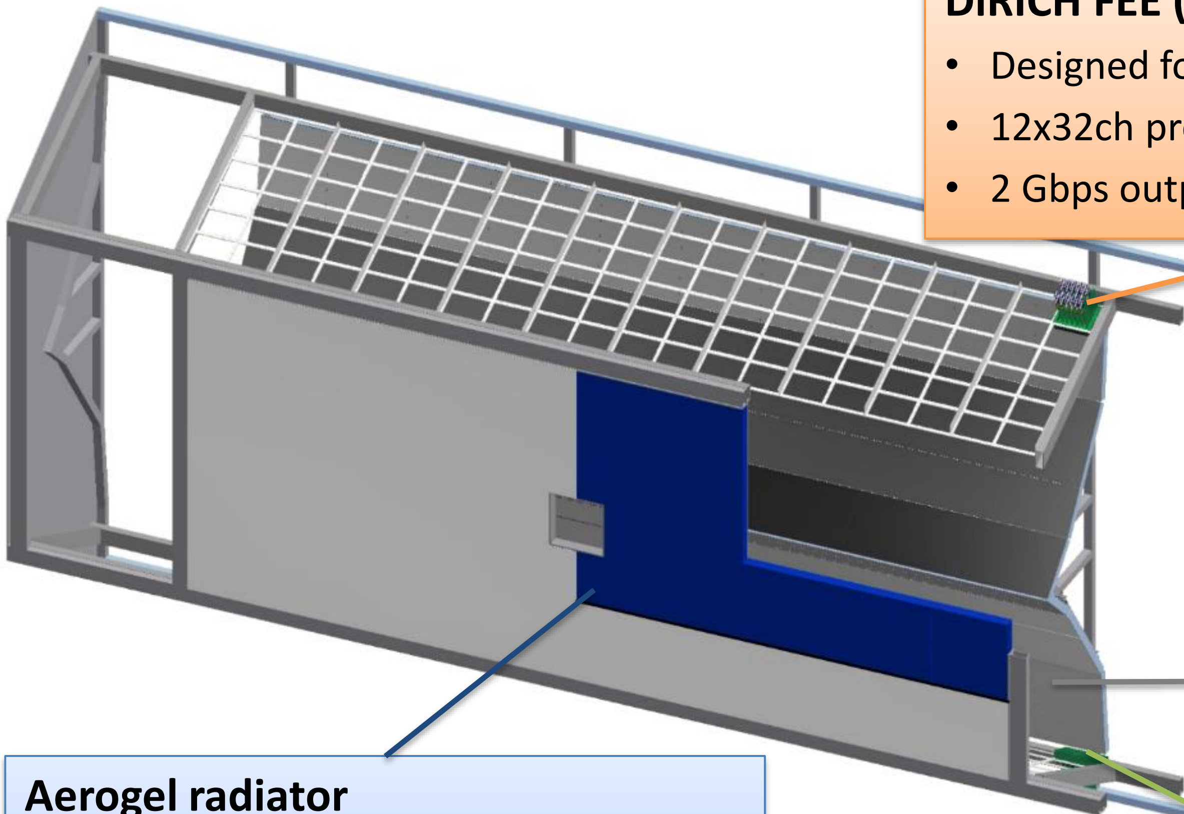
- Antiprotons P=1.5 – 15 GeV/c with $\sigma_p/p = 10^{-5} \ldots 10^{-4}$
- Luminosity up to $2{\cdot}10^{32}$ cm^{-2} s^{-1}
- $\bar{p}p$ Interaction rate up to $2{\cdot}10^{7}$ s^{-1}

For details of the PANDA experiment see the talk on the PANDA DIRC detectors by J. Schwiening in the Saturday morning session

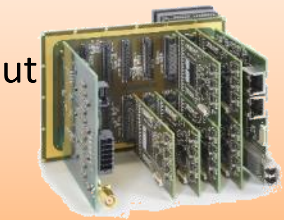
Requirements for the PANDA Forward RICH

- Charged PID in the Forward Spectrometer
- $|\theta x| < 10°$, $|\theta y| < 5°$
- Approximately 3 x 1 m^2 transverse active size, ~0.8 m space occupied along the beam
- Working momentum range for 3σ separation
  - π /K: 2÷10 GeV/c
  - μ/π: 0.5÷2 GeV/c possible
    may complement the muon system
- Physics cases: processes with high charged hadrons multiplicity in the final states for high beam momenta

PANDA FRICH baseline design



DiRICH FEE (GSI)
- Designed for H12700 readout
- 12x32ch preamp+disc+TDC
- 2 Gbps output link

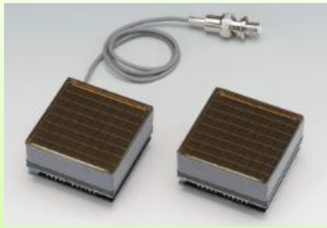


Mirrors
- 2 mm float glass
- Al+SiO_2 coating

Aerogel radiator
- Focusing 2- or 3-layer aerogel
- n≈1.05
- Total thickness – 40 mm

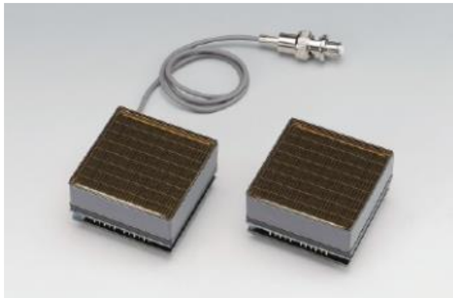
Photon Detector

H12700 MaPMTs (Hamamatsu)
- flat panel
- 8x8 anode pixels of 6mm size



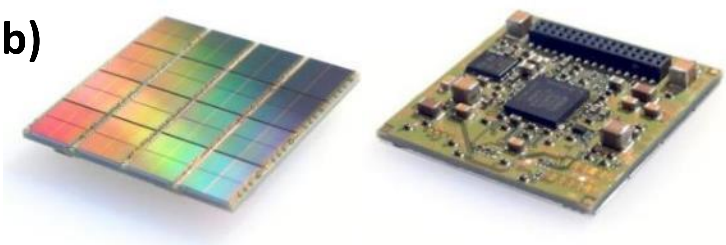
Readout candidates for PANDA FRICH

a)

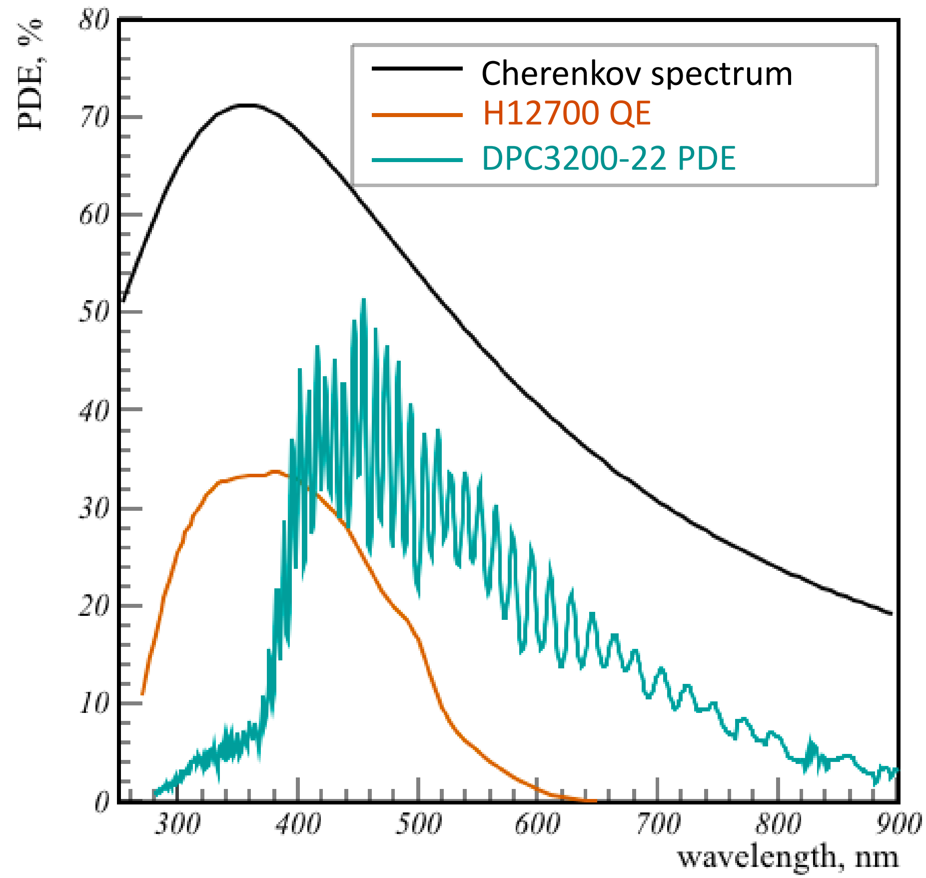


MaPMT Hamamatsu H12700B
with DiRICH (GSI) FEE

b)

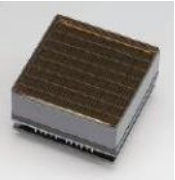


Digital Photon Counter
Digital silicon photomultiplier
TDC on-chip



Comparison of photon detector options

MaPMT H12700

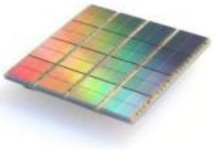


(Hamamatsu, Japan)

- High active/total area ratio 87%
- Robust
- Long lifetime
- High single photon efficiency

The MaPMT option was chosen for PANDA Forward RICH

Digital Photon Counter

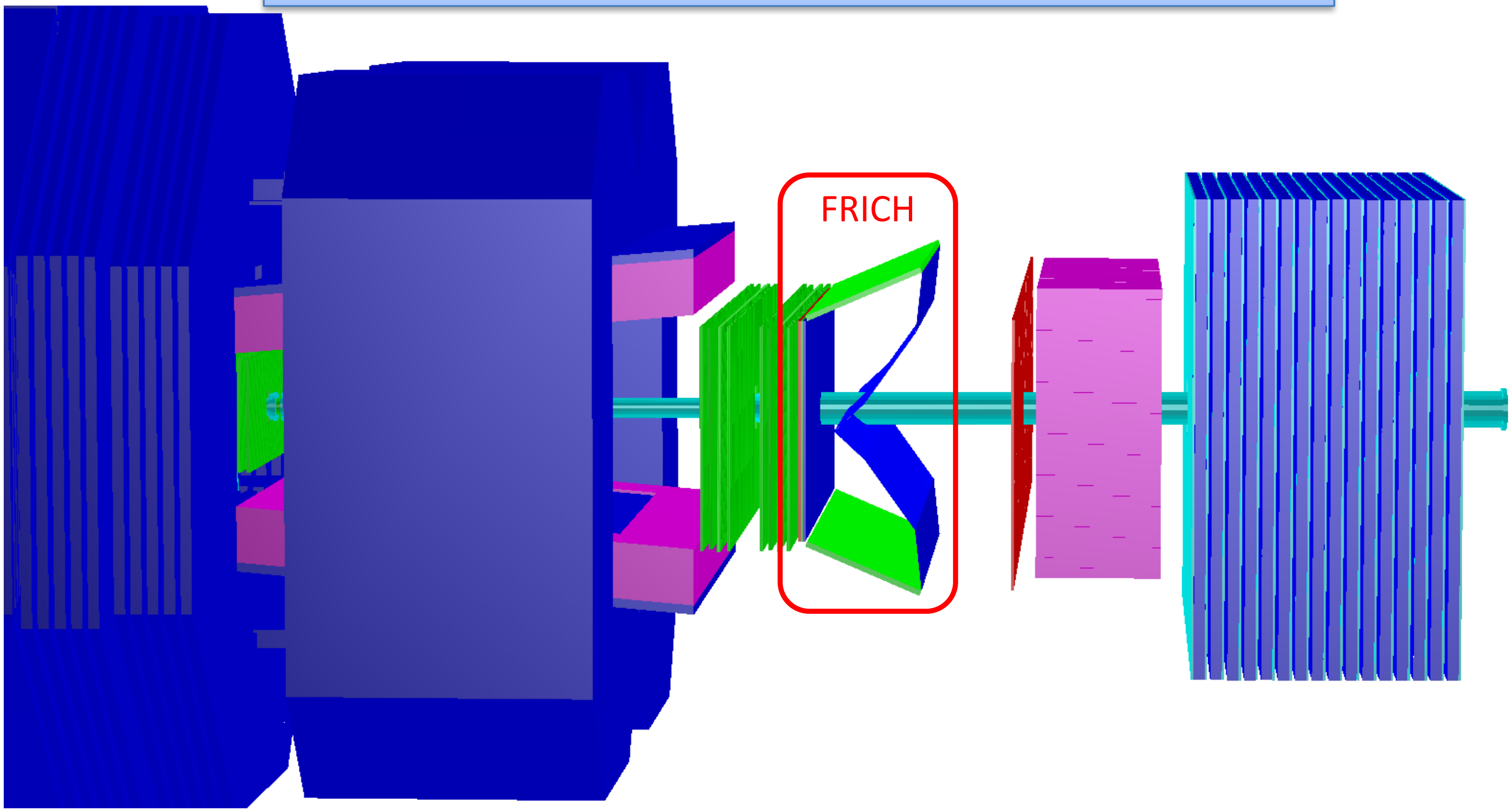


(Philips Digital Photon Counting, Aachen, Germany)

- Interesting readout solution – SiPM integrated with ASIC: TDC with 20 ps LSB, able to inhibit individual cells
- Immune to magnetic field (not an issue for the PANDA FRICH)
- High dark count rate, long dead-time (720 ns) – needs to be cooled for single photon detection
- Low measured N_{pe} and PDE – about 2 times lower than expected from the producer's data
- Radiation hardness issues (DPC lifetime would be less than 1 year in the PANDA HL mode)

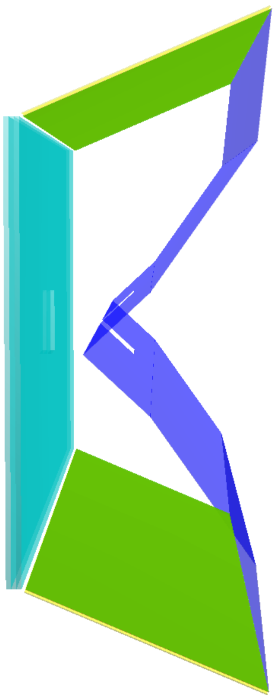
MC simulation of the PANDA Forward RICH

PANDA Forward Spectrometer geometry in PandaRoot

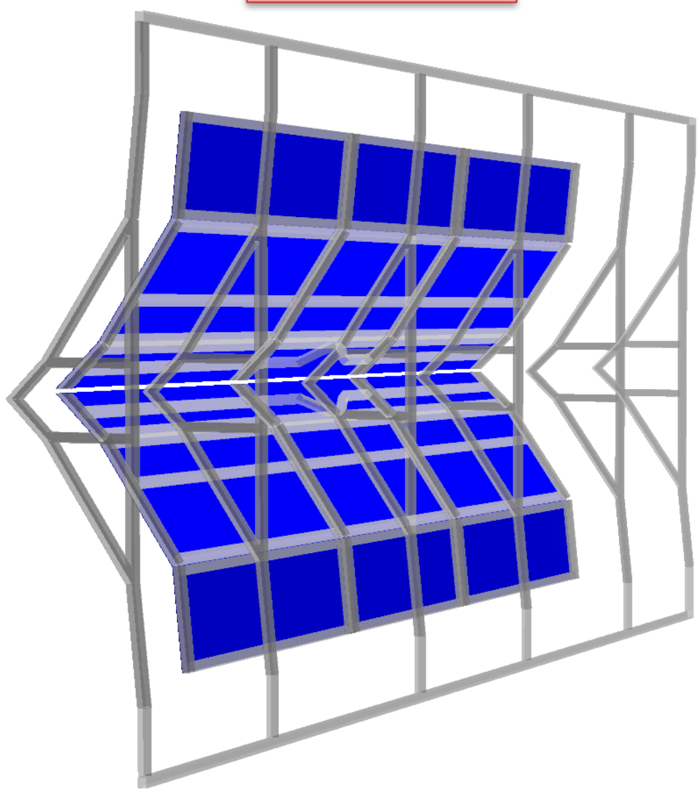


Description of inactive material in PandaRoot

Current version
only main elements



Full version
in progress



Elements to be described

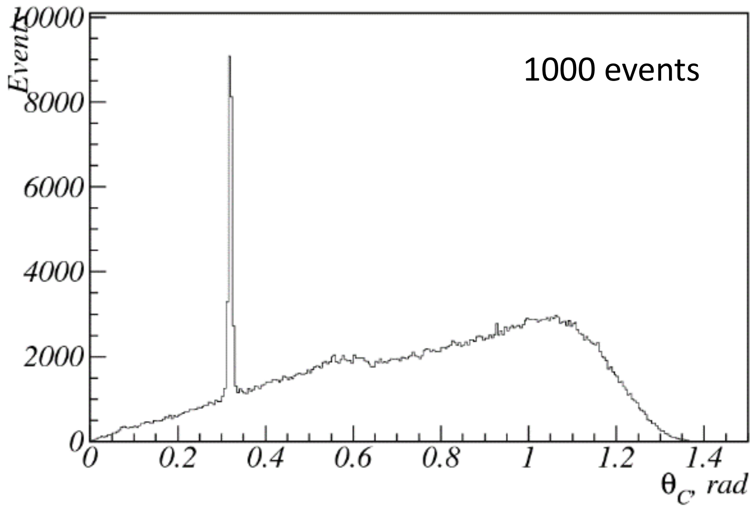
1. Aerogel+Frame
2. Mirror+Frame
3. Photodetector+Frame
4. Envelope

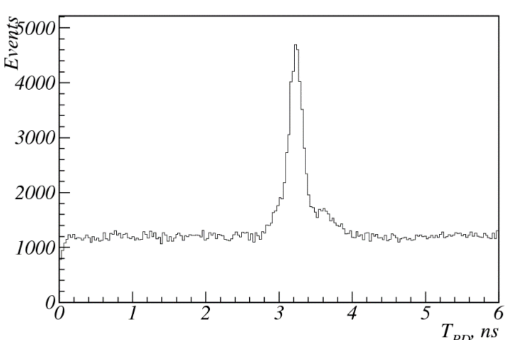
Simulation code variants

Processes described in two simulation variants

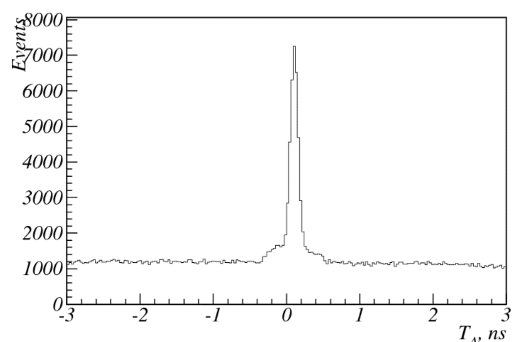
FULL	FAST
Passage of particles through matter	
Optical processes	-
Digitization	-
Tracking	
Full event reconstruction	Calibration based event reconstruction
PID	

Hit pre-selection

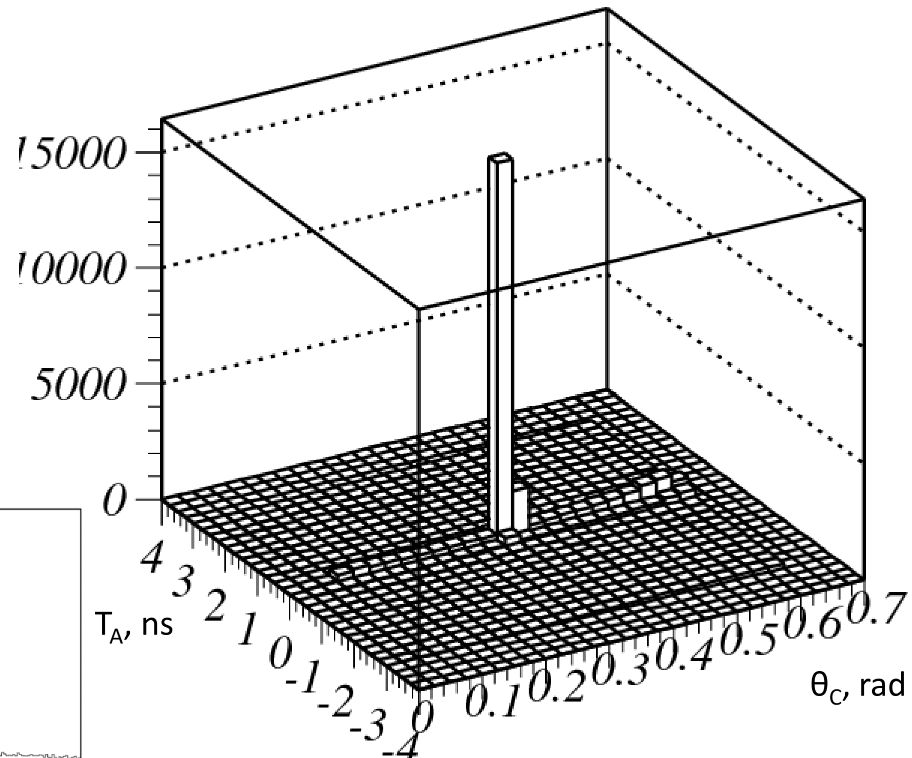




hit time

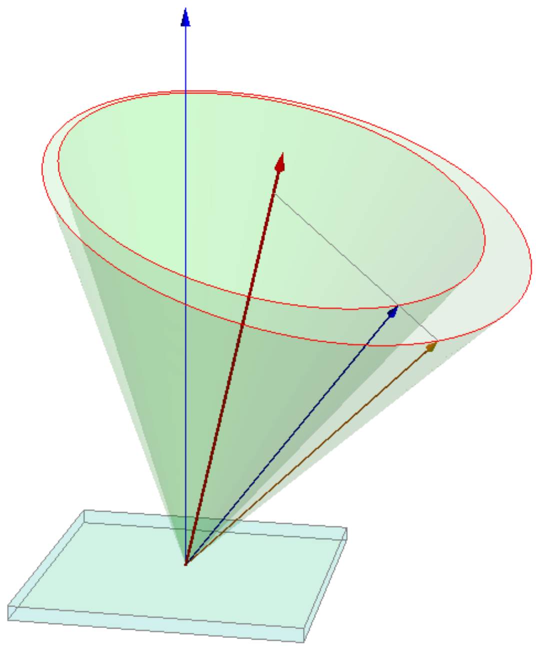


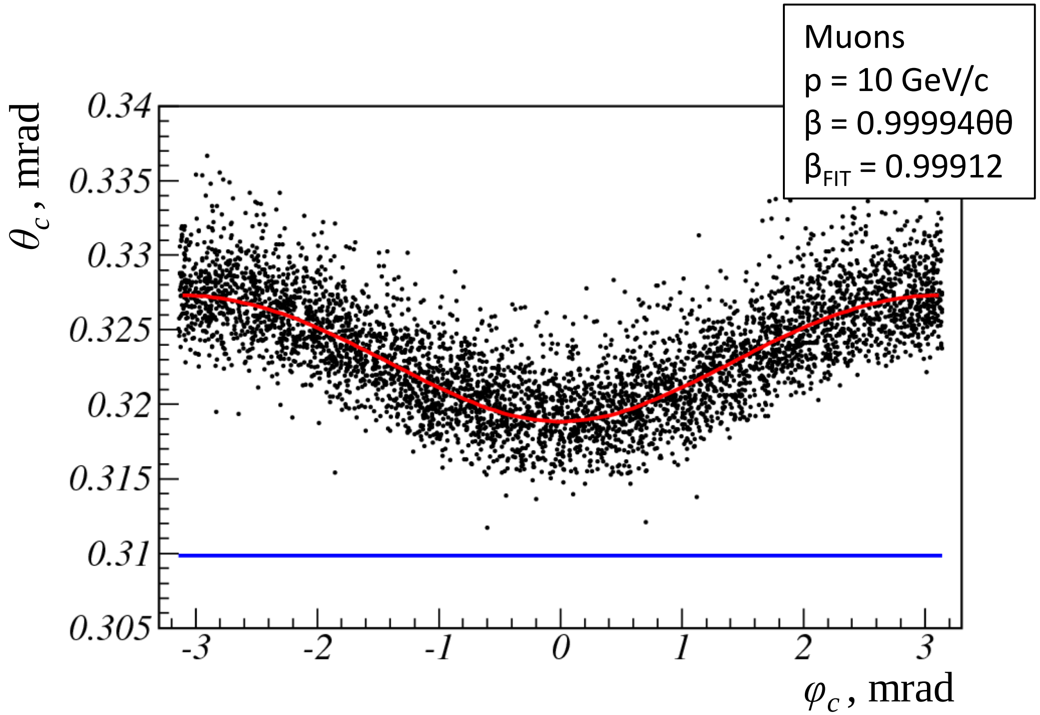
time in aerogel



Hits around peak in θ_c-T_A are selected for fitting

Ring fitting



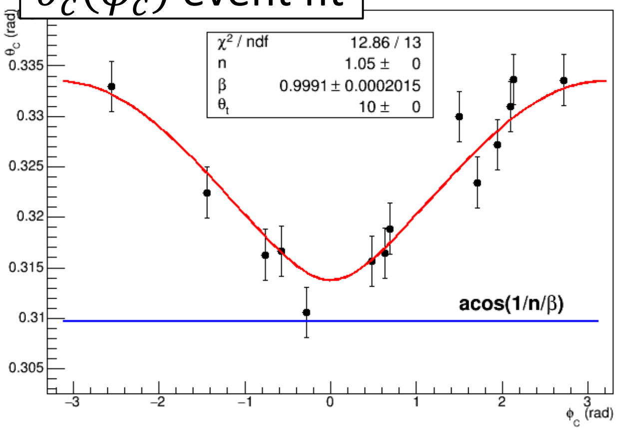


Fit $\theta_c(\varphi_c)$ dependence by an analytical formulae for each event and obtain particle's velocity β as a result

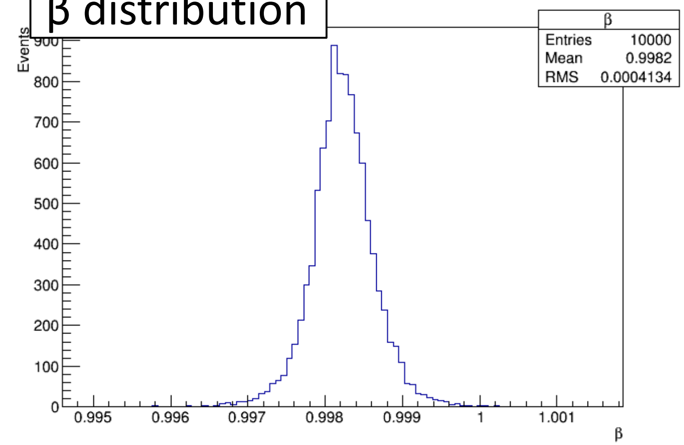
Event reconstruction in simulation

DPC photon detector

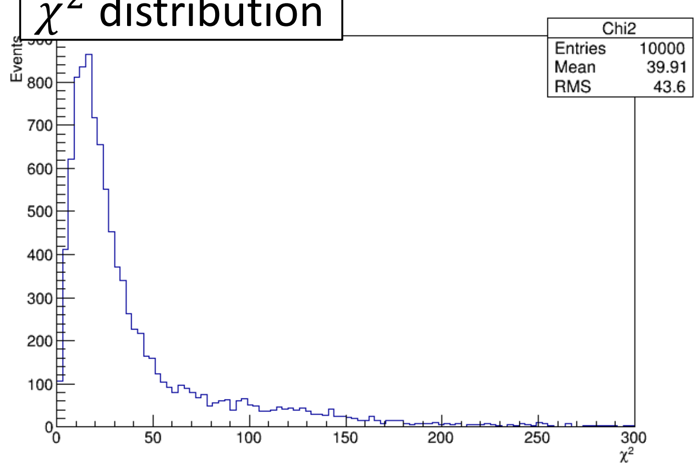
$\theta_c(\varphi_c)$ event fit



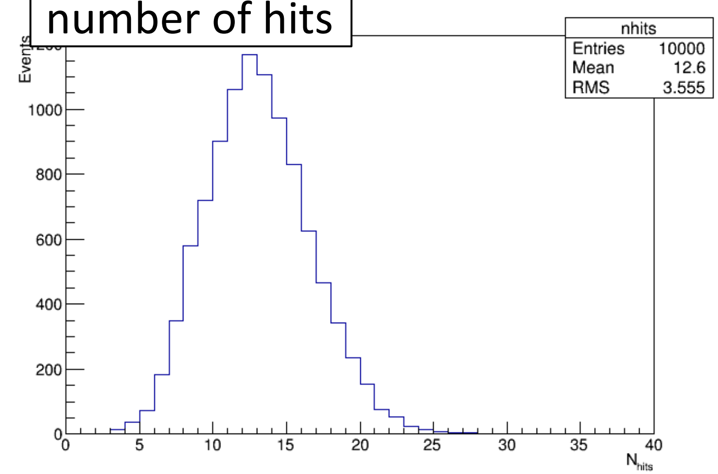
β distribution



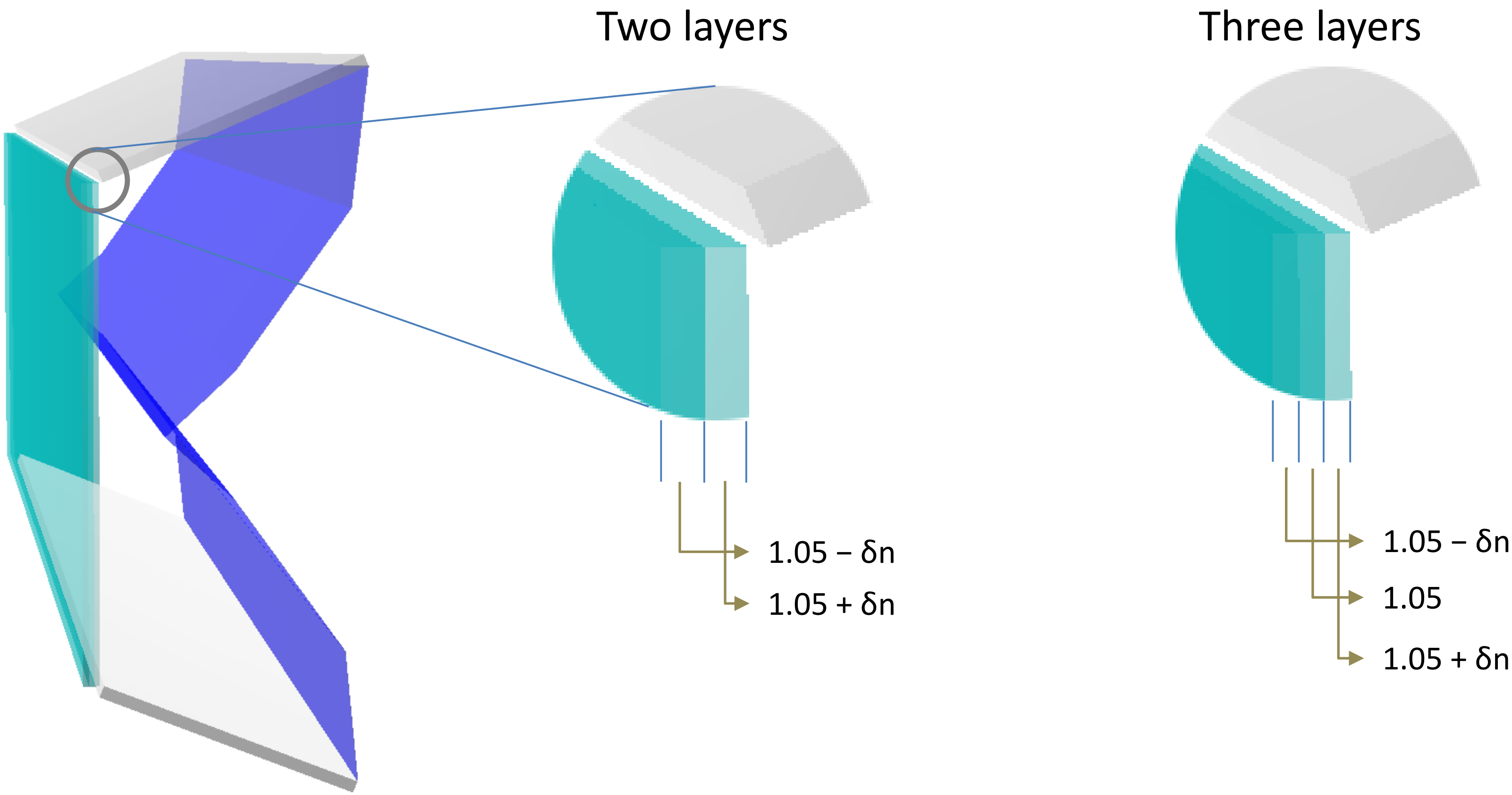
χ^2 distribution



number of hits

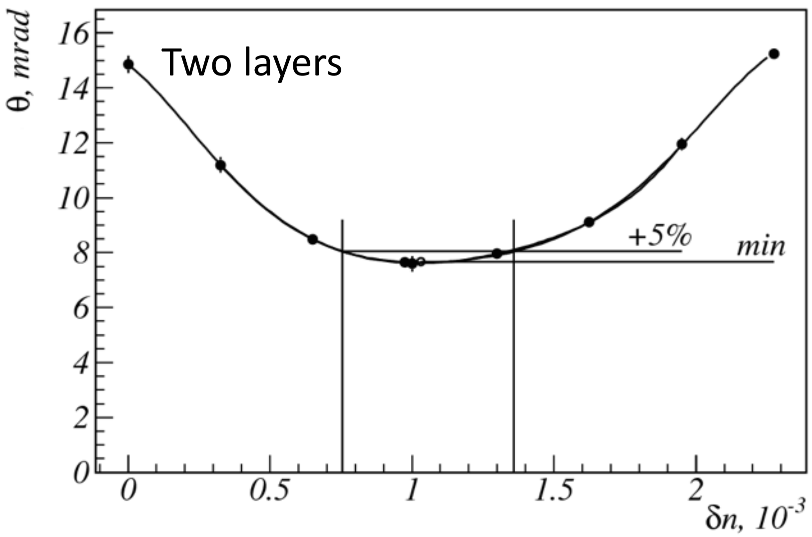


Focusing aerogel optimization (1)

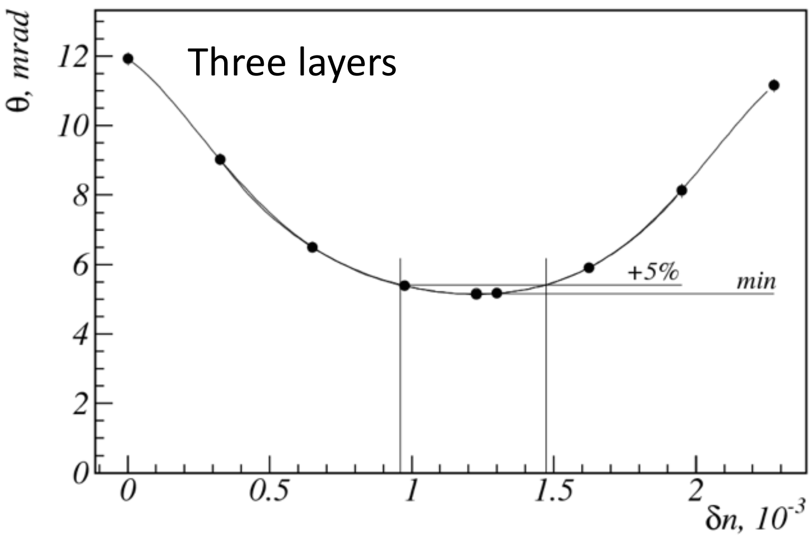


Optimize Cherenkov angle resolution by varying δn

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

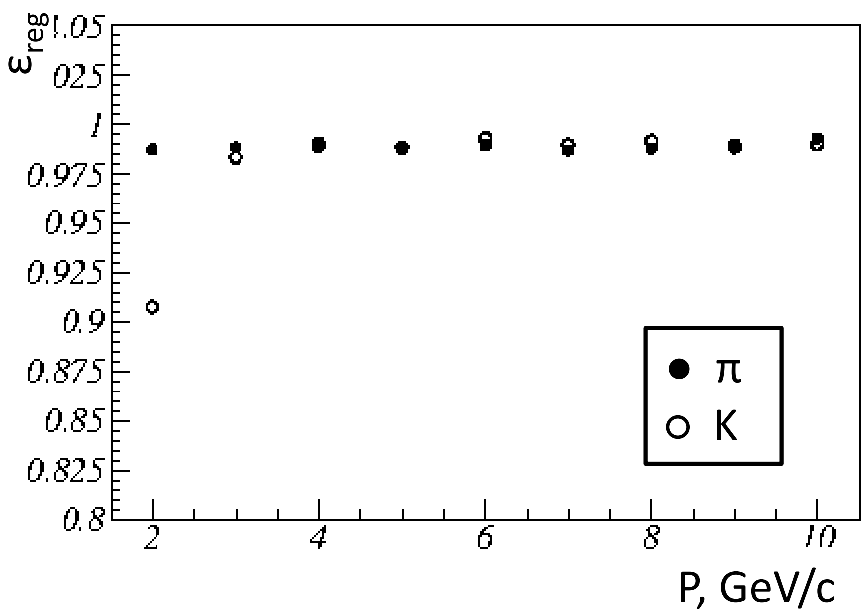


Optimal values:
$\delta n = 1.23^{+0.24}_{-0.27} \cdot 10^{-3}$
$\sigma_\theta = 5.2$ mrad

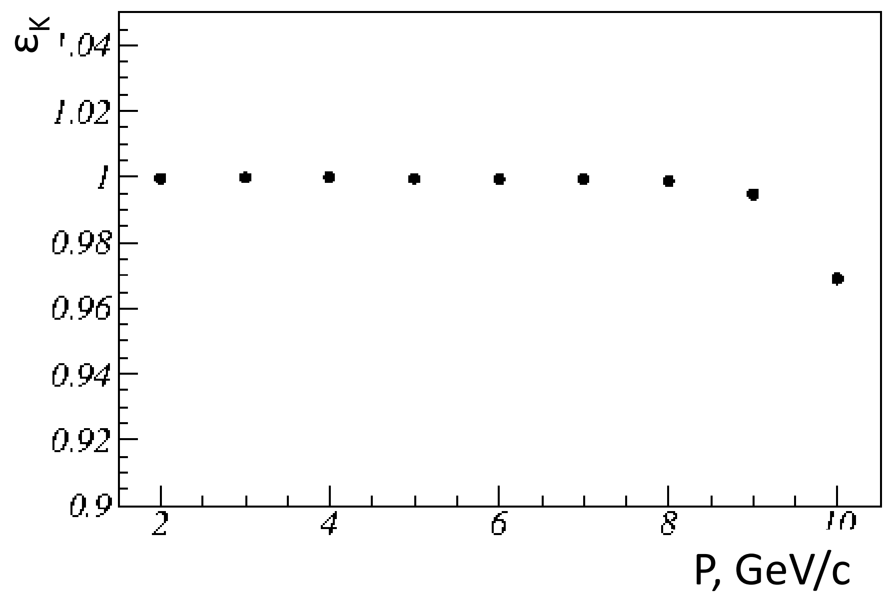
3-layer aerogel was chosen for the following simulation

MC FRICH PID vs momentum
H12700 photon detector

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

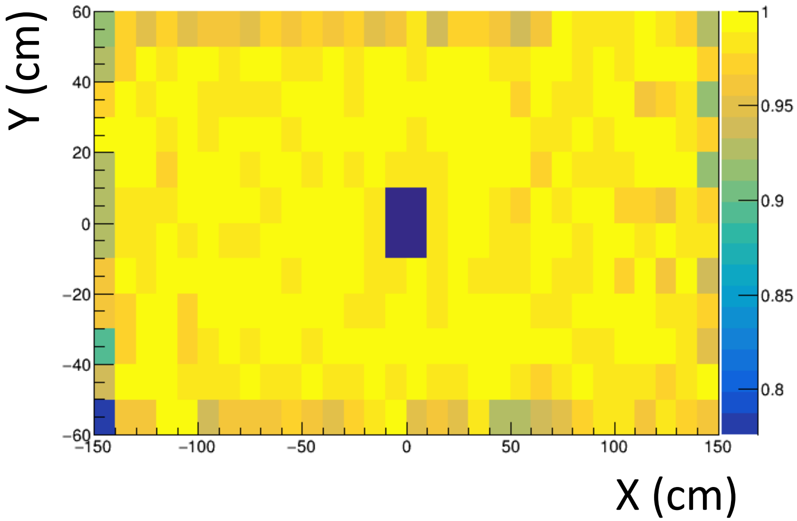


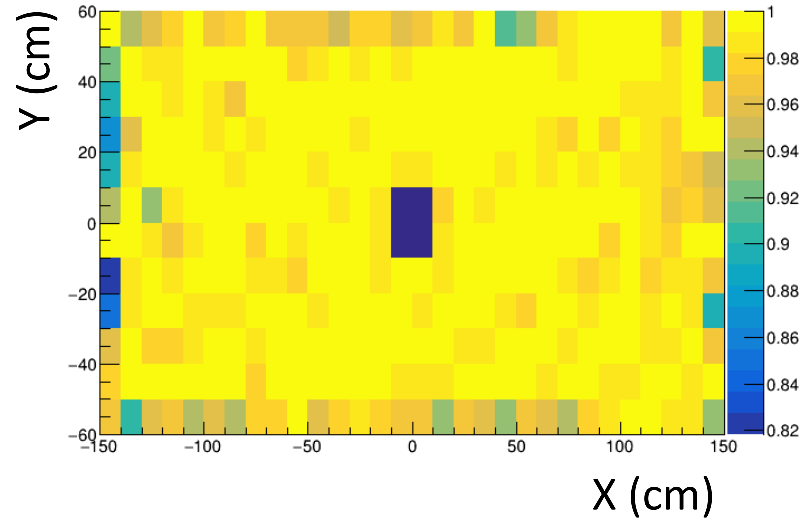
K identification efficiency
at 1% π misidentification



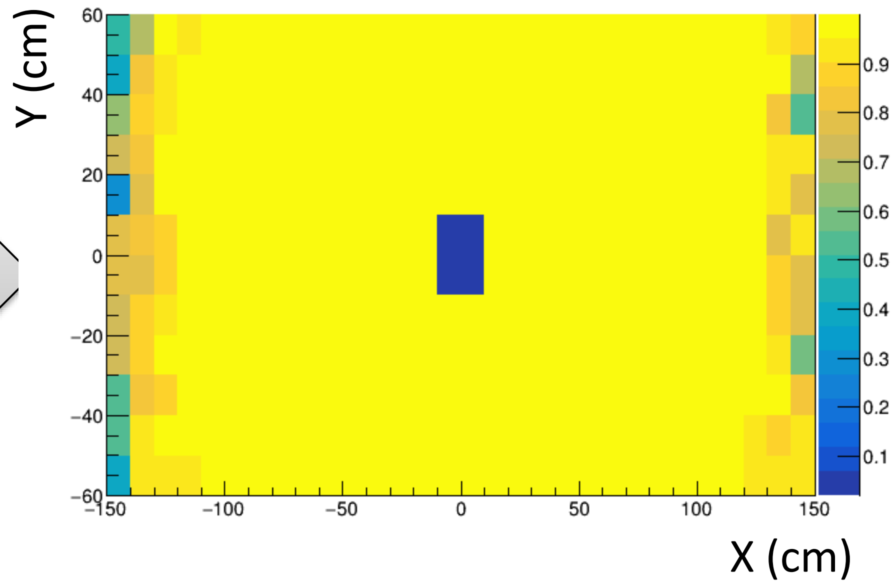
MC FRICH PID uniformity

H12700 PD, p^- beam@ 10 GeV/c



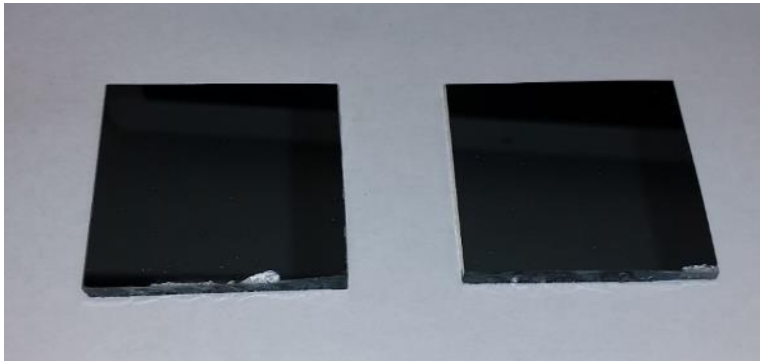


K identification efficiency at 2% π misidentification

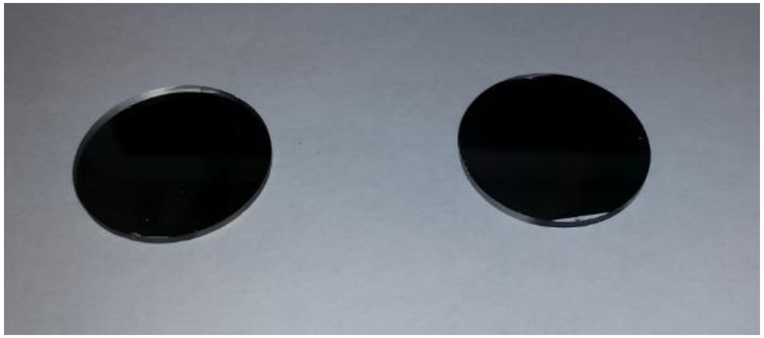


Mirrors for Forward RICH

- Float glass + Al + SiO_2
- Requirements on flatness for float glass (few µm) are met.
- Mirror samples from two producers were obtained and compared by reflectivity.



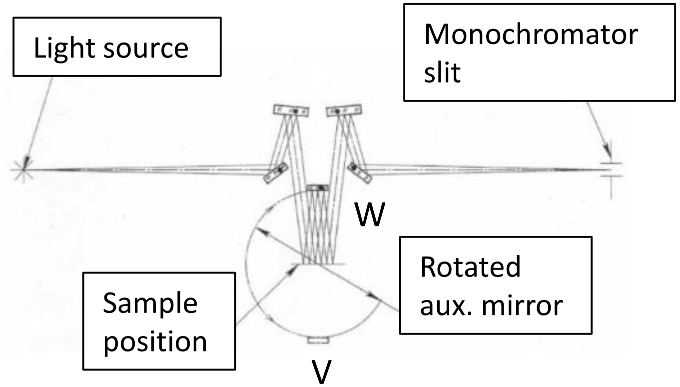
Samples from the Tomsk Institute of High-Current Electronics:
Float glass(4mm)+Al+SiO_2



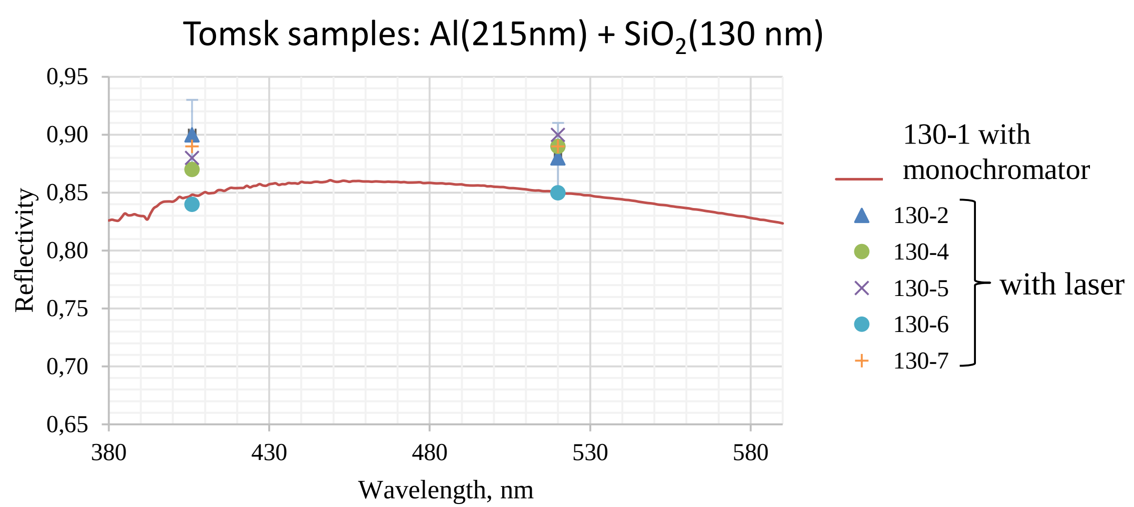
Samples from BINP:
Glass(2mm)+Al+MgF_2

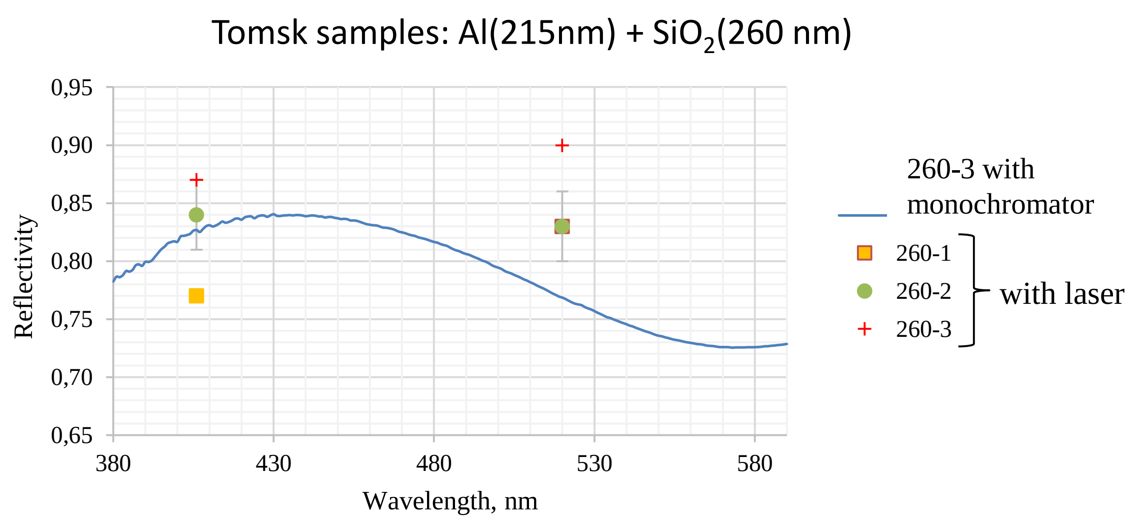
Mirror reflectance measurements

V-W scheme for reflectance measurement

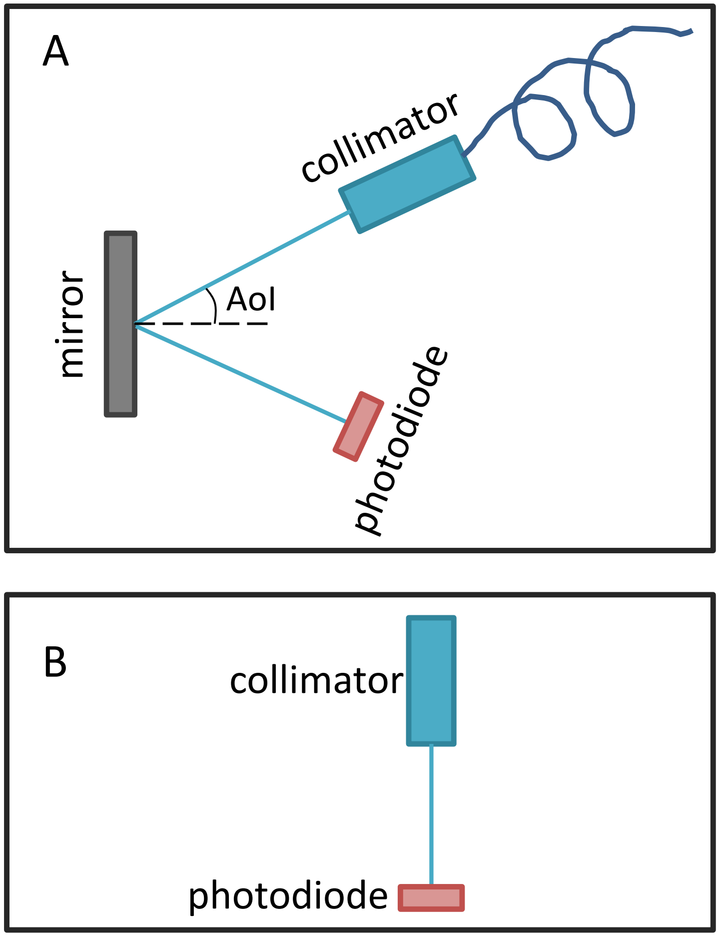


$$R = \sqrt{\frac{I_W}{I_V}}$$

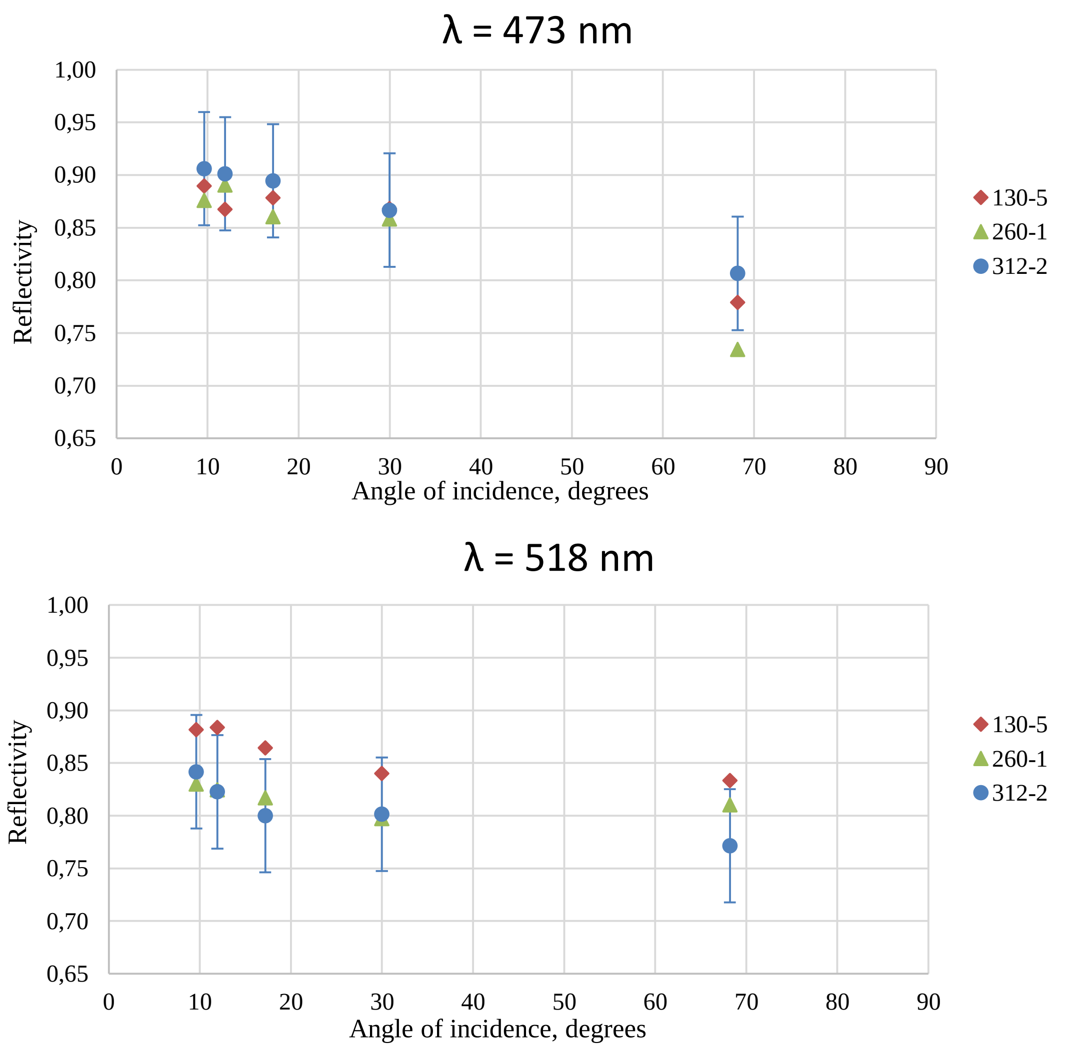




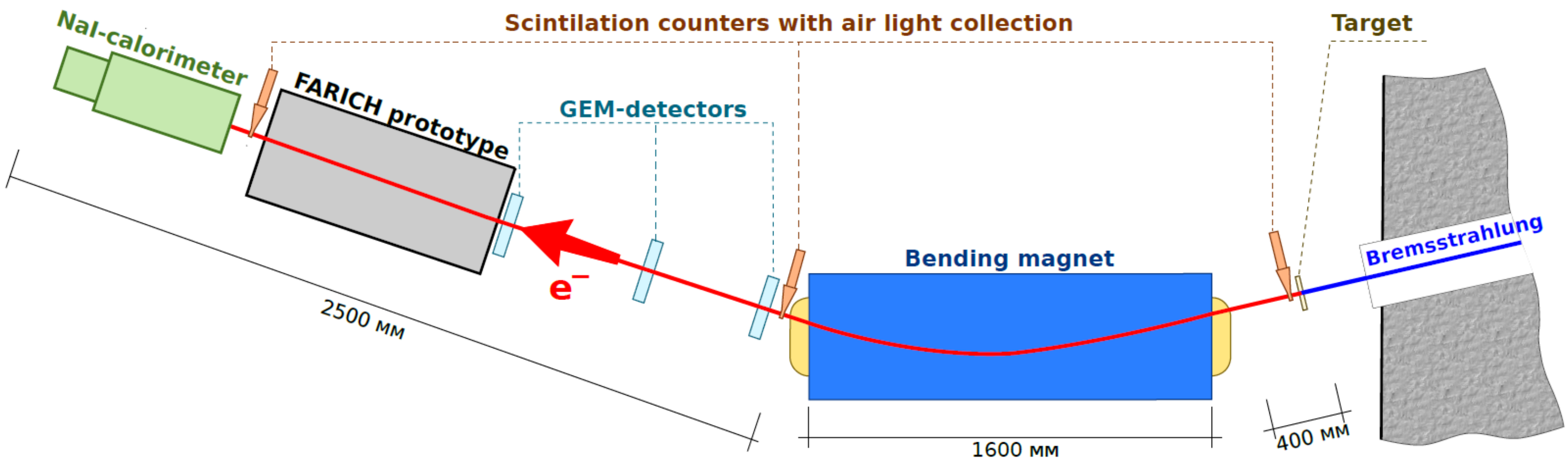
Reflectance vs angle of incidence



$$R = \frac{I_A}{I_B}$$



Test beam of F(A)RICH prototype at BINP VEPP-4 (2018)



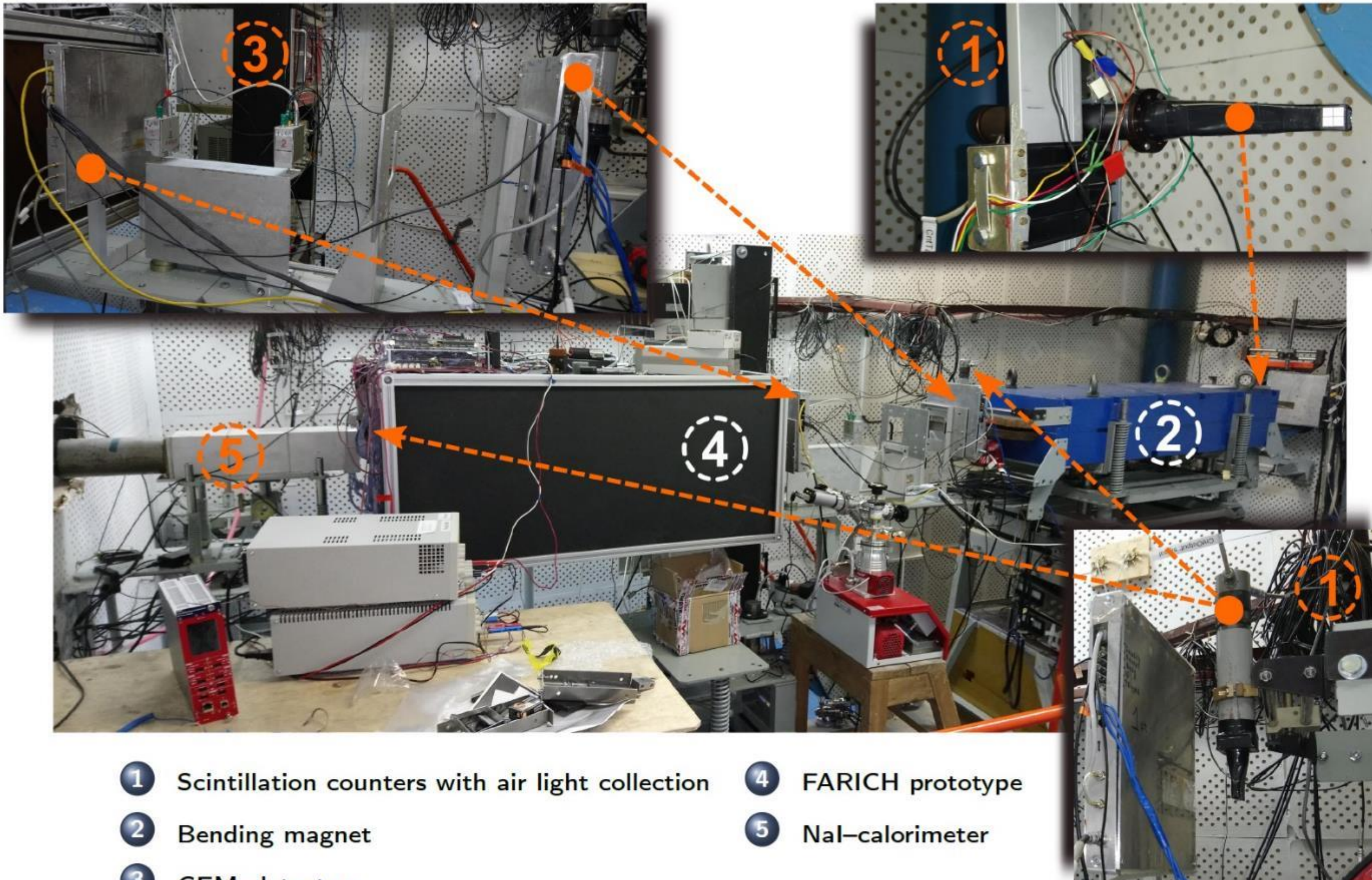
Electron beam parameters in 2018	
Energy range	3 GeV
Averaged intensity	up to 100 e⁻ / s
Energy spread	2.6%

Purpose of beam tests for PANDA FRICH:

- Test H12700 MaPMTs and PADIWA&TRB3 readout
- Obtain single photon resolution for several aerogel configurations and compare with expected ones

Test beam of electrons: Infrastructure

Example disposition of equipment in experimental hall (15/03/2018)

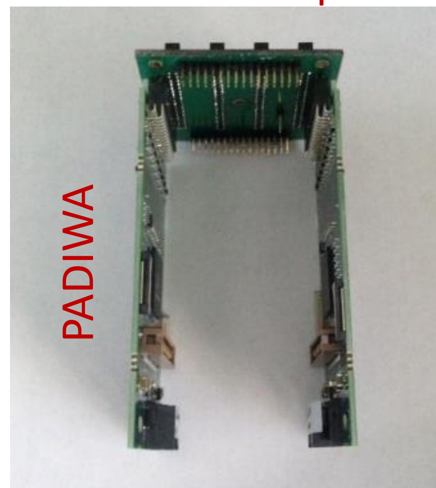


1. Scintillation counters with air light collection
2. Bending magnet
3. GEM–detectors
4. FARICH prototype
5. NaI–calorimeter

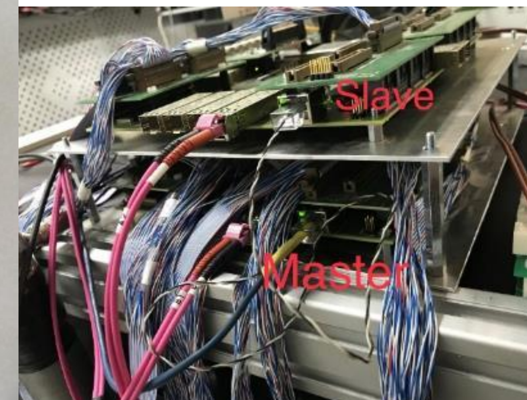
F(A)RICH prototype readout

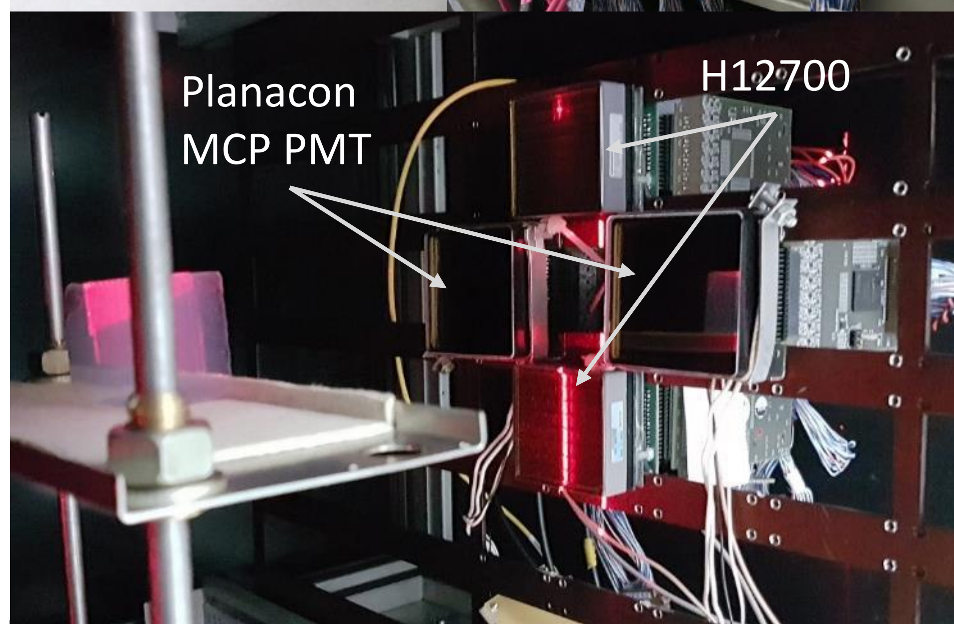
- Custom adapter board to couple 4 PADIWAs to a H12700 MaPMT (PADIWA couple with Planacon MCP PMT without adapter)
- 2 TRB3 boards and 14 PADIWA3 boards – 224 channels (three and a half MaPMTs)
- Each TRB board transmits data via Gbit-ethernet switch to a PC
- GSI DABC software used for DAQ from TRB
- Triggered by coincidence of signals from the sc. counter before F(A)RICH and the NaI calorimeter
- Trigger signal is blocked by PC for readout period. Sync between subsystems is assured by the same event number observed

Custom adapter

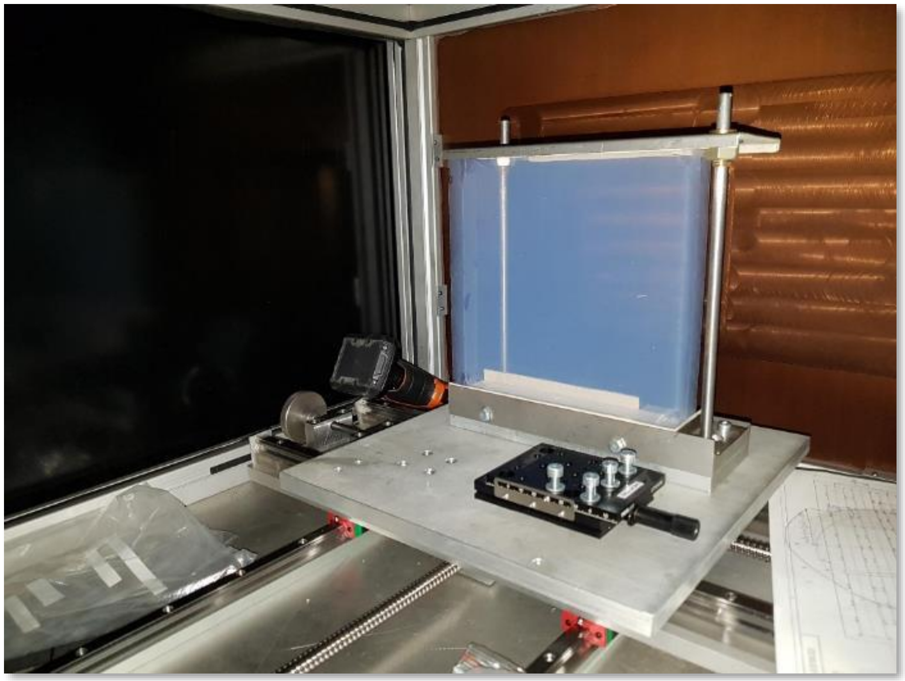


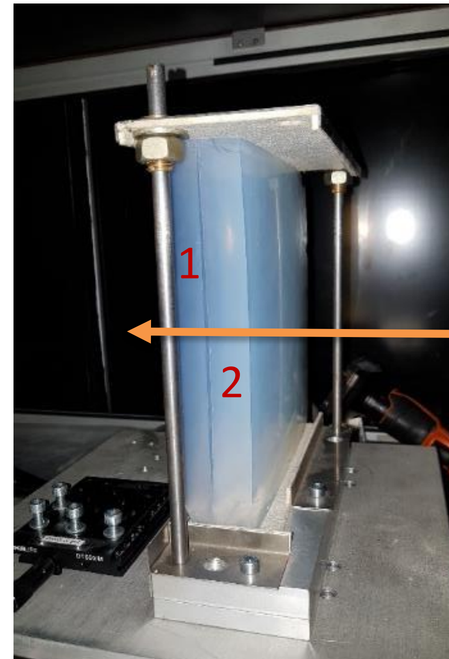
TRB3 boards





Tested aerogel radiator samples (test beam run on 3-4 June 2018)





Configuration 1
n_1 = 1.0514, t_1 = 2 cm
n_2 = 1.0503, t_2 = 2 cm

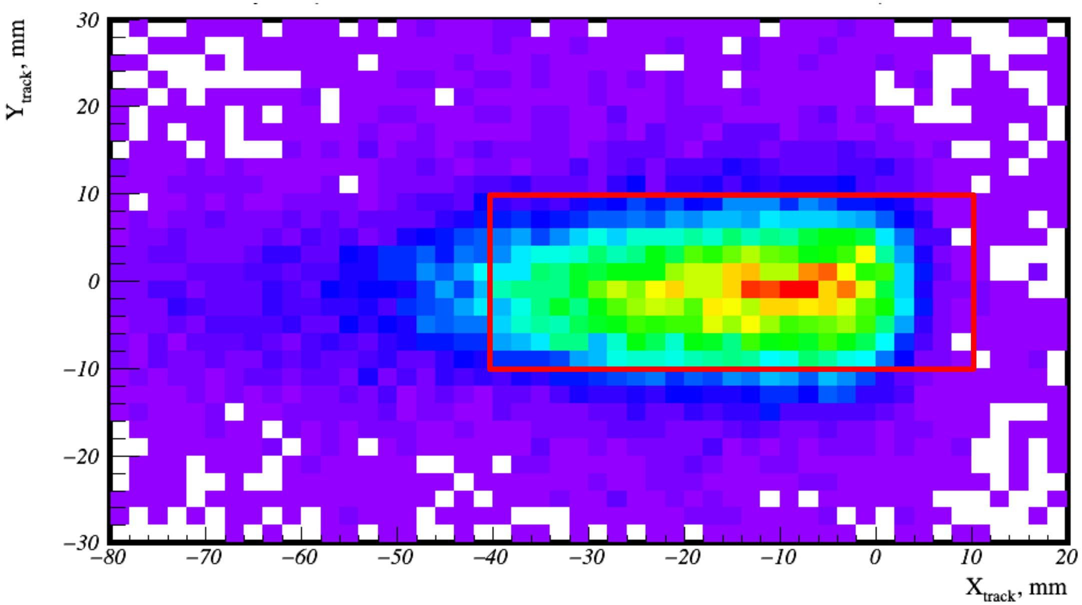
Configuration 2
n_1 = 1.0514, t_1 = 2 cm
n_2 = 1.0514, t_2 = 2 cm

Monolithic aerogels:
3 three-layer samples of 30-40 mm thickness

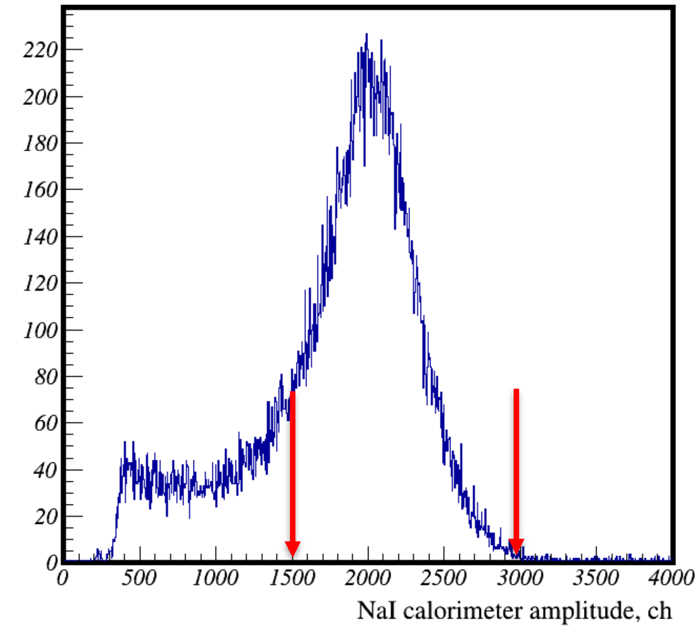
About 300k event per setup configuration were collected

Event selection

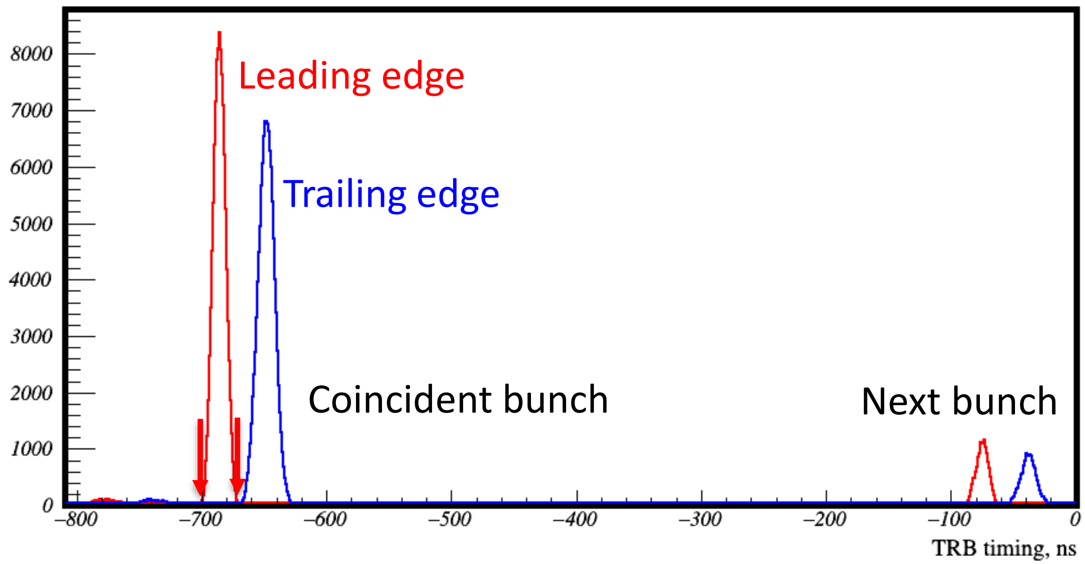
Reconstructed track position XY-map at PMT and selected region

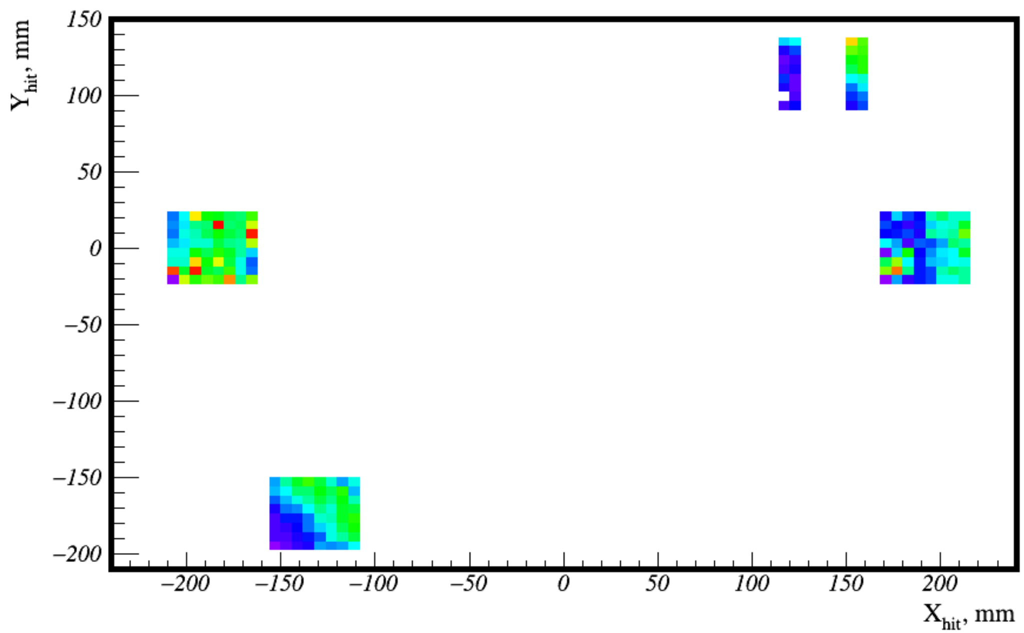


NaI calorimeter amplitude distribution and selected interval



Hit plots





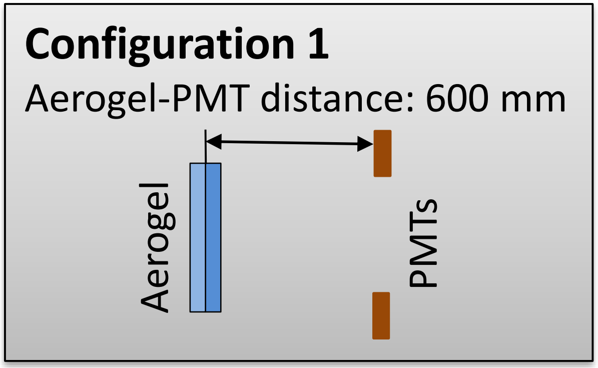
Hit timing distribution

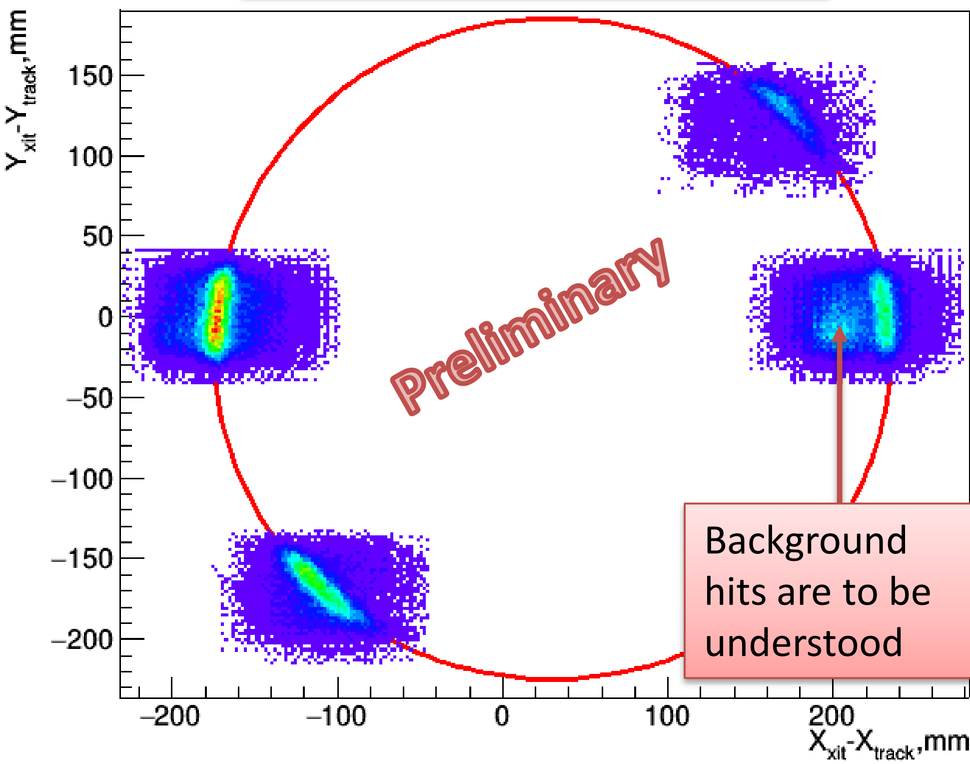
- VEPP-4M bunch structure can be seen with 600 ns separation.
- Timing resolution here is determined by the rough measurement of reference timing in TRB3
- Hits are selected by leading edge timing in 30ns interval

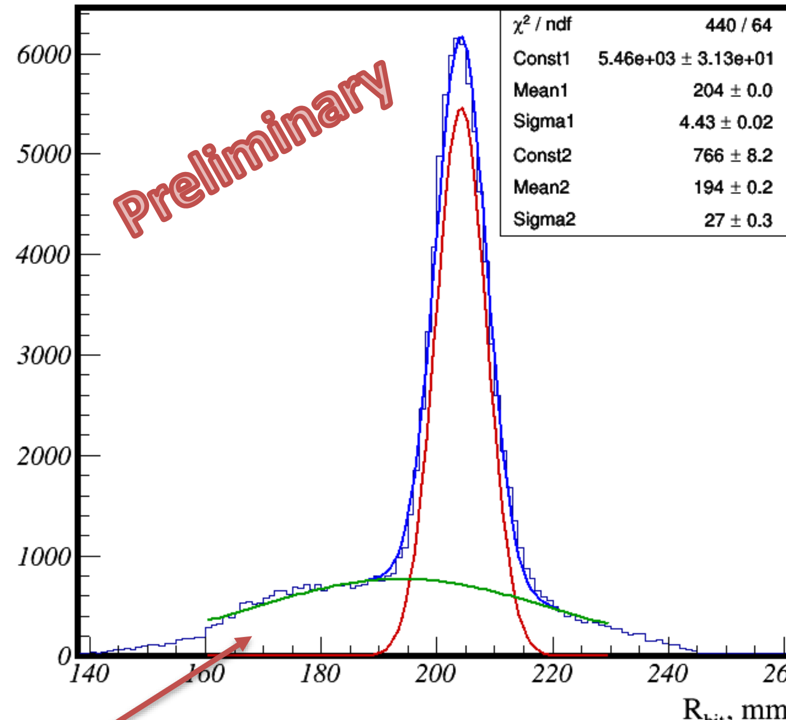
Hit XY map

Ring is not seen here because the e^- beam is wide

Track adjusted hit position







Background hits are to be understood

Preliminary results:

R = 204 mm

σ_{R1} = 4.4 mm (6.6 mrad)

Conclusion and outlook

- Forward RICH PandaRoot simulation is almost ready.
- Mechanical design draft is almost ready.
- MaPMTs and FEE tests are in progress. DiRICH electronics is to be tested.
- Mirror samples for FRICH were produced. Absolute reflectance measured is close to 85% — satisfactory.
- FRICH prototype based on H12700 MaPMTs and PADIWA3+TRB3 with beams was tested in 2018. Data analysis is in progress.
- TDR to be ready in 2019