The Forward Rich Project at PANDA

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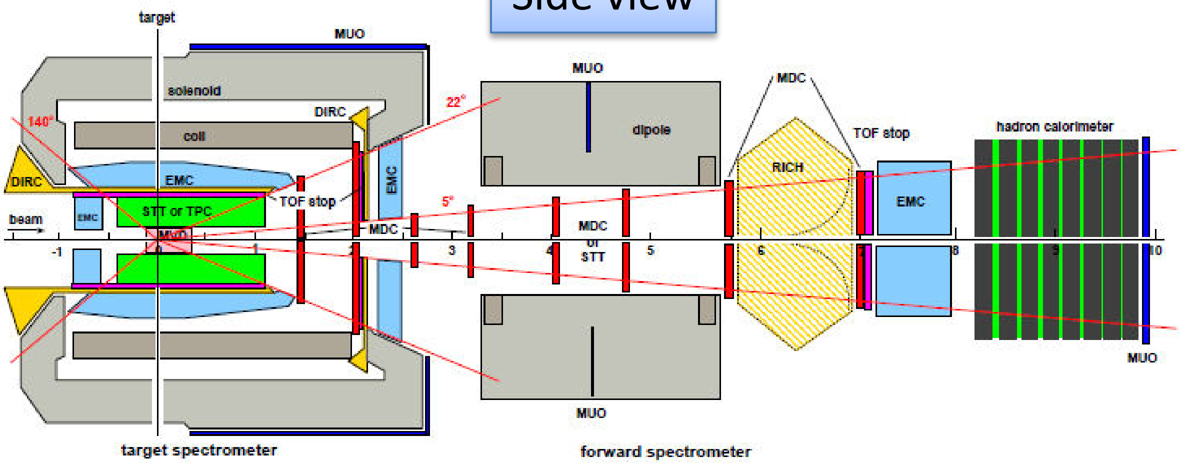
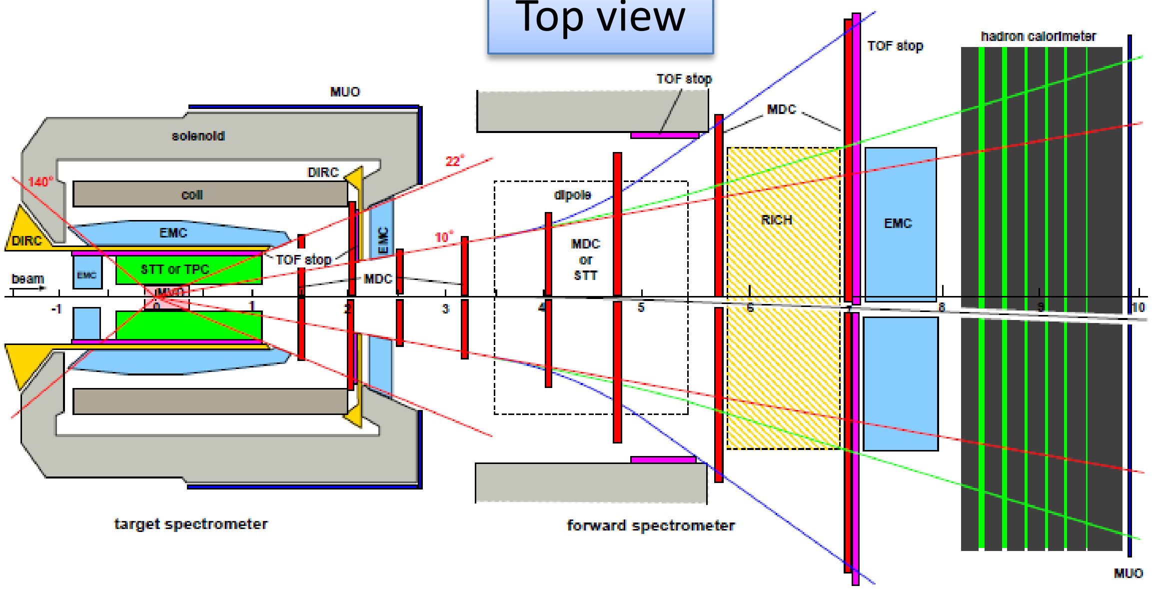
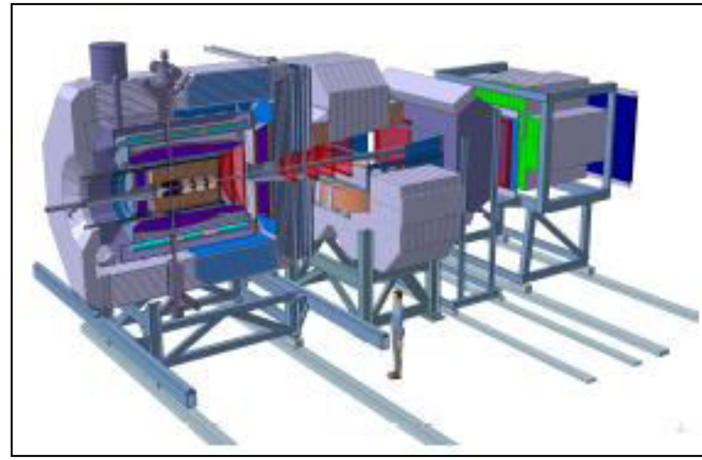
PANDA detector

Side view



Top view





High-Energy Storage Ring:

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

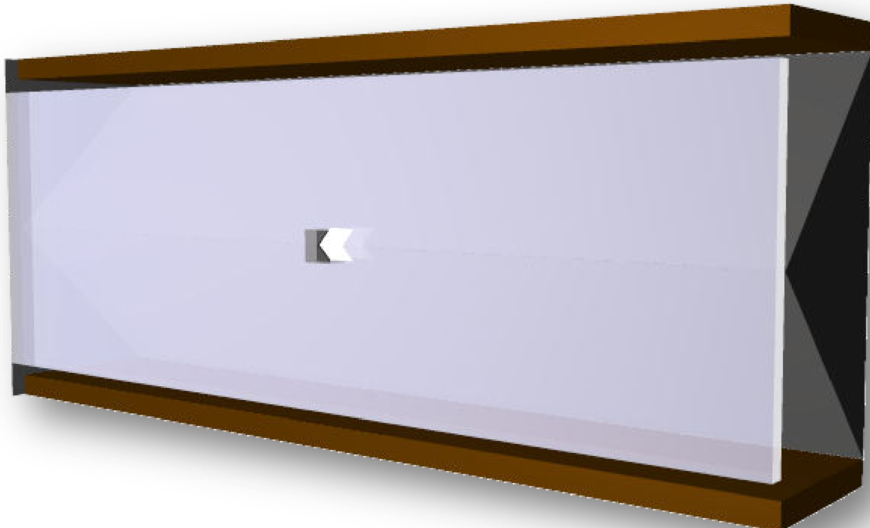
PANDA physics program:

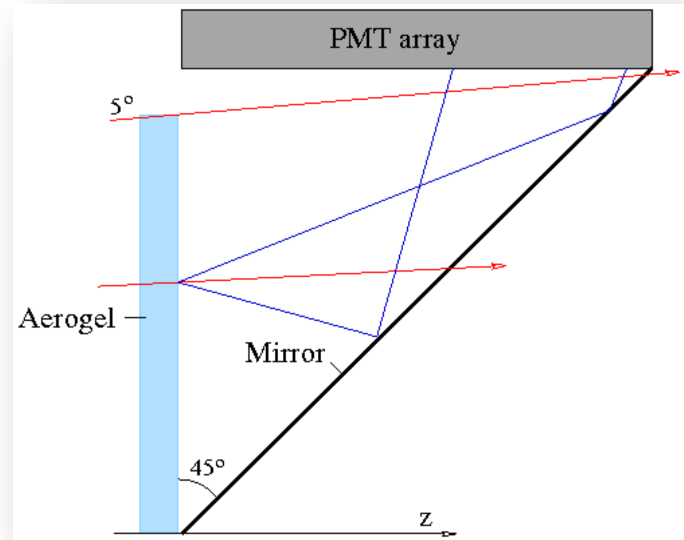
- Charmonium spectroscopy
- Search for Gluonic Excitations (glueballs and hybrids)
- Study of Hadrons in Nuclear Matter
- Open Charm Spectroscopy
- Hypernuclear Physics
- Electromagnetic Processes

Requirements to Forward RICH

- 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: 3÷10 GeV/c
  - μ/π: 0.5÷2 GeV/c possible
- Physics cases application: processes with high charged hadrons multiplicity in the final states for high beam momenta

Conceptual design proposal

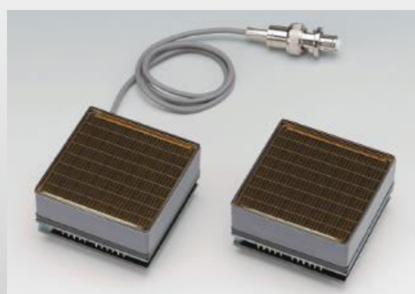




Baseline DP option

<u>Hamamatsu H12700 MaPMT</u>

- 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
- Relatively cheap (≈€1600 / unit)
- Robust
- Long lifetime

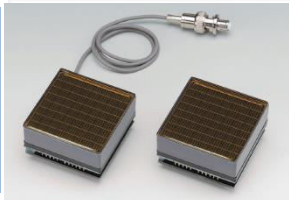


- Focusing aerogel radiator (non-homegenious)
- No gaseous radiator
- Flat mirrors
- MaPMT readout (other options possible)

Readout options

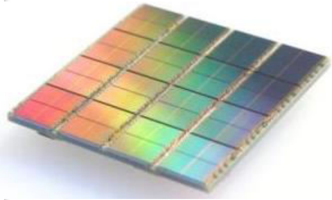
MaPMT	FEE	TDC
H12700	PADIWA	TRB

Baseline option
H12700B price: 1700 € per tube (~1400 tubes in total)



DPC	Tile FPGA	Module FPGA	Data concentrator FPGA

Dare-to-try option
DPC price: 3500 € per module (~800 modules in total)
Needs liquid cooling.



Production of aerogel in Novosibirsk

- Started in 1986 by the Boreskov Institute of Catalysis SB RAS in cooperation with the Budker Institute of Nuclear Physics SB RAS
- Hydrophilic (absorbs moisture)
- Refraction indices 1.006 – 1.08 (1.08-1.13 produced by sintering)
- Block dimensions up to 200x200x50 mm^3 (for n=1.03)
- Remarkable optical quality has been achieved:

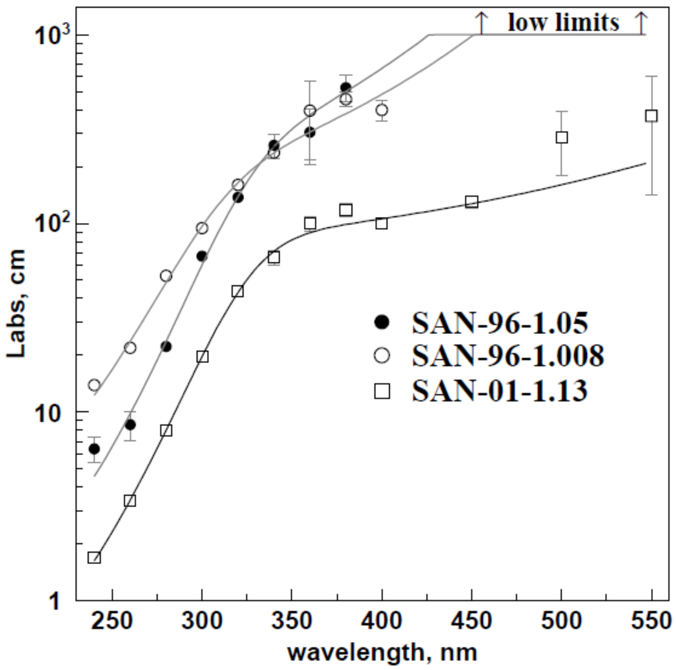
  L_{abs} (400nm) = 5 – 7 m

  L_{sc} (400nm) = 4 – 6 cm

  (Clarity = 0.0043 – 0.0064 μm^4/cm)

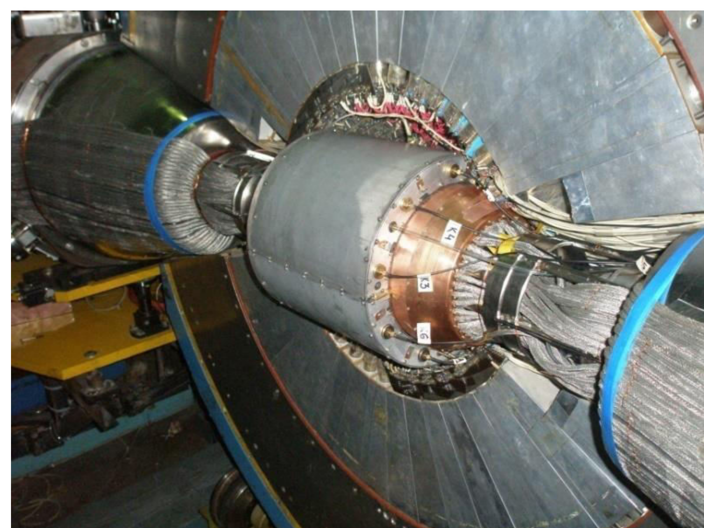
- Used in the experiments:
  - KEDR/VEPP-4M: n=1.05 (1000 l)
  - SND/VEPP-2000: n=1.13 (5 l) + n=1.05 (5 l)
  - LHCb RICH: n=1.03 (20 l)
  - AMS-02/ISS RICH: n=1.05 (60 l)
  - DIRAC-II/CERN PS: n=1.015 (26 l) + n=1.008 (13 l)

Absorption length



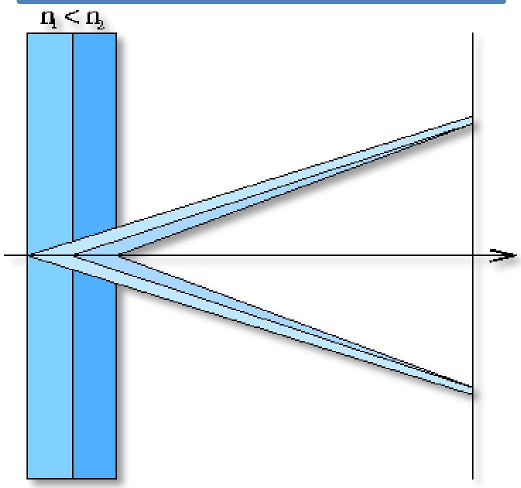
KEDR ASHIPH counters: 1000 liters of aerogel

SND ASHIPH counters: n=1.13 (n=1.05)

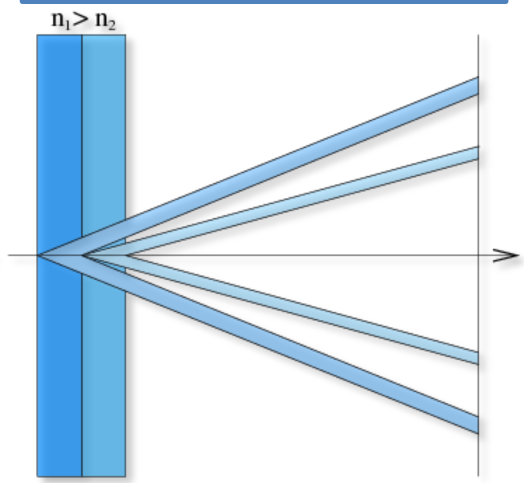


FARICH – Focusing Aerogel RICH

Single ring option



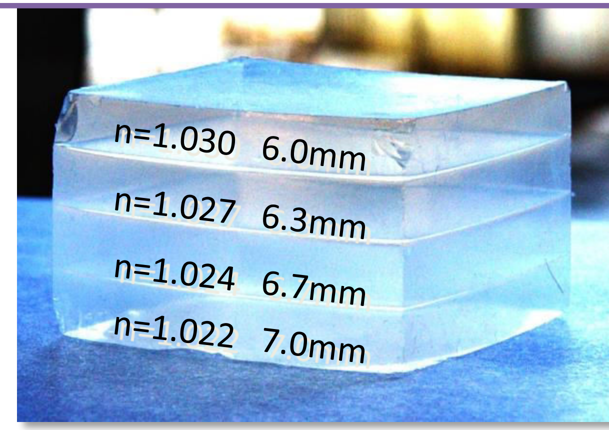
Multi-ring option



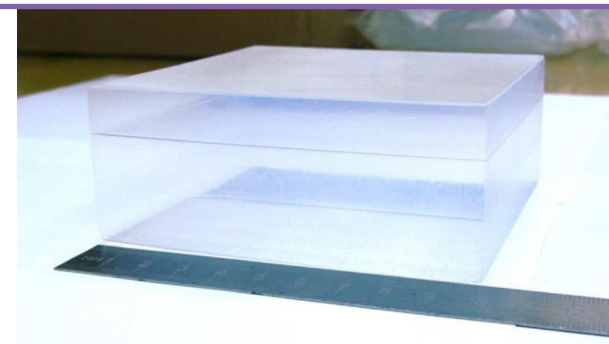
Focusing aerogel improves proximity focusing design by reducing the contribution of radiator thickness into the Cherenkov angle resolution

Multi-layer monolith aerogels are produced by the Boreskov Institute of Catalysis in coop. with BINP since 2004.
In 2012 we succeeded in production of continuous density gradient aerogels.

First sample of 4-layer aerogel by BIC

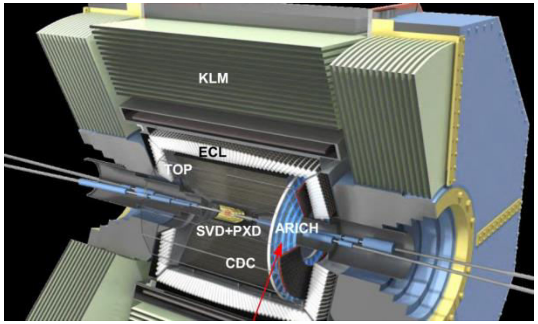


3-layer aerogel 115x115x41 mm^3

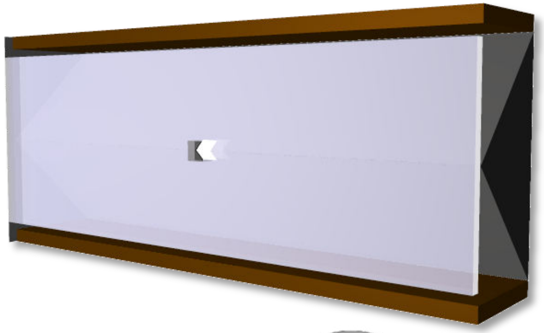


T.Iijima et al., NIM A548 (2005) 383
A.Yu.Barnyakov et al., NIM A553 (2005) 70

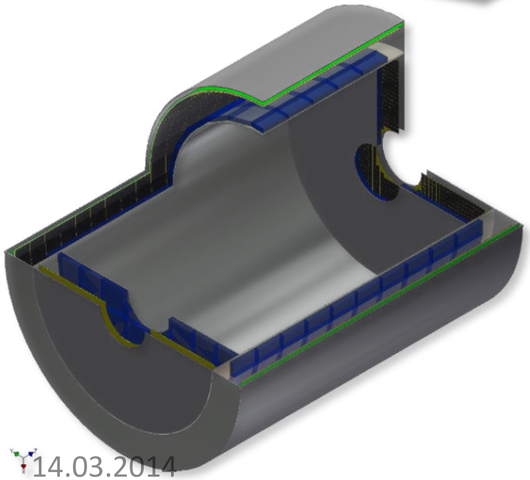
FARICH projects and proposals



Belle II ARICH (Belle coll.)
Particle ID: π/K up to 4 GeV/c
Forward end-cap: ~$3m^2$
Two (separate) layers of aerogel: n_1= 1.045, n_2= 1.055
Photon detector: HAPD (Hamamatsu)



PANDA Forward RICH (BINP&BIC)
Particle ID: π/K/p up to 10 GeV/c
$3m^2$ detector area (MaPMTs or SiPMs)

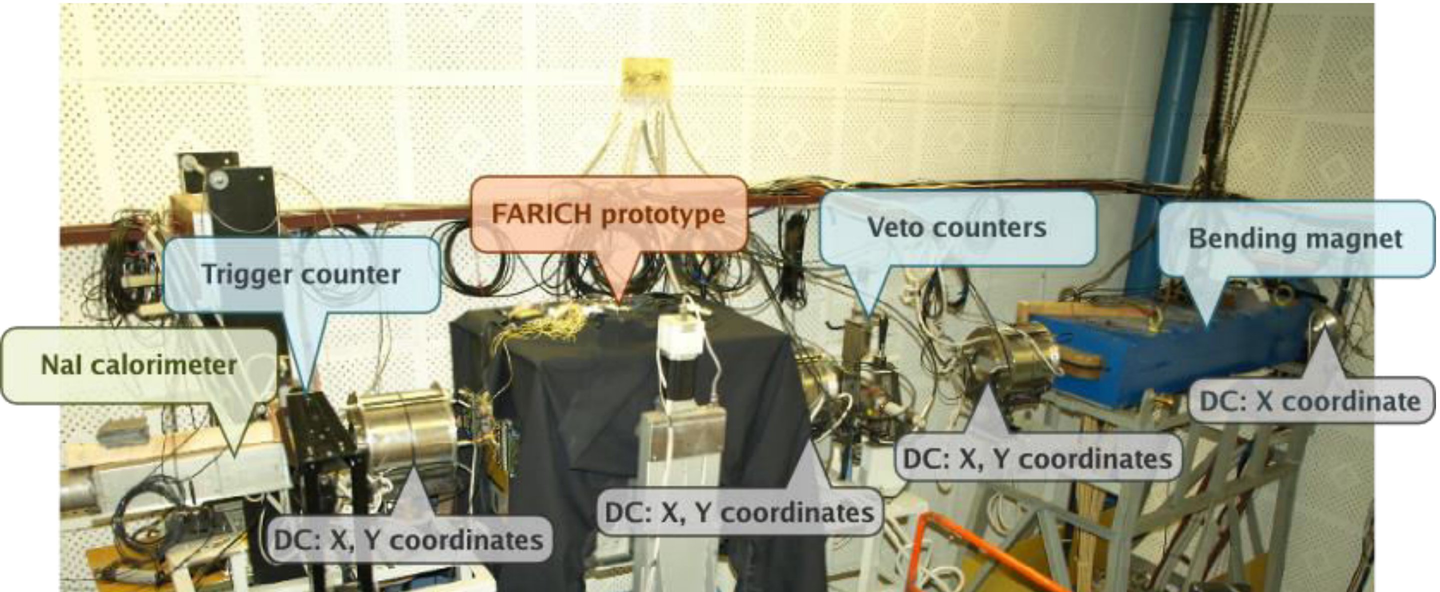


FARICH PID system for Super c-τ factory (BINP&BIC)
Particle ID : μ/π up to 1.7 GeV/c
~$21m^2$ detector area (SiPM)
~10^6 pixels with 4 mm pitch

FARICH R&D at BINP

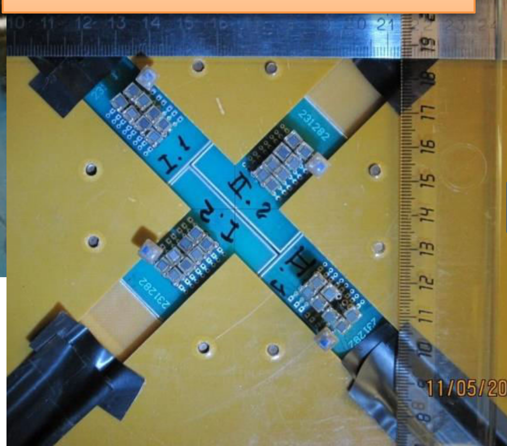
- 2003: Aerogel RICH R&D started.
- 2004: FARICH idea and first publications.
- 2004-2011: Studies with MC simulation for applications in SuperB, ALICE, PANDA, SCTF.
- 2011: First beam test of FARICH prototype at BINP electron beam facility.
- 2012: Cooperation with Philips started on application of digital SiPMs (DPC) in FARICH.
- June 2012: First beam test of FARICH prototype with DPC at CERN. Proof of concept.
- December 2012-Febrary 2013: Beam tests of focusing aerogels with three prototypes including FARICH with DPC.

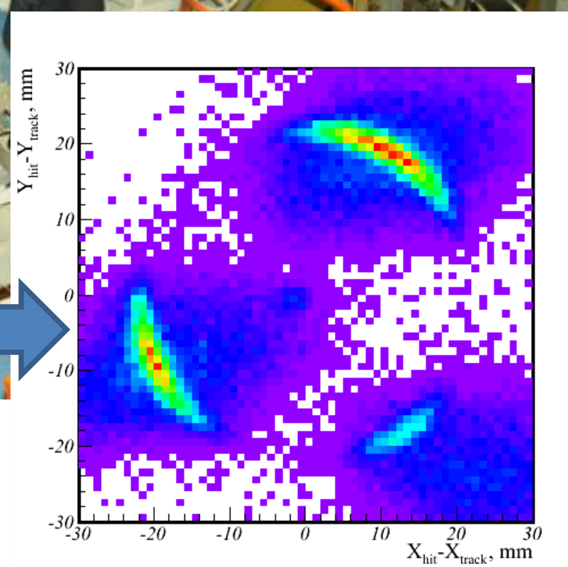
Electron and gamma beam test facility at BINP



e⁻ beam
E_e = 0.06÷3 GeV
σ_E/E = 2% @ 1 GeV
Rate up to 100 s^{-1}

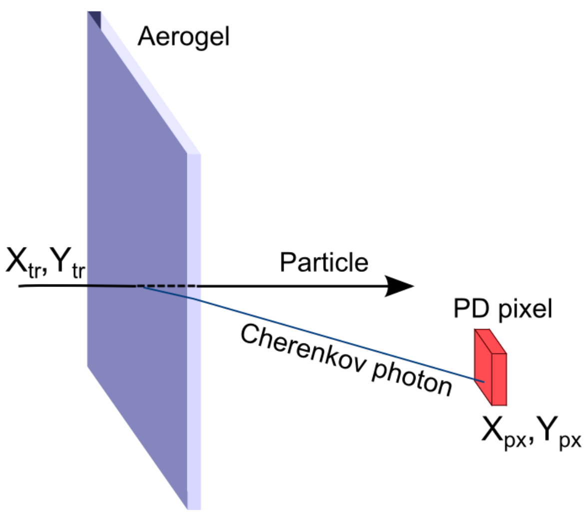
32 CPTA MRS APDs
pixel size 2.1x2.1mm^2

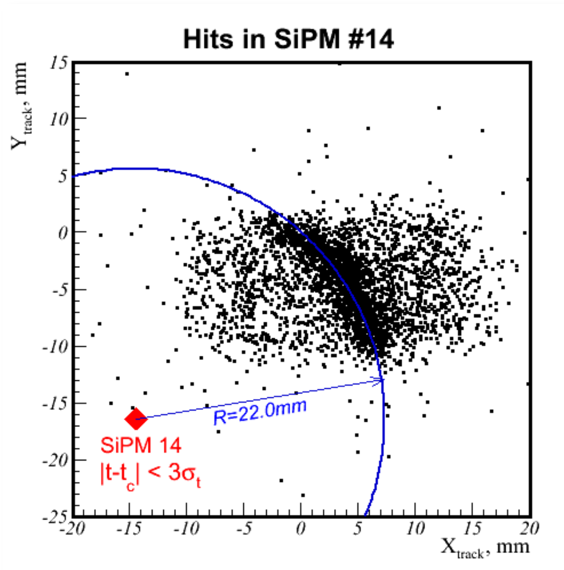


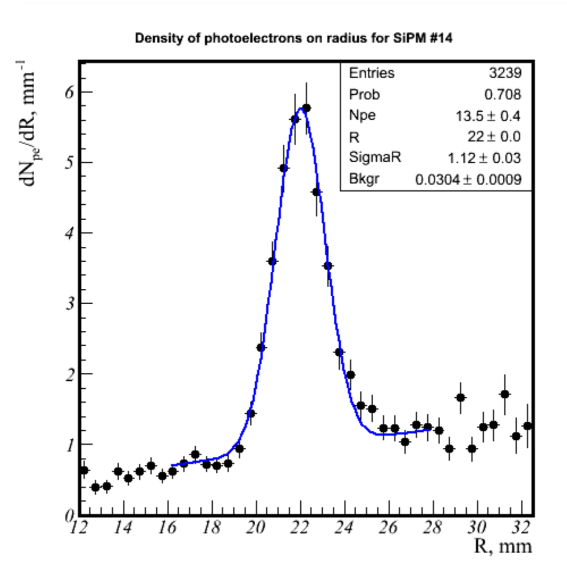


Tagged γ beam
(to be completed)
E_γ = 0.05÷1.5 GeV
σ_E/E = 0.5% @ 1.5 GeV
Rate up to 10^3 s^{-1}

Single pixel approach for aerogel characterization







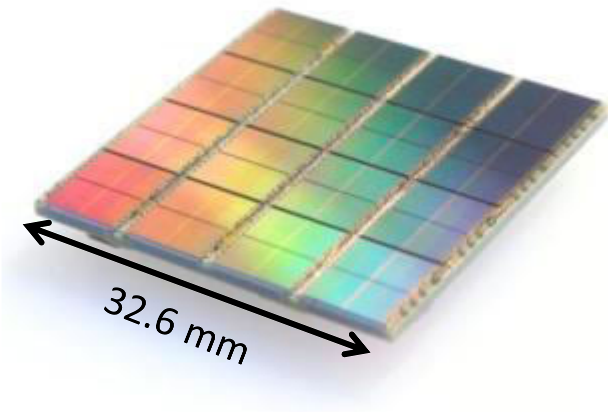
Sum of all pixels w.r.t. track position

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 can be combined to improve accuracy and align the tracking system with the PD pixels

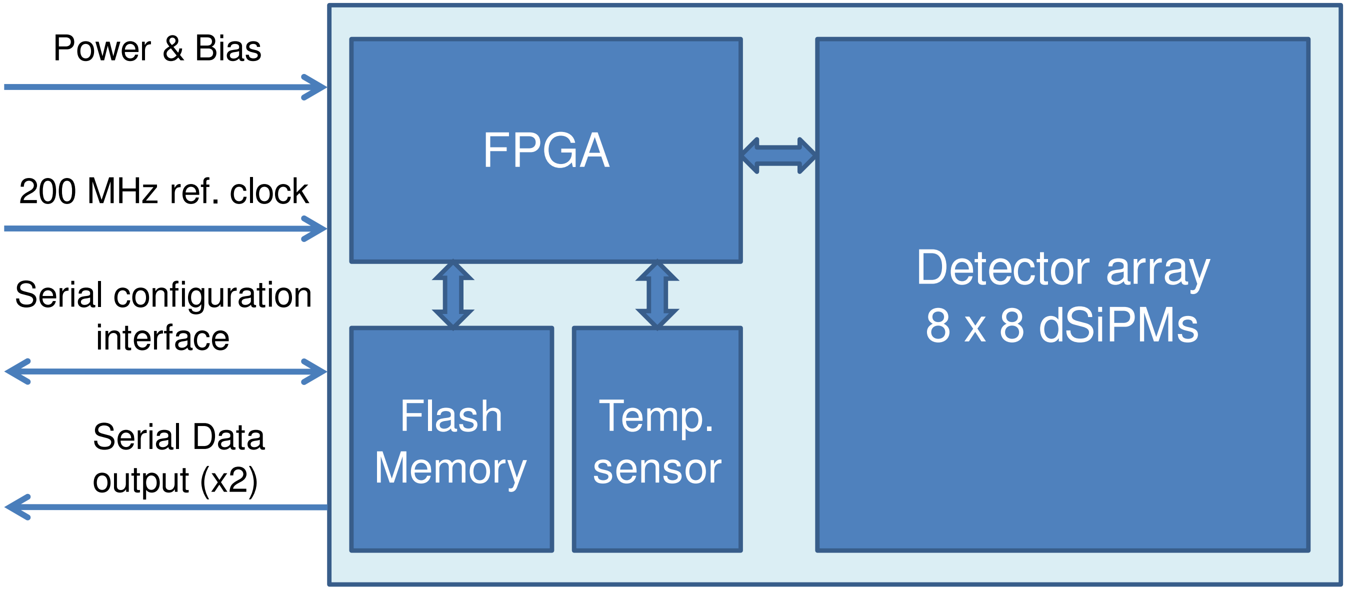
DPC is an Integrated "Intelligent" Sensor by Philips Digital Photon Counting

DPC3200-22-44 – 3200 cells/pixel
DPC6400-22-44 – 6396 cells/pixel



FPGA
- Clock distribution
- Data collection/concentration
- TDC linearization
- Saturation correction
- Skew correction

Flash
- FPGA firmware
- Configuration
- Inhibit memory maps



First test of DPC in RICH:

PDPC-FARICH prototype @ CERN PS T10, June 2012

Main objective:

Proof of concept: full Cherenkov ring detection with a DPC array

Details:

- Operation temperature is −40°C to suppress dark count rate
  - Dead time is 720 ns.
  - DCR(+25°C) ≈ 10 Mcps/sensor single photon detection is not feasible!
  - DCR(-40°C) ≈ 100 kcps/sensor inefficiency is 7% .
- 2 stage cooling: LAUDA process thermostat + Peltiers.
- Dry N_2 constant flow to avoid condensation.

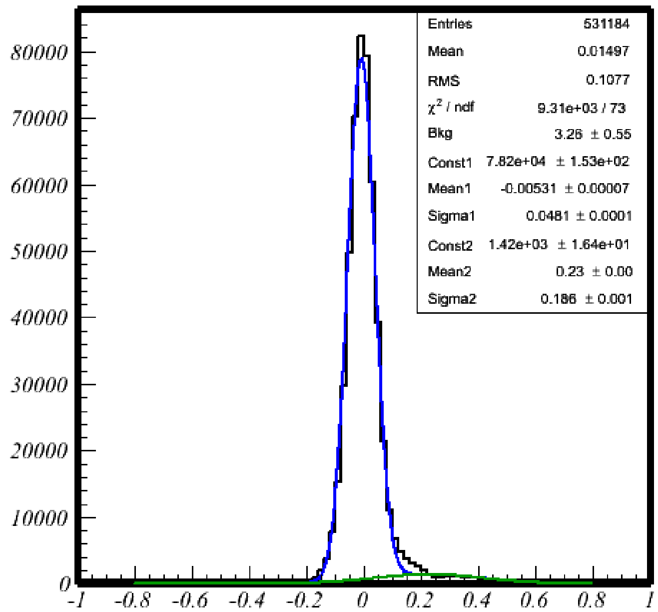
PDPC-FARICH setup

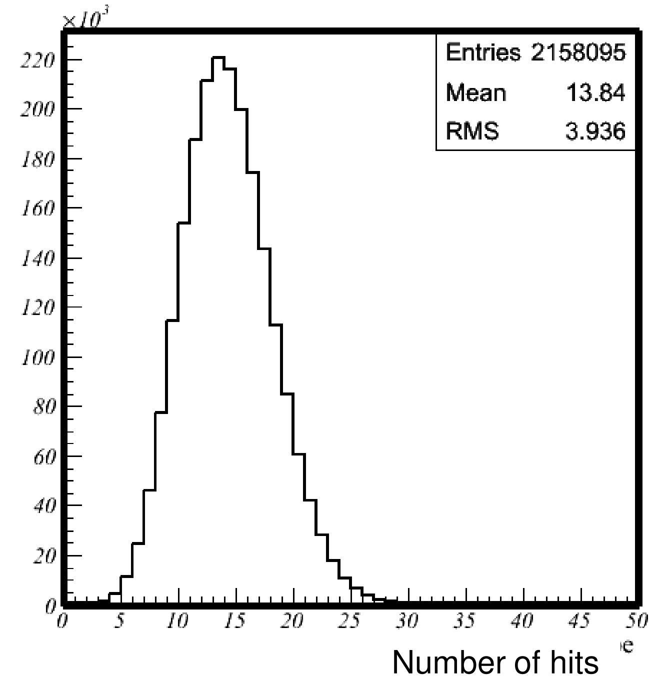
4-layer aerogel
- n_{max} = 1.046
- Thickness 37.5 mm
- Focal distance 200 mm

Test conditions
- Beam content: e^+, μ^+, π^+, K^+, p
- Momentum: 1–6 GeV/c
- Trigger: 2 sc counters 1.5x1.5 cm^2 in coincidence separated by 3 m
- No external tracking, particle ID, precise timing of trigger

Square DPC array 20x20 cm^2
- DPC3200-22 sensors
- 3200 cells per pixel of 3.2x3.9 mm^2
- 3x3 modules = 6x6 tiles
  = 24x24 sensors = 48x48 pixels
- 576 timing channels
- 2304 amplitude channels (pixels)
- 3 levels of FPGA readout: tiles, modules, data collection board.

PDPC-FARICH: timing resolution and number of photoelectrons



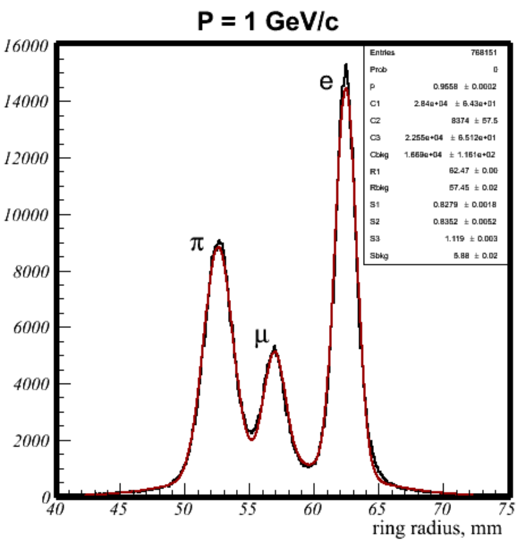


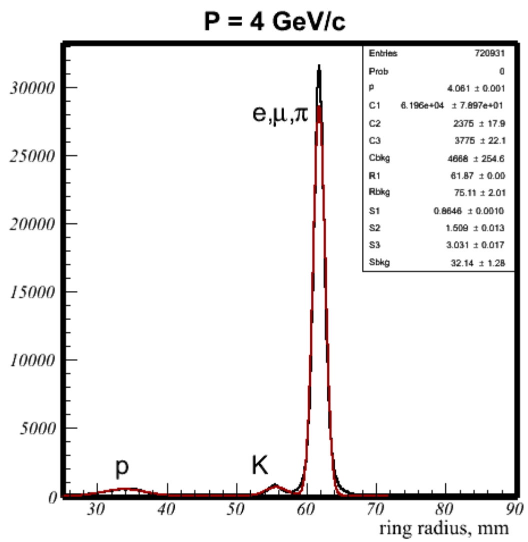
σ_{narrow} = 48ps
for single photons

$\langle N_{p.e.} \rangle$ = 12
(accounted for optical crosstalks)
1.7 times lower than expected

PDPC-FARICH: Particle ID evaluation

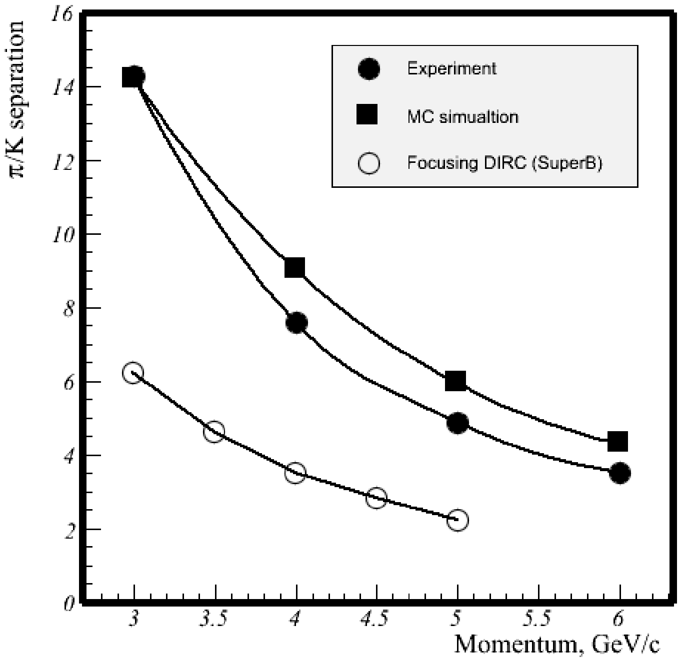
Ring distribution on radius





A.Yu. Barnyakov, et al., NIM A 732 (2013) 352

$$S(\pi/K)=\frac{R_\pi - R_K}{\sigma_\pi}$$

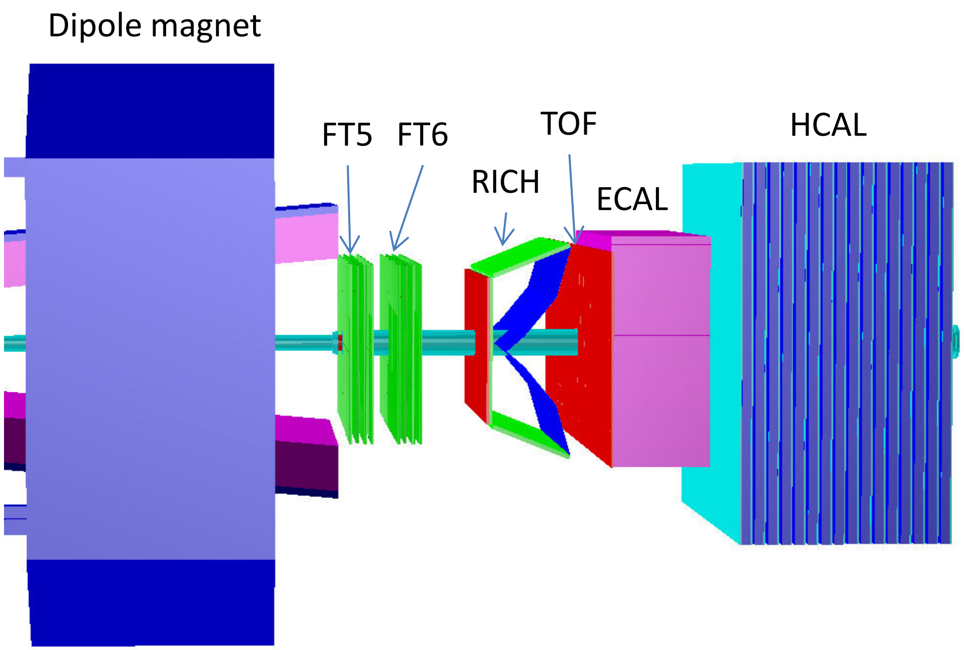


π /K: 7.6σ @ 4 GeV/*c*
μ/π: 5.3σ @ 1 GeV/*c*

2.3 times higher than SuperB FDIRC
1.4 times higher than Belle II ARICH
2.6 times less than in initial MC simulation

Aerogel to be optimized
DPC PDE lower than expected

Forward RICH (simulation)



RICH	
Main goal	➢PID ➢information for higher level triggers
π/K-separation	up to ~10 GeV/c
Radiator	Focusing aerogel
Refractive indices	~1.05
Radiator thickness	4 cm
Placement	Between FT5 and FT6
Vertical angle	±5°
Horizontal angle	±10°

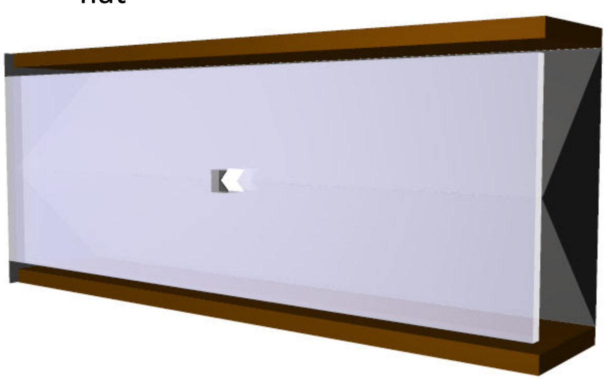
Geometric requirements

1. Placement along beam axis: ***between forward trackers 5 and 6***
2. Angular acceptance: ***dimensions are the same or close to forward trackers dimensions***
3. Aerogel radiator: ***multi-layer***

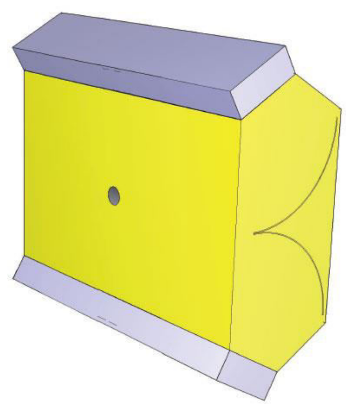
4. Mirror: ***simple shape (flat, round, spheric)***
5. Geometric efficiency: ***all Cherenkov photons should be detected if it possible***
6. Photon detector: ***less sizes as it possible (due to cost optimization)***
7. Shape of Cherenkov “ring” on the photodetector surface: ***simple (circle, ellipse)***

8. …

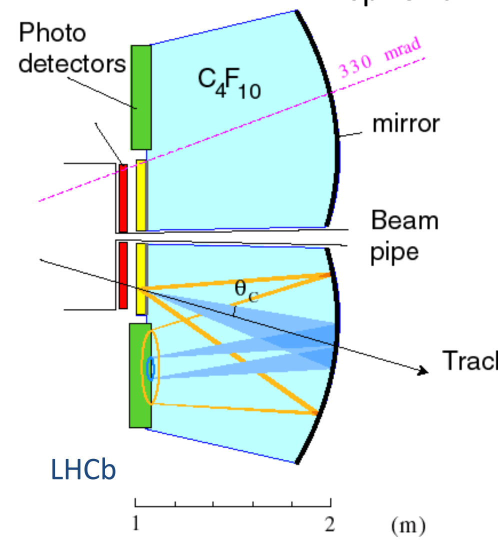
flat



round

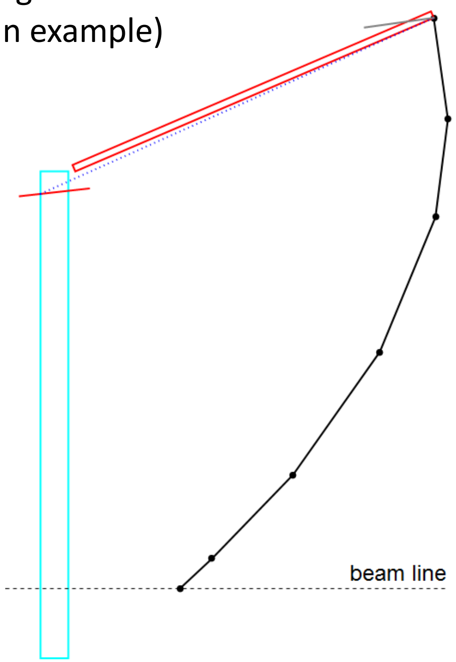


spheric



Mirror parameters optimization

Six segments flat mirror
(as an example)



<u>Geometric efficiency:</u>

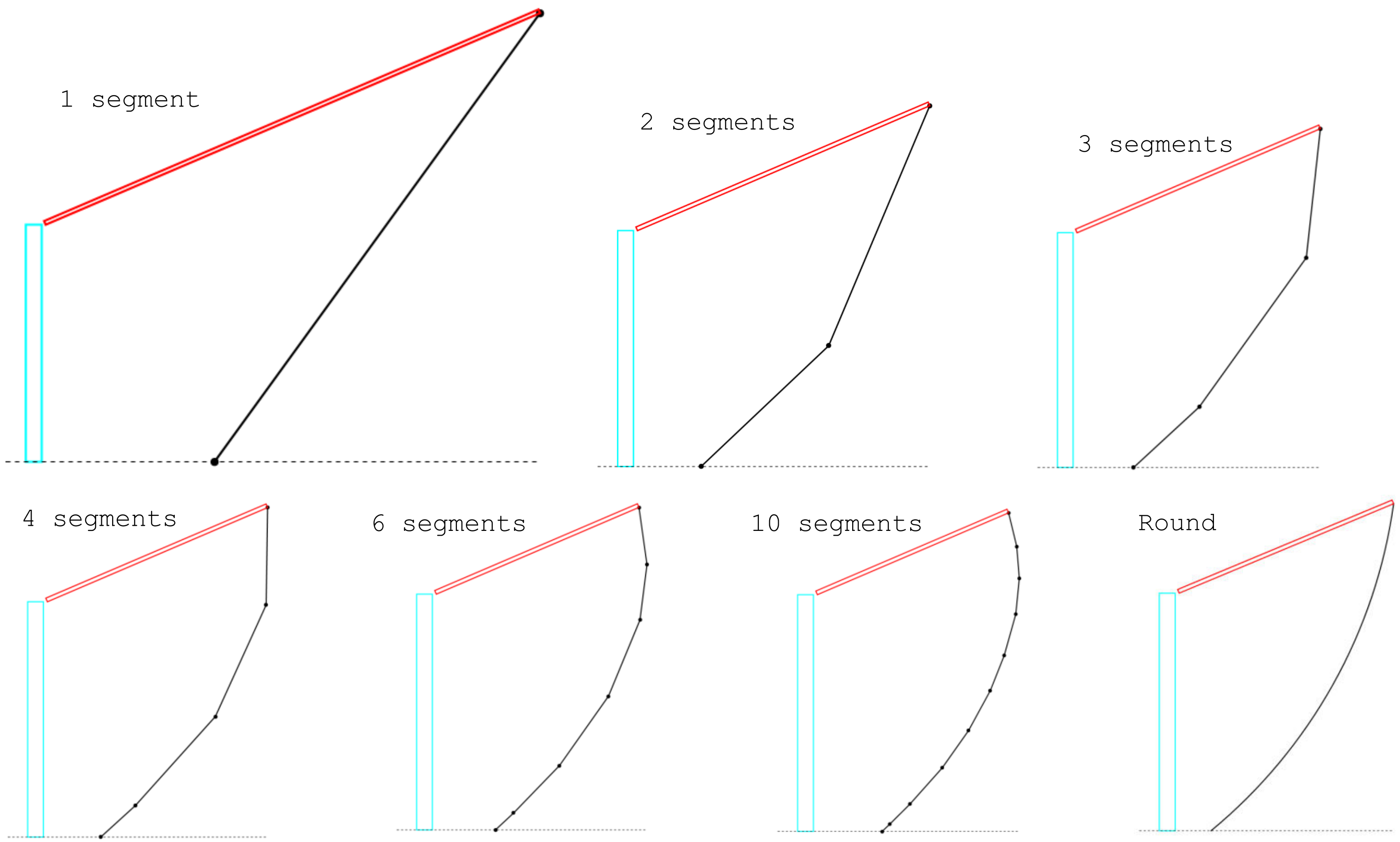
1. Lower Č photon hits PhDet
2. Upper Č photon hits PhDet
3. All other Č photons automatically do the same

<u>Photo detector width:</u>

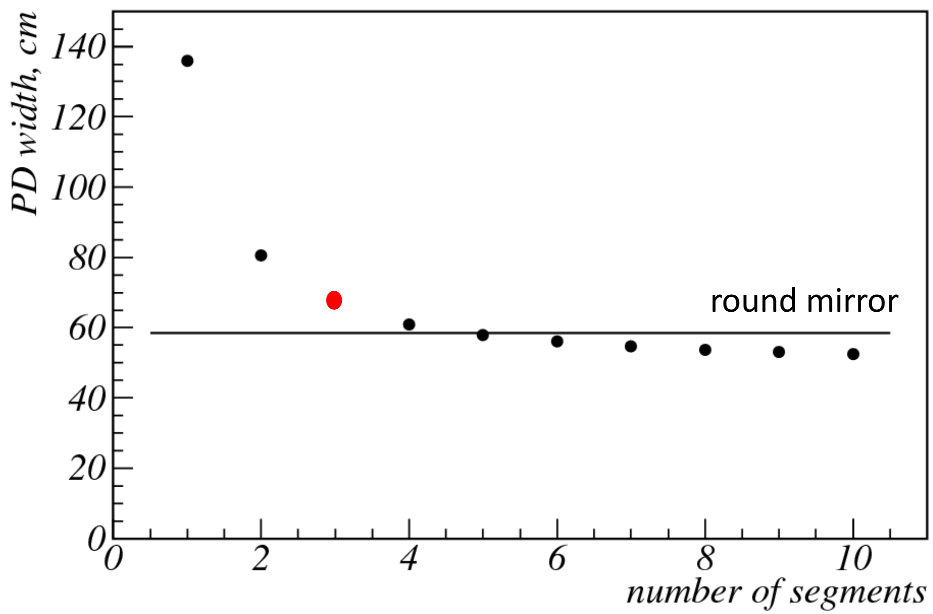
$$w(z, l_1, l_2, l_3, \ldots) \rightarrow w_{min}$$

First segment has major influence on PhDet size!

Optimal mirror configurations



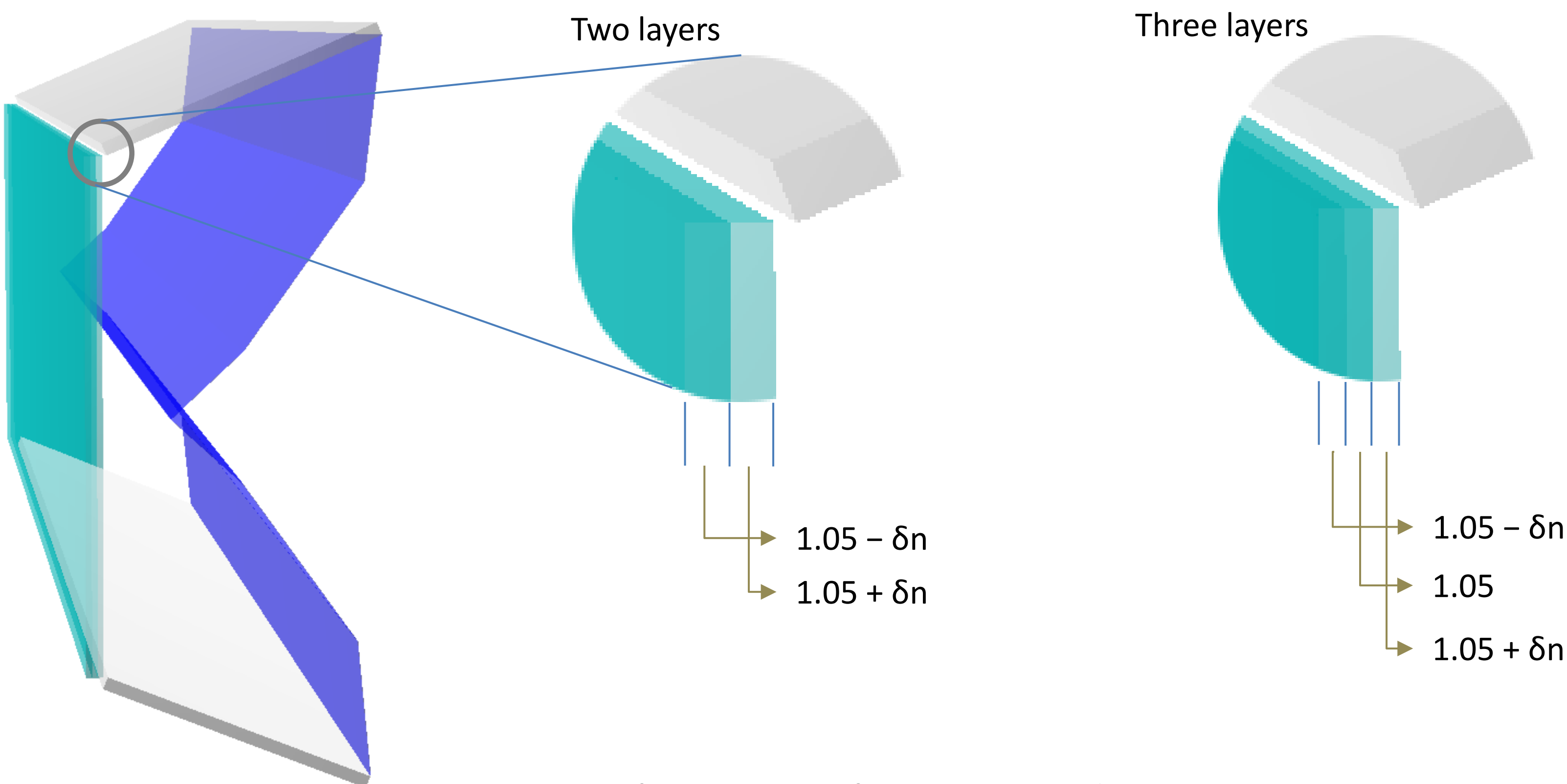
Some features of flat and round mirrors



feature	3 segments	Round
PD width, cm	67.5	58.5
Mirror focusing	no	yes
Aerogel focusing	yes	no
combinatorial background	yes	no
Cherenkov "ring" shape on PD surface	elliptical	complicated
Number of parts	3	1

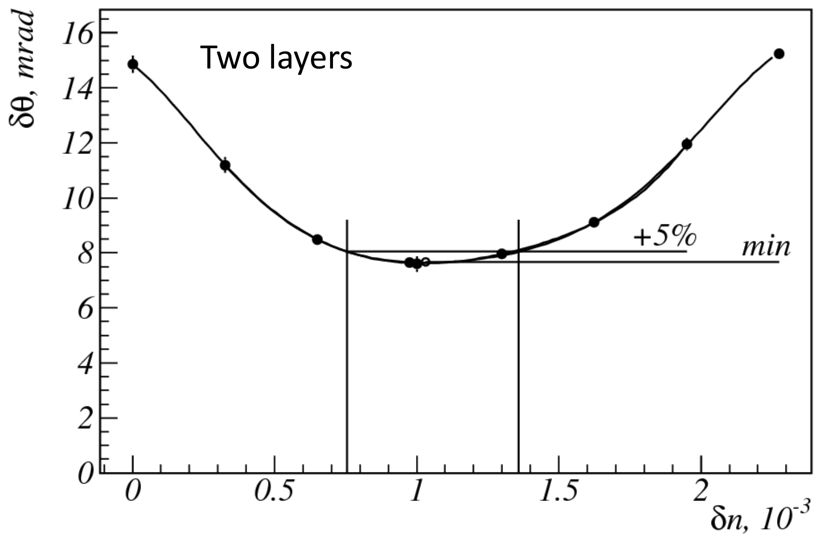
Aerogel plate size = 60 cm (half height)

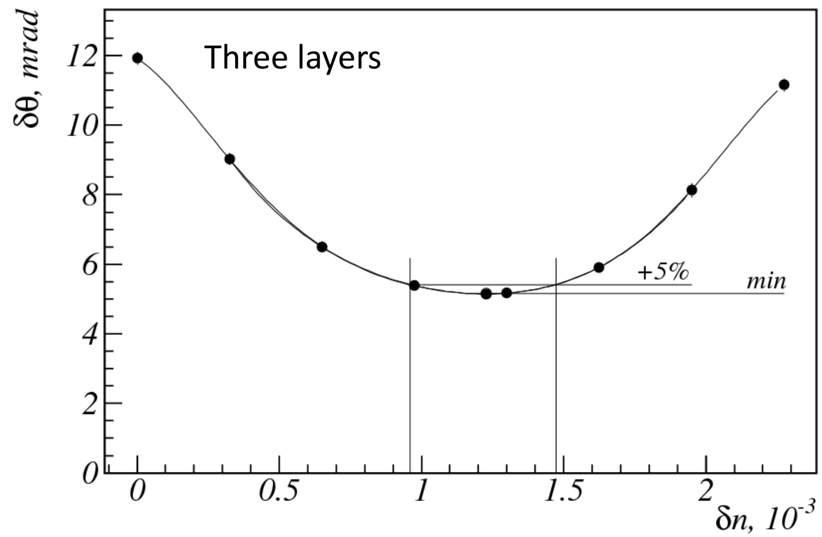
Multi-layer aerogel: parameter optimization



Software: **FairSoft** – *apr13*, **PandaRoot** – *scrut14*

Multi-layer aerogel: optimal parameter



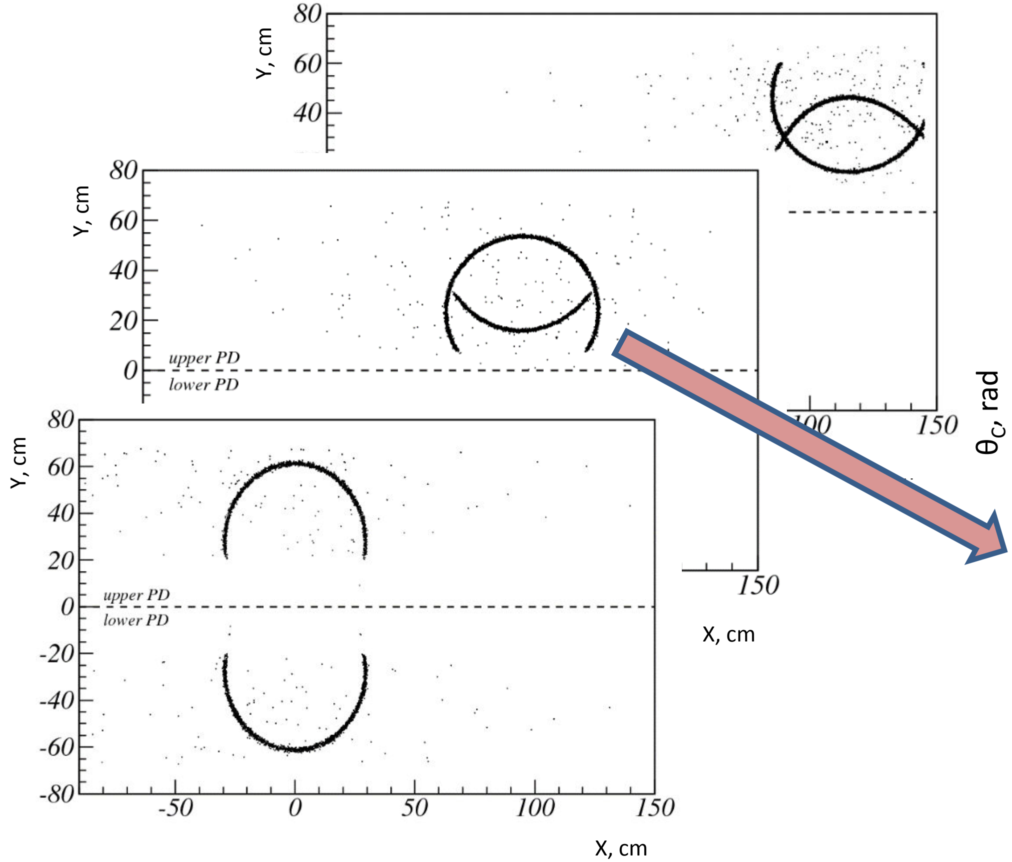


$n = 1.05$
$\delta n_{opt} = 1.03 \cdot 10^{-3}$
$\delta n_{min} = 0.76 \cdot 10^{-3}$
$\delta n_{max} = 1.36 \cdot 10^{-3}$

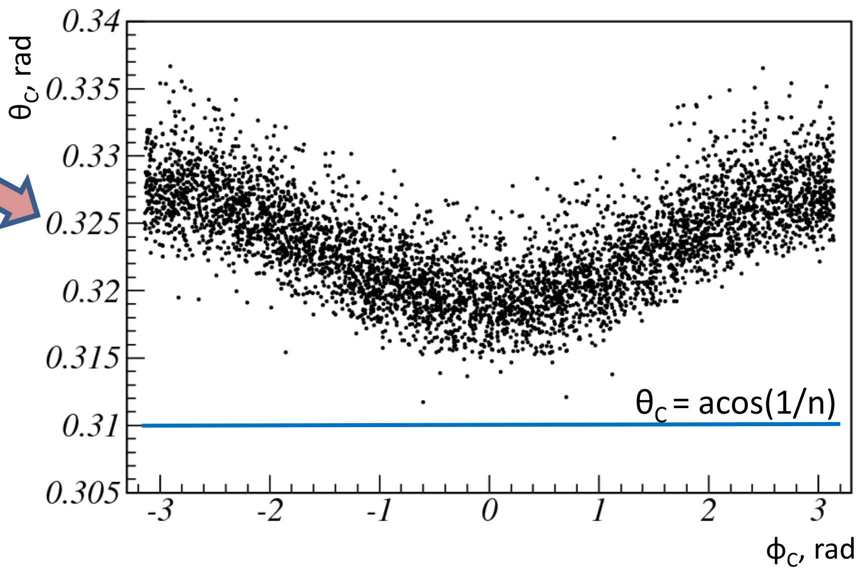
$n = 1.05$
$\delta n_{opt} = 1.23 \cdot 10^{-3}$
$\delta n_{min} = 0.96 \cdot 10^{-3}$
$\delta n_{max} = 1.47 \cdot 10^{-3}$

Three segments mirror and three layer aerogel were used in further simulations

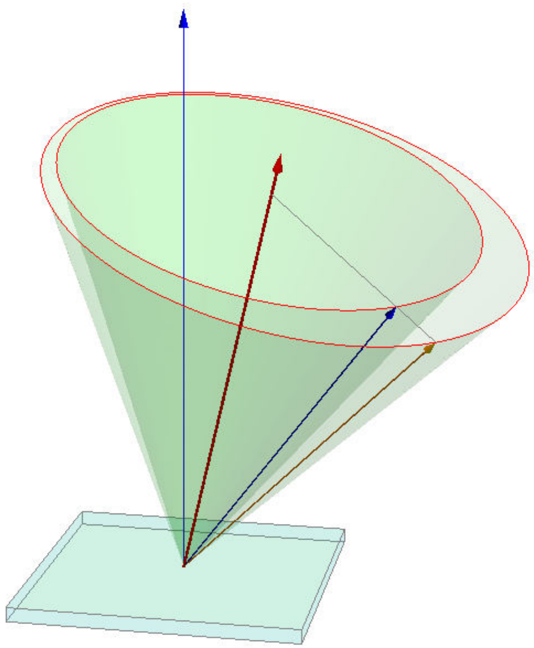
Events simulation and reconstruction

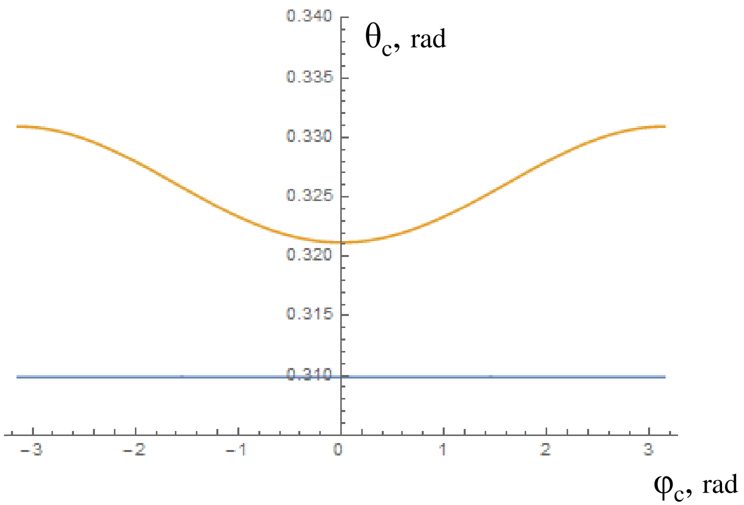


Reconstruction methods:
- on photodetector surface (template)
- photon track reconstruction (in order to obtain cherenkov angles for each hits)



Refraction on the surface of the aerogel

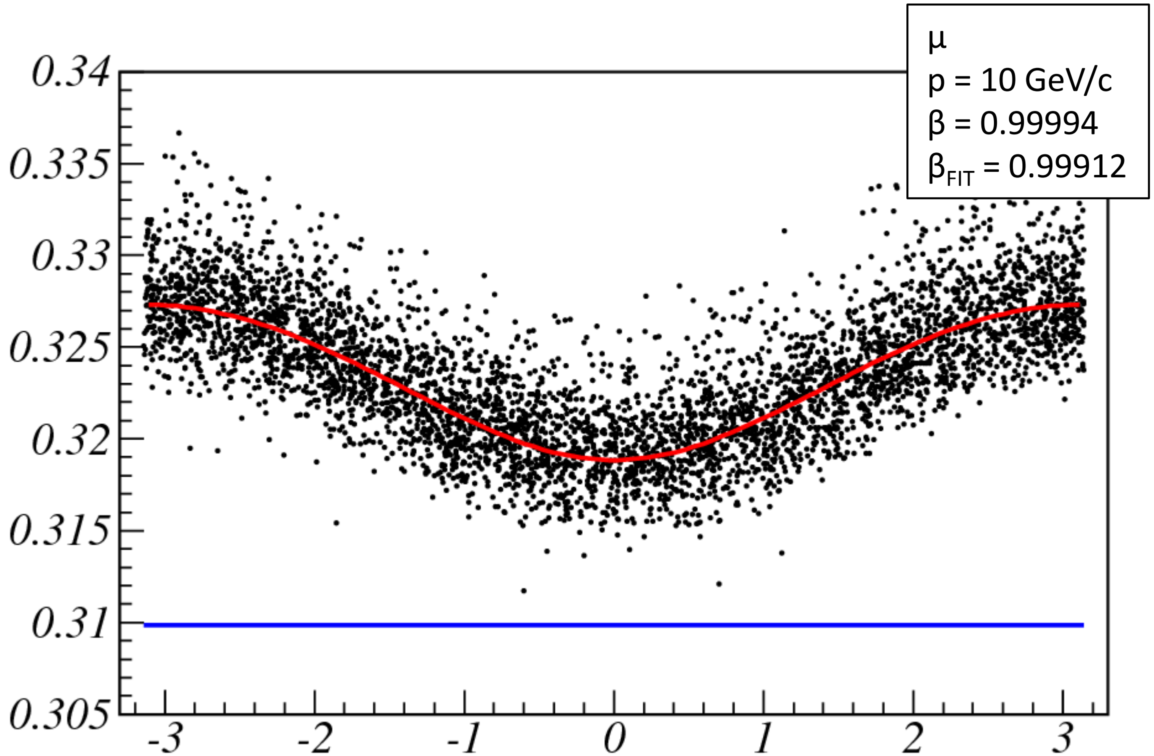




$\theta_c = f(\varphi_c; \beta, n, \alpha)$

- φ_c – azimuthal angle
- β – velocity of the charge particle
- n – refraction index of the aerogel
- α – polar angle of the charge particle

Fit result

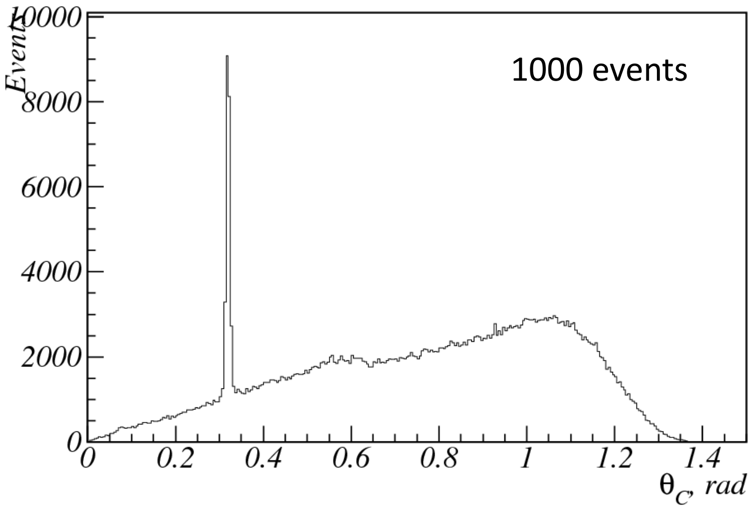


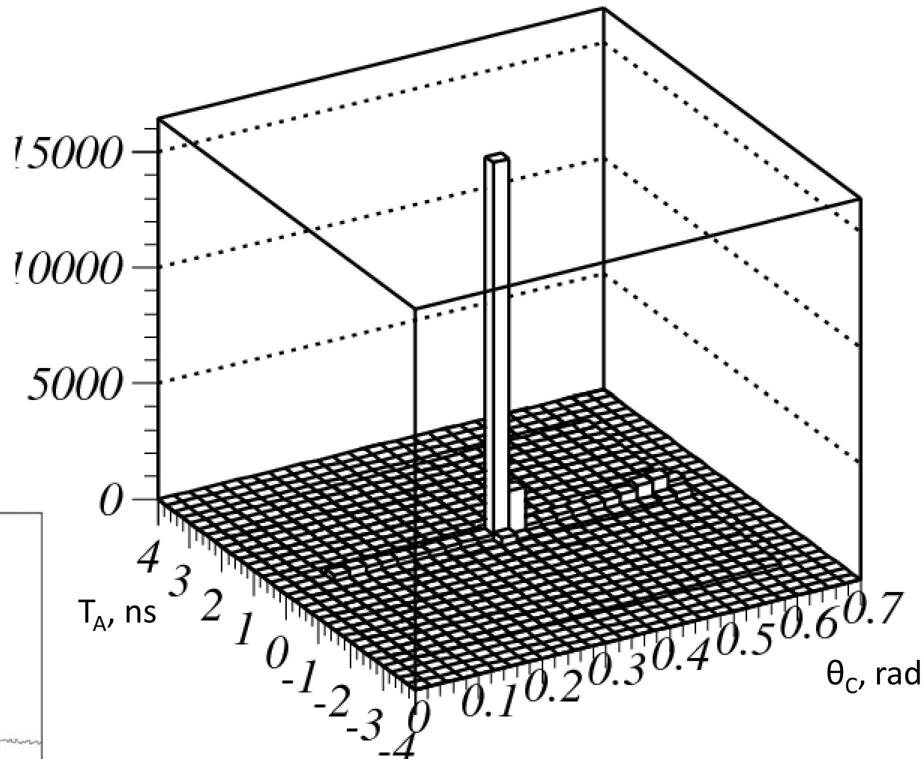
μ
p = 10 GeV/c
β = 0.99994
β_{FIT} = 0.99912
0.34
0.335
0.33
0.325
0.32
0.315
0.31
0.305
-3
-2
-1
0
1
2
3

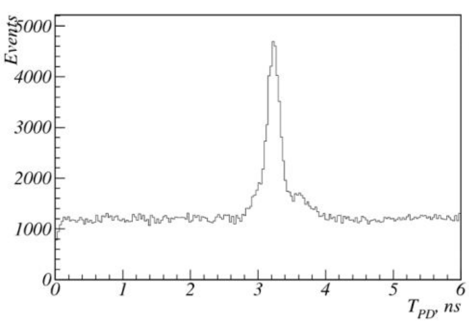
Simulated effects

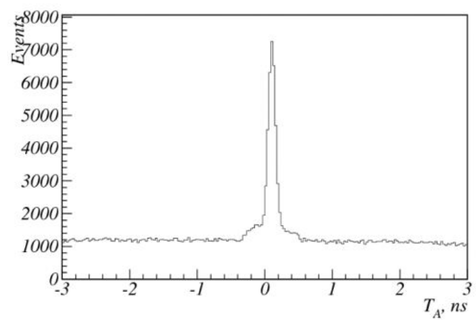
1. Simulation
   - ✓ Geometry description
     - RICH position
     - Aerogel (size, number of layers, refraction index)
     - Mirror geometry (round, flat)
   - ✓ Materials properties for Cherenkov photons
2. Digitization
   - ✓ Pixelation
   - ✓ Quantum efficiency of photodetector
   - ✓ Photodetector noise
   - ✓ Dead time of photodetector
   - ✓ Photodetector time resolution
   - ✓ Crosstalks (not done)
3. Reconstruction (simple mode)
   - ✓ Hit preselection
   - ✓ Fit $\theta(\phi)$ dependence
4. PID (not done)
   - ✓ Probability calculation

Hit selection for fit

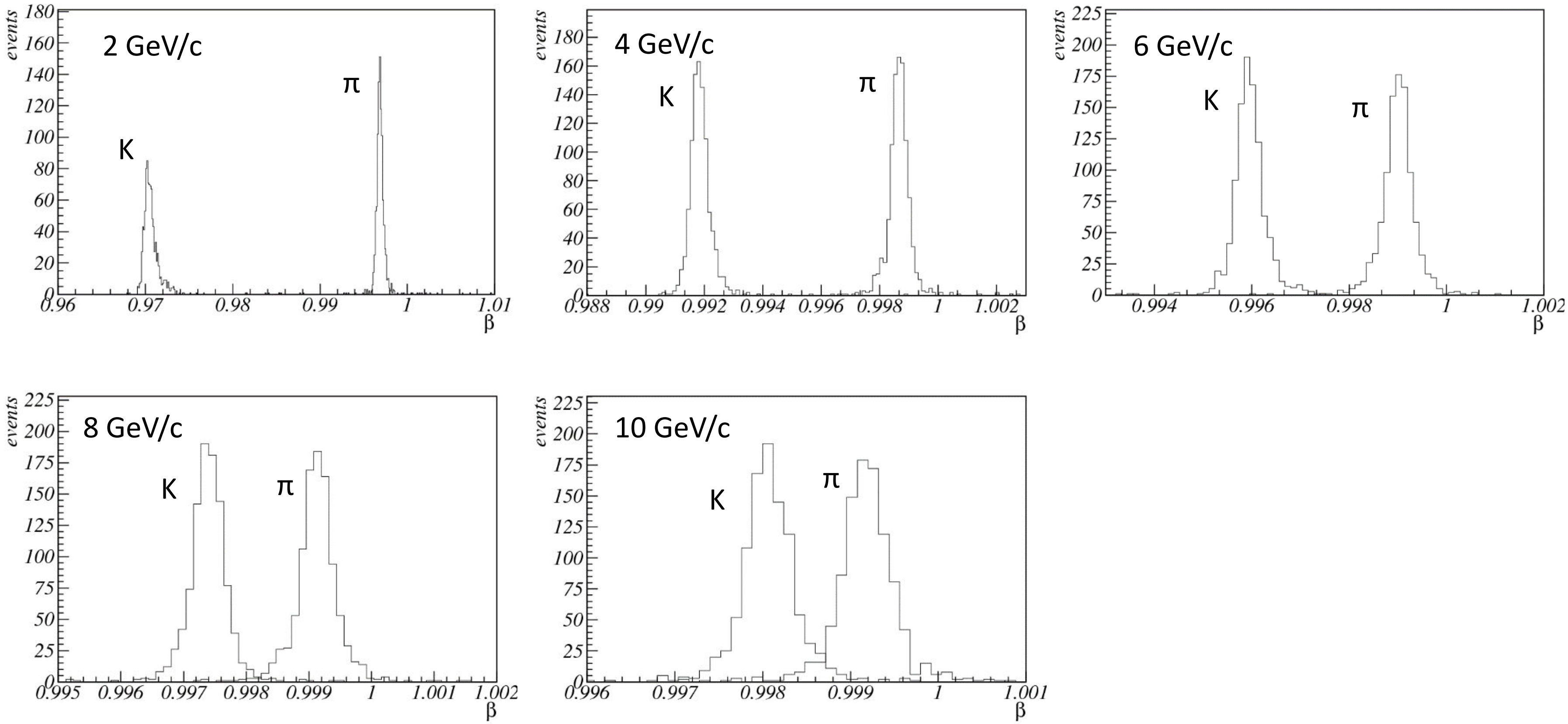








π/K-separation: first result



Conclusion

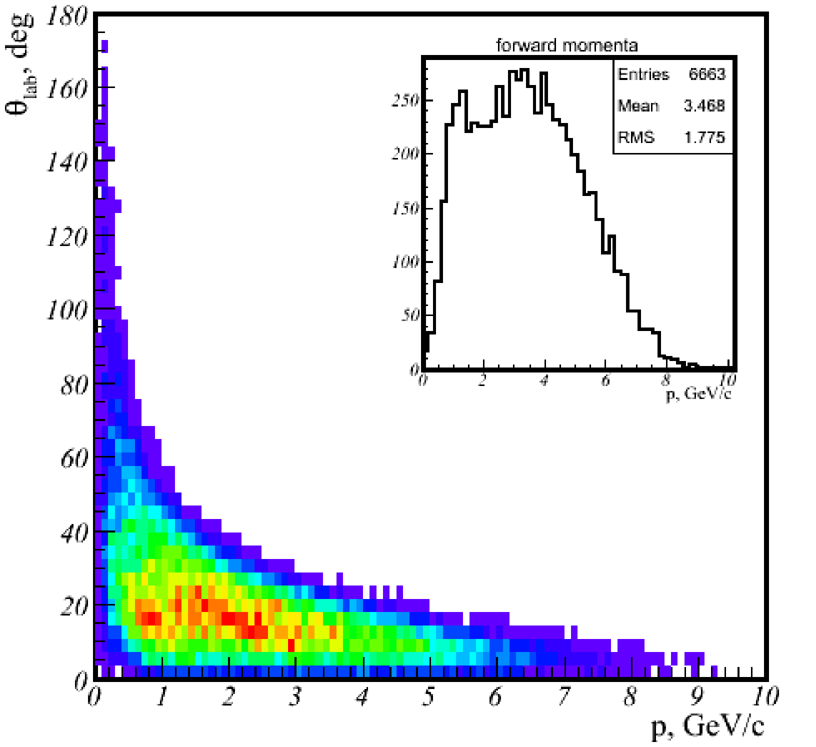
- Conceptual design of the Forward RICH is fixed (focusing aerogel, flat mirrors, photodetector)
- Concept of FARICH was proofed in test with beams in CERN
- First steps is PANDARoot simulation was done:
  - Geometry optimization with flat mirrors
  - Optimal aerogel parameters (refraction indexes)
  - Reconstruction of simple events
  - π/K separation is shown

Thank you for your attention!

Use cases of PANDA Forward RICH 2010

- Covered solid angle: |θx| < 10°, |θy| < 5°
- Identification of high momentum (>3GeV/c) kaons in presence of a large pionic background
- Separation of other charged particles: μ/π, e/π, K/p

Distribution of pions and kaons



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

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

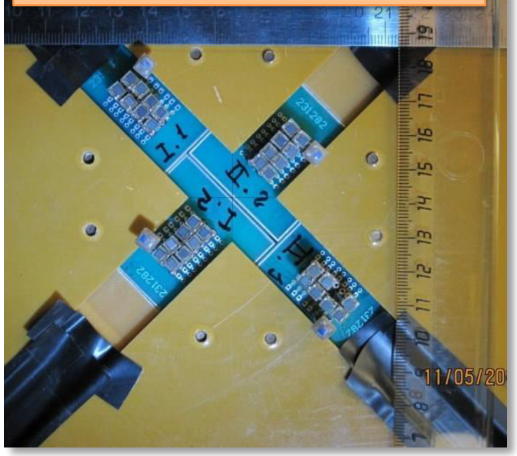
Fast MC simulation shows:

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

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.

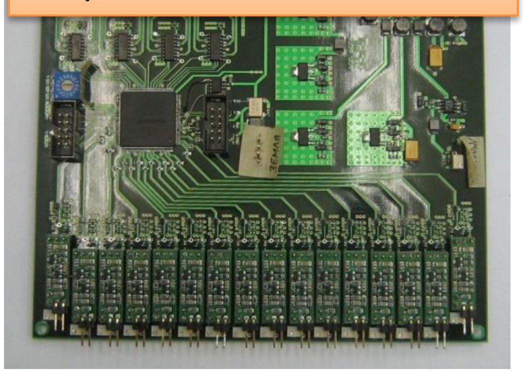
SiPM detectors and electronics

32 CPTA MRS APDs
pixel size 2.1x2.1mm^2



+

Custom 16ch
amplifier-disc. boards

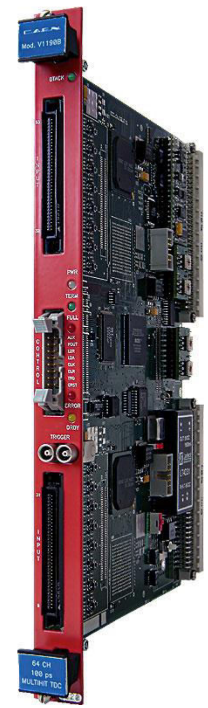


60 CPTA MRS APDs
pixel diam. 1.28 mm

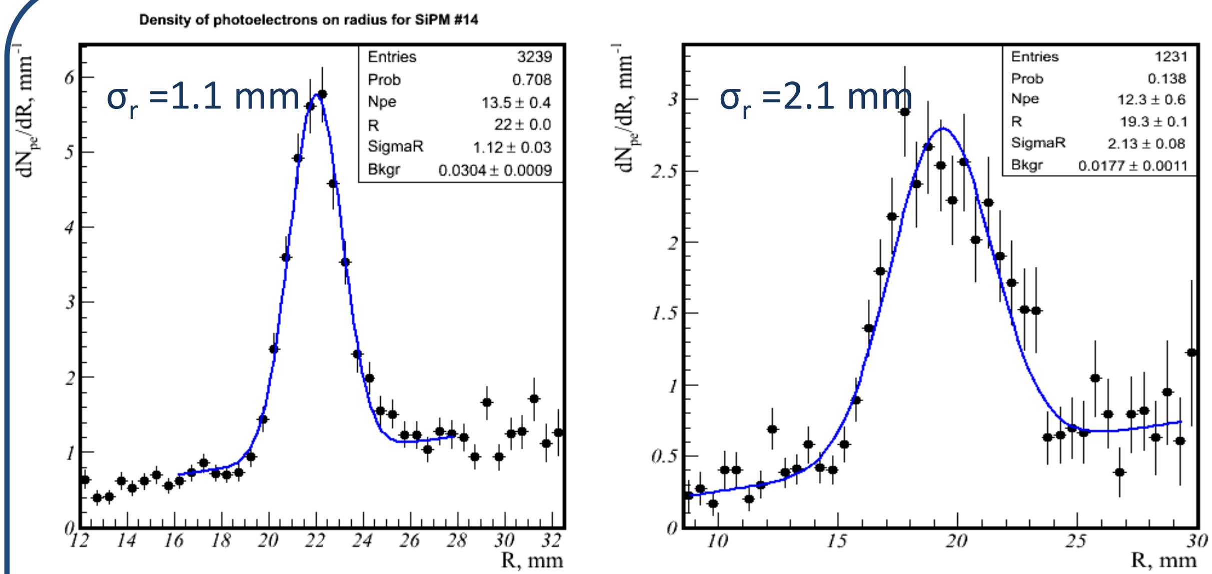
+

ALICE TOF
NINO-based board

CAEN V1190B
multihit TDC board



Beam test 2011 results



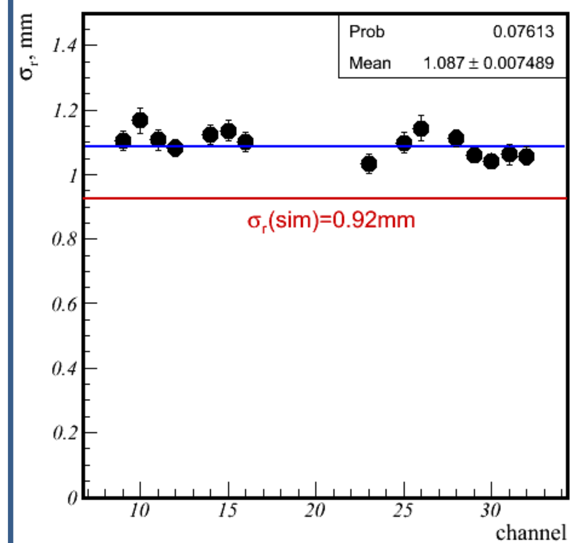
4-layer aerogel (t=3cm) vs single layer aerogel (t=2cm)

Focusing effect has been observed.

σ_r=1.1 mm – in rough agreement with MC simulation

$\langle N_{p.e.} \rangle$ = 13 – 2 times less than expected

σ_r vs channel



$N_{p.e.}$ vs channel