Tests of FARICH prototype with fine photon position detection

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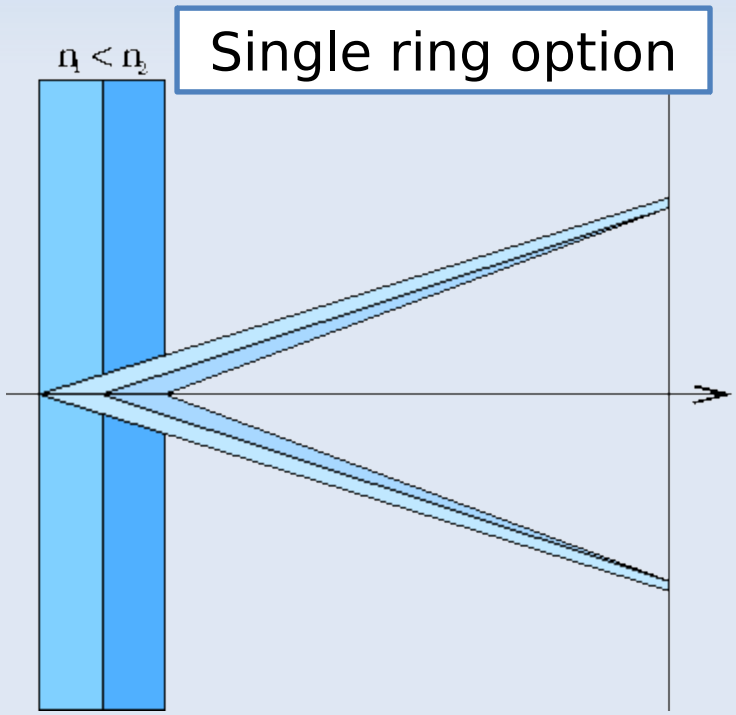
Outline

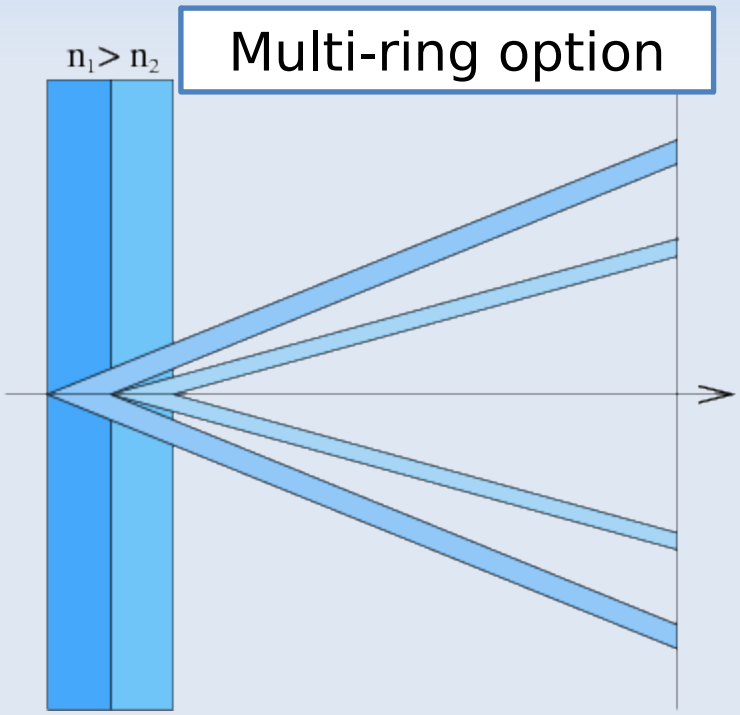
- Project of FARICH PID system for detector at Super Charm-Tau Factory
- Beam test experiment with FARICH ptototype #1 at VEPP-4M in Novosibirsk
- Beam test experiment with PDPC FARICH prototype at CERN
- Focusing aerogel radiator development and FARICH with fine photon position measurement
- Dreams :-)
- Conclusions

Focusing Aerogel RICH

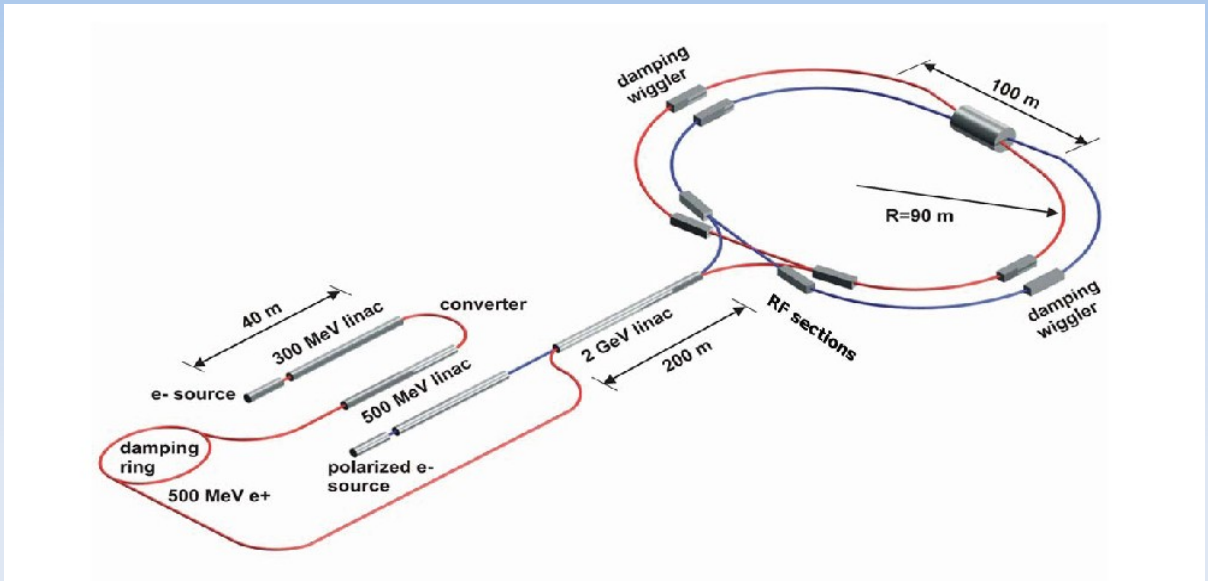
Focusing Aerogel RICH – FARICH

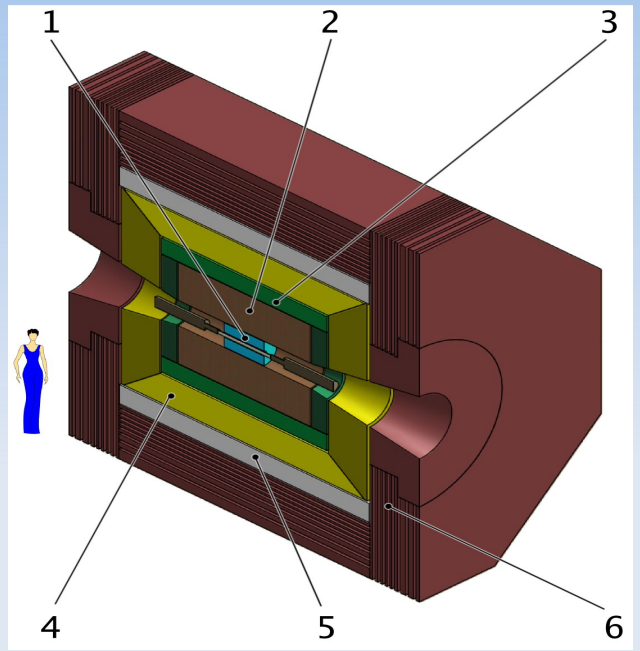
Improves proximity focusing design by reducing radiator thickness contribution into the Cherenkov angle resolution





Super Charm-Tau Factory project





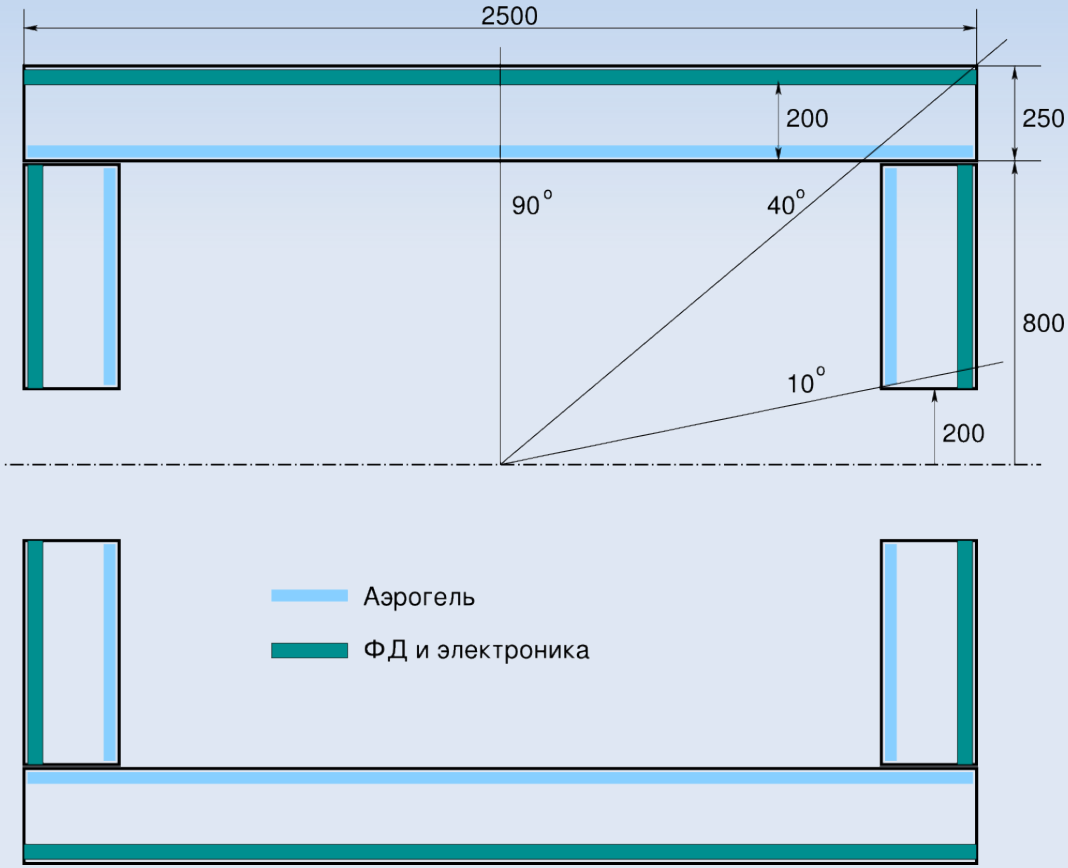
- e^+e^- collider, Ecm=2–5 GeV
- Luminosity = 10^{35} $cm^{-2}s^{-1}$

Status of the project:

- SCTF is one of four Mega Science projects currently discussed in the Ministry of Education and Science
- The documentation for civil construction of the main ring and buildings is ready.

- 1 – Vertex Detector
- 2 – Drift Chamber
- 3 – PID => FARICH
- 4 – EMC
- 5 – Superconducting Solenoid
- 6 – IFR

FARICH for Super Charm-Tau Factory



Physics motivation

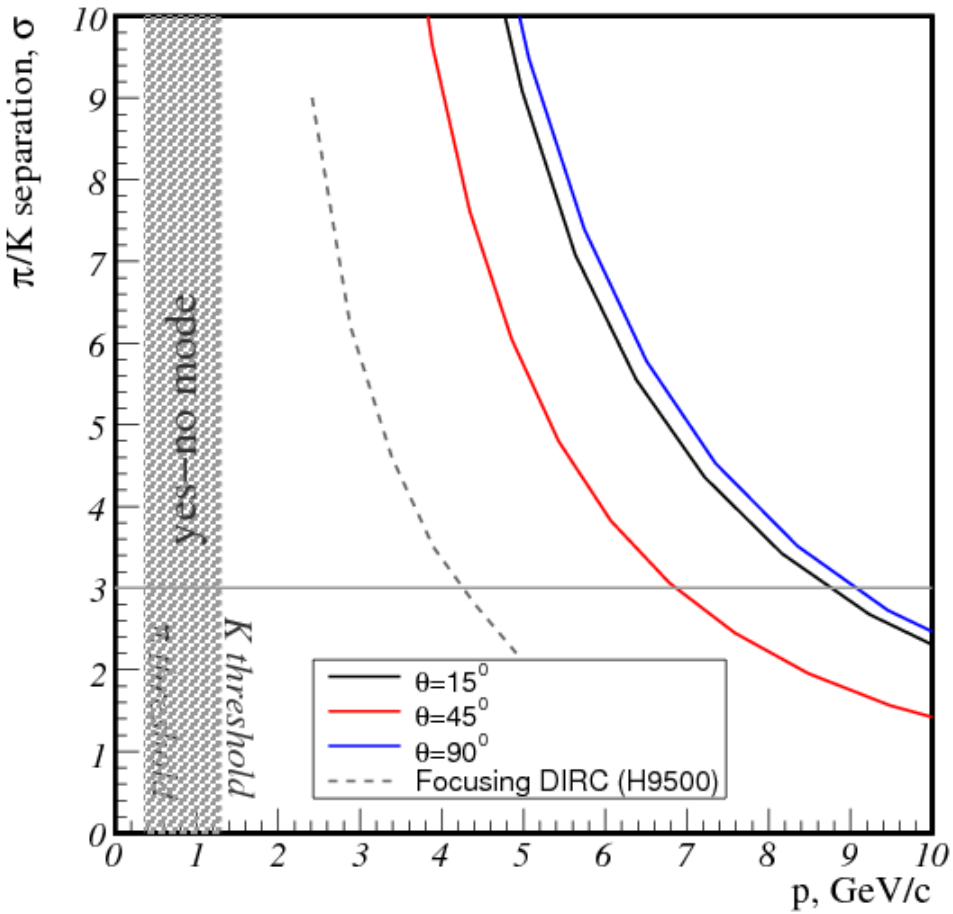
Search of LFV decay $\tau \to \mu\gamma$ requires good μ/π separation from 0.5 to 1.5 GeV/c momentum

Main FARICH parameters

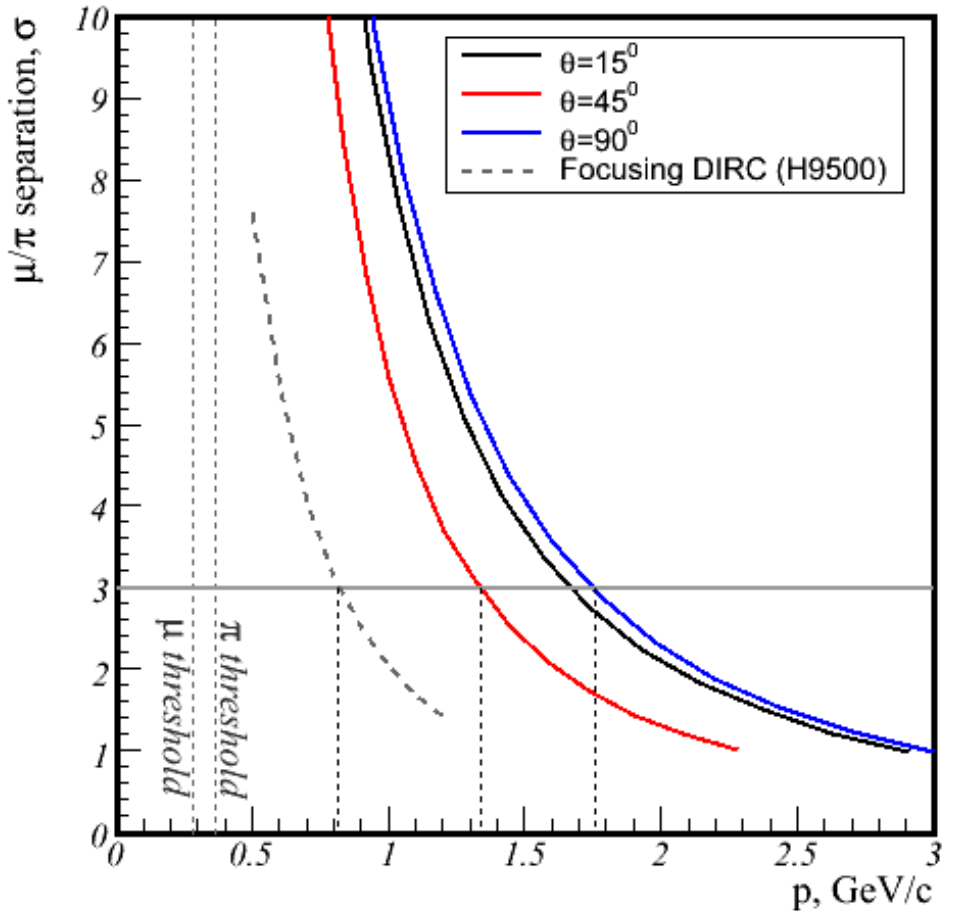
- Focusing aerogel radiator, n_{max}=1.07, 4 layers
- Photon detector: PDPC or MPPC, ~3x3mm^2, pitch 4 mm
- Area of the photon detector: 20 m^2
- Area of the radiator: 14 m^2
- ~10^6 channels

FARICH design parameters (MC simulation)

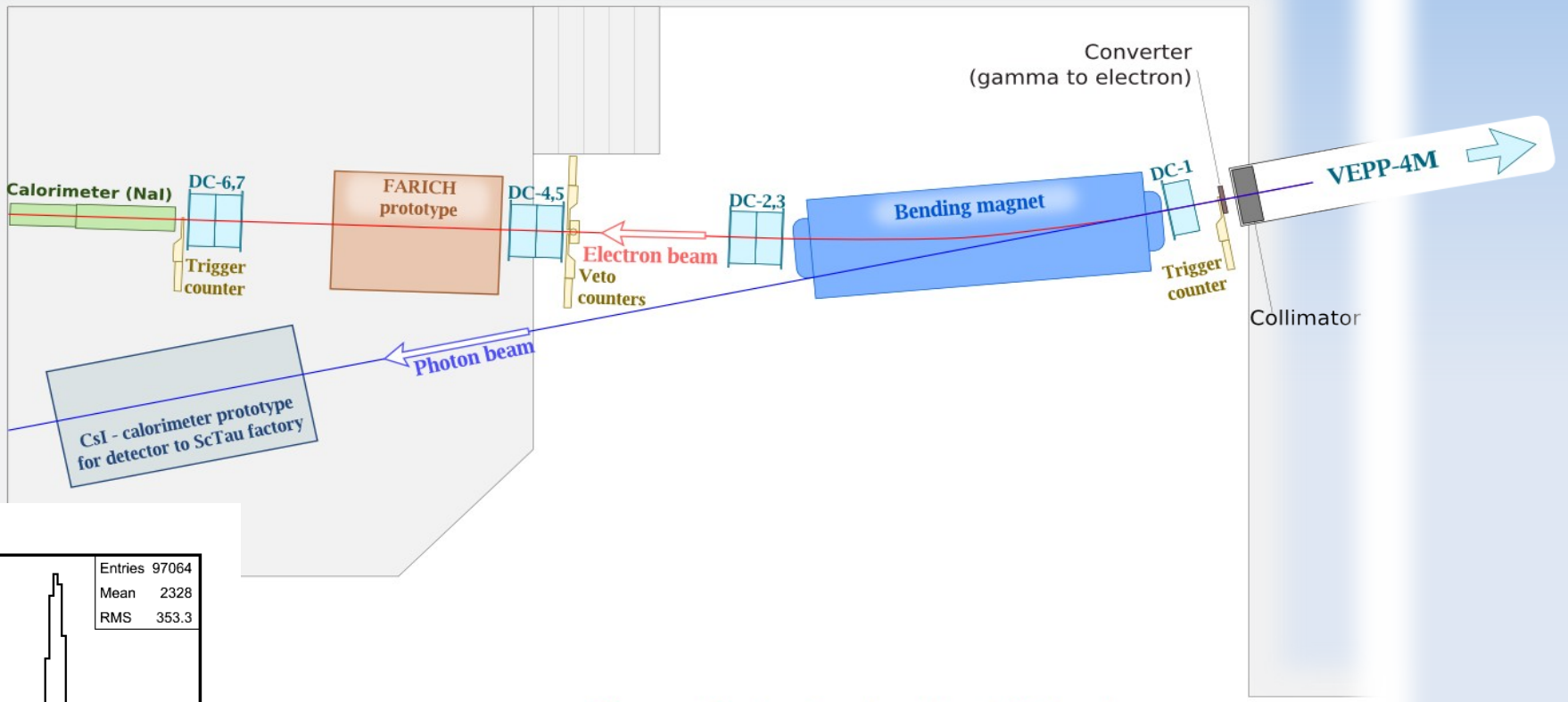
π/K-separation

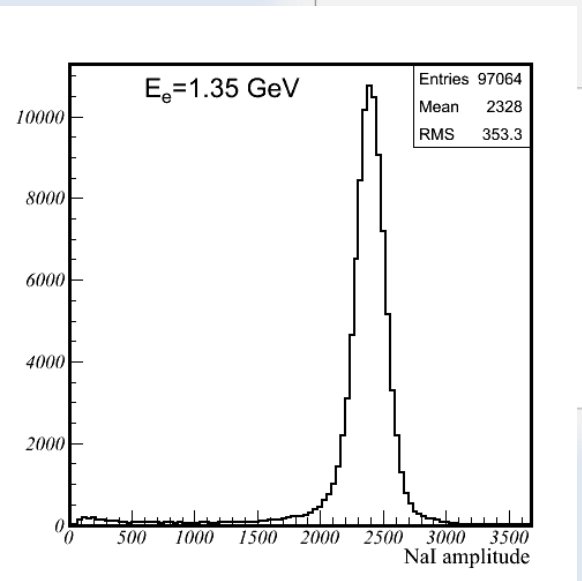


μ/π-separation



Test beam line at VEPP-4M

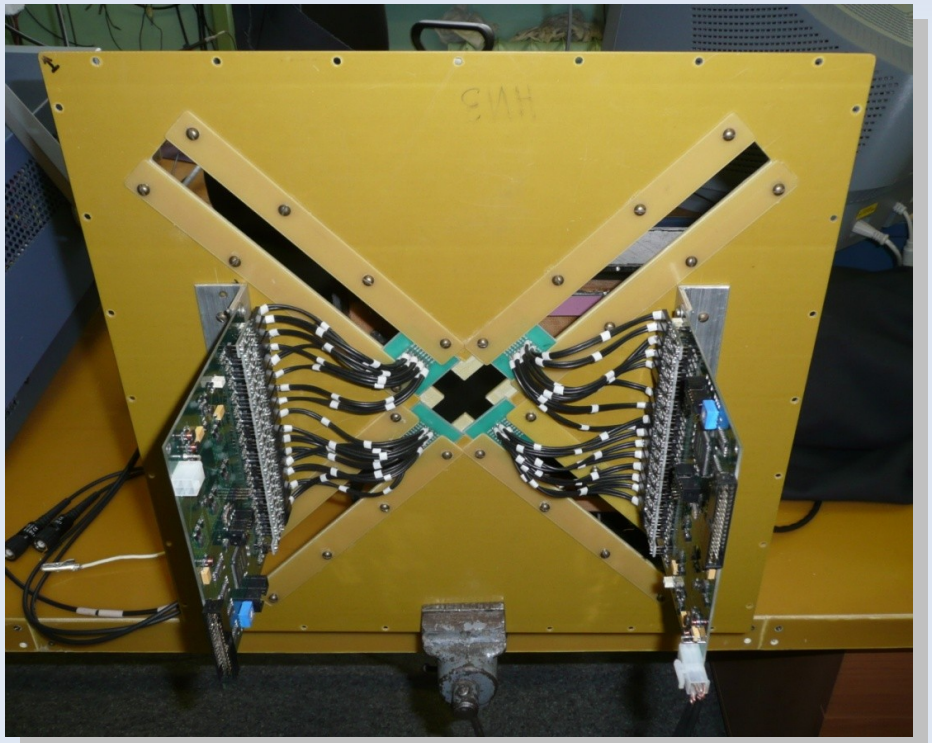




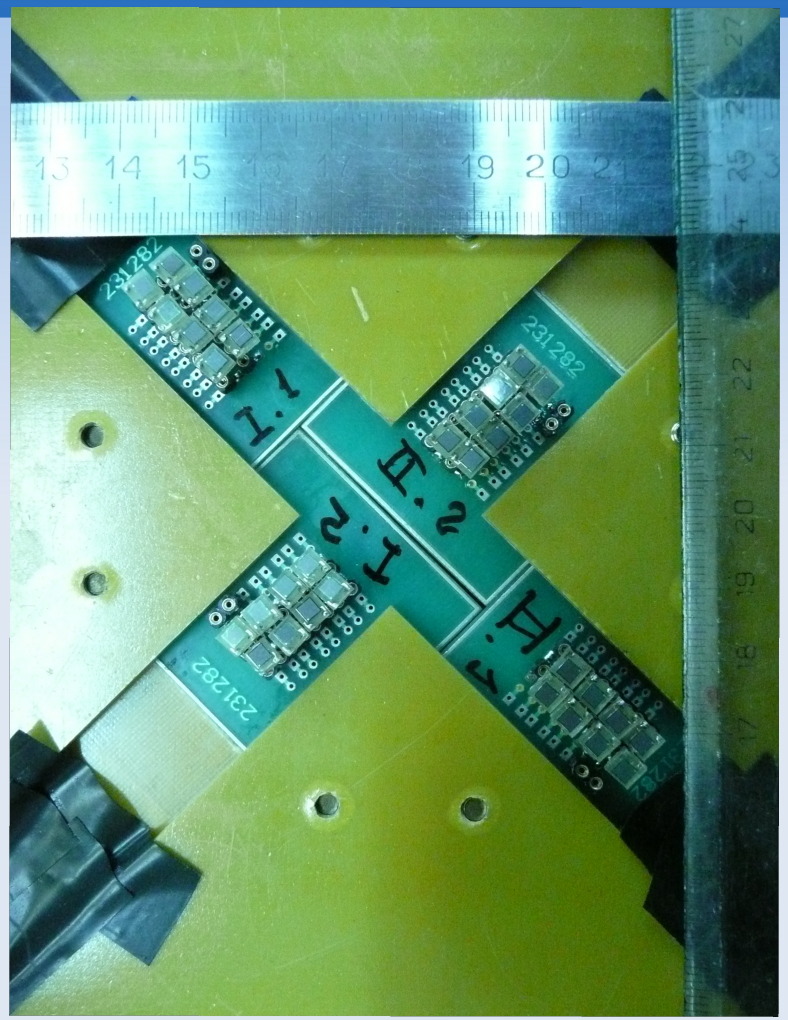
- Particle load: ~100 Hz of 1.3 GeV secondary electrons (3 GeV maximum)
- 50x15 mm^2 beam crossection (defined by trigger counter dimentions)
- 0.1--0.5 mm track spatial resolution

FARICH prototype №1

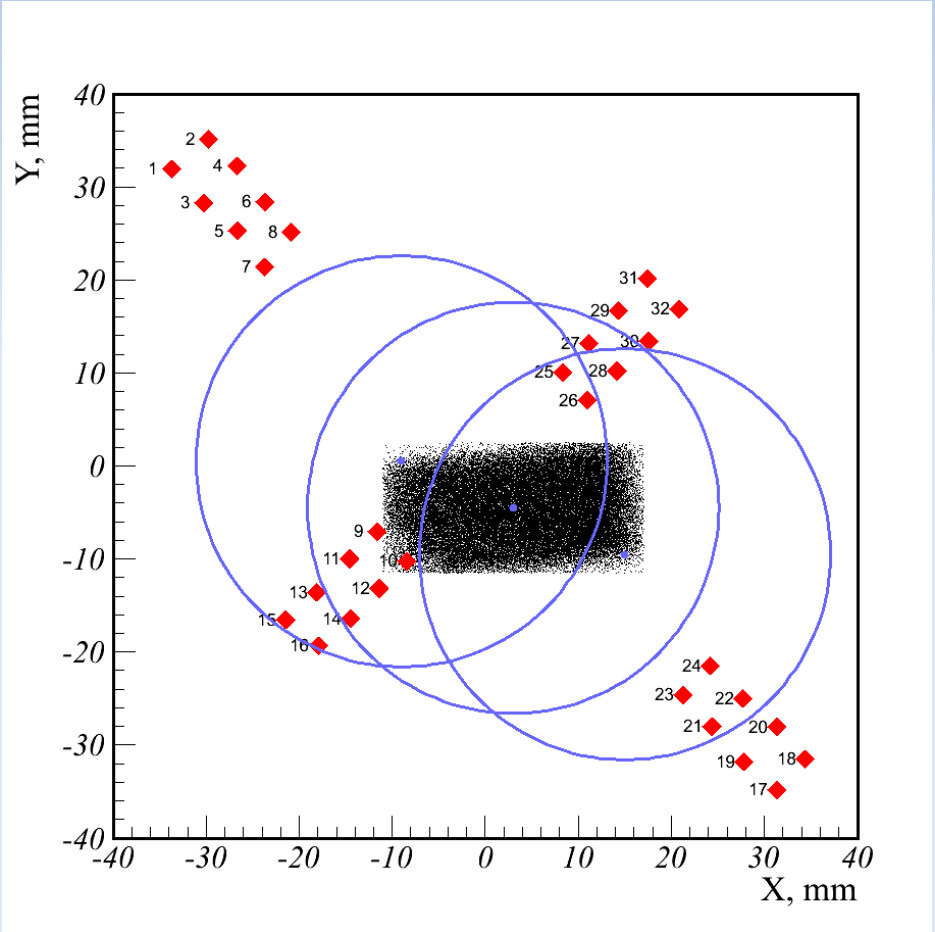
- Photon detectors: 32 SiPMs (CPTA 149-35), 2.1x2.1 mm
- Distance from aerogel to photon detector could be changed from 30 to 700 mm.
- 2 special 16-channel amplifier-discriminator boards with LVDS output
- 64-channel multihit TDC CAEN V1190B
- 100x100x31 mm^3 4-layer aerogel tile (focal distance 60 mm), n_{max}=1.05



Photodetectors layout



SiPM coordinates and trigger area

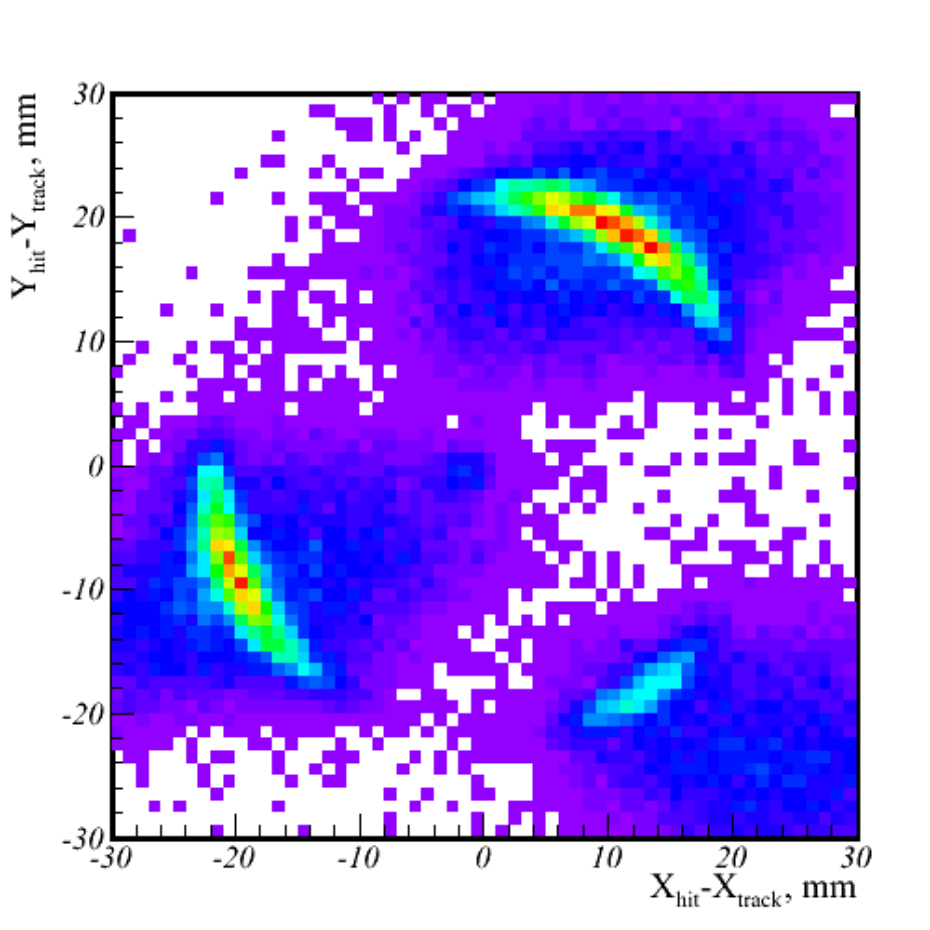


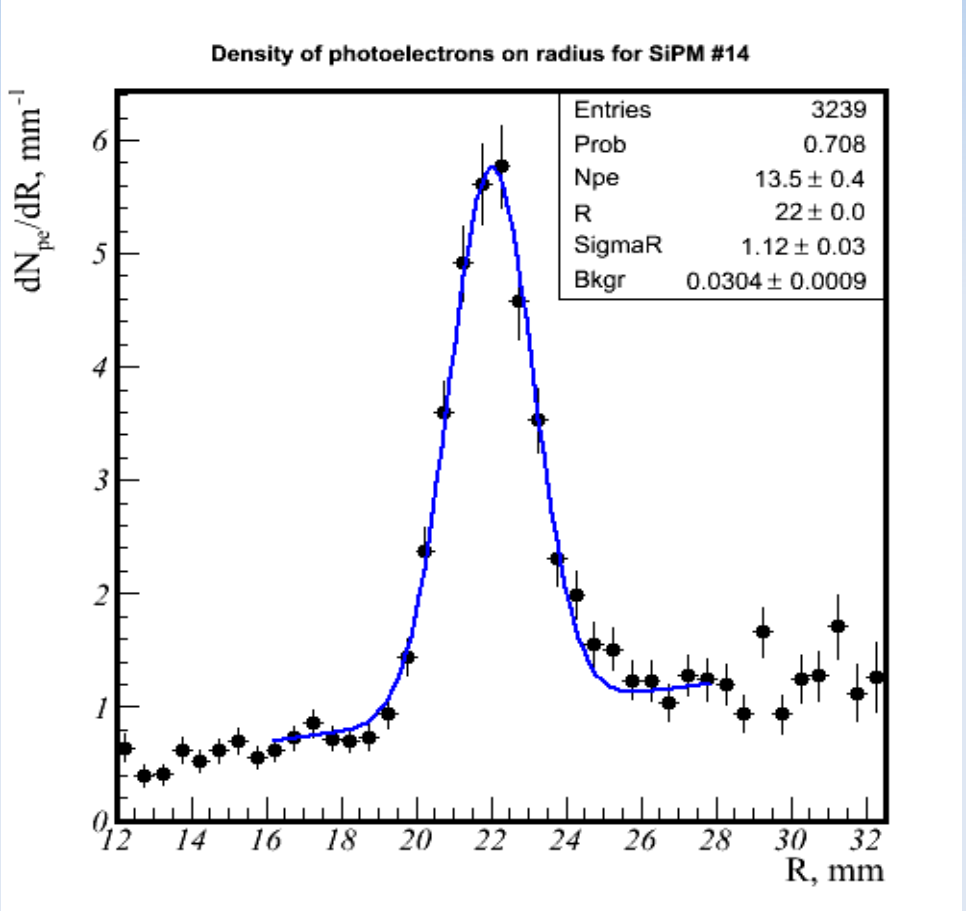
Electrons could pass at different distances from SiPM.

Cherenkov ring radius measurement (2011)

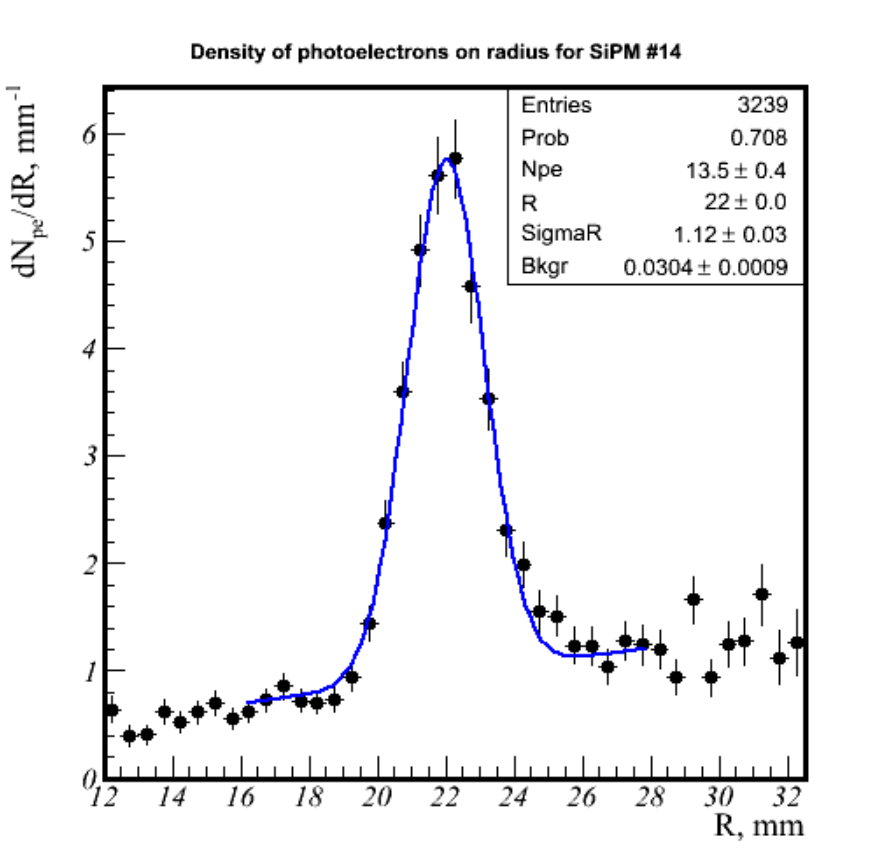
(X,Y)hit-(X,Y)track

$R^2=(X_{hit}-X_{track})^2+(Y_{hit}-Y_{track})^2$





Conclusions from experiment with prototype №1



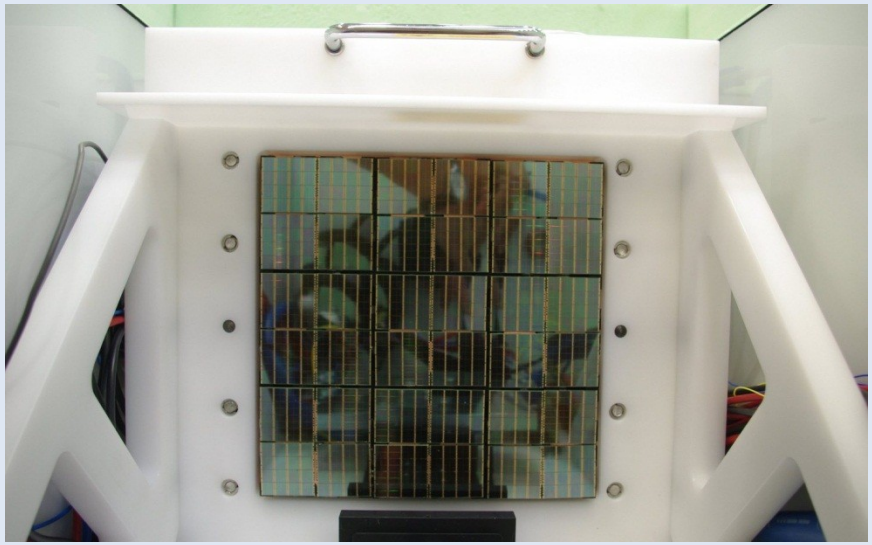
- **Test beam experiment with full ring detection is needed**
- It is possible to work with SiPM noise upto 2 MHz/mm^2 (single photon timing resolution <1 ns required)
- dN/dR distribution: ”Pure Gaussian” + flat background (from randome coincedence with SiPM noise) at least in ±5σ region
- $\sigma_r^2 = \sigma_{aerogel}^2 + \sigma_{pixel}^2 + \sigma_{track}^2$ =>

  $\sigma_{aerogel} = \mathrm{sqrt}(\sigma_r^2 - \sigma_{pixel}^2 - \sigma_{track}^2)$

  $= \mathrm{sqrt}(1.1^2 - 2.1^2/12 - 0.5^2) = 0.8$ mm
- **To invesigate parameters of focusing aerogel tiles we need to improve coordinate resolution of photon detection.**

Beam test with PDPC FARICH prototype at CERN (2012)

- 4-layer aerogel
- n_{max} = 1.046
- thickness 37.5 mm
- focal distance 200 mm
- hermetic box with acrilic glass window was used to prevent moisture condensation on aerogel tile



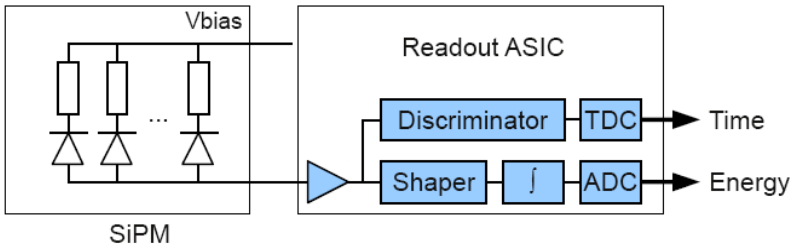
Photon matrix 20x20 cm^2

- Sensors DPC3200-22
- 3200 micro-cells in pixel,
- 3x3 modules = 6x6 tiles = 24x24 dies = 48x48 pixels
- 576 time channels
- 2304 amplitude (position) channels
- Pixel dimension 3.2x3.9 mm^2
- 3 levels of FPGA readout: tiles, modules, bus boards
- to detect single photons detector was cooled to -40° Celsius

DPC: Front-end Digitization by Integration of SPAD & CMOS Electronics

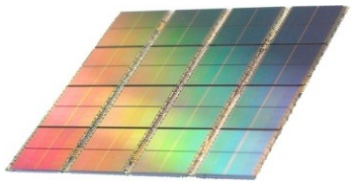
Analog SiPM

Analog Silicon Photomultiplier Detector

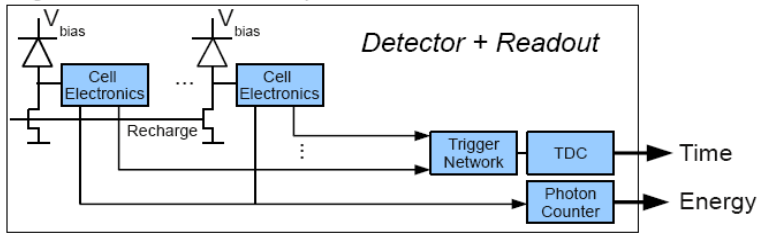


- discrete, limited integration
- analog signals to be digitized
- dedicated ASIC needed
- difficult to scale

Digital SiPM

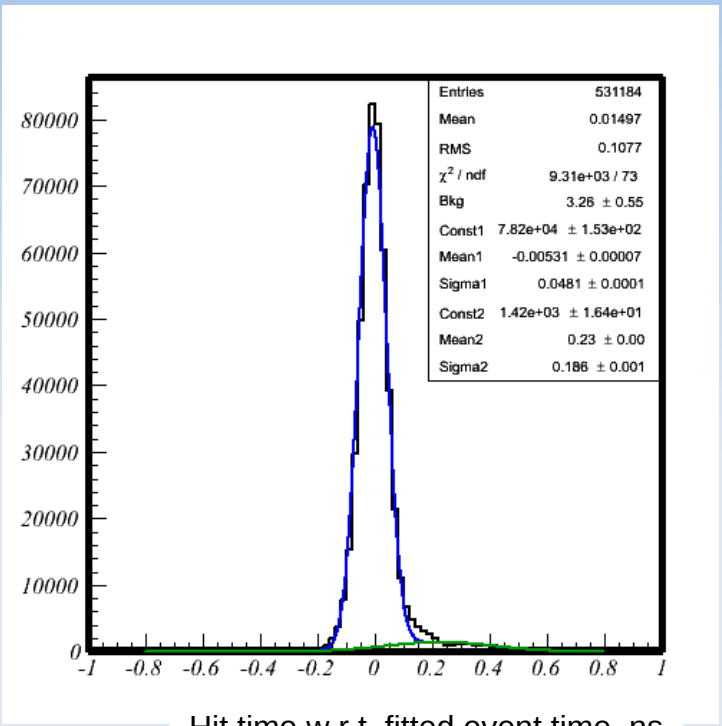


Digital Silicon Photomultiplier Detector

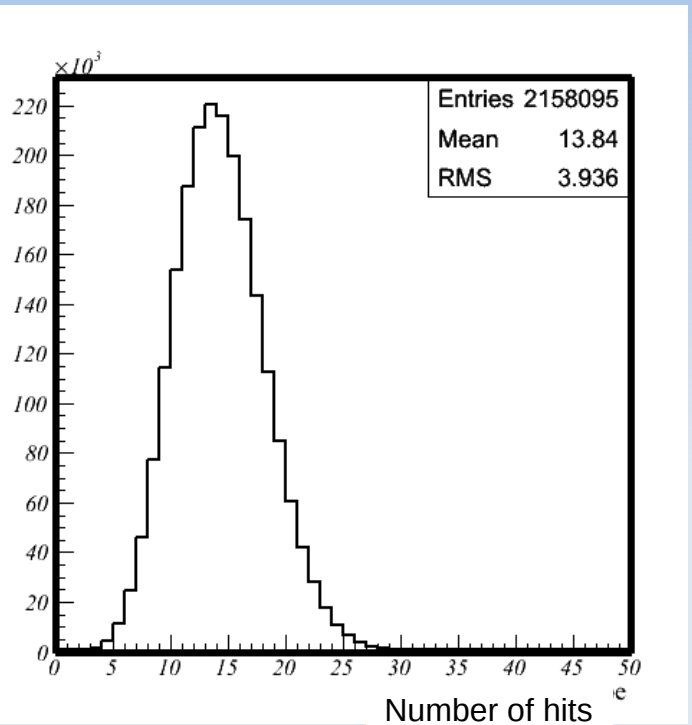


- fully integrated
- fully digital signals
- no ASIC needed
- fully scalable

Beam test results: timing resolution and number of detected photons



Hit time w.r.t. fitted event time, ns



Number of hits

σ_{narrow} = 48ps

Record single photon timing resolution for SiPM

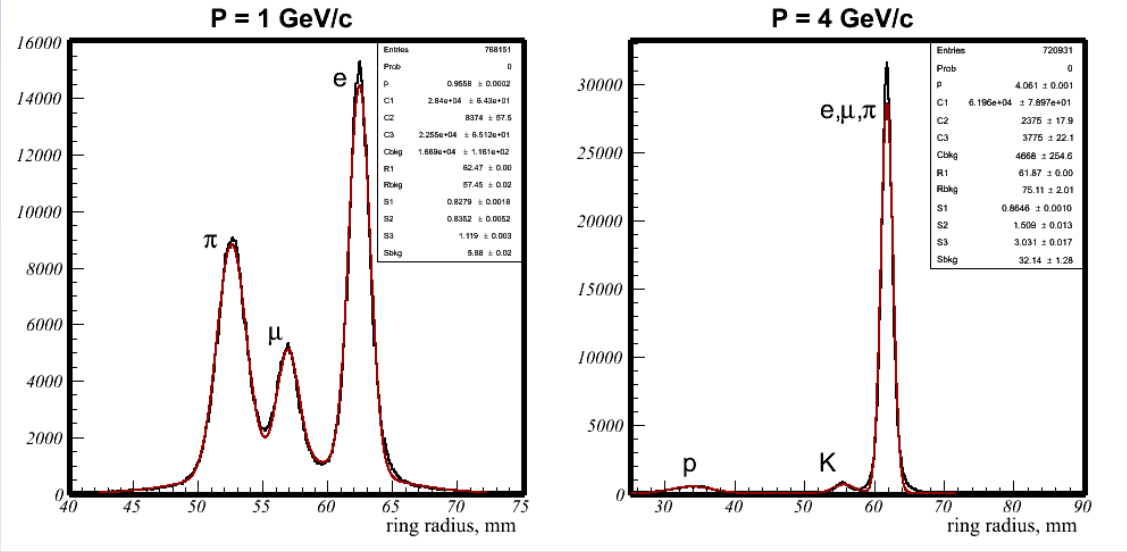
$\langle N_{pe} \rangle$ = 12

(optical crasstalk corrected)

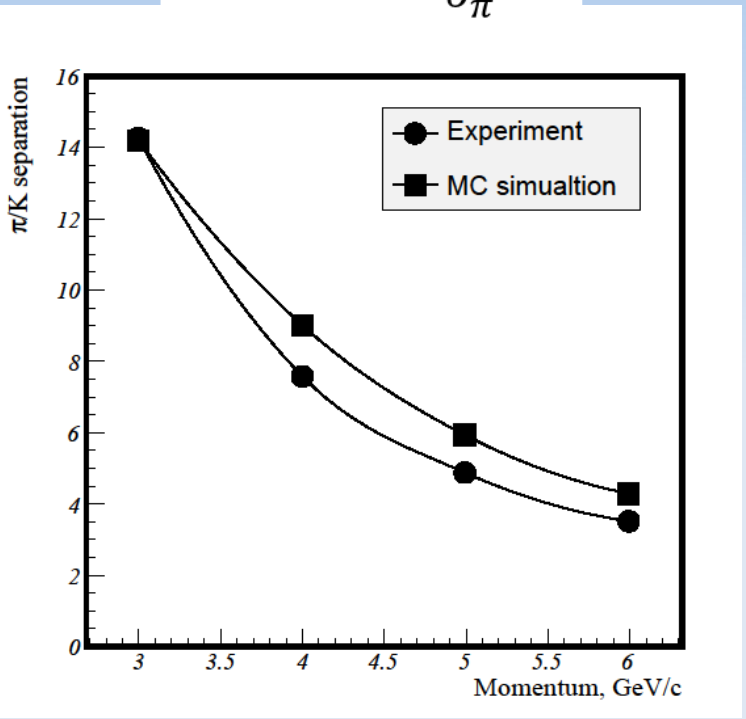
1.7 times less than in MC simulation

Beam test results: particle identification

Cherenkov rings radius distribution



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



μ/π: 5.3σ @ 1 GeV/*c*
π /K: 7.6σ @ 4 GeV/*c*
π /K: 3.5σ @ 6 GeV/*c*

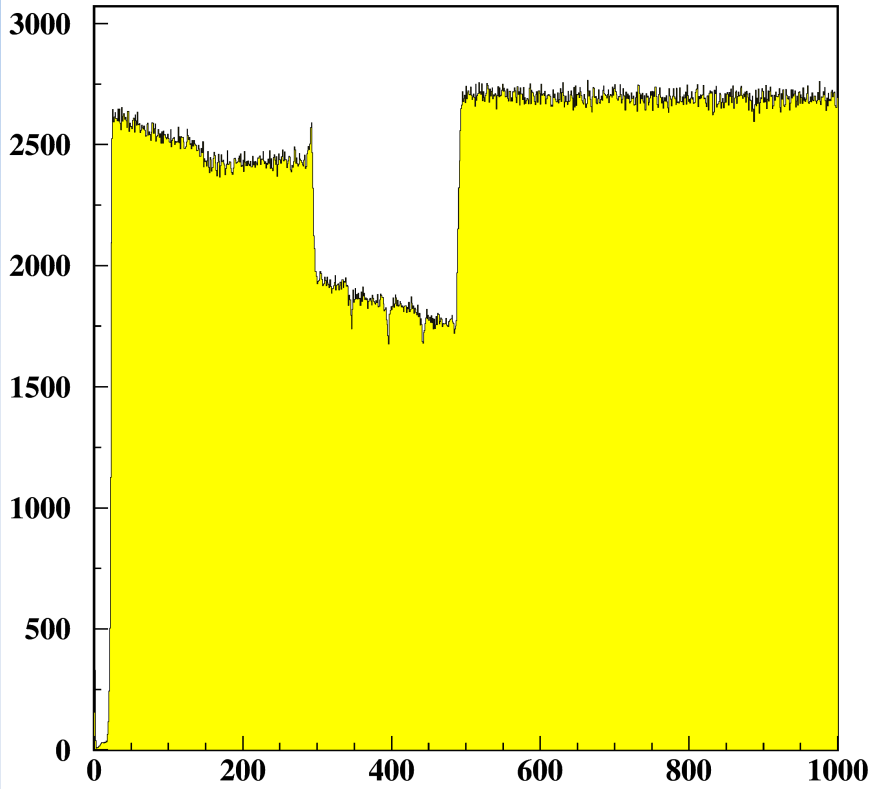
2.3 times more than SuperB FDIRC
1.4 times more than Belle II ARICH
2.6 times less than in initial MC simulation

A.Yu. Barnyakov, et al., Nuclear Instruments & Methods in Physics Research A (2013), http://dx.doi.org/10.1016/j.nima.2013.07.068, Article in Press

Conclusions from experiment with PDPC FARICH prototype

- DPC is a VERY promising technique for the photon detection in FARICH systems
- DPC photon detection efficiency needs additional investigations
- To achieve design parameters more investigation of focusing aerogel parameters need to be done => special test detector is needed.

Focusing aerogel radiator development



Focus destructive effects:

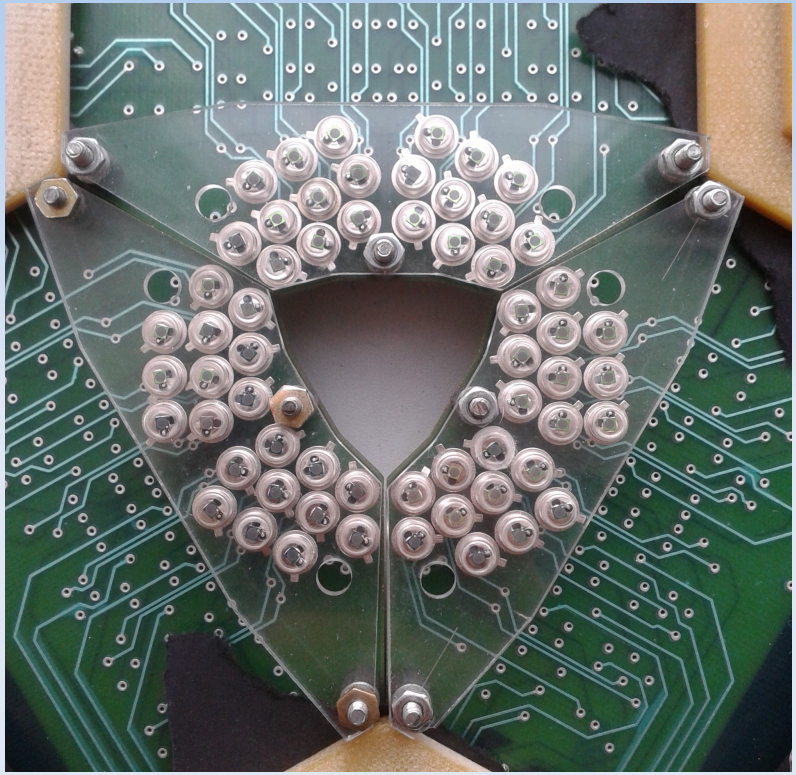
- Difference between actual and design values of the refractive index of the layers
- Uncontrolled refractive index variations (See poster ”Aerogel for FARICH detector”)

We start development of a new technology of focusing aerogel tile production with continuous designed profile of density gradient. (See poster ”Aerogel for FARICH detector”).

The effects of incomplete focusing must form structures in the distribution of photons on the Cherenkov ring radius. To observe such structures we suggest to use RICH detector with fine photon position detection. Spacial resolution of about 300 μm is needed.

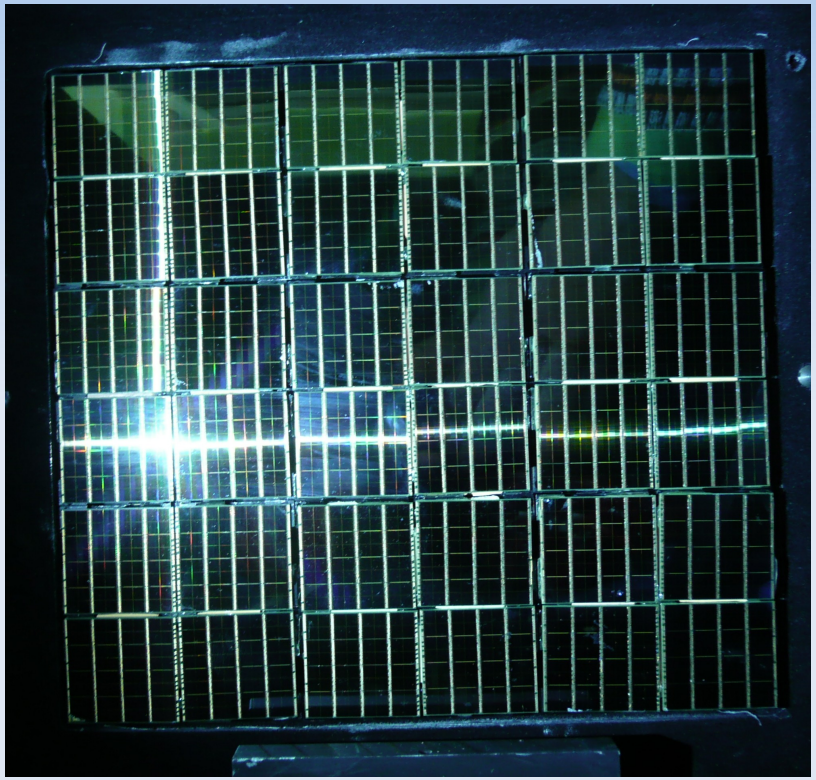
FARICH detector with fine photon position detection.

FARICH prototype @2



60 SiPMs CPTA 151, ∅1.28 mm, noise 1-2 MHz/mm^2 at room temperature, $\sigma_{pixel}=\varnothing/\sqrt{12\pi}=200\mu m$

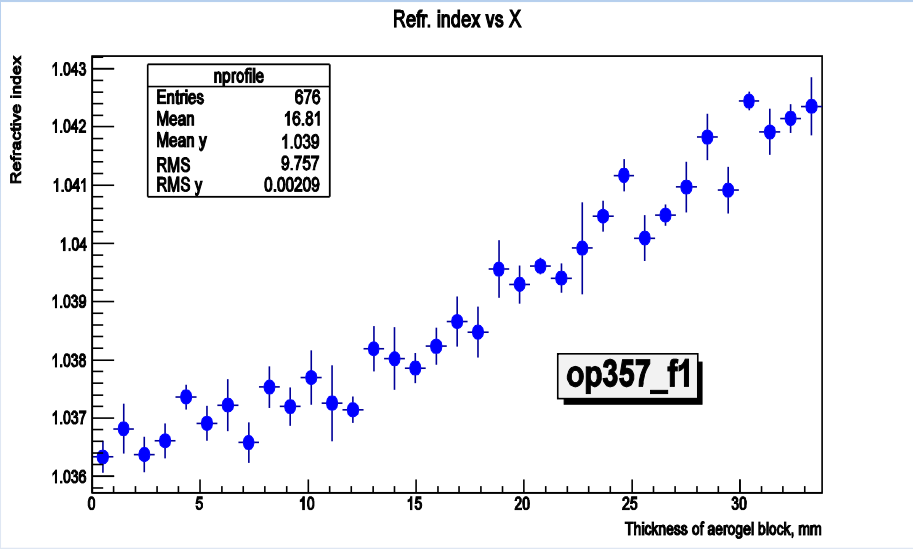
PDPC FARICH



92% micro-cells in each pixel were Inhibited, active area was redused from 3.2x3.9 mm2 to 1x1 mm2, 1216 working channels,

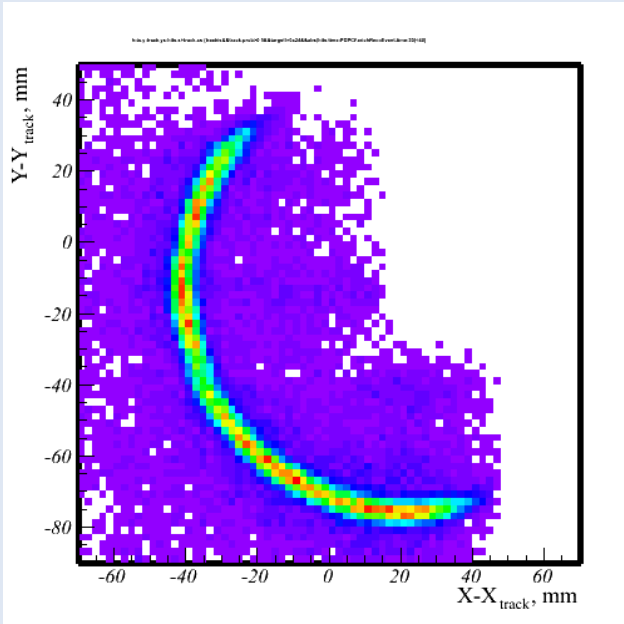
$\sigma_{pixel}=\Delta/\sqrt{12}=300\mu m$

Experiment with gradient aerogel tiles on the beam(1)



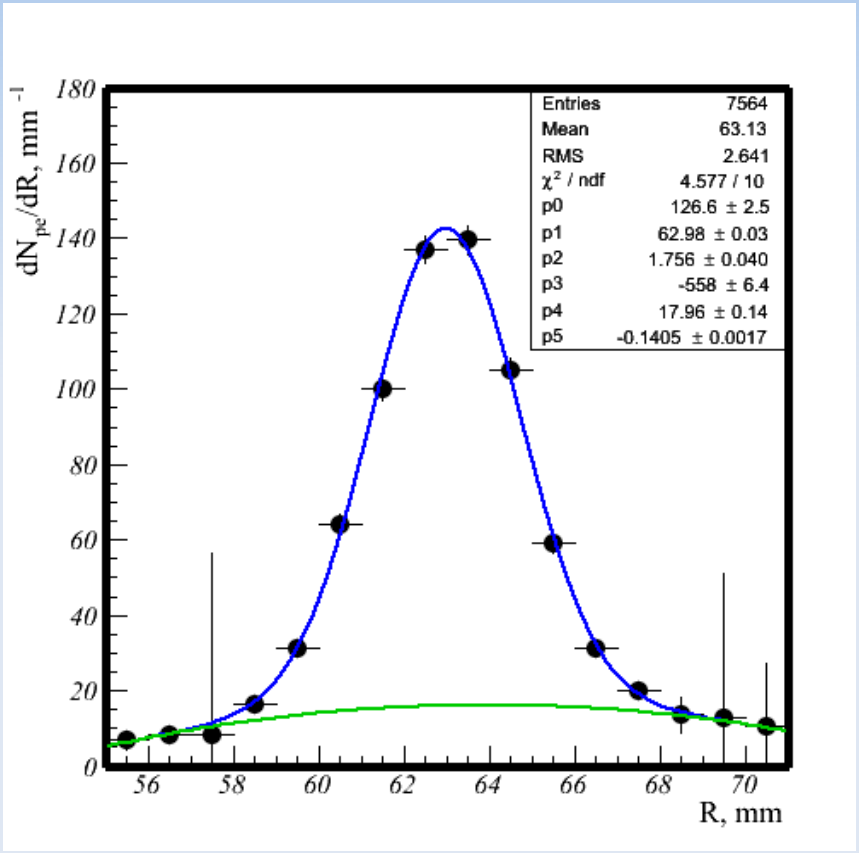
- Several samples of gradient aerogel tiles where tested on the beam with PDPC FARICH prototype working in the mode of fine photon position detection

n(x) dependance was measured using digital x-ray detector

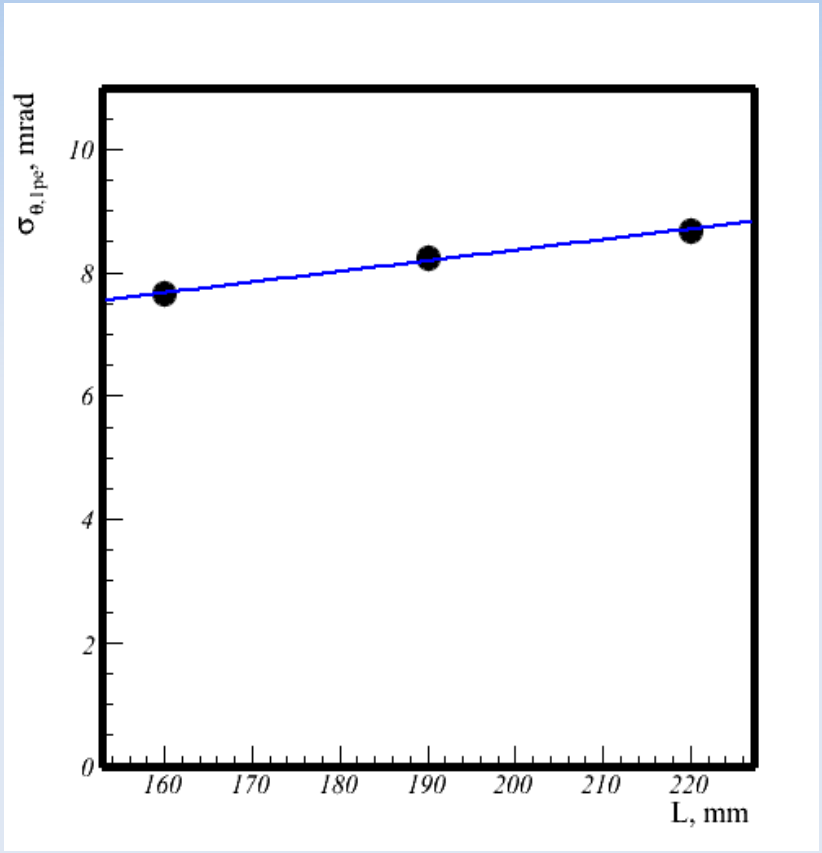


Experiment with gradient aerogel tiles on the beam(2)

dN/dR



σ_Θ for 1 pe

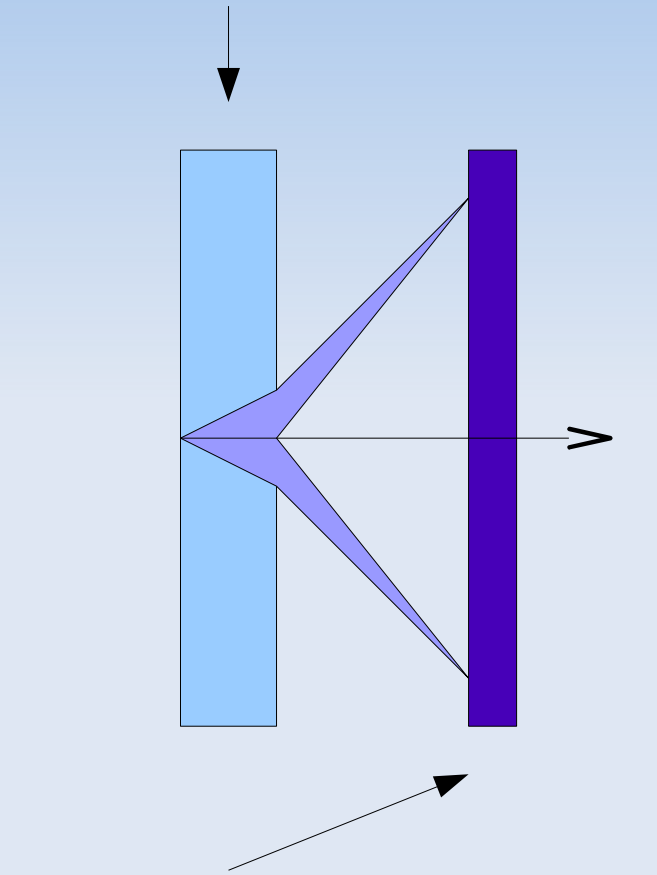


- **σ_Θ is about the same as for 4-layer tile => it is focusing**
- **DPC is working in fine position detection mode**
- **Coordinate system of the beam line need to be modernized**

My dreams

For the proximity focusing RICH detectors there are 3 main contributions to the resolution: $\sigma_{\Theta}^{2} = \sigma_{chr}^{2} + \sigma_{geom}^{2} + \sigma_{phot}^{2}$

- Suggested technilogy of gradient aerogel tile production could give us radiators with $\sigma_{geom} << \sigma_{chr}$
- Philips Digital Photon Counting are working on the next version of the sensor which could read out the time and micro-cell number(instead of the number of fired cells)of the hit, $\sigma_{phot} \approx 20\ \mu m << \sigma_{chr}$
- **Could we build RICH with $\sigma_{\Theta}^{2} \approx \sigma_{chr}^{2}$?**

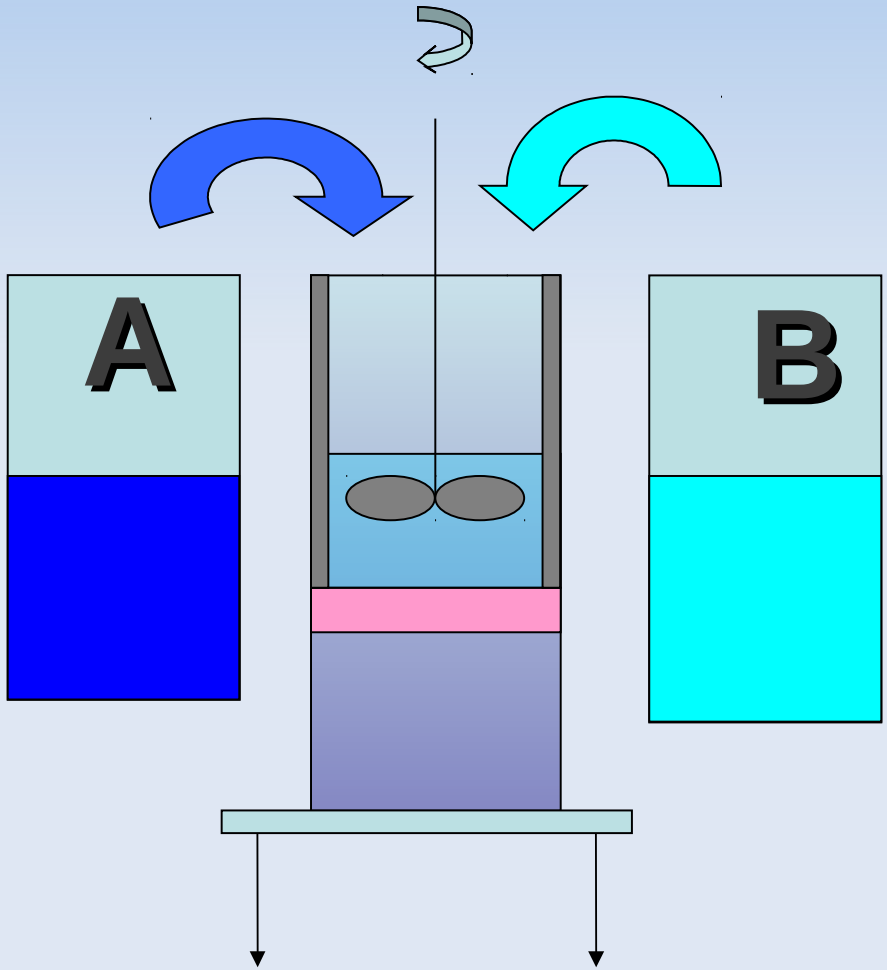


Conclusion

- In 2011-2013 several tests of Focusing Aerogel RICH prototypes equipped with MRS APD (CPTA name of SiPM) and DPC (Philips) photodetectors where performed on the electron beam at BINP and hadron beam at CERN
- The focusing of Cherenkov light is close to calculations for multi-layer aerogel tiles
- At the test experiment at PS T10 beam line (CERN) we have got 7.6σ π/K-separation at P=4 GeV/*c*, 5.3σ μ/π-separation at P=1 GeV/*c*
- Number of detected photons is much less than expected in all tests. Expectations where based on producer's data. Additional measurements of photon detection efficiency are needed.
- Investigations of focusing aerogel tiles of different types will continue in test beam experiments with fine photon position detection

Additional slides

Production of focusing aerogel tiles with designed desity profile

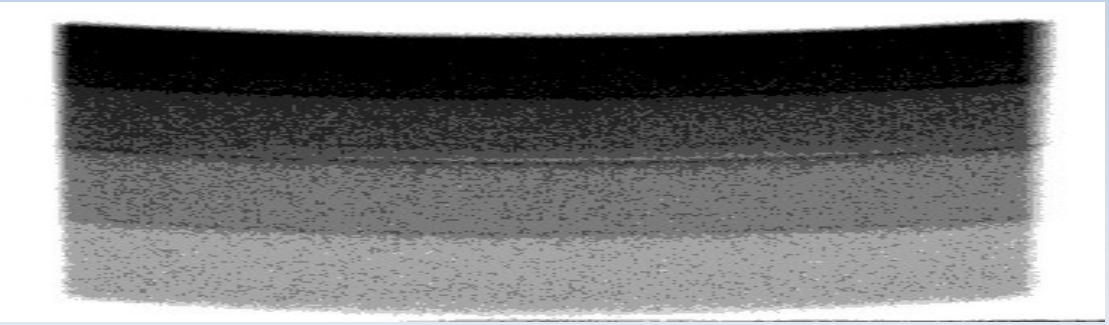


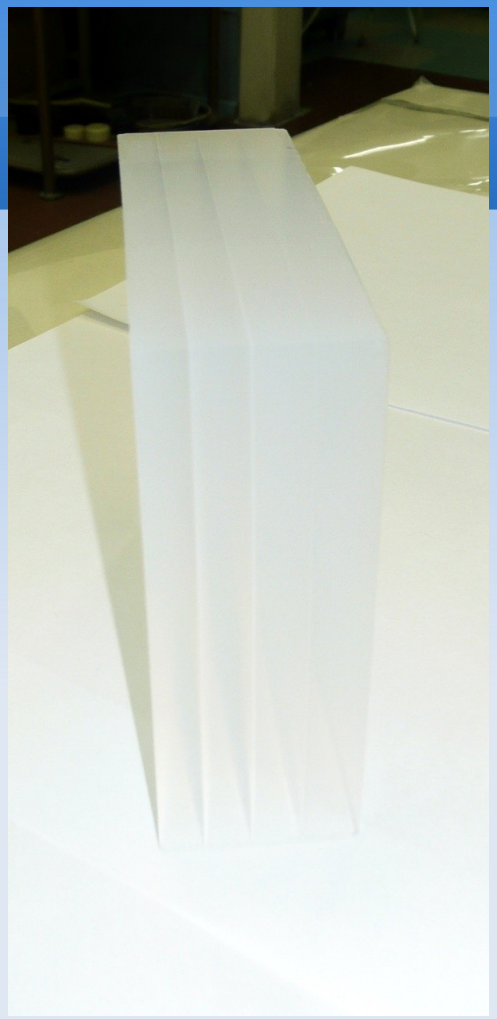
To produce aerogel tiles with designed profile of gradient we modernized the method suggested by S.M. Jones [*]:

- There are two pre-prepared mixtures with the high and low content of silicon compound in vessels A and B. With the help of peristaltic pumps mixtures enter the mixer.
- The obtained mixture with designed concentration of silicon compound seeps through the filter to the mould where gelation takes place.
- The mould is positioned on the vertically moving table. The peristaltic pumps and moving table are controlled by a computer.

[*] Steven M. Jones, “A method for producing gradient density aerogel”, J Sol-Gel Sci Technol. 44 (2007) 255

Aerogel sample

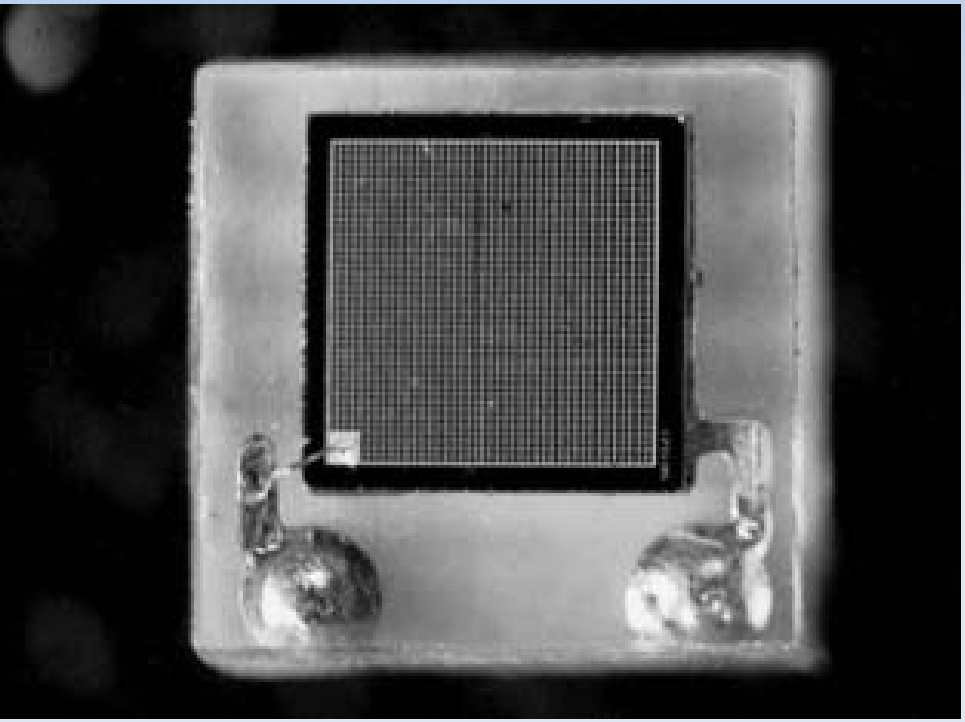




	n	h, mm
Layer 1	1.050	6.2
Layer 2	1.041	7.0
Layer 3	1.035	7.7
Layer 4	1.030	9.7

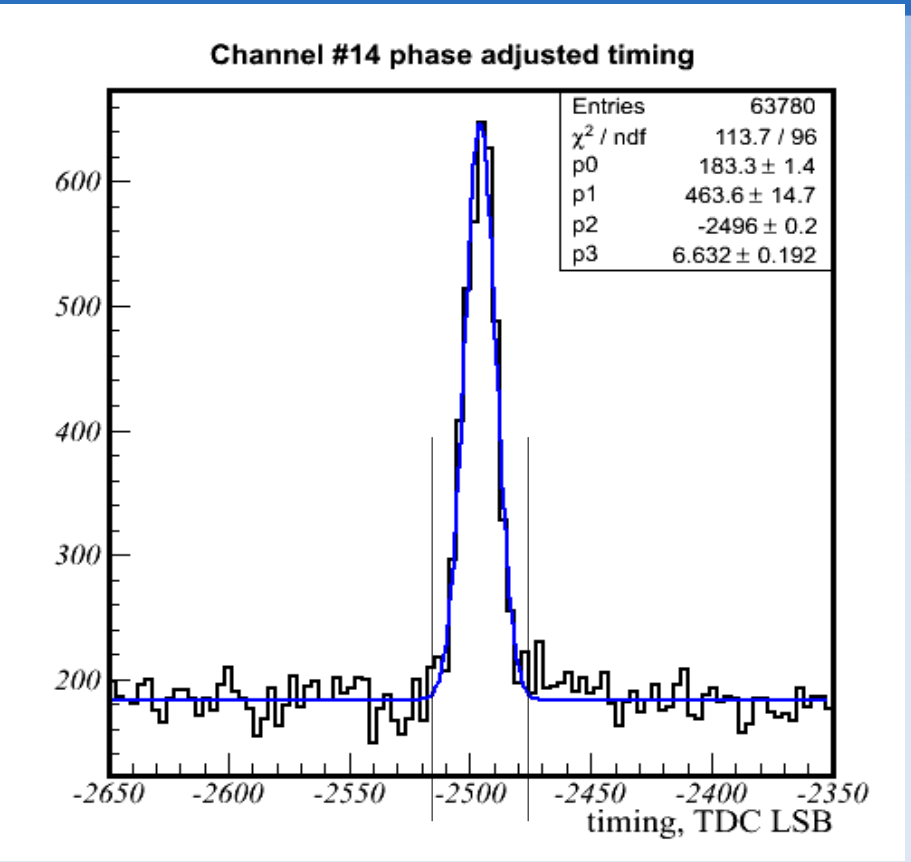
- 100x100x31 mm^3
- Lsc(400nm)=43 mm
- $n^2=1+0.438*\rho$

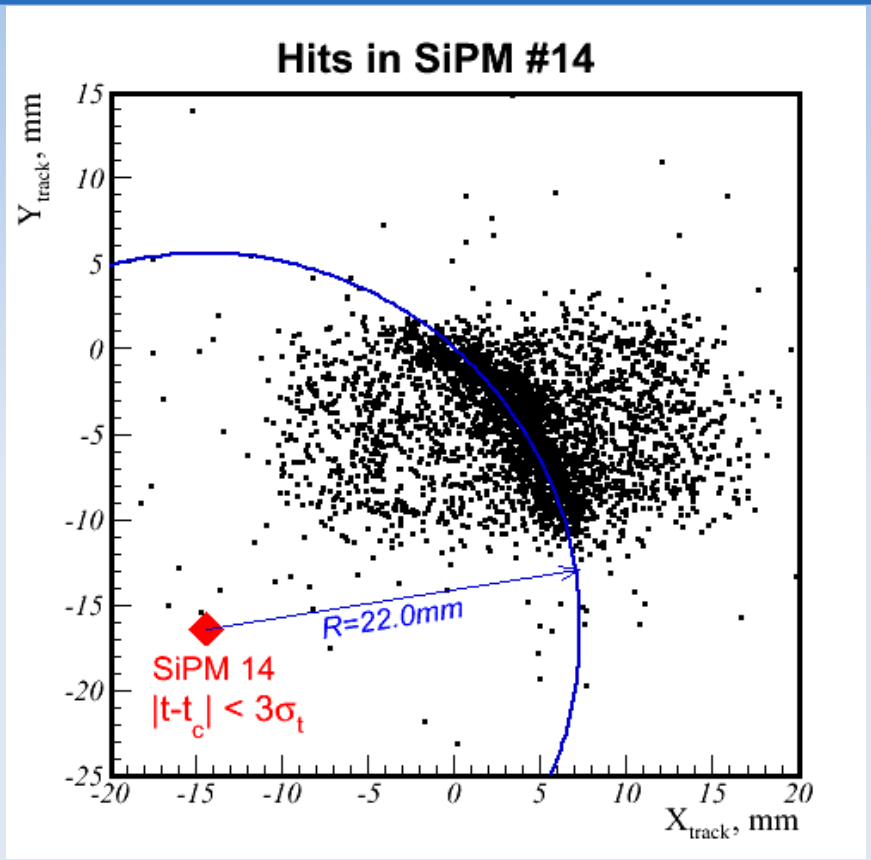
MRS APD Parameters



- Producer - Center of Perspective Technology and Apparatus – CPTA, Moscow http://www.spta-apd.ru/
- Genuine name - MRS APD (other names: silicon photomultiplier, PPD,MPPC…)
- 2.1x2.1 mm sensor
- 4x4 mm case size
- PDE=40% @ 600 nm (?)
- Gain ~ $4 \cdot 10^5$
- Time resolution ~100 ps
- Dark counts ~5--10 MHz (0.5pe threshold)

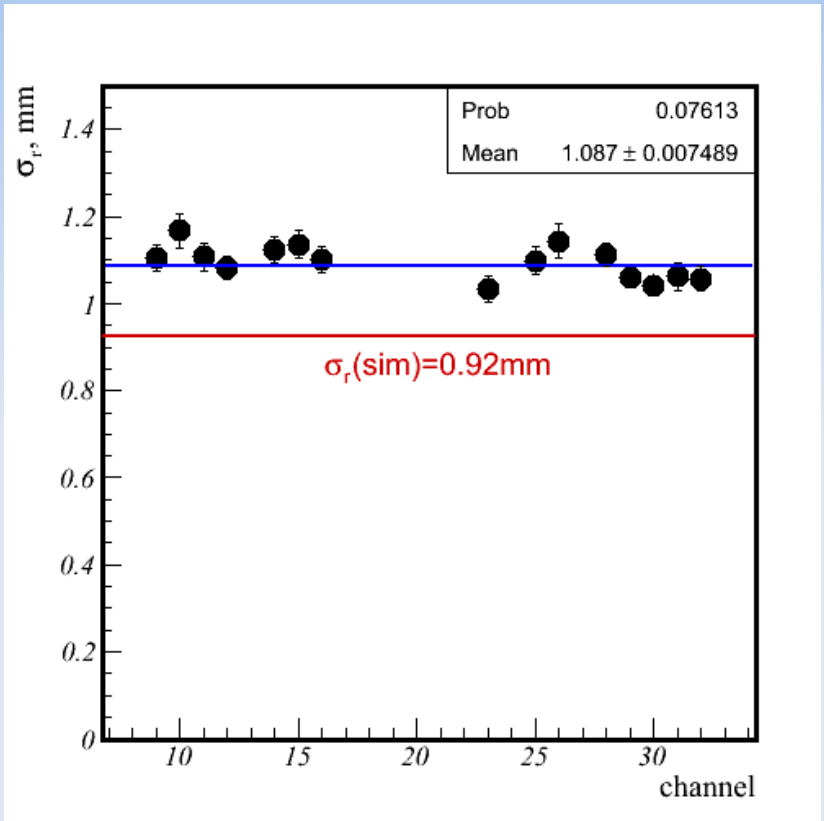
Event selection

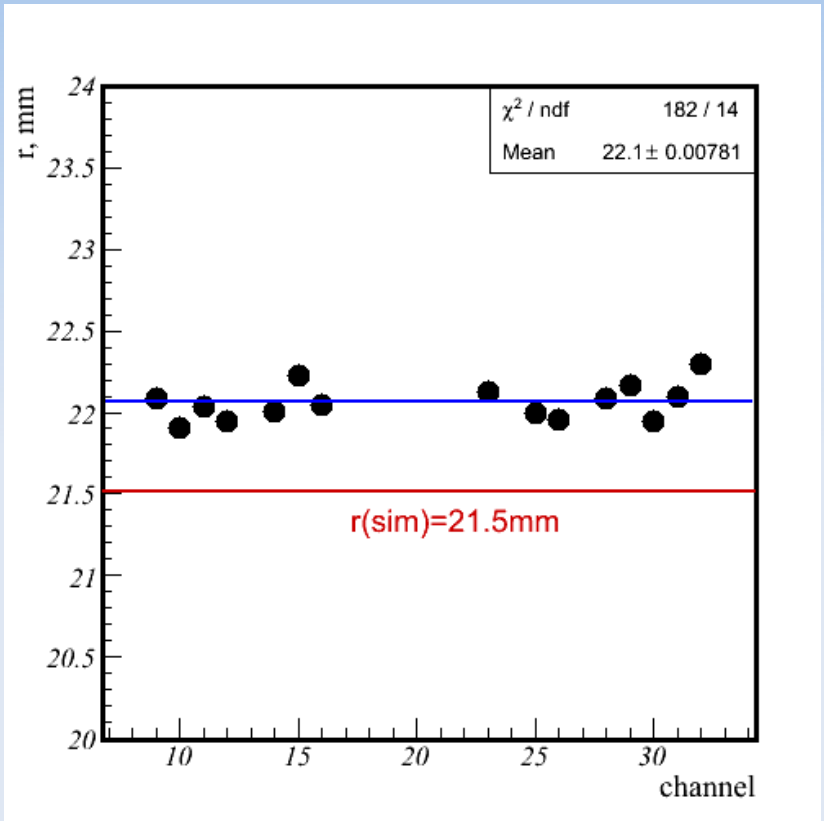




- **We select events with $|t-t_{ch}|<3\sigma_t$**

Cherenkov ring radius measurement(2)

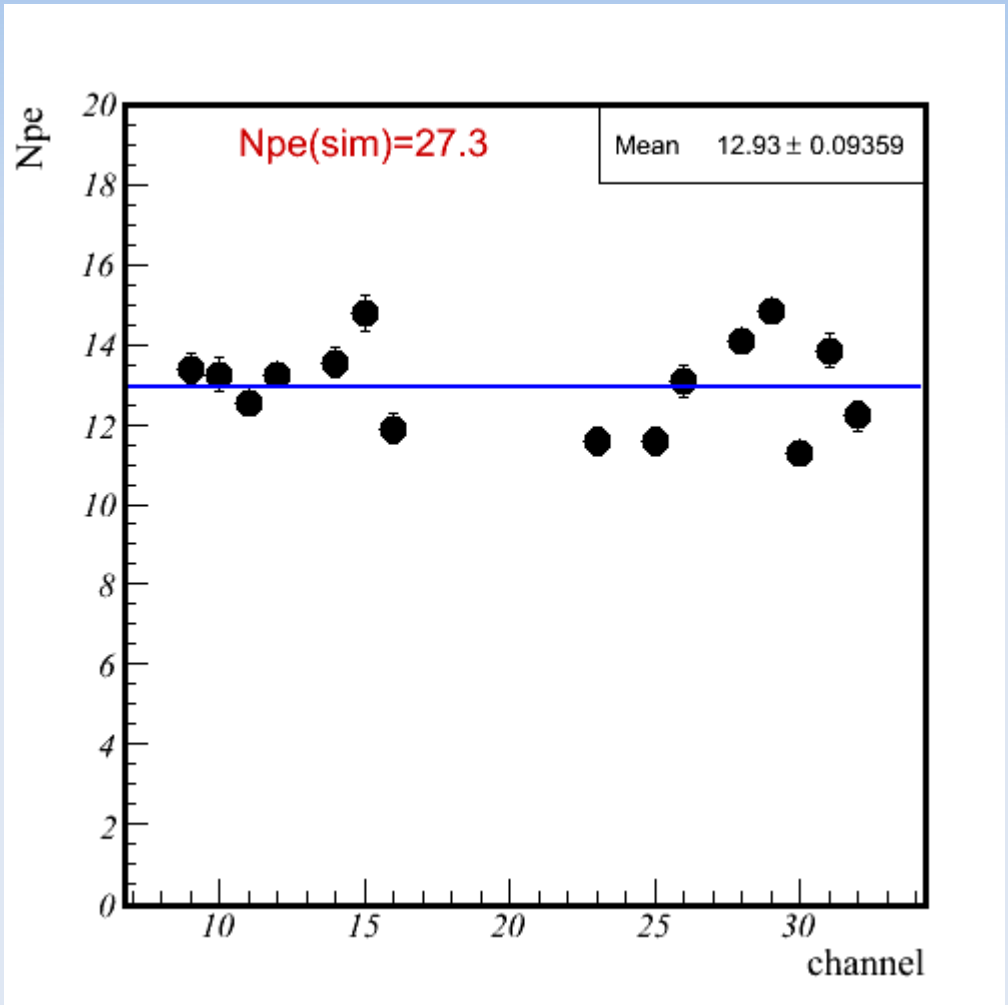




Difference between σ_r and σ_r(sim) comes mainly from track resolution (~0.5 mm)

22.1 – 21.5 = 0.6 mm –> 2.7%
Position accuracy –> 1.7%
error in $n_{aerogel}$ from dencuty –>

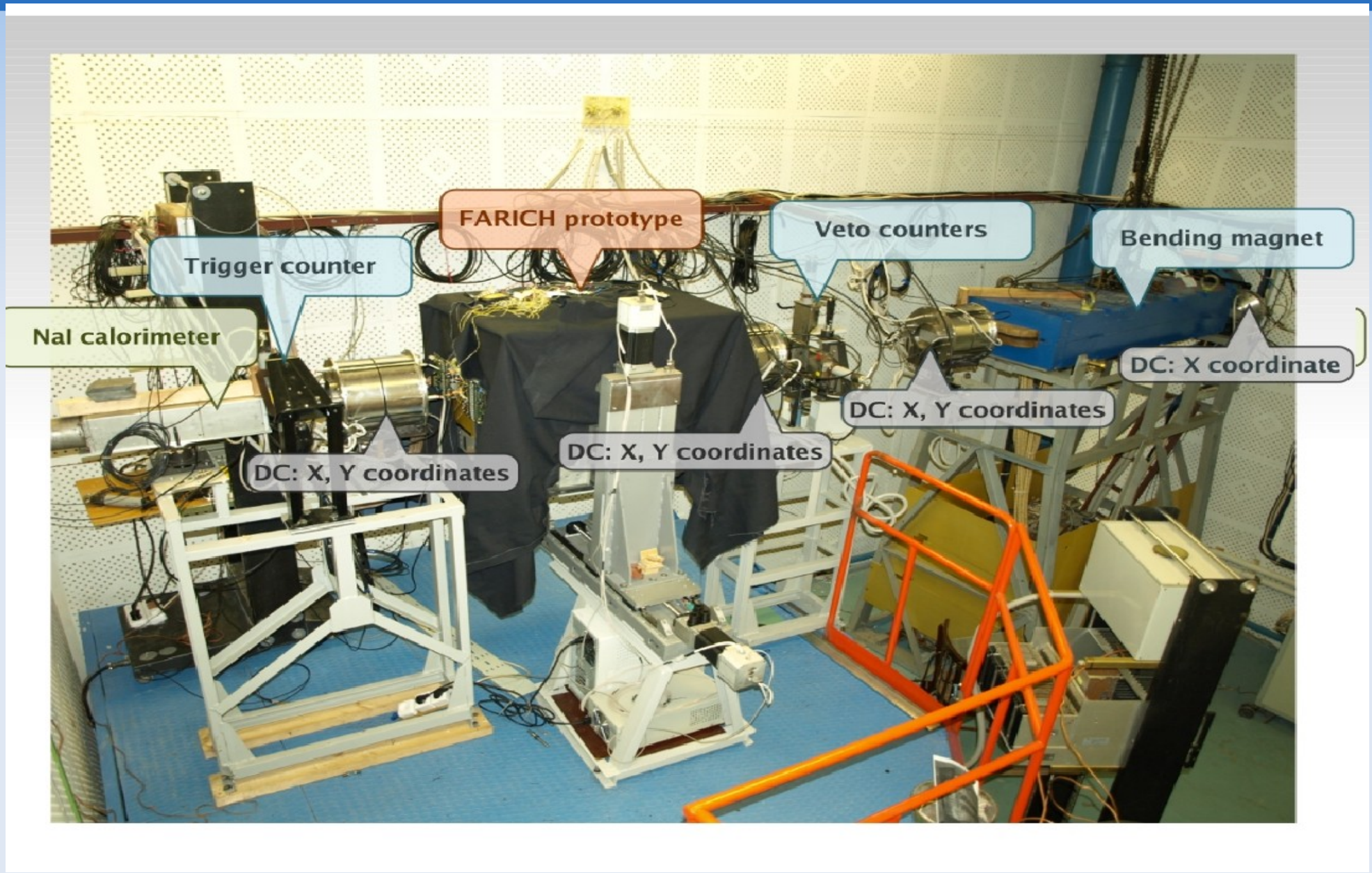
Number of photoelectrons (4-layer)



Discrepancy between Npe in simulation and experiment could be explained by:

- real detection efficiency of G-APDs is smaller than in data book
- electronics miscount

Test beam line



Test beam apparatus