Development of the Forward RICH detector for the PANDA experiment

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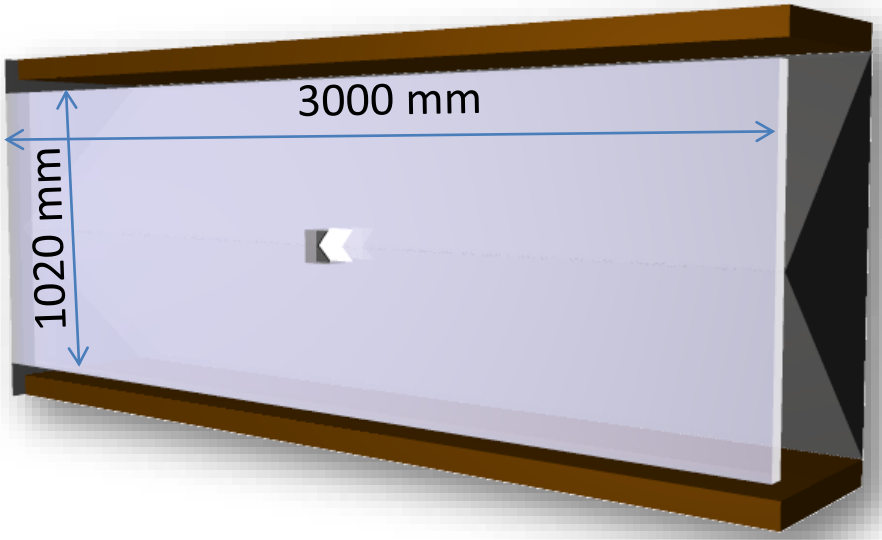
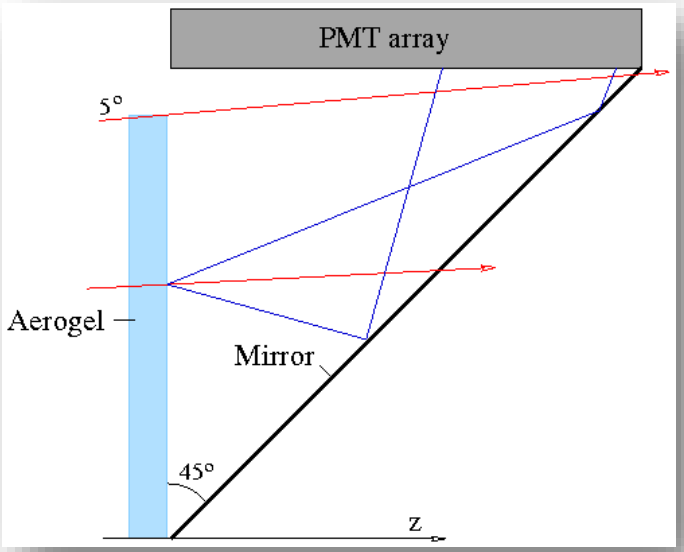
PANDA Russia Workshop

May 25, 2015

Conceptual design based on FARICH 2010





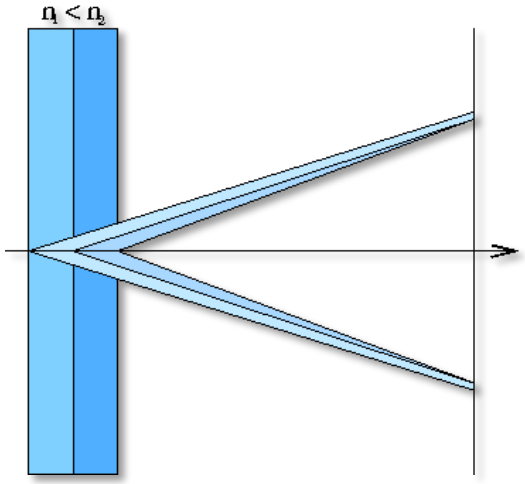
Hamamatsu H8500 MaPMT

- flat panel,
- 8x8 anode pixels of 6mm size
- 89% active area ratio
- Bialkali photocathode
- Gain: $1.5 \cdot 10^6$
- Relatively cheap (≈€1800 / unit)
- Robust
- Long lifetime

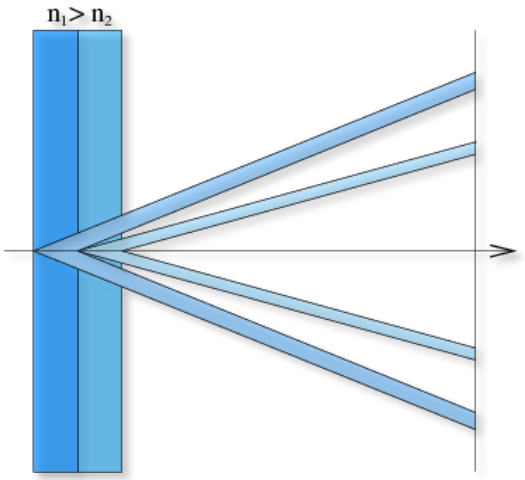
- 2-layer aerogel n_1=1.050, n_2=1.047 (no gas)
- Flat mirrors only
- MaPMT readout
- MC simulated PID performance:
  - π/K up to P = 10 GeV/c
  - μ/π up to P = 2 GeV/c

FARICH – Focusing Aerogel RICH

Single ring option



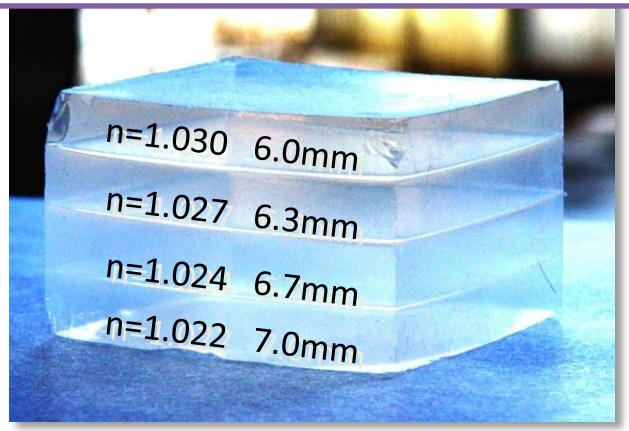
Multi-ring option



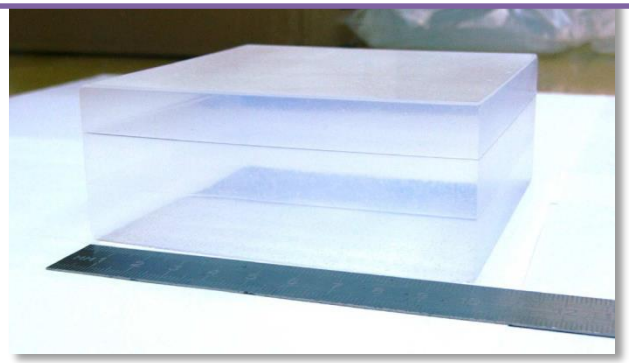
Focusing aerogel improves proximity focusing design by reducing the contribution of radiator thickness into the Cherenkov angle resolution

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

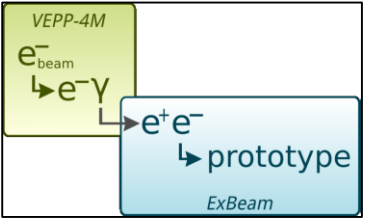
First sample of 4-layer aerogel by BIC



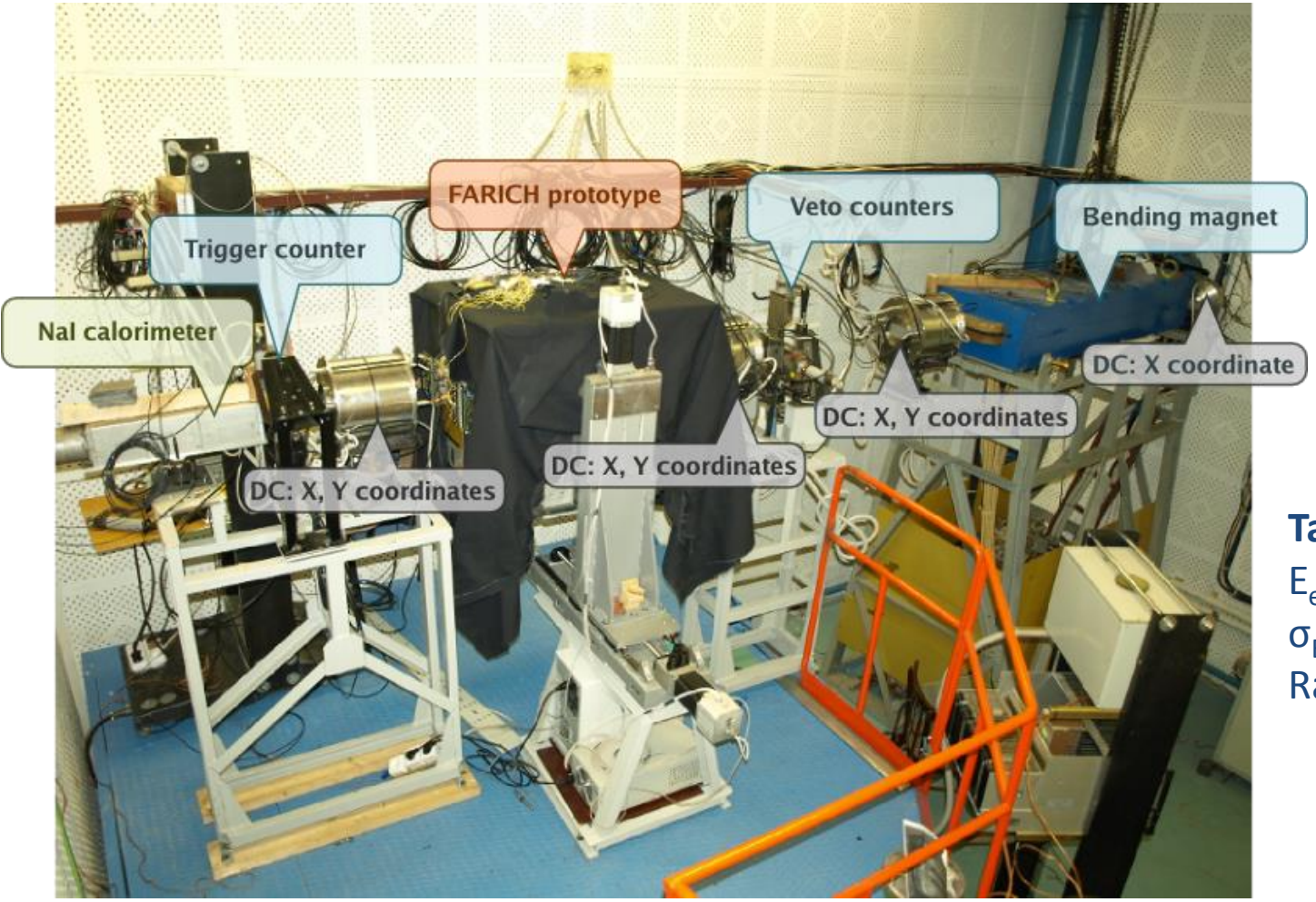
3-layer aerogel 115x115x41 mm^3



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



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}

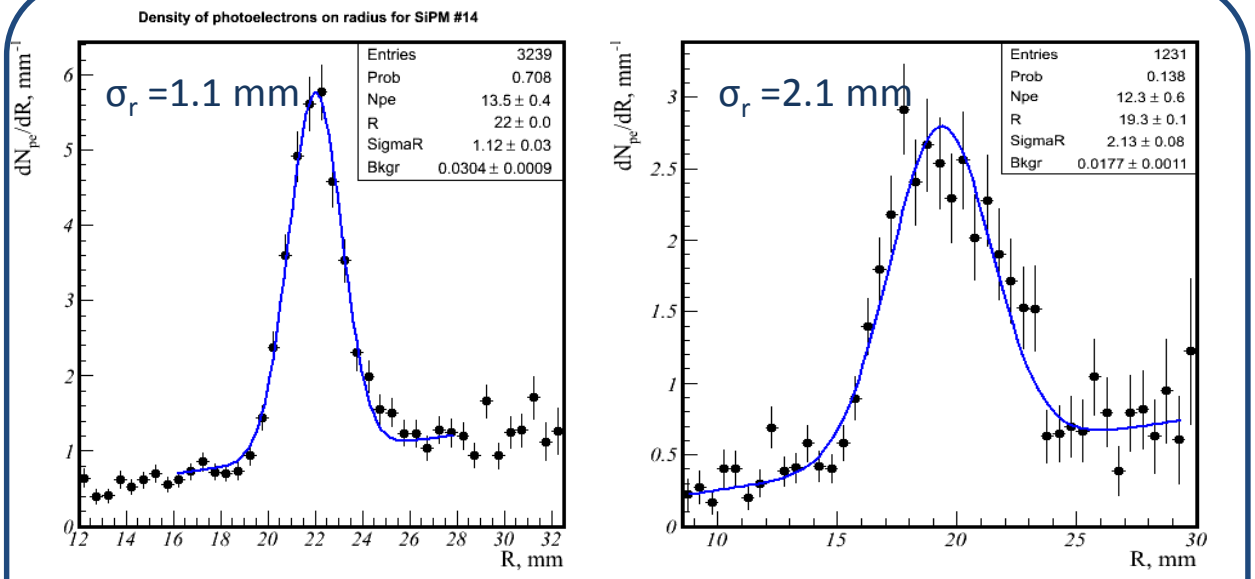
Tagged γ beam

E_e = 0.05÷1.5 GeV

σ_E/E = 0.5% @ 1.5 GeV

Rate up to 10^3 s^{-1}

e⁻ beam test with FARICH prototype 2011

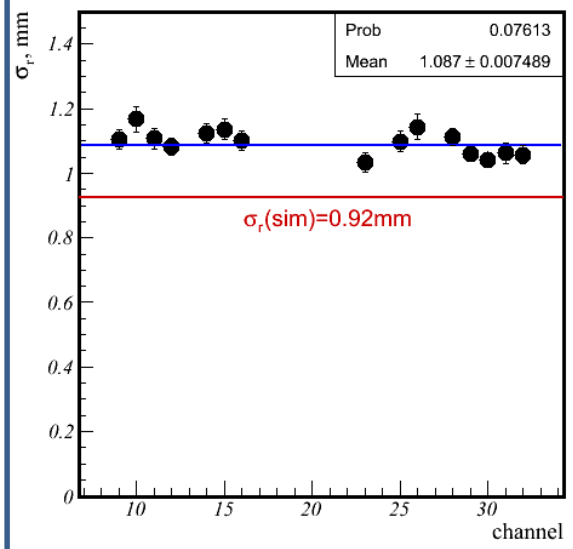


4-layer aerogel (t=3cm) vs single layer aerogel (t=2cm)
Focusing effect has been observed.

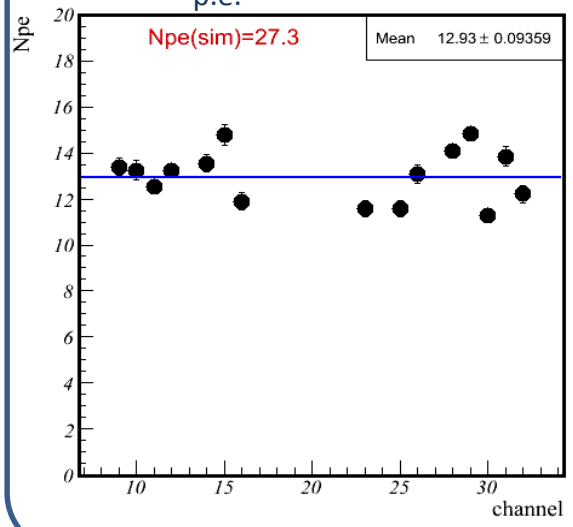
σ_r=1.1 mm – in rough agreement with MC simulation

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

σ_r vs channel



$N_{p.e.}$ vs channel

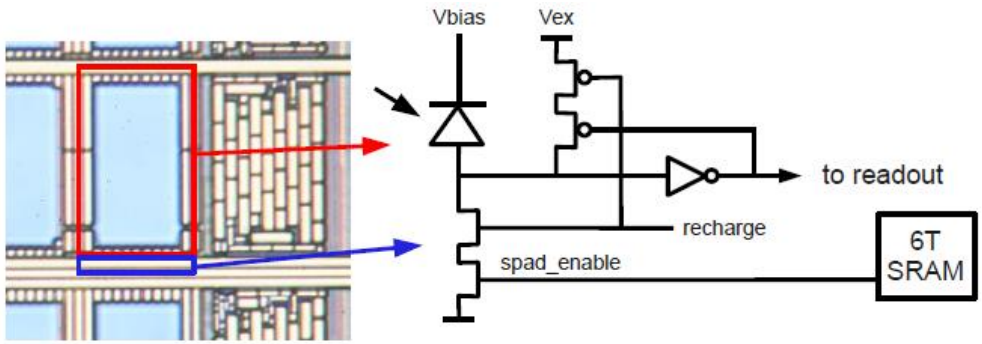


Detection&readout options presently considered

Baseline option
H12700B price: 1600 € per tube
Total MaPMT cost with spares: 2.2 M€

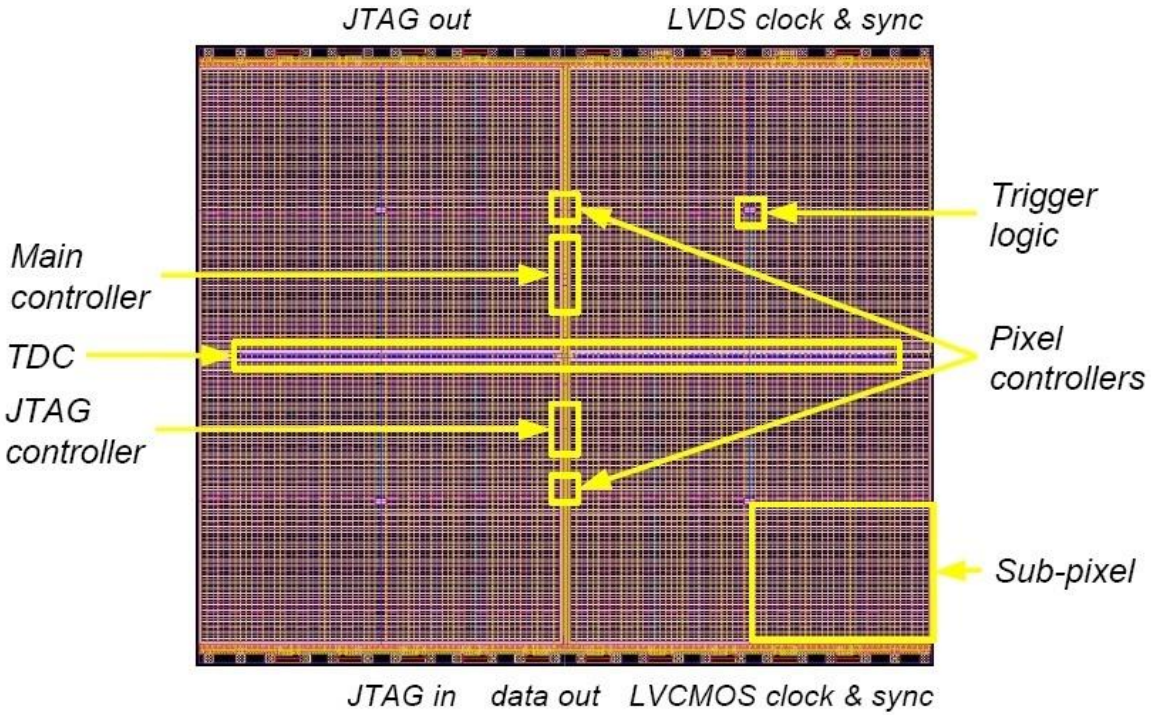
Dare-to-try option
Total modules cost with spares: 2.8 M€
Needs liquid cooling.

Philips Digital Photon Counter



Cell: SPAD+electronics

- Active quenching
- Logical output
- Cell enable/disable

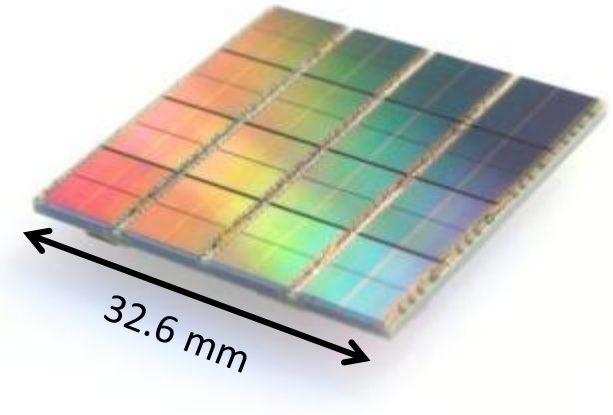


Die DPC-3200-22

- 2x2 pixels = 4 photon counters
- 3200 cells/pixel
- TDC (20 ps LSB)

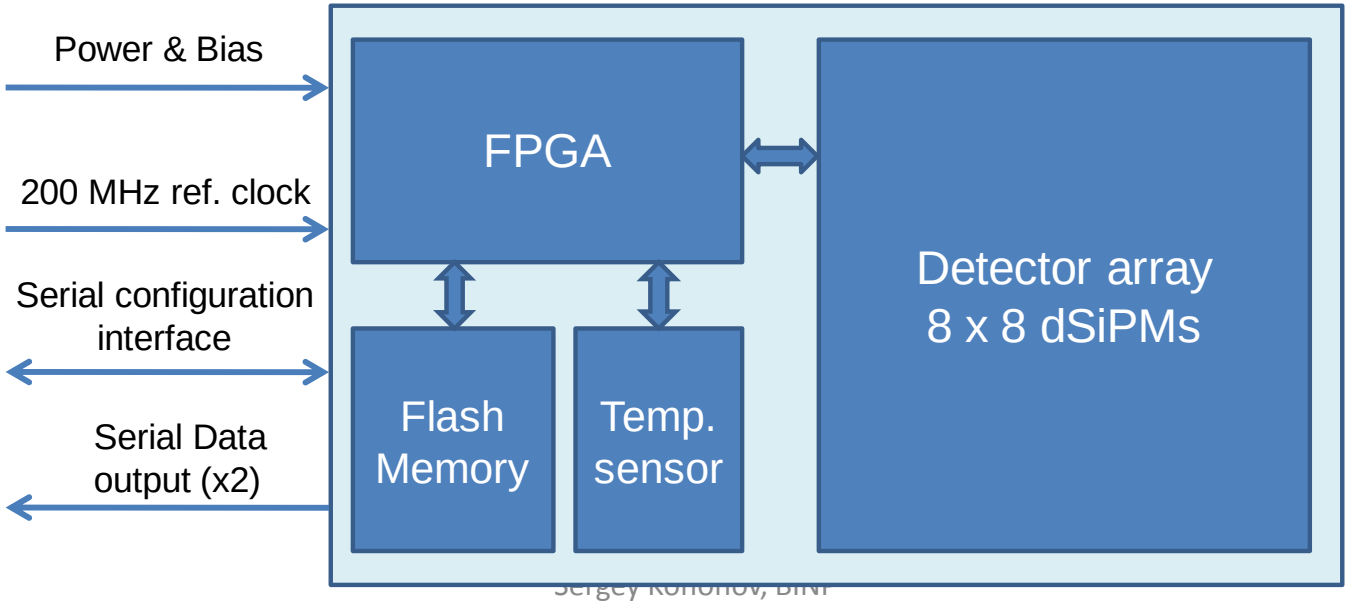
Digital Photon Counter tile

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



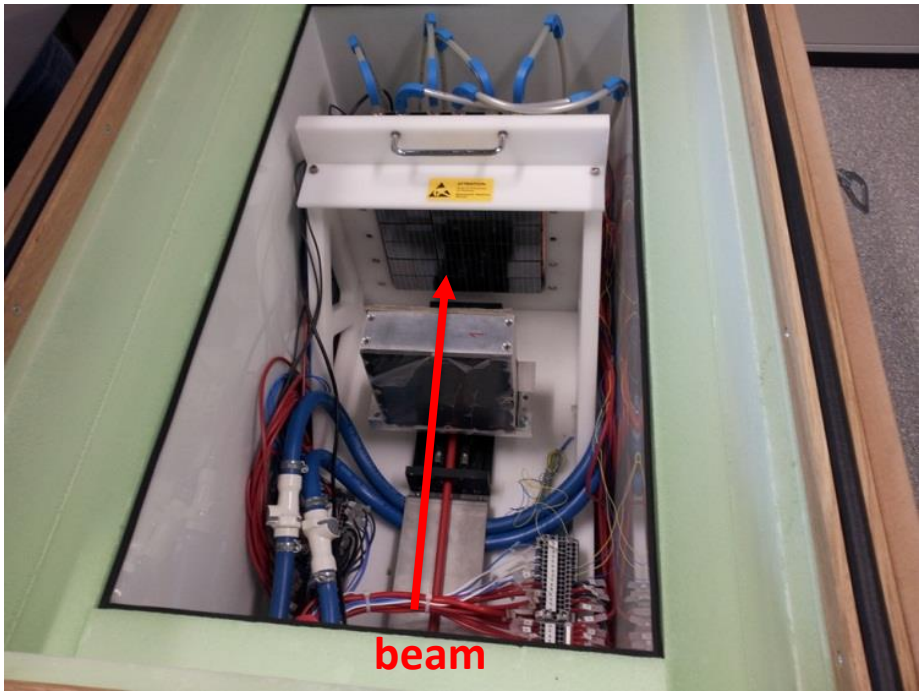
FPGA
- Clock distribution
- Data collection/concentration
- TDC linearization
- Saturation correction
- Skew correction

Flash
- FPGA firmware
- Configuration
- Inhibit memory maps

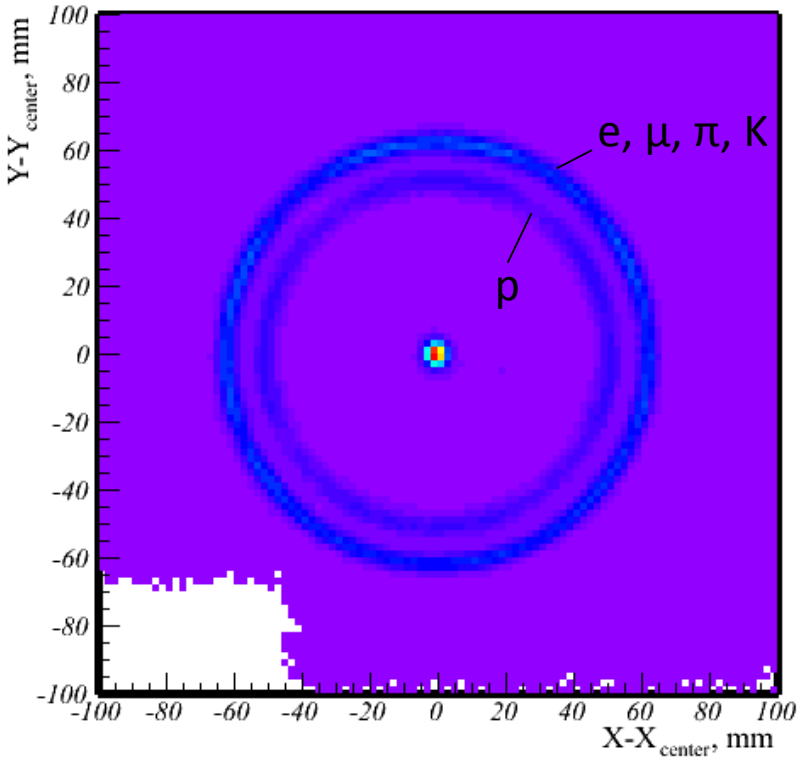


Beam test of FARICH-PDPC prototype

CERN PS/T10, June 2012

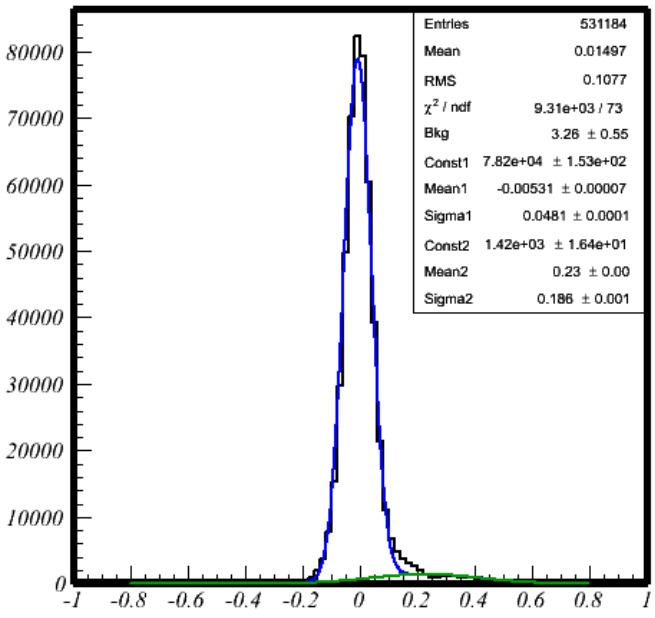


P=6 GeV/c, L=200mm

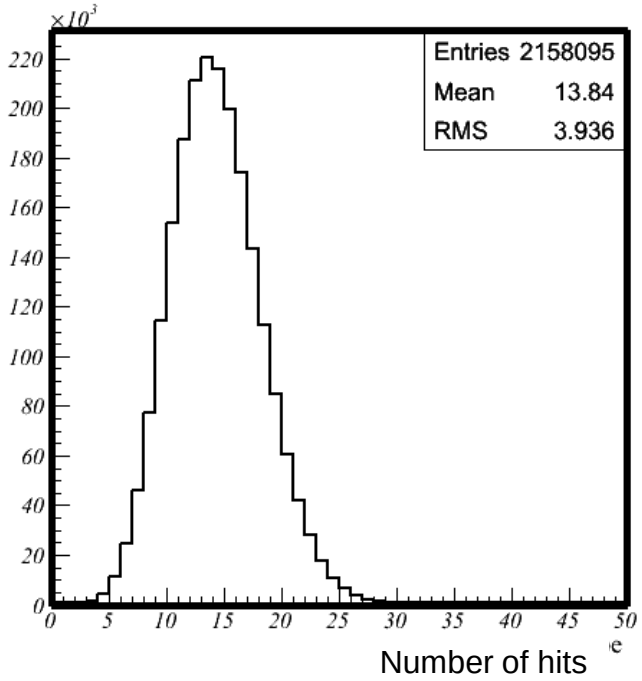


- Philips DPC array: 2034 pixels, 20x20cm^2
- Cooled down to -40°C to reduce dark count rate
- 4-layer aerogel with a focusing length of 200mm

PDPC-FARICH: timing resolution and number of photoelectrons



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



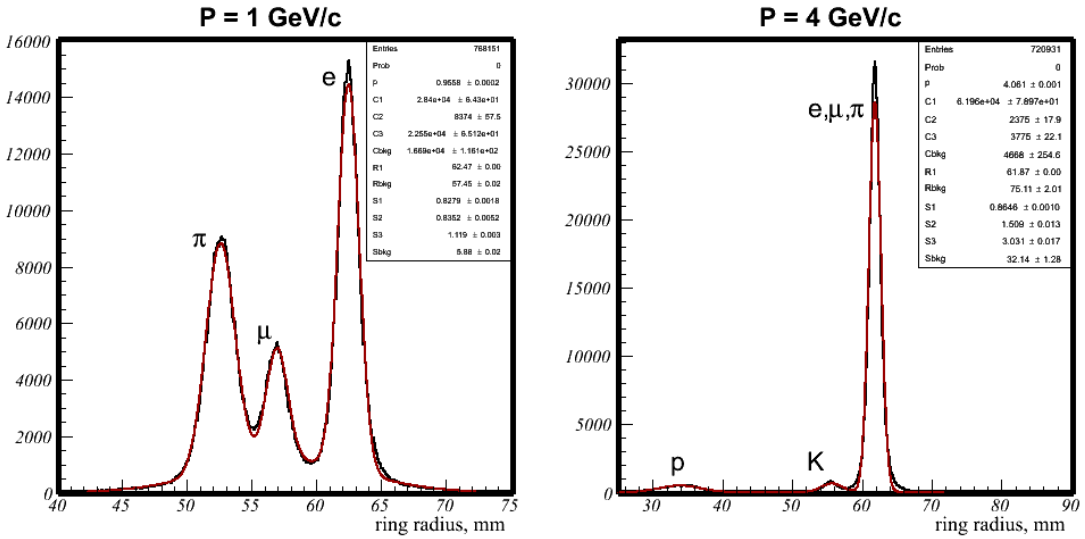
Number of hits

σ_{narrow} = 48ps for single photons

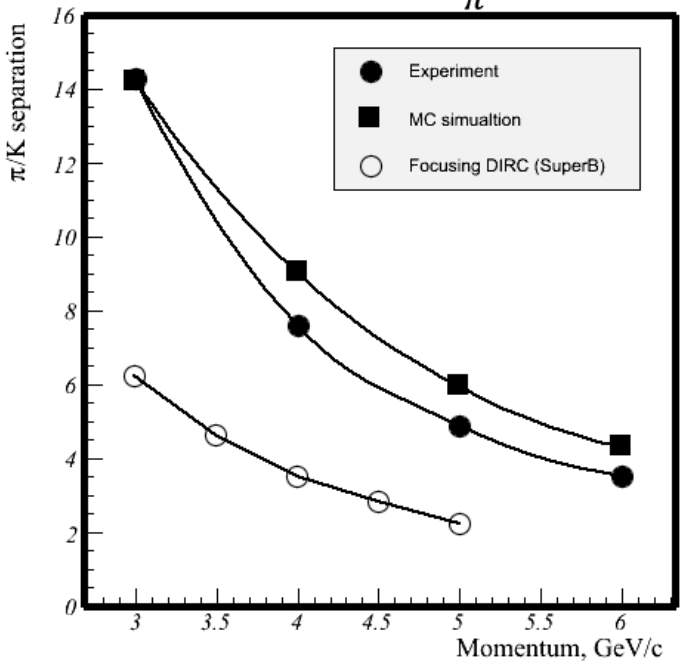
$\langle N_{p.e.} \rangle$ = 12
(accounted for optical crosstalks)
1.7 times lower than expected

PDPC-FARICH: Particle ID evaluation

Ring distribution on radius



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



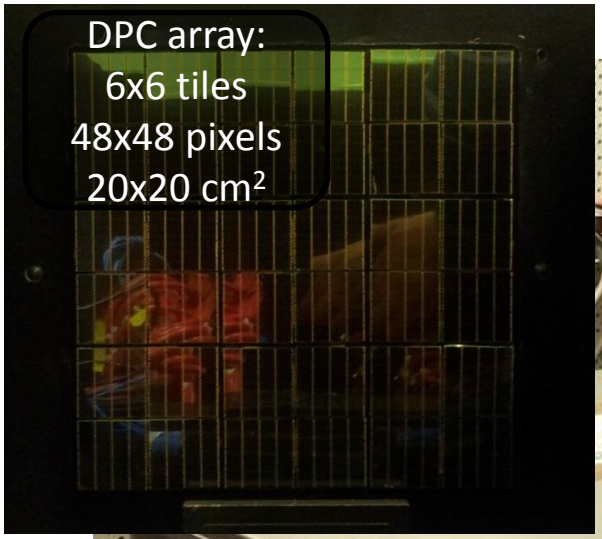
A.Yu. Barnyakov, et al., NIM A 732 (2013) 352

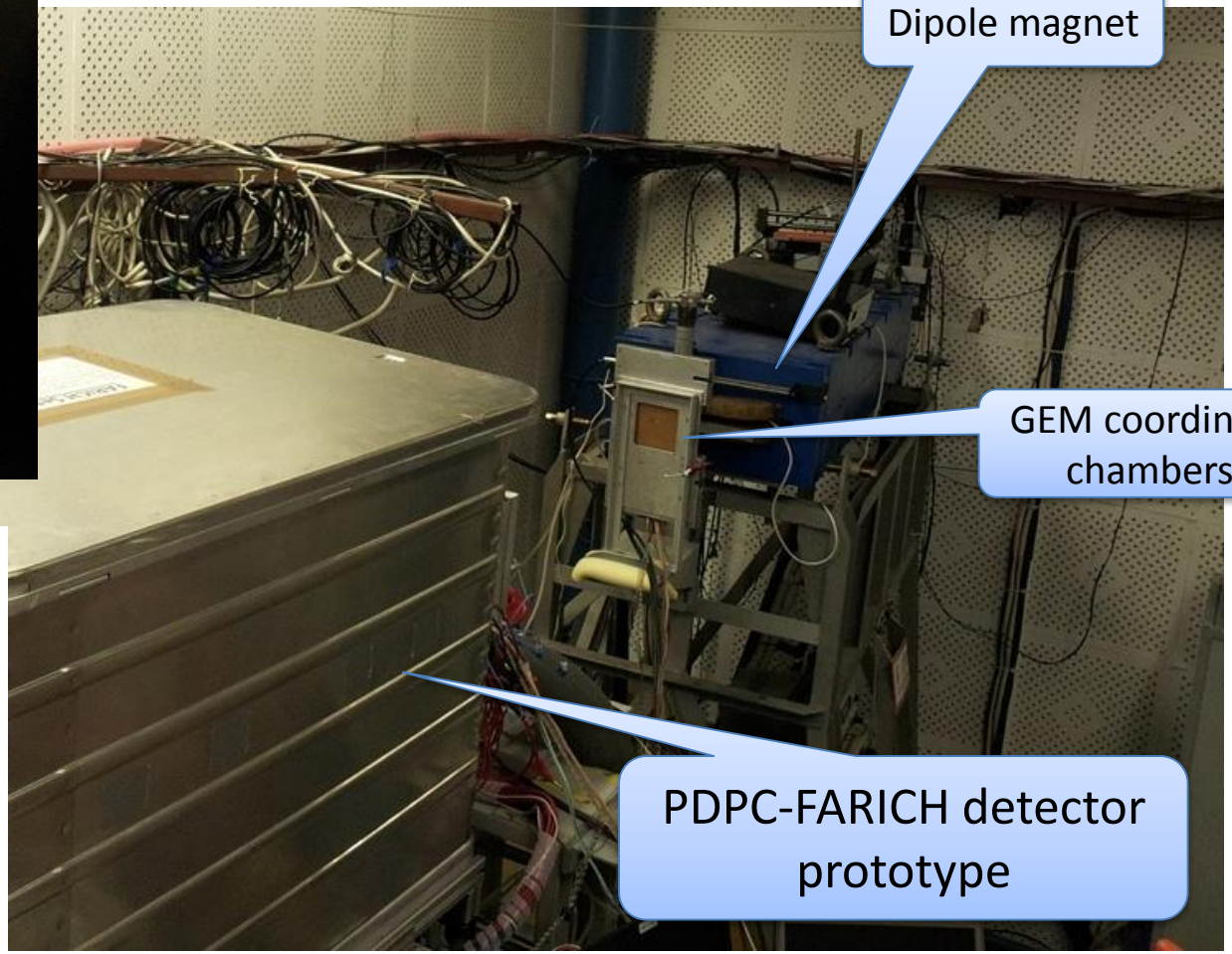
π /K: 7.6σ @ 4 GeV/*c*
μ/π: 5.3σ @ 1 GeV/*c*

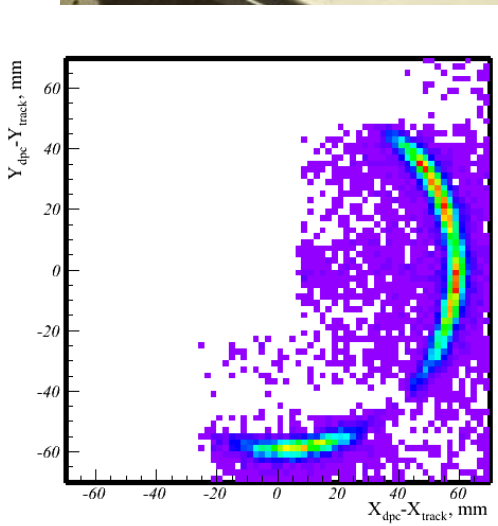
2.3 times higher than SuperB FDIRC
1.4 times higher than Belle II ARICH
2.6 times less than in initial MC simulation (with producer's PDE)

Aerogel to be optimized
DPC PDE lower than expected

PDPC-FARICH beam test. 2013 г.

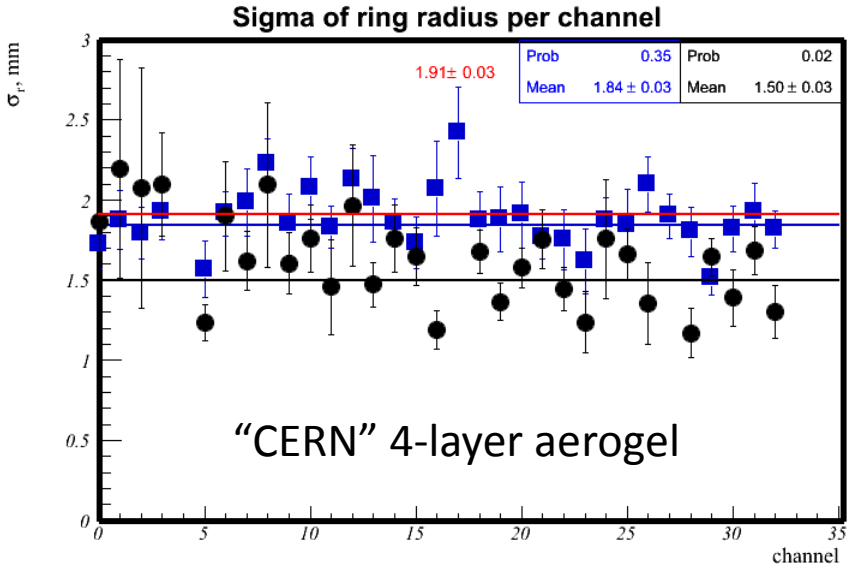


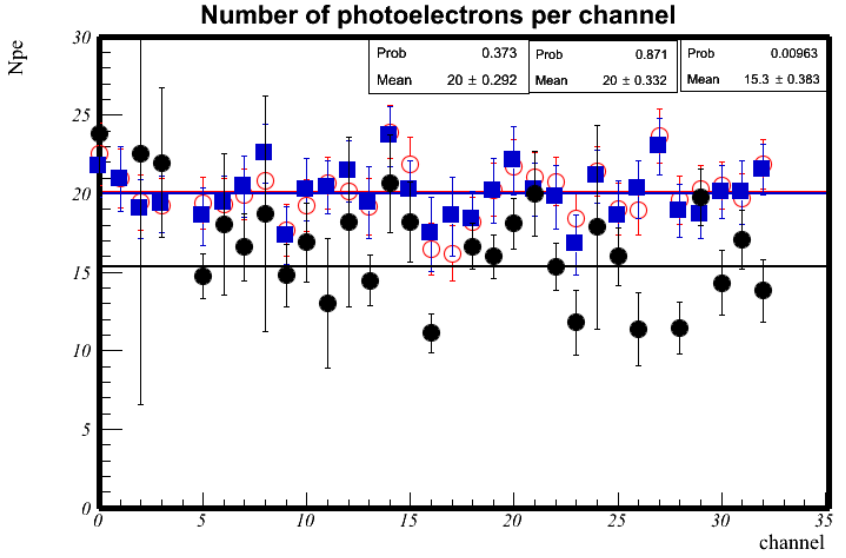




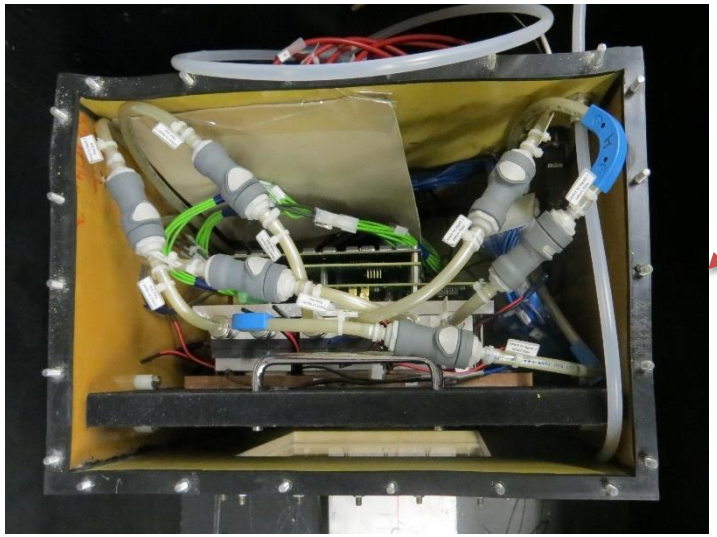
Beam test 2013 preliminary results

- Only 17 of 36 DPC tiles were functioning due to an initial failure. Still more than enough for aerogel characterization.
- Each DPC pixel was electronically masked to 1x1 mm^2 size (part of SPADs were disabled)
- 4 GEM strip chambers with 75x200µm internal resolution were used for tracking.
- 14 aerogel samples including ones with continuous density gradient were measured in several positions each. 7M events were acquired.

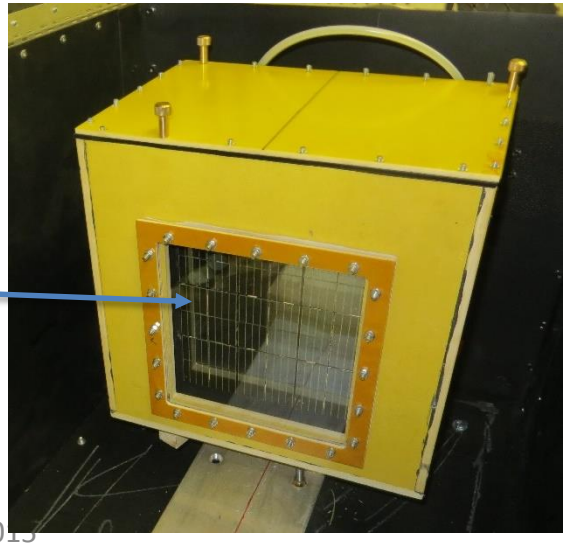




Upgrade of PDPC-FARICH prototype to Forward RICH prototype

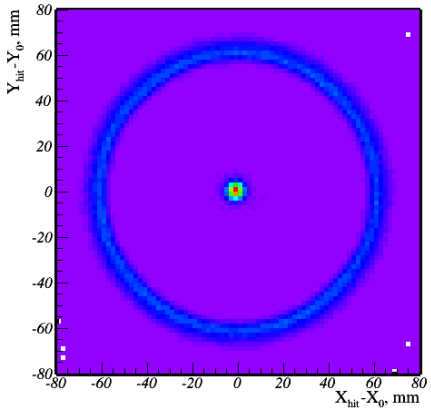


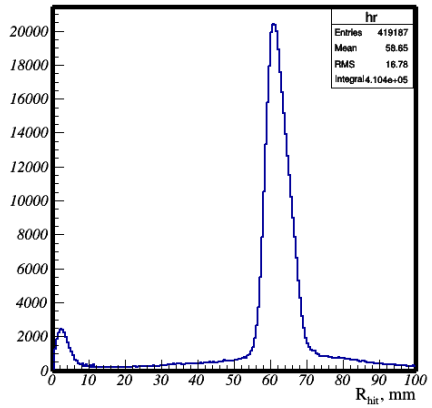
- Cold box for DPC photon detector. Aerogel is placed at room temperature and can be easily exchanged
- Extend aerogel-PD distance to ~500 mm
- Dark envelop box with moving stage for aerogel and mirror (under construction)



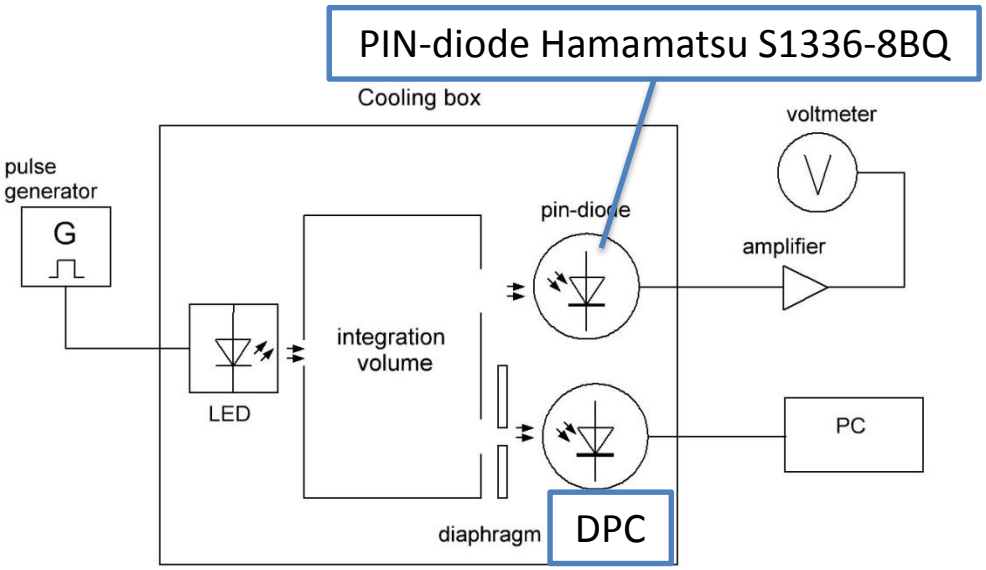
PMMA window

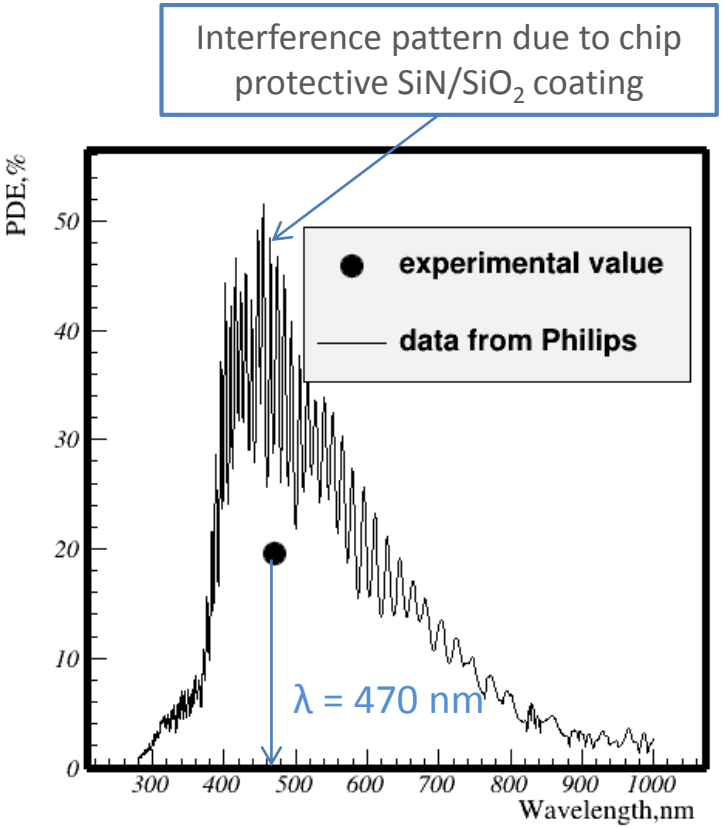
Test of upgraded DPC detector with e^- beam in March 2015





Absolute PDE measurement of DPC (2013)



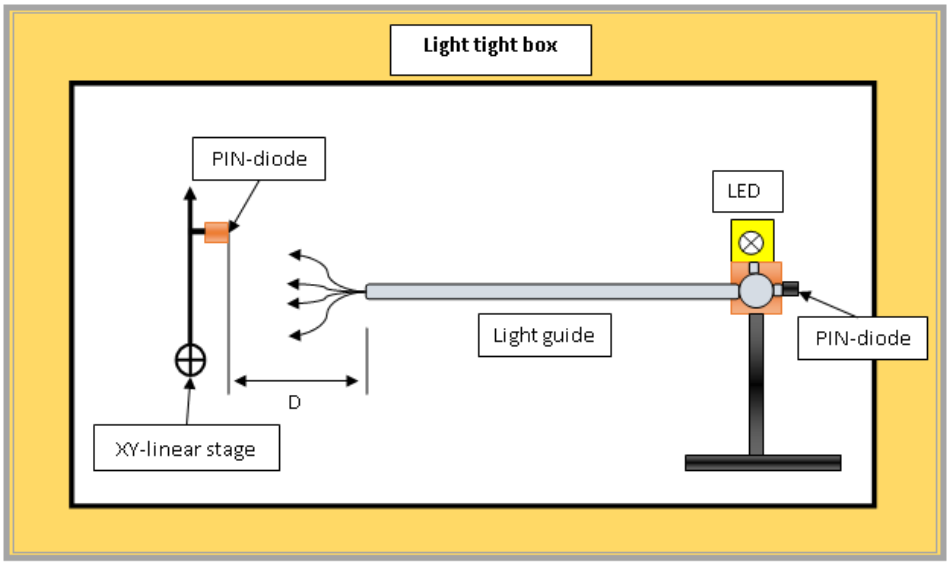


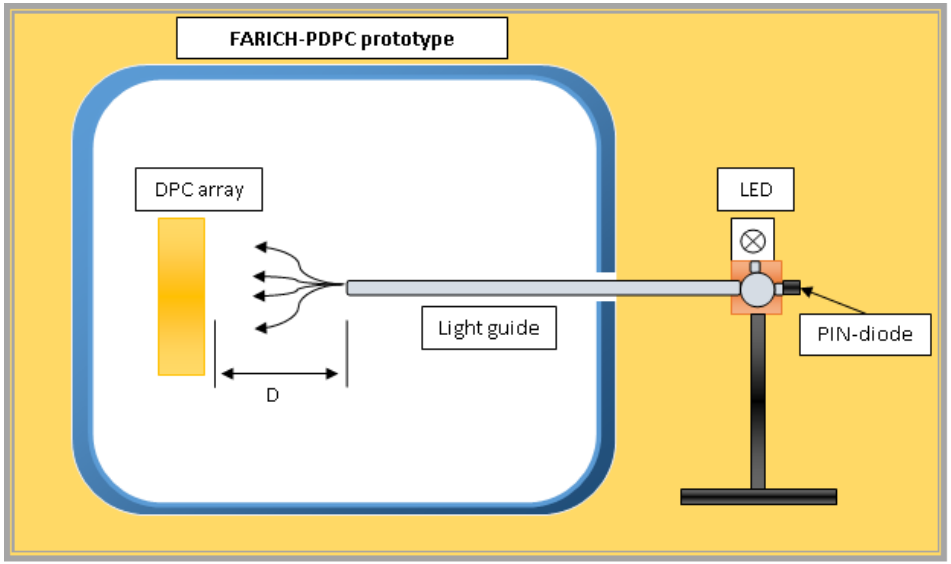
Measurement was done at T=−30°C. No temperature dependence was studied.

PDE(470nm)=19±1%
vs
36% according to PDPC data

DPC PDE measurement

Measurement scheme

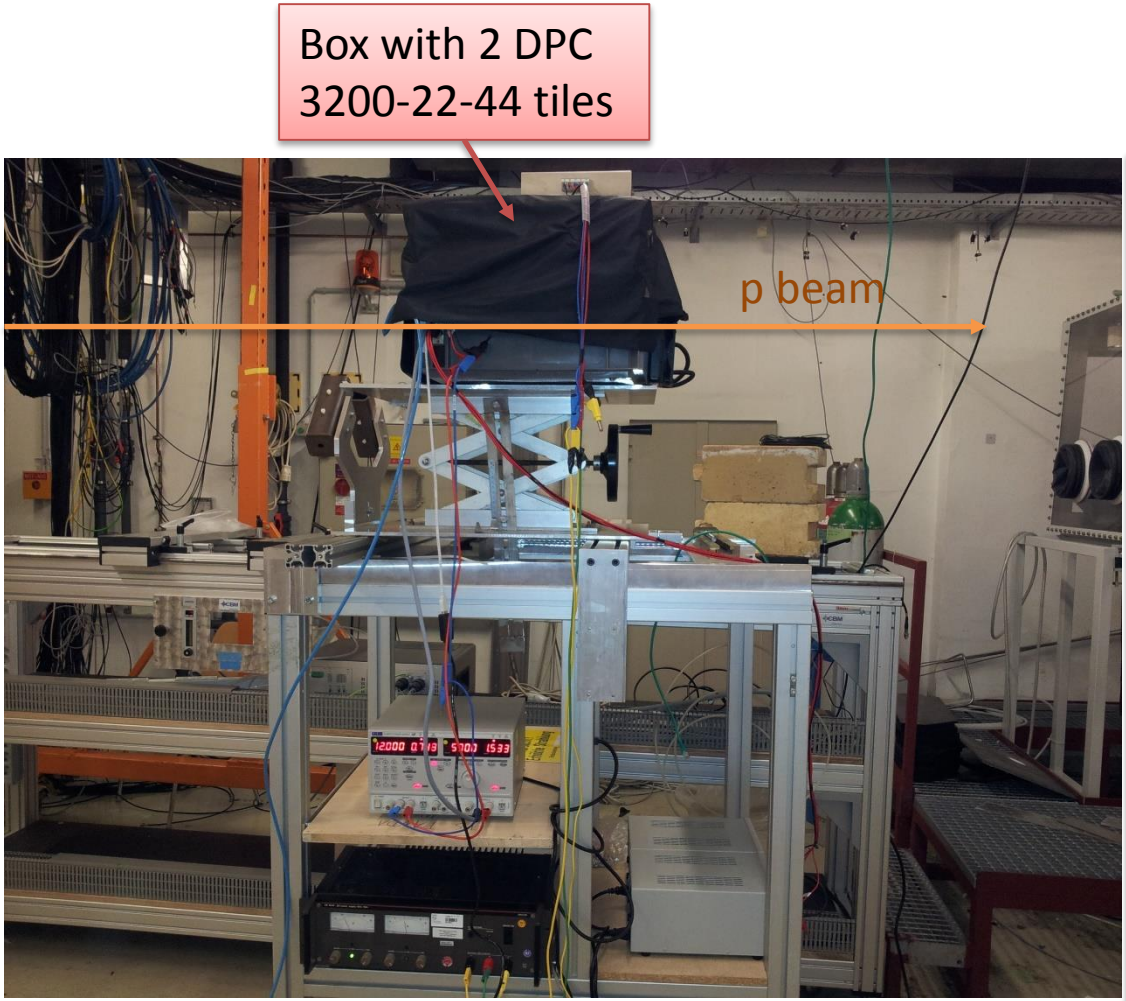




Scanning setup to calibrate wide-angle light source intensity

As PDPC-FARICH prototype is being refurbished we decided to switch to measurements with PDPC M-TEK instead. Now cooling system for M-TEK is set up. Calibrated Newport SiPD 918D-UV-OD3R will be used for absolute calibration.

Proton irradiation of DPC at COSY August 1-4, 2014

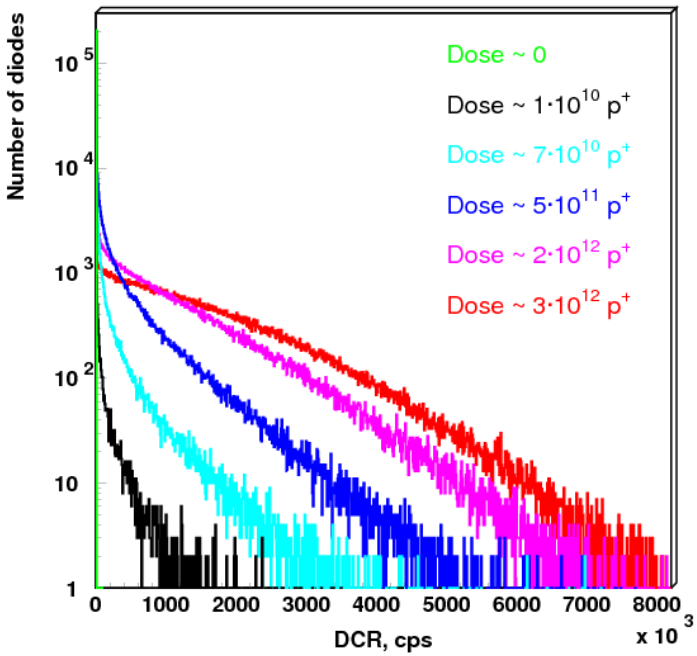


- Protons with P=800 MeV/c (T=295 MeV)
- Maximum fluence ~$4 \cdot 10^{11}$ p/cm^2 accumulated in 9 steps
- Tiles irradiated at -18°C
- DCR scan of cells was done in beam stops
- Total dose is measured by ionization chamber provided by COSY team
- Beam profile was determined by data

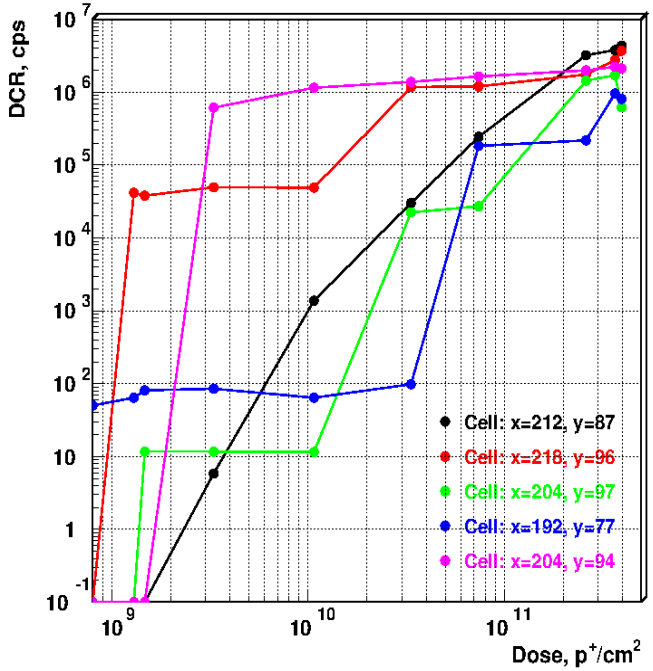
Poster by M. Barnyakov on Pisa2015 conference

Effect of irradiation on cell DCR

DCR distribution of cells for several total doses



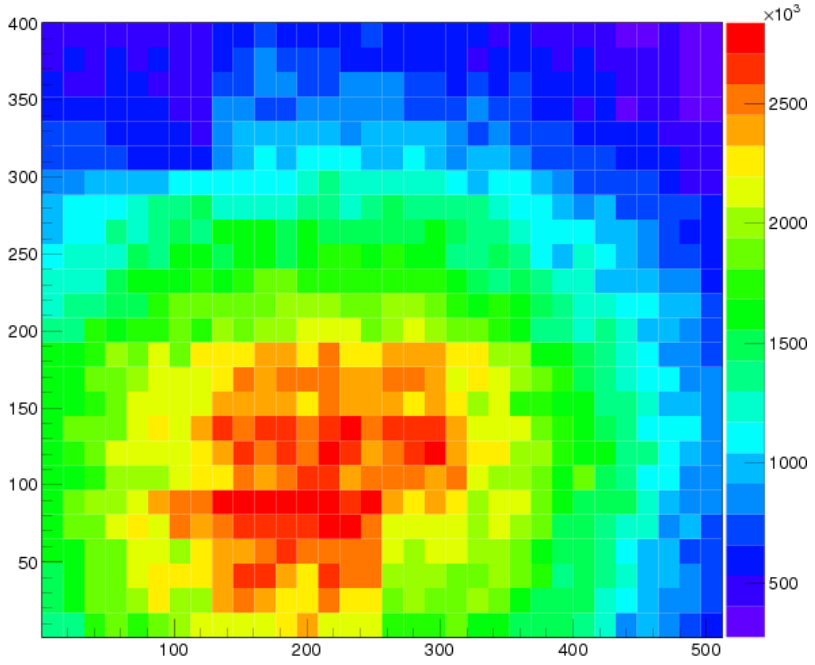
Change of DCR for 5 cells vs fluence



With the dose accumulation the number of noisy cells increases rather than DCR of each cell. ⇒ Cell damage caused by single interaction of protons with Si lattice.

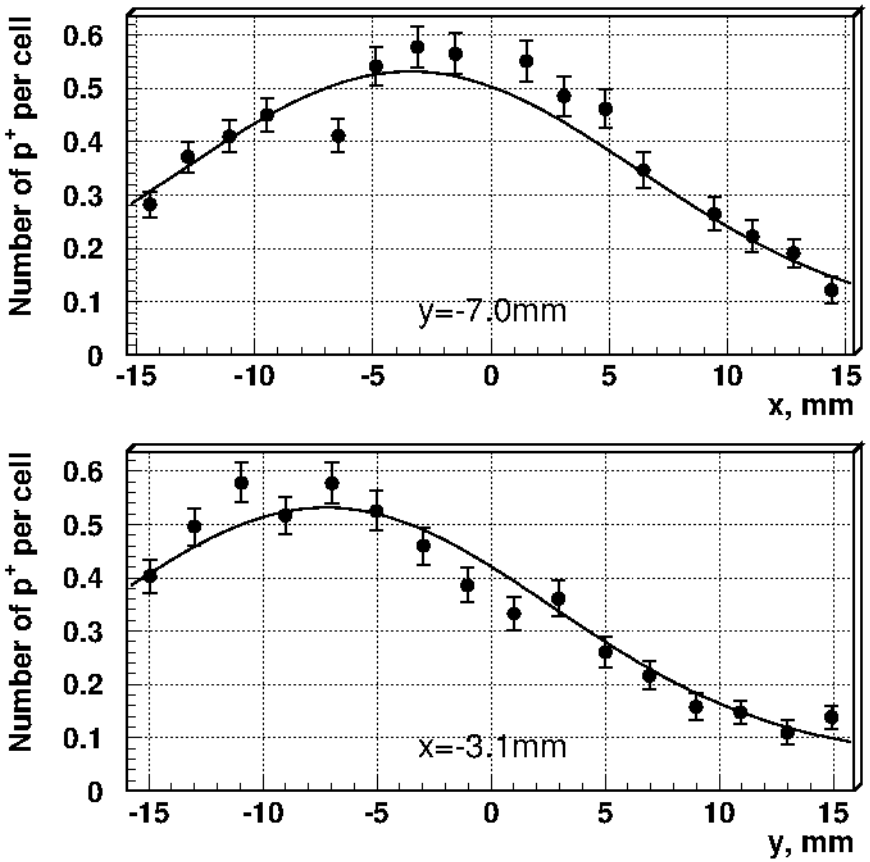
Beam profile and fluence evaluation

Dark count rate map after final dose



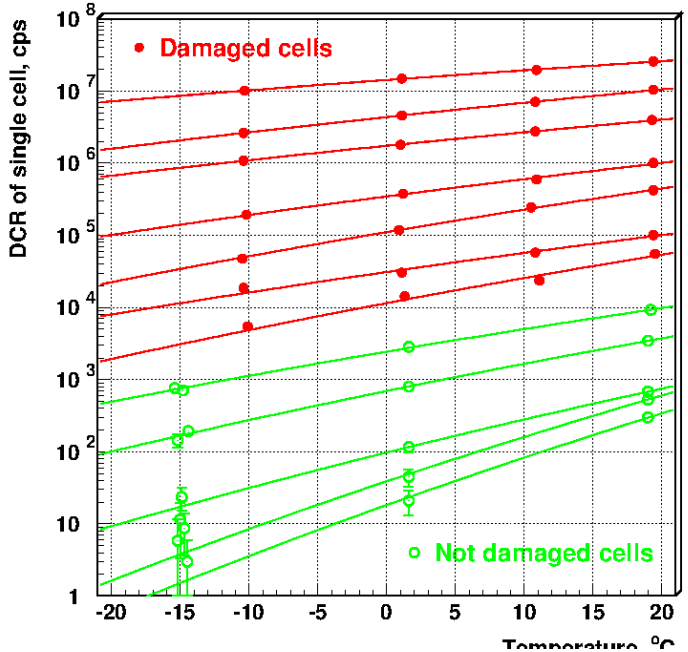
Gaussian fit of beam profile

evaluated from the fraction of damaged cells per subpixel (32x25 cells)



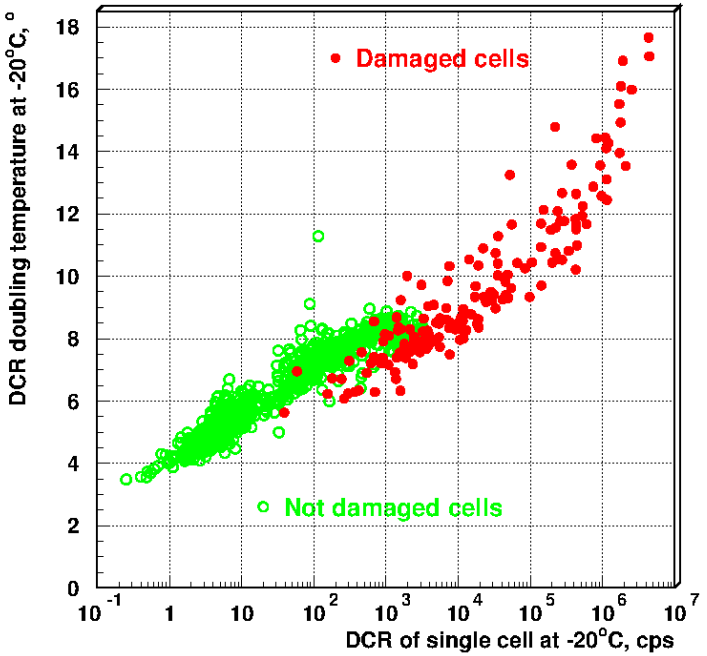
DCR vs temperature

DCR vs temperature fit



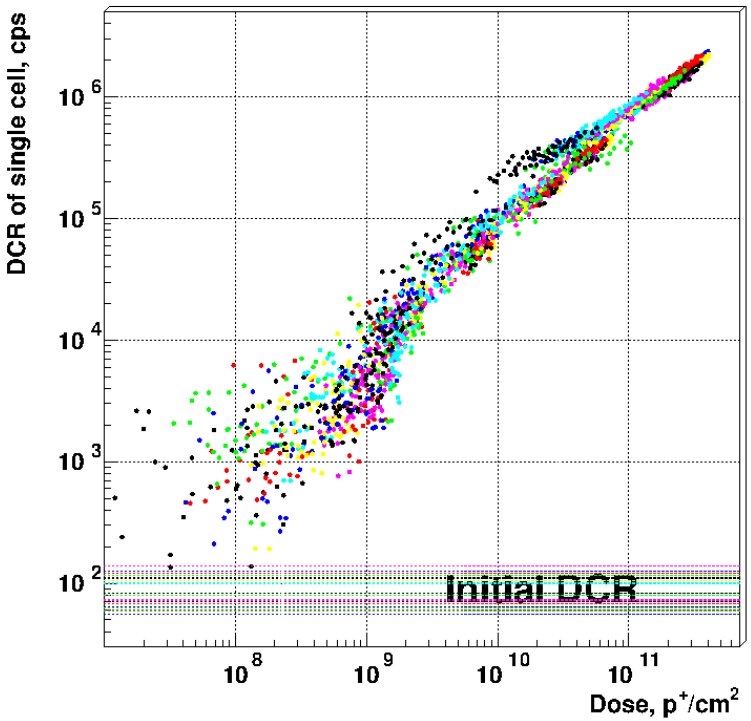
Richardson's law fit: $AT^2\exp(-{}^{\alpha}/_{T})$

Temperature difference that doubles DCR



Dark count rate vs fluence

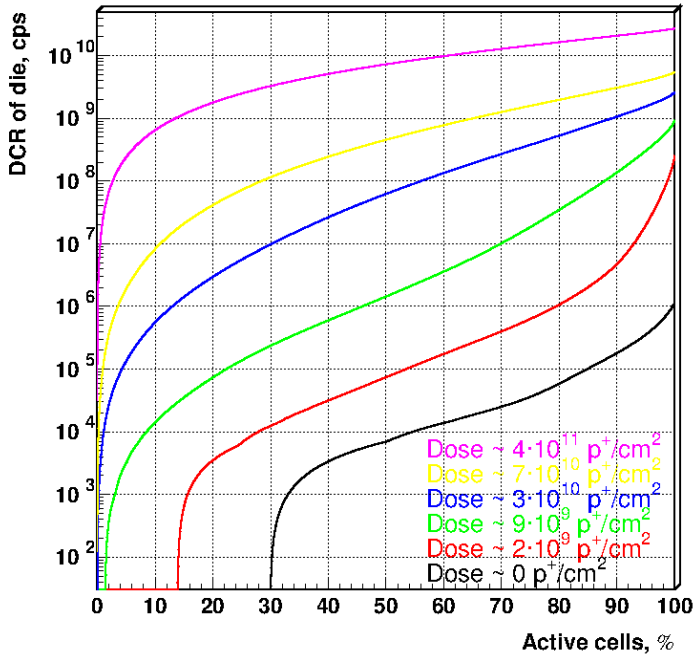
Single cell DCR averaged over one subpixel (32x25 cells).
Different colors for different dies.



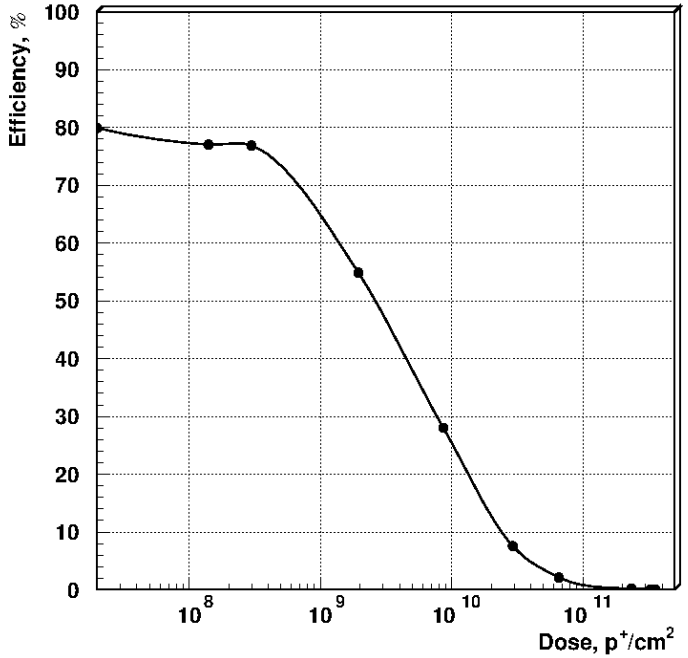
- Maximum fluence of protons (T=295 MeV) is ~$4x10^{11}cm^{-2}$.
- NIEL scaled fluence of 1MeV Each point indicates single cell

Estimation of efficiency degradation

DCR of a die as a function of active cells fraction for different proton fluences.

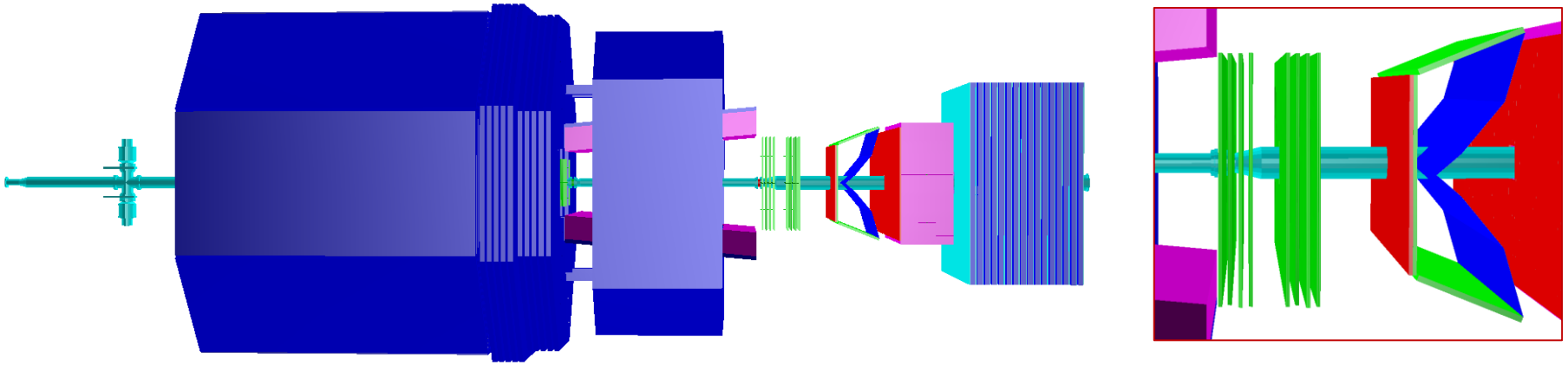


Optimal efficiency of single photons detection as a function of proton fluence.

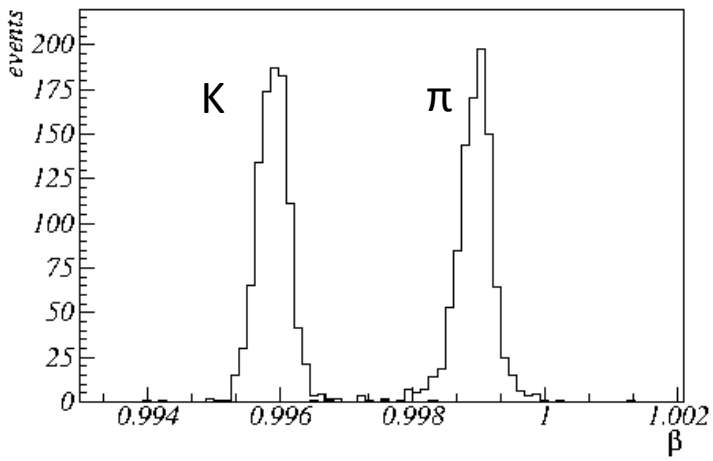


Optimal efficiency is a tradeoff between number of active cells and dead time due to dark conting rate. Minimum dead time for current chip design is 720 ns.

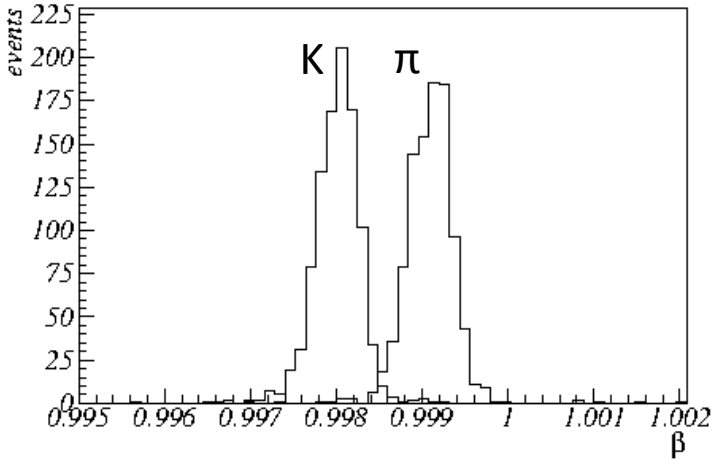
PANDAroot simulation of the Forward RICH



P=6 GeV/c

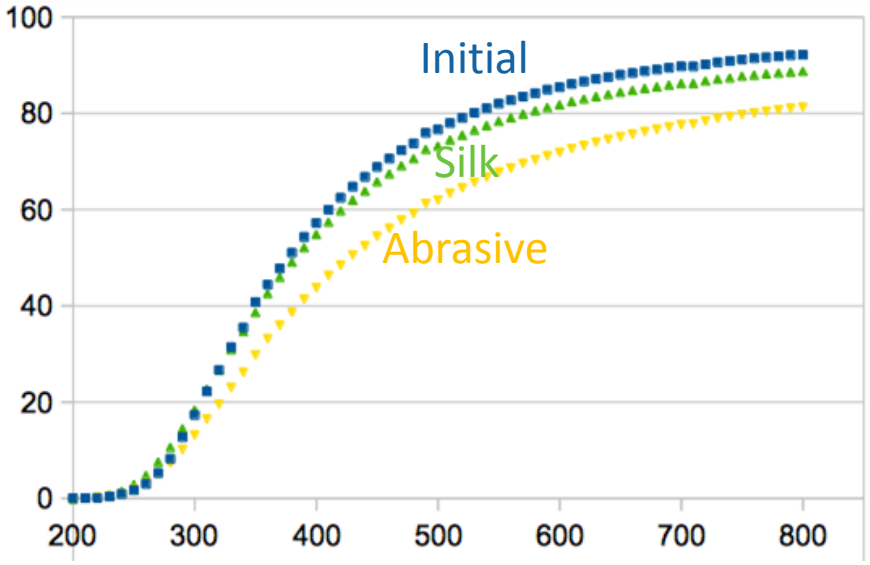


P=10 GeV/c



Aerogel polishing

Transmittance (%) as function of wavelength



Fit transmittance by

$$T(\lambda) = A \exp\left(-\frac{t}{L_{sc}(\lambda/400\text{nm})^4} - \frac{M}{(\lambda/400\text{nm})^2}\right)$$

	Initial	Abrasive	Silk
A	94.9±0.8	91.2±1.7	92.4±1.2
L_{sc}	51.3±0.9	56.8±2.2	50.3±1.5
M	0.01±0.01	0.36±0.03	0.05±0.02

Optical smooth surfaces after polishing will allow us to

- construct RICH radiator of two separate aerogel layers and increase production yield,
- improve light output from cut tile sides.

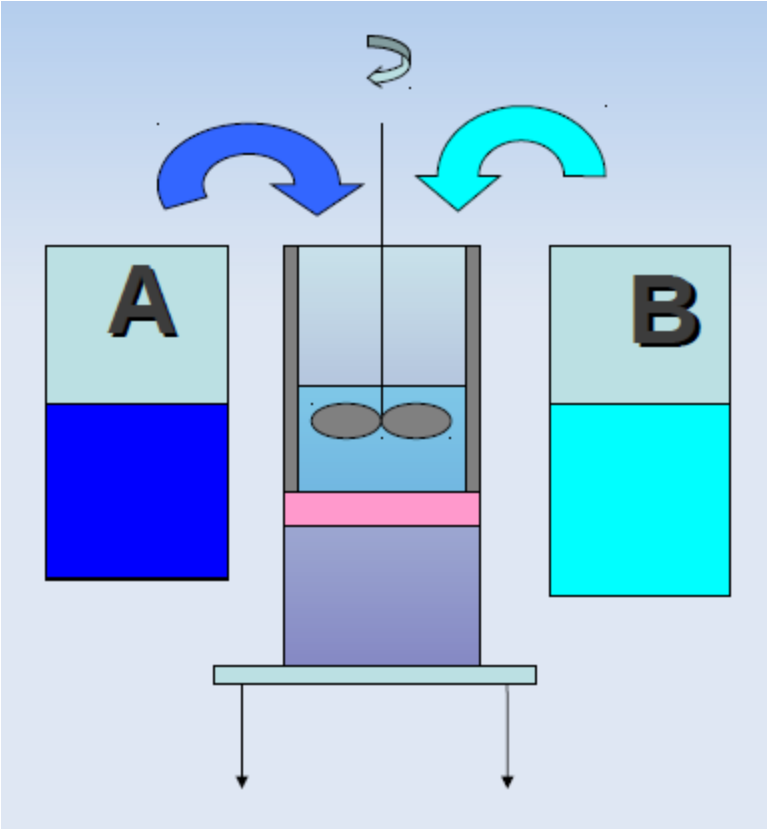
R&D funding

Agencies	Sum per year, kEuro	Period	Status
Helmholtz Ass. & Rosatom through ITEP/FRRC	78	2014-2017	approved
Russian Fund for Basic Research (on FARICH)	10	2014-2016	approved
Novosibirsk State University (PANDA lab is founded)	31	2014-2016	approved
Russian Fund for Basic Research (on PANDA FRICH)	10	2015-2017	Not supported

Project status

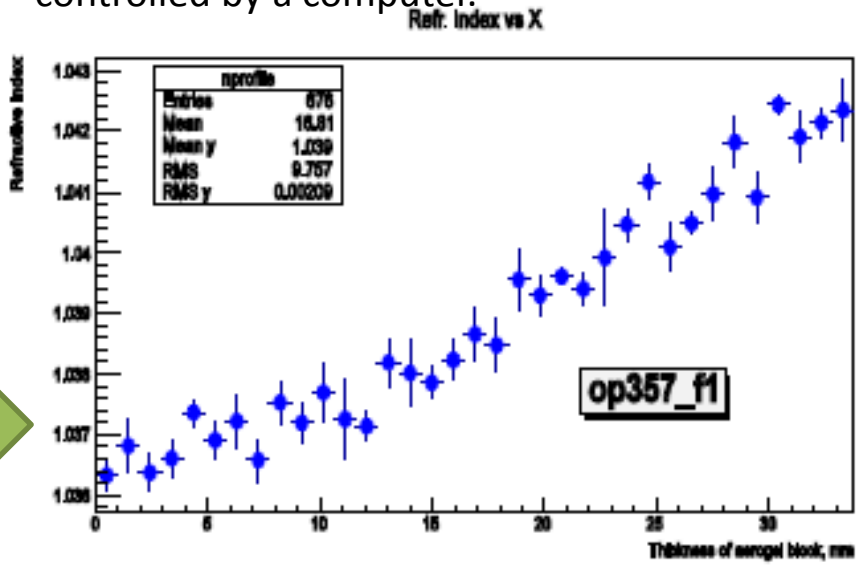
- Funding up to 2017 has been secured
- Core team has been formed (~5 FTE).
- PANDAroot simulation is in progress. First results on PID performance of FRICH have been obtained.
- Aerogel polishing technique has been developed.
- DPC PDE measurement is in progress.
- FRICH-DPC prototype is being constructed
- Option with MaPMT H12700 is to be studied

Continuous density gradient aerogel



To produce aerogel tiles with designed profile of gradient we modernized the method suggested by [S.M. Jones "A method for producing gradient density aerogel", J Sol-Gel Sci Technol. 44 (2007) 255]

- We mix two pre-prepared mixtures with different content of TEOS fed by peristaltic pumps from vessels A and B.
- The mixture with designed concentration of TEOS 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.



Refractive index profile along thickness