FARICH detector for the Super Charm-Tau factory in Novosibirsk

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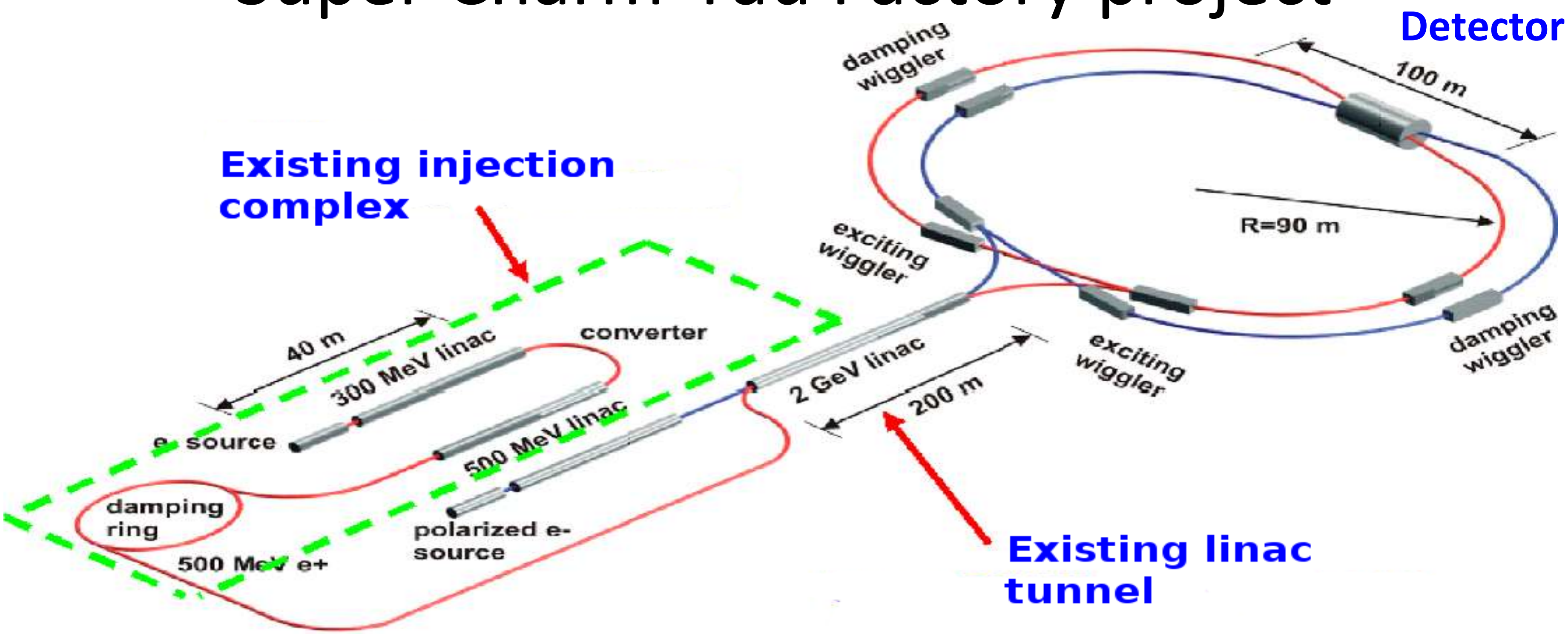
CERN-BINP workshop for young scientis

Outline:

- Super Charm-Tau factory detector concept
- Focusing Aerogel RICH (FARICH)
  - Method
  - Prototype beam test results
  - FARICH detector for SCTF
- Status of aerogel production in Novosibirsk
- Beam test facilities in BINP
- Photon detectors issues
- Summary

Super Charm-Tau Factory project



Factory outline:

- Double ring Symmetric e^+e^- collider with Crab Waist scheme
- $E_{c.m.} = 2 \div 5$ GeV
- $L = 10^{35}$ $cm^{-2}s^{-1}$
  (100 times more than existing c-τ factories)
- Longitudinal polarization of e^- - beams in IP

Detector for Super CT-factory

Factory outline:

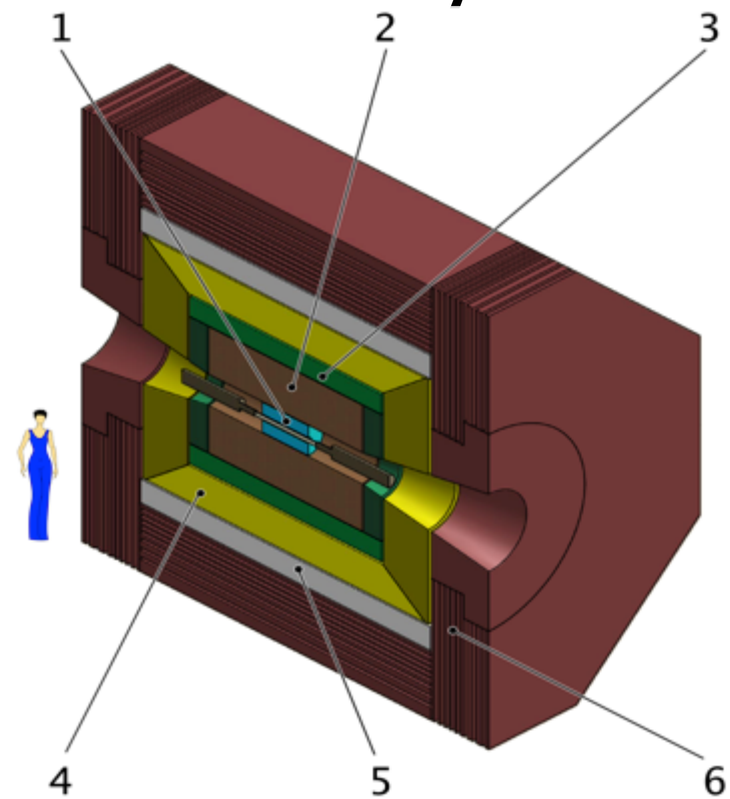
- Symmetric e^+e^- collider
- $E_{c.m.} = 2–5$ GeV
- $L = 10^{35}$ $cm^{-2}s^{-1}$
  (100 times more than existing c-τ factories)

Physical program:

- Rare decays of D mesons, τ lepton;
- $D^0\check{D}^0$ oscillations;
- Searches for lepton-flavor-violating decays of τ (for instance $\tau \to \mu\gamma$);
- …

Detector requirements

- An excellent momentum resolution for charged particles and a good energy resolution for photons;
- K/π separation higher than 3σ;
  μ/π separation up to 1.2 GeV/c;
- DAQ system, which is able to read events at a rate of 300–400 kHz with 30kB event length;
- …



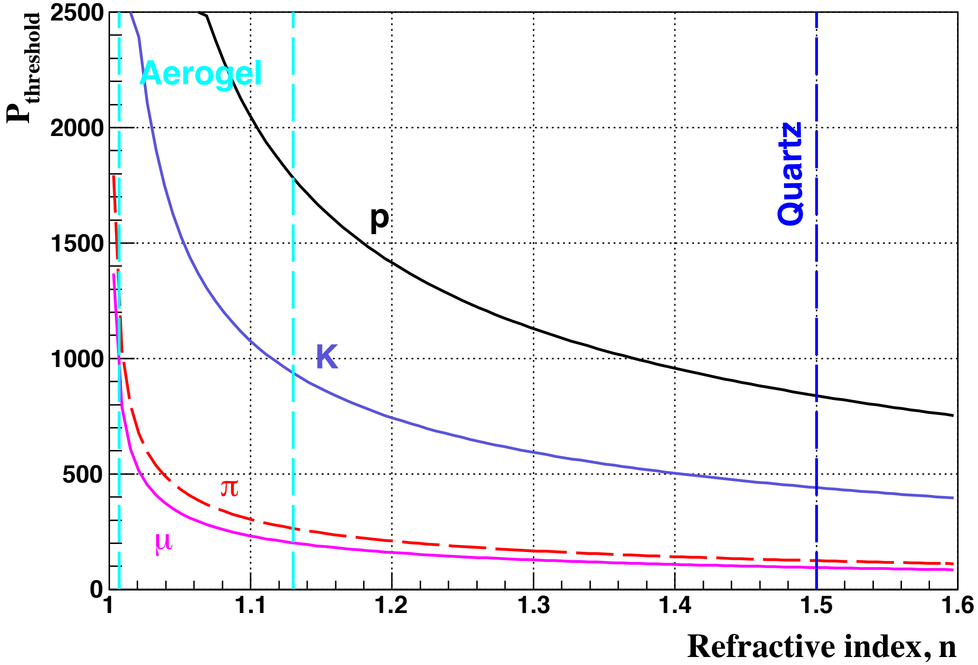
- 1 – Vertex Detector
- 2 – Drift Chamber
- 3 – PID => FARICH
- 4 – EMC
- 5 – Superconducting Solenoid
- 6 – IFR

See CTF CDR (https://ctd.inp.nsk.su/docs/ScTau_CDR_en/CDR_en_ScTau.pdf)

Focusing Aerogel RICH for PID system

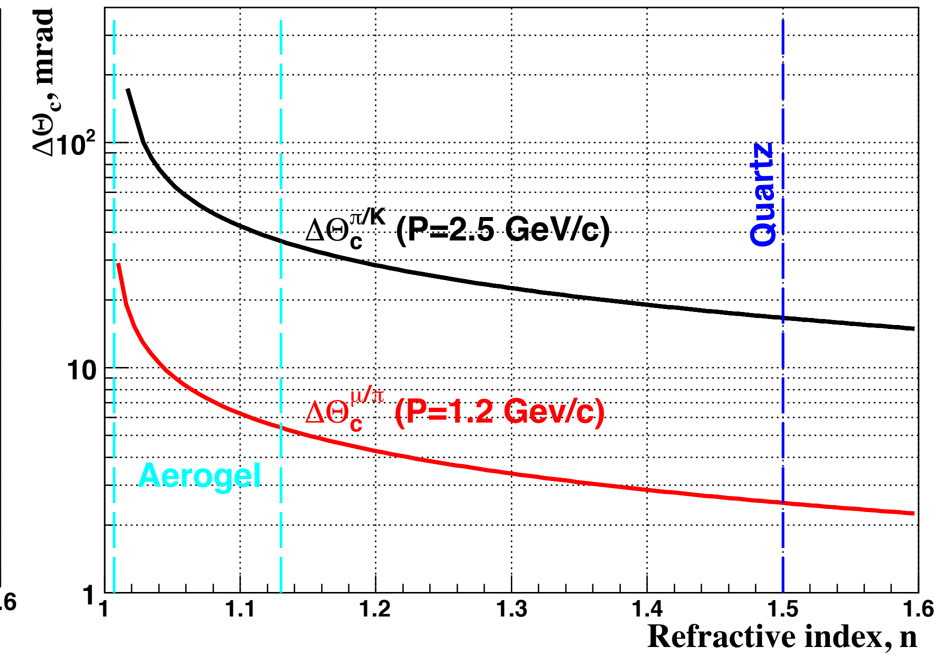
(Motivation)

Dependence of Cherenkov threshold momentum on refractive index



Aerogel threshold counters could be used for reliable K/π separation.

Dependence of $\Delta\Theta_c$ on refractive index



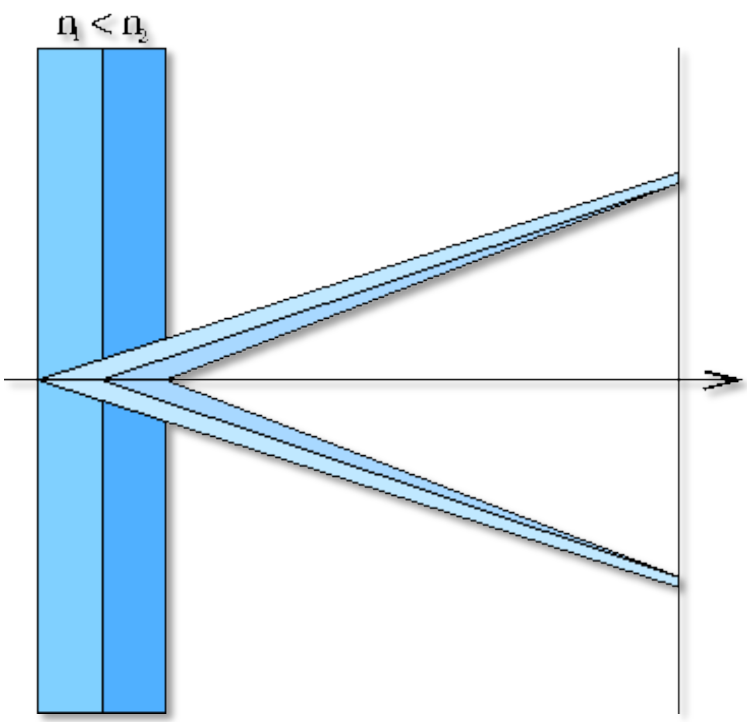
For reliable μ/π separation we need aerogel RICH with $\sigma_{track}(\Theta_c) < 2.5$ mrad

See the topic of Ivan Ovtin
"Aerogel Cherenkov counters of the KEDR detector"

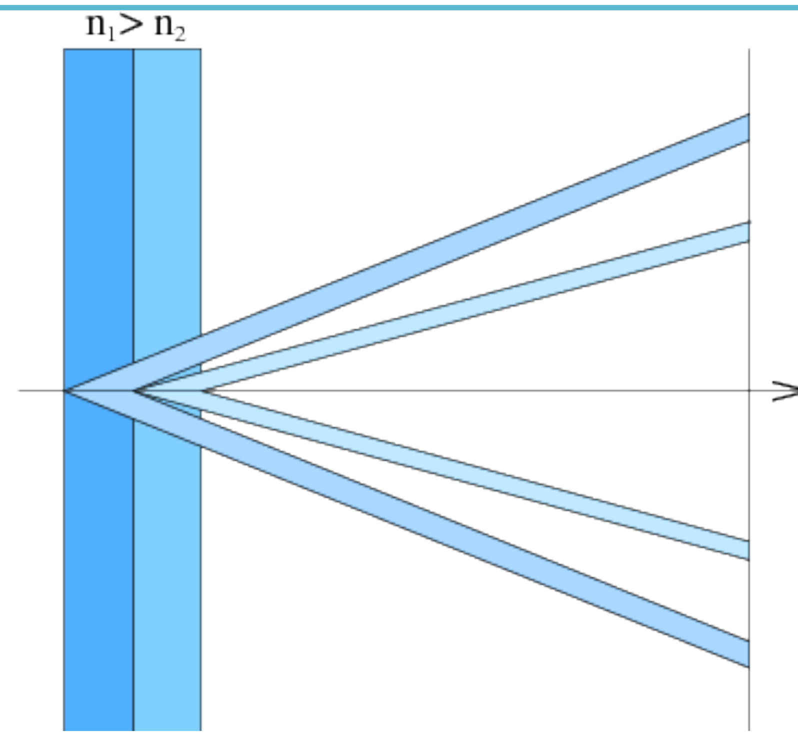
Focusing Aerogel RICH – FARICH
(Concept)

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

Single ring option



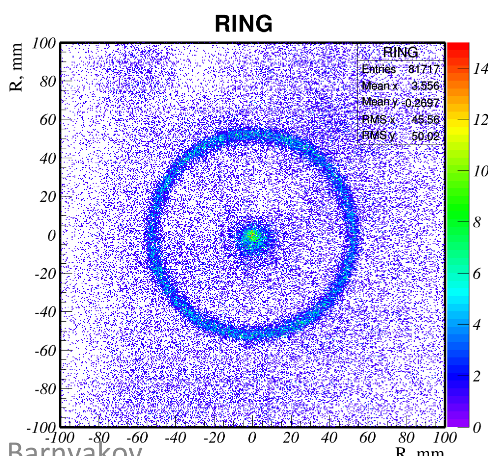
Multi-ring option

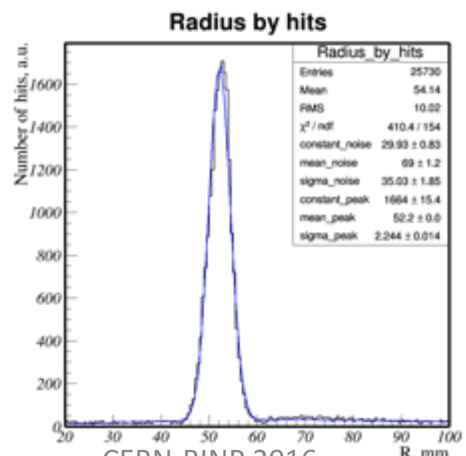


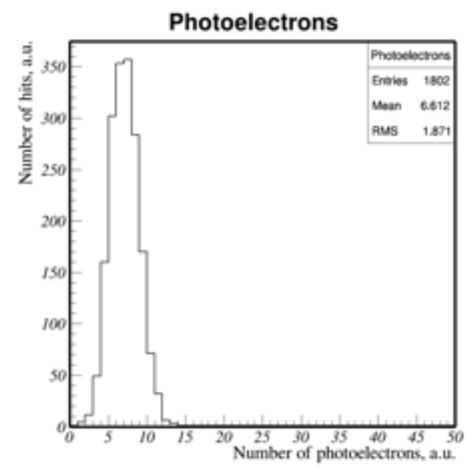
T.Iijima et al., NIM A548 (2005) 383
A.Yu.Barnyakov et al., NIM A553 (2005) 70

Single ring option: two approaches

Two blocks	**Two layer block**
• Aerogel RICH for Belle-II: – n_1=1.045, n_2=1.055 – Thickness – 20 + 20 mm – Distance – 200 mm • HAPD with 5x5 mm pixel • σ_Θ=15.8 mrad and N_{pe}=8.6 $\sigma_\Theta(track)= \sigma_\Theta/\sqrt{N_{pe}} \approx 5.4$ mrad *S.Nishida et al., NIM A 766 (2014) 28*	• Aerogel from BINP&BIC: – n_1=1.045, n_2=1.053 – Thickness – 15 + 15 mm – Distance – 200 mm • Philips DPC3200 – 4x4 mm pixel • σ_Θ=11.2 mrad and N_{pe}=6.6 $\sigma_\Theta(track)= \sigma_\Theta/\sqrt{N_{pe}} \approx 4.4$ mrad *Preliminary results of BINP testbeam 2016*



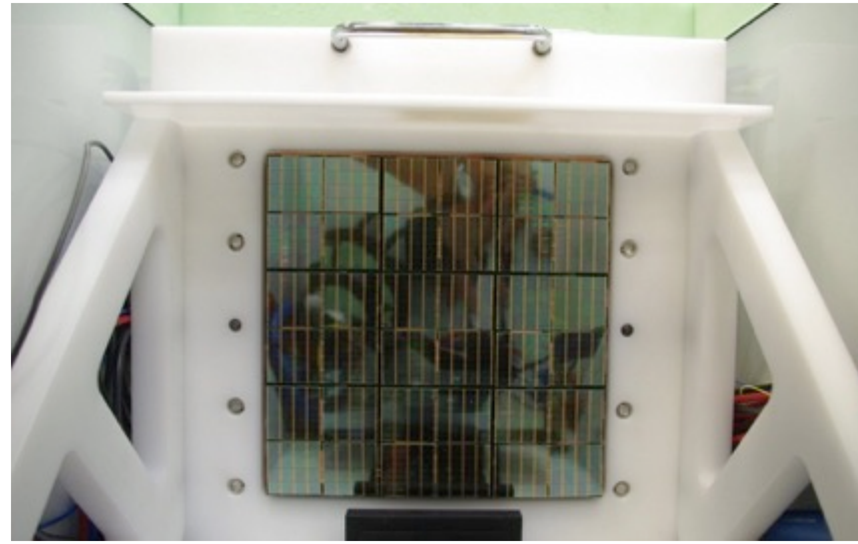




Beam test of FARICH at CERN PS T10, June 2012

4-layer aerogel

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



Test conditions

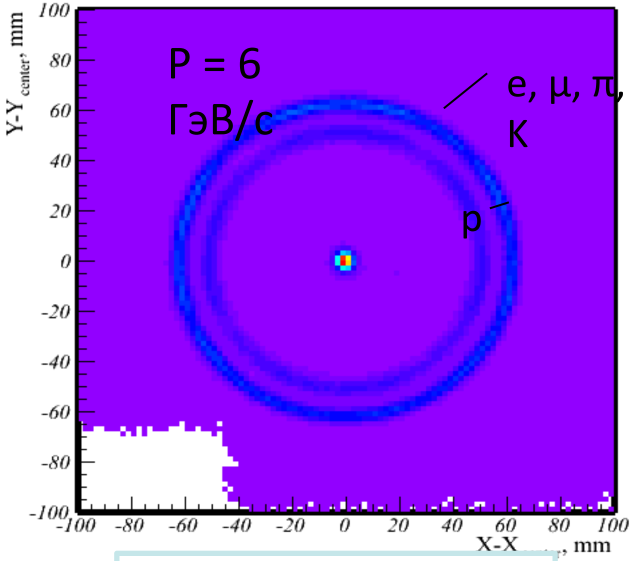
- Positive polarity: e^+, μ^+, π^+, K^+, p
- Momentum: 1–6 GeV/c
- Trigger: a pair of sc. counters 1.5x1.5 cm^2 in coincidence separated by ~3 m
- No external tracking, particle ID, precise timing

DPC matrix 20x20 cm^2

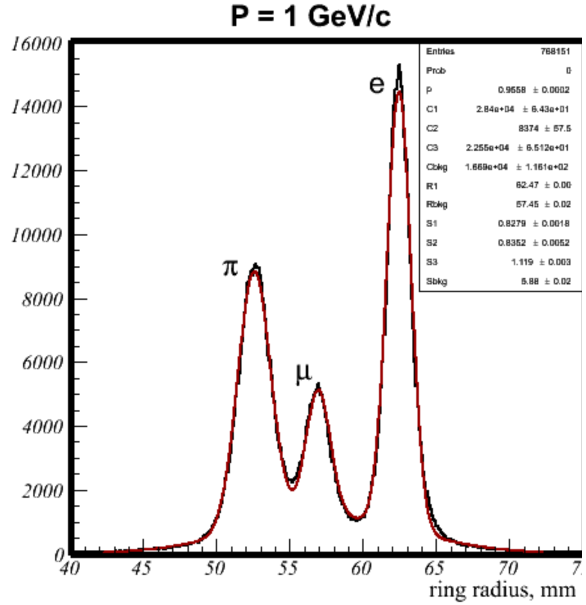
- Sensors: DPC3200-22-44
- 3x3 modules = 6x6 tiles =
  24x24 dies = 48x48 pixels
- 576 time channels
- 2304 amplitude (position) channels
- Operation at –40°C to reduce
  dark counts

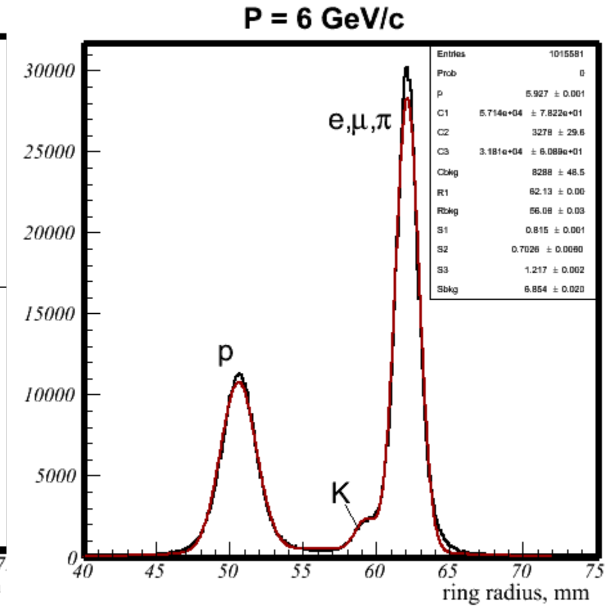
Beam test results

Hit positions

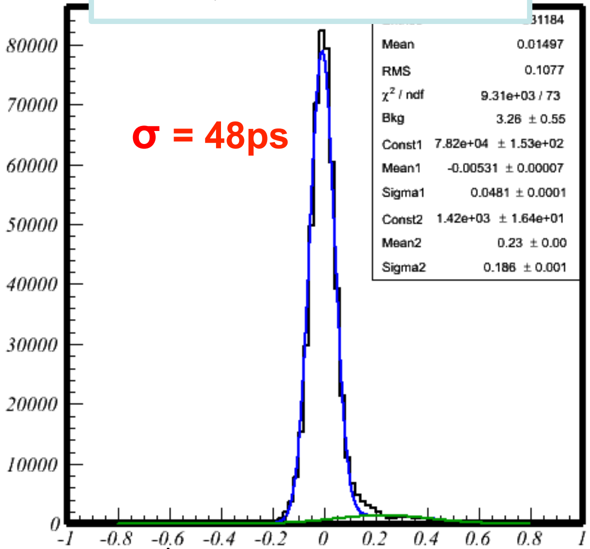


Ring radius distributions





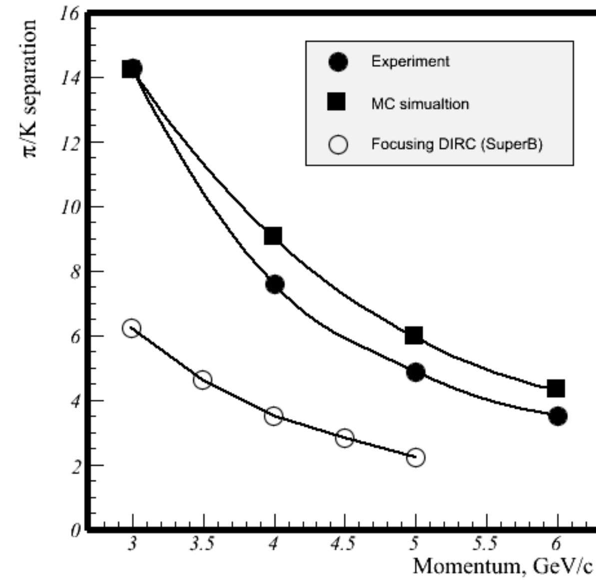
Time resolution



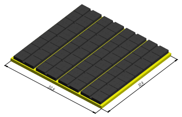
$$S(\pi/K)= \frac{R_{\pi} - R_{K}}{\sigma_{\pi}}$$

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

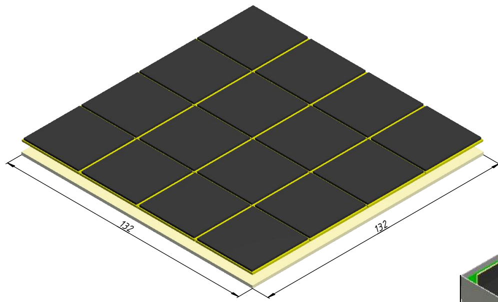
A.Yu. Barnyakov, et al., NIM A 732 (2013) 352



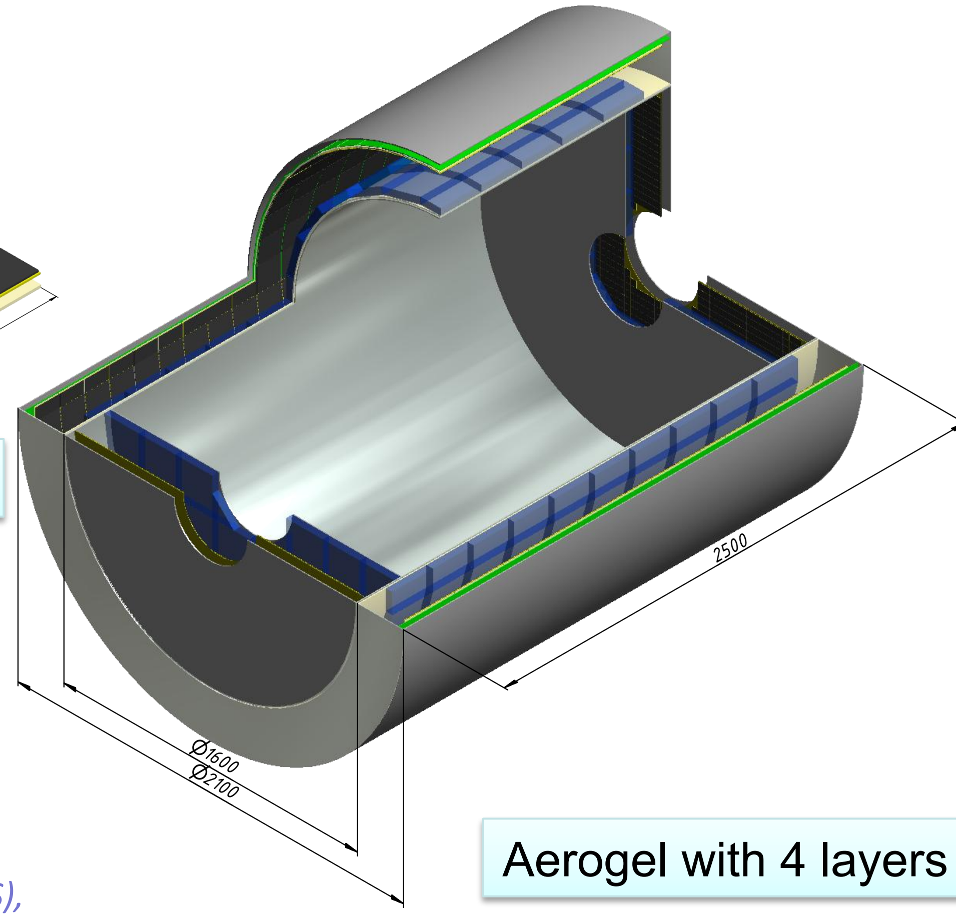
FARICH system



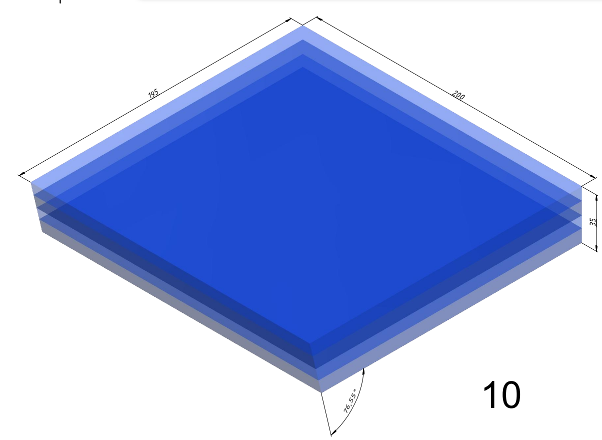
Tile with 64 pixels



Module with 16 tiles



Aerogel with 4 layers



Main parameters

- Focusing aerogel radiator, n_{max}=1.07, 4 layers
- Photon detector:~3x3mm^2, pitch 4 mm

DPC (Philips), MPPC (Hamamatsu), NUV-HD (FBK-IRIS), Array-C (SensL)

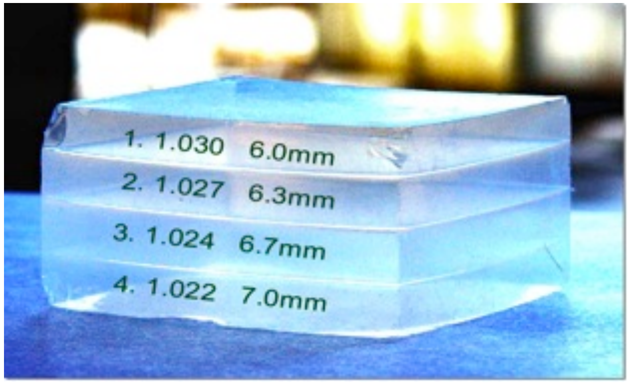
- Area of the photon detector: 20 m^2
- Area of the radiator: 14 m^2
- ~10^6 channels

Status of aerogel production in Novosibirsk

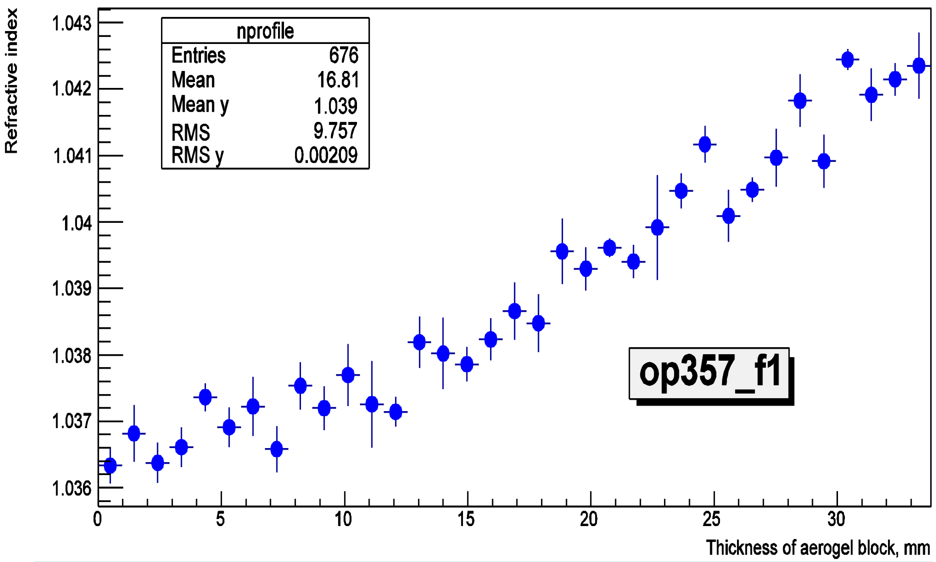
- Aerogel production in Novosibirsk was started in1986.
- $n=1.006 \div 1.13$; $L_{sc}(400nm) \geq 43$ mm.
- In 2004 first 4-layer tile was produced
- 2,3,4-layer blocks with $n_{max}=1.05$ 100x100x30 mm were produced in recent years.
- Tiles with n=1.05 and 200x200x30 mm are produced for J-Lab CLAS12 experiment. Total amount is 6 m^2.
- In 2012 development of aerogel production with continuous designed profile of density gradient was started.

The aims:

- Regular production of 3,4-layer tiles with $n_{max}=1.07$ and 200x200x35 mm.
- Development of “gradient” aerogel production.

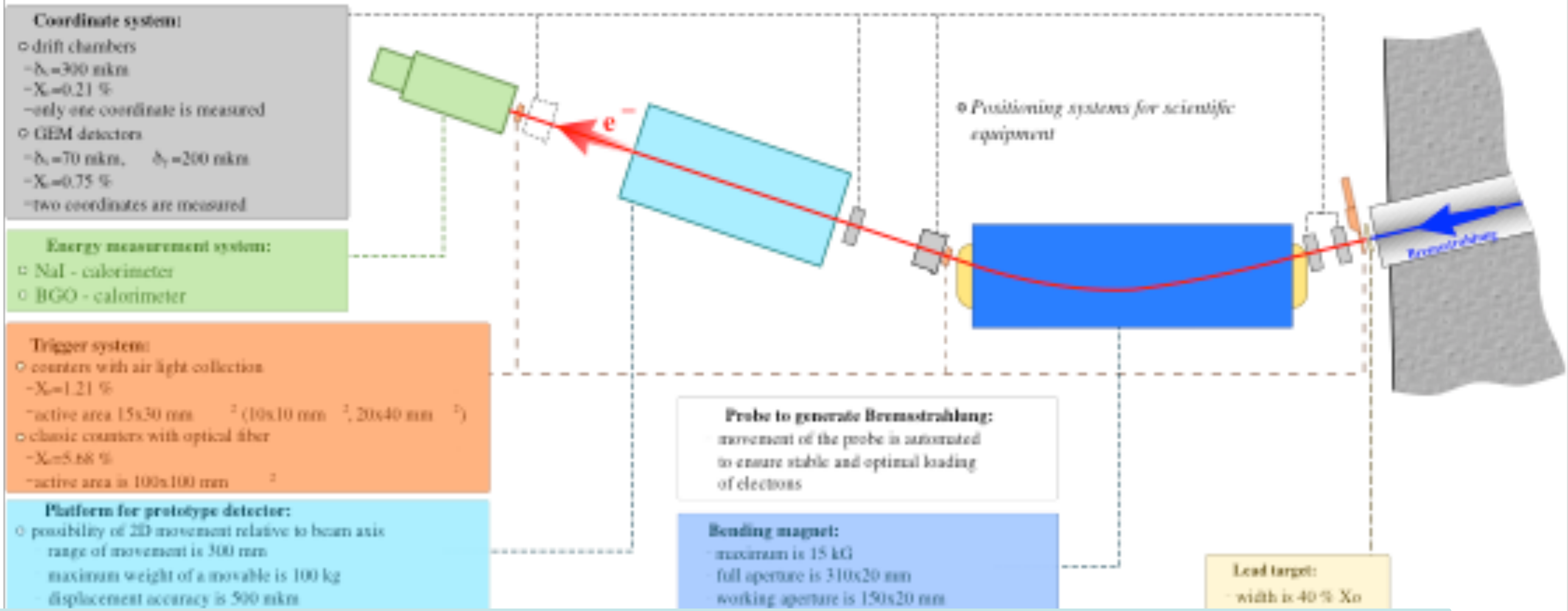


A.Yu.Barnyakov et al., NIM A553 (2005) 70



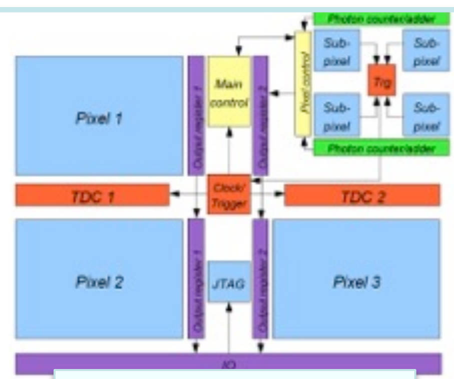
A.Yu.Barnyakov et al., NIM A766 (2014) 88
A.Yu.Barnyakov et al., NIM A766 (2014) 235

Test beam facilities at BINP



See V.S. Bobrovnikov et al., 2014 *JINST* **9** C08022 and G.N.Abramov et al., 2016 JINST 11 P03004

- **Philips DPC matrix 20x20 cm^2**
- Sensors: DPC3200-22-44
- 3x3 modules = 6x6 tiles =24x24 dies = 48x48 pixels
- 576 time channels
- 2304 amplitude (position) channels
- Size of pixel could be changed from 3x3 mm^2 to 50x50 μm^2
- Operation at –40°C to reduce dark counts



Die Architecture

Photon detectors

The general candidates is SiPMs:

- Analog SiPM:

  Advantages:
  - Magnetic field immunity
  - High PDE
  - Acceptable DCR at room temperature

  Disadvantages
  - Especial designed electronic is needed
  - Low radiation hardness
- DSiPM

  Advantages
  - Magnetic field immunity
  - Digitizing electronics is integrated
  - Timing resolution ~ 50 ps

  Disadvantages
  - Lower PDE
  - Low radiation hardness
  - Operation at – 20÷40°C to reduce DCR

Photon detectors

Optional candidates:

- HAPDs:
  - Magnetic immunity to axial fields
  - Radiation hardness is enough for SuperB factories
  - Readout electronics is developed
- MCP PMTs
  - Magnetic immunity to axial fields
  - PE collection in 2 times smaller in magnetic field 1T&45°
  - Radiation hardness is enough for SuperB factories
  - Readout electronics is developed
- Possible solution:
  - MCP PMTs or HAPD – endcap part of the system
  - (D)SiPM – barrel part of the system

Summary

- FARICH method provides excellent

  K/π-separation up to 6GeV/c – **7.6σ** @ 4 GeV/*c*

  π/μ-separation up to 1.5GeV/c – 5.3**σ** @ 1 GeV/*c*
- BINP in cooperation with BIC are able to produce multilayer aerogel tiles with transvers dimensions 200x200 mm^2.
- Beam test facility in BINP was developed for FARICH and other prototype studying. It provides electron beams from 0.1 to 3 GeV energy and gammas.
- Photon detector based on PDPC sensors matrix and tracking system based on GEM detectors allow us to investigate aerogel radiator properties almost without impact of pixel size.

TO DO:

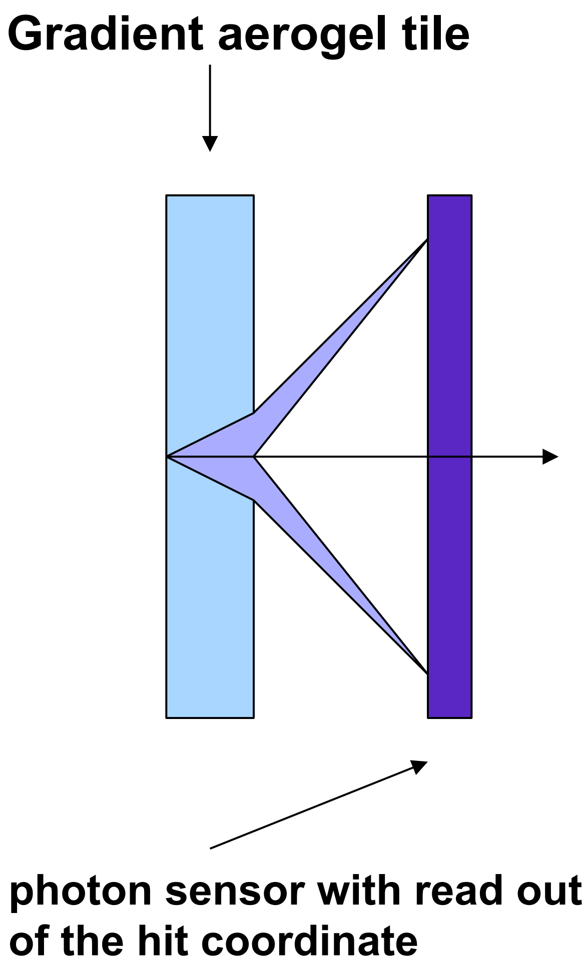
- For p/K-separation from 1.3GeV/c it is necessary to develop production of aerogel tiles (multilayer or gradient) with $n_{max} \geq 1.07$
- Improve technology of “gradient” aerogel production to minimize impact of layer thickness in Cherenkov angle resolution
- Start development of electronics and readout system for SCTF detector.
- Start to create programs of background and physical effects simulation in SCTF for more accurate estimation of radiation condition in photon detectors and electronic regions.
- Choose the type and manufacturer of photon detectors: magnetic field immunity, high PDE, low DCR, enough radiation hardness.
- …

Addendum

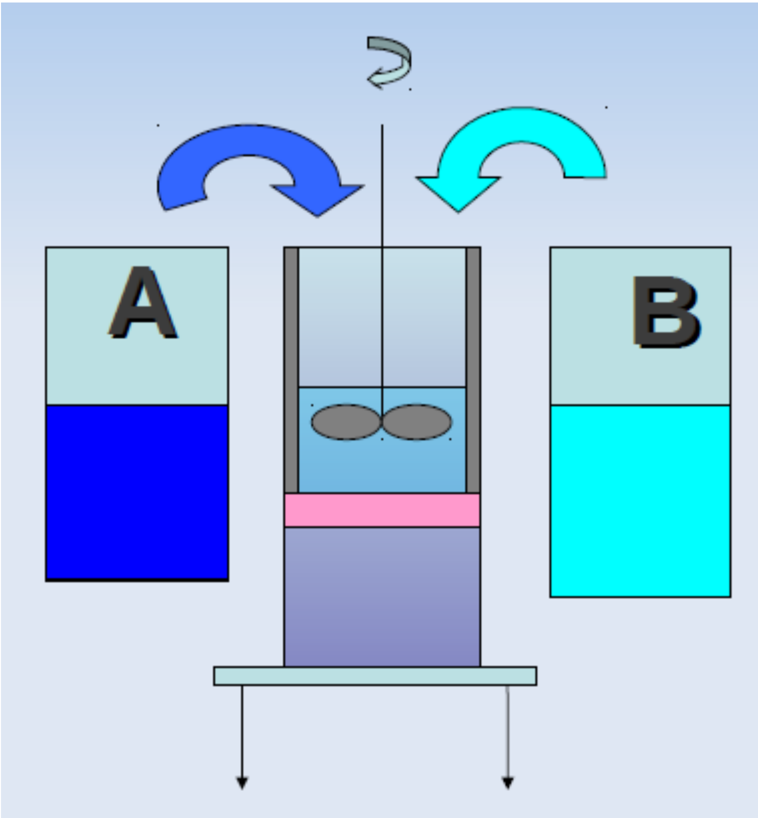
FARICH perspectives

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 $\sigma_\Theta^2 \approx \sigma_{chr}^2$?**

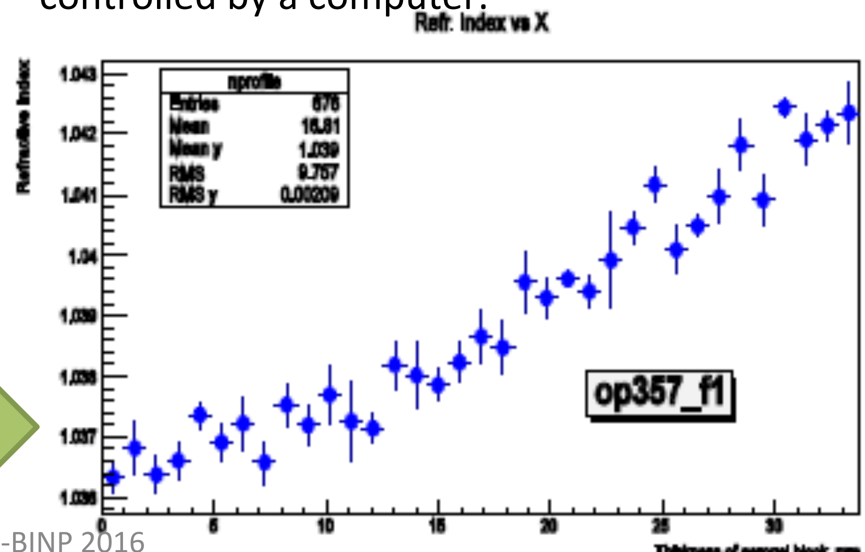


Continuous density gradient aerogel



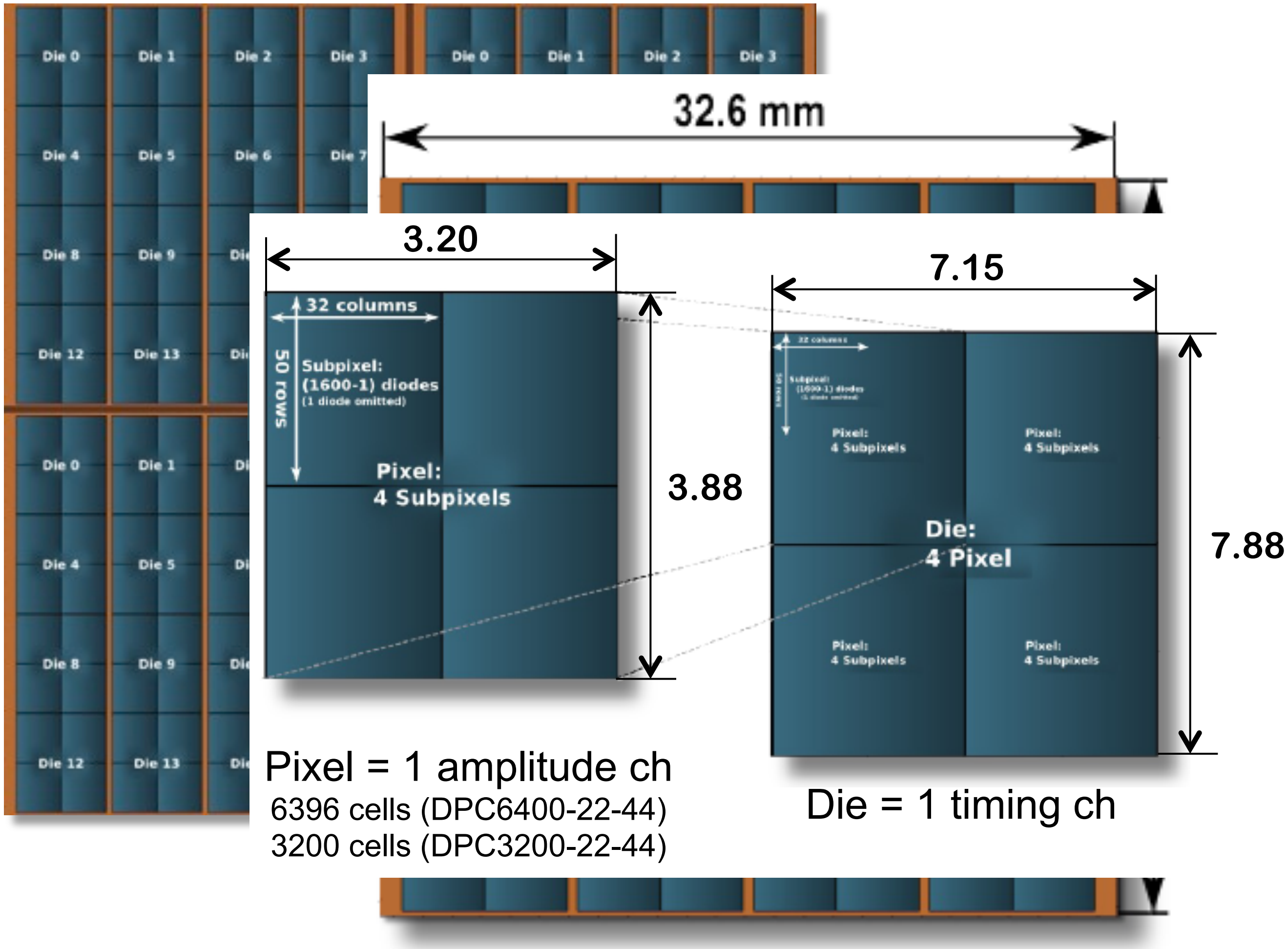
To produce aerogel tiles with designed profile of gradient we modernized the method suggested by [S.M. Jones "A method for producing gradient density aerogel", J Sol-Gel Sci Technol. 44 (2007) 255]

- 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

DPC hierarchy in PDPC-FARICH



Pixel = 1 amplitude ch
6396 cells (DPC6400-22-44)
3200 cells (DPC3200-22-44)

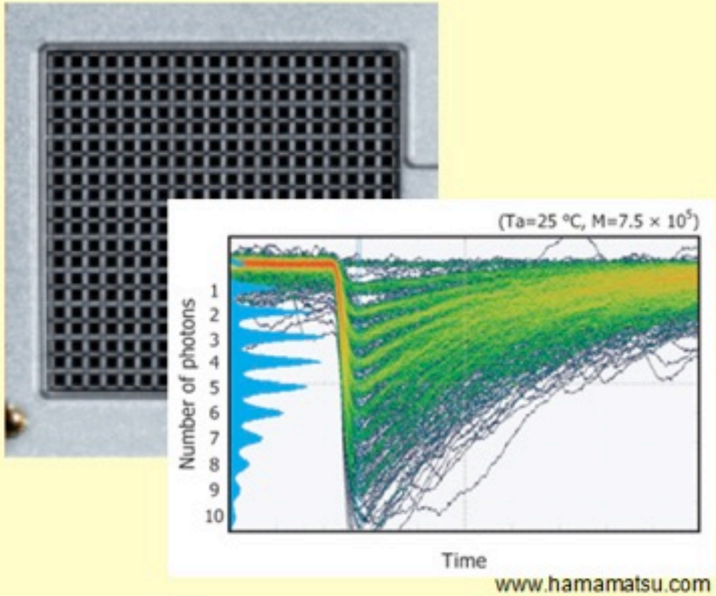
Die = 1 timing ch

Pixel-in-module packing density ≈70%

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

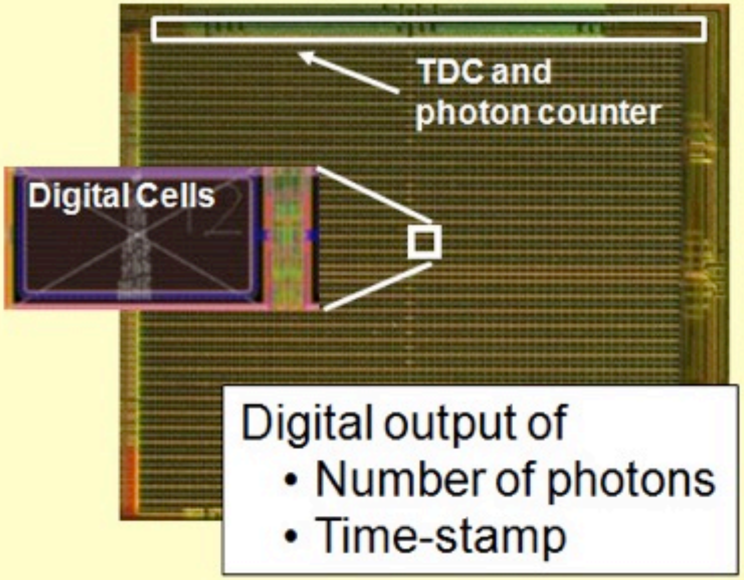
Philips Digital Photon Counting (PDPC)

analog SiPM



Summing all cell outputs leads to an analog output signal and limited performance

Digital Photon Counter (DPC)

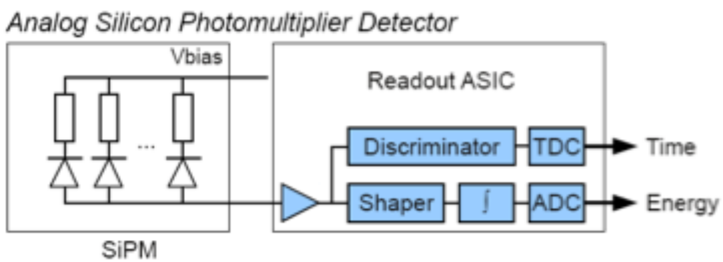


Integrated readout electronics is the key element to superior detector performance

T. Frach, G. Prescher, C. Degenhardt, B. Zwaans, IEEE NSS/MIC (2010) pp.1722-1727
C. Degenhardt, T. Frach, B. Zwaans, R. de Gruyter, IEEE NSS/MIC (2010) pp.1954-1956

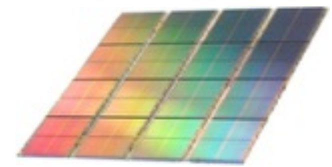
DPC: Front-end Digitization by Integration of SPAD & CMOS Electronics

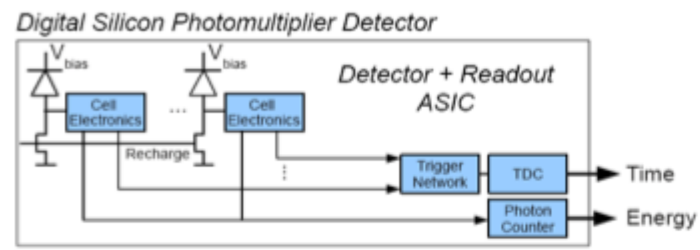
Analog SiPM



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

Digital SiPM

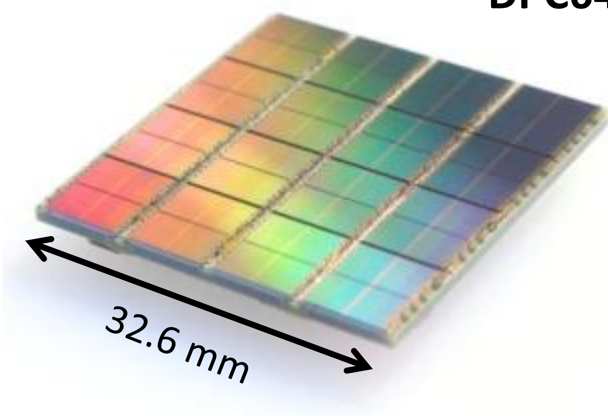




- fully integrated
- fully digital signals
- no ASIC needed
- fully scalable

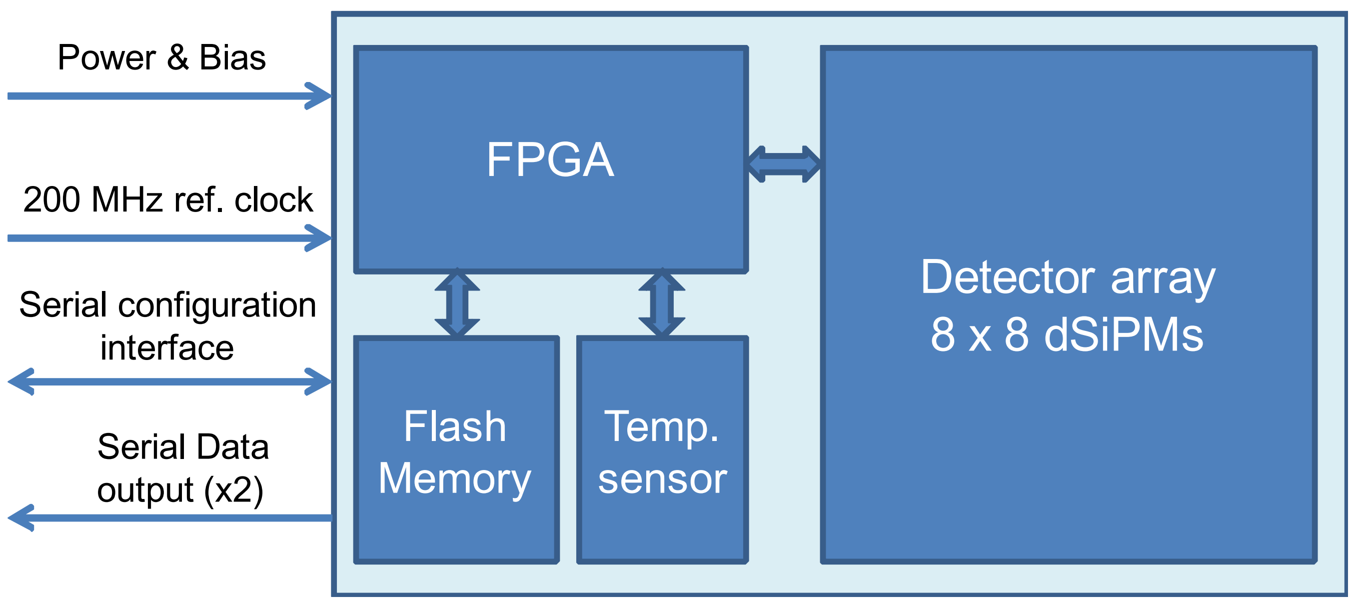
DPC tile – PCB with densely packed 4x4 sensors (8x8 pixels)

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

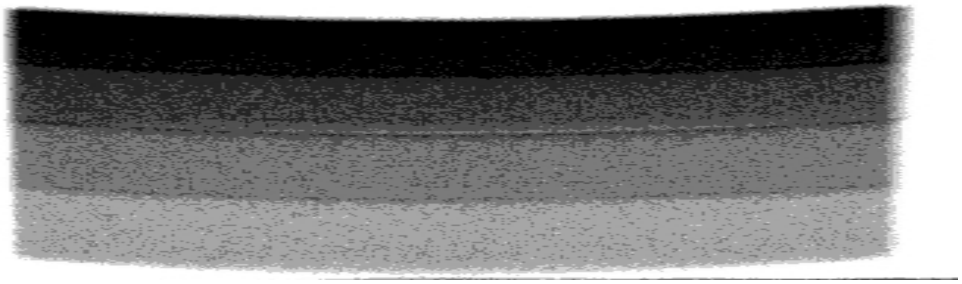


FPGA
- Clock distribution
- Data collection/concentration
- TDC linearization
- Saturation correction
- Skew correction

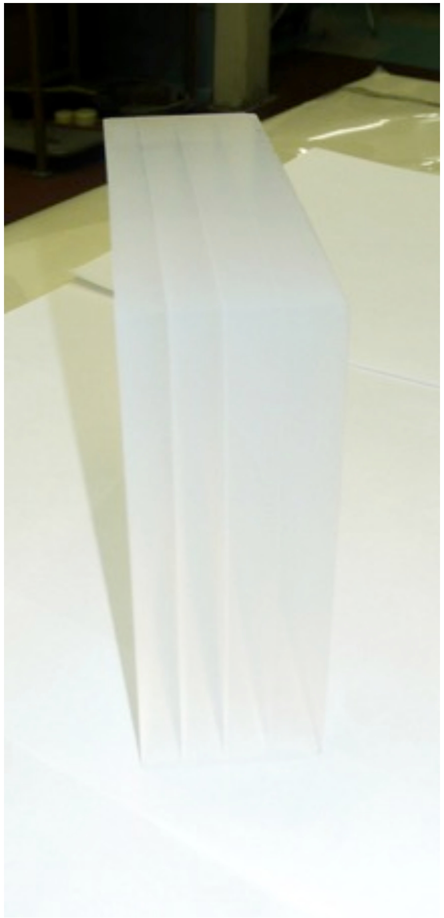
Flash
- FPGA firmware
- Configuration
- Inhibit memory maps



Aerogel study with digital X-ray setup

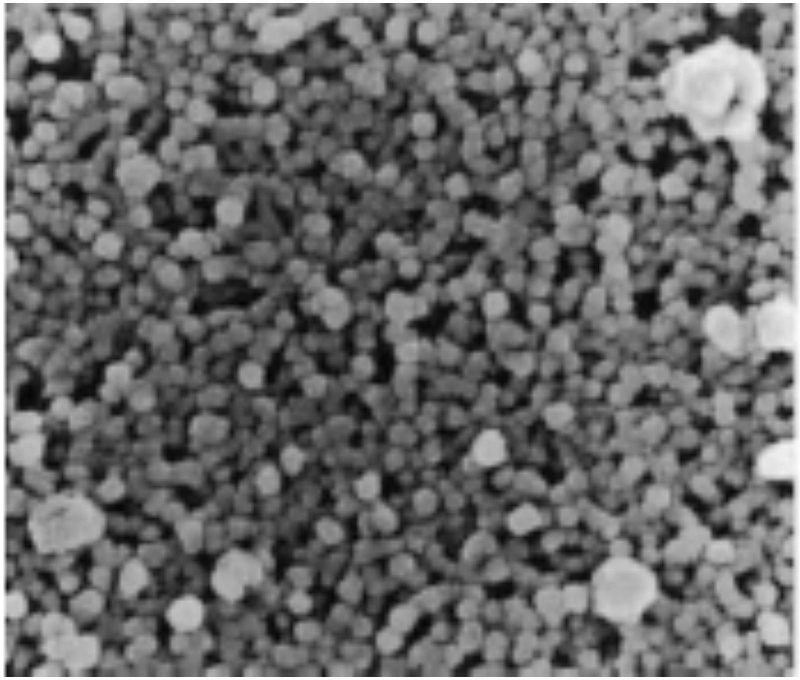


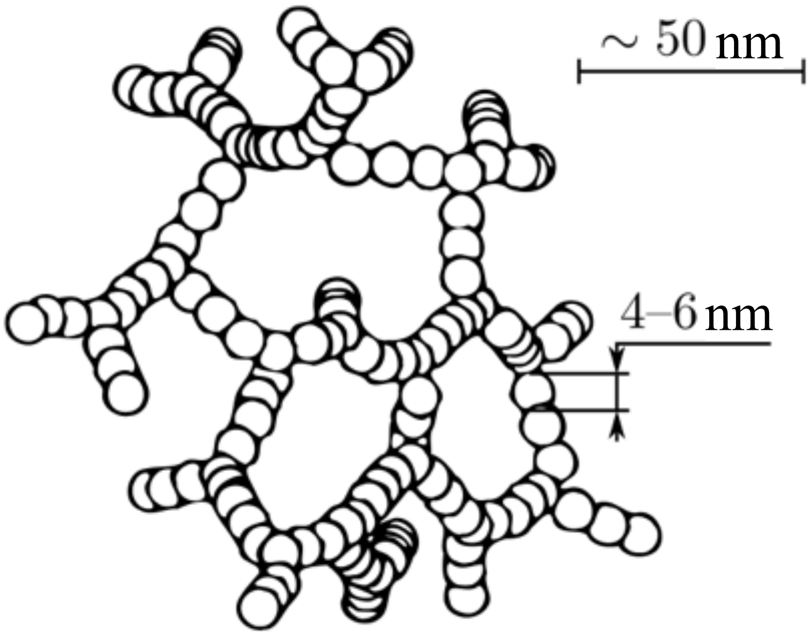
	n	h, mm
Layer 1	1.050	6.2
Layer 2	1.041	7.0
Layer 3	1.035	7.7
Layer 4	1.030	9.7



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

Refractive index





$SiO_2 + H_2O(1 \div 5\%)$

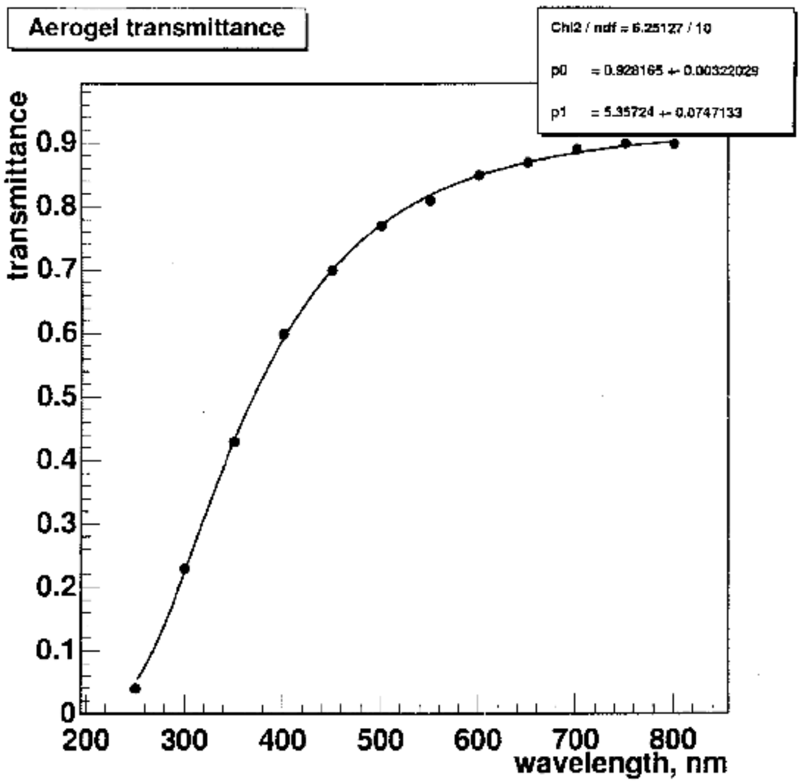
$$n^2 = 1 + 0.438 \cdot \rho$$

n=1.006…1.070 – synthesis
n=1.070…1.130 – sintering

Light scattering

Rayleigh scattering on aerogel structure elements

Transmittance: $$T = \frac{I}{I_0} = A \cdot \exp \frac{-d}{L_{sc} \cdot (\lambda/400)^4} = A \cdot \exp \frac{-C \cdot d}{\lambda^4}$$

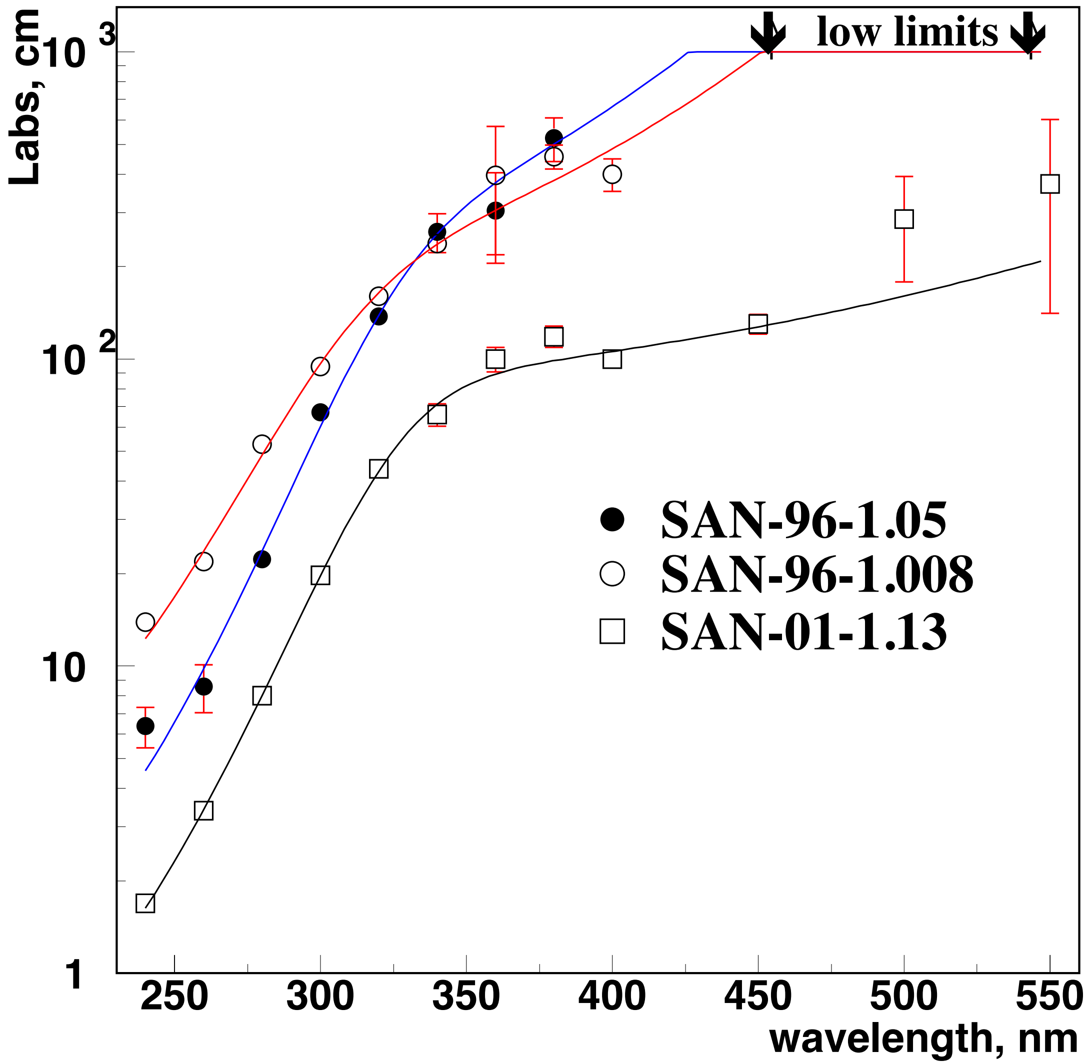


A – surface scattering coefficient
~0.95 for intrinsic surface
~0.70 for polished surface

L_{sc} – scattering length at λ=400nm
> 4.5 cm

C – clarity ($0.4^4 / L_{sc}$)
< 0.0057 μm^4/cm

Light absorption

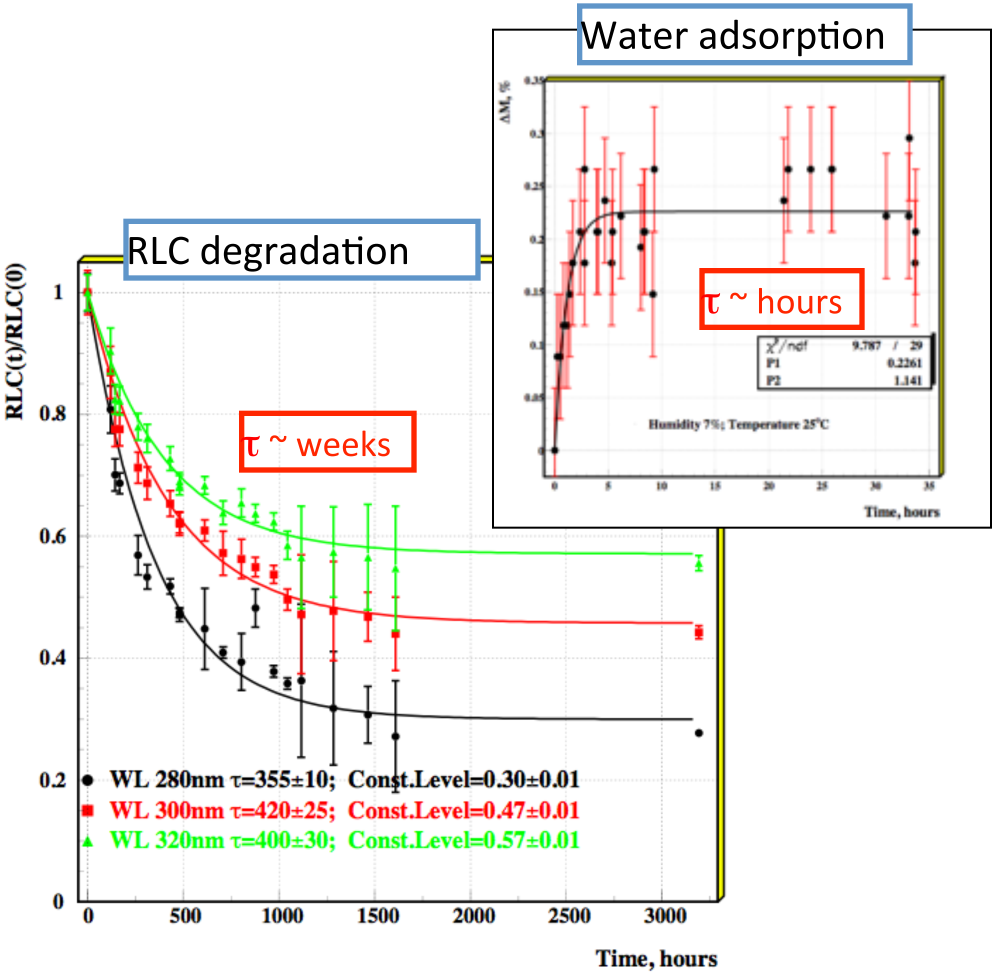


Light is absorbed by impurities.

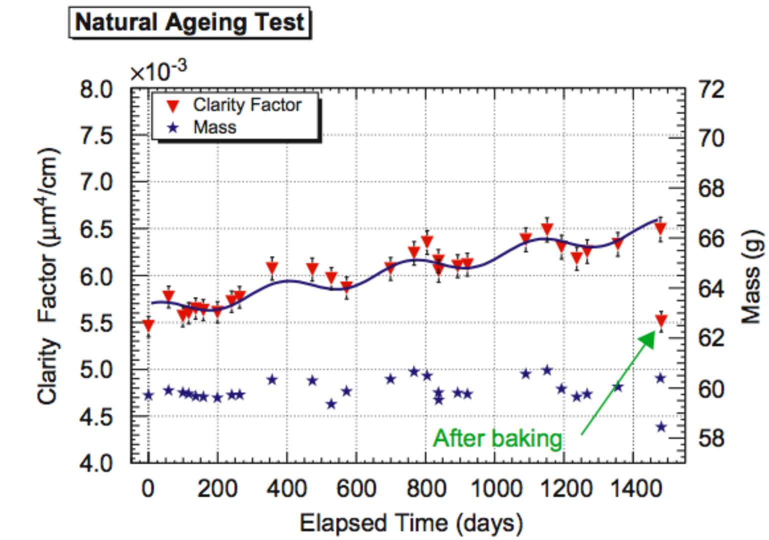
Contamination of metals (Fe, Co, Cu, Mn, etc.) is determined by raw material quality and synthesis technology.

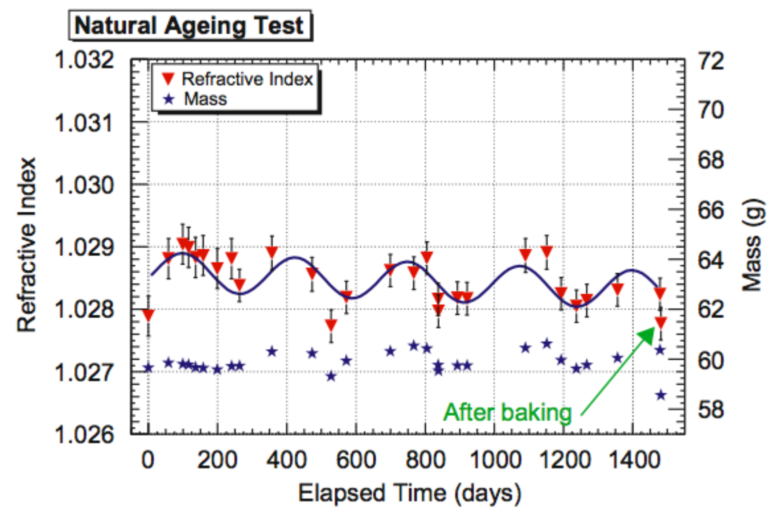
Water adsorption

$1\ cm^3 \Rightarrow S_{inner} \sim 100\ m^2$



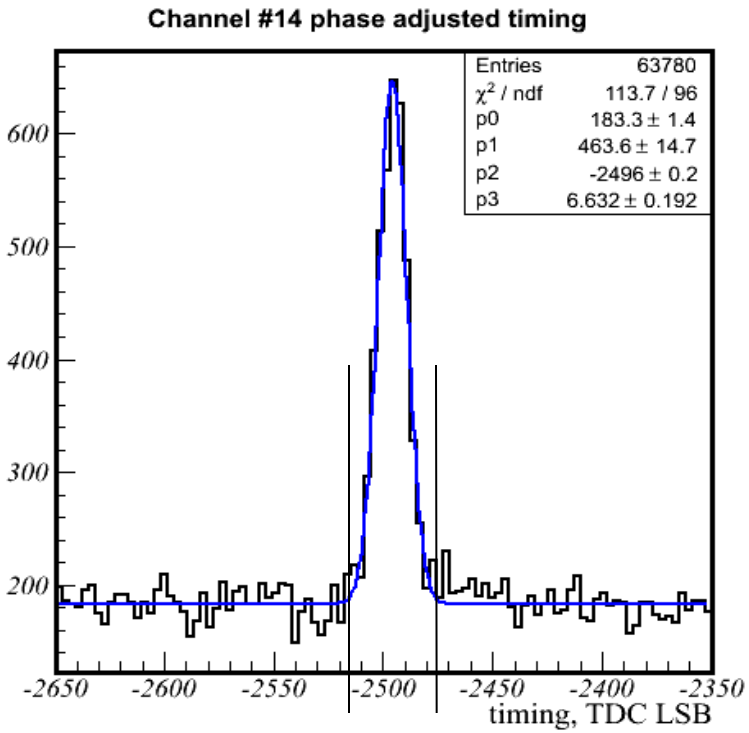
A.Yu.Barnyakov et al., NIM A598 (2009) 166

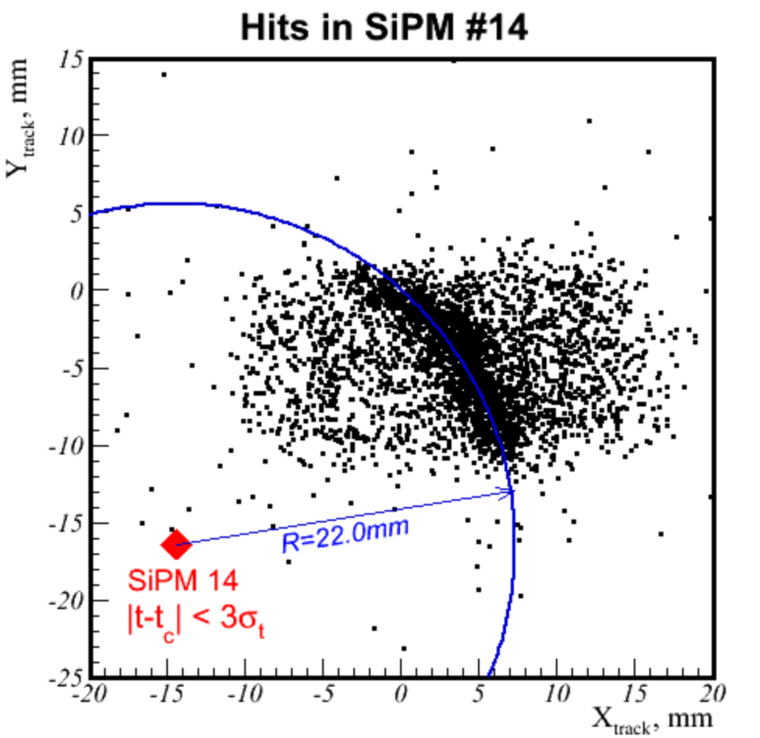




D.L.Perego, NIM A595 (2008) 224

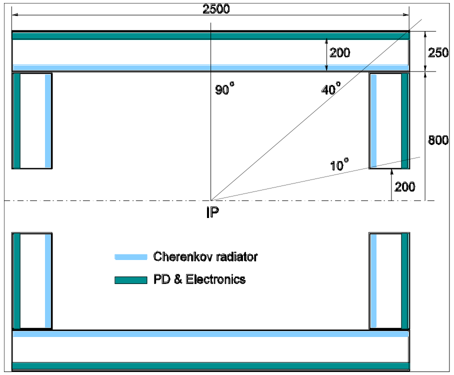
Event selection





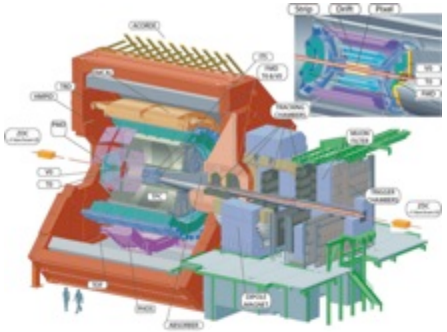
- **We select events with $|t\text{-}t_{ch}|<3\sigma_t$**

FARICH proposals



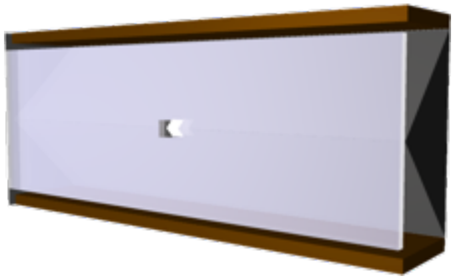
FARICH for Super Charm-Tau Factory (Novosibirsk)

PID: μ/π up to 1.7 GeV/c
21m² detector area (SiPMs)
~1M channels



FARICH for ALICE HMPID upgrade

PID: π/K up to 10 GeV/c, K/p up to 15 GeV/c
3m² detector area (SiPMs)



Forward Spectrometer RICH for PANDA

PID: π/K/p up to 10 GeV/c
3m² detector area (MaPMTs or SiPMs)