Прогресс 2020 – 2023 гг. в разработке аэрогелевых черенковских счетчиков в Новосибирске

А. Ю. Барняков и др.

План:

- Счетчики АШИФ
  - Эксперимент КЕДР и СНД
  - Долговременная стабильность счетчиков АШИФ
  - АШИФ с КФЭУ, модернизация счетчика АШИФ для эксперимента СНД
- Детекторы черенковских колец с фокусировкой
  - Счетчики с линзой Френеля (mRICH for EIC project)
  - ФАРИЧ для Супер С-Тау фабрики
- Позиционно-чувствительные фотодетекторы
  - Матрицы КФЭУ
  - ФЭУ с МКП

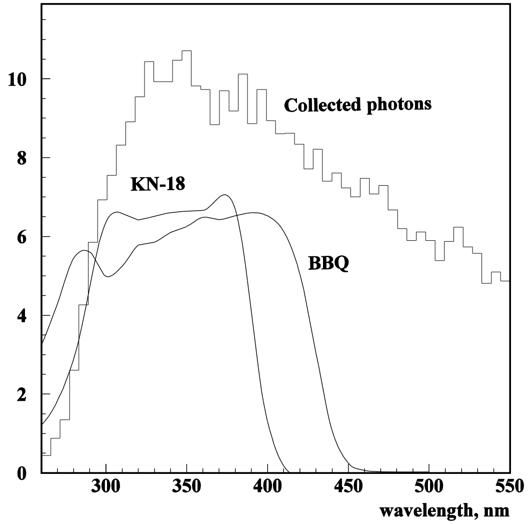
Progress 2020 – 2023 in aerogel Cherenkov counters development in Novosibirsk

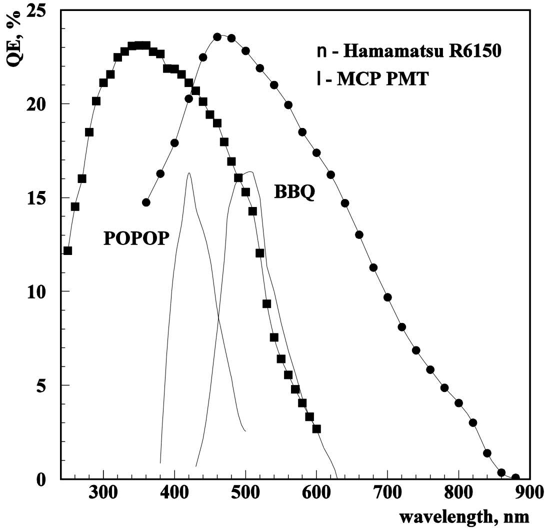
A. Yu. Barnyakov & other.

Contents:

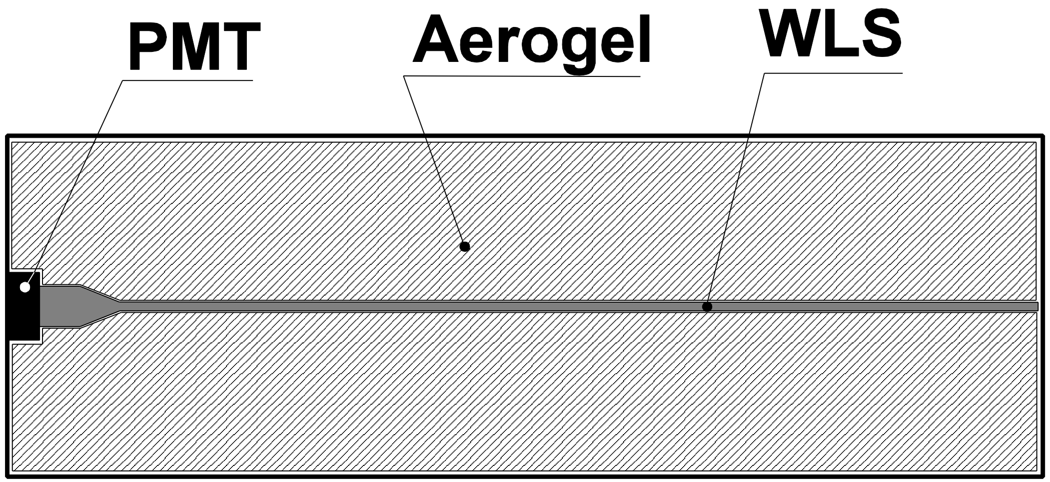
ASHIPH technique is 30 years old!!!

ASHIPH detectors





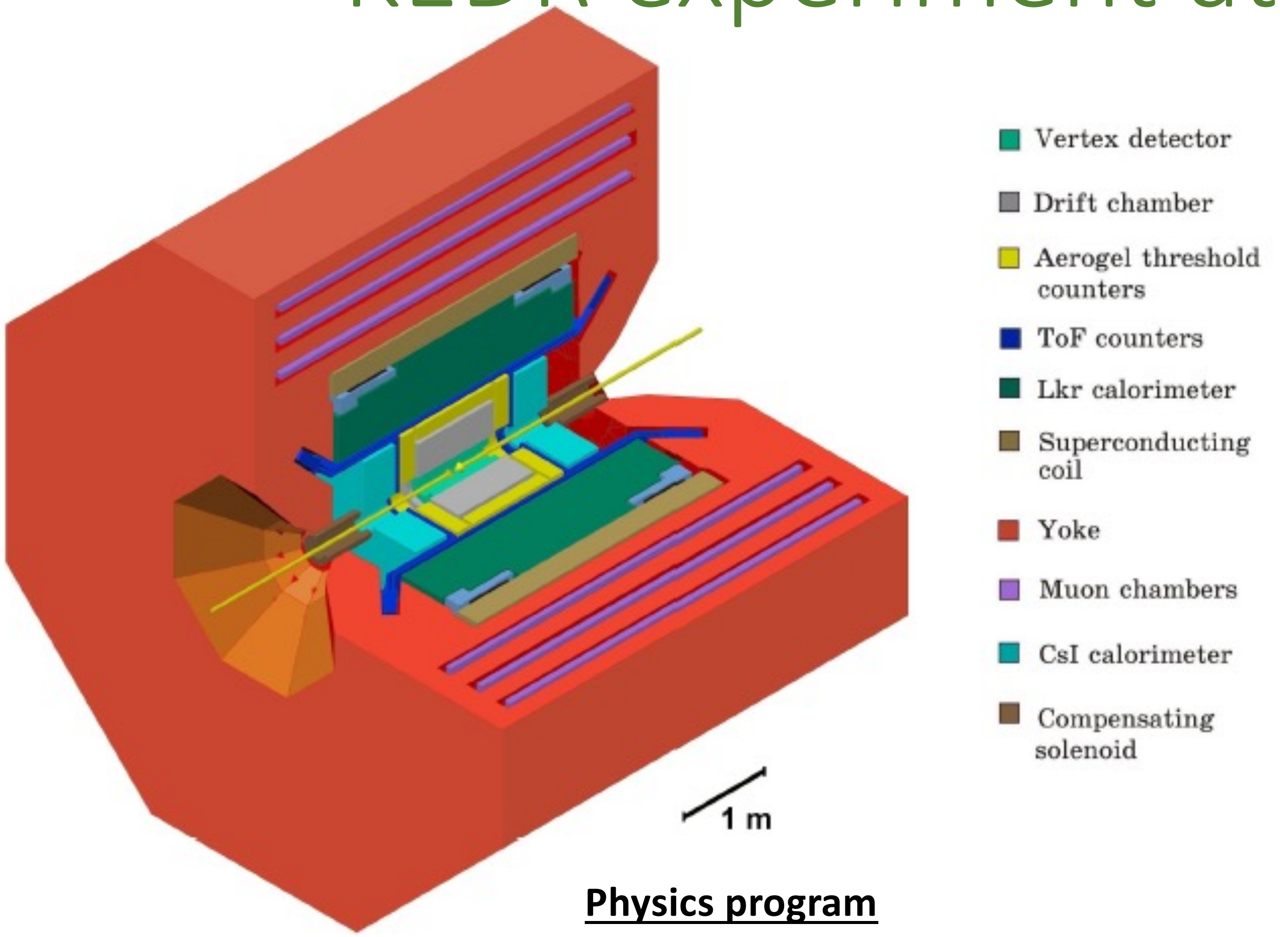
Aerogel SHIfter and PHotomultiplier



PMMA light guide doped with BBQ dye
is used as wavelength shifter

Suggested at BINP. A.Onuchin et.al. NIM A315(1992)517

KEDR experiment at VEPP-4M



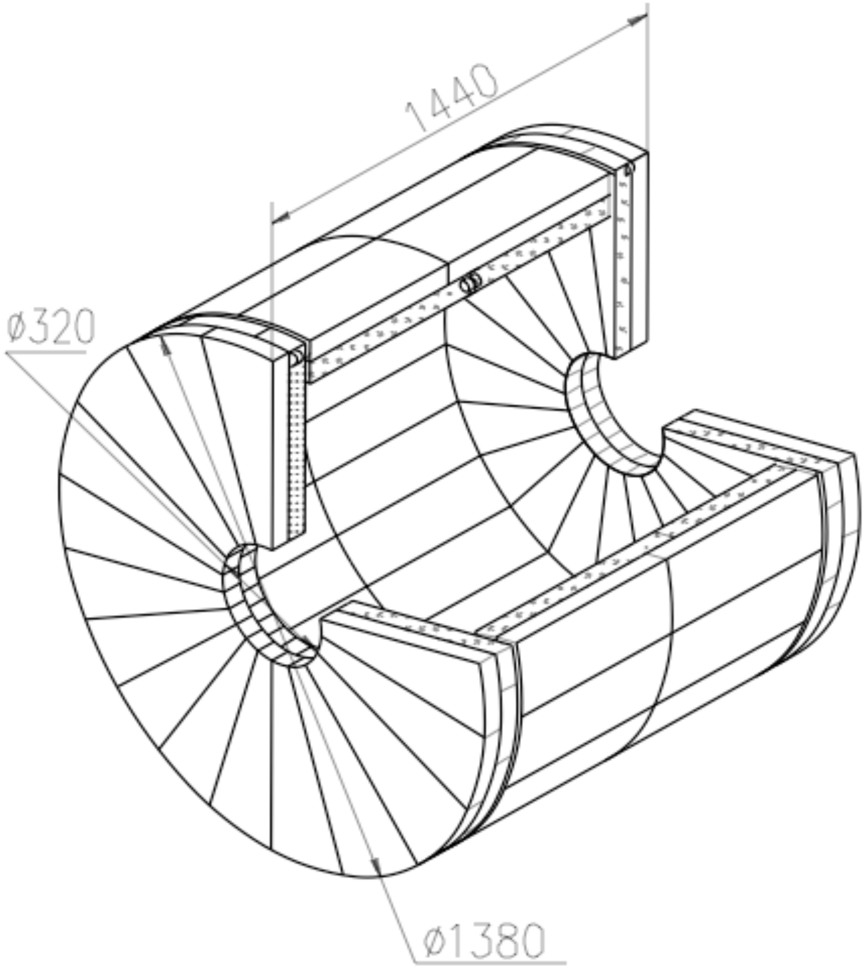
VEPP-4M

- Symmetric e^+e^- collider
- $E_{c.m.}$ = 2–10 GeV
- L = (1÷80) x 10^{30} $cm^{-2}s^{-1}$
- Precise energy calibration:
  RD: (5÷15)x10^{-6}
  CBS: 3x10^{-5}

Physics program

- Precise particle mass measurements: *J/ψ, ψ*(2S), *ψ*(3770), *τ* lepton, *D* mesons, *Υ* mesons
- Measurements of *ψ* and *Υ* mesons lepton width
- R measurement in 2-10 GeV c.m. energy range
- γγ→*hadrons* and other 2γ processes
- Branching fractions measurements in charm and bottom quark systems (above 10^{-4})

KEDR ASHIPH system

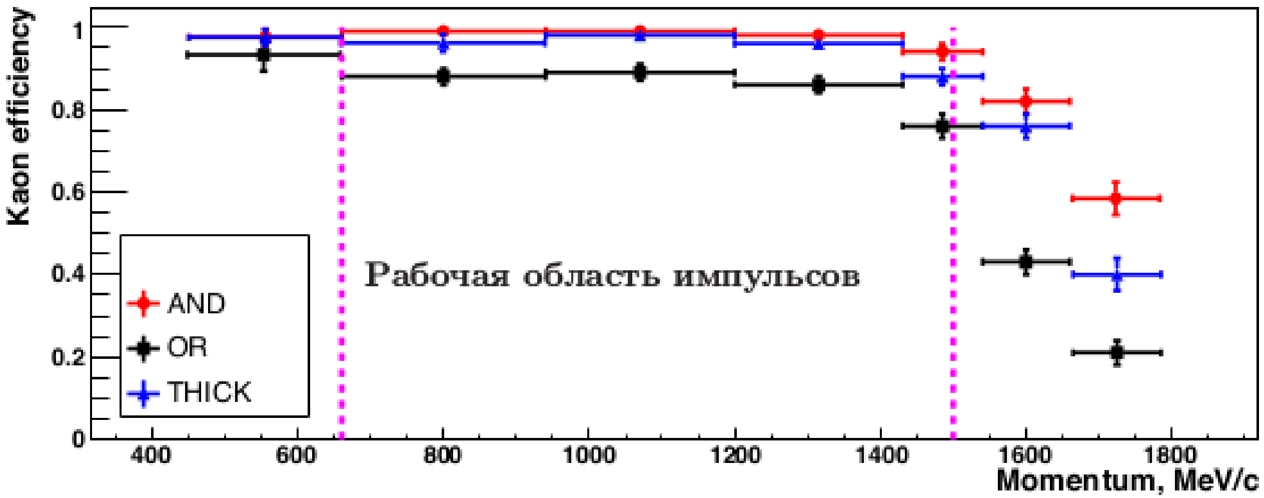


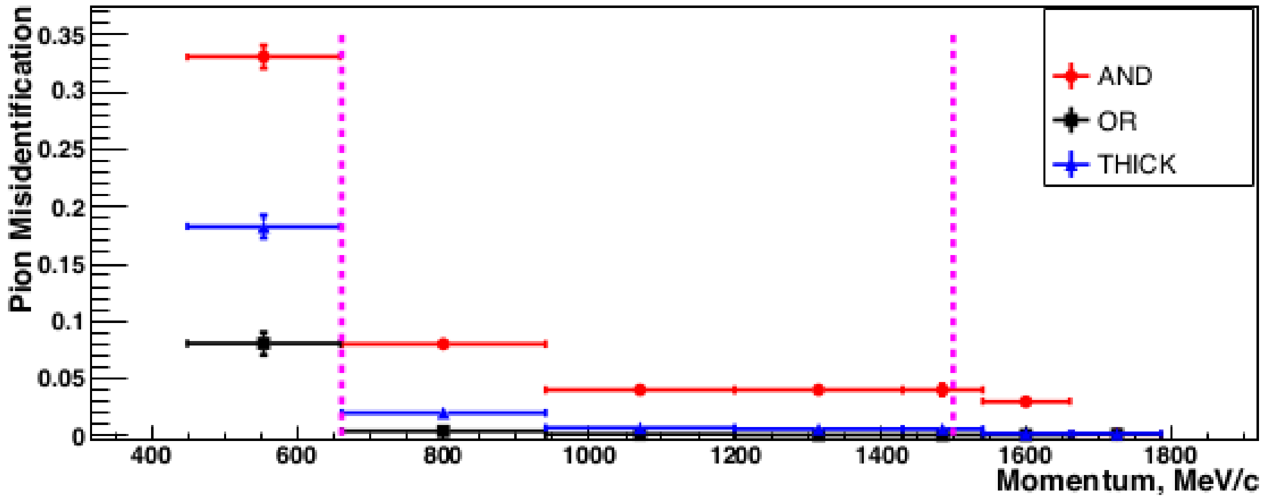
- 160 counters in 2 layers
- Solid angle 96% of 4π
- n=1.05, V_{Σ}=1000 l, high transparency SAN-96 aerogel
- π/K- separation in the momentum range 0.6÷1.5 GeV/*c*
- 160 MCP PMTs, photocathode diameter ø18mm, able to work in the magnetic field up to 2 T
- Fully installed in the detector in 2013. Now is in operation.

KEDR ASHIPH system (2)

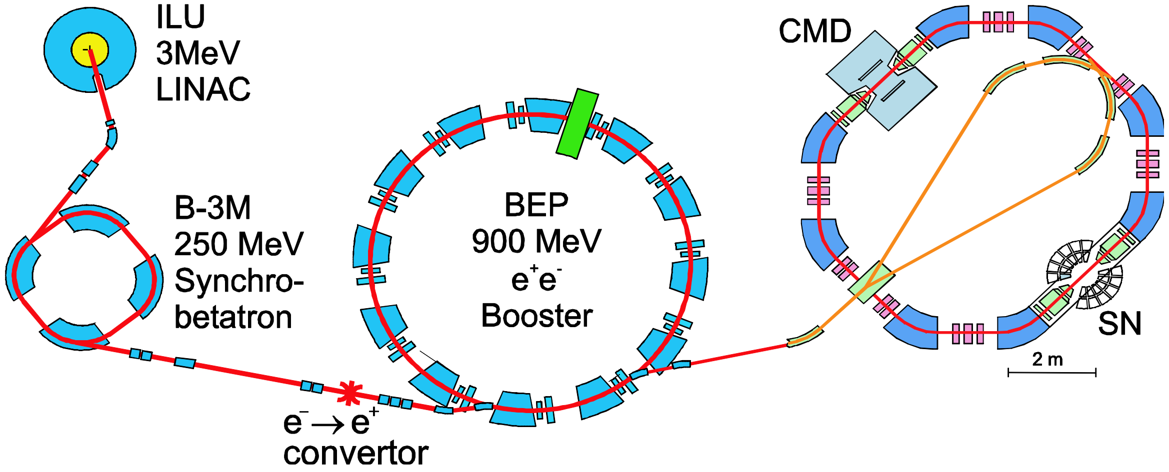
- Npe = 6.4±0.2 – layer 1
- Npe = 5.0±0.2 – layer 2
- Npe = 10.9±0.2 – sum of the signals in 2 layers (80%)
- π/K-separation at 1.2GeV/*c* is 4.3σ

A.Yu.Barnyakov et al., NIM A824 (2016) 79





SND at VEPP-2000



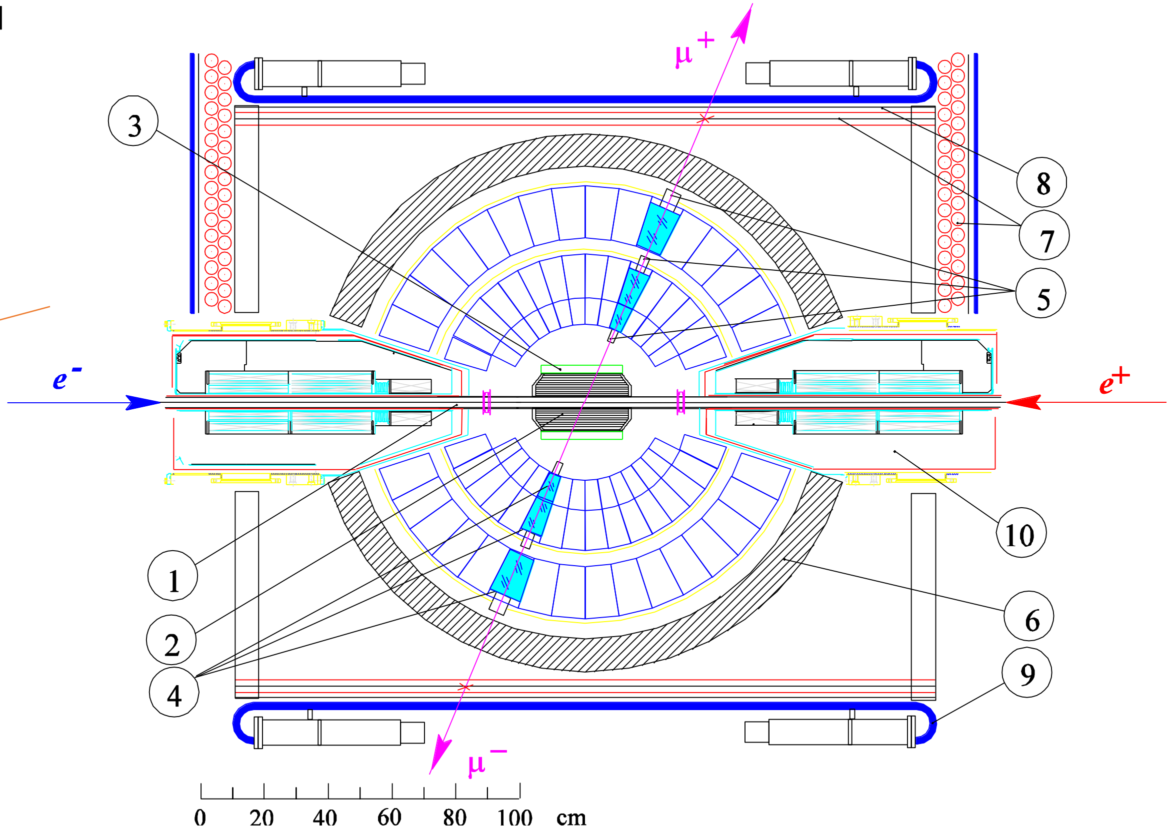
Symmetric e⁺e⁻ collider with round beams

$2E_{max}$=2000 MeV

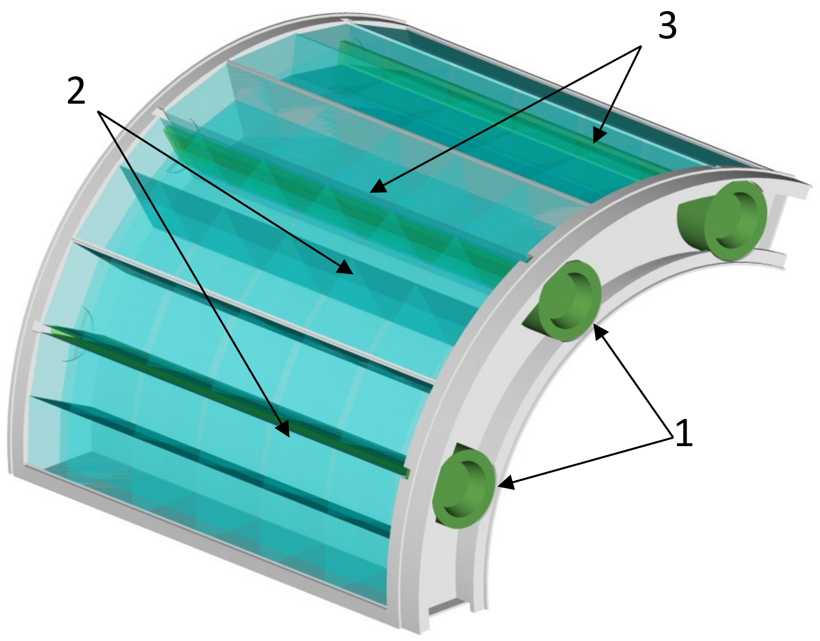
L=10^{31}cm^{-2}s^{-1} at E=510 MeV

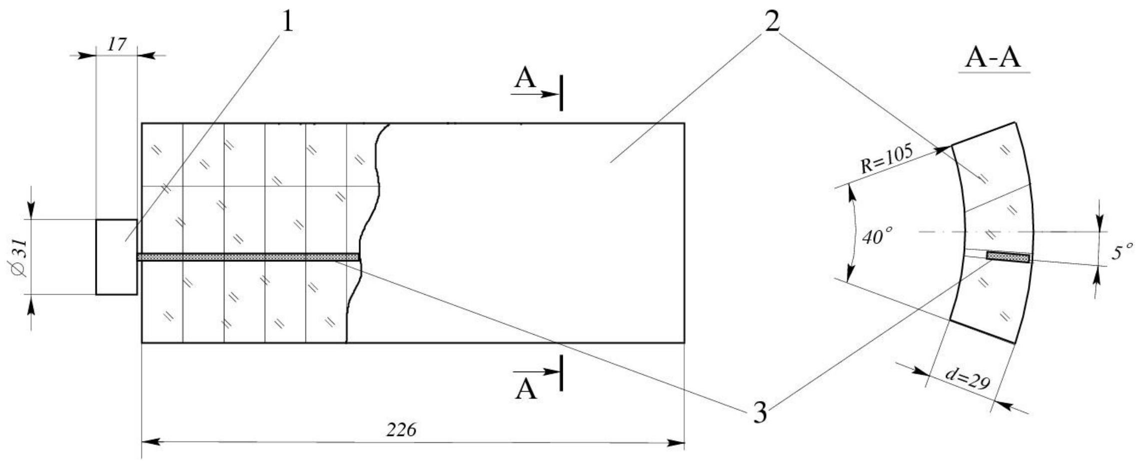
L=10^{32}cm^{-2}s^{-1} at E=1000 MeV

1. VEPP-2000 beam pipe
2. Tracking system
3. Aerogel Cherenkov counters
4. NaI(Tl) crystals } EMC
5. Vacuum phototriodes } EMC
6. Fe absorber
7. } Muon system
8. } Muon system
9. } Muon system
10. VEPP-2000 s.c. focusing solenoids



ASHIPH counters for SND





Counter Design

- Scheme: ASHIPH
- WLS position: displaced by ~5° from counter center
- Aerogel thickness: ~30 mm

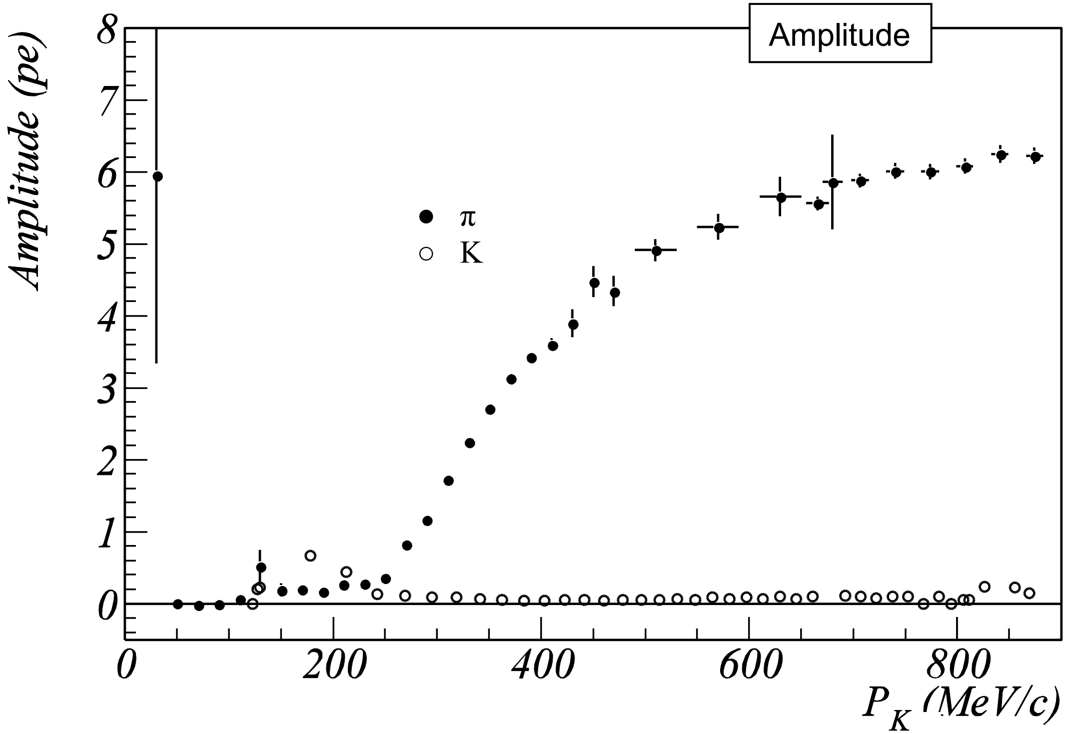
Outline

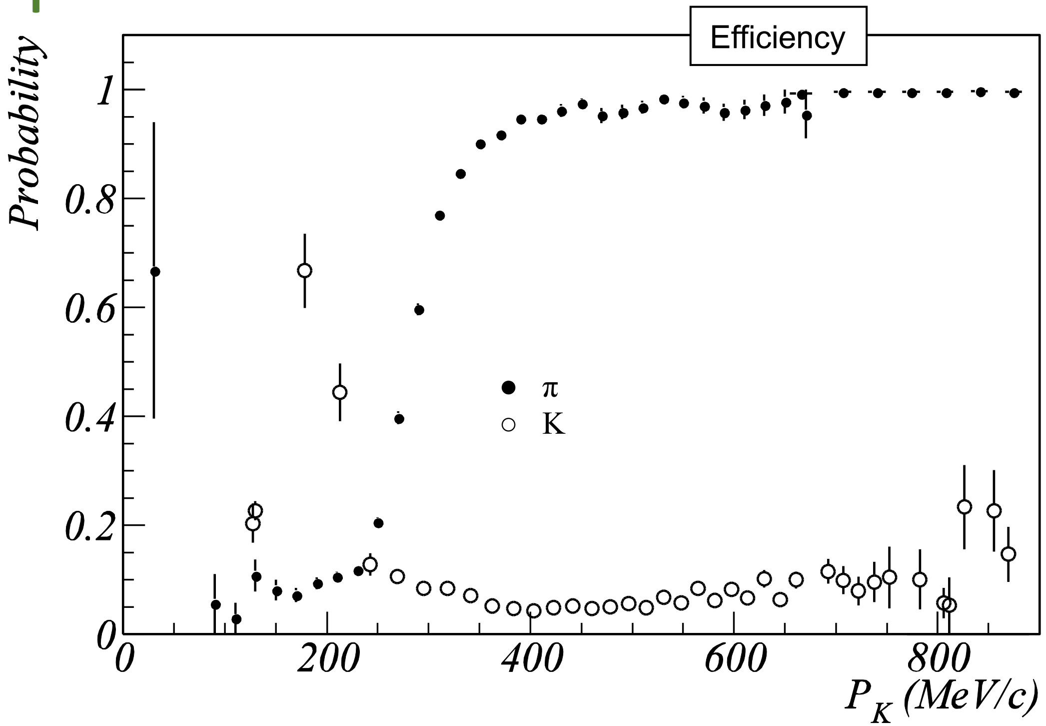
- π/K separation from 300 to 870 MeV/c
- Cylindrical shape: R=105÷141 mm
- Case material: 1mm of Al
- 3 segments of 3 counters in each
- Solid angle: ~60% of 4π
- Thickness: 0.09 X_o

Aerogel parameters

- Refraction index: **n=1.13±0.01**
- Density: ρ=0.65 g/cm^3
- L_{sc}=19 mm at λ=400 nm
- L_{abs}=100 cm at λ=400 nm

SND ASHIPH: π/K separation



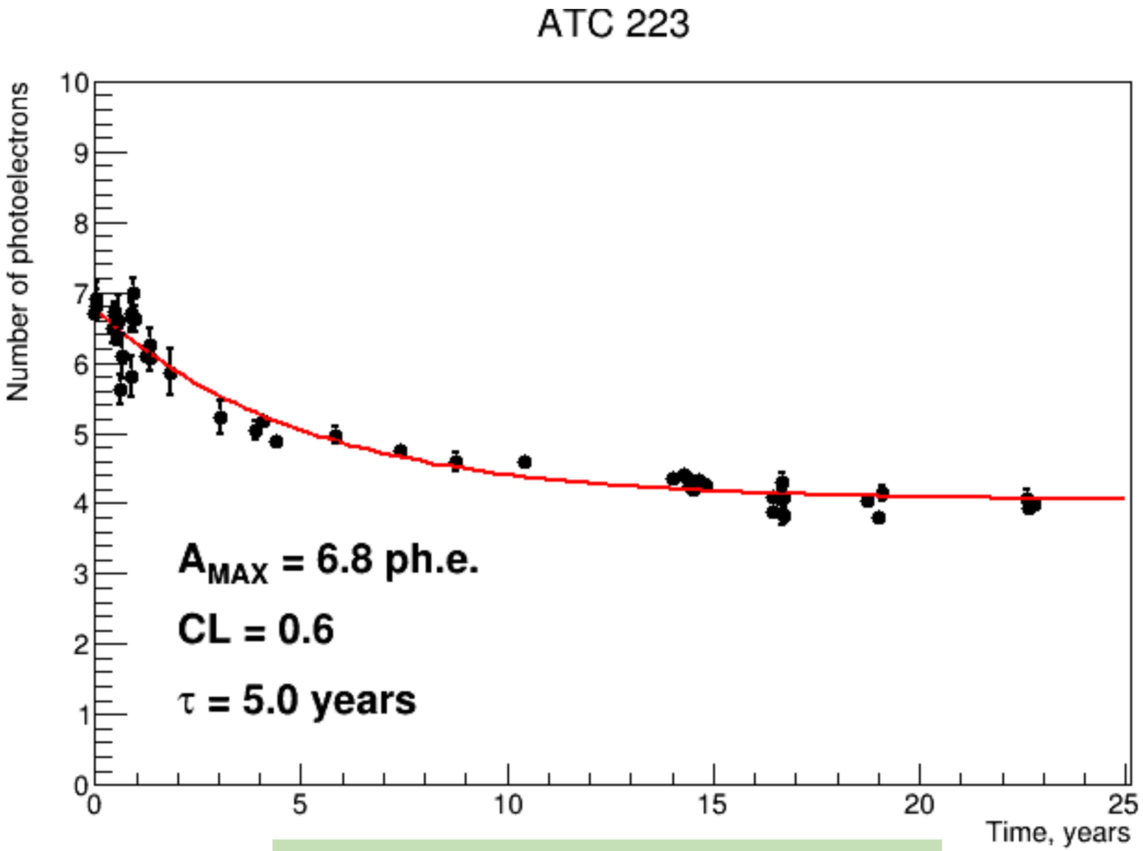


P, MeV/c	ε_K, %	E_π, %	Sep, σ
300	~10	68	1,7
350	~7	90	2,8
400	~5	96	3,4
600-800	~9	>99	3,7

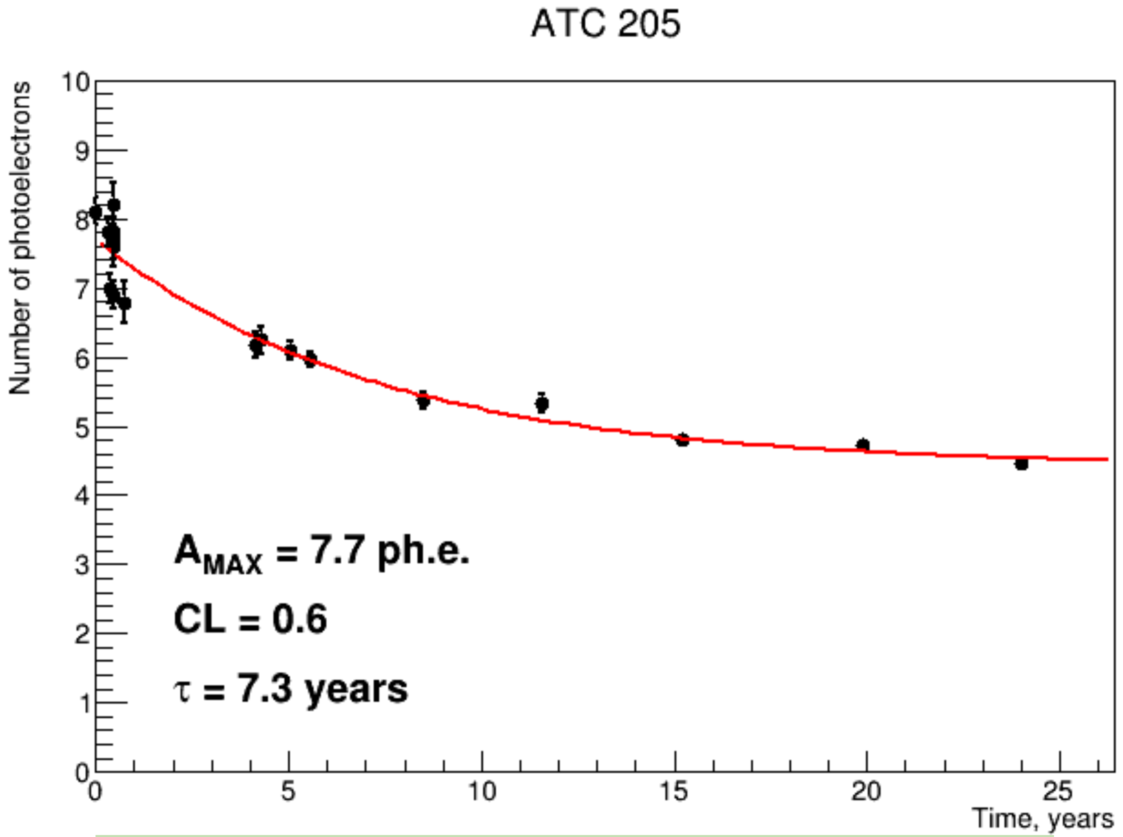
1. For momenta above 350 MeV/c separation level is sufficient
2. Below 350 MeV/c separation will be supplemented by other subsystems (DC)

A Yu Barnyakov *et al* 2014 *JINST* **9** C09023

Long-term stability of ASHIPH counters



ASHIPH prototype for the KEDR. After tests with mixed hadron beams at JINR (Dubna) in 2000 is under operation from time to time.

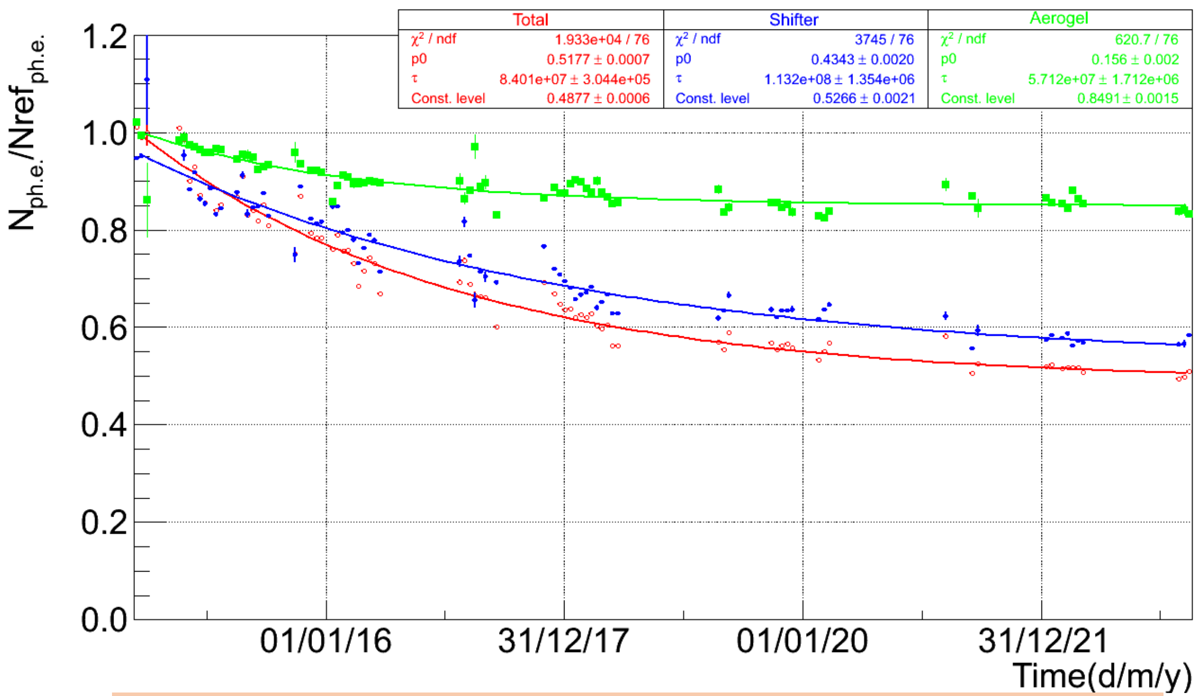


One of the first ASHIPH counters for the KEDR detector was under operationin the experiment from 2000 to 2003.

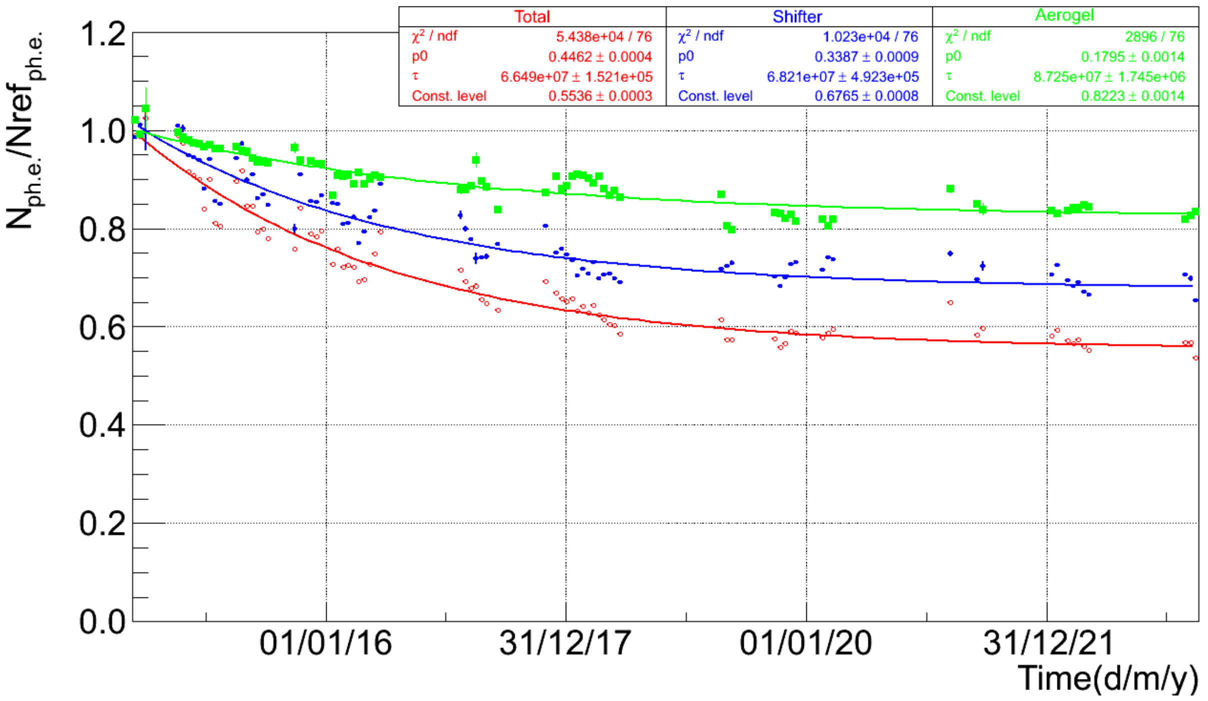
A Yu Barnyakov *et al* 2014 *JINST* **9** C09005

Amplitude decrease reasons for the ASHIPH system

which is in operation at the KEDR detector since 2014



ASHIPH counters with 2MCP-PMTs from 1999÷2000



ASHIPH counters with 3MCP-PMTs from 2006÷2007

$\delta N_{фэ}(aer) \approx 16\%$

$\delta QE\ (WLS) \approx 47\%$ – 1999

$\delta QE\ (WLS) \approx 32\%$ – 3MCP 2006

$\delta QE\ (WLS) \approx 33.5\%$ – 2MCP 2008

} Evaluated with help of cosmic tracks hitted the WLS

ASHIPH with SiPM

MCP PMT → SiPM

Pros:

	MCP PMT	**SiPM**
PDE=QE*CE	25*0.6≈15%	30-45%
Magnetic field imm.	Axial	Any direction
Power supply	2÷4 kV	<100V

Cons:

- High level of noise → New specific FEE → Cooling system
- Radiation tolerance is still low.

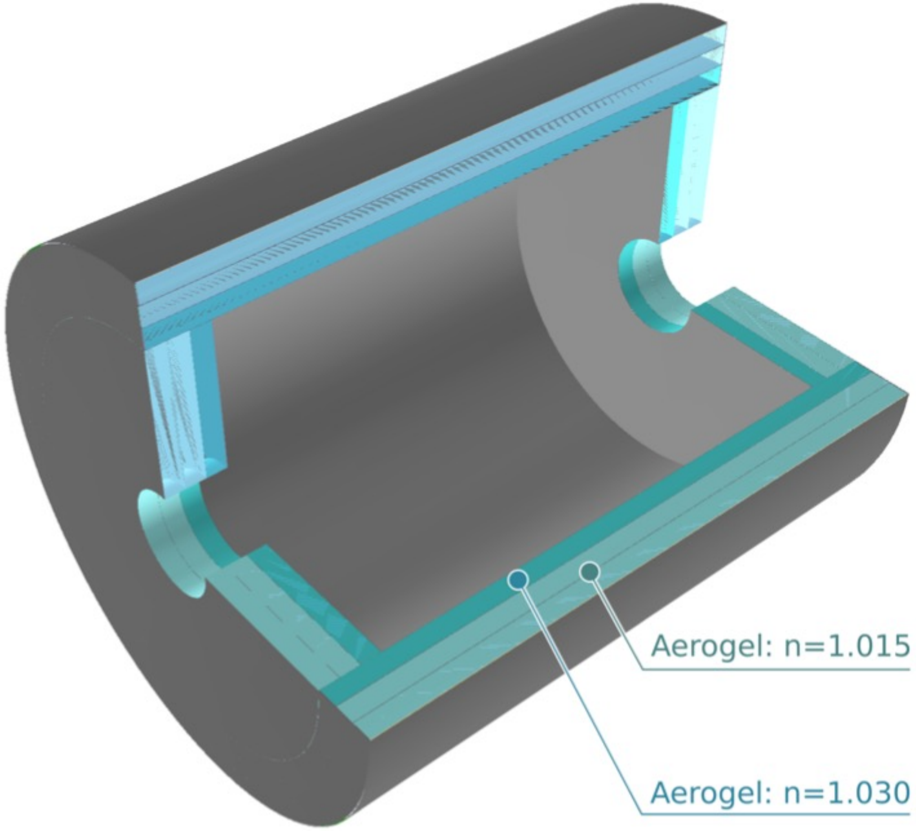
It is possible to upgrade KEDR and SND ASHIPH systems right now.

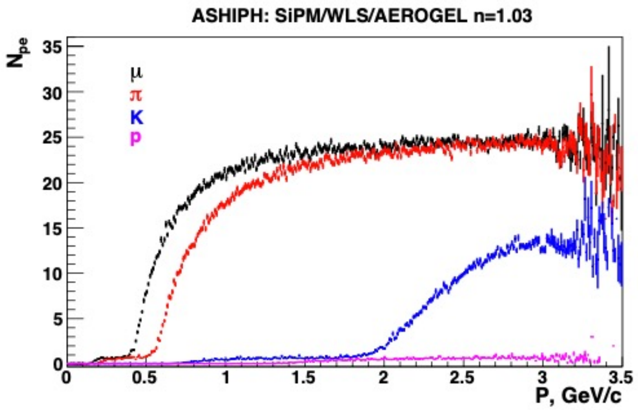
For Super Cτ (B)- Factories SiPM radiation tolerance study is needed.

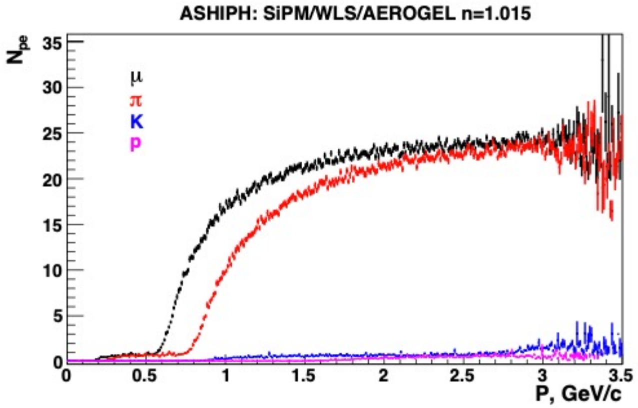
ASHIPH option for Super C-Tau factory

1400 counters 18x30x8 cm^3
System consists of 3 layers:
- n=1.03 (8 cm) – 2000 liters
- n=1.015 (8+8 cm) – 4000 liters

28k SiPM 3x3 mm^2
WLS based on PMMA doped by BBQ
0.3x6x28 cm^3







π/K – separation up to 3.5 GeV/c
μ/π – separation from 0.5 to 0.9 GeV/c

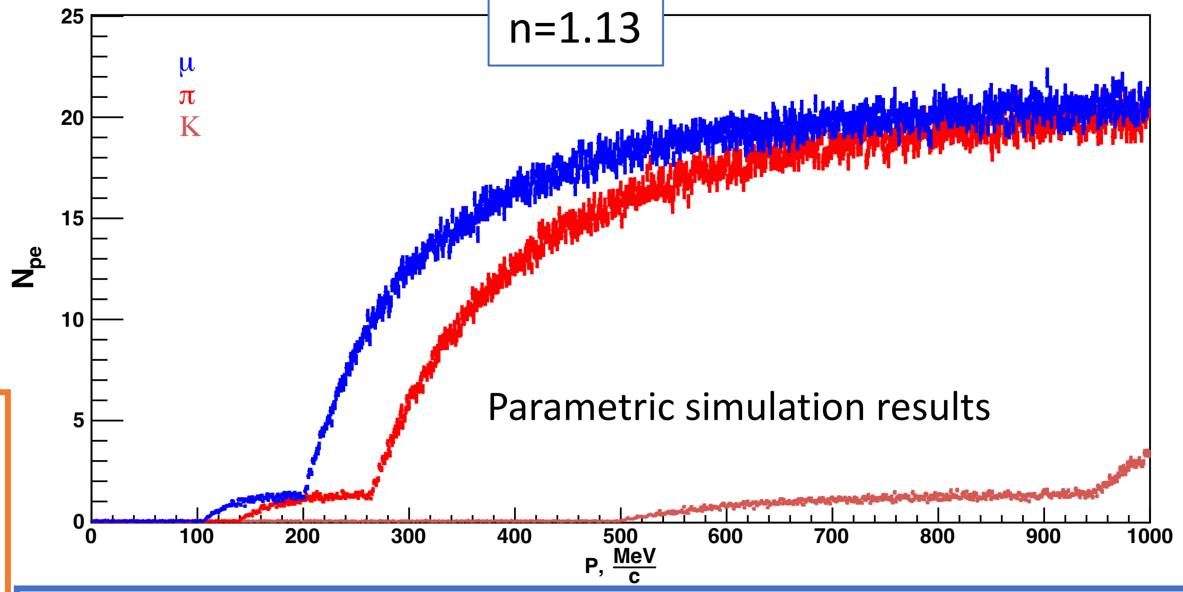
Upgrade of ASHIPH system for the SND

- Change of MCP-PMT to SiPM lead to increase of amplitude by two or more times:

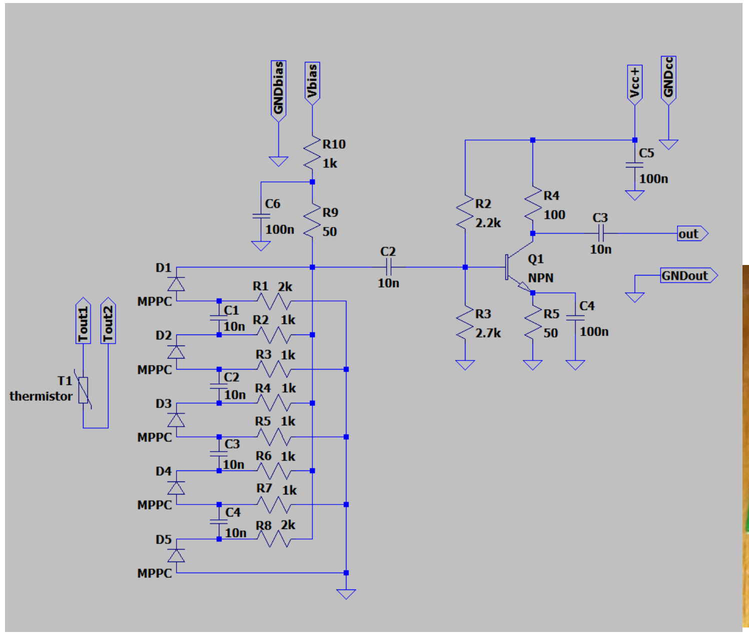
– ASHIPH system with n=1.05: 4.5 pe → 8÷10 pe

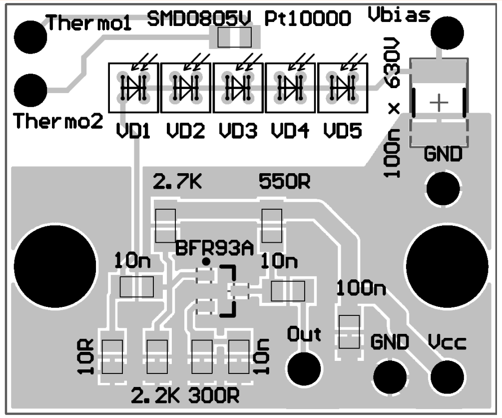
– ASHIPH system with n=1.13: 9.5 pe → 18÷20 pe

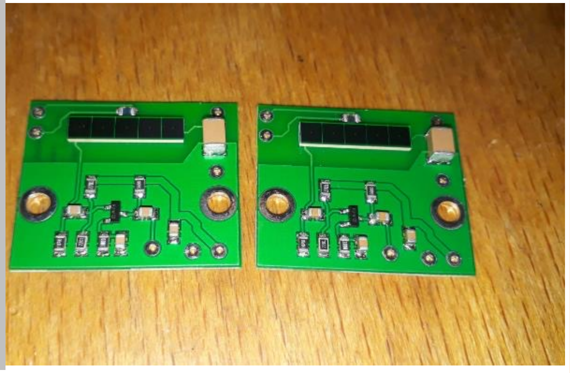
- π/K-separation become more reliable



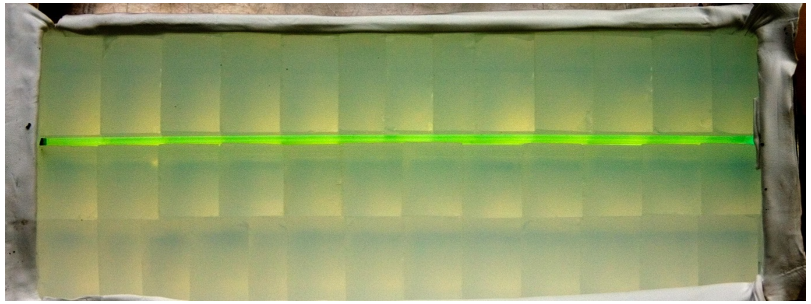
Scheme with consequently-parallel connection of SiPM







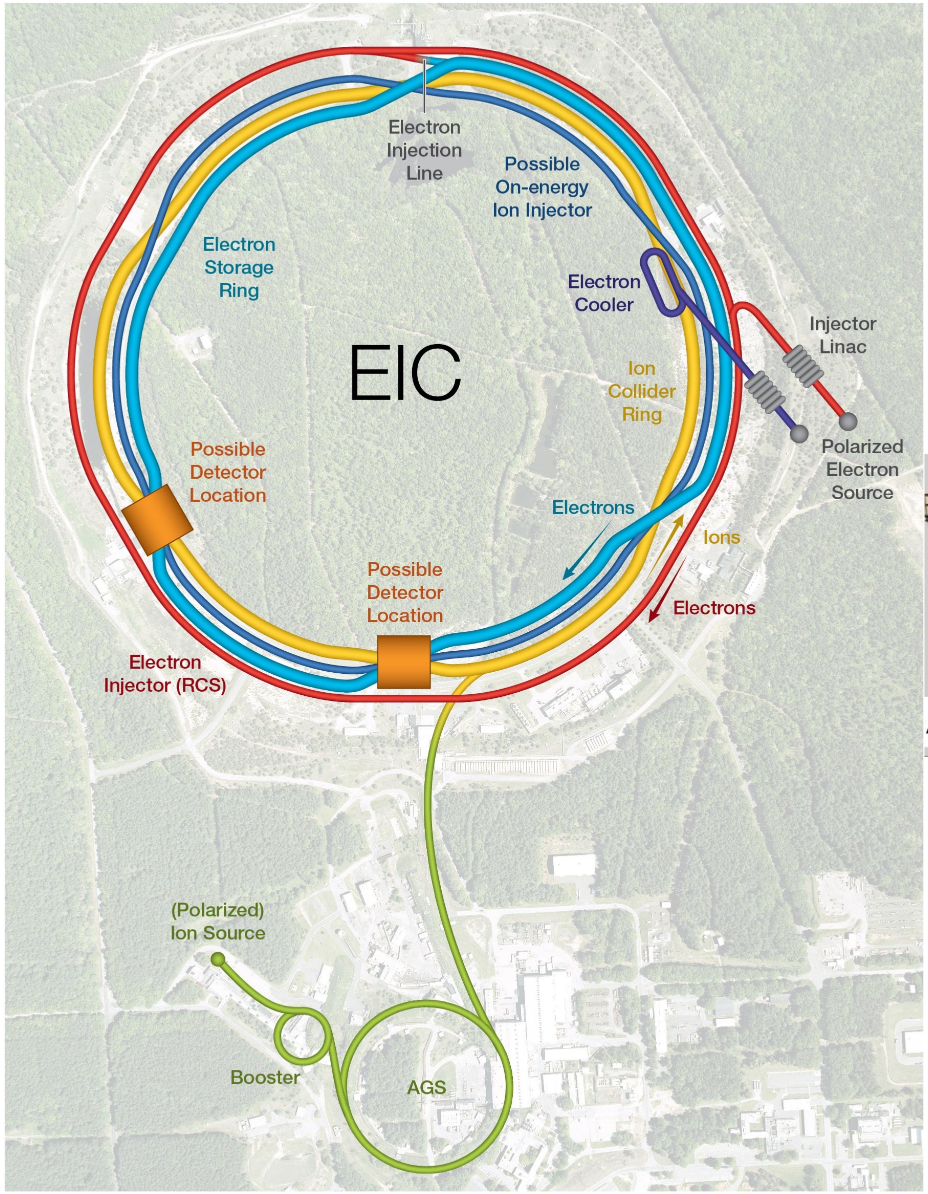
Aerogel radiator made from 38 sintered blocks 50x50x25 mm^3



Aerogel radiator made from single block 200x200x40 mm^3

RICH with Fresnel lens

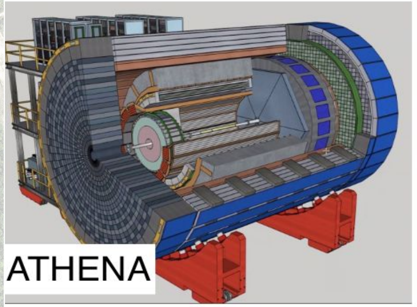
EIC project



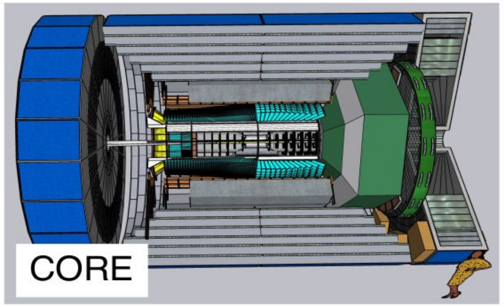
Key EIC Characteristics (parameters)

- High particle collision rate $L = 10^{34} cm^{-2} s^{-1}$ $\left(\int L\, dt = 100 fb^{-1}/year\right)$
- Large center-of-mass energy range $E_{CM} = 20 \div 140\ GeV$
  - electrons $2.5 \div 18\ GeV$
  - protons $40 \div 275\ GeV$ $(ions: Z/A \times E_p)$
- Polarized beams of electrons and ions $(up\ to\ 70\%)$
- Large range of ion species $(p \rightarrow U)$
- At least one large-acceptance detector
- Projected budget: $\approx \$2.4\ billion$ – Start date: ≈ 2031

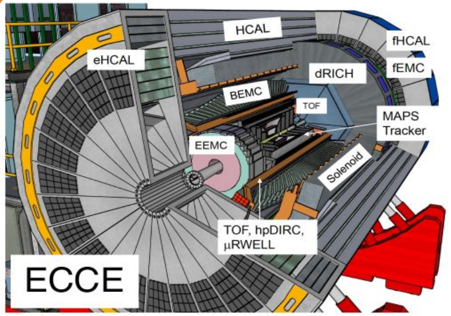
EIC detector proposals



- **backward**
  proximity-focus RICH
- **central**
  high-performance DIRC
  AC-LGAD TOF
- **forward**
  dual-radiator RICH



- **backward**
  AC-LGAD TOF
- **central**
  high-performance DIRC
- **forward**
  dual-radiator RICH

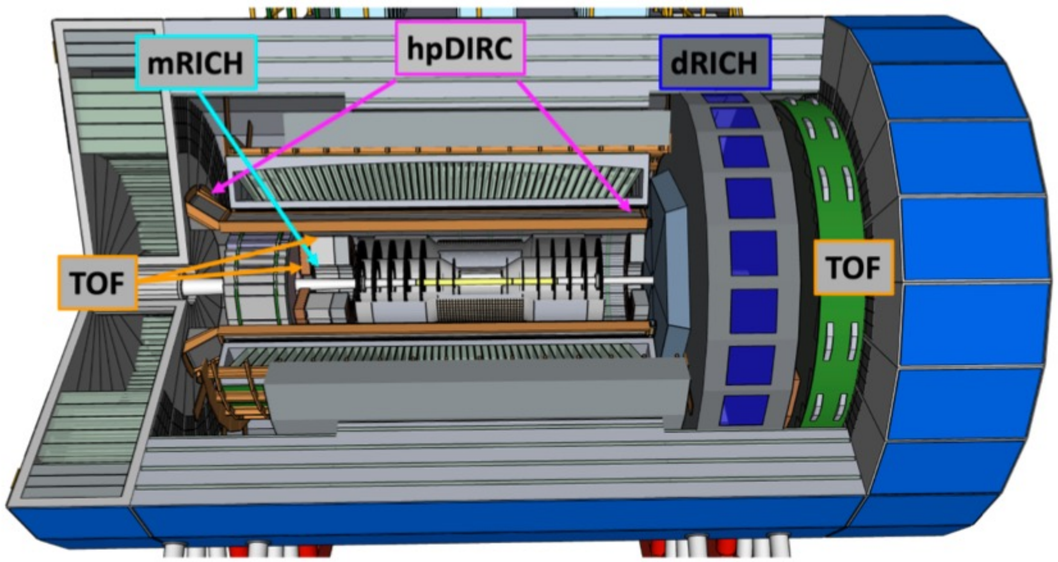


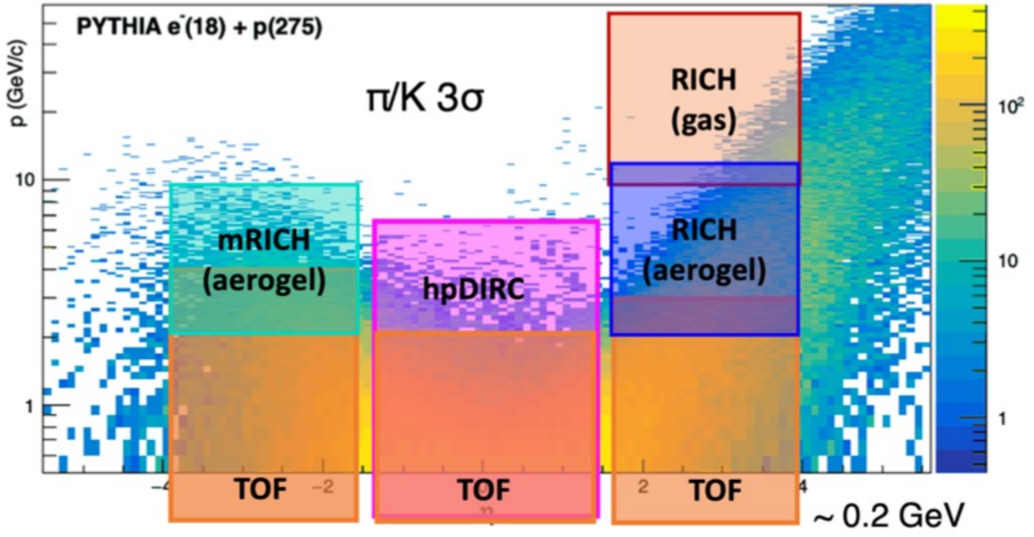
- **backward**
  modular RICH
  AC-LGAD TOF
- **central**
  high-performance DIRC
  AC-LGAD TOF
- **forward**
  dual-radiator RICH
  AC-LGAD TOF

Almost approved concept since begin of 2022

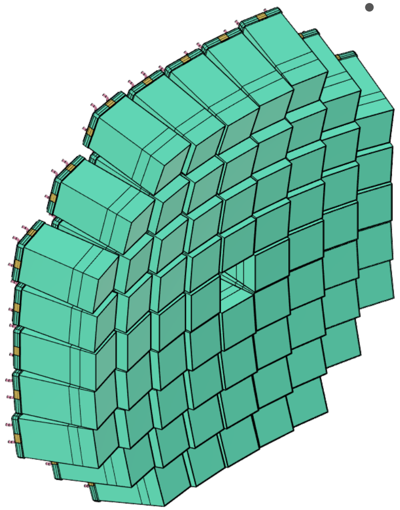
ECCE-PID & mRICH system concepts

ECCE = EIC Comprehensive Chromodynamics Experiment





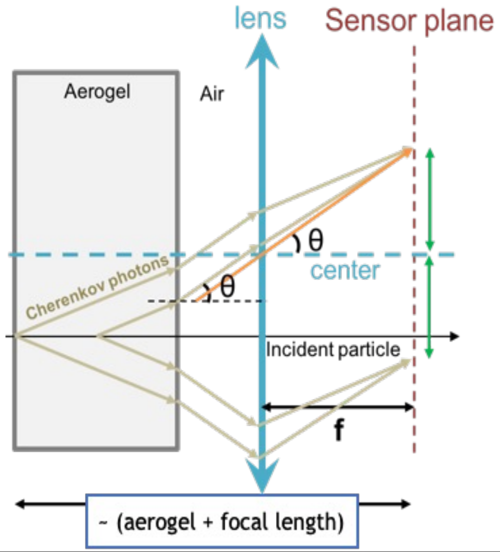
- **Physics requirements**
  - pion, kaon and proton ID
  - over a wide range |η| ≤ 3.5
  - with better than 3σ separation
  - significant pion/electron suppression
- **Momentum-rapidity coverage**
  - forward: up to 50 GeV/c
  - central: up to 6 GeV/c
  - backward: up to 10 GeV/c
- **Demands different technologies**
- **Cherenkov detectors:**
  - dRICH = dual RICH (aerogel + gas)
  - hpDIRC = high-performance DIRC (synthetic fused silica)
  - mRICH = modular RICH (aerogel + Fresnel lens)

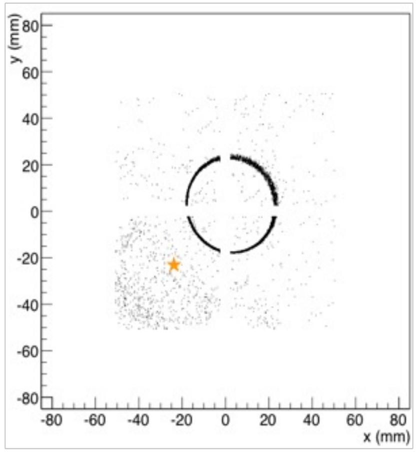


68 modular counters oriented to IP:
– aerogel n=1.03 100x100x40 mm^3
– acrylic Fresnel lens with focal distance 6”
– position sensitive photon detector HRRPD (MCP-PMT) or SiPM arrays

Aerogel RICH with Fresnel lens

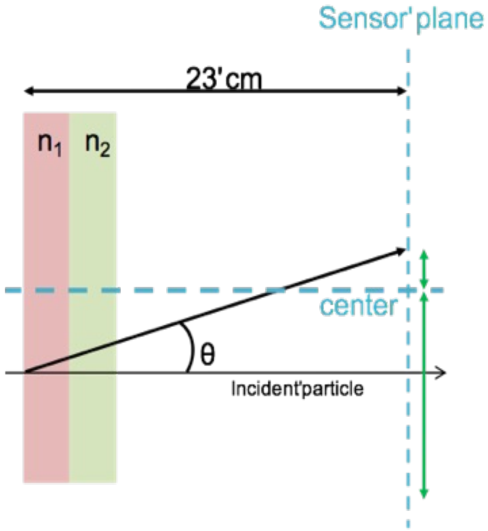
Lens-Based mRICH Design

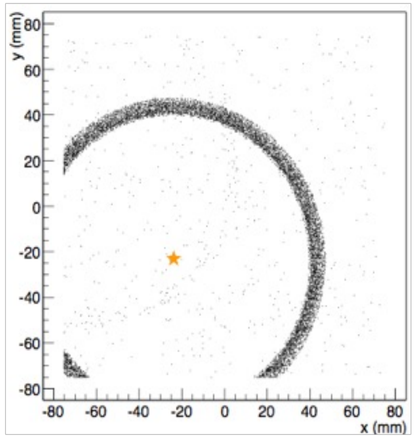




- 9 GeV/c pion beam incident at third quadrant (**star**) in simulation
- Ring image is **shifted toward the central region** on the sensor plane

Two-Layer Proximity Focusing Design (BELLE-2 ARICH)





- 9 GeV/c pion beam incident at third quadrant (**star**) in simulation
- Ring is centered at point of incidence

Such approach allows us to improve Cherenkov angle resolution and optimize photo detectors area!

The thick aerogel for mRICH

There are two way to increase the aerogel thickness:

- Arrange the stack of several aerogel samples with moderate thickness like as 20 mm
- Produce the larger (thicker) aerogel samples as for LHCb (n=1.03; 200x200x50 mm^3)

According to Marco Contalbrigo, so far the only manufacturer that achieved thickness larger than 2cm is in Russian.

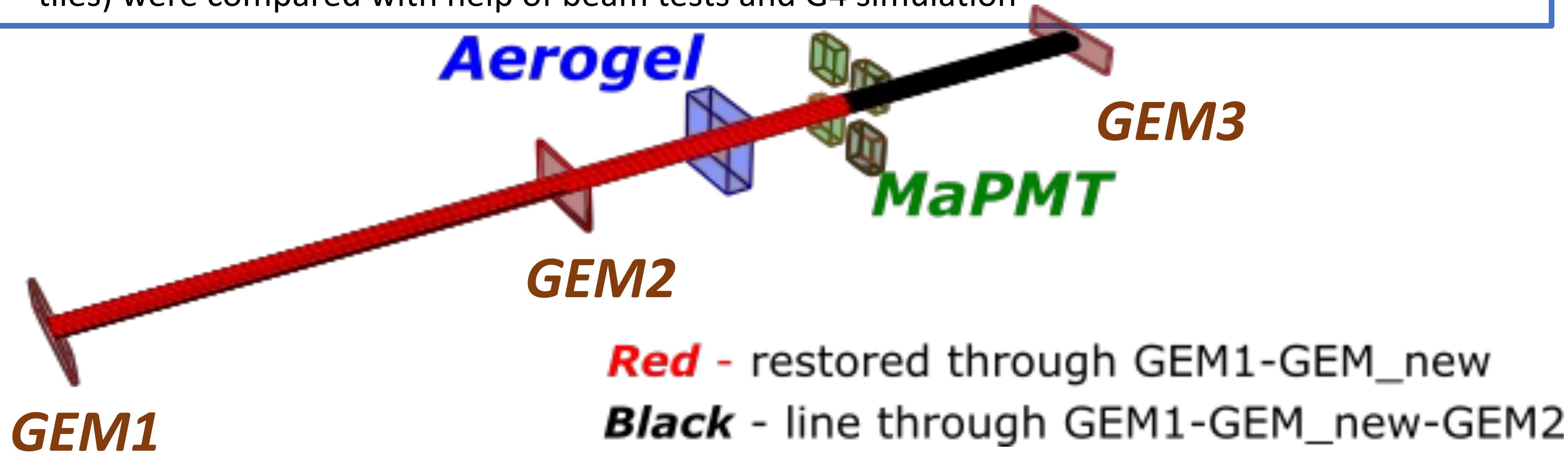
- In both cases there is no reason to make the aerogel thickness more than $(1 \div 2) \cdot L_{sc}$:

$$N_{out} = N_0 \frac{L_{sc}}{h}\left(1 - e^{-\frac{h}{L_{sc}}}\right), \qquad L_{sc} \sim \lambda^4$$

- In case of approach “stack” the additional Cherenkov photons loss is occured due to reflectance and scattering on the additional surfaces
- There are two not cuttied surfaces in aerogel
  - “Optical surface@ – which contacts only with air during the production
  - “Bottom”   it contacts with metallic frame during the production processes
- Several configuration of the aerogel Cherenkov radiators were tested with relativistic elecron beams at BINP beam test facilities in 2022.

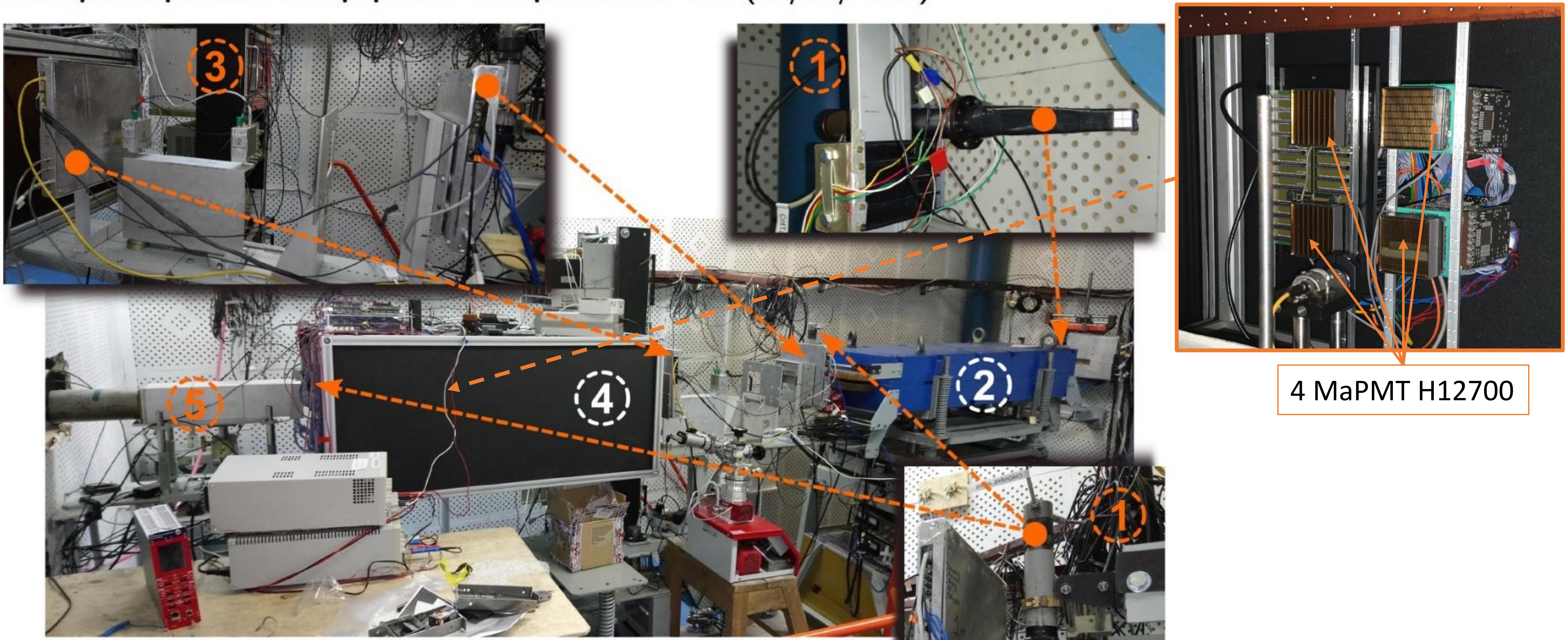
Beam tests schem of aerogel RICH in 2022 at BINP

- Three short runs (2 shifts: 12+12 hours) with electrons E=2.5 GeV was done in May, November and December 2022.
- Four MaPMTs H12700 (Hamamatsu) with pixel 6x6 mm were placed in such way to register 85% (for May run) and 60% (for Nov and Dec run) of Cherenkov photons per track.
- Three GEMs with spatial resolution $\sigma_{X,Y}$≤100 μm were used at beamline.
  - ✓ Two before aerogel sample and one behind
- Two approaches to create a thick aerogel Cherenkov radiators (single thick tile or stack of two tiles) were compared with help of beam tests and G4 simulation



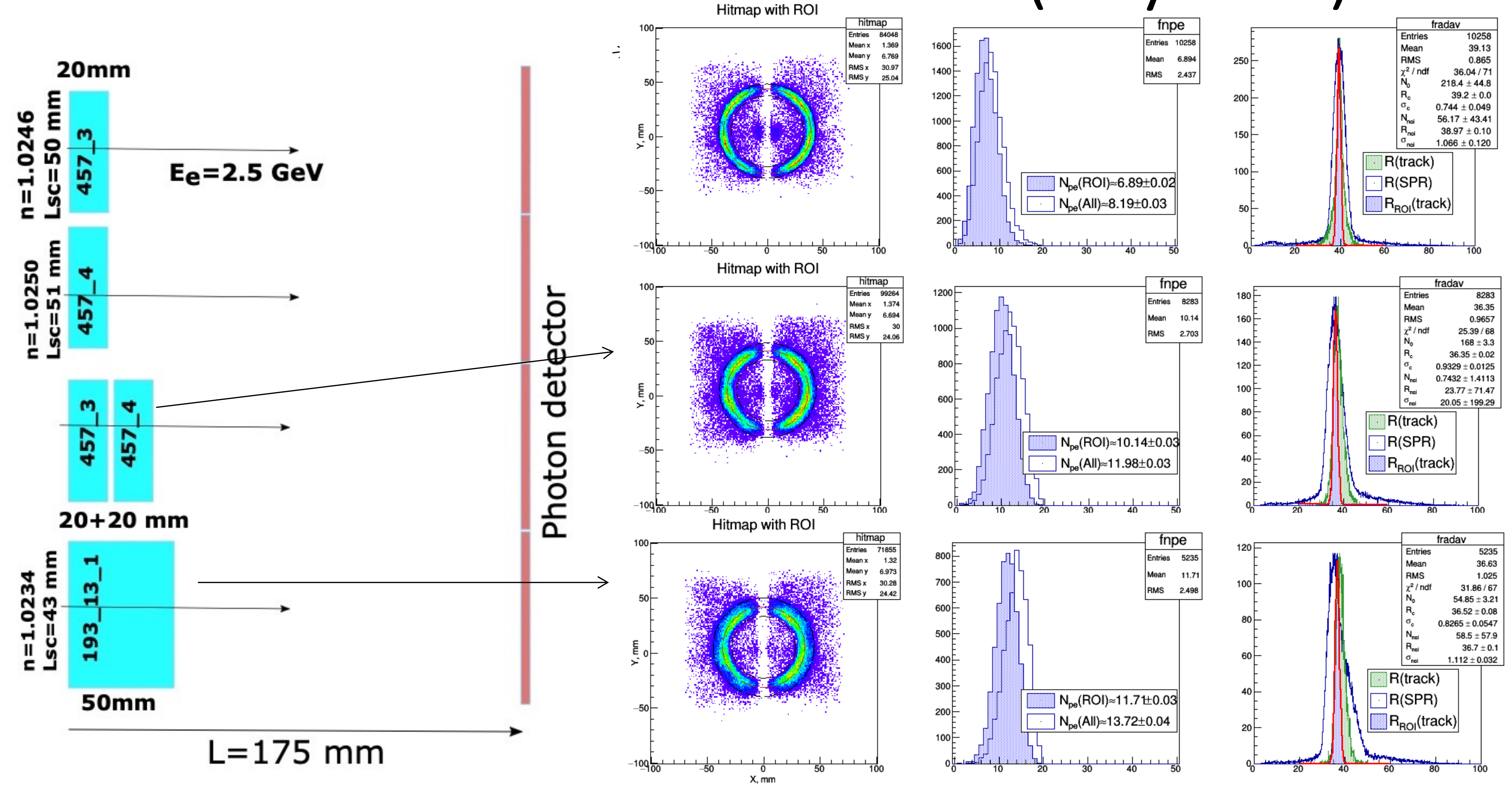
BINP beam test facility

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

Scheme&Results of beam test (May 2022)

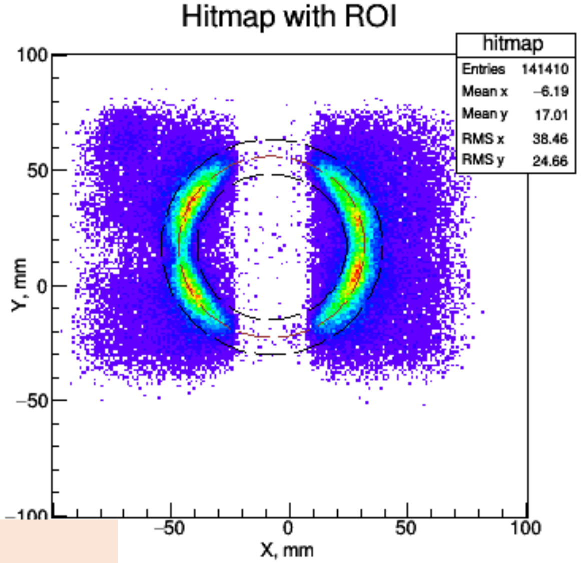


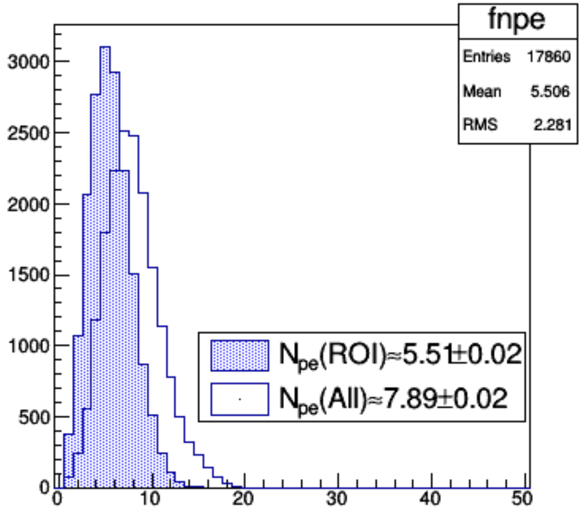
Влияние эффектов поверхности в стопке (457f3+457f4)

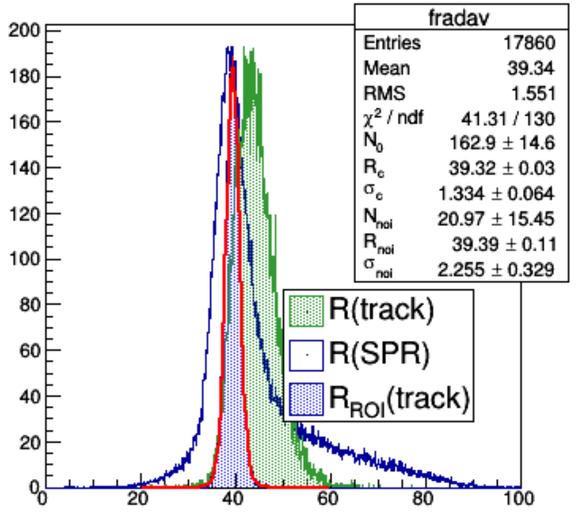
$$\frac{\sigma_R^{opt.s+opt.s}}{\sigma_R^{opt.s+bot.s}} \approx 1.03 \pm 0.07$$

$$\frac{N_{pe}^{opt.s+opt.s}}{N_{pe}^{opt.s+bot.s}} = \frac{5.51}{5.34} \approx 1.032 \pm 0.005$$

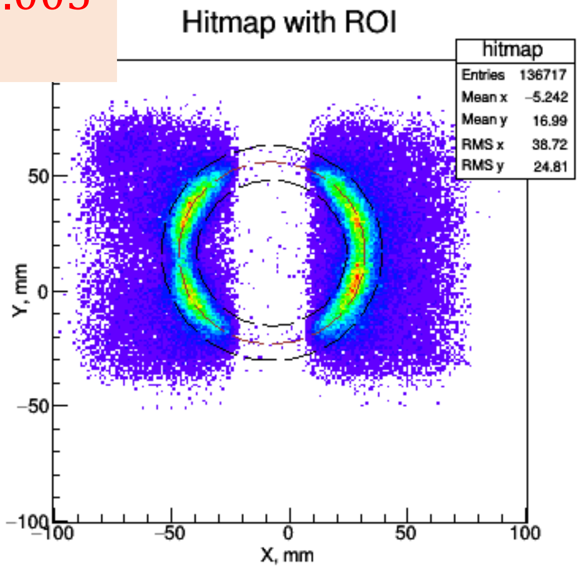
"Opt.s"+"Opt.s" → PD

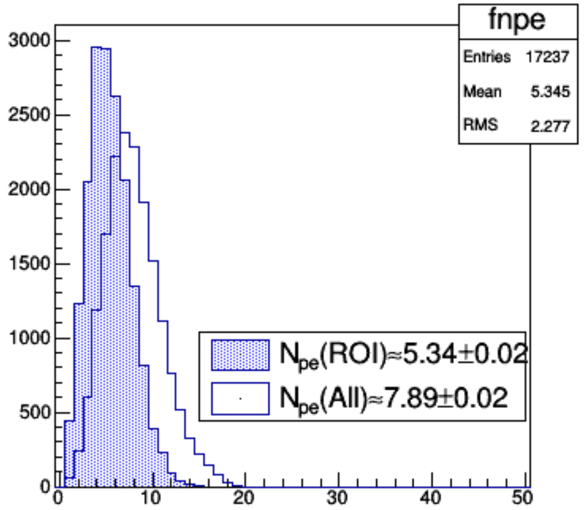


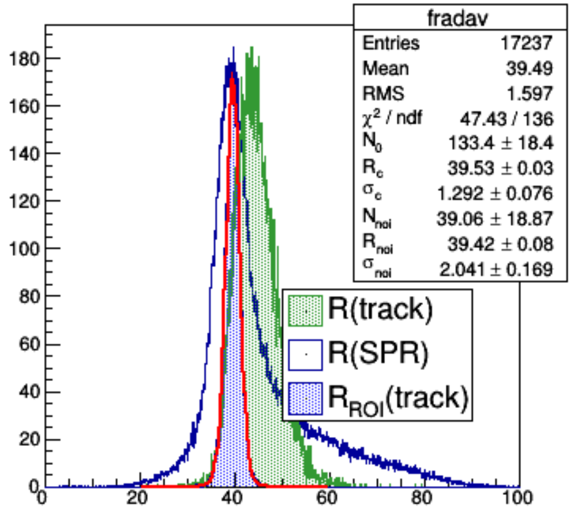




"Opt.s"+"Bot.s" → PD



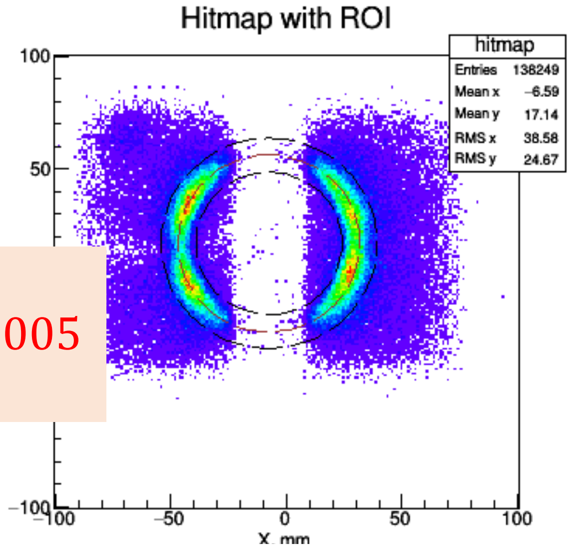




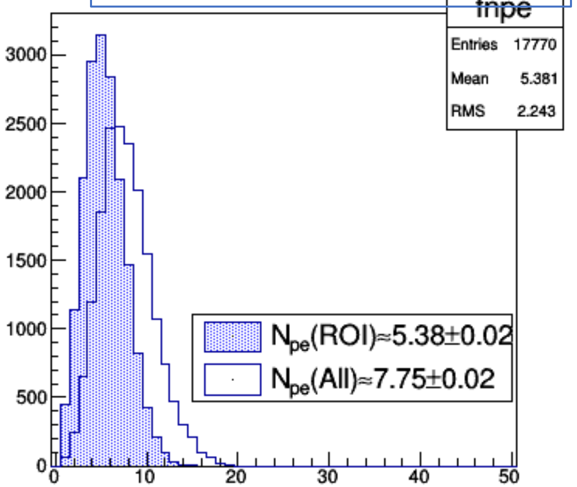
Влияние эффектов поверхности в стопке (457f3+457f4)(2)

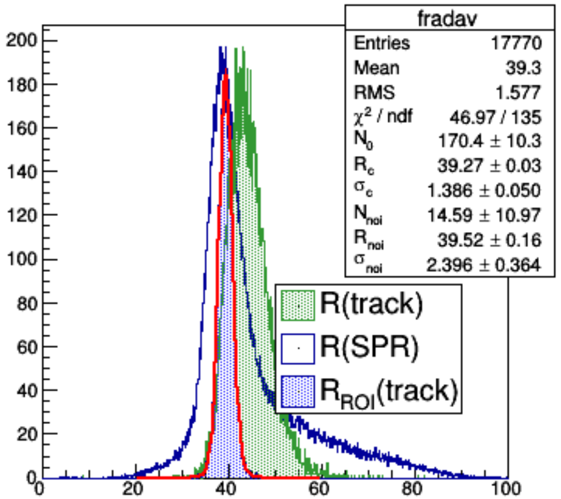
$$\frac{\sigma_R^{opt.s+opt.s}}{\sigma_R^{bot.s+opt.s}} \approx 0.96 \pm 0.07$$

$$\frac{N_{pe}^{opt.s+opt.s}}{N_{pe}^{bot.s+opt.s}} = \frac{5.51}{5.38} \approx 1.024 \pm 0.005$$



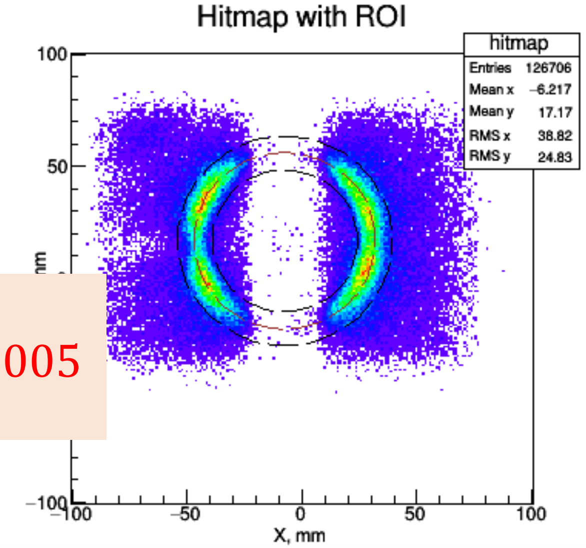
“Bott.s”+“Opt.s” → PD



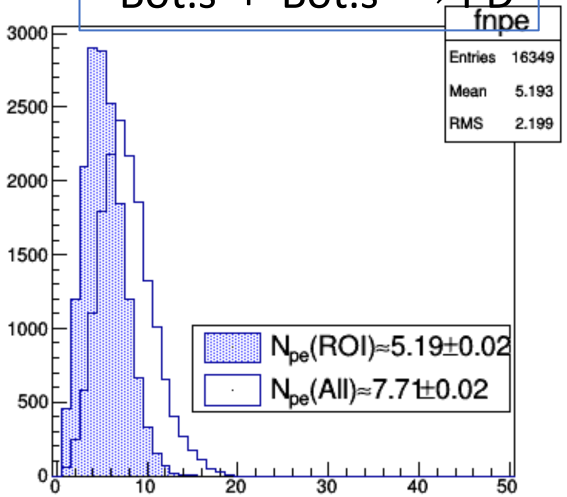


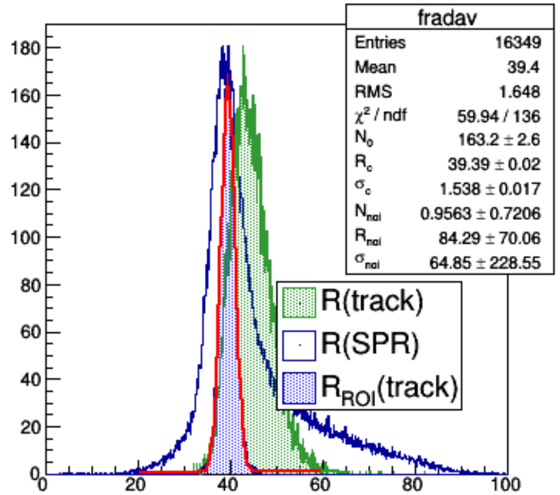
$$\frac{\sigma_R^{opt.s+opt.s}}{\sigma_R^{bot.s+bot.s}} \approx 0.87 \pm 0.07$$

$$\frac{N_{pe}^{opt.s+opt.s}}{N_{pe}^{bot.s+bot.s}} = \frac{5.51}{5.19} \approx 1.062 \pm 0.005$$



“Bot.s”+“Bot.s” → PD



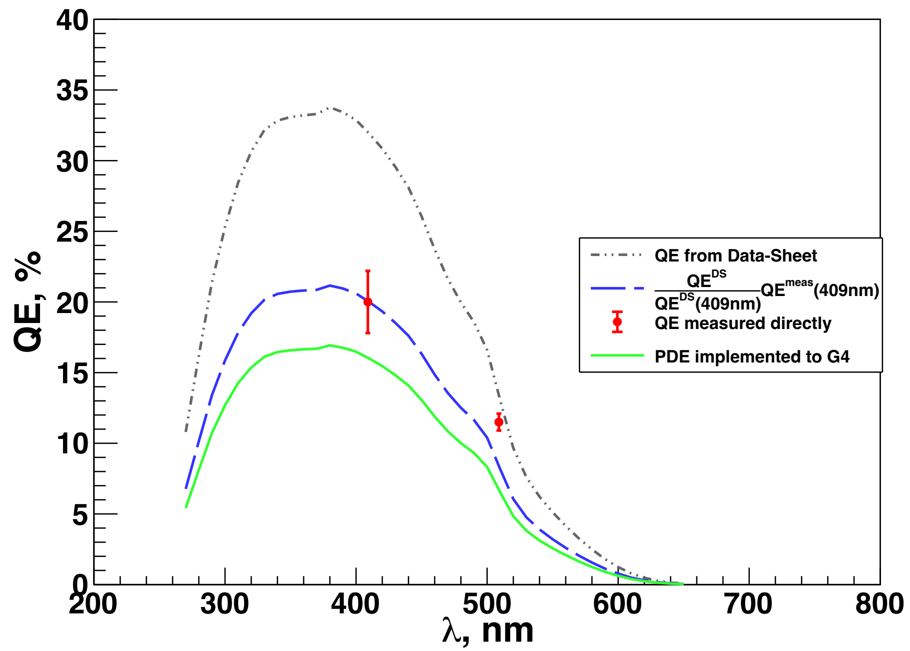


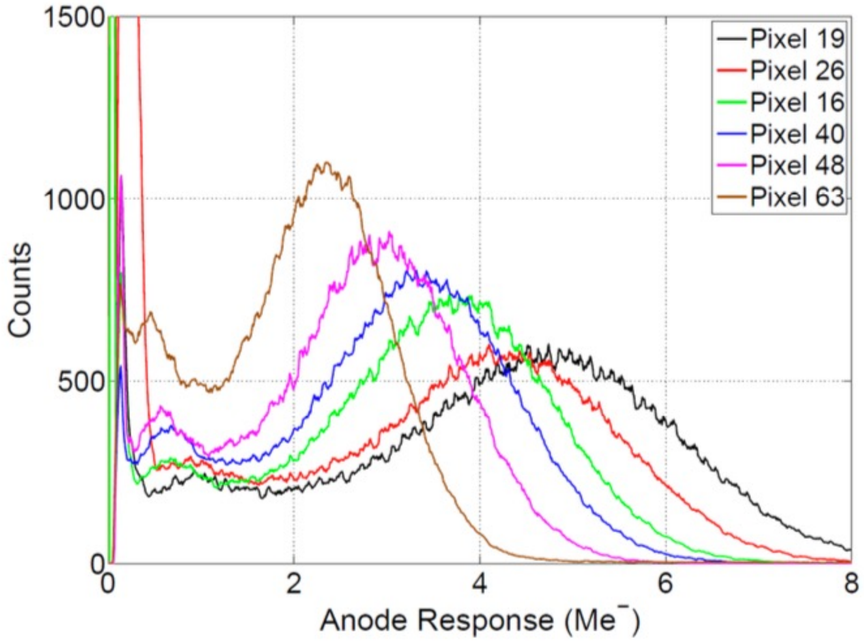
Due to scattering effects on the bottom aerogel surfaces the N_{pe} loss is about 3–4% for single layer samples and about 6% for stack of two samples. While the resoultion degradation becomes sensable (13%) only in case of stack of two aerogel samples.

TBeam simulation with G4: input data.

- To perform quntitively comparison TBeam results with G4 simulation it is necessary to implement in simulation very correct data on aerogel parameters (n, L_{sc}, thick) and also about photon detector parameters such like Geometry and PDE.
- As a QE(λ) we will use data for MaPMT H12700 from manufacturier (Hamamatsu) data-sheet (DS) normalized on our own direct measurement QE(λ=409nm) performed with laser light sourse(see the pictures below: left).
- Also it is necessary to take into account that flat-pannel MaPMTs have non 100% photoelectron collection efficiency (CE). According to invetigations (Ref. *arXiv:1506.04302v2 [physics.ins-det] 5 Oct 2015*) about 20% of photoelectrons are able to give by 5 times smaller amplitude than a single photoelectron peak due to skip of the first dynode stage (see the pictures below: right). It means that if the read out electronics discriminator threshold is set ~0.1-0.2pe we will lose about 20% of photoelectrons.
- In the G4 simulation is implemented recalculated photon detection efficiency (PDE):

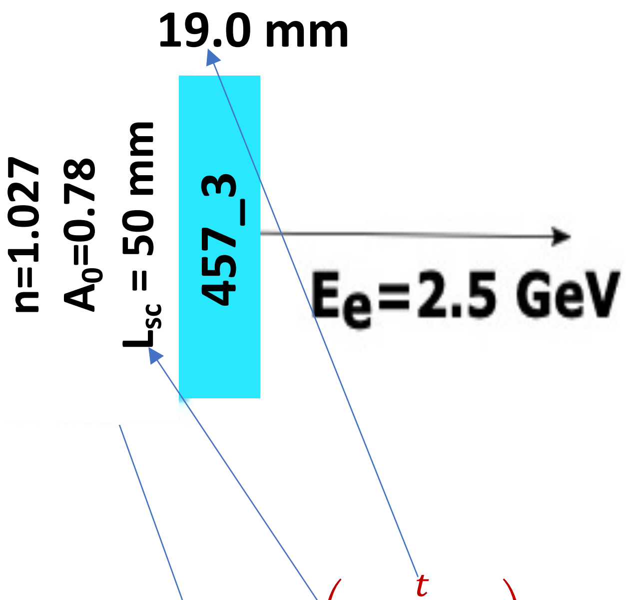
$$PDE(\lambda) = \frac{QE(\lambda)^{DS}}{QE(409nm)^{DS}} QE(409nm)^{Meas} \cdot CE = \frac{QE(\lambda)^{DS}}{32\%} 20\% \cdot 0.8$$



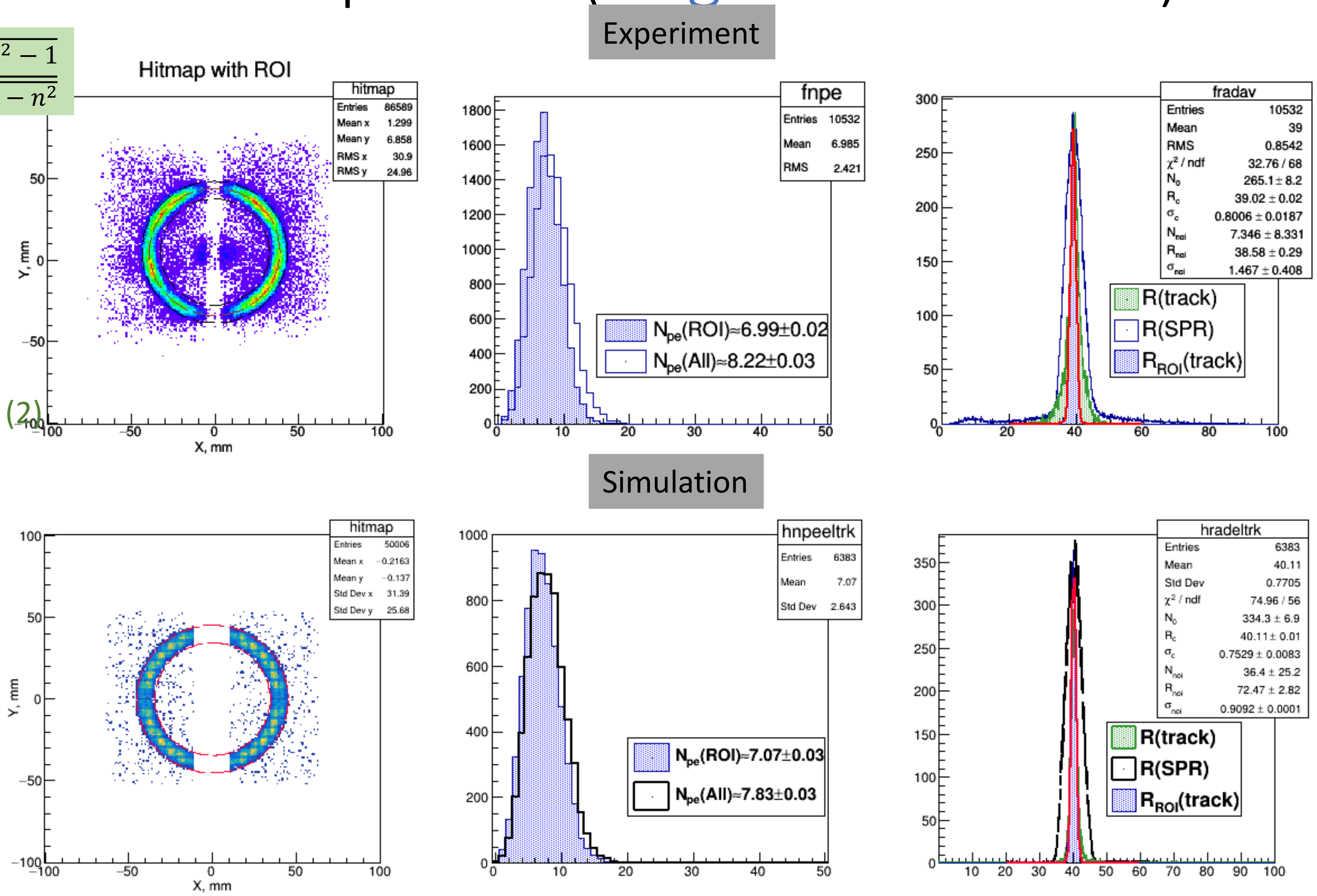


Tbeam and G4sim comparison (single – thin 457-3)

$$(L - t_{Aer})\cdot\sqrt{n^2-1} \le R_{ROI} \le L\cdot\frac{\sqrt{n^2-1}}{\sqrt{2-n^2}}$$



$$\frac{I}{I_0} = A_0 \cdot e^{-\left(\frac{t}{L_{sc}\cdot\left|\frac{\lambda}{400}\right|^4}\right)}$$

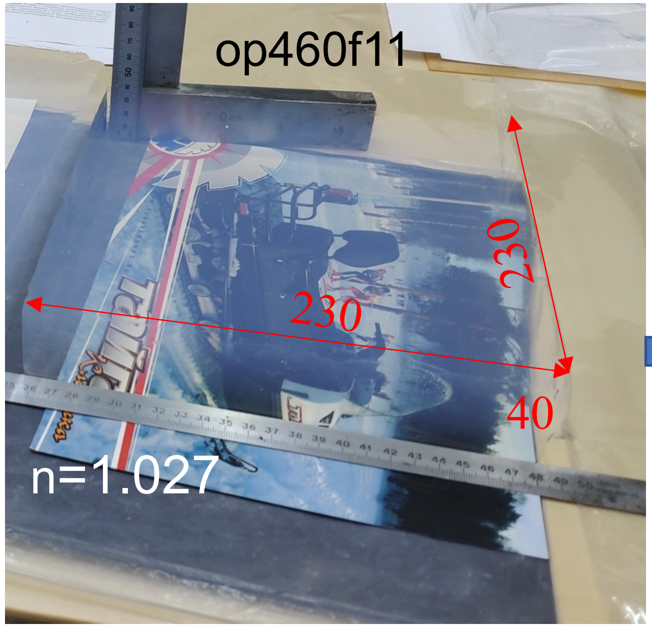


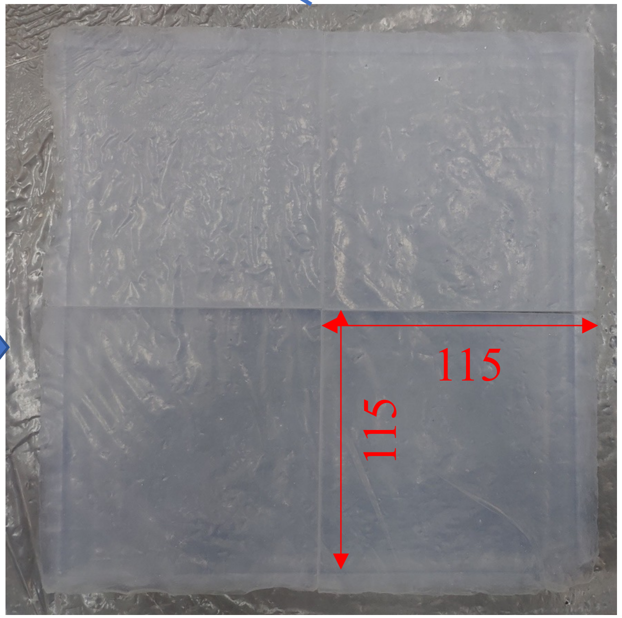
Scheme&Results of beam test (Dec 2022)

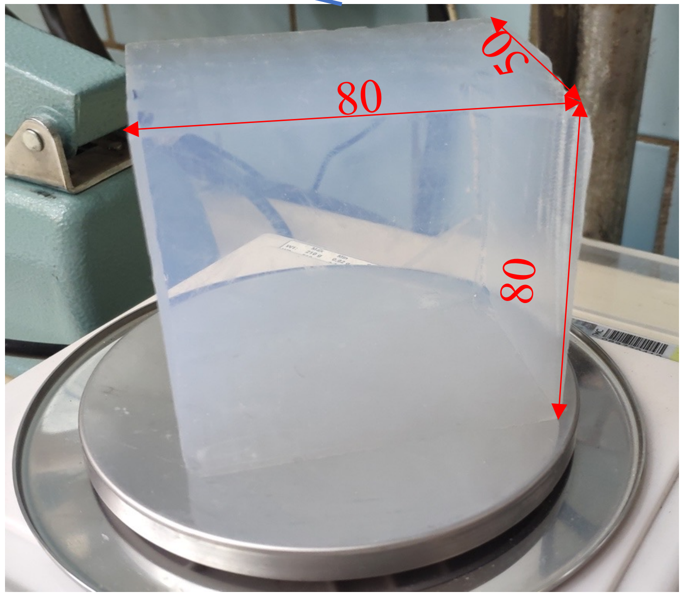
- The new aerogel samples were produced in 2022 to be tested in mRICH prototype with mixed hadron beams in 2023-2024.

  Refractive index of all tiles n = 1.028±0.001;
  L_{sc}(400nm) for all blocks ≥43mm;
  7 aerogel tiles 30 mm 100x100 mm
  4 aerogel tiles 40 mm 100x100 mm
  1 aerogel tile 50 mm 80x80 mm;

- The general idea of the experiment was to investigate the quality of new aerogels and estimate the impact from aerogel itself to overal mRICH prototype resolution.
- PD and beamline configurations were the same as in Novembe 2022. It allow us to perform direct comparison of results from these two beam test campaigns (Nov and Dec 2022).







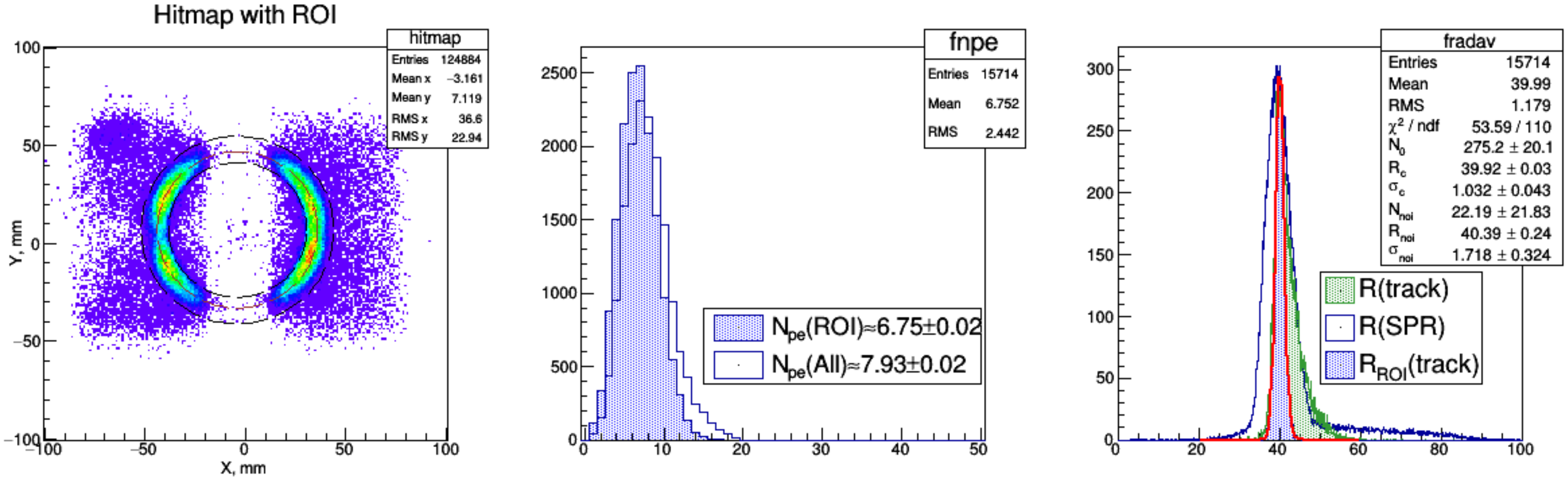
Aerogel with 30 mm thickness (460f4)

460f4_4

T(5 hours)=470˚C

n=1.027

L_{sc}(400nm)=47.0±0.7 mm

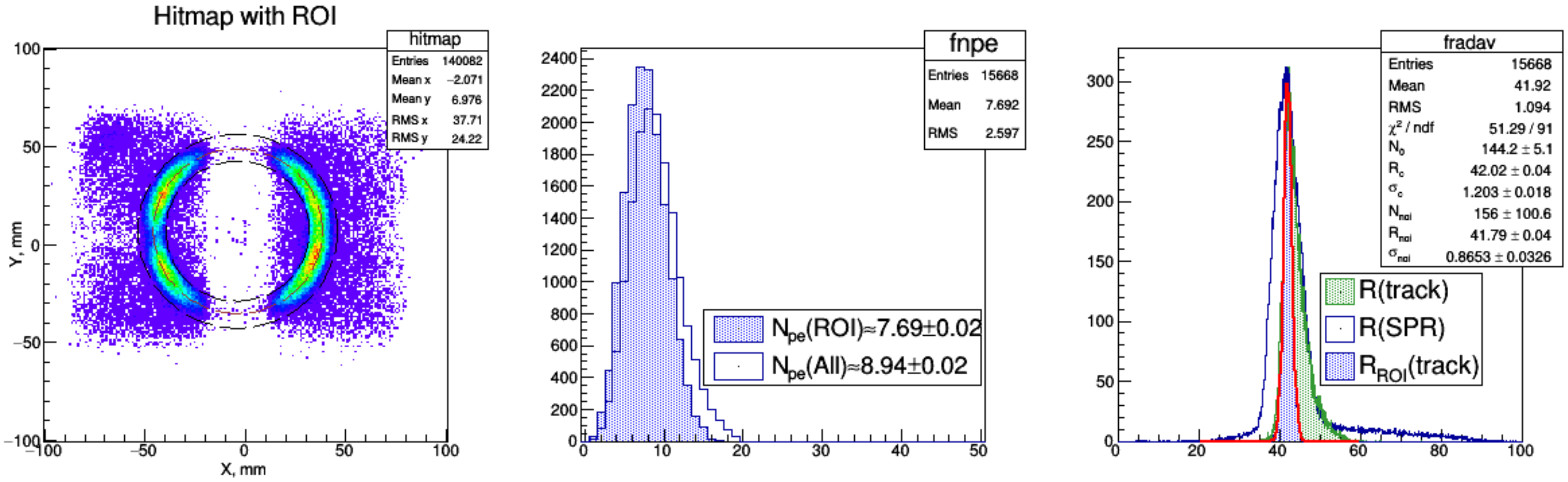


460f4_3

T(5 hours)=600˚C

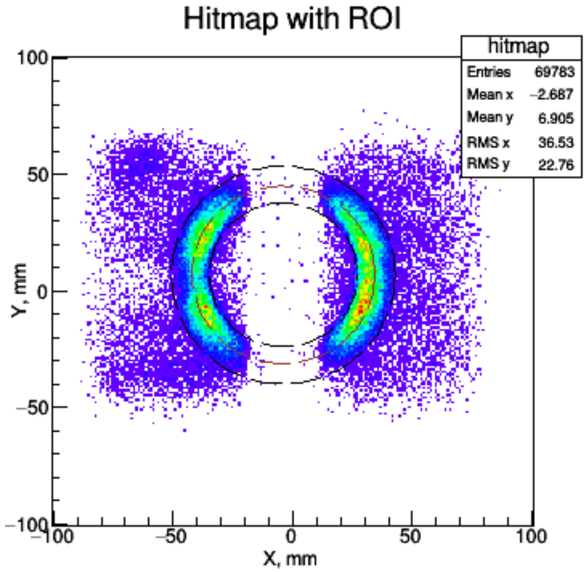
n=1.029

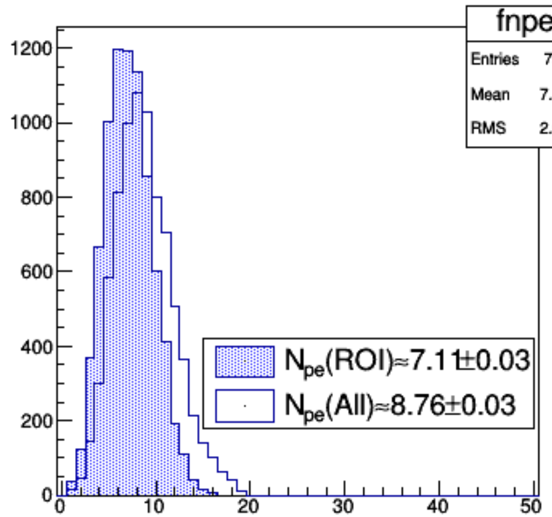
L_{sc}(400nm)=41.8±0.7 mm

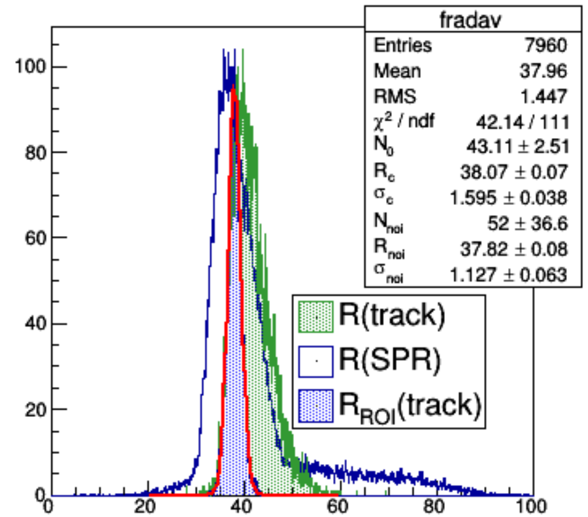


Aerogel with 40 mm thickness (460f11)

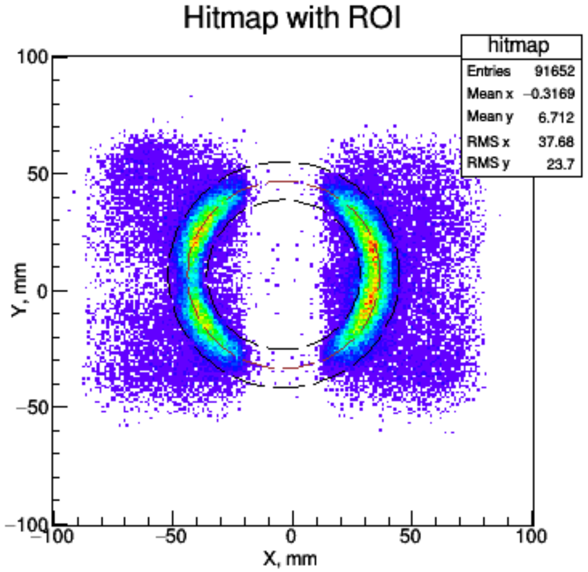
460f11_21
T(5 hours)=470˚C
n=1.028
L_{sc}(400nm)=48.2±0.7 mm

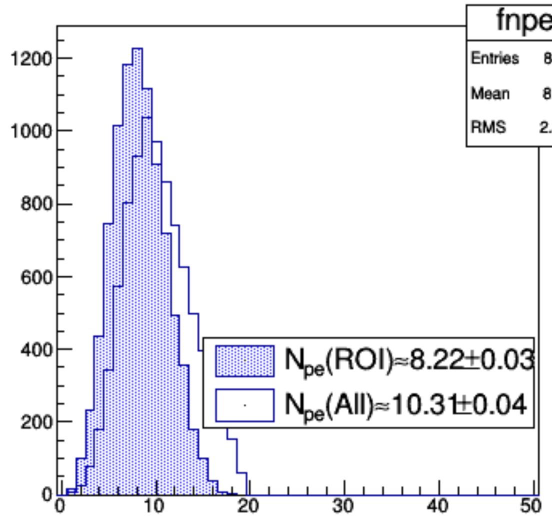


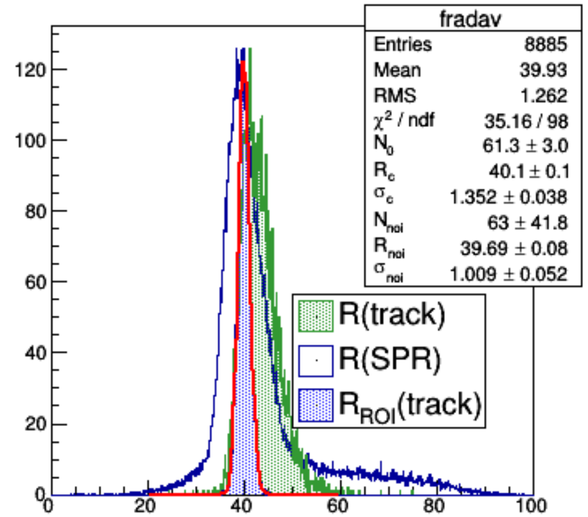




460f11_22
T(5 hours)=600˚C
n=1.029
L_{sc}(400nm)=42.7±0.7 mm







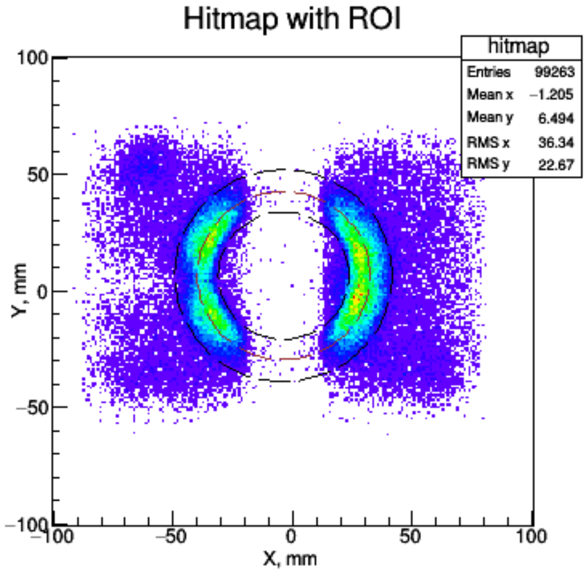
Aerogel with 50 mm thickness (460f15)

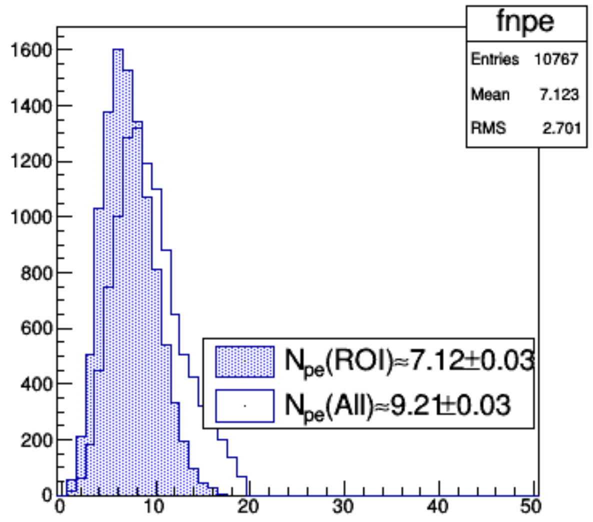
460f15_1

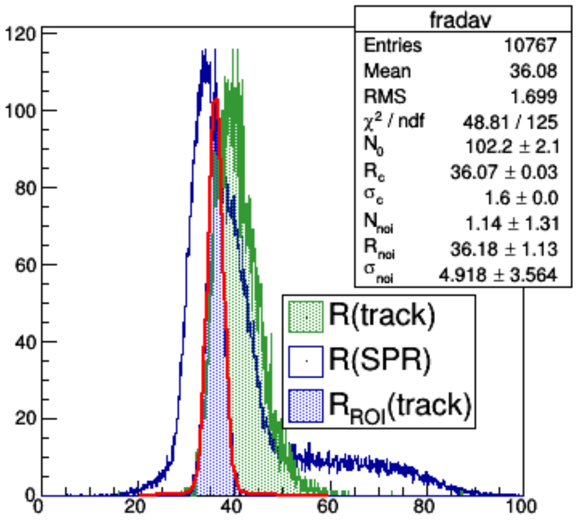
T(5 hours)=470˚C

n=1.027

L_{sc}(400nm)=43.7±0.6 mm





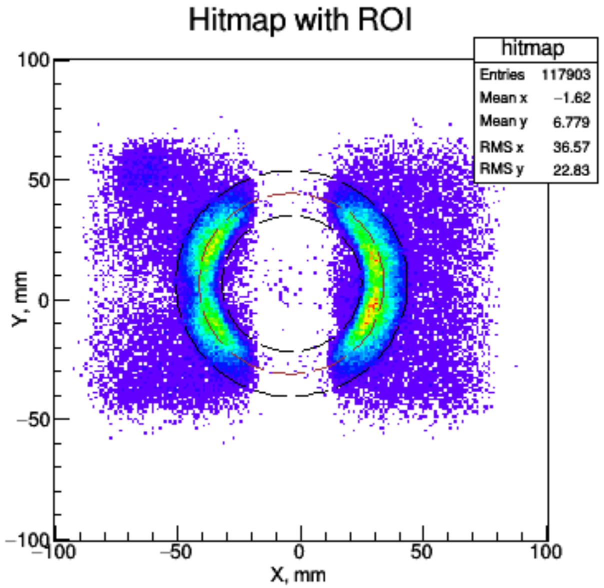


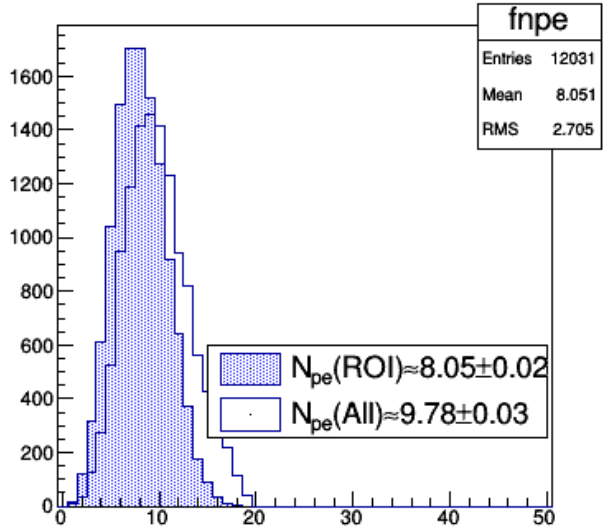
460f15_3

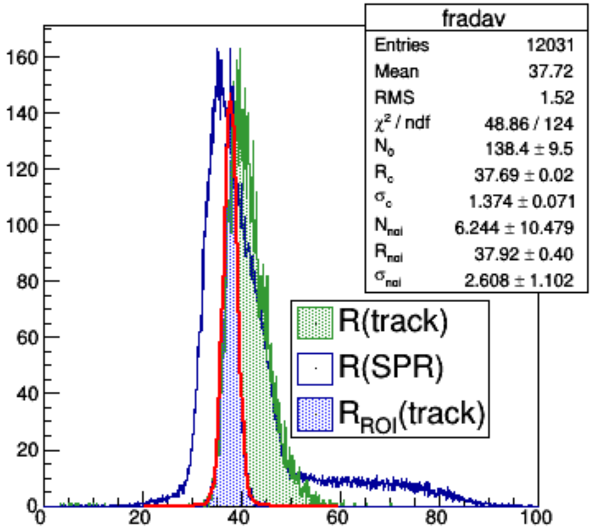
T(5 hours)=600˚C

n=1.029

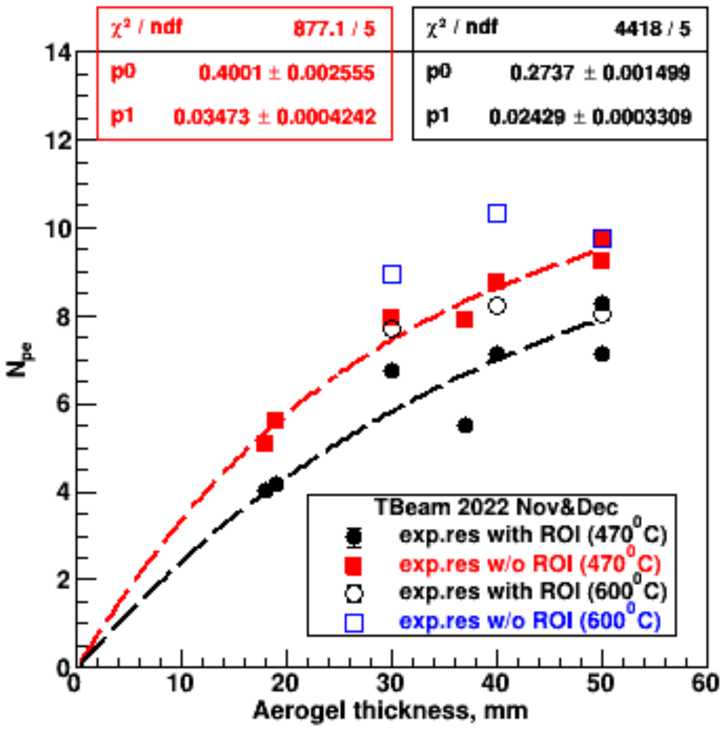
L_{sc}(400nm)=41.7±0.6 mm

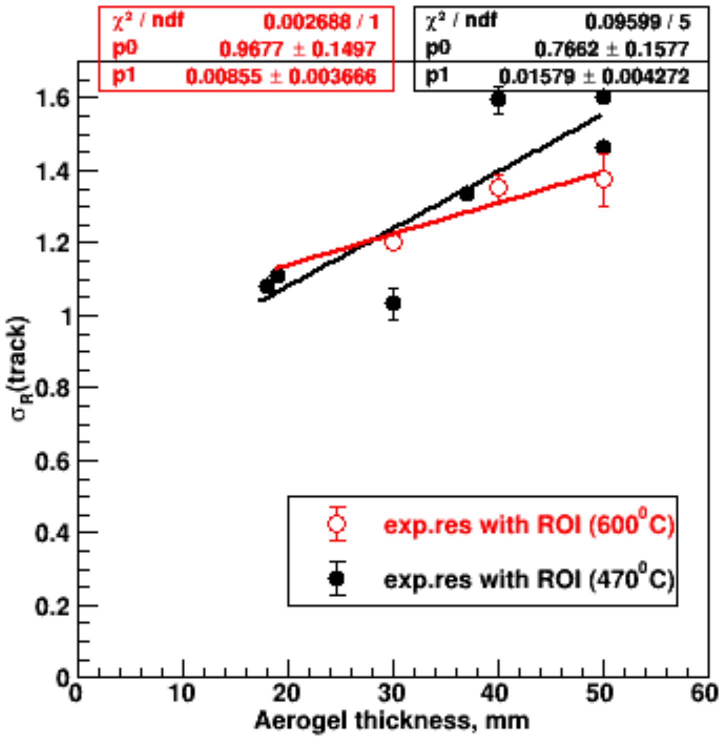


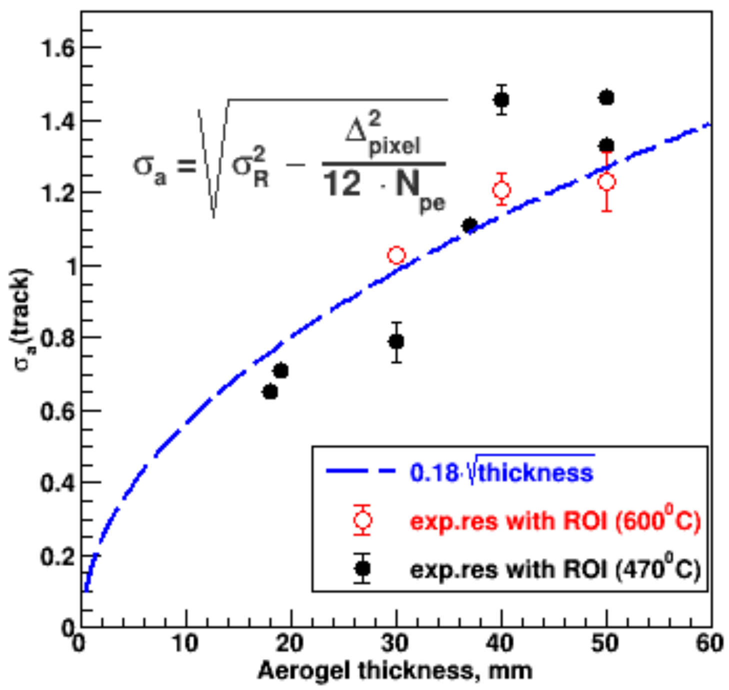




Dependence of N_{pe} and σ_R on aerogel thickness

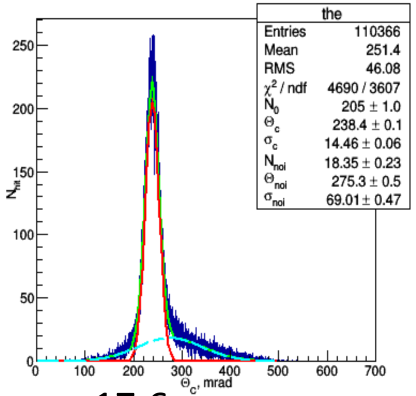






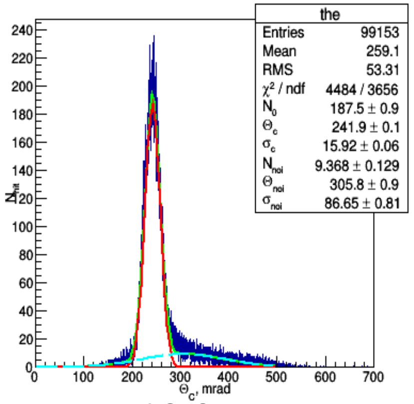
- N_{pe} dependes on the aerogel thickness as expected and limitted by the Releigh light scattering law.
- Some ssytematical increase of N_{pe} (~13÷15%) are observed in new thick aerogels after increase of backing temperature (470˚C –> 600˚C). This effect could not be quantatively explained by increase of refractive indexes (1.027 –> 1.029) and it is contra to N_{pe} decrease (~5÷6%) expected due to Releigh light scattering decrease ($L_{sc}(400nm, 1.027) \approx 47mm \ \rightarrow L_{sc}(400nm, 1.029) \approx 41mm$)
- $\sigma_R \sim \sqrt{thickness}$ (as expected), while for several aerogel samples some deviations σ_R from the dependence are observed. The reason of this effect could be in some impurites inside the aerogel which are able to give additional small angle forward scattering.

Cherenkov angle single photon resolution (SPR)



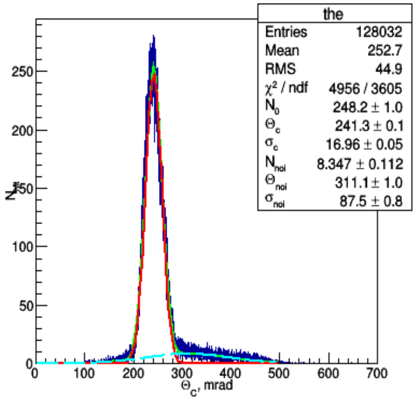
17.6 mm

457f4



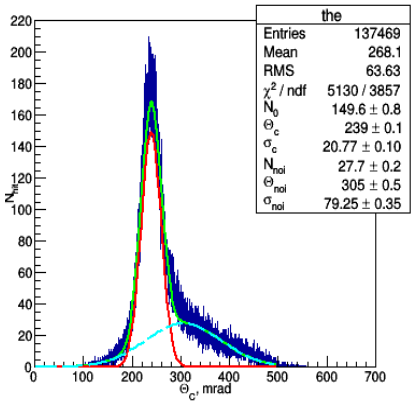
19.0 mm

457f3



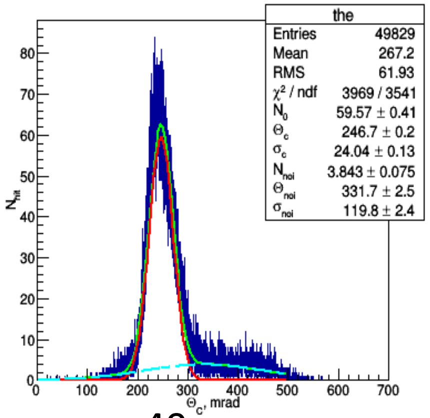
30.0 mm

460f4_3



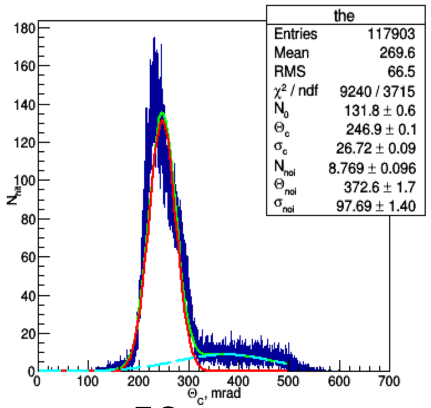
19.0+17.6 mm

457f3+457f4



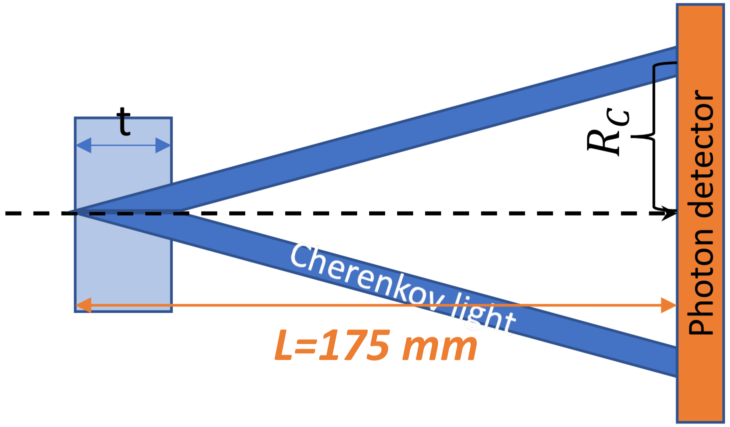
40. mm

460f11_22



50. mm

460f15_3



	457f4	457f3	460f4_3	457f3_f4	460f11_22	460f15_3
t/L, mm	17.6/185	19.0/175	30.0/185	36.6/185	40.0/185	50.0/185
$\sigma_{\theta_C}^{SPR}$, mrad	14.46±0.06	15.92±0.06	16.96±0.05	20.8±0.1	24.0±0.1	26.7±0.1
N_{pe}* – 60% of the ring	4.01±0.01	4.16±0.01	7.69±0.02	5.51±0.02	8.22±0.03	8.05±0.02
$\sigma_{\theta_C}^{trk} = \frac{\sigma_{\theta_C}^{SPR}}{\sqrt{N_{pe}}}$,mrad	7.2	7.8	6.1	8.9	8.4	9.4
$\sigma_{R_C}^{ROI}$, mm	1.11±0.03	1.08±0.04	1.20±0.02	1.33±0.06	1.35±0.04	1.37±0.07
$\sigma_{\theta_C}^{R} \approx \frac{1}{n^2}\frac{\sigma_{R_C}}{L-t/2}$	5.9	6.15	6.65	7.5	7.7	8.1

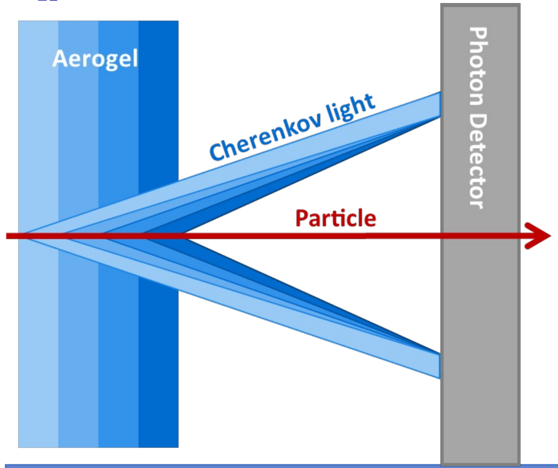
$$\theta_C^R = arctan\left(\frac{R_C}{L-t/2}\right),$$

$$\sigma_{\theta_C}^R = \cos^2\theta_C\left(\frac{1}{L-t/2}\right)\cdot\sqrt{\sigma_{R_C}{}^2 + \tan^2\theta_C\cdot(\sigma_L^2+\sigma_t^2)} \approx \frac{1}{n^2}\frac{\sigma_{R_C}}{L-t/2},$$

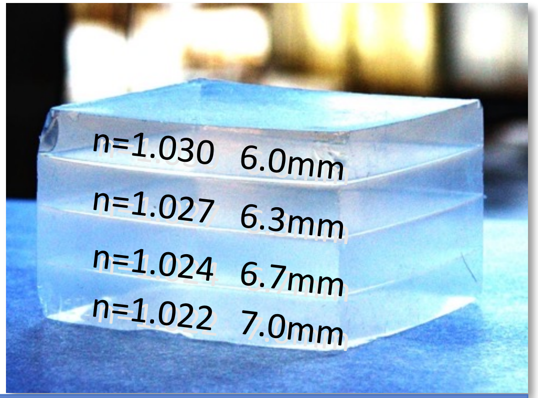
How much effect from Fresnel lens is expected?!

FARICH – Focusing Aerogel RICH

FARICH option for SCTF



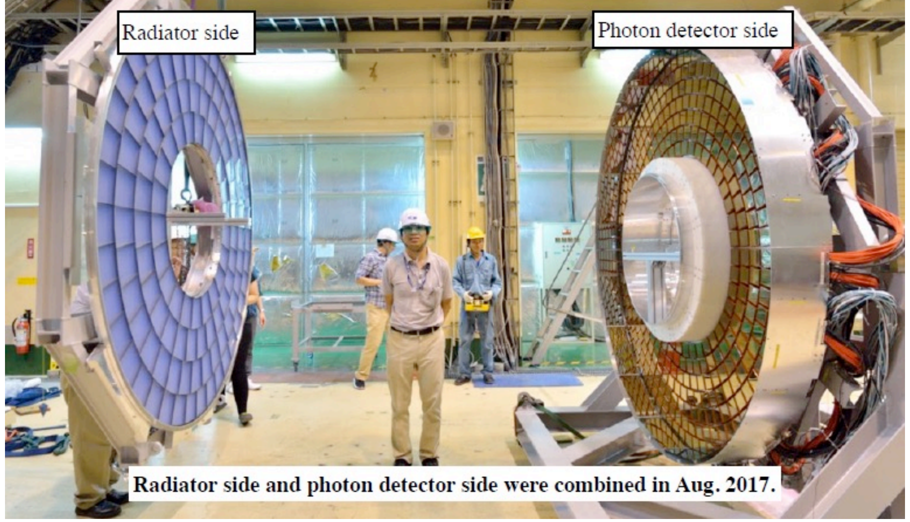
The first 4-layer monolithic sample



Increase N_{pe} due thickness increase without $\sigma_{\Theta c}$ degradation

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

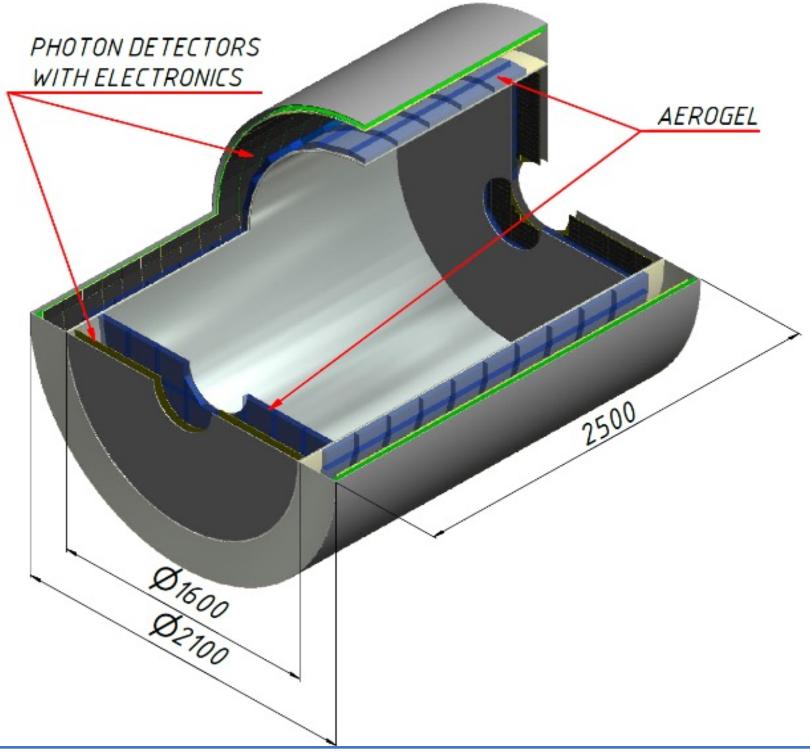
The Belle II (ARICH) is the first application of the method



Radiator side and photon detector side were combined in Aug. 2017.

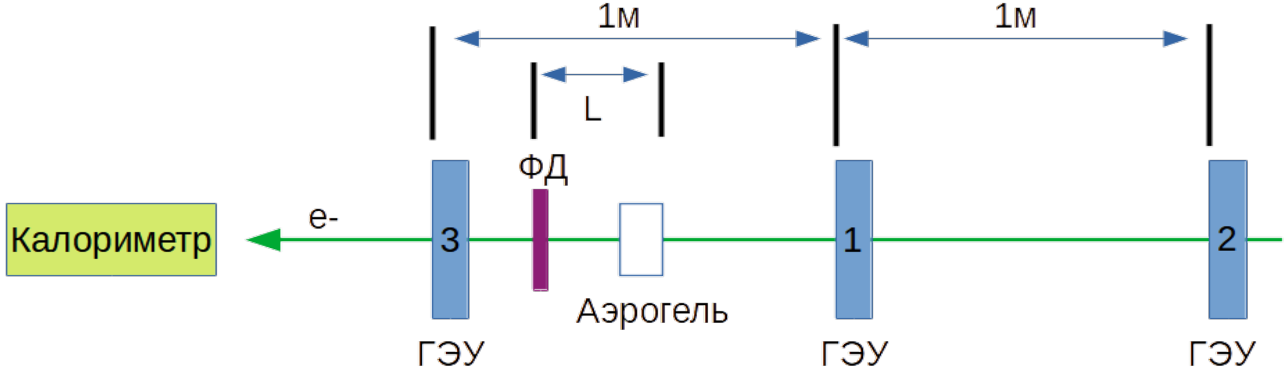
The capability of μ/π-separation at the level of ≥3σ for P=1 GeV/c was shown at CERN beam test in 2012

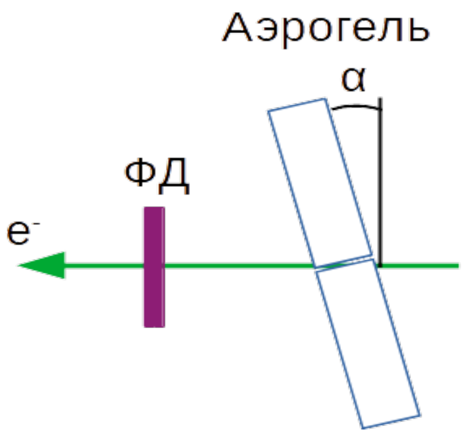
A.Yu. Barnyakov, et al., NIM A 732 (2013) 352



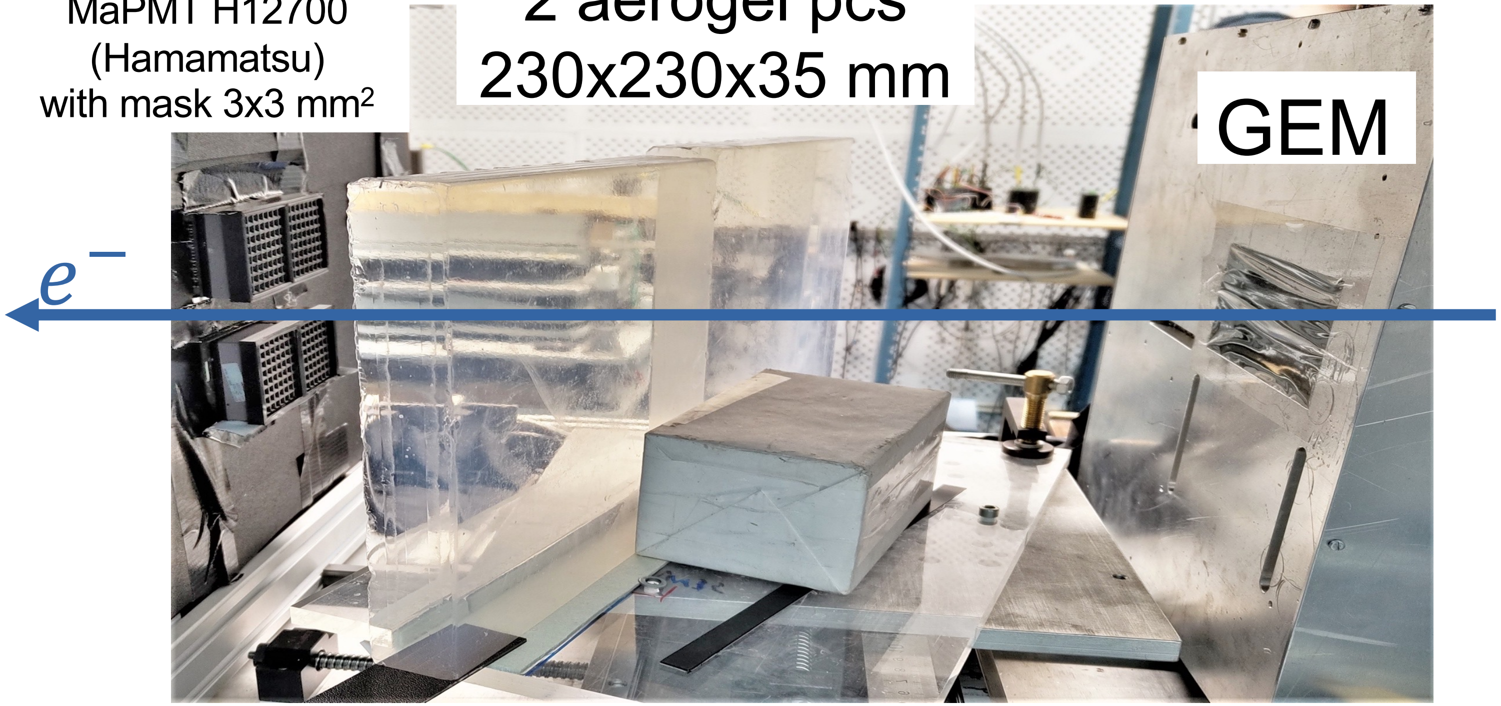
- Proximity focusing RICH
- 4-layer focusing aerogel
  - n_{max} = 1.05 (1.07?), total thickness 35 mm
  - $S_{aer} = 15\ m^2$
- 21 m^2 – total area of photon detectors
  - SiPMs – barrel part (16 m^2)
  - MCP-PMT – endcap parts (4 m^2)
- ~10^6 pixels 3x3 mm^2 with pitch 4 mm

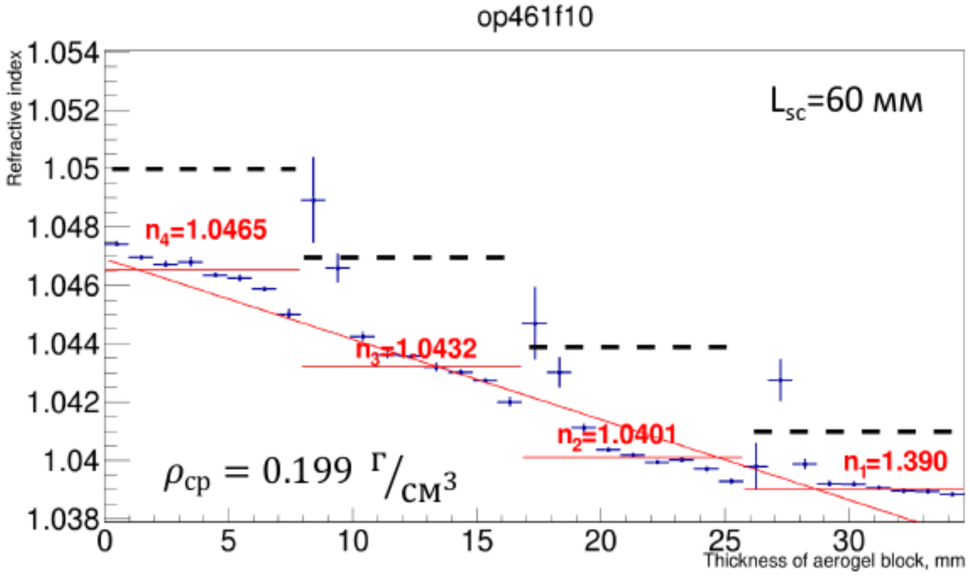
The largest 4-layers focusing aerogel samples





MaPMT H12700 (Hamamatsu) with mask 3x3 mm²

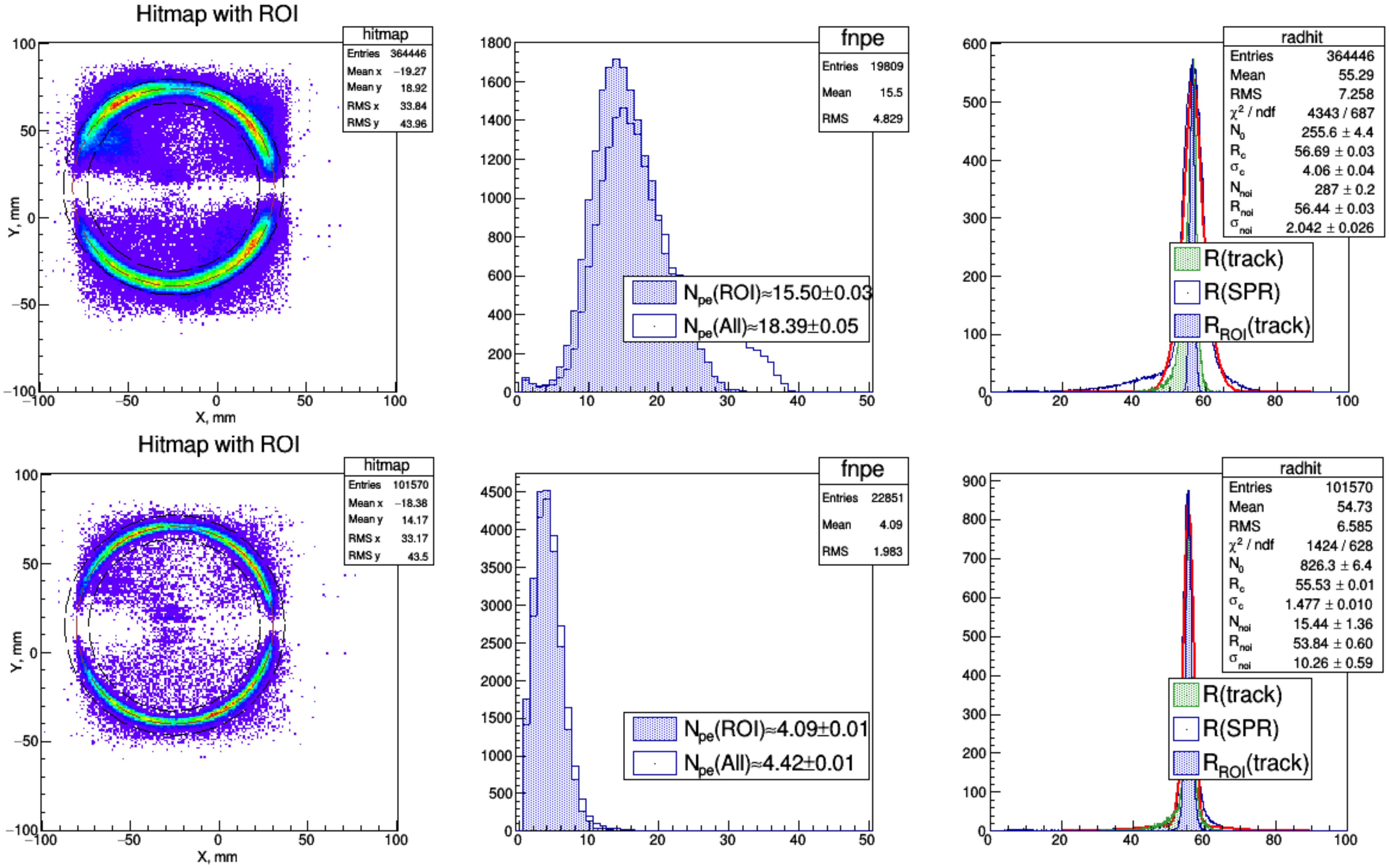




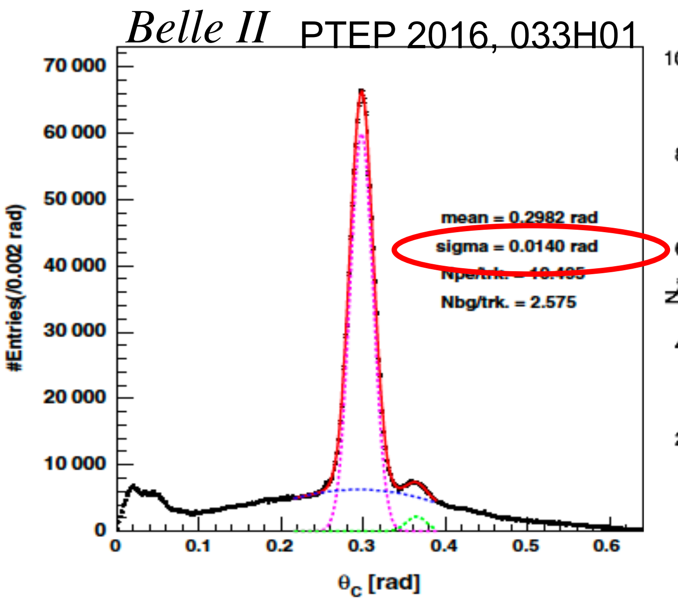
Beam test results

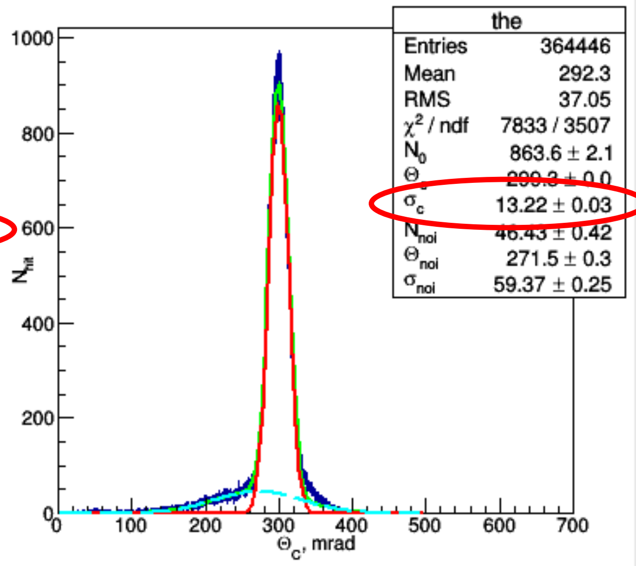
Pixel 6x6 mm
Geom.Eff. ~ 80%

Pixel 3x3 mm
Geom.Eff. ~ 20%

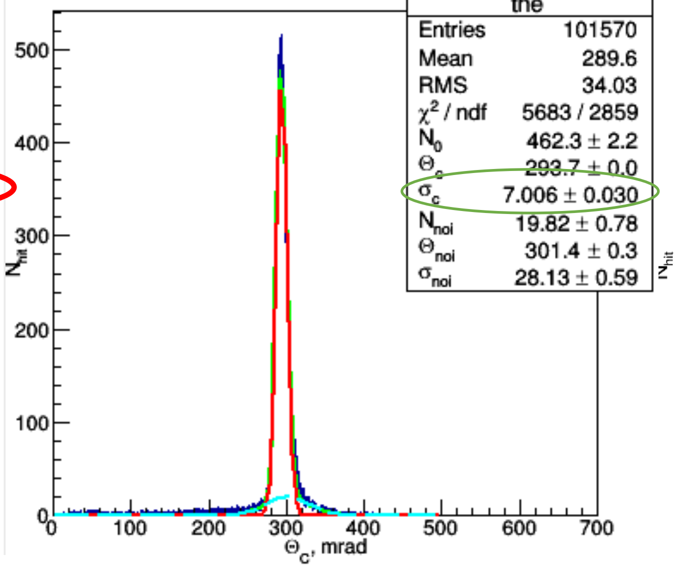


Cherenkov angle Single PhotoElectron (*SPE*) resolution

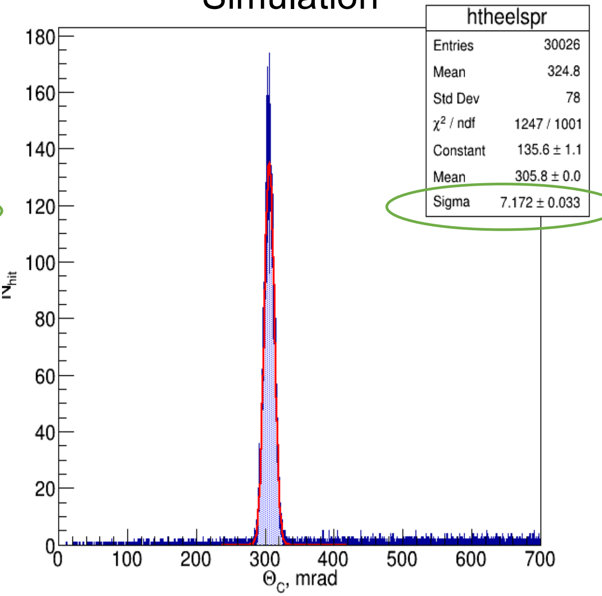




Measured



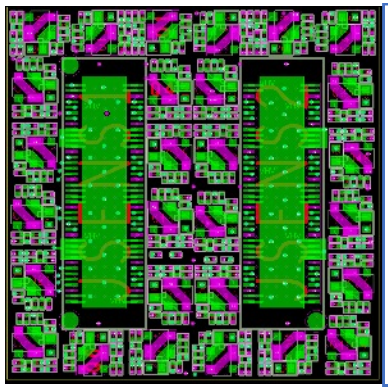
Simulation



Аэрогель: 20+20 mm (Tchiba Univ.)	4-layers (Novosibirsk) –>	–	4-layers (ideal profile)
n(400nm): 1.045 +1.055	1.039 ÷ 1.046	–	1.041 ÷ 1.050
Pixel: 5x5 mm	6x6 mm	3x3 mm	3x3 mm

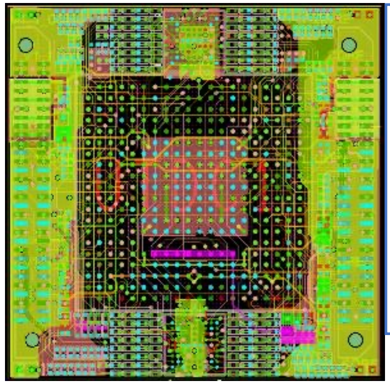
Position-sensitive photon detectors

FEE based on FPGA-TDC



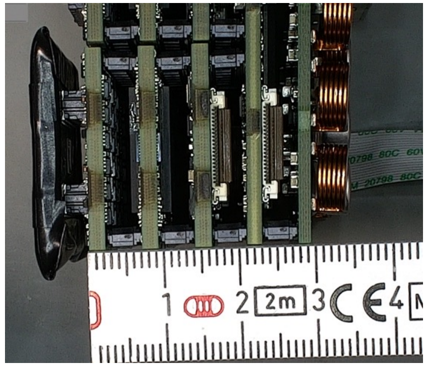
Amplifier board

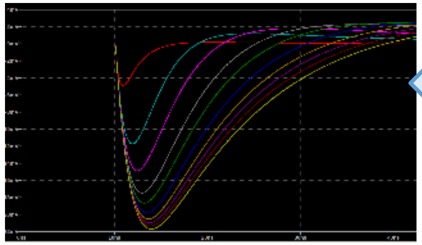
- 27×27 mm^2 size
- 14-layer PCB
- 30x gain, 64 channels
- couples to KETEK 8×8 SiPM array



TDC board

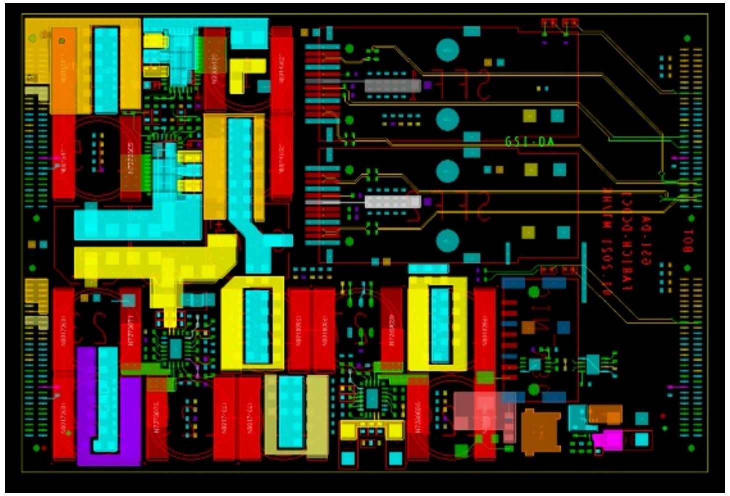
- 64 channels
- 2 TDC + 4 threshold FPGAs
- 10ps precision





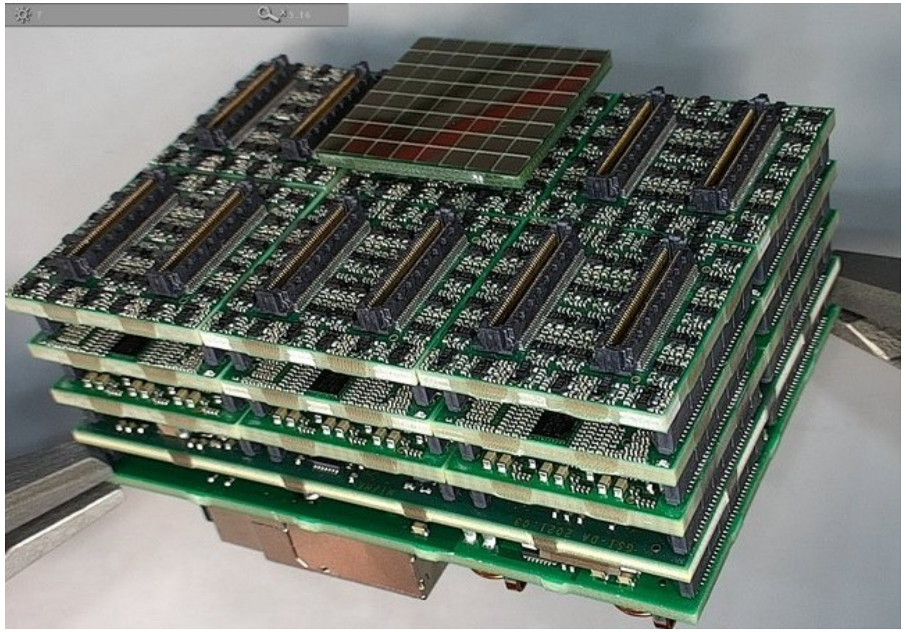
Simulated single photon pulse shapes from amplifier for different input resistance. ~ 22mV amplitude can be achieved.

- Each module readouts 6 arrays 8x8 pixels and equipped with optical transceiver.
- Thickness of 5-layer design is less than 5 cm.



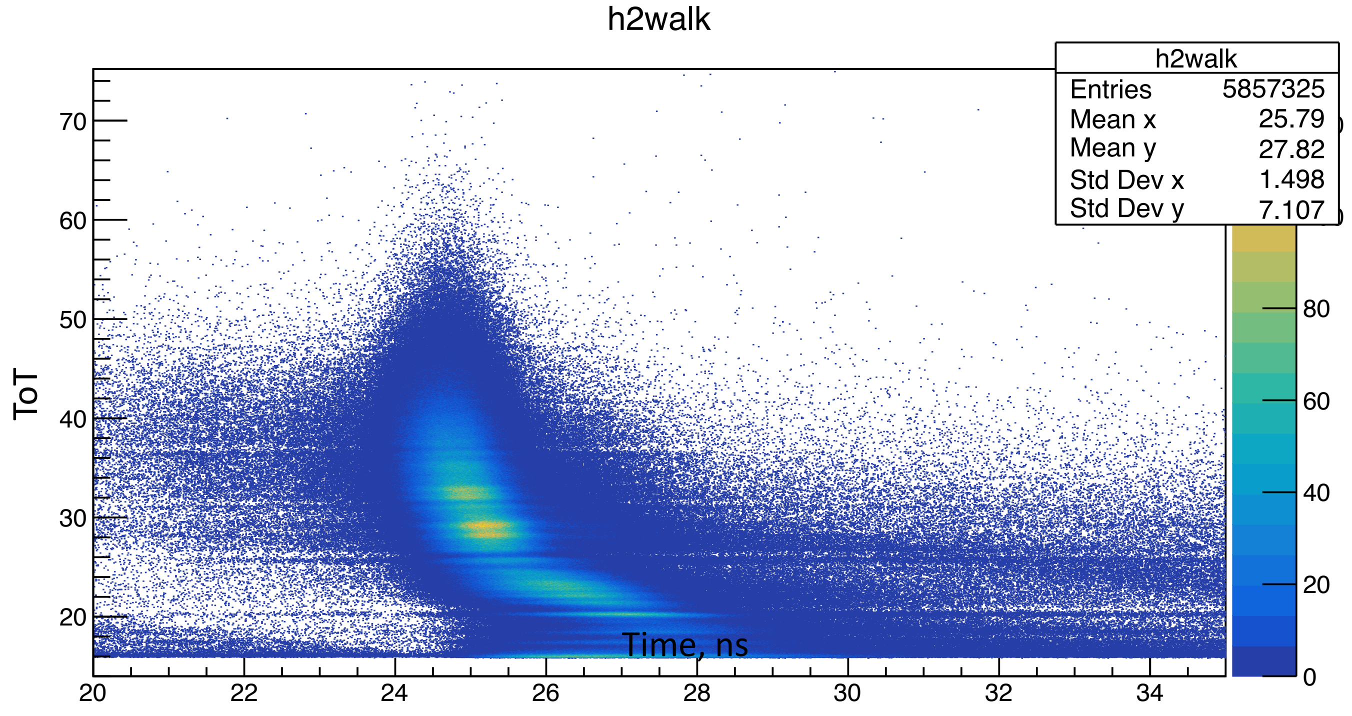
DC-DC convertor board

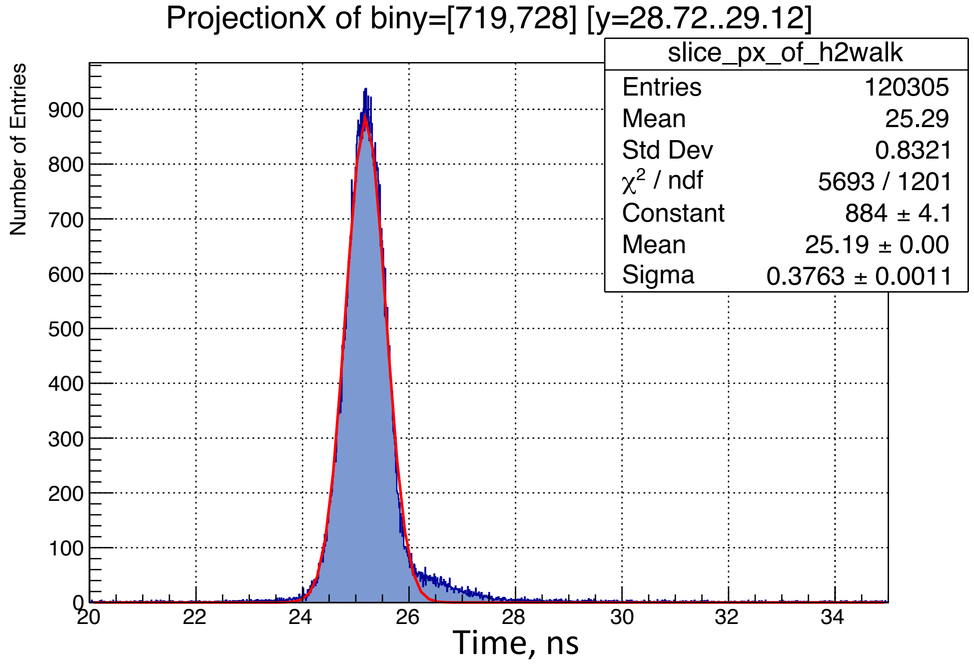
- goes behind the backplane
- 51×84 mm^2 size
- provides power to SiPMs, amplifiers, FPGA
- uses air inductive coils to operate in the detector magnetic field
- power, trigger & clock connectors



The first tests of *FaRICH-Auslese-System*

FPGA-TDC (FaRICH-Auslese-System) to readout 2304 SiPMs developed and produced in GSI.

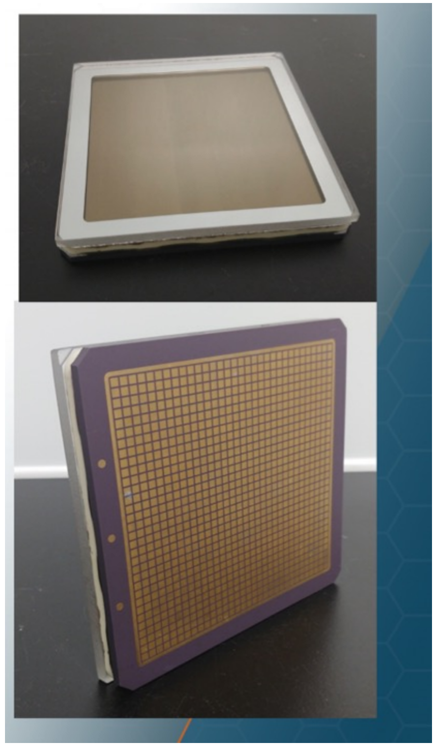




The tests performed bu Mechael Traxler, Matthias Hoek and Merlin Böhm at HIM-Institute in Mainz.

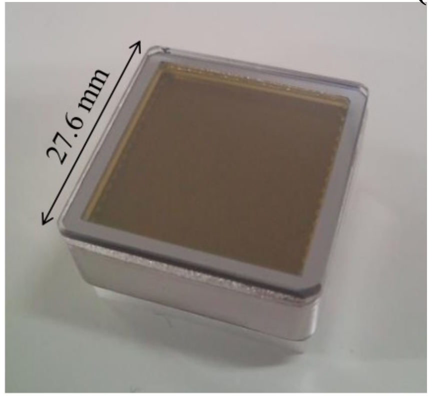
- Everything works as expected: ToT(Time) is as expected for single photon distribution.
- Single photon detection time resolution without any corrections and proper TDC calibration is about 380ps (it is good enough value for FARICH), while intrinsic resolution of TDC is about 8÷12 ps.
- A lot of dark counts are in the data (every 3rd hit is noise). Thermostabilization or cooling is needed for future tests.

Позиционно-чувствительные ФЭУ с МКП



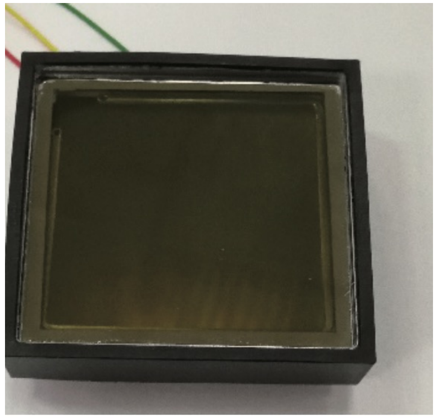
HRPPD (Income)
10x10 см; пиксел 2.5x2.5 мм
Цена: ~20k$

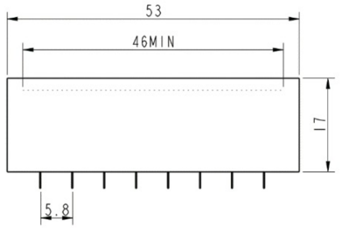
Hamamtsu R10754-016-M16(N)



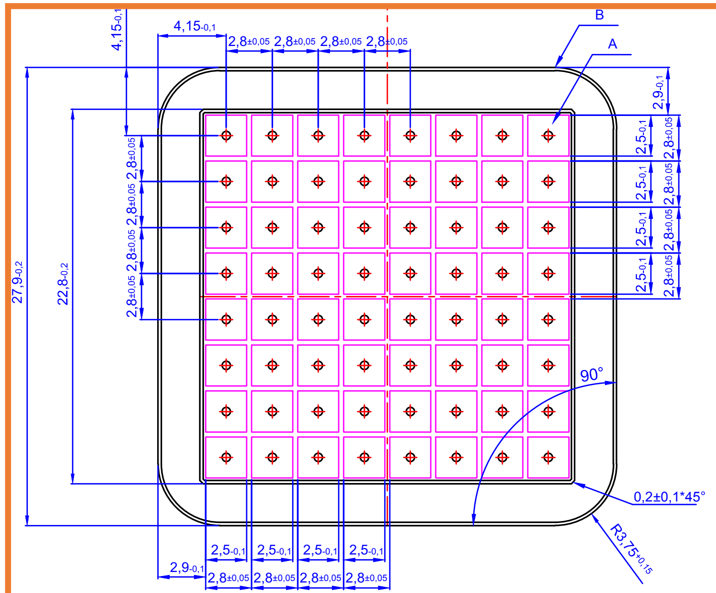
4x4 пикселя; 5x5 мм
Цена: 900 тыс. Йен

Planacon XP85112
8x8 пикселей; 6x6 мм
Цена: 15k$





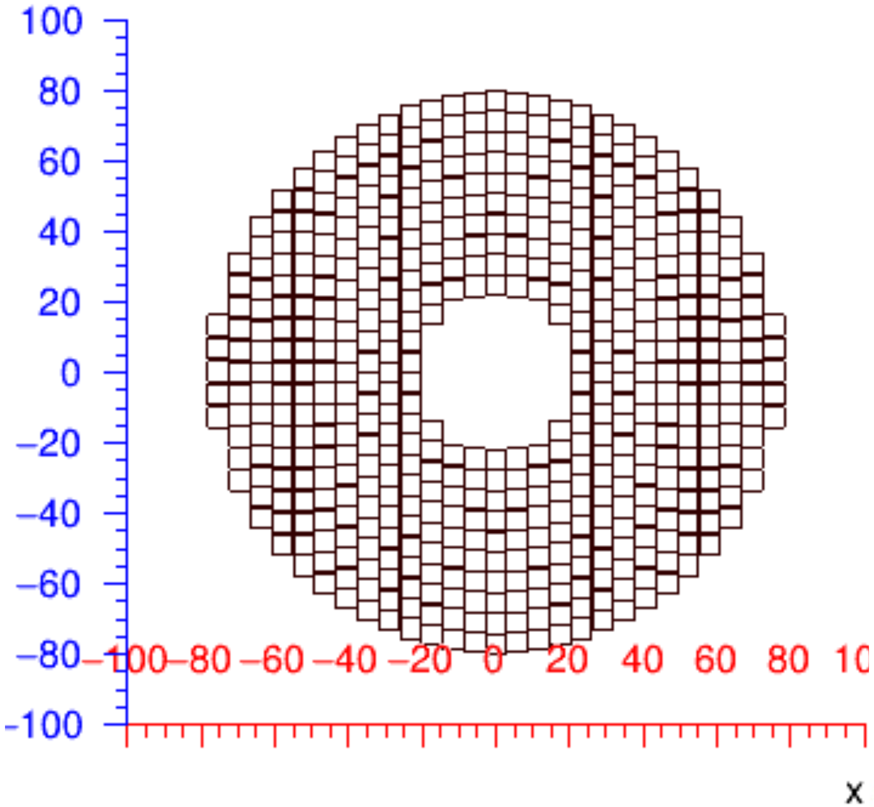
NNVT (Китай)
Цена: 18кЕвро

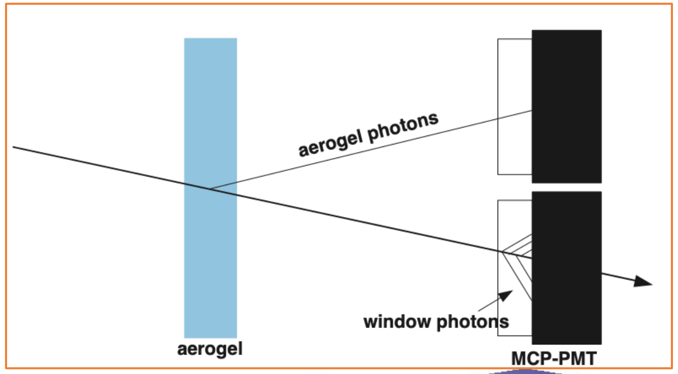


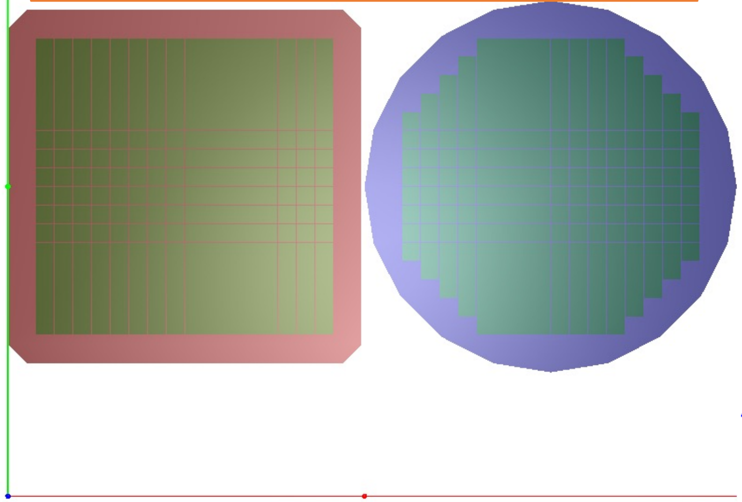
Коллектор ФЭУ с МКП
Концепция Экран ФЭП
(лето 2022г.)

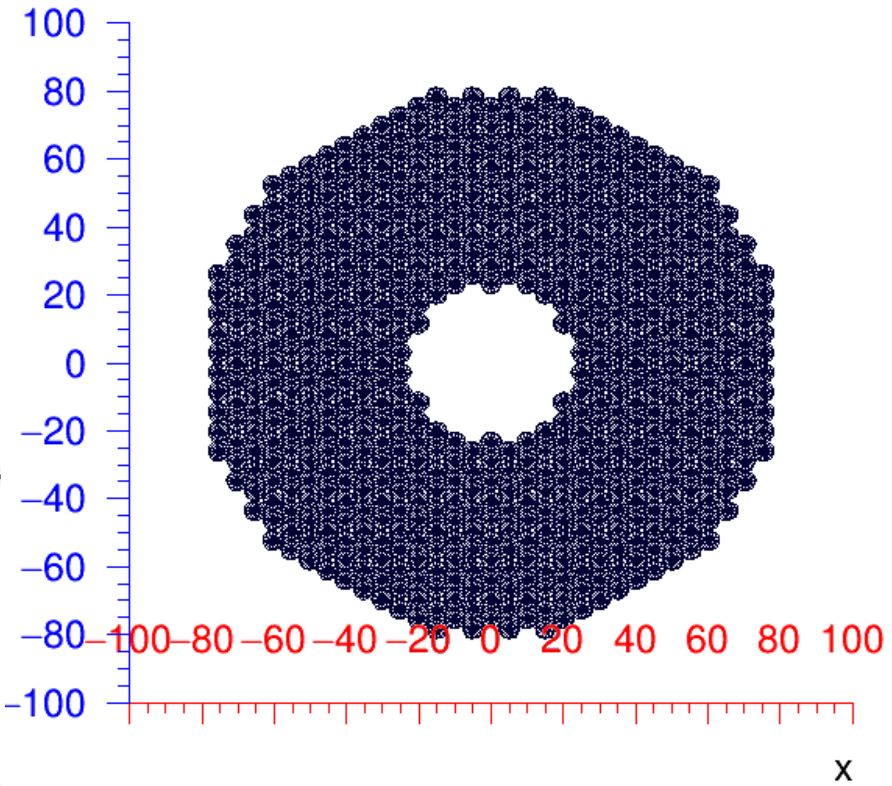
Доступность: ???
Цена: ???

Round vs Square MCP-PMT for the RICH









516 PMTs ■58x58 mm (PC ■ 50x50 мм) –>

$$Eff = \frac{516 \cdot 5{\times}5}{S_{endcap}} = \frac{12900\ cm^2}{18850\ cm^2} \approx 0.68$$

16x16=256 pixels 2.9x2.9 mm

$$Eff = \frac{516 \cdot 256 \cdot 0.29{\times}0.29}{S_{endcap}} = \frac{11109\ cm^2}{18850\ cm^2} \approx 0.59$$

594 PMTs Ø58 mm (PC Ø50 mm) –>

$$Eff = \frac{594 \cdot \pi \cdot 2.5^2}{S_{endcap}} = \frac{12370\ cm^2}{18850\ cm^2} \approx 0.65$$

216 pixels 2.9x2.9 мм

$$Eff = \frac{594 \cdot 216 \cdot 0.29{\times}0.29}{S_{endcap}} = \frac{11444\ cm^2}{18850\ cm^2} \approx 0.57$$

Round vs Square MCP-PMT for the RICH (2)

To evaluate expected performance we can use recent FARICH beam test data:

- $N_{pe}^{H12700} \approx 16$
- $CE^{H12700} \approx 0.8$ – photoelectron collection efficiency ($CE^{MCP} \approx 0.6$)
- $GE^{TB} \approx 0.8$ – Geometrical Efficiency of Test Beam setup (GE^{exp} is determined by fill factor of photon detectors for the experimental setup)

$$N_{pe}^{expect} = \frac{N_{pe}^{H12700} \cdot CE^{MCP} \cdot GE^{exp}}{CE^{H12700} \cdot GE^{TB}}$$

Square shape MCP-PMT

- $GE^{exp} \approx 0.59$
- $N_{pe}^{expect} = \frac{16 \cdot 0.6 \cdot 0.59}{0.8 \cdot 0.8} \approx 8.8pe$ (for $\beta = 1$)
- $\sigma_{tr}^{\theta} = \frac{\sigma_{SPE}^{\theta}}{\sqrt{N_{pe}}} = \frac{7 \div 8\ mrad}{\sqrt{8.8}} = 2.3 \div 2.7\ mrad$

Round shape MCP-PMT

- $GE^{exp} \approx 0.57$
- $N_{pe}^{expect} = \frac{16 \cdot 0.6 \cdot 0.57}{0.8 \cdot 0.8} \approx 8.5pe$ (for $\beta = 1$)
- $\sigma_{tr}^{\theta} = \frac{\sigma_{SPE}^{\theta}}{\sqrt{N_{pe}}} = \frac{7 \div 8\ mrad}{\sqrt{8.5}} = 2.4 \div 2.7\ mrad$

μ/π @ 1 GeV/c: $\frac{\theta_C^{\mu} - \theta_C^{\pi}}{\sigma_{tr}^{\theta}} = \frac{292 - 278}{2.5} = 5.6\sigma$

π/K @ 6 GeV/c: $\frac{\theta_C^{\pi} - \theta_C^{K}}{\sigma_{tr}^{\theta}} = \frac{309 - 299}{2.5} = 3.9\sigma$

Addendum

HRPPD

Hihg Rate Picosecond Photon Detector

HRPPD – High Rate Picosecond Photodetector

- **10 cm x 10 cm MCP-PMT**
  - Chevron pair of ALD-functionalized MCPs **(10 µm)**
  - Glass/Ceramic package
  - Capacitive (CC) or Direct (DC) Coupling
  - **100 cm²** active area (only spacers on edges)
- **High Gain (~10^7)**
- **Bialkali Antimonide Photocathode**
  - Sodium-Potassium-Antimony Na_2KSb
  - **>30%** QE at 365 nm
  - **>95%** spatial uniformity
- **Timing Resolution**
  - SPE: **~23 ps** (Vagnoni, INFN for 10 um pores)
- **Position Resolution**
  - **< 0.6 (mm)** (dependent on readout board)
  - DC version has 1024 2.5 x 2.5 mm pixels

Available today!

INCOM BRIGHT IDEAS

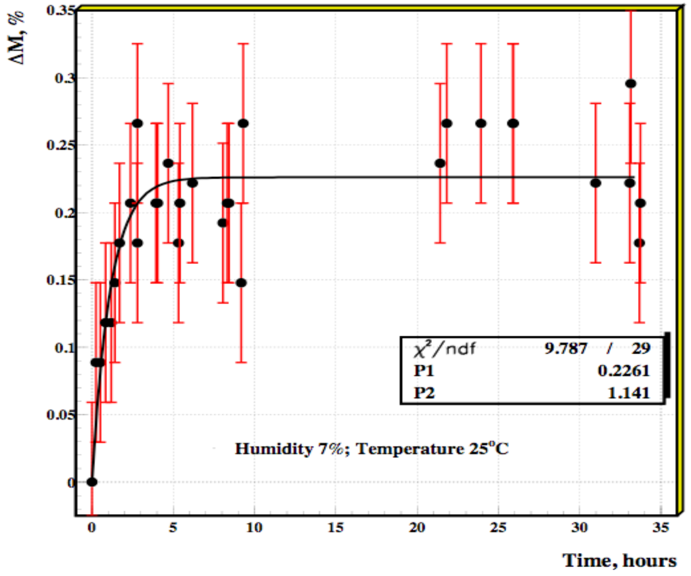
LAPPD Workshop – October 26, 2022

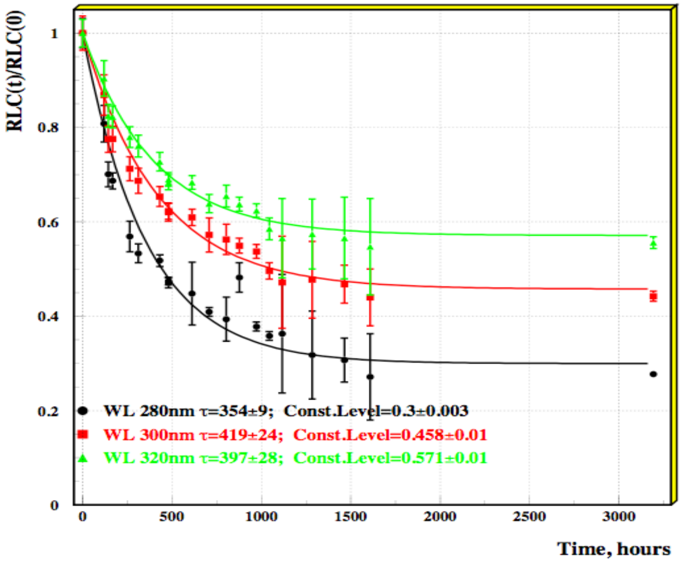
Parameter	LAPPD / HRPPD
Gain	1.00E+07
SPE Timing Resolution	<50 ps
MPE Timing Resolution	8 ps
Pixel Size	Any / 2.5 mm X 1024
Spatial Resolution	<1 mm
Room temp Dark Noise	≤2 kHz/cm²
Radiation hardness	>1E15 15 MeV protons
Single-Photon readout	Yes
Magnetic Field Tolerance	1.4 T demonstrated
@ Degrees from Normal	TBD
PC QE @365 nm	30%
PC QE @450 nm	>20%
PDE @450 nm	TBD (≥20% = 70% OAR X 30% QE)
Demonstrated Tile Life	TBD (> 5 C/cm²)

Aerogel degradation due to water adsorption(1)

- Aerogel internal surface is 10^6 times greater than external. Adsorption of water is very fast process (1-10 hours).
- Degradation of the light absorption length is very slow process (1-2 months) after water absorption.
- The time and the level of the degradation are depend on the impurities in aerogel from raw materials and production procedure (Fe, Mn, Cr, etc.).

Concentration of metals in aerogel, ppb				
Fe	Cu	Mn	Cr	Ni
500	56	7	26	





Aerogel degradation due to water adsorption(2)

- The refractive index (n-1) and light scattering length depends on amount of adsorbed water and are changed less than 10% after water adsorption of 2-4% of aerogel mass.
- The light absorption length (L_{abs}) in different aerogel samples after baking is the same, but after water impregnation could be very different
- It is possible to make aerogel selection after water impregnation
- One atom Fe is able to attract 6 molecules of water
- To achieve maximum degradation of L_{abs} it is enough to adsorb 1ppm of water.

(NIM A598 (2009) 166-168)