CREMLIN PLUS
Connecting Russian and European Measures for Large-scale Research Infrastructures

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SCTF FARICH simulation and prototyping

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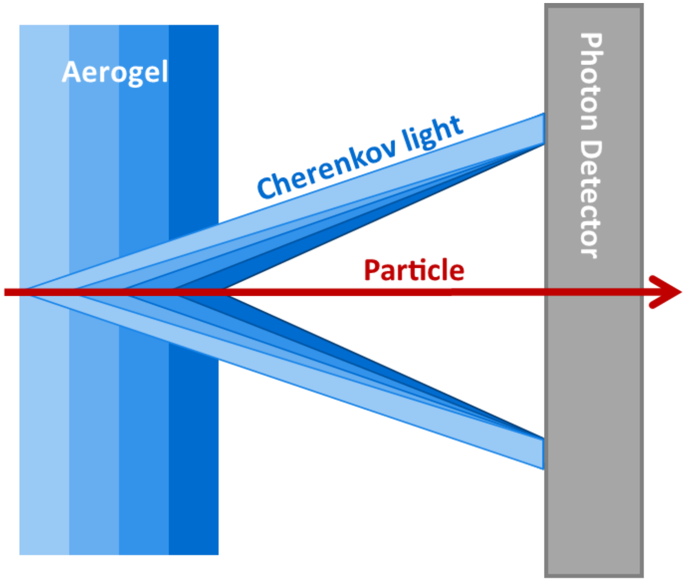
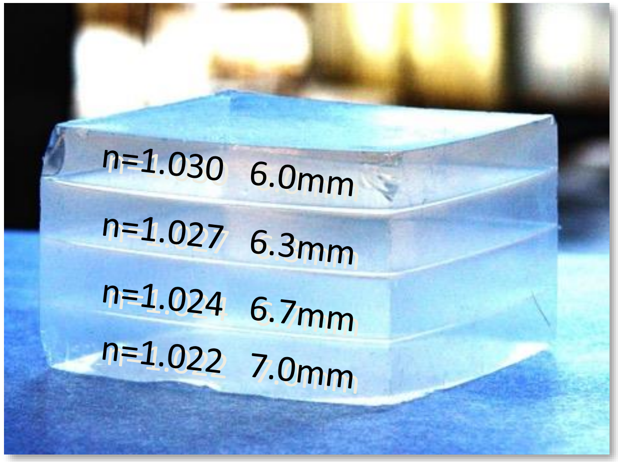
The 3rd CREMLINplus WP5 general meeting

18 February 2021

Focusing Aerogel RICH (FARICH)



First sample of 4-layer aerogel

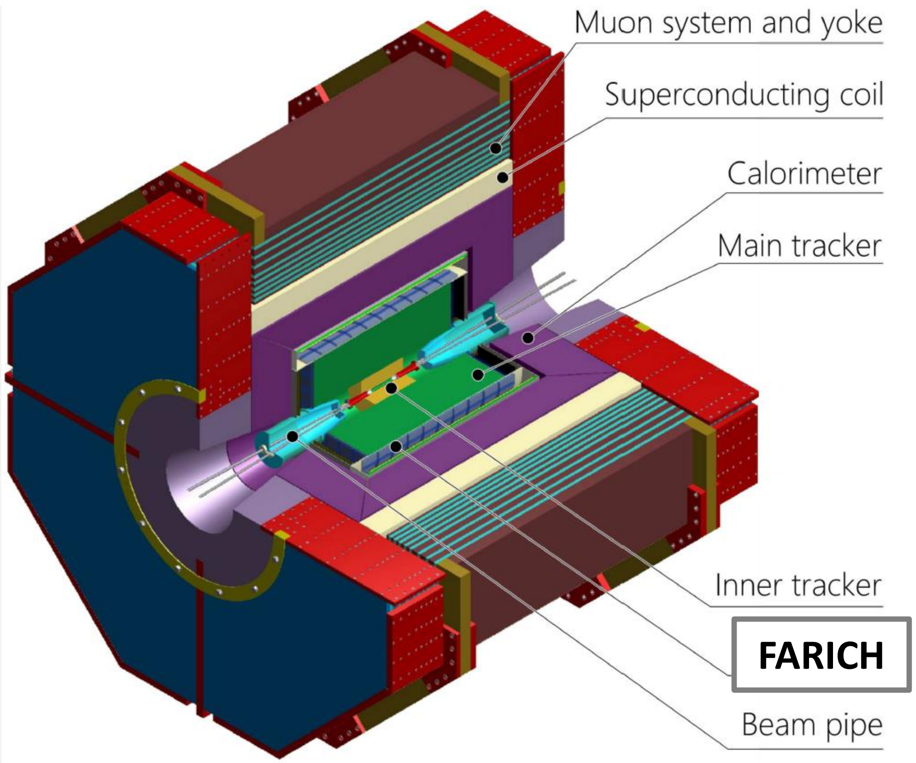


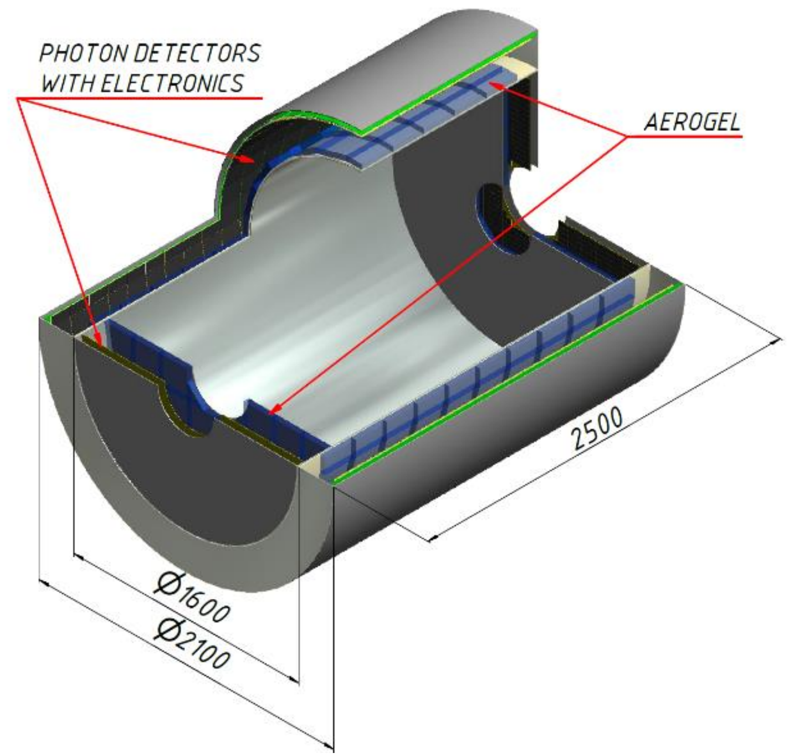
First real-life application in Belle2 ARICH

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

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

FARICH for Super Charm-Tau Factory



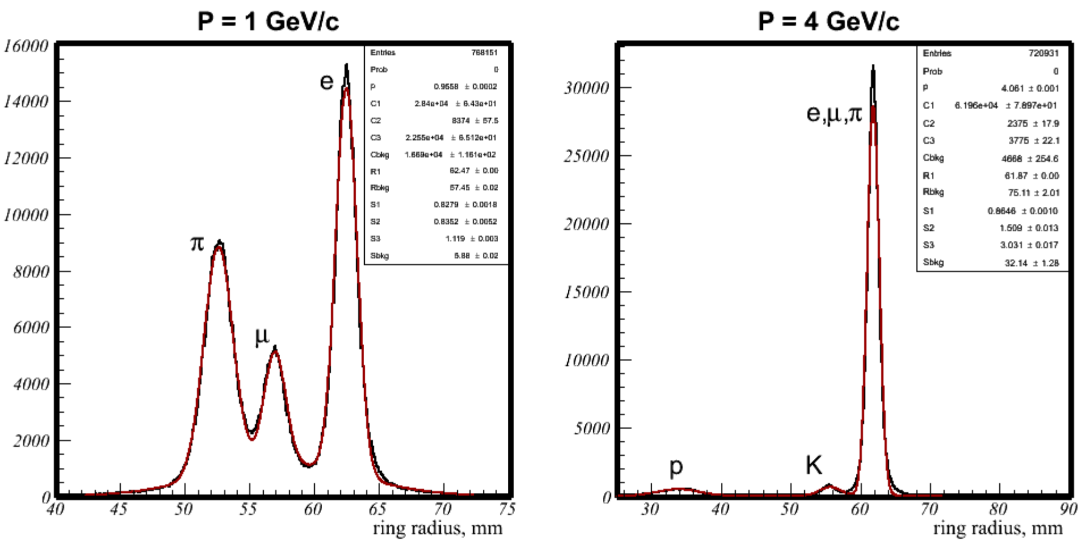


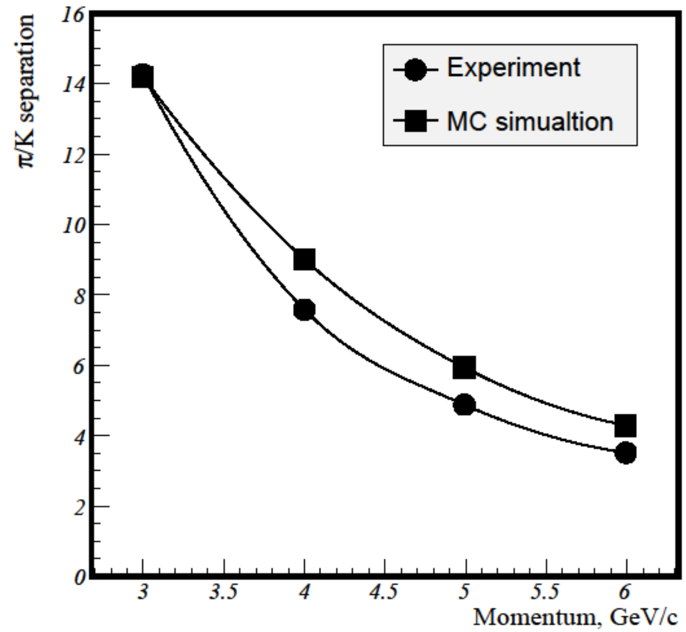
- Proximity focusing RICH
- 4-layer or gradient aerogel radiator
  n_{max} = 1.05 (1.07?), thickness 35 mm
- 21 m^2 total photon detector area
  - SiPMs in barrel (16 m^2)
  - MCP PMTs in endcaps (5 m^2)
- ~10^6 pixels with 4 mm pitch

PDPC-FARICH beam test results

Ring distribution on radius

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





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

Npe = 12 observed
for a relativistic particle

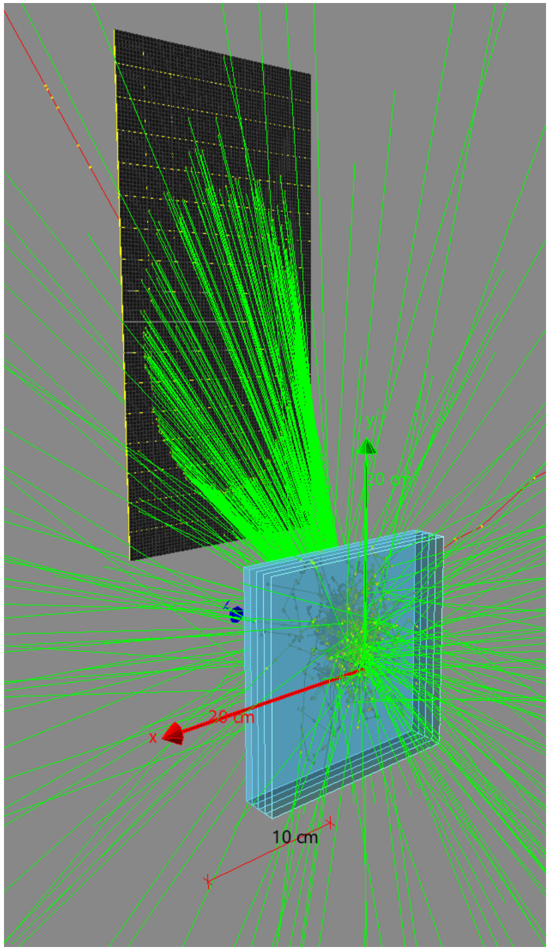
π /K: **7.6σ** @ 4 GeV/c
μ/π: **5.3σ** @ 1 GeV/c

SCTF FARICH simulation

Standalone Geant4 simulation of a simple proximity RICH geometry

Described effects:

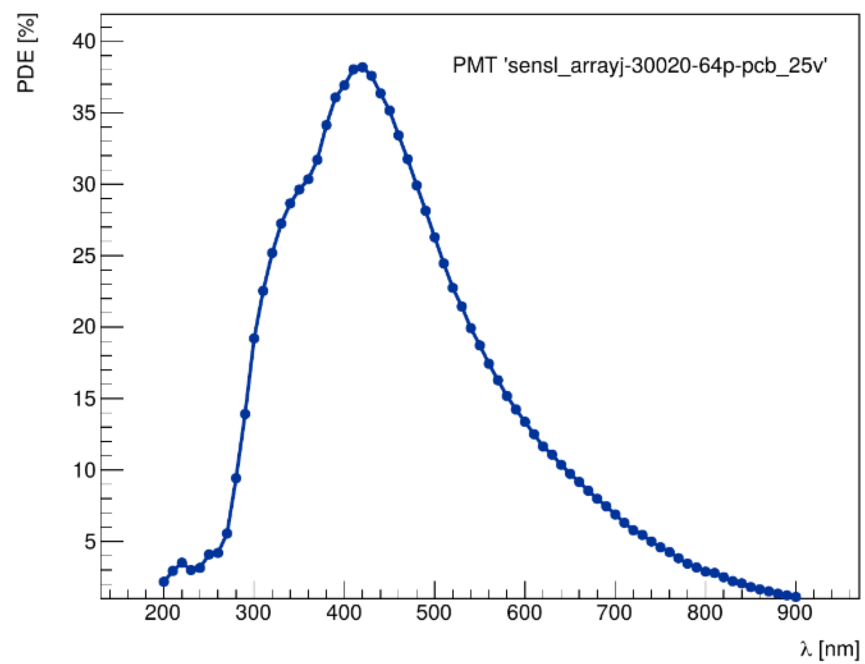
- Multiple Coulomb scattering
- Cherenkov emission
- Aerogel chromatic dispersion
- Rayleigh light scattering in aerogel
- Light absorption in aerogel
- Photon detection efficiency (producer's datasheet)
- PD pixel size (no crosstalks)
- Ideal discriminator efficiency



SCTF FARICH simulated configuration

Photon detector

- ON Semiconductor (SensL) ArrayJ-30020-64P-PCB
- Pixel size 3.16×3.16 mm^2
- Pixel pitch 3.36 mm
- U_{bias} = 2.5V
- λ_{max}≈400 nm, PDE_{max}≈ 38%
- Sensor geom. fill factor ≈ 88%



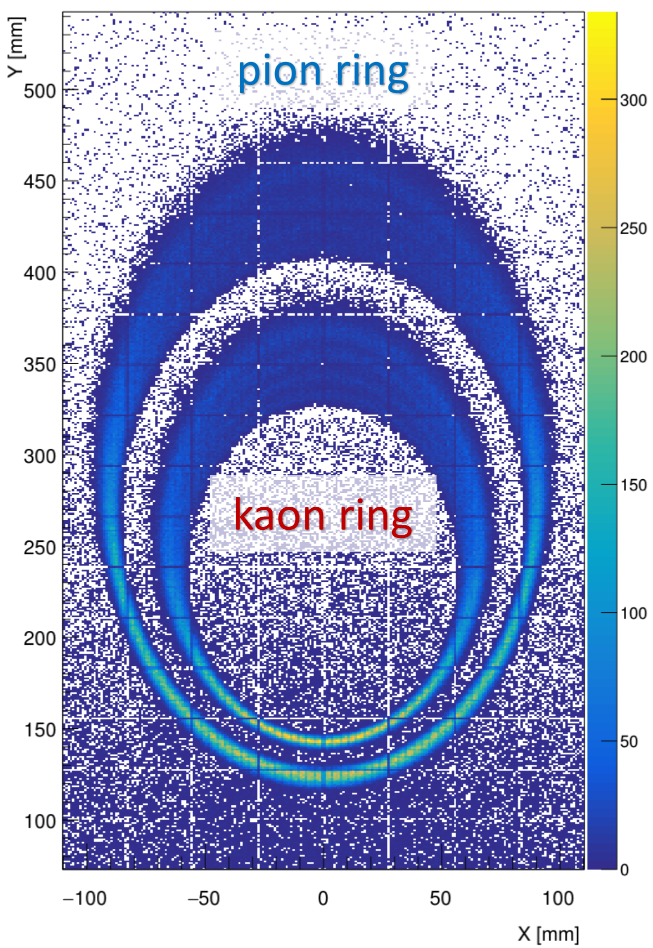
Radiator

- 4-layer focusing aerogel
- n_{max} = 1.05
- 35 mm thickness

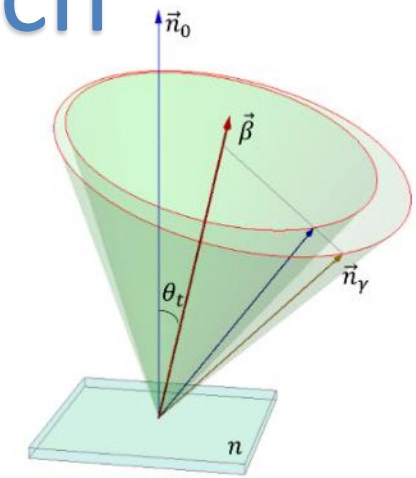
PD-Radiator distance: 200 mm

Event reconstruction using geometric approach

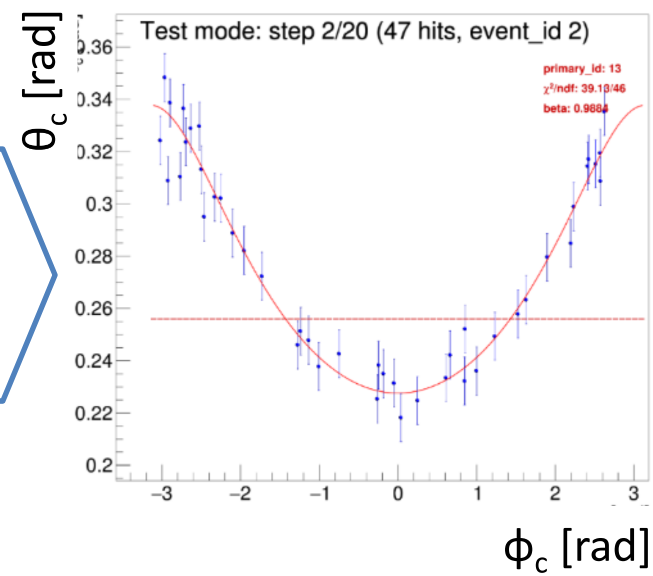
Accumulated hit map
P = 2.4 GeV/*c*, θ_p = 45°



θ_c, ϕ_c – photon angles in the nominal point of origin w.r.t. particle direction

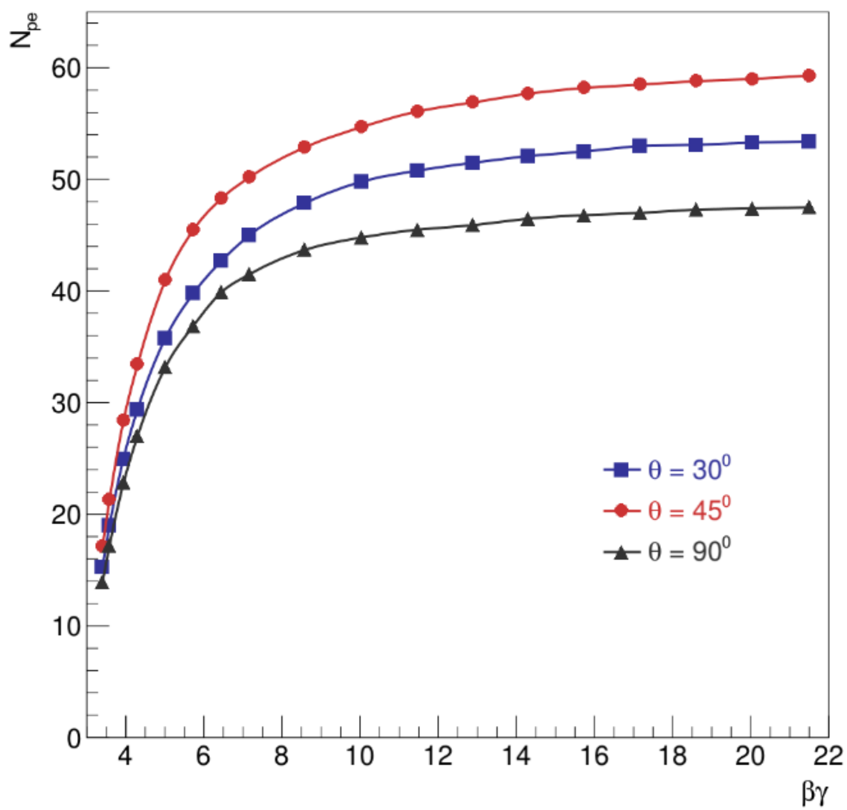


Fit analytical formula to (θ_c,ϕ_c) distribution and obtain β

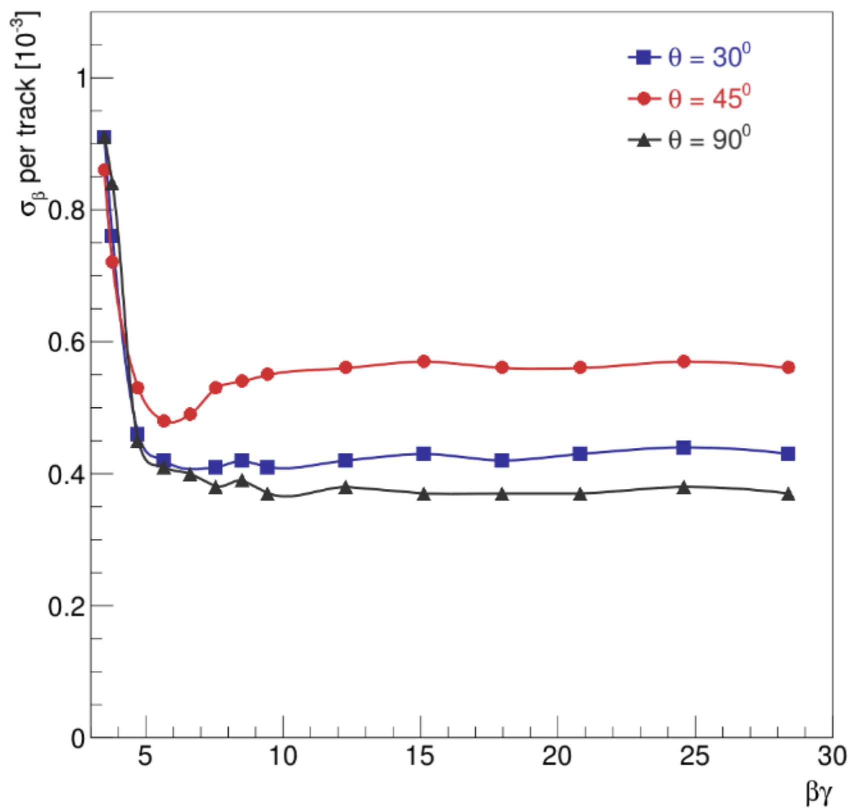


Simulated $N_{p.e.}$ and β resolution

$N_{p.e.}$ vs βγ

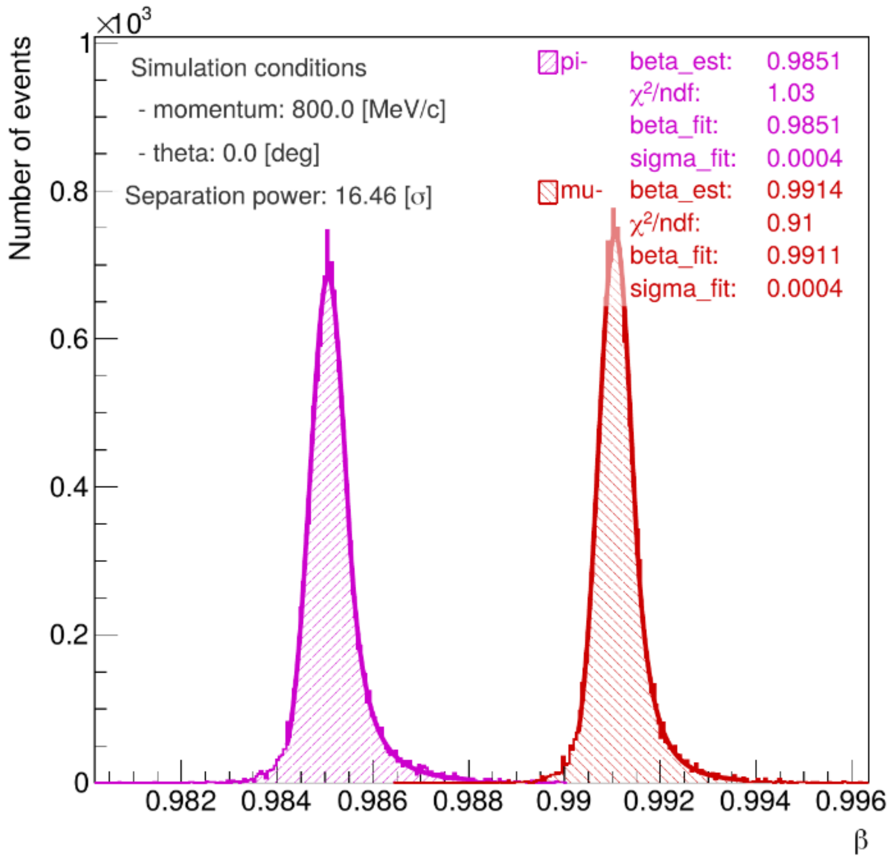


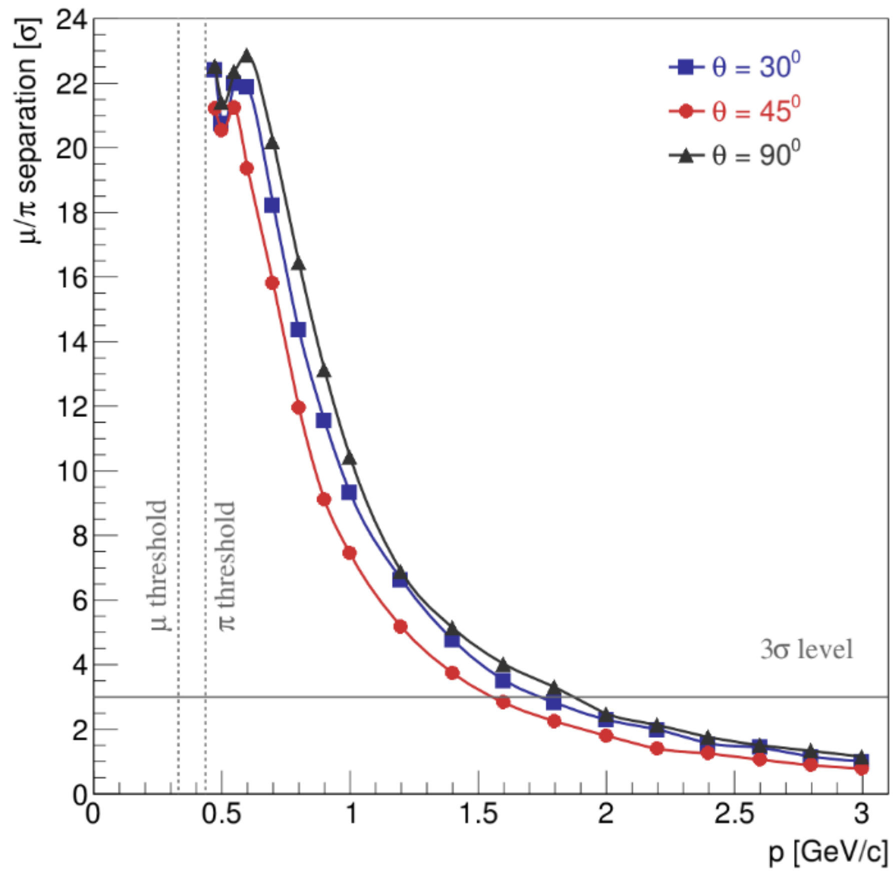
$σ_β$ vs βγ



θ – particle angle w.r.t. beam line

Simulated μ/π separation power





θ – particle angle w.r.t. beam line

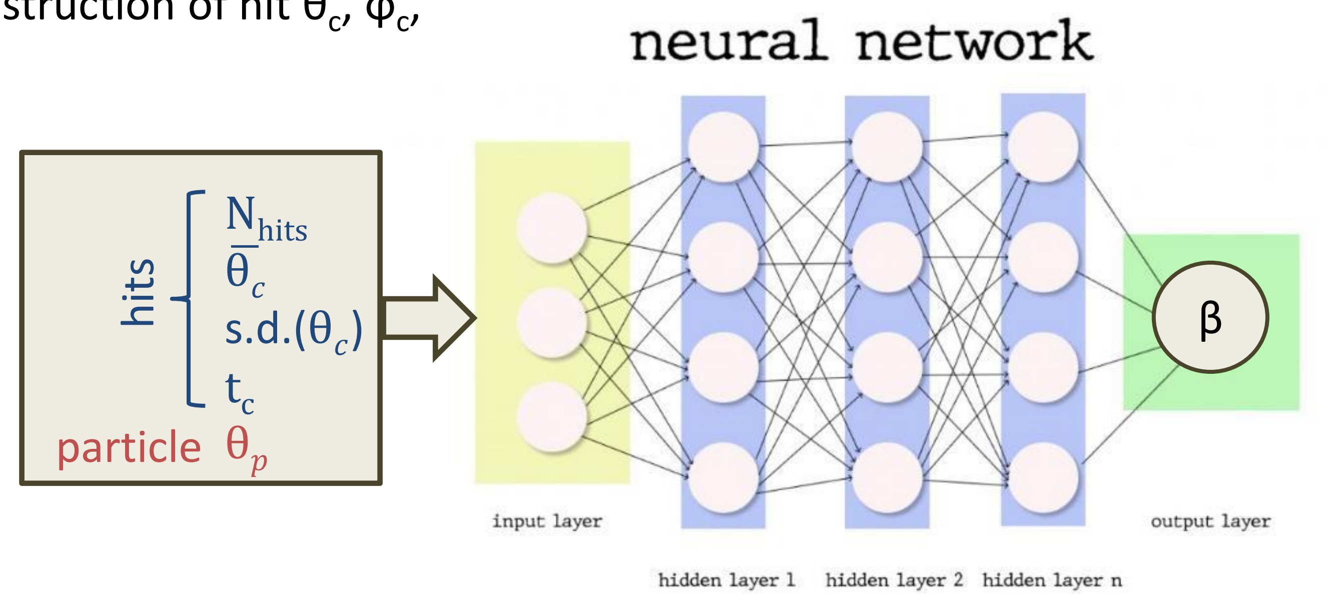
Event reconstruction using Neural Networks

Motivation

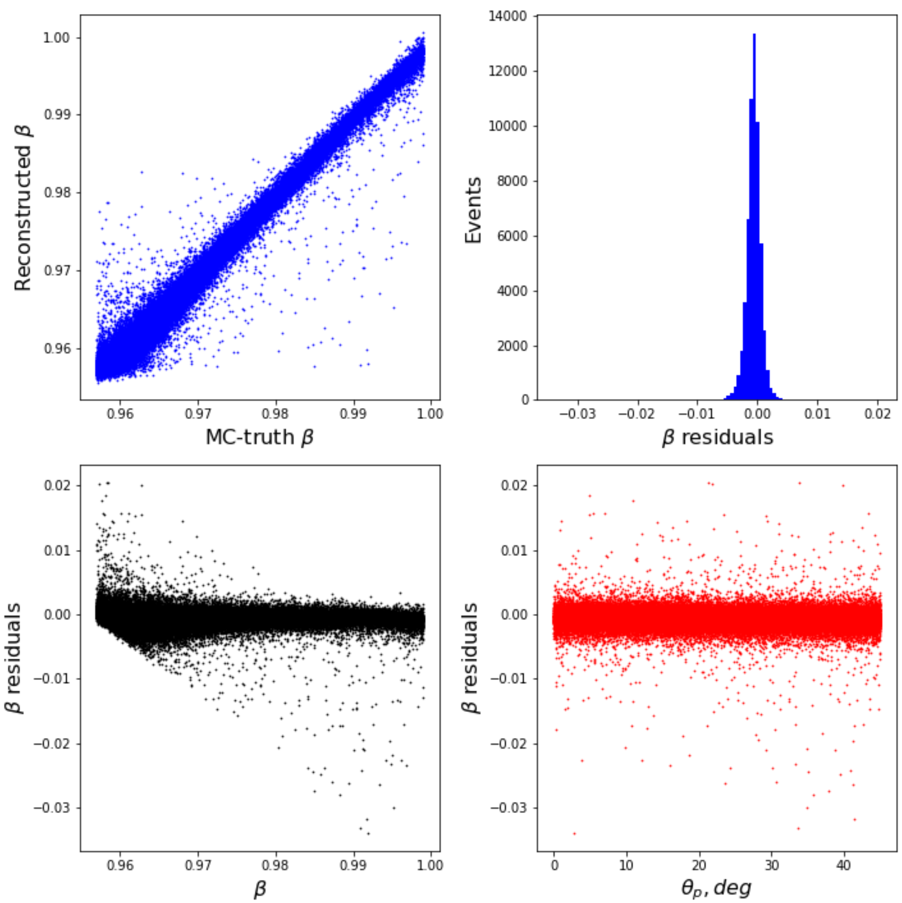
- Alternating approach to event reconstruction with a potential to include all observed data without knowing PDFs → flexibility
- More straightforward and attractive for developer

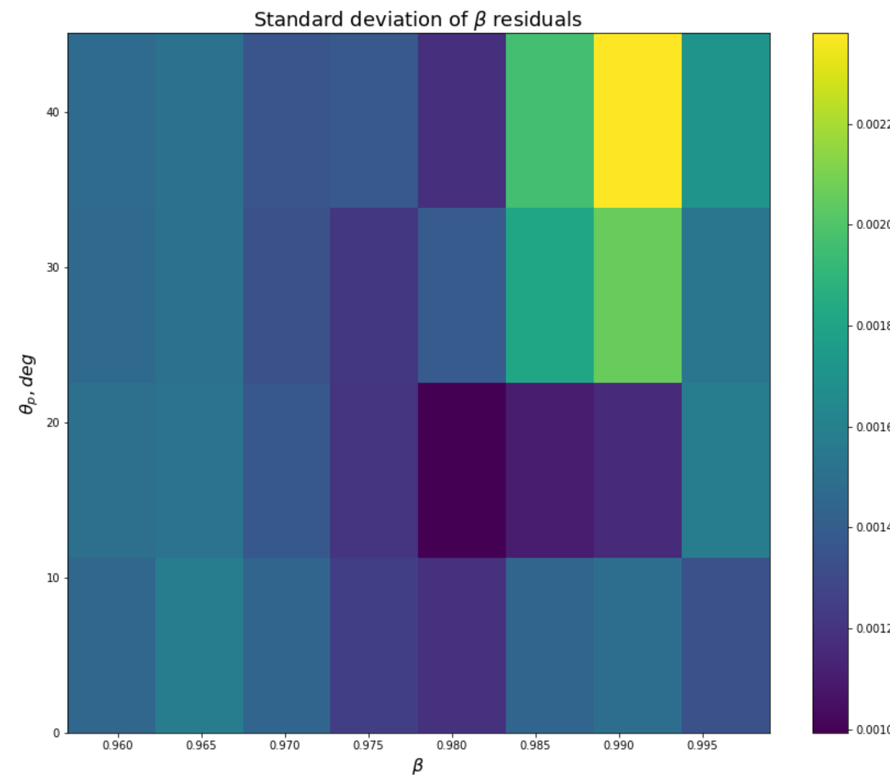
Implementation (started in Fall 2020)

- Python with Pandas, Tensorflow packages
- Geometrical reconstruction of hit θ_c, φ_c, then NN training
- Obtain particle's β from a single NN output



Preliminary results of NN event reconstruction





~10^{-3} β resolution achieved so far.

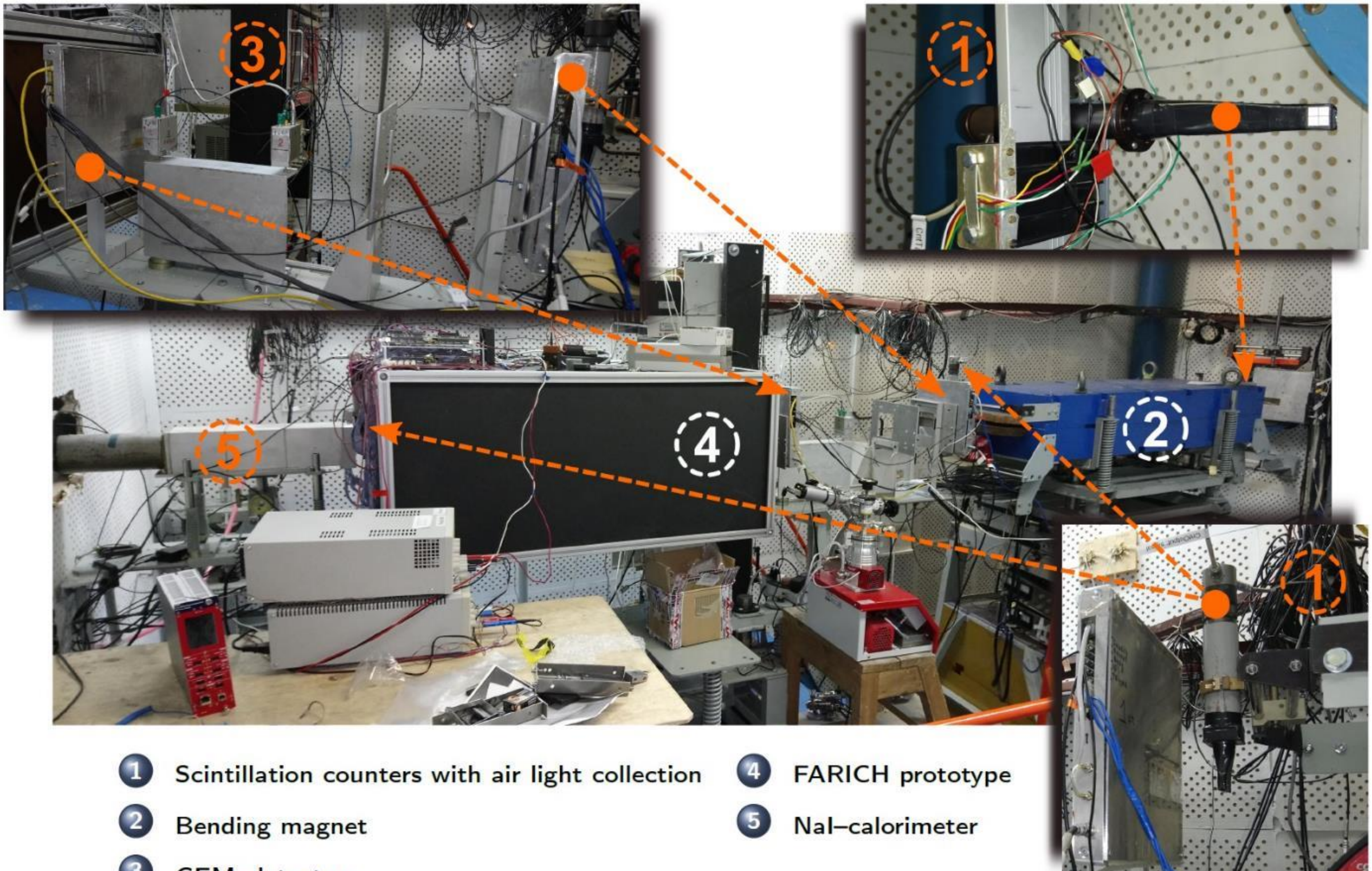
Plans: improve resolution in 2 times to the level of "classical" reconstruction.

Plans on MC simulation

- Response parameterization for fast simulation – Q2 2021
- NN reconstruction implementation – Q2 2021
- Full simulation in Aurora with optical photons – second half of 2021

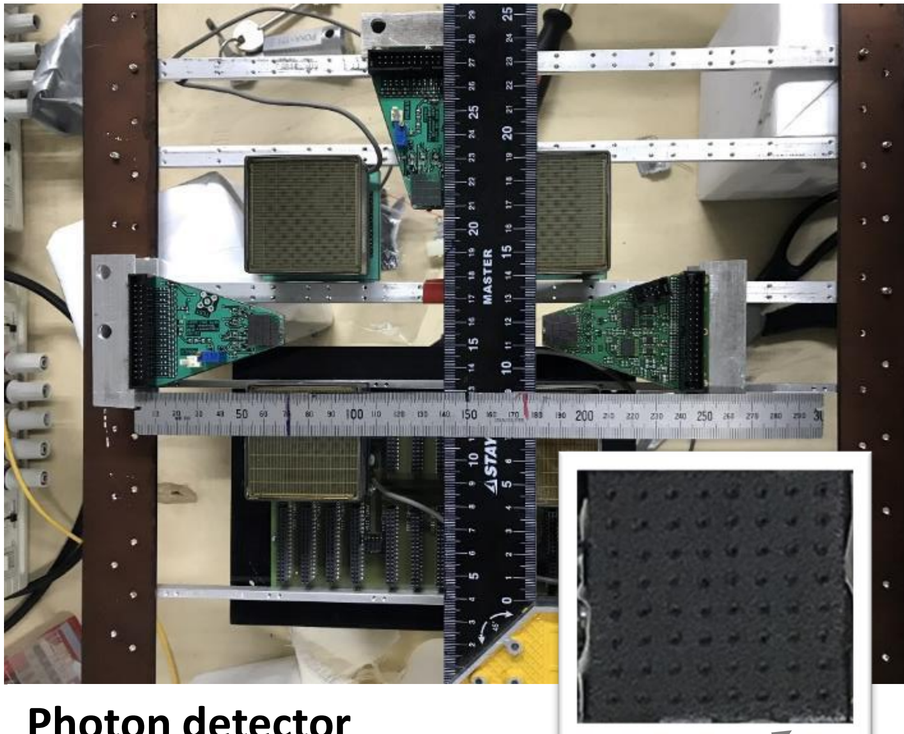
Test beam of electrons: Infrastructure

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

FARICH3 prototype (2019)



Photon detector

- 4 H12700 MaPMT: 8x8 anodes □6 mm
  Optional 1mm-hole mask on MaPMTs
- 2 ONSEMI ArrayJ-30035-16P-PCB SiPM arrays: 4x4 pixels □3 mm

Readout electronics

DiRICH & PADIWA & TRB3 (GSI)

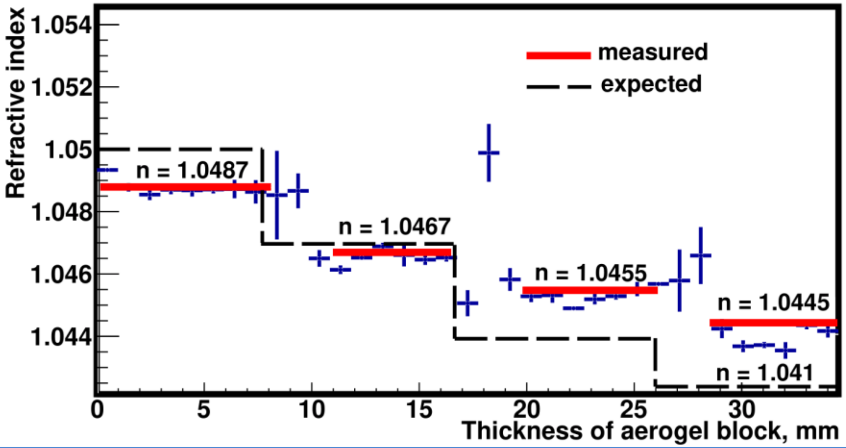
MCP detector for the time reference

Radiator

Several aerogel samples at 200mm distance from PD

Flat mirror was used to reflect light on PD and keep sensors from away from the beam line

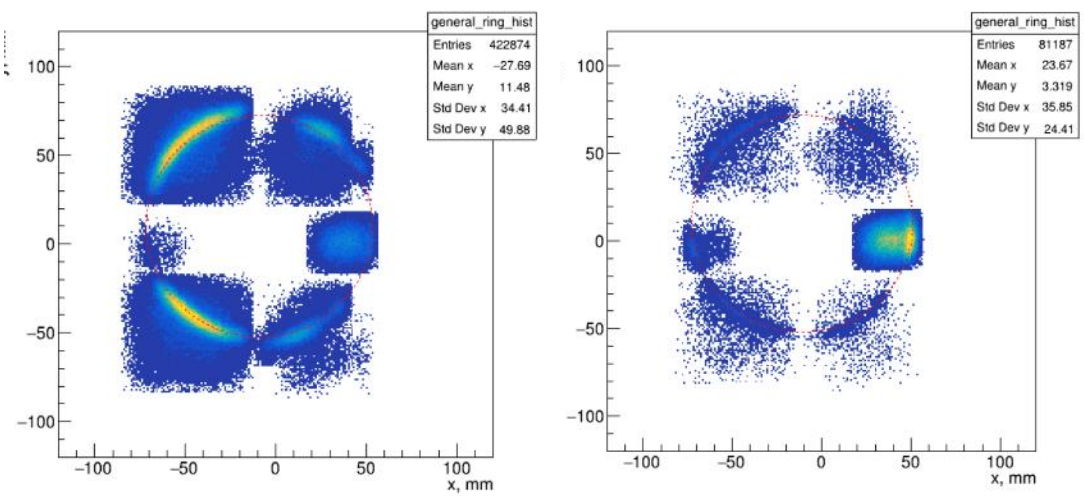
Beam test of FARICH prototype with op430f61 aerogel sample



2019 beam test results and comparison with MC

PD pixel size	σ_R(MC) [mm]	σ_R(EXP) [mm]
H12700 Ø1 mm	1.98	1.97±0.04
SiPM 3×3 mm^2	2.18	2.16±0.04

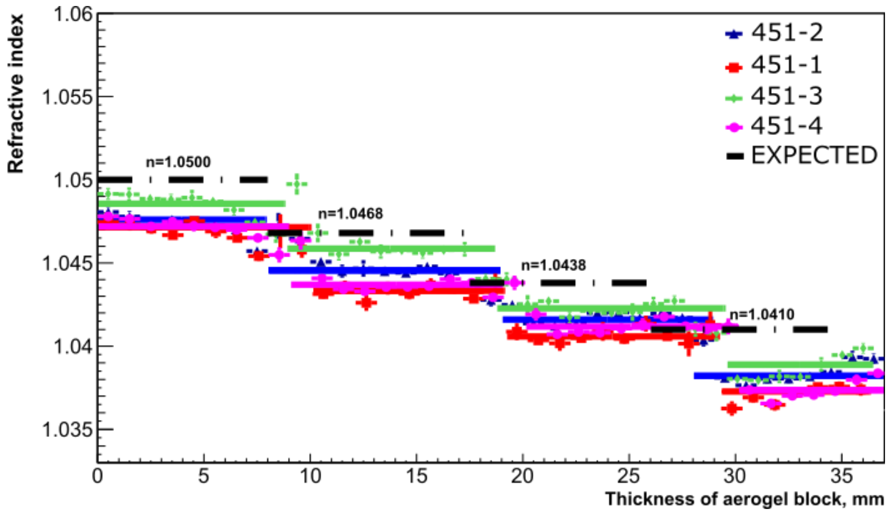
JINST **15** (2020) C10014



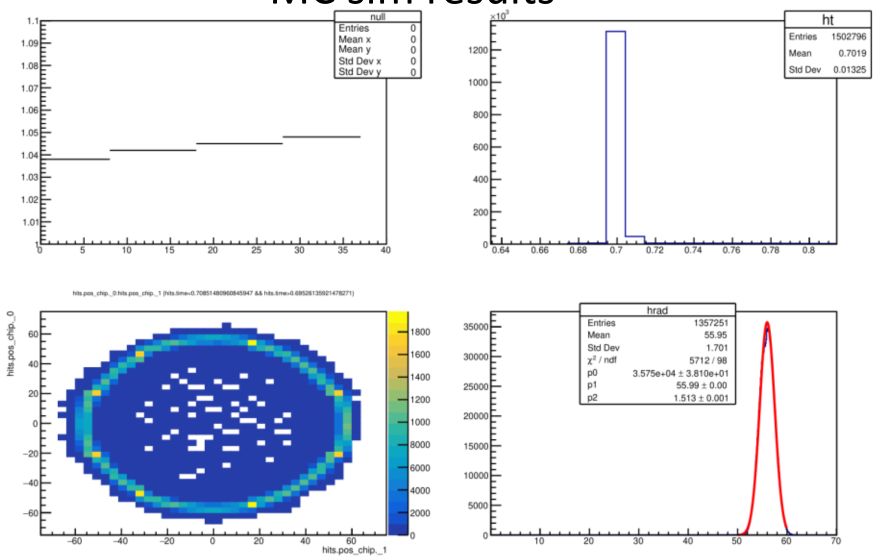
MAPMT w/o mask
6×6 mm^2 pixels

MAPMT with ø1 mm mask

New multilayer aerogels



MC sim results



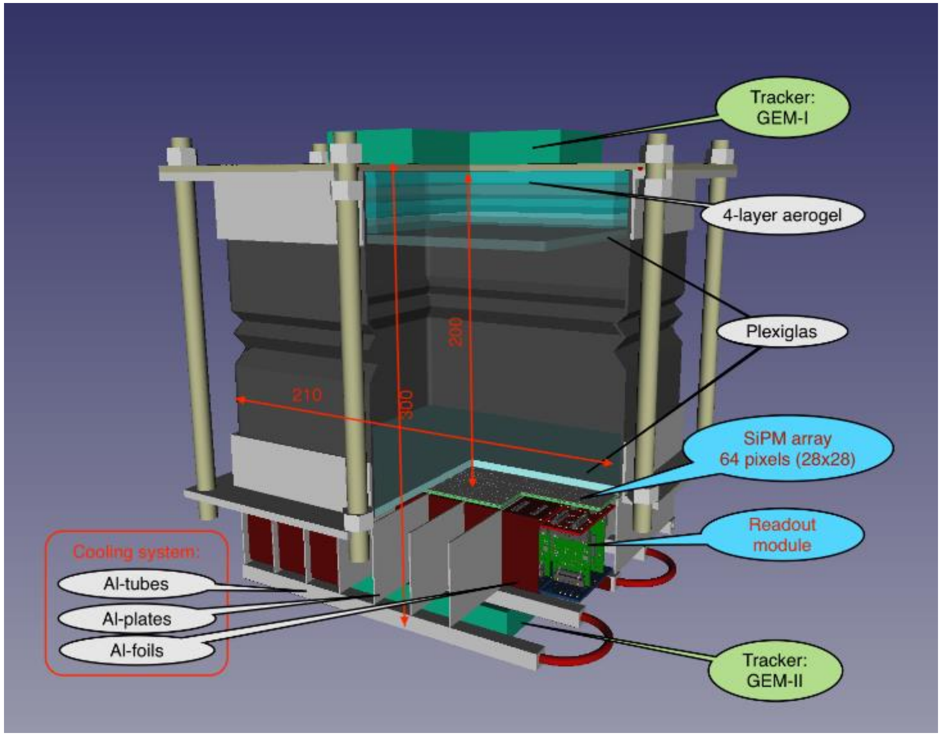
Aerogel	PD pixel size	σ_R(MC) [mm]
op451	SiPM 3×3 mm^2	1.55
Ideal 4-layer		1.45

Beam tests of newly produced aerogels are planned for Q1-2 of 2021

Full-scale FARICH prototype

Full-scale prototype will detect full Cherenkov rings with SiPM arrays & compact readout FEE.

- photon detector size ≈21×21 cm^2
- 64 × (8×8) = 4096 pixels of 3×3 mm^2
- aerogels up to 20×20 cm^2 size
- aerogel isolated from environment
- folding envelope enabling focal distance adjustments
- liquid cooling system to operate at −30°C (≤ 5%X_0)



Full-scale prototype should be ready for test beam in 2022 well ahead of MS5.6 due date (M42)

R&D of front-end electronics for FARICH

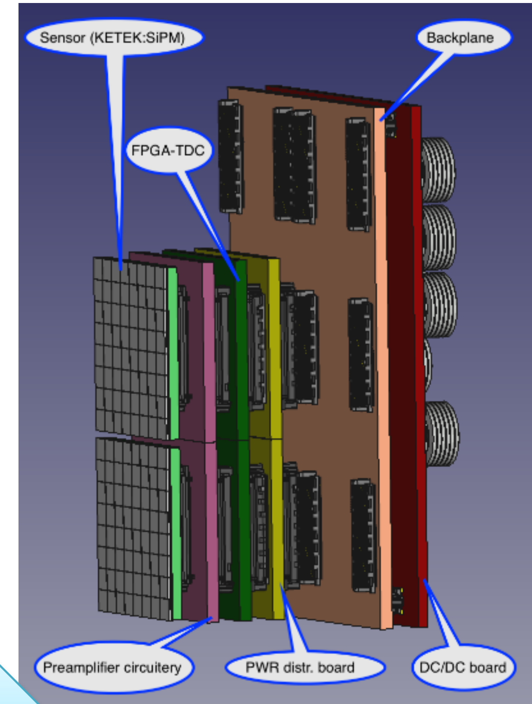
Objectives:

- High-density electronics with footprint of 3.4x3.4 mm per channel
- Fit SiPMs + FEE into ~5 cm radial space in barrel
- Power consumption as low as possible with a goal of 10-20 mW/ch
- TDC with ~100 ps timing resolution & coarse amplitude measurement (ToT)
- Possibility to cool down to −40°C

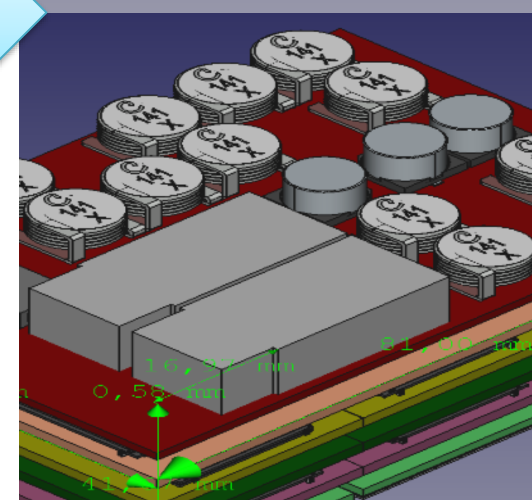
Very challenging project!

Status & plans:

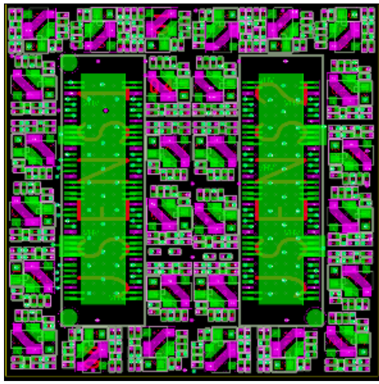
- R&D has been started by GSI digital electronics group (M. Traxler) in 2020
- Concept: FPGA-based TDC (TRB3 platform)
- Layouts of 3 of 5 boards are ready
- Production will start in Spring 2021



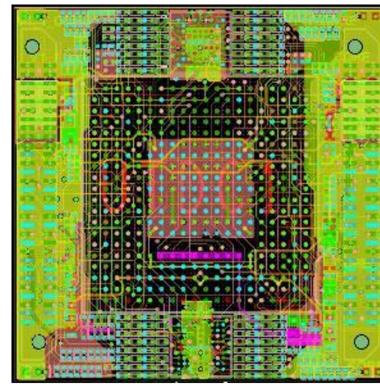
FARICH FEE module for 3x2 KETEK SiPM arrays



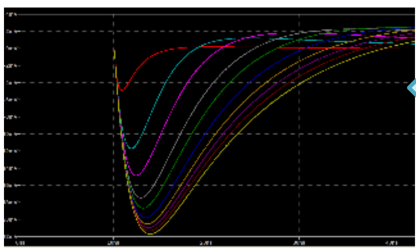
First version of FEE board layouts



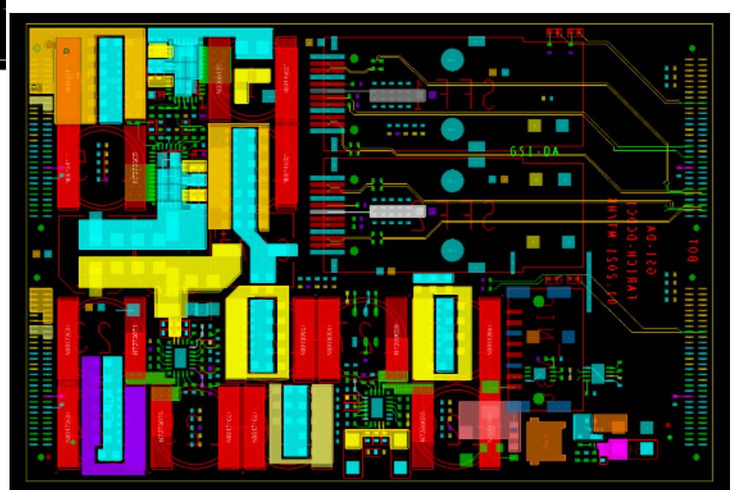
Amplifier board
- $27 \times 27\ mm^2$ size
- 14-layer PCB
- 30x gain, 64 channels
- couples to KETEK 8×8 SiPM array



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.

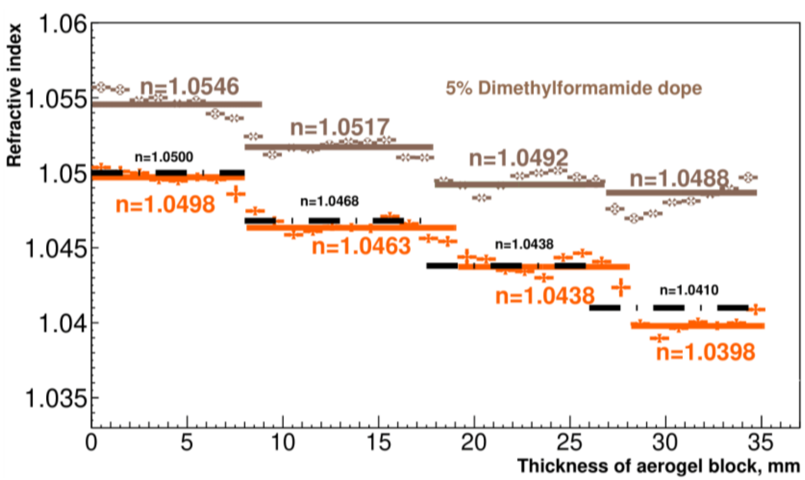


DC-DC convertor board
- goes behind the backplane
- $51 \times 84\ mm^2$ size
- provides power to SiPMs, amplifiers, FPGA
- uses air inductive coils to operate in the detector magnetic field
- power, trigger & clock connectors

R&D towards high refractive index aerogel

- RI n=1.05 results in quite high momentum threshold $P_\pi \approx 450$ MeV/*c*
- Usually, the higher RI, the lower transparency of aerogel
- Two approaches to increase RI are being developed in Novosibirsk

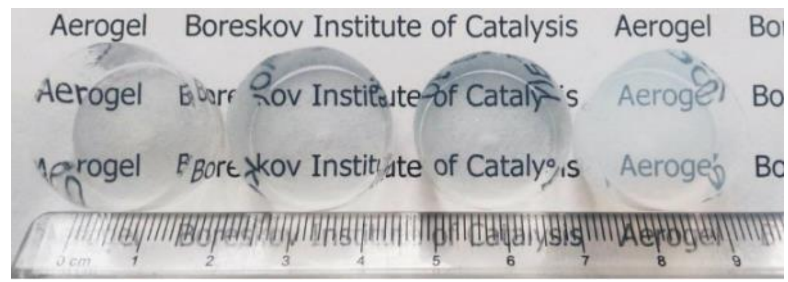
Doping with Dimethylformamide (DMF) $(CH_3)_2NC(O)H$

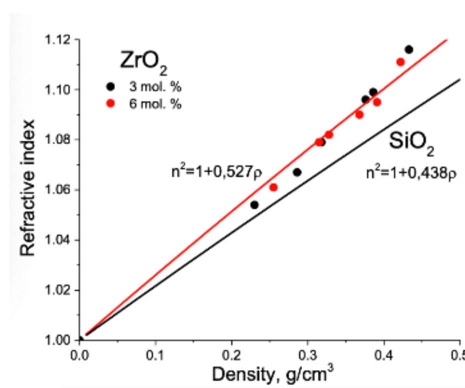


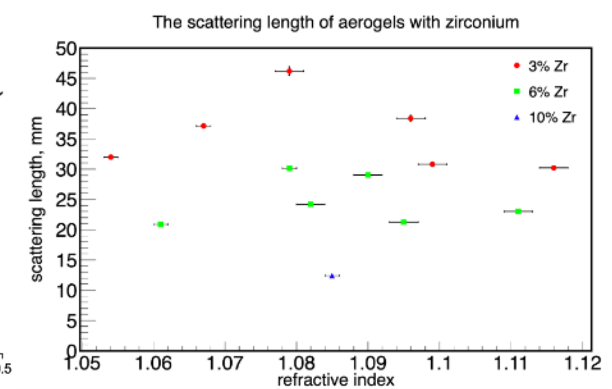
	n_{max}	L_{sc}(400nm)
Ordinary	1.0498	32 ± 0.5 mm
+5% DMF	1.0546	40 ± 0.5 mm

l simula

ZrO_2 doping







Successful production of small aerogel samples with n≤1.12 and L_{sc}(400nm)≥30mm by doping with 3-6% ZrO_2

Summary

- FARICH PID performance is studied with Geant4 simulation using different event reconstruction techniques. μ/π separation is achievable up to P=1.6GeV/c at the level of 3 s.d.
- Several FARICH prototypes have been tested since 2011 at the BINP electron beam. Latest beam test was in 2019. Next ones are planned in Q1-2 2021. Full-scale FARICH prototype will be ready for test in 2022. Beam test results and publication by M42 (July 2023).
- Experimental single photon resolution for FARICH prototypes for normal incidence relativistic electrons agrees with simulation. There is a space for the focusing aerogel improvement.
- Compact front-end electronics for FARICH readout is being developed at GSI. First iteration will tentatively be ready by mid-2021.
- Initial R&D results towards denser transparent aerogel are presented.