Progress and perspectives of FARICH R&D for the Super Charm-Tau Factory project

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Connecting Russian and European Measures for Large-scale Research Infrastructures

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PID system for SCTF project

Requirements:

- π/K separation $> 4\sigma$ up to 3.5 GeV/c
- μ/π suppression ~1/40 for to 0.5-1.2 GeV/c
- good μ/π separation at low momentum

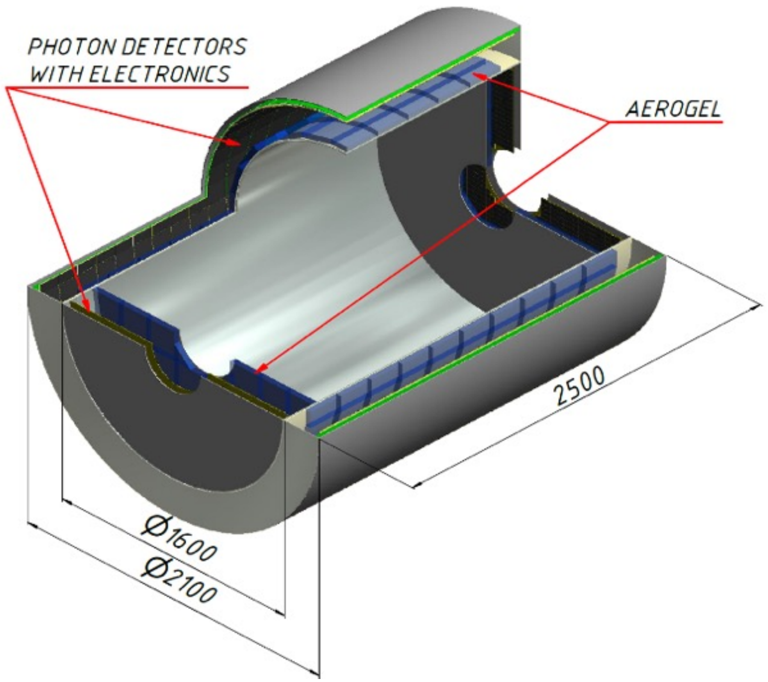
Several option are being considered:

FARICH, FDIRC, ASHIPH, TOF

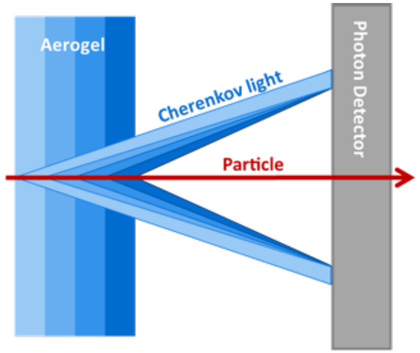
A.Yu.Barnyakov et al., NIMA 958 (2020) 162352

A.Yu.Barnyakov et al., JINST 15 (2020) 04, C04032

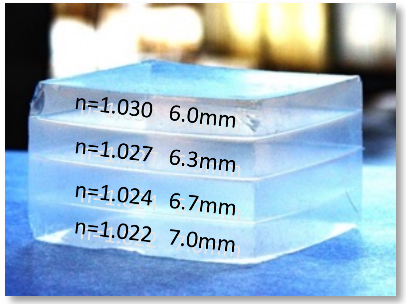
FARICH system for SCTF project



Focusing Aerogel RICH



First 4-layer aerogel



2012 test beam: μ/π separation $>3\sigma$ at P=1 GeV/c was demonstrated

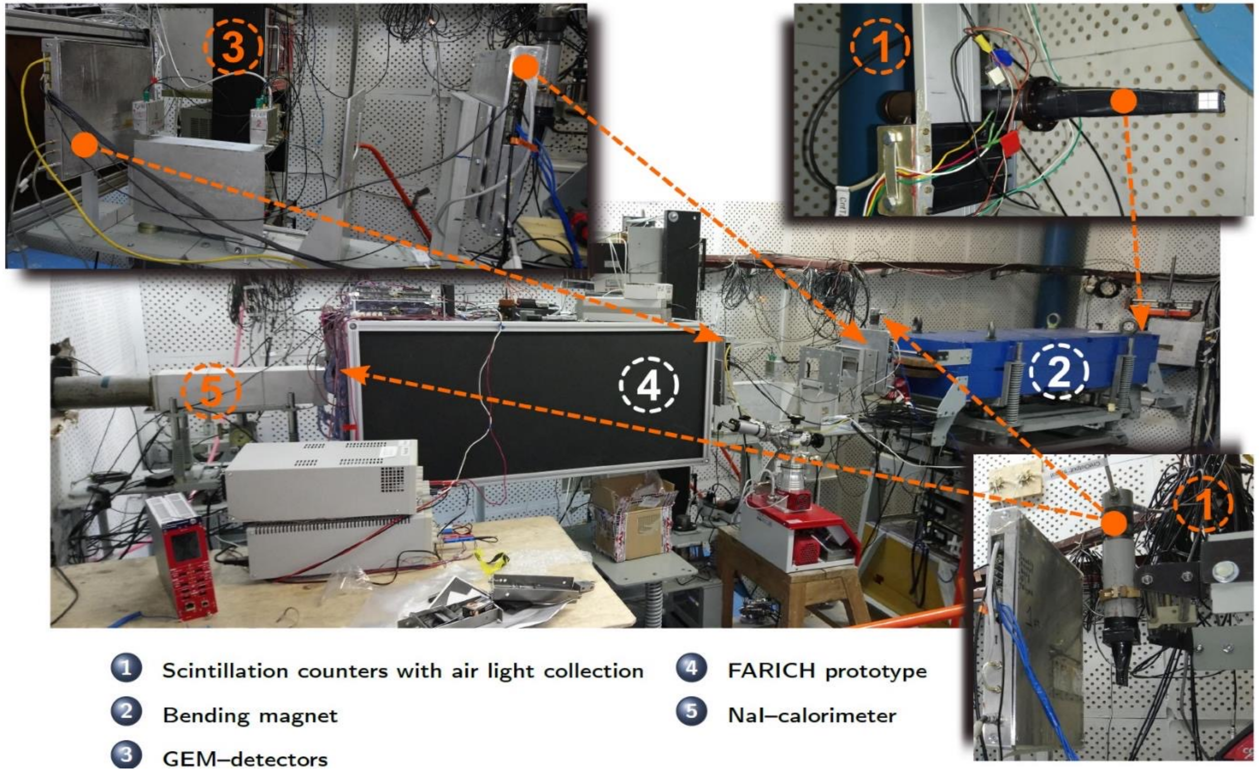
Variable n allows to increase N_{pe} using thicker radiator without compromising $\sigma_{\Theta c}$

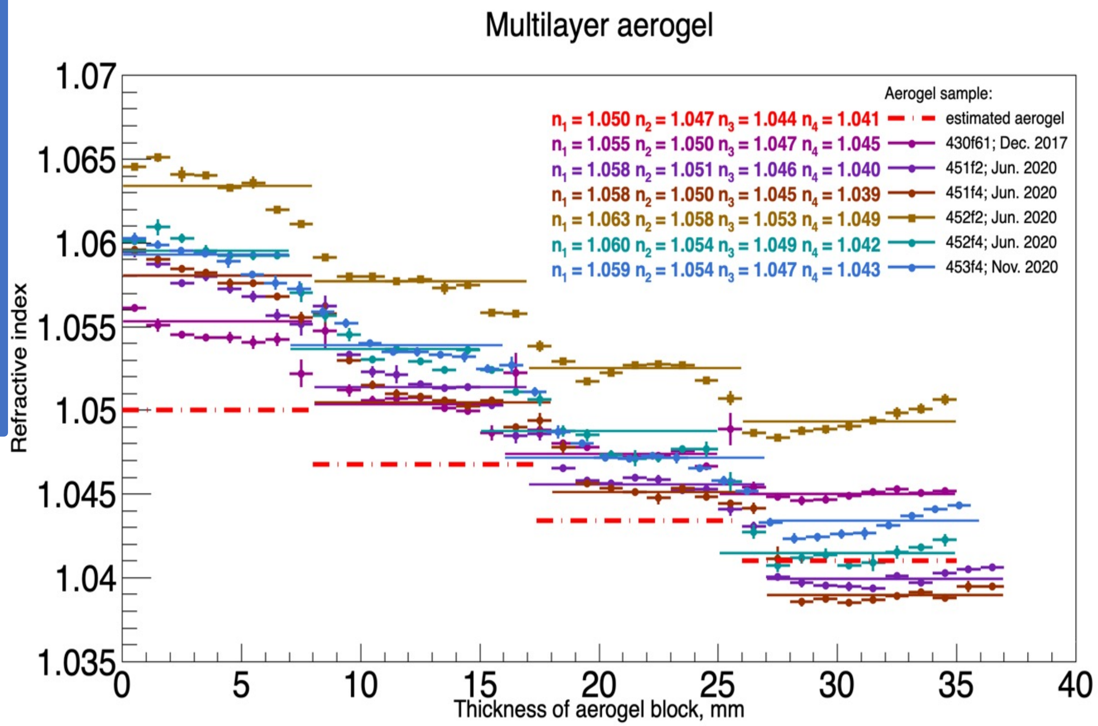
T.Iijima et al., NIM A548 (2005) 383
A.Yu.Barnyakov et al., NIM A553 (2005) 70
A.Yu. Barnyakov, et al., NIM A 732 (2013) 35

- 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

Beam tests with FARICH in 2021 at BINP

- Electrons with E=2 GeV are used
- 4 MaPMTs (H12700 from Hamamatsu with pixel 6x6 mm) were used with different masks to reduce effective pixel size:
  - Ø1 mm to investigate contribution from aerogel itself
  - 3x3 mm to measure realistic Single Photon Resoulution (SPR)
- Three GEMs are used at beamline:
  - ✓ Two before aerogel sample and one behind
  - ✓ It allows us to restore Chernekov angle for each detected photon and mitigate multiple scattering affects at beam-line.

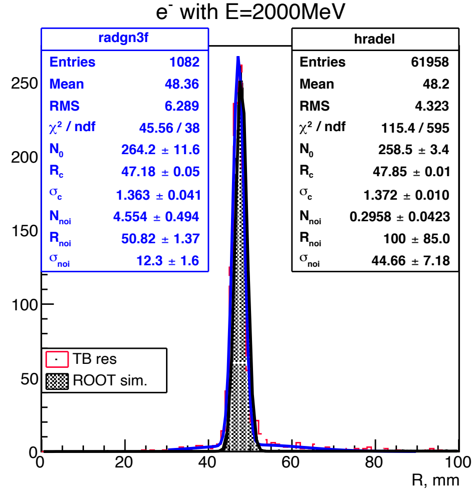


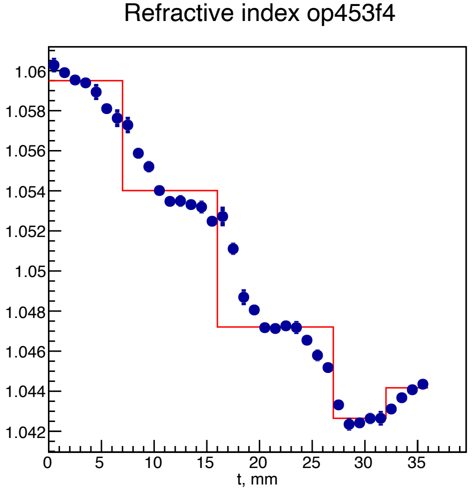


Focusing aerogel samples with 100x100mm size produced and tested in 2020-2021

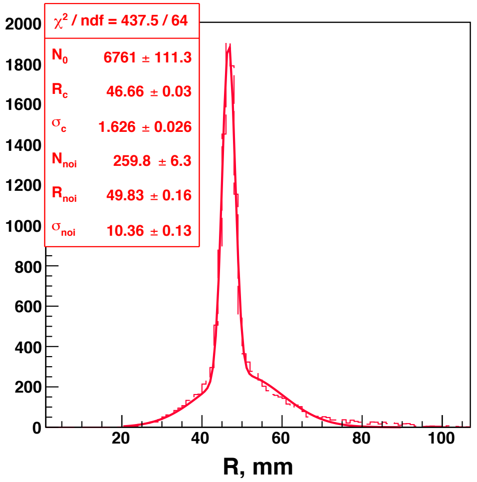
G N Abramov *et al* 2014 *JINST* **9** C08022

Beam test results & simulation



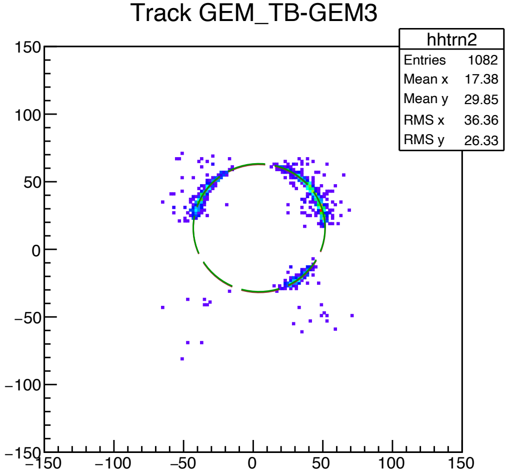


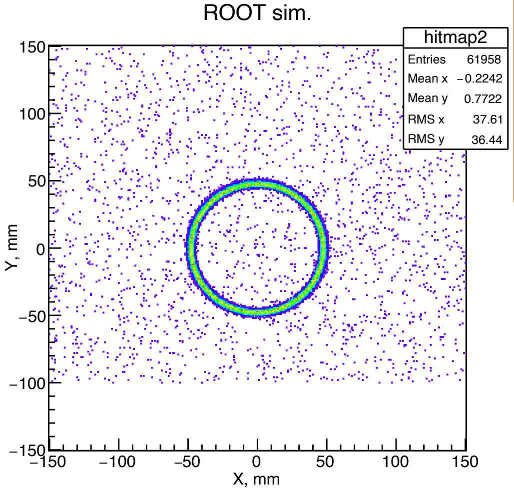
$$\sigma_R^{calc}(\blacksquare 3\text{mm}) = \sqrt{1.36^2 + \left(\frac{3}{\sqrt{12}}\right)^2} = 1.613\ mm$$

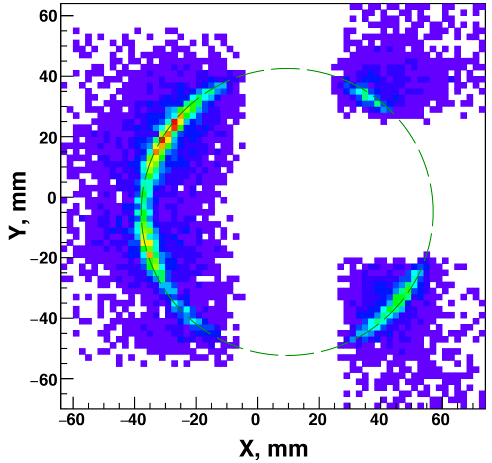


Beam test results in May-Dec of 2021 show us that we are very close to target resolution

$\sigma_R(\blacksquare 3\text{ mm}) = 1.4\ mm$ (from G4)







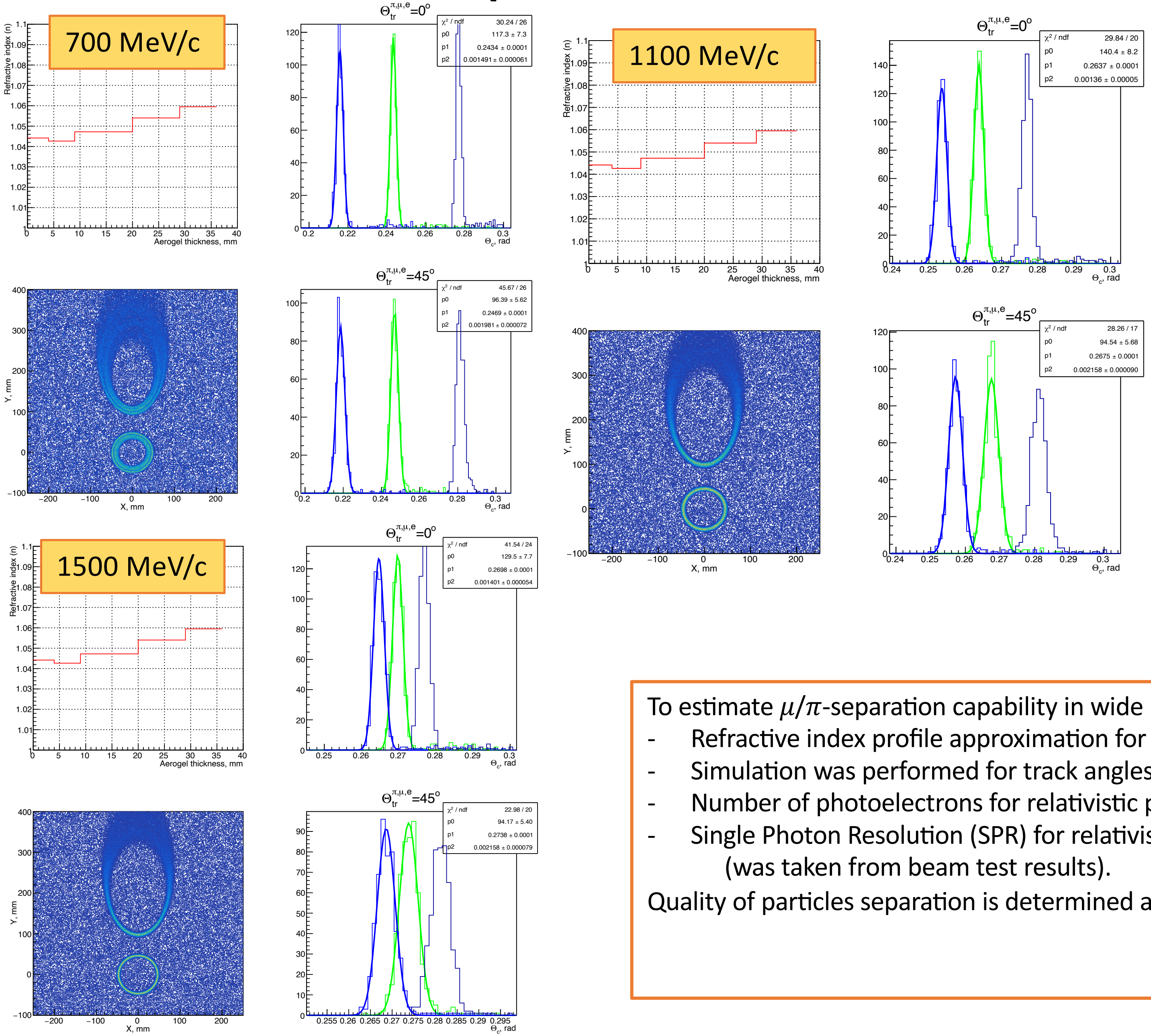
Pixel ø1 mm

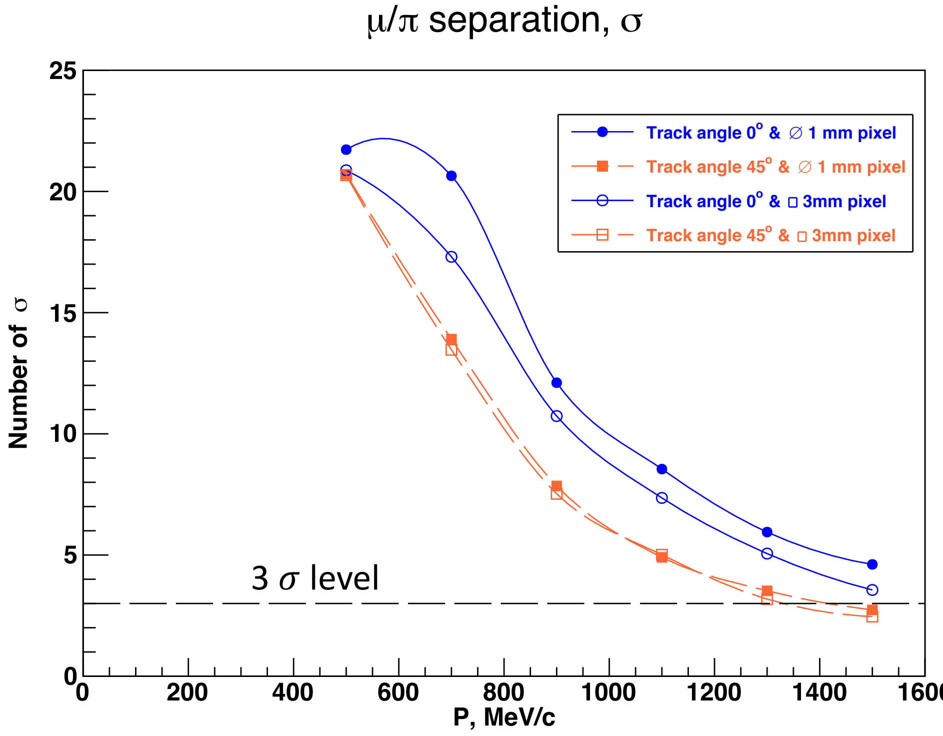
$\sigma_R = 1.36 \pm 0.04\ mm$

Pixel ■3 mm

$\sigma_R = 1.63 \pm 0.03 mm$

Expected e/μ/π – separation up to 1.5 GeV/c





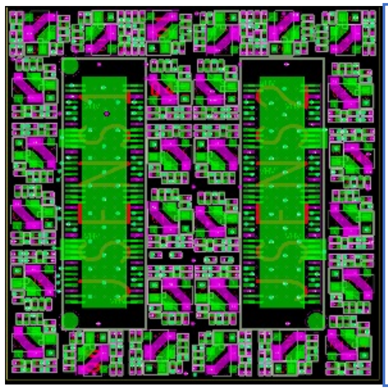
To estimate μ/π-separation capability in wide momentum range results of parametric simulation were used:

- Refractive index profile approximation for aerogel sample *453f4* and its focusing distance *L=160 mm*
- Simulation was performed for track angles *0º* and *45º*.
- Number of photoelectrons for relativistic particles (beta=1) is equal to 39 (was taken from G4 simulation).
- Single Photon Resolution (SPR) for relativistic particles SPR(■3 mm) =1.63 mm and SPR(ø1 mm)=1.36 mm (was taken from beam test results).

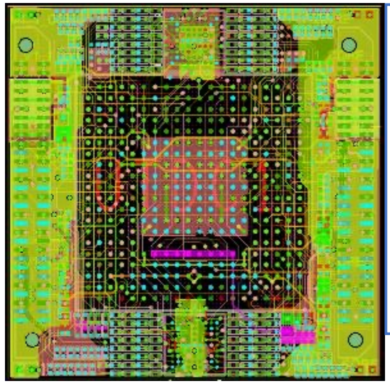
Quality of particles separation is determined as:

$$N_\sigma = \frac{\bar{\theta}_1 - \bar{\theta}_2}{(\sigma_1 + \sigma_2)/2}.$$

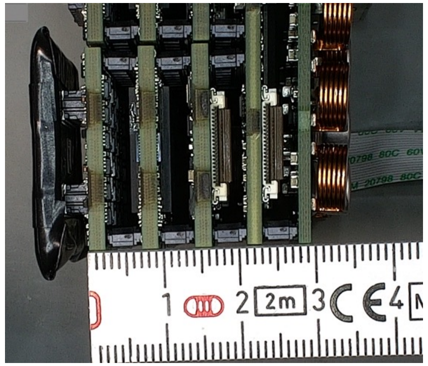
FEE based on FPGA-TDC

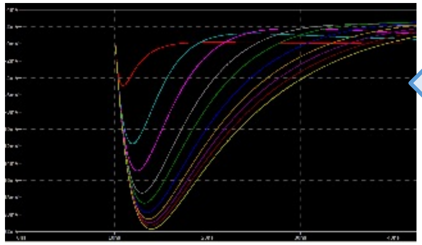


Amplifier board
- 27×27 mm^2 size
- 14-layer PCB
- 30x gain, 64 channels
- couples to KETEK 8×8 SiPM array



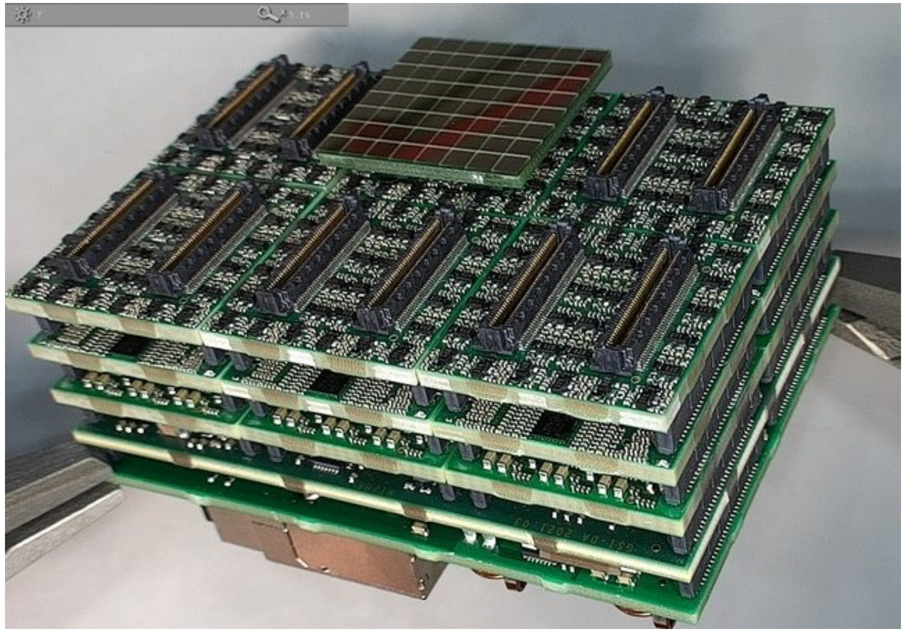
TDC board
- 64 channels
- 2 TDC + 4 threshold FPGAs
- 10ps precision

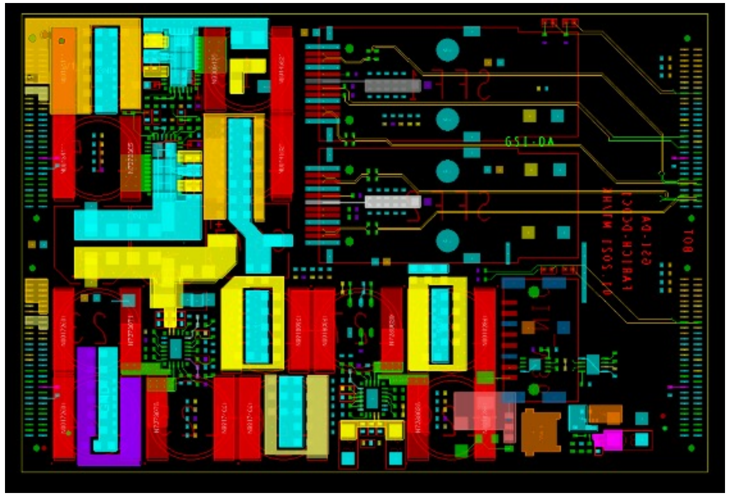




Simulated single photon pulse shapes from amplifier for different input resistance. ~ 22mV amplitude can be achieved.

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

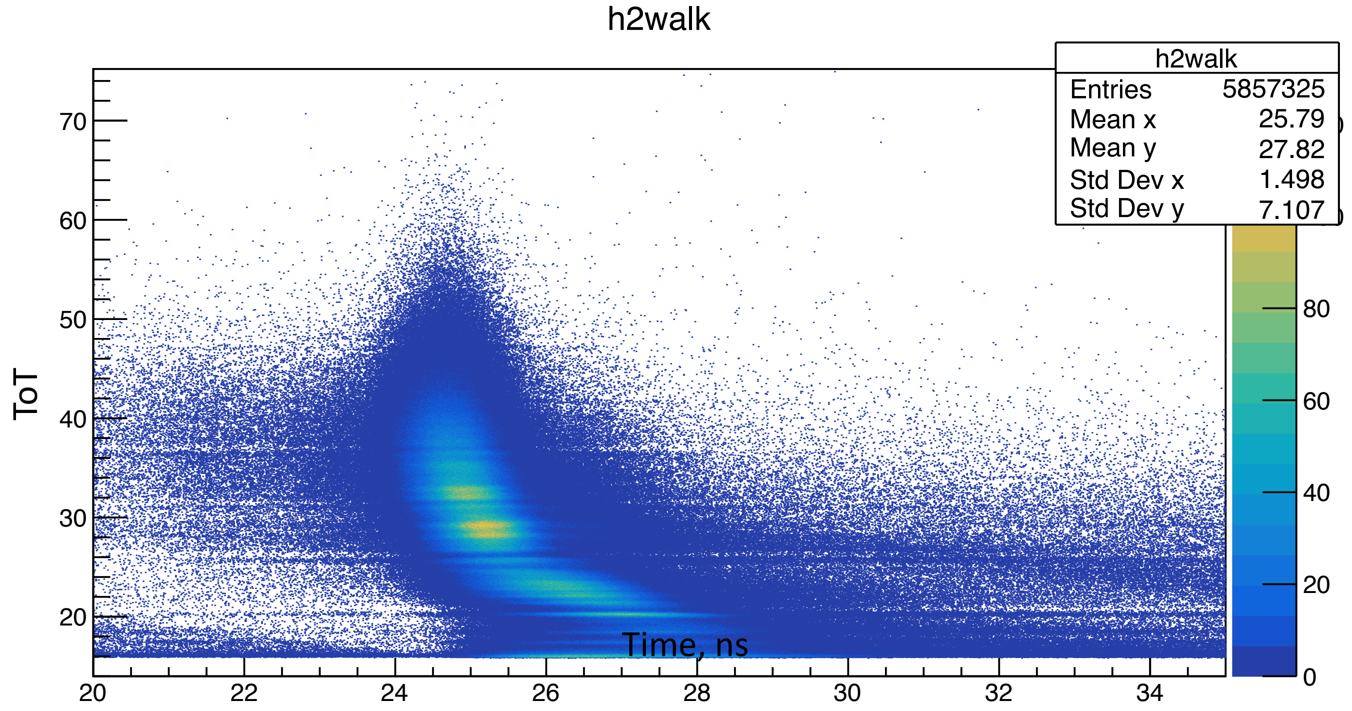


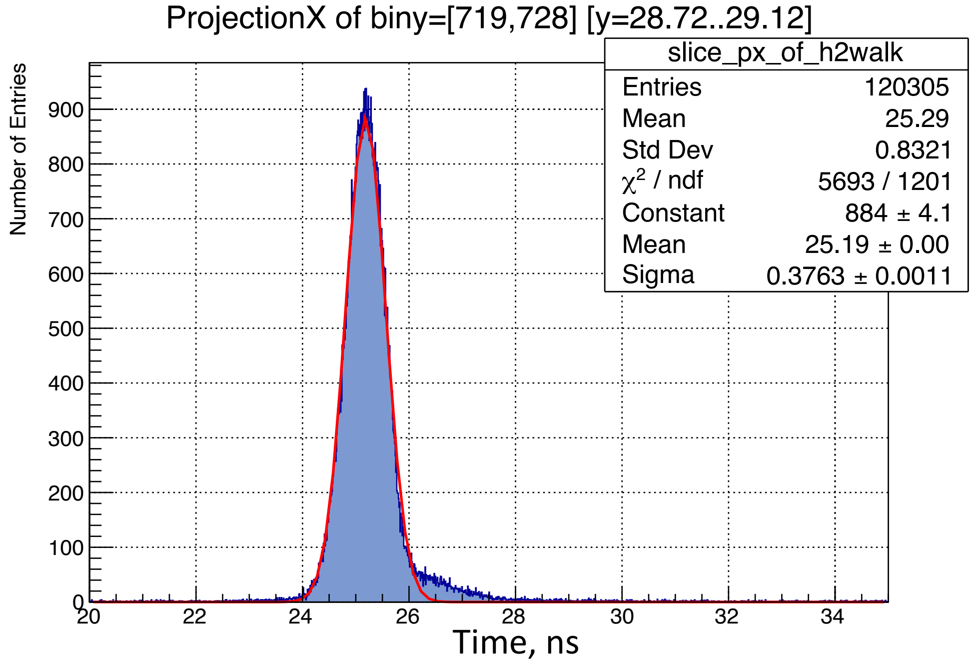


DC-DC convertor board
- goes behind the backplane
- 51×84 mm^2 size
- provides power to SiPMs, amplifiers, FPGA
- uses air inductive coils to operate in the detector magnetic field
- power, trigger & clock connectors

The first tests of *FaRICH-Auslese-System*

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



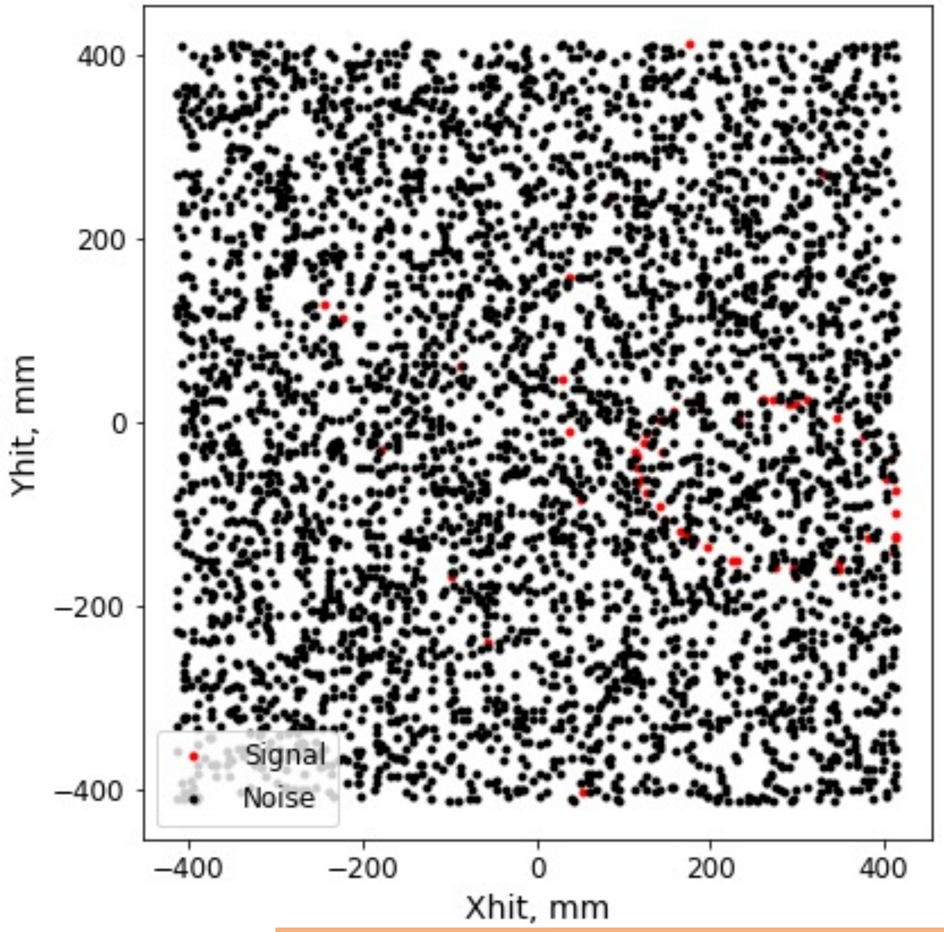


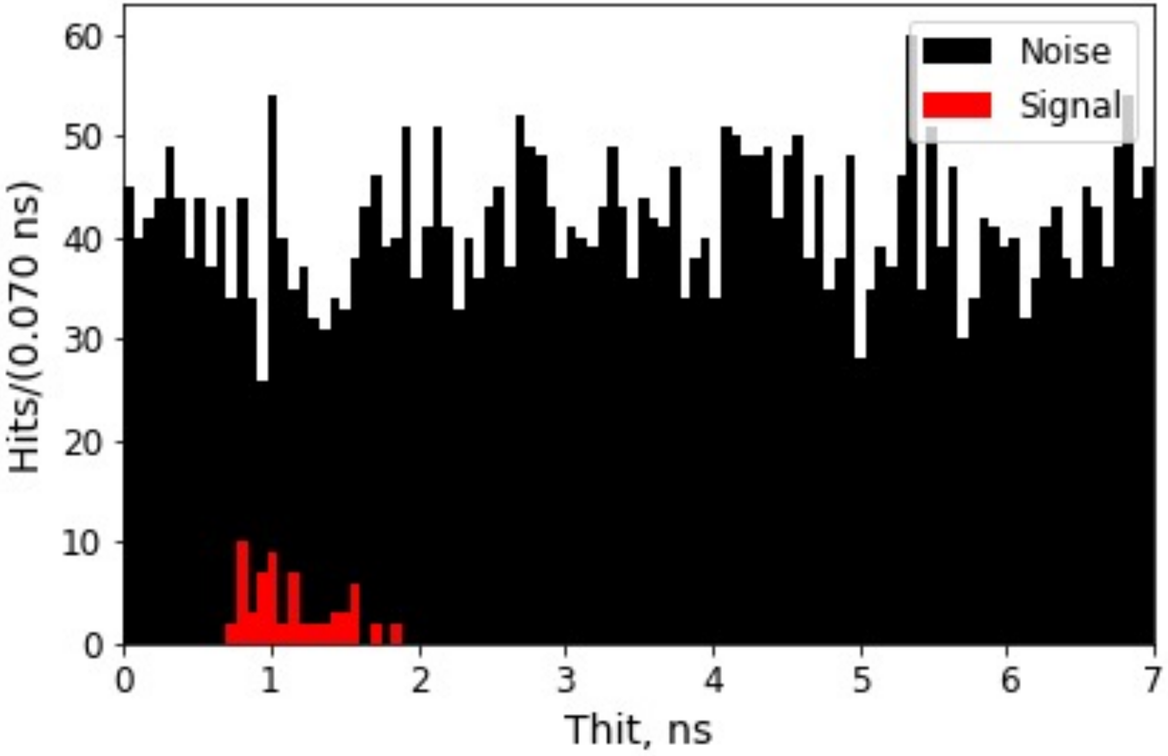
The tests performed bu Mechael Traxler, Matthias Hoek and Merlin Böhm at HIM-Institute in Mainz.

- 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.

FARICH event with expected dark hits rate

Main motivation to implement NN approach for event reconstruction in FARICH is high level of SiPM intrinsic noises, which also will depend on accumulated dose of neutrons during the experiment.





Simulated Cherenkov photon hits and dark counts plotted in the spatial coordinates and on time for DCR ~ 10^6 cps/mm^2.

Event reconstruction in FARICH using Neural Networks

Photon detector

- ON Semiconductor (SensL)

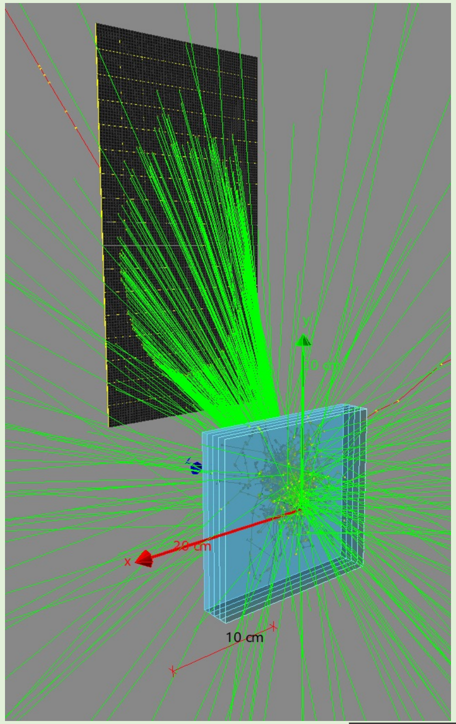
ArrayJ-30020-64P-PCB

- 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



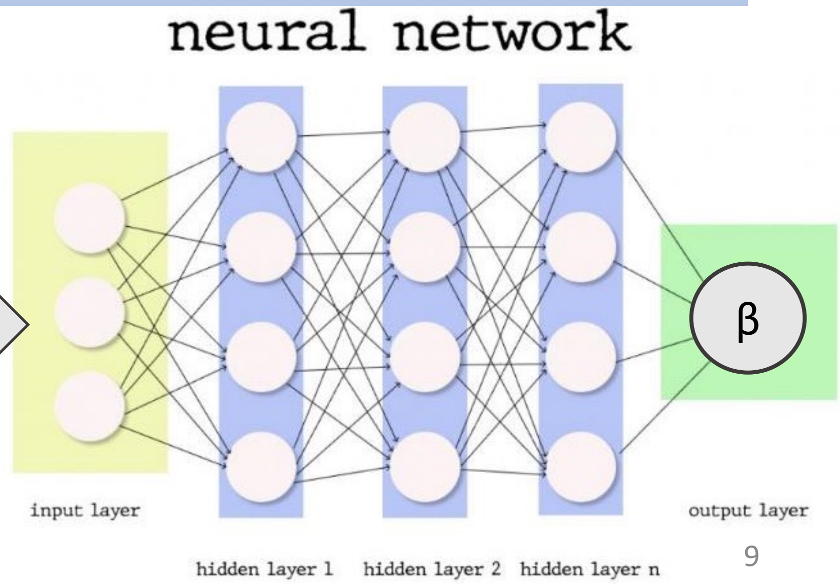
Implementation

- Python with Pandas, TensorFlow etc. packages
- Fully connected feedforward NN
- Feature extraction with analytical reconstruction of hit θ_c, φ_c,
- Obtain particle's β from a single NN output

Full FARICH GEANT4 simulation was used for NN training and comparison of NN based reconstruction approach with geometrically based one

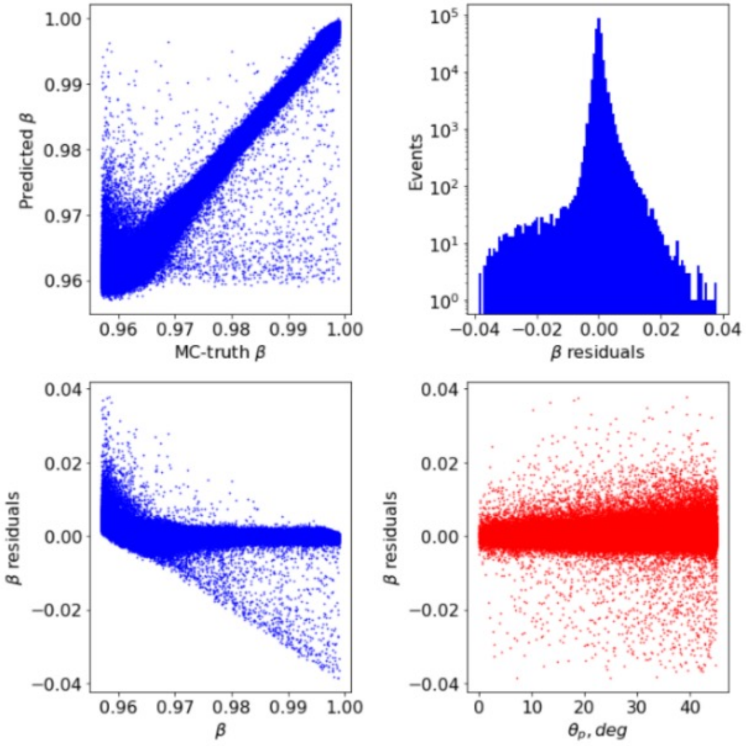
N_{hits} (i, j, k)
i – bin on ϕ_c
j – bin on θ_c
k – bin on time

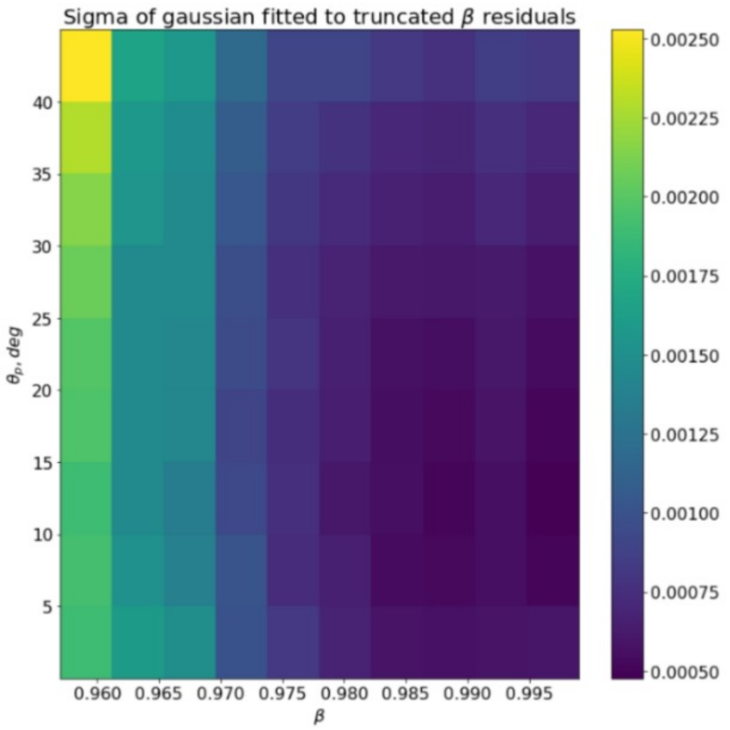
particle inc. angle

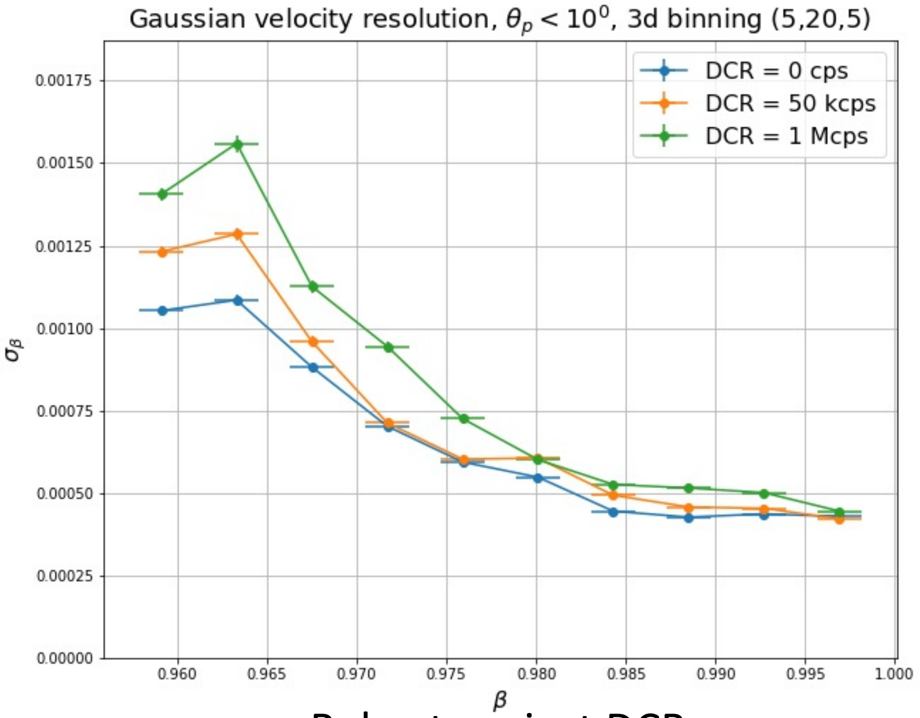


Results of NN event reconstruction

DCR = 1 Mcps/mm^2







Robust against DCR

- NN reconstruction gives the best β error $5{\cdot}10^{-4}$ for 1 Mcps/mm^2 dark count rate
- Minimum β error for geometrical reconstruction (w/o dark noise) ~ $4{\cdot}10^{-4}$
- Theoretical limit (w/o dark noise) ~ $3{\cdot}10^{-4}$

Plans :

- compare NN reco vs “classical” reco with dark noise
- compare speed

Summary

- Results of FARICH beam tests in 2021 demonstrate single photon resolution at the level of 10 mrad. It is very close to theoretical expectations for ideal focusing aerogel refractive index profile (7 mrad). And it is enough to provide μ/π-separation at the level of 3 STDEV up to momentum equal to 1.5 GeV/c.
- First version of compact FEE for FARICH prototype based on FPGA was developed and produced. First test results looks very promissing.
- Reconstruction of particle velocity in FARICH with help of Neural Networks was developed. The reconstraction demonstrates very good ability to work with high level of intrinsic noises.