ePIC PID Status Update

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Yale University

ePIC Central detector systems

Hadronic Calorimeters

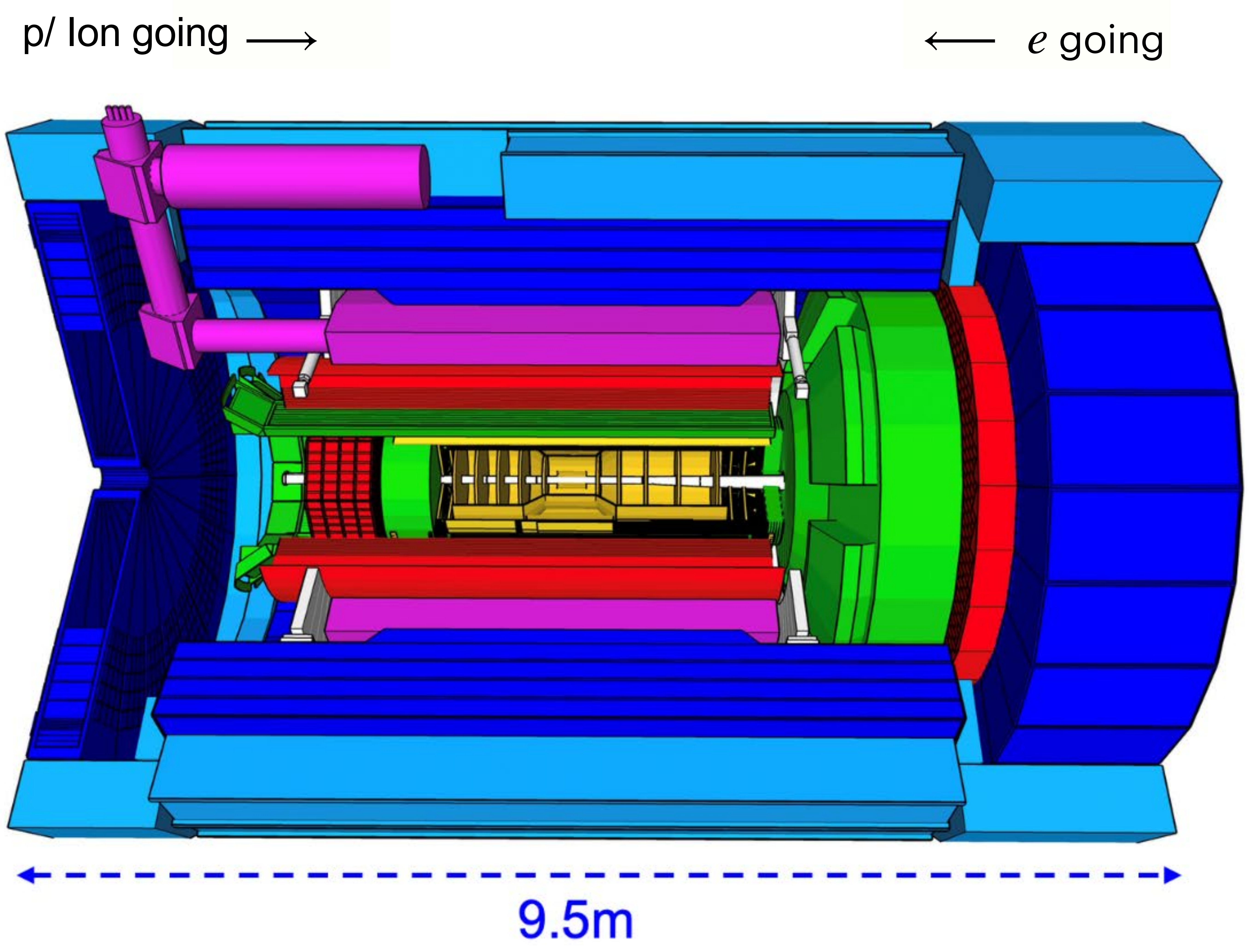
Solenoidal Magnet

Electromagnetic Calorimeters

ToF, DIRC, RICH Detectors

MPGD Trackers

MAPS Trackers



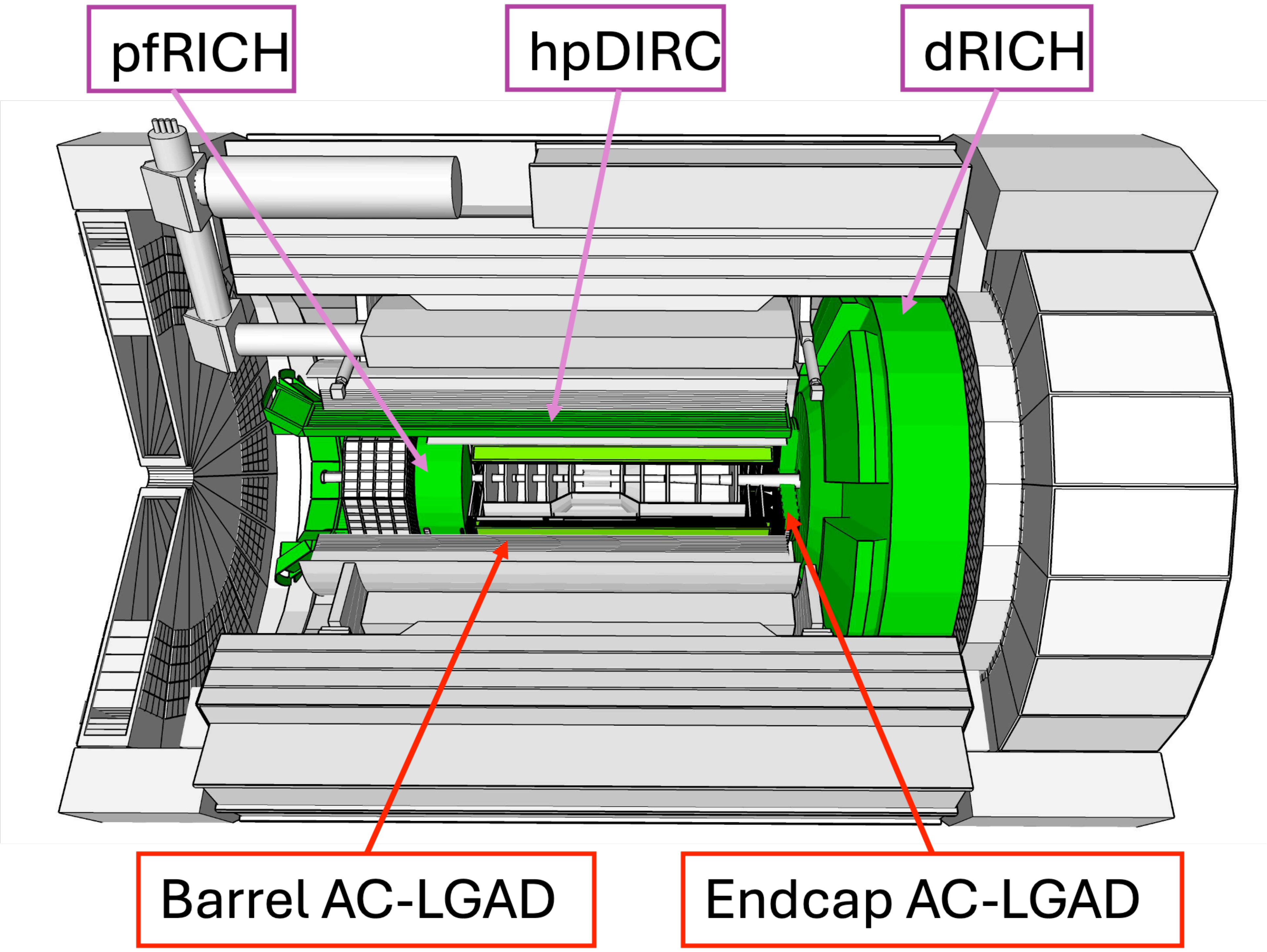
PID:

Cherenkov based detector systems

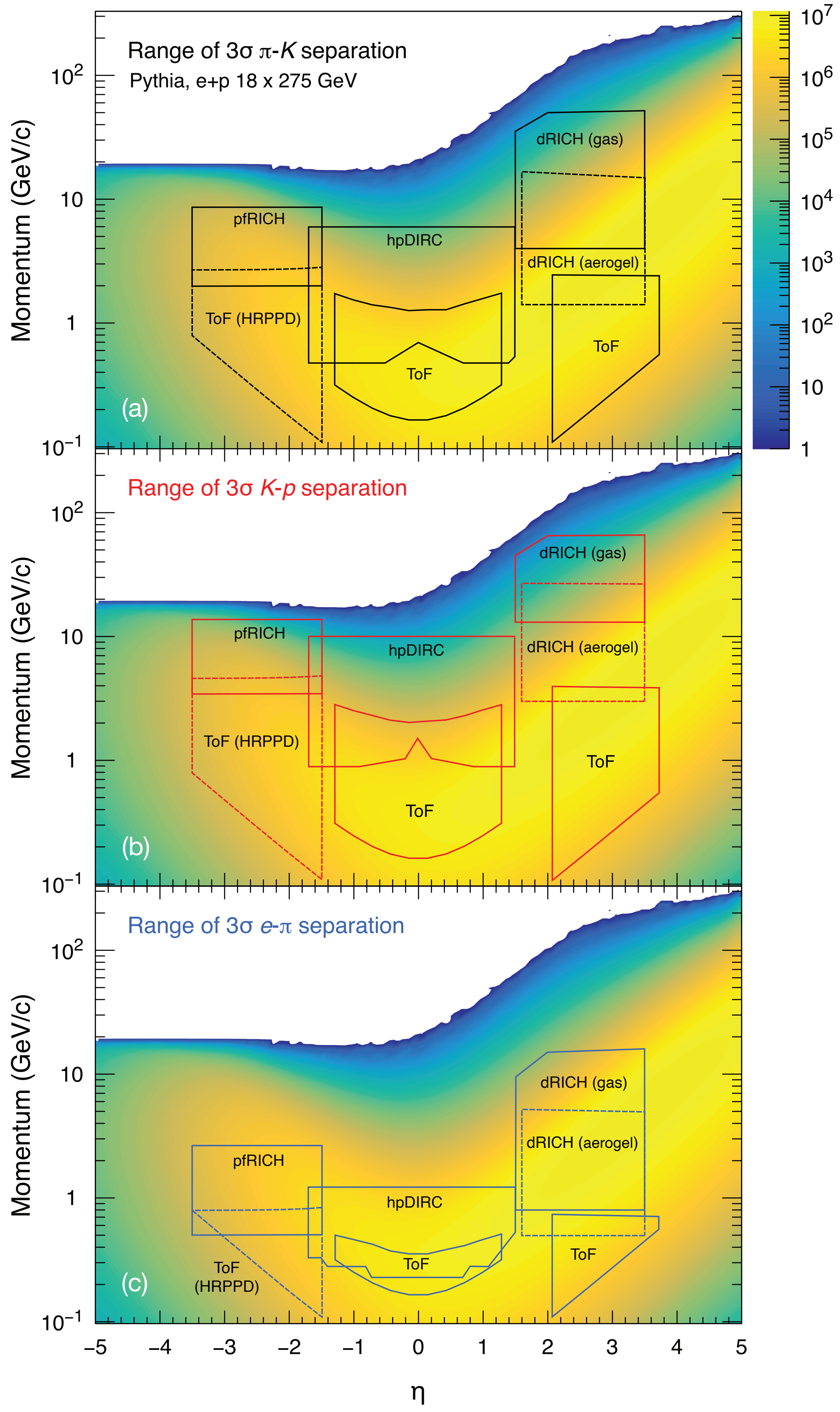
(Incremental Preliminary Design and Safety Review in April -2025)

+

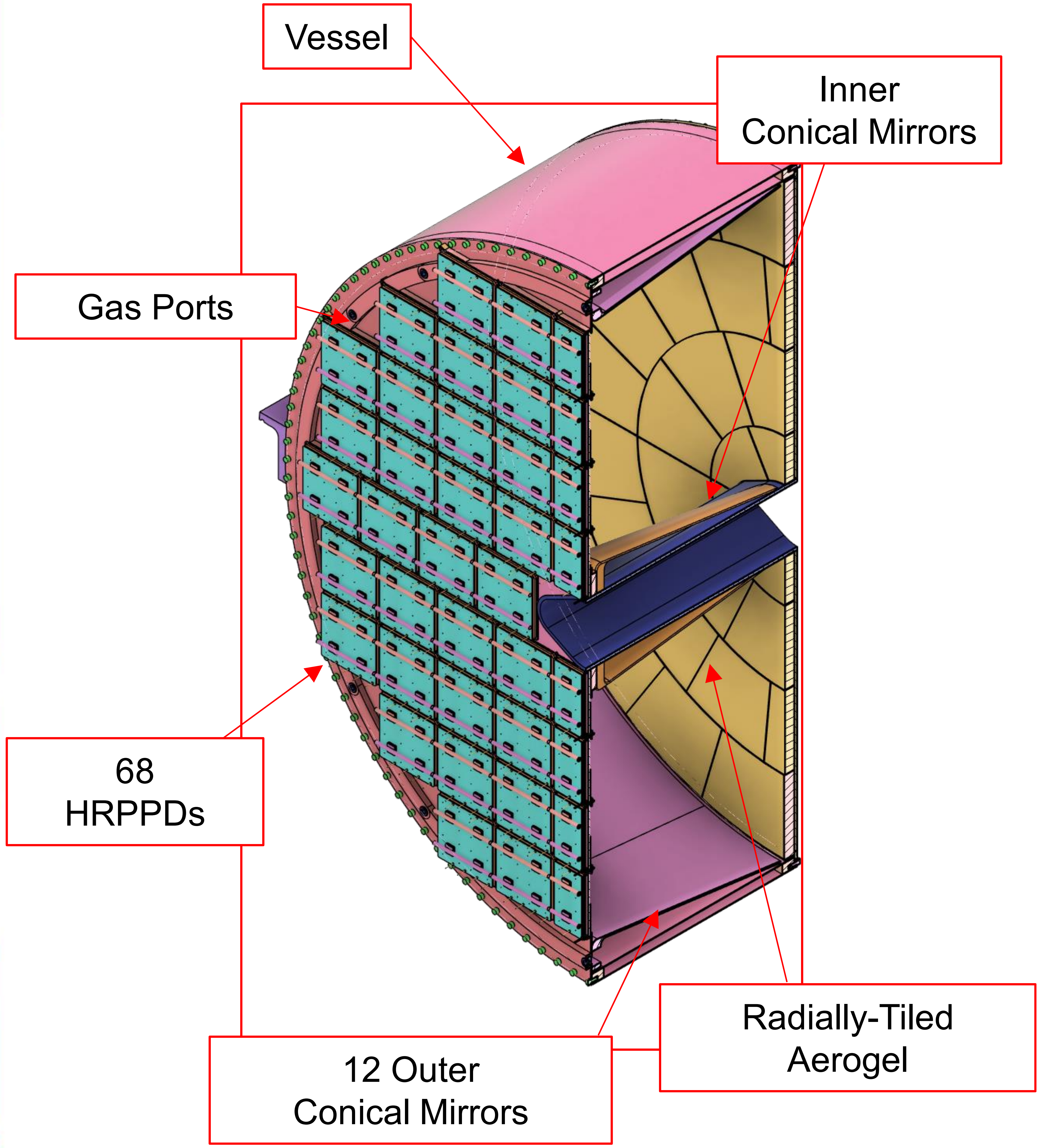
AC-LGAD based ToF detector systems



Caution
Few Minor details might be updated



Proximity Focusing RICH (pfRICH) Overview



- Aerogel
  - Three radial bands
  - Opaque dividers
  - 2.5 cm thick, 42 tiles total
- Vessel
  - Lightweight structure
  - Reinforced carbon fiber and 3D printed materials
  - Filled with nitrogen
- HRPPD photosensors
  - 120 mm size
  - Tiled with a 3.0 mm gap
  - 68 sensors total

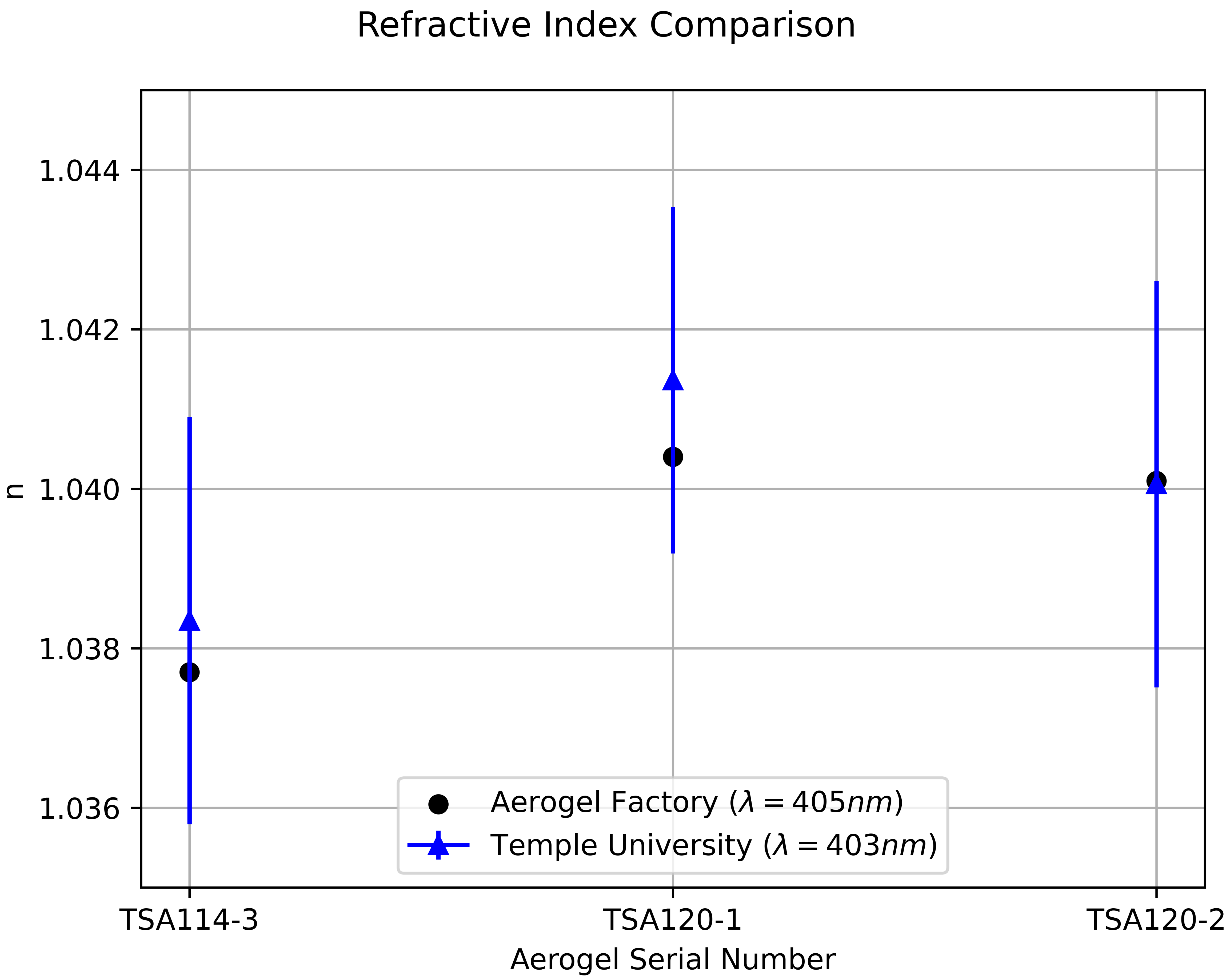
Aerogel Evaluation

- ❑A relatively moderate momentum reach is required for this RICH detector
- ❑HRPPD PDE is expected to be substantially smaller than of the SiPMs
  - ➢And peak value shifted to the UV range, where it cannot be used for ring imaging

- ❑Consider using a high n ~ 1.040
  - ➢300 nm acrylic filter cutoff for imaging
  - ➢$<N_{pe}>$ ~ 11-12

  - ➢*For ToF still make use of the UV range for abundant Cherenkov light produced in the window*

  - ➢Hardware reference: Chiba University aerogel (n = 1.040)
  - ➢3 sample tiles have been purchased
  - ➢Extensive characterization / QA by Temple University group
  - ➢Confirm manufacturer specs and develop QA procedures



Mirror Fabrication

- Inner and outer conical mirrors and pyramidal mirrors increase detector photon acceptance

- Mirrors fabricated “in-house”
  - Straight and curved substrates produced by Purdue
  - Lexan co-bonded to carbon fiber – optimization of bonding procedure ongoing
  - Mirror coating applied using evaporator setup at SBU

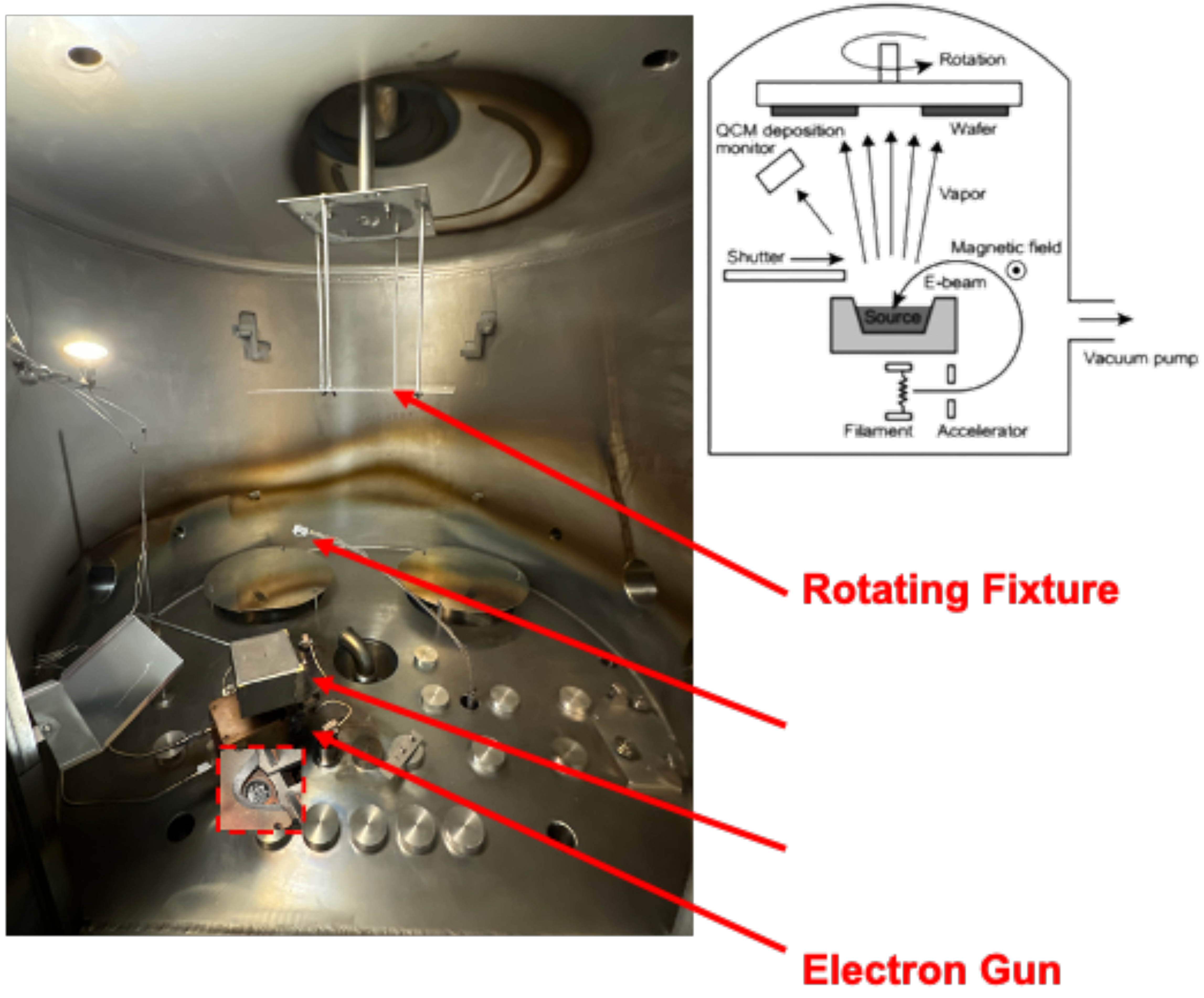
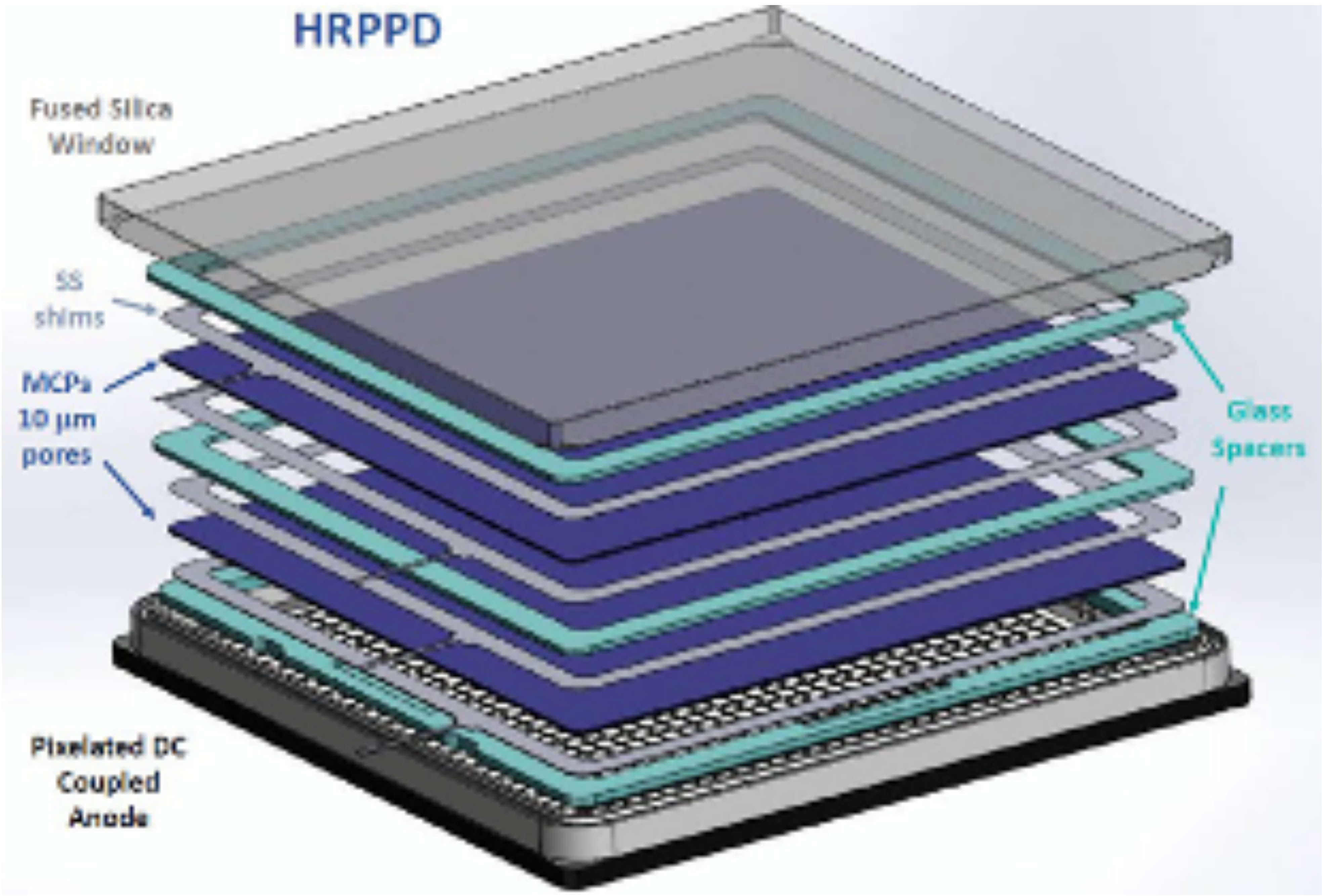


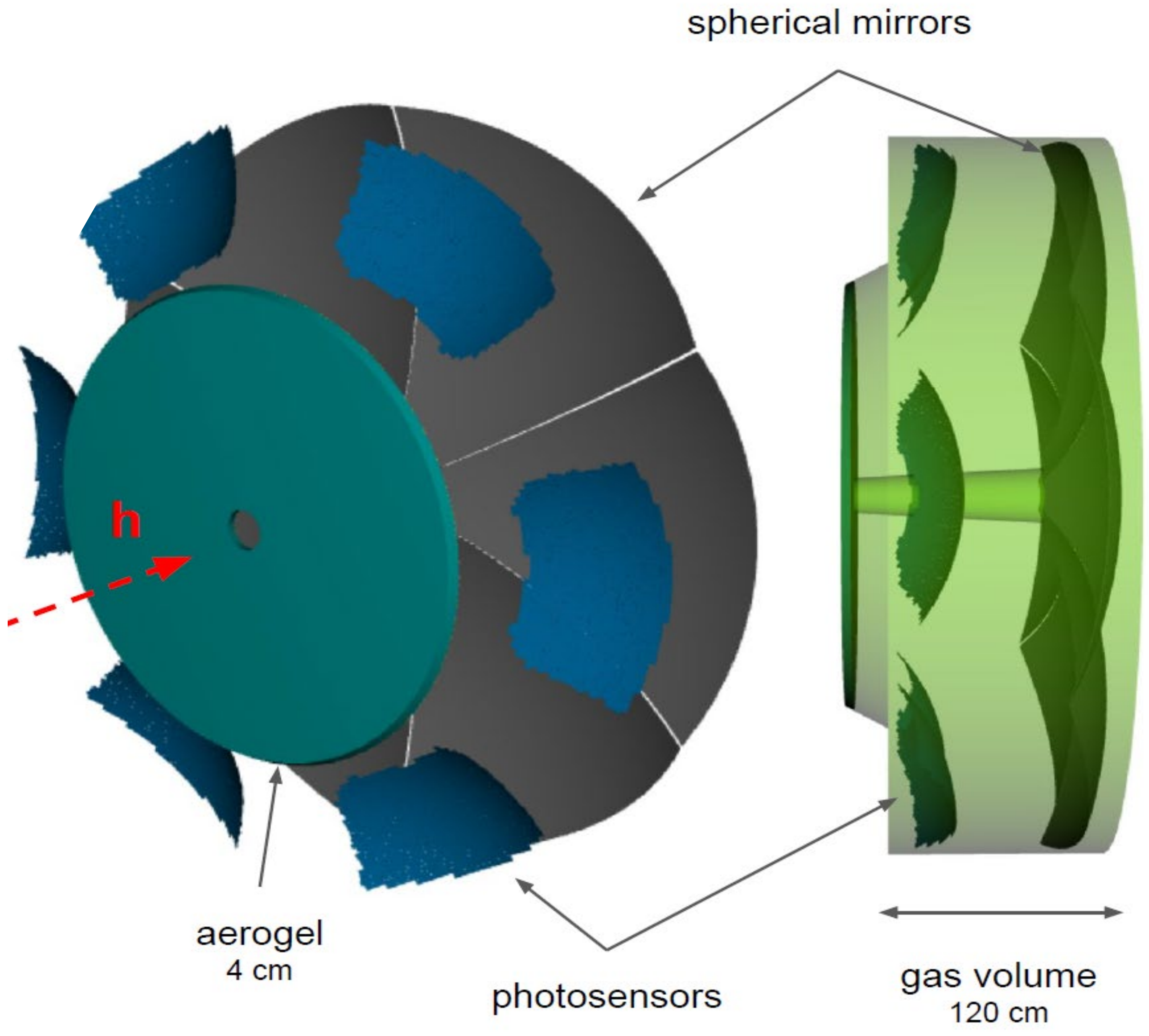
Photo-Sensors

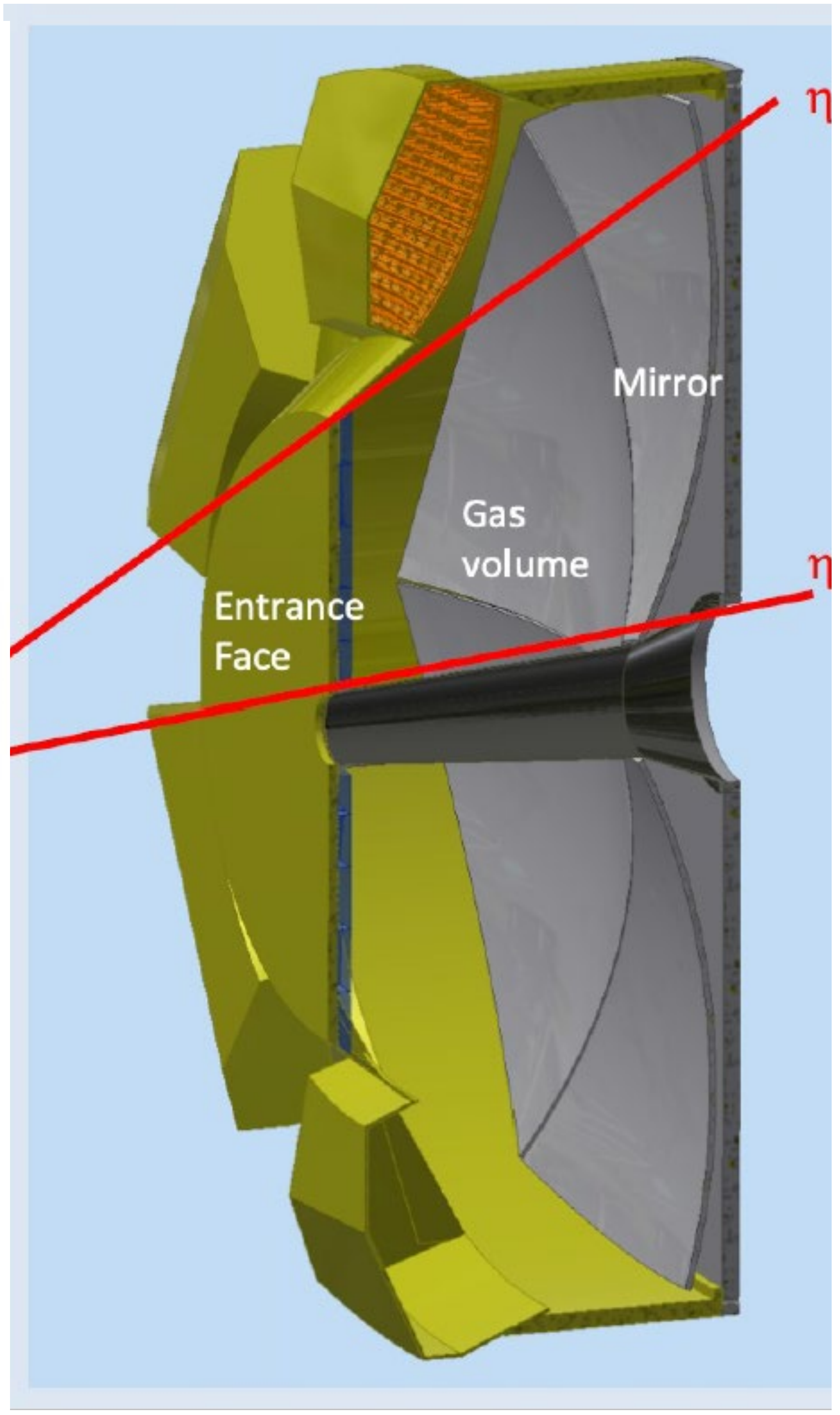
- Basic requirements:
  - Provide a timing reference at the level of ~20 ps for the barrel and forward ToF subsystems
  - Provide spatial resolution ~1mm
  - Have small Dark Count Rate
  - Have reasonable power dissipation in mW per channel
    - a low material budget cooling system in front of the PWO EmCal
    - as little influence on the thermal environment around the EmCal as possible
- Allow for a compact solution to leave more space for the proximity gap



- **Photosensor: HRPPD by Incom Inc.**
  - High intrinsic SPE timing resolution
  - Low Dark Count Rate (compared to SiPMs)
  - Low cost (compared to other MCP-PMTs)

Dual Radiator RICH (dRICH) Overview





Goals:

- Hadron 3s-separation between 3 - 50 GeV/c
- Complement electron ID below 15 GeV/c
- Cover forward pseudorapidity 1.5 - 3.5

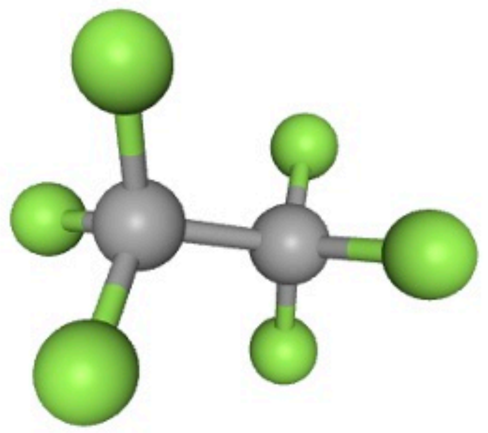
dRICH Features:

- Extended 3-50 GeV/c momentum range --> Dual radiator
- Single-photon detection in high Bfield --> SiPM
- Limited space --> Compact optics with curved detector

Gas Radiator

Transmission in UV range > 98 %

Baseline Hexsafluoroethane validated with lab and beam tests



C_2F_6 molecular weight: 138.01 g/mol

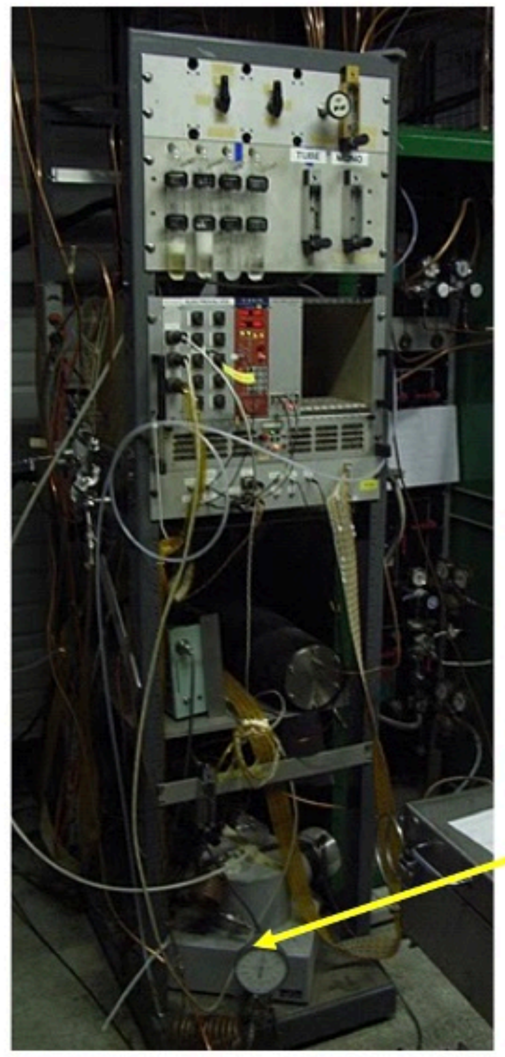
boiling point: -78.1 °C

melting point: -100.6 °C

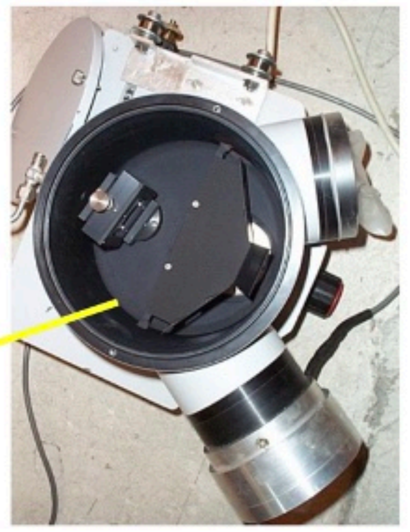
density: 5.734 kg/m³ at 24 °C

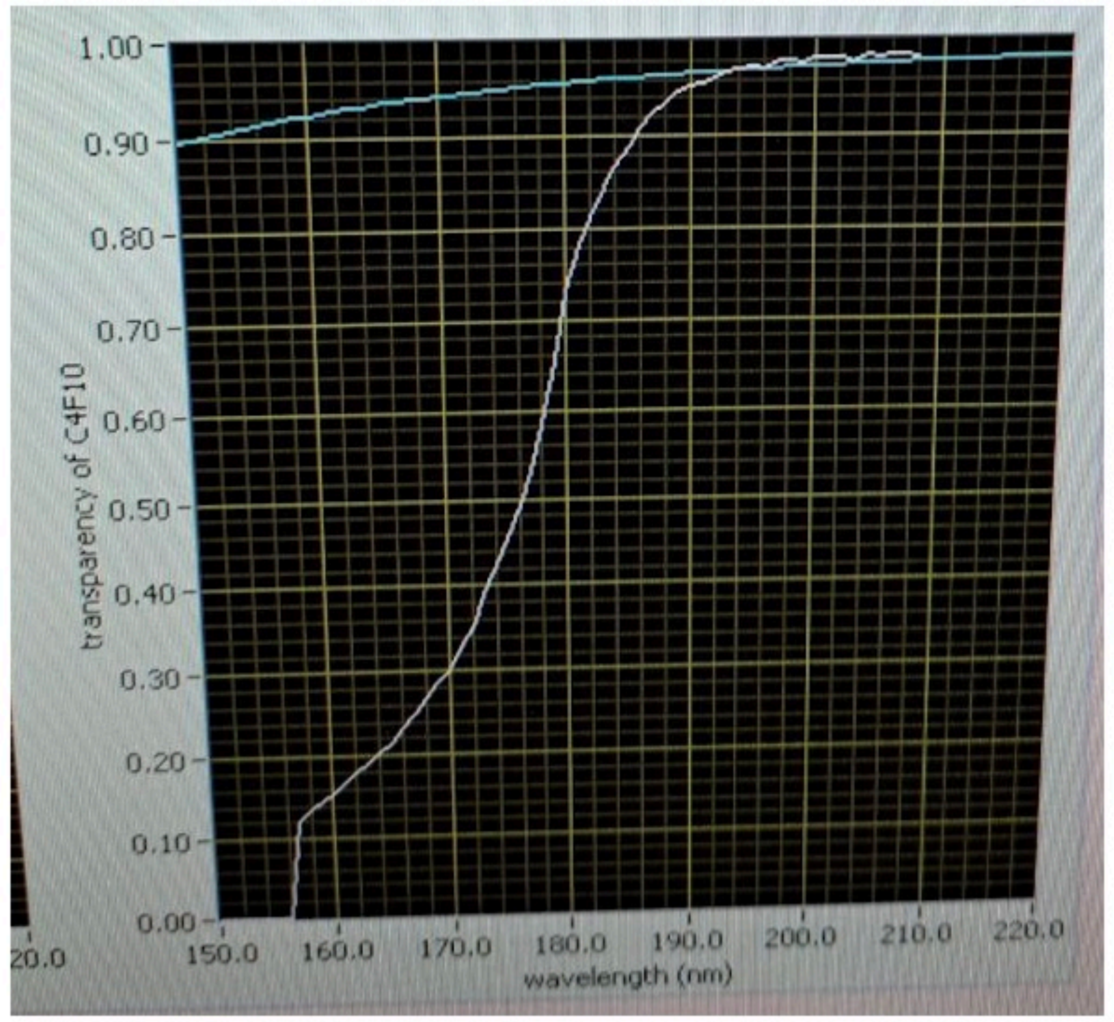
density: 16.08 kg/m³ at -78 °C

Gas	Npe(π/K)	θ_π	θ_K	σ_π	σ_K	N_σ	ρ = Δθ/θ (λ = 300 nm)
C_2F_6	16.0/14.9	36.8	35.7	0.32	0.33	3.5	1.8 %
C_4F_{10}	24.8/23.8	48.6	47.8	0.29	0.30	2.8	2.4 %



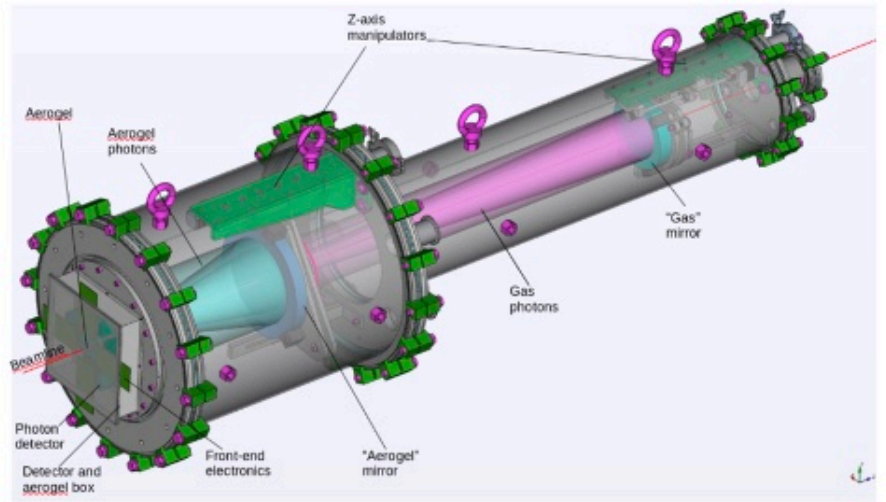
Deuterium UV lamp, Monochromator system, 1.6 m column for gas transparency measurement





Measured 139.7 m/s speed of sound confirms negligible contaminants after few year in bottle

Expected performance obtained with dRICH prototype



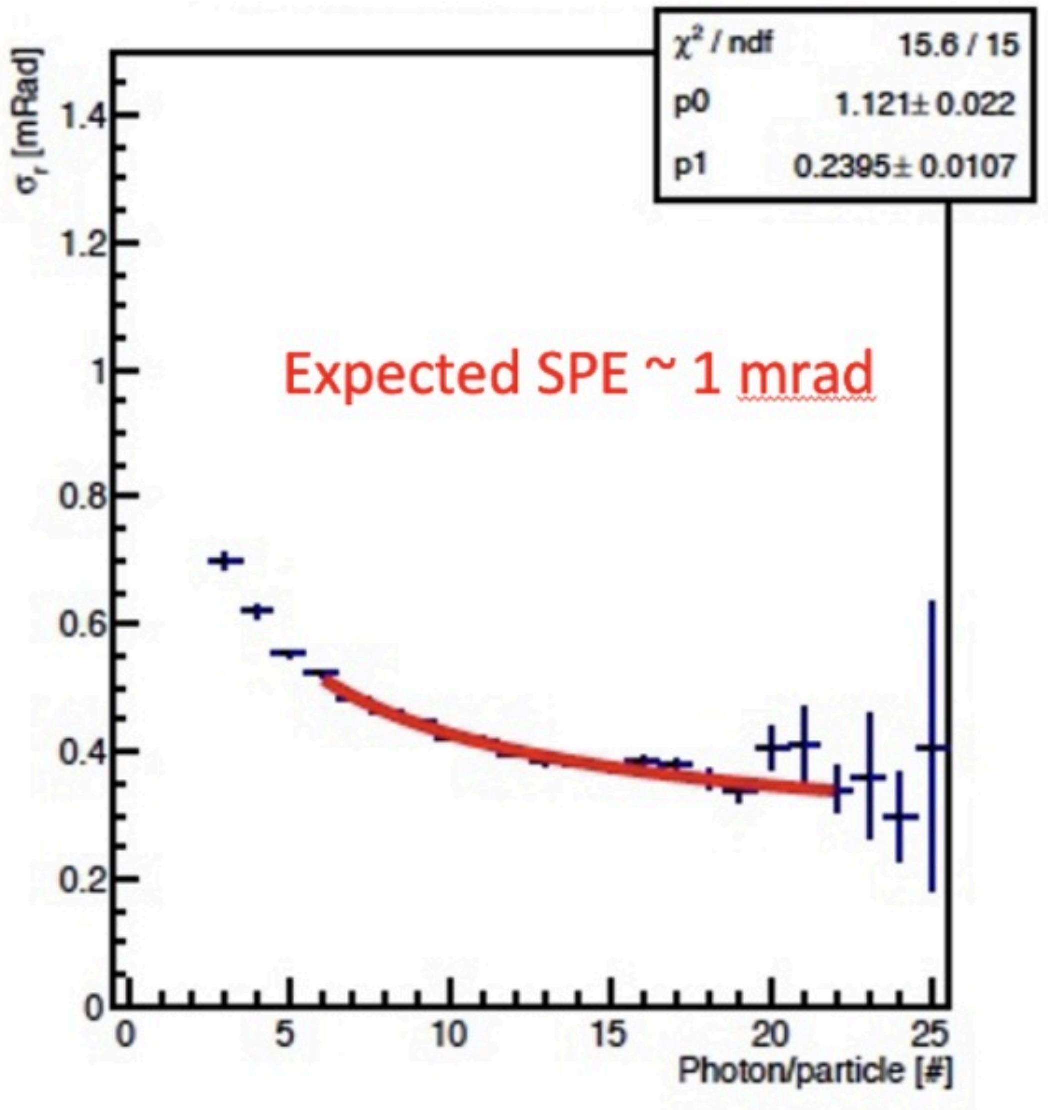
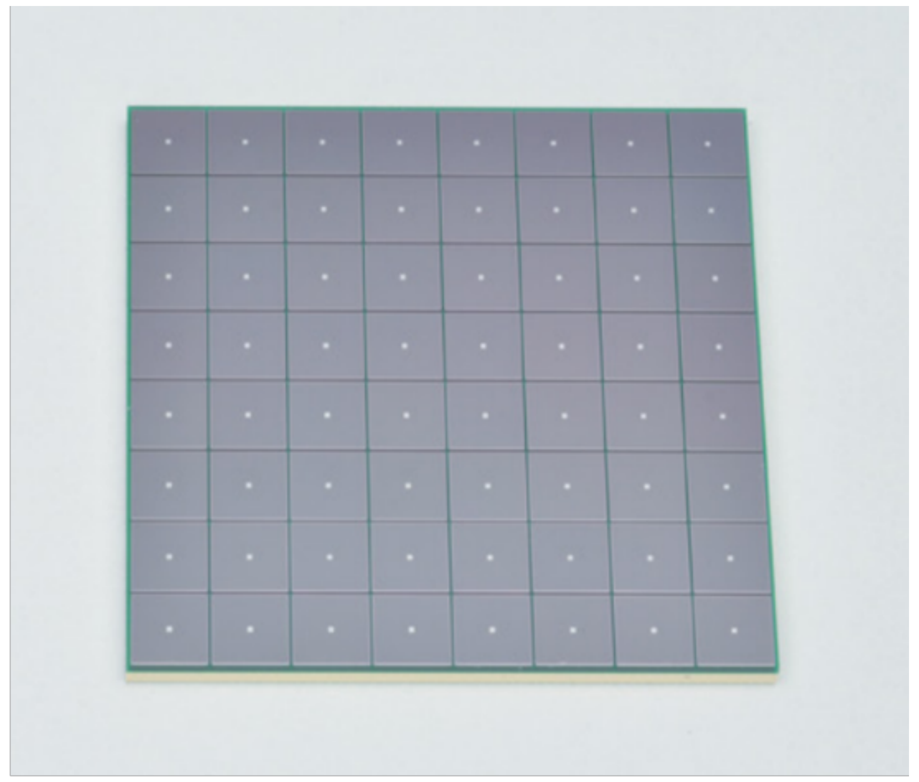


Photo-Sensors

- **SiPM sensors**
  - ~ 3 m^2 total surface
  - 3x3 mm^2 pixel
- **baseline device**
  - 64 (8x8) channel SiPM array



- Pros:
  - single-photon detection
  - high efficiency
  - excellent time resolution
  - insensitive to magnetic field
- Cons
  - large dark count rates
  - not radiation tolerant

technical solutions and mitigation strategies

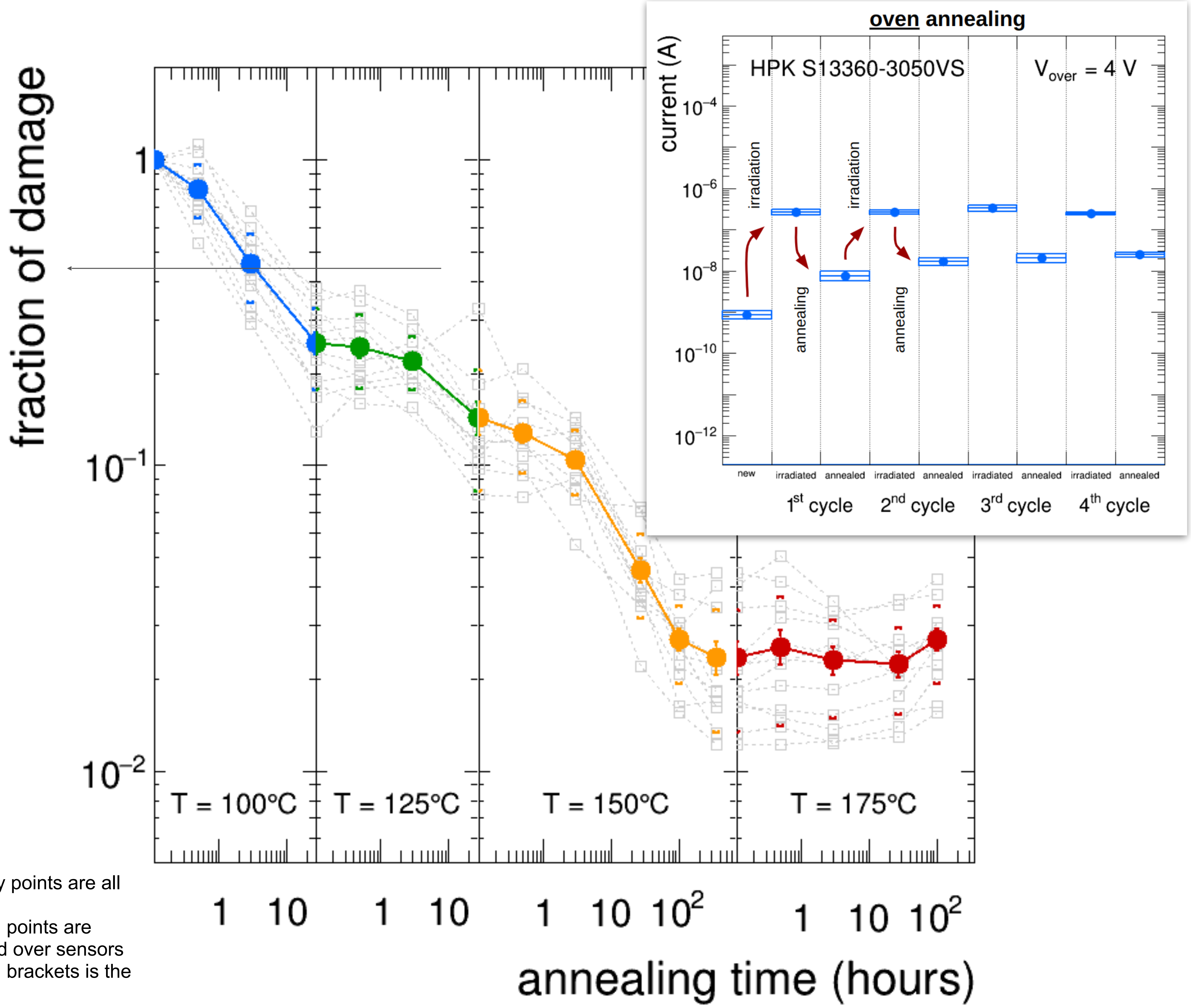
cooling
timing
annealing

Parameter	Value	Notes
Package type	SiPM array	
Package dimension	$< 26 \times 26$ cm^2	
Mounting technology	surface mount	
Number of channels	64	
Matrix layout	8×8	
Channel size	3×3 mm^2	
Fraction of active area in package	$> 85\%$	
Microcell pitch	50 - 75 μm	
Protective window material	silicone resin	radiation & heat resistant
Protective window refractive index	1.55 - 1.57	
Spectral response range	300 to 900 nm	
Peak sensitivity wavelength (λ_{peak})	400 - 450 nm	
Photon detection efficiency at λ_{peak}	$> 40\%$	
Breakdown voltage (V_{break})	< 60 V	
Operating overvoltage (V_{over})	< 5 V	
Operative voltage (V_{op})	< 64 V	
Max V_{op} variation between channels	< 100 mV	at T = -30°C
Channel dark count rate (DCR)	< 50 kHz	
DCR at T = -30°C	< 5 kHz	at T = -30°C
DCR increase with radiation damage	< 500 kHz/10^9 n_{eq}	at T = -30°C
Residual DCR after annealing	< 50 kHz/10^9 n_{eq}	at T = -30°C
Terminal capacitance	< 500 pF	
Gain	> 1.5 10^6	
Recharge time constant (τ)	< 100 ns	
Crosstalk (CT)	$< 5\%$	
Afterpulsing (AP)	$< 5\%$	
Operating temperature range	-40 to 25°C	
Single photon time resolution (SPTR)	< 200 ps FWHM	

Table 8.5: Baseline specifications of the SiPM sensor devices for the dRICH photodetector. All parameters are defined at room temperature (T = 25°C) and at the operating voltage V_{op}, unless otherwise specified.

Photo-Sensors: Annealing Studies

online self-annealing with forward bias



light gray points are all sensors
coloured points are averaged over sensors
coloured brackets is the RMS

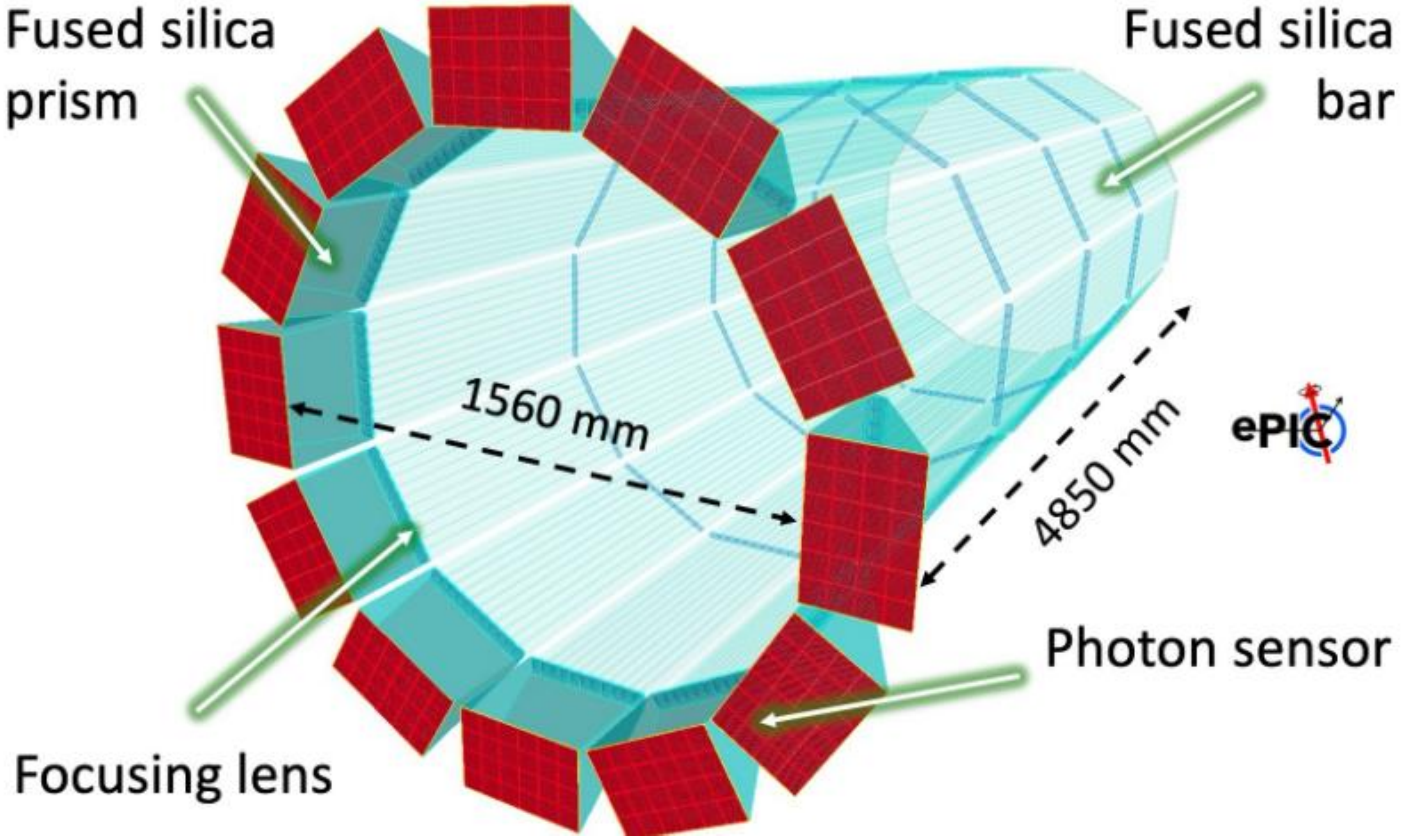
test on a large number SiPM sensors how much damage is cured as a function of temperature and time

the same sensors have undergone self-annealing
increasing temperature steps
increasing integrated time steps

- started with T = 100 C annealing
  - performed 4 steps up to 30 hours integrated
- followed by T = 125, 150 and 175 C

residual damage saturates at 2-3%
reached same level of "oven" annealing
higher T = 175 C does not reduce further

hpDIRC Design



Radiator bars:

- Barrel radius: 780 mm, 12 sectors
- 10 long bars per sector, 4500 mm x 35 mm x 17 mm (L x W x T)
- Long bar: 4 bars, glued end-to-end,
- Short bars made from highly polished synthetic fused silica
- Flat mirror on far end

Focusing optics:

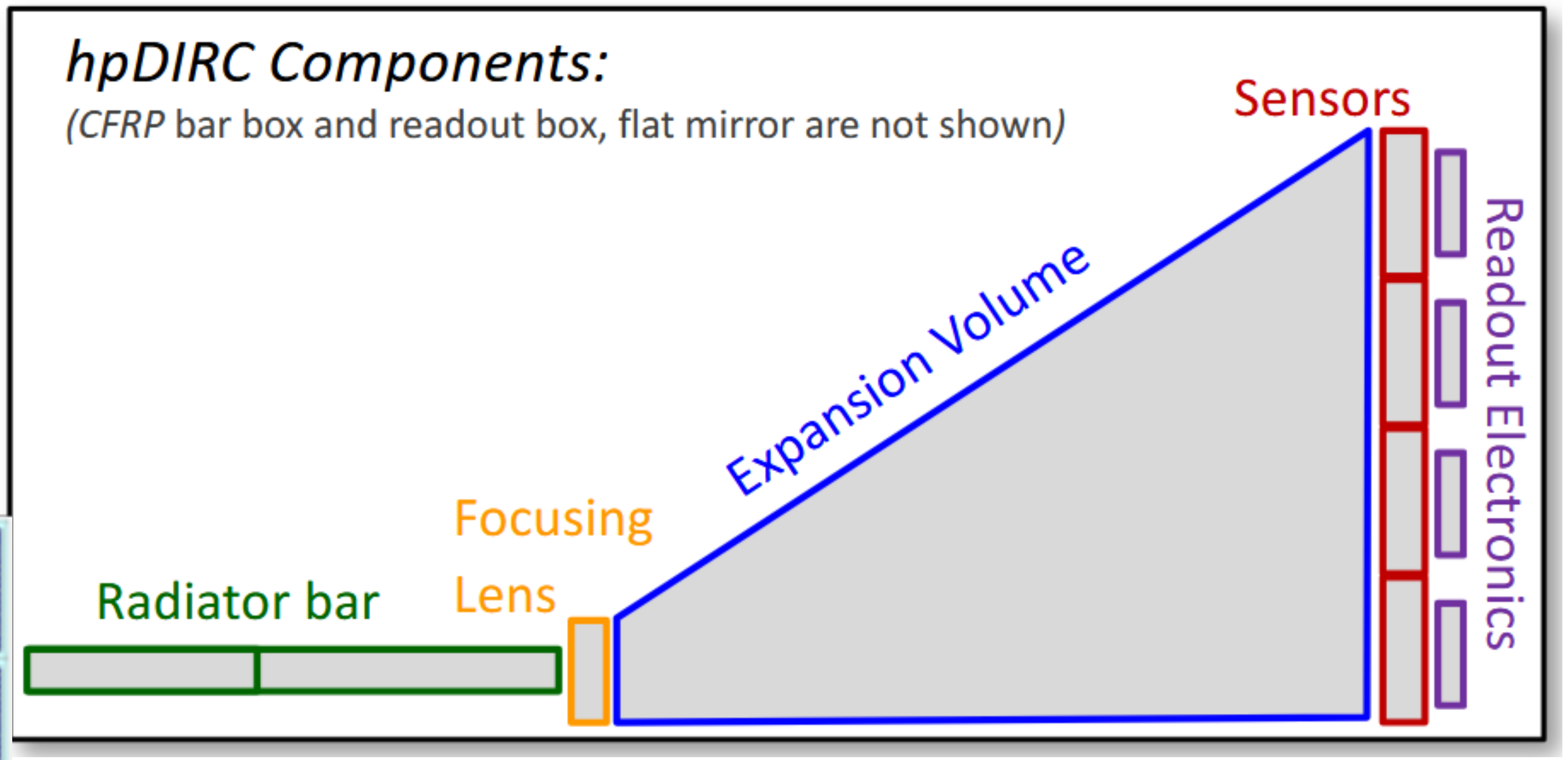
- Radiation-hard 3-layer spherical lens (sapphire)

Expansion volume:

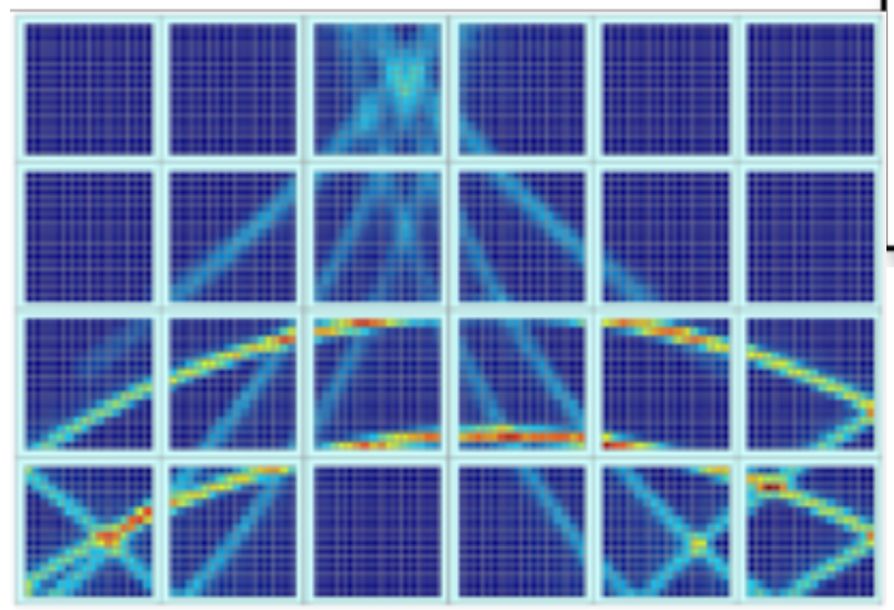
- Solid fused silica prism: 25 x 35 x 30 cm^3 (H x W x L)

Readout system:

- MCP-PMT Sensors (Photek/Incom)
- ASIC-based Electronics (FCFD)

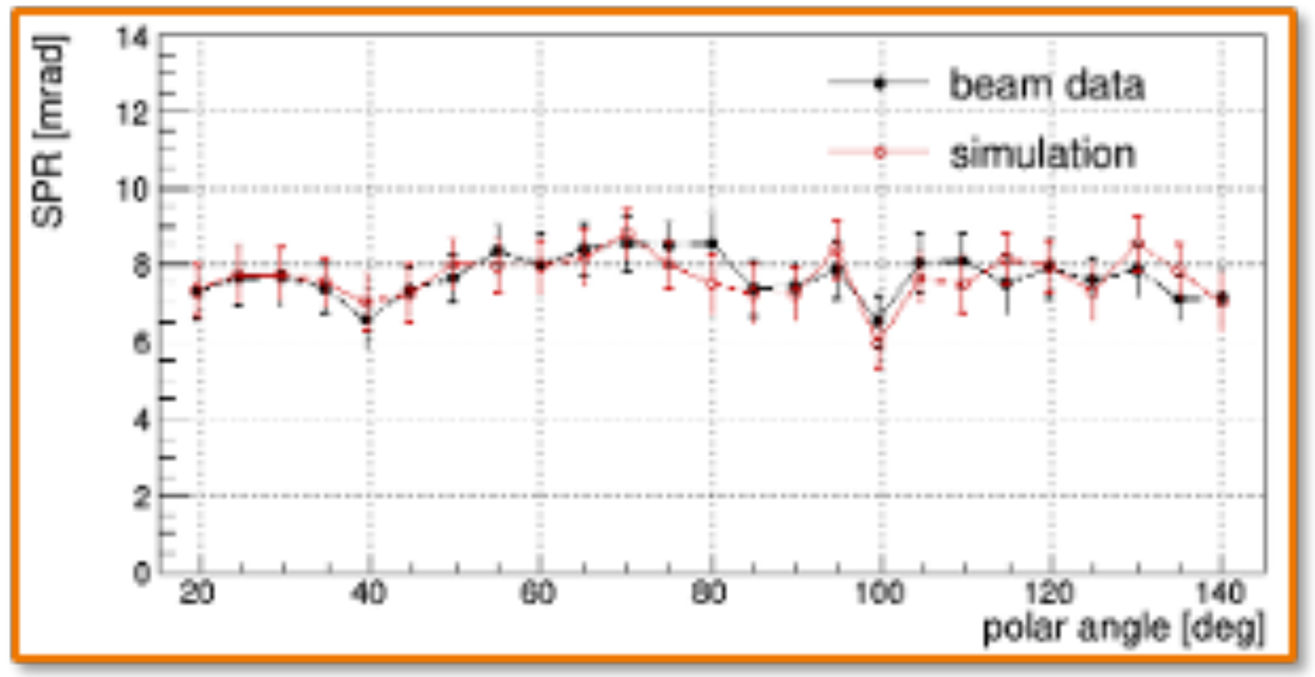


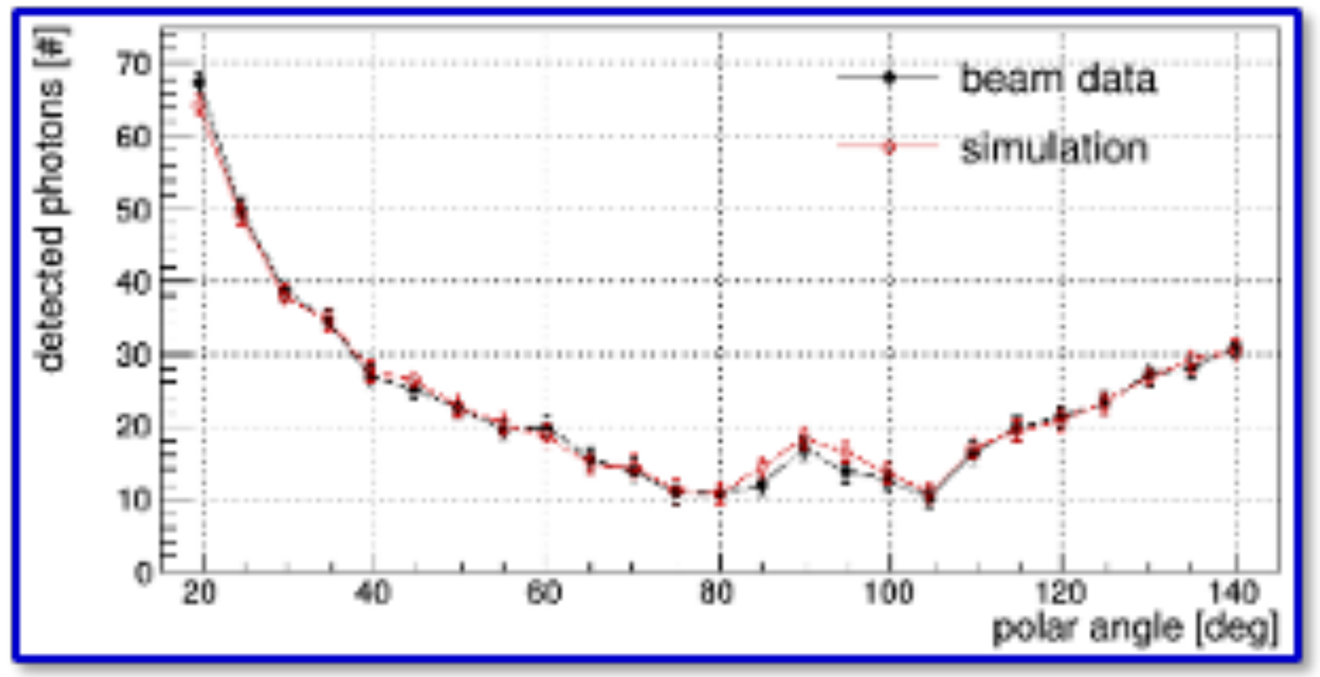
Accumulated ePIC hpDIRC hit pattern (Geant4)



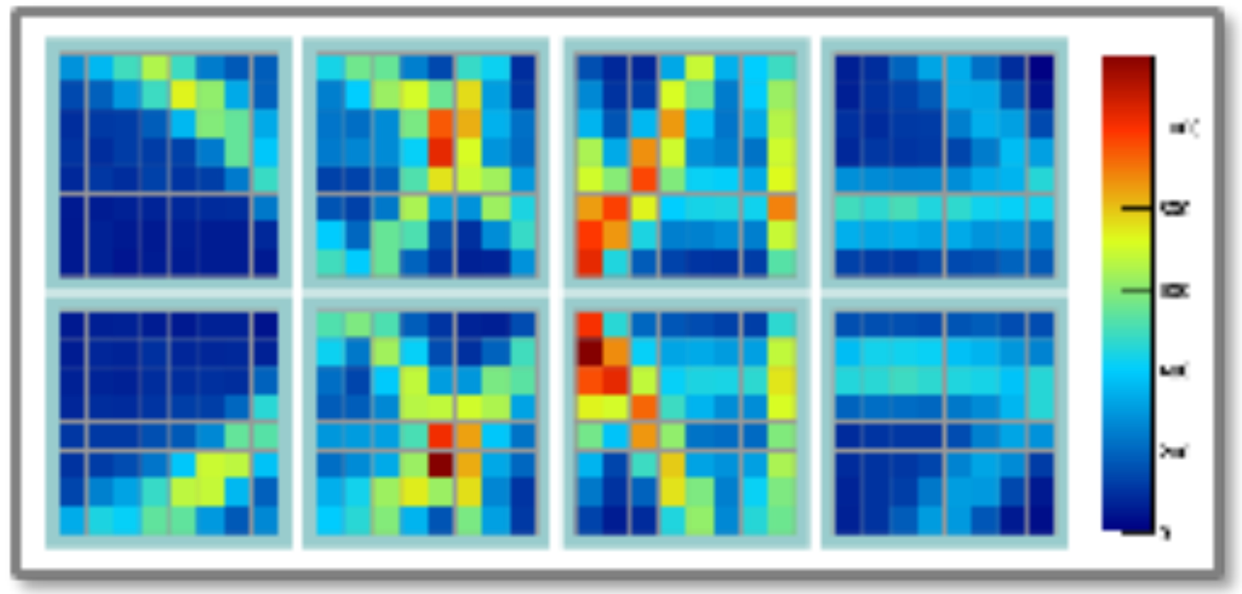
Validation of Simulation and Components

Performance validation: 2018 prototype at CERN PS

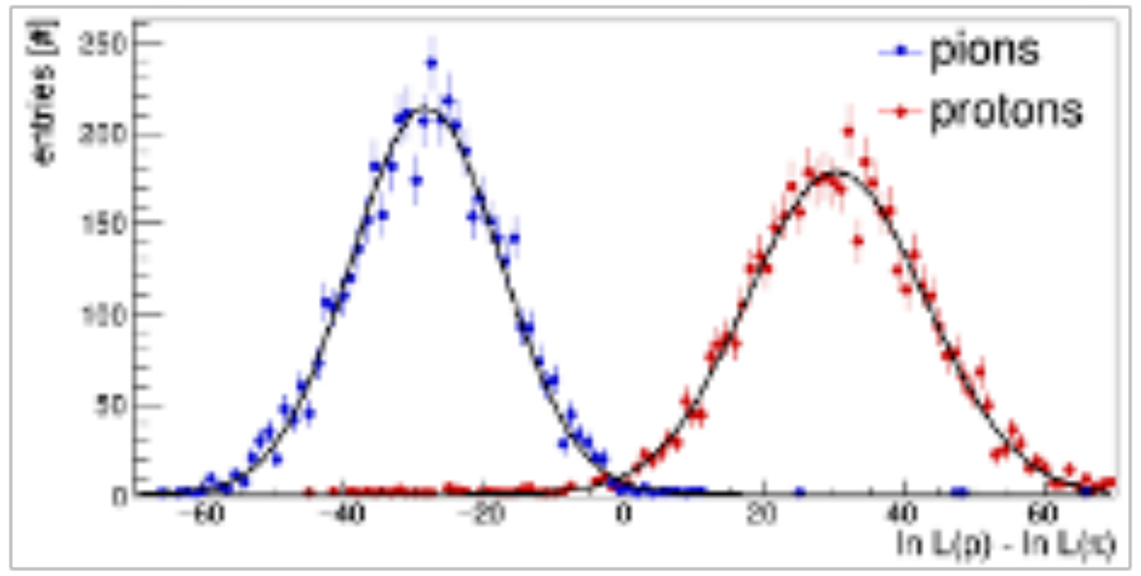


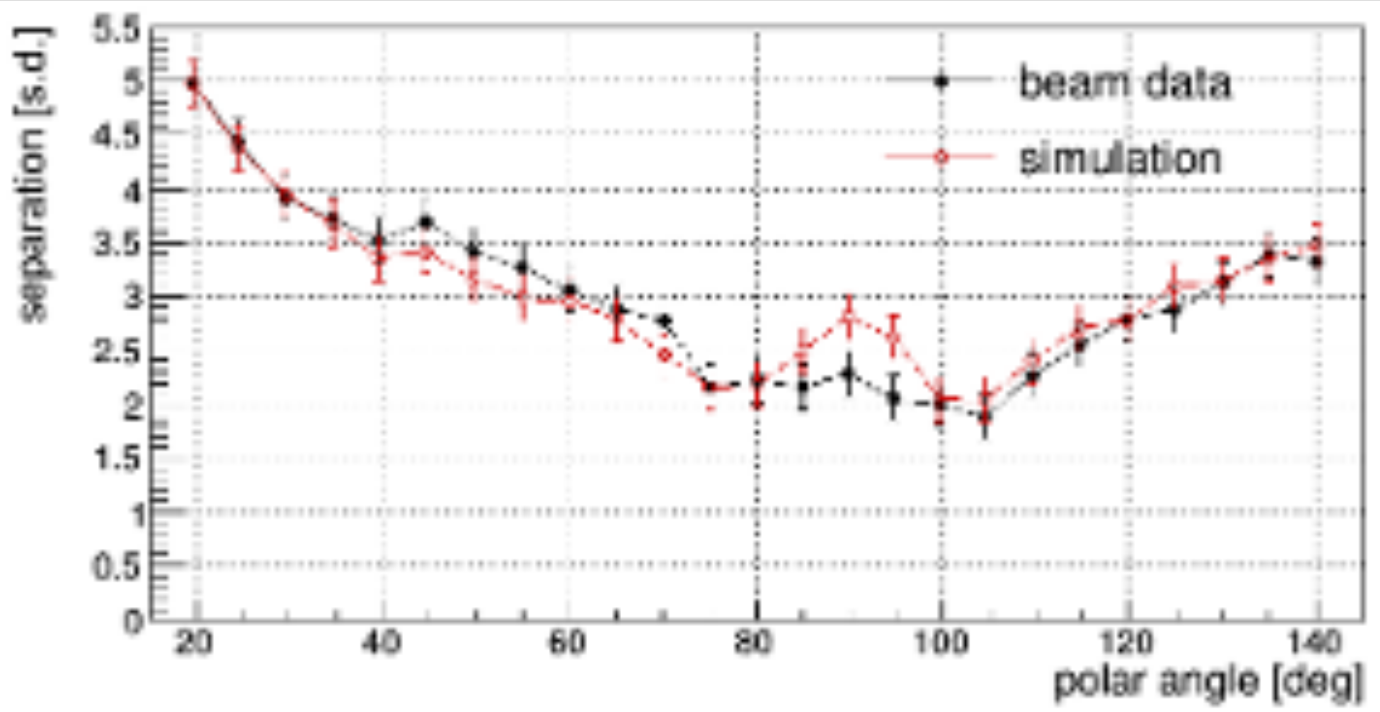


observed hit pattern at polar angle 20°



π/p separation power @ 7 GeV/c





- Measured Cherenkov angle resolution per photon (SPR), photon yield, and π/K separation in excellent agreement with expectation and Geant4 simulation
- Achieved π/K separation power of N_{sep}=5.2 s.d. with time imaging reconstruction for PANDA configuration, will improve with smaller pixels, better PDE and timing
- Same simulation/reconstruction code used for EIC high-performance DIRC
  -> Confidence in Geant prediction for hpDIRC performance

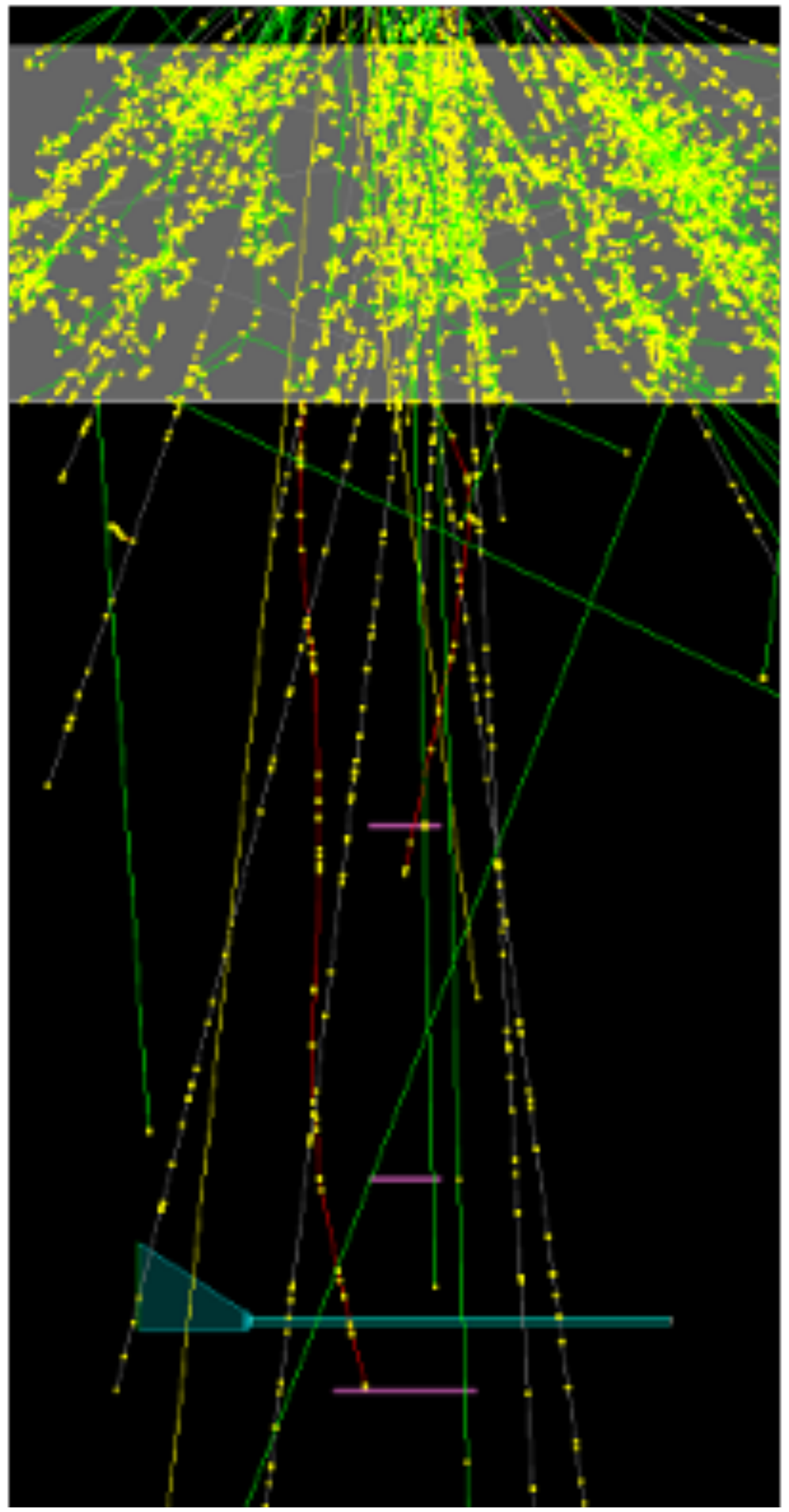
Validation of Simulation and Components

Cosmic Ray Telescope (CRT) at SBU

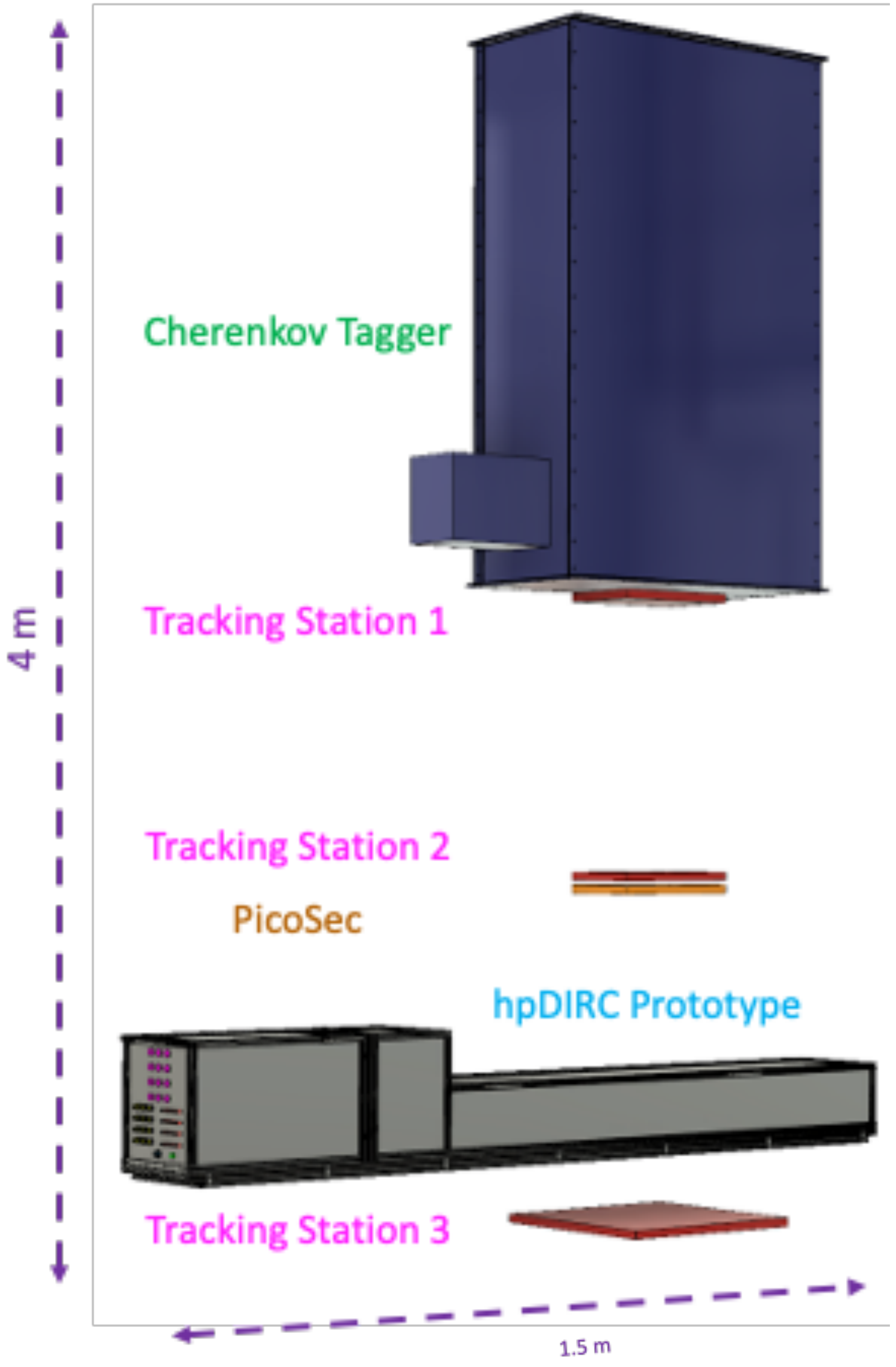
Facility to test incremental upgrades of prototype components, performance evaluation

- Initial PANDA Barrel DIRC-based prototype to commission setup
- Modular design will allow to add new ePIC hpDIRC components once they become available
- Cherenkov Tagger to select muons above 3.5 GeV/c
- Three tracking stations for high-precision 3D-track reconstruction (location optimized with simulations)
- PicoSec detector for event timing (Jlab group committed prototype and personnel to project)
- Geant4 simulation used to optimise setup arrangement

Geant4 simulation of CRT setup



CRT setup CAD schematic

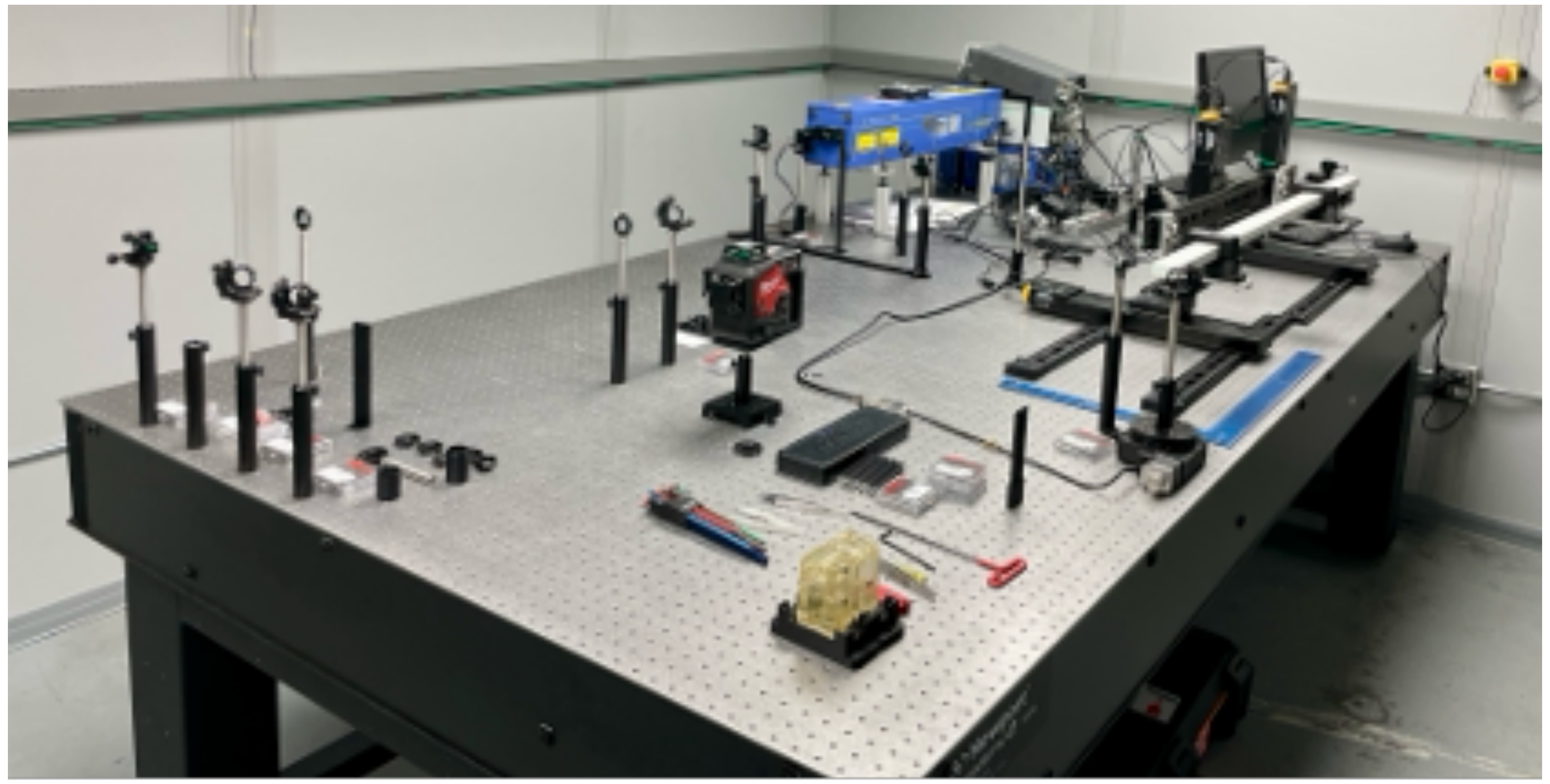


BaBar DIRC Bars Evaluation at JLab is ongoing

Successful transport of 8 DIRC bar boxes in April 2024

- Low altitude road from SLAC, CA to JLab, VA
- Goal: Kept shocks on Bar box below 1g

(Transportation crates with inner suspension, shock-absorbing foam, hydraulic shocks, air shocks, shock-absorbing donuts, air-ride and temperature control trucks)



- Laser setup built at JLab based on similar setup at GSI for PANDA Barrel DIRC
- Reflection coefficient measurement allows to evaluate surface quality of the bars with sub nm precision
- HeCd laser with two wavelengths is used (325 nm, 442 nm)

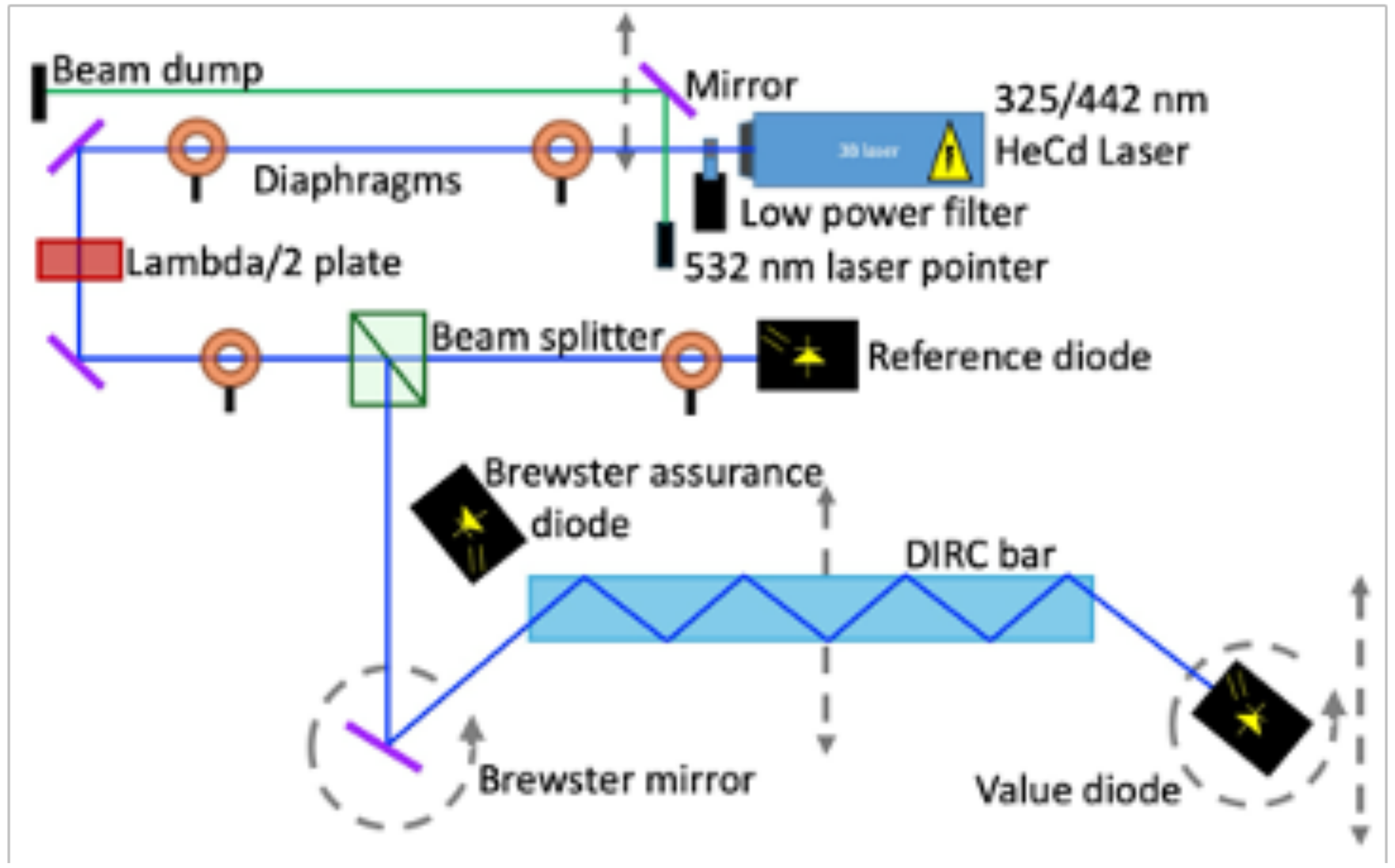


Photo-Sensors

hpDIRC readout: Microchannel-Plate PMTs + ASIC-based electronics

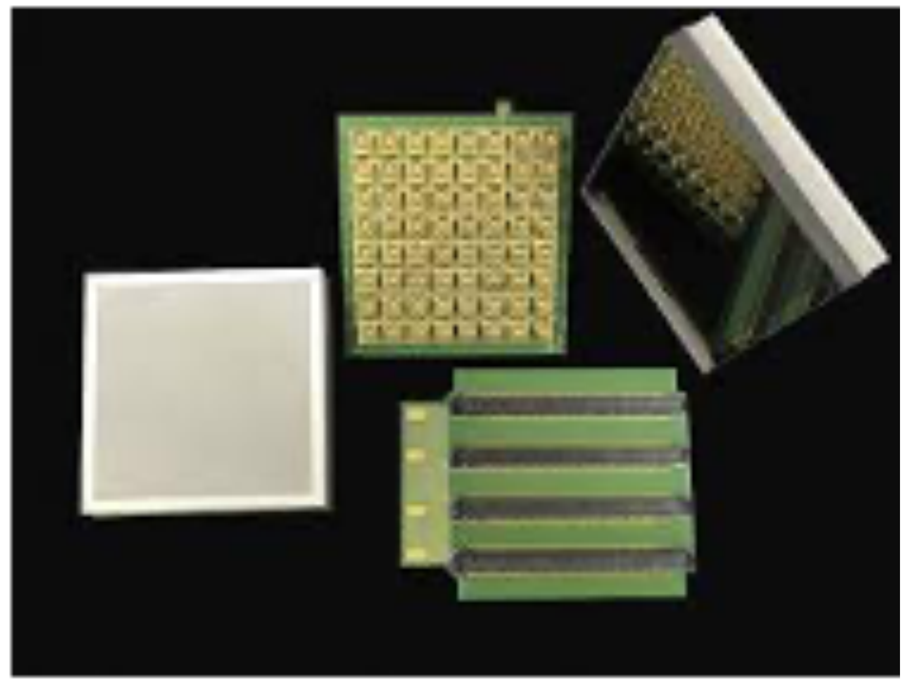
- MCP-PMTs capable of meeting all hpDIRC requirements (A. Lehmann review talk at RICH2022)
- Baseline sensor for hpDIRC: 2" Photek MAPMT 253 MCP-PMTs
- Potential solution: DC-coupled Incom HRPPD

  Making use of synergy with pfRICH, optimizing cost and workforce

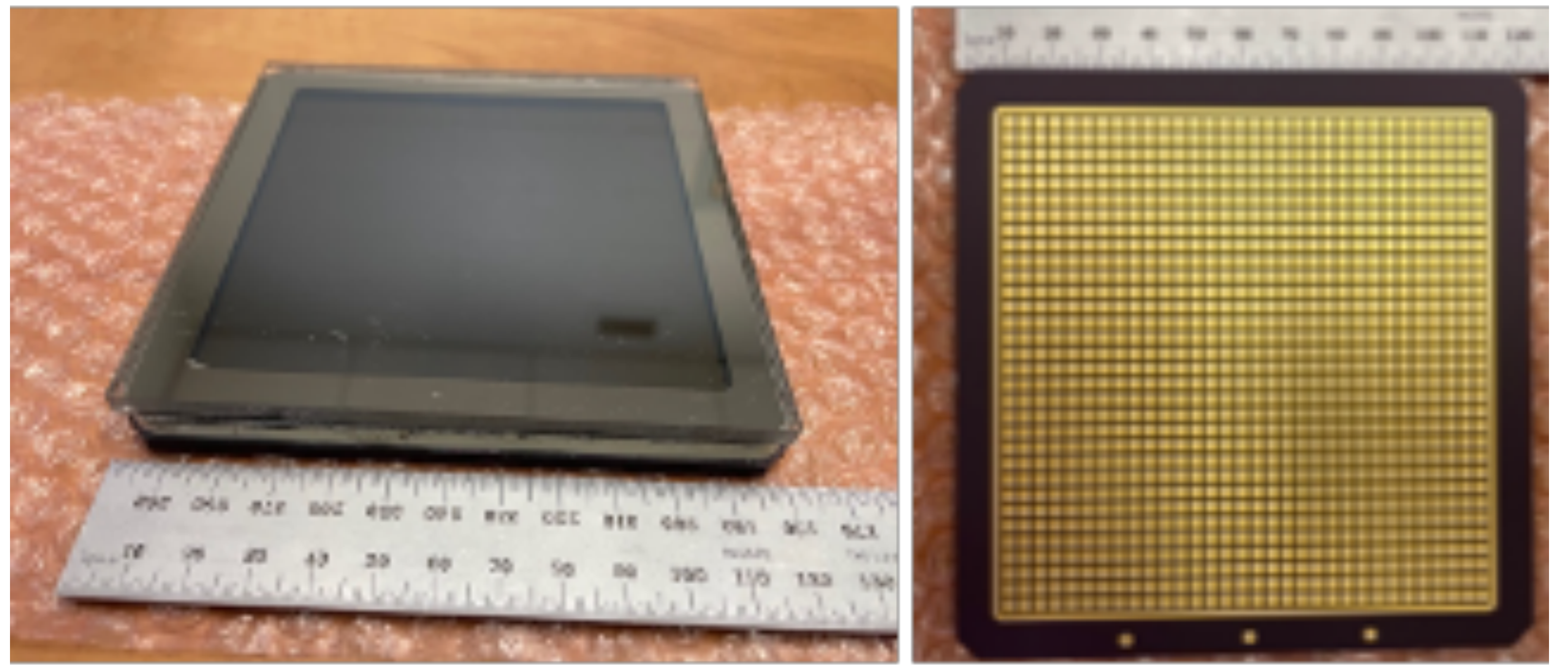
Baseline front-end board: FCFD

- Synergetic development with ePIC AC-LGAD and pfRICH systems
- Low-power ASIC, 128 channels per board
- Will deliver hit time, time over threshold

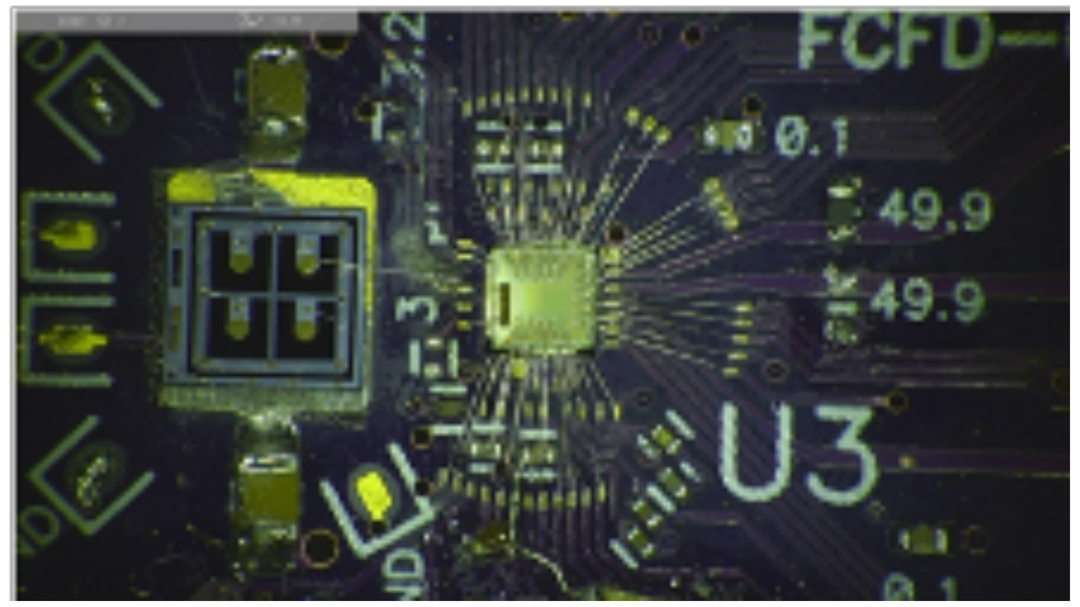
Photek MAPMT 253



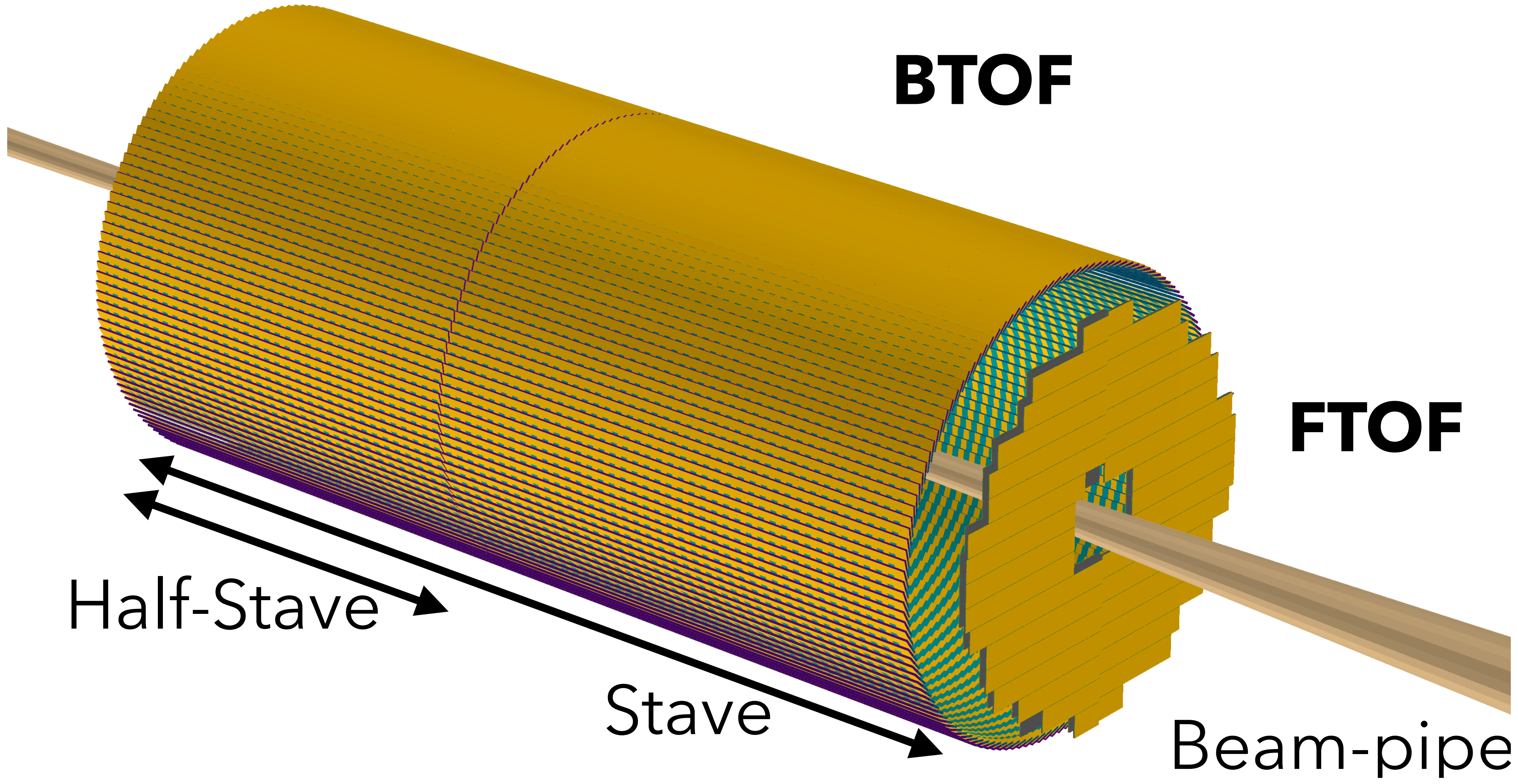
INCOM Gen III HRPPD prototype (front/back view)



FCFDv0



AC-LGAD Time of Flight overview



Two types of AC-LGAD TOF, BTOF and FTOF for the low-p PID

BTOF covers mid-rapidity (-1.33<η<1.74) composed of tilted 144 staves (288 half-staves)

- π/K separation below 1.2 GeV/c is performed
- Strip-type AC-LGAD sensor is used
- It is placed at ~64 cm from the beam-pipe

FTOF covers forward-rapidity (1.84<η<3.61), hadron going direction

- π/K separation below 2.5 GeV/c is performed
- Pixel-type AC-LGAD sensor is used

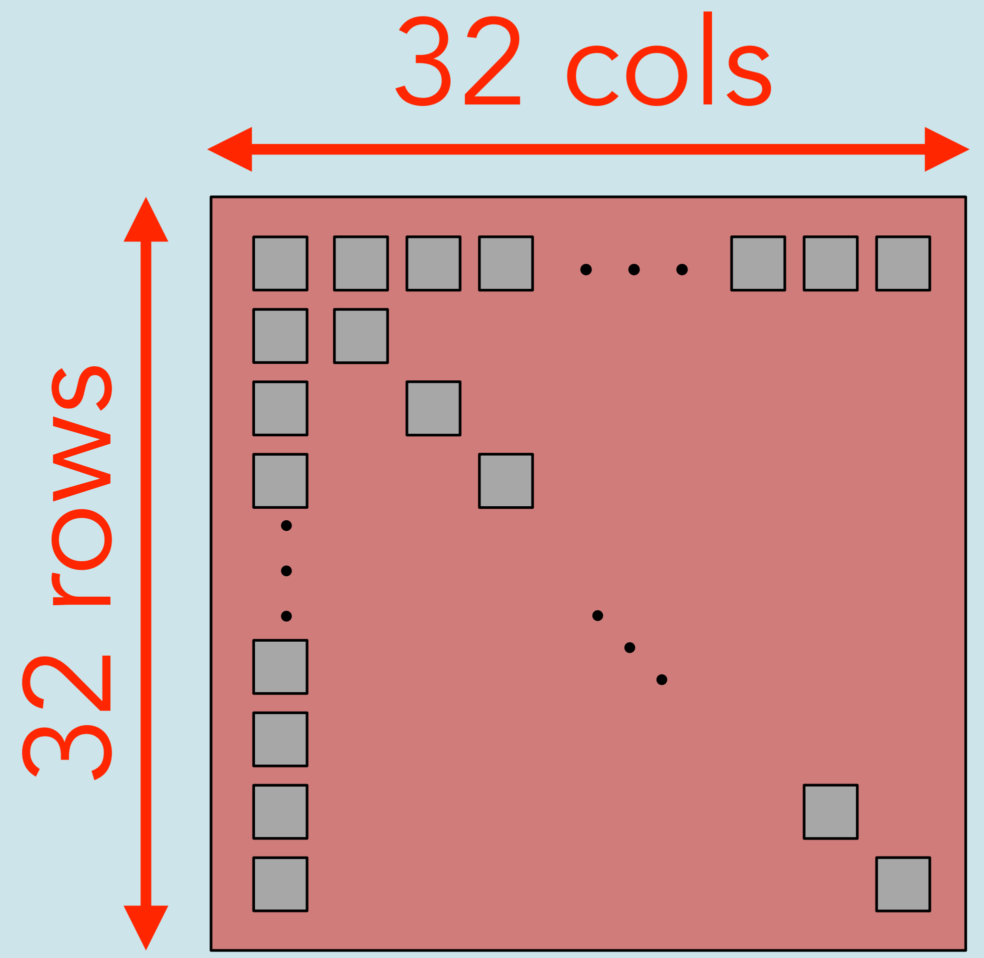
Baseline for sensor design

Pixel-type AC-LGAD sensor

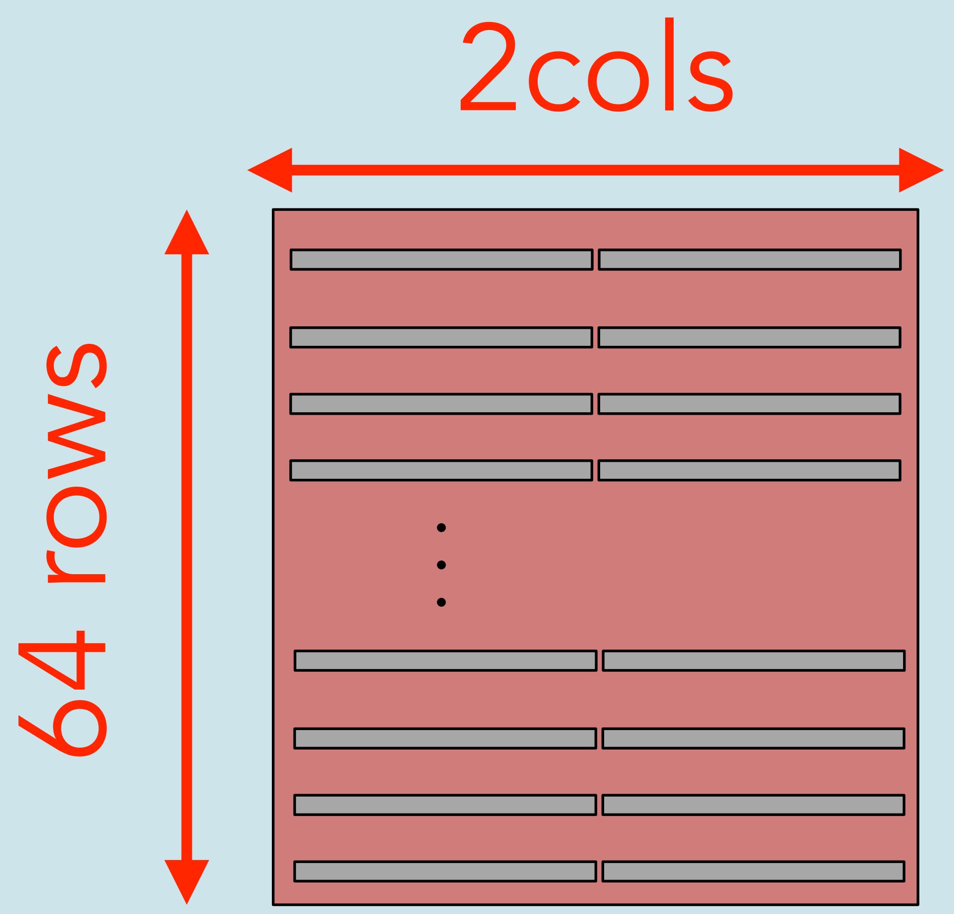
- 1.6 x 1.6 cm^2 sensor size with 0.5 x 0.5 mm^2 metals, is used in **FTOF**
- The readout metal geometry is 32 x 32 and 1024 channels in total each
- 1 ASIC (2D 32x32) is attached to the one sensor

Strip-type sensor

- **3.2 x 2 cm^2** sensor size with 0.5 x 10 mm^2 metals with 0.5 mm pitch, is used in **BTOF**
- The readout metal geometry is **64x2=128** channels in total each
- **1** ASICs are attached to each sensor with wire bonding



- FTOF pixel sensor
  - **3632 sensors**
  - **1.1 m^2**
  - **3.6 M readout channels**



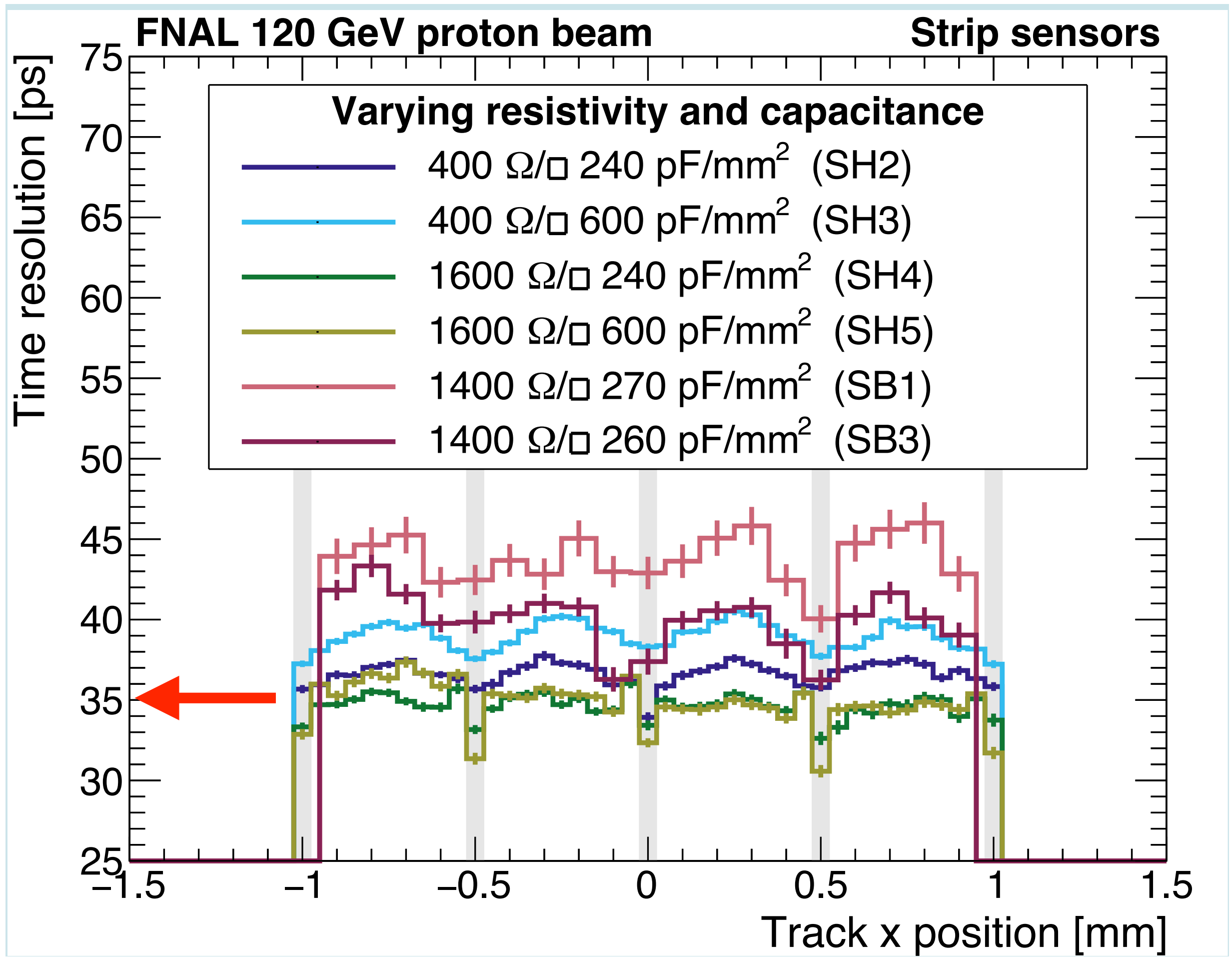
- BTOF strip sensor
  - **18432 sensors**
  - **12 m^2**
  - **2.4 M readout channels**

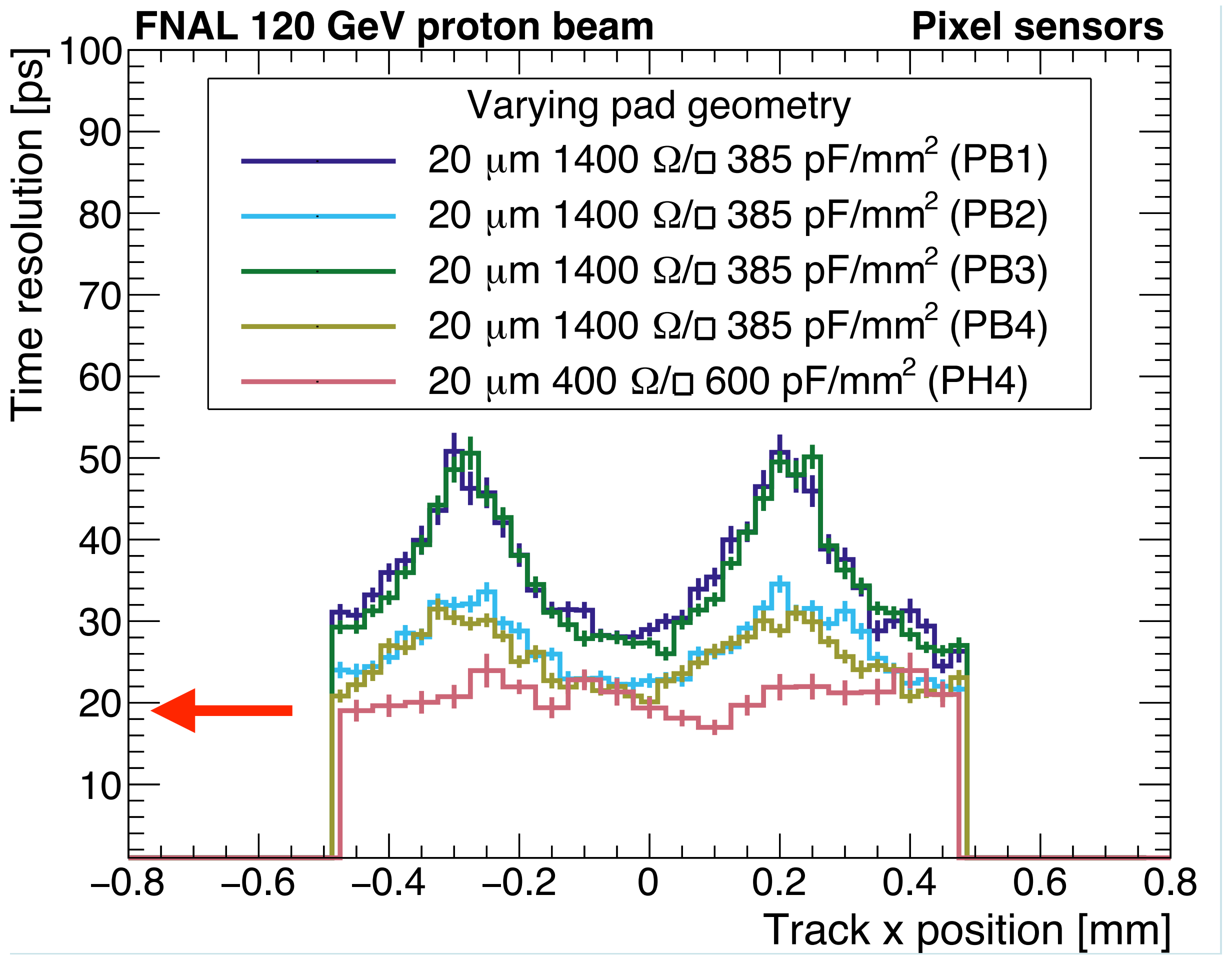
PID momentum range covered by TOF

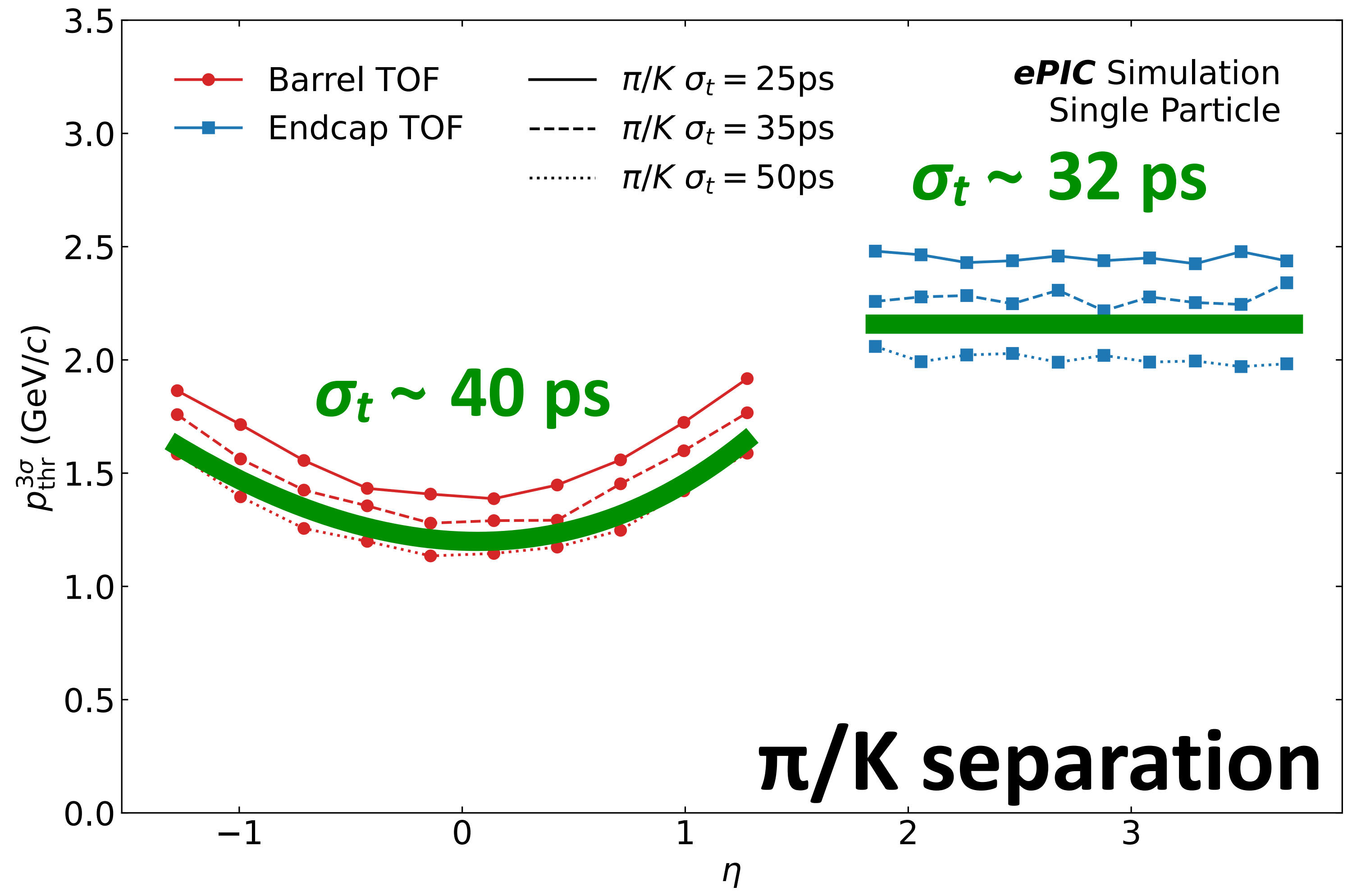
- The best timing resolution is~35 ps and ~20 ps for strip and pixel sensor, respectively

Timing resolution of "BTOF" is 43ps (Δt_{ASIC} = 20 ps, and Δt_{T0} = 15 ps are assumed)

Timing resolution of "FTOF" is 32ps (Δt_{ASIC} = 20 ps, and Δt_{T0} = 15 ps are assumed)



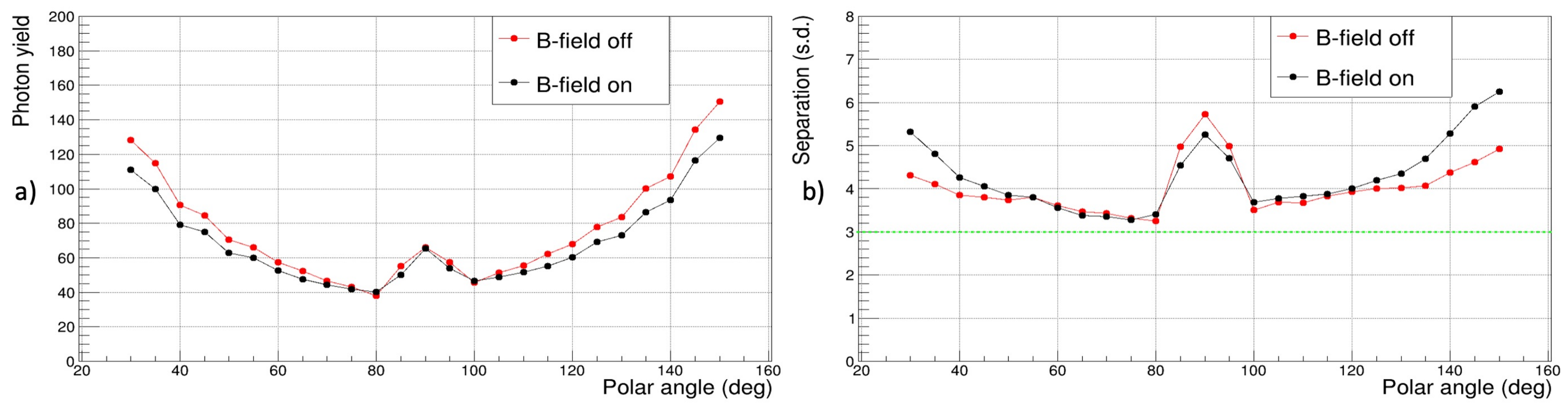


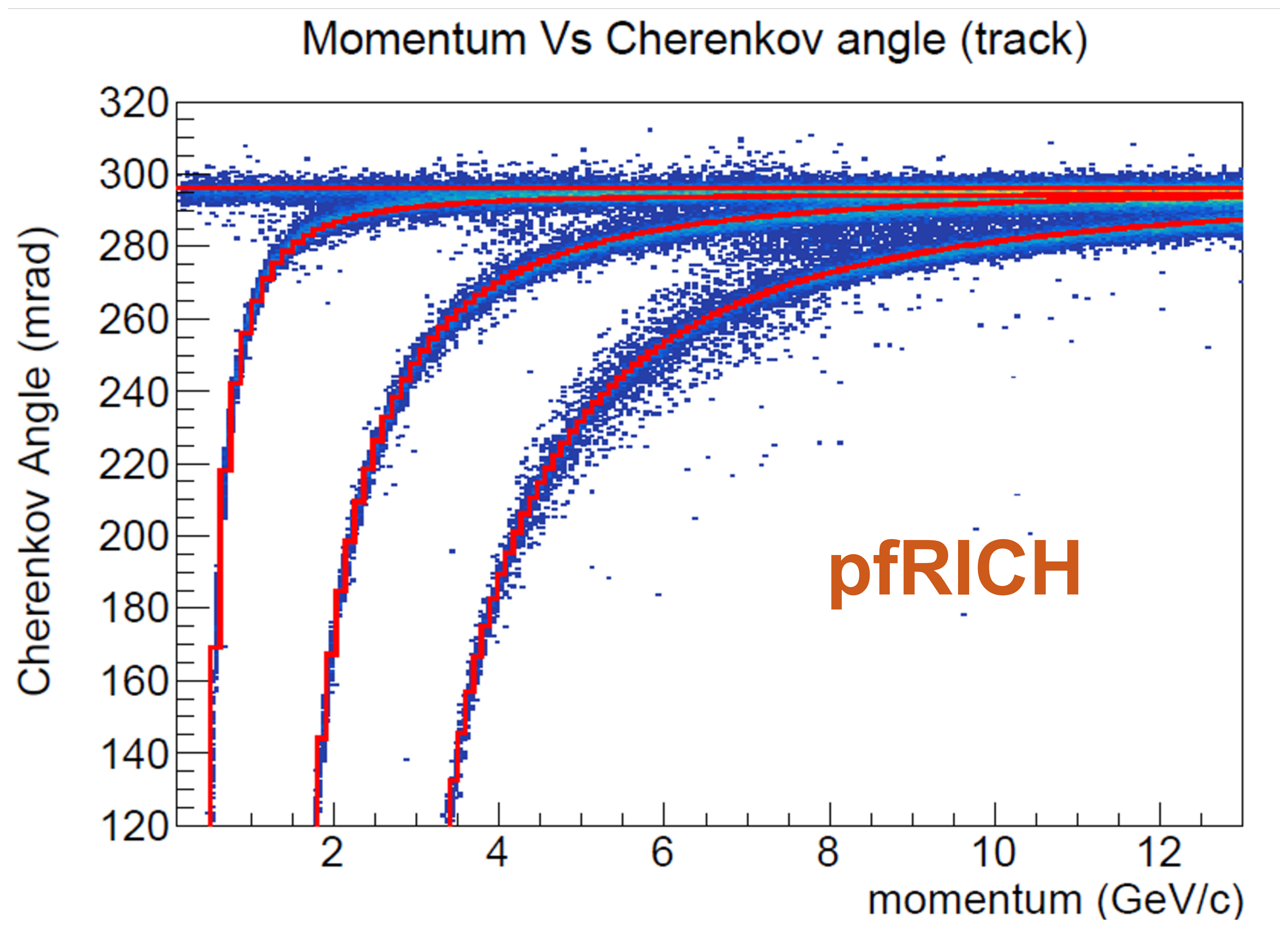


Summary

- ✦ Detailed design is setting down to achieve the requirement performance
- ✦ A lot of progress on various fronts
- ✦ Exciting time ahead to achieve these **Simulated results**!

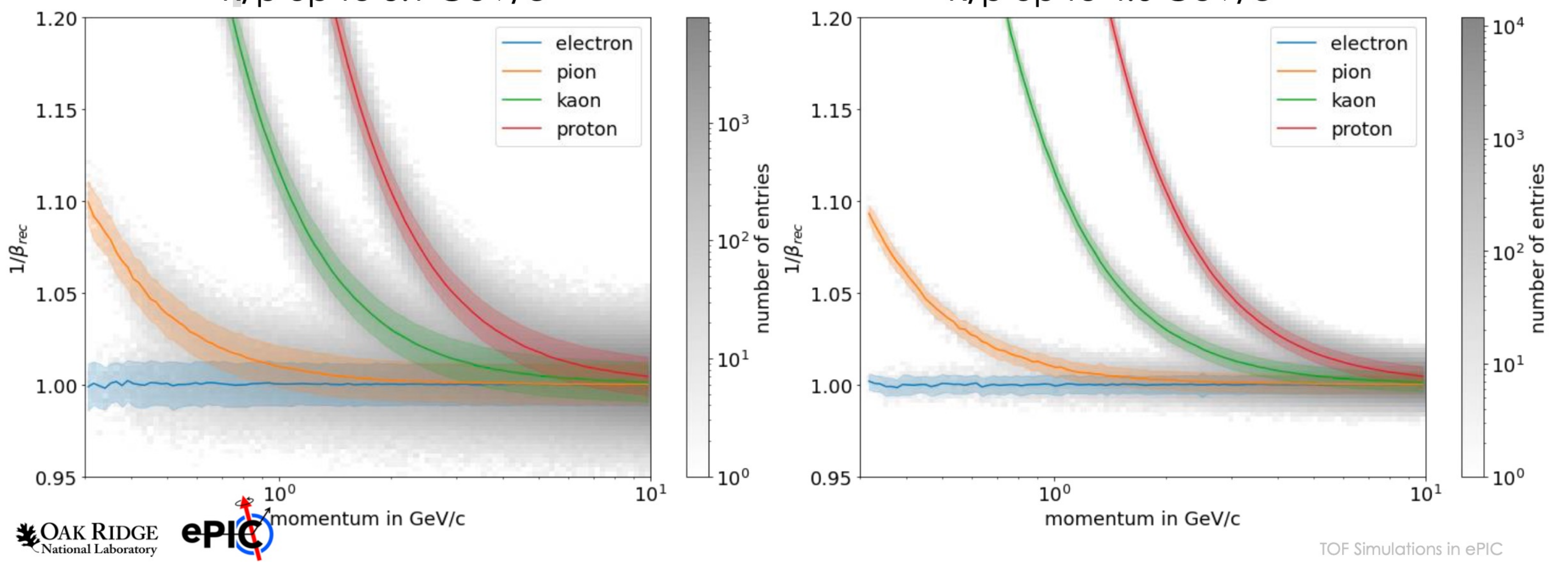
hpDIRC



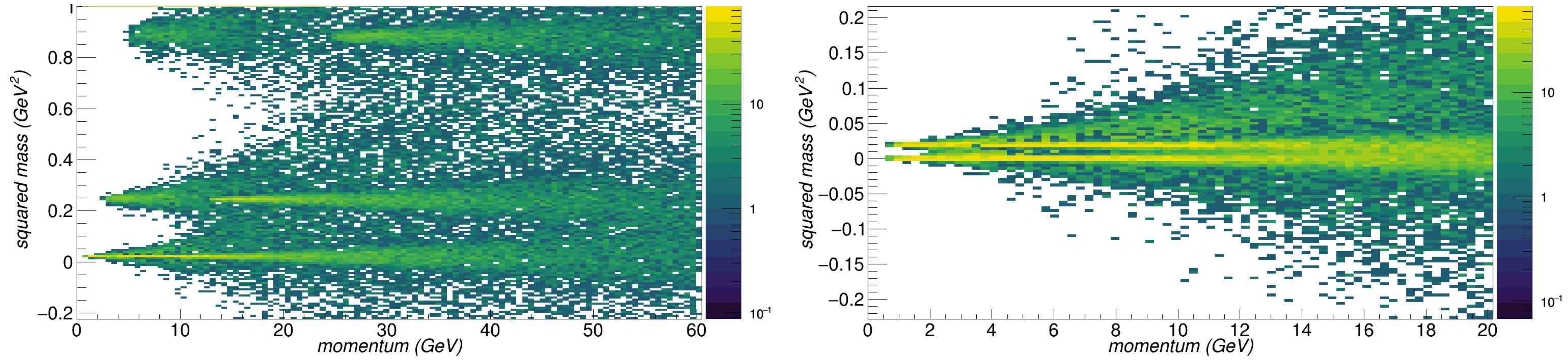


ToF

- Barrel Region
  - e/pi up to 0.5 GeV/c
  - pi/K up to 1.9 GeV/c
  - K/p up to 3.1 GeV/c
- Endcap Region
  - e/pi up to 0.8 GeV/c
  - pi/K up to 2.7 GeV/c
  - K/p up to 4.6 GeV/c



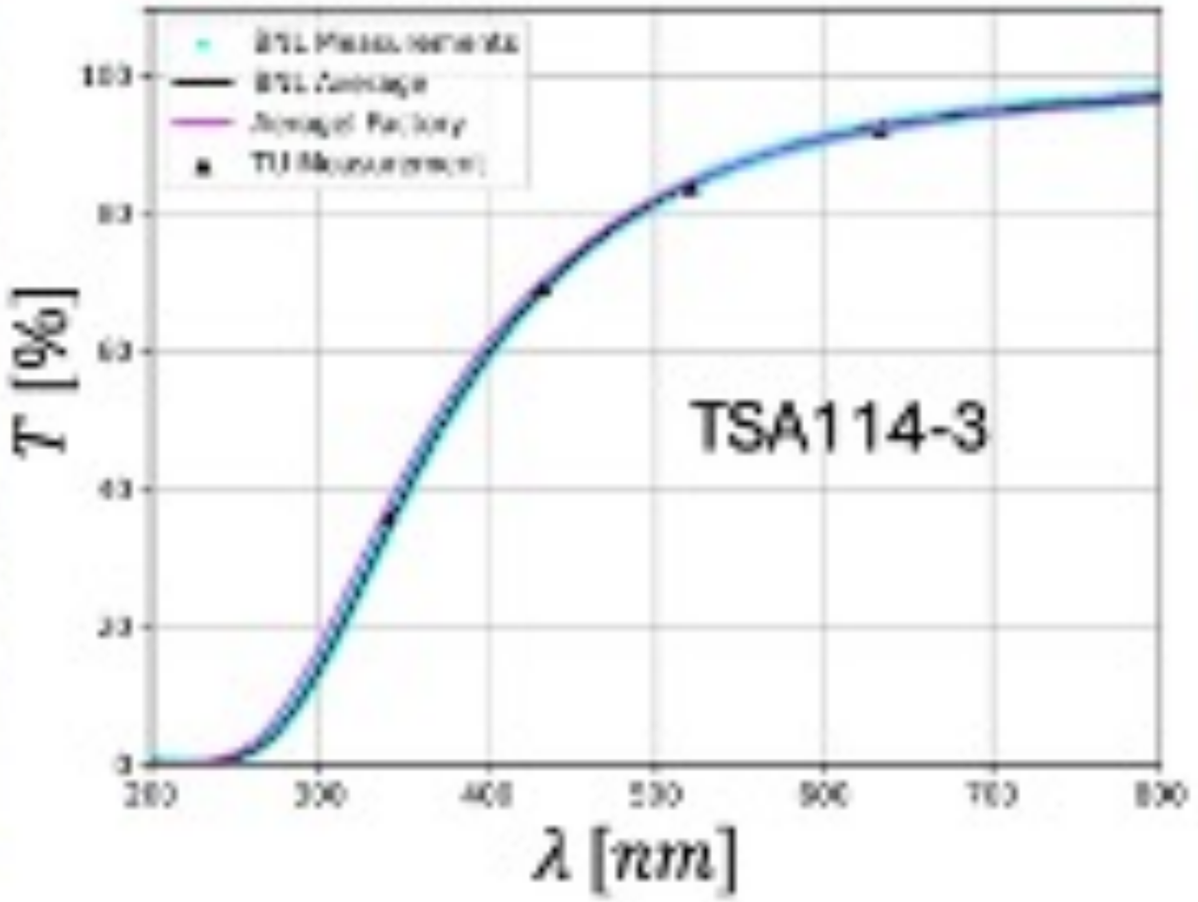
dRICH



Aerogel Evaluation

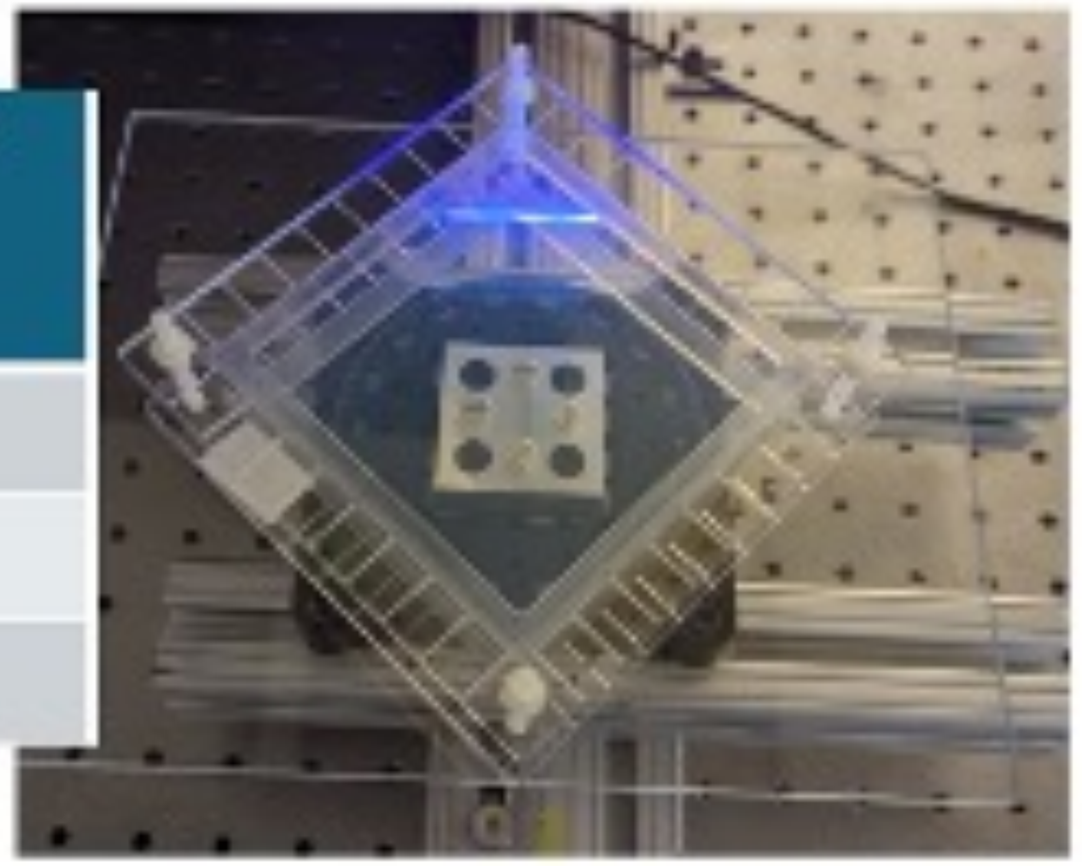
Primary station at Temple University devloped as a common facility

Transmission by LEDs + Integrating sphere – Temple U.



Refractive index by Prisma test – Temple U.

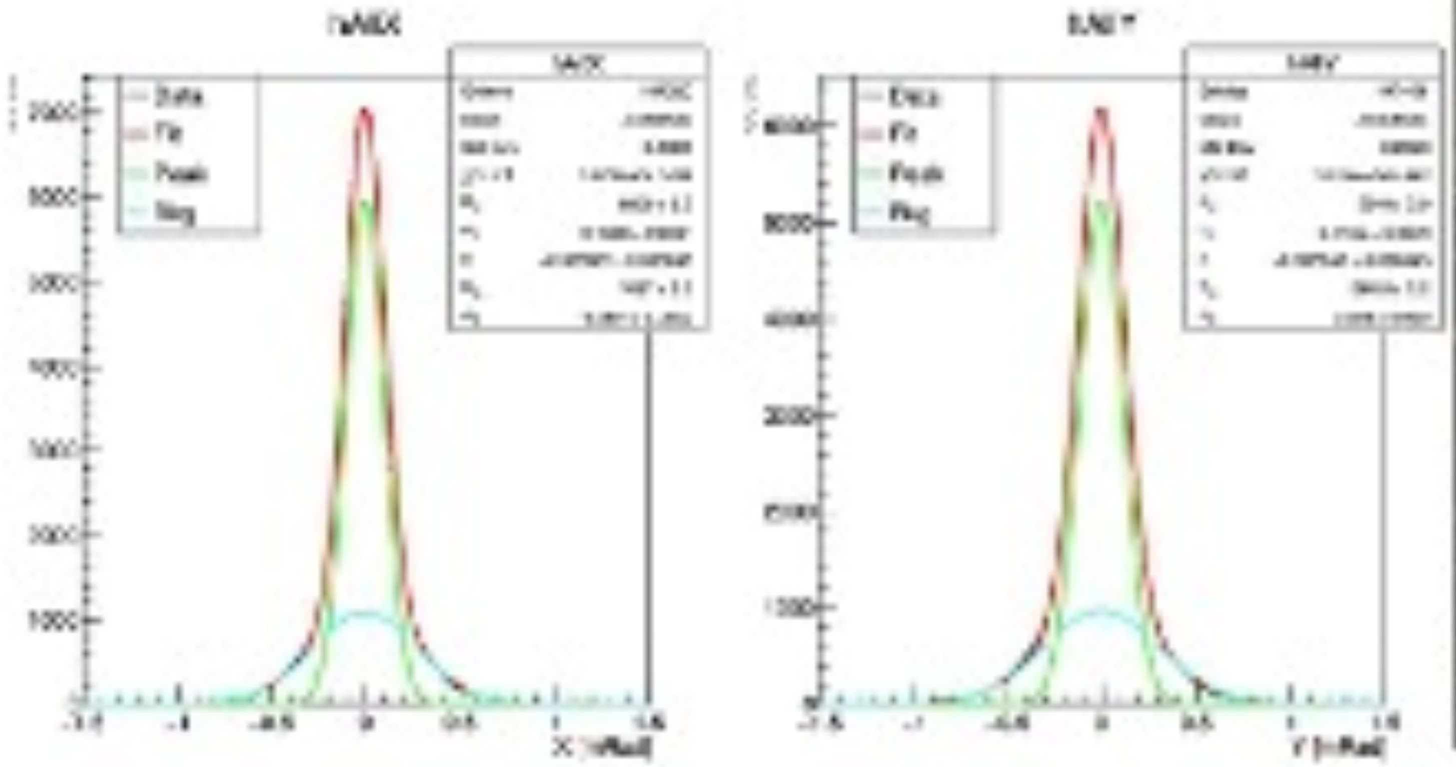
Tile	(TU-AF)/AF [%]
TSA120-1	0.087
TSA120-2	0.000
TSA114-3	0.062

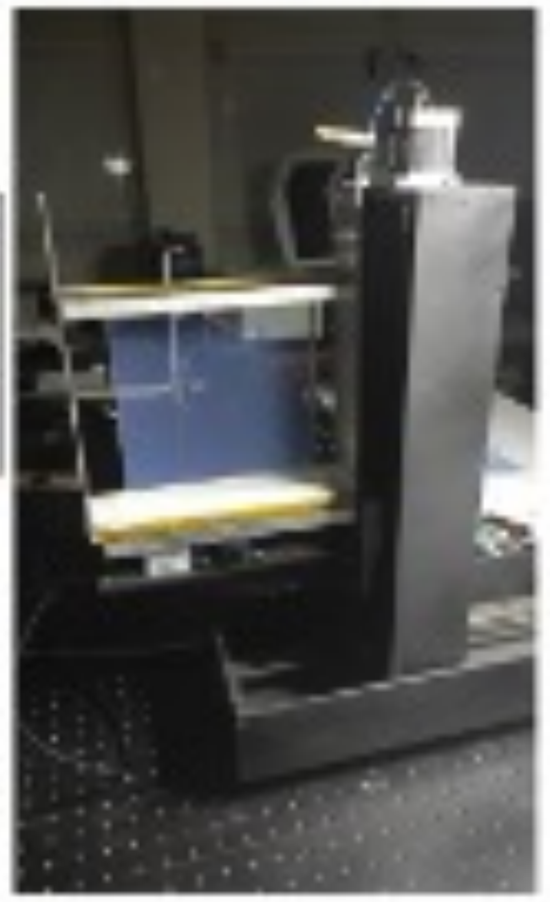


Secondary station at INFN (BA-FE) available for sample tests or in-depth characterization

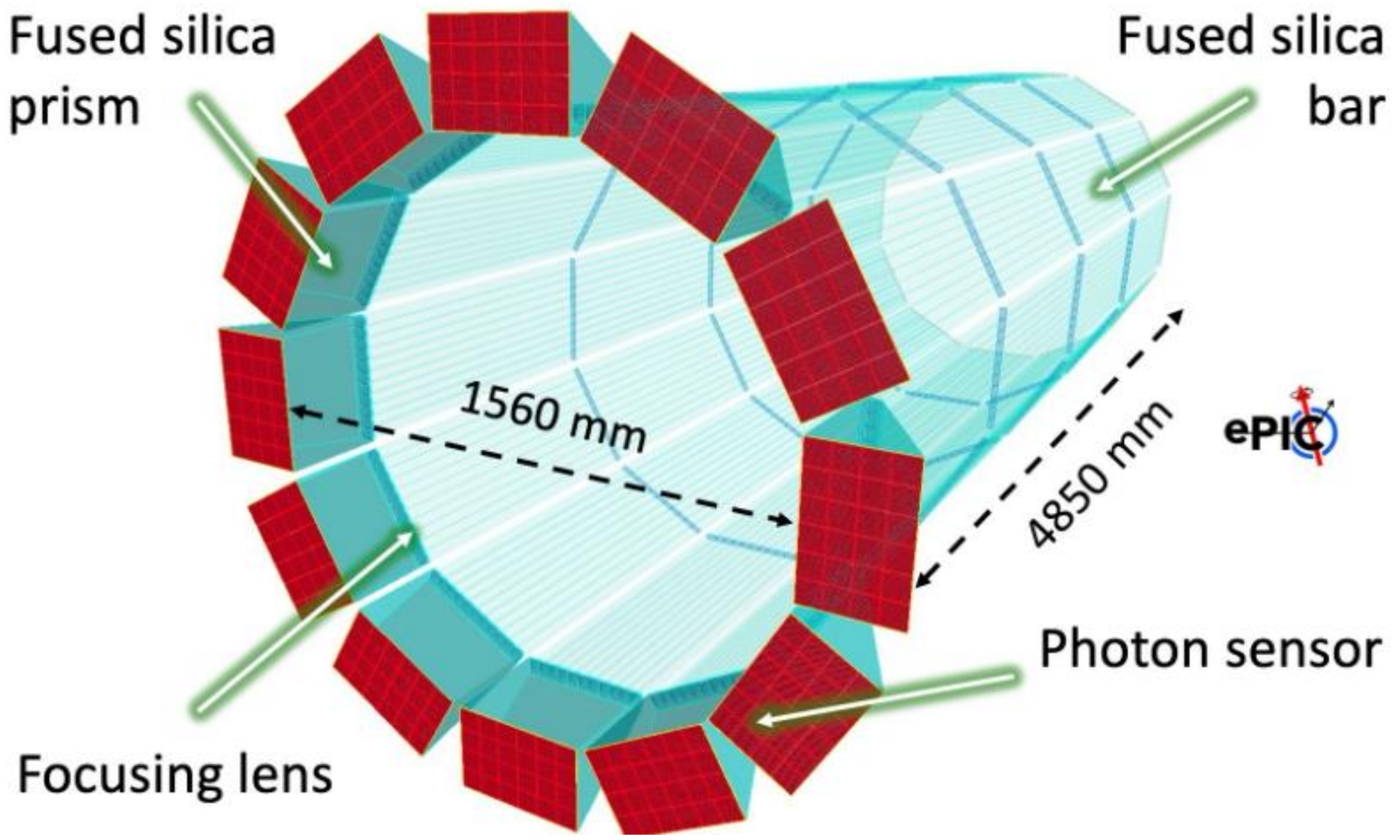
Perkin Elmer 650S (INFN FE) Transmission by Spectro-photometers Agilet Cary (INFN BA)

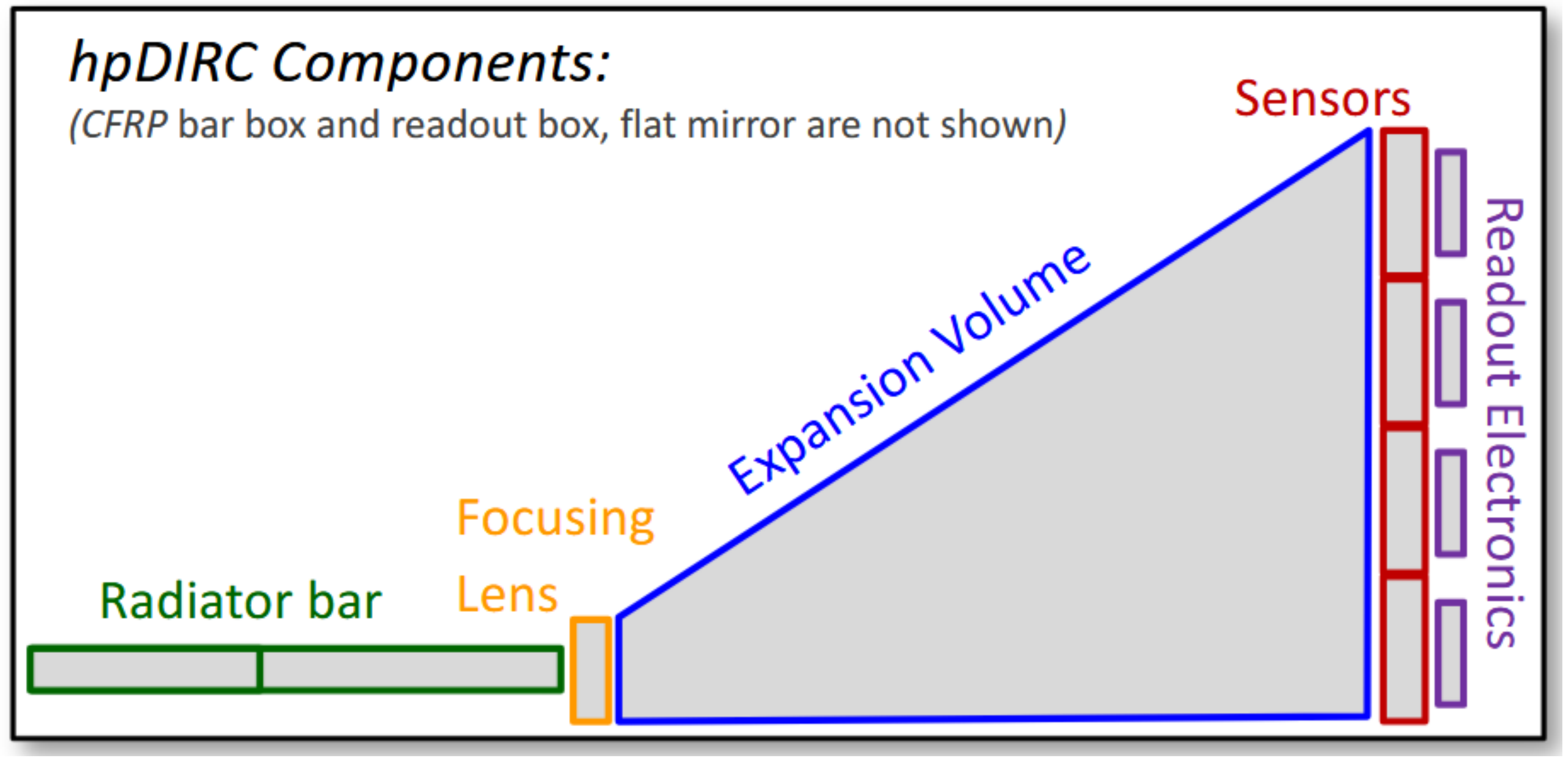
Forward Scattering by Laser + CMOS camera



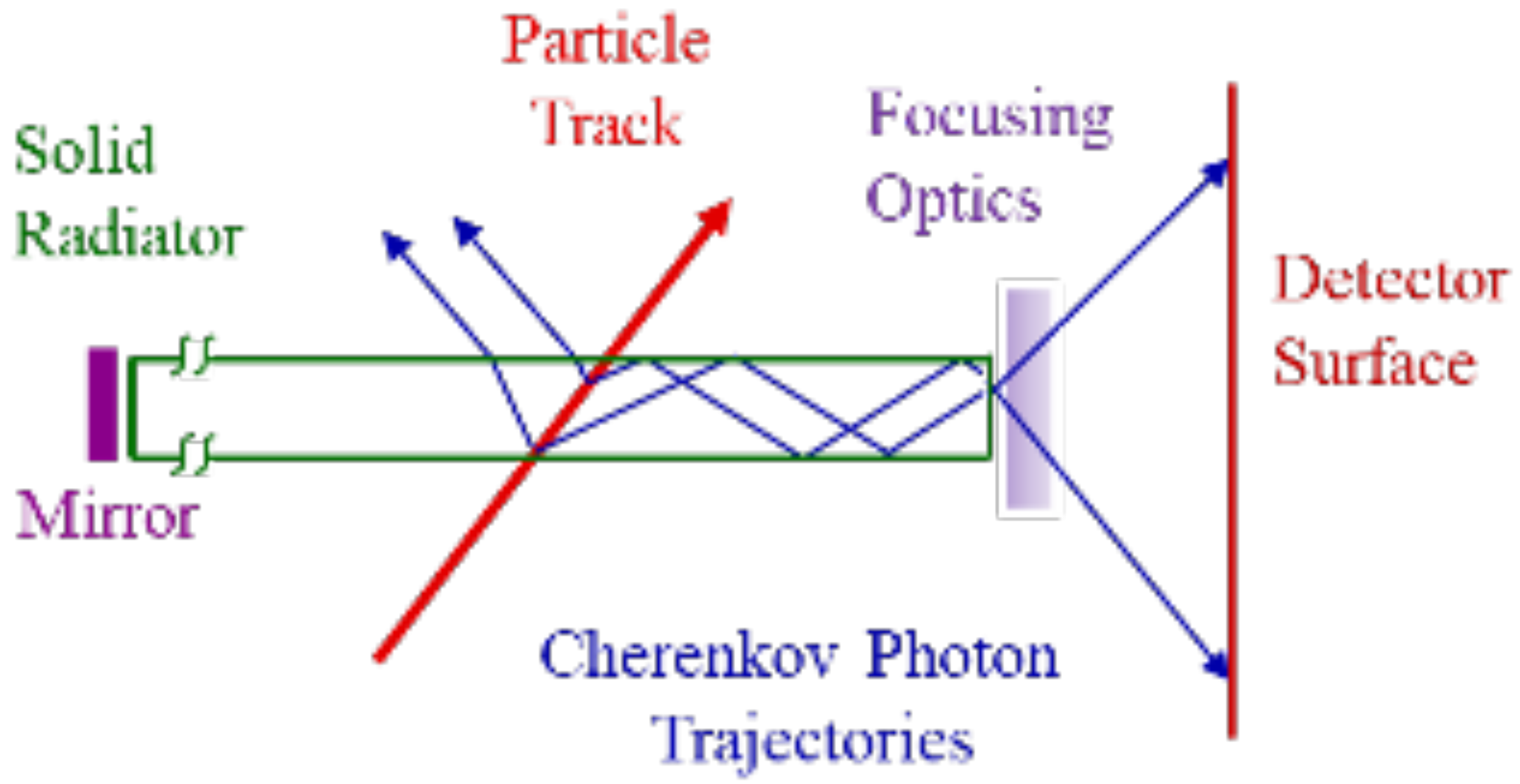


High Performance DIRC (hpDIRC) Overview

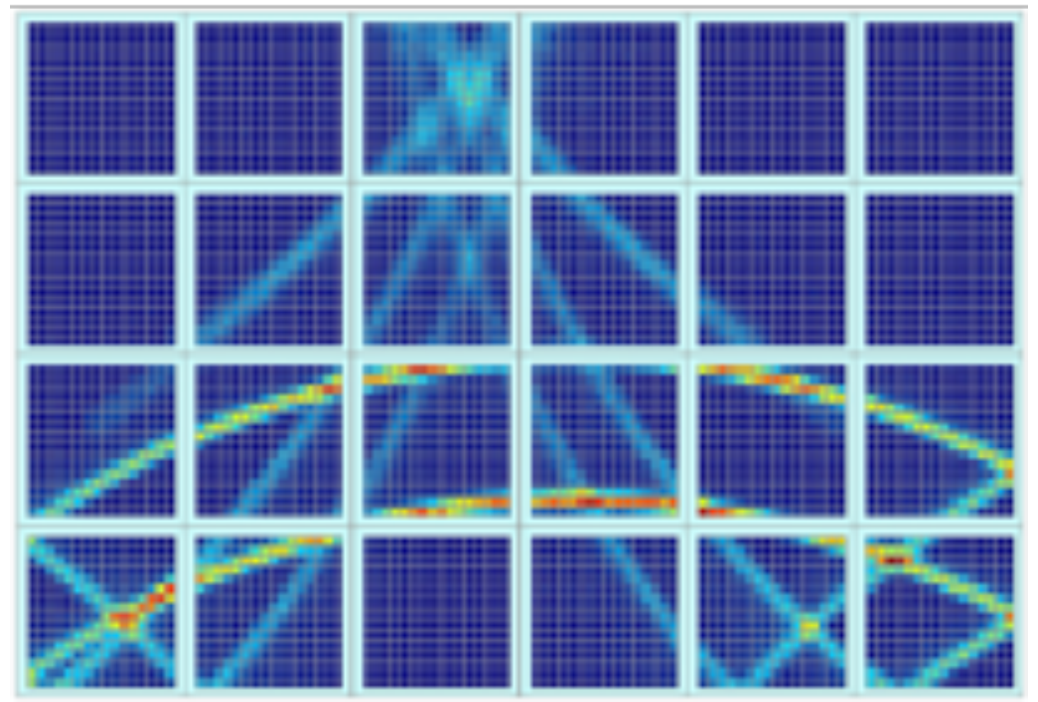




- Pioneered by the BaBar experiment at the SLAC National Accelerator Laboratory
- Fused silica bars or plates used as radiator and light guide
- Detector surface is outside active volume
- Cherenkov angle is conserved during internal reflections and reconstructed from detected photons
- Ultimate deliverable: PID likelihoods



Accumulated ePIC hpDIRC hit pattern (Geant4)



Baseline for Stave Structure

- The double-side sensor structure is the baseline for BTOF
  – Due to readout geometry and efficient cooling ACISs

- Development of the long (135cm) and low material FPC is very, very challenging
  – A total material budget of ~0.7 % X/X0 is the current target (2~3% X/X0 in total)
  – Exploring the feasibility of using shortened pieces connecting with several bonding techniques

- The material budget effect on the hpDIRC PID performance is under evaluation