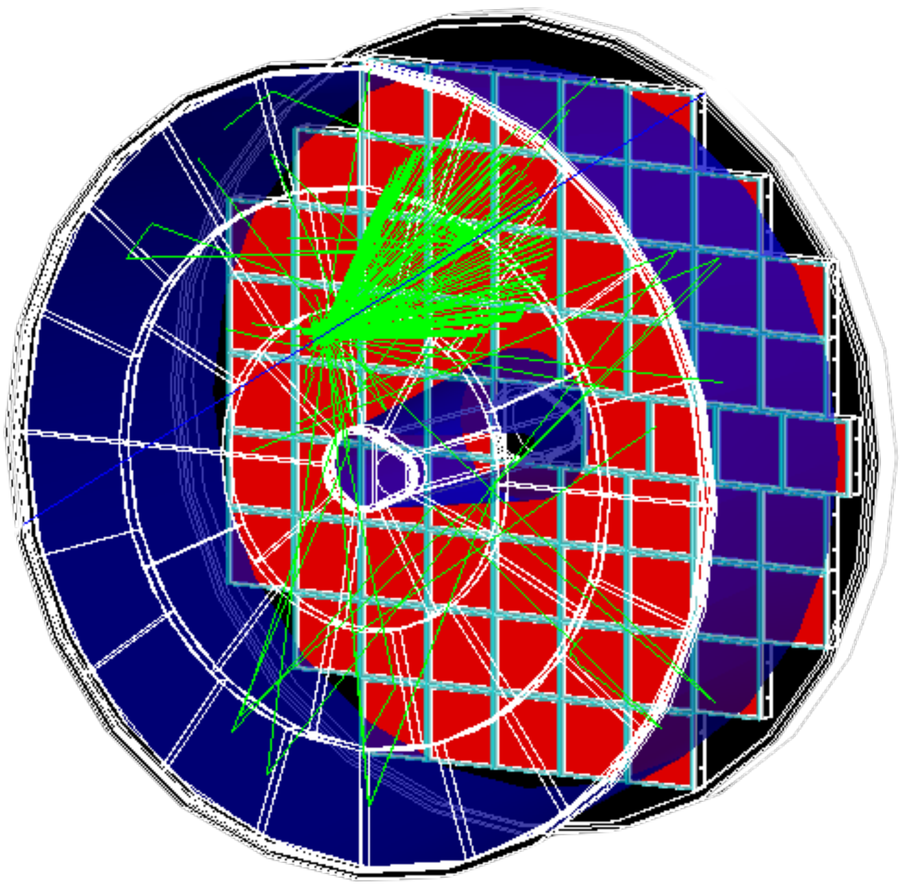
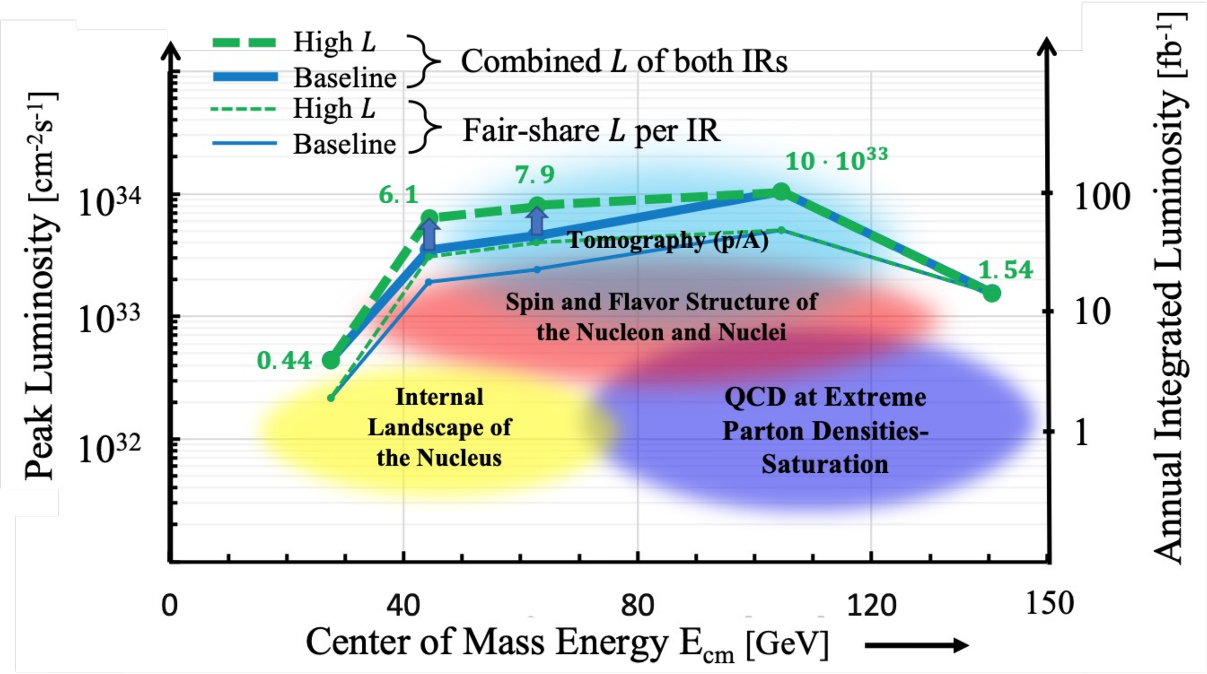


Hadron PID in the EIC ePIC detector backward endcap

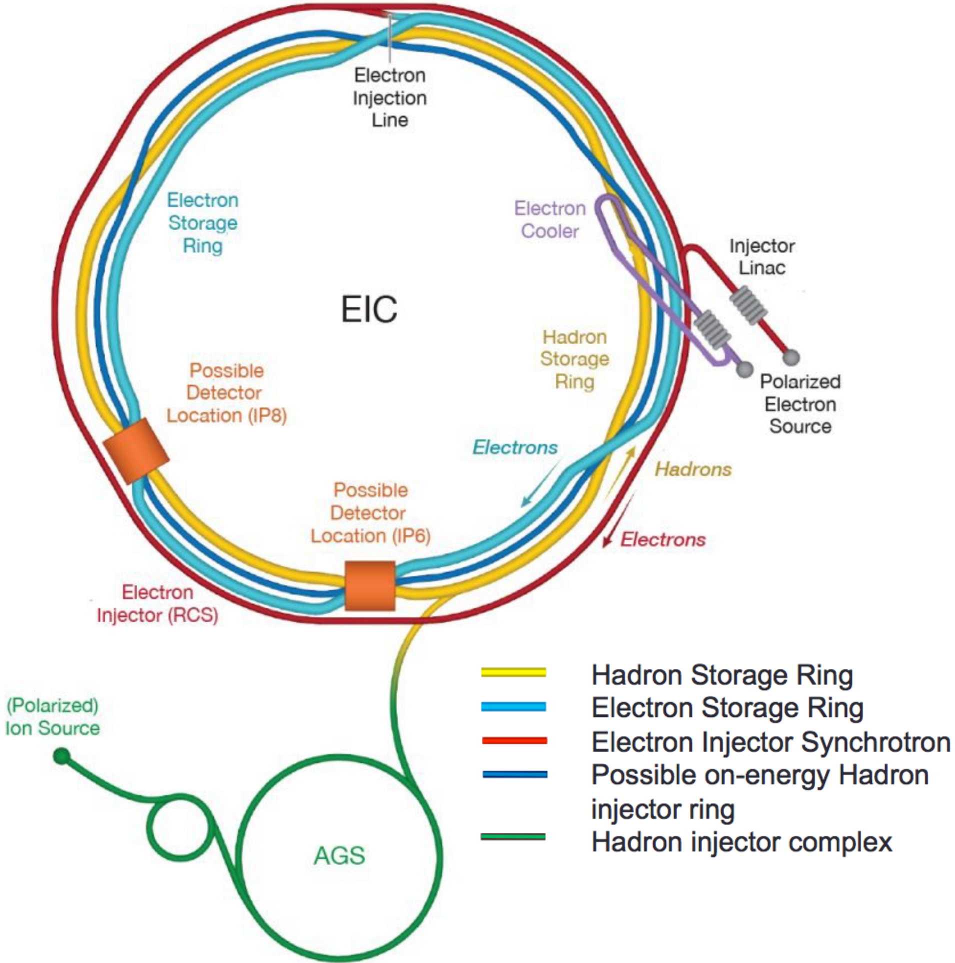
Alexander Kiselev (BNL)

HADRON 2023 Genova, Italy

Electron-Ion Collider at Brookhaven



- Re-use one of the RHIC hadron rings
- Add electron storage ring
- Build a new general purpose detector in IP6



- Electron & proton beams with >70% polarization
- Ion beams, up to U
- Center-of-mass energy range $\sqrt{s}$ ~ 20 – 140 GeV
- Luminosity 100 … 1000 times compared to HERA
  - up to 100 fb^{-1} / year

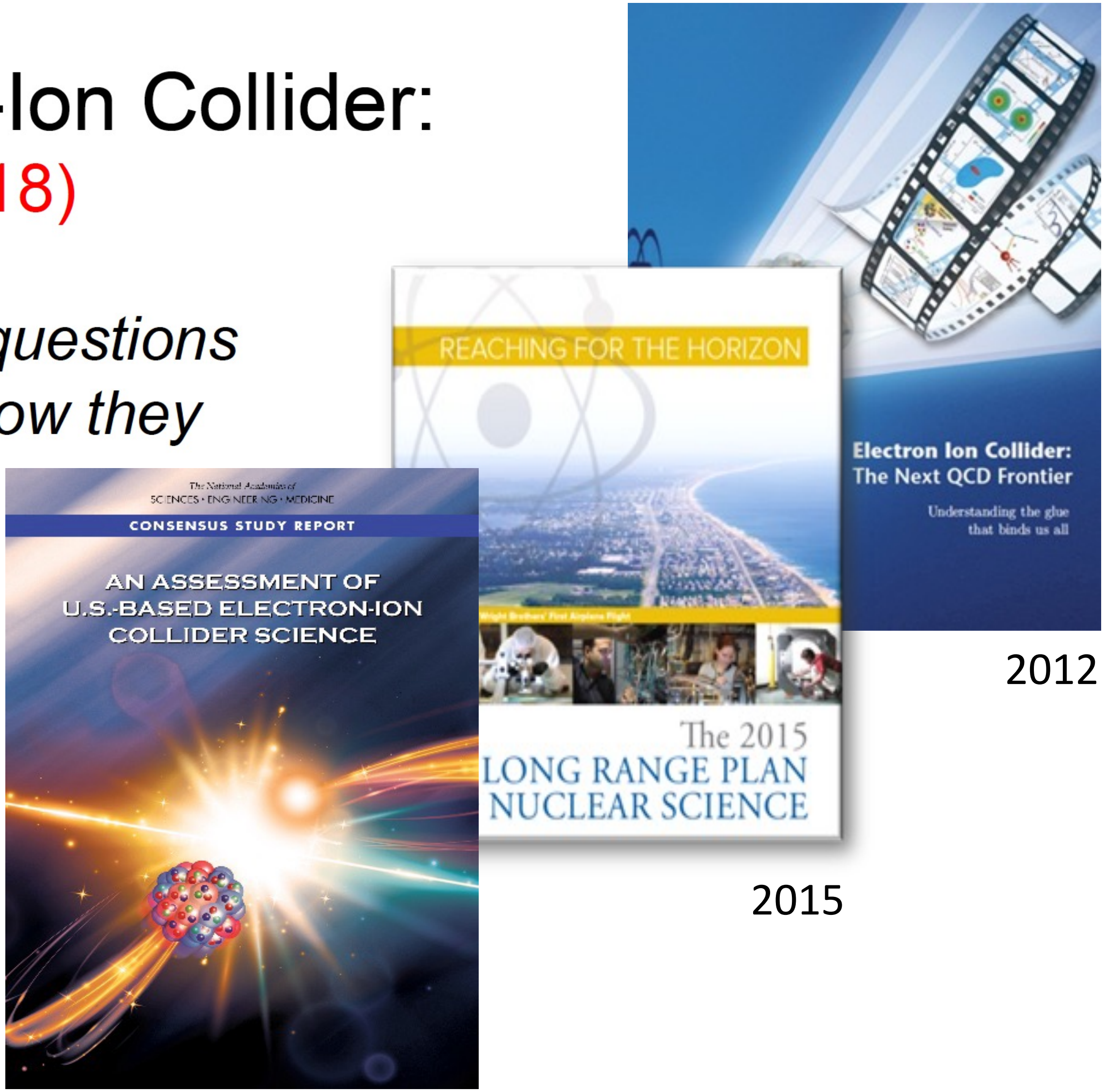
Start of construction in ~2 years from now

EIC science case

Assessment of US-based Electron-Ion Collider:
(National Academy of Science Report, 2018)

"An EIC can uniquely address three profound questions about nucleons - neutrons and protons - and how they are assembled to form the nuclei of atoms:

- ***How does the mass of the nucleon arise?***
- ***How does the spin of the nucleon arise?***
- ***What are the emergent properties of dense systems of gluons?"***



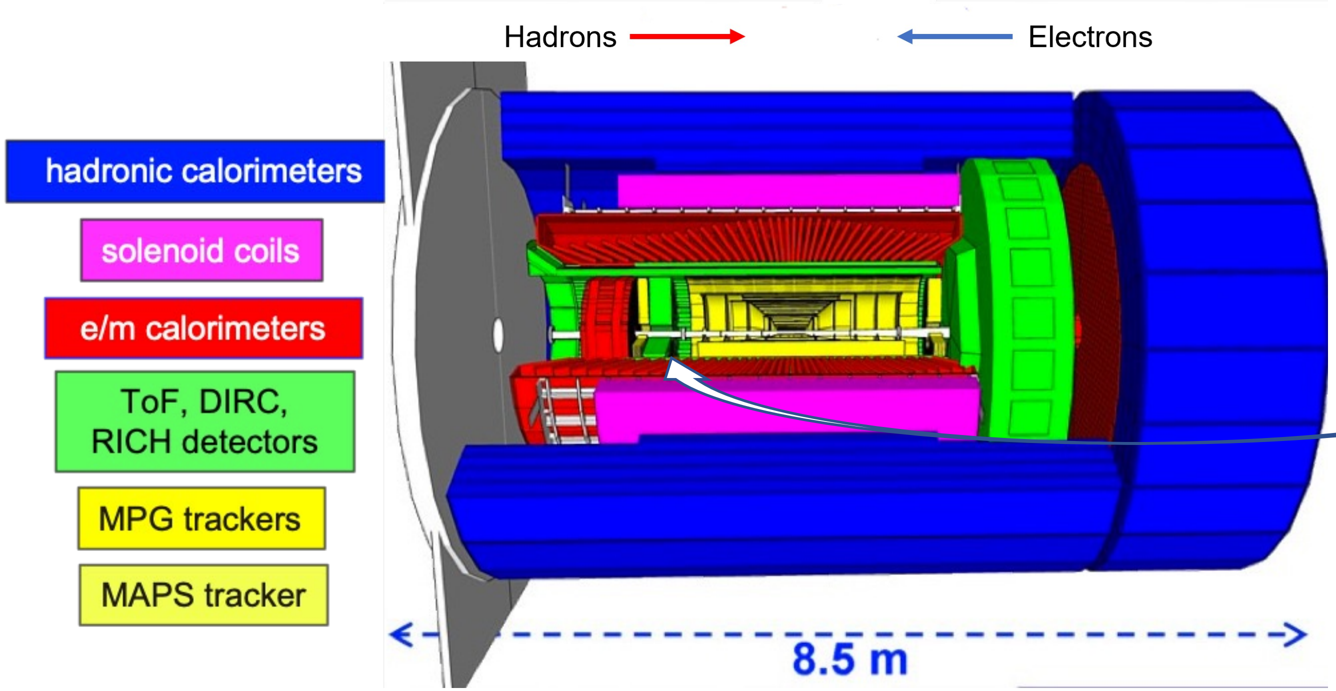
2012

2015

2018

A plenary talk by Silvia Dalla Torre tomorrow

ePIC: EIC general purpose detector @ IP6



Tracking:
- New 1.7 T solenoid magnet
- Si MAPS Tracker
- MPGDs (μRWELL/μMegas)

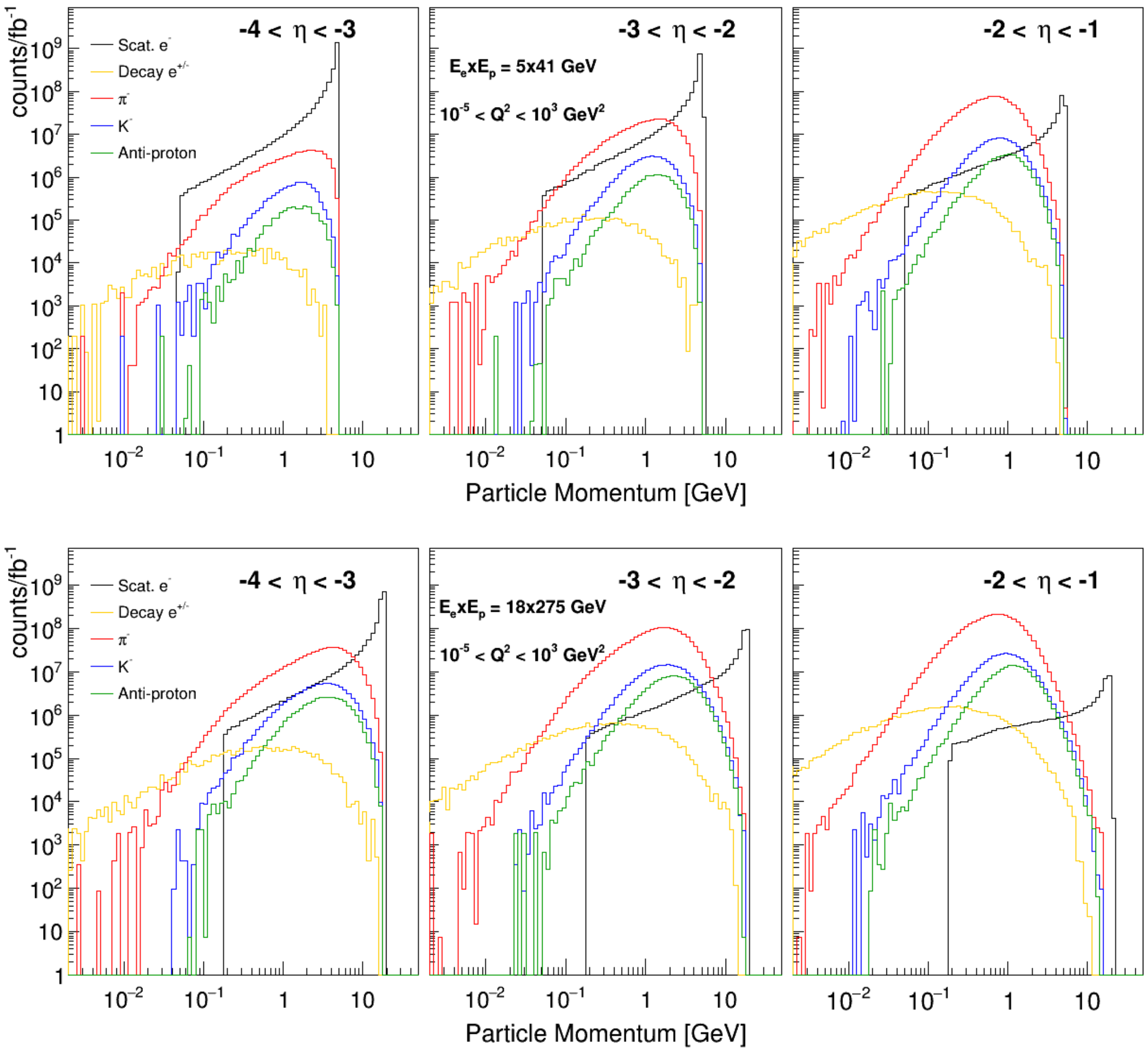
PID:
- hpDIRC
- pfRICH — focus of this talk
- dRICH
- AC-LGAD (~30ps TOF)

Calorimetry:
- Imaging Barrel EMCal
- PbWO4 EMCal in backward direction
- Finely segmented EMCal + HCal in forward direction
- Outer HCal (sPHENIX re-use)
- Backwards HCal (tail-catcher)

- A compact central detector with several subsystems
  - (Almost) hermetic coverage in tracking, calorimetry & PID $-3.5 < \eta < +3.5$

ePIC PID: previous talk by Chandradoy Chatterjee

Particle distributions in the ePIC e-endcap



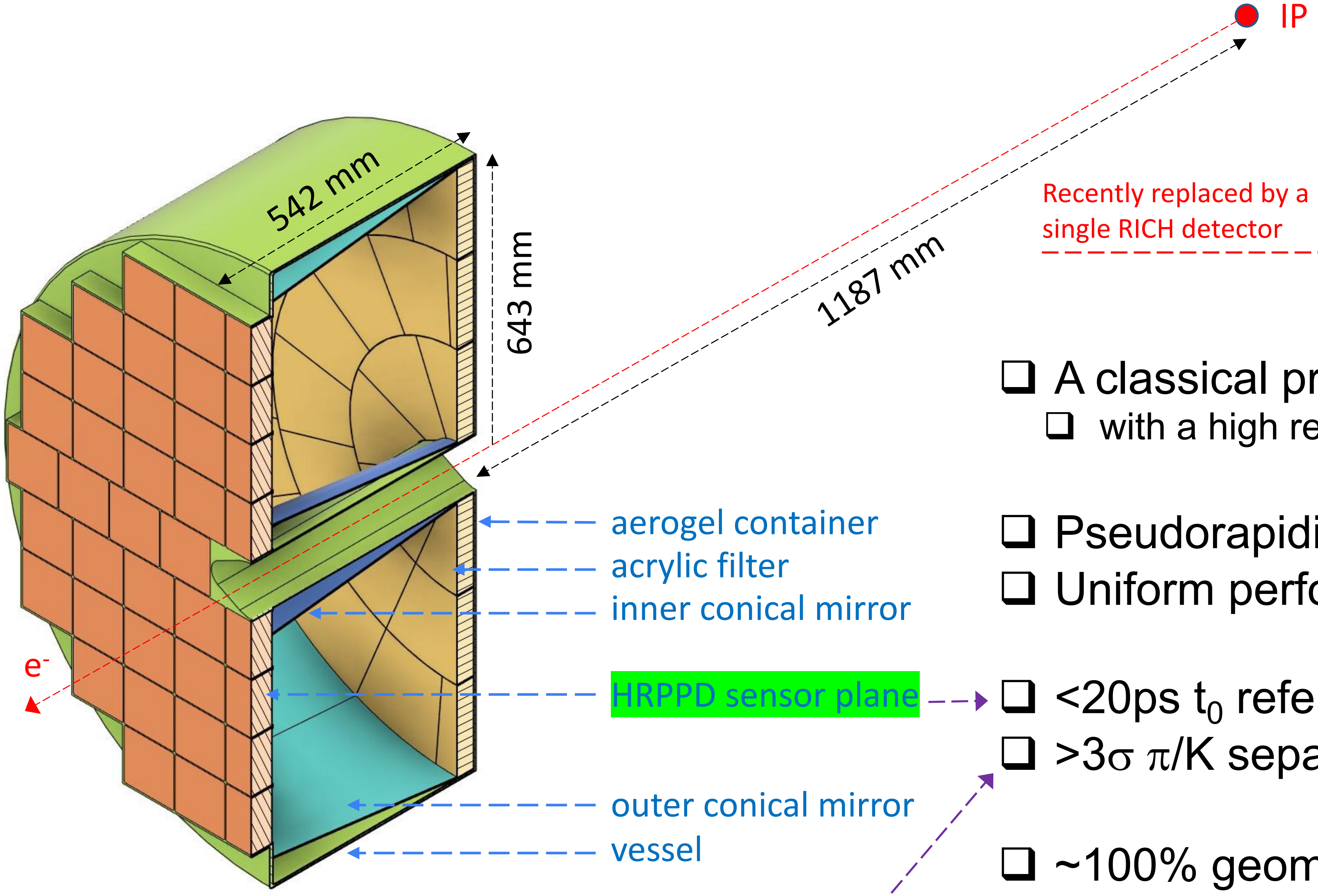
5 x 41 GeV

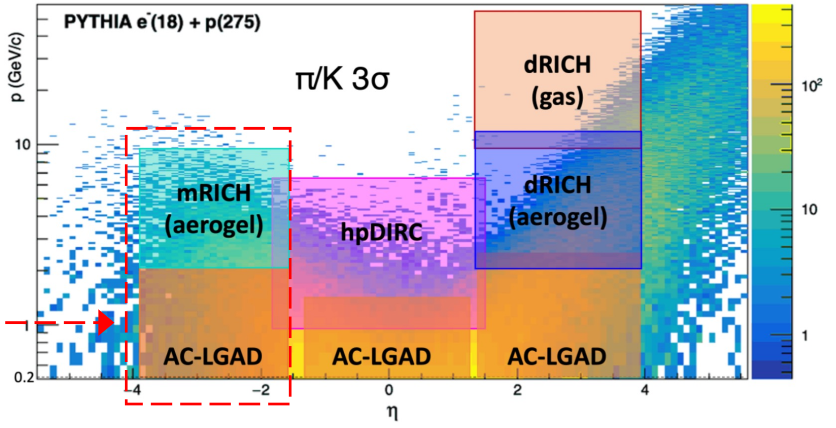
- Momentum dependency of π/K/p distributions is similar
  - With a π:K ratio ~3
- There is not much above ~7 GeV/c, especially at lower beam energies

18 x 275 GeV

Proximity focusing RICH with HRPPD sensors for EIC

e-endcap RICH for ePIC detector





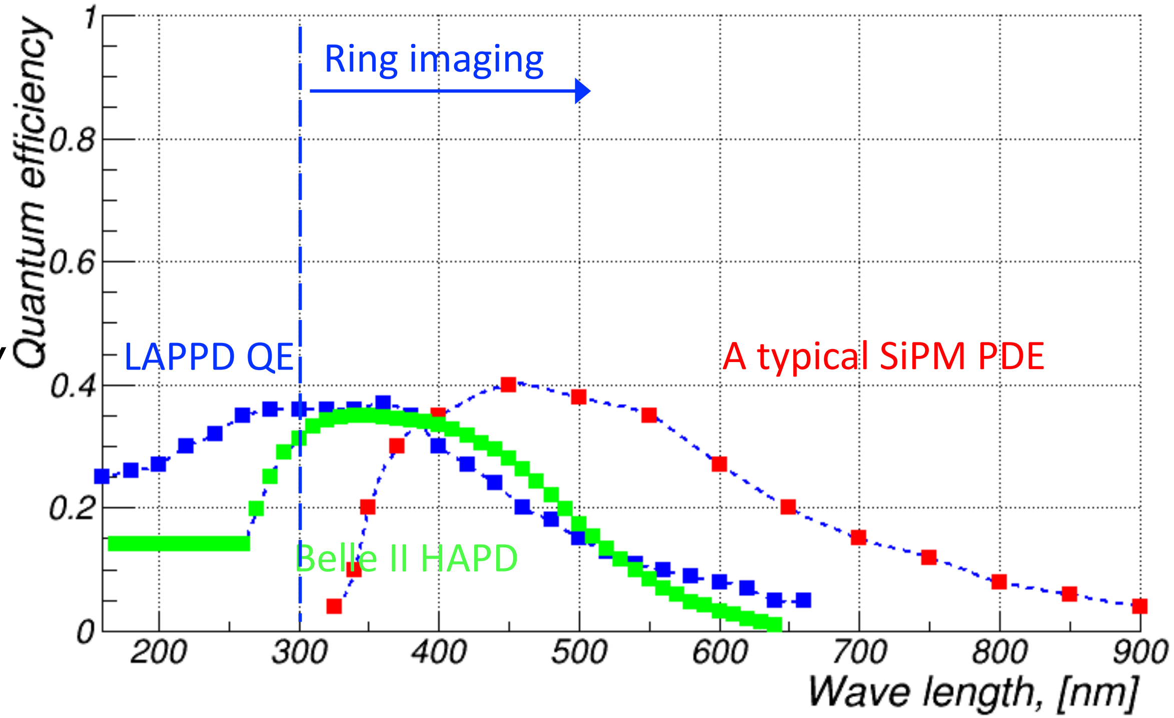
- A classical proximity focusing RICH
  - with a high resolution timing capability
- Pseudorapidity coverage: $-3.5 < \eta < -1.5$
- Uniform performance in this $\{\eta,\phi\}$ range
- <20ps t_0 reference for the ToF subsystems
- >3σ π/K separation up to ~ 9.0 GeV/c
- ~100% geometric efficiency

EIC Yellow Report requirement: better than 3σ π/K separation up to 7 GeV/c

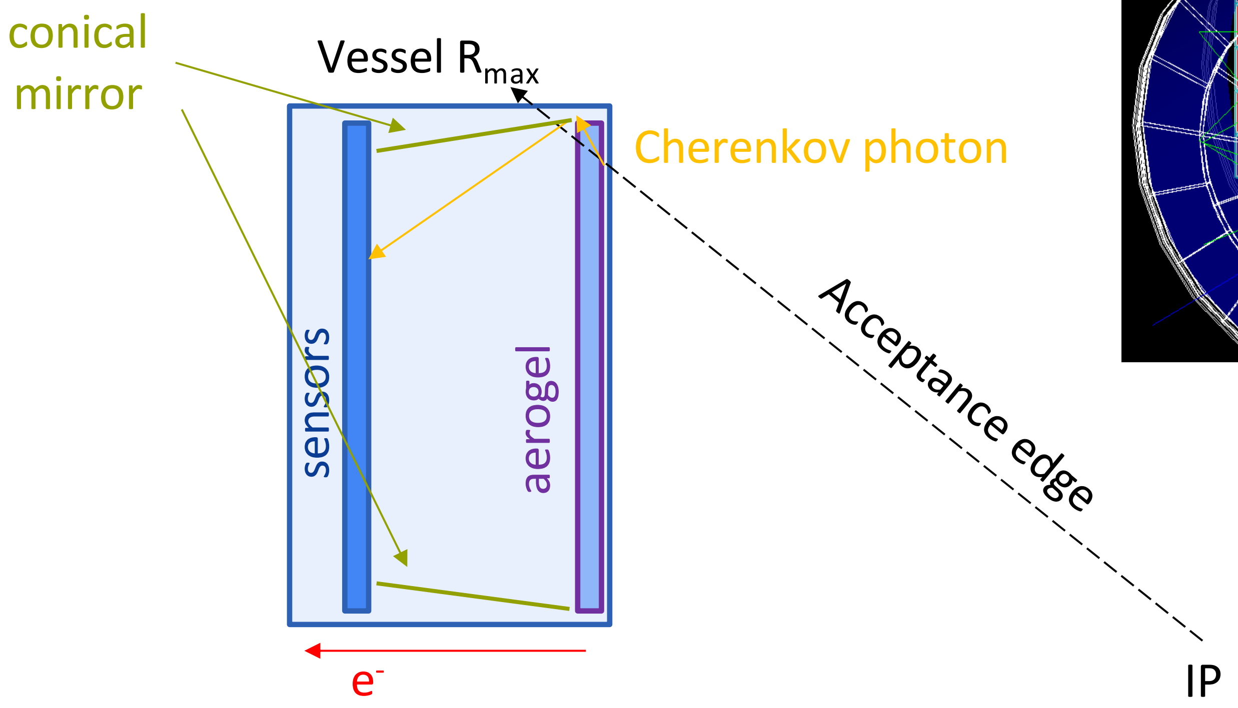
Aerogel by Chiba University

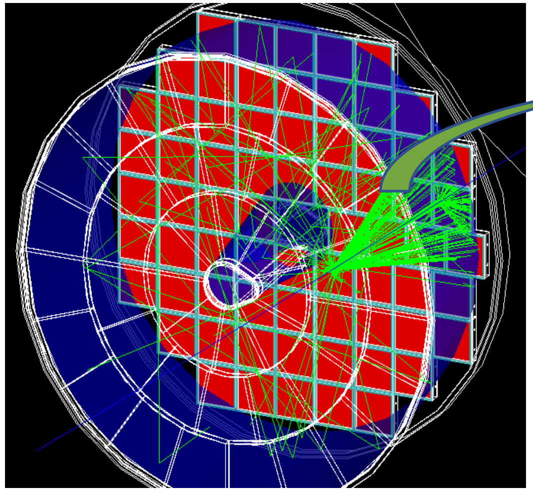
- A relatively moderate momentum reach is required for this RICH detector
- HRPPD PDE is expected to be substantially smaller than of the SiPMs
  - And peak value shifted to the UV range, where it cannot be used for ring imaging

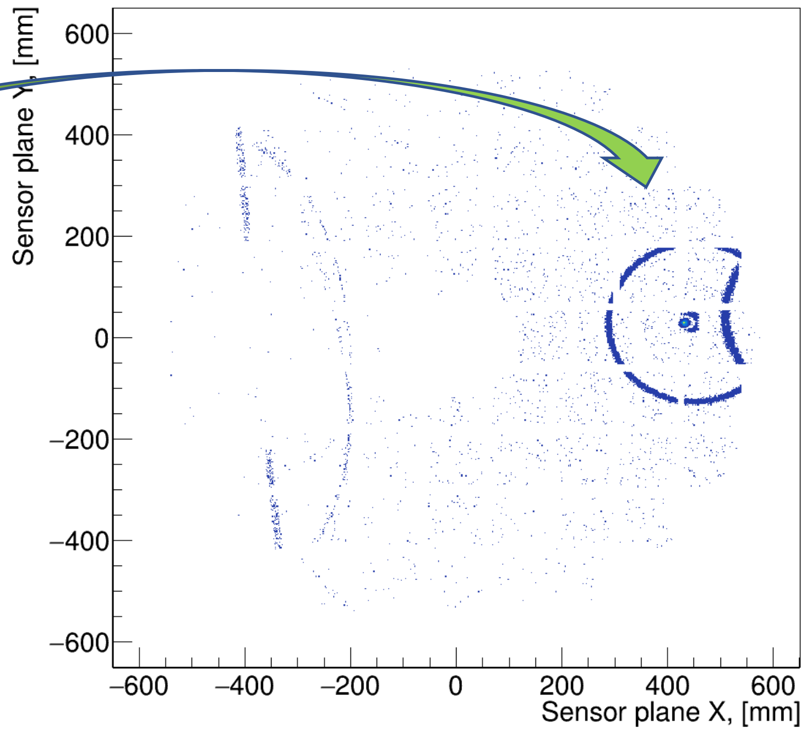
- Consider using a high n ~ 1.040 … 1.050
  - 300 nm acrylic filter cutoff for imaging
  - $\langle N_{pe} \rangle \sim 11\text{-}12$
  - *For ToF still make use of the UV range for abundant Cherenkov light produced in the window*
  - Natural choice for simulations: Belle II (n ~ 1.045)
  - Natural hardware reference: Chiba University aerogel recently produced for J-PARC (n = 1.040)
  - Test samples will be produced by the end of 2023



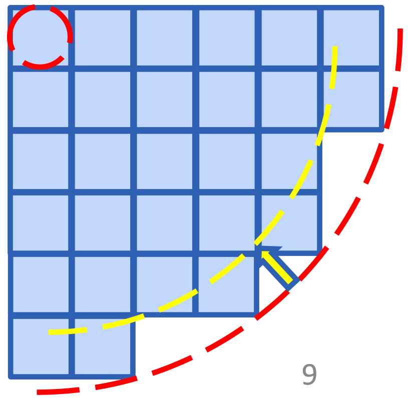
Angular acceptance optimization



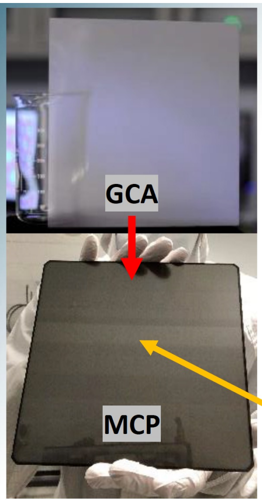




- Use side wall mirrors to increase η acceptance
  - Achieve -3.5 < η < -1.5 coverage (hence overlap with the DIRC)
  - Make mirrors *conical* to avoid inefficiency on the sensor plane

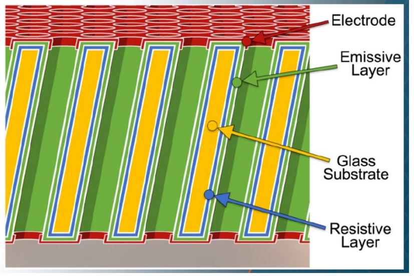


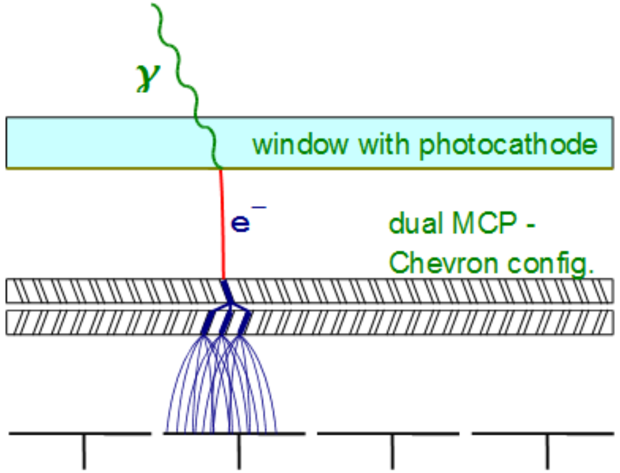
HRPPD photosensors by Incom Inc.

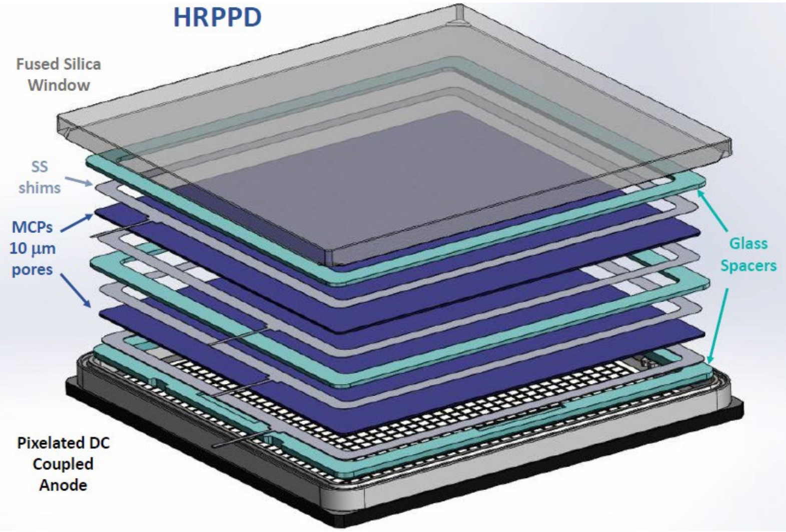


- *Hollow core* **Glass Capillary Array** (GCA) substrate
  - Borosilicate glass (AKA Pyrex)
    - Little radioactive ^{40}K
  - *No etching necessary! Already hollow*
- **Atomic Layer Deposition** (ALD) is a thin-film deposition technique used to functionalize GCAs
  - **GCA + ALD = MCP**
- Flexible adjustment of film composition and resistivity

Open Area Ratio (OAR) **up to 74%**

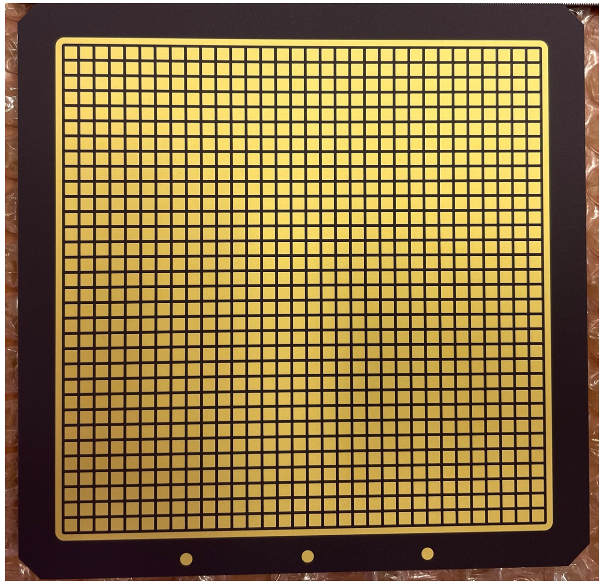






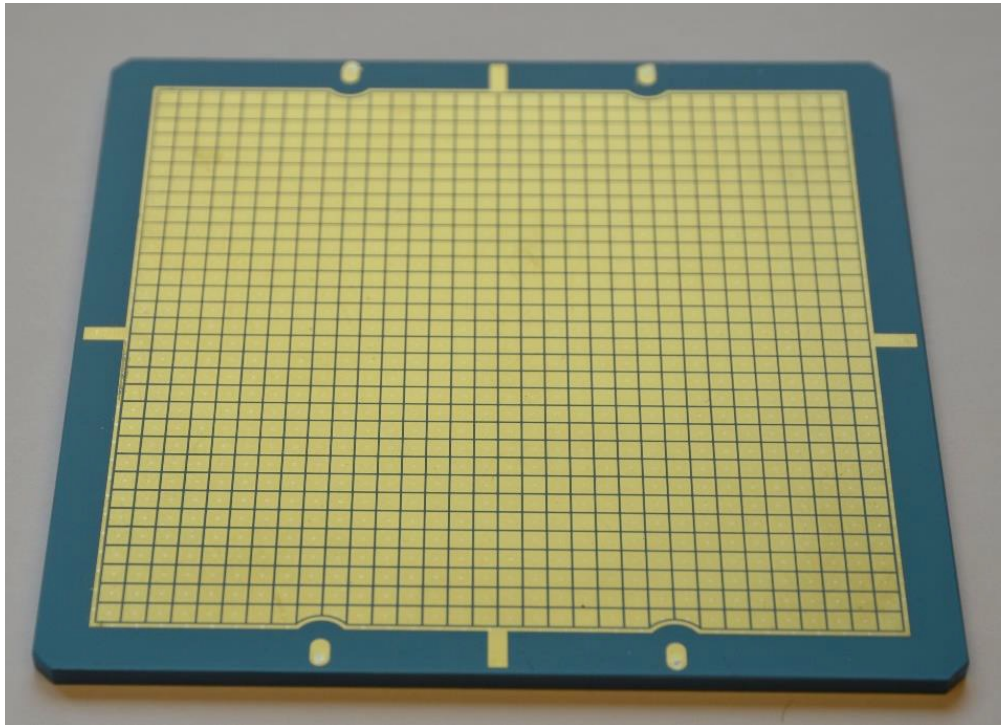
- An affordable large area vacuum photosensor
  - Up to ~3 times more cost efficient in $$ per mm^2 than other commercially available MCP-PMTs
- 10x10 cm^2 active area
- DC-coupled square pads
- Quantum efficiency above 30%
- SPE timing resolution ~50 ps level or higher

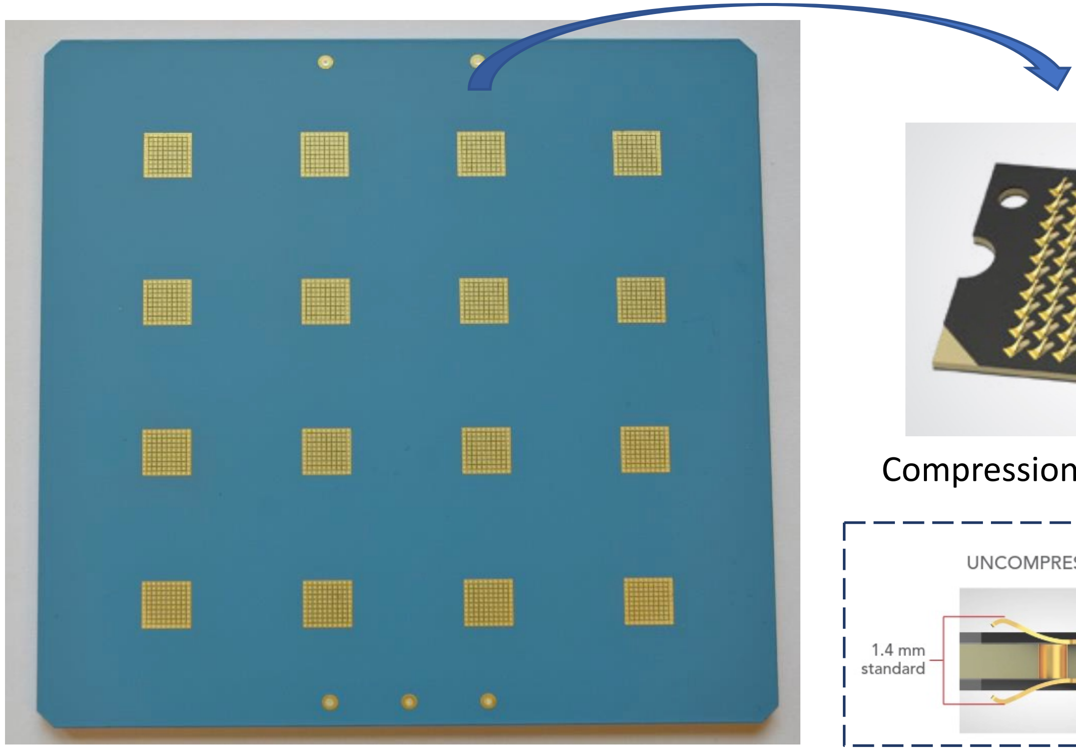
Adaptation to EIC needs is ongoing



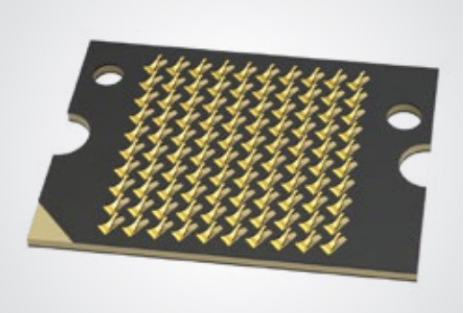
1024 ~3.2mm pads

Custom pixellation and ASIC board interface

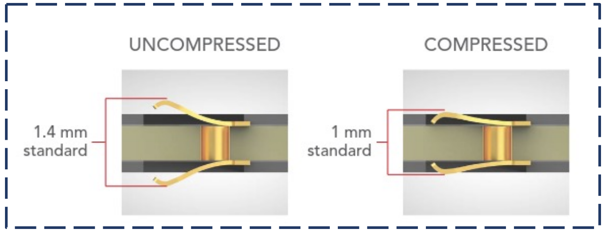




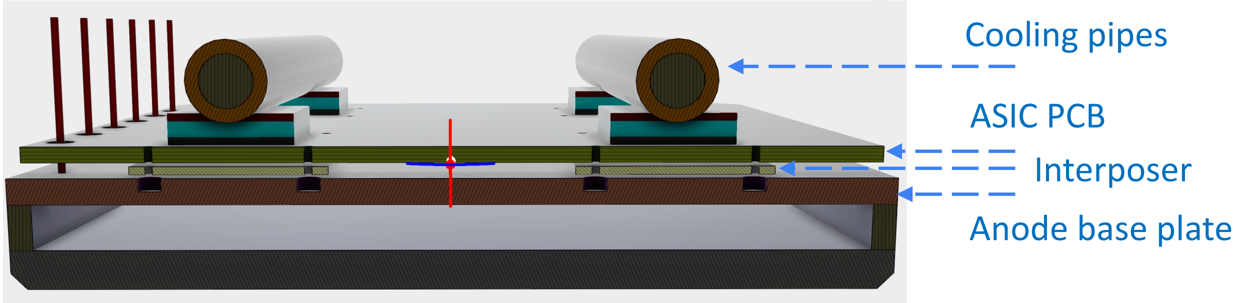
HRPPD anode plate with a non-trivial internal trace routing



Compression interposer interface



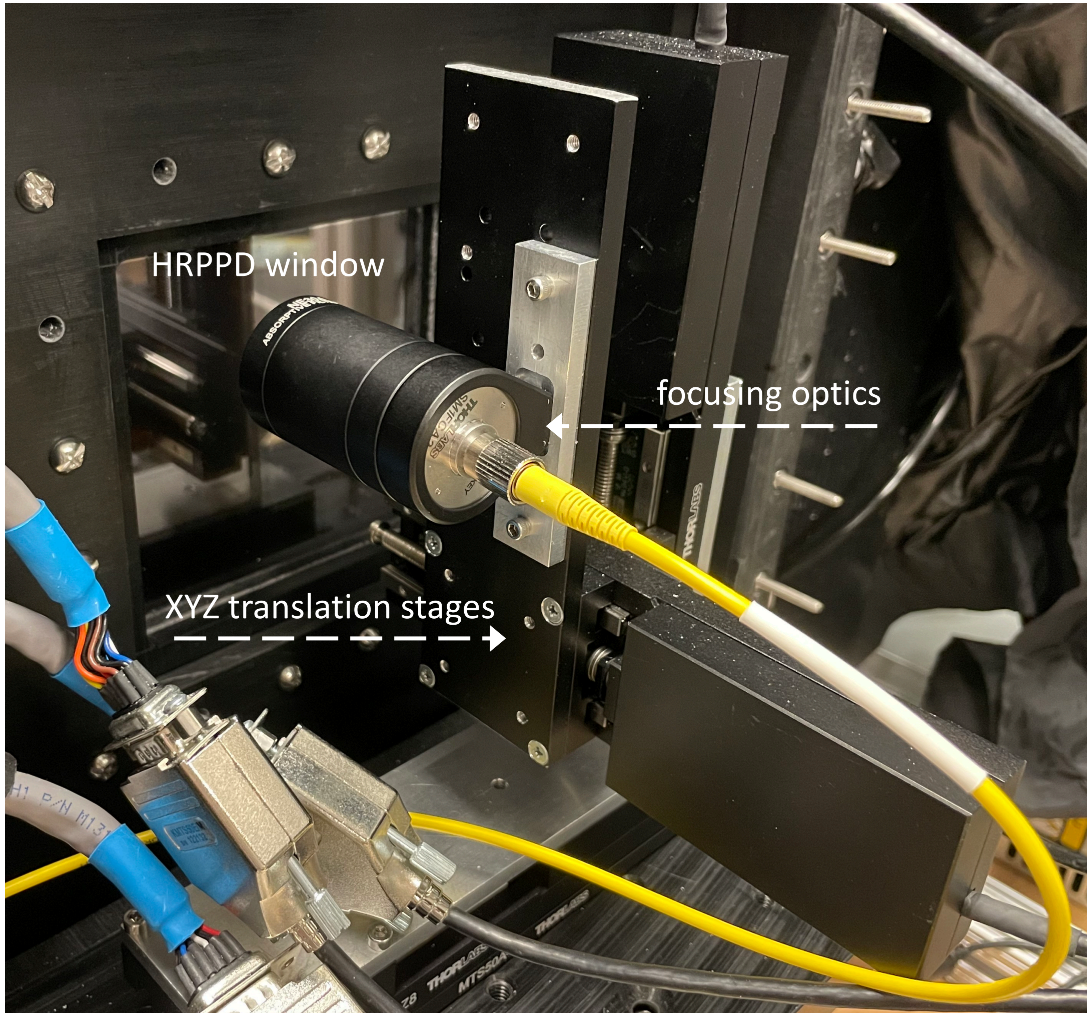
- First prototypes look promising
- Once all this is confirmed to work, pixellation of the DC-coupled HRPPDs becomes *almost* as much configurable as AC-coupled ones



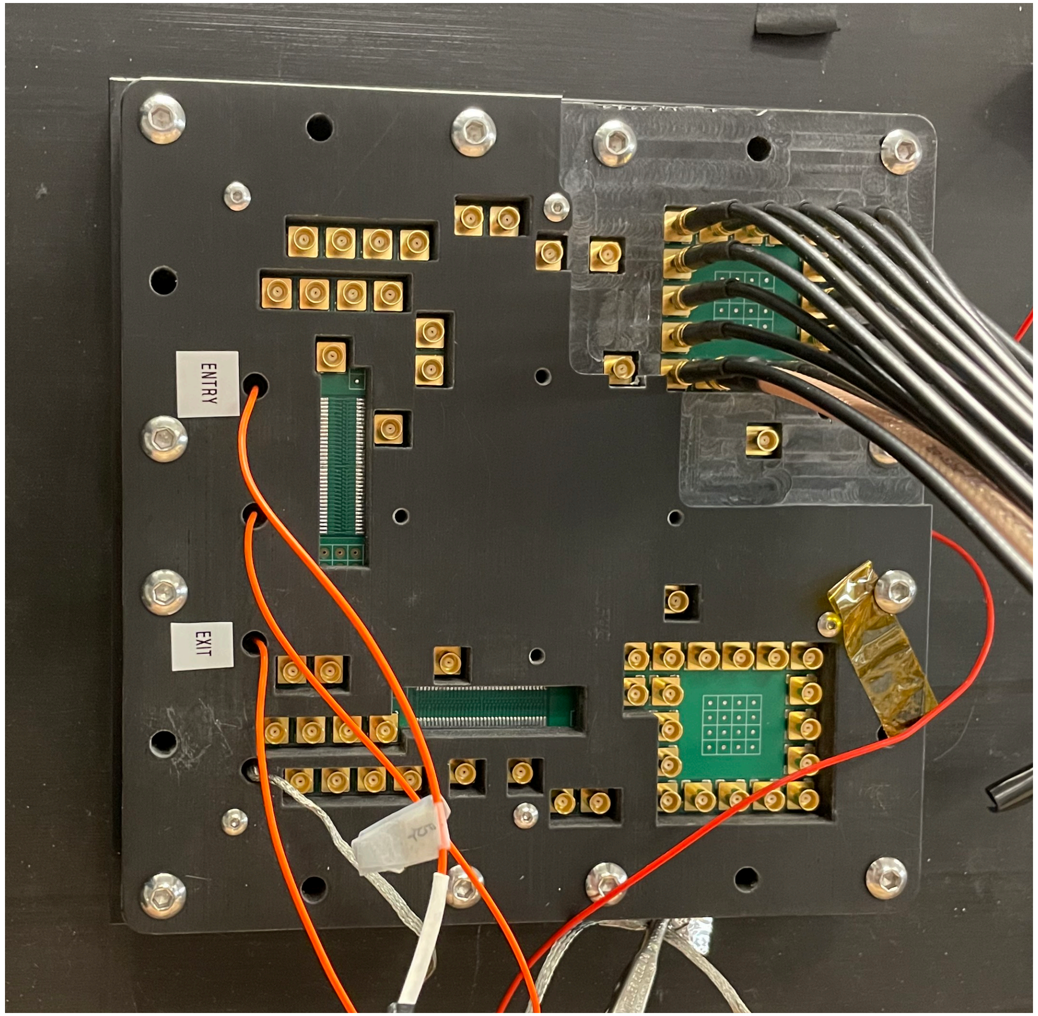
HRPPD face down

Photosensor lab measurements and beam test data

HRPPD test stand at BNL

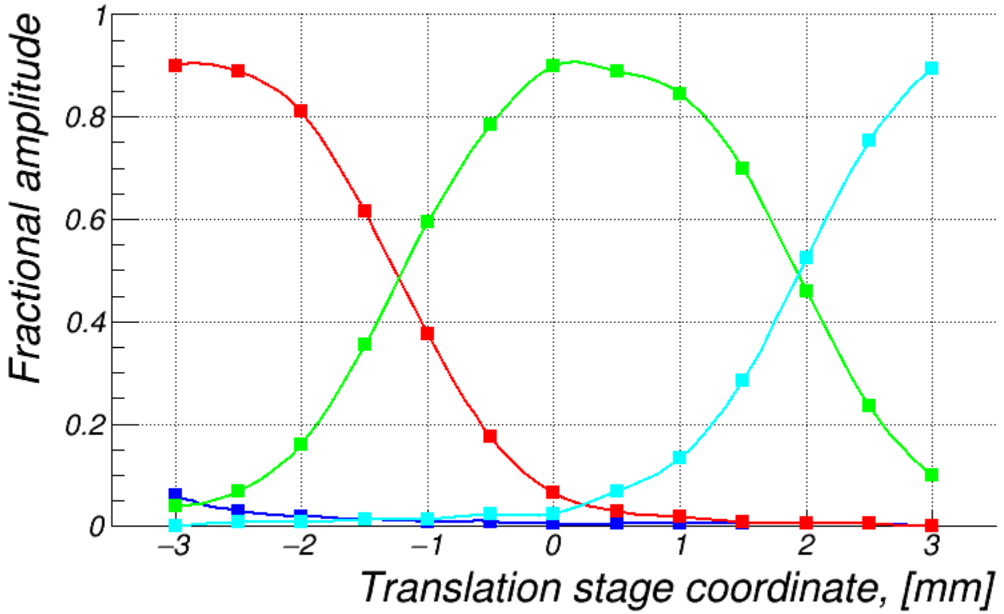


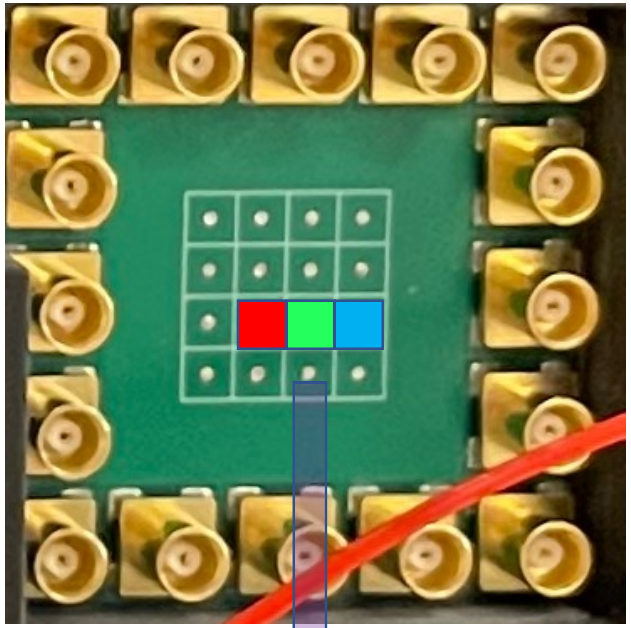
Light tight enclosure



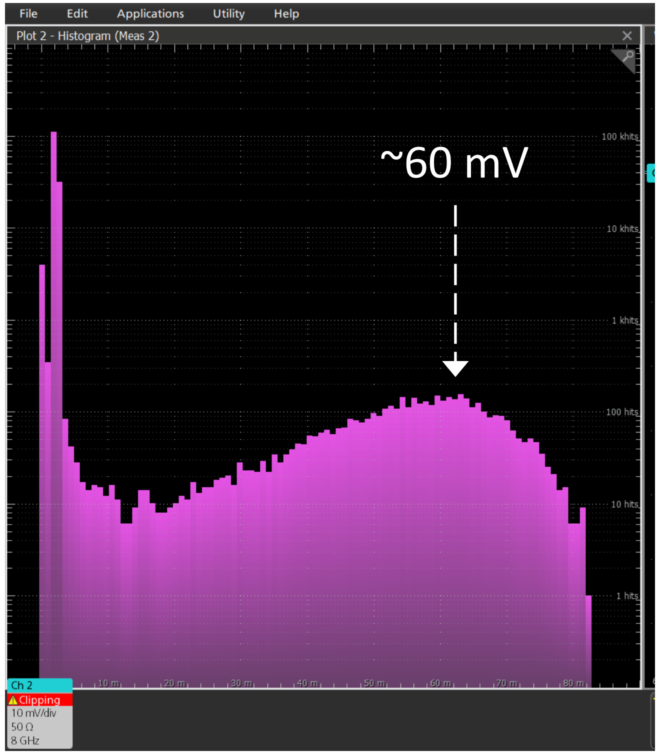
Pogo pin interface board side

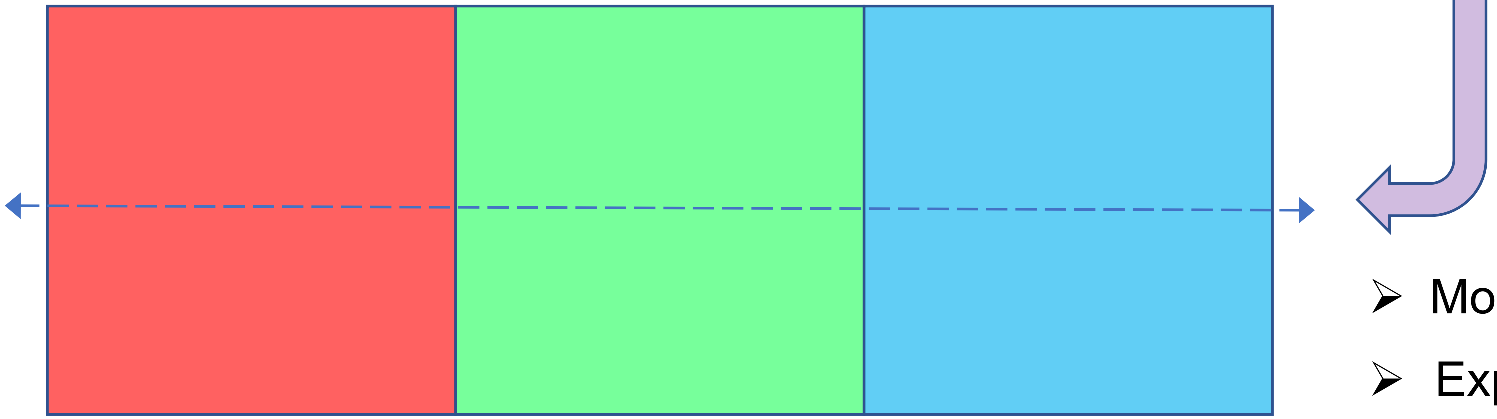
Pixellation, charge sharing, spatial resolution





Amplitude spectrum on a scope

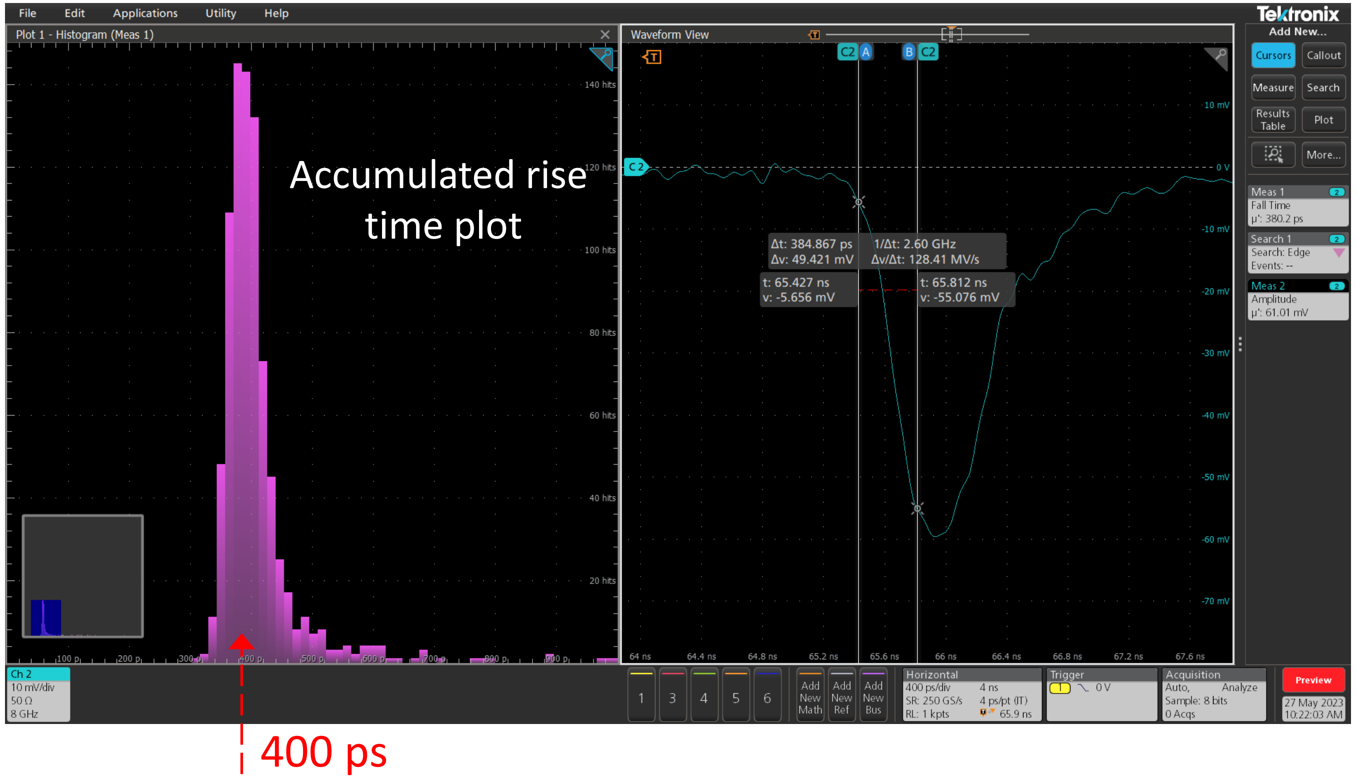




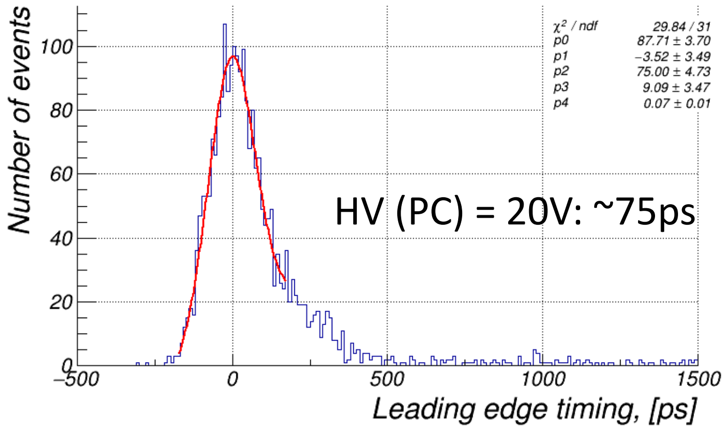
amplitude scan across three neighbor pads

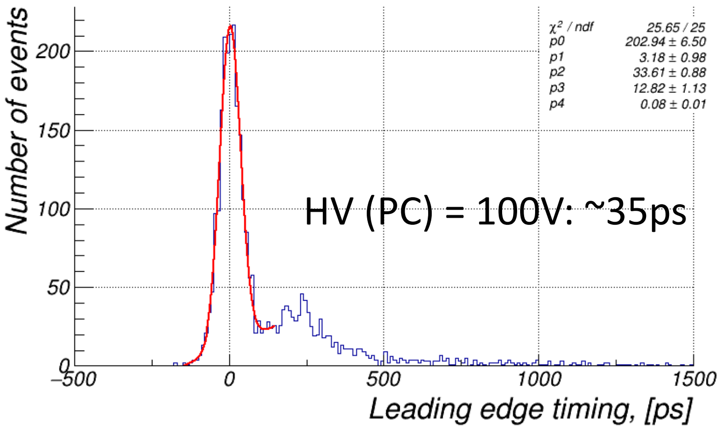
- ➢ Moderate charge sharing (even without a B field)
- ➢ Expect ~3.2mm/√12 spatial resolution or better

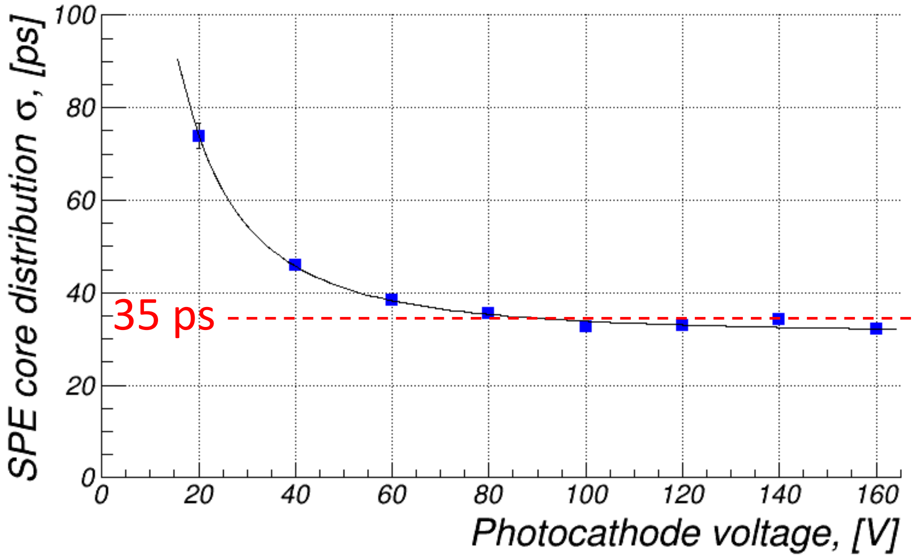
SPE timing performance with a 420nm laser



- Laser focused to a pad center
- Intensity tuned down to ~95% empty events
- Δt data taken with a V1742 DRS4 module
  - Channel #0 – HRPPD pulse
  - Channel #1 – laser synchro pulse
- *Neither laser pulse width nor other instrumental effects unfolded*

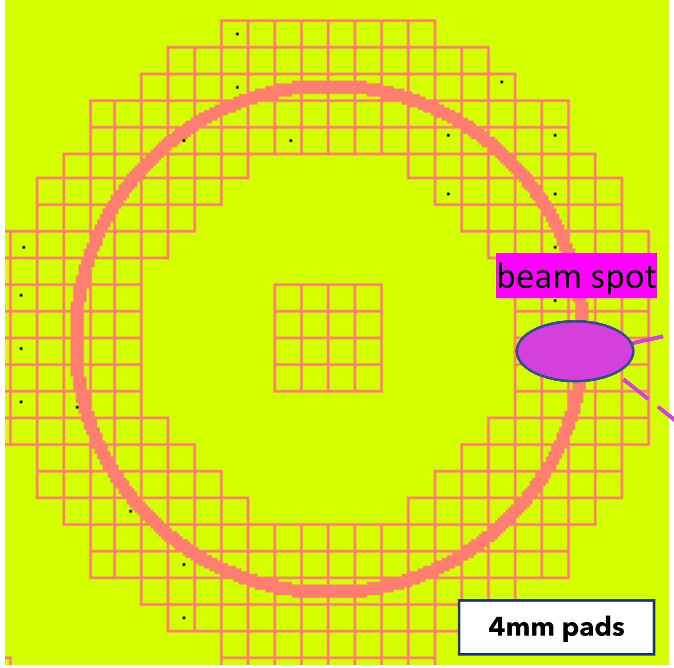




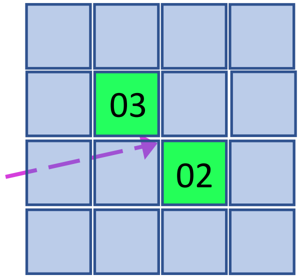


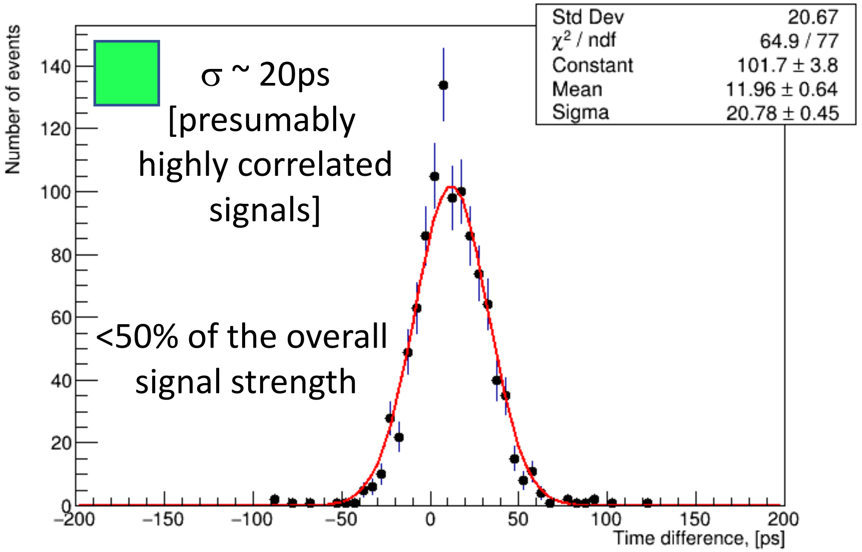
A hint of timing resolution in a multi-photon mode

LAPPD quartz window as a Cherenkov radiator



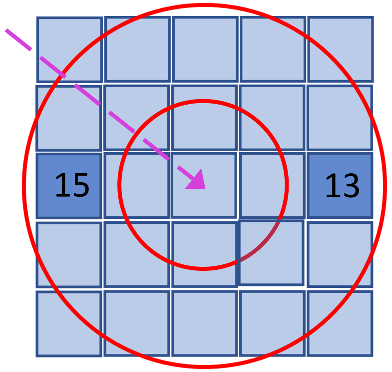
Event selection (A)

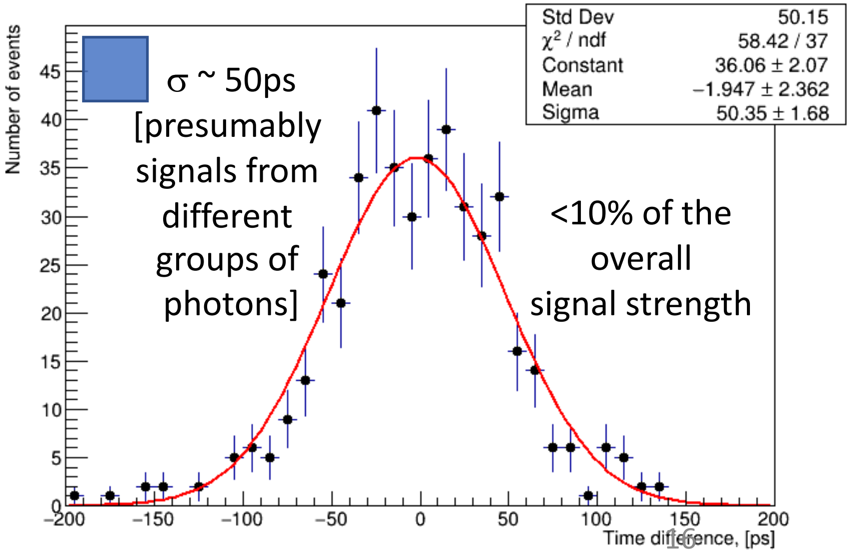




DRS4 chip#0: time(ch#03) – time(ch#02)

Event selection (B)





DRS4 chip#1: time(ch#15) – time(ch#13)

- *Single* photon TTS <50 ps
- 5mm thick UV grade quartz window: a 120 GeV proton produces a **blob of ~100 p.e.'s**

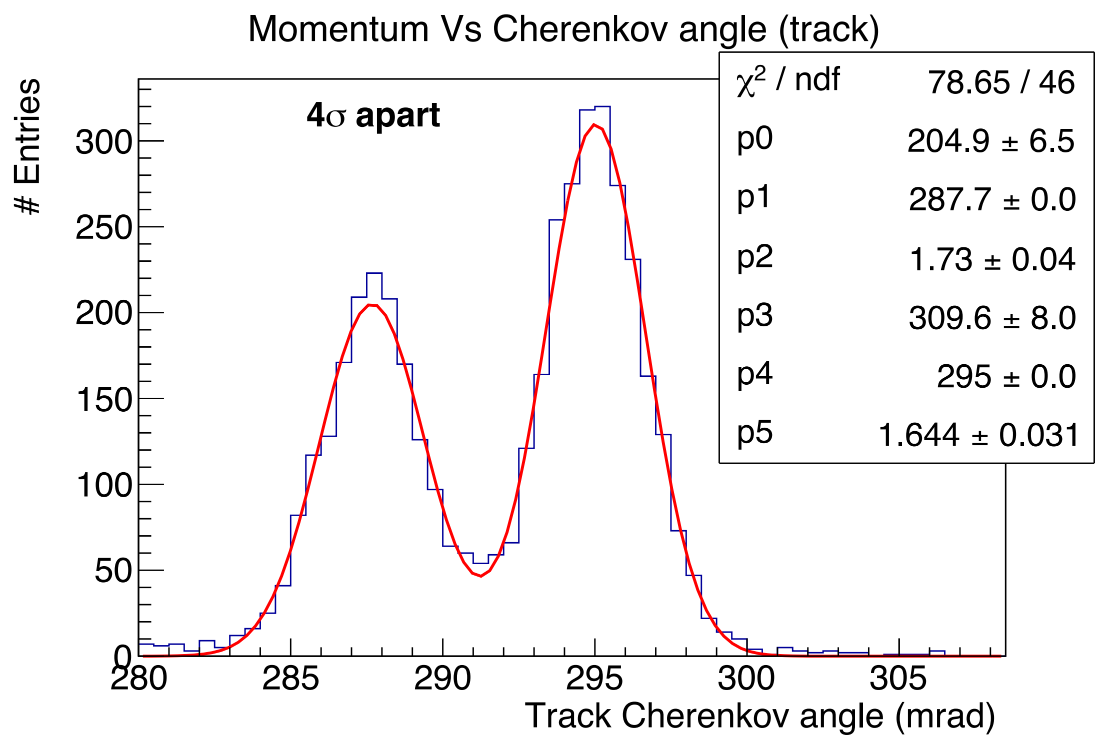
Due to the TIR, photons only hit the PC in a radial band ~[5.5 .. 12.0] mm

Fermilab test beam [AC-coupled sensors, no t_0 reference]

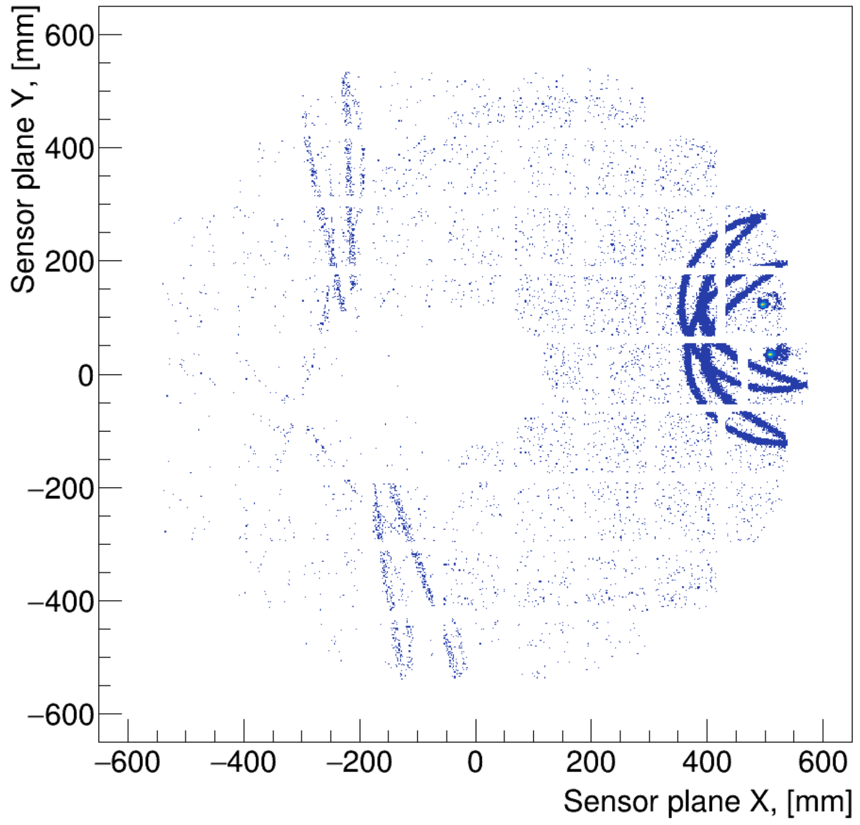
Monte-Carlo simulations

Expected performance highlights

- Standalone GEANT4 code with a particle gun or HEPMC3 import
- Simulation with (almost) all known optical effects included
- Event-level digitization / reconstruction chain
  - χ^2 based algorithm with a full combinatorial hit-to-track ambiguity resolution

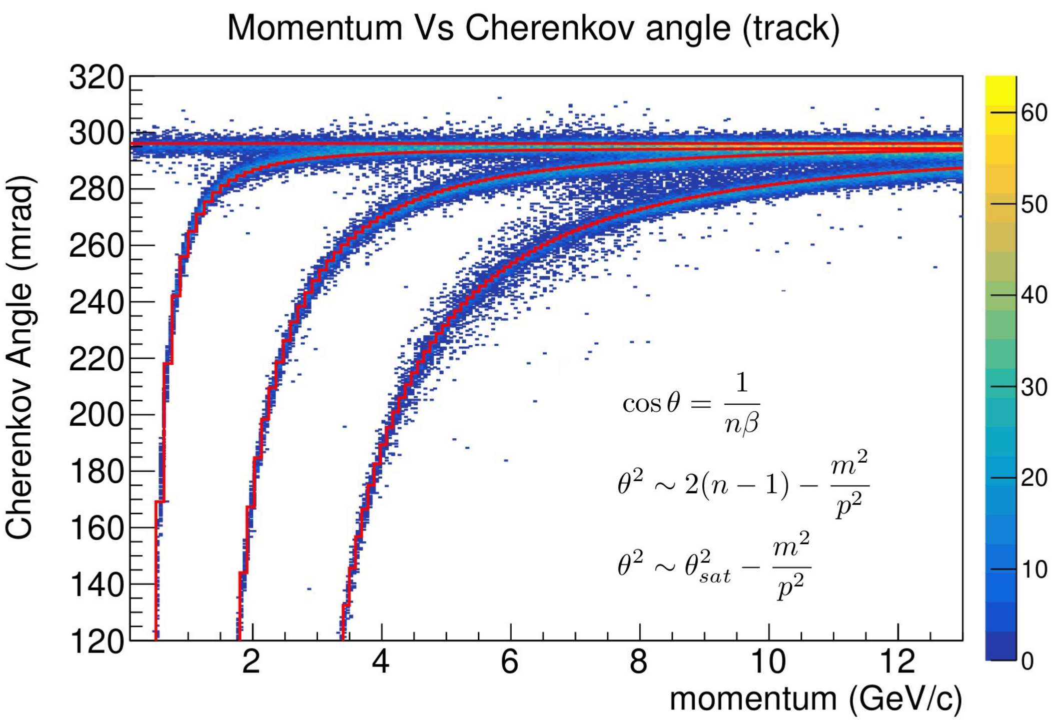


π and K @ 7.25 GeV/c: >4 σ separation

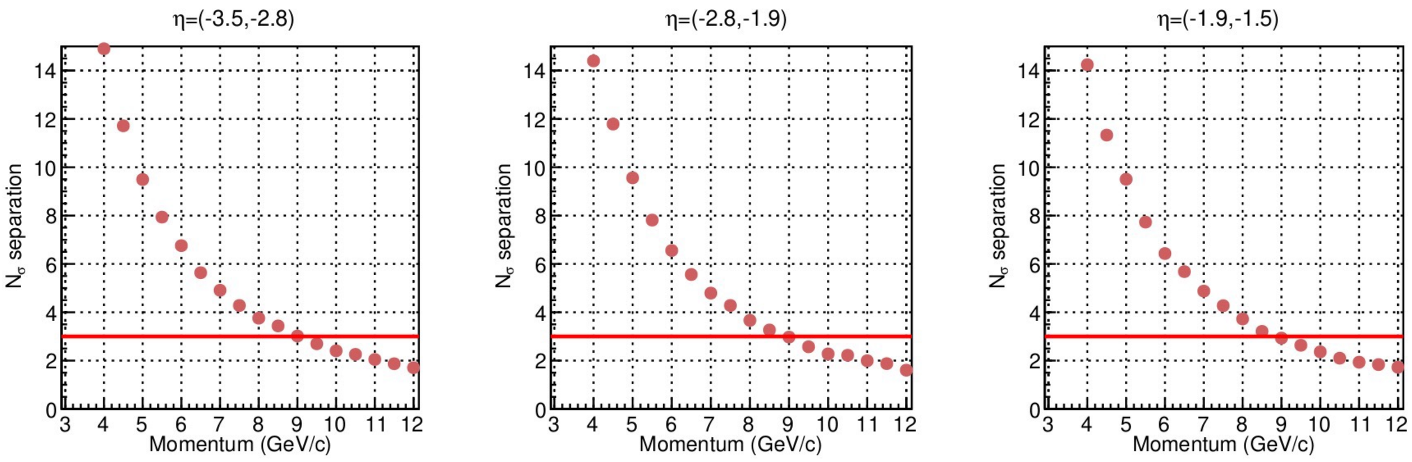


7 GeV/c π and K @ η = -1.9: <5% misidentification rate
(plot accumulated over 1000 two-track events)

(e/)π/K/p separation



e/π/K/p response integrated over the whole η acceptance

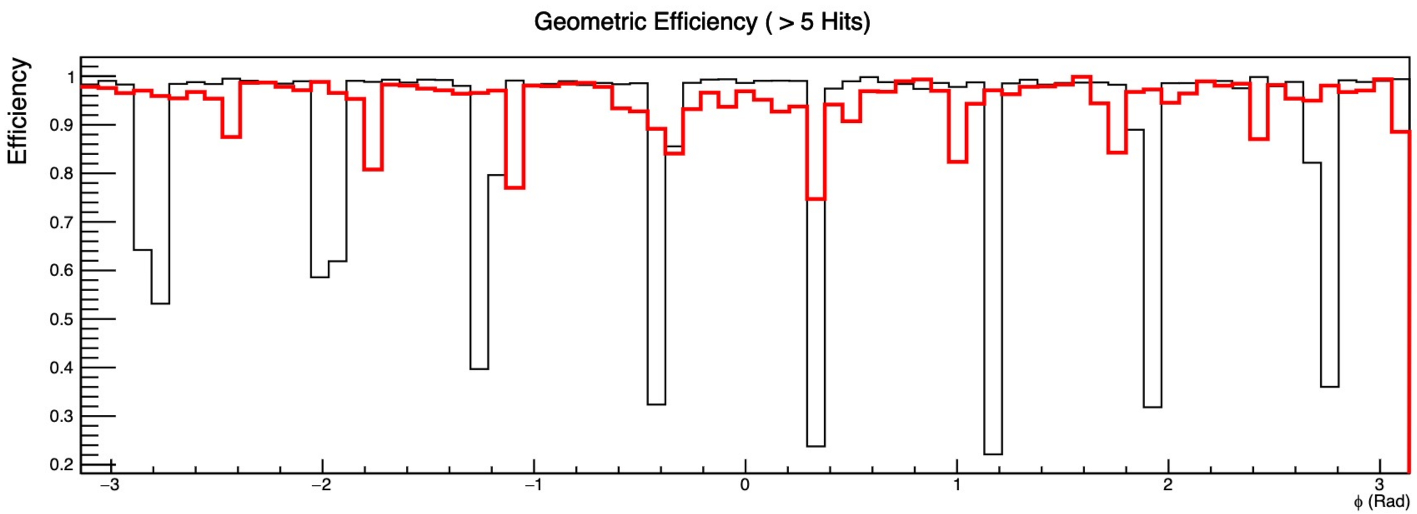


π/K N_σ separation in η bins

- Comfortably reach 7+ GeV/c momentum range with a higher than 3σ π/K separation level

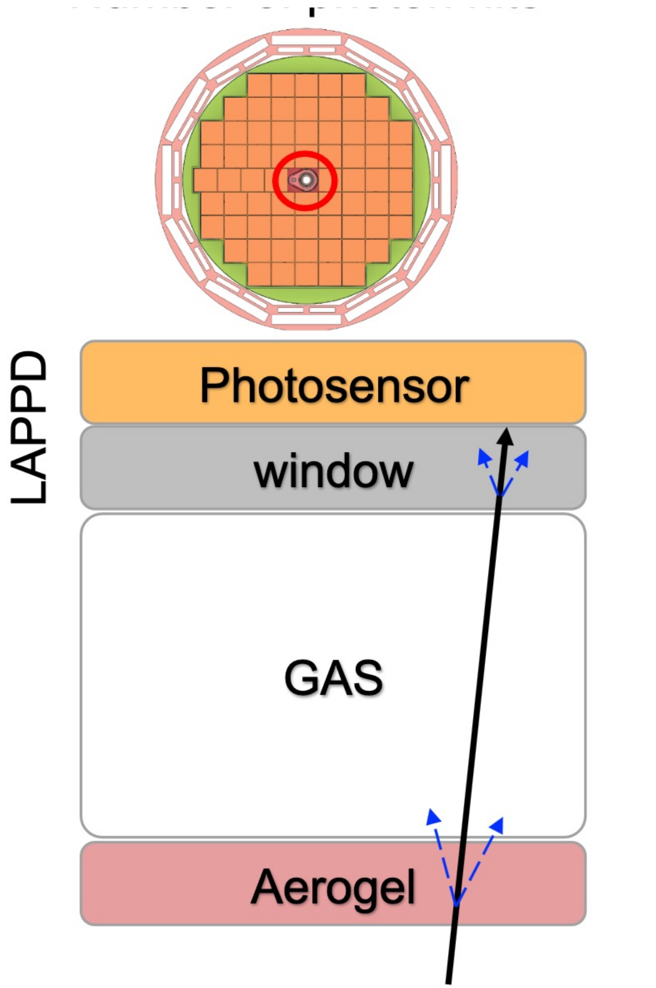
Geometric efficiency for timing purposes

- **ToF** meas. ← # photon hits created by particles
  - pfRICH receives photon hits from aerogel, acrylic filter, gas in expansion volume, and **LAPPD window**
- **Efficiency** (η, ϕ): prob. of particle creating $N_{pe} > 5$.
  - **20 ps t_0 resolution** by having 6 photons, assuming 50 ps single photon time resolution (timing resolution **20ps = 50ps / $\sqrt{6}$**).



Red dips → ribs from Aerogel wall

Black dips → ribs from window ceramic boundary

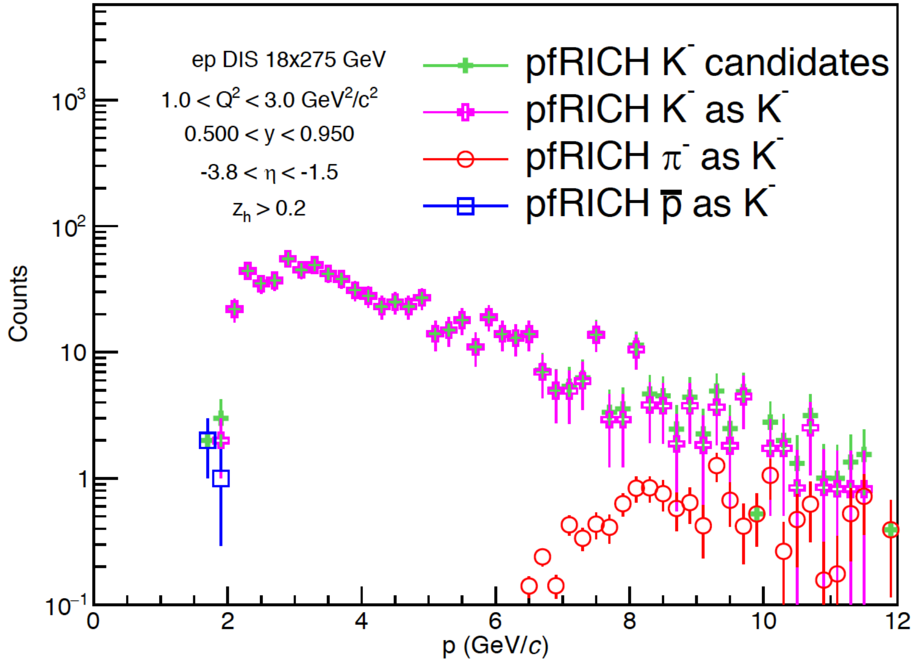


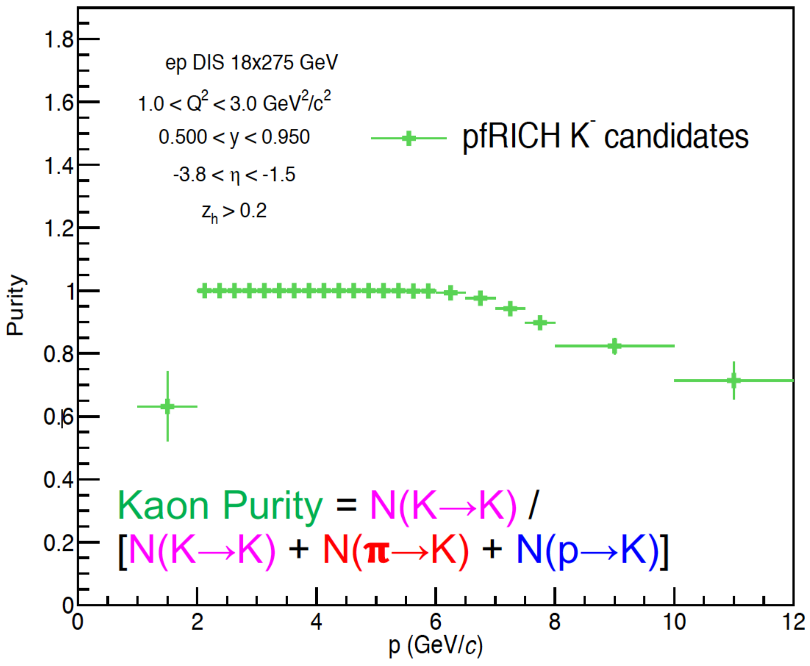
Single Particles fired at $\eta = -3$

- Timing provided by both aerogel ($\langle N_{pe} \rangle$ ~12) and HRPPD window photons ($\langle N_{pe} \rangle$ above 80)
  - Their combined geometric acceptance will be ~100%

SIDIS modeling results

- PYTHIA 18 x 275 GeV simulation
- Parameterized pfRICH hadron PID response, assuming 100% kaon detection efficiency

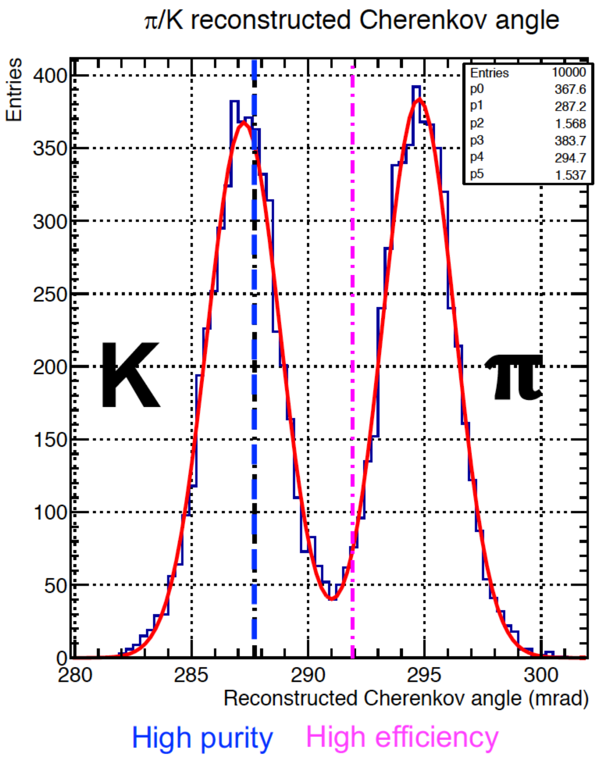


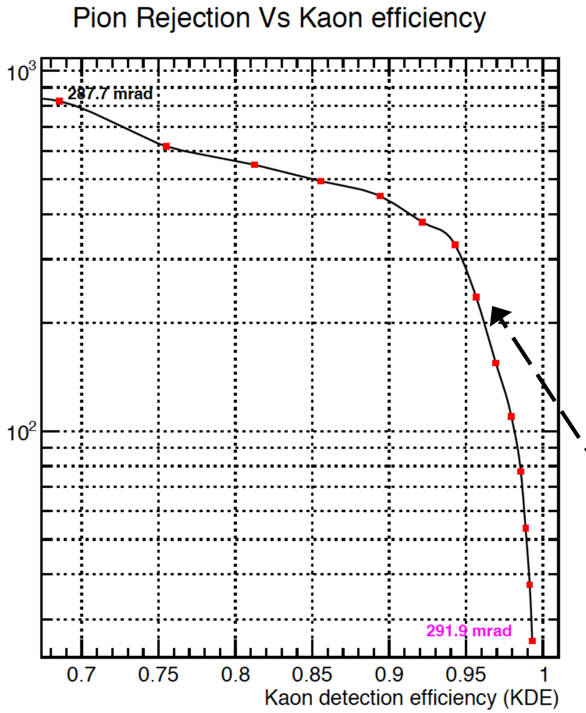


High Kaon Purity ~ 95% at 7 GeV/c

→ this **goes beyond** the requirement of SIDIS physics in the YR

Detection efficiency vs rejection factor argument





For 7 GeV/c pions and kaons:

- Pion Rejection Factor (PRF) as a function of Kaon detection efficiency (KDE) is computed.
- The tunable theta cut is varied from Kaon Cherenkov angle (~287 mrad) to the overlap region (292 mrad).
- PRF > 250 is at 95% KDE.

- Reconstructed Cherenkov photon emission angle is available on a track-by-track basis
  - in a real experiment as well
- A cut on this quantity can be used as a trade off between KDE and PRF

Summary & outlook

- A proximity focusing RICH with HRPPD photosensors is selected for the baseline ePIC configuration
  - Ring imaging and high resolution timing in one detector

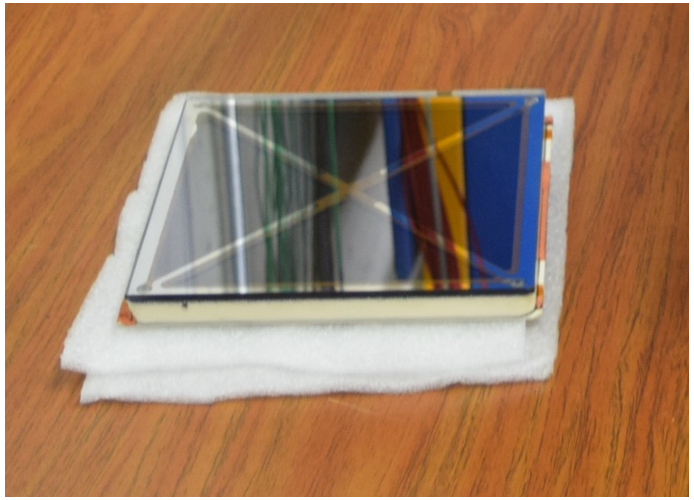
- Monte-Carlo modeling shows that it meets EIC Yellow Report requirements
  - Track-level π/K/p identification up to 7 GeV/c (or higher, if efficiency can be somewhat sacrificed)
  - In particular, will provide high purity kaon samples in the electron-going endcap

- Work on adapting Incom's HRPPDs for EIC needs is ongoing
  - Pre-final HRPPD design by September 2023
  - First five tiles production: one by one between September 2023 and March 2024
  - Comprehensive lab and beam test evaluation as of Fall 2023

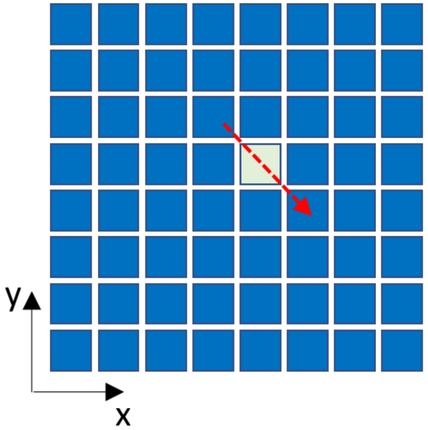
- pfRICH prototype beam test expected in a year from now
  - Confirm π/K separation reach (ring imaging) and high resolution timing performance at once

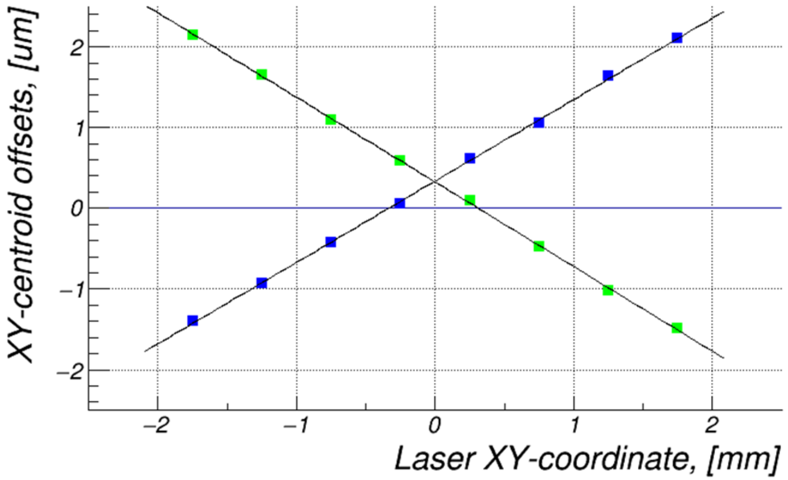
Backup

Spatial resolution with 3mm square pixels



- Gen II LAPPD tile #97 provided by Incom
  - 2mm thick ceramic base

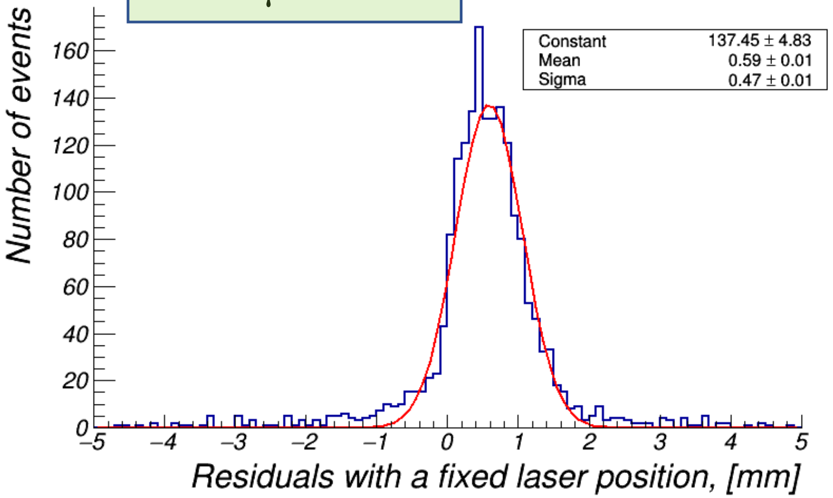




- 8x8 field with 3mm pixels, connected to a pair of V1742s
- Linearity scan along the diagonal direction shown

Photo cathode	2375 V
MCP#1 top	2300 V
MCP#1 bottom	1375 V
MCP#2 top	1175 V
MCP#2 bottom	250 V

~500 μm width

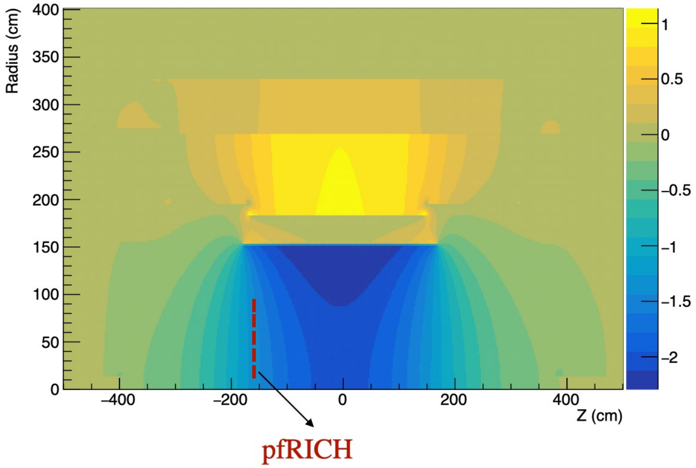


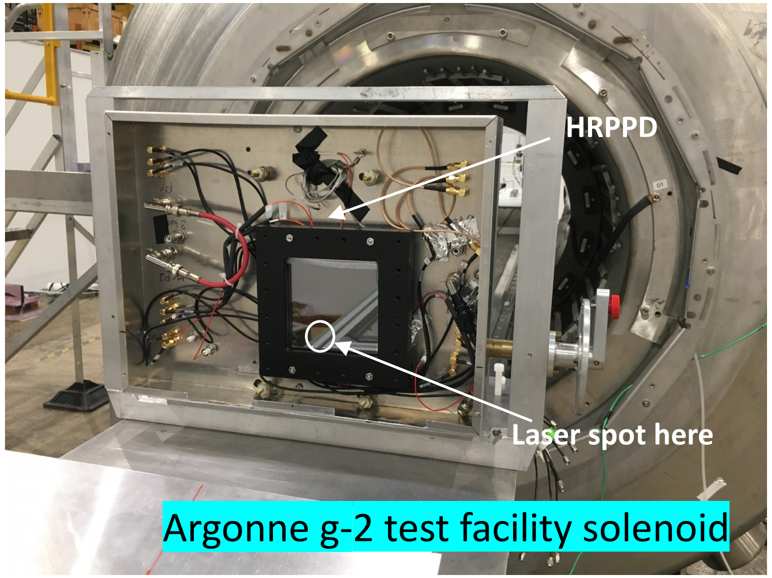
- “Single-photon” mode

$$X \sim \frac{\sum_i^n q_i x_i}{\sum_i^n q_i}$$

HRPPDs in the Magnetic Field

ePIC solenoid magnetic field (Tesla) in **Z direction**;

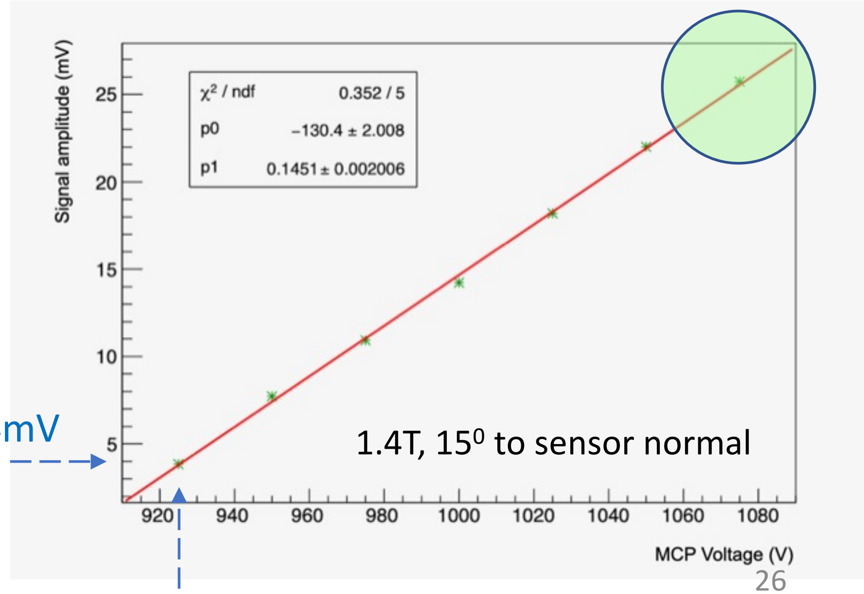




- ➢ In ePIC pfRICH HRPPDs will be exposed to a magnetic field of ~1.4 Tesla at an angle up to 12.6 degrees
- ➢ Tests of a HRPPD prototype in a high magnetic field were carried out by Argonne and Incom using g-2 calibration solenoid
- ➢ Data analysis by eRD110 members of pfRICH team

Preliminary conclusion: gain in this high magnetic field can be fully restored by increasing HV from 925V to ~1075V

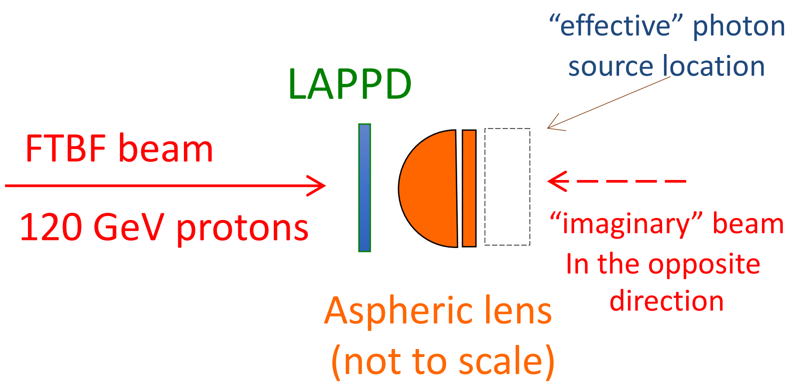
~4mV

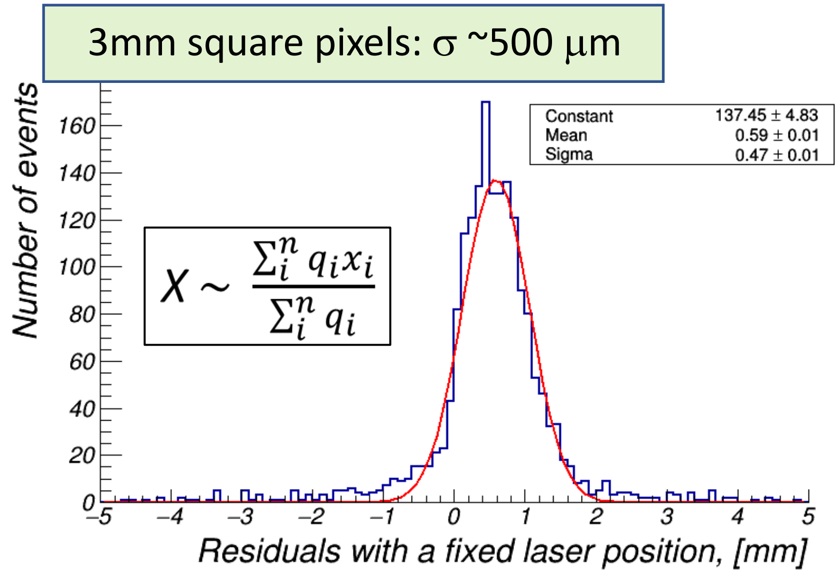


Nominal HV to achieve 25mV signals at B=0T

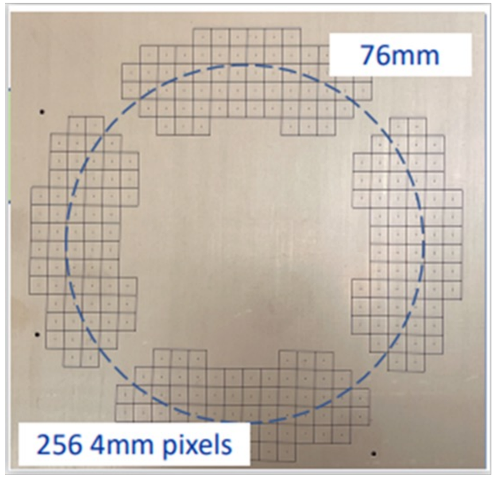
Spatial resolution (capacitively coupled LAPPDs)

Sub-mm level, using 3..6 mm pads

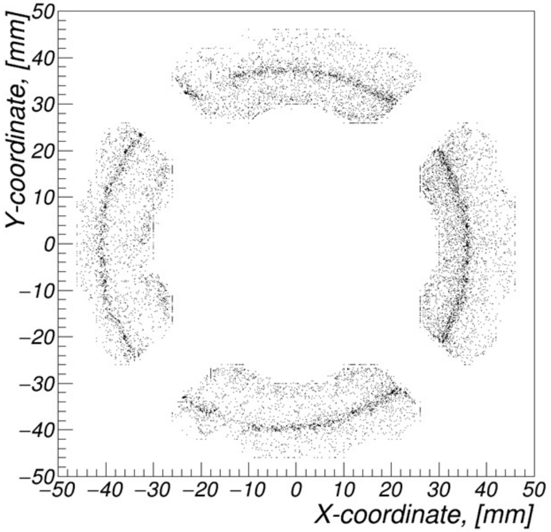


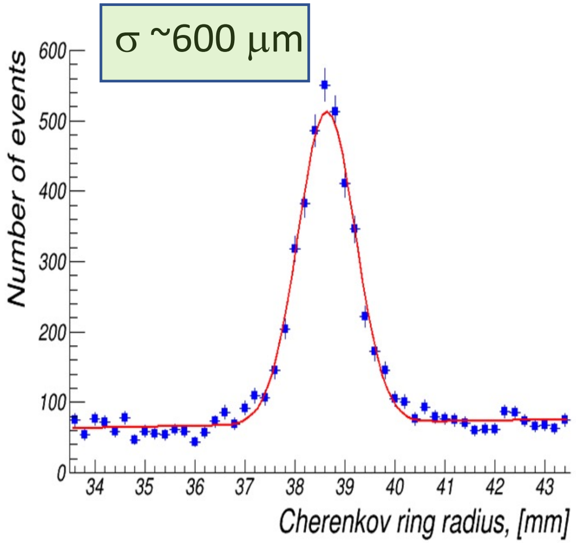


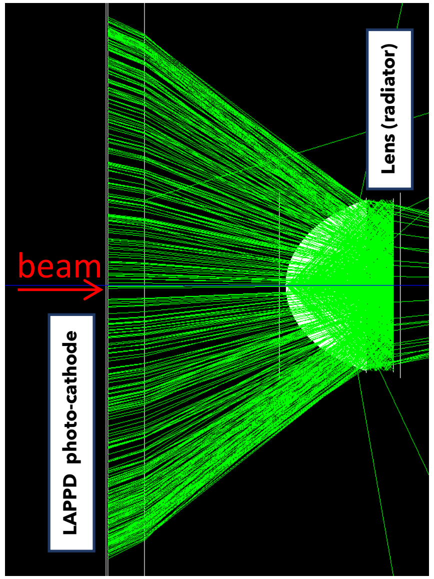
Lab results with a laser



accumulated over several events

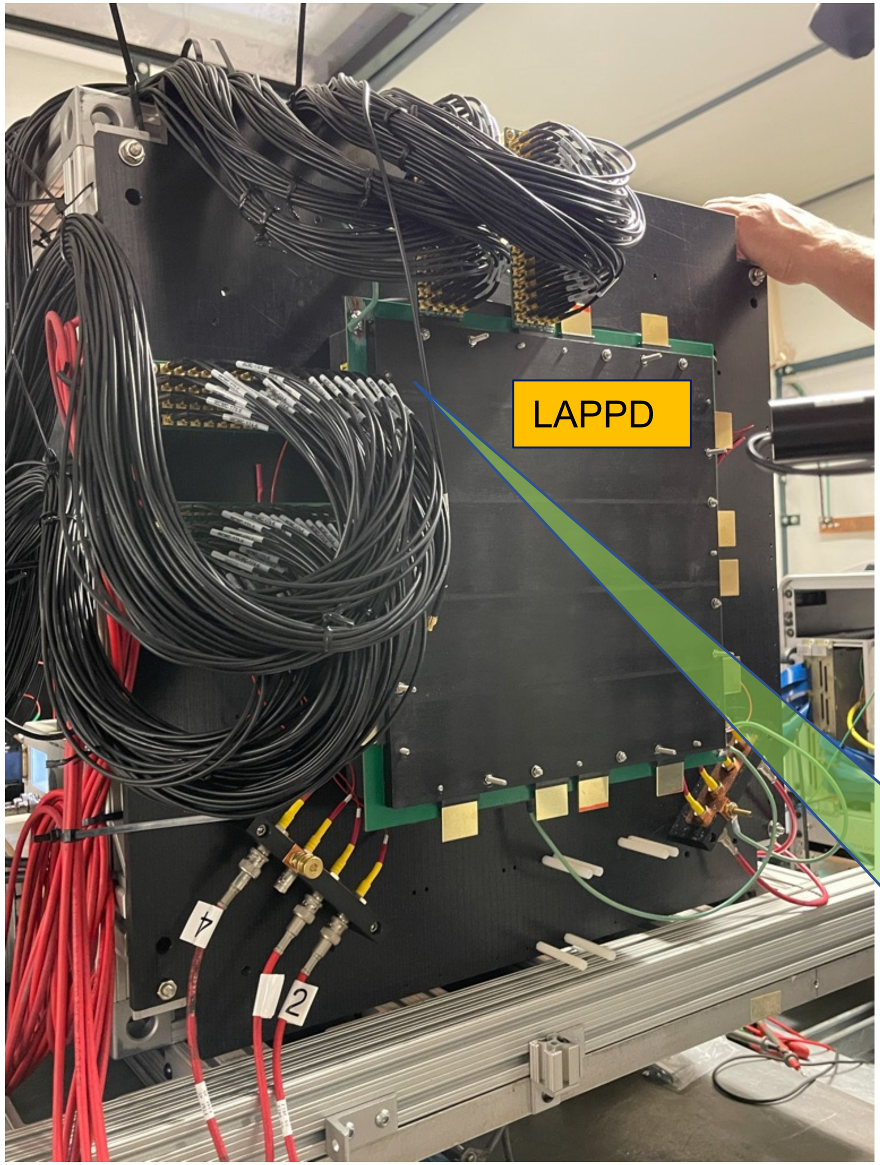




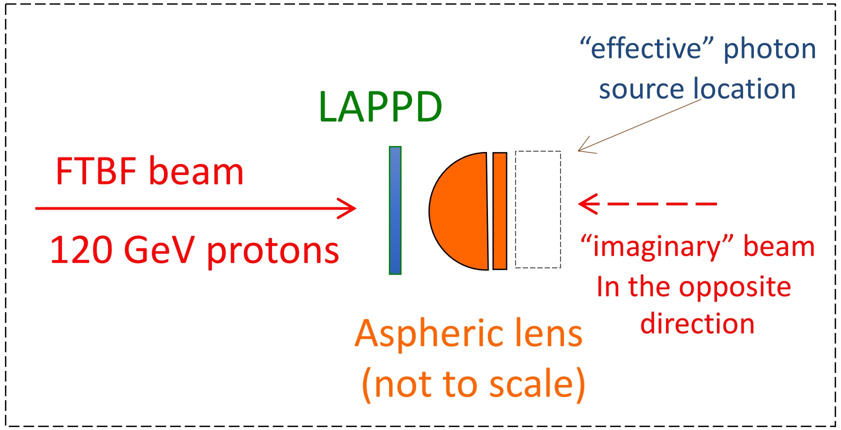


Fermilab beam data

2021 setup and Cherenkov ring radius resolution

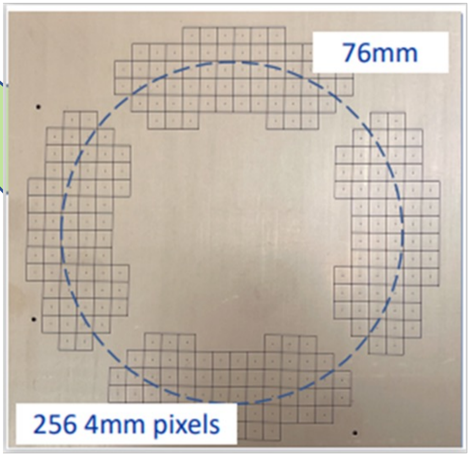


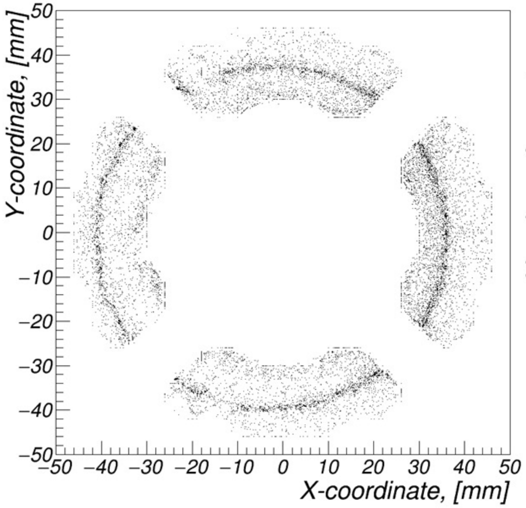
- The same setup as in the lab, but instead of a laser use *a thick aspheric lens* as a well controlled Cherenkov light source

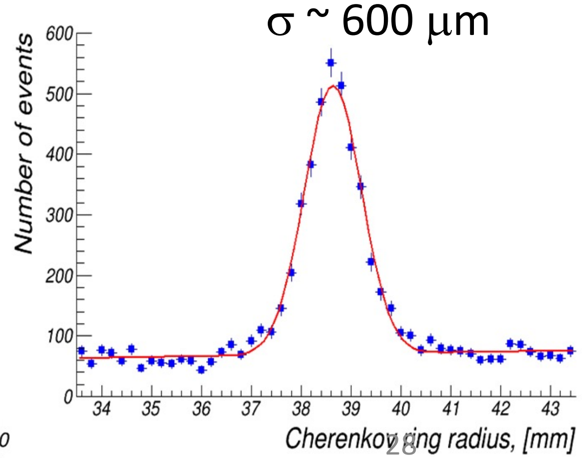


- Off-the-shelf component
- (Almost) no stray photons
- To first order no need in tracking
- The used model (Edmund Optics #67-265, EFL 20.0mm) produces a crisp ~76mm diameter ring at the focal plane

Pixel pattern & accumulated single photon XY-coordinates

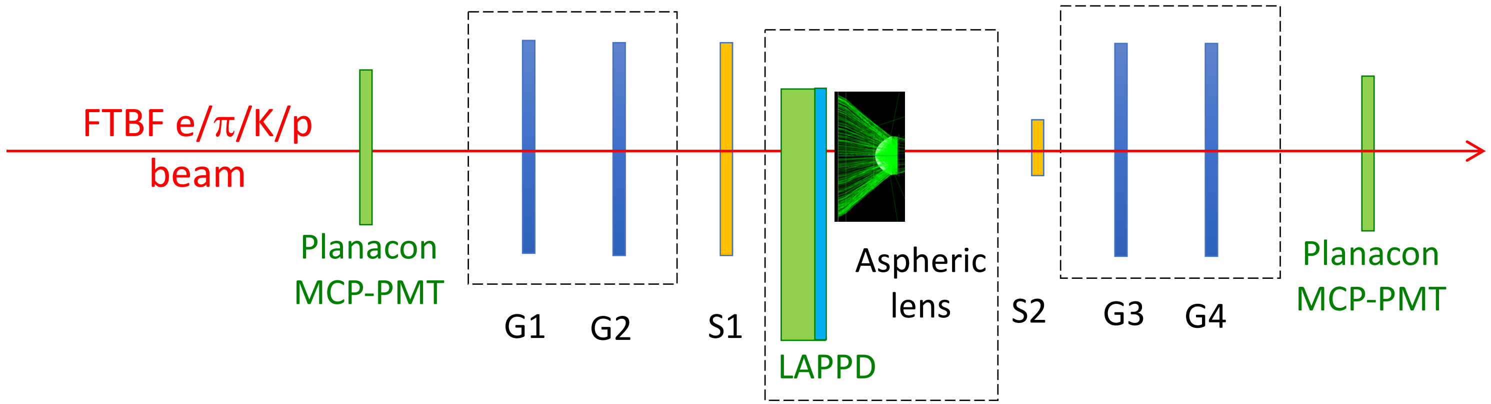


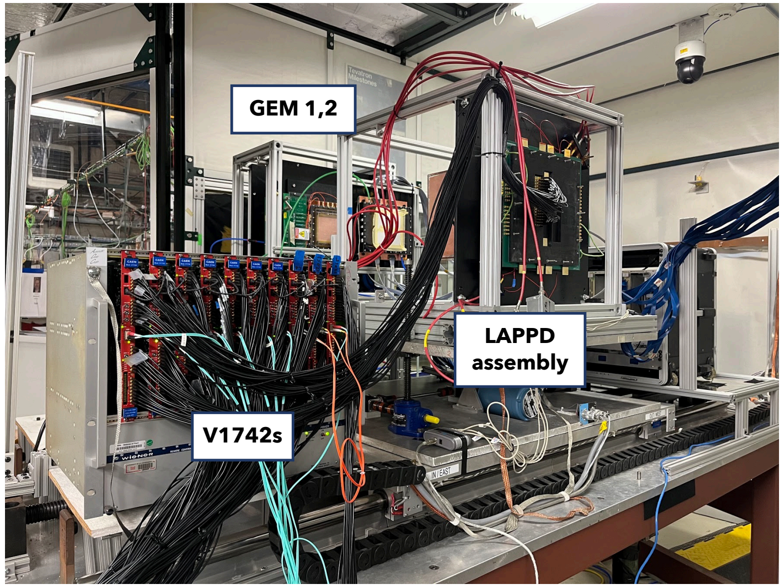




2022 setup

- G1 .. G4 – COMPASS GEM reference tracker
- S1 .. S2 – trigger scintillator counters





- A new 20 cm Gen II LAPPD tile 136
  - 10 μm pore MCPs
  - Full glass body (implies 5 mm thick anode base plate)
  - Window material -> UV grade quartz
- GEM reference tracker
- New set of the pixelated readout boards
- A pair of Planacon MCP-PMTs as a timing reference

Enough data on tape to quantify **single-photon** timing resolution

Aspheric lens as a source of coherent Cherenkov photons