LAPPDs / ePIC pfRICH

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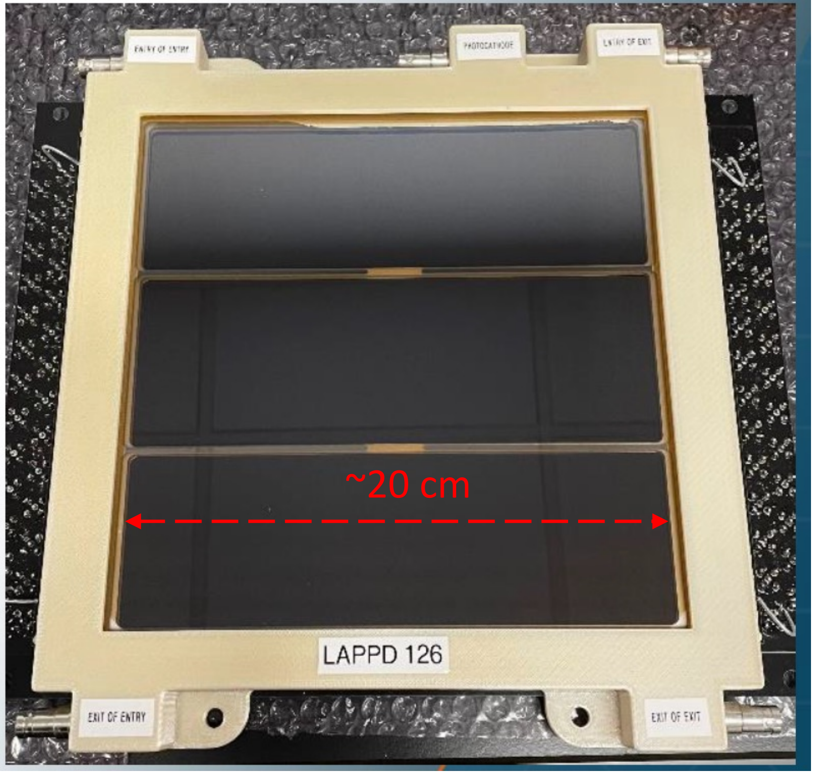
BNL EIC Group Meeting, November 17, 2022

LAPPD / HRPPD

LAPPDs: history & notation

- **2009**: LAPPD Collaboration founded by Prof. Henry Frisch (U Chicago)
  - Motivation: Low cost, large detection coverage with picosecond timing
- **2015**: Early commissioning trials at Incom, Inc.
- **2018**: Demonstrated pilot production of LAPPDs
- **2022**:
  - 141 LAPPDs starts all time
  - 6 HRPPDs starts in 2022
  - Current capability of 36 LAPPDs / year
  - Current max capacity of 96 LAPPDs / year
- **Future**:
  - Improved performance
  - Commercial production

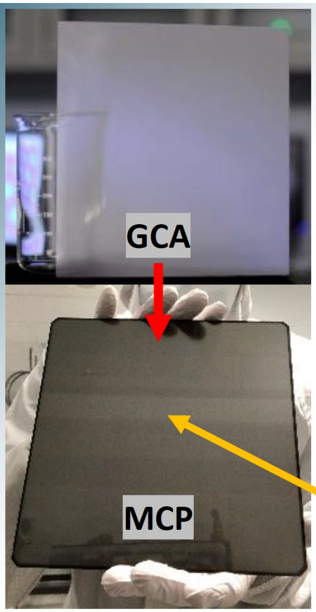
Incom Inc. → (Current capability of 36 LAPPDs / year; Current max capacity of 96 LAPPDs / year)



LAPPD (20cm): Large Area Picosecond Photon Detector

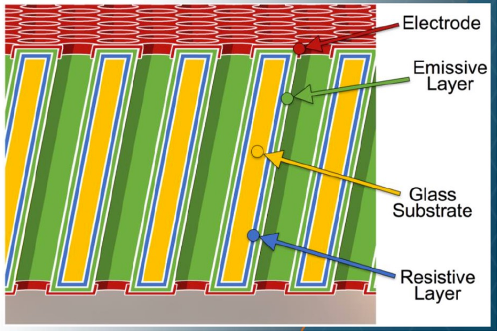
HRPPD (10cm): High Rate Picosecond Photon Detector

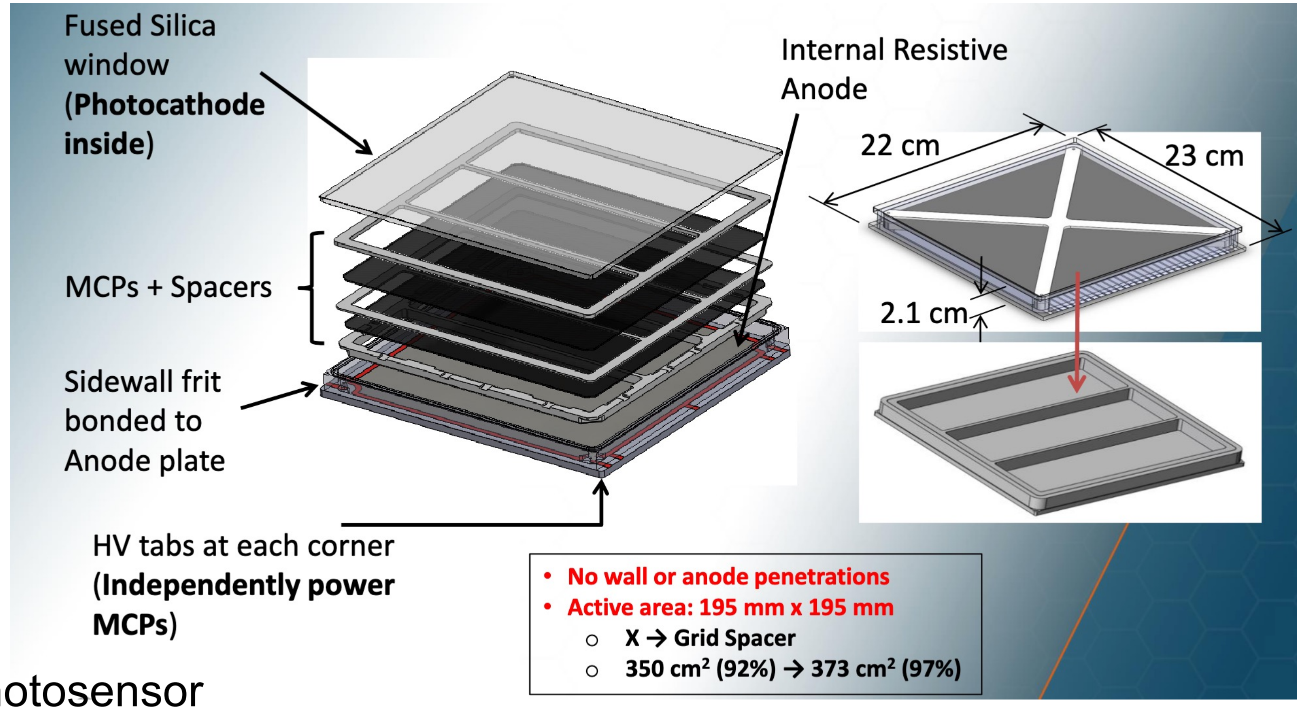
LAPPDs / HRPPDs by Incom Inc.



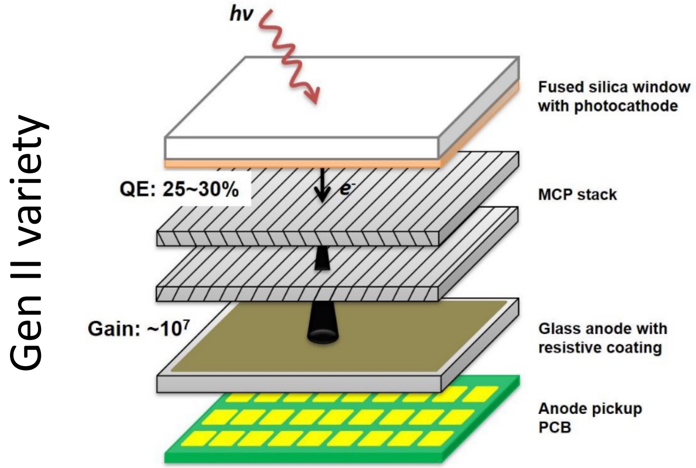
- *Hollow core* **Glass Capillary Array** (GCA) substrate
  - Borosilicate glass (AKA Pyrex)
    - Little radioactive ^{40}K
  - *No etching necessary! Already hollow*
- **Atomic Layer Deposition** (ALD) is a thin-film deposition technique used to functionalize GCAs
  - **GCA + ALD = MCP**
- Flexible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

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

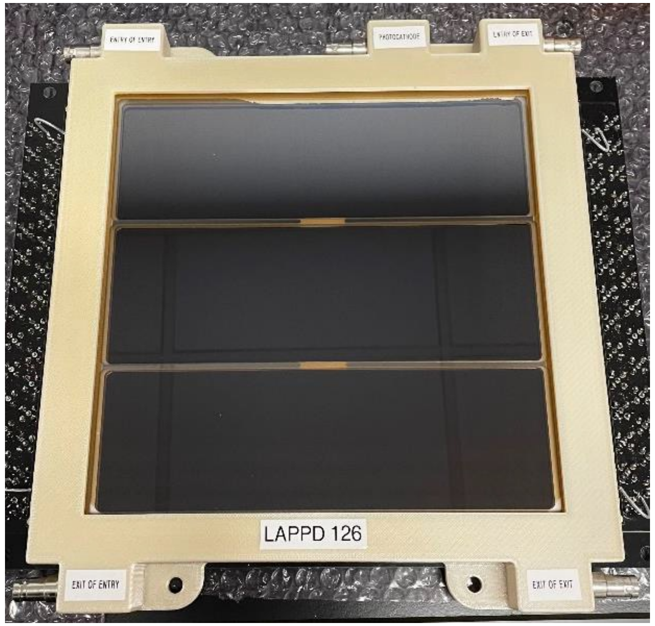




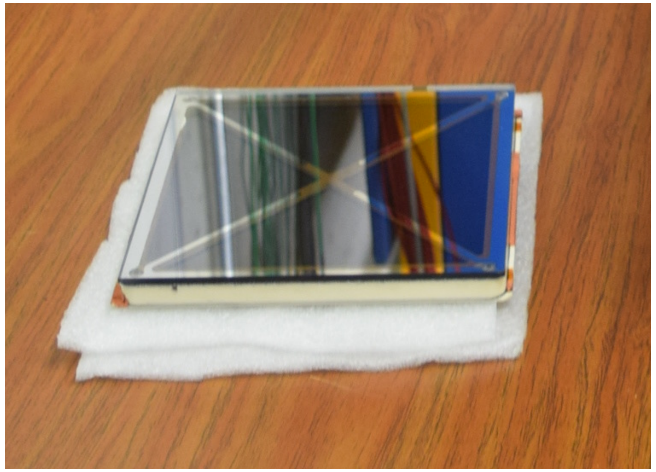
- An affordable large area (finely pixelated) vacuum photosensor
- 10x10 cm^2 or 20x20 cm^2 active area
- DC- (Gen I) or capacitively (Gen II) coupled species
- DC-coupled strips or 2D pixellation
- Expected to be (very) cost efficient in mass production
- High enough quantum efficiency and uniform high gain up to ~10^7
- Sub-mm spatial resolution for finely pixelated tiles
- Single-photon timing resolution on a ~50ps level or higher



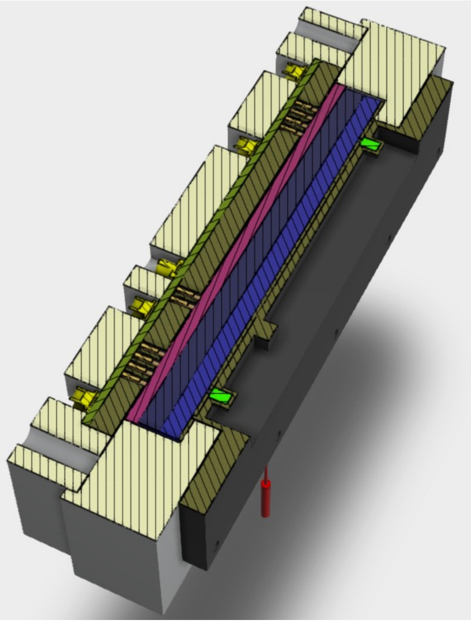
Picture gallery

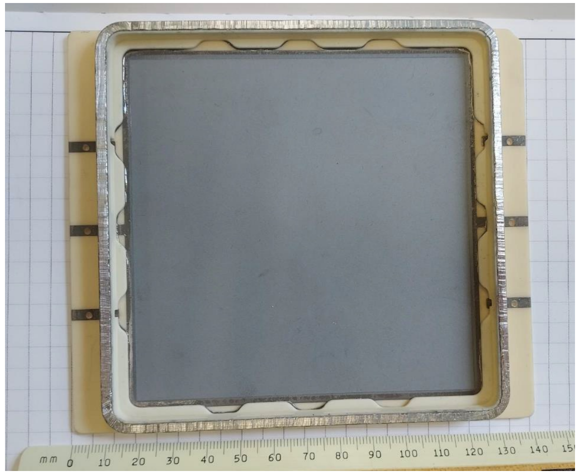


Capacitively coupled 20cm LAPPD

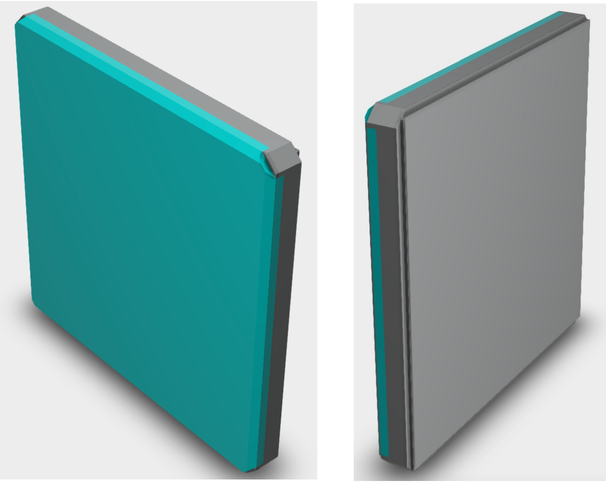


DC-coupled 10cm HRPPD





Capacitively coupled 10cm HRPPD

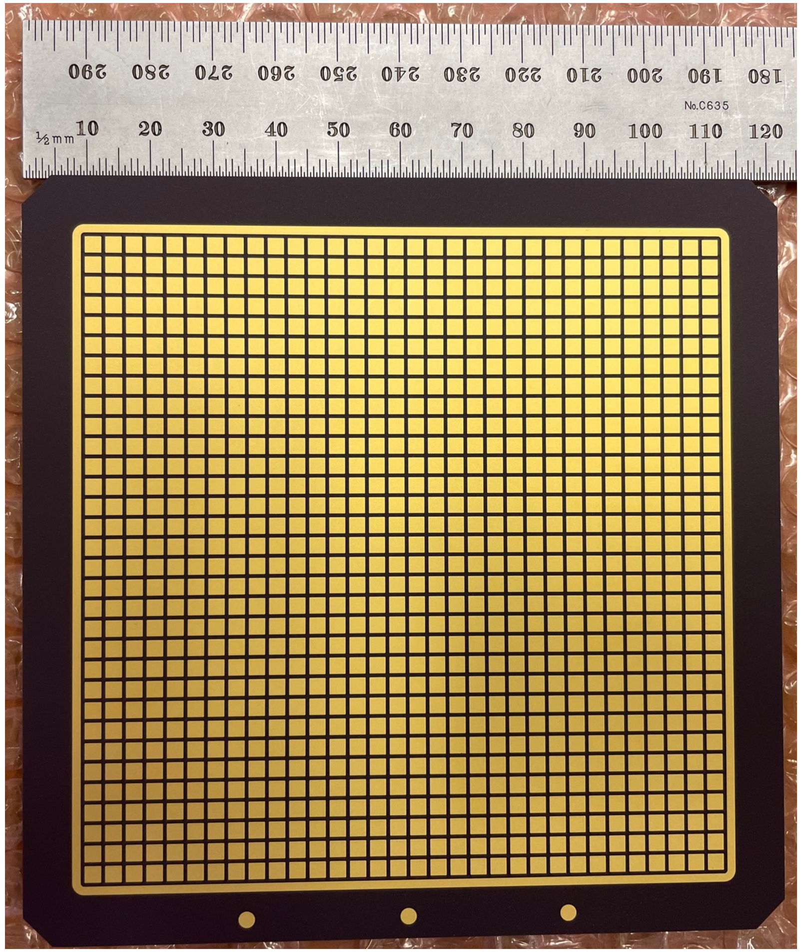


Current focus: “shape them up”

- None of them was initially designed for high geometric acceptance efficiency

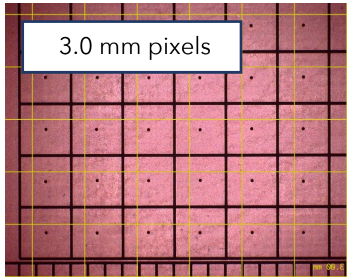
Pixellation (for Cherenkov imaging purposes)

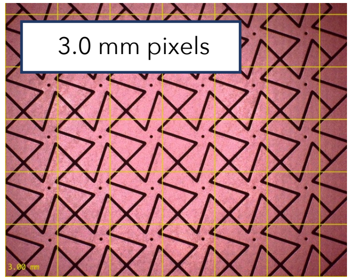
DC-coupled HRPPD

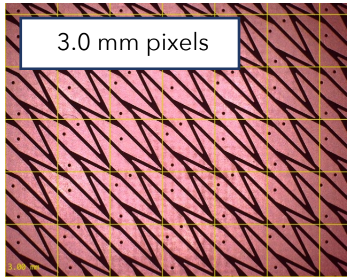


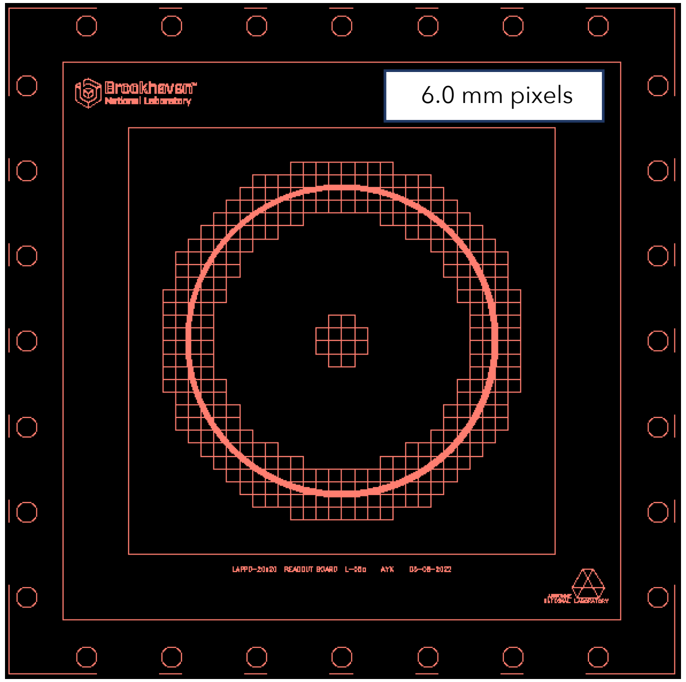
- ~100x100 mm^2 active area
- 1024 pads, 1/8” (~3.2 mm) pitch

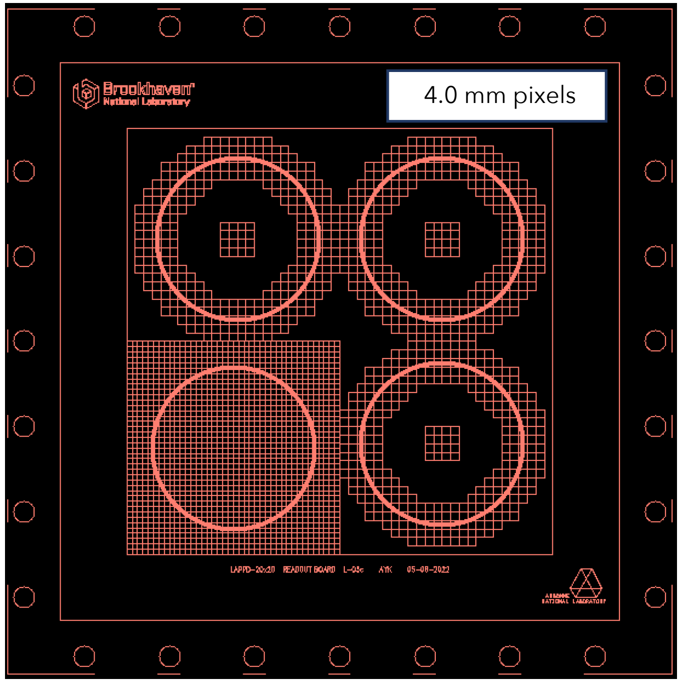
Capacitively coupled LAPPD / HRPPD









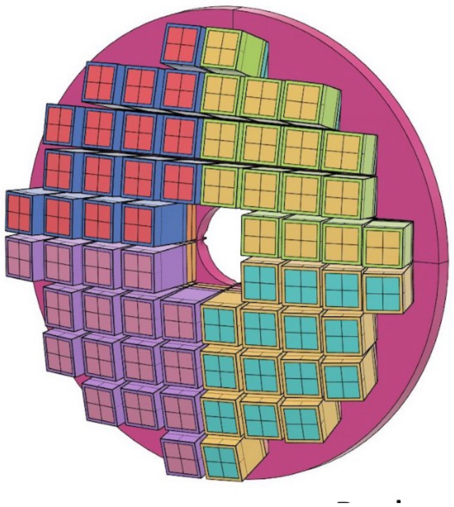


- Pixellation is defined by the user

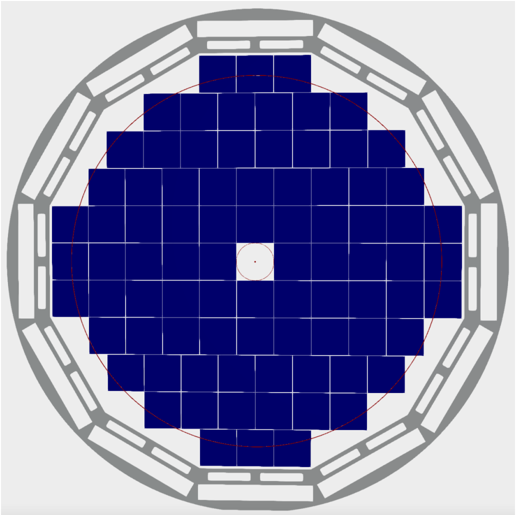
Possible applications in the EIC

- mRICH / pfRICH: low dark noise, Time of Flight capability (vs SiPMs)
- DIRC: expected to be more cost-efficient (vs other MCP-PMTs)
- dRICH: problematic, because of the magnetic field orientation
- Preferred variety:

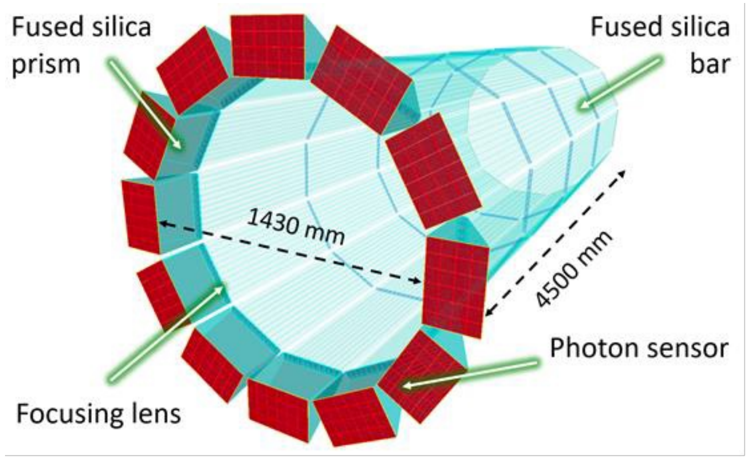
mRICH	either DC-coupled or Gen II, 10cm formfactor
pfRICH	Gen II, either 10cm or 20cm
DIRC	DC-coupled, 10cm



mRICH: 64 tiles total

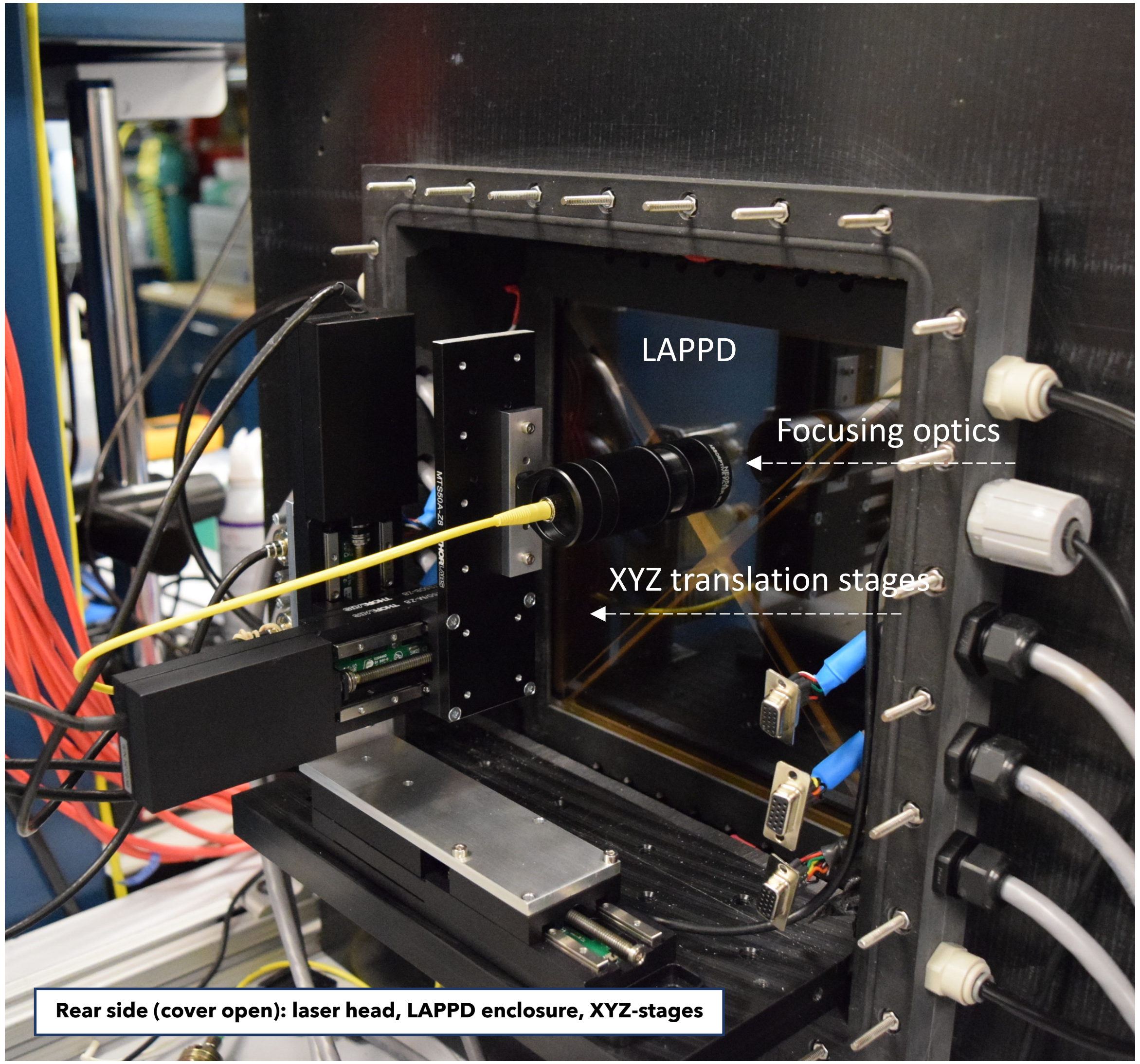


pfRICH sensor plane: 84 tiles total



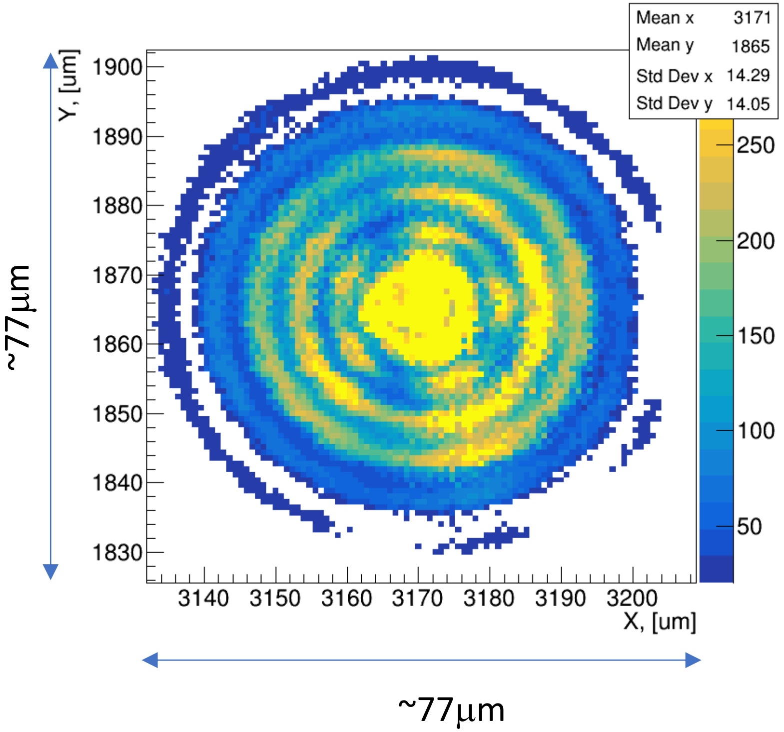
DIRC: 12*3*2 = 72 HRPPDs total

Test setup at BNL

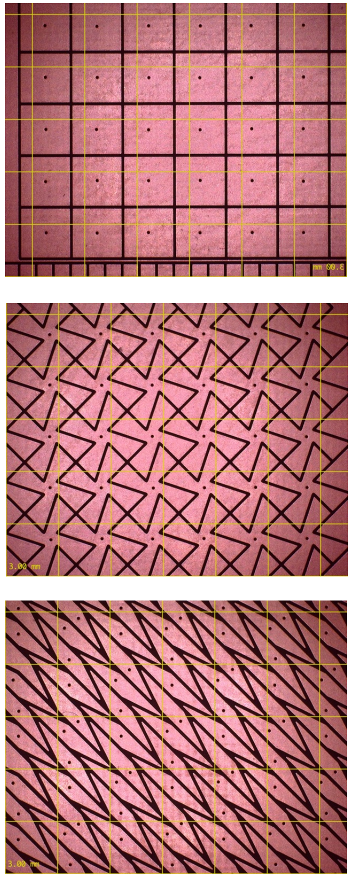


Rear side (cover open): laser head, LAPPD enclosure, XYZ-stages

- Remotely controlled XYZ-stages
- 420nm pulsed "picosecond" laser (spot size <100 μm)
- A variety of multi-pattern pixelated readout boards

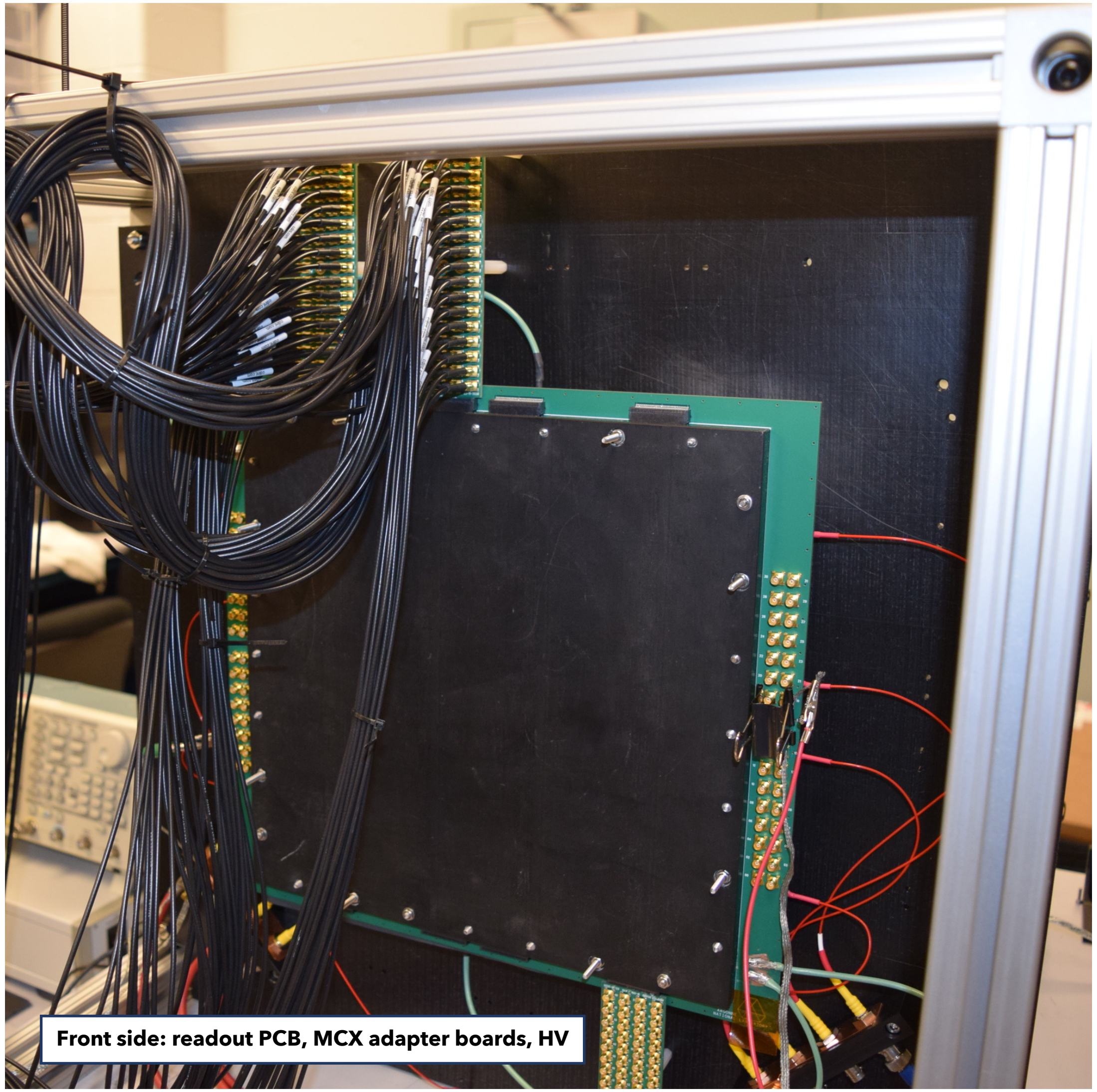


Laser spot as measured by a CMOS camera



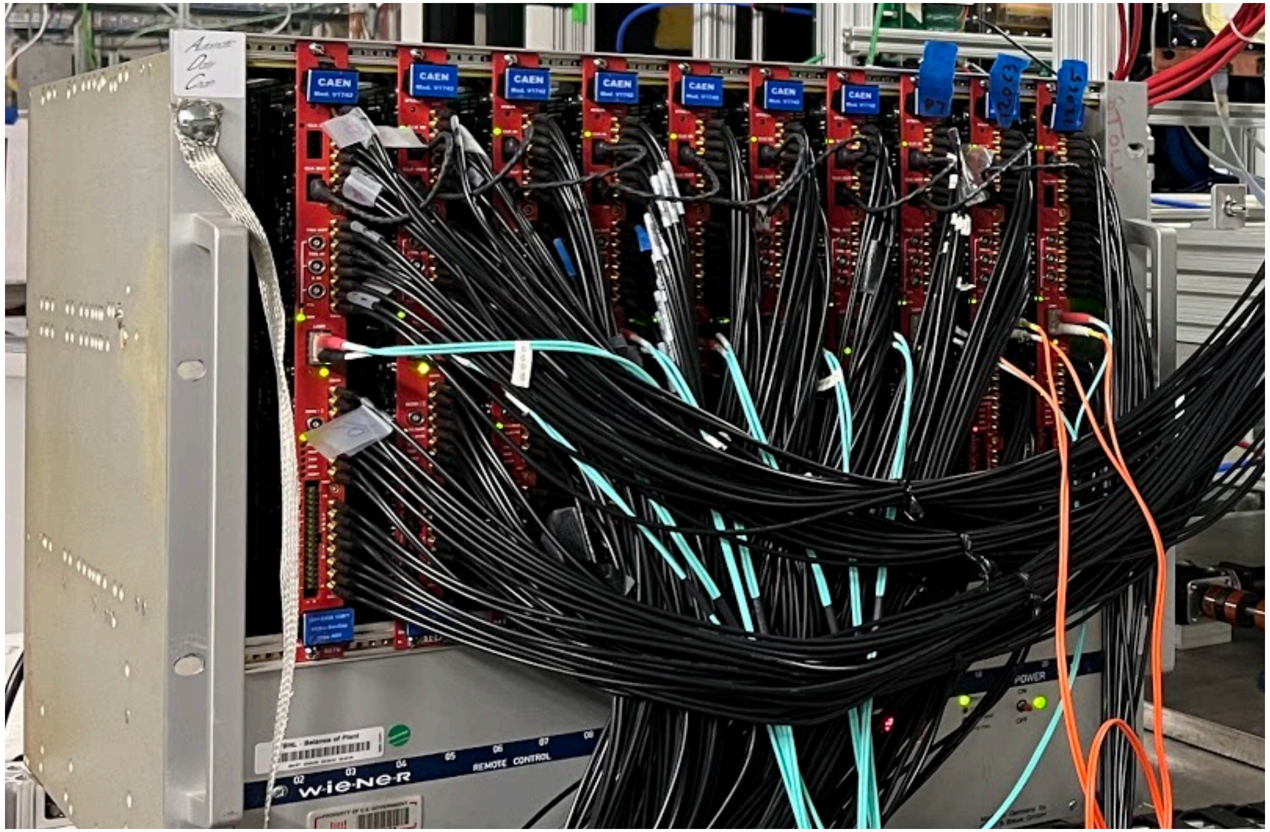
here: all 3mm pitch

Test setup at BNL



Front side: readout PCB, MCX adapter boards, HV

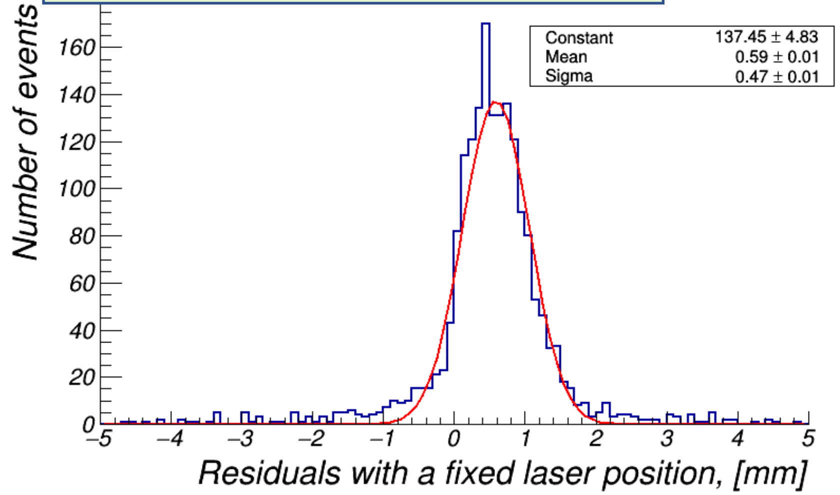
- Light-tight enclosure
- 320 (512) DRS4 channels (V1742 digitizers)
- MCX to high-density Samtec adapter cards
- Coming soon: femtosecond laser



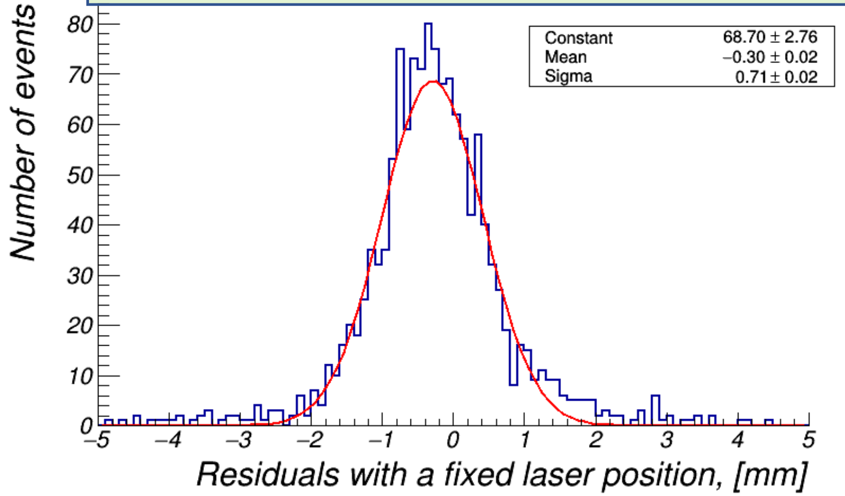
Modular setup: it takes one only half an hour to exchange (or rotate) the readout board

Our spatial resolution results

3mm square pixels: σ ~500 μm

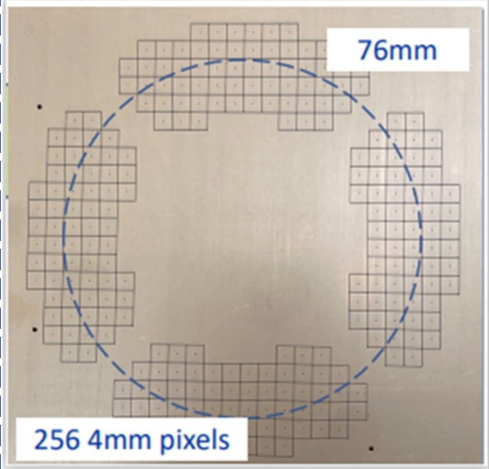


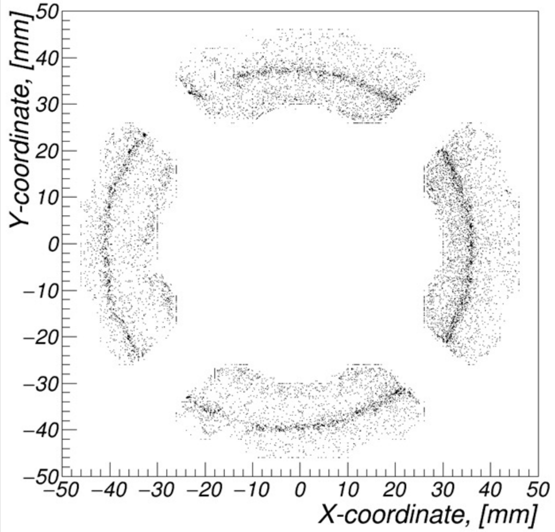
6mm segmented pixels: σ ~700-800 μm



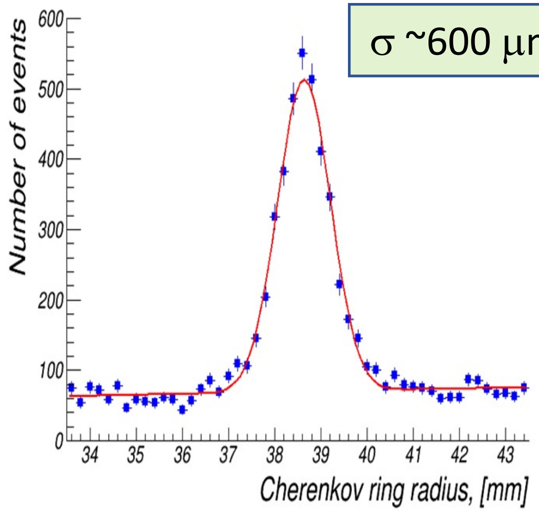
Lab results with a laser

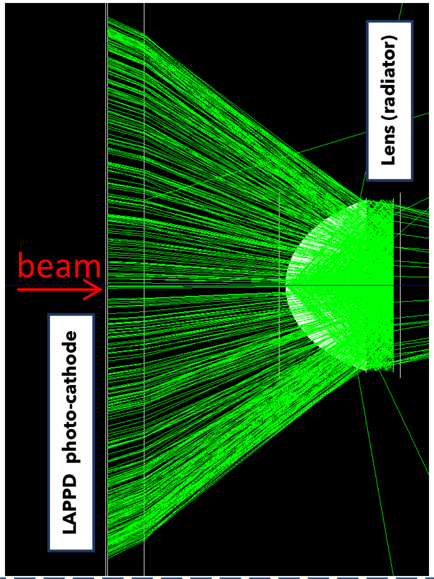
$$X \sim \frac{\sum_i^n q_i x_i}{\sum_i^n q_i}$$





σ ~600 μm

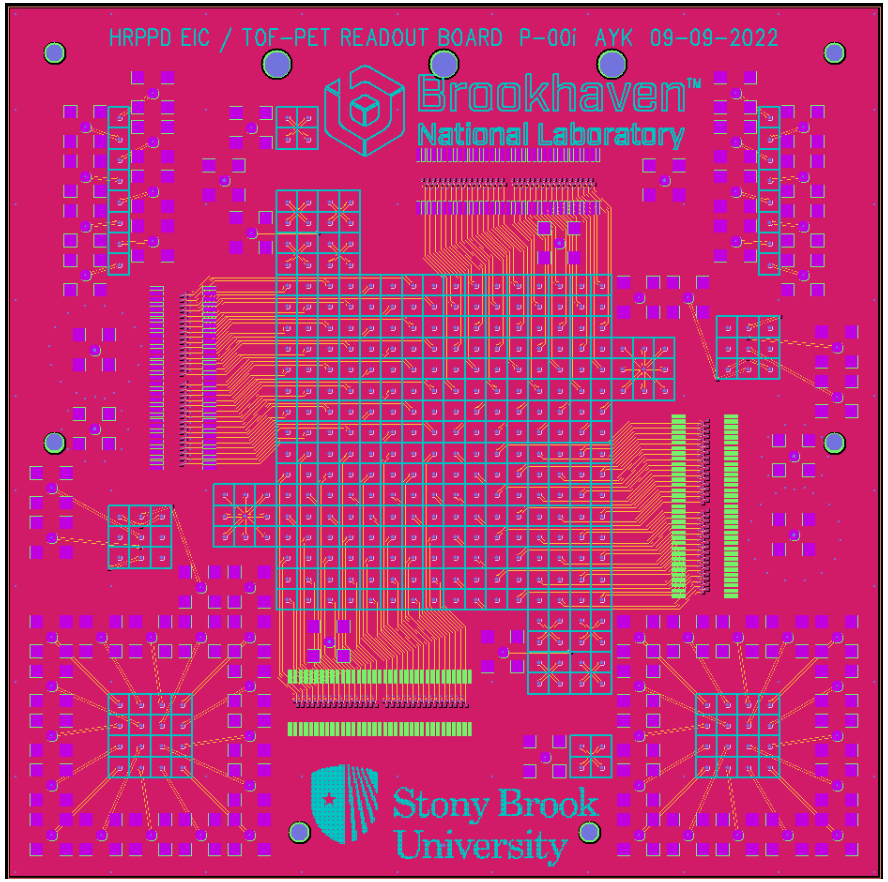


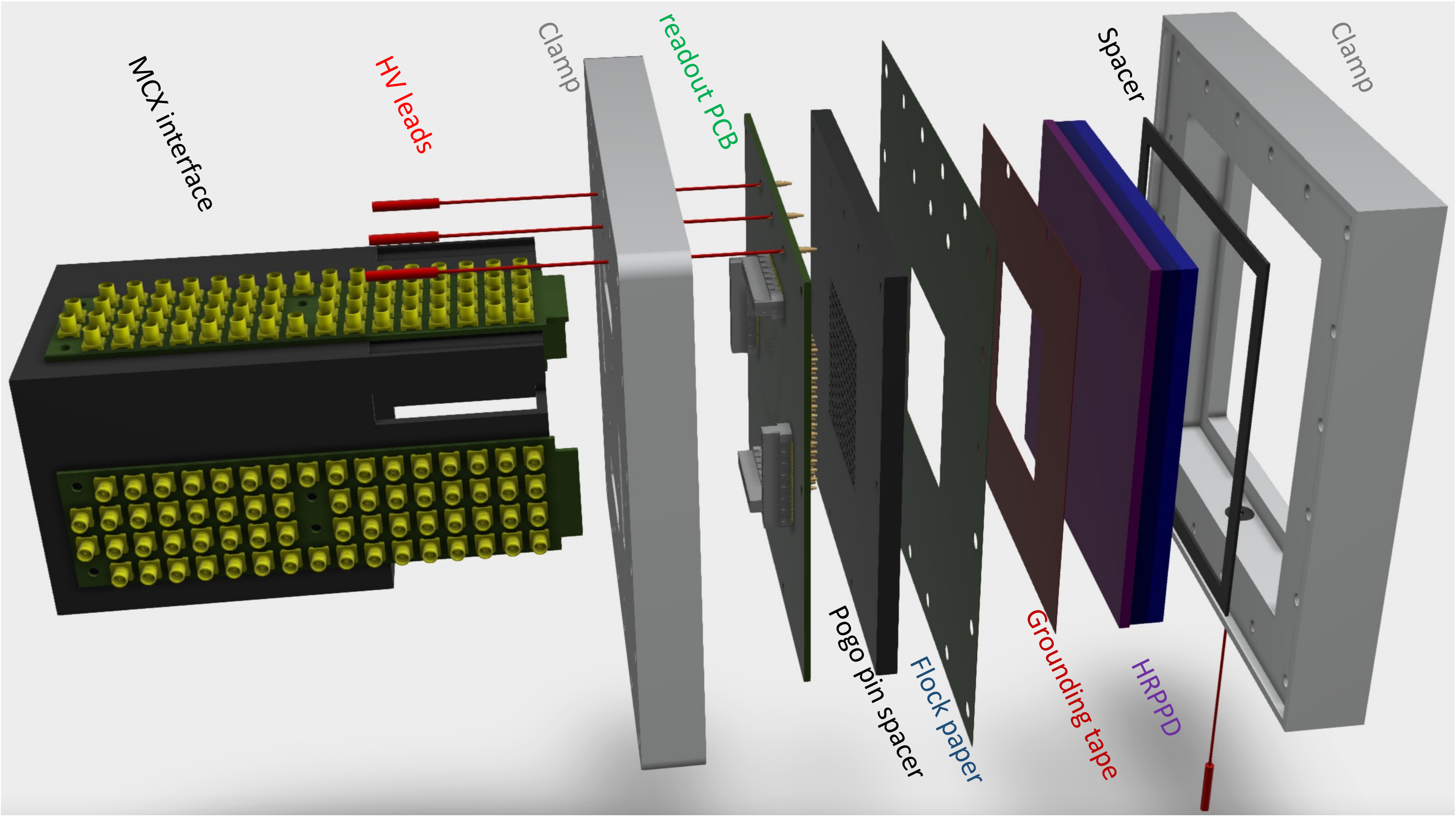


Beam data

Sub-mm resolution, even without pre-amplification

DC-coupled HRPPD evaluation





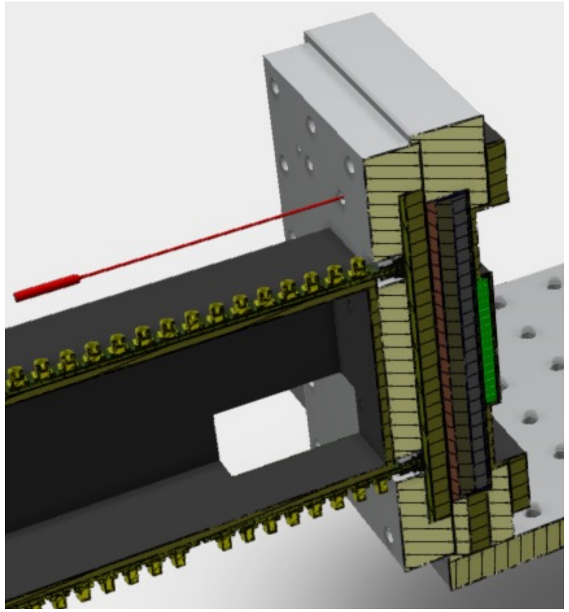
- Recent effort
  - Readout boards are being assembled this week by a PCB shop
  - Enclosure parts are machined, and / or 3D printed

SBU / BNL Seed Grant proposal

- *"LAPPDs for TOF PET: a breakthrough in ultra-high sensitivity Positron Emission Tomography using fast affordable Micro-Channel Plate photomultipliers"* was approved and started in July 2022
  - Quite some synergy with the HEP / NP LAPPD R&D activities

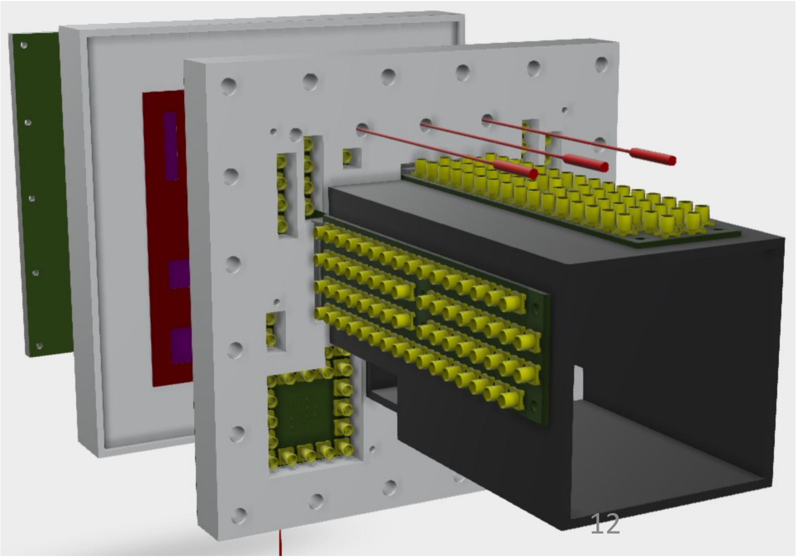
Combine expertise and equipment gained via the earlier and ongoing NIH- & DOE-funded projects with a brand new Incom HRPPD as a photosensor

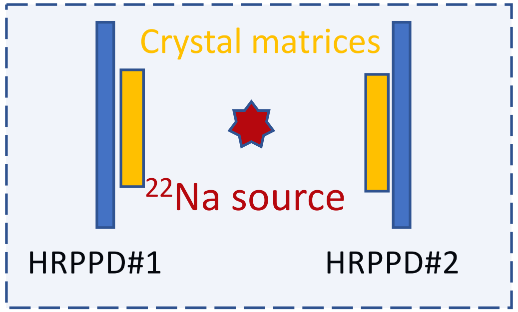
- Same readout board as to be used for EIC-related HRPPD evaluation
- 16x16 LYSO crystal matrices matching HRPPD pixellation
- Prism-PET for Depth-of-Interaction compensation
- 512 DRS4 electronics channels

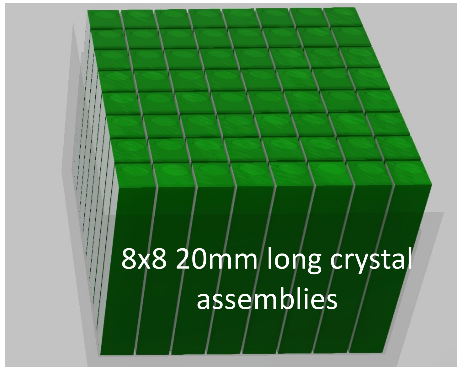


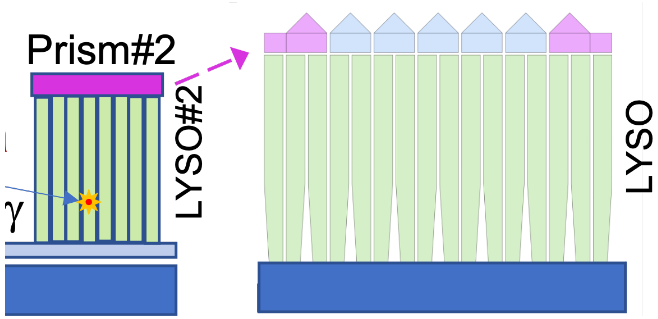
Assembly variant with a 16x16 5mm long crystal matrix

Assembly variant for systematic studies









eRD110: FY23 R&D plan & proposed milestones

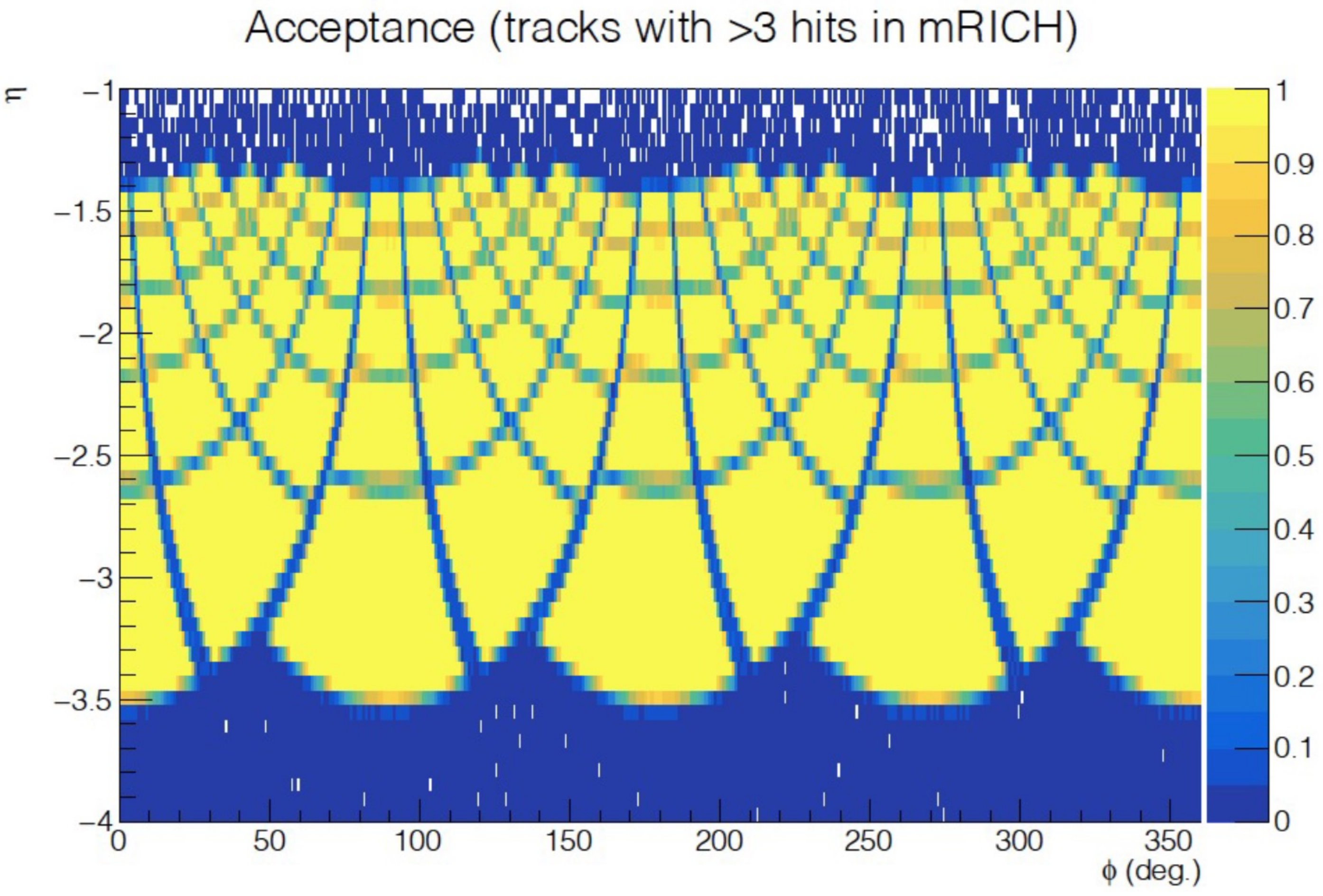
Task	Details	Timeline
LAPPD / HRPPD characterization in the magnetic field	At least one state of the art Gen II and one DC-coupled tile, as pre-selected by the spatial and timing resolution studies; gain dependency on the field-to-normal angle and feasibility of gain recovery by the HV settings tuning	September 2023
DC-coupled HRPPD interface feasibility study	Limitations of the DC-coupled interface in terms of the tile footprint increase, and pad density per cm^2 unless using custom low insertion force sockets	May 2023
Report on a simultaneous spatial and timing performance optimization for a selected subset of Gen II and DC-coupled tiles	Cluster size, spatial and timing single photon resolution evaluation for pixel sizes anticipated for ePIC mRICH/pfRICH and DIRC detectors	September 2023
Report on a "routine" Q&A characterization of a selected subset of tiles	Gain and QE uniformity	September 2023

ePIC pfRICH

(BNL, Duke, INFN Trieste, MSU, SBU)

Objective(s) as formulated in September 2021

- Look for a “simple” RICH version which
  - Would meet the YR requirements
  - Is kind of “safer” & easier to defend at the proposal writing stage, given the absence of a direct experimental proof of a π/K separation reach by mRICH
  - Has perhaps a similar material budget
  - Is easier to have implemented in the ~~ATHENA~~ *ePIC* simulation (and reconstruction!) sequence NOW
  - Does not preclude one from thinking of a Fresnel-lens-based upgrade to boost the performance

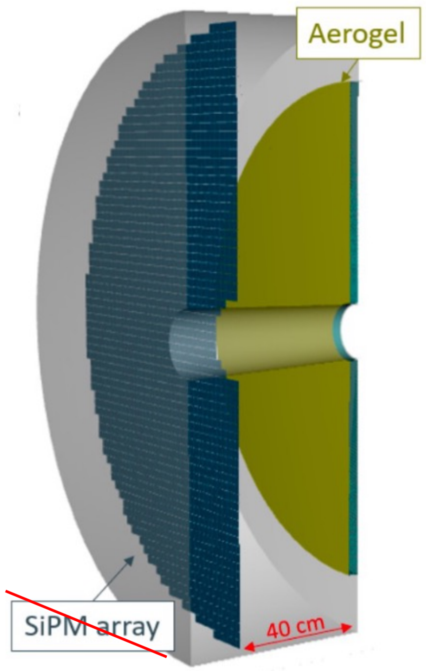


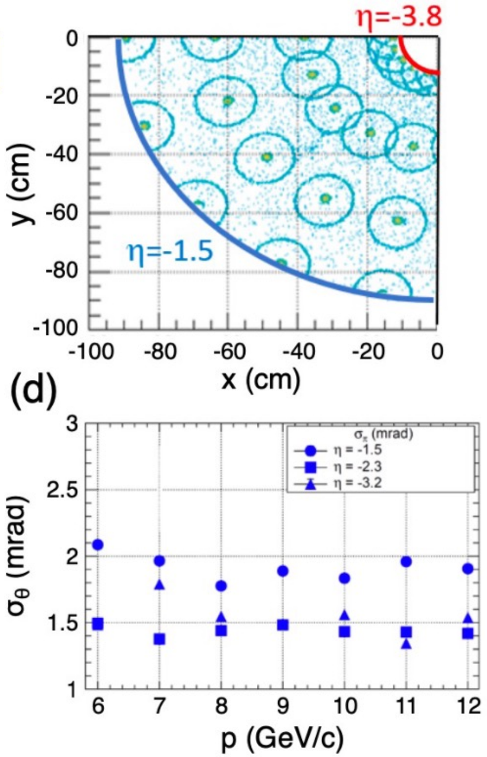
π^- p:05-11.5 GeV/c && $-4 < \eta < -1$ and full azimuth
vertex (x,y,z) = (0,0,0)
Efficiency = (Tracks with at least 3 hit in mRICH)/ (all tracks)

The Yellow Report leaves some wiggle room for interpretation for the hadron PID in the electron endcap: 3σ π/K separation up to 7 GeV/c (page 21) or up to 10 GeV/c (table 3.1)

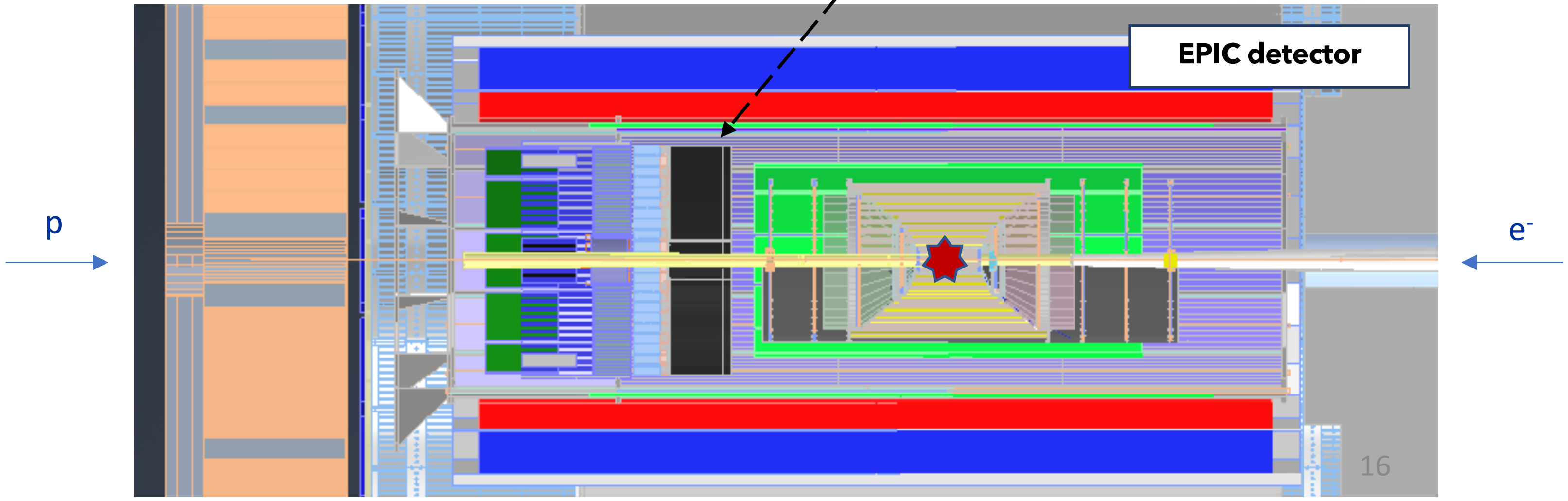
Detector concept

- Recycle pfRICH concept & simulation materials from the ATHENA EIC proposal
  - A "simple" proximity focusing RICH
  - n ~ 1.020 – 1.050 aerogel (perhaps in a two-layer configuration)
  - ~40 cm long expansion volume
- Convert it into a pfRICH+LAPPD configuration ...
- ... complemented by a high-performance (sampling digitizer) electronics to provide ~10ps timing reference in addition to imaging





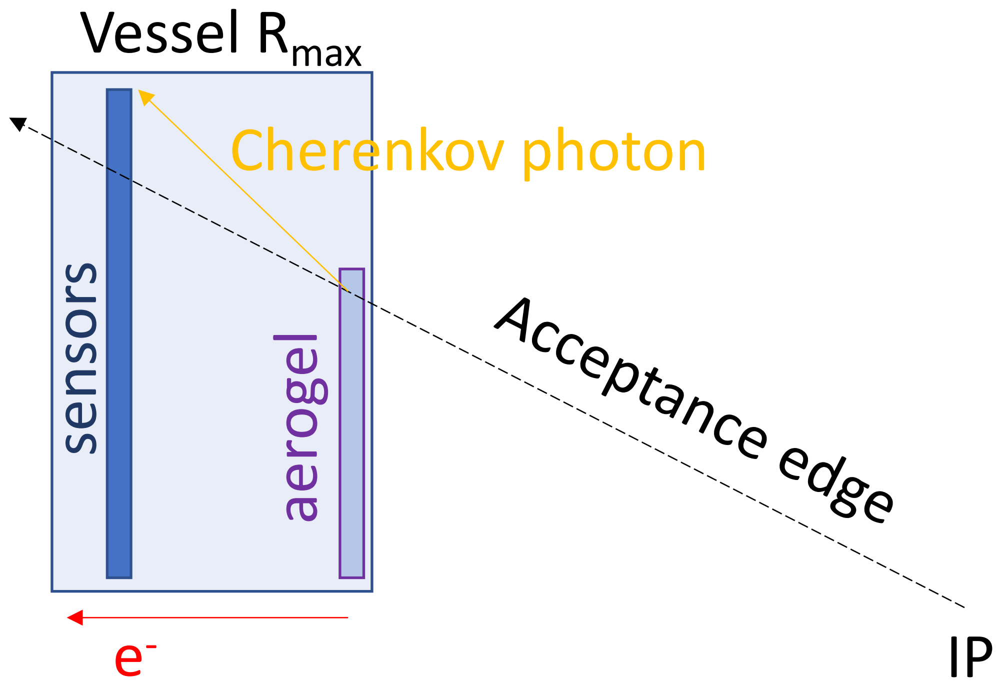
Inner radius	~59 mm
Outer radius	~650 mm
Total length	~540 mm



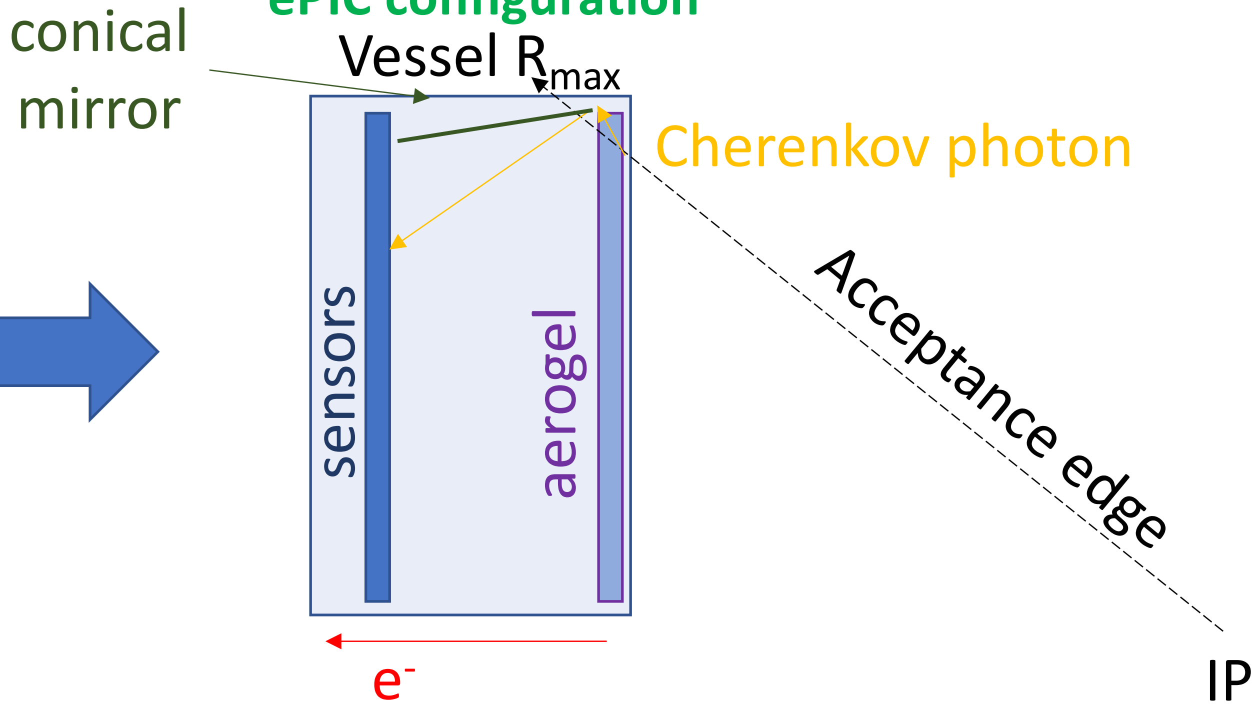
~9.5m along the beam line

Acceptance optimization

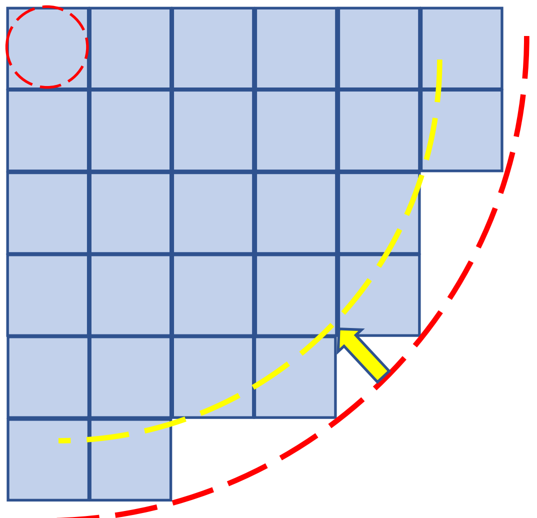
ATHENA configuration



ePIC configuration



- No reason to lose this acceptance *in* η
  - (1) Increase aerogel radius all the way up to $\sim R_{max}$
  - (2) Install a cylindrical mirror at $\sim R_{max}$
- No reason to lose acceptance *on the sensor plane*
  - Use a conical (or a piece-wise flat *tilted*) mirror at $\sim R_{min}$ & $\sim R_{max}$



GEANT implementation

- Vessel: full available length (54 cm), starting at Z = -1187mm
- Gas volume (nitrogen): R_{min} = 72 mm, R_{max} = 628 mm

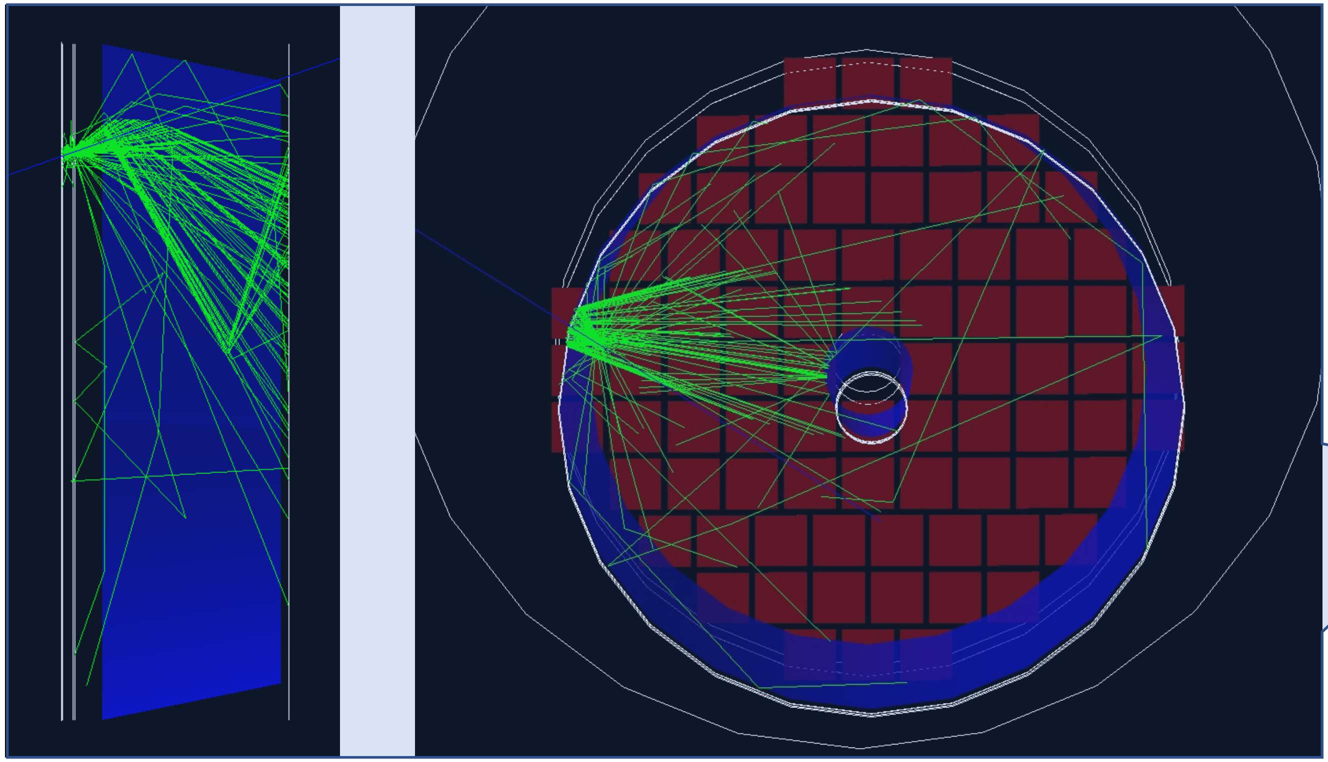
- Aerogel: 3cm thick n ~ 1.020 and 2cm thick n ~ 1.045 (no segmentation yet)
- Aerogel RINDEX / ABSLENGTH / RAYLEIGH parameterizations following CLAS12 data
- Acrylic filter with a 300nm wavelength cutoff

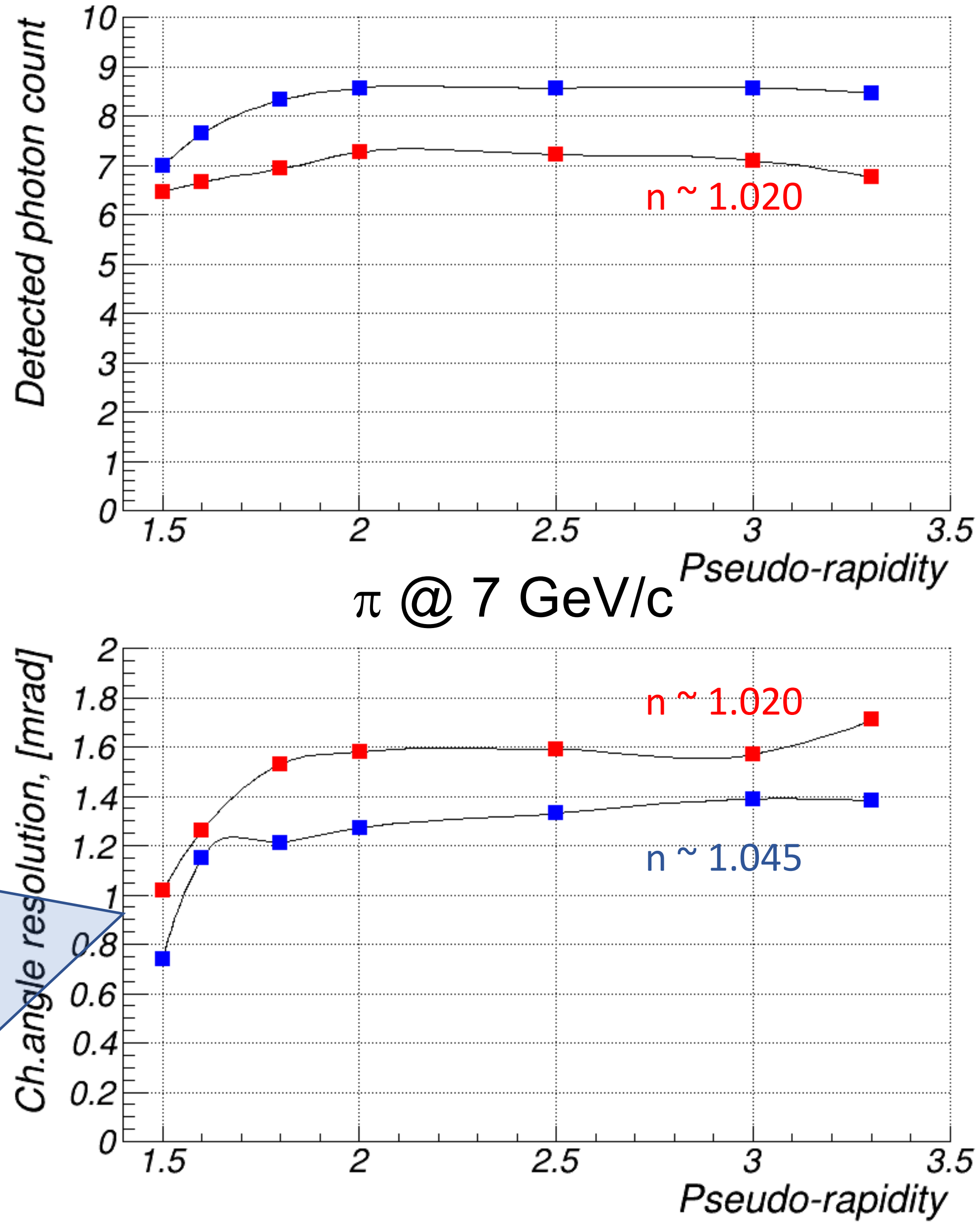
- Sensor plane at 12 cm from the rear side of the vessel (hit XY-resolution ~600 μm)
- QE plot as provided by Incom + 70% safety factor
- Tile segmentation matching suggested HRPPD formfactor (~116 mm x 116 mm)
- Active area 80% of the tile footprint, as suggested by Incom for future HRPPD models

- IRT: conical mirrors (and multiple optical paths per sensor) implemented

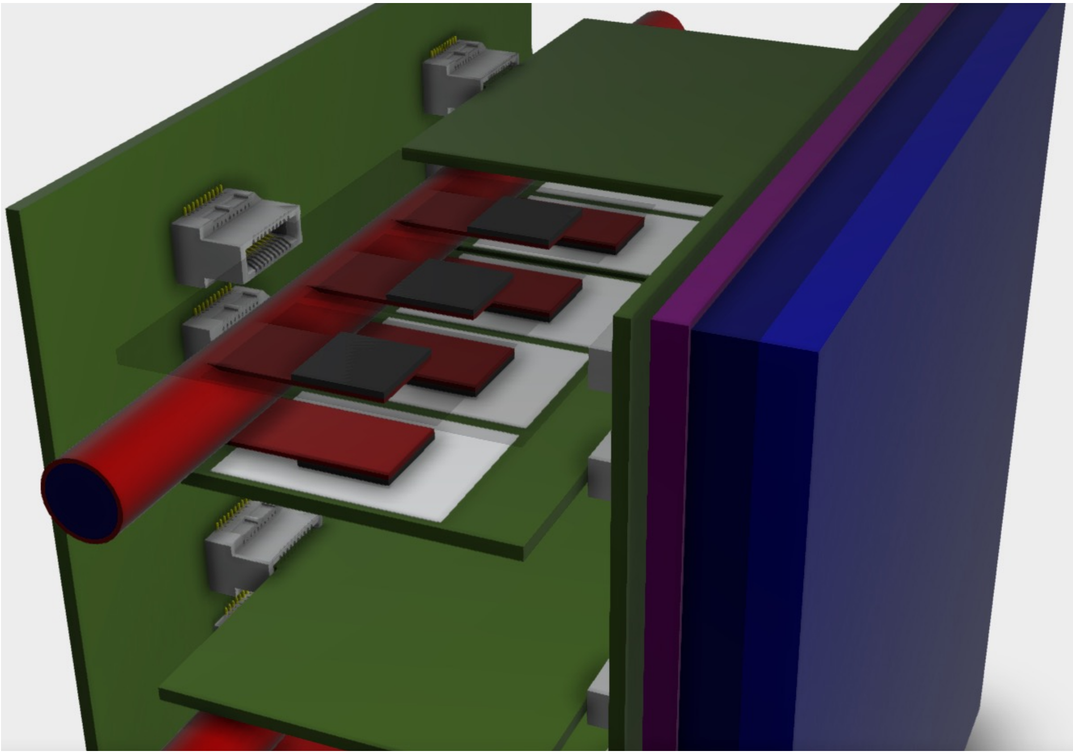
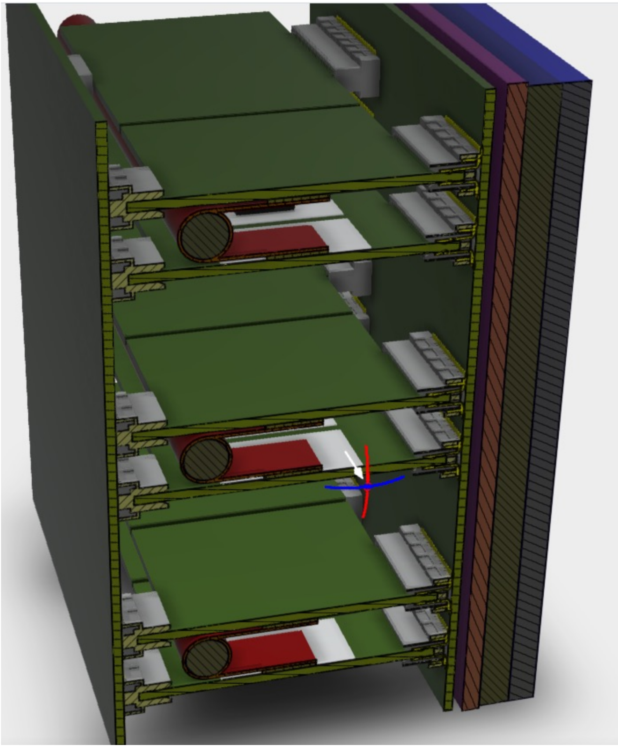
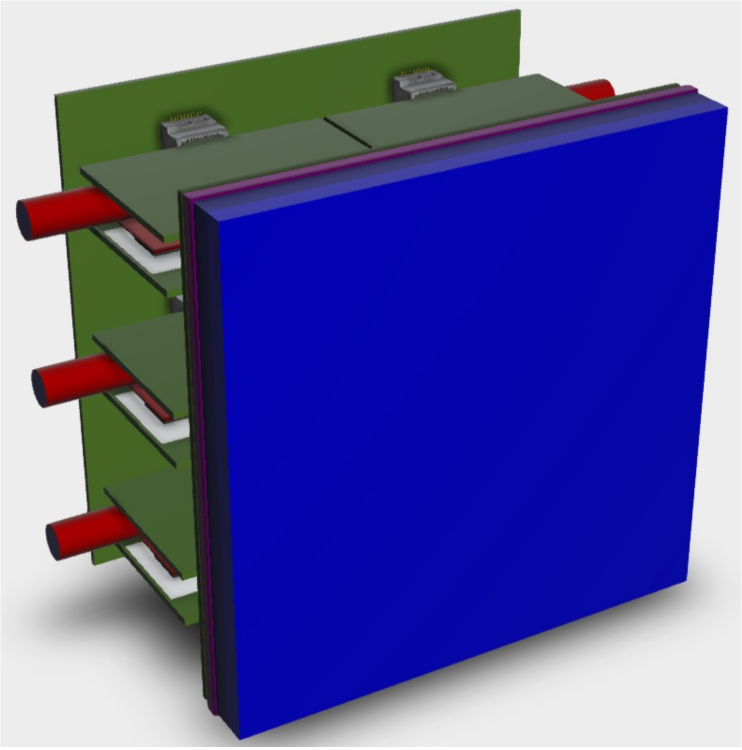
Photon count and Cherenkov angle resolution

- Two different aerogel options considered so far:
  - n ~ 1.020 (ρ ~ 110 mg/cm³), 3cm thick, effective attenuation length ~ 31 mm
  - n ~ 1.044 (ρ ~ 225 mg/cm³), 2cm thick, effective attenuation length ~ 16 mm



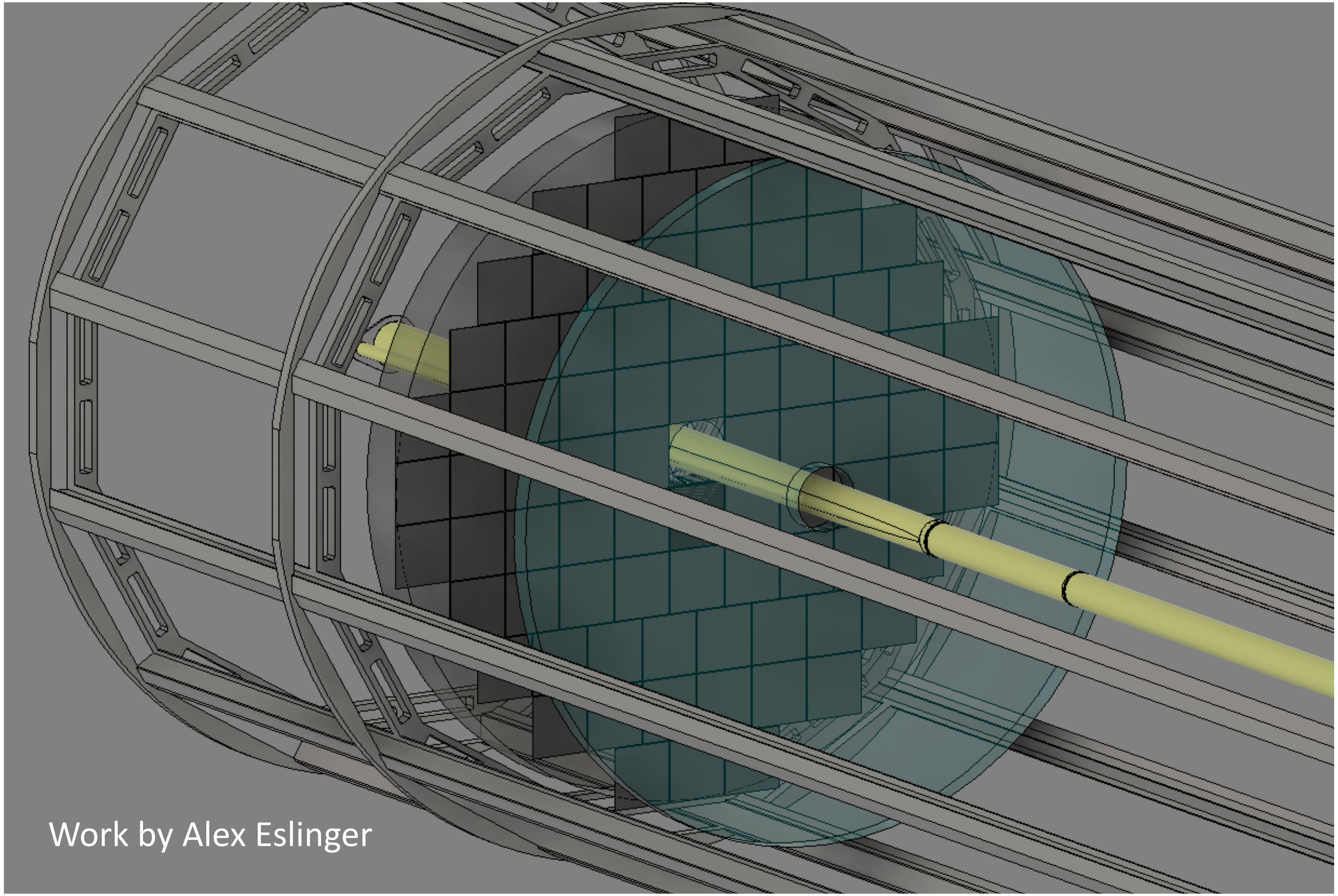


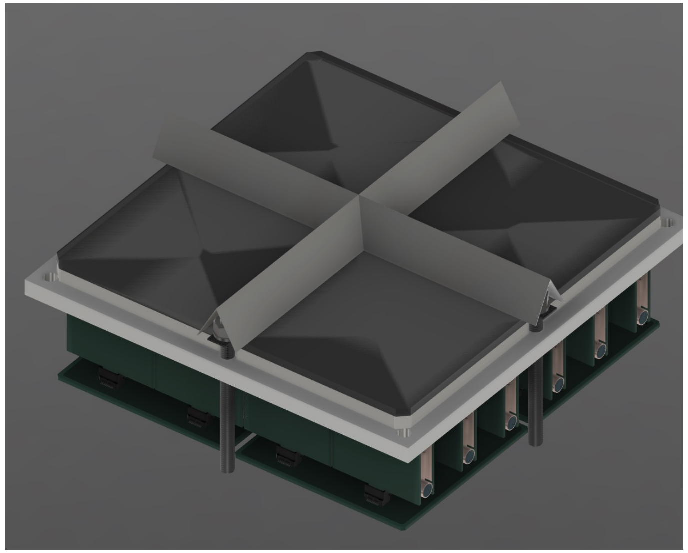
Integration, electronics, etc.

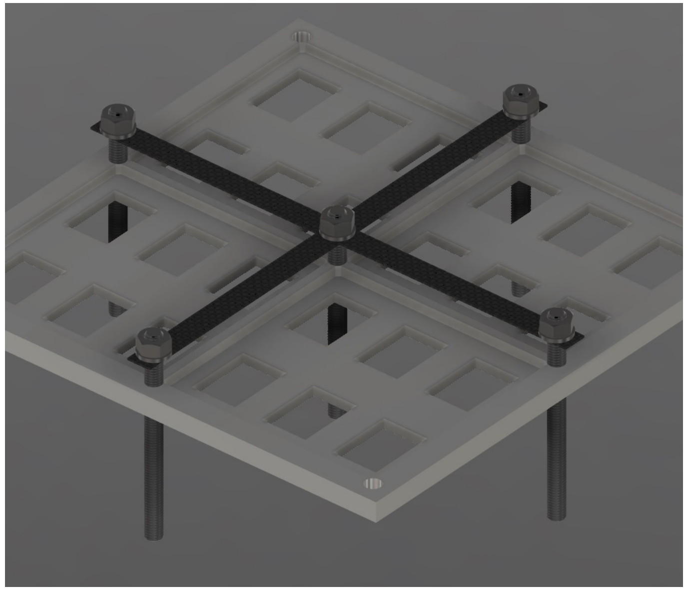




- Assume 24x24 HRPPD pixellation suffices (~4.2mm pads) -> 576 pixels per ~12x12 cm^2 footprint
- A hybrid of Nalu Scientific UDC and AARDVARC v4 chips assumed as a "reference ASIC"
  - 16-channel ASICs (would be better to have 32- or 64-channel ones, of course)
  - ~10GS/s digitizer, ~2GHz ABW, feature extraction, streaming capability (whatever it means), etc.
  - 0dB buffer amplifier (12 mW/ch) available in ARRDVARC V4 -> need a similar solution for a ~20dB preamp
  - Few kW of power dissipation for the whole pfRICH-like system seems to be a real-life estimate

Engineering model





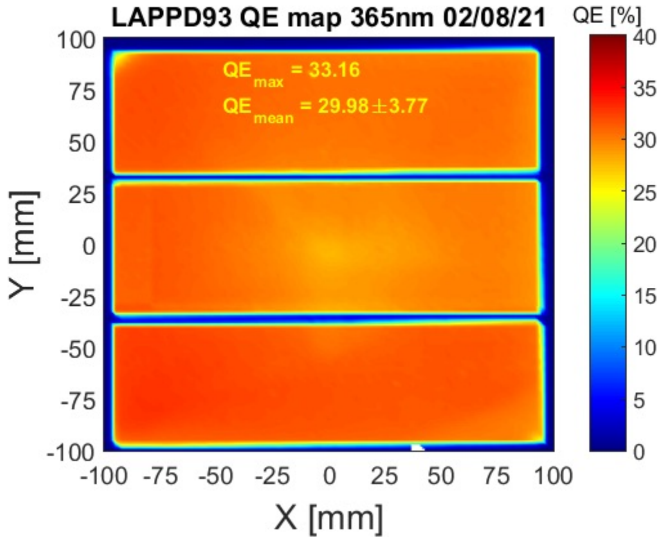


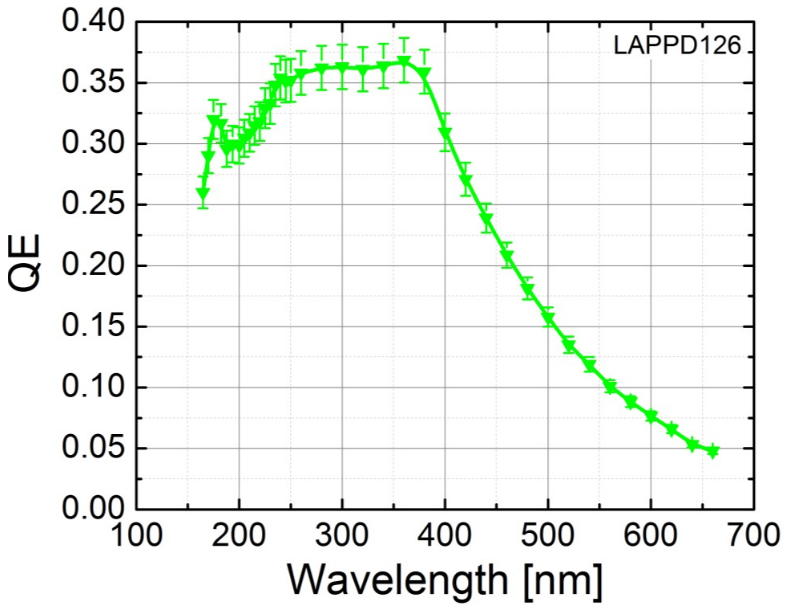
Further information

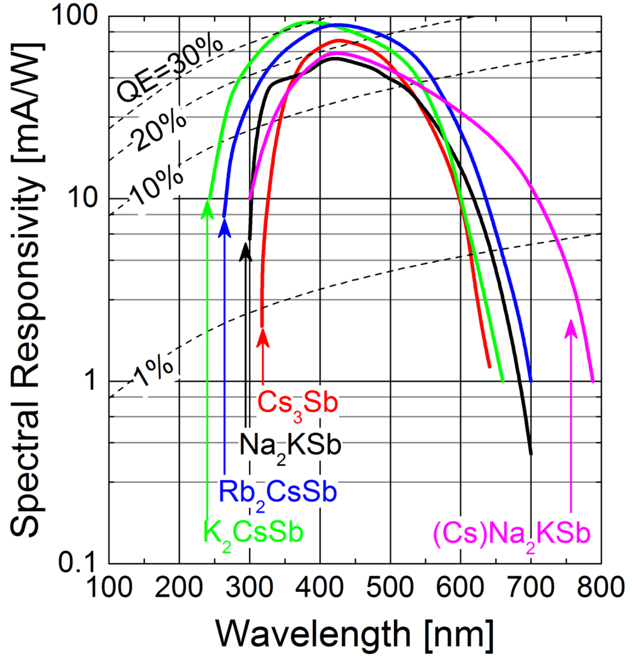
- Mailing lists: lappd-l@lists.bnl.gov, eic-projdet-pfRICH-l@lists.bnl.gov
- (Bi-)weekly pfRICH meetings: Wednesday 10am (or 2pm) NY time
- LAPPD workshops:
  - https://indico.bnl.gov/event/17475/
  - https://indico.bnl.gov/event/15059/

Backup

Quantum Efficiency & PDE





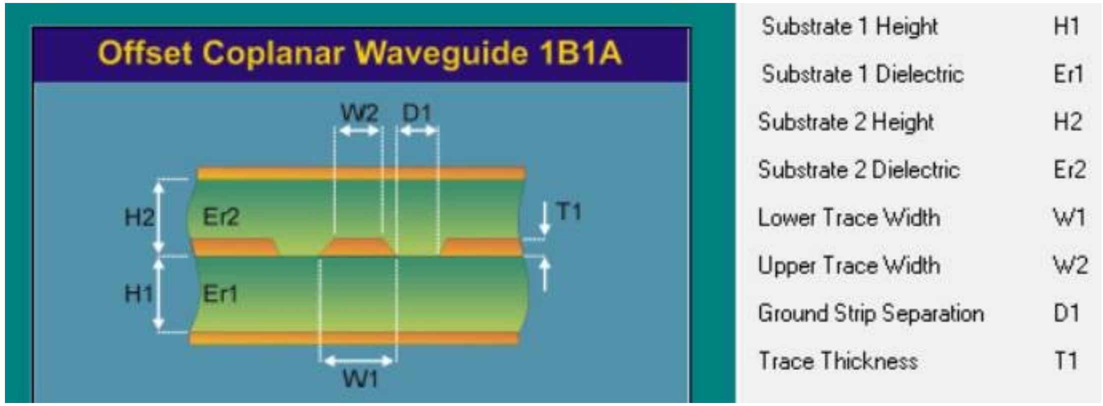


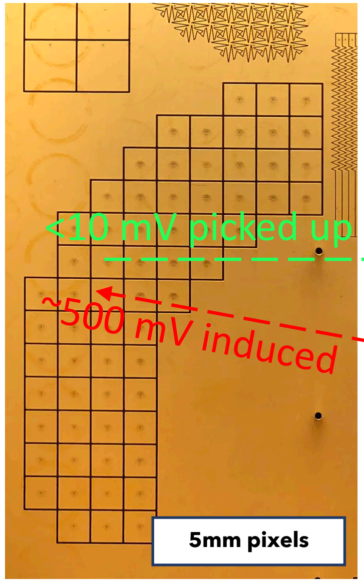
- QE is high enough, but peaked at ~300 nm
- As such, the wavelength range is not optimized for aerogel
- Besides this, the actual PDE was not yet measured

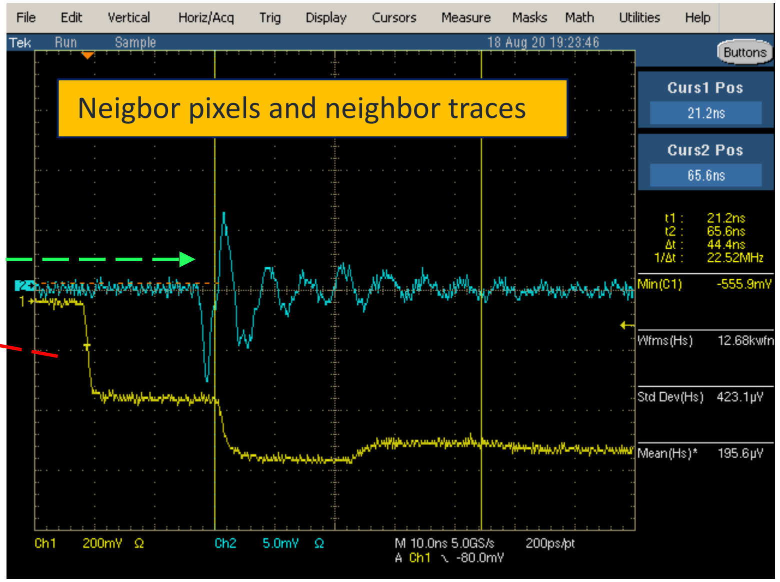
This is a concern, but Incom is making an effort to fix the problem for EIC (see SBIR topics)

- This proposed SBIR would bring LAPPD PC QE to 30% at 450 nm
  - At best PDE=QE
  - Measure this value
- Steps to improve LAPPD PDE
  - Higher QE
  - Funnel-shaped MCP Pores
  - Electron Steering

PCB design, cross-talk, single photon cluster size

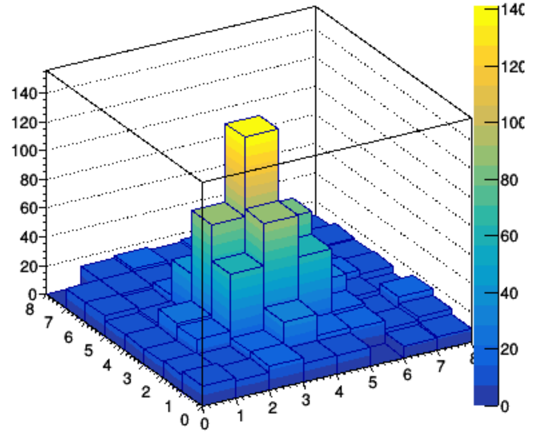




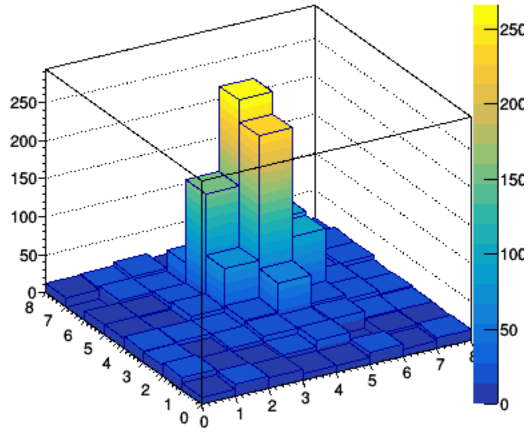


- Multi-layer stack-up; through vias; isolated traces
- Worst case X-talk ~few % level

3mm pixels



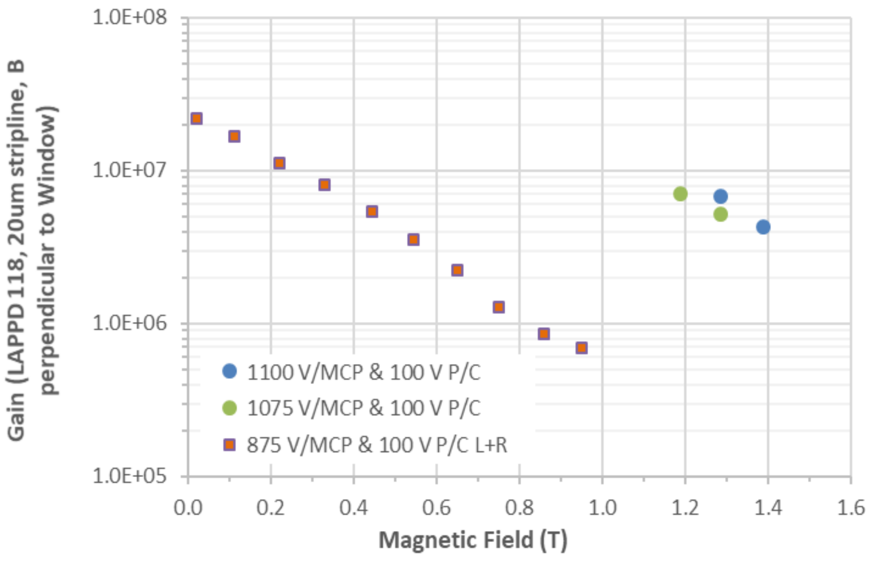
6mm pixels

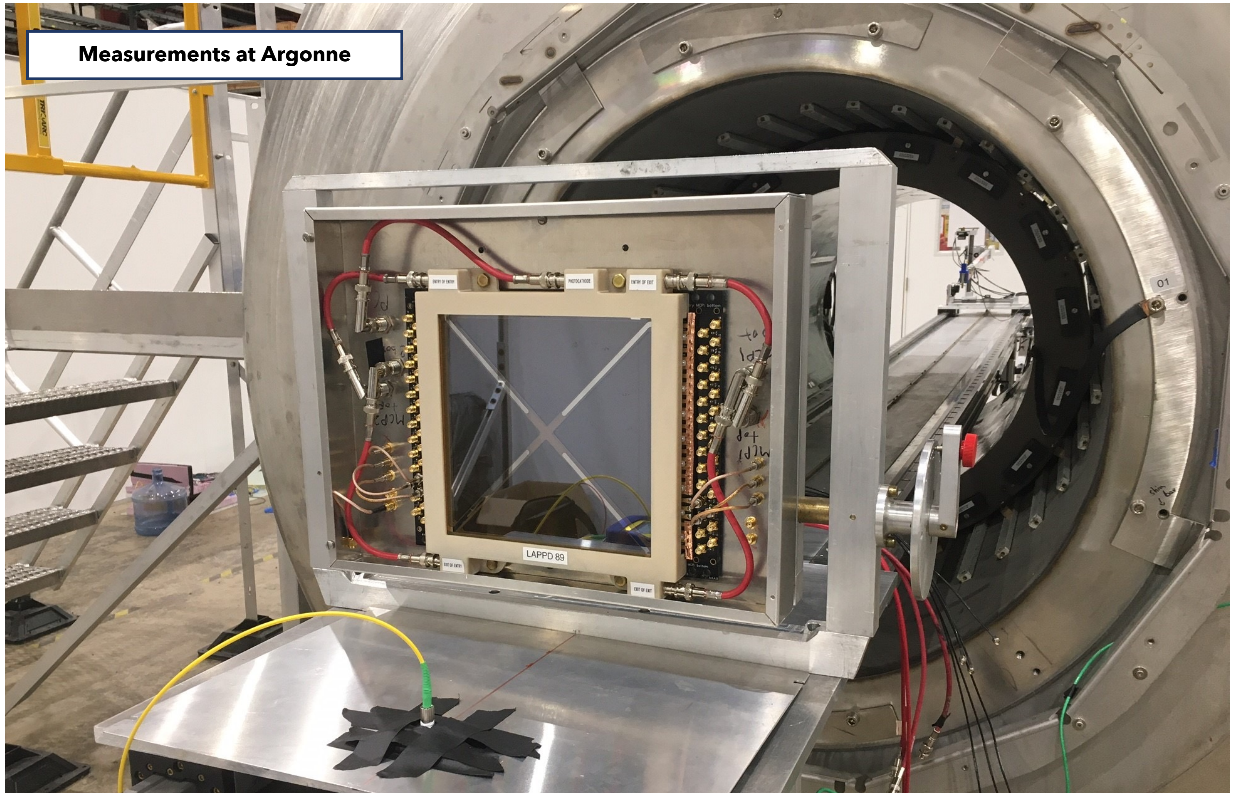


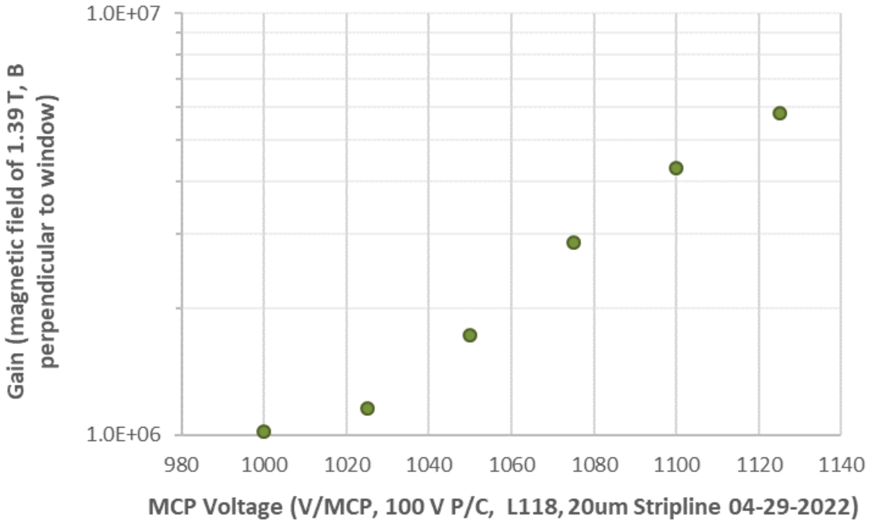
- For a capacitively coupled LAPPD with a “standard” stack and 2mm thick anode base cluster size RMS ~3.5mm
- Will be certainly smaller in a “short” stack configuration
- No data for DC-coupled tiles yet

Magnetic field tolerance

Gen I LAPPD; magnetic field normal to the sensor surface



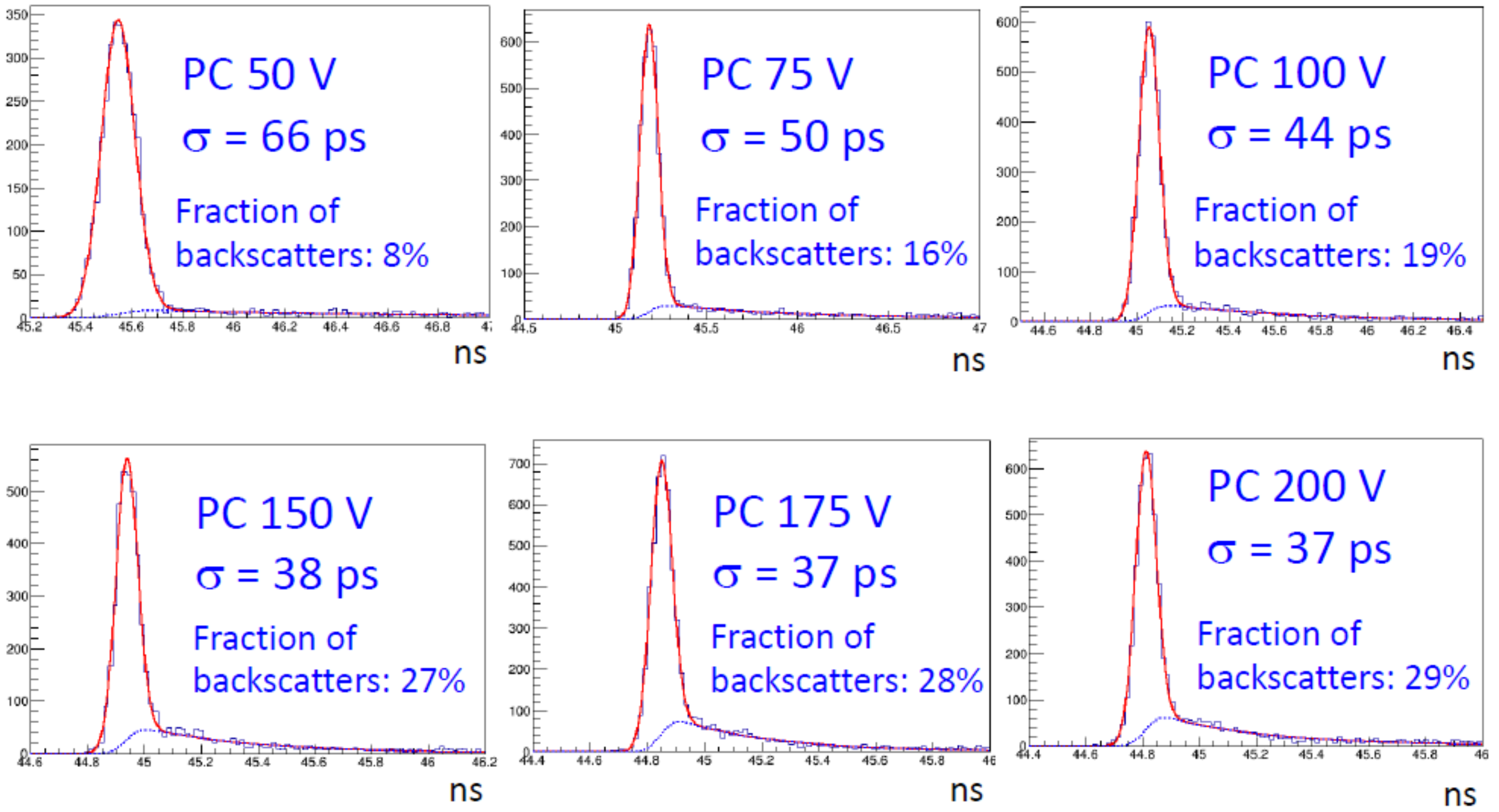




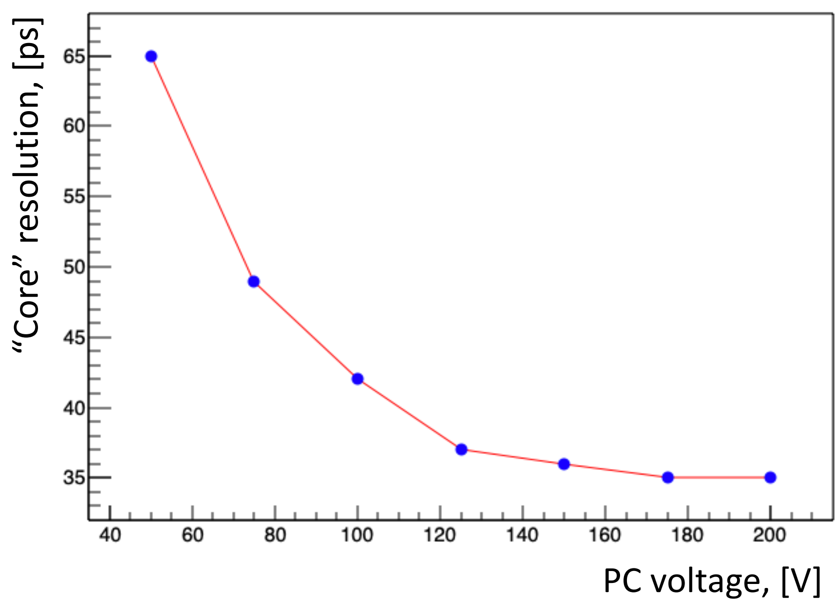
- ❑ LAPPD shows similar behavior trends as R&D MCP-PMT
  - ❑ Gain went down from over $2x10^7$ to ~$7x10^5$ as the field strength was increased from 0.02 T to ~0.9 T.
- ❑ At a field strength of 1.39 T, the gain was recovered to $6x10^6$ by significantly increasing the MCP voltages.

Need to verify up to ~2T and at (reasonable) non-zero angles

Single photon timing resolution



Data: V. Vagnoni (INFN Bologna)

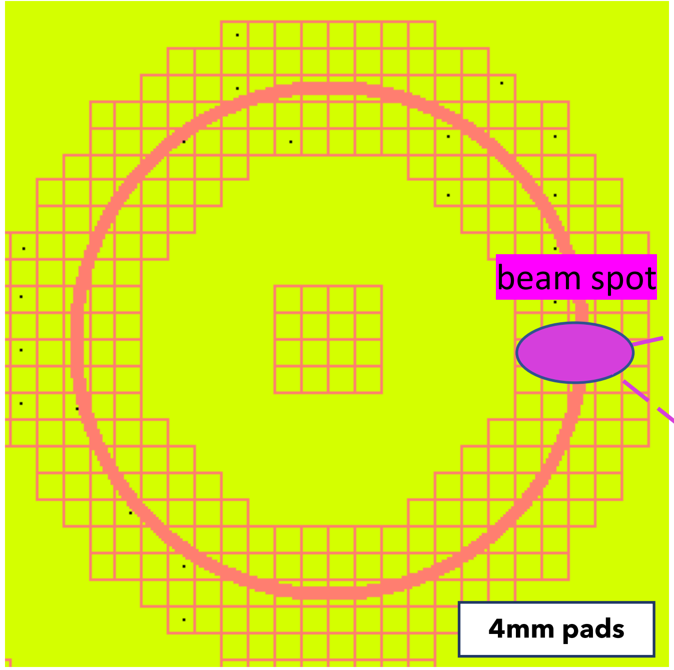


Data: V. Vagnoni (INFN Bologna)

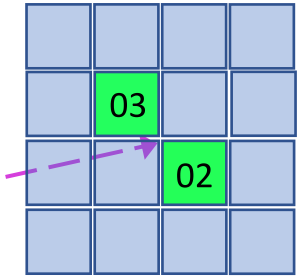
- Remember: EIC requirement is "<100 ps"
- Tail is of course a concern for the DIRC
- We are collecting our own beam data on this (INFN, BNL)

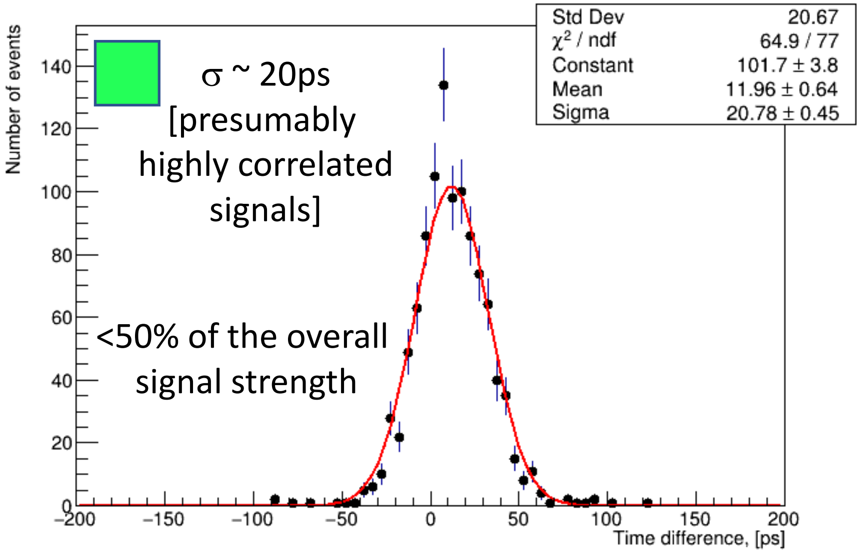
Timing for Time-of-Flight applications

LAPPD quartz window as a Cherenkov radiator



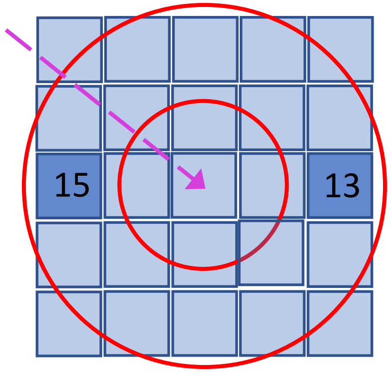
Event selection (A)

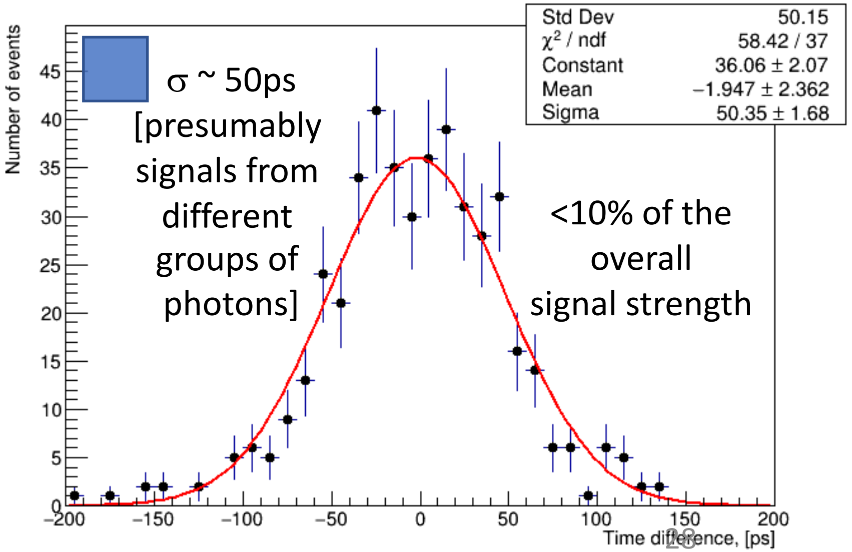




DRS4 chip#0: time(ch#03) – time(ch#02)

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

DRS4 and trace delay calibrations are still "in progress"

eRD110: open R&D questions before CD-3

- In brief, we need to come up with a detailed assessment of the current state of the art and projected LAPPD photosensor performance, evaluate their potential use in various EIC PID detector subsystems, and assist Incom in modifying their existing product line to meet EIC requirements
  - Spatial resolution for Cherenkov imaging applications in a variety of fine pixellation schemes
  - Timing resolution in a single photon mode, for a selected subset of pixellation scenarios
  - Timing resolution for Time-of-Flight purposes
  - Performance in a strong (inhomogeneous) magnetic field

  - QE spectrum tuning and evaluation for ePIC detectors
  - Overall PDE and gain uniformity tuning and measurement
  - Geometric formfactor optimization

  - Prospects of integration in particular ePIC detector subsystems (together with the respective groups and / or consortia), as well as the on-board electronics integration (together with eRD109 and ASIC manufacturer candidates)