LAPPD R&D @ Brookhaven Lab
status update

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LAPPD Workshop, October 26, 2022

Topics

- June 2022 beam test at Fermilab
- DC-coupled HRPPD interface
- HRPPD application in a TOF PET setup
- Proximity focusing RICH with LAPPD photosensors for EIC

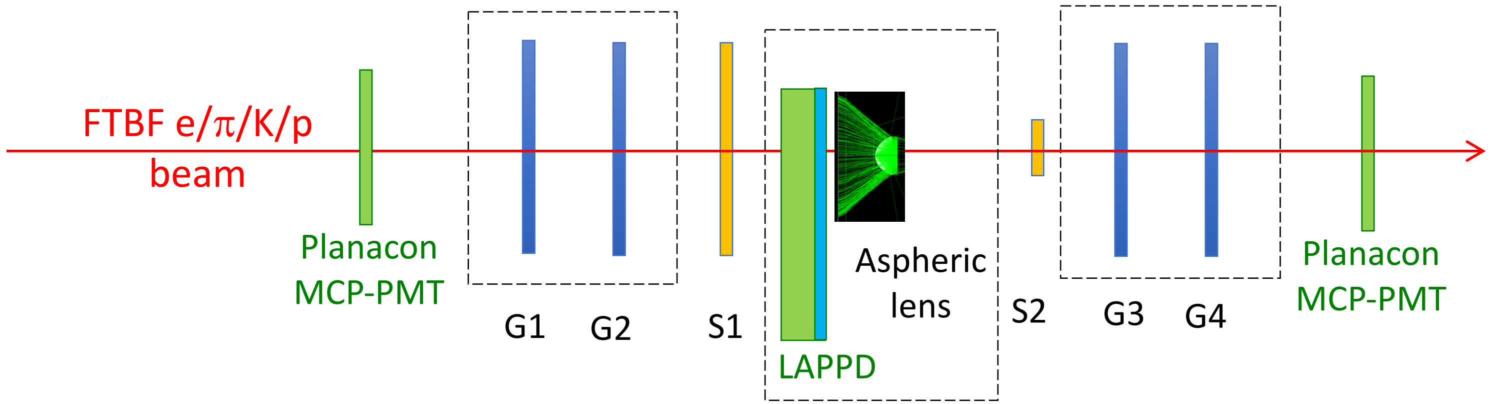
Work is mostly funded by EIC Project Detector R&D Program (eRD110 consortium “Photosensors for EIC”)

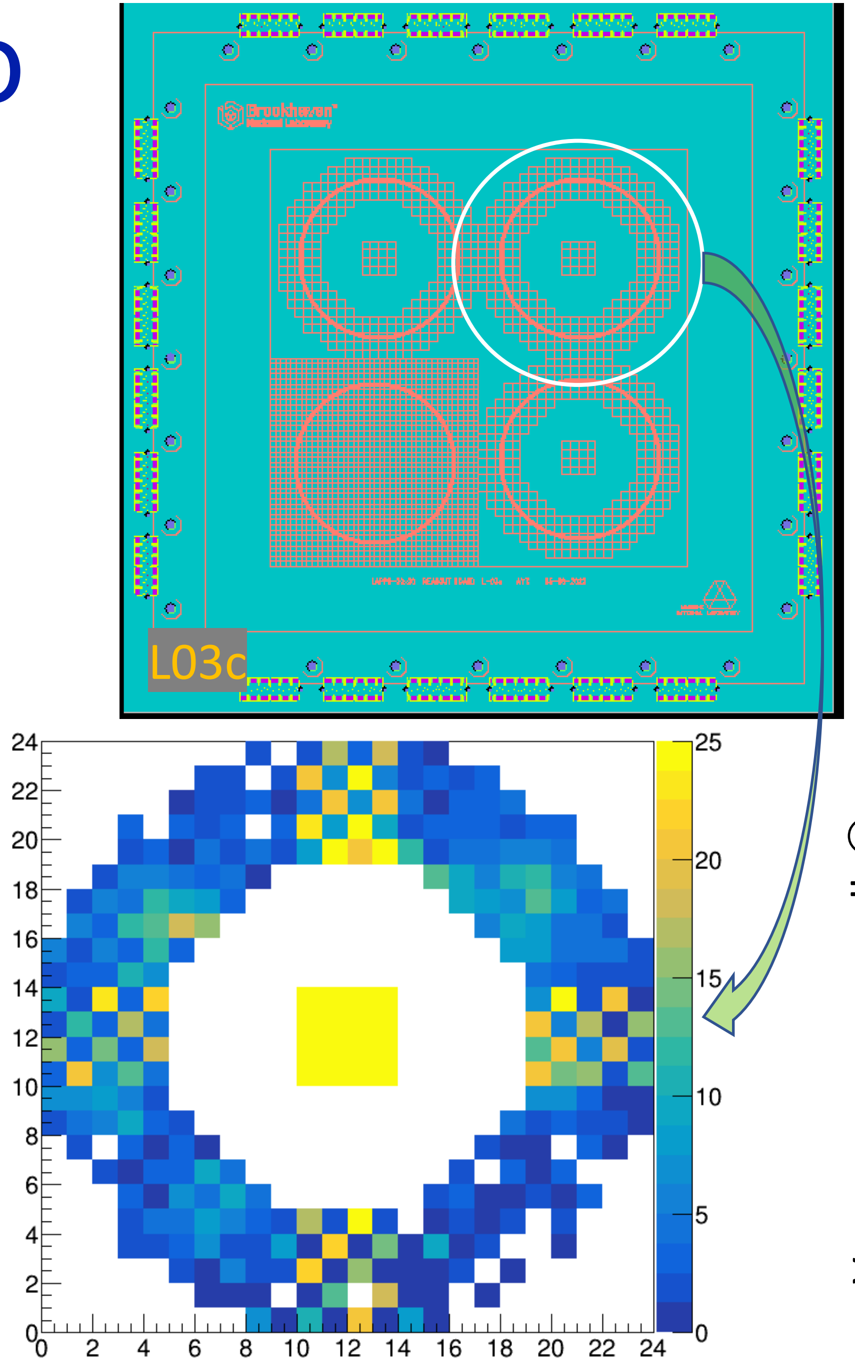
Beam test at Fermilab in June 2022

(BNL, Incom Inc., Argonne, MSU, INFN Trieste)

Experimental setup at Fermilab

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

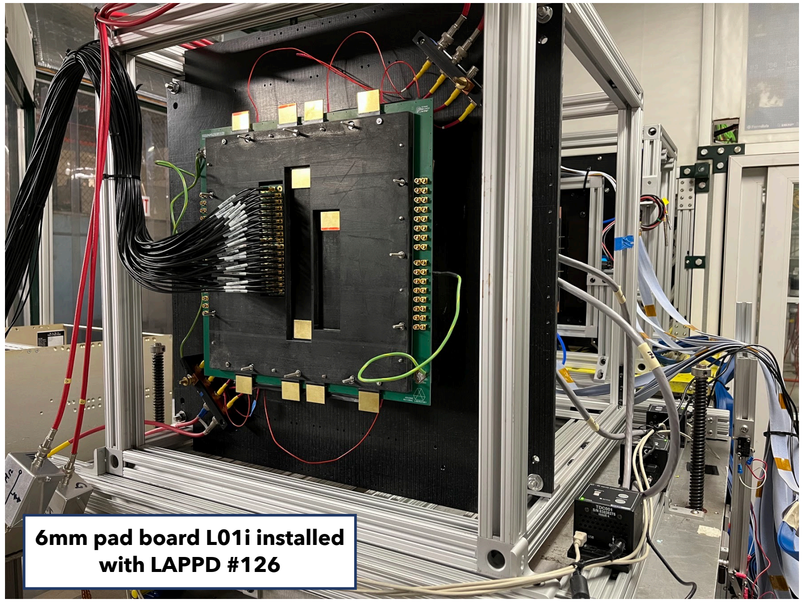




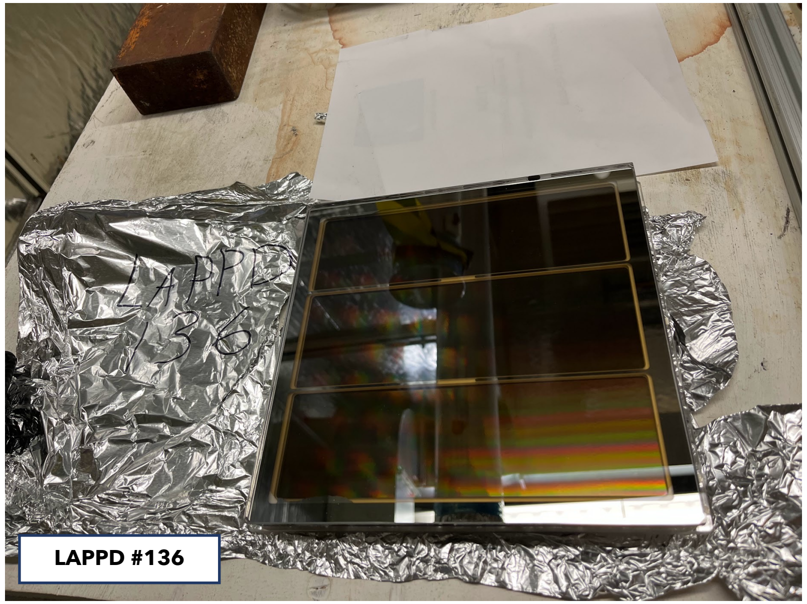
Very strong cross-talk ☹

- 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
- Time-of-Flight and imaging in the same setup
- A pair of Planacon MCP-PMTs as a timing reference

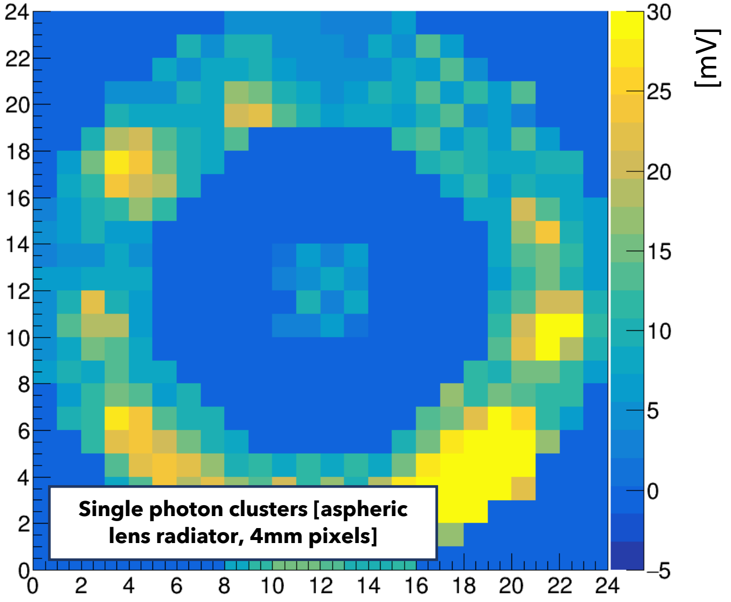
Picture gallery



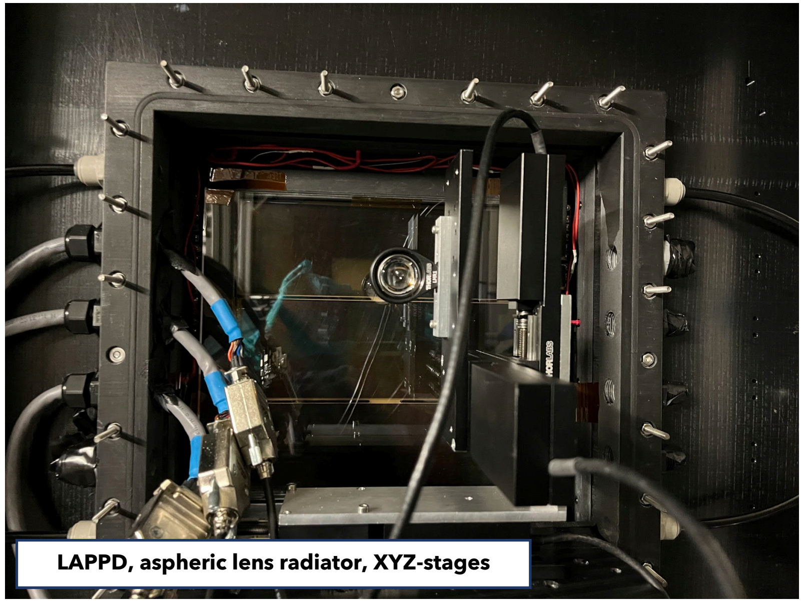
6mm pad board L01i installed with LAPPD #126



LAPPD #136

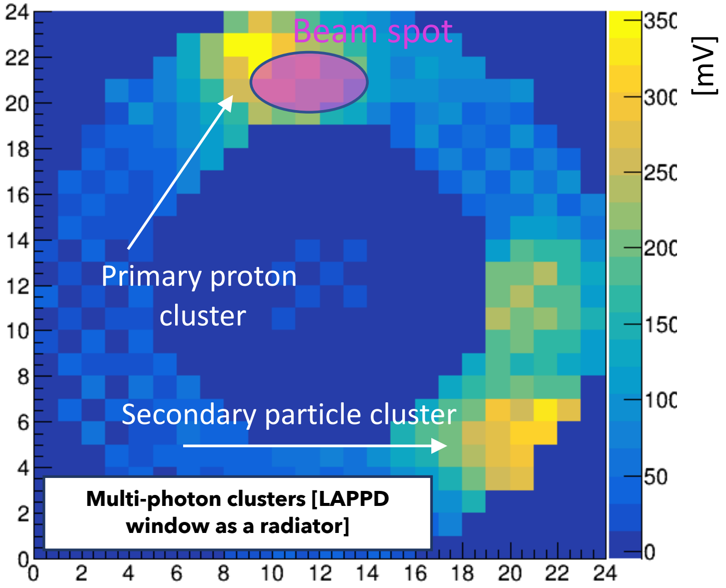


Single photon clusters [aspheric lens radiator, 4mm pixels]



LAPPD, aspheric lens radiator, XYZ-stages

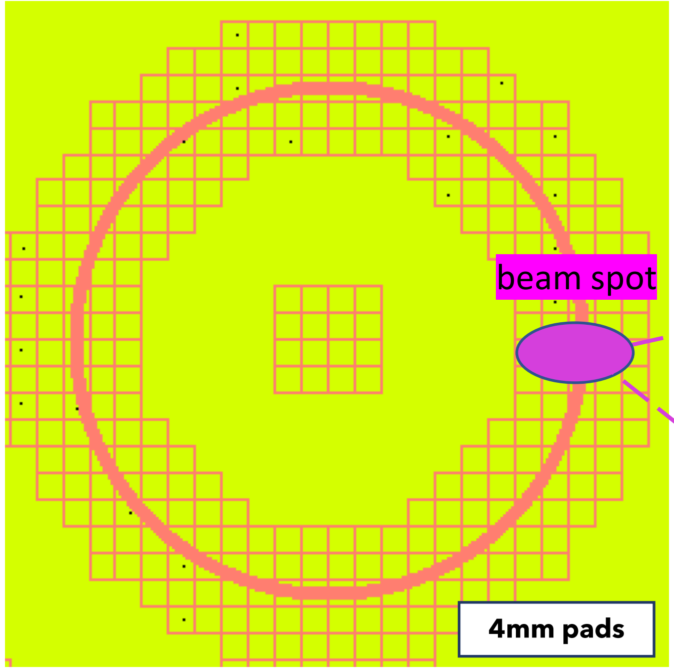
Mark Popecki grounding the central spot on the L03c board



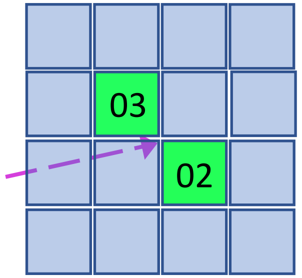
Multi-photon clusters [LAPPD window as a radiator]

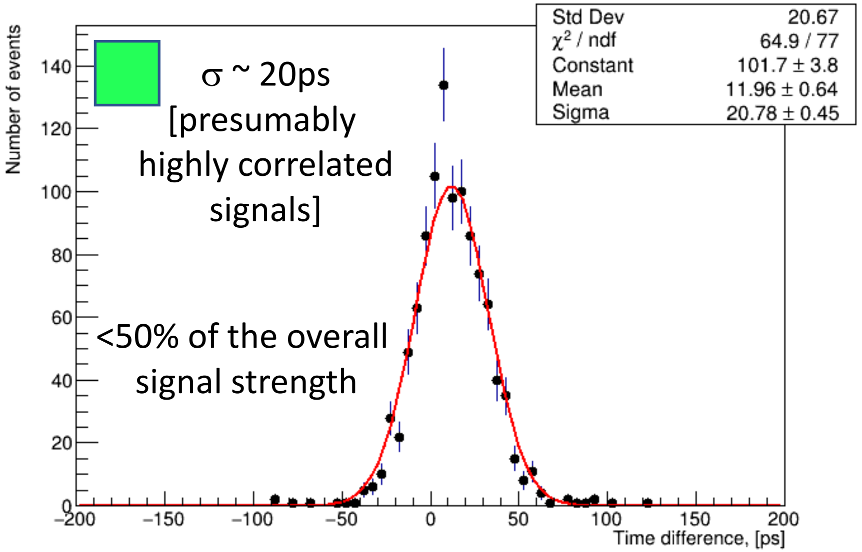
Timing for Time-of-Flight applications

LAPPD quartz window as a Cherenkov radiator



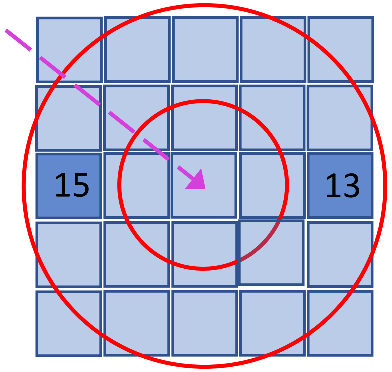
Event selection (A)

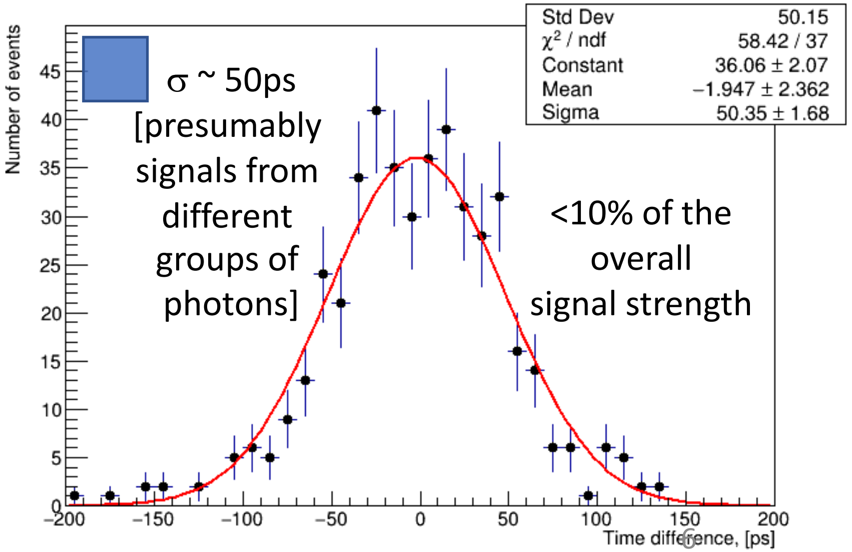




DRS4 chip#0: time(ch#03) – time(ch#02)

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**

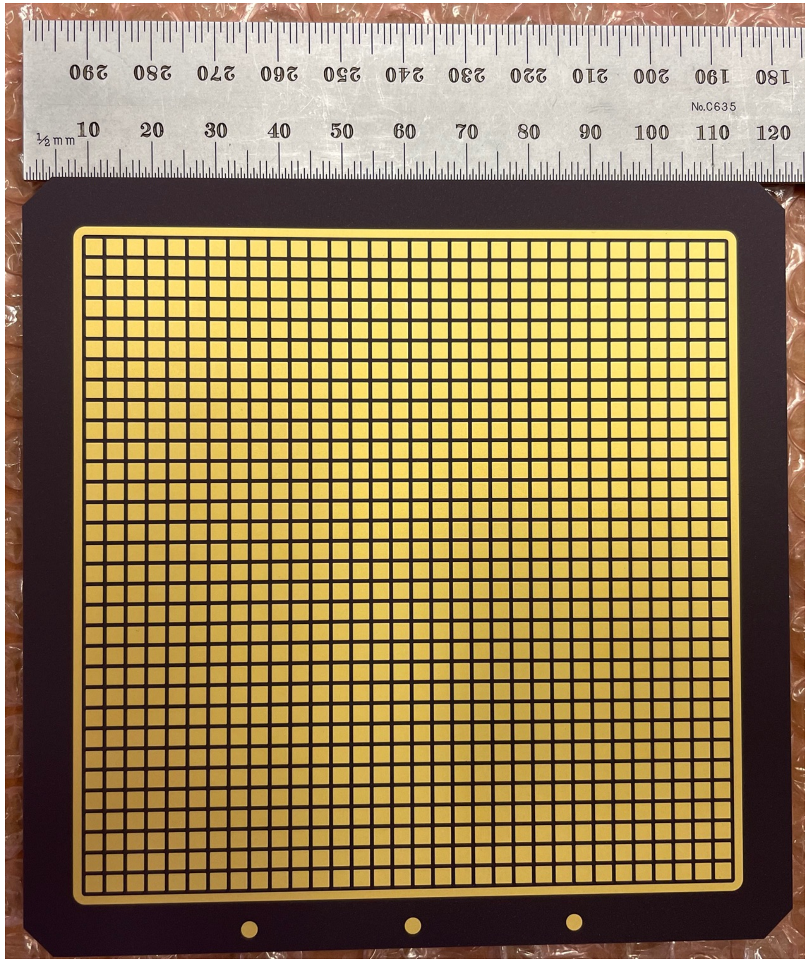
Due to the TIR, photons only hit the PC in a radial band ~[5.5 .. 12.0] mm

DRS4 and trace delay calibrations are still "in progress"

DC-coupled HRPPD interface

DC-coupled HRPPD

Tile #4 delivered to BNL beginning of October

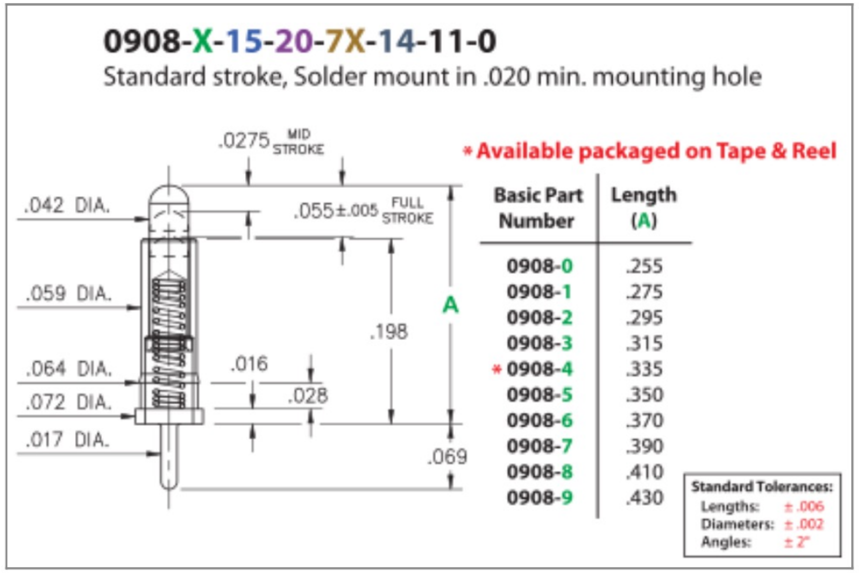


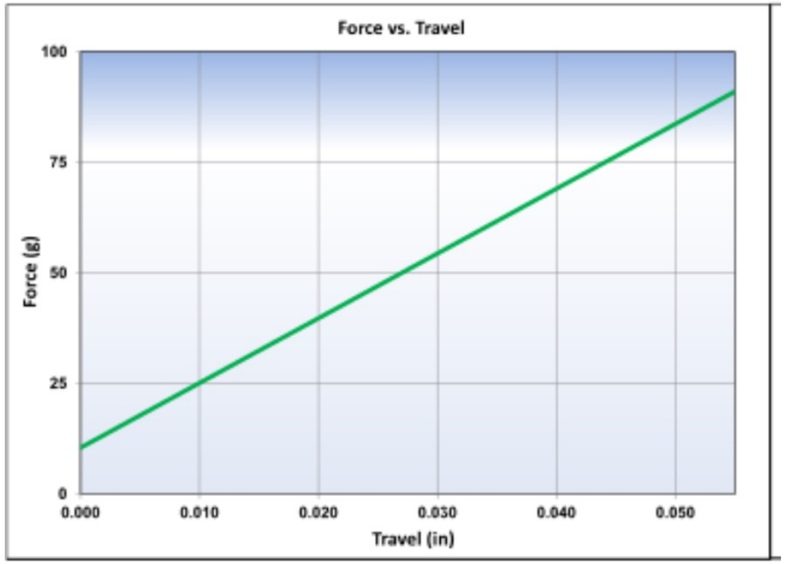
- ~120 x 120 mm^2 footprint; ~100x100 mm^2 unobscured active area
- 1024 pads, hermetic through vias, 1/8” (~3.2 mm) pitch
- Short MCP stack with 5mm thick quartz window and 3mm thick ceramic base plate

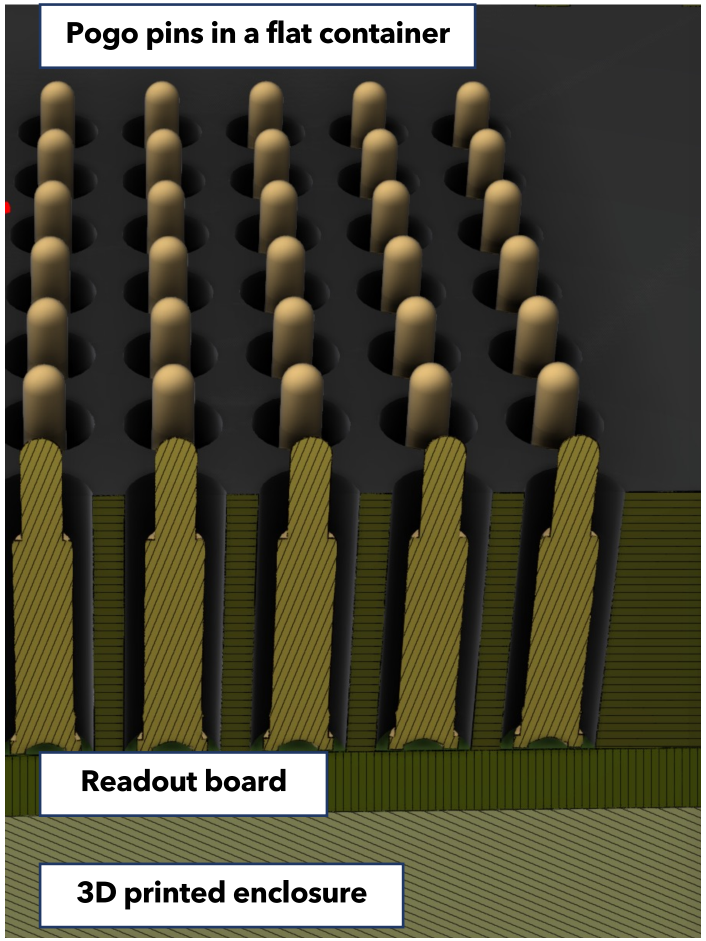
Signal connection

Signal pogo pins: Mill Max 0908 series

#72 SPRING LOW FORCE SPRING	Full Stroke Capability : .055"± .005" [1,4 ± 0,127]
Spring Material : Beryllium Copper Alloy 172	Force @ Mid. Stroke : 45 g ± 20 g
Mid. Stroke : .0275" [0,7]	Initial Force (Pre-Load) : 15 g

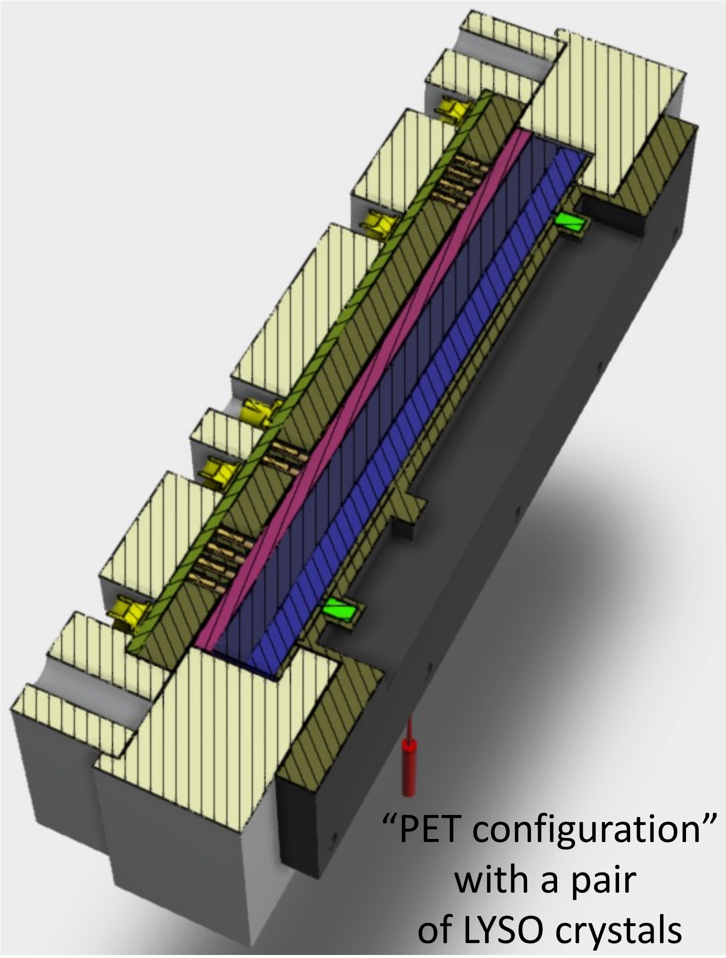


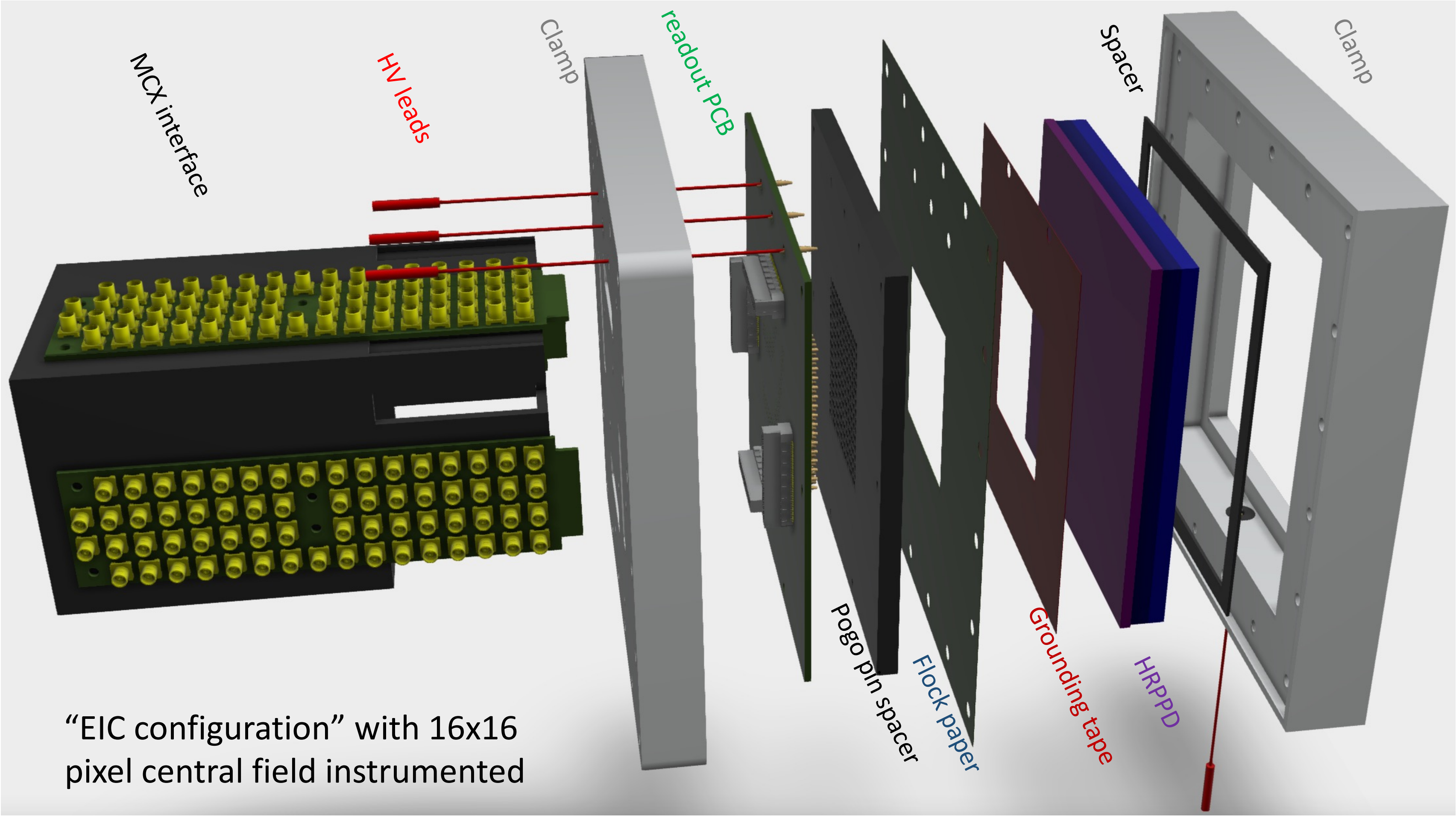




- Should suffice for a basic performance evaluation (and for our TOF PET project application)
- Pogo pin container thickness may require tuning to end up around 50g force per pin

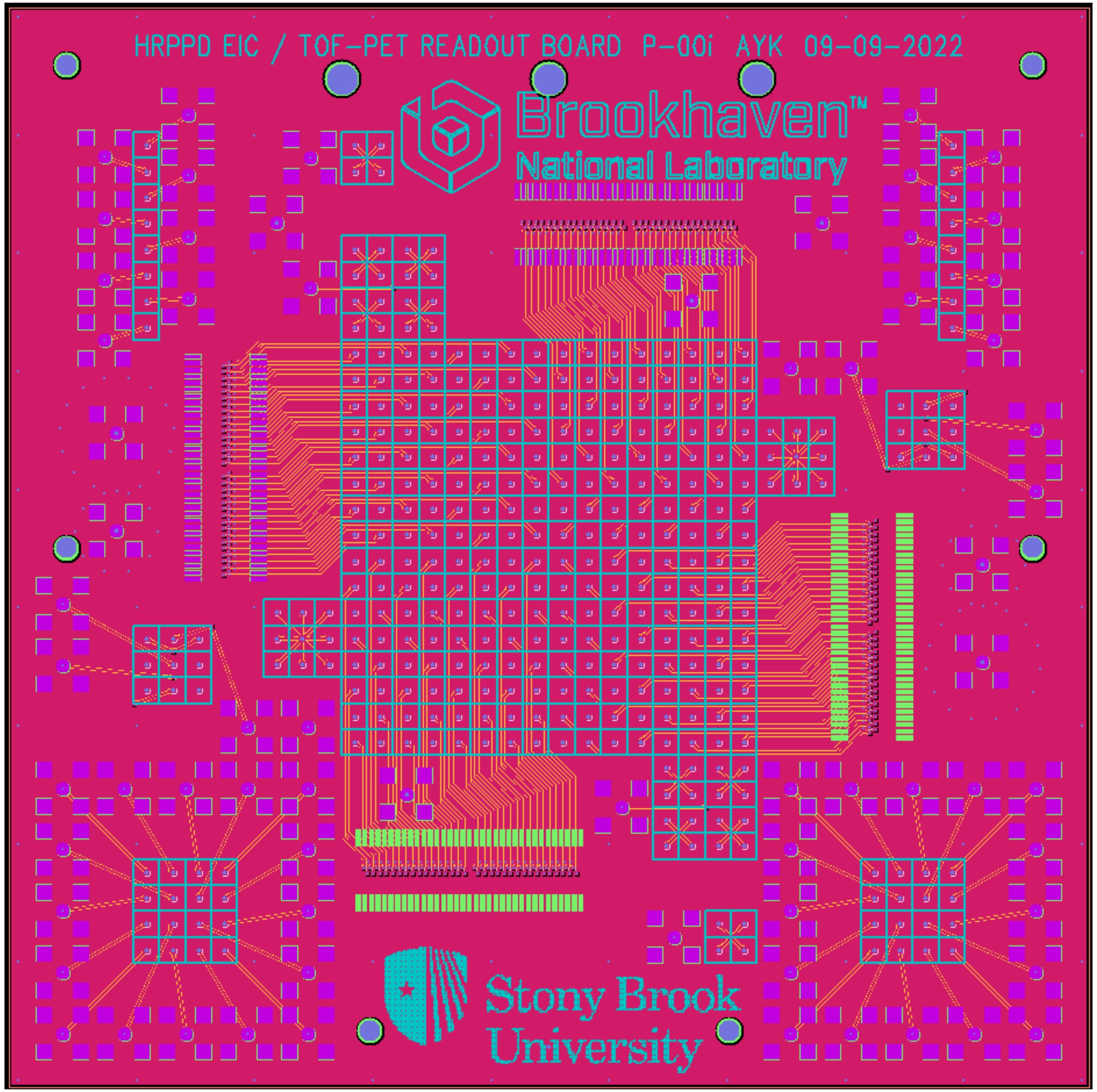
3D integration model





- Parts are being machined and 3D printed as we speak **(to be ready first half of November)**
- The "final" integration design (custom LGA or ZIF sockets, BGA + a PCB, ..?) will require more work

Dual purpose readout PCB



- A compact universal 132 x 132 mm^2 board
- Pixellation follows ~3.2mm HRPPD pad pitch
- Two "main" instrumentation options:
  - A 16x16 pad field in the center
  - Pairs of individual pad fields for systematic studies
- Connectivity via either MCX->MCX cables or Samtec->MCX adapters
- Can be used for the DC-coupled HRPPDs (assembly with the pogo pins), as well as for the capacitively coupled HRPPDs / LAPPDs (assembly without the pogo pins)
- Can also be used in a coincidence setup with a picosecond laser

Bare boards are on their way from HK to BNL

TOF PET Seed Grant project

(SBU & BNL)

Application requirements in HEP/NP & TOF PET

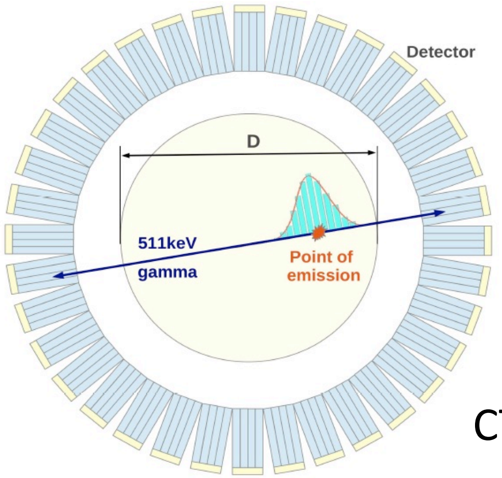
"Conventional" HEP/NP Cherenkov light detectors

But for TOF applications: σ_t< 20 ps

	Single photon time resolution	MCP-PMT anode plane segmentation
CERN: LHCb TORCH	~70 ps	1mm wide "strips"
FAIR: PANDA endcap DIRC	<100 ps	<0.5 mm wide "strips"
(e)RHIC: EIC barrel DIRC	<100 ps	3x3 mm^2 pixels

Time of Flight Positron Emission Tomography (TOF PET)

<1 mm spatial resolution required in transverse direction



Time difference between the two 511 keV gammas in opposing crystals can be used to localize the decay *along the line of response*

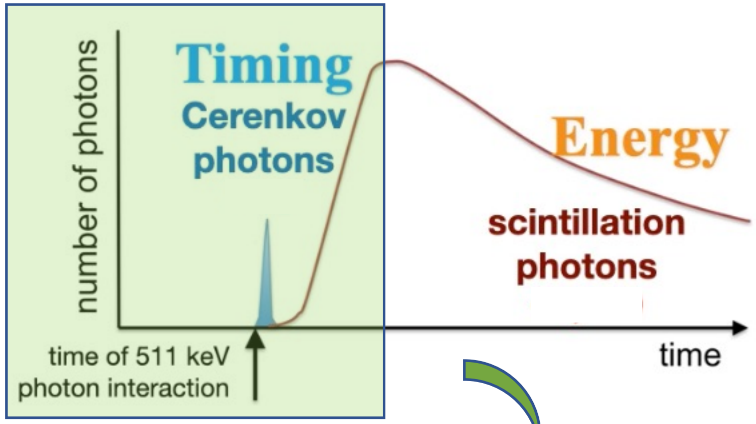
S/N Gain with TOF

$$G = \frac{SNR_{TOF}}{SNR_{non\,TOF}} = \sqrt{\frac{2 * D}{c * CTR}}$$

CTR	G
100	5.2
50	7.3
10	16.3

CTR (Coincidence Time Resolution) = 100 ps $\Rightarrow$ Δx = 1.5 cm

When a 511 keV gamma photon interacts in a scintillator, a number of Cerenkov photons are produced promptly by energetic electrons.

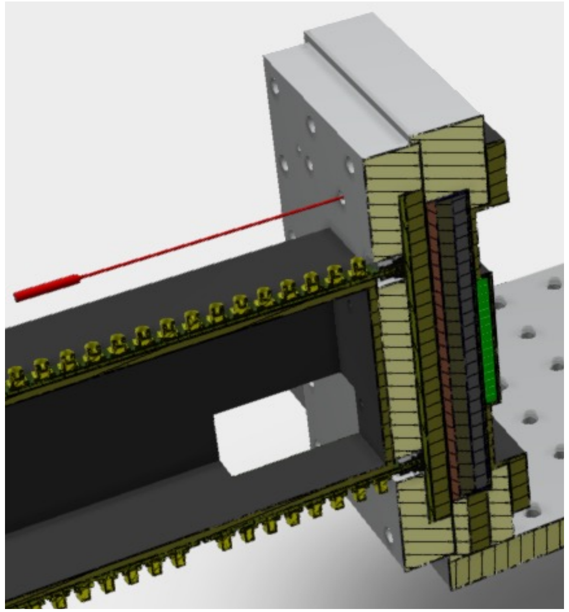


Reducing CTR to dozens of ps opens a possibility to use *direct imaging* instead of multi-event reconstruction

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

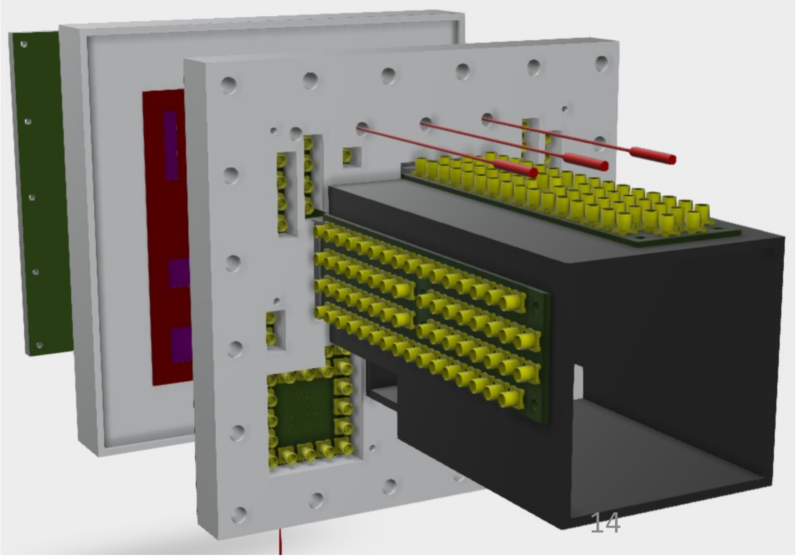
Combine expertise and equipment gained via the earlier and ongoing NIH- & DOE-funded projects with a brand new Incom HRPPD as a photosensor

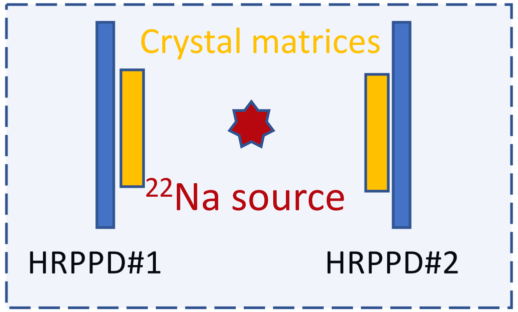


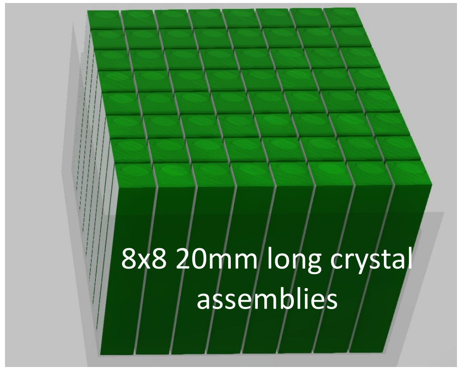
Assembly variant with
a 16x16 5mm long crystal matrix

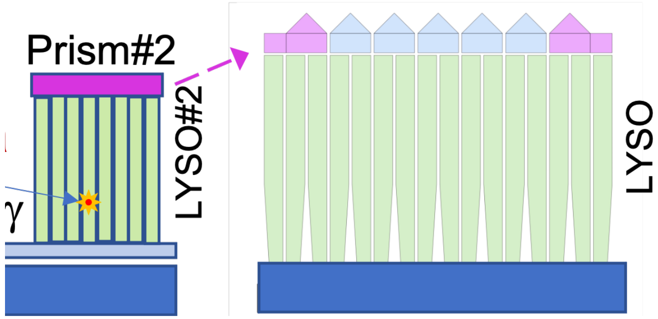
- Same readout board as to be used for EIC-related HRPPD evaluation
- 16x16 LYSO crystal matrices matching HRPPD pixellation
- Prism-PET for Depth-of-Interaction compensation
- 512 DRS4 electronics channels

Assembly variant for systematic studies









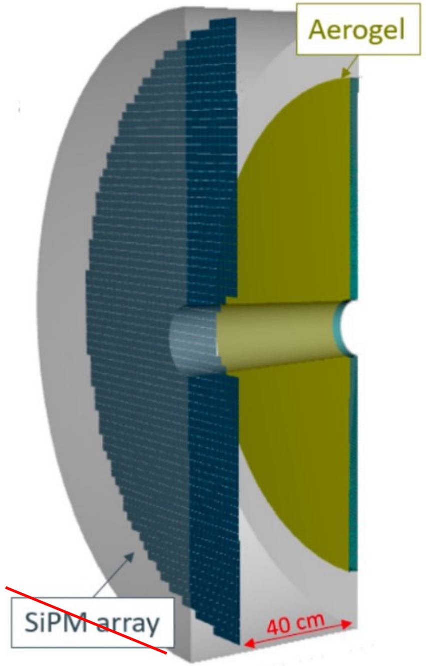
Proximity focusing RICH for EIC

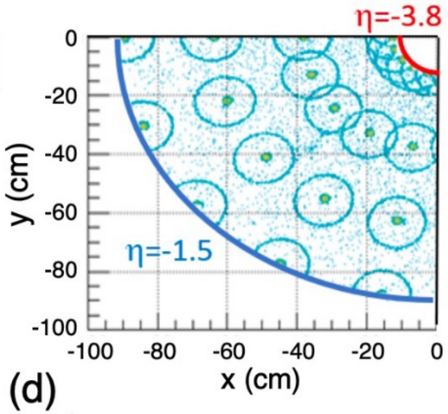
(BNL, Duke, INFN Trieste, MSU, SBU)

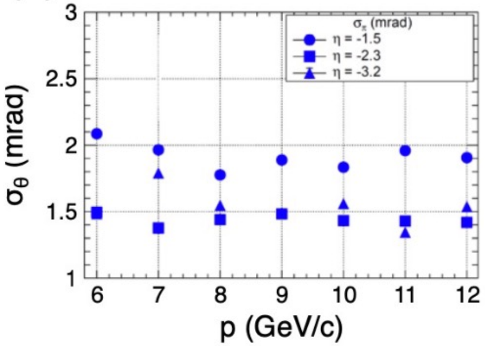
Detector concept

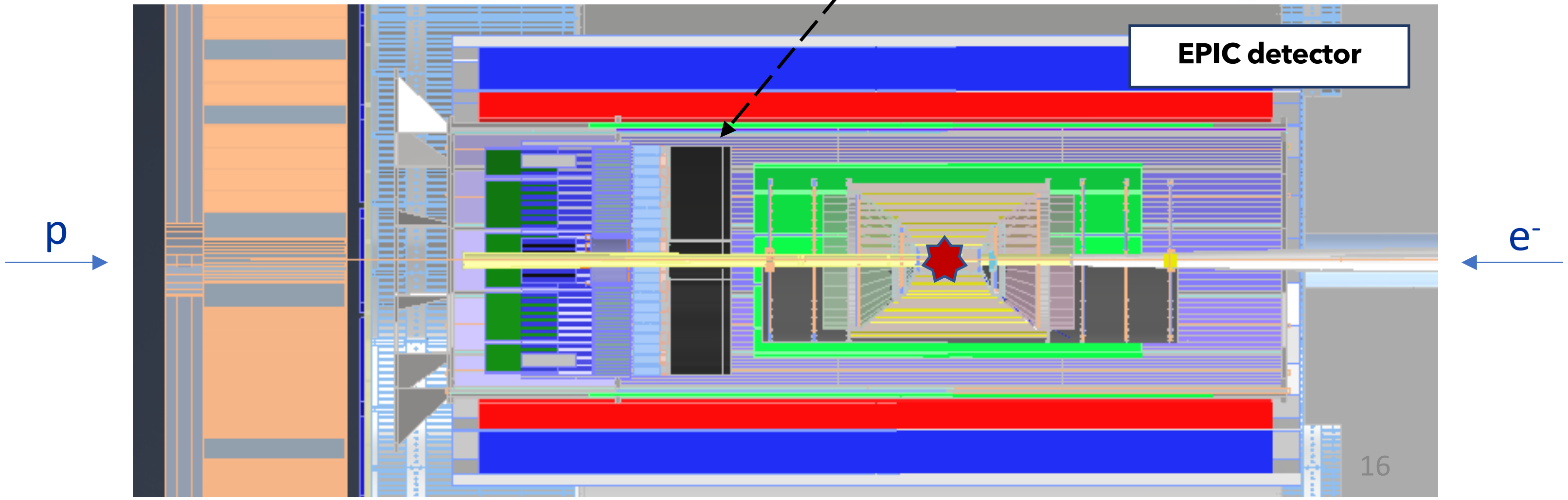
- Recycle pfRICH simulation materials from the ATHENA EIC proposal
  - A “simple” proximity focusing RICH
  - n ~ 1.020 aerogel
  - ~40 cm long expansion volume
- Convert it into a pfRICH+LAPPD concept ...
- ... complemented by a high-performance sampling digitizer electronics to provide ~10ps timing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

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



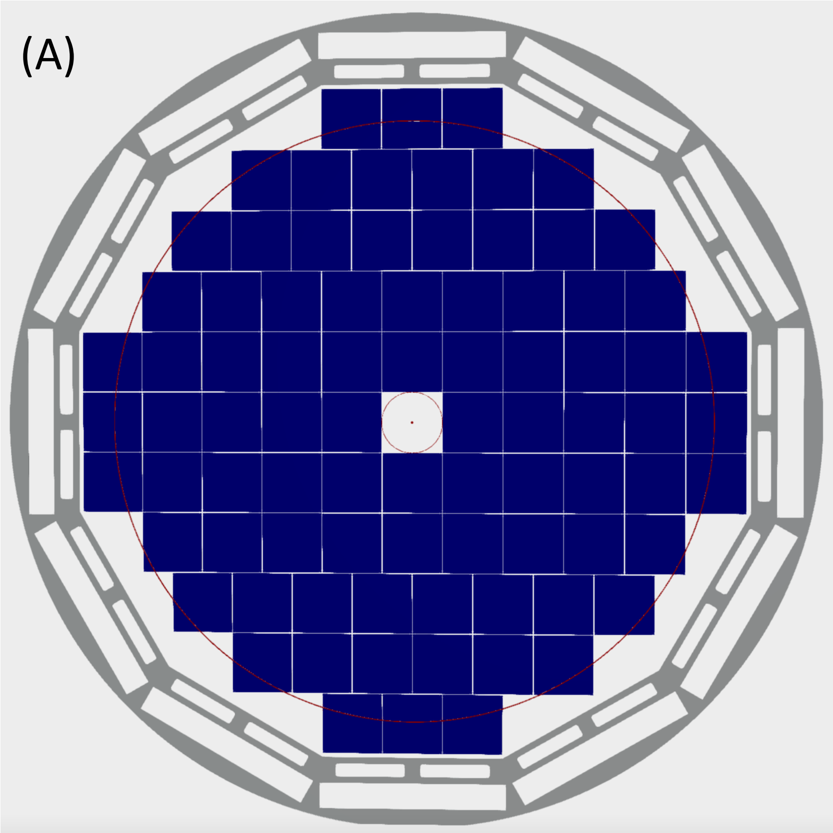


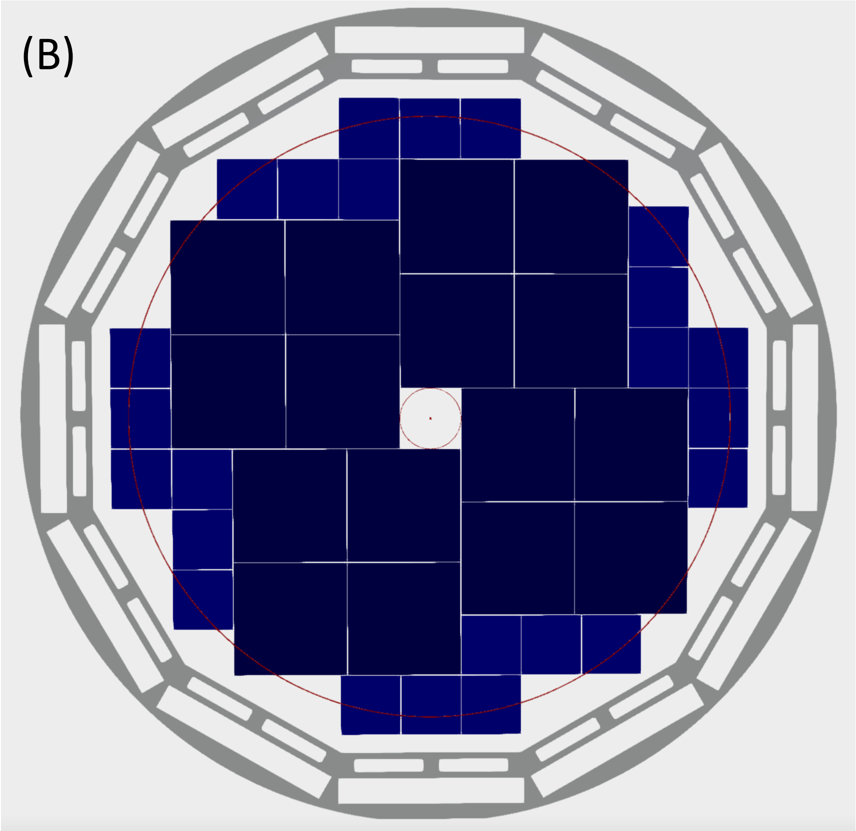


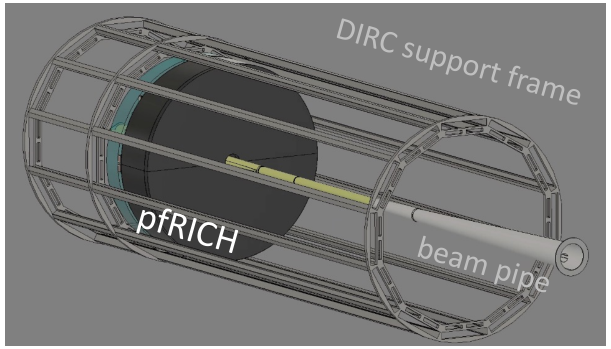


~9.5m along the beam line

Sensor plane segmentation

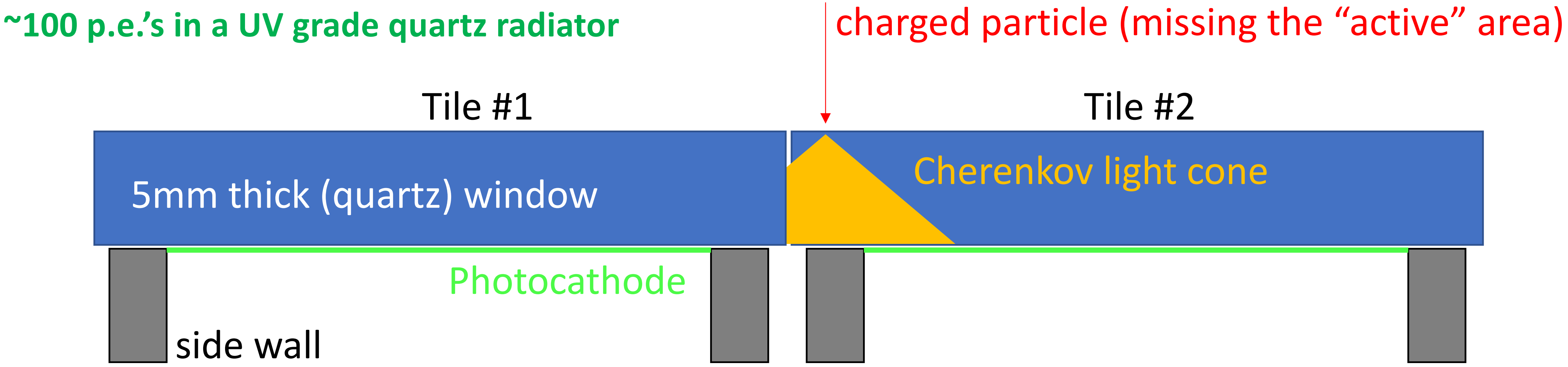






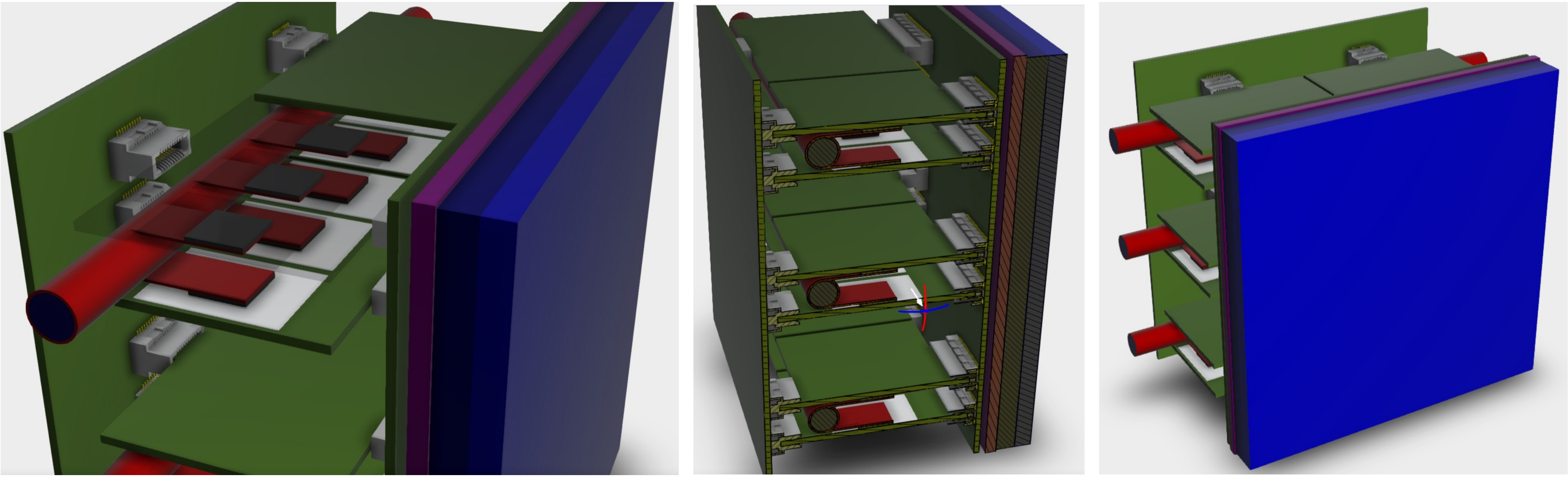
- Flat sensor surface with minimal gaps
- Consider either 10cm Gen II HRPPDs (A) or a mix of 10cm and 20cm ones (B)
- Grey structure: DIRC support frame boundary

Towards ~100% Time-of-Flight geom. efficiency



- Even that the HRPPD active area (the photocathode and the MCP stack) is much smaller than the tile footprint, the Cherenkov light cone spot in a 5 mm thick quartz window has a base of ~11 mm diameter
  - By making use of tile metallization (or perhaps just relying on a TIR) one should be able to gain timing performance over the whole surface, even though with a degraded resolution towards the tile edges, apparently

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