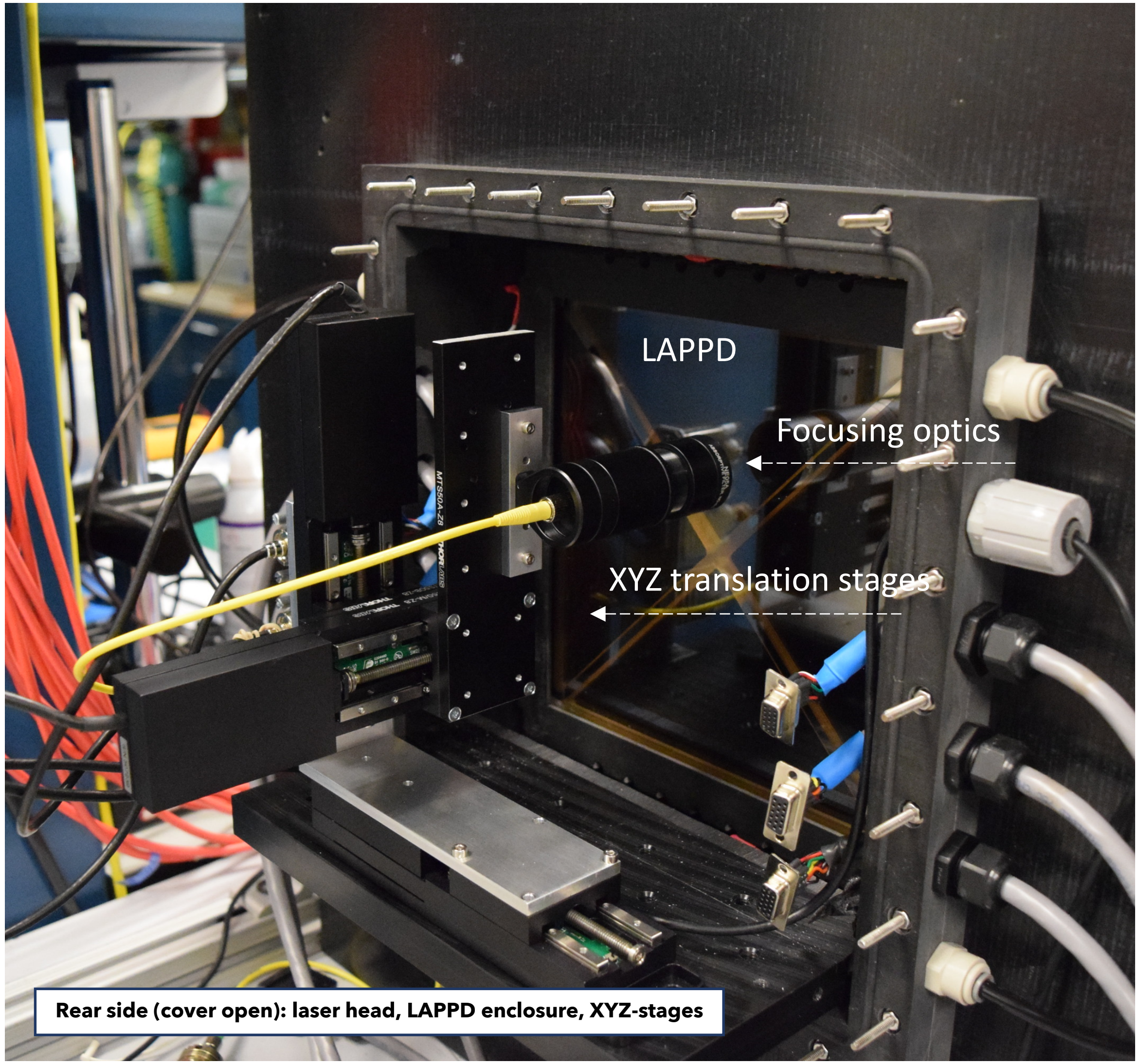
LAPPD R&D Status Report

Alexander Kiselev (BNL)

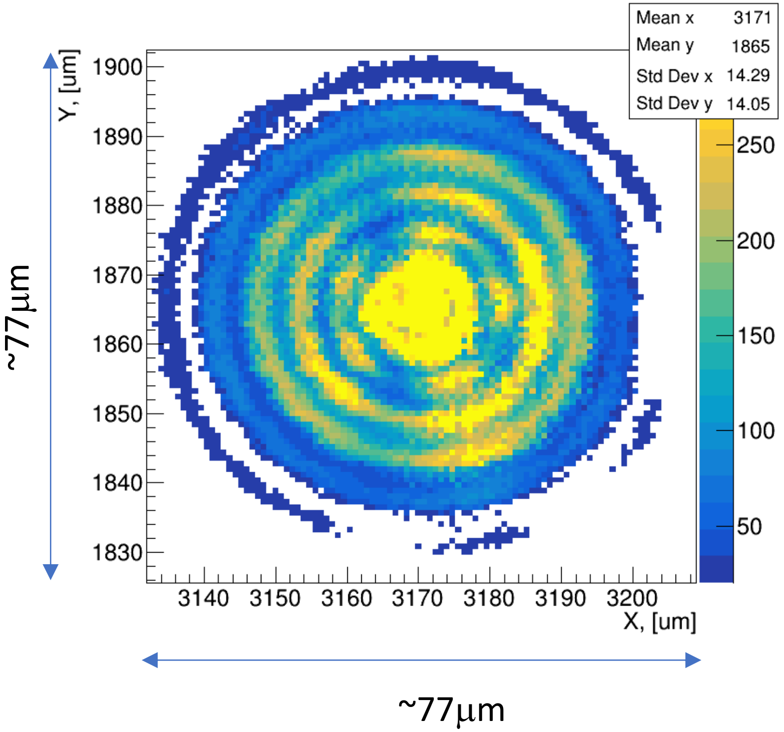
EIC PID Consortium meeting, October 17, 2022

Lab measurements at Brookhaven

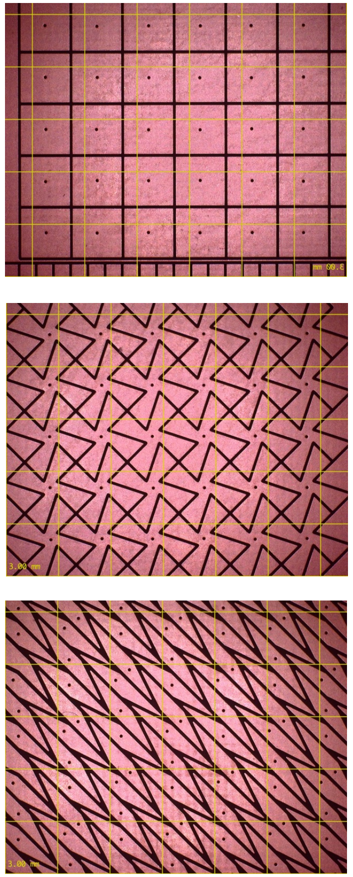
Test bench setup



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

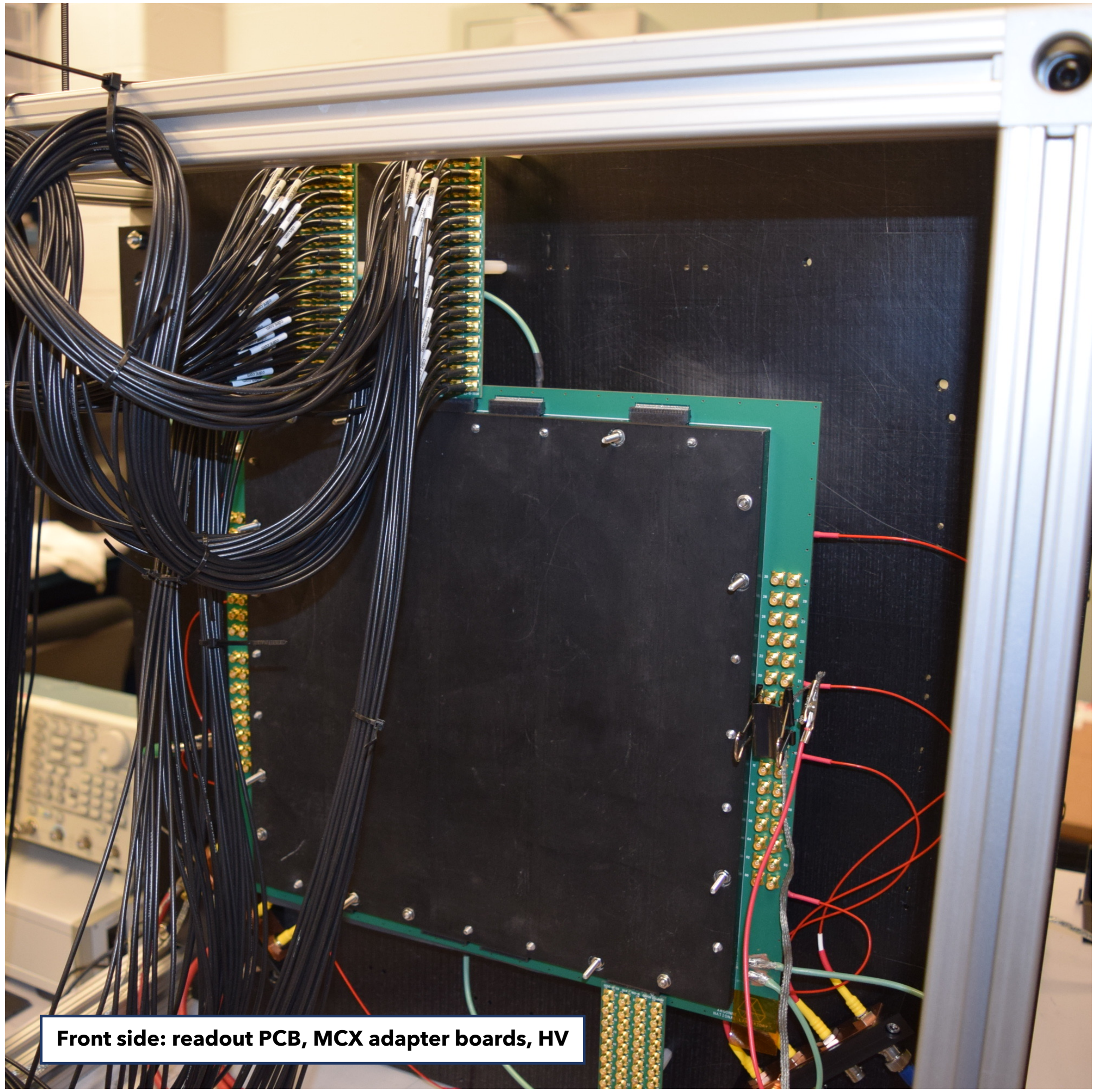


Laser spot as measured by a CMOS camera



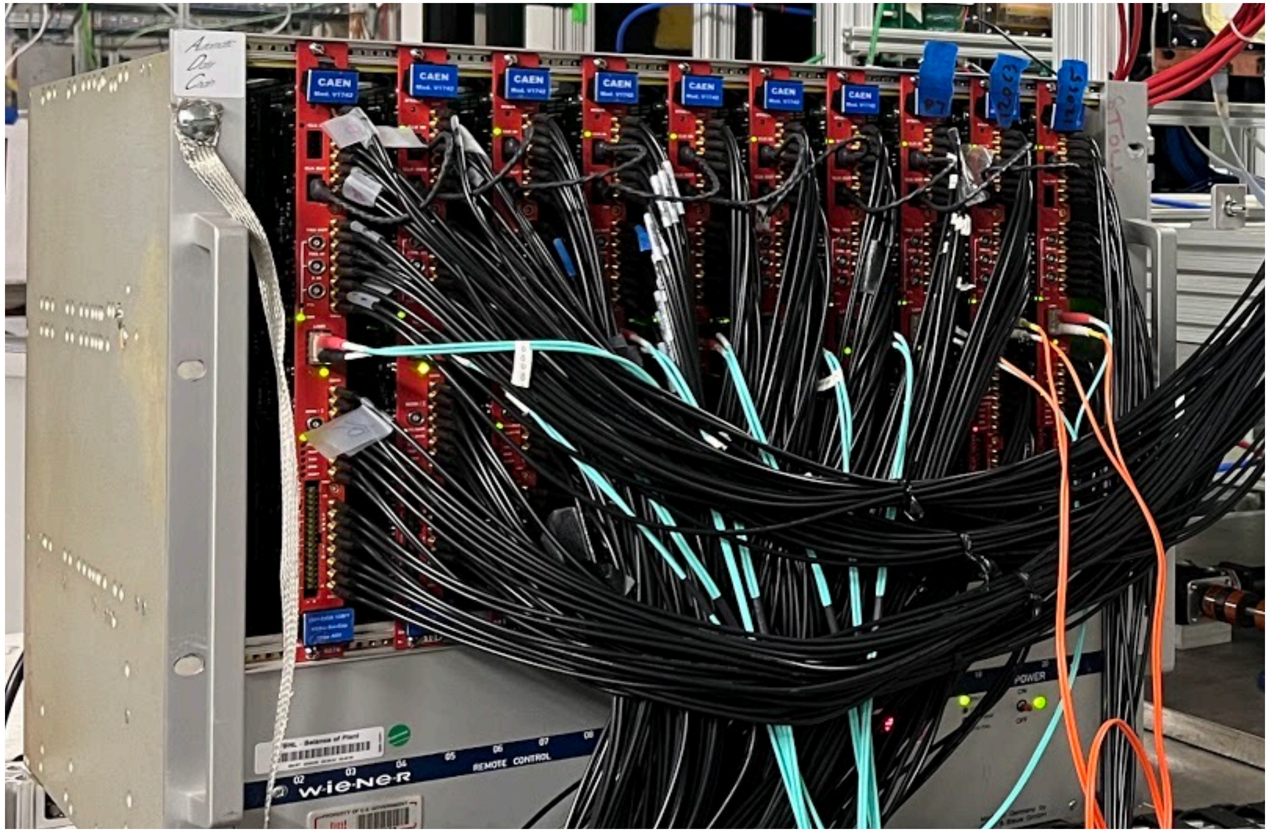
here: all 3mm pitch

Test bench setup



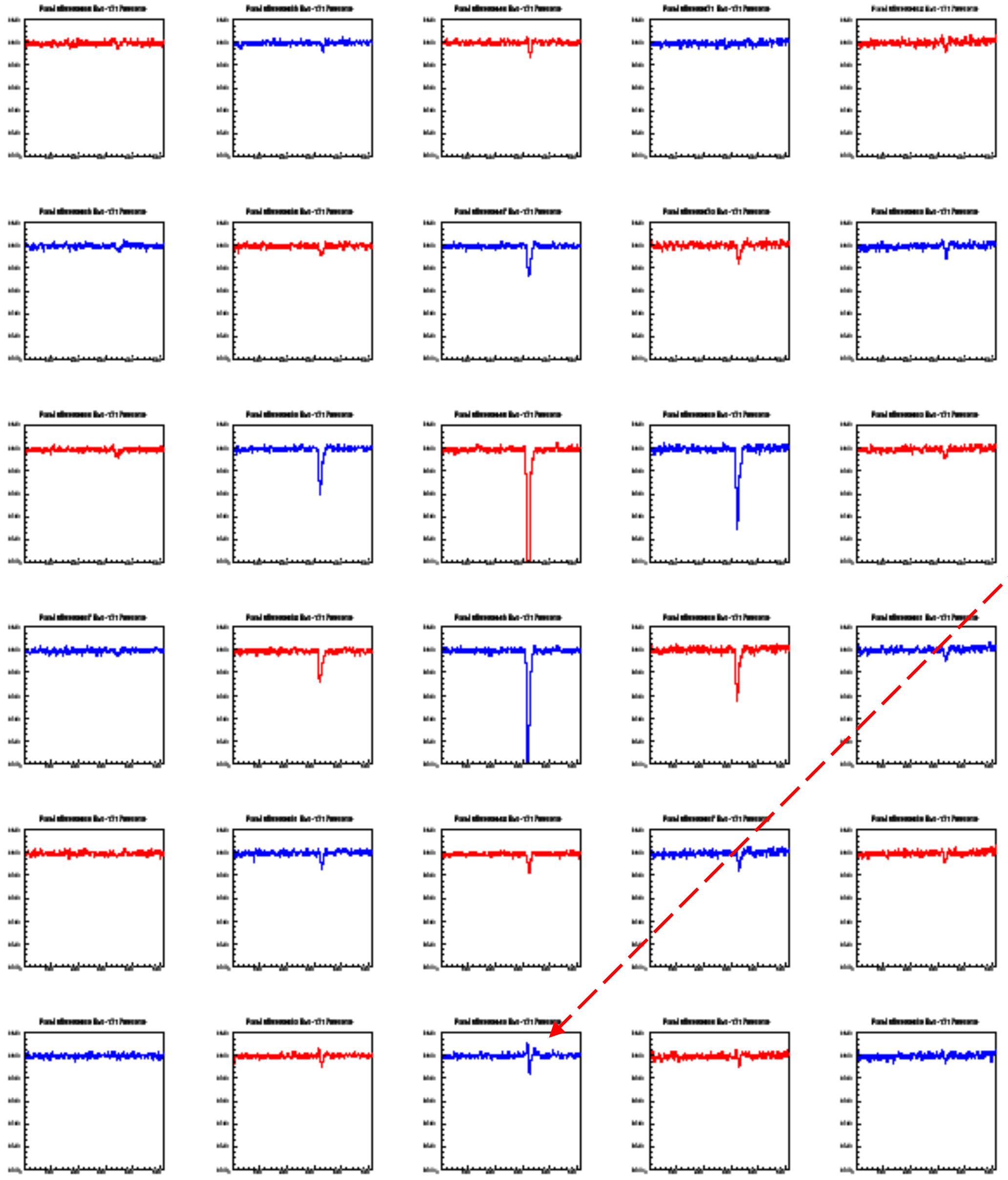
Front side: readout PCB, MCX adapter boards, HV

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



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

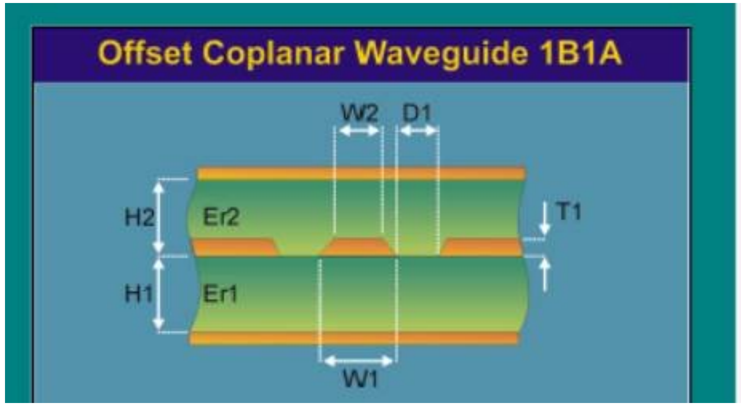
PCB stack details & cross-talk evaluation



6x pads vertically; ~12 mV central pixel amplitude

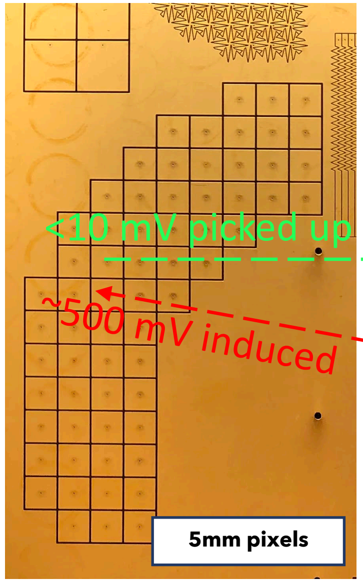
5x 4mm pads horizontally; 50ns time window

Certain level of cross-talk is present (traces here are routed in Y-direction)

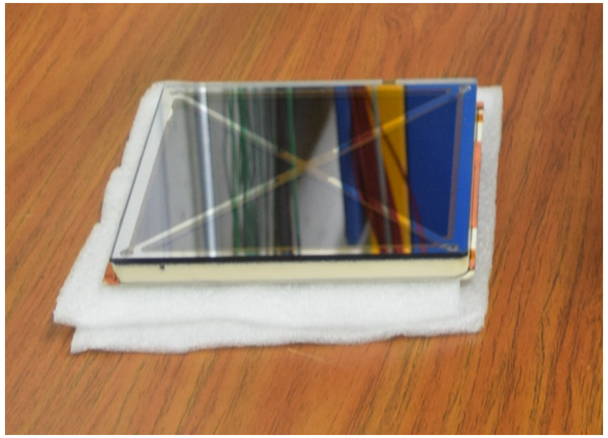


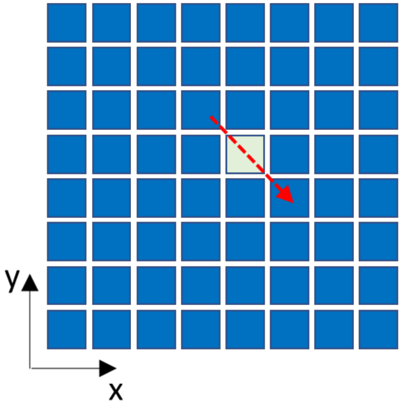
Substrate 1 Height	H1
Substrate 1 Dielectric	Er1
Substrate 2 Height	H2
Substrate 2 Dielectric	Er2
Lower Trace Width	W1
Upper Trace Width	W2
Ground Strip Separation	D1
Trace Thickness	T1

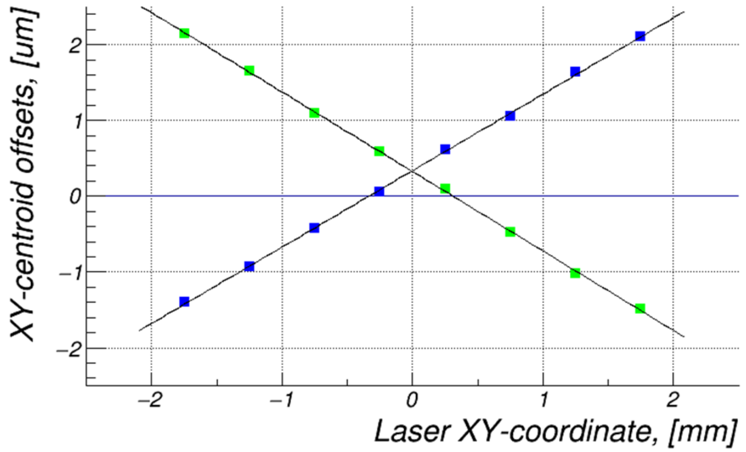
- Multi-layer stack-up; through vias; isolated traces
- Worst case X-talk ~few % level



Spatial resolution with the 3 mm square pixels







- "Single-photon" mode

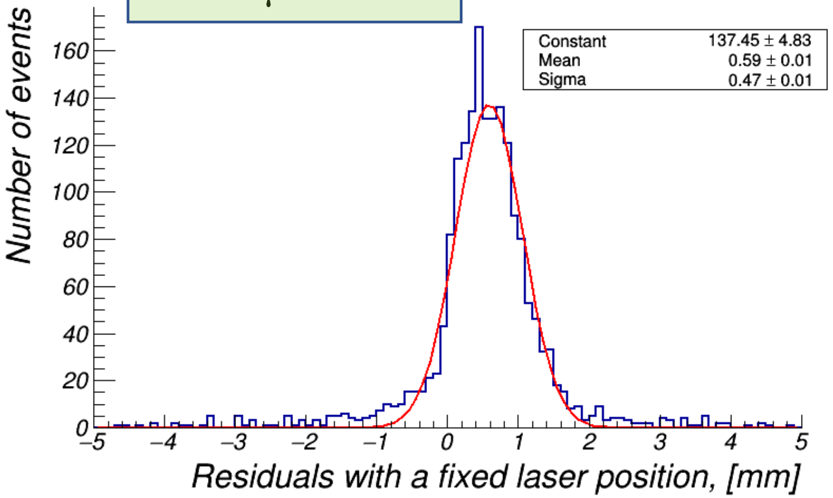
$$X \sim \frac{\sum_i^n q_i x_i}{\sum_i^n q_i}$$

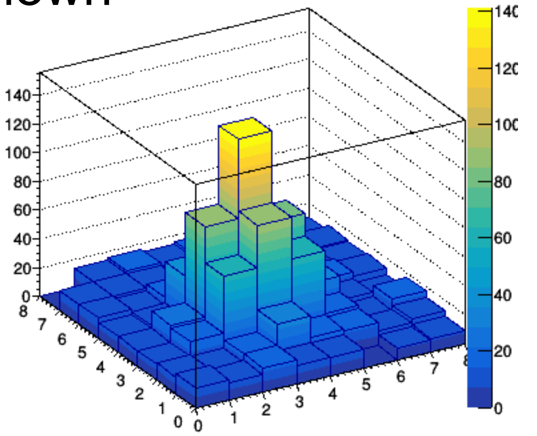
- Gen II LAPPD tile #97 provided by Incom
  - 2mm thick ceramic base

- 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

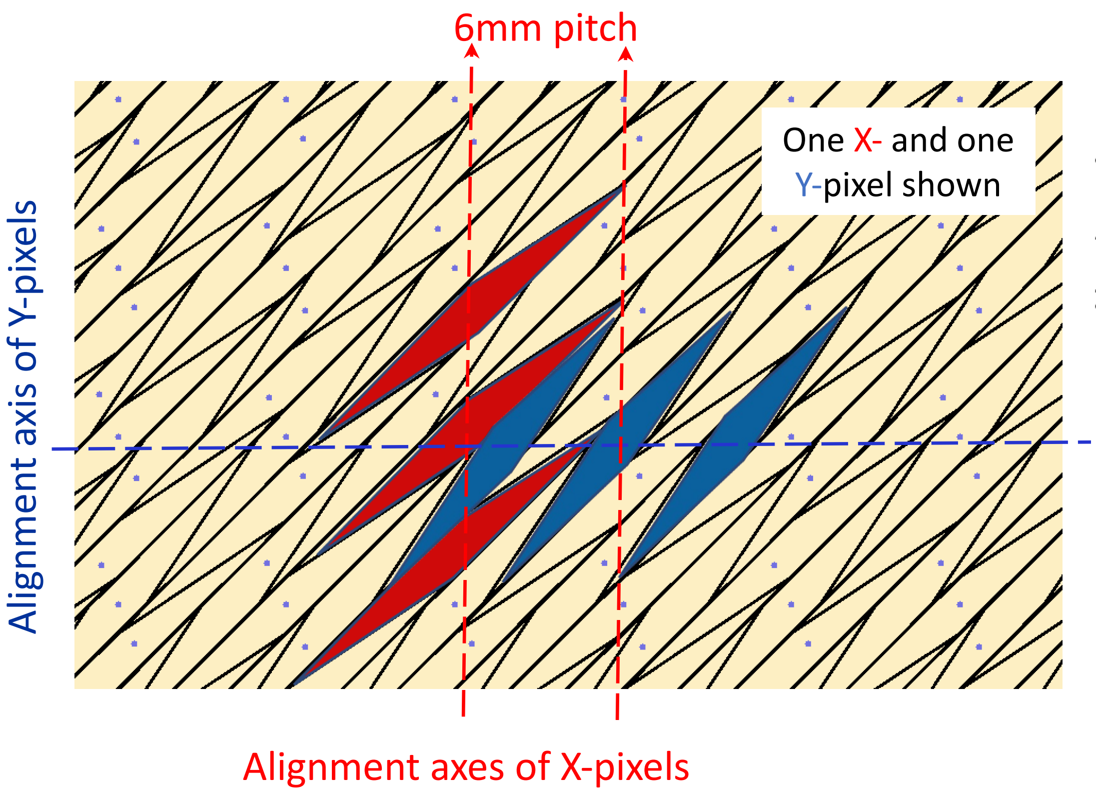
~500 μm width

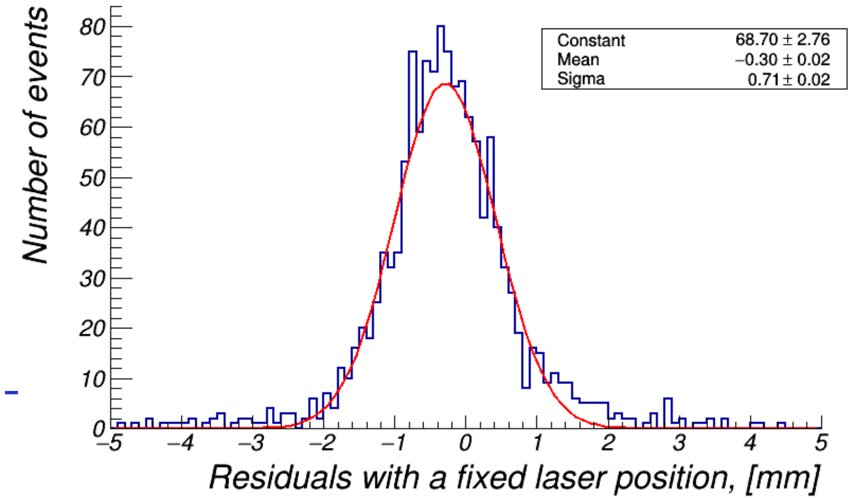




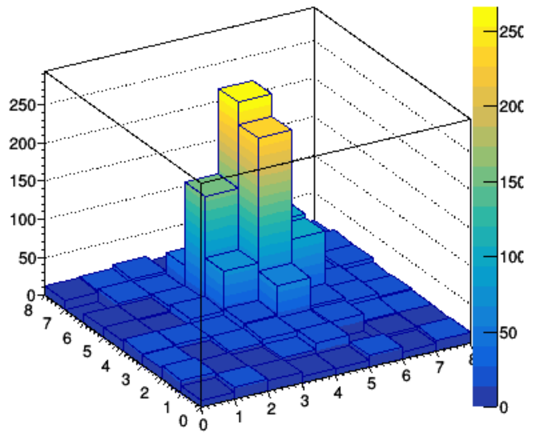
Typical single photon cluster has RMS ~ 3.5 mm

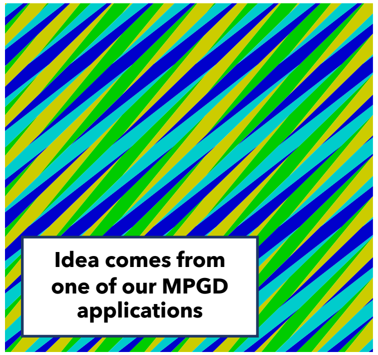
2D zigzag pixels with a 6 mm pitch



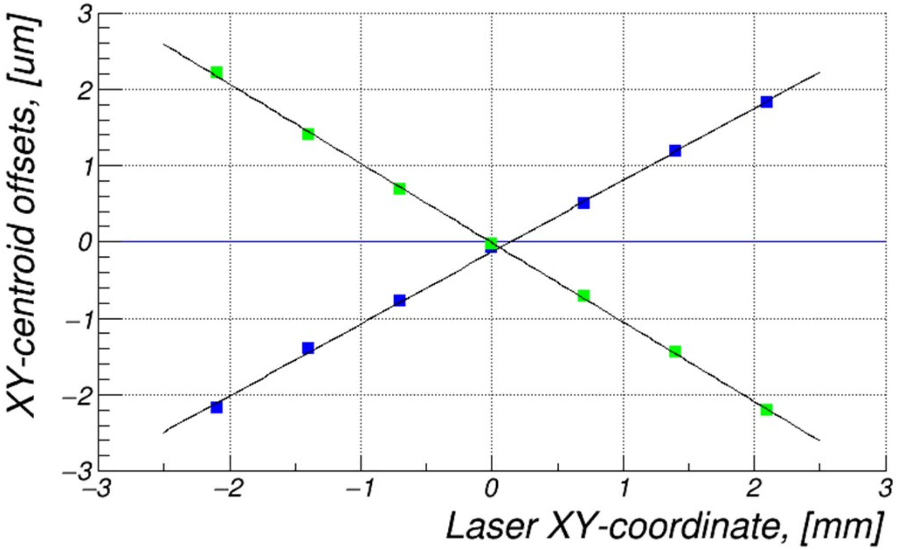


Typically, 3x3 pixel clusters





Linearity scan results



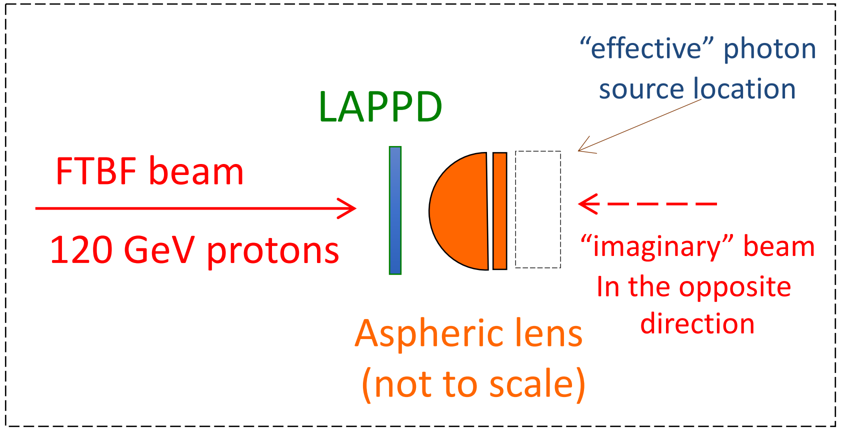
- Pretty good linearity
- Spatial resolution typically ~700-800 μm (given the S/N ratio)
- As long as occupancy is acceptable one can increase the effective pad size (length!) without losing spatial resolution

Beam test at Fermilab in June 2021

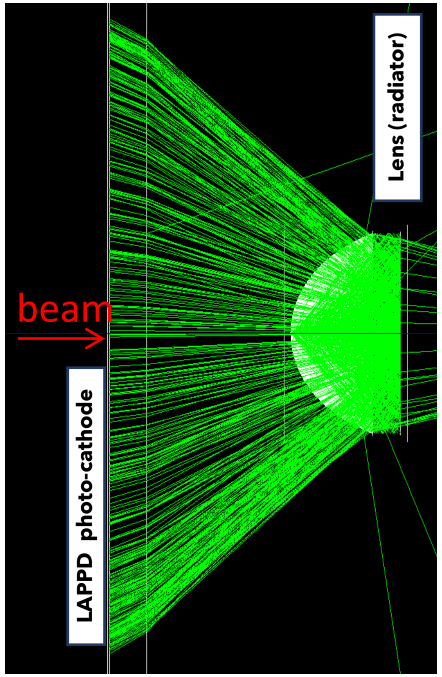
(BNL, Incom Inc., Argonne, GSU, Stony Brook & other groups)

Experimental setup

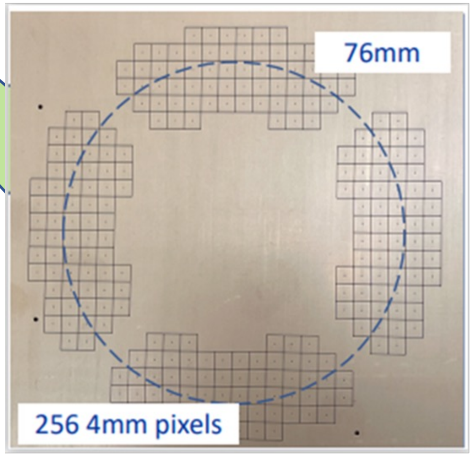
- The same setup as in the lab, but instead of a laser use *a thick aspheric lens* as a well controlled Cherenkov light source

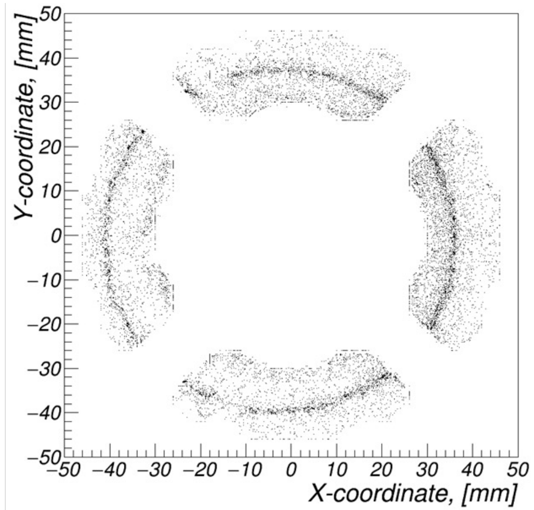


- Off-the-shelf component
- (Almost) no stray photons
- To first order no need in tracking
- The used model (Edmund Optics #67-265, EFL 20.0mm) produces a crisp ~76mm diameter ring at the focal plane



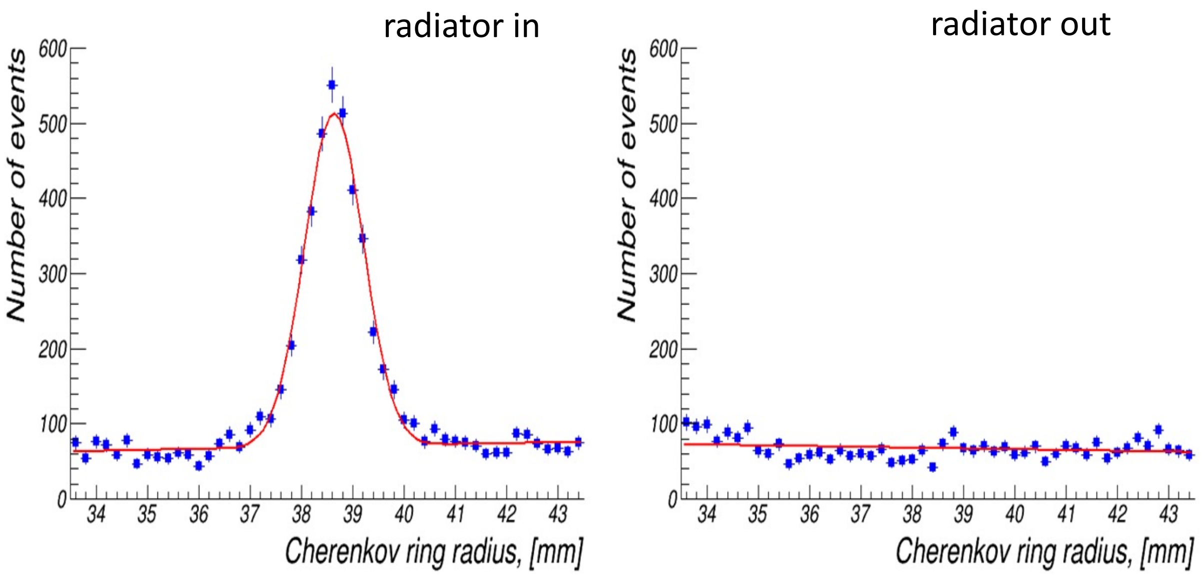
Pixel pattern & accumulated single photon XY-coordinates



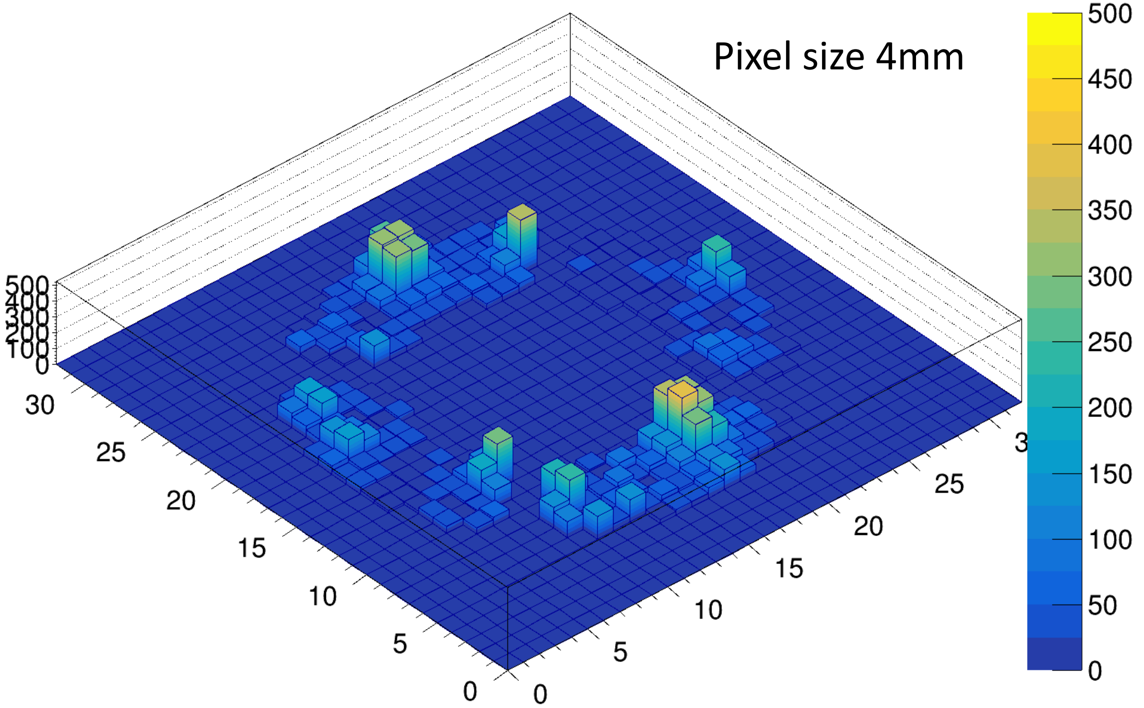


Cherenkov ring radius resolution

σ_R ~ 600 μm



Single photon ring radius resolution



Single event with multiple photon clusters

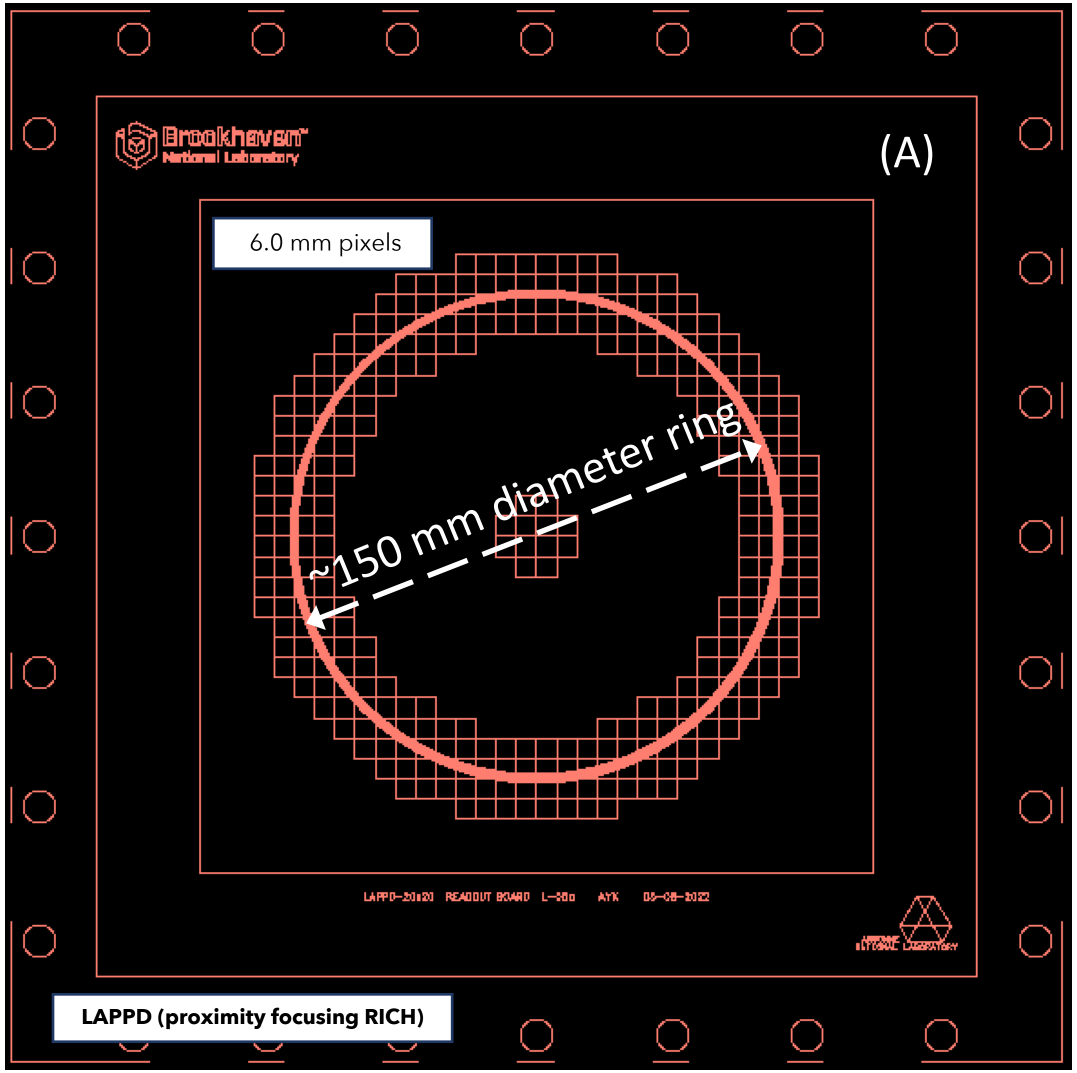
- Yes, one can measure single Cherenkov photons with sub-mm spatial resolution using pixelated Gen II LAPPDs!

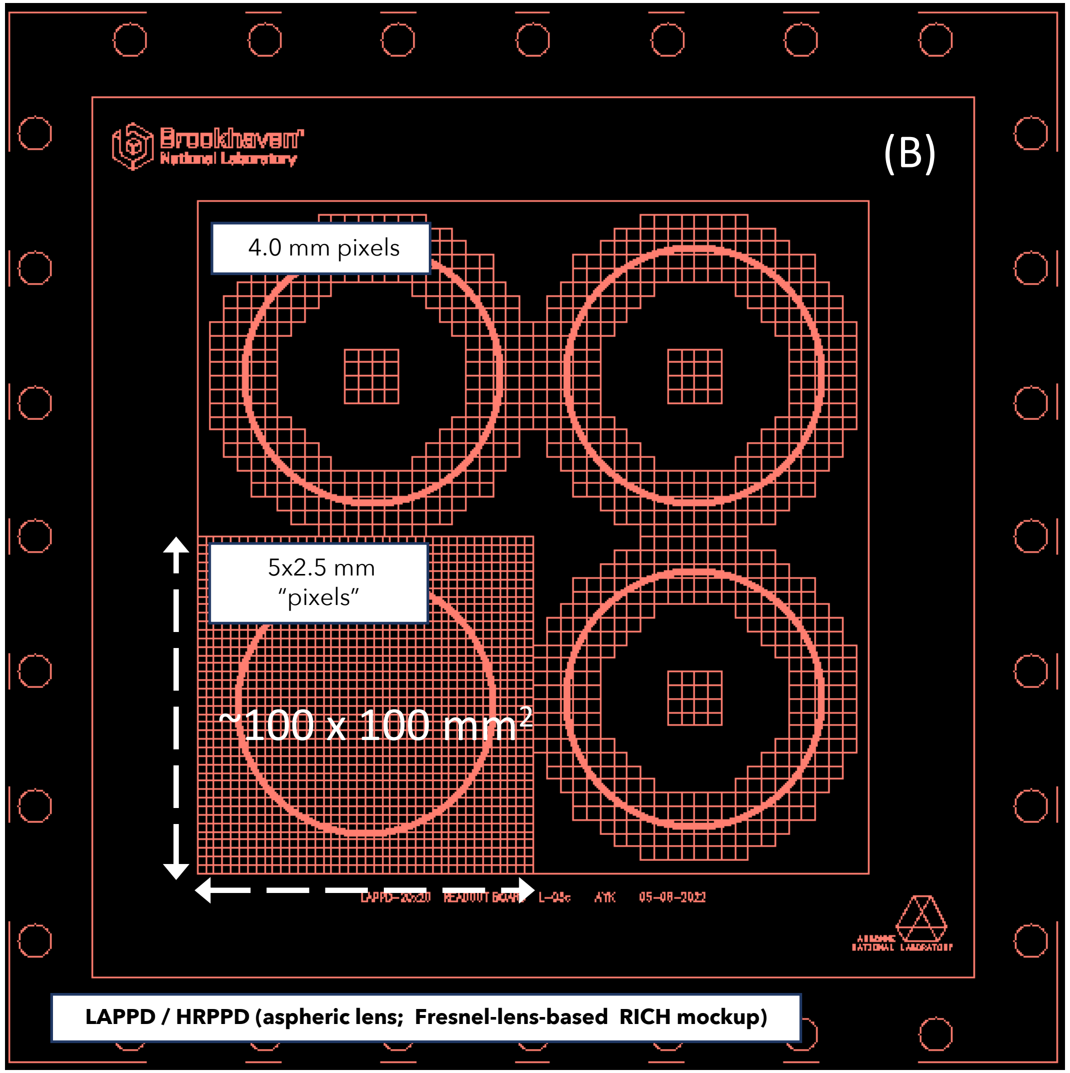
Paradigm change in the Cherenkov ring imaging data analysis: overlapping clusters rather than single pixel hits

Beam test at Fermilab in June 2022

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

Readout boards

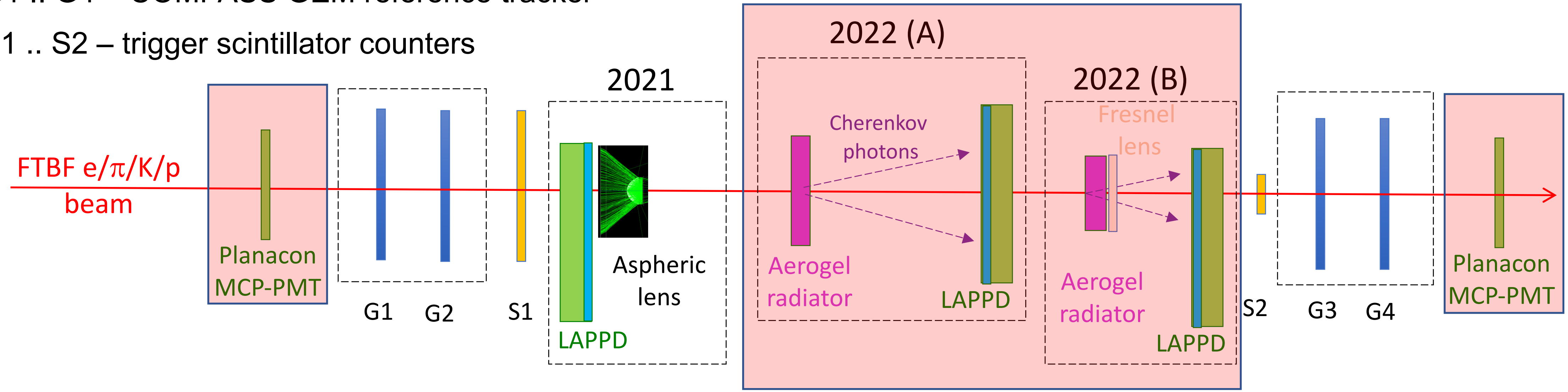




An attempt to demonstrate a *simultaneous* ring imaging and time-of-flight performance

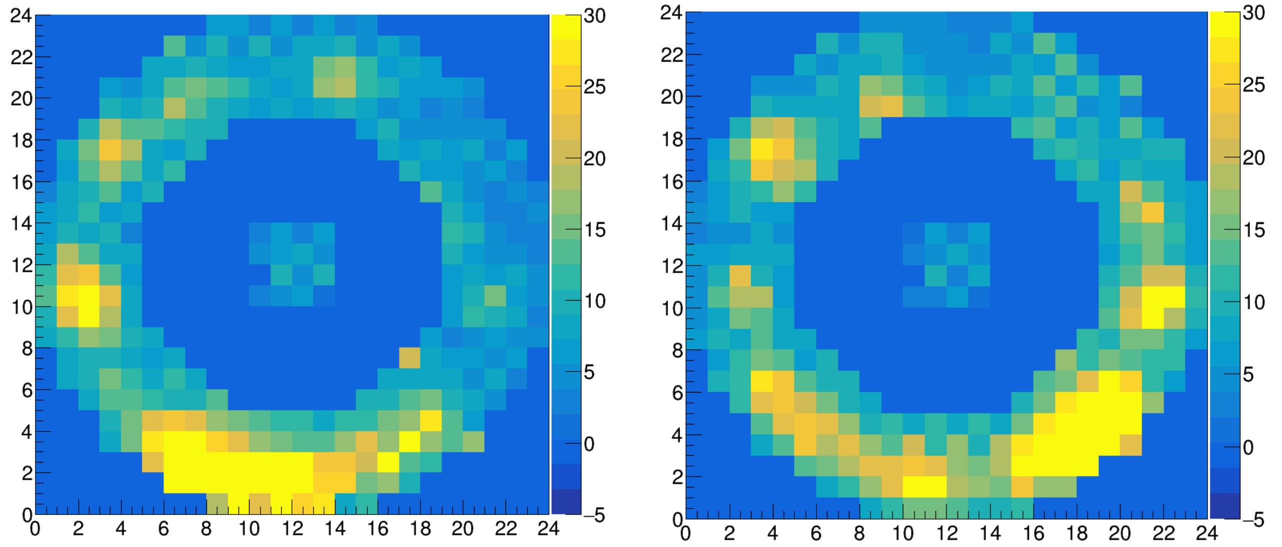
Experimental setup

- 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

Aspheric lens as a source of coherent Cherenkov photons

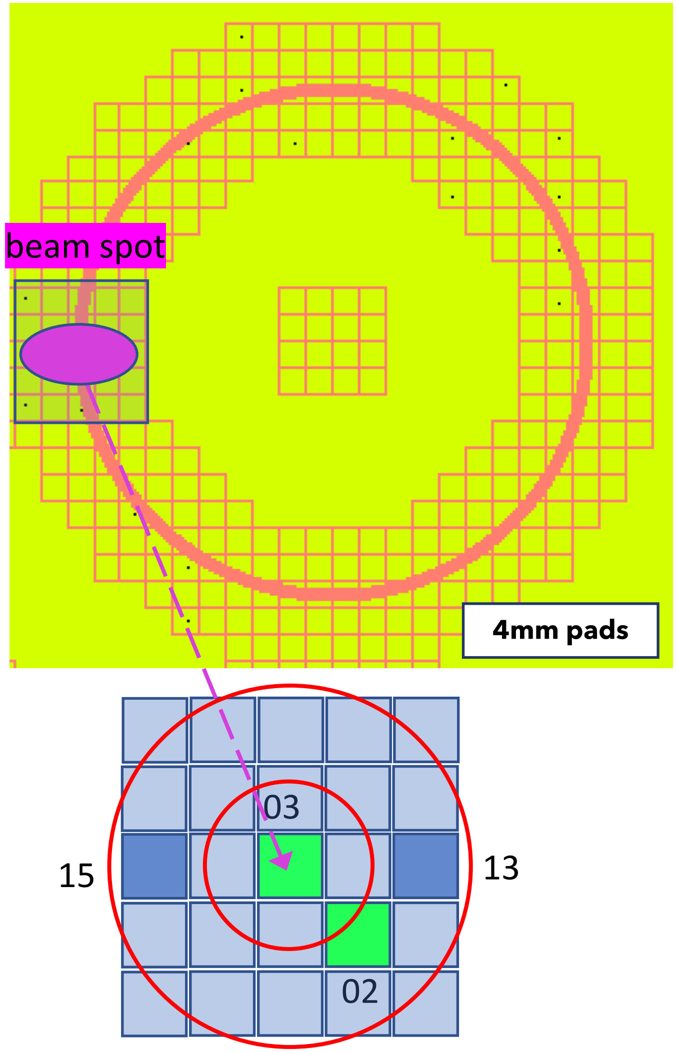


Enough data on tape to quantify **single-photon** timing resolution

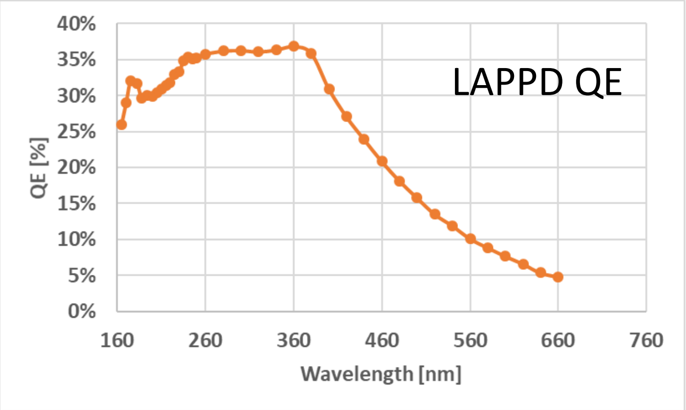
Single events: no filter, 24x24 4mm pixel field, [mV] units

A quest for <10 ps timing for *TOF* applications

LAPPD quartz window as a Cherenkov radiator

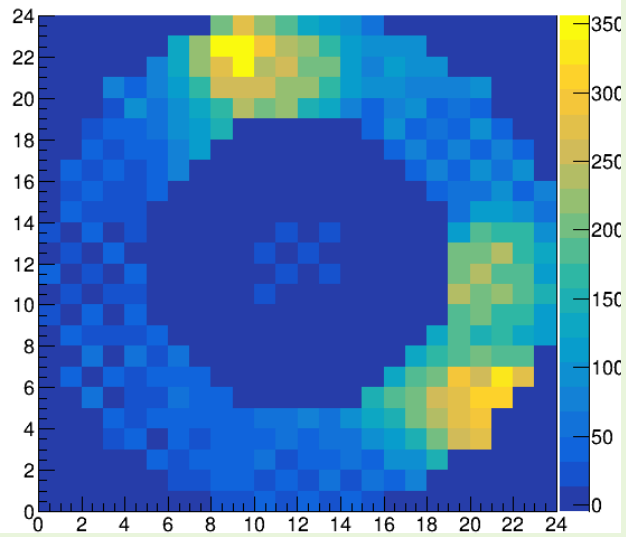


Due to the TIR, photons only hit the PC in a radial band ~[5.5 .. 12.0] mm

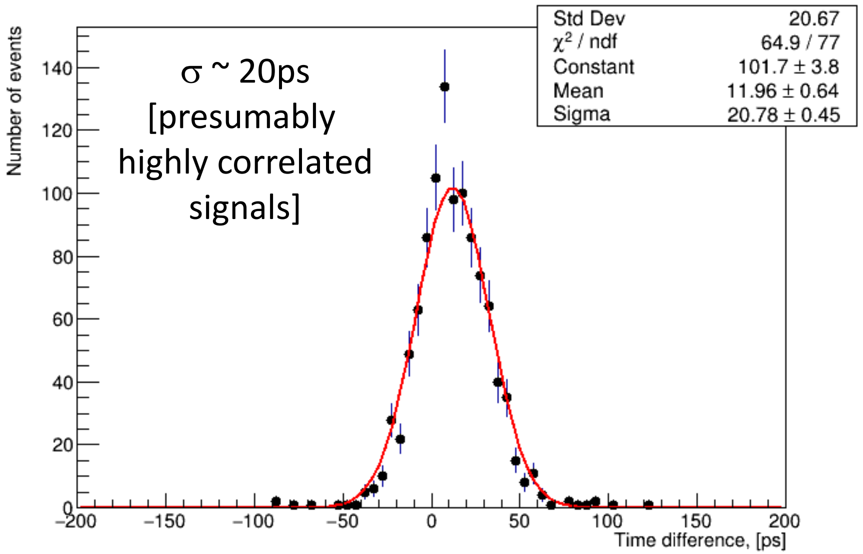


- *Single* photon TTS ~50 ps
- UV grade quartz window: a 120 GeV proton produces a **blob of ~100 p.e.'s**

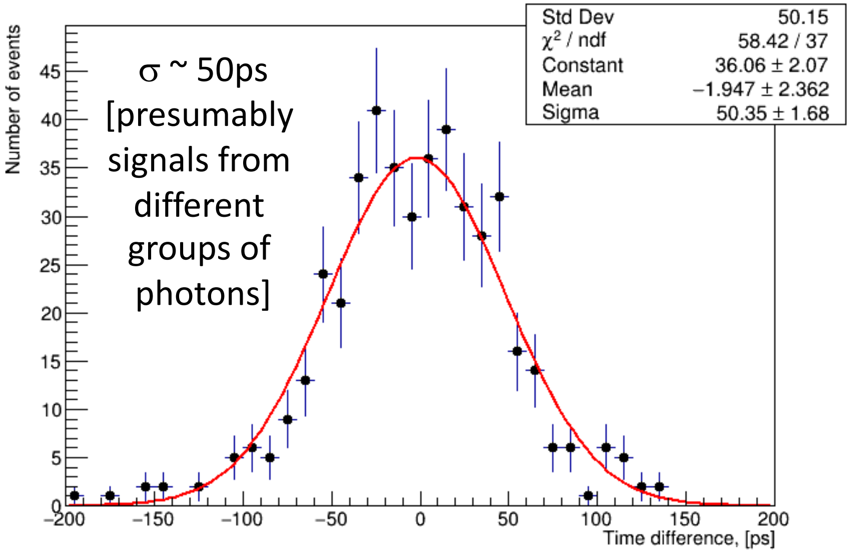
Future work: how to circumvent the missing high precision t_0 timing reference?



Single event with two beam particles; [mV] units



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

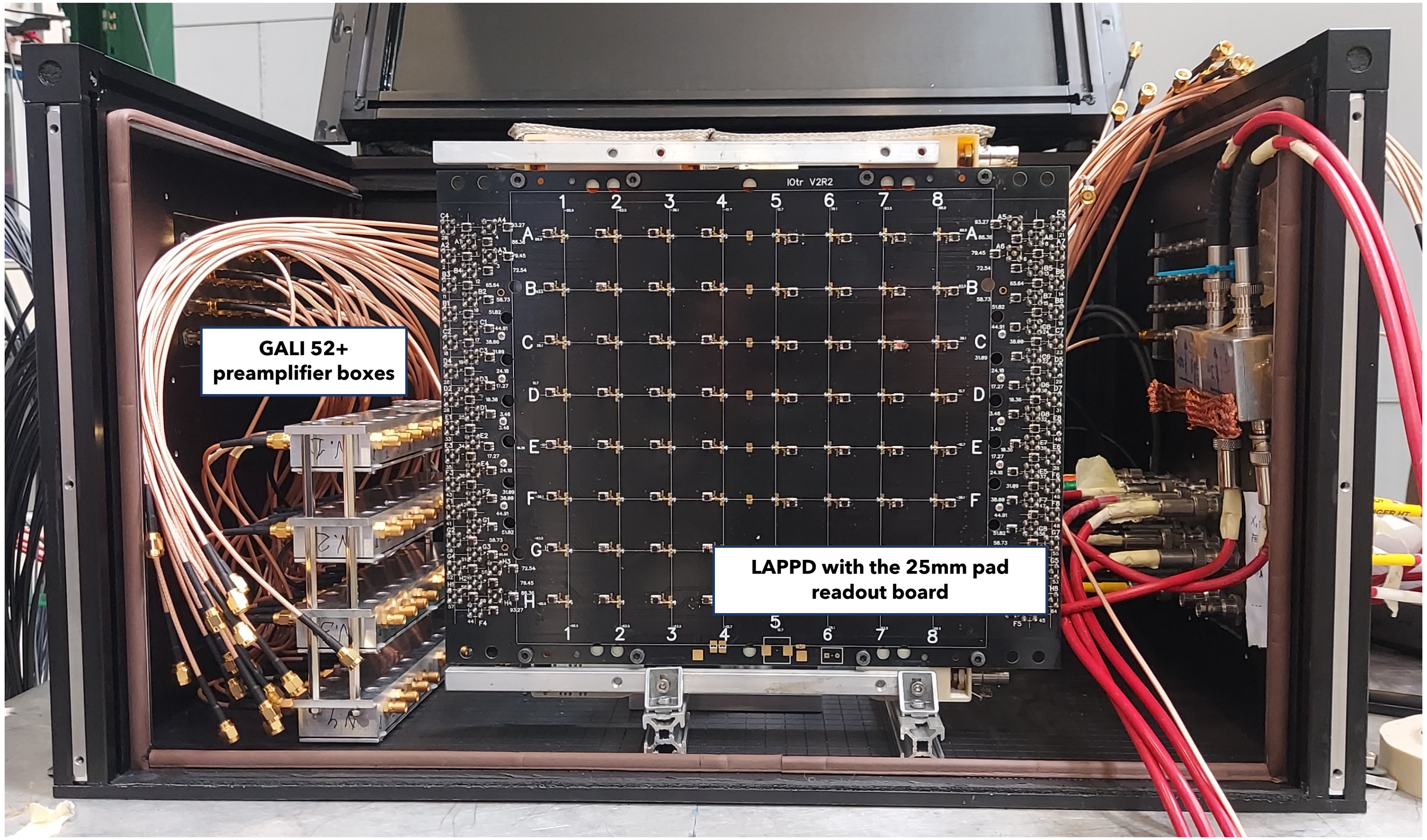


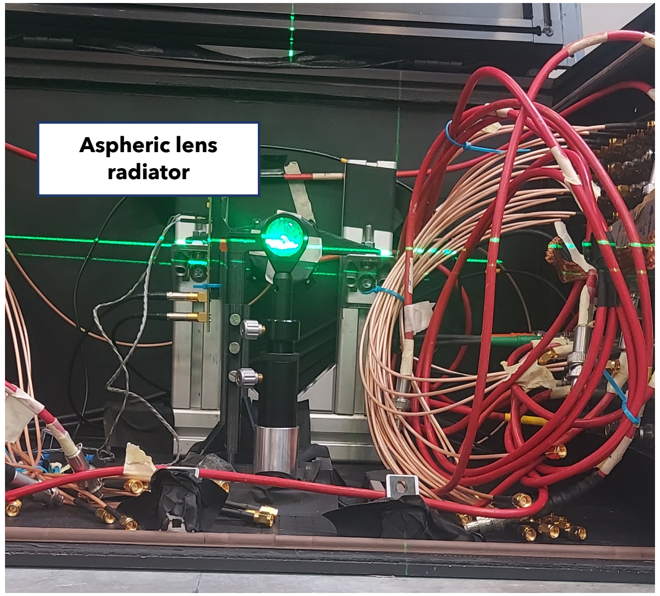
DRS4 chip#1: time(ch#15) – time(ch#13)

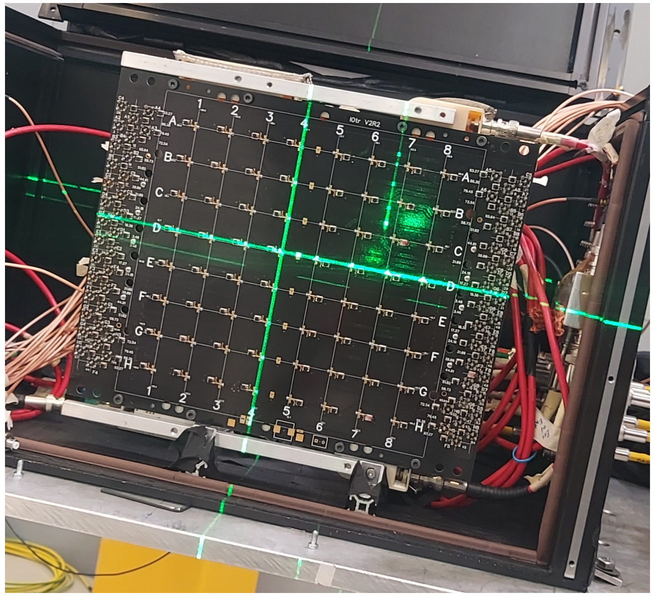
Beam test at CERN in October 2022

(INFN Trieste, INFN Genoa, Incom Inc., BNL)

Experimental setup at CERN in October 2022







- A standard 20 cm Gen II LAPPD tile 124 with 20 μm pore MCPs
- Incom's own 8x8 pad board
- x10 amplifier boards
- Hamamatsu MCP-PMTs as a timing reference

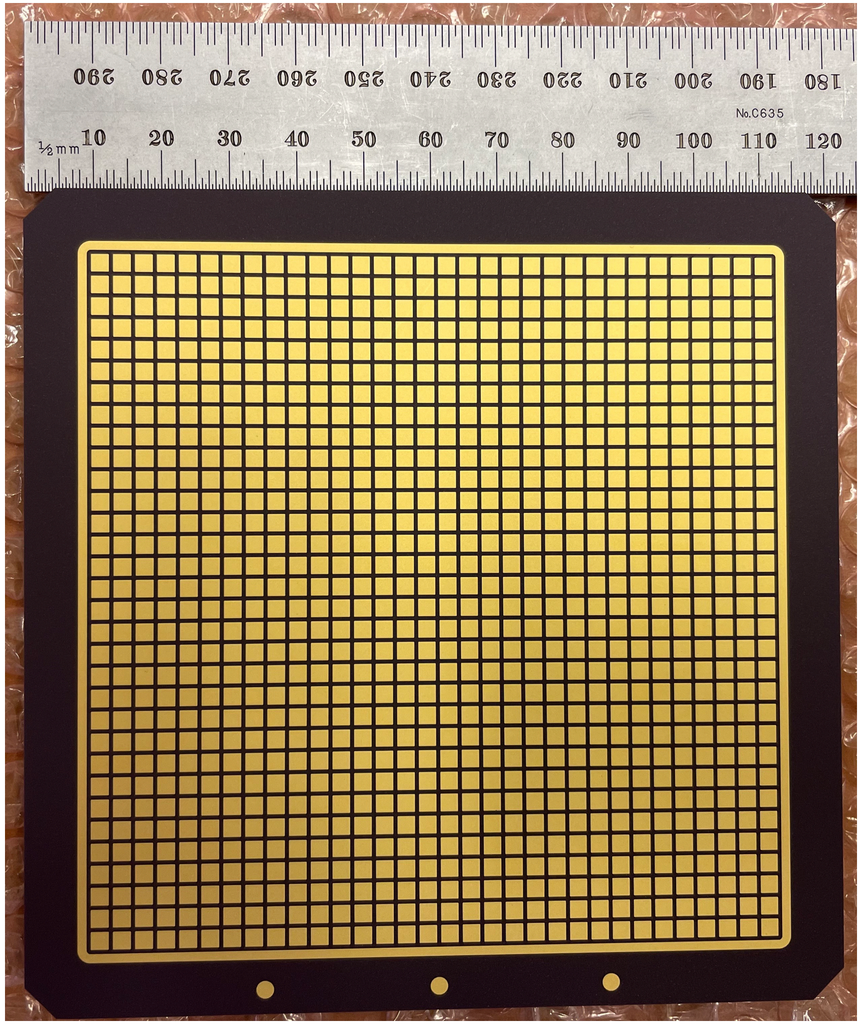
Other news

- October 26, 2022, second one in the series: https://indico.bnl.gov/event/17475/
- The first workshop (https://indico.bnl.gov/event/15059/) happened in March 2022
  - Attended by 80+ participants
  - Talks by Incom, Nalu Scientific, NP/HEP research groups

- Stony Brook / Brookhaven 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 (Amir Goldan & AK)
  - Quite some synergy with the HEP/NP LAPPD R&D activities

DC-coupled HRPPD interface

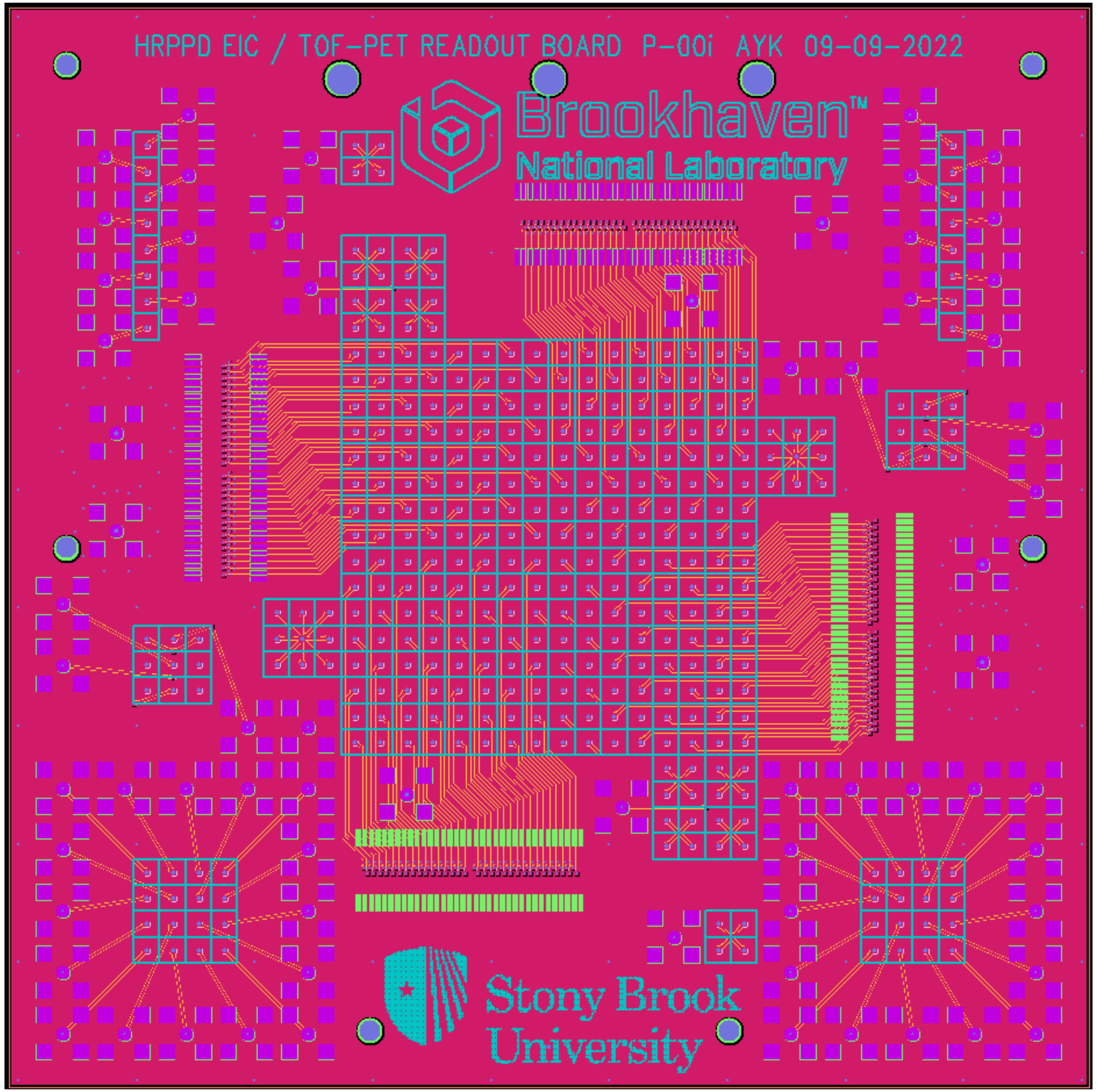
DC-coupled HRPPD



Tile #4 delivered to BNL two weeks ago

- ~120 x 120 mm^2 footprint; ~100x100 mm^2 active area (no spacers); 1/8” (~3.2 mm) pad pitch
- Short MCP stack with 5mm thick quartz window and 3mm thick ceramic base plate

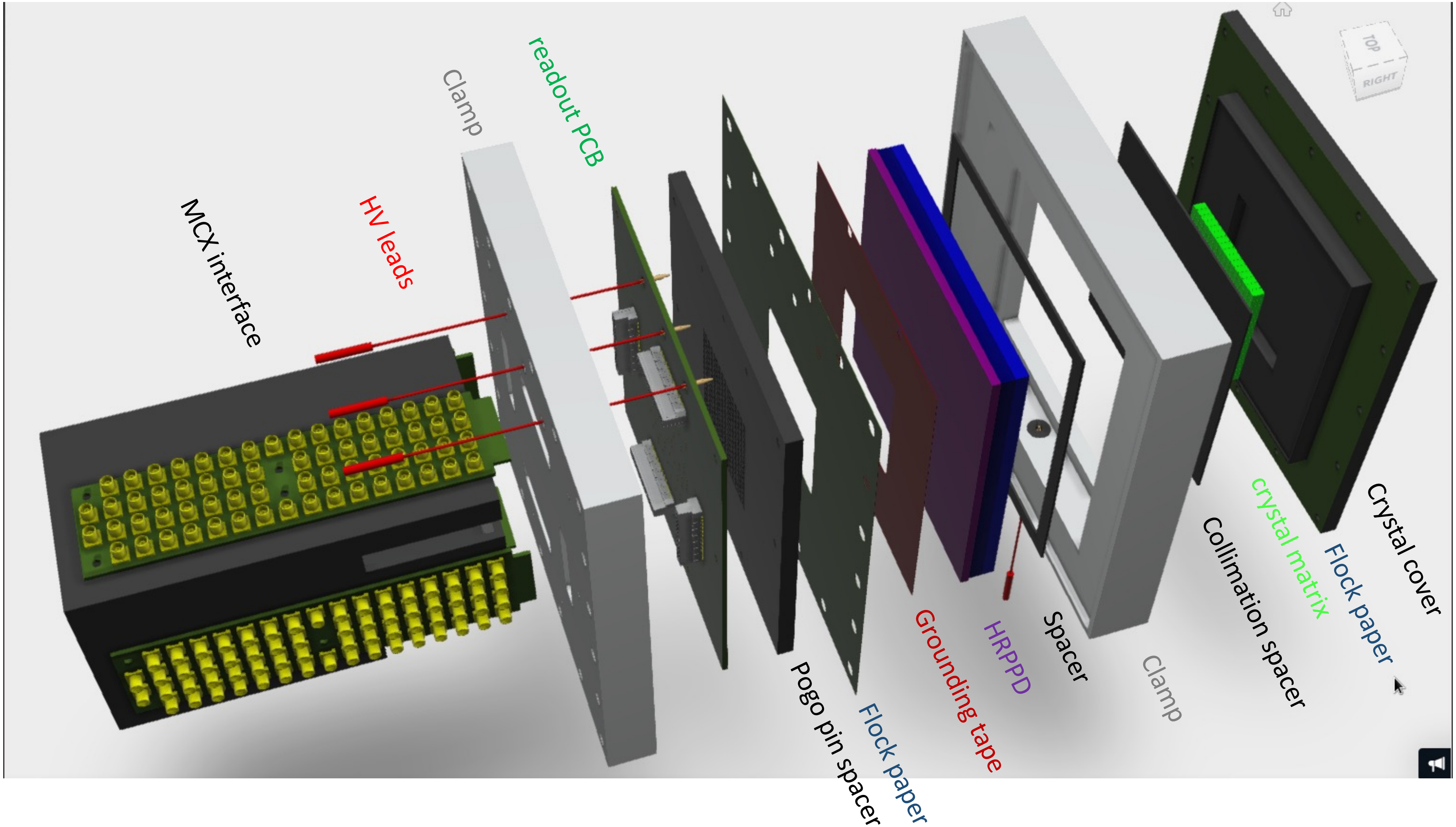
Dual purpose readout PCB



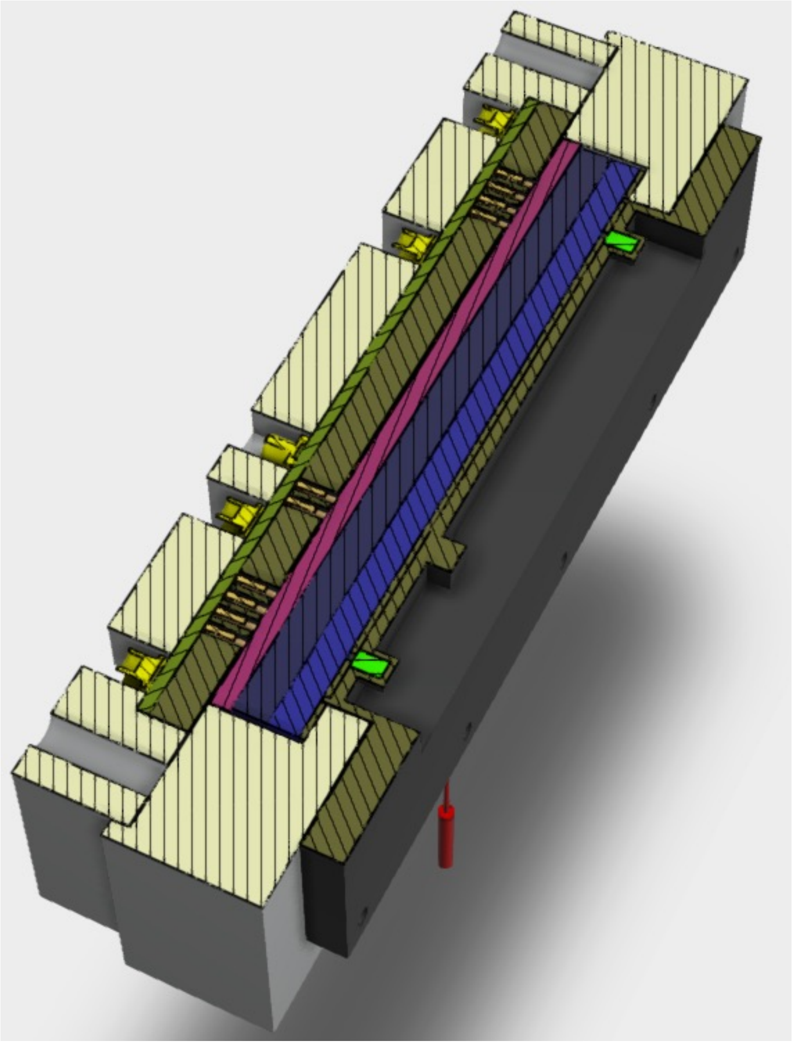
- A compact universal 132 x 132 mm^2 board
- Pixellation follows ~3.2mm HRPPD pad pitch
- Two "main" instrumentation options:
  - A 16x16 pad field in the center
  - Pairs of individual pad fields for systematic studies
- Connectivity via either MCX->MCX cables or Samtec->MCX adapters
- Can be used for 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

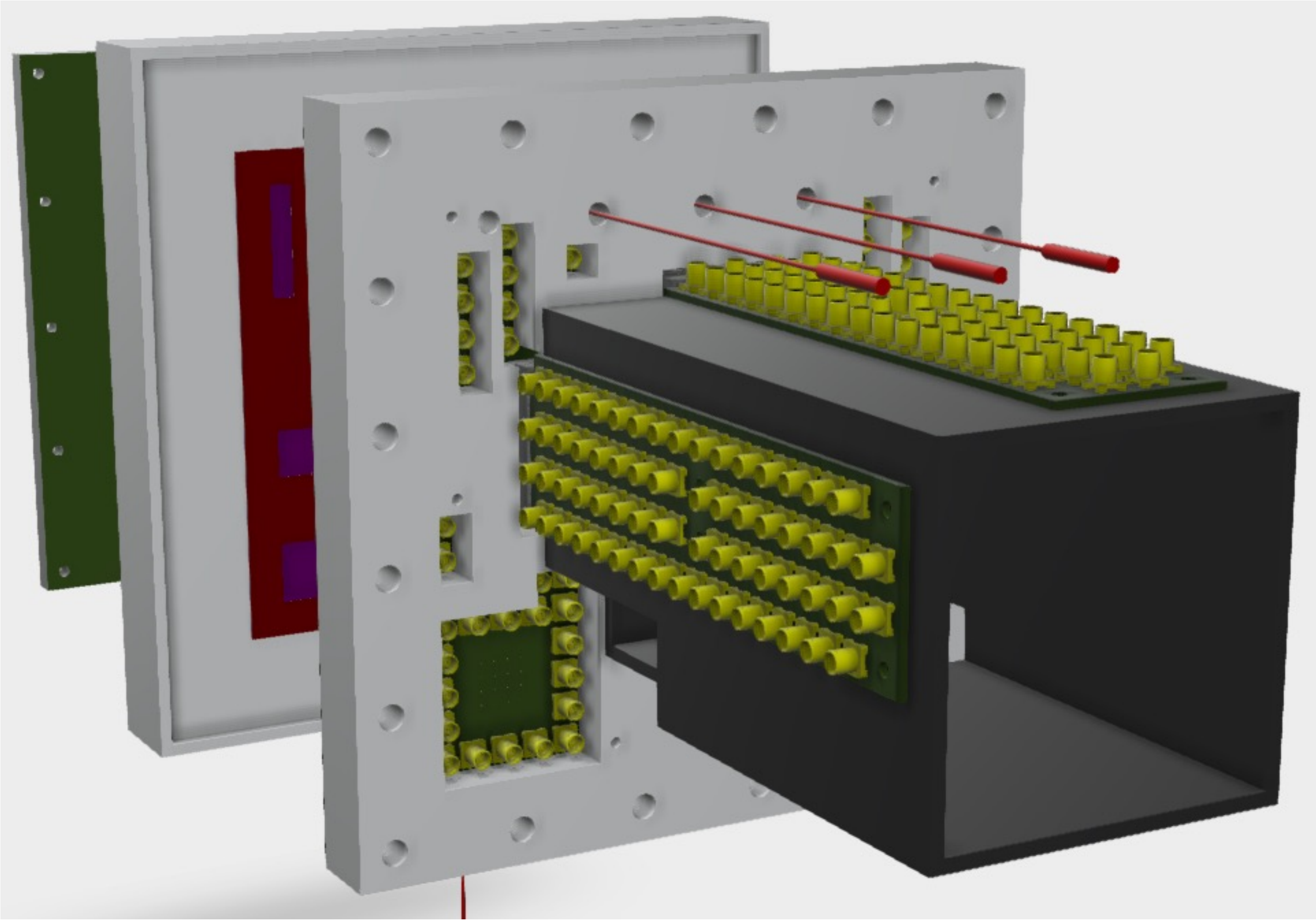
Bare boards will be shipped to BNL end of the month

3D integration model (here: a 16x16 pad PET setup)



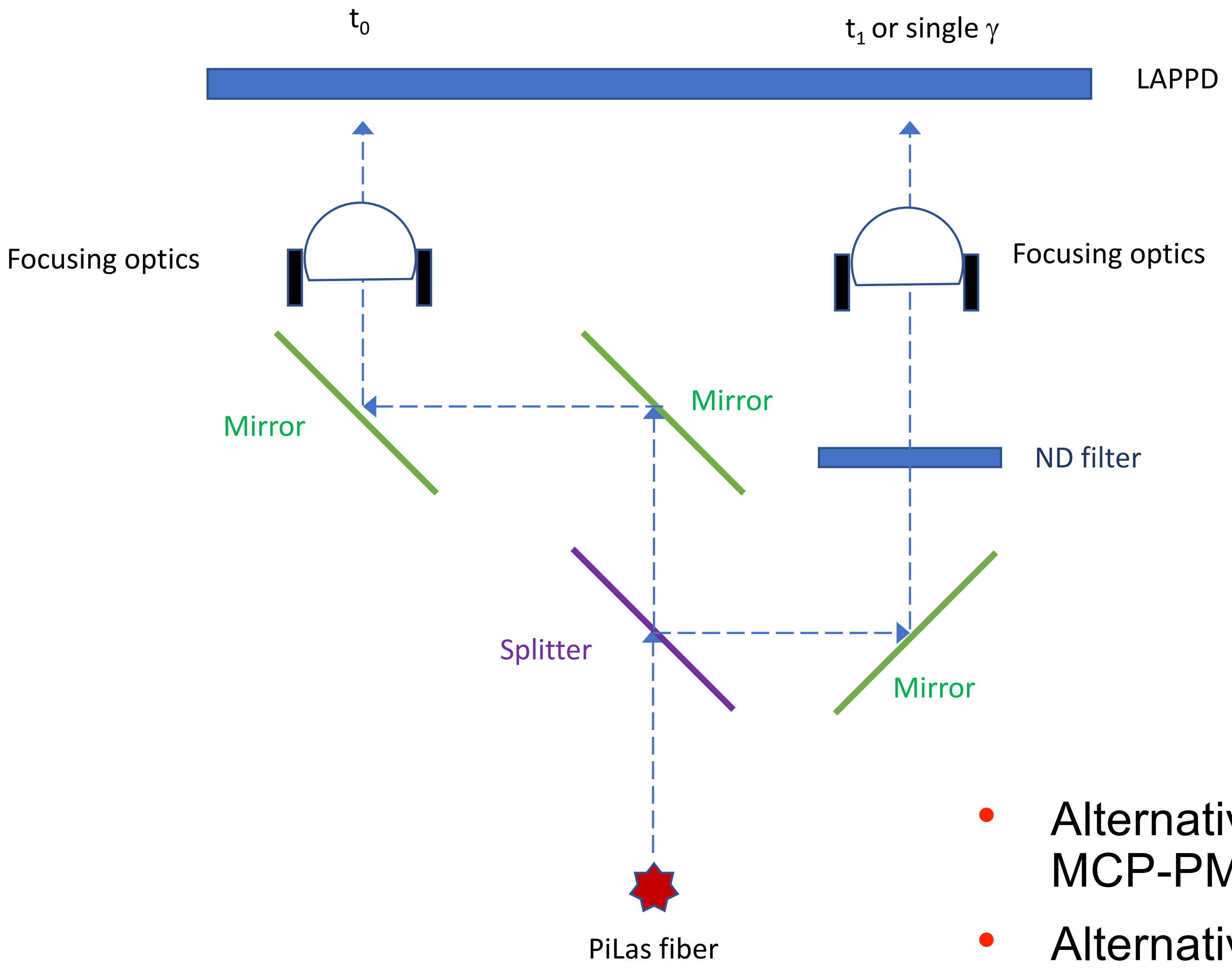
3D integration model (for systematic studies)





- Several pairs of spots with different pad and trace configurations and connections to MCX cables implemented

Laser-based timing evaluation setup



- Alternatively, use PHOTONIS single anode MCP-PMT as a timing reference
- Alternatively, consider a femtosecond laser

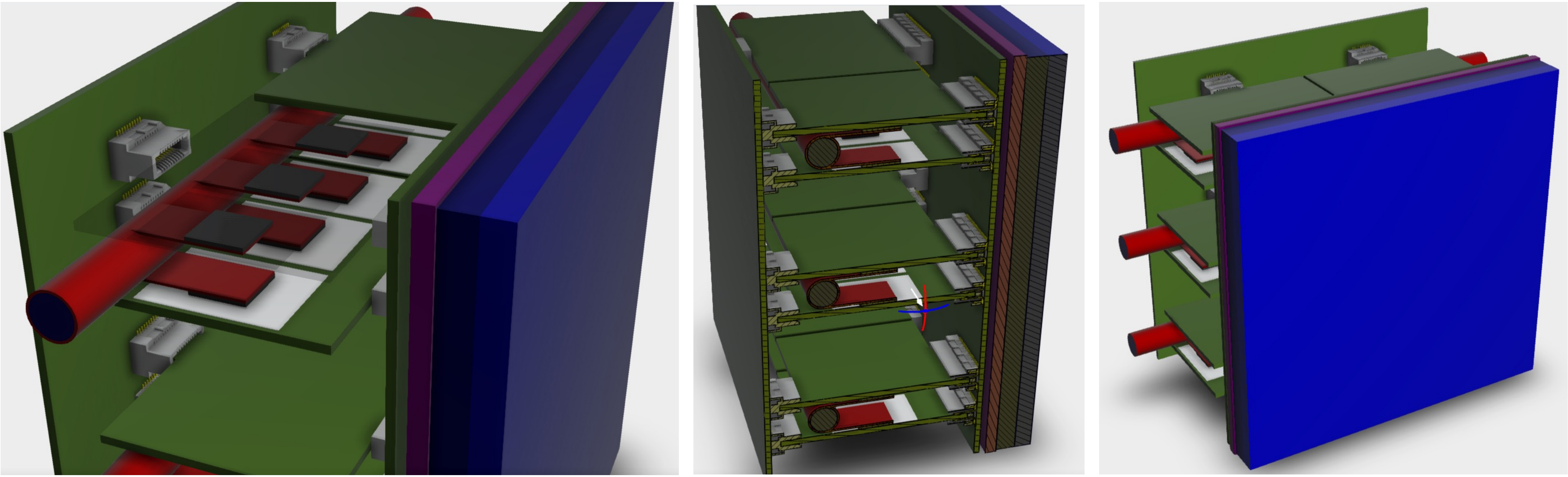
Summary & FY23 Outlook

- Proof of principle measurements confirming feasibility of Gen II LAPPD use for single photon detection in Cherenkov imaging applications are performed in the test bench setup and with a particle beam; *spatial resolution* quantified, looks satisfactory ...
  - ... and can only become better once the preamplifiers are used

- *Timing performance* in a finely pixelated configuration requires more work
  - DRS4 calibration (by now have two independent *almost* working procedures / codes)
  - Existing beam test data analysis
  - Back to the bench top evaluation ... then another beam test at Fermilab and / or at CERN

- DC-coupled HRPPD performance evaluation
  - A better mechanical / electrical interface may be required
- Work on practical LAPPD / HRPPD applications for EIC detectors
  - pfRICH, mRICH, ..?
  - On-board electronics integration

Backup: a draft of Gen II HRPPD-for-pfRICH 3D model



- Assume 24x24 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)
  - 20dB preamplifier on die (~6mW additional power per channel)
  - ~10GS/s digitizer, ~2GHz ABW, feature extraction, streaming capability (whatever it means), etc.
  - Few kW of power dissipation for the whole system seems to be a real-life estimate