Brookhaven Lab R&D on Capacitively Coupled LAPPDs with 2D Pixelated Readout Planes for Ring Imaging Cherenkov Detectors

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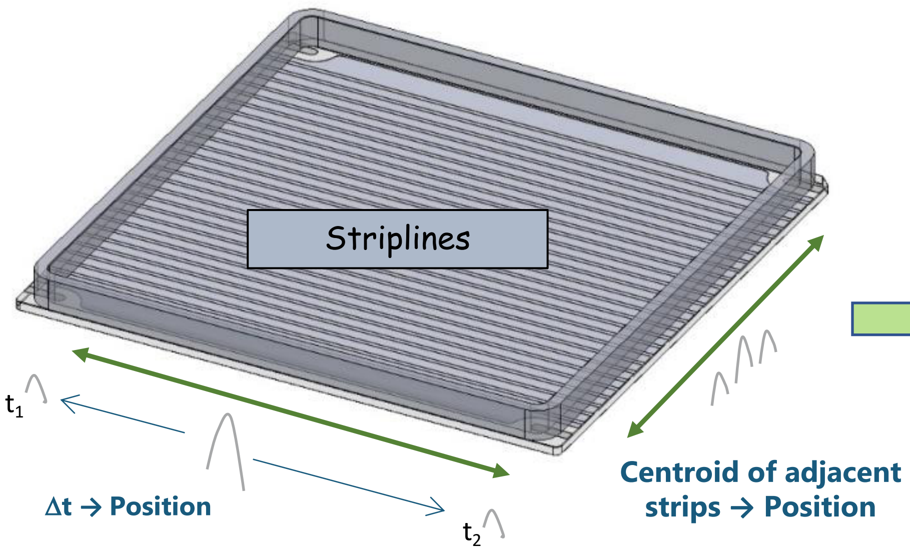
Ad hoc LAPPD workshop

March 21, 2022 (via Zoom)

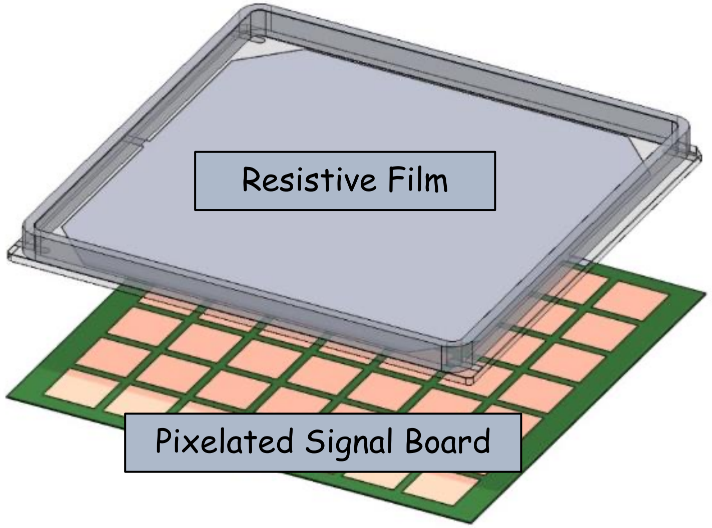
Introduction

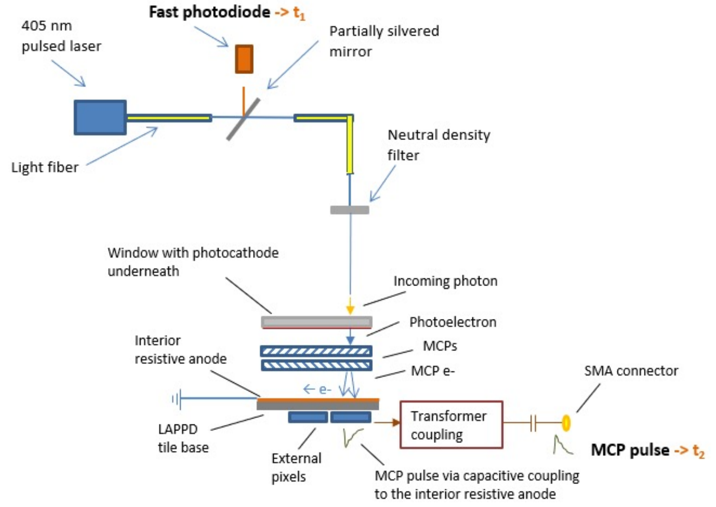
Gen II: capacitively coupled LAPPD

Gen I (DC-coupled) LAPPD



Gen II (capacitively coupled) LAPPD





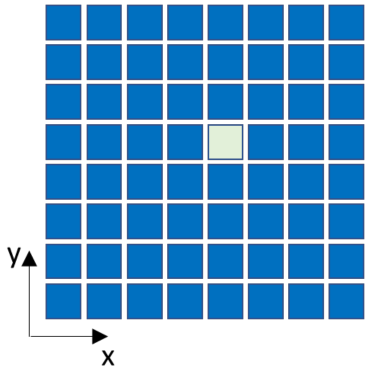
- ~1 mm spatial resolution, ~50 ps TTS SPE
- Good compromise between the number of electronics channels and spatial coverage.

- **User-defined anode pattern design** for balancing rate, spatial resolution and electronics channel count.
- <1 mm spatial resolution, no substantial degradation in time resolution.

Current status: neither DC- nor AC-coupled LAPPDs are available in finely pixelated *configurations* required for RICH applications

Gen II: capacitively coupled LAPPD

- Conventional high-resolution timing sensors for single photon detection such as MaPMTs, [MCP-PMTs,] SiPMs :



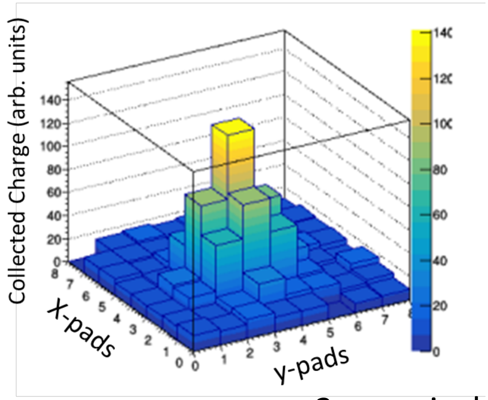
One photon –
one pixel hit

Manufacturer defined (square) pixels

Spatial resolution σ is limited by ~pitch/√12

Channel count for σ ~ 1mm (~3.5 mm pixels) is ~ 10^5 / m^2

- Using capacitively coupled LAPPDs one can do it differently:



One photon –
a multi-pixel cluster

3 mm pixels, rms ~ 3.5 mm [BNL test stand data]

User defined pixel readout board

Spatial resolution σ can be times higher than pitch/√12

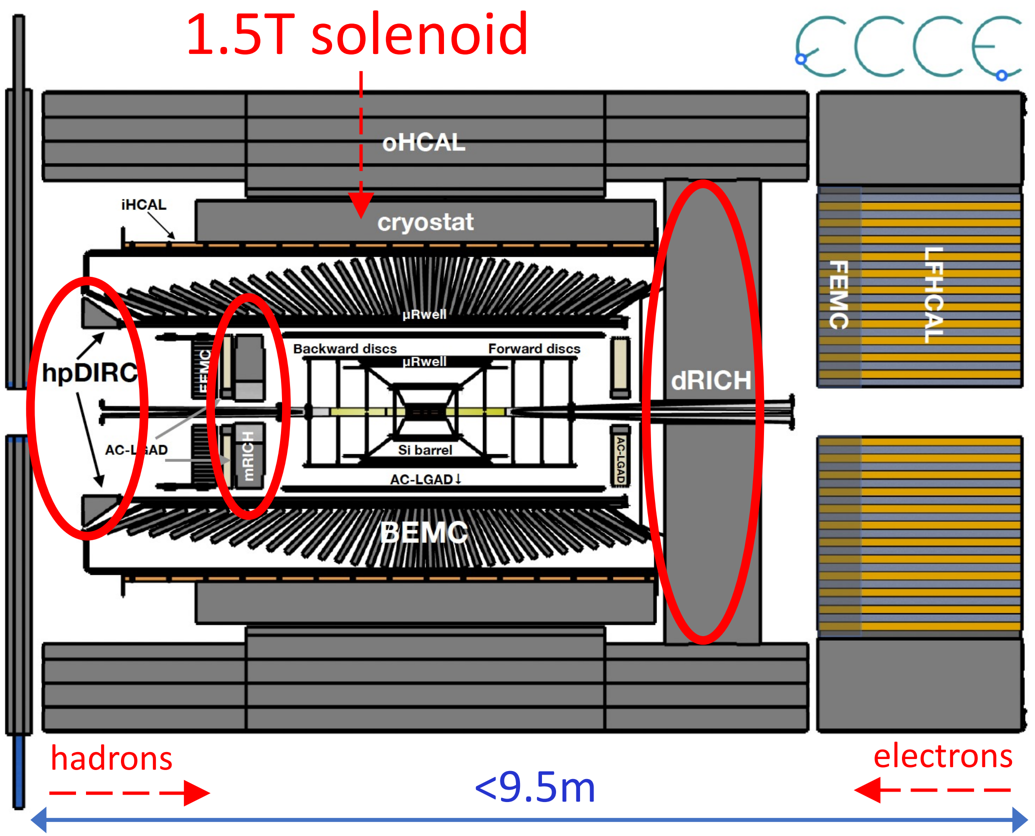
Channel count for σ ~ 1mm resolution: perhaps ~ 10^4 / m^2

BNL R&D effort: Gen II pixellation via custom readout board design

Primary target of this R&D: EIC general-purpose detectors

EIC: Electron-Ion Collider @ Brookhaven Lab

EIC physics detector proposal selection	Concluded few weeks ago
DOE CD-3 (Approve start of construction)	End of FY24
ECCE PID subsystems ready for installation	End of FY28



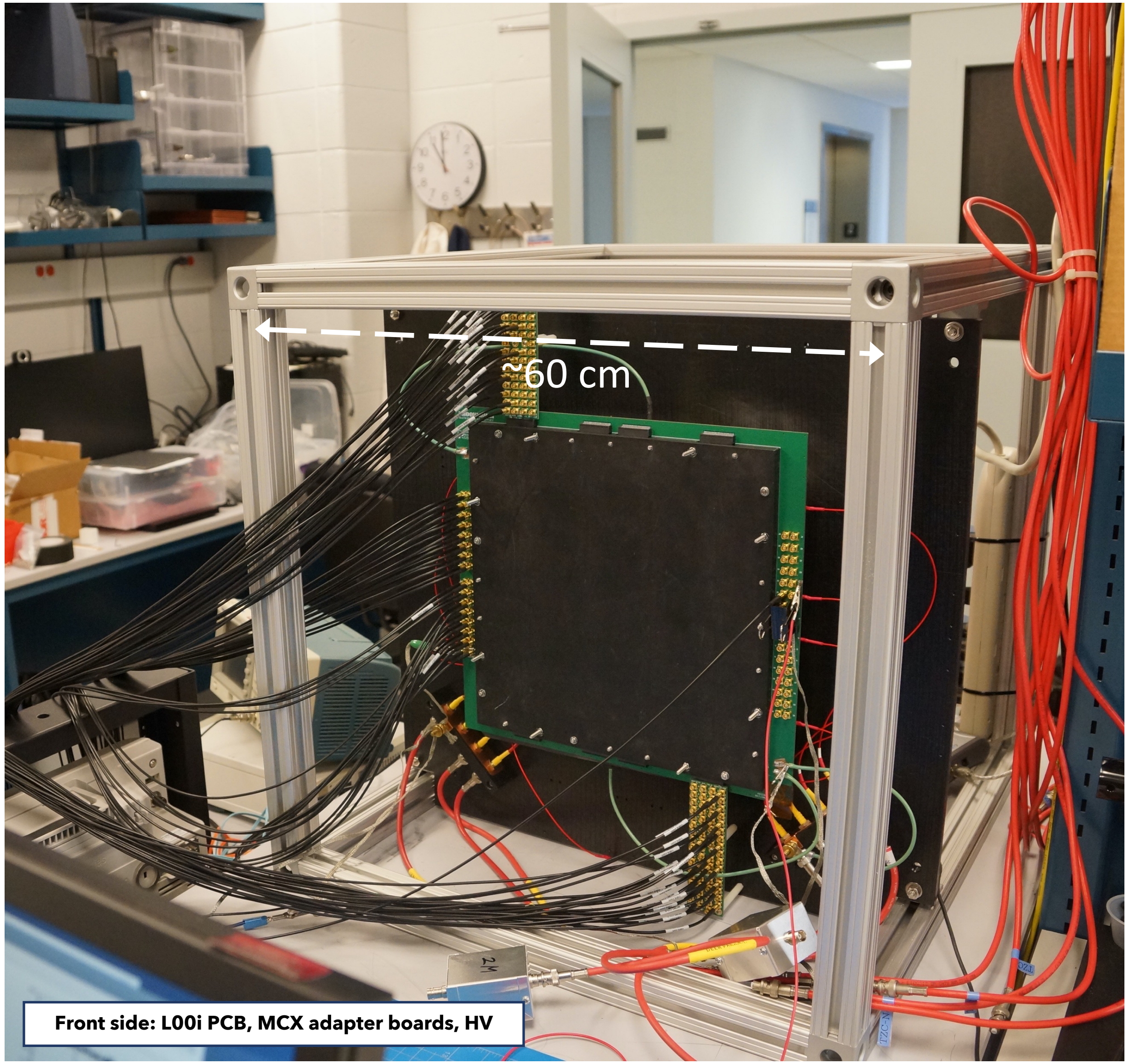
- LAPPDs are supposed to
  - be more cost-efficient than MCP-PMTs
  - provide better timing and have (much) smaller dark noise rate than SiPMs

Barrel DIRC likely requires "Gen I" MCP-PMT type

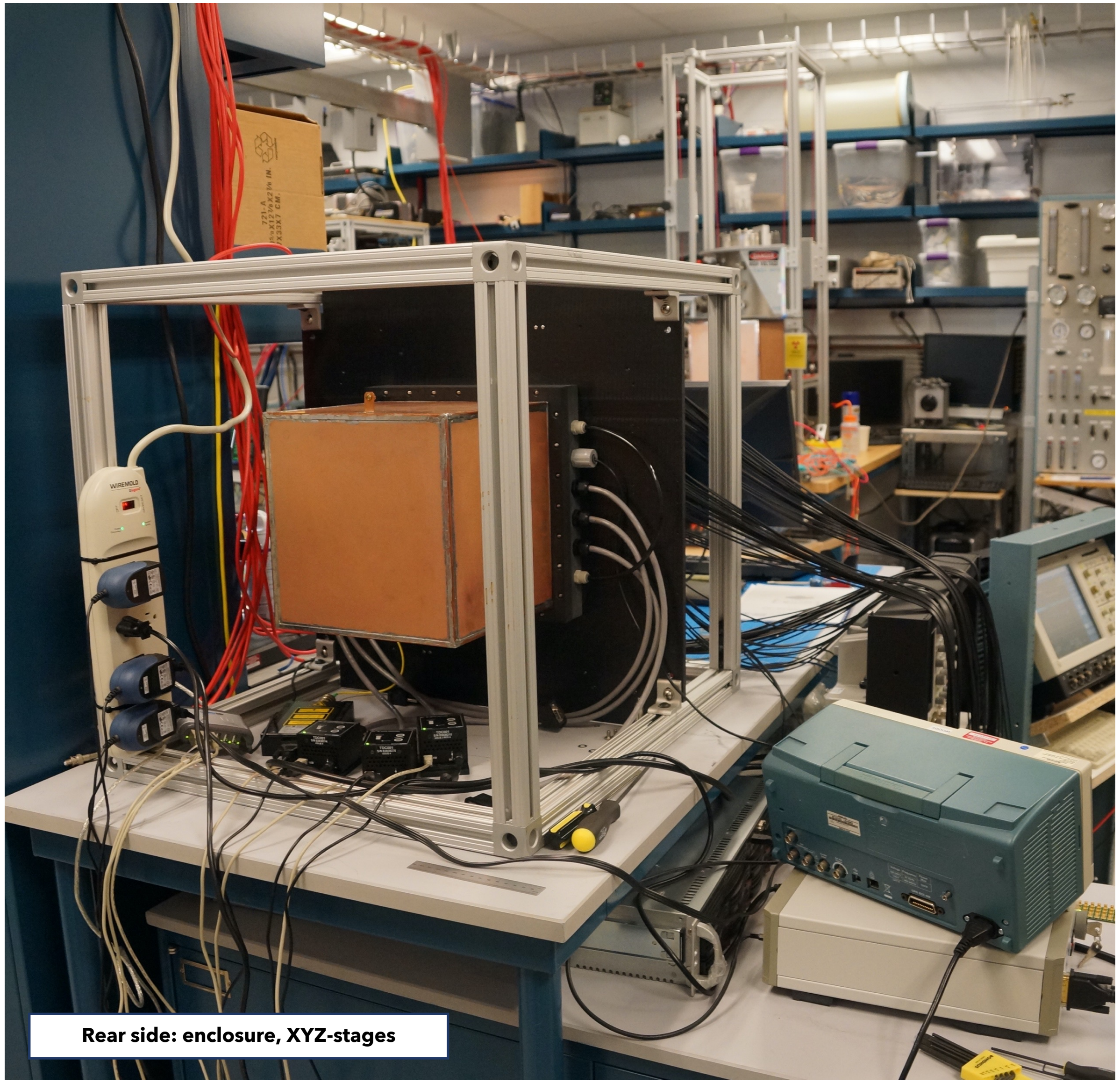
	Default option	Single photon time resolution	Spatial resolution equivalent	Sensor area
E-endcap mRICH	SiPMs	best possible	~3mm pixels	64 ~10x10 cm^2 spots
Barrel DIRC	MCP-PMTs	<100 ps	~3mm pixels	~0.65 m^2 total
H-endcap dRICH	SiPMs	~100 ps	~3mm pixels	~3.10 m^2 total

Lab measurements at Brookhaven

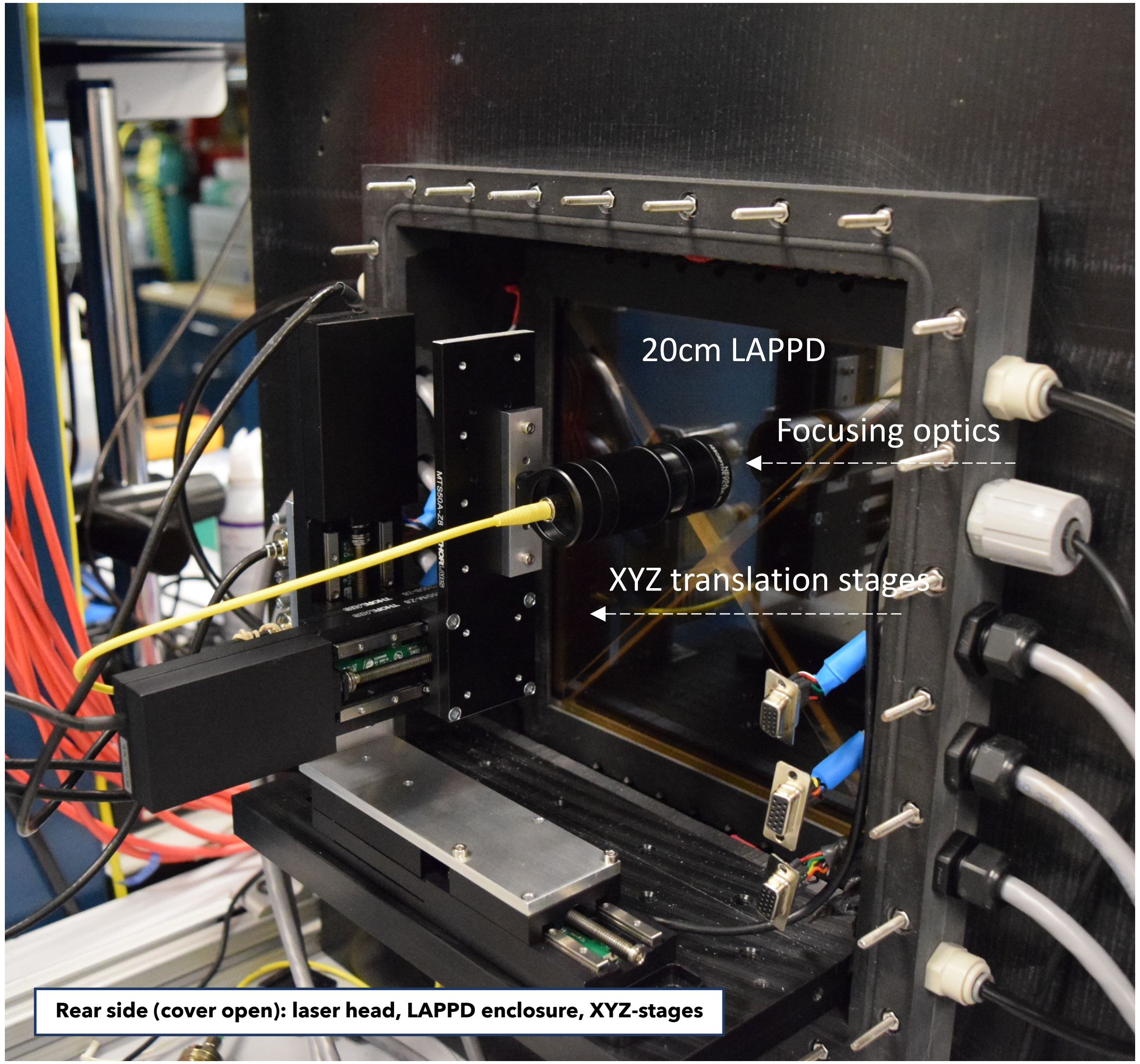
Test stand equipment



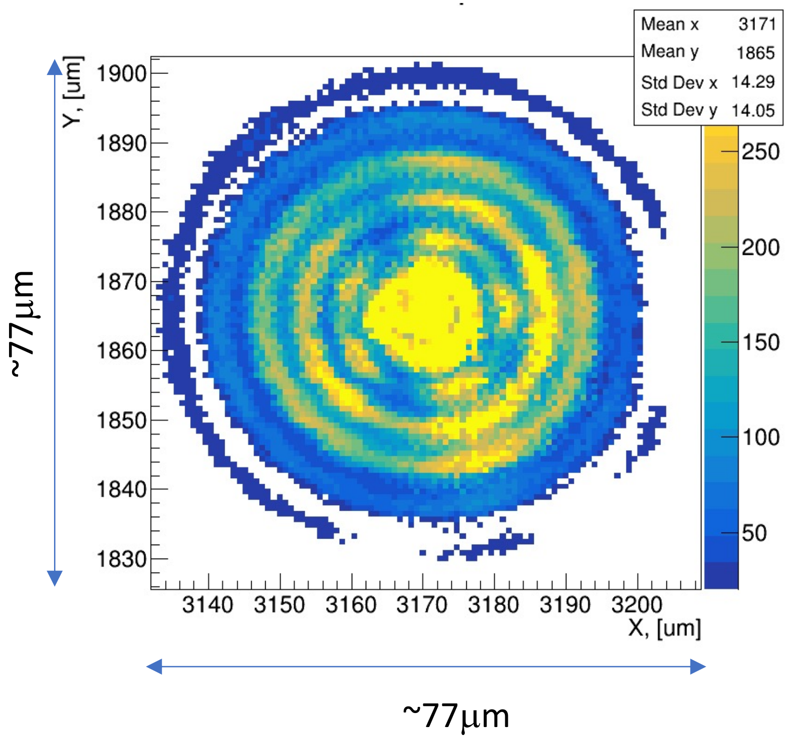
Front side: L00i PCB, MCX adapter boards, HV


Rear side: enclosure, XYZ-stages

Test stand equipment

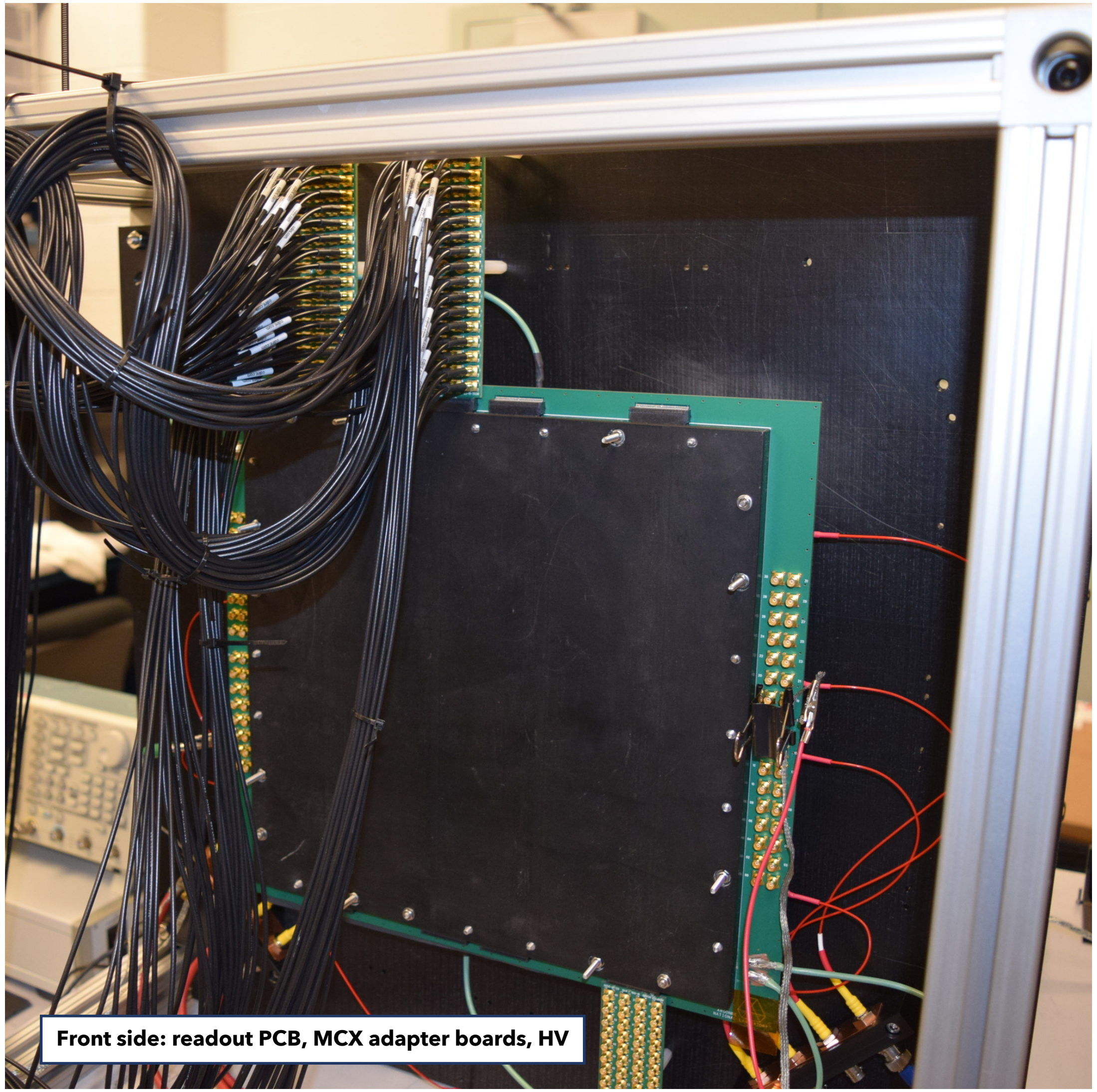


- Light-tight enclosure
- Remotely controlled XYZ-stages
- 420nm pulsed "picosecond" laser (spot size <100 μm)



Laser spot as measured by a CMOS camera

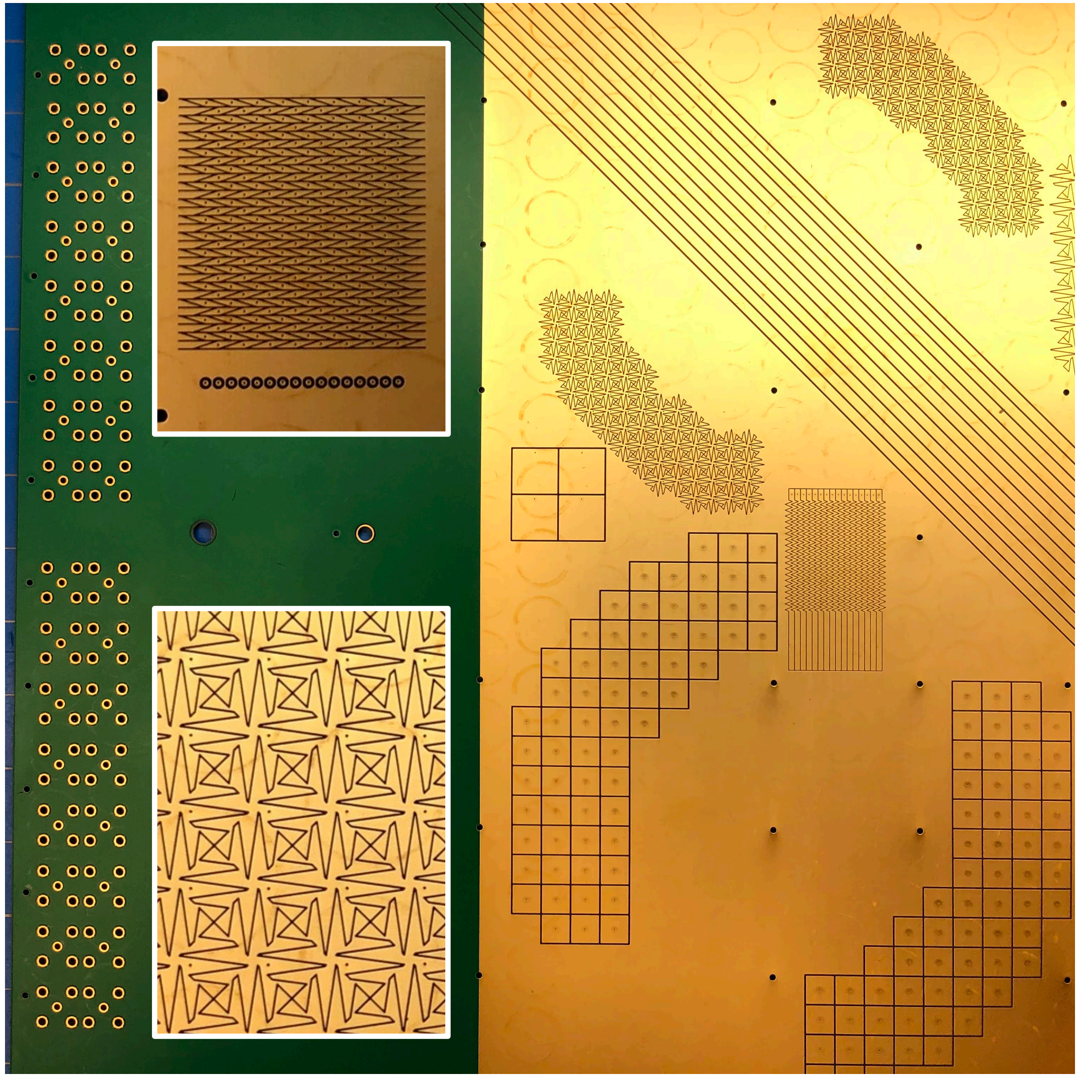
Test stand equipment

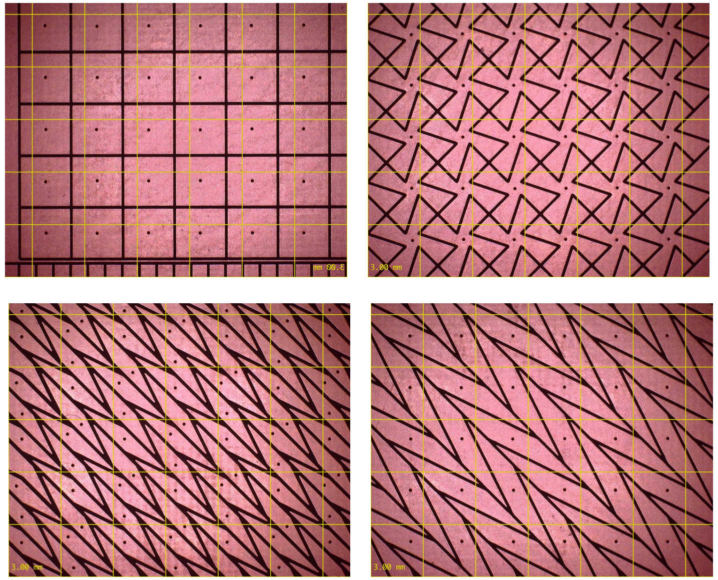


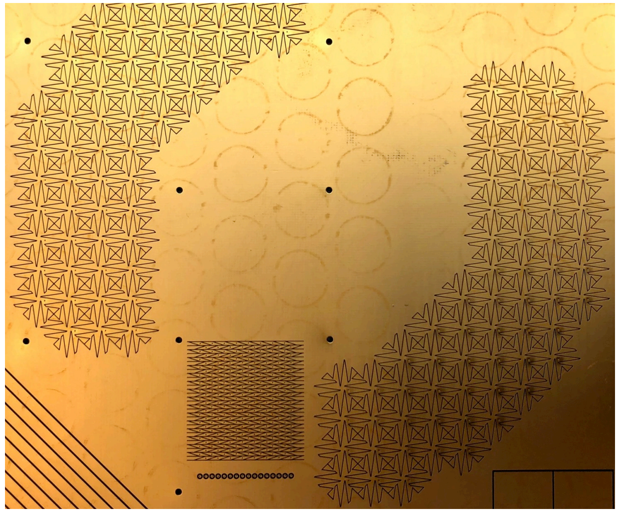
- Up to 320 DRS4 channels (V1742 digitizers; 5 GS/s)
- A variety of multi-pattern pixelated readout boards
- MCX to high-density Samtec adapter cards

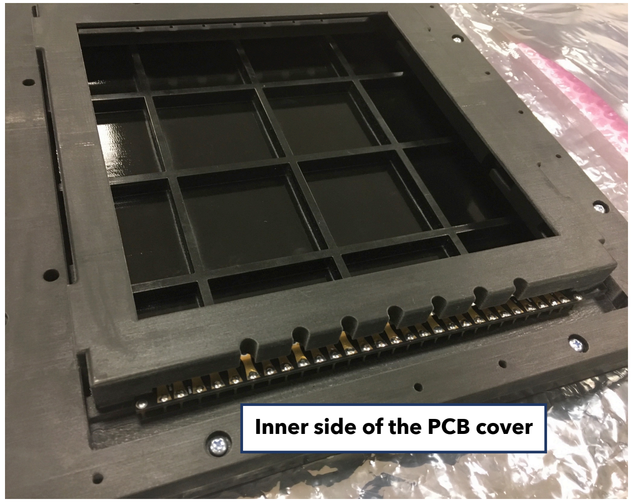
Modular setup: it takes one only half an hour to exchange (or rotate) the readout board

Test stand equipment

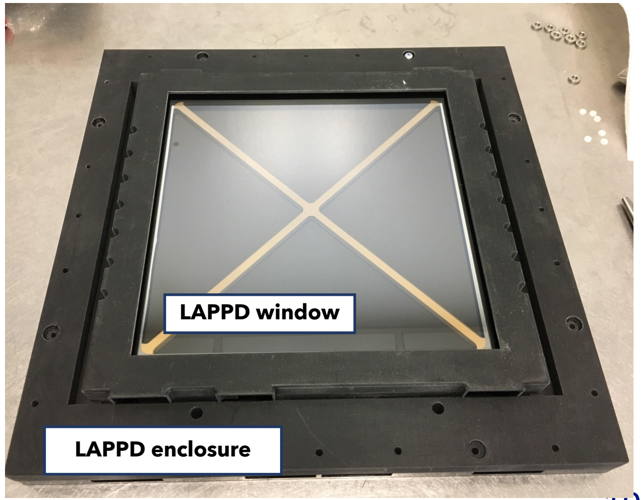






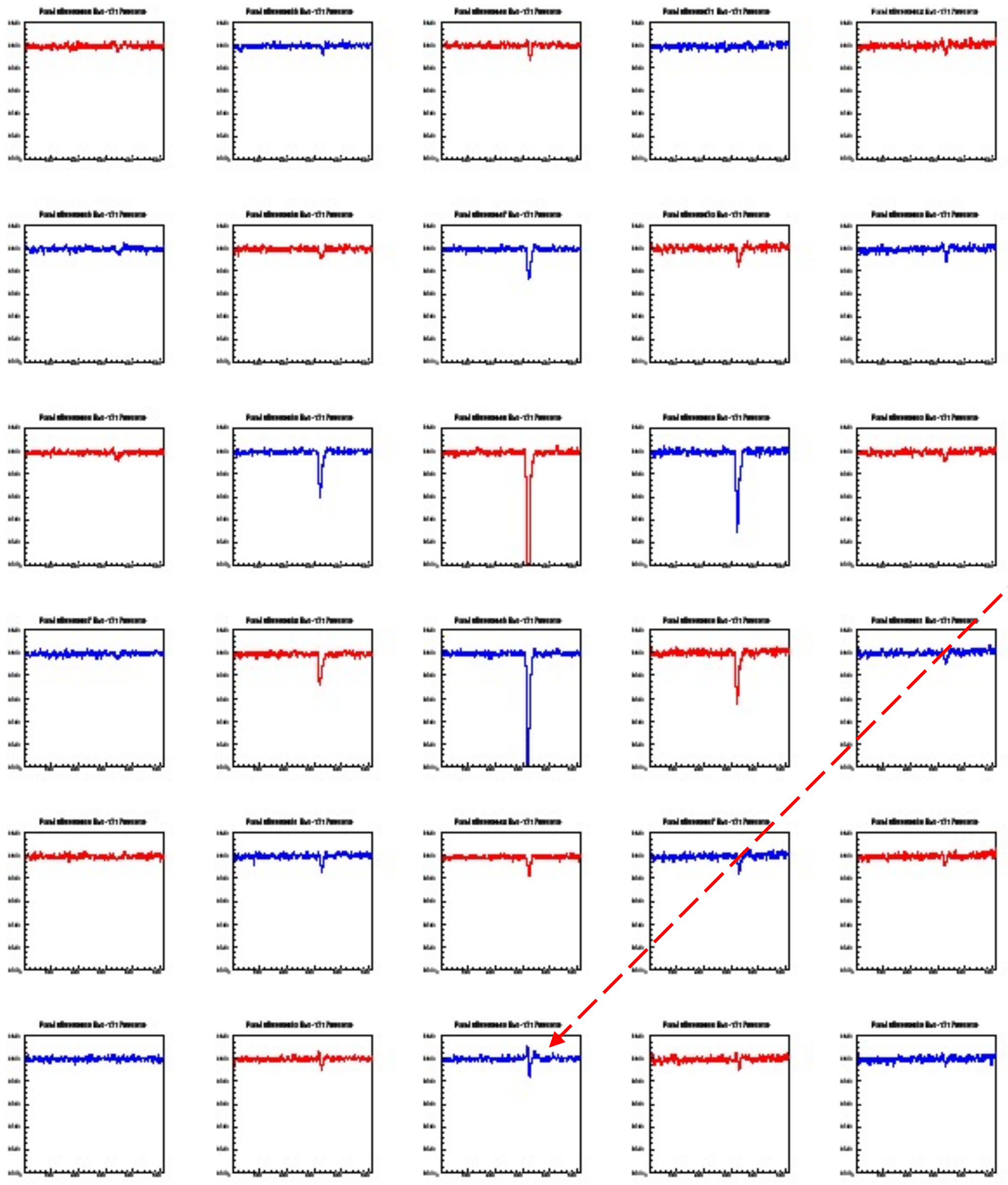


- Custom 3D printed LAPPD enclosure



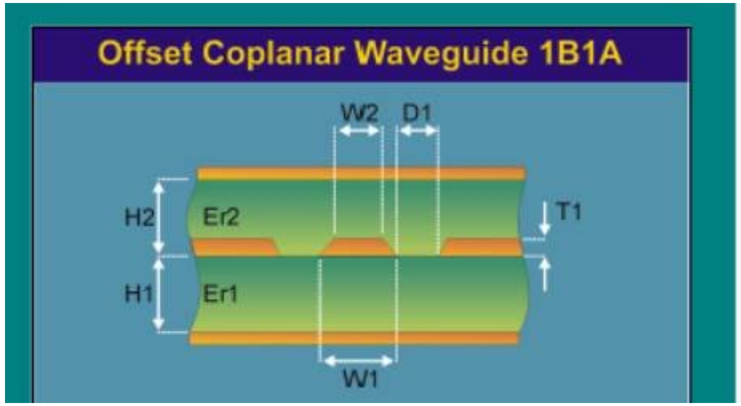
- Several iterations of multi-pattern readout boards

PCB stack details & cross-talk evaluation



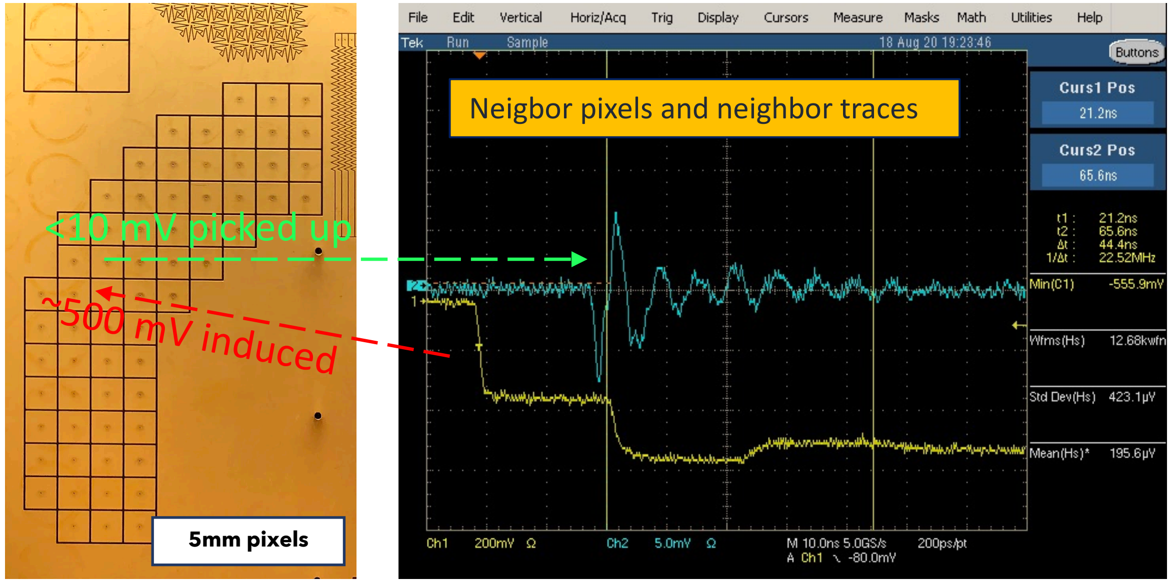
Certain level of cross-talk is present (traces here are routed in Y-direction)

4mm square pixels; 5x6 field; 50ns range waveforms

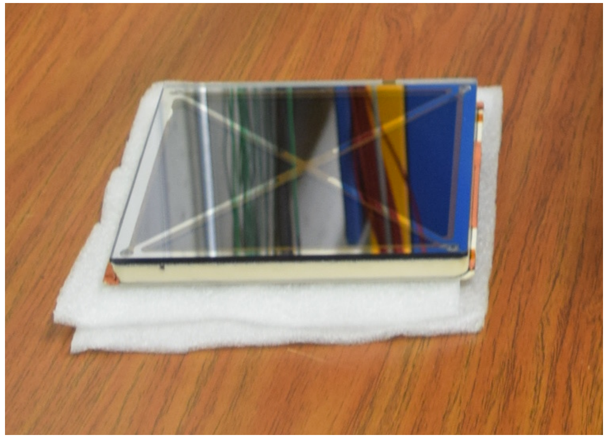


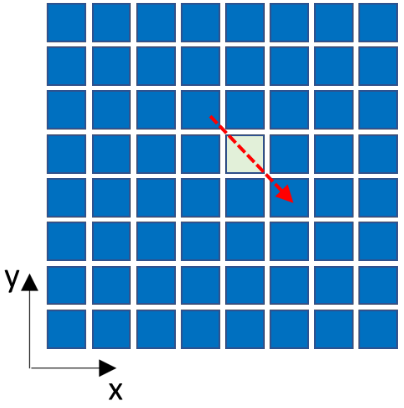
Substrate 1 Height	H1
Substrate 1 Dielectric	Er1
Substrate 2 Height	H2
Substrate 2 Dielectric	Er2
Lower Trace Width	W1
Upper Trace Width	W2
Ground Strip Separation	D1
Trace Thickness	T1

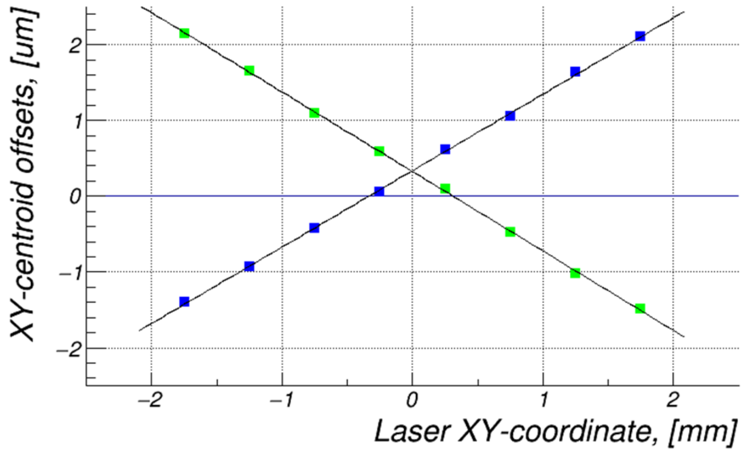
- Multi-layer stack-up; through vias; isolated traces
- Worst case X-talk ~few % level



Spatial resolution with the 3mm square pixels







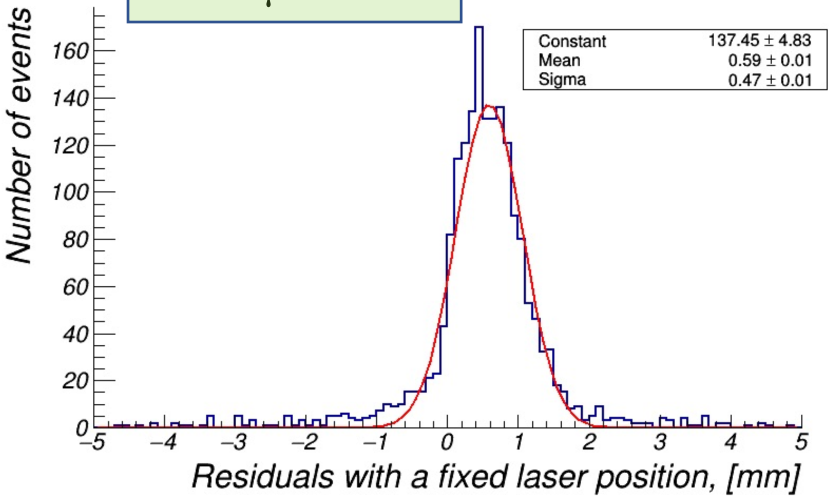
- “Single-photon” mode
  - ~10 mV signals

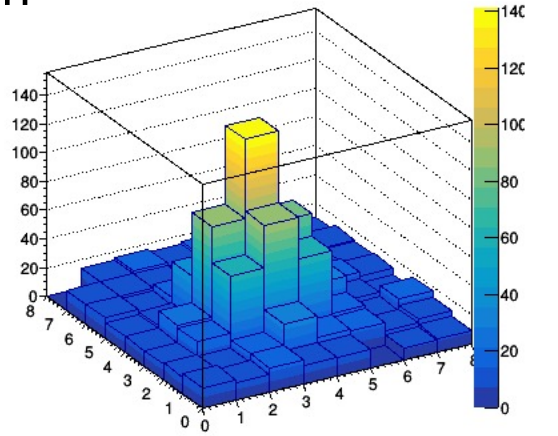
- Gen II LAPPD tile #97 provided by Incom
  - 2mm thick ceramic base

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

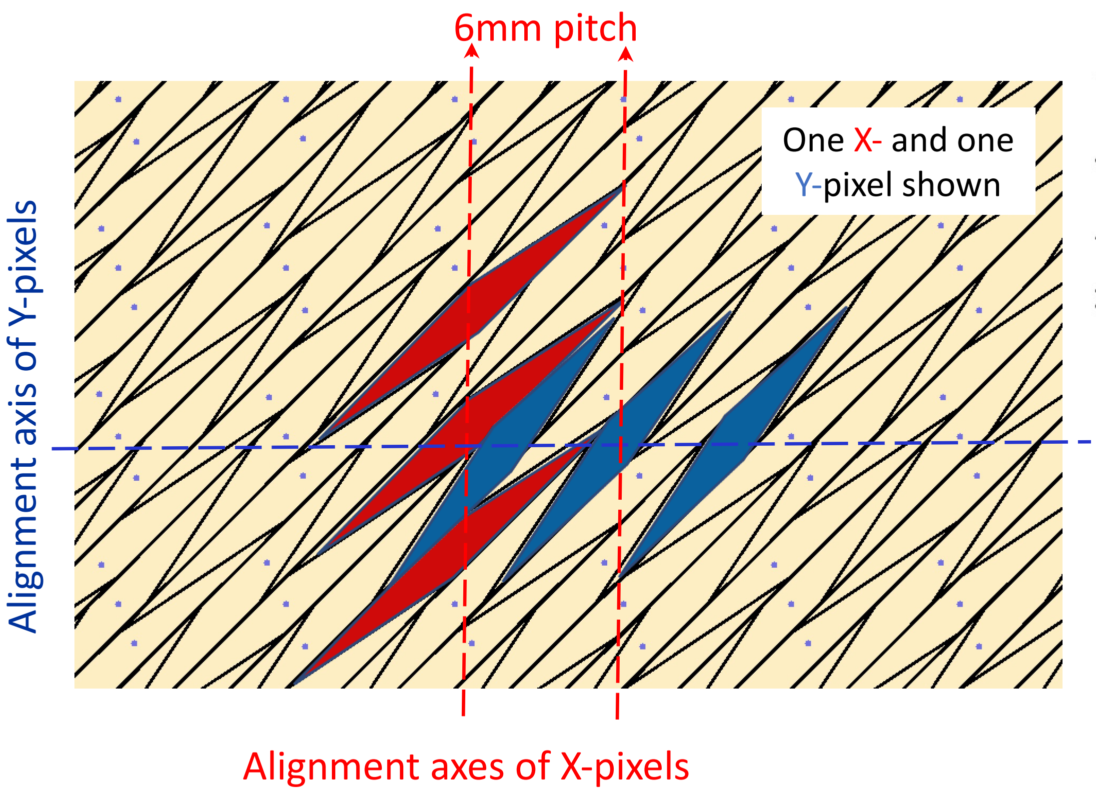
~500 μm width

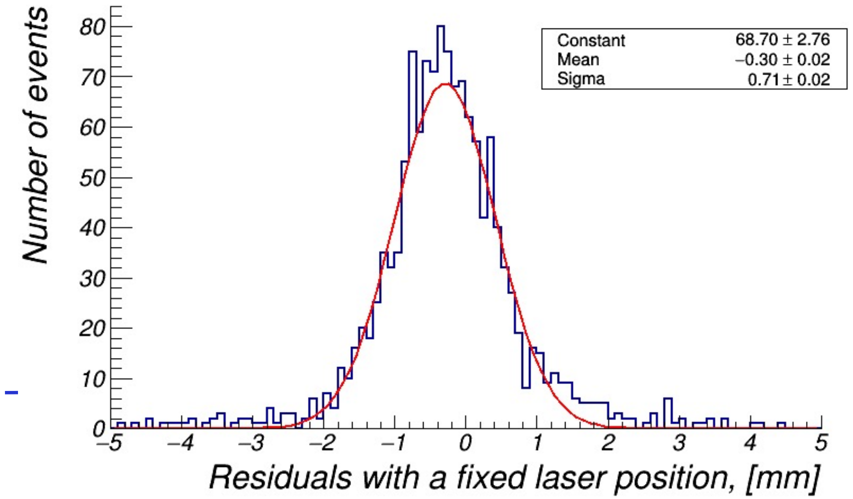




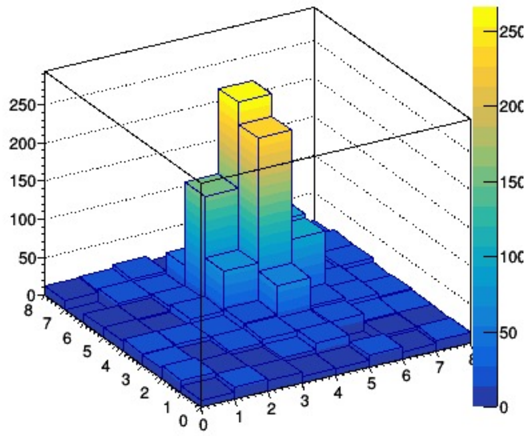
Typical single photon cluster has RMS ~ 3.5 mm

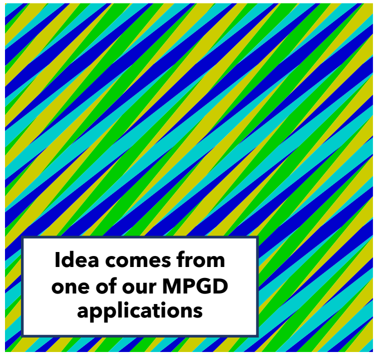
2D zigzag pixels with a 6mm pitch



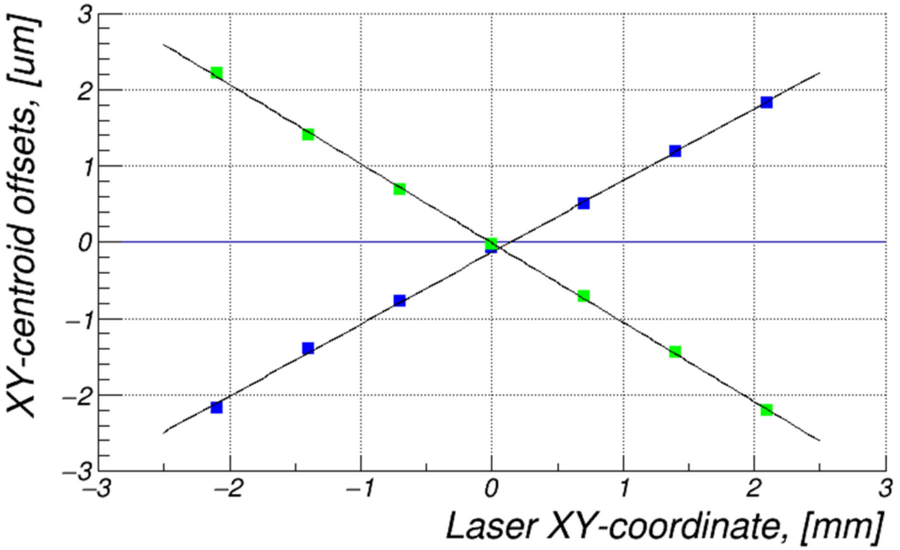


Typically, 3x3 pixel clusters





Linearity scan results



- Pretty good linearity
- Spatial resolution typically ~700-800 μm (given the S/N ratio)

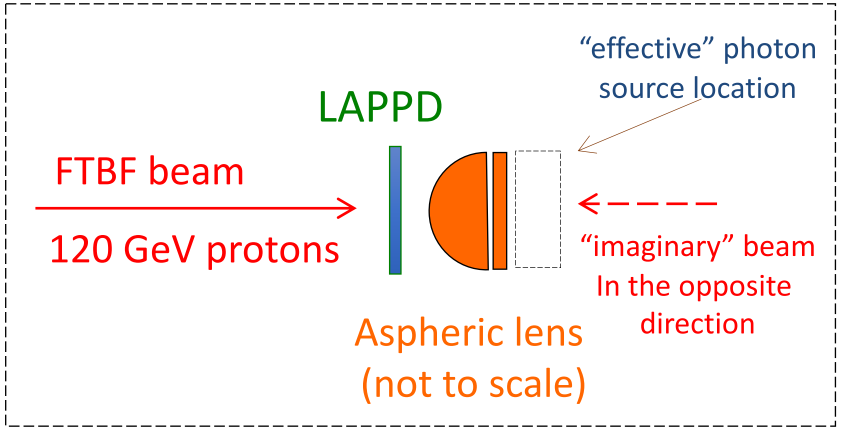
- As long as occupancy is acceptable one can increase the effective pad size (length!) without losing spatial resolution

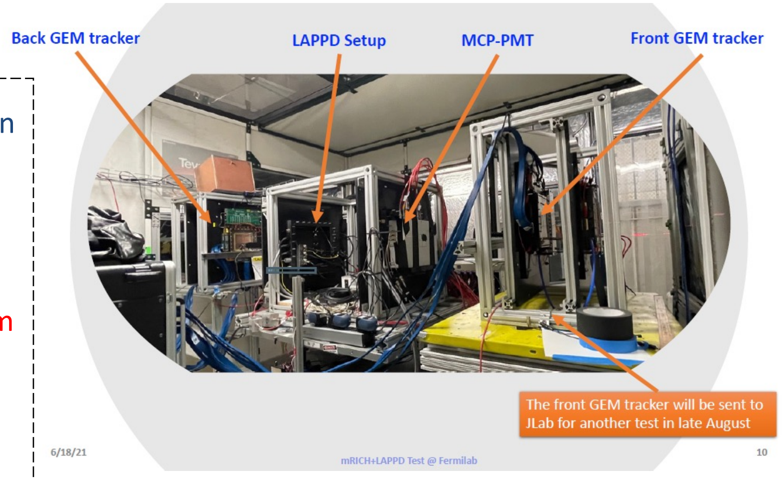
Beam test at Fermilab in June 2021

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

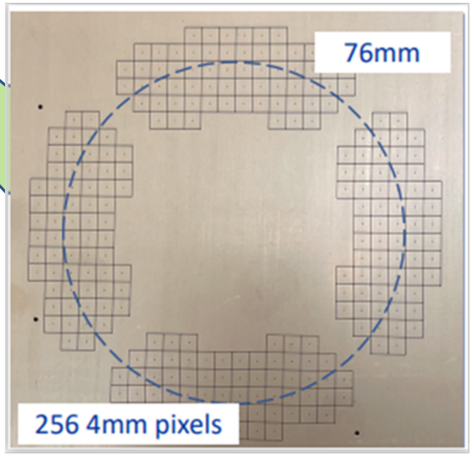
Experimental setup (Fermilab Test Beam Facility)

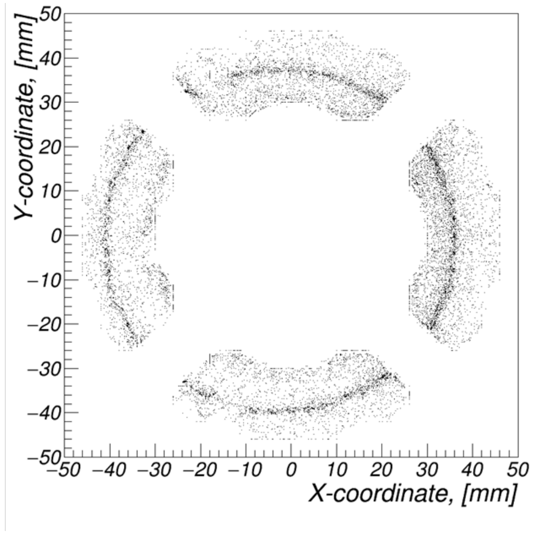
Beam test schematic view

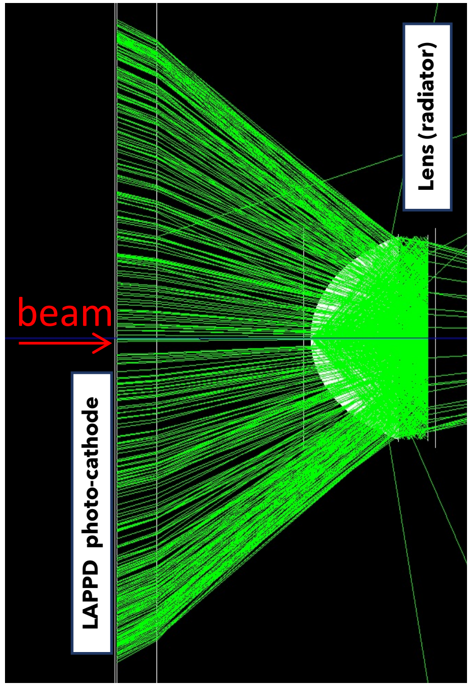




Pixel pattern & accumulated single photon XY-coordinates

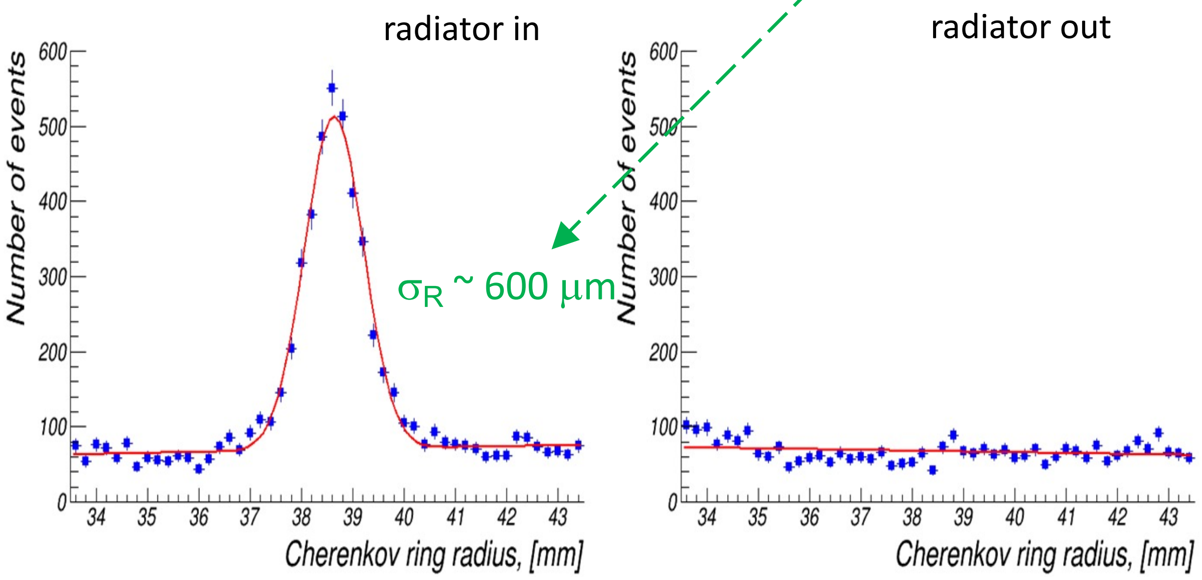




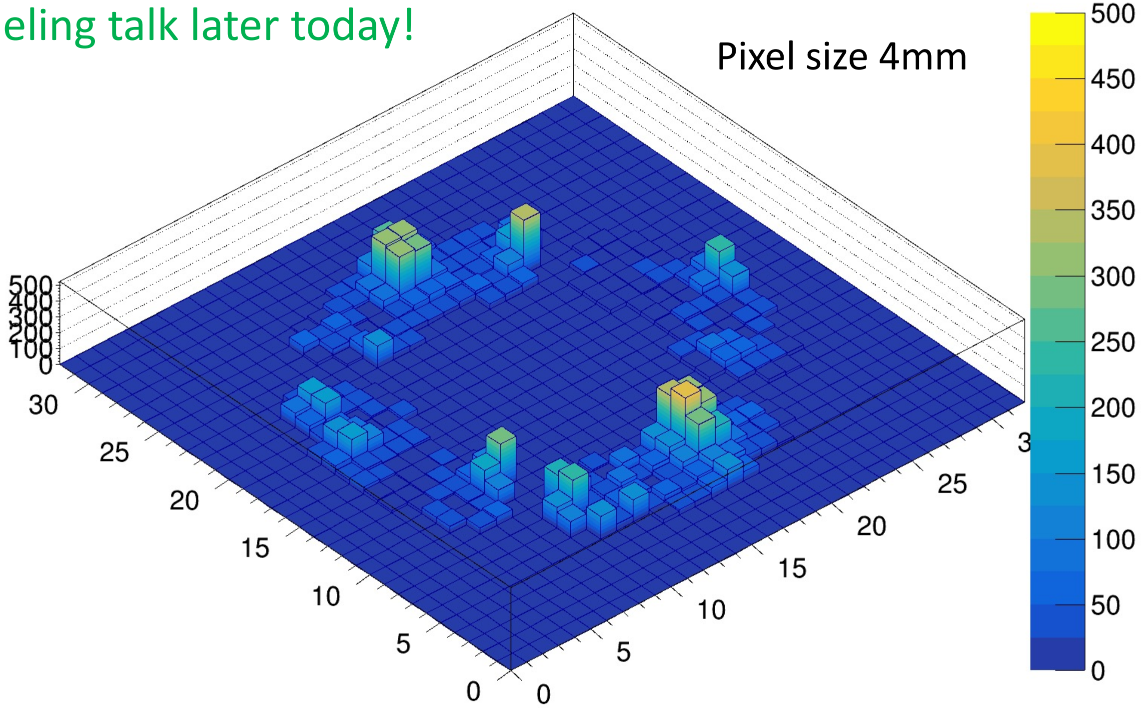


Cherenkov ring radius resolution

Compare to Luca's modeling talk later today!



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

Summary and 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
- Several ideas for readout board optimization were tried out, in terms of the spatial resolution performance, cross talk suppression and instrumented channel count optimization

- Further work:
  - Additional readout board optimization for high resolution timing
  - Perhaps more advanced pixellation schemes (redundant strip configurations, mixed timing & spatial coordinate measurement geometries, etc.)
  - Practical applications in the scope of EIC detector R&D program
  - On-board electronics integration
  - TOF PET application?

Next beam test campaign @ Fermilab: June 2022