Capacitively Coupled LAPPDs with 2D Pixelated Readout Planes for Ring Imaging Cherenkov Applications in High Energy and Nuclear Physics Experiments

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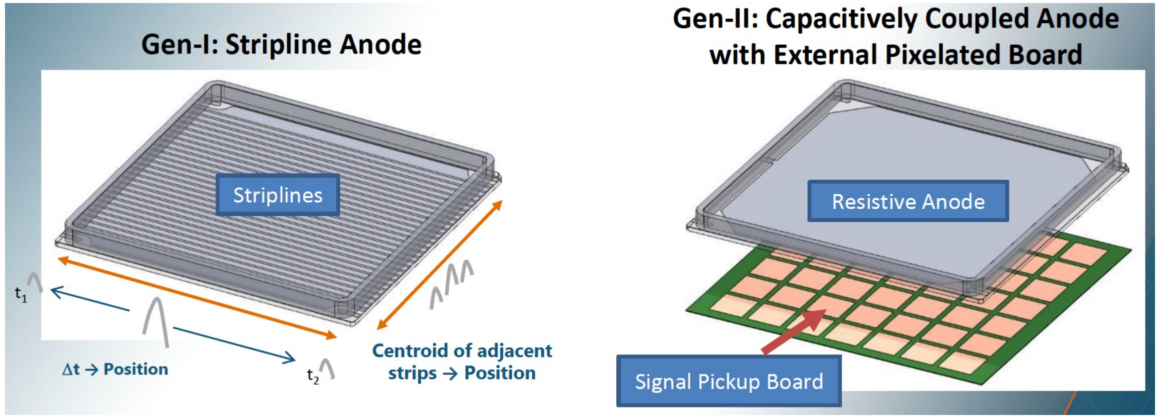
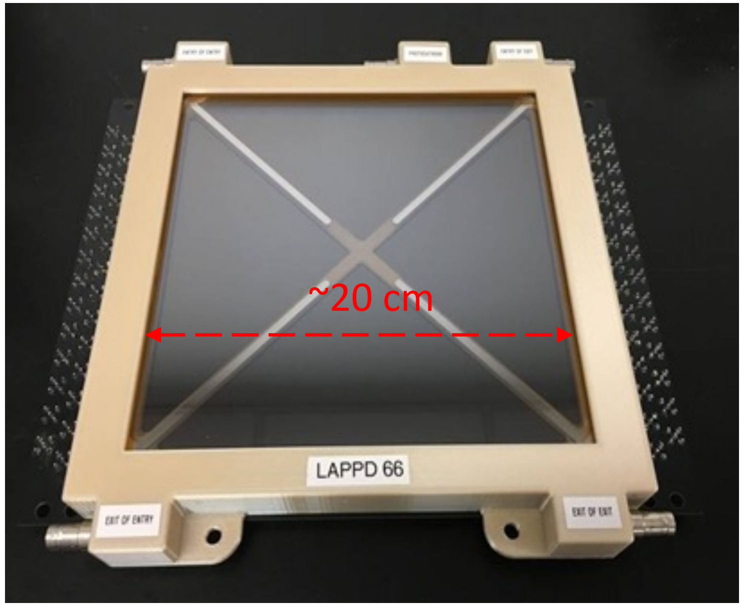
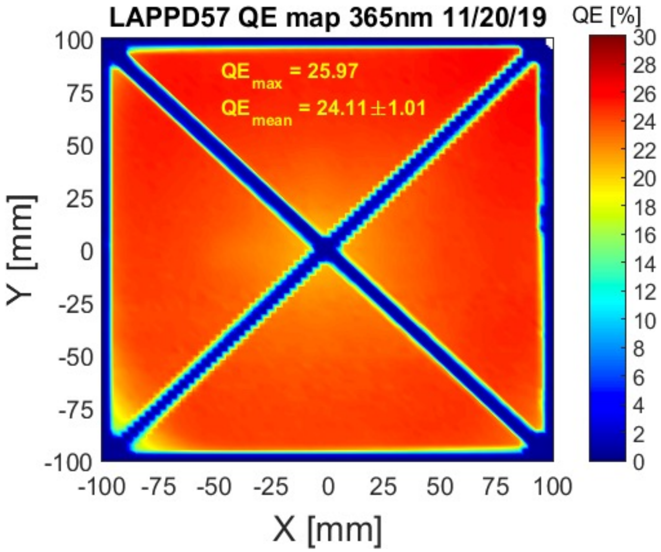
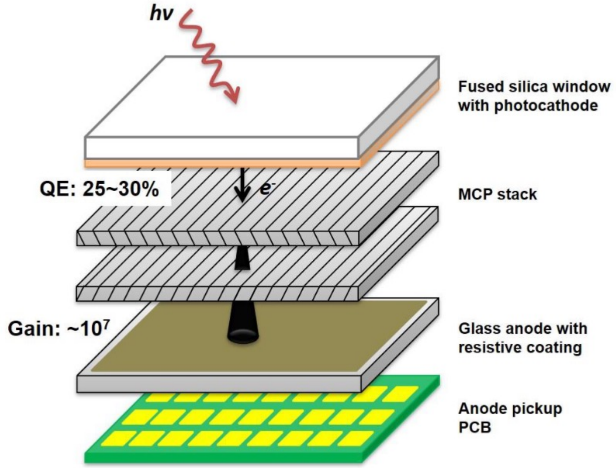
Motivation

- An affordable large area finely pixelated photosensor would be greatly appreciated by the NP and HEP experimental communities
- Incom Gen II LAPPDs is a promising candidate
  - 10x10 cm^2 or 20x20 cm^2 active area
  - Expected to be (very) cost efficient in mass production
  - High quantum efficiency and uniform high gain
  - User-defined pixellation scheme: unprecedented flexibility
  - Single-photon timing resolution is preserved on a ~50ps level





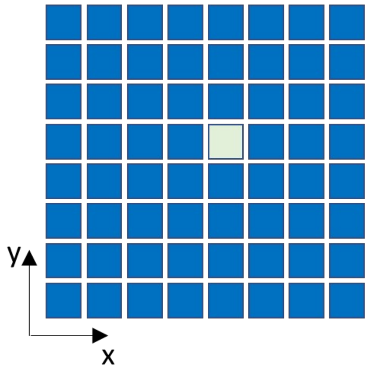




But: a fine (few mm pitch) pixellation needs to be confirmed!

Gen II: capacitively coupled LAPPD

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



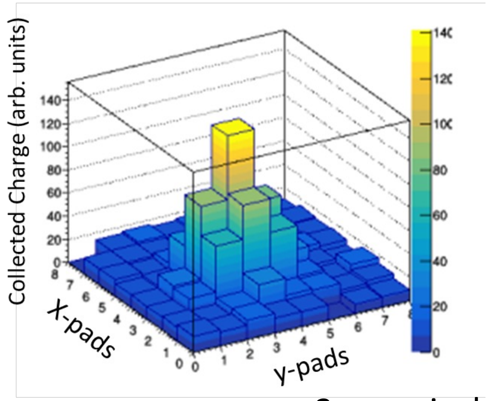
One photon –
one pixel hit

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:



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

One photon –
a multi-pixel cluster

User defined pixel readout board

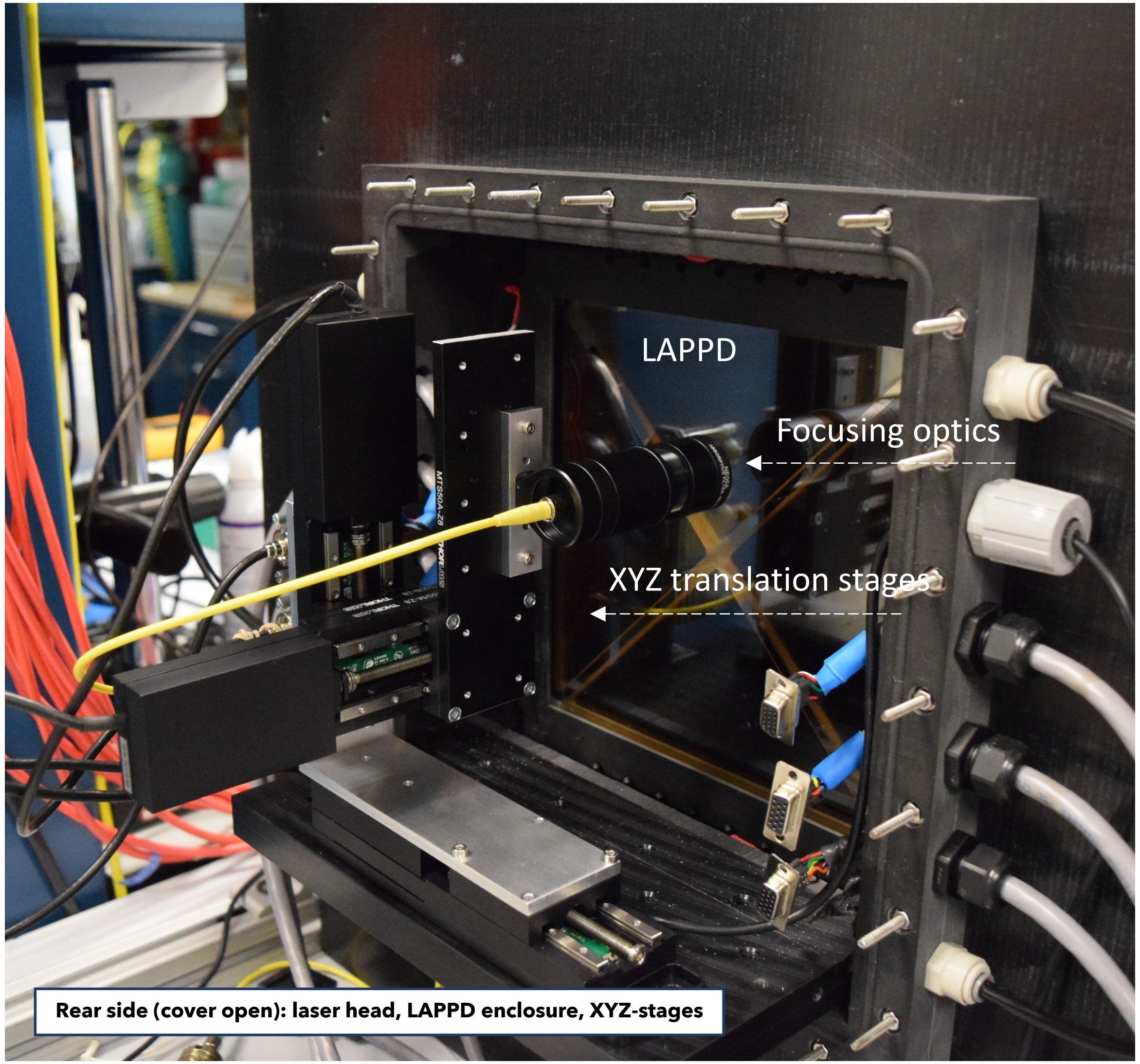
Spatial resolution σ can be times higher than pitch/√12

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

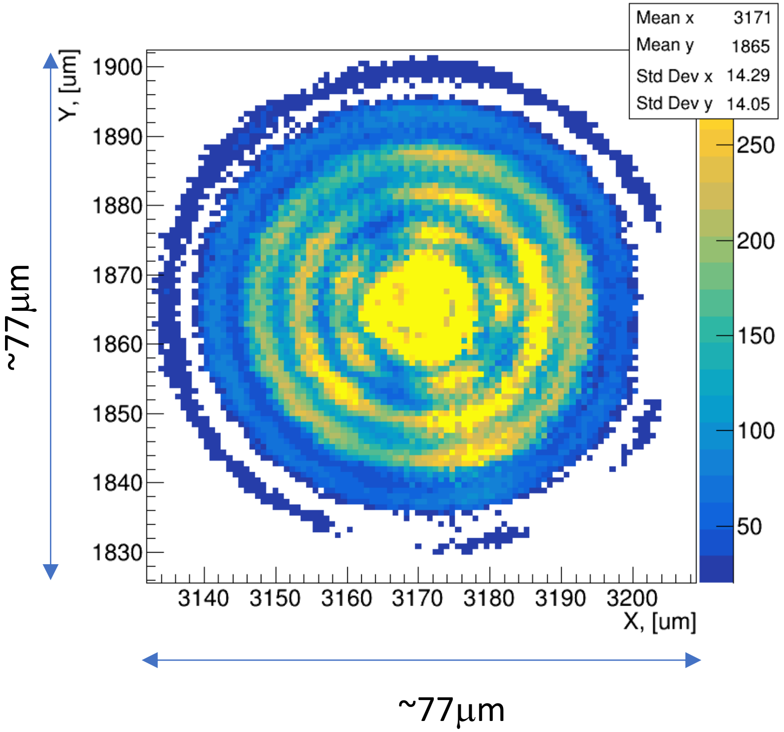
Focus of this talk: Gen II LAPPD pixellation via custom readout board design

Lab measurements at Brookhaven

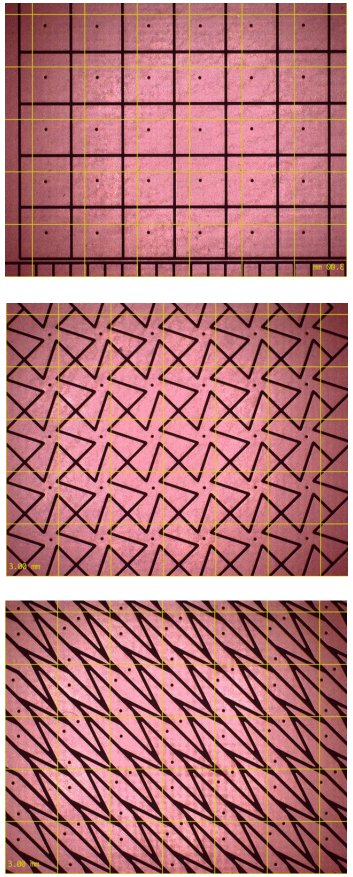
Test setup



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

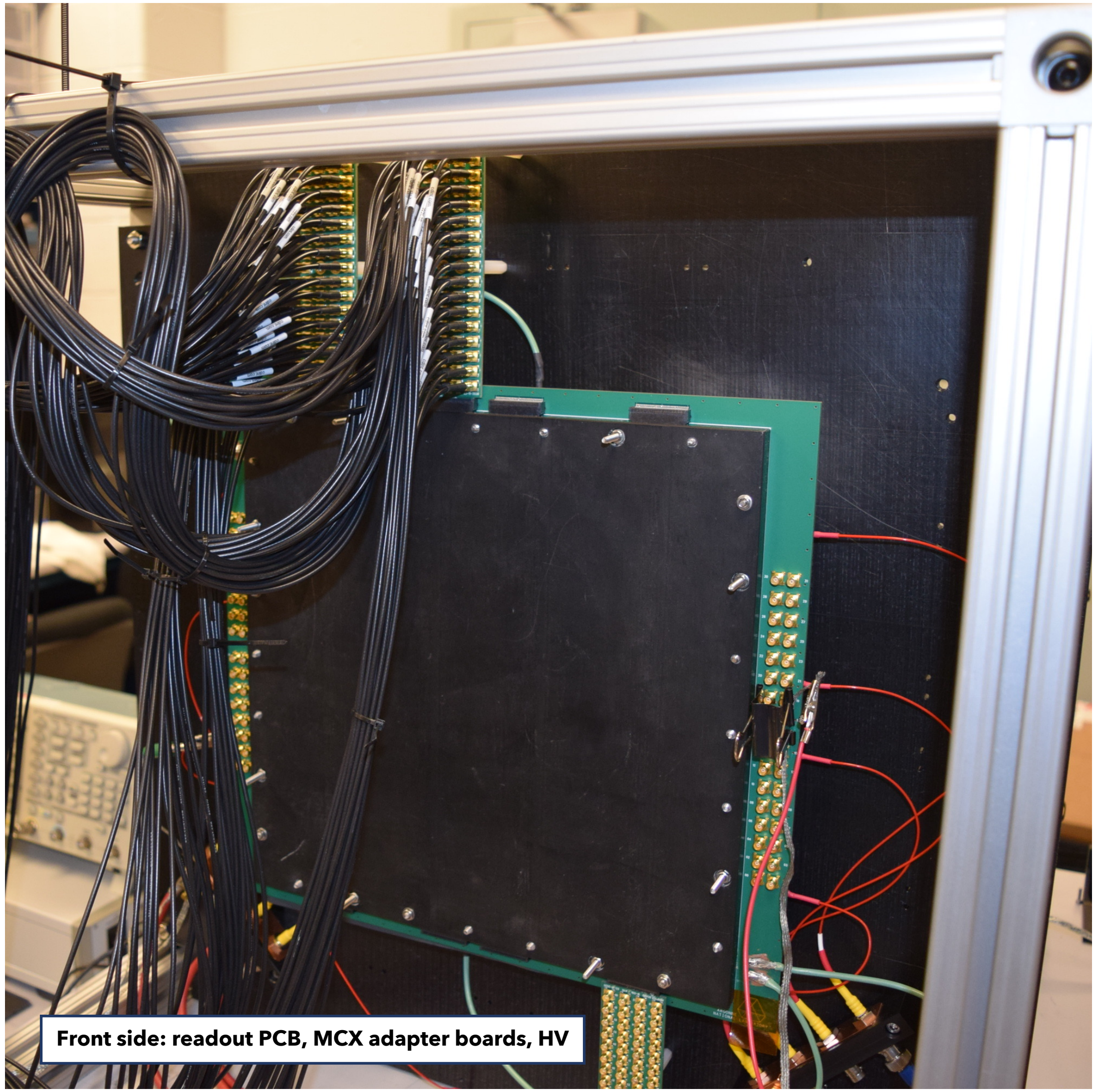


Laser spot as measured by a CMOS camera



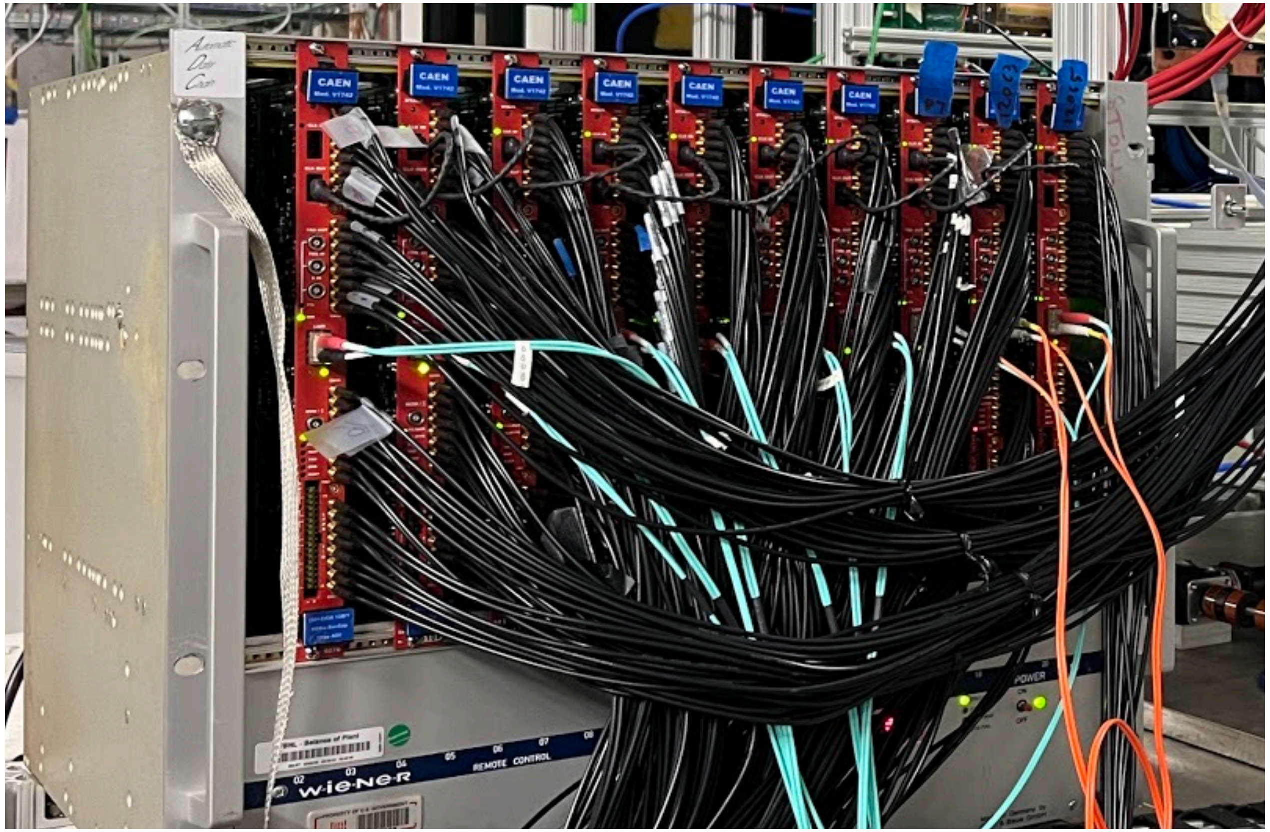
here: all 3mm pitch

Test setup



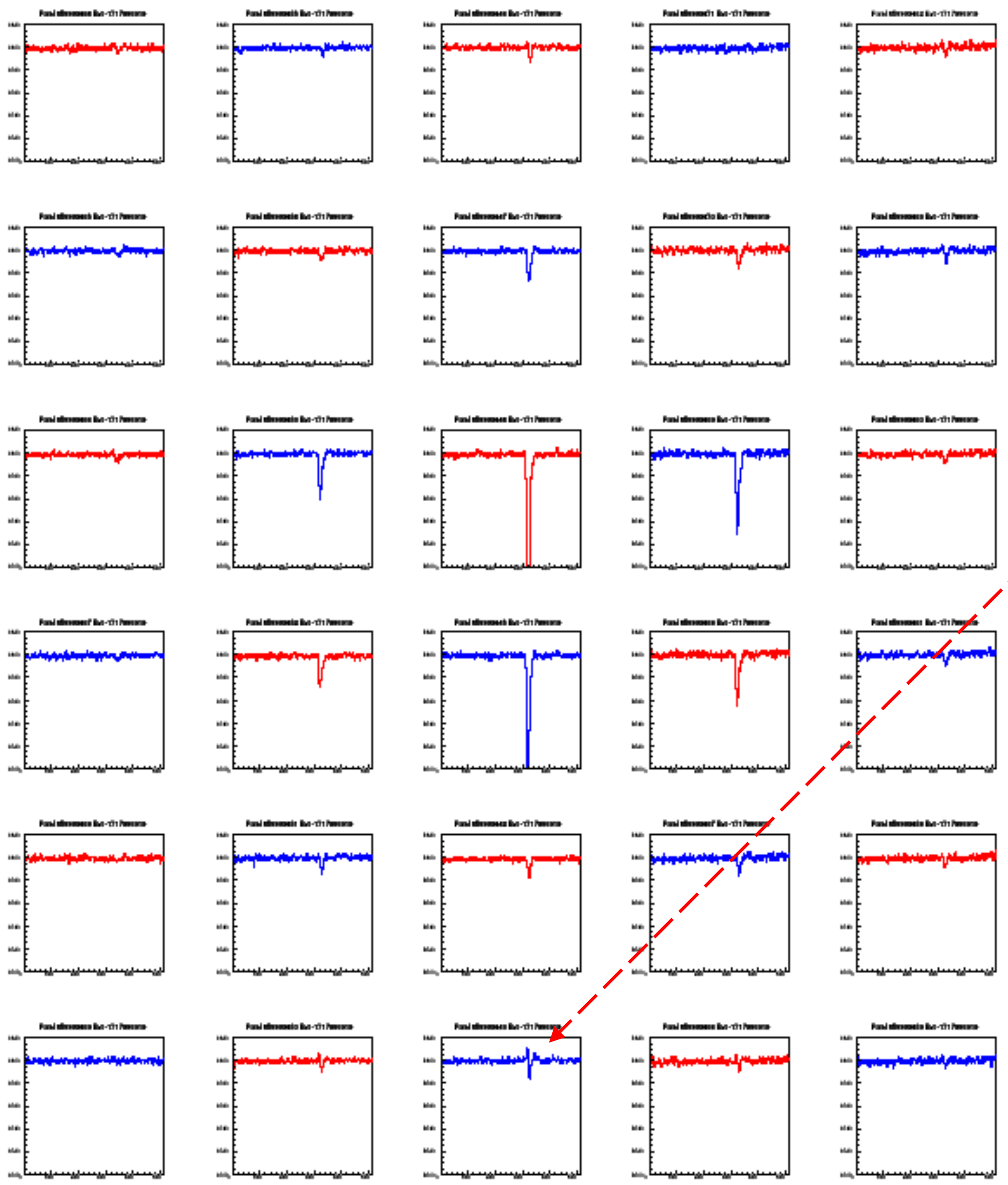
Front side: readout PCB, MCX adapter boards, HV

- Light-tight enclosure
- 320 DRS4 channels (10x 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

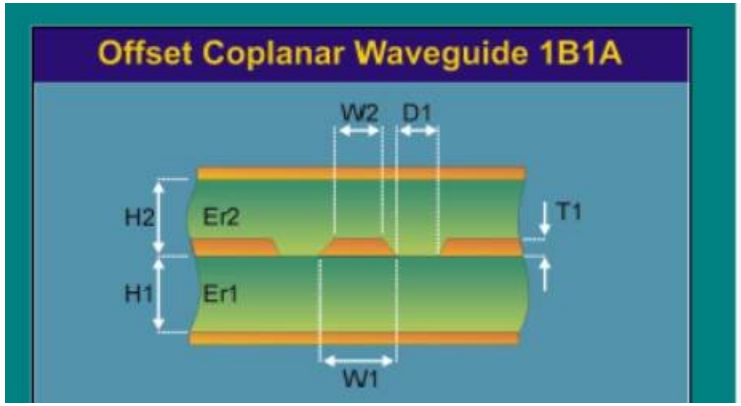
PCB stack details & cross-talk evaluation



6x pads vertically; ~12 mV central pixel amplitude

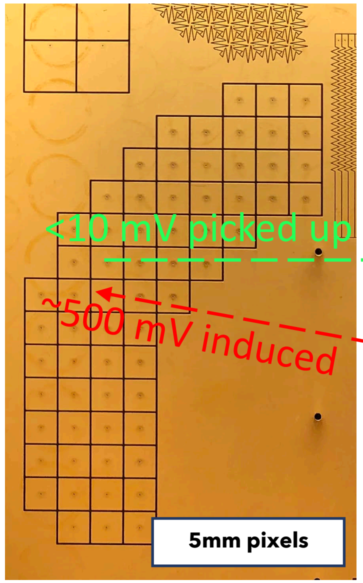
5x 4mm pads horizontally; 50ns time window

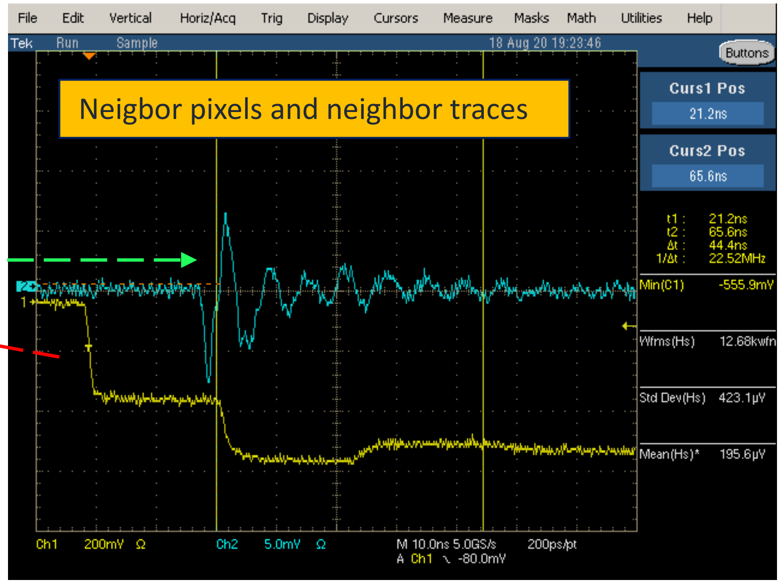
Certain level of cross-talk is present (traces here are routed in Y-direction)



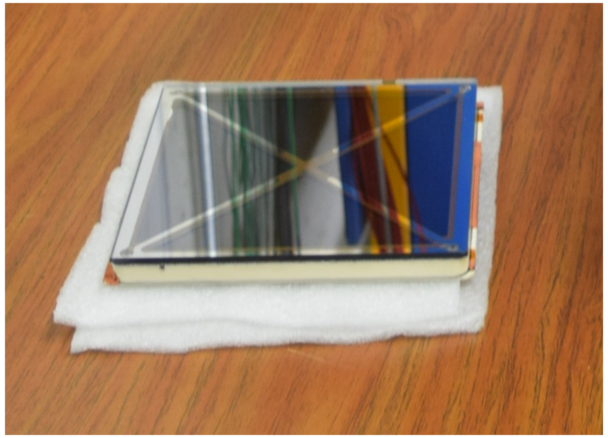
Substrate 1 Height	H1
Substrate 1 Dielectric	Er1
Substrate 2 Height	H2
Substrate 2 Dielectric	Er2
Lower Trace Width	W1
Upper Trace Width	W2
Ground Strip Separation	D1
Trace Thickness	T1

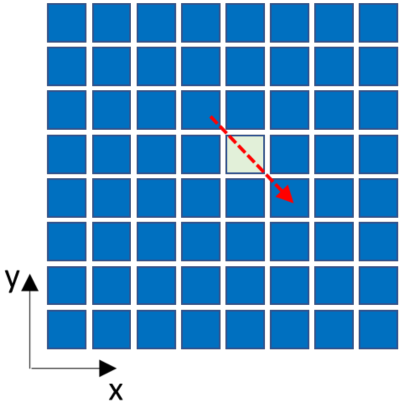
- Multi-layer stack-up; through vias; isolated traces
- Worst case X-talk ~few % level

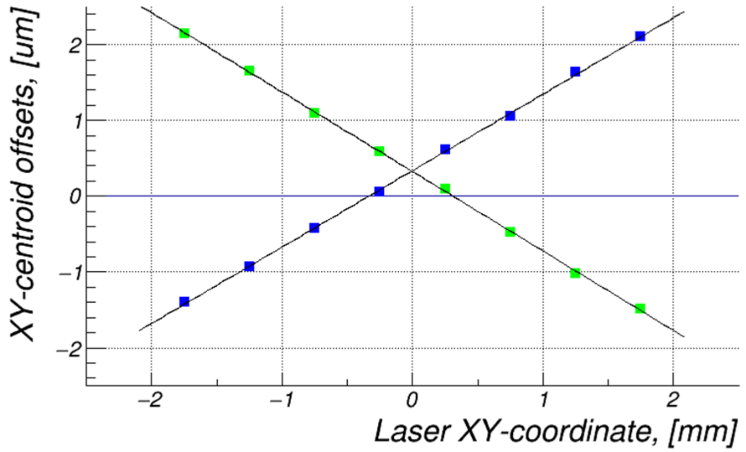




Spatial resolution with the 3 mm square pixels







- "Single-photon" mode

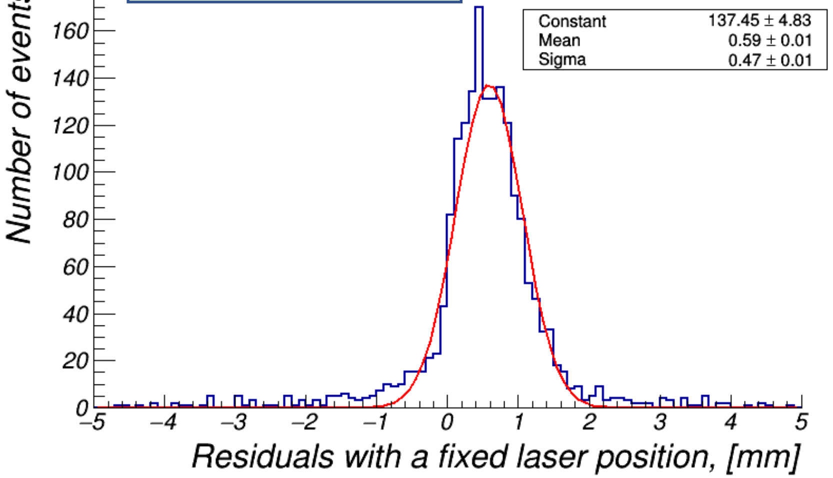
$$X \sim \frac{\sum_i^n q_i x_i}{\sum_i^n q_i}$$

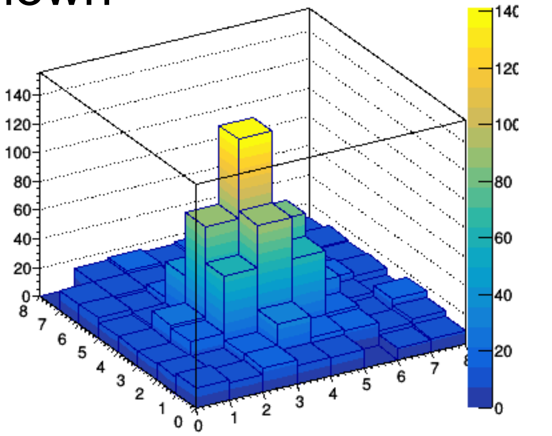
- Gen II LAPPD tile #97 provided by Incom
  - 2mm thick ceramic base

- 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

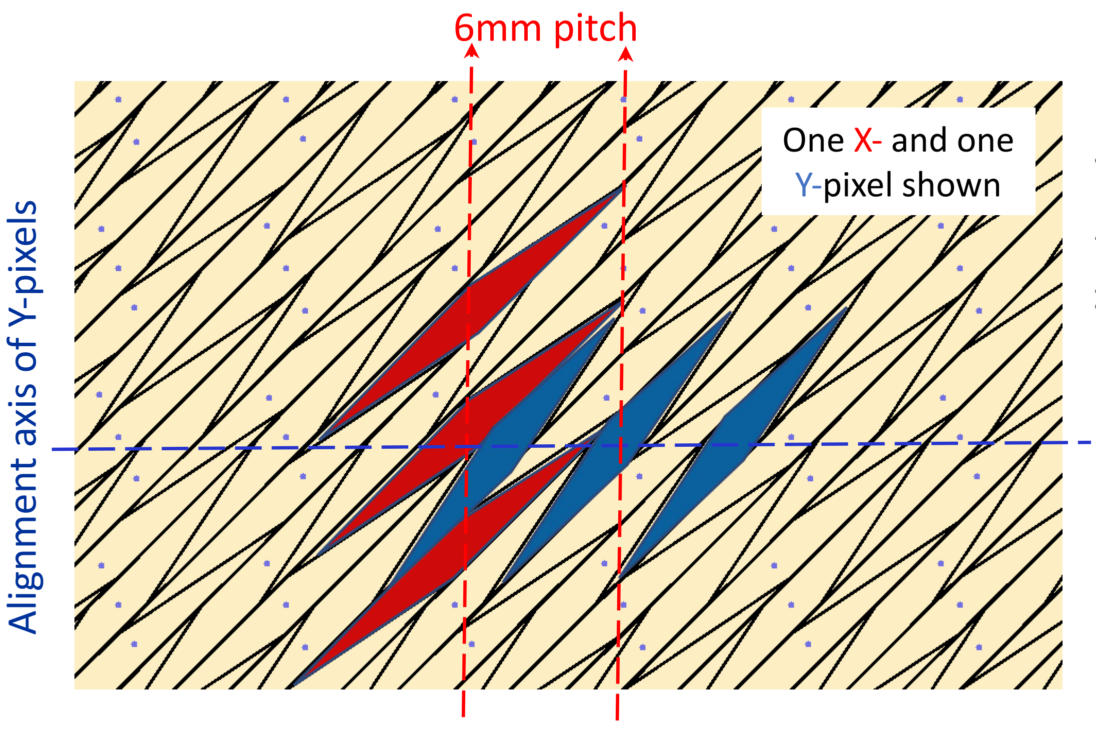
~500 μm width

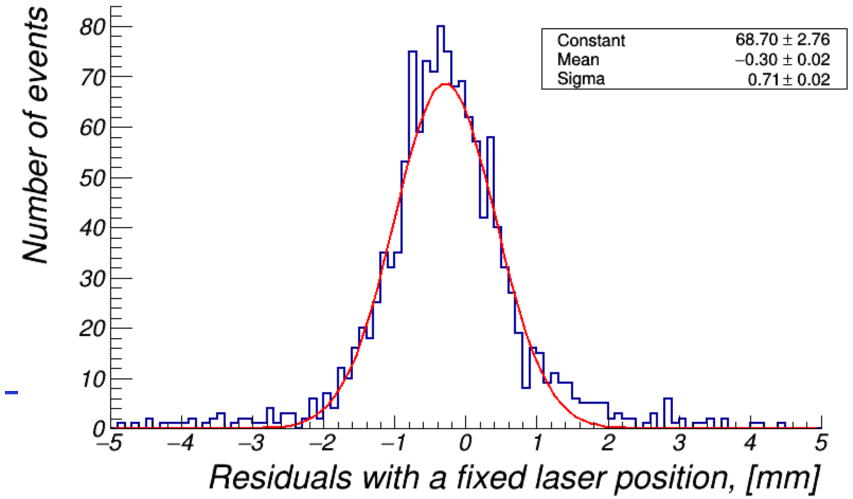




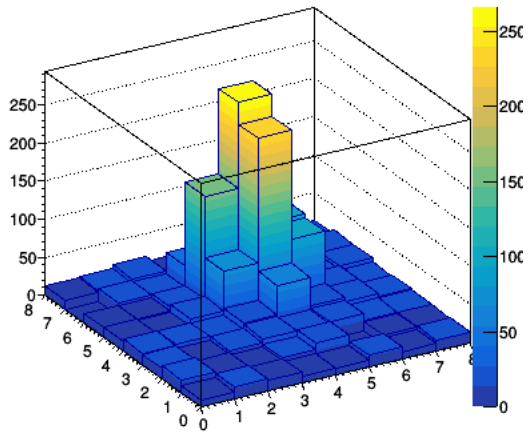
Typical single photon cluster has RMS ~ 3.5 mm

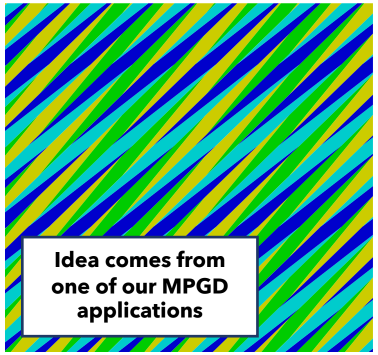
2D zigzag pixels with a 6 mm pitch



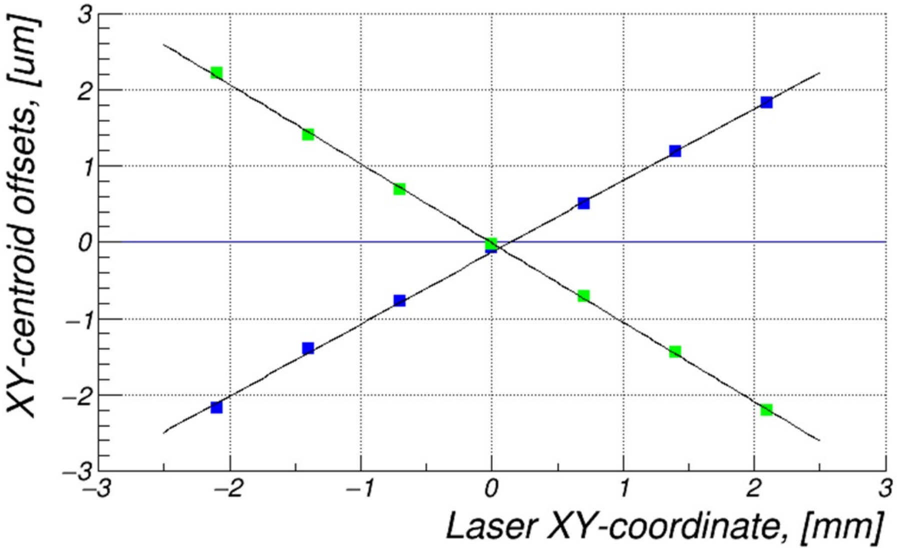


Typically, 3x3 pixel clusters





Linearity scan results



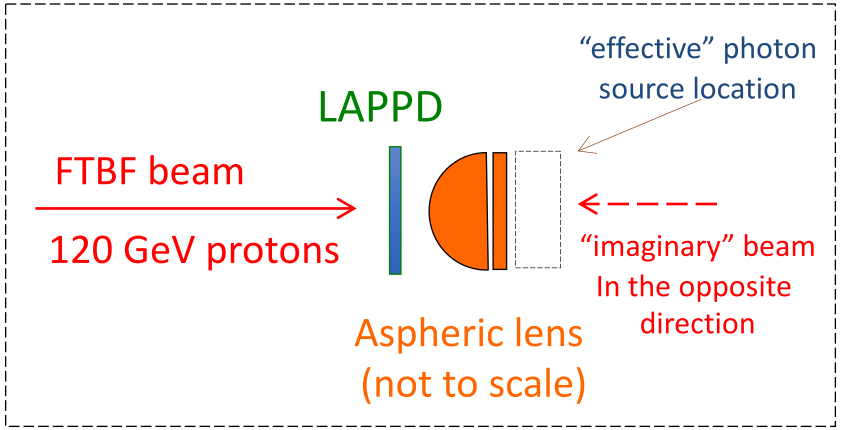
- Pretty good linearity
- Spatial resolution typically ~700-800 μm (given the S/N ratio)
- As long as occupancy is acceptable one can increase the effective pad size (length!) without losing spatial resolution

Beam test at Fermilab in June 2021

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

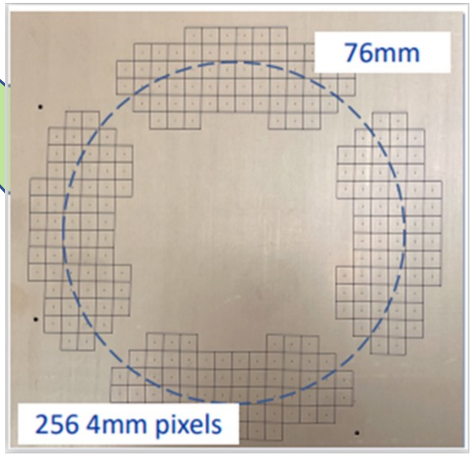
Experimental setup (Fermilab Test Beam Facility)

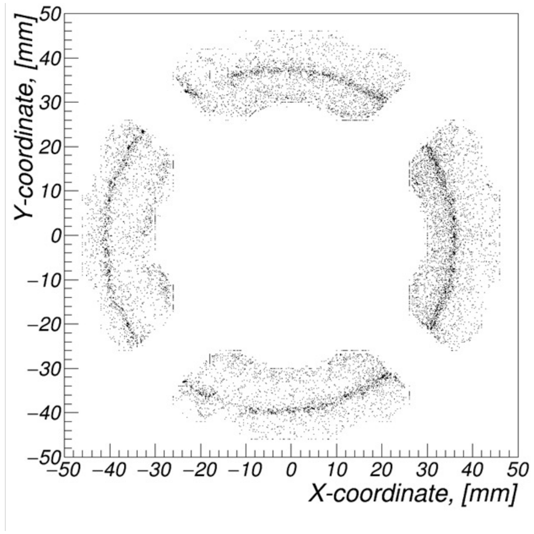
- The same setup as in the lab, but instead of a laser use *a thick aspheric lens* as a well controlled Cherenkov light source

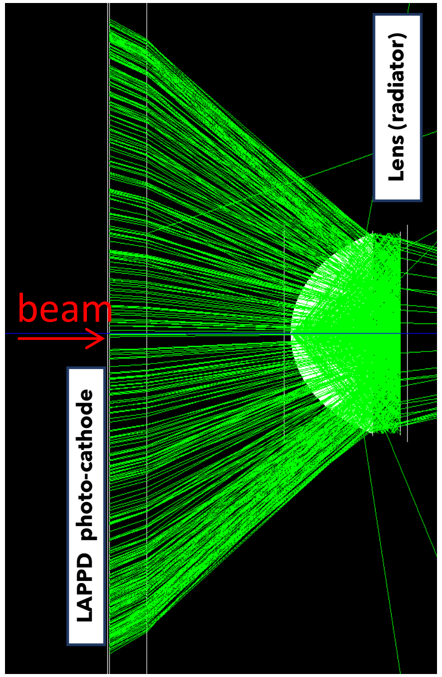


- Off-the-shelf component
- (Almost) no stray photons
- To first order no need in tracking
- The used model (Edmund Optics #67-265, EFL 20.0mm) produces a crisp ~76mm diameter ring at the focal plane

Pixel pattern & accumulated single photon XY-coordinates

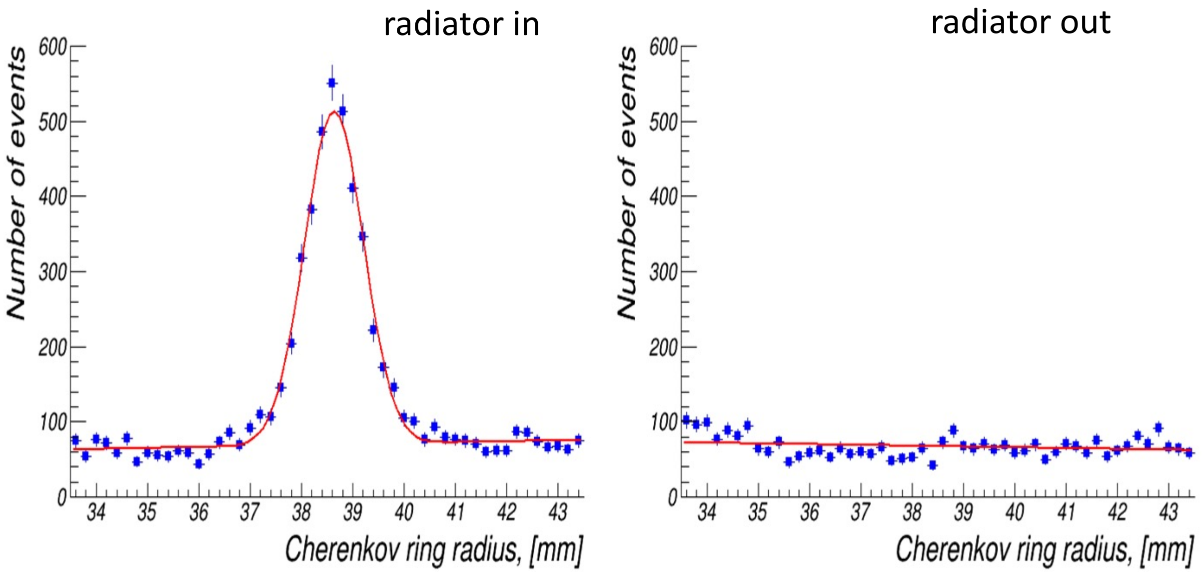




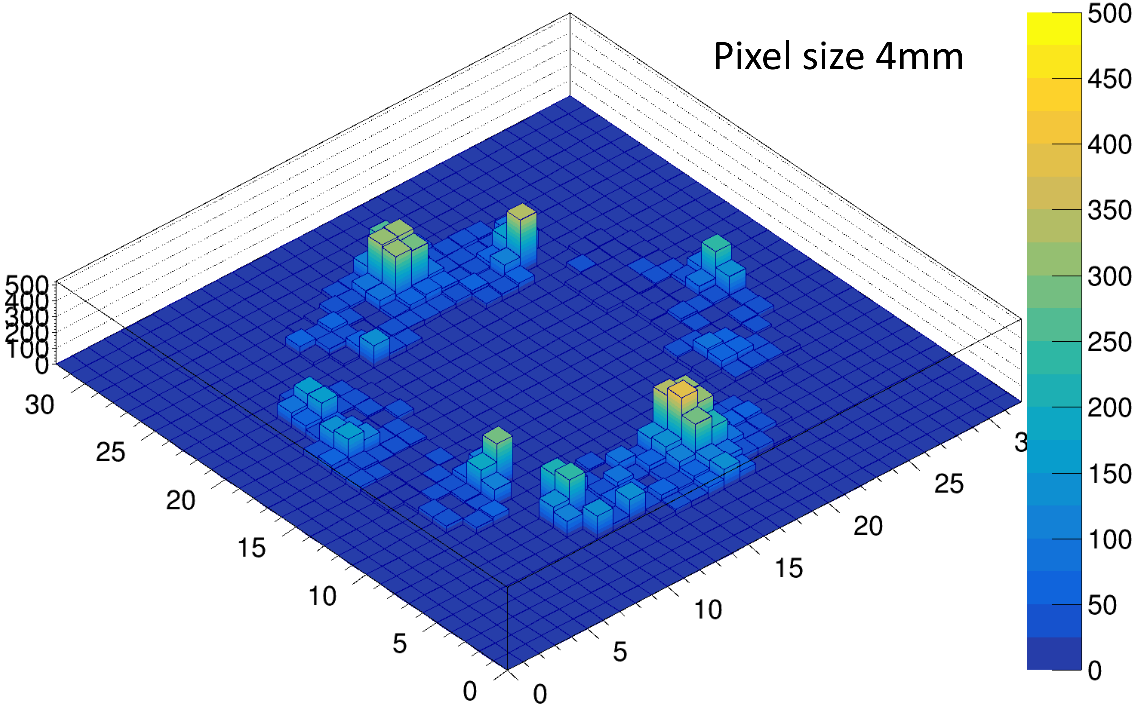


Cherenkov ring radius resolution

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!

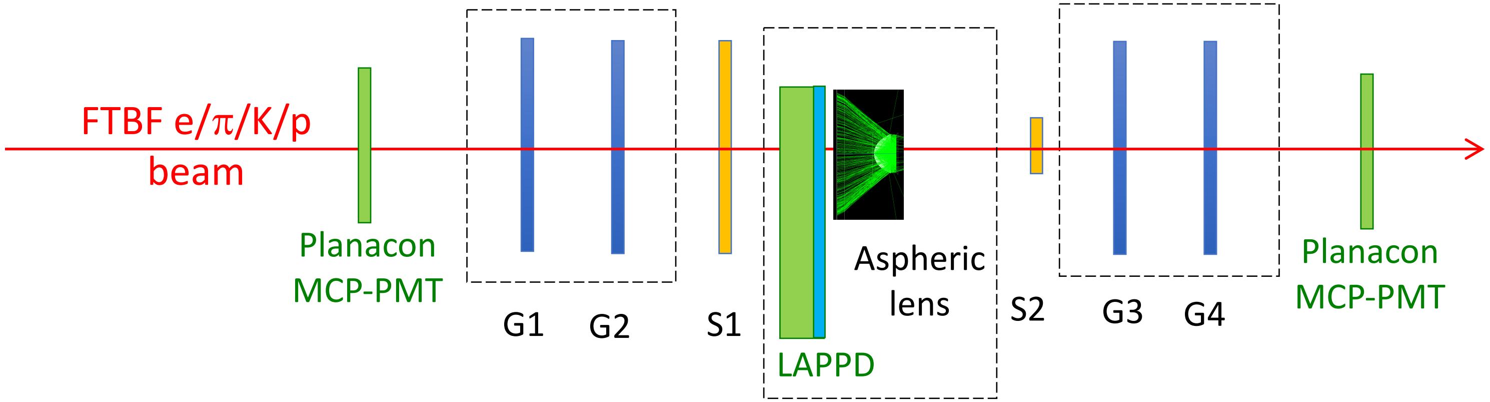
Paradigm change in the Cherenkov ring imaging data analysis: overlapping clusters rather than single pixel hits

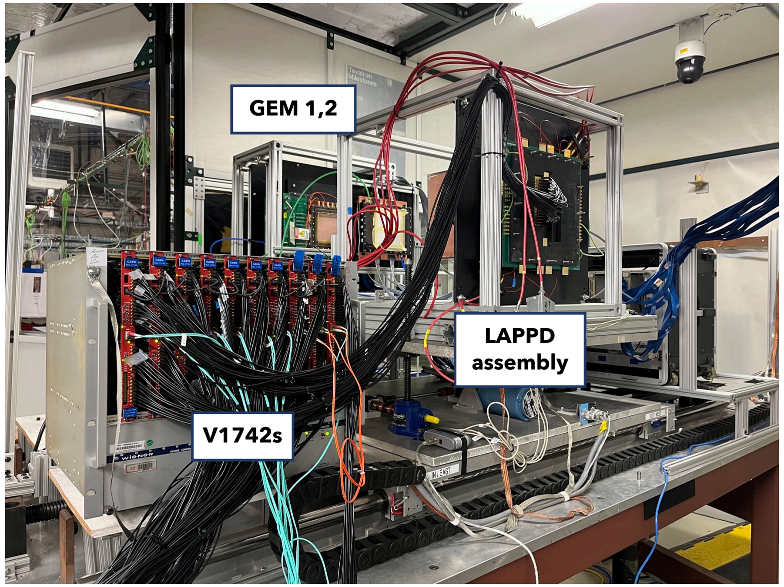
Beam test at Fermilab in June 2022

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

Experimental setup at Fermilab in June 2022

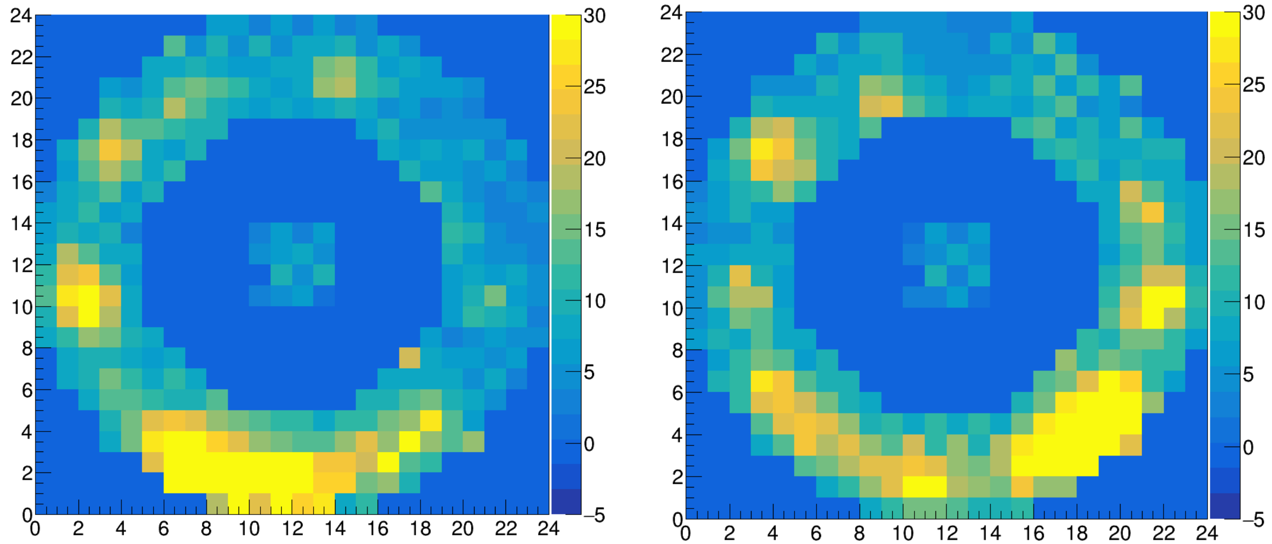
- G1 .. G4 – COMPASS GEM reference tracker
- S1 .. S2 – trigger scintillator counters





- 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

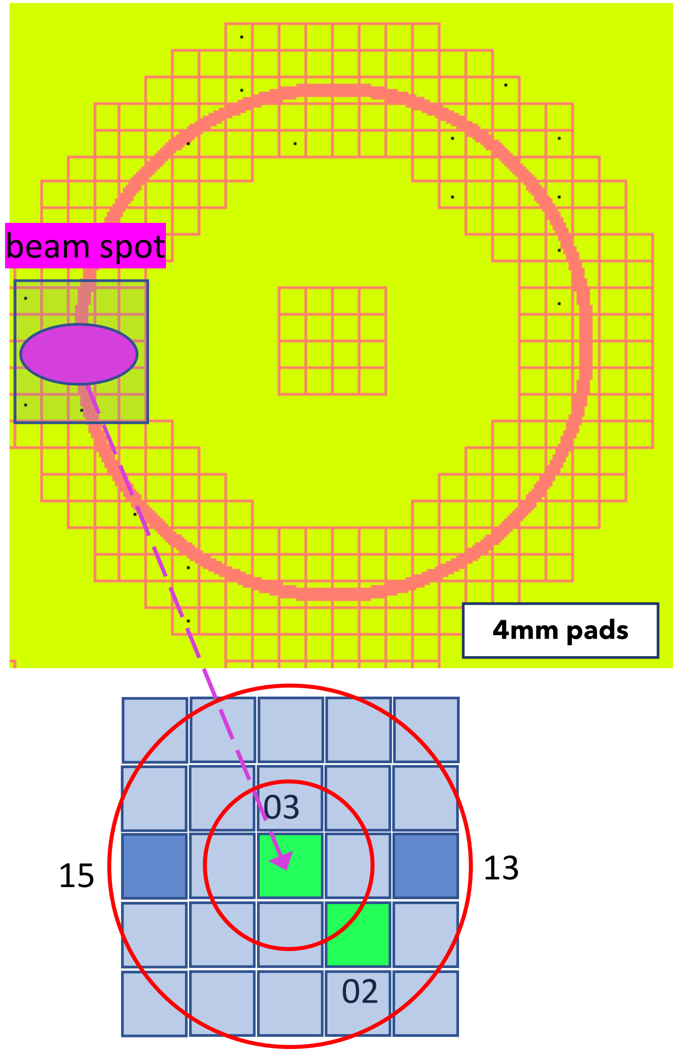


Enough data on tape to quantify **single-photon** timing resolution

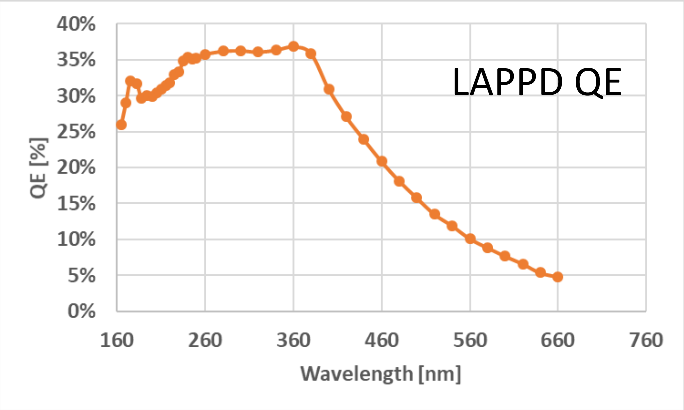
Single events: no filter, 24x24 4mm pixel field, [mV] units

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

LAPPD quartz window as a Cherenkov radiator

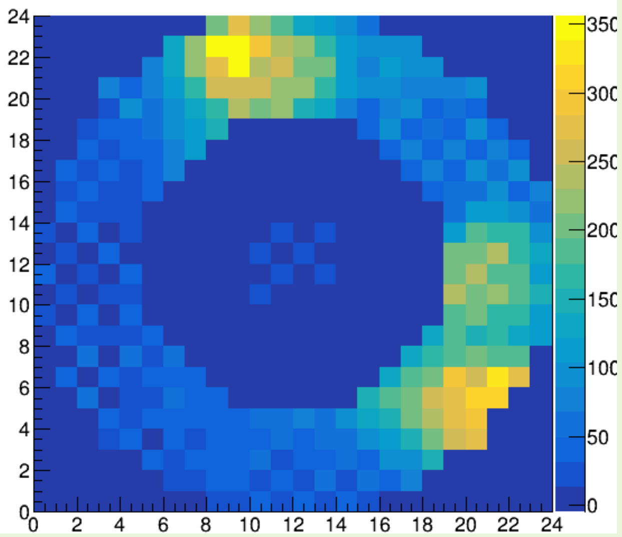


Due to the TIR, photons only hit the PC in a radial band ~[5.5 .. 12.0] mm

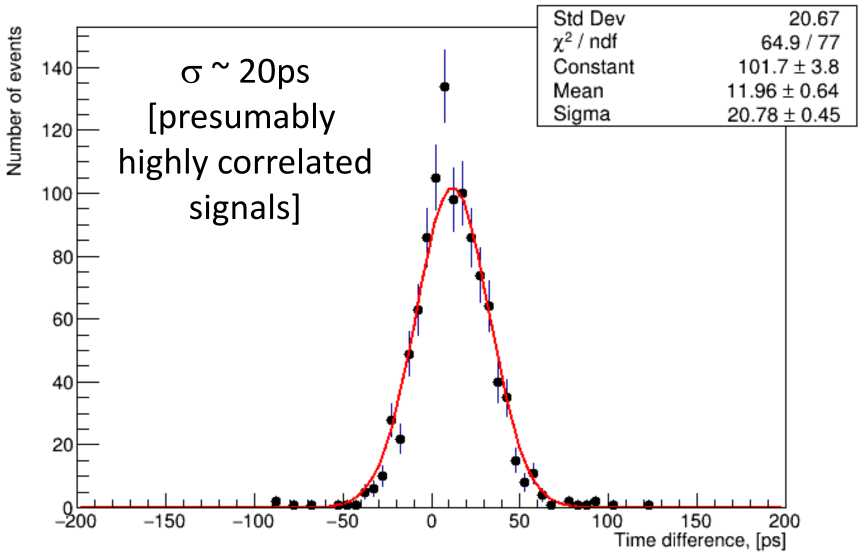


- *Single* photon TTS ~50 ps
- UV grade quartz window: a 120 GeV proton produces a **blob of ~100 p.e.'s**

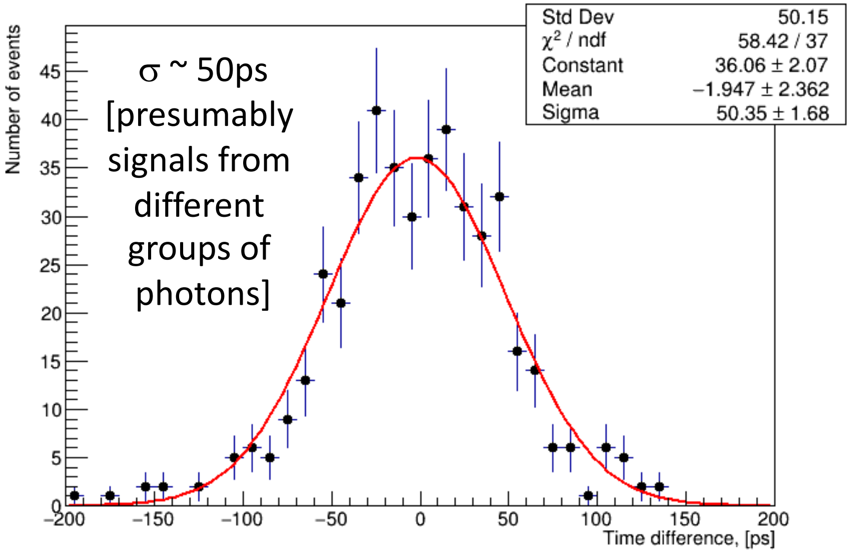
Future work: how to circumvent the missing high precision t_0 timing reference?



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)

Summary

- 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
- Several ideas for readout board optimization were tried out, in terms of the spatial resolution performance, cross talk suppression and instrumented channel count optimization
- Data collected to quantify *timing performance* in a finely pixelated configuration

- Further work:
  - Demonstrate *simultaneous* timing and spatial resolution performance in the same setup
  - Practical applications in the scope of EIC detector R&D program
  - On-board electronics integration
  - TOF PET application?