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

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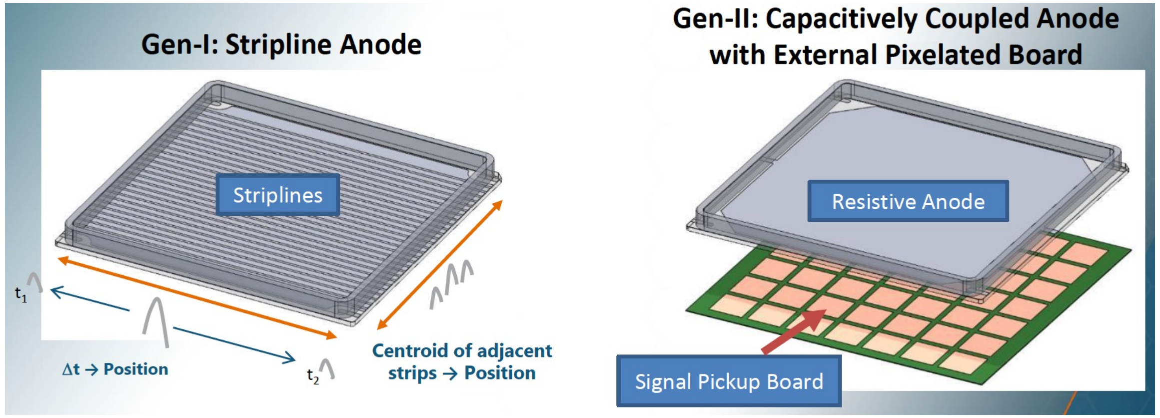
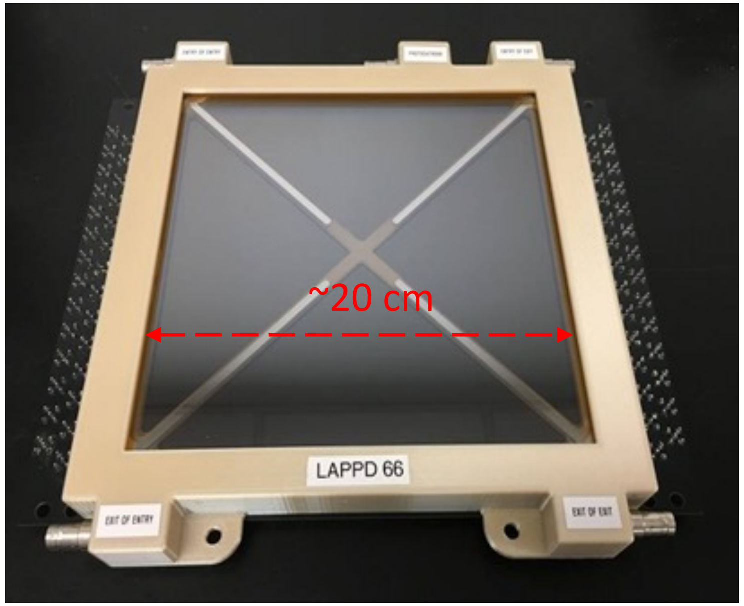
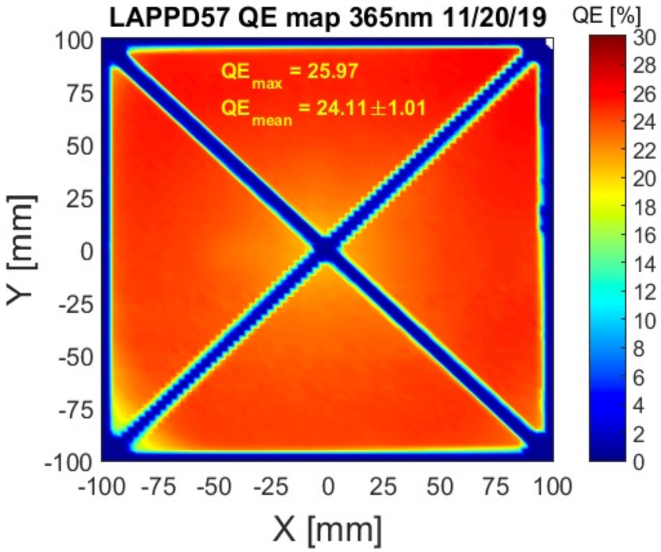
15th Pisa Meeting on Advanced Detectors
May 22-28, 2022, La Biodola – Isola d'Elba (Italy)

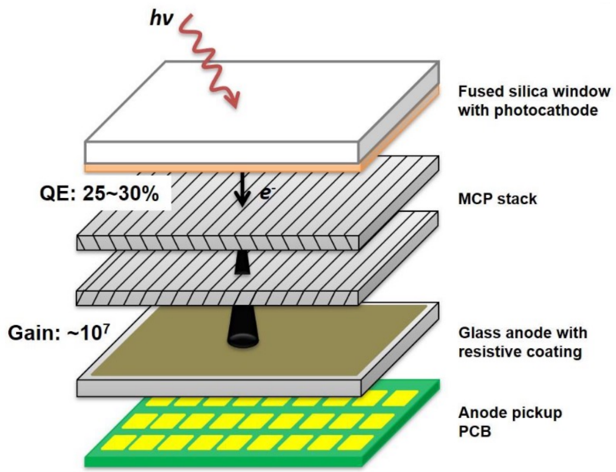
Motivation

- 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





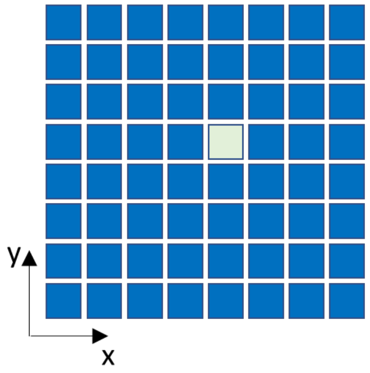




But: a fine (few mm pitch) pixellation needs to be confirmed!

Gen II: capacitively coupled LAPPD

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



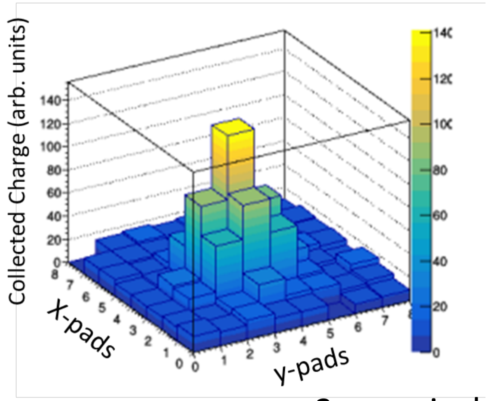
One photon – one pixel hit

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

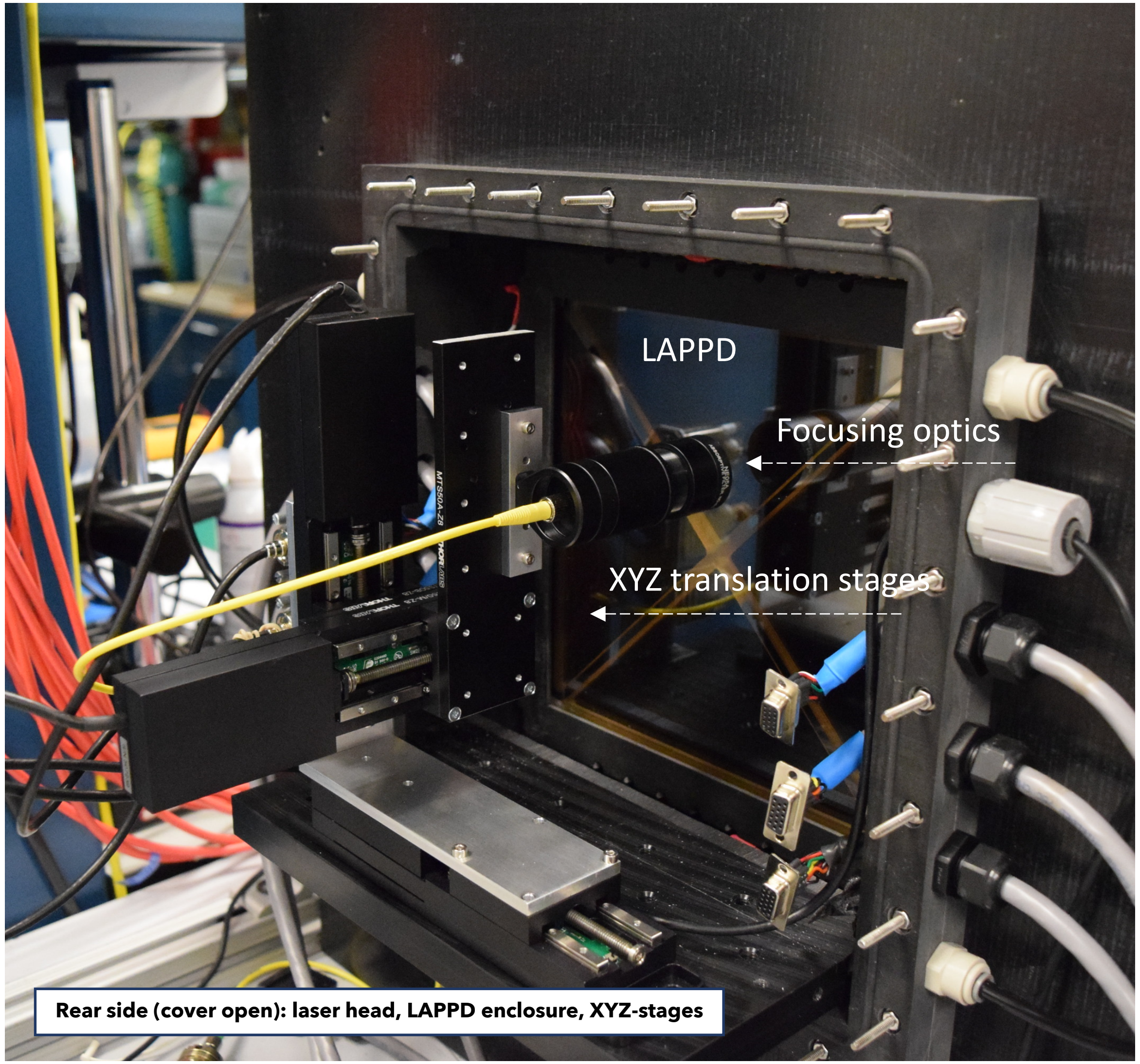
Spatial resolution σ can be times higher than pitch/√12

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

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

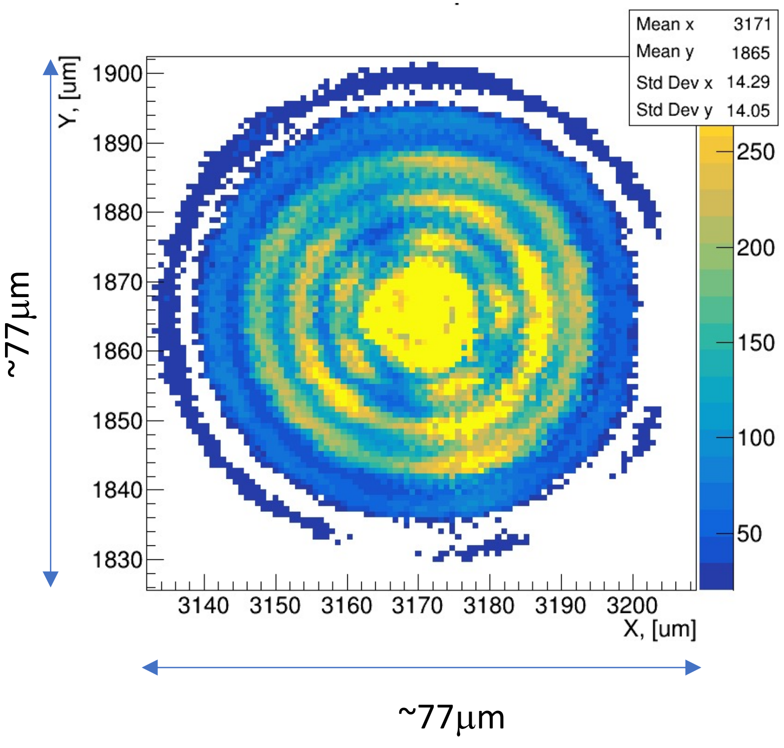
Lab measurements at Brookhaven

Test setup

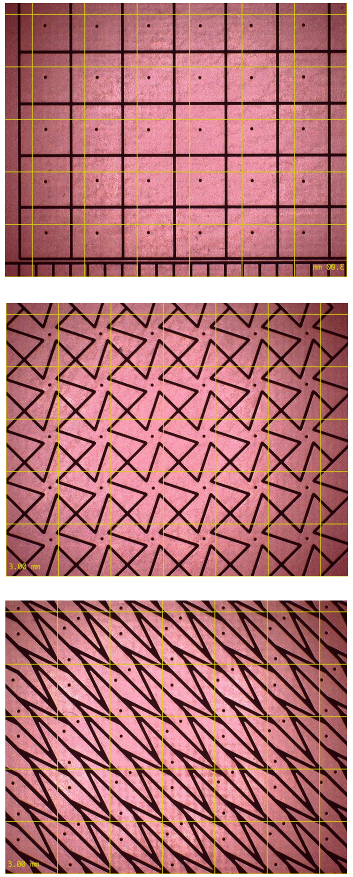


Rear side (cover open): laser head, LAPPD enclosure, XYZ-stages

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

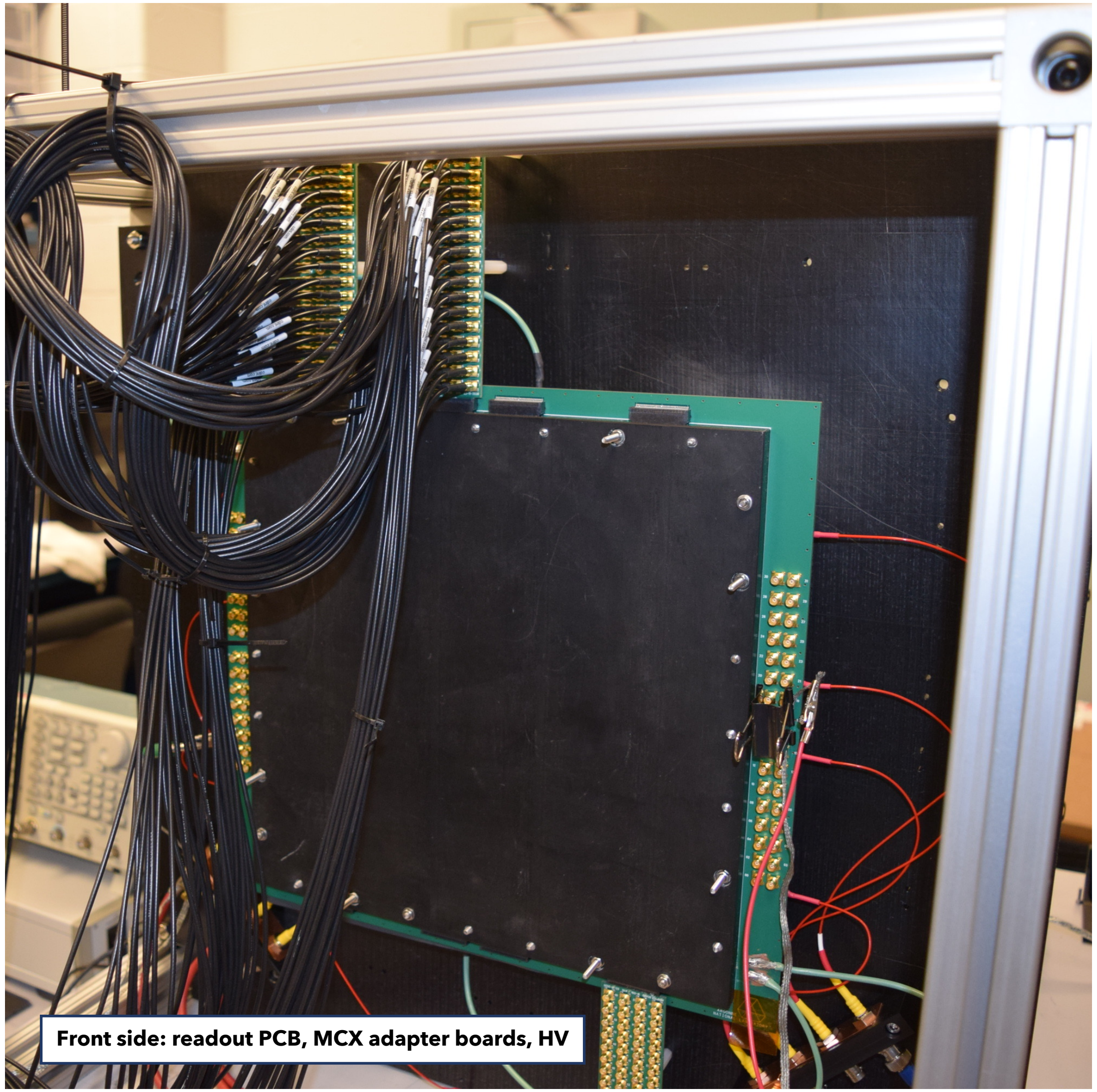


Laser spot as measured by a CMOS camera



here: all 3mm pitch

Test setup



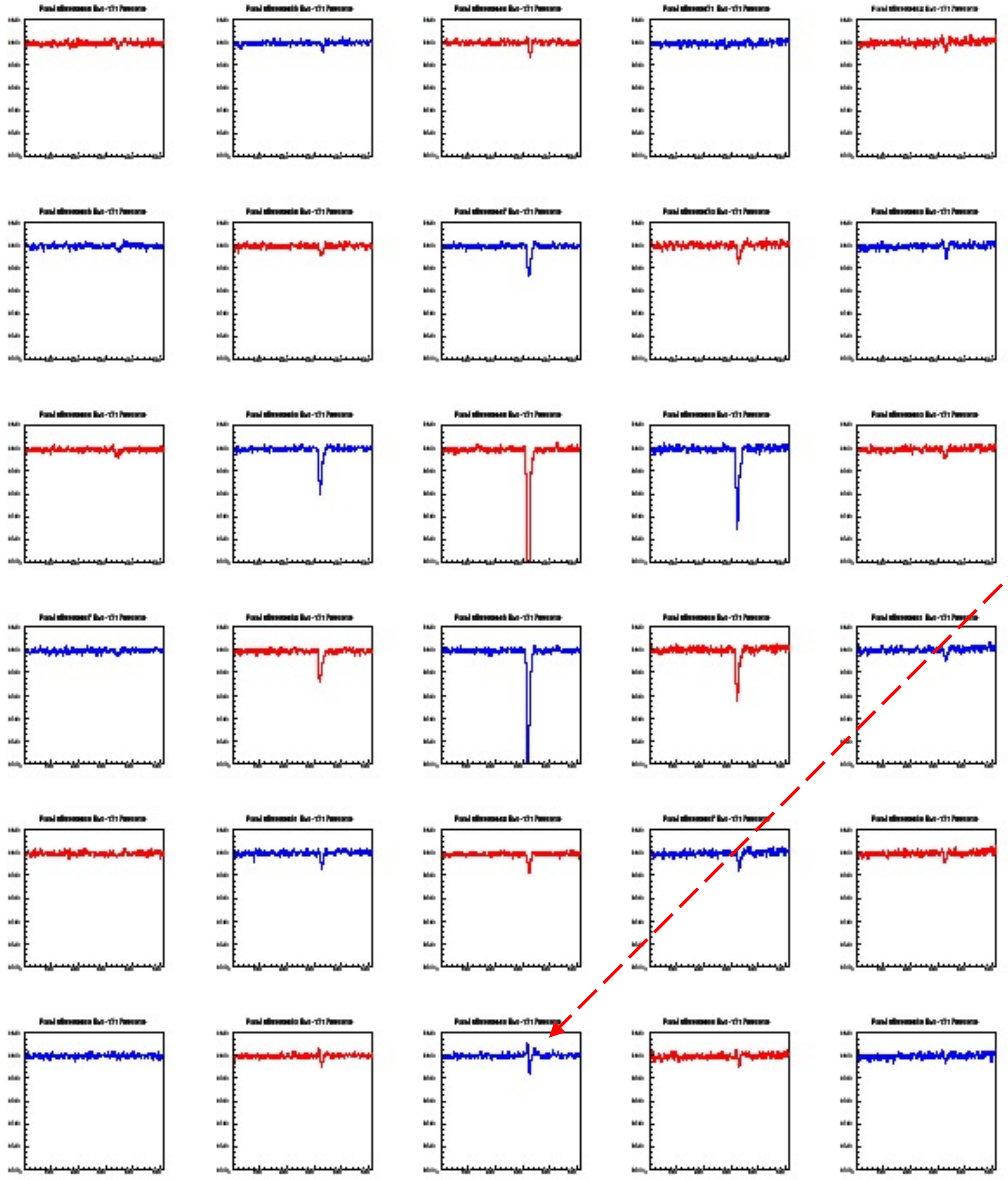
Front side: readout PCB, MCX adapter boards, HV

- Light-tight enclosure
- Up to 320 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

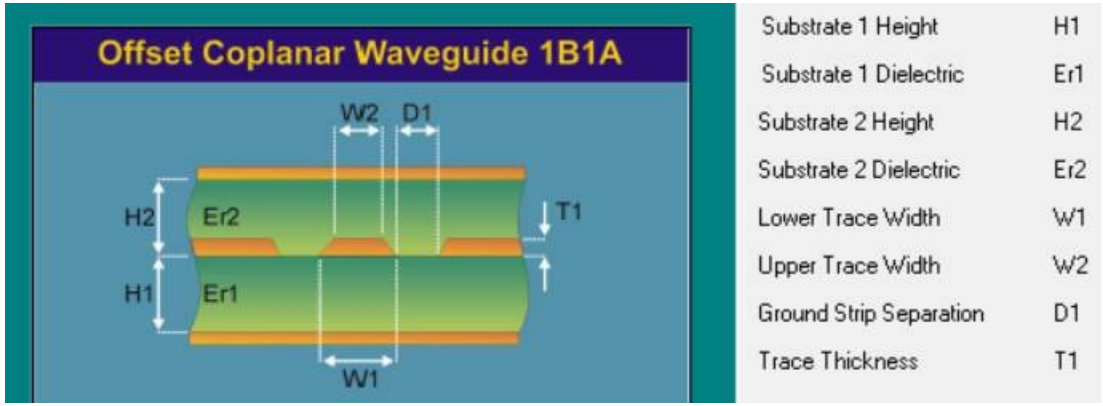
PCB stack details & cross-talk evaluation

6x pads vertically; ~12 mV central pixel amplitude

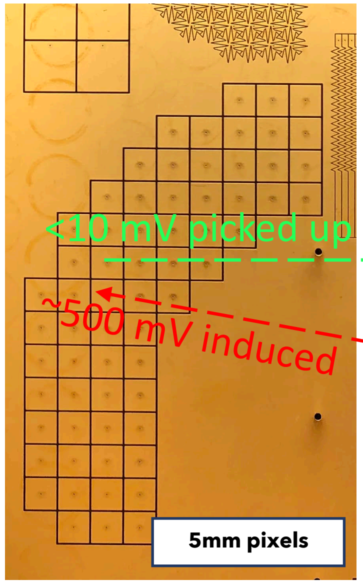


5x 4mm pads horizontally; 50ns time window

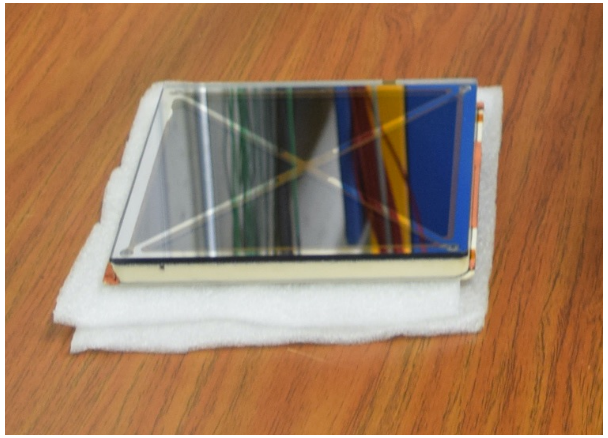
Certain level of cross-talk is present (traces here are routed in Y-direction)

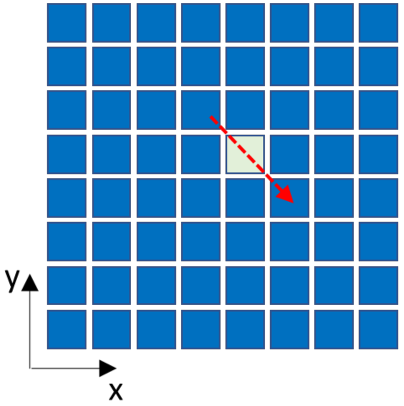


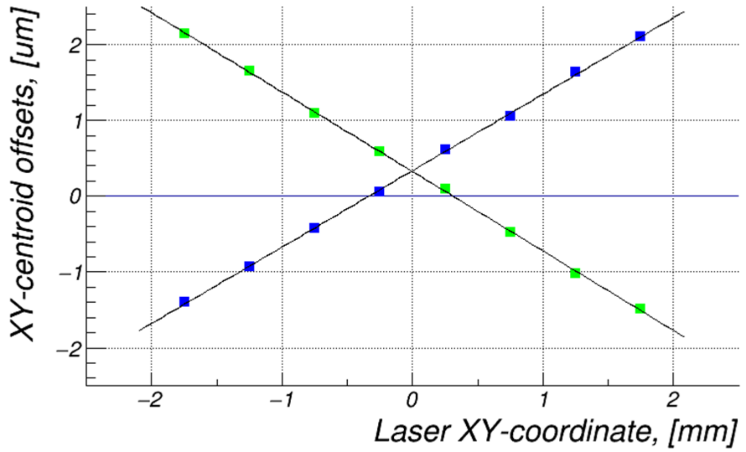
- Multi-layer stack-up; through vias; isolated traces
- Worst case X-talk ~few % level



Spatial resolution with the 3 mm square pixels







- "Single-photon" mode
  - ~10 mV signals

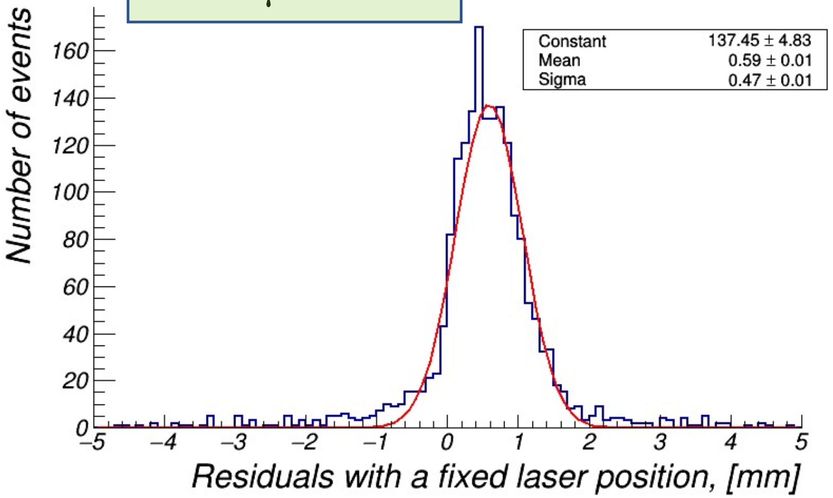
$$X \sim \frac{\sum_i^n q_i x_i}{\sum_i^n q_i}$$

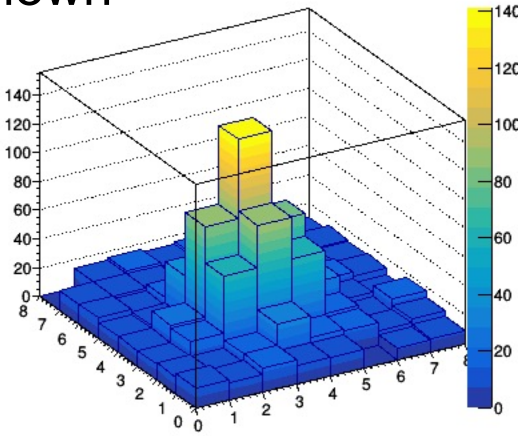
- Gen II LAPPD tile #97 provided by Incom
  - 2mm thick ceramic base

- 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

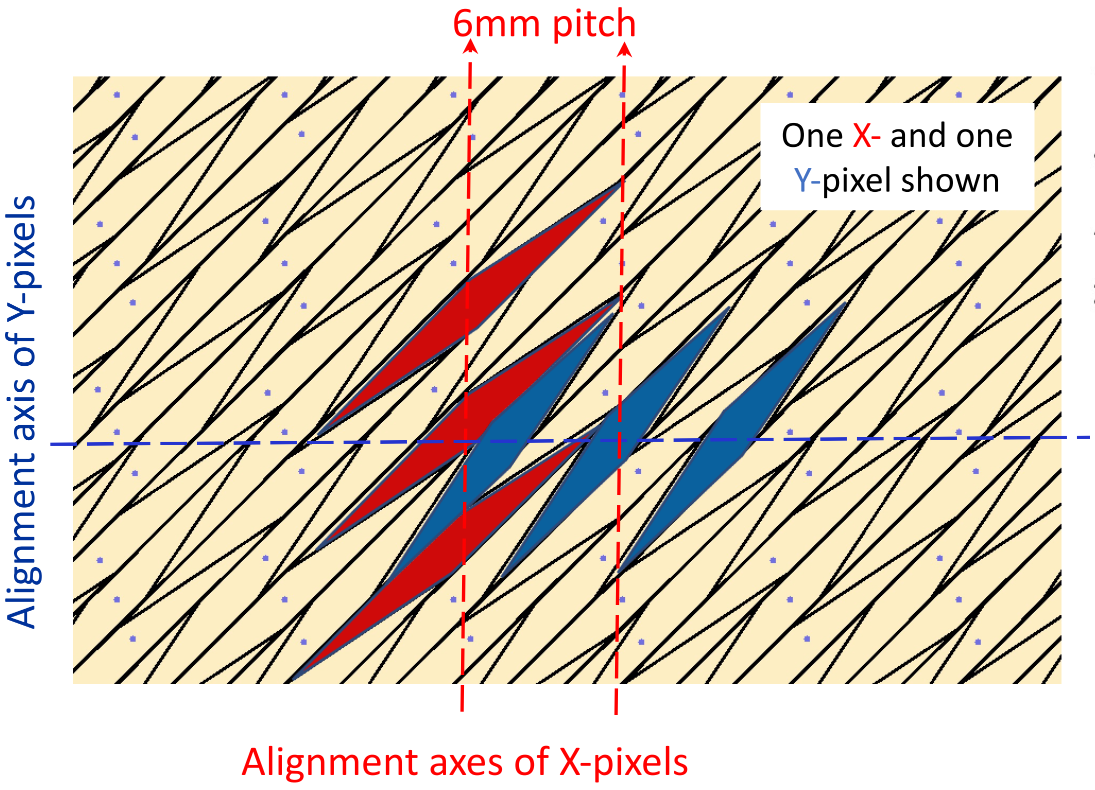
~500 μm width

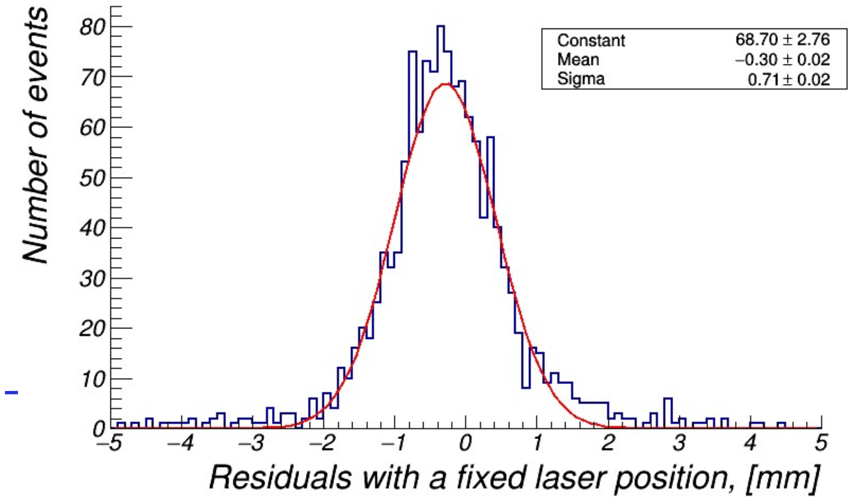




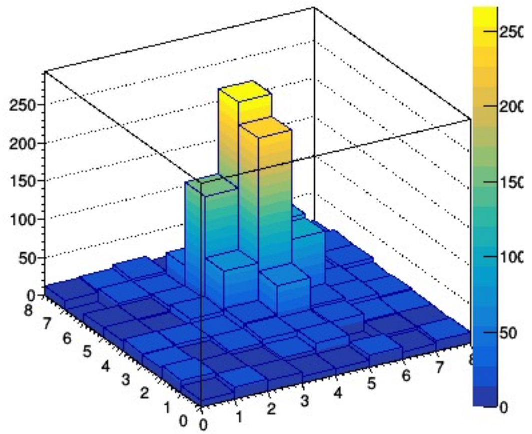
Typical single photon cluster has RMS ~ 3.5 mm

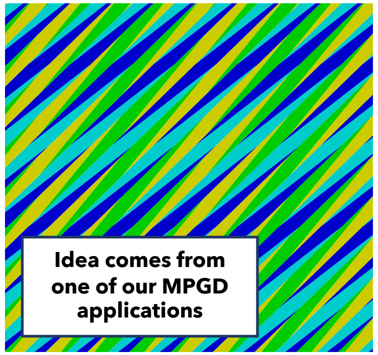
2D zigzag pixels with a 6 mm pitch



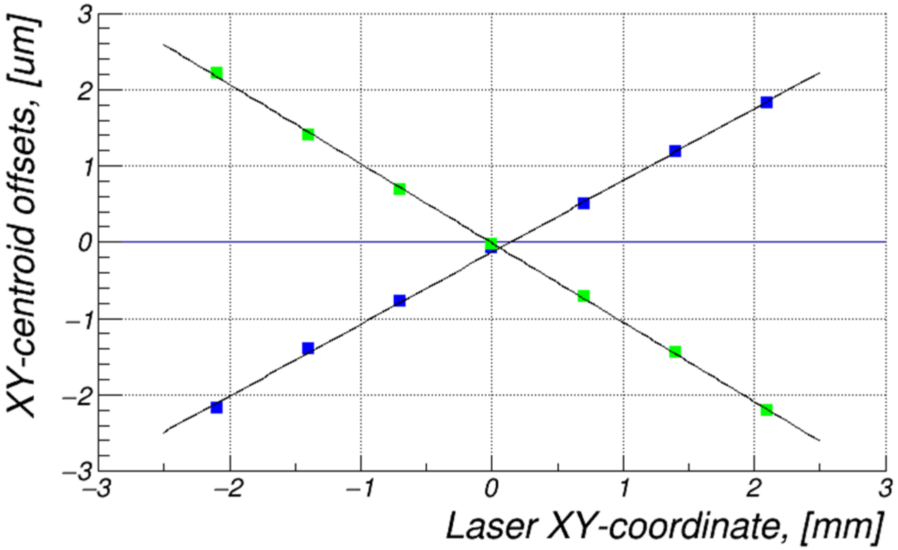


Typically, 3x3 pixel clusters





Linearity scan results



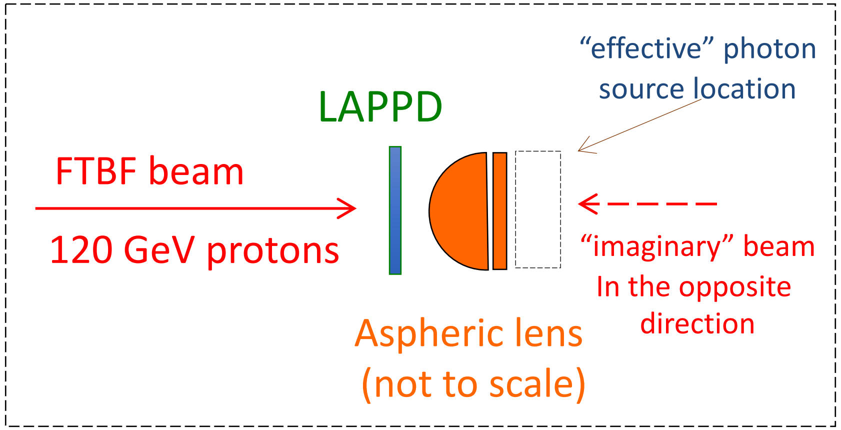
- Pretty good linearity
- Spatial resolution typically ~700-800 μm (given the S/N ratio)
- As long as occupancy is acceptable one can increase the effective pad size (length!) without losing spatial resolution

Beam test at Fermilab in June 2021

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

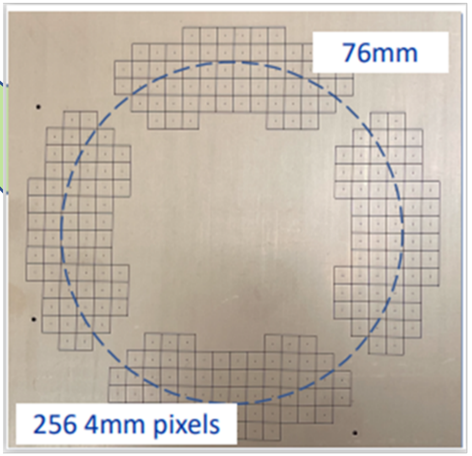
Experimental setup (Fermilab Test Beam Facility)

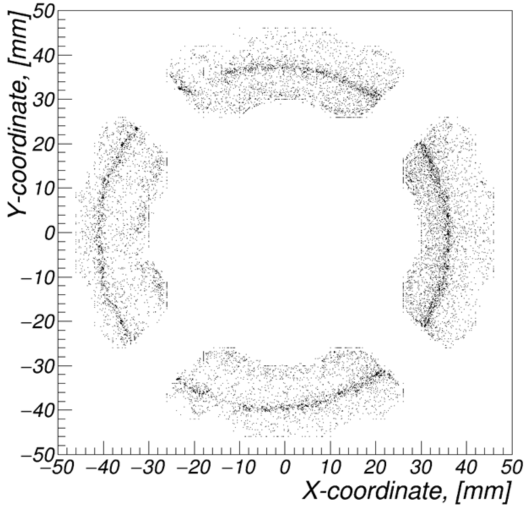
- The same setup as in the lab, but instead of laser use *a thick aspheric lens* as a well controlled Cherenkov light source

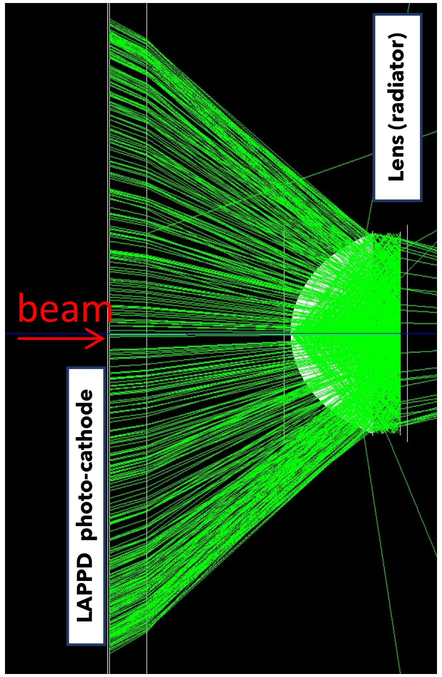


- Off-the-shelf component
- (Almost) no stray photons
- To first order no need in tracking
- The used model (Edmund Optics #67-265, EFL 20.0mm) produces a crisp ~76mm diameter ring at the focal plane

Pixel pattern & accumulated single photon XY-coordinates

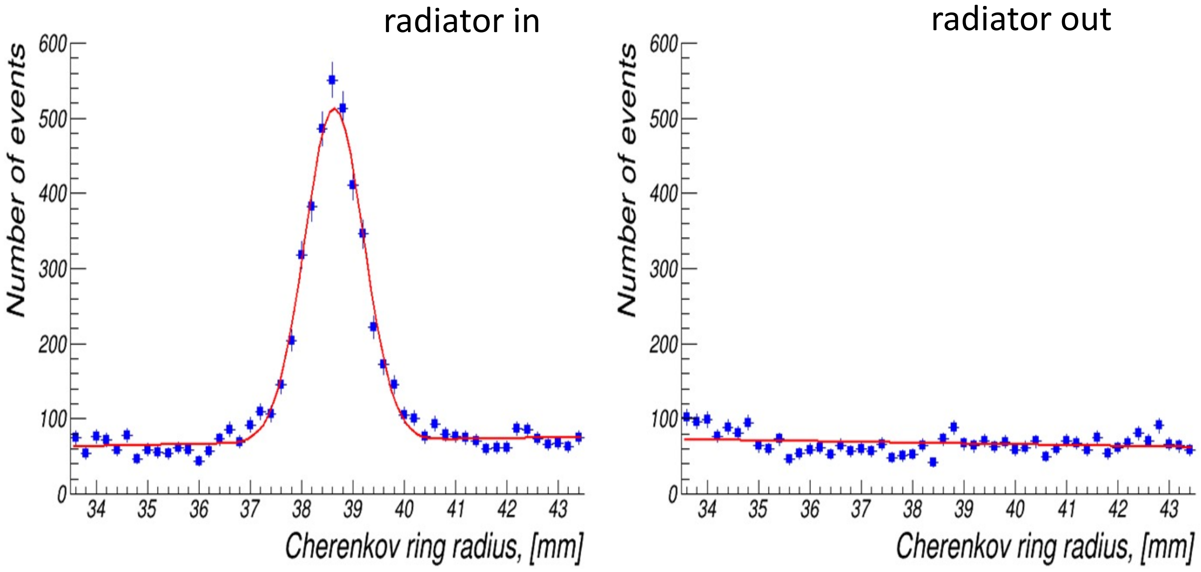




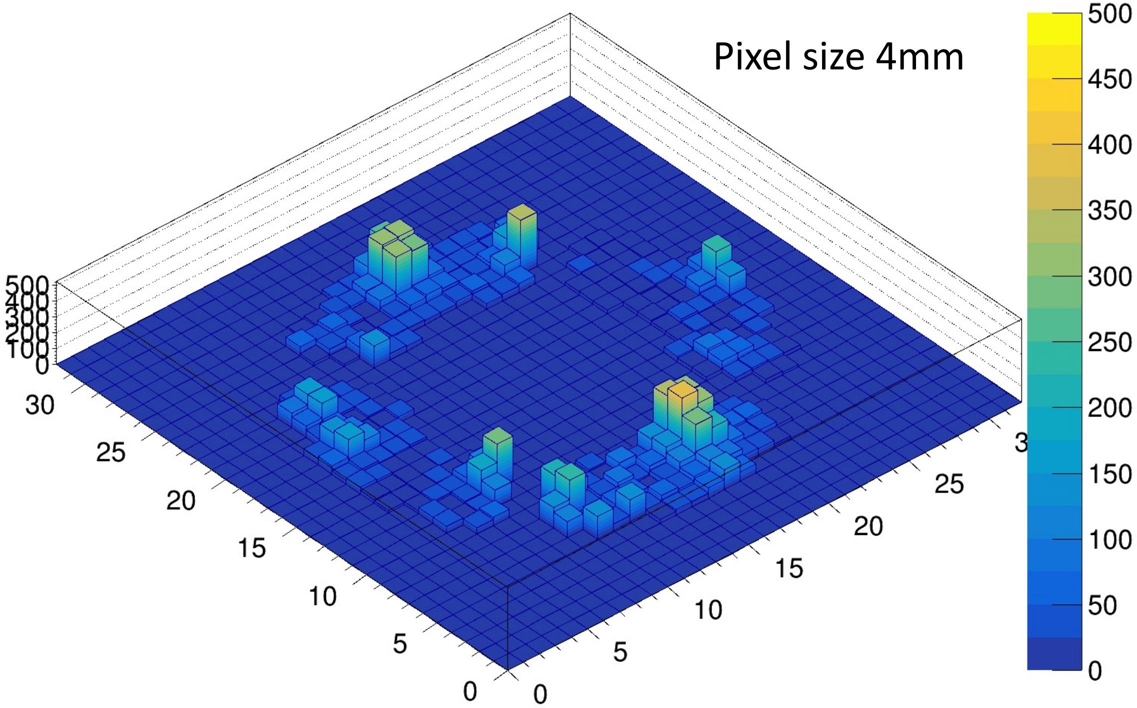


Cherenkov ring radius resolution

$\sigma_R \sim 600\ \mu m$



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

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

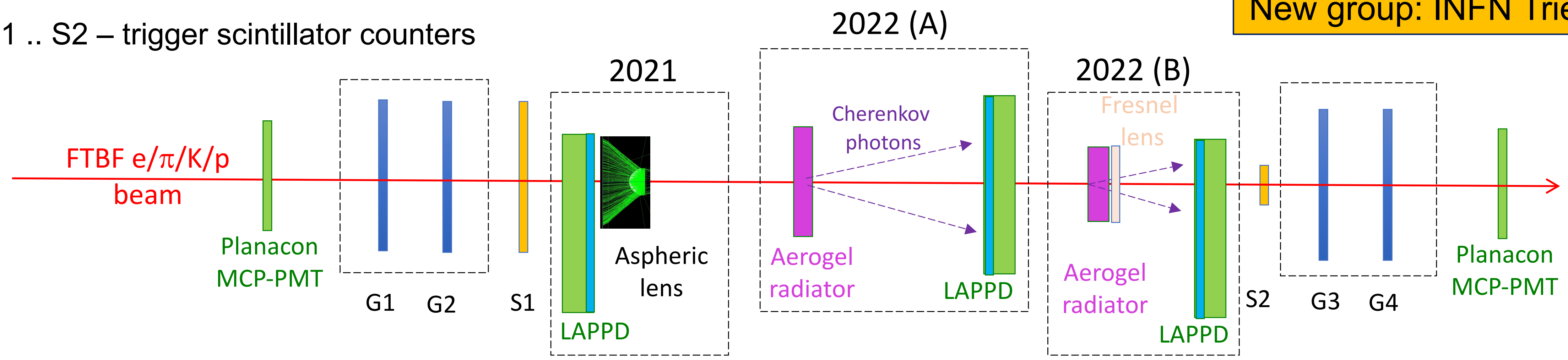
- Further work:
  - Additional readout board optimization for high resolution timing
  - Perhaps more advanced pixellation schemes (redundant strip configurations, mixed timing & spatial coordinate measurement geometries, etc.) can be considered if needed
  - Practical applications in the scope of EIC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

Next beam test campaign @ Fermilab: June 2022

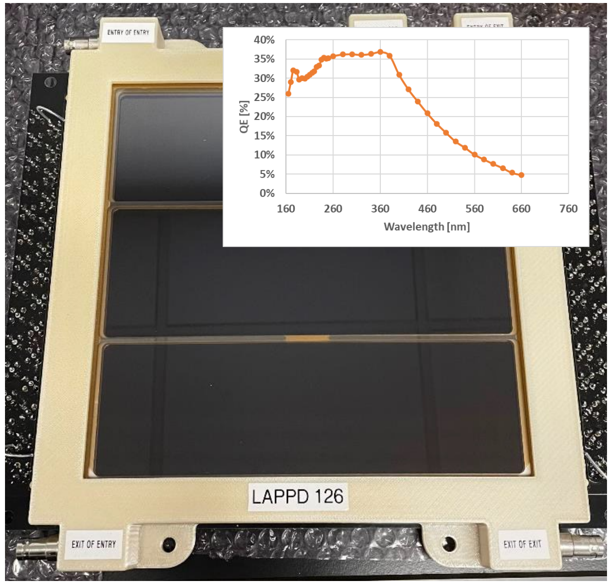
Experimental setup at Fermilab in June 2022

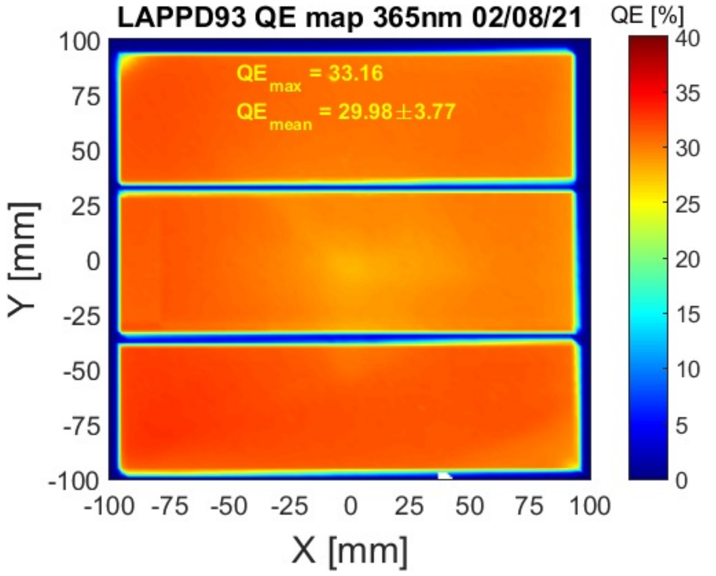
- G1 .. G4 – COMPASS GEM reference tracker
- S1 .. S2 – trigger scintillator counters

New group: INFN Trieste

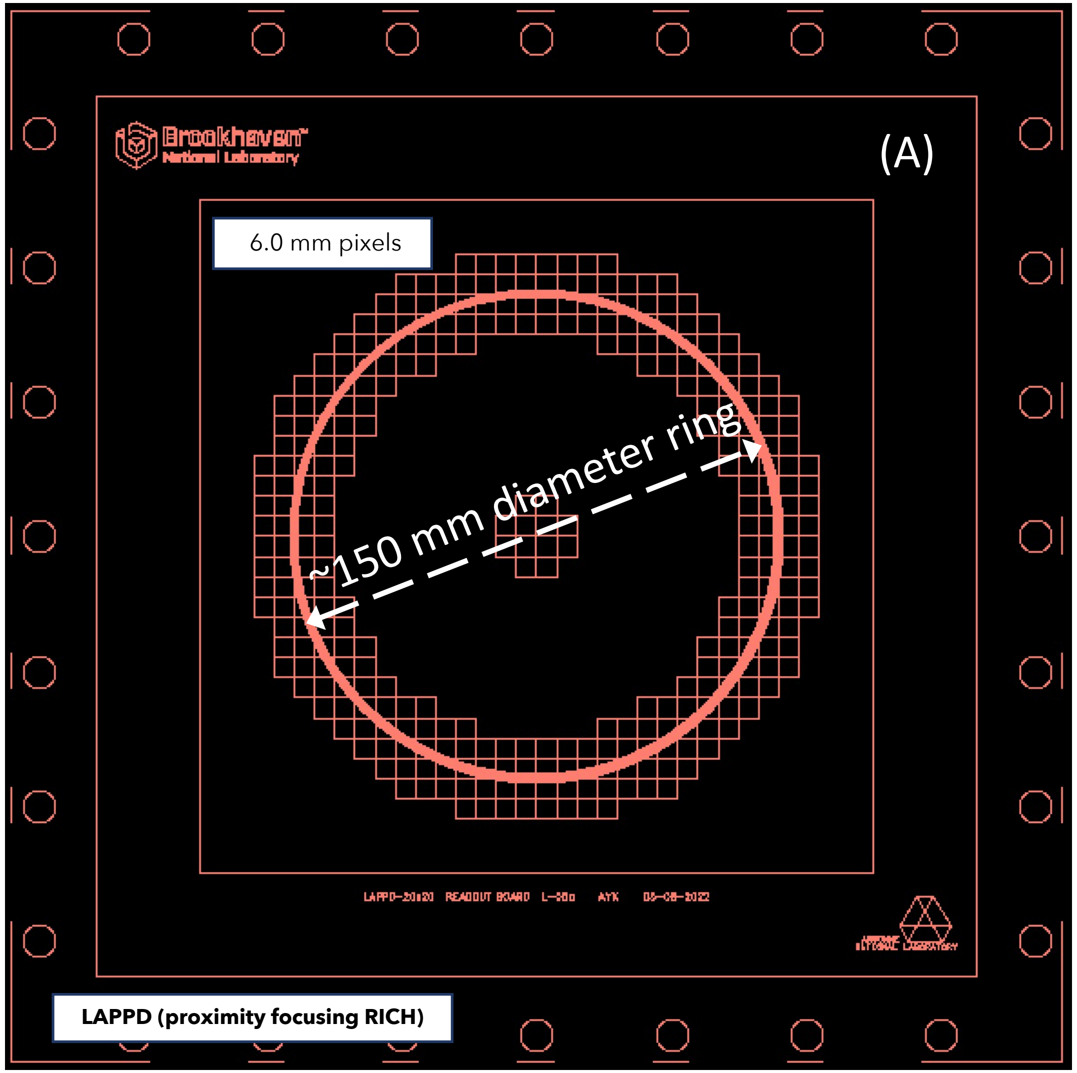


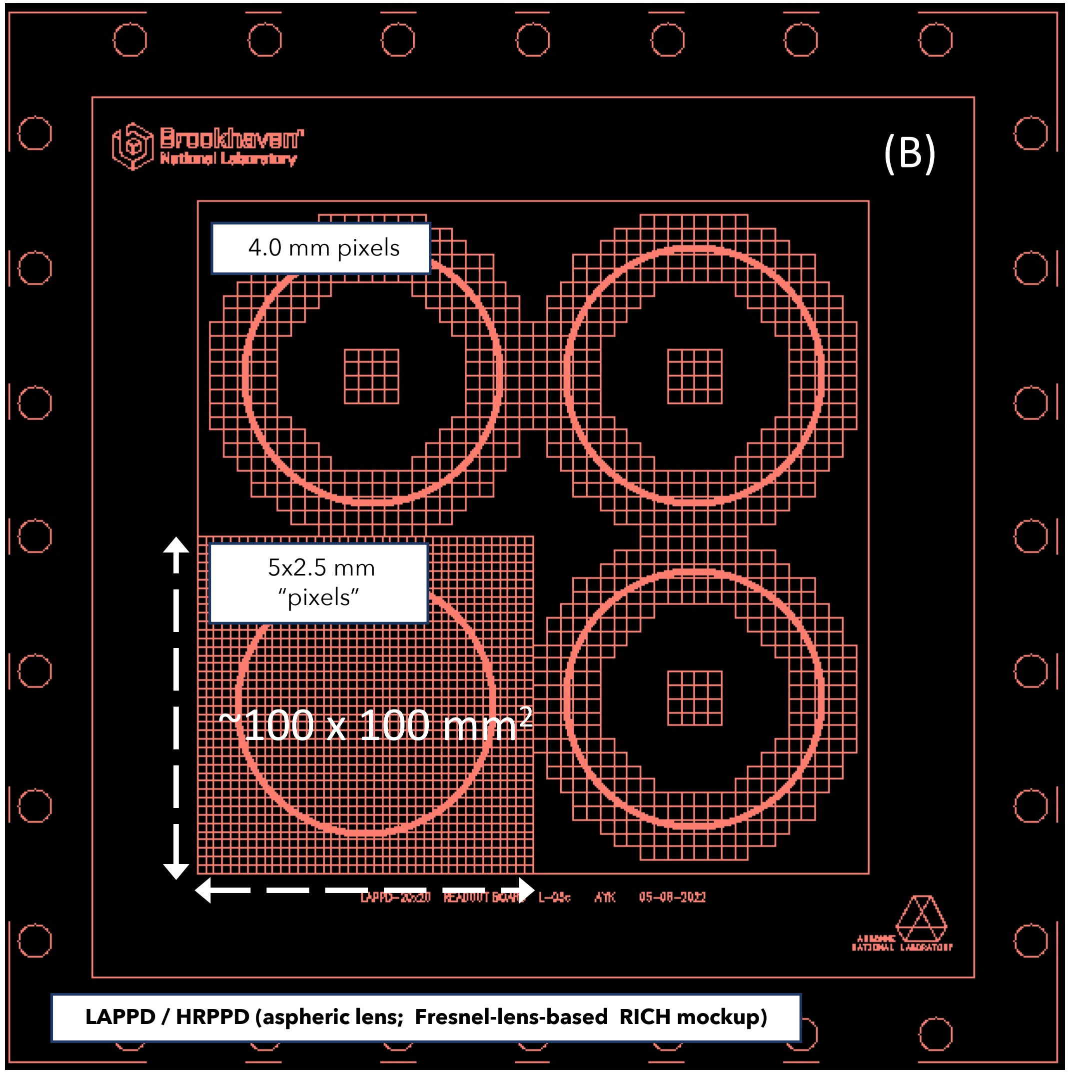
- A new 20cm Gen II LAPPD
  - New spacer configuration ☹
  - 10 μm pore MCPs
  - 2 mm thin ceramic base plate and short ceramic walls
  - Na_2KSb photocathode
  - Window material -> UV grade quartz
    - → Being sealed now; expected at BNL end of May
- 10cm Gen II HRPPD of a similar build (?)





June 2022 beam test: readout boards





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

LAPPD workshop series

https://indico.bnl.gov/event/15059/

75+ participants

LAPPD Workshop

Monday 21 Mar 2022, 08:00 → 12:00 America/New_York

Description Organizers: Silvia Dalla Torre (INFN), Alexander Kiselev (BNL), Deb Sankar Bhattacharya (INFN), Junqi Xie (ANL)

Hosted by CFNS: https://stonybrook.zoom.us/j/98025752609?pwd=WTlicTlwTmxkNE9wODlOZEx2NU1sUT09

Argonne National Laboratory · Brookhaven National Laboratory · INFN · Center for Frontiers in Nuclear Science

Incom Inc.: LAPPD overview, LAPPD Photocathode Development, HRPPD Development

Nalu Scientific: LAPPD Readout Plane - Modelling and Optimization, Digitizer ASIC options for LAPPD applications

		Speaker
8:00 AM → 8:10 AM	**Introduction**	Silvia Dalla Torre (INFN, Trieste)
8:10 AM → 8:30 AM	**LAPPD overview** (LAPPD Overview_S...)	Shawn Shin (Incom Inc.)
8:30 AM → 8:40 AM	**LAPPD Photocathode Development**	Alexey Lyashenko (Incom Inc.)
8:40 AM → 8:55 AM	**HRPPD Development** (2022-03-21 Foley H...)	Michael Foley (Incom Inc.)
8:55 AM → 9:15 AM	**LAPPD R&D effort at INFN Bologna**	Vincenzo Vagnoni (INFN Bologna)
9:15 AM → 9:30 AM	**LAPPD R&D effort at BNL**	Alexander Kiselev (BNL)
9:30 AM → 9:50 AM	**LAPPD R&D effort at IJS Ljubljana**	Rok Pestotnik (IJS)
9:50 AM → 10:00 AM	**A short break**	
10:00 AM → 10:20 AM	**LAPPD R&D effort at Argonne**	Junqi Xie (ANL)
10:20 AM → 10:35 AM	**Cherenkov and scintillation separation in water-based liquid scintillator**	Ed Callaghan (UC Berkeley)
10:35 AM → 10:50 AM	**LAPPDs in ANNIE: from test bench to a full experiment**	Matthew Wetstein (Iowa State University)
10:50 AM → 11:15 AM	**LAPPD Readout Plane - Modelling and Optimization** (Nalu-Incom-HFAD-S...)	Luca Macchiarulo (Nalu Scientific)
11:15 AM → 11:30 AM	**Digitizer ASIC options for LAPPD applications**	Isar Mostafanezhad (Nalu Scientific)
11:30 AM → 12:00 PM	**Discussion, ad hoc contributions, future plans, closing remarks**	