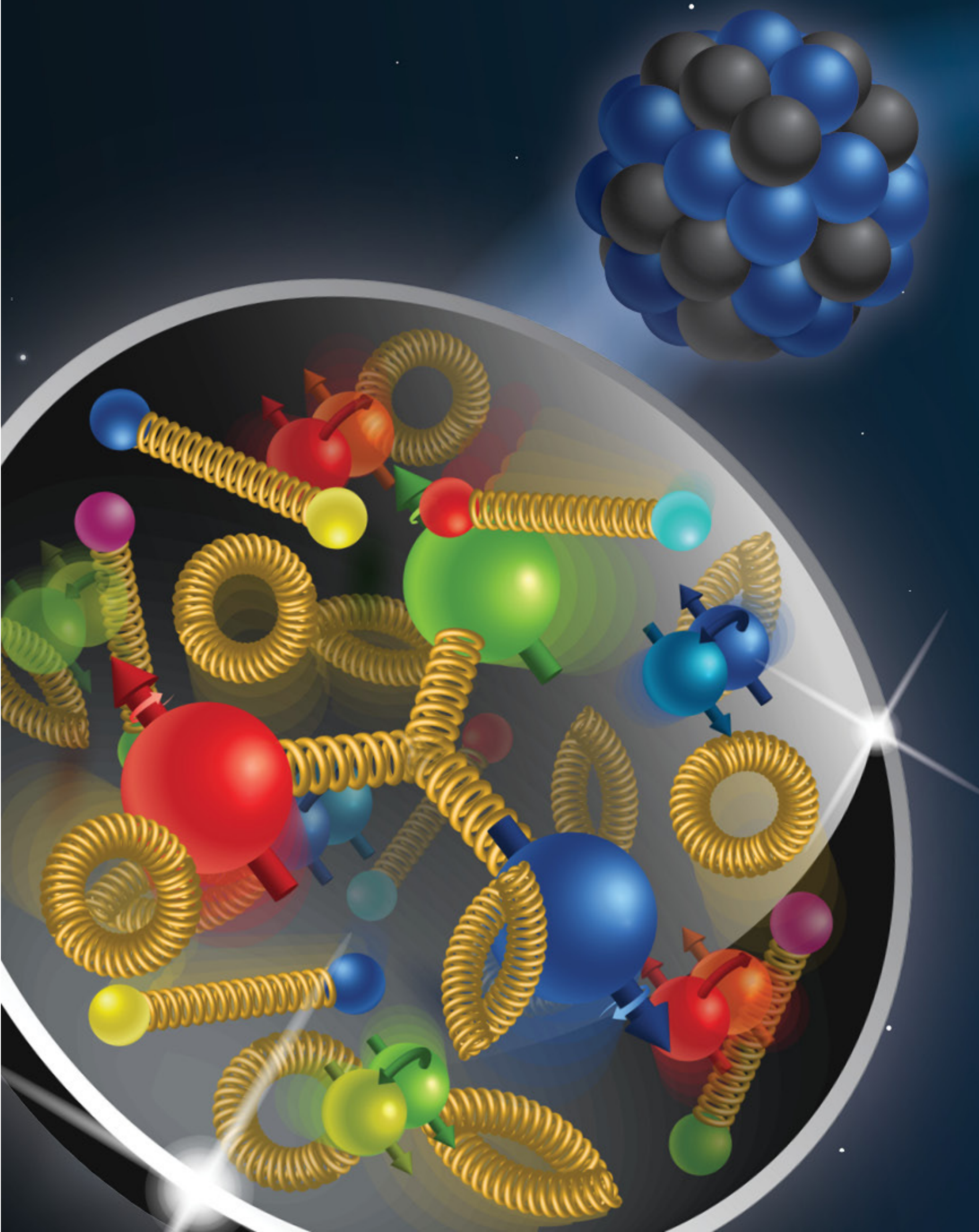


Readout and sensor status: LAPPD / HRPPD

Alexander Kiselev, BNL

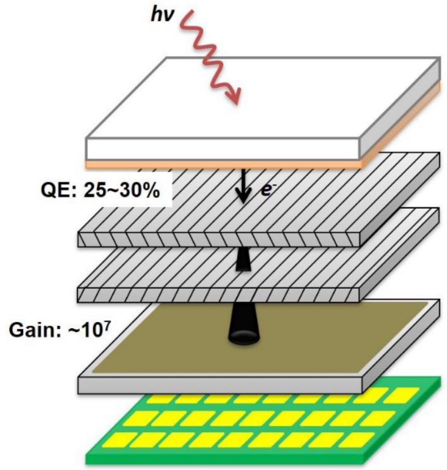
EIC Project Detector PID Review

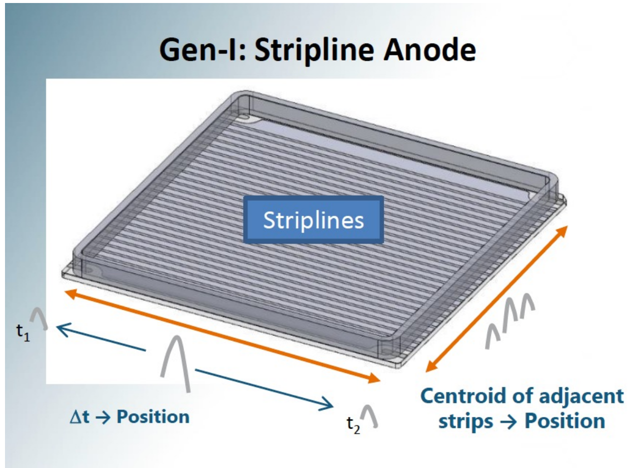
July 5-6, 2023

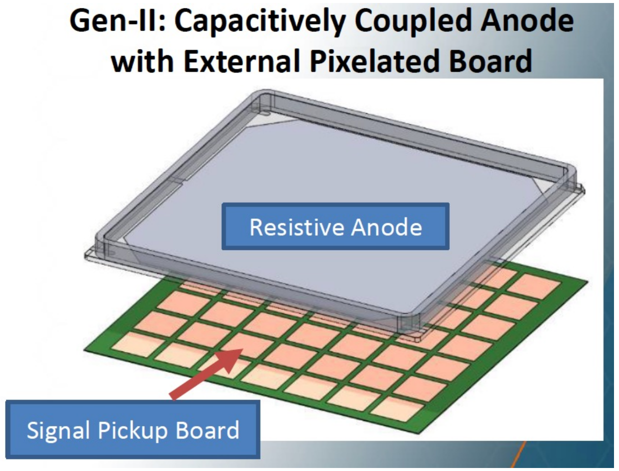
Electron-Ion Collider

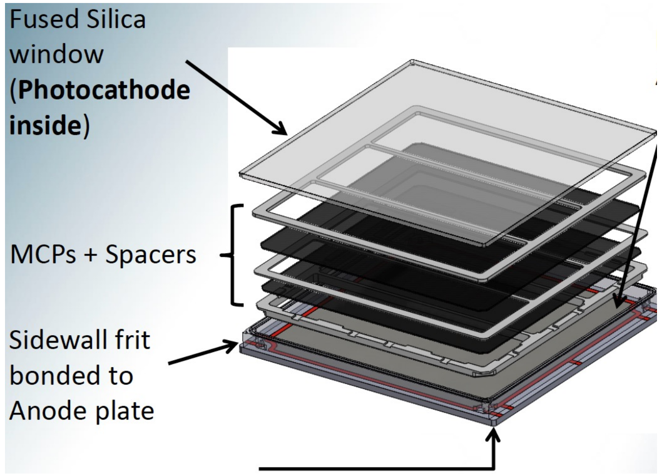
Brookhaven National Laboratory · Jefferson Lab · U.S. Department of Energy Office of Science

LAPPD / HRPPD by Incom Inc.



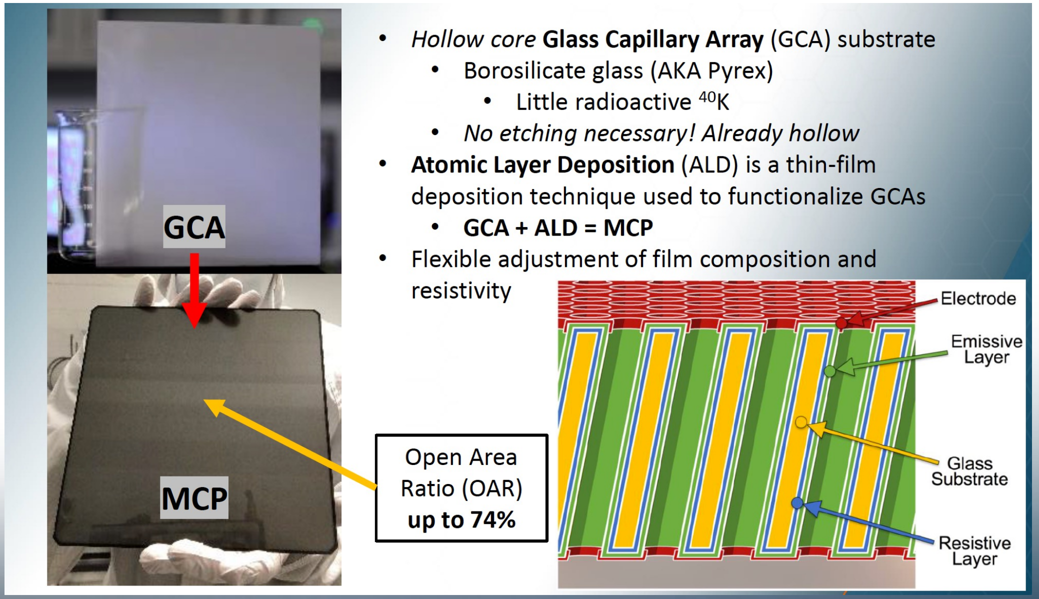






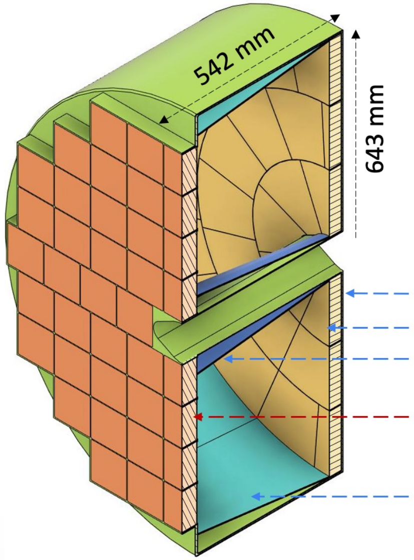
Gen II variety

- An affordable large area (finely pixelated) vacuum photosensor
- 10x10 cm^2 or 20x20 cm^2 active area
- 10 μm or 20 μm pore MCPs
- DC- (Gen I) or capacitively (Gen II) coupled species
- Either DC-coupled 1D strips or 2D pixellation
- Expected to be (very) cost efficient in mass production
- Quantum efficiency above 30% and uniform high gain up to ~10^7
- Sub-mm spatial resolution for finely pixelated tiles
- Single-photon timing resolution on a ~50 ps level or higher

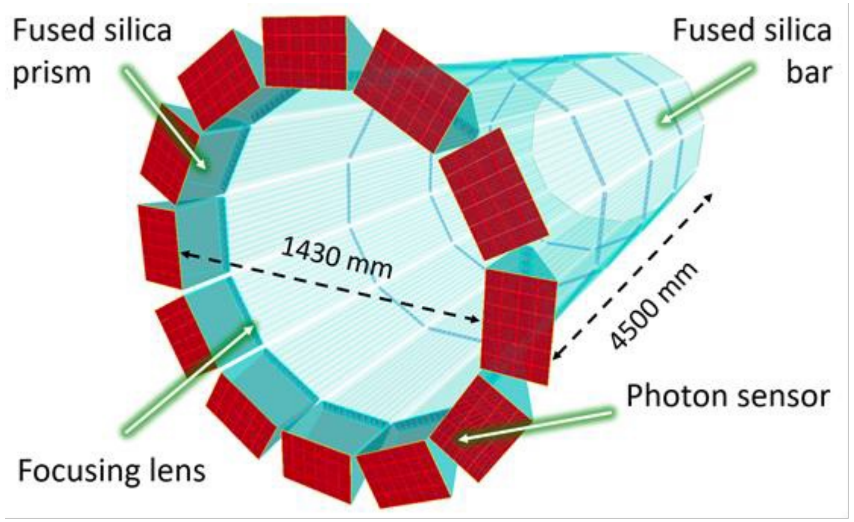


LAPPD / HRPPD for EIC

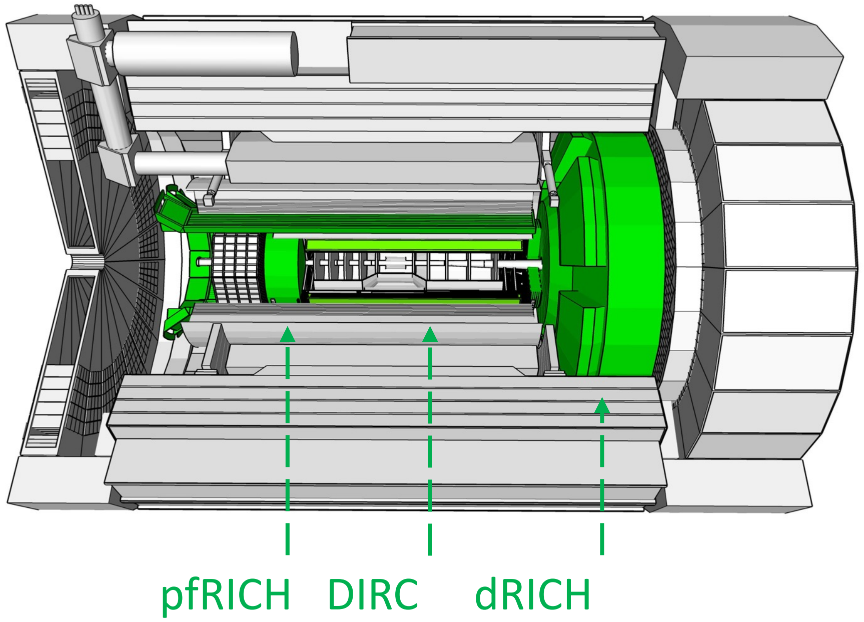
- Backward RICH: low dark noise, ToF capability (vs SiPMs)
- DIRC: expected to be more cost-efficient (vs other MCP-PMTs)
- dRICH: problematic, because of the magnetic field orientation



pfRICH: 68 HRPPDs total



DIRC: 12*3*2 = 72 HRPPDs total



Focus so far was on the pfRICH application, where HRPPDs were a baseline photosensor choice from the very beginning

	pfRICH	DIRC
Spatial resolution	Sub-mm	Sub-mm
SPE timing resolution	σ of the core part <50ps	<75ps RMS, including tail
Dark count rate	Few kHz/cm^2 is acceptable	Few kHz/cm^2 is acceptable
Occupancy	Small: can work with large Gen II clusters	Large: require one SPE – one hit

ePIC choice: DC- or capacitively coupled sensors?

Capacitively coupled (Gen II)

- Pros
  - Most of our experience is based on Gen II LAPPDs
  - Flexibility in the readout board design
- Cons
  - Broad clusters -> occupancy, overlaps, etc
  - Resistive layer -> additional R&D topic
  - Somewhat smaller cluster amplitudes

DC-coupled

- Pros
  - Single pad hits -> better for timing
  - Same design for pfRICH & DIRC
- Cons
  - Missing interface to the readout board
  - Performance yet to be verified
  - Spatial resolution limited by pitch/$\sqrt{12}$

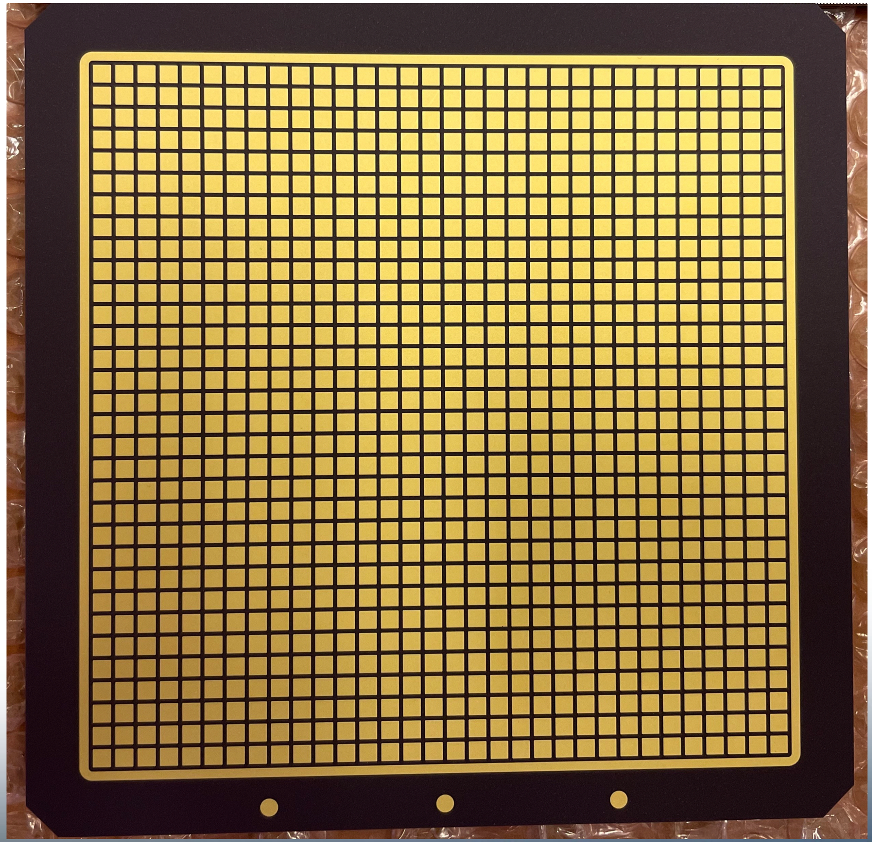
The rest of the talk is focused on DC-coupled HRPPDs

-> see backup slides 18-22 for the highlights of Gen II LAPPD evaluation

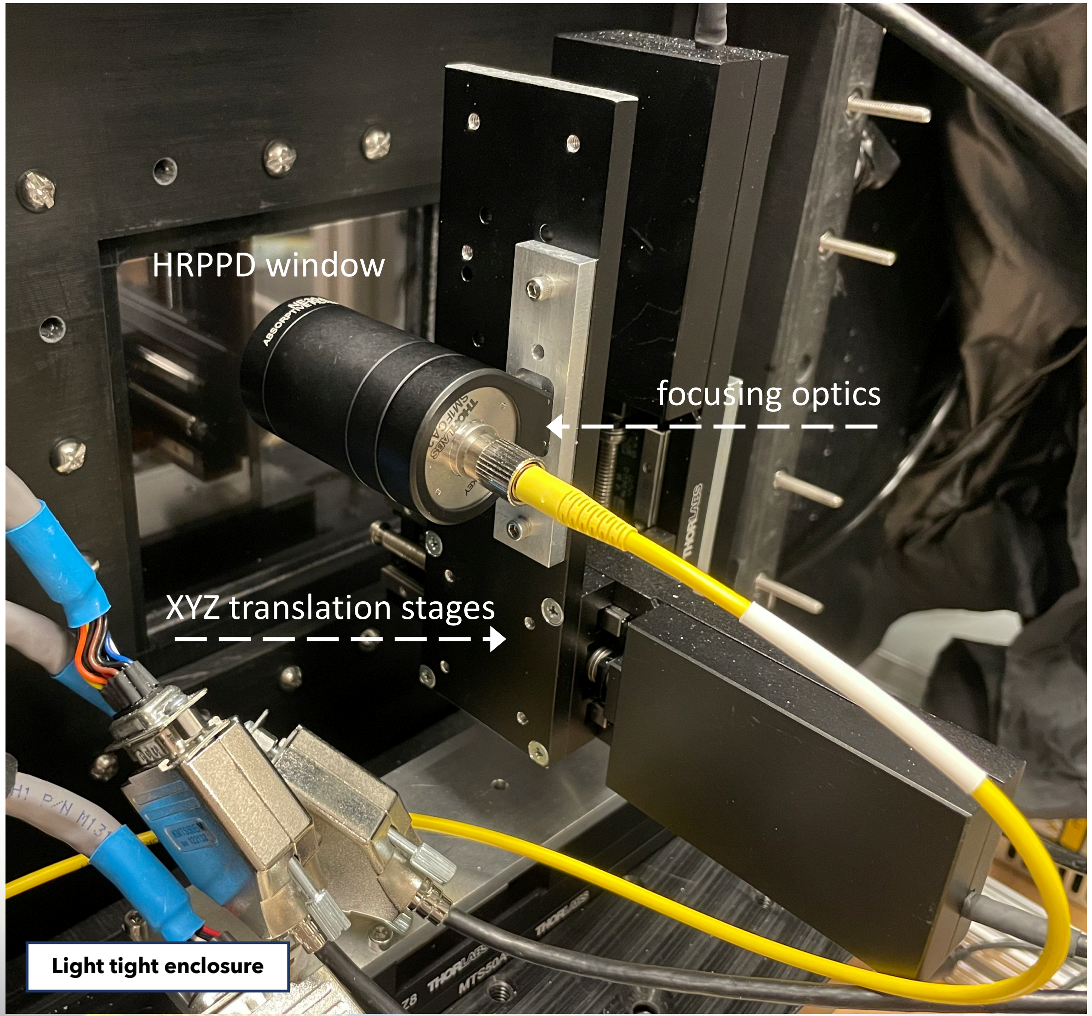
HRPPD photosensor

- ~120 x 120 mm^2 footprint; ~70% unobscured active area
- 1024 pads, hermetic through vias, 1/8” (~3.2 mm) pitch
- ~15mm thick stackup (window, side walls, base plate)

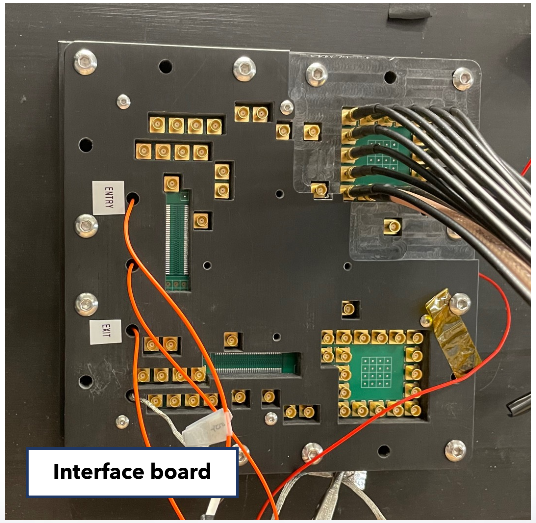
For EIC we want to increase the active area fraction to 75-80%, and make integrated [sensor + ASIC board] assemblies fully tile-able without gaps

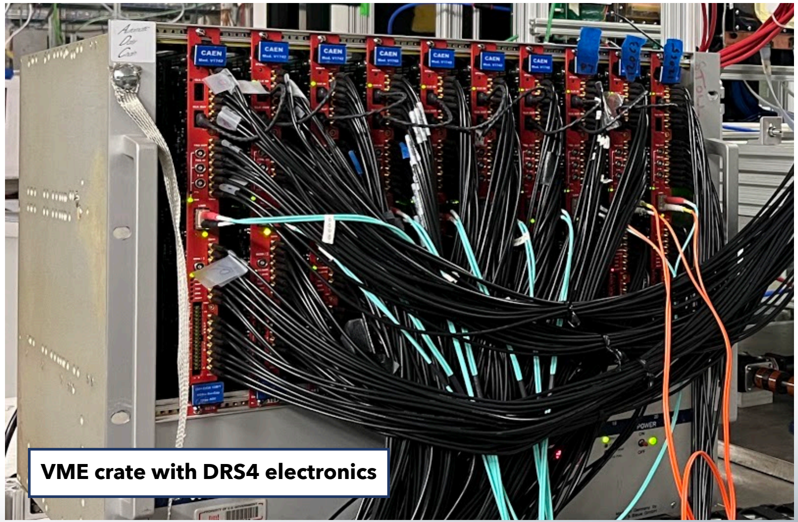


HRPPD test stand at Brookhaven



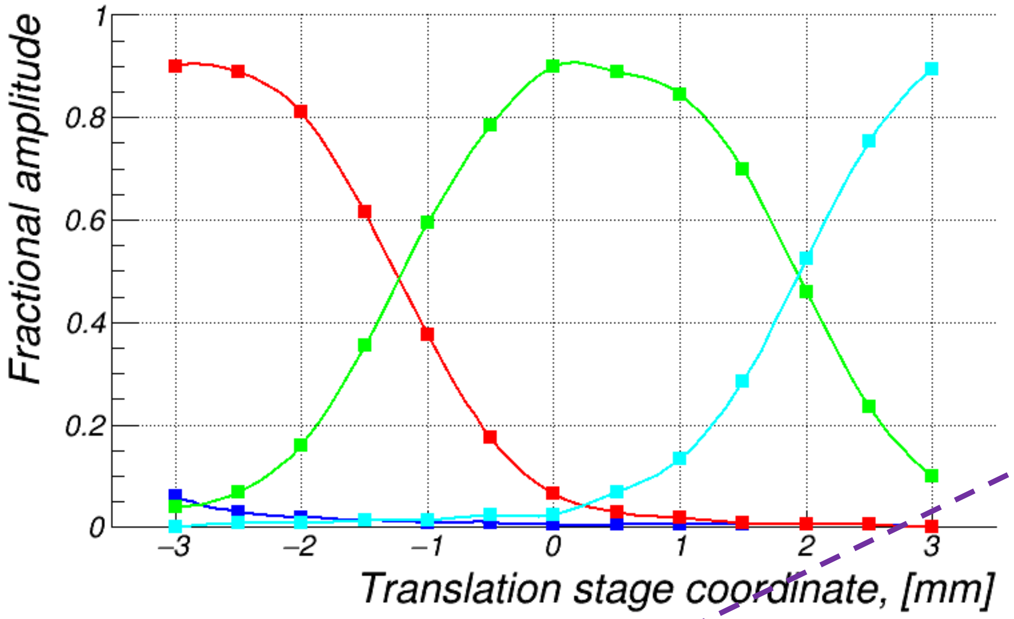
- Picosecond PiLas laser
- Compact light-tight enclosure
- 512 DRS4 channels (V1742 digitizers)
- Readout board with a pogo pin interface
  - About 1/3 of 1024 pads can be instrumented
  - MCX and high-density Samtec connector interface to DRS4

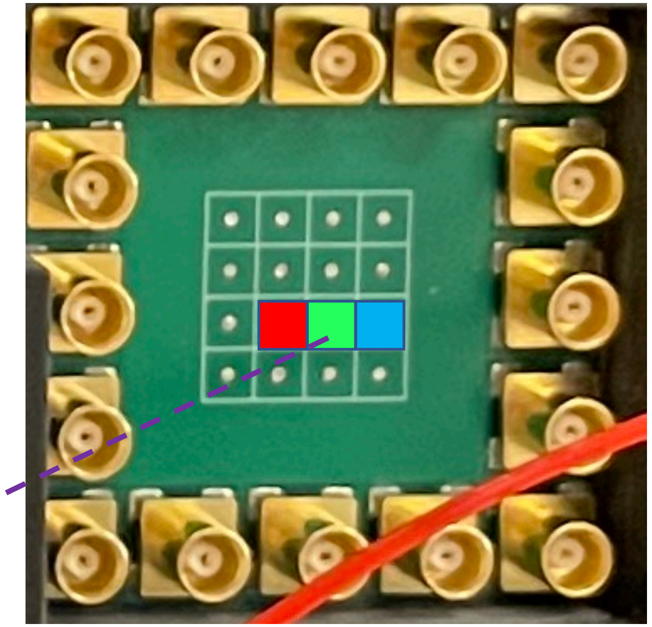




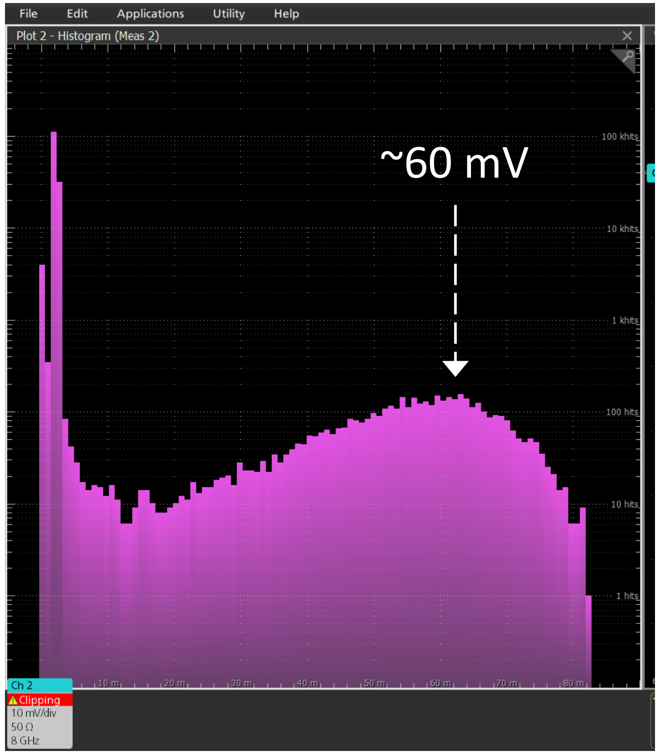
Similar setups exist at Argonne, INFN Trieste & Glasgow, however they are all oriented on capacitively coupled LAPPDs, and typically, have only up to 32 channels of DRS4 electronics

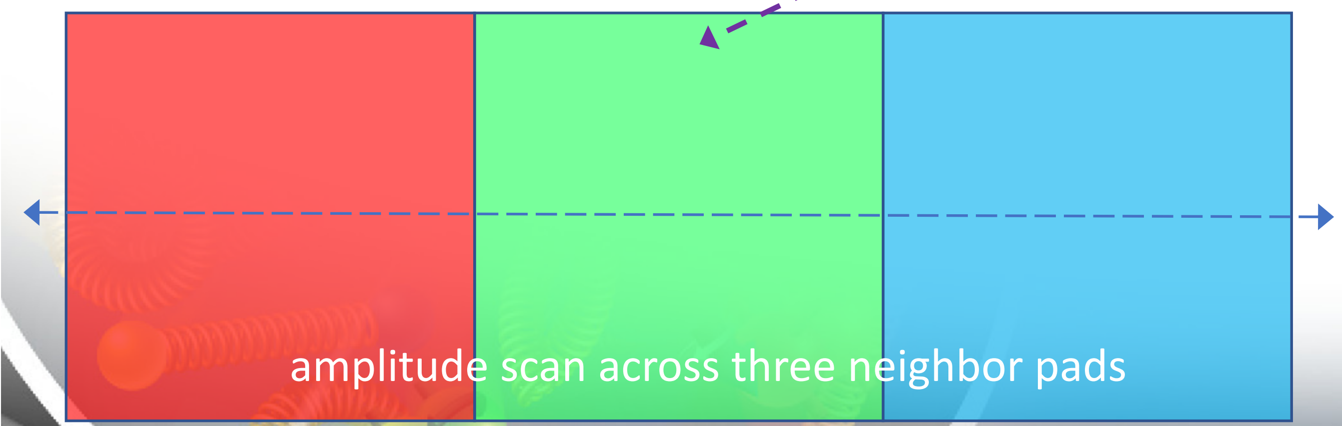
Charge sharing & spatial resolution





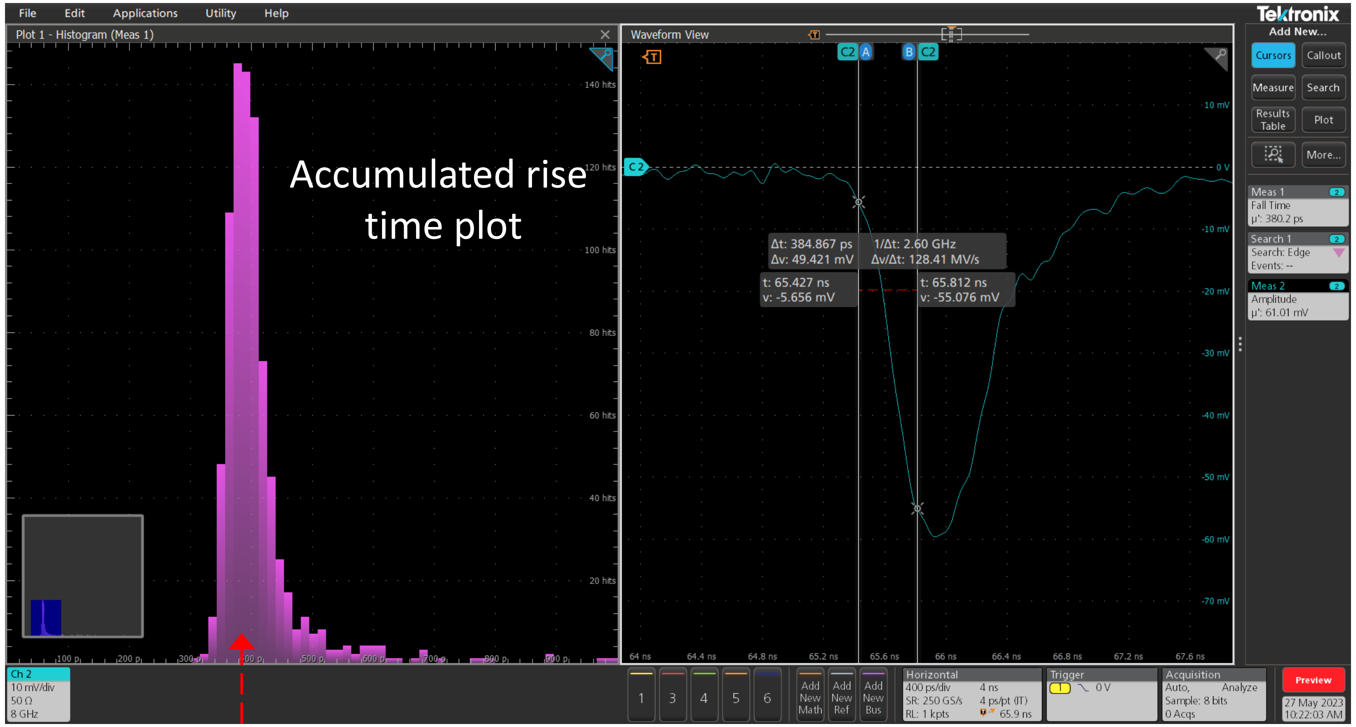
Amplitude spectrum on a scope



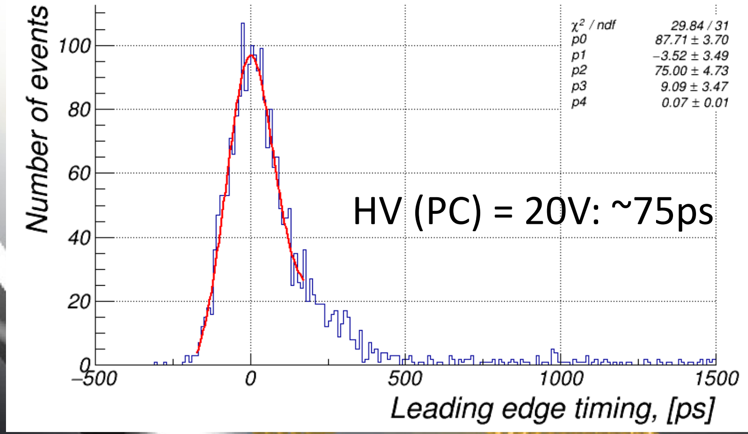


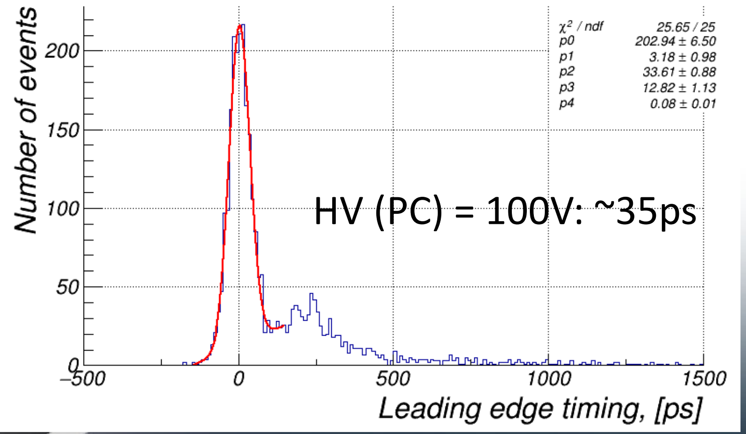
- Healthy ~60 mV signals
- Moderate charge sharing (no B field)
  - Was shown to be very small in a ~1T field

Single photon timing resolution

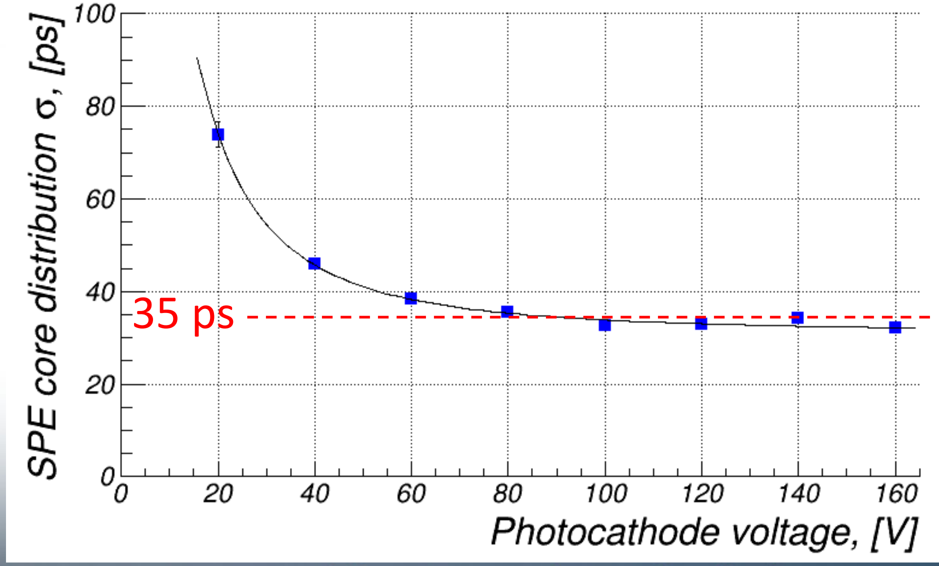


Leading edge: ~400 ps avg

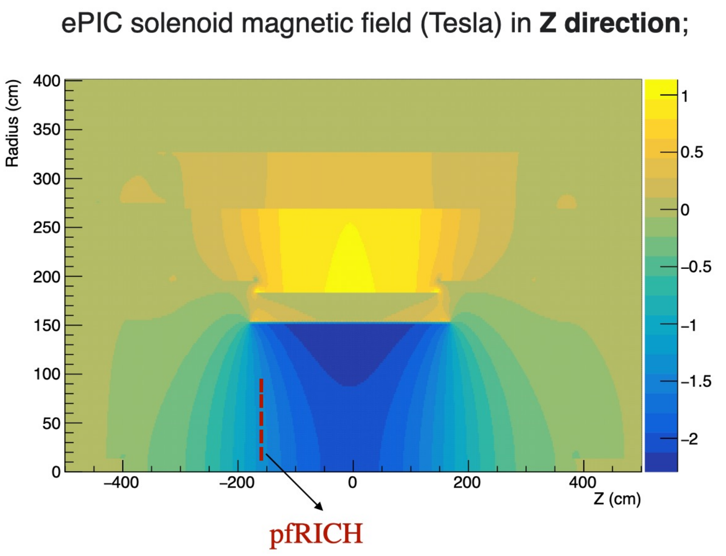


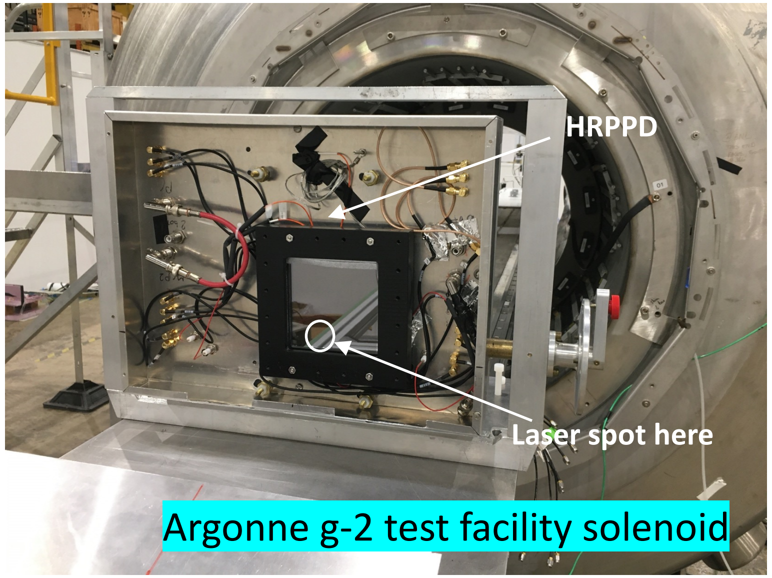


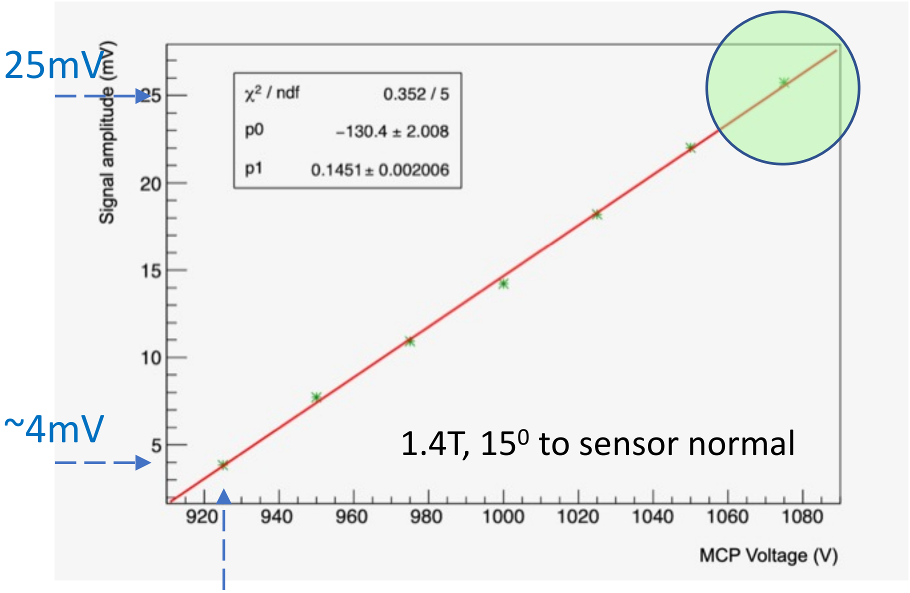
- Laser focused to a pad center
- Intensity tuned down to ~95% empty events
- Δt data taken with a V1742 DRS4 module
  - Channel #0 – HRPPD pulse
  - Channel #1 – laser synchro pulse
- *Neither laser pulse width nor other instrumental effects unfolded*



Resilience to the magnetic field







- In ePIC pfRICH HRPPDs will be exposed to a magnetic field of ~1.4 Tesla at an angle up to 13 degrees
  - ePIC hpDIRC: ~0.3 T at up to ~35 degrees
- Tests of a HRPPD prototype in a high magnetic field were carried out by Argonne and Incom using g-2 calibration solenoid in February 2023

Preliminary conclusion: gain in this high magnetic field can be fully restored by increasing HV from 925V to ~1075V

EIC-Incom PED contract

- Came as a result of the EIC leadership team visiting Incom facility in Charlton MA in January 2023
- Signed by both Incom & JLAB last week

- Two phases foreseen

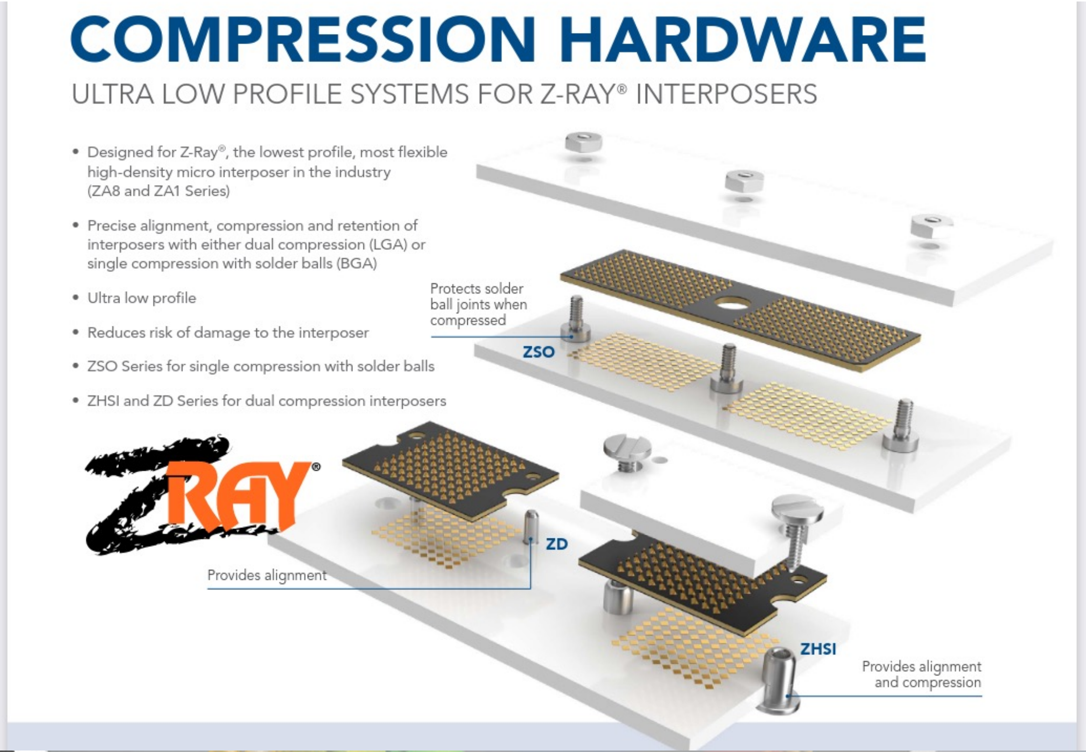
Phase	Milestone
#1: finalize the HRPPD design details for the first EIC-oriented production	September 2023
#2: produce five HRPPDs for a thorough evaluation by EIC groups	March 2024

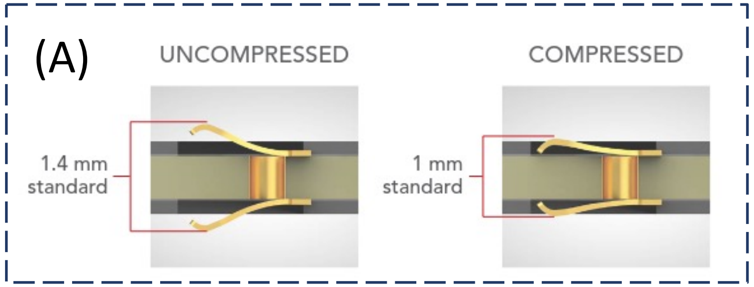
-> see pre-brief materials for technical specifications

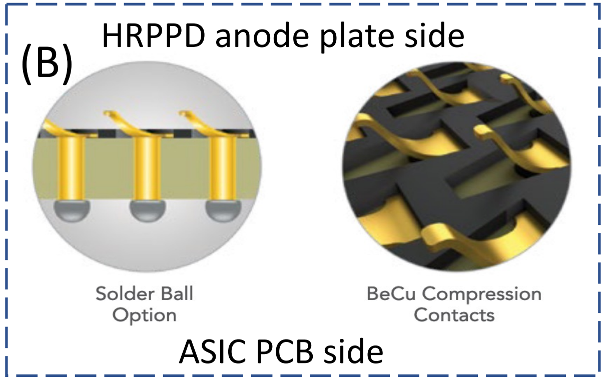
De facto a joint BNL-Incom effort aligned with the Phase #1 objectives was ongoing since January 2023 (see next slides)

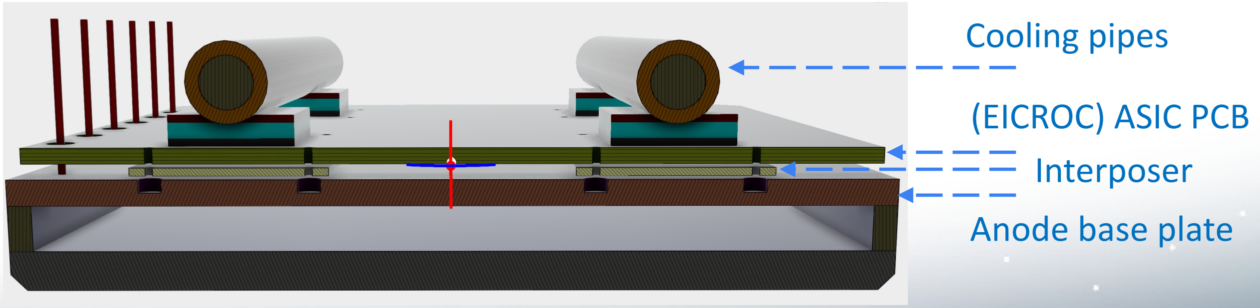
Anode base plate design and ASIC board interface

- Custom pixelated LTCC anode base plates
  - Samtec compression interposers as a lead interconnect option
  - Fallback solution: conductive epoxy screen printing





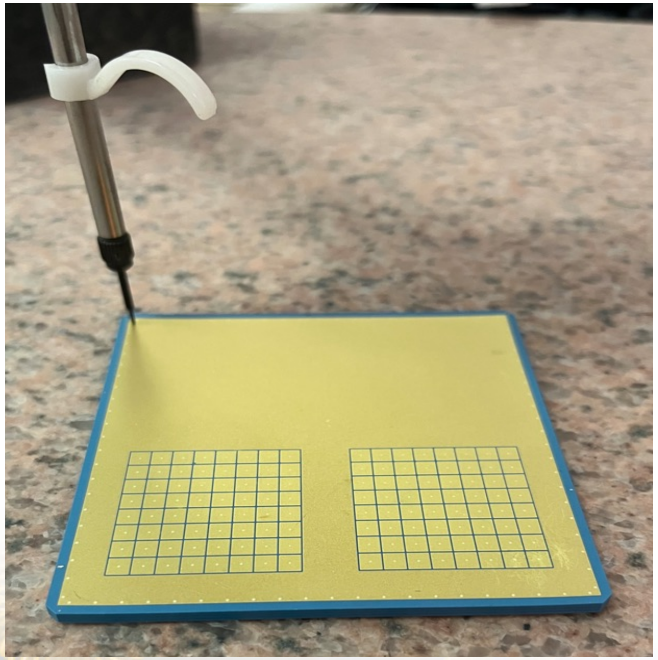


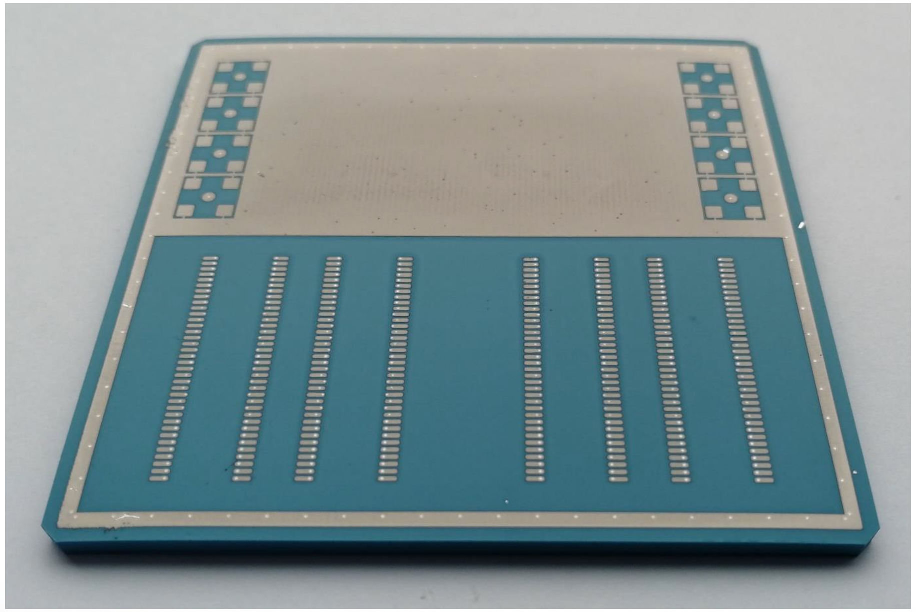


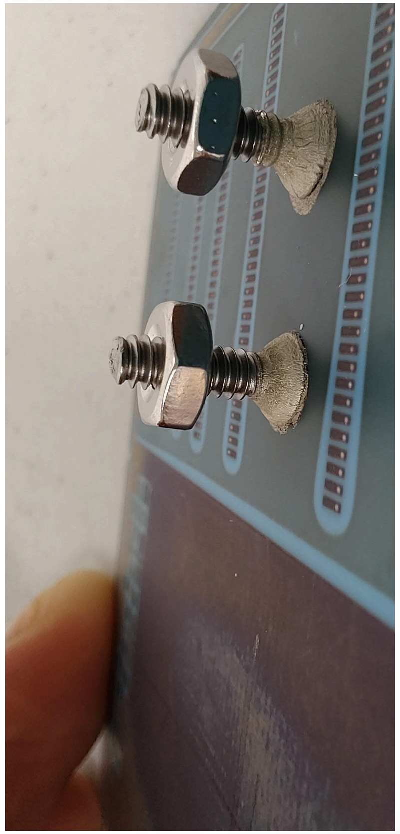
HRPPD face down

Small size prototypes by Techtra (Poland)

- Two 3” LTCC anode plates were examined at Incom
  - Flatness is tolerable on a 3.0mm thick plate
  - Vacuum tightness of the 3.0 mm thick plate confirmed


flatness check on the inner side

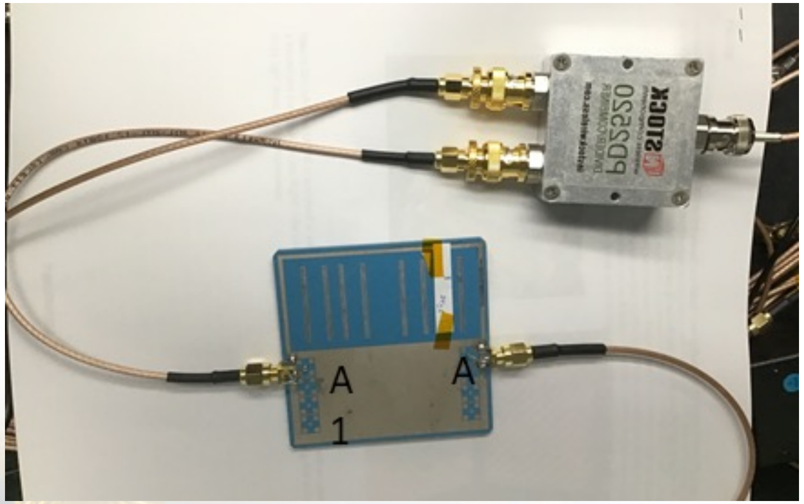

outer (connector) side

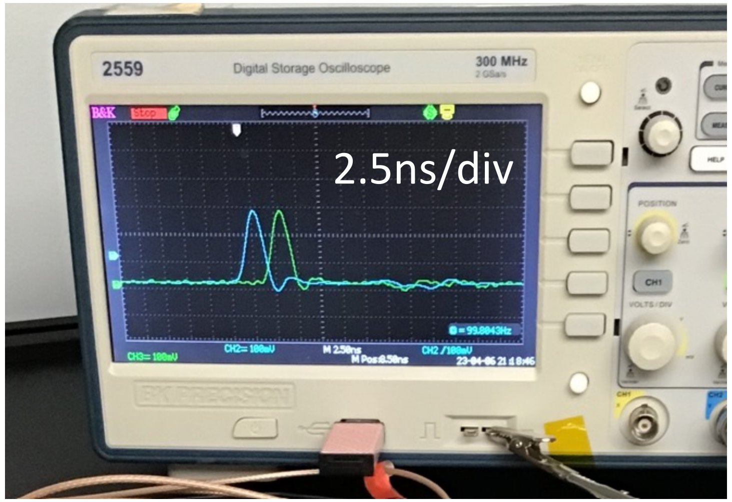

brazed screws

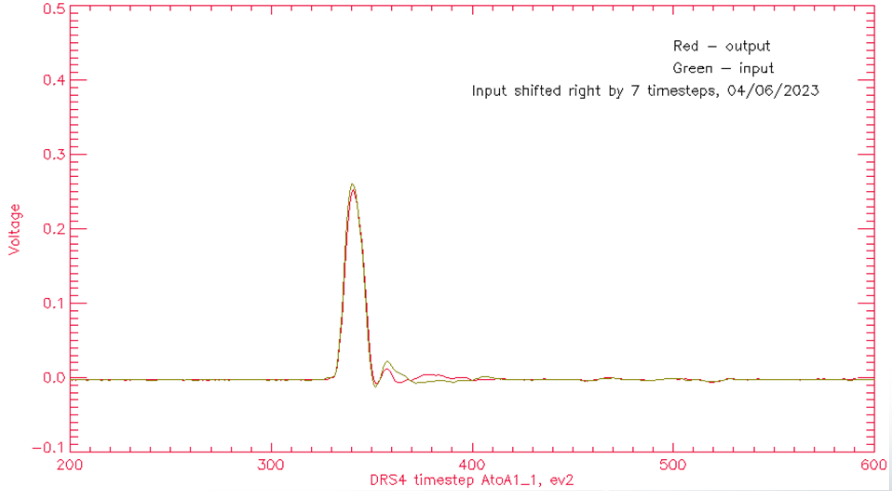
vacuum tightness check

Small size prototypes by Techtra (Poland)

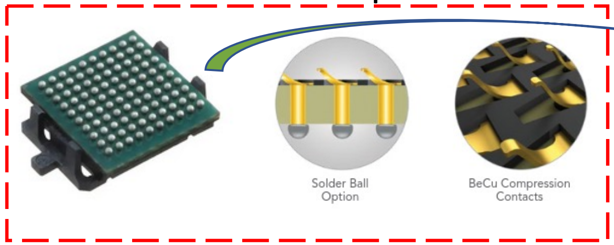
- Two 3” LTCC anode plates were examined at Incom
  - No measurable cross-talk introduced in the ceramic stack
    - 50 Ohm impedance matched isolated coplanar waveguide trace configuration
  - Small trace capacitance (<2pF/cm) confirmed
  - Signal degradation confirmed to be marginal, and only on very long (6cm) traces

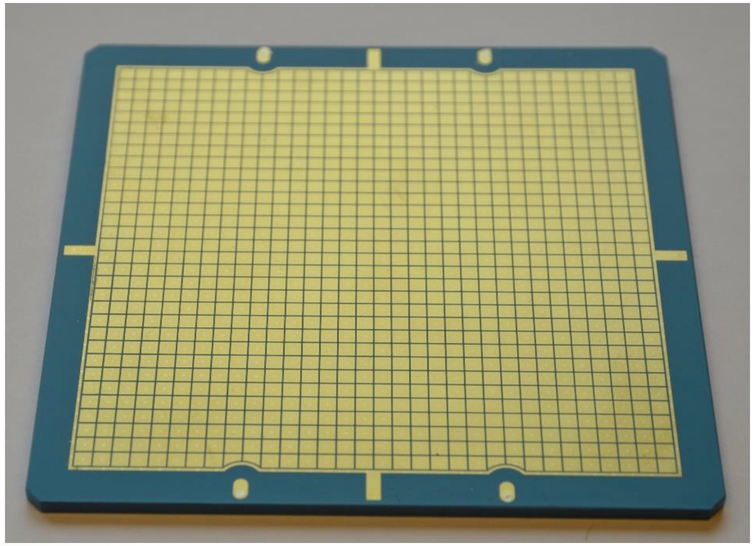




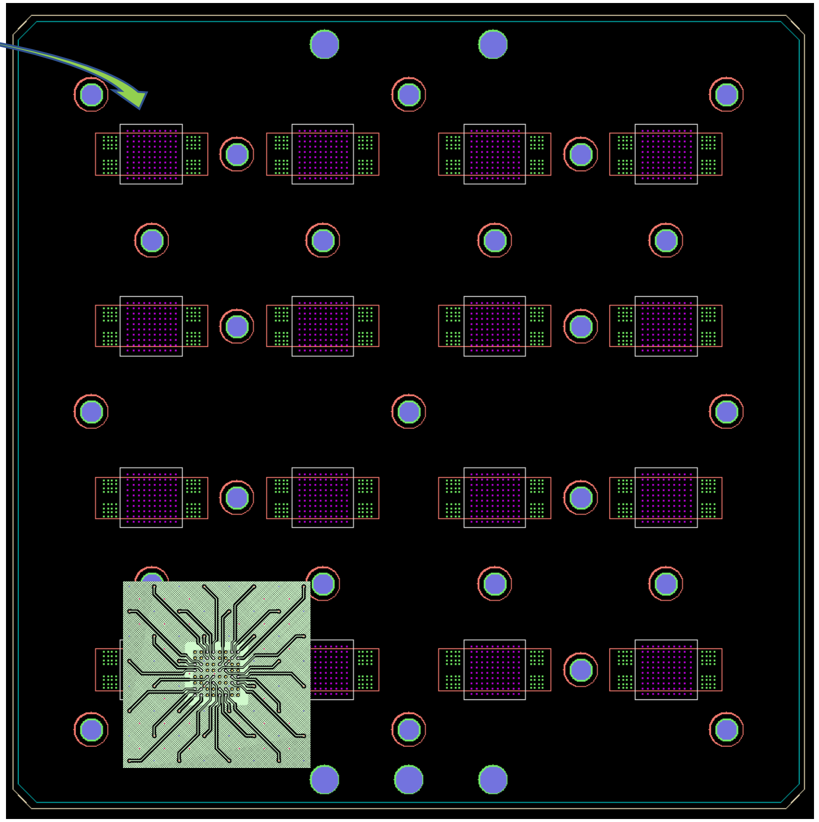


Full size prototype by Techtra (Poland)

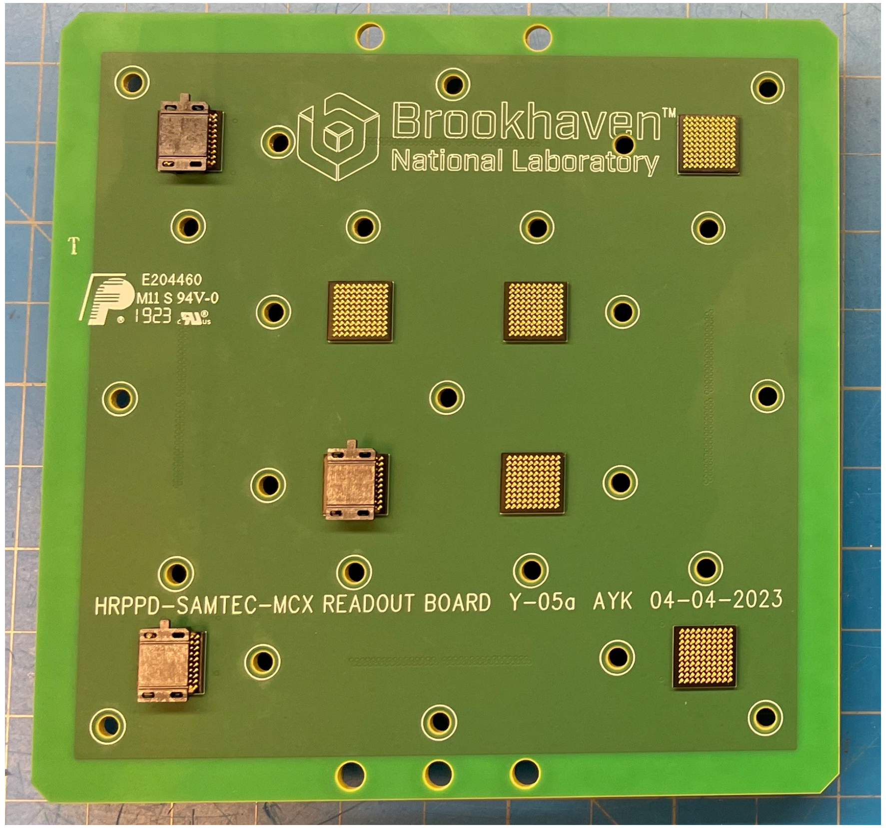




Inner side of a 32x32 pad ceramic 120mm base plate



Outer side overlaid with a HGCROC PCB template



A "simple connectivity" PCB (Samtec interposers on the front side & MCX + high density connectors on the rear side)

- Integration TODO list between now and September:
  - Optimize screw layout (as well as overall count & material)
  - Increase pitch on the outer side; order custom interposers
  - Build a functional HRPPD tile (even that this first plate had several shorts)

The first five EIC tiles will be built by Kyocera (Japan)

Electron-Ion Collider

eRD110 (photosensors) FY24 R&D proposal

EIC Project R&D milestones & timeline

eRD110 (photosensors)

- Establish production readiness of a LAPPD/HRPPD-based photon-sensor readout for a Ring-Imaging Cherenkov Detector on the electron-side end cap of the EIC detector, including validation by prototype beam tests. [September 2024]

- Focus on evaluation of the first five EIC HRPPDs by Incom
  - HRPPD mechanical / electrical interface matching the new formfactor
    - Ship new tiles to EIC groups in this standardized package
  - Lab evaluation as of late Fall 2023 (also using a new femtosecond laser at BNL)
    - At Argonne, BNL, INFN Trieste / Genova, Glasgow & Yale
  - Beam test at Fermilab in early 2023 with a subset of the produced tiles
  - Magnetic field resilience measurements at Argonne and in Italy
  - pfRICH prototype test at Fermilab in May-June 2024 with HRPPD sensor plane

Summary

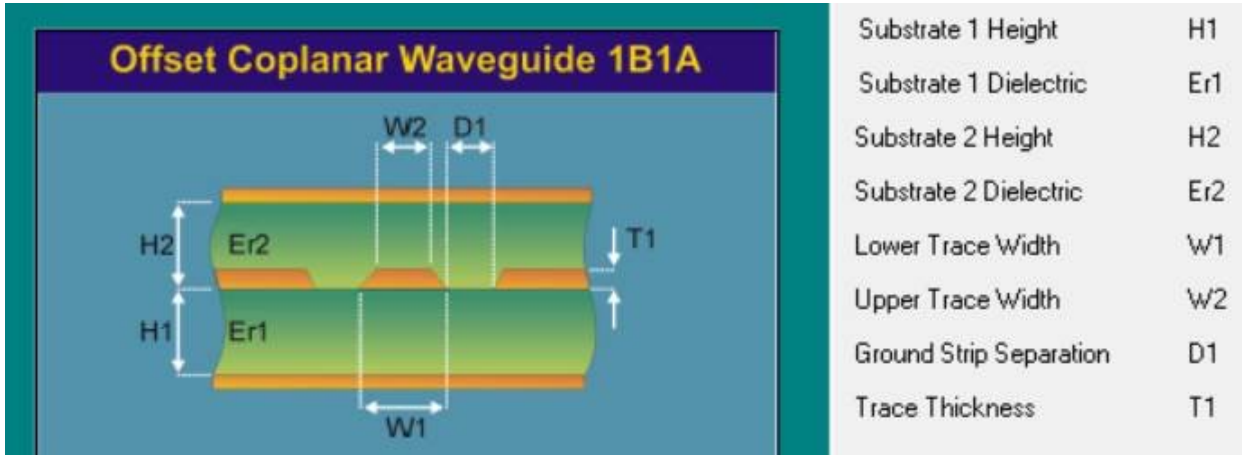
- HRPPD is a baseline photosensor for pfRICH and DIRC
  - DIRC application may require additional R&D to meet timing requirements

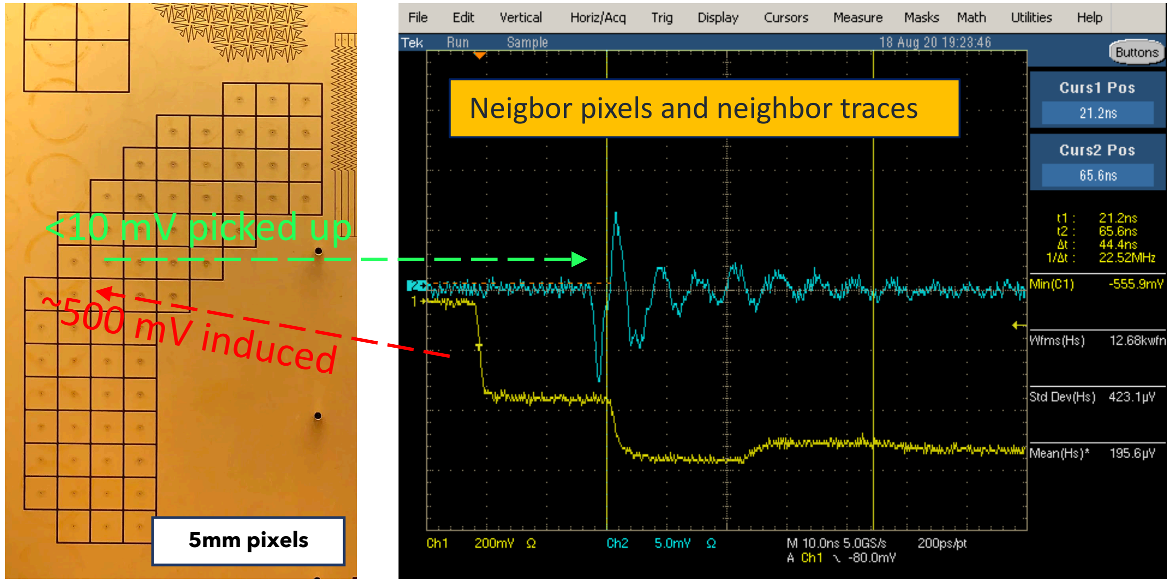
- EIC – Incom PED contract is being placed
  - Custom photosensor design for EIC
  - First five HRPPDs to become available by early spring 2024

- eRD110 R&D consortium activities between now and FDR in Fall 2024 will be focused on evaluation of the first five EIC HRPPDs and fine tuning of the sensor design, working closely with the manufacturer
  - Lab evaluation
  - Beam tests, including a full chain pfRICH prototype test with HRPPD sensor plane
  - Magnetic field resilience studies

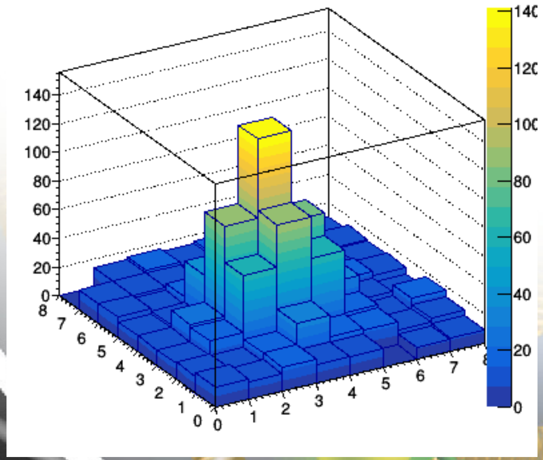
Backup

Gen II LAPPDs: PCB design, cluster size

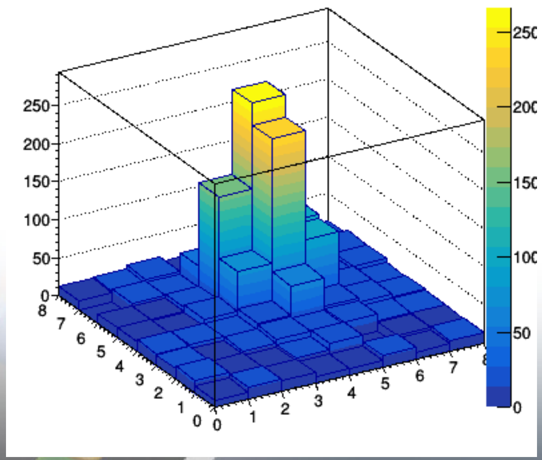




3mm pixels



6mm pixels

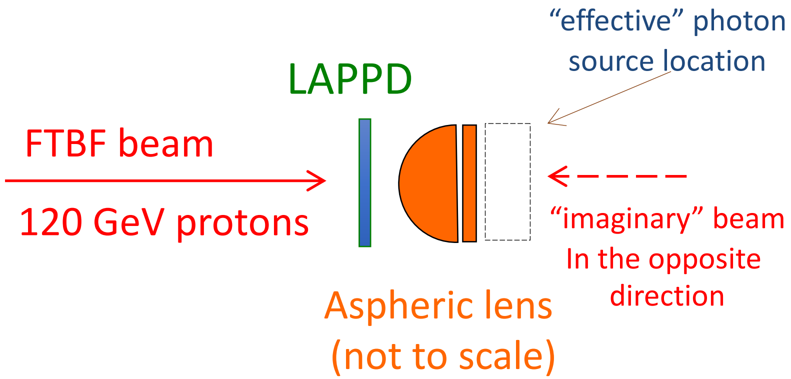


Single photon events

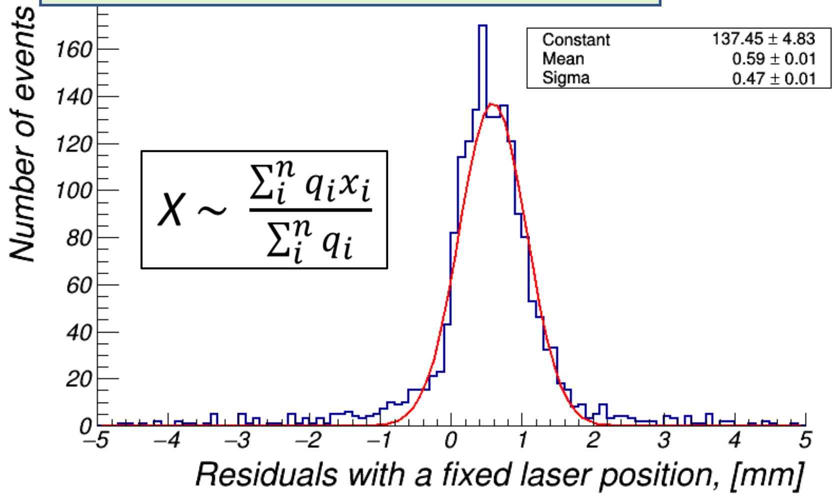
- "Standard" LAPPD stack, 2mm thick anode base plate: cluster size RMS ~3.5mm
- Multi-layer PCB stack-up can be used
- Worst case X-talk ~few % level

Gen II LAPPDs: spatial resolution

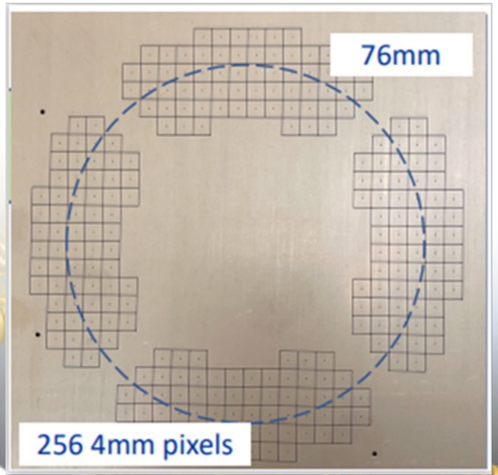
Sub-mm level, using 3..6 mm pads



3mm square pixels: σ ~500 μm

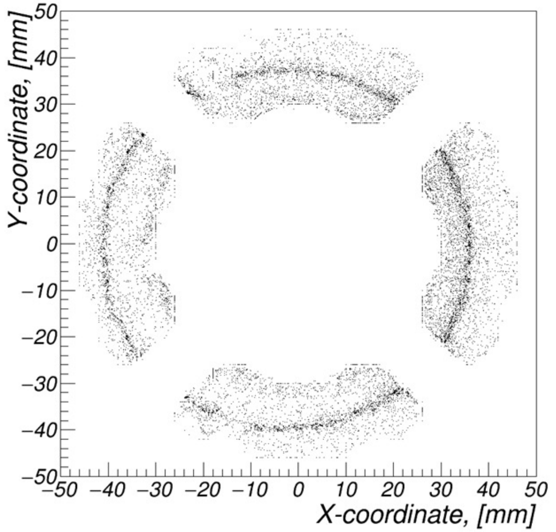


Lab results with a laser

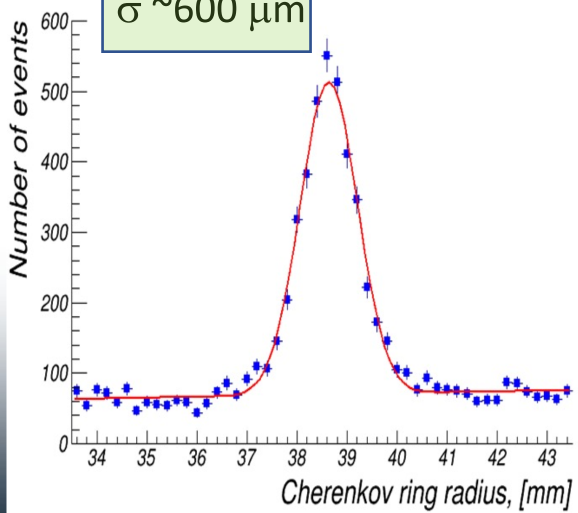


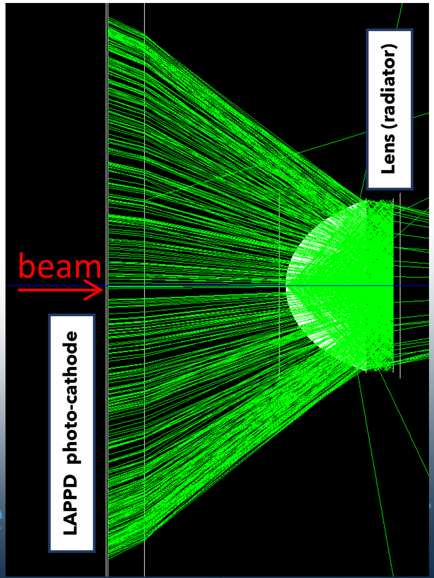
PCB pad layout

accumulated over several events



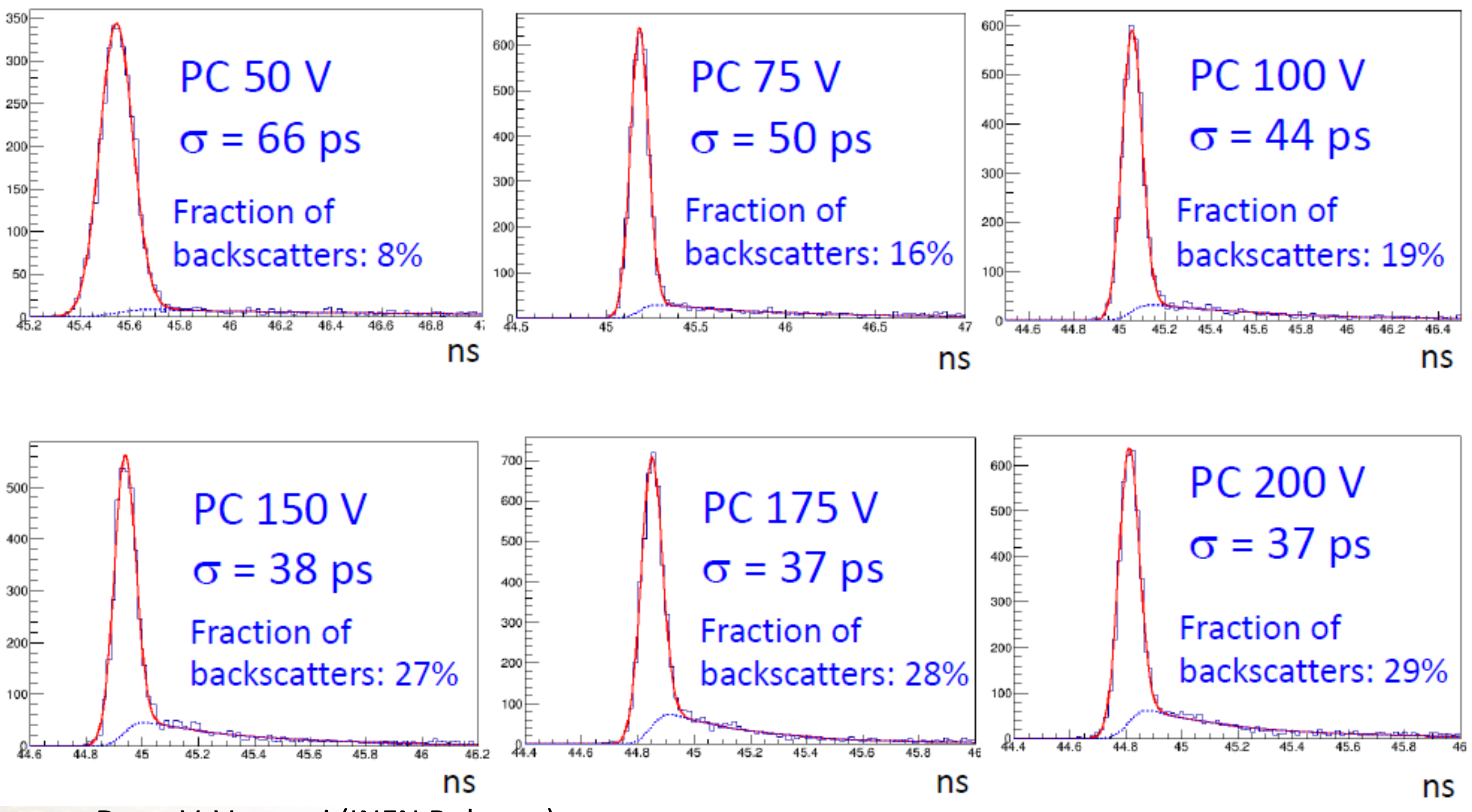
σ ~600 μm



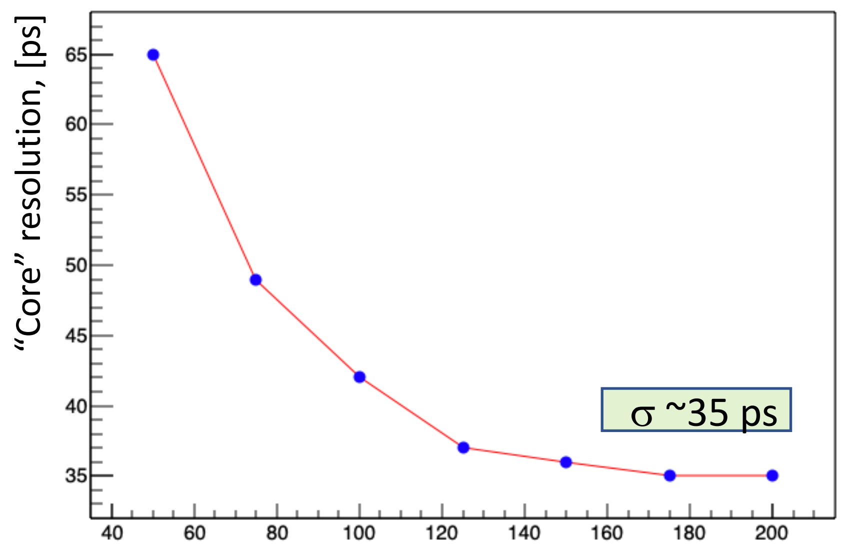


Fermilab beam data

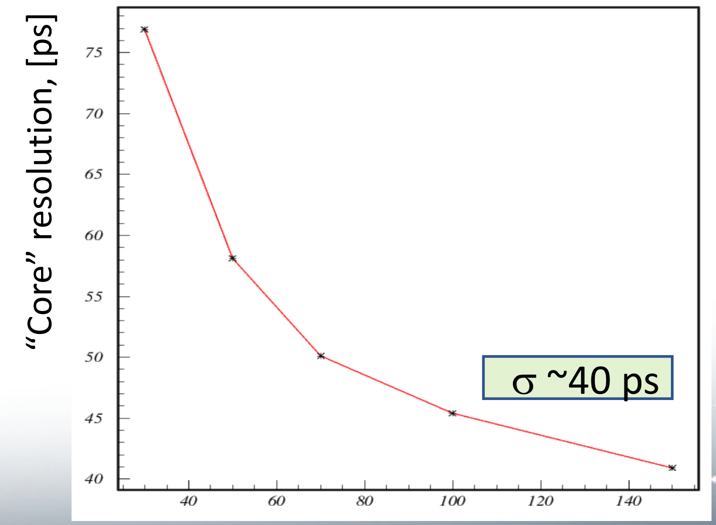
Gen II LAPPDs: SPE timing resolution



Data: V. Vagnoni (INFN Bologna)



Data: V. Vagnoni (INFN Bologna)



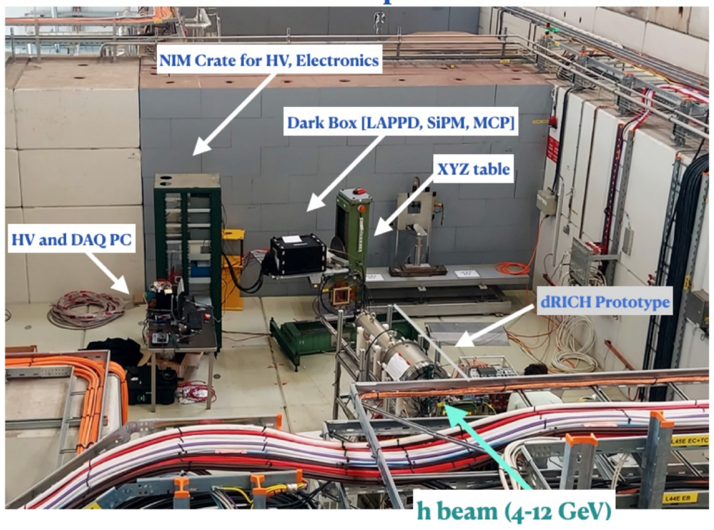
Data: S. Korpar (IJS)

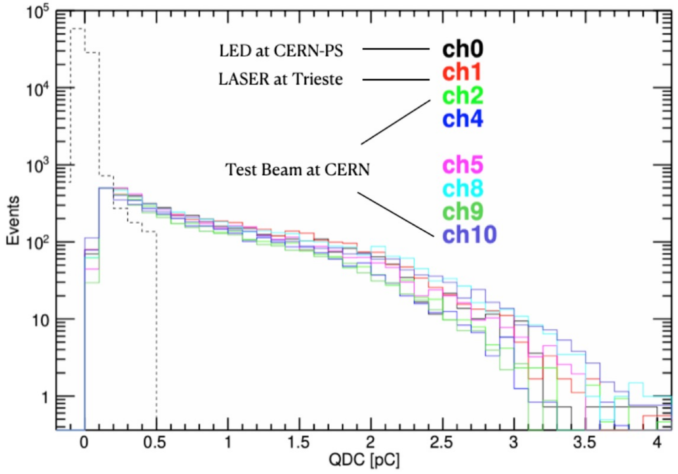
- Can be optimized for either high resolution core and longer tail (RICH with a timing capability) or more conservative resolution but smaller overall RMS (DIRC)

Lab data taken with a picosecond laser, 25mm pads

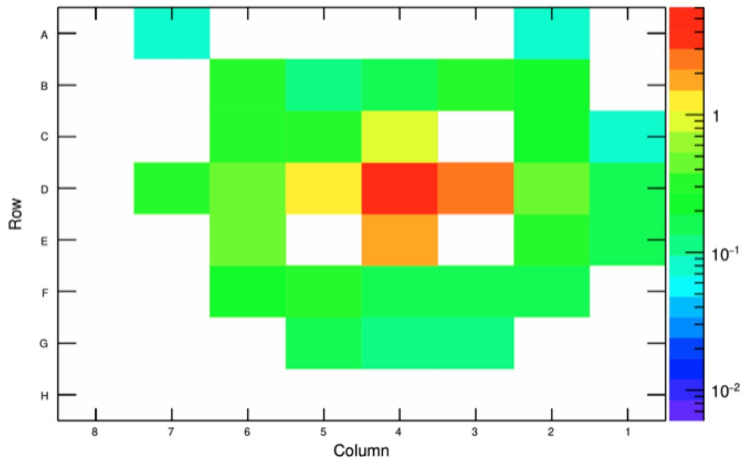
Gen II LAPPDs: SPE timing resolution

First Beam Test of LAPPD in parasitic mode at CERN-PS

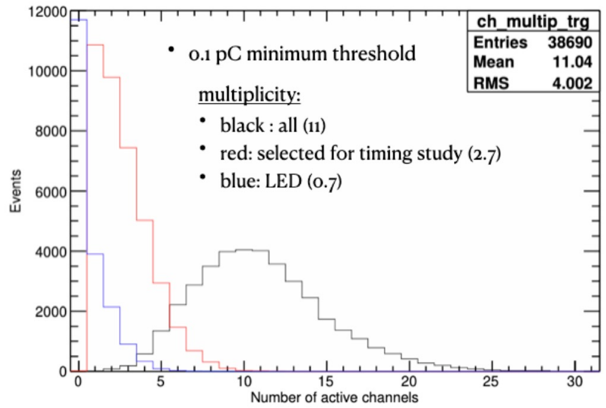




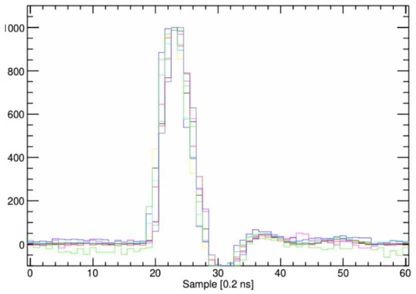
- Primary charge-spectra calibration in SPE is performed.



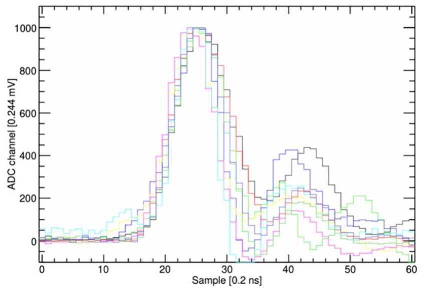
- Average charge collected in the Ring is lower that the SPE .



- Central Pad was flooded
- Only 24% of the hits were selected for timing

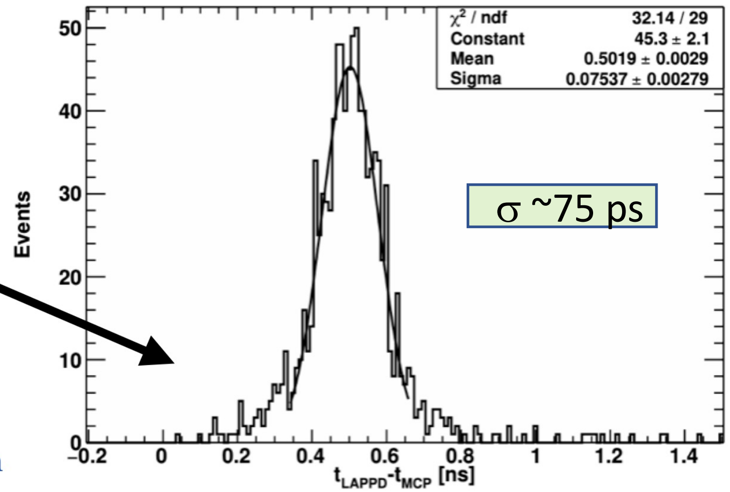


- Digitised MCP signal



- Digitised LAPPD signal

- The time difference is fitted by a Gaussian within 2σ
- The mean of 0.5 ns agrees with a preliminary GEAN4 simulation
- The obtained σ varies within 80-130 ps, within <10 ps error
- The best resolution found in Channel 2 is 75 +-3 ps



- Timing difference between channel 2 and MCP

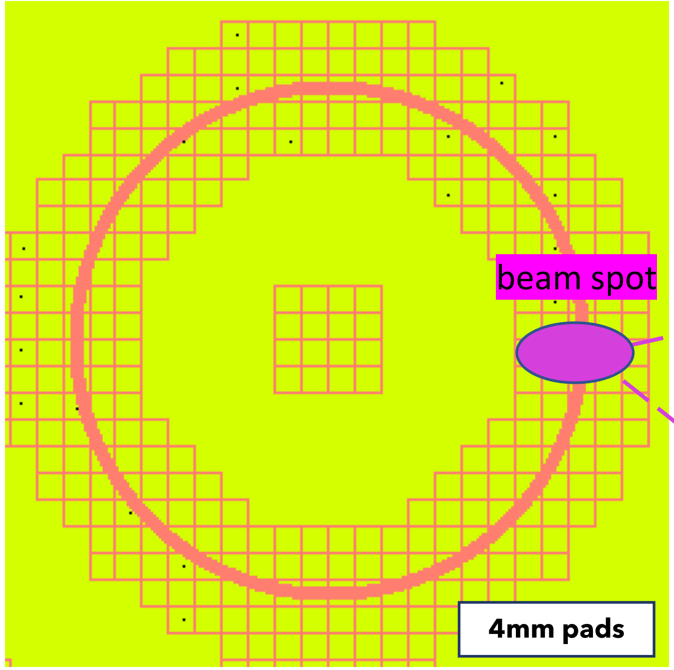
Data: M. Osipenko (INFN Genova)

Electron-Ion Collider

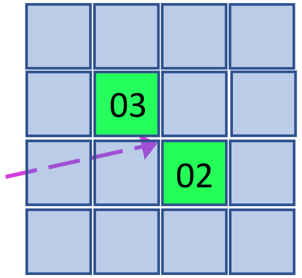
Test beam at CERN-PS (INFN Trieste / Genova & Co), 25mm pads

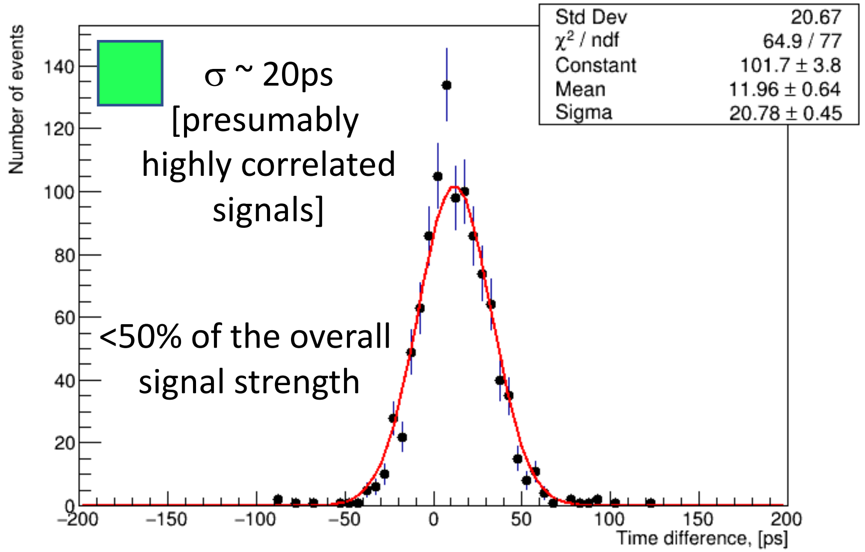
Gen II LAPPDs: Timing resolution for TOF applications

LAPPD quartz window as a Cherenkov radiator



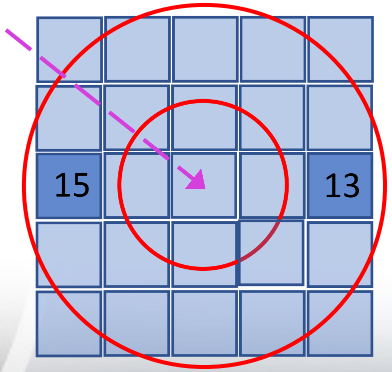
Event selection (A)

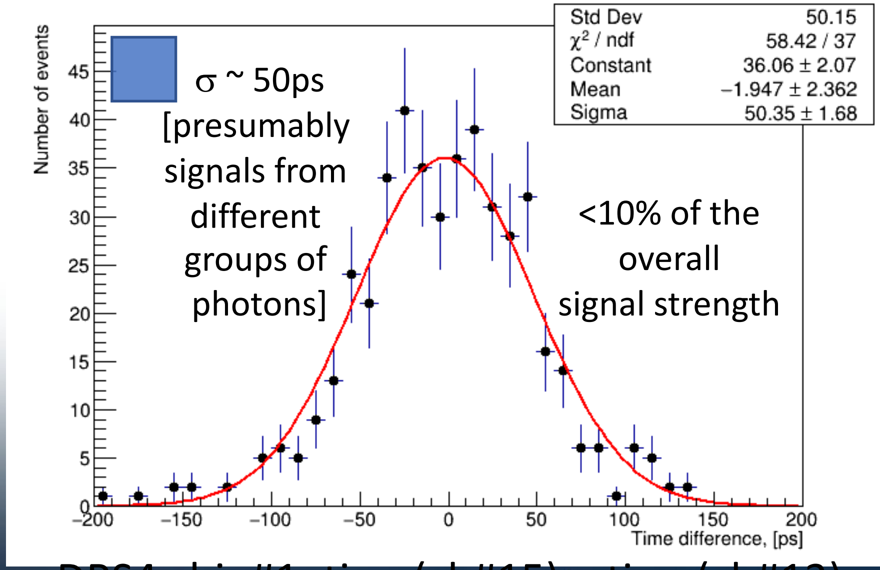




DRS4 chip#0: time(ch#03) – time(ch#02)

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

Fermilab test beam (BNL, Argonne & Co), 4mm pads