eRD110: Photosensors (HRPPDs, LAPPDs, other MCP-PMTs)

Alexander Kiselev (BNL)

EIC Project R&D Detector Advisory Committee meeting, August 31, 2023

Outline of the presentation

- Introduction

- FY23 report
  - LAPPD beam test at CERN
  - HRPPD interface / integration effort
  - LAPPD / HRPPD magnetic field resilience measurements at Argonne
  - HRPPD timing resolution studies in the lab

- FY24 proposal
  - Comprehensive performance evaluation of the new EIC HRPPDs
  - HRPPD ageing studies
  - Beam test(s) at Fermilab
  - Photek and Photonis MCP-PMT evaluation
  - Deliverables, milestones, budget request

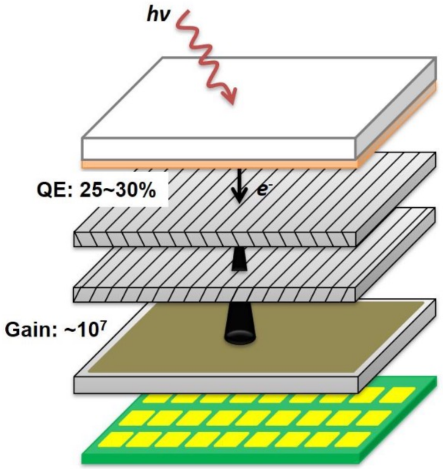
- Summary

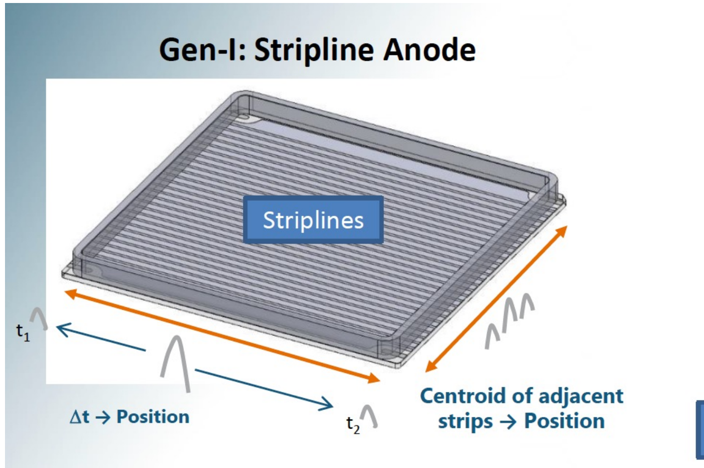
Participating institutions / people

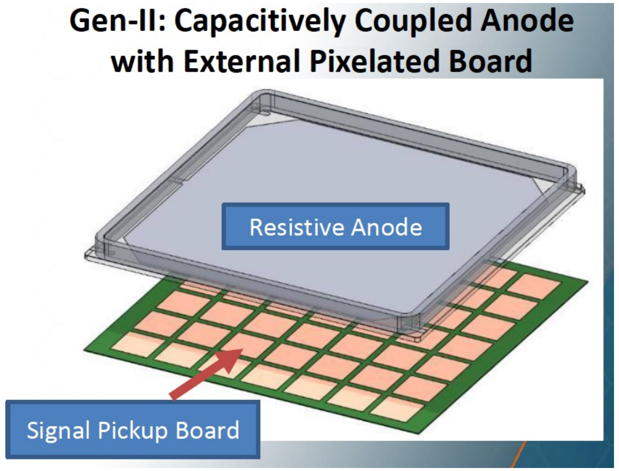
Argonne Lab	J. Xie
Brookhaven Lab	B. Azmoun, D. Cacace, A. Kiselev, M. Purschke, C. Woody
Catholic University of America	G. Kalicy
CNRS/IN2P3 (OMEGA group)	C. De La Taille, P. Dinaucourt, D. Thienpont
Debrecen University	M. Czeller, G. Nagy
Erlangen University	A. Lehmann
GSI	C. Schwarz, J. Schwiening
INFN Genova	M. Osipenko, S. Minutoli
INFN Trieste	D.S. Bhattacharya, S. Dalla Torre, C. Chatterjee, F. Tessarotto
Oak Ridge Lab	N. Novitzky
Stony Brook University	T.K. Hemmick, P. Nadel-Turonski
Jefferson Lab	J. McKisson, S. Park, C. Zorn
University of Glasgow	B. Seitz, R. Montgomery, F. Thomson
University of South Carolina	Y. Ilieva
Yale University	H. Caines, P. Garg, L. Havener, N. Smirnov

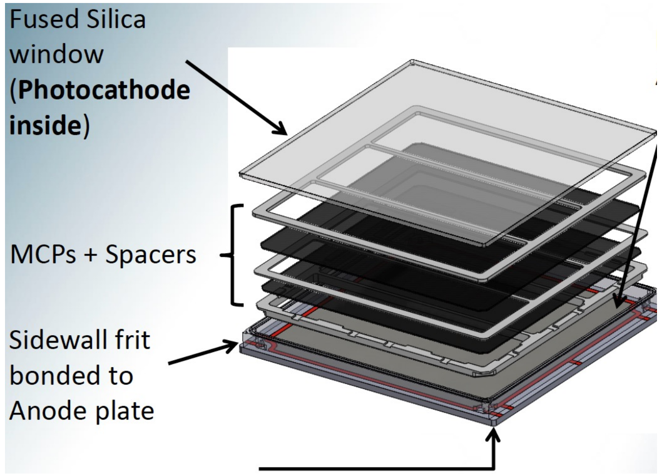
Introduction

LAPPD / HRPPD by Incom Inc.



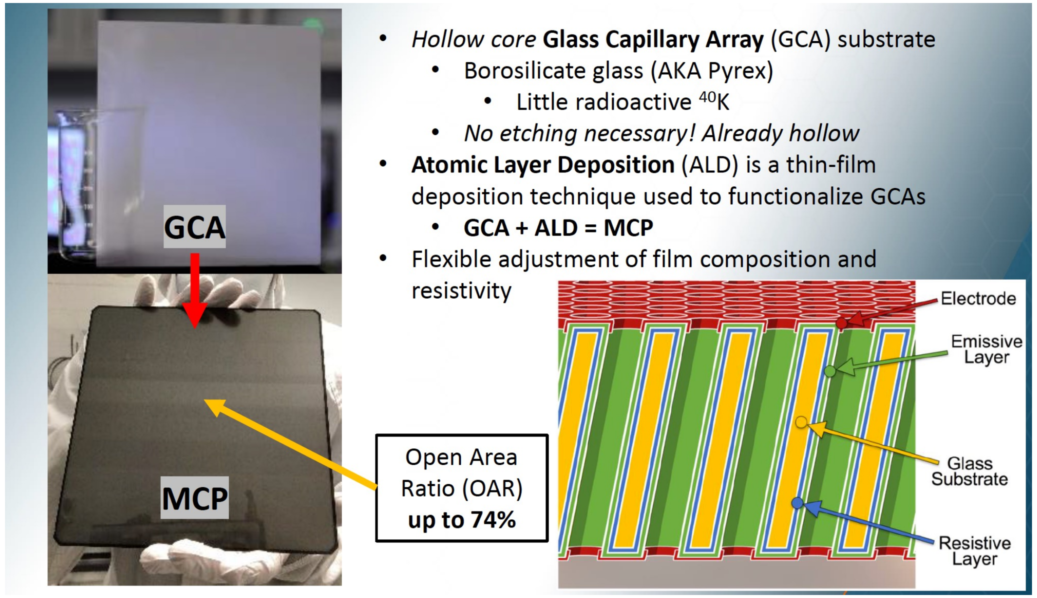






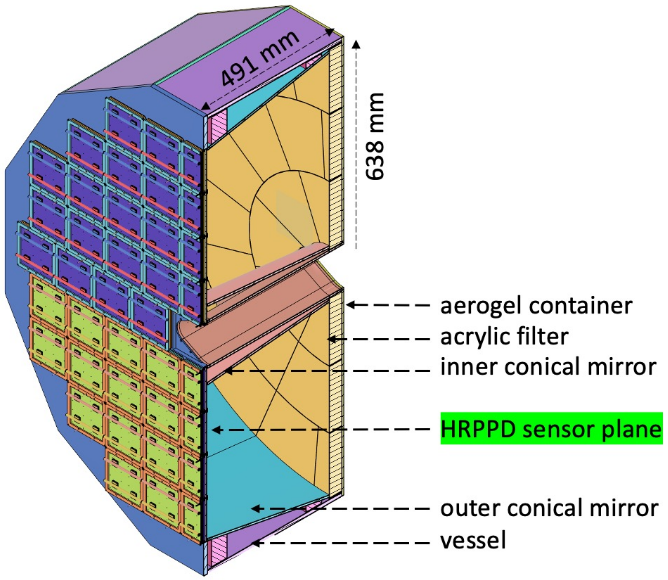
Gen II variety

- An affordable large area (finely pixelated) vacuum photosensor
- 10x10 cm² or 20x20 cm² 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 better

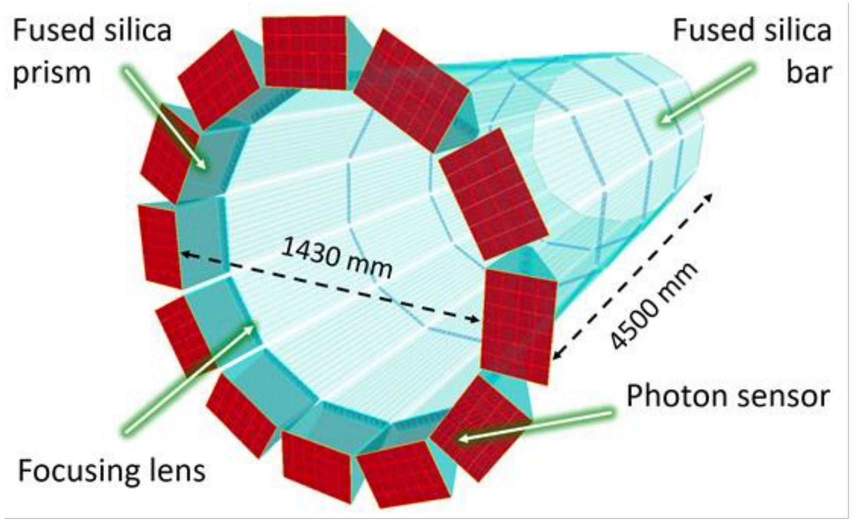


LAPPD / HRPPD for EIC

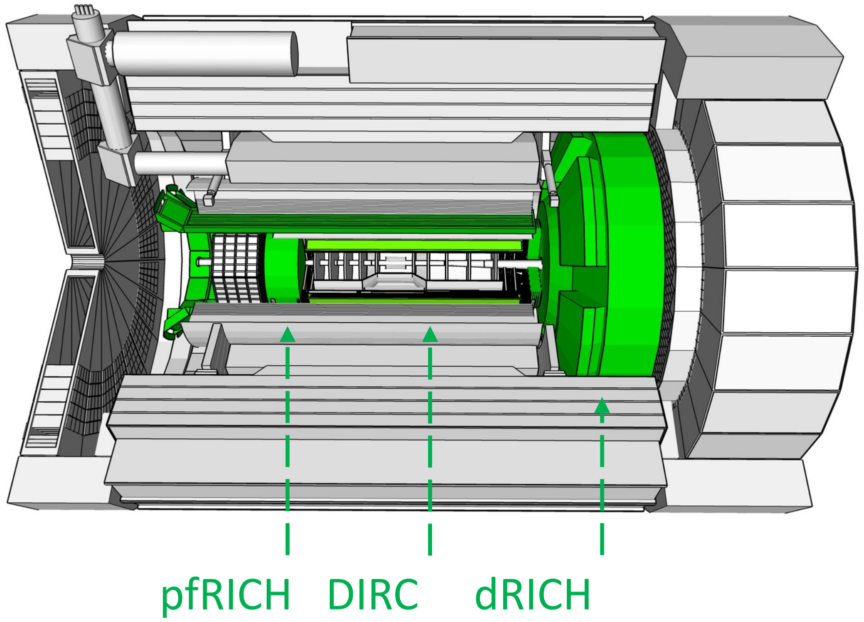
- Backward RICH: low dark noise, ToF capability (vs SiPMs)
- DIRC: expected to be more cost-efficient (vs other MCP-PMTs)
- dRICH: problematic, because of the magnetic field orientation



pfRICH: 68 HRPPDs total



DIRC: 12*3*2 = 72 HRPPDs total



Focus so far was on the pfRICH application, where HRPPDs are a baseline photosensor choice

	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/$\sqrt{12}$

While R&D effort in FY23 was a mix of Gen II LAPPDs and DC-coupled HRPPDs, FY24 activities will be primarily focused on the DC-coupled ones

FY23 report

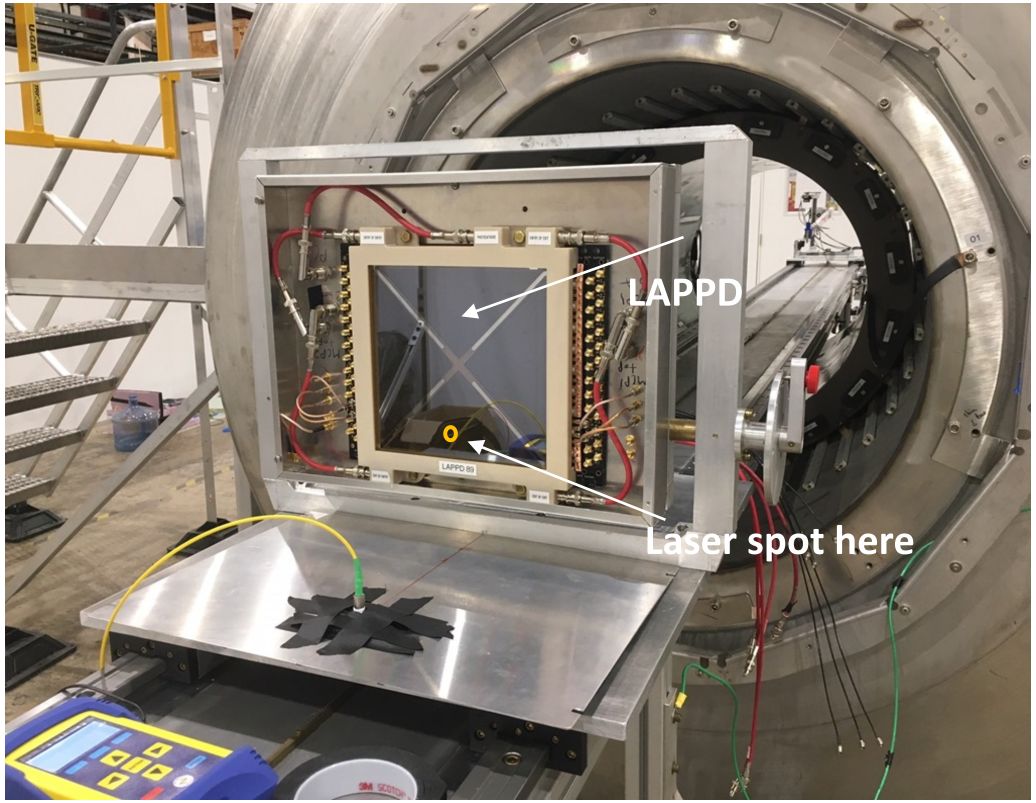
B field tolerance studies at Argonne (LAPPD)

Magnetic field strength:
- 0.02 T to 1.45 T

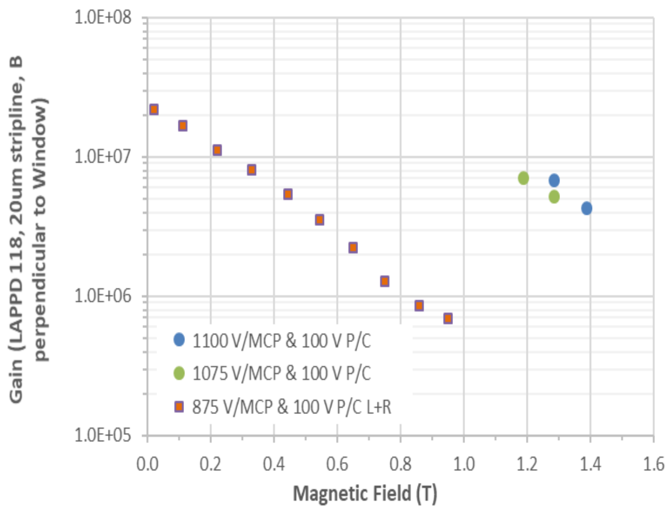
Photon source:
- Picosecond laser system
- Fiber optics
- Digital attenuator.

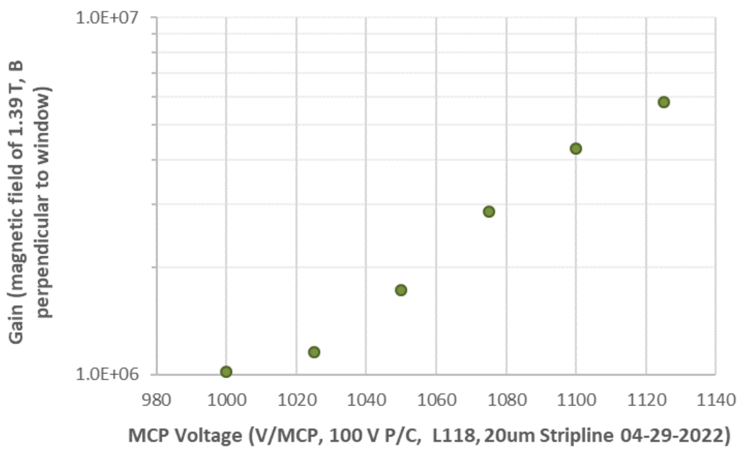
Dark box:
- Movable on a rail into the magnet

DAQ:
- CAEN DT5742b desktop digitizer



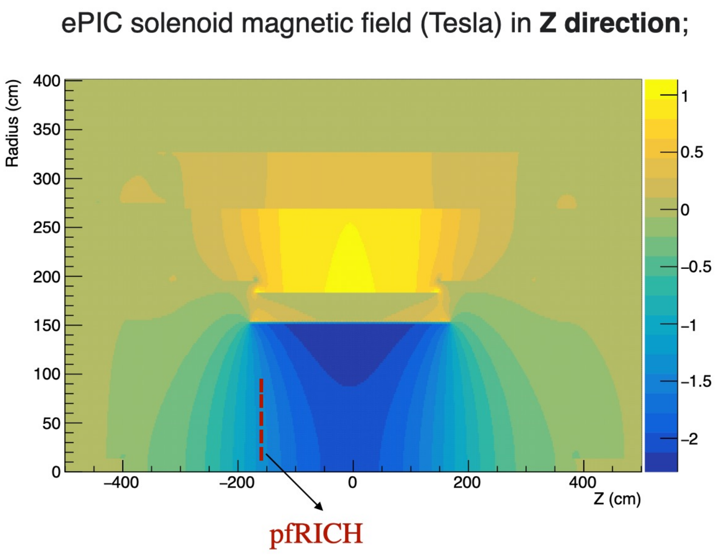
Gain recovery in 20μm pore Gen I/II LAPPDs

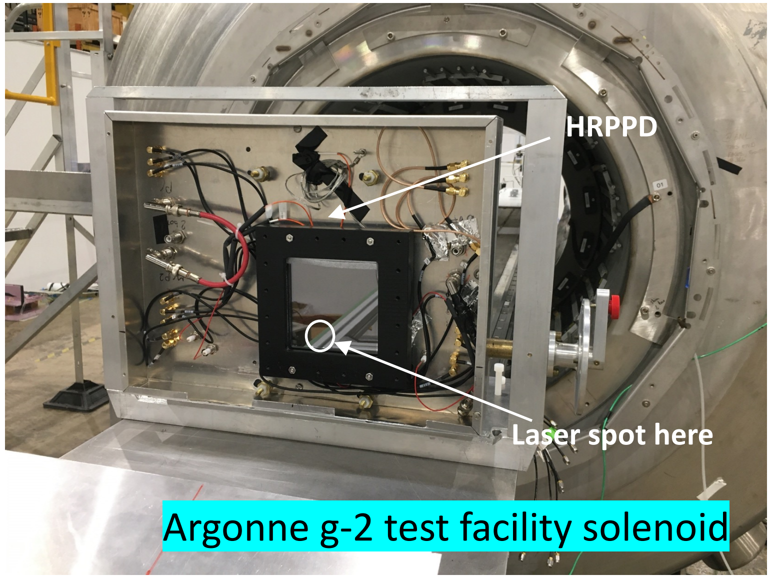


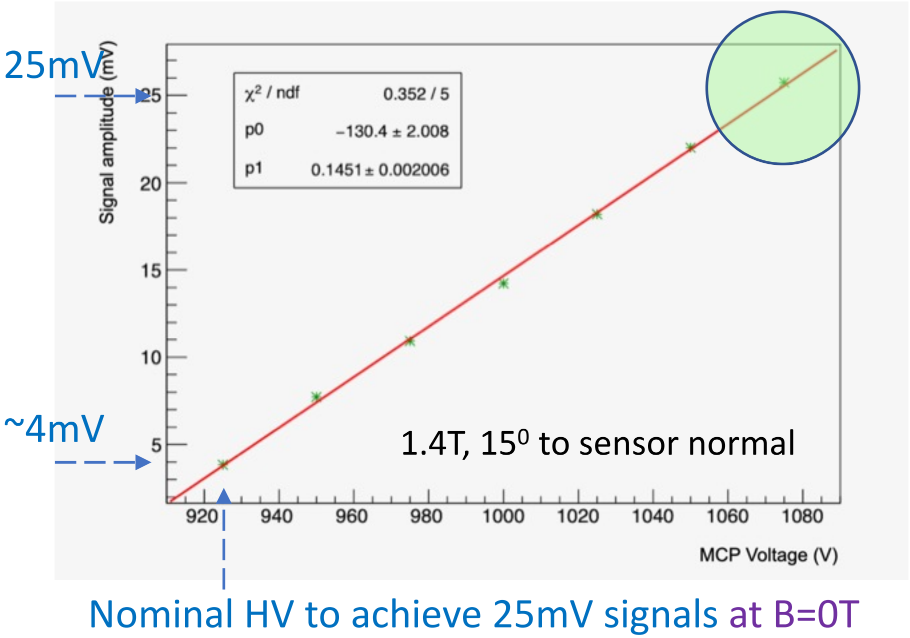


Gain goes down with the magnetic field, but can be partly recovered by increasing MCP voltage

B field tolerance studies at Argonne (HRPPD)







- 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

B field tolerance studies in Italy by INFN (LAPPD)

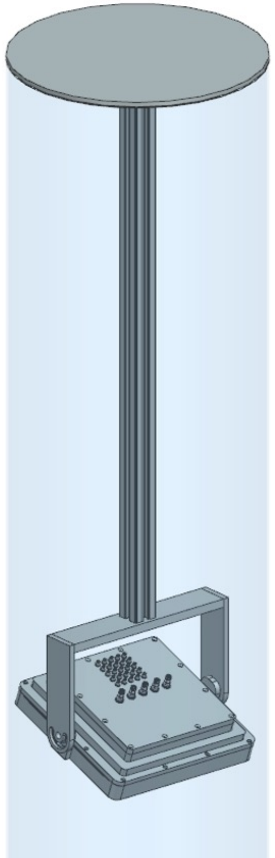
Planning

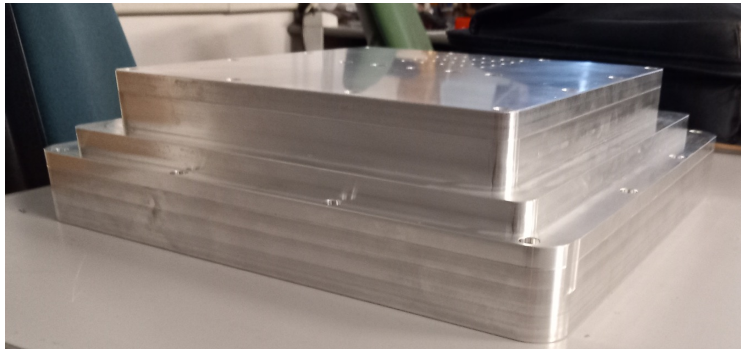
- Measurements at 2 field intensities:
  - 0.5 T – September 2023
  - 1.5 T – October 2023
- Measurements at different inclinations respect to the field lines

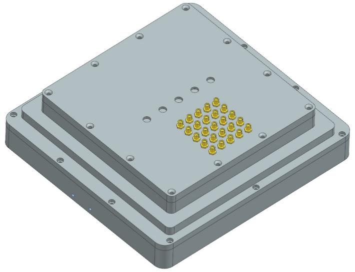
- Measured parameters:
  - Single PE pulse height distribution (gain)
  - Transit Time Spread
  - Effective efficiency
  - After pulse characterization

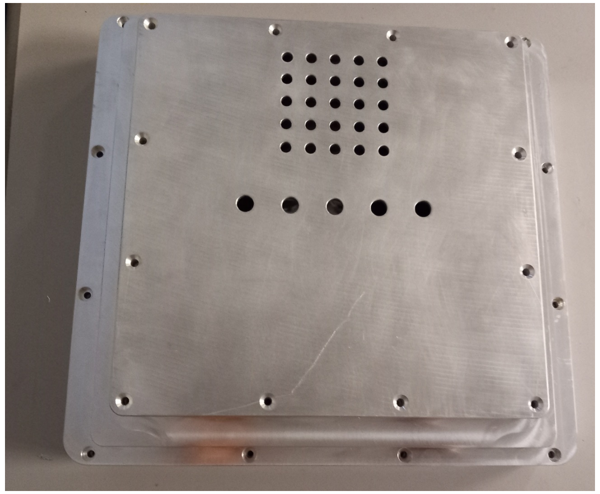
- Electronics equipment for data collection:
  - digitizer V1742 by CAEN using DRS4 ASICs
  - oscilloscope LeCroy OSCILLOSCOPE WAVERUNNER 9254, 2.5 GHz

Designing and building a dedicated dark box



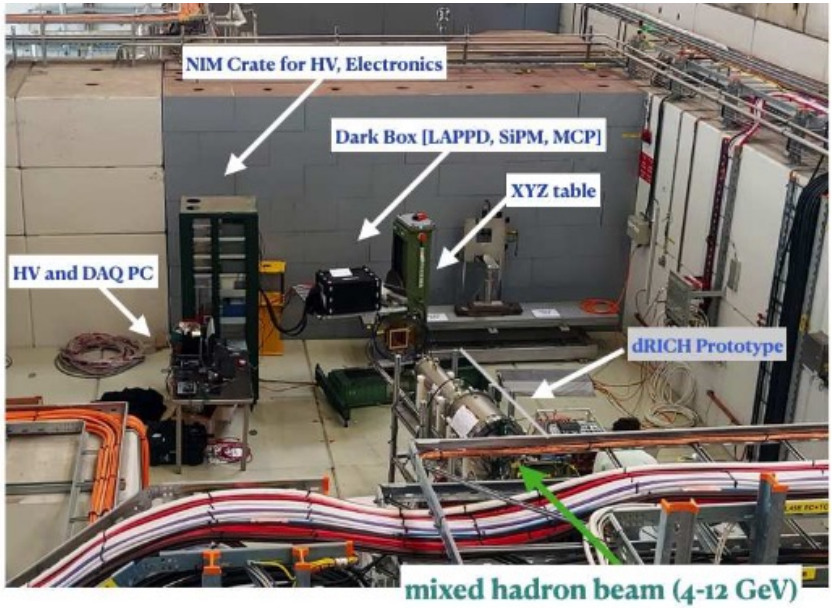


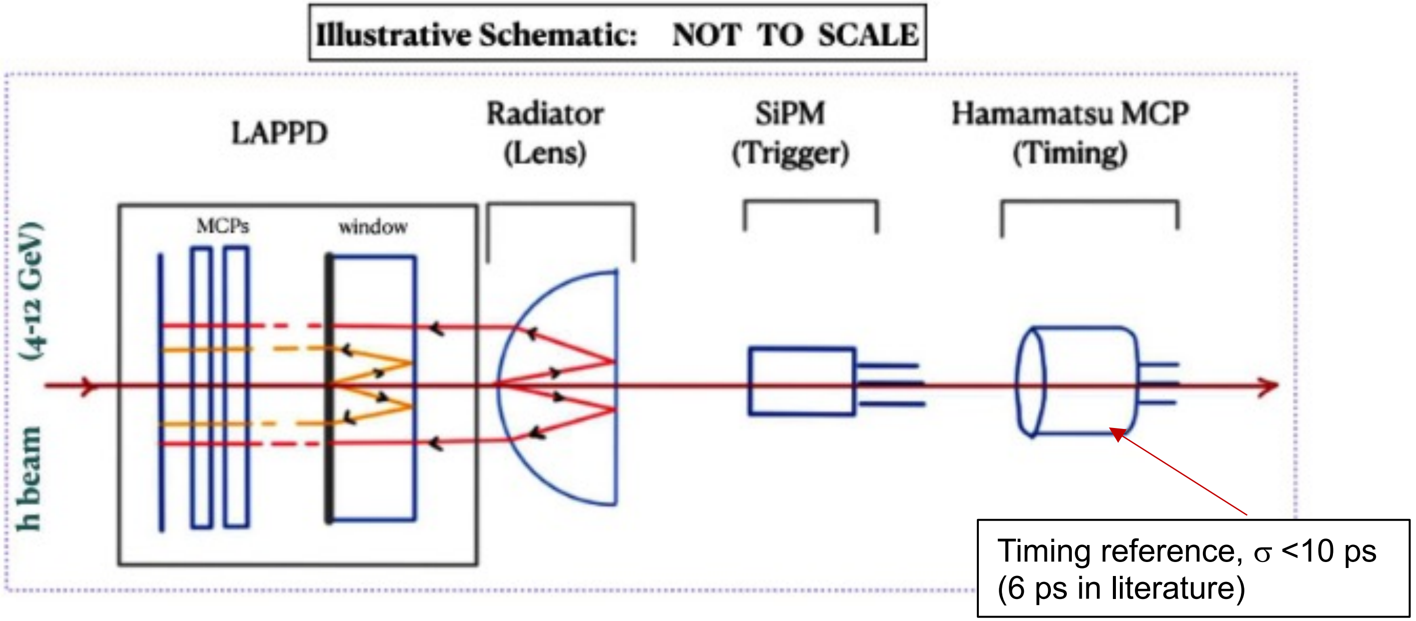




Will continue into FY24, for the new EIC HRPPDs

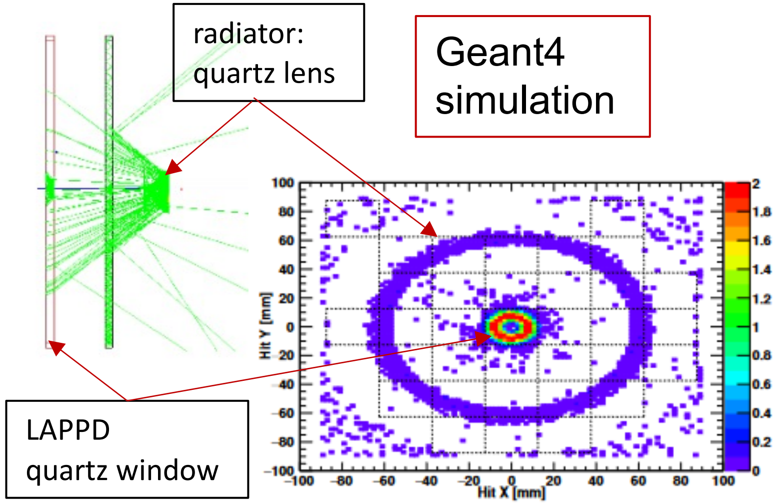
Beam test at CERN PS by INFN Trieste & Genova

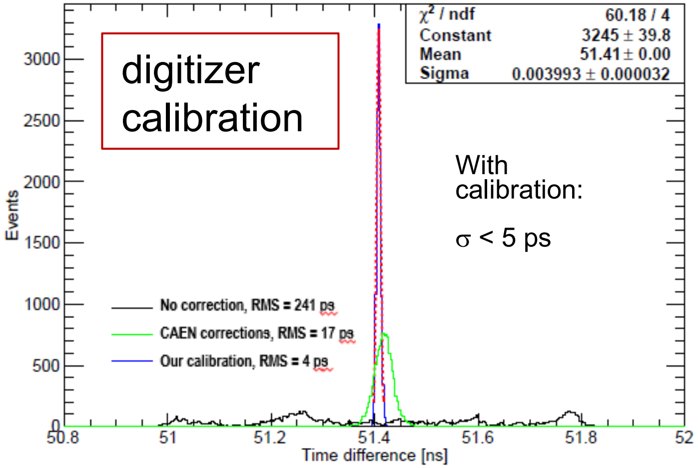




Preparatory and complementary exercises :

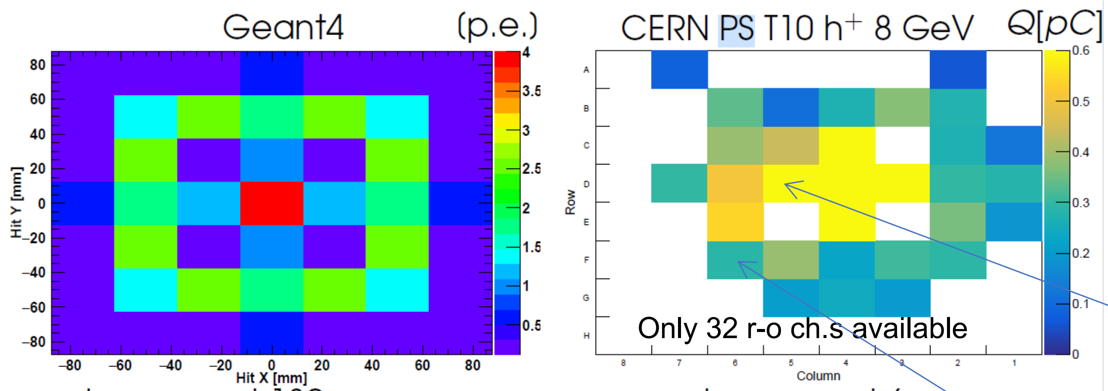
- LAPPD characterization in the lab
- Complete simulation by Geant4
- Construction of dedicated amplifiers (~ x 10)
- Calibration of the digitizer (V1742 by CAEN using DRS4 ASICs)





Beam test at CERN PS by INFN Trieste & Genova

"Ring" image

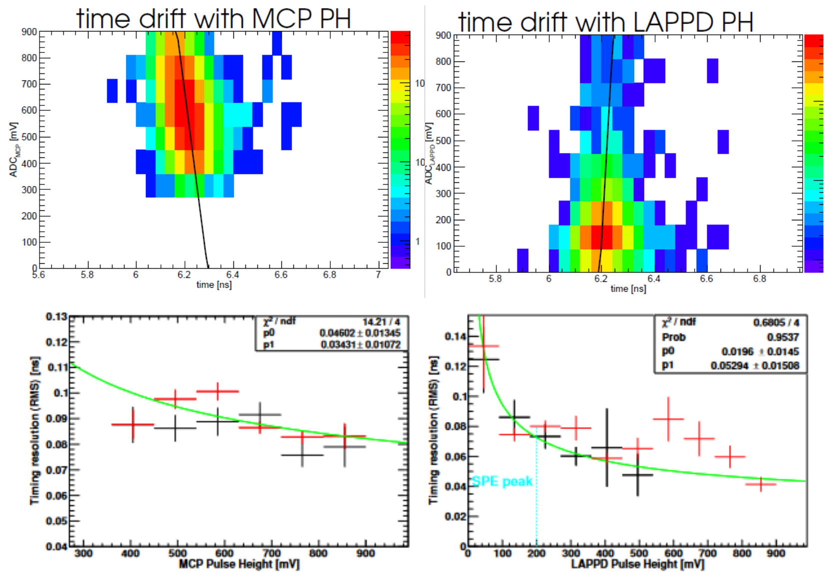


beam spot 180 p.e. beam spot 6 p.e.

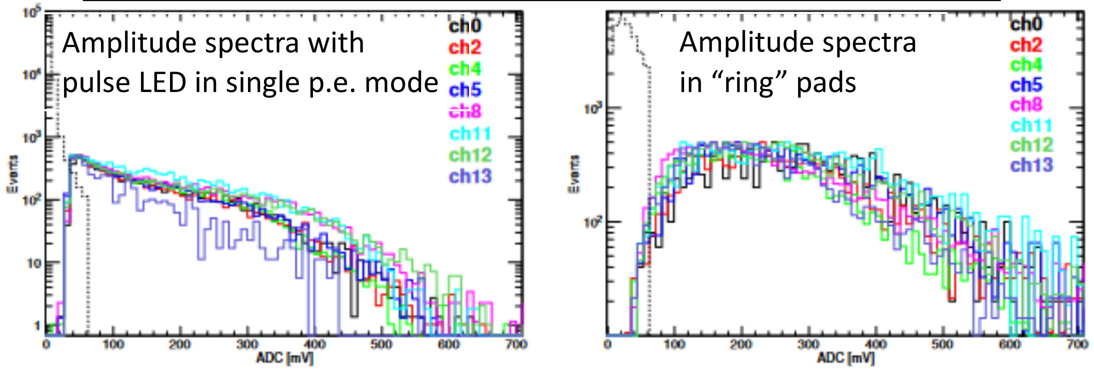
A large fraction of the beam spot p.e. absorbed applying locally on the LAPPD window a piece of black tape couple with optical grease

Accurate check of the systematics:

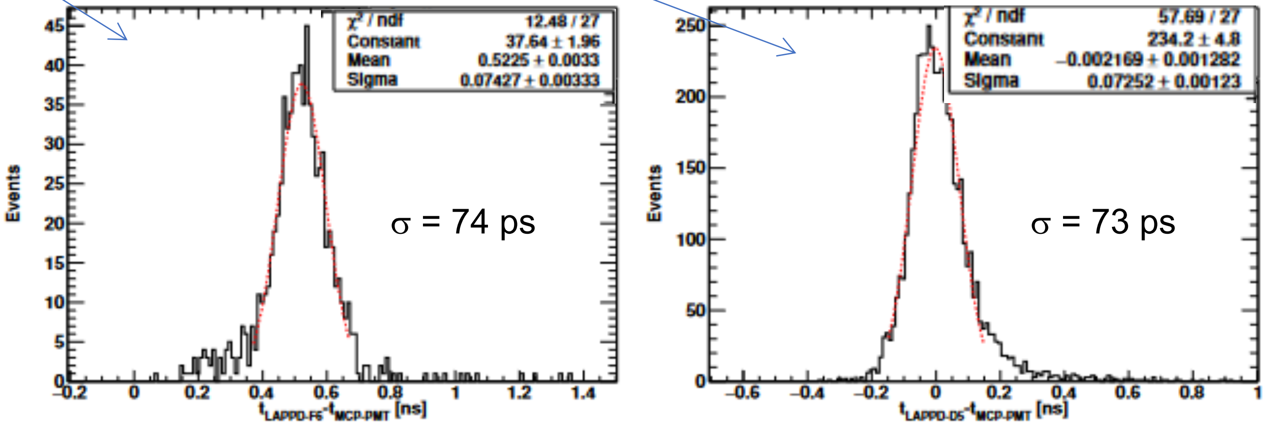
- correct for the "CFD" effect
- estimation of the residual uncertainty



Confirming the single p.e. mode in the ring pads



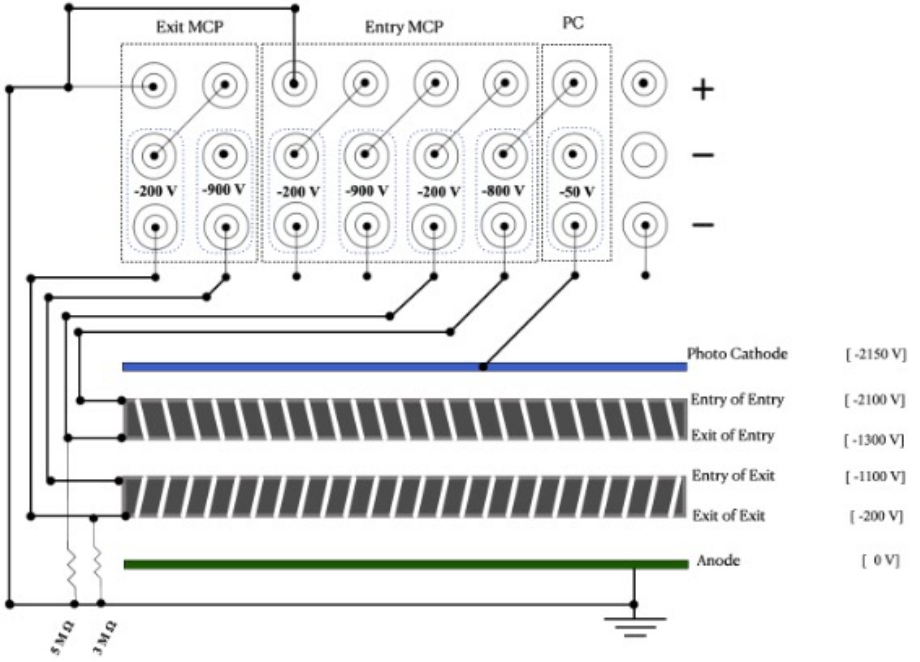
Time resolution: here for 2 different pads



Beam test at CERN PS by INFN Trieste & Genova

Correct powering of LAPPDs
- **Scheme:** HV stacking connection scheme (daisy chain)
- **Power supply :** no common grounding of the HV channels !

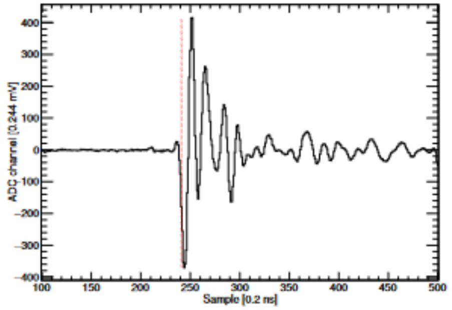
Used: CAEN power supply, model DT1415ET (developed for GEMs)



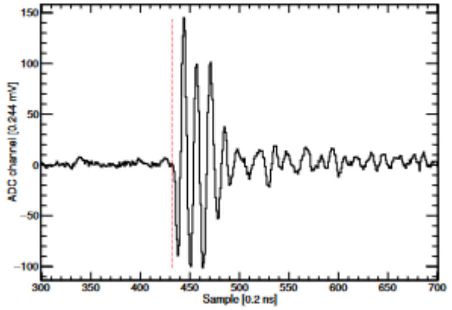
LAPPD (resistive anode) Cross-Talk

- Dumping oscillations generated by large signals
- Long-range effect (propagated in the whole sensor)
- Effect cross-check in the lab

Observed at the test beam

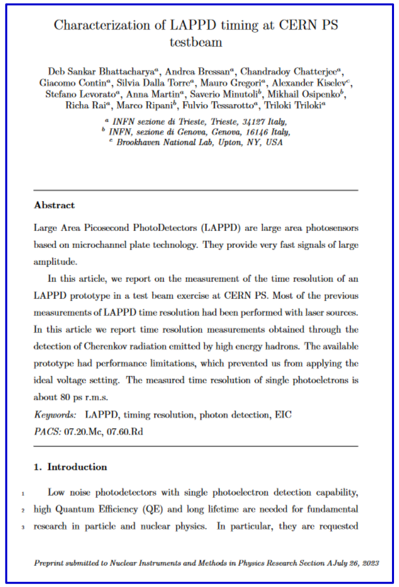


Detected in laboratory tests



Test beam, summarizing:

- **First ever performed measurement of LAPPD TTS with Cherenkov light !**
- **Test beam Data analysis and complementary investigation now completed**
- **A manuscript ~ready for submission to NIMA**



Characterization of LAPPD timing at CERN PS testbeam

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Abstract

Large Area Picosecond PhotoDetectors (LAPPD) are large area photosensors based on microchannel plate technology. They provide very fast signals of large amplitude.

In this article, we report on the measurement of the time resolution of an LAPPD prototype in a test beam exercise at CERN PS. Most of the previous measurements of LAPPD time resolution had been performed with laser sources. In this article we report time resolution measurements obtained through the detection of Cherenkov radiation emitted by high energy hadrons. The available prototype had performance limitations, which prevented us from applying the ideal voltage setting. The measured time resolution of single photoeletrons is about 80 ps r.m.s.

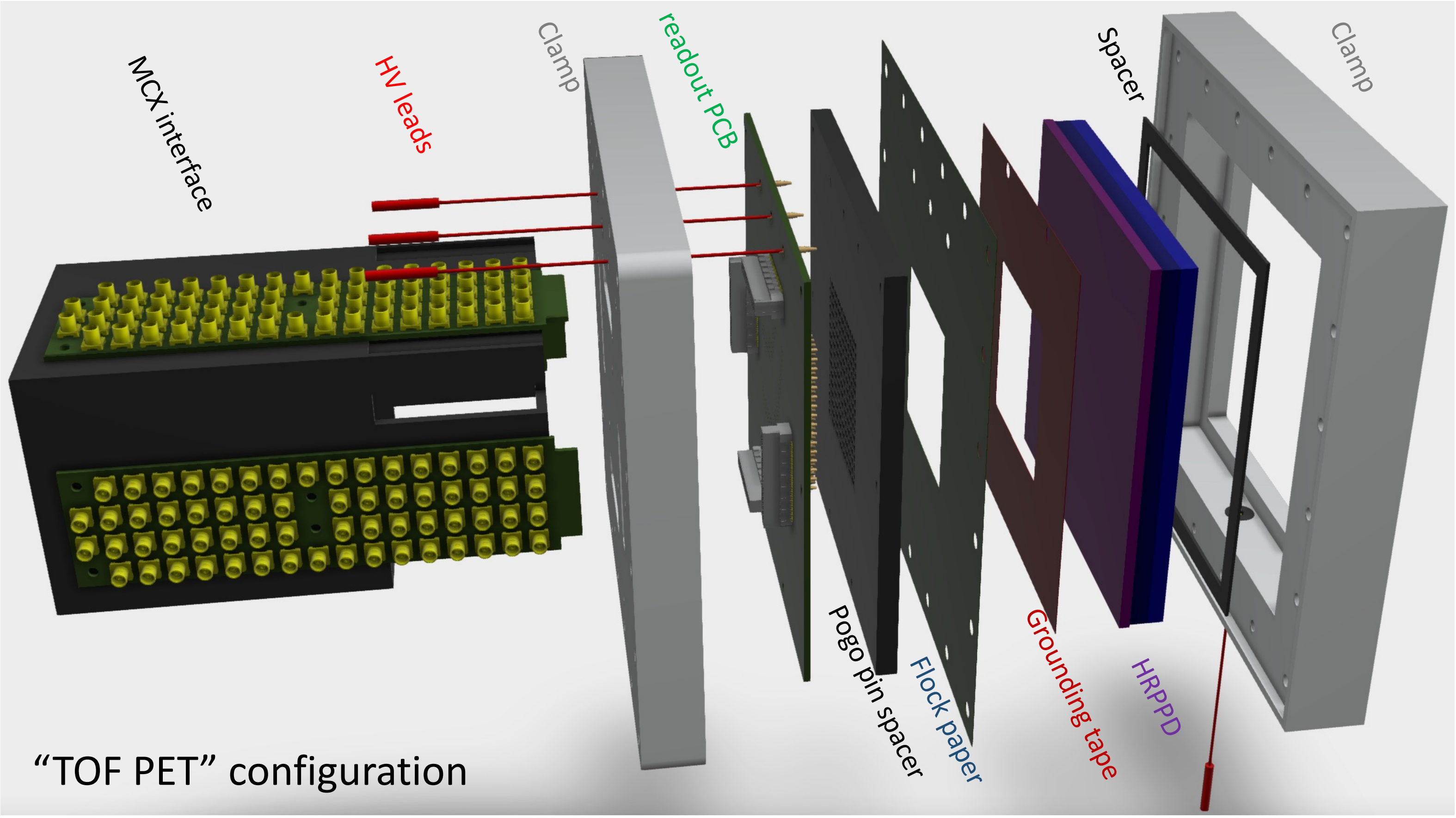
Keywords: LAPPD, timing resolution, photon detection, EIC
PACS: 07.20.Mc, 07.60.Rd

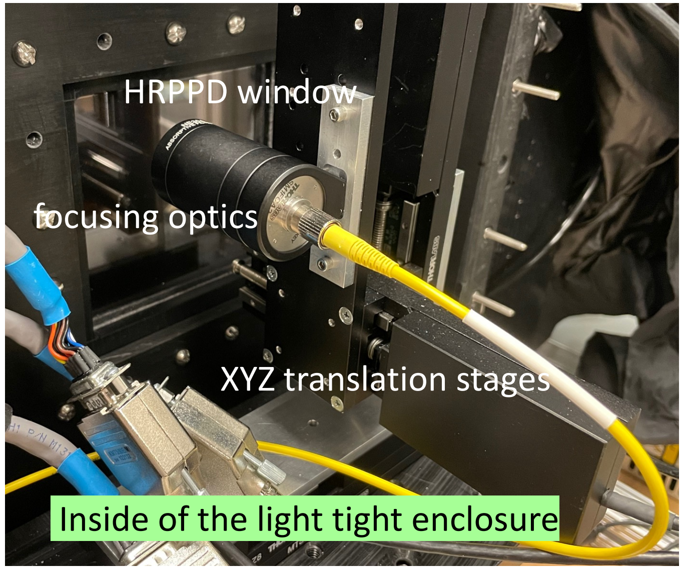
1. Introduction

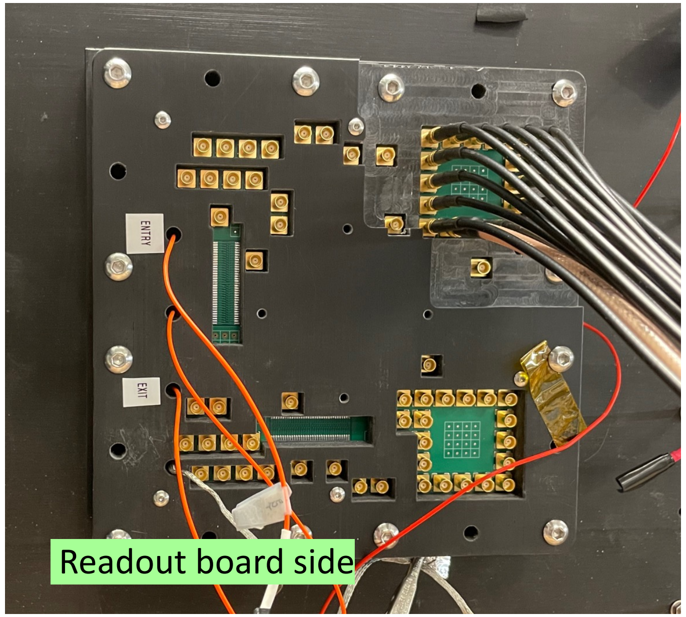
Low noise photodetectors with single photoelectron detection capability, high Quantum Efficiency (QE) and long lifetime are needed for fundamental research in particle and nuclear physics. In particular, they are requested

Preprint submitted to Nuclear Instruments and Methods in Physics Research Section A July 26, 2023

HRPPD integration attempt #1 by BNL: pogo pins

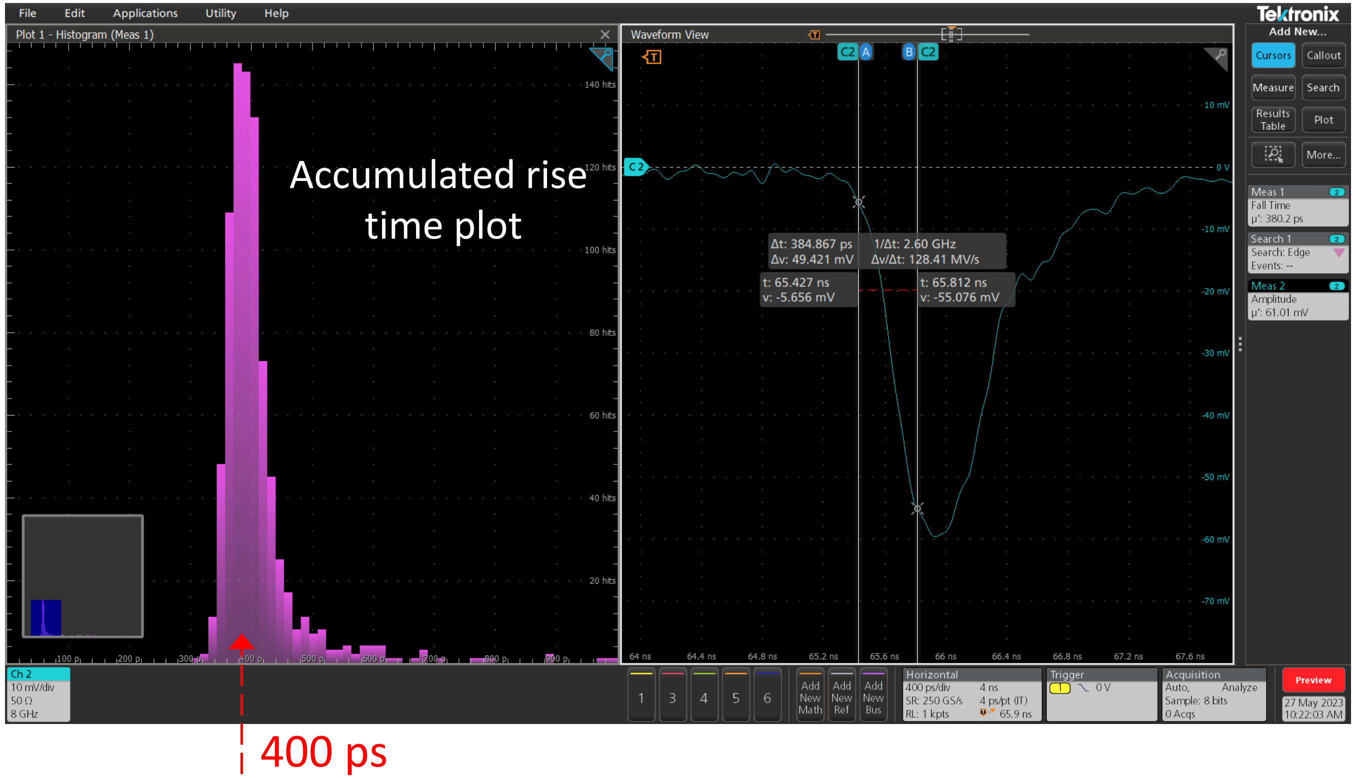




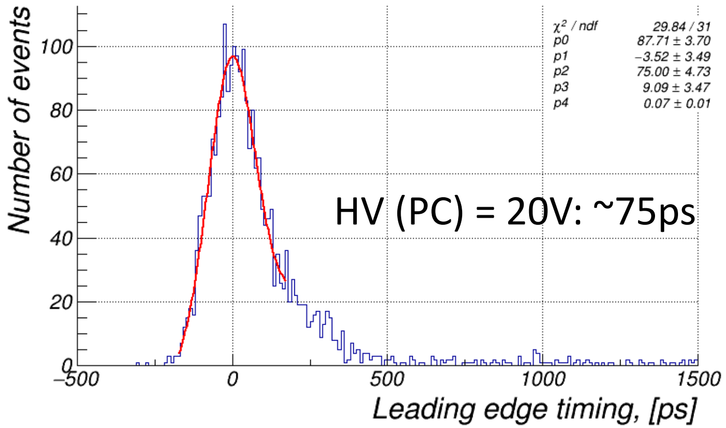


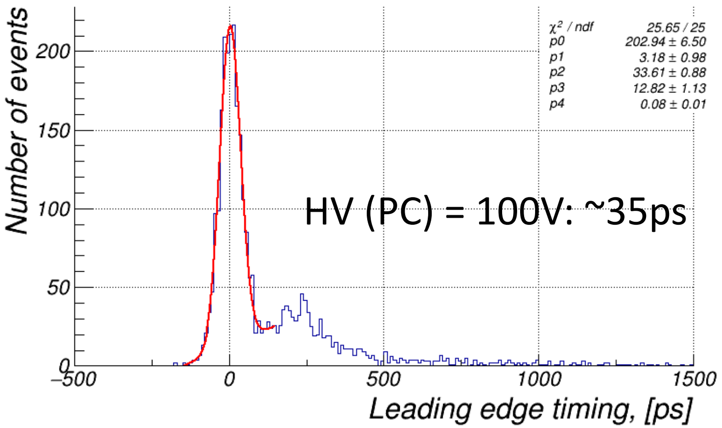
- Suffices for a basic performance evaluation
- (Does not look practical for a real-life installation in the experiment)

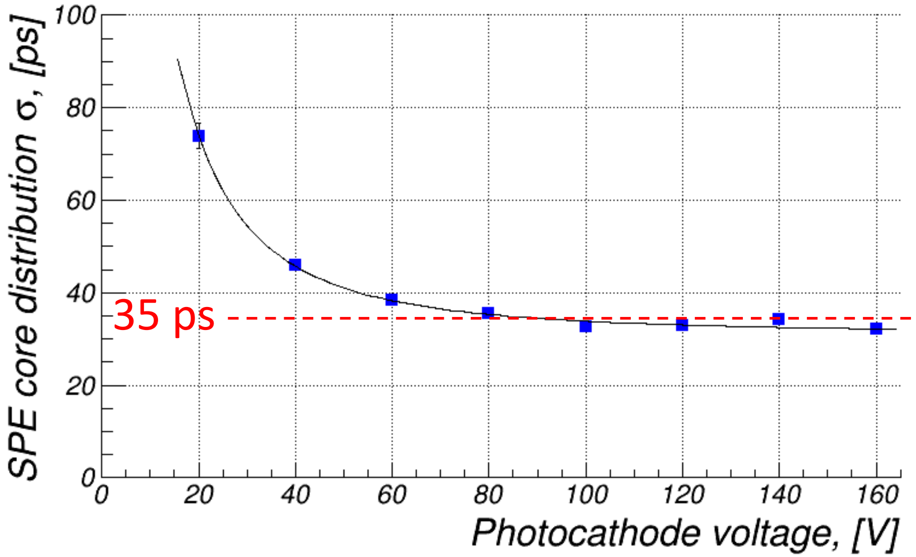
HRPPD #6: SPE timing performance with a laser



- Laser focused to a given 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*

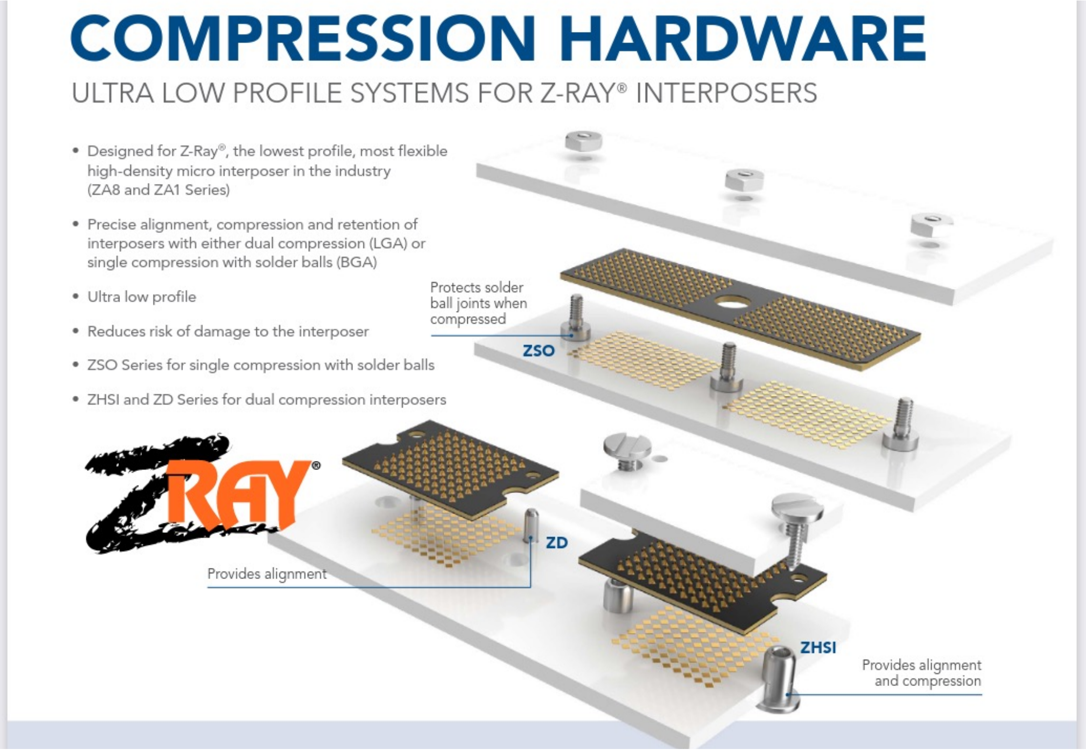


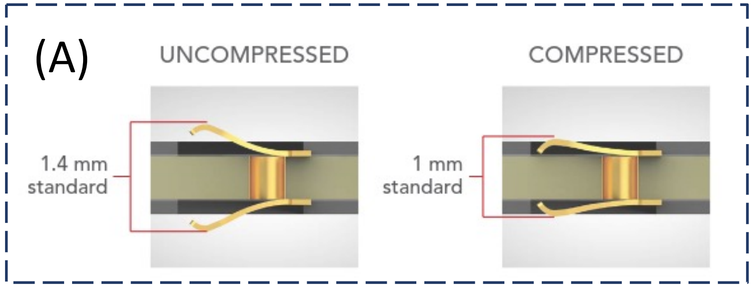


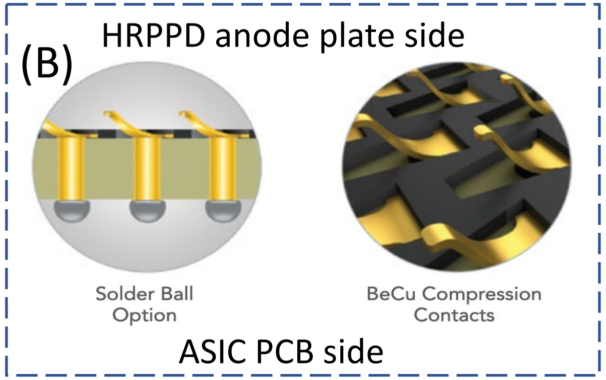


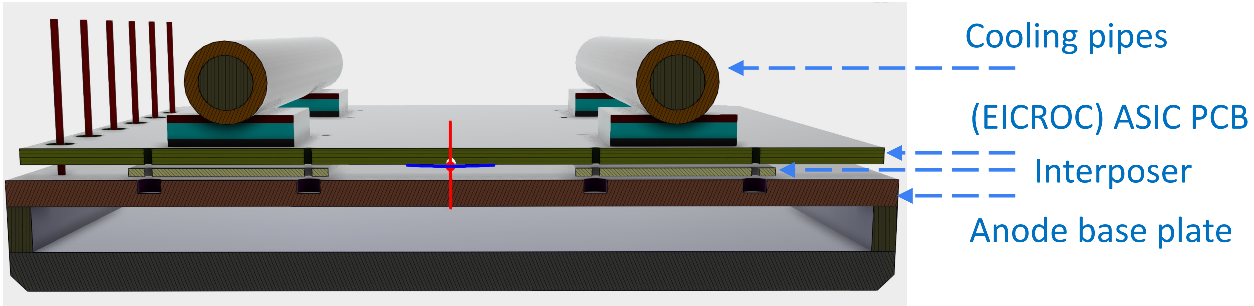
Integration attempt #2: compression interposers

- Design custom LTCC anode base plates for new EIC HRPPDs
  - Samtec compression interposers look like a reasonable interconnect option
  - Fallback solution: conductive epoxy screen printing







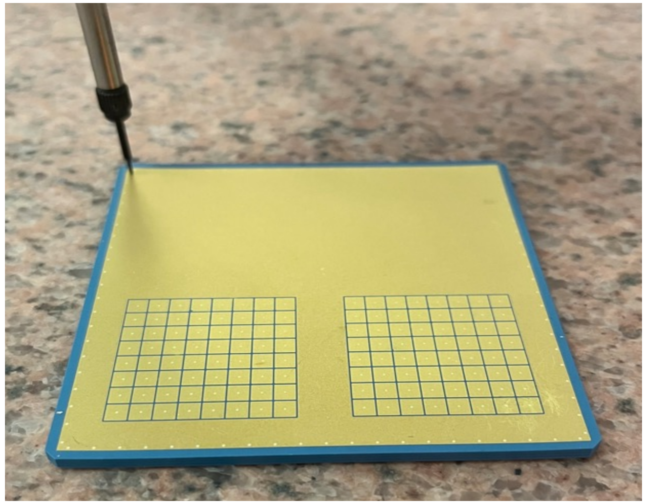


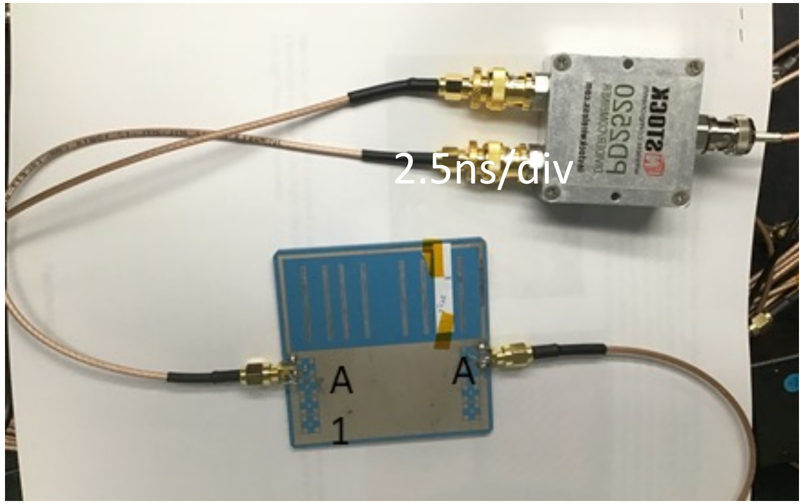
HRPPD face down

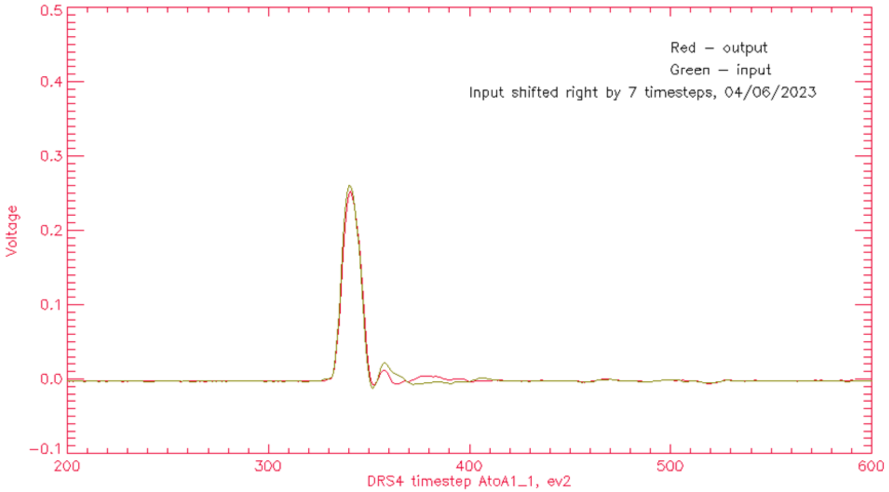
Small size LTCC prototypes by Techtra (Poland)

- First two 3” LTCC anode plates were examined at Incom
  - Flatness and vacuum tightness look fine

  - 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

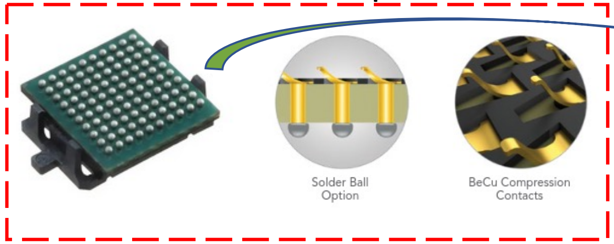


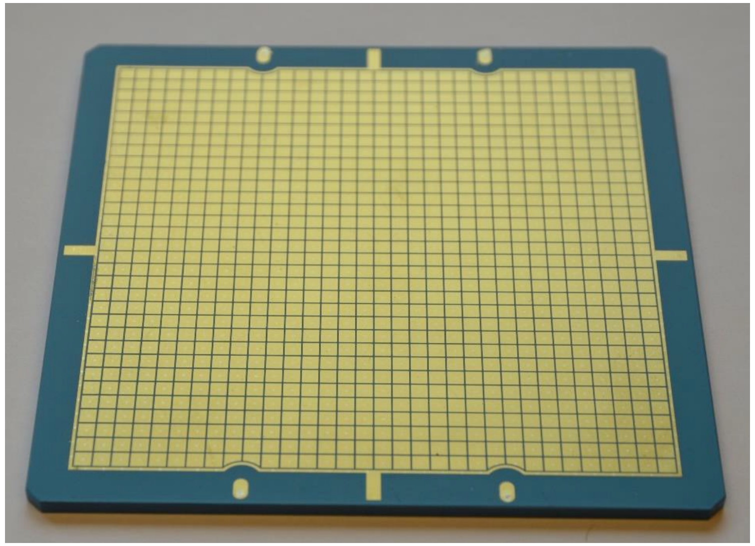




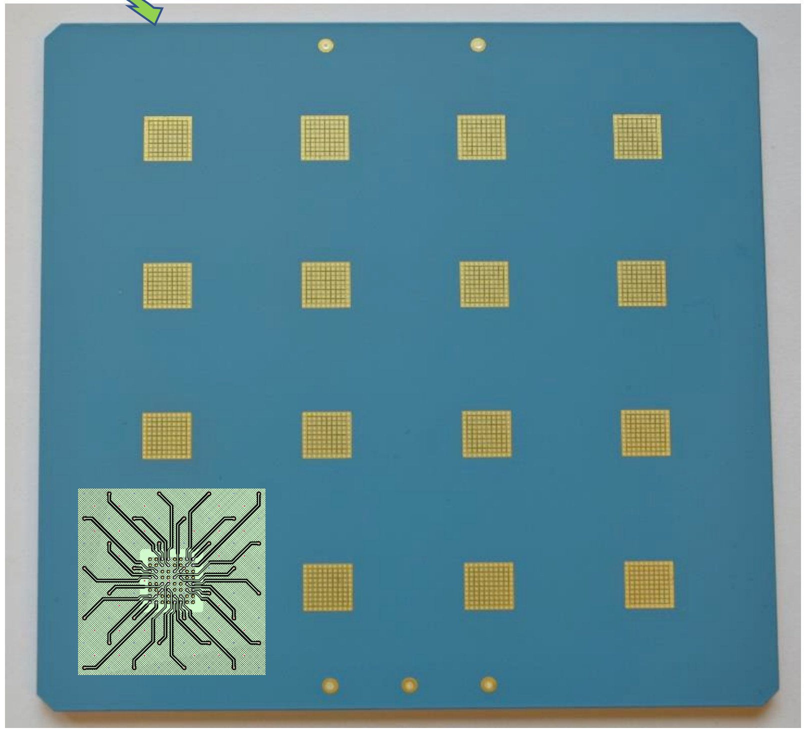
Full size prototype by Techtra (Poland)

Samtec interposer

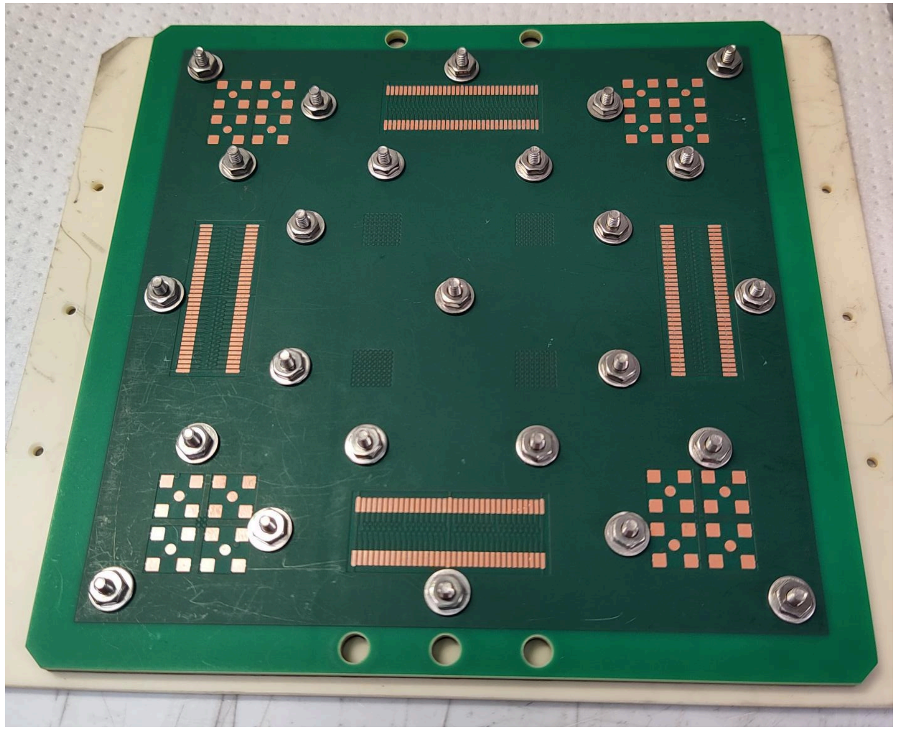




Inner side of a 32x32 pad ceramic 120mm base plate



Outer side with 4x4 800 μm pitch 64-pixel fields & a routing snapshot



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

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

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

Finalization of the EIC HRPPD design

(for this iteration)

- Formfactor
  - Decided to stick to the same 120mm x 120mm size, but increased active area to ~75%
- Window material
  - Switched to sapphire (equalize thermal expansion with the ceramic side walls; several other benefits; no apparent drawbacks)
- Anode plate
  - Finalized the design, with a trace routing matching the proposed readout board integration scheme
- Readout board interface
  - Developed a custom compression interposer design and a mounting scheme

Essentially, the “first five” EIC HRPPD design is frozen by now

EIC-Incom PED contract

- Came as a result of the EIC leadership team visiting Incom facility in Charlton MA in January 2023
- A lot of work in the background, to produce a specification document

- Signed by both Incom & JLAB two months ago

- 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

De facto, a joint BNL-Incom effort aligned with the Phase #1 objectives was ongoing since January 2023 (see the FY23 report)

FY24 proposal

FY24 proposal highlights

eRD110 (photosensors)

EIC Project R&D milestones & timeline

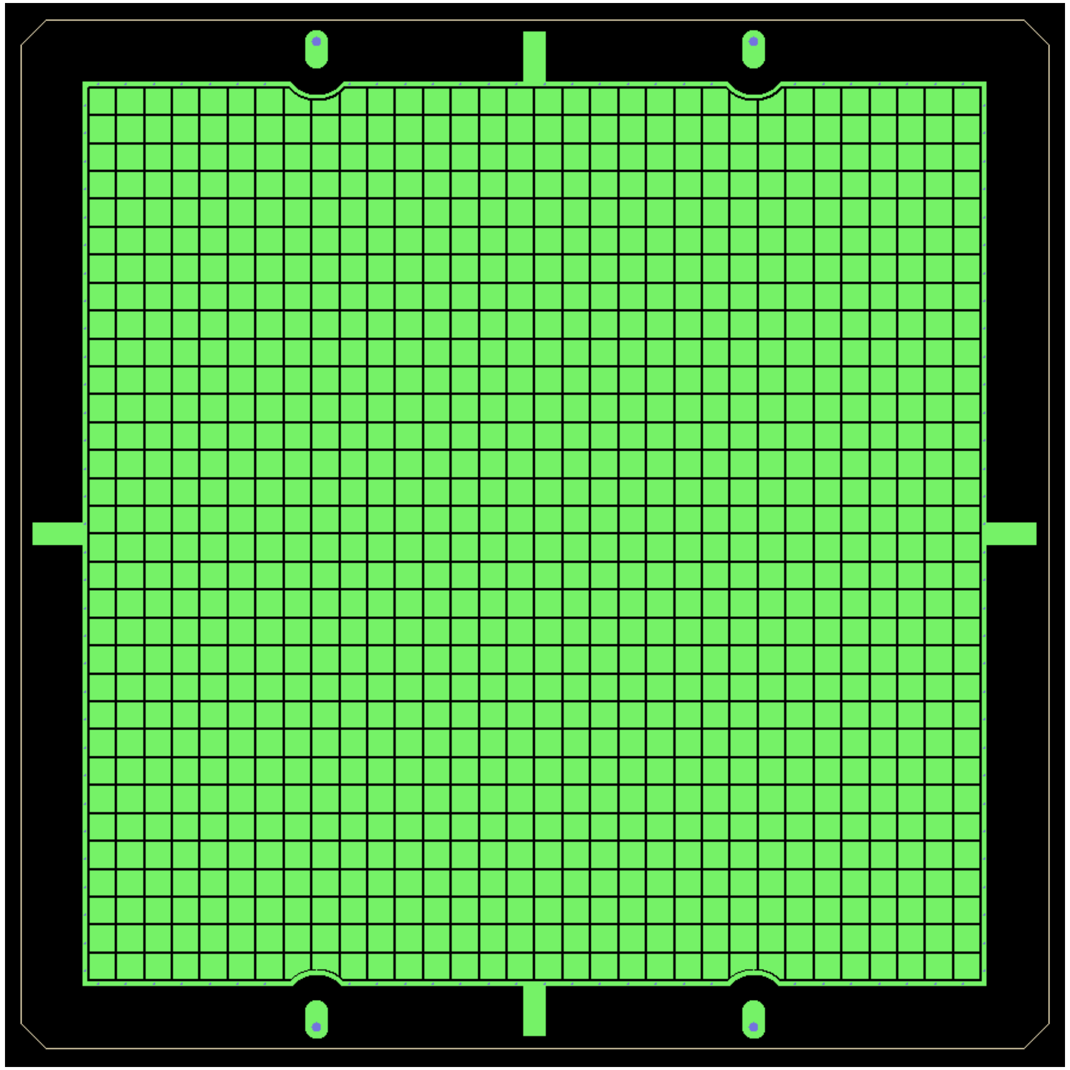
- Establish production readiness of a LAPPD/HRPPD-based photon-sensor readout for a Ring-Imaging Cherenkov Detector on the electron-side end cap of the EIC detector, including validation by prototype beam tests. [September 2024]

- Focus on evaluation of the first five EIC HRPPDs by Incom (see next slide)
  - HRPPD mechanical / electrical interface matching the new formfactor
    - Ship new tiles to EIC groups in these standardized package(s)
  - Lab evaluation as of late Fall 2023 (also using a new femtosecond laser at BNL)
    - At Argonne, BNL, INFN Trieste / Genova, Glasgow & Yale
    - [A direct PDE measurement is a must]
  - Beam test at Fermilab in early 2024 with a subset of the produced tiles
  - Magnetic field resilience measurements at Argonne and in Italy
    - [Confirmation of a *timing resolution* restoration by HV tuning is a must]
  - Ageing studies at INFN
  - pfRICH prototype test at Fermilab in ~June 2024 with HRPPD sensor plane

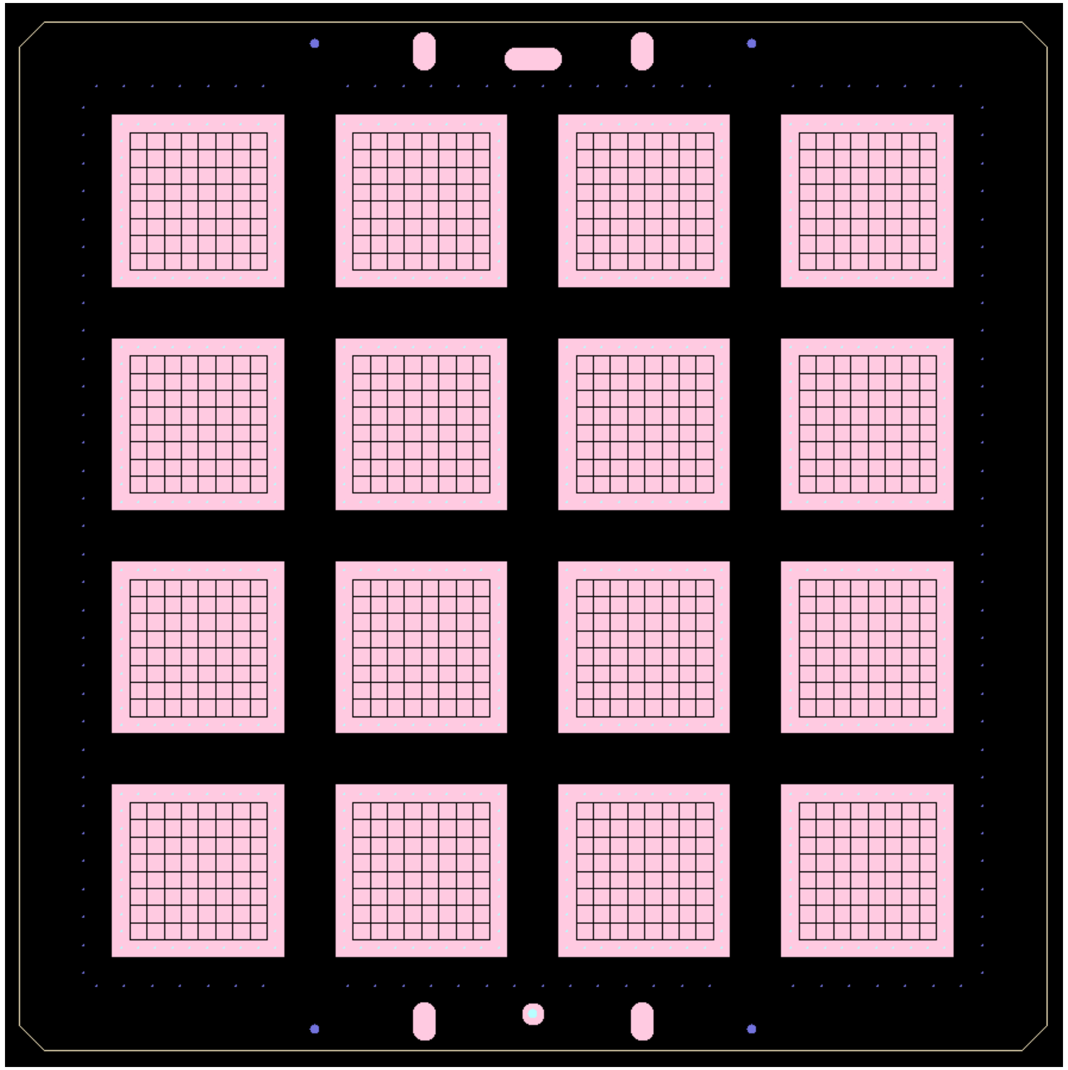
eRD114 proposal

- Fallback strategy
  - Proceed with evaluation of a Photek and a Photonis 2” MCP-PMTs in parallel

“EIC HRPPDs”: base plate Y03h (Kyocera)



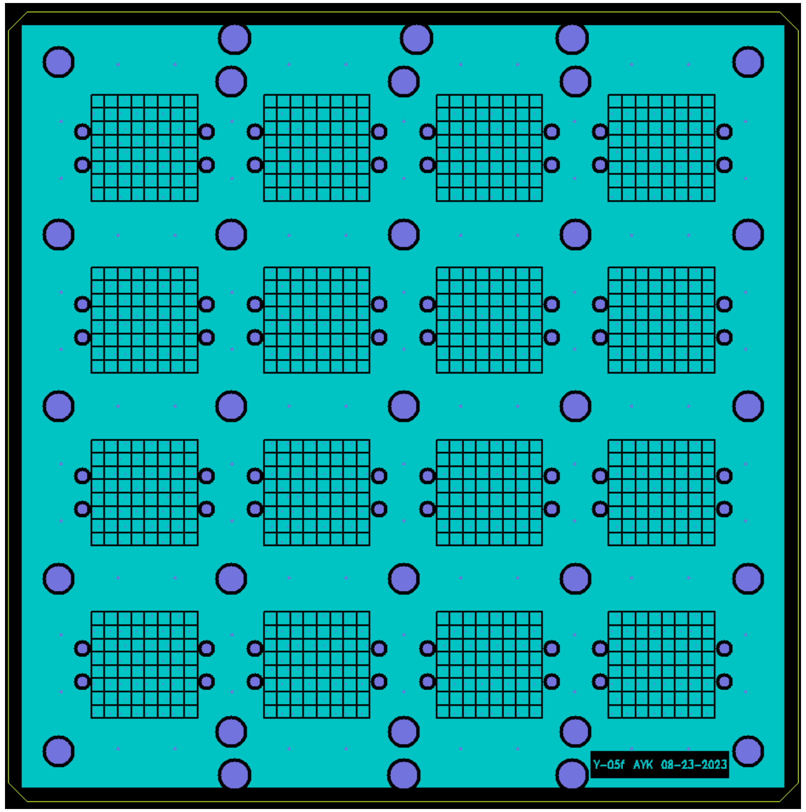
Inner side with a 32x32 pad uniform layout (3.25mm pitch)



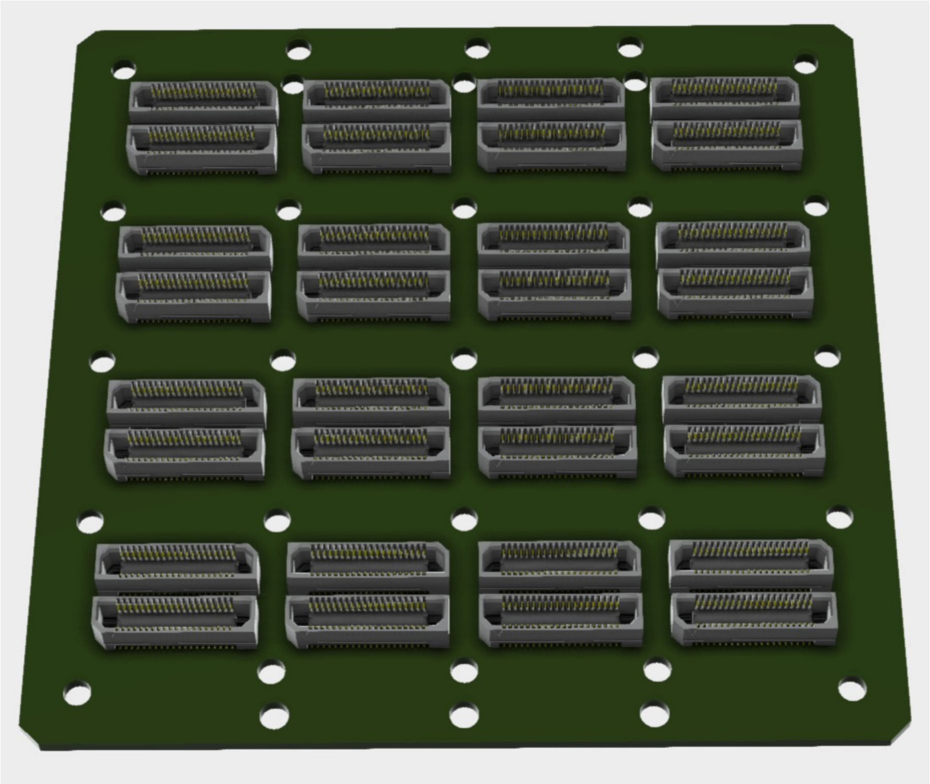
Outer side with 4x4 8x8 pad fields (2.0mm pitch)

Ordered by Incom in early 2023, as shown

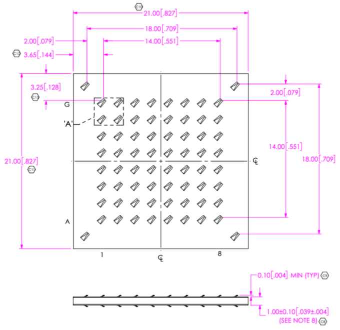
A passive HRPPD readout board interface



bottom side (matches HRPPD rear side)



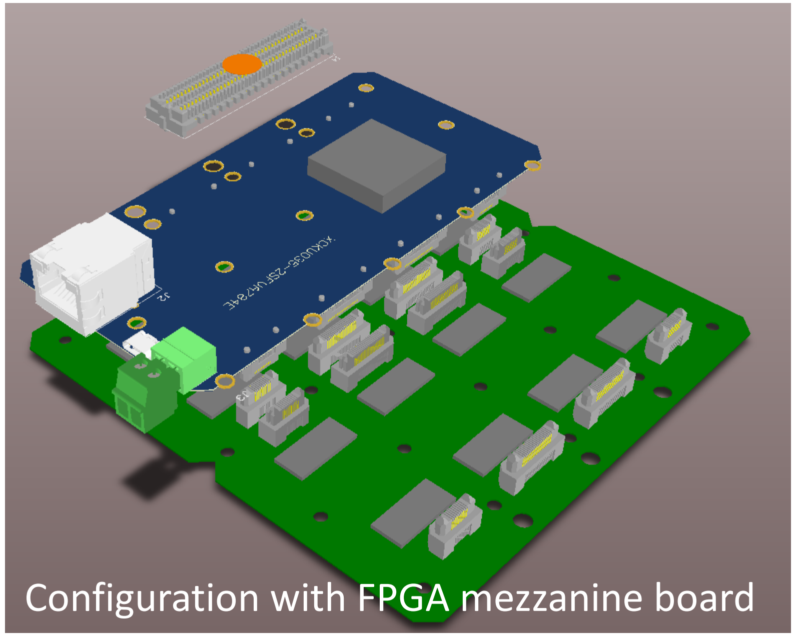
top side (32x Samtec ERF8 connectors)

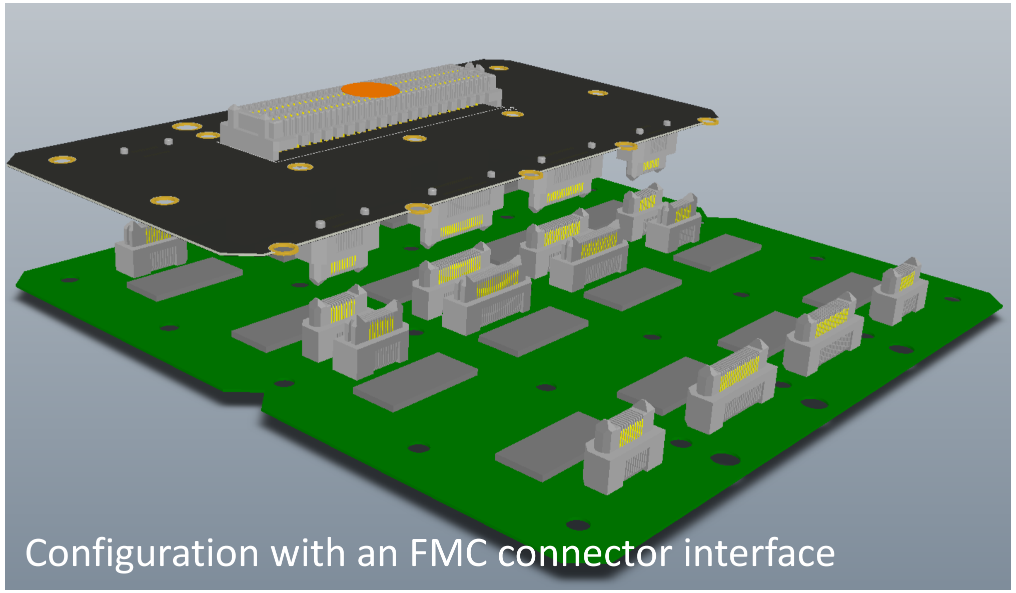


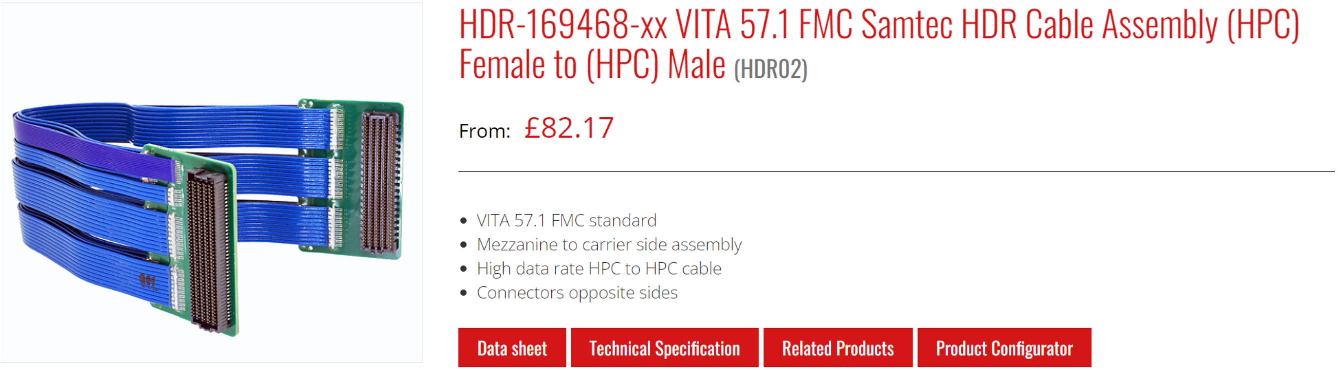
Samtec interposer

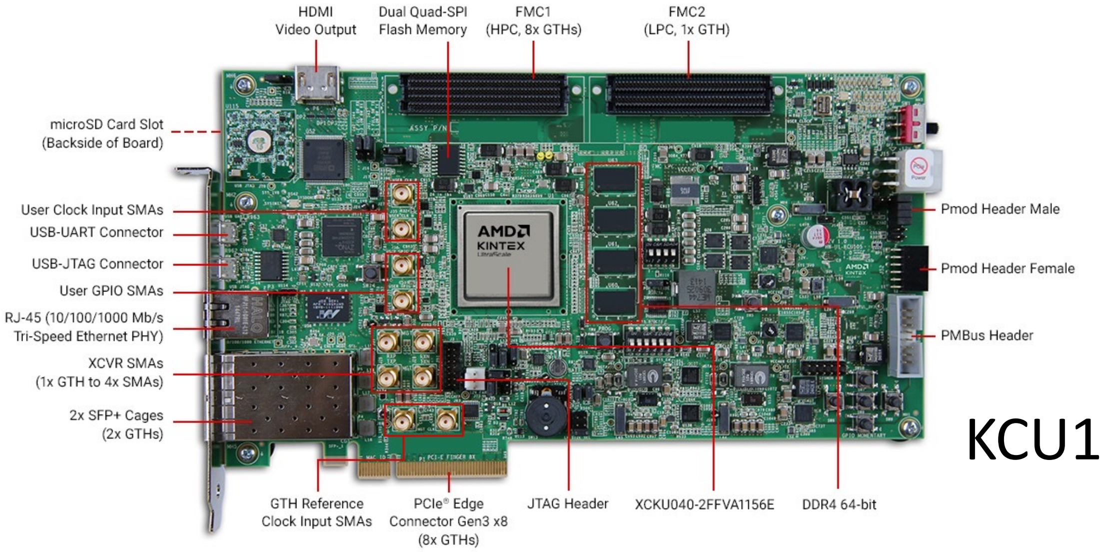
- A short-term solution, sufficient for a basic HRPPD evaluation using existing DRS4 electronics:
  - A set of [2x Samtec ERM8 -> MMCX] adapters, most likely 32ch (4x8) at a time
  - A set of ERM8-based grounding caps for all other 8x8 fields
  - Will be shipped to the research groups, bolted onto an HRPPD, in a unified 3D printed enclosure

HRPPD HGCROC3 ASIC FEE development


Configuration with FPGA mezzanine board


Configuration with an FMC connector interface

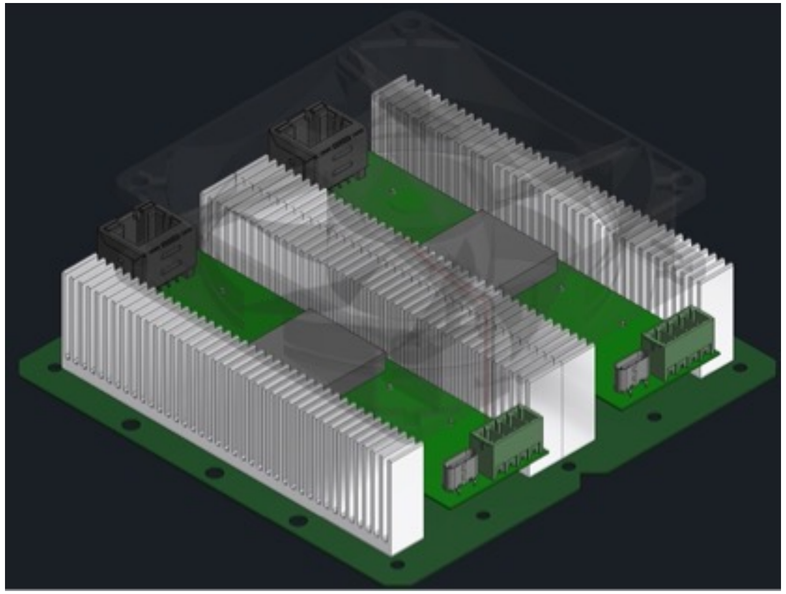
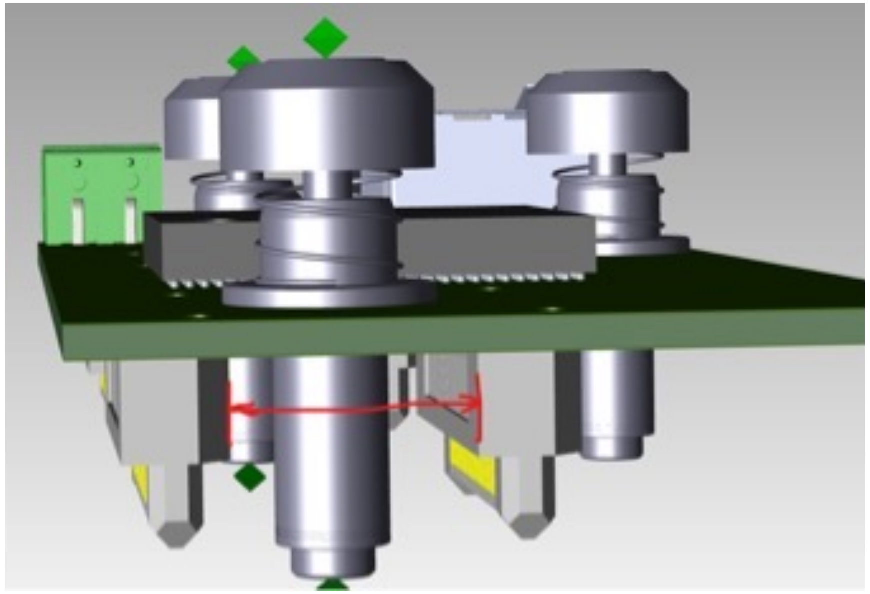




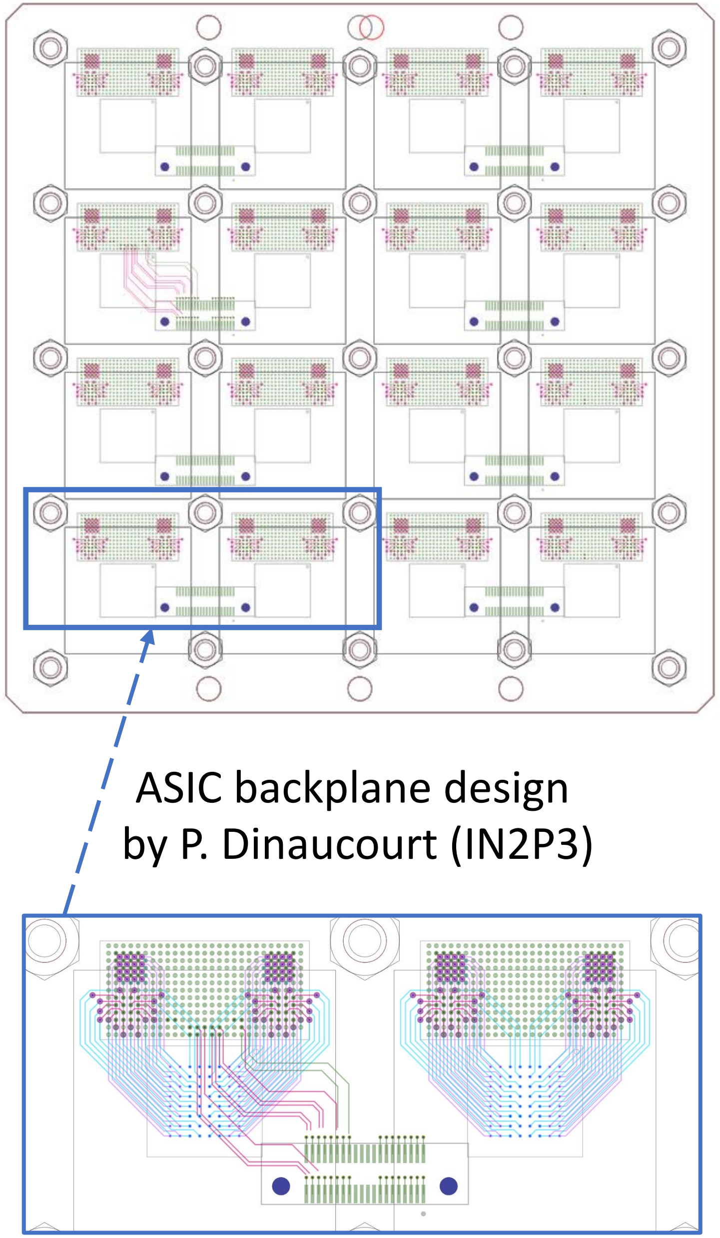
KCU105

- A more ambitious and longer-term option
  - Yet, we need it way ahead of the pfRICH prototype beam test at Fermilab in ~June 2024

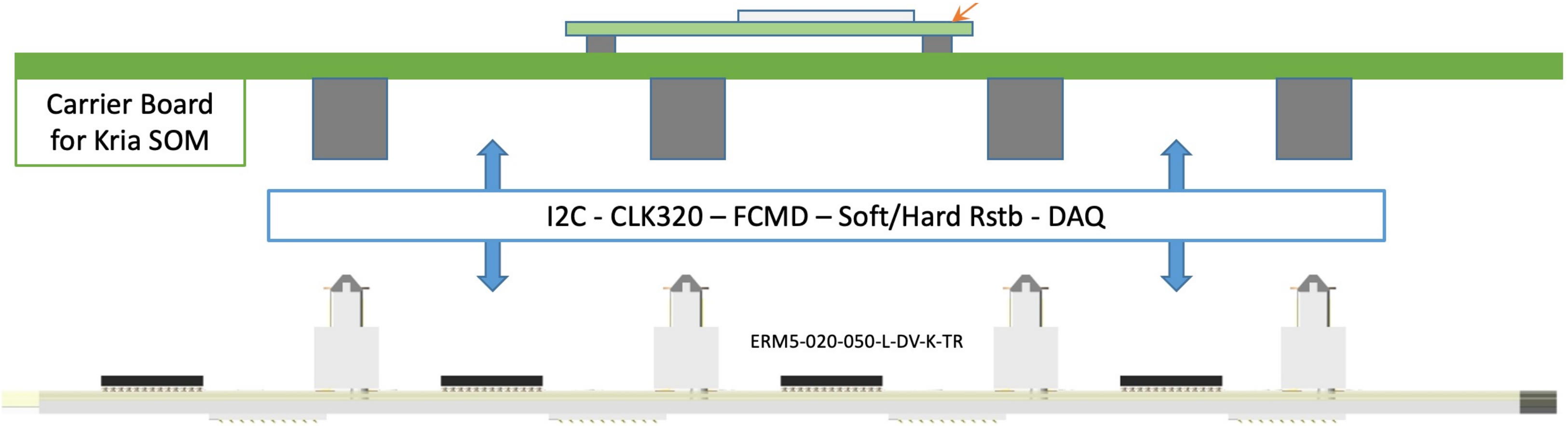
HRPPD ASIC FEE development

3D integration and cooling options by G. Nagy (Debrecen) and D. Cacace (BNL)

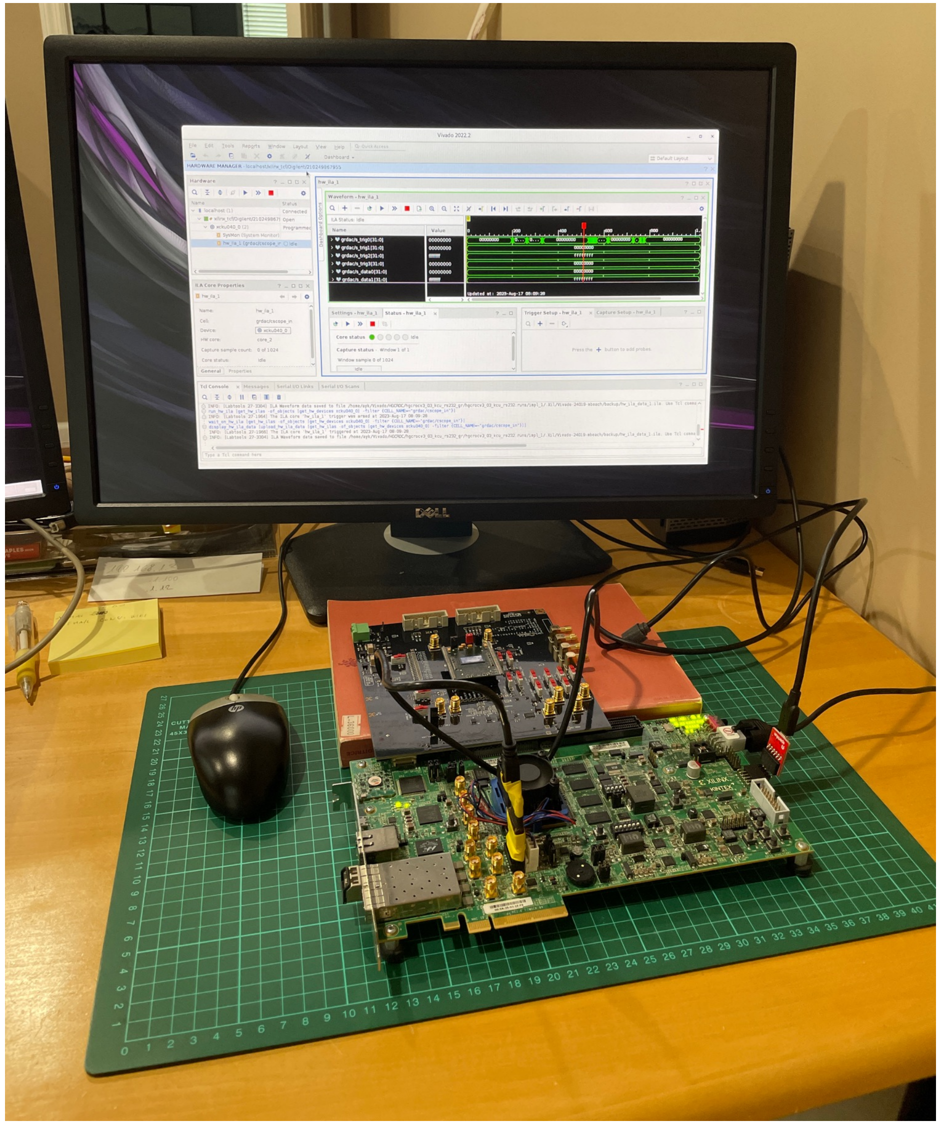


ASIC backplane design
by P. Dinaucourt (IN2P3)

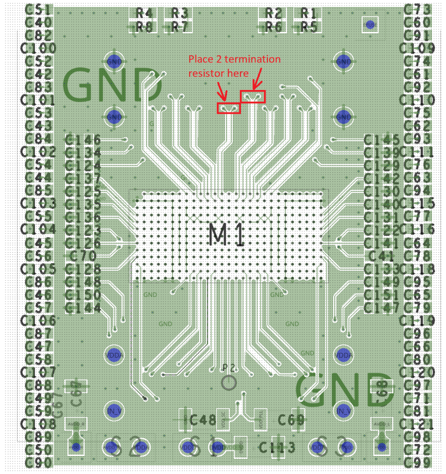


FRONT END BOARD 16 x BGA HGCROC HD 350 0.6mm

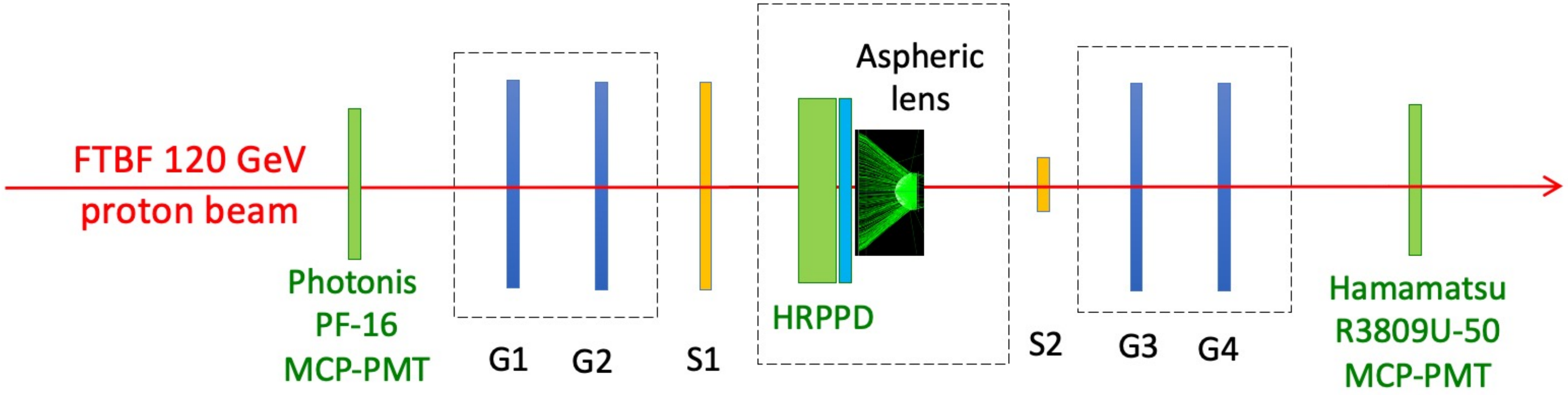
HRPPD ASIC FEE development (DAQ driver)



- A small HGCROC3 installation at BNL
  - Essentially a Linux-based copy of Oak Ridge LFHCal setup
    - KCU105 FPGA kit provided by John Kuczewski (BNL)
    - Carrier board by Norbert Novitzky (ORNL)
    - HGCROC3 mezzanine board by Damien Thienpont (IN2P3)
    - FPGA firmware by Miklos Zeller (Debrecen)
  - Should be sufficient for writing an RCDAQ driver
    - First via USB, then via gigabit ethernet
  - Only partially functional so far
    - Issues with the on-board termination
    - ASIC board on its way to CERN for being fixed



Beam test at Fermilab in early 2024



- Use well-established technique and equipment, in a bare minimum setup
  - GEM tracker (G1 .. G4) & reference MCP PMTs
  - High performance scope & V1742 DRS4 electronics
  - [Passive HRPPD interface board with MCX connectivity]
  - RCDAQ data acquisition system

- Main objectives:
  - Gaining working beam test experience with the new EIC HRPPDs shortly after a primary lab evaluation
  - A direct assessment of HRPPD performance as a t_0 reference sensor for ePIC ToF subsystems
  - Optional confirmation of no long-range cross-talk in a typical “pfRICH ring” configuration

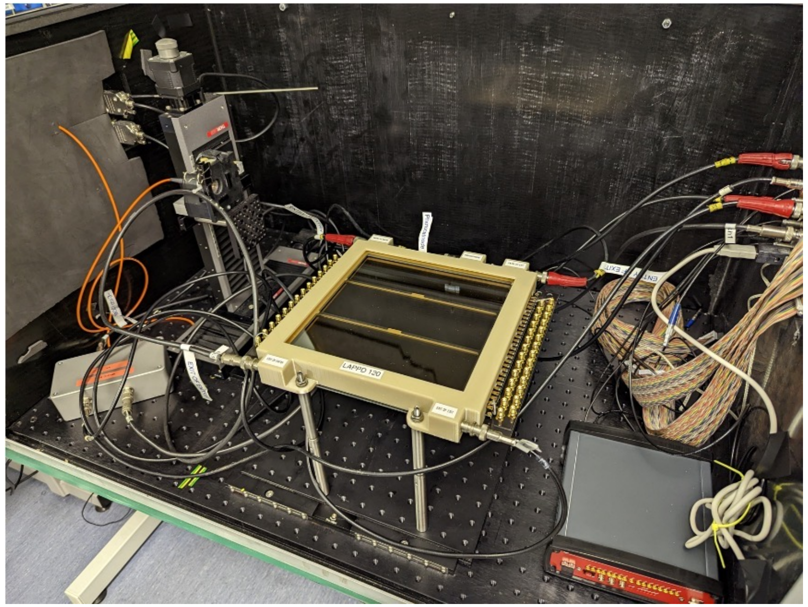
Ageing studies @ INFN

- **Motivations:**
  - **Fundamental study before equipping a detector that has to run > 10 years**
  - **Event more urgent, due to the very short lifetime of 2 preliminary HRPPD prototypes (QE failure)**
- **Strategy** (inspired by various past measurements described in literature)**:**
  - **Test only a small portion of the HRPPD** (not to compromise the whole sensor, repeated measurement at different spots possible)
  - **Collect large integrated charge by illuminating with a lamp with stable intensity and measuring the anode current**
  - **Periodically, pause the illumination, use the pulsed laser source at low rate in single PE mode and check the performance parameters (same as for the test in magnetic field)**
    - Single PE pulse height distribution (gain)
    - Transit Time Spread
    - Effective efficiency
    - After pulse characterization
- **Setup as for previous studies, apart:**
  - SUPER-QUIET MERCURY-XENON LAMP
    - L2422 by Hamamatsu (to be procured)
  - Keithley picoammiter 6485/E
    - (available at the lab)

AGEING STUDIES - procedure cycle

performance check in SPE mode	collect charge by continuos illumination	performance check in SPE mode	collect charge by continuos illumination	...	performance check in SPE mode

MCP-PMT / HRPPD performance evaluation @ UoG



Existing piLas ps laser scanning set up in University of Glasgow - capable of sub-mm scans or flood field illumination

Will be upgraded, mostly to allow for *absolute* gain measurements and increase number of channels readout

- Purchase 1x Photonis Planacon and 1x Photek Auratek MCP PMTs
- Purchase some upgrade equipment for test stand in UoG
  - e.g. 32 channel VME-based CAEN digitiser; calibrated photodiode and optical components…

- Receive 1x new EIC HRPPD and perform basic performance tests (gain, time resolution, scans of response)
- Test HRPPD with digitiser initially, then receive and test with the ASIC readout when it is available

- Perform comparison studies of MCP PMTs, important for DIRC and for contingency planning
- Studies will include: gain, QE, crosstalk/ringing artefacts, time resolution, scans of response

Major milestones

Passive HRPPD integration package	November 2023
Beam test at Fermilab	February 2024
HGCROC3 ASIC backplane + FPGA interface	March 2024
QE uniformity scans at Argonne	Report by May 2024
Test stand upgrade at Glasgow	May 2024
Gain and PDE uniformity scans at BNL	July 2024
Magnetic field studies at Argonne and in Italy	Reports by September 2024
Consolidated HRPPD performance report & assessment	September 2024

These milestones assume funding becomes available in early FY24

Budget request

	ANL	INFN	Glasgow	BNL	JLab	USC
B-field maintenance, He consumption	$8.0k					
B-field studies, QE scans (staff effort support)	$18.0k					
B-field studies, QE scans (engineering support)	$15.0k					
B-field studies (travel)		$16.0k			$4.0k	$4.0k
Consumables for ageing studies		$6.0k				
Postdocs and students		$20.0k				
Beam test travel and freight		$4.0k	$10.0k	$12.0k	$4.0k	
Five HRPPD passive integration packages				$12.0k		
HRPPD ASIC integration package				$15.0k		
Samtec compression interposers				$16.0k		
Photek / Photonis MCP-PMT procurement						$50.0k
Photek / Photonis MCP-PMT interface				$4.0k		
Test stand M&S and technical support	$2.0k		$9.0k	$8.0k		$16.0k
TOTAL	**$43.0k**	**$46.0k**	**$19.0k**	**$67.0k**	**$8.0k**	**$70.0k**

A full breakdown of costs per position is given in the proposal text

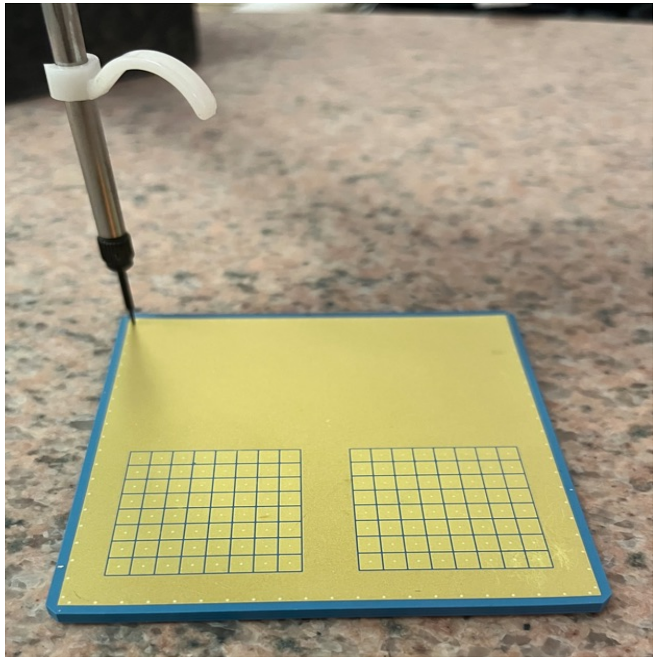
Summary

- HRPPD is a baseline photosensor for pfRICH and its use is possible for 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 (Incom)
  - Lab evaluation
  - Beam tests, including a full chain pfRICH prototype test with HRPPD sensor plane
  - Magnetic field resilience studies
  - Ageing studies
- We propose to resume other MCP PMT evaluation as a fallback strategy

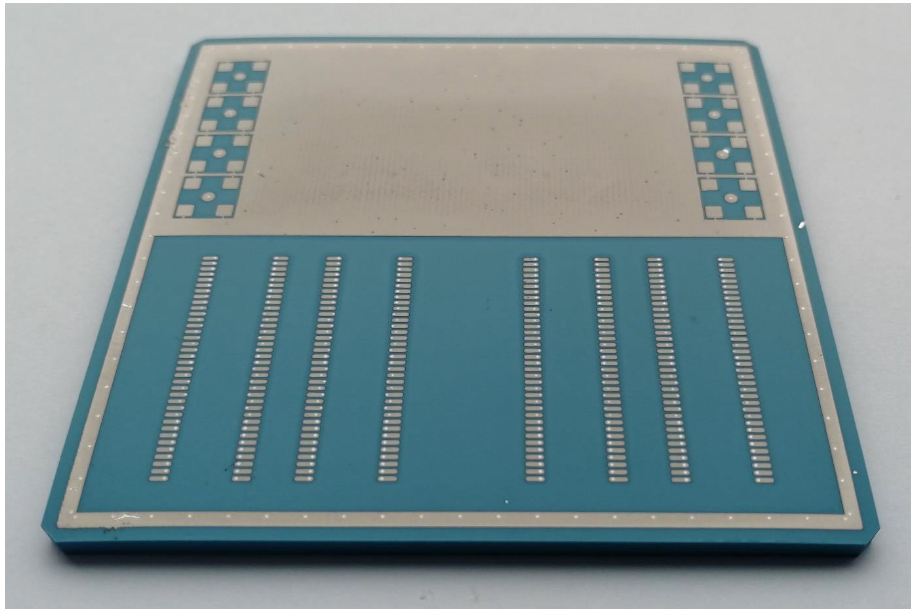
Backup

Small size LTCC prototypes by Techtra (Poland)

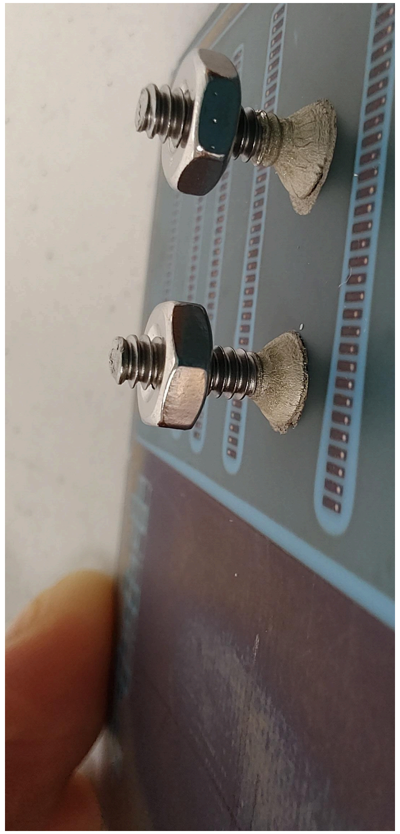
- First two 3” LTCC anode plates were examined at Incom
  - Flatness is tolerable on a 3.0mm thick plate
  - Vacuum tightness of the 3.0 mm thick plate confirmed



flatness check on the inner side



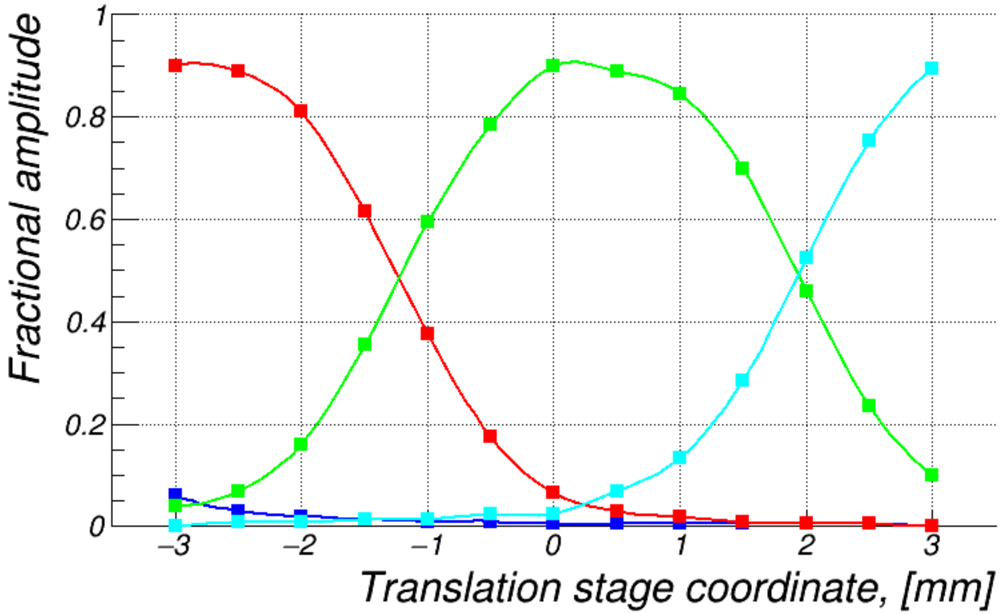
outer (connector) side

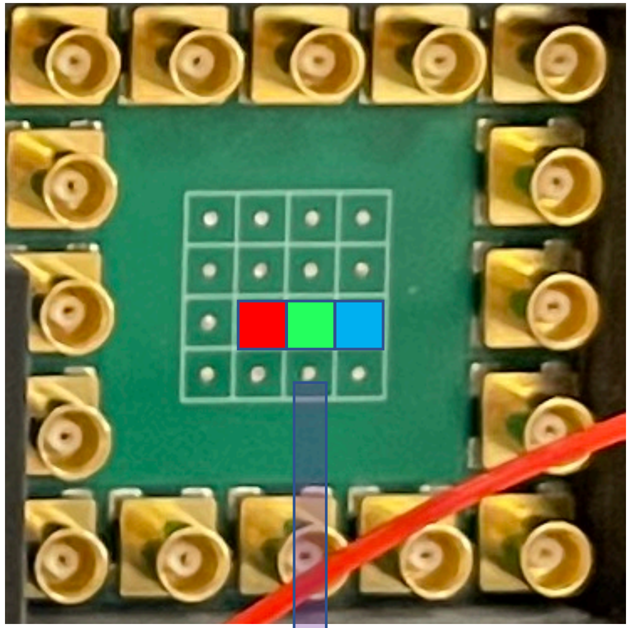


brazed screws

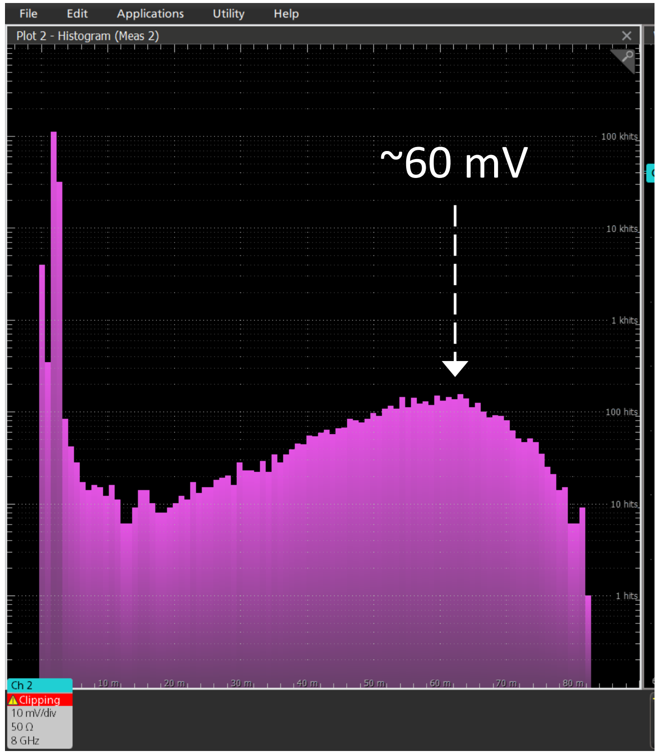
vacuum tightness check

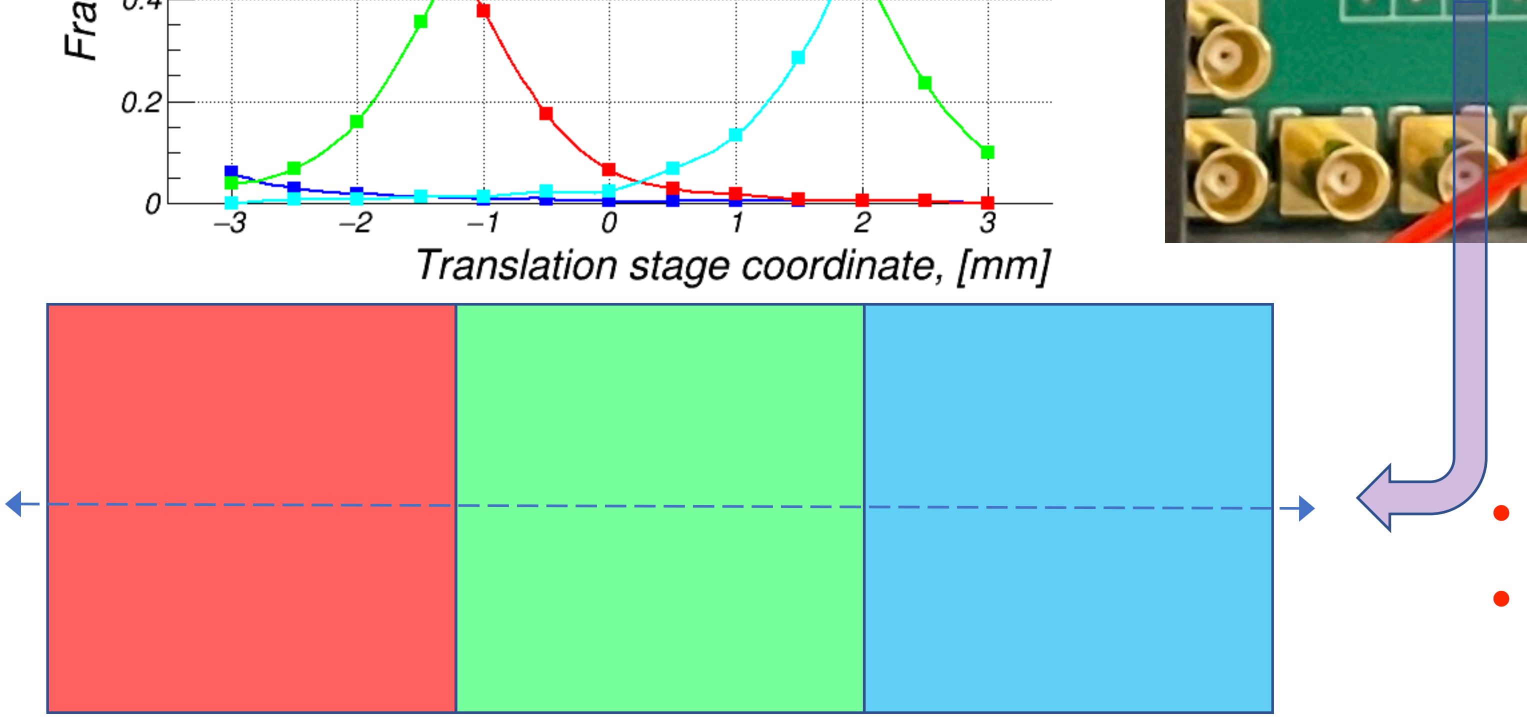
HRPPD #6: signal amplitude, charge sharing





Amplitude spectrum on a scope

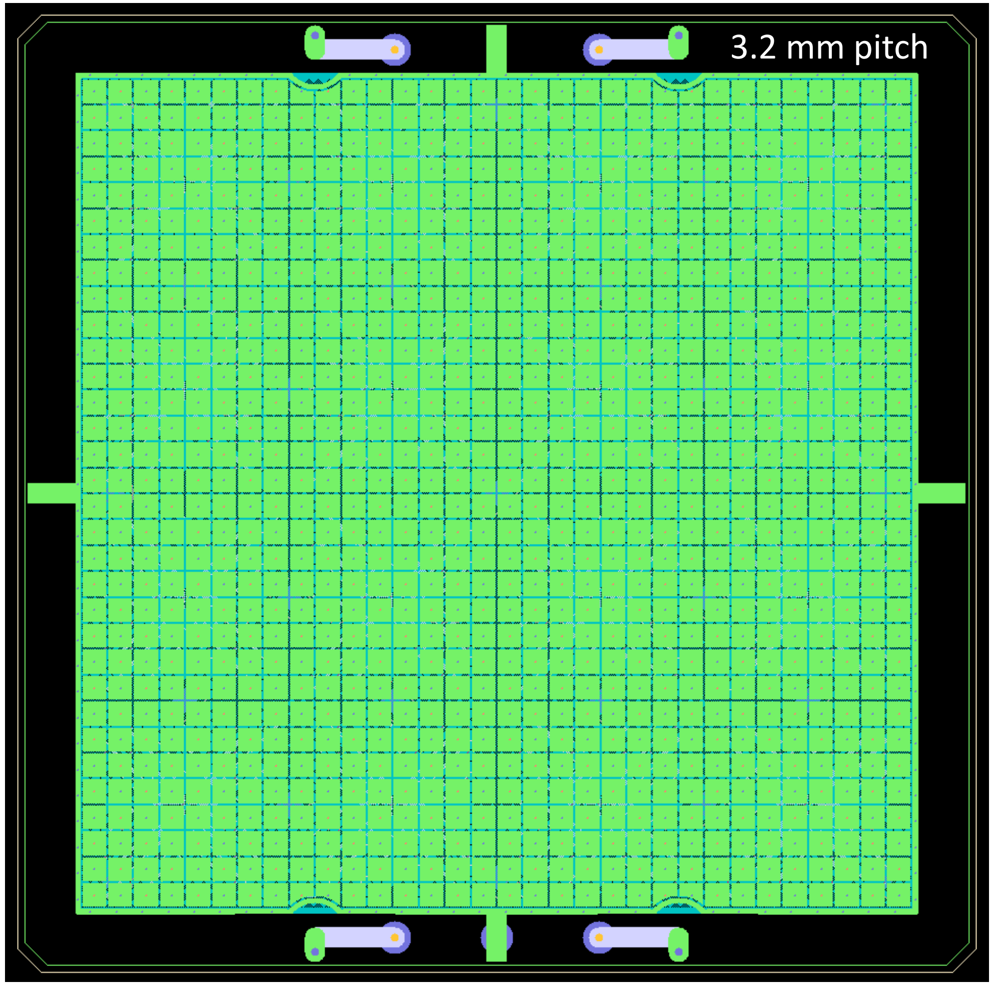




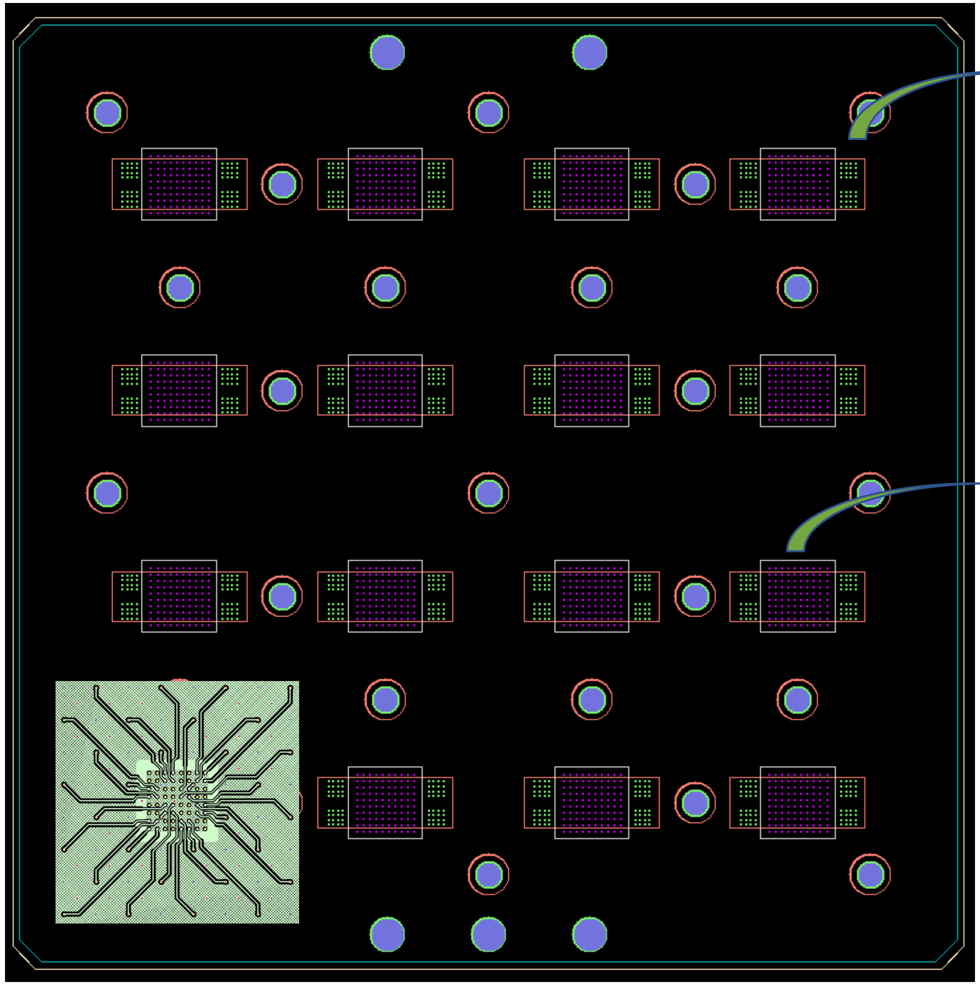
amplitude scan across three neighbor pads

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

Full size HRPPD anode base plate prototype

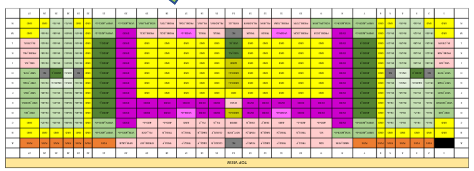


Inner side of a 32x32 pad ceramic base plate



Outer side overlaid with a 16x HGCROC PCB template

600 μm pitch



HGCROC ASIC

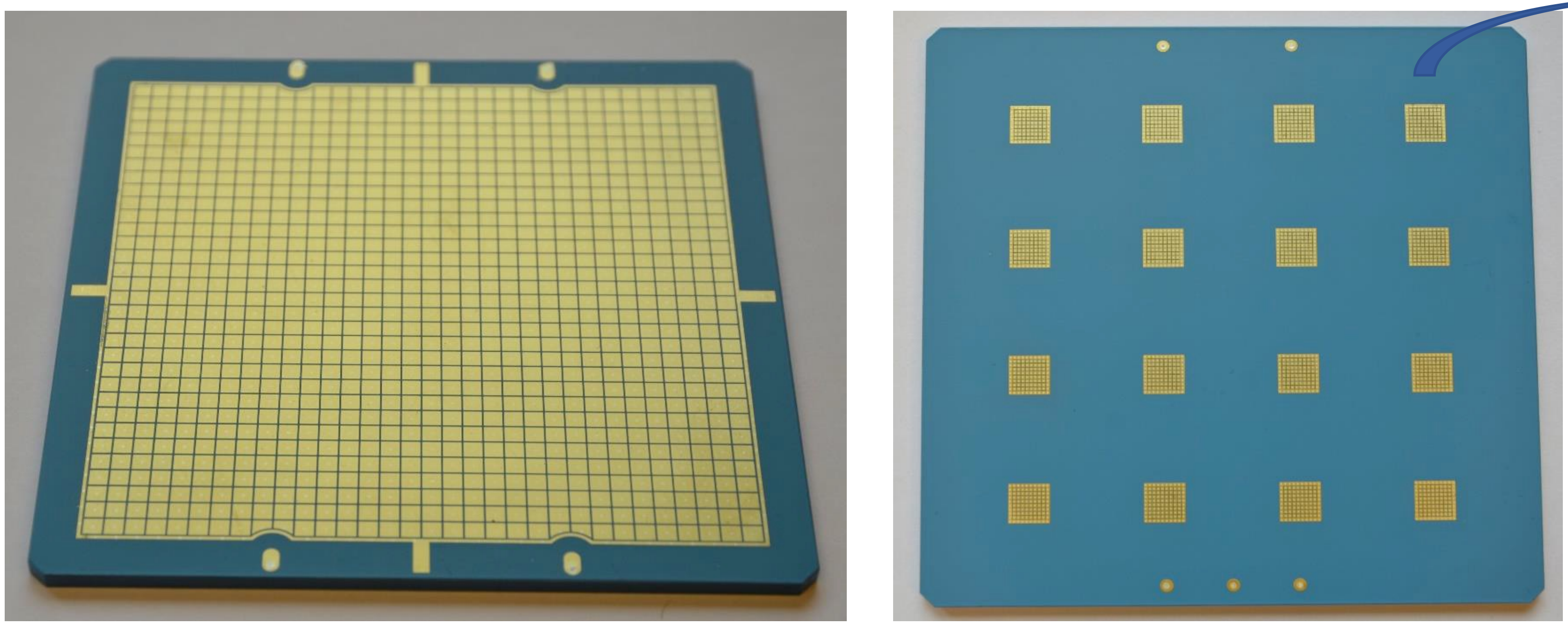
800 μm pitch

Samtec interposer

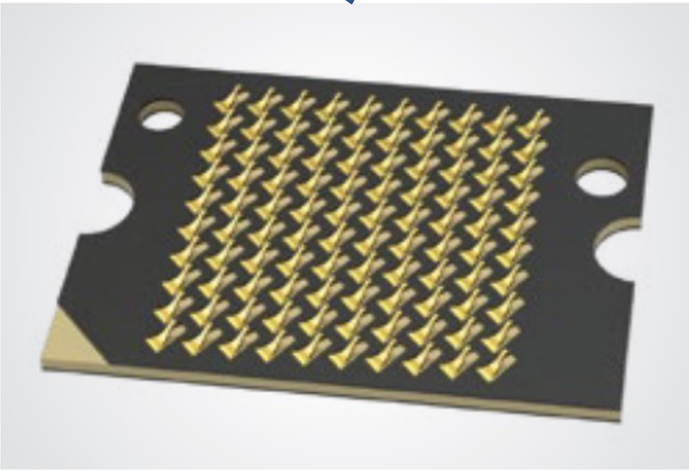
Solder Ball Option

BeCu Compression Contacts

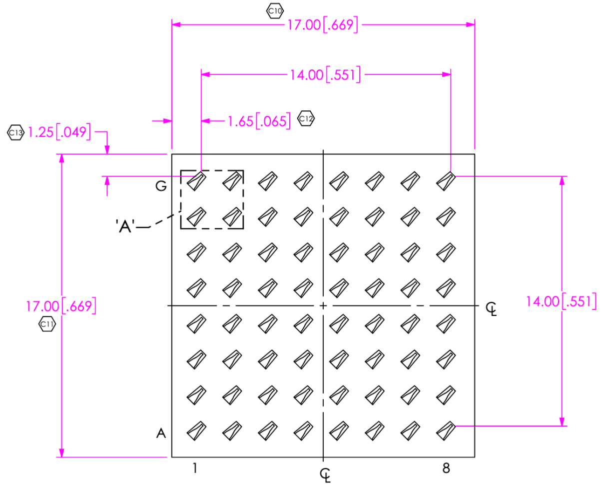
Full size HRPPD anode base plate prototype



Full size (120mm) HRPPD anode plate by Techtra



Stock interposer with 800 μm pitch

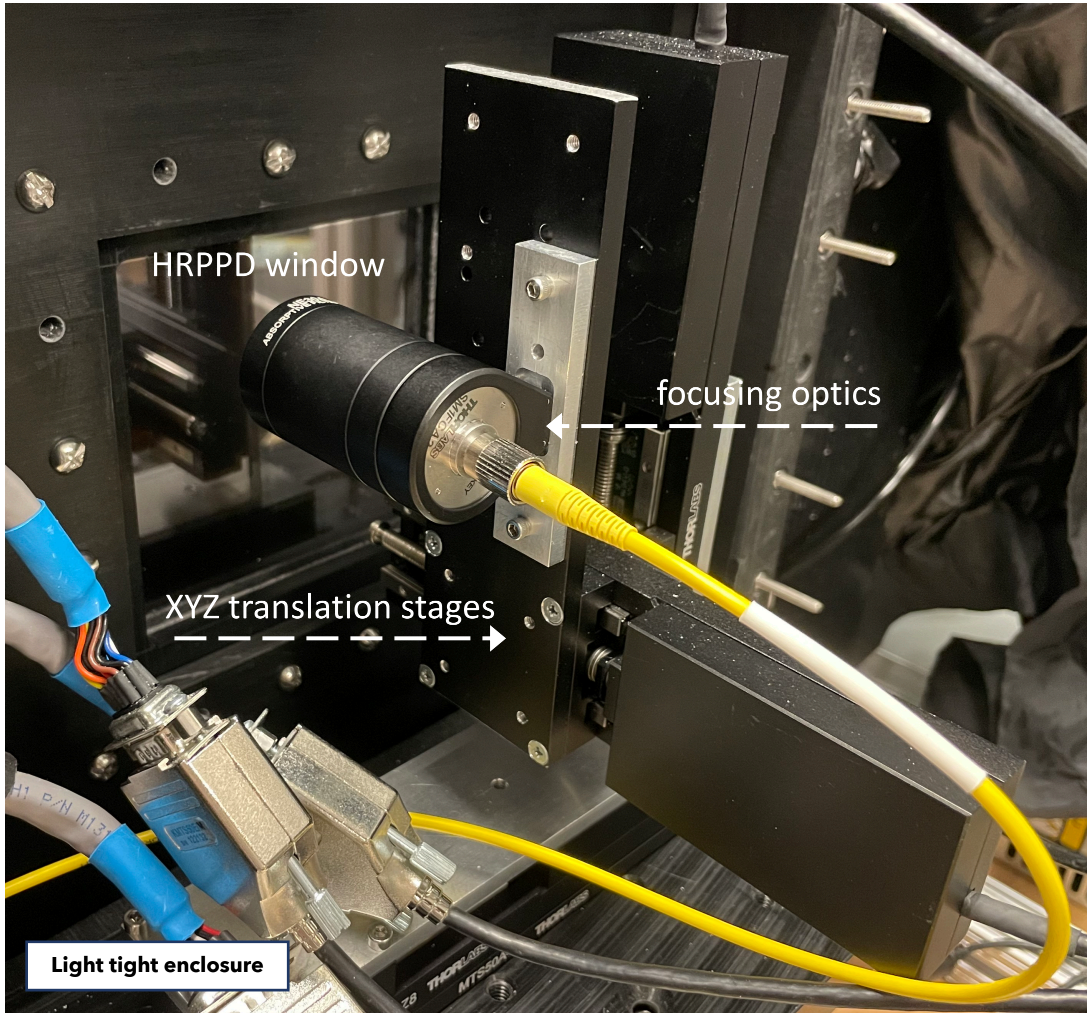


Custom interposer with 2mm pitch

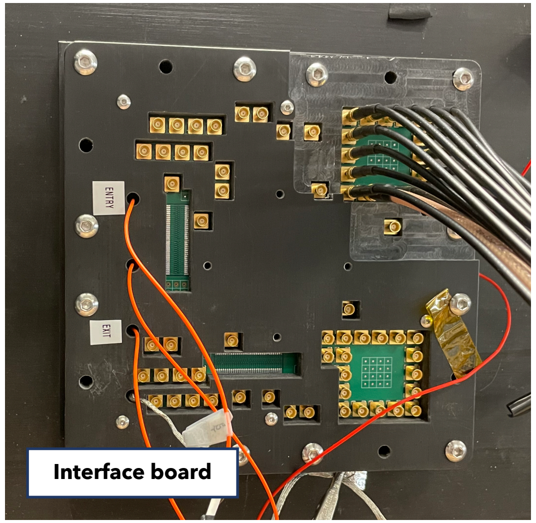
- Looks fine, but a lot of shorts inside -> specs are relaxed for next iteration
- A matching readout PCB and stock Samtec interposers are delivered
  - Will check integration once the anode plate gets shipped to the US (next week?)
- Use custom Samtec interposers with a 2mm pitch?

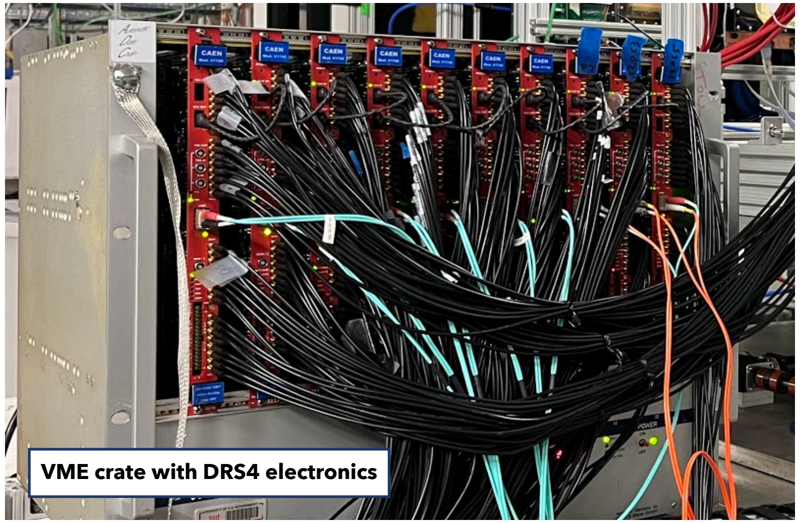
- Once all this is confirmed to work, pixellation of the DC-coupled HRPPDs becomes *almost* as much configurable as Gen II ones

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

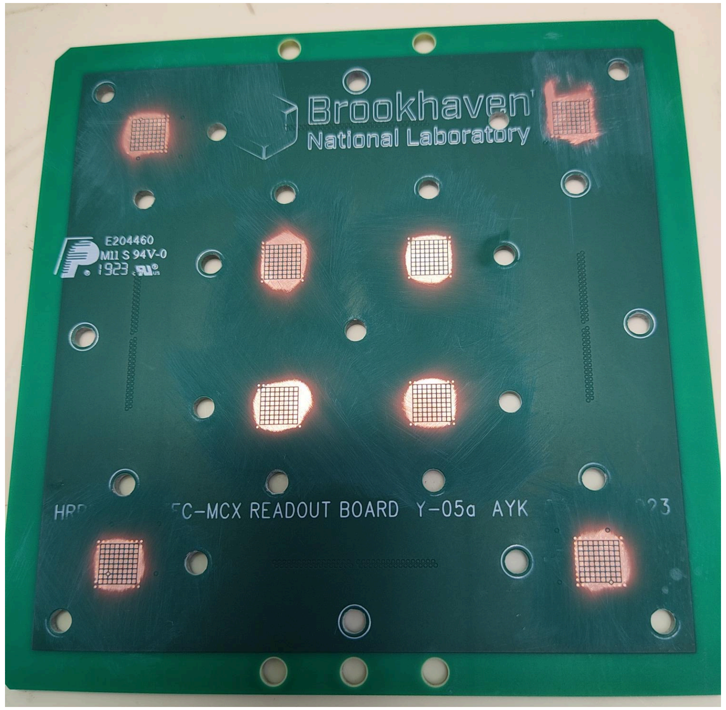




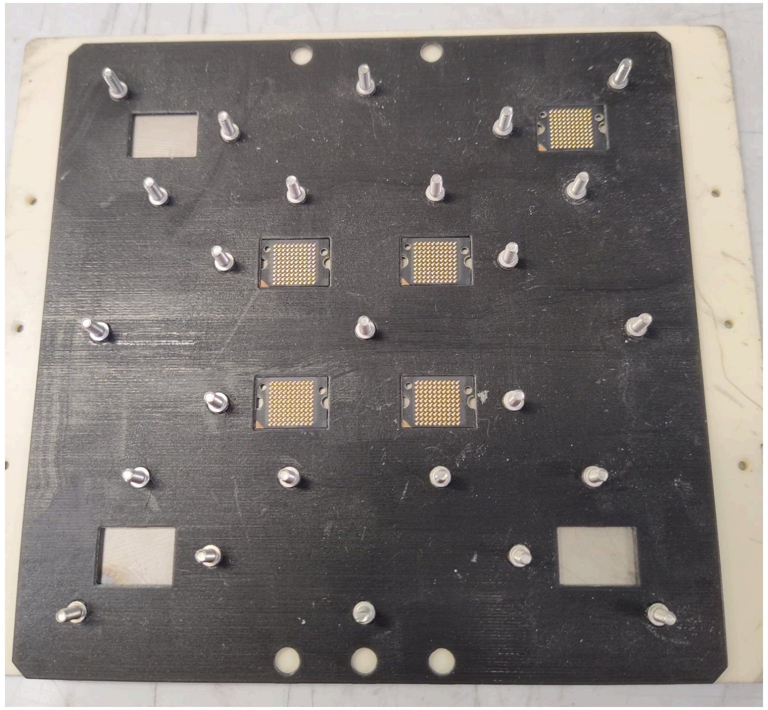
Similar setups exist at Argonne, INFN Trieste & Glasgow, however they are all oriented on capacitively coupled LAPPDs, and typically, have only up to 32 channels of DRS4 electronics

First iteration: a matching Y05a connector board

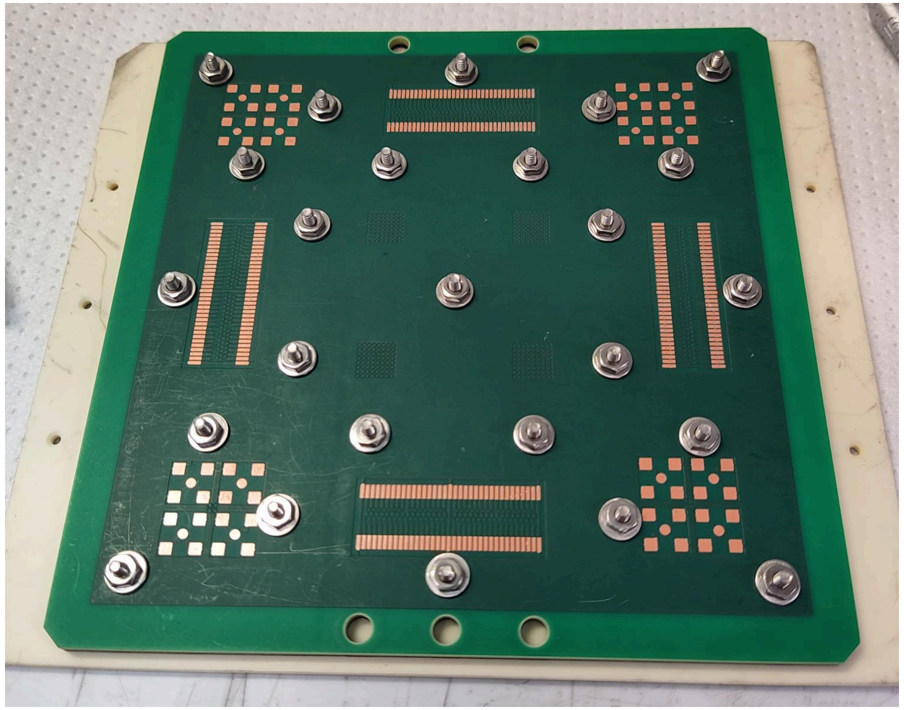
Case #1: double-sided (floating) 800 μm pitch Samtec interposers



Bottom (interposer) side



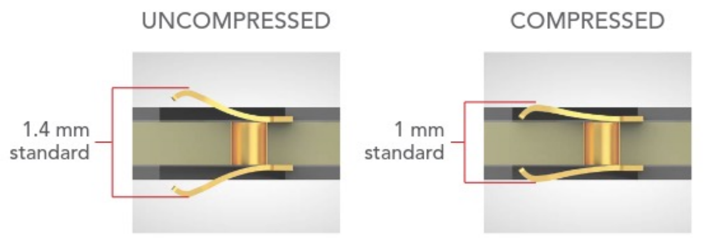
3D printed spacer, screws, interposers



Full assembly; top (connector) side

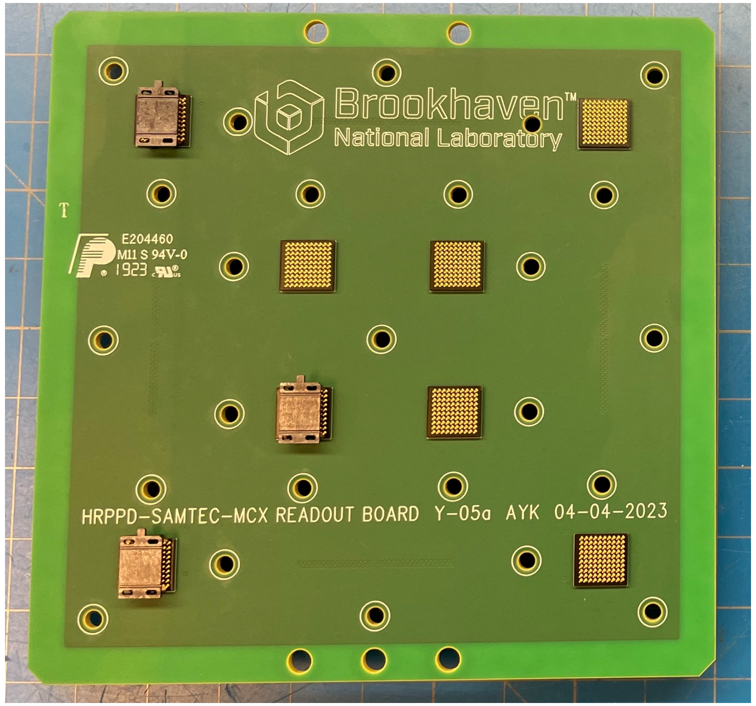
-> Electrical connectivity is confirmed, as well as mechanical integration overall

Next step: signal quality check

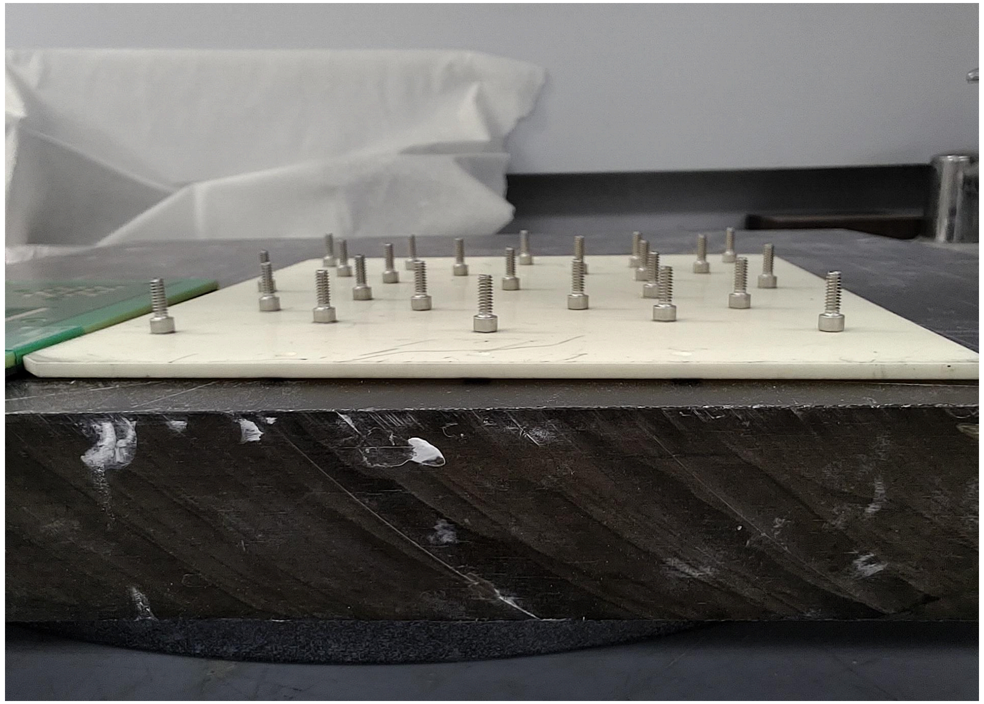


First iteration: a matching Y05a connector board

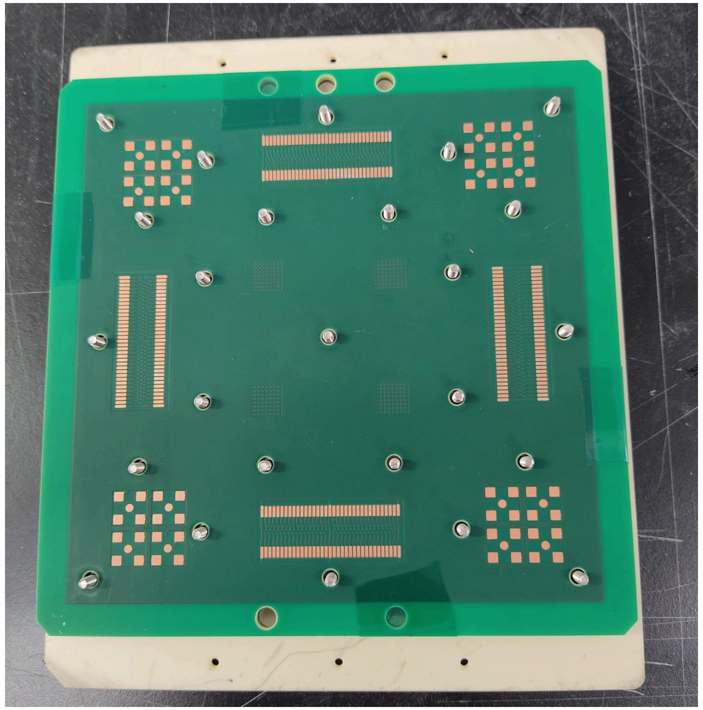
Case #2: single-sided (soldered) 800 μm pitch Samtec interposers



Bottom (interposer) side



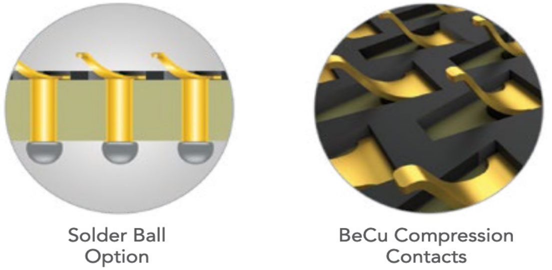
Screws epoxy glued onto a dummy ceramic plate



Top (connector) side

-> Have not been tried out yet
(but is not a leading option either)

HRPPD anode plate side



ASIC PCB side