eRD110 FY25 Progress Report

Alexander Kiselev (BNL) on behalf of the eRD110 Consortium

ePIC / EIC Project Detector R&D Days, April 16-17, 2025

eRD110 milestones in P6

eRD110 (Photosensors)

Ensure applicability of SiPM readout for Ring-Imaging Cherenkov detectors. This implies validation of operation in the single photon regime, and studies of irradiation and in-situ annealing to ensure operation in a "radiation damaged and annealed" mode is possible. [September 2022]

Done. Per 2024 Detector R&D Day: complete. Continuation of the studies is driven by INFN as part of the PED effort.

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

Obsolete. Production readiness of HRPPDs is captured as PED effort. Engineering test article of proximity-focusing Ring-Imaging Cherenkov Detector ongoing. Performance evaluation of the first seven EIC HRPPDs is ongoing, including aging and B-field studies at JLab, BNL and INFN Trieste. A final EIC HRPPD design iteration and a small batch production is being planned in 2025 as a renewed PED contract with Incom, Inc. Beam test(s) planning in 2026-2028 will depend on Fermilab FTBF and CERN PS availability, as well as on the progress with ASIC front-end electronics.

SiPM FY22 milestones

1. Comparative assessment of commercial (and prototypes not yet available on the market) of SiPM performance after irradiation.

Accomplished. Irradiation campaigns done on sensors produced by HPK, OnSemi, FBK. Results reported at various conferences and related proceedings.

See for example: R. Preghenella @ RICH2022 DOI: *Nucl.Instrum.Meth.A* 1058 (2024) 168834

2. Definition of an annealing protocol

Accomplished. Experimental results about damage and ability to recover the sensors via annealing obtained with different techniques and used to elaborate ageing model as a function of irradiation at EIC. Results reported at various conferences and related proceedings.

See for example: R. Preghenella @ EPS-HEP2023 DOI: https://pos.sissa.it/449/515

FY25 activities and budget

Slide contents as shown in August 2024 DAC Review

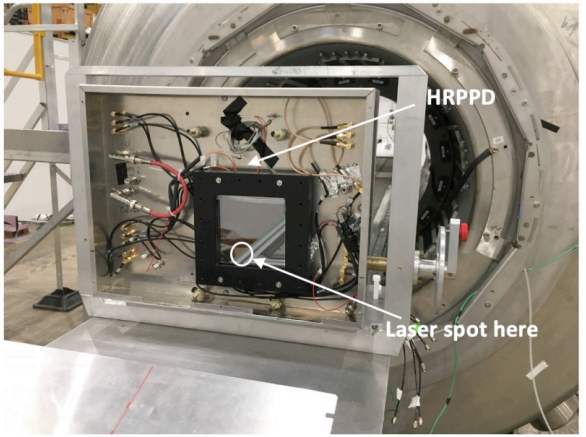
- Essentially a continuation / finalization of approved FY24 activities:

Activity	Group(s)	Funding request
B field studies at Argonne	ANL / BNL / JLab / USC	FY24 carryover
HRPPD ageing studies	INFN	$20k
HRPPD timing studies	BNL	$7k
MCP-PMT performance evaluation	Glasgow	None

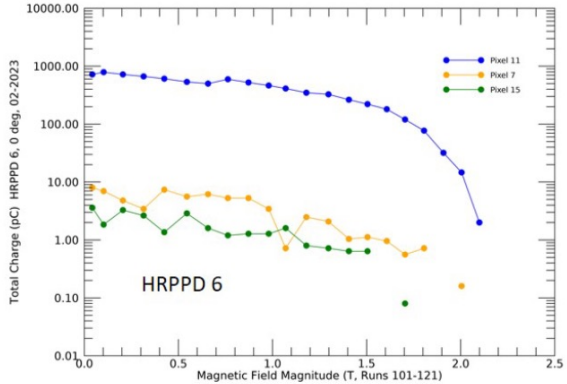
- Deliverables are comprehensive reports on concluded activities in the above table, by the end of FY25:
  - Confirmation of Photek MCP-PMT resilience to expected ePIC B-field
  - Confirmation of HRPPD resilience to expected extracted charge for ePIC pfRICH
  - Evaluation of HRPPD timing performance as a fallback option for hpDIRC application
  - Assessment of Photek MCP-PMT as an HRPPD fallback option for ePIC pfRICH

Performance studies in a B-field at Argonne

- Generic LAPPDs and first available HRPPD were tested at the Argonne g-2 magnet in 2022-2023
  - Gain decreases as the magnetic field strength increases
  - Gain can be recovered by increasing the bias voltage of the MCPs and the photocathode
  - Conclusion: HRPPDs would work for hpDIRC and pfRICH, not suitable for dRICH due to the sensor plane orientation
- FY24: Photek MCP-PMT testing planned



HRPPD #6 (with 10 μm pores) operational up to ~1.8 T

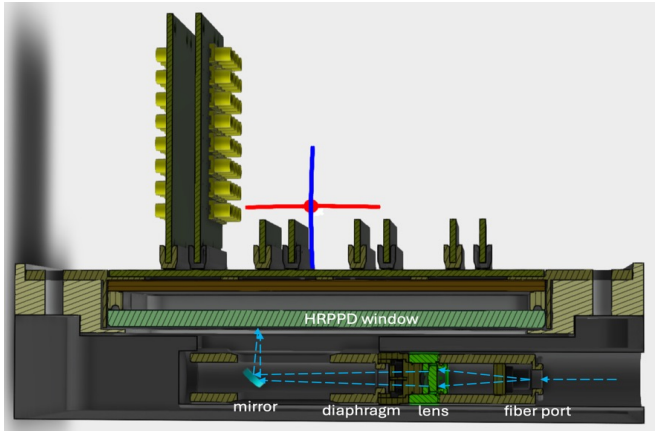


Tasks	Timeline
Magnetic field test facility at Argonne ready for 2'' MCP-PMTs	June 2024
Receive MCP-PMTs, ready for fitting and test	July 2024
Magnetic field test of received MCP-PMTs	Aug 2024
Magnetic field tolerance report	Dec 2024

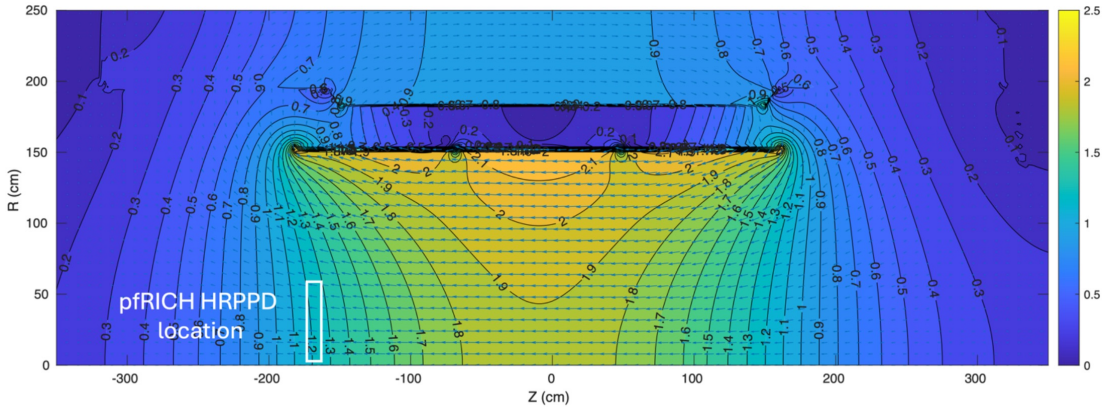
Slide as shown in March 2024 R&D Day report: a one-year delay in conducting these studies (waiting for a Photek MCP-PMT)

HRPPD B-field studies at BNL

A type 18D72 2.2 Tesla dipole with a 6” gap



Dark “box” setup



ePIC MARCO solenoid field map

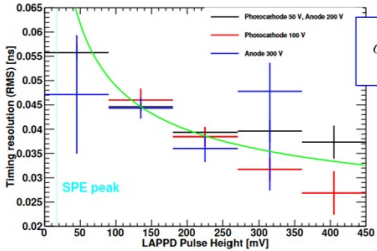
- All optical components as shown in the above picture have been received
- Mechanical setup is being finalized

Measurements in May 2025

LAPPD studies by INFN groups(*)

PAST

Timing characterization at test beam, detecting Cherenkov light



$$\sigma_t = p_0 + \frac{p_1}{\sqrt{V_{peak}/1V}}$$

Single photon time resolution: 75 ps

Asymptotic limit for large amplitude (multiple detected photons) : 18 ps

Nuclear Instruments and Methods in Physics Research A 1058 (2024) 168937

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

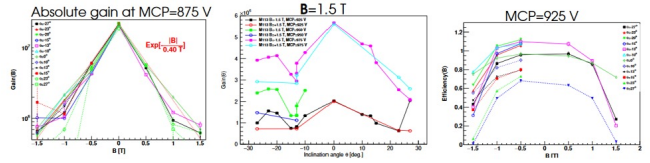
journal homepage: www.elsevier.com/locate/nima

Full Length Article

Characterization of LAPPD timing at CERN PS testbeam

Deb Sankar Bhattacharya [a], Andrea Bressan [a,b], Chandradoy Chatterjee [a], Silvia Dalla Torre [a], Mauro Gregori [a], Alexander Kiselev [c], Stefano Levorato [a], Anna Martin [a,b], Saverio Minutoli [d], Mikhail Osipenko [d,*], Richa Rai [a], Marco Ripani [d], Fulvio Tessarotto [a], Triloki Triloki [a]

➢ **Two campaigns of measurements in magnetic field at CERN**



- tests performed at CERN MNP-17 and M113 magnets,
- LAPPD gain drops exponentially with **B**-magnitude,
- gain reduction was almost independent of the field angle, except $\theta = -13$ deg. and $|\theta| \geq 20$ deg.,
- at **B**>0 MCP bias could be increased on +100 V beyond limits, reaching at 1.5 T 1/3 of **B**=0 gain,
- efficiency is also reduced in magnetic field, especially at $\theta = -13$ deg. and $\theta \geq 13$ deg.,
- most of inefficiency **B**-dependence can be recovered by increase of MCP and PC biases.

Nuclear Instruments and Methods in Physics Research A 1072 (2025) 170122

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

Full Length Article

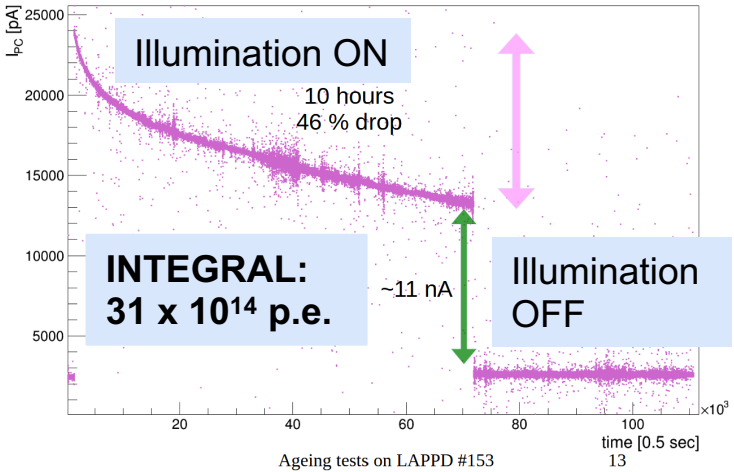
Performance of an LAPPD in magnetic fields

Jinky Agarwala [a], Andrea Bressan [a,b], Chandradoy Chatterjee [a], Silvia Dalla Torre [a], Mauro Gregori [a], Stefano Levorato [a], Anna Martin [a,b], Saverio Minutoli [c], Mikhail Osipenko [c,*], Richa Rai [a], Marco Ripani [c], Fulvio Tessarotto [a]

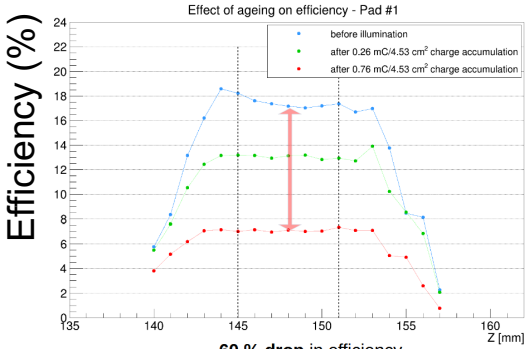
(*)INFN groups: Trieste & Genova

HRPPD aging studies by INFN groups

➢ **Preliminary measurement using an LAPPD (Summer 2024)**



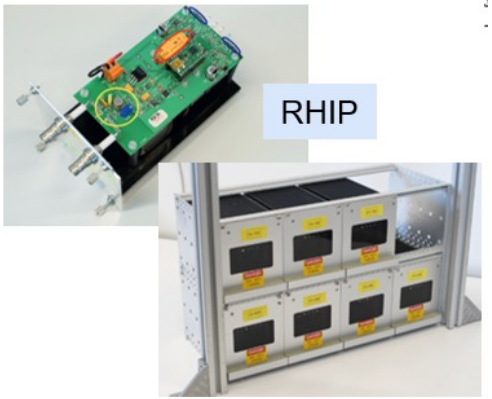
Clear evidence of ageing



The quantification and monitoring of all the parameters was not yet well established for this preliminary test → learning about the strategy and needed equipment

HRPPD aging studies by INFN groups

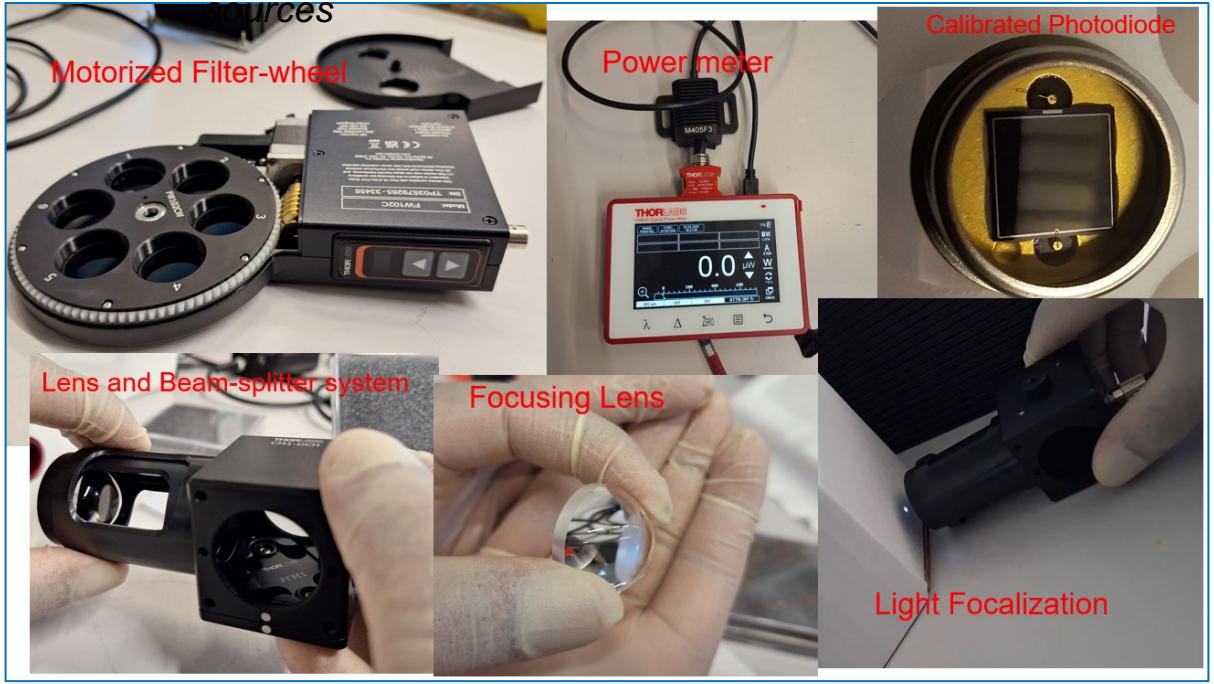
➢ Dedicated equipment



fully floating remotely controlled picoampermeters *(custom RHIP: http://dx.doi.org/10.22323/1.322.0068)*

RHIP system makes possible the current measurements at all electrodes (also at the photocathode)

Equipment for the control and monitoring the light sources

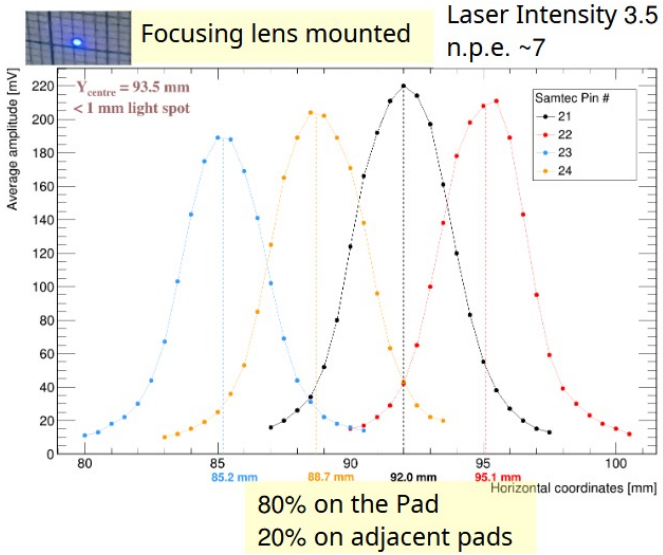


HRPPD aging studies by INFN groups

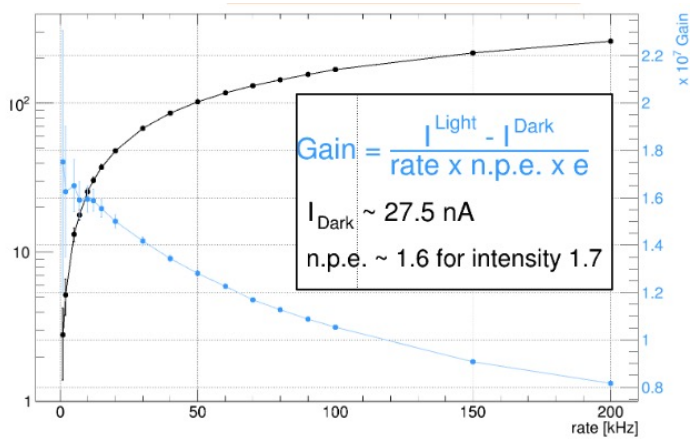
First HRPPD at INFN: end of December 2024

- **Preparatory exercises, examples**

Pad response scanning with a focused light source



Gain saturation as effect of increasing light intensity

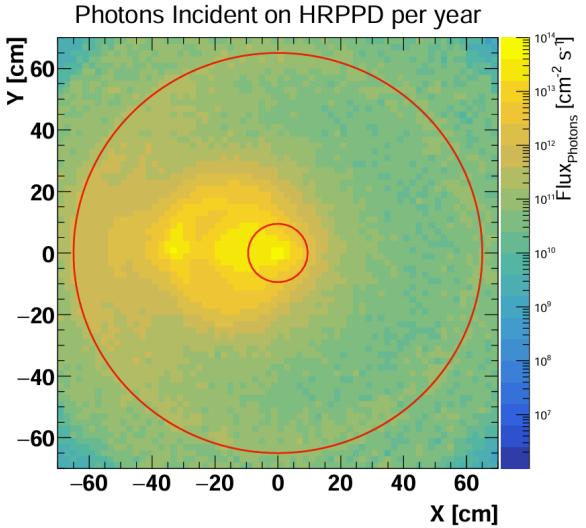


HRPPD aging studies campaign

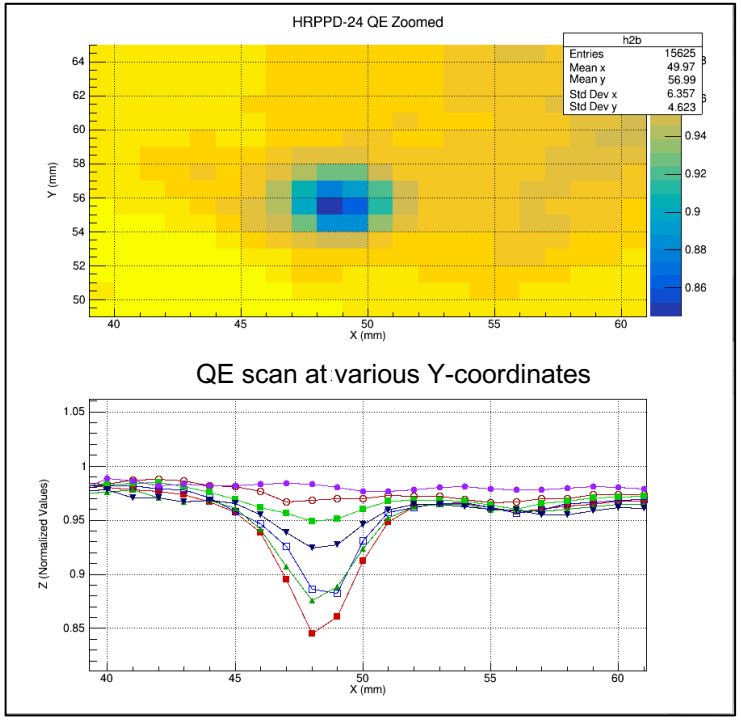
Measurements are starting in April 2025

- Setups at JLab / BNL / INFN Trieste
- Experts in LAPPD aging (UT Arlington) participating
- Expected photon fluence at ePIC pfRICH location modeling by BNL and Yale

https://indico.bnl.gov/category/605/



Monte-Carlo charged particle fluence estimate



First HRPPD aging data from JLab
[after ~2*10^{19} γ/cm^2 irradiation at a nominal HV]

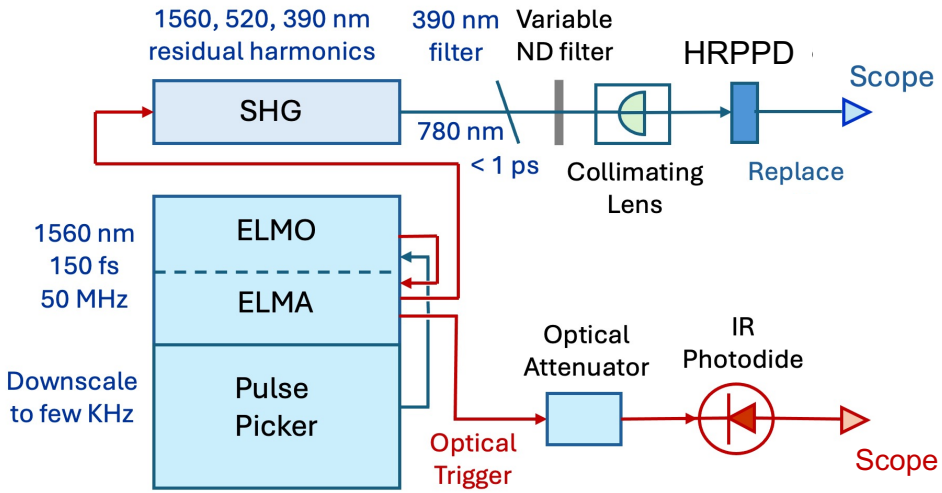
Elmo 780 femtosecond laser at BNL

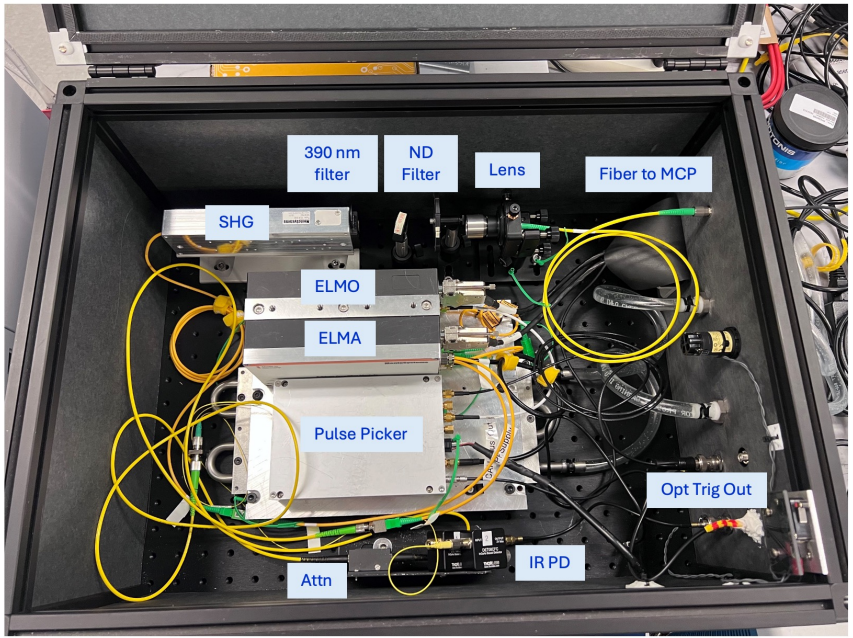
Menlo Systems Elmo 780 Erbium Fiber Femtosecond Laser

ELMO = Primary Laser Oscillator

ELMA = Optical Amplifier

SHG = 2nd Harmonic Generator

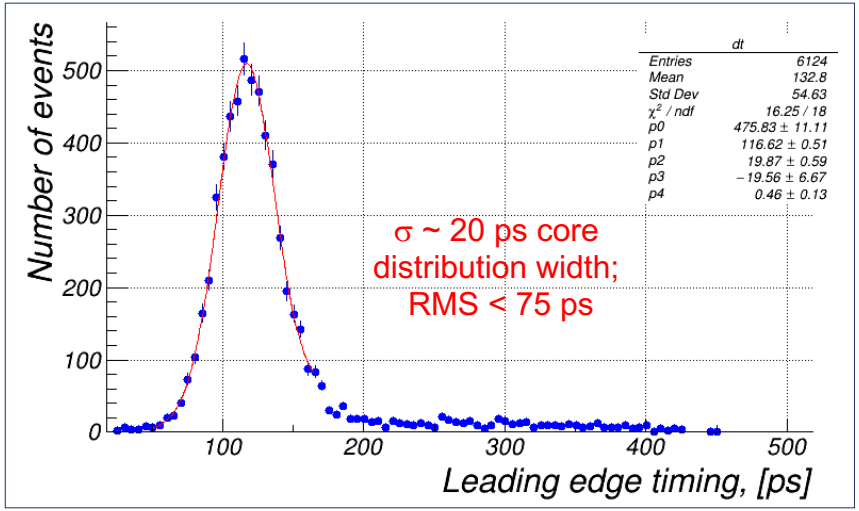


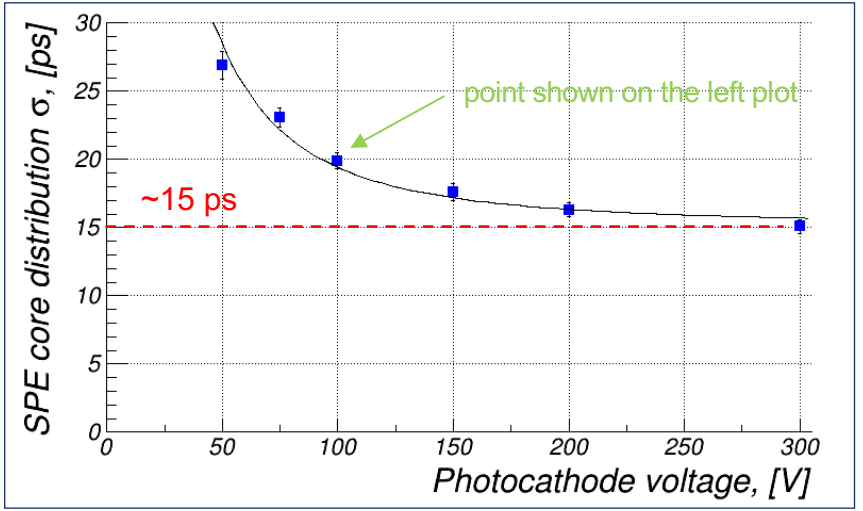


We make use of a very low intensity 3rd harmonic @ 390 nm

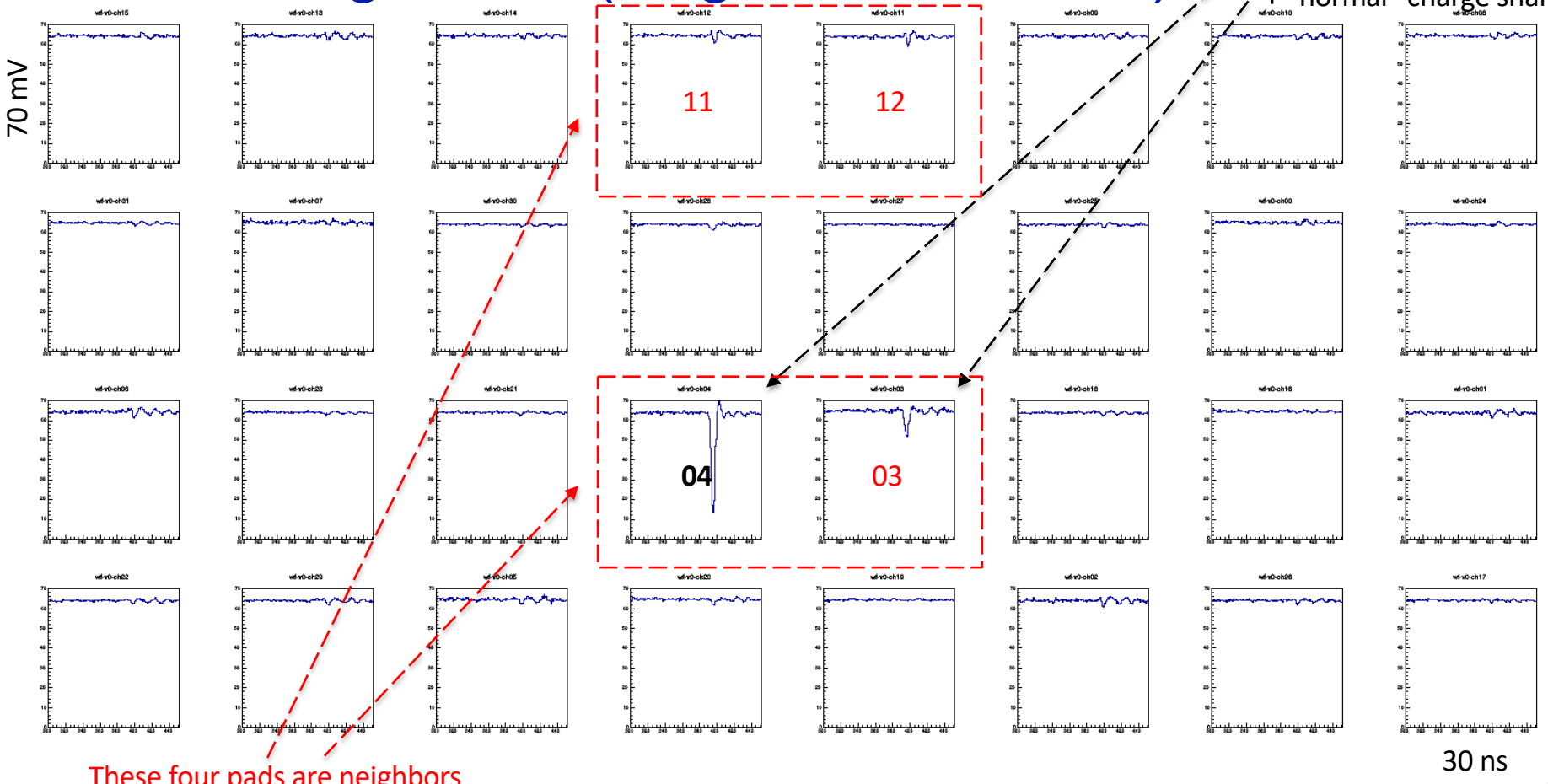
HRPPD single photon timing resolution

- Laser beam focused on a single HRPPD pad center; intensity tuned down to >95% empty events
- HRPPD signal used for triggering (5 mV effective threshold)
  - To increase data taking efficiency
- Signal waveform data taken with a Tektronix MSO66B scope (50 GS/s, 8 GHz ABW)
  - Leading edge fits [10% .. 90%] performed offline; $\Delta t = t_{HRPPD} - t_{FastPD}$ is a plotted quantity



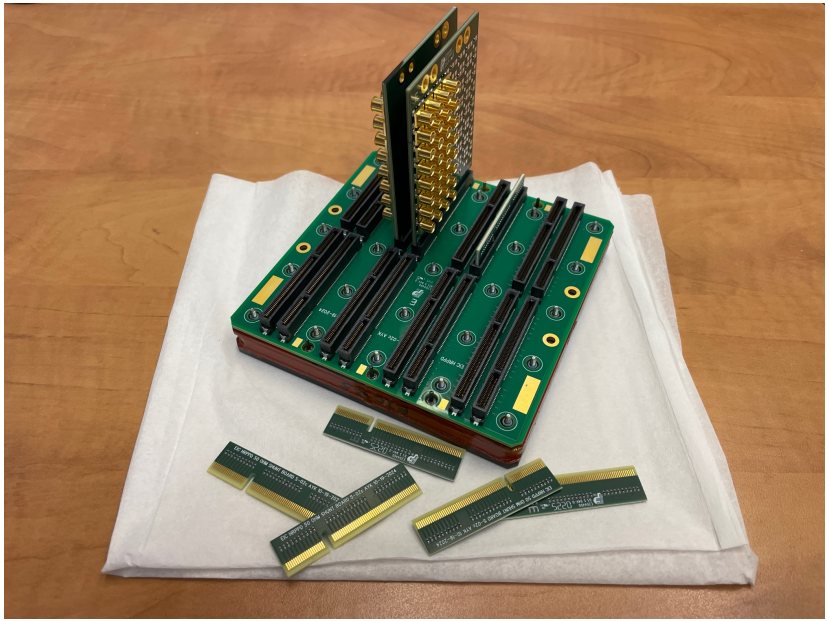


Crosstalk signature (August 2024 slide)

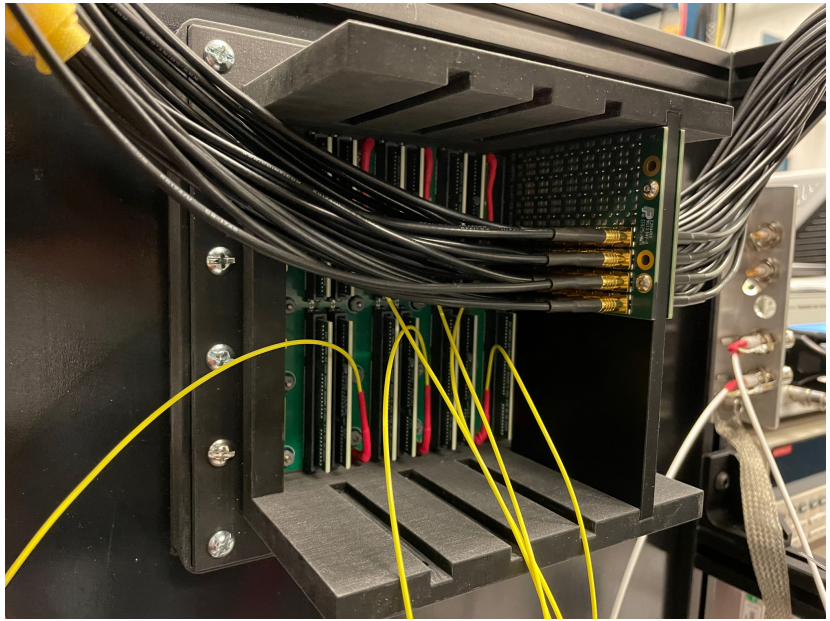


Waveforms of 8x4 neighboring pads (one event; single photon)

Backplane with a better trace isolation



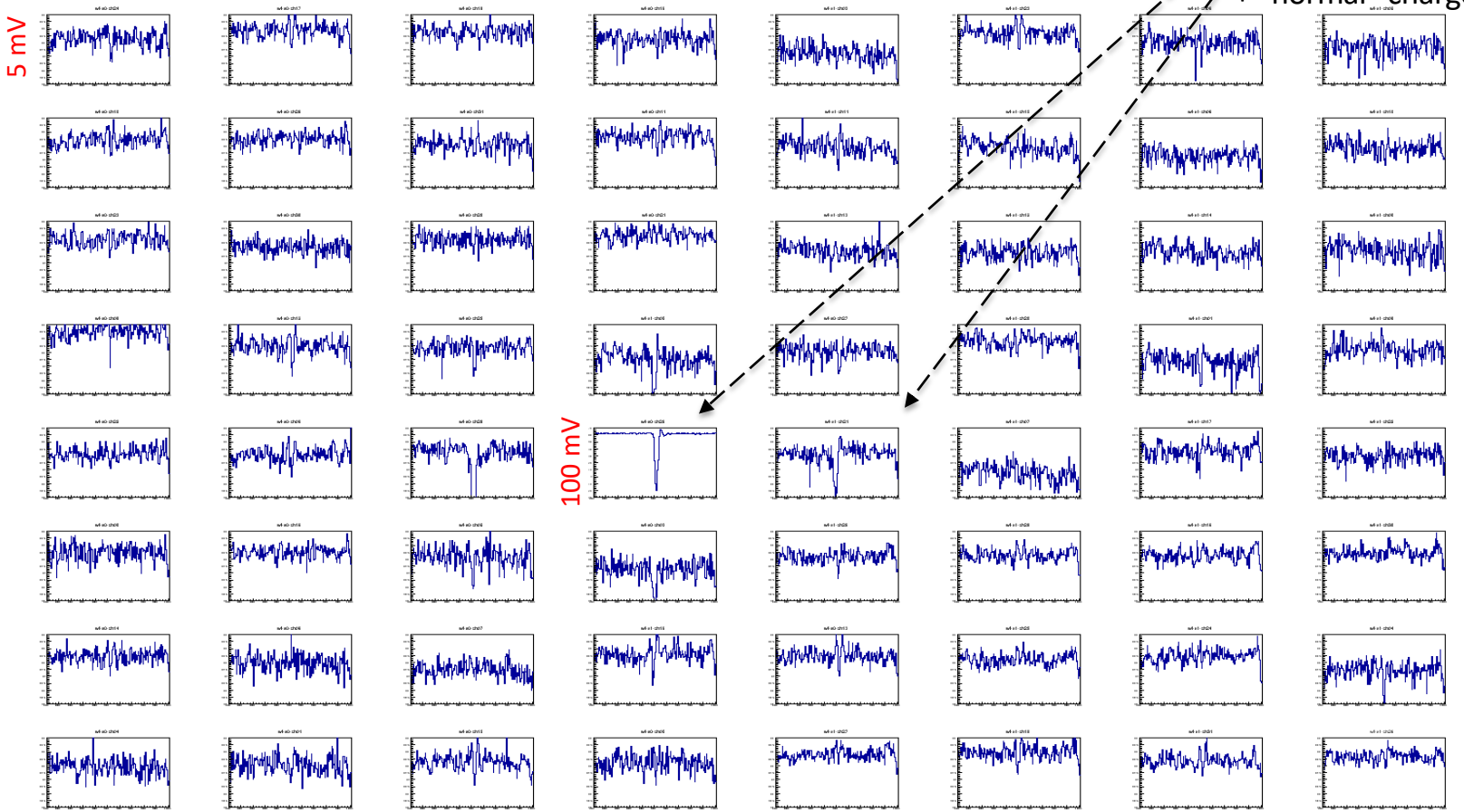
Q02c backplane, MCX adapters,
50 Ohm termination cards



HRPPD with this backplane mounted
in a QA station at BNL

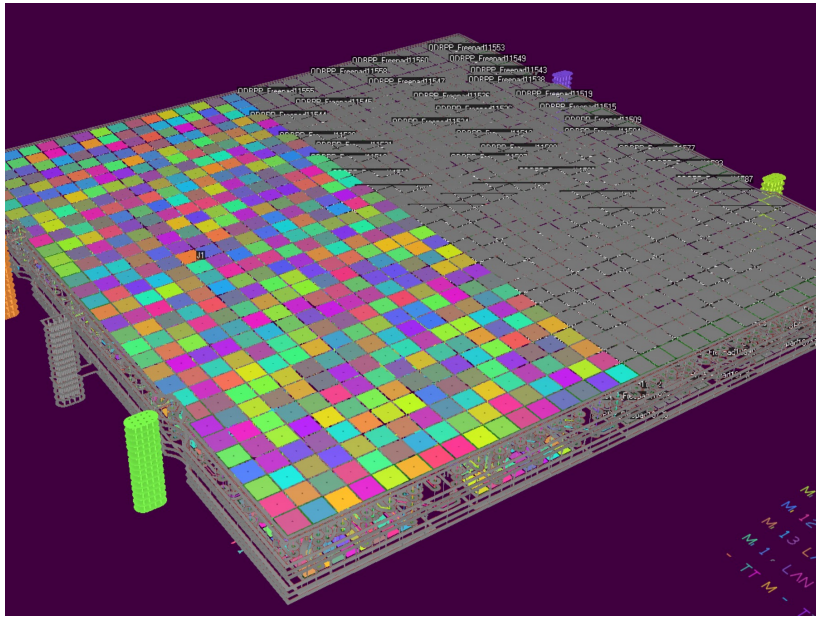
- Substantially improved grounding / individual trace isolation
- 50 Ohm termination of un-instrumented pads

Evidence of a reduced cross-talk



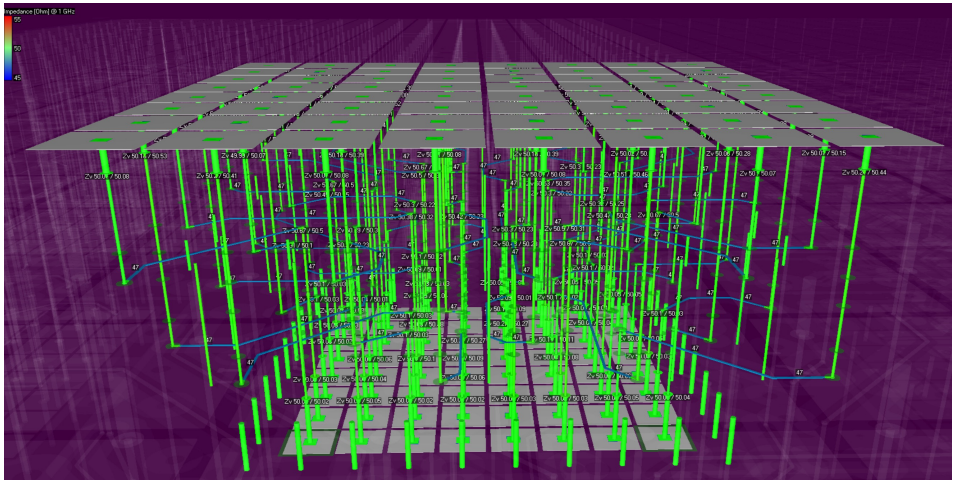
Cross-talk reduced to ~1-2% level? [TBC]

HRPPD + backplane signal modeling at JLab



A full HRPPD anode stackup

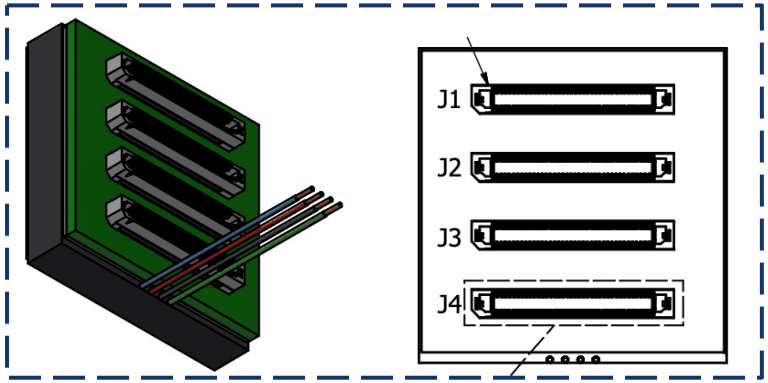
Use SIMBEOR (3D Electromagnetic Signal Integrity Modeling Software)



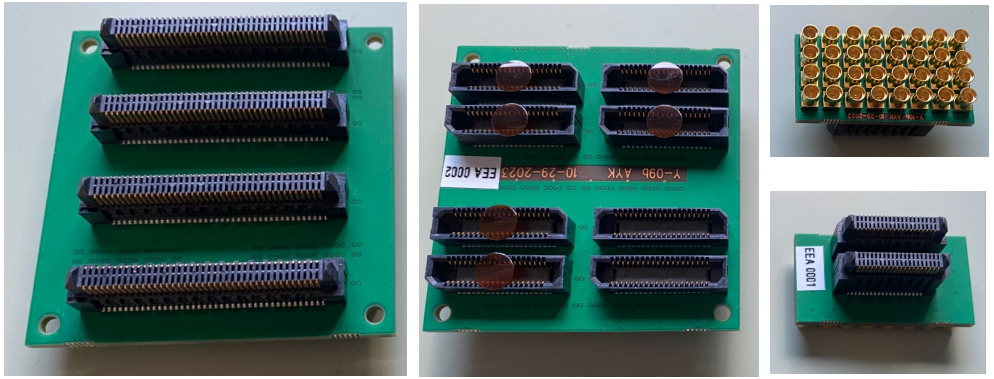
A zoomed in 8x8 pad area

- Work in progress; so far confirmed via and trace impedance ~50 Ohm, as well as absence of cross-talk in a 2D configuration (within a single layer)
- Goal: perform a complete 3D modeling and provide recommendations for final HRPPD design modifications, including HV circuitry

Photek MCP-PMT evaluation at University of Glasgow



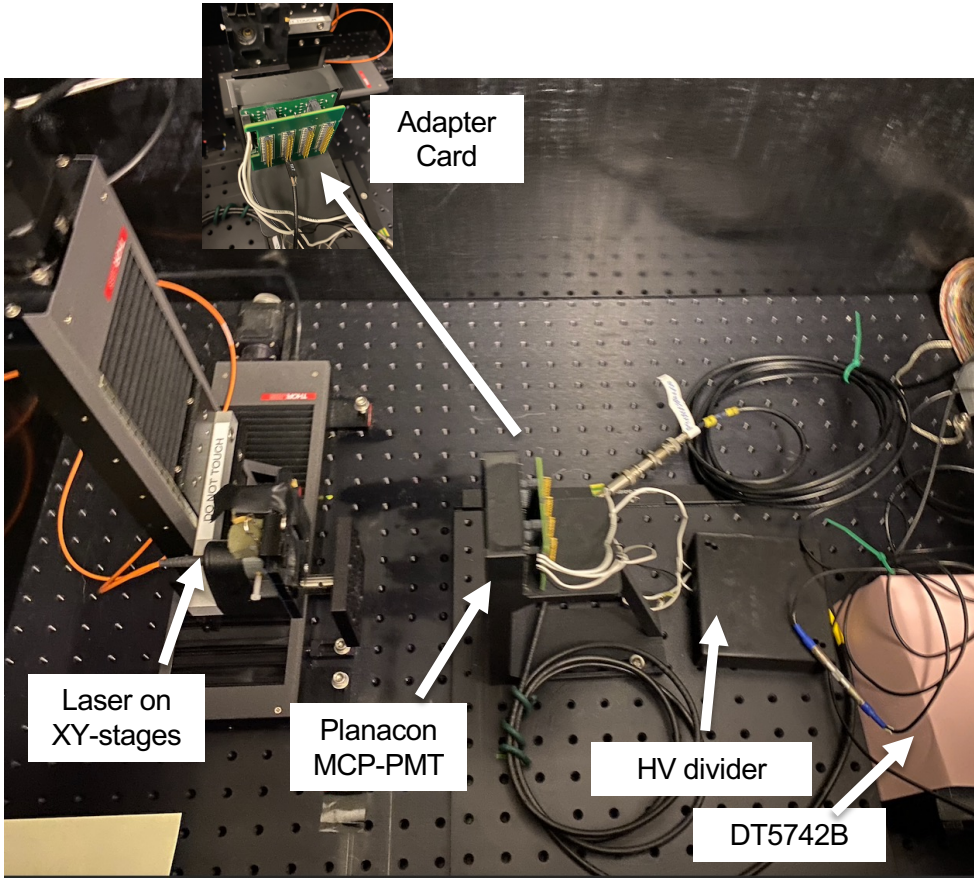
2” Photek Auratek stock configuration



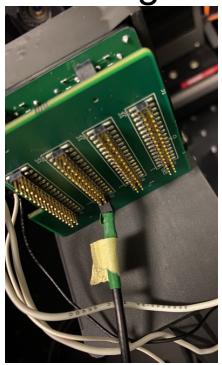
A set of adapters to “HRPPD world”

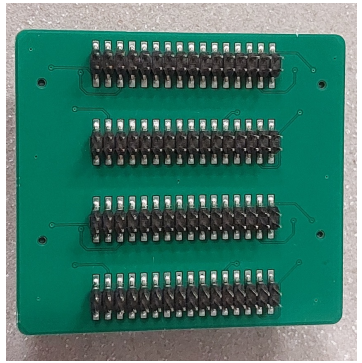
- Model: MAPMT253 16x16 pixel Multi-anode MCP-PMT
  - 10 μm pores, peak QE up to ~35%, TTS ~40ps RMS
  - *Shipment to Glasgow is now expected by mid June 2025*
- Adapter boards available (see pictures above), as well as DRS4 electronics

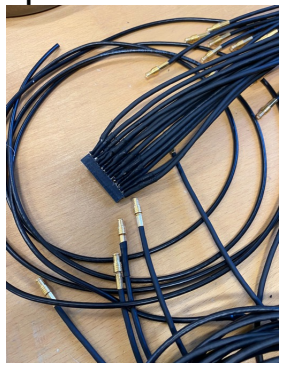
Photek MCP-PMT evaluation at University of Glasgow



- Borrowed Planacon XP85112-S-BA MCP-PMT from GSI
  - This is the one which was thoroughly tested at Erlangen by A. Lehmann
  - Will be used as a reference tube
- Adapter board for connecting to CAEN V1742 digitizer and MCX cables manufactured
- One of the EIC HRPPDs will be shipped to Glasgow for a side-to-side comparison







Summary

- eRD110 is concluding its activities by the end of 2025
- We should be able to meet the remaining (internal) milestones
  - This partly depends on the Auratek MCP-PMT delivery by Photek

- The whole effort is migrating into the PED world entirely
  - HRPPD and Photek Auratek MCP-PMT evaluation, and a side-to-side comparison [a document, outlining the selection procedure, was requested]
  - Integration into pfRICH & hpDIRC detector first articles

Backup

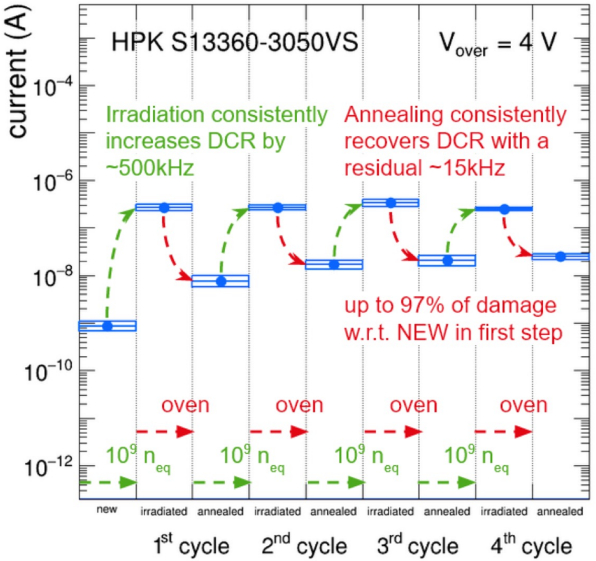
R&D on SiPM (INFN BO-FE-CS-SA-TO)

Main aim: establish usability of SiPM for RICH detectors (single photon sensitivity) with emphasis on radiation damage recovery

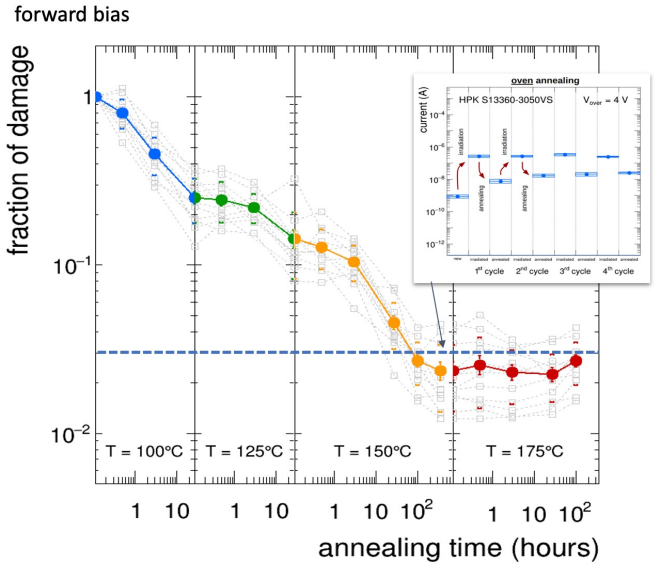
Important Note: this stream of R&D work was funded by eRD1100 for FY22 (all milestones accomplished). Since FY23 this work has been supported via PED funding

Highlights of R&D results

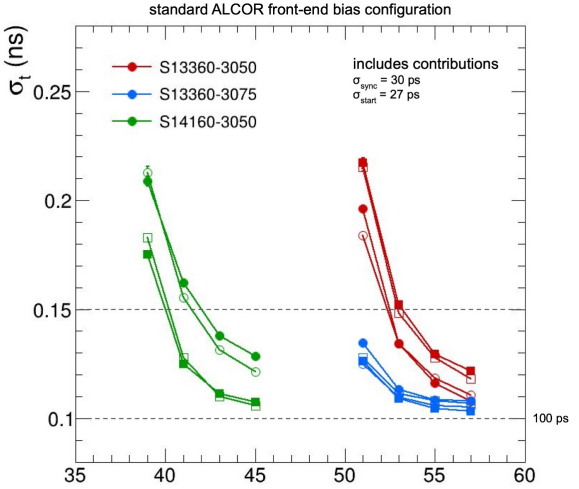
annealing cycles (oven)



electrically induced annealing



time resolution

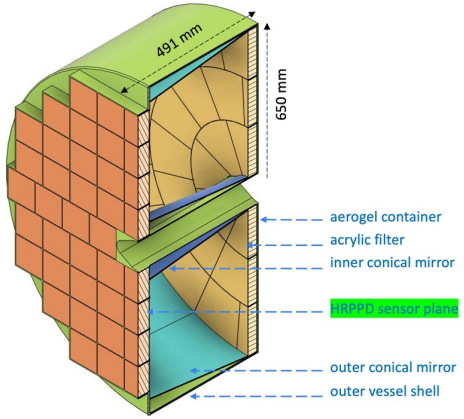


irradiation and annealing studies
full results recently reported at PID review

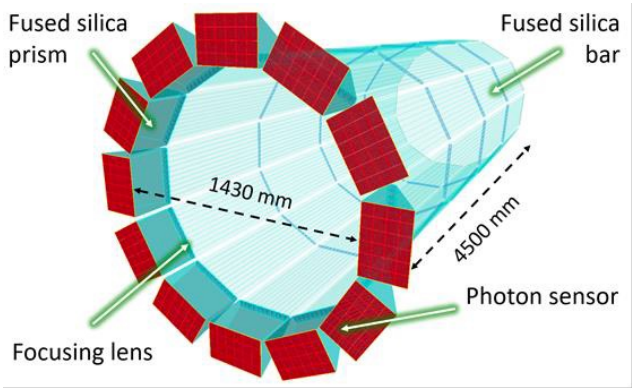
ALCOR ASIC used for sensor characterization

Photosensor Choice for pfRICH and hpDIRC

Charge Question 1



pfRICH: 68 4” HRPPDs total



hpDIRC: 12*6*4 = up to 288 2” MCP-PMTs total

	pfRICH	DIRC
Baseline solution	DC-coupled HRPPD by Incom Inc.	Auratek MAPMT253 by Photek
Alternative solution	Auratek MAPMT253 by Photek	DC-coupled HRPPD by Incom Inc.
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 per event	Small: could work with CC-coupled sensors	200+ p.e. / event: need DC-coupled sensors

We would clearly prefer to have the same photosensor solution for both subsystems

Summary & Outlook

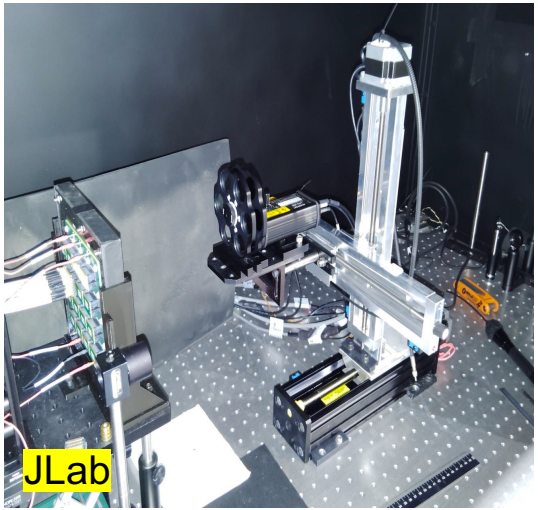
- Incom HRPPDs were adopted as ePIC pfRICH baseline photosensor
- An EIC PED contract with Incom Inc. was successfully completed in 2024
  - Re-design and production of 5+2 EIC HRPPDs
- Evaluation effort is ongoing in several institutions working on the EIC Project
- The results are very promising so far
- A moderate final design update and a test production are anticipated in 2025

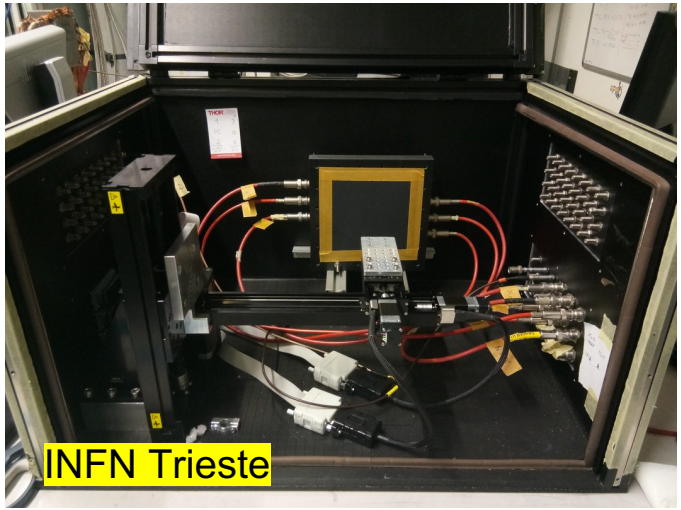
  -> HRPPDs are becoming our preferred solution for both pfRICH and hpDIRC

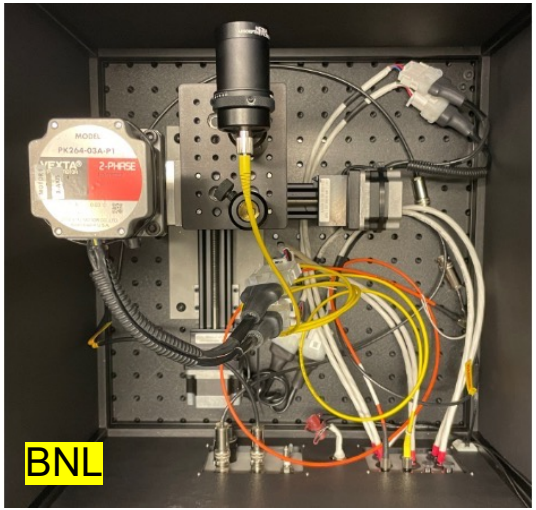
- Photek Auratek MCP-PMT evaluation as a baseline photosensor for ePIC hpDIRC is awaiting a tube delivery to Glasgow

  -> This is our backup solution

EIC HRPPD / MCP-PMT test setups







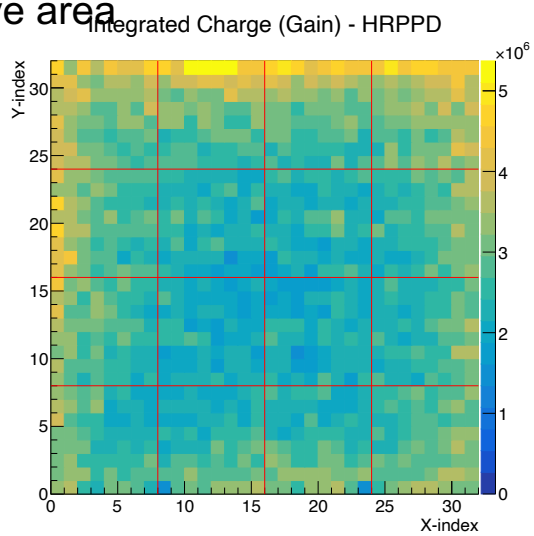
- Three fully functional QA / test stations available at JLab / BNL & INFN Trieste
  - See next slide for a distribution of responsibilities
- There is also an MCP-PMT / HRPPD test stand at Glasgow …
- ... and a clone of BNL old HRPPD setup at Yale

EIC HRPPD / MCP-PMT testing procedure

- Primary QA at JLab
- More systematic active area scans (including picosecond timing) at BNL
- Magnetic field resilience studies at BNL in May 2025 and possibly later at INFN
  - Staffed by BNL, Incom, USC, INFN Trieste / Genova
  - Main objective: performance recovery in a “typical” pfRICH and hpDIRC B-field
- Aging studies at JLab / BNL / INFN Trieste
- Side by side Photek Auratek & Incom HRPPD comparison in Glasgow

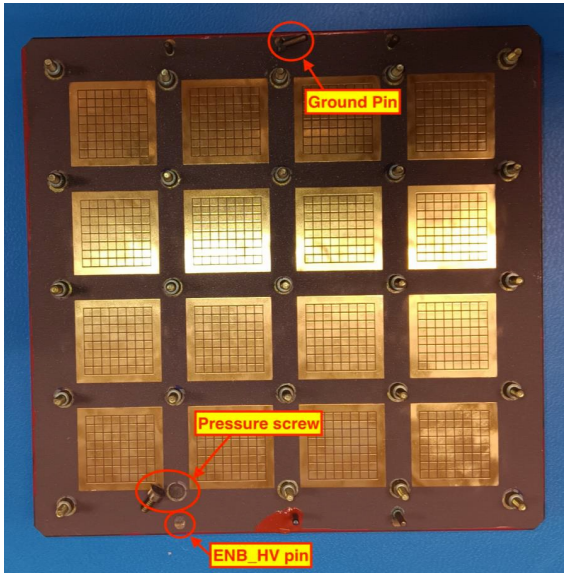
Our present EIC HRPPD performance assessment

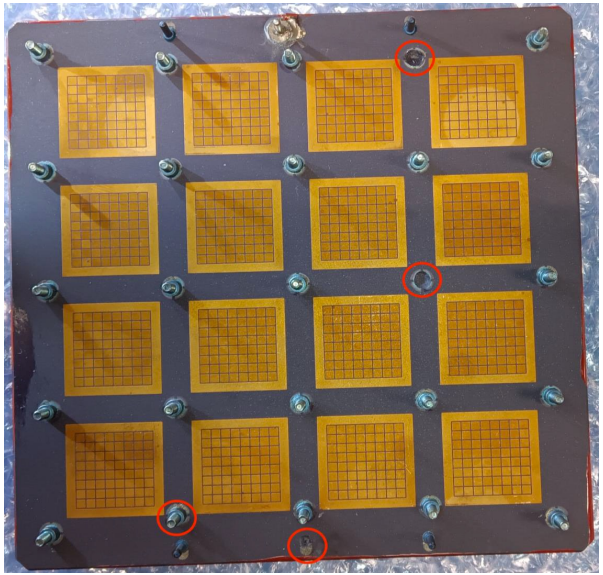
- Yields: **all ten** Kyocera anodes were functionalized into working HRPPDs at the end
  - s/n 15 .. 17 (success)
  - s/n 18 .. 22 (failure, after an attempt to use a second sealing tank)
  - s/n 23 .. 29 (success, after establishing a way to recycle the lower tile assemblies)
- QE: higher than expected and remarkably uniform across the active area
- Gain: stable operation at ~10^7 and beyond
  - We will not need more than 10^6 in the experiment
  - Uniformity is relatively poor, with gain going up by a factor of ~2 towards the active area edge
- Timing: looks better than expected
  - pfRICH should be able to use single photons as a complementary t_0 measurement
- Dark rates: very small, even at mid-10^6 gain



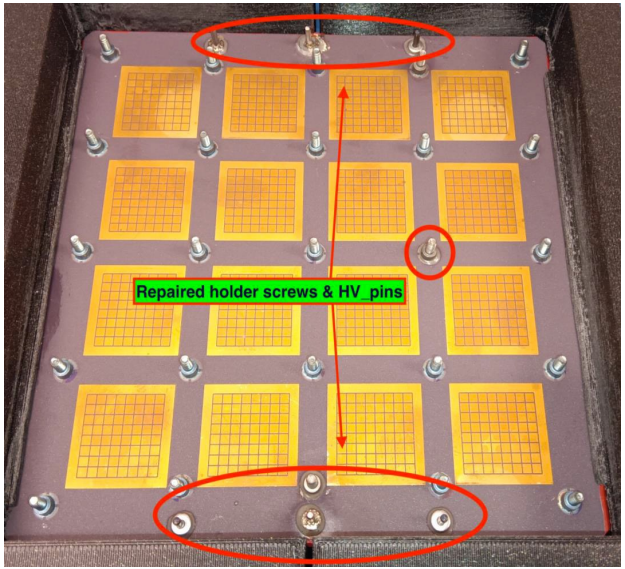
Overall, everything looks very promising & one more iteration is expected

Highlights of HRPPD QA process at JLab





Examples of failed HV pins and screws

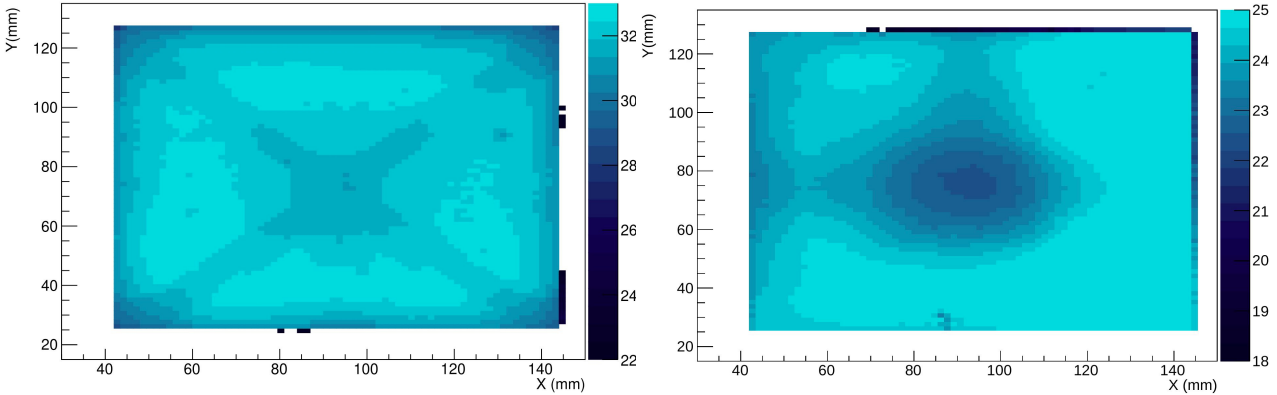


A present fix by Incom

- Several HRPPDs showed issues with falling off HV pins and mechanical screws
  - Those were promptly fixed by Incom
- Solutions for a “final EIC HRPPD design” are being developed
  - Remove HV pins; embed screws into the ceramic anode body

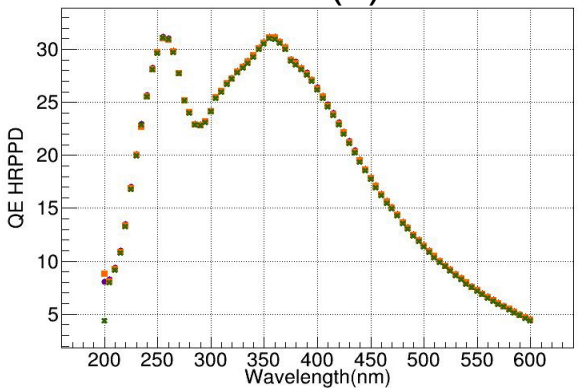
Quantum efficiency measurements at BNL

2D surface scans @ 365 nm

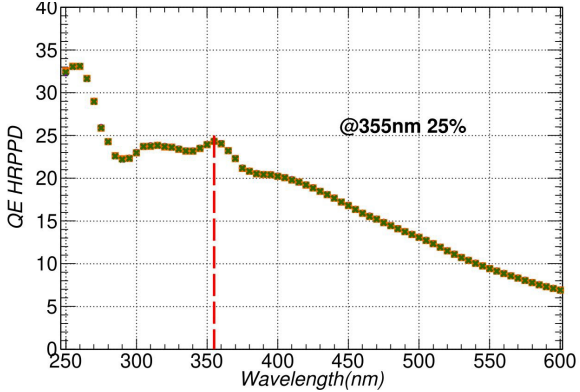


- Pretty uniform across the active area
- Origin of non-uniformity is well understood
- All HRPPDs sealed in tank #1 have peak QE way above 30%

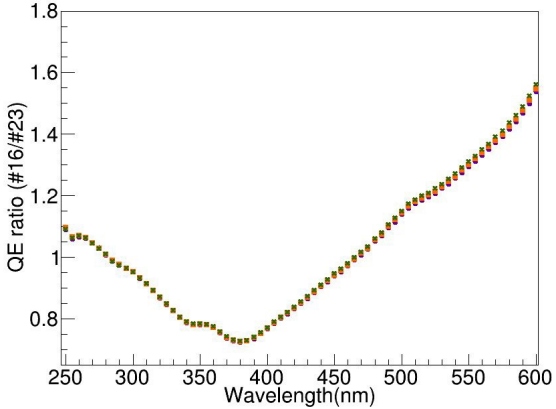
QE(λ) measurements with a monochromator



HRPPD 16 (sealing tank #1)



HRPPD 23 (sealing tank #2)



HRPPD 23 / HRPPD 16 QE ratio

Towards converging on a single photosensor solution

- (1) Complete evaluation of the first batch of EIC HRPPDs
  - Systematic scans: QE, PDE, gain, DCR, timing, …
  - Aging, B-field resilience, after-pulsing, high occupancy events
- (2) Proceed with a final PED iteration with Incom
  - Repeat a systematic evaluation
- (3) Perform a selective side to side comparison of HRPPD and Photek MCP-PMT
  - If Photek MCP-PMTs show no substantial performance advantage, take a note
- (4) Evaluate functionality of an existing HGCROC3 backplane prototype with an HRPPD
- (5) Assuming it provides a reasonable performance, build 5-7 full sets

Towards converging on a single photosensor solution

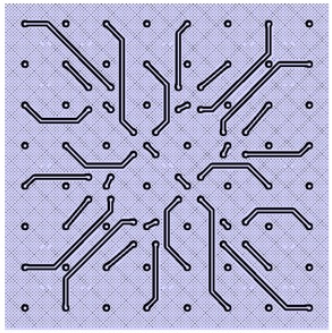
- (6) Install a pfRICH prototype with 4-5 HRPPDs on a Cosmic Ray Telescope at SBU
  - See this talk
- (7) At some point move the on-board electronics onto the hpDIRC CRT prototype
  - And verify the performance on real life multi-hit muon events (cross talk, ringing, etc)

- (8) Wait for FCFD evaluation boards
  - Perform intermediate bench top testing with final EIC HRPPDs (and Photek MCP-PMTs?)

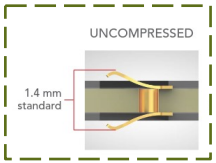
- (9) Build a full FCFD backplane
  - Repeat a fraction of HRPPD performance studies

- (10) Perform beam test(s) for both pfRICH and hpDIRC

EIC HRPPD Assembly



8x8 pad pattern
compressed
from 3.25mm (inner side)
to 2.00mm (outer side) pitch



Fused silica window

MCPs, spacers, etc

Side wall

Anode plate, a pre-routing
ceramic circuit board

Compression interposers
(not shown)

Interface PCB

4x4 spots, each with 8x8 square pads; 3.25mm pitch