EIC HRPPD requirements, re-design and evaluation

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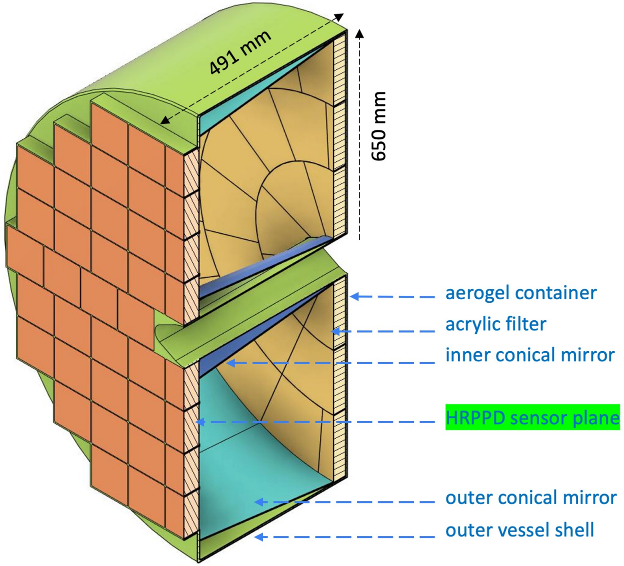
ePIC Collaboration meeting @ BNL, January 21, 2026

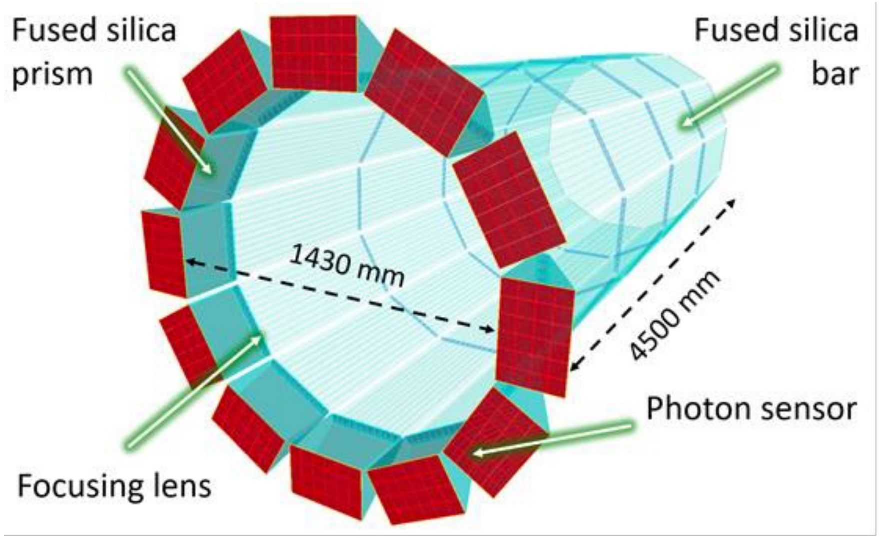
Contents of the talk

- Introduction
  - EIC HRPPD initial design from 2023; EIC-Incom PED contract
- Recent studies
  - PDE, aging, B-field, afterpulsing
- Re-design activities towards a final engineering run
- HRPPD specifications in the 2026 EIC-Incom PED contract
- Summary

Photosensor choice for ePIC pfRICH & hpDIRC



pfRICH: 68 4” HRPPDs total



hpDIRC: 12*6*4 = up to 288 2” MCP-PMTs (or 72 HRPPDs) 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.
Occupancy per event	Small: could work with CC-coupled sensors	200+ p.e. / event: need DC-coupled sensors

2023 EIC contract with Incom Inc.

- Perform a first stage of the design adaptation to EIC needs
  - In general, be as much conservative as possible in this first iteration
  - Focus on a mechanical and electrical interface, including a complete re-design of the anode plate

First generation HRPPDs were "bare sensors" & lacked interfacing completely

- Produce five HRPPD tiles of a new design (at the end we bought seven)
- Demonstrate production capability and reproducibility of key performance parameters
  - Gain, QE, Photon Detection Efficiency (PDE), Dark Count rates (DCR), timing resolution, …

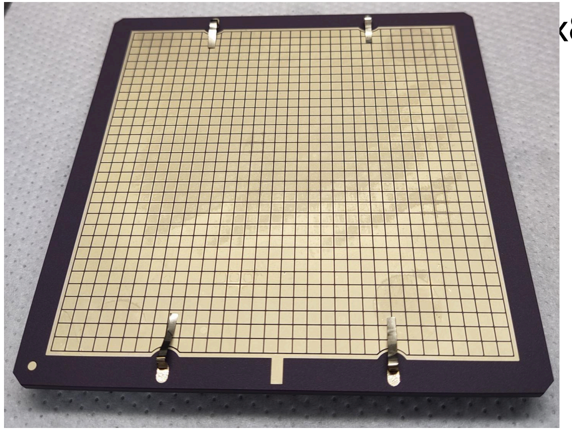
First generation yielded only a couple of low QE devices out of a dozen of trials

Contract completed successfully in April 2024

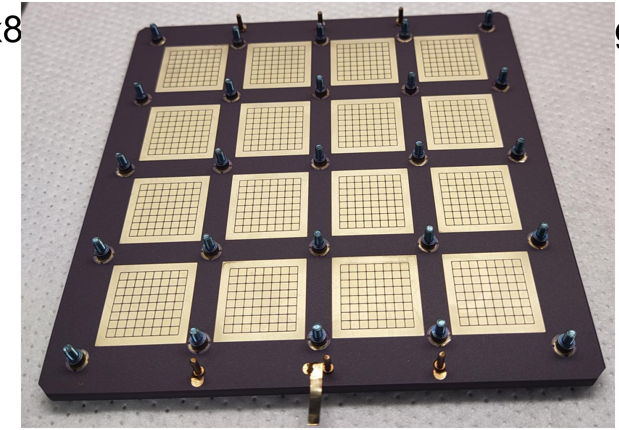
Incom's DC-coupled EIC HRPPDs

- ~120mm x 120mm footprint, 32x32 pads
- 10 μm pore MCPs, 5 mm thick fused silica window

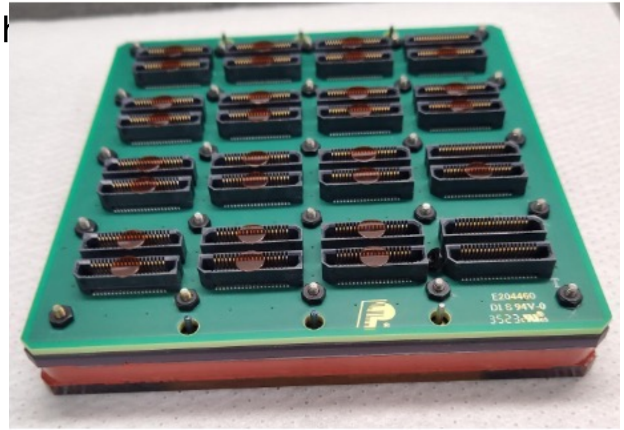
- 2023 design (first EIC-Incom PED contract)
  - Non-trivial signal trace routing in the ceramic anode plate
  - 104mm x 104mm active area (increased to ~75% geometric efficiency), pitch 3.25 mm



Anode plate vacuum side

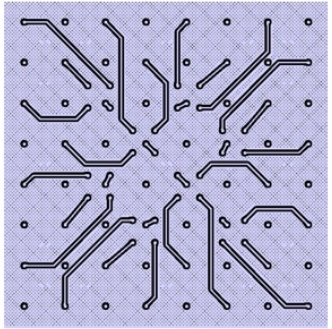


Anode plate air side

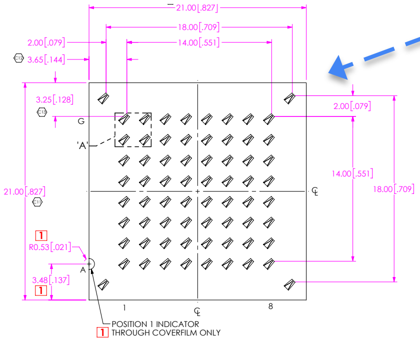


HRPPD with a passive backplane

Incom's DC-coupled EIC HRPPDs



8x8 pad pattern compressed from 3.25mm to 2.00mm pitch



Fused silica window

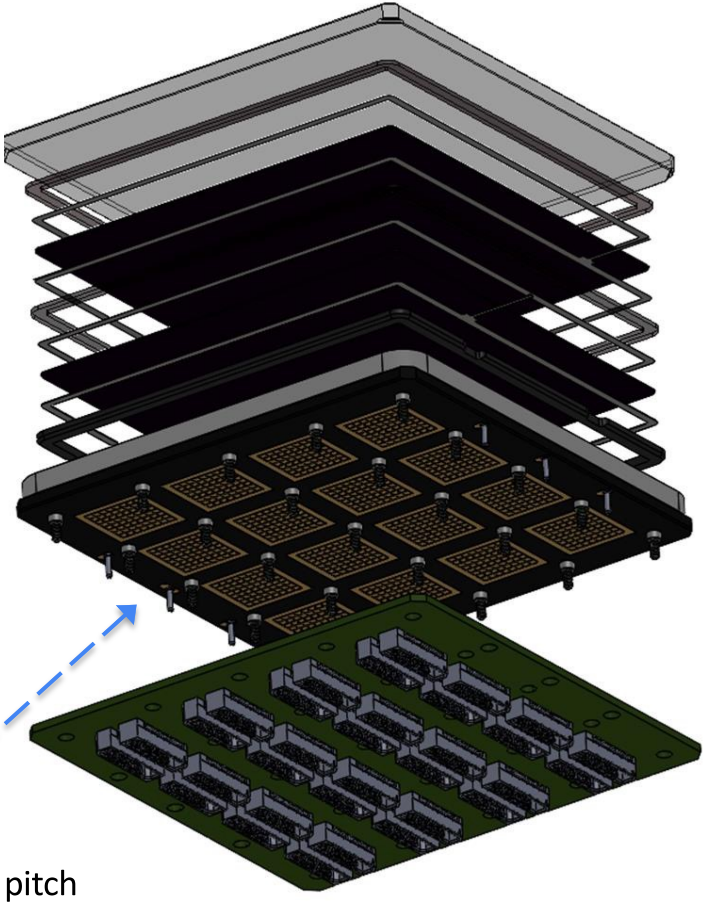
MCPs, spacers, etc

Side wall

Anode plate, a pre-routing ceramic circuit board

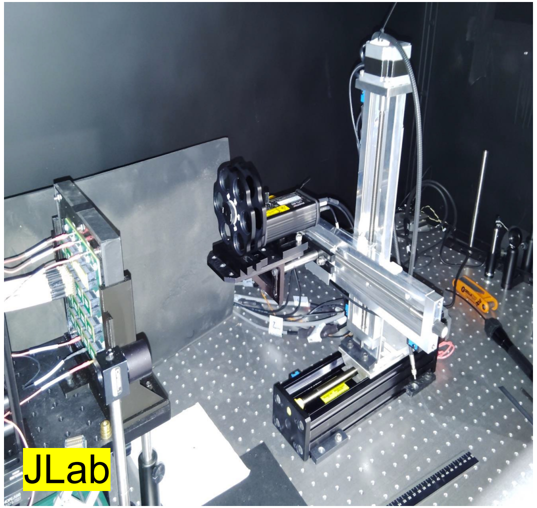
Compression interposers (not shown in the blown-up view)

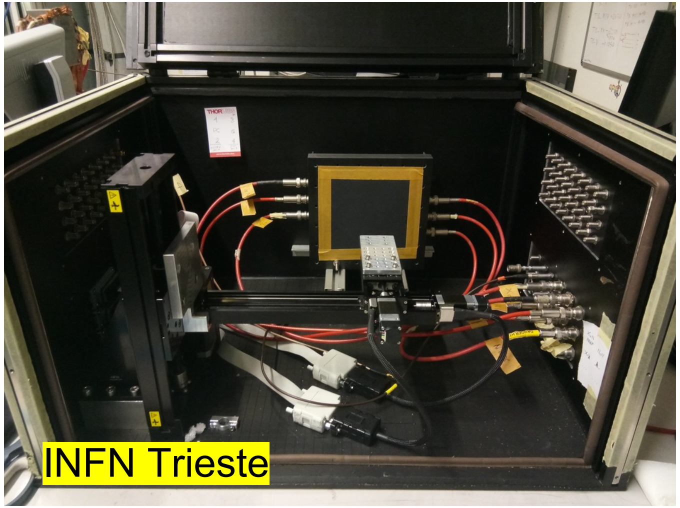
Interface PCB (here: Y05f)

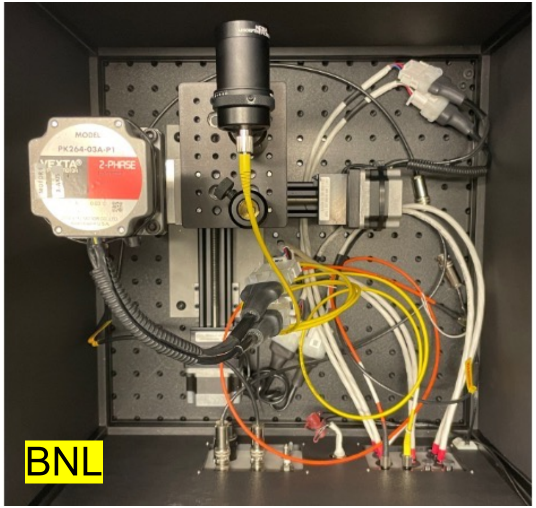


4x4 spots, each with 8x8 square pads; 3.25mm pitch

EIC HRPPD / MCP-PMT test setups

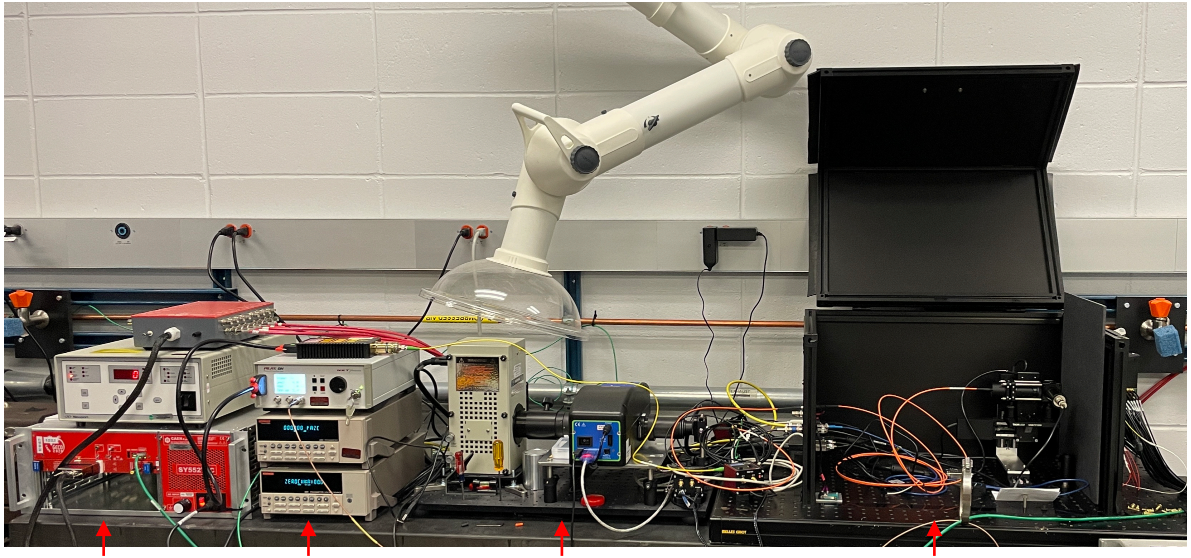






- Three fully functional QA / test stations available at JLab / BNL & INFN Trieste
- There is also an MCP-PMT / HRPPD test stand at Glasgow …
  - To be used for Photek vs Incom comparisons & high occupancy studies for hpDIRC
- … a new HRPPD aging test station at BNL …
- … customized B-field studies setups at BNL and INFN …
- ... and another emerging HRPPD setup at Yale

Recent studies: PDE & collection efficiency @ BNL



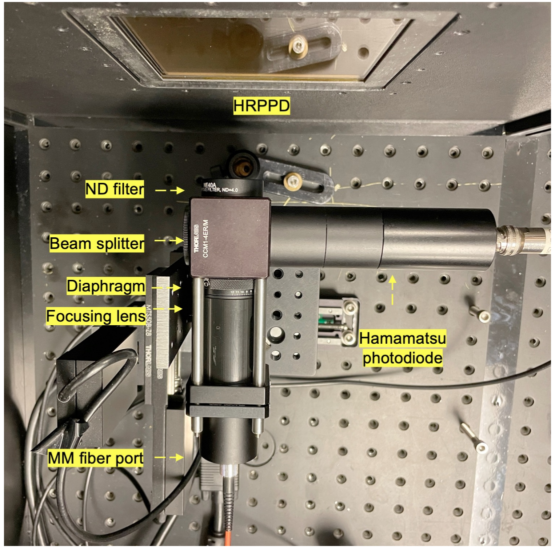
HV

Picoammeters

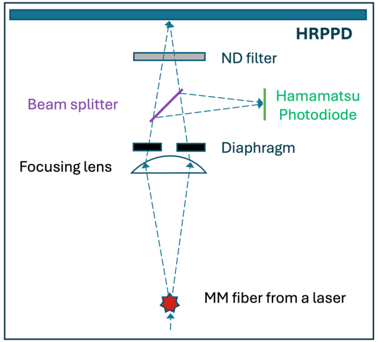
PiLas laser

Monochromator

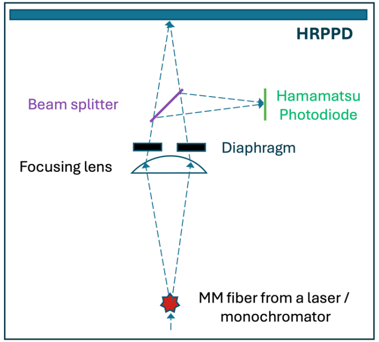
Dark box



- ➢ Use a newly built HRPPD aging test station
- ➢ Usable to measure PDE (in a pulse counting mode)
  - ➢ Where from **CE = PDE / QE ~ 70.3 +/- 1.6%**



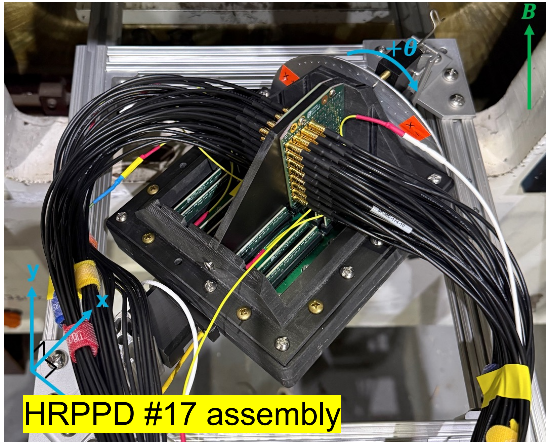
PDE (counting mode)



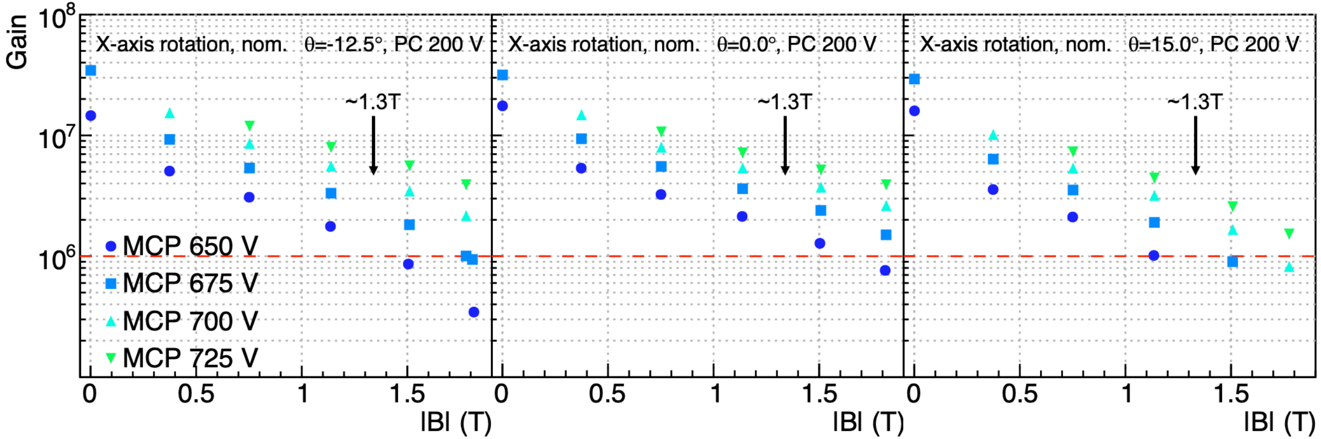
QE (PC current mode)

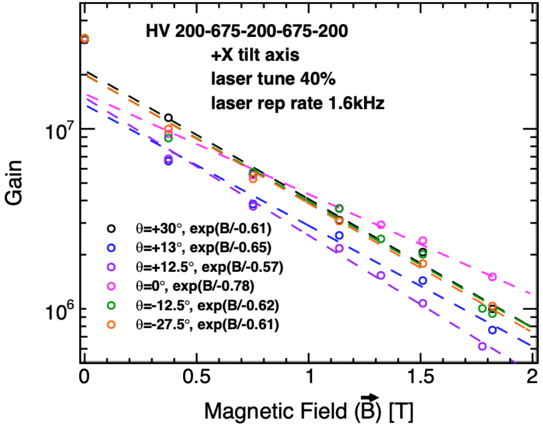
Recent studies: B-field measurements @ BNL

Presentation at a recent TIC meeting



pfRICH sensor plane location in ePIC: up to ~1.3T field, tilt angles up to 13°



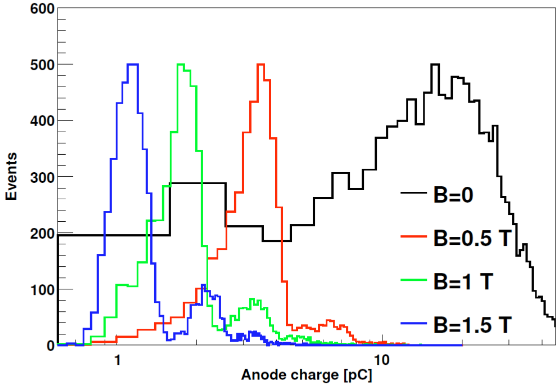


Expected exponential gain drop as a function of field magnitude

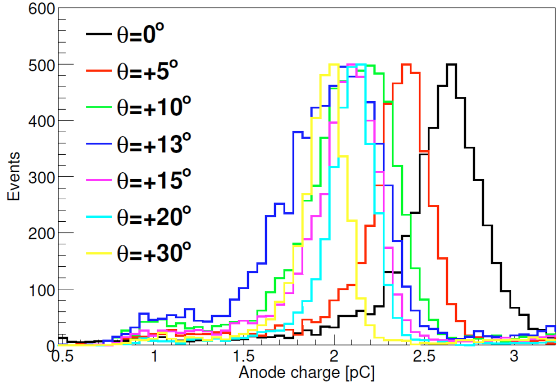
Recent studies: B-field measurements by INFN

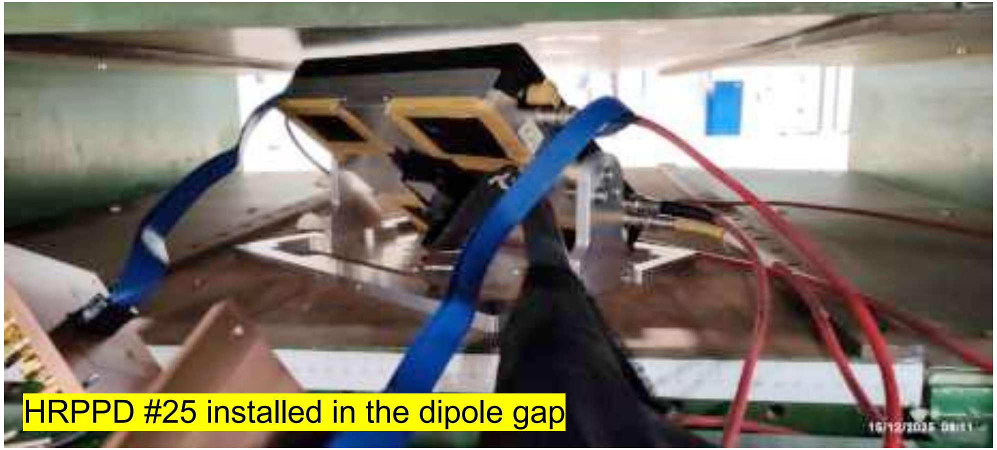
Presentation at a recent TIC meeting

θ=0, MCP=750 V

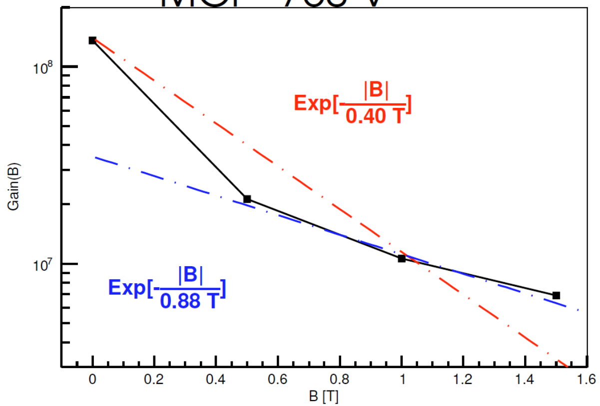


B=1.5 T, MCP=875 V





MCP=750 V



Expected exponential gain drop as a function of field magnitude

HRPPDs in a magnetic field: present assessment

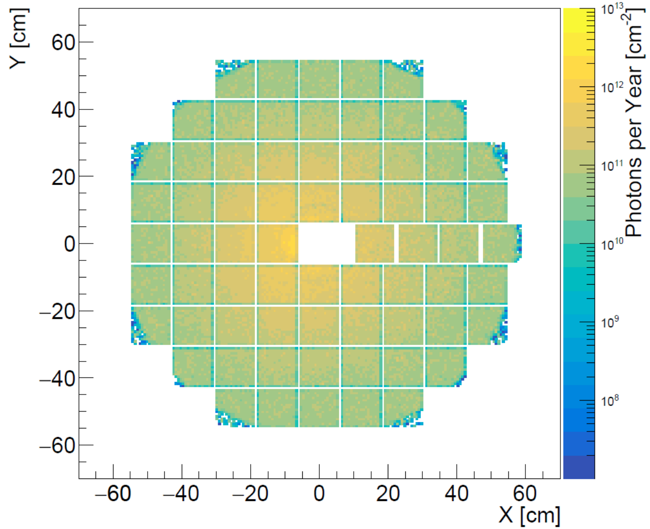
- Studies performed by two groups
  - A broad range of HV settings, B-field magnitude and orientation

- It looks like ePIC solenoid magnetic field will be of a relatively little concern for HRPPD operation in the pfRICH detector (and presumably hpDIRC as well?)
  - Devices appear to be less sensitive to a B-field than LAPPDs (higher SEY?, stackup details?)
- Few things to clarify:
  - Timing resolution
  - Loss of the active area due to a Lorenz angle effect
  - Aging in a magnetic field at a particular gain required for FCFD frontend
  - HV choice for HRPPD gain adjustment in an inhomogeneous magnetic field

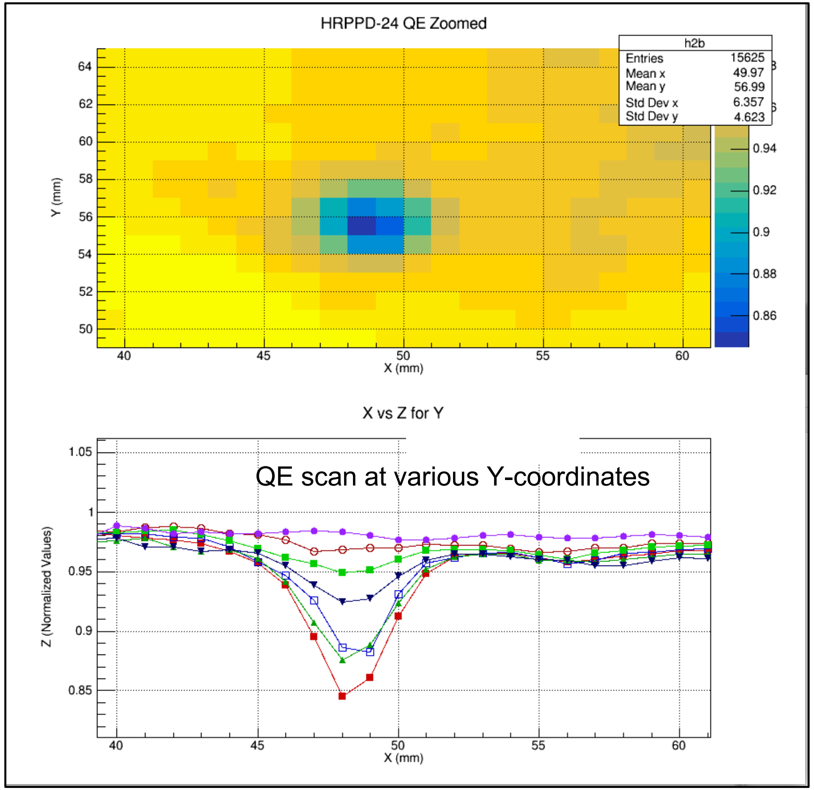
Recent studies: aging

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

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

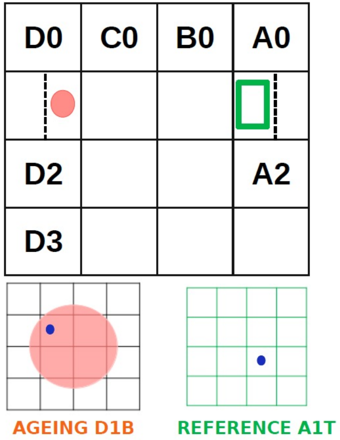


10^{12} - 10^{13} γ/cm^2/year from all sources

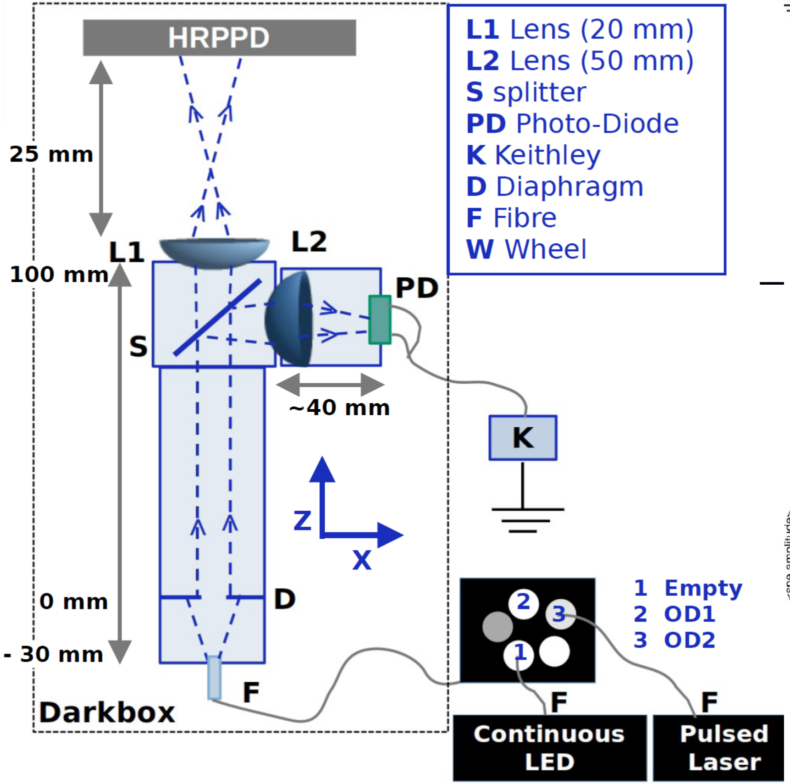


First HRPPD aging data from JLab
[after ~2*10^{19} γ/cm^2 irradiation at a nominal HV]

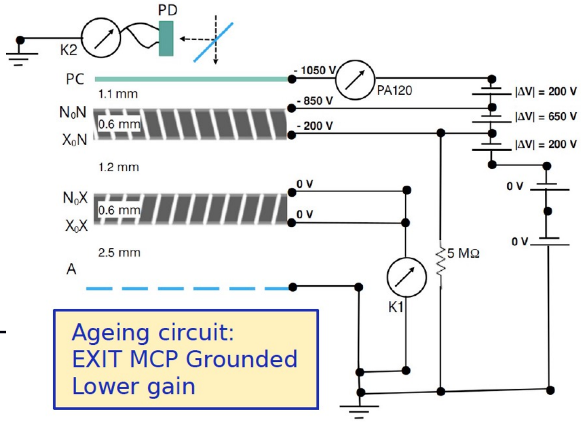
Recent studies: pixel-based aging @ INFN



r_{AGEING}: 5.32 mm
$r_{FOCUSED}$: <0.5 mm

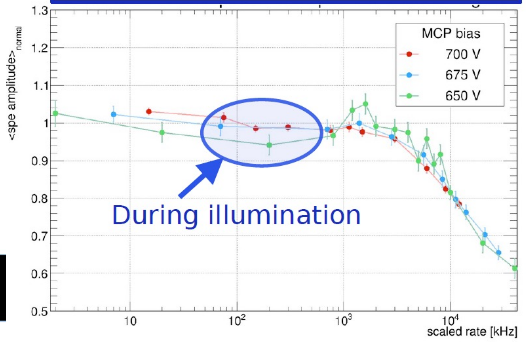


L1 Lens (20 mm)
L2 Lens (50 mm)
S splitter
PD Photo-Diode
K Keithley
D Diaphragm
F Fibre
W Wheel



Ageing circuit:
EXIT MCP Grounded
Lower gain

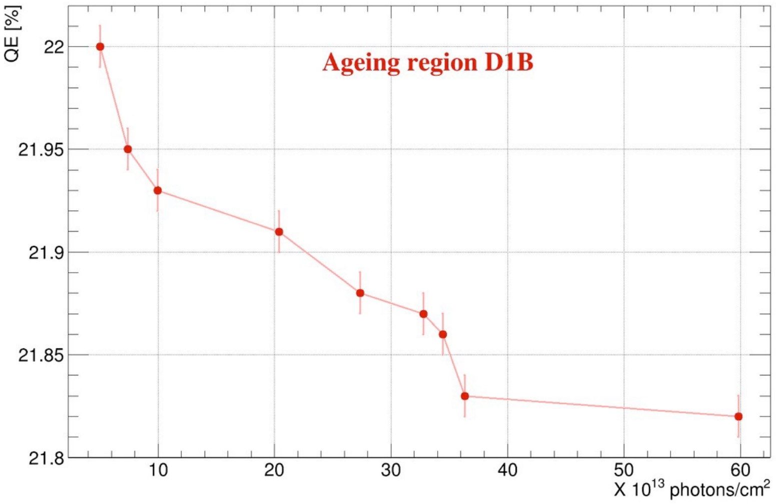
Universal amplitude vs. rate curve
(10^6 gain)



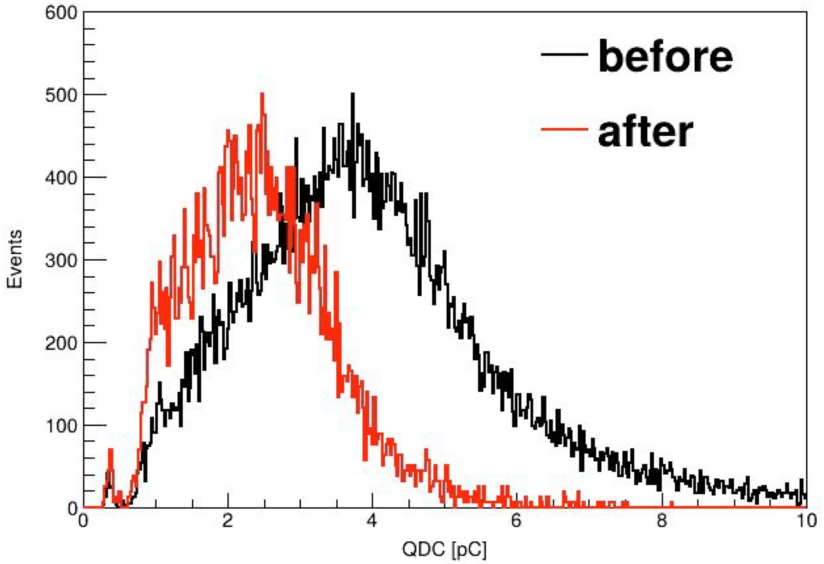
Rate capability is a concern

Recent studies: pixel-based aging @ INFN

- Preliminary results after illumination equivalent to ~60 (?) years of ePIC pfRICH running



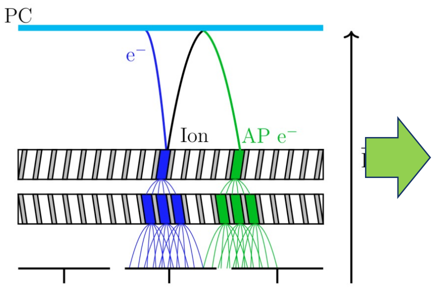
No measurable QE degradation

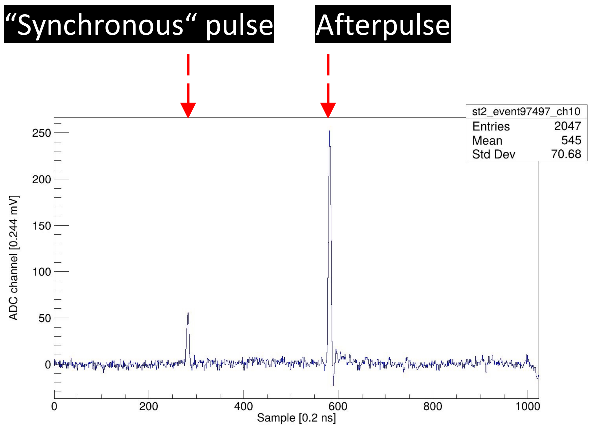


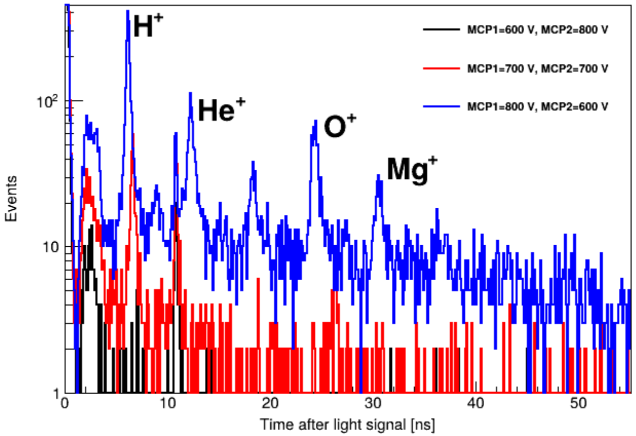
Gain drop of ~40%

Recent studies: afterpulsing (AP)

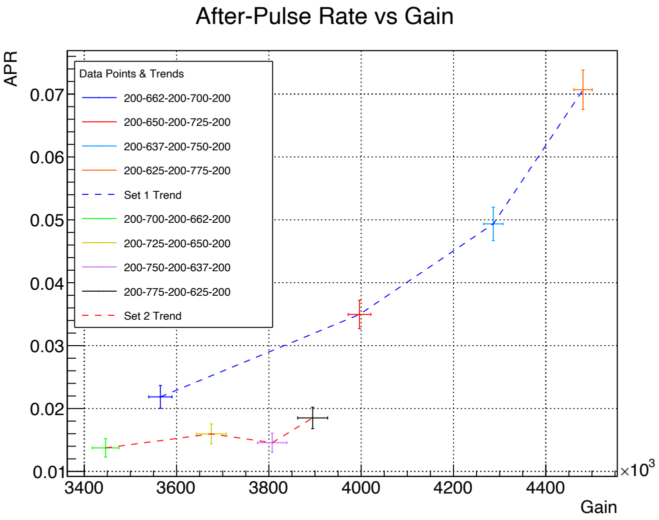
- A well-known effect in MCP-PMTs
  - Directly related to aging
- Can be partly mitigated by asymmetric MCP biasing (see the plots)
  - At the same gain: decrease bias voltage on MCP#1 and increase on MCP#2
- We should be able to keep AP rate ~1%







AP ion identification with B=0T (M.Osipenko, INFN)



AP rate in a 1.3T field (Y.Jin, BNL)

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
  - Though PDE may not be sufficient for hpDIRC at its presently anticipated performance level
- Gain: stable operation at ~10^7 and beyond
  - We will hopefully not need more than 10^6 in the experiment
  - Uniformity is relatively poor, variation more than a factor of ~2 across the active area
- Timing: looks better than expected (though we will not be able to make a full use of it)
  - Performance in a magnetic field yet to be confirmed
- Dark rates: acceptable, at a level of few kHz/cm^2 at mid-10^6 gain
- Instantaneous rate capability needs to be verified
- B-field resilience (& aging resilience for ePIC pfRICH use?) confirmed

HRPPD re-design & 2026 EIC-Incom PED contract

- Effort ongoing since early summer 2025; an ad hoc series of meetings has been set up starting from early December last year: https://indico.bnl.gov/category/729/
  - Subject matter experts from BNL (Tim Camarda, AK, Takao Sakaguchi), JLab (Raymond Dawson and Alex Eslinger), Incom (Alexey Lyashenko and Mark Popecki) & ISU (Gerard Visser)
- Topics (mostly related to the ceramic anode design)
  - Reduction of cross-talk to <1%; re-design of compression interposers
    - A very substantial modeling effort by Raymond Dawson (JLab) over the last several months
  - Elimination of fragile mechanical screws in the design
  - Elimination of HV pins in favor of pads and spring-loaded fixtures; other improvements in the HV lead layout
  - Adjustment of the HRPPD footprint and other small mechanical design improvements
- The goal is to converge by the end of January

- PR at JLab has been signed in early January, which means EIC-Incom PED contract will start soon
  - We are ordering six HRPPDs in this (final) iteration; anticipated limelines:
    - Kyocera anodes will be (hopefully) ordered in March and delivered to Incom by the end of summer
    - The HRPPDs will then be (hopefully) produced by the end of 2026

Requirements table summary

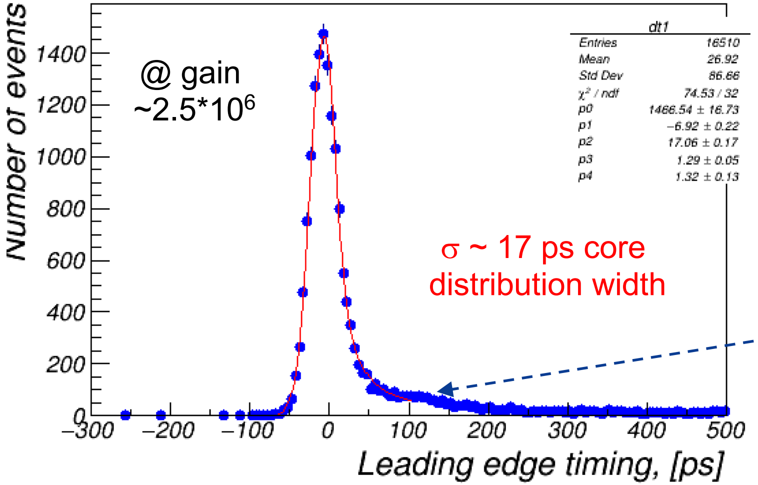
The PED contract SOW contains a narrative describing expected design improvements (HV connectivity, mechanical integration, fully efficient active area, window material type, ion getters, etc) and an appendix table with the performance parameters, see a subset here:

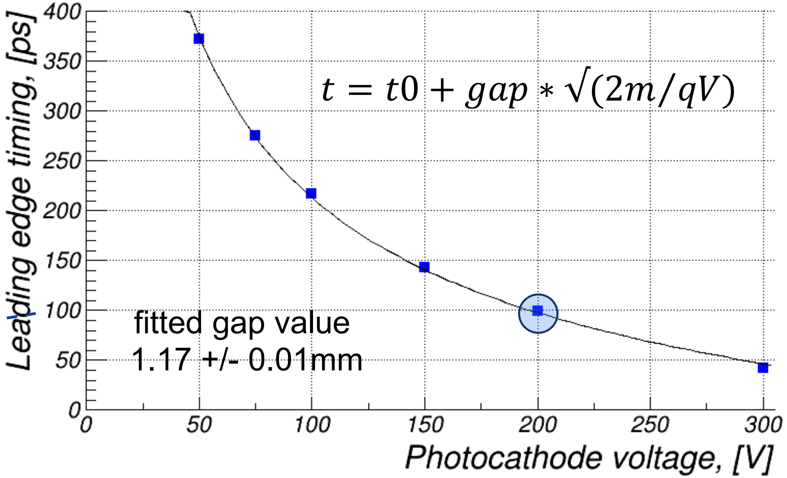
Parameter	Specification	Comment
Gain	$>5*10^6$	We will hardly need $>10^6$ in the experiment
Gain uniformity	RMS / MEAN < 0.25	
Single photon timing resolution	σ of the core part <40ps	
Dark Count Rate	<2 kHz/cm^2	
Quantum efficiency (QE)	>27%	With a goal of 30% across the six HRPPDs
QE uniformity	RMS / MEAN < 0.20	
Photon detection efficiency (PDE)	>20% average across six tiles	

Additional hpDIRC requirements (on a best effort basis)

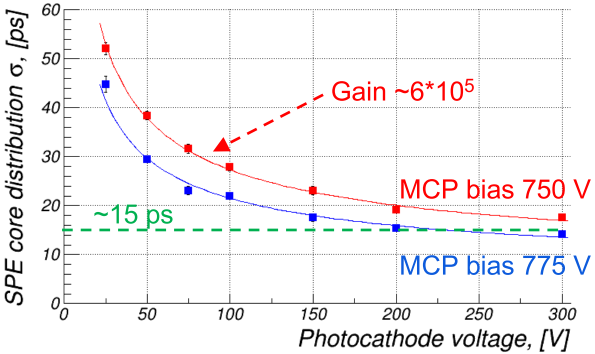
Parameter	Specification
RMS of a single photon TTS in a [-0.5 .. +2.0] ns window	< 75ps
Simultaneous multi-photon excitation	Be able to detect >100 γ at once
Enhanced PDE	Peak value ~25% average over six tiles

Single photon timing distribution: a core σ & RMS





Primary electron drift time PC->MCP#1



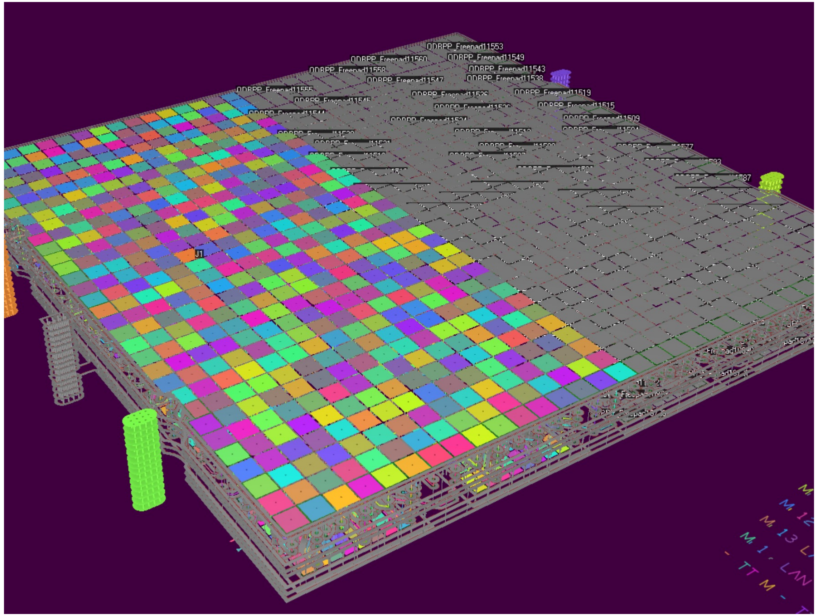
- Extreme single photon timing resolution is not needed for either pfRICH or hpDIRC
  - FCFD will not preserve it on a ~20ps level anyway
- Bouncing photoelectron tail can likely be compressed by a photocathode voltage increase at an overall moderate gain
  - Same trick as used for PANDA Planacons by changing a HV divider ratio

Photon Detection Efficiency increase

- Contrary to e.g. SiPMs, for MCP-PMTs a PDE is typically much smaller than QE
  - Primary photoelectrons hitting MCP#1 between the pores tend to be “lost”
  - For HRPPDs, the Open Area Ratio (a fraction of pores to the overall surface) is ~70%
- Not that many options available to mitigate this effect:
  - Thin down the capillary walls in a draw process (few % gain at a cost of making MCPs more fragile)
  - Funnel the pores (wet etching as an extra non-trivial production step; an additional chemical residue)
  - Cover the nichrome electrode of MCP#1 by the same MgO ALD emissive layer as the pore surface

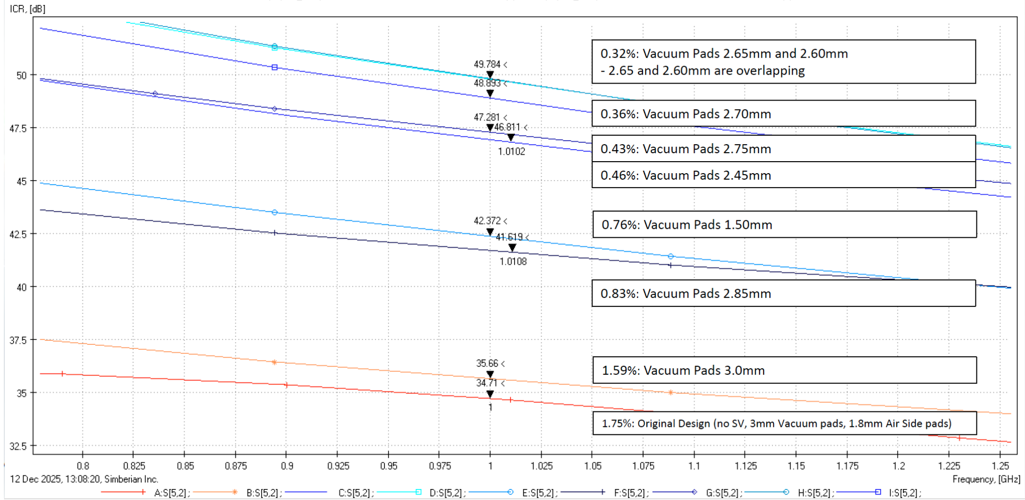
- Will rent a pair of capacitively coupled HRPPDs (one with and one without MgO coating)
  - Part of the 2026 PDE contract (expect these two CC-HRPPD tiles in May-July)
  - Six DC-coupled HRPPDs EIC is ordering from Incom will be built based on the outcome of this study

HRPPD + backplane signal modeling at JLab



Original HRPPD anode stackup

Use SIMBEOR (3D Electromagnetic Signal Integrity Modeling Software)

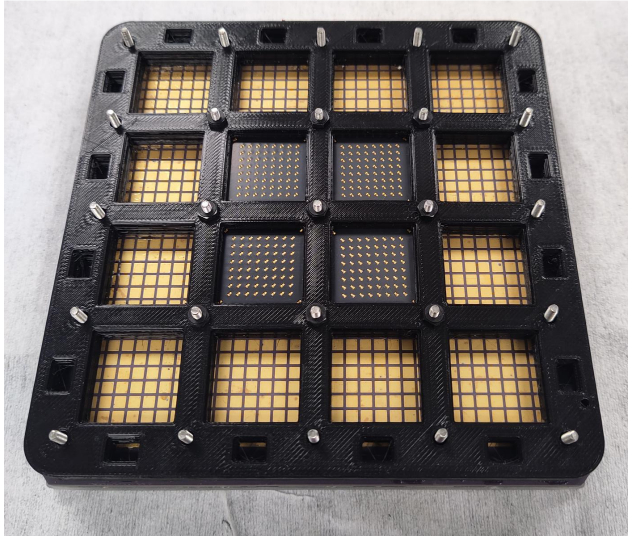


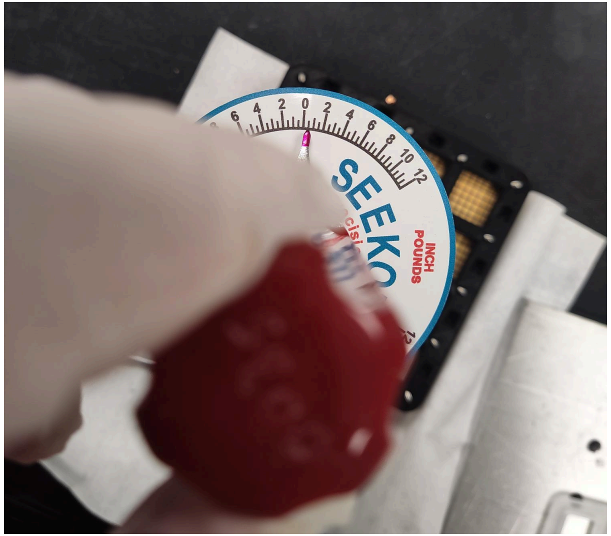
Cross-talk dependency on pad size and ground vias

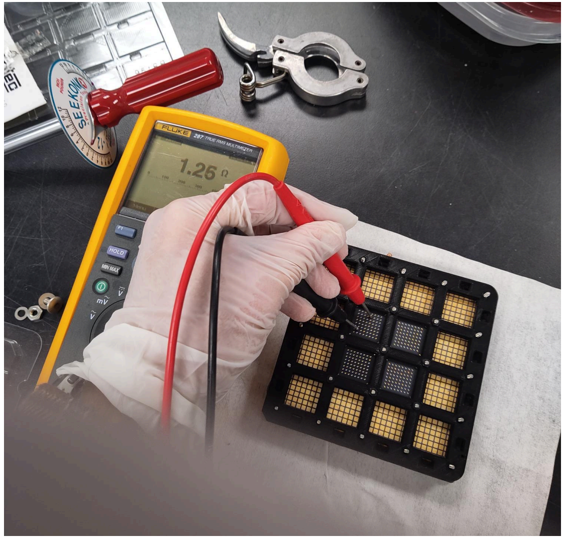
- Confirmed crosstalk in the present anode design on a ~2.0 % level
- Plan on reducing this crosstalk by up to a factor of ~3; other incremental improvements
  - Fencing vias, pad-to-pad gap increase (vacuum side), air side pad minimization, etc

Mechanical interface redesign

- Trials at Incom using an old HRPPD (here: screws embedded into a thick spacer)
  - Step #1: align and glue screws to this 3mm thick 3D printed spacer
  - Step #2: glue the spacer with screws onto the anode



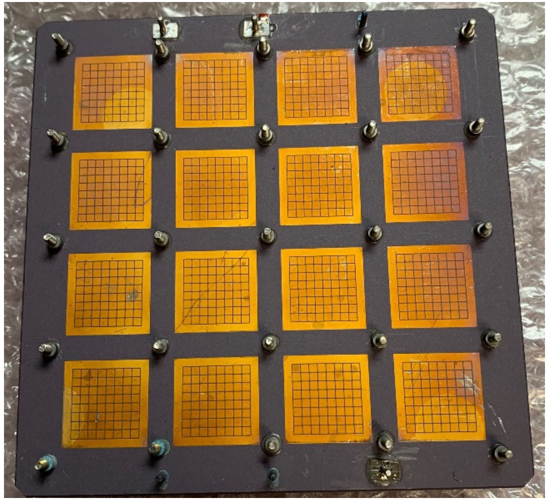




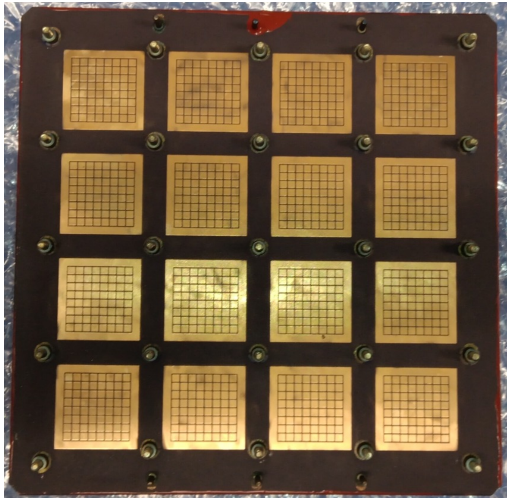
- Presently looking into using helical inserts (female fixtures rather than screws)
  - A final decision does not affect the anode design

Gold plating tarnish issue

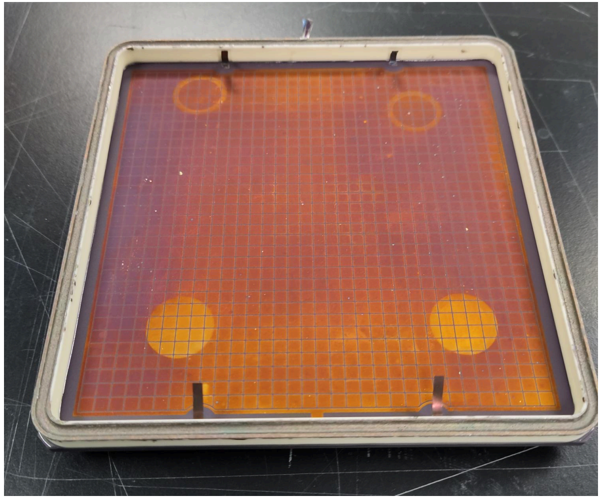
tarnish was sanded off this one



HRPPD #15 (air side)

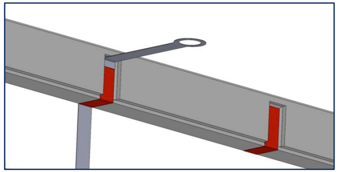


HRPPD #17 (air side)



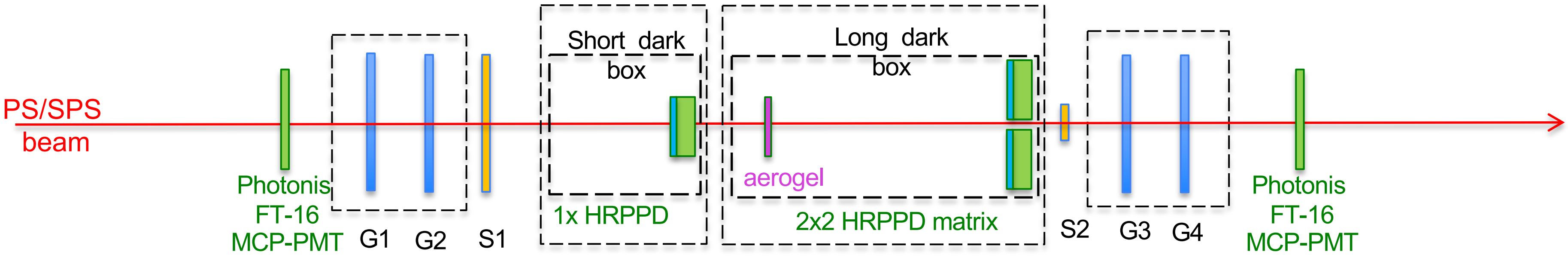
HRPPD #18 (vacuum side)

- An apparent tarnish is seen on all Kyocera HRPPD anodes
  - A study at BNL CFN confirmed it to be a Ni oxide deposit after thermo cycling
- Mitigation strategy: avoid brazing (extreme heating), just fritting & baking out
  - Use side wrap metallization rather than brazed HV contacts on the vacuum side
  - Neither HV pins nor screws need to be brazed on the air side any longer



pfRICH test beam runs @ CERN PS/SPS

- ➢ Collaborating with dRICH group (similar program, experience @ CERN, etc)
- ➢ Agreed on bringing a simplified setup (no full-size vessel in particular)



S1&S2: trigger scintillators; G1..G4: GEM trackers (may be problematic)

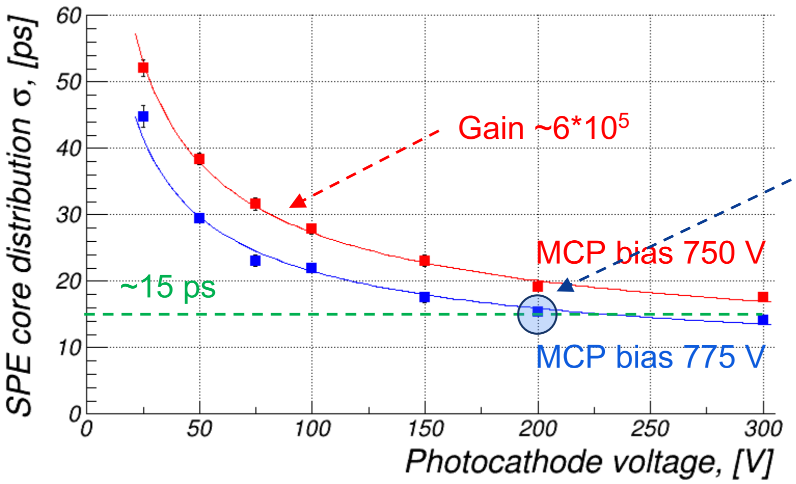
- ➢ **Dates**: 1 week at SPS in May in parallel with LFHCal and dRICH /TBC/
- ➢ **Dates**: 2 weeks at PS June 10-24 in parallel with dRICH
  - ➢ Custom HRPPD backplane, funding, GEANT modeling, online analysis software, etc

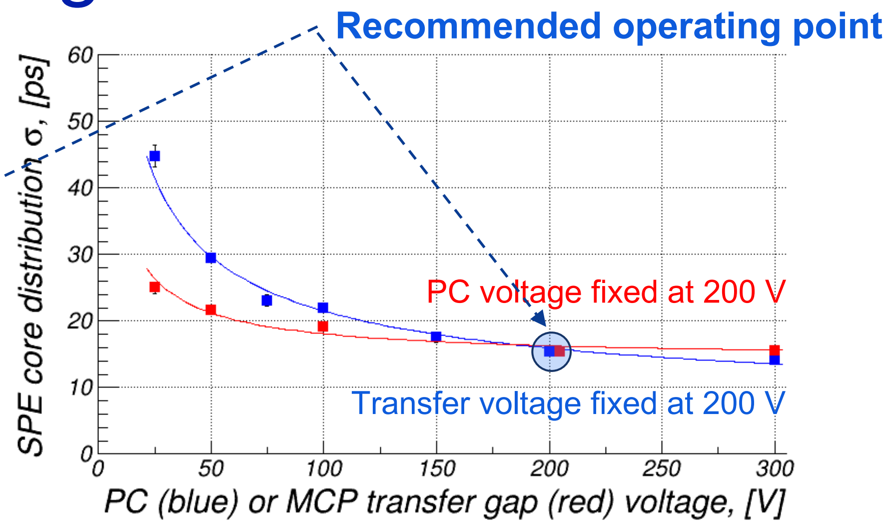
Summary & Outlook

- The first EIC HRPPD engineering run in 2023-2024 is seen as a success story so far
  - Though evaluation studies are still ongoing
  - pfRICH beam test at CERN in May-June 2026 will be a first HRPPD use with a particle beam
- Re-design effort for the final engineering run in 2026 is converging shortly
  - Specifications in the EIC-Incom PED contract are mostly the same for pfRICH and hpDIRC
  - Few outstanding hpDIRC requirements will be handled by Incom on a best effort basis
- A procurement process at JLab has started
  - We are expecting the first HRPPDs to be delivered in early Fall 2026
- Last, but not least: EIC HRPPDs are considered for Belle II and LHCb upgrades

Backup

HRPPD single photon timing resolution





	25	50	75	100	150	200	300
750 mV	11	13	15	17	21	25	30
775 mV	27	34	38	42	49	55	61

Average signal amplitude in [mV]

	25	50	75	100	150	200	300
	22	30		42		55	59
	27	34	38	42	49	55	61

Average signal amplitude in [mV]

- SPE timing resolution is <20 ps for nominal HRPPD 15 HV settings (bias 775 V, PC & transfer 200 V)
- Photocathode voltage dependency present, beyond just a varying S/N ratio
- Much less pronounced dependency on MCP1->MCP2 transfer voltage