Development of HRPPDs for RICH Detectors at the EIC

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ILC Workshop on Fast Timing Detector Technology

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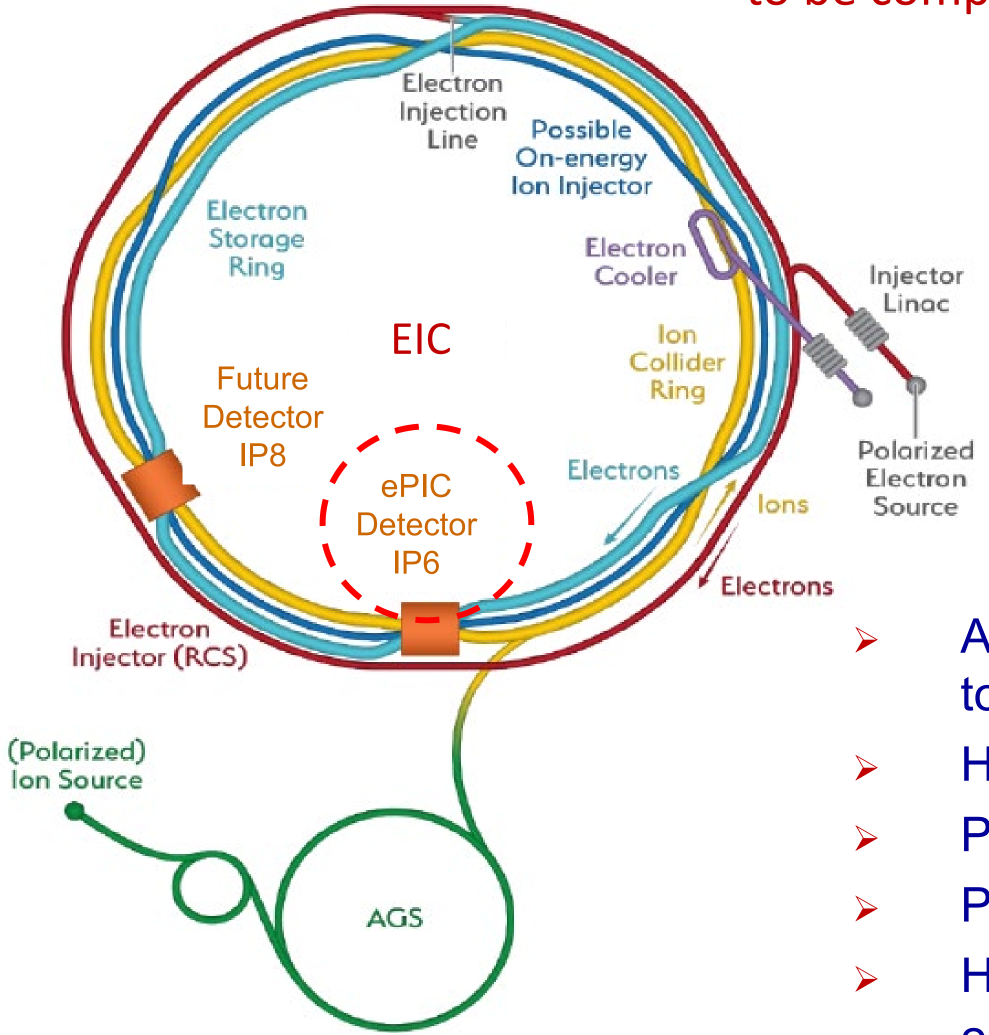
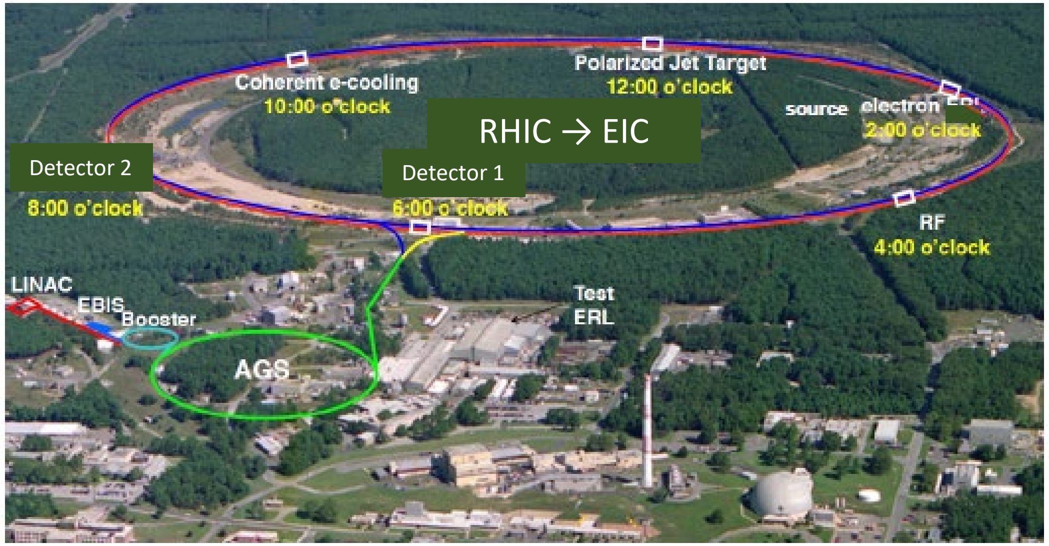
The Electron Ion Collider (EIC)

RHIC → EIC

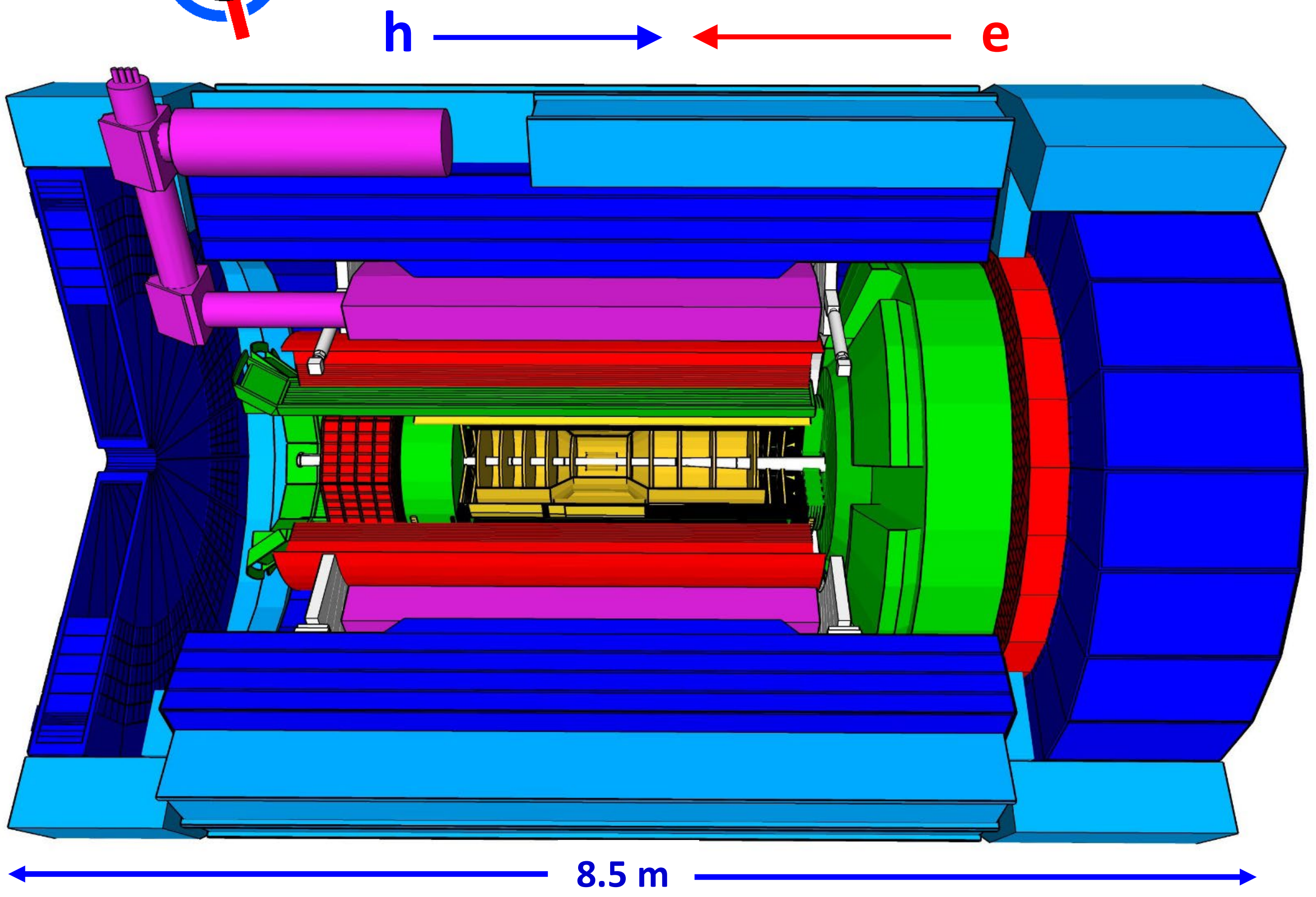
New DOE Nuclear Physics Facility at Brookhaven National Lab (~ $2.8B) scheduled to be completed in the early 2030's – *Start of construction in 2 years*





- Add an Electron Storage Ring (ESR) to the existing RHIC collider to provide polarized electrons with energies 2.5-18 GeV
- Hadron storage ring provides beams from 40 - 275 GeV/c
- Provide ion beams up to 100 GeV/A (light ions → Uranium)
- Polarized e, p, light ions (d, He^3...) with P ~ 70%
- High luminosity ~ $10^{33} \rightarrow 10^{34}$ cm^{-2}/s^{-1} (10-100 fb^{-1} per year)
- 2 Intersection Regions (currently only one funded → ePIC)

The ePIC Detector at EIC



Large Multipurpose Spectrometer
(Almost) Hermetic coverage from $-3.5 < \eta < 4.0$

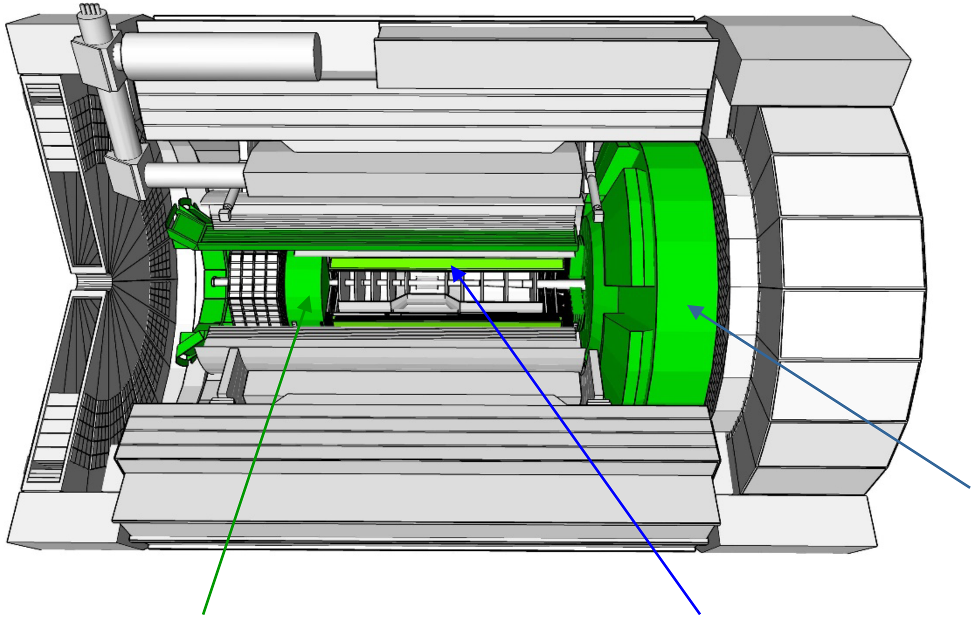
Tracking
- New 1.7 T solenoid magnet
- Si MAPS tracker
- MPGDs (uRWELLs/uMegas)

PID
- hpDIRC
- pfRICH
- dRICH
- AC-LGAD (TOF)

RICH Detectors (hpDIRC, pfRICH, dRICH)

Calorimetry
- Imaging Barrel EMCAL
- Outer HCAL (sPHENIX re-use)
- PbWO4 EMCAL (backward direction)
- Backward HCAL
- Finely segmented EMCAL + HCAL (forward direction)

High Resolution Picosecond Photon Detectors (HRPPDs) in ePIC



Backward RICH – Proximity Focused RICH (pfRICH)

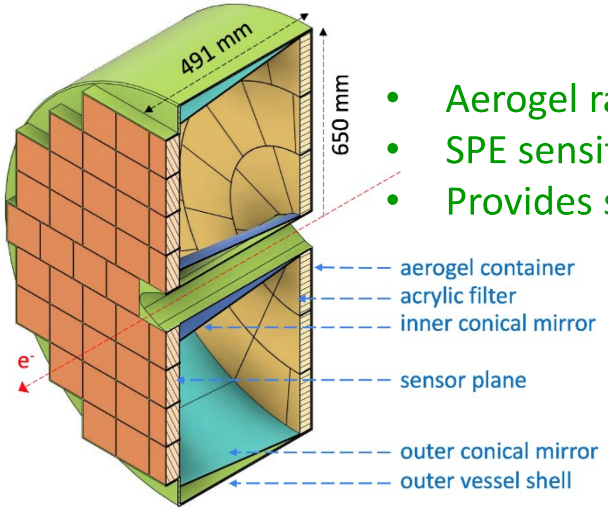
- Aerogel radiator
- < 50 ps timing for single photons on Č ring
- ~ 10-20 ps timing for multiple photons produced in the entrance window
- < 1 mm spatial resolution

HRPPD/MCPs

Dual Radiator (aerogel + C_2F_6 gas) RICH (dRICH)

- problematic due to location in magnetic field
- No stringent timing requirements (~ 200 ps)

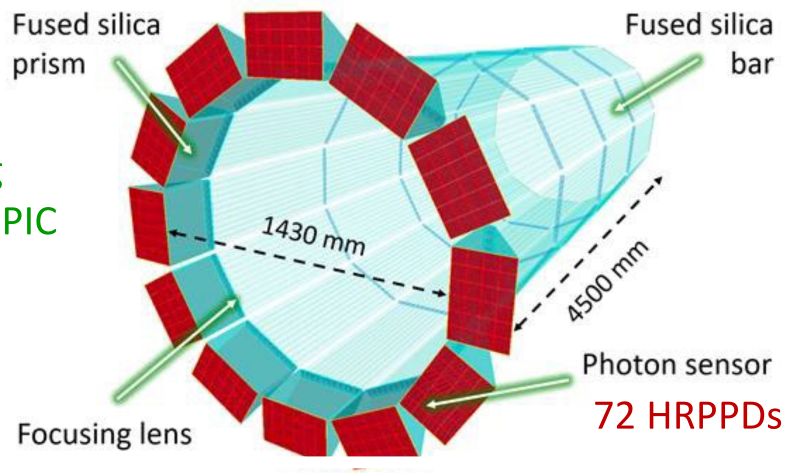
SiPMs



- Aerogel radiator
- SPE sensitivity for Č ring
- Provides start time for ePIC

68 HRPPDs

Reuses BaBar DIRC bars



72 HRPPDs

DIRC

MCP/HRPPDs

- SPE & ToF capability (< 75 ps)
- < 1 mm spatial resolution
- High occupancy

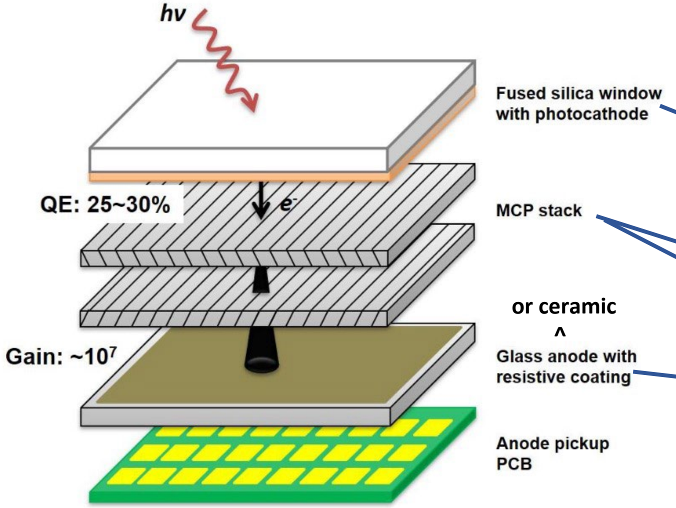
140 HRPPDs Total

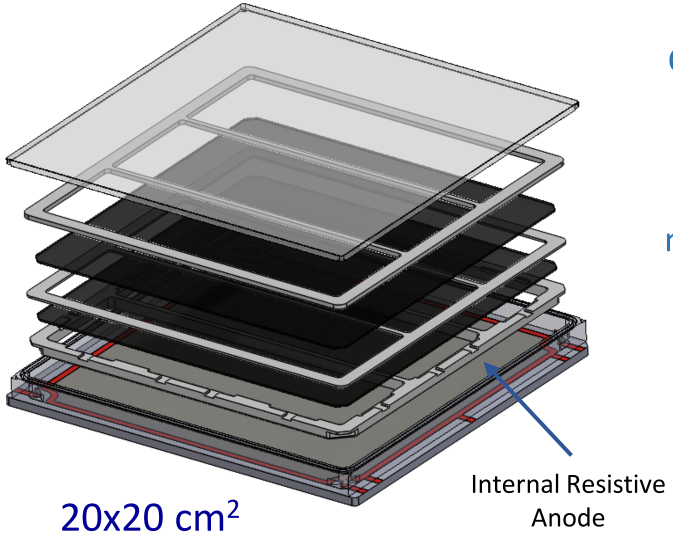
Large Area Picosecond Photon Detectors (LAPPDs)

Originally developed at Argonne for use in HEP. Now produced by Incom*, Charlton, MA

*Experts in fused fiber optic technology

Principle of Operation

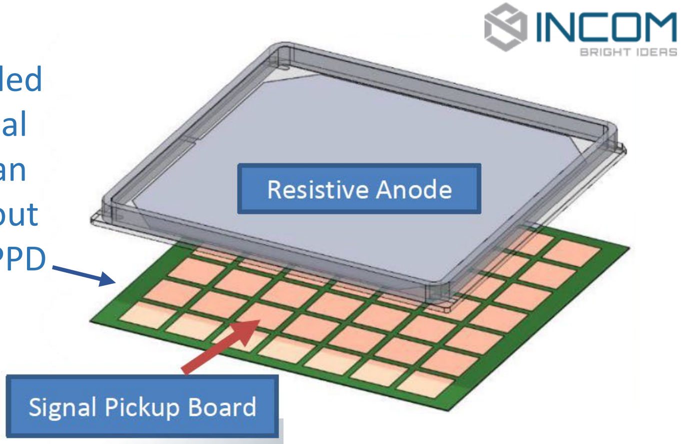




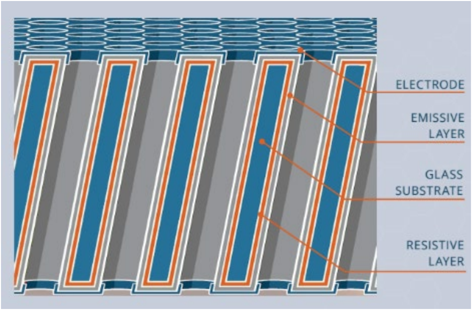
20x20 cm^2

GEN II

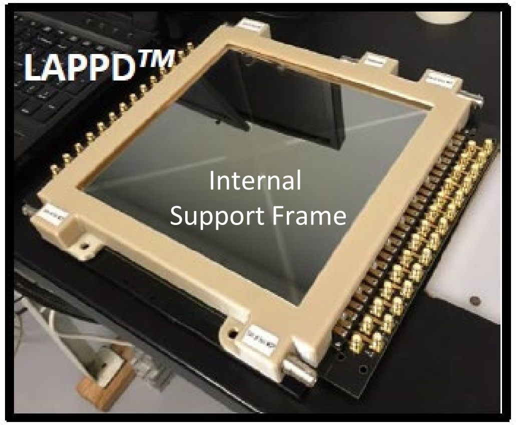
Capacitively coupled pixellated external readout board can be changed without modifying the LAPPD detector



Initially used an anode strip delay line readout

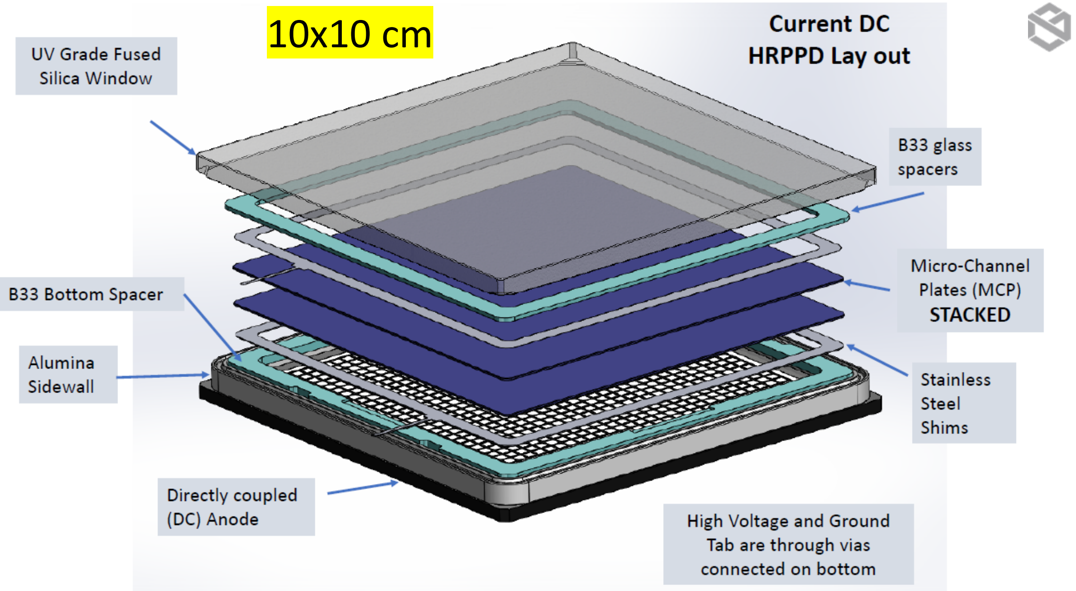


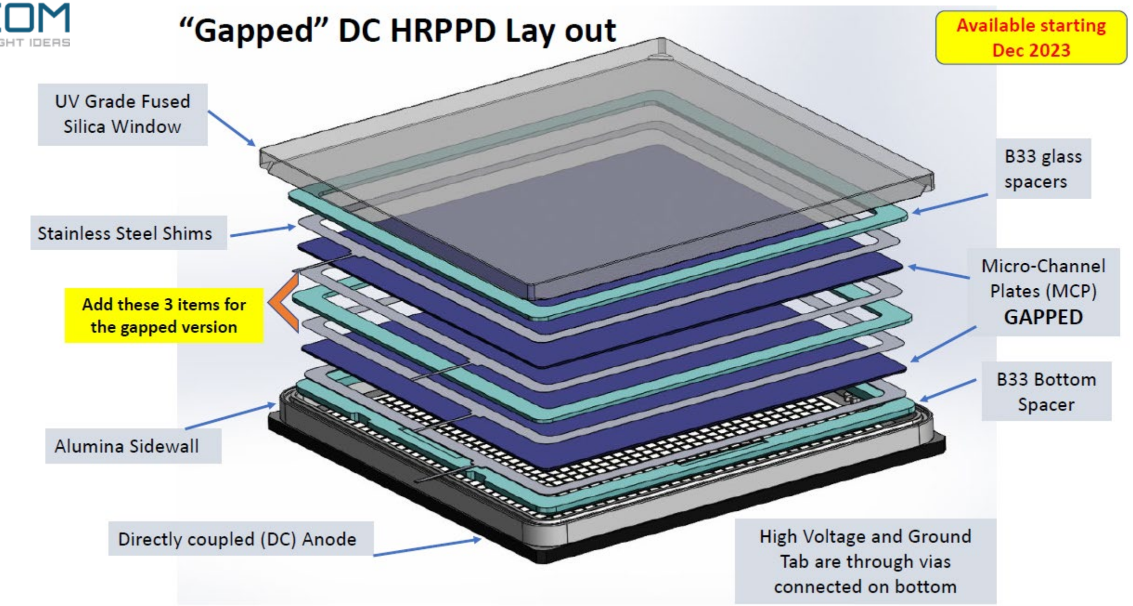
MCP stack consists of two planes of chevron shaped 20 μm or 10 μm glass capillaries with emissive ALD coating

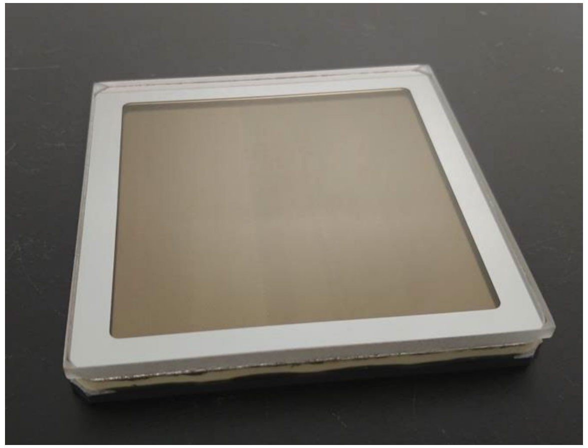


- 20 μm or 10 μm pore diameter
- Gain ~ 10^7 (⇒ single photon sensitivity)
- Bialkalai Photocathode (QE ~ 30% @ 365 nm)
- Capacitively Coupled readout
- Magnetic field compatible (w/limitations)
- Single Photon Timing Resolution ~ 50 ps
- Position Resolution < 1 mm (depending on readout)

High Resolution/High Rate Picosecond Photodetectors (HRPPDs)







10x10 cm^2 HRPPD

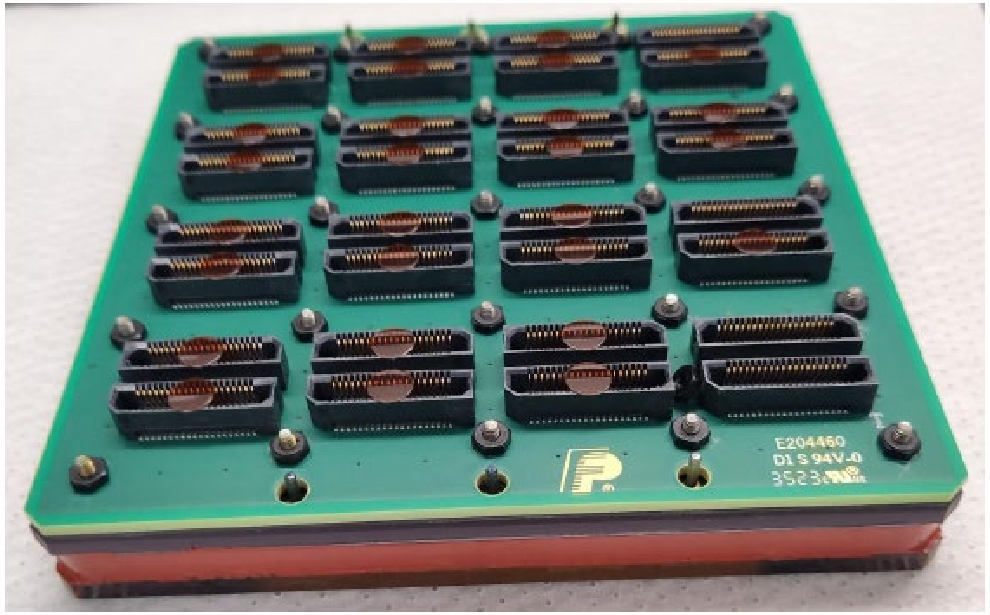
DC Readout 32x32 array
0.100" pixels on 0.125" pitch

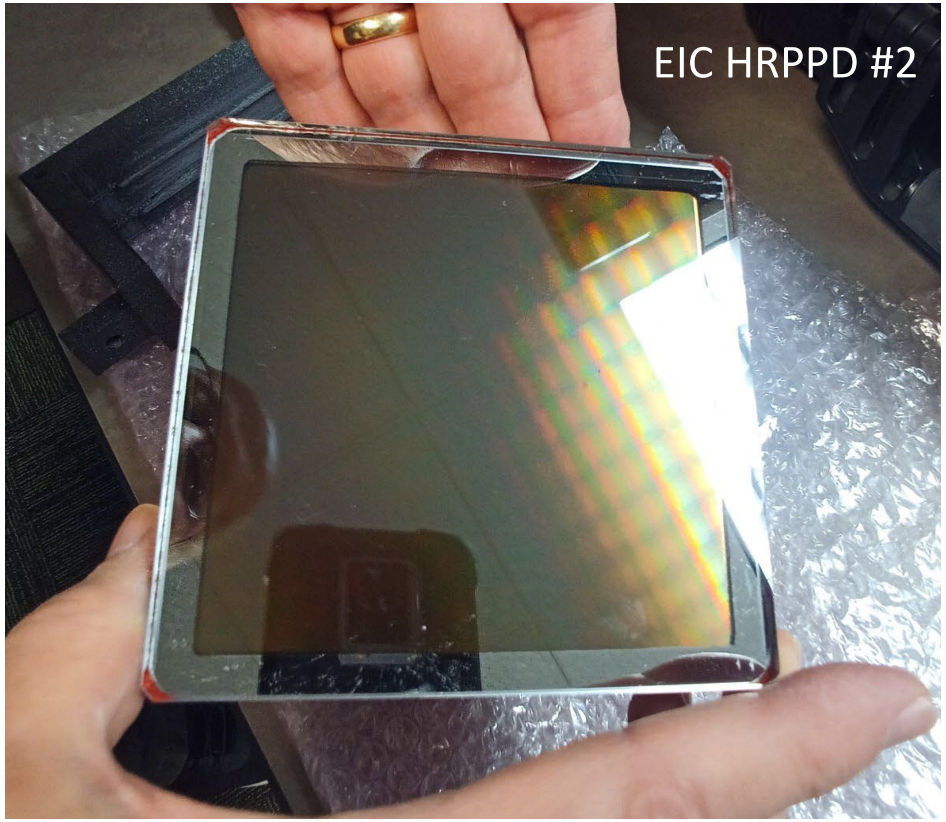
- 10 μm pore diameter (improved TTS)
- Improved magnetic field tolerance
- Eliminates internal window support (reduced dead regions and improved uniformity)
- Ceramic base allows direct connection to readout pads, HV and anode
- Thinner sidewall frames (increased active area)
- Tileable (4 side buttable)

EIC HRPPDs

Five "tiles" were ordered as a pre-production order for EIC in spring of 2023

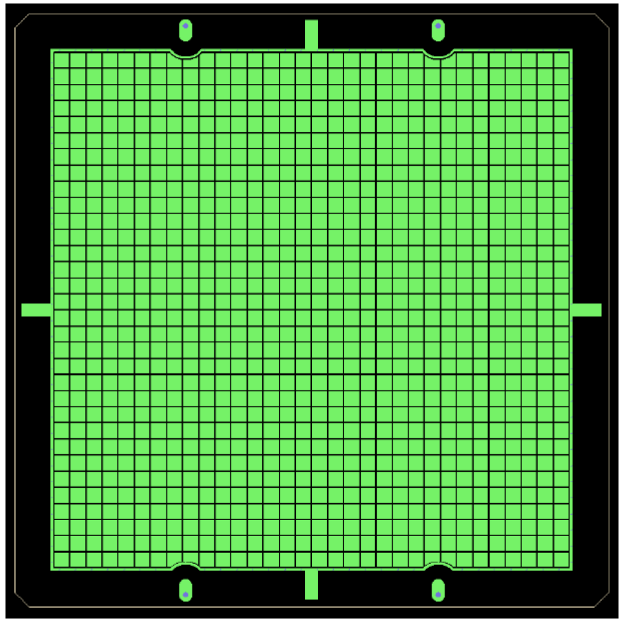
- Increased active area (69% → 75%)
- "Gapped" MCPs
- Ceramic base with DC readout
- Improved QE performance



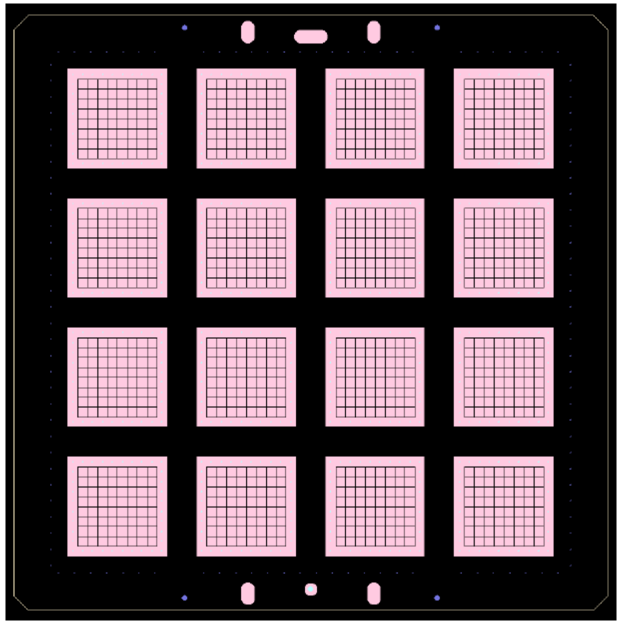


First 3/5 tiles delivered to JLAB for initial testing
Final testing will be done at BNL

Electrical Connections and Readout

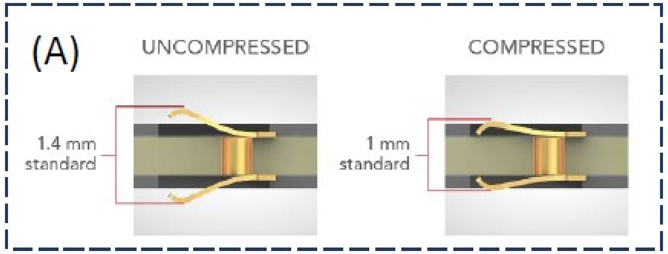


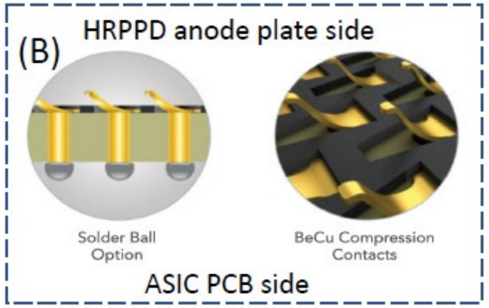
Inner Side
32x32 Pad Plane (3.25 mm pitch)

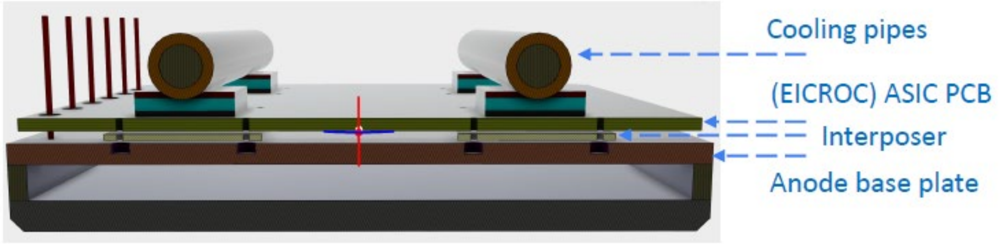


Outer Side
4x4 Array of 8x8 Pads (2.0 mm pitch)

Connection to electronics via Compression Interposers



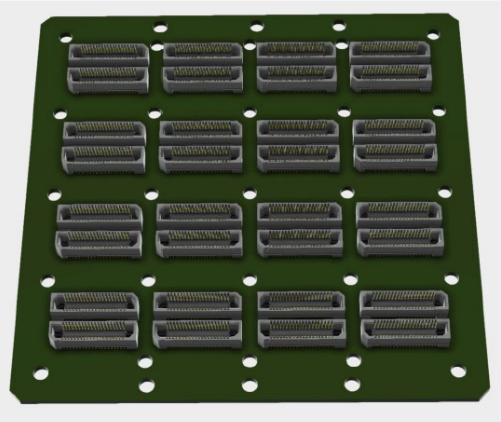




HRPPD face down

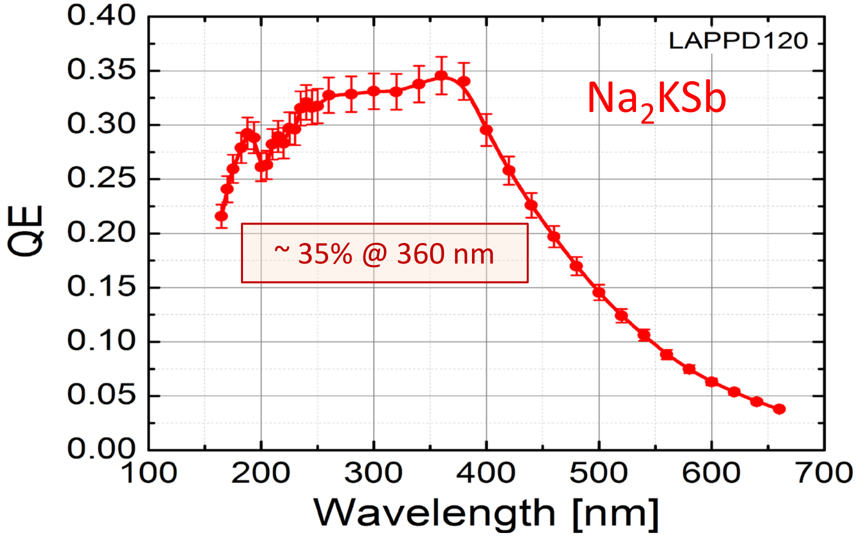
Final design will connect to EICROC ASIC Readout

- With Direct Coupled Anode Readout, signals from the internal pad plane must be brought to the outside of the detector module to connect to the readout electronics.
- A High Temperature Co-Fired Ceramic (HTCC) anode base plate will provide the feedthrough connections.
- Connection to the readout electronics will use Compression Interposers.

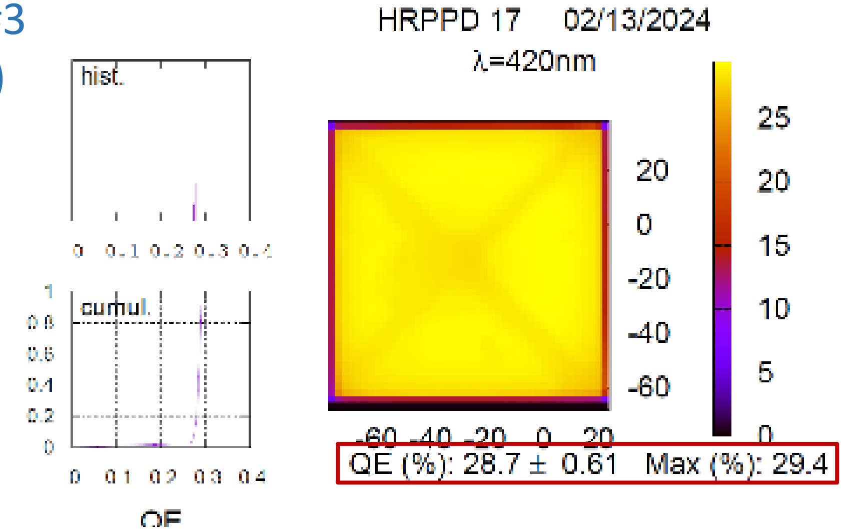


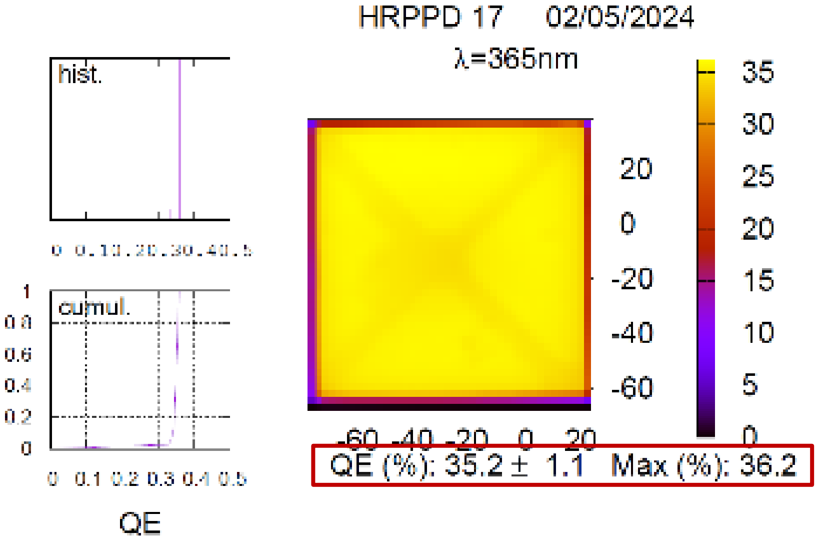
Connections for testing and prototyping will use conventional Samtec connectors

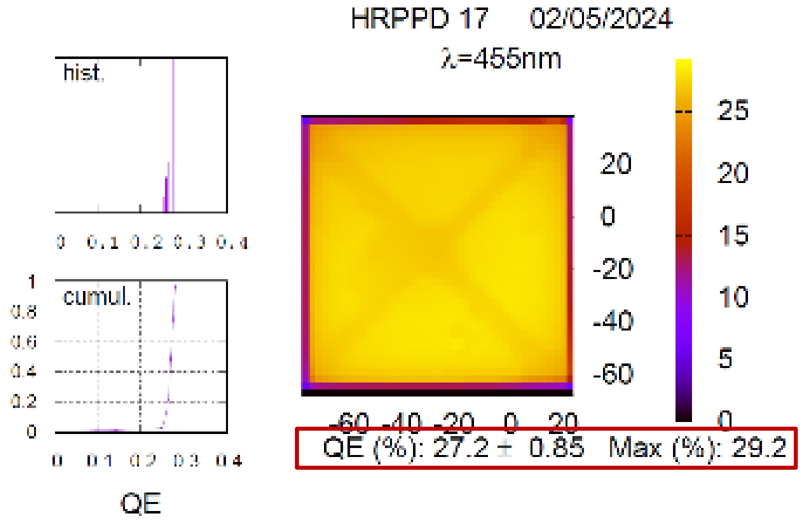
Quantum Efficiency



EIC HRPPD #3
(HRPPD 17)



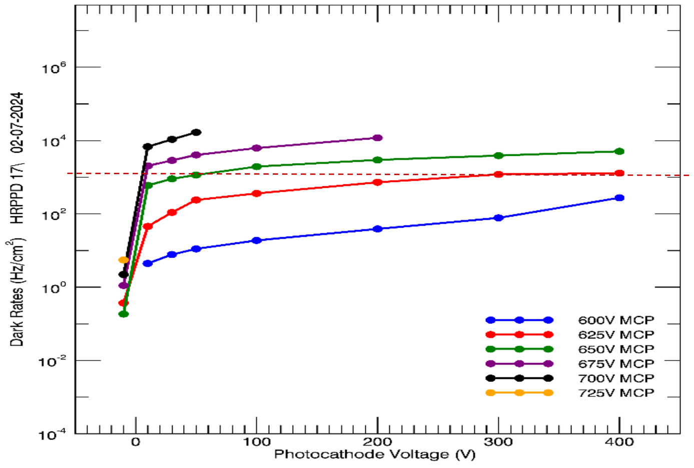




Dark Noise & Gain

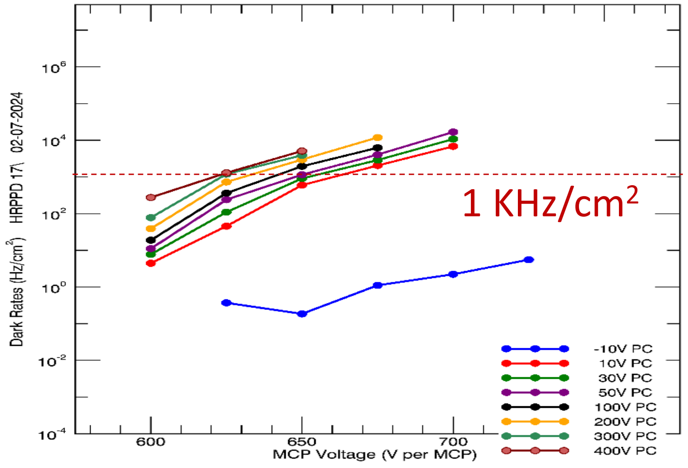
EIC HRPPD #3

Dark Counts



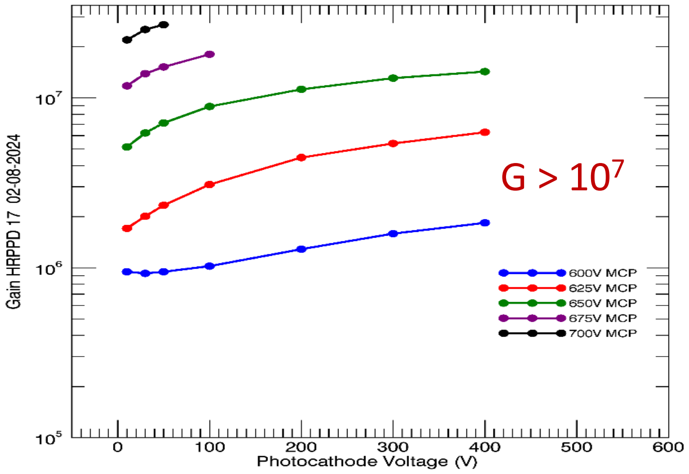
vs PC Voltage

Dark count rate
~ 1 KHz/cm^2 at nominal gain



vs MCP Voltage

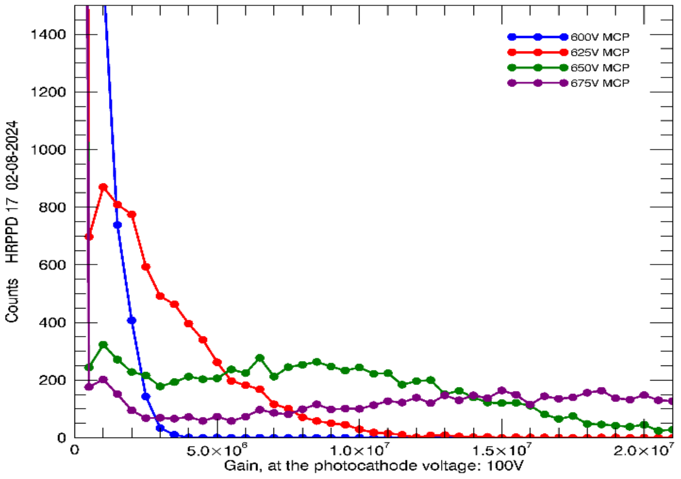
SPE Gain



vs PC Voltage

Single Photoelectron Sensitivity

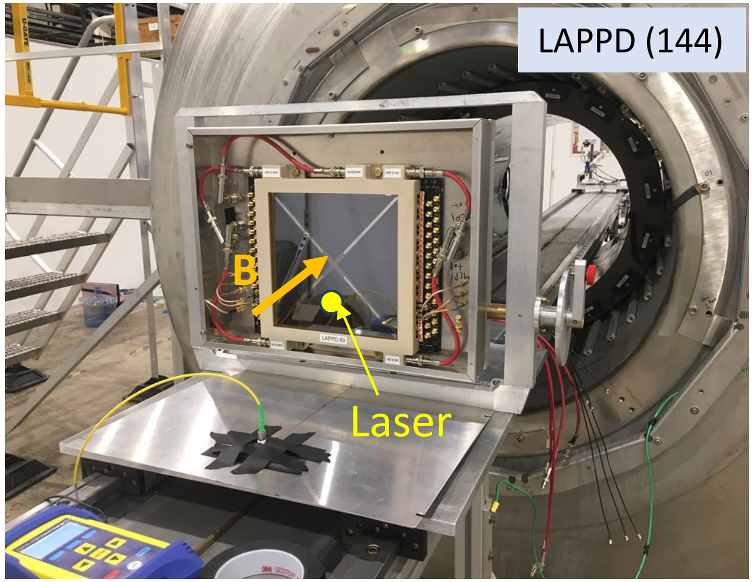
SPE Pulse Height Distribution

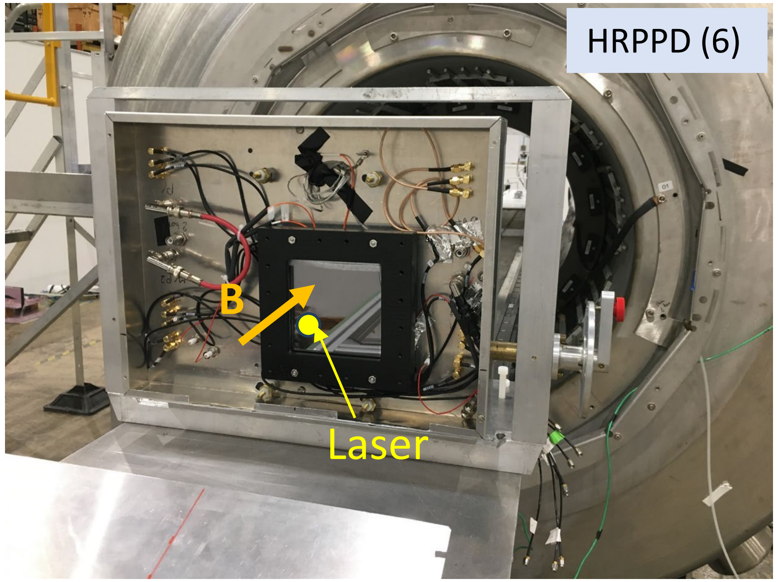


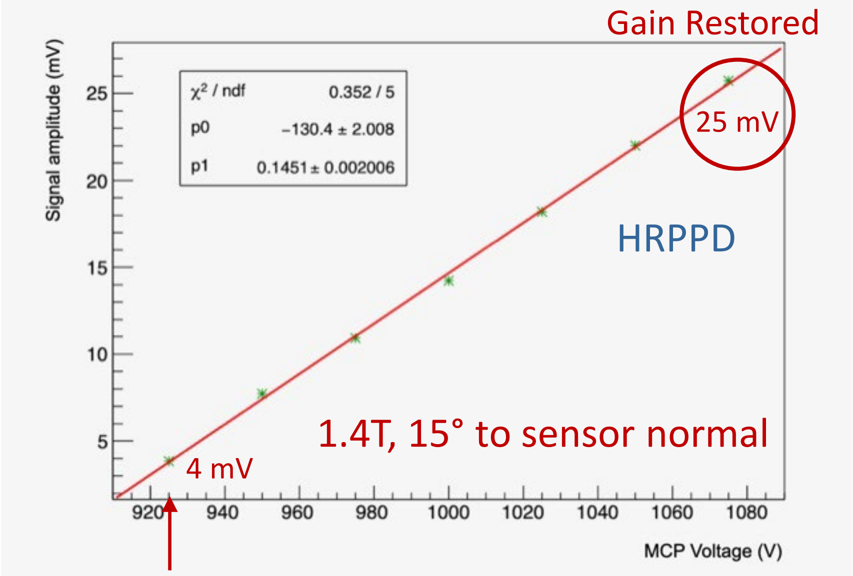
vs MPC Gain

Magnetic Field Tests

g-2 Solenoid Test Magnet at ANL







Nominal HV (925V) to achieve 25 mV signals at B=0

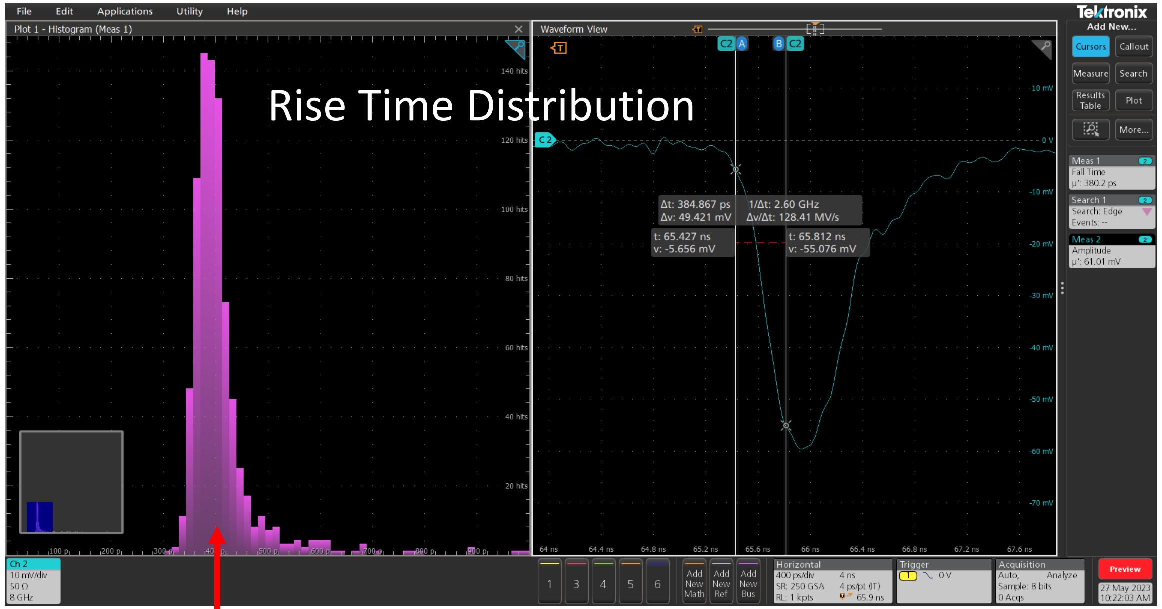
LAPPD and HRPPD tested under various magnetic field conditions

- 0.02-2.0 T
- Angles: 0° (perpendicular to window) → 35°
- Measured gain, dark counts, charge spread
- Gain restoration by increasing HV

HRPPDs in pfRICH will be exposed to a magnetic field ~ 1.4 T at an angle of 13° (hpDIRC ~ 0.3 T at 35°)

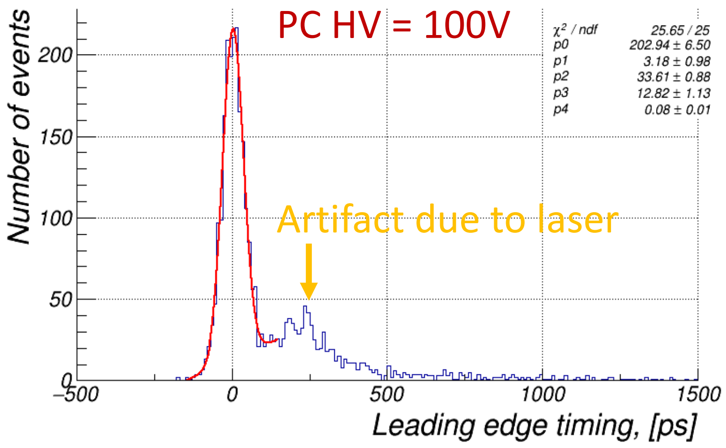
Increasing the MCP voltage from 925 V to 1075 V is sufficient to restore gain to its B=0 value in a 1.4 T field at 15°

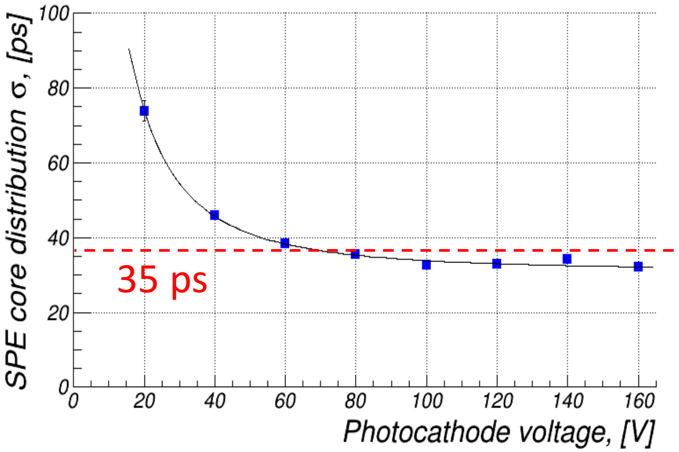
Timing Resolution



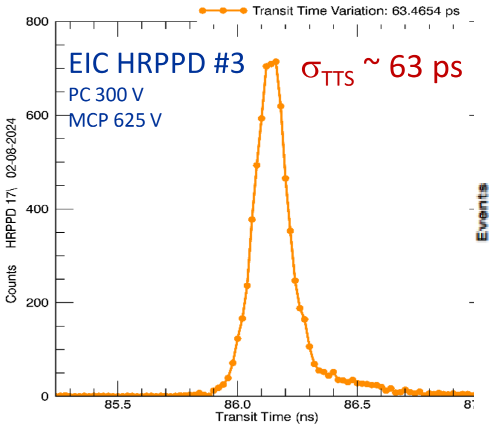
HRPPD 6

- Picosecond laser focused on a single pad
- Very low intensity (~95% empty events)
  $\Rightarrow$ SPE sensitivity
- Measured with CAEN V1742 DRS4 (5 GS/s)
- Not corrected for laser pulse width or other instrumental effects
- TTS was also measured in test beam at CERN with Č light (INFN Trieste & Genova)

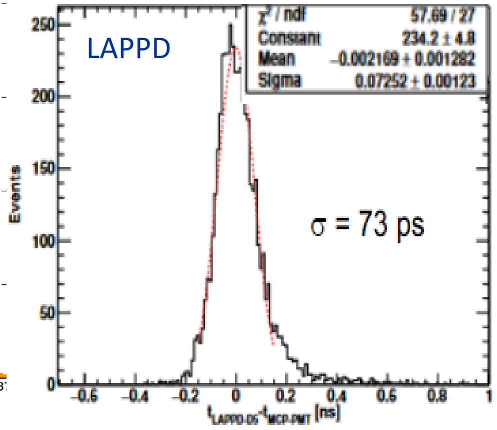




Transit Time Spread



Laser
(corrected for laser jitter but not electronic jitter)

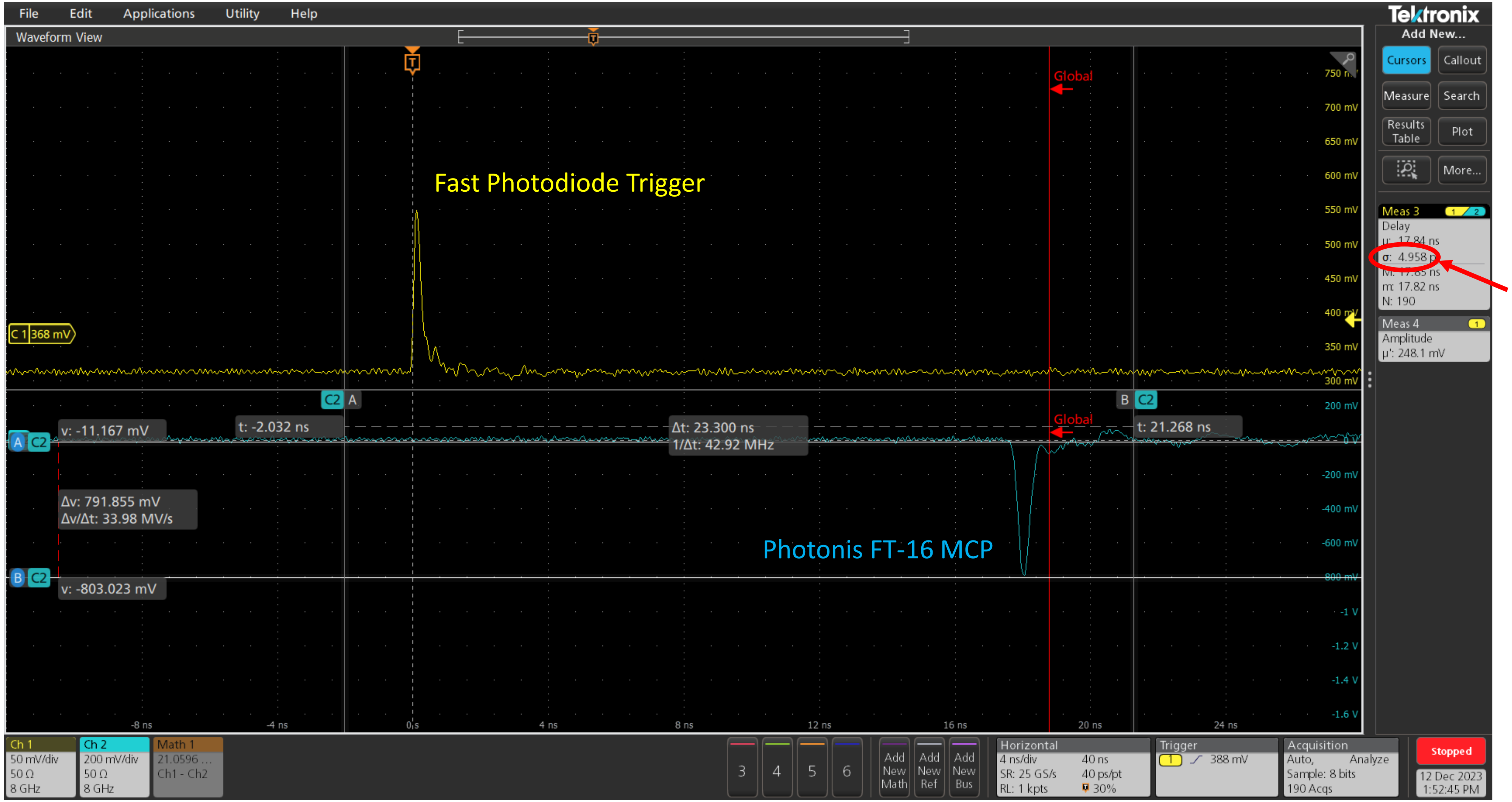


Č light (Test Beam)

Fast Timing Measurements

Er fiber femtosecond laser
Menlo Systems Elmo 780
4^{th} harmonic at 390 nm

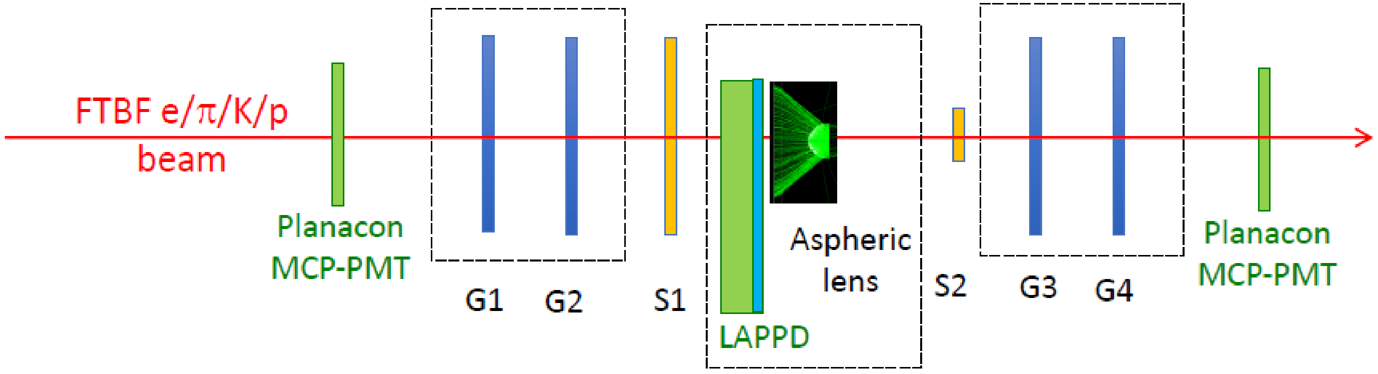
Tektronix MSO66B Scope
8 GHz bandwidth



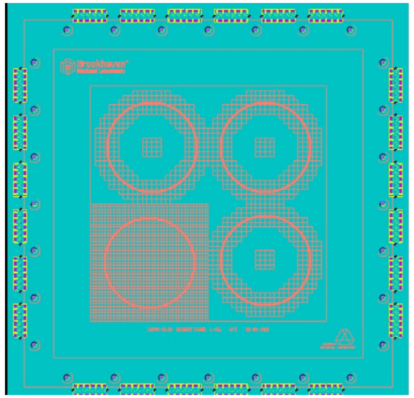
σ < 5 ps

Beam Test to Measure Cherenkov Rings

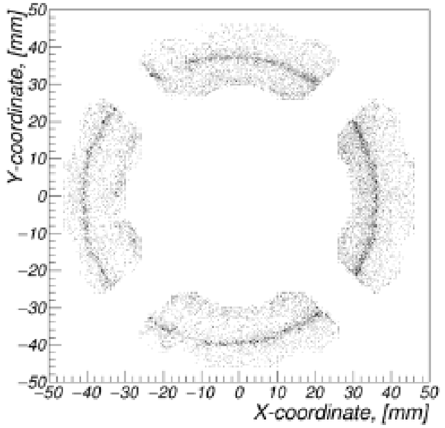
Beam Tests at Fermilab (2021 & 2022)



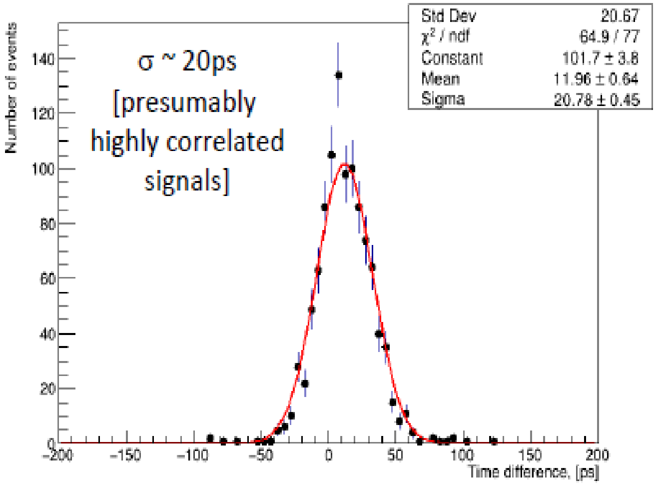
Gen II LAPPD (10 μm pores)
Capacitive Coupled Readout



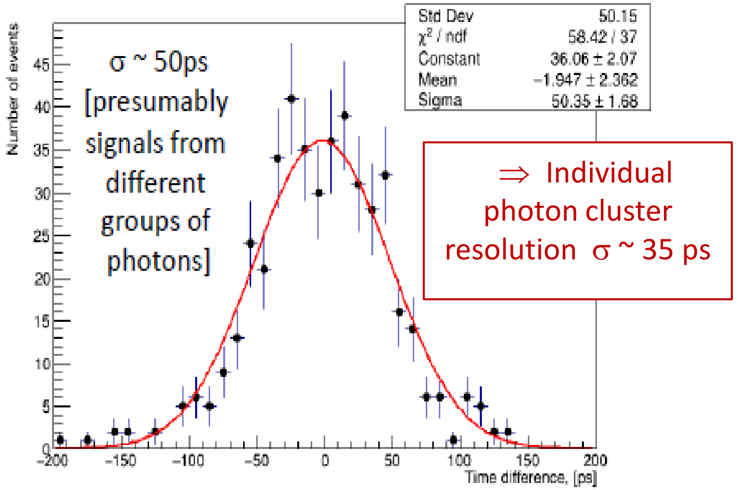
LAPPD Readout Board
4x4 mm^2 readout pads



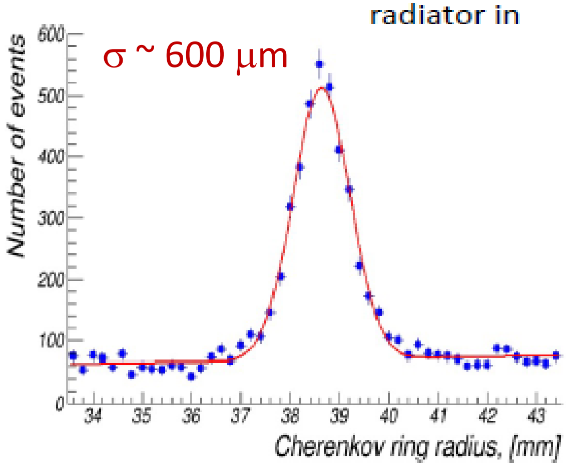
Cherenkov ring imaged by the LAPPD for multiple beam events



Time resolution for correlated single photon hits on the Cherenkov ring



Time resolution for photon hits from different groups on the ring



Spatial resolution for the radius of the Cherenkov ring for multiple events

Summary and Conclusions

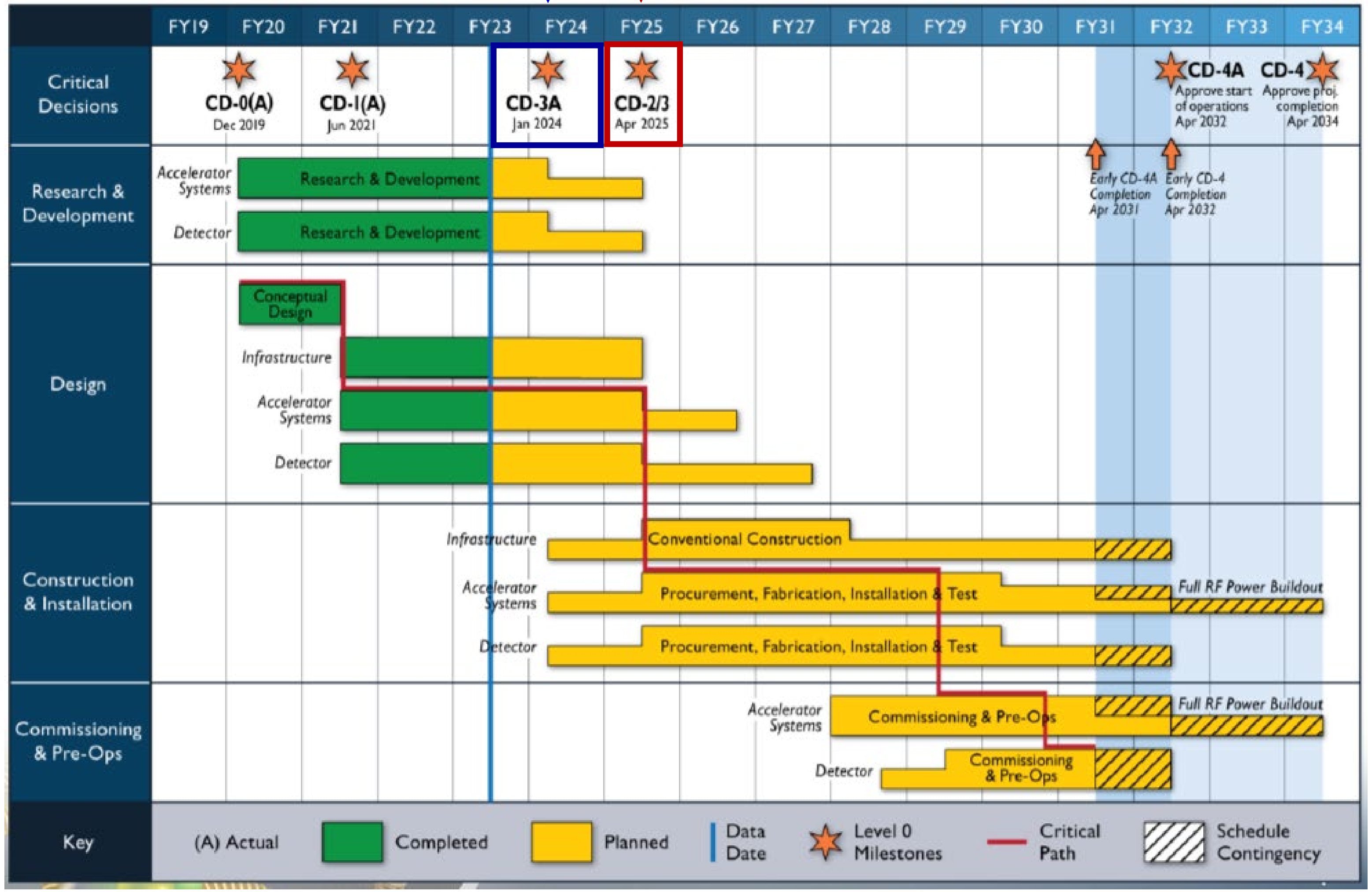
- HRPPDs utilize the same technology as LAPPDs but have a smaller overall area (10x10 cm^2 vs 20x20 cm^2) and incorporate a number of improvements that will improve their performance.
- The ePIC experiment at EIC plans to use ~ 140 HRPPDs in two of its RICH detectors (pfRICH and DIRC). These HRPPDs require a timing performance ~ 50-75 ps for single photons and ~ 10-20 ps for multiple photons produced in the entrance window.
- The new HRPPDs being developed for EIC are expected to meet these requirements and the delivery of the first five detectors is expected by the end of March 2024 .
- The second future EIC detector will also have similar PID requirements where HRPPDs and similar photodetectors will be needed.

Backup

EIC Schedule

Goal for the next 1.5 years is to produce a TDR for CD-2/3 approval in 2025 (⇒ Start of Construction)

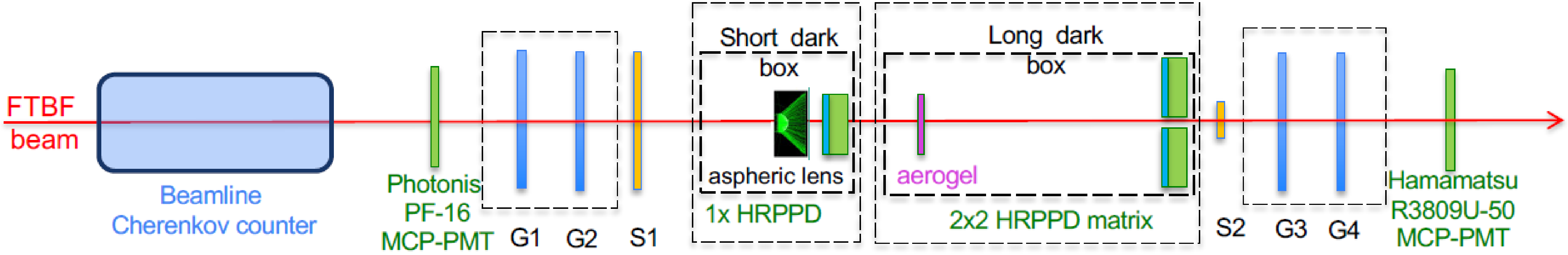
CD-3A approval for Long Leadtime Procurement items in Jan 2024



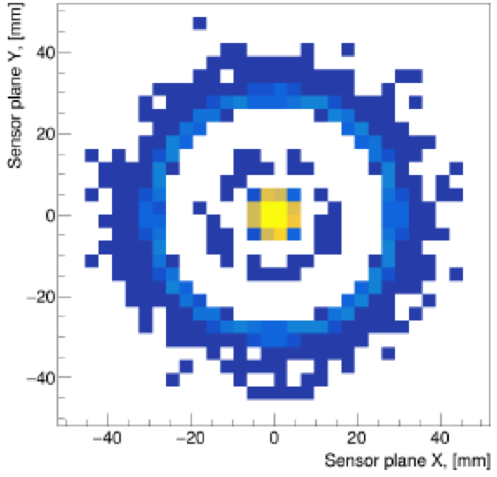
J. Yeck, EC Project Director, July 2023

Fermilab beam test plans

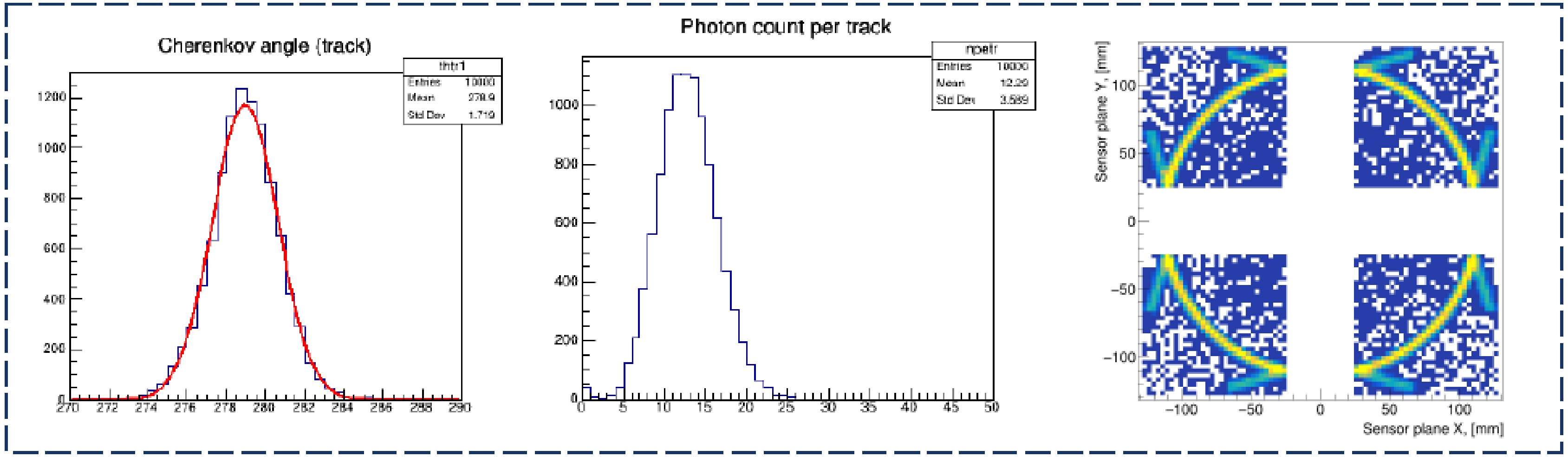
Either May this year or 2025+



"flash" timing   ring imaging



1x HRPPD

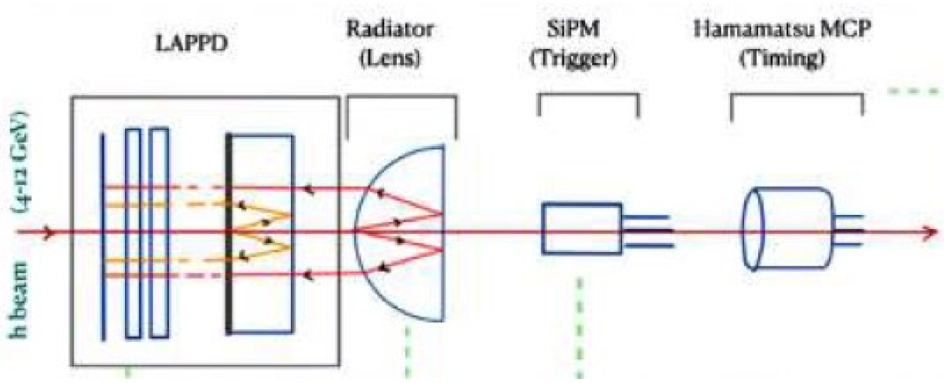


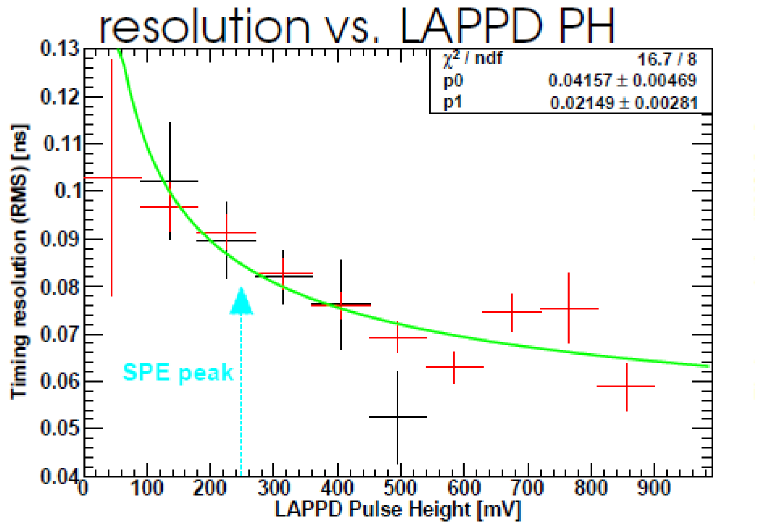
2x2 HRPPD matrix

7

CERN Beam Tests

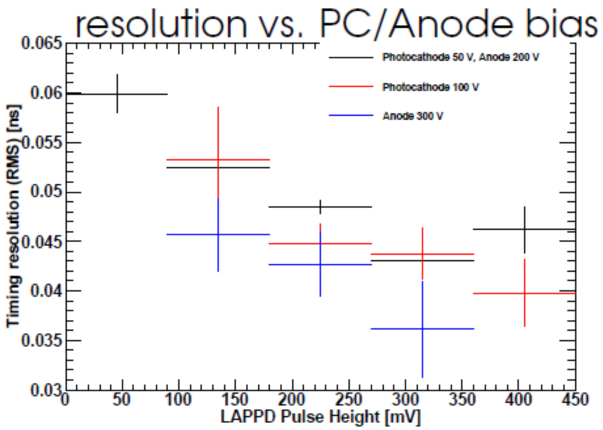
Beam tests of LAPPDs conducted by INFN Trieste and Genova (Oct 2022)

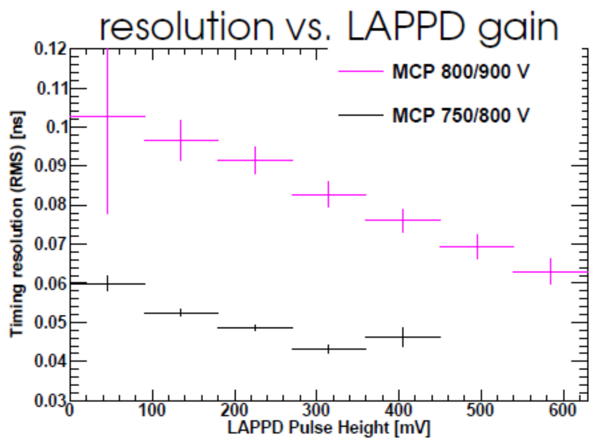




LAPPD with 20 μm pores, 1” pads, capacitively coupled to readout board with 1” pads, read out with DRS4 digitizers @ 5 Gs/s

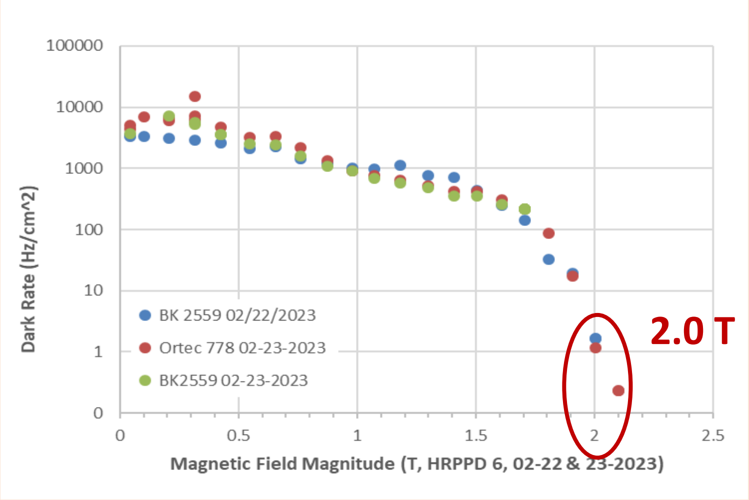
- Time resolution 40ps/$\sqrt{N_{pe}}$ + 40 ps
- SPE timing ~ 80 ps RMS
- Timing improves with PC voltage, Anode voltage and gain
- Large crosstalk between pads

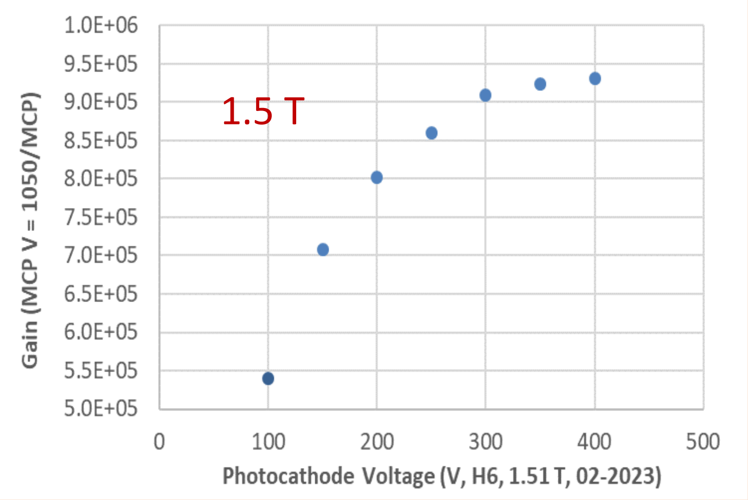


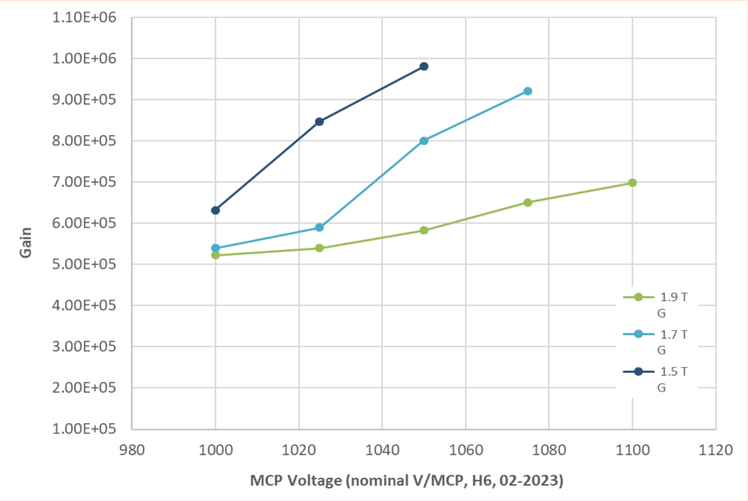


Magnetic Field Performance

HRPPD 6







Dark Count Rate vs Field

Gain vs PC Voltage

Gain vs MCP Voltage

LAPPD 144