HRPPD photosensors for RICH detectors with a high resolution timing capability

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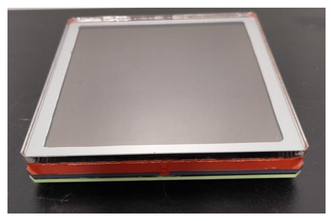
Abstract: High Rate Picosecond Photodetectors (HRPPDs) are Micro-Channel Plate (MCP) based directly-coupled readout photosensors recently introduced by Incom, Inc. that have an active area of 104 mm x 104 mm, pixel pitch 3.25 mm, peak quantum efficiency in excess of 30%, exceptionally low dark count rates and timing resolution of about 20 ps for a single photon detection. As such, these photosensors are very well suited for Ring Imaging CHerenkov (RICH) detectors that can also provide high resolution timing capability, especially in a configuration where a detected charged particle passes through the sensor window and produces a localized flash with a few dozens of Cherenkov photons in it.

Recently, a new version of direct coupled or DC-HRPPDs (32 x 32 pixelated anode array) has been developed that were substantially re-designed for use at the Electron-Ion Collider (EIC), which will be sited at Brookhaven National Laboratory in the US. A first batch of seven "EIC HRPPDs" was manufactured in early 2024. Results of a systematic evaluation of these first EIC HRPPD tiles, including gain and quantum efficiency (QE) uniformity, timing resolution, and dark count rates (DCR) are presented below.

High Rate Picosecond Photon Detector (HRPPD) overview



Planar geometry MCP-PMT featuring:
- **120 mm x 120 mm footprint, 104 mm x 104 mm active area**
- **75% active area ratio**
- **ALD functionalized glass 10 μm pore MCPs**
- **Direct (32 x 32 pixelated anode array)**

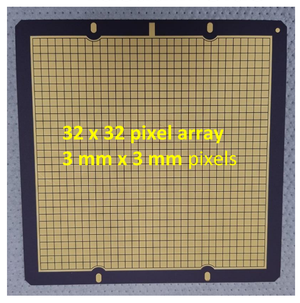
or Capacitively coupled readout

Potential applications: Scientific Research, Homeland Security, and Medical Diagnostics

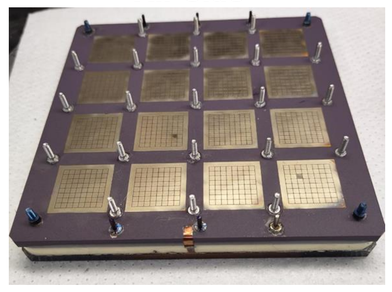
Trials are underway for the following applications:
EIC pfRICH, LHCb ECAL Upgrade 2, Positron emission Tomography (PET) and others

Anode plate directly coupled (DC) signal readout

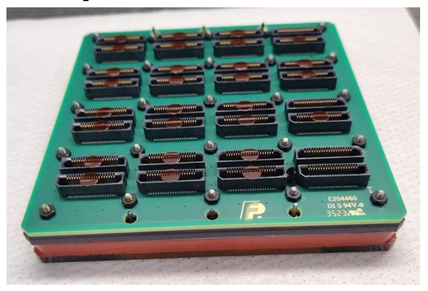
Vacuum Side



Air Side



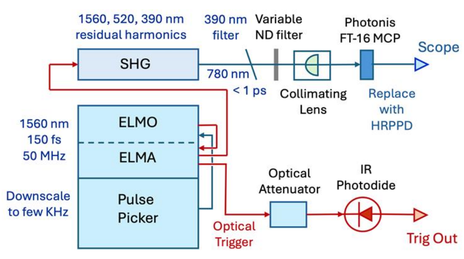
Test PCB board attachment using Samtec compression interposers



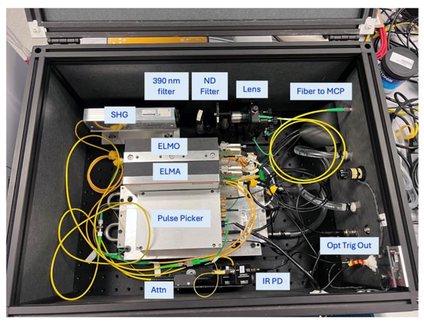
Timing Measurements

Menlo Systems Elmo 780 Erbium Fiber Femtosecond Laser

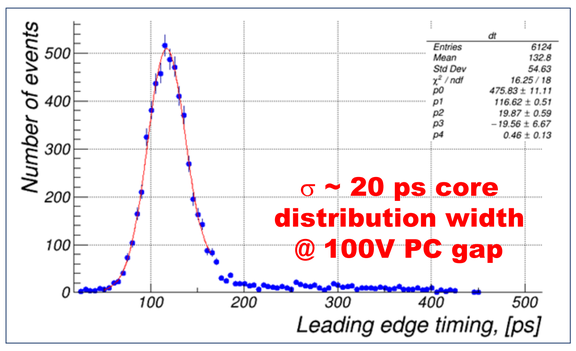
ELMO = Primary Laser Oscillator
ELMA = Optical Amplifier
SHG = 2nd Harmonic Generator



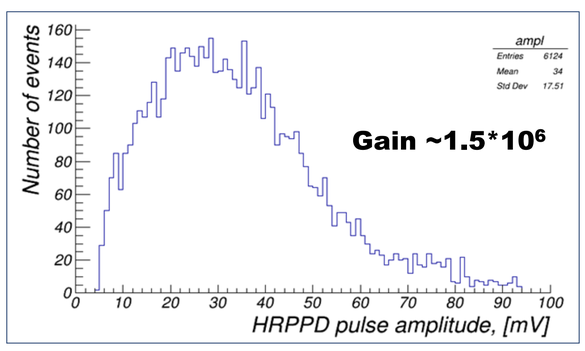
BNL test setup comprised of Menlo Systems Model Elmo 780 1560 nm femto-second laser followed by a Second Harmonic Generator (SHG). Residual fourth harmonic 390 nm laser pulse was fed into HRPPD15.



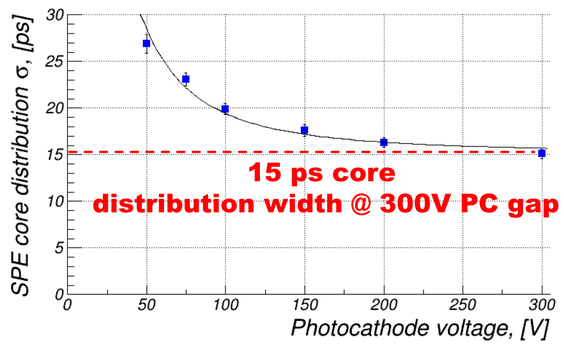
- **Laser beam focused on a single HRPPD pad center; intensity tuned down to >95% empty events**
- **HRPPD signal used for triggering (5 mV effective threshold). To increase data taking efficiency**
- **Signal waveform data taken with a Tektronix MSO66B scope (50 GS/s, 8 GHz ABW). Leading edge fits [10% .. 90%] performed offline; $\Delta t = t_{HRPPD} - t_{FastPD}$ is a plotted quantity**
- **SPE timing resolution is below 20 ps for nominal HRPPD15 HV settings (bias 775 V, PC 200 V, gain ~$1.5*10^6$)**
- **A scale cross-check: primary electron drift time decreases with PC voltage as expected**
- **Nominal PC->MCP#1 gap is 1.1 mm per design [compare to a fit value of ~1.2 mm]**



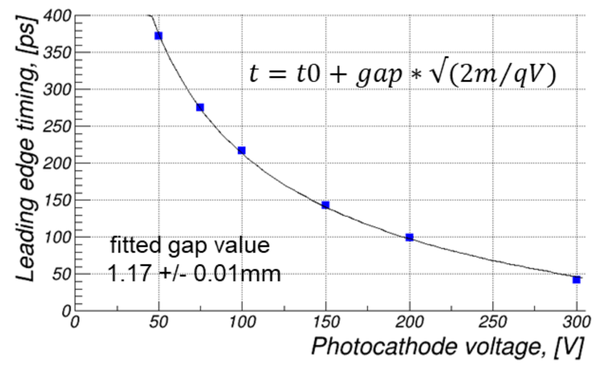
Single photoelectron (SPE) transit time spread distribution example



Pulse Height Distribution (no amplification)

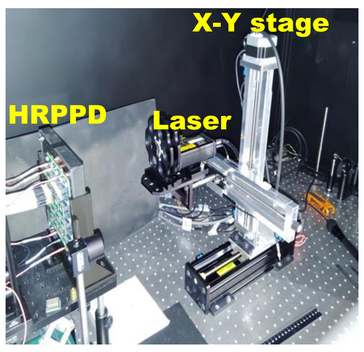


SPE timing resolution as a function of Photocathode gap voltage

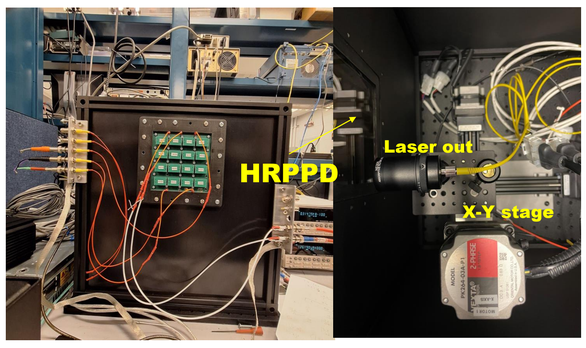


Primary electron drift time PC->MCP#1

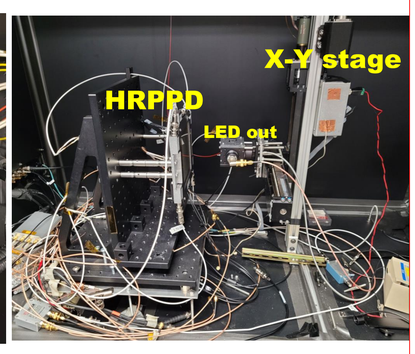
Test Facilities



TJNAF

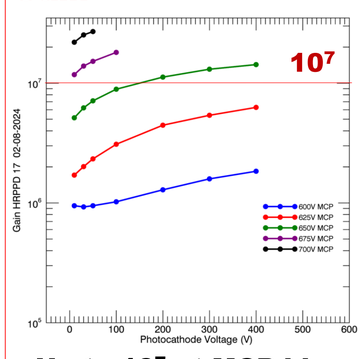


BNL

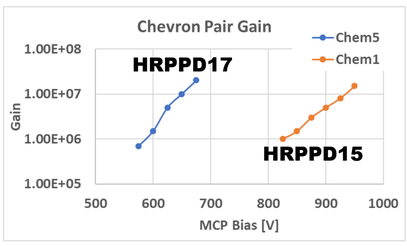


INCOM

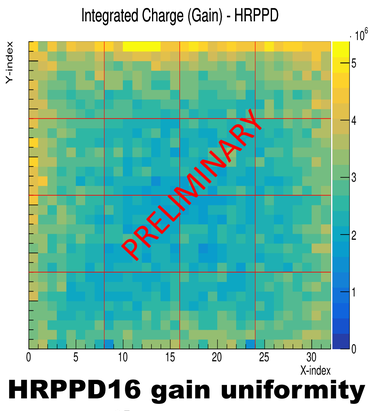
Gain



Up to 10^7 at MCP bias voltage of 650V



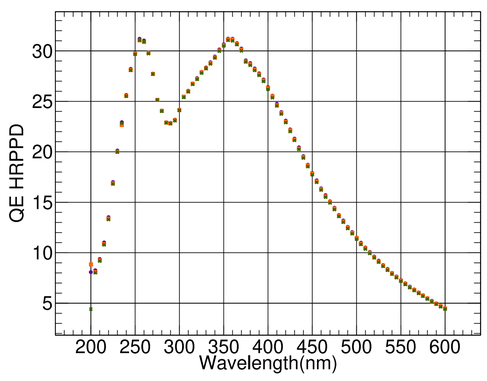
New Chem5 MCP ALD SEE layer chemistry provides higher gain at lower bias



HRPPD16 gain uniformity across the area

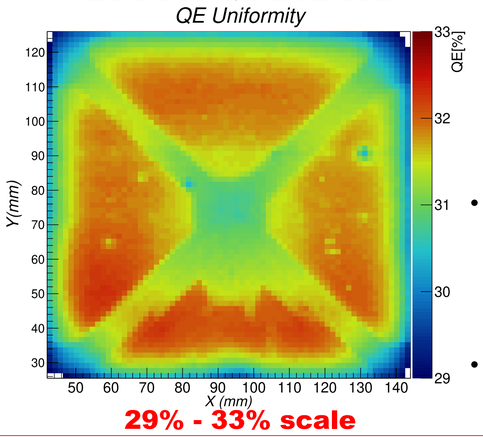
Quantum Efficiency

HRPPD16 QE spectrum

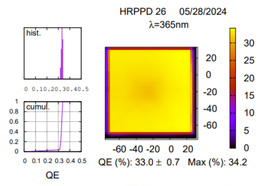


HRPPD16 QE area scan

QE Uniformity



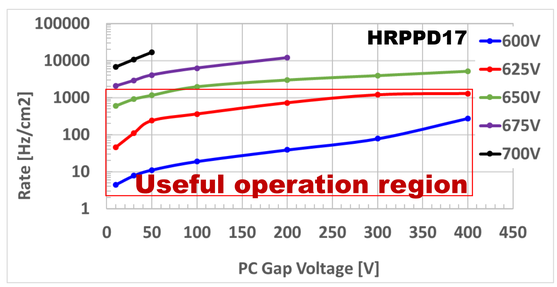
29% - 33% scale



0% - 35% scale

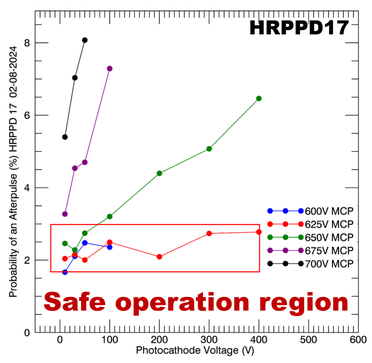
- **Average QE in excess of 30% has been reported for five out of seven HRPPDs for EIC**
- **QE uniformity of >80% was measured**

Dark Count Rate



> 1 kHz/cm² @ gain $5*10^6$

After Pulse Fraction



~ 2.5% @ gain $5*10^6$

Conclusions and Summary

- **In 2024 a test batch of seven new design DC-HRPPDs was manufactured by Incom Inc. for EIC collaboration**
- **15 ps timing resolution for single photoelectrons was demonstrated**
- **These HRPPDs are characterized by high QE in excess of 30%, low dark count rates of < 1.8 kHz/cm² @ gain $5*10^6$, low afterpulse ratio of <2.8% @ gain $5*10^6$**
- **Life time studies are ongoing**
- **Evaluation of HRPPD performance in Magnetic Field is scheduled for March 2025**

HRPPD#	Mean QE @ 365 nm	Dark rates @ 100V PC gap, gain $5*10^6$	Afterpulse Fraction @ 100V PC gap, gain $5*10^6$
15	33%	1.8 kHz/cm²	2.8%
16	34%	0.2 kHz/cm²	3%
17	35%	0.4 kHz/cm²	2.5%
23	27%	0.7 kHz/cm²	0.5%
24	36%	1.3 kHz/cm²	0.2%
25	27%	0.4 kHz/cm²	0.3%
26	33%	1.8 kHz/cm²	0.8%

References

- A. Lyashenko et al, Performance of large area picosecond photo-detectors (LAPPD™), NIMA 958 (2020) 162834
- S. Shin et al, Advances in the Large Area Picosecond Photo-Detector (LAPPD™): 8" × 8" MCP-PMT with Capacitively Coupled Readout, JINST 19 (2024) P06040

Acknowledgements

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