High Rate Picosecond PhotoDetector or HRPPD Development

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Incom, Inc., Charlton, MA 01507

DOE NP SBIR/STTR Exchange Meeting

August 15-17, 2023

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Outline

- **The Phase II SBIR** was entitled:
  - **"Large Area Multi-Anode MCP-PMT for High Rate Applications"**
    - **aka Incom "HRPPD" or the "10 cm device"**
- **Incom, Inc. - The Company Overview**
- **Phase II Technical and Commercialization Goals**
  - HRPPD development successes are applied to LAPPD
  - HRPPD platform transitioned from **glass to ceramic LTA package**
- **Application Successes (All devices)**
- **Devices & Pilot Production**
- **Year Two HRPPD Development**
  - Measurement & Testing: Performance and B-Field Tests
  - Device Design: Next Gen
  - Signal pickup methodology: 1024 (~3 mm) pixels
- **Summary of Program**
- **Future Device Commercialization**

Lexicon is on last slide

Incom Inc. – Enabling the Vision of Tomorrow

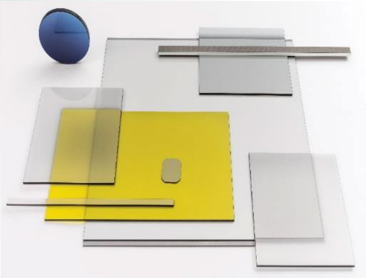
Founded 1971 (Fused Fiber Optics)

Long history of Innovation

~170 Employees

Three facilities: 3 Business Units

- Incom East (2) - Charlton, MA
  (Glass and Detector)
  Plus the R&D & Pilot Production Facility
- Incom West (1) - Vancouver, WA (Polymer)



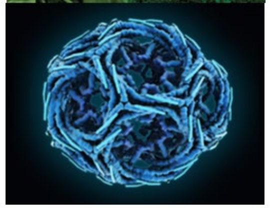
Life Science / Medical

Digital X-Ray systems

Mammography

Panoramic and Intra-oral X-Ray

DNA sequencing



Defense & Homeland Security

Night Vision

Biometric Identification

Neutron Detection

Display

Gaming

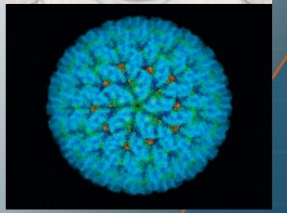
Automotive

Audio/Video Editing

VR/AR

Holographic Imaging

Light Field Technology



Scientific Cameras

X-Ray crystallography

DNA Sequencing

Electron Microscopy

Dark Matter Research

INCOM BRIGHT IDEAS

HRPPD Technical & Commercialization Goals

- **Ultimate Goal**
  - Demonstrate **Pilot Production** feasibility of HRPPD devices with device performance metrics of:
    - **high rates (200 kHz/cm^2)**, B-field tolerance (**2-3 Tesla)** & **deliver** devices.
  - **Two primary objectives:**
    - Fabricate devices using 10 µm pore size MCPs with full active area.
    - Develop a novel anode with a highly pixelated **directly coupled (DC) signal** readout for high rates.
  - **Phase II Year Two Focus:**
    - Continue Sealing trials on fully assembled HRPPD (in existing Sealing Tanks)
      - Using newly designed kit components
        - Extra HV connections and taller sidewall for gapped MCPs
      - Designed new DC anode (with **BNL**)
        - For EIC: **pfRICH** & **hpDIRC**
    - HRPPD M&T Characterization Schemes (CC & DC)
      - Magnetic field testing – Baseline tests completed at ANL
      - New Dark Box geared up to read up >100 channels
    - Secure additional funding
  - **Commercialization Plans** (with our LAPPD Production Sales Priorities)
    - **Early Collaborator interest: (EIC)**
      - BNL, Stony Brook University, TJNAF, INFN, BELLE II at CERN
    - **NP, HEP, PET, Homeland, Bioluminescence (Medical)**

LAPPD/HRPPD Applications

PROGRAM	AFFILIATIONS	2020 – 2023 STATUS
ANNIE - Atmospheric Neutrino Neutron Interaction Experiment	Iowa State, U. of Tübingen, Florida State	**Seven LAPPDs** delivered; 4 to 6 more stripline
Neutron Imaging Camera, Nanoguide scintillating polymer	Sandia National Lab (CA), U of Hawaii	**LAPPD #22** delivered
Fermilab Test Beam Facility, IOTA KOTO	U of Chicago, Fermilab	Demonstrate achievable LAPPD TOF resolution and particle identification in a working beamline setting. **Four LAPPDs delivered.**
WATCHMAN, UK STFC	U. of Sheffield, The University of Edinburgh	**Two LAPPDs delivered**
CHESS, WATCHMAN, THEIA Cherenkov & Scintillating Imaging	Lawrence Berkeley National Laboratory	**One LAPPD delivered.**
SoLID (Solenoidal Large Intensity Device) Alternatives to PMTs in Cherenkov Applications– JLab funded	ANL, JLab	**Three CC-LAPPD** testing at JLab
Electron Ion Collider (EIC) Particle ID	Brookhaven National Laboratory	Fermilab beam line testing 2021 to 2024; **LAPPDs** and **HRPPDs**. Also **HRPPD** characterization with a femtosecond laser in Fall '23
CERN LHCb RICH phase-2 upgrade	The U. of Edinburgh, U. of Ferrara INFN, Jozef Stefan Institute,	**Two LAPPDs** delivered, one more **LAPPD** on order
i-MCPs for ECAL upgrade II (CERN LHCb) EIC collaboration	Silvia Dalla Torre, Vincenzo Vagnoni INFN Trieste, INFN Sezione di Bologna	Testing of MCP and multiple **LAPPDs (stripline, CC, Z-stack and future HRPPD)** for precision timing of electromagnetic showers in a calorimeter plus photocathode ageing study in FY23
LAPPD based Time of Flight PET (TOF-PET) Sensor	UC Davis, MGH – Harvard, PicoRad Imaging, Université de Sherbrooke	Measurements of the energy spectra produced by 511 keV photons and spatial resolution are being made. **(LAPPD #57)**
Medical ET (TOF-PET) Sensor	Brookhaven National Laboratory, Stony Brook University Univ of Glasgow	Funded program starting 2022, will use **HRPPDs** **CC-LAPPD delivered**
LAPPD Femtosecond Timing Trials	PicoRad Imaging, MA., & MGH - Harvard	TTS timing trials with **LAPPD** at MGH, using a femtosecond laser, and 4-ch 4GHz bandwidth Tektronix MSO64 scope with 25GSPS per channel.
Neutron Radiography System using Incom Nanoguide, and LAPPD	Starfire Industries LLC.	Portable x-ray/fast neutron radiography system
LAPPD Read-out Board	Nalu Scientific, LLC, and University of Hawaii	Fully integrated, high channel count signal processing read-out board using NSL's AARDVARC ASIC tested on **LAPPD**.
Life Testing of LAPPD, Role of ion feedback.	UT Arlington	**Life Testing LAPPD #105 underway**
Neutron Beam Line testing	Los Alamos National Laboratory	**CC LAPPD** delivered
Gen-II LAPPD for scintillation light	Tohoku University	**CC LAPPD** on order, up to **four more** in 2024
They need to develop WbLS before they want more LAPPDs	Korea University	**CC LAPPD** delivered

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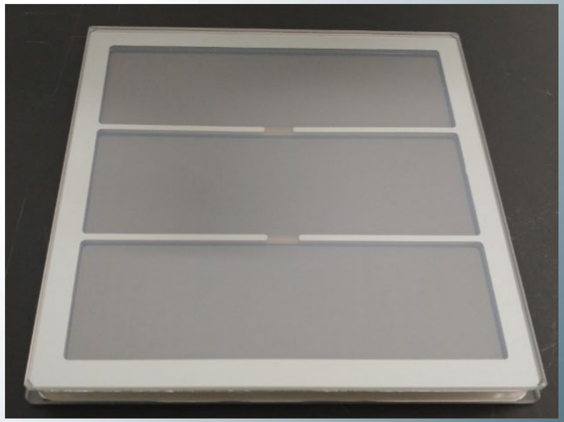
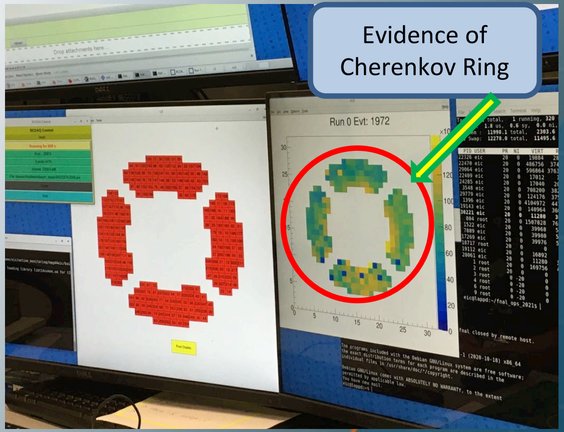
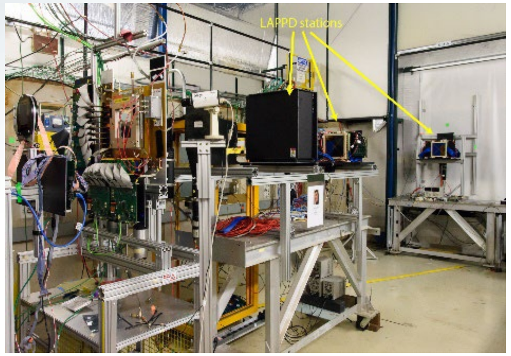
Aug 2021 – Aug 2023: Started 60 LAPPDs (>95% capacitively coupled) and 13 HRPPDs
Past 12 months: 24 LAPPDs and 8 HRPPDs

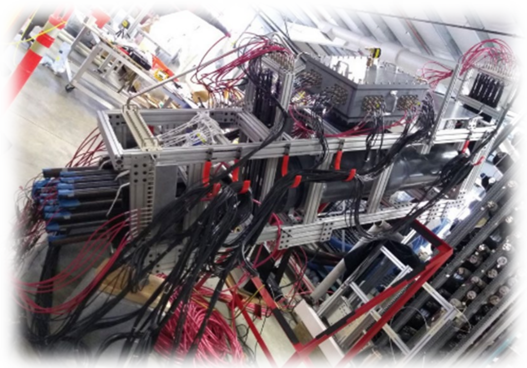
Gen II LAPPD Phase IIA Program Summary

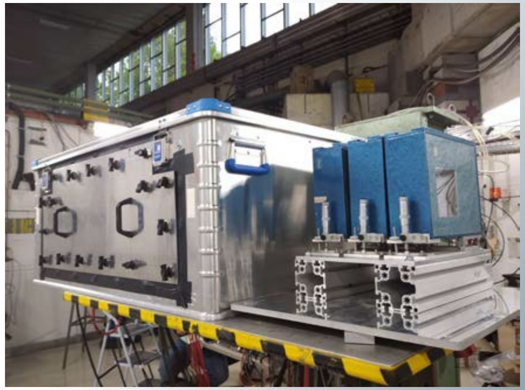
1. **Optimize Capacitively Coupled (Gen-II) tile design/window seal/component stack.**
   1. **SUCCESS** – Incom will keep exercising process with minor improvements as needed
2. **Expand Measurement and Test capabilities**
   1. **SUCCESS**
      1. In-house and out sourced testing (life testing to continue)
3. **Beamline Tests at Fermilab**
   1. Huge **SUCCESS** with EIC, UC and ANNIE
4. **Business Development and Commercialization (Success!)**
   1. **Domestic, Europe, Korea, Japan**

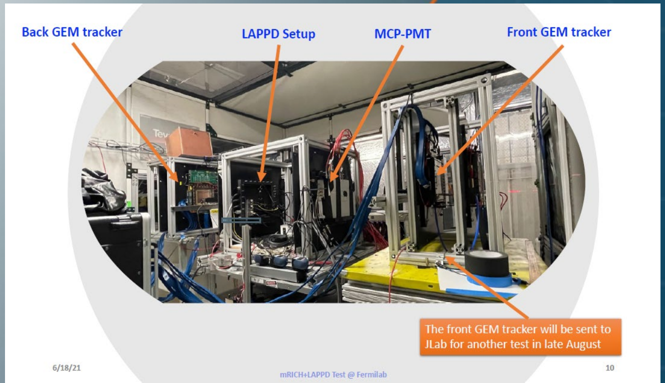












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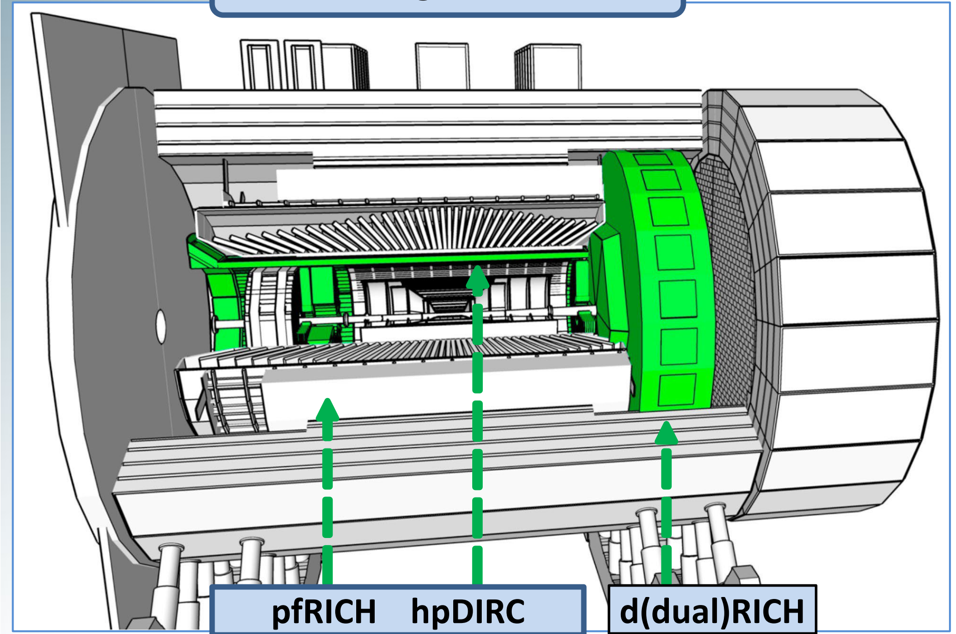
HRPPD applications for the EIC (courtesy of A.Y. Kiselev)

Brookhaven National Laboratory

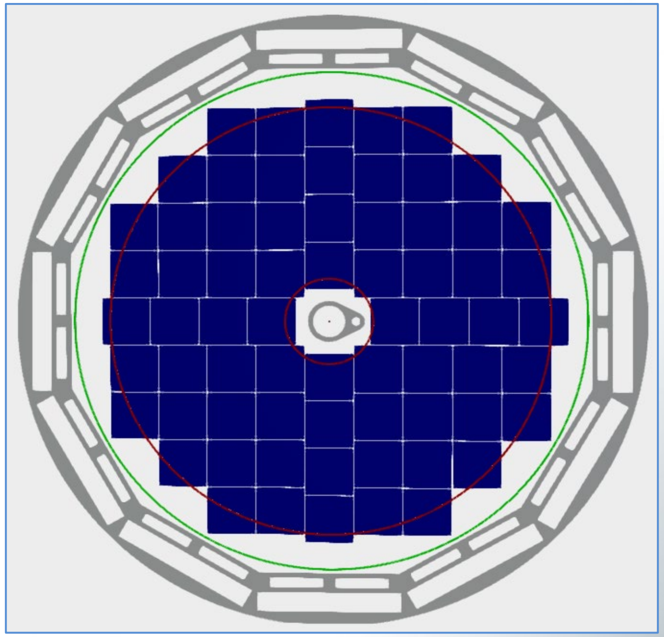
HRPPD benefits:

- pfRICH: low dark noise, ToF capability (vs SiPMs)
- hpDIRC: expected to be more cost-efficient (vs other MCP-PMTs)
- *dRICH: problematic, because of the magnetic field orientation*
- HRPPDs can supply up to (**68** plus **72** for total of 140+ tiles + spares)

~9.5m along the beam line

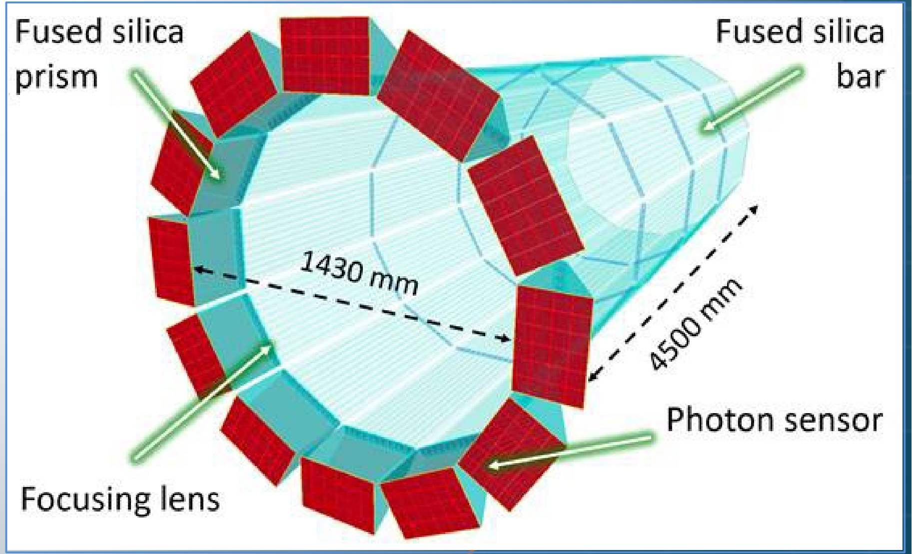


pfRICH = (proximity focusing) Ring Imaging Cherenkov



pfRICH sensor plane: **68** HRPPDs total

hpDIRC = (high performance) Detector of Internally Reflected Cherenkov



hpDIRC: 12 arrays of 3x2 devices = **72** HRPPDs total

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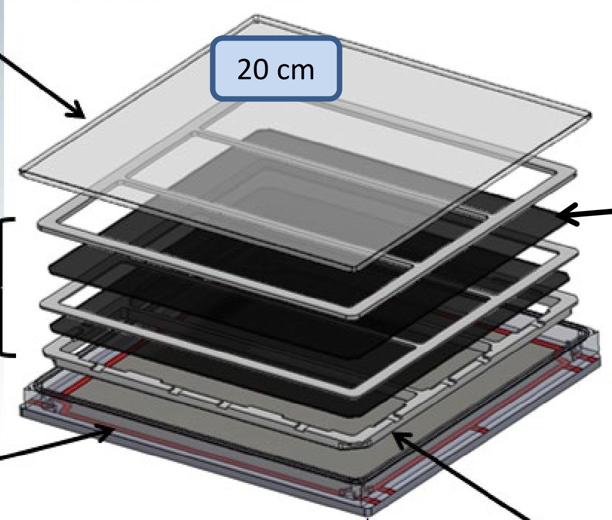
ALD-MCP-PMT Device design – How do they work?

LAPPD - Large Area Picosecond Photo Detector

Fused Silica window (**Photocathode inside**)



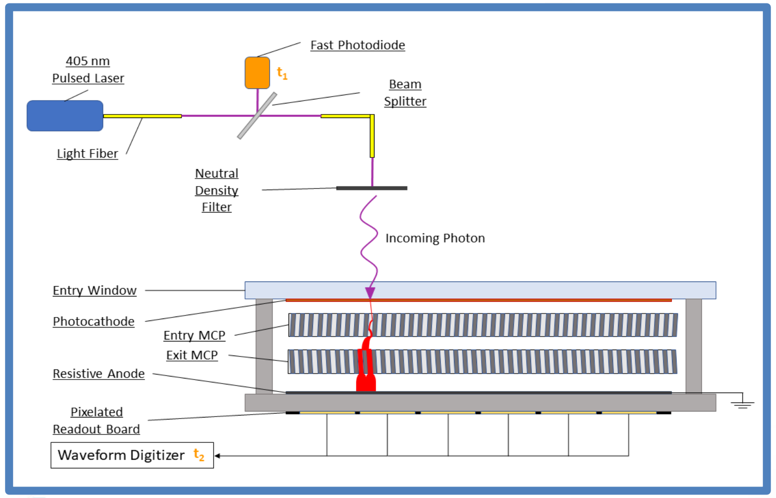
MCPs + Spacers

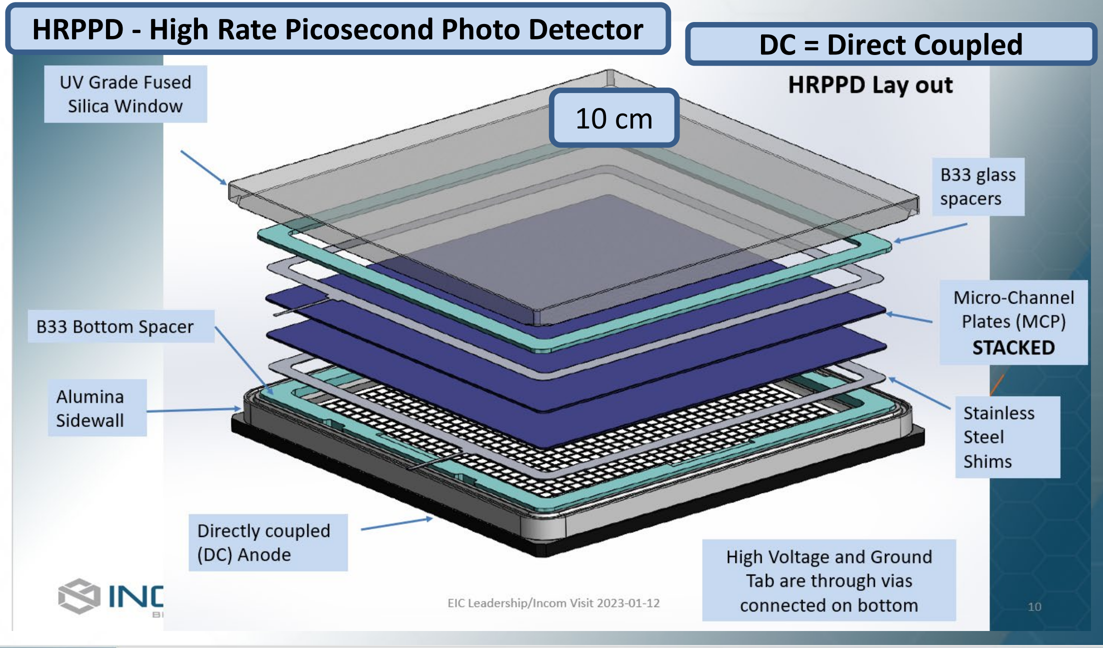
Sidewall frit bonded to Anode plate

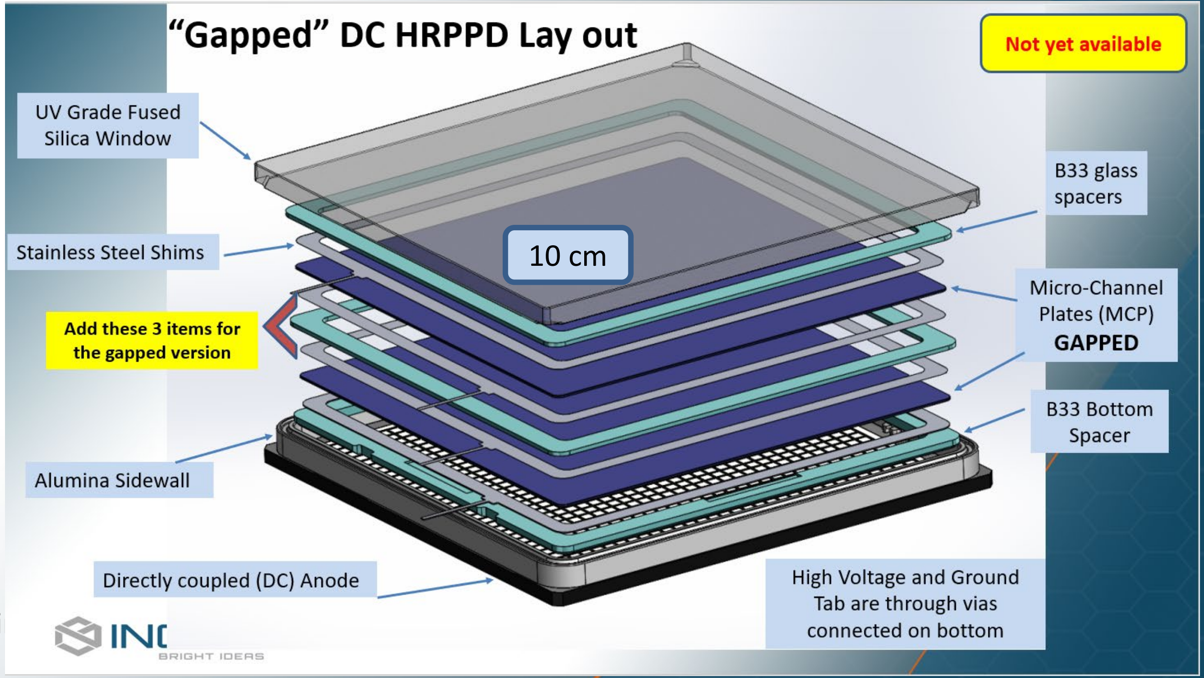
Internal Resistive Anode

HV tabs at each corner (**Independently power MCPs**)

- No wall or anode penetrations
- Active area: 195 mm x 195 mm
  - 373 cm^2 (97%)







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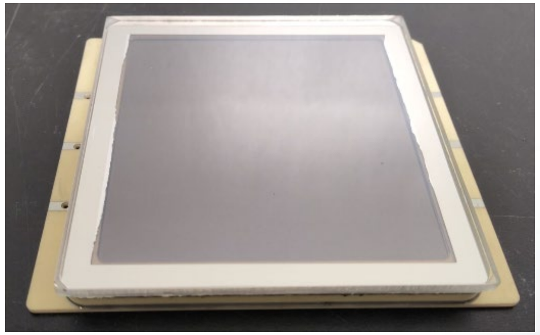
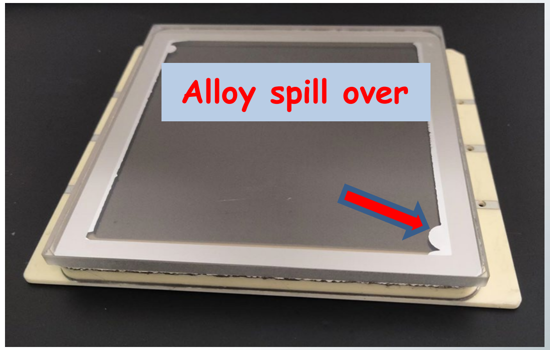
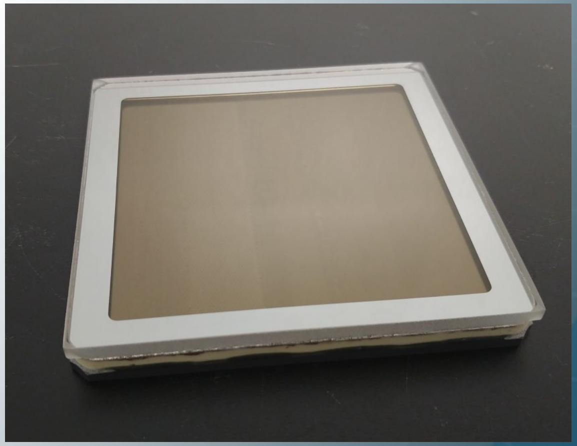
HRPPD Pilot Production

- **13 HRPPDs starts (Ph II)**
  - **11 ceramic**
    - DC – #s: 3, 4, 6, 7, 11
      - In-process 13
    - CC – #s: 5, 8, 9, 10, 12
    - **7 of 10 sealed**
    - Two failure modes
      1) Internal **alloy spill** over (3, 5, 9)
         Alloy volume is done manually
           - CNC tool coming on line
      2) Incomplete **window seal** (7, 8, 10)
         Inferior metallization alloy was root cause
           - Replaced with new batch
  - **Leftovers (Ph I)**
    - **2 glass**
      - failed due to **design flaws** (fractured)

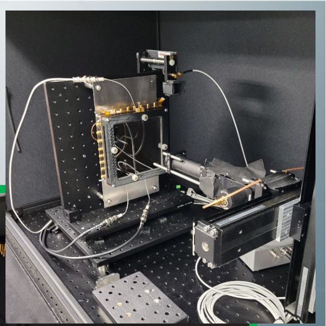




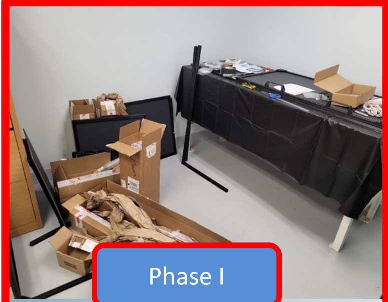


DC HRPPD Testing Configuration (Dark Box #3)

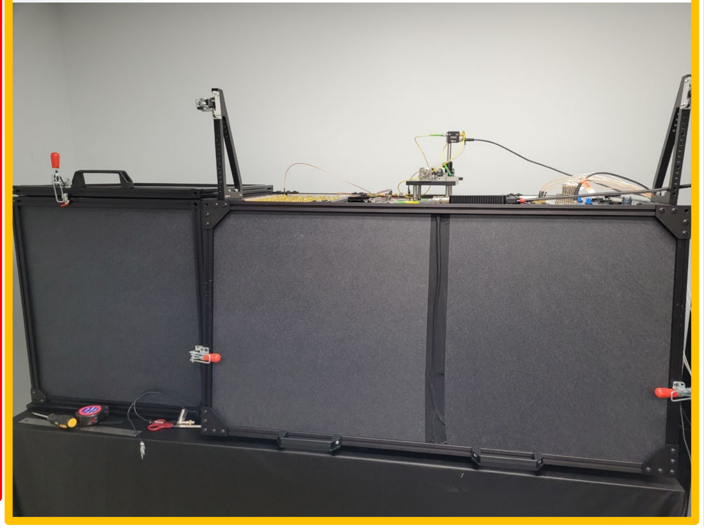
DB I



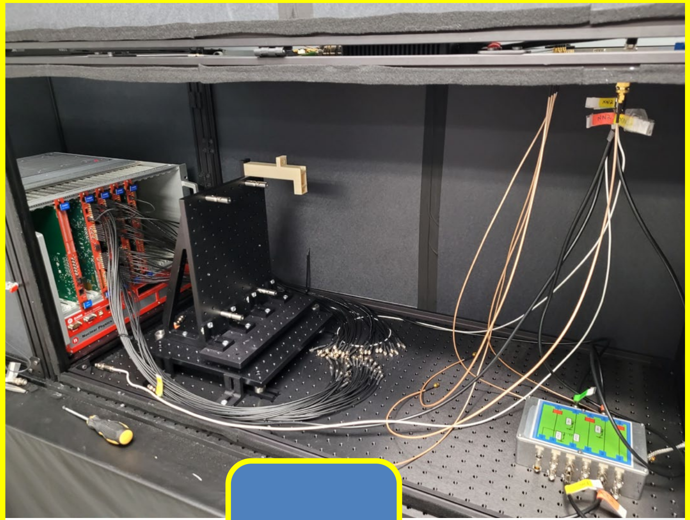
Phase I



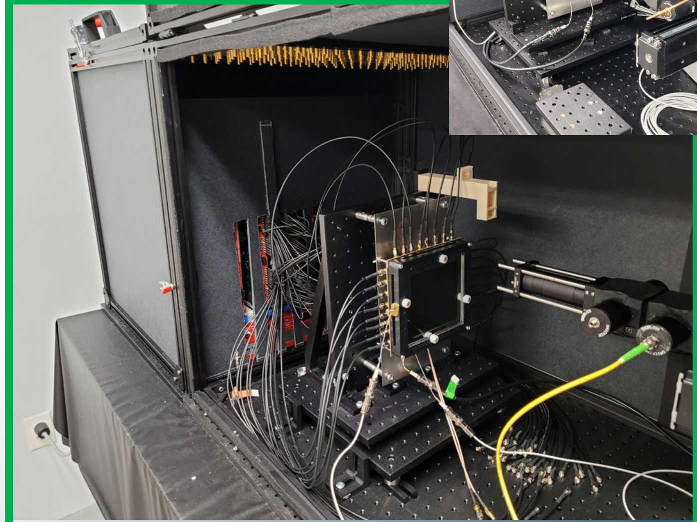
Phase 2

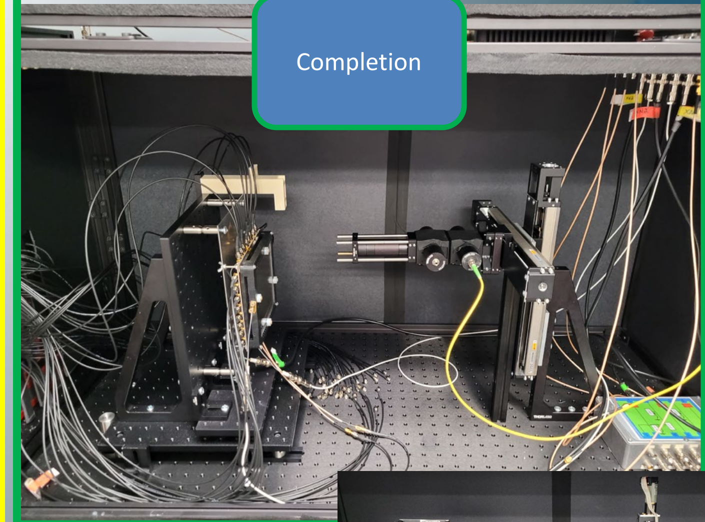


Phase 3

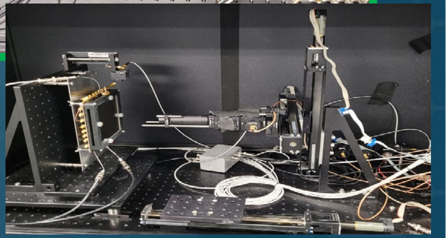


Completion





DB 2



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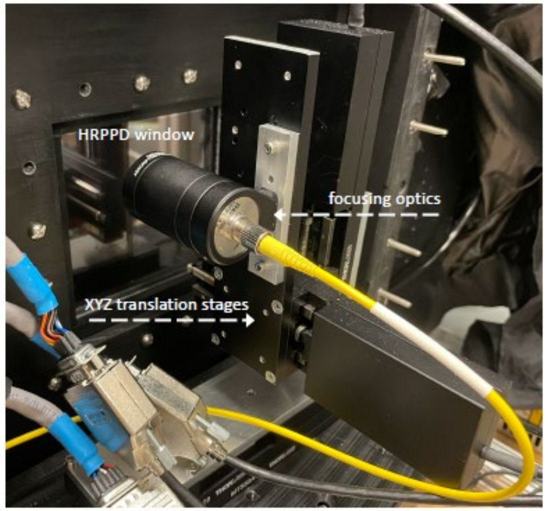
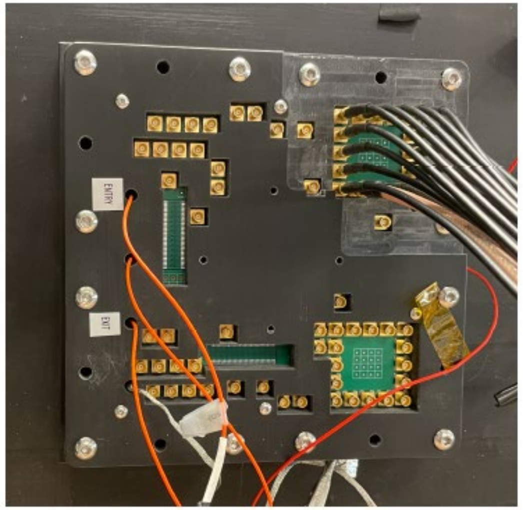
Testing @ Brookhaven National Laboratory

(courtesy of A. Y. Kiselev)

HRPPD 6



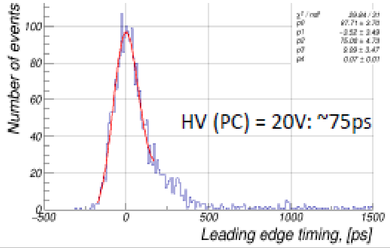
Light tight enclosure

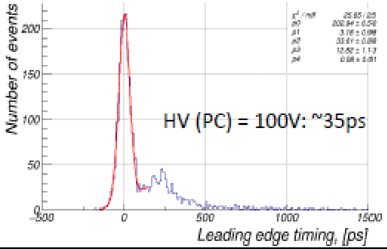


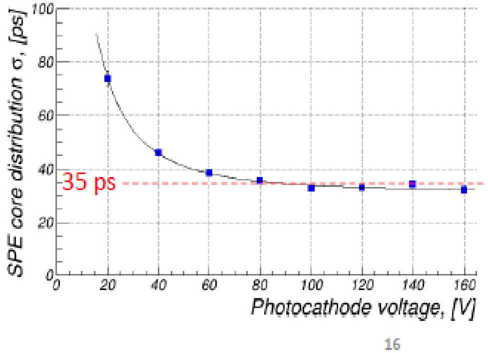
Pogo pin interface board side

HRPPD 6 SPE timing performance with a laser

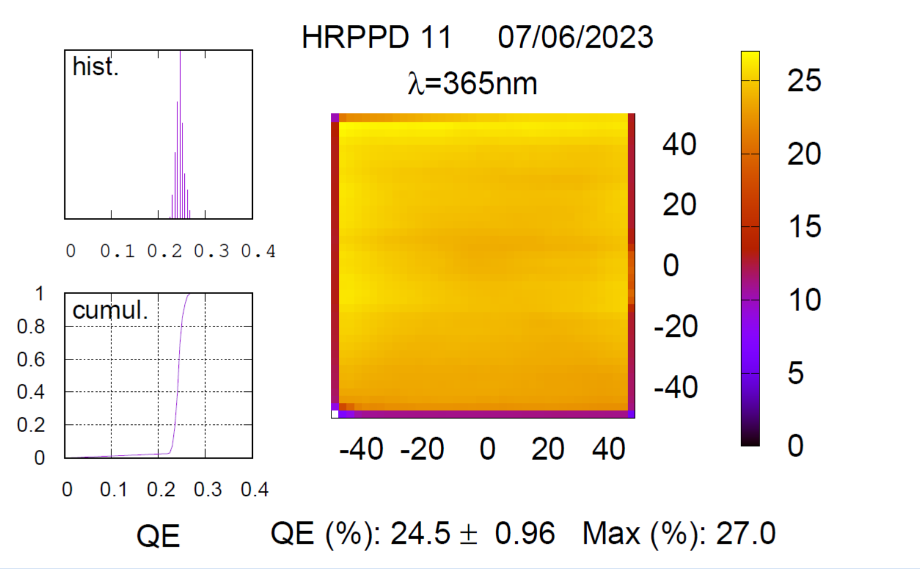
- Laser focused to a pad center
- Intensity tuned down to ~95% empty events
- Δt data taken with a V1742 DRS4 module
  - Channel #0 – HRPPD pulse
  - Channel #1 – laser synchro pulse
- *Neither laser pulse width nor other instrumental effects unfolded*

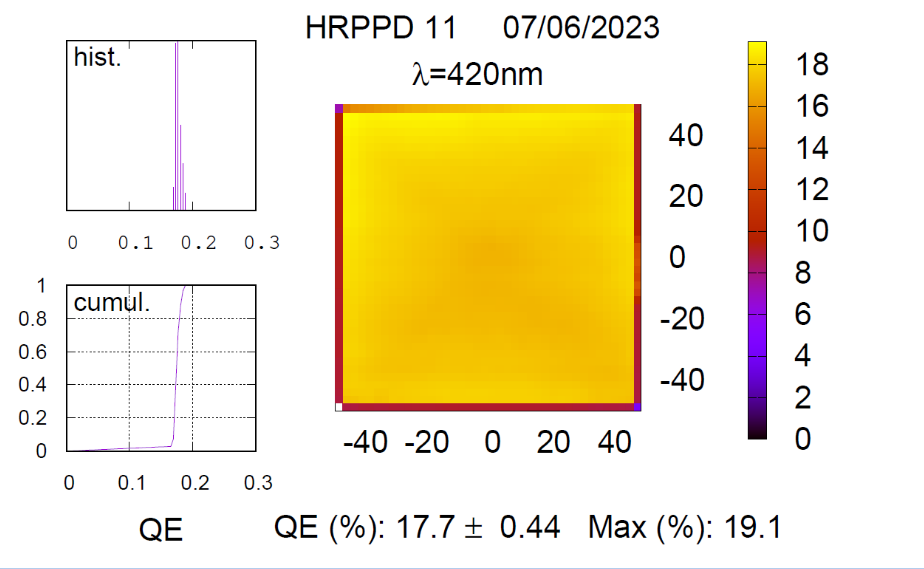


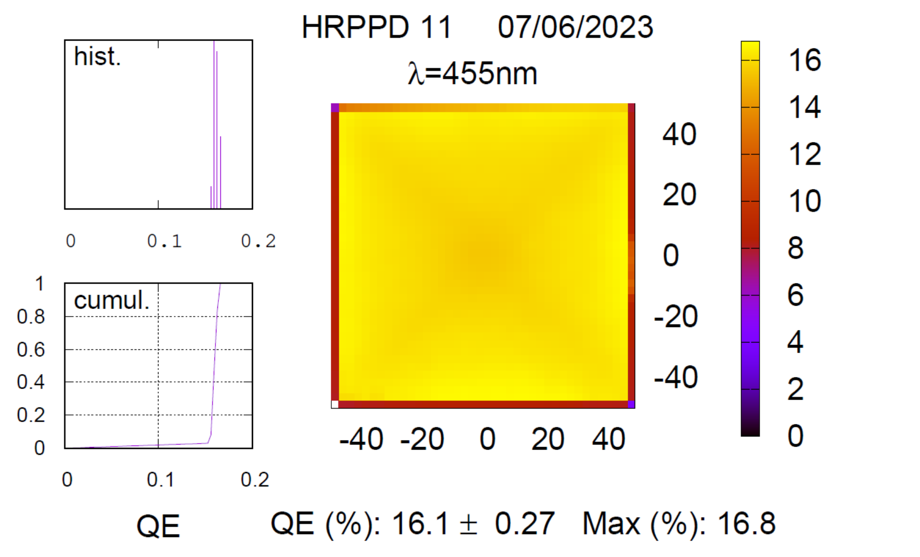


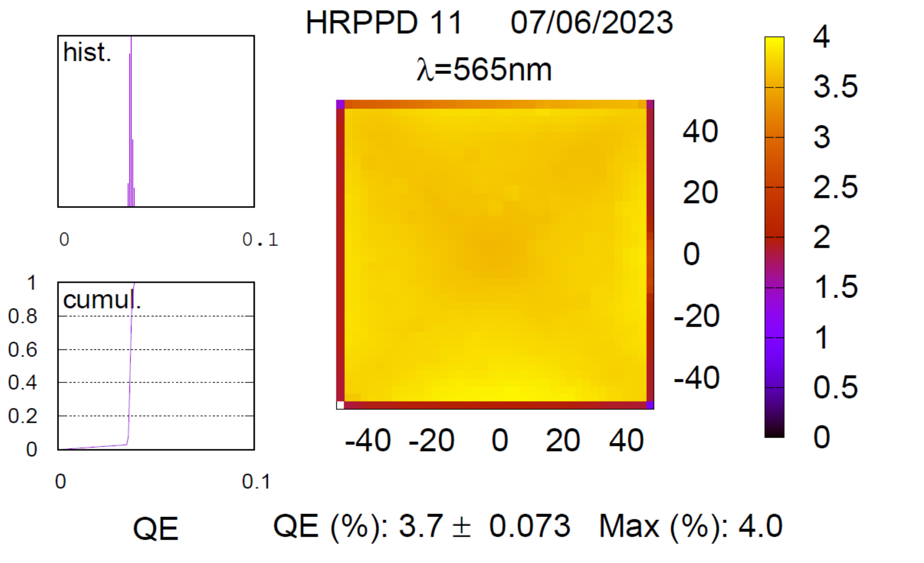


HRPPD 11 QE Scans





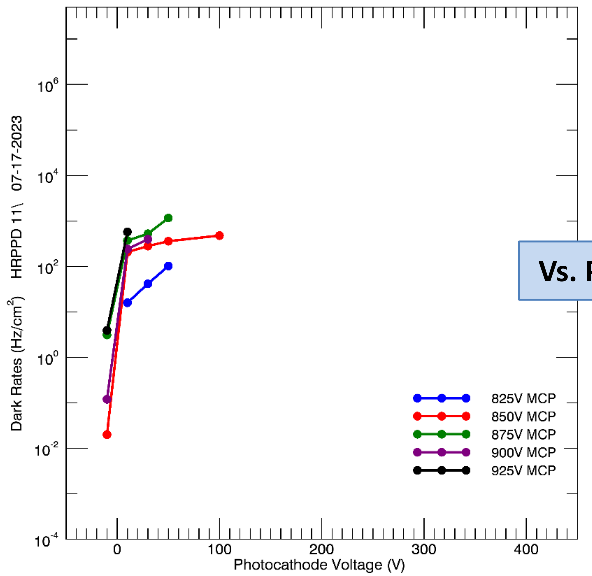




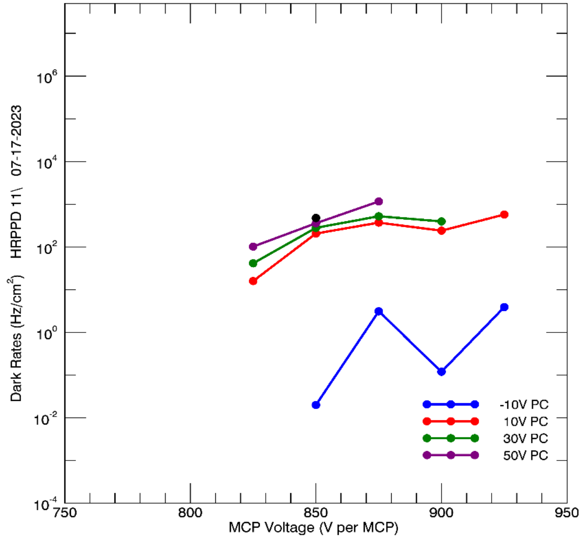
HRPPD 11 Performance Data

HRPPD 11 Dark Rates

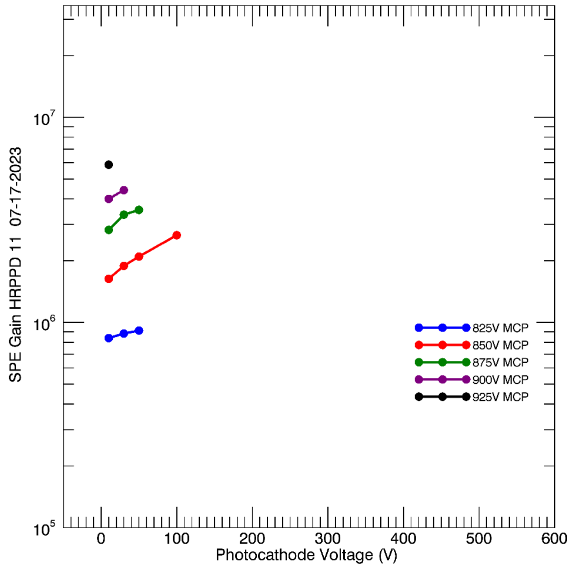
Vs. Photocathode voltage

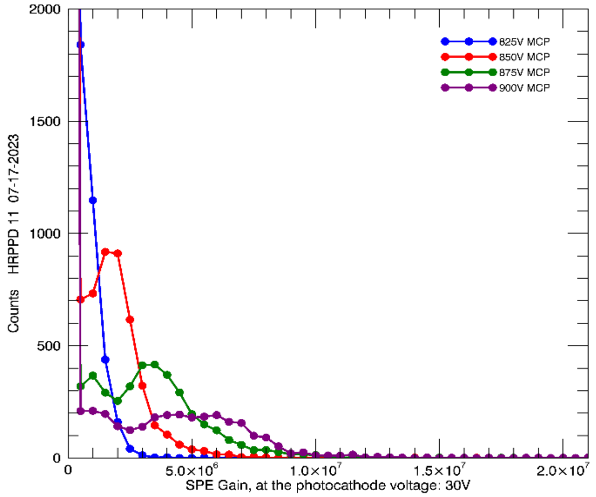


Vs. MCP voltage

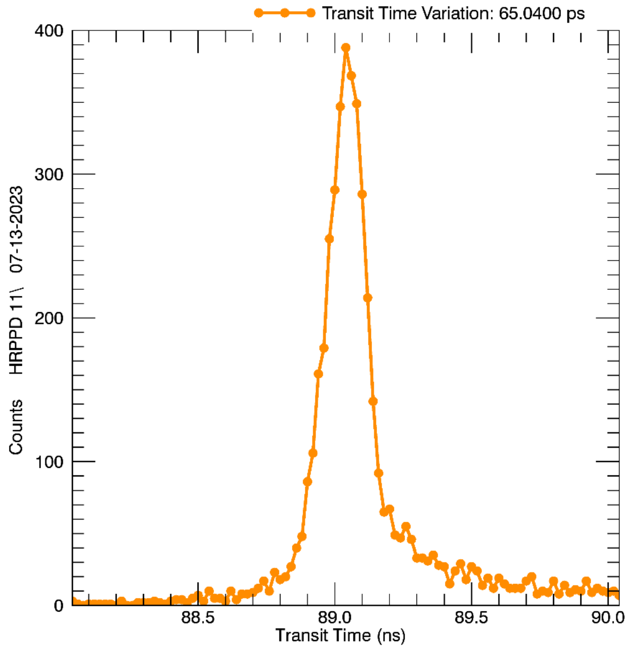


HRPPD 11 SPE Gain





HRPPD 11 SPE TTS



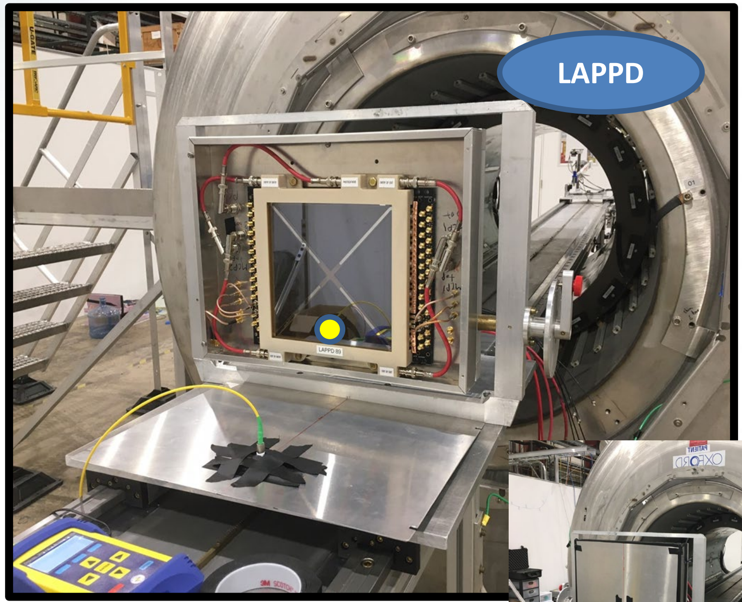
TTS is only corrected for Laser jitter, not electronics (~ ±5%)

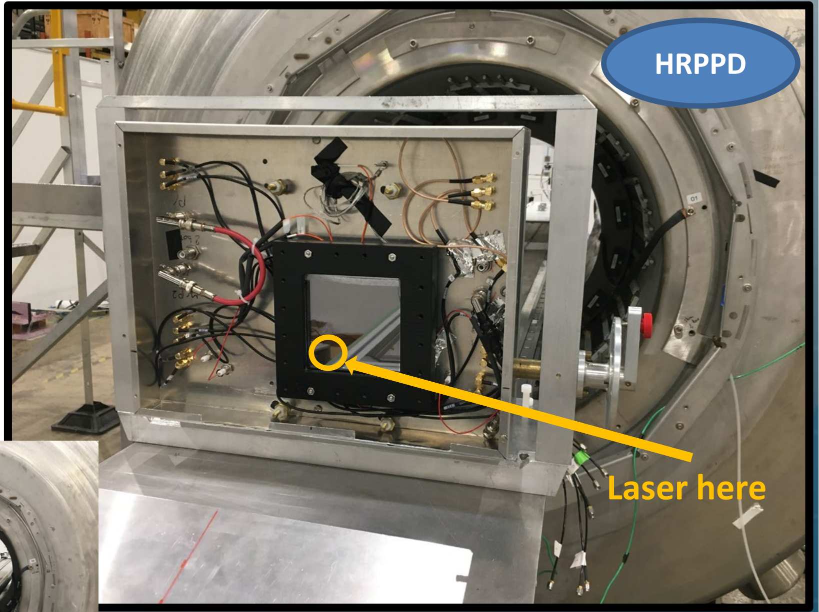
One LAPPD & One HRPPD at a Solenoid Magnet: 2nd tests – part 1

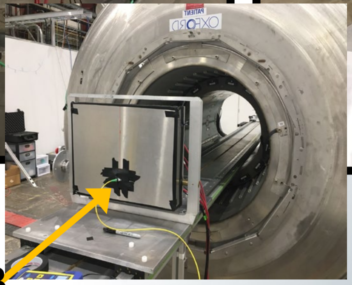
In collaboration w/ Junqi Xie @ ANL

Argonne NATIONAL LABORATORY

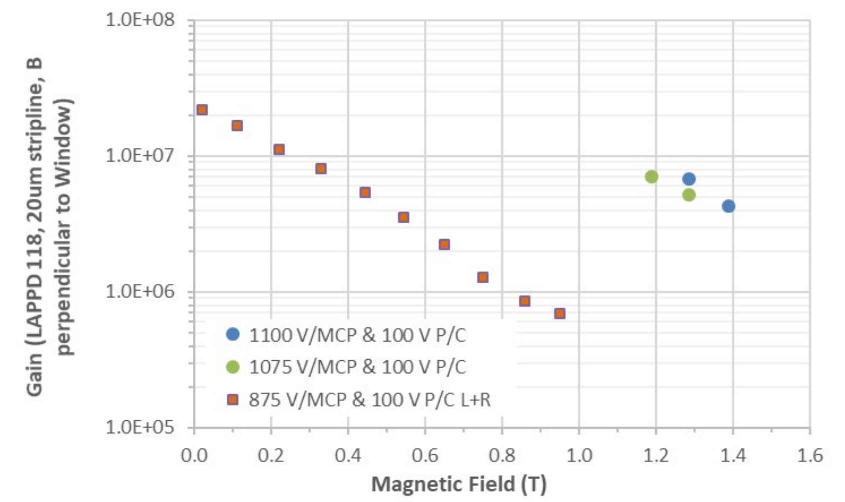
- One LAPPDs and One HRPPD
  - 20 µm, glass: 144
  - DC-HRPPD: 6
- Magnetic field strength: 0.02 T to 2.0 T
- Dark box
  - Aluminum case
  - Laser input fixed in the center near the bottom – on the centerline of the solenoid when the LAPPD is vertical.
  - Waveforms collected for 12 pixels (LAPPD)
    - and 16 pixels (DC-HRPPD)
- **Rotation** in the magnetic field: (pfRICH, hpDIRC)
  - LAPPD tips into or out of the region of stronger magnetic field
  - Move the LAPPD in or out at each angle to compensate for the change in field strength
- Data products
  - Gain
  - Position
  - Position resolution
  - Transit Time Spread
  - Afterpulse rate
  - Detection efficiency estimate
  - Dark rates







B

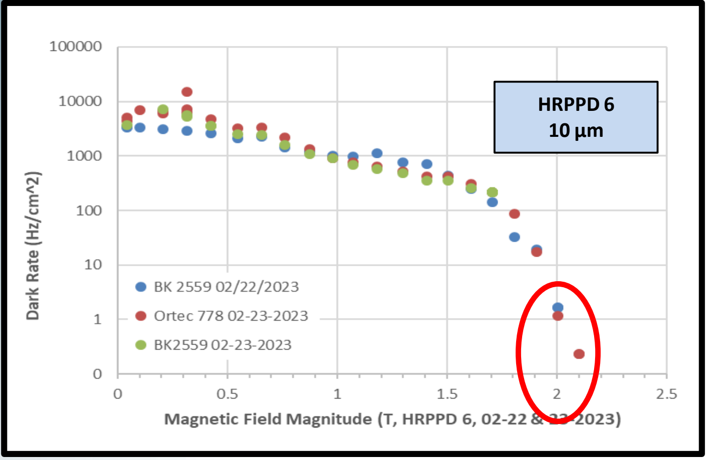


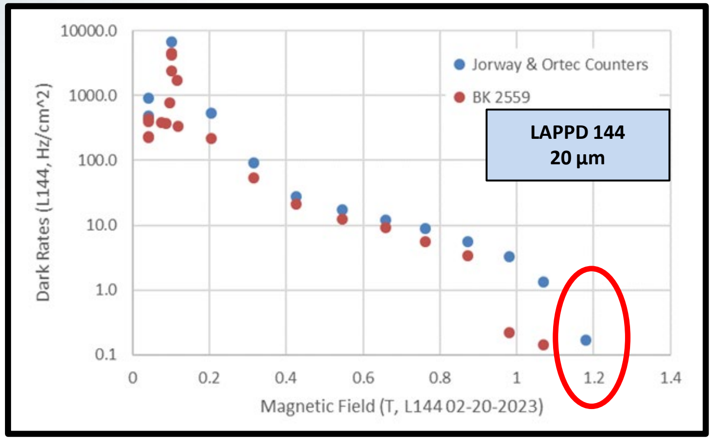
- The gain decreased with increasing magnetic field strength.
- Gain could be recovered with a higher MCP voltage.

INCOM BRIGHT IDEAS

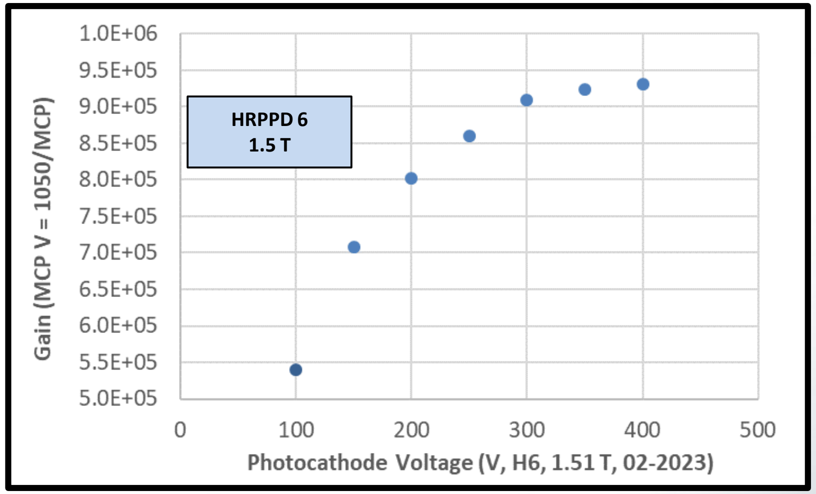
HRPPD & LAPPD Dark Rates/Gain in B-Field

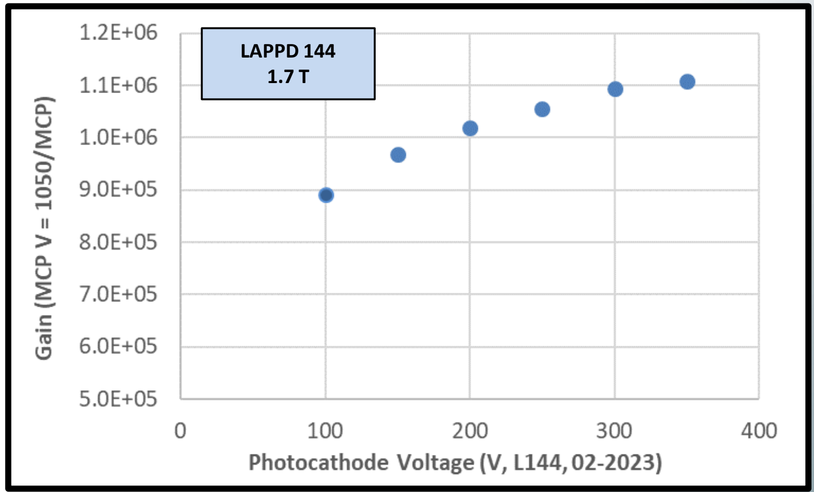
- **B field perpendicular to the window.**
- Dark rates were measured as a function of the magnetic field strength
- The **dark rates continue in H6 out to 2.0T**, rather than falling off at 1.2 T as with the 20 um L144.



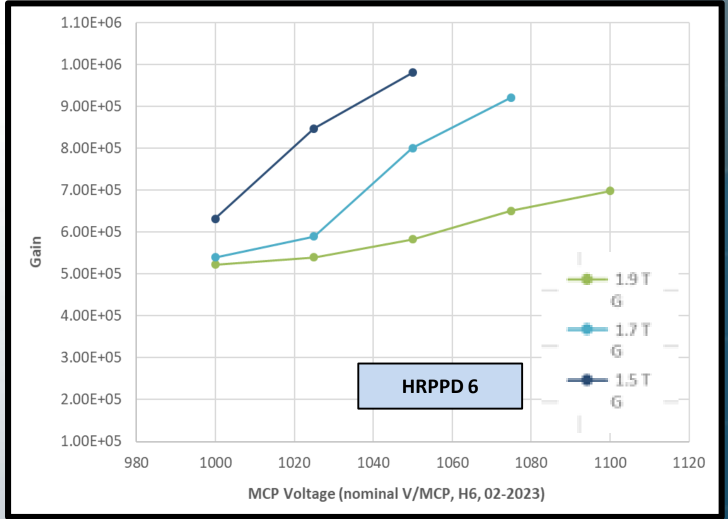


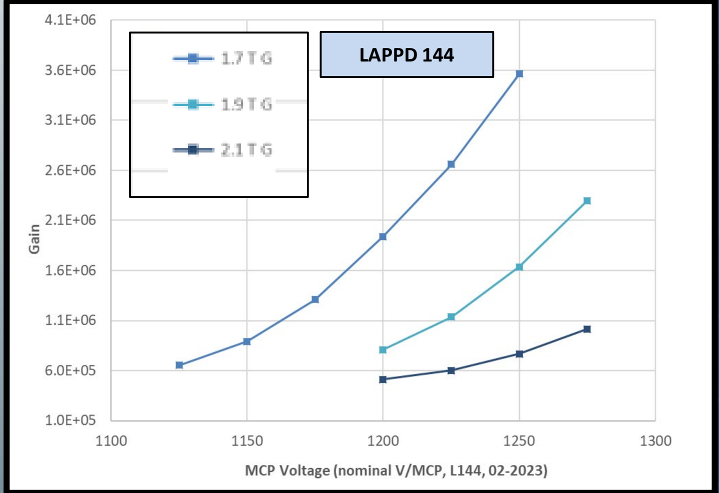
- Gain increases slightly with **photocathode** voltage.





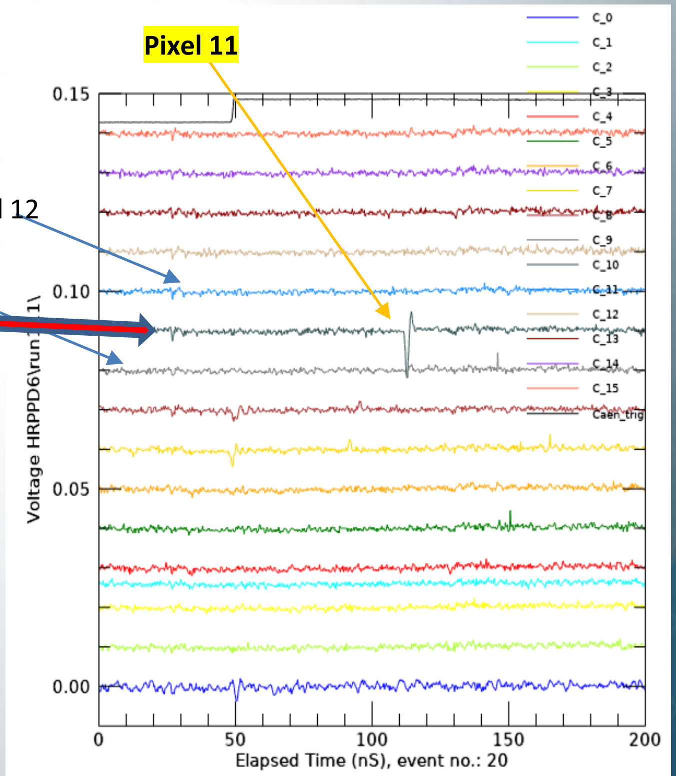
- Gain may be recovered in a strong magnetic field by increasing the **MCP** voltage.





Localization of Directly Coupled Signal: HRPPD6

- Tests @ 1.0 T
  - B-field perpendicular to the window
- Looked @ three 3 mm discrete pixels
  - (#s 10, 11 & 12 are adjacent)
- **The signal appears to be confined to a** single 3 mm pixel.
- This is appropriate for detecting Cherenkov Rings
  - especially when they are over lapping

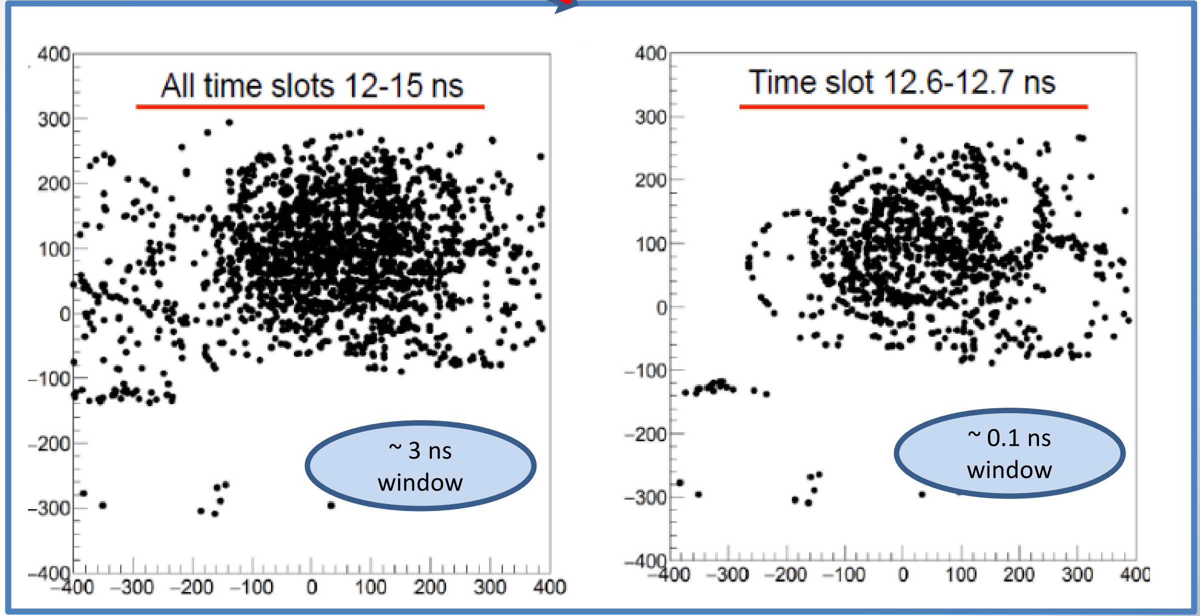


Possible solution

TIME READOUT on RICH detectors

Simulation of Cherenkov Rings from a RICH Detector (CERN upgrade)

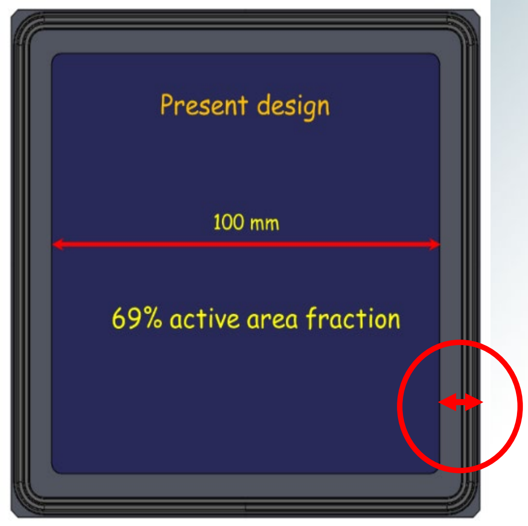
Courtesy of F. Oliva.
Incom LAPPD Workshop
April 2023

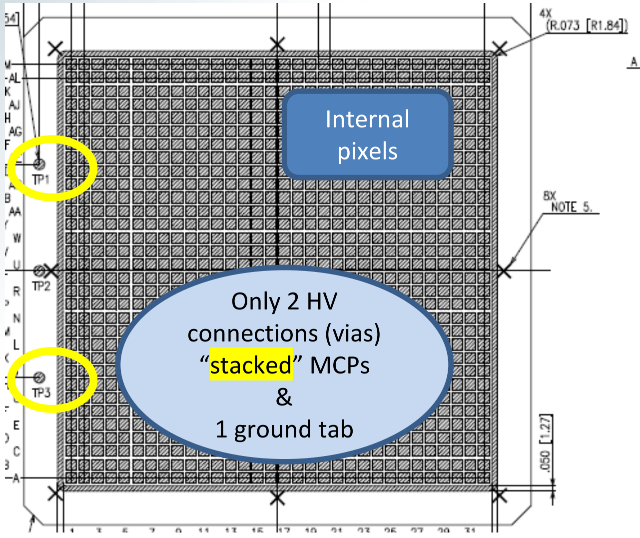


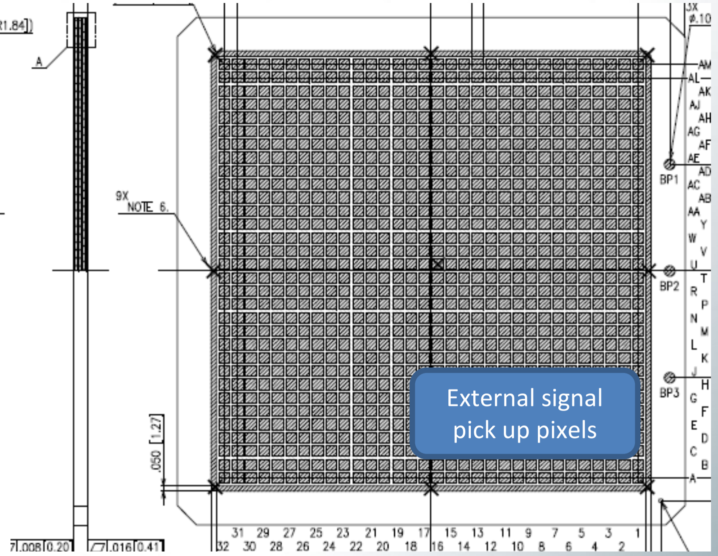
- Accelerator beam intensities are becoming very high to detect rare phenomena
- Viewing Rings therefore requires **fast response** and **good spatial resolution**

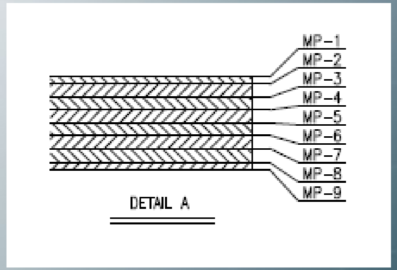
INCOM BRIGHT IDEAS

Present and new sidewall and anode (CC & DC) designs (Vendor 1) for increased device active area and new signal pickup methodology.

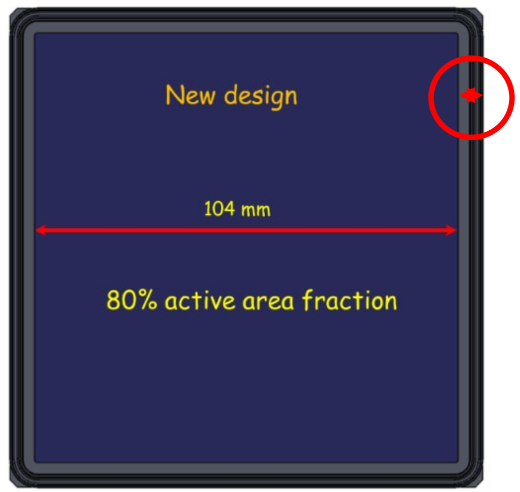


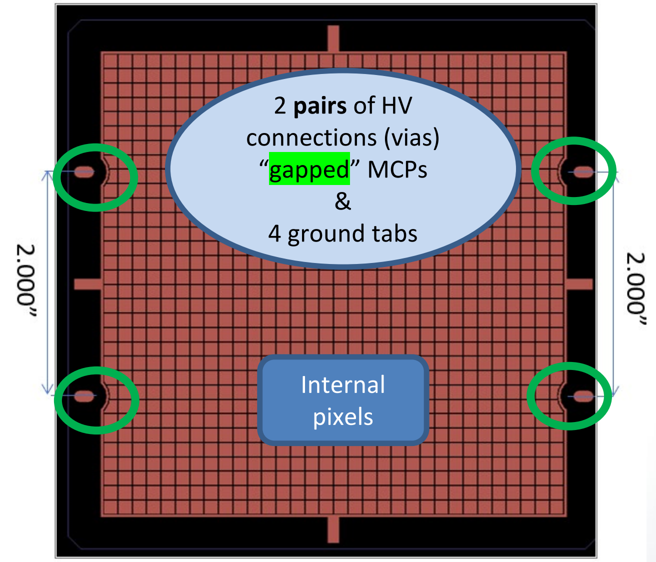


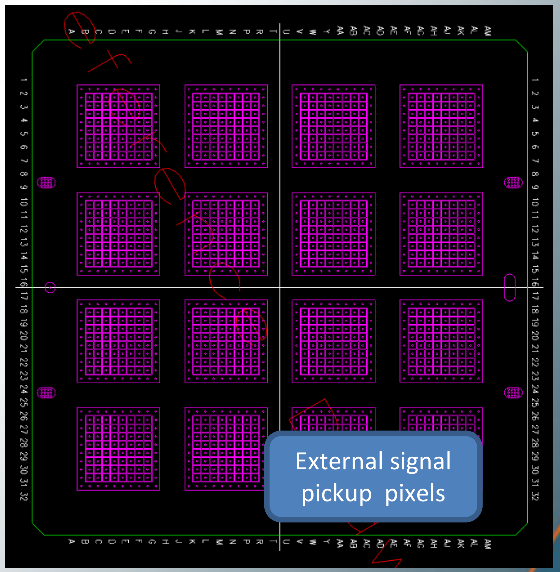


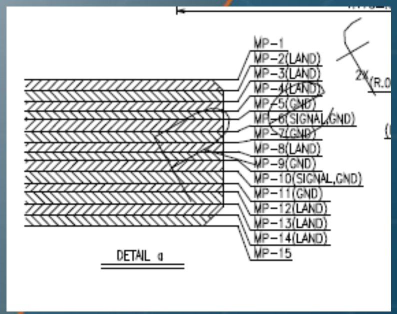


LTCC anode layers

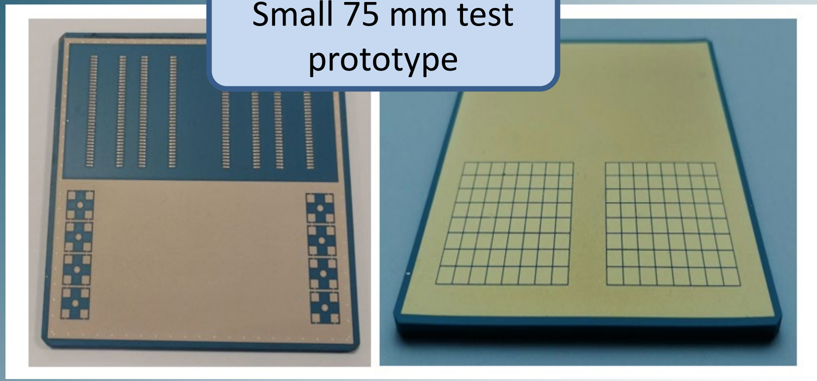


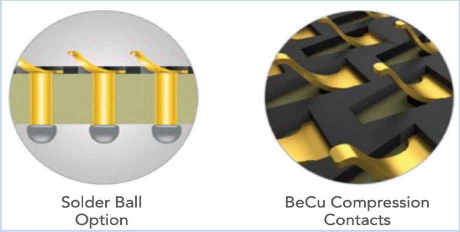


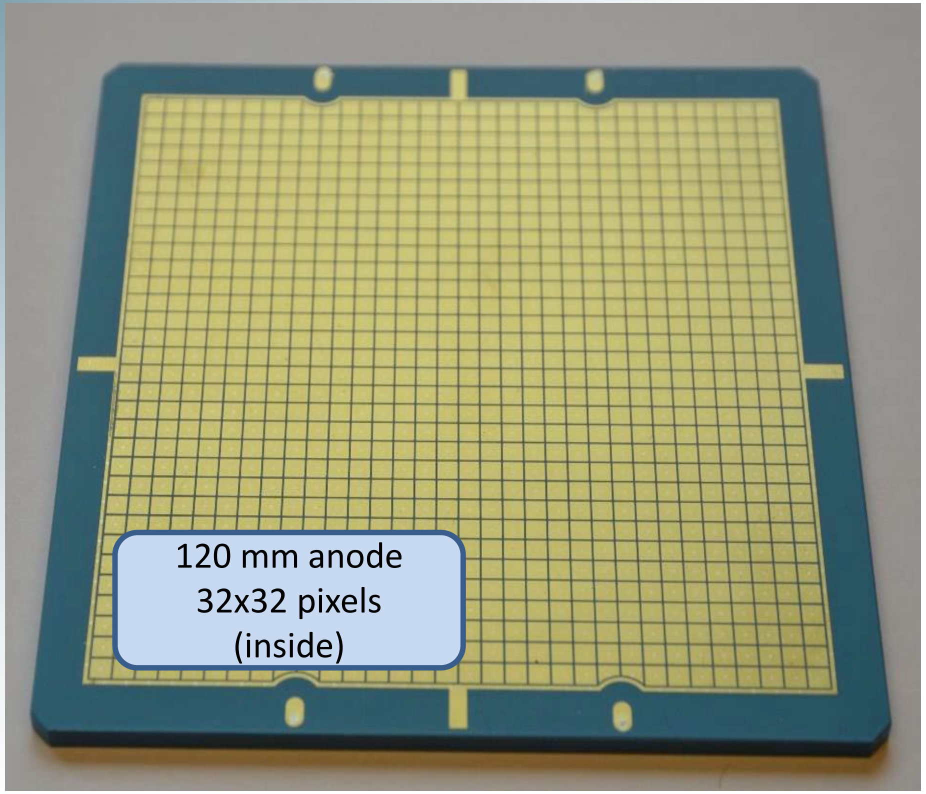


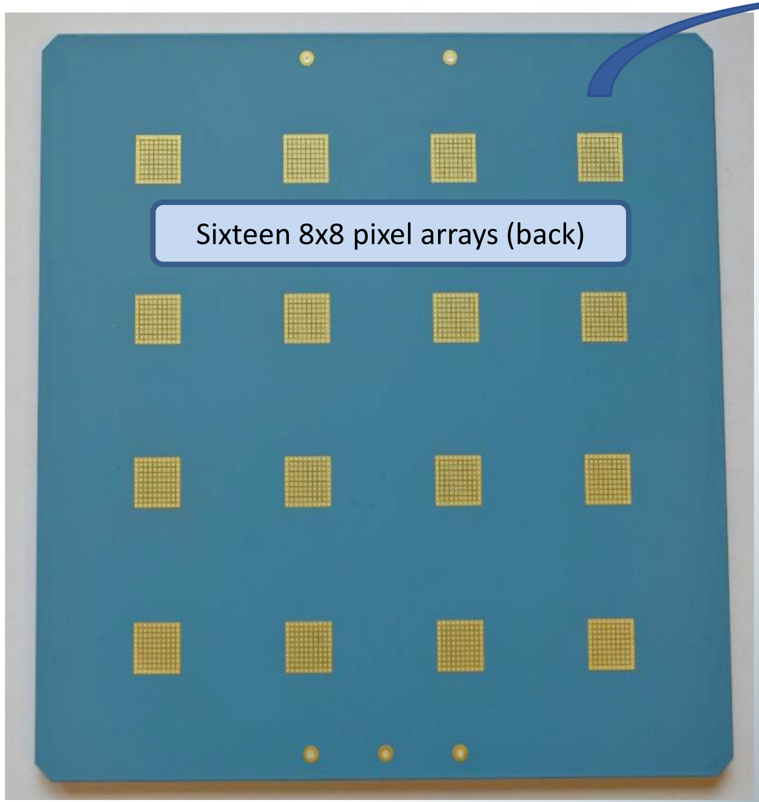


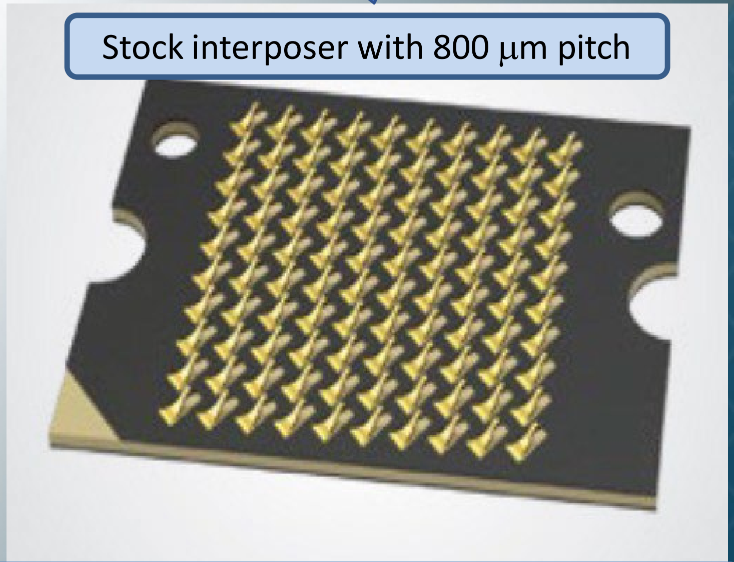
First iteration: (Vendor 2) anode base plate

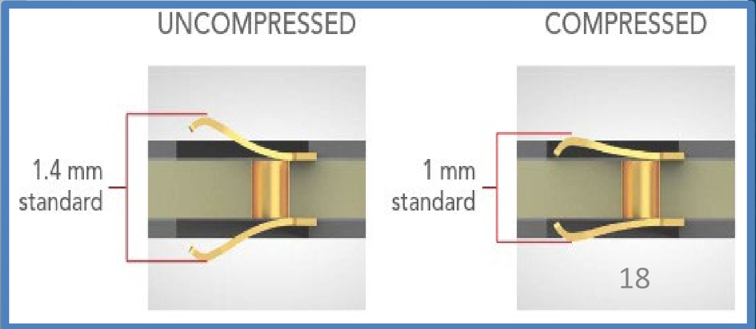




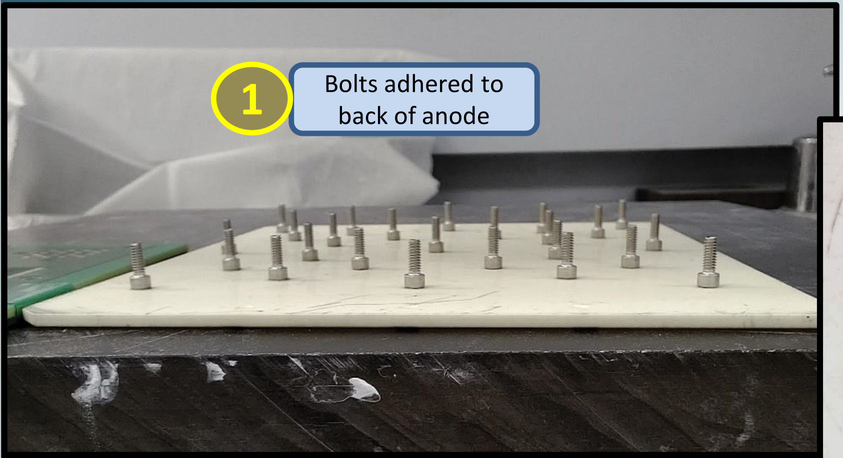


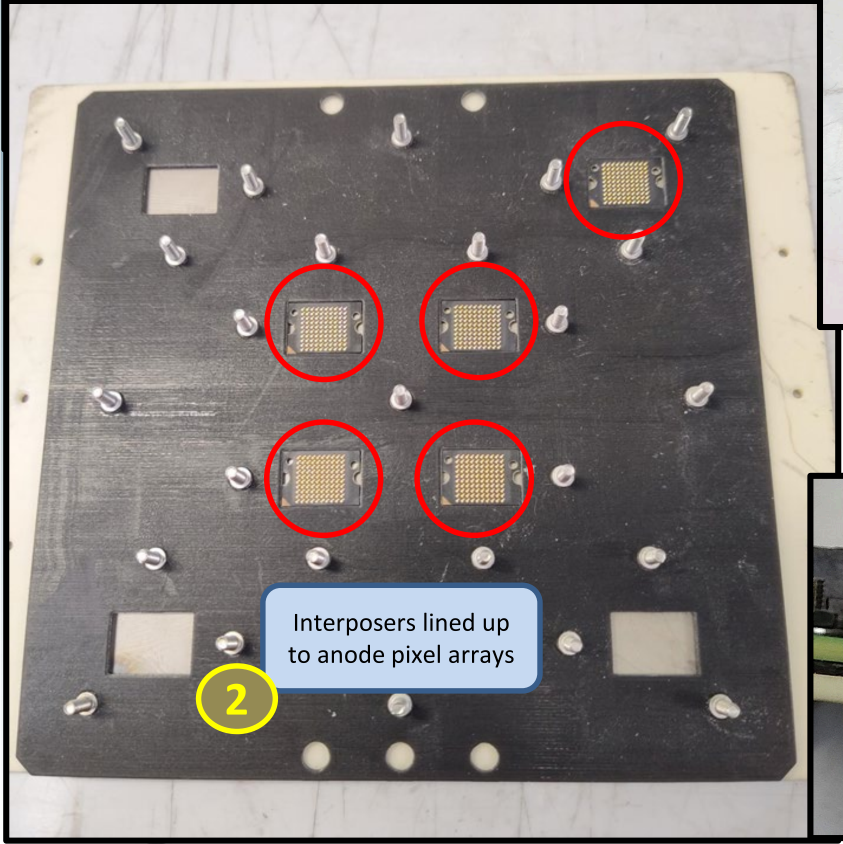


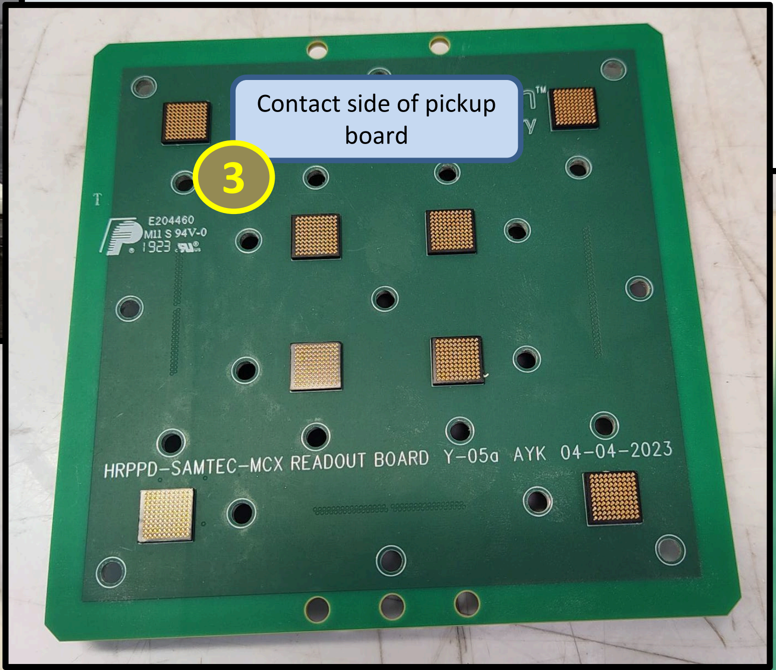




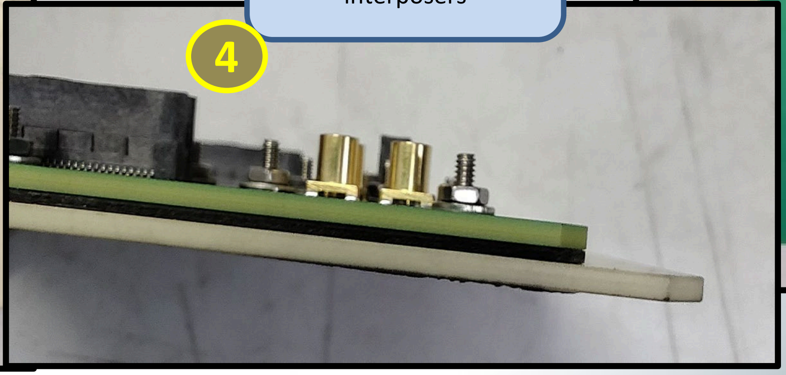
Interposer connection trials



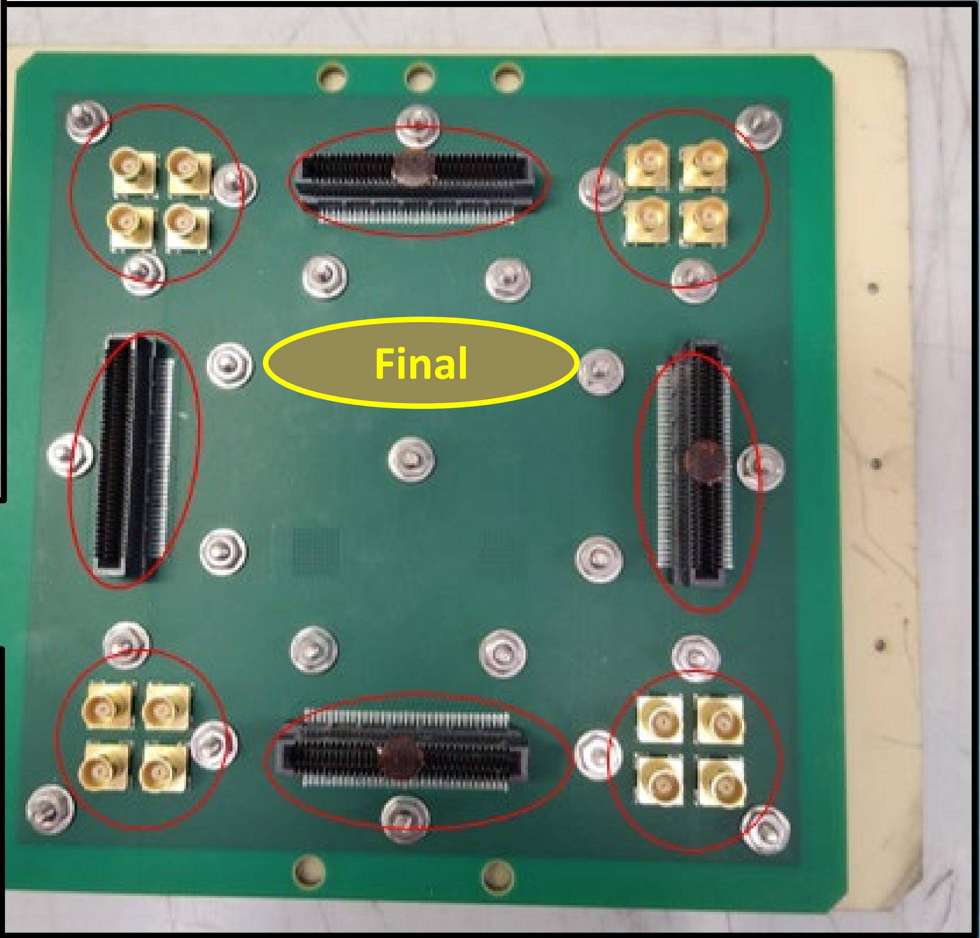




Signal board attached and compressed interposers



All 64 (4x) & (4x4) contacts checked **successfully** for continuity



Phase II Technical and Commercialization Summary

- **HRPPD development successes can be applied to 20 cm LAPPD**
  - HRPPD platform to accelerate transition from glass to **ceramic LTA package**
- **CC (Gen II) LAPPD Sales Are Strong**
- **HRPPD Testing, Sales, Rentals - inquiries are building**
  - **Post HRPPD Phase II Funding**
    - **EIC Preliminary Engineering Development Program**
      - **pfRICH and hpDIRC**
    - 18 months in three 6–month stages
      - (**$$$**) Now to Feb '24 Incom to develop new custom HRPPD (higher Active Area, new anode, tileable)
        - (**$$**) Fabricate and deliver 5 custom devices
      - Mar to Sept '24 – EIC to test and propose any revisions
        - Test any new prototypes
        - Design then locked in for EIC
      - **140+ tiles** past EIC CD-3 ~ Spring 2025
      - (**$**) Start higher volume production fabrication of "final" sensor design
        - **And affordable for others!**

Current Funding & Personnel Acknowledgements

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DOE DE-SC0020578, Phase II – "Large Area Multi-Anode MCP-PMT for High Rate Applications" (**HRPPD**) being developed for **Nuclear Physics** (Complete)

DOE, DE-SC0015267, NP Phase IIA – "Development of Gen-II LAPPDTM Systems For **Nuclear Physics** Experiments" (Complete)

DOE DE-SC0017929, Phase II– "High Gain MCP ALD Film" (Alternative SEE Materials)

DOE DE-SC0018778, Phase II "ALD-GCA-MCPs with Low Thermal Coefficient of Resistance"

DOE DE-SC0019821, Phase II- Development of Advanced Photocathodes for LAPPDs (Complete)

DOE DE-SC0021782, Phase I – "Development of LAPPDs for LHCb ECAL and other High Rate High Radiation Applications" being developed for Nuclear Physics (Complete)

DOE DE-SC0021437, Phase I : "High Fluence Anode Design" being developed for Nuclear Physics (Complete)

NASA 80NSSC19C0156, Phase II "Curved Microchannel Plates and Collimators for Spaceflight Mass Spectrometers" (Complete)

Thank You!

&

any questions?

Lexicon for Slide Deck

GCA = Glass Capillary Array
MCP = Micro Channel Plate
PMT = Photo Multiplier Tube
PC = Photo Cathode
HV = High Voltage
LTA = Lower Tile Assembly
LAPPD = Large Area Picosecond Photodetector
HRPPD = High Rate Picosecond Photodetector
(pf, d)RICH = (proximity focusing, dual) Ring Imaging Cherenkov
(hp)DIRC = (high performance) Detector of Internally Reflected Cherenkov
M&T = Measurement & Test
PHD = Pulse Height Distribution
SPE = Single Photo-Electron
MPE = Multiple Photo-Electron
SMA = Sub-Miniature Version A (coaxial RF connector)
LTCC = Low Temperature Co-fired Ceramic