High **R**ate **P**icosecond **P**hoto**D**etector
or **HRPPD** Development

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DOE NP SBIR/STTR Exchange Meeting
August 23-25, 2022

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Lexicon for slides

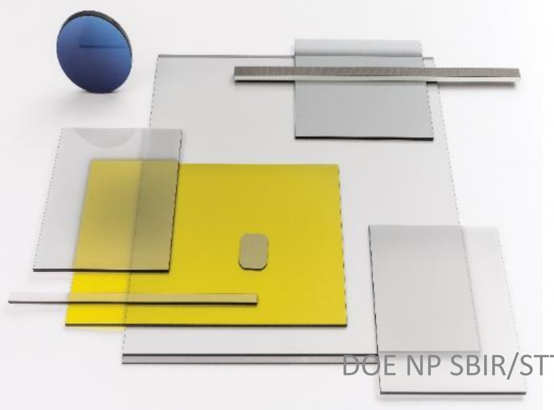
GCA = Glass Capillary Array
MCP = Micro Channel Plate
PMT = Photo Multiplier Tube
PC = Photo Cathode
HV = High Voltage
LTA = Lower Tile Assembly
LAPPD = Large Area Picosecond Photodetector
HRPPD = High Rate Picosecond Photodetector
M&T = Measurement & Test
PHD = Pulse Height Distribution
SMA = Sub-Miniature Version A (coaxial RF connector)

Outline

- **The Phase II SBIR** is actually entitled:
    - **"Large Area Multi-Anode MCP-PMT for High Rate Applications"**
        - **aka Incom "HRPPD" or the "10 cm device"**
- **Incom, Inc. - The Company**
    - Our Photodetector Overview
- **Phase II Technical and Commercialization Goals**
    - HRPPD development successes can be applied to 20 cm LAPPD
        - HRPPD platform to accelerate transition from **glass to ceramic LTA package**
- **Review Phase I research**
- **Year one HRPPD development**
- **Next plans/pilot production time line**
    - Started 36 **LAPPDs** **(>80% Gen II**) and 5 **HRPPDs** since we met last
        - Despite changeover in 4 DBU team members (of 11 Total), supply chain delays and price increases

Incom Inc. – Enabling the Vision of Tomorrow

Founded 1971 (Fused Fiber Optics)
Long history of Innovation
~200 Employees
Three facilities:
- Incom East (2) - Charlton, MA
  (includes R&D Pilot Production Facility)
- Incom West - Vancouver, WA
- Three Business Units:
  - Glass, Polymer, **Detector**



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Incom Market Leadership

Life Science / Medical

Digital X-Ray systems

Mammography

Panoramic and Intra-oral X-Ray

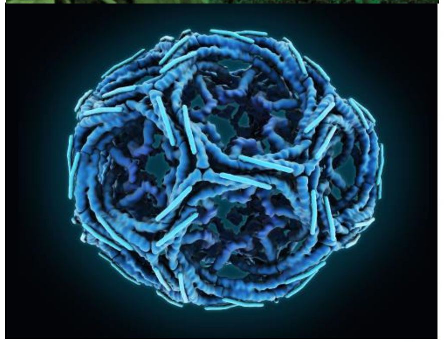
DNA sequencing

Defense & Homeland Security

Night Vision

Biometric Identification

Neutron Detection



Display

Gaming

Automotive

Audio/Video Editing

VR/AR

Holographic Imaging

Light Field Technology

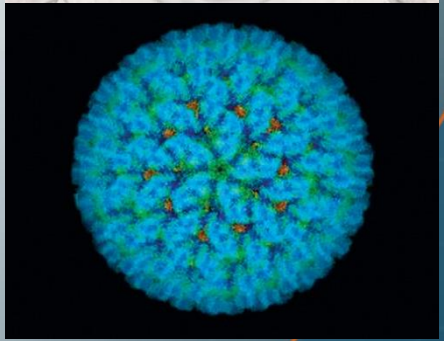
Scientific Cameras

X-Ray crystallography

DNA Sequencing

Electron Microscopy

Dark Matter Research



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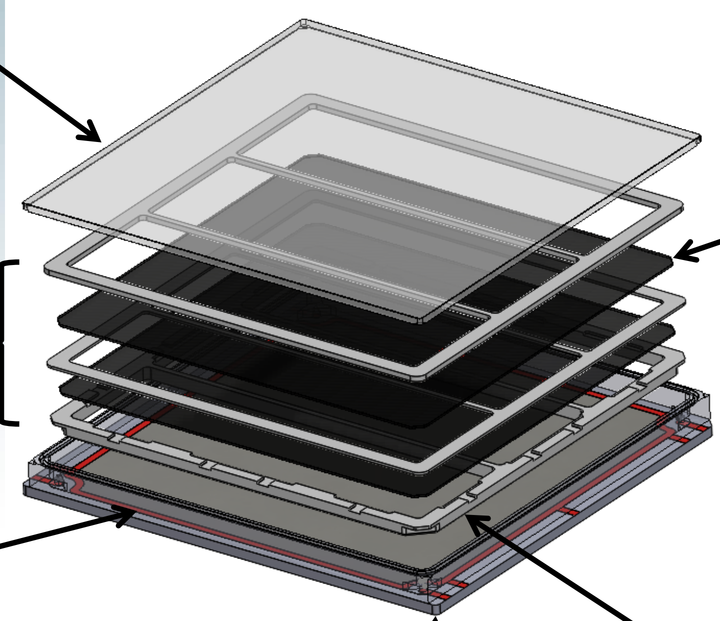
LAPPD Design (and HRPPD) – How does it work?

Fused Silica window (**Photocathode inside**)

MCPs + Spacers

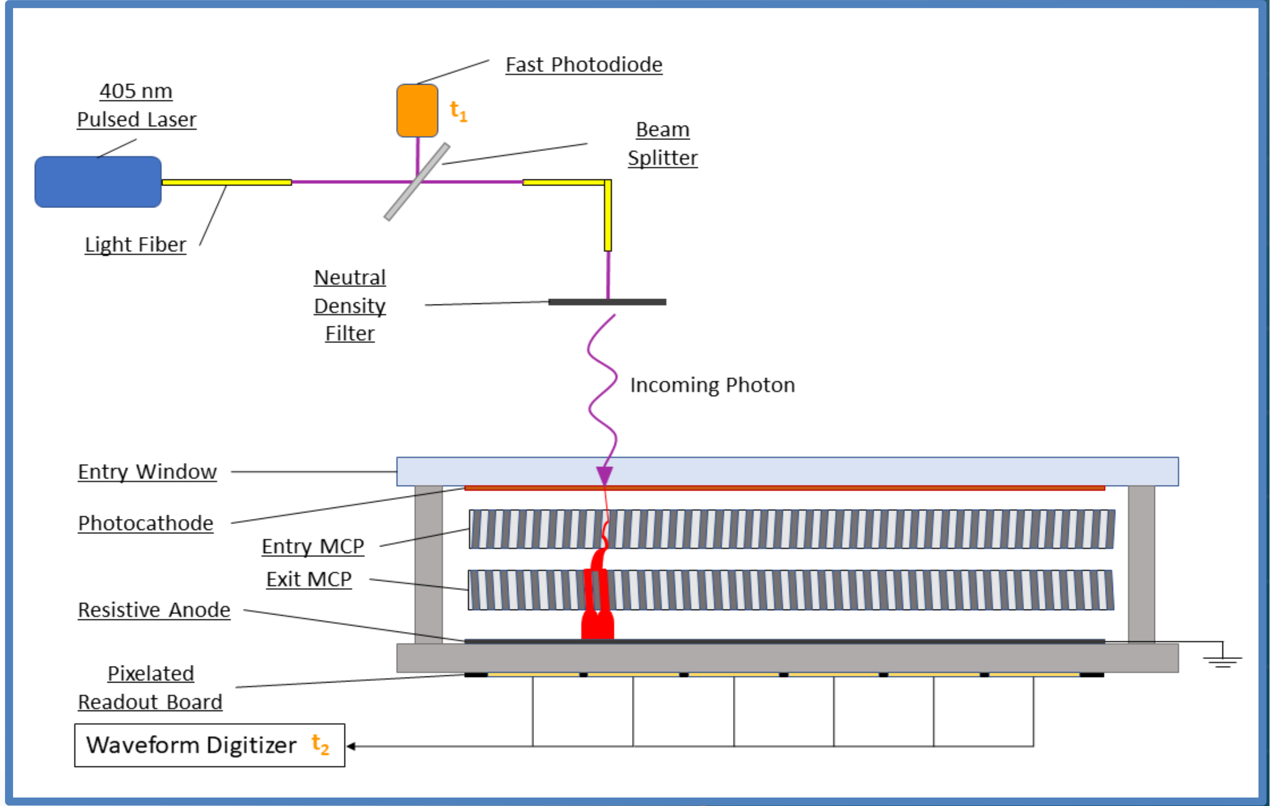
Sidewall frit bonded to Anode plate

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



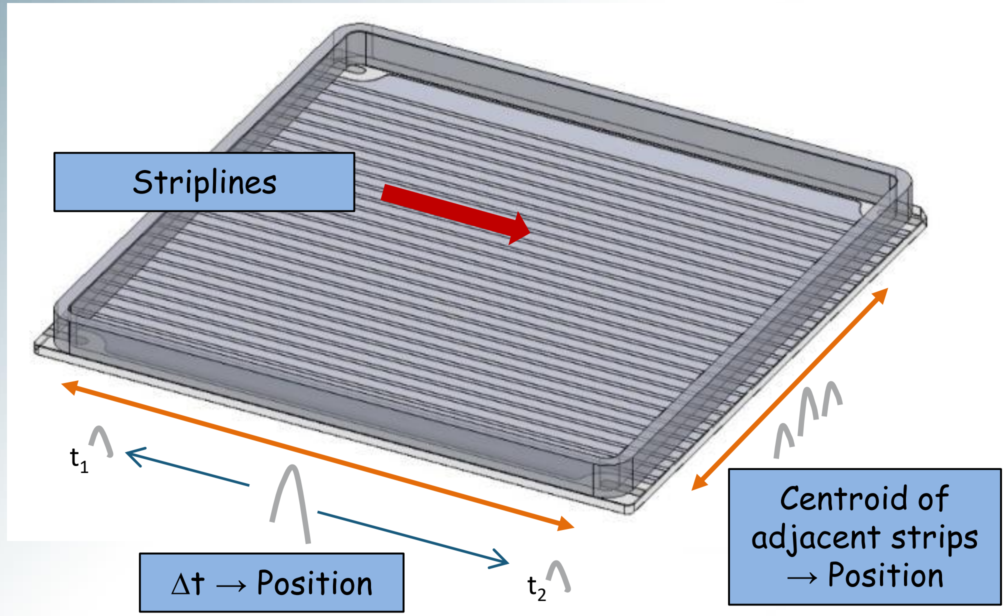
Internal Resistive Anode

- **No wall or anode penetrations**
- **Active area: 195 mm x 195 mm**
  - **X → Grid Spacer**
  - **350 cm^2 (92%) → 373 cm^2 (97%)**



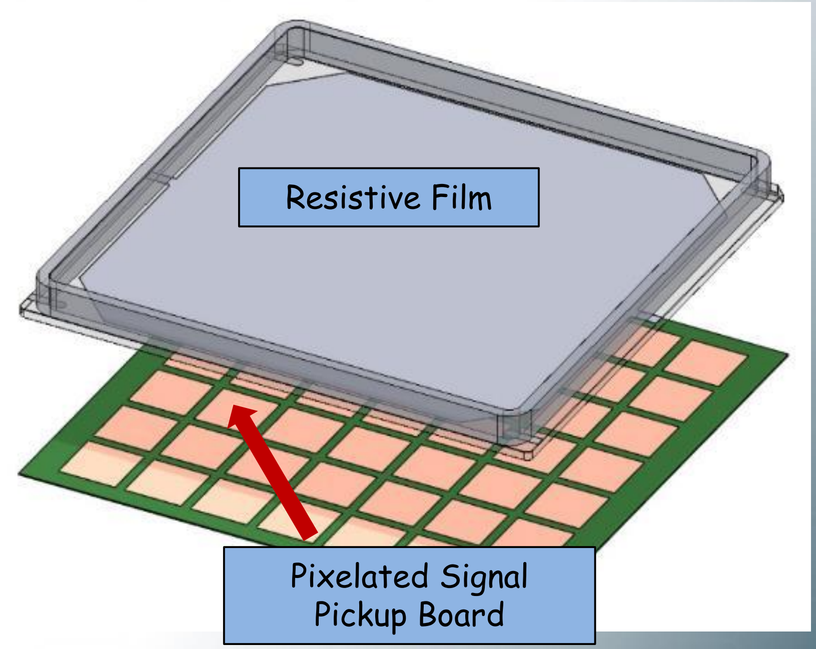
Gen-I vs Gen-II LAPPD™ Design

Gen-I Strip Line Anode



- ~1 mm spatial resolution, ~50 ps TTS SPE
- Good compromise between the number of electronics channels and spatial coverage.

Gen-II Capacitively Coupled Anode with Pixelated Board



- **Customizable anode pattern, user-changeable**.
- Good detection of **multiple simultaneous** photons.
- **Flexible anode design** for balancing rate, spatial resolution and electronics channel count.

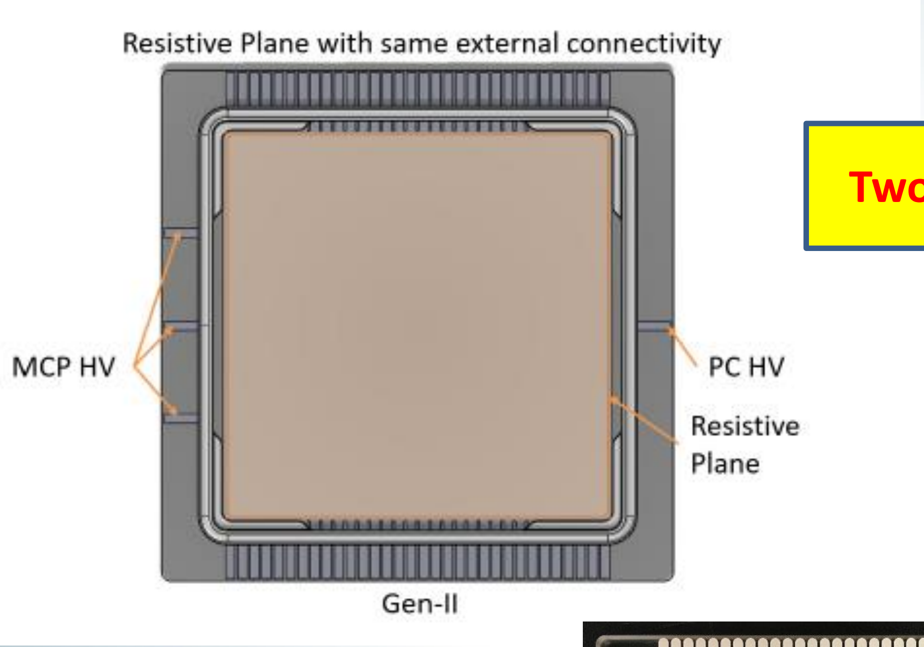
F. Tang et al., TWEPP 2008, Naxos, Greece, September 15-18, 2008
H. Grabas et al., Nuclear Instruments and Methods in Physics Research A 711 (2013) 124–131
B. Adams et al., Nuclear Instruments and Methods in Physics Research A 846 (2017) 75–80

HRPPD Technical & Commercialization Goals

- **Ultimate Goal**
  - Demonstrate **Pilot Production** feasibility of HRPPD devices
  - Target Device Performance**: high rates (200 kHz/cm^2**), B-field tolerance (**2-3 Tesla)** & **deliver** devices.
- **Phase I had two primary objectives:**
  - Fabricate a mock device using **small pore size** and **stacked MCPs** and an **unobstructed** active area for testing.
  - Develop a novel anode with a **highly pixelated direct signal** readout for **high rates**.
- **Phase II Technical Development**
  - Ceramic body to fused silica window seal – **solved**.
  - Development of kit components –for **gapped** high quality MCPs (10 μm pores).
    - MCPs with spacing add to gain and timing for high rate.
  - Sealing trials on fully assembled HRPPD (**5 trials to date** in existing sealing tanks).
  - HRPPD M&T Characterization – (**Two new** methodologies for HRPPD: capacitively coupled (CC) and direct coupled (DC) readout.
  - B-field testing – First tests on **LAPPDs** complete (@ANL – J. Xie/Popecki). HRPPD to test in Fall '22.
- **Commercialization Plans** (with our LAPPD Production Sales Priorities)
  - Time line for HRPPDs: primary is capacitively coupled, 2nd is highly pixelated direct readout.
  - Early Collaborator interest: (EIC, DIRC)
    - BNL, TJNAF, INFN, BELLE II at CERN.
  - Push out date for integration and sealing tank for batch production of multiple HRPPDs.
    - (learn from on-going trials in existing tanks).

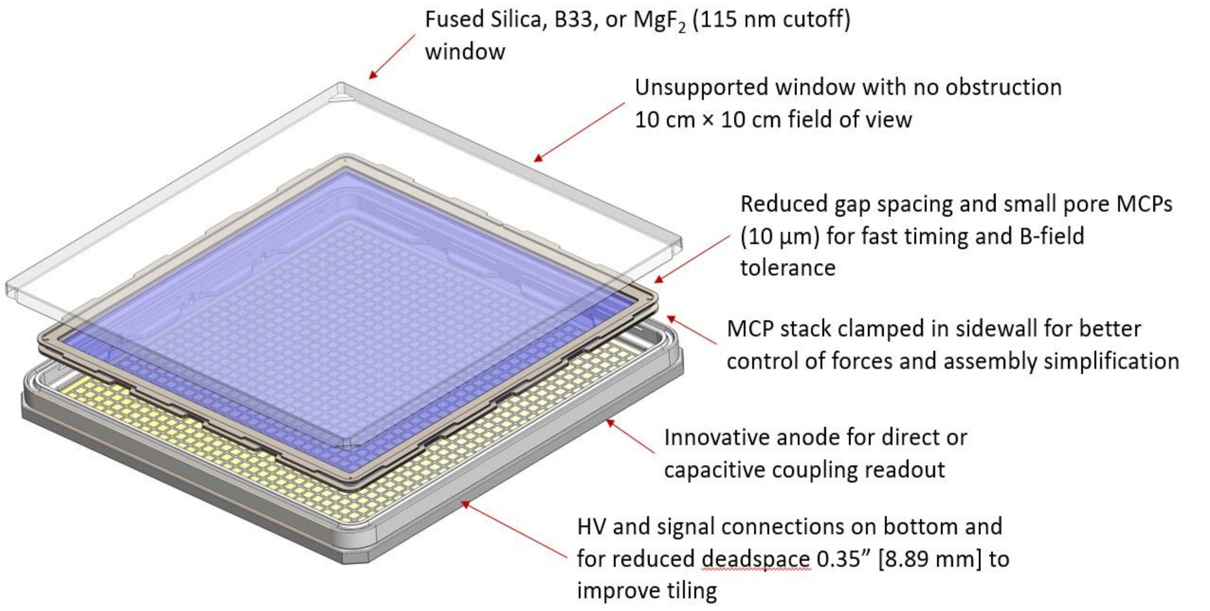
Phase I Review

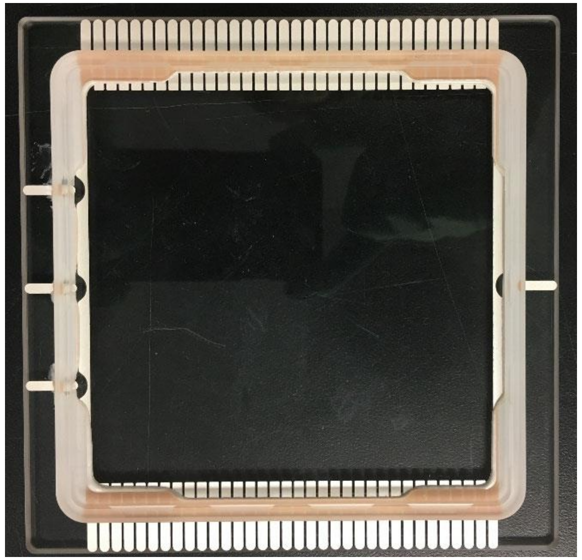
Capacitively coupled (CC) model

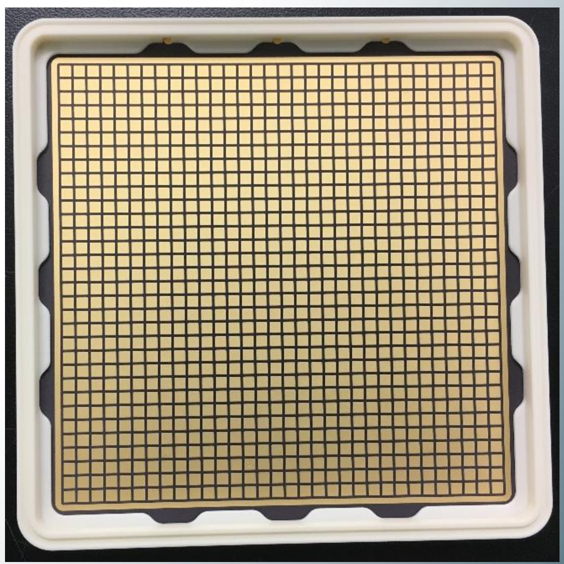


Two styles for R&D

Directly coupled (DC) model







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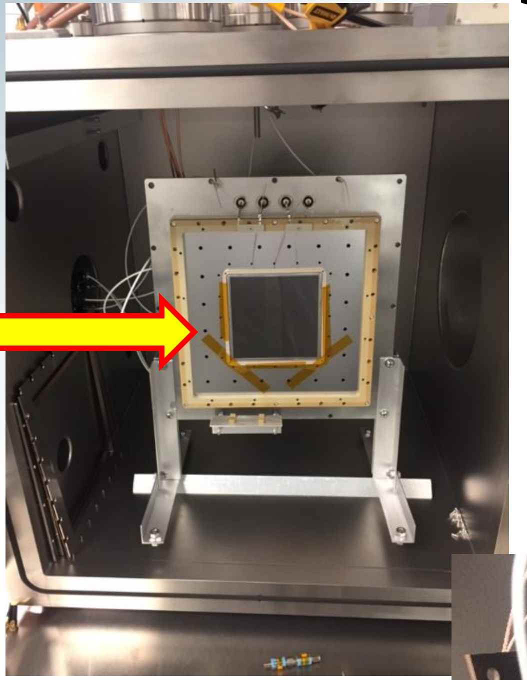
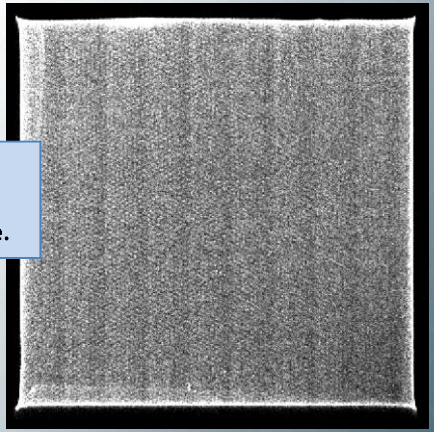
Device testing: Proof of Concept

The HRPPD sidewall with MCPs loaded.



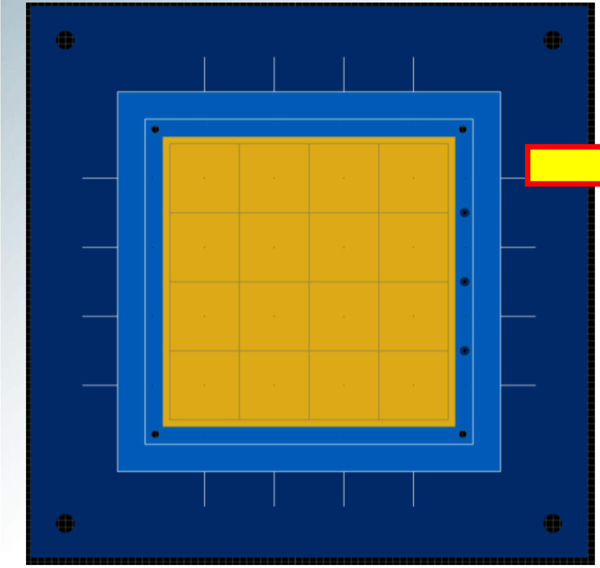
HRPPD sidewall and MCP testing. The MCPs were mounted in HRPPD sidewall.

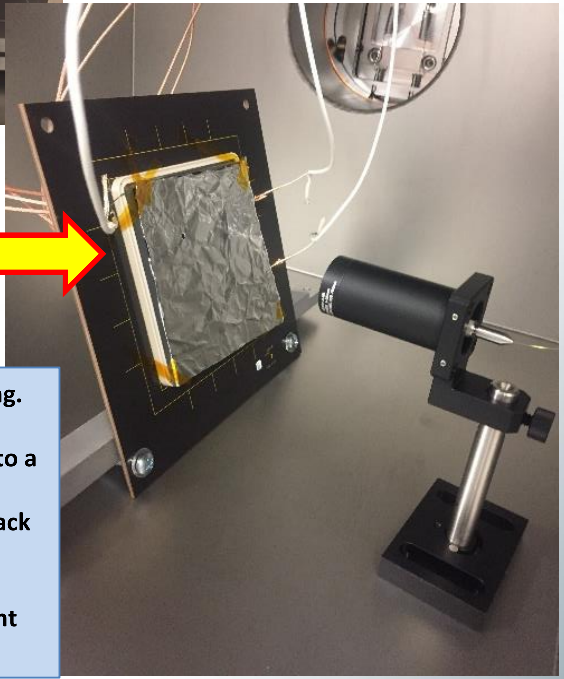
Imaging was done using a cross-delay line anode.



Photon image made with HRPPD detector mounted above a cross delay line anode.

Schematic of the simplified readout board for testing the HRPPD detector

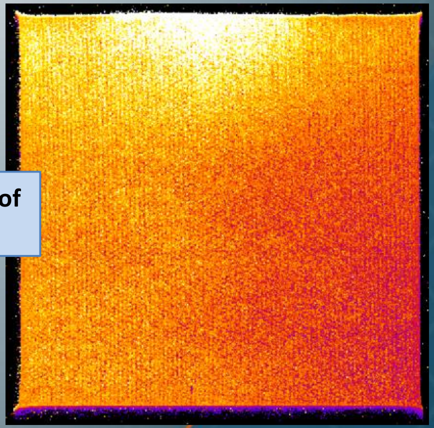




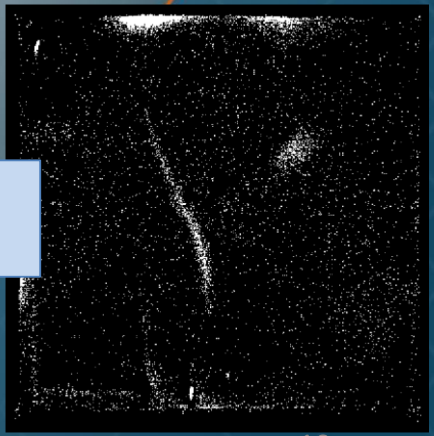
HRPPD sidewall, MCP, and anode testing.

The MCPs and sidewall were mounted to a PCB. The PCB has a pixel array directly connected to SMA connectors on the back of the board.

Aluminum foil mask was used to prevent scattered events.



Gain map image. Mean gain of ~3×10^6 gain (1075 V/MCP)



Background image. Dark rate of ~ 100 cts/sec over the whole image was observed.

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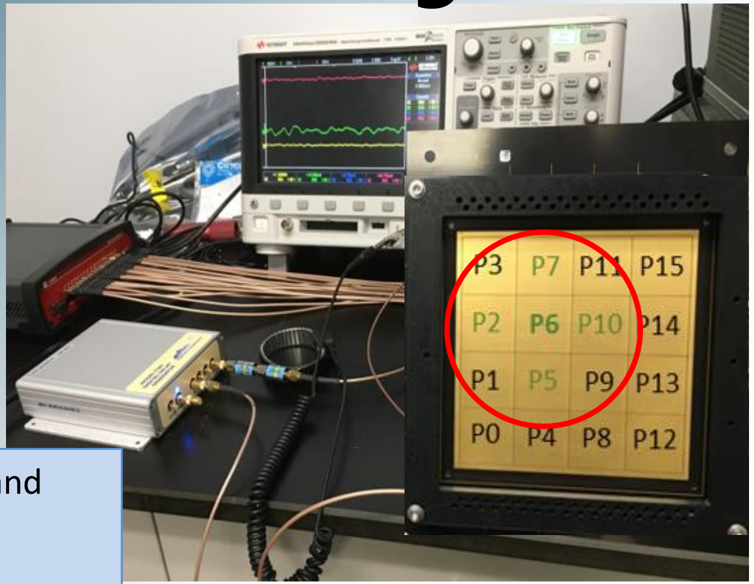
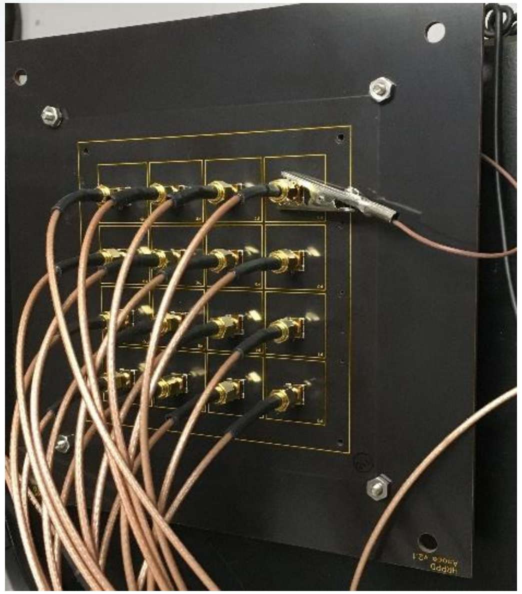
HRPPD Signal Board Test

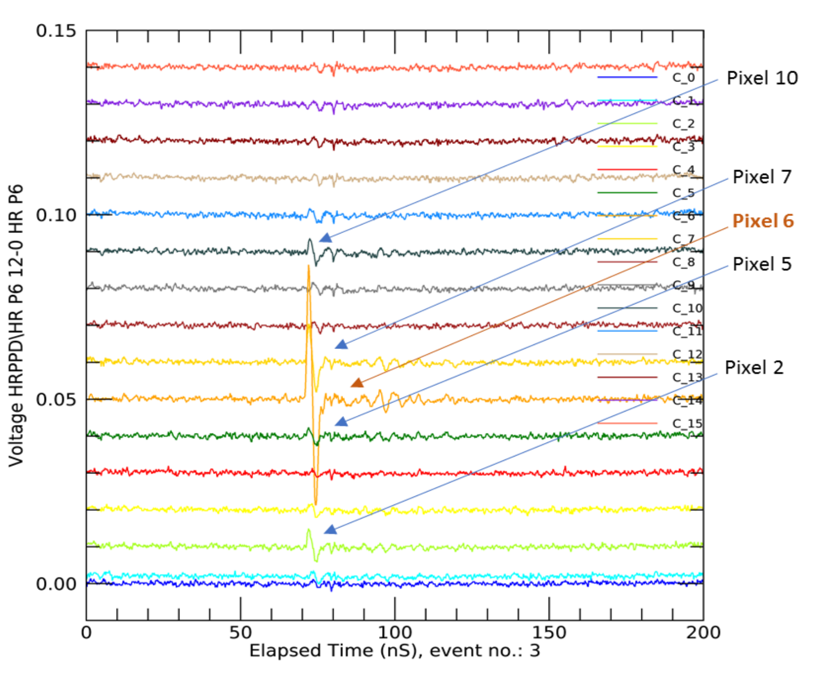




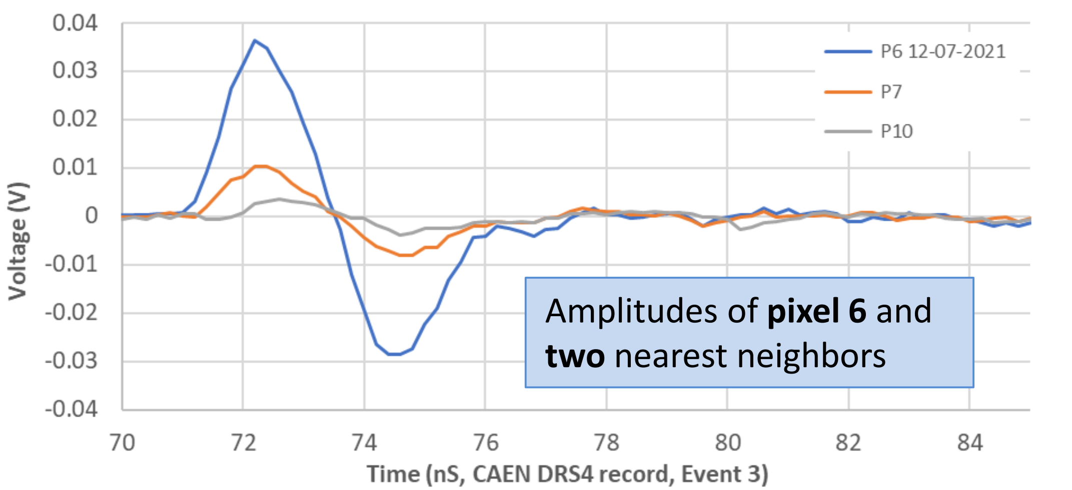
Top - Oscilloscope and 4x4 array of pixels.

Bottom – SMA connectors on back side of pixel signal board

The pixel responses are shown from a pulse applied to the resistive anode above **pixel 6**. The nearest neighbors are **2, 5, 7 and 10**



pulse by DRS4 ch HR P6 Event 3 12-7-2021.png



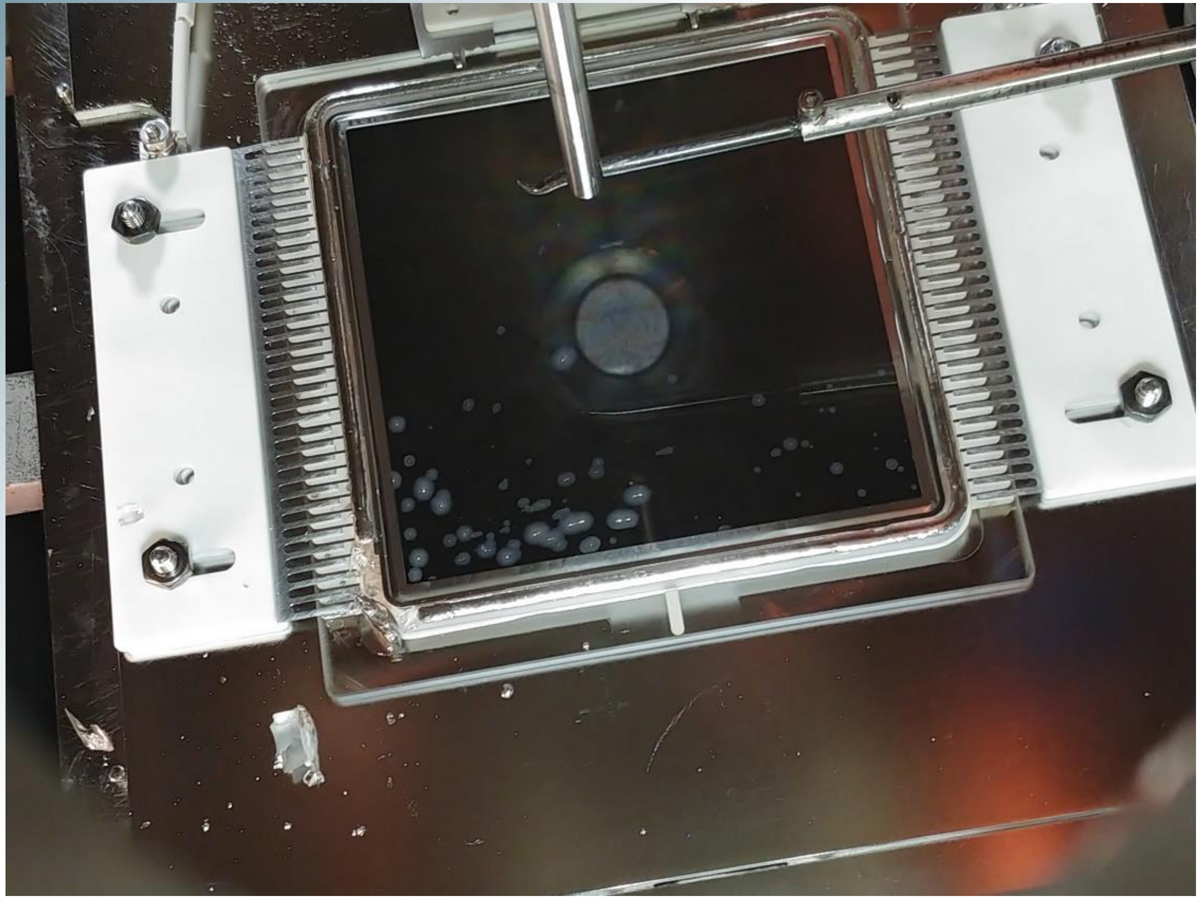
Amplitudes of **pixel 6** and **two** nearest neighbors

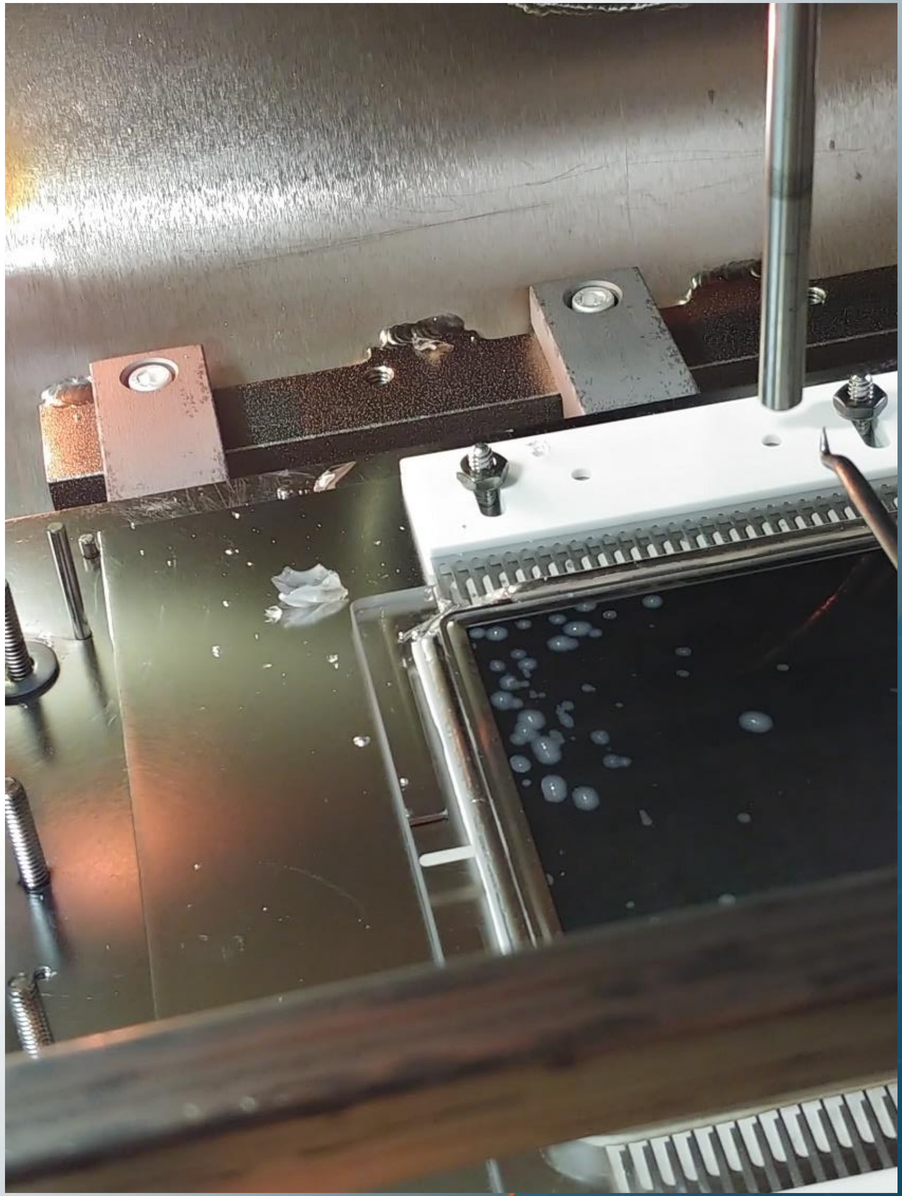
HRPPD Phase II Work Plan Status

- **Main Year One Focus:**
  - Sealing trials on fully assembled HRPPD (in existing Sealing Tanks)
    - Newly designed kit components in house
      - Extra HV connections and taller sidewall for gapped MCPs
  - HRPPD M&T Characterization Schemes (CC & DC)
- **Next tasks (in parallel with above):**
  - Magnetic field testing – Baseline tests completed at ANL
  - New Dark Box geared up to read up >100 channels
  - Deliver devices to collaborators

HRPPD #s 1 & 2

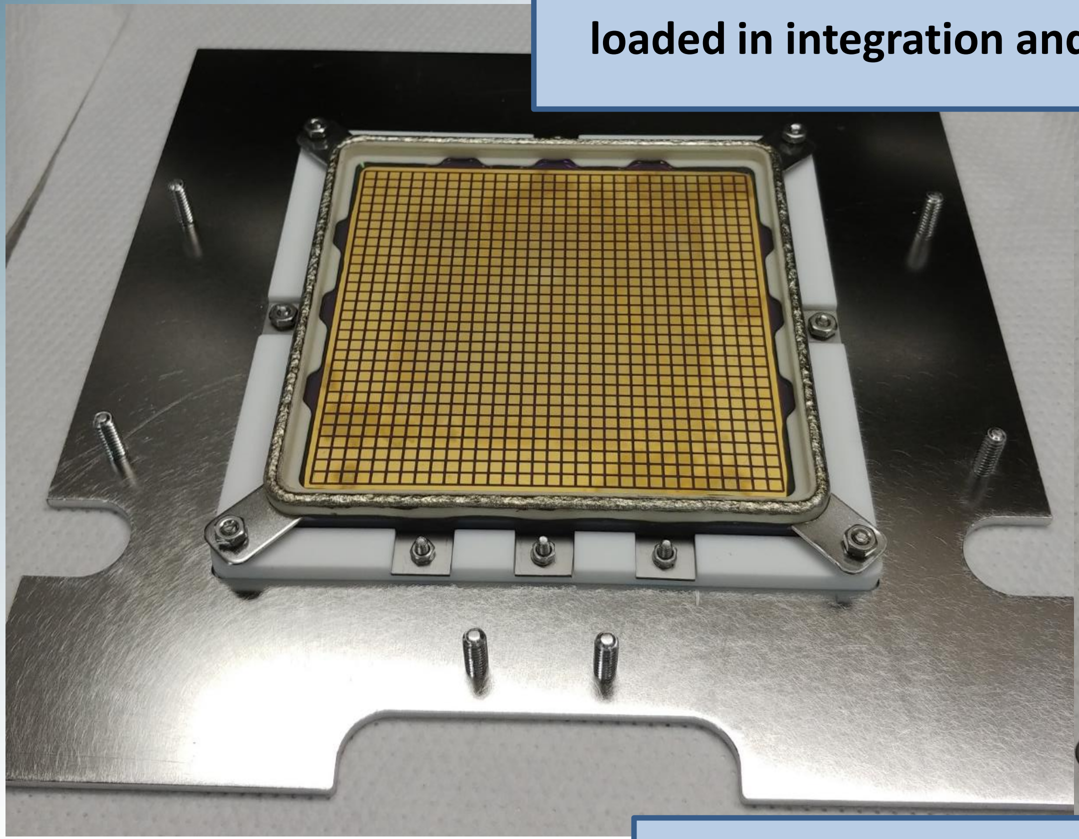
LTA: B33 grooved
Window: 5mm B33
Anode: resistive anode (CC)

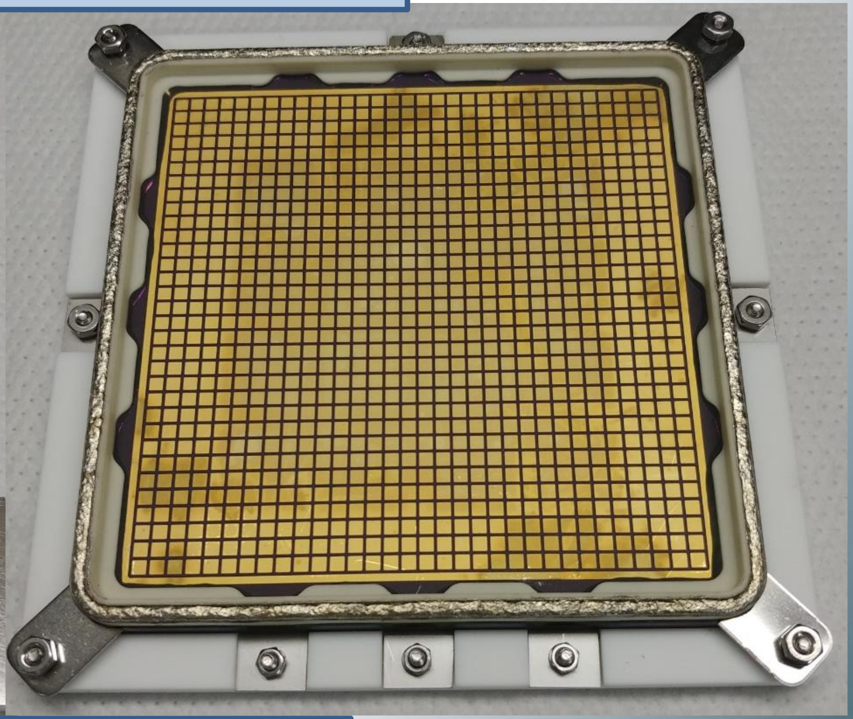




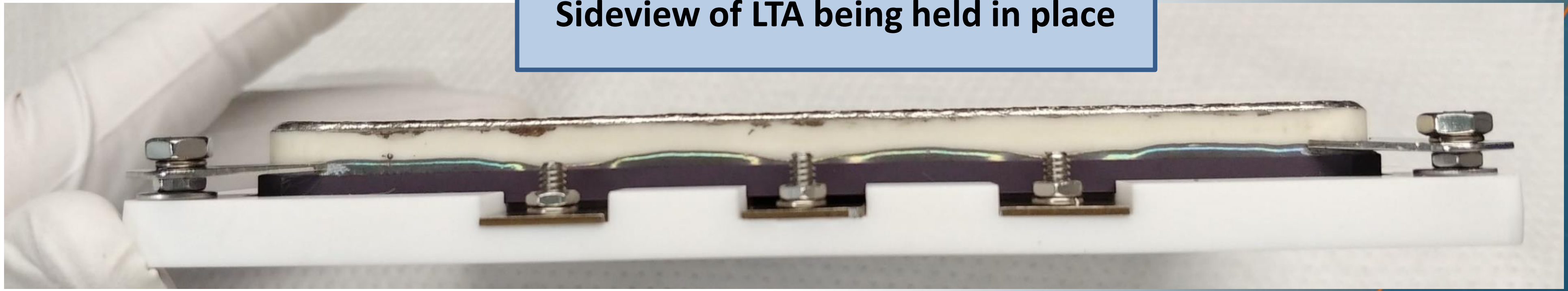
HRPPD (#3)

Metallized co-fired lower tile assembly loaded in integration and seal tank holder

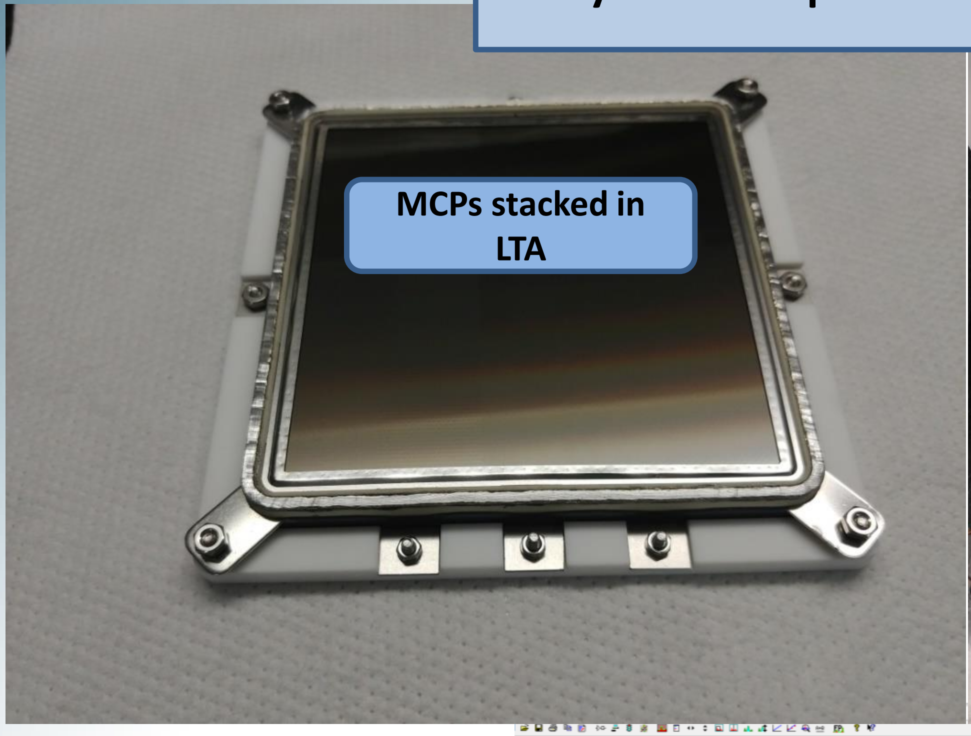


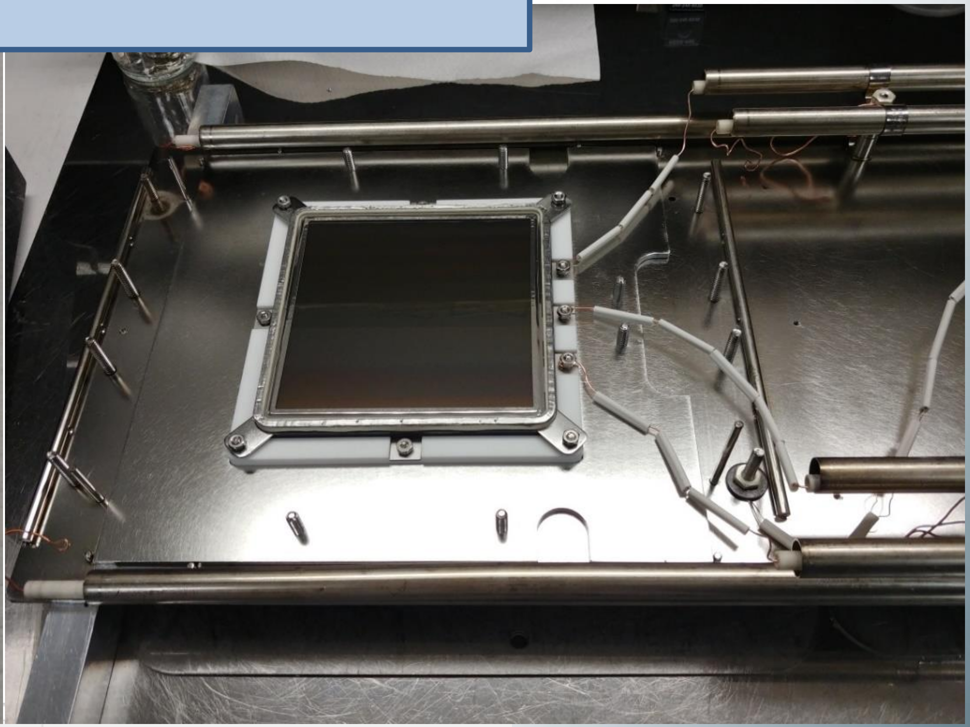


Sideview of LTA being held in place

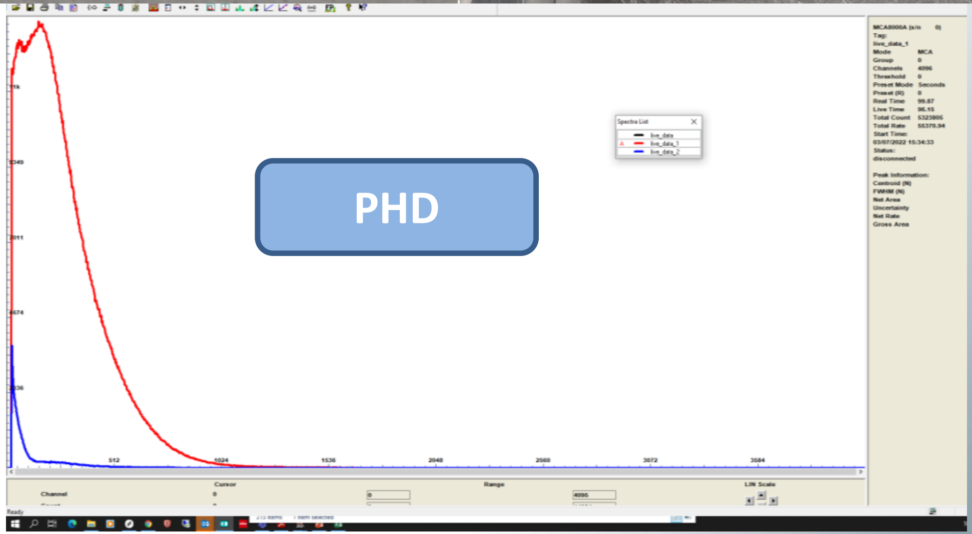


Fully stacked up LTA with electrical connections

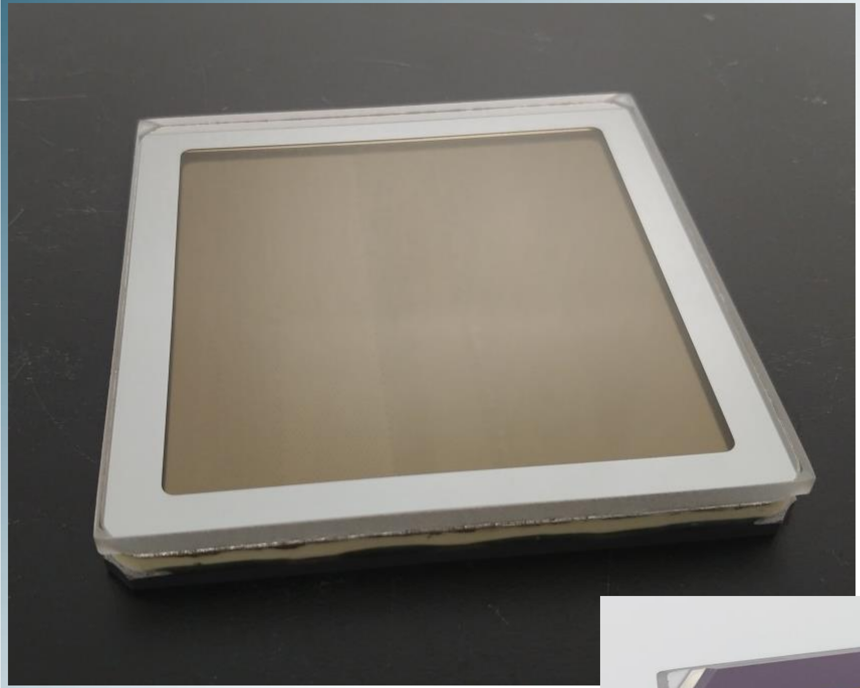


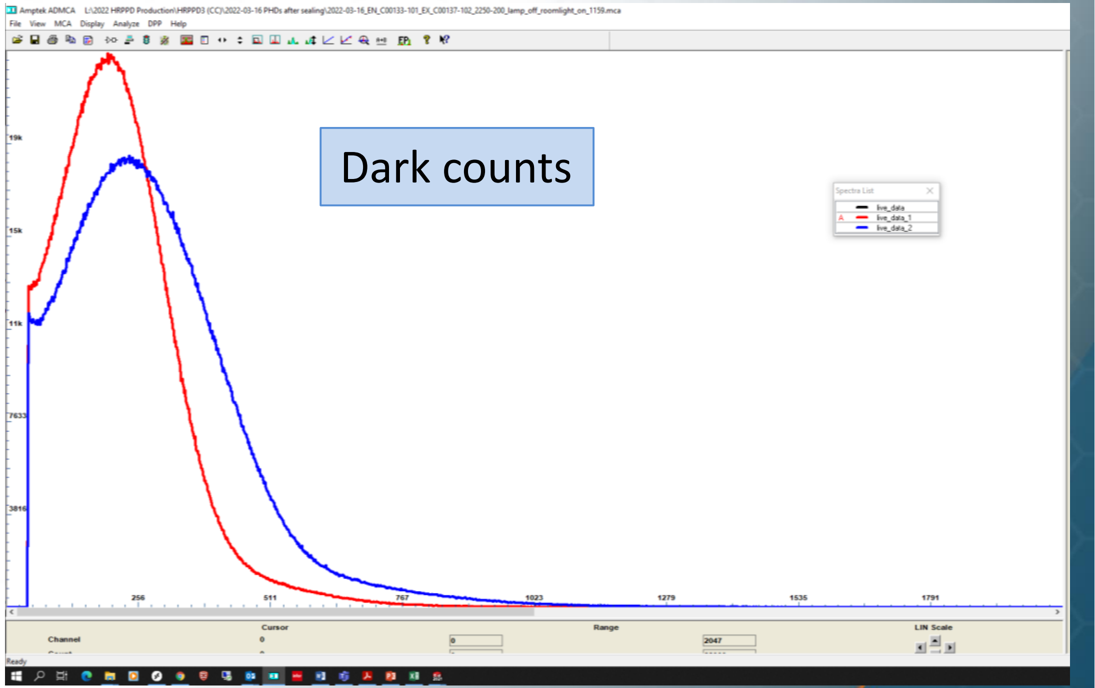


HRPPD (#3)



1st Sealed HRPPD (#3) March '22

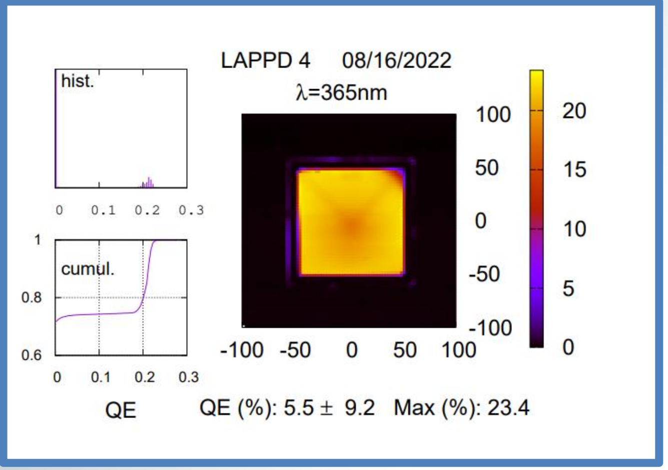


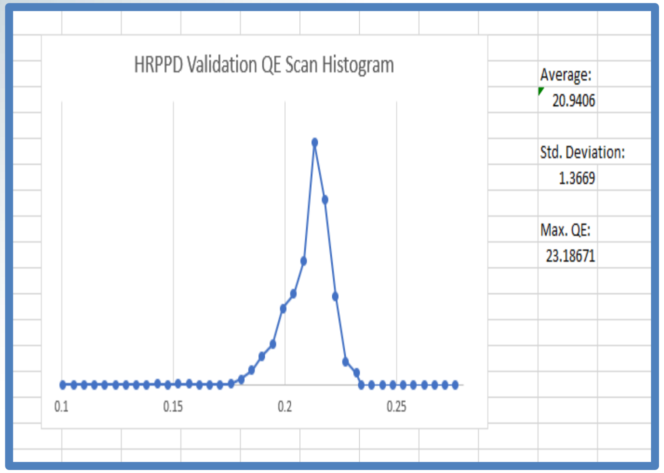


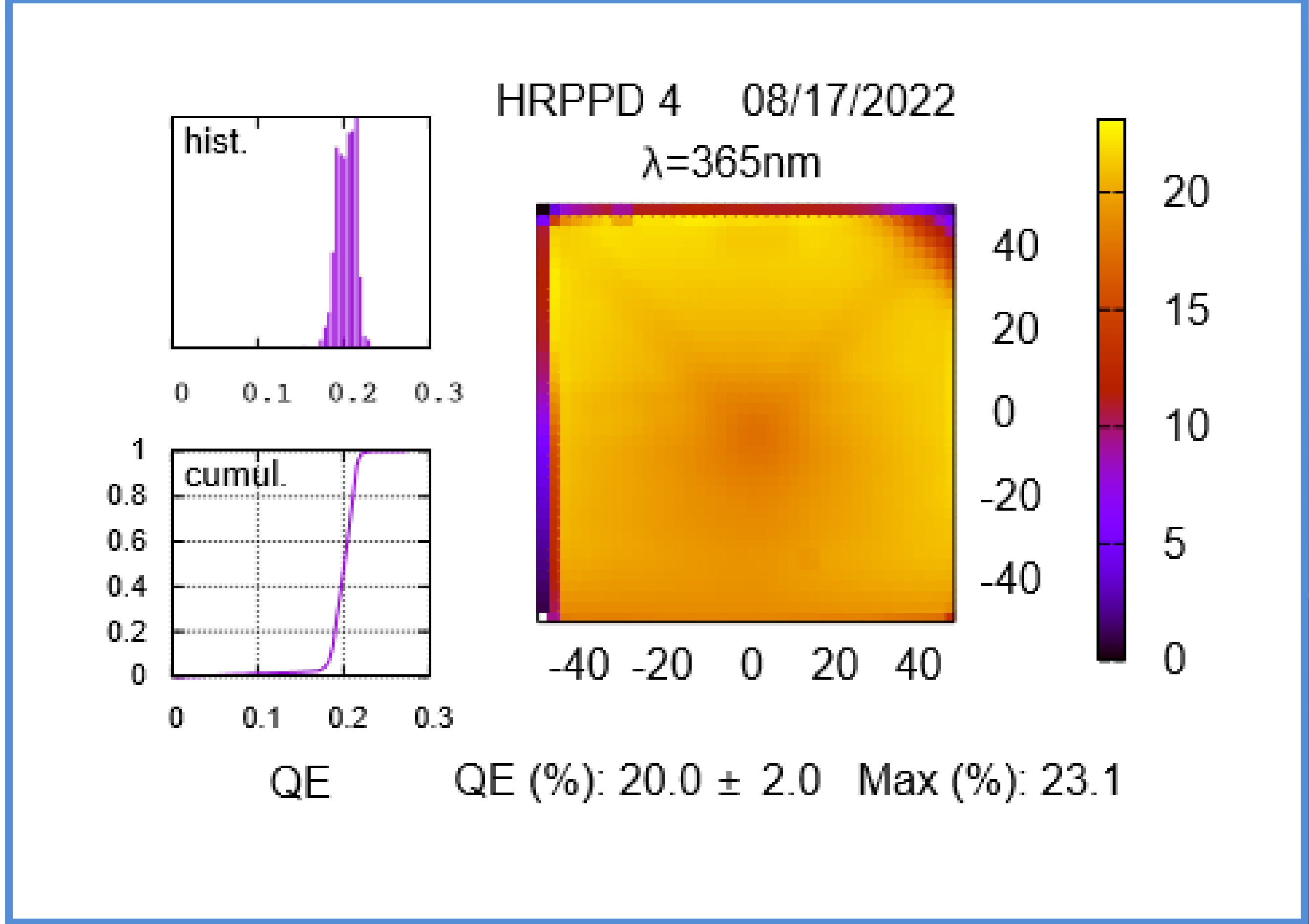
Co-fired anode with
1024 pads @ 2.5 mm sq.

Challenge to find economic way to read all channels

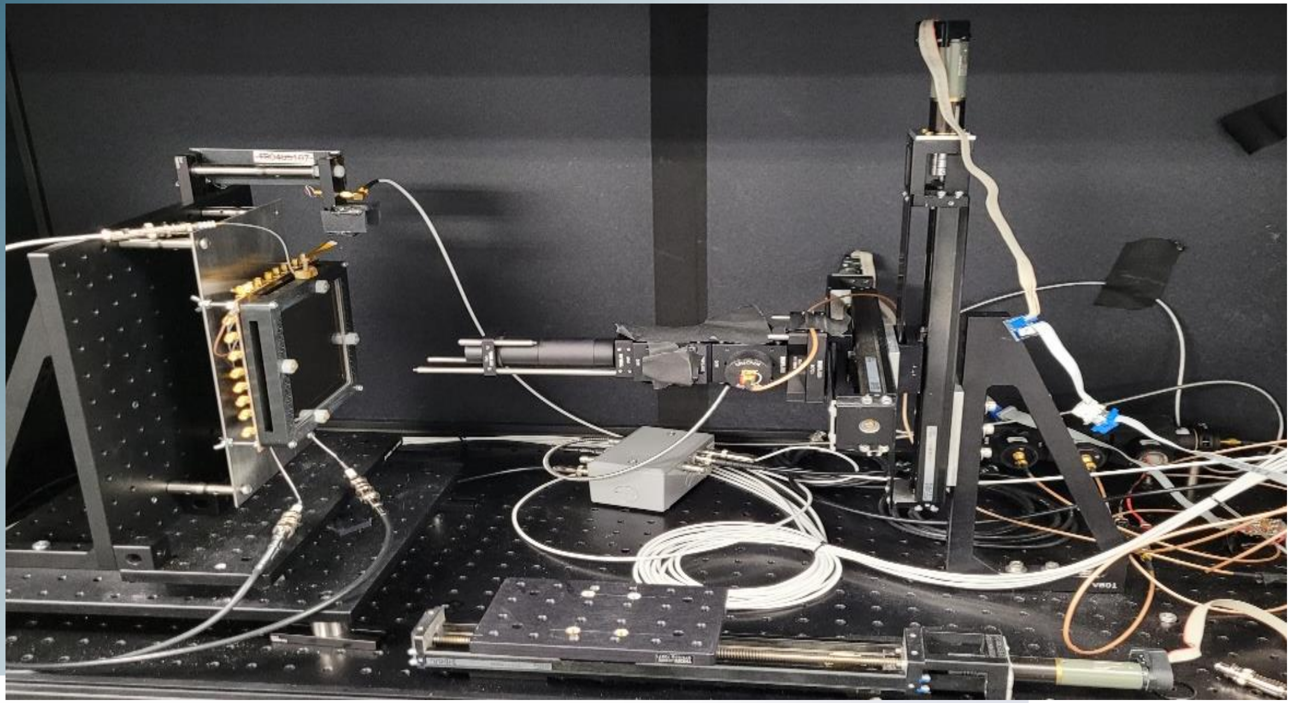
DC HRPPD (#4) Validation QE Scan

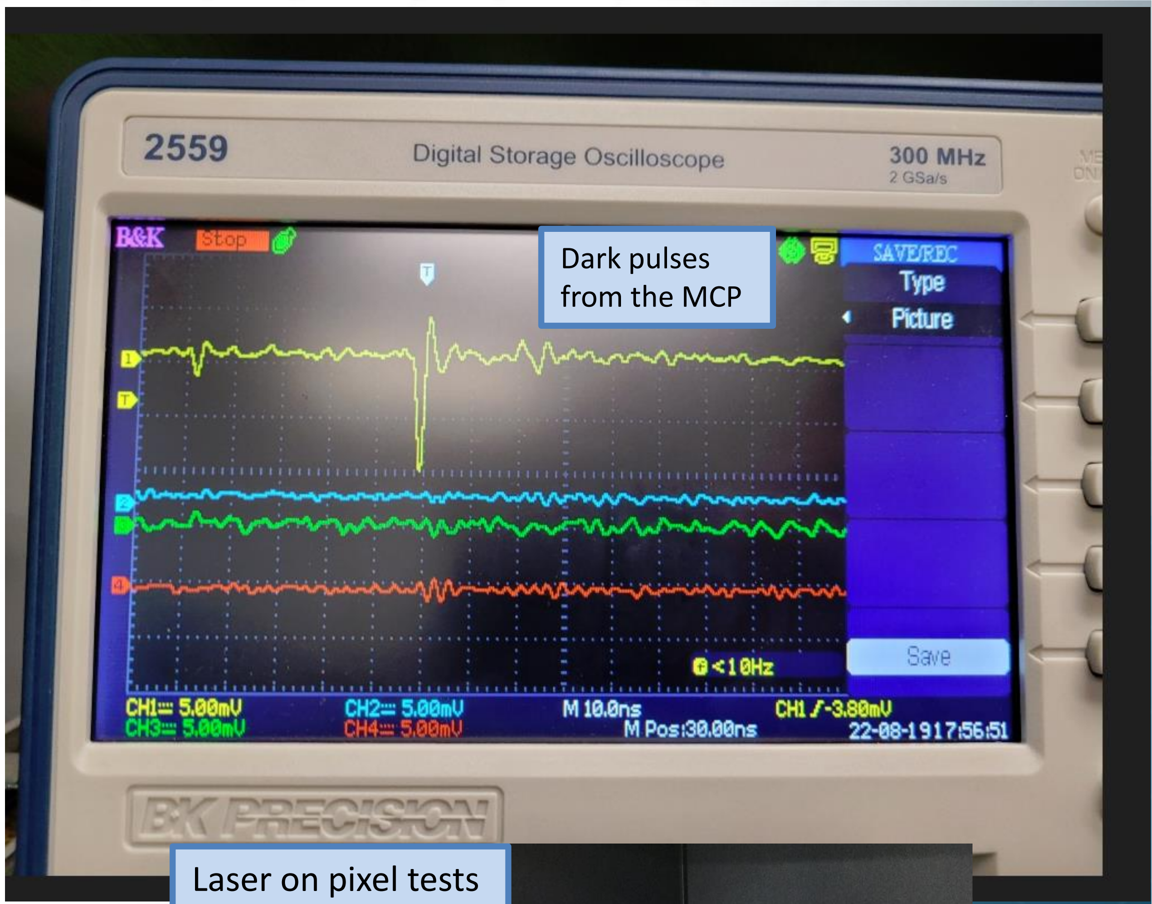






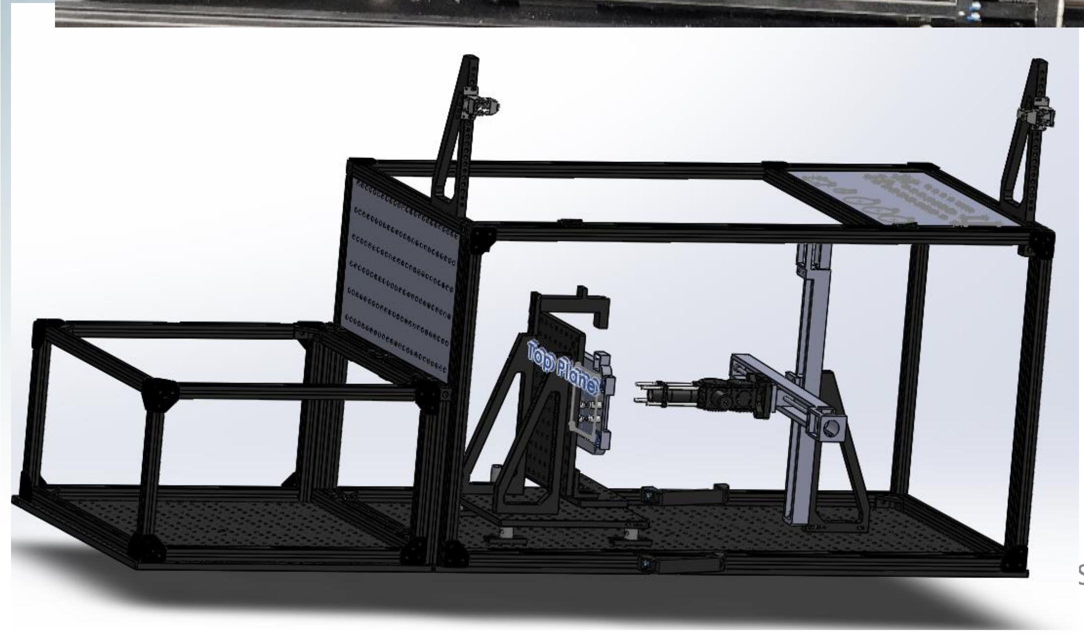
DC HRPPD Testing Configuration

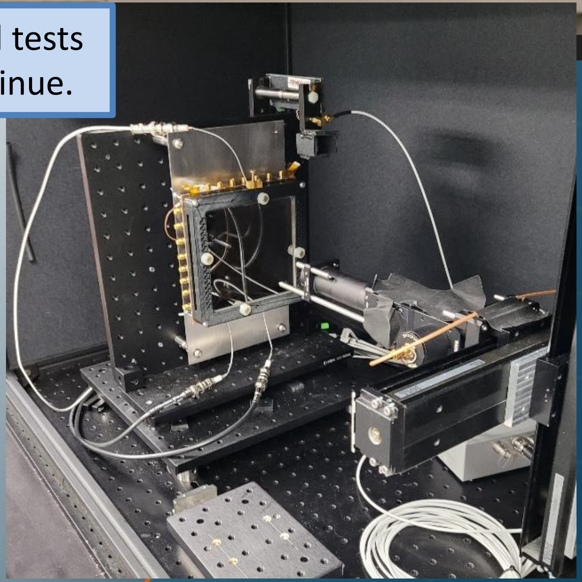




Dark pulses from the MCP

Laser on pixel tests will now continue.

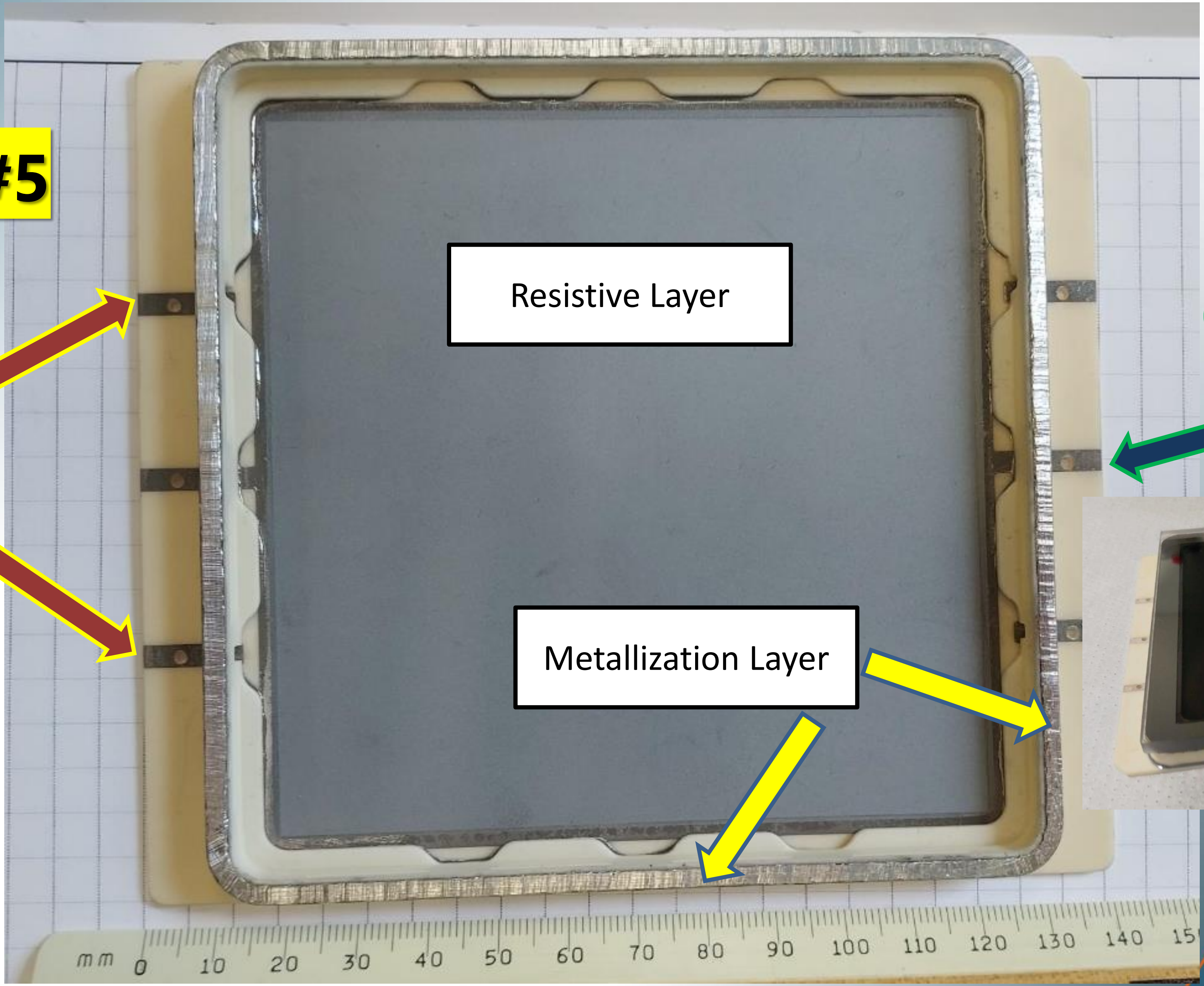




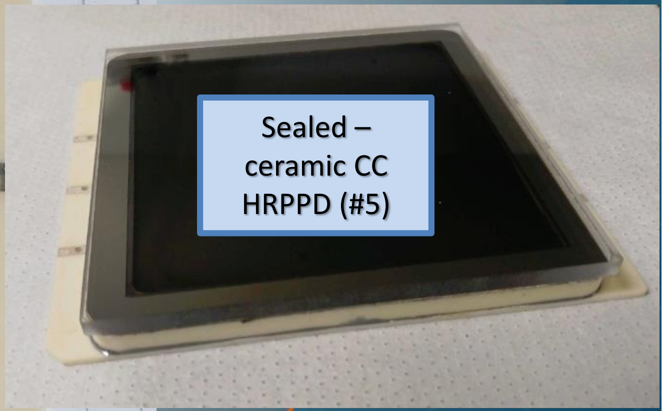
Scheme for new Dedicated Dark Box for HRPPD

CC HRPPD #5

MCP high voltage connections (4)



Ground plane connections (2)



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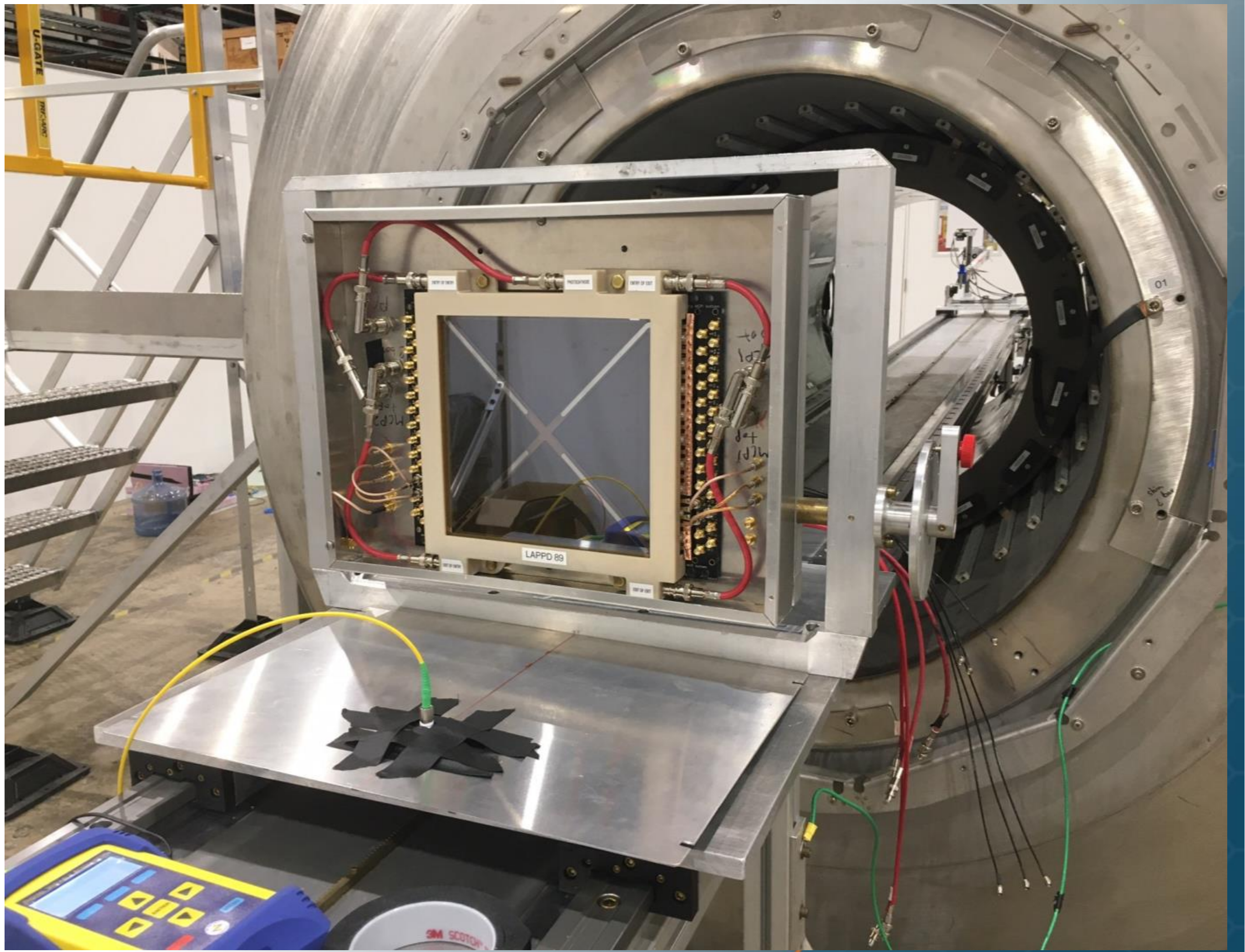
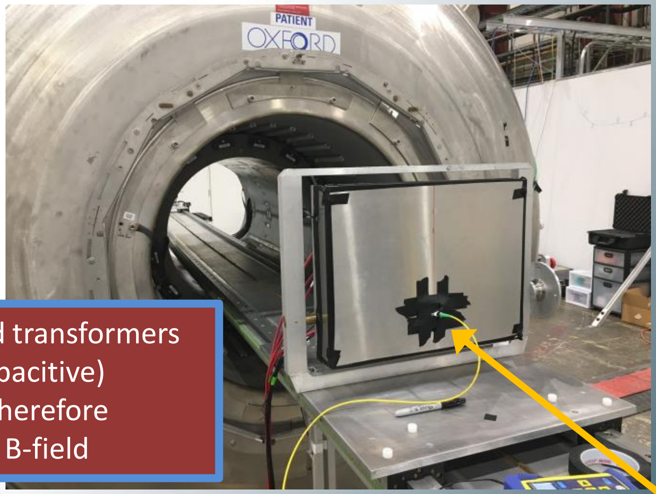
Three LAPPDs at a Solenoid Magnet

- Two stripline LAPPDs
  a. 118, 20 µm MCPs
  b. 89, 10 µm MCPs
  c. One capacitively-coupled LAPPD: 126, 20 µm MCPs
- Magnetic field strength: 0.02 T to 1.4 T
- Stronger fields are possible with a modification of the dark box frame
- Dark box
  a. Aluminum case
  b. Laser input fixed in the center near the bottom – on the centerline of the solenoid when the LAPPD is vertical.
- Rotation in the magnetic field:
  a. LAPPD tips into or out of the region of stronger magnetic field
  b. Move the LAPPD in or out at each angle to compensate for the change in field strength
- Data products
  a. Gain
  b. Position
  c. Position resolution
  d. Transit Time Spread
  e. Afterpulse rate

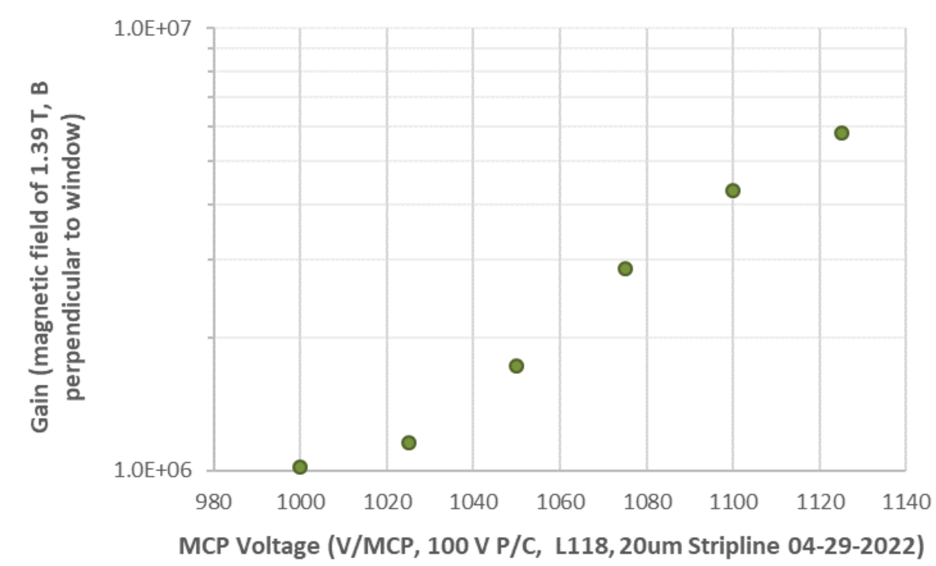


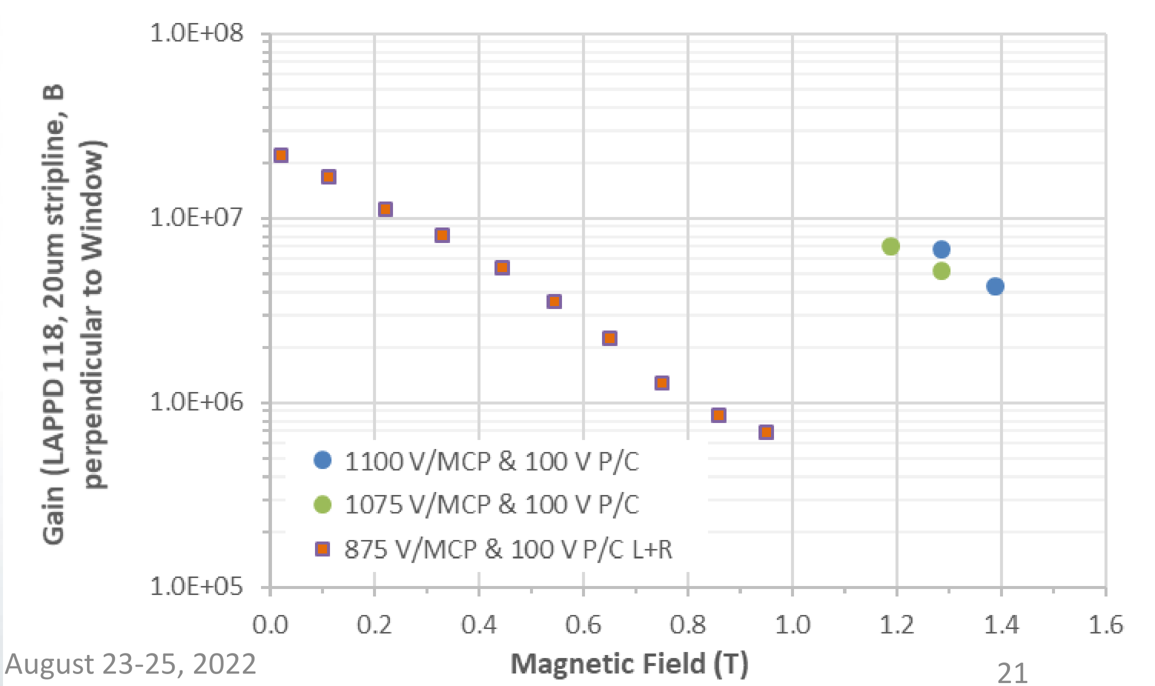
Gain vs. Magnetic Field Strength, B || P/C e-

- LAPPDs were pushed toward the solenoid and stronger magnetic field in steps
- B Field was measured with a gaussmeter at each step, units of kGauss
  - 1 T = 10 kGauss
  - Earth's field is 0.5 Gauss
- The gain decreased with increasing magnetic field strength.
- Gain could be recovered with a higher MCP voltage.
- Dark rates decreased even in the 0.02 T field
  - (200 Gauss, 400x Earth's field)



Incom's CC signal board transformers (inductive and capacitive) "locked up" and therefore unusable in the B-field





Next Plans: HRPPD Fabrication Time Line

- **May "21 – May '22 (end of 1st year)**
  - **Verified new ceramic components:** metallize sidewalls, fuse lower tile assemblies, apply resistive anode layer.
  - Fabrication trials with leftover **Phase I components in parallel.**
    - Process both capacitively coupled devices and direct coupled versions.
    - **The target for the first sealed working HRPPDs is now Sept '22.**
    - **Once Incom tested**, these will be made available to the **EIC consortium. BNL** to start with a DC HRPPD.
  - Incom's glass manufacturing team processing 10 μm pore glass capillary array material for **HRPPD MCPs**.
    - Proper handling and novel processing are key for **high quality and yield** of the thin (**600 μm**) GCAs.
- **Year 2 (May '22 to May '23)**
  - Fabrication of ceramic **capacitively coupled** HRPPD will continue (1+ starts/month).
  - **Direct readout** fabrication is a 2nd priority. (design modifications are in process).
    - Measurement & Testing for 1024 pads will be a challenge. **Working with BNL on design schemes.**
      - Directly coupled anode is now read with a subset of pixels for testing.
      - Alternative readout plan for the DC anode is to make it capacitively coupled with a resistive film and a thin dielectric.
  - Magnetic Field tests: started with Baseline LAPPD, then HRPPD in Fall '22.
- Currently in design and procurement for a 3rd dark box to test 128 channels of direct readout HRPPD.
- Apply for a sequential SBIR to finish R&D and accelerate commercialization.

Thank you to Offices of DOE NP/HEP and NASA Programs

ANY QUESTIONS?

Current Funding & Personnel Acknowledgements

DOE (NP, HEP, NNSA, SBIR) Personnel: Dr. Alan L. Stone, Dr. Michelle Shinn, Dr. Helmut Marsiske, Dr. Kenneth R. Marken Jr. Dr. Manouchehr Farkhondeh, Dr. Elizabeth Bartosz, Dr. Gulshan Rai, Dr. Donald Hornback, Dr. Manny Oliver, Dr. Claudia Cantoni, Carl C. Hebron.

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

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

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)

INCOM
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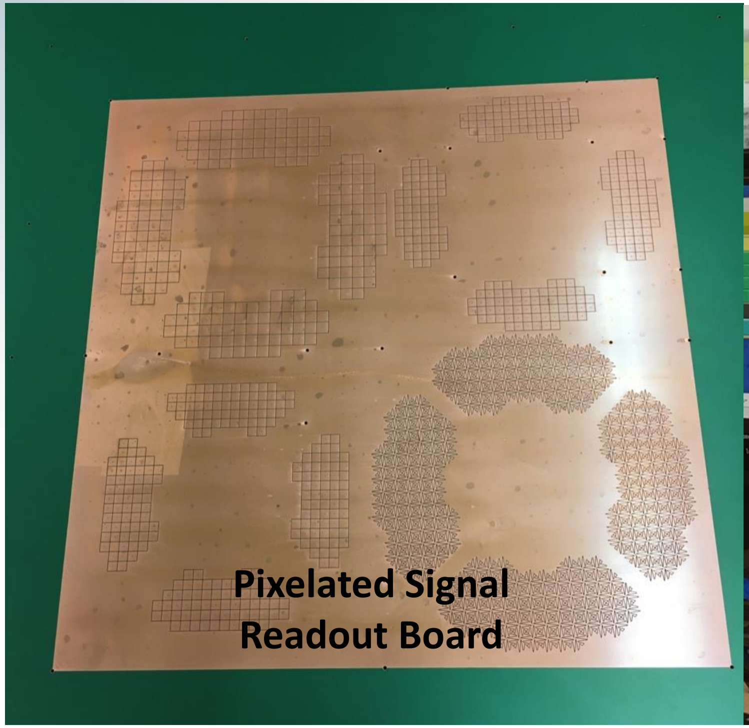
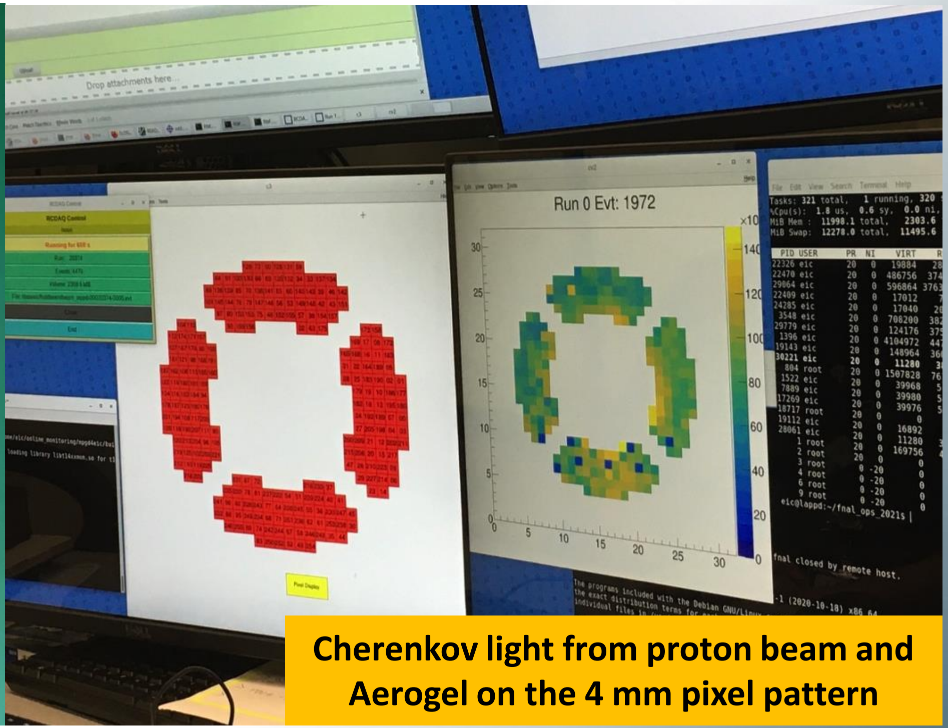
BACK UP SLIDES

Application Example

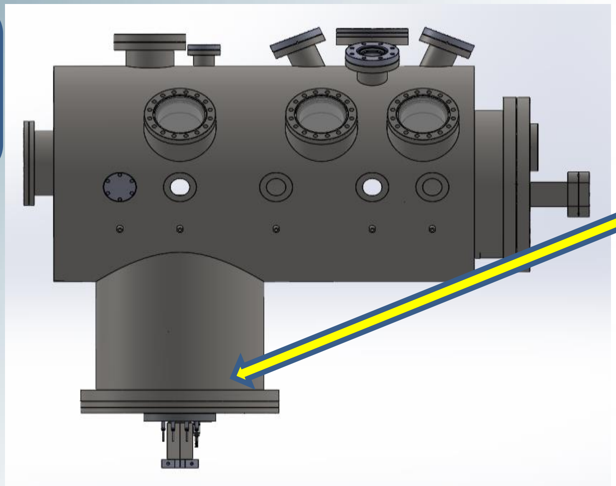
- Cherenkov Ring Imaging at Brookhaven National Laboratory



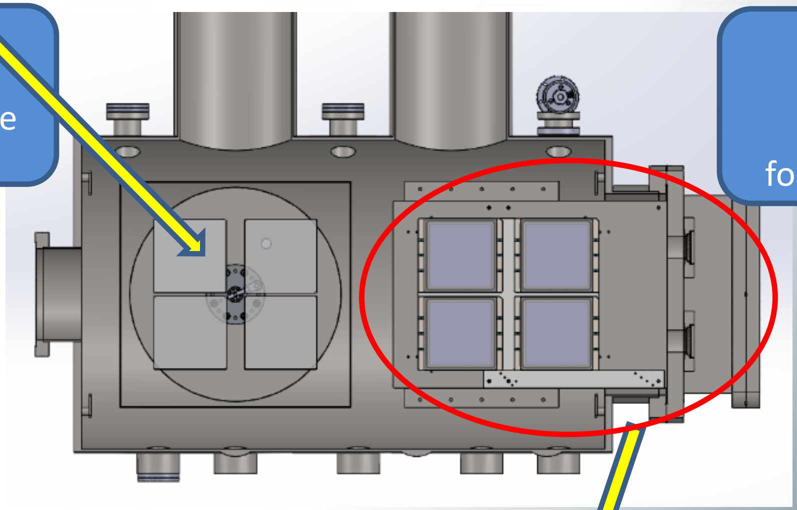


Quad Sealing Tank Model

Similar to two existing tanks

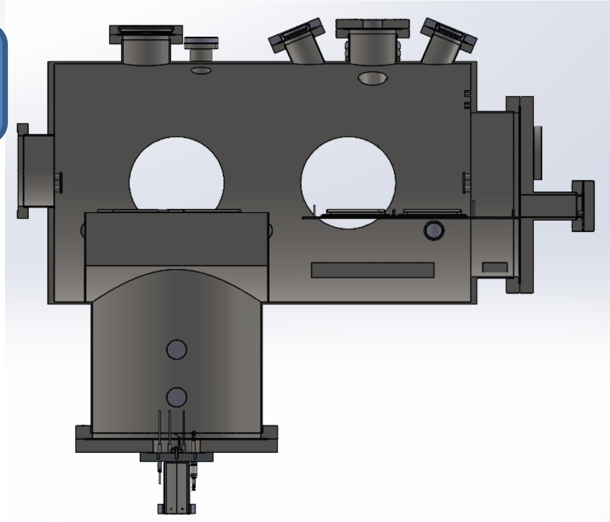


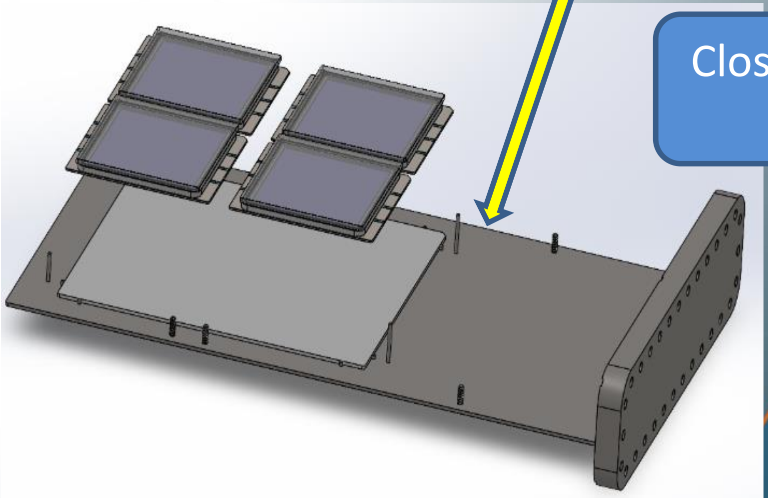
Windows above photocathode chamber



Cutaway – top view
four windows
&
four lower tile assemblies

Cutaway – side view





Closeup of loading tray – four LTAs