Development of Gen-II (Capacitively Coupled) LAPPD™ Systems For Nuclear Physics Experiments

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Outline

- **Incom, Inc**
- **LAPPD**
  - **What** is it**, where** can it be used and **how** does it work?
  - Review Capacitively Coupled (Gen II) vs Stripline (Gen I)
- **Review Phase IIA Program Objectives**
- **Capacitively Coupled Performance Data**
  - Photocathode QE, Gain, Dark Counts
  - Timing and Position Resolution
  - Electronics and readout cards
    - Nalu, Ultralytics, UChicago
- **Current Applications/Collaborations**
- **Recent Developments**
  - 10 cm HRPPD device and early B-Field tests
  - Crosstalk and modeling – open source for others
- **Summary**
  - Objectives Summary

INCOM BRIGHT IDEAS

Incom Inc. – Enabling the Vision of Tomorrow

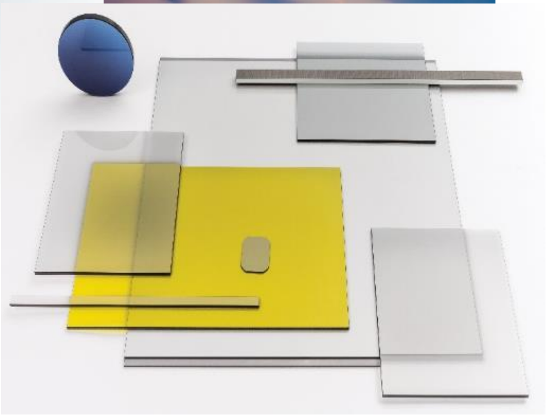
Founded 1971 (Fused Fiber Optics)

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**



Incom Market Leadership

Life Science / Medical

Digital X-Ray systems

Mammography

Panoramic and Intra-oral X-Ray

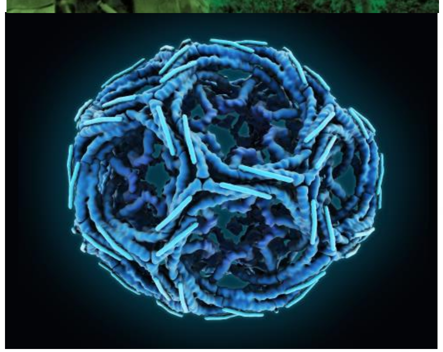
DNA sequencing

Defense & Homeland Security

Night Vision

Biometric Identification

Neutron Detection



Display

Gaming

Automotive

Audio/Video Editing

VR/AR

Holographic Imaging

Light Field Technology

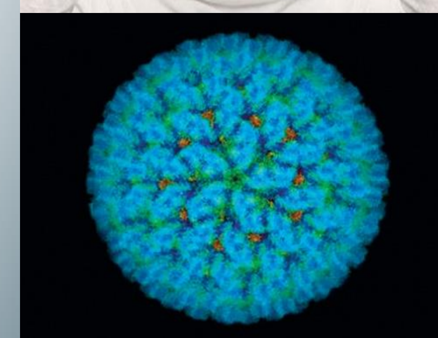
Scientific Cameras

X-Ray crystallography

DNA Sequencing

Electron Microscopy

Dark Matter Research



INCOM BRIGHT IDEAS

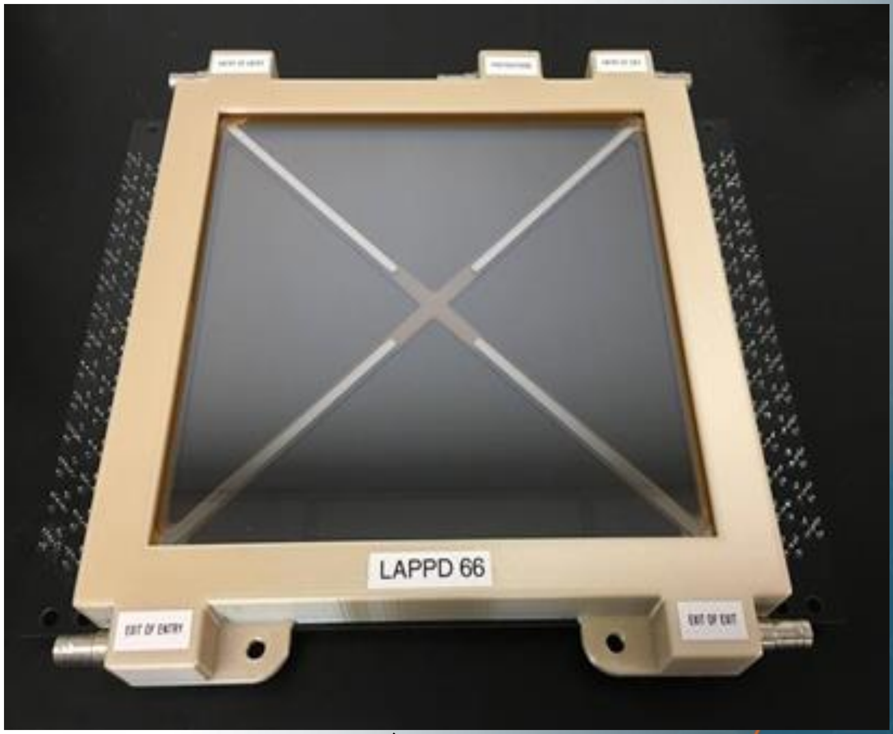
Large Area Picosecond Photodetector (LAPPD^{TM}) What is it?

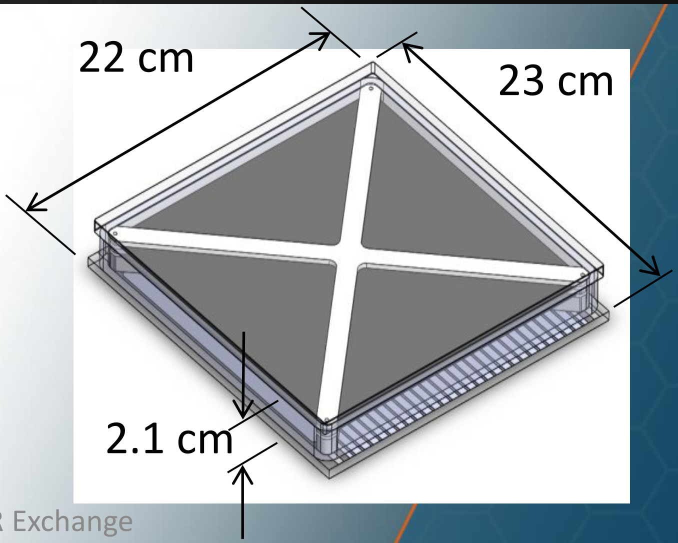
- **MCP photomultiplier**
  - Good timing resolution
  - Position sensitivity
  - High gain
- **8" x 8" : active area 350 cm^2, 92% open area**
- **High gain: mid-10^6 or higher for single photoelectrons**
- **Blue-sensitive photocathode: Potassium-Sodium-Antimony (K_2NaSb)**
  - QE is 20-30% at 365 nm

Time and position measurement for:

- Photons, with **Single** or **Multiple** photoelectrons
- Penetrating energetic particles

- **Time resolution: (stripline anode style)**
  - **SPE (Core distribution 37 ps Vagnoni) and ~ 54 ps for entire distribution**
  - **MPE (Core only 9.0 ps Vagnoni)**
- **Position resolution: ~ 1x1 mm**



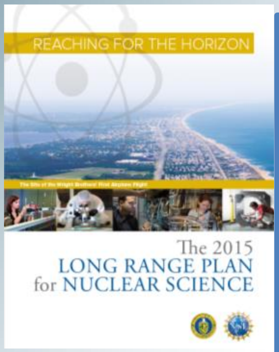


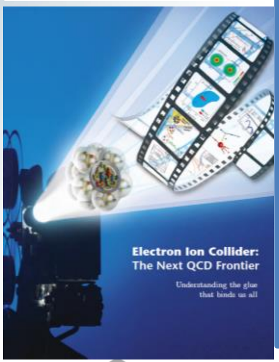
Large Area Picosecond Photo Detectors –LAPPDs

Where can it be used?

Applications: NP, HEP and others

- Nuclear physics applications such as Electron Ion Collider (**EIC**), Neutrinoless double-beta decay (**NuDoT**)
- Deep Underground Neutrino Experiment (**DUNE**),
- Accelerator Neutrino Neutron Interaction Experiment (**ANNIE**) and (**WATCHMAN)**
- Medical imaging: **PET** scanning, proton therapy beam targeting



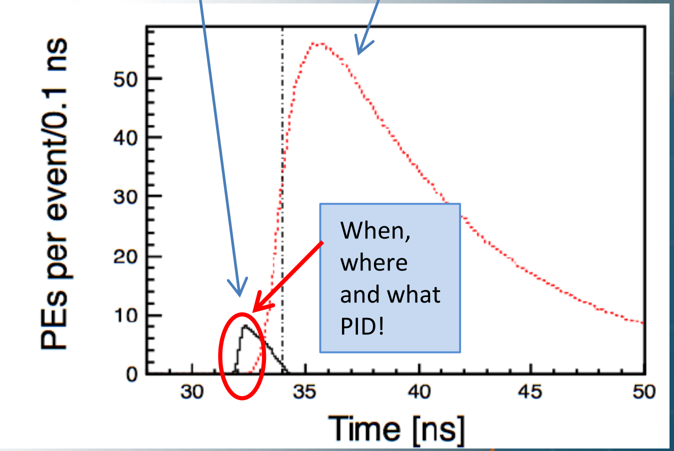


Electron Ion Collider

- The world's first Electron Ion Collider (EIC) has been **recommended** in the **2015 Long Range Plan for Nuclear Science** as the **highest priority** for a new facility construction in US. (**BNL w/ TJNAF**)
- **Excellent particle identification** (PID) ($e/\pi/K/p$) over a wide range of momentum is essential for the proposed measurements, requiring low cost large area Multi-channel Plate (MCP) type **detector with high time and spatial resolution, high rate capability, radiation tolerance and magnetic field tolerance.**
- **Incom, Inc.**, the industrial partner of LAPPD collaboration, has **successfully commercialized the production of LAPPD™**, making it possible to construct EIC PID sub-systems with LAPPD™.

- Prompt, brief **Cherenkov** light.
- Requires:
  - Fast timing
  - High gain

scintillation light



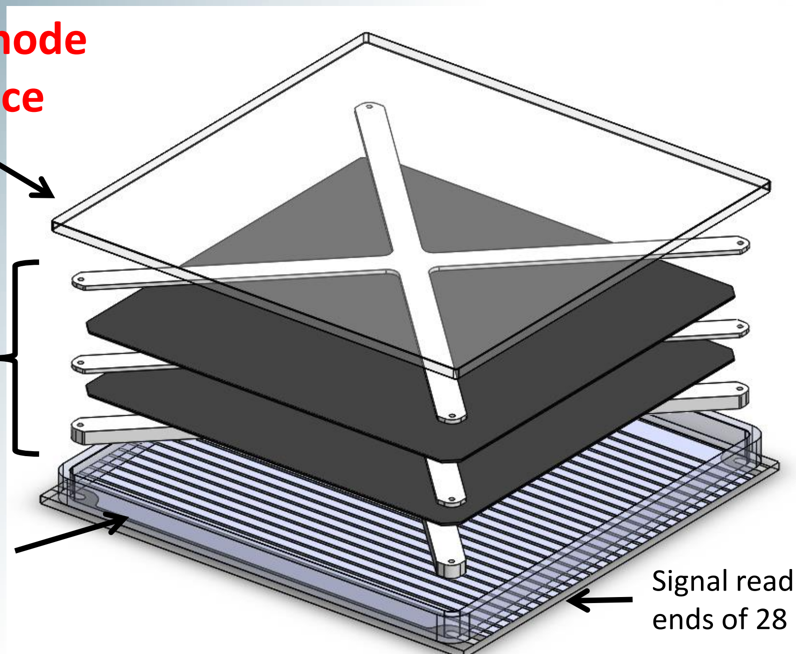
References from:
ANNIE (M. Wetstein),
WATCHMAN (M. Malek),
NuDot (J. Gruszko, L. Winslow)
JINST 9 (2014) P06012

LAPPD Design – **How does it work?**

Fused silica window with **photocathode on inside surface**

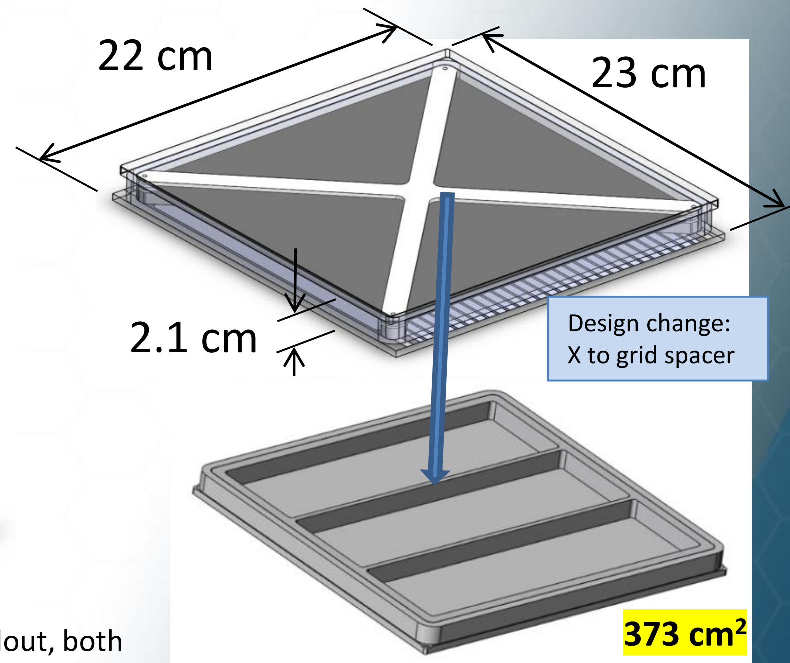
20 cm x 20 cm **MCPs**, spacers

Strip line anode and sidewall

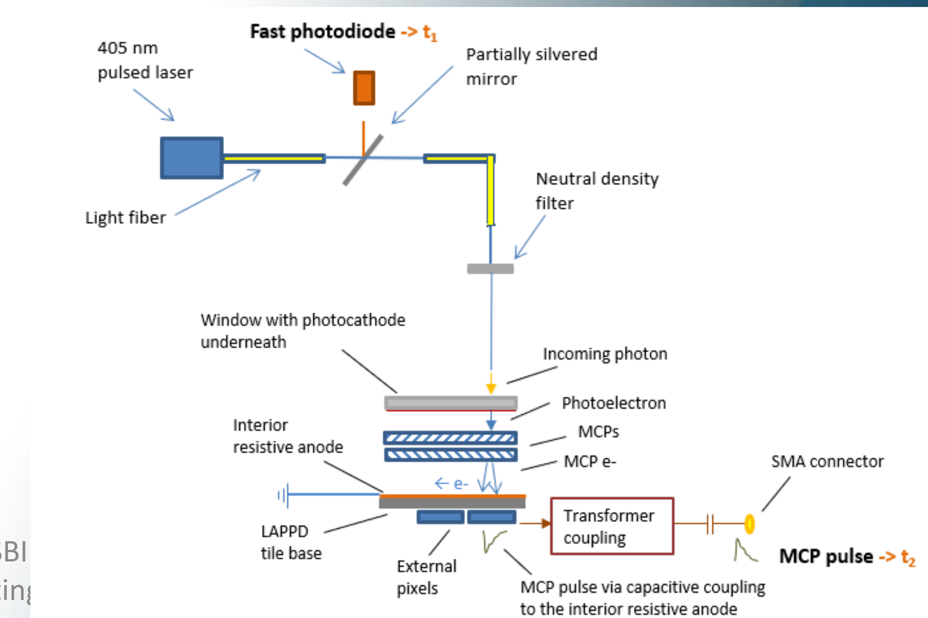


Signal readout, both ends of 28 strip lines

Voltage tab at each corner to **independently power MCPs**



- Signal and high voltage delivered on strips passing under a frit bond.
- **No wall or anode penetrations**.
- **Active area: 193 x 193mm**
  - **350 cm^2**
  - 92% active area



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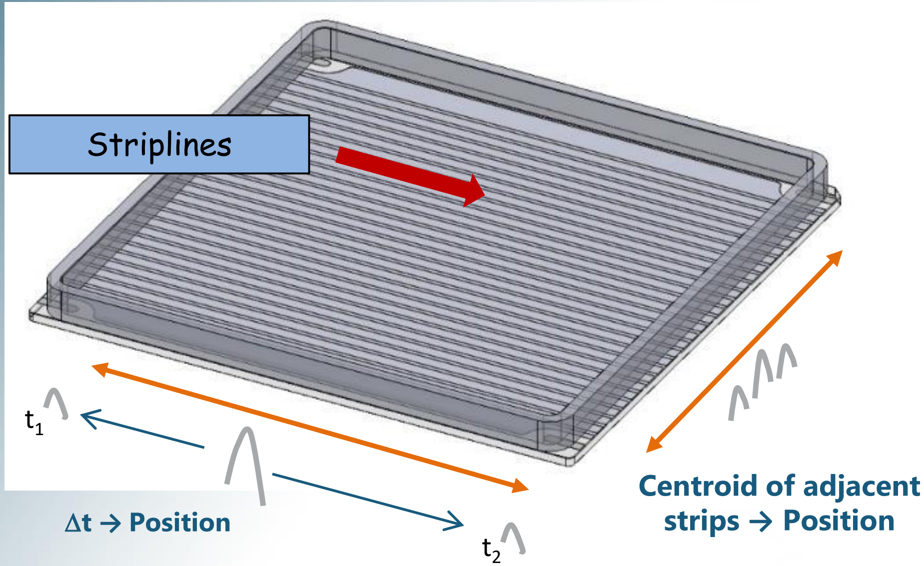
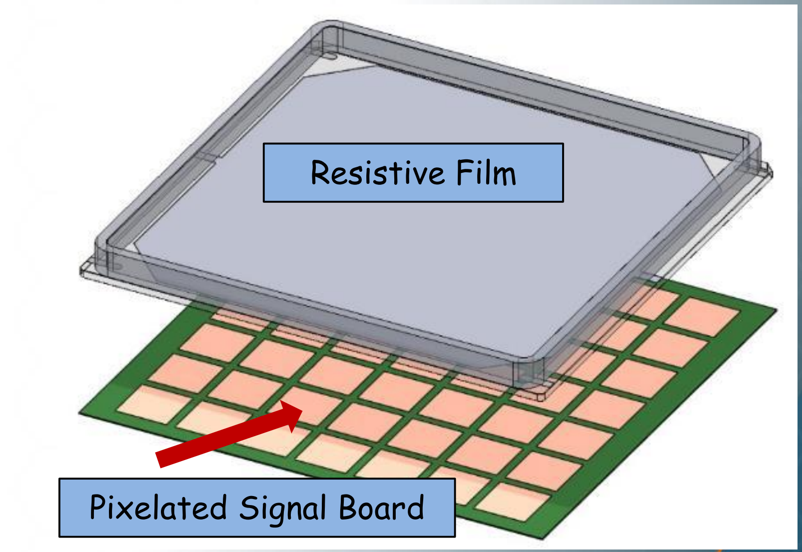
Gen-I vs Gen-II LAPPD™ Design

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

- **On going research: 10 cm device with 10 µm MCPs**
- **Made and tested an unsealed prototype (Ph II has started)**

Phase IIA Program Objectives

1. **Optimize Capacitively Coupled (Gen-II) tile design/window seal/component stack.**
    1. Developed both a **Baseline Glass** and an **Experimental Ceramic** Lower Tile Assembly
        1. Glass has a 5 mm thick anode
        2. Ceramic can have a 2 mm anode (allows for a **stronger coupling** between Resistive Film and **small** pixels)
2. **Expand Measurement and Test capabilities**
    1. Two Identical Dark Box test Stations and a Pre-Test Chamber in clean room used prior to Sealing process
    2. Life testing is outsourced with Collaborator UTexas Arlington
        1. Data from 2 LAPPDs with extracted charge to 5 C/cm^2 to date, **more to come**
3. **Beamline Tests at Fermilab**
    1. UChicago (User Facility), BNL (EIC) (ANNIE as well)
4. **Business Development and Commercialization: 109 LAPPD starts total**
    1. **Capacitively Coupled Only**
        1. 31 starts (20 ceramic, 11 Glass) over the entire Program
            1. **25 in Ph IIA**
        2. **Domestic and Europe:** Sold (4), rented (1), loaned (5)
        3. Two new PO's issued for Gen IIs (eventually at CERN)

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Challenges/Struggles

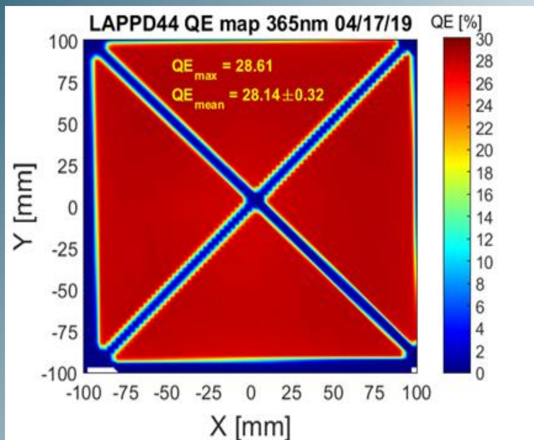
- **Research**
  - **Ceramic to Glass Seal**
    - metallization (sidewall/window)
    - CTE mismatch between ceramic and fused silica windows
  - **Glass vs Ceramic LTA**
    - More fabrication experience (glass) vs. Tougher, stronger (ceramic)
    - Frit (anode/sidewall) and window/sidewall seals
  - **Uniform and Stable Resistive anode**
    - Thin layer can oxidize
    - Signal strength & timing = f (anode material and thickness)
- **Exercise process**
  - **Pilot Production Yield (costs)**
    - Stack up tolerances and geometric dimensions
    - Alloy spill over
    - Noise (dark rate) = PC degradation
    - Internal component noise
    - I&S Tank issues
  - **Performance**
    - Incom's Measurement & Test Methodology
      - Update/expand test equipment
      - Report Format
      - Modeling

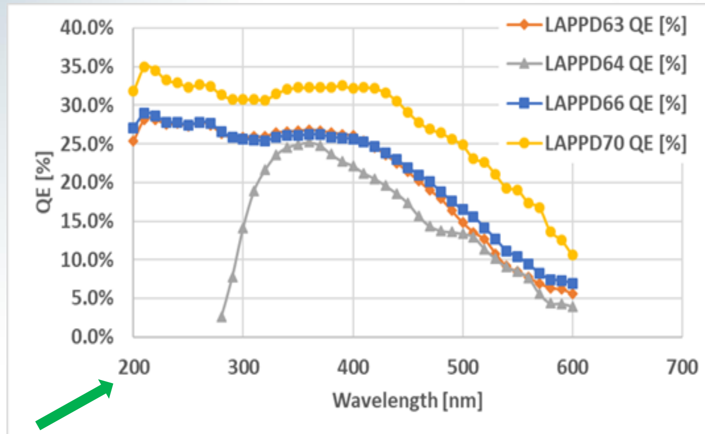
Constant Feedback

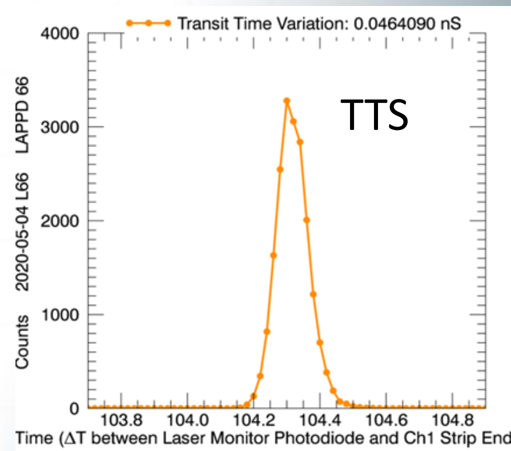
Feedback & validation

- **Work with Collaborators** (influence our design)
  - Validate test data, life testing, SPE & high fluence tests, vs competition (e.g. Ma-PMTs), etc.
- **Commercialize (data exchange with loaners, new lease program, actual Sales!)**

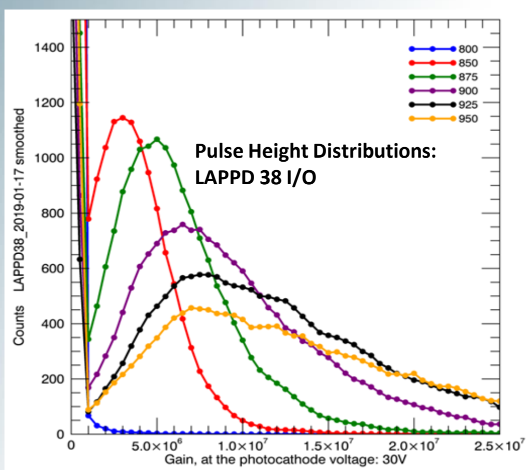
Key Performance Takeaways

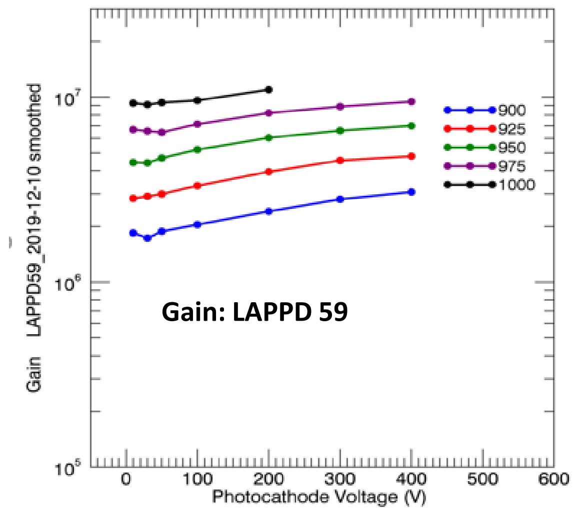


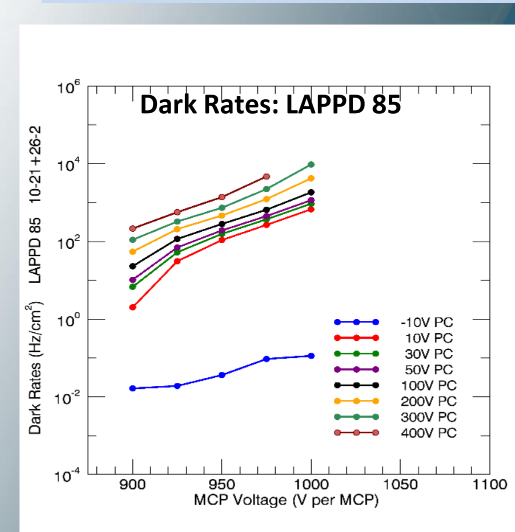




LAPPD 66, 46 ps multiple P/E Capacitively-coupled





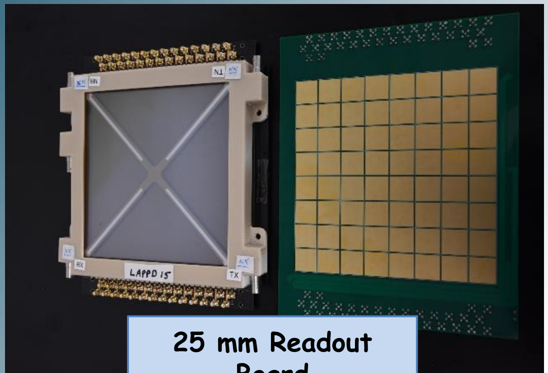


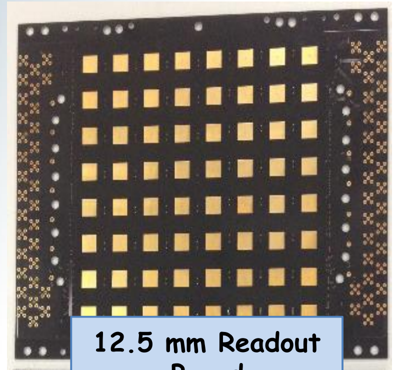
Spatial resolution is in the mm and even sub mm range **(0.6 mm for Gen II)**

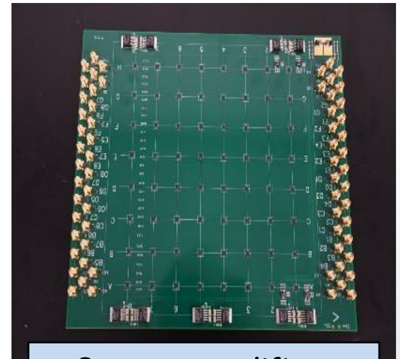
Dark rates are ~10^3 Hz/cm^2 in the mid-10^6 gain range.

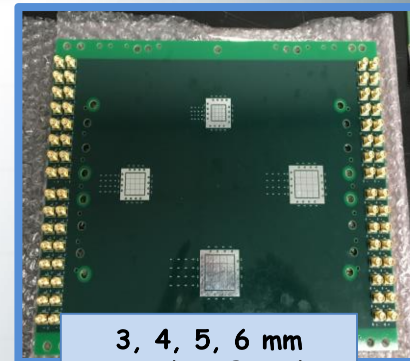
INCOM BRIGHT IDEAS

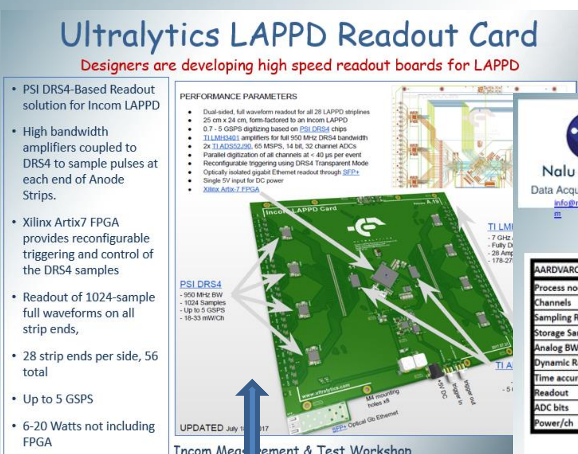
Electronics and Readout Cards - Collaboration w/Incom


25 mm Readout Board


12.5 mm Readout Board


Bottom – amplifiers


3, 4, 5, 6 mm Readout Board



Ultralytics LAPPD Readout Card

Designers are developing high speed readout boards for LAPPD

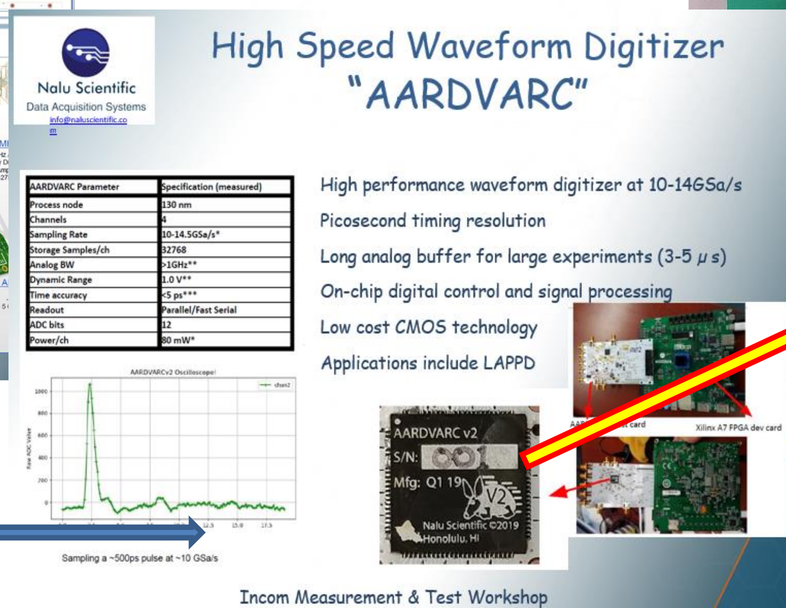
- PSI DRS4-Based Readout solution for Incom LAPPD
- High bandwidth amplifiers coupled to DRS4 to sample pulses at each end of Anode Strips.
- Xilinx Artix7 FPGA provides reconfigurable triggering and control of the DRS4 samples
- Readout of 1024-sample full waveforms on all strip ends,
- 28 strip ends per side, 56 total
- Up to 5 GSPS
- 6-20 Watts not including FPGA

PERFORMANCE PARAMETERS

- Dual-sided, full waveform readout for all 28 LAPPD striplines
- 25 cm x 24 cm, form-factored to an Incom LAPPD
- 0.7 - 5 GSPS digitizing based on PSI DRS4 chips
- TI LMH3401 amplifiers for full 950 MHz DRS4 bandwidth
- 2x TI ADS52J90, 65 MSPS, 14 bit, 32 channel ADCs
- Parallel digitization of all channels at < 40 µs per event
- Reconfigurable triggering using DRS4 Transparent Mode
- Optically isolated gigabit Ethernet readout through SFP+
- Single 5V input for DC power
- Xilinx Artix-7 FPGA

Incom Measurement & Test Workshop

Only ONE Data Cable



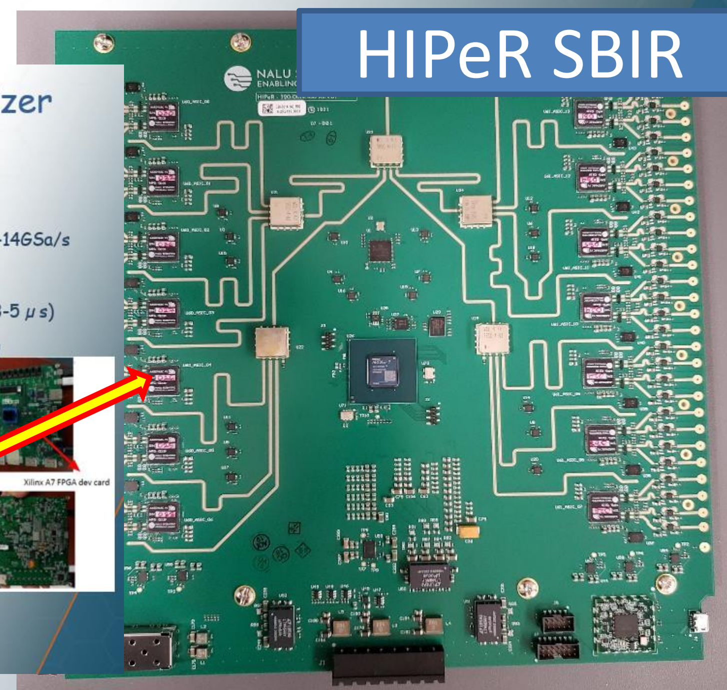
Nalu Scientific
Data Acquisition Systems
info@naluscientific.com

High Speed Waveform Digitizer "AARDVARC"

AARDVARC Parameter	Specification (measured)
Process node	130 nm
Channels	4
Sampling Rate	10-14.5GSa/s*
Storage Samples/ch	32768
Analog BW	>1GHz**
Dynamic Range	1.0 V**
Time accuracy	<5 ps***
Readout	Parallel/Fast Serial
ADC bits	12
Power/ch	80 mW*

- High performance waveform digitizer at 10-14GSa/s
- Picosecond timing resolution
- Long analog buffer for large experiments (3-5 μs)
- On-chip digital control and signal processing
- Low cost CMOS technology
- Applications include LAPPD

Incom Measurement & Test Workshop



HIPeR SBIR

Alphacore and **Pacific Microchip** working on chips as well

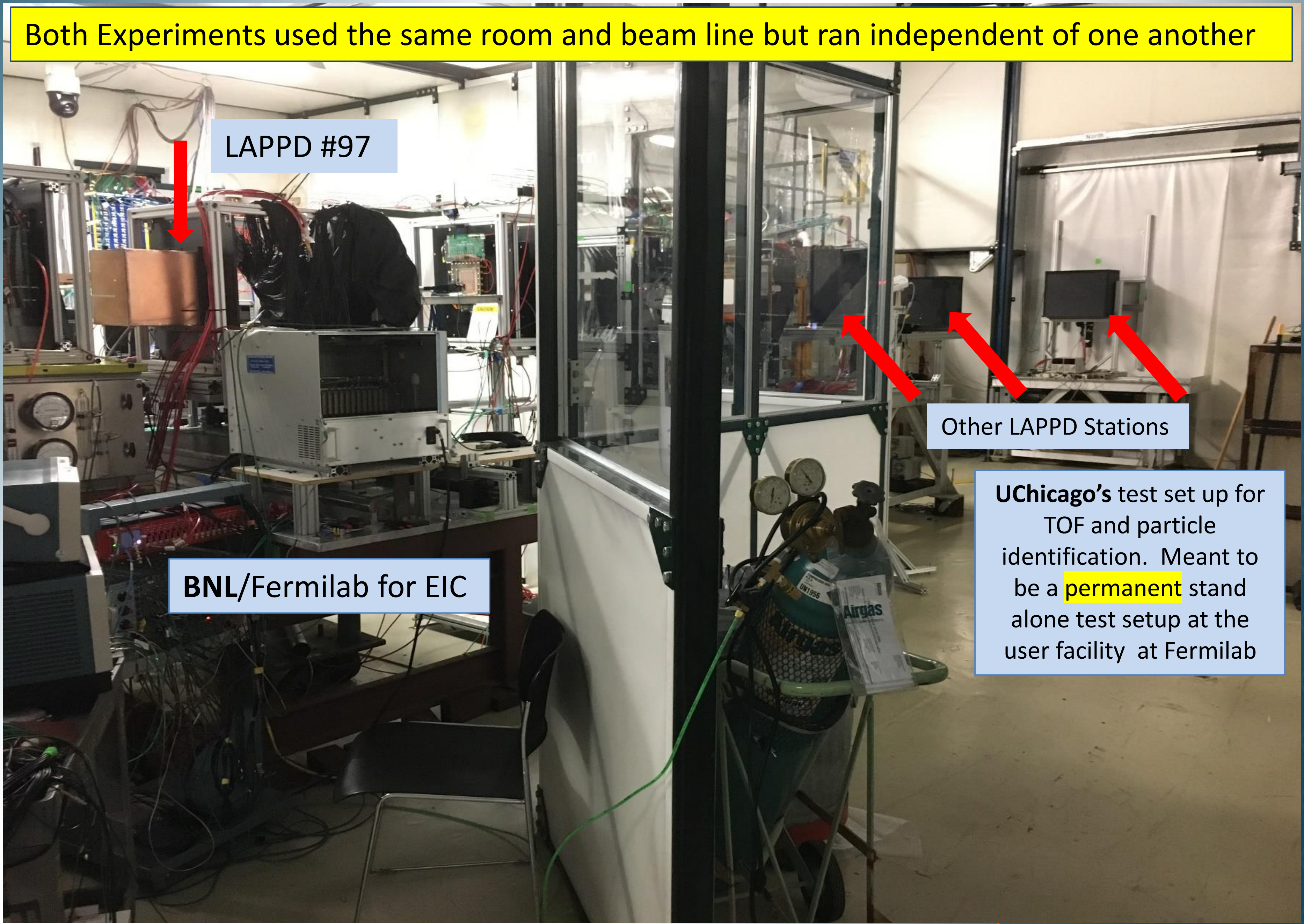
Capacitively Coupled (Gen II) LAPPDs installed in beam lines

Programs	Affiliations	LAPPDs	Status
Fermilab Test Beam Facility	**UChicago, Fermilab Frisch, & now TBD**	**36*, 42, 51, 86, (45**)** ***36 - first part tested at UC** ****45 – damage in set up**	Demonstrate achievable LAPPD TOF resolution and particle identification in a working beamline setting. Evan Angelico PhD Thesis
	Waiting on new Staff at Fermilab		
SoLID (Solenoidal Large Intensity Device)	**ANL, TJNAF Z.-E. Meziani, J. Xie, S. Malace**	**(41), 38**	#38 has been to UTA, Cath Univ., Temple (wavelength shifter coating), TJNAF, back to Incom and now at TJNAF again (see below)
	SPE tests		
FY22 TJNAF Lab Directed R&D Proposal	**TJNAF S. Malace**	**38/new LAPPD**	Assessing the performance of LAPPD 38 and of a new LAPPD for the **next generation** of detectors.
	SPE tests		
EIC PID - eRD14	**BNL, ANL, TJNAF, Stony Brook, FL A&M U**	**66, 97**	tested 66 at BNL, 97 at Fermilab and now back at BNL. Tested multiple signal boards and range of small pixel sizes.
	SPE tests		
i-MCPs for ECAL upgrade II (CERN LHCb)	**Vincenzo Vagnoni INFN, DESY Sezione di Bologna**	**(69), 87**	Tested # 69 (Gen I) first, then #87 at INFN, then DESY
	High fluence tests	**PO's issued for more Gen IIs** **UEdinburgh and Jozef Institute** **Both intended for CERN work**	**charge-replenishment time** at high rates is a limiting factor: need a **10 µm MCP tile**
Neutron Beam Line testing	**Los Alamos National Laboratory**	**85**	Light box on its way, good on cables, **fire up next month**, develop a **position sensitive energy resolve neutron beam diagnostic** for radioactive isotope R&D

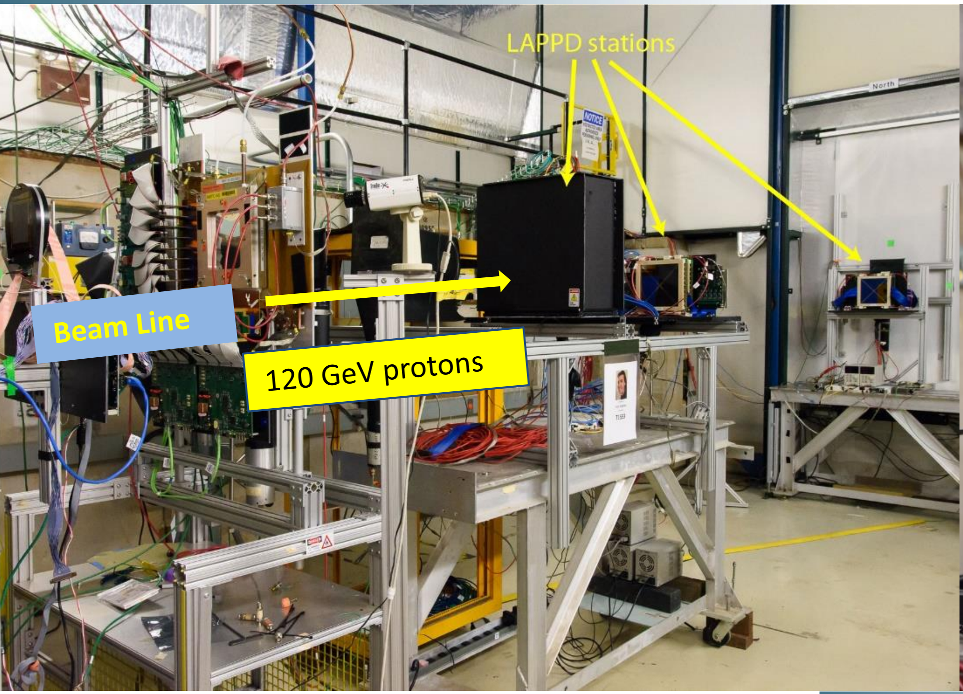
INCOM BRIGHT IDEAS

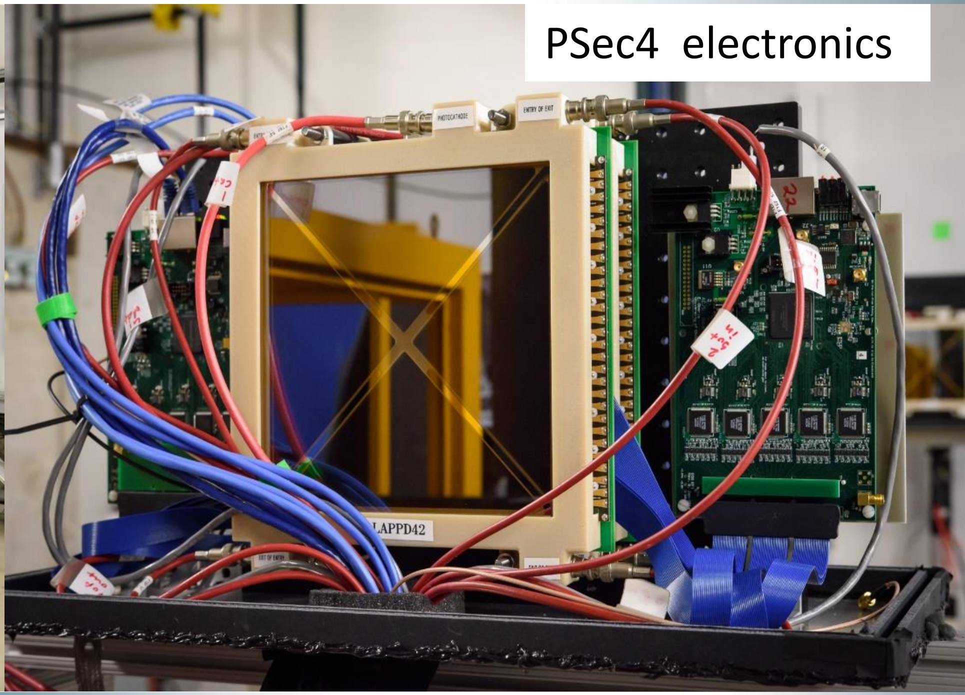
11 Capacitively Coupled Gen-II LAPPDs have been sold or loaned since 10/16/2018	**18 Stripline Gen-I LAPPDs** have been sold or loaned since 10/10/2017

BNL/UChicago LAPPDs installed @ Fermilab Test Beam

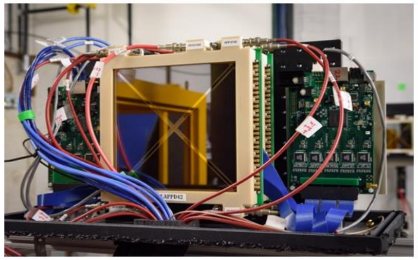


UChicago LAPPDs installed @ Fermilab Test Beam





Development of Large-Area MCP-PMT Photodetectors for a Precision Time-of-Flight System at the Fermilab Test Beam Facility



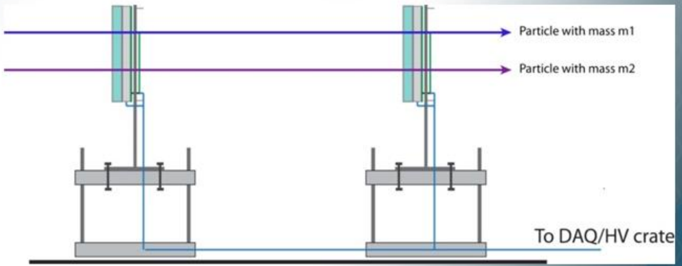
EVAN ANGELICO, PhD Defense, June 1, 2020

INCOM
BRIGHT IDEAS

2021-08-1

Time-of-flight (TOF)

- Any two detectors that can measure position and time-of-arrival
- Knowledge of separation and time-of-arrival difference implies velocity
- Knowledge of momentum or energy implies mass



$$\Delta t = d/\beta$$

$$\Delta t = d\sqrt{1+\frac{m^2}{p^2}}$$

$$\Delta t = \frac{Ed}{p}$$

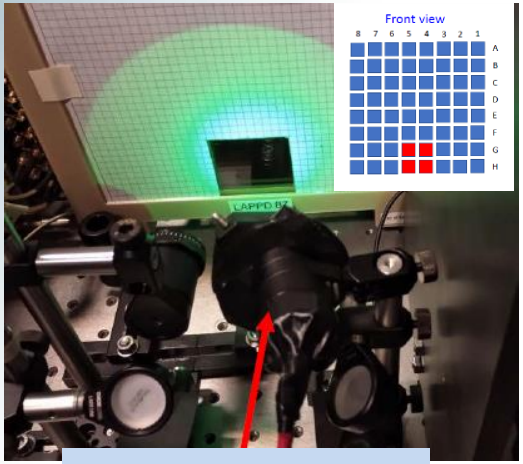
TOF difference between two particles of the same momentum, p >> m

$$\tau_{12} \approx \frac{d}{2p^2}(m_1^2 - m_2^2)$$

INFN/DESY Beam Tests (V. Vagnoni)

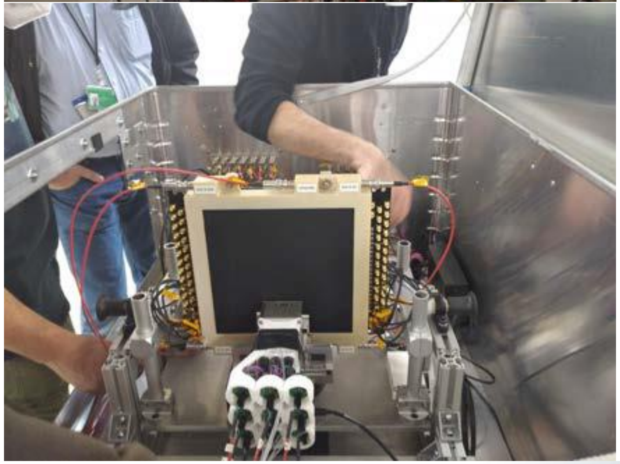
Istituto Nazionale di Fisica Nucleare

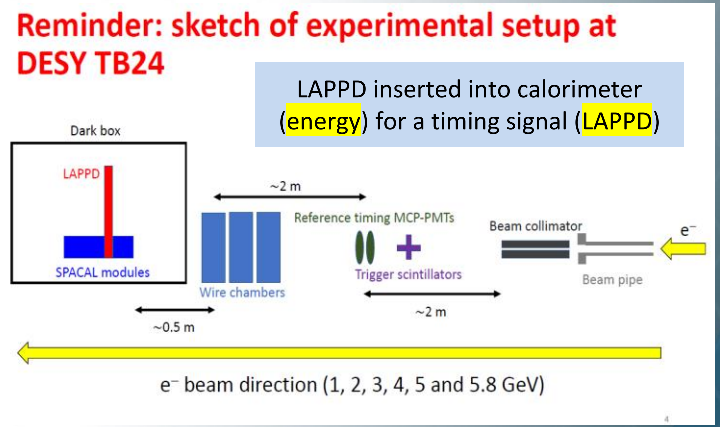
First studies of Gen-II performances at realistic LHCb rates around the beam pipe using laser and LED light at INFN

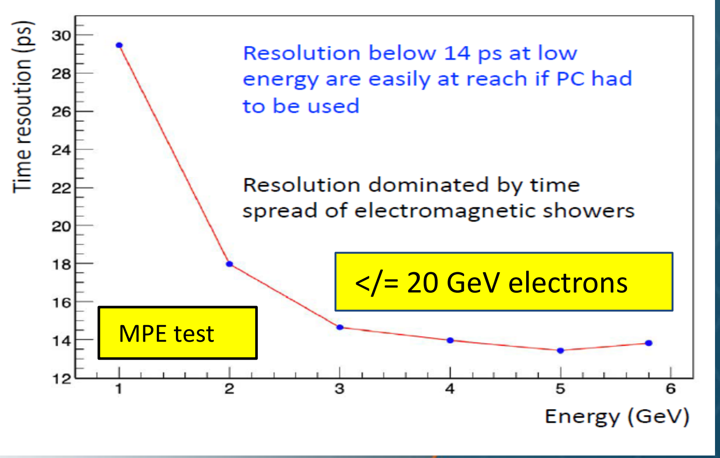


Green-light LED gun

Deutsches Elektronen-Synchrotron DESY





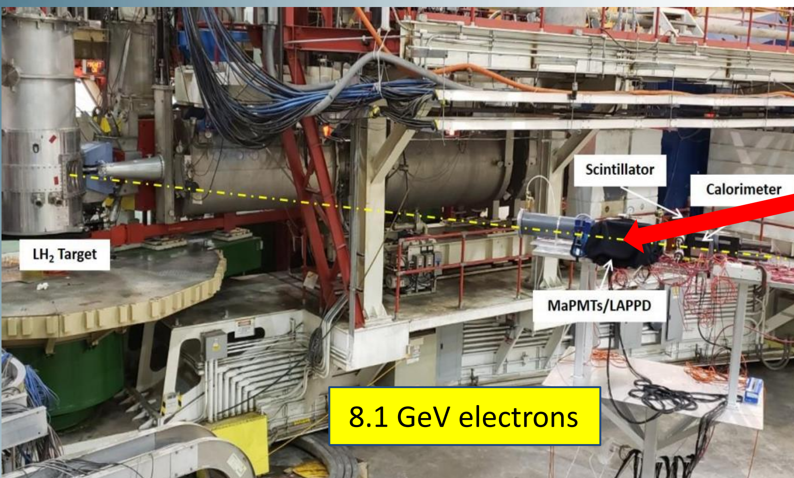


- Performance of Gen-II (#87) very similar to Gen-I (#69)
- Reduced pore size needed, < 20 ps can be reached
- Incom to supply 10 µm MCP – LAPPD in Sept '21
  - for better rate and timing resolution
- Will test high rates at INFN using LED/Laser

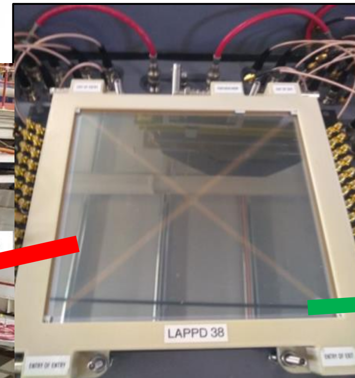
INCOM BRIGHT IDEAS

Beam Testing @ TJNAF

SoLID Preliminary Testing
(J. Xie et. al.)

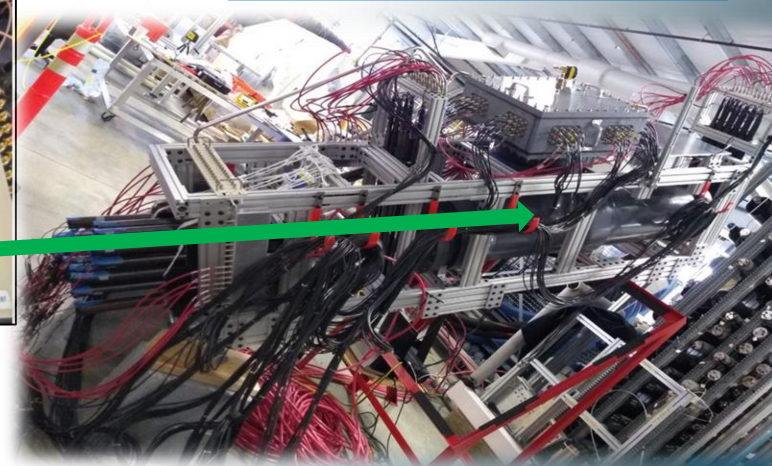


8.1 GeV electrons



#38 @ Hall C

SPE ID R&D of LAPPDs
(S. Malace et. al.)



- Paper and report on #41 (Gen I) and #38 (Gen II). (J. Xie)
- Pixelated is better than stripline
- Need higher 20-25% QE and
- pixels smaller than 25 mm more important for EIC

arXiv.org > physics > arXiv:2011.11769

- Compare LAPPD vs. Ma-PMTs @ $2-3k (5 x 5 cm)
- Need 16 Ma-PMTs vs 1 LAPPD (20 x 20 cm)
- Potential need is up to 60 LAPPDs
- Study reduced spacing (exit MCP and anode) for more localized position measurement
  - e.g. from 6.5 to 3 mm.

Definitive tests on LAPPD to provide a practical, cheaper alternative to PMTs for use in Cherenkov Detectors for Nuclear and High Energy Physics Experiments

Journal of Instrumentation

PAPER

Single photoelectron identification with Incom LAPPD 38

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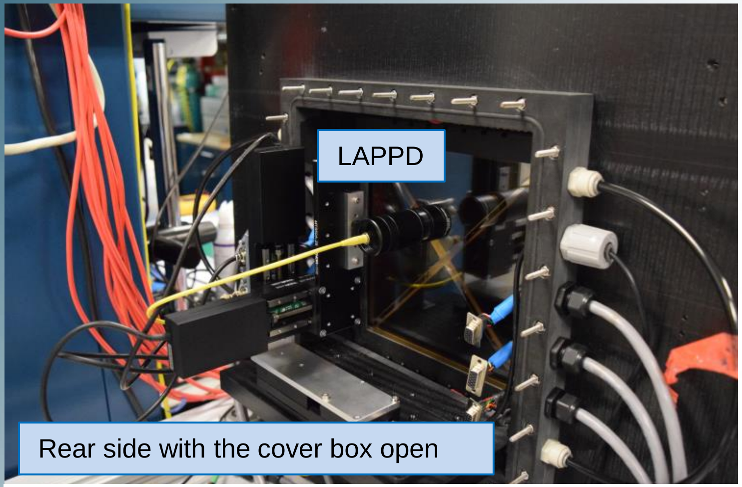
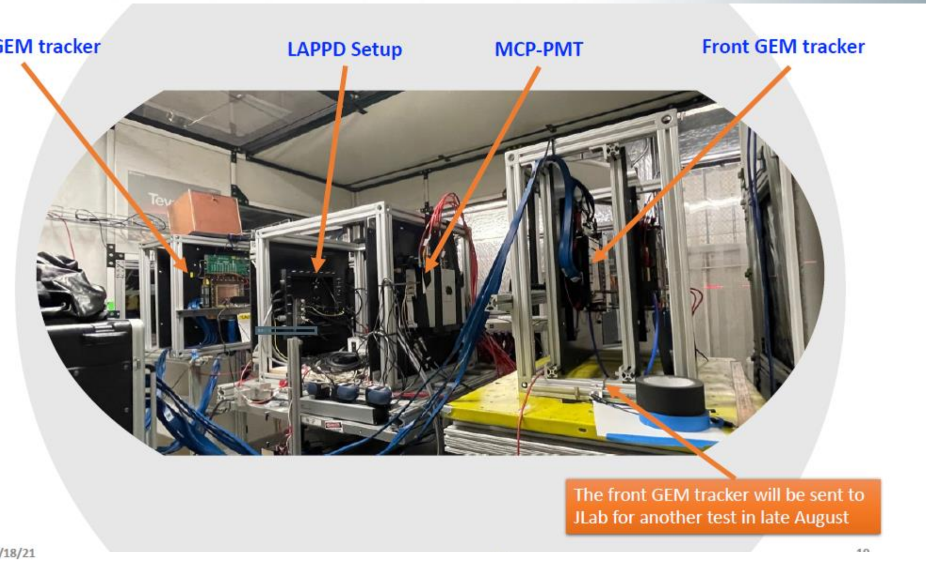
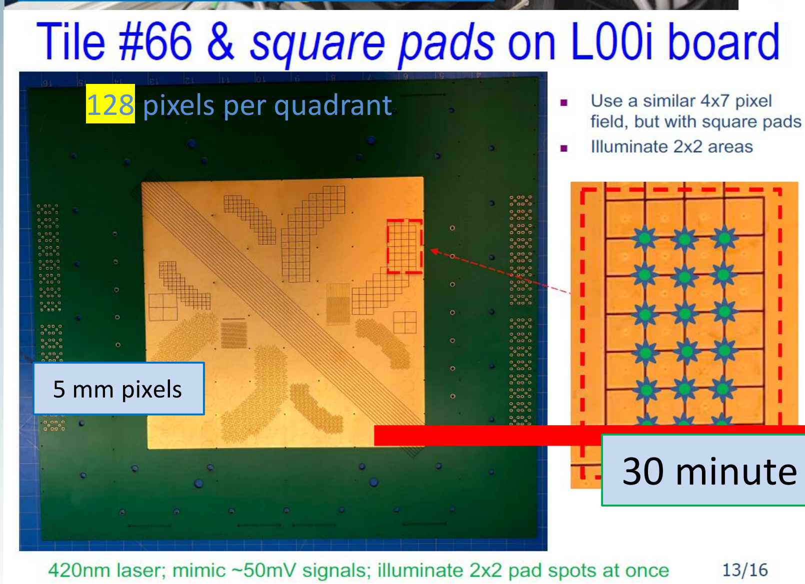
Brookhaven (#66)

BNL/Fermilab Beam tests for EIC (Kiselev et. al.)

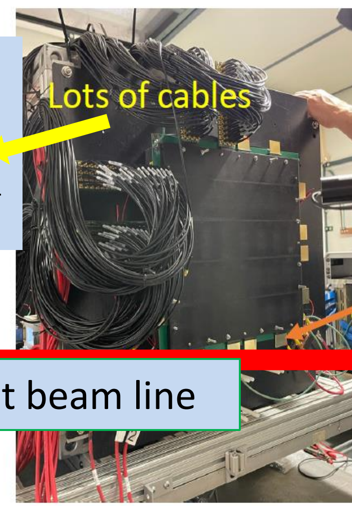
Fermilab (#97)

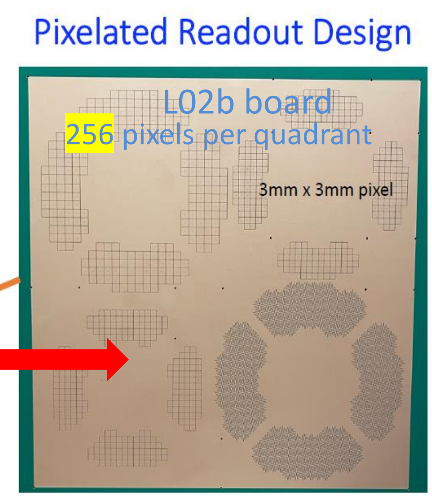






MCX adapters to eight 32-channel V1742 DRS4 digitizers

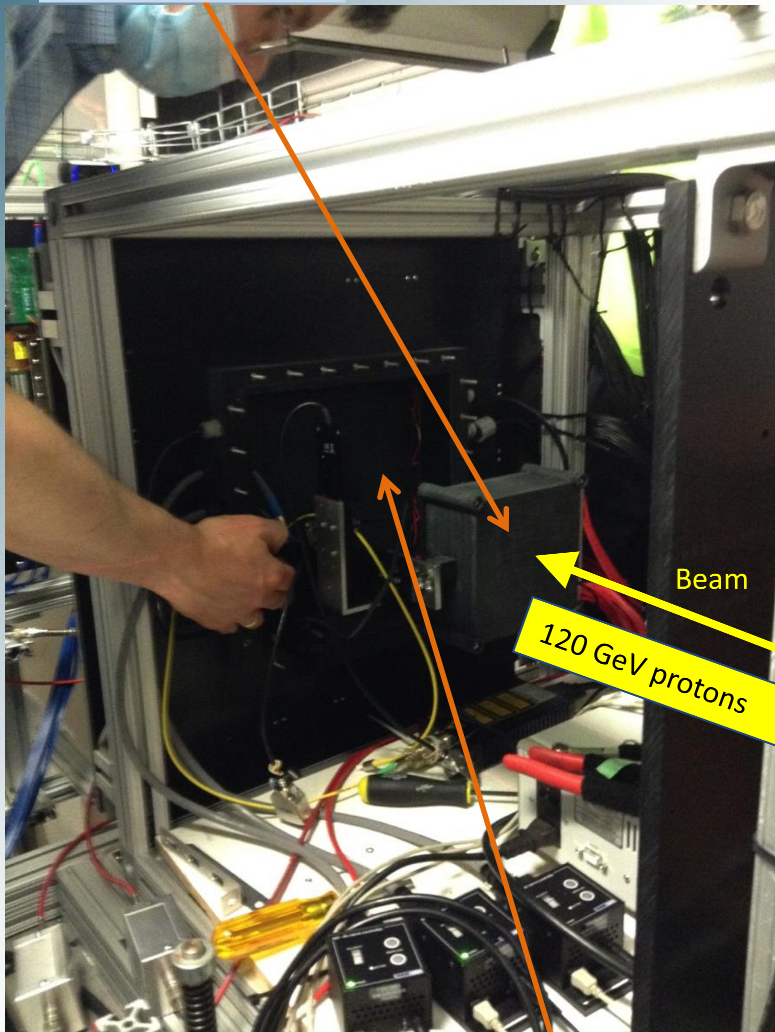


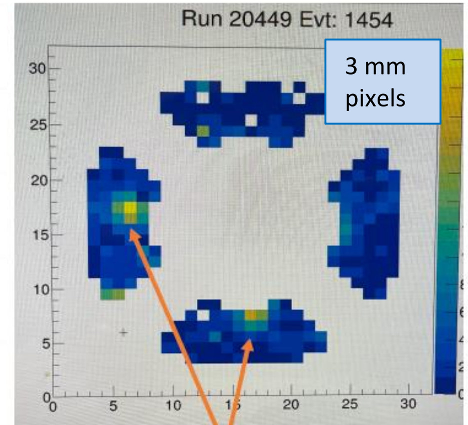


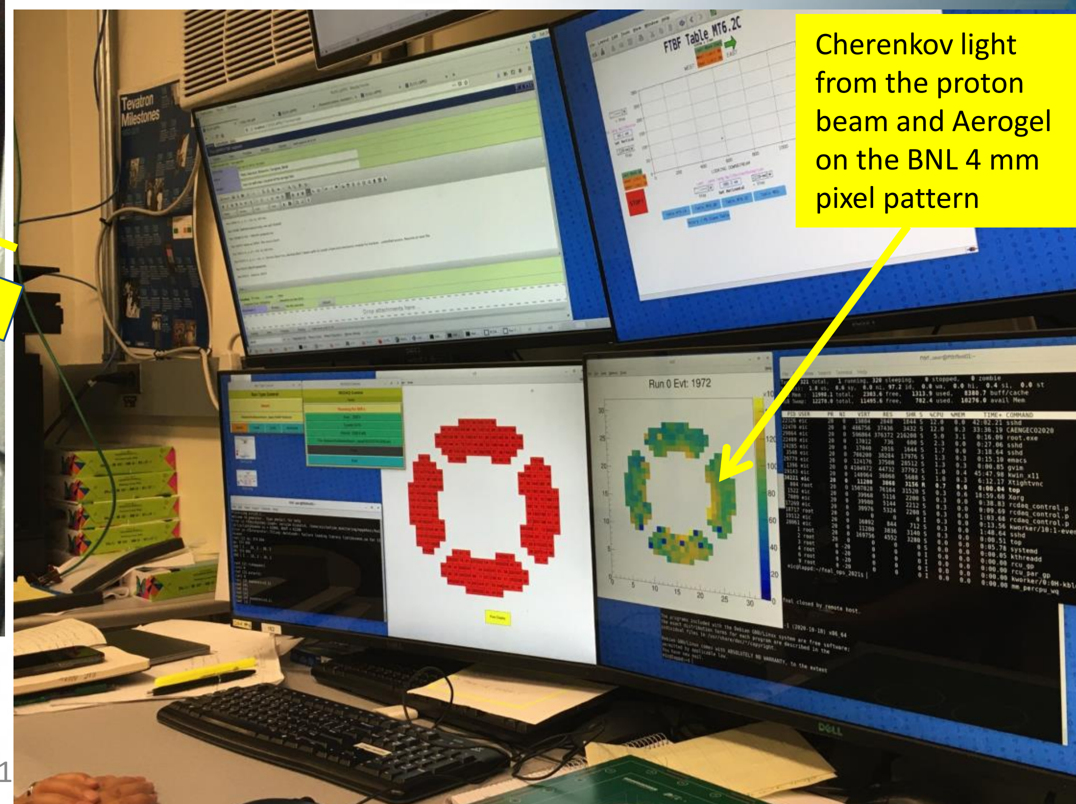
30 minute change at beam line

- We had a first beam test of a LAPPD from Incom, mainly led by BNL team.
- Several photon sources have been used during the test: laser, photons from LAPPD glass window, Aerogel (mRICH like), aspherical lens, for characterizing the LAPPD properly
- Future test of LAPPD will be needed to verify its performance for EIC RICH-based PID detectors

BNL/Fermilab for EIC







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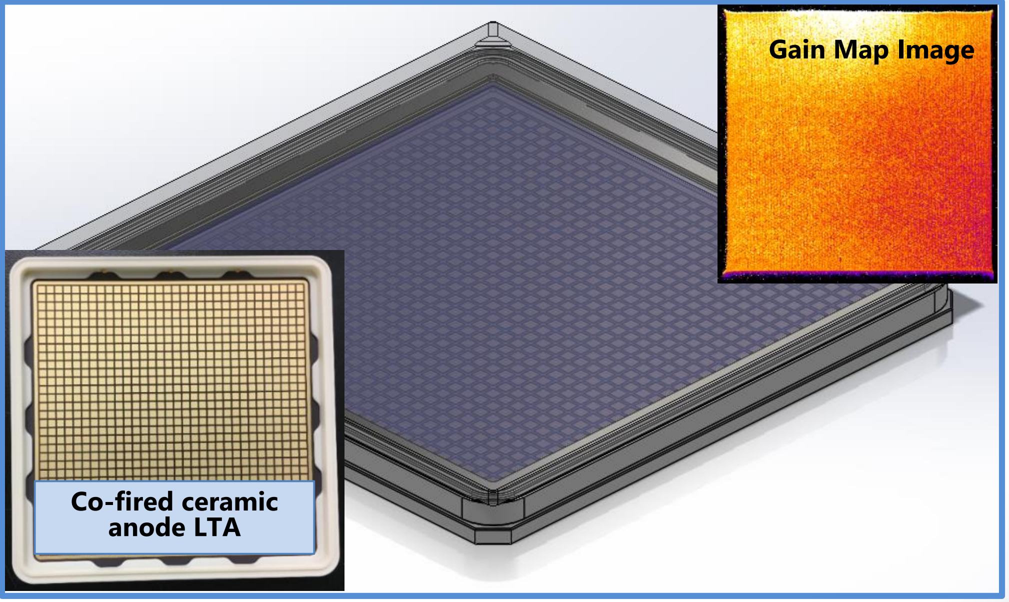
10 cm HRPPD Detector Design

The HRPPD 10 cm detector is the newest development of Incom's large area picosecond photodetectors, incorporating innovations made developing full size GEN I & II LAPPD.

- Taking advantage of the 10 μm pore MCPs for ***better timing*** and B-field tolerance
- Reduced gap spacing for improved ***spatial resolution***, and B-Field tolerance
- An unobstructed FOV (no window support)



Glass (B33) or Ceramic (Al_2O_3) Bodies
Several window options

- Fused Silica, B33, Sapphire, or MgF_2 (115 nm cutoff)
- Unsupported window with no obstruction
- 10 cm × 10 cm field of view

Reduced gap spacing and small pore MCPs (10 μm) for B-field tolerance

- MCP Stack clamped into sidewall
- 1.75 mm PC-MCP (drop face window option to reduce this)
- 50 um between MCPs
- 2 mm MCP-Anode

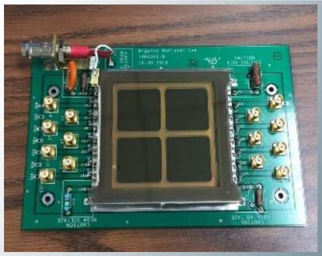
Several readout schemes possible

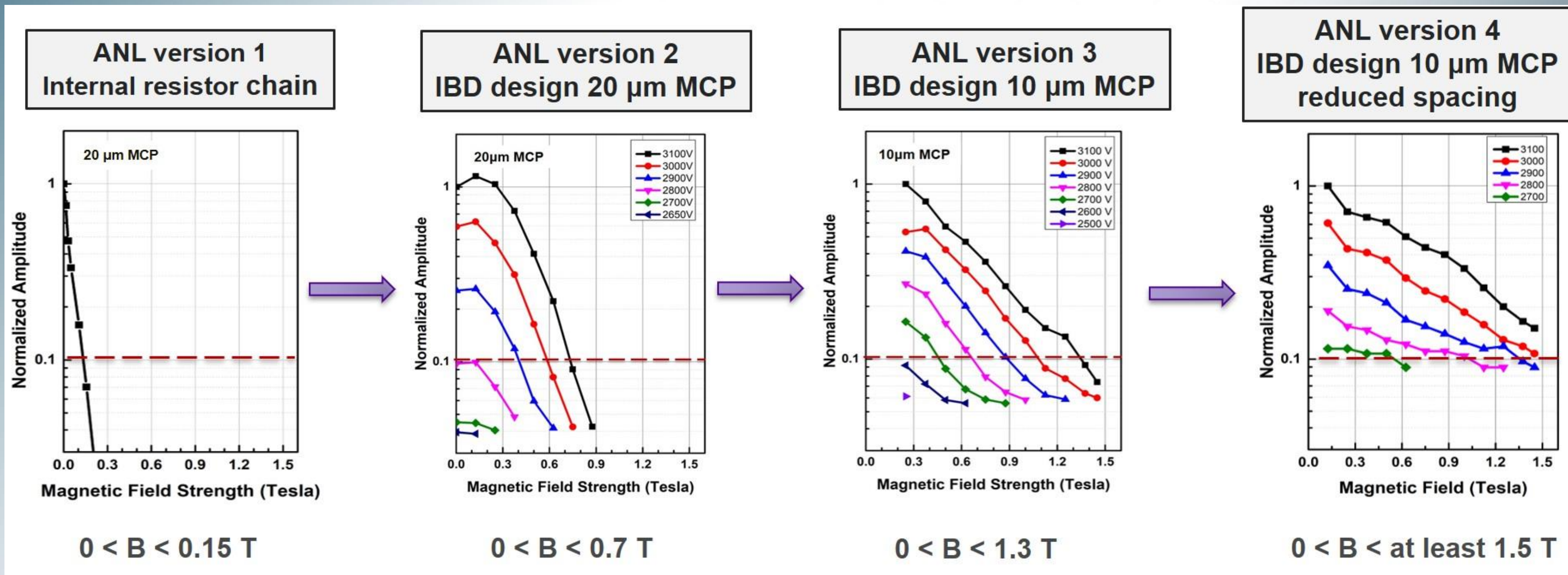
- Gen-I Strip-Line
- Gen-II Capacitive Coupling
- Gen-III Pixelated Cofired Anode

Narrow Sidewall and spacers for reduced dead space in Gen-III Design

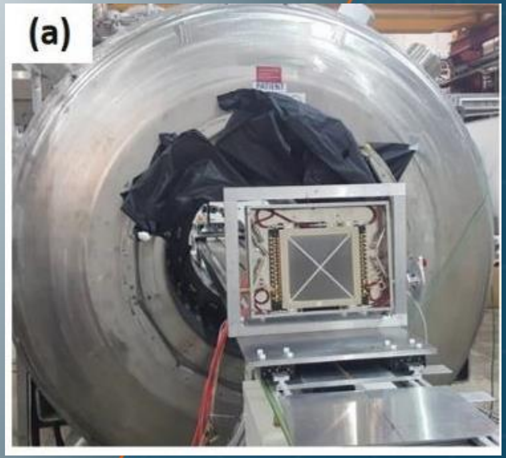
- Dimensions: 142.12 cm2
- Active Area: 103.23 cm2
- HV and anode connections on bottom (4-side abuttable)

IMPROVEMENT OF ARGONNE MCP-PMT PERFORMANCE IN MAGNETIC FIELD (J. XIE, ANL)





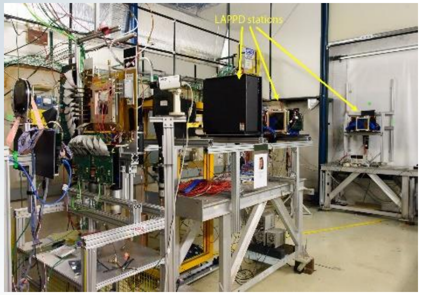
- Optimization of biased voltages: **version 1 -> 2**
- Smaller pore size MCPs: **version 2 -> 3**
- Reduced spacing: **version 3 -> 4**
- Further improvement is needed and testing of:
  - **10 μm MCPs in both LAPPD and 10 cm HRPPD**

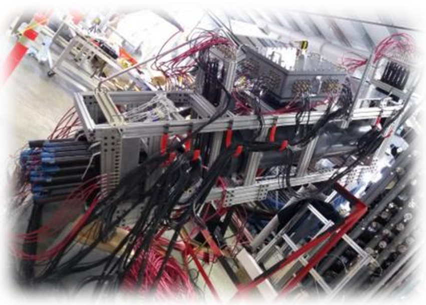


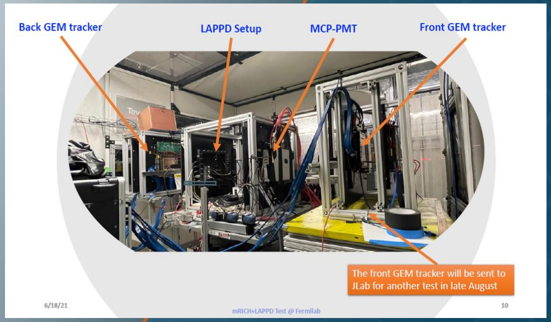
Phase IIA Program Objectives

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 (Home Run!)**
    1. 31 starts (20 ceramic, 11 Glass) over the entire Program
        1. **25 in Ph IIA**
    2. **Domestic and Europe:** Sold (4), rented (1), loaned (5), MUCH INTEREST EVERYWHERE!!!
    3. Two new PO's issued for Gen IIs (eventually at CERN)







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-SC0015267, NP Phase IIA – "Development of Gen-II LAPPD™ Systems For Nuclear Physics Experiments"

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

DOE DE-SC0021437, Phase I : "High Fluence Anode Design" 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-SC0019821 Phase II- Development of Advanced Photocathodes for LAPPDs

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

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Thank you

Contact information: mrf@incomusa.com
www.incomusa.com

Back up Slides

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LAPPD™

LARGE AREA PICOSECOND PHOTODETECTOR

Enabling the vision of tomorrow through experimental scientific discovery.

Incom's LAPPD™ is the world's largest flat panel position sensitive MCP based photodetector with picosecond level timing resolution. The LAPPD™ was developed in partnership with the Department of Energy, Argonne National Labs, and the University of Chicago with the vision to explore the elementary constituents of matter and energy, the interactions between them, and the nature of space and time. After nearly ten years of development, Incom is proud to bring this revolutionary technology to market.

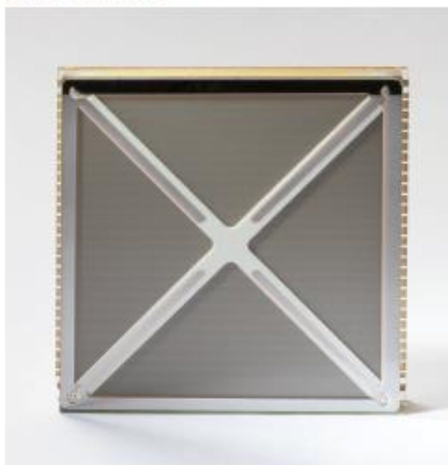
FEATURES

- Large area 200 mm x 200 mm
- Quantum Efficiency > 20% (90% uniformity)
- Chevron pair of 203 mm x 203 mm ALD-GCA-MCP's
- Gain > 1 x 10^7
- Independent control of voltage to the photocathode and MCPs
- High temporal resolution
- 1mm Spatial resolution
- Dark count rate less than 150 Hz/s/Cm^2

APPLICATIONS

- High energy physics
- Nuclear physics
- Medical imaging
- Proton Beam therapy
- X- Ray imaging,
- PET
- Neutron detection
- Neutrino interaction

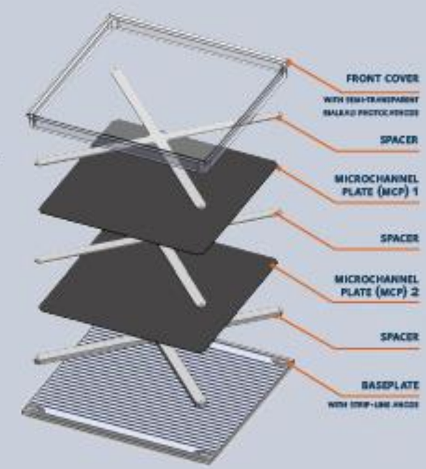
20 CM SQUARE LAPPD™



508-909-2200 / incomusa.com / sales@incomusa.com

A CLOSER LOOK

Incom's tillable 20 cm square LAPPD™ is seen in this exploded view. This revolutionary detector utilizes Incom's proprietary microchannel plate technology in a chevron pair.



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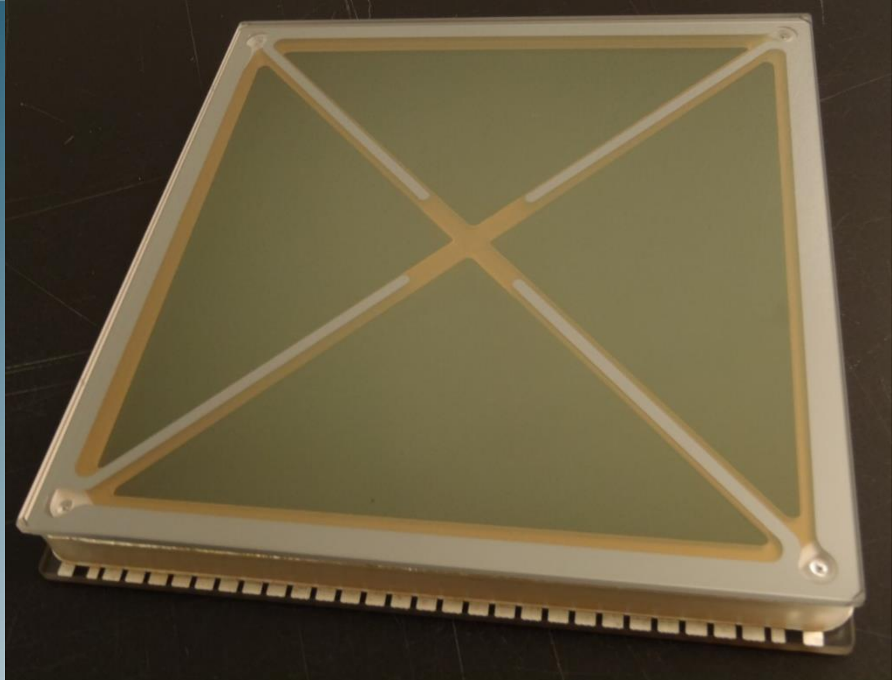
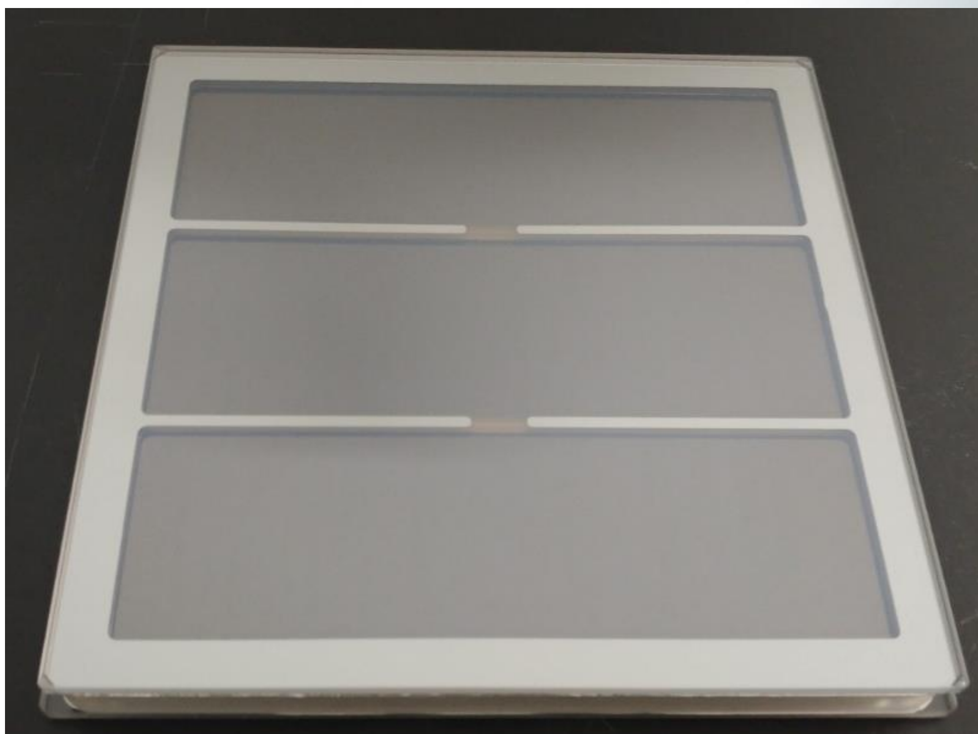
LAPPD^{TM} Availability

1) Baseline LAPPDs (both Capacitively Coupled and Stripline Version) are being produced routinely in our Pilot Production Facility
   a) In 2020, production was slowed by Pandemic.
   b) Incom is committed to increasing throughput and future scale-up
      a) **Present capacity is 3 LAPPDs/month – plans to increase by late 2021**.
      b) **Two new hires dedicated to LAPPDs**
      c) **Capacity can be rapidly and significantly increased when full production is implemented.**
2) Prototypes are available for **rent or purchase** by customers that wish to qualify LAPPD for their applications.
   a) Minimum renewable term per month: (mrf@incomusa.com)
   b) Qualified prospects that don't presently have a budget or the ability to either rent or purchase an LAPPD, may qualify for special negotiated terms.
3) Incom Inc. hosts quarterly **Measurement & Test Workshops**
   a) familiarize potential users with the LAPPD,
   b) facilitate direct participation with the Incom team,
   c) hands on, characterizing an LAPPD,
   d) no cost early LAPPD access to large numbers of early adopters.

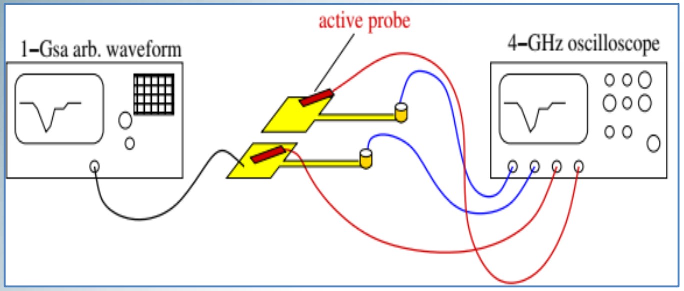




Crosstalk simulation & measurement

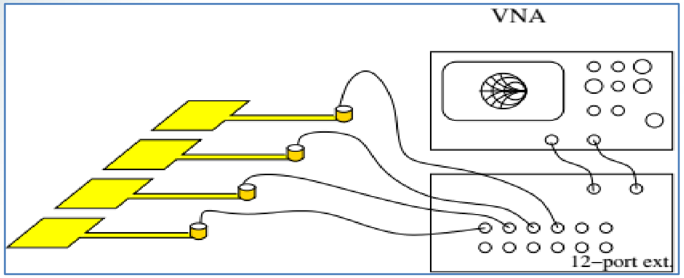
- Simulate and verify experimentally to understand cross-talk and its role in interpolation for spatial resolution (also improve time res.)
- Vary parameters and simulate to find optimum pixel configuration

measurement in time domain

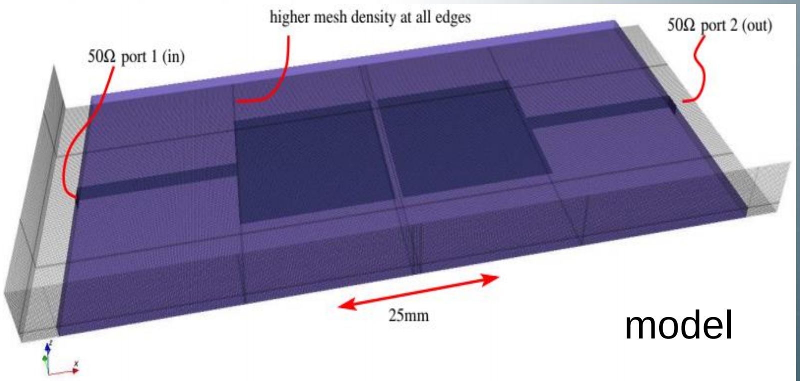


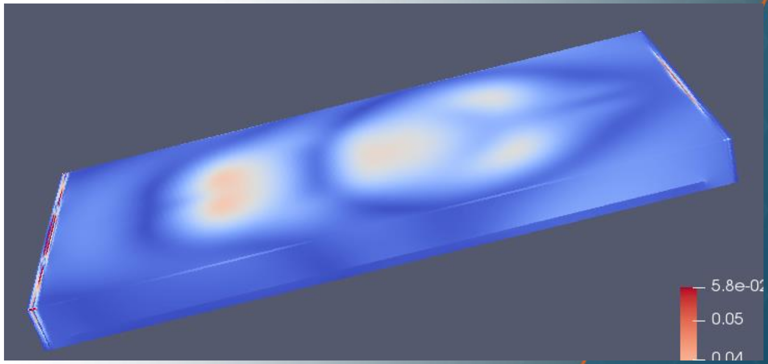
Replicates pulses acquired in LAPPD operation

measurement in frequency domain



Gives insights into origin of coupling





Visualization of E-field helps design pad structure

Simulation results should agree with both TD and FD measurements

LAPPD Applications

PROGRAM	AFFILIATIONS	2020 – 2021 STATUS
ANNIE - Atmospheric Neutrino Neutron Interaction Experiment	Iowa State	**Five LAPPDs** delivered;
Neutron Imaging Camera, Nanoguide scintillating polymer	Sandia National Lab (CA), U of Hawaii	LAPPD #22 being evaluated
Fermilab Test Beam Facility, IOTA KOTO	U of Chicago, Fermilab	Demonstrate achievable LAPPD TOF resolution and particle identification in a working beamline setting **(3 delivered including Gen II) plus another**
WATCHMAN, UK STFC	U. of Sheffield, The University of Edinburgh	**Two-Three LAPPDs planned** for 2020 delivery
CHESS, WATCHMAN, THEIA	Lawrence Berkeley National Laboratory	LAPPD under evaluation Possible tile upgrade in 2020
SoLID (Solenoidal Large Intensity Device)	ANL, J-LABS	**Gen II LAPPD #38** for testing at J-Labs Delayed due to COVID19 **RESTARTING**
Neutrino-less Double-Beta Decay	U of Chicago	TBD
EIC PID - eRD14	BNL, ANL, J-LABS, Stony Brook, INFN	FermiLab Beamline Trials delayed due to COVID19, **Gen II LAPPD waiting to ship**
CERN LHCb RICH phase-2 upgrade	The U. of Edinburgh, U. of Ferrara & INFN	CERN LHCb RICH phase-2 upgrade
i-MCPs for ECAL upgrade II (CERN LHCb)	Vincenzo Vagnoni INFN, Sezione di Bologna	Testing of MCP and **LAPPD #69** for precision timing of electromagnetic showers in a calorimeter.
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)**
LAPPD Femtosecond Timing Trials	PicoRad Imaging, MA., & MGH - Harvard	TTS timing trials underway 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 **Planned September delivery**
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.
Life Testing of LAPPD, Role of ion feedback.	UT Arlington	**Life Testing LAPPD #64 underway**
Neutron Beam Line testing	Los Alamos National Laboratory	**GEN II LAPPD** planned September delivery