Development of Gen II LAPPD™
(Large Area Picosecond Photo Detector)
Systems for Nuclear Physics
(DE-SC0015267)

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2019 Nuclear Physics SBIR/STTR Exchange Meeting
Gaithersburg, MD
Gen II LAPPD™ Year 2 Review

• Incom background
• Where we were a year ago and challenges
• Ceramic Seal success for Gen I and Gen II style
  • LAPPD Yield
    • Incom
    • UChicago
• Incom LAPPD performance results
• UChicago collaboration
  • Fermilab LAPPD tests
• Summary, conclusions and Ph IIA plans
  • Early Adopters
    • UTexas Arlington (#38 Gen II)
    • JLab (#41 – CLTA Gen I)
Incom Inc. – Enabling the Vision of Tomorrow

Founded 1971 (Fused Fiber Optics)
Long history of Innovation
~220 Employees
Three facilities:
  Incom East (2) - Charlton, MA
  (includes R&D Pilot Production Facility)
  Incom West - Vancouver, WA
Medical
- Digital X-Ray systems
- Mammography
- Panoramic and Intra-oral X-Ray
- DNA sequencing
- Filtration

Display
- Gaming
- Automotive
- Audio/Video Editing
- VR/AR
- Holographic Imaging
- Light Field Technology

Defense
- Night Vision
- Biometrics
- Neutron Detection

Detector
- Particle Identification
- Electron Spectroscopy
- Ion Spectrometry
- Space Flight Instrumentation

DARC glass privacy filter

Large Fiberoptic Face Plate for medical diagnostics

Night Vision

Curved MCP 25mm x 120mm

Plano MCP 53mm x 53mm

LAPPD (MCP-PMT) 200mm x 200mm
Major goals/tasks for the Phase II Gen II LAPPD™
(Original Proposal: ’17)

• **Simplifying** the ceramic lower tile assembly
• **Optimize glass-to-ceramic sidewall sealing process**
• **Fabricate working Gen-II LAPPD™s** for both pad and stripline applications.
• **Optimize electrical properties** of the inside-out capacitively coupled anode design.
• **Document** LAPPD™ pilot production processes
• Build Test and measurement stations for performance and life testing.
• Work closely with **University of Chicago**
  - Characterization, batch production techniques and applications

(Year 2 Challenges: Aug ’18)

• Solve the Indium **sealing process** on the Gen II ceramic LTA to top window
• **Fabricate** working detector tiles
• Fine-tune the entire **LAPPD fabrication process**
• **Document control** for bill of materials, standard operating procedures
• Finalize **development of the testing electronics and measurement protocols** for working Gen II LAPPDs
• Collaborate with **UTexas at Arlington on lifetime testing** while setting up Incom’s own life test station
• **Supply Gen-II LAPPD™s** to specific NP, HEP or commercial applications
LAPPD™ Design

- **Two-part Glass or Alumina** packaging (Lower Tile Assembly)
- Signal and high voltage delivered on strips **passing under a frit bond** (i.e. no wall or anode penetrations)
- Active area: 195 x 195mm

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Semi-Transparent Photocathode

Photon → electron

Pair of 20 × 20 cm ALD-GCA-MCP

1 electron → 10⁷ electrons

Glass Spacers (3)

Provides window support

Patterned Anode

Collect electron signal
Gen-I vs Gen-II LAPPD™ Design

Gen-I Strip Line Anode

Gen-II Resistive Anode with Coupled Patterned Anode

Optimized for fast timing applications.
~1 mm spatial resolution, ~50 ps TTS

Customizable anode pattern.
Maintains performance for most applications.

F. Tang et al., TWEPP 2008, Naxos, Greece, September 15-18, 2008
Gen-II LTA (ceramic lower tile assembly)

**Incom Inc.**
Two-part design

- Vacuum Transfer
- Capacitively coupled signals
- User defined device using stripline or ground plane pattern
- Easily changed external pickup board

**UChicago**
In-Situ design

- Mono base design
- Air transfer
- Pins and tubes brazed in for PMT-like batch production
- Easily changed external pickup board

Internal Ag stripline anode

Alumina Ceramic Bodies

Thin Metal Ground Plane

HV and ground tabs

Thin Metal Ground Plane

HV pins and cesiation tubes

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Figure 1: Shows the smooth surface of amorphous glass (Gen-I LAPPD) and the granular structure of the ceramic viewed in the FEI Quanta 650 FEG SEM.

Figure 2: pores or grain pullout as deep as 20-25 μm on the machined ceramic surface
Window to Ceramic Sealing (Incom)

- Metallization of ceramic lower tile assembly sealing surface
- X-ray inspection of corner and length of sealing surface
- Too many voids
- X-ray of early metallization
- X-ray of Current processing
- Vendor metallization
- X-ray of vendor metallization
- Voids
GEN II LAPPD

- **Capacitive signal coupling:** to an external PCB anode
- **A robust ceramic body:** for durability and dielectric properties
- **Pixelated anodes:** to enable high fluence applications

The capacitive readout scheme preserves rise-time of pulses (rise time is a key factor in timing resolution)
For pad pattern: 80% of the directly coupled amplitude

Sealing process established, high QE demonstrated.
Inner design optimization on-going

Large Area Photocathode production process is established \textbf{(independent of LAPPD type)}

QE $\sim$20\% and higher and 90\% uniformity demonstrated in recently sealed LAPPDs
Incom LAPPD Sealing Yield

• From onset: photocathode deposition and sealing (glass) was in question.
  • Since 2016: A total of **51 LAPPDs** have been “started
    • Since Aug 2018 (while bringing on a 2\(^{nd}\) IST):
      • **19 LAPPD** (starts up 50% from one start/month)

• Sealed Tile Yield in the last year (~80%)
  • **15 in a row sealed Integration & Sealing Tank #1**
    • PC deposition, **check**!
    • Sealing of glass tile, **check**!
    • Fabricating LAPPDs is now a **Routine Process**
  • **NOW, SIX out of SIX** ceramic to window seals, **check**!
    • FOUR are capacitively coupled Gen II, TWO with Gen I striplines
      • Five are **Incom** thick film metallization process
      • One is a **vendor** thick film metallization process
    • NINE glass Gen I thin film metallization sealed

• The failed seals were:
  • Thin film metallization error, cracked anode
  • First trials in our 2\(^{nd}\) Integration & Sealing Tank (#47 & 50)
Gen-II LAPPD Darkbox for Measurement & Testing

3d model

LAPPD being set-up for QE scan

Optics head

Scanning stages

LAPPD mount

Scanning stages

Darkbox installed at Incom

Optics head

Construction plans are being disseminated to users. A near-complete duplicate already at FNAL.

INCOM BRIGHT IDEAS

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Gen II Capacitive Coupling

This board has been used for tests of capacitive coupling temporal and spatial resolution.

Capacitively coupled pickup in MCP-based photodetectors using a conductive metallic anode
Gen-II readouts for PHDs, transit time (SPE) and spatial resolution

Amplified signals show PHDs nicely separated from noise and gain as high as $10^7$

How is transit time variation/spread measured

Outline of experiment to measure spatial resolution.

A strip line circuit board was capacitively coupled to the back of the LAPPD.

Charge is concentrated on the strip closest to where the charge cloud made contact but can still be observed on adjacent strips, enabling centroiding. This allows for mm and even sub mm spatial resolutions (0.6 mm for Gen II)

Gen I Resolution:
- along strip is 1.3 mm
- across strip is 0.76 mm
High Resolution Imaging using GEN II LAPPD Capacitively Coupled to a Cross Delay Line Anode

Preliminary high resolution image formed using a cross delay line anode capacitively coupled to GEN II LAPPD #44.

200 mm square cross delay line anode. X serpentine on surface and Y serpentine connected by through-hole-via to surface pads. (UC Berkeley)

Preliminary results suggest spatial resolution in the 100-200 µm range.
“Margherita” Batch Production Chamber
Evan Angelico, Andrey Elagin, Henry J. Frisch, Eric Spieglan (University of Chicago)

Goal: Develop a batch production process for LAPPDs capable of >50/week (>2000/year)

Three key technological challenges:
• Hermetic seal
  Challenges: indium oxide, metallization quality, surface quality
• Air-transfer photocathode method
  Challenges: purity of Cs source, quality and thickness of antimony precursor, optimization of temperatures and rates
• Recovery of MCP after cesiation
  Challenges: pre-scrubbing, baking after cesiation

We believe that this process is close to a commercialization stage, with the goal of a prototype commercial batch production facility
1. **Hermetic seal** (patent applied for)

Big steps were:
- No oxide in sealing area, using capillary action to wick solder into the gap
- Diagnostics and process QC with large format X-ray

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**2 out of 2 ceramic to glass seals** have succeeded using capillary action method. Margherita chambers allow for in-situ helium leak checking. Both are hermetic to $10^{-12}$ Torr L/s

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![Image of hermetic seal with labels](image.png)
2. Air-transfer photocathode method
   a) Demonstration in-situ with Tile 31 (~3% Cs-Sb)
   b) Optical monitoring of Cs quality
   c) Air-transfer method used by commercial photomultiplier manufacturer, MELZ
   d) Barois paper (below) suggests bi-alkali can and should be formed via thermal equilibration process practiced in Margherita chambers


3. MCP Recovery following cesiation
   a) MCP resistance drops while cesium valve was open, but recovers to original resistance when closed
   b) Single photo-electron pulses are observed after the entire cesiation process. High voltage is stable when MCPs are in gain mode.
LAPPDs at the Fermilab Test Beam Facility

Goals:
- Factor of 100 improvement for TOF resolution
- Optimize LAPPD temporal resolution for charged particles at the psec level
- Collaboration with Incom Inc., FNAL personnel, and ANNIE
- PhD Thesis for E. J. Angelico

Status: have measured ~1000s of charged particle events synchronized to beam spills with 2-LAPPDs, 120 channels of PSEC4 readout

Thank you to Helmut Marsiske, Michelle Shinn, and offices of DOE HEP and NP.
Summary & Conclusions

• Current Pilot Production **Sales**
  • Seven - ANNIE, Sandia, Fermilab
  • Three Pending sales
    • UChicago, USheffield (2)
    • Four **loaned** out for testing and validation

• Ceramic to PC window **vacuum-transfer sealing process** has been **solved**
  • Incom, UC and Vendor
  • **Transition from glass to ceramic** body for Gen I striplines or Gen II capacitive coupling

• Two Incom Measurement & Test Stations running
  • **“Typical” performances** meet early adopter needs:
    • Either Gen – I or Gen – II
      • Gain ~10^7
      • Mean QE ~ 20 - 25% @ >90% uniformity
    • Gen – I (Gen – II TBD)
      • Time Resolution < 70 Picoseconds, and mm Spatial Resolution
      • Dark rate 50-70 Hz/cm2 @ gain 3*10^6

• The UChicago **air-transfer fabrication process** is close to a commercialization stage, with the goal of a prototype commercial batch production facility

• Early adopters are **currently testing** Gen I and Gen II LAPPDs in **beamlines** and **lifetime** test stations
  • Fermilab (UChicago & ANNIE), UTA, JLab
  • Others (B-Field tests (ANL), Medical (PET), CHESS, Neutron camera)
Phase IIA Gen II Plans

- **Optimize Gen-II tile design/window seal/component stack**
  - Tighter component tolerances and internal design optimization
  - Pre-sealing test station: shorter sealing cycle
  - Automation: frit, metallization, indium
  - HV instability sources: internal free surfaces/edges/corners

- **Address outstanding performance issues and goals**
  - Reduce high voltage instabilities and high dark rates
  - Assess unwanted pulse coupling to pads
  - Minimize photocathode damage and after pulsing
  - Demonstrate high rate capability with pixelated signal boards
  - Perform life testing

- **Beamline testing at Fermilab**
  - Demonstrate high speed capabilities
  - Optimize LAPPD temporal resolution for charged particles at the psec level
  - Permanent set up @ FNAL for PID

- **Business Development and Commercialization**
  - Coordinate with early adopters: Incom workshops, validation, feedback
  - Test Gen-II devices for collider and double-beta decay applications
  - Cost models, yields, and SOPs with support from MassMEP (NIST partner)
  - UChicago in-situ PMT-like batch process for industrial viability

Constant feedback
Current Funding & Personnel Acknowledgements

THANK YOU!

DOE, DE-SC0015267, NP Phase IIA – “Development of Gen-II LAPPD™ Systems For Nuclear Physics Experiments”

DOE, DE-SC0011262 Phase IIA - “Further Development of Large-Area Micro-channel Plates for a Broad Range of Commercial Applications”

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

DOE Phase I - Development of Advanced Photocathodes for LAPPDs

DOE DE-SC0018778 Phase II “ALD-GCA-MCPs with Low Thermal Coefficient of Resistance”

NASA DE-SC0017929 Phase II “Curved Microchannel Plates and Collimators for Spaceflight Mass Spectrometers”

NASA Phase I - Improvement of GCA center to edge of high spatial/timing resolution applications

DOE (NP, HEP, NNSA) Personnel: Dr. Michelle Shinn, Dr. Elizabeth Bartosz, Dr. Manouchehr Farkhondeh, Dr. Gulshan Rai, Dr. Alan L. Stone, Dr. Helmut Marsiske, Dr. Donald Hornback, Dr. Manny Oliver Carl C. Hebron, Dr. Kenneth R. Marken Jr.
Back up slides
### III. LAPPD™ Early Adopters

<table>
<thead>
<tr>
<th>PI &amp; SPONSOR</th>
<th>PROGRAM TITLE</th>
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<tbody>
<tr>
<td>Mayly Sanchez and Matthew Wetstein, Iowa State</td>
<td>ANNIE: Atmospheric Neutrino Neutron Interaction Exp.</td>
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<tr>
<td>Henry Frisch, Evan Angelico (U of Chicago), Sergei Nagaitsev, Petra Merkel (Fermilab)</td>
<td>FERMILAB TEST BEAM IOTA (Integrable Optics Test Accelerator) KOTO (Rare Decays)</td>
</tr>
<tr>
<td>Andrey Elagin (U of Chicago), Mickey Chiu (BNL), Lindley Winslow (MIT)</td>
<td>Neutrino-less Double-Beta Decay Phoenix Project - eIC Fast TOF Neutrino-less Double-Beta Decay (NuDot)</td>
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<tr>
<td>Erik Brubaker, Sandia National Lab/CA</td>
<td>NEUTRON IMAGING CAMERA NanoGuide Scintillating Polymer with Incom West</td>
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<tr>
<td>John Learned, U. of Hawaii, and Virginia Tech</td>
<td>Short Baseline Neutrino (NuLat) NanoGuide Scintillating Polymer with Incom West</td>
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<tr>
<td>Andrew Brandt, Varghese Anto Chirayath (UT Arlington)</td>
<td>LAPPD LIFE TESTING, ROLE OF ION FEEDBACK</td>
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<tr>
<td>Silvia Dalla Torre (INFN Sezione di Trieste)</td>
<td>Confidential / TBD</td>
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<tr>
<td>Robert Wagner (ANL), J. Xie, E. May, F. Skrzecz, F. Cao</td>
<td>LAPPD B-Field Testing</td>
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<td>Matthew Malek, (U of Sheffield)</td>
<td>WATCHMAN, UK STFC</td>
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<td>Josh Klein, U of Penn</td>
<td>Spectrally Sorting of Photons, using Dichroic Films and Winston Cones, WATCHMAN, THEIA</td>
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<tr>
<td>Gabrial D. Orebi Gann (UC Berkeley)</td>
<td>CHESS, WATCHMAN, THEIA</td>
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<td>Zein-eddine Meziani</td>
<td>high rate threshold CHERENKOV LIGHT DETECTION Jefferson Labs, SoLID</td>
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<tr>
<td>Simon Cherry, Stan Majewski (UC Davis), William A. Worstell (PicoRad Imaging)</td>
<td>LAPPD based Time-of-Flight PET Sensor</td>
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I. Incom Measurement & Test Workshops

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<tr>
<th>Next Workshop Dates</th>
<th>Workshop #5, Feb 12-14, 2019</th>
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<tr>
<td>Sep 10-12, 2019</td>
<td>Jack McKisson, Electonical Eng. JLAB, Dr. Anatoli Arodzero, Director, Detection Division, RadiaBeam Technologies, LLC</td>
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<tr>
<td>Feb 11-13, 2020</td>
<td>Evan Angelico, University of Chicago</td>
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<td>May 12-14, 2020</td>
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<th>Workshop #4, October 9 – 11th, 2018</th>
<th>Workshop #3, May 15-17th, 2018</th>
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<tr>
<td>Mitaire Ojaruega (NGA-DOD)</td>
<td>Junqi Xie (ANL)</td>
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<td>Kevin Richard Jackman (NGA-DOD)</td>
<td>Mickey Chiu, (BNL)</td>
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<td>Varghese Anto Chirayath, (Physics, UTA)</td>
<td>Carl Zorn, (Jefferson Lab)</td>
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<tr>
<th>Workshop #2, January 24-26, 2018</th>
<th>Workshop #1, November 13 – 16th, 2017</th>
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<tr>
<td>Matthew Malek (University of Sheffield)</td>
<td>Kurtis Nishimura (U of Hawaii / Sandia)</td>
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<tr>
<td>Matt Wetstein (ISU – ANNIE Program)</td>
<td>Josh Brown (Sandia)</td>
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<tr>
<td>Lindley Winslow, Julieta Gruszko (MIT, NuDot)</td>
<td>Julieta Gruszko (MIT)</td>
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<td>Albert Stebbins (Fermilab, Cosmology Group)</td>
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<tr>
<td>Andrew Brandt, Varghese Chirayath (UTA)</td>
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<td>Klaus Attenkofer – BNL</td>
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II. Active & Pending SBIR Development programs:

1. “GEN II LAPPD“ - Gen-II LAPPD™ Systems For Nuclear Physics Experiments (Phase IIA, SBIR DOE, Michelle Shinn)
2. “ALD-GCA-MCPs with Low Thermal Coefficient of Resistance” (Phase II SBIR, DOE, NNSA, Donny Hornback)
3. "High Gain MCP ALD Films", SEE layer development (Phase II SBIR DOE, Helmut Marsiske)
4. “Development of Advanced Photocathodes for LAPPDs” (Phase I SBIR DOE HEP, Helmut Marsiske)
6. “Improvement of GCA center to edge of high spatial/timing resolution applications” (Phase I SBIR, NASA)
7. “Curved MCPs and Collimators for Spaceflight Mass Spectrometers: (Phase II SBIR, NASA, Edward Sittler)
8. DOE Phase I Release 1 NP Submission: “Large Area Multi-Anode MCP-PMT” LOI due September 3d, Applications due October 15th
Gen-I LAPPD™ Spatial Resolution

**ALONG STRIPS**

DRS4 waveform sampler: Position by $\Delta t$ for signal at both ends of single strip.

- Resolution = 1.3 mm

**ACROSS STRIPS**

DRS4 waveform sampler: Position by center of mass for 5 adjacent strip signals.

- Resolution = 0.76 mm

Reconstructed position vs. laser position