Performance of Large Area Picosecond Photo-Detectors (LAPPD™)

Alexey Lyashenko
Incom Inc.
LAPPD development group:

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- A. U. Mane, J. W. Elam, **Argonne National Laboratory**

- O. H. W. Siegmund, **University of California, Berkeley**

- Prof. H. J. Frisch's group (E. Angelico, A. Elagin, E. Spieglan), **University of Chicago**

- Prof. M. Wetstein's group, **Iowa State University**

- R. Wagner, J. Xie, **Argonne National Laboratory**
**Benefits of fast timing**

Neutrino: More efficient background rejection

HEP applications: Precise TOF & PID

Neutrino: High vertex resolution in large scale experiments

Neutrino, rare decay: Precise track reconstruction

Obb decay: Directionality information

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**C. Aberle et al., JINST 9 (2014), arXiv:1307.5813**

Incom Inc. LAPPD Performance, VCI19, Feb 18 – 22, 2019, Vienna, Austria
LAPPD applicability **ANNIE Experiment**

**5 LAPPDs are being installed**

- Even a small number of LAPPDs can make a big difference in the right context

![ANNIE Simulation](image)

- In ANNIE, the addition of 5 LAPPDs greatly improves reconstruction of muon track parameters

Details: [http://annie.fnal.gov](http://annie.fnal.gov)
LAPPD Pilot Production Timeline

• DOE Funding to create infrastructure and demonstrate a pathway toward pilot production (April 2014)
• Facility operational (November 2015)
• LAPPD Commissioning trials initiated (December 2015)
  
  #9 - 9/14/2016, First Sealed Tile - Aluminum Photocathode
  #15 - 03/31/2017, QE >20% demonstrated
  #22 - 10/10/2017, moderate QE, High Gain MCPs, Peaked SPE PHD,
  #31 - 5/25/2018 Functional Tiles with “Personality”
  #36 - 10/16/2018 - First GEN II, Ceramic Body LAPPD
  #37 - 11/13/2018 - High QE ~24% and high gain ~$10^7$ in the same tile
  #39 - 01/23/2019 - High QE ~25%, low noise @ high gain ~ $10^7$

• Exploitation (2018-)

  Currently Producing prototypes for early adopters
  Process Optimization
MCPs are marketed as a separate product line. Standard dimensions DIA33mm, SQ53mm, SQ60mm, SQ127mm, SQ200mm. Curved MCPs.

Gain Uniformity in 203mm X 203mm MCP

Gain >10^7

MgO, Al_2O_3

Fig. 8: Average gain image “map” (<15% overall variation). 8” MCP pair 20μm pore, 60:1 L/D ALD-MCP pair. ~7 x 10^6 gain, 0.7mm inter-MCP gap/200V.

Fig. 9: 20 cm ALD MCP pair background, 500 sec, 0.03 events/cm^2/sec. Overall background ~8x better than standard glass MCPs (less K^40).
MCPs are marketed as a separate product line. Standard dimensions DIA33mm, SQ53mm, SQ60mm, SQ127mm, SQ200mm. Curved MCPs.

Launched Dec 2018

200 x 200mm XDL spectroscopy detector (DEUCE rocket, James Green, PI, Colorado) with KBr photocathode on ALD MCPs.
LAPPD features

- Glass/ceramic body
- Large Active Area: 195 x 195 mm²
- Picosecond timing resolution
- mm spatial resolution
- QE >20% w/ bi-alkali photocathode
- Fused Silica/Borosilicate window
- Flat square geometry, high filling factor
- Lower Cost per Unit Area
Photocathode (five most recent tiles)

Large Area Photocathode production process is established
QE >20% and 90% uniformity demonstrated in sealed LAPPDs (five recent tiles shown)
Photocathode

Stable for 6.5 month and counting

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Gain $\sim 10^7$ achieved at relatively low MCP voltage of 950V-1000V per plate

Read out with DRS4 eval. or CAEN waveform digitizers
**Spatial Resolution**

### Along a Strip

- **Jitter in \( \Delta t \) for a fixed laser position**

**DRS4 waveform samplers**

- Pulses observed at both ends of a strip.

**FWHM 2.4mm**

**Reconstructed position vs laser position**

### Across Strips

- **Center of Mass of five adjacent strip signals**

**St. dev. from linear fit 0.75mm**

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Time Resolution

Testing at Iowa State University, Matt Wetstein, ANNIIE Program

Low Gain

10 mV SPE peak

LAPPD25

64 psec with 40pS FWHM laser pulses

High Gain

31 mV SPE peak

LAPPD25

Assuming $\sigma_{\text{Meas}}^2 = \sigma_{\text{LAPPD}}^2 + \sigma_{\text{Laser Width}}^2$ the extracted TTS is 50pS
Time Resolution

Testing at Iowa State University, Matt Wetstein, ANNIE Program

Typical Single PE Pulses

FWHM: 1.1 nsec
Rise time: 850 psec

Transit Time Spread

80pS with 63pS FWHM laser pulses

Assuming $\sigma_{\text{Meas}}^2 = \sigma_{\text{LAPPD}}^2 + \sigma_{\text{LaserWidth}}^2$ the extracted TTS is 49pS
### Dark Count Rate

#### LAPPD39 (QE = 25.3%)

<table>
<thead>
<tr>
<th>PC Voltage [V]</th>
<th>MCP Voltage [V]</th>
<th>Gain</th>
<th>Dark rate [Hz/cm²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 (800V/cm)</td>
<td>925</td>
<td>$3 \times 10^6$</td>
<td>50–70</td>
</tr>
<tr>
<td>200</td>
<td>975</td>
<td>$7 \times 10^6$</td>
<td>200–300</td>
</tr>
<tr>
<td>200</td>
<td>1000</td>
<td>$10^7$</td>
<td>700–1000</td>
</tr>
</tbody>
</table>

#### LAPPD40 (QE = 18.4%)

![Graphs showing dark count rate for LAPPD39 and LAPPD40]
Linearity

**Good Linearity to ~300KHz/cm²**
Afterpulses (worst case scenario)

- Laser pulse downscaled to fit on histogram
- 3.5% afterpulse ratio
- With $K_2CsSb$ photocathode
Preliminary LAPPD & Small Format Tile B-Field Testing
Bill Worstell (PI), Mark Popecki, Cole Hamel, Bernhard Adams, Bob Wagner, Junqi Xie, Ed May

12/14/2018 B-Field Testing LAPPD #37
ANL 6cm Tile, 10 & 20μ MCPs

Phase I SBIR Preliminary Results: B field limit
Gain decreases with increasing field
Max with field aligned with MCP pore
~0.7 T with 20 microns
~1.3 T with 10 microns
Further Analysis Pending
Phase II SBIR Targets Design Optimization

Conservative
GEN II LAPPD

- A robust ceramic body
- Capacitive signal coupling: to an external PCB anode
- Pixelated anodes: to enable high fluence applications

Sealing process established, high QE demonstrated, inner design optimization on-going
Early Adopters

- Opinion leaders able to influence the adoption of LAPPD for established or future technical programs.
- Collaborators that have access to special facilities: magnetic fields, neutron beam, Cherenkov light, Fermi Lab Particle Beams, Neutrino-less Double-Beta Decay, life testing, etc.
- Incom works with early adopters to insure that LAPPD are available to be evaluated for appropriate applications.
  - Measurement & Test Workshop
  - Discounted pricing to Early Adopters with DOE funded programs.
  - Swaps & Warranty
  - Options for Short term loan of LAPPD
- Discussions underway to explore joining end user programs as a collaborator or sub-contractor rather than just a vendor.
# Incom Measurement & Test Workshops

http://www.incomusa.com/mcp-and-lappd-documents/

<table>
<thead>
<tr>
<th>Workshop #6, May 14 - 16th, 2019</th>
<th>Workshop #5, February 11 - 13th, 2019</th>
<th>Workshop #4, October 9 - 11th, 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants:</td>
<td>Participants:</td>
<td>Participants:</td>
</tr>
<tr>
<td>• Everybody is welcome</td>
<td>• Anatoli Arodzero (RadiaBeam</td>
<td>• Mitaire Ojaruega (NGA-DOD)</td>
</tr>
<tr>
<td></td>
<td>Technologies LLC)</td>
<td>• Kevin Richard Jackman (NGA-DOD)</td>
</tr>
<tr>
<td></td>
<td>• Jack McKisson (JLAB)</td>
<td>• Varghese Anto Chirayath, (Physics,</td>
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<td></td>
<td>• Evan Angelico (UChicago)</td>
<td>UTA)</td>
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<td>Workshop #3, May 15-17th, 2018</td>
<td>Workshop #2, January 24-26, 2018</td>
<td>Workshop #1, November 13 – 16th, 2018</td>
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<tr>
<td>Participants:</td>
<td>Participants:</td>
<td>Participants:</td>
</tr>
<tr>
<td>• Junqi Xie (ANL)</td>
<td>• Matthew Malek (The University of</td>
<td>• Kurtis Nishimura (U of Hawaii / Sandia)</td>
</tr>
<tr>
<td>• Mickey Chiu, (BNL)</td>
<td>Sheffield)</td>
<td>• Josh Brown (Sandia)</td>
</tr>
<tr>
<td>• Carl Zorn, (Jefferson Lab)</td>
<td>• Matt Wetstein (ISU – ANNIE Program)</td>
<td>• Julieta Gruszko (MIT)</td>
</tr>
<tr>
<td>• Wenze Xi, (Jefferson Lab)</td>
<td>• Lindley Winslow, Julieta Gruszko (MIT, NuDot)</td>
<td></td>
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<tr>
<td>• Camden Ertley (UC B, now Incom Inc.)</td>
<td>• Albert Stebbins (Fermilab, Cosmology Group)</td>
<td></td>
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<tr>
<td></td>
<td>• Andrew Brandt, Varghese Chirayath (UTA)</td>
<td></td>
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<tr>
<td></td>
<td>• Klaus Attenkofer - BNL</td>
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</tbody>
</table>
### LAPPD™ Early Adopter Programs

<table>
<thead>
<tr>
<th>PI &amp; SPONSOR</th>
<th>PROGRAM TITLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mayly Sanchez and Matthew Wetstein, Iowa State</td>
<td>ANNIE - Atmospheric Neutrino Neutron Interaction Experiment</td>
</tr>
<tr>
<td>Erik Brubaker, Sandia National Lab/CA</td>
<td>Neutron Imaging Camera</td>
</tr>
<tr>
<td>Graham Smith, Klaus Attenkofer (BNL)</td>
<td>Gamma &amp; Neutron Detectors</td>
</tr>
<tr>
<td>Henry Frisch (U of Chicago), Dmitri Denisov (Fermilab)</td>
<td>Precision Time-of-Flight with Commercial Photodetectors at the Fermilab Testbeam Facility</td>
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<tr>
<td>Matthew Malek, (u of Sheffield)</td>
<td>WATCHMAN, UK STFC</td>
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<tr>
<td>Josh Klein, U of Penn</td>
<td>Spectrally Sorting of Photons, using Dichroic Films and Winston Cones, WATCHMAN, THEIA</td>
</tr>
<tr>
<td>Gabrial D. Orebi Gann (UC Berkeley)</td>
<td>WATCHMAN, THEIA</td>
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<tr>
<td>Zein-eddine Meziani</td>
<td>High Rate Trials at Jefferson Labs, EIC</td>
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<tr>
<td>Andrey Elagin (U of Chicago)</td>
<td>Neutrino-less Double-Beta Decay</td>
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<tr>
<td>Mickey Chiu (BNL) -</td>
<td>Phenix Project - “eIC Fast TOF”</td>
</tr>
<tr>
<td>John Learned, U. of Hawaii, and Virginia Tech</td>
<td>Short Baseline Neutrino (NuLat)</td>
</tr>
<tr>
<td>Lindley Winslow (MIT)</td>
<td>Neutrino-less Double-Beta Decay (NuDot) Using Fast Timing Detectors</td>
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<tr>
<td>Andrew Brandt, (UT Arlington)</td>
<td>Life Testing of LAPPD</td>
</tr>
<tr>
<td>J. Xie</td>
<td>PID, EIC</td>
</tr>
</tbody>
</table>
Summary & Conclusions

I. GEN I - Incom LAPPD Pilot Production is now underway

A. GEN I LAPPD - Available Today!
   o Artifacts are being resolved as production volume and experience increases.
   o Life Testing is on-going
   o Providing early adopters a means to explore potential of PSEC timing.

B. “Typical” performances meet early adopter needs:
   o Gain \( \sim 10^7 \)
   o Mean QE \( \sim 25\% \) @ \( >80\% \) uniformity
   o Time Resolution < 70 Picoseconds, and mm Spatial Resolution
   o Dark rate 50-70 Hz/cm\(^2\) @ gain 3*10\(^6\)

II. GEN II - Capacitive coupling works, ceramic package demonstrated, high QE demonstrated.

III. A good candidate for the use in collider, neutrino and rare decay experiments

IV. We will work with you to make LAPPD available for test & evaluation.
Current Funding & Personnel Acknowledgements

- DOE, DE-SC0015267, NP Phase II - “Development of Gen-II LAPPD™ Systems For Nuclear Physics Experiments”
- DOE DE-SC0018445 NP Phase I “Magnetic Field Tolerant Large Area Picosecond Photon Detectors for Particle Identification”
- DOE, DE-SC0011262 Phase IIA - “Further Development of Large-Area Microchannel Plates for a Broad Range of Commercial Applications”
- DOE DE-SC0017929, Phase II- “High Gain MCP ALD Film” (Alternative SEE Materials)
- NIH 1R43CA213581-01A Phase I - “Time-of-Flight Proton Radiography for Proton Therapy”
- DOE DE-SC0018778 Phase I “ALD-GCA-MCPs with Low Thermal Coefficient of Resistance”
- NASA 2018-I SBIR Proposal: S1.06-1093 Phase 1 “Curved Microchannel Plates and Collimators for Spaceflight Mass Spectrometers”
- DOE (HEP, NP, NNSA) Personnel: Dr. Alan L. Stone, Dr. Helmut Marsiske, Carl C. Hebron, Dr. Kenneth R. Marken Jr, Dr. Michelle Shinn, Dr. Elizabeth Bartosz, Dr. Gulshan Rai, Dr. Manouchehr Farkhondeh, Dr. Donald Hornback, Dr. Manny Oliver.
For more information

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Michael J. Minot
Director R&D, Incom Inc.
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Office: 508-909-2369
Cell: 978-852-4942

Thank you!
Selected LAPPD References & Links

- Craven, Christopher A. et al - "Recent Advances in Large Area Micro-Channel Plates and LAPPD™" TIPP’17 International Conference on Technology and Instrumentation in Particle Physics, Beijing, People’s Republic of China, May 22-26, 2017
INCOM MCPs at cryogenic temperatures

I-V curves for cryogenic temperatures

MCP current takes off indicating thermal runaway

$R_{RT} = 200 \, \Omega$

$\beta = -0.07 \, \text{K}^{-1}$

T fit range: 90 to 160 K

INCOM Inc. LAPPD Performance, VCI19, Feb 18 – 22, 2019, Vienna, Austria
MCP chevron pair detector in cooled environment

1200 V across each MCP,
Stack resistance : 126 M
Background rates: 0.35 cnts/sec/cm$^2$.

$T = -50^\circ$C

1300/1400V across each MCP;
stack resistance: 1 G$\Omega$
LAPPD Price Projections

- Current costs are driven by overhead rates, non-reimbursed R&D Costs, and low volume
- Costs drop rapidly, as demand and volume increases.
- Incom projects price to drop from current levels as follows:

<table>
<thead>
<tr>
<th>Timing</th>
<th>Cmrcl Price</th>
<th>DOE Price</th>
<th>Cum Vol.</th>
<th>Annual Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>$ 75,000</td>
<td>$ 50,000</td>
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<td>48</td>
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<tr>
<td>1</td>
<td>$ 56,250</td>
<td>$ 37,688</td>
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<td>502</td>
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<td>5</td>
<td>$ 30,032</td>
<td>$ 20,121</td>
<td>1,000</td>
<td>278</td>
</tr>
</tbody>
</table>

With full scale production, and cumulative volumes of product produced approaching 10,000 units, a price of $10,000 or less, for a full size LAPPD, is entirely plausible.