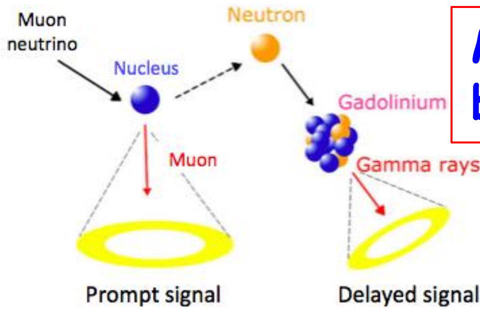
Performance of Large Area Picosecond Photo-Detectors (LAPPD™)

A. Lyashenko
Incom Inc.

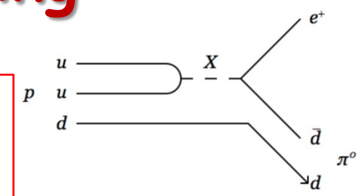
LAPPD development group:

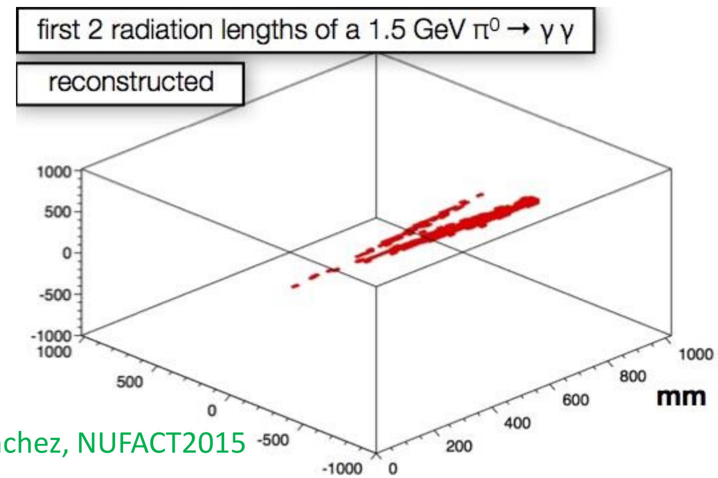
- **A. V. Lyashenko (alyashenko@incomusa.com)**, B. W. Adams, M. Aviles, T. Cremer, C. D. Ertley, M. R. Foley, C. J. Hamel, M. J. Minot, M. A. Popecki, M. E. Stochaj, W. A. Worstell, **Incom Inc, Charlton, MA**
- A. U. Mane, J. W. Elam, **Argonne National Laboratory**
- O. H. W. Siegmund, **University 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**

Benefits of fast timing



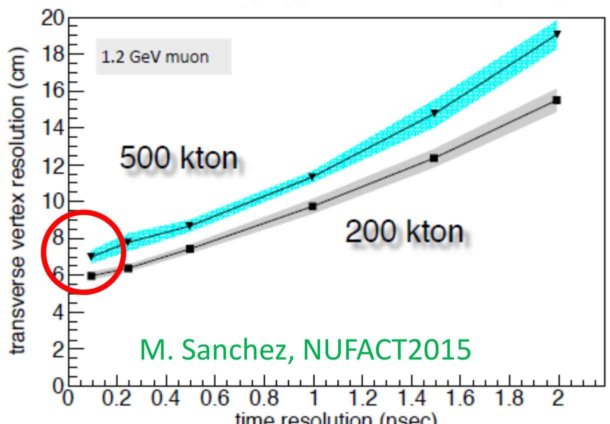
More efficient background rejection



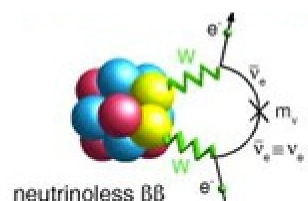


M. Sanchez, NUFACT2015

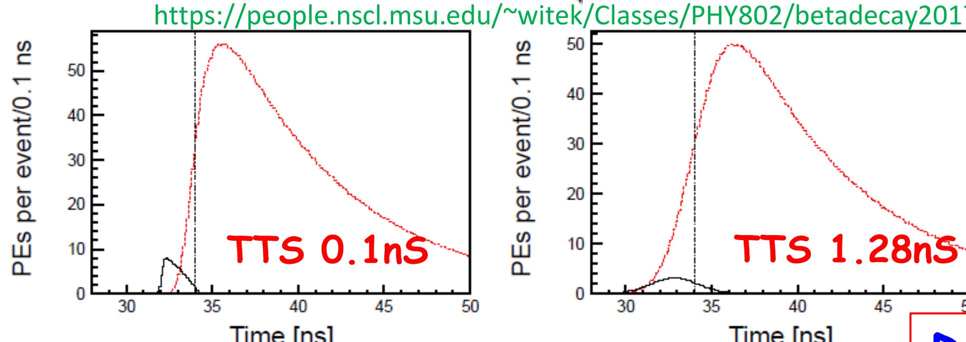
Precise track reconstruction



High vertex resolution in large scale experiments



https://people.nscl.msu.edu/~witek/Classes/PHY802/betadecay2017a.pdf

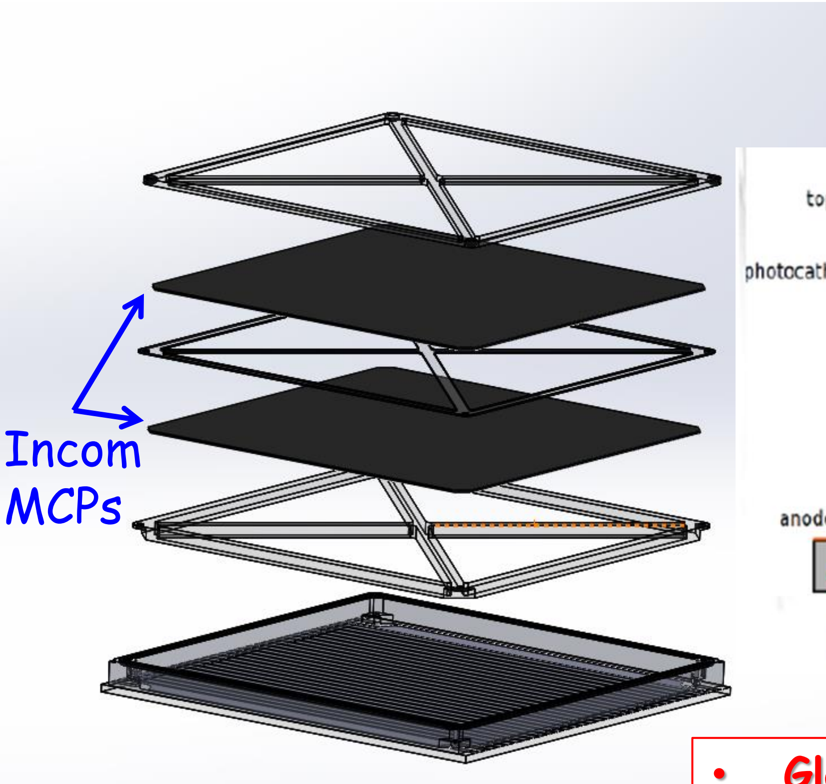


(a) Default simulation. (b) Increased TTS (1.28 ns).

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

Directionality information

LAPPD features



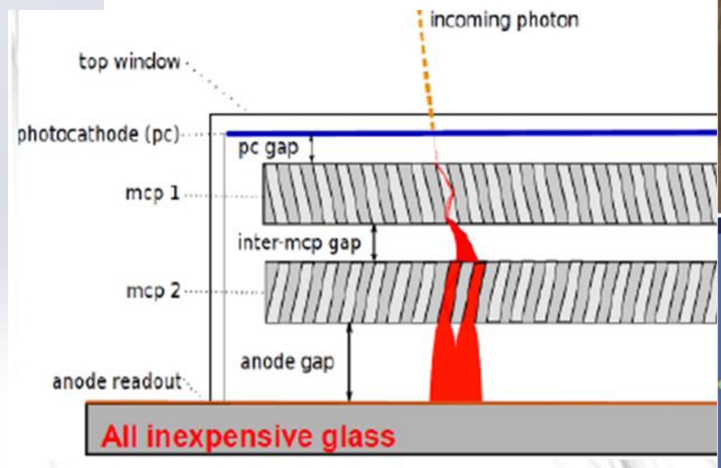
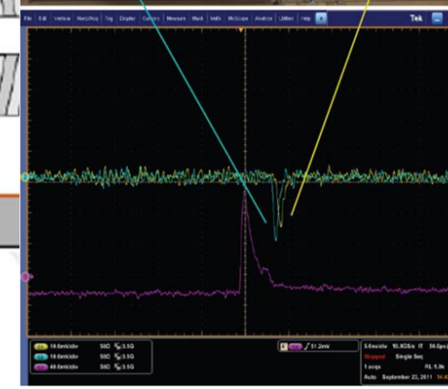
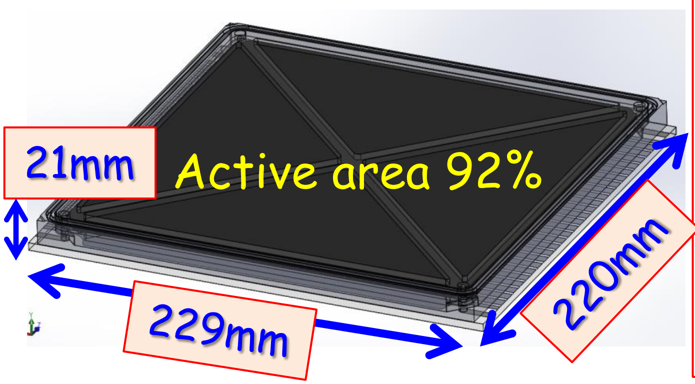
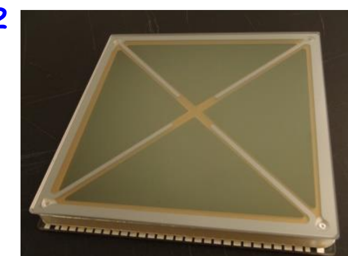


Illustration provided by Univ. of Chicago



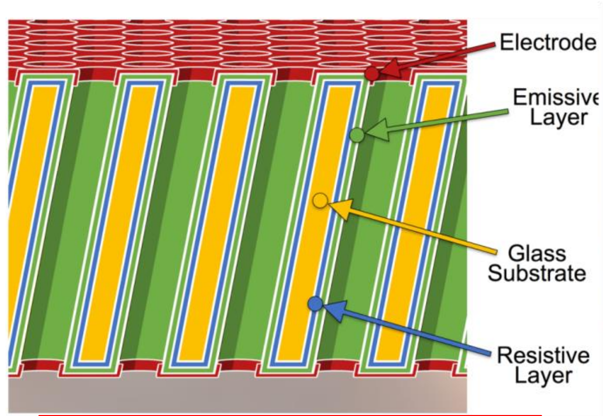


- Glass/ceramic body
- Large Active Area: 195 x 195 mm^2
- Picosecond timing resolution
- mm spatial resolution
- QE >20% w/bi-alkali photocathode
- Fused Silica/Borosilicate window
- Flat square geometry, high filling factor
- Lower Cost per Unit Area



Incom MCPs

Glass capillary arrays functionalized in-house with ALD



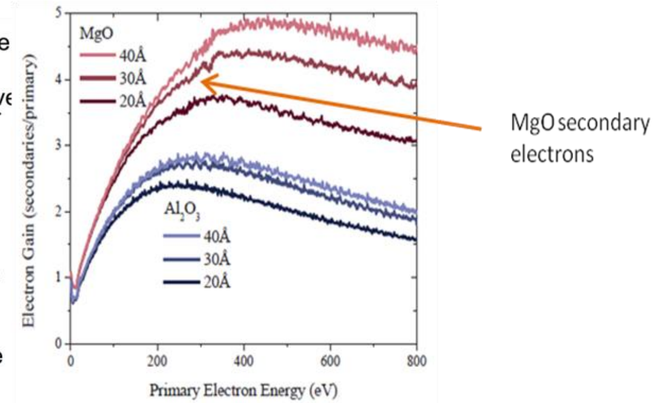
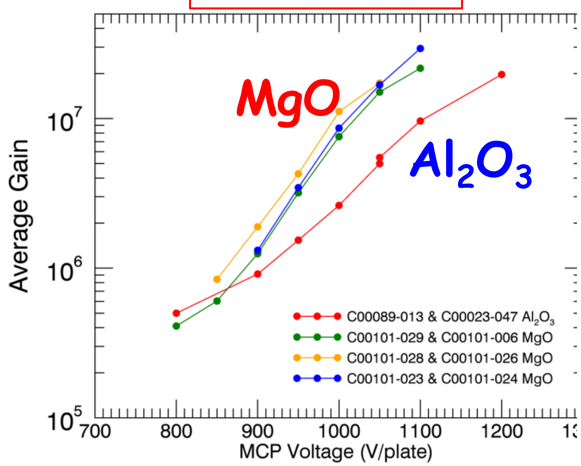


Figure 2. Secondary electron yield from select thicknesses of ALD MgO and Al_2O_3. See Figure 3 for the entire data set.

Gain Uniformity in 203mm X 203mm MCP

Gain >10^7



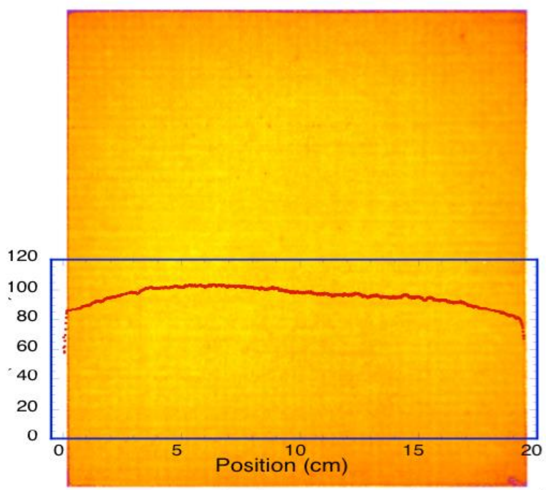


Fig. 8: Average gain image "map" (<15% overall variation). 8" MCP pair 20µm pore, 60:1 L/D ALD-MCP pair. ~7 × 10^6 gain, 0.7mm inter-MCP gap/200V.

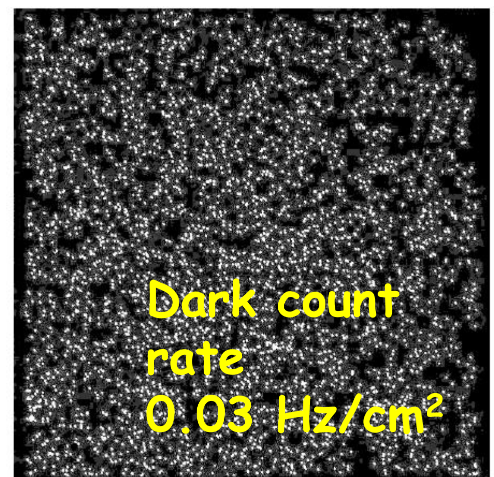
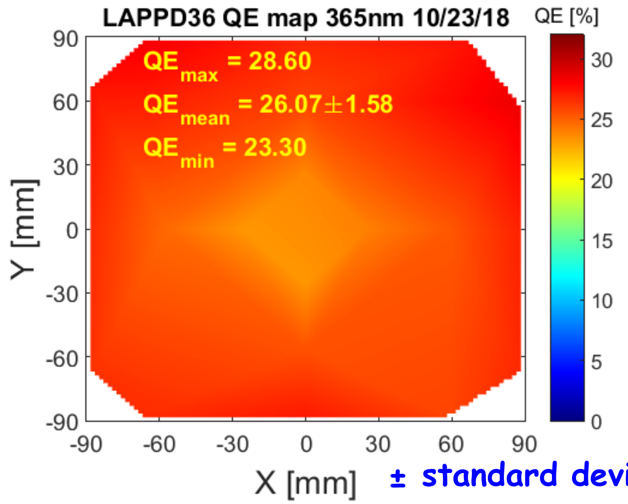


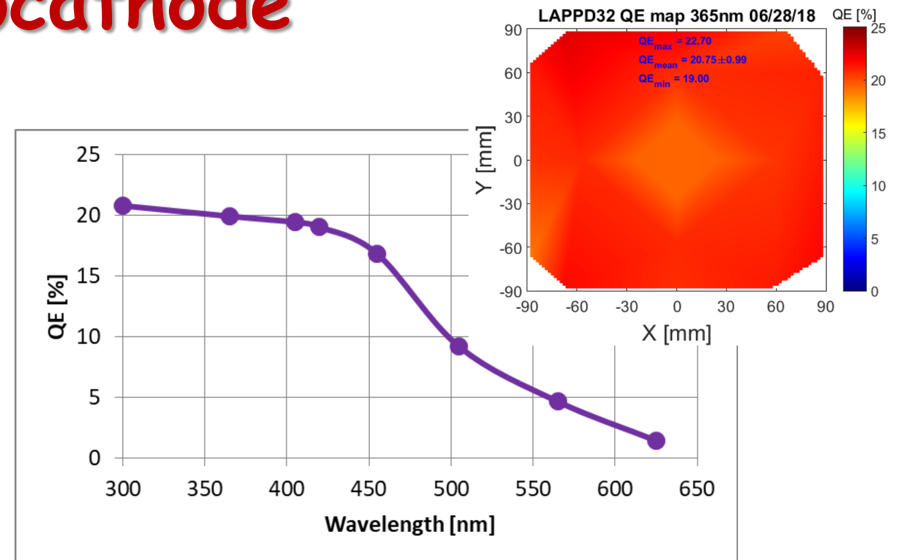
Fig. 9: 20 cm ALD MCP pair background, 500 sec, 0.03 events/cm^2/sec^1. Overall background ~8× better than standard glass MCPs (less K^{40}),

MCPs are a separate product line.
Standard dimensions DIA33mm, SQ53mm, SQ60mm, SQ127mm, SQ200mm. Curved MCPs.

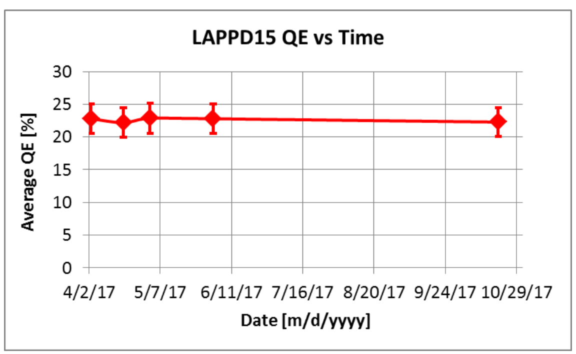
Photocathode



± standard deviation



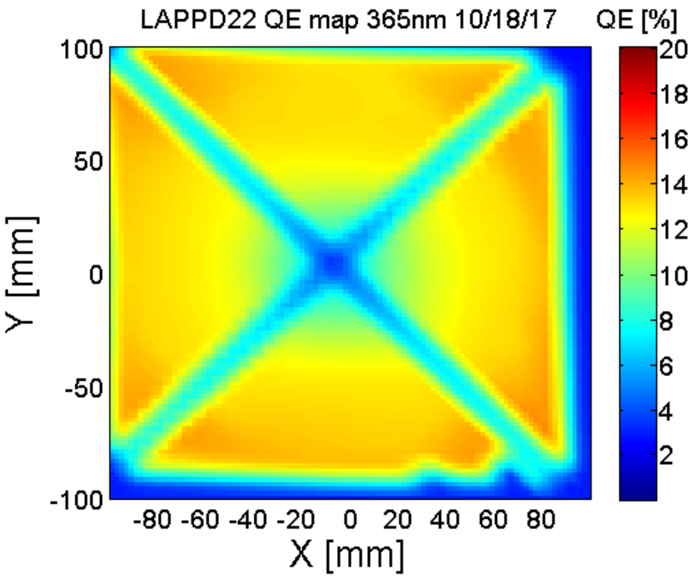
- Bi-alkali: Na_2KSb
- QE measured at 365 nm
- Highest avg. is 26%
- LAPPD 15 photocathode stable for > 6+ months and counting.

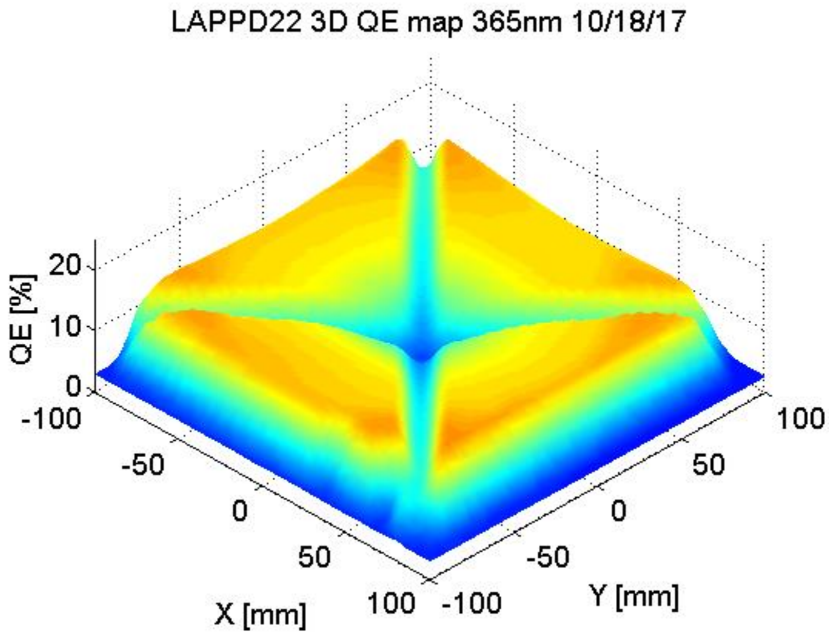


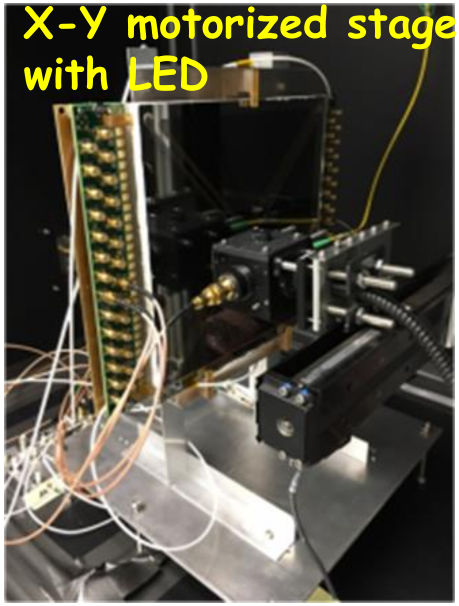
Large Area Photocathode production process is established
QE >20% demonstrated in sealed LAPPDs

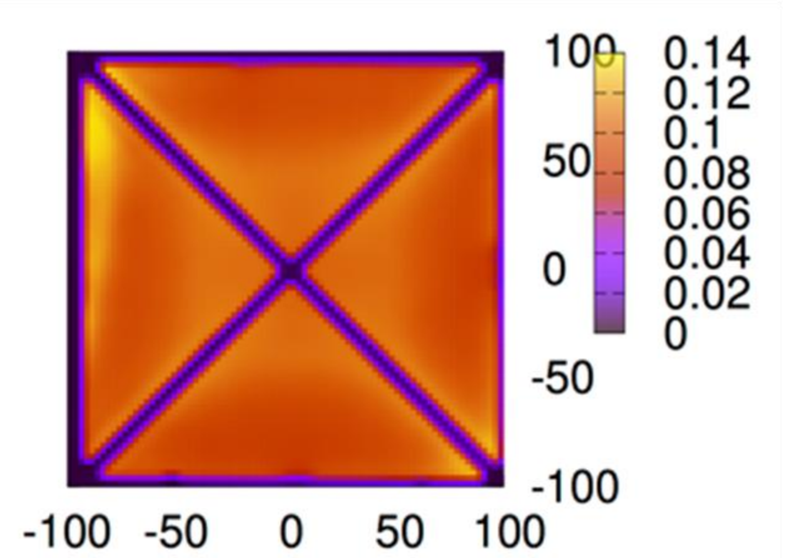
LAPPD S/N	Maximum %	Average %	Minimum %
LAPPD #13:	23.5	18.6±3.3	13.5
LAPPD #15:	25.8	22.3±3.0	15.7
LAPPD #22:	14.7	10.6	7.0
LAPPD #25:	10	7.1	5.0
LAPPD #29:	19.6	13.0±6.0	3
LAPPD #30:	22.9	17.2±2.5	13
LAPPD #31:	19.6	16.0±1.9	12.1
LAPPD #32:	22.7	20.8±1.0	19.0
LAPPD #36:	28.6	26.1±1.6	23.3

QE scanner

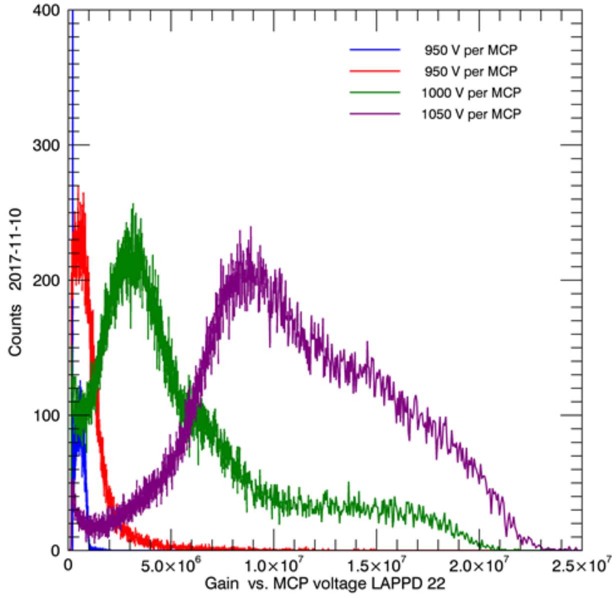

LAPPD22 QE map 365nm 10/18/17
QE [%]
20
18
16
14
12
10
8
6
4
2
100
50
0
-50
-100
Y [mm]
-80 -60 -40 -20 0 20 40 60 80
X [mm]

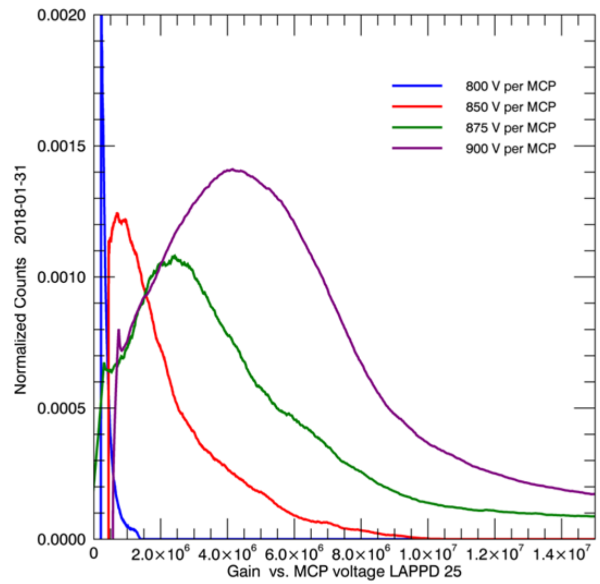

LAPPD22 3D QE map 365nm 10/18/17
QE [%]
20
10
0
-100
-50
0
50
100
X [mm]
-100
-50
0
50
100
Y [mm]

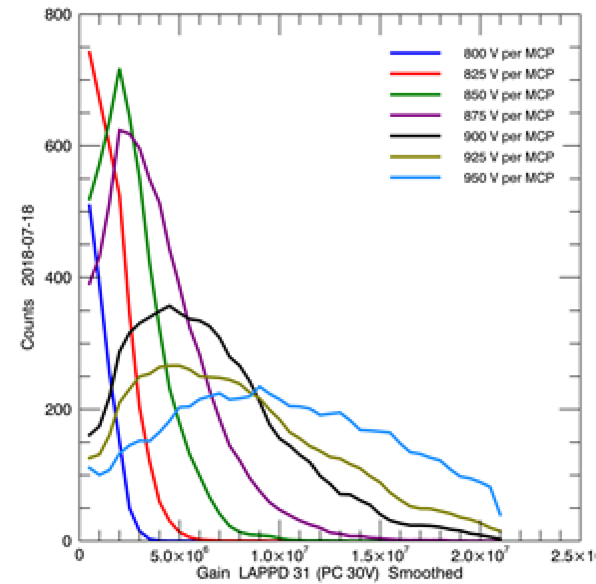

X-Y motorized stage
with LED

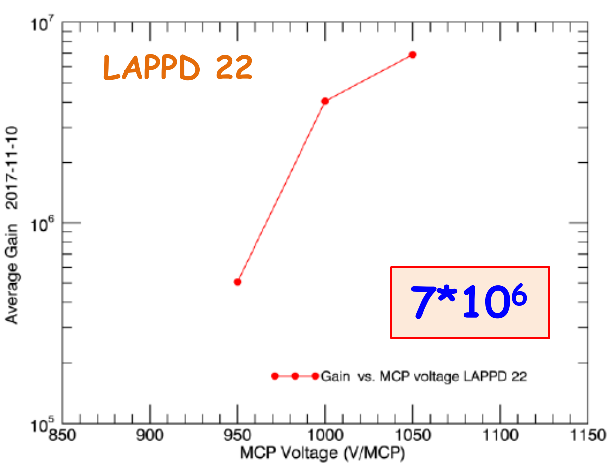

100
50
0
-50
-100
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-100 -50 0 50 100

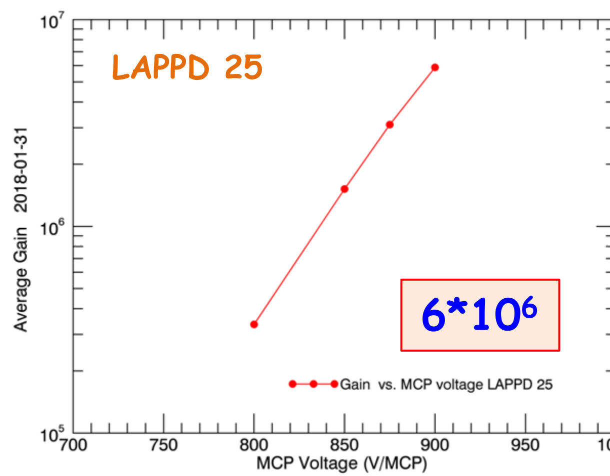
LAPPD Gain

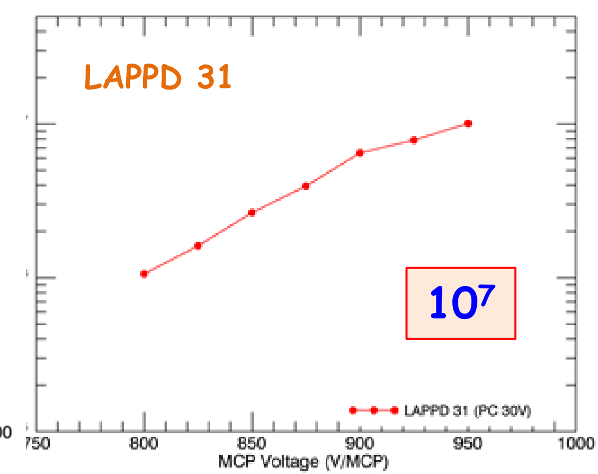












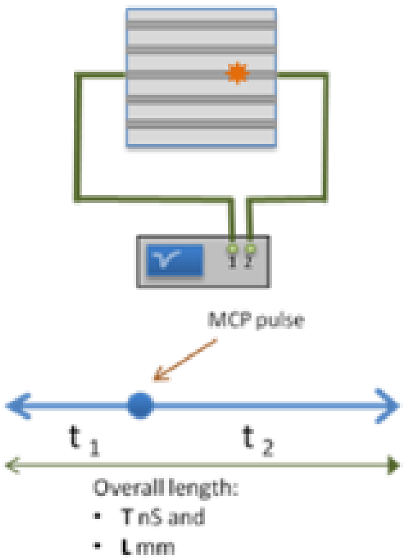
Read out with DRS4 eval. or CAEN waveform digitizers

Gain >5*10^6

Spatial Resolution

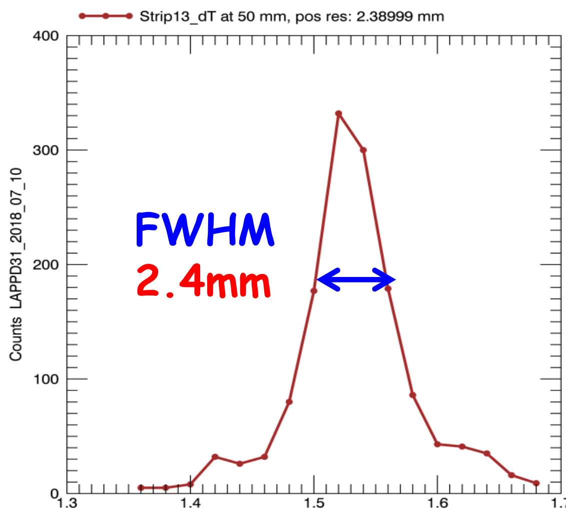
Along a Strip

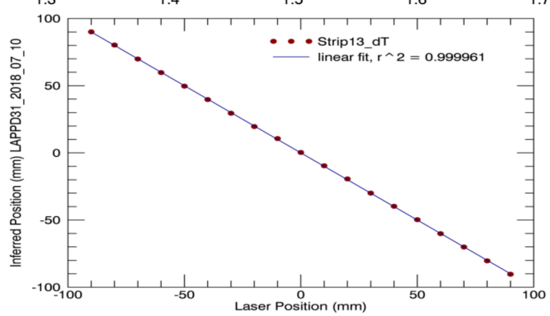
Jitter in Δt for a fixed laser position



DRS4 waveform samplers

Pulses observed at both ends of a strip.

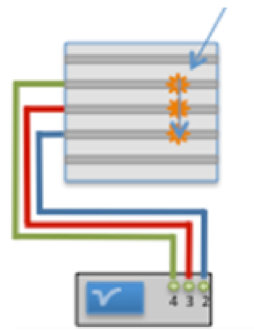


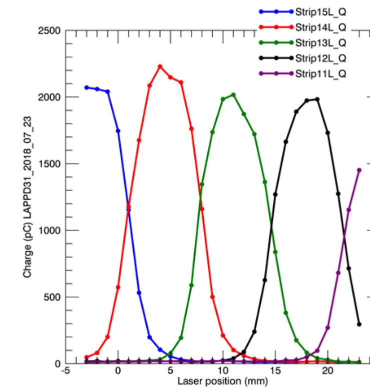


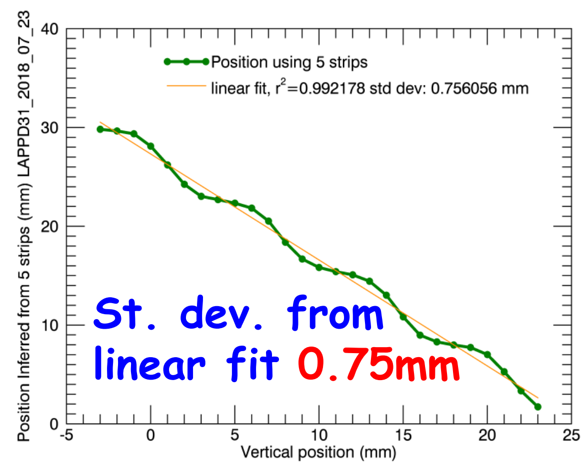
Reconstructed position vs laser position

Across Strips

Center of Mass of five adjacent strip signals

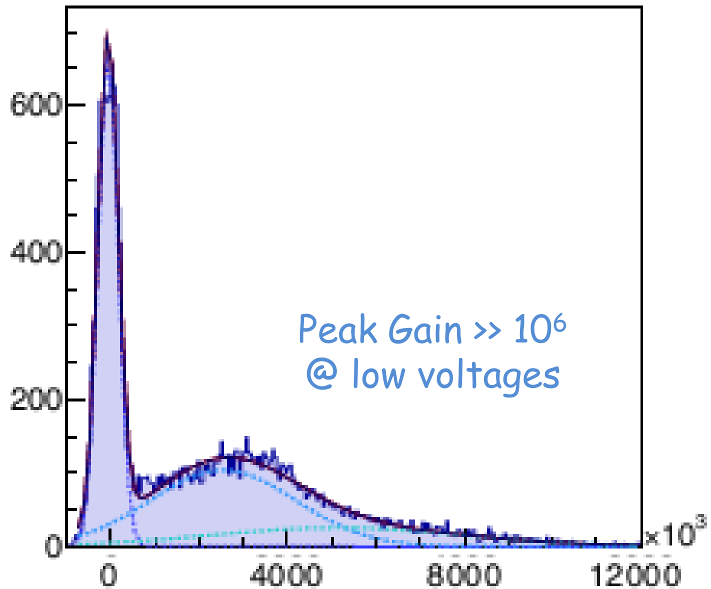


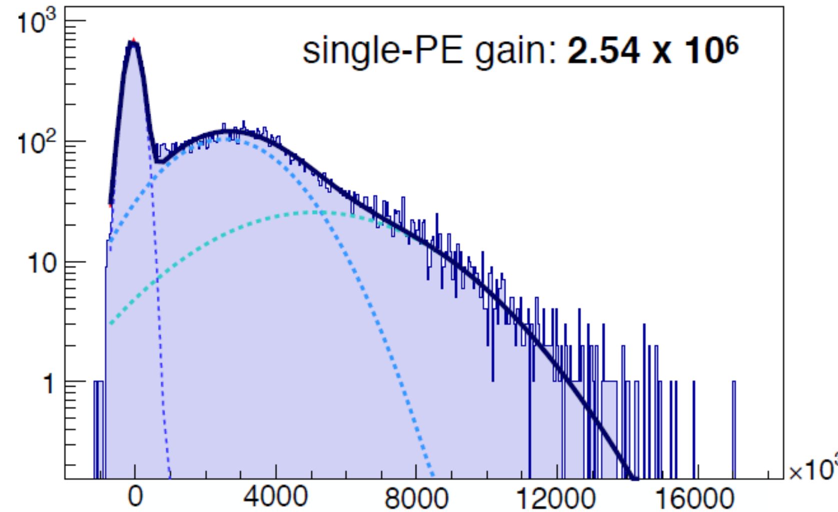


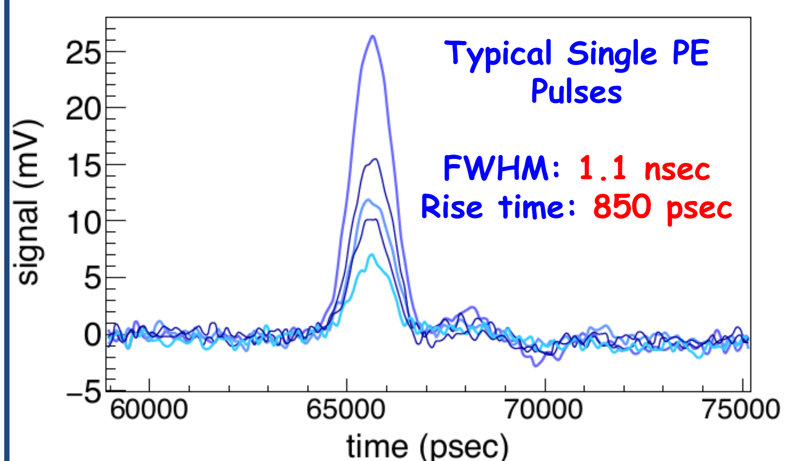


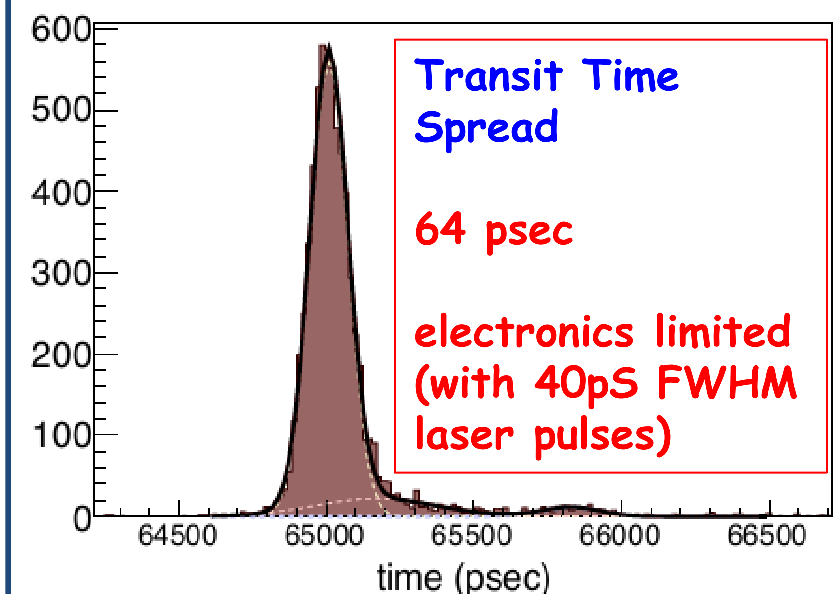
Time Resolution

Testing at Iowa State University, Matt Wetstein, ANNIE Program
for more details see **talk by Dr. Vincent Fischer on Saturday**









Dark Count Rate

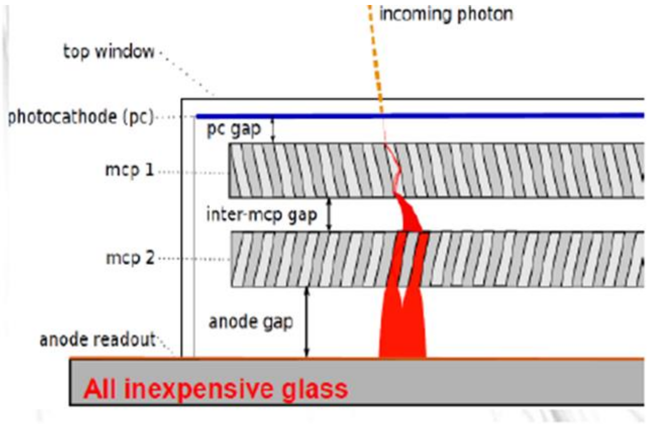
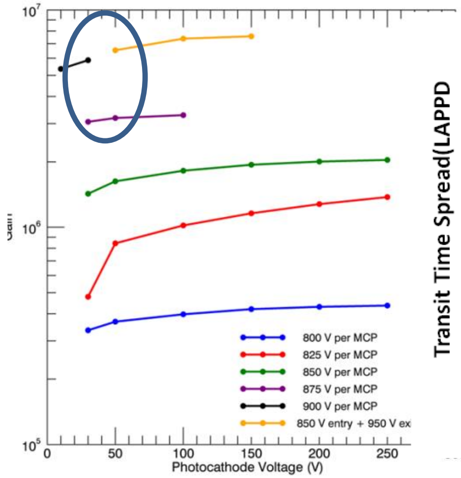
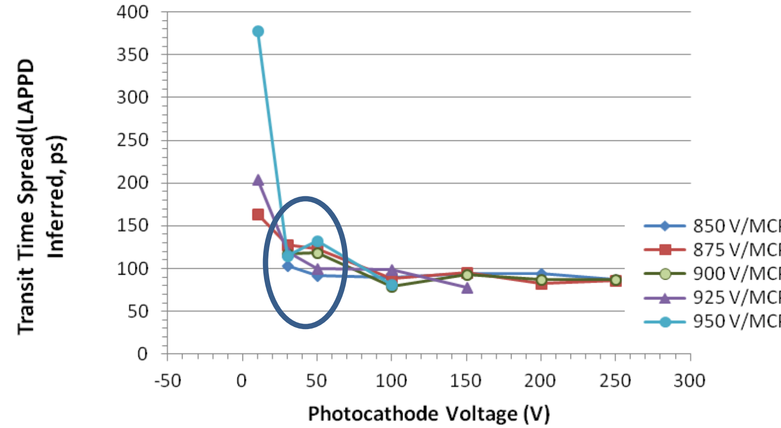
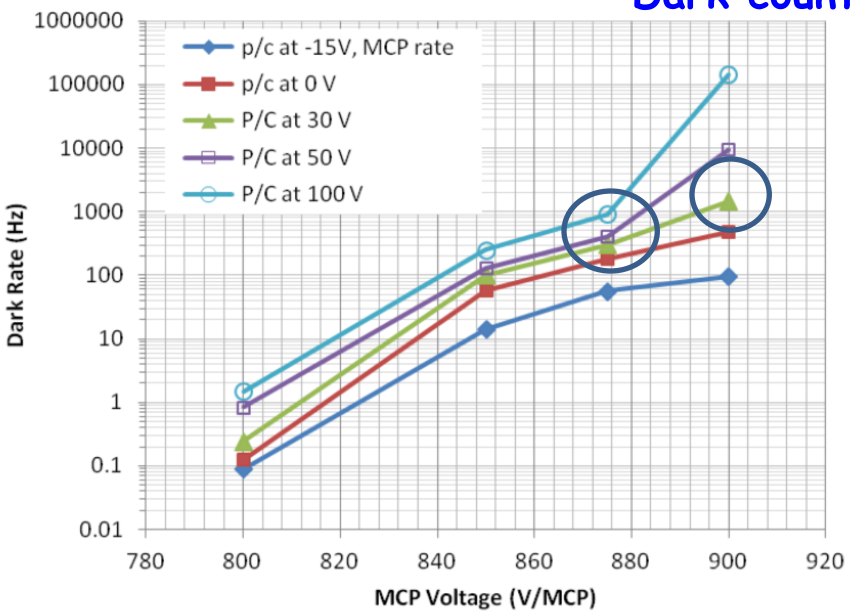


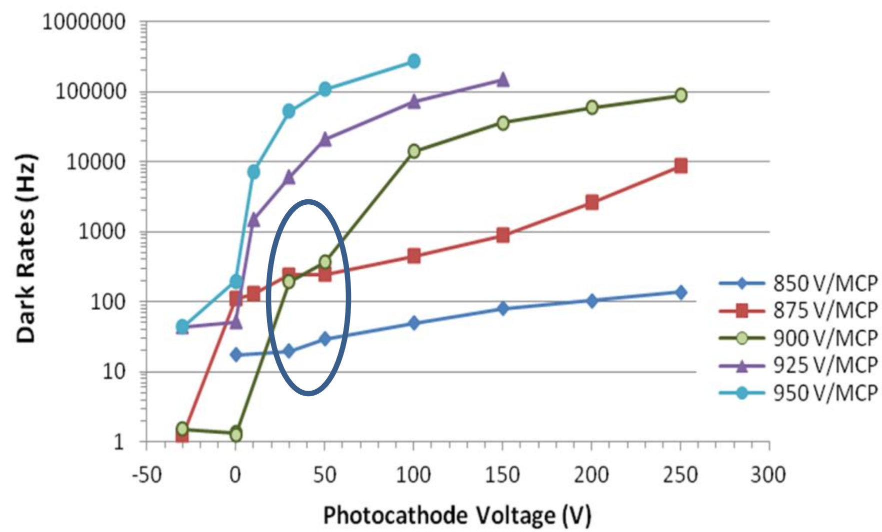
Illustration provided by Univ. of Chicago





Dark count rates per 13.5cm² strip

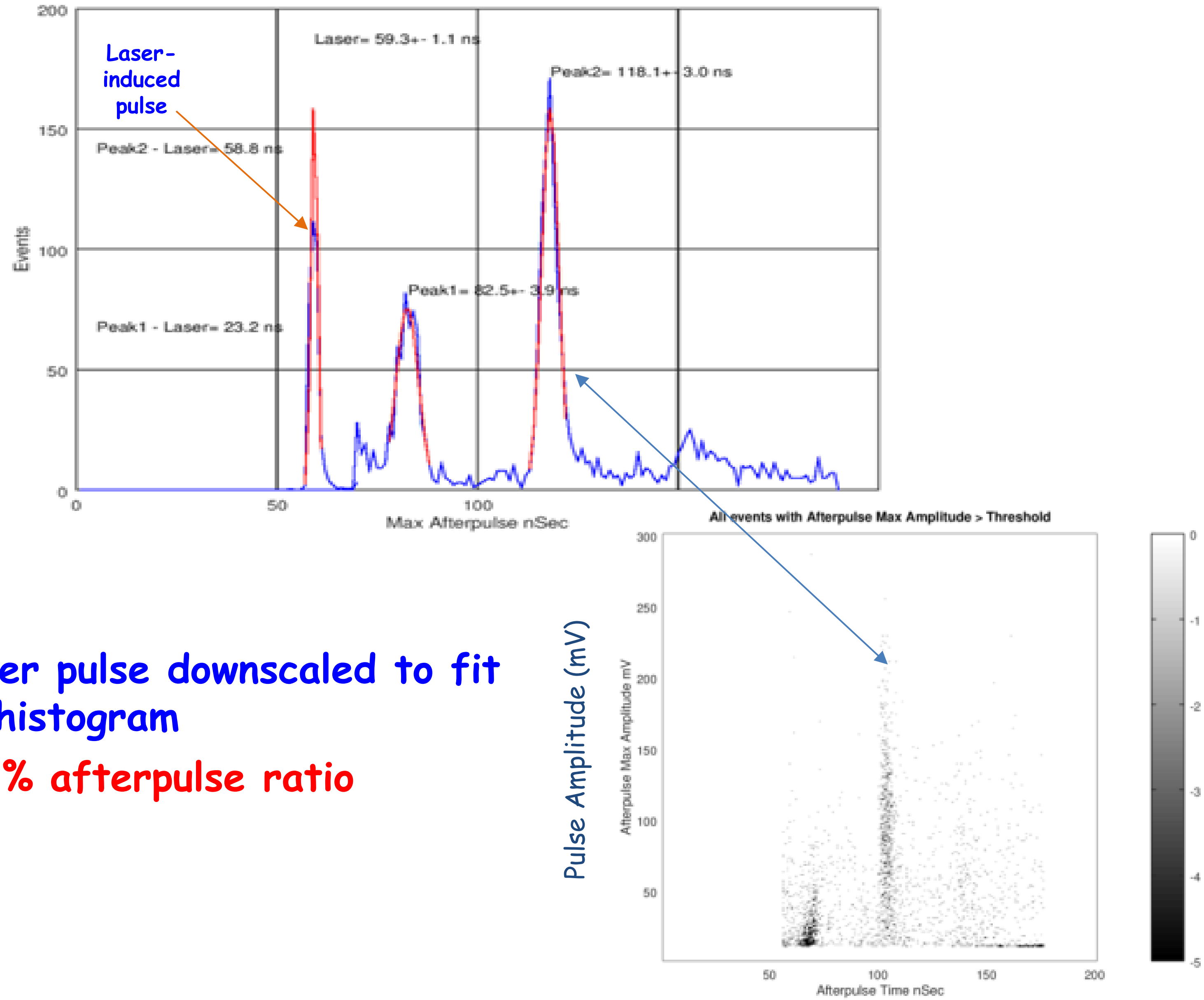




At optimal operation conditions @ 50V extraction voltage, 875V-900V MCP voltage with

Dark count rate 30-60 Hz/cm²

Afterpulses



- Laser pulse downscaled to fit on histogram
- 3.5% afterpulse ratio

LAPPD Pilot Production Timeline

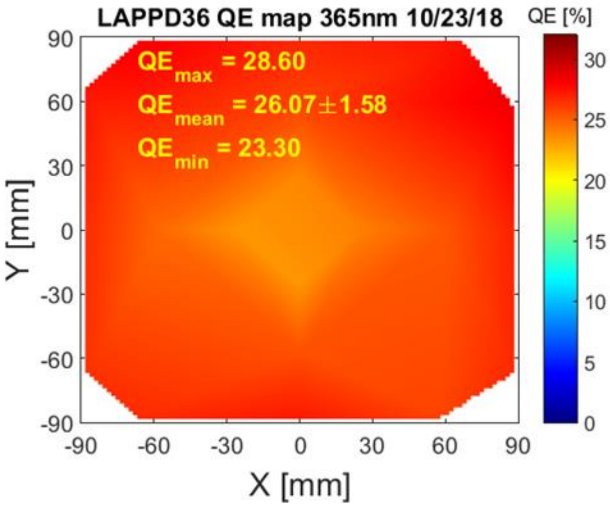
- DOE Funding to create infrastructure and demonstrate a pathway toward pilot production (April 2014)
- Facility operational (November 2015)
- LAPPD Commissioning trials initiated (December 2015)

  #9 – 9/14/2016, First Sealed Tile – Aluminum Photocathode
  #15 – 03/31/2017, Photocathode QE Optimization
  #22 – 10/10/2017, Mean 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
- Exploitation (2018)

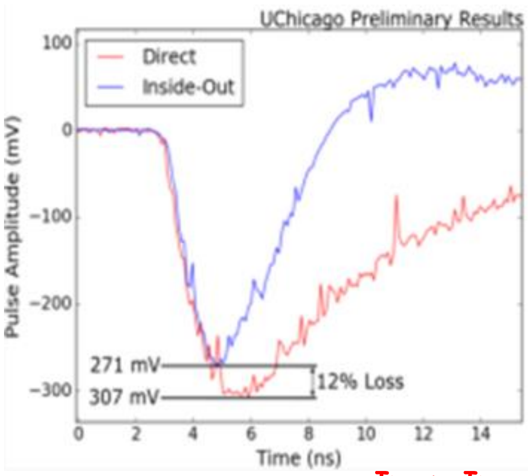
  Currently Producing prototypes for early adopters
  Process Optimization

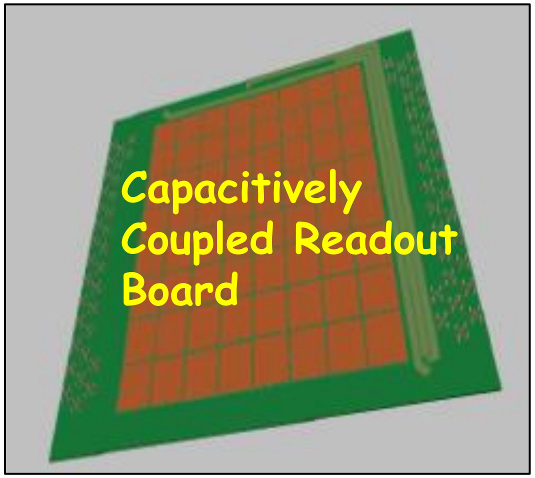
GEN II LAPPD

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



Only 12% loss in signal amplitude due to capacitive coupling





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/

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Workshop #5,

February 11 – 13th, 2019

Participants:

- Coming up

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Workshop #4,

October 9 – 11th, 2018

Participants:

- Mitaire Ojaruega (NGA-DOD)
- Kevin Richard Jackman (NGA-DOD)
- Varghese Anto Chirayath, (Physics, UTA)

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Workshop #3,

May 15-17th, 2018

Participants:

- Junqi Xie (ANL)
- Mickey Chiu, (BNL)
- Carl Zorn, (Jefferson Lab)
- Wenze Xi, (Jefferson Lab)
- Camden Ertley(UC B, now Incom Inc.)

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Workshop #2,

January 24-26, 2018

Participants:

- Matthew Malek (The University of Sheffield)
- Matt Wetstein (ISU – ANNIE Program)
- Lindley Winslow, Julieta Gruszko (MIT, NuDot)
- Albert Stebbins (Fermilab, Cosmology Group)
- Andrew Brandt, Varghese Chirayath (UTA)
- Klaus Attenkofer – BNL

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Workshop #1,

November 13 – 16th, 2018

Participants:

- Kurtis Nishimura (U of Hawaii / Sandia)
- Josh Brown (Sandia)
- Julieta Gruszko (MIT)

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LAPPD™ Early Adopter Programs

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

Summary & Conclusions

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

   A. GEN I LAPPD - Available Today!
      - Artifacts to be resolved as production volume and experience increases.
      - Providing early adopters a means to explore potential of PSEC timing.

   B. "Typical" performances meet early adopter needs:
      - Gain > $7X10^6$, or higher
      - Max PC QE (#36) ~ 27.7%, Mean ~ 25.8%
      - Time Resolution < 70 Picoseconds, and mm Spatial Resolution

II. GEN II - Capacitive coupling works, **ceramic package demonstrated**.

III. A good candidate for the use in 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 Micro-channel 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.

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Thank you!

Selected LAPPD References & Links

- **http://www.incomusa.com/mcp-and-lappd-documents/**
- 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
- Lyashenko, Alexey et al "**Further progress in pilot production of Large Area Picosecond Photo-Detectors (LAPPD™)"** New Technologies for Discovery III: The 2017 CPAD Instrumentation Frontier Workshop, University of New Mexico, Albuquerque, NM October 12-14, 2017
- Angelico, E. et al, "**Capacitively coupled pickup in MCP-based photodetectors using a conductive metallic anode"**, Nuclear Instruments and Methods in Physics Research A 846 (2017) 75–80
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- Siegmund, Oswald et al, "**Single Photon Counting Large Format Imaging Sensors with High Spatial and Temporal Resolution"**, Proceedings of the Advanced Maui Optical and Space Surveillance (AMOS) Technologies Conference, 2017.
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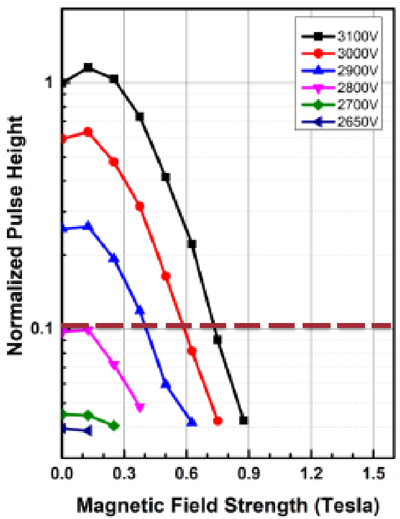
- Adams, B.W et al. "**A Brief Technical History of the large-Area Picosecond Photodetector (LAPPD) Collaboration"** - Submitted to: JINST arXiv:1603.01843 [physics.ins-det] FERMILAB-PUB-16-142-PPD, March, 2016
- M.J. Minot, et al., **Pilot production & commercialization of LAPPD™**, Nuclear Instruments and Methods in Physics Research A 787 (2015) 78–84

LAPPD & Small Format Tile Magnetic Field Testing

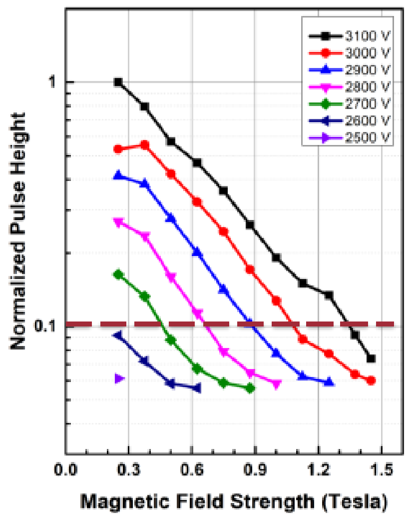
ANL 6cm Small Format Tile - 10 & 20 μ MCPs

Tube #69



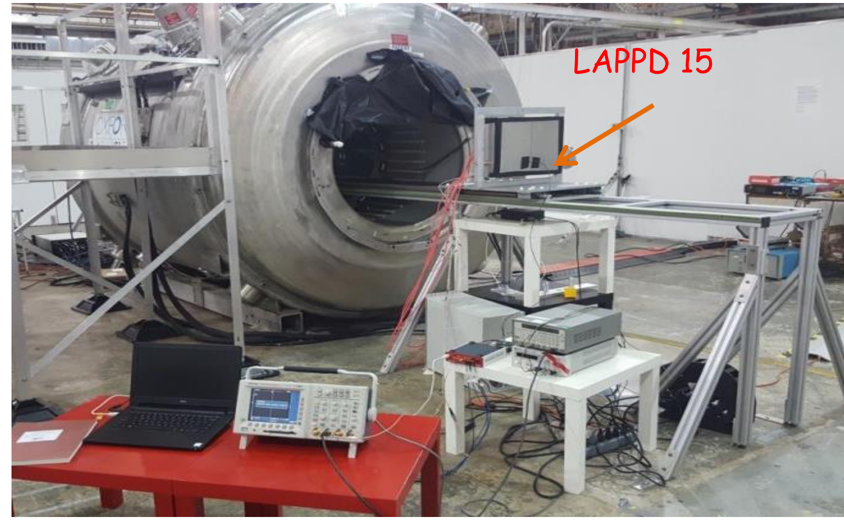
20 μm MCP-PMT 0.7 T

Tube #85



10 μm MCP-PMT 1.3 T

LAPPD #15



B field limit

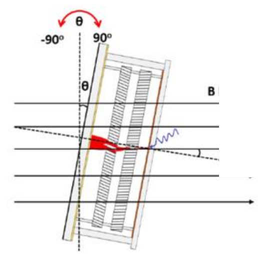
Gain decreased with increasing field

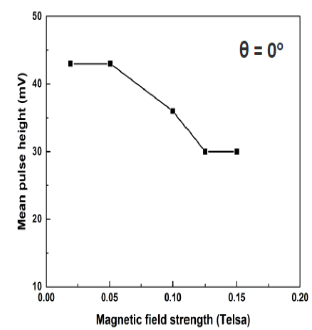
Max with field aligned with MCP pore

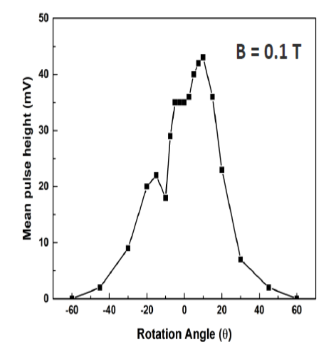
~0.7 T with 20 microns

~1.3 T with 10 microns

Angle dependence







J. Xie et al., ICHEP 2018, S. Korea

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:

Timing	Cmrcl Price	DOE Price	Cum Vol.	Annual Capacity
Current	$ 75,000	$ 50,000	48	48
1	$ 56,250	$ 37,688	58	82
2	$ 45,000	$ 30,150	144	120
3	$ 36,900	$ 24,723	268	204
4	$ 31,365	$ 21,015	502	264
5	$ 30,032	$ 20,121	1,000	278

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.