2018 IEEE Nuclear Science Symposium and Medical Imaging Conference
Sydney, Australia, November 10-17, 2018

N-31, Photodetectors II, Cockle Bay I., Thursday, Nov. 15, 2018 - 08:00 AM

Large Area Picosecond Photodetector (LAPPD) Performance Test Results

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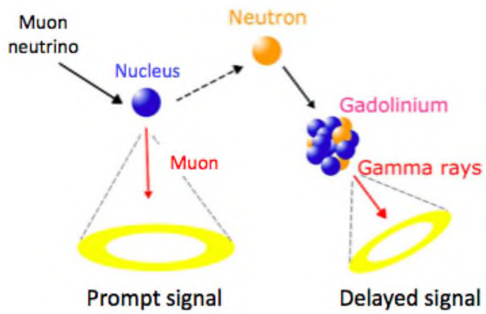
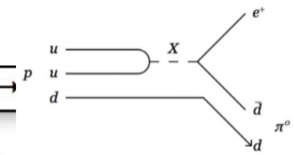
2) Iowa State University, Ames, IA USA

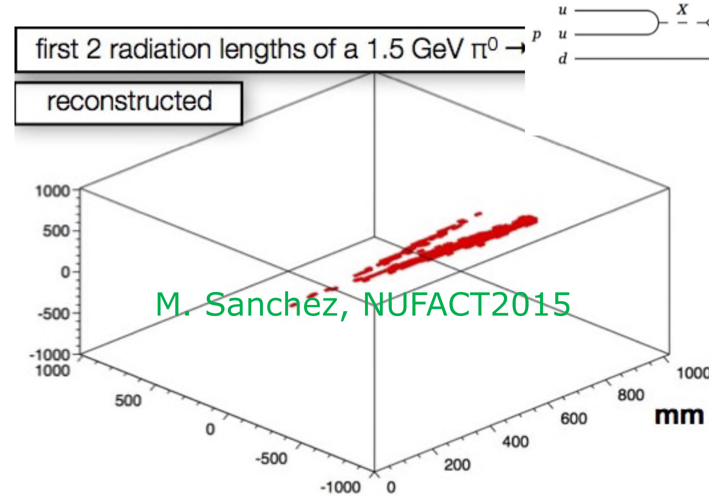
Bernhard W. Adams[1], Melvin Aviles[1], Till Cremer[1], Camden D. Ertley[1], Michael R. Foley[1], Cole J. Hamel[1], Alexey Lyashenko[1], Michael E. Stochaj[1], William A. Worstell[1],

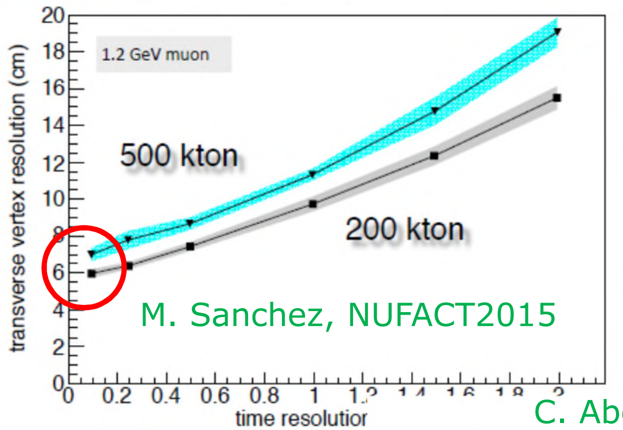
Fast timing enables many benefits

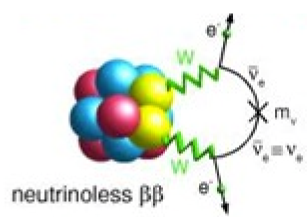


1) More efficient background rejection







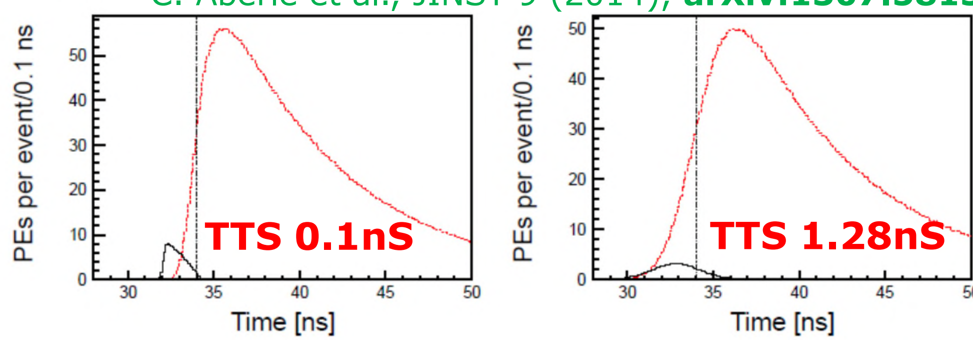


https://people.nscl.msu.edu/~witek/Classes/PHY802/betadecay2017a.pdf

5) Precise track reconstruction

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

2) High vertex resolution in large scale experiments

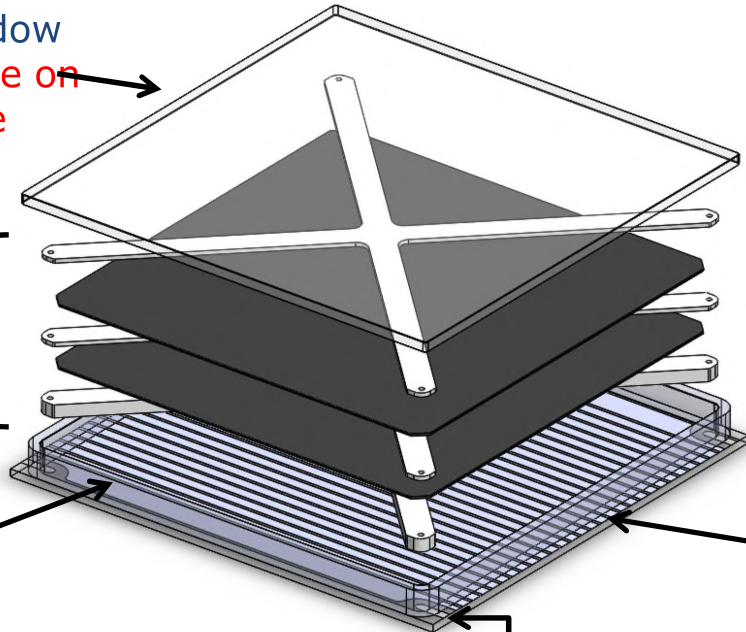


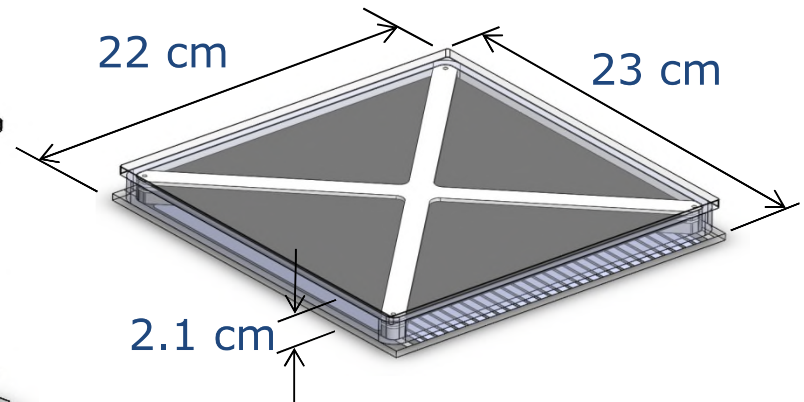
(a) Default simulation. (b) Increased TTS (1.28 ns).

4) Directionality information

3) Separation of Cherenkov and Scintillation light

LAPPD™ - An MCP based photodetector, capable of imaging with single-photon sensitivity at high spatial and temporal resolutions in a hermetic package with an area of 400 cm^2.





- Pin Free
- Signal & HV pass under frit bonded side walls.
- Active area: 195 x 195mm =34,989 mm^2, 350 cm^2 , 92% active area

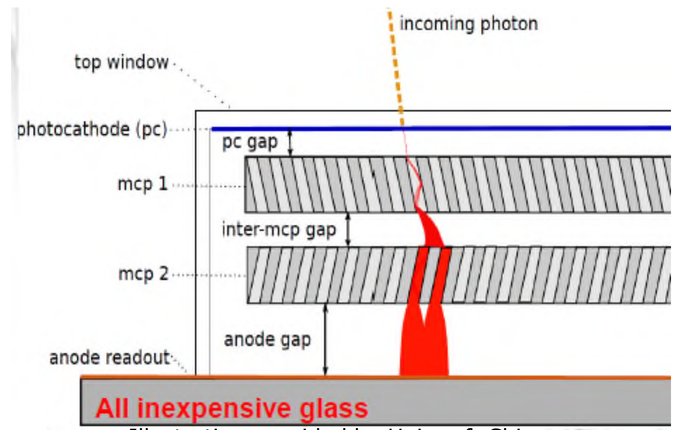
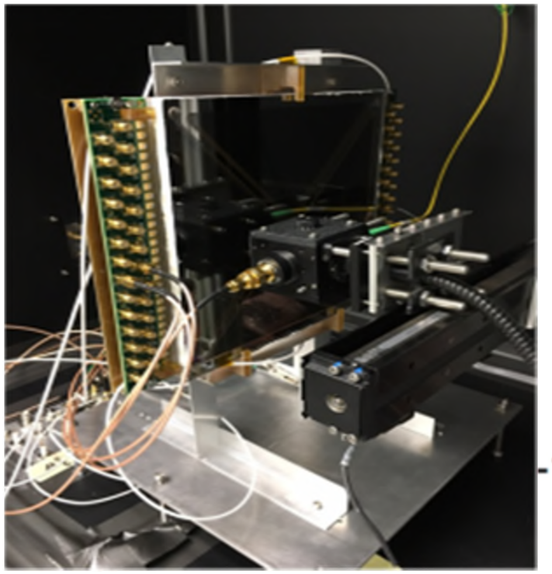


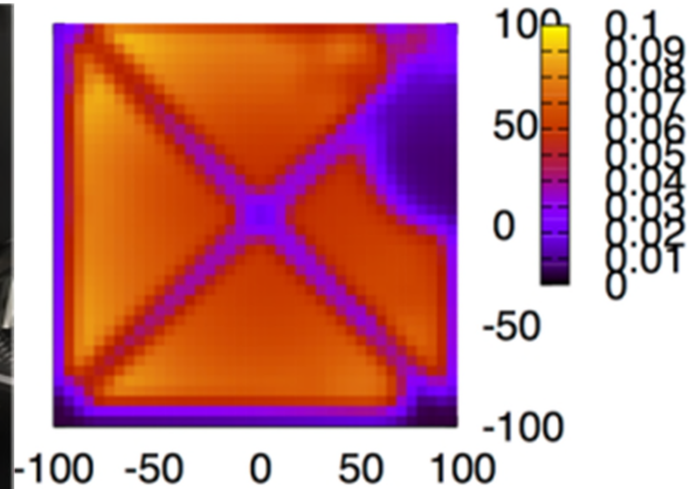
Illustration provided by Univ. of Chicago

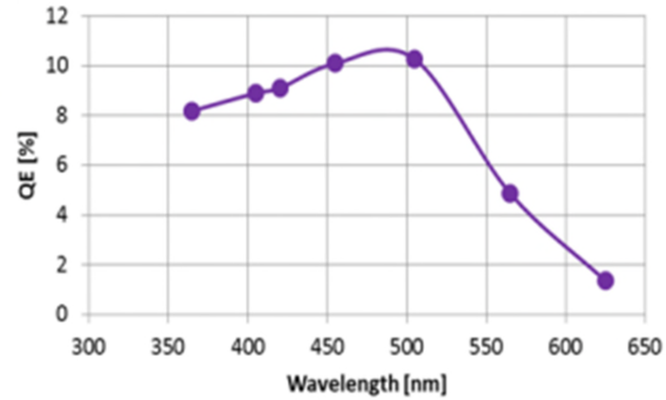
LAPPD #25 & #31 Performance Summary

Parameter	LAPPD 25	LAPPD 31
MCP resistance (Entry/Exit; MΩ)	10.7 / 14.2 MΩ at 875 V	9.7 / 10.5 MΩ at 900 V
QE @365 nm	Max: 10%, Mean: 7.1%, s = 0.8% @455 nm: Mean: 10.2%	Max: 14%, Mean: 9.8%, σ = 1.1%
Gain 30 V on the photocathode	7.5 x10^6 @ 850/950 V (entry/exit)	8.0 X10^6 @ 925/925 V (entry/exit), $\sigma \leq$ 50% mean
Dark rate (Single 13.5 cm2 strip)	9.5 Cts/s-cm^2 @ 50 volts on the P/C, 850 V/MCP, and Threshold of 7.6x10^5 gain	14 Cts/s-cm^2 @ threshold of 8E5 gain (134 fC), 900 V/MCP, 30 V on photocathode
After pulses	Typical for MCP PMT – about 3.5%	Very few!
Along-strip **Spatial Resolution** Cross-strip	2.8 mm RMS 1.3 mm RMS	2.4 mm RMS 0.76mm RMS
Transit Time Spread	(Provisional: limited by current instrumentation)	
	64 psec MCP Pulse Risetime: 850 psec, FWHM: 1.1 nsec	99 psec

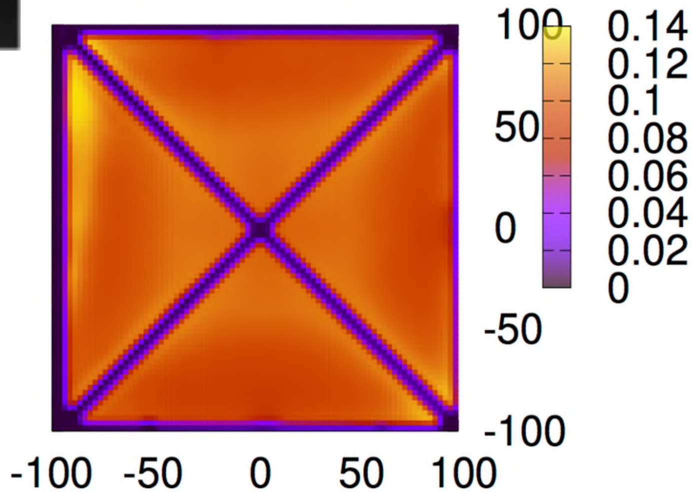
Photocathode QE - LAPPD #25 & #31



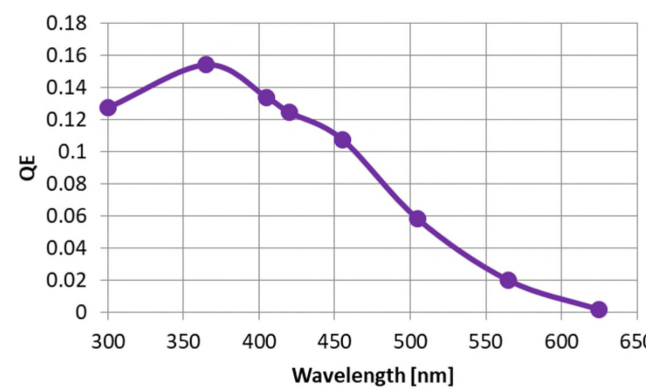




- 365 nm UV LED
- ~2.5 mm dia.
- 3 mm scan steps



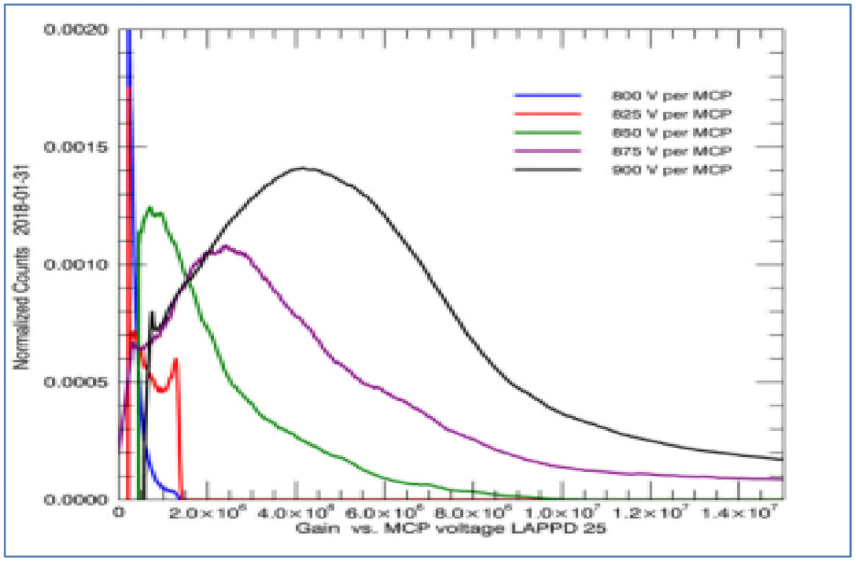
PC QE map @ 365 nm

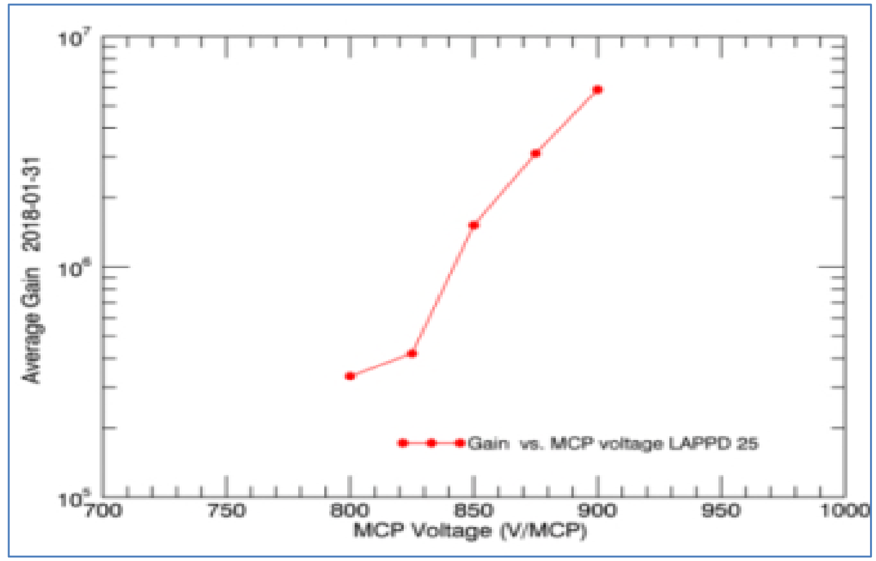


QE vs. λ @ PC deposition temperature

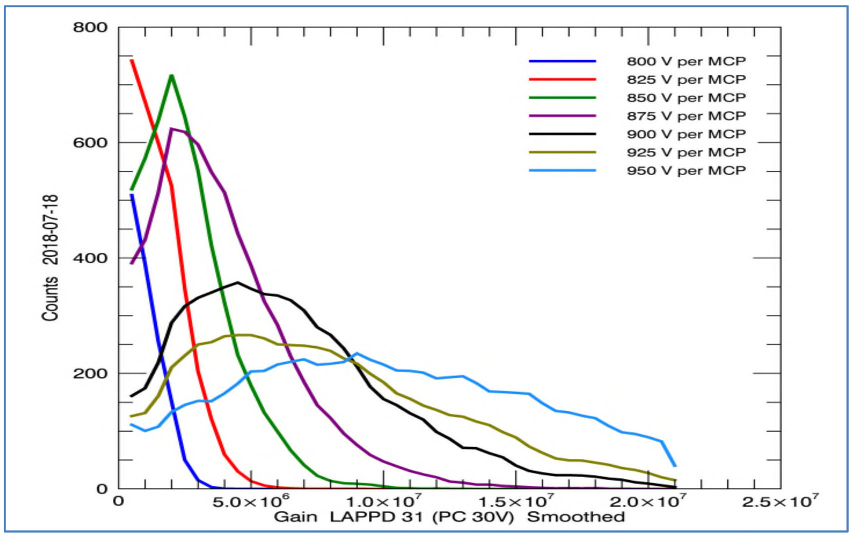
Single PE Gain vs. MCP voltage

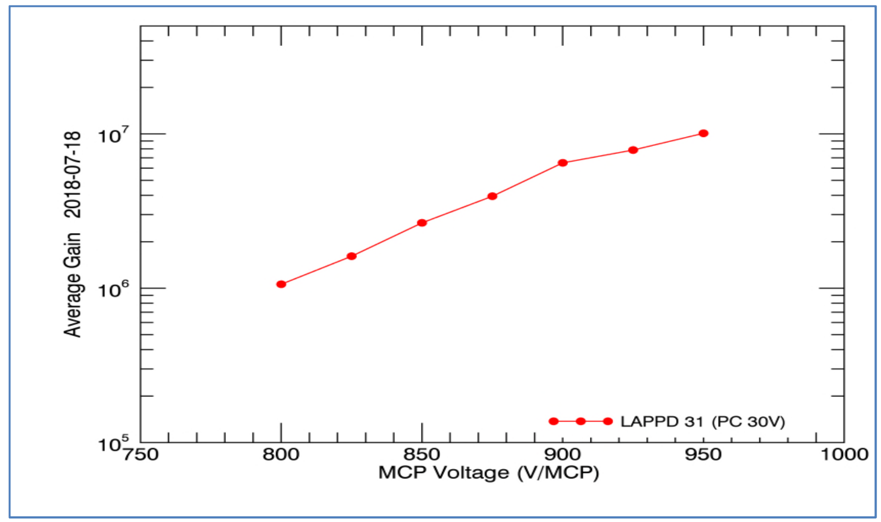
LAPPD #25





LAPPD #31



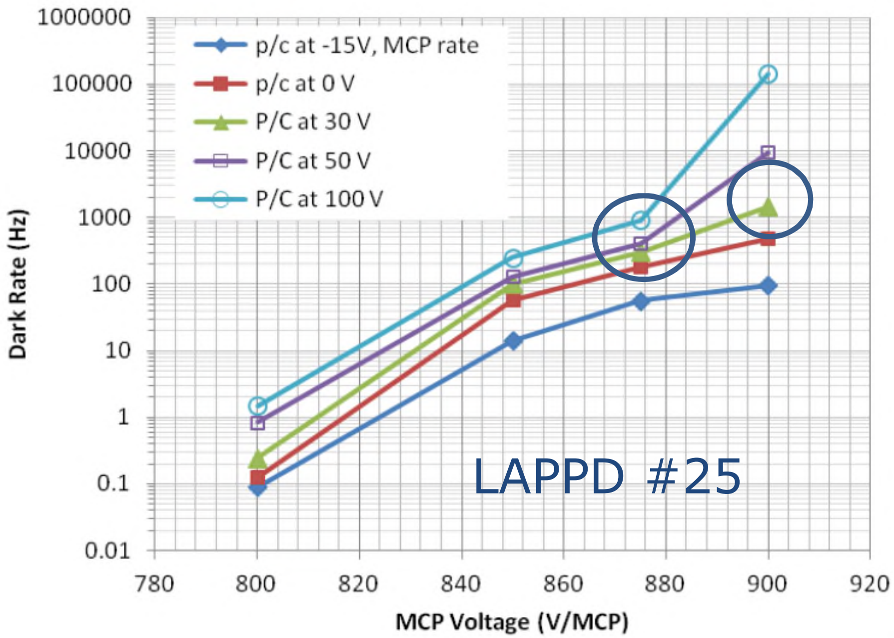


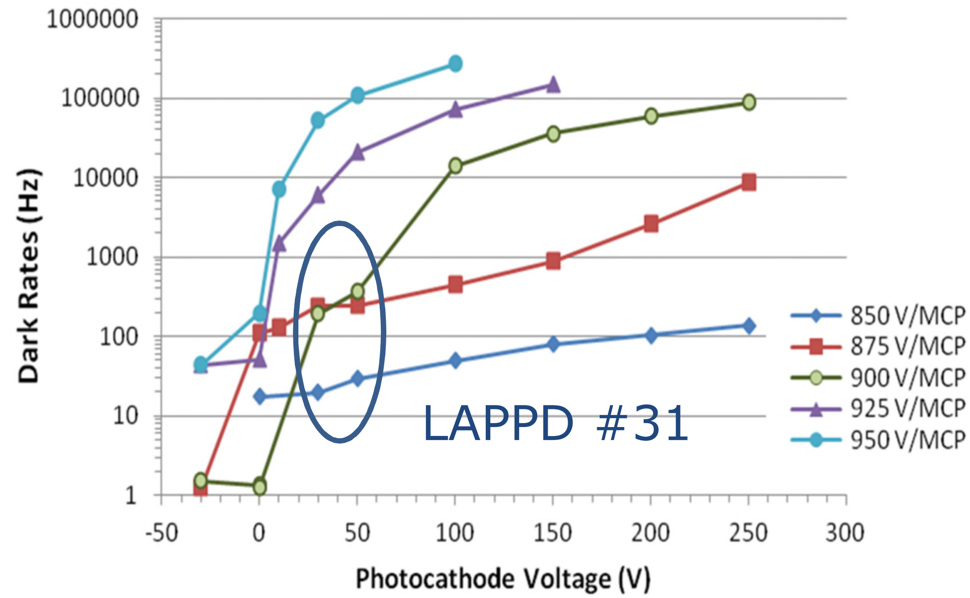
Single PE Pulse Height Distributions

Average gain vs. MCP voltage

Dark Count Rate

Dark count rates / 13.5 cm² strip





For Optimal Operating Conditions

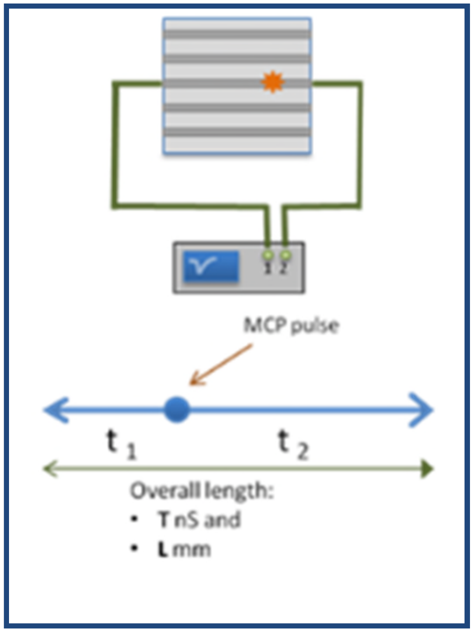
@ 50V extraction voltage,

@ 875V-900V MCP voltage

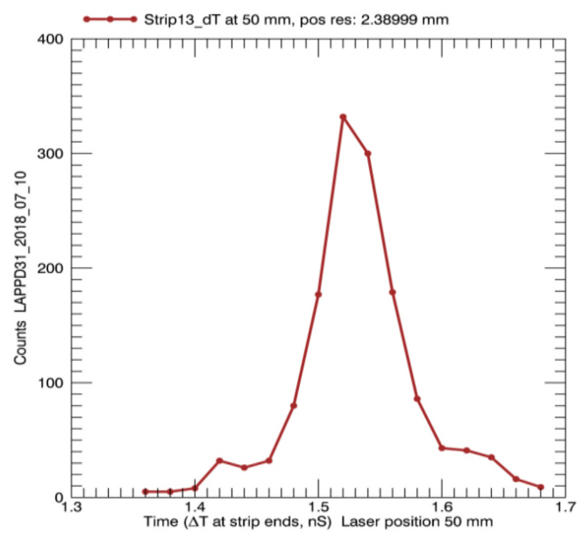
Dark Count Rate = 30-60 Hz/cm²

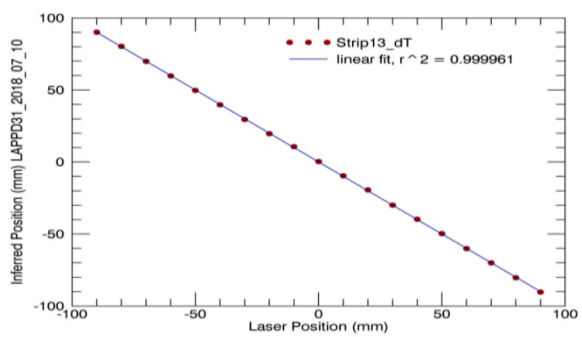
Spatial Resolutions - LAPPD #31

Along a Strip



Relative time of arrival, for a single laser position on the strip

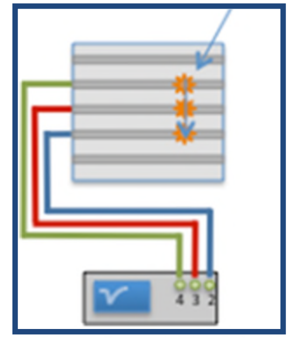


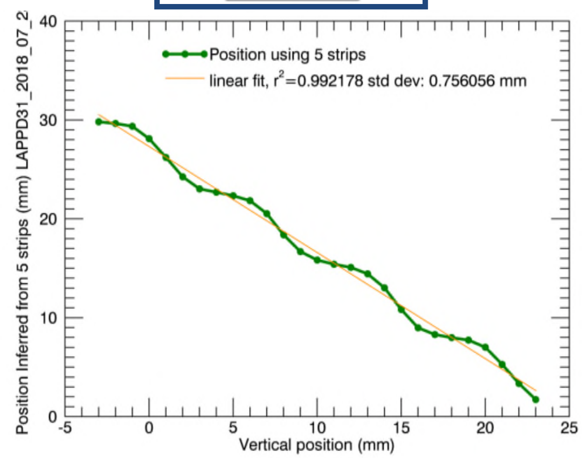


DRS4 waveform samplers

- Pulses observed at both ends of a strip.
- Resolution= **2.4 mm**

Across Strips

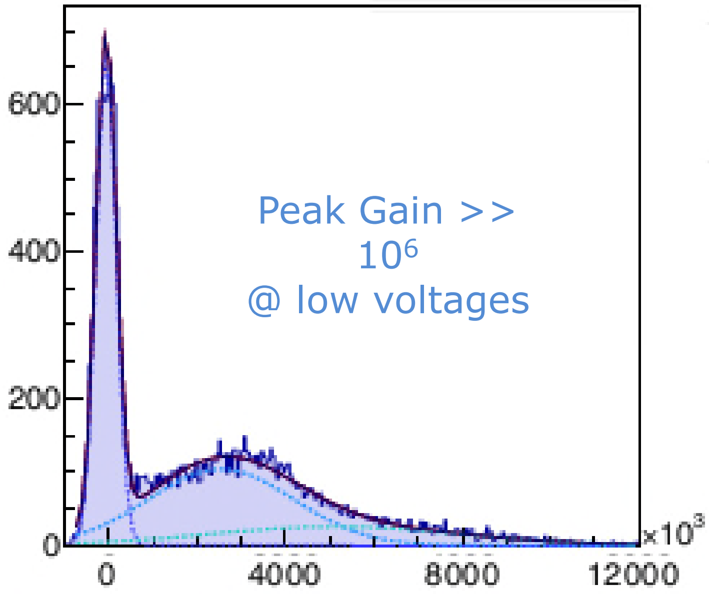


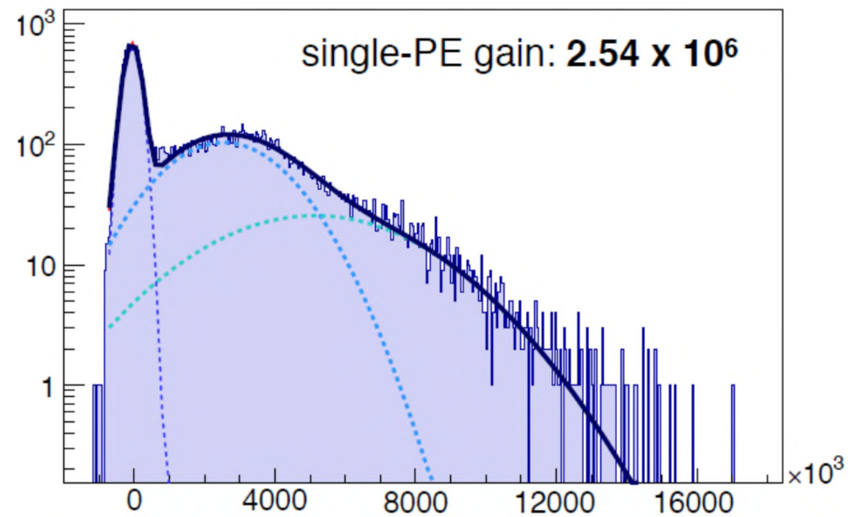


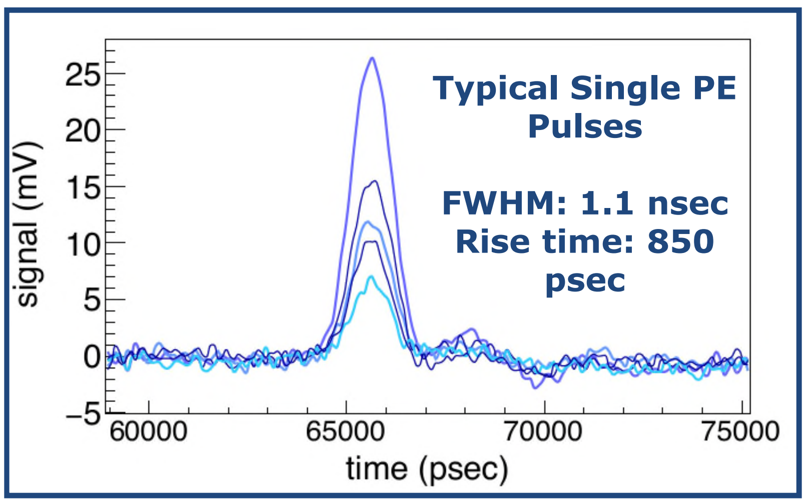
- Position by centroiding five adjacent cross-strip signals.
- Resolution= **0.76 mm**

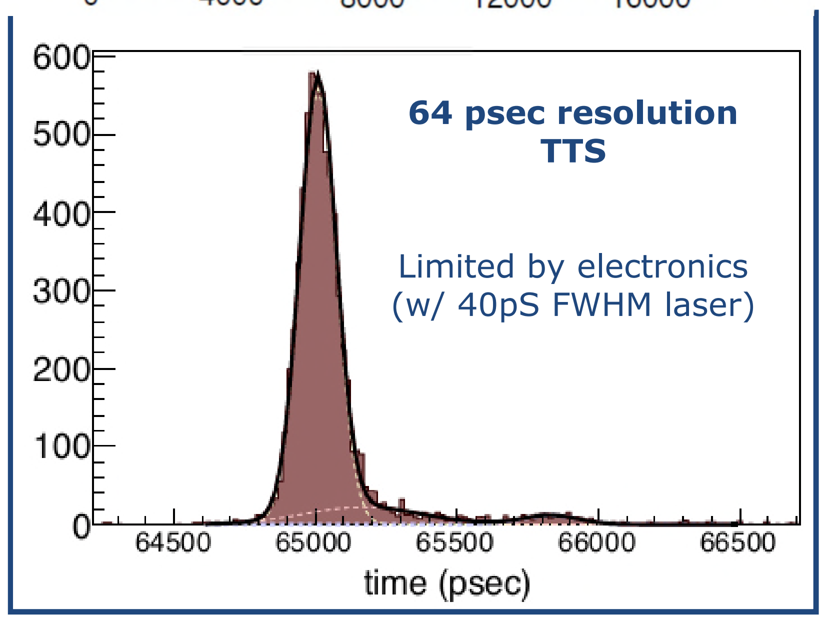
Time Resolution LAPPD #25

Testing at Iowa State University, Matt Wetstein, ANNIE Program





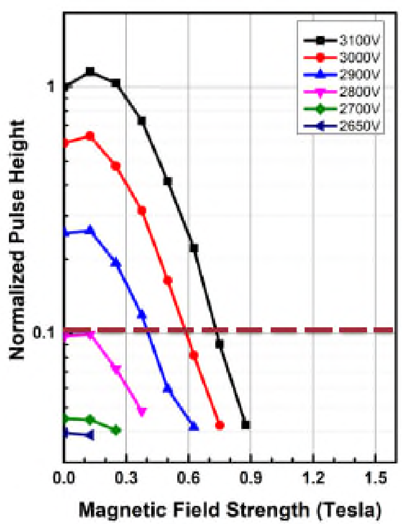




LAPPD & Small Format Tile Magnetic Field Testing

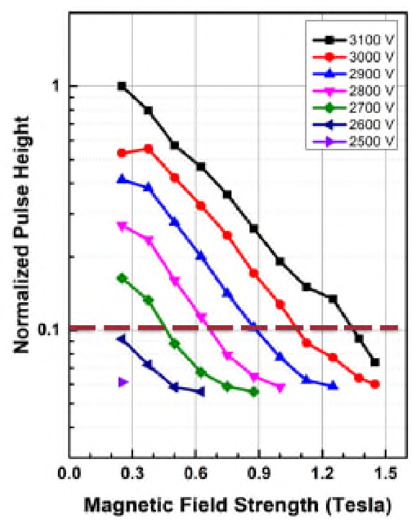
ANL 6cm Small Format Tile, 10 & 20µ MCPs

Tube #69



20 µm MCP-PMT 0.7 T

Tube #85



10 µm MCP-PMT 1.3 T

LAPPD #15

B field limit

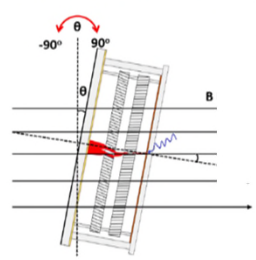
Gain decreases with increasing field

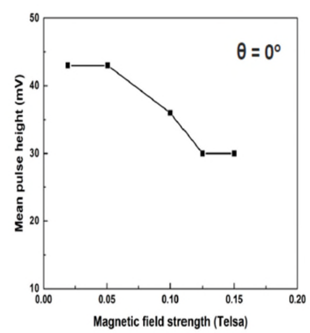
Max with field aligned with MCP pore

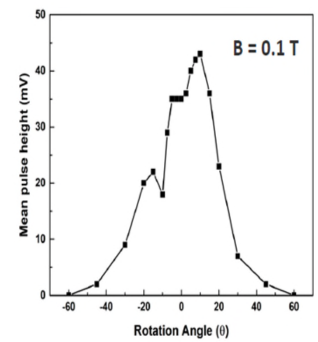
~0.7 T with 20 microns

~1.3 T with 10 microns

Angle dependence



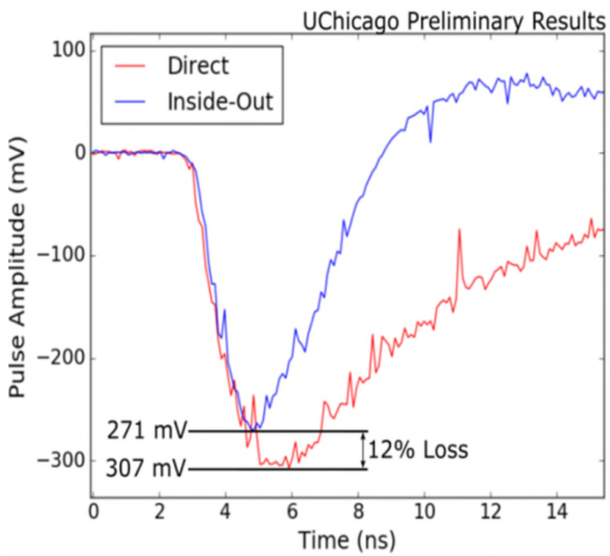




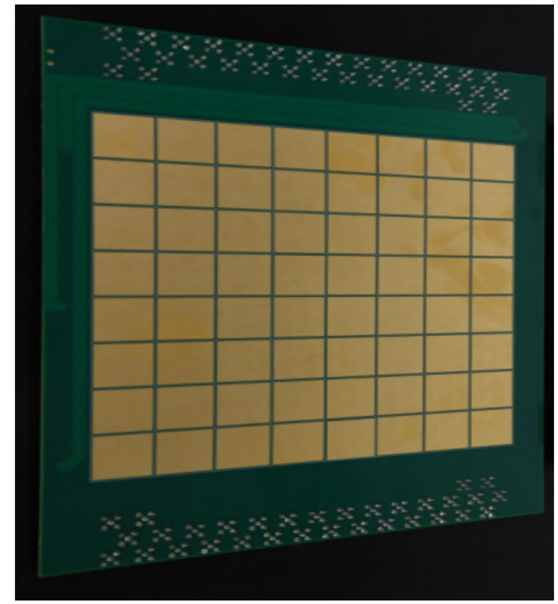
J. Xie et al., ICHEP 2018, S. Korea

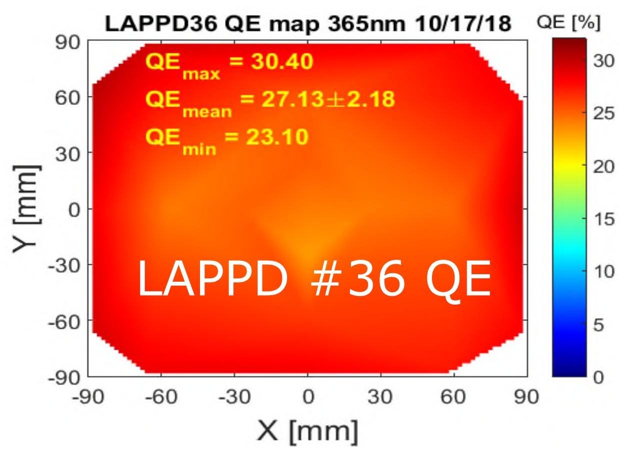
GEN II LAPPD

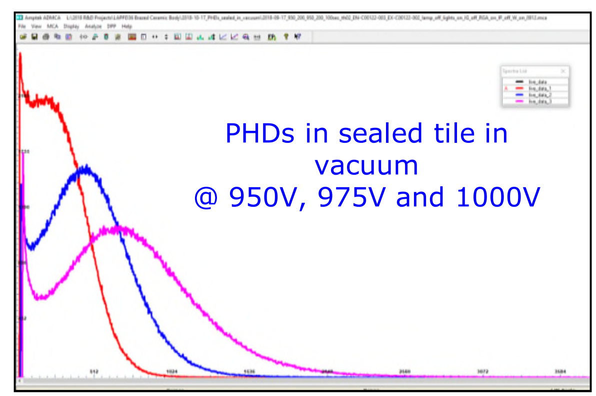
- A robust ceramic body,
- Capacitive signal coupling: to an external PCB anode
- Pixelated anodes: to enable high fluence applications



The MCP fast signal pulse was capacitively coupled through the ceramic, to strips or pads on the outside.





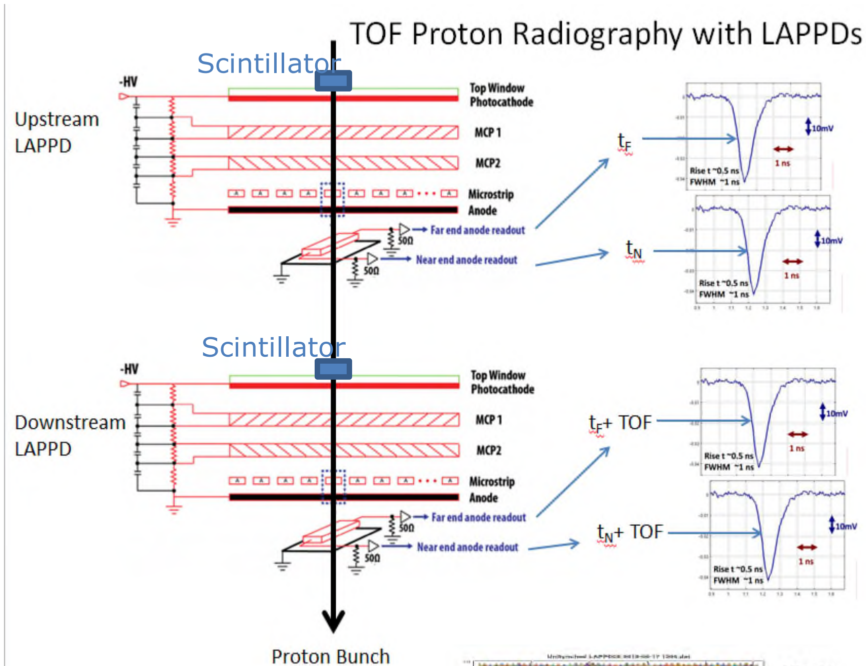


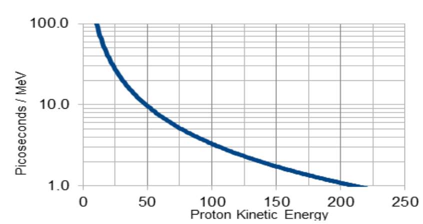
LAPPD™ Early Adopters

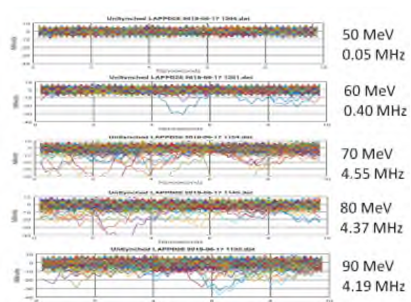
PI & SPONSOR	PROGRAM TITLE
Mayly Sanchez and Matthew Wetstein, Iowa State	**ANNIE**: Atmospheric Neutrino Neutron Interaction Exp.
Erik Brubaker, Sandia National Lab/CA	**NEUTRON IMAGING CAMERA**
Graham Smith, Klaus Attenkofer (BNL)	Gamma & Neutron Detectors
Henry Frisch (U of Chicago) , Dmitri Denisov (Fermilab)	Precision Time-of-Flight with Commercial Photodetectors at the **FERMILAB TEST BEAM**
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**)
Andrew Brandt, (UT Arlington)	Life Testing of LAPPD

Medical Imaging Applications of LAPPDs

TOF Proton Radiography for Proton Therapy Imaging



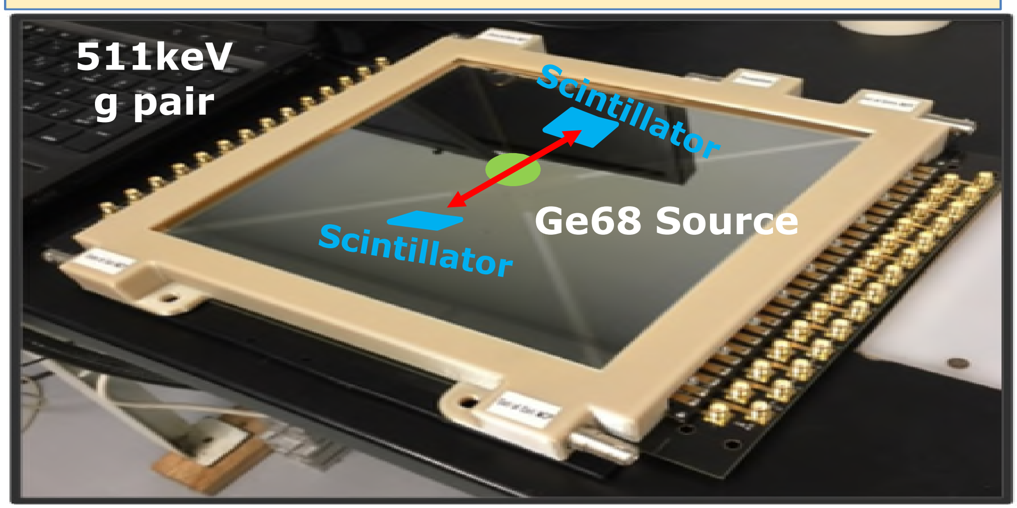




First Proton Waveforms

Portable LAPPD Telescope

Time-of-Flight PET Development



Summary & Conclusions

I. GEN I LAPPD - Available Today!
   - o Artifacts are being resolved as production volume and experience increase.
   - o Providing early adopters a means to explore potential of PSEC timing.

II. "Typical" performances meet early adopter needs:
   - o Gain > $7X10^6$, or higher
   - o Max PC QE (#36) Max ~ 27.7%, Mean ~ 25.8%
   - o Time Resolution < 70 Picoseconds, and Spatial Resolution 2.4mm

III. GEN II - Capacitive coupling & ceramic package demonstrated.

IV. Picosecond timing & high spatial resolution:
   - o Brings transformative change to detector technology
   - o Applications: Particle physics, Cherenkov imaging, Medical imaging, Homeland security, Neutron imaging and others.

V. Incom works with early adopters 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.

For more information

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

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Cell: 978-852-4942

Matthew J. Wetstein
Iowa State University
wetstein@iastate.edu
Cell: 630-885-9742

Cheers!

BACK UP

Incom Measurement & Test Workshops

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

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Workshop #4,

October 9 – 11th, 2018

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

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Workshop #3,

May 15-17th, 2018

- 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

- Matthew Malek (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, 2017

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

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LAPPD Price Projections

Incom targets a price of

$10,000 or less

as cumulative volumes of product produced approach 10,000 units.

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

- Costs driven by overhead rates, non-reimbursed R&D Costs, & low volume
- Costs drop rapidly, as demand and volume increases.

LAPPD #	Seal Date	Indium Seal	MCP GAIN	QE % @365 nm Performance	Disposition
22	10/10/2017	Good	**7 X10^^{6}** @ 1050 V σ ≤ 50% mean	Max / Mean =14.74 / **10.62** QE % @420 nm (Mean) = 11.5%	**Sandia** Final Report Available
25	12/14/2017	Good	**7.5 x10^{6}** @ 850/950 V (entry/exit)	@ 365 nm (Mean / s)= **7.1** / 0.8% @455 nm (Mean) = 10.2% ± 1.5	**ANNIE** Final Report Available
28	2/8/2018	Good	**3X10^^{7}** (M&T Gain) Low dark rate = 7 cnts/cm^2 .	Experimental PC, no Sodium Mean = **1.96%** ± 0.6%	**Available** **MGH Proton Therapy Experiment** Report Pending, Heavy after pulses Suitable for triggered applications,
31	5/25/2018	Good	**8.0 X10^^{6}** @ 925/925 V (entry/exit)	Max / Mean / s = 14 / **9.8** / 1.1	**ANNIE** Final Report Available
35	9/19/2018	Stabilized following Initial Drop	**Mid-10^^{6}** range at ~975 V/MCP Dark rates sensitive to PC voltage High voltage performance is OK	Max / Mean / SDev = 3.4 / **1.5** / 0.5	**Available** Functional Report Pending
36	10/16/2018	Good	C14 MCPs **Under Test**	Max/Mean/Min = 27.7 / **25.8** / 22.7 Excellent QE	**1st Gen II Ceramic Tile** Functional Report Pending

Large Area Photocathode Capability Demonstrated

Average QE >20%, Average QE >15%, Average QE >10%,

LAPPD#	Seal Date	Maximum QE %	**Average QE %**	Minimum QE %
9	9-14-2016		Typical for Al	
10	10/11/2016		4.2-6.5	
12	12/21/2016	16.5	11.1	6.7
13	1/25/2017	**23.5**	18.6	13.5
15	3/31/2017	**25.8**	**22.3**	15.7
22	10/10/2017	14.7	10.6	7
23	11/2/2017	17.5		
25	12/14/2017	10	7.1	5
28	2/8/2018		2.0	
29	3/21/2018	19.6	13.0	3.0
30	4/10/2018	**22.9**	17.2	13.0
31	5/25/2018	14.0	9.8	1.1
32	6/27/2018	**22.7**	**20.8**	19
33	8/7/2018		**~ 21** @ Temp	
34	8/29/2018		11.2	
35	9/19/2018	3.4	1.5	0.5
36	10/16/2018	**27.7**	**25.8**	**22.7**

Early Adopter	Application	LAPPD Shipped	Pending Order	Month Oct-18	Month Nov-18	Month Dec-18	Month Jan-19	Month Feb-19	Month Mar-19	Month Apr-19	Month May-19
Mayly Sanchez and Matthew Wetstein, Iowa State	ANNIE - Atmospheric Neutrino Neutron Interaction Experiment	2	2	Sale	Sale	Sale					
			1			Loaner					
Erik Brubaker, Sandia National Lab/CA	Neutron Imaging Camera	1	0								
Graham Smith, Klaus Attenkofer (BNL)	Gamma & Neutron Detectors		1							Sale	
Henry Frisch (U of Chicago) , Dmitri Denisov (Fermilab)	Precision TOF with Commercial Photodetectors at the Fermilab Testbeam Facility		2				Sale	Sale			
Matthew Malek,(u of Sheffield)	WATCHMAN, UK STFC		1						Sale		
Josh Klein, U of Penn	Spectrally Sorting of Photons, using Dichroic Films and Winston Cones, WATCHMAN, THEIA		1								Sale
Gabrial D. Orebi Gann (UC Berkeley)	WATCHMAN, THEIA		1					Loaner			
Zein-eddine Meziani	High Rate Trials at Jefferson Labs, EIC		1				Loaner				
Andrey Elagin (U of Chicago)	Neutrino-less Double-Beta Decay		0								
Mickey Chiu (BNL) -	Phenix Project - "eIC Fast TOF"		0								
John Learned, U. of Hawaii, and Virginia Tech	Short Baseline Neutrino (NuLat)		0								
Lindley Winslow (MIT)	Neutrino-less Double-Beta Decay (NuDot) Using Fast Timing Detectors		1		Loaner						
Andrew Brandt, (UT Arlington)	Life Testing of LAPPD		1						Loaner		
		Total Tiles =	12	1	2	2	2	2	2	1	1

Selected LAPPD References & Links

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

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- Ertley, Camden et al, "**Microchannel Plate Imaging Detectors for High Dynamic Range Applications"**, IEEE Transactions on Nuclear Science, 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