R&D on LAPPDs

Simona Malace

Jefferson Lab

Outline

→ Timeline of my R&D on LAPPDs

→ Results so far

→ What’s in the works and projected results for FY24

→ On my must/wish list for FY24 and beyond

Timeline of my R&D on LAPPDs: 2021

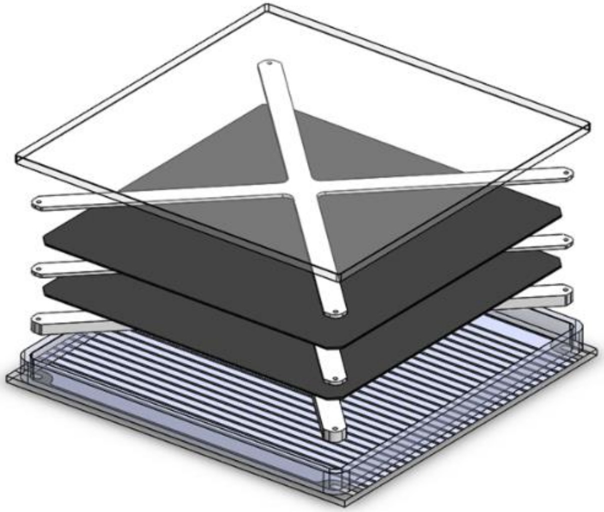
- Identification of single photoelectron signals on Incom Inc. LAPPD38 with a Hamamatsu maPMT as witness

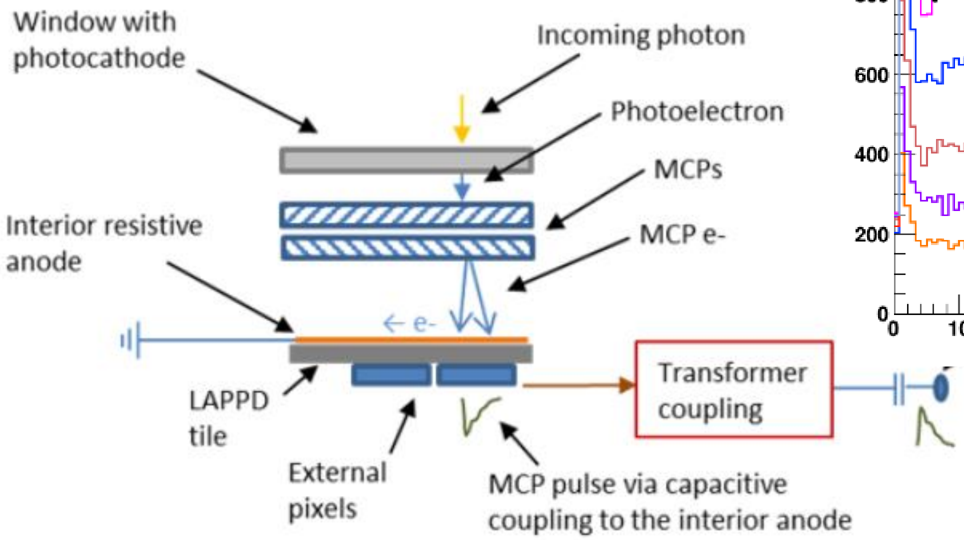
Single photoelectron identification with Incom LAPPD 38

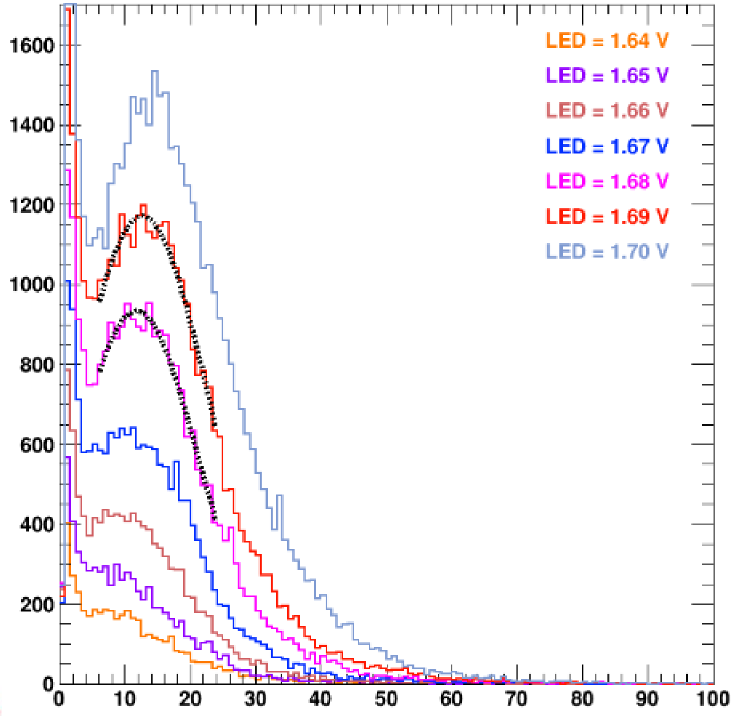
S.P. Malace (Jefferson Lab), S. Wood (Jefferson Lab) (Apr 29, 2021)

Published in: *JINST* 16 (2021) 08, P08005 • e-Print: 2104.14597 [physics.ins-det]

window	5 mm thick borosilicate
photocathode	potassium, sodium, antimony 0.345 μm thick
photocathode - first MCP gap	2.8 mm created via X-spacers
first MCP	borosilicate, 65% open area ratio 1.2 mm thick
gap between first and second MCP	1.1 mm created via X-spacers
second MCP	borosilicate, 65% open area ratio 1.2 mm thick
second MCP - anode gap	6.6 mm created via X-spacers
anode	3.8 mm borosilicate with 12 μm thick silver strips







Timeline of my R&D on LAPPDs: 2021-2022

LDRD Funding awarded for FY22 for LAPPD studies to S. Malace:

- → A new LAPPD with good quantum efficiency, uniform gain across the MCP area and optimized distance between MCP2-anode (3 mm instead of 6.6) would be fabricated by Incom Inc. specifically for my tests
- → The smaller MCP2-anode gap is needed to reduce the spread of the charge cloud at the anode
- → The smaller distance between the second MCP and anode would also hopefully improve the resistance of the LAPPD to magnetic field
- → Once delivered the LAPPD would be characterized in terms of gain vs voltage curves and dark rates
- → An attempt at measuring the charge cloud radius would be made
- → Potential gain variation due to pore sharing would also be investigated
- → A test setup to use cosmic rays and a tank with C4F8 gas would be assembled to test the new LAPPD with Cherenkov light from cosmic rays using a scintillator and calorimeter as trigger

Order Placed on 11/09/2021, LAPPD 159 delivered 06/2023 although initial lead time was 16 weeks

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LAPPD 159 Operating Performance (ROP = Recommended Operating Point)

Parameter	Performance
Photocathode Quantum efficiency @ 365 nm	Mean QE (@365 nm) = 27.8%, Maximum: 30.3%
Photocathode QE Spatial Variability (σ)	0.89%
ROP Voltages Please Note Dark rates vs. MCP and photocathode voltage section	400V above anode, 200V between MCPs, 900V/MC nominal, 100V on photocathode
LAPPD Gain @ ROP	3.40×10^6
LAPPD Gain @ 10V on Photocathode, 900/1000 V MCP	8.14×10^6
LAPPD Dark Count rate @ ROP (threshold = 4mV)	363.3 Hz/cm^2 at a threshold of 8×10^5 gain (134 fC), 900 V/MCP nominal, 50 V on photocathode [A]
Dark Rate @ 10 V on PC, 950V MCP	624.4 Hz/cm^2
Optimal Transit Time Variation (single P/E)	70.6 ps

Note: INCOM TTS results are "Provisional". Work recently done at INFN Bologna Italy shows that Incom reported TTS understate the true timing capability of LAPPD. Efforts at Incom are now focused on resolving calibration issues and other factors that can introduce jitter into the TTS result.

The new LAPPD

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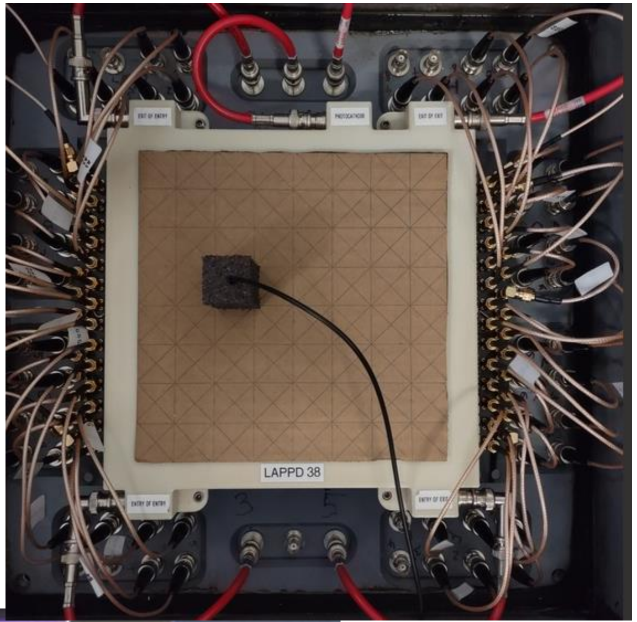
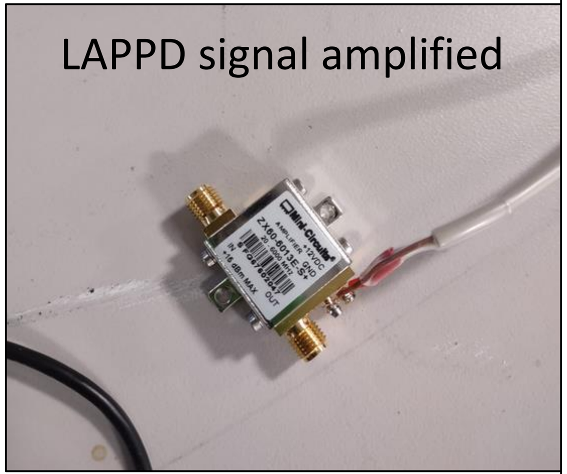
All of my studies so far have been done on LAPPD 38

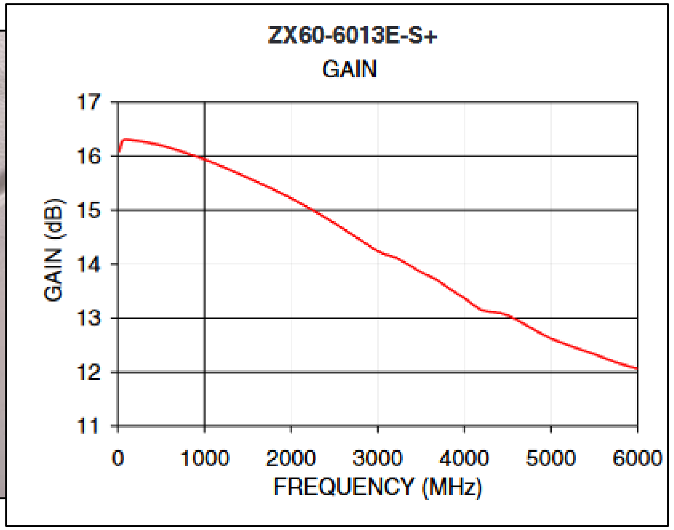
Results So Far: 2022 – Test Setup

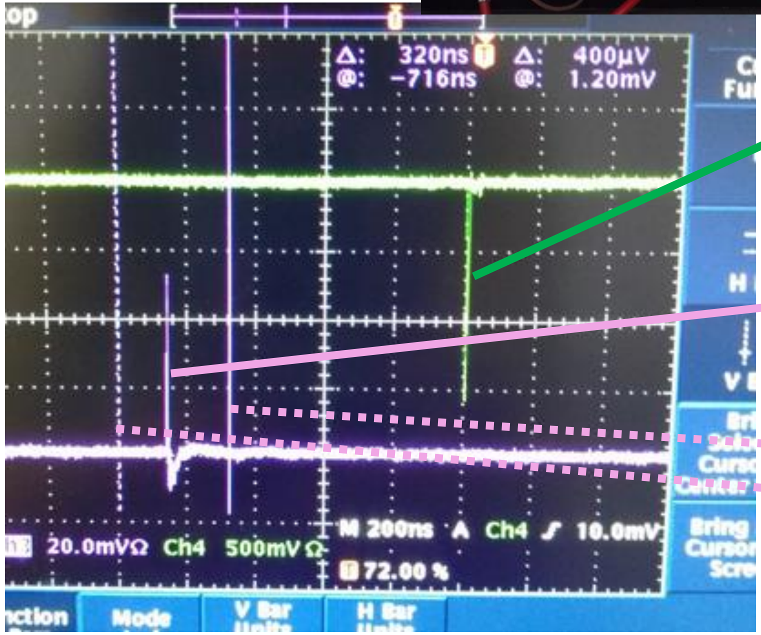
LAPPD 38 with a mask that allows LED light on photocathode through a 2 mm hole



LAPPD signal amplified







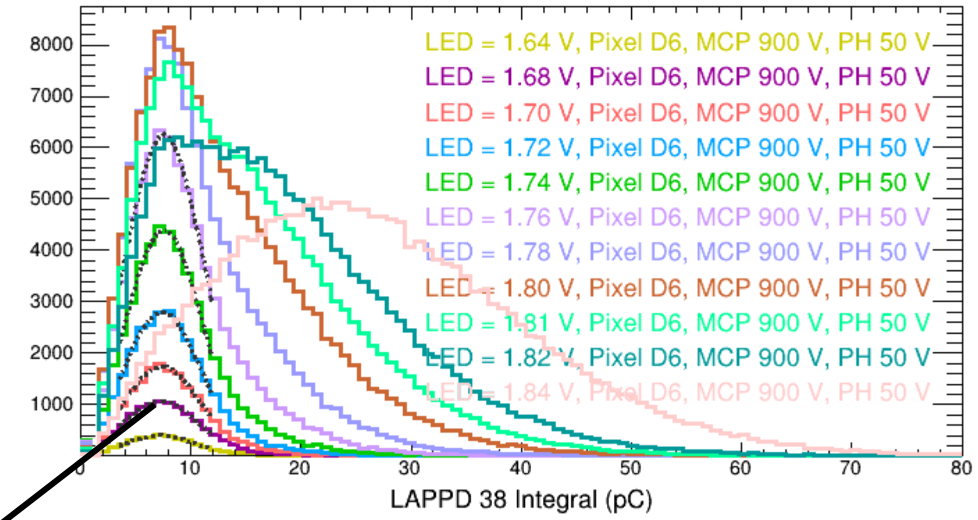
Trigger: pulse that drives LED

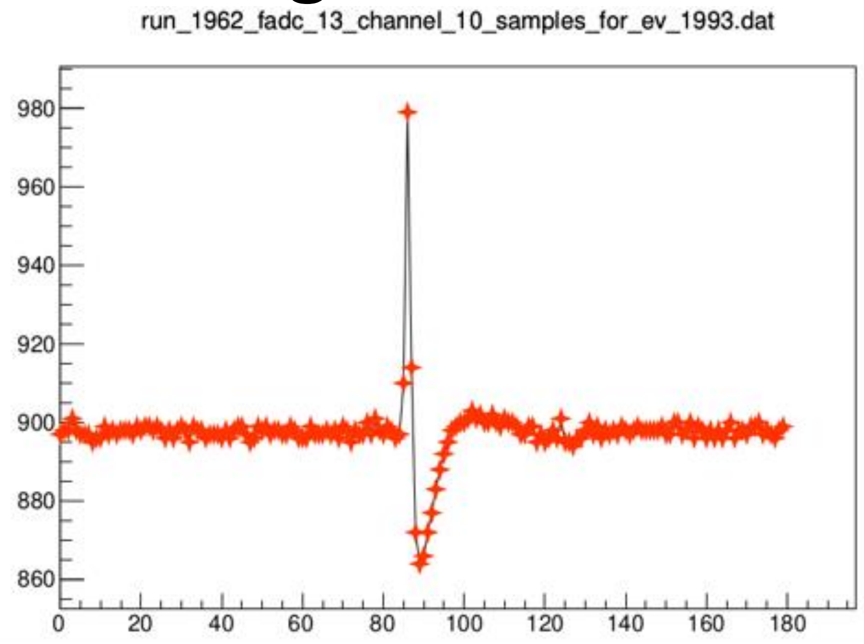
LAPPD pulse (unamplified)

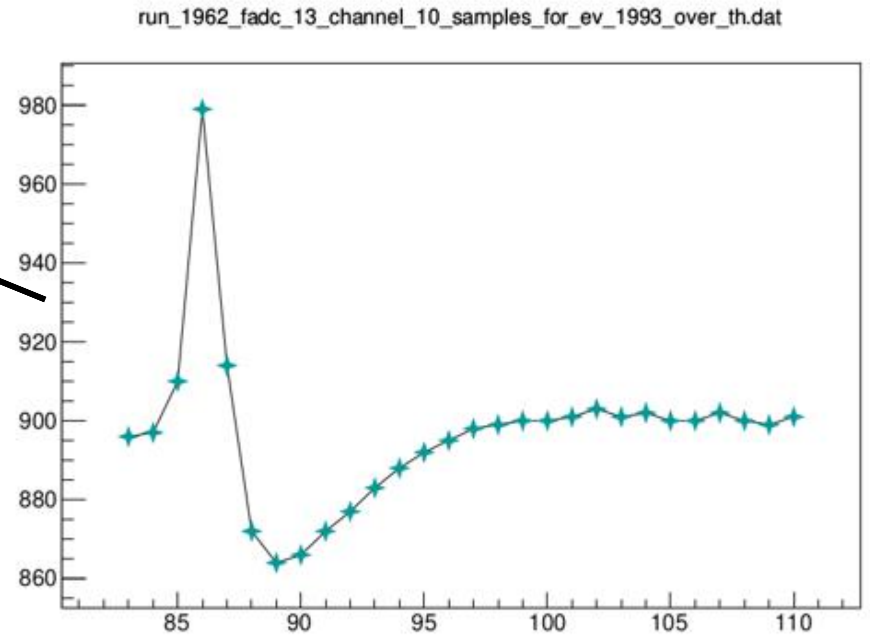
FADC250 sampling window (samples every 4 ns)

DAQ crates with FADC250 digitizers

Results So Far: 2022 – Identification of SPE Signal







→ Each distribution of charge integral corresponds to a fixed LED voltage and a fixed number of triggers

→ Therefore comparing distributions means comparing probabilities for producing a certain number of photoelectrons

Definition of pulse integral from the FADC250 samples per trigger (or event)

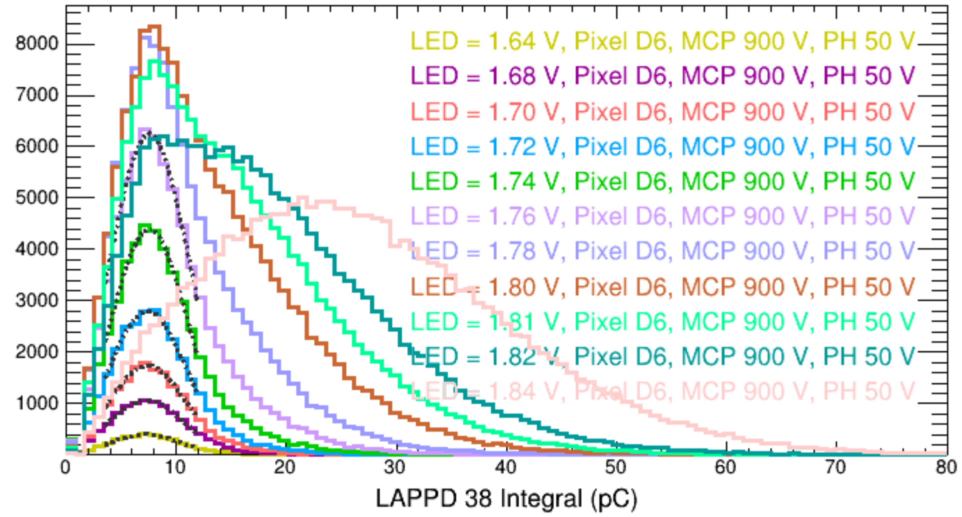
→ The FADC is sampling every 4 ns, the dynamical range is set to 1 V

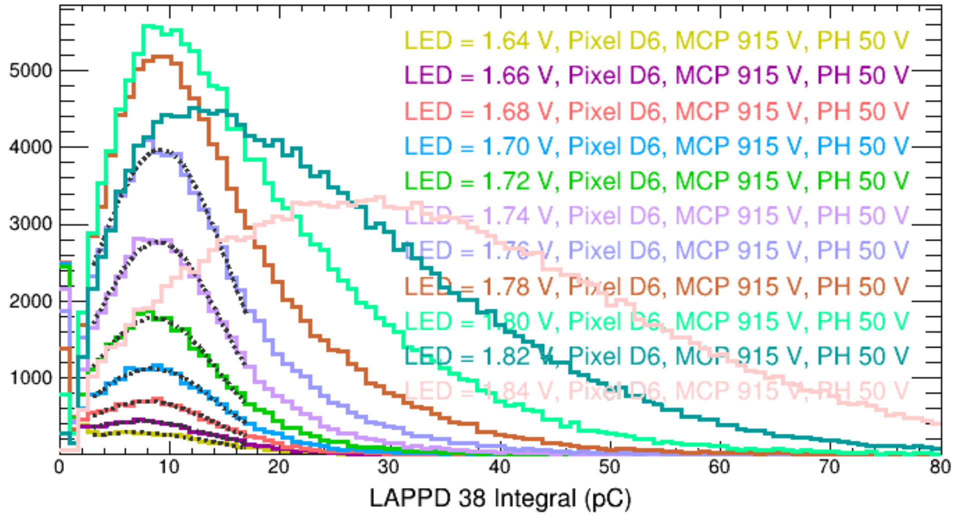
→ The FADC thresholds are set to 20 channels above pedestal

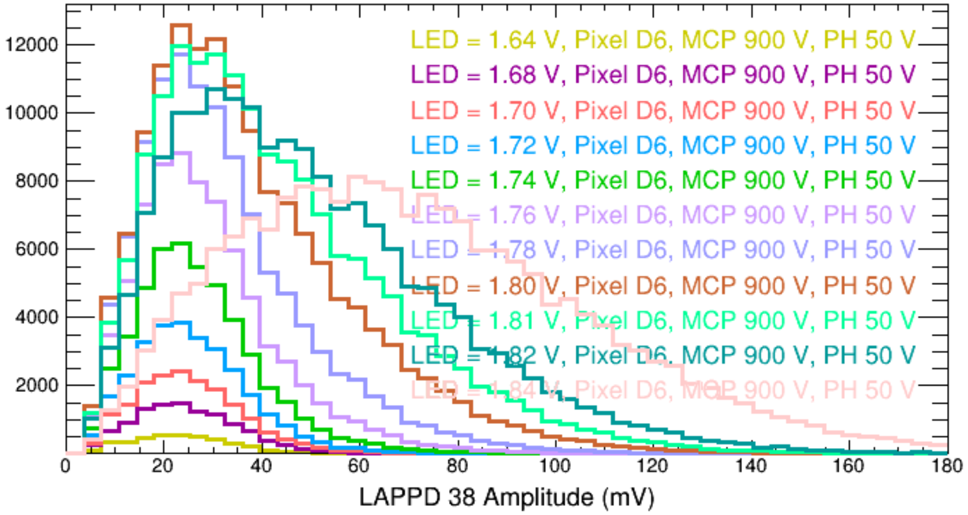
→ The pedestal is calculated as the average of the previous 4 samples once a sample registers above threshold

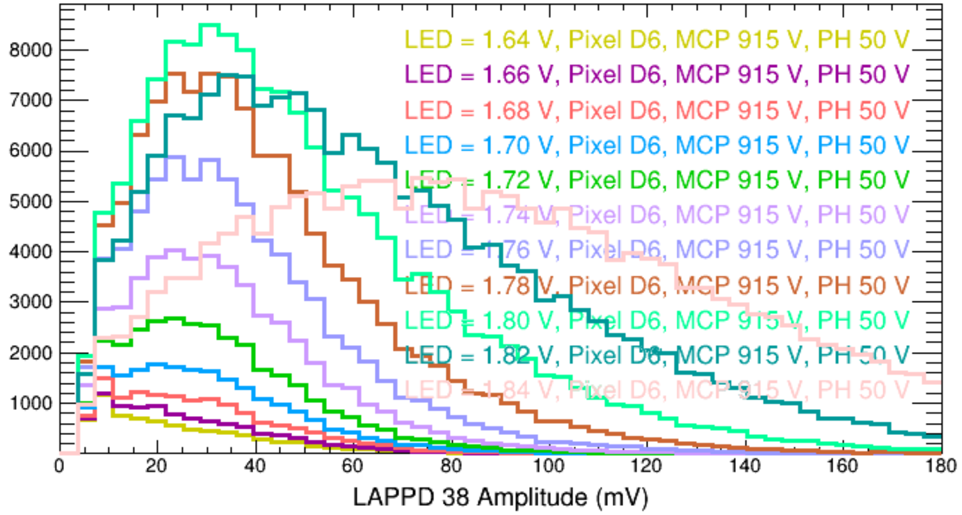
→ The pulse is defined as the first 28 samples above threshold once a sample registers above threshold

Results So Far: 2022 – MCP High Voltage Scan





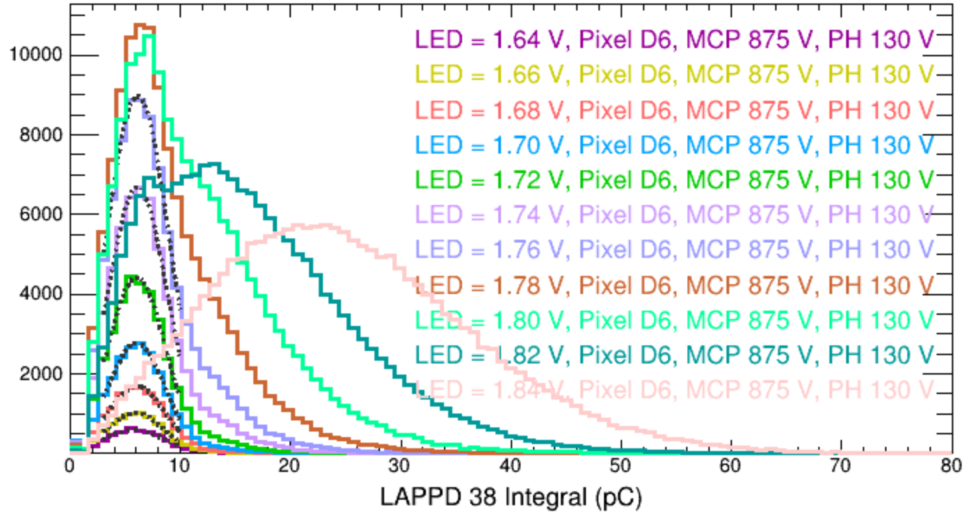


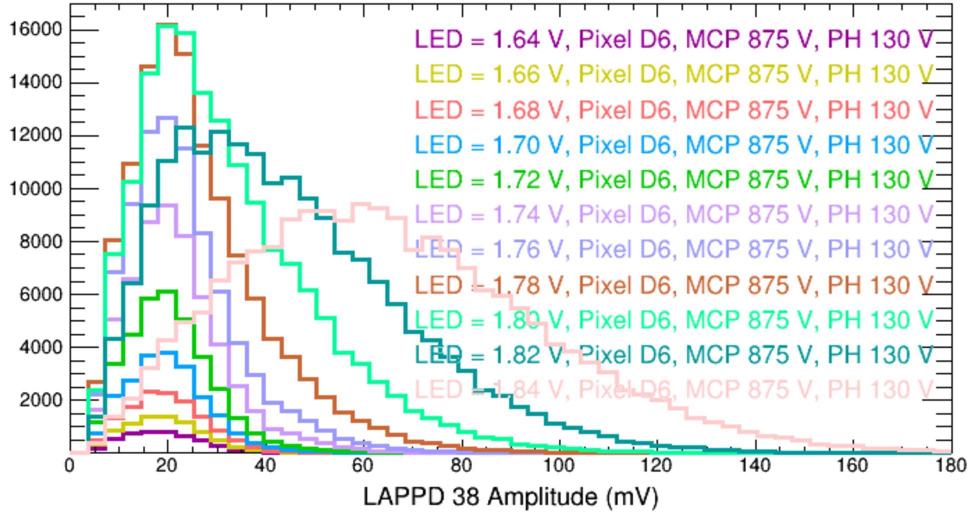


Single and multi photoelectron distributions obtained from LAPPD 38 at a **MCP voltage of 900 V and a photocathode voltage of 50 V**.

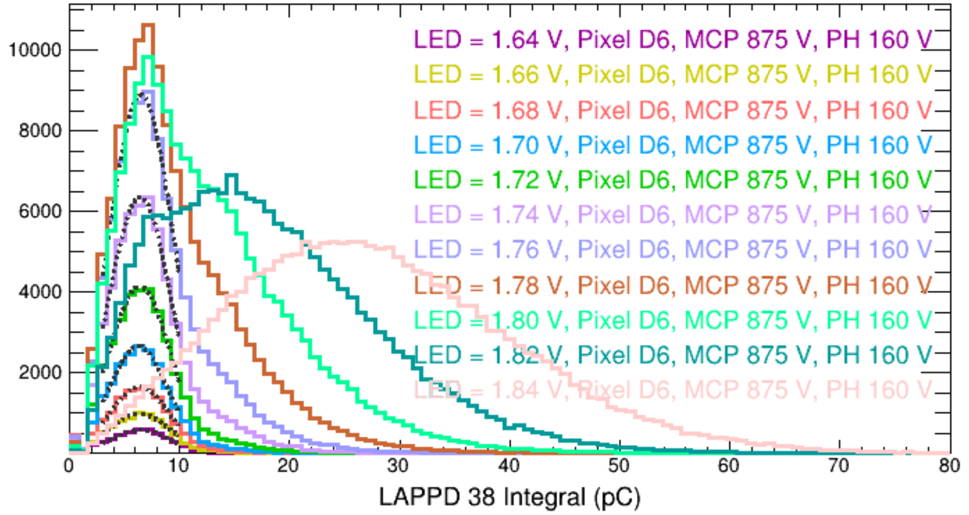
Single and multi photoelectron distributions obtained from LAPPD 38 at a **MCP voltage of 915 V and a photocathode voltage of 50 V**.

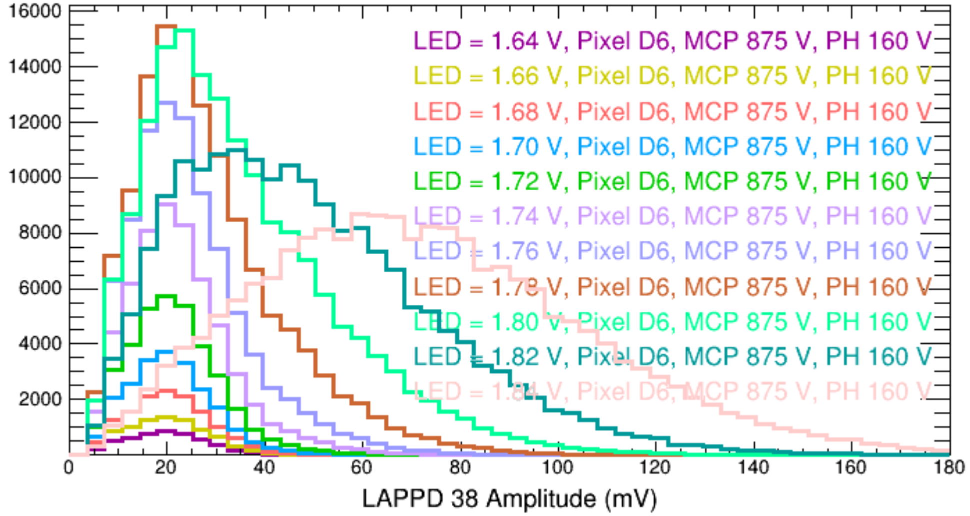
Results So Far: 2022 – Photocathode High Voltage Scan





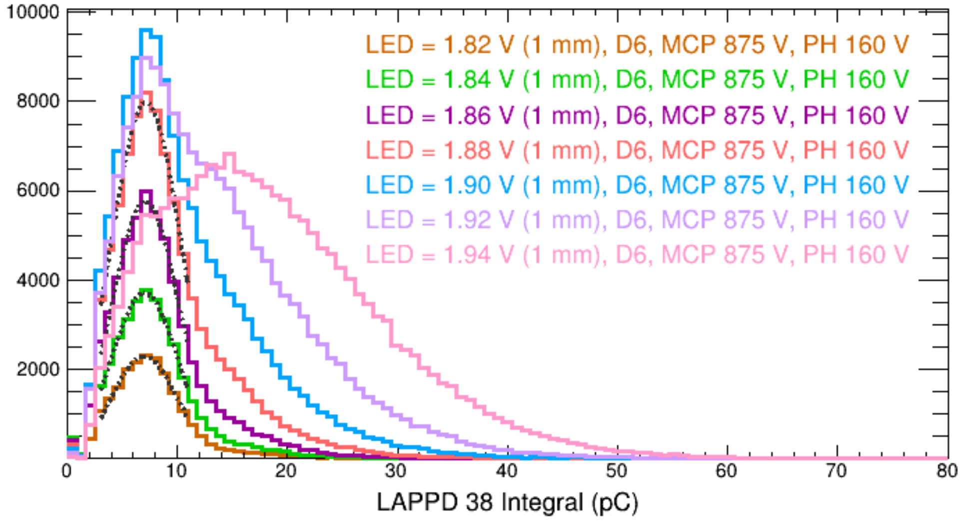
Single and multi photoelectron distributions obtained from LAPPD 38 at a **MCP voltage of 875 V and a photocathode voltage of 130 V**.

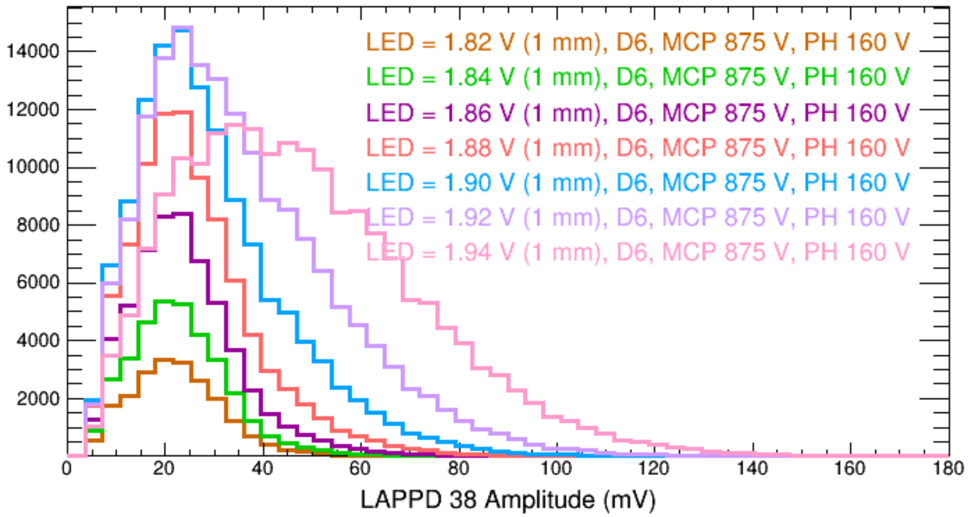




Single and multi photoelectron distributions obtained from LAPPD 38 at a **MCP voltage of 875 V and a photocathode voltage of 160 V**.

Results So Far: 2022 – Charge Cloud Size Studies





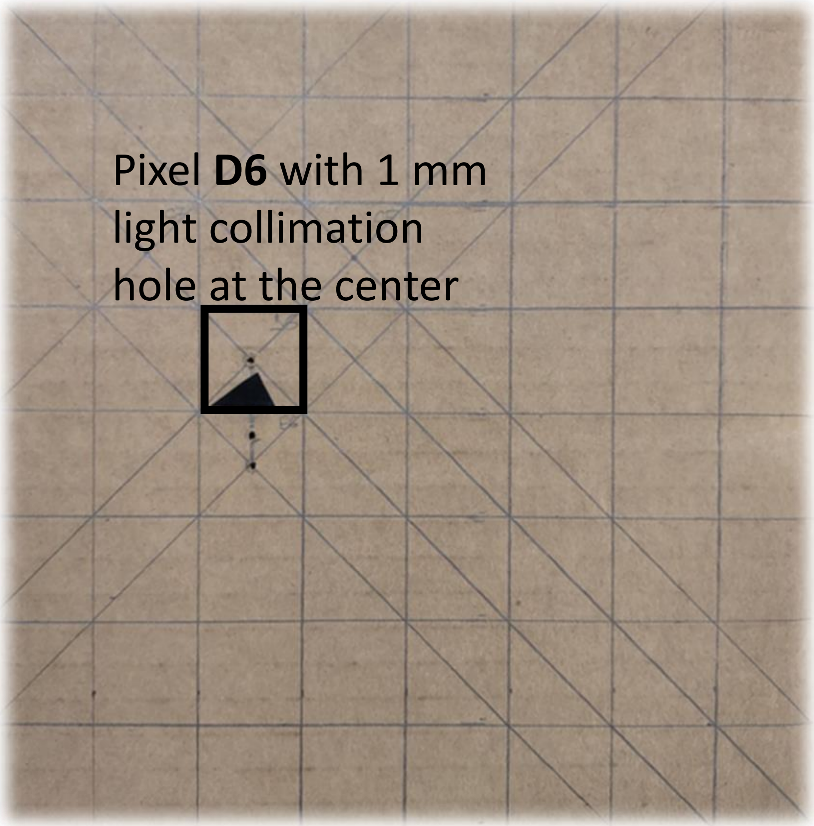
Single photoelectron distributions obtained from LAPPD 38 at a MCP voltage of 875 V and a photocathode voltage of 160 V with LED photons collimated through a 1 mm hole

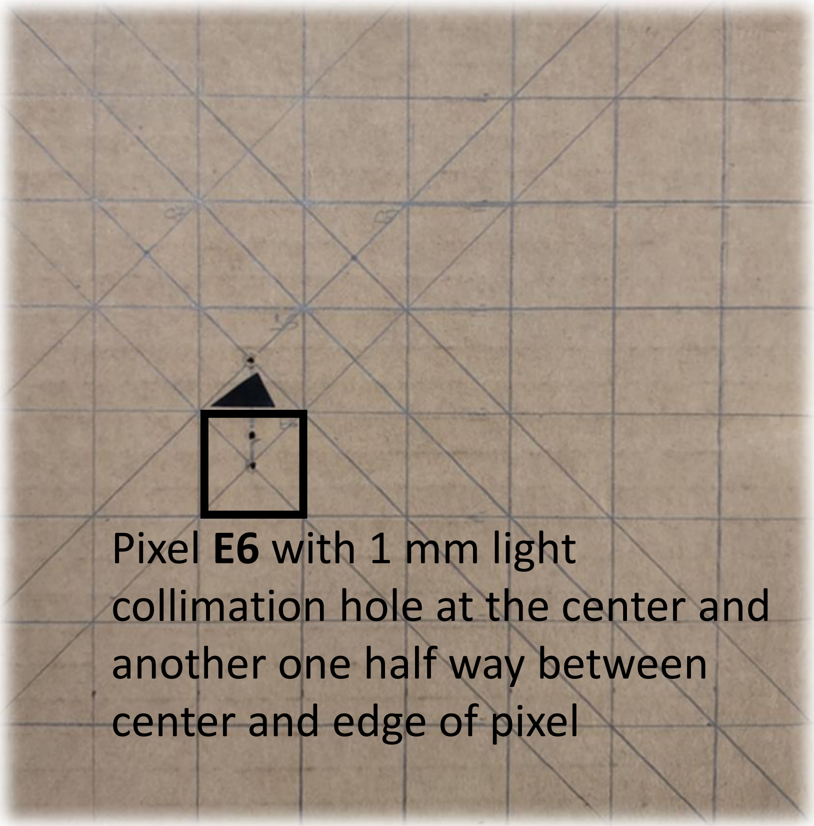
→ Here the 1 mm hole is placed at the center of a "pixel"
→ No significant charge is registered on adjacent pixels meaning that the charge cloud is confined to the illuminated pixel
→ The idea is to "move" the 1mm hole towards the edge of the illuminated pixel and determine when the adjacent pixel registers ~30% of the charge
→ Then the distance between the location of the collimation hole and the edge of the pixel ~ the radius of the charge cloud

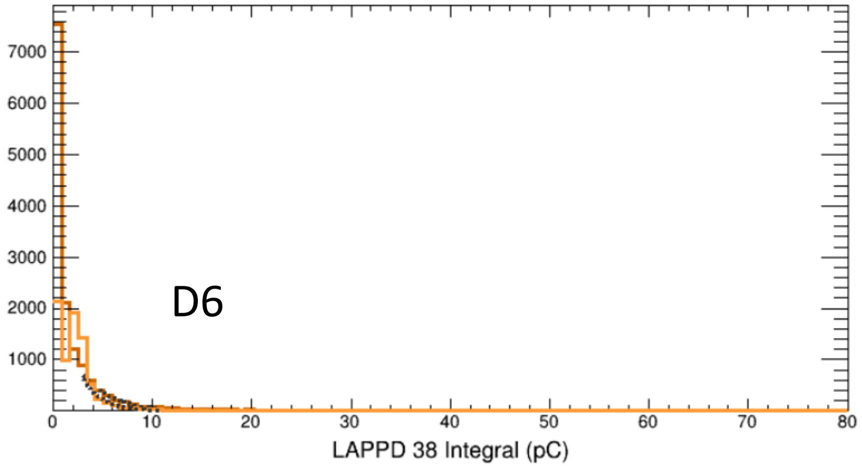
The size of the collimation hole was chosen to maximize the probability of going through 1 single amplification pore in the first MCP

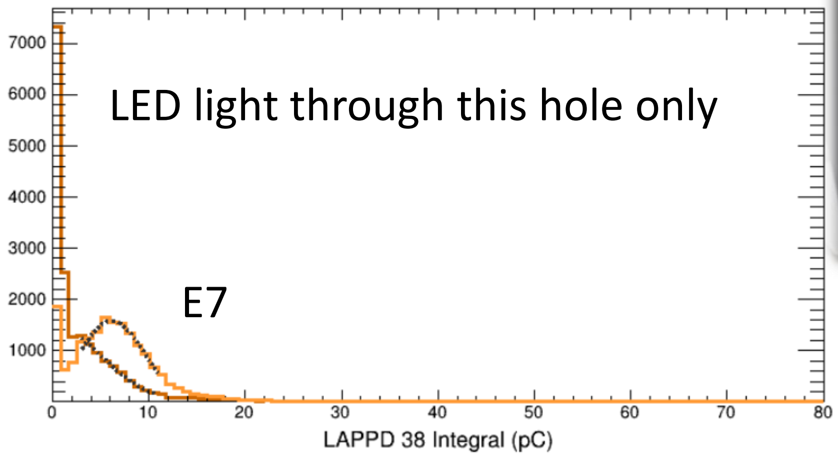
This work is ongoing, I don't have yet a number for the radius of the charge cloud

Results So Far: 2022 – Charge Cloud Size Studies





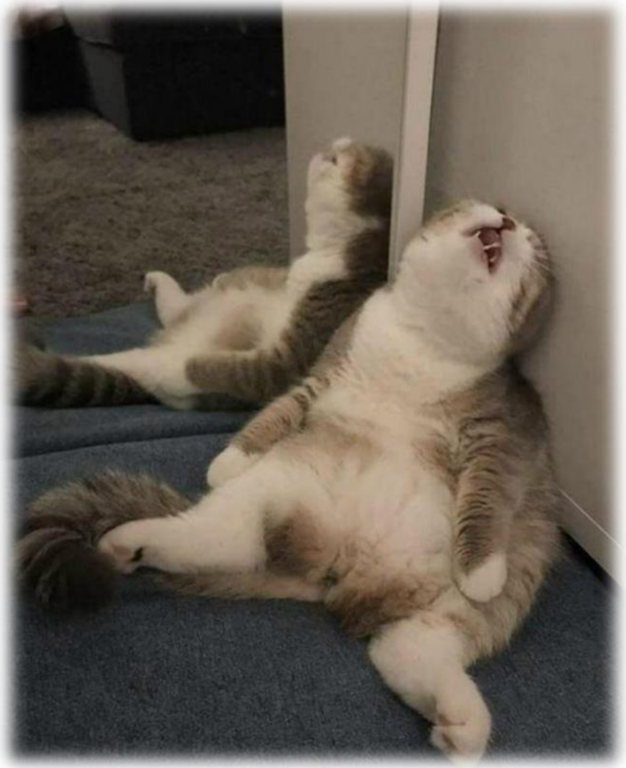




My Time Between End of Jan. 2023 and Sep. 2023

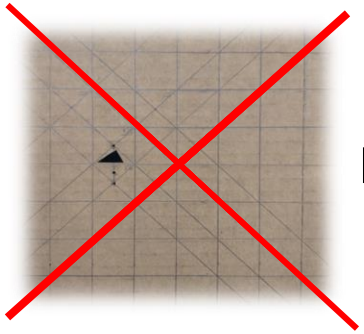
Testing and Installation of the NPS calorimeter in Hall C: 150% of my time

Time spent on my other projects



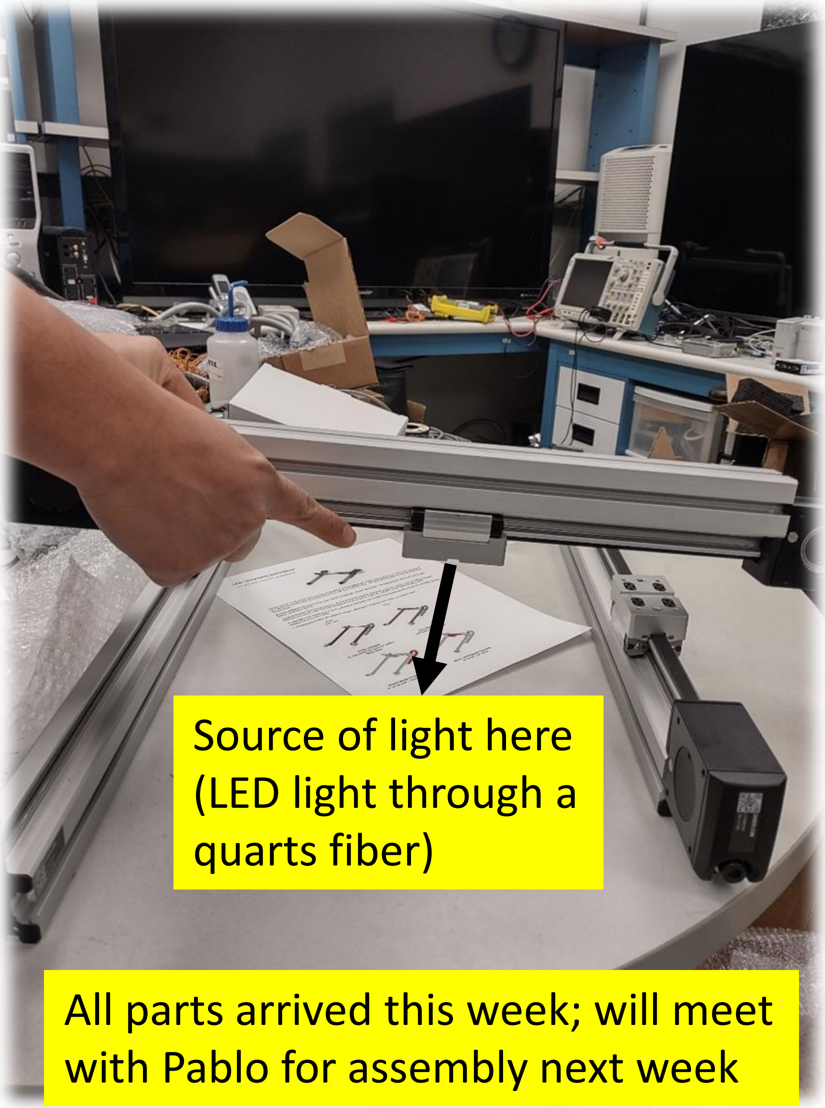
Fortunately, I got off the NPS project mid-September once the installation was completed…

What's in the Works – Precision System to Illuminate the LAPPD



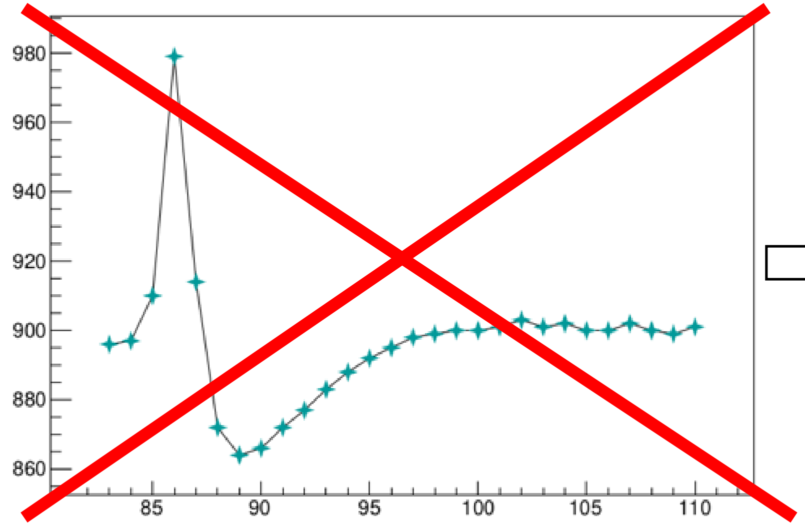
LC40B0300 part of the LC40 Gantry 1	T-slot extrusion stage, single carriage, belt-driven, 300 mm travel
LC40G0350 part of the LC40 Gantry 1	T-slot extrusion stage, single carriage, passive guide, 350 mm travel
NMS23-E08P1T3A part of the LC40 Gantry 1	Stepper motor with encoder, home sensor, NEMA 23, for LC40B guides
X-MCC2-KX14B part of the LC40 Gantry 1	Universal drive controller, 2 axis, with IO, up to 6 A per phase *Included items:* ▪ 1 x X-MCC2 ▪ 1 x PS14S-48V37 ▪ 1 x U-DC06 ▪ 1 x X-DC02
K0068 part of the LC40 Gantry 1	Kit *Included items:* ▪ 2 x AB188 ▪ 2 x AB189
AB188 part of the LC40 Gantry 1	LC40B Mounting Clamps, Set of 2
AC183 part of the LC40 Gantry 1	LC40B Coupling, for 8 mm Shaft
AP187 part of the LC40 Gantry 1	Limit Sensor Mount for LC40 Series
AP237 part of the LC40 Gantry 1	LC40 Gantry Cable Guide Support, X-Axis, Active
AP239 part of the LC40 Gantry 1	LC40 Gantry Cable Guide Support, X & Y-Axis, Fixed, Inverted
CG01 part of the LC40 Gantry 1	Cable Guide, 30 mm Width, 38 mm Bend Radius, Single Link
CG01T	Cable Guide Termination Set, Series 09, 30 mm Width

Engineering support:
Pablo Campero Rojas



The per-axis accuracy of LC40B0300-KM02 is 400µm, the repeatability is <20µm, and the minimum incremental move will be 35µm-70µm

What’s in the Works – A Faster Digitizer Than FADC250 → CAEN V1742



Channels

- 32 channels
- 2 special channel (TR0, TR1)
- Single ended

Bandwidth

- 500 Mhz

Absolute max analog input voltage

- 3Vpp (with Vrail max +3V or -3V) for any DAC offset in single ended configuration

Impedance

- Z_{in} = 50 Ω

DC Offset

- Programmable 16-bit DAC for DC offset adjustment on each channel. Range ± 1 V

Connector

- MCX

Full Scale Range (FSR)

- 1 V_{pp}

Resolution

- 12 bits

Dead Time (A/D Conversion)

- 110 µs, analog inputs only
- 181 µs, digitizing TR0 and TR1

Switched Capacitor Array

- Domino Ring Sampler chip (DRS4), 8+1 channels with 1024 storage cells each

Sampling Rate

- 5 GS/s – 2.5 GS/s – 1 GS/s – 0.75 GS/s SW selectable, simultaneously on each channel

Sampling at 250 MS/s (one sample every 4 ns) it’s not enough when dealing with tens of ps rise time signals

DAQ support: Steve Wood/Brian Moffit

Sampling at a max of 5 GS/s (one sample every 0.2 ns)

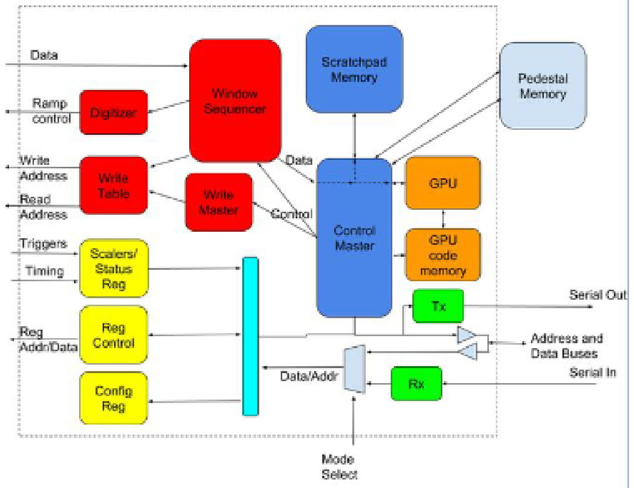
→ NOT based on a flash ADC, but on switched capacitor design. 1024 capacitors perform the A-to-D conversion one after another. When these conversions are complete the information must be read out before the capacitors can be re-armed and prepared to accept more data

→ Inherent dead time of ~180 microseconds and a limitation between ~5.5 KHz and 9KHz trigger rate

- I ordered 2 V1742 modules, one is in my VME crate already
- The libraries and rol have been written (Steve Wood)
- We are now trying to sample a PMT pulse… don’t have one to show you yet

What's in the Works – A Faster Digitizer Than FADC250 → AARDVARC V3

Digital Block



AARDVARC digital block diagram: Red Blocks: Analog control blocks, yellow blocks: general registers, Blue blocks: master control, orange blocks: GPU, green blocks: Serial interface

Current Specs

Spec	
Sampling Rate	10-13 GSa/s
ABW	> 1GHz
Depth	32k Sa
Channels	4
Supply/Range	1.2V/0.3-0.9V
ADC bits	12
Timing accuracy	<5ps
Technology	130 nm CMOS
Power	80mW/ch

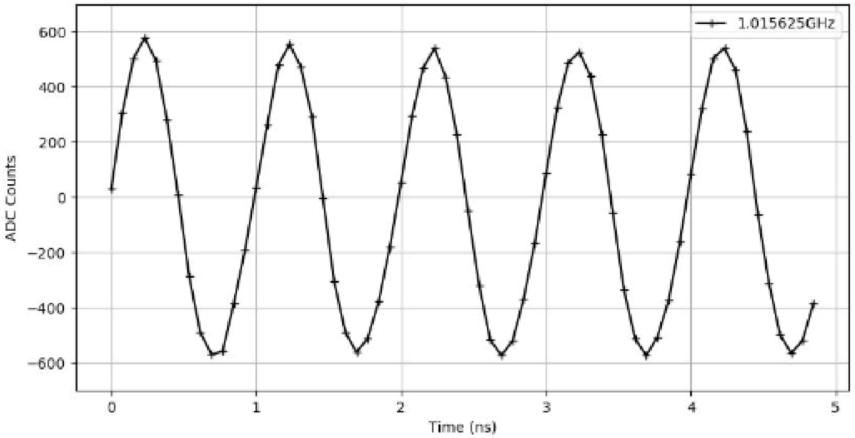
→ I got a AARDVARC V3 from Alex; I need to play with it

→ I plan to use both digitizers and compare occasionally results obtained with both

Example 1 GHz Sine wave input @ 13 Gsa/s

From Nalu

Nalu Scientific
Data Acquisition Systems



The channel density for AARDVARC is smaller than for the V1742 so I will be using the V1742 for digitizing for most of my bench tests.

Projected Results for FY24: To Be Done…

Characterize the new LAPPD: LAPPD 159

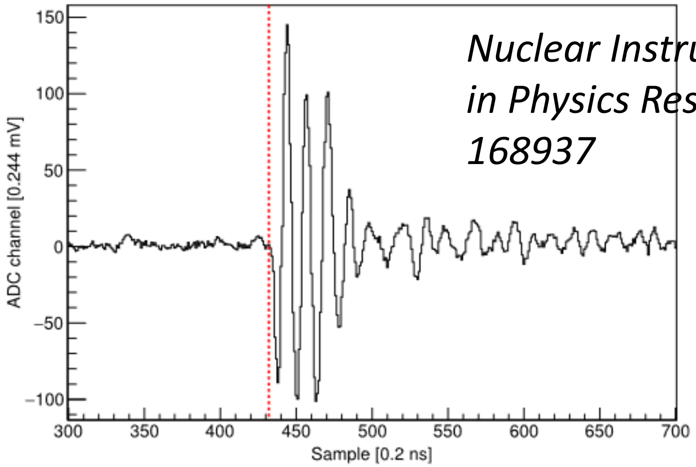
→ Gain vs MCP and Photocathode voltages

→ Gain vs trigger rate curves

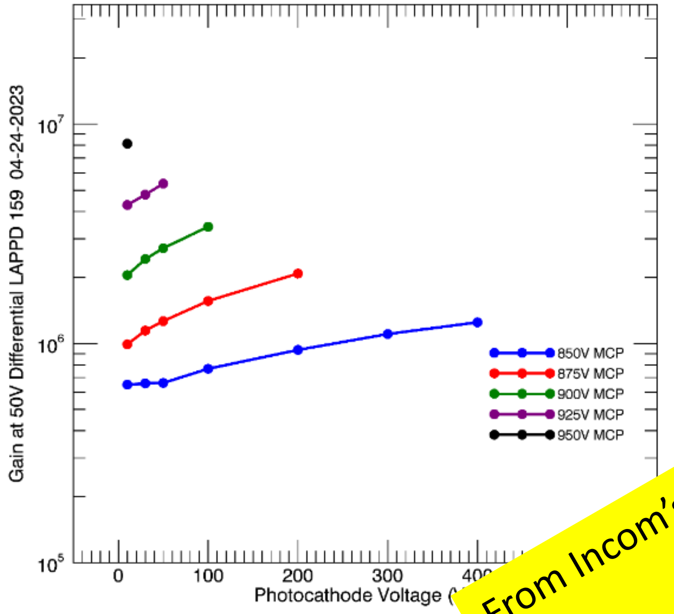
→ Dark rates

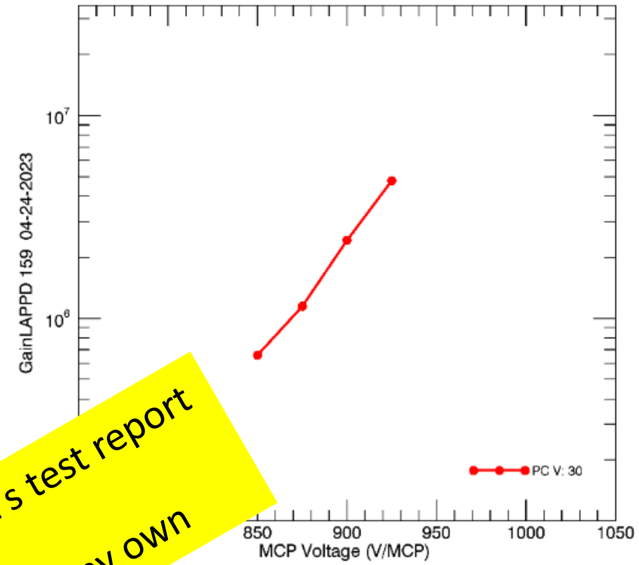
→ Charge cloud radius measurements and impact of pore sharing on gain

→ Measure cross talk



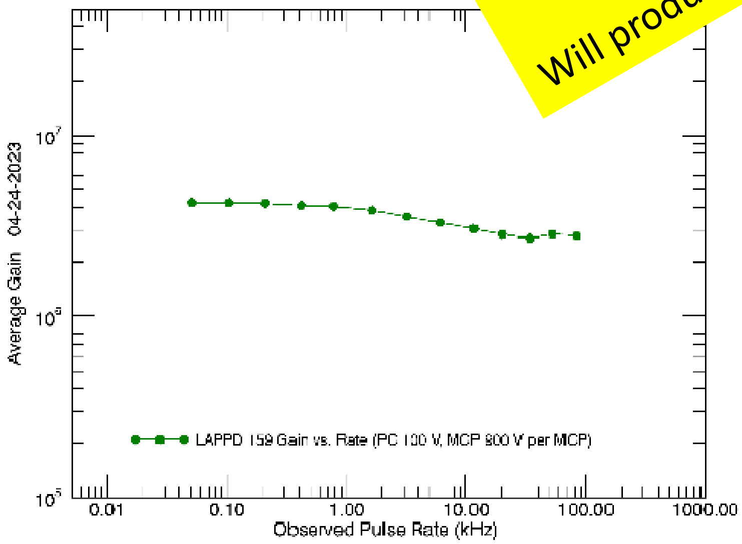
Nuclear Instruments and Methods in Physics Research A 1058 (2024) 168937

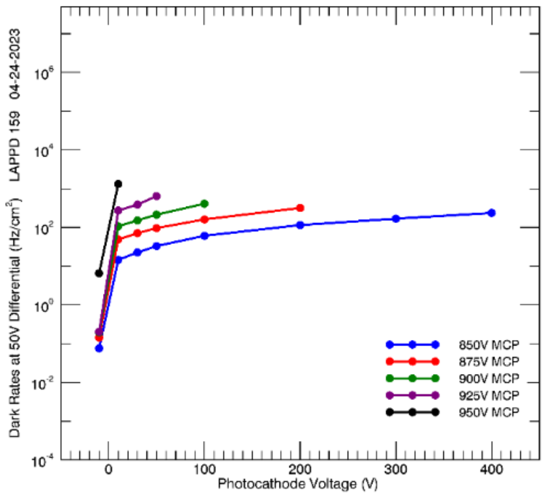




From Incom's test report

Will produce my own





Projected Results beyond FY24

Characterize the new LAPPD: LAPPD 159

→ Gain vs MCP and Photocathode voltages

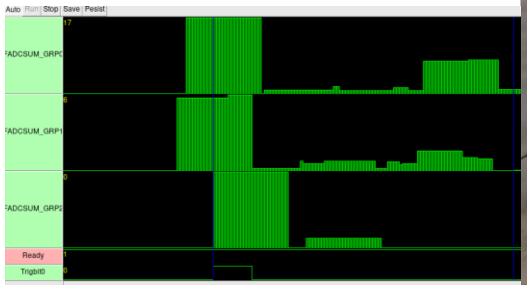
→ Gain vs trigger/oserved rate curves

→ Dark rates

→ Charge cloud radius measurements and impact of pore sharing on gain

→ Measure cross talk

→ Tests with comic muons (Cherenkov light in C4F8): VTP trigger with calorimeter and scintillators – need to run a simulation



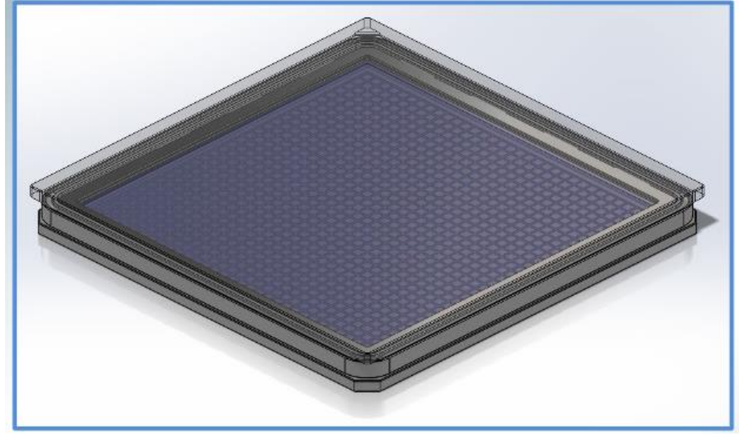
Magnetic Field Tests

→ A new LAPPD to fulfill the EIC needs: HRPPD

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

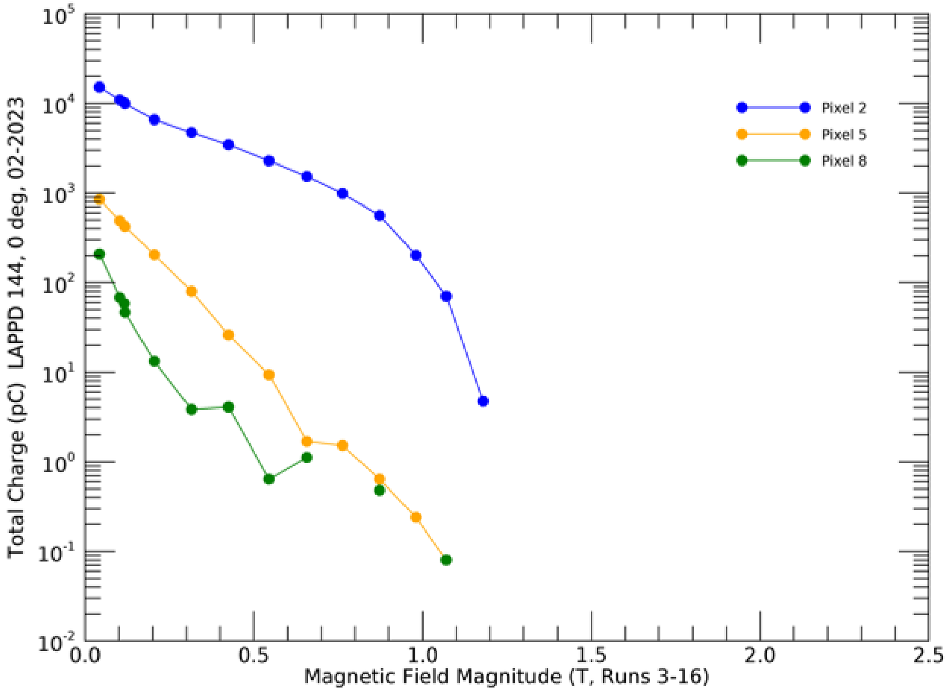
Several readout schemes possible

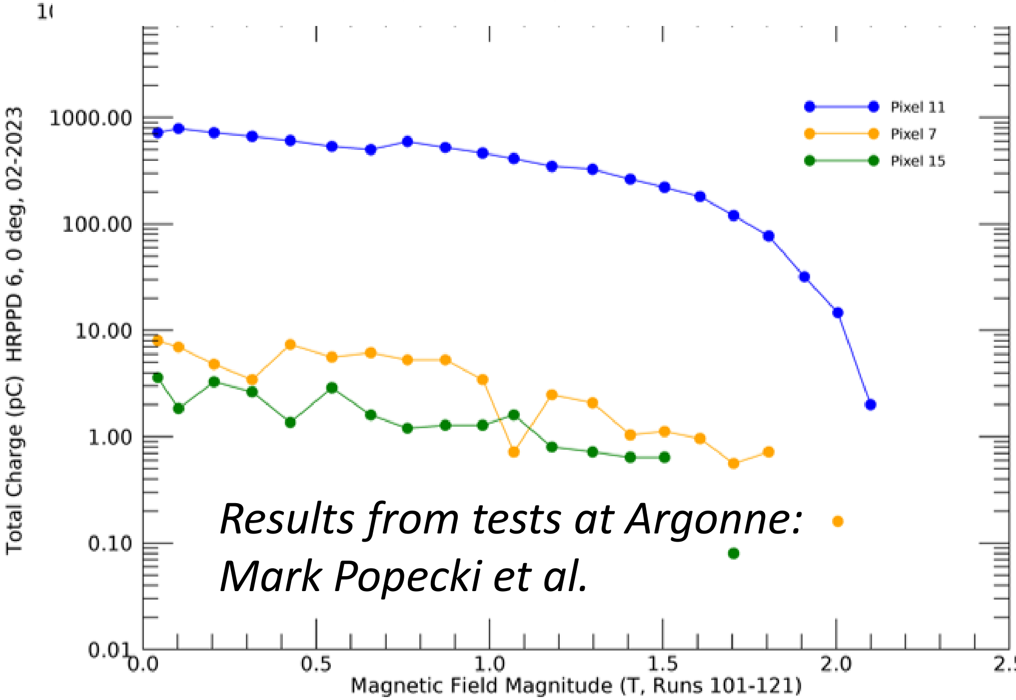
- Gen-I Strip-Line
- Gen-II Capacitive Coupling
- Gen-III Pixelated Cofired Anode

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)

From Michael R. Foley

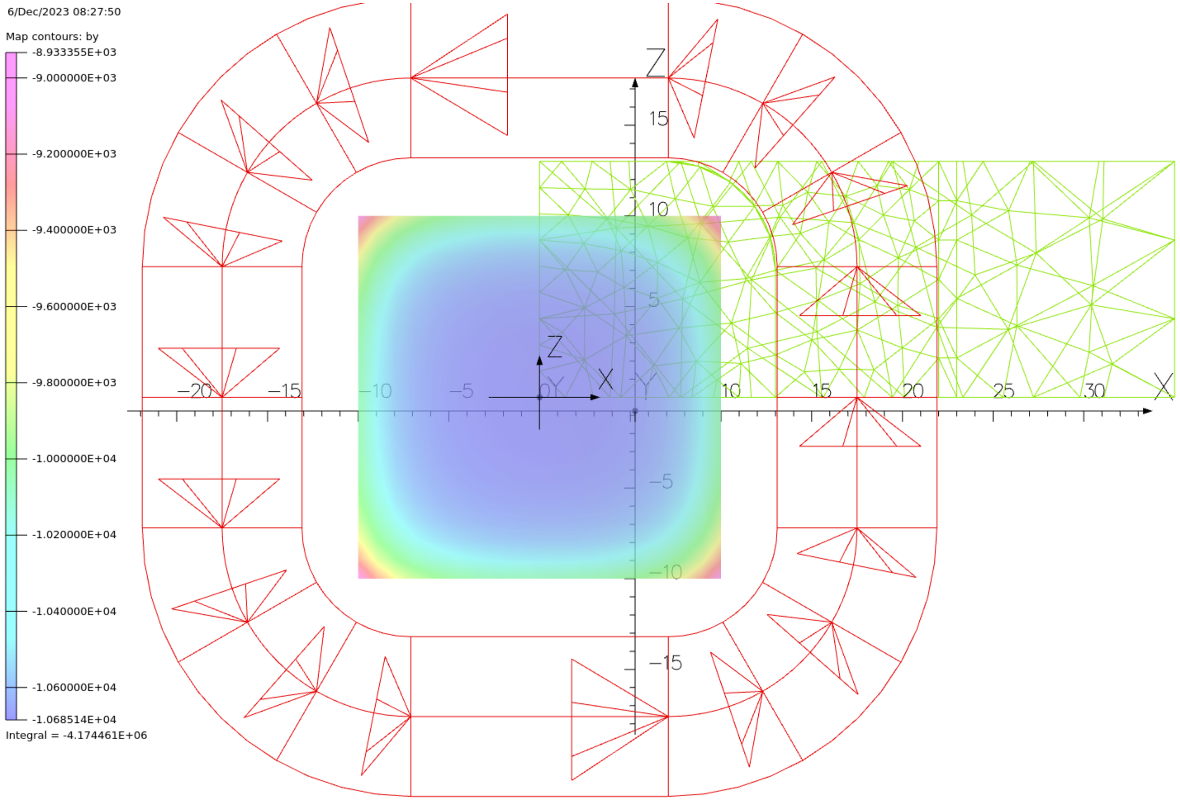


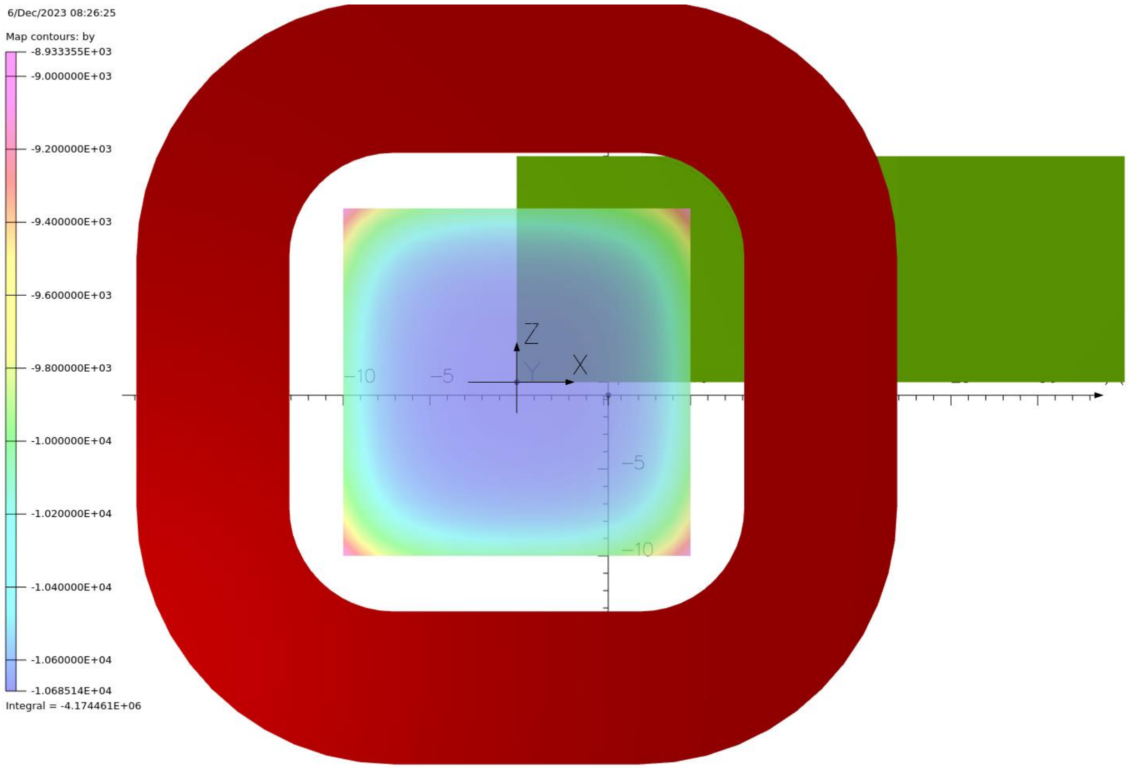


Results from tests at Argonne: Mark Popecki et al.

What's in the Works – Magnetic Field Tests at JLab **Please**

→ A magnet that will fit in a large dark box and will reach 1 T field; the LAPPD would be inserted between the 2 coils





Magnet design support:
Jay Benesch

Meeting with Jay, Jian-Ping, Mark and Whit on Thursday next week

Summary

The best is yet to come:

→ Fully characterize Gen II LAPPD 159 (reduced gap last MCP - anode)

→ Use two different fast digitizers

→ Use cosmic muons to get Cherenkov light on this LAPPD (need to run a simulation to check the feasibility of it)

→ Magnetic field tests at JLab!! It’s a must!!

→ Do the same with a HRPPD

→ Beam tests