LAPPD R&D at JLab

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 wish list for FY24 and beyond

Timeline of my R&D on LAPPDs: 2020-2021

- 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)

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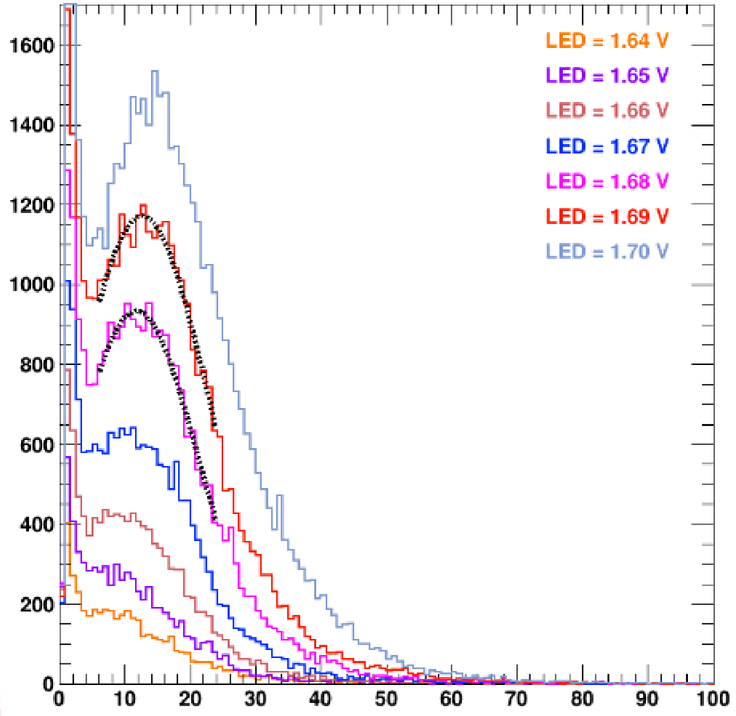
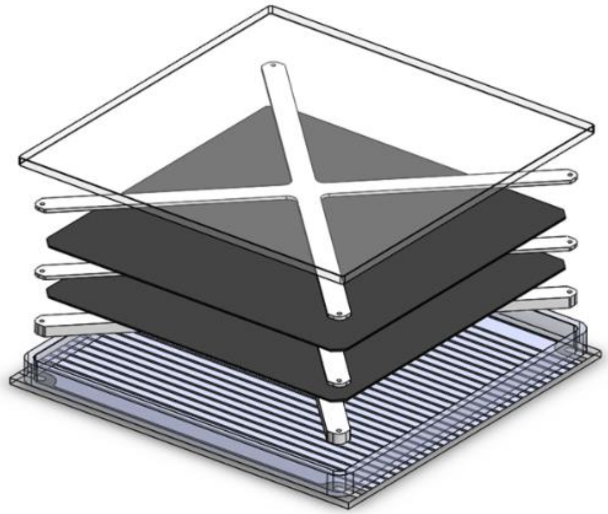
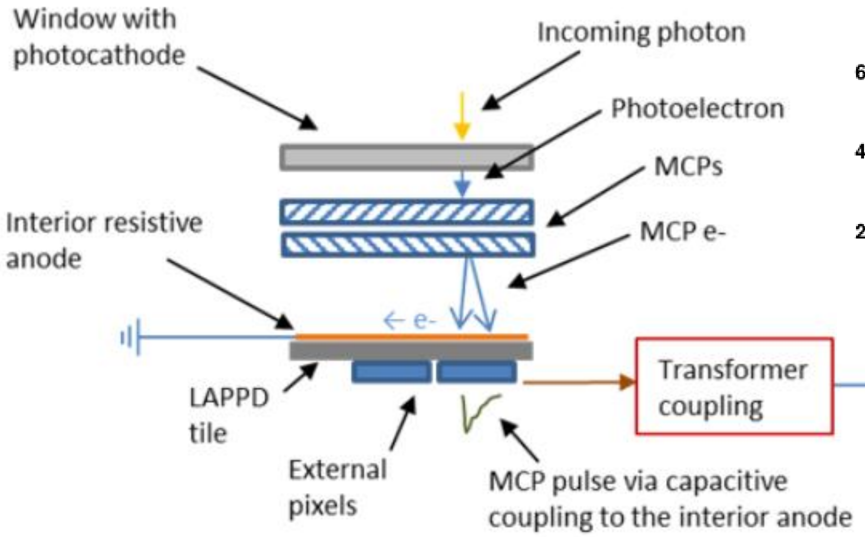
window	5 mm thick borosilicate
photocathode	potassium, sodium, antimony 0.345 μm thick
photocathode - first MCP gap	2.8 mm created via X-spacers
first MCP	borosilicate, 65% open area ratio 1.2 mm thick
gap between first and second MCP	1.1 mm created via X-spacers
second MCP	borosilicate, 65% open area 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) was fabricated by Incom Inc. specifically for my tests

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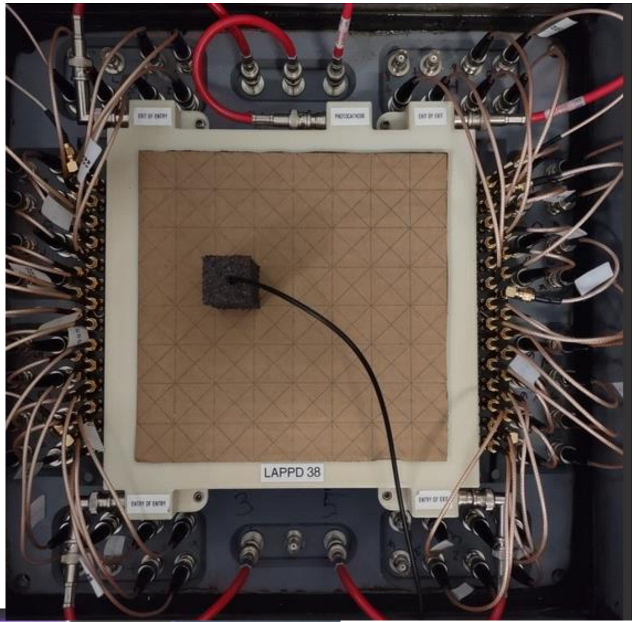
LAPPD 159 Operating Performance (ROP = Recommended Operating Point)

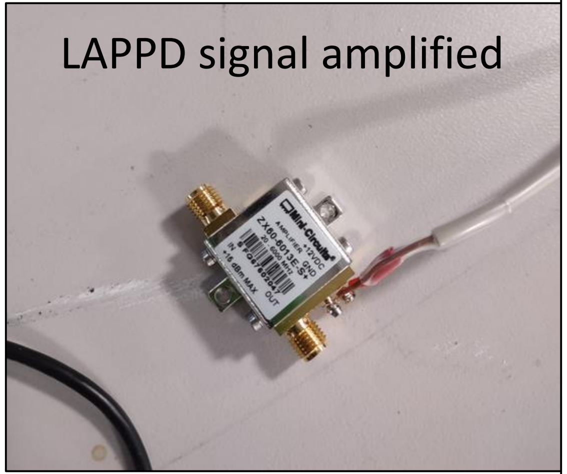
Parameter	Performance
Photocathode Quantum efficiency @ 365 nm	Mean QE (@365 nm) = 27.8%, Maximum: 30.3%
Photocathode QE Spatial Variability (σ)	0.89%
ROP Voltages Please Note Dark rates vs. MCP and photocathode voltage section	400V above anode, 200V between MCPs, 900V/MC nominal, 100V on photocathode
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 ... gain (134 fC), 900 V/MCP nominal, 50 V o... cathode [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.	

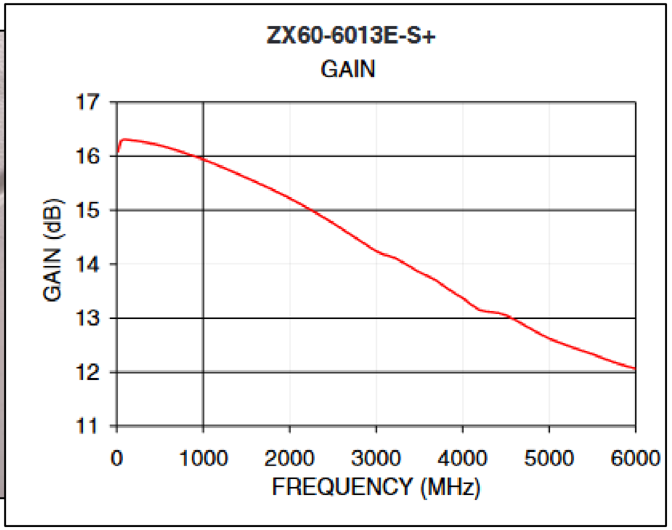
The new LAPPD 159 delivered 06/2023

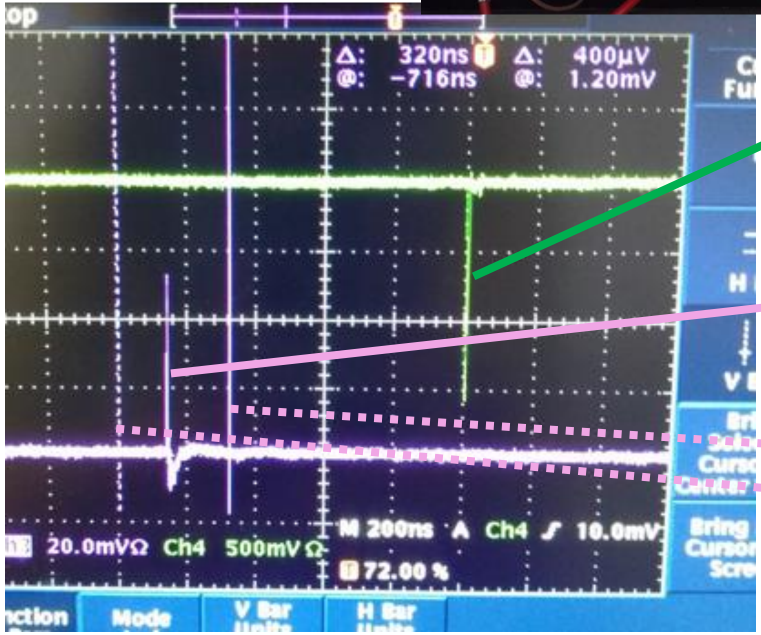
Results on LAPPD 38: 2022 – Test Setup

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







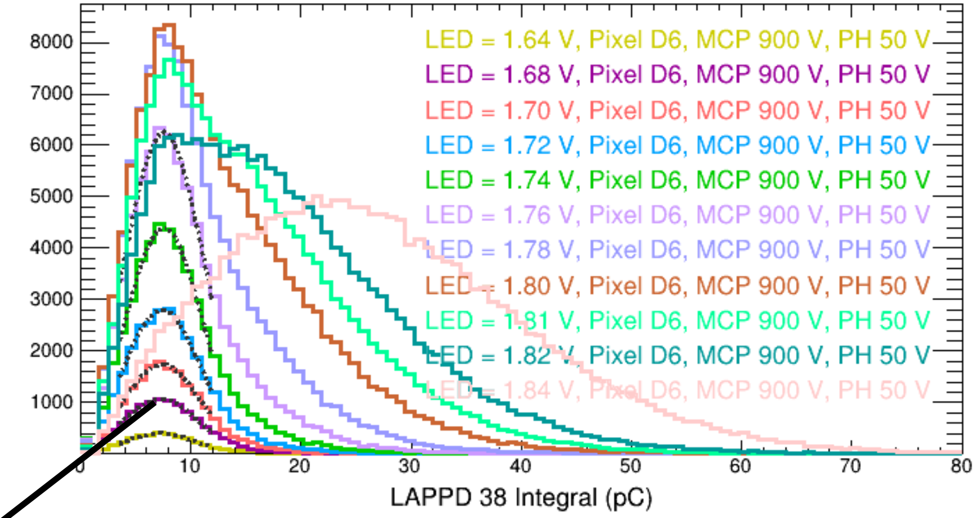


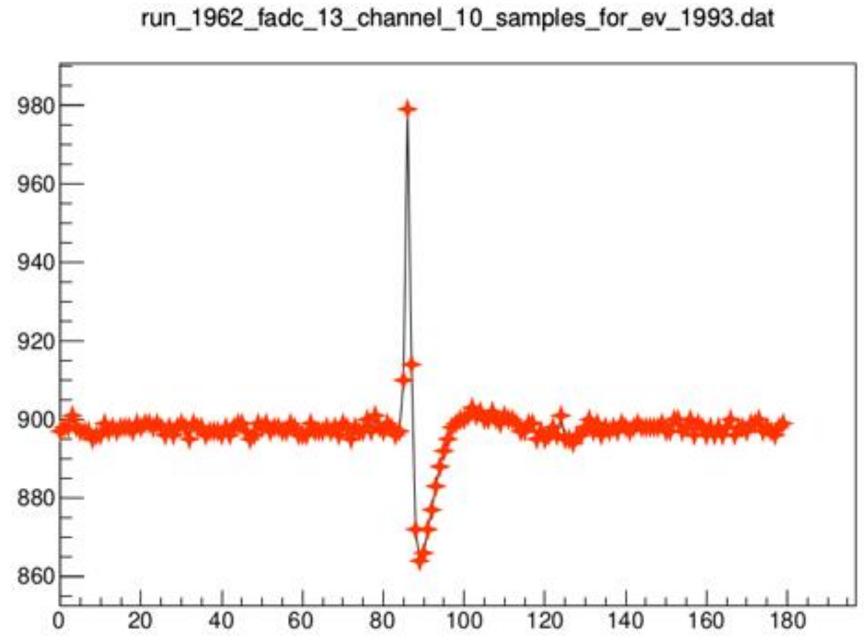
Trigger: pulse that drives LED

LAPPD pulse (unamplified)

FADC250 sampling window (samples every 4 ns)

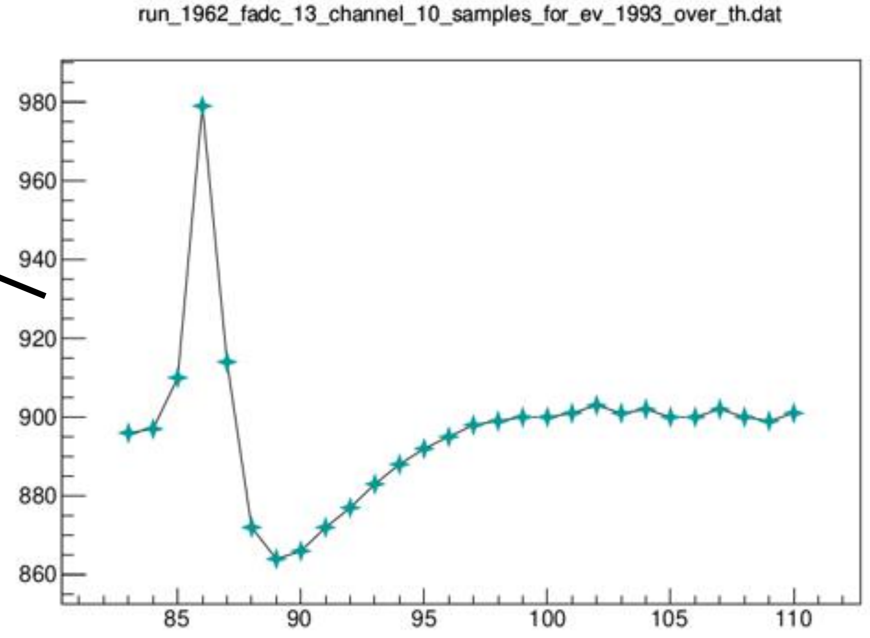
2022 – Identification of SPE Signal on LAPPD 38





→ 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)

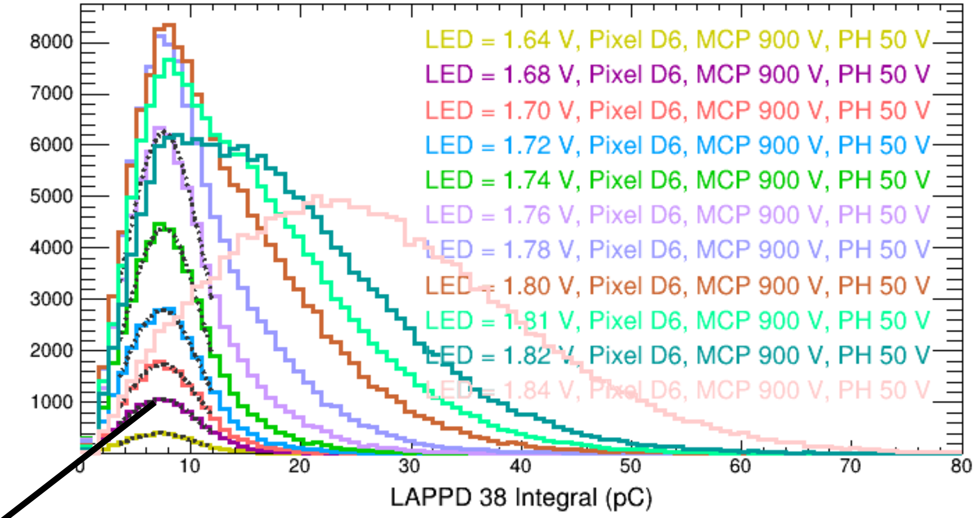
→ The FADC is sampling every 4 ns, the dynamical range is set to 1 V

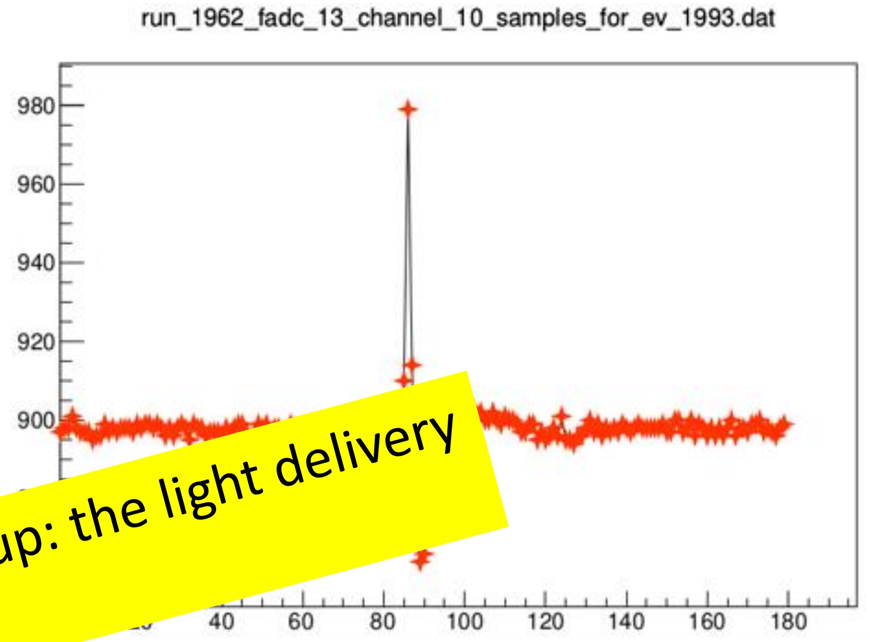
→ The FADC thresholds are set to 20 channels above pedestal

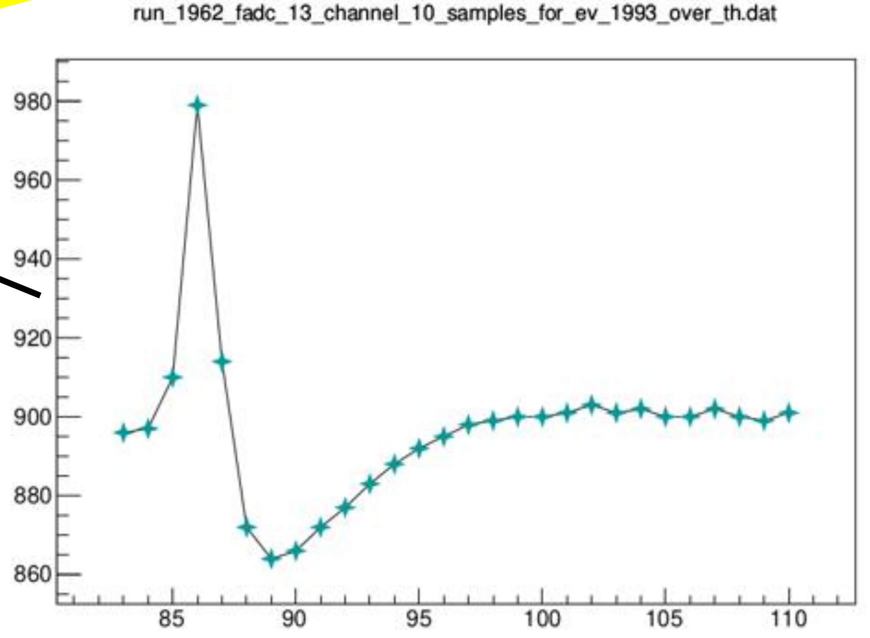
→ The pedestal is calculated as the average of the previous 4 samples once a sample registers above threshold

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

2022 – Identification of SPE Signal on LAPPD 38







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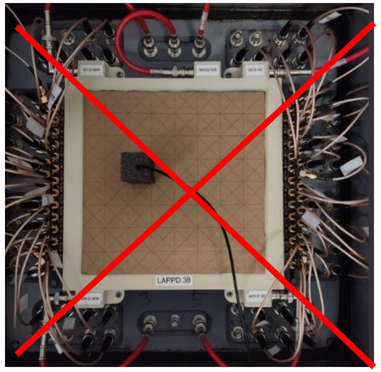
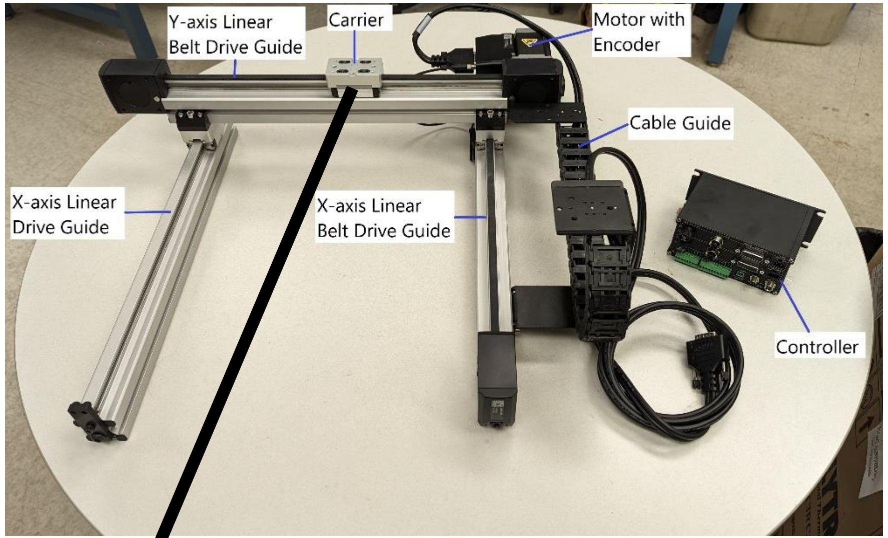
I wanted to make improvements to my test setup: the light delivery system and the digitizer primarily

In the Works 2023-2024 – Precision System to Illuminate the LAPPD

Zaber motors for precise placement of LED light on the LAPPD window



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



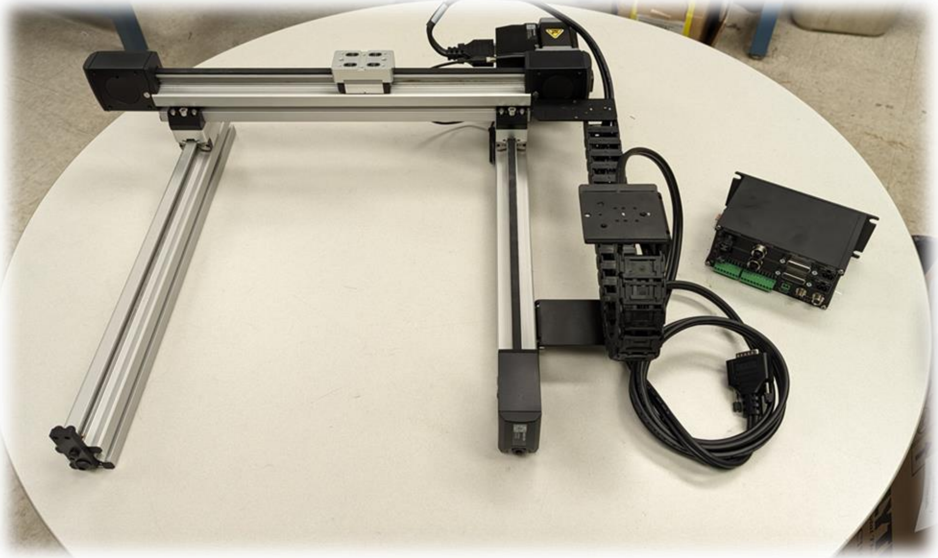
Source of light here (LED light through a 1 mm quartz fiber)

Engineering support from JLab: Pablo Campero Rojas and Marc McMullen

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

In the Works 2023-2024 – Precision System to Illuminate the LAPPD

2023-present: assembled and almost done calibrating the illumination system



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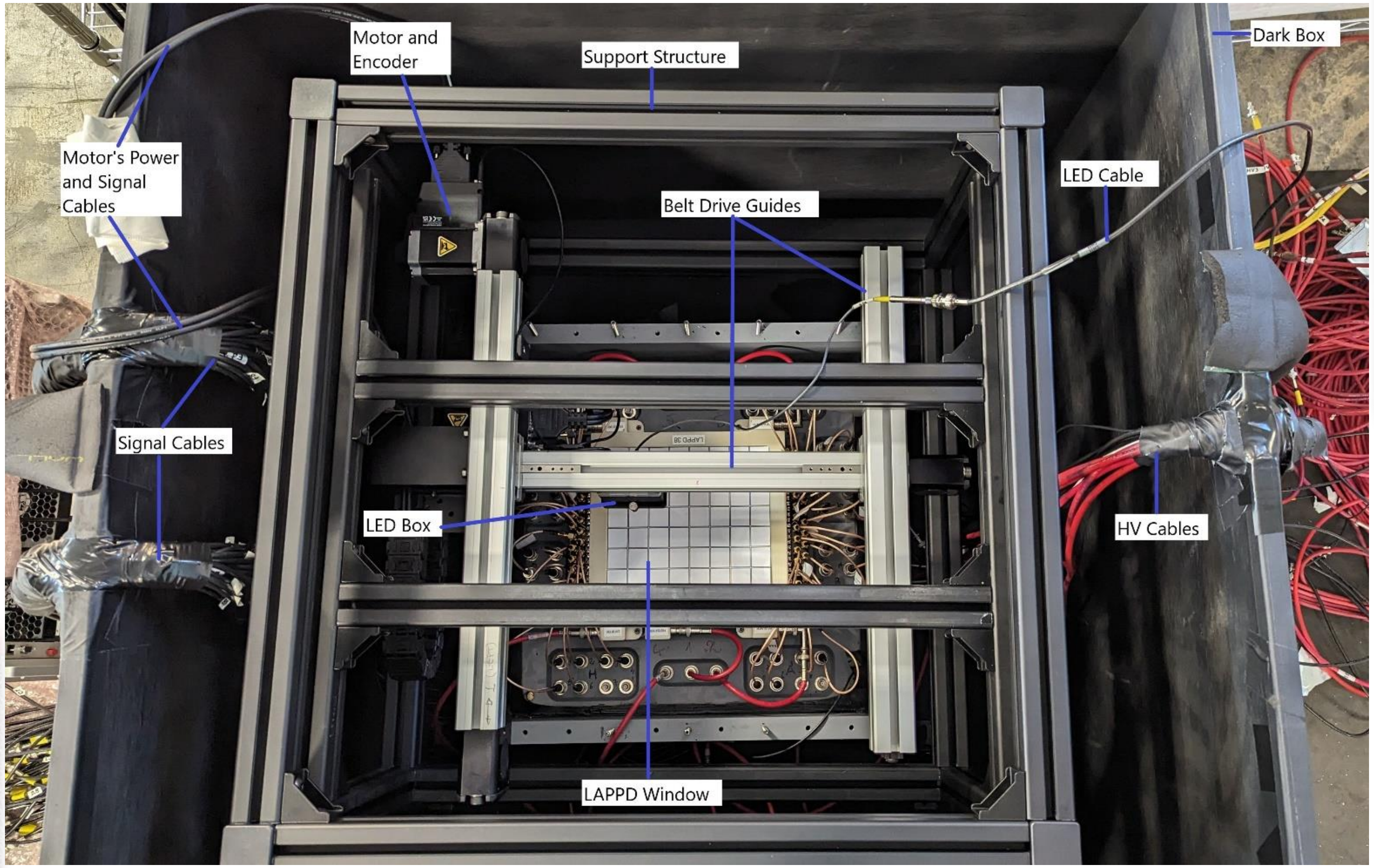
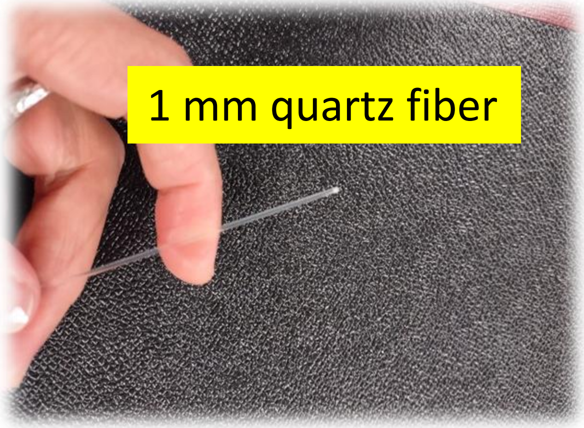
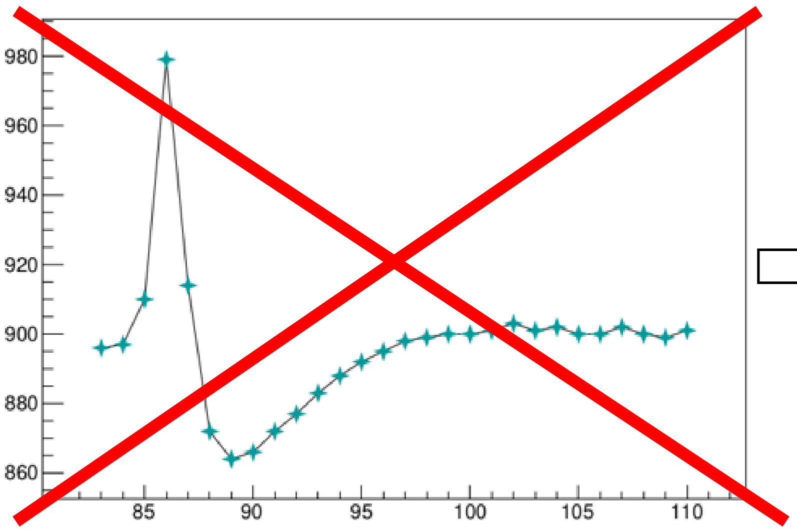



1 mm quartz fiber

In the Works 2023-2024 – Faster Digitizer Than FADC250 → CAEN V1742



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

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

- $Z_{in} = 50\ \Omega$

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 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 have 2 V1742 modules, one is in my test setup already
- The libraries and rol have been written (Steve Wood)
- We sampled maPMT pulses

In the Works 2023-2024 – Faster Digitizer Than FADC250 → CAEN V1742

Channels

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

Impedance

- Z_{in} = 50 Ω

DC Offset

Connector

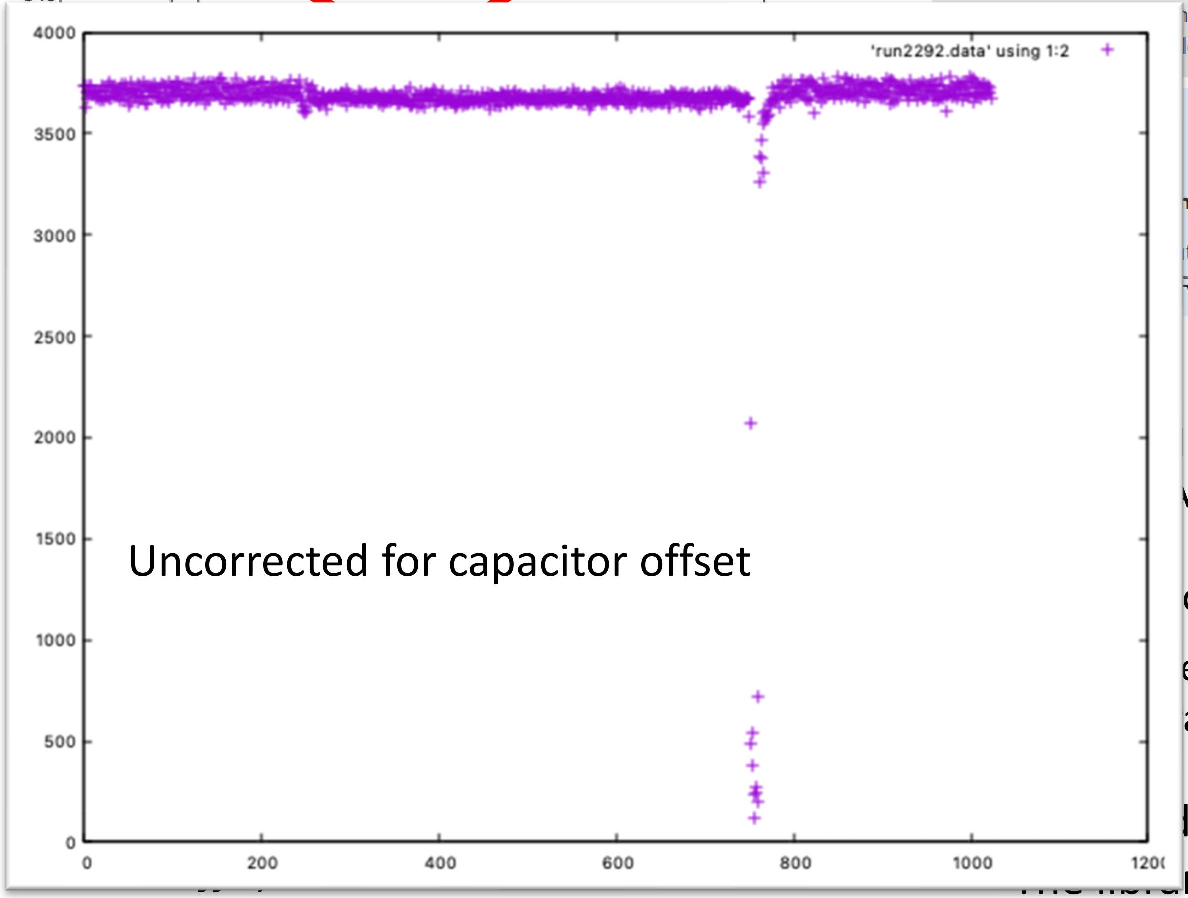
- MCX

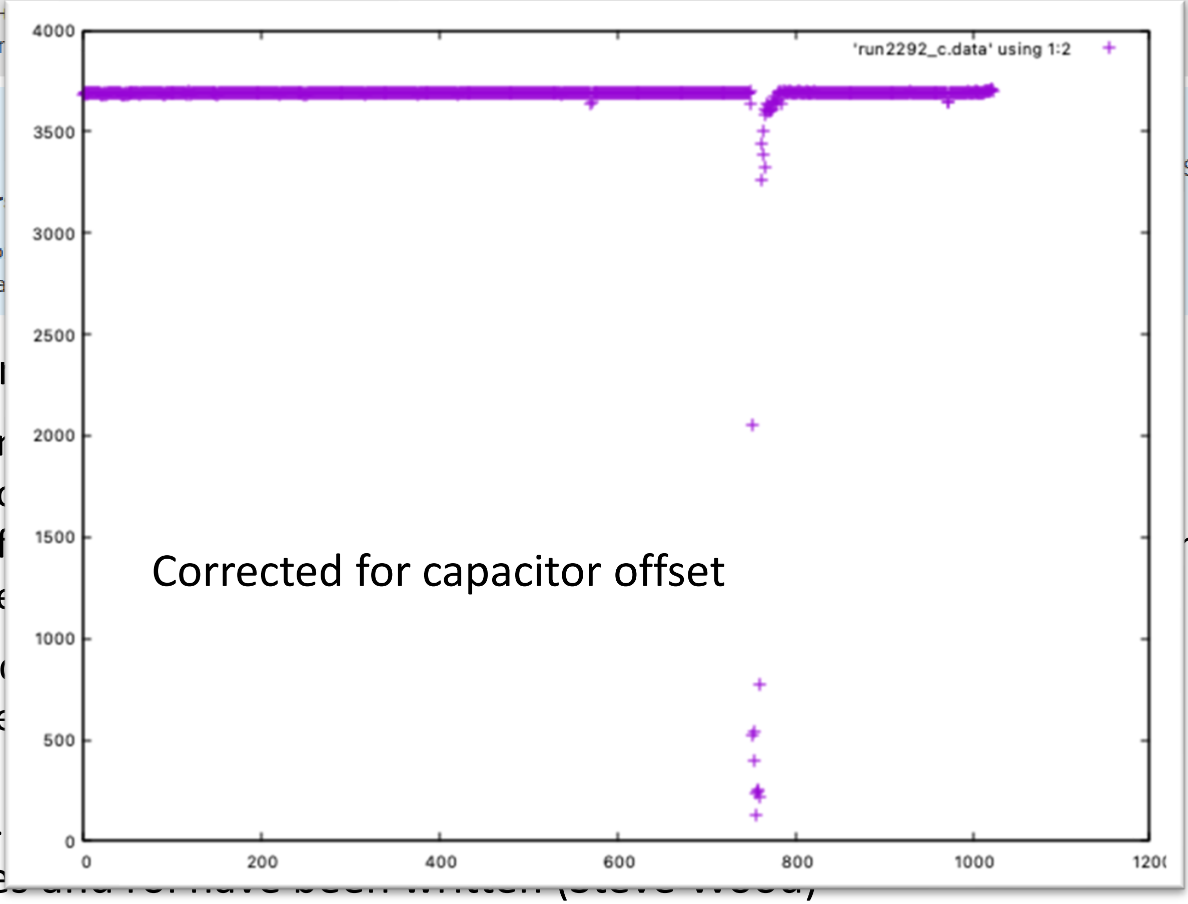
Full Scale Range (FSR)

- 1 V_{pp}

Absolute max analog input voltage

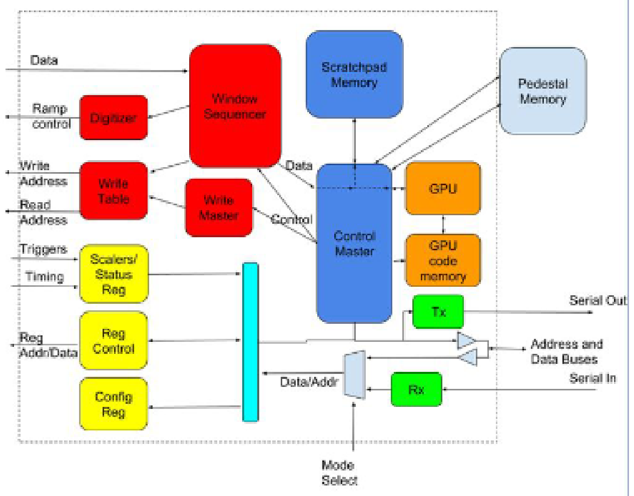
Sampling of a maPMT pulse with CAEN V1742 in my test setup





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

Digital Block

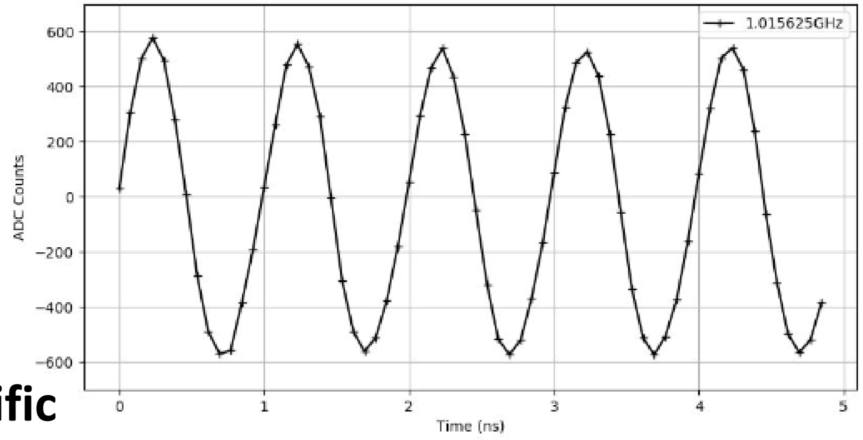


AARDVARC digital block diagram: Red Blocks: Analog control blocks, yellow blocks: general registers, Blue blocks: master control, orange blocks: GPU, green blocks: Serial interface

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

Example 1 GHz Sine wave input @ 13 Gsa/s



From NALU Scientific

→ I got a AARDVARC V3 from NALU; I need to download the software NaluScope: "easy-to-use application designed to control and read from Nalu hardware"

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

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

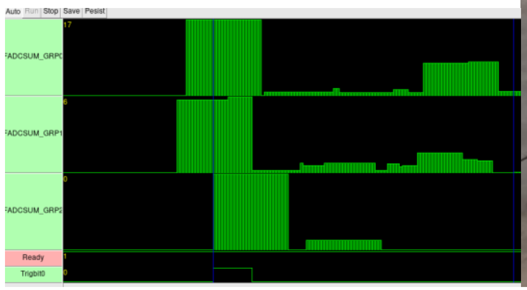
→ Gain vs MCP and Photocathode voltages

→ Gain vs trigger rate curves

→ Dark rates

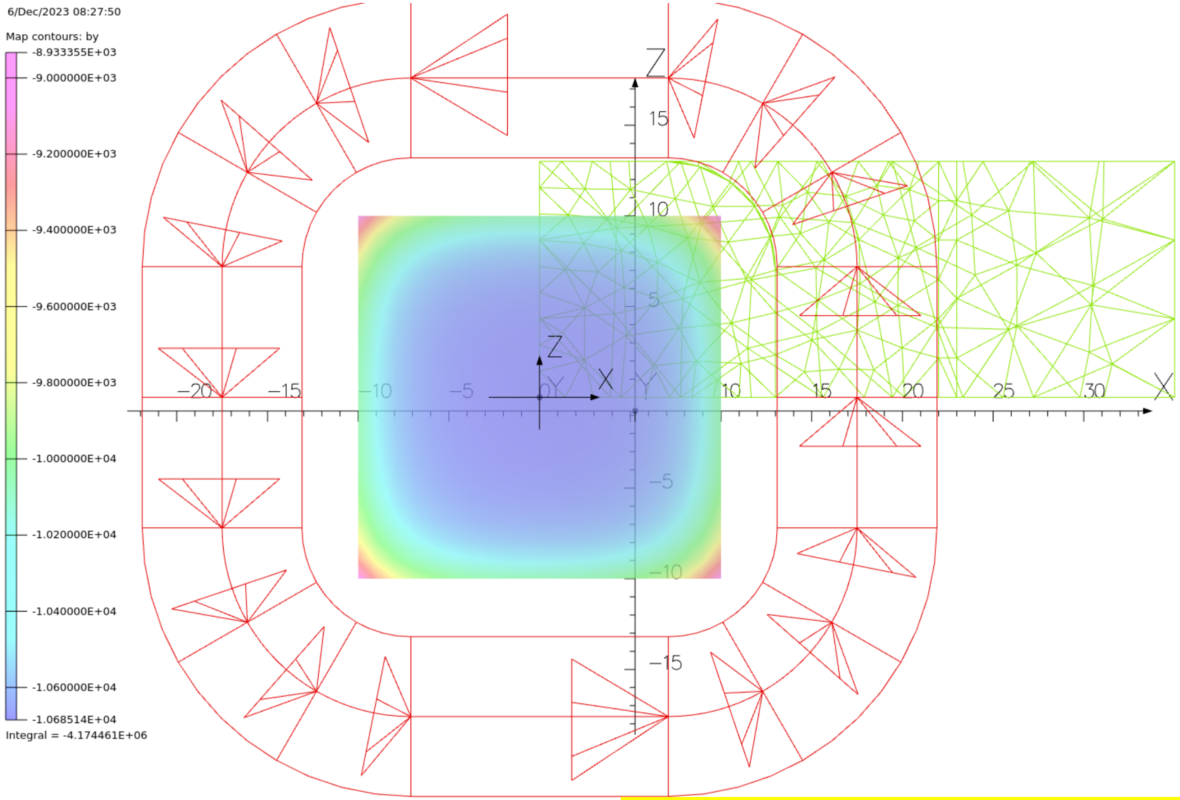
→ Measure cross talk

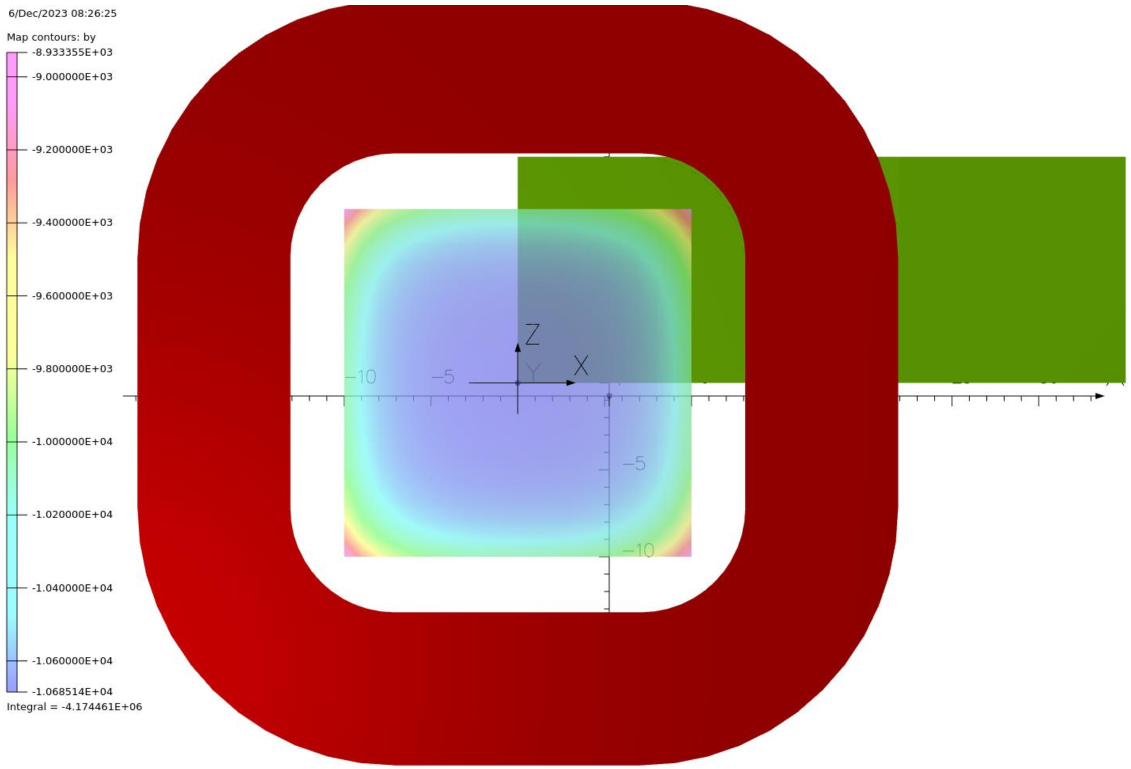
→ Tests with comic muons (Cherenkov light in C4F8): VTP trigger with calorimeter and scintillators



What Else is in the Works – Magnetic Field Tests at JLab?

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





Magnet design support:
Jay Benesch (JLab)

December 2023: met with JLab management & engineering to discuss the possibility of building a magnetic field test setup at JLab; I was advised to write a proposal and find others that might be interested in having a high-filed, large bore magnet at JLab for B-field studies of large-size photosensors and other detectors (please e-mail simona@jlab.org if you could make use of such setup)

Summary

→ Illumination system for LAPPD test installed and calibration almost done

→ V1742 integrated in test setup and ready to digitize LAPPD pulses

→ AARDVARC V3 unit available; need to download software and try it

→ In the works a proposal for a mini-facility at Jlab for magnetic filed tests of photosensors and other detectors