

Scintillator Characterization for the Single Volume Scatter Camera

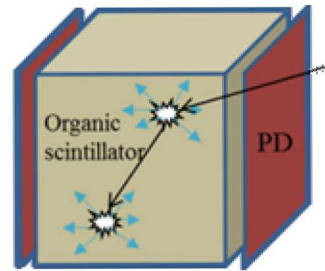


PRESENTED BY

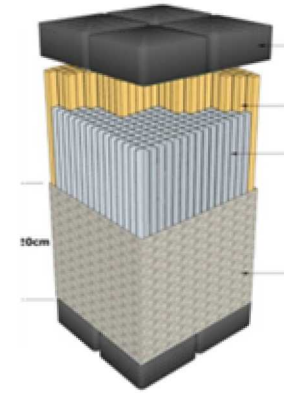
Juan Manfredi, Josh Brown

Prototyping

Monolithic

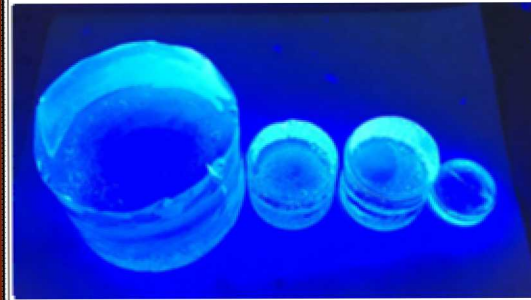


Opt. Segmented



Components

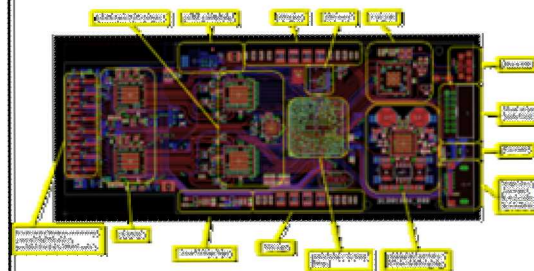
Scintillators



Photodetectors



ELECTRONICS



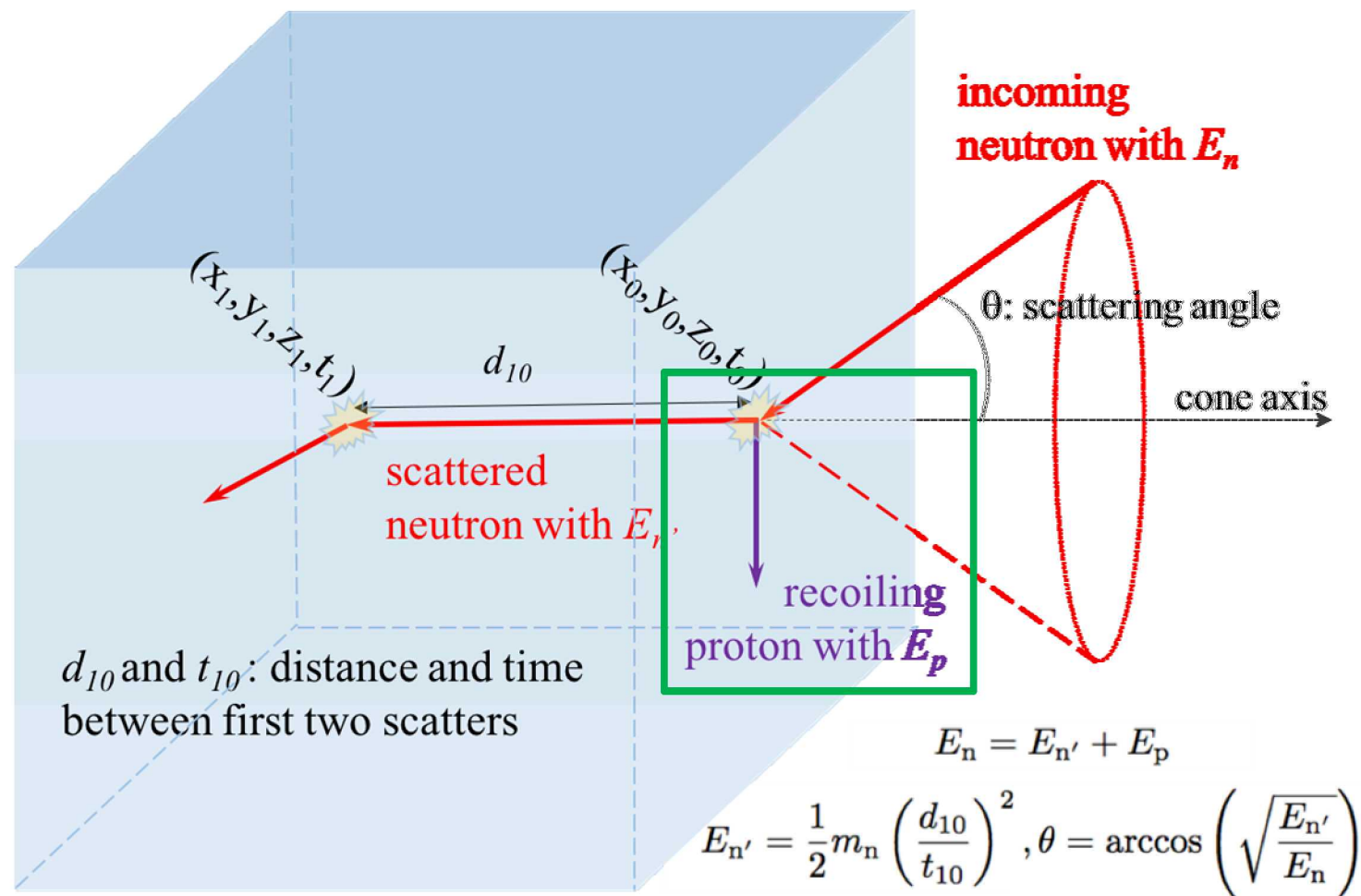
Algorithms

[illegible]

Proton light yield

- To calculate incoming neutron angle we must know the mapping between measured light and proton recoil energy (E_p), called the **relative proton light yield relation (PLY)**
- PLY affects imaging performance

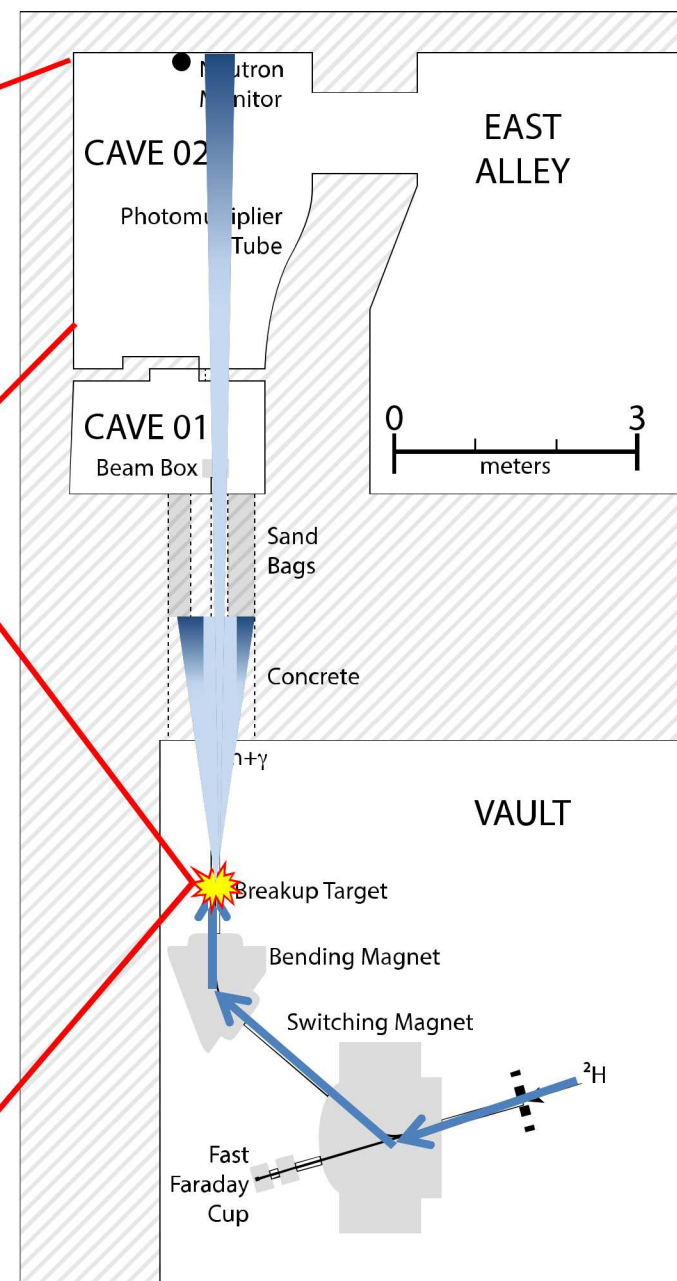
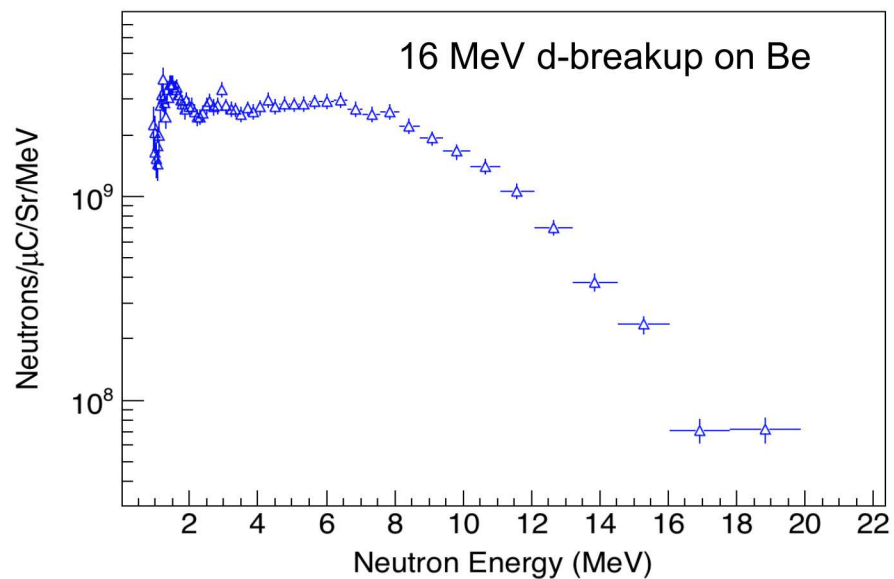
Scintillator Material	Status	Notes
EJ200	Published	Plastic
EJ204	Published	Plastic
EJ208	Published	Plastic
EJ230	Submitted	Fast plastic
EJ232	Submitted	Fast plastic
EJ232Q	Submitted	Fast plastic



T.A. Laplace et al, NIM A 842 (2018).

Sweany, et al. NIM A 927 (2019).

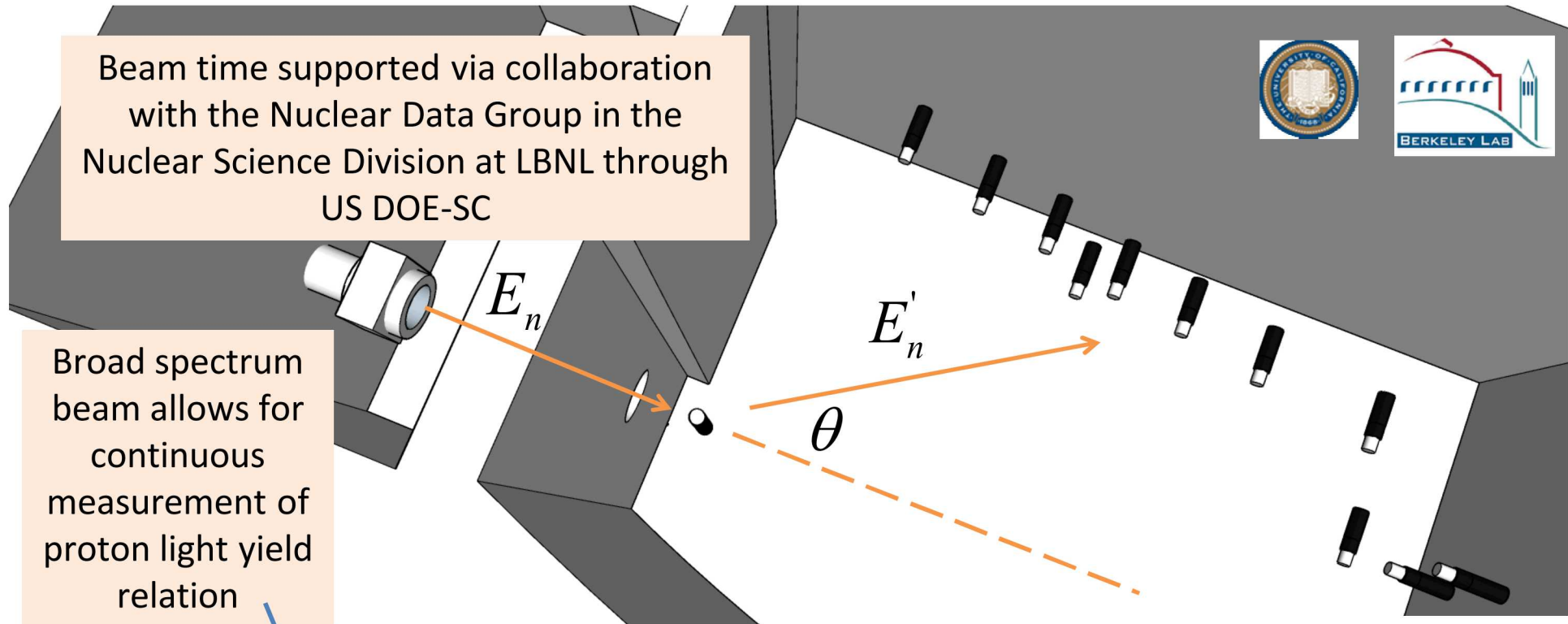
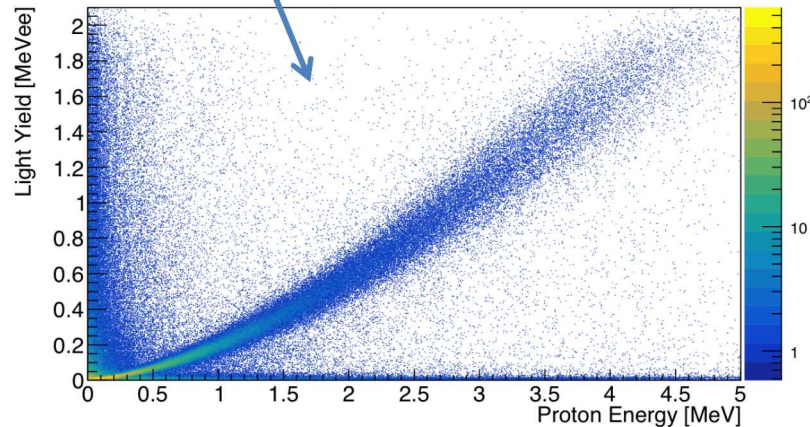
D-Breakup neutron source



PLY measurements at UCB/LBNL

Beam time supported via collaboration with the Nuclear Data Group in the Nuclear Science Division at LBNL through US DOE-SC

Broad spectrum beam allows for continuous measurement of proton light yield relation



Kinematically over-constrained system provides systematic check

$$E_p = E'_n \tan^2 \theta$$

$$E_p = E_n \sin^2 \theta$$

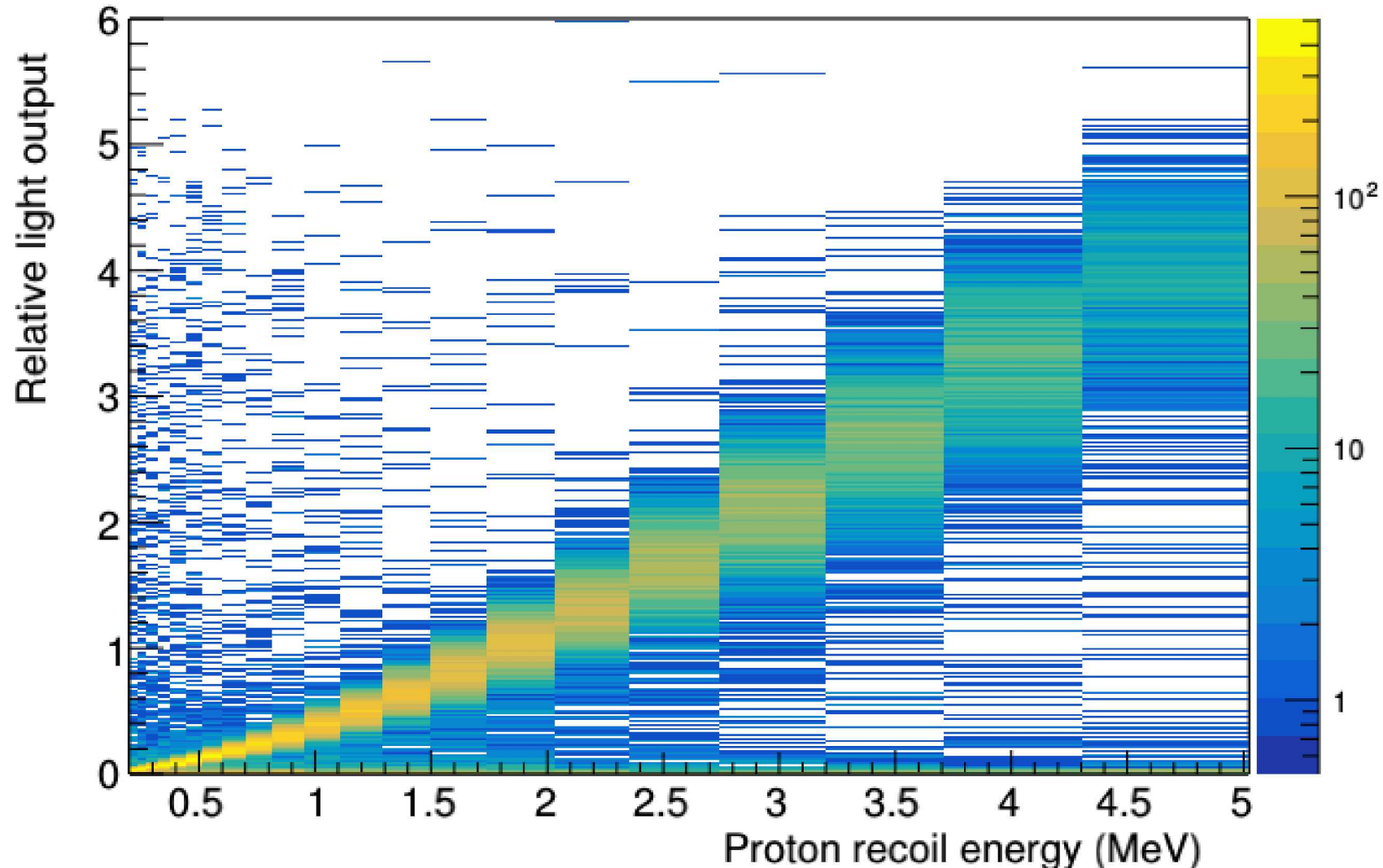
$$E_p = E_n - E'_n$$

J.A. Brown, PhD Thesis, UC Berkeley 2017.

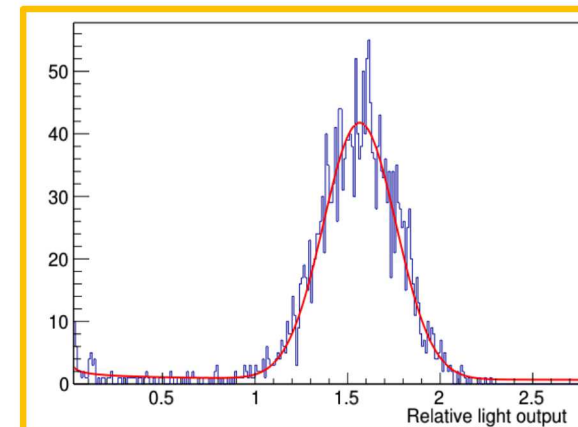
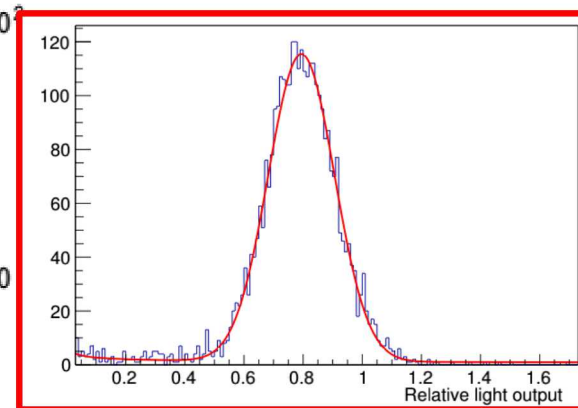
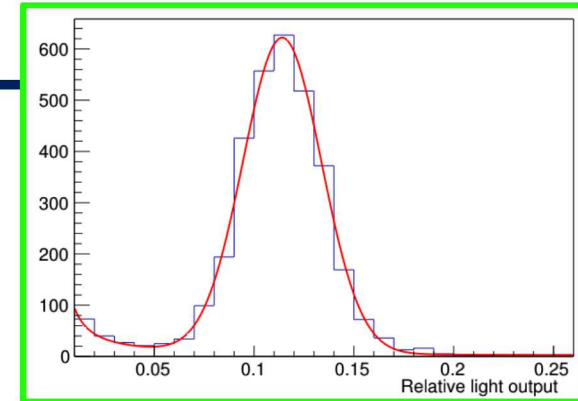
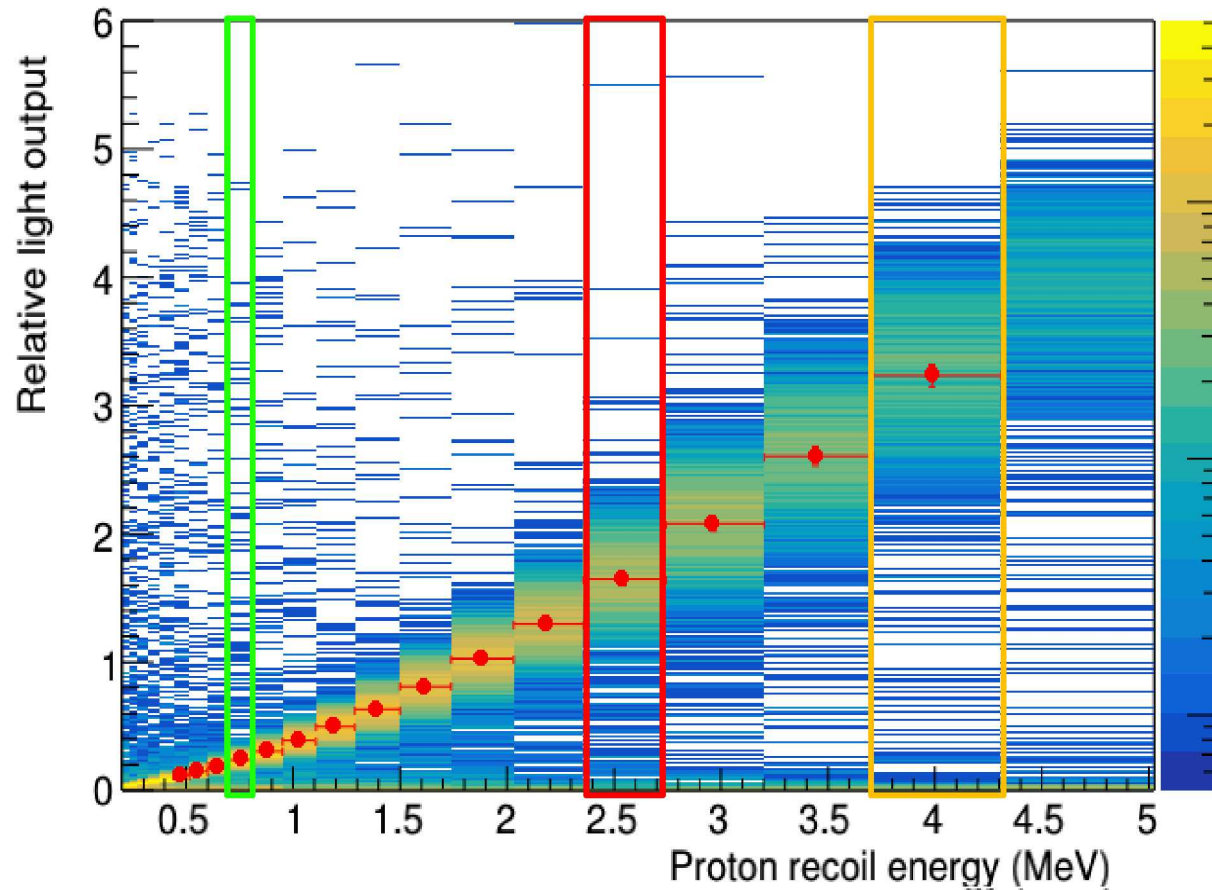
J.A. Brown, et al. Journal of Applied Physics 124, 045101 (2018).

Proton recoil energy vs. light yield (EJ-230)

Relative light output of 1 = Light from a 477 keV recoil electron (Compton edge of ^{137}Cs)

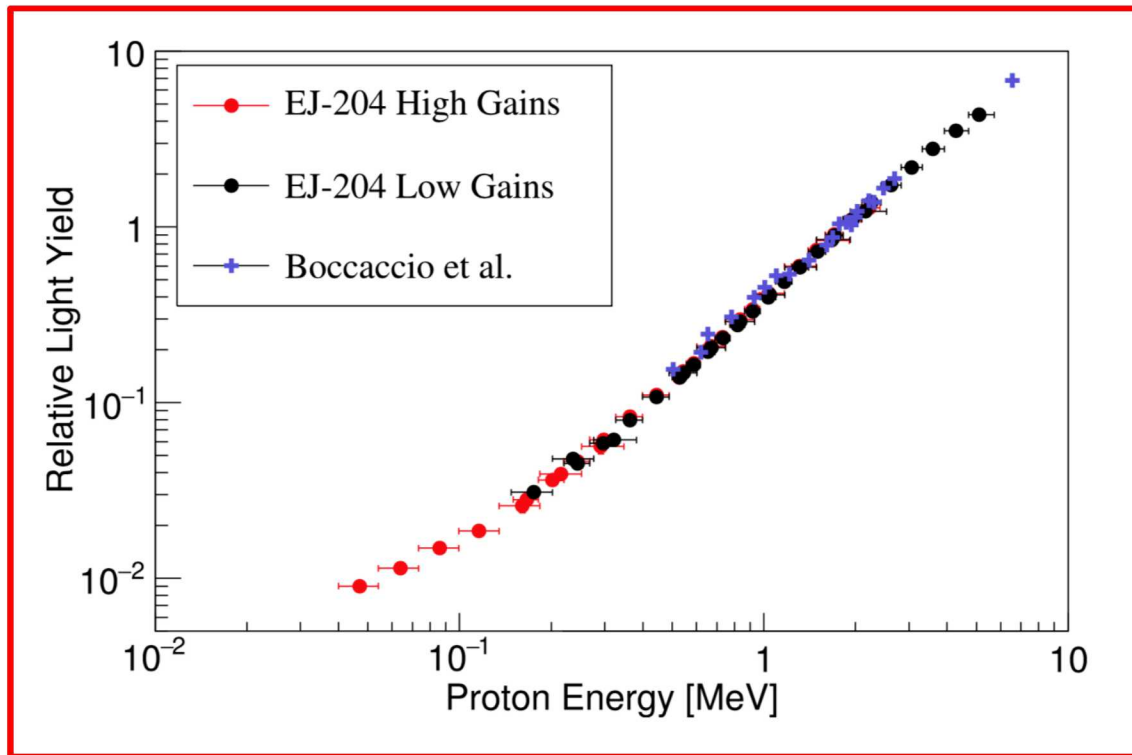


Light-yield fitting (EJ-230)

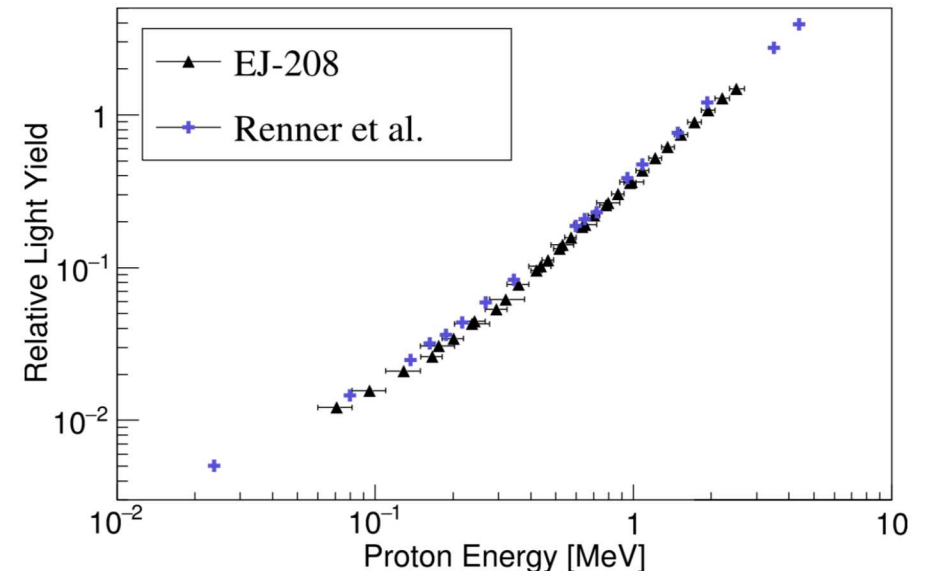
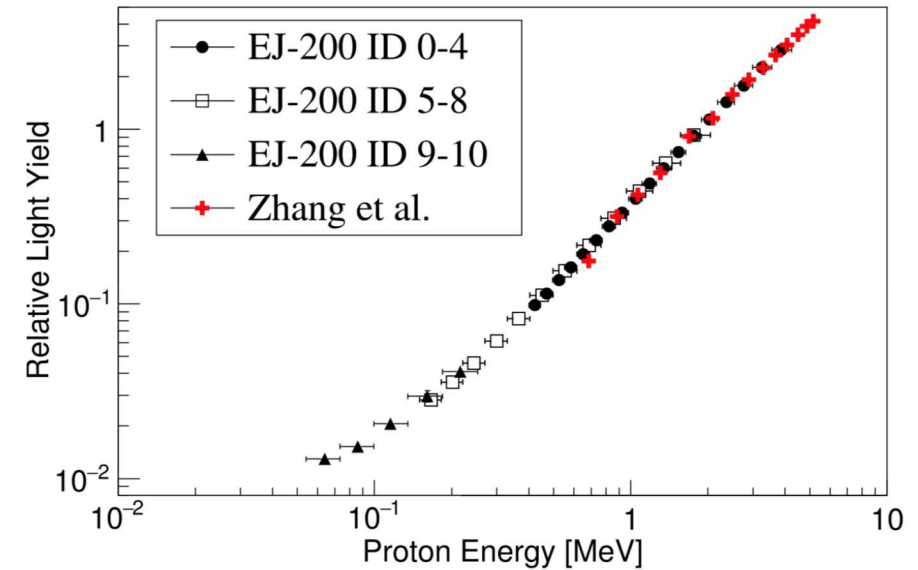


PLY results: EJ200, EJ204, and EJ208

- Measurements of EJ20x series agree with literature
- First measurement of PLY to such low energies (~ 50 keV for EJ204)

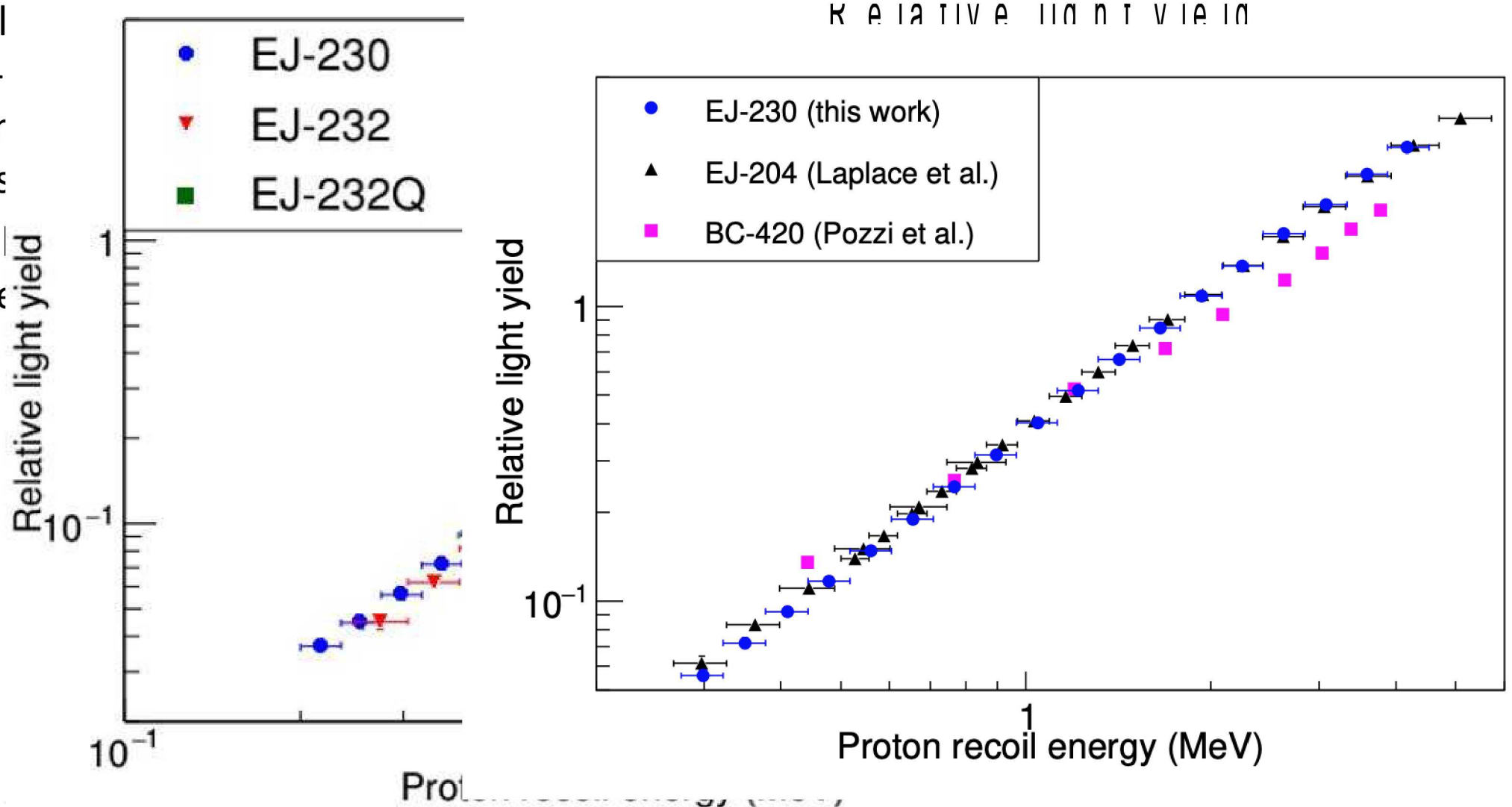


T.A. Laplace et al, NIM A 842 (2018).



PLY results: EJ230, EJ232, and EJ232Q

- EJ-23x results are those of EJ-230, EJ-232, and EJ-232Q, which have the same polymer and similar densities.
- EJ-230 results are from previous literature.

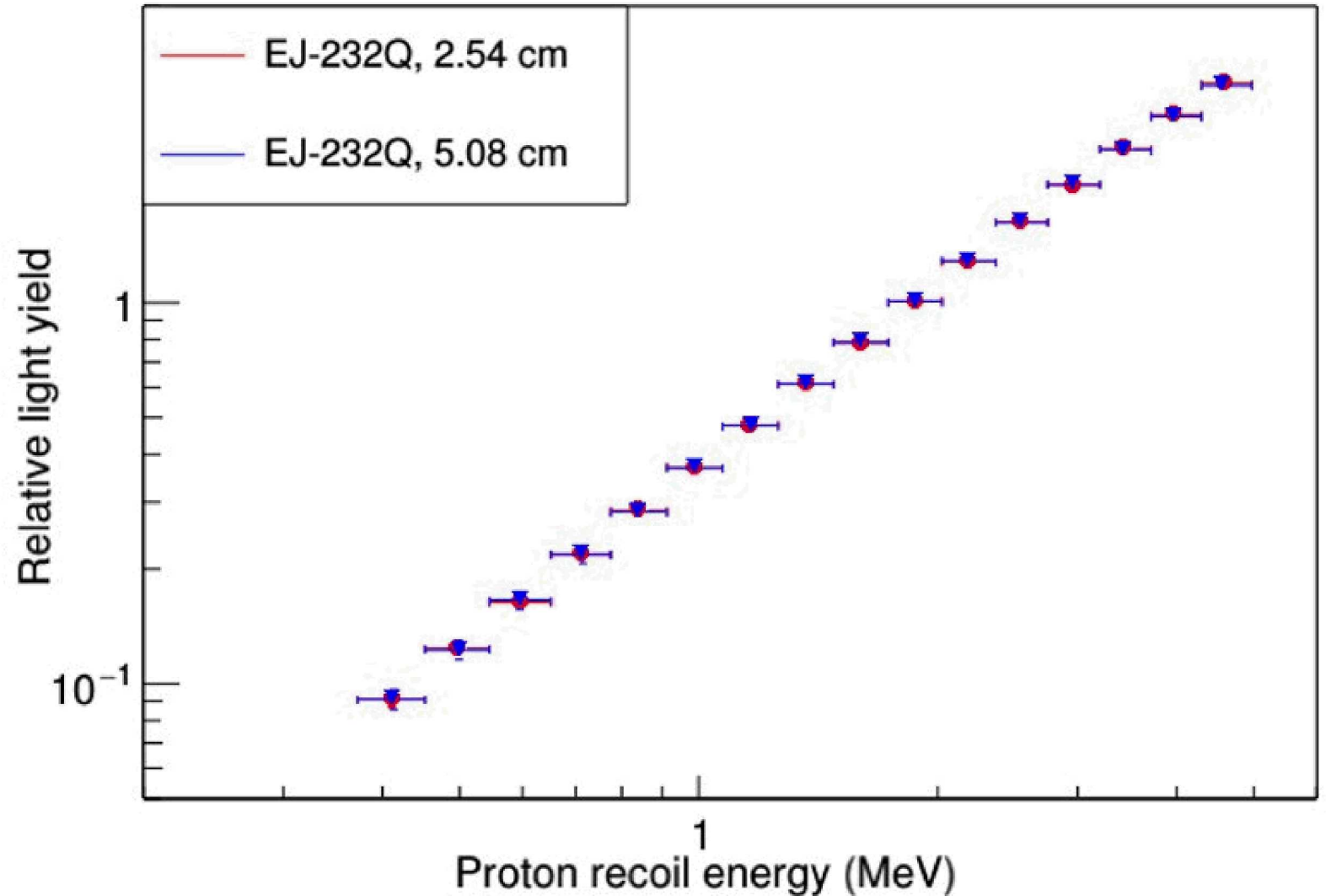


Laplace, et al. NIM

Pozzi, et al. NIM A 524 (2004).

PLY results: size comparison

- Enqvist, et al: relative light yield depends on scintillator size (i.e. not just a property of material)
- This should be visible in EJ232 and EJ232Q due to short attenuation lengths
- Relative proton light yields for 2-inch and 1-inch cells are within error



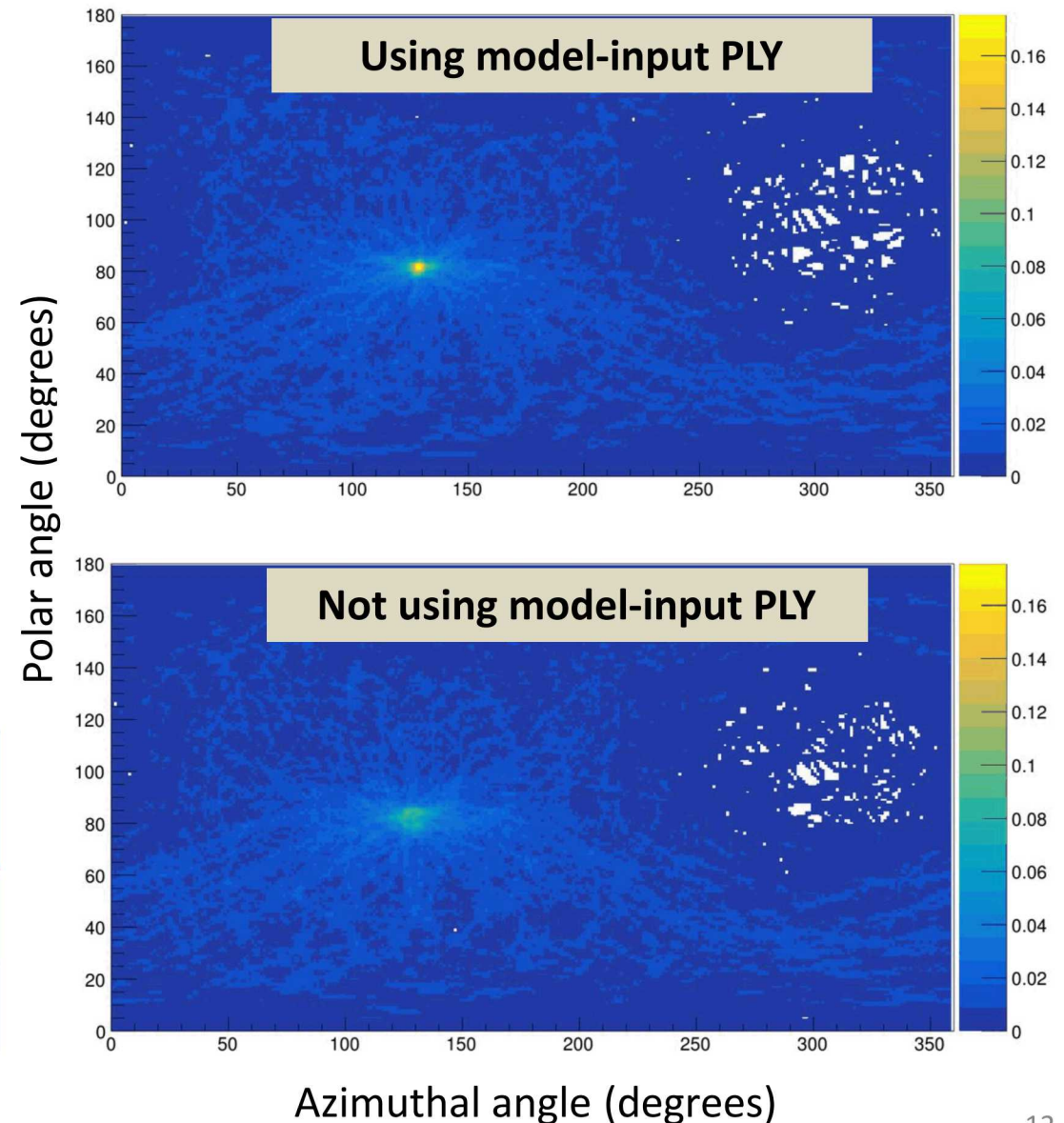
Enqvist, et al. NIM A 715 (2013).

Does PLY matter?

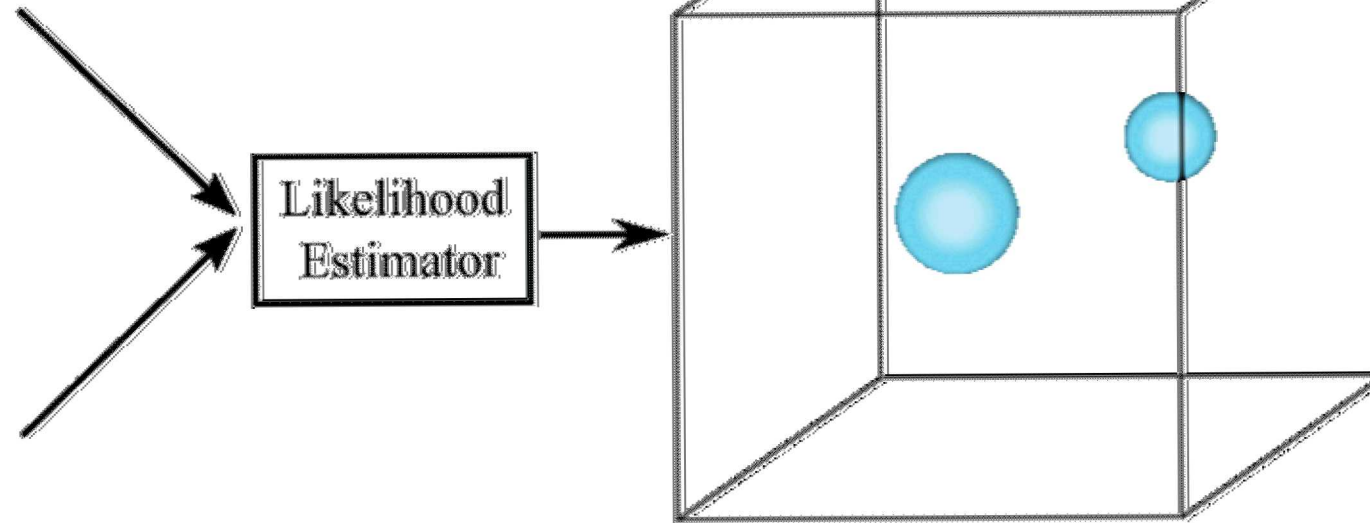
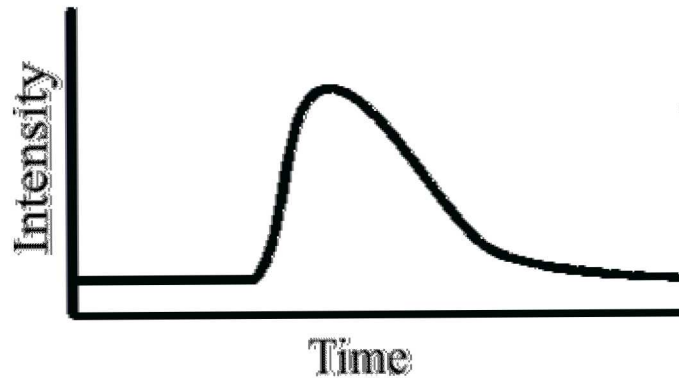
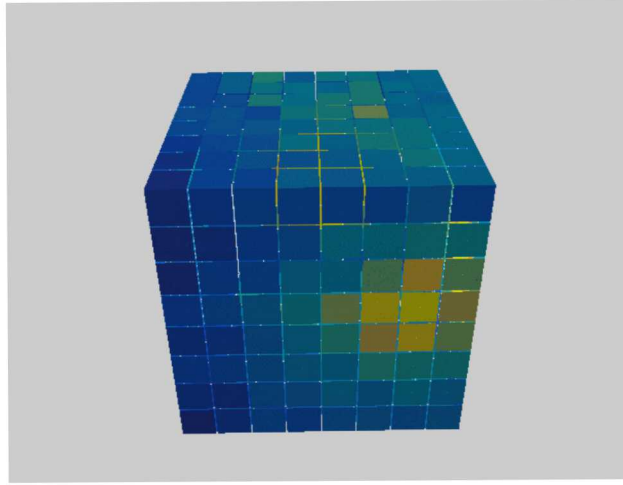
Yes!

- In simulation, we use a PLY to generate light from proton recoils
- Then, analyze data using either the appropriate model-input PLY or with a separate PLY from the literature to calculate the recoil energy
 - Model-input: Laplace, NIM 2018.
 - Non-model-input: Pozzi, NIM 2004.
- The final backprojected images show a clear impact

w/ model input FWHM (deg)	w/o model input FWHM (deg)	Diff. (%)
9.0	14.4	60
20.1	41.6	107

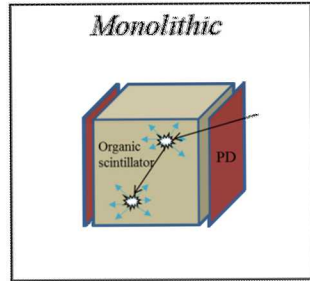


Scintillator Pulse Shape Measurements

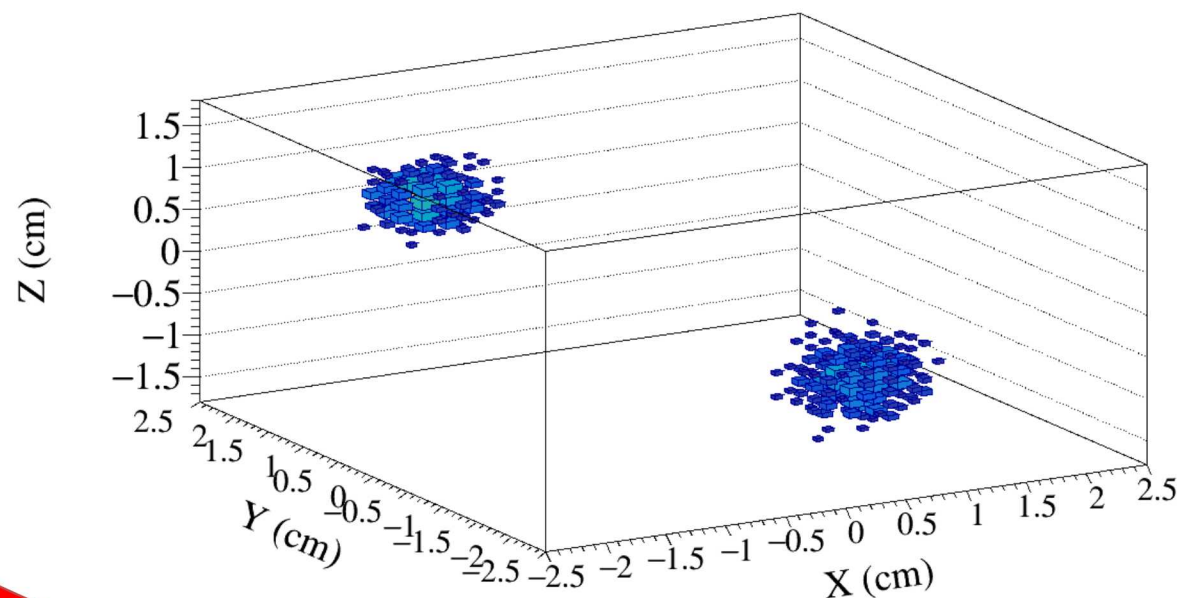
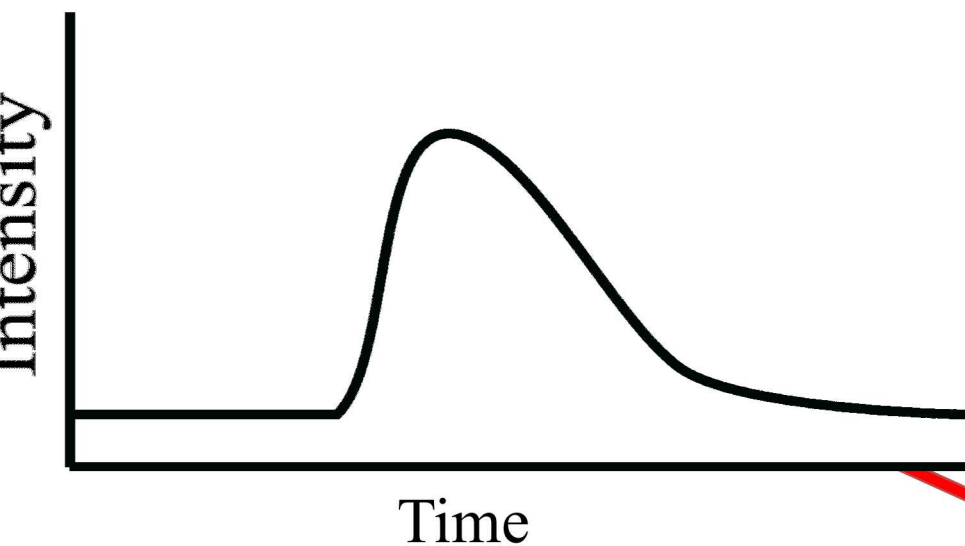


For multiple interactions

- Position (x,y,z)
- Time
- Proton Energy

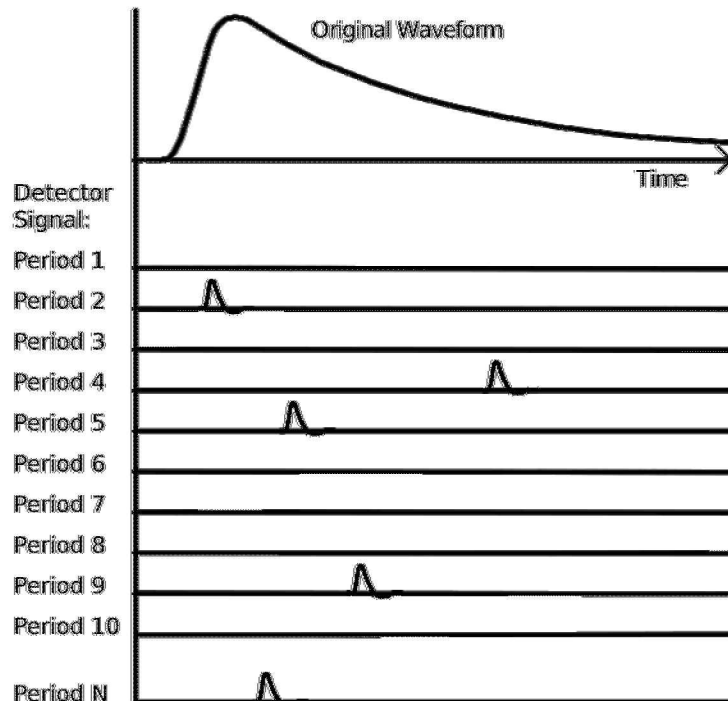
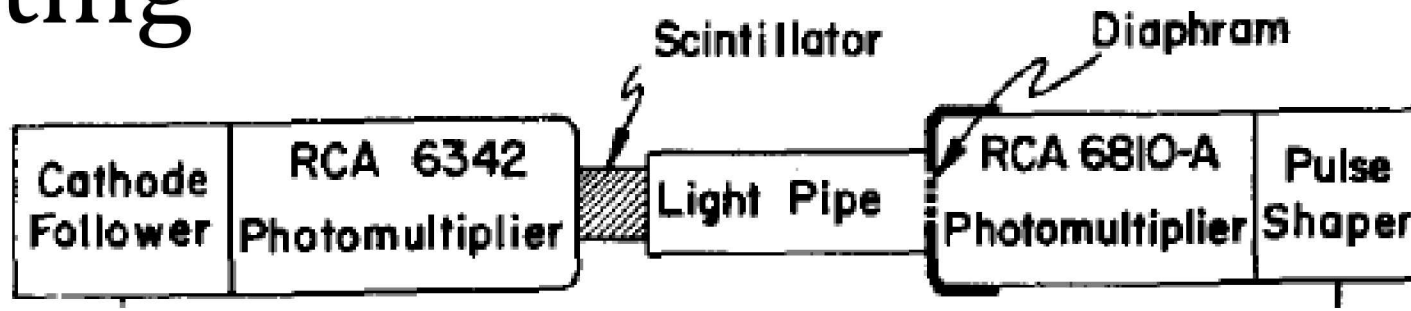


Pulse Shapes In Event Localization

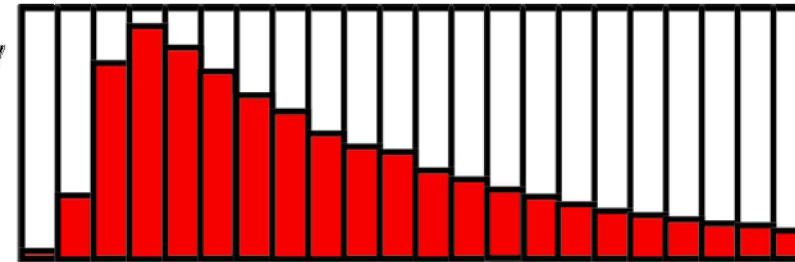


$$P_{ji} = \frac{\Omega_{jk(i)} Q_{k(i)} e^{\frac{-d_{jk(i)}}{\lambda}}}{4\pi \sum_k \frac{\Omega_{jk}}{4\pi} Q_k e^{\frac{-d_{jk}}{\lambda}}} f \left(t_i - t_j - \frac{d_{jk(i)} N}{C} \right)$$

Time Correlated Single Photon Counting



Result
after many
Photons



Principle of the TCSPC technique

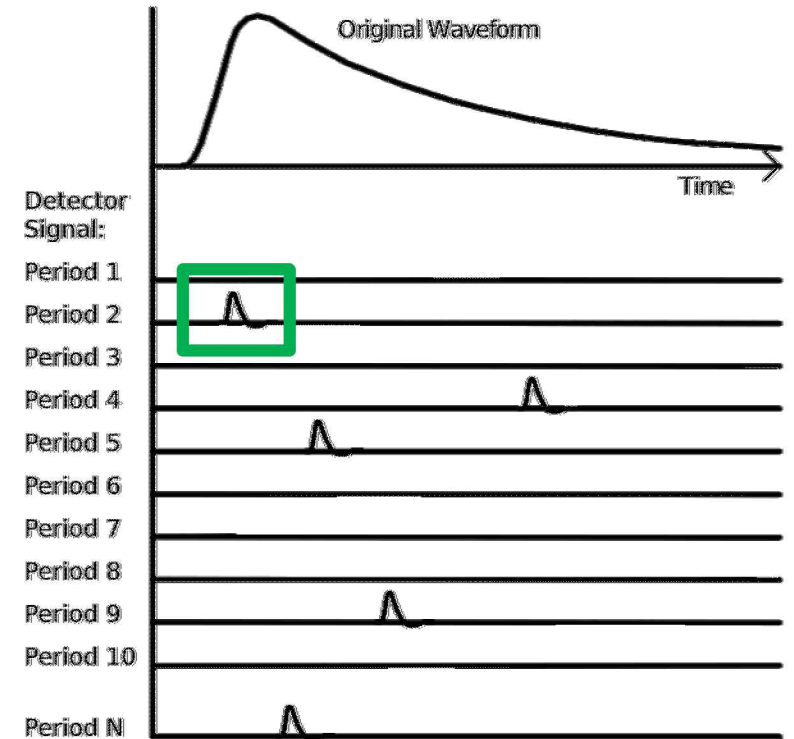
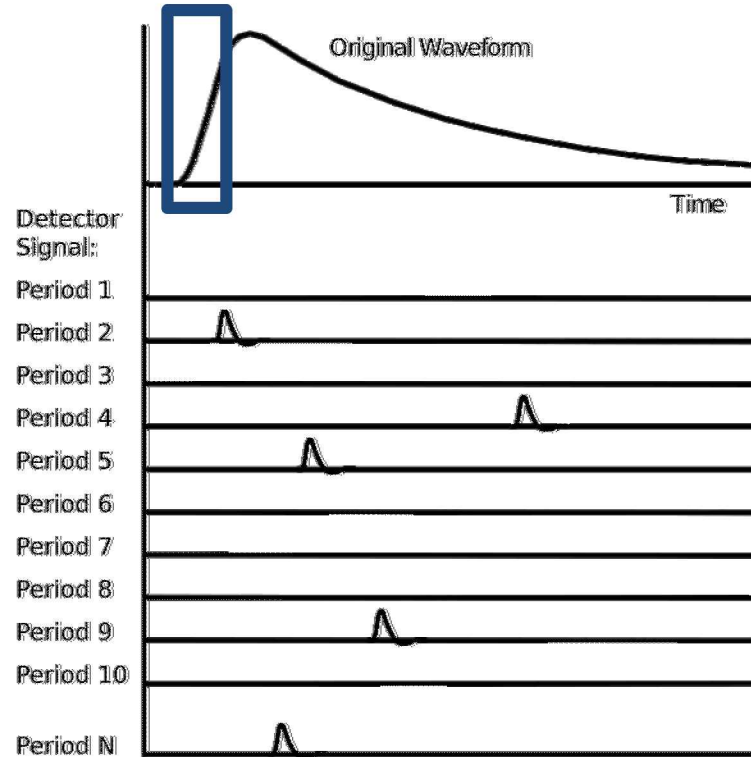
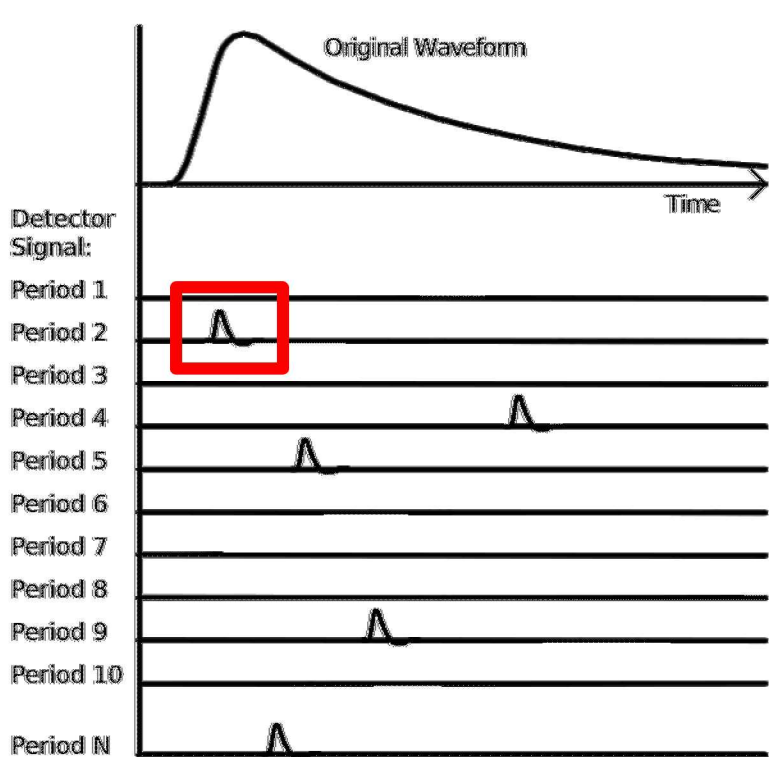
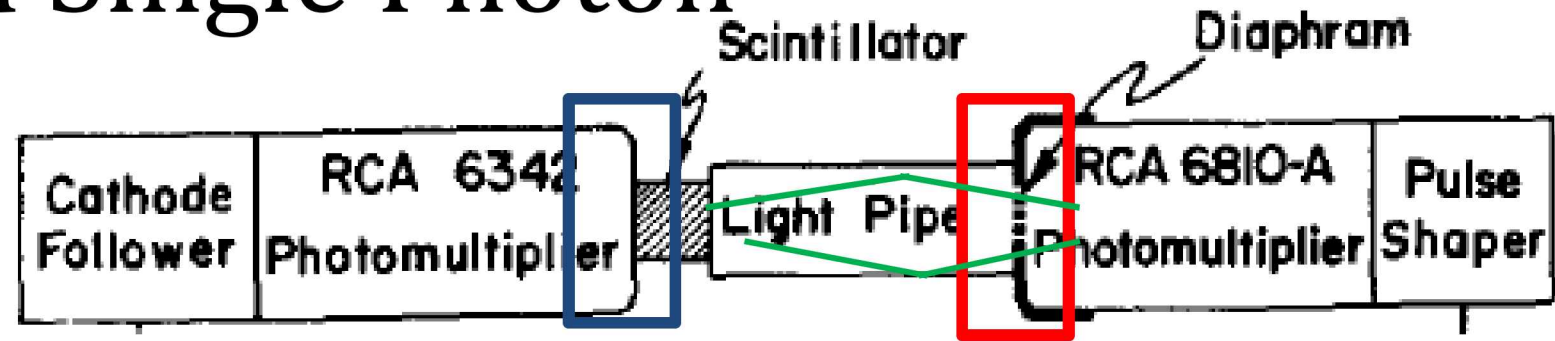
Measurement of the Time Dependence of Scintillation Intensity by a Delayed-Coincidence Method*

L. M. BOLLINGER AND G. E. THOMAS

Argonne National Laboratory, Argonne, Illinois

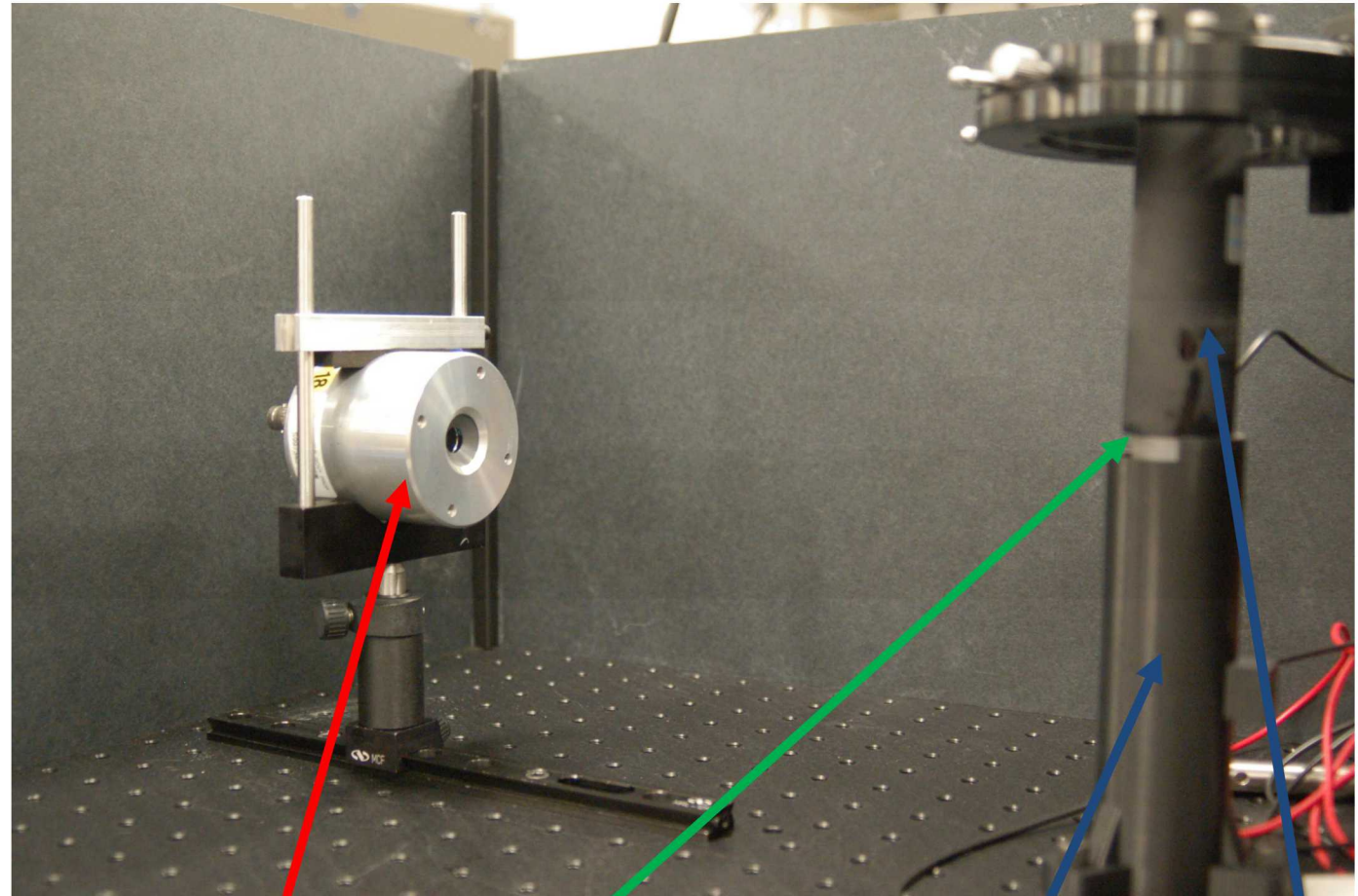
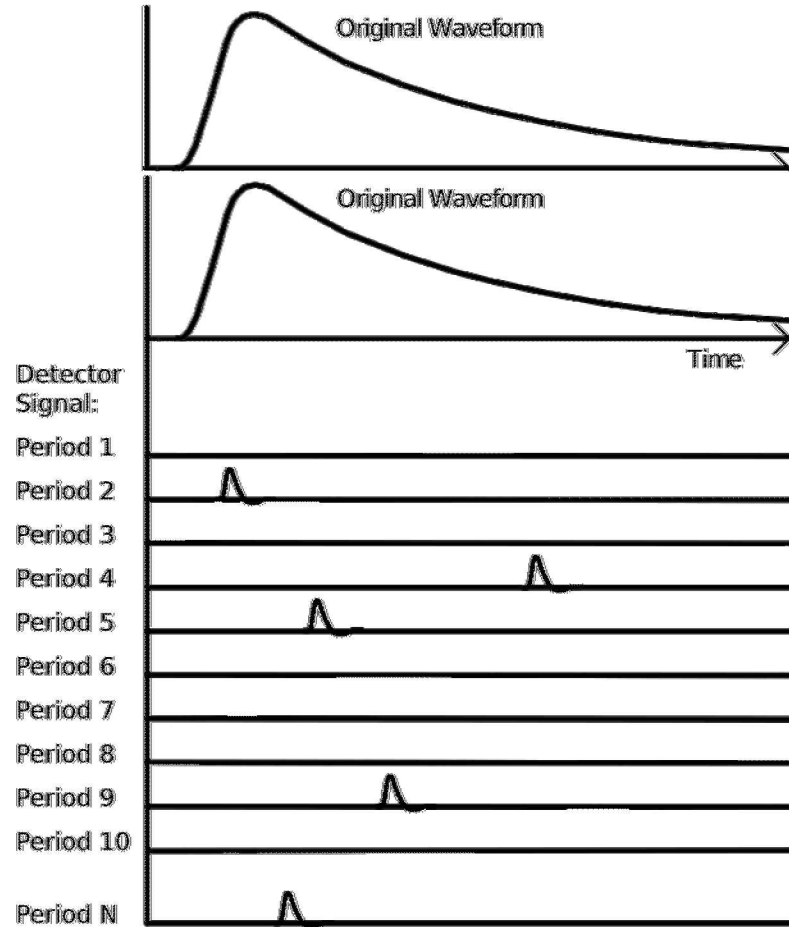
(Received January 13, 1961; and in final form, April 11, 1961)

Temporal Resolution of Time Correlated Single Photon Counting



Time Correlated Single Photon Counting

(A Modern Interpretation)

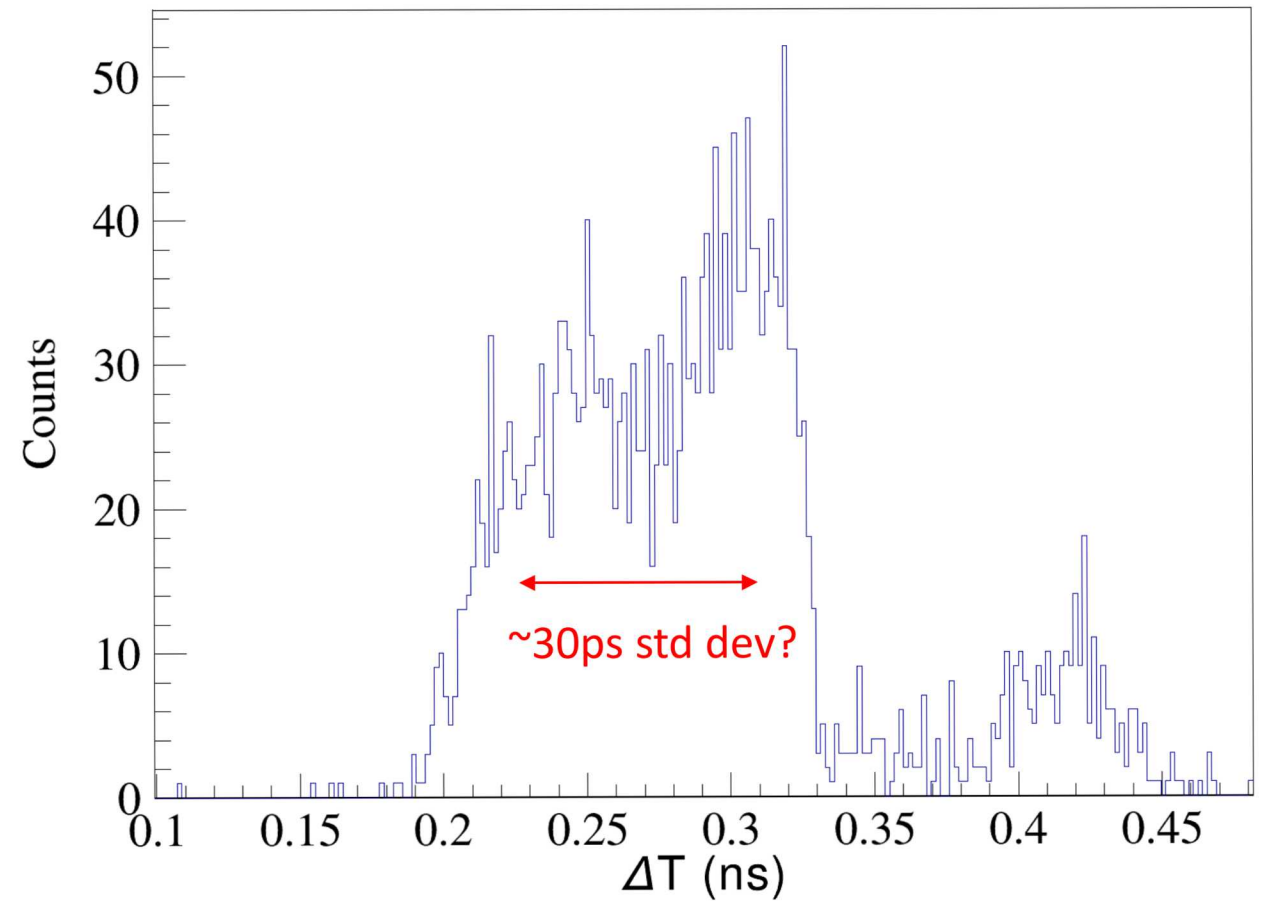
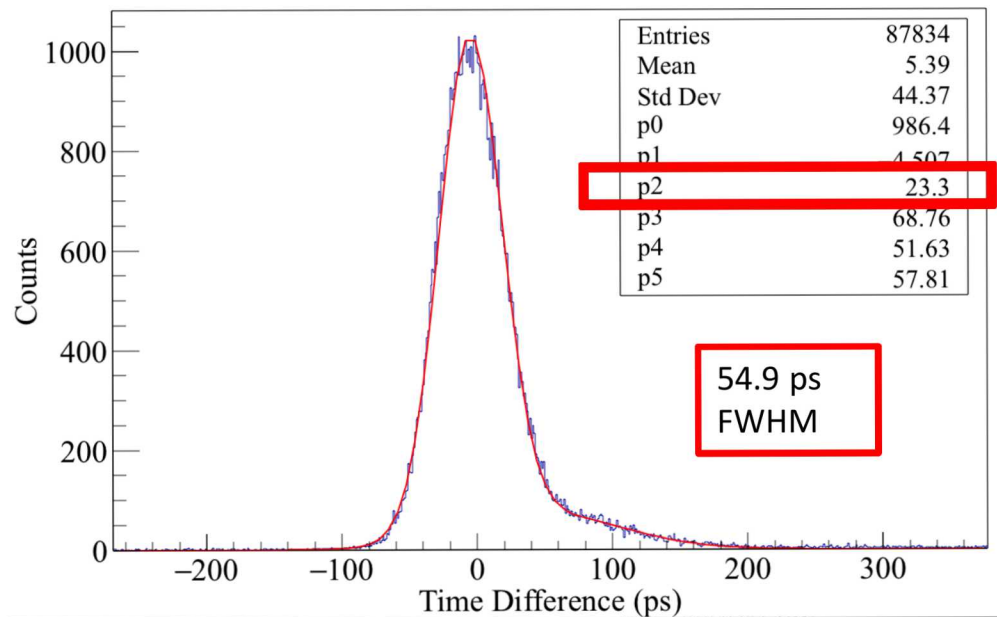
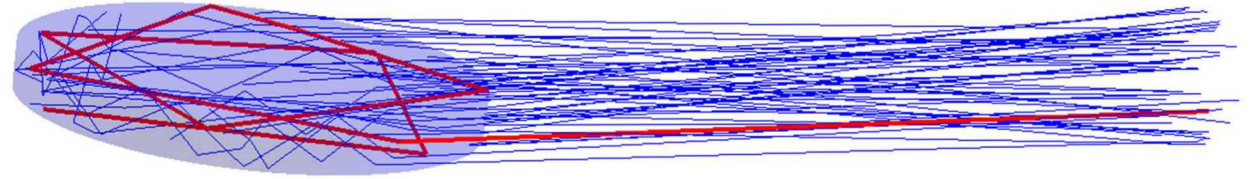
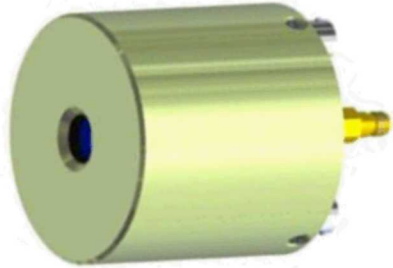


PHOTEK PMT-210
~30ps std dev SPTR

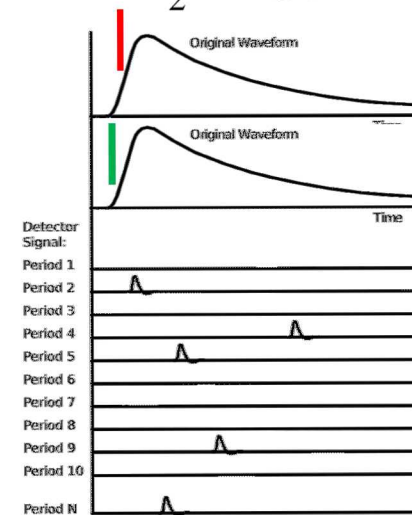
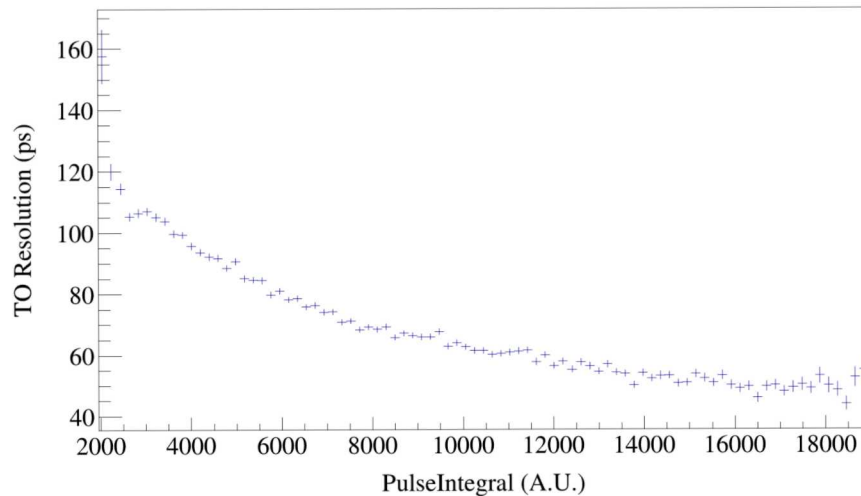
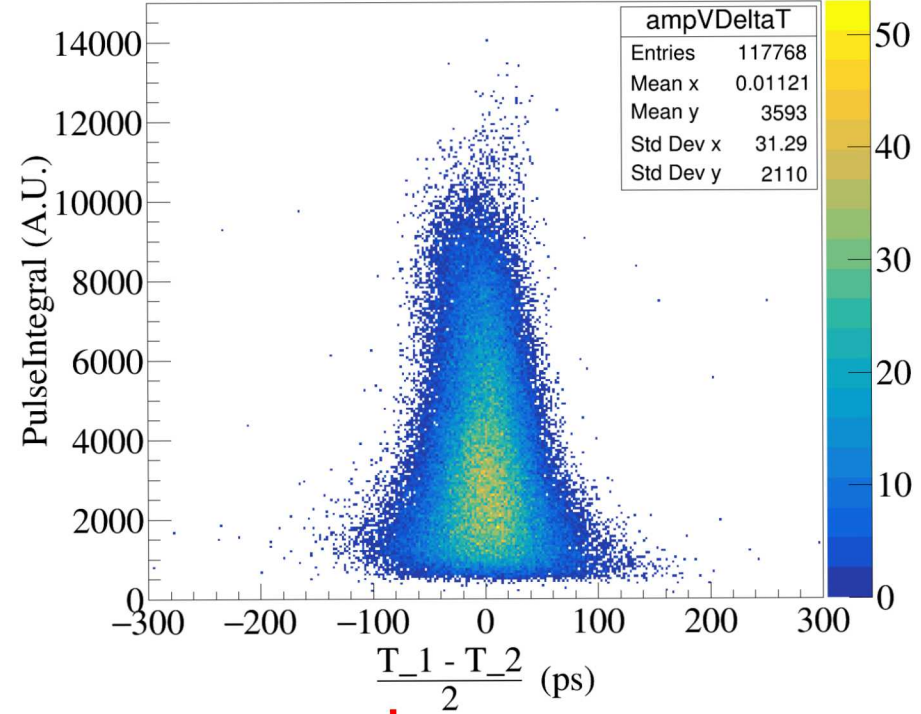
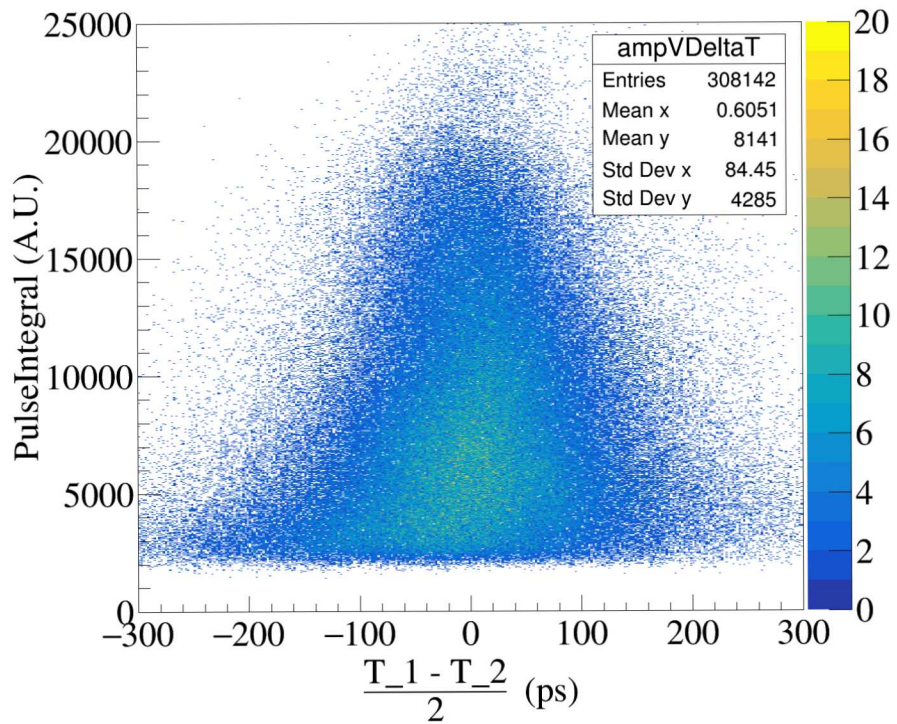
Fast Plastic
Scintillator

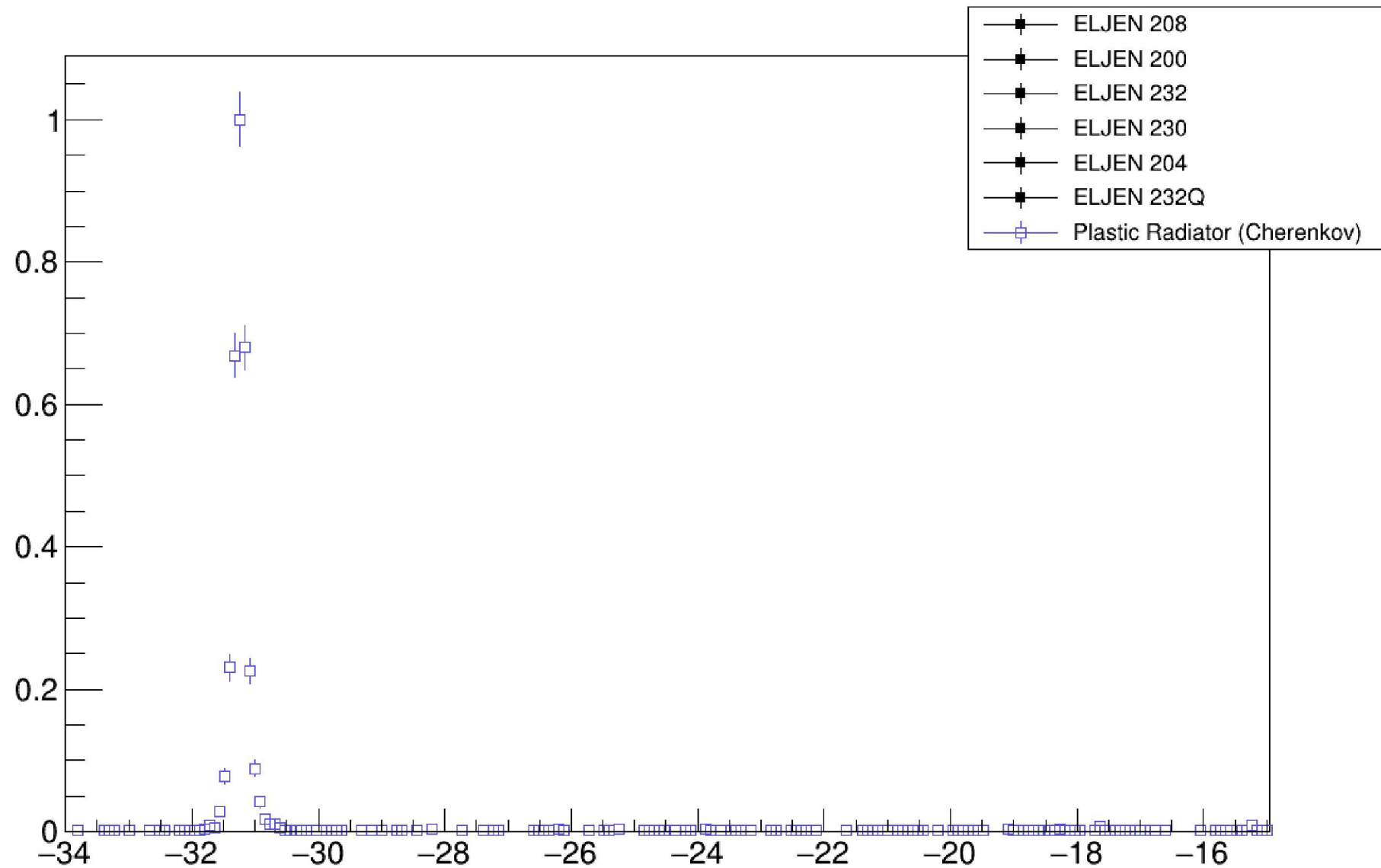
H6533 PMT Assemblies
~70ps std dev SPTR

Resolution of Modern Setup

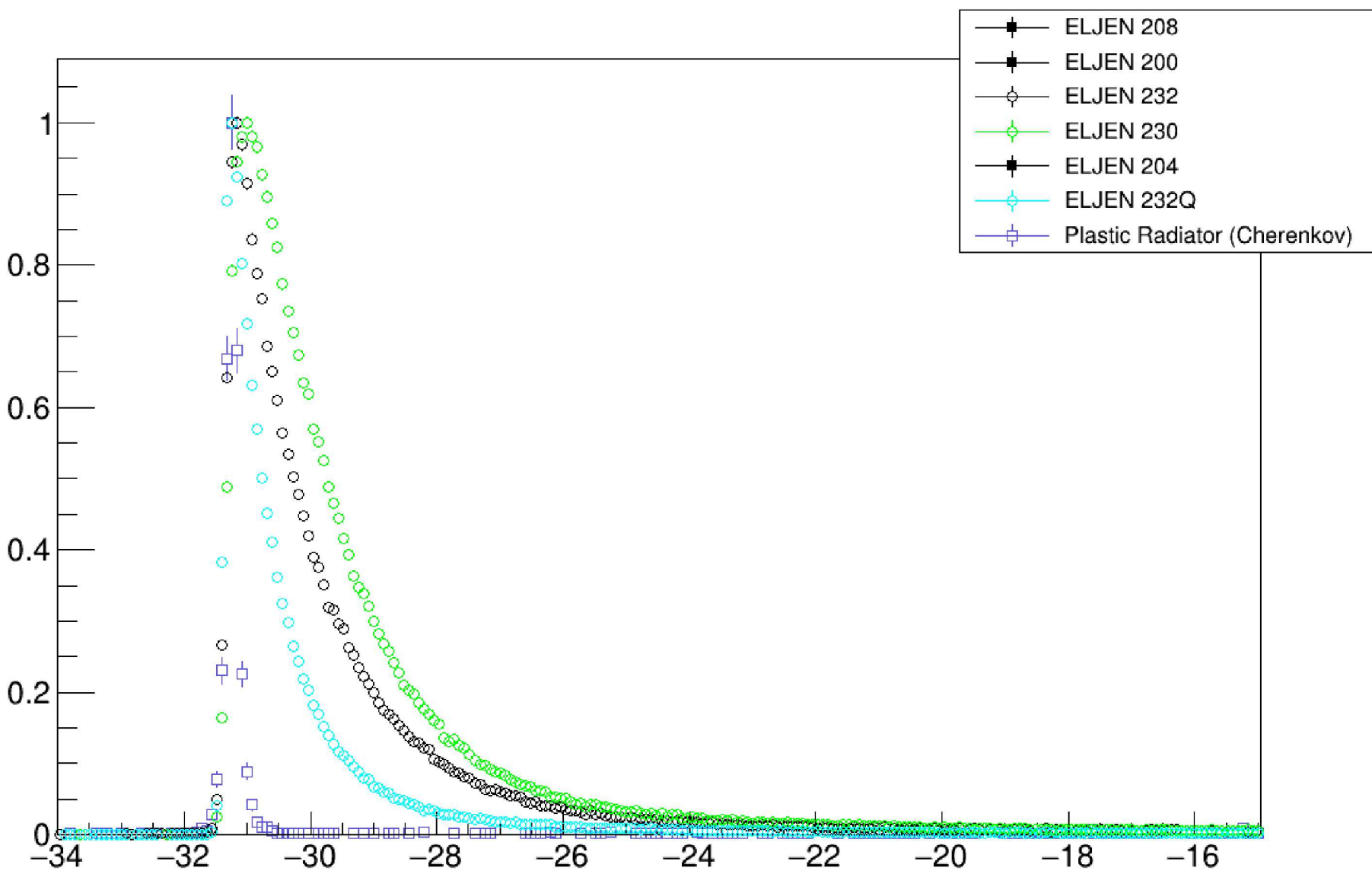


Resolution of Modern Setup

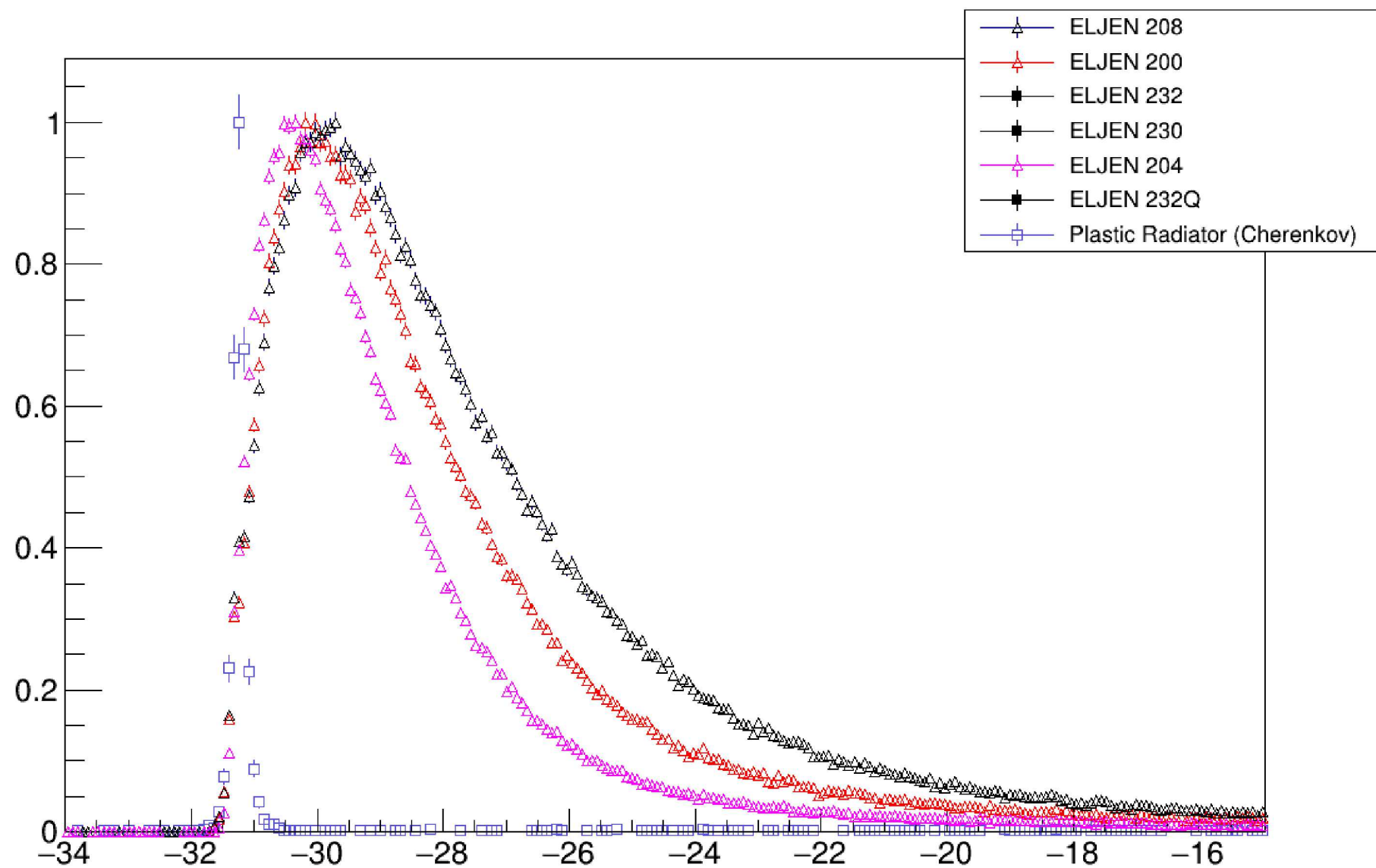




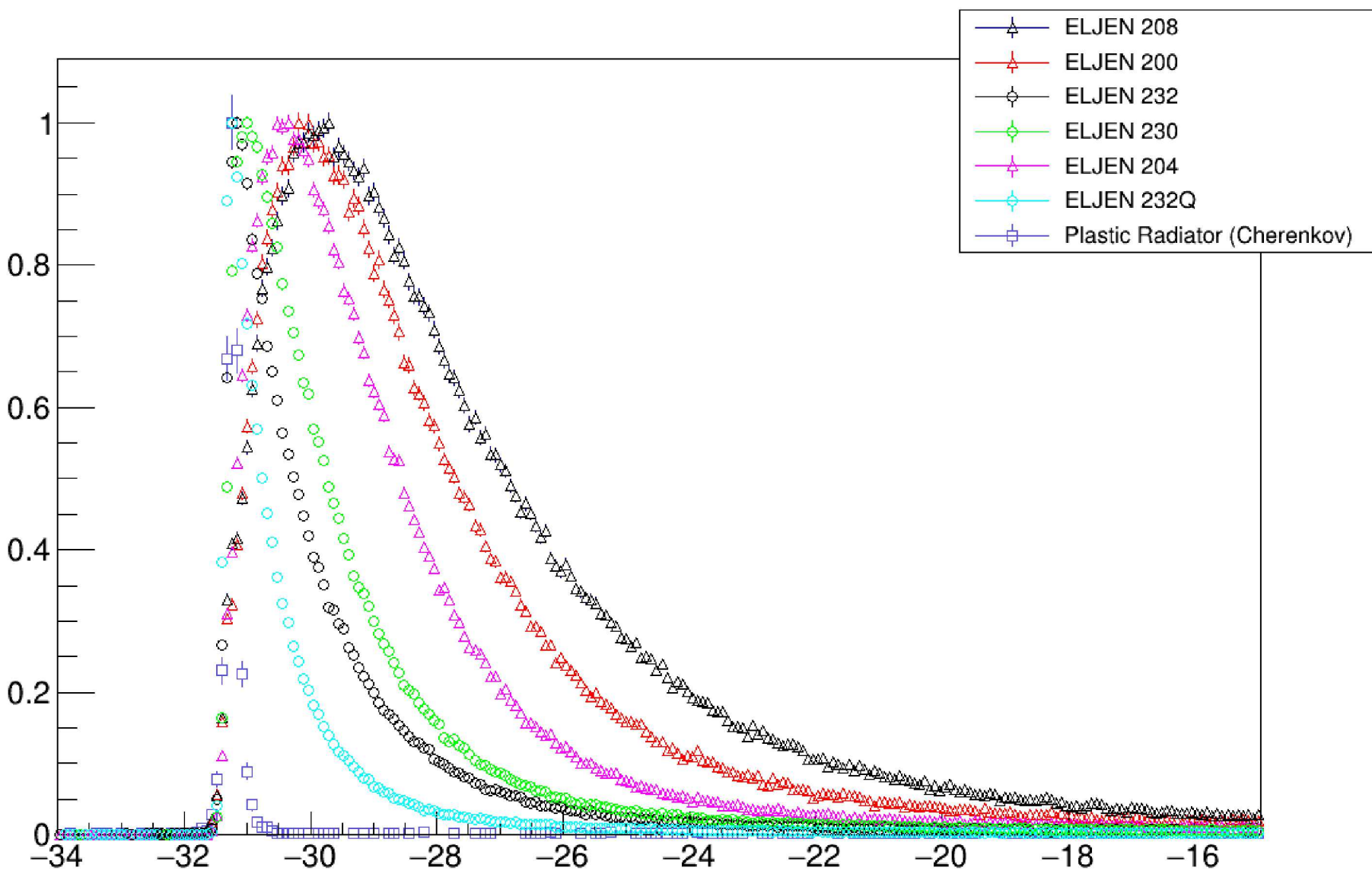
Pulse Shapes



Pulse Shapes



Pulse Shapes

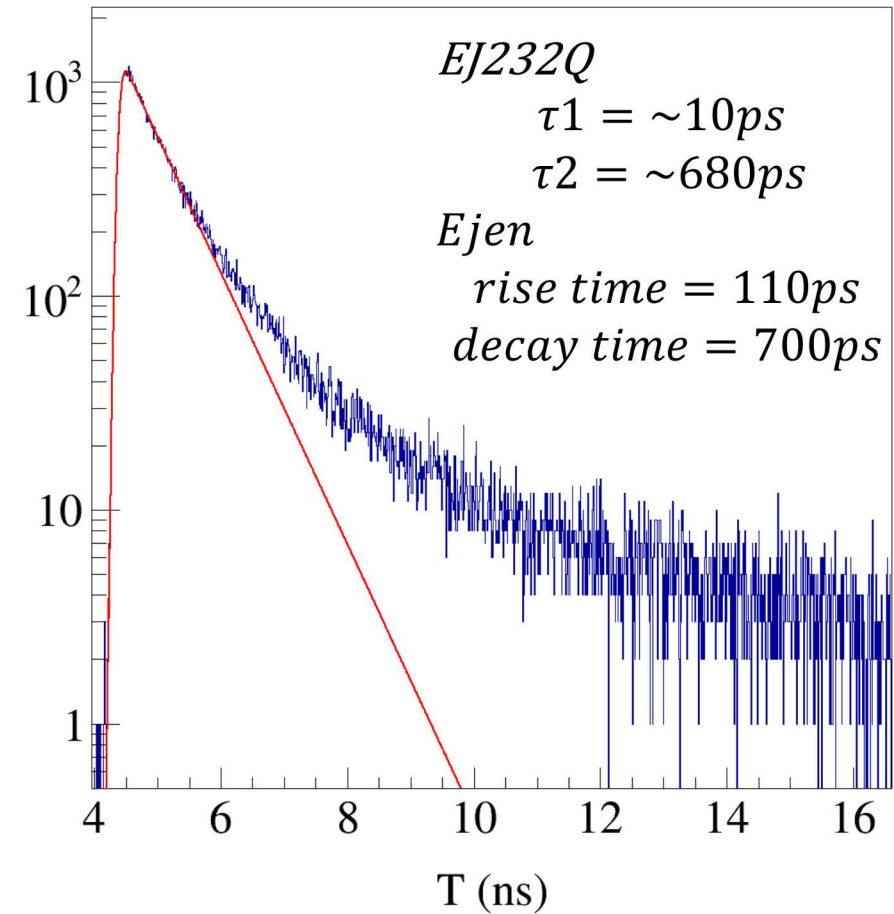
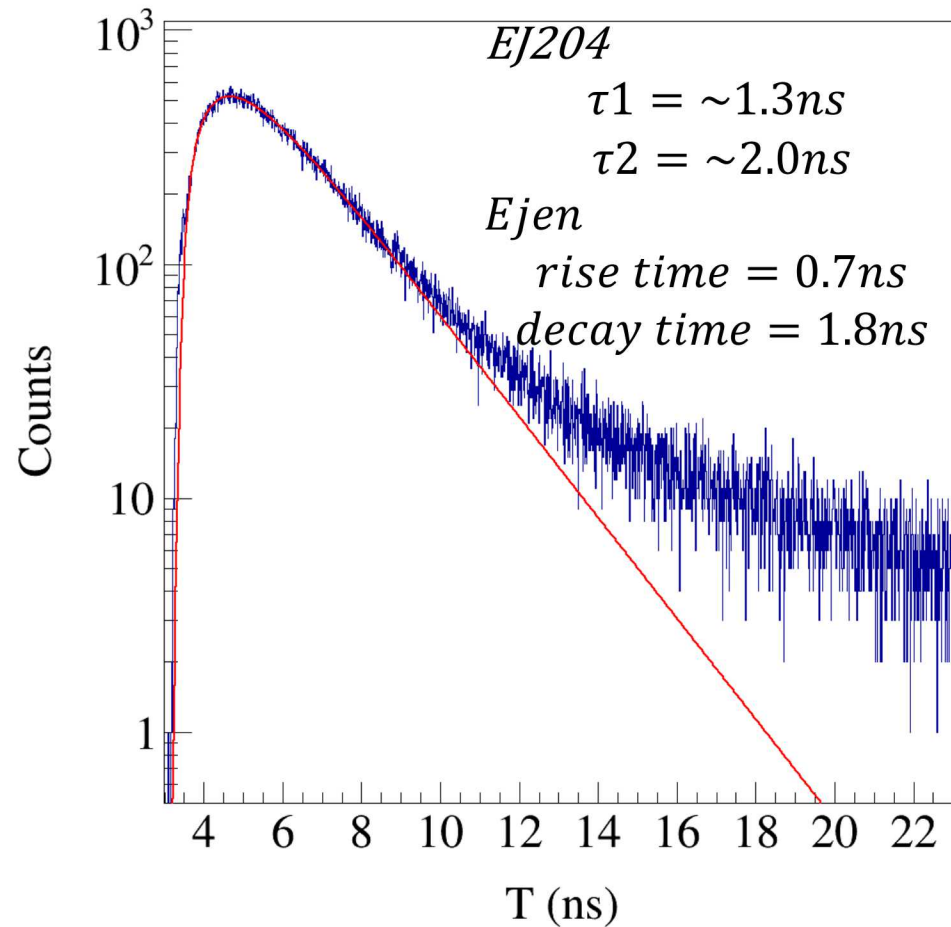


Model Comparison

$$I(\tau_1, \tau_2, t) = \frac{(\tau_1 + \tau_2)}{\tau_2^2} e^{-\frac{t}{\tau_2}} \left(1 - e^{-\frac{t}{\tau_1}}\right) \Theta(t)$$

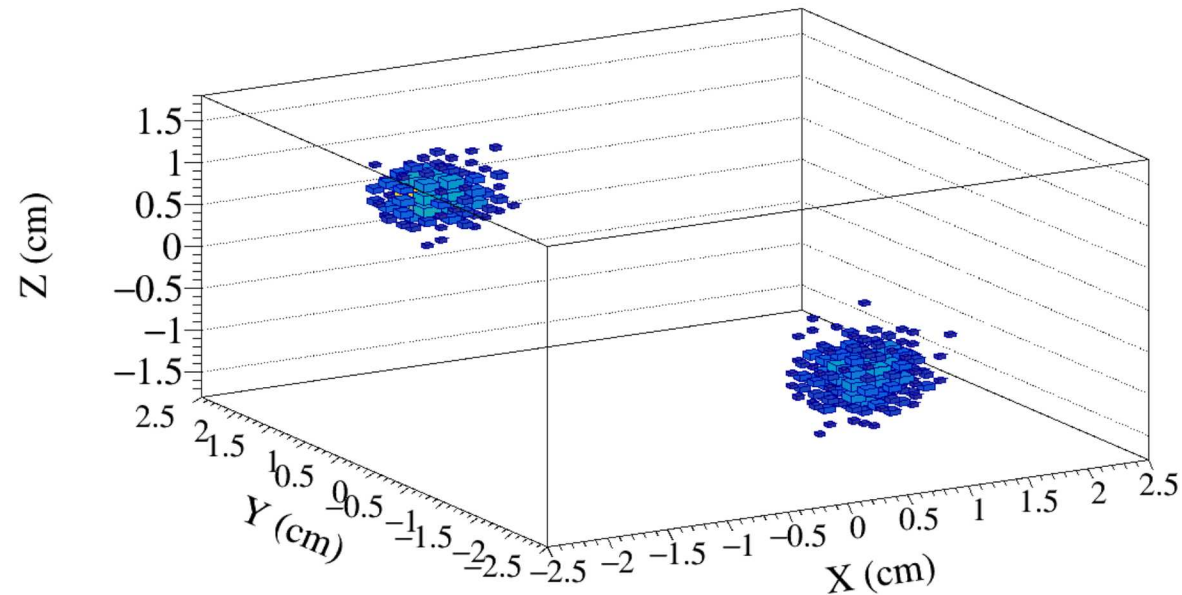
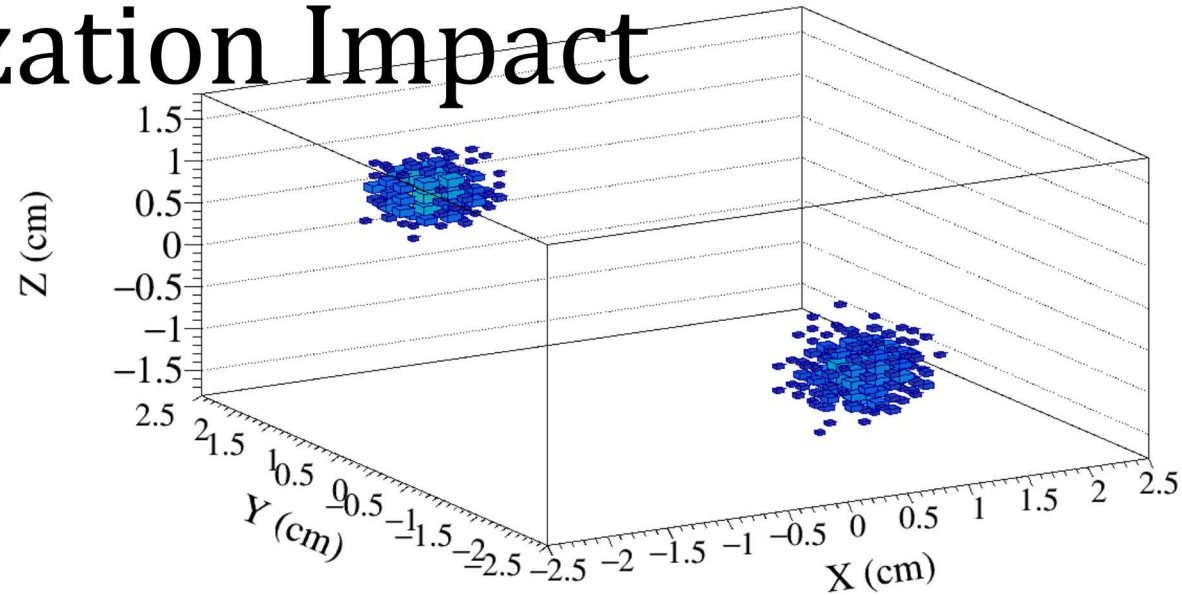
$$F = \text{IRF}(t) * I(\tau_1, \tau_2, t)$$

- IRF is considered a normal distribution with standard deviation equal to the quadrature sum of the outlined uncertainties



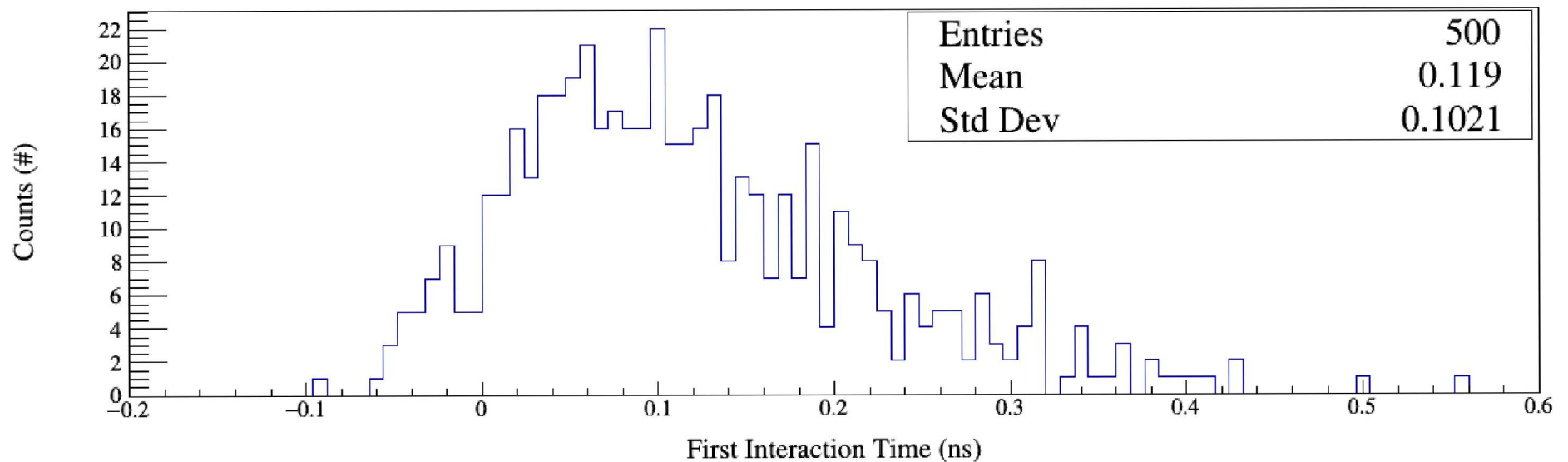
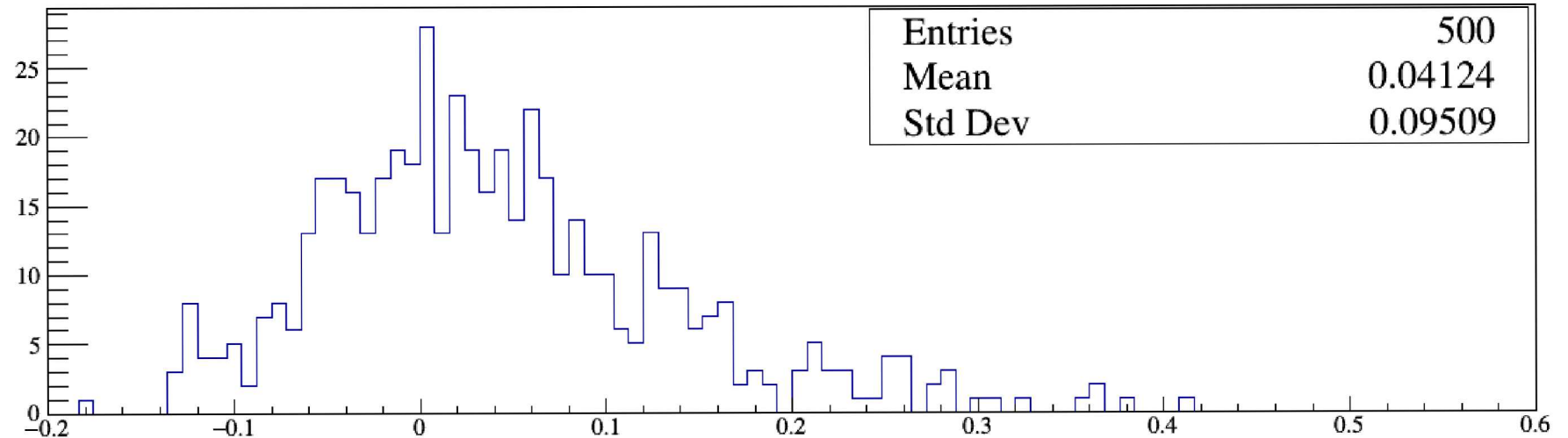
Event Localization Impact

- Spatial information is negligibly affected by incorrect time constants



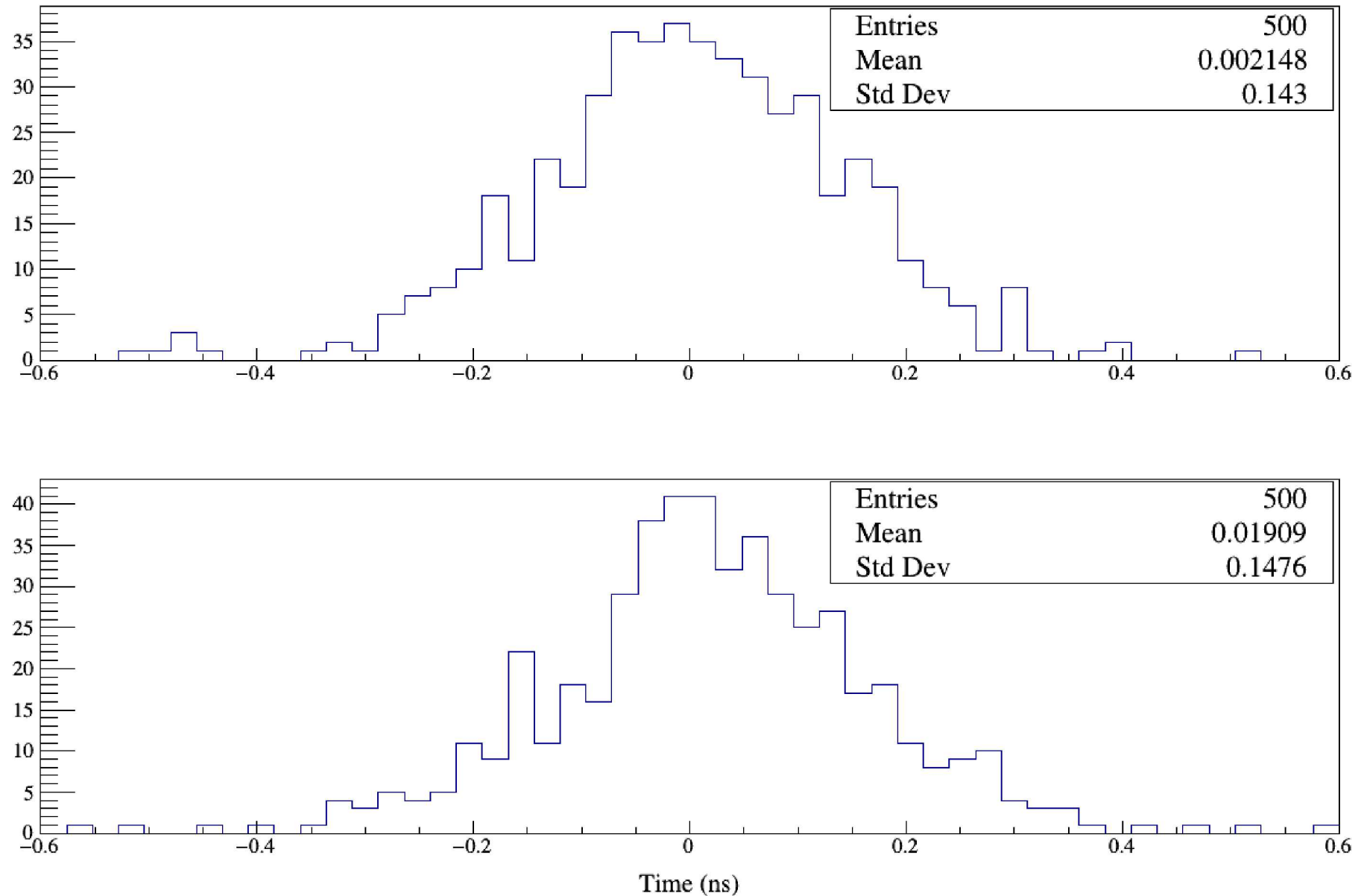
Event Localization Impact

- Spatial information is negligibly effected by incorrect time constants
- Timing of single interaction is adversely affected



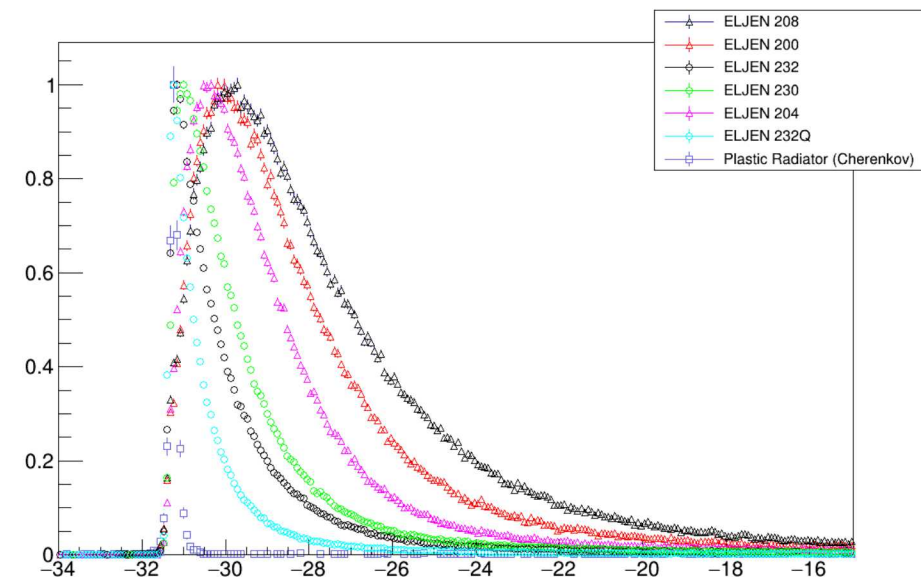
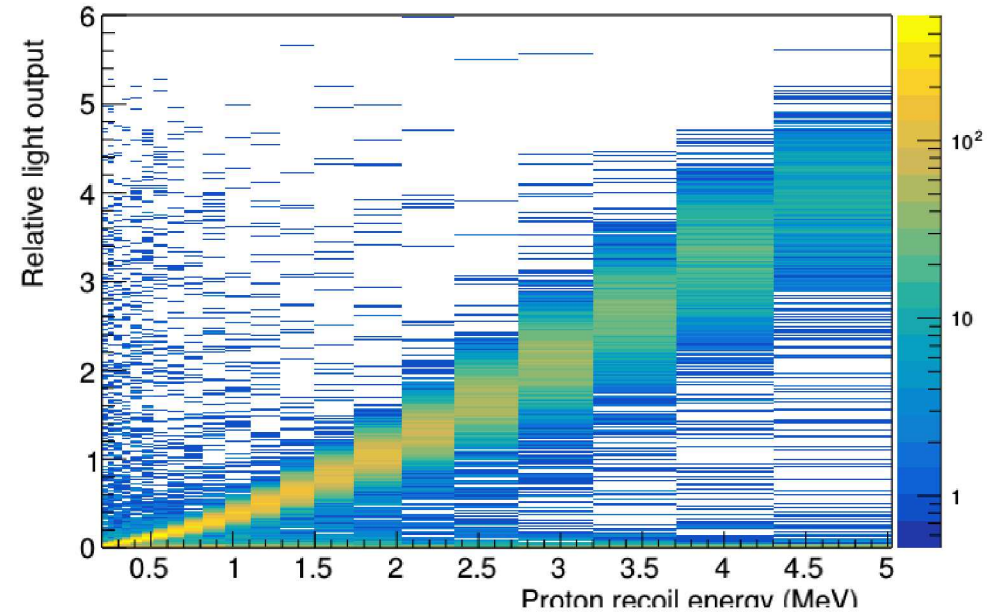
Event Localization Impact

- Spatial information is negligibly effected by incorrect time constants
- Timing of single interaction is adversely effected
- Time *difference* is less affected by the use of incorrect time constants



Summary And Outlook

- Proton Light Yields have been measured for an array of prospective scintillator candidates.
- Scintillator Pulse Shapes have been measured with temporal resolutions under the anticipated uncertainties of the monolithic detector
- Results are being shared with the community via publications in peer reviewed journals
- Initial experiments have been conducted at the 88-Inch Cyclotron for measuring proton pure pulse shapes.
- Design and construction of apparatus for measuring the absolute light production in scintillators of interest is underway



Atomic Layer Deposition for Microchannel Plates (MCPs) Functionalization

Anil Mane*, Max Gebhard, Steven Letourneau, Jeff Elam

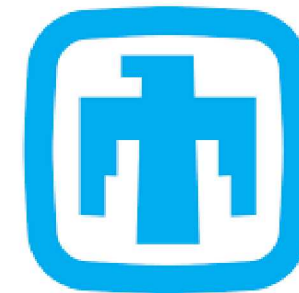
(SVSC Project Review Meeting @ SNL)

06/25/2019

(*amane@anl.gov)

Acknowledgements

ALD group members



**Sandia
National
Laboratories**

Dr. Donny Hornback for support and encouragement

Discussion Topics:

1. Our role and objectives
2. ALD process development for (SEE and Resistive layers)
3. Understanding the ALD layers composition stability
4. Construction of In-situ ALD-MCP testing system
5. Near Term Plans

Microchannel Plates (MCPs): Applications

- Photodetectors, time-of-flight (ToF) mass spectrometry, molecular and atomic collision studies, electron microscopy, field emission displays, and night vision goggles and binoculars, medical imaging (PET scanners), homeland security (scanners for shipping containers and trucks), X-ray and Neutrons detection

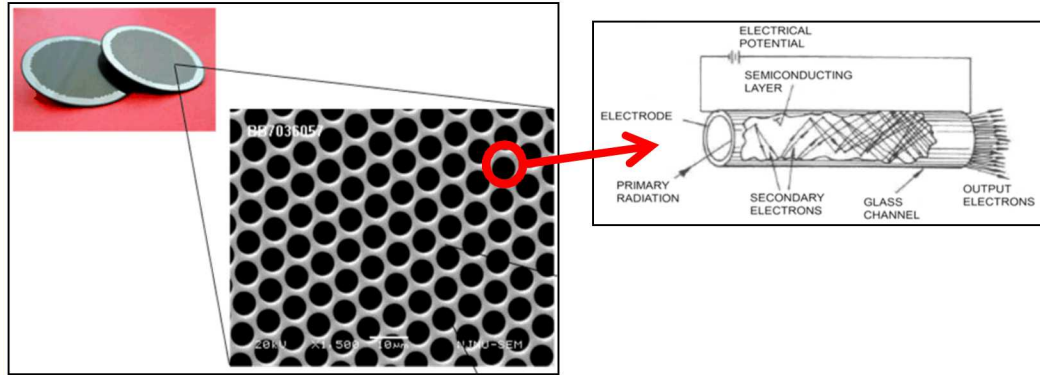
- **HEP experiments**

LBNE/DUNE/ μ BooNE @Fermi Lab,
Super-K RICH and BELLE II @Japan,
LHC, ATLAS and CMS @CERN,
Mark-I @SLAC

PANDA @FAIR Germany,
JUNO @China,
CLAS12 @Jefferson Lab,
NASA Space Mission

SNL SVSC Project: Fission-energy neutron imaging

Conventional MCPs



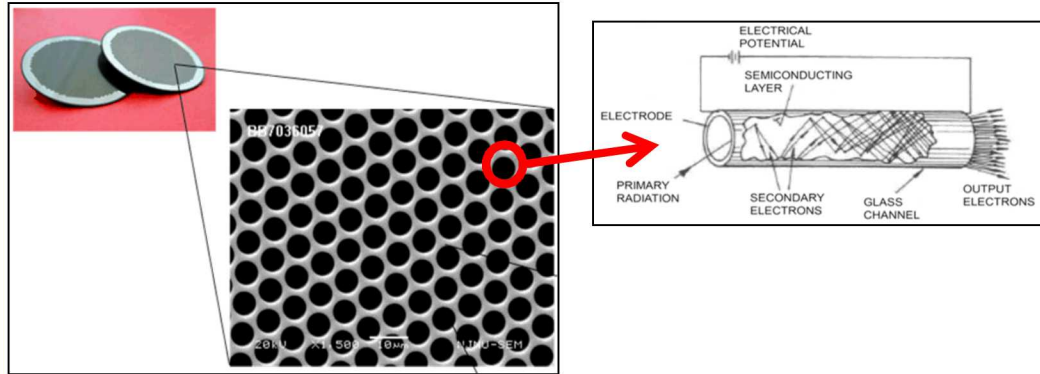
Conventional Fabrication Method:

- Draw lead glass fiber bundle
- Slice and polish
- Chemical etch
- Hydrogen firing

Issues:

- Expensive and need to import
- Resistance of MCP and secondary electron emission properties are linked PbOx
- Very long conditioning timing
- Available in small form factor

Conventional MCPs



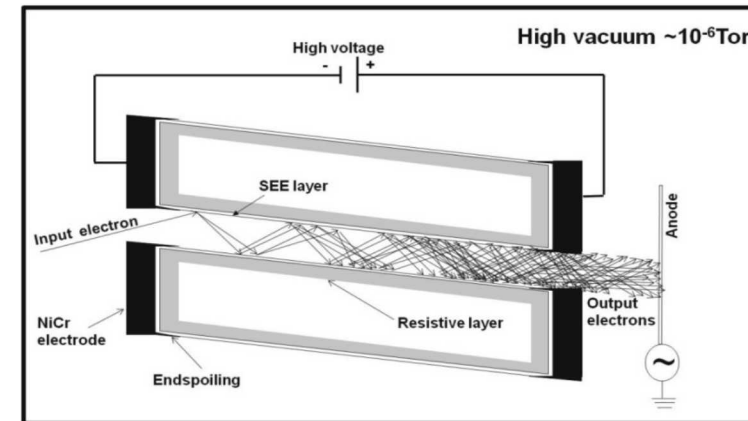
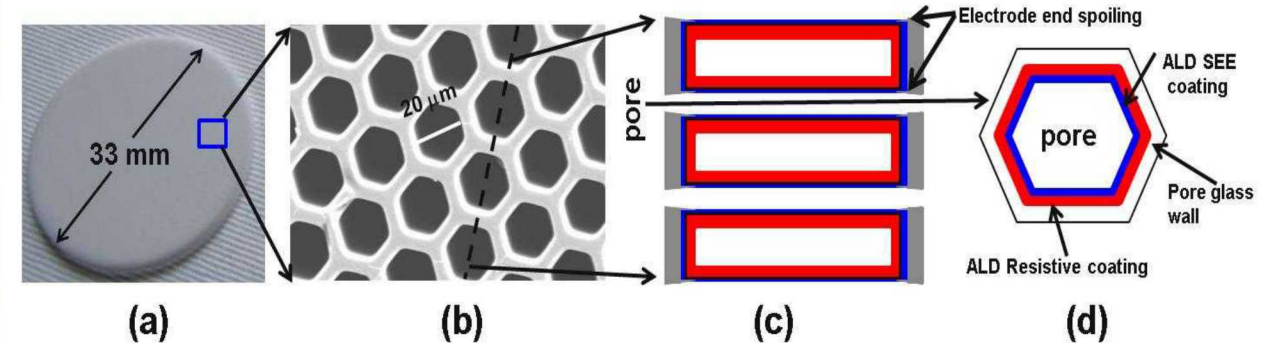
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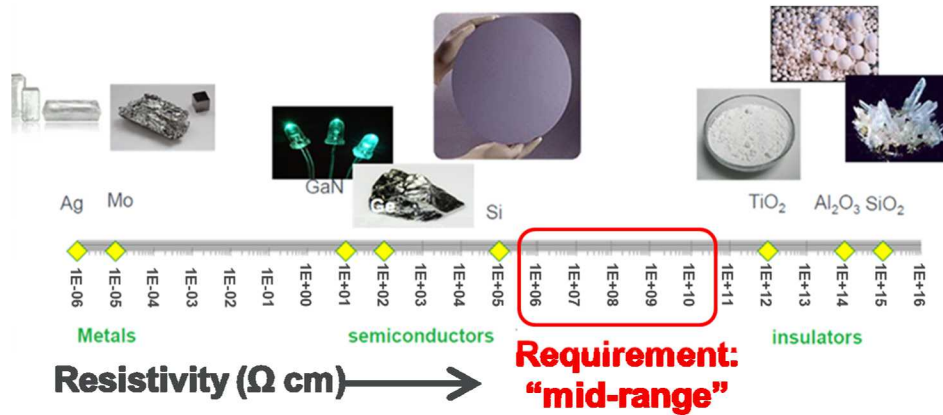
ALD-MCPs



- 1) Resistive coating (ALD)
- 2) Electron Emission coating (ALD)
- 3) Contact electrode (PVD)

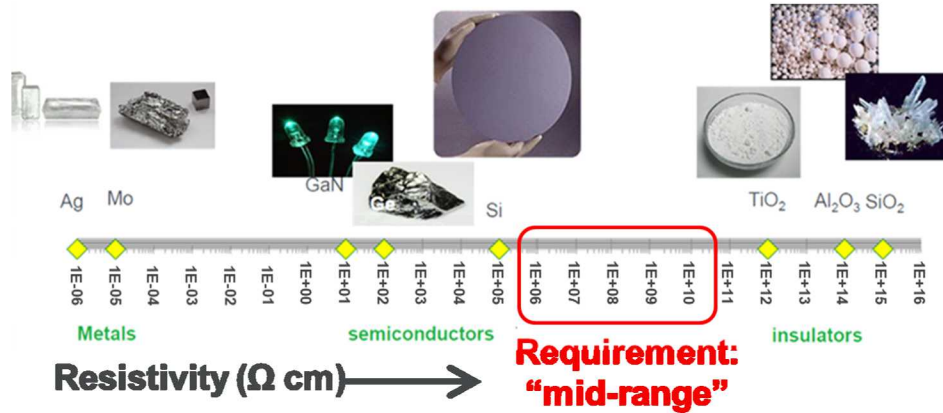
1. A. Mane et. al., SPIE (2011)
2. D. Beaulieu, et. al., Nucl. Instr. Meth. Phys. A, 633, S59, (2011)

Resistivity for MCPs



- Practically no naturally occurring materials with "mid-range" resistivity of 10^6 - 10^{10} $\Omega \text{ cm}$
- **Must be synthesized or engineered**

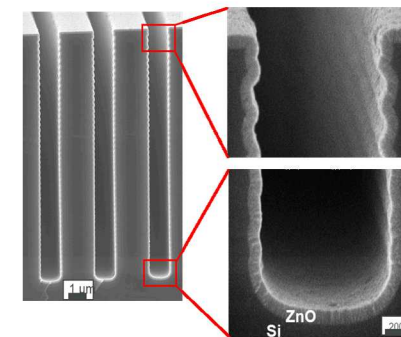
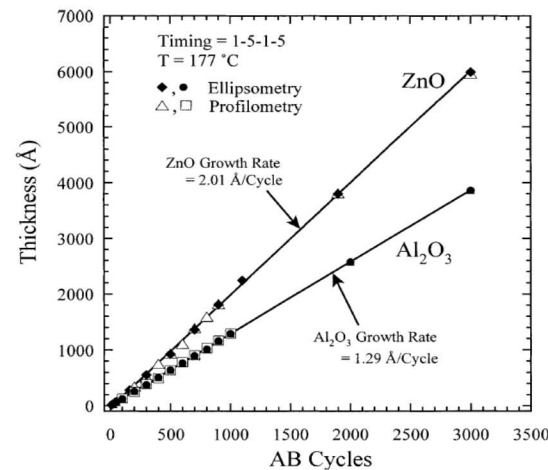
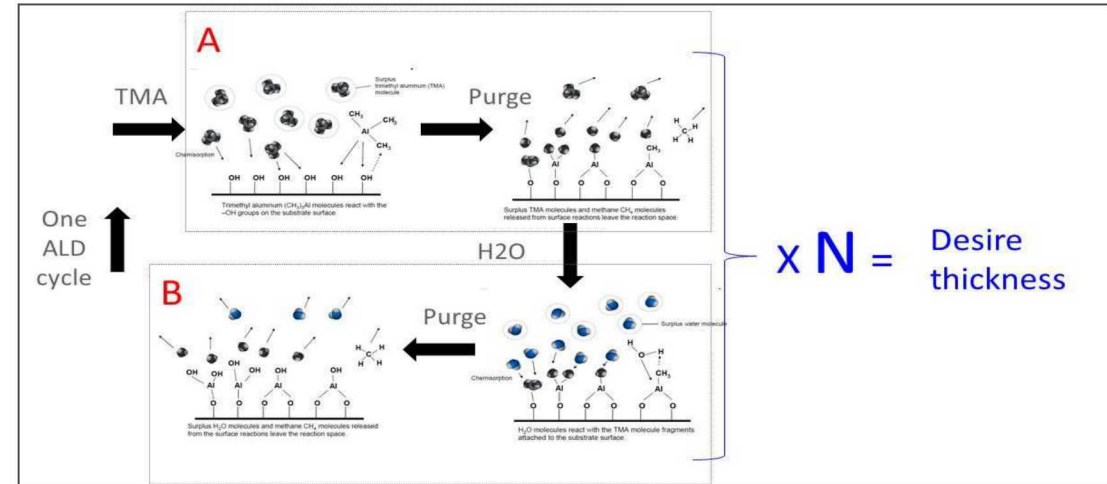
Resistivity for MCPs



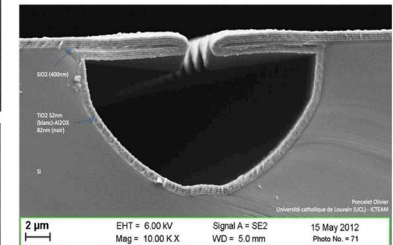
- Practically no naturally occurring materials with "mid-range" resistivity of 10^6 - 10^{10} $\Omega \text{ cm}$
- Must be synthesized or engineered**

Atomic Layer Deposition (ALD)

Example: ALD Al_2O_3 using TMA- H_2O



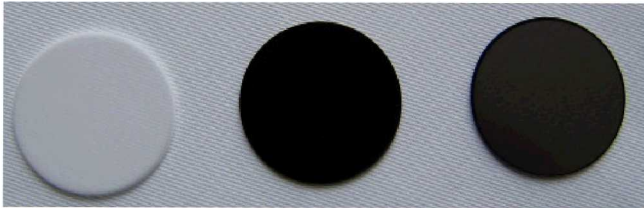
Aspect ratio (length/width) ~ 10



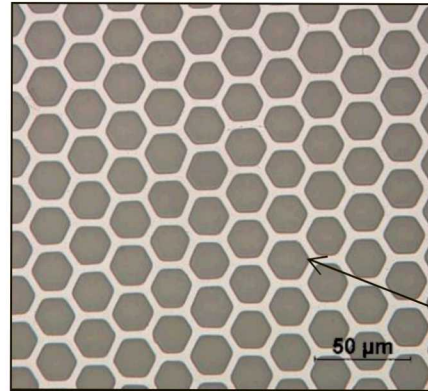
Current strategy for preparing ALD-MCPs: Functionalization of porous capillary glass

For development work

Micro capillary array (MCA) Glass Plate



- 1) Resistive coating (ALD)
- 2) Electron Emission coating (ALD)
- 3) Contact electrode (PVD)

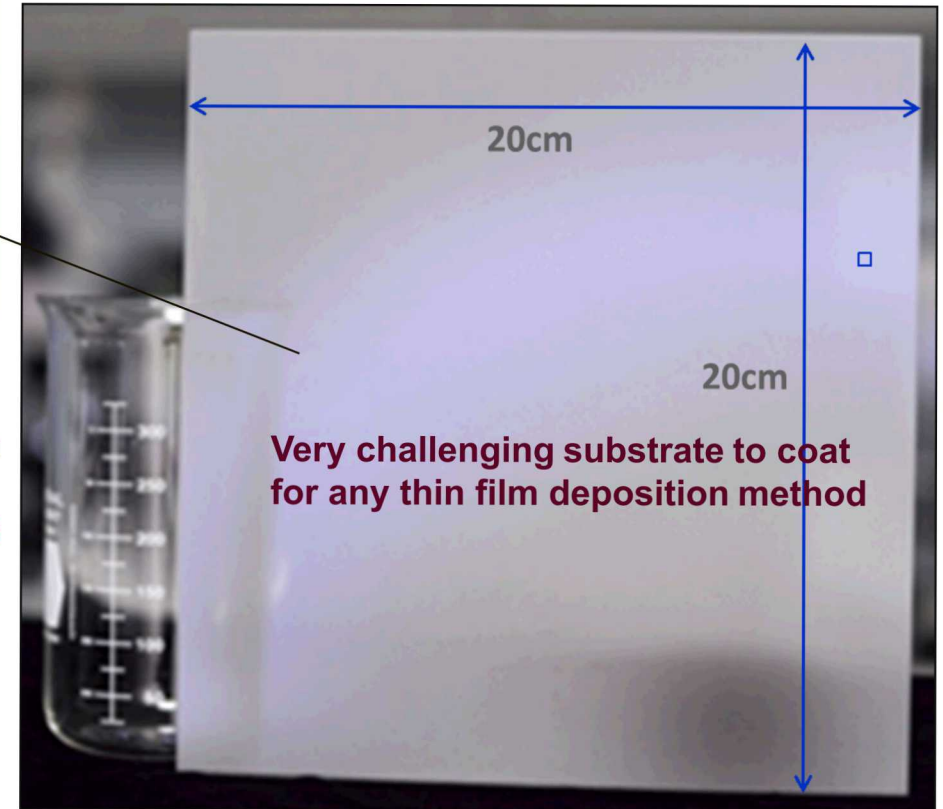


- Surface area = 8.7 m^2
- Pore size = $20 \mu\text{m}$
- Thickness of plate = 1.2 mm
- Aspect Ratio = 60
- No. of Pores = ~80 Millions
- Porosity = 65%
- Bias Angle = 8°
- Sensitive Surface to OH
- Complex Geometry



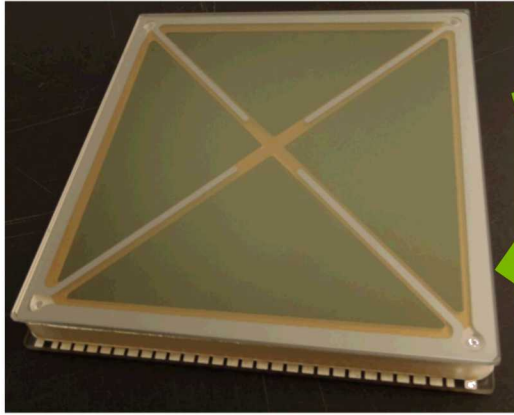
As MCPs are electron amplifier → All the material processing issues also gets amplify 😊

Worlds largest MCPs



Objectives:

Present LAPPD



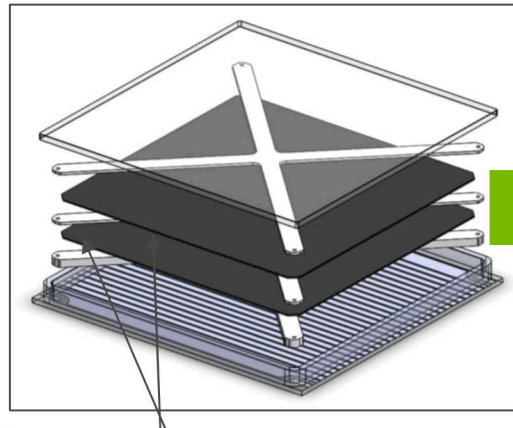
(LAPPD =
Large Area (20cm x 20cm)
Picosecond Photo-Detector)

Value Features:

- Stable high gain (10^6 - 10^7)/pair
- Least scrubbing time (few days)
- Low dark counts (20 Cts/s/cm²)
- mm spatial & time resolution (<50ps)
- Long life robust performance

Application:

Fission-energy neutron imaging
(SVSC project)



Key component ALD-MCPs

Our role and solutions: ALD coatings segment

- Secondary electron emission (SEE) layer
- Resistive (R) layer
- Processing cost optimization
- Constant support (biweekly call)
- MCP supply as and when needed

Next generation ALD MCPs:

- Materials design & stability analysis
- Fast screening of SEE materials via in-situ ALD-MCP testing
- Regulating TCR properties of R layer
- Harsh environmental effect testing (CO₂, OH*, etc.)

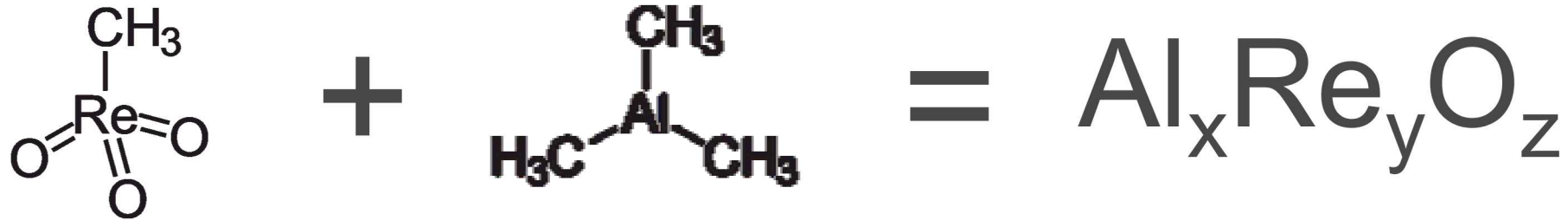
Development of alternative resistive coatings via ALD

(E.g. F-Free ALD chemistry)

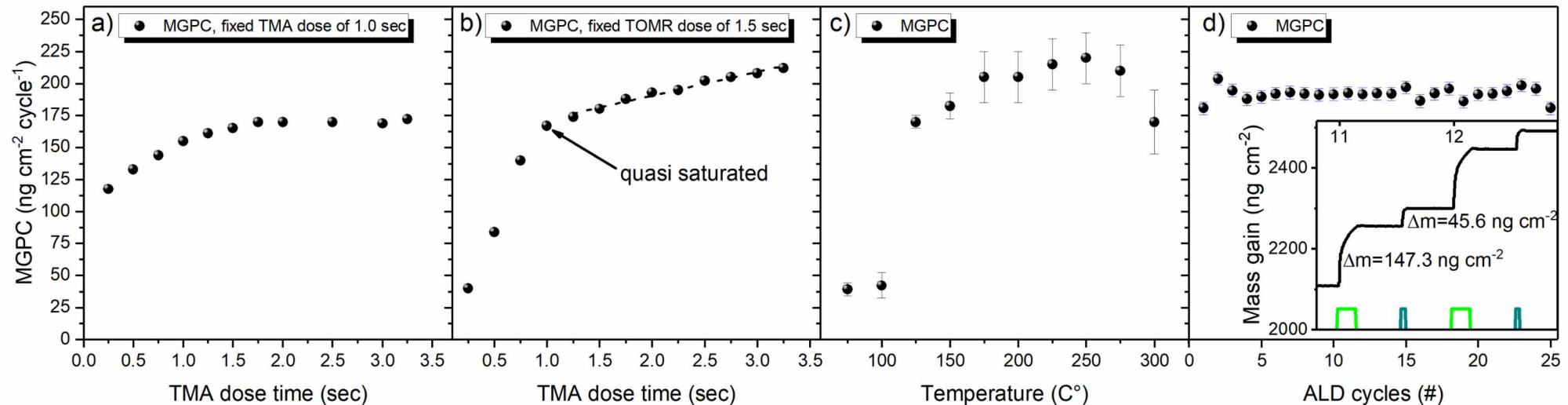
- Paper submitted to Chemistry of Materials
- Invention Submitted (ANL-IN-19-0057)

ReAlO resistive coating: ALD Process optimization, *in-situ* QCM

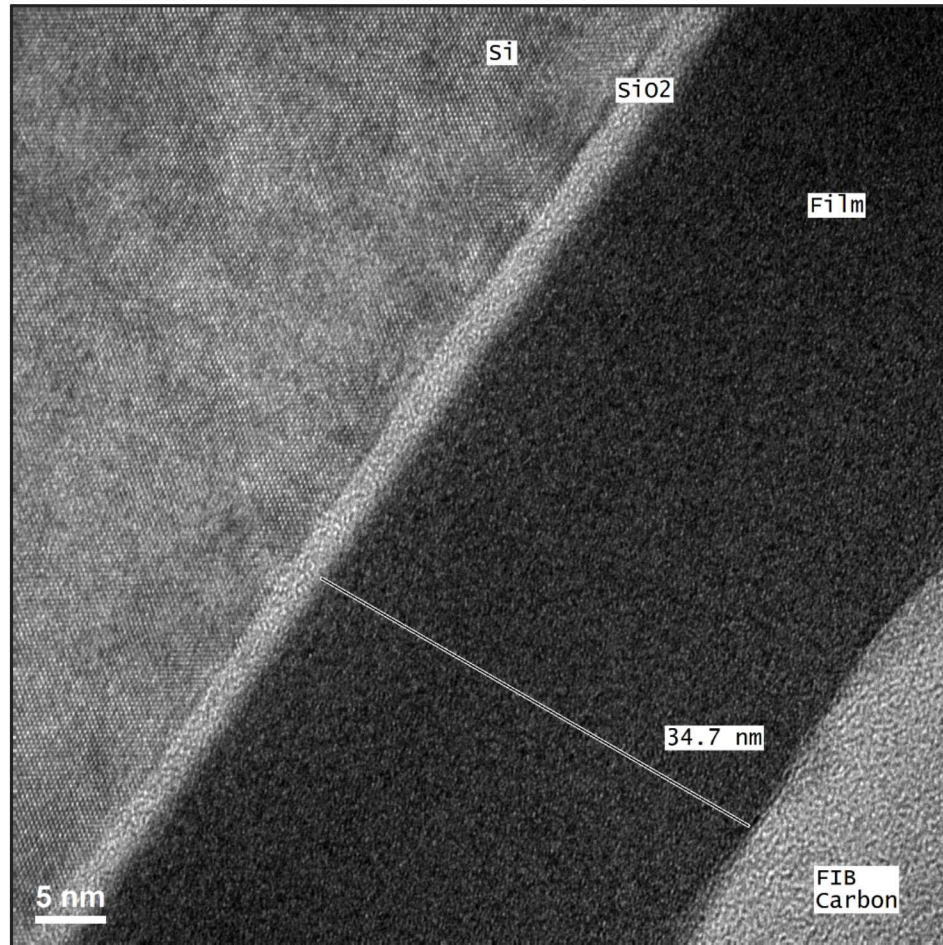
- Trioxymethylrhenium(VII) + Trimethyl aluminium (TMA)



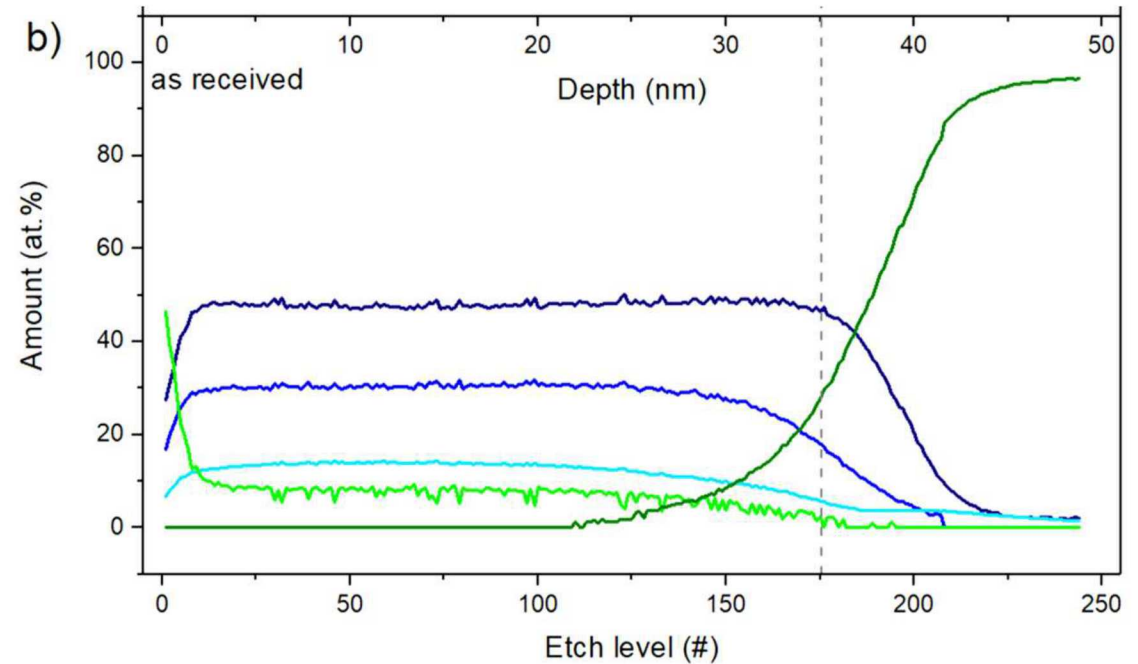
Idea is based on current LAPPD baseline ALD-MCPs process that TMA can be use as a “reducing precursor”



Microstructure and Composition of ReAl_xO_y



Amorphous microstructure

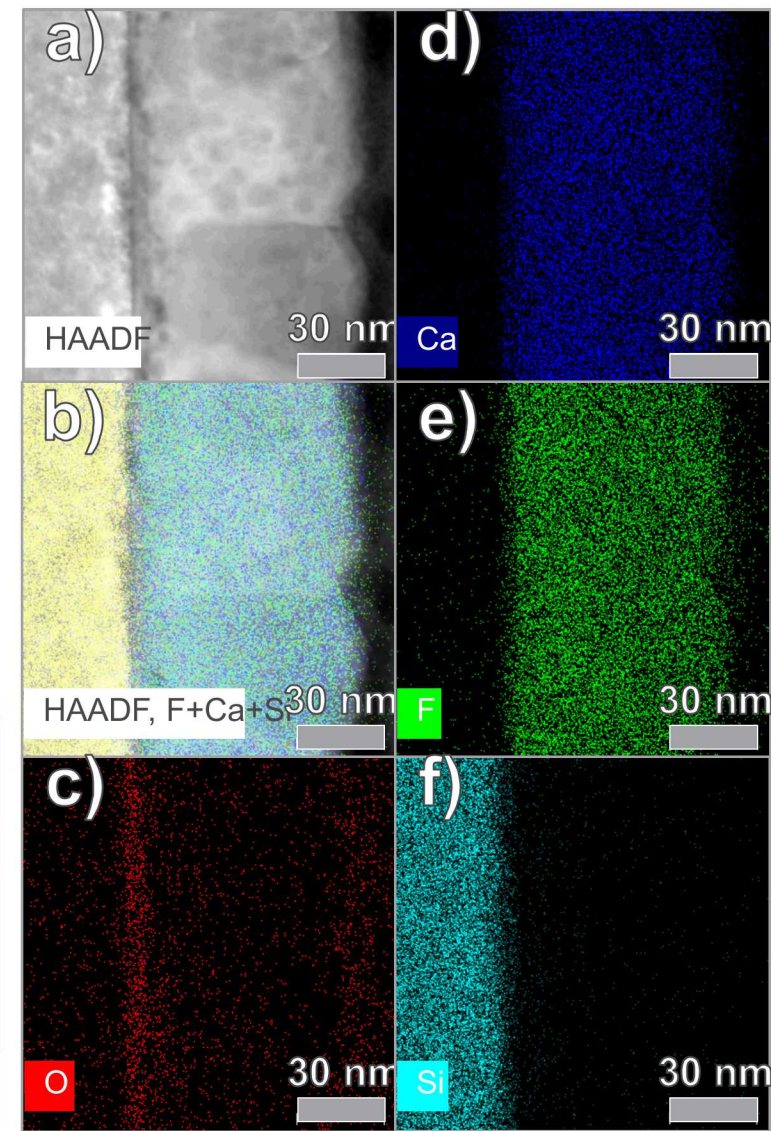
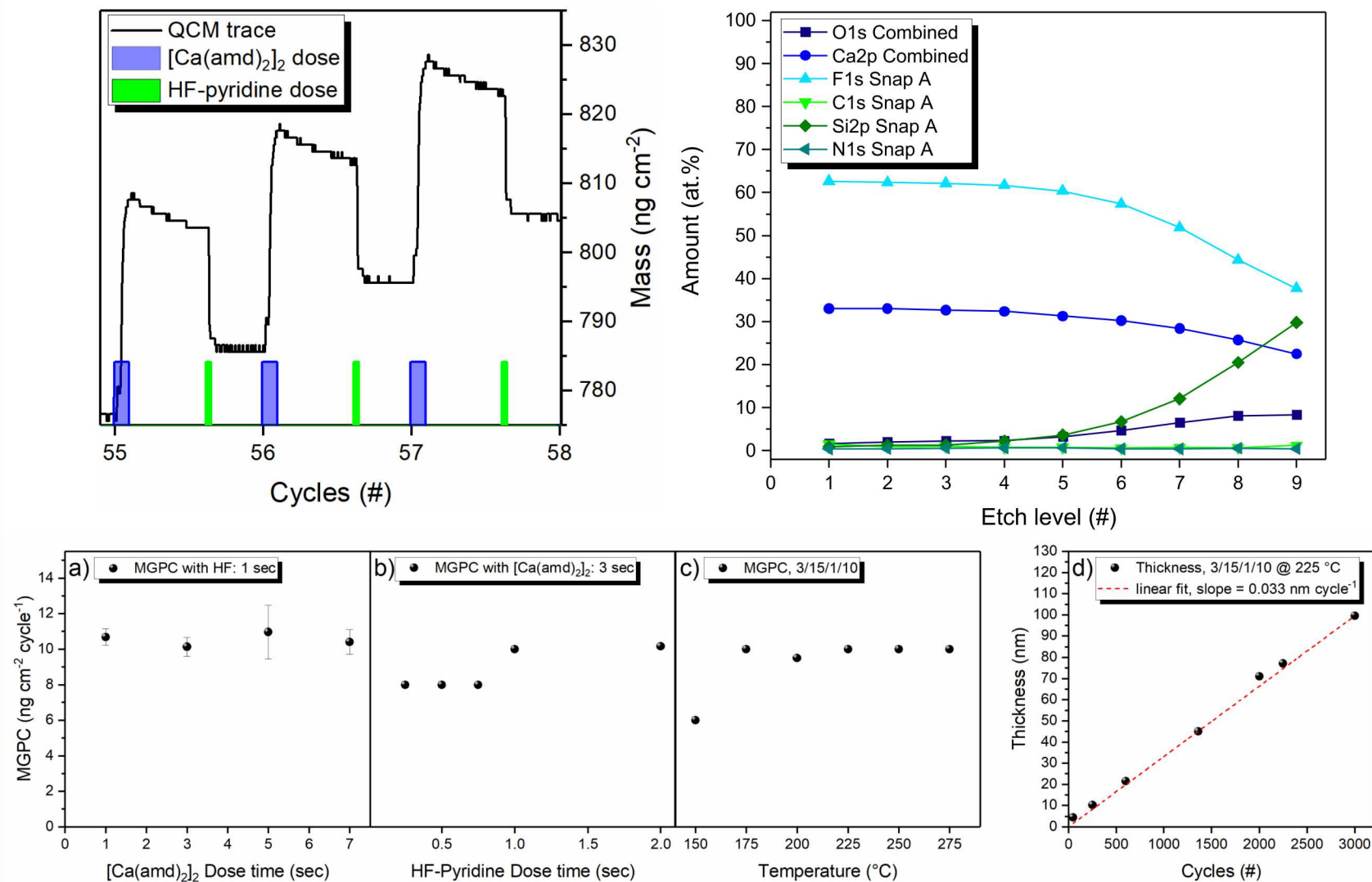


Uniform coating

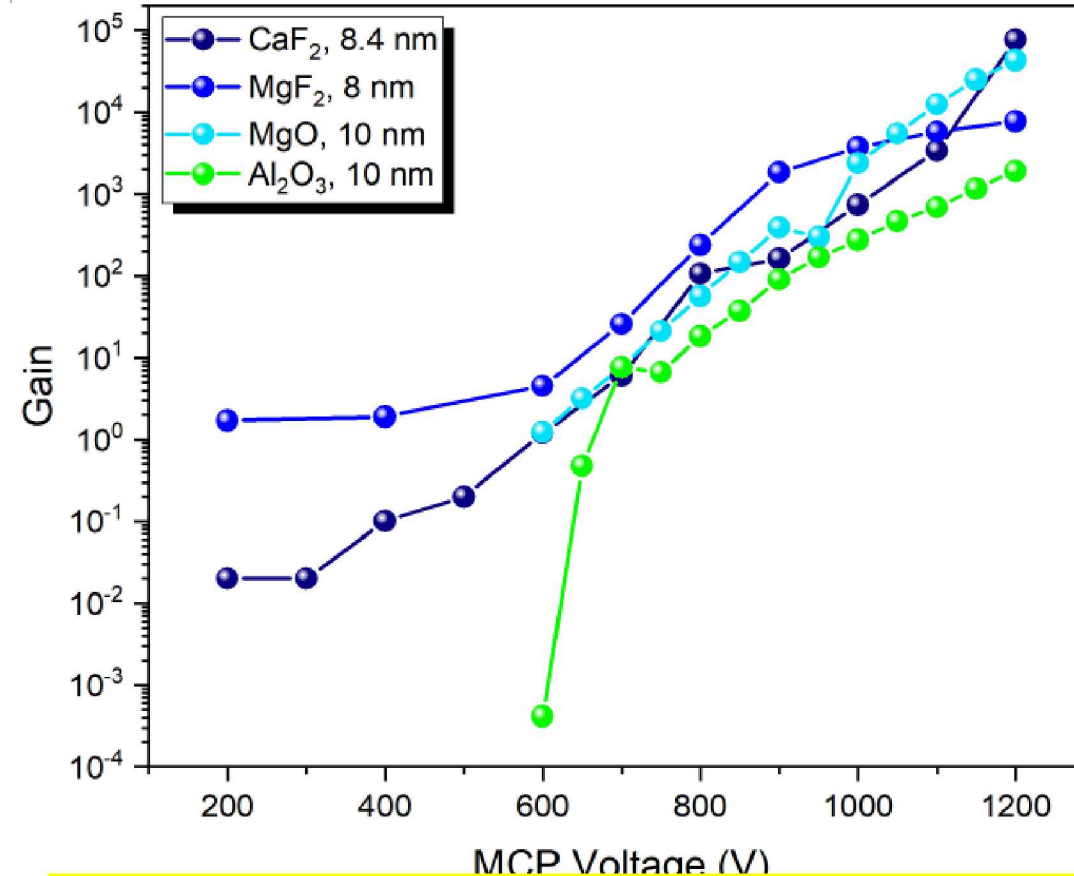
Development of secondary electron emission (SEE) layers

- Paper draft is circulated
- Pending Patent Application (ANL-IN-19-039)

Development of ALD CaF_2 SEE layer for MCPs



SEE layer variation MCPs gain comparisons



- High gain for MgO, CaF₂ and MgF₂

Understanding of Fluorine in Current ALD baseline process for 8"x8" MCPs that used in LAPPDs

Current baseline ALD process for MCPs that used in LAPPDs

- 1) Current resistive coating process called as “Chem-1”
 - Has combination of (Al_2O_3 oxide + W metal)
 - W process is based on WF_6 which results in complex material **AIFOWC**
- 2) Secondary electron emission coating is MgO on top of “Chem-1”
 - When we do final annealing of the MCP **F** from **AIFOWC** intermixed with **MgO** and forms stable complex SEE layer

Questions:

- Effect of F on MCP properties especially resistance?
- How to trailer F intermixing?
- How to prevention of F-migration?
- Can SEE properties tuned?
- Over all stability ?

Samples Details: (ALD grown layer on Silicon (100))

Current Baseline for MCPs

R	SEE (10nm)	Annealing for 4 hrs in N2
Chem-1		
Chem-1	MgO	
* Chem-1	MgO	400C

5nm Al₂O₃ barrier after chem-1 + baseline

R	Barrier (5nm)	SEE (10nm)	Annealing for 4 hrs in N2
Chem-1	Al ₂ O ₃		
Chem-1	Al ₂ O ₃	MgO	
* Chem-1	Al ₂ O ₃	MgO	400C

400C after chem-1 + baseline

R	1 st Annealing for 4 hrs in N2	SEE (10nm)	2 nd Annealing for 4 hrs in N2
Chem-1	400C		
Chem-1	400C	MgO	
* Chem-1	400C	MgO	400C

400C after chem-1 + 5nm Al₂O₃ barrier after 400C + baseline

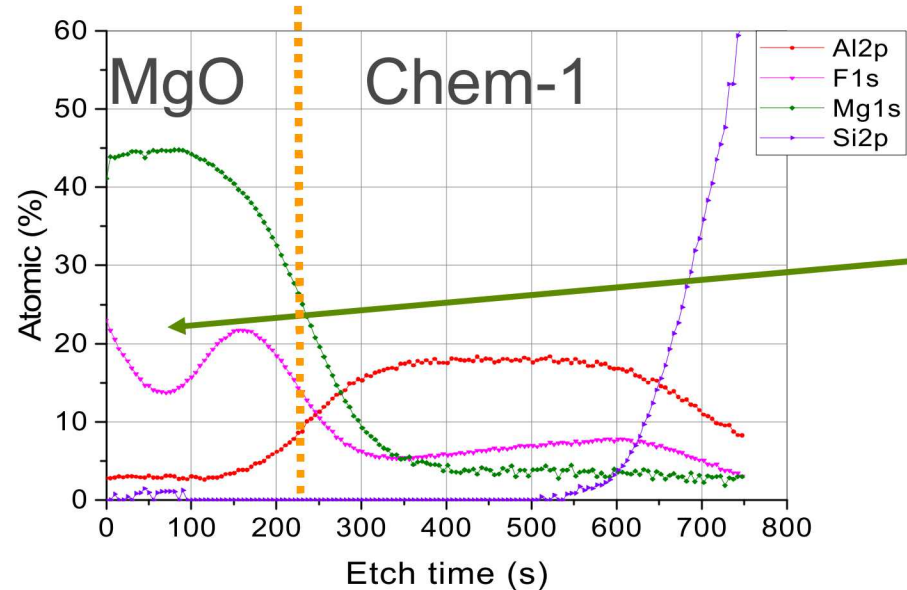
R	1 st Annealing for 4 hrs in N2	Barrier (5nm)	SEE (10nm)	2 nd Annealing for 4 hrs in N2
Chem-1	400C	Al ₂ O ₃		
Chem-1	400C	Al ₂ O ₃	MgO	
* Chem-1	400C	Al ₂ O ₃	MgO	400C

Observation matrix:

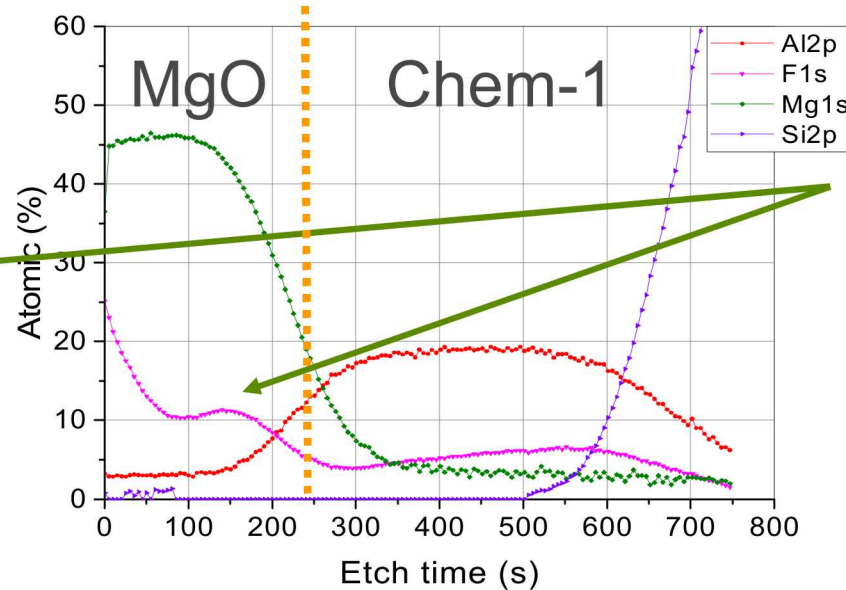
- Annealing effect on overall composition of Chem-1, MgO, ALO
- Overall F level variation across the thin films stack
- F -interaction with MgO, and ALO
- Interaction of MgO –ALO
- Interface of MgO-ALO, MgO-Chem-1, ALO-Chem-1 (as deposited, and with thermal treatment)

Final Comparison (removed W, O, and C peaks)

Baseline = (Chem-1+ MgO + 400C)



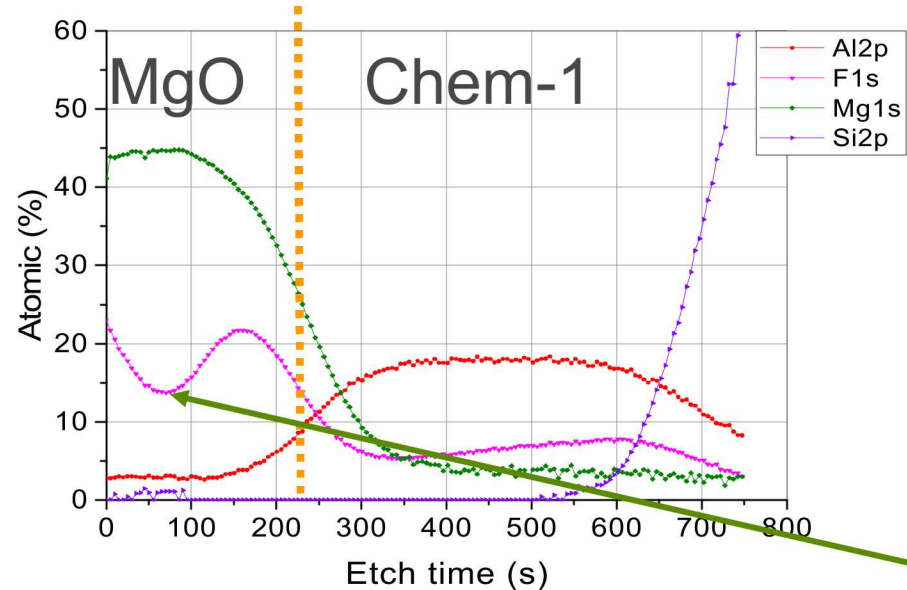
(**400C**+ Chem-1+ MgO + 400C)



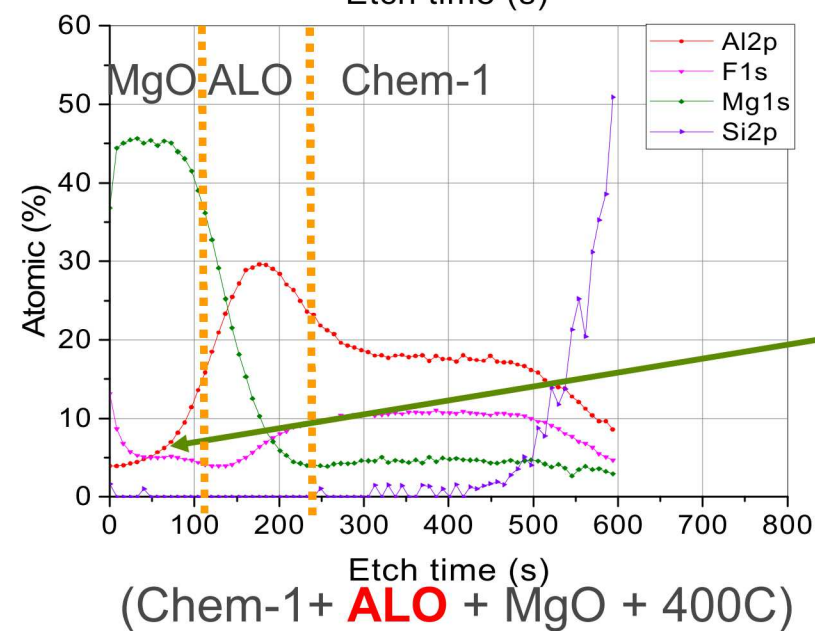
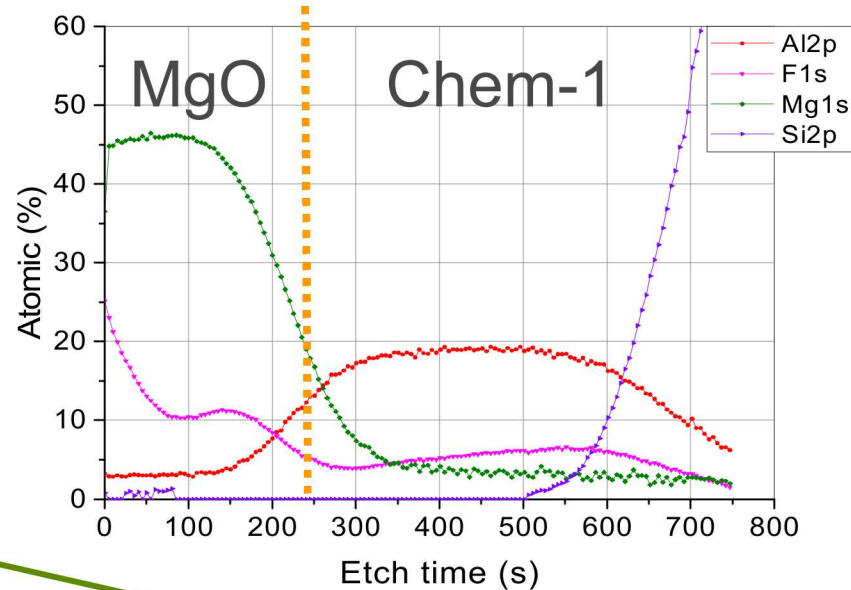
• Annealing after Chem-1 process shows ~50 less F migration in MgO

Final Comparison (removed W, O, and C peaks)

Baseline = (Chem-1+ MgO + 400C)



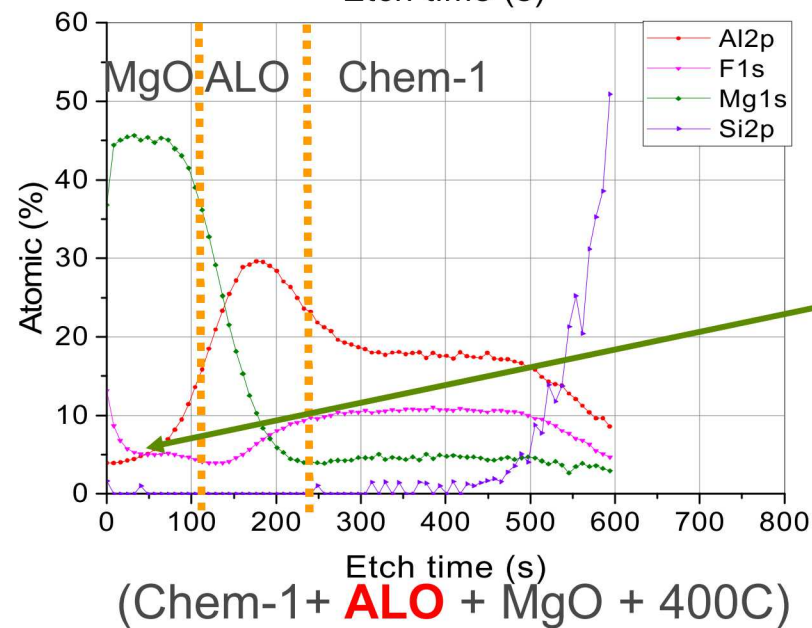
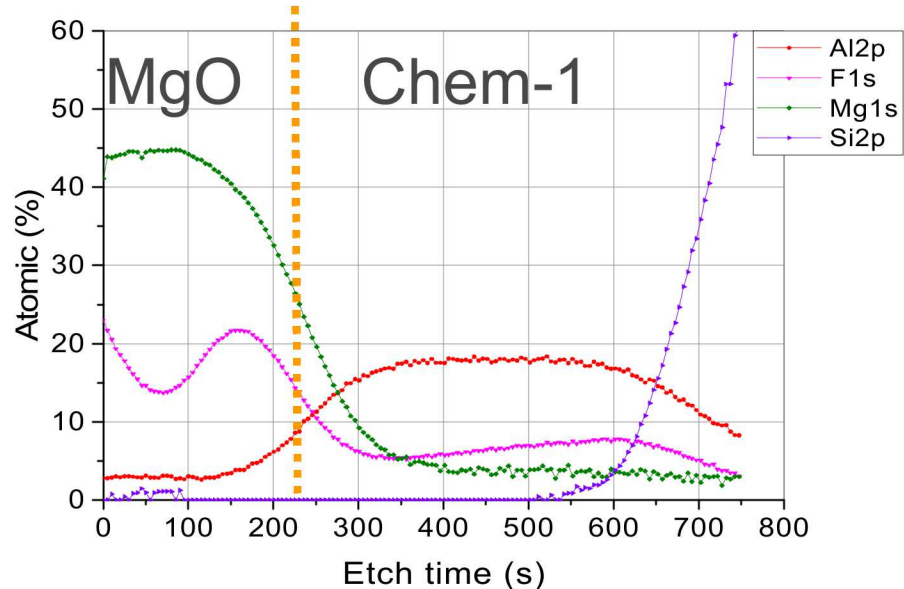
(400C+ Chem-1+ MgO + 400C)



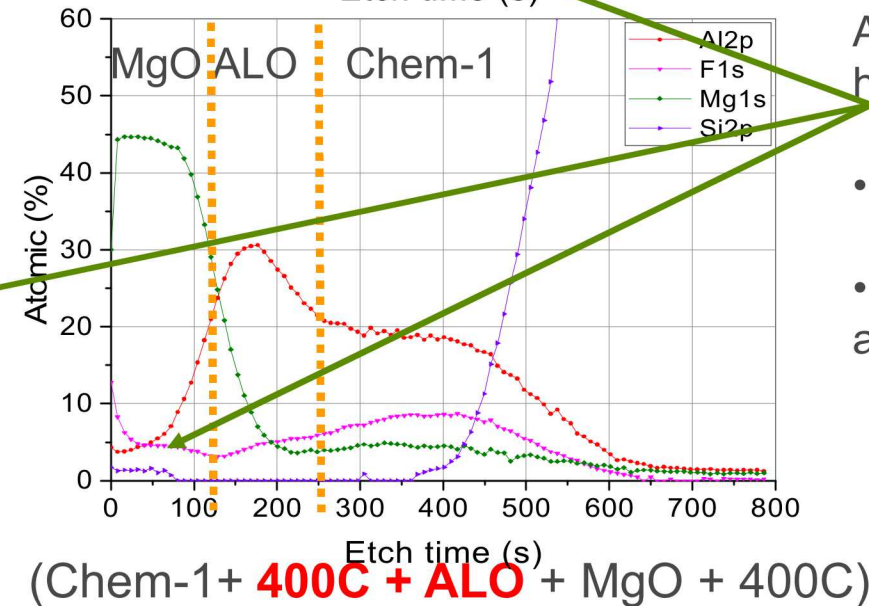
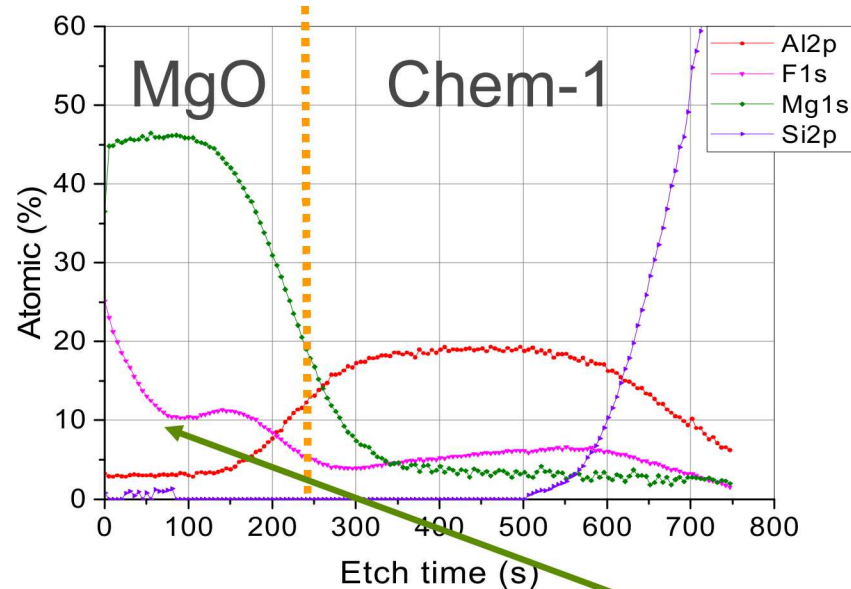
• F migration is ~75% less for Al₂O₃ capping.

Final Comparison (removed W, O, and C peaks)

Baseline = (Chem-1+ MgO + 400C)

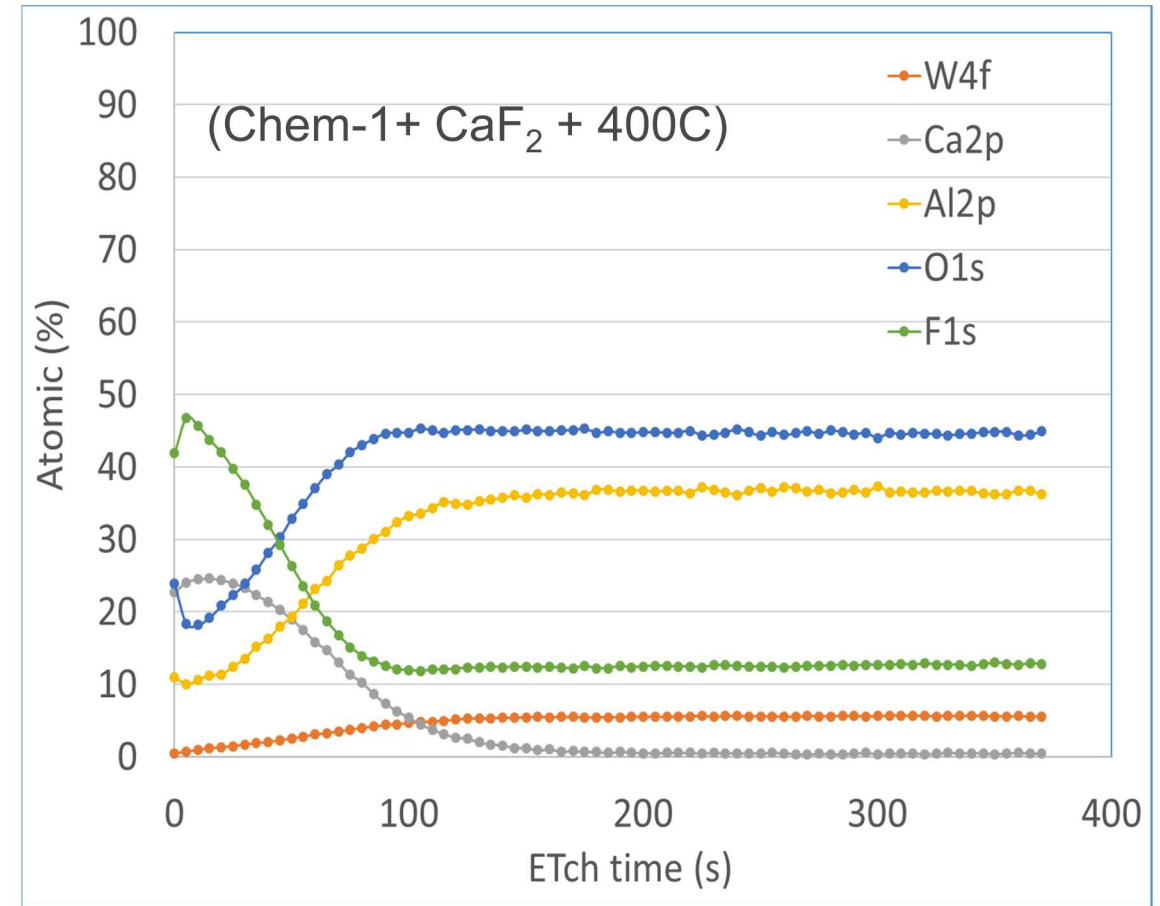
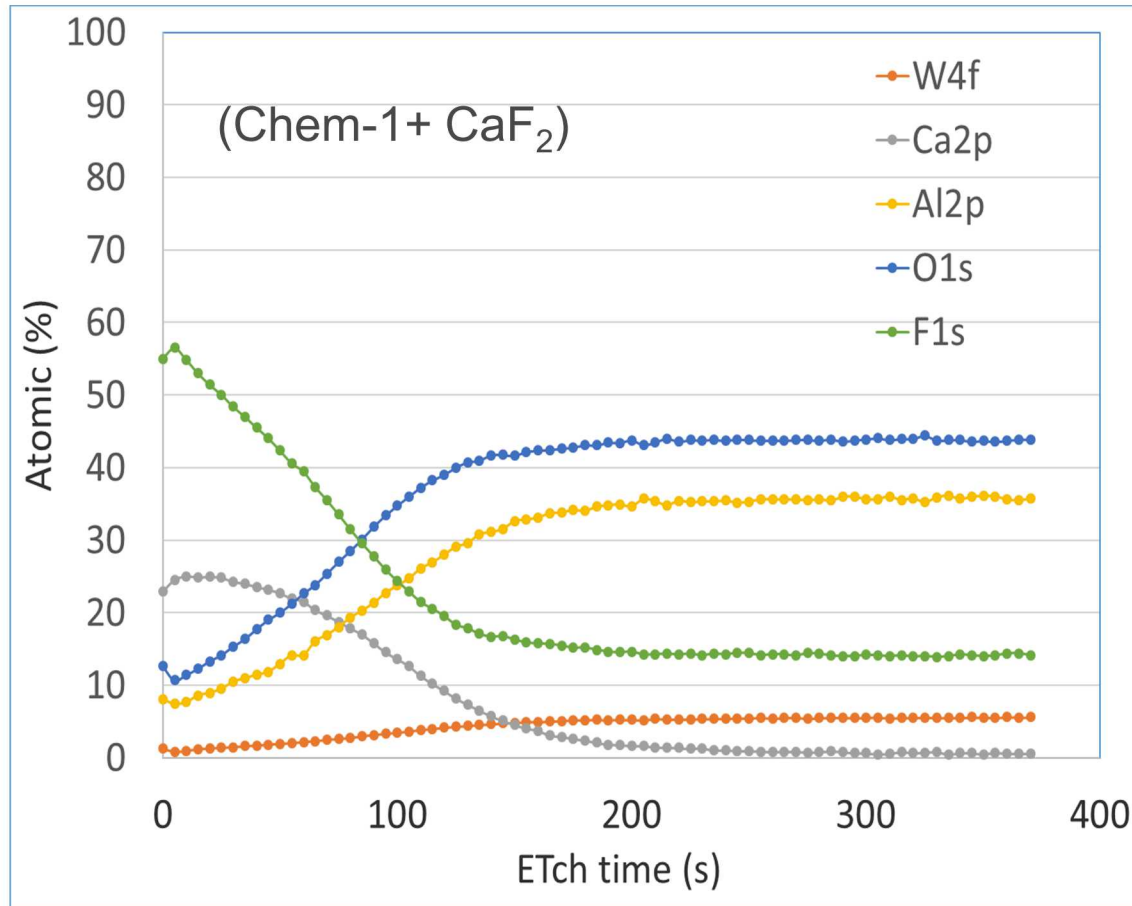


(400C+ Chem-1+ MgO + 400C)



- Both 400C annealing (Or/and) ALO capping after chem-1 process has strong bias effect on F diffusion.
- Looks like MgO stays ~ same
- Final annealing still has adequate effect on F migration

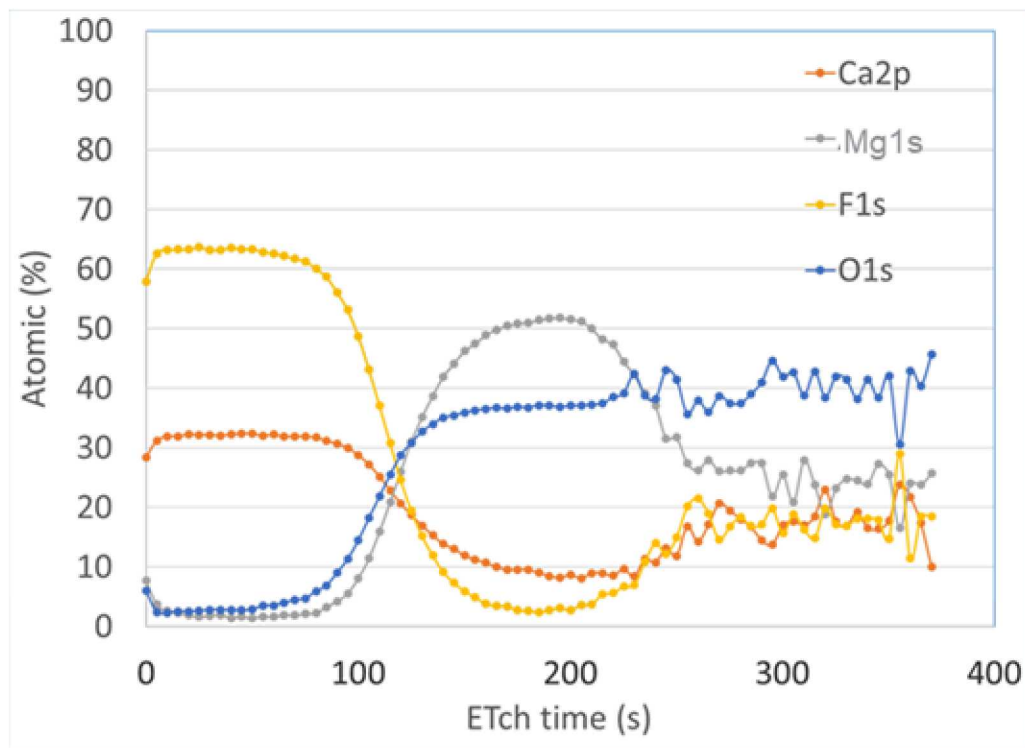
CaF₂ as SEE layer on Chem-1 baseline R process (WAlOFC)



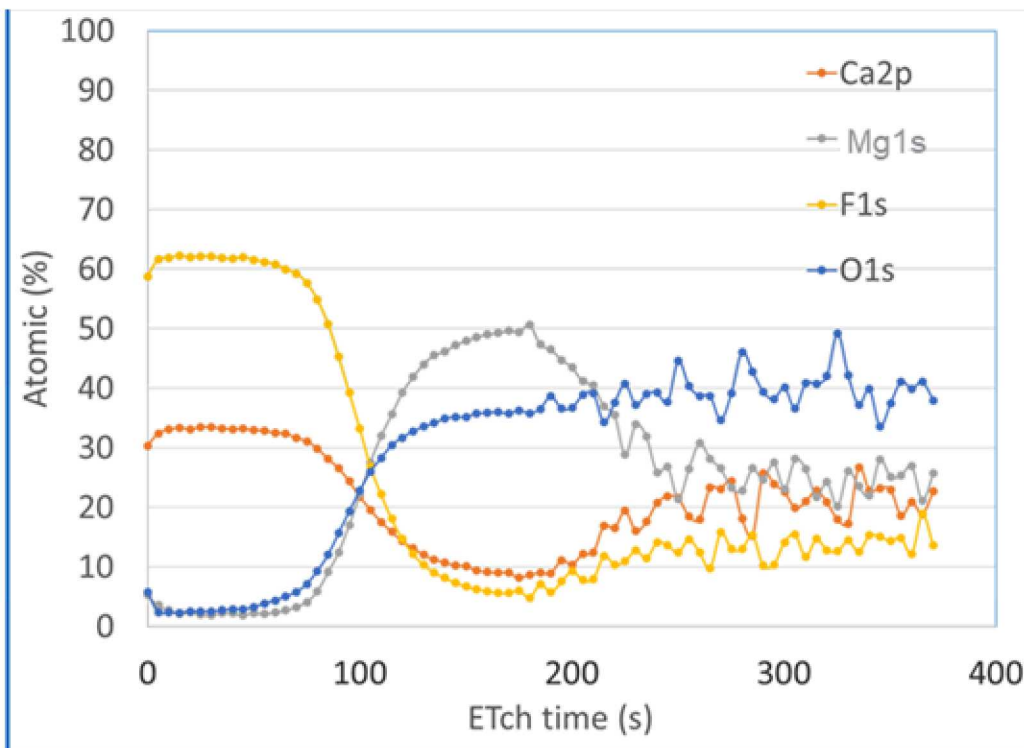
- No significant change on both CaF₂ SEE and Chem-1 R layers

Understanding F- migration with MgO-CaF₂

8nm MgO -20nm CaF₂



8nm MgO - 20nm CaF₂- 400C (4hrs at 1Torr with 300sscm N₂)



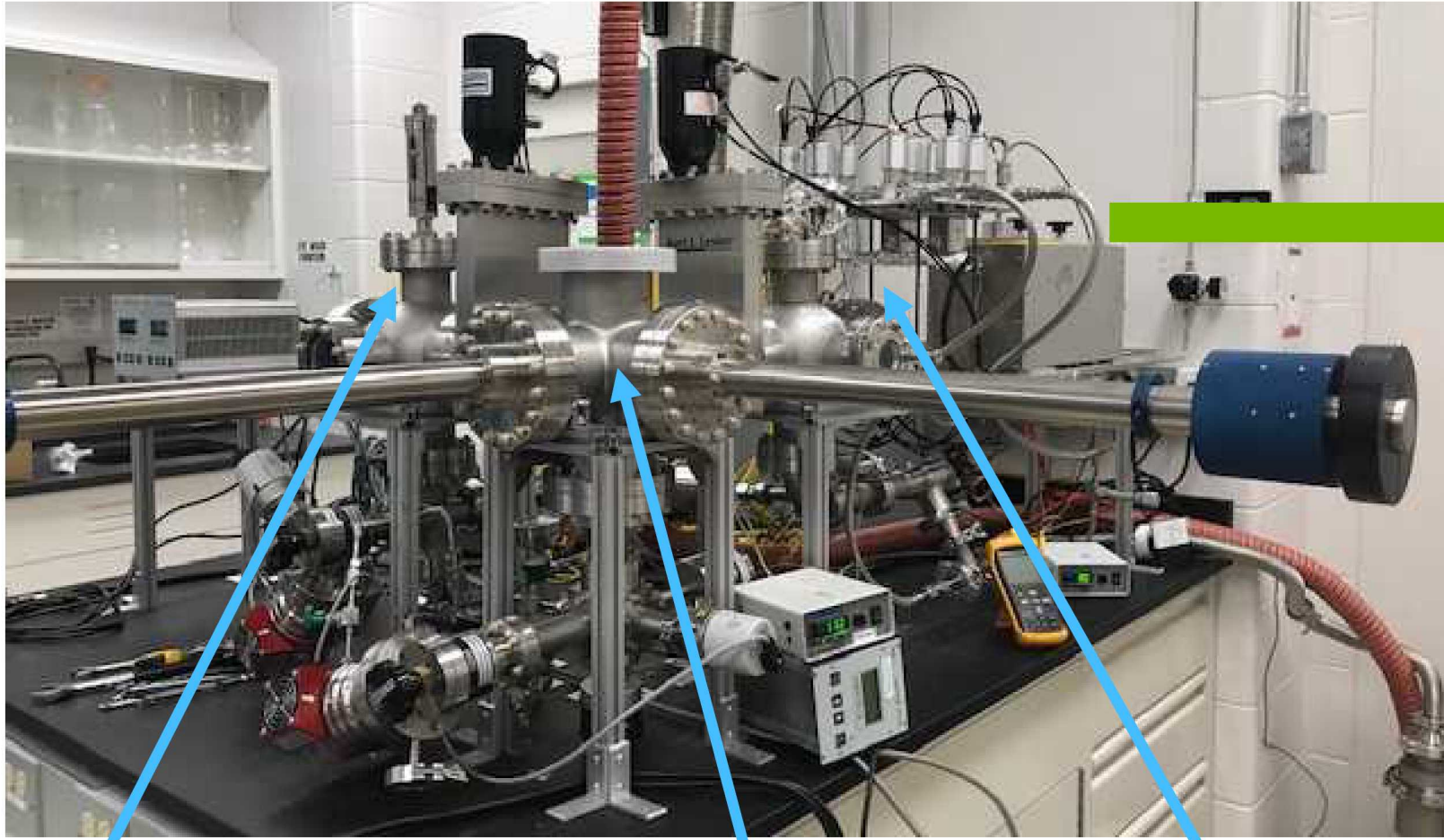
- F-migration did not occur in MgO due to stable CaF₂ stoichiometry
- This suggest that F in Chem-1 is un-bonded

Construction of the in-situ ALD reactor-MCP testing system

Advantages:

- **Quick screening of secondary electron emission (SEE) materials**
(Thickness optimization and complex material testing)
- **No air exposure after ALD coatings**
- **Study of different atmosphere exposure on MCPs**
- **TCR measurement in high vacuum condition**
- **Degassing and scrubbing of final MCPs**

In-situ ALD reactor-MCP testing system



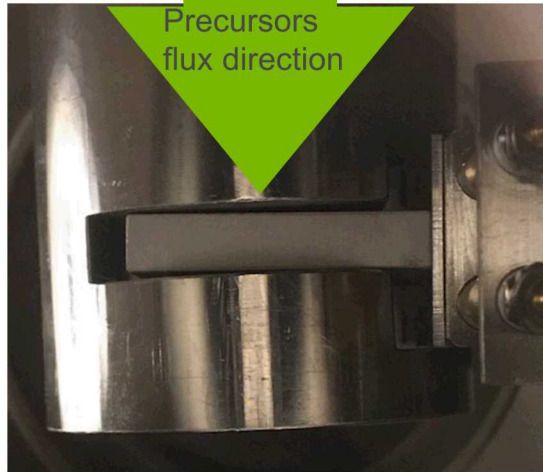
MCP testing chamber

Transfer chamber

ALD chamber



In-situ ALD reactor-MCP testing system



33mm MCP in Ceramic holder
Inserted in ALD precursors path

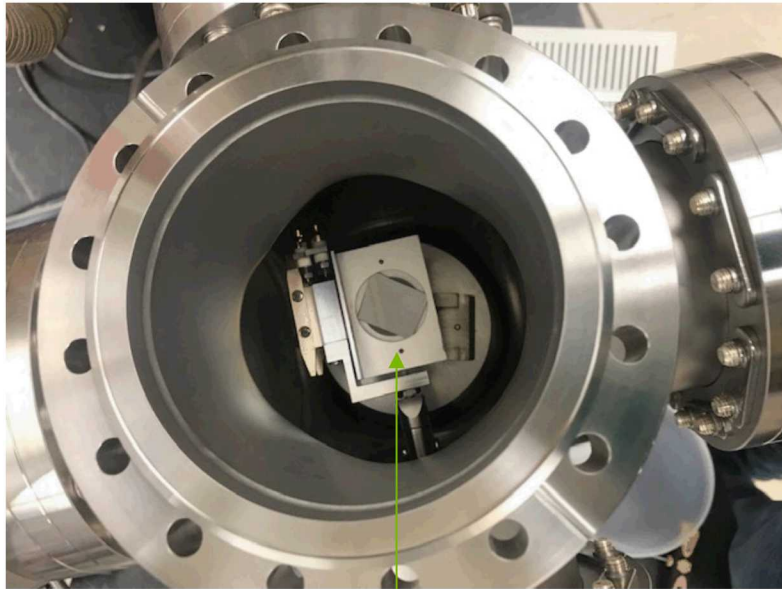


Precursor valve manifold
(up to 6 precursors)

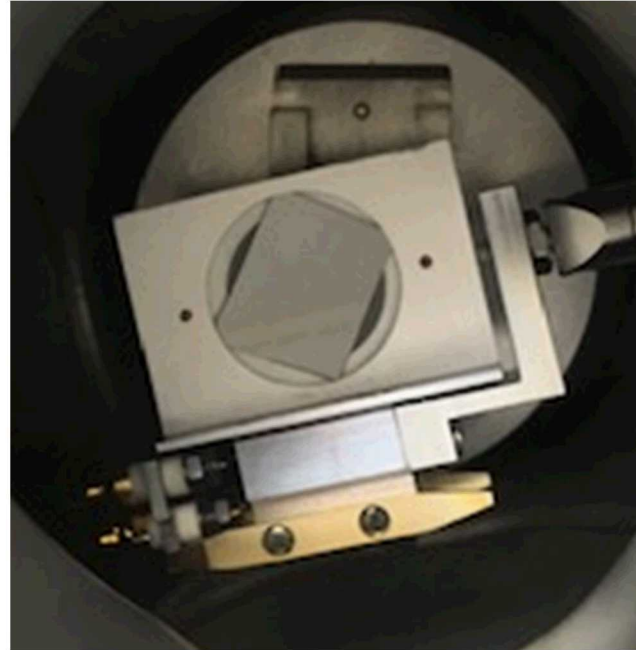
Vaporizer for solid
subliming precursor

In-situ ALD reactor-MCP testing system

Si coupon placing
on 33mm MCP
For ALD qualification



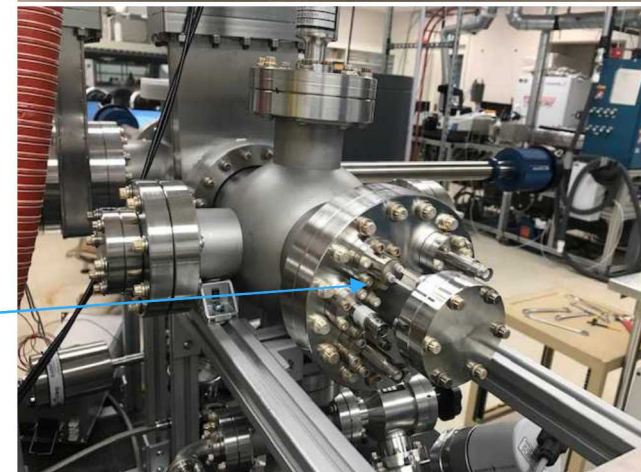
33mm MCP in
Ceramic holder



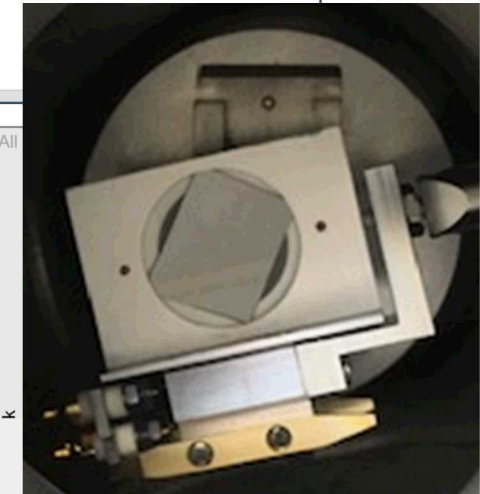
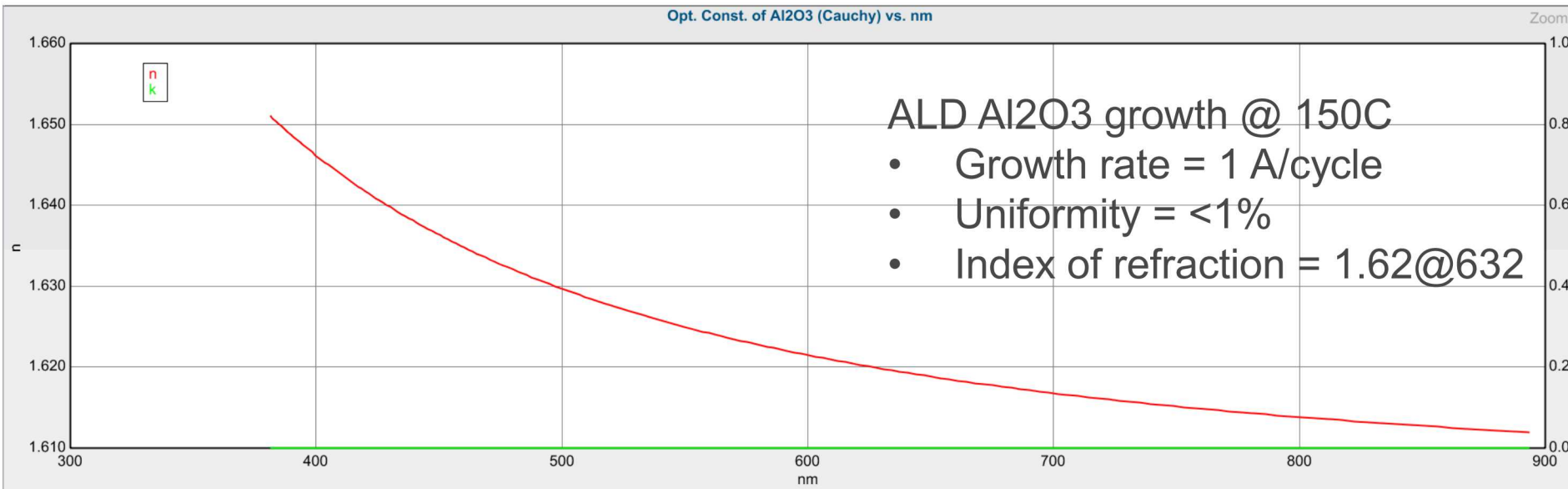
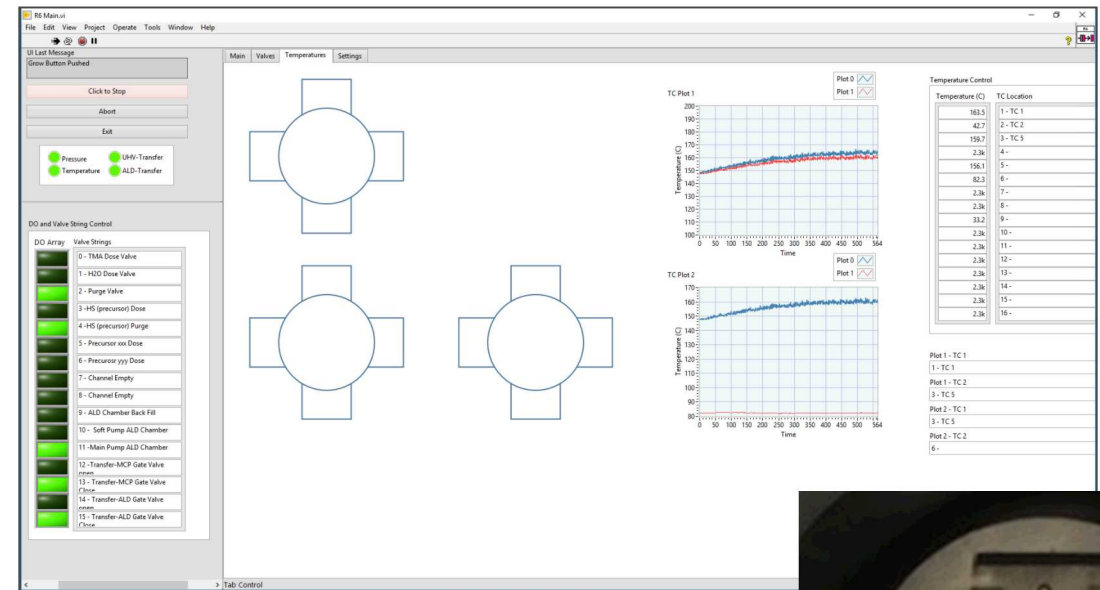
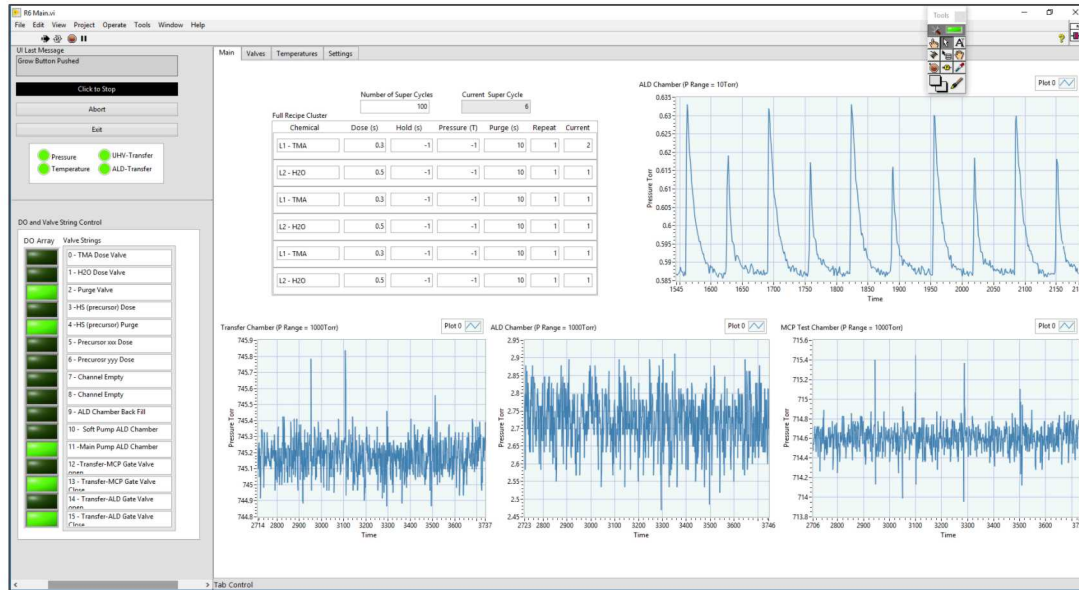
MCPS gain measurement
arrangement



Feedthrough for various
electrical connections



In-situ ALD reactor-MCP testing system: LabVIEW program



Next tasks:

- Perform in-situ ALD MCP-gain measurements with various SEE layers
 - Al_2O_3 , MgO , MgF_2 , CaF_2 , TiO_2 , CsO , and many more
 - Establish empirical relation of gain vs. SEE yield (δ)
 - Environmental study on potential SEE layers
- Transfer process knowledge to Incom for next generation LAPPDs
- Continue search for Resistive and SEE layer
- Explore new low TCR ALD materials
- Submit papers

Thank you !!

Frequency domain multiplexing of pulse mode radiation detectors

Mudit Mishra, John Mattingly

North Carolina State University

June 25, 2019

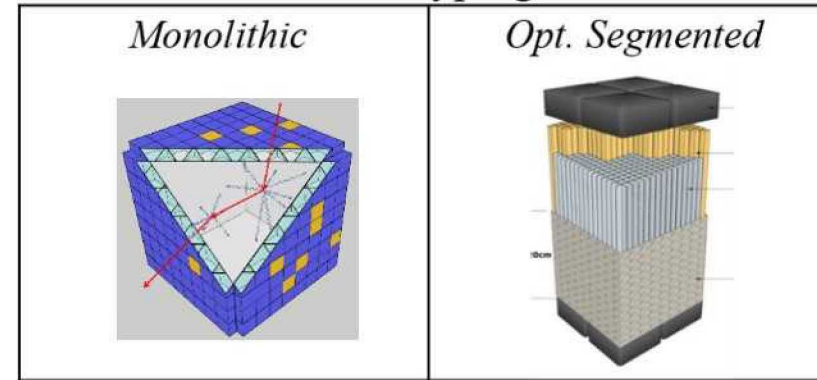
Motivation

- Large number of readout channels in a radiation detection system requires a high channel-density data acquisition system
- Frequency domain multiplexing combines multiple detector signals into a single readout channel
- This enables reduction of digitizer input channels for data acquisition

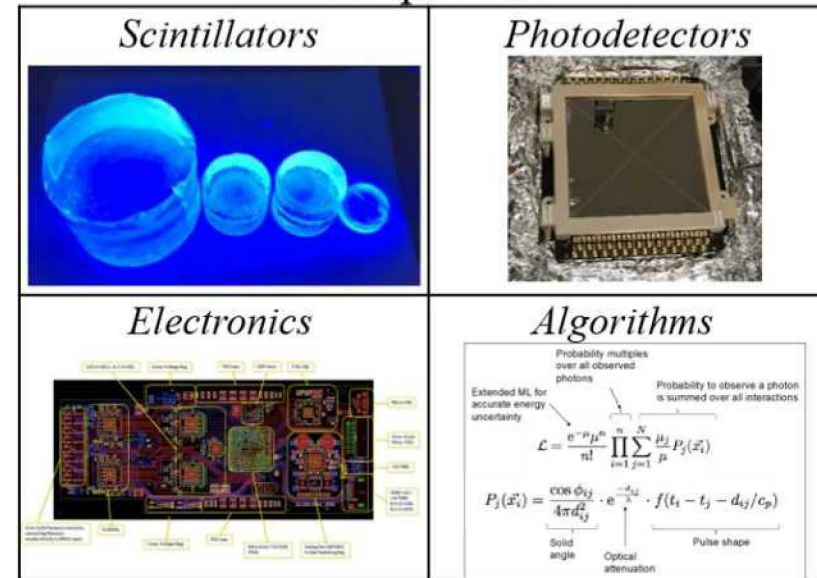
Application to SVSC

- The Single Volume Scatter Camera prototype will have 128 photodetector output channels to reconstruct the incoming neutron path
- We can multiplex at least 10 channels into 1

Prototyping

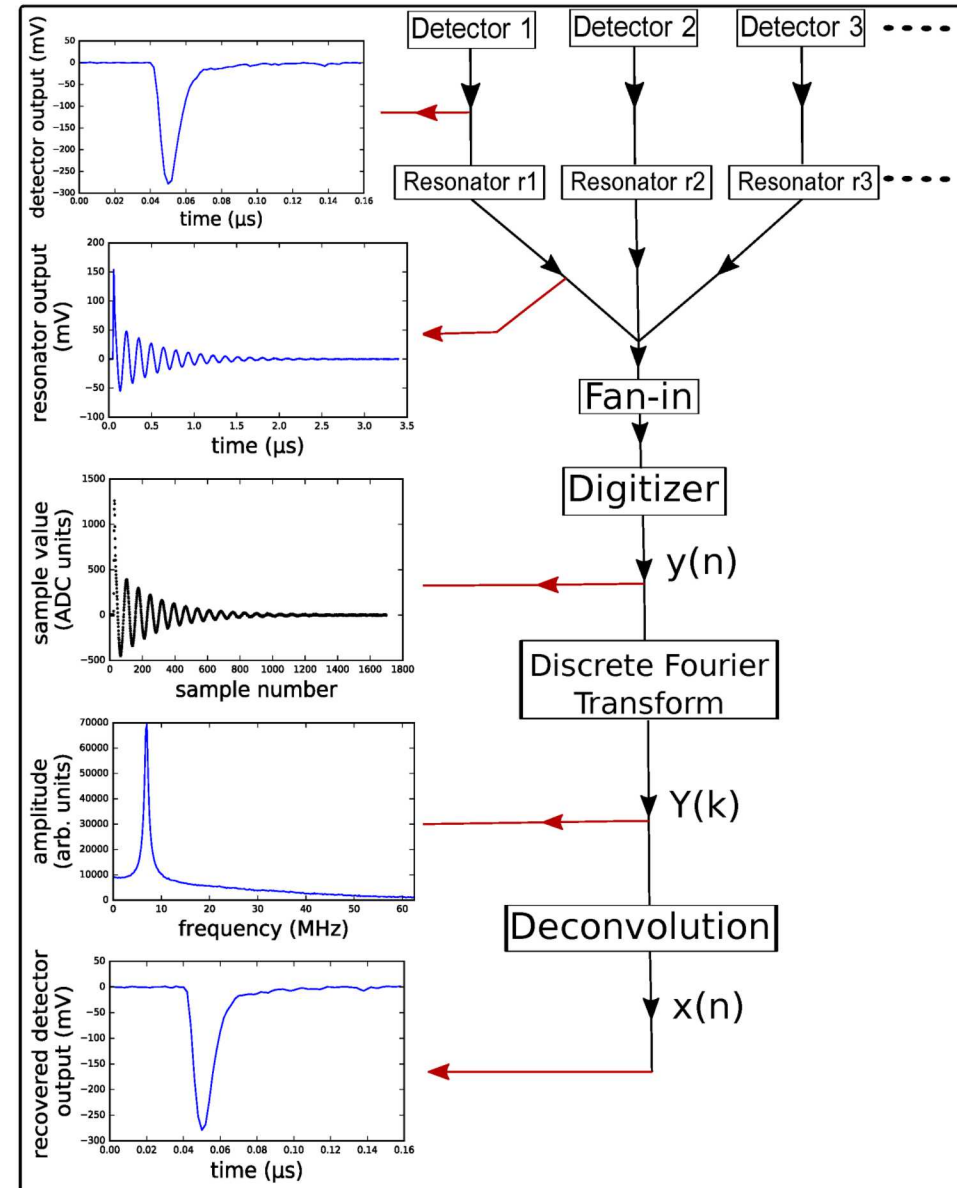


Components



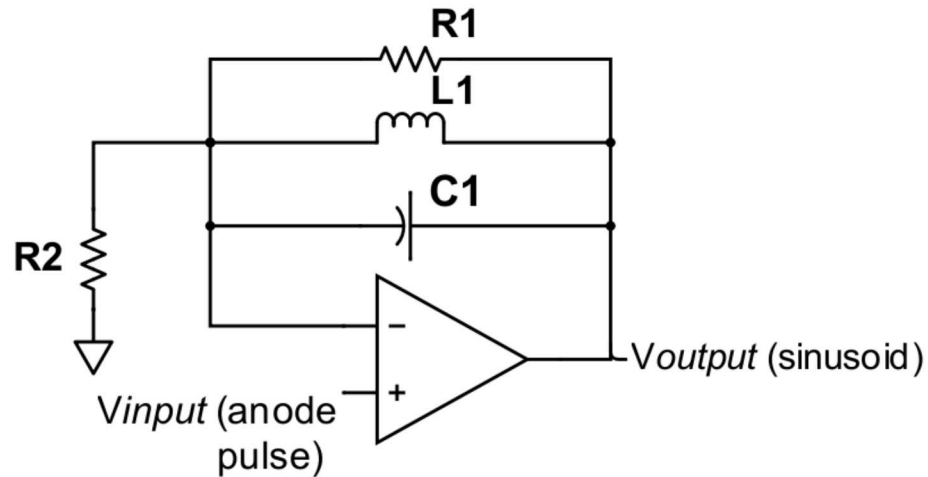
Introduction

- Frequency domain multiplexing (FDM) has been previously implemented for current-mode radiation detectors using modulation and demodulation
- We have developed a new way to multiplex *pulse-mode radiation detectors* by **convolution** and **deconvolution**



Circuits

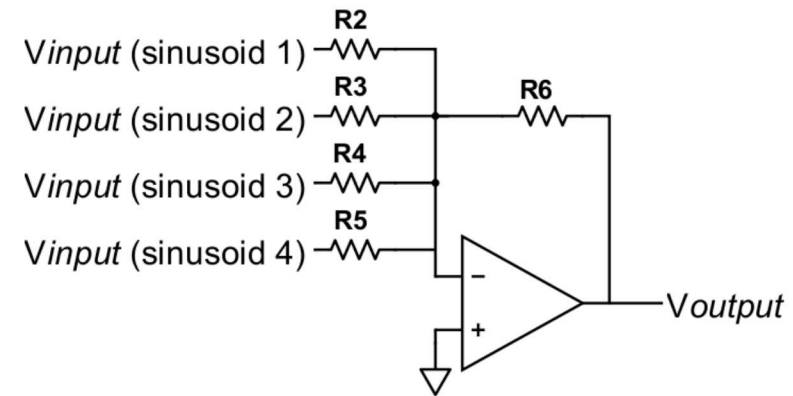
Resonator



Resonant frequency, $f_r \approx \frac{1}{2\pi\sqrt{L_1 C_1}}$

Q-factor, $Q = R_1 \frac{C_1}{L_1}$

Fan-in

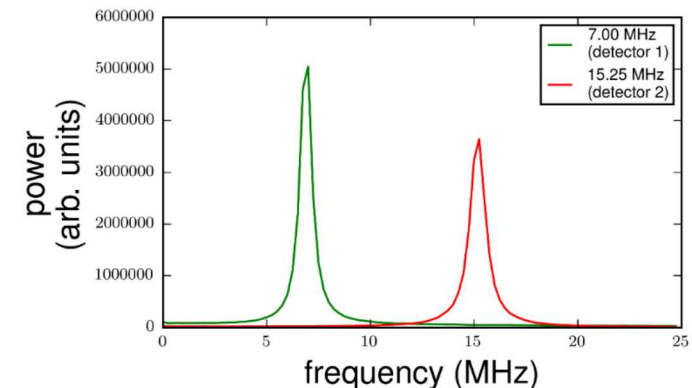
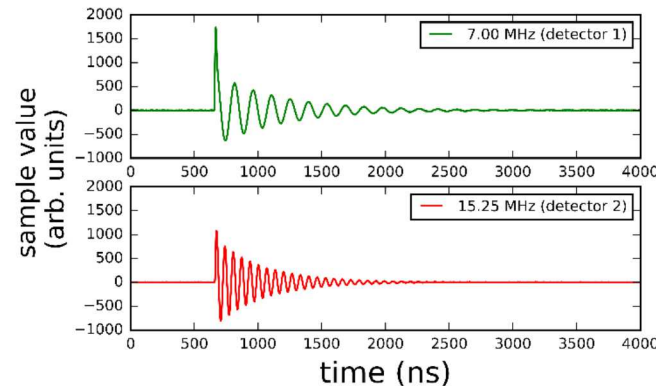
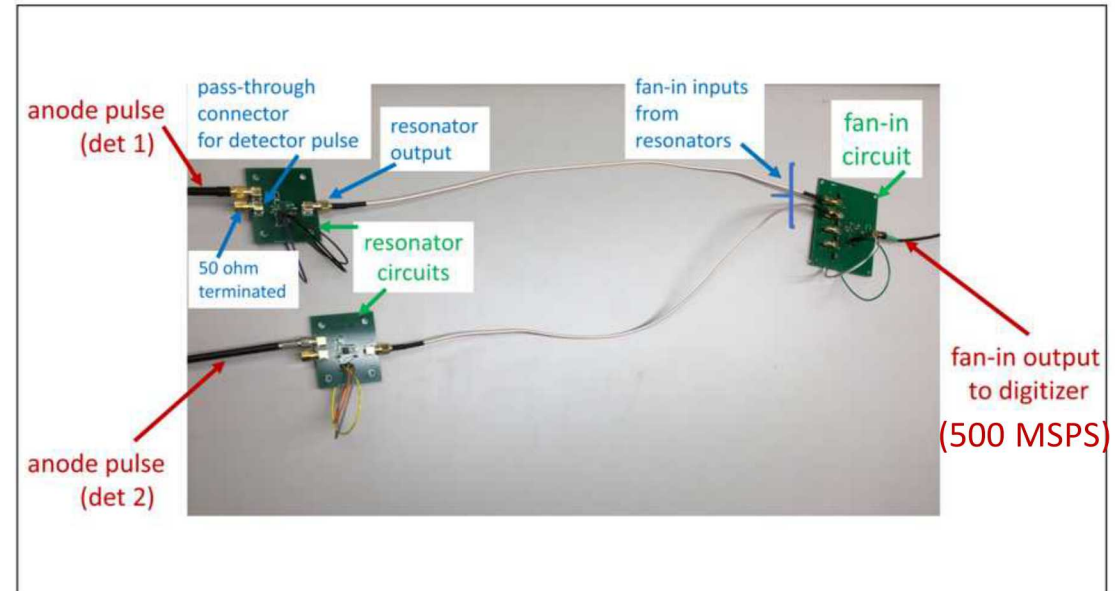


$$V_{output} = -\left(\frac{R_6}{R_2} V_{sine1} + \frac{R_6}{R_3} V_{sine2} + \frac{R_6}{R_4} V_{sine3} + \frac{R_6}{R_5} V_{sine4}\right)$$

Gain = 2

FDM Setup

- Two EJ-309 fast organic detectors were connected to two resonators respectively
- Two resonators were combined by the fan-in circuit
- Each resonator has a pass-through for simultaneous digitization of the detector pulse



Frequency-domain multiplexed detector signals

Impulse Response and Deconvolution

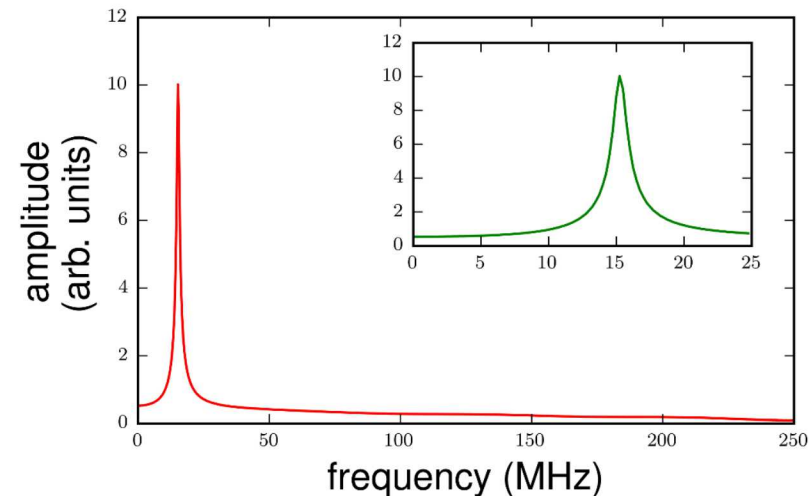
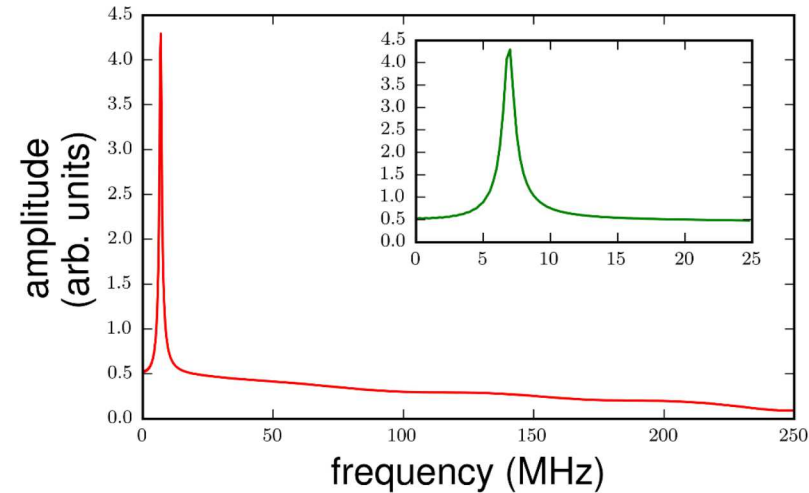
- Deconvolution is performed in the frequency domain

$$X(f) = \frac{Y(f)}{H(f)}$$

- The FDM impulse response is measured from

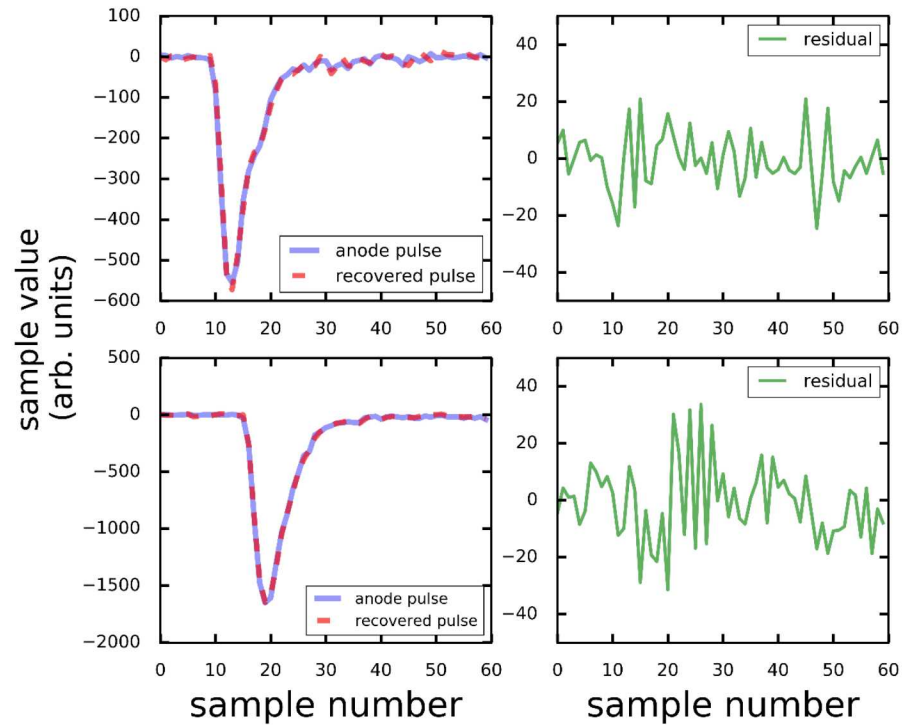
$$H(f) = \frac{S_{yx}(f)}{S_{xx}(f)}$$

- $S_{yx}(f)$ is the cross-correlation of output with noise input
- $S_{xx}(f)$ is the autocorrelation of noise input

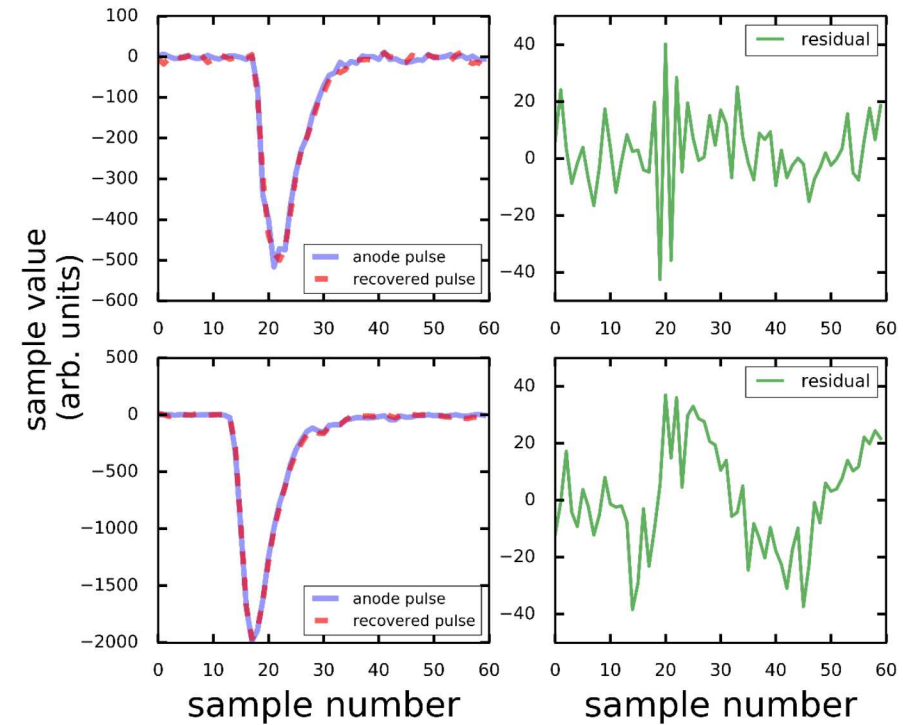


Signal Reconstruction

Detector 1, 7.00 MHz resonator

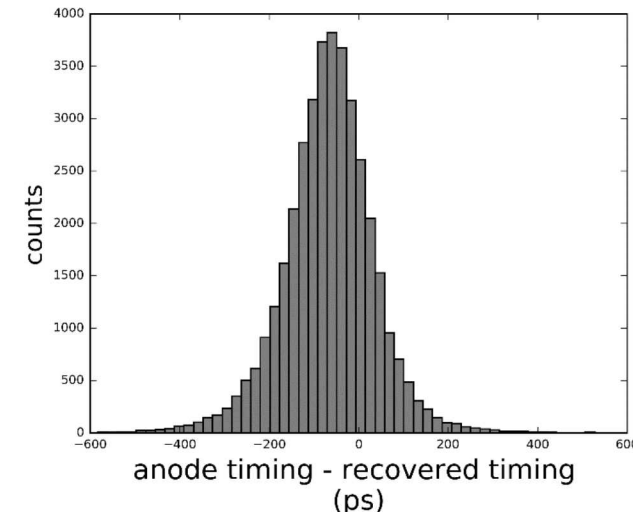
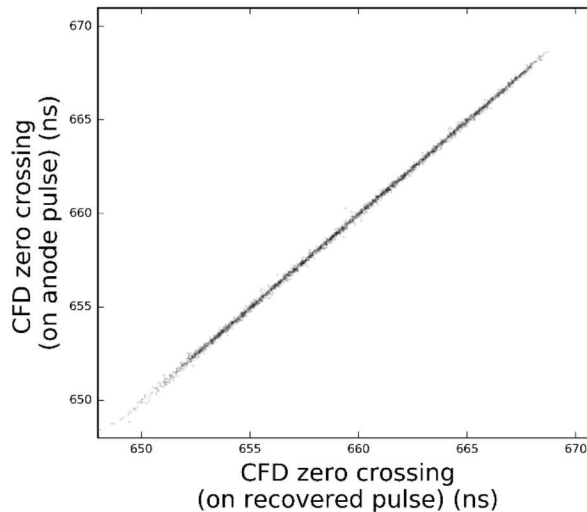
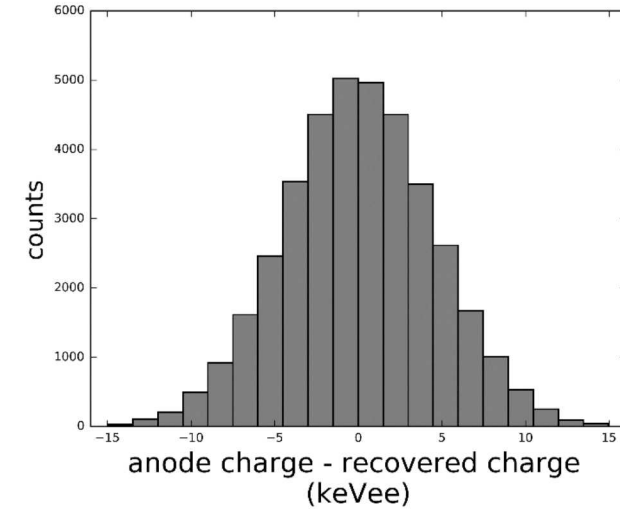
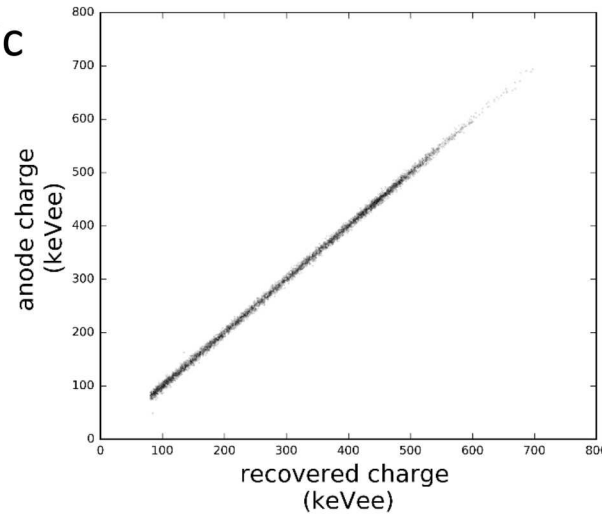


Detector 2, 15.25 MHz resonator



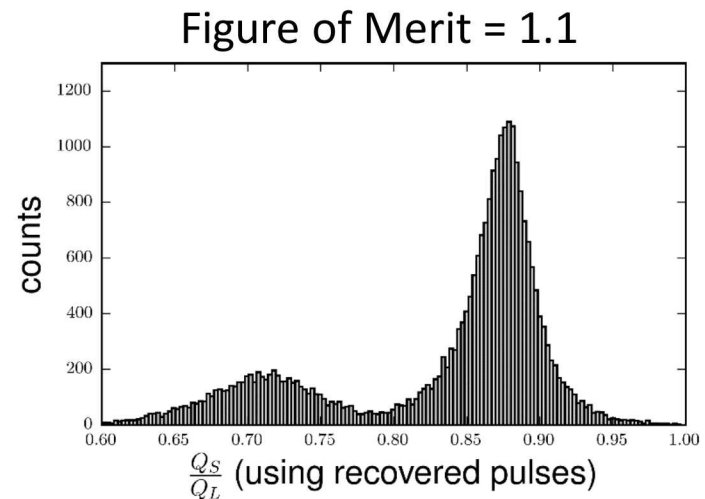
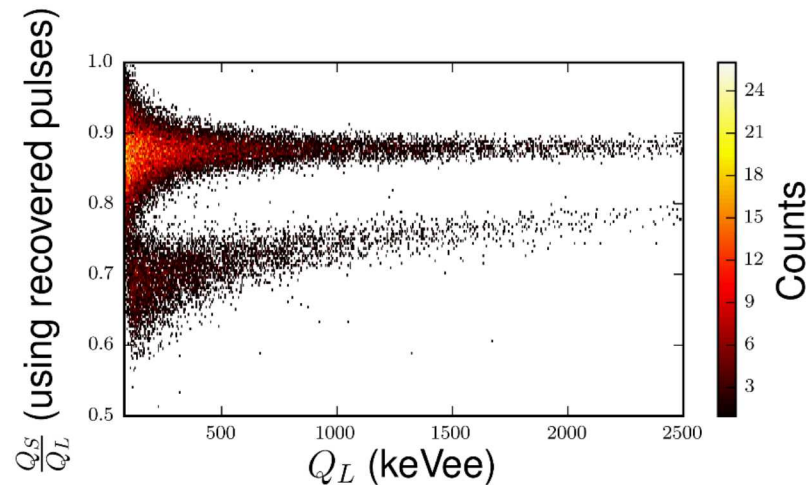
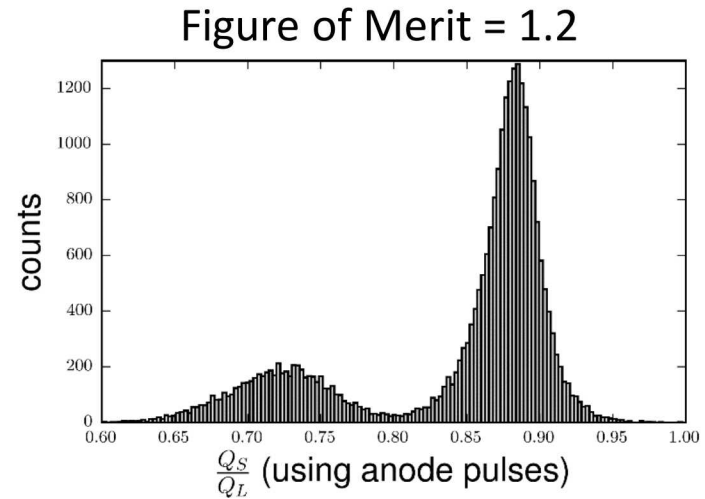
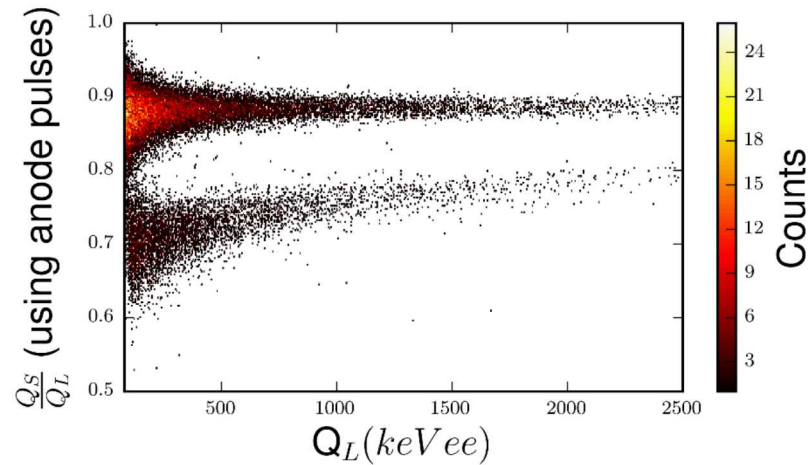
Energy and Timing Estimation Using the Recovered Pulse

- For a EJ-309 fast organic detector, the pulse energy can be estimated from the recovered pulse with a small 4 keV increase in the energy uncertainty
- The pulse time pick-off can be estimated from the recovered pulse with a small 100 ps increase in the timing uncertainty



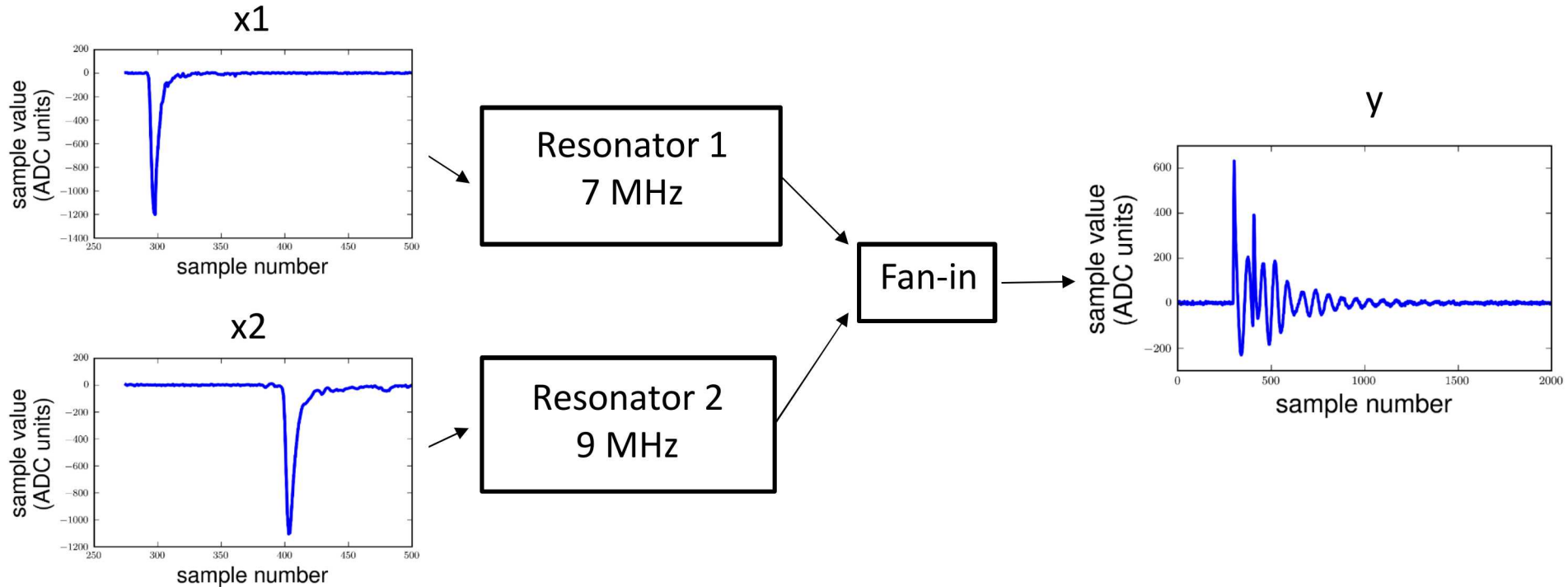
Application of deconvolution to recover frequency-domain multiplexed detector pulses, NIMA (2019)

Particle Identification via Pulse-Shape Discrimination

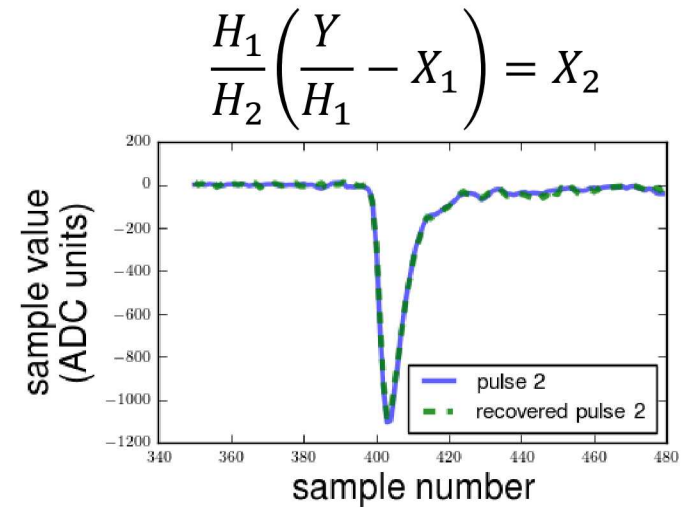
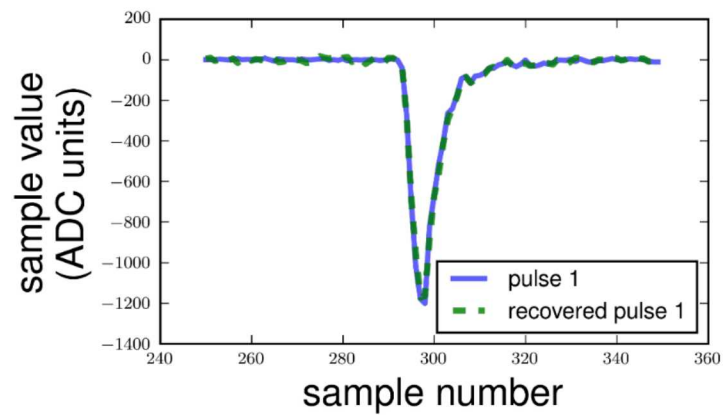
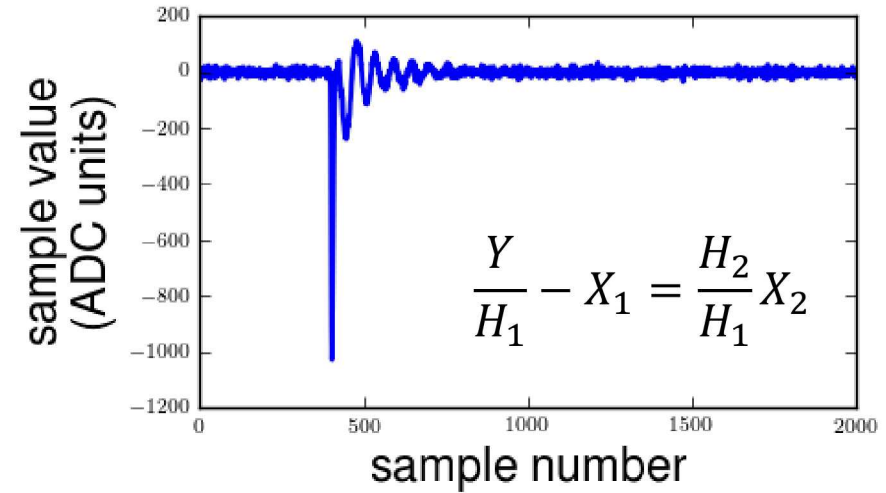
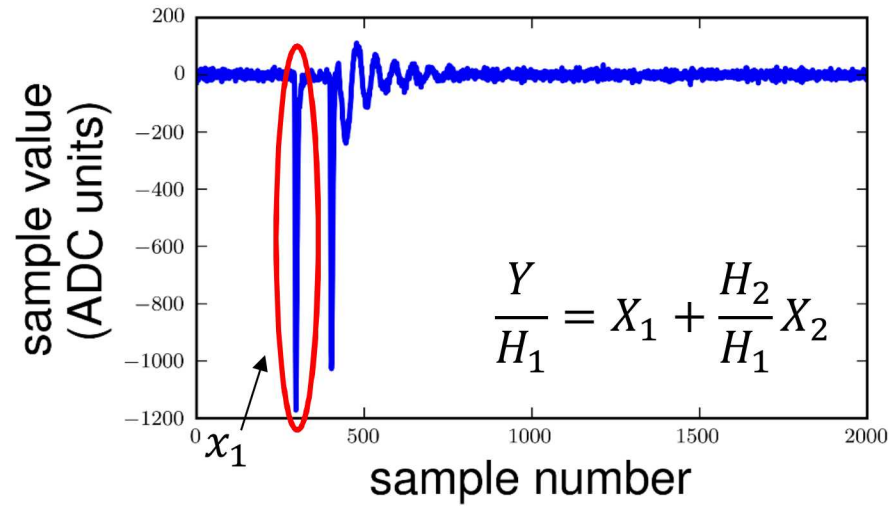


Double Occupancy

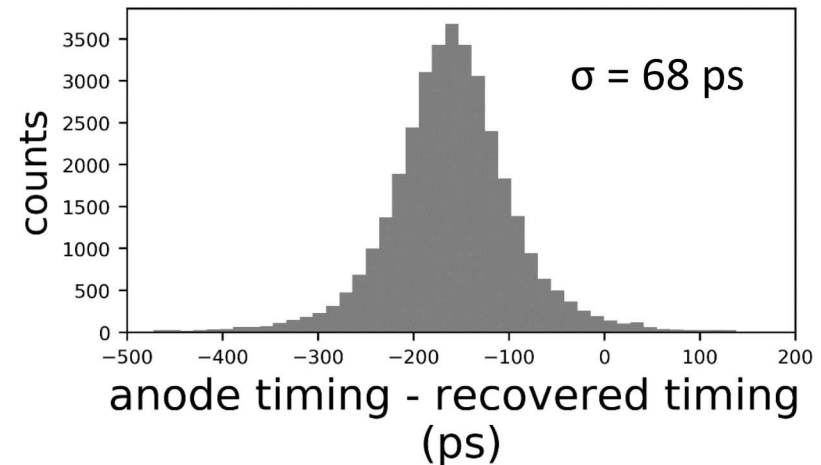
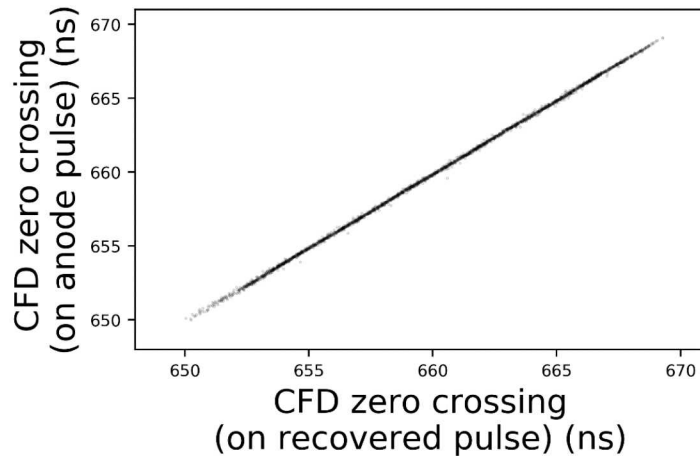
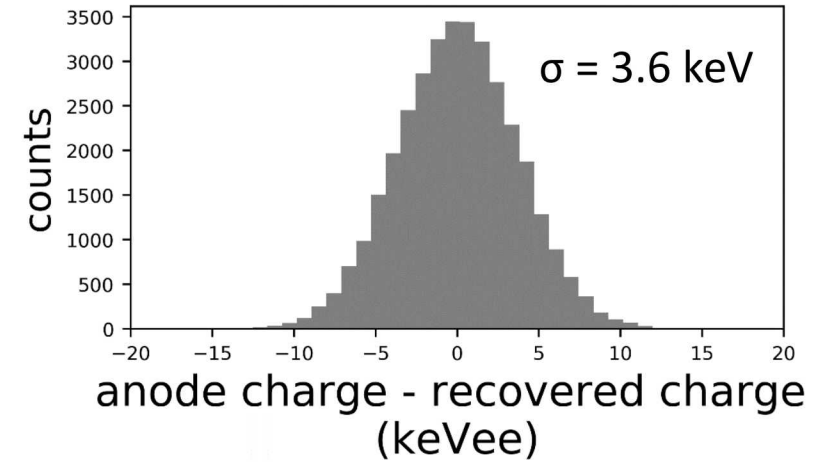
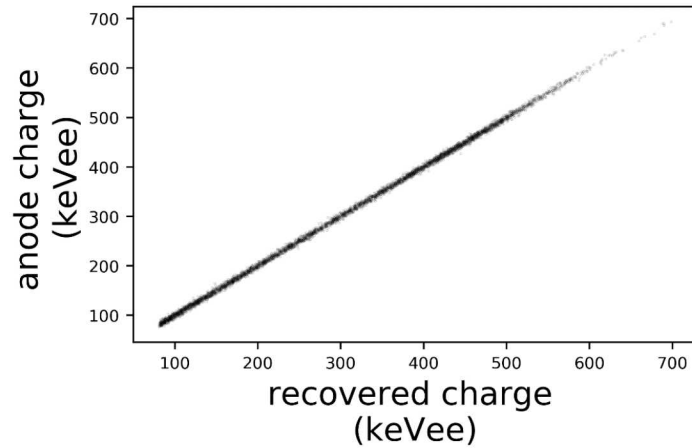
- When two detectors produce signals in the same digitizer record, but the pulses do not overlap
- In frequency domain, $Y = H_1X_1 + H_2X_2$



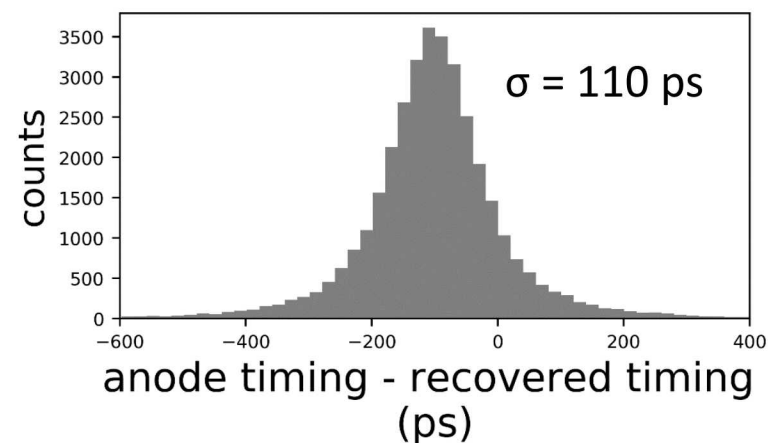
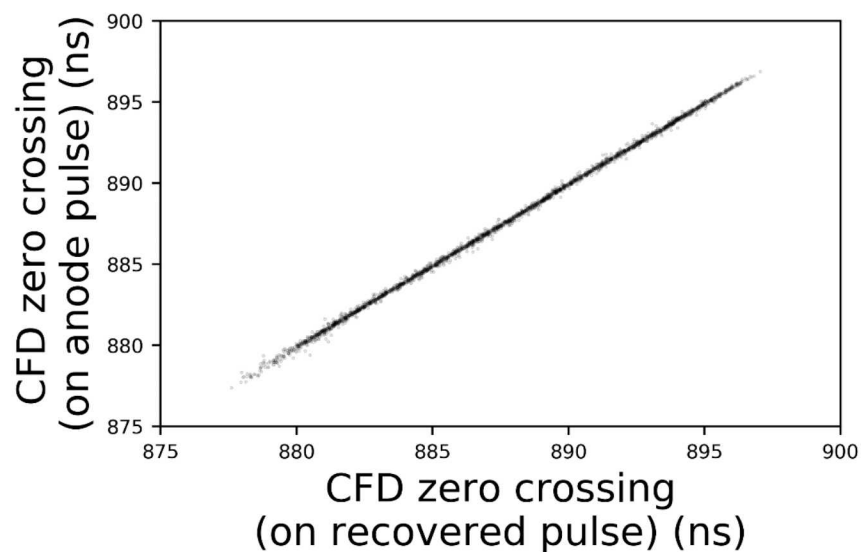
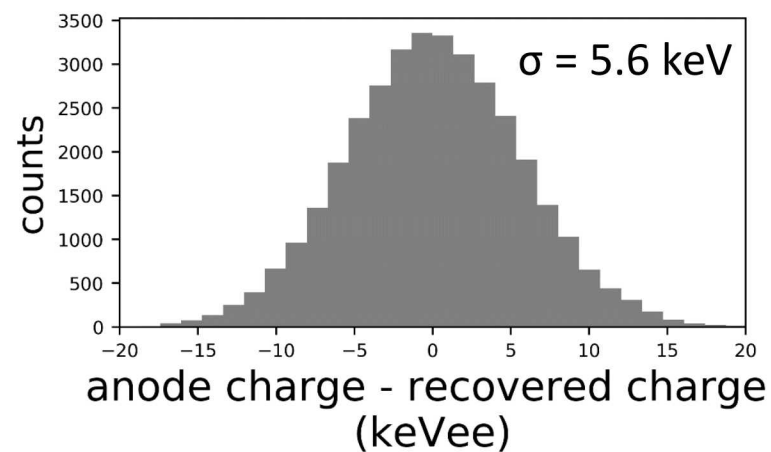
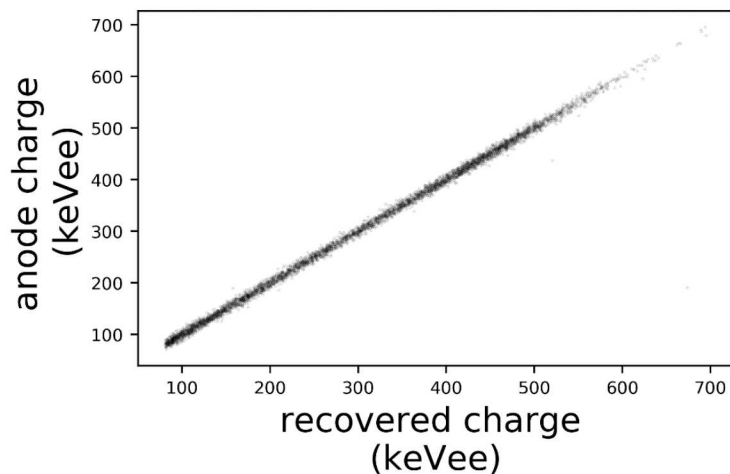
Double Occupancy



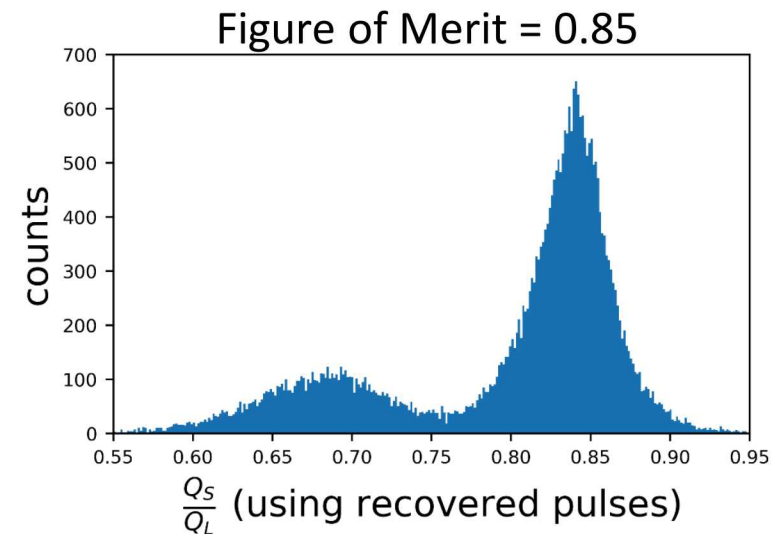
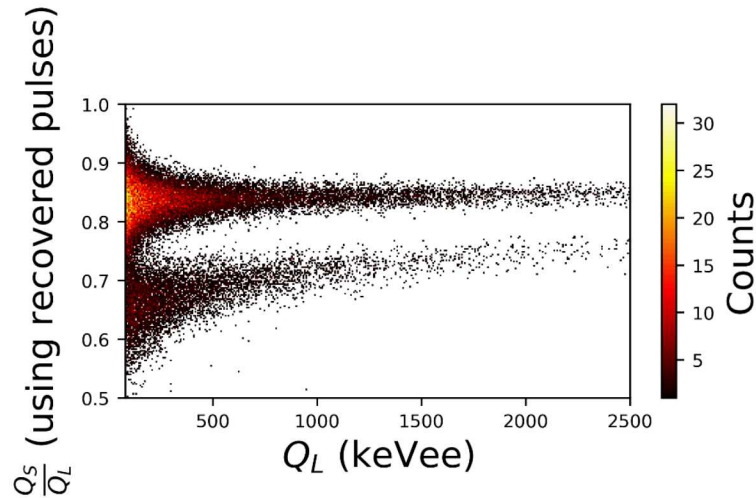
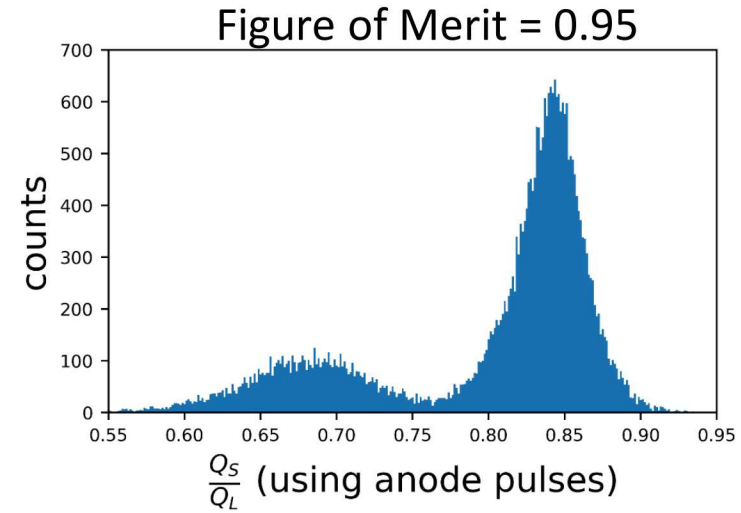
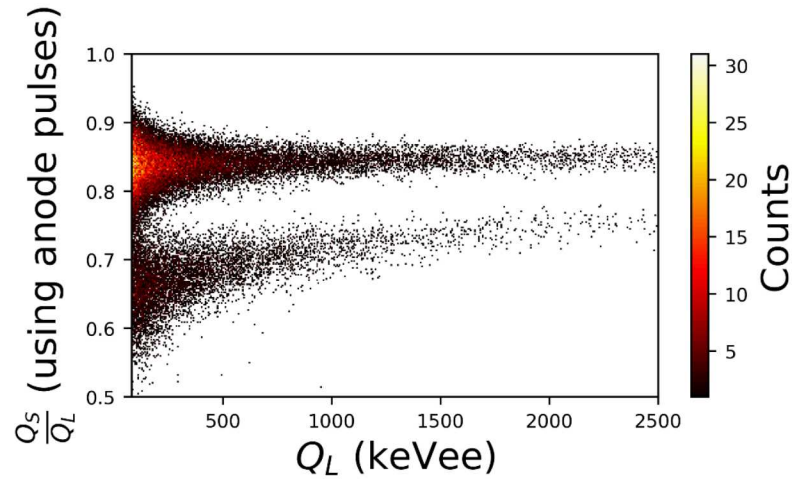
Energy and Timing Estimation for Pulse x1



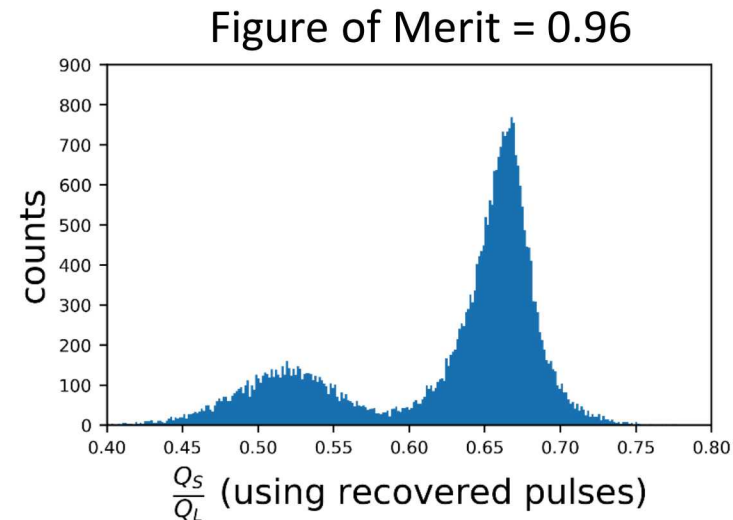
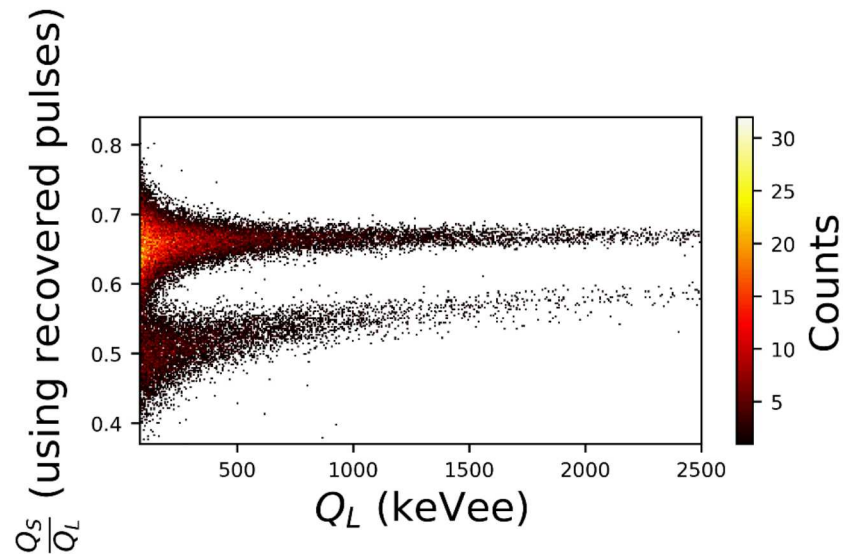
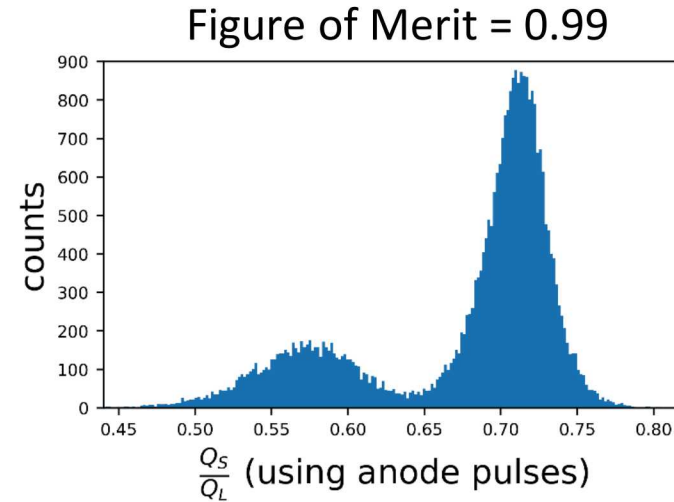
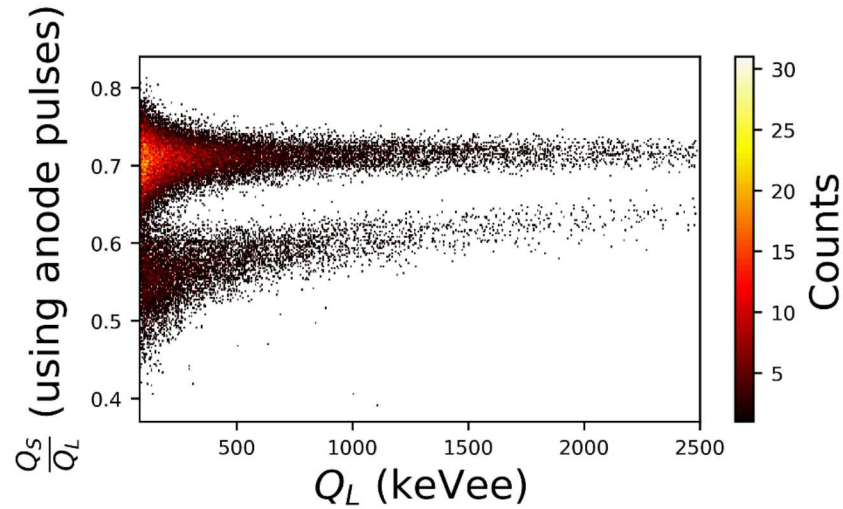
Energy and Timing Estimation for Pulse x2



Particle Identification for Pulse x1

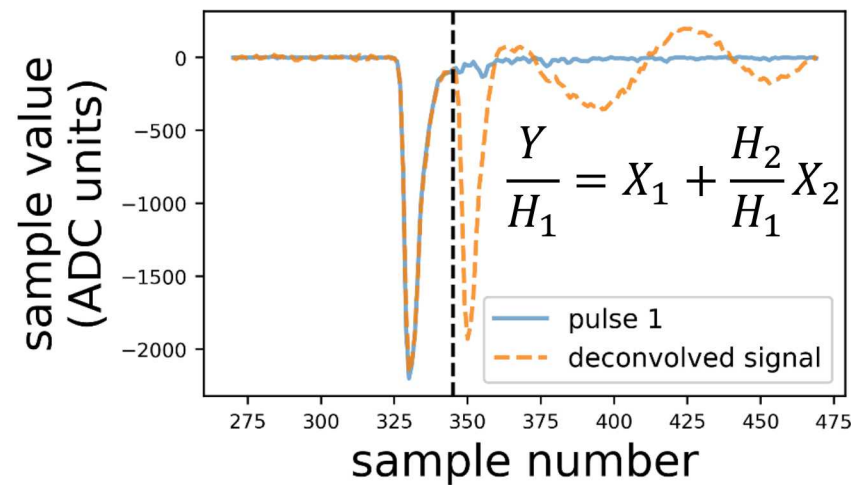
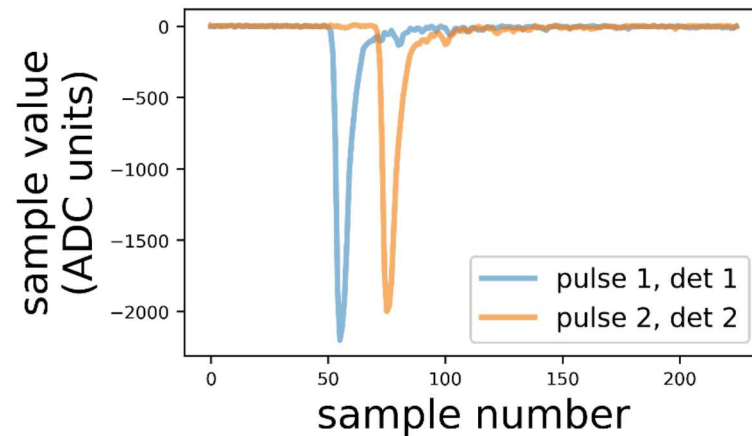


Particle Identification for Pulse x2



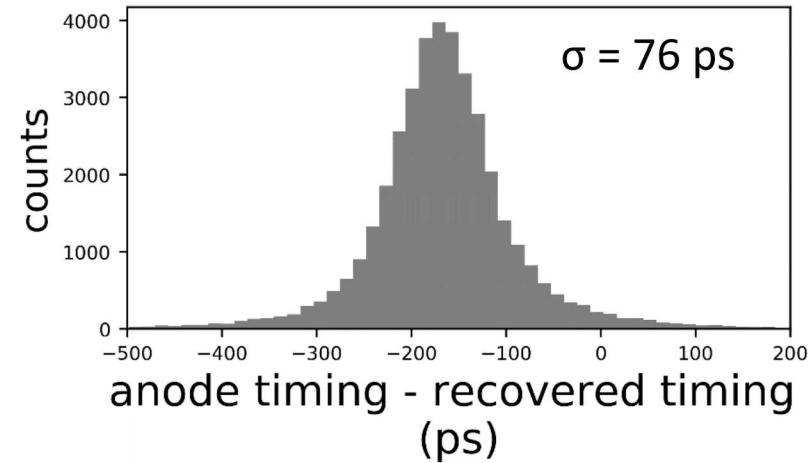
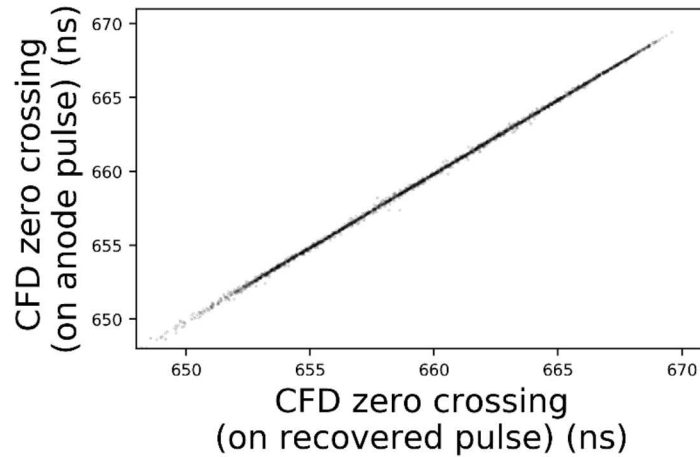
When pulses overlap?

- When second pulse arrives at the tail of the first pulse
- The first pulse is partially recoverable

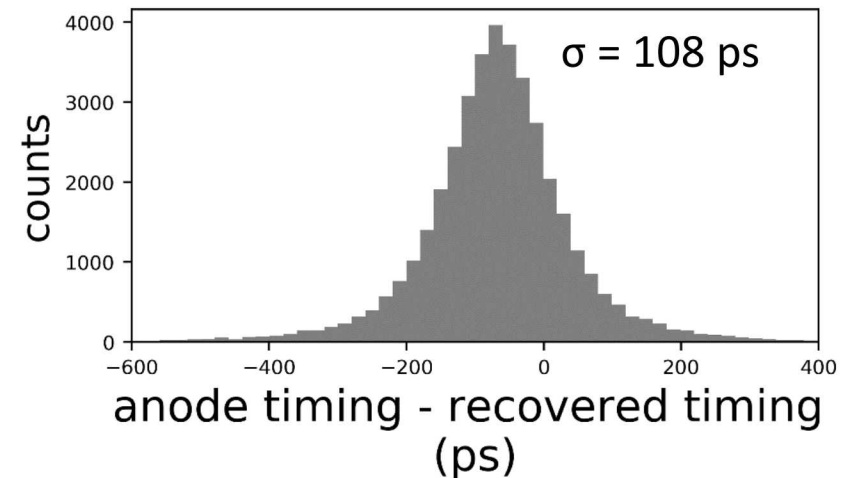
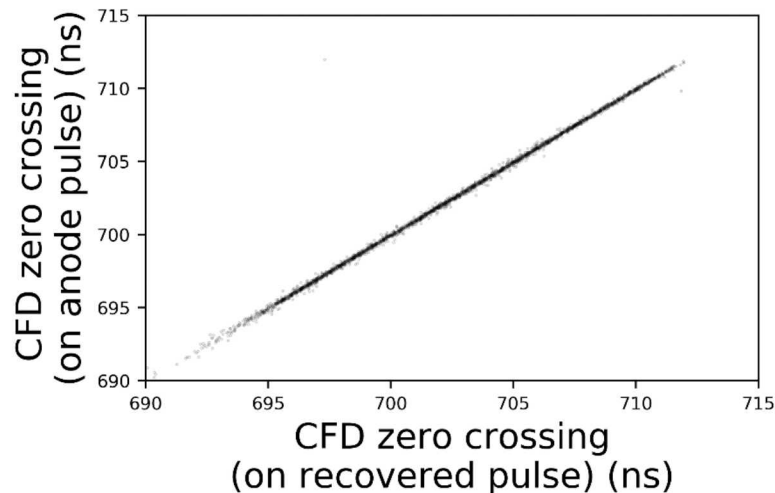


Timing Estimation in overlapping case

First Pulse

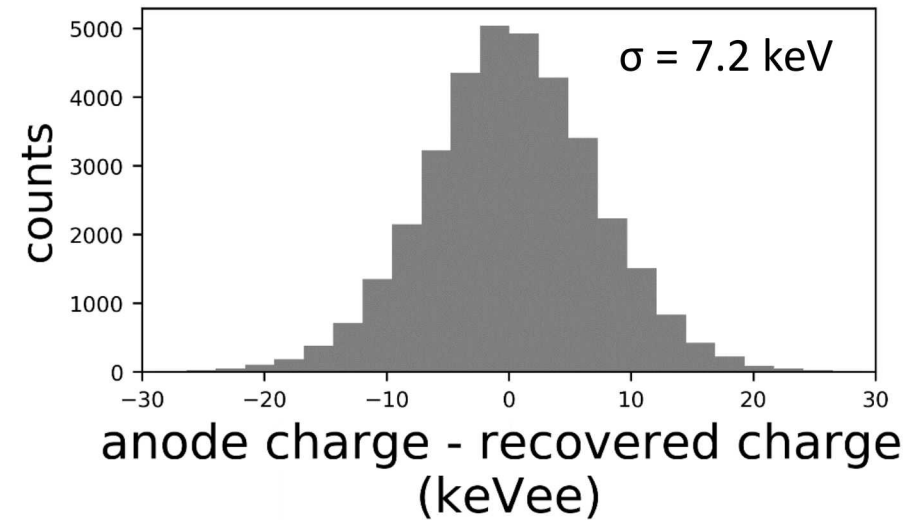
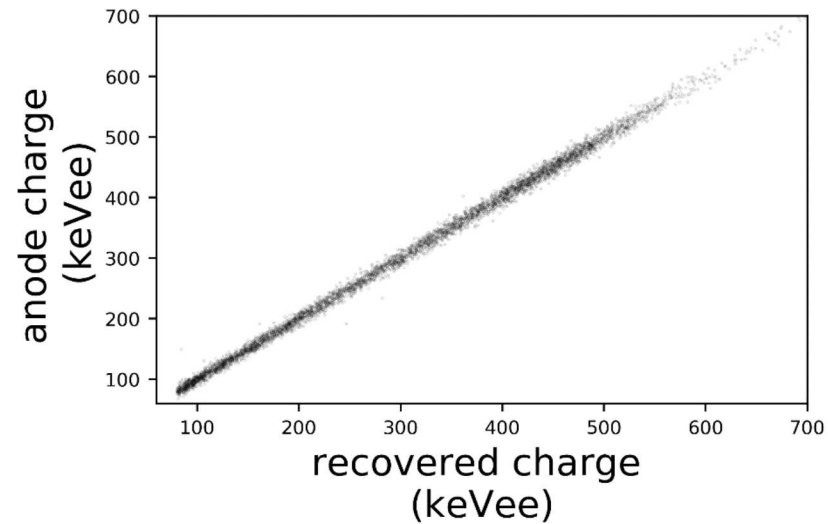


Second Pulse



Energy estimation in overlapping case

Second Pulse



Conclusion

- We performed frequency domain multiplexing of two EJ-309 fast organic scintillator detectors with
 - 4 keV increase in the energy precision
 - 100 ps increase in the timing precision
- Pulse-shape discrimination using recovered pulse resulted in a small decrease in the figure of merit
- Most significant loss in precision was observed in the energy estimation of the second pulse in the double occupancy case
- We are working to implement frequency domain multiplexing with
 - EJ-204 scintillator bars
 - SiPM readouts
 - DRS4 digitizer
- Using simulated annealing, we are currently working to find an optimal multiplexing pattern for the SVSC channels to minimize double occupancy

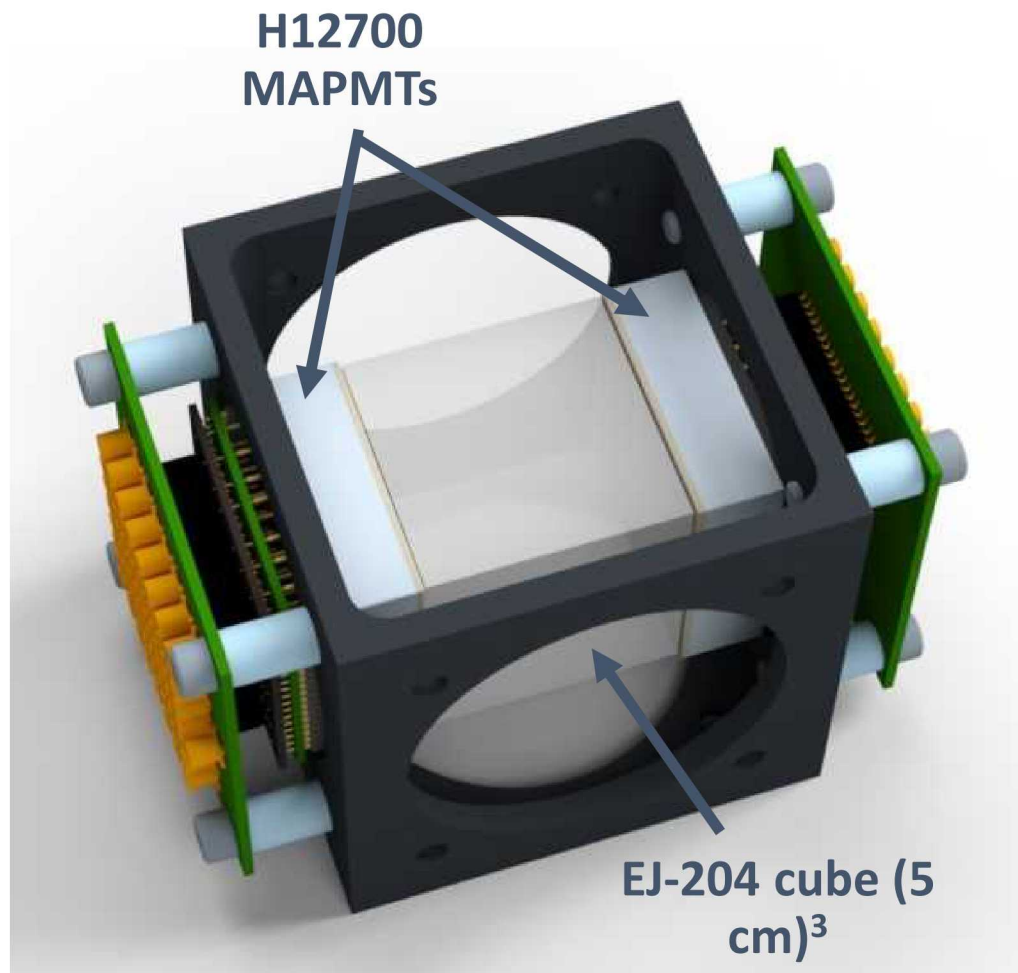
SVSC next steps and future plans

SVSC independent review

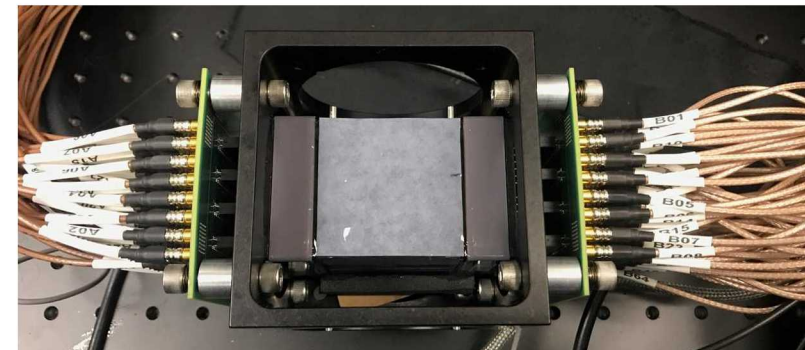
25 June 2019

E. Brubaker, SNL/CA

Prototype Monolithic Imager



Scintillator and
PMTs



4 CAEN V1742 32-
channel, 5 GSs⁻¹, 12 bit digitizers

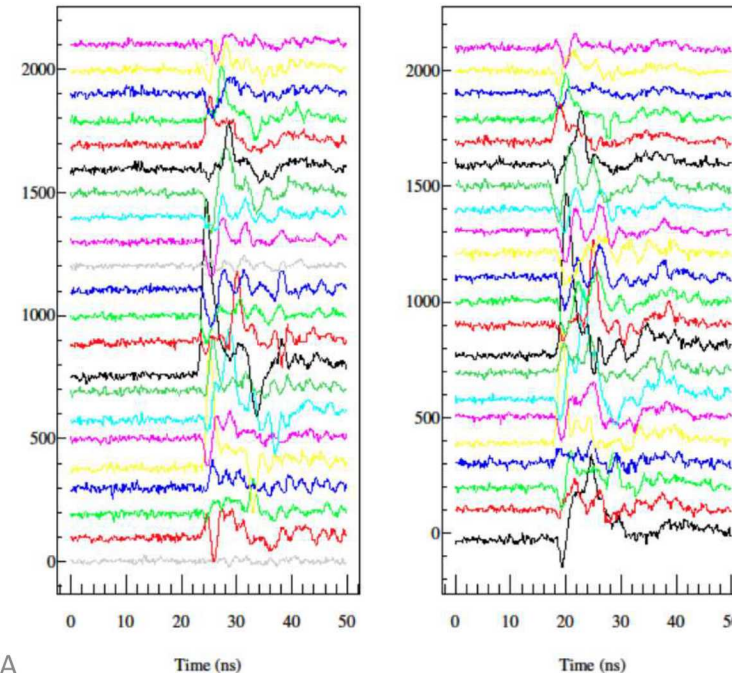
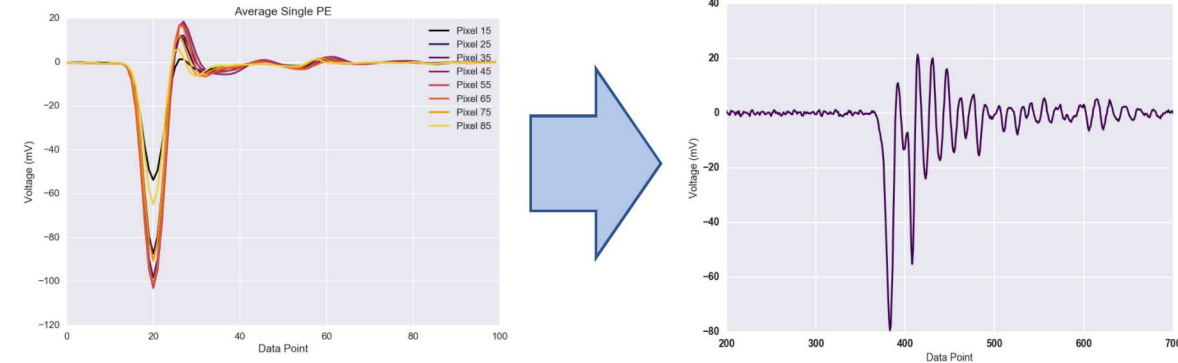


Dell 7920 16-core
workstation + CAEN
A3818 optical
interface



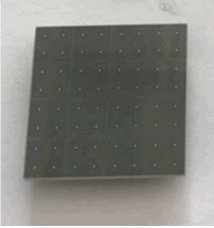
Crosstalk issues

- Possible mitigations:
 - Reduce crosstalk by changing voltage divider
 - Handle crosstalk in analysis using SIRT
- Note crosstalk is reminiscent of observations on Planacon, LAPPD.
- High simultaneous occupancy regime is not common use case for these detectors.
- Probably requires work at the hardware level to truly resolve.



- Laser diffused over LAPPD face
- Grey strips have bad cables
- Signals inverted
- Laser level increased to avg 10-20 photons
- Wow, who knows what's going on there

Two directions for next monolithic prototype



- Incremental changes

- Continue with multi-anode PM
 - Possibly H12700 -> Planacon
- Continue with SIRT or related methods to disentangle crosstalk
- Electronics move to more compact implementation: SCEMA + SMACC



- Wholesale shift

- Switch to SiPMs on the grounds that they are fundamentally more independent and crosstalk should be avoidable
- Move toward high channel count analog electronics, i.e. PetSYS ecosystem to support small pixels with low occupancy
- Unknown issues TBD

Make decision based on ongoing studies on current monolithic prototype as well as SCEMA testing and PetSYS evaluation.

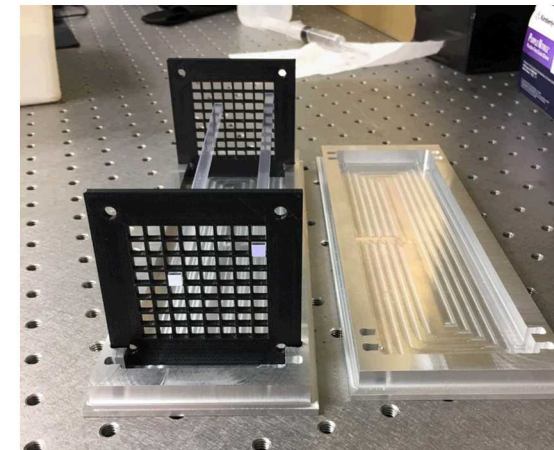
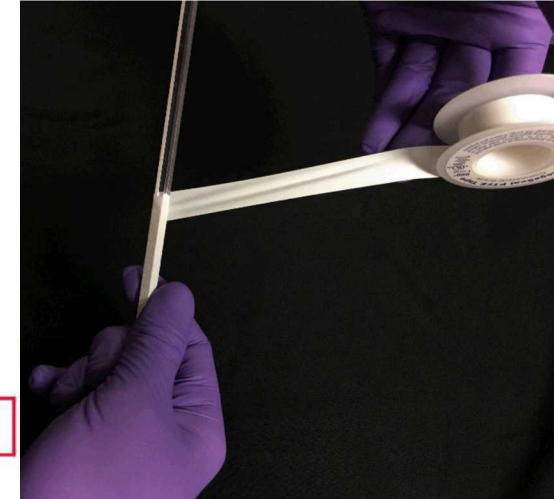
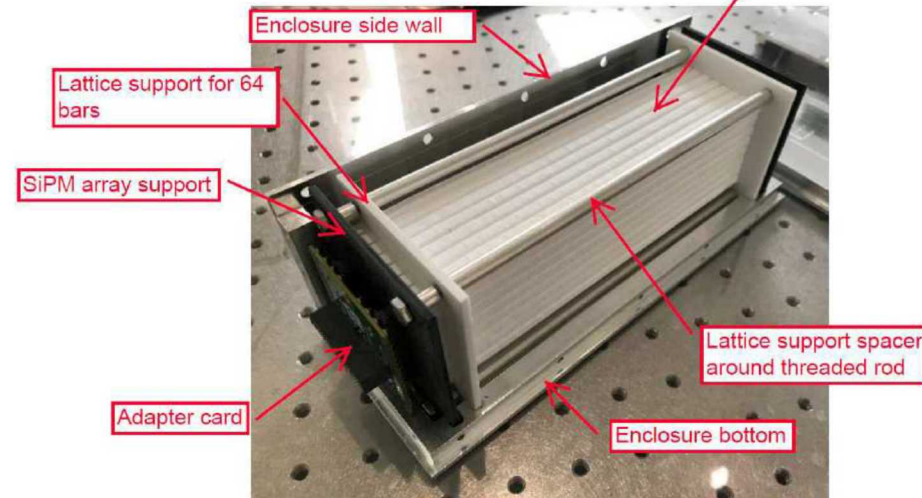
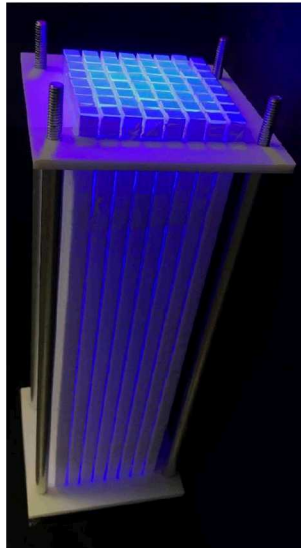


First OS Prototype @UH:

Summary:

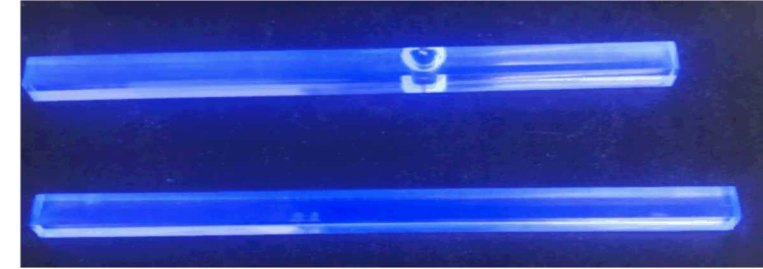
- Photodetector: SensL J-series 6x6mm using FOUT
- Readout electronics and trigger: 1 GB/s 12-bit from UH
- Scintillator: 5x5x200 mm EJ-204 bars, Teflon-wrapped
- Algorithms: BLUE of two z-measurements:

$$\ln \frac{A_1}{A_2} = \ln \frac{e^{-z/\lambda}}{e^{-(L-z)/\lambda}} = \frac{L}{\lambda} - \frac{2z}{\lambda},$$
$$t_1 - t_2 = \frac{z}{v} - \frac{L-z}{v} = \frac{2z}{v} - \frac{L}{v}.$$



Next OS prototype

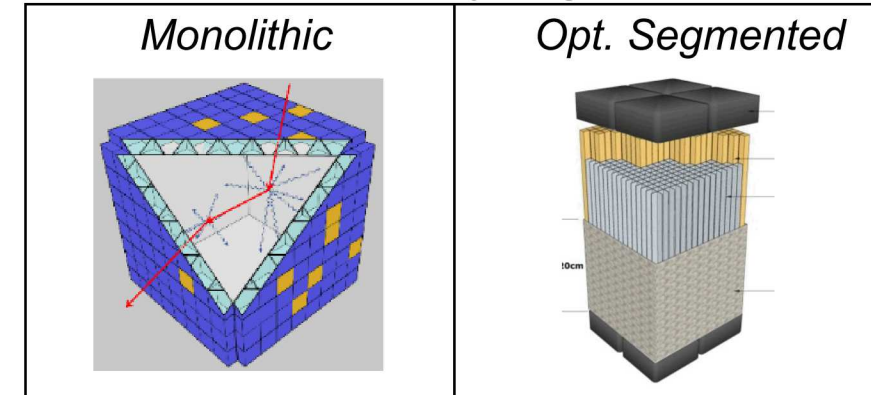
- Identify and reduce electronic crosstalk in SiPM/readout
- Understand levels of optical crosstalk in current prototype
- Possible upgrade paths:
 - Scintillator: PSD-capable material. O-glass could provide EJ-204 performance plus PSD, but fabrication difficult. Consider advanced optical reflectors.
 - Photodetector: Hamamatsu S13361-6050 MPPC could provide better performance, but not currently a critical limitation.
 - Electronics: Evaluate PetSYS TOFPET2-based analog system. No change or DRS4-based digitization also options.
- Underlying this is using the simulation-reconstruction-imaging software that has been developed to understand the impact of each possible upgrade.



Future summary

- Work is proceeding on multiple fronts:
 - Short-term develop, prototype, evaluate, iterate:
 - Monolithic concept
 - Optically segmented concept
 - Longer-term efforts, incorporate outcomes in 1-3 yrs
 - Component test & evaluation
 - Tranloc material, PetSYS analog electronics, scintillator properties
 - Technology development
 - Scintillators, LAPPD, SCEMA, algorithms
- Work toward hardware demonstrations, peer-reviewed publications, and conference presentations.
- Downselect approach in FY20 if appropriate.
- Multi-anode vacuum photodetectors need to be abandoned for many-photon regime?
- Consider high-channel-count analog electronics, or integrated sensor/front end chips?

Prototyping



Components

