Single Volume Scatter Camera:

Development Towards a Compact Neutron Imager

PRESENTED BY

Josh Brown on behalf of the SVSC Collaboration

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The SVSC Collaboration

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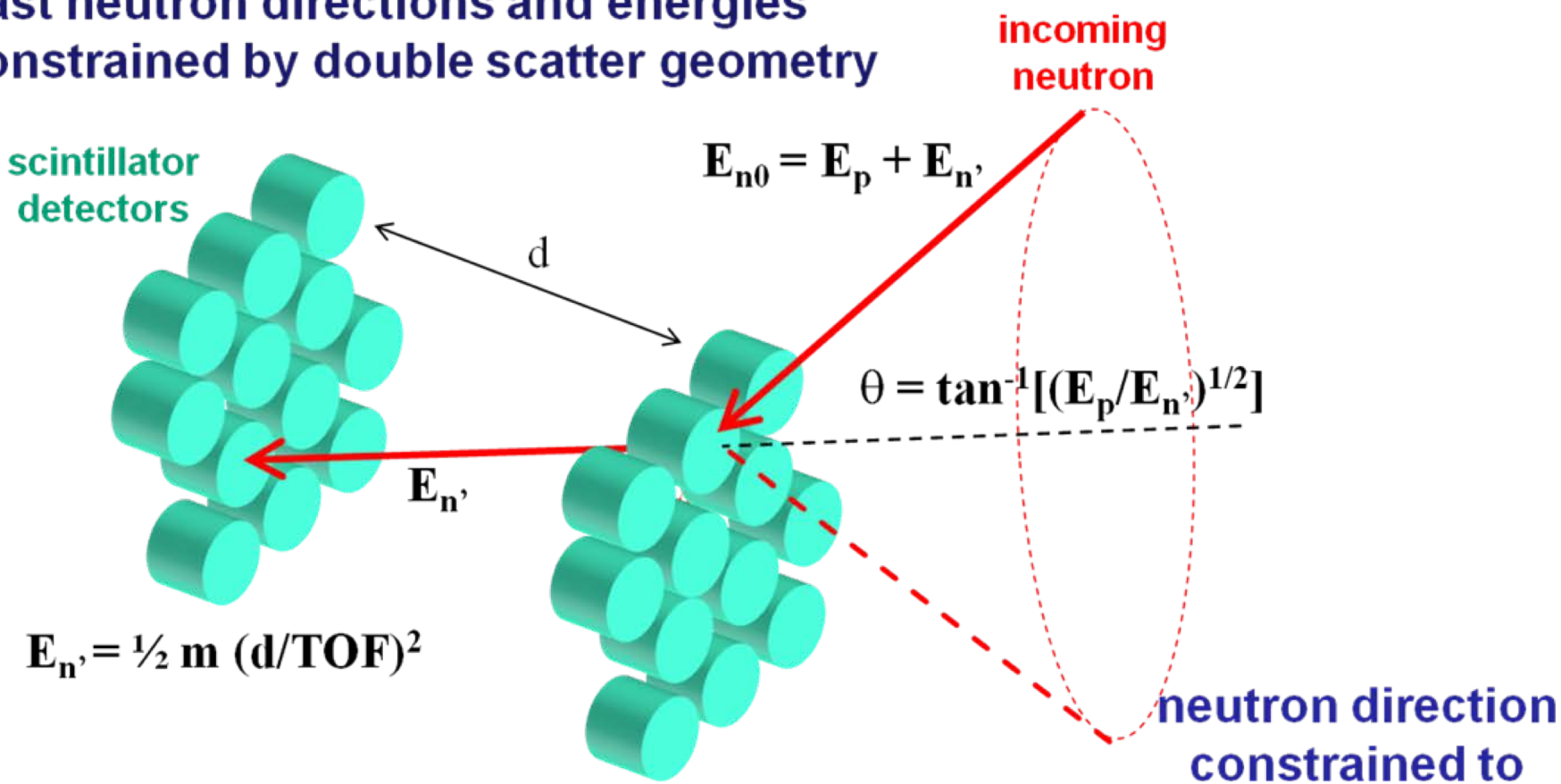
Kinematic Neutron Imaging

Fast neutron directions and energies constrained by double scatter geometry



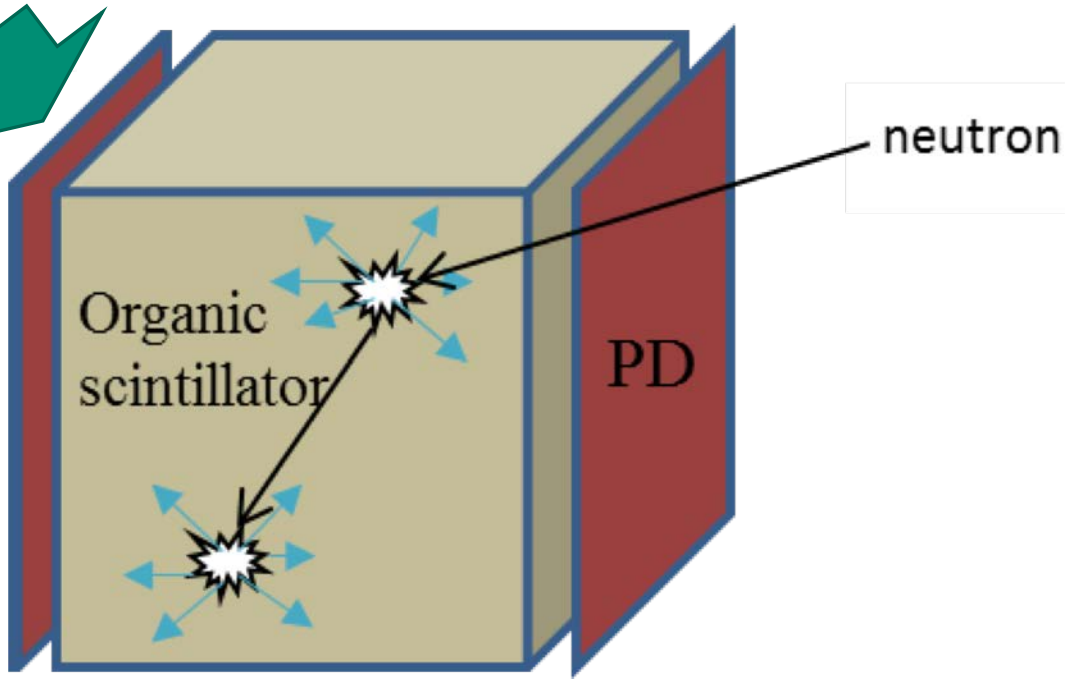
Multimode capability includes

- ***Neutron energy spectrum.***
- ***Compton imaging.***

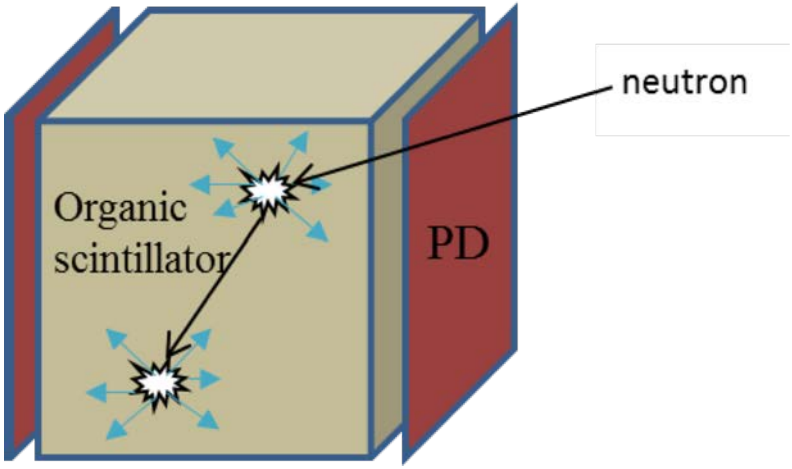
Motivation

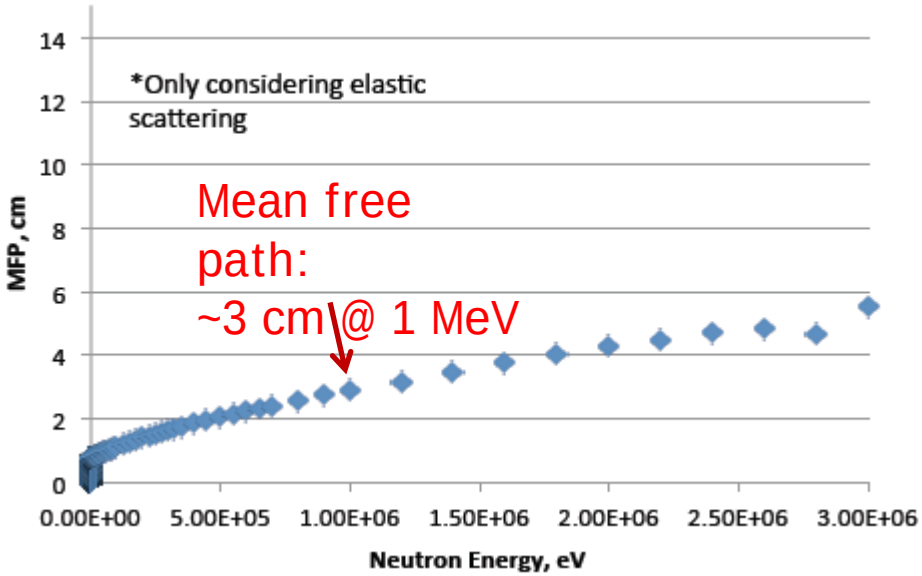
3m x 2m x 2m

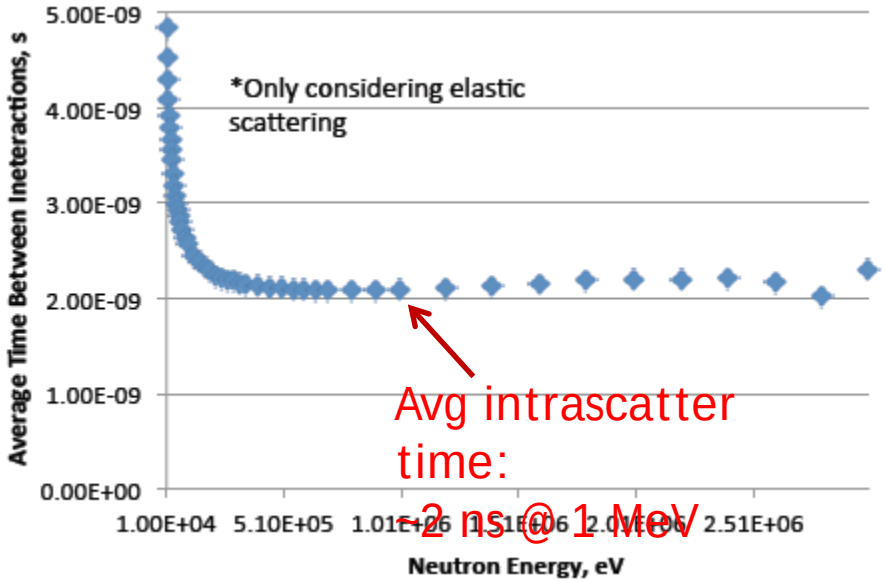
10 x10 x 10 cm



Challenges


neutron
Organic scintillator
PD

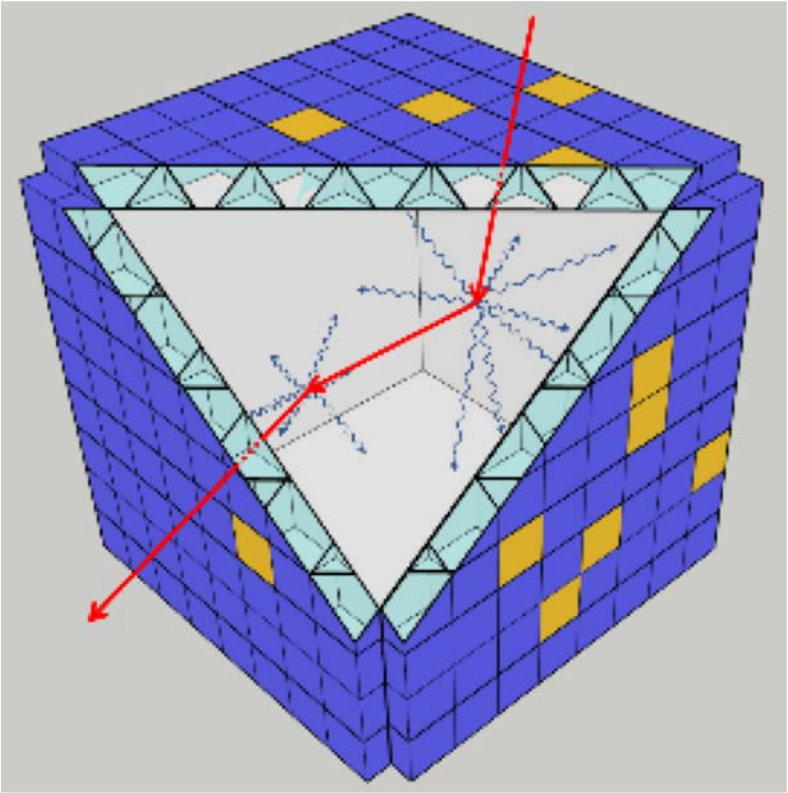

*Only considering elastic scattering
Mean free path:
~3 cm @ 1 MeV
MFP, cm
Neutron Energy, eV
0
2
4
6
8
10
12
14
0.00E+00
5.00E+05
1.00E+06
1.50E+06
2.00E+06
2.50E+06
3.00E+06


*Only considering elastic scattering
Avg intrascatter time:
2 ns @ 1 MeV
Average Time Between Ineteractions, s
Neutron Energy, eV
0.00E+00
1.00E-09
2.00E-09
3.00E-09
4.00E-09
5.00E-09
1.00E+04
5.10E+05
1.01E+06
1.51E+06
2.01E+06
2.51E+06

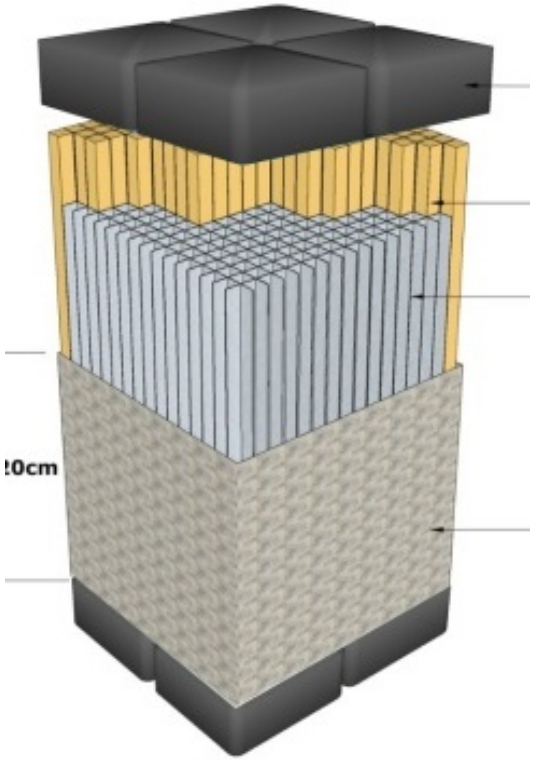
Prospective Methods

Concept requires a method of determining ***two*** (or more) event locations within a compact scintillator to sub-cm precision. $\vec{X} = (x, y, z, t)$

1. **Monolithic**: Arrival positions and times of isotropically emitted photons at surfaces of the volume determine most likely $\vec{X}$.

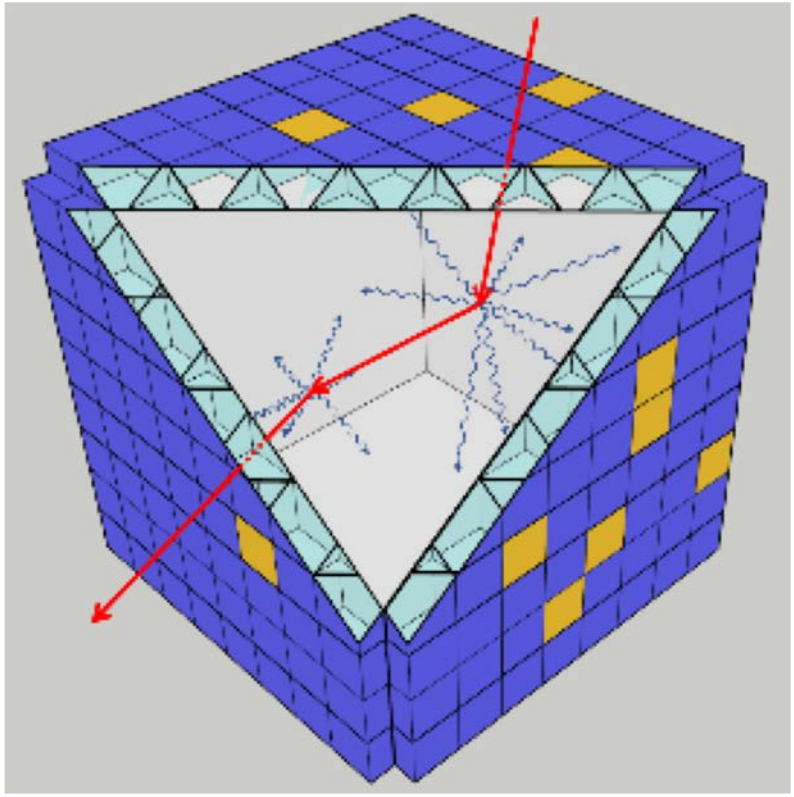


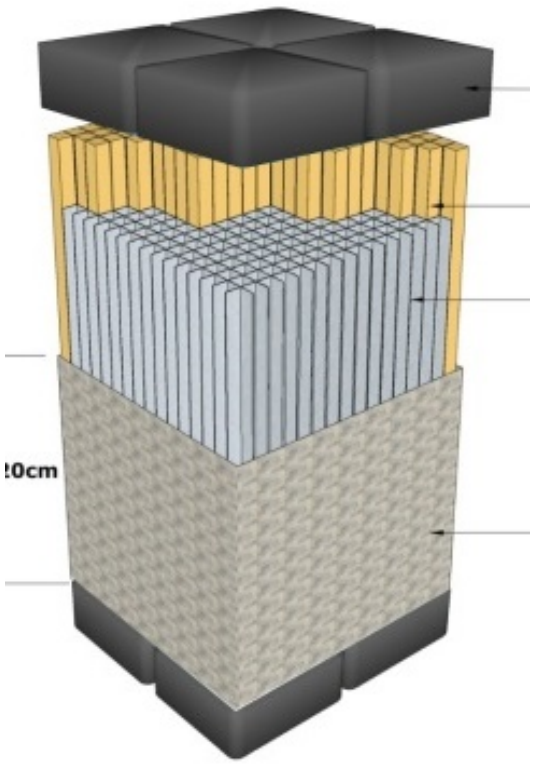
2. **Optically segmented**: Constrain photon propagation within bulk to associate specific PD channels with $\vec{X}$.



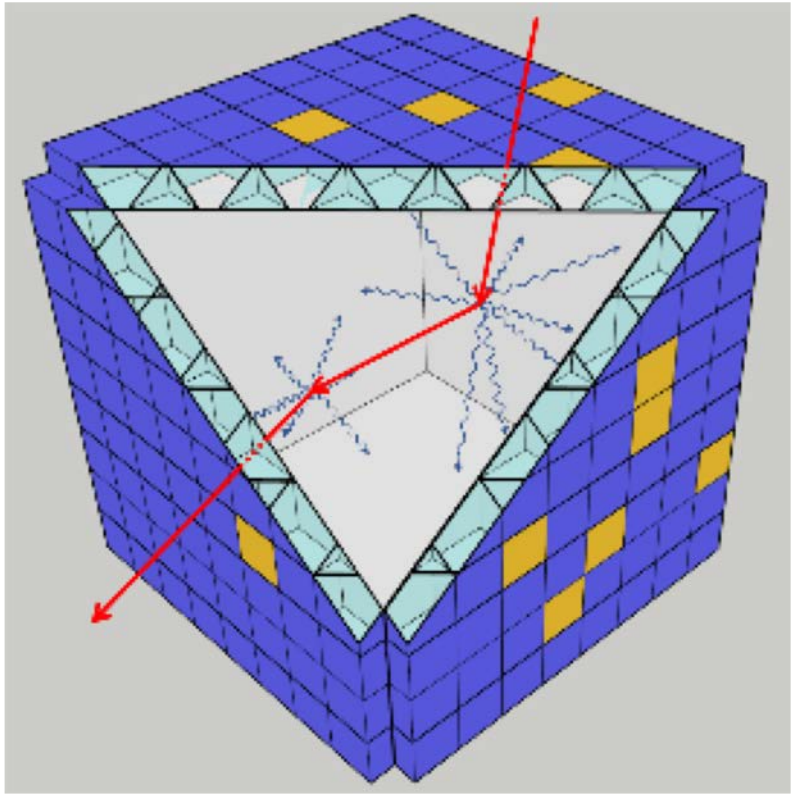
SVSC at AAP

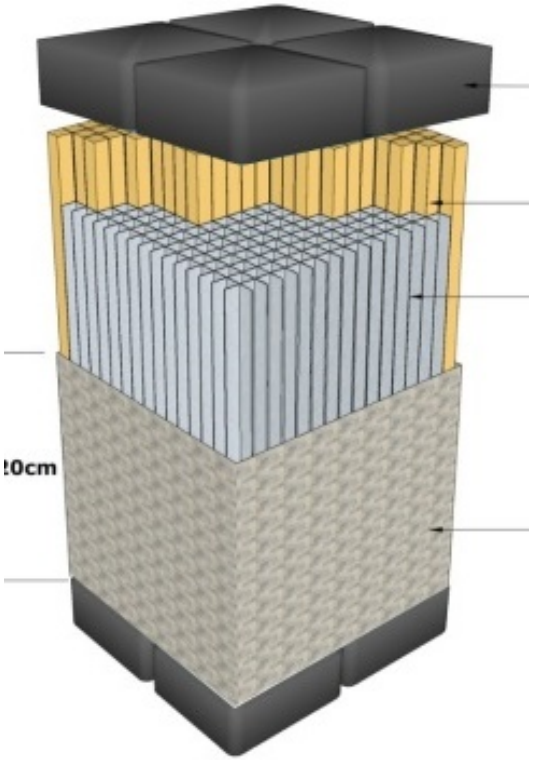
Strong technical parallels to both prospective and previously realized neutrino detectors





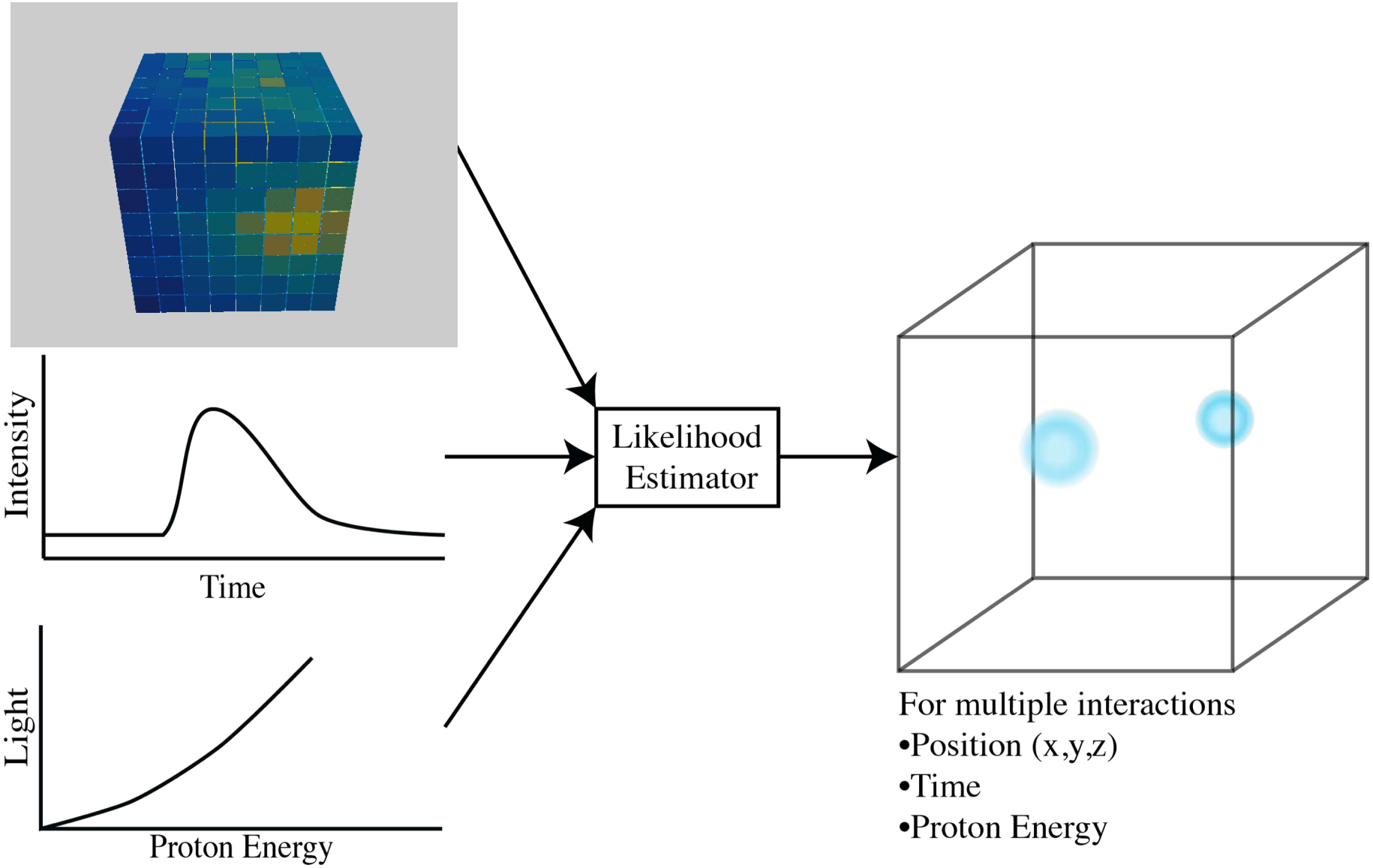
SVSC at AAP





Both teams are pursuing both component level characterization and development as well as system level prototyping.

Focusing on the Monolithic Case



Reconstructing Events

Likelihood Estimator

Probability multiplies over all observed photons

Extended ML for accurate energy uncertainty

Probability to observe a photon is summed over all interactions

$$\mathcal{L} = \frac{e^{-\mu}\mu^n}{n!} \prod_{i=0}^{n} \sum_{j=0}^{N} \frac{\mu_j}{\mu} P_j(x_i)$$

$$P_j(x_i) = \left[\frac{\cos\phi_{ij}}{4\pi|\vec{x}_i - \vec{x}_j|^2} e^{\frac{-|\vec{x}_i - \vec{x}_j|}{\lambda}} f(t;\mu,\sigma,\lambda) \right]$$

Solid angle

Pulse shape

Optical attenuation

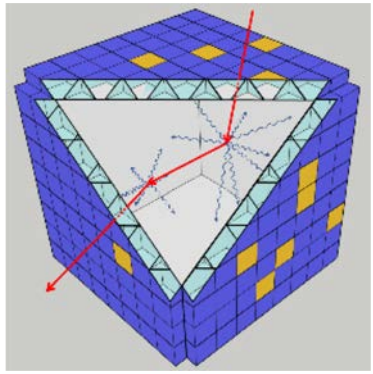
Event reconstruction via likelihood maximization.

- MINUIT: SIMPLEX, MIGRAD
- Deterministic Likelihood Maximization

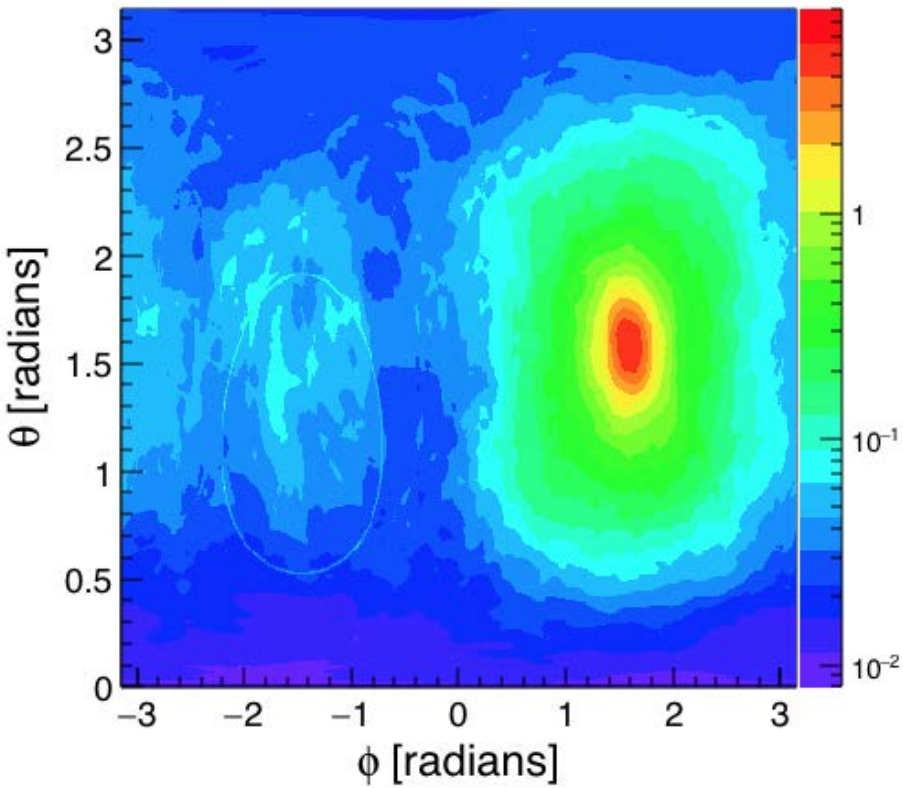
Can it work? (DR)

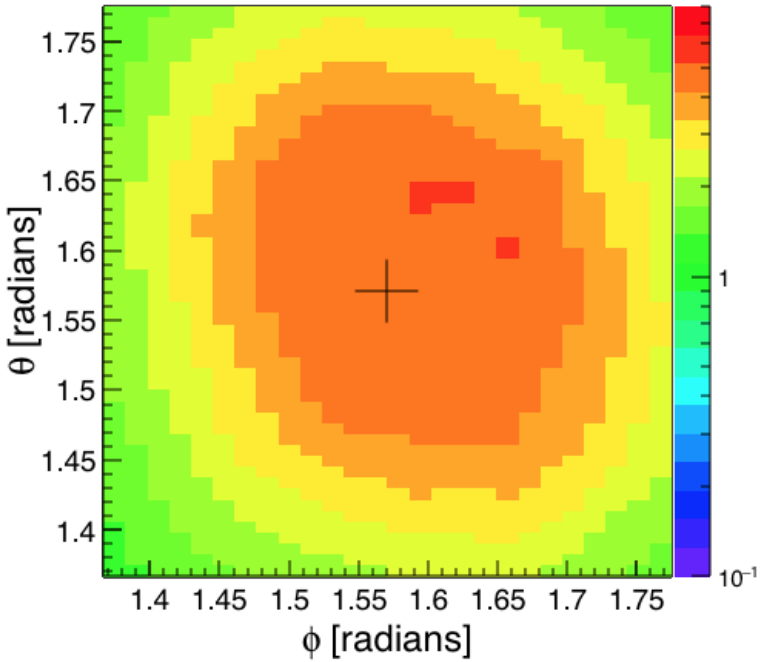
	σ
Δx_0	3.02 mm
Δy_0	3.05 mm
Δz_0	3.02 mm
Δt_0	0.08 ns
Δn_0	45 photons

	σ
Δx_1	4.94 mm
Δy_1	5.08 mm
Δz_1	4.95 mm
Δt_1	0.14 ns
Δn_1	30 photons



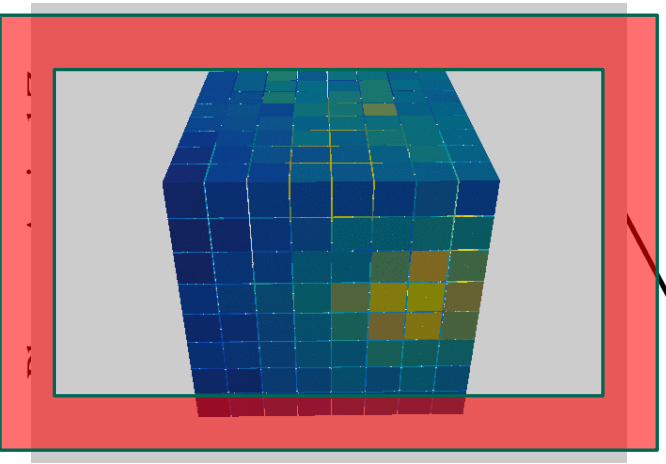
Belkis Cabrera-Palmer (SNL)

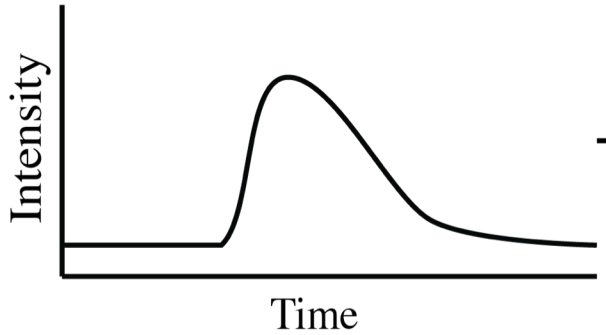


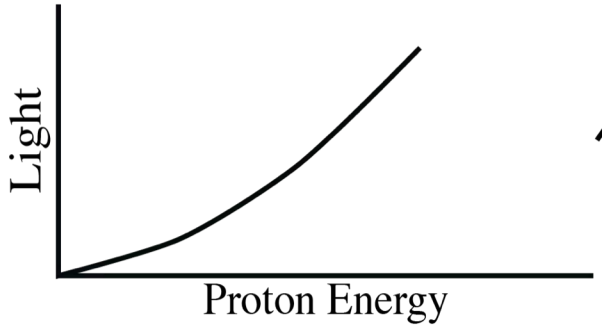


For a simulated 2.7 uCi Cf252 neutron source located at 1 m, this image is equivalent to 29 minutes of measurement time, without background.

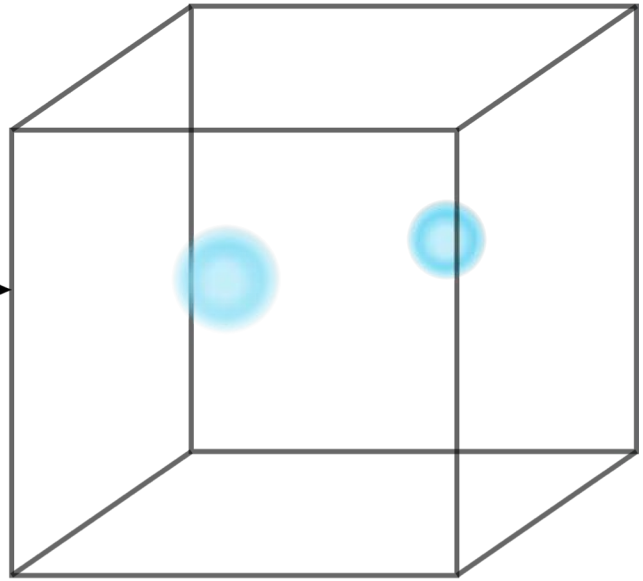
Focusing on the Monolithic Case





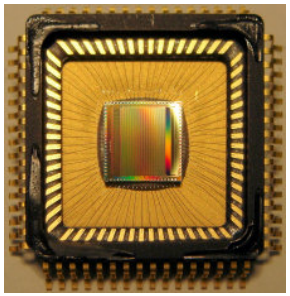


Likelihood Estimator



For multiple interactions
- Position (x,y,z)
- Time
- Proton Energy

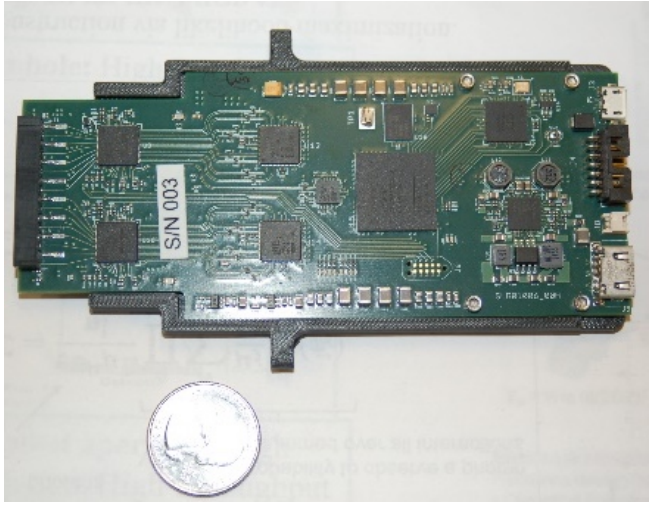
DRS4 waveform capture



PSI

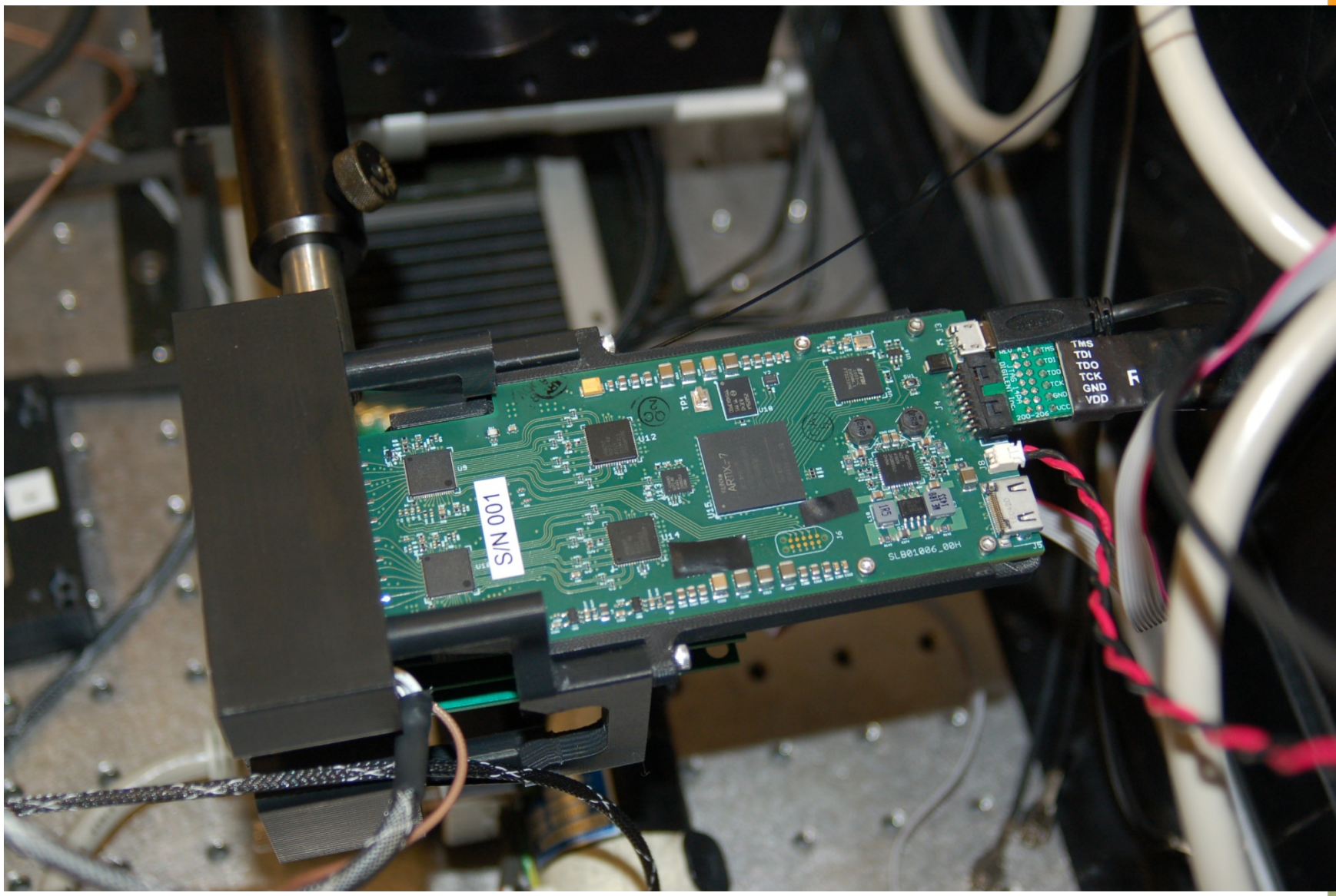
- DRS4: 9-ch switched capacitor array ASIC
- 5 GS/s, 950 MHz, 11.5 enob, 1024 samples
- Long readout time

- 4-channel DRS4 eval board (PSI)
- Not scalable

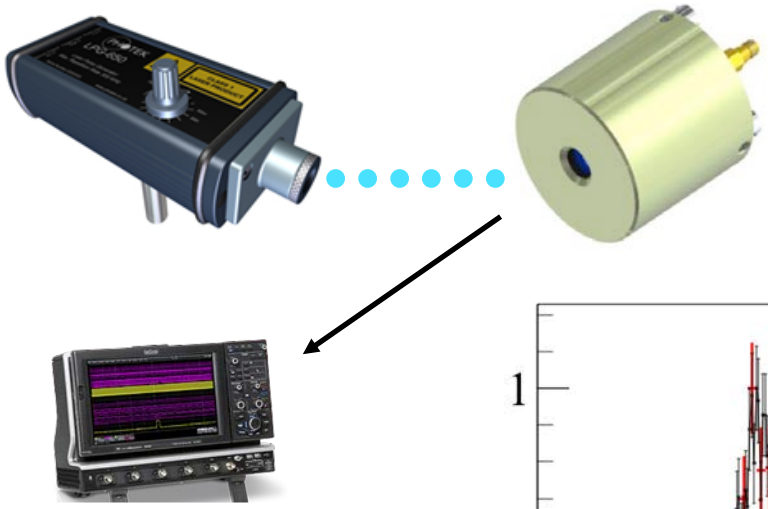


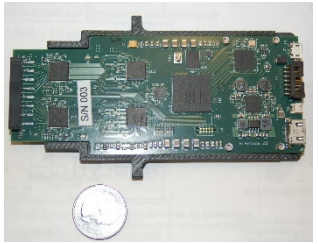
- Caen V1742
- 32-channel
- DRS4-based

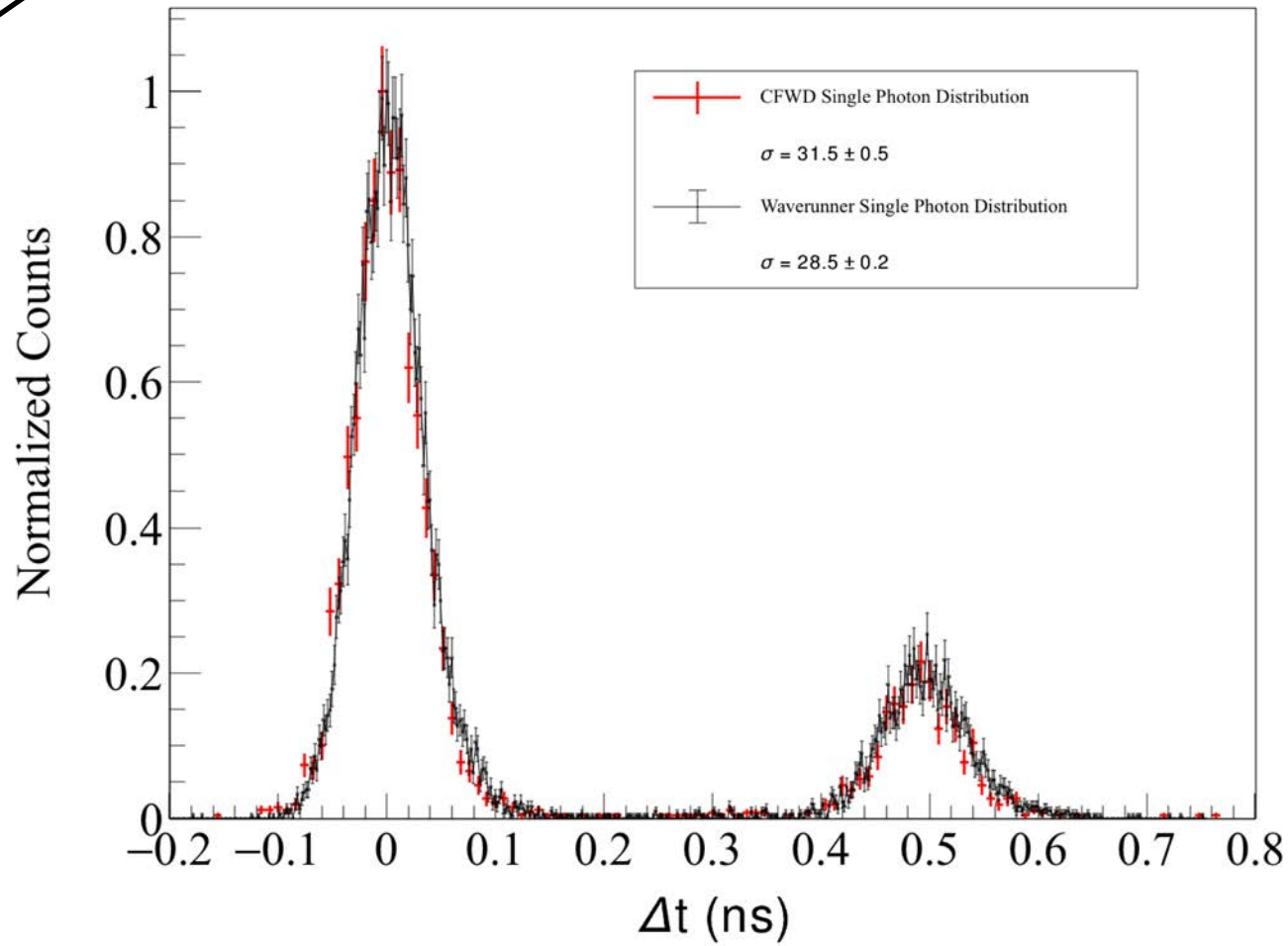
SCEMA Module Directly Coupled to Planacon



Establishing SCEMA Single Photon Performance





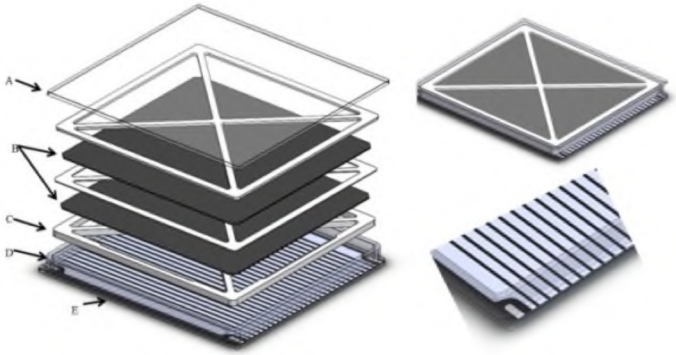


Photodetectors

Photek PMT210

- 1 cm MCP-PMT
- Gold standard for timing
- Not scalable

Large Area Picosecond Photodetector

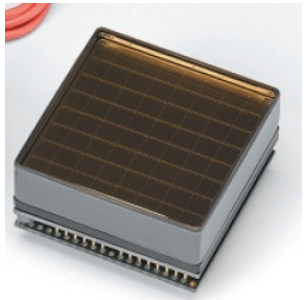


http://www.incomusa.com/wp-content/uploads/2018/06/2018-06-27-Large-Area-Picosecond-Photodetector-LAPPD-Pilot-Production-and-Development-Status.pdf

Photonis Planacon XP85012

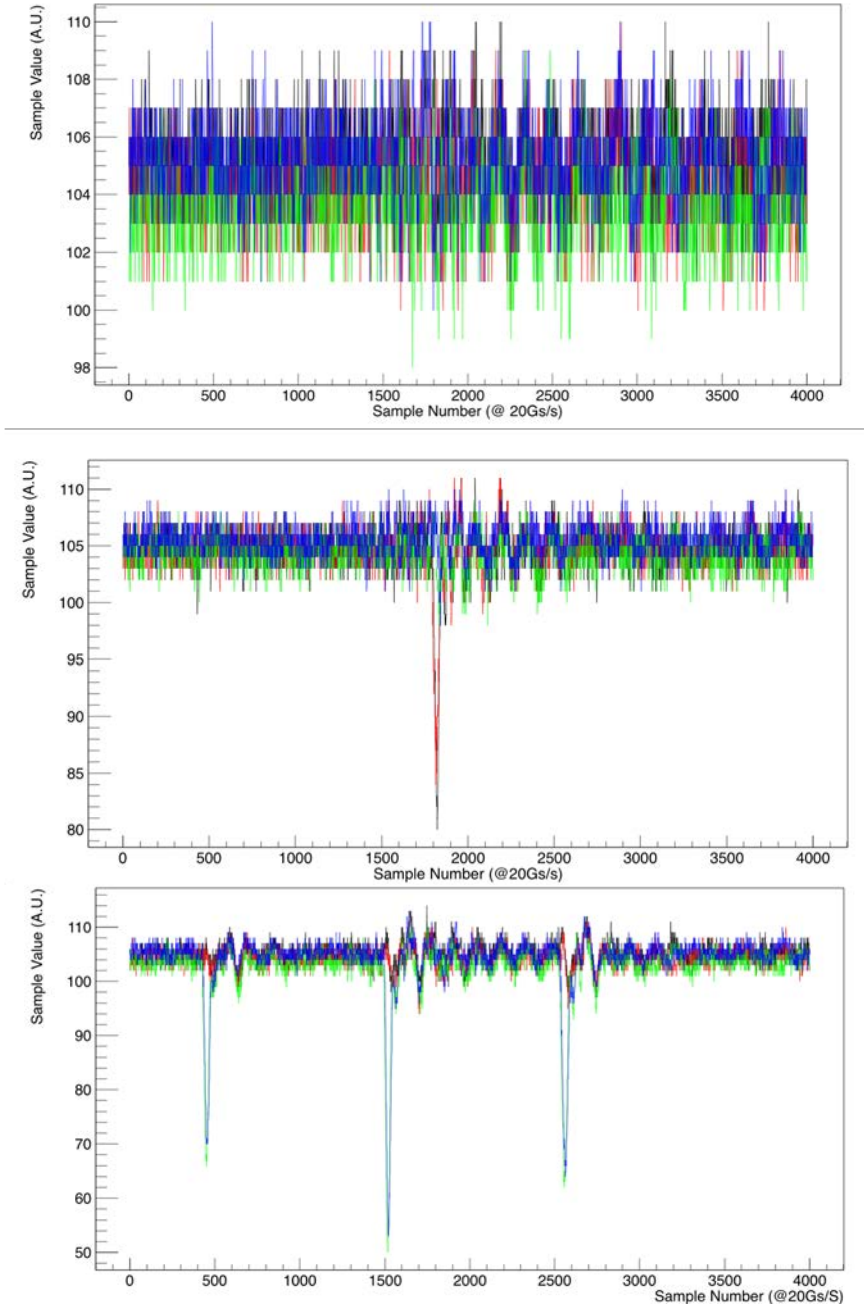
- 25 mm pore MCP-PMT
- 8x8 anode (6 mm)

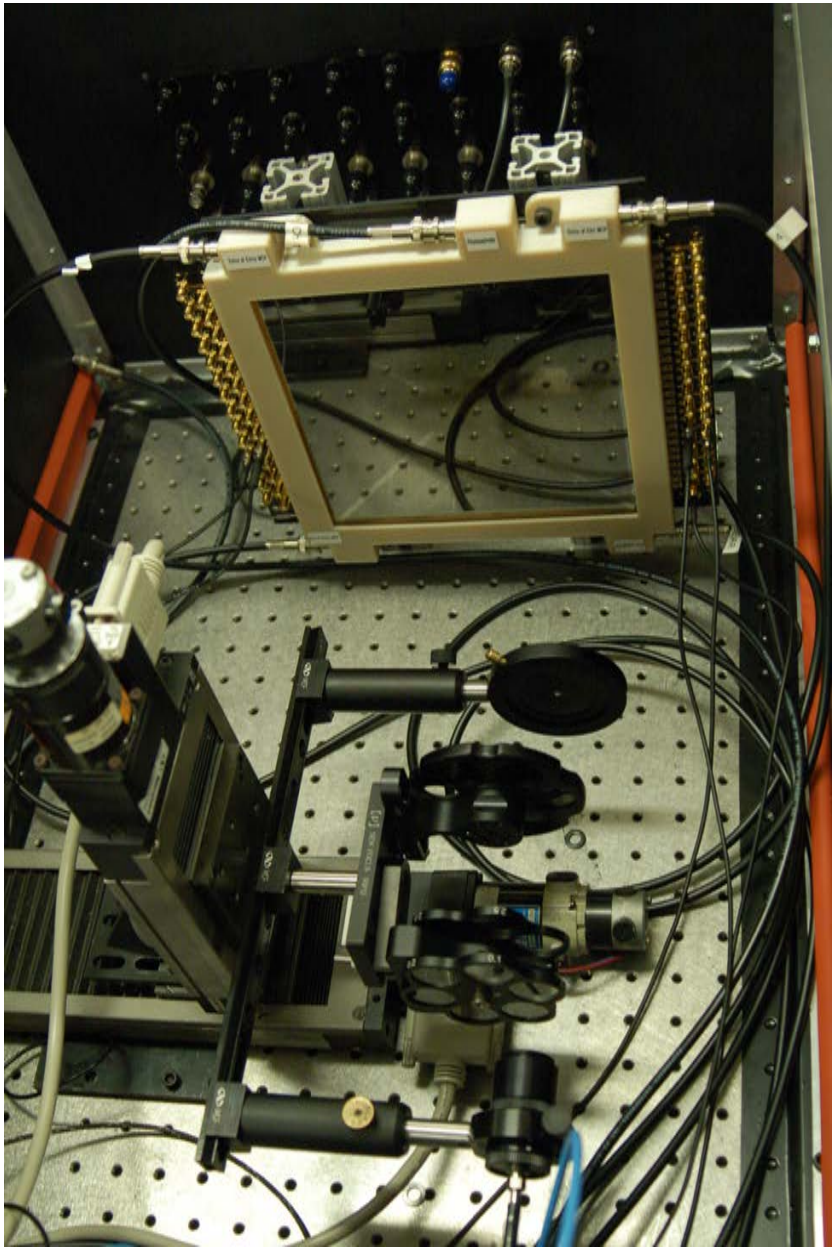
Hamamatsu H8500 MAPMT



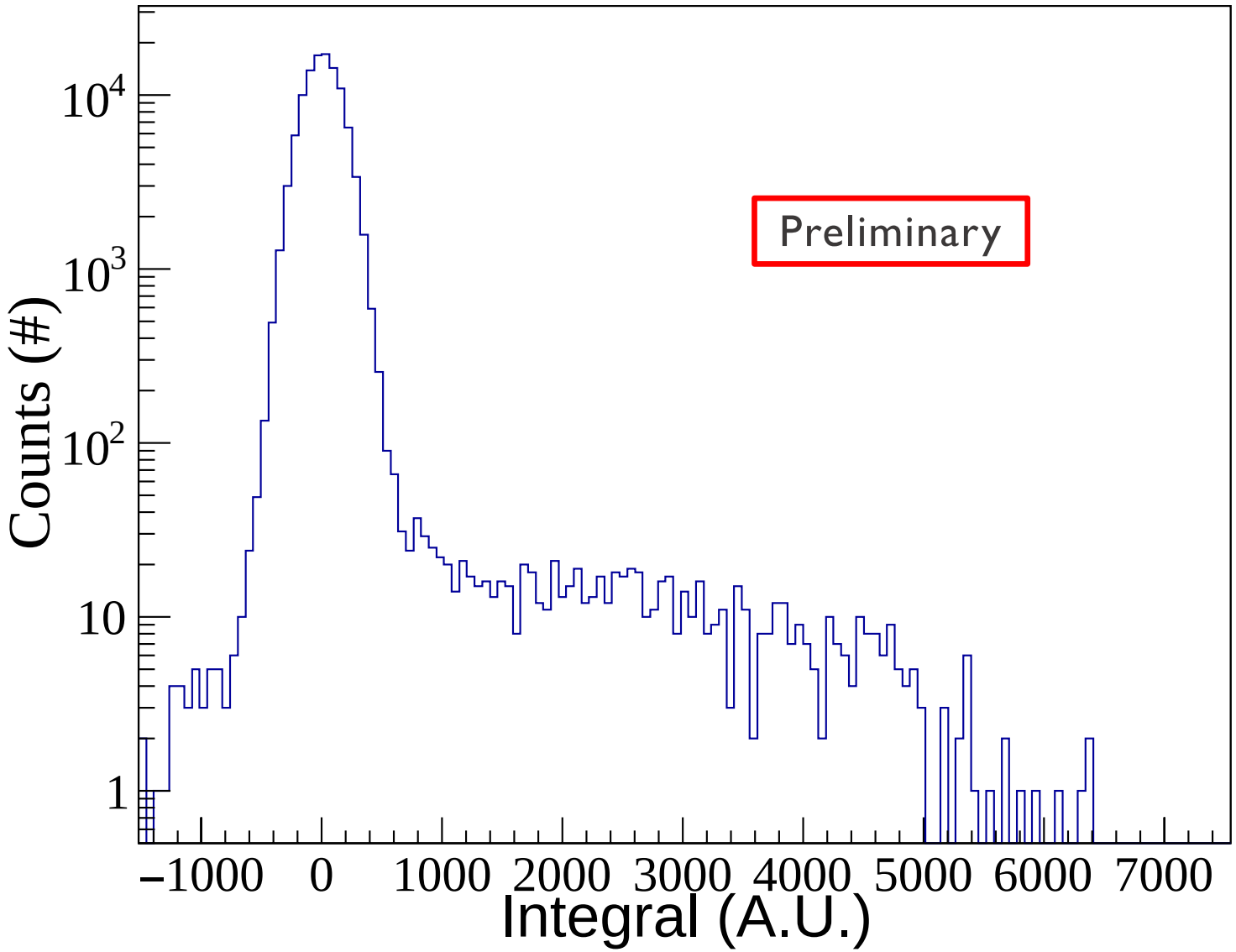
- Metal channel multi-anode PMT
- 8x8 anode (6 mm)

LAPPD Mounted with moveable light source

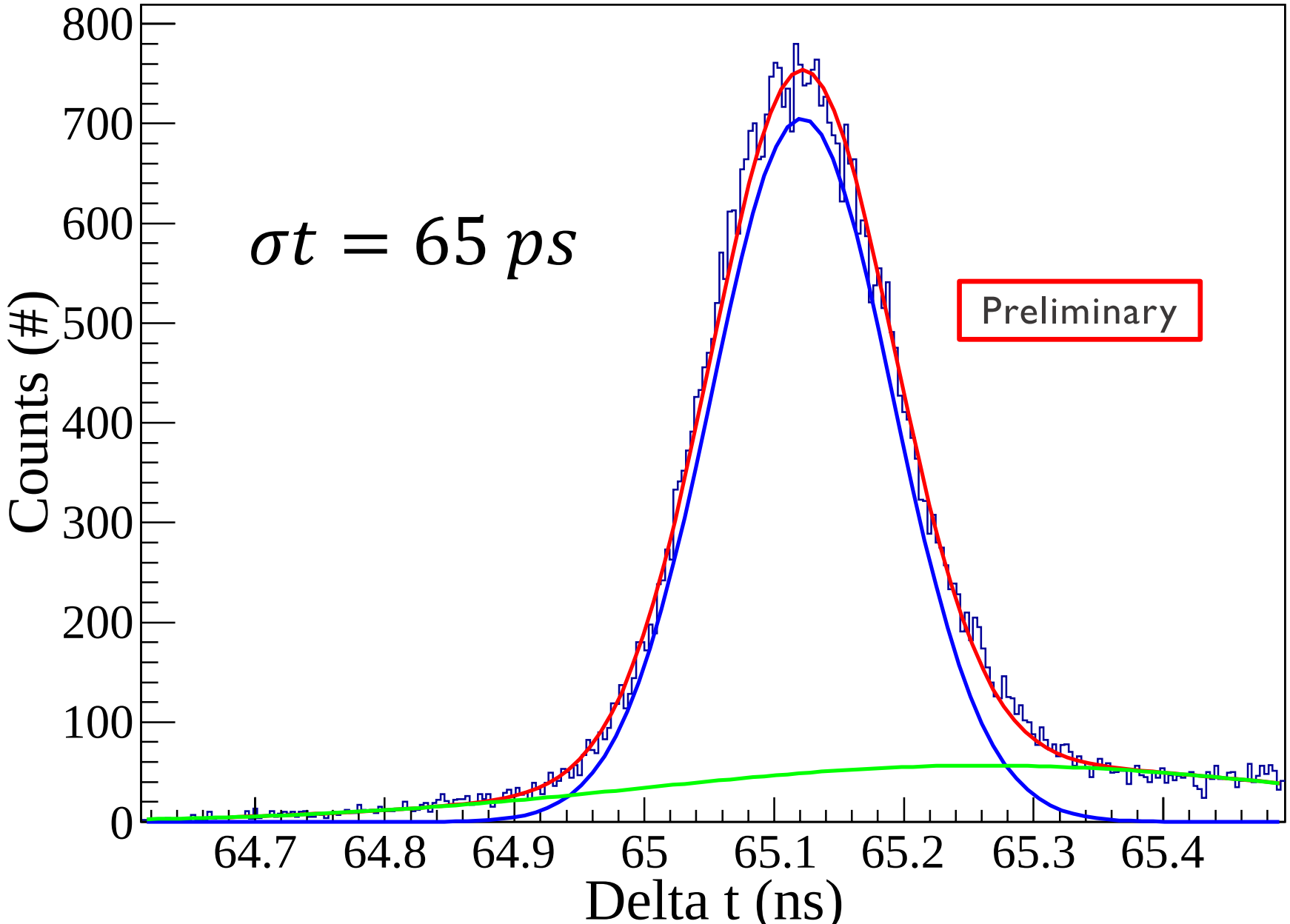




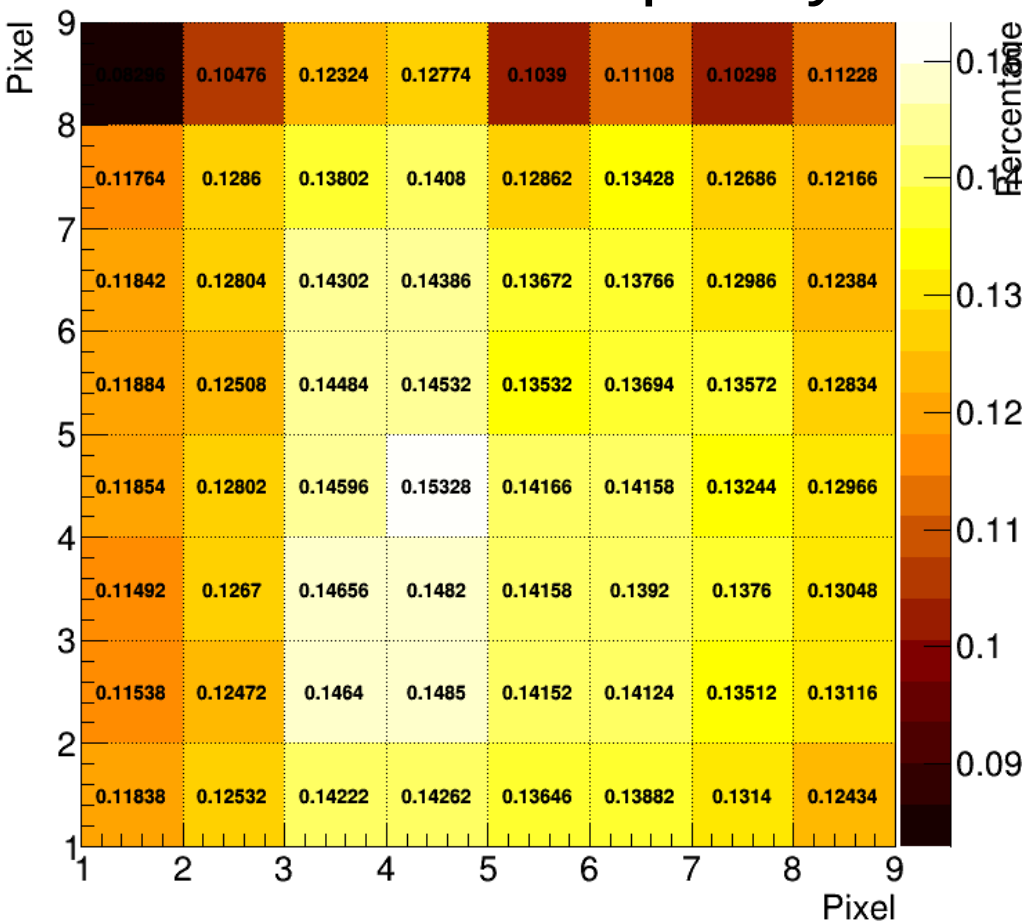
Single Point Results

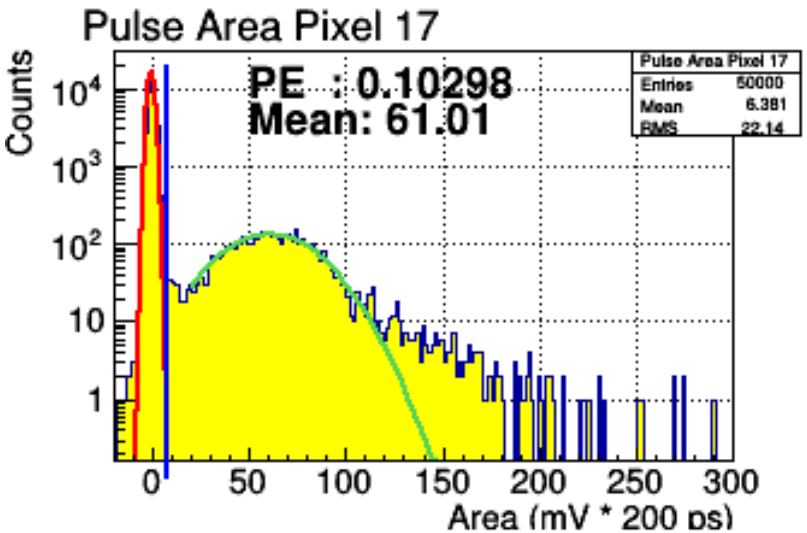


Single Point Results



Relative Occupancy

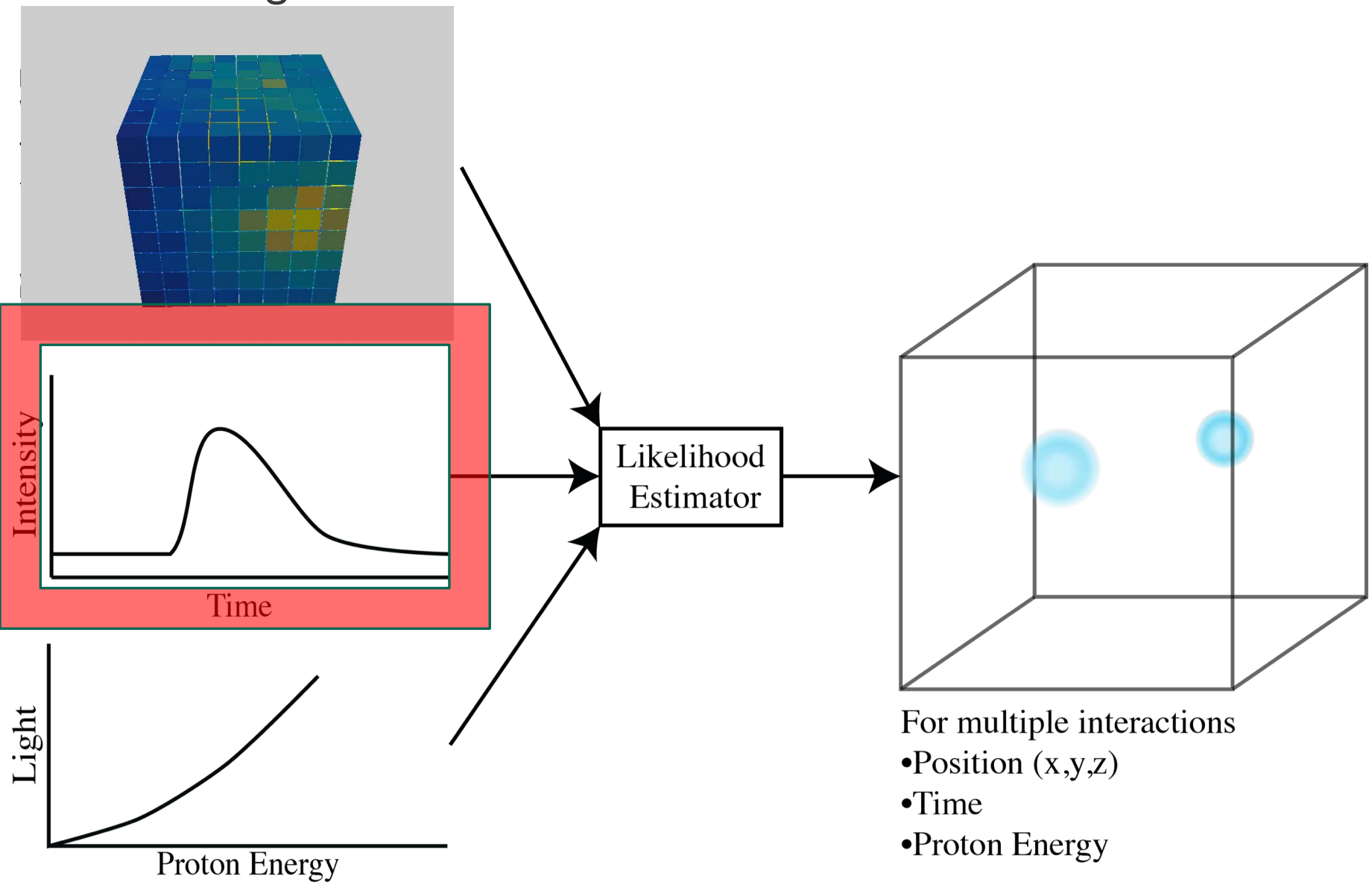




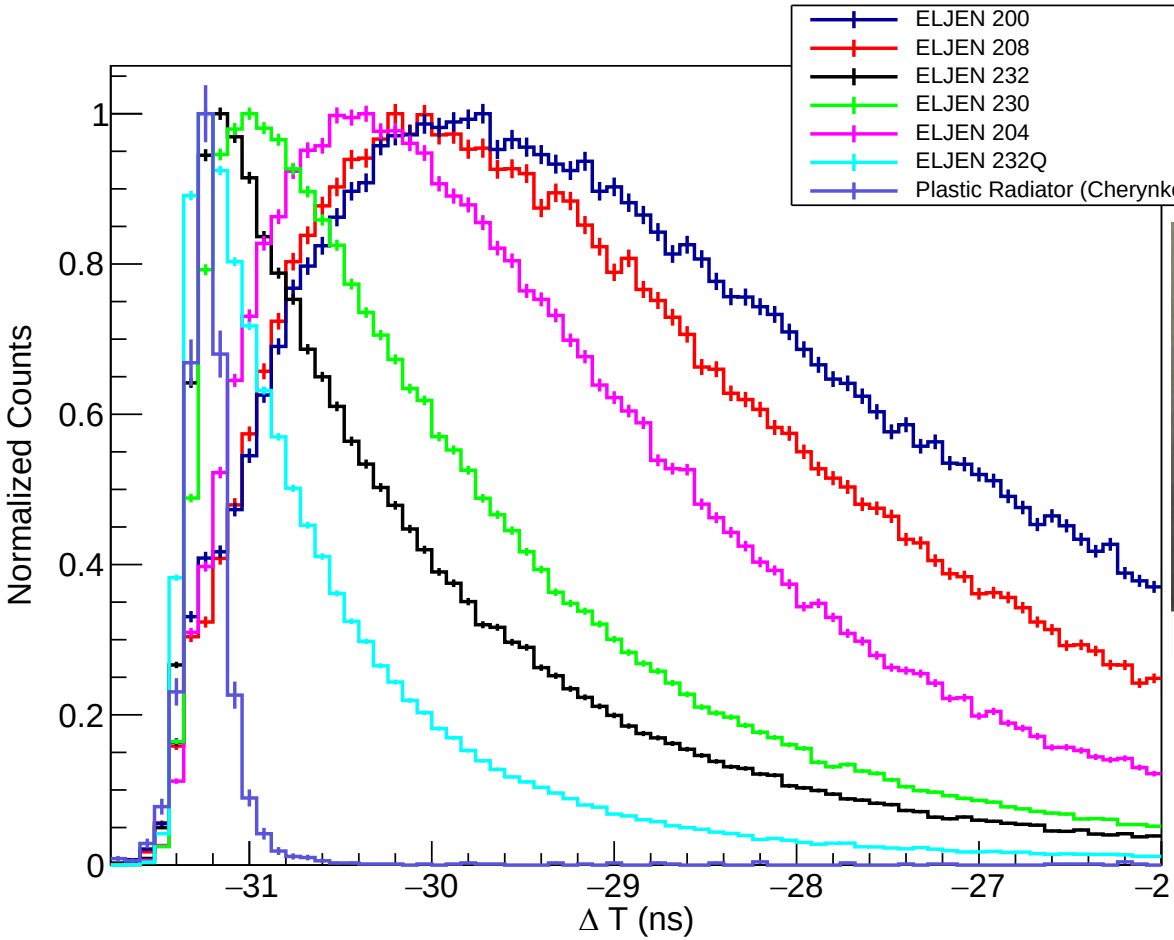
Relative occupancy = percentage of counts above threshold

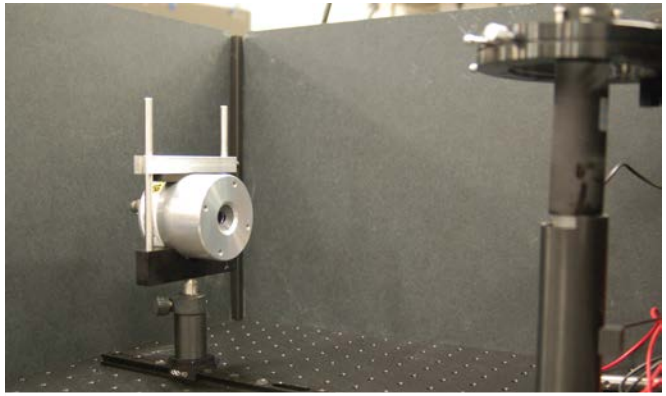
Kyle Weinfurther

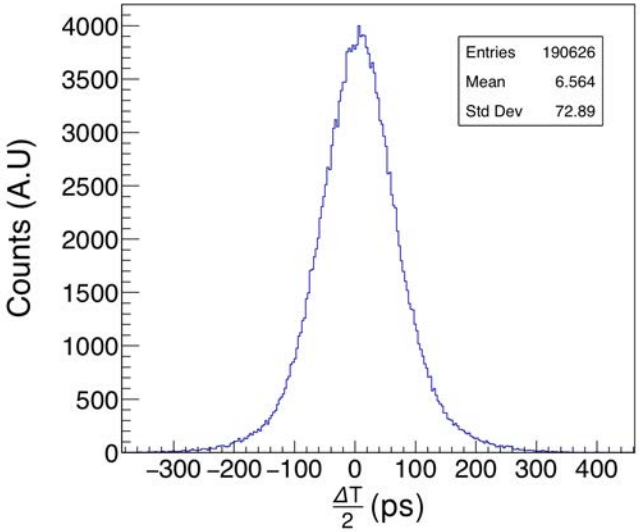
Focusing on the Monolithic Case



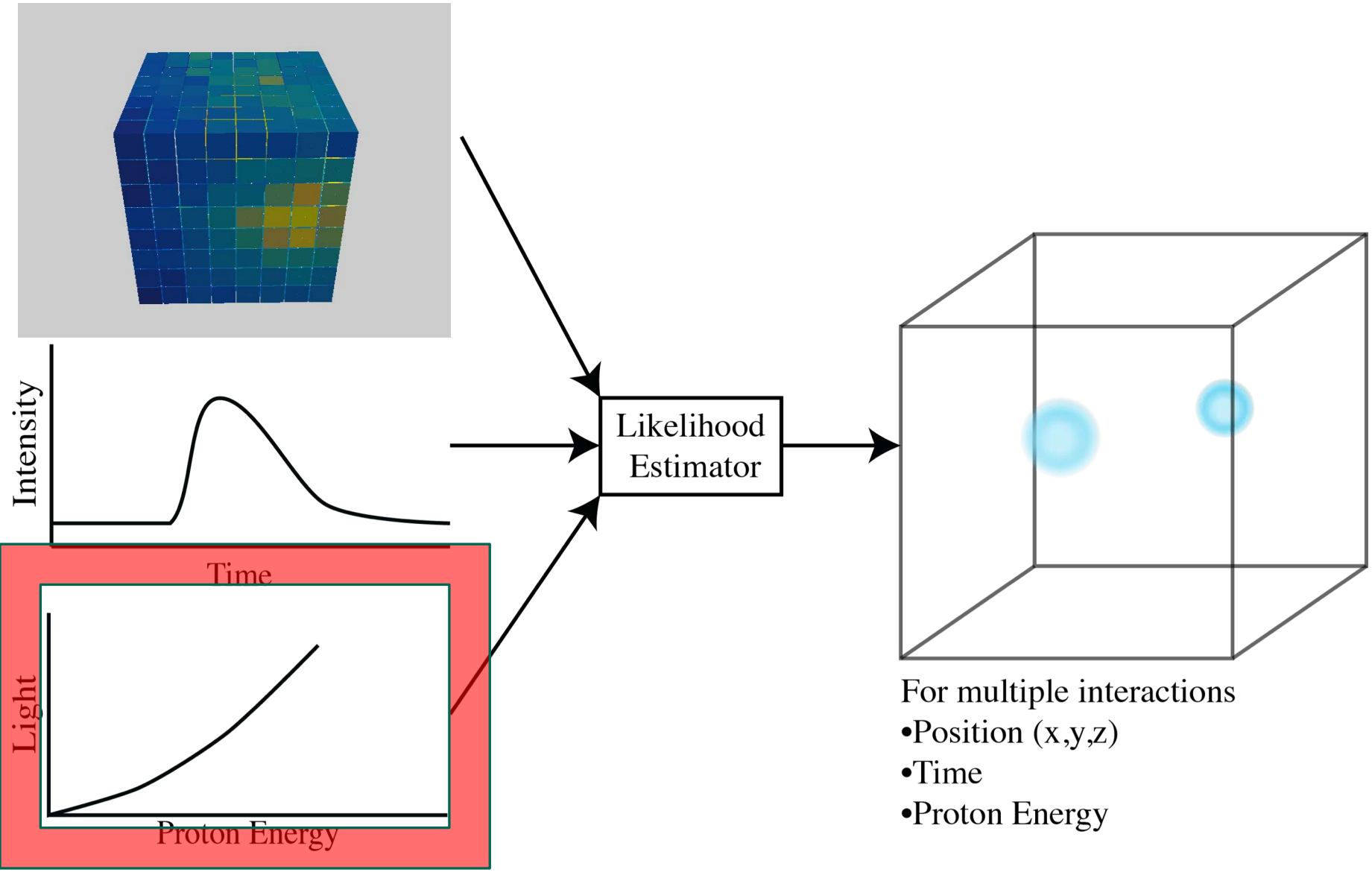
Measuring Scintillator Pulse Shapes





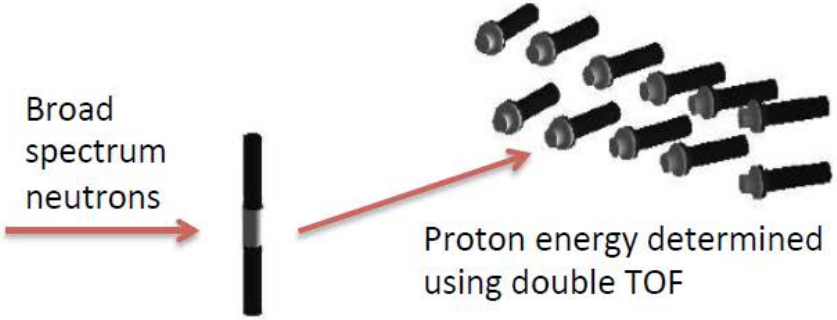


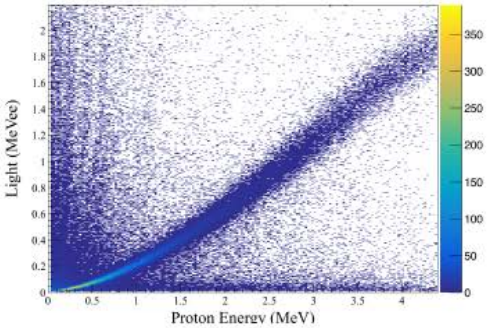
Focusing on the Monolithic Case



Light Yield Measurements – LBNL/UCB Approach

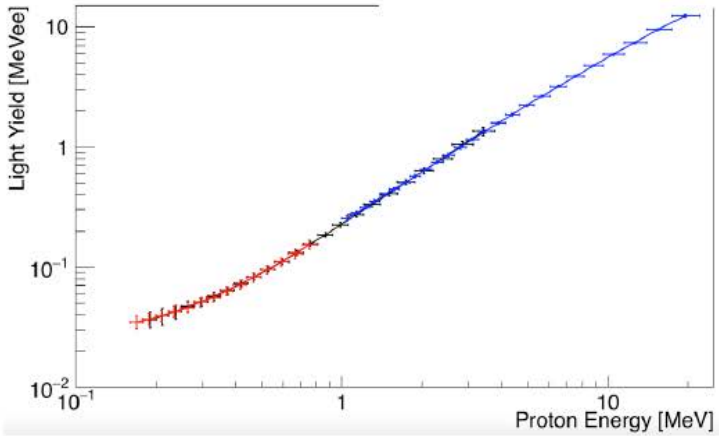
New dTOF method developed at LBNL extends the indirect technique using a high-flux tunable broad spectrum d-breakup neutron source





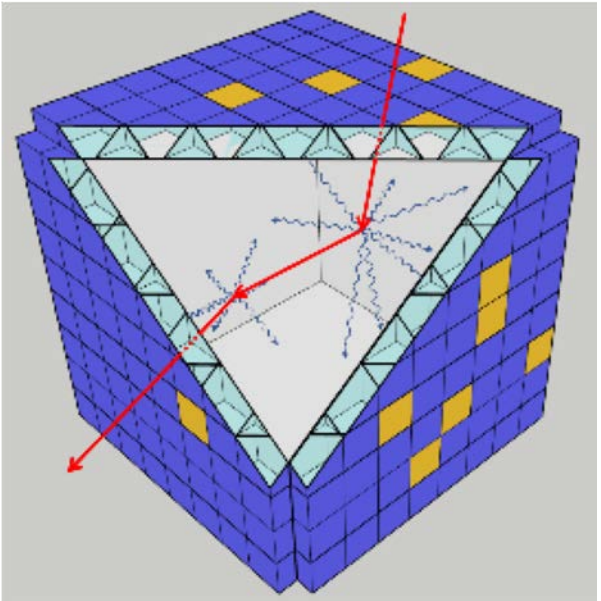
Each detector pair results in a continuous light yield measurement over a broad energy range

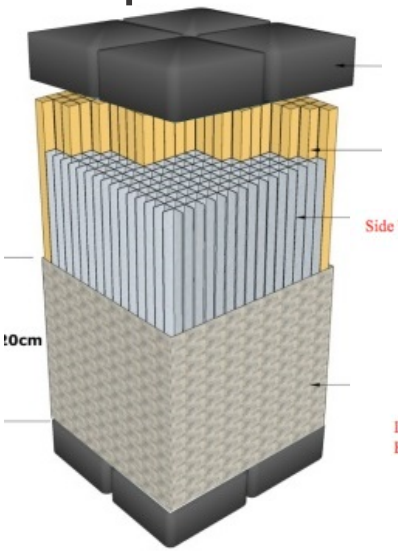
- ***Higher flux = Shorter measurement times***
  - DT generator (commercial): $<10^7$ n/s/sr
  - ***88-Inch Cyclotron: $>10^{11}$ n/s/sr at 0°***
- ***Higher flux = More accurate measurements***
  - Smaller detectors and larger flight times while maintaining reasonable event rates
- ***Multiple secondary detectors***
  - Increased statistics
  - Same result from independent detectors as systematic check



Outcome: Enables accurate simulation of advanced neutron detection systems, neutron image reconstruction, and next-gen detector materials prospecting

Prototypes For Both Concepts are Nearly Operational





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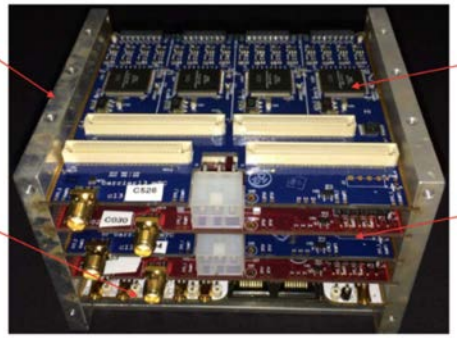
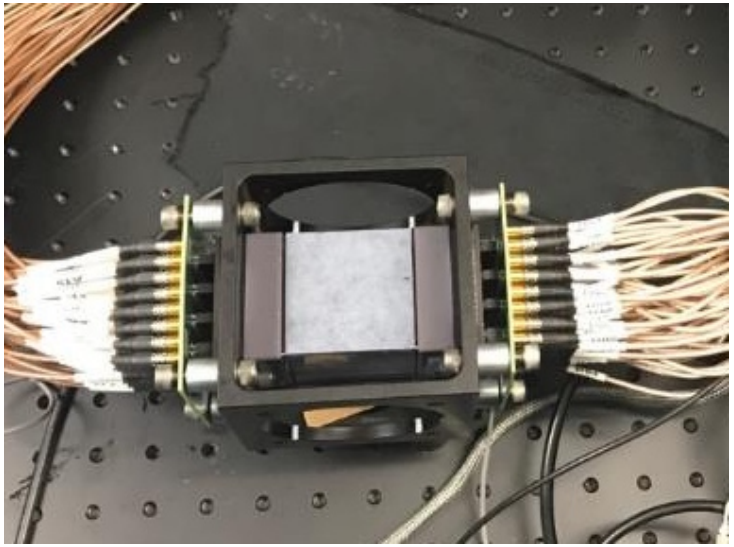
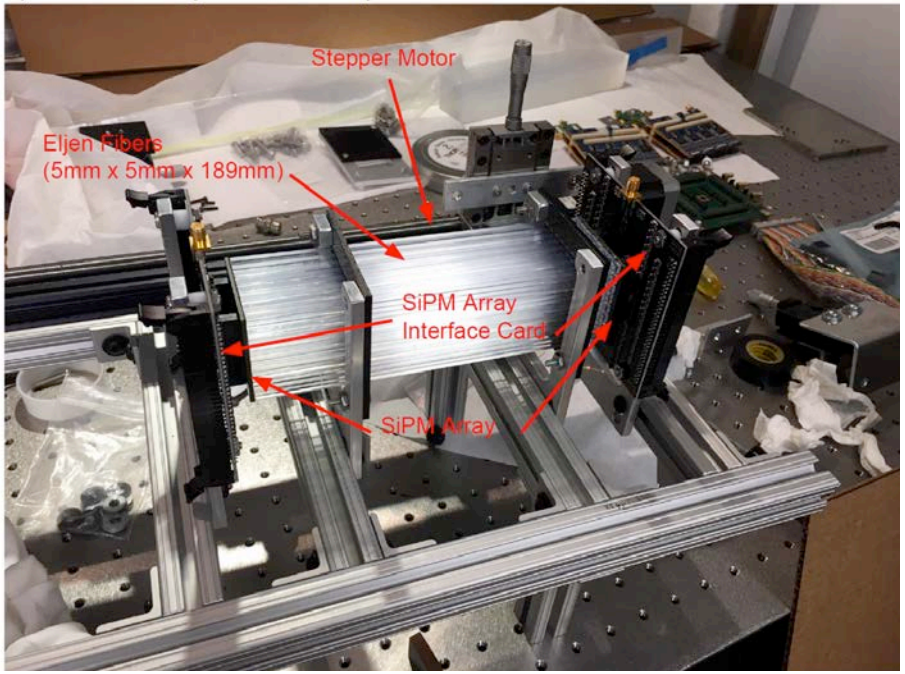


Full (8x8) Fiber Array Test Setup:





SVSC collaboration

SNL/CA: E. Brubaker, M. Sweany, J. Brown, J. Steele, B. Cabrera-Palmer, P. Marleau, J. Carlson

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UC Berkeley: B. L. Goldblum, T. Laplace, J. Manfredi

NCSU: J. Mattingly, K. Weinfurther, M. Mishra

ANL: J. Elam, A. Mane, M. Gebhard

SVSC collaboration

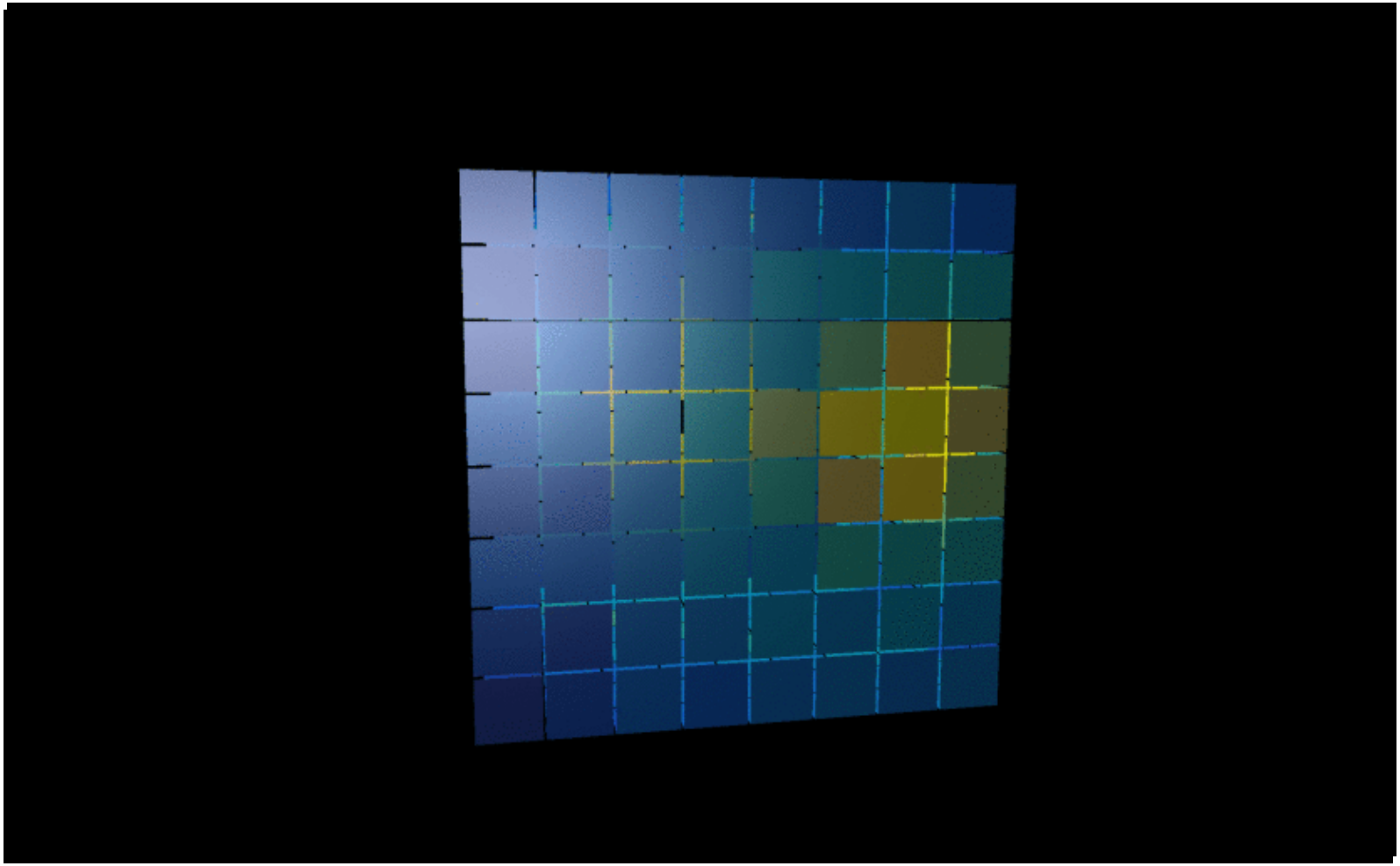
Sandia National Laboratories

Oak Ridge National Laboratory

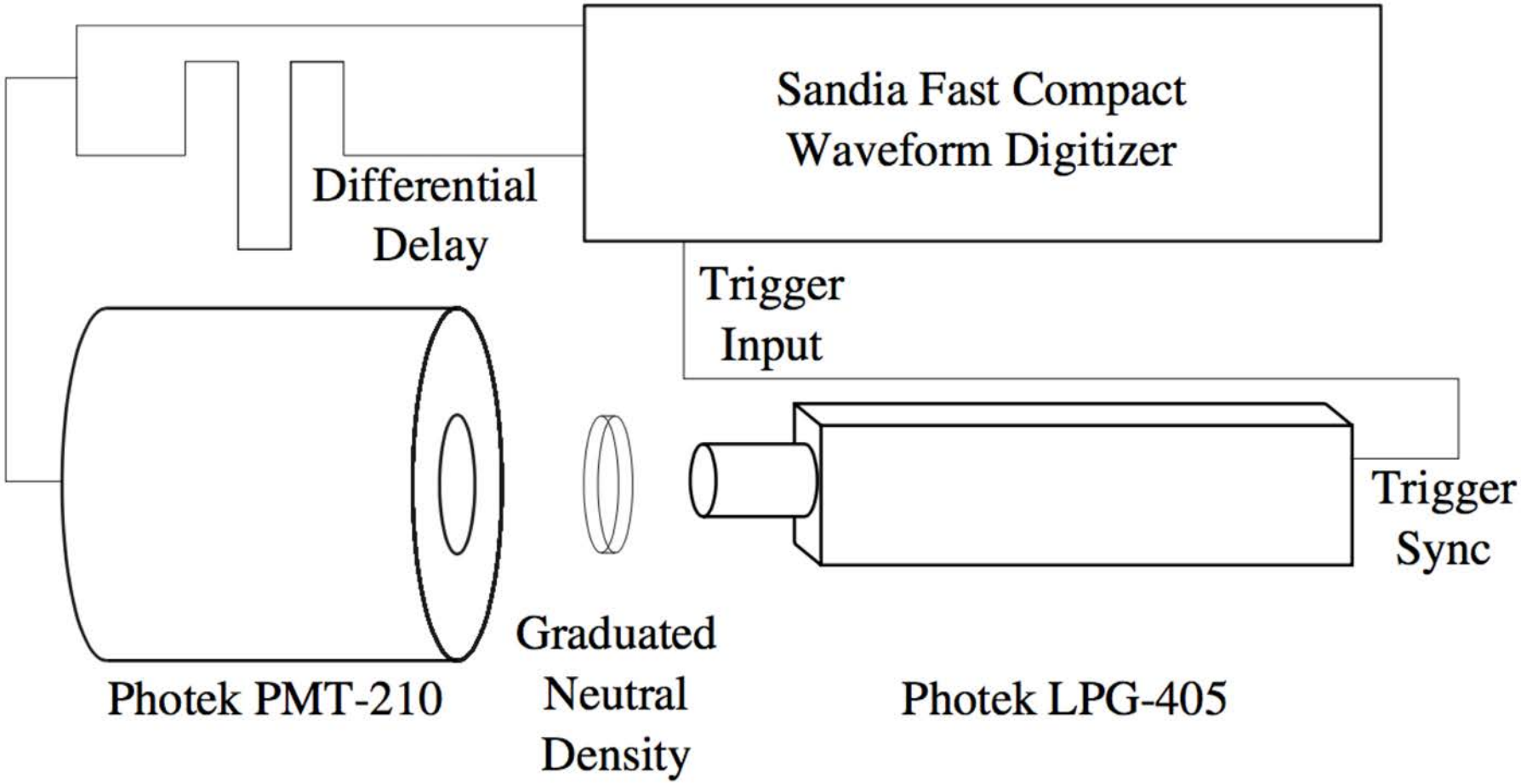
University of Hawai'i Mānoa

NC State University

Argonne National Laboratory

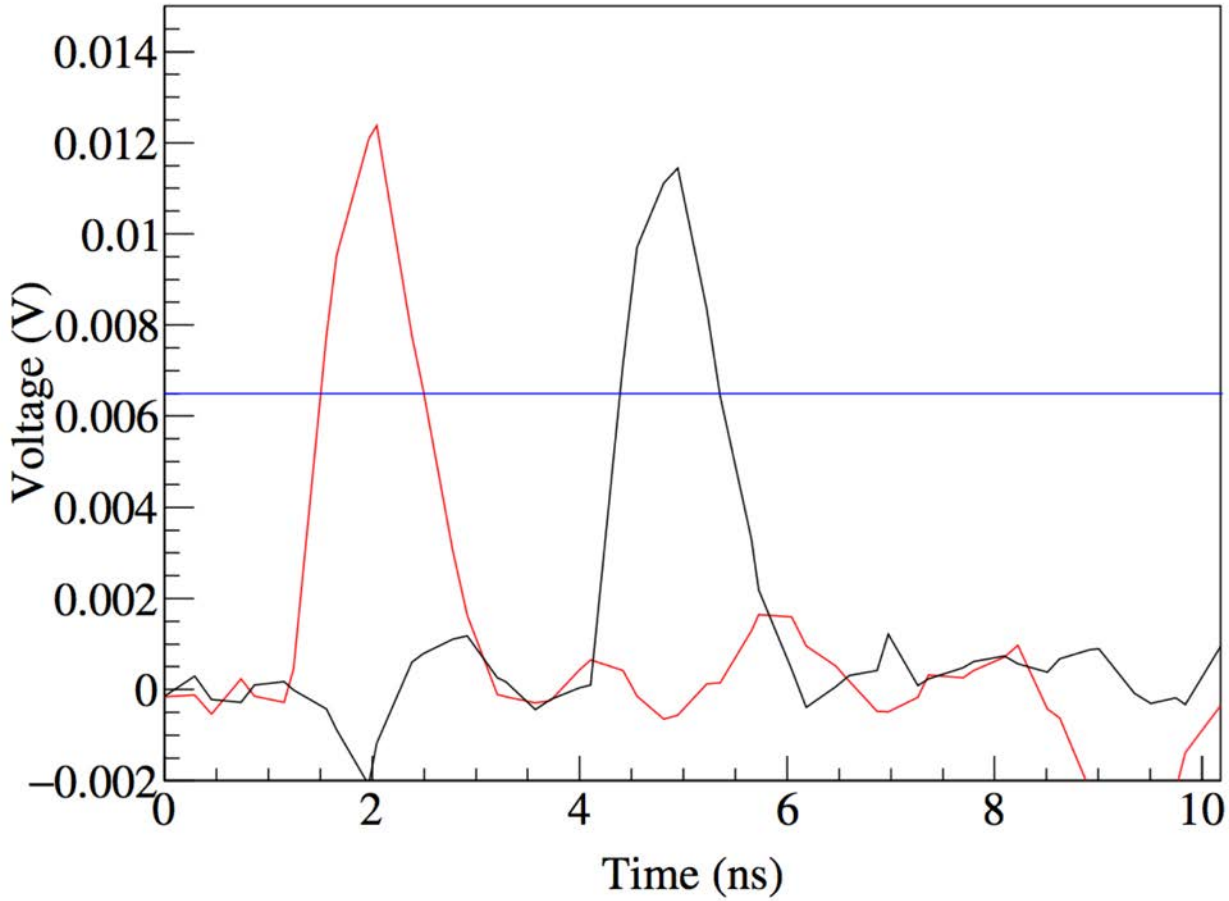


Pulse Pair Resolution Test Schematic



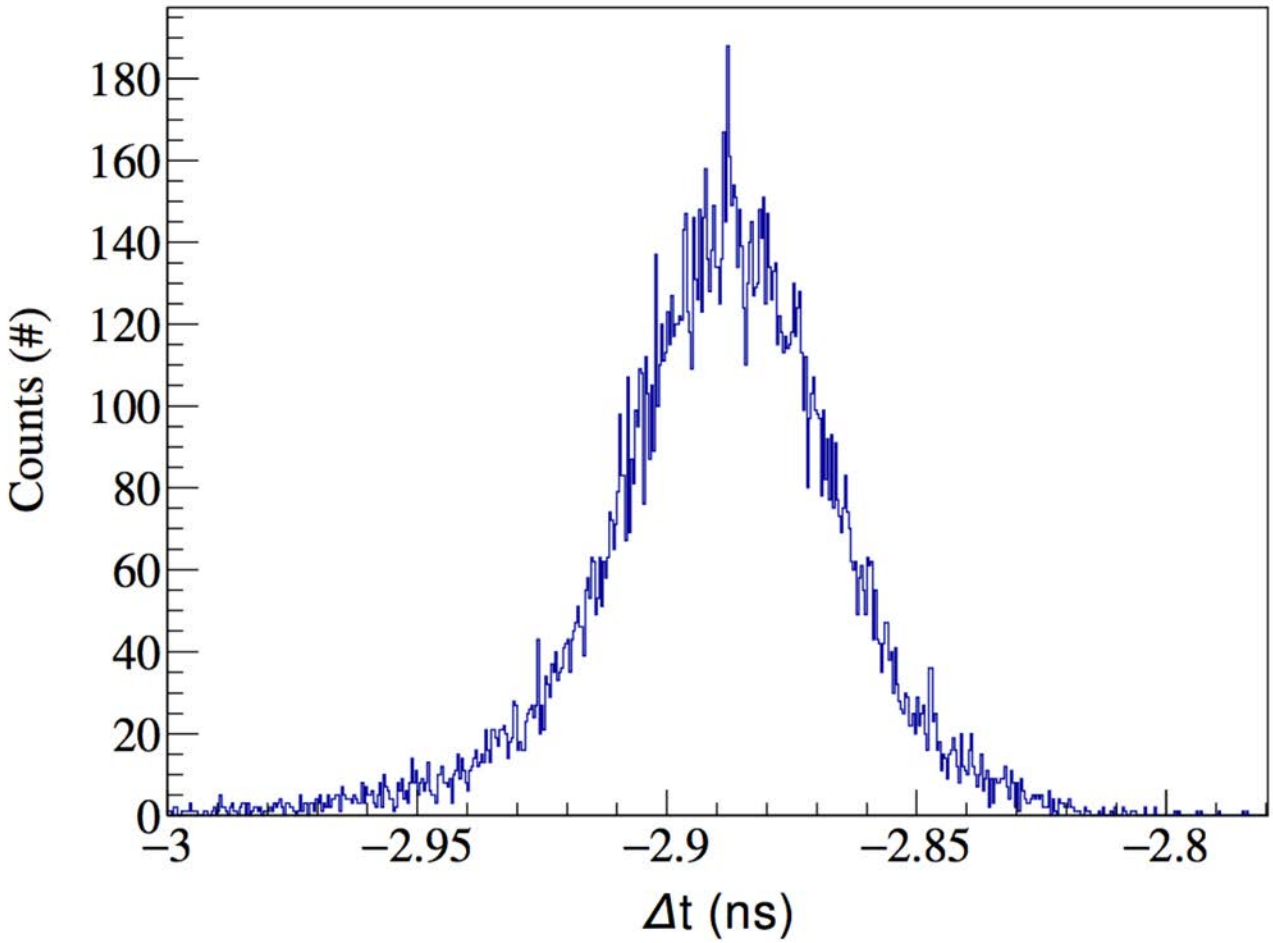
(a) Schematic of the layout for the pulse pair resolution test

Pulse Pair Resolution Test Event Example



(b) A characteristic event from the pulse pair test using a Photek PMT-210 and a Photek LPG-405 ps class pulsed laser. The pulse shape observed is a good approximation to the instrument response function given the FWHM of PMT-210 pulse is 130ps.

Pulse Pair Resolution Test Result



(c) Temporal distribution resulting from the accumulation of the time difference of events. The standard deviation of is 21.7 ps which is much lower than the anticipated single photon jitter of the pixelated detectors under consideration