

Single Volume Scatter Camera:

Development Towards a Compact Neutron Imager



PRESENTED BY

Josh Brown on behalf of the SVSC Collaboration



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Berkeley
UNIVERSITY OF CALIFORNIA

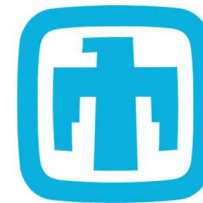


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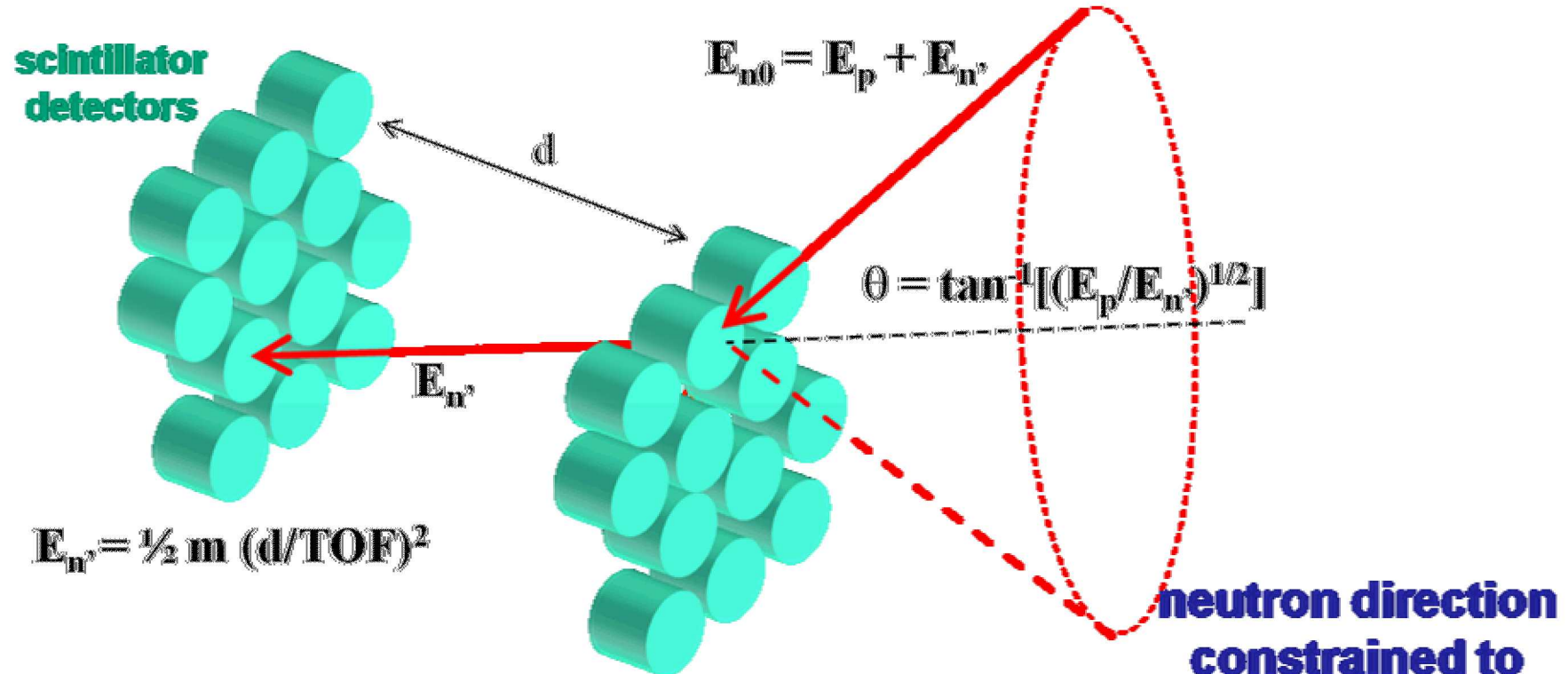


Argonne
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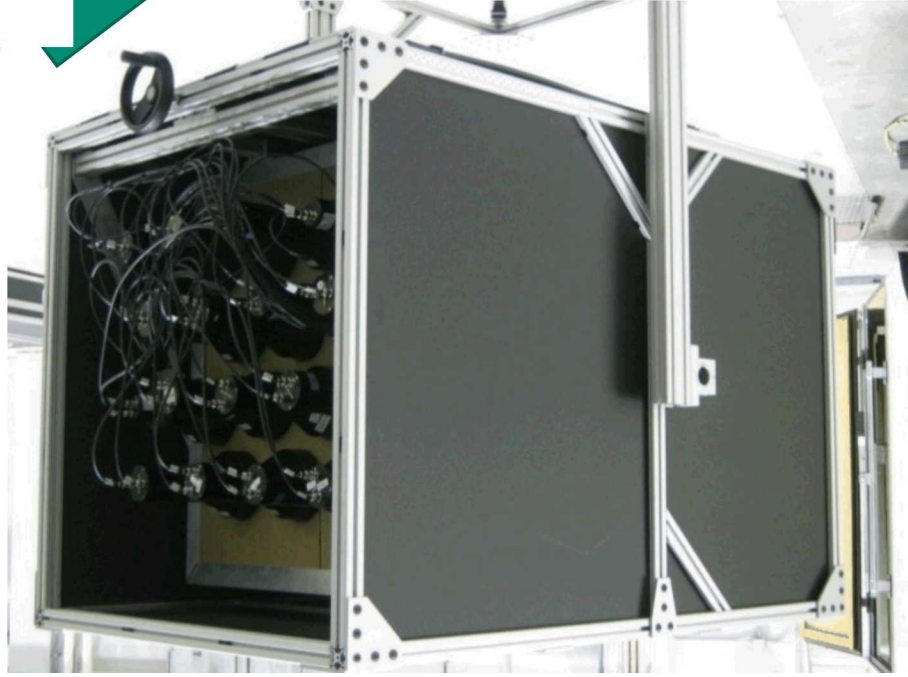
Sandia
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Laboratories

Fast neutron directions and energies constrained by double scatter geometry

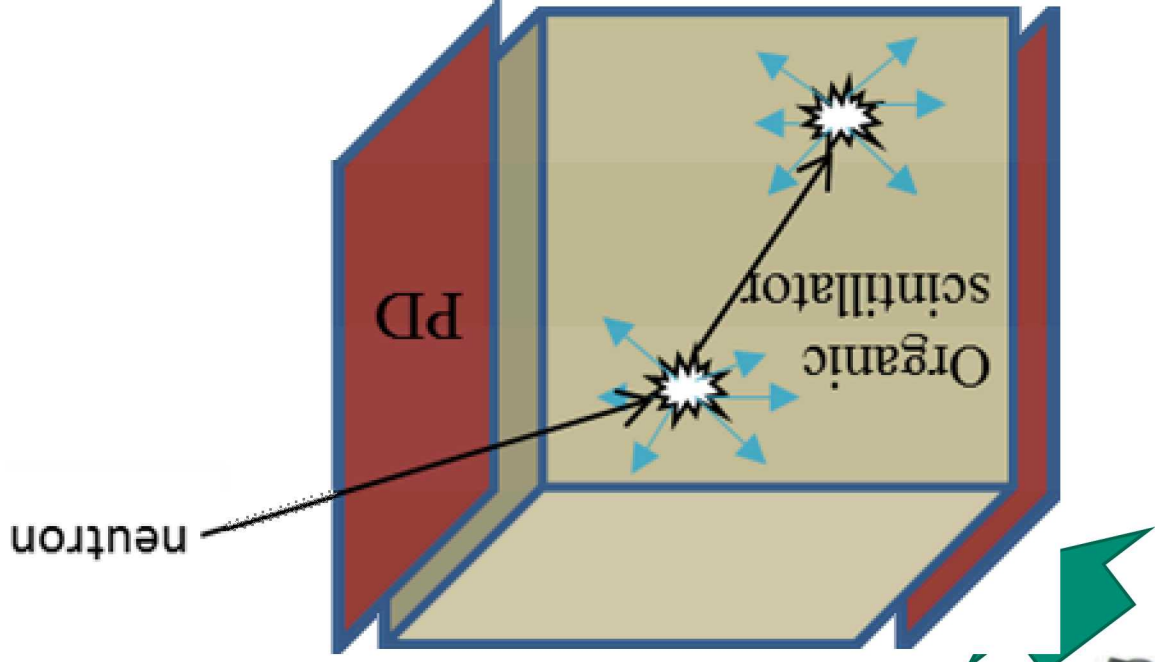


Multimode capability includes

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

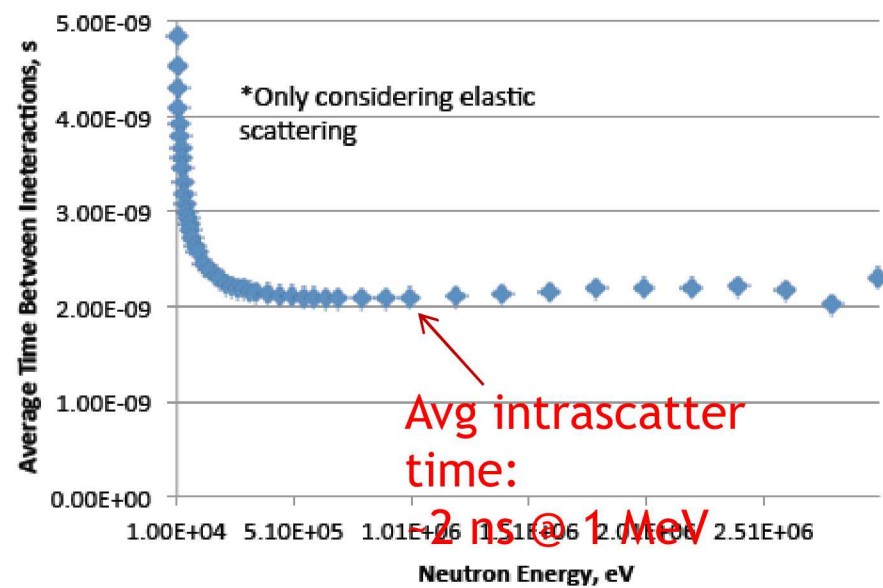
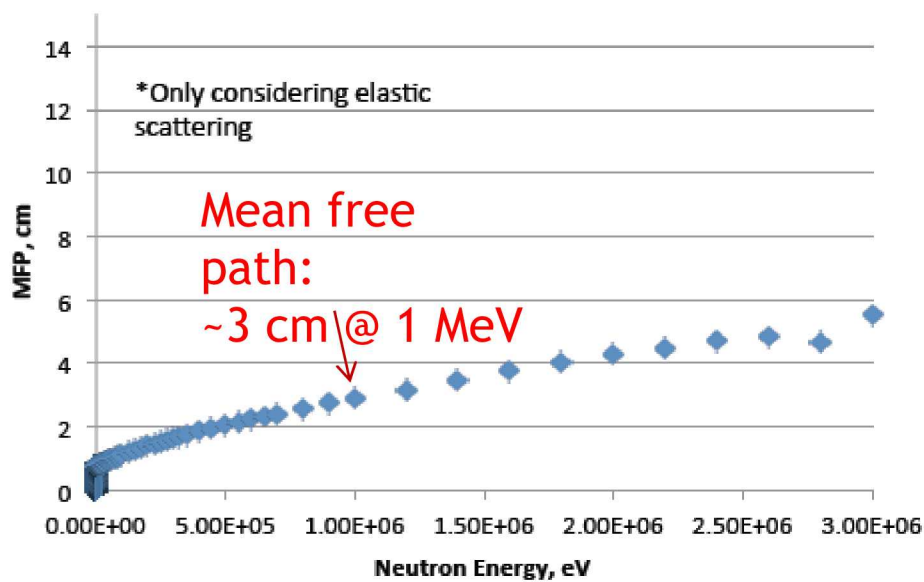
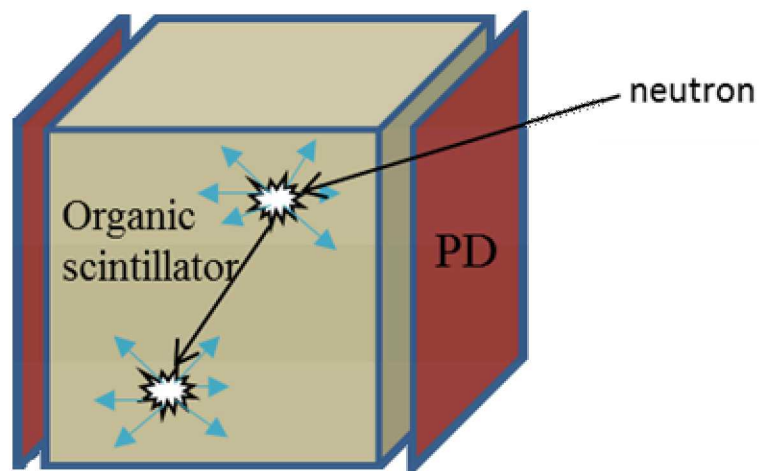


10 x 10 x 10 cm



Challenges

5

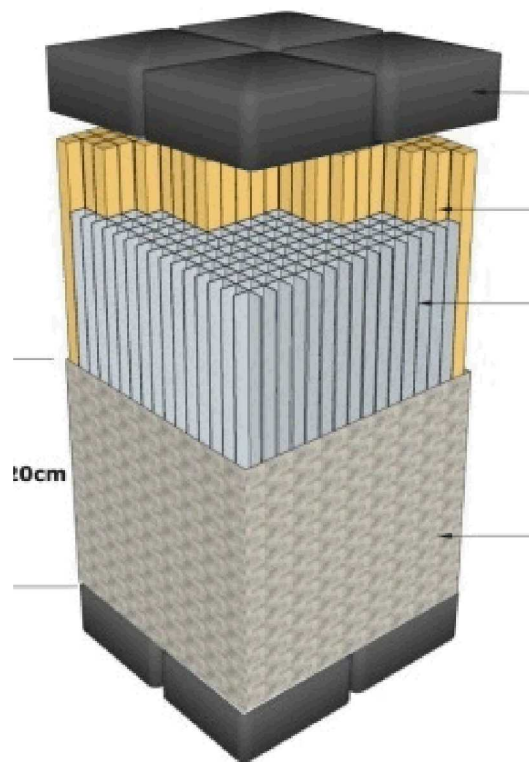
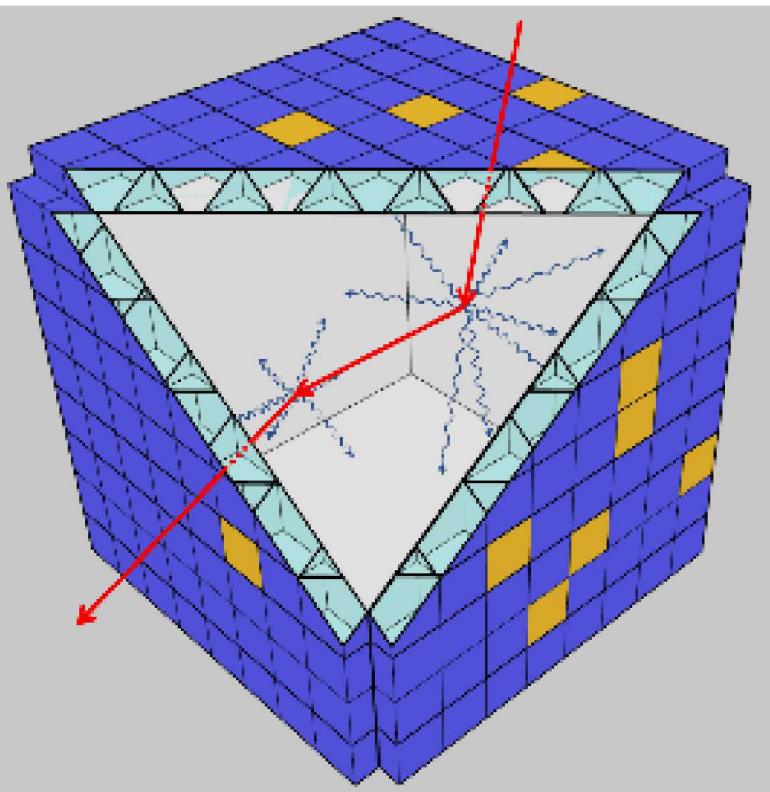


6 Prospective Methods

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

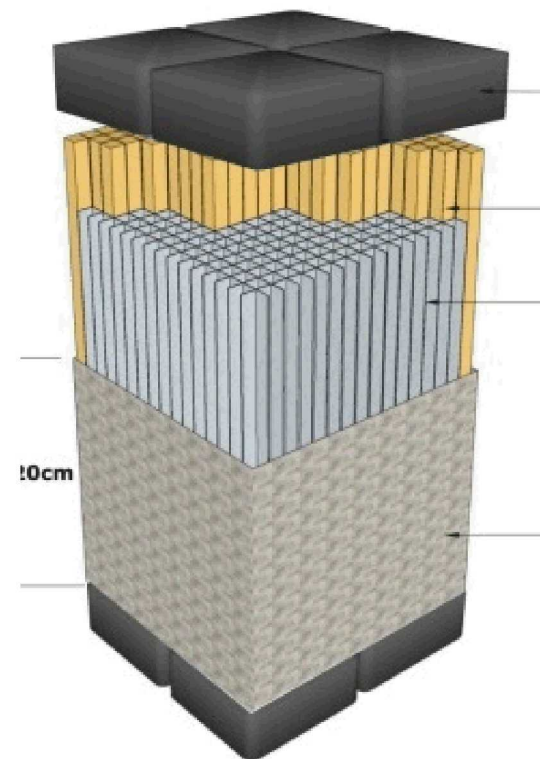
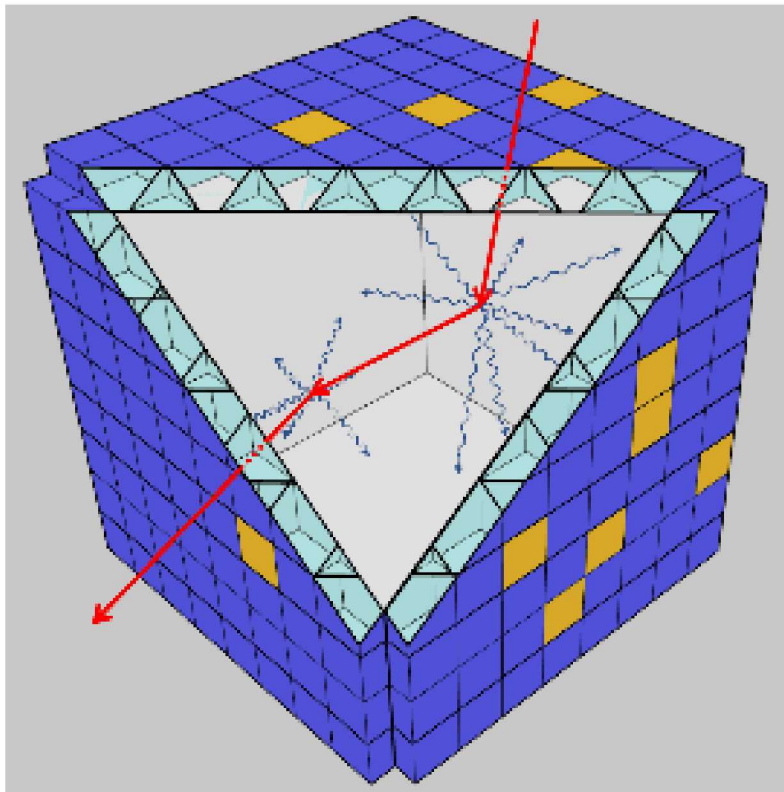
1. **Monolithic:** Arrival positions and times of isotropically emitted photons at surfaces of the volume determine most likely $\vec{X}$.

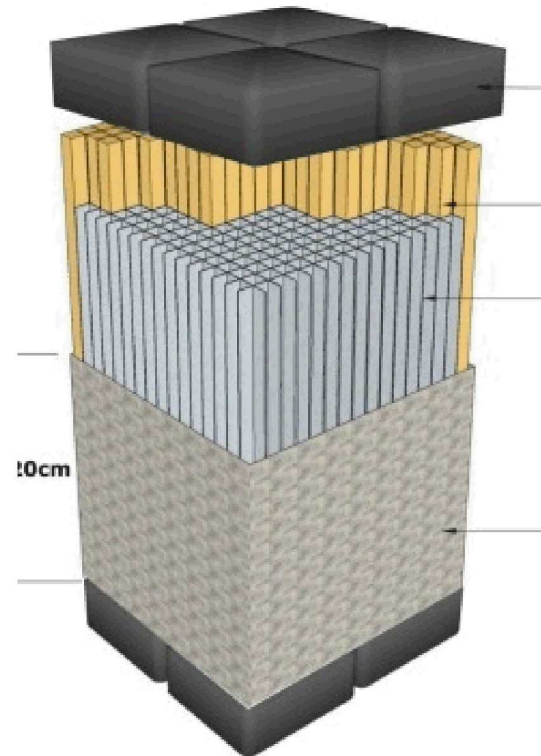
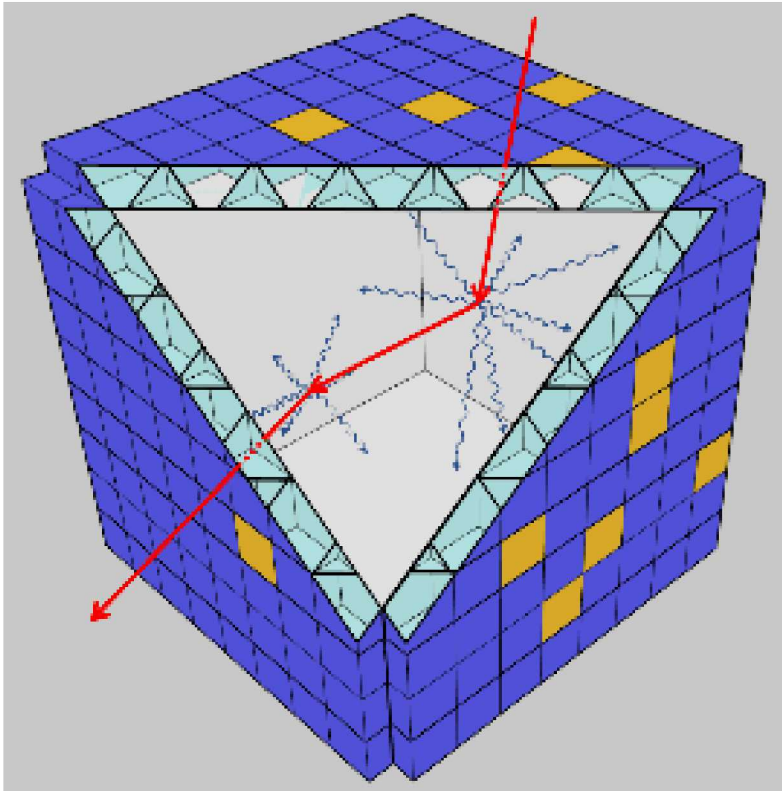
2. **Optically segmented:** Constrain photon propagation within bulk to associate specific PD channels with $\vec{X}$.



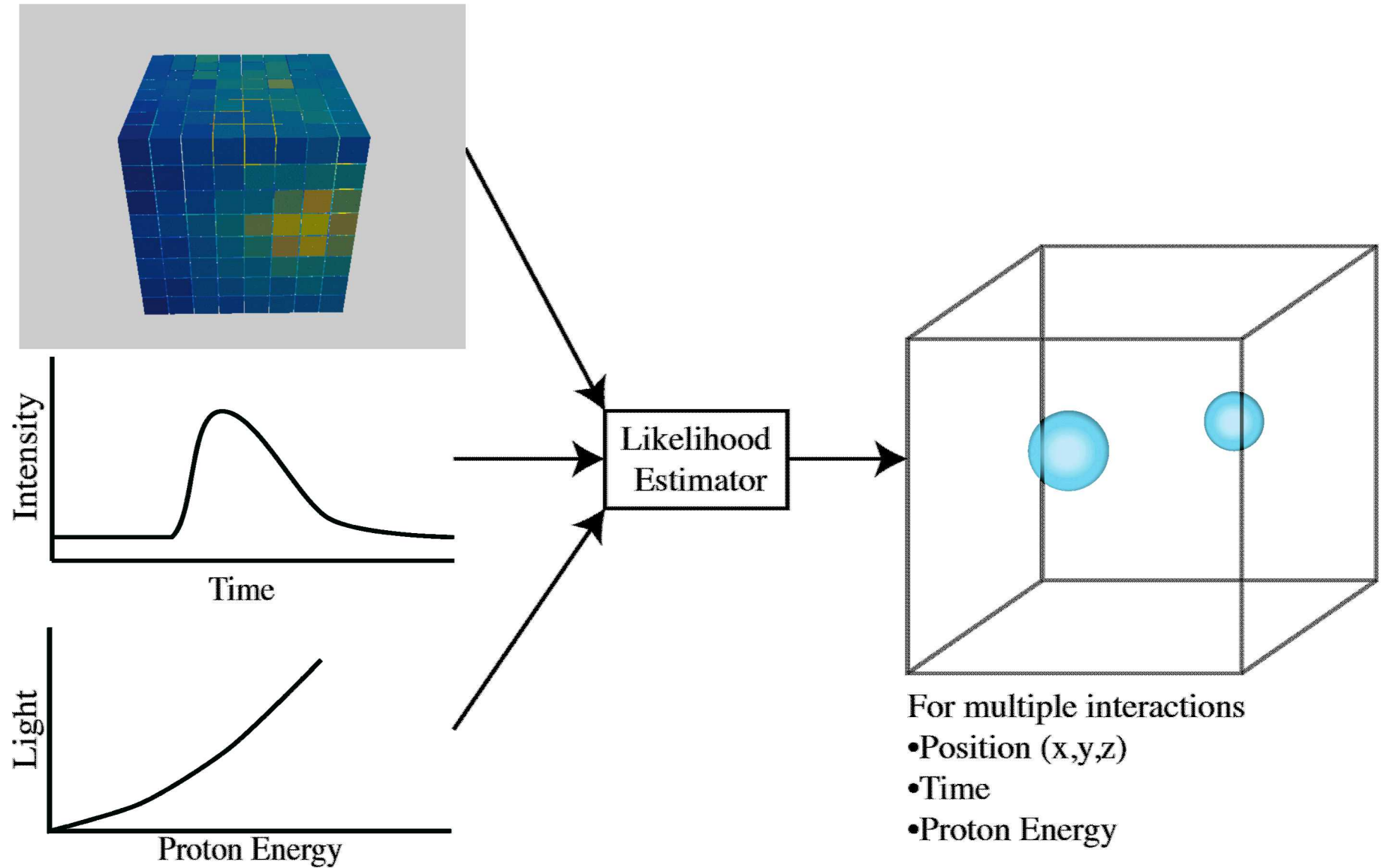


Strong technical parallels to both prospective and previously realized neutrino detectors





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



Reconstructing Events

Extended ML for accurate energy uncertainty

Probability multiplies over all observed photons

Probability to observe a photon is summed over all interactions

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

$$P_j(x_i) = \left[\underbrace{\frac{\cos \phi_{ij}}{4\pi |\vec{x}_i - \vec{x}_j|^2}}_{\text{Solid angle}} \underbrace{e^{\frac{-|\vec{x}_i - \vec{x}_j|}{\lambda}}}_{\substack{\text{Optical} \\ \text{attenuation}}} \underbrace{f(t; \mu, \sigma, \lambda)}_{\text{Pulse shape}} \right]$$

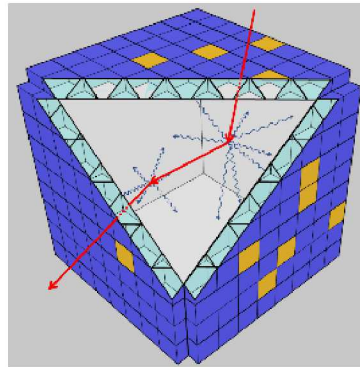
Likelihood Estimator



Event reconstruction via likelihood maximization.

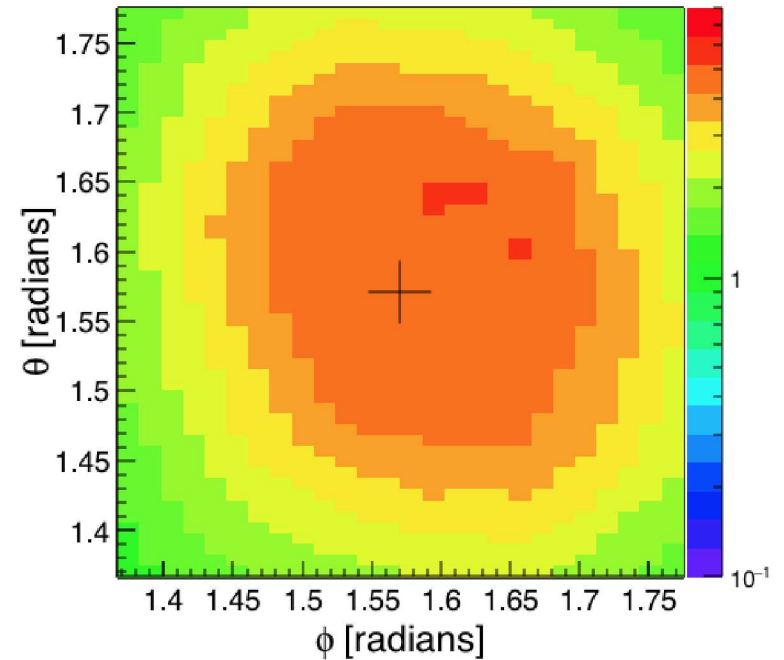
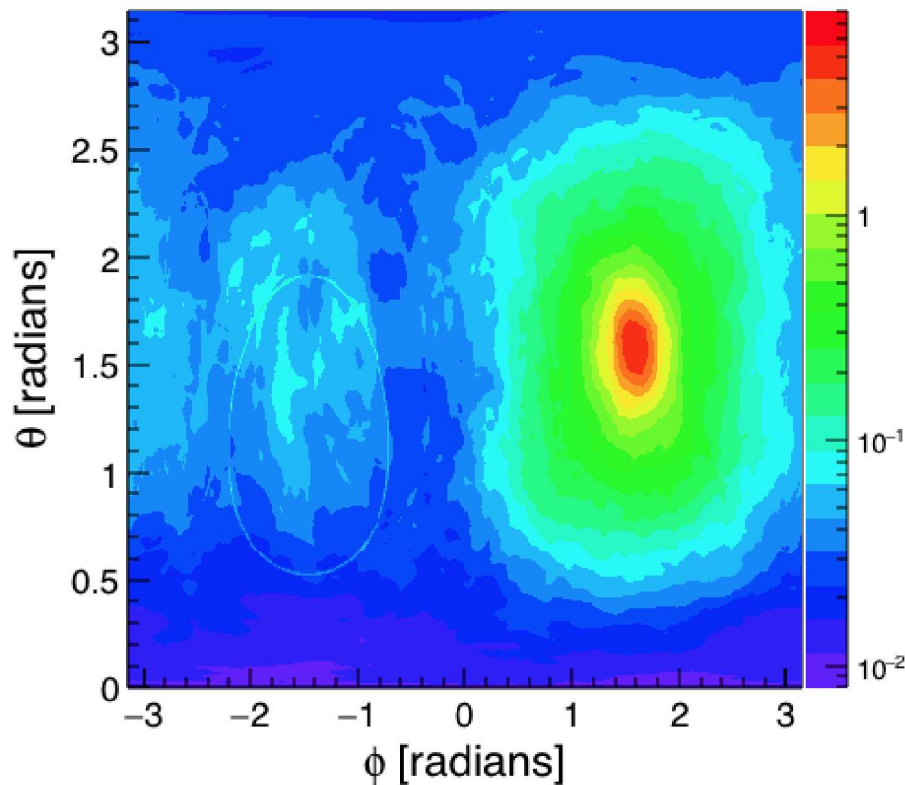
- MINUIT: SIMPLEX, MIGRAD
- Deterministic Likelihood Maximization

Can it work? (DR)

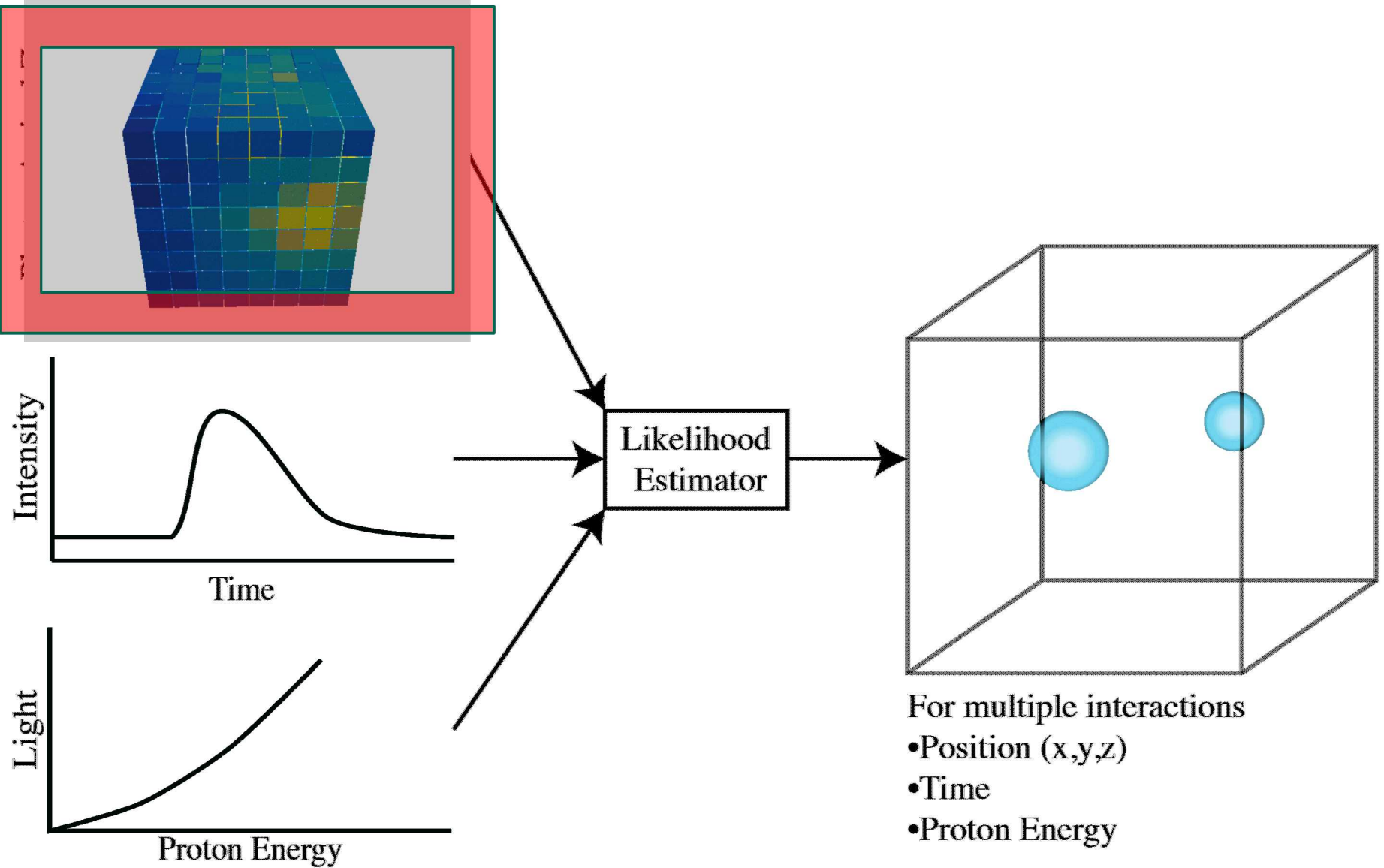


Belkis Cabrera-Palmer
(SNL)

	σ		σ
Δx_0	3.02 mm	Δx_1	4.94 mm
Δy_0	3.05 mm	Δy_1	5.08 mm
Δz_0	3.02 mm	Δz_1	4.95 mm
Δt_0	0.08 ns	Δt_1	0.14 ns
Δn_0	45 photons	Δn_1	30 photons

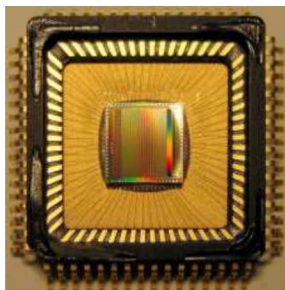


For a simulated 2.7 μCi Cf252 neutron source located at 1 m, this image is equivalent to 29 minutes of measurement time, without background.



DRS4 waveform capture

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



PSI

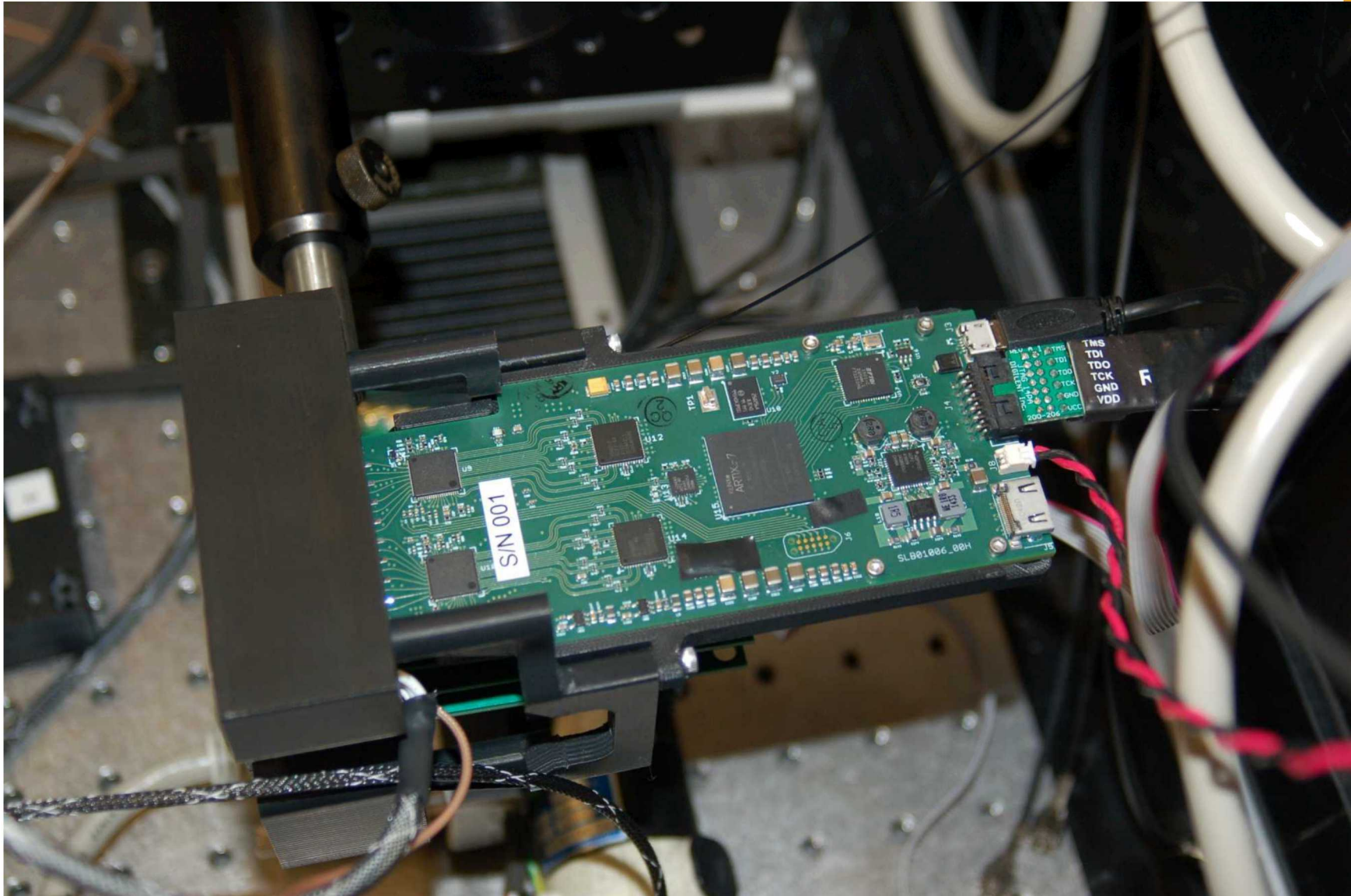


- 4-channel DRS4 eval board (PSI)
- Not scalable

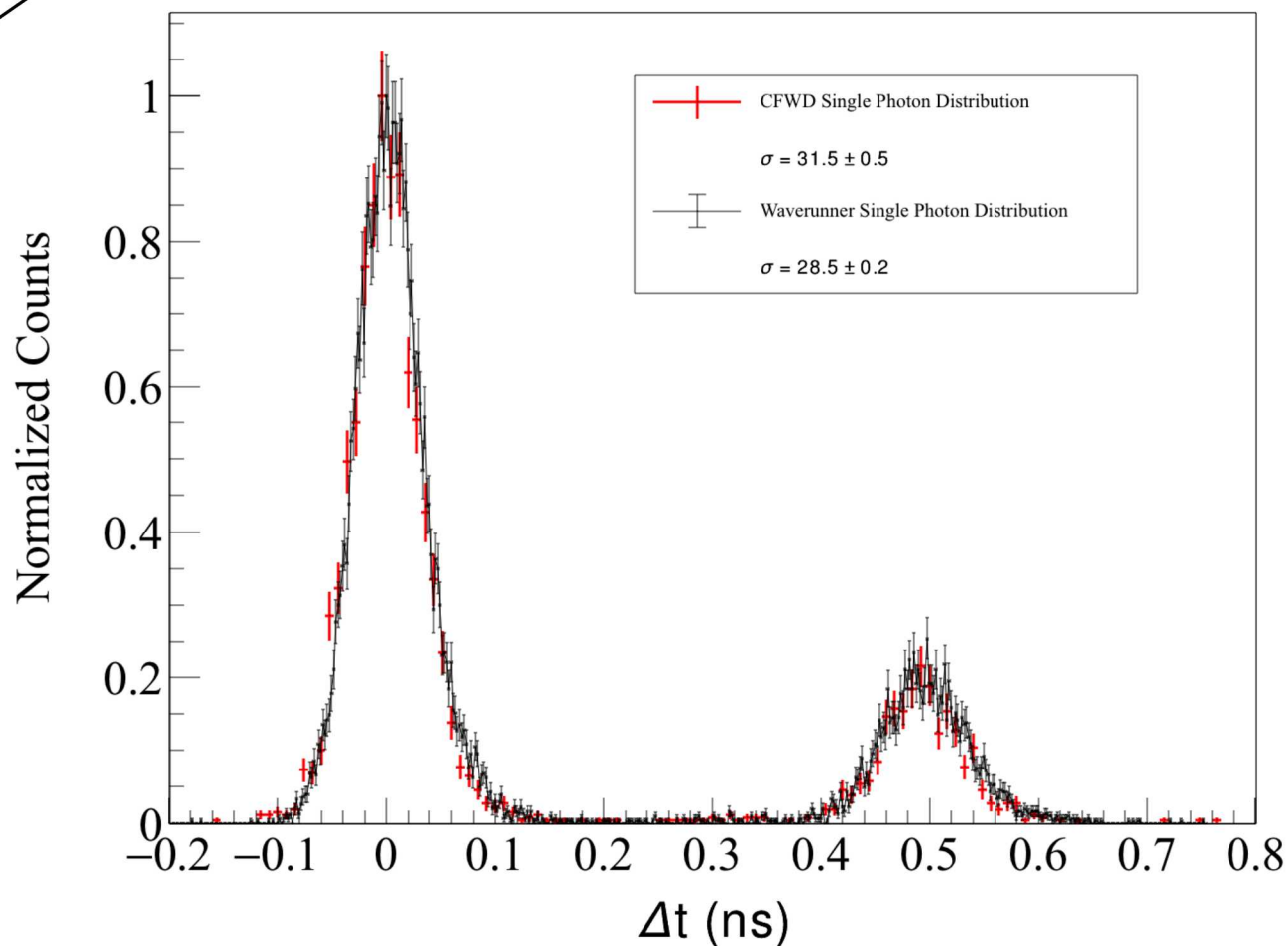
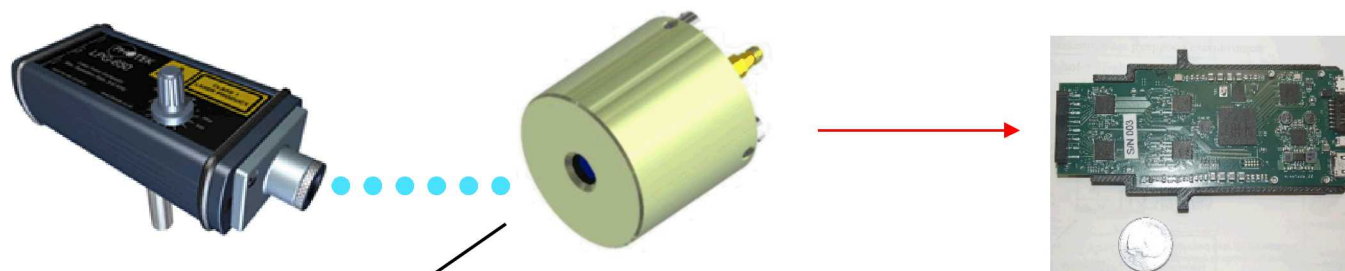


- Caen V1742
- 32-channel
- DRS4-based

SCEMA Module Directly Coupled to Planacon



Establishing SCEMA Single Photon Performance



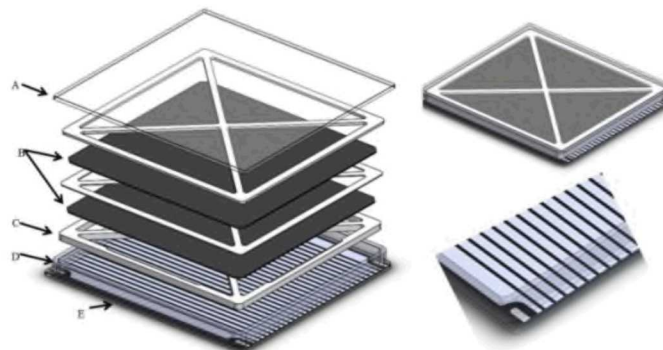
Photodetectors

Photek PMT210



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

Large Area Picosecond Photodetector



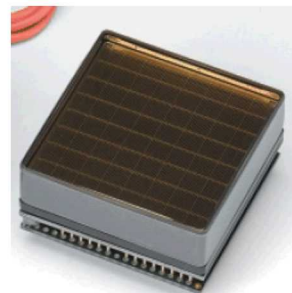
<http://www.incomusa.com/wp-content/uploads/2018/06/2018-06-27-Large-Area-Picosecond-Photodetector-LAPPD-Pilot-Production-and-Development-Status.pdf>

Photonis Planacon XP85012



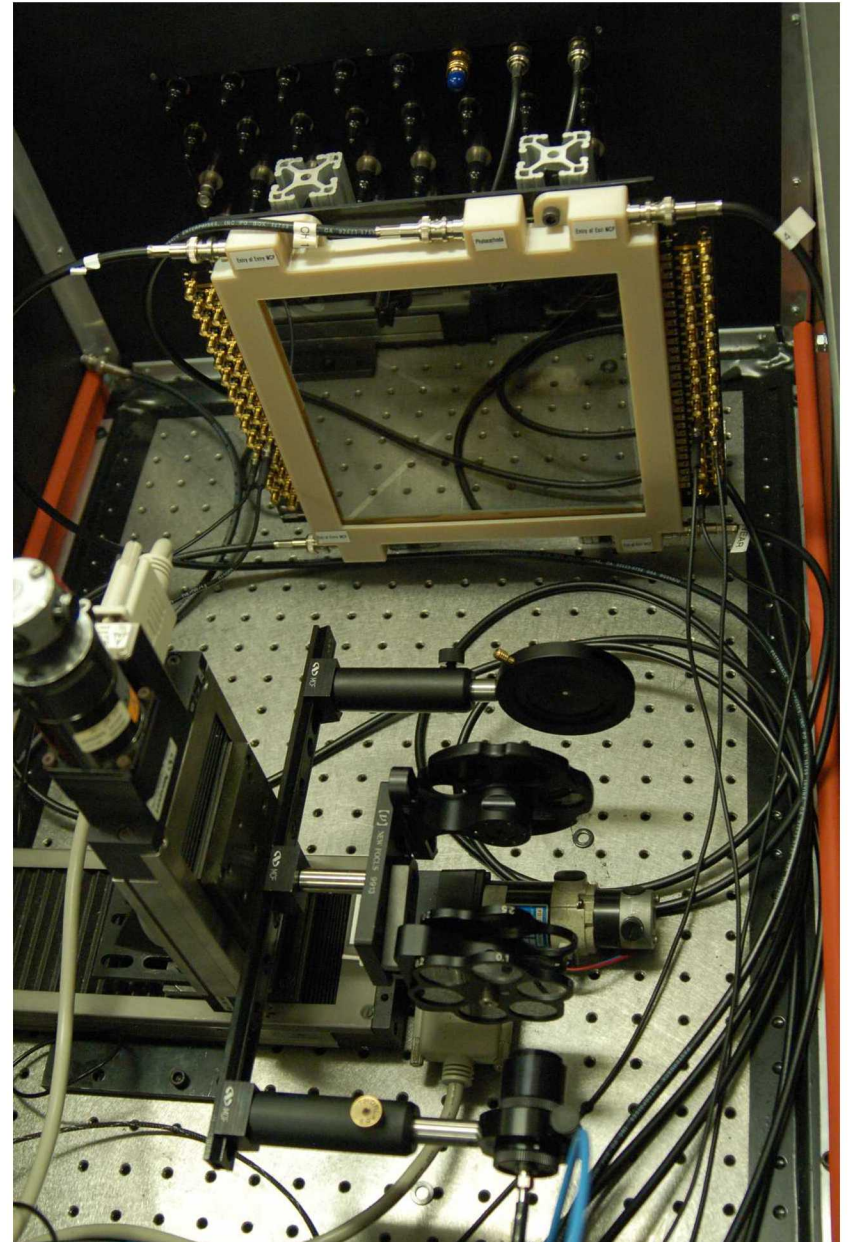
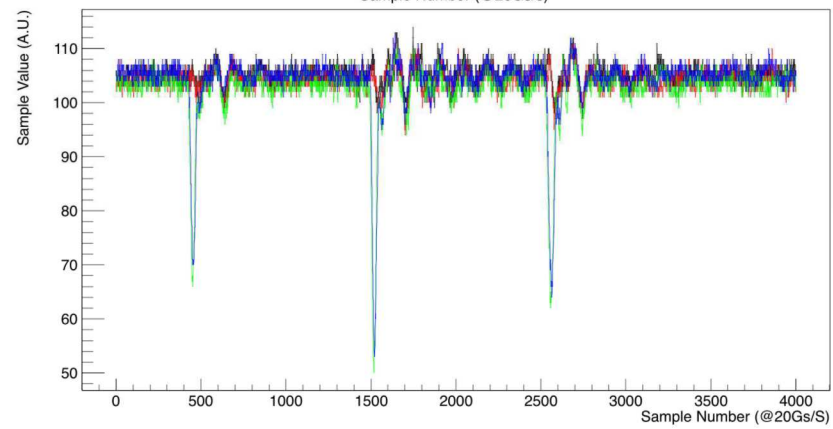
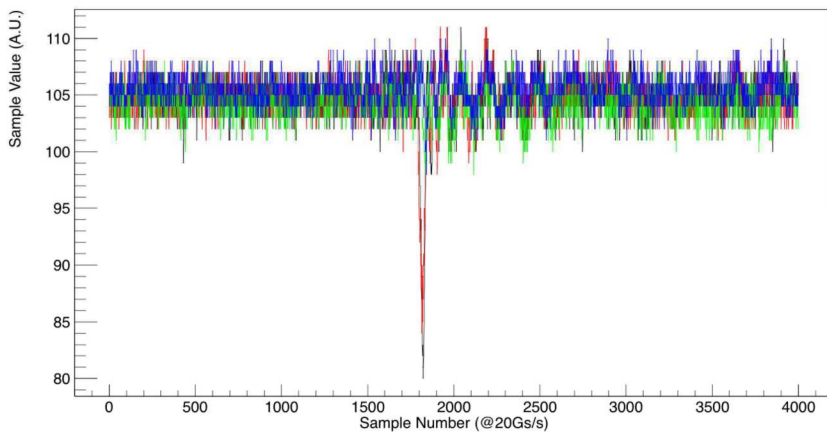
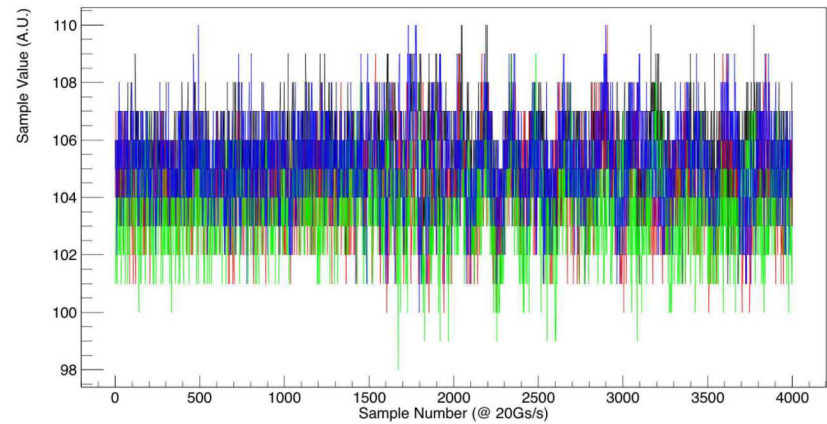
- 25 mm pore MCP-PMT
- 8x8 anode (6 mm)

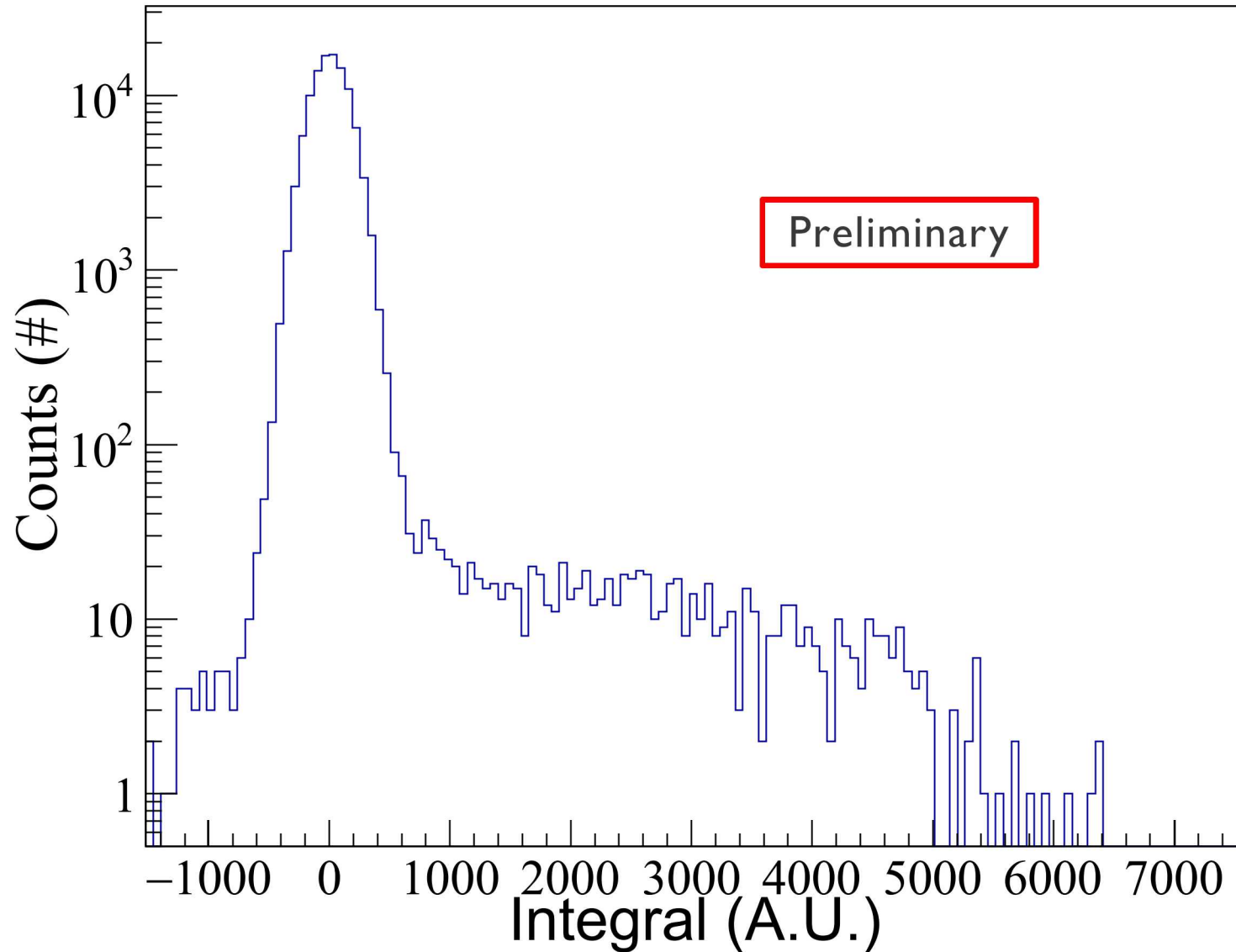
Hamamatsu H8500 MAPMT

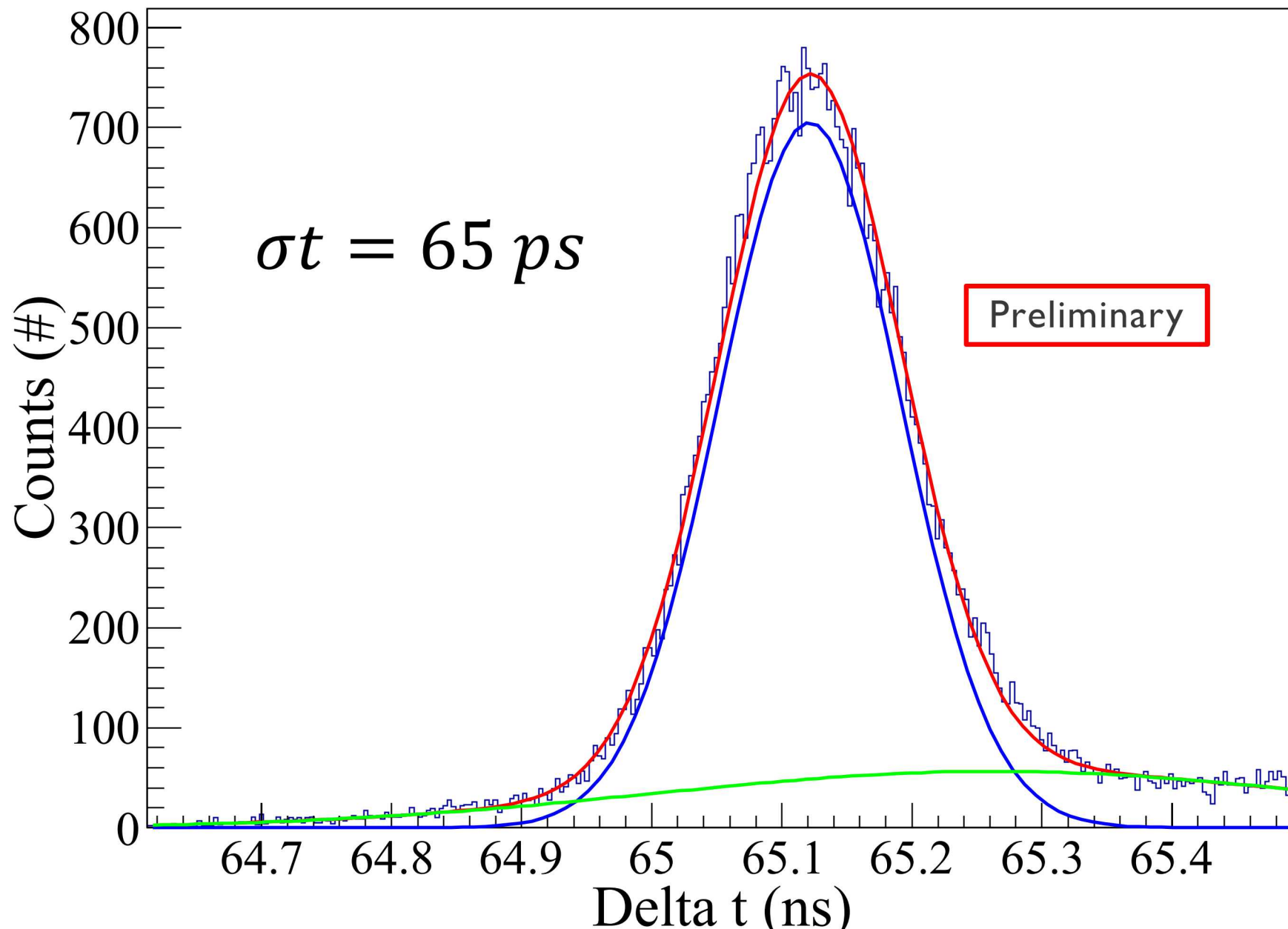


- Metal channel multi-anode PMT
- 8x8 anode (6 mm)

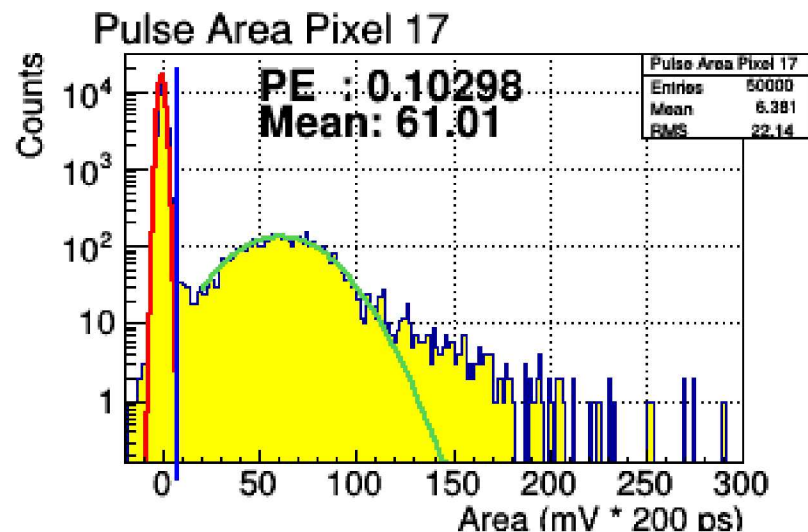
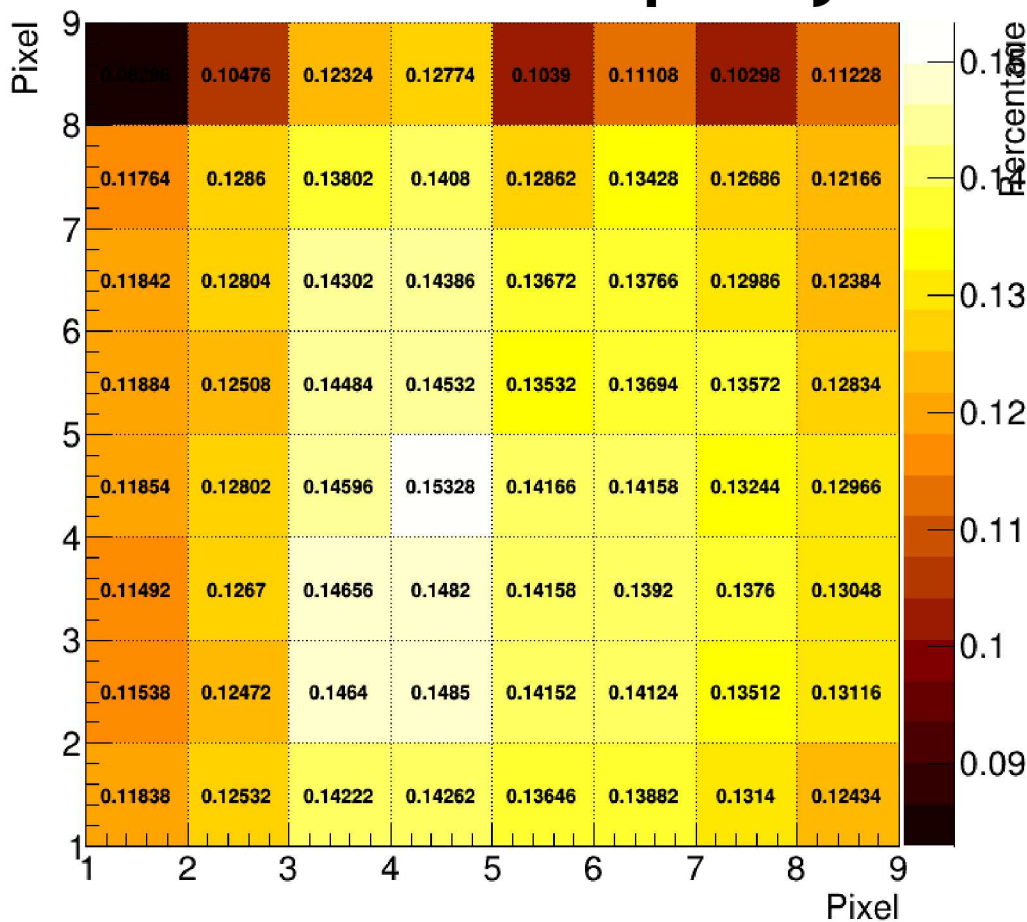
LAPPD Mounted with moveable light source





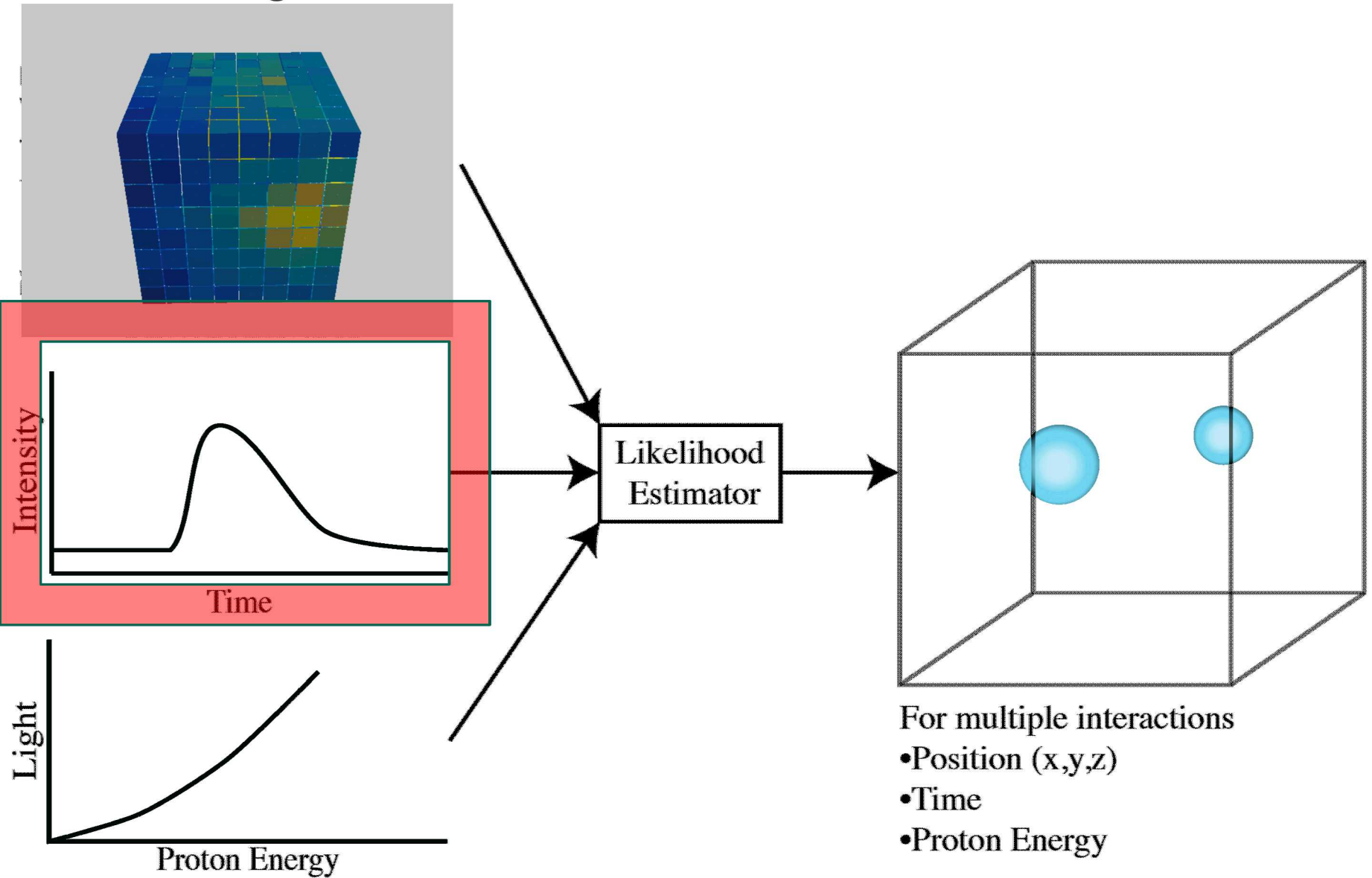


Relative Occupancy



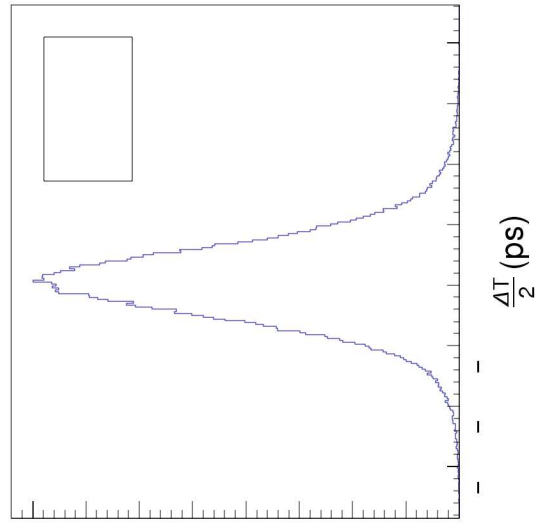
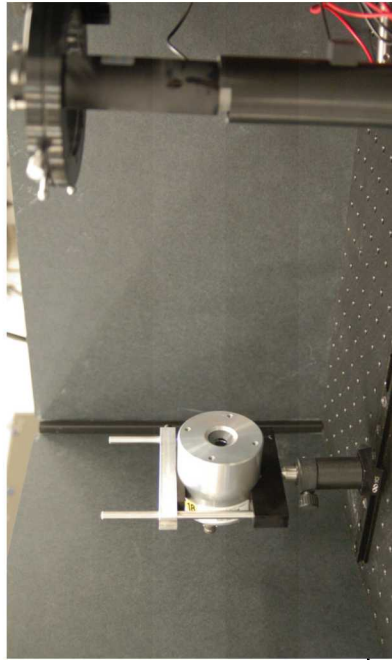
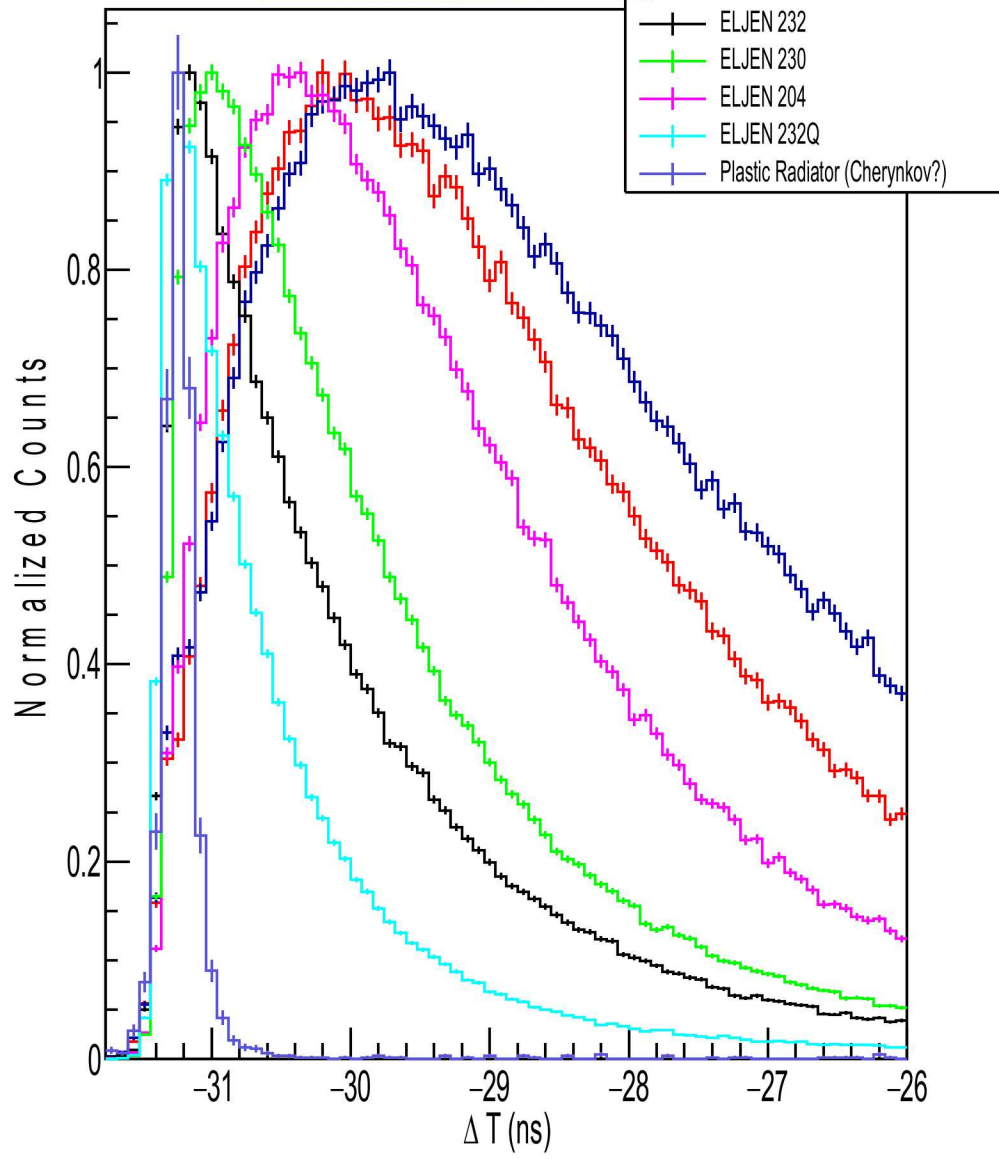
Relative occupancy =
percentage of counts
above threshold

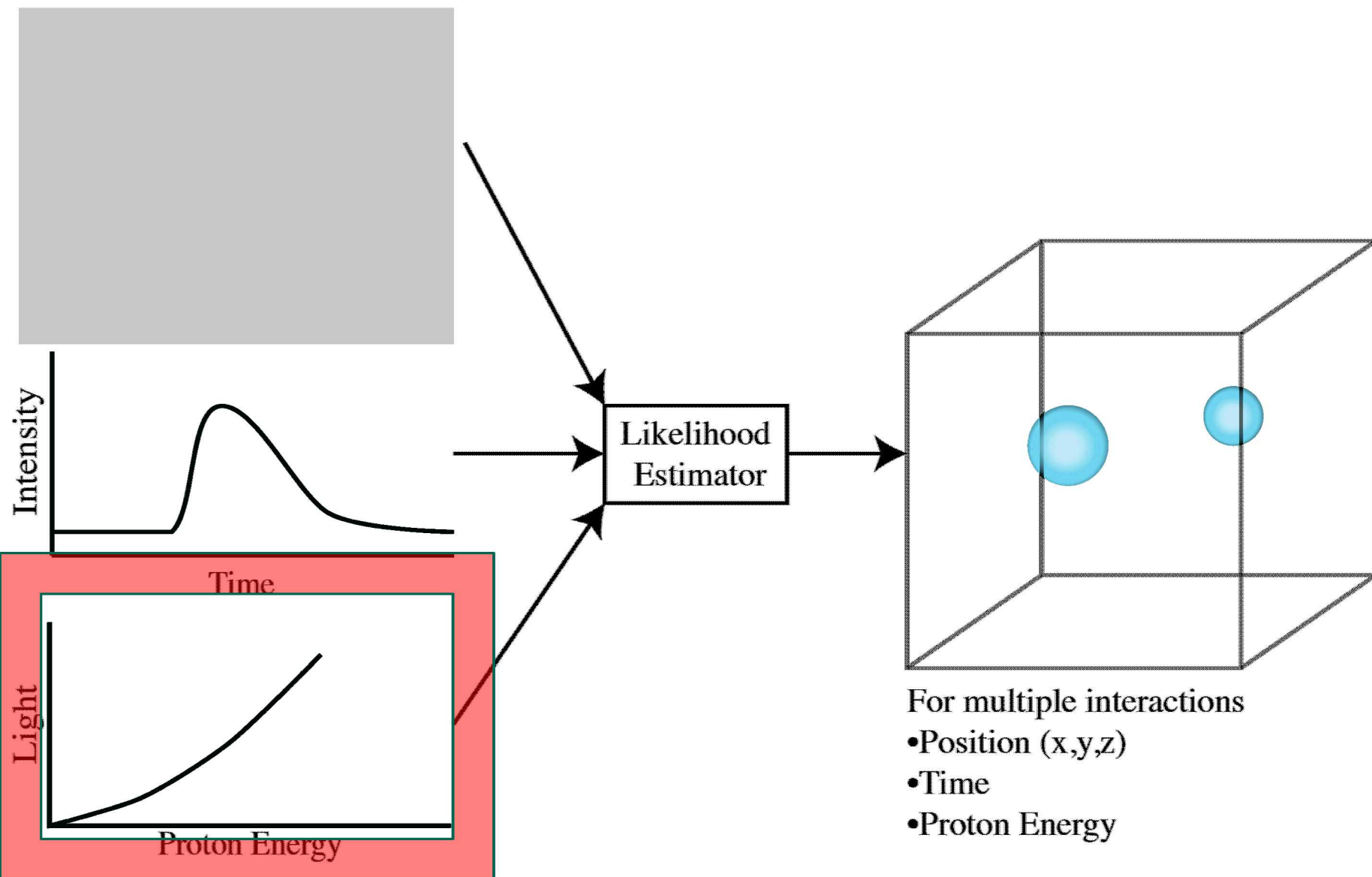
Focusing on the Monolithic Case



Measuring Scintillator Pulse Shapes

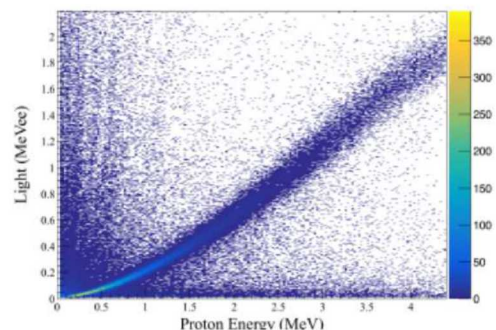
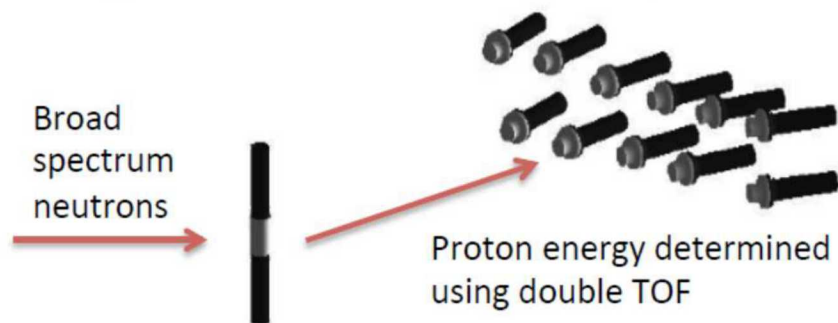
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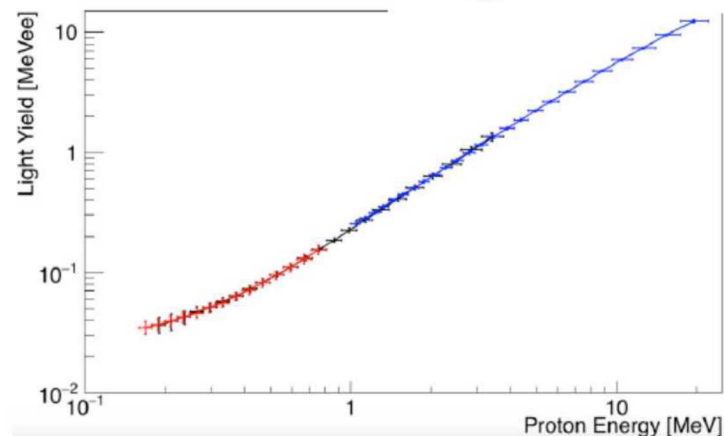
Light Yield Measurements – LBNL/UCB Approach

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

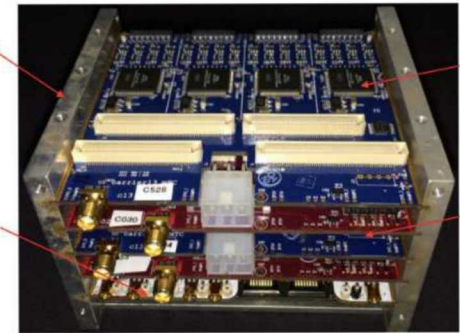
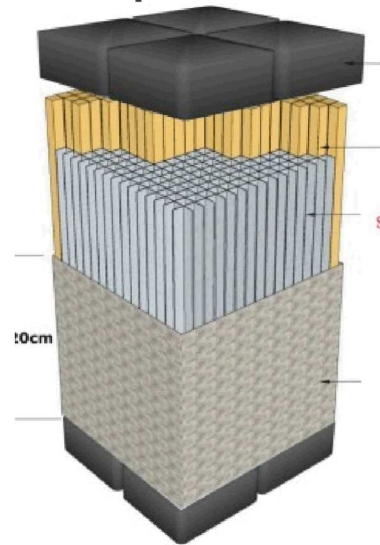
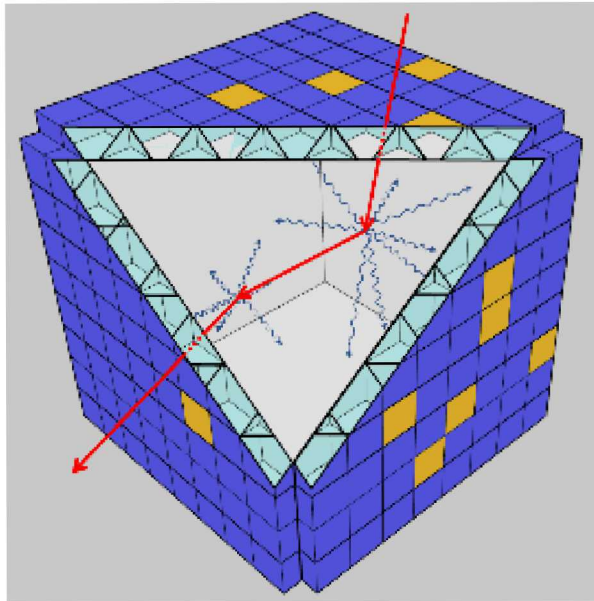


Outcome: Enables accurate simulation of advanced neutron detection systems, neutron image reconstruction, and next-gen detector materials prospecting

Prototypes For Both Concepts are Nearly Operational



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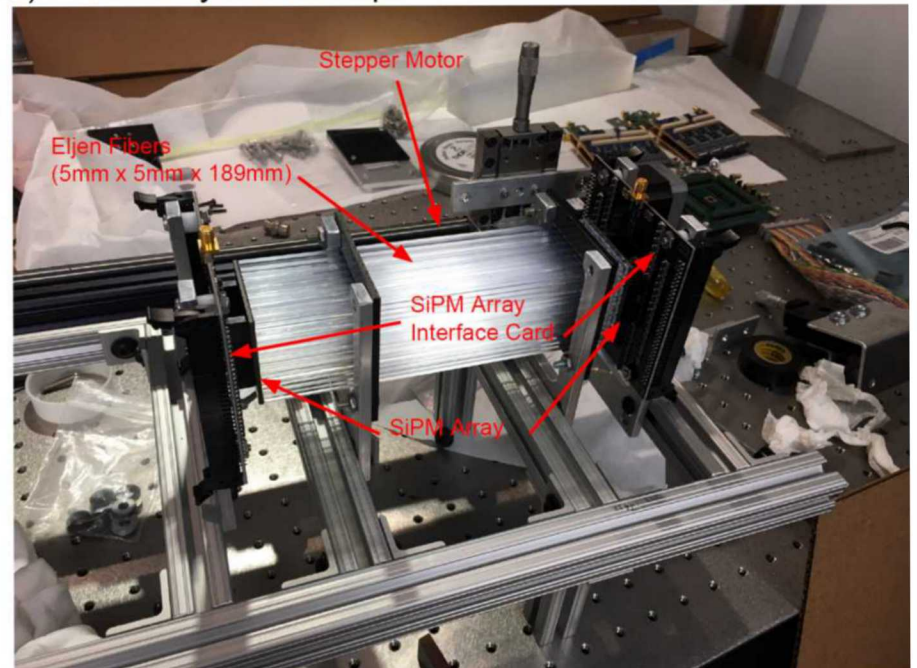
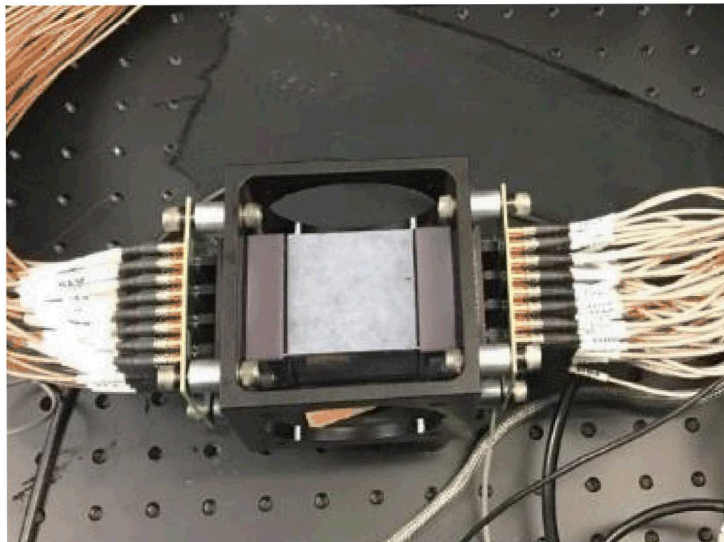
Side Walls

Interconnect Board

ASIC

Carrier Board
(4 Typical)

Full (8x8) Fiber Array Test Setup:



Stepper Motor

Eljen Fibers
(5mm x 5mm x 189mm)

SiPM Array
Interface Card

SiPM Array



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



ORNL: P. Hausladen, M. Febbraro, K. Ziock, M. Folsom



U of Hawaii: J. Learned, K. Nishimura, A. Druetzler, A. Galindo Tellez,



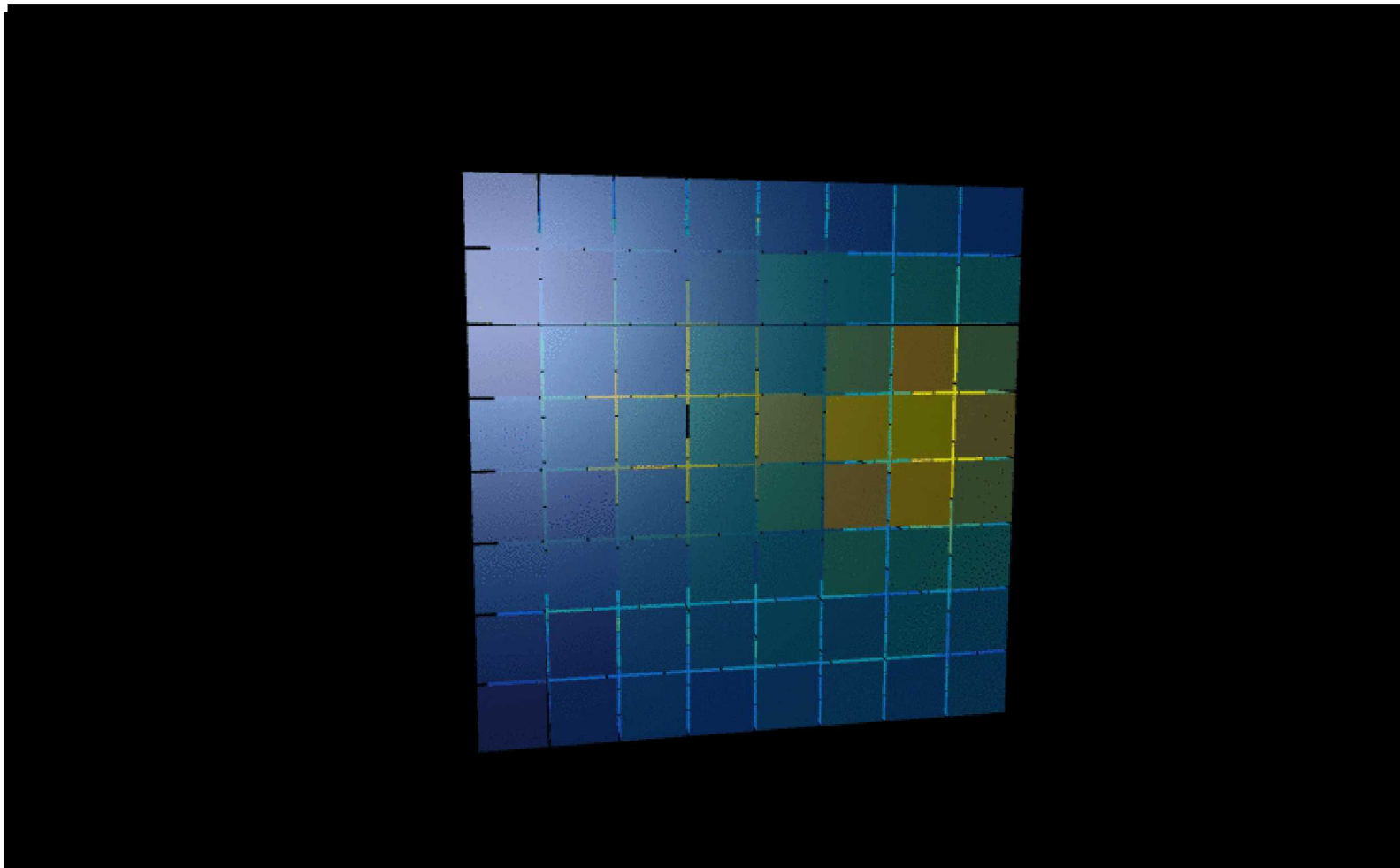
UC Berkeley: B. L. Goldblum, T. Laplace, J. Manfredi

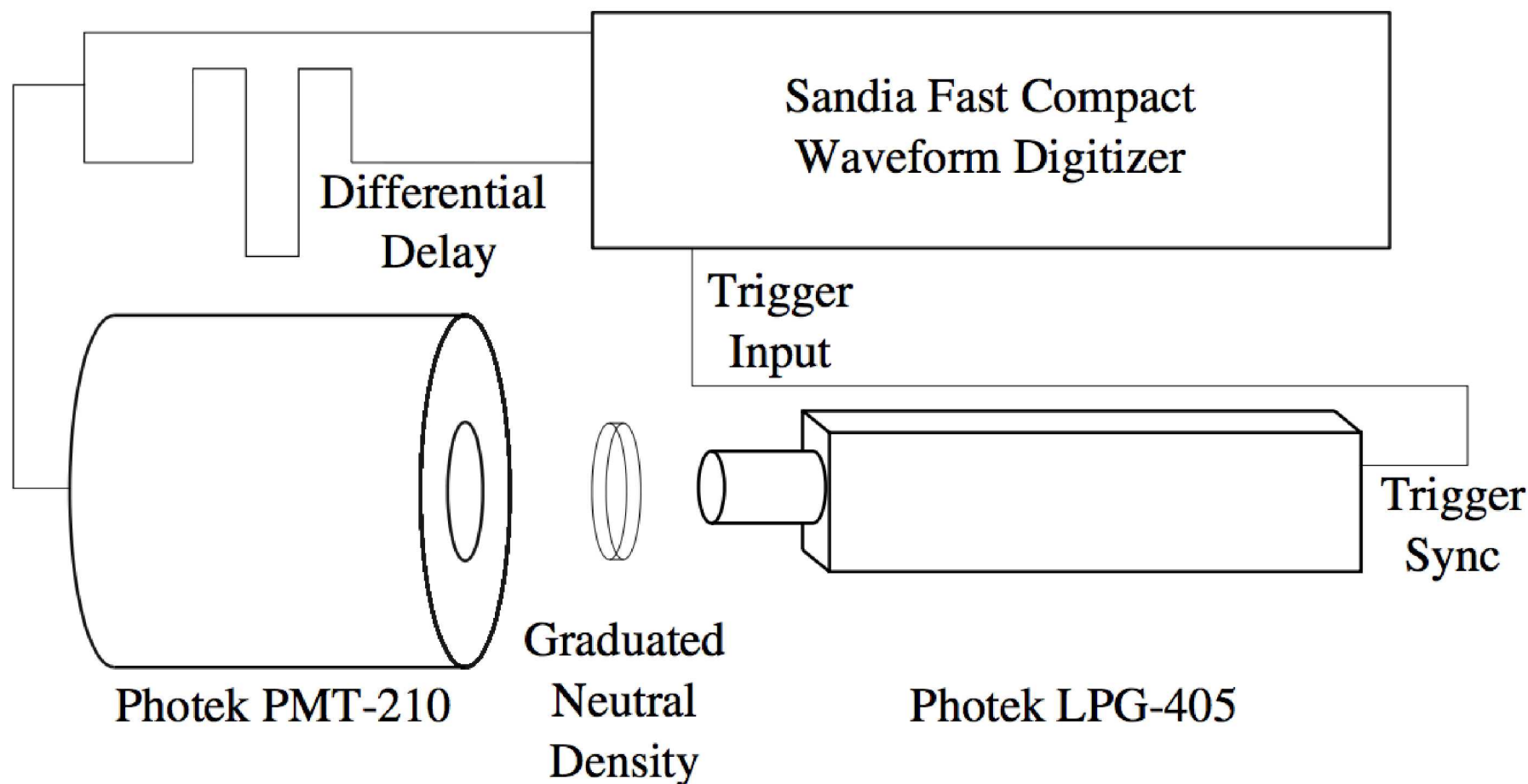


NCSU: J. Mattingly, K. Weinfurther, M. Mishra

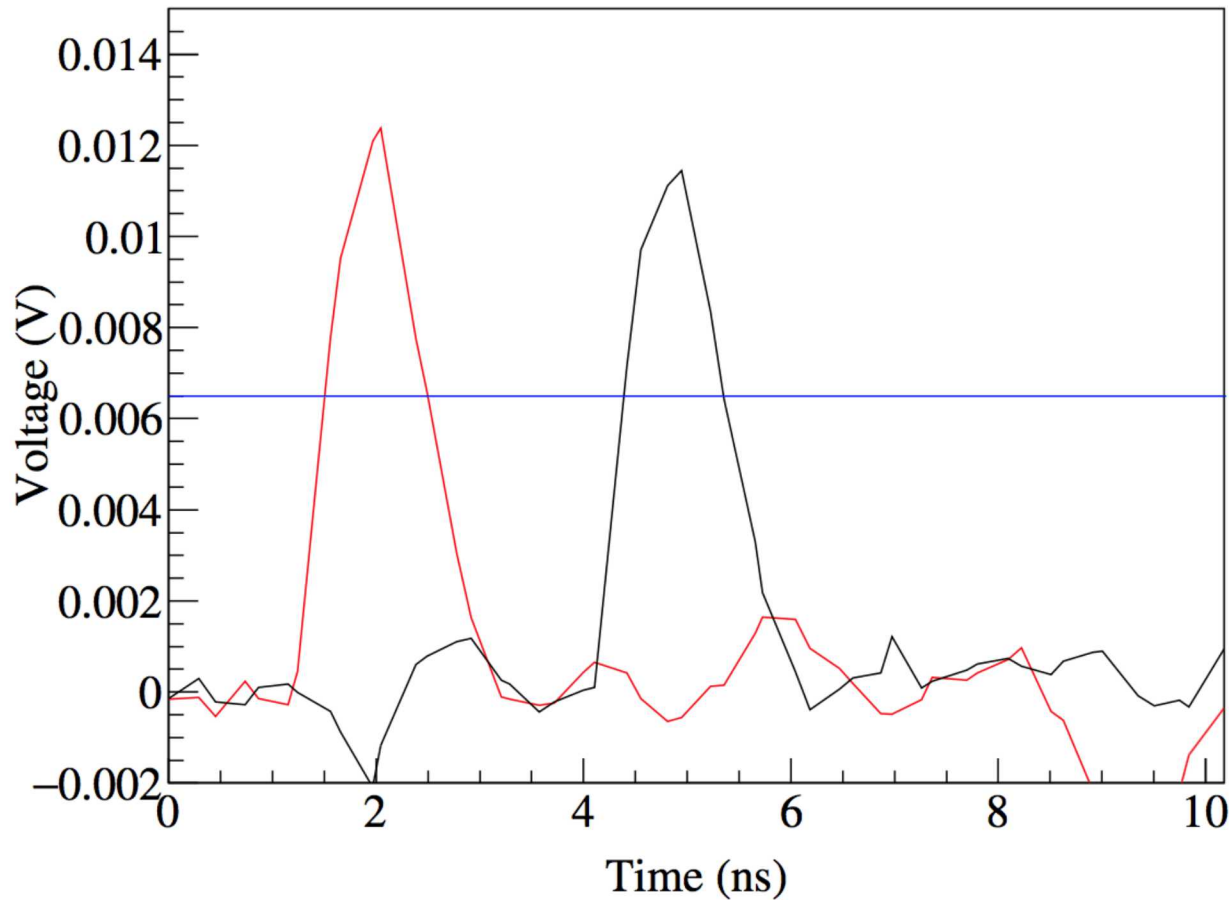


ANL: J. Elam, A. Mane, M. Gebhard

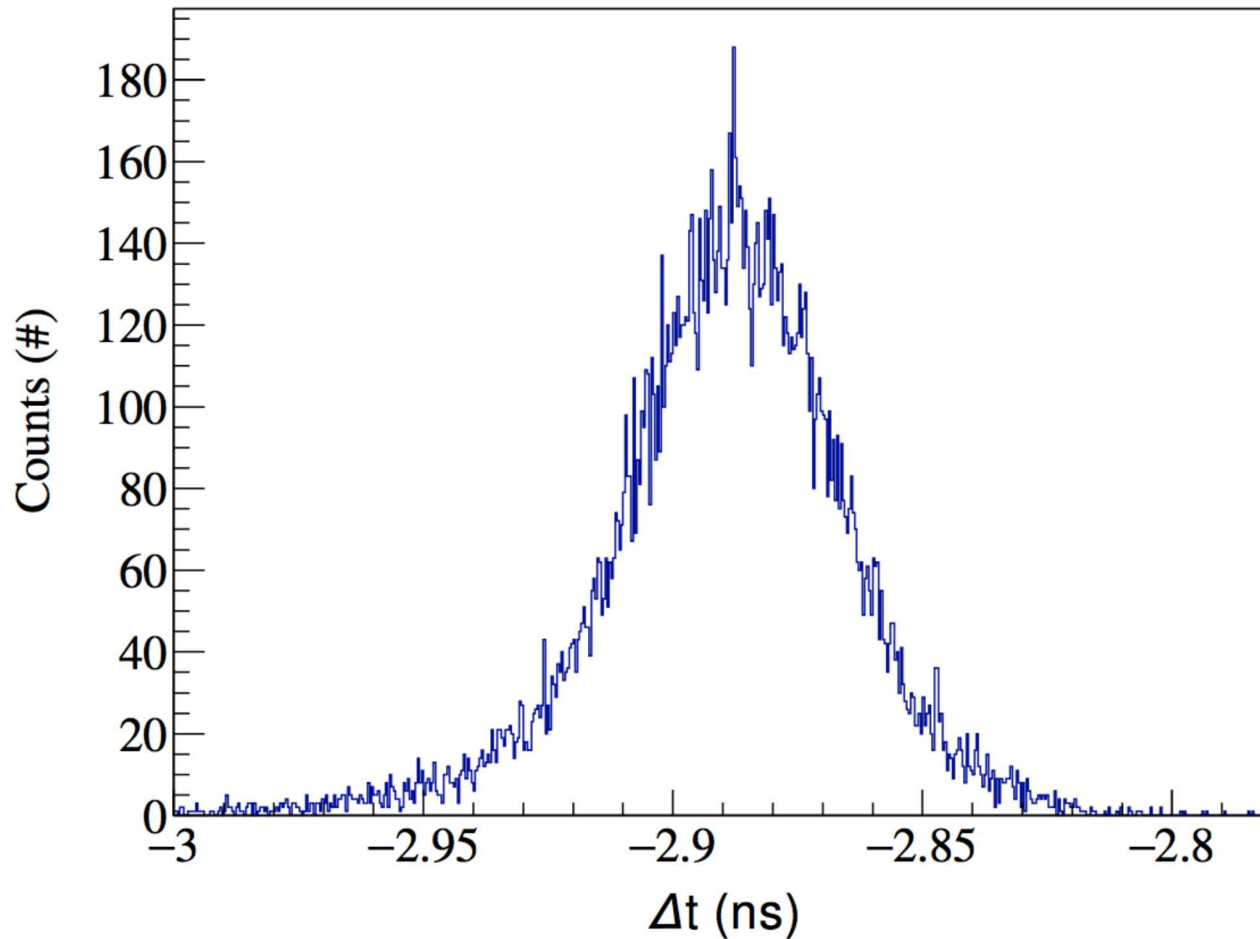




(a) Schematic of the layout for the pulse pair resolution test



(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.



(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