SAND2022-12298C

The Temporal Response of Fast Plastic Scintillators

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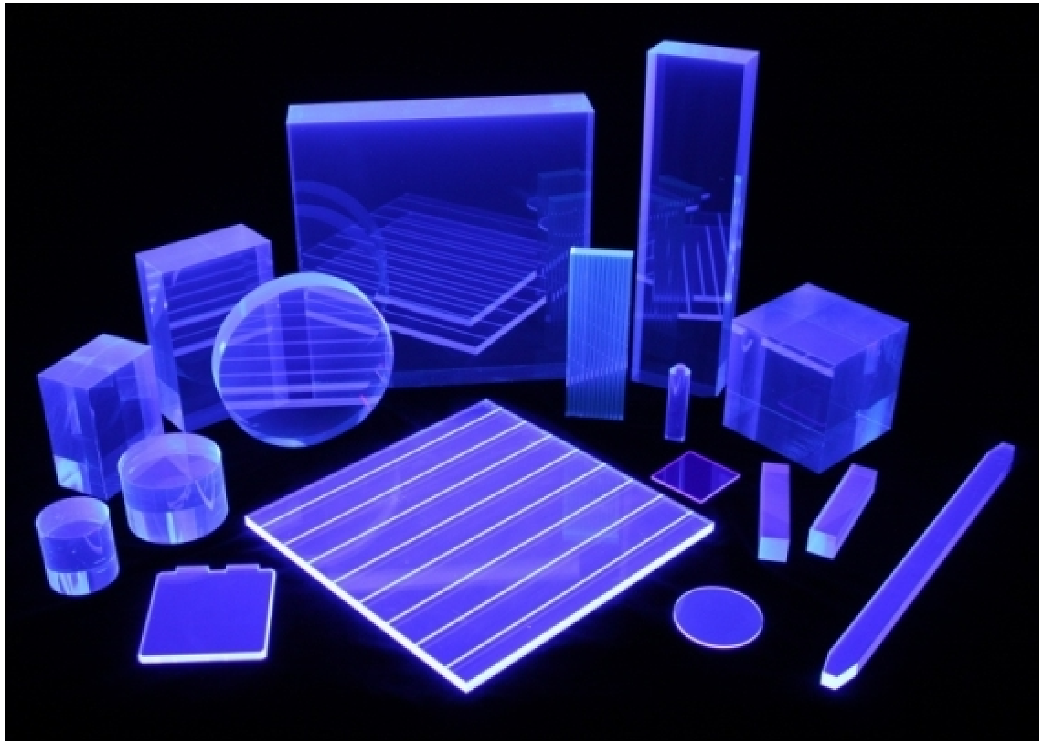

[1] Eljen Technologies. Plastic Scintillators. Photograph. eljentechnology.com/products/plastic-scintillators

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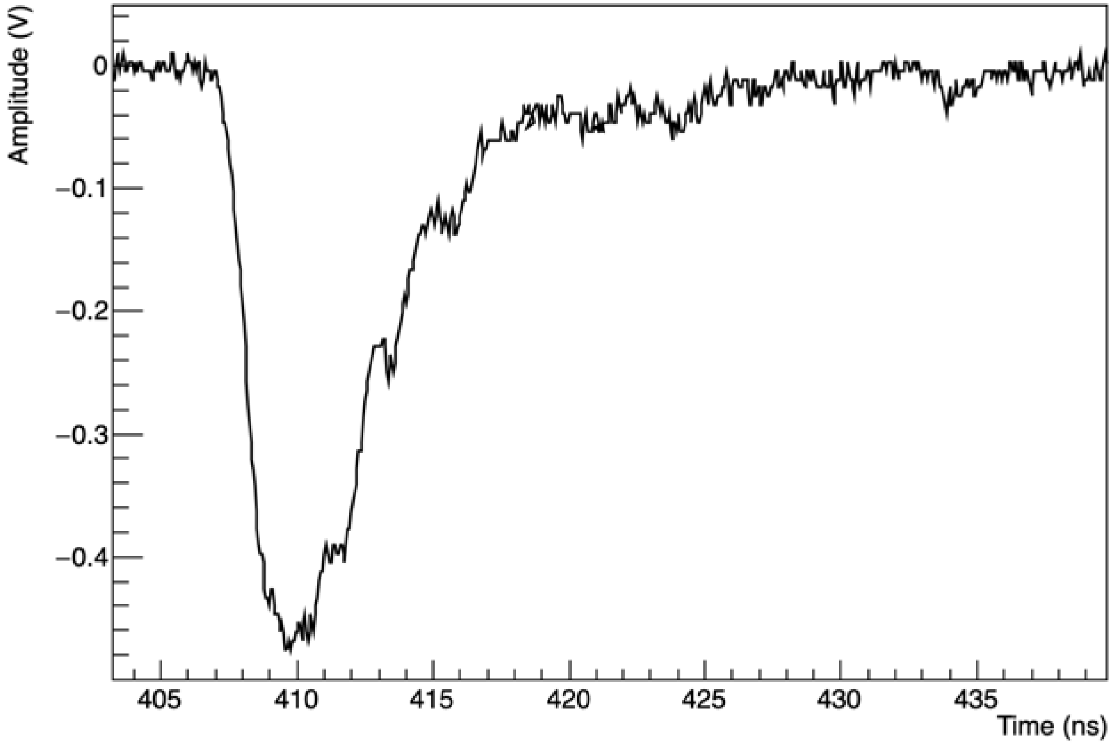
Outline

- Motivation/Application
- Theory of Time Correlated Single Photon Counting
- Experimental Setup
- Systematic Uncertainty
- Preliminary Results/Future Work



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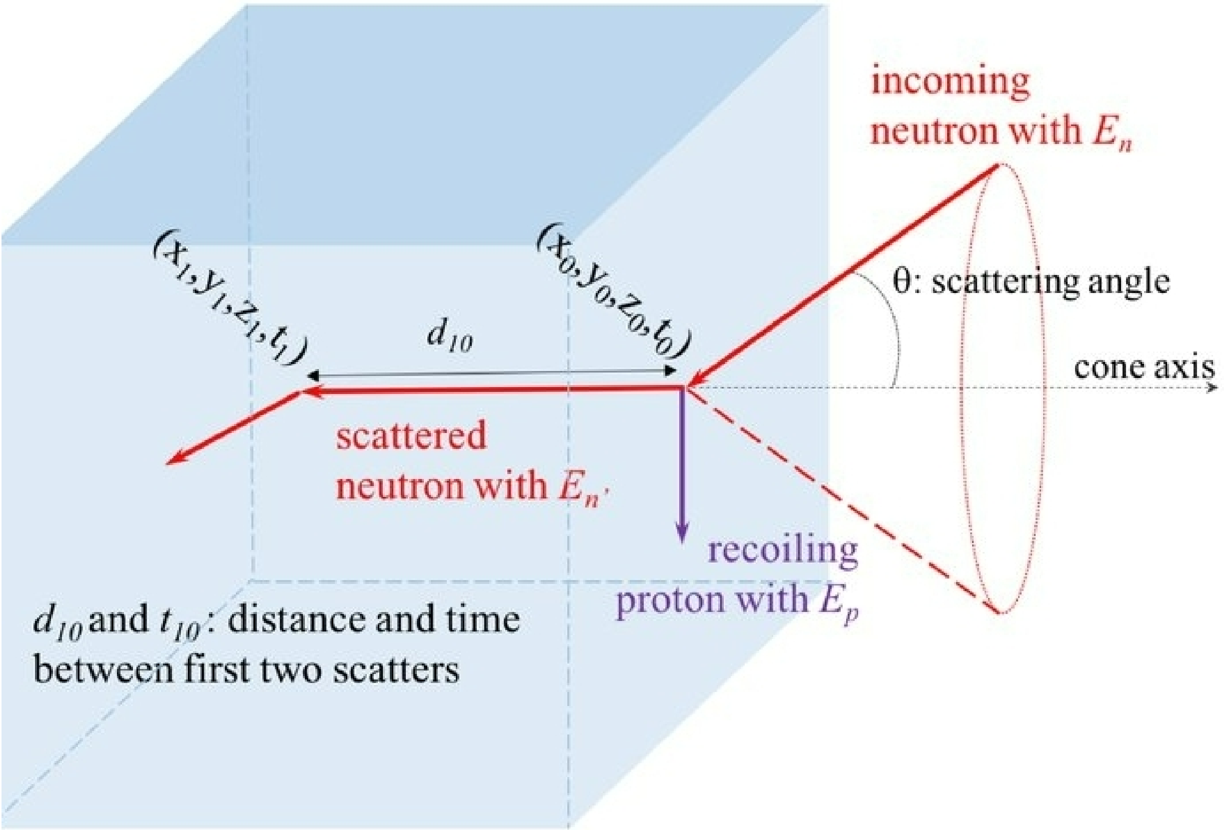
Motivation

- Light Intensity as a function of time
- Single Volume Scatter Camera
- Fundamental attribute of scintillators



[2] Manfredi, Juan J., et al. "The single-volume scatter camera." In *Hard X-Ray, Gamma-Ray, and Neutron Detector Physics XXII*, vol. 11494, pp. 121-131. SPIE, 2020.

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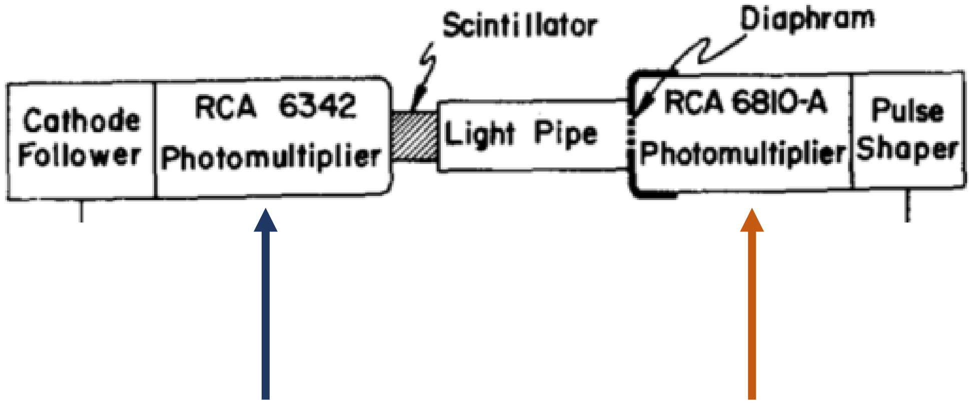
Motivation – Application

- Single Volume Scatter Camera
- Fundamental inputs for likelihood reconstruction and high-fidelity models of system response
- Meta-materials development
- Collaboration with Eljen Technologies

[3] Eljen Technologies. Eljen Technologies Logo. Logo. eljentechnology.com

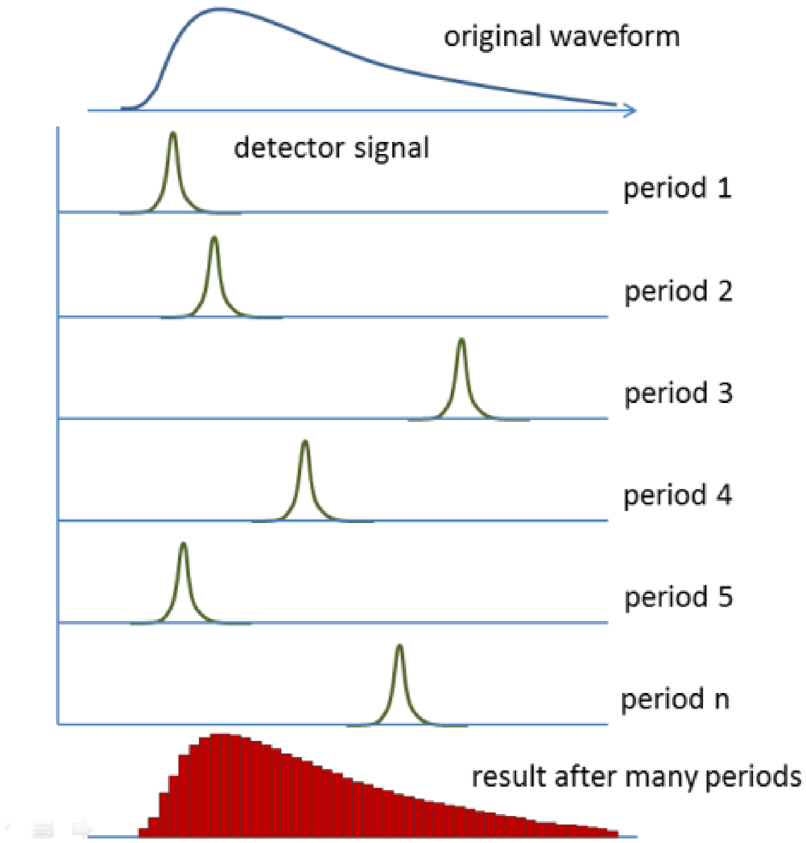
Time Correlated Single Photon Counting (TCSPC)

- Theory
  - Bollinger and Thomas



Primary PMT, observes t_0

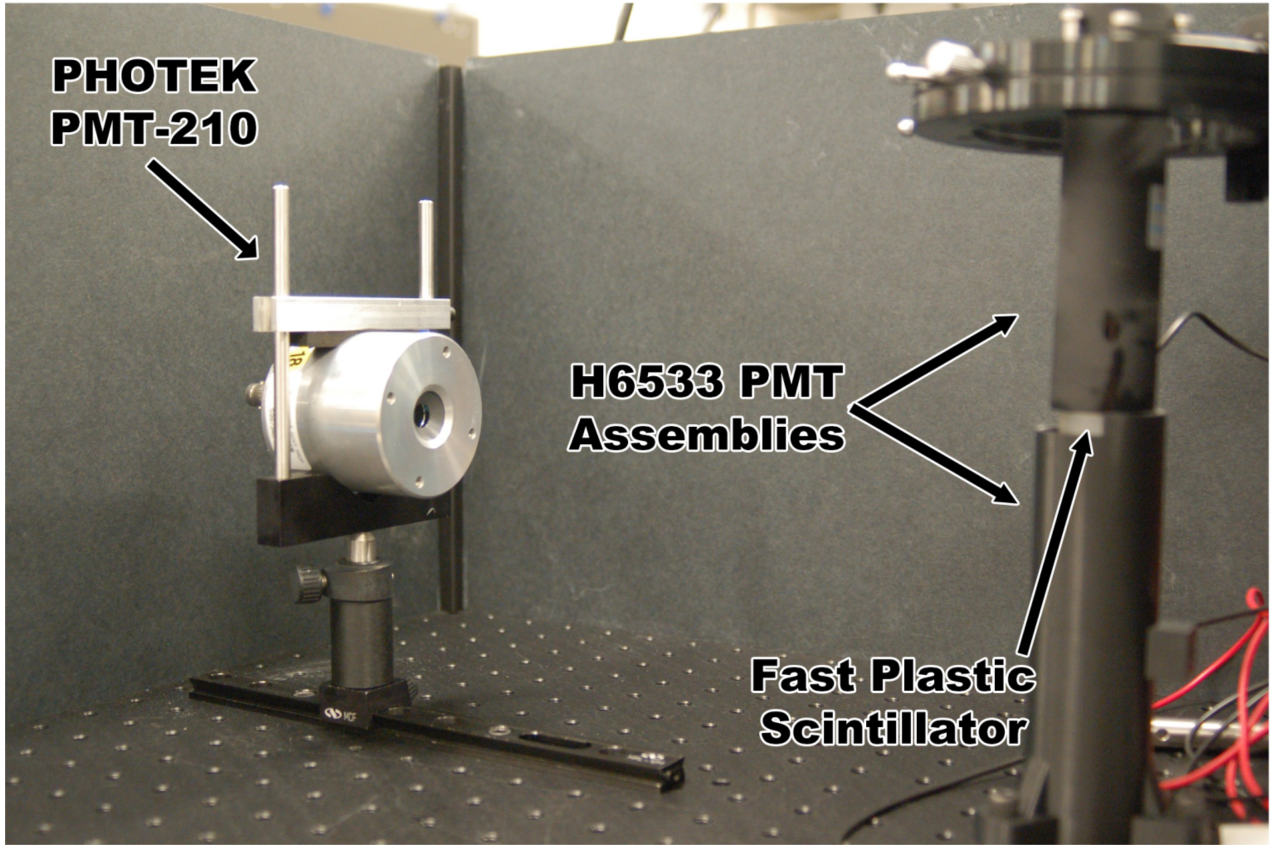
PMT "viewing" scintillation, observes t_{sp}



[4] QuTools. Time Correlated Single Photon Counting. Diagram. qutools.com/qutag/time-correlated-single-photon-counting/

Experimental Setup

- 2 closely coupled PMTs for more accurate t_0
  - Allows us to quantify t_0 uncertainty
  - Reduces t_0 uncertainty
- MCP-PMT at a standoff distance to ensure its only receiving single photons
- Standoff Distance v. Light pipe
- Systematic Uncertainty is dependent on the scintillator

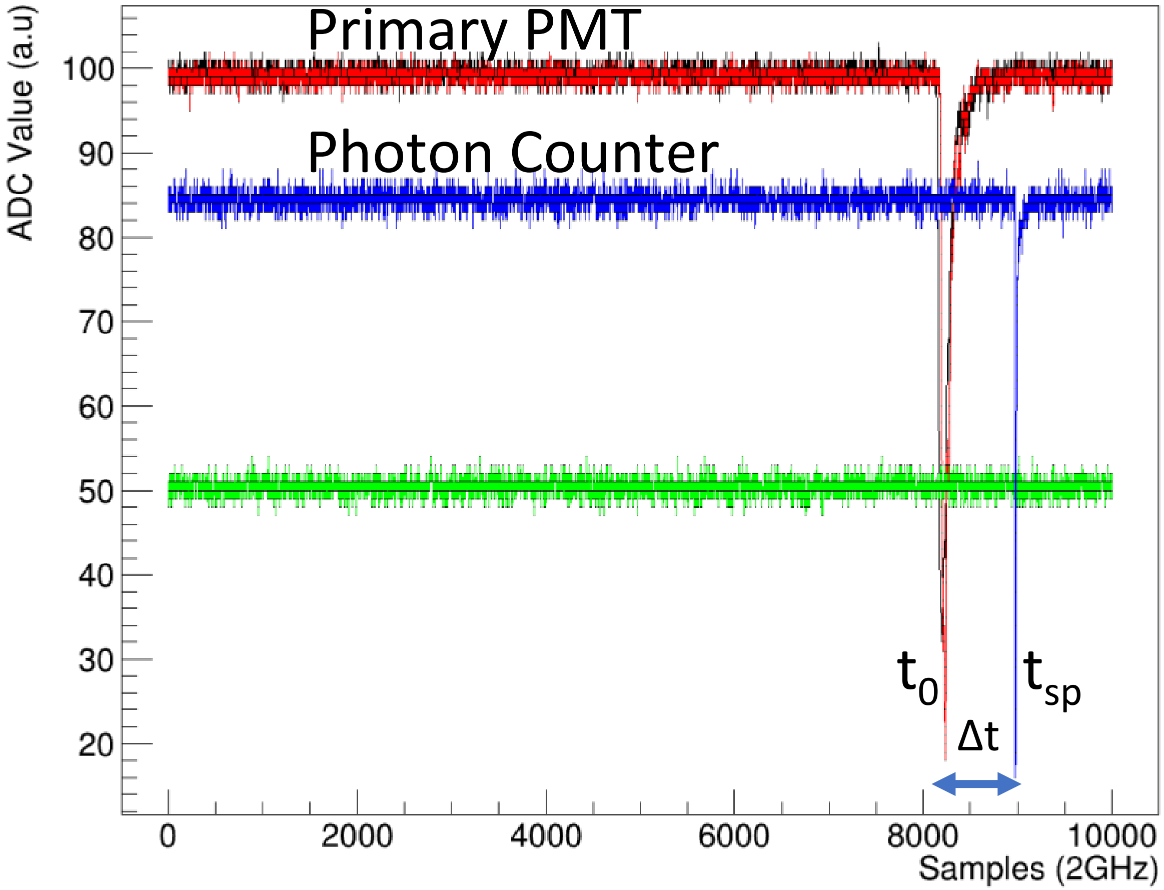


Quantity of Interest - Δt

Δt – the time between the primary PMT pulse and the photon counter pulse

Uncertainty Factors:

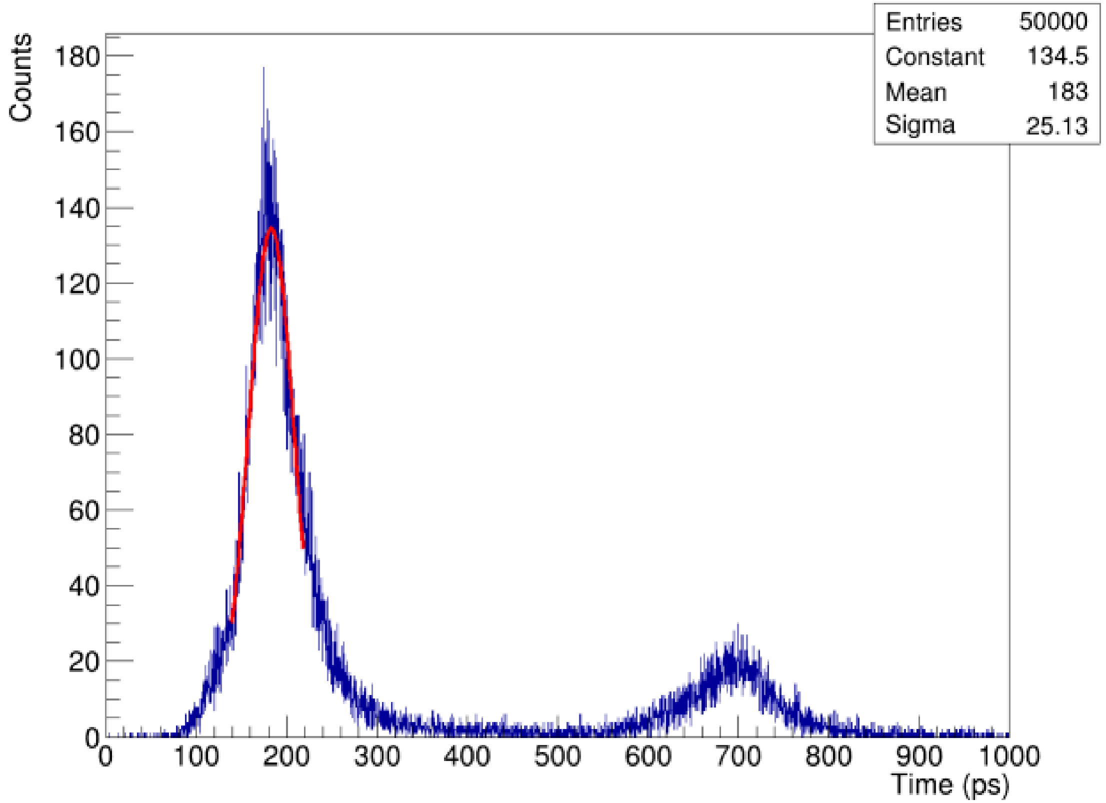
- Uncertainty of t_{sp} (Temporal Resolution of Photon Counter)
- Uncertainty of t_0
- Geometric Uncertainty (future work)



$$\Delta t = t_{sp} - t_0$$

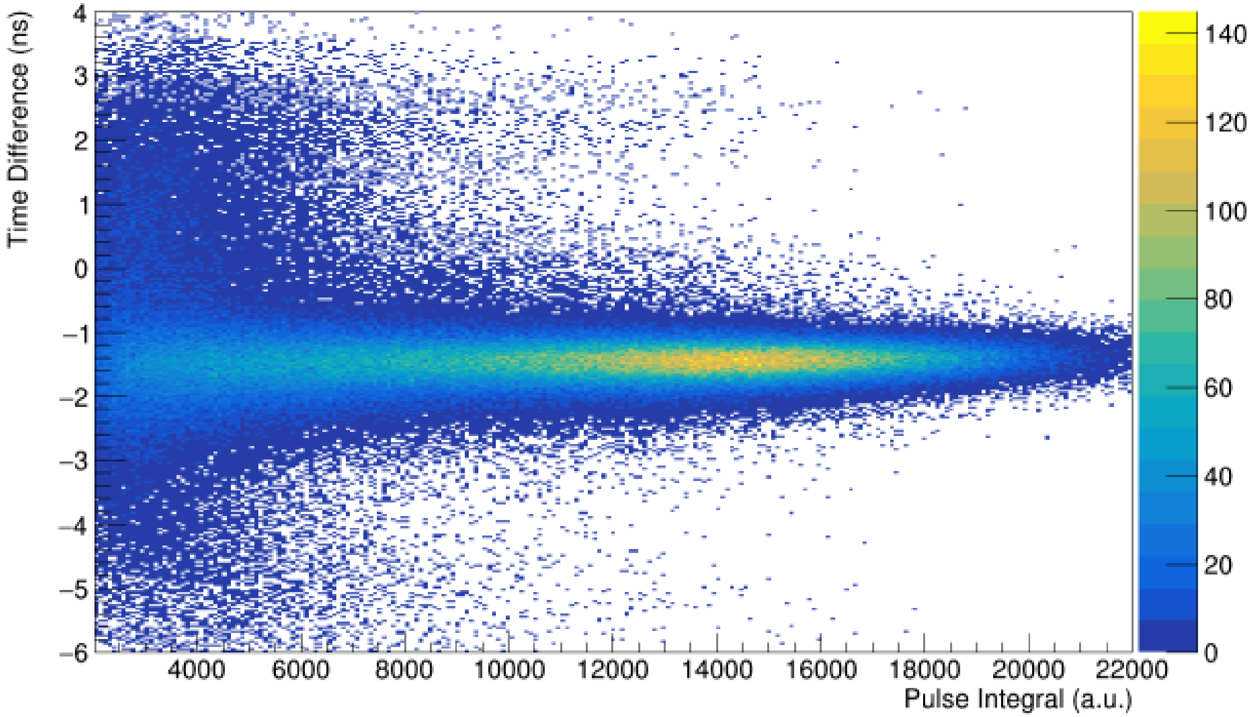
Uncertainty – t_{sp}

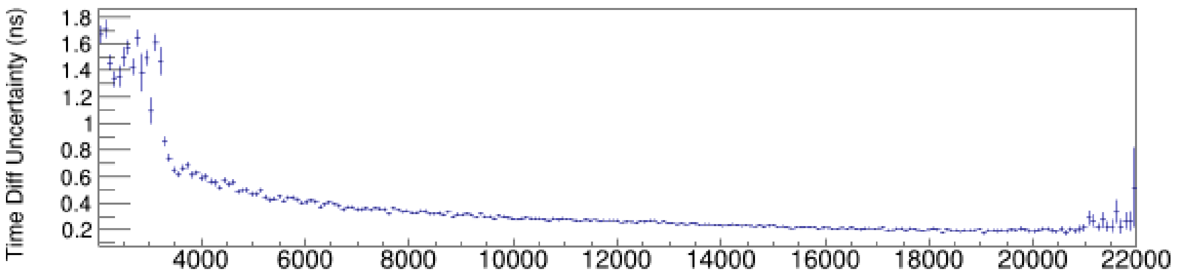
- Temporal Resolution of Photon Counter
- Fast, precise laser
- Time difference between laser sync signal and single photon pulse
- Fit a gaussian to that distribution in order to determine temporal resolution
- Temporal Resolution of PMT-210: 25.13ps



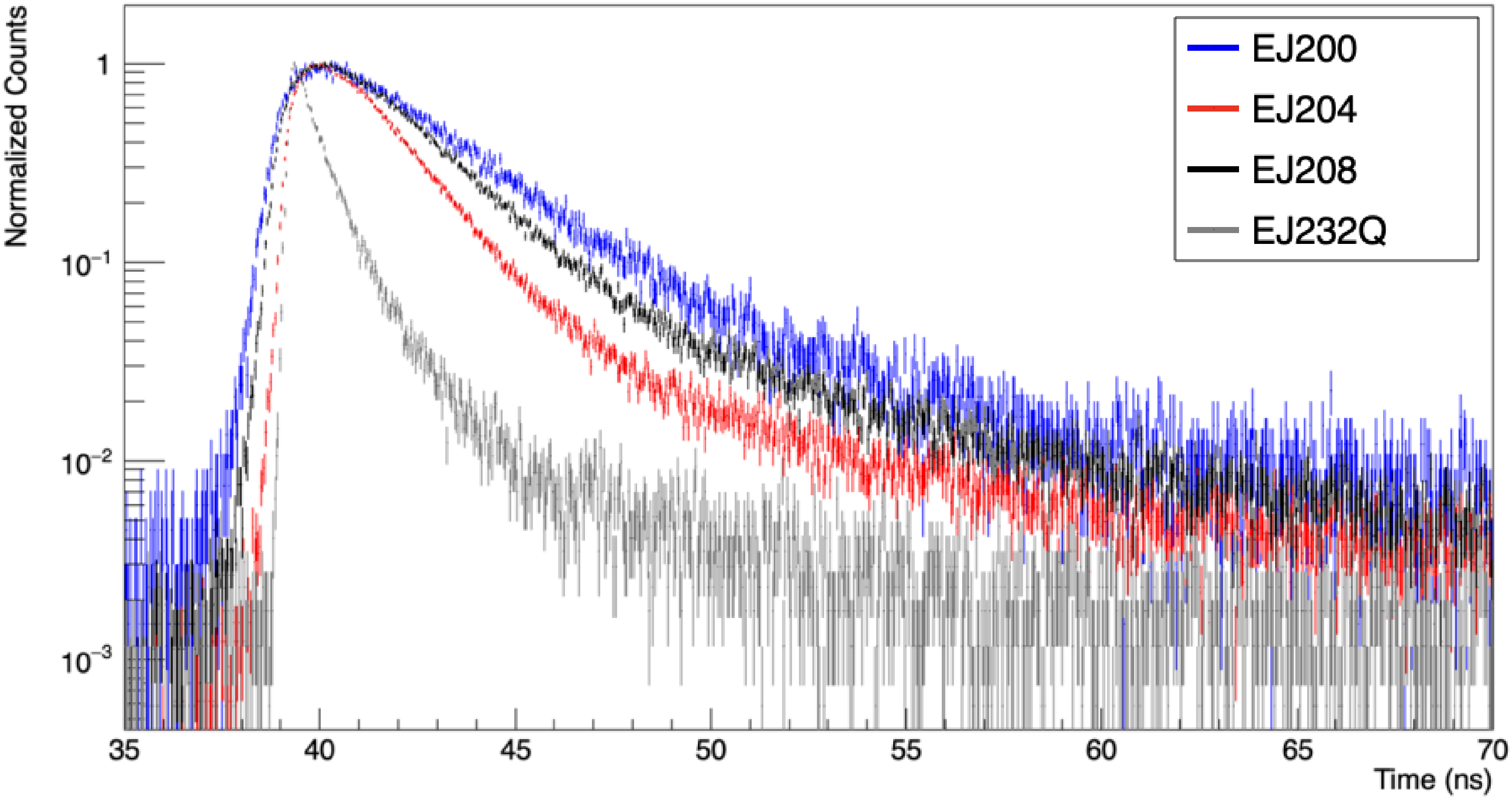
Uncertainty – t_0

- How accurately can we determine the beginning of a scintillation event?
- Measure the distribution of the difference between the 50% pickoff time of the two primary PMTs
- Dependent on scintillator being measured
- Dominant uncertainty
- t_0 Uncertainty for EJ-208: 117ps
    - EJ-232Q: 45.9ps

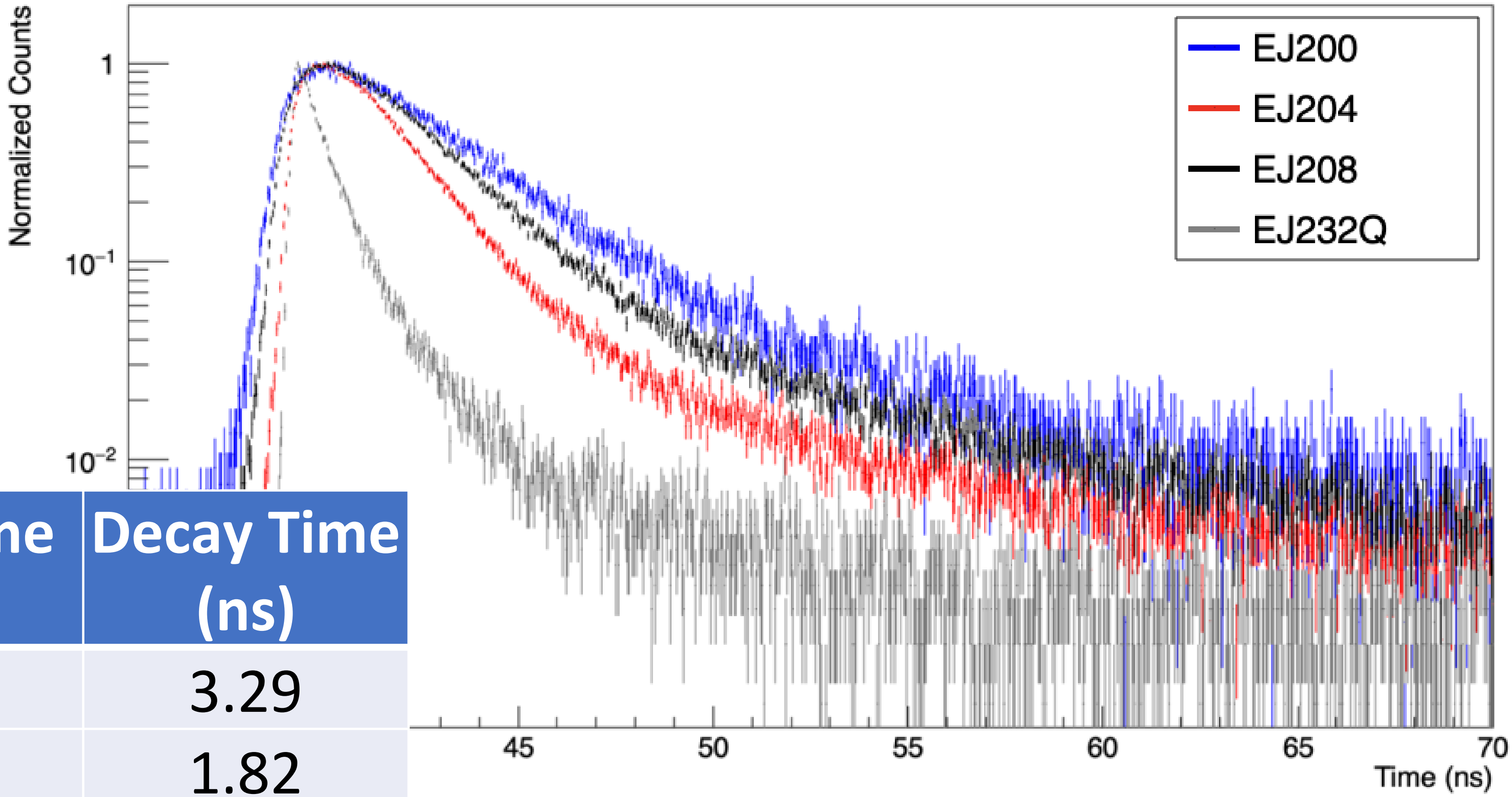




Preliminary Results



Preliminary Results



	Rise Time (ns)	Decay Time (ns)
EJ-200	1.16	3.29
EJ-204	0.68	1.82
EJ-208	0.96	2.48
EJ-232Q	0.25	0.81

Future Work

- Fitting Models to Data
- Cataloging a wider suite of scintillators with Eljen
  - Quantifying geometric uncertainty
- Neutron pure pulse shapes @ LBNL's 88-inch Cyclotron
  - Depending on the results of the Neutron measurements
    - Mixed field experiment
    - Particle isolation in mixed field

[3] Eljen Technologies. Eljen Technologies Logo. Logo. eljentechnology.com

[5] Lawrence Berkeley National Laboratory. LBNL Logo. Logo. creative.lbl.gov/visual-identity/

Acknowledgements

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Appendix
Supplementary Slides

Abstract

A Time Correlated Single Photon Counting (TCSPC) system was developed at Sandia National Laboratories capable of measuring scintillator pulse shapes in response to neutron and gamma irradiation with resolution of approximately 30 ps. The system was designed to minimize the primary contributors to the temporal uncertainty in a TCSPC measurement. The results of this research and development effort will be presented along with preliminary measurements of the temporal response of a series of fast plastic scintillators. These data provide fundamental inputs for likelihood reconstruction approaches to neutron imaging and high-fidelity models of system response for detectors employing these fast plastic scintillators.

Why TCSPC

- Why not just couple the PMT210 to the scintillator?
- MCPs suffer from gain fluctuations, and long recovery time
  - Not guaranteed to accurately capture a scintillation pulse when closely coupled
  - These concerns are mitigated by loosely coupling the PMT210 to count single photons
  - Easy to saturate?
  - Long dead time because of high resistance?
- When an MCP is irradiated by a pulsed electron current, a positive charge is generated at the MCP output end in accordance with the released electron current. This phenomenon deforms the potential distribution and weakens the electric fields so that the subsequenct electron multiplication is suppressed.
- saturation

Cable Delay Validation

- The PMT210 pulse needs to occur after the primary pulse so that we can prime our oscilloscope on the primary pulse and trigger on a PMT210 pulse. This assures that we collect the long tails of the temporal response
- Add a cable delay to the PMT210
- Increased cable length brings with it increase capacitance and therefore the possibility of increased jitter

Uncertainty – Zero-time pickoff

Measured Quantity:

$$\Delta t = t_1 - t_2$$

MQ Uncertainty:

$$\sigma_{\Delta t}^2 = \sigma_{t_1}^2 + \sigma_{t_2}^2$$

Assume $\sigma_{t_1}^2 = \sigma_{t_2}^2$ and solve for $\sigma_{\Delta t}$

$$\sigma_{\Delta t}^2 = 2\sigma_{t_1,t_2}^2$$

$$\sigma_{\Delta t} = \sqrt{2}\,\sigma_{t_1,t_2}$$

Quantity of Interest:

$$t_0 = \frac{1}{2}(t_1 + t_2)$$

QoI Uncertainty:

$$\sigma_{t_0}^2 = \left(\frac{1}{2}\right)^2 \sigma_{t_1}^2 + \left(\frac{1}{2}\right)^2 \sigma_{t_2}^2$$

Recall $\sigma_{\Delta t}^2 = 2\sigma_{t_1,t_2}^2$ and substitute

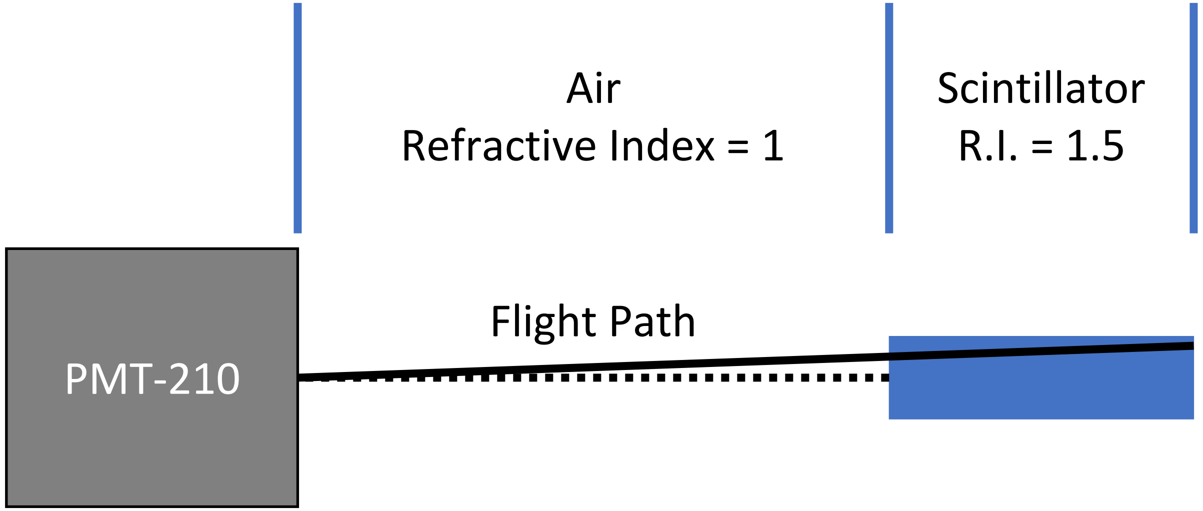
$$\sigma_{t_0}^2 = 2\left(\frac{1}{4}\right)\sigma_{t_1,t_2}^2 = \frac{1}{2}(\frac{1}{2}\,\sigma_{\Delta t}^2)$$

$$\sigma_{t_0}^2 = \frac{1}{4}\sigma_{\Delta t}^2$$

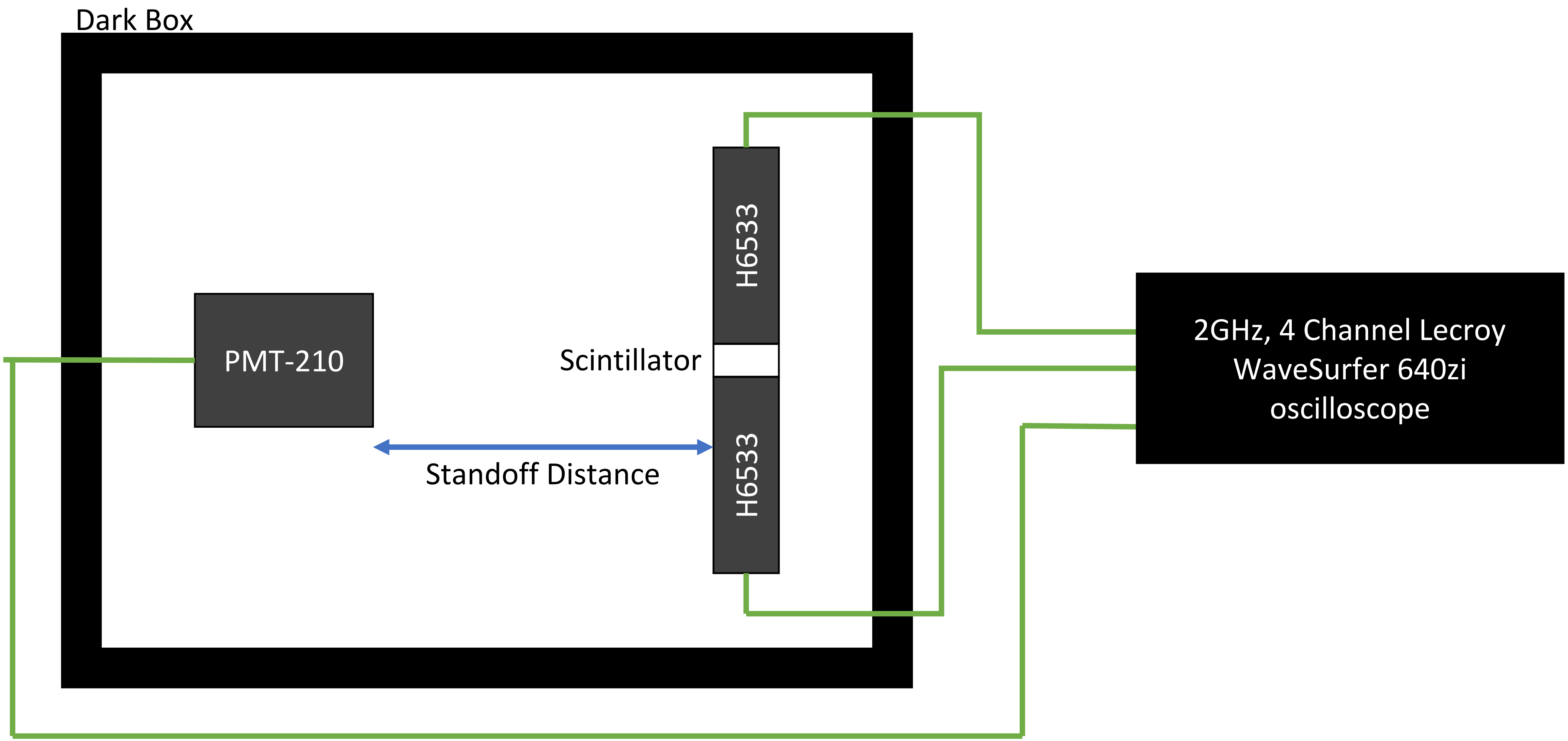
$$\sigma_{t_0} = \frac{1}{2}\sigma_{\Delta t}$$

Uncertainty – Geometric

- How does the shape and size of a scintillator effect our uncertainty?
- Simplified Model:
  - Sampling n points in a cylindrical volume using Monte Carlo methods
  - Predicted Uncertainty: ~15ps
- Practical
  - Test new suite of scintillators with varying shapes and sizes



Experimental Setup



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