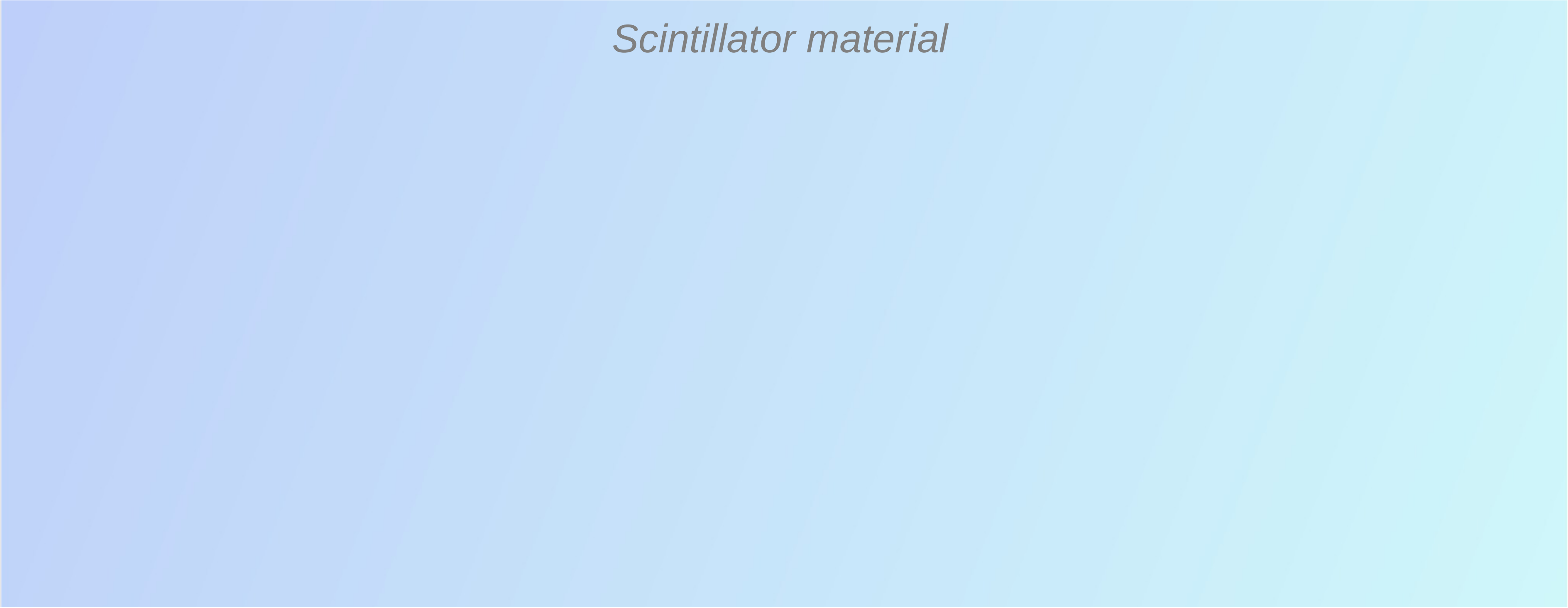
# Neutron-Induced Scintillation in Organics

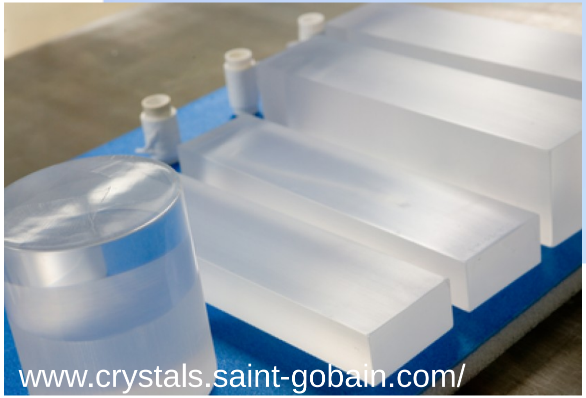
NICHOLAI MAURITZSON
DEPARTMENT OF PHYSICS | FACULTY OF SCIENCE | LUND UNIVERSITY

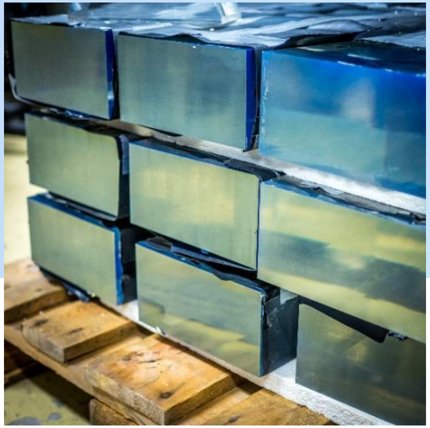
# Scintillation principle

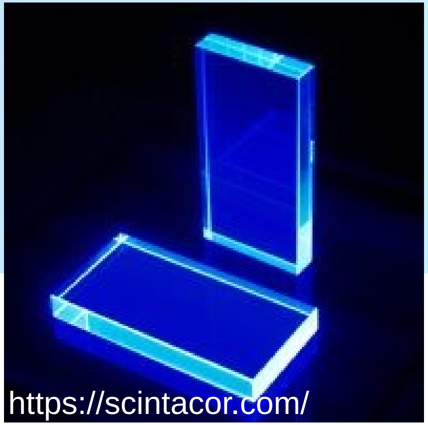


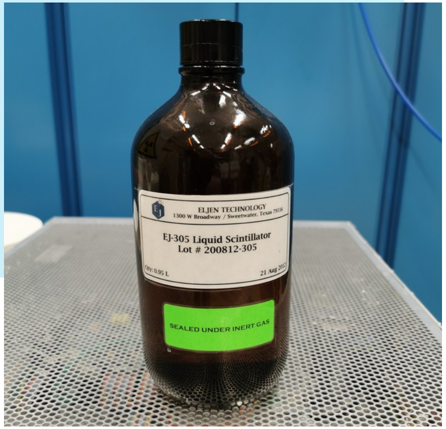
# Scintillation principle

*Scintillator material*





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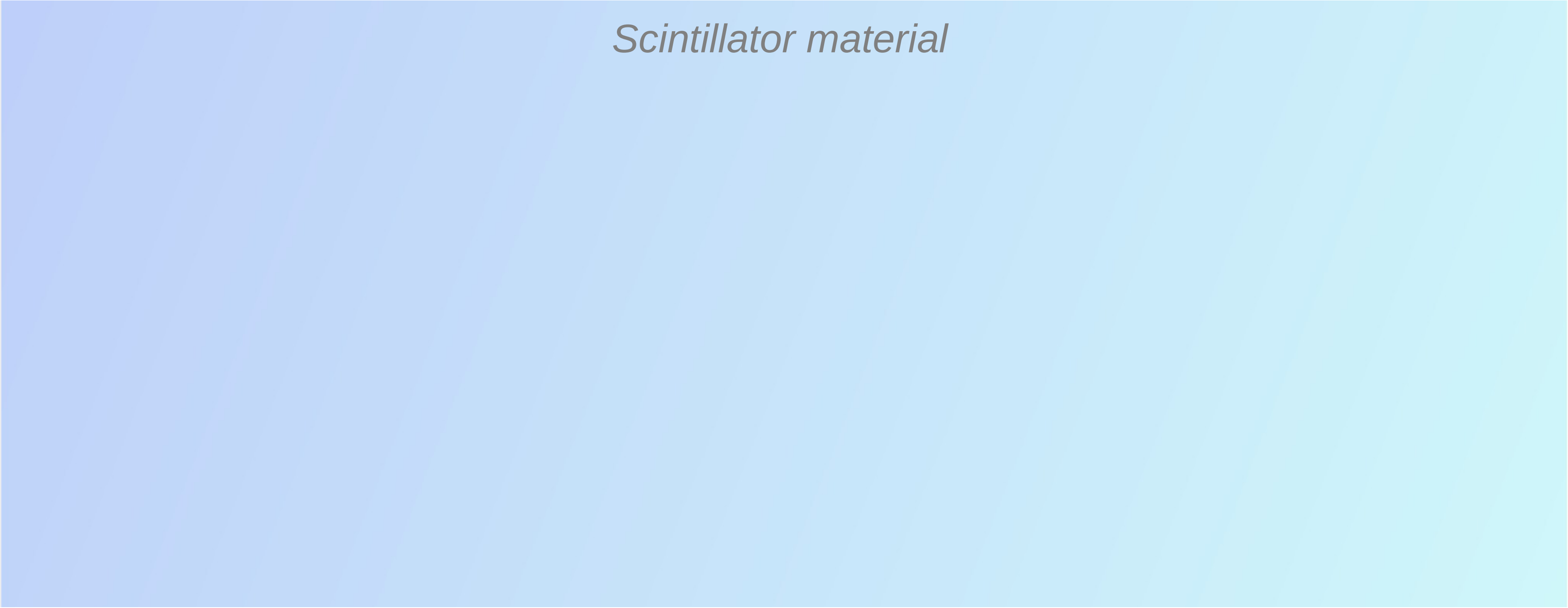

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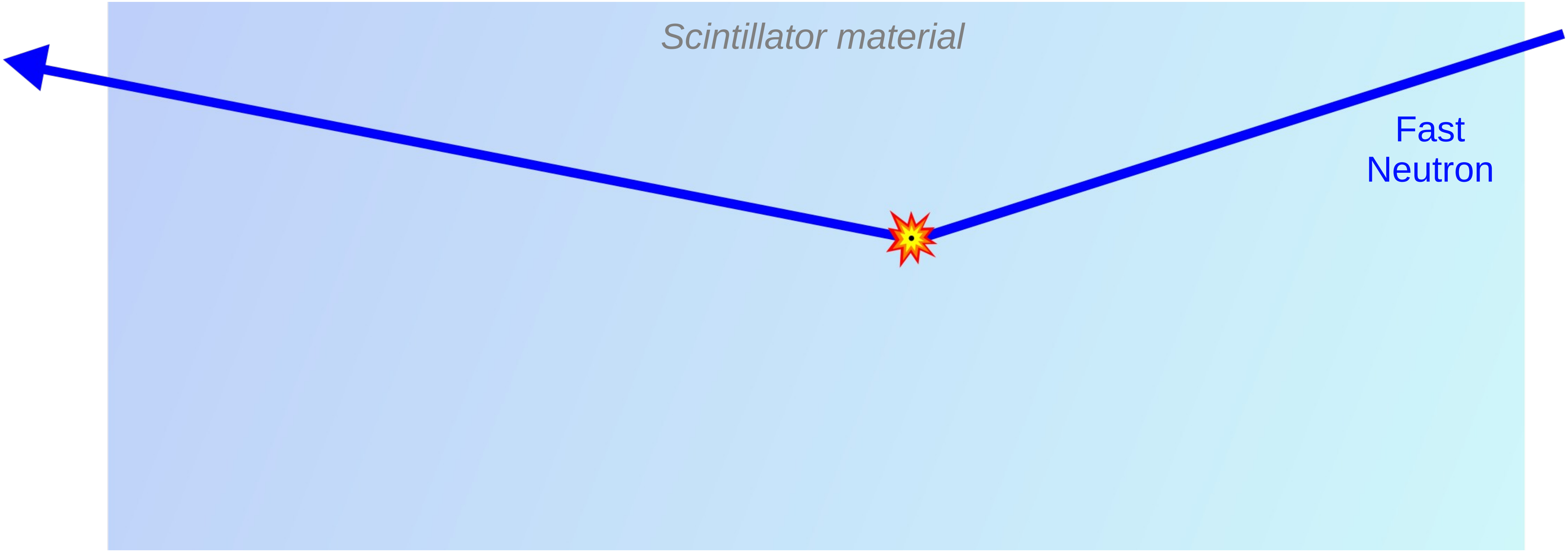

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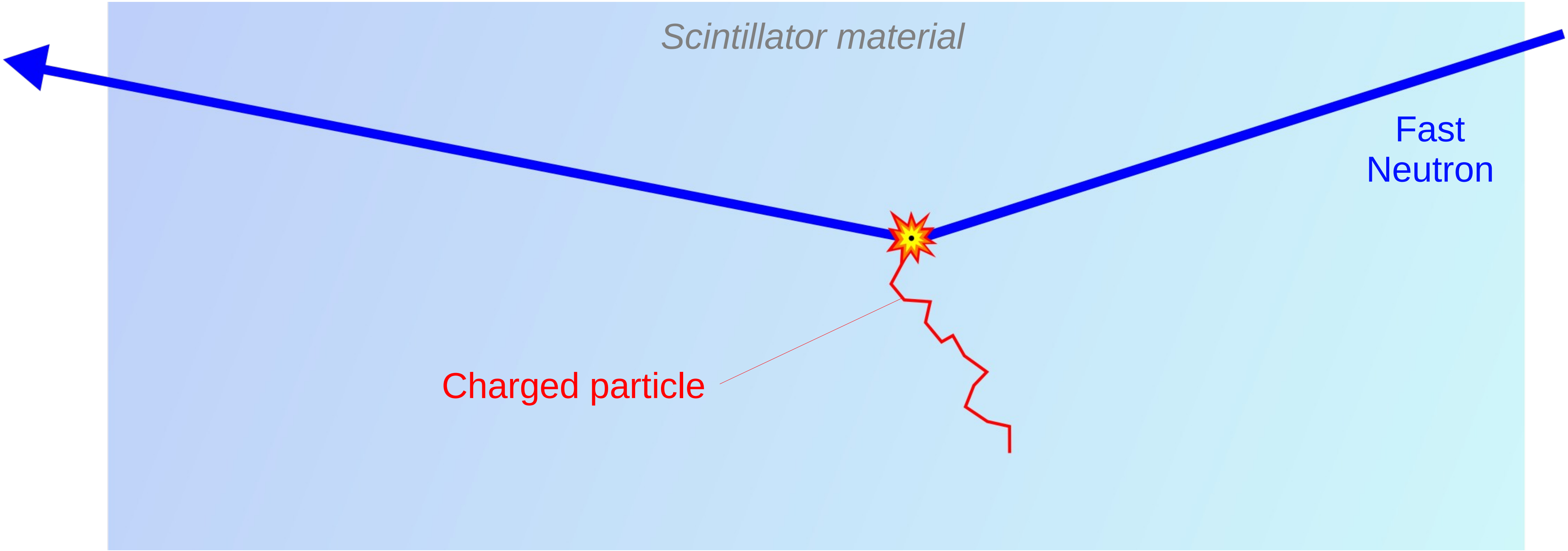

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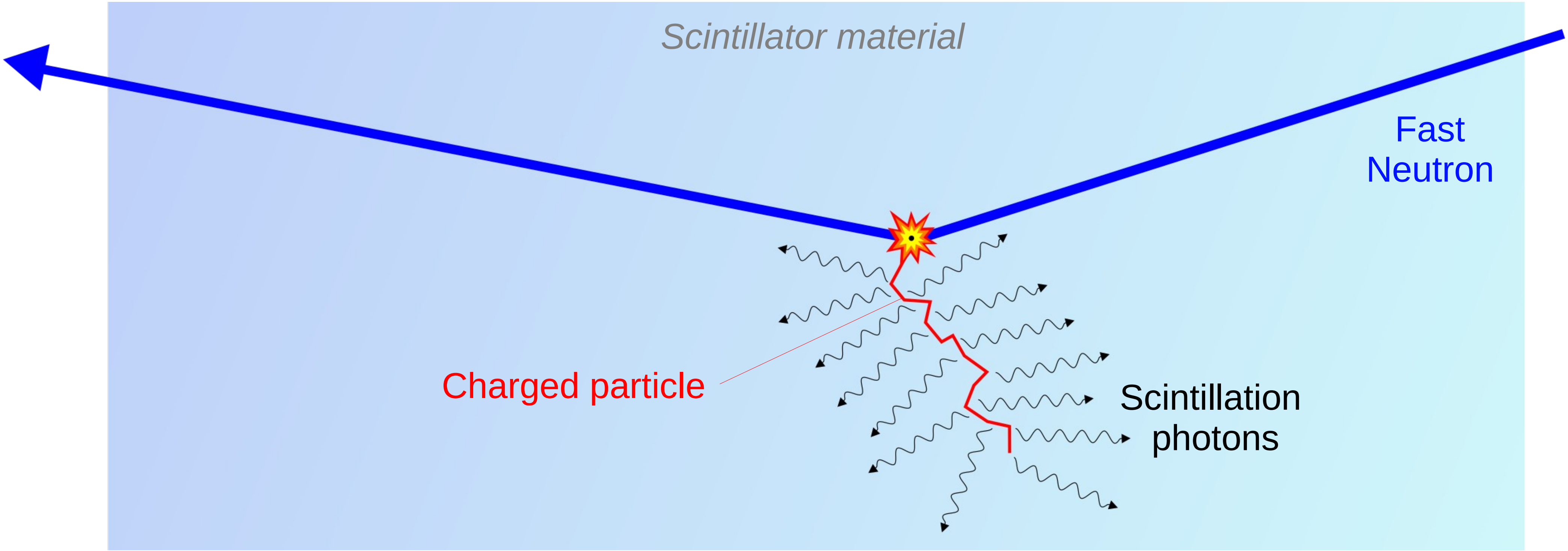

# Organic Scintillators

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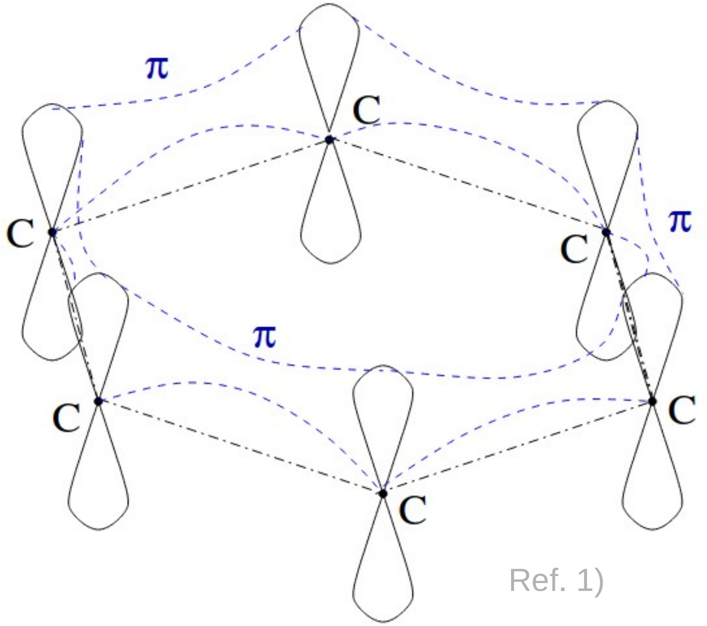
A Symmetric Hydrocarbon!




Ref. 1)

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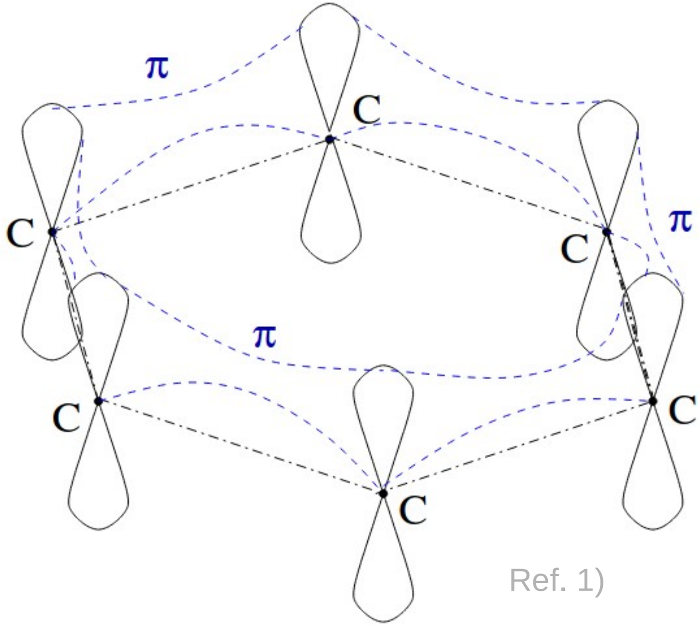


Ref. 1)

- Toulene ($C_7H_8$)
- Xylene ($C_8H_{10}$)
- Pseudocumene ($C_9H_{12}$)

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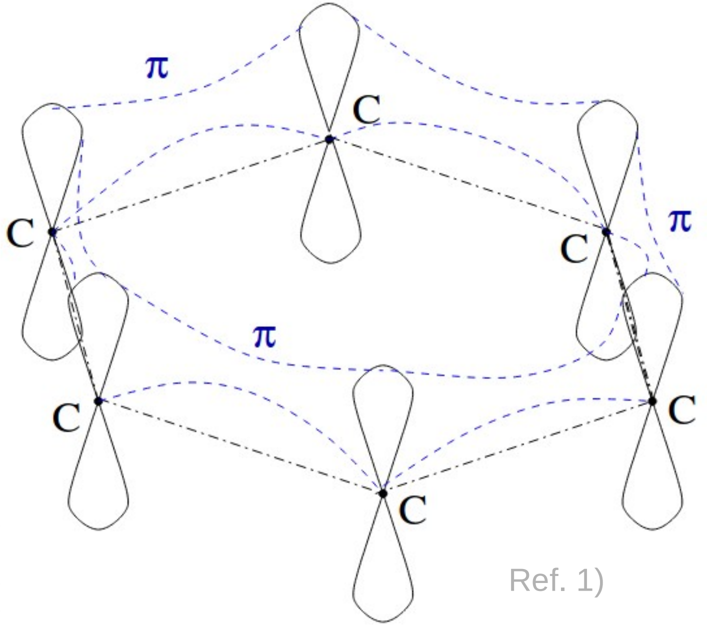

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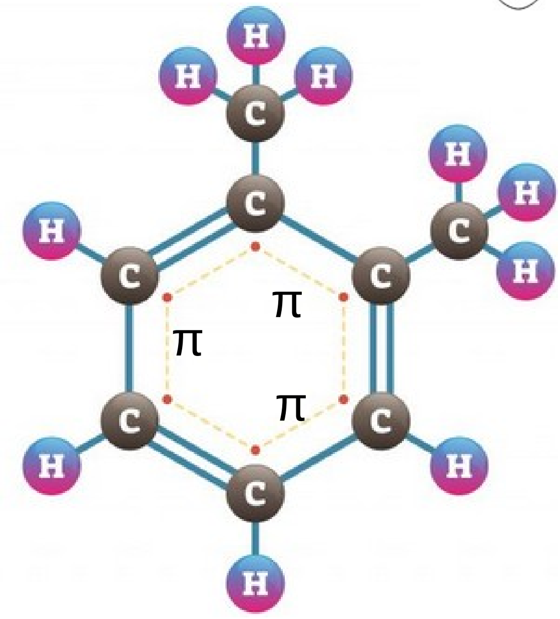

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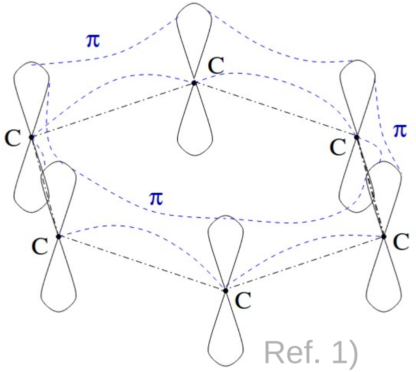


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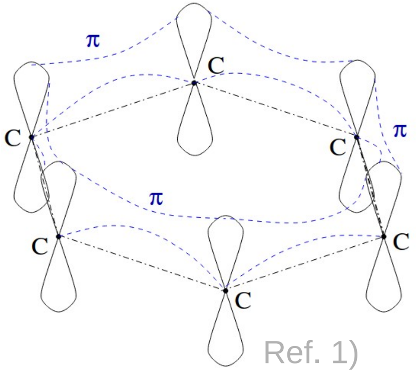


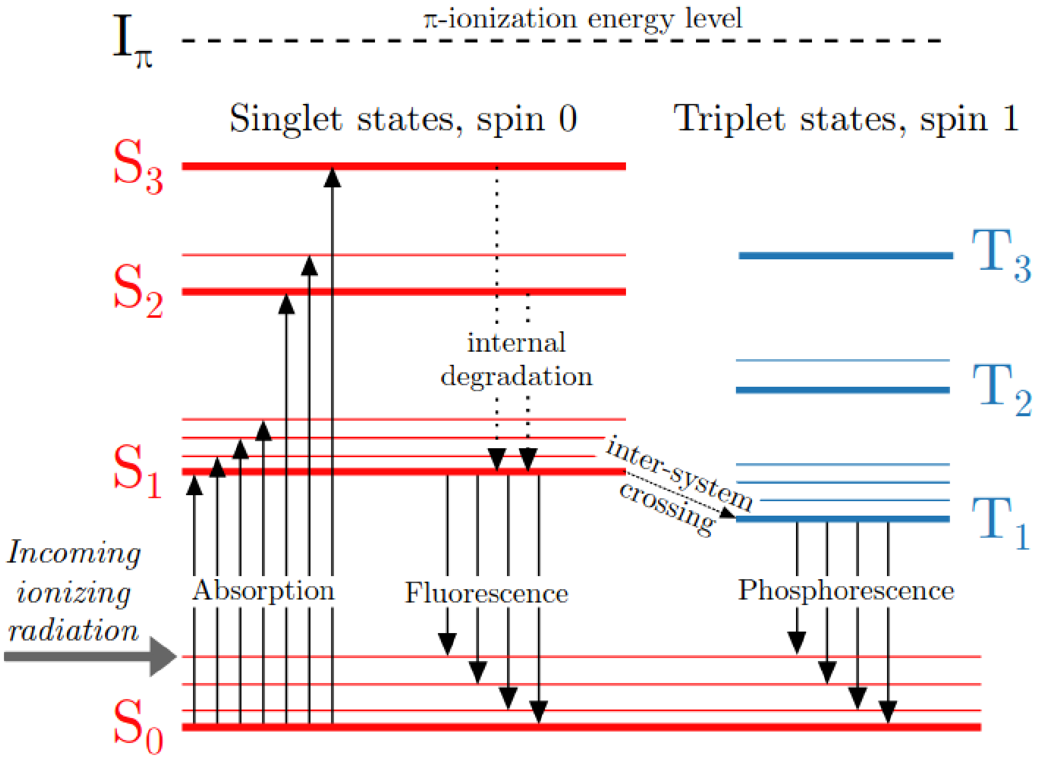

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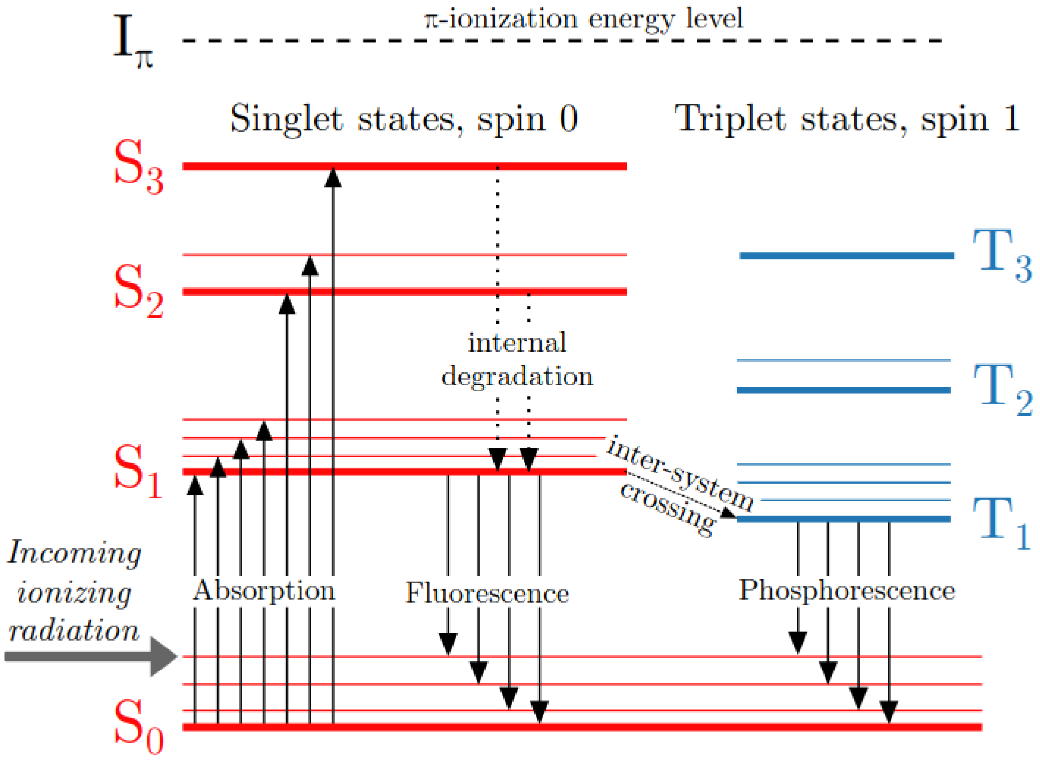


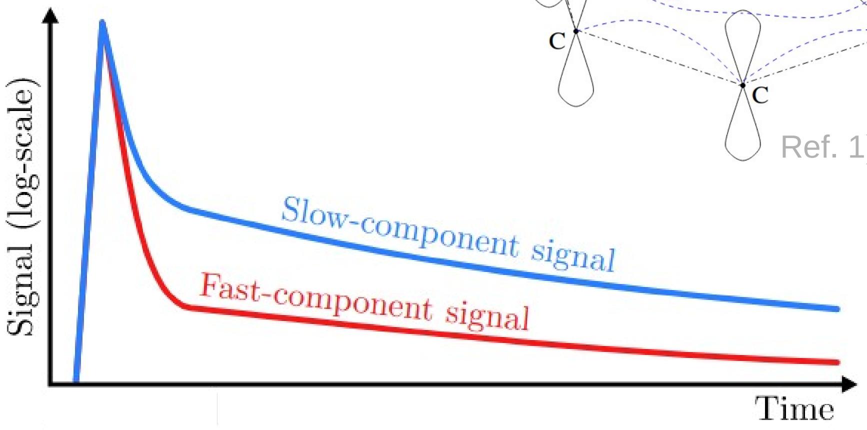


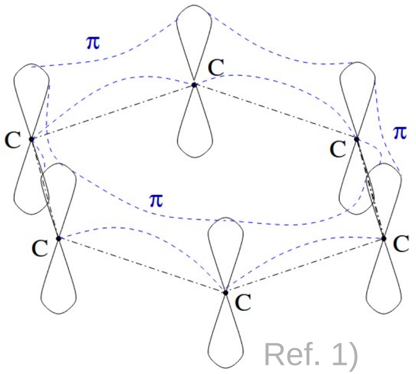


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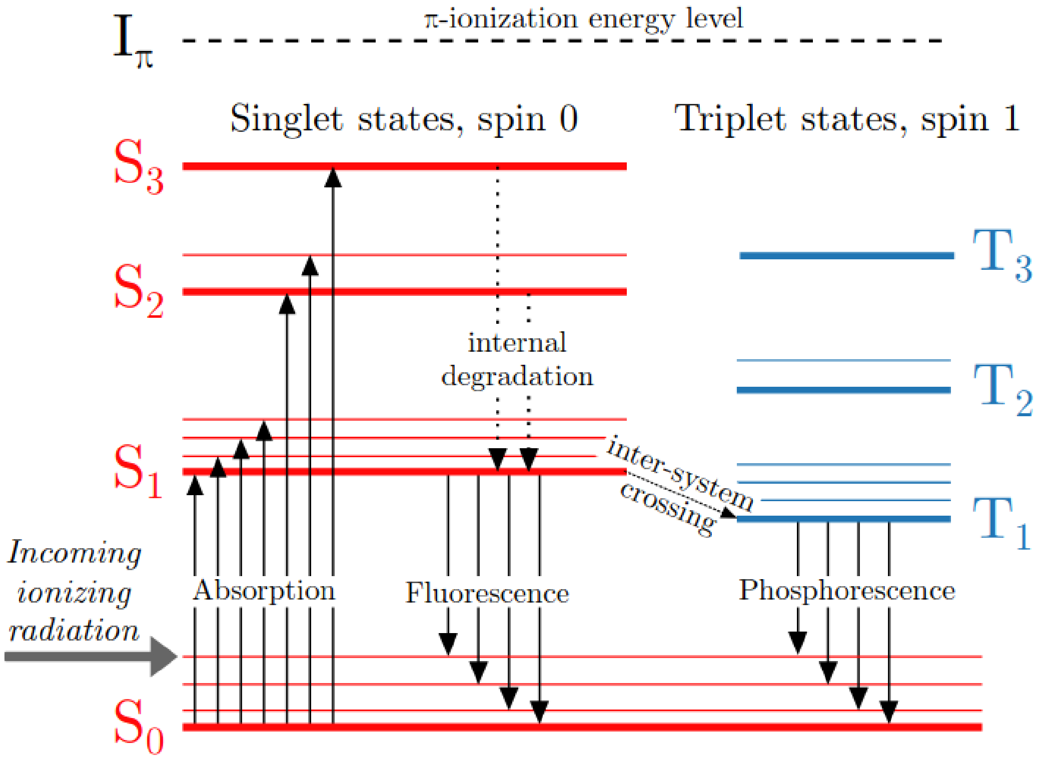


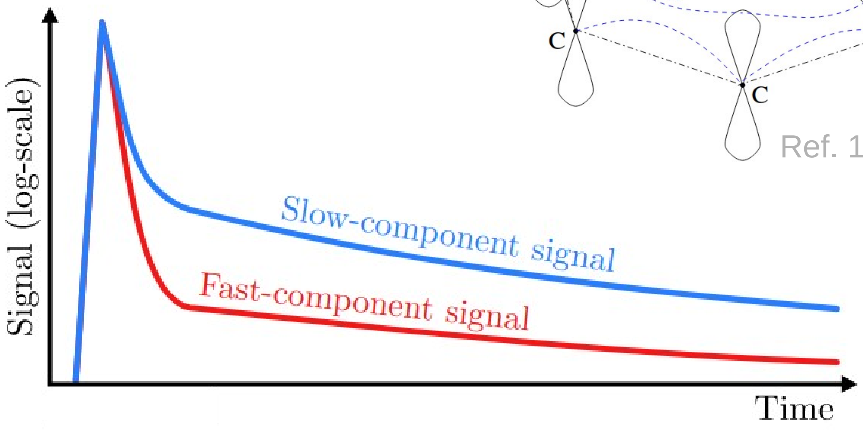


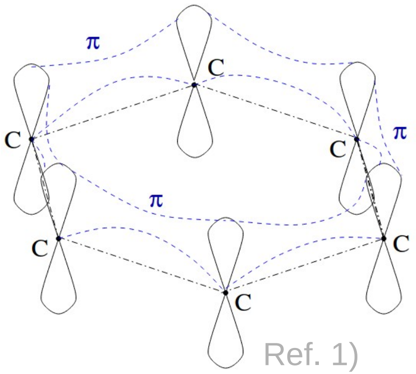


Ref. 1)

High ionization density: more slow component (protons, alphas …)

Low ionization density: less slow component (electrons)

# Light Output

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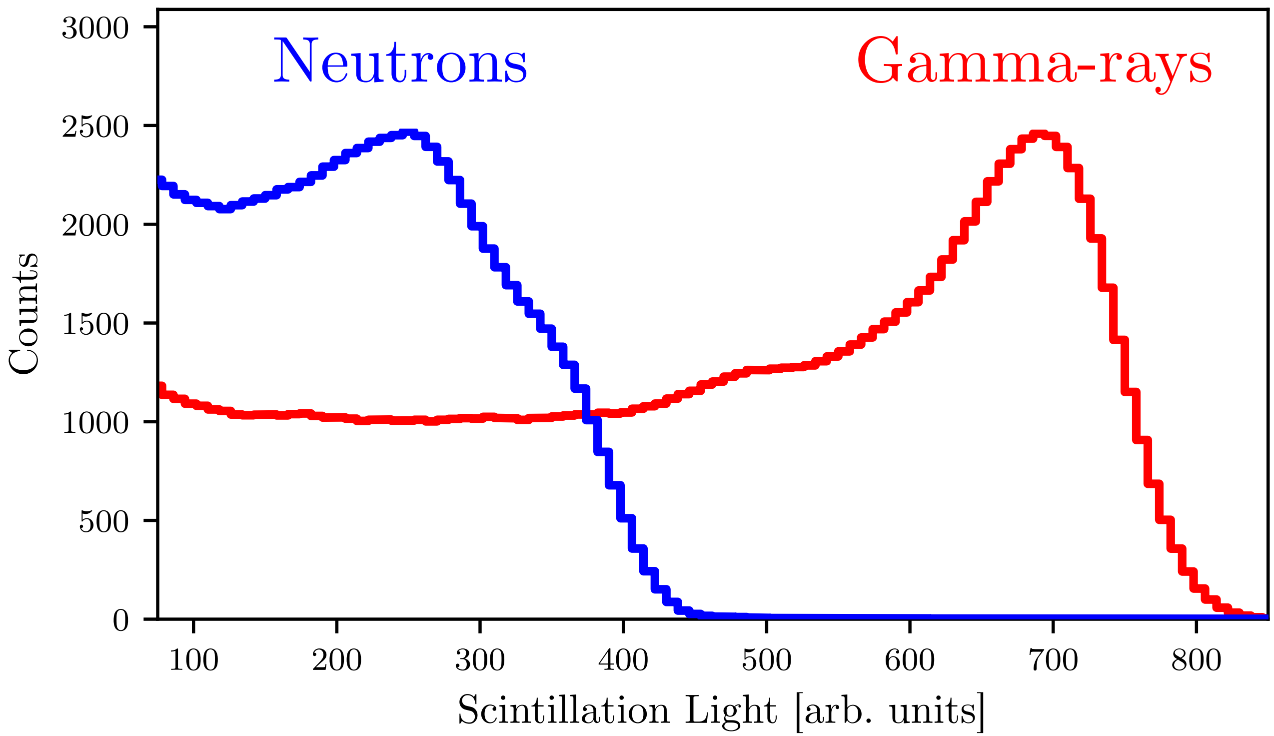

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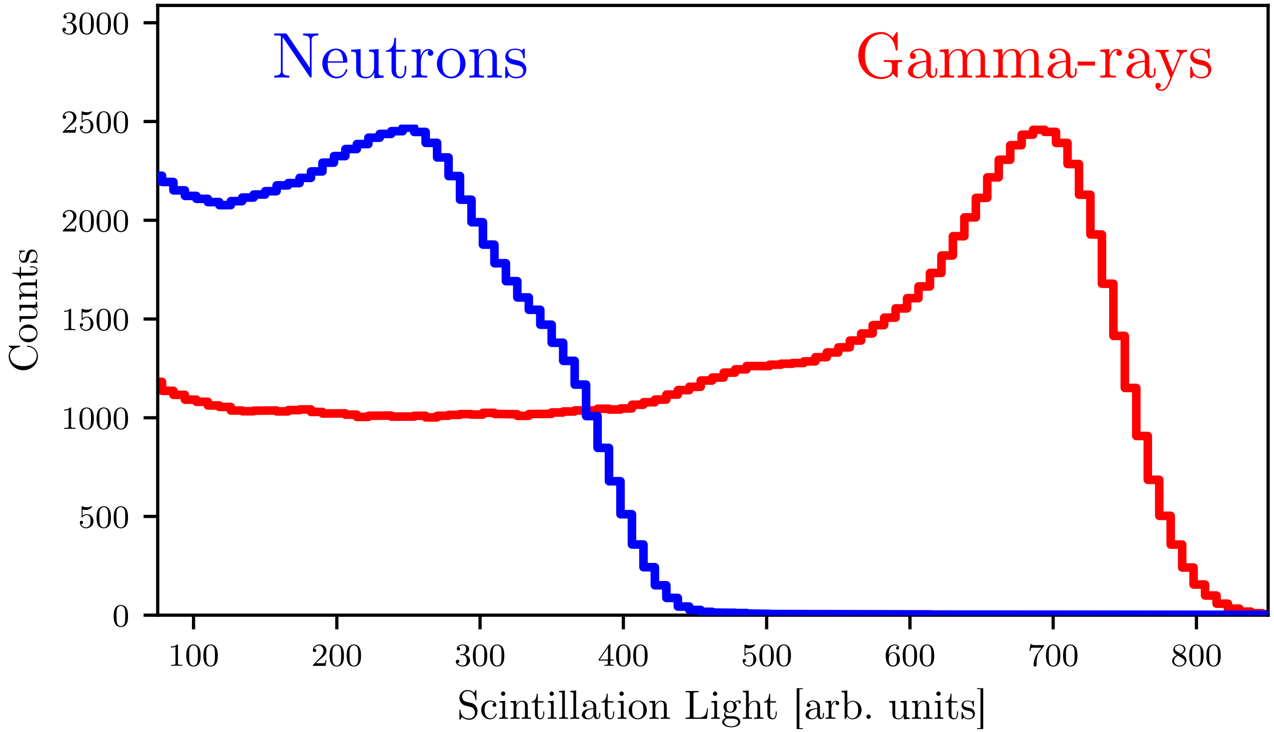


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# Light Output

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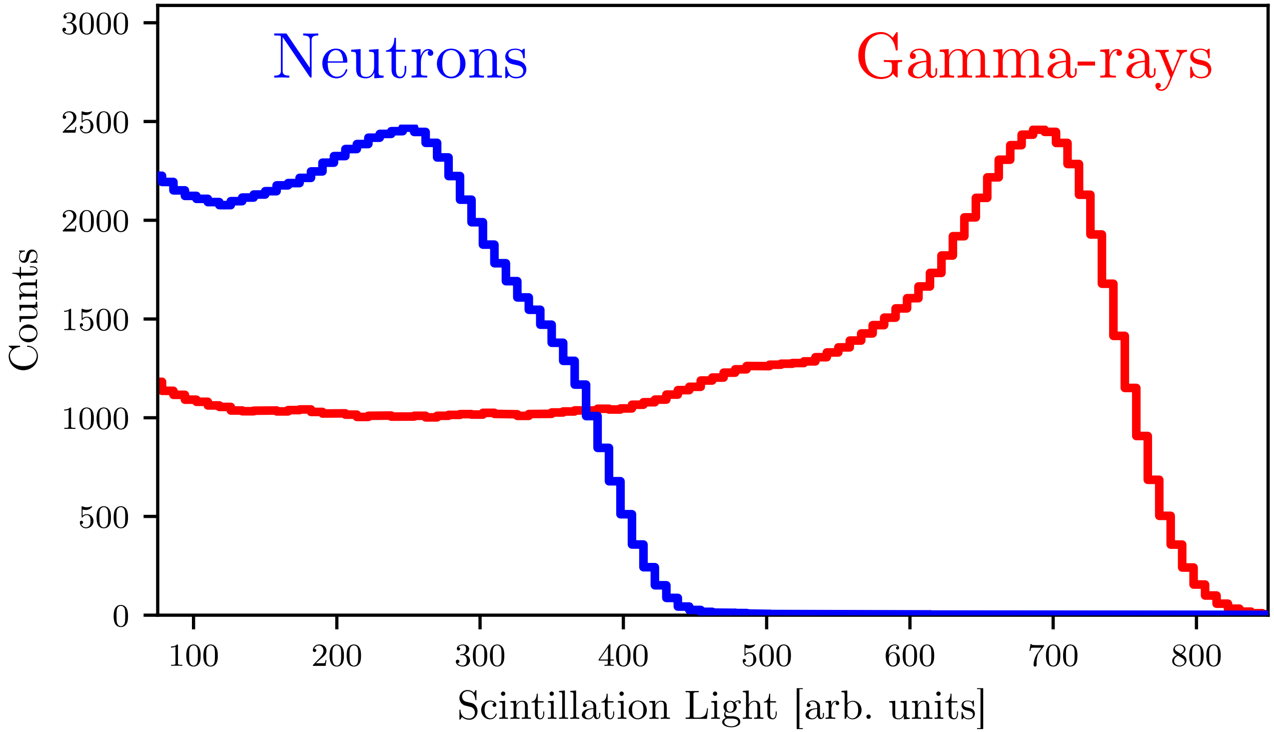


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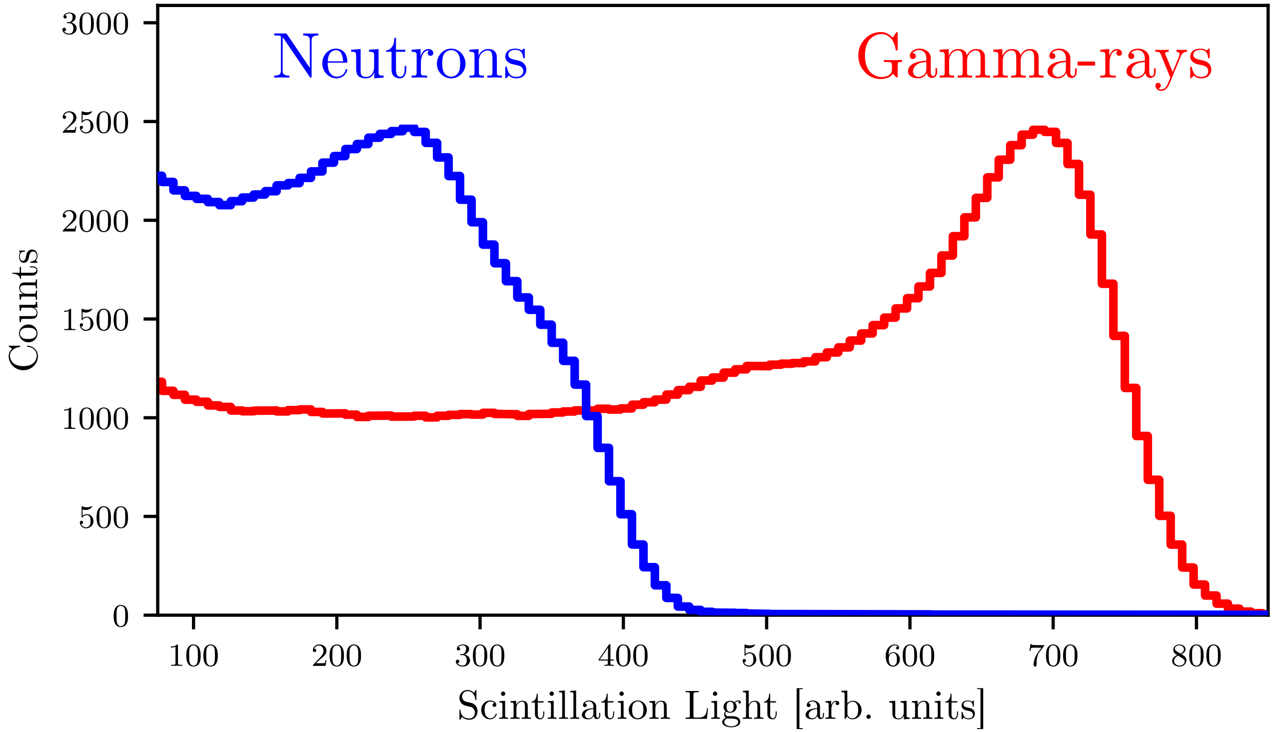


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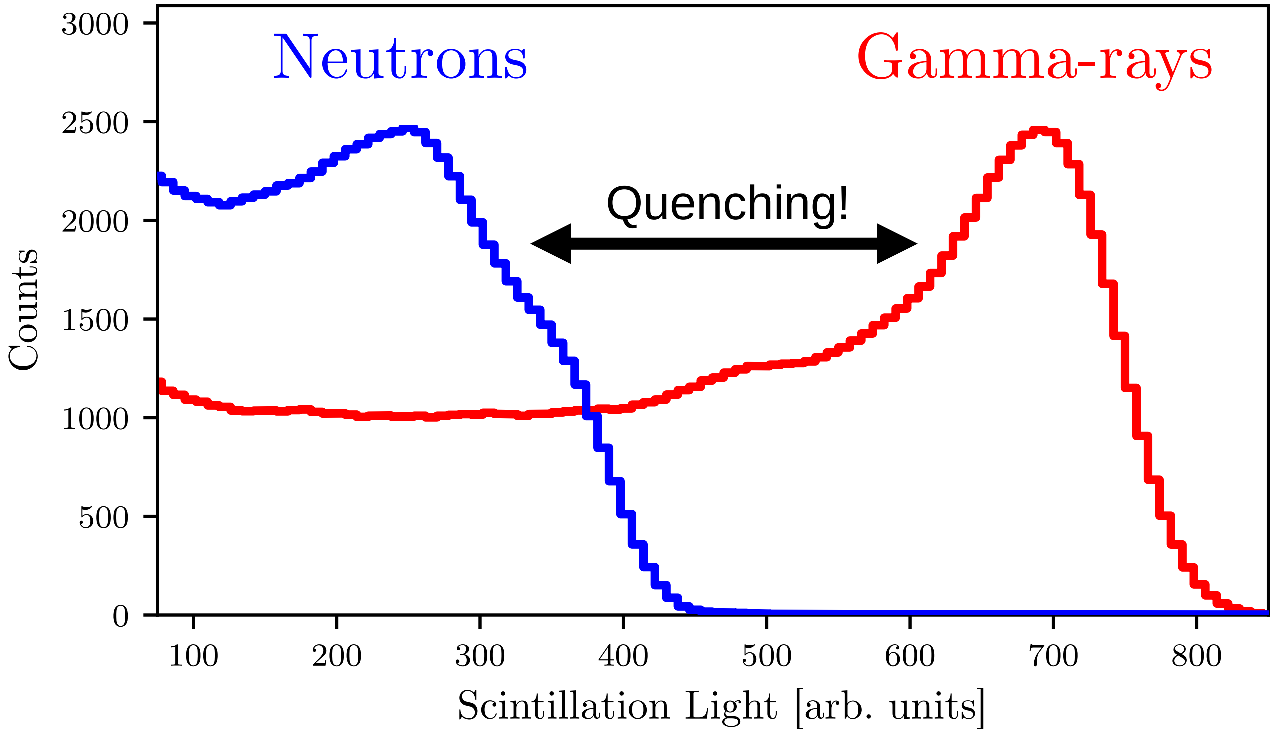


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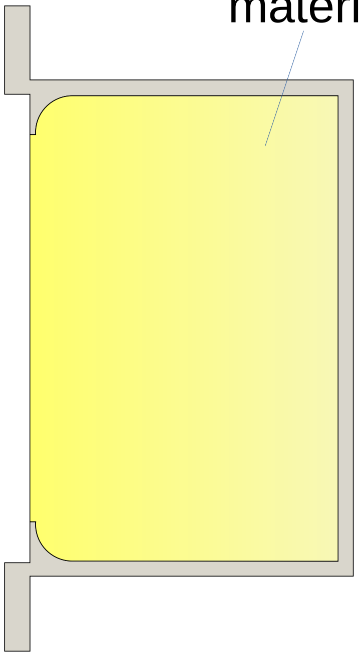
# Liquid Organic Scintillator Detector



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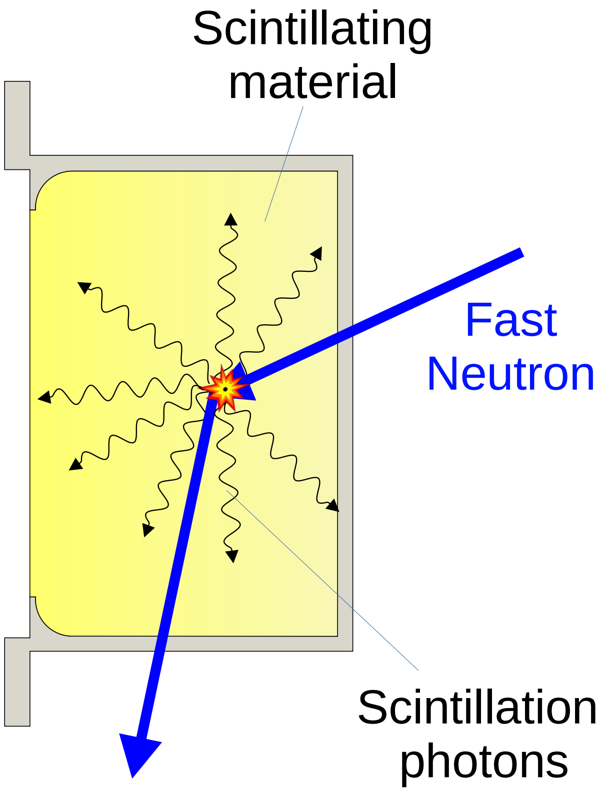

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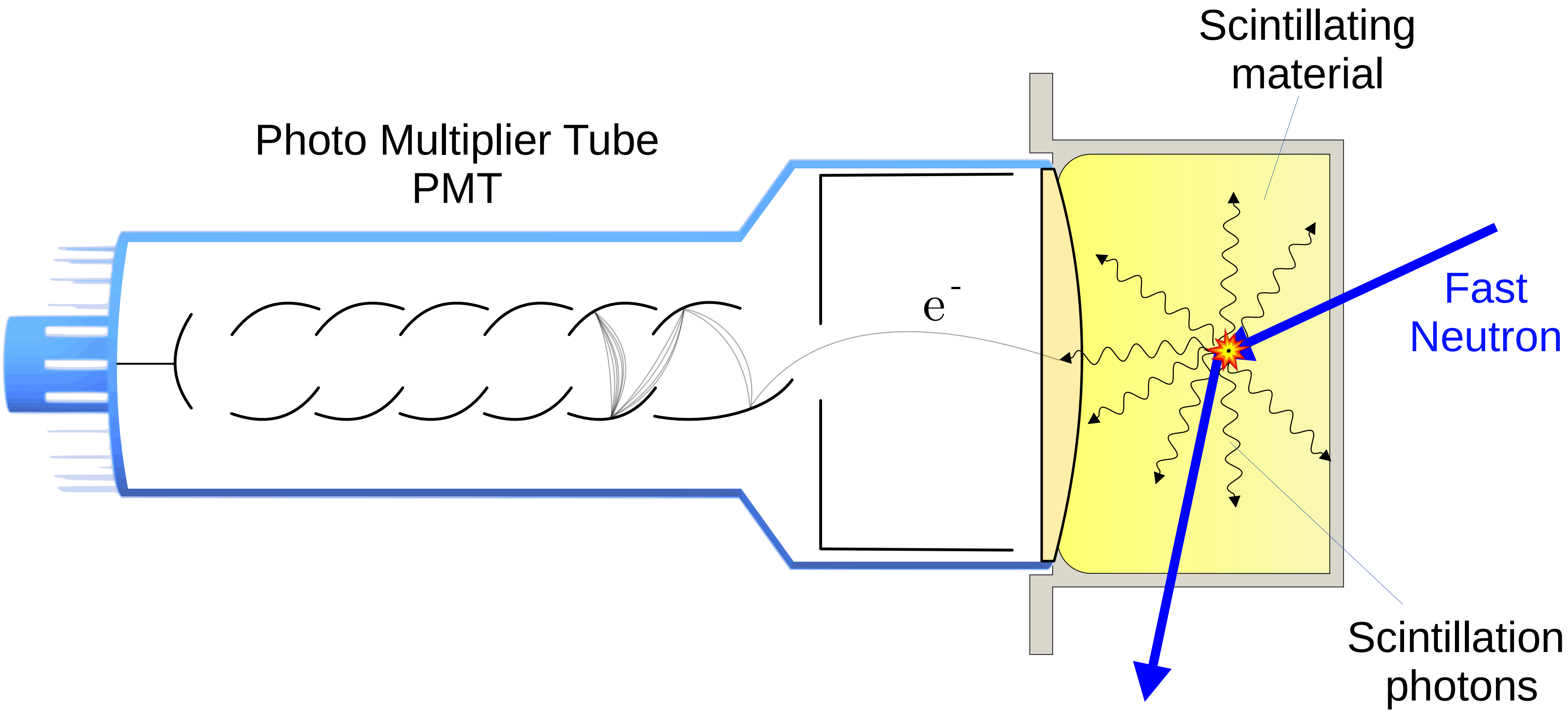

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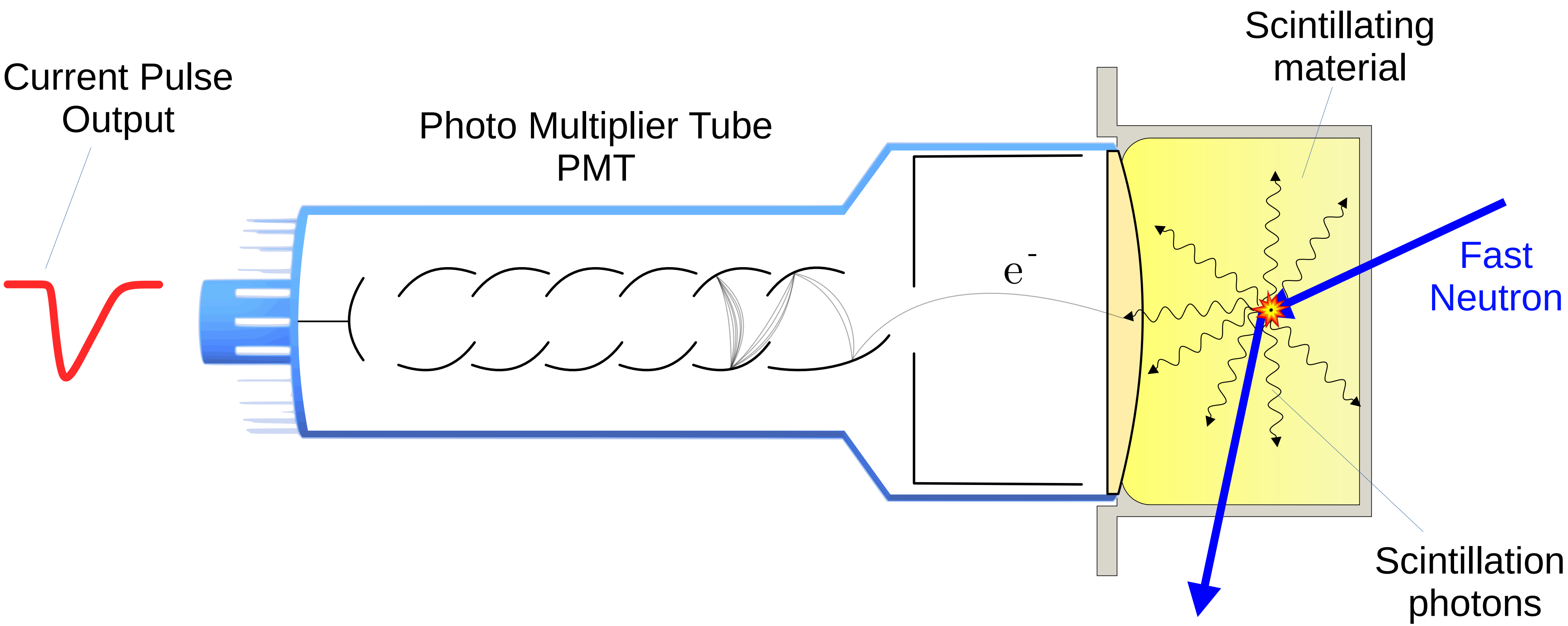

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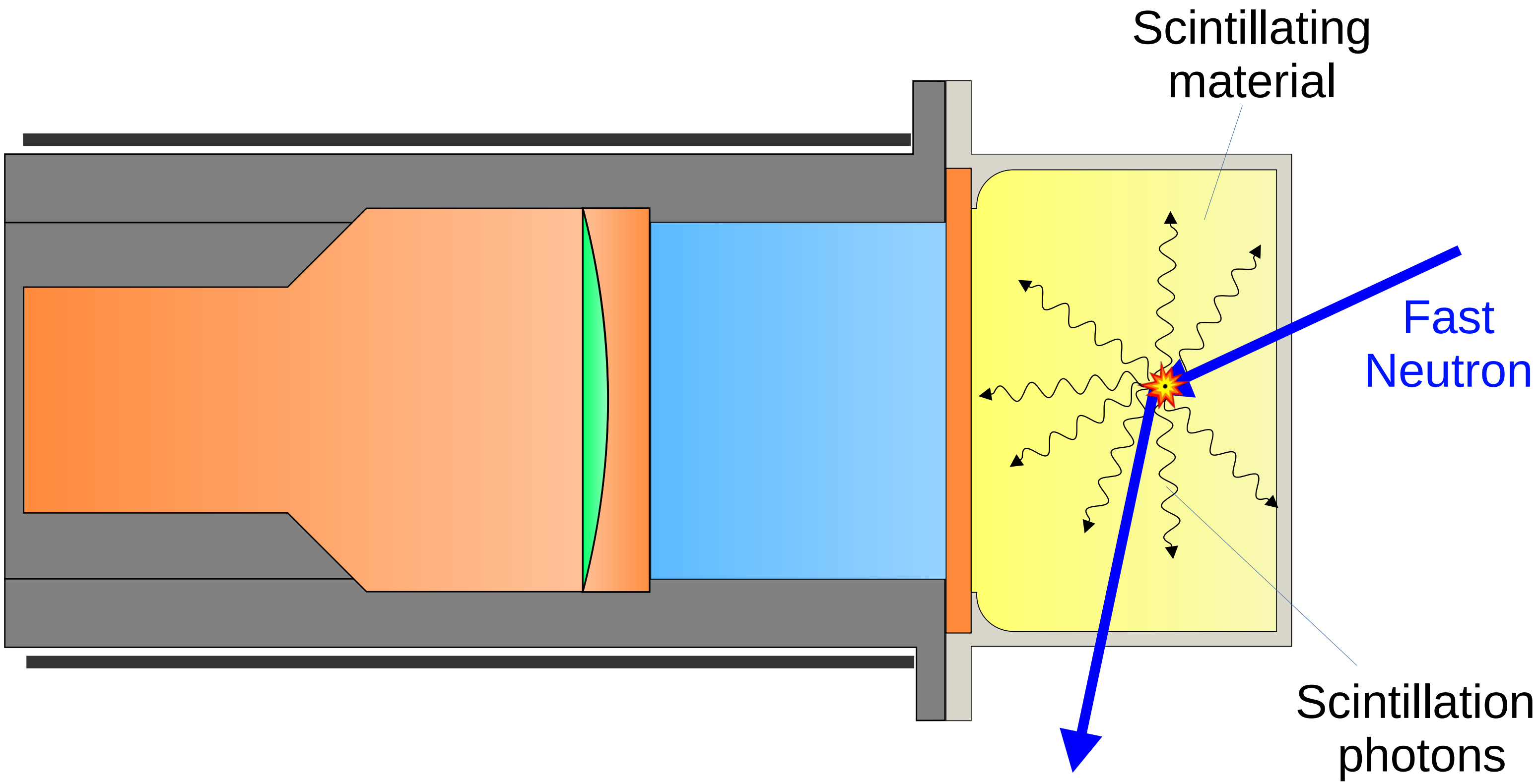

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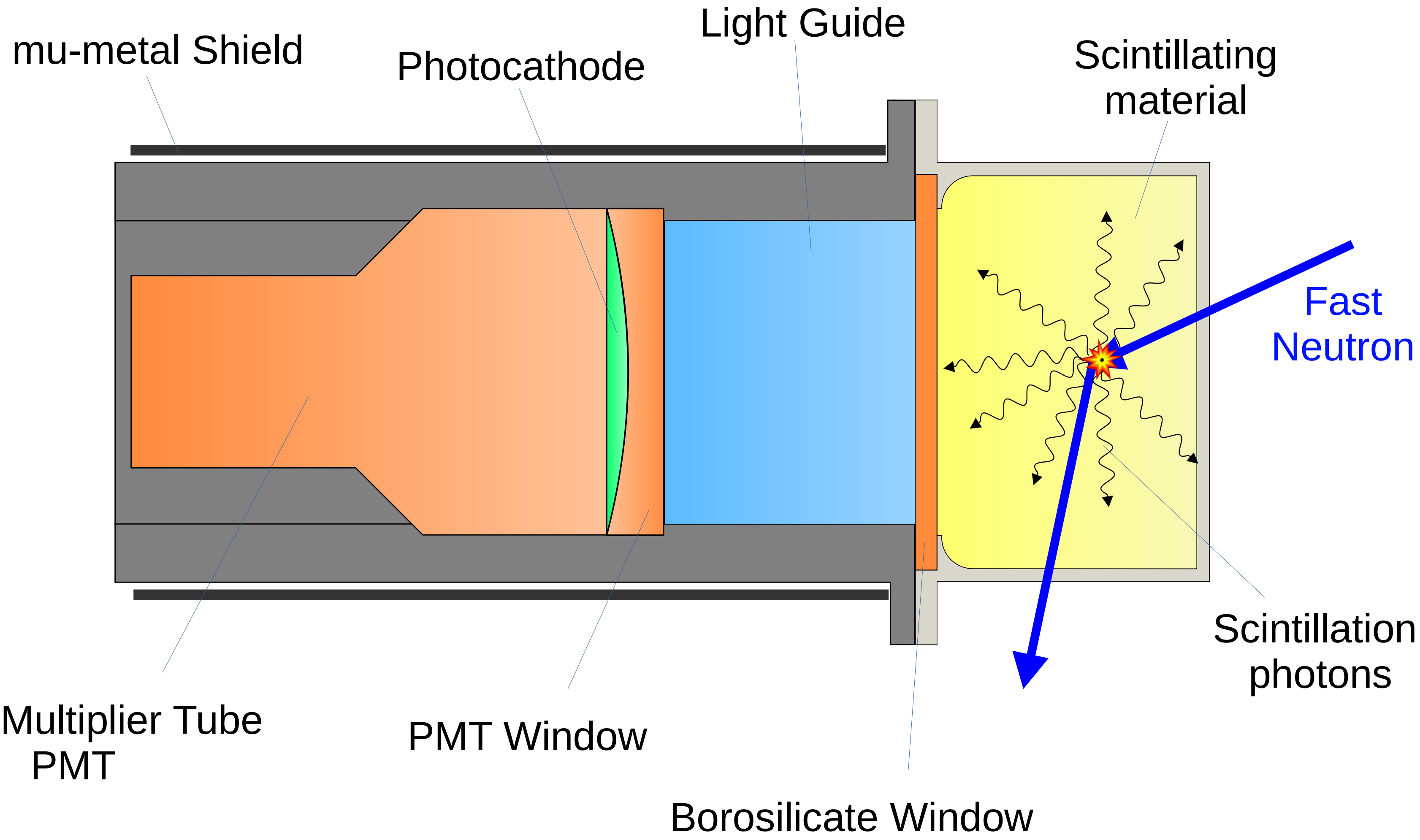

# My Scintillator Detectors

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**Liquid Organic Scintillators:**

- NE 213A *(PSD, benchmark)*
- EJ 305 *(high light-yield)*
- EJ 331 *(Gd doped)*
- EJ 321P *(mineral oil, flash point)*

# Detector Response?

- Relate signal size to neutron energy?
- Separation of gamma-rays and neutrons?
- Calibration?

# Relate signal size to neutron energy?

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NO

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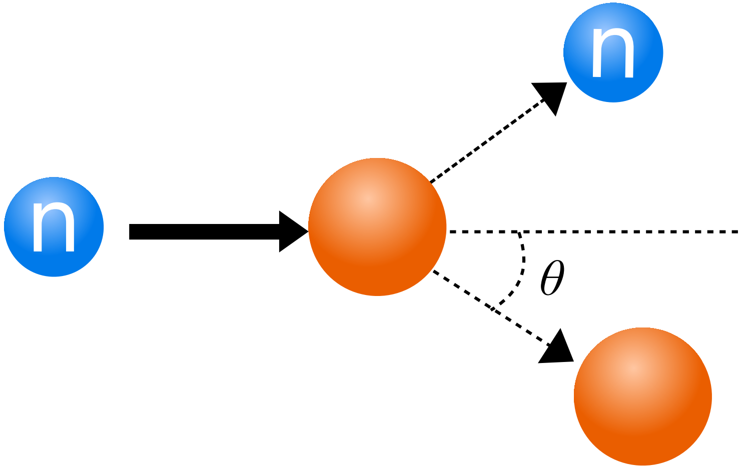
Neutron Scattering



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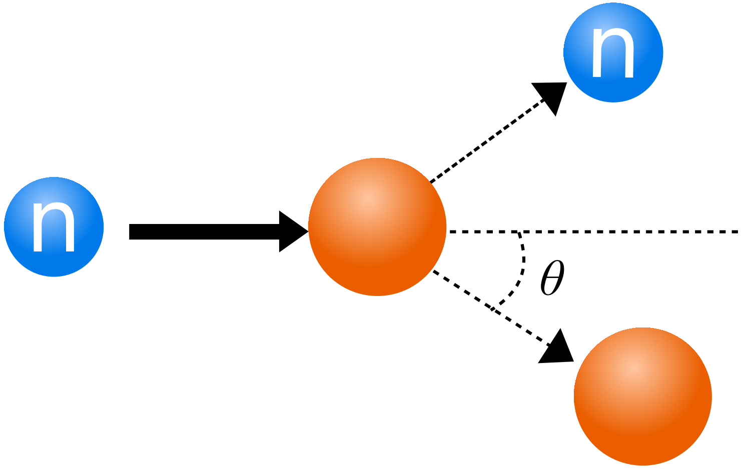


$$E_R^{\max} = \frac{4A}{(1+A)^2} E_n$$

| Nucleus | Max energy transfer |
|---|---|
| Hydrogen ($^1$H) | 100% |
| Deuterium ($^2$H) | 89% |
| Helium-3 ($^3$He) | 75% |
| Carbon ($^{12}$C) | 28% |
| Oxygen ($^{16}$O) | 22% |

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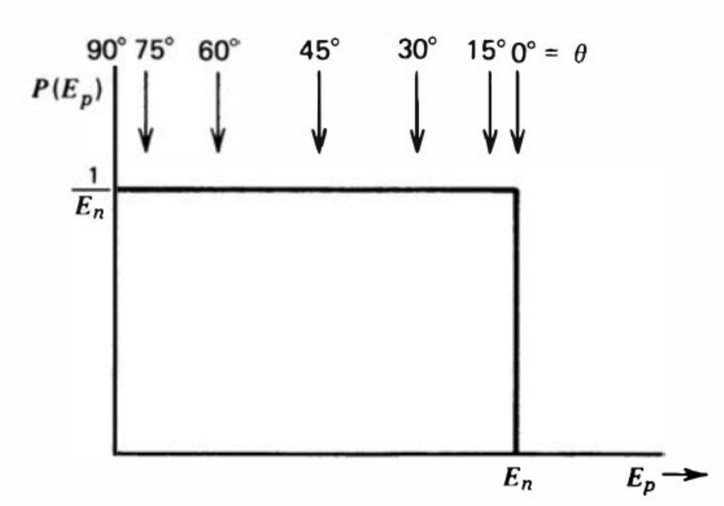


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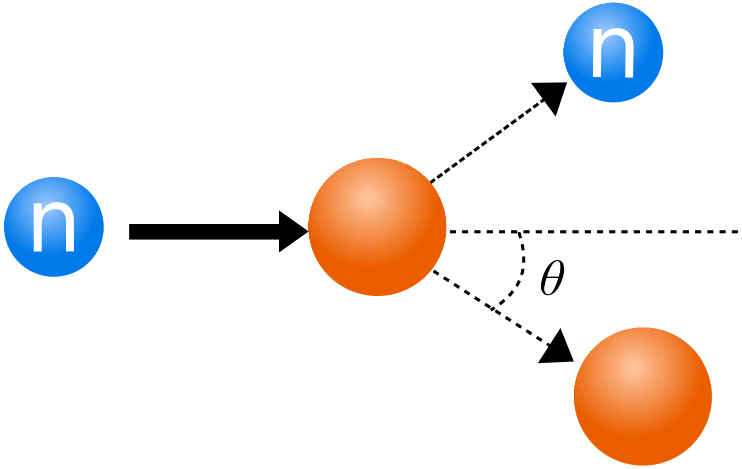


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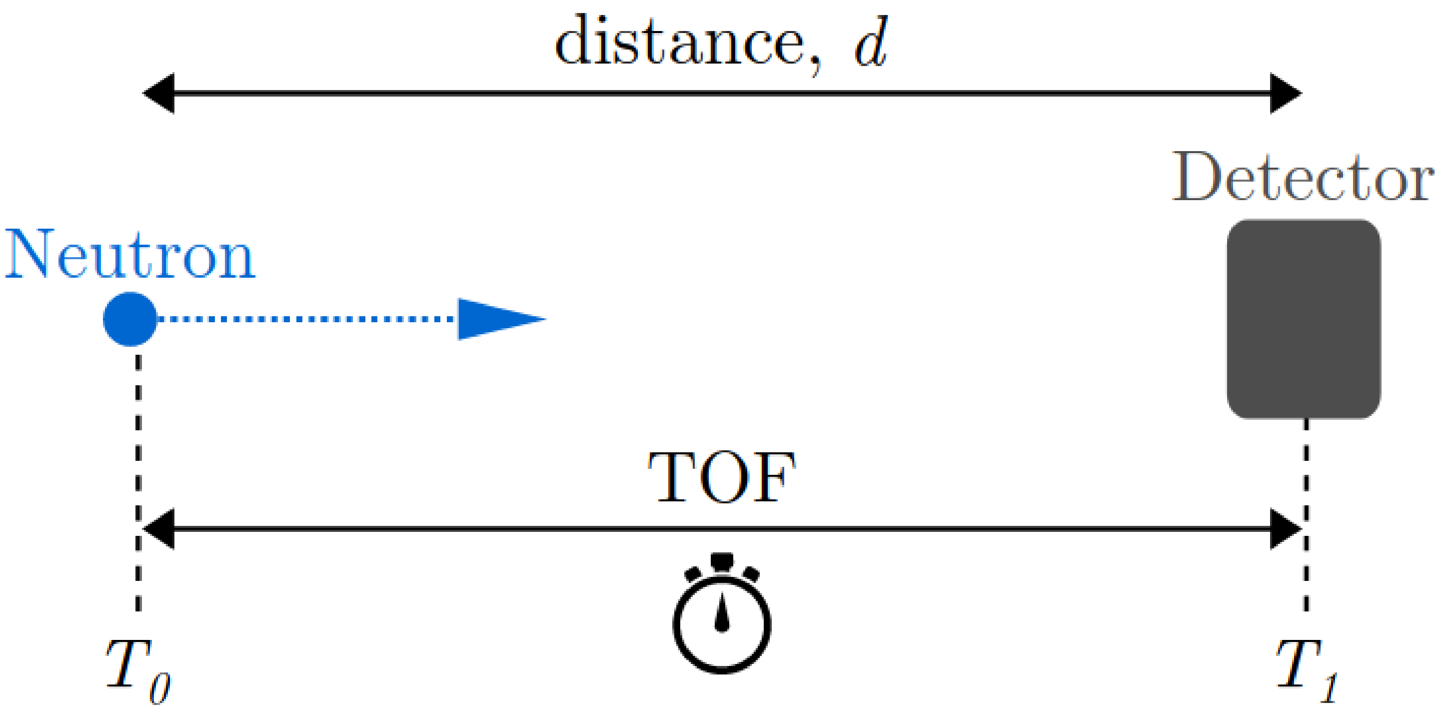

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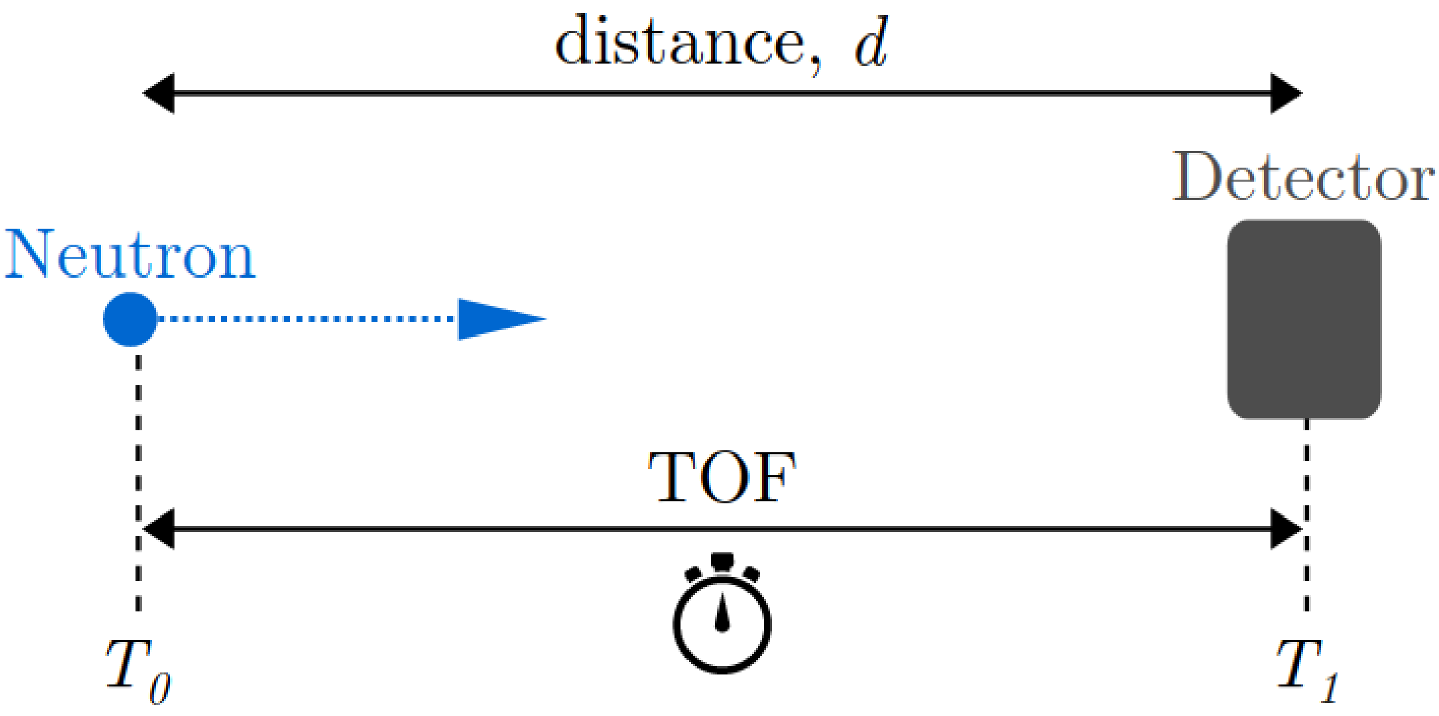


$$E_n = \frac{1}{2} m_n \frac{d^2}{\mathrm{TOF}^2}$$

# My Goals

Calibrated scintillation light-yield of organics using mixed-field gamma-neutron radioactive sources and TOF.

# Toolbox

?

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Sources

Experimental methods

Computational methods

?

# Experimental Setup

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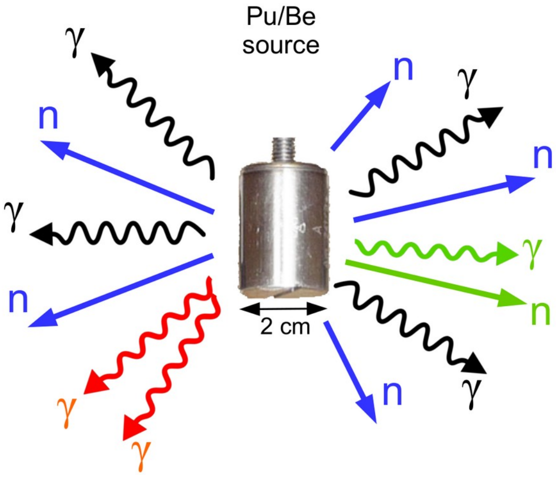

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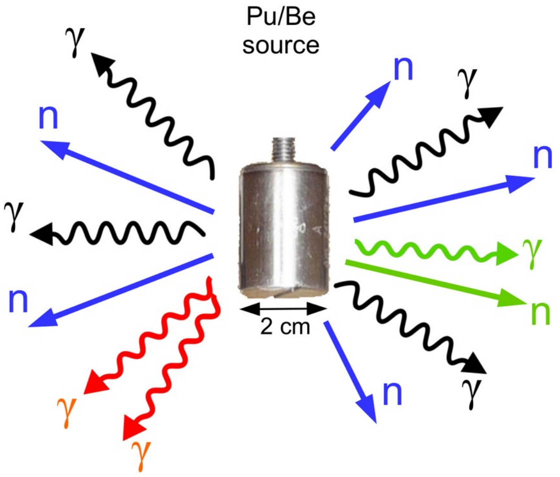


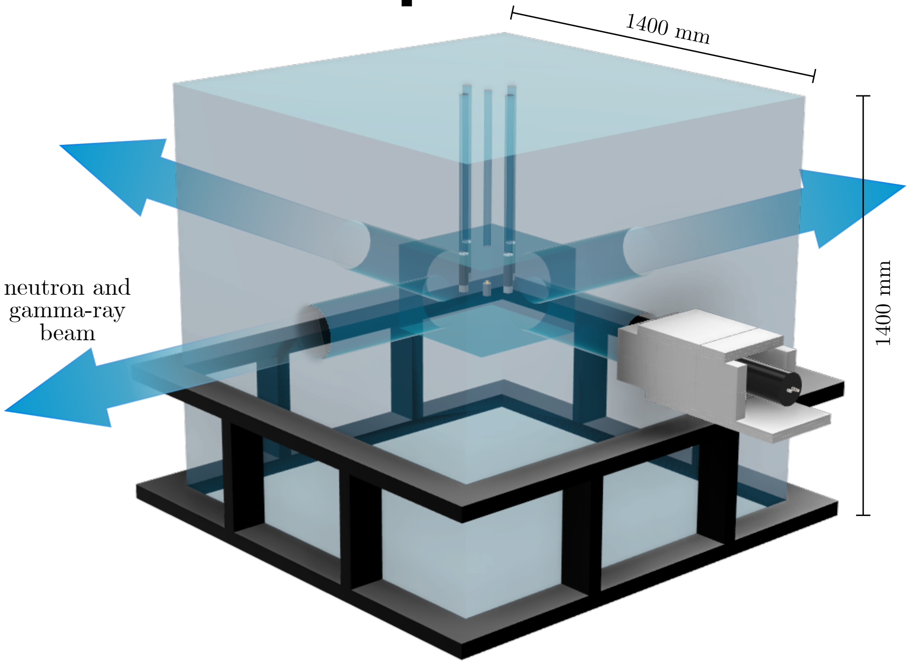

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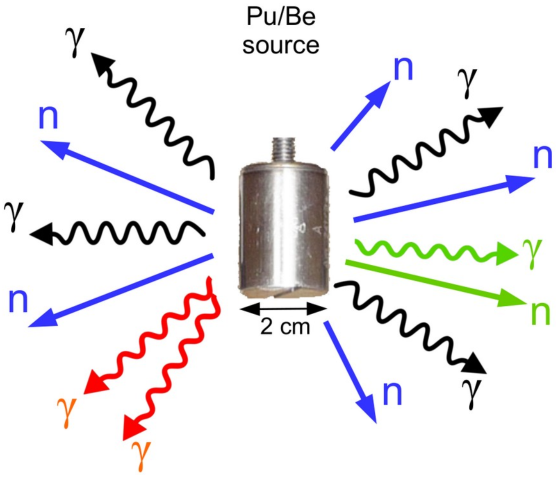


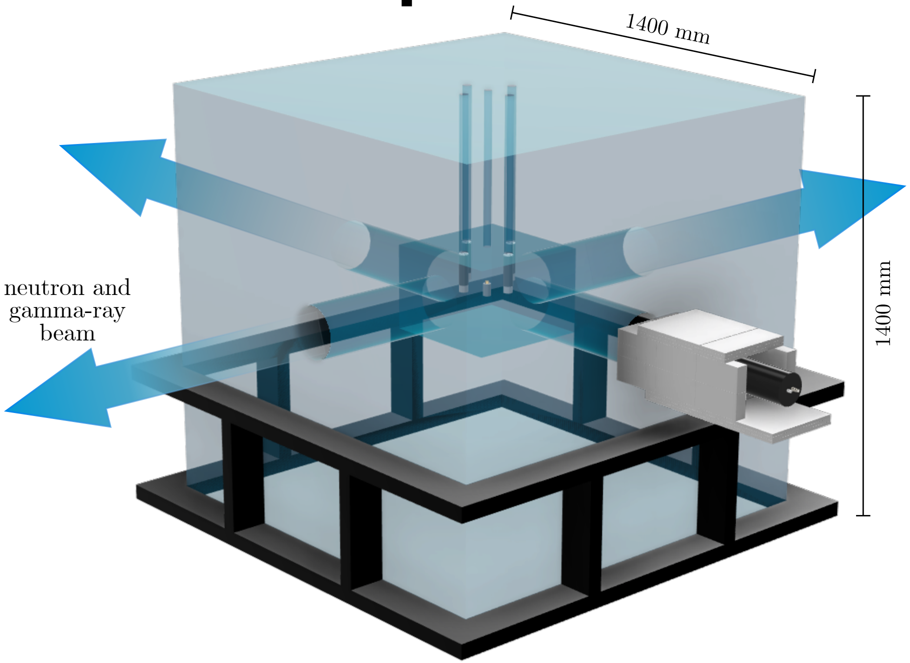


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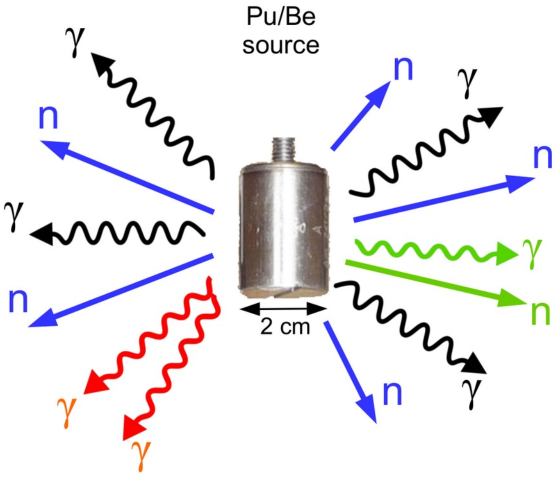


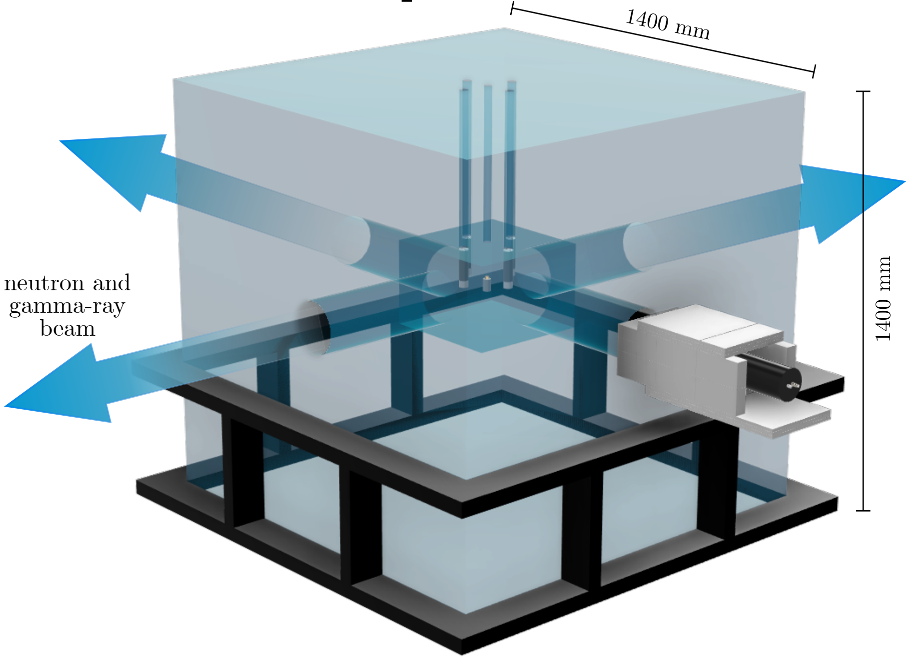


Signal recording with digitizer

www.caen.it

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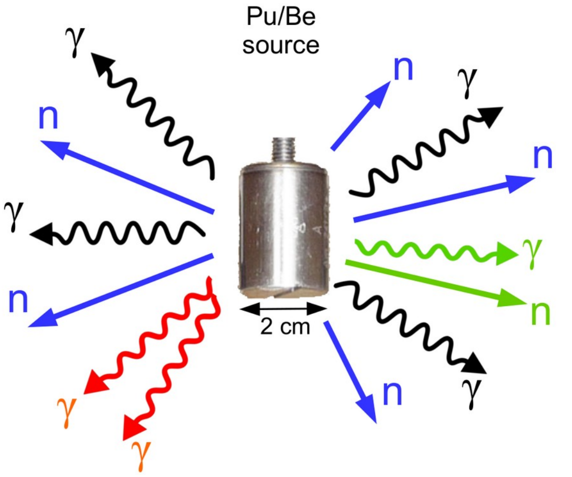


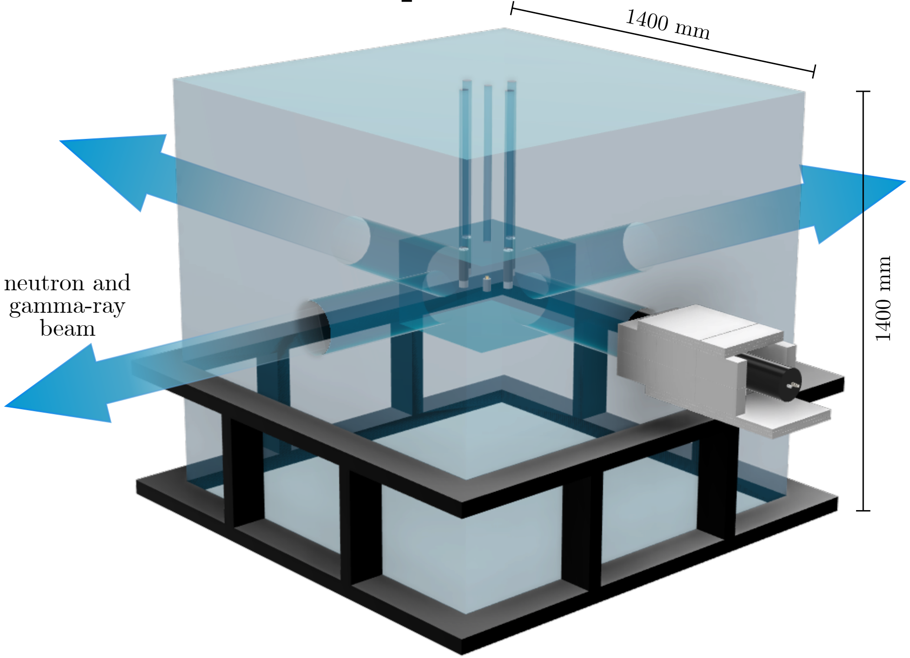


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Signal processing …

# Pu/Be Source

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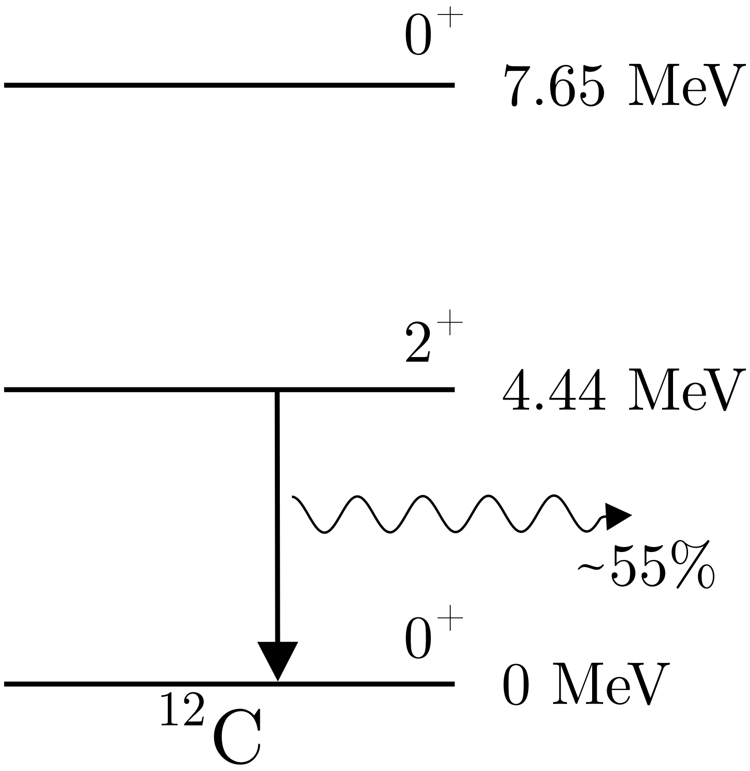



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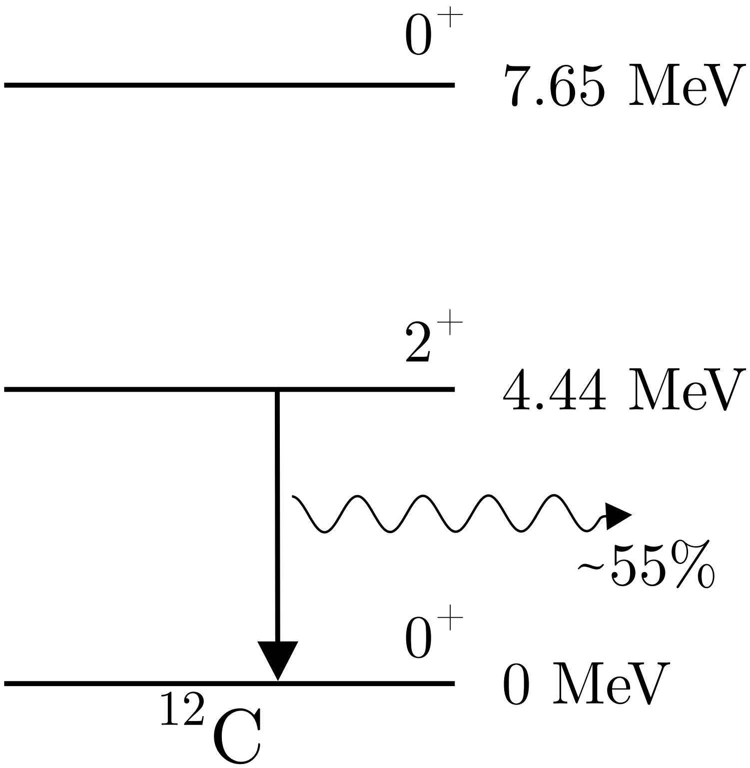



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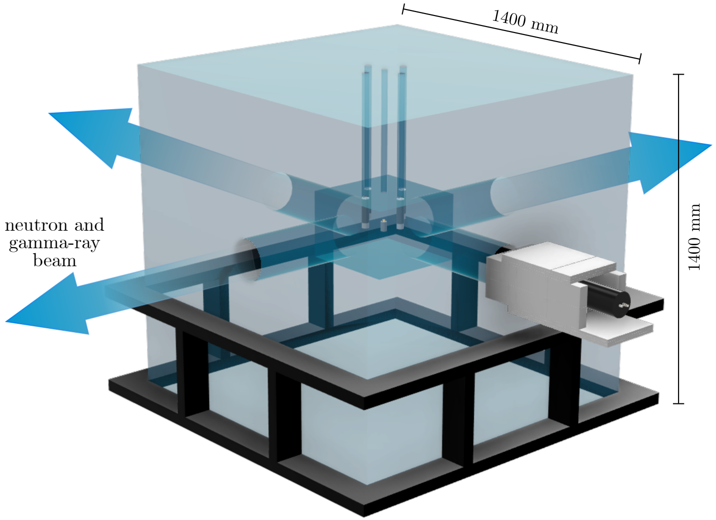

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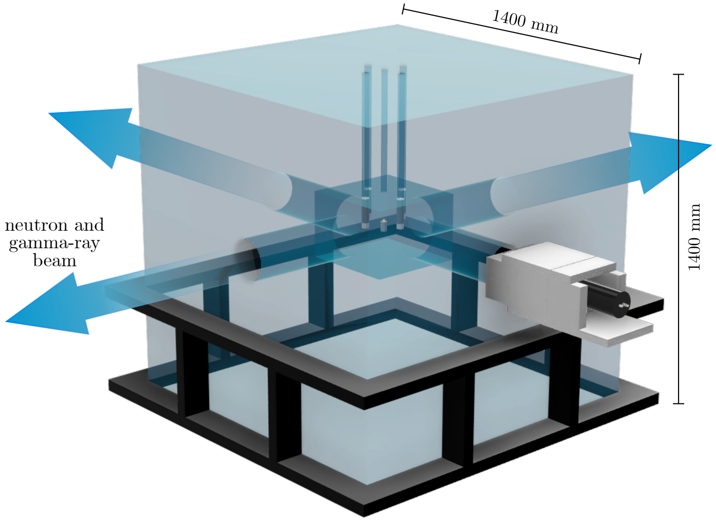


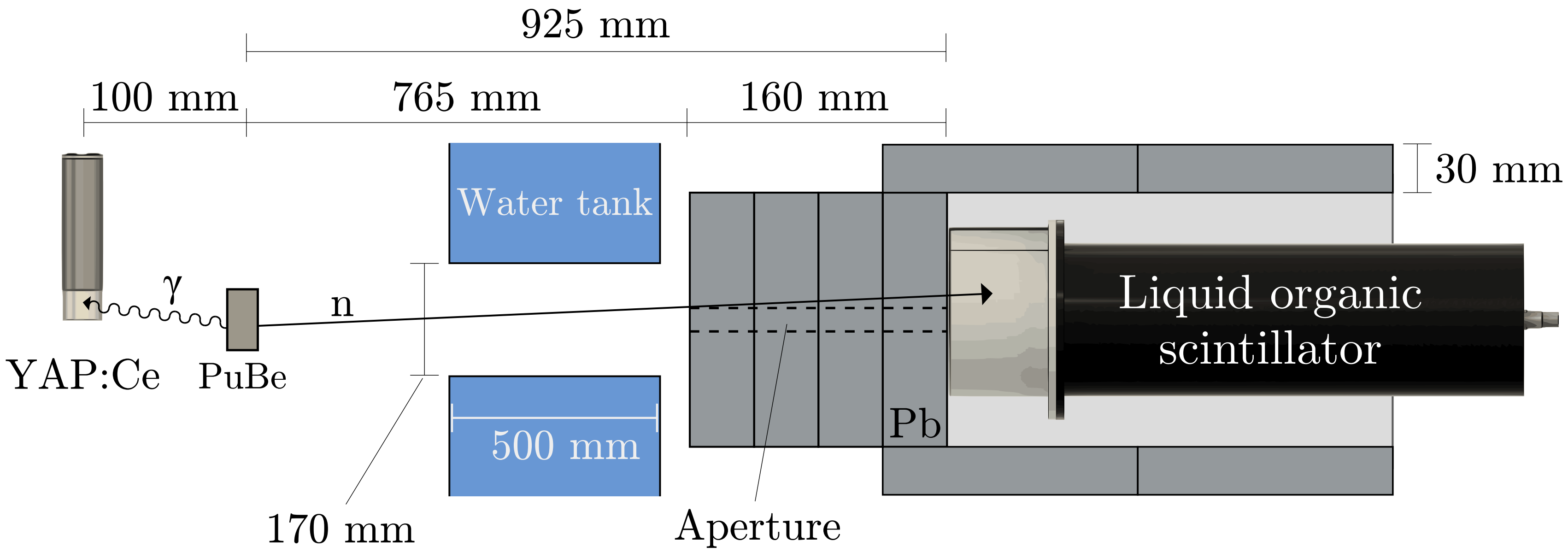

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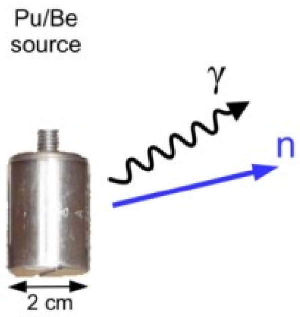

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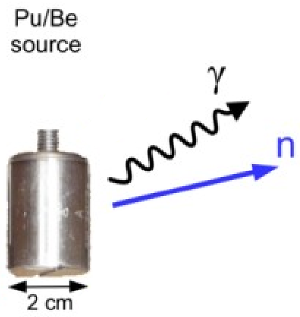

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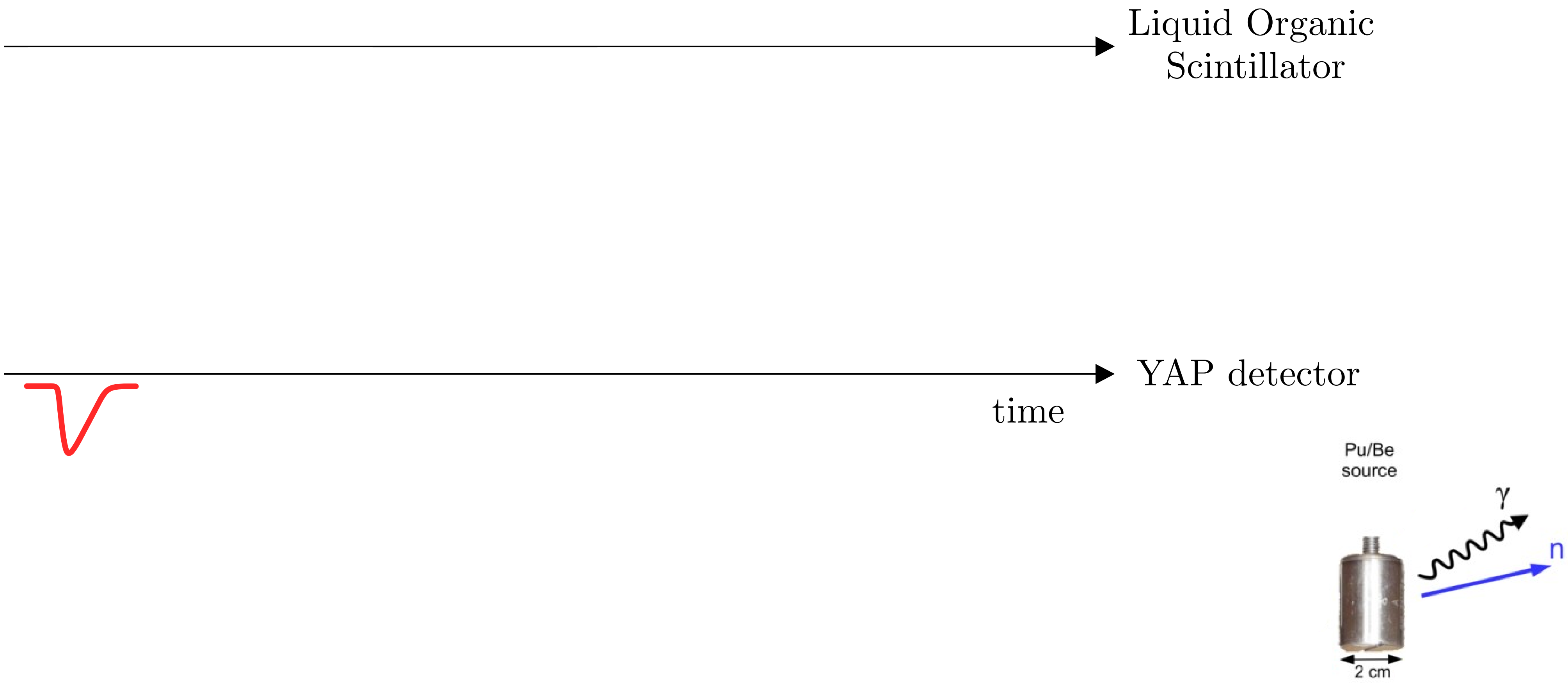

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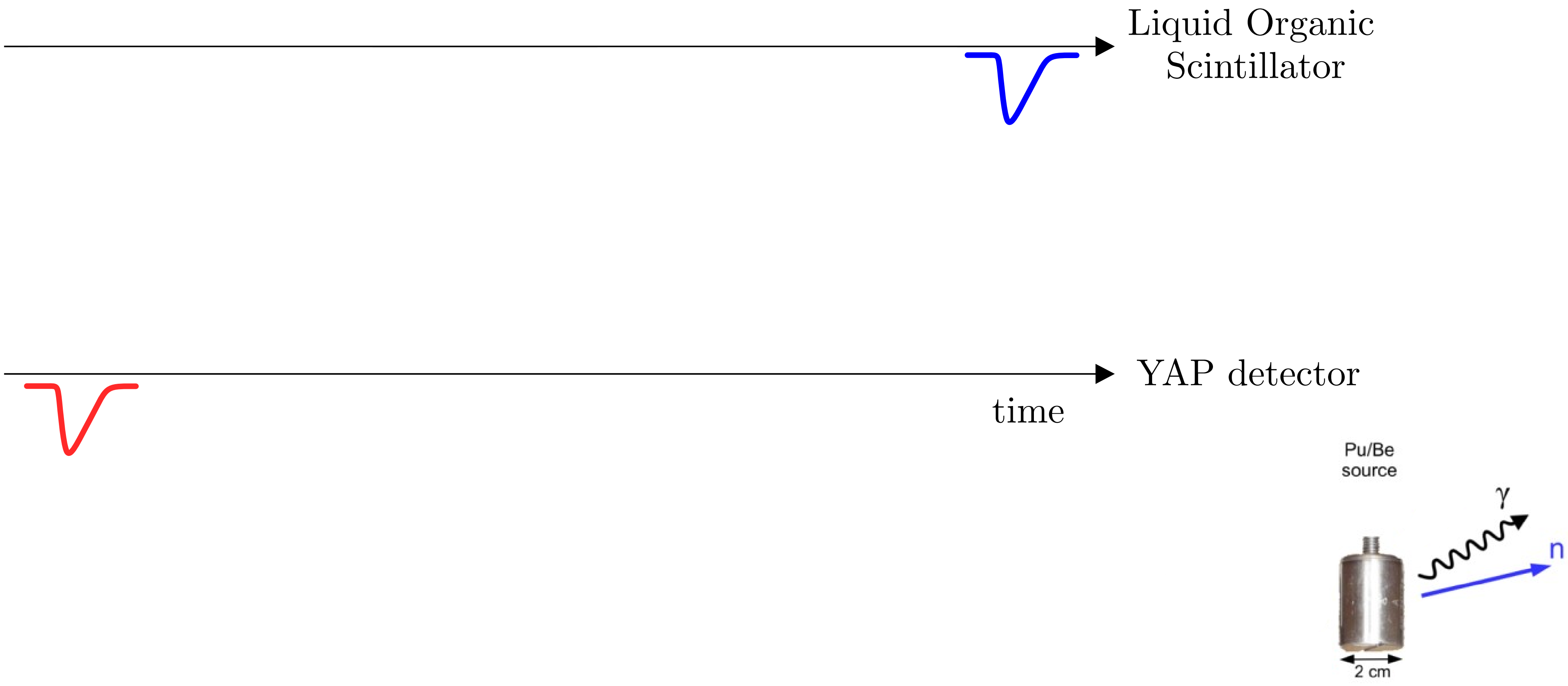

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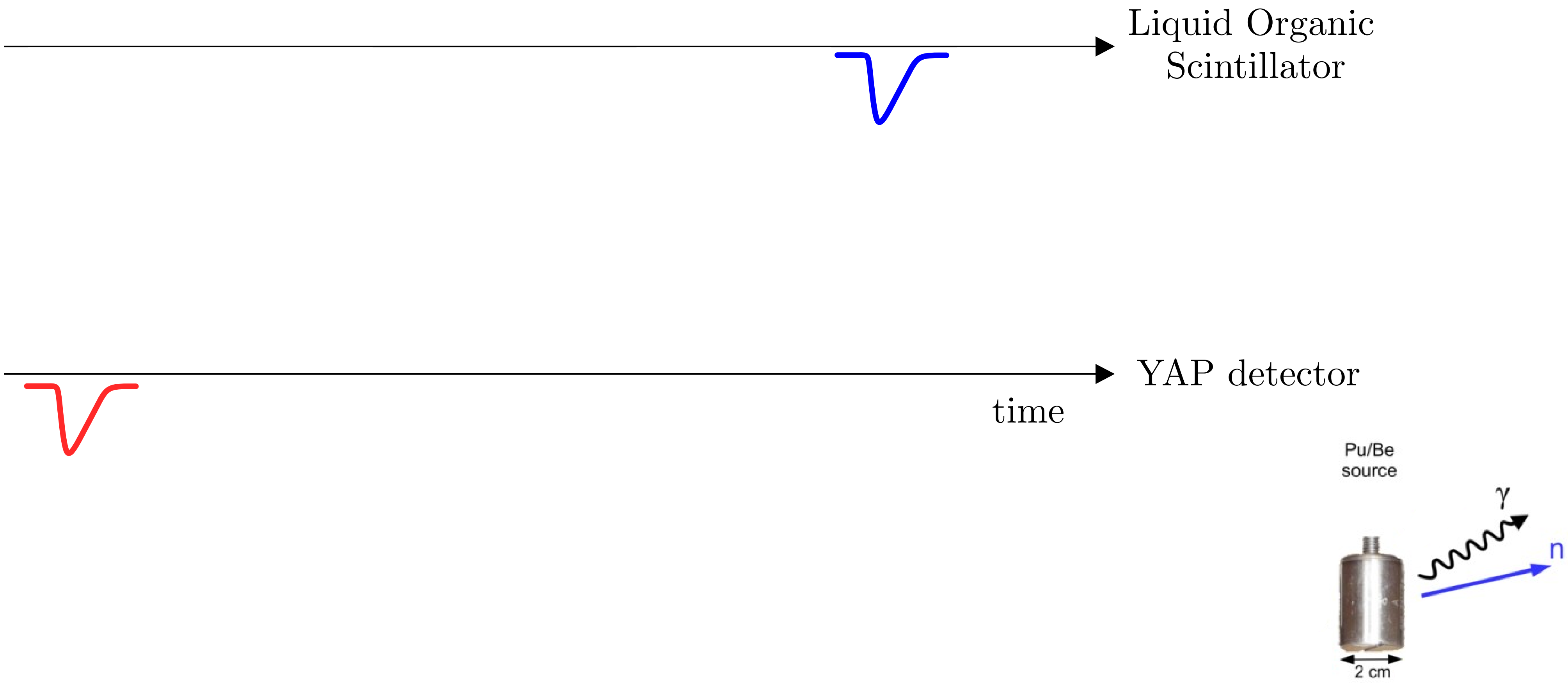

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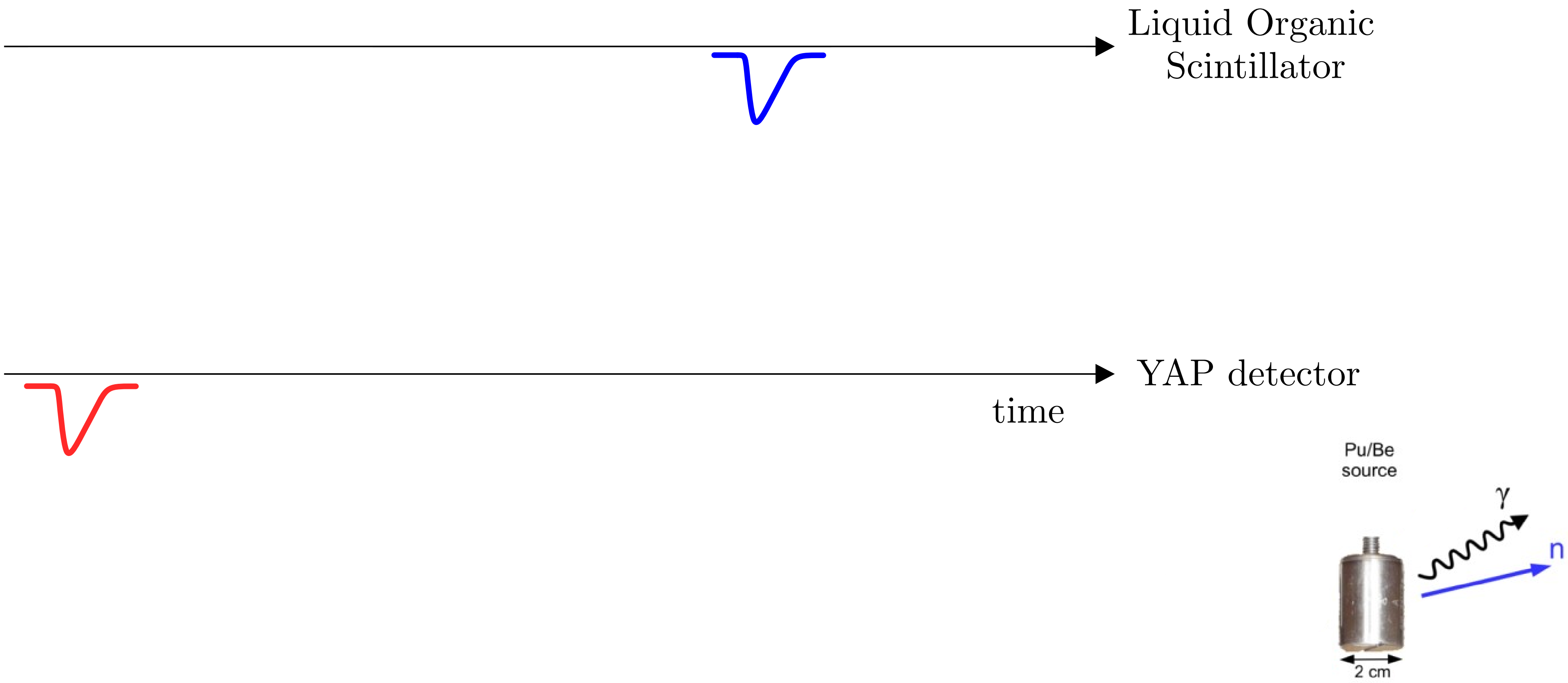

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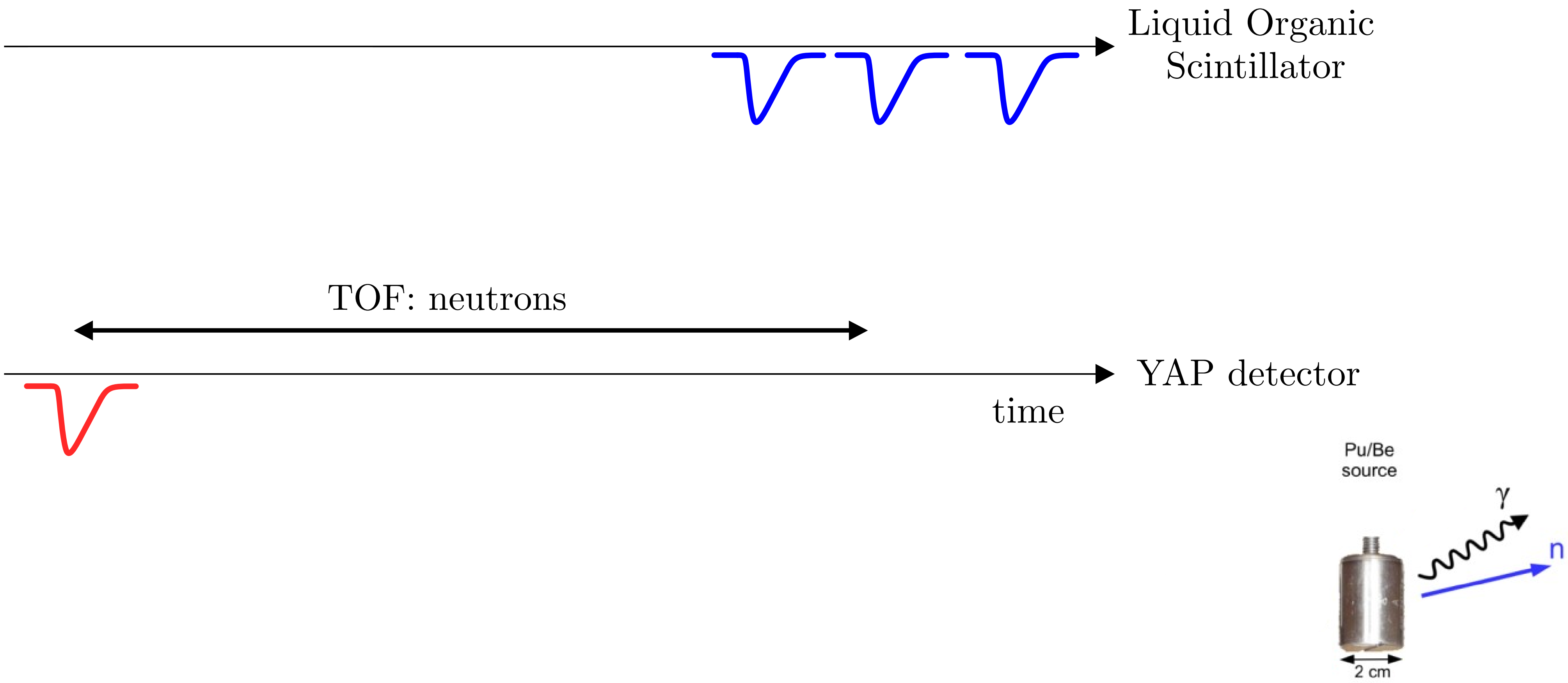

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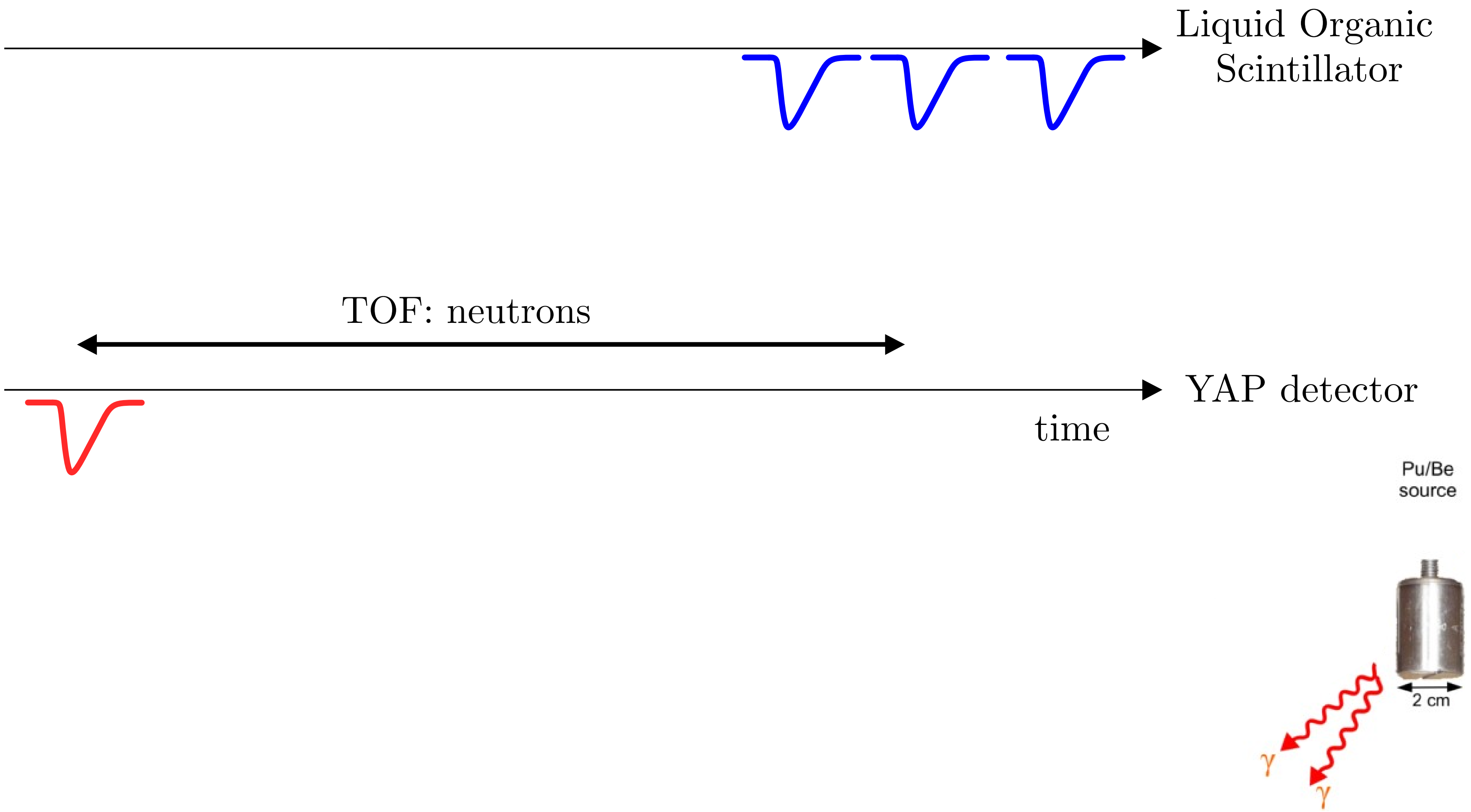

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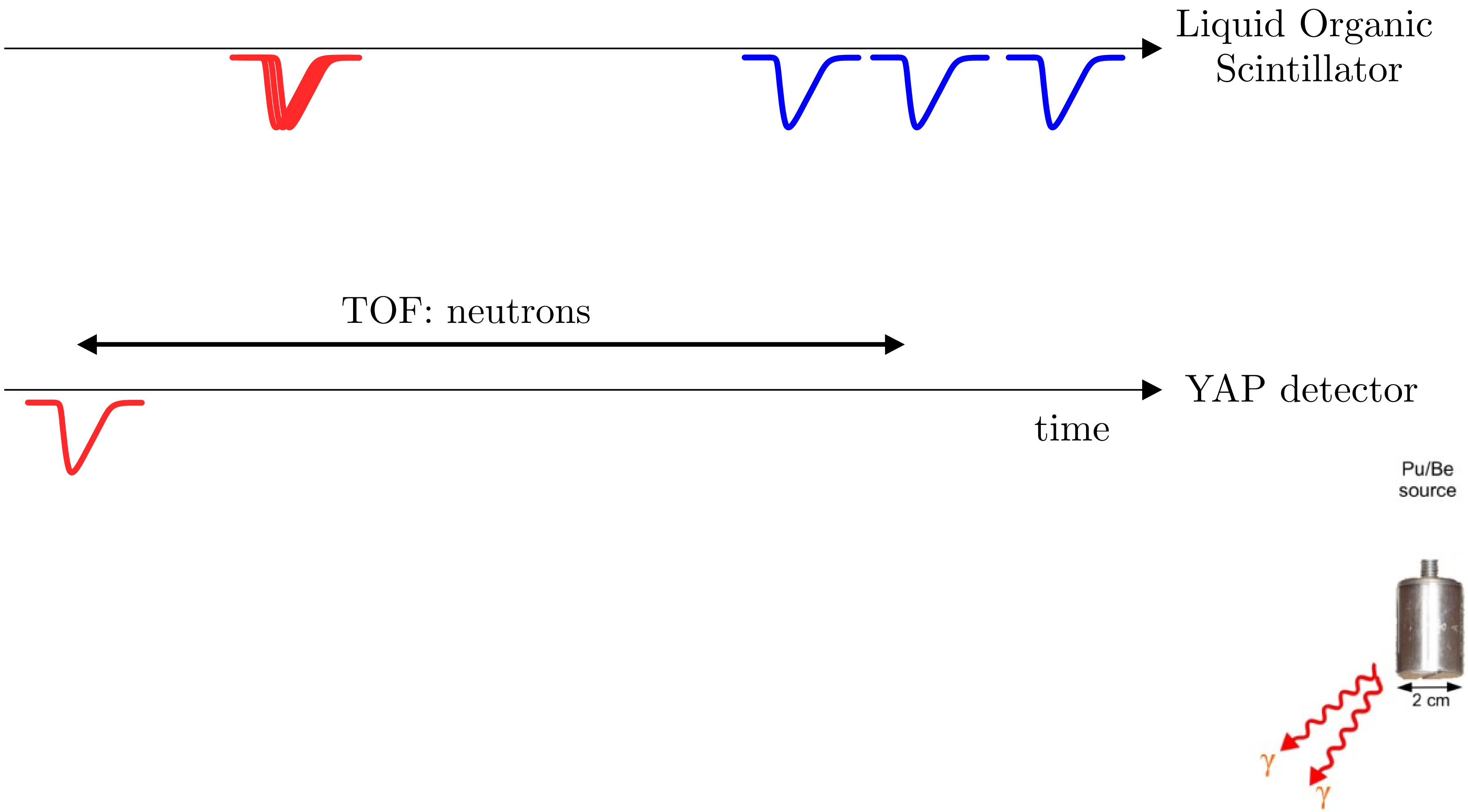

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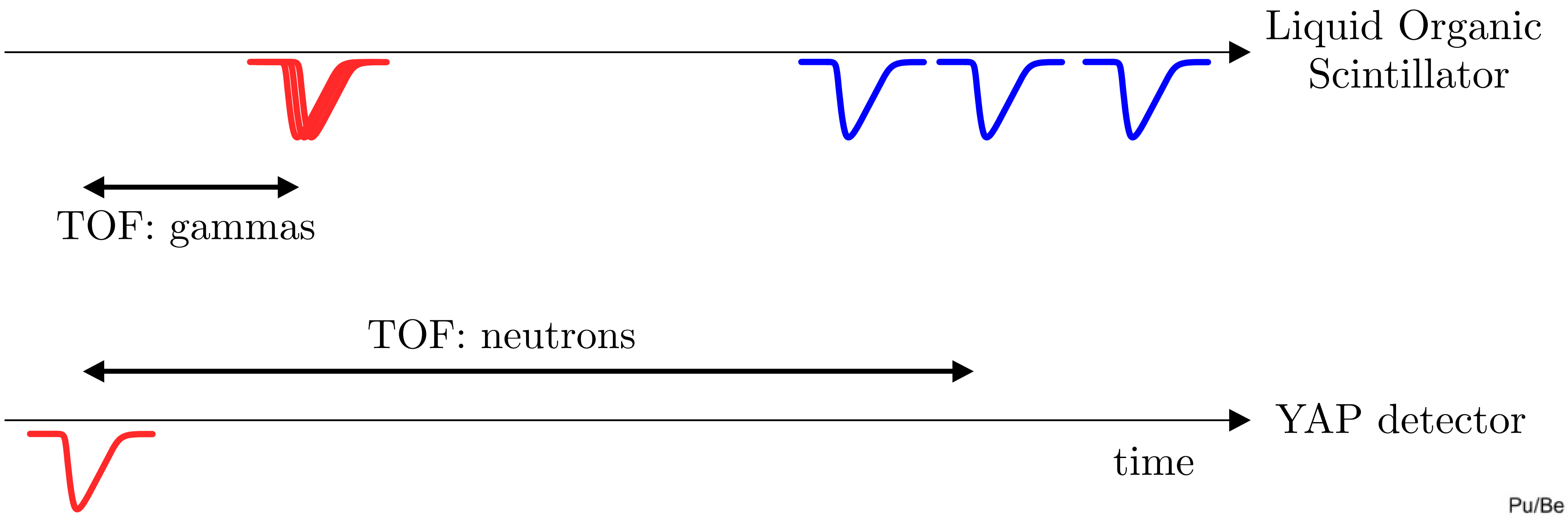


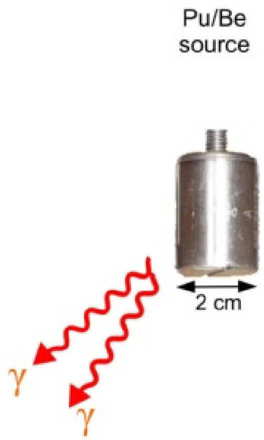

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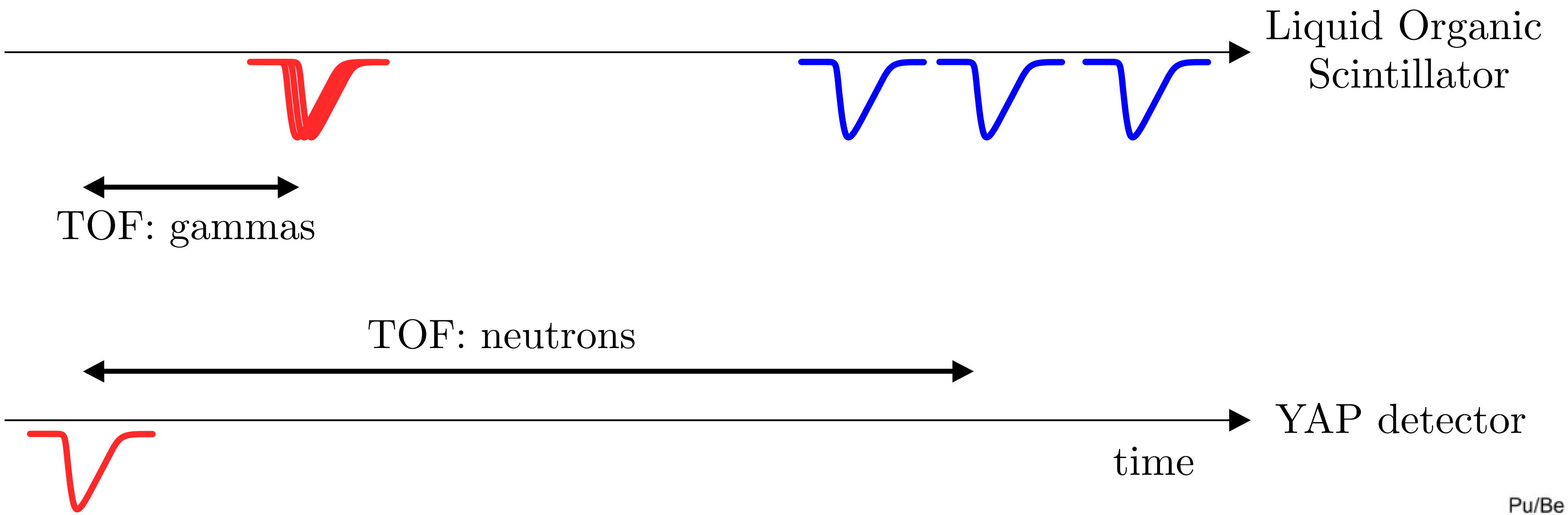
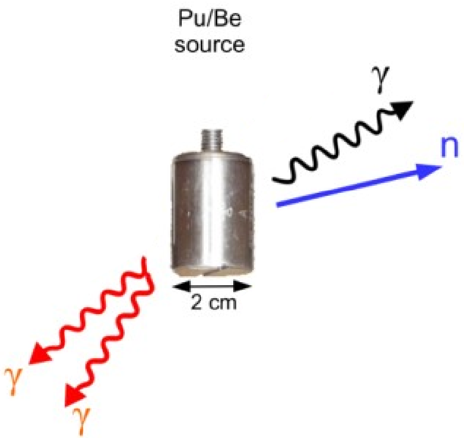



$$E_n = \frac{1}{2} m_n \frac{d^2}{\mathrm{TOF}^2}$$



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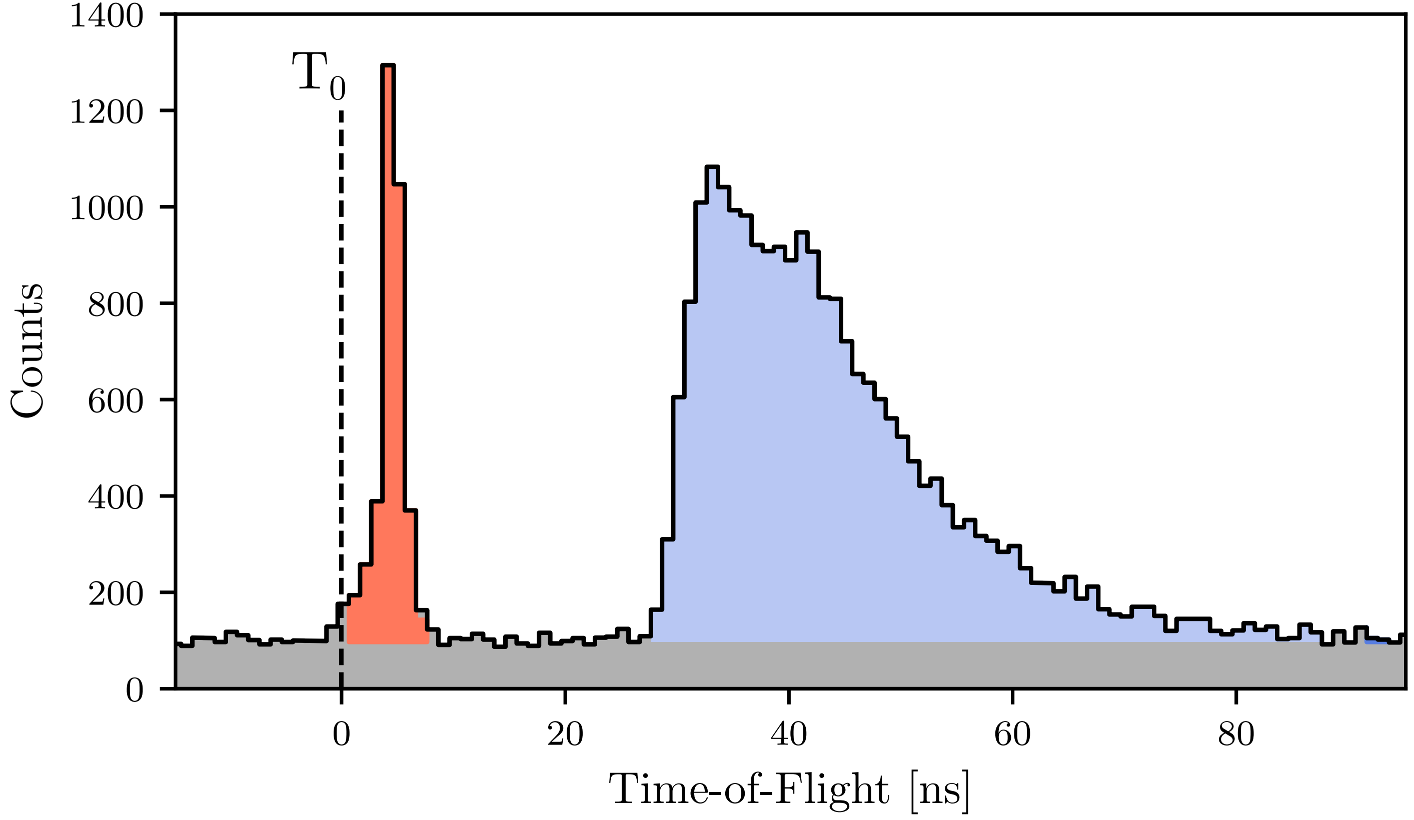

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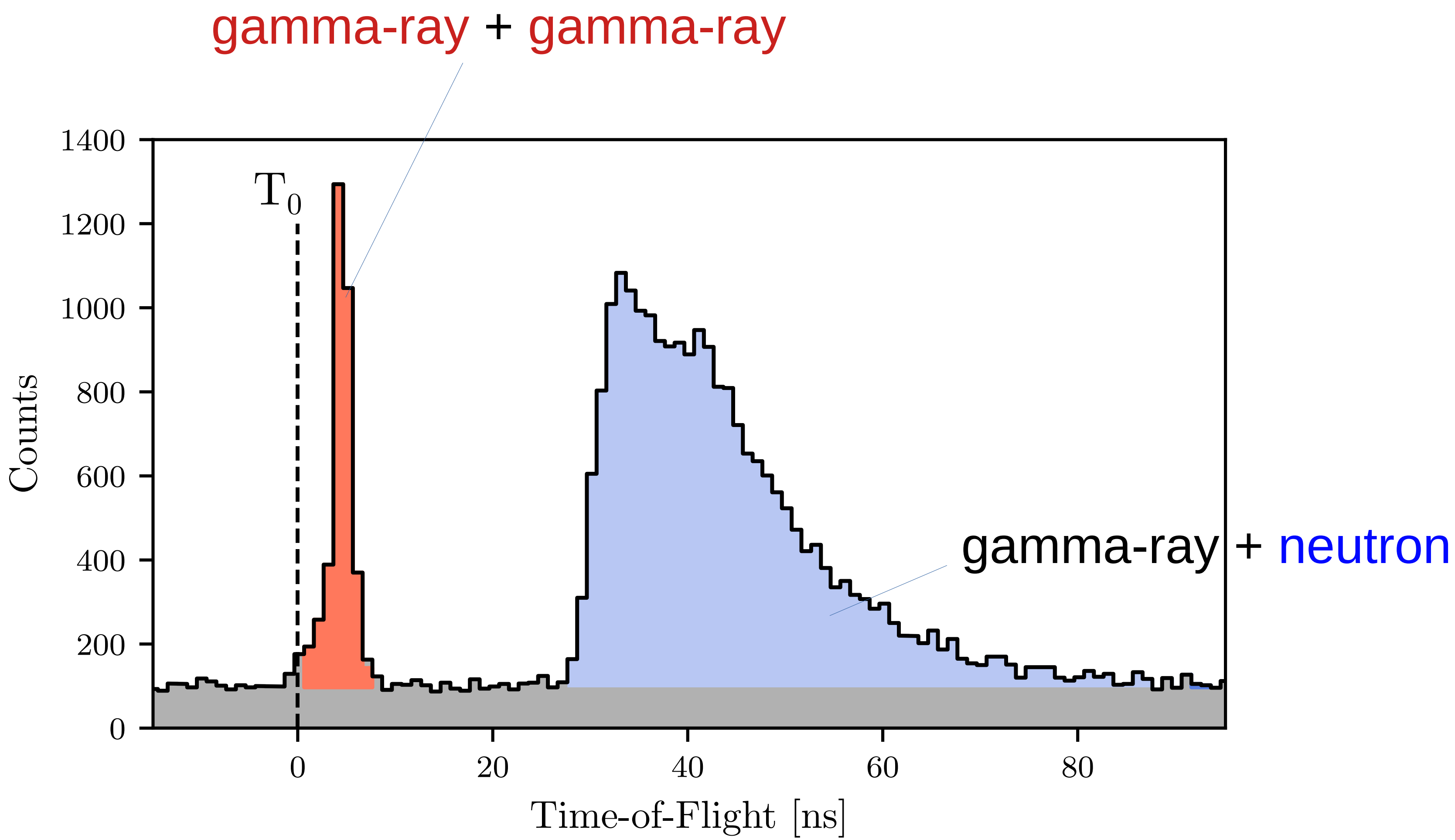

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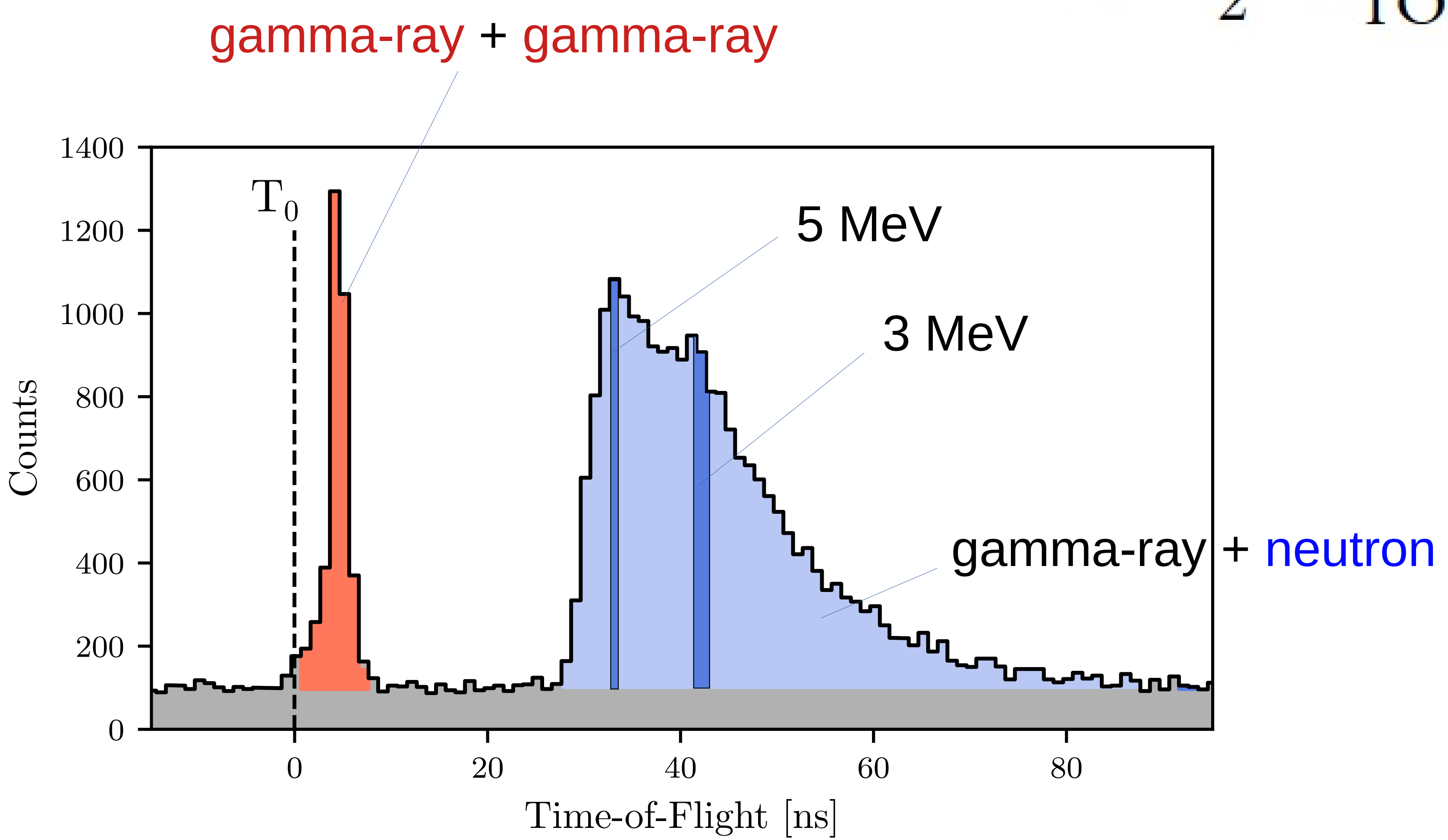

# Electronics

# Electronics

| Waveform Digitizer | CAEN VX1751 |
|---|---|
| Sampling | 1 GHz |
| Acquisition window | 1 μs |
| Bandwidth | 500 MHz |
| Dynamic input | 1 Vpp |
| Trigger threshold | 25 mV |

www.caen.it

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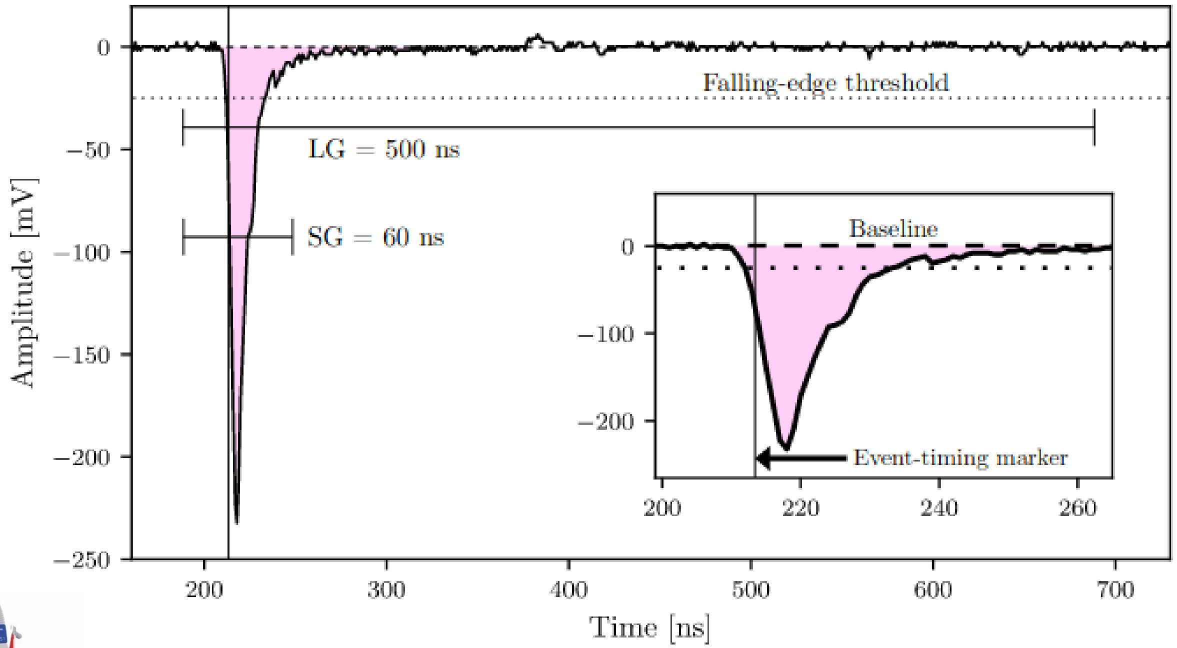

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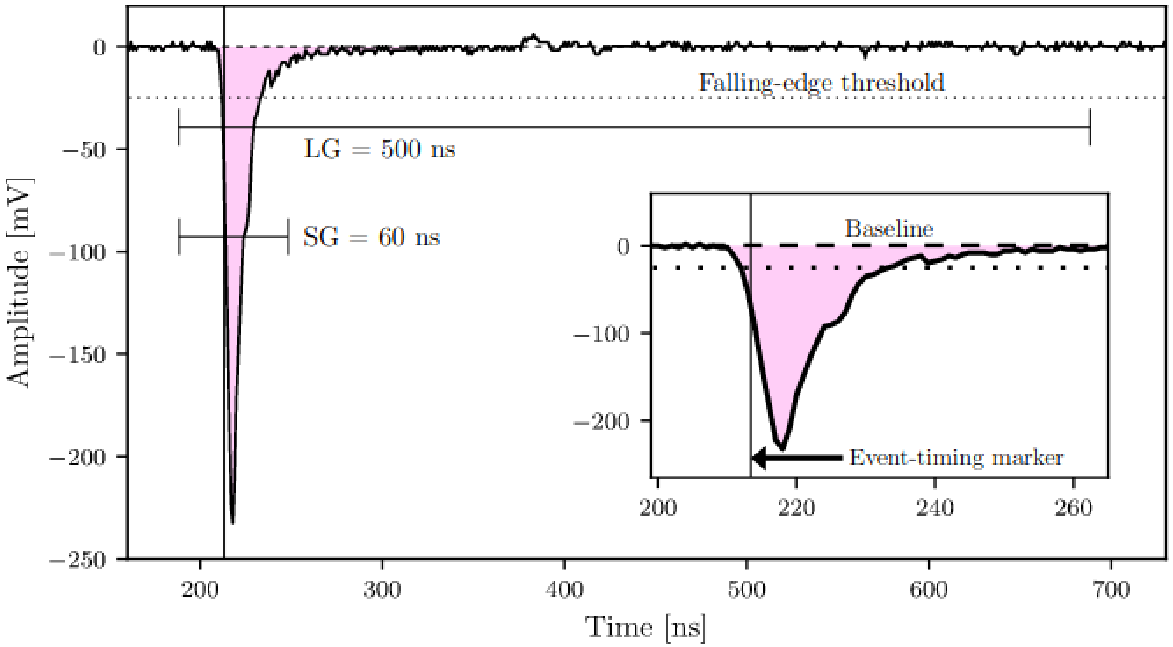


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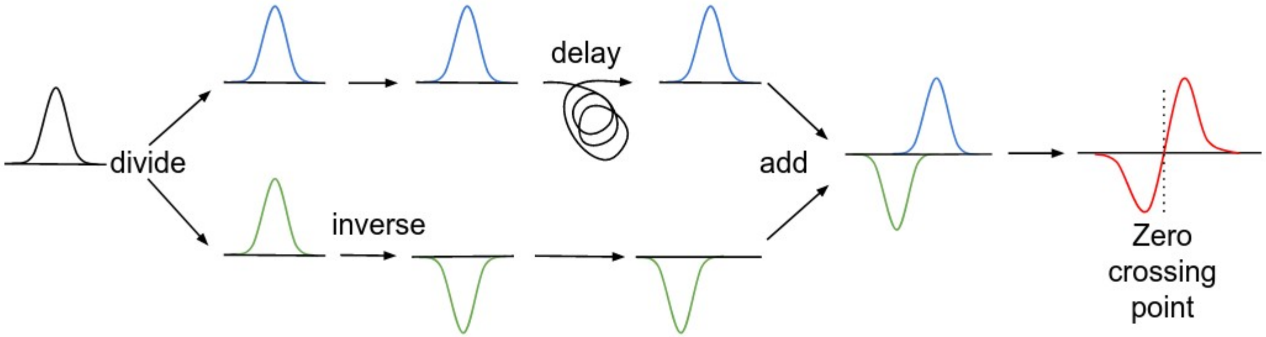

# Data selection

# Data selection

- 140 h TOF data for each scintillator material
- 1 hour gamma-ray runs for each source
- 10 h background runs
- Total: ~3.0 TB

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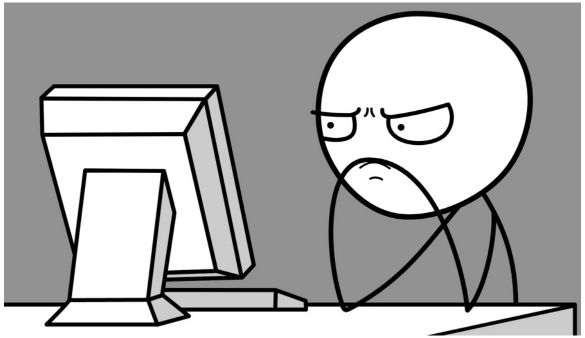

Data in place!

Need simulation ...

# Computational Methods: Simulation

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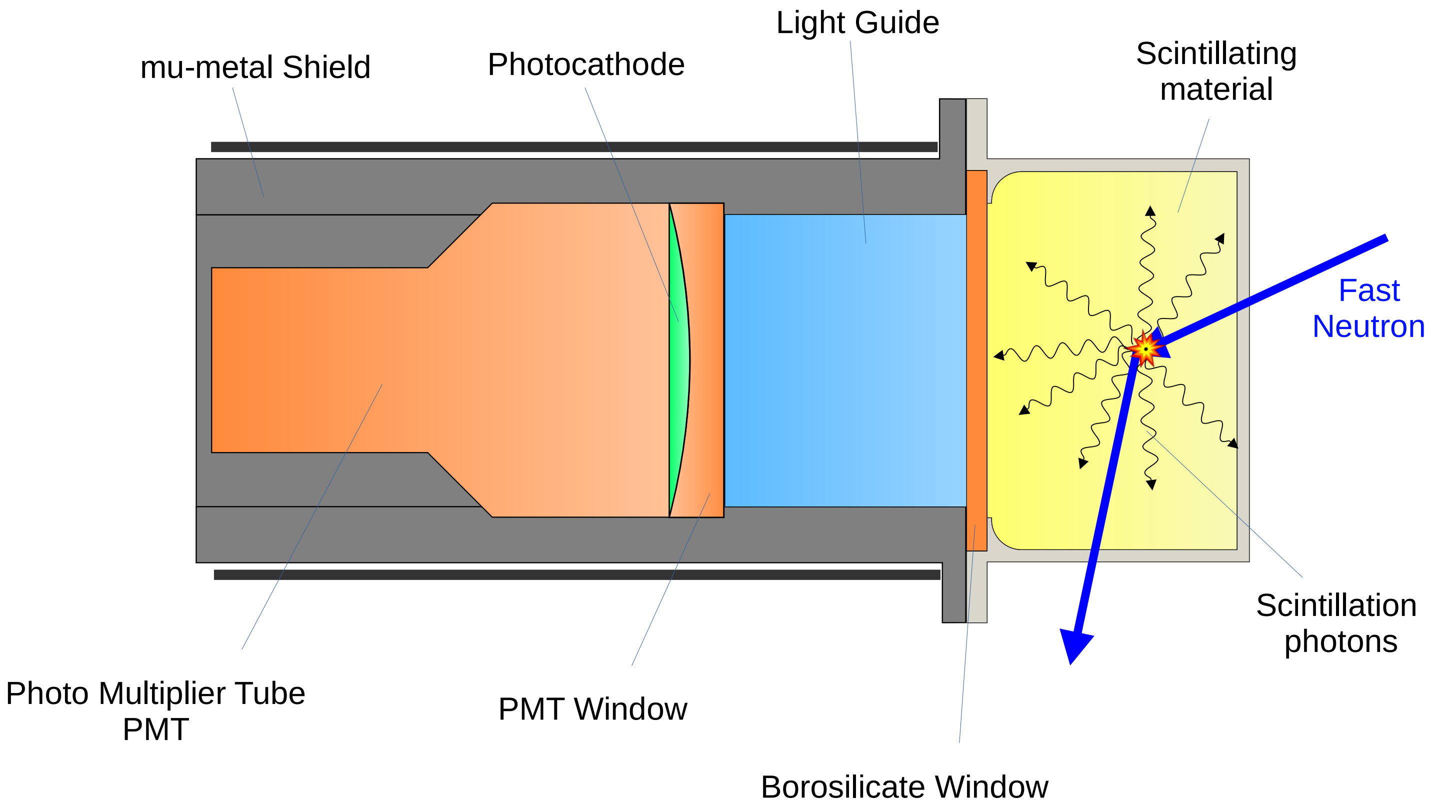

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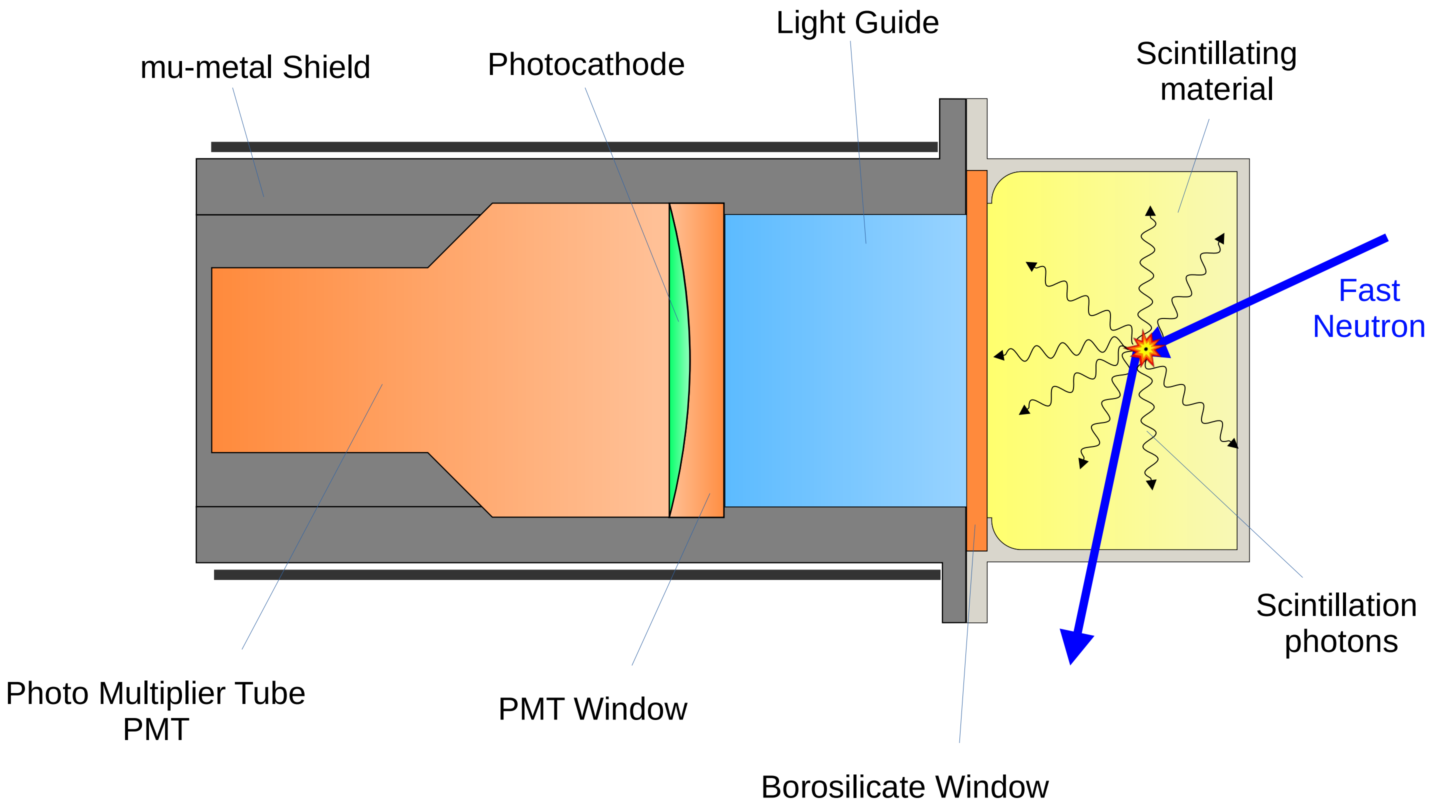
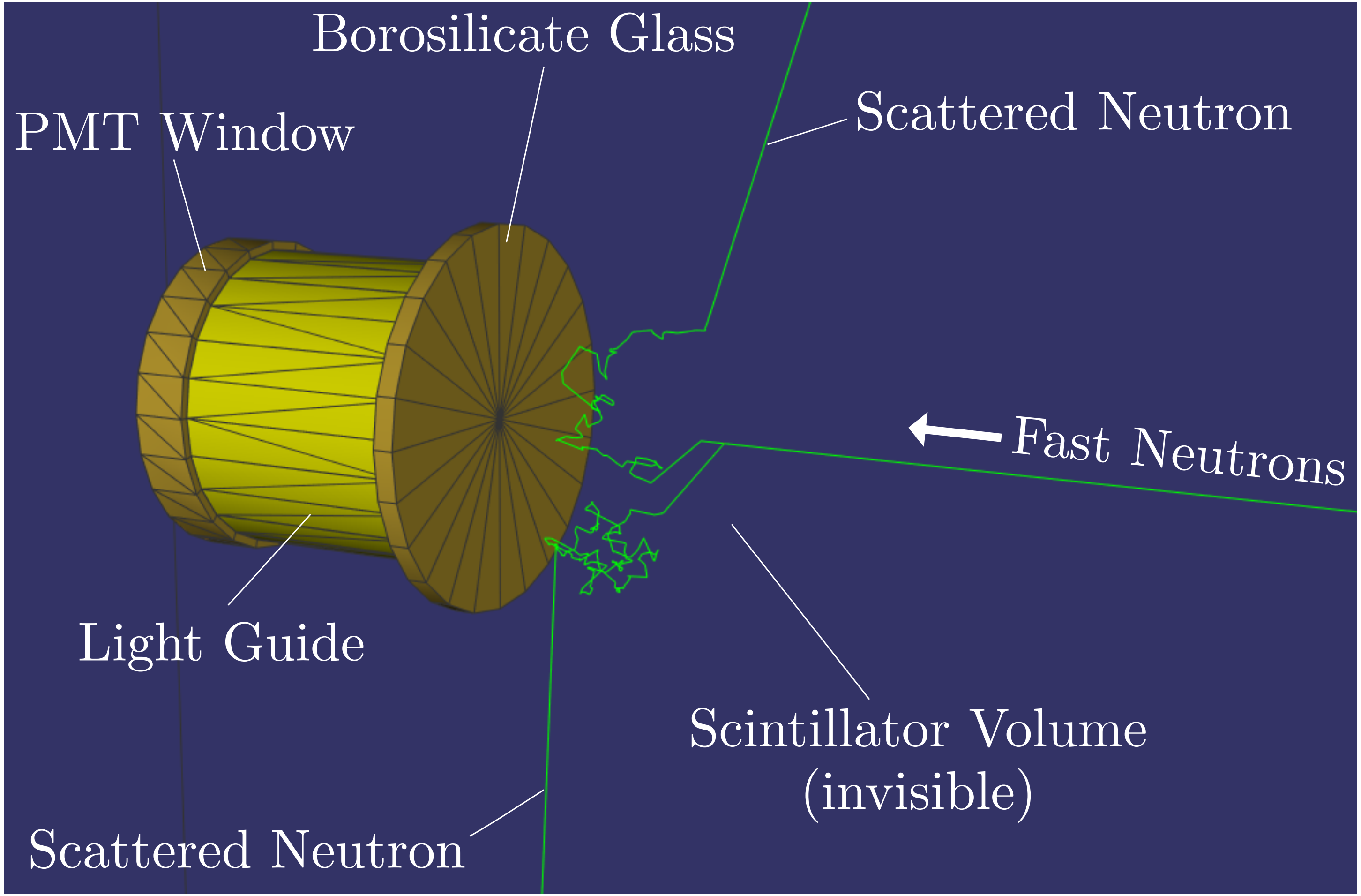



- Detector Geometry
- Material Properties
- Optical Material Properties
- Single Scintillation Photon Tracking

# Computational Methods: Simulation

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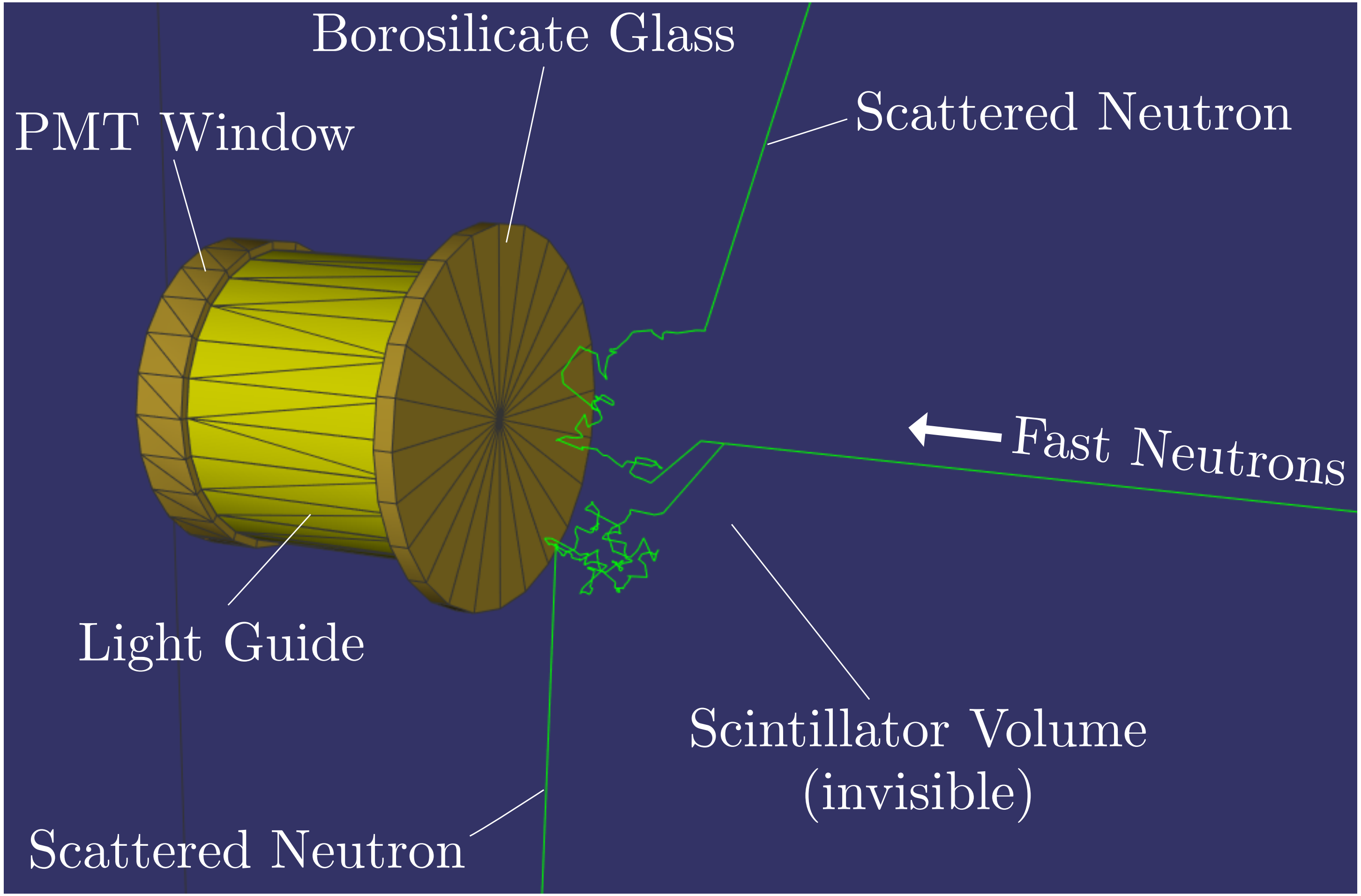



- Detector Geometry
- Material Properties
- Optical Material Properties
- Single Scintillation Photon Tracking

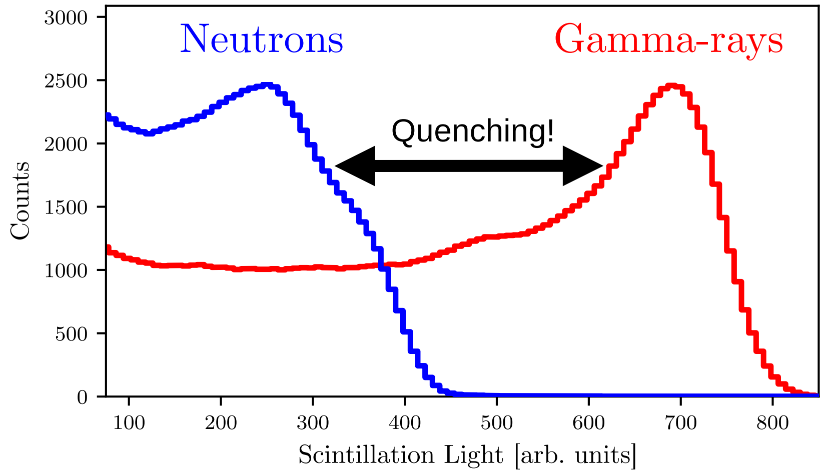
~350 TB data ...

# Toolbox

- ✔ Sources
- ✔ Experimental methods
- ✔ Computational methods

# Energy Calibration

# Energy Calibration



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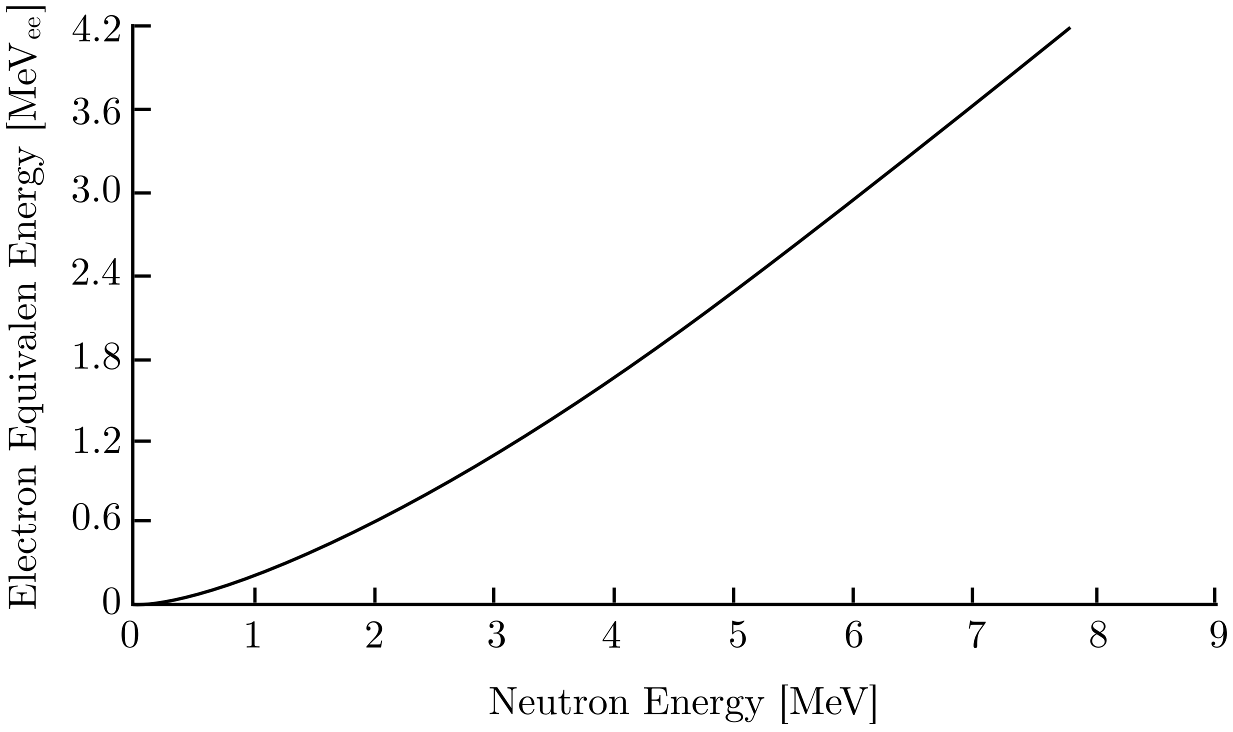


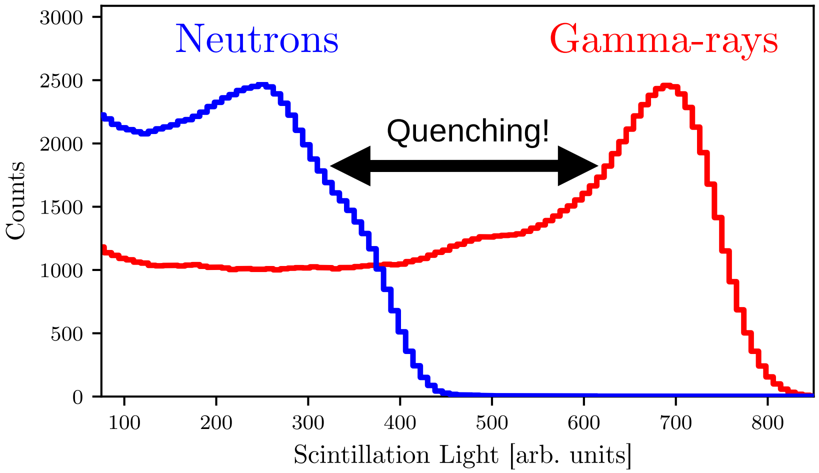

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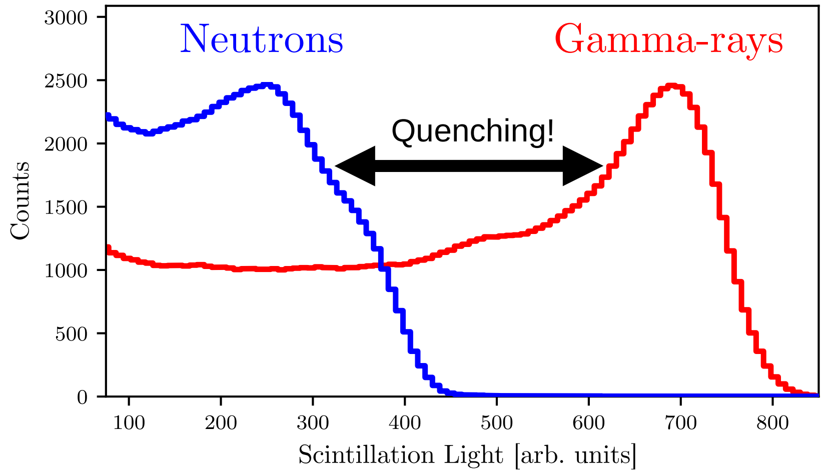


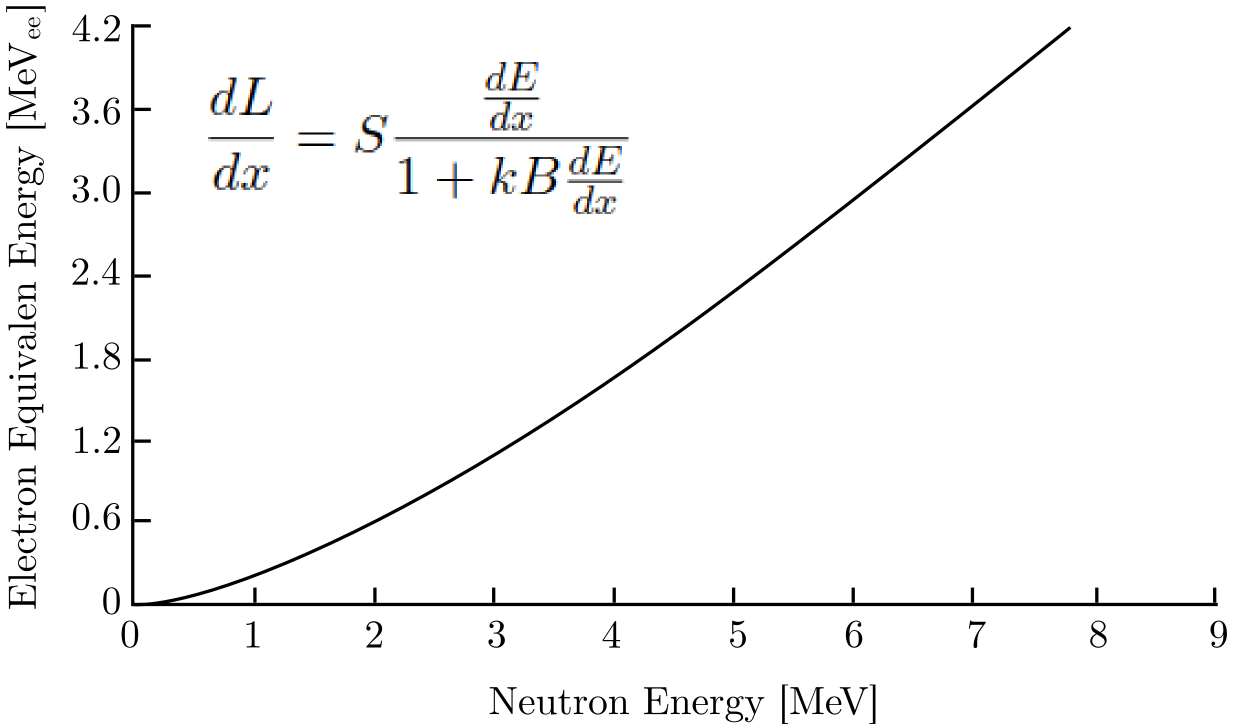

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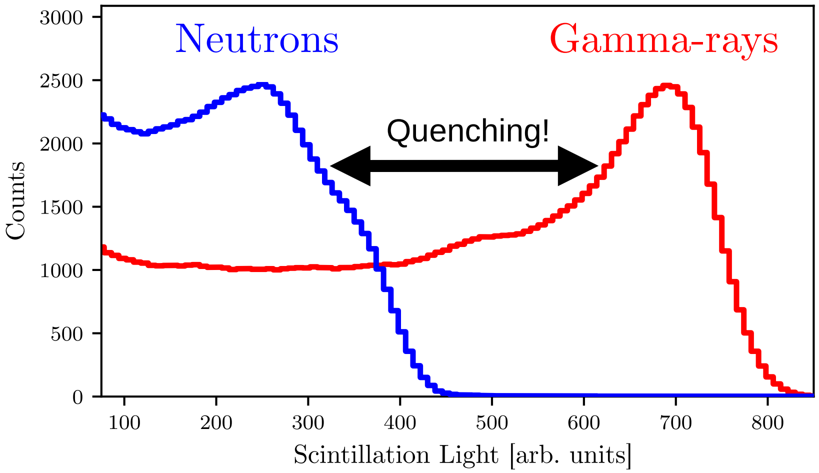
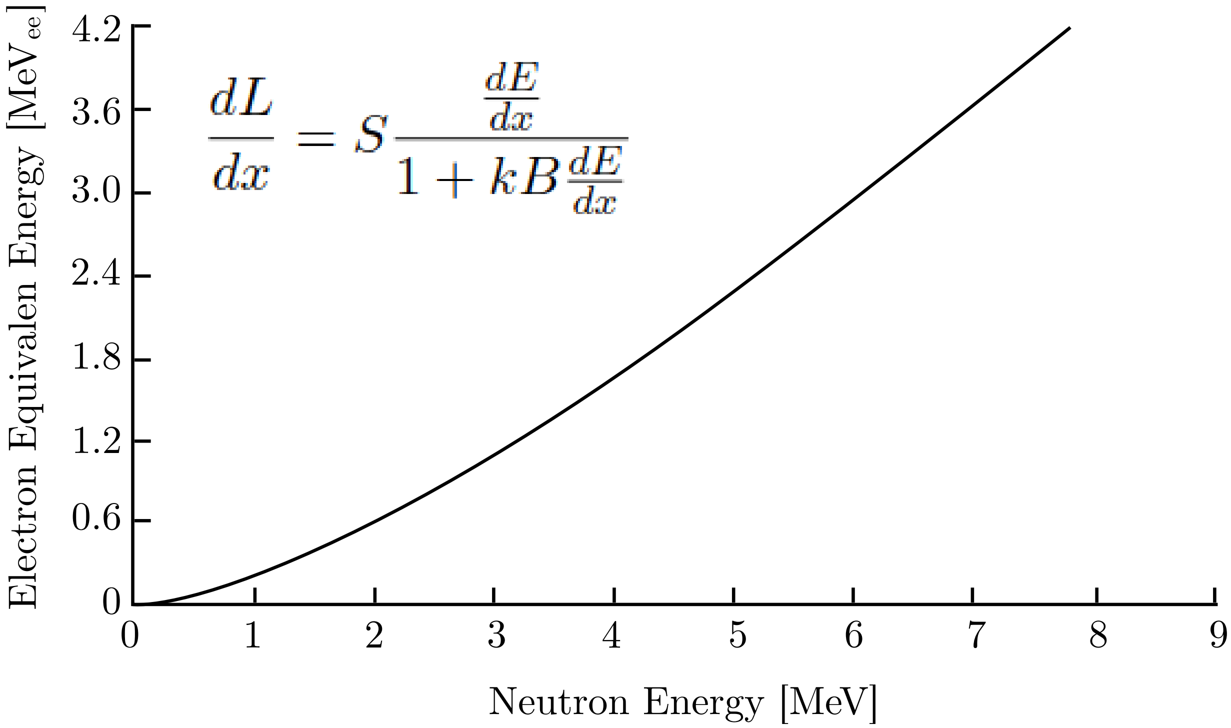



$$\frac{dL}{dx} = S\frac{\frac{dE}{dx}}{1 + kB\frac{dE}{dx}}$$

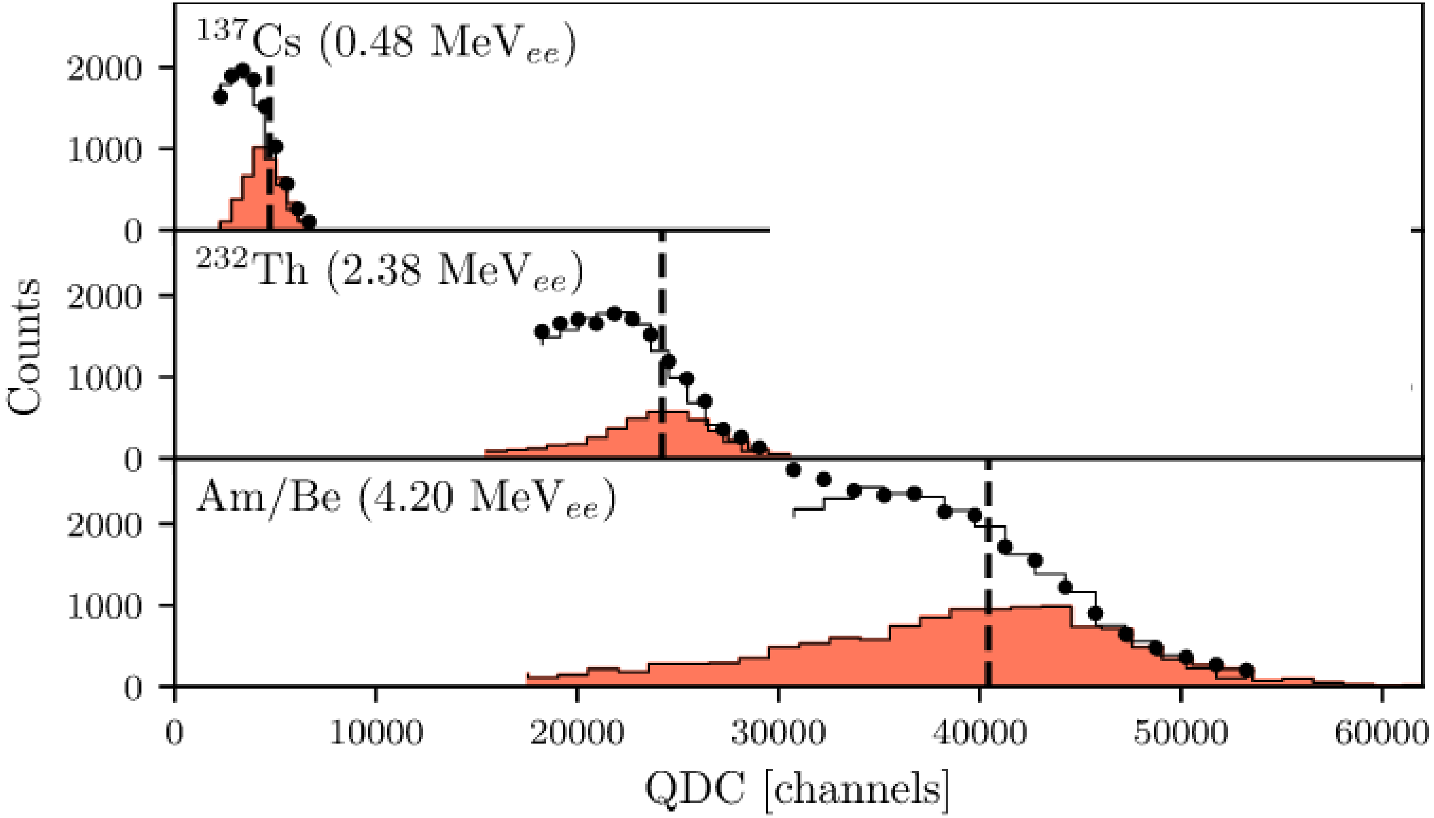
- Gamma-sources are easy!
- No quenching!

$$\frac{dL}{dx} = S\frac{dE}{dx}$$

# Energy Calibration

# Energy Calibration

Compton edge location?



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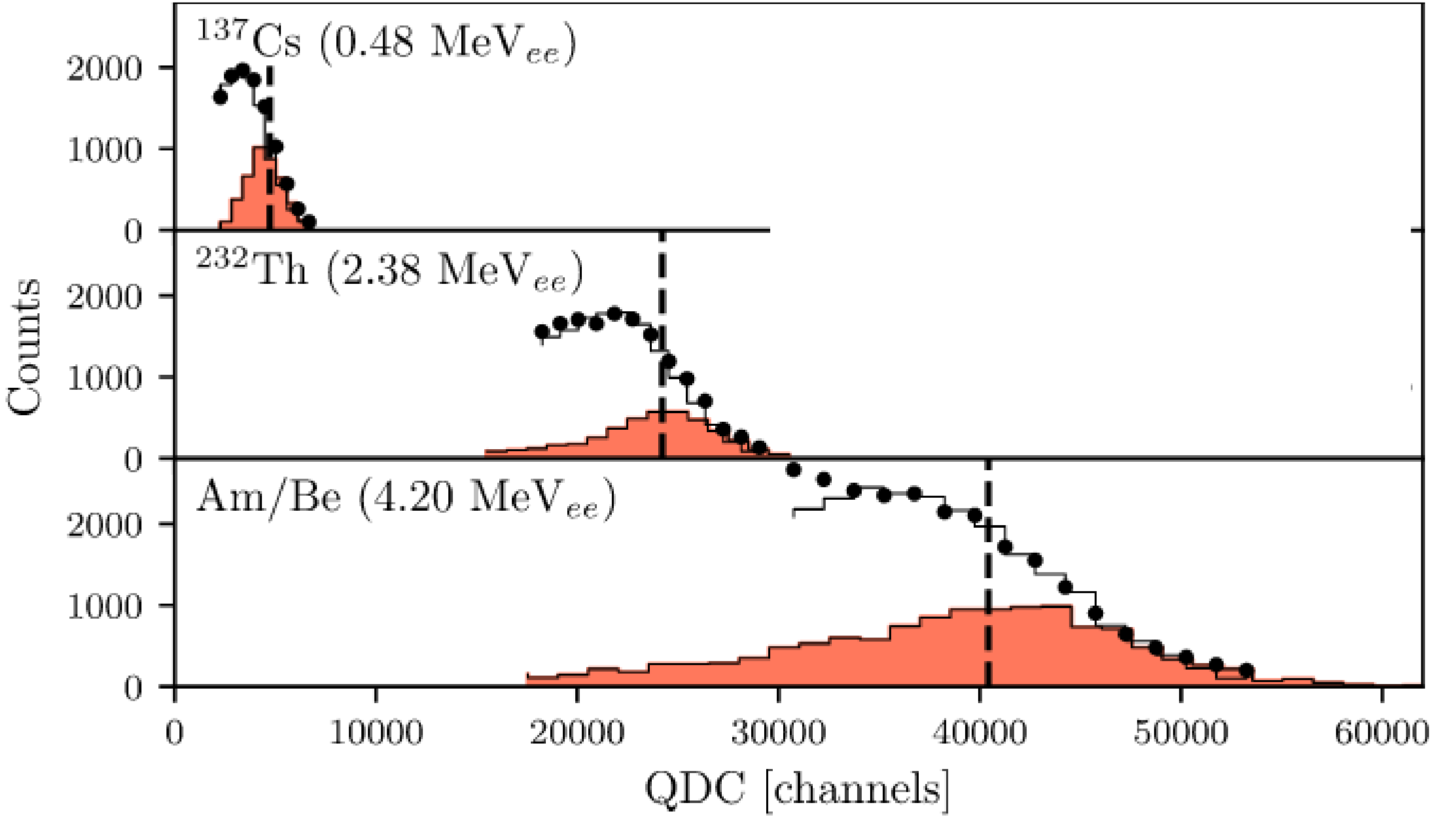


**Simulation constraints**

- Pencilbeam
- 2 keV within Compton max energy

# Energy Calibration

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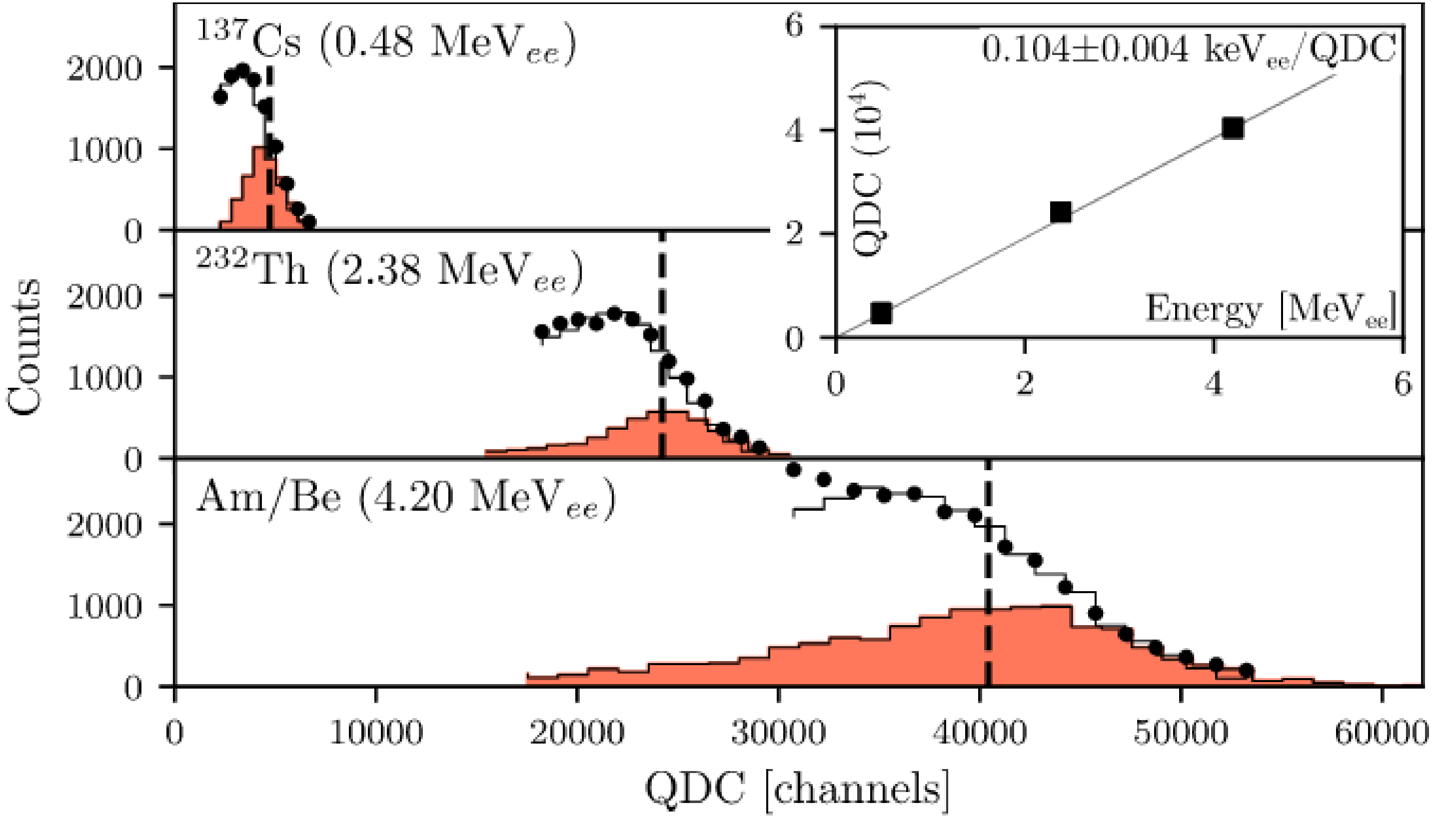


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# Intrinsic Pulse-Shape

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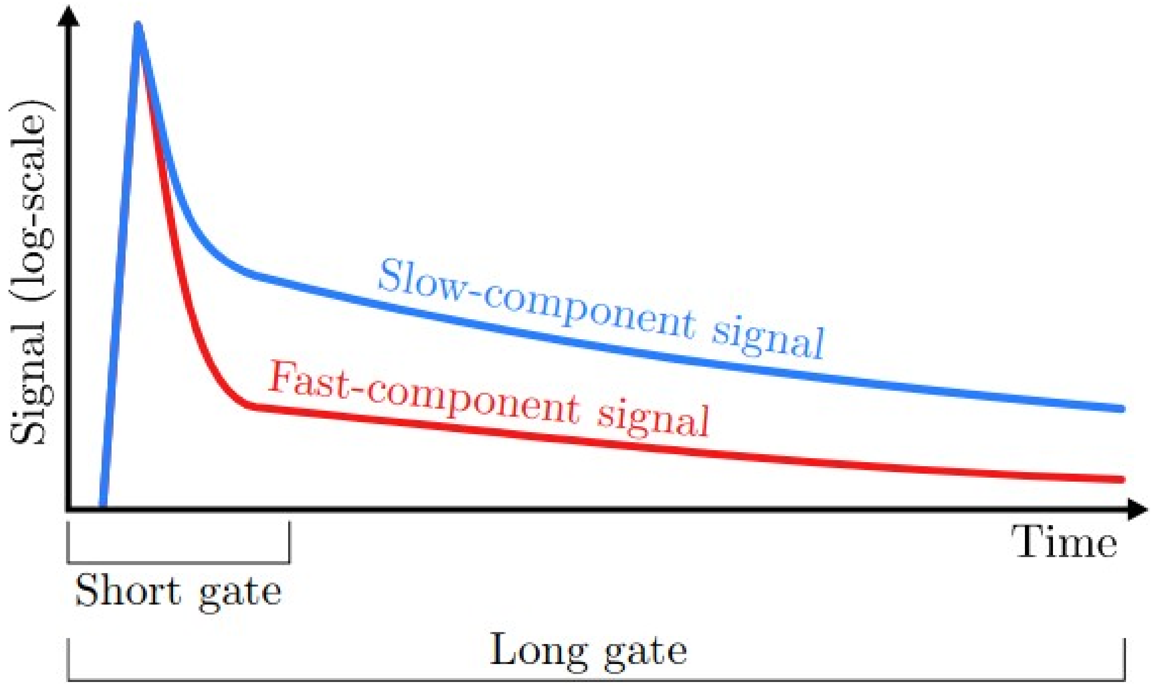
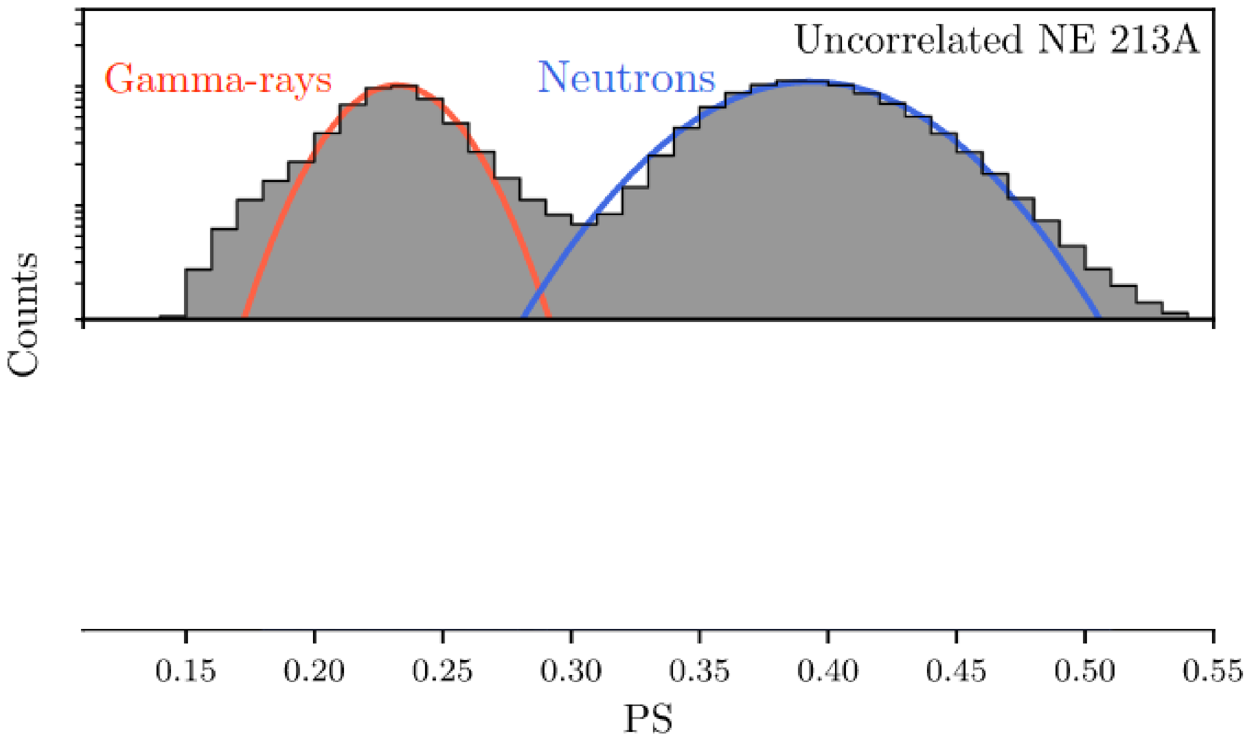



$$PS = \frac{\text{Long gate integral} - \text{Short gate integral}}{\text{Long gate integral}}$$

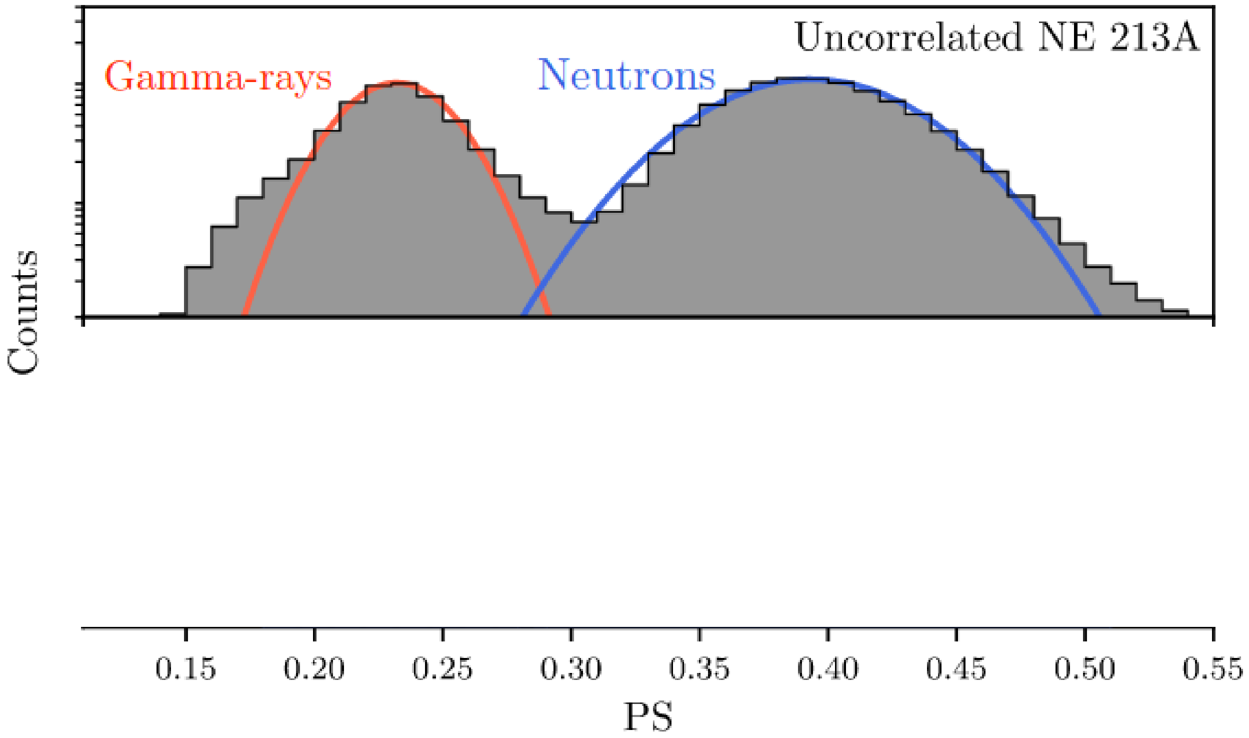
# Intrinsic Pulse-Shape




Event-by-event processing

$$PS = \frac{\text{Long gate integral} - \text{Short gate integral}}{\text{Long gate integral}}$$

# Intrinsic Pulse-Shape

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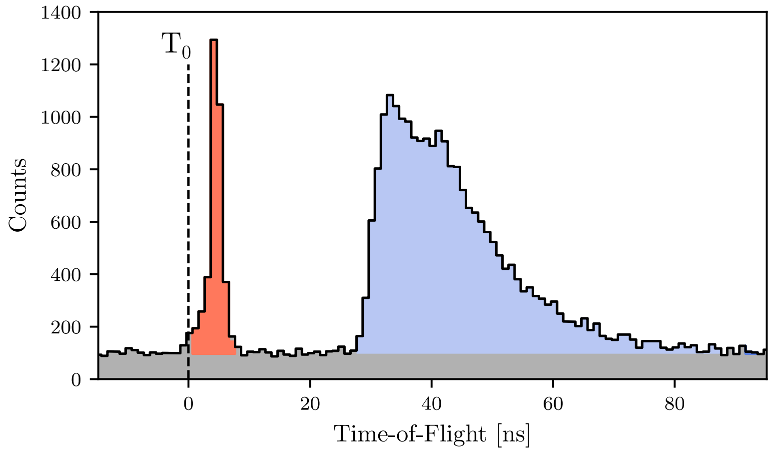


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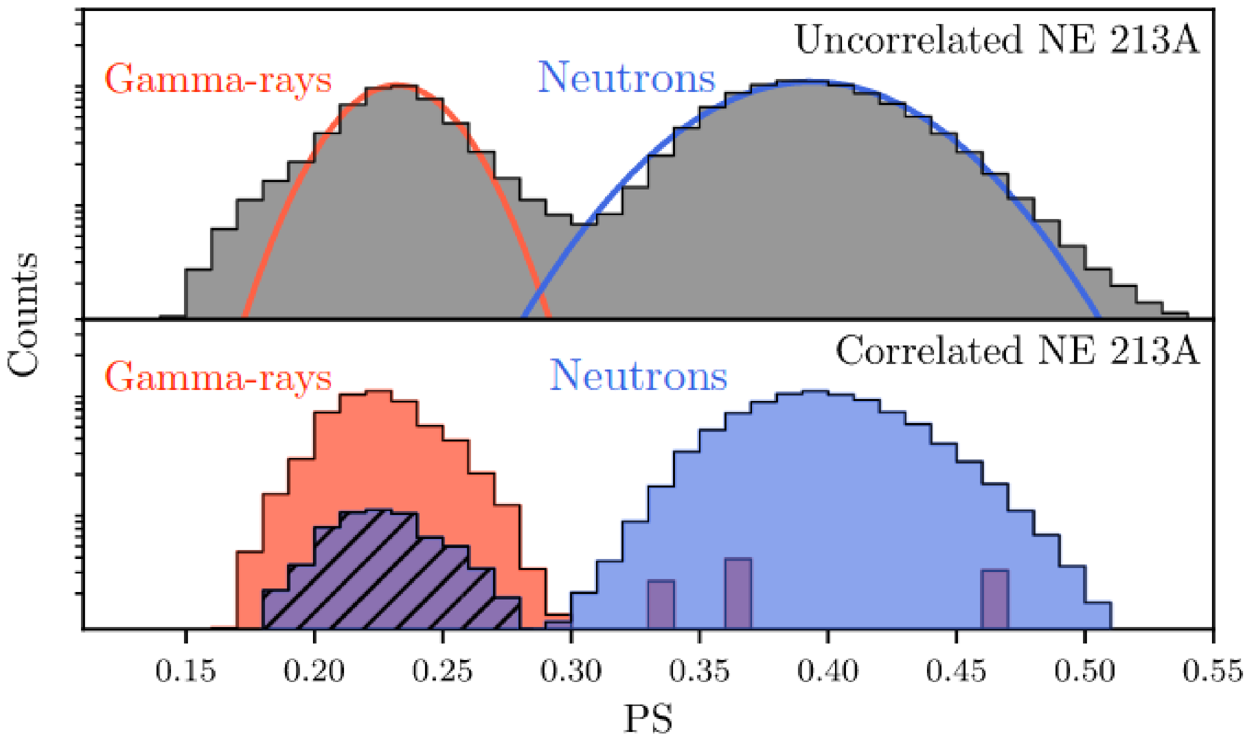
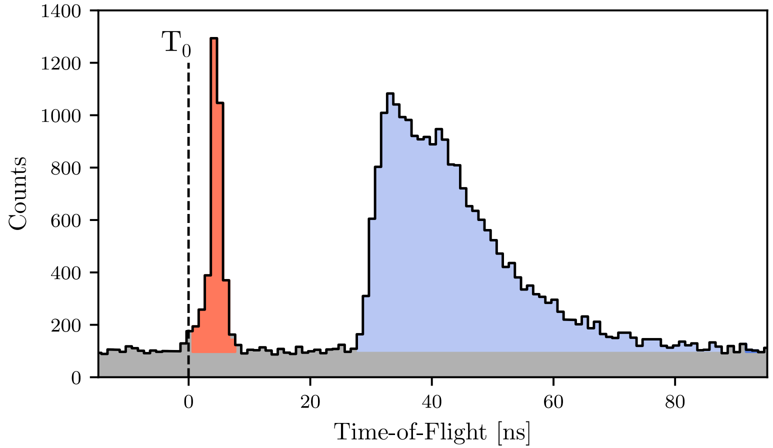



Event-by-event processing

Removed randoms

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# Neutron Light Yield

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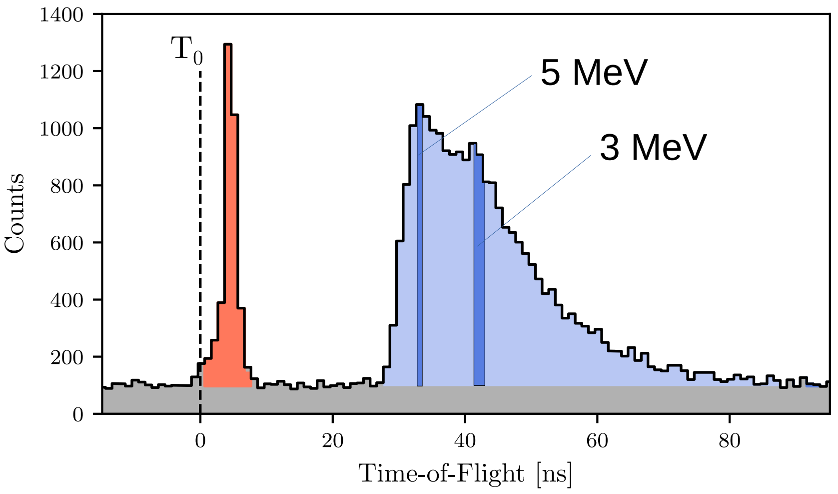
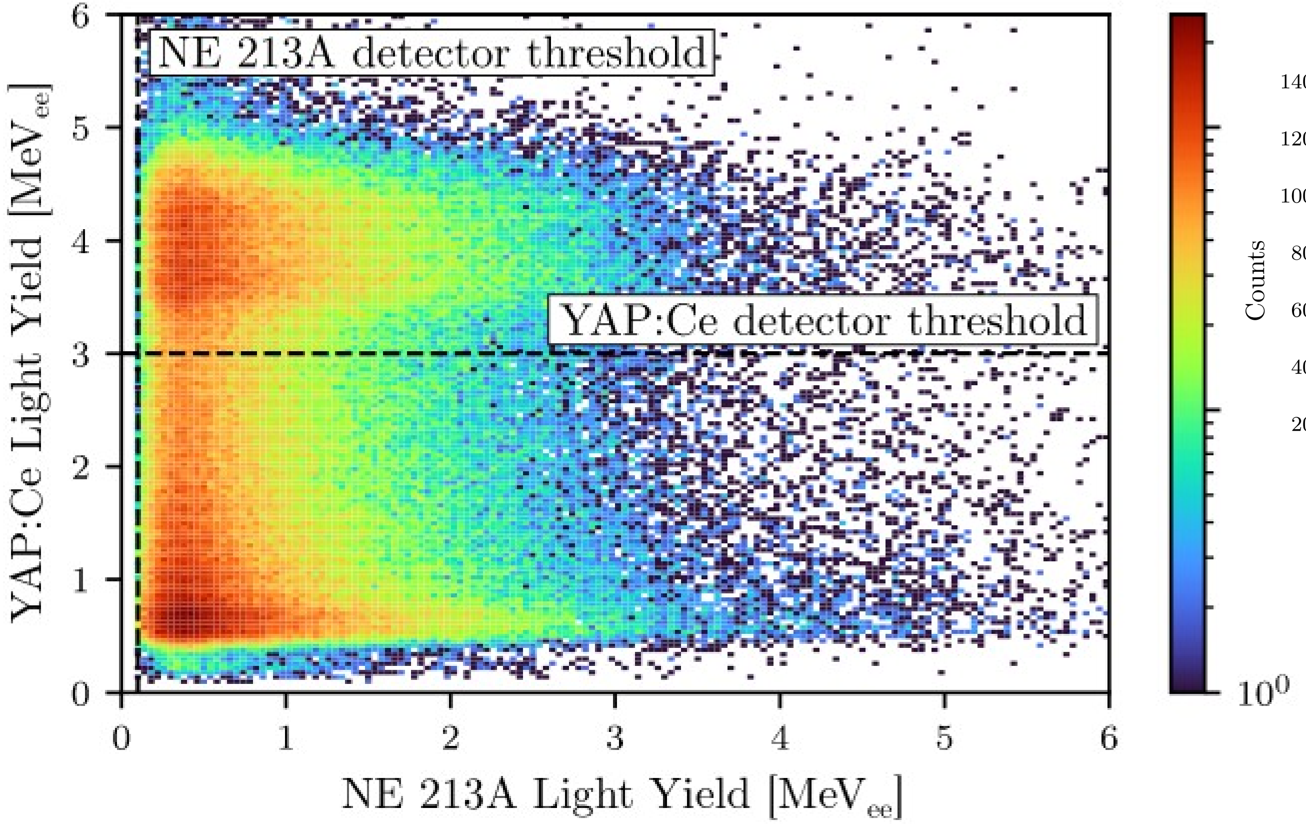
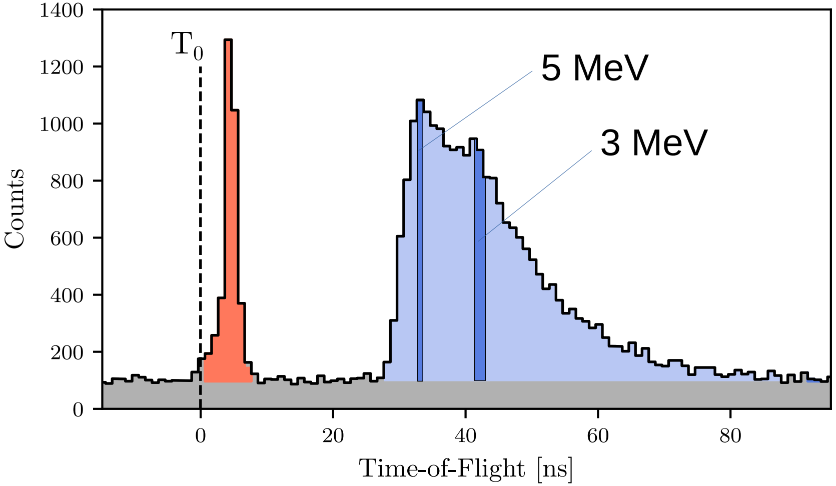



2-6 MeV, 0.25 MeV bins

# Neutron Light Yield



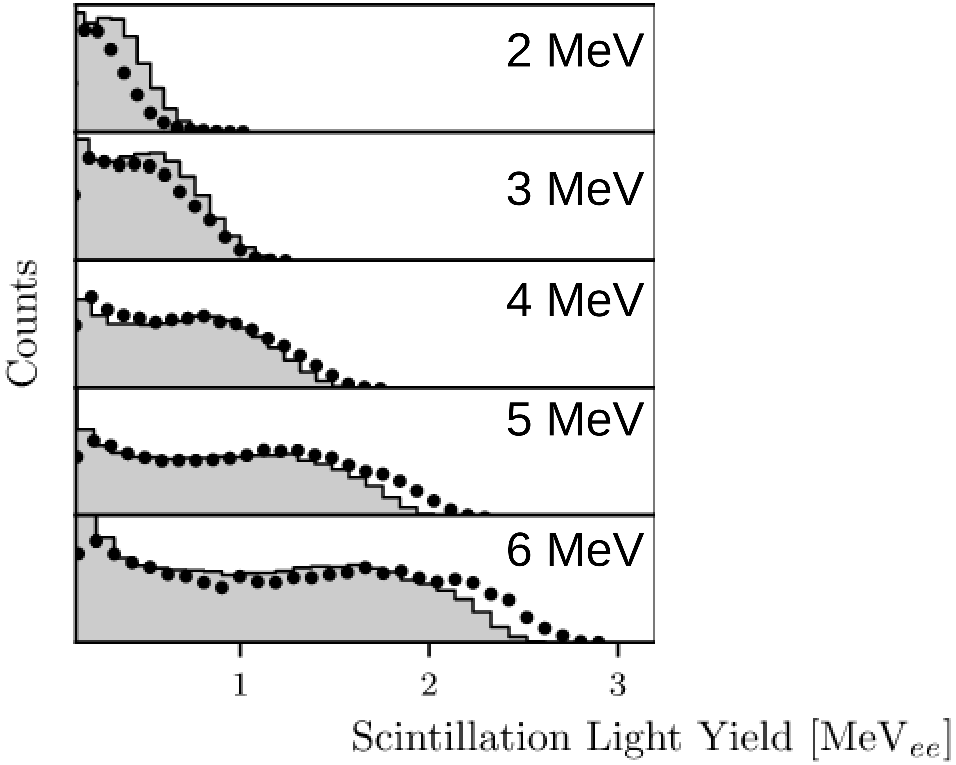

2-6 MeV, 0.25 MeV bins

# Neutron Light Yield

What Birks parameter (*kB*) to use?

$$\frac{dL}{dx} = S \frac{\frac{dE}{dx}}{1 + kB\frac{dE}{dx}}$$

# Neutron Light Yield



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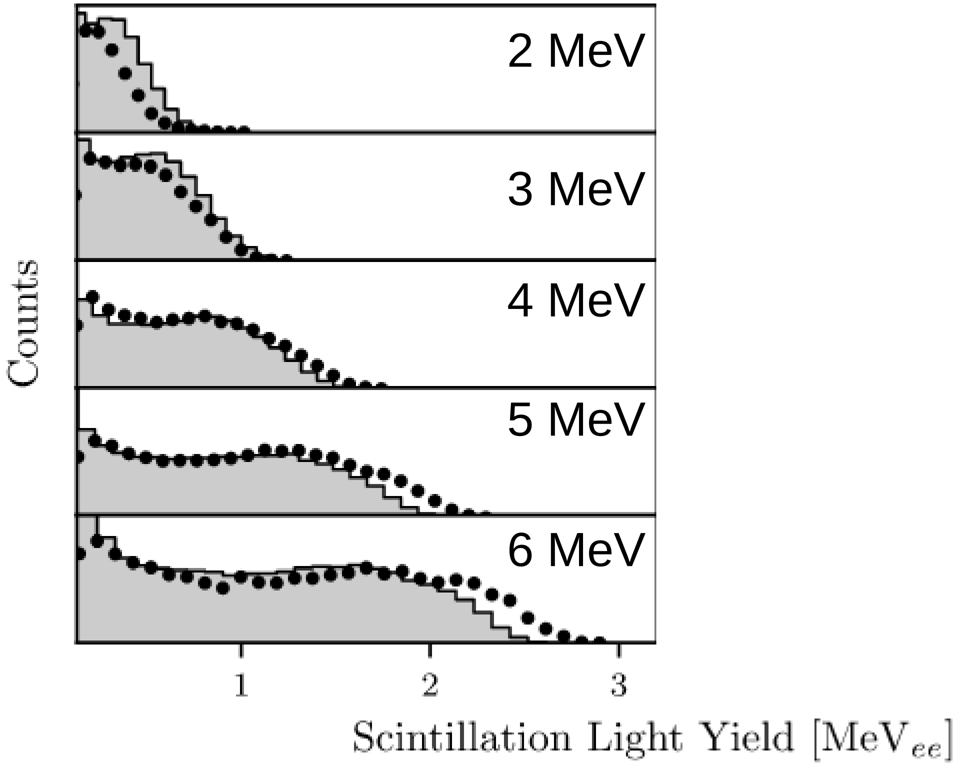

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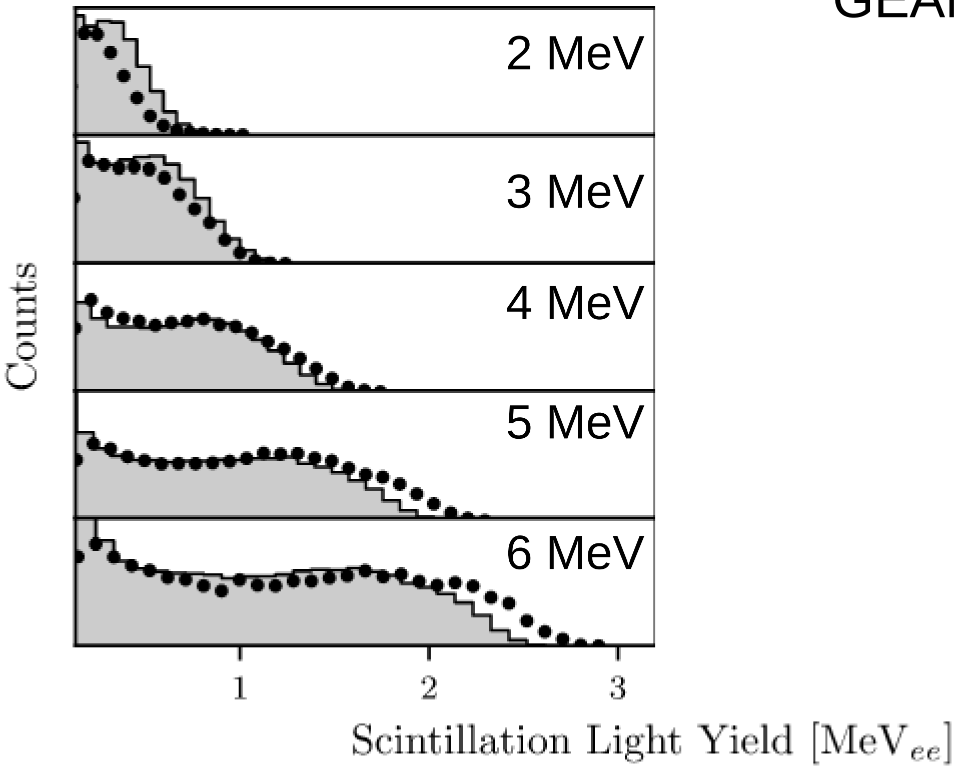
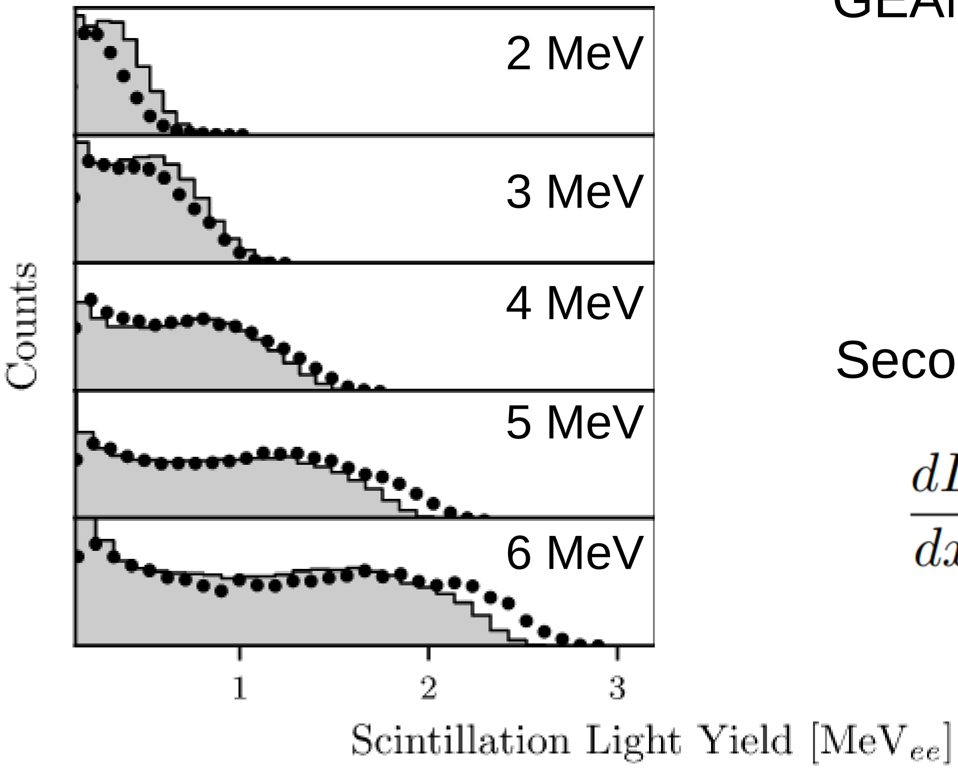



GEANT4 quenching mechanism:

$$\frac{dL}{dx} = S \frac{\frac{dE}{dx}}{1 + kB\frac{dE}{dx}}$$

# Neutron Light Yield



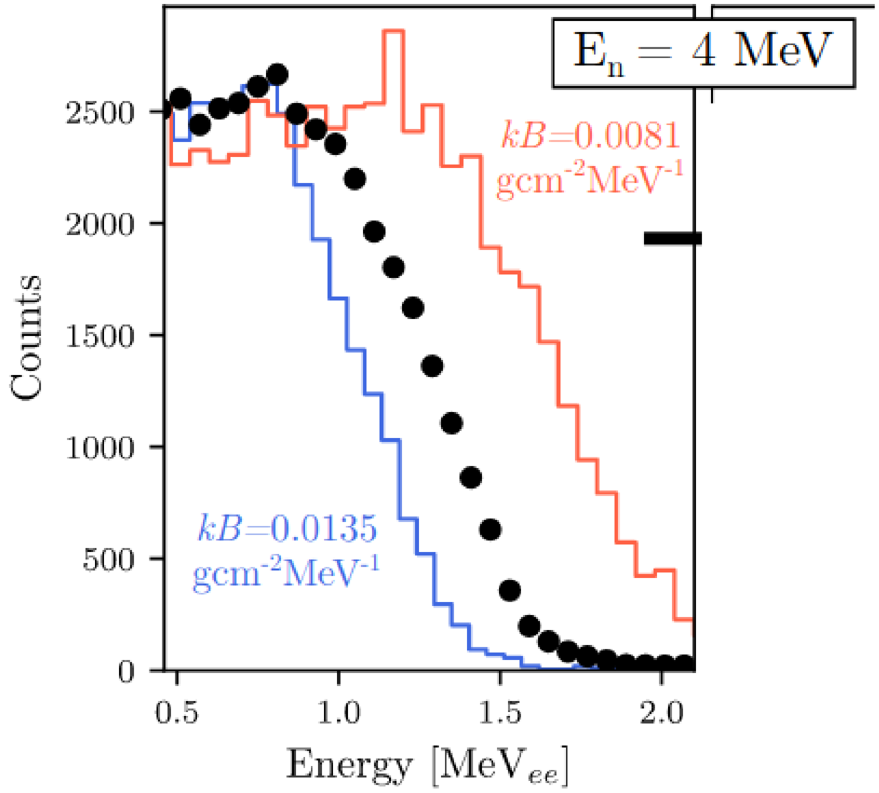

GEANT4 quenching mechanism:

$$\frac{dL}{dx} = S\frac{\frac{dE}{dx}}{1 + kB\frac{dE}{dx}}$$

Second order terms?

$$\frac{dL}{dx} = S\frac{\frac{dE}{dx}}{1 + kB\frac{dE}{dx} + C\left(\frac{dE}{dx}\right)^2}$$

# Neutron Light Yield



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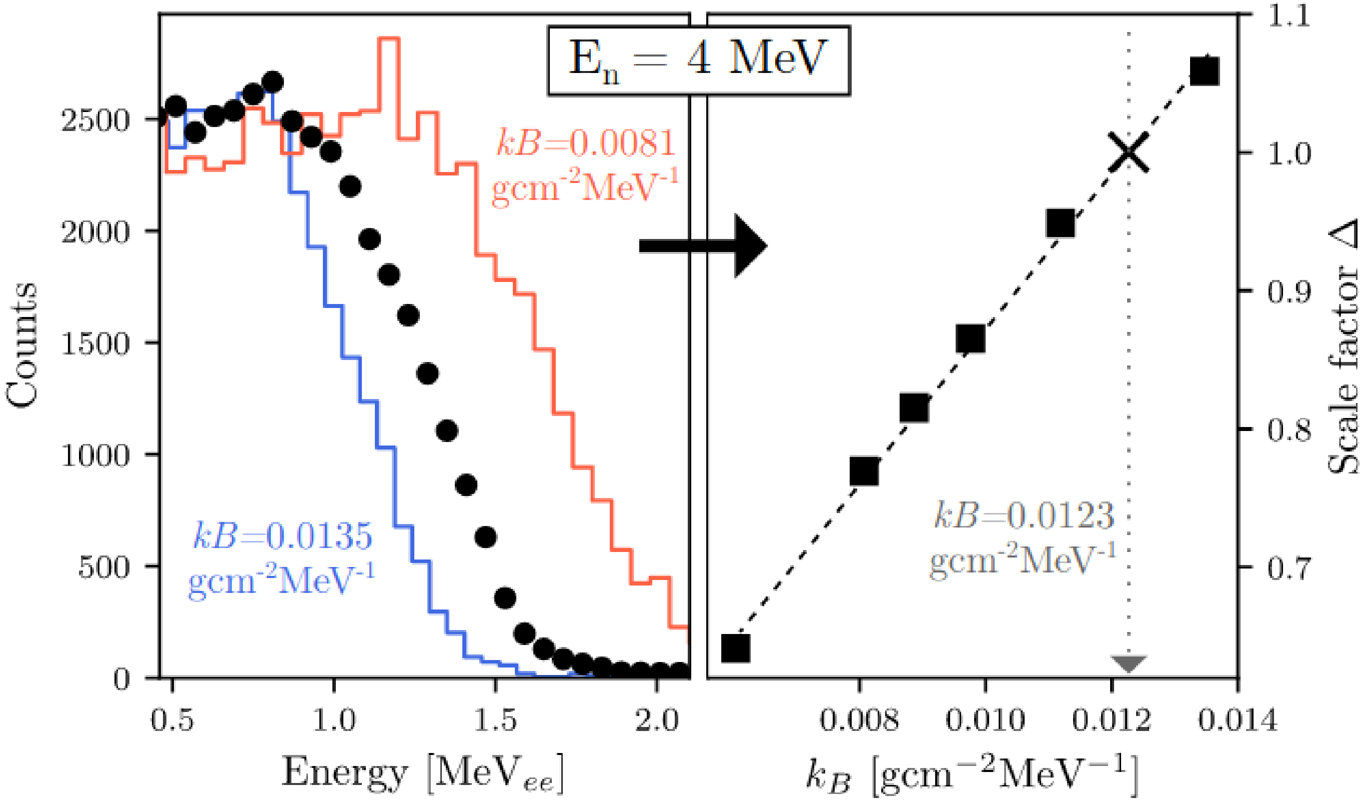

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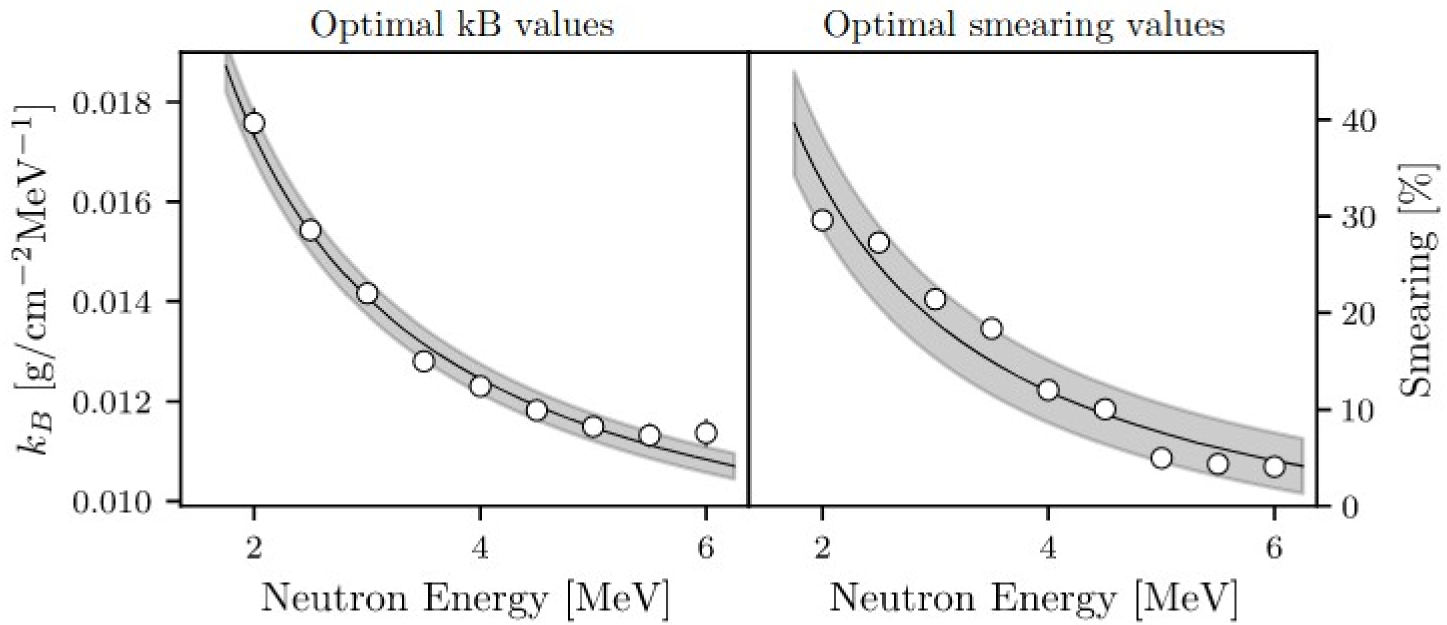

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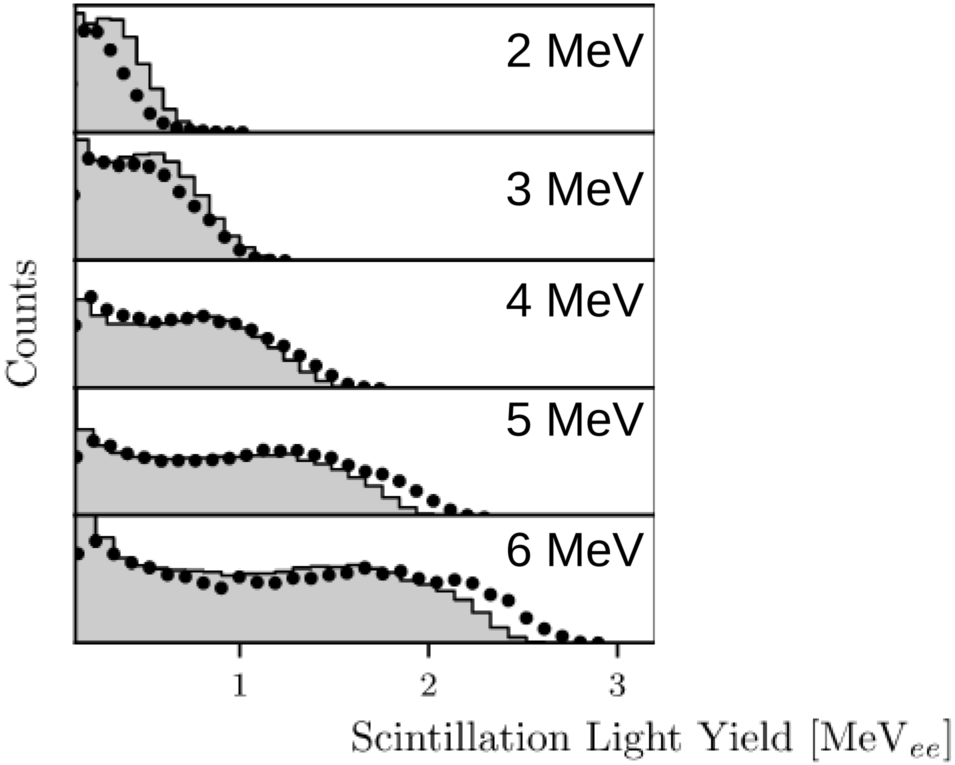

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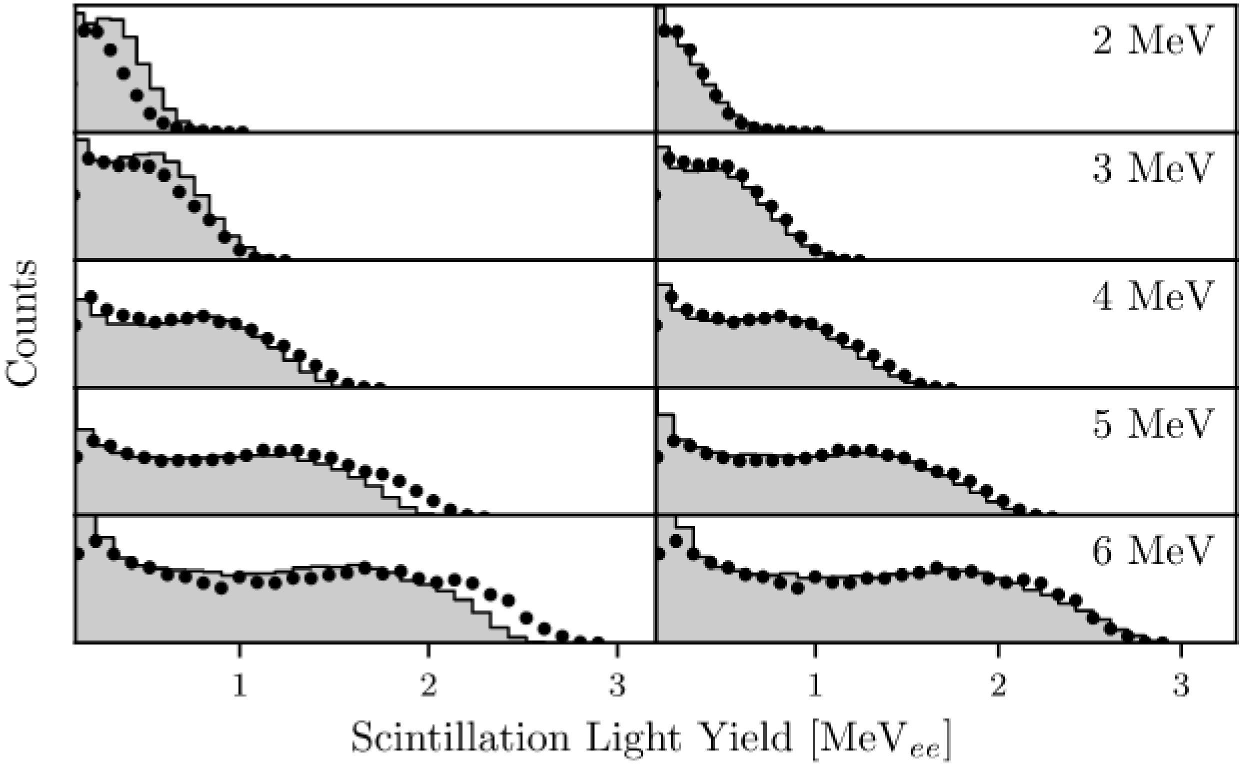

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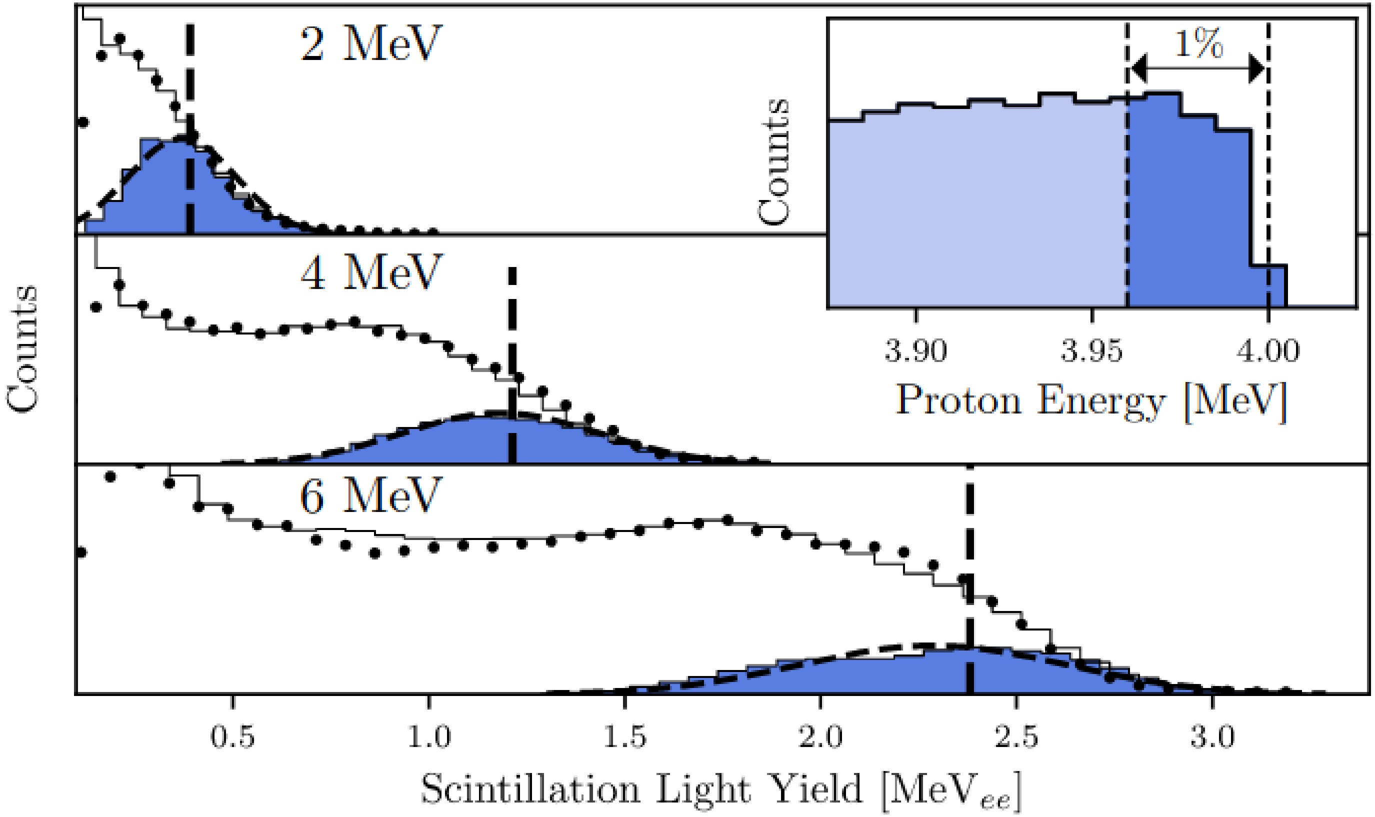

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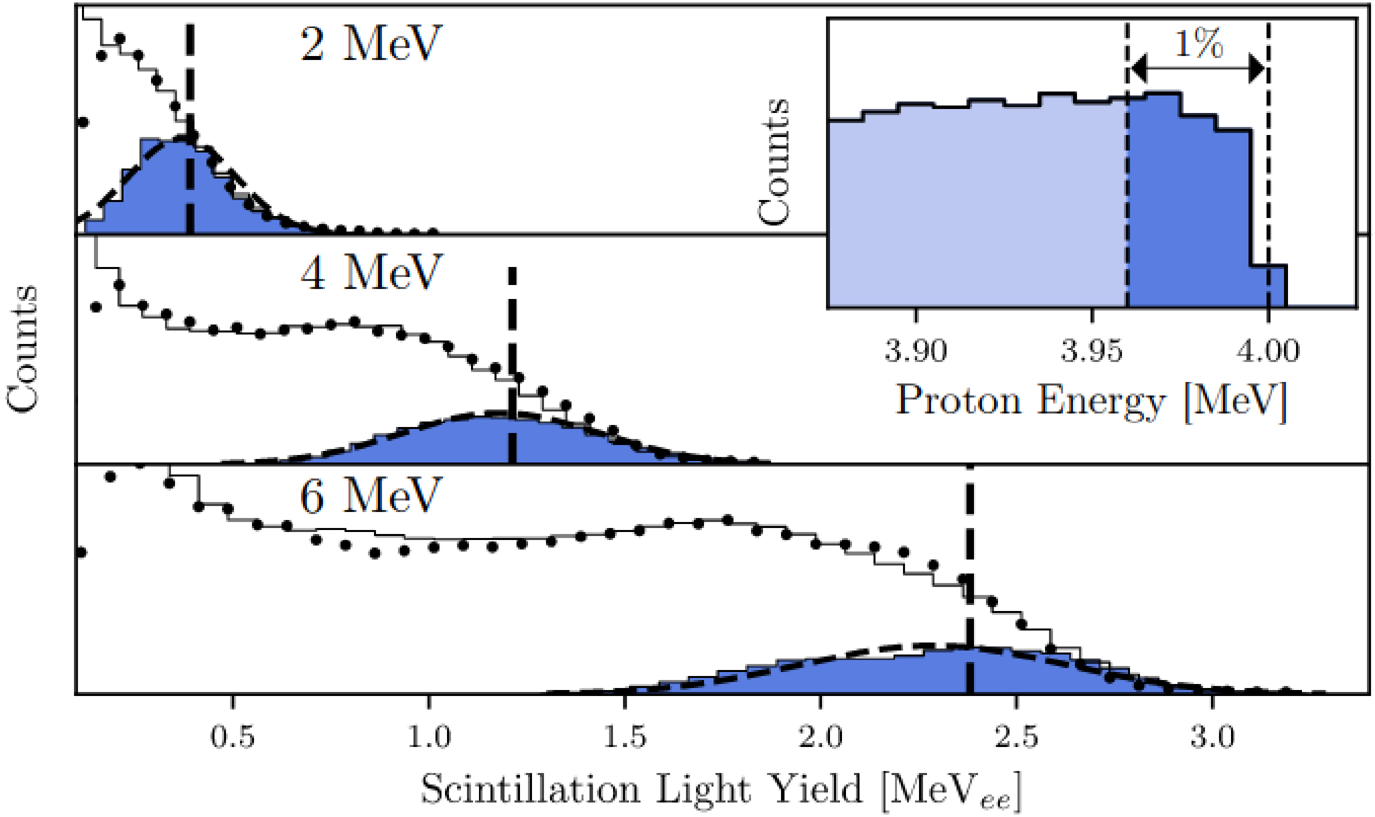
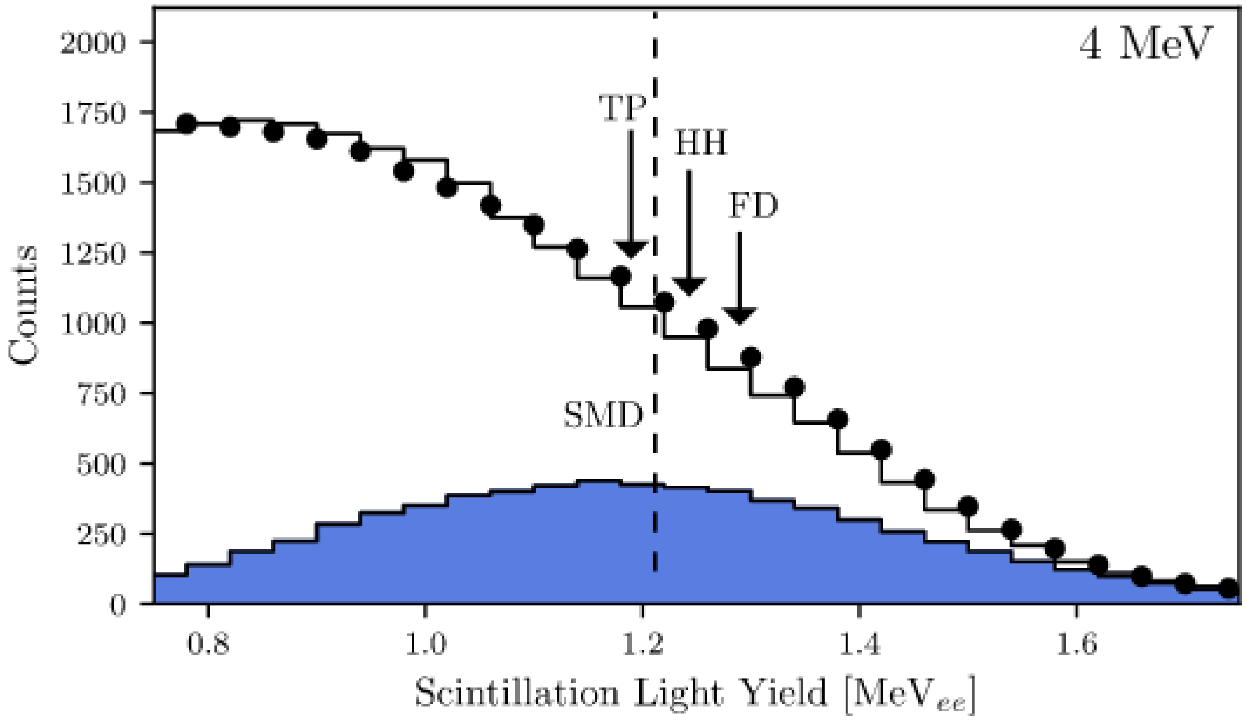



**Simulation constraints**

- Pencilbeam
- Neutron Edep within 1% of neutron energy
- Proton scattering only!
- Energy optimized *kB* values

# Neutron Light Yield



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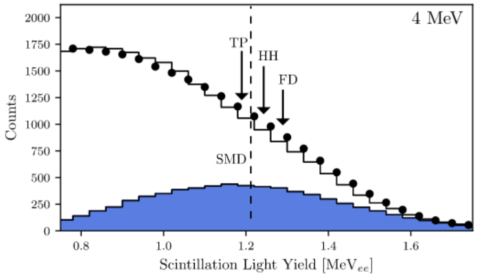


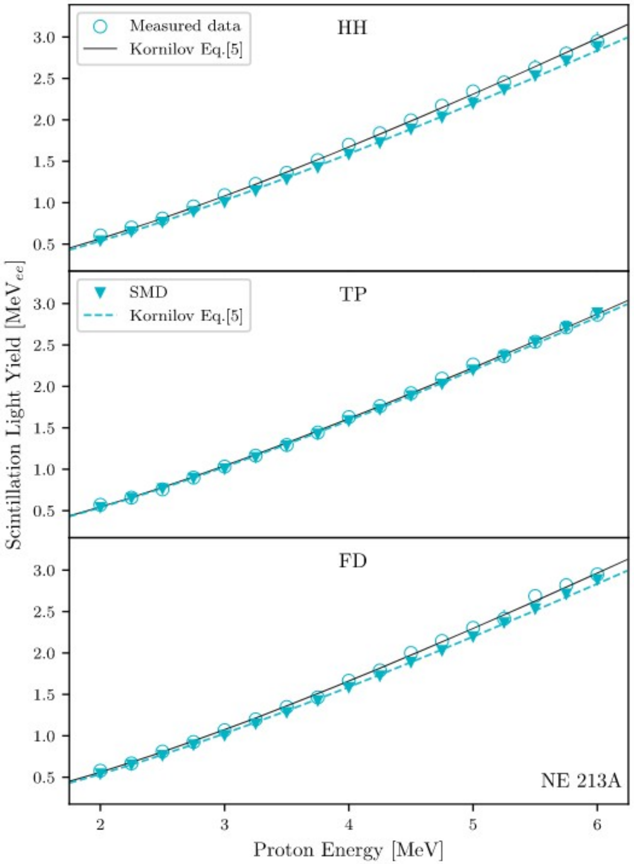

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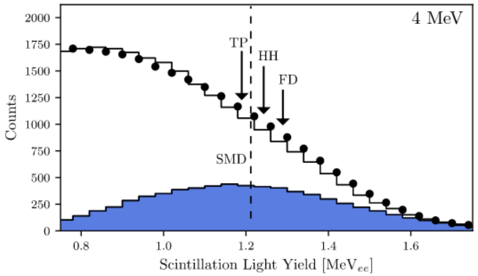


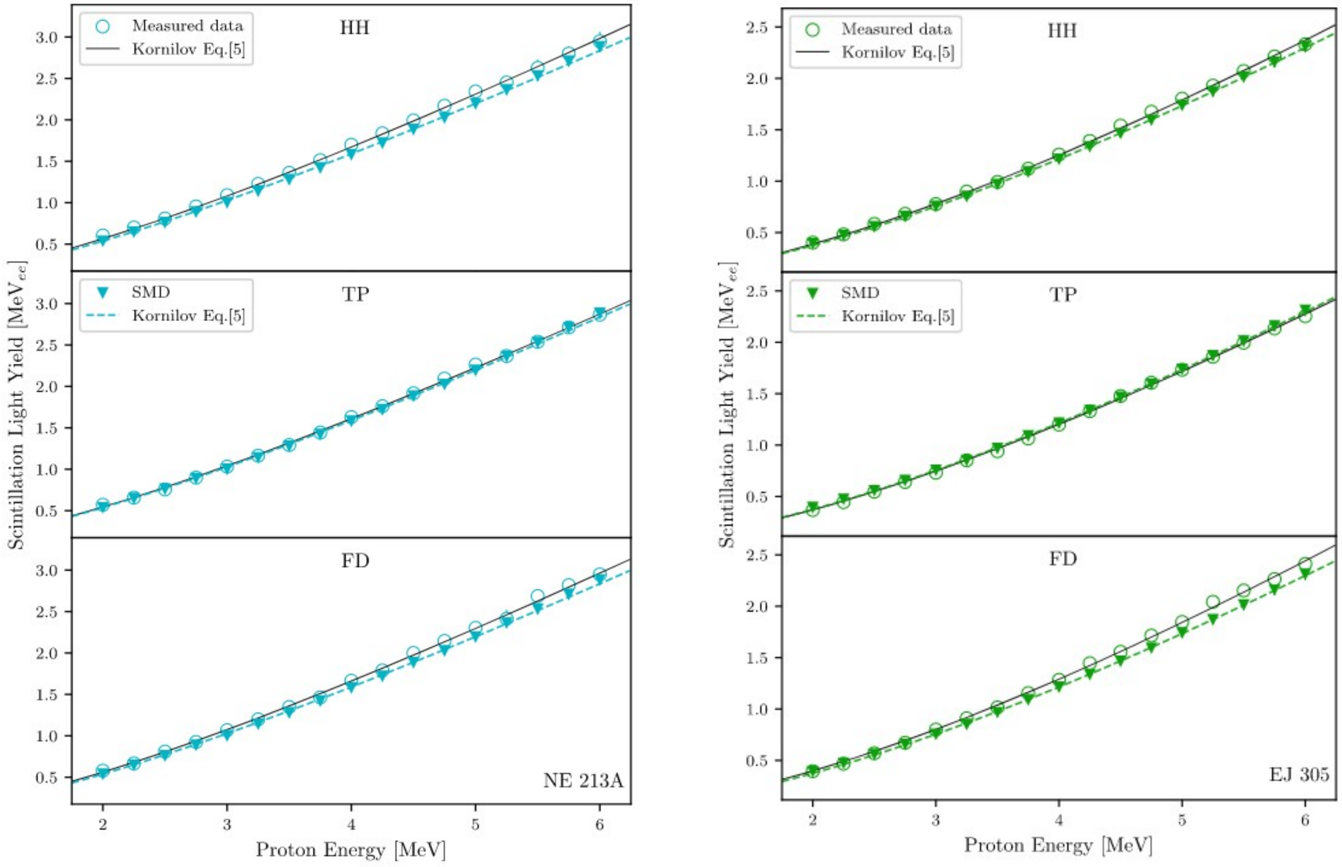

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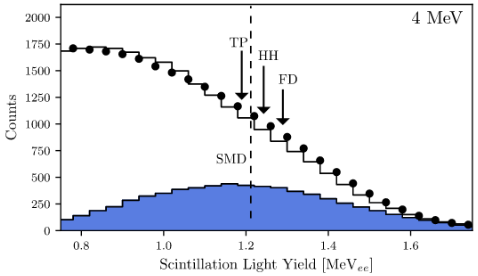
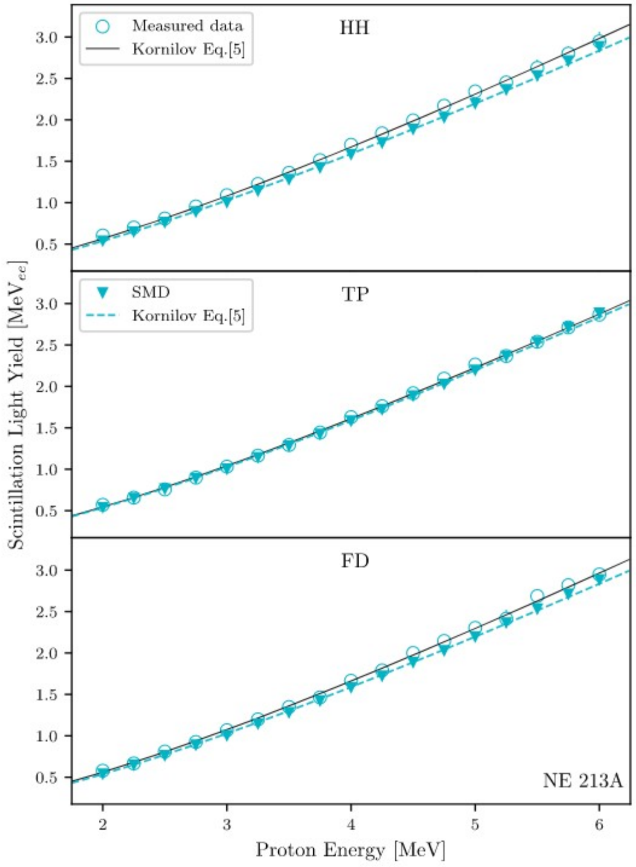
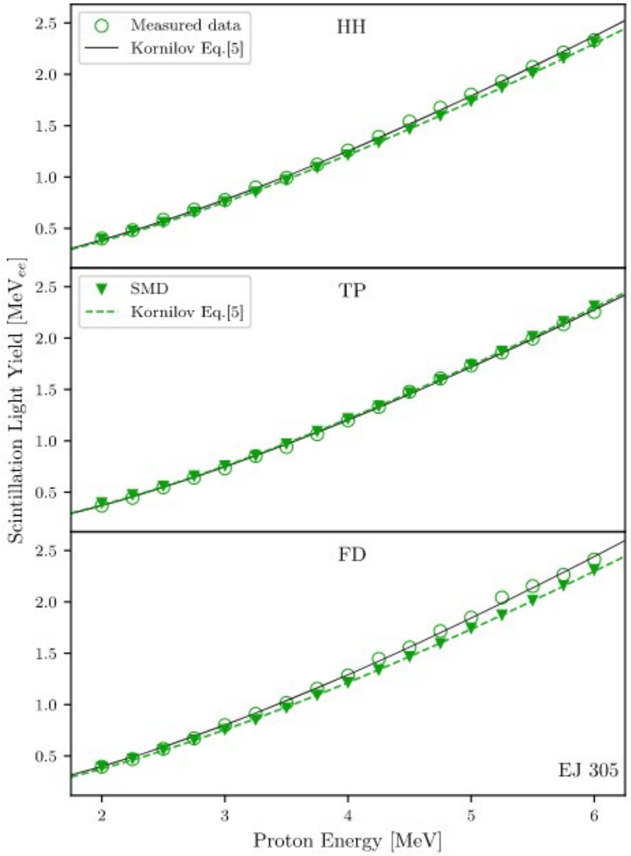
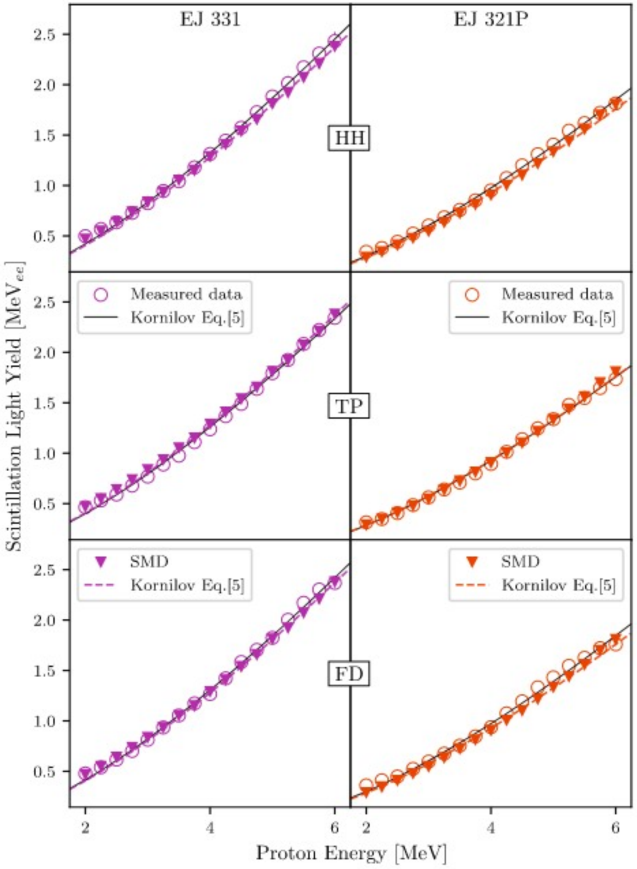


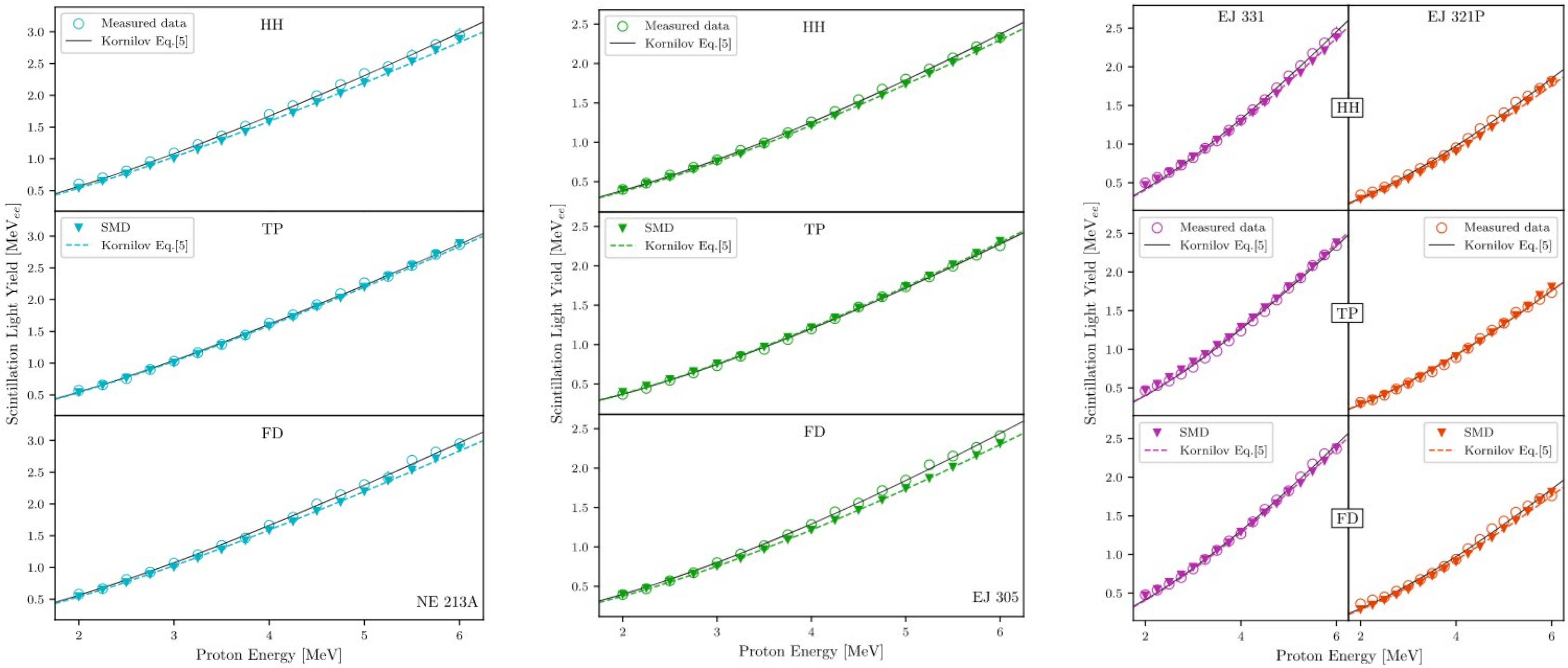



# Neutron Light Yield

$$L(E_p) = L_{ee} = K\left[p_1 E_p - p_2\left(1 - e^{-p_3 E_p^{p_4}}\right)\right]$$

$$L(E_p) = L_{ee} = L_0 \frac{E_p^2}{E_p + L_1}$$



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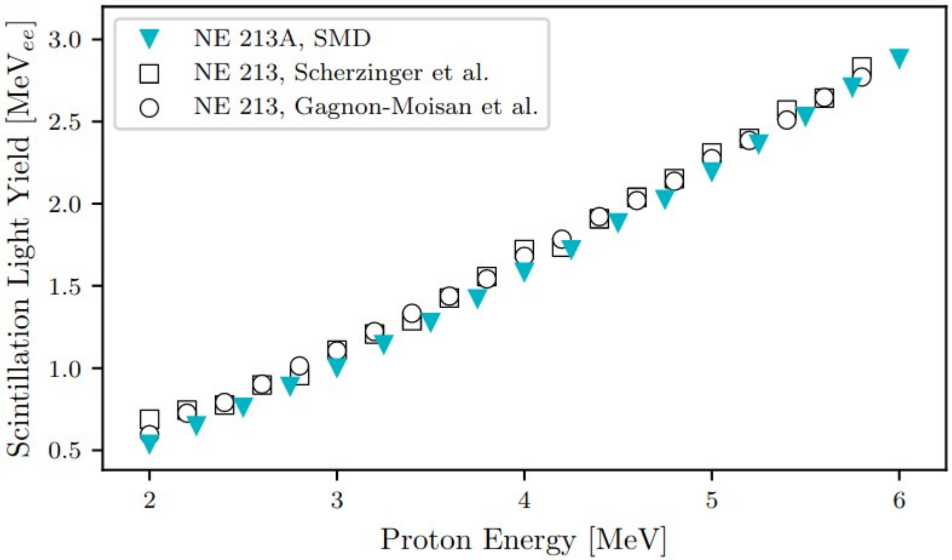

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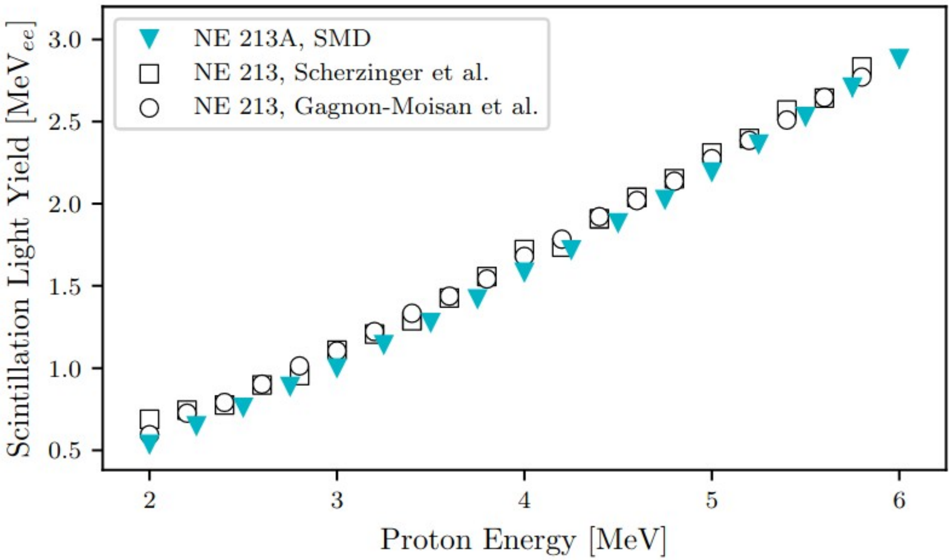
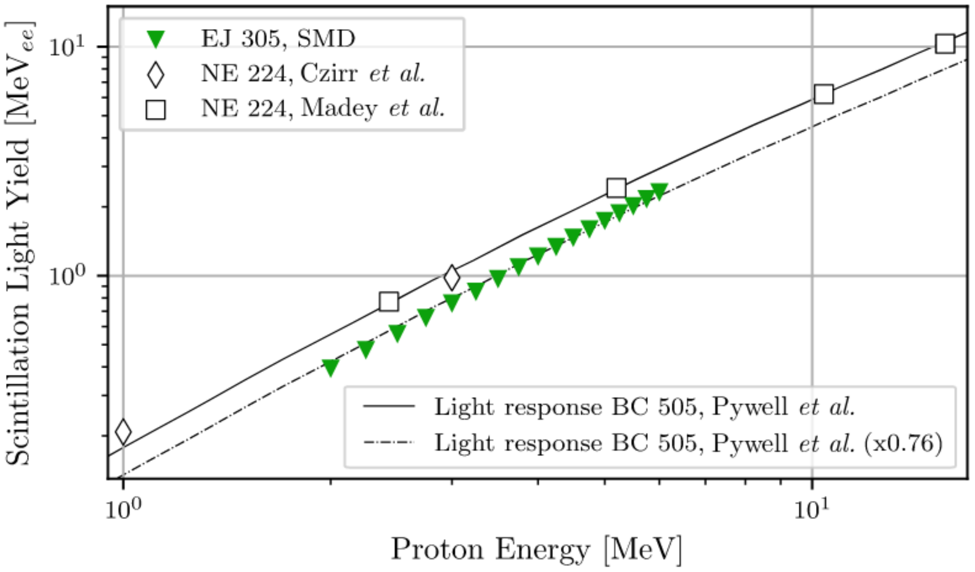
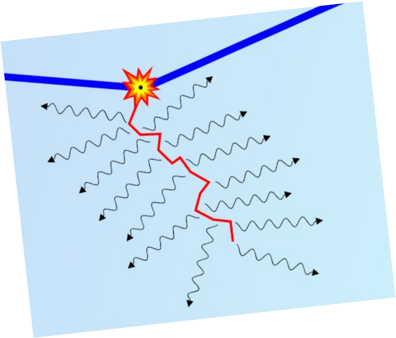


# Summary

# Summary

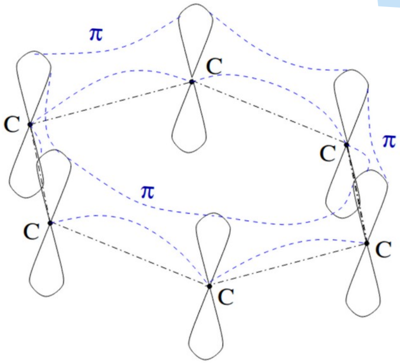


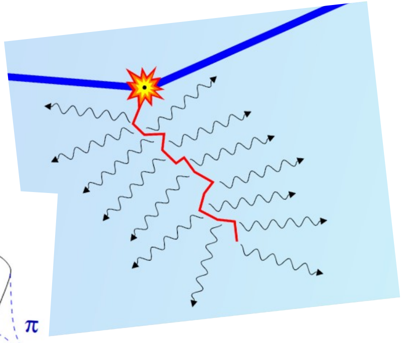
- Scintillation process

# Summary

- Scintillation process

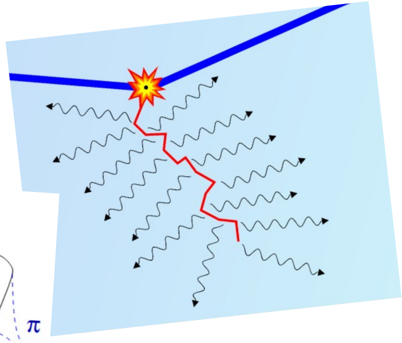
- Organic scintillators

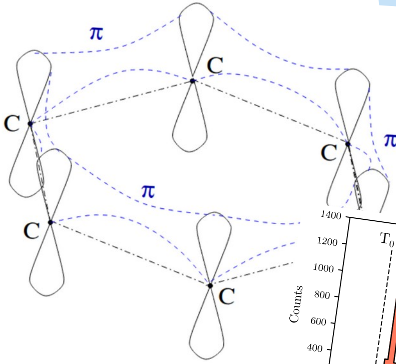


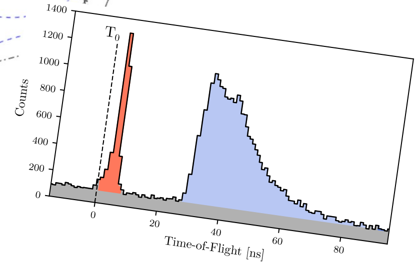



# Summary

- Scintillation process
- Organic scintillators
- Neutron TOF

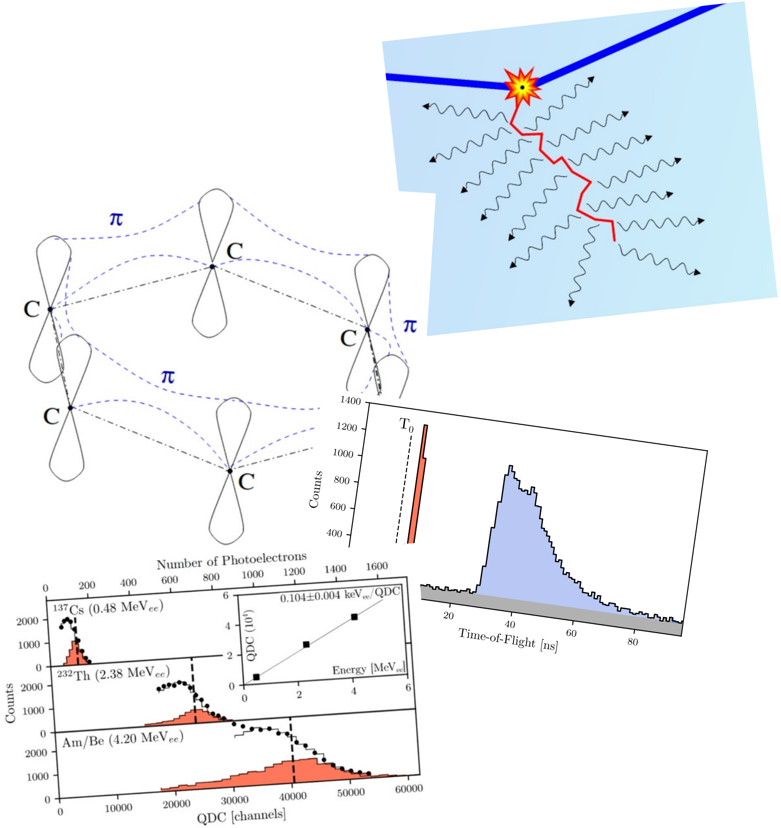




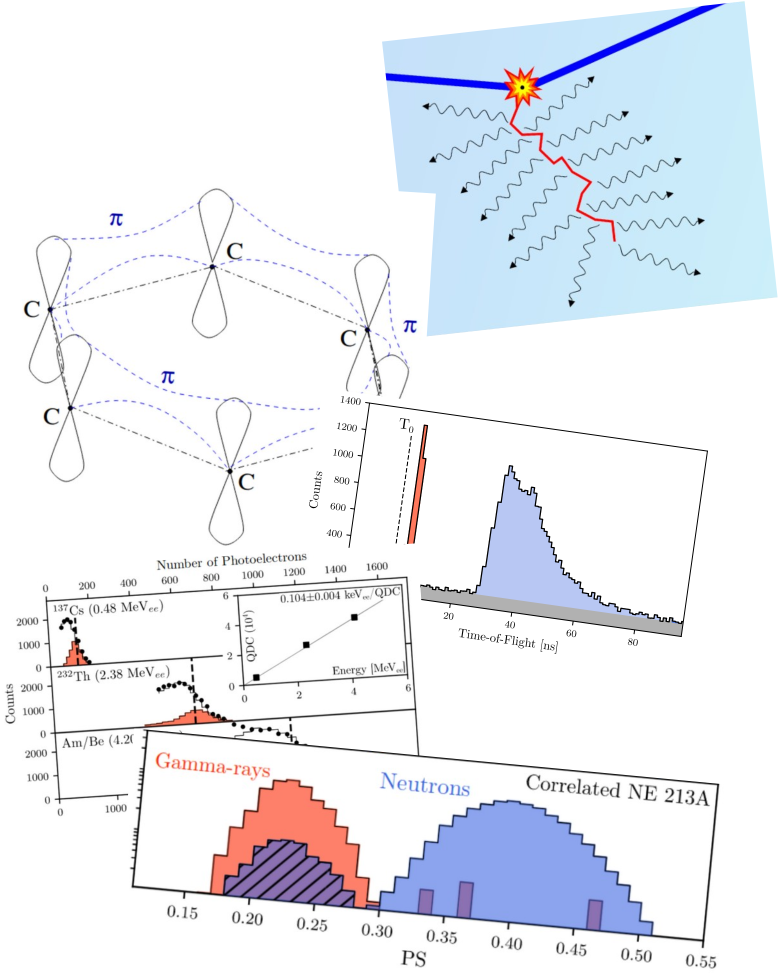
# Summary

- Scintillation process
- Organic scintillators
- Neutron TOF
- My Simulation-based calibration



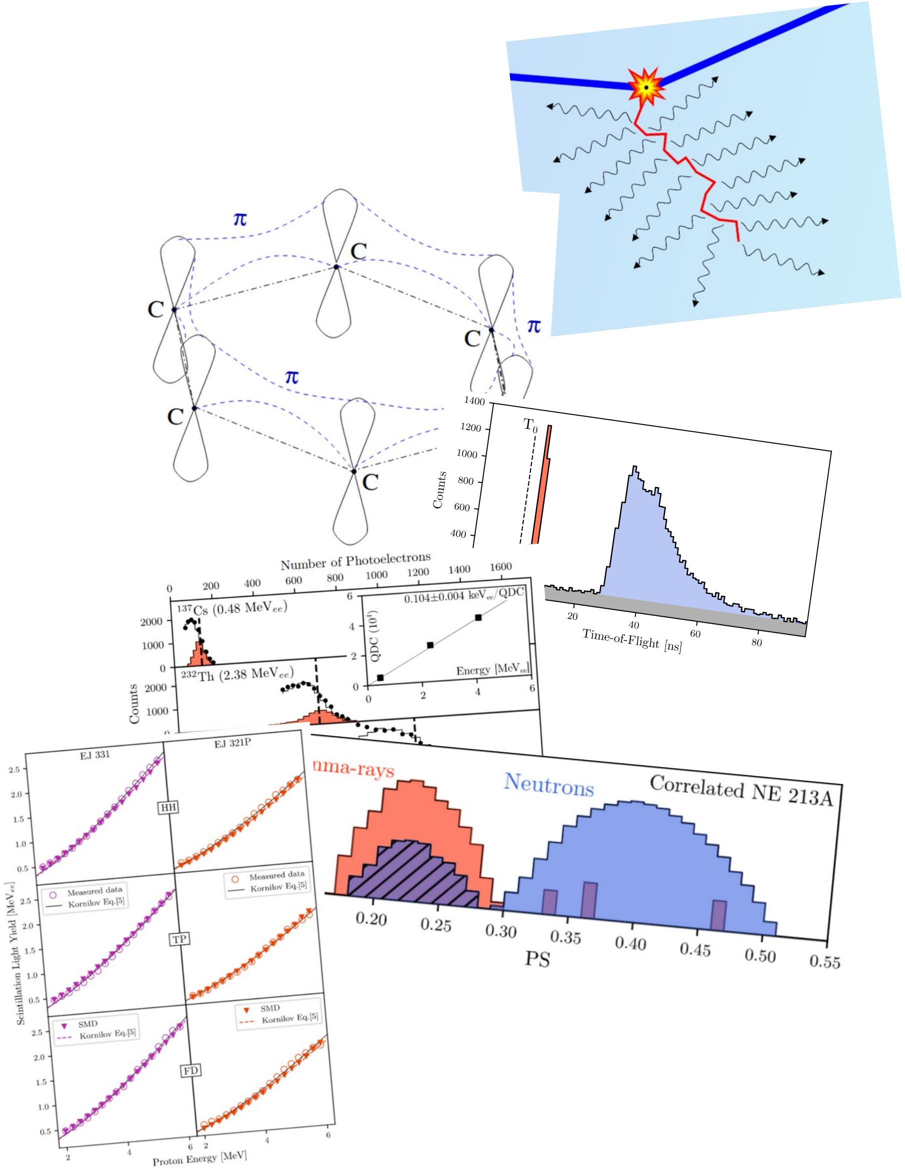
# Summary

- Scintillation process
- Organic scintillators
- Neutron TOF
- My Simulation-based calibration
- Intrinsic pulse-shape



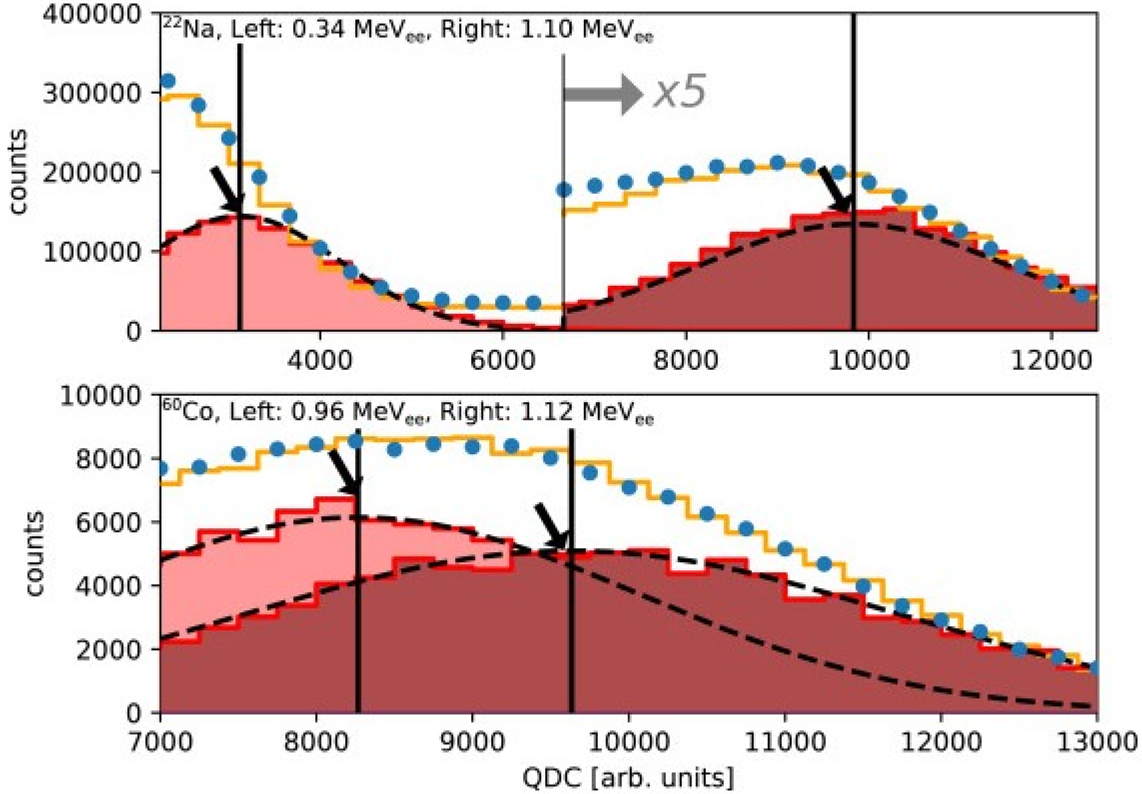
# Summary

- Scintillation process
- Organic scintillators
- Neutron TOF
- My Simulation-based calibration
- Intrinsic pulse-shape
- Neutron light-yield response

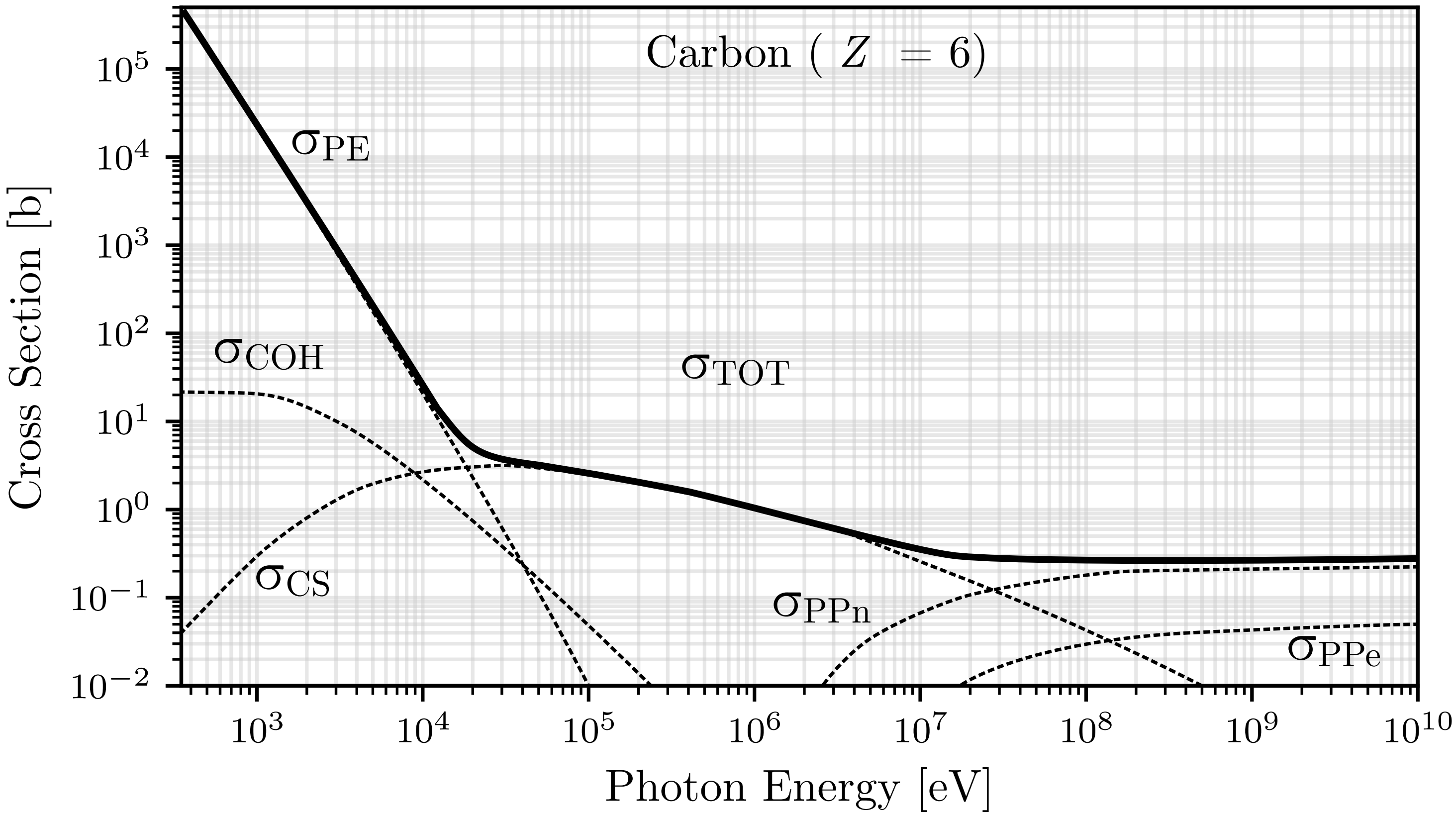


# Backup slides

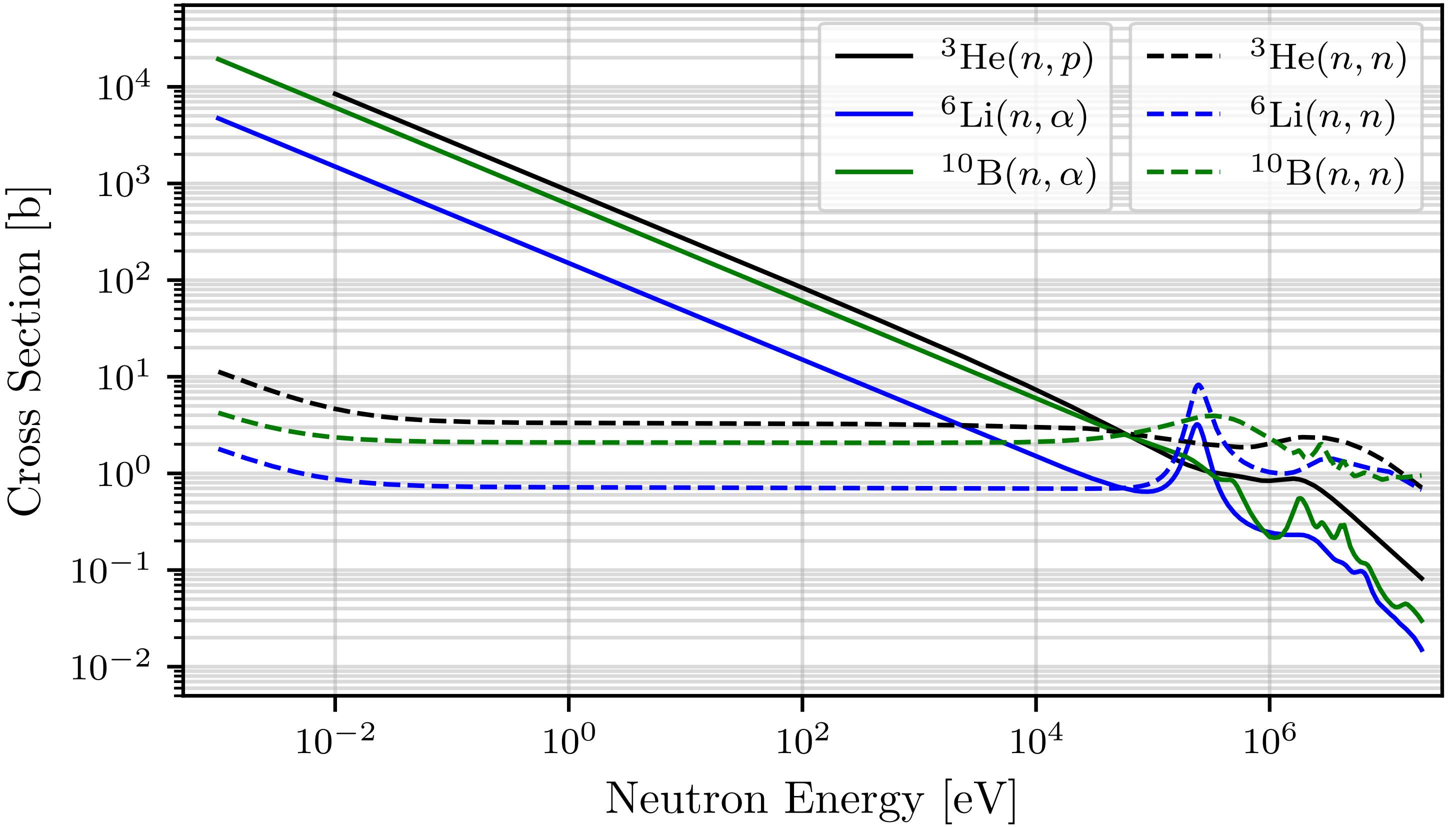
# Multiple gamma-ray sources



# Photon cross-section



# Photon cross-section

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