SAND2019-13122C

Measurement of the carbon light yield of organic scintillators over a continuous energy range

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[1] **University of California, Berkeley**

[2] **Sandia National Laboratories, Livermore**

[3] **Lawrence Berkeley National Laboratory**

[4] **Lawrence Livermore National Laboratory**

October 30, 2019

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Fast Neutron Response of Organic Scintillators

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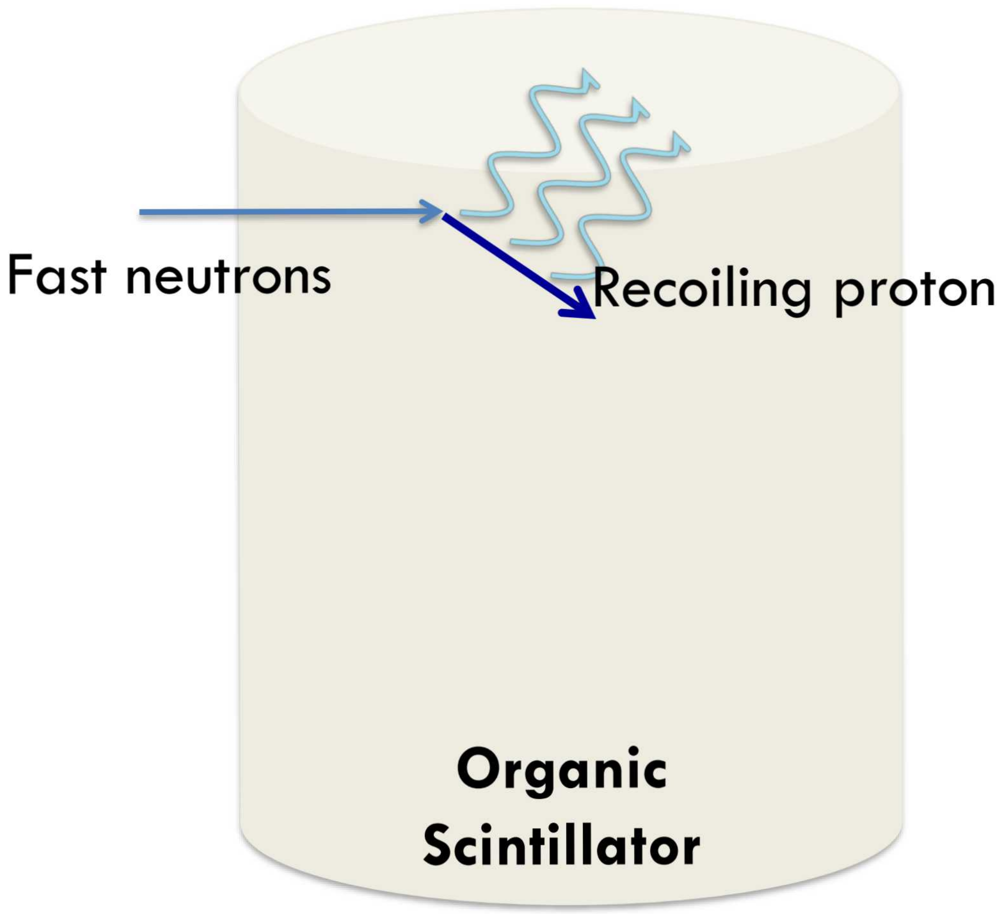

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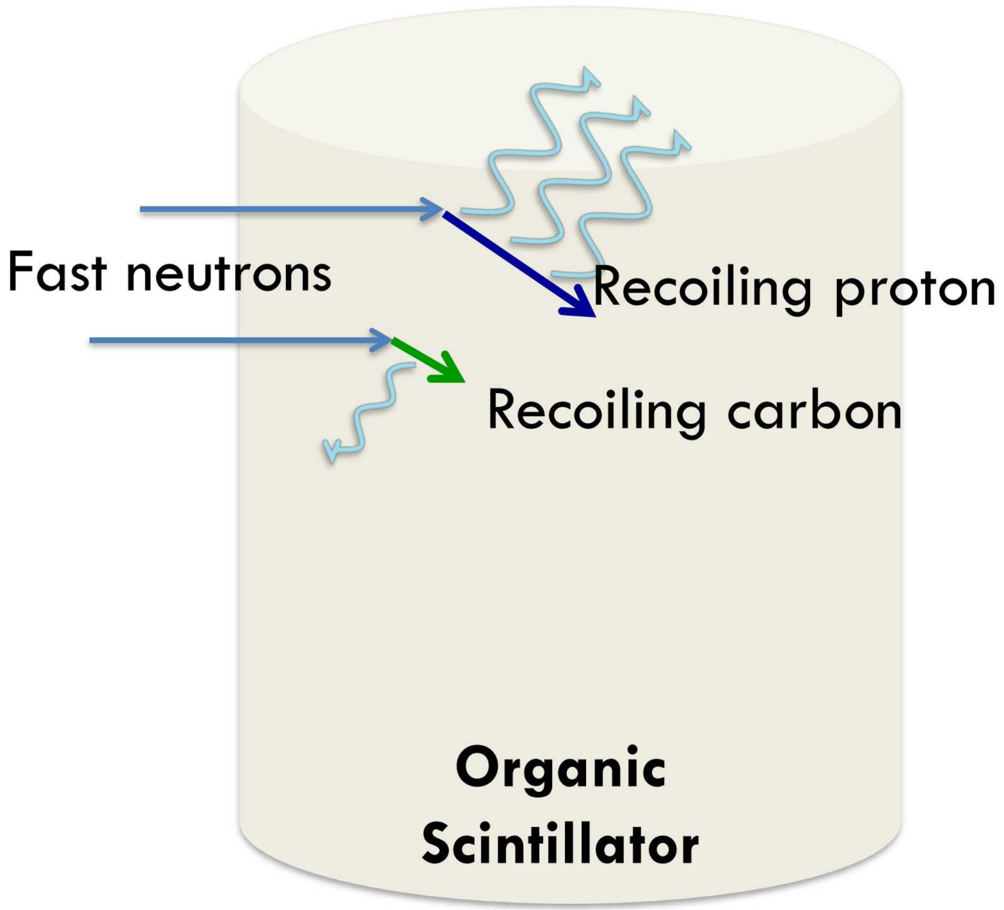

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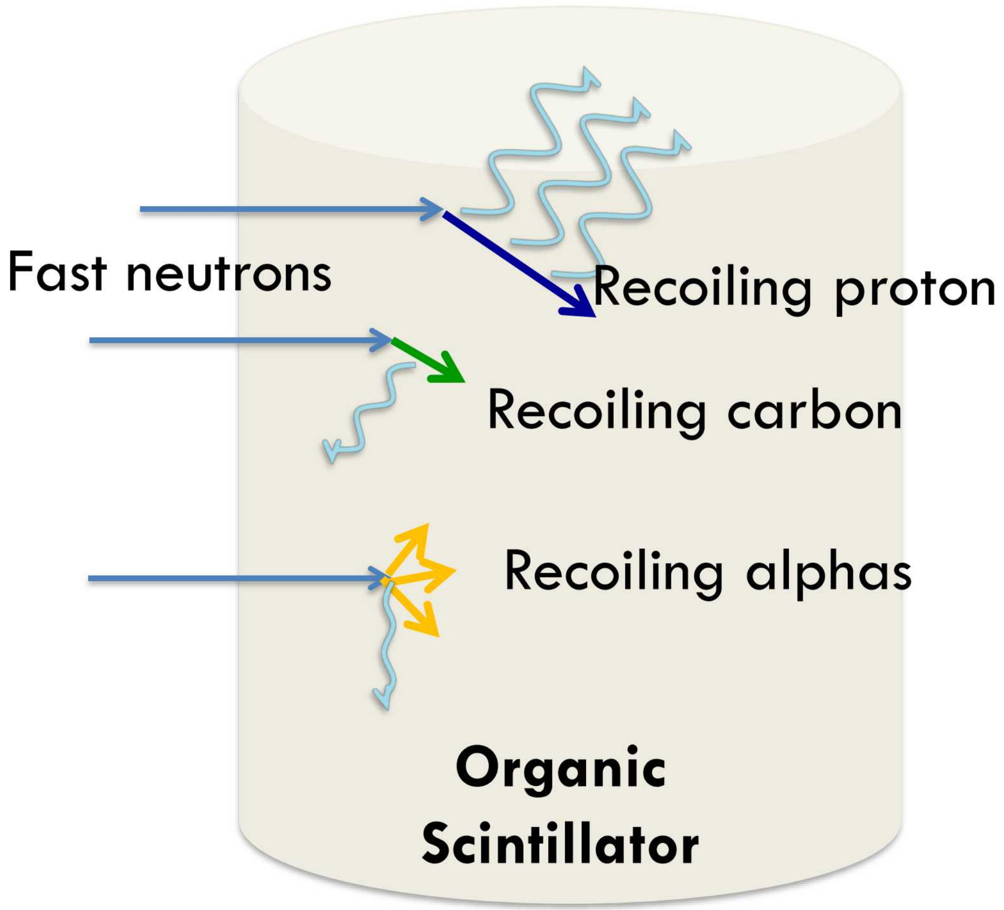

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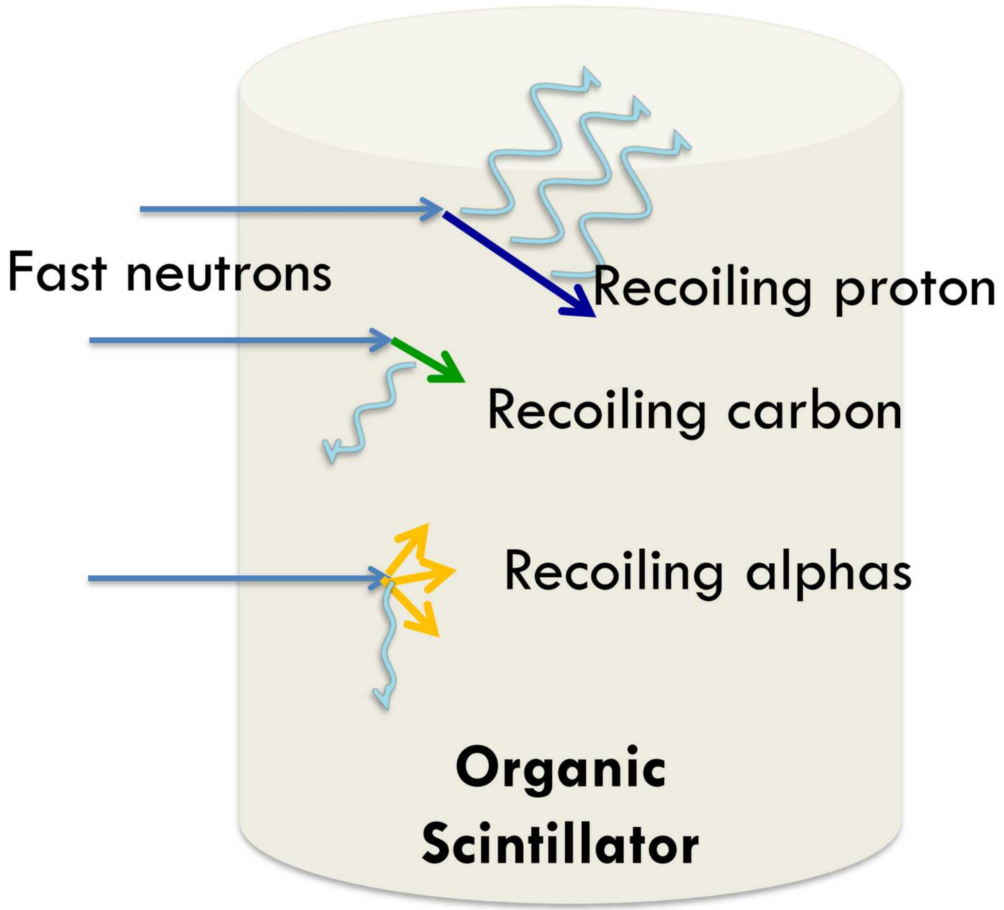

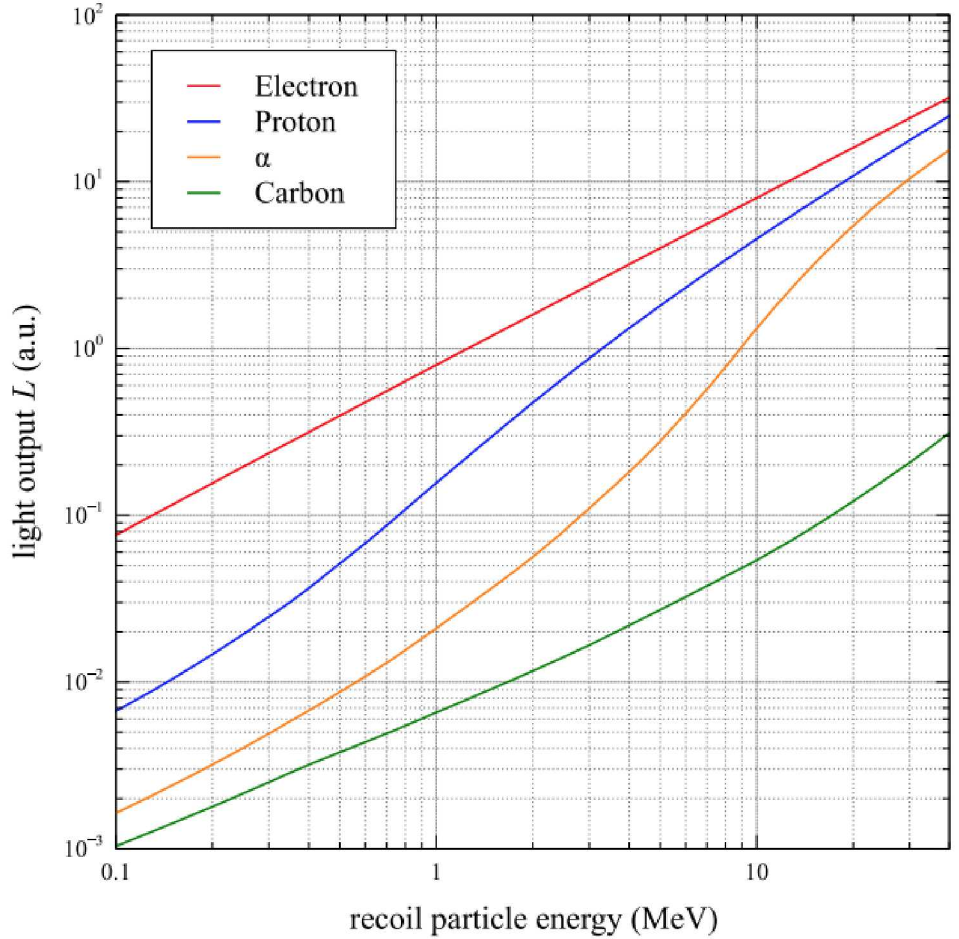

Fig. 1 Liquid scintillator light output L as a function the recoil particle energy. Data adapted from [19]

[1]Cecconello, Jour. Fus. Energy 38(2019)
adapted from Verbinski et al. NIM (1968)

Carbon Light Yield For Simulation Of Detector Response

Max carbon recoil energy:

$E_C^{max} \approx 0.284 E_n$

Quick rule of thumb:

1 MeV proton ≈ 25% light of 1MeV electron

1 MeV carbon ≈ 1% light of 1 MeV electron

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Particularly matters for:

- Accurate simulation of detector performance
- Inform design of new detection system such as the Single Volume Scatter Camera (see presentation N-27-03)

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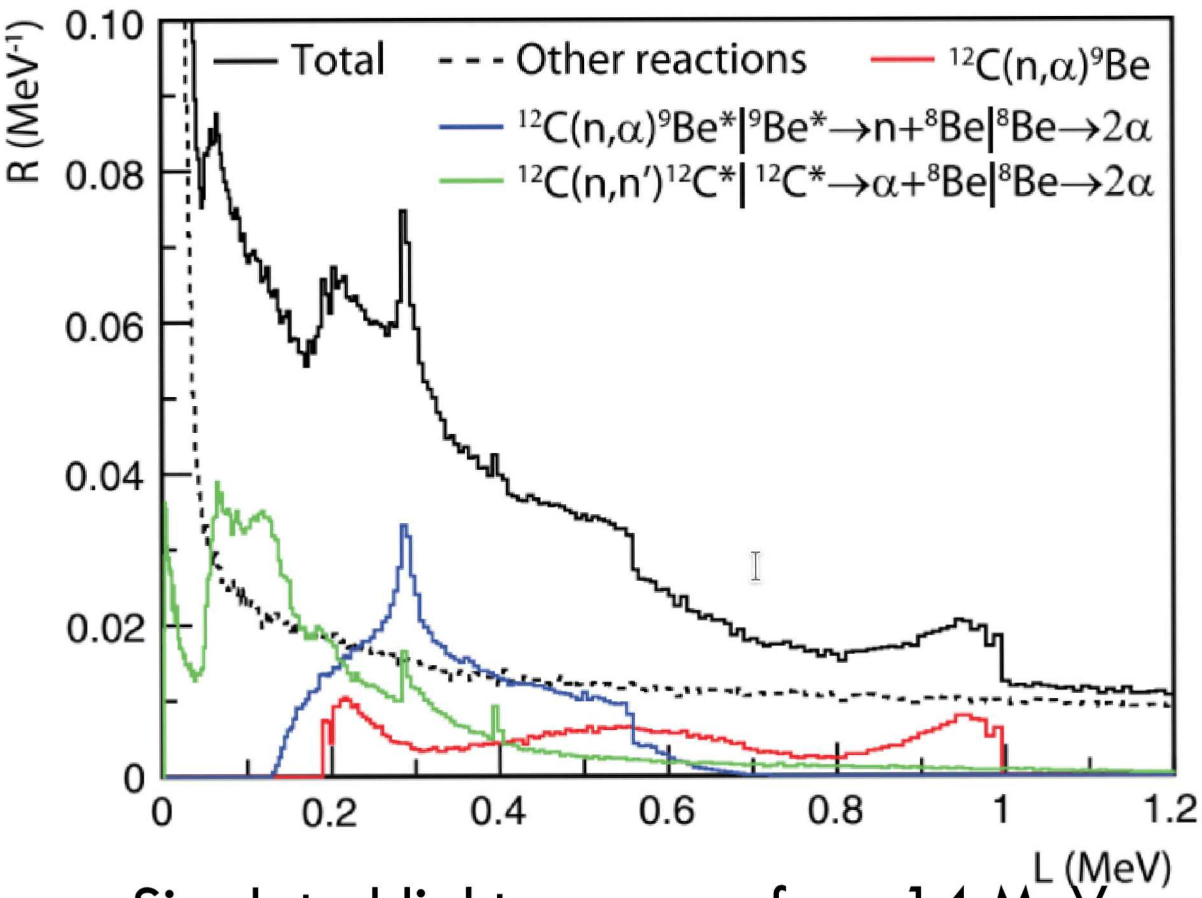

Simulated light response from 14 MeV neutrons

[2]A.R. Garcia et al., NIM A 868 (2017)

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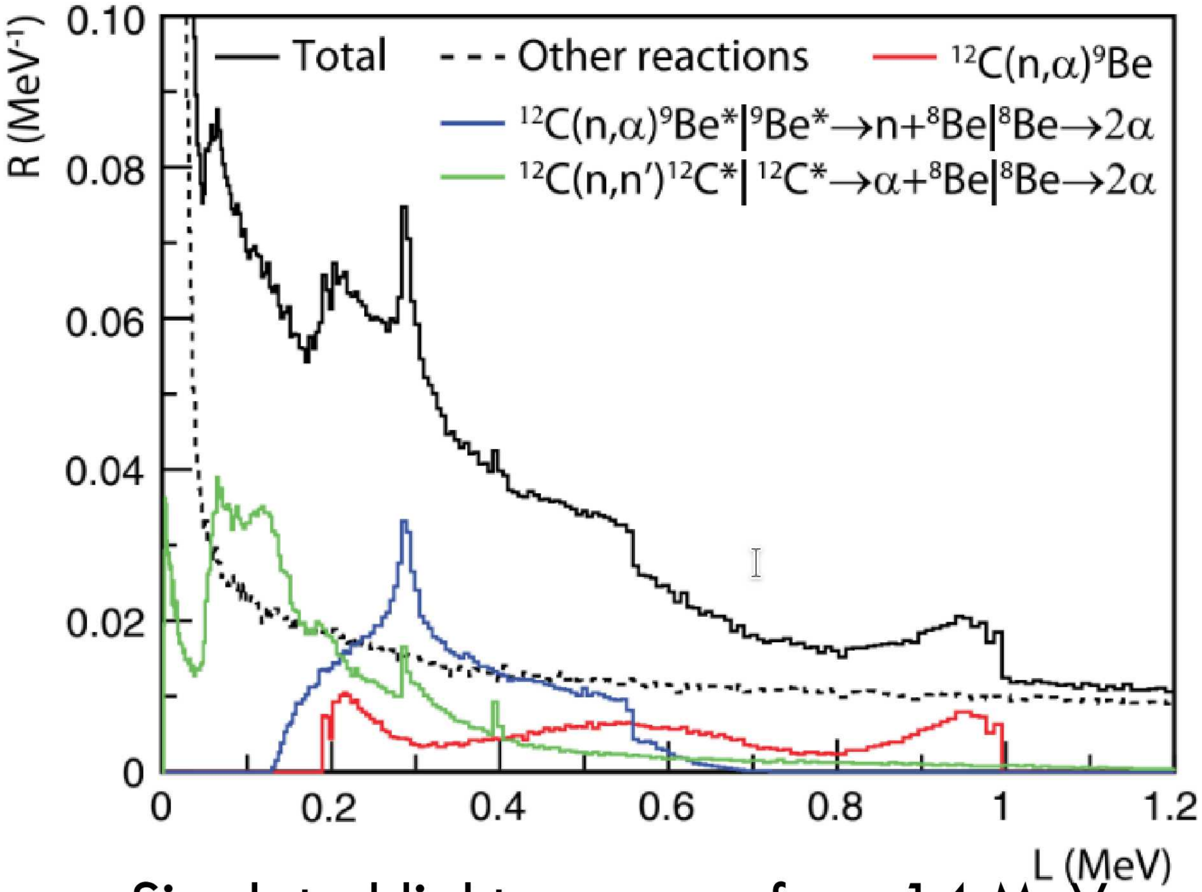
See: Single Volume Scatter Camera presentation by Erik Brubaker (N-27-03)



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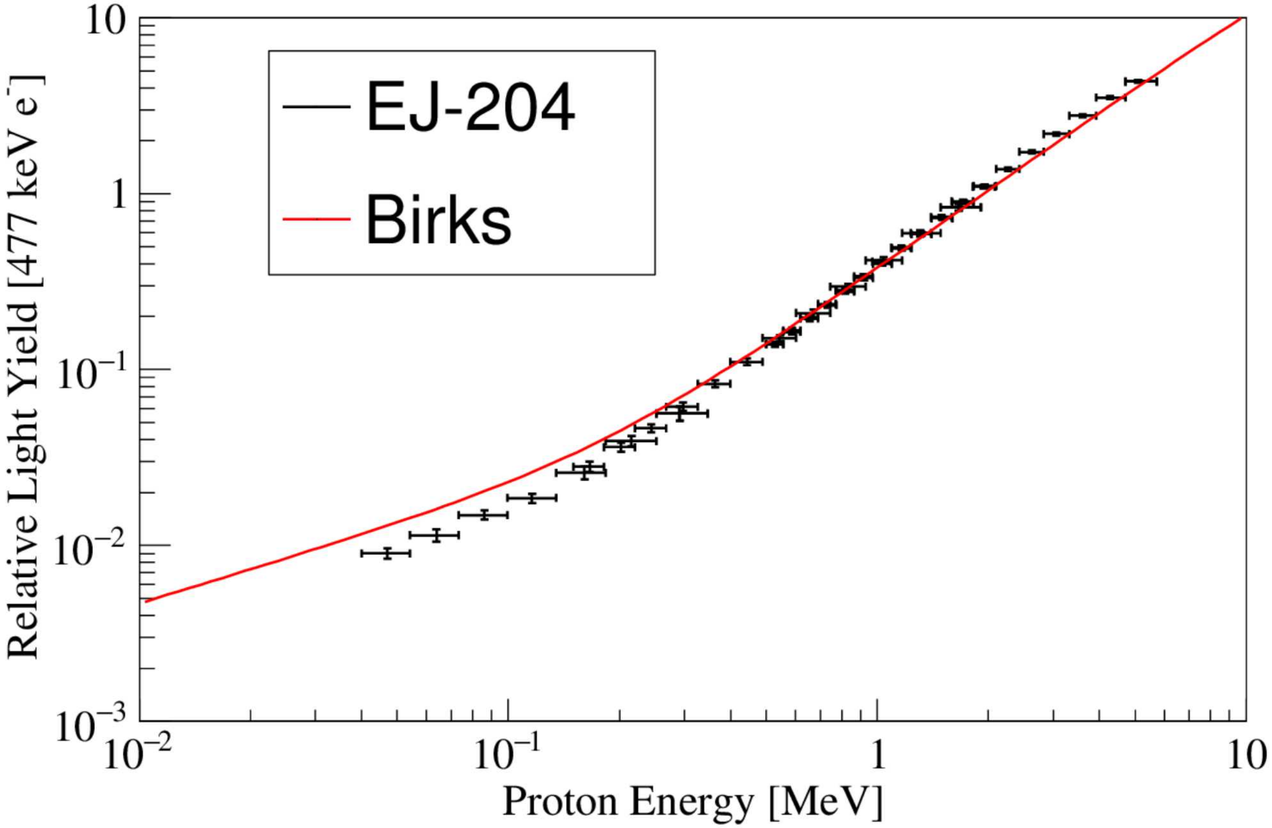
Carbon Light Yield – Constrain scintillation response models

Physics based model of the scintillation response

Canonical quenching model proposed by Birks (1951) [3]:

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



EJ-204 data from: T.A Laplace et al. NIMA (2018)

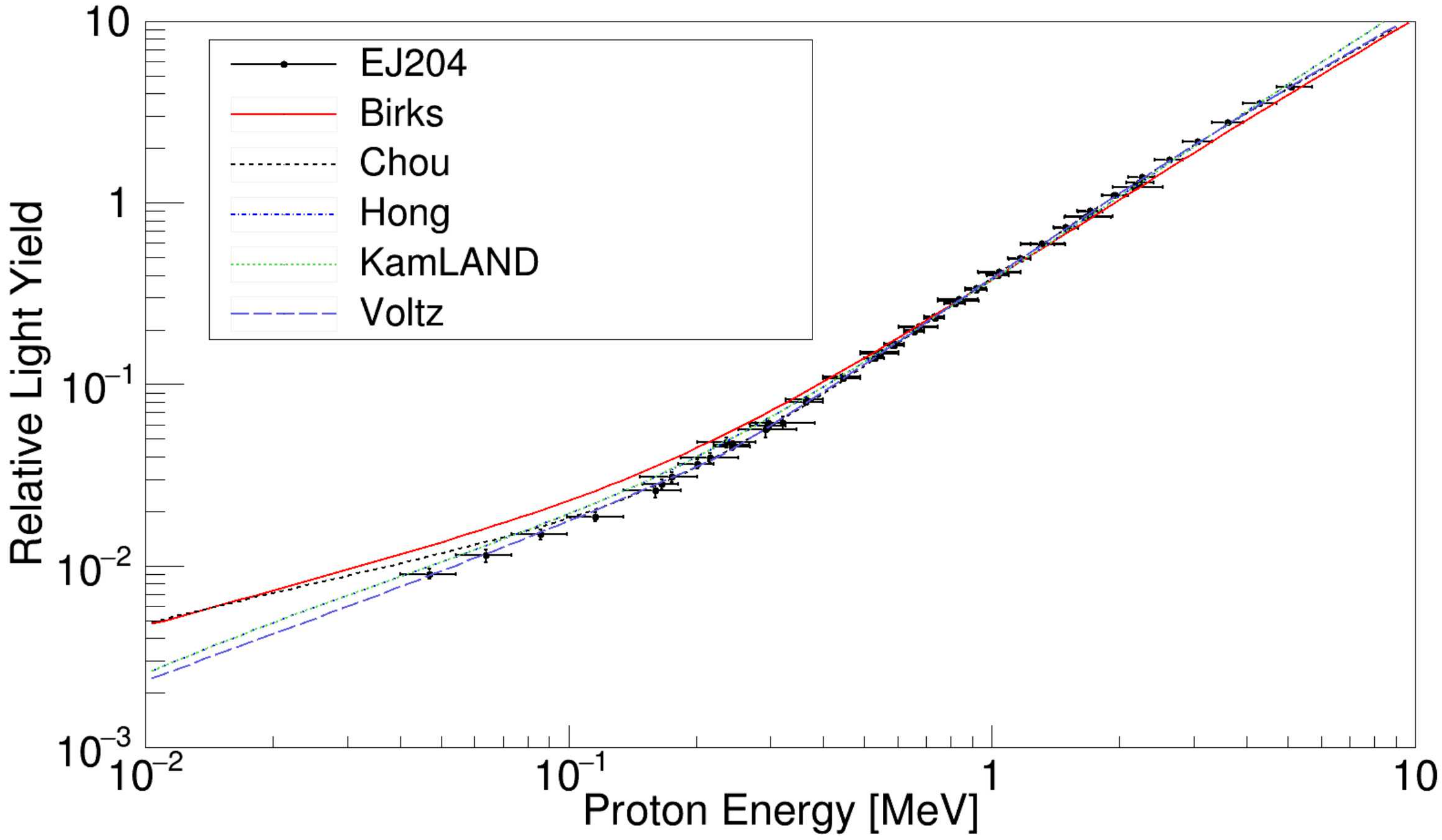
[3] J.B. Birks, Proc. Phys. Soc. A, 64(10), (1951)

Carbon Light Yield – Constrain scintillation response models

Physics based model of the scintillation response

Second order quenching introduced by Chou (1952)[4]:

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



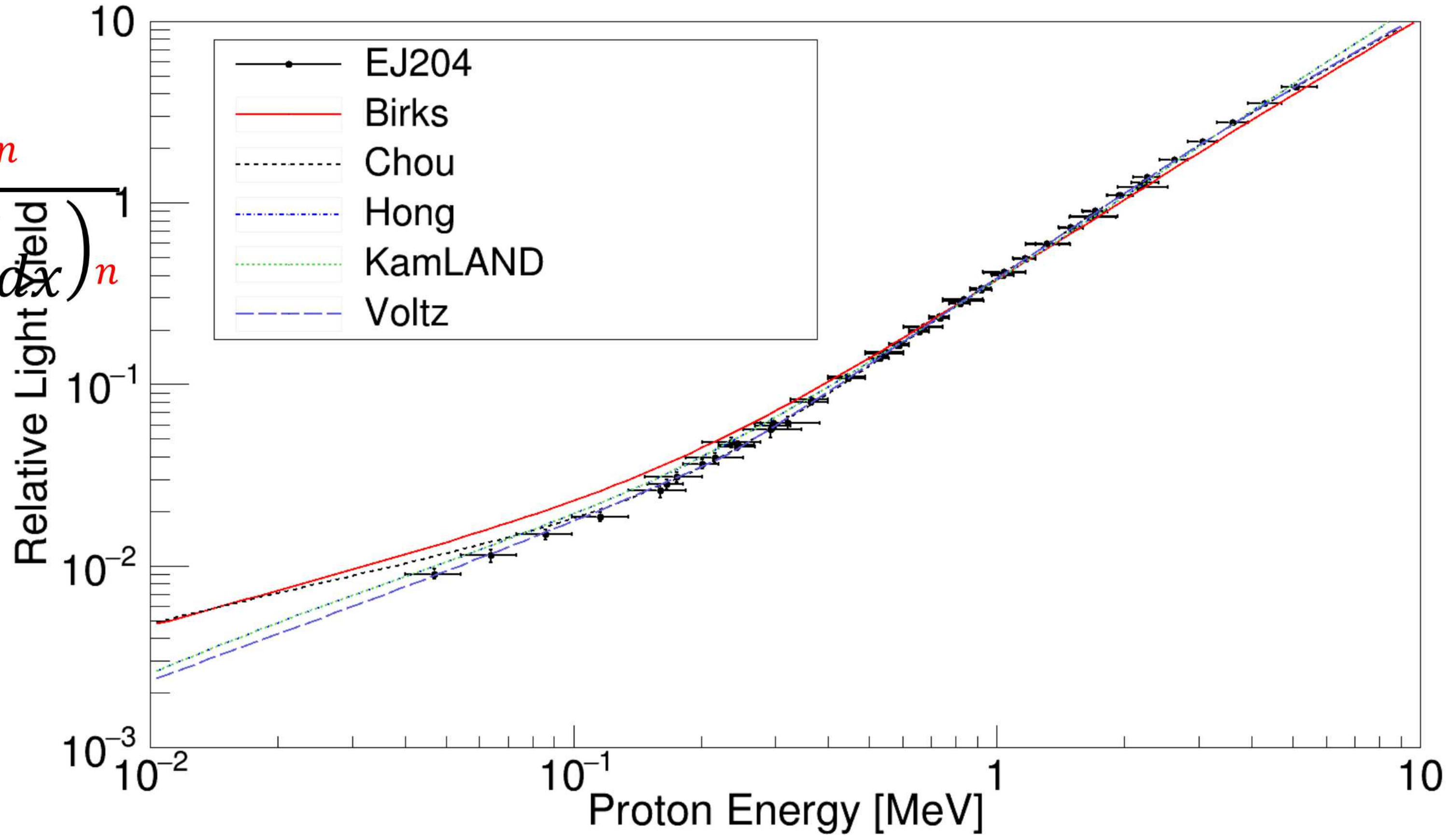
[4]C.N. Chou, Phys. Rev. 87, (1952)

Carbon Light Yield – Constrain scintillation response models

Physics based model of the scintillation response

Separation of nuclear and electronic stopping power by Hong (2002) [5]:

$$\frac{dL}{dx} = \frac{S_e\left({dE}/{dx}\right)_e + S_n\left({dE}/{dx}\right)_n}{1 + kBe\left({dE}/{dx}\right)_e + kB_n\left({dE}/{dx}\right)_n}$$



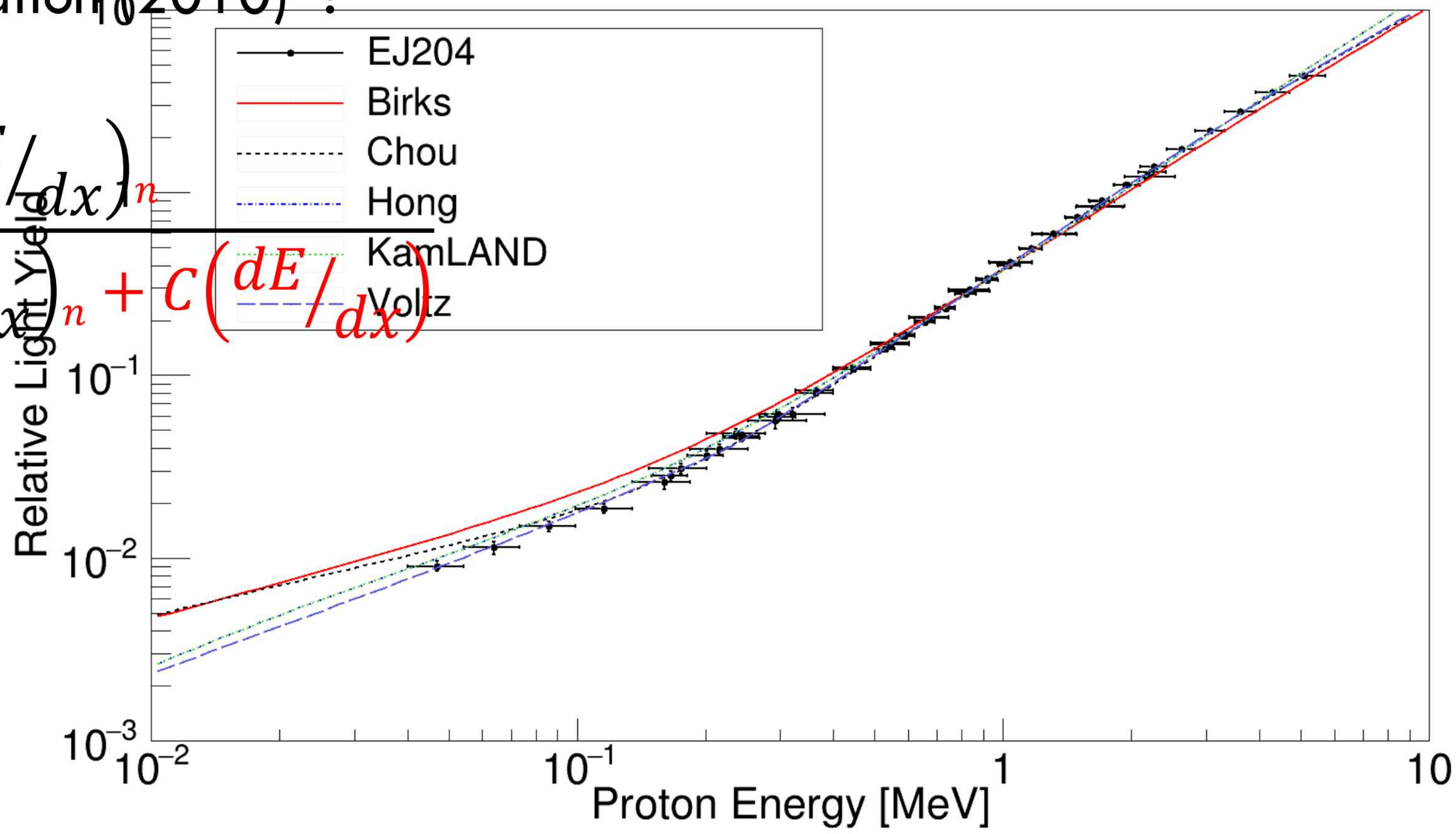
[5] J. Hong et al., Astro. Phys. , 16(3), (2002)

Carbon Light Yield – Constrain scintillation response models

Physics based model of the scintillation response

Separation of nuclear and electronic stopping power and second order quenching by the KamLAND collaboration (2010) [6]:

$$\frac{dL}{dx} = \frac{S_e\left(dE/_{dx}\right)_e + S_n\left(dE/_{dx}\right)_n}{1 + kBe\left(dE/_{dx}\right)_e + kB_n\left(dE/_{dx}\right)_n + C\left(dE/_{dx}\right)}$$



[6] S. Yoshida et al., NIMA 622 (2010)

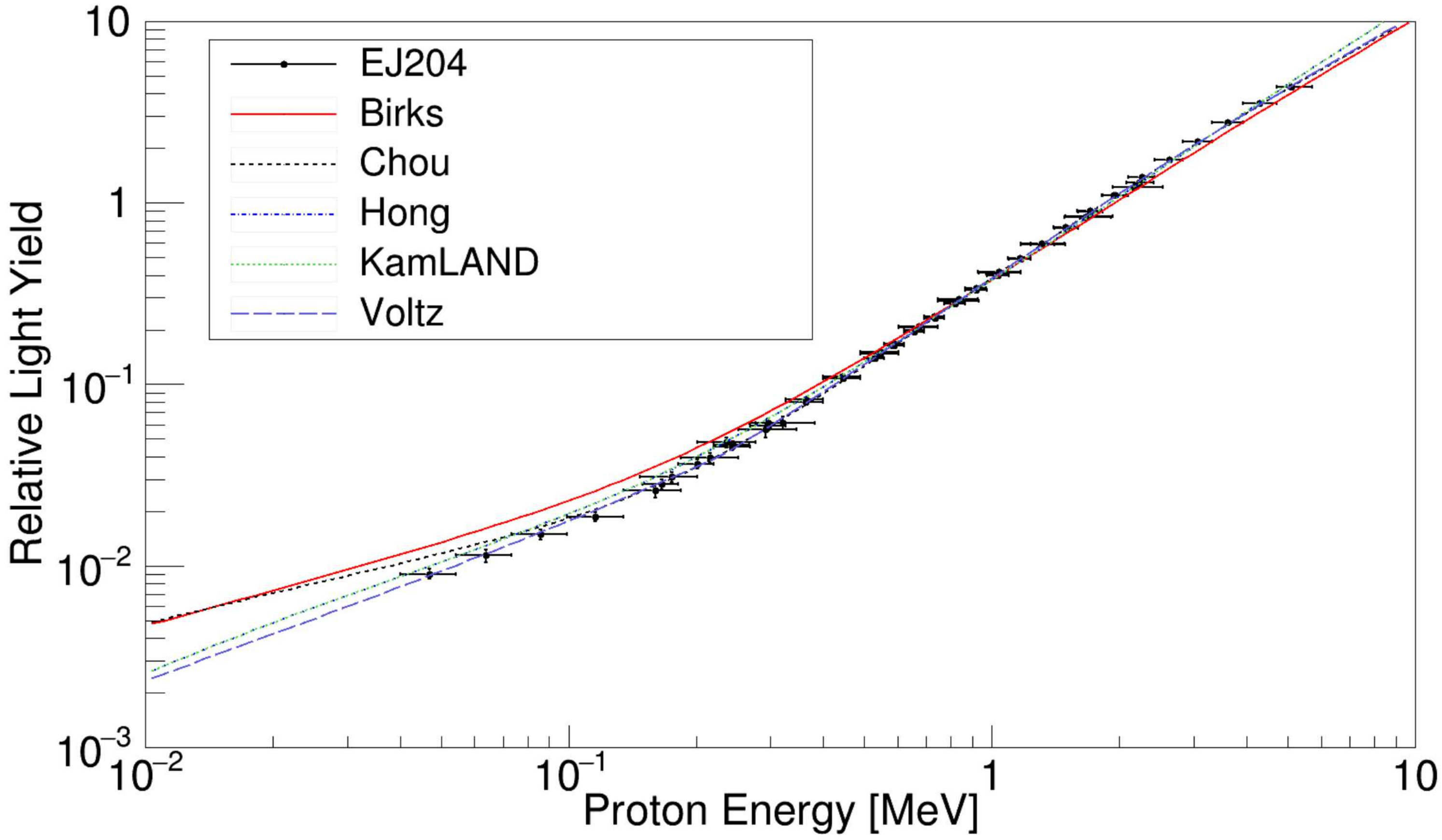
Carbon Light Yield – Constrain scintillation response models

Physics based model of the scintillation response

Separation prompt and delayed components by Voltz (1966)[7]:

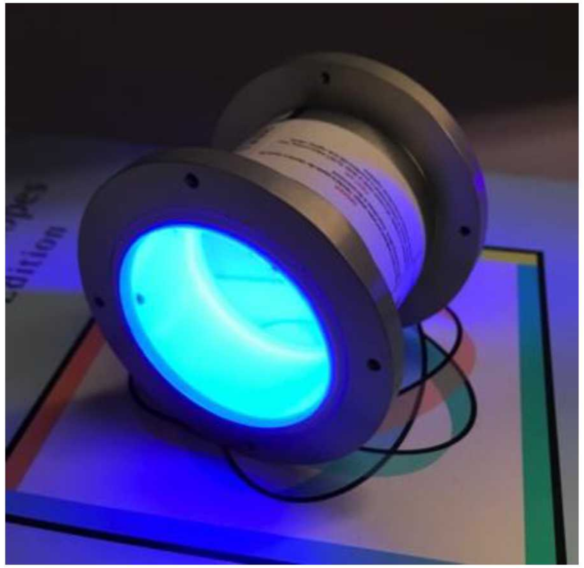
$$\frac{dL}{dx} = \left(\frac{dL}{dx}\right)_{prompt} + \left(\frac{dL}{dx}\right)_{delayed}$$

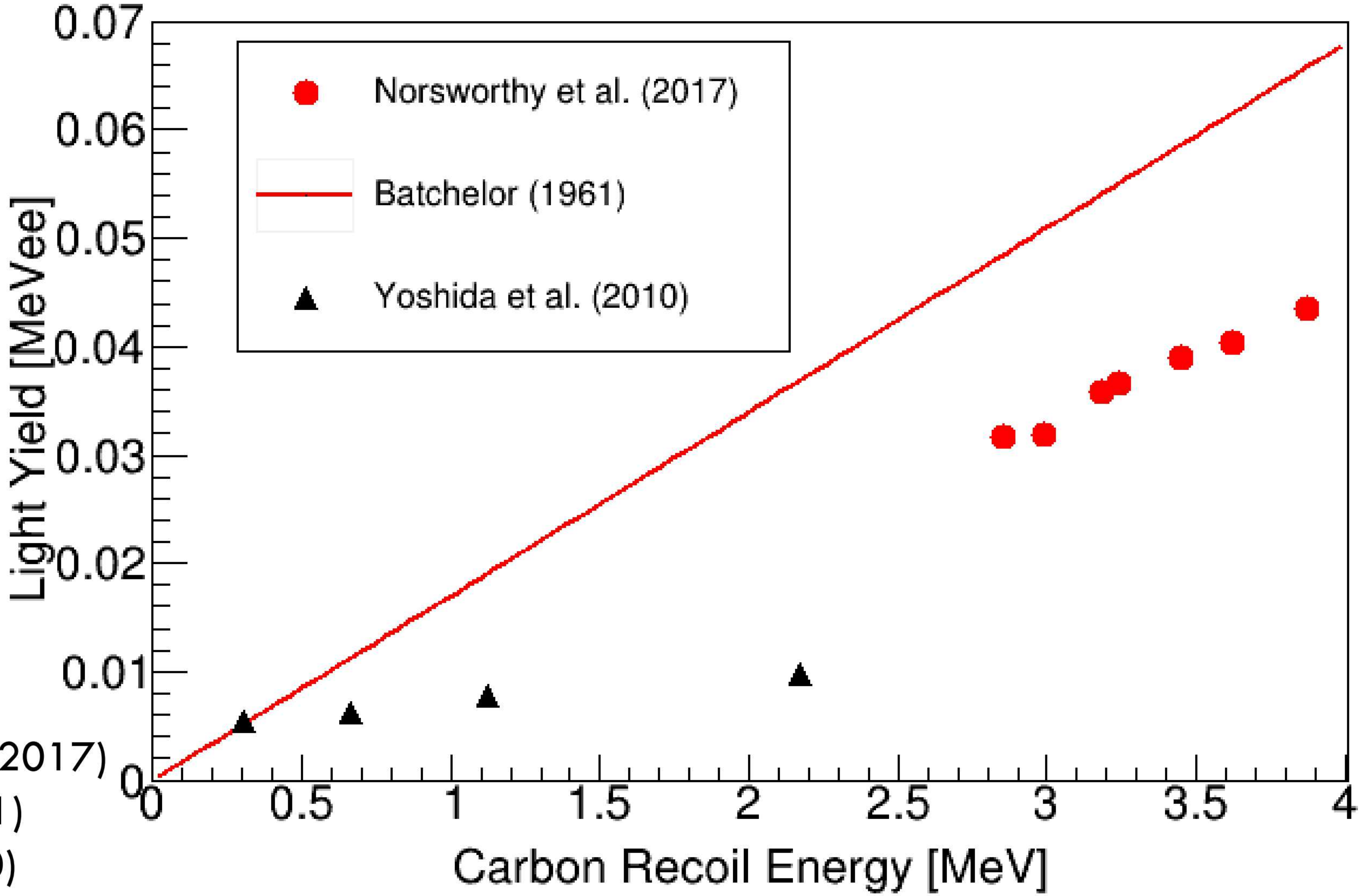
Both are function of the stopping power



[6]R. Voltz et al., J. Chem. Phys. 45 (1966)

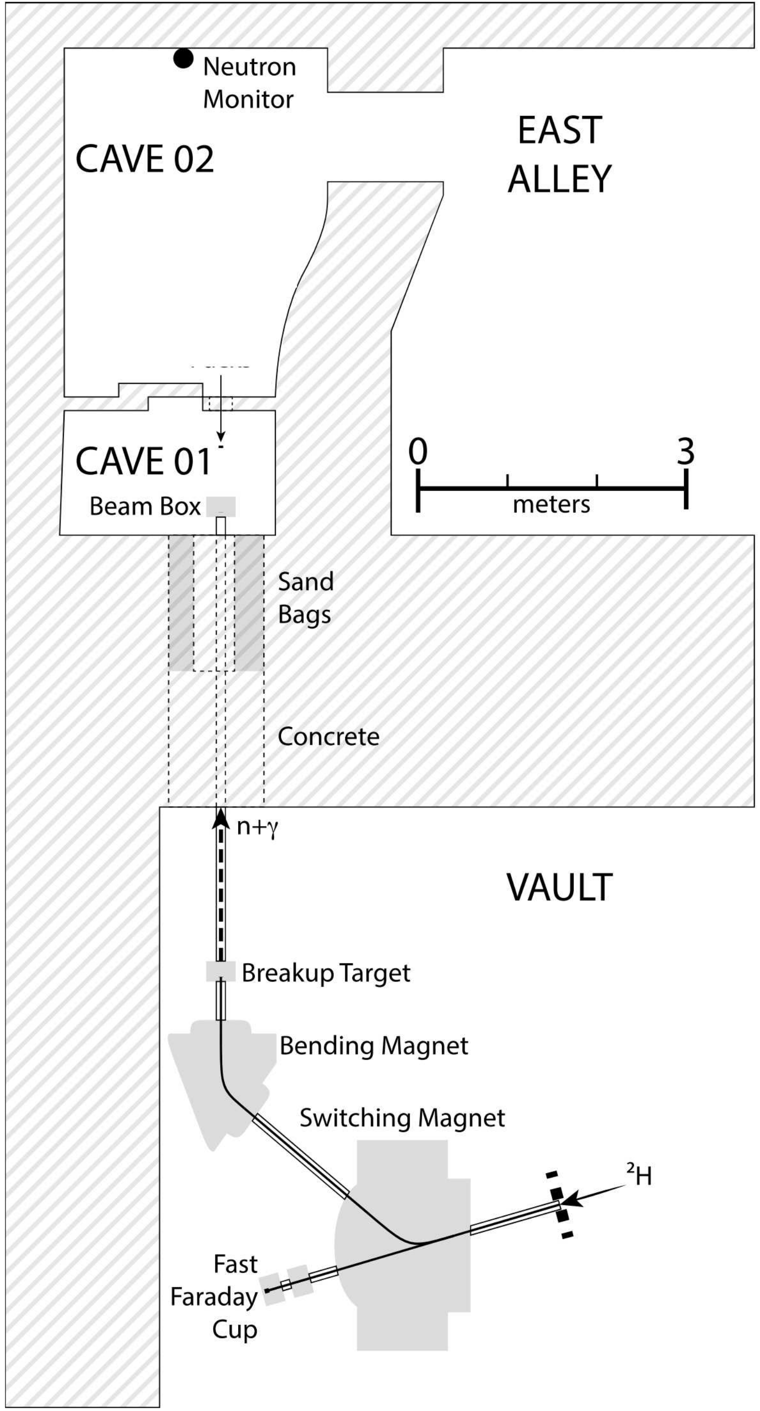
Recent Measurements





M. Norsworthy et al., NIMA 842 (2017)
R. Batchelor et al., NIMA 13 (1961)
S. Yoshida et al., NIMA 622 (2010)

D-Breakup Neutron Source



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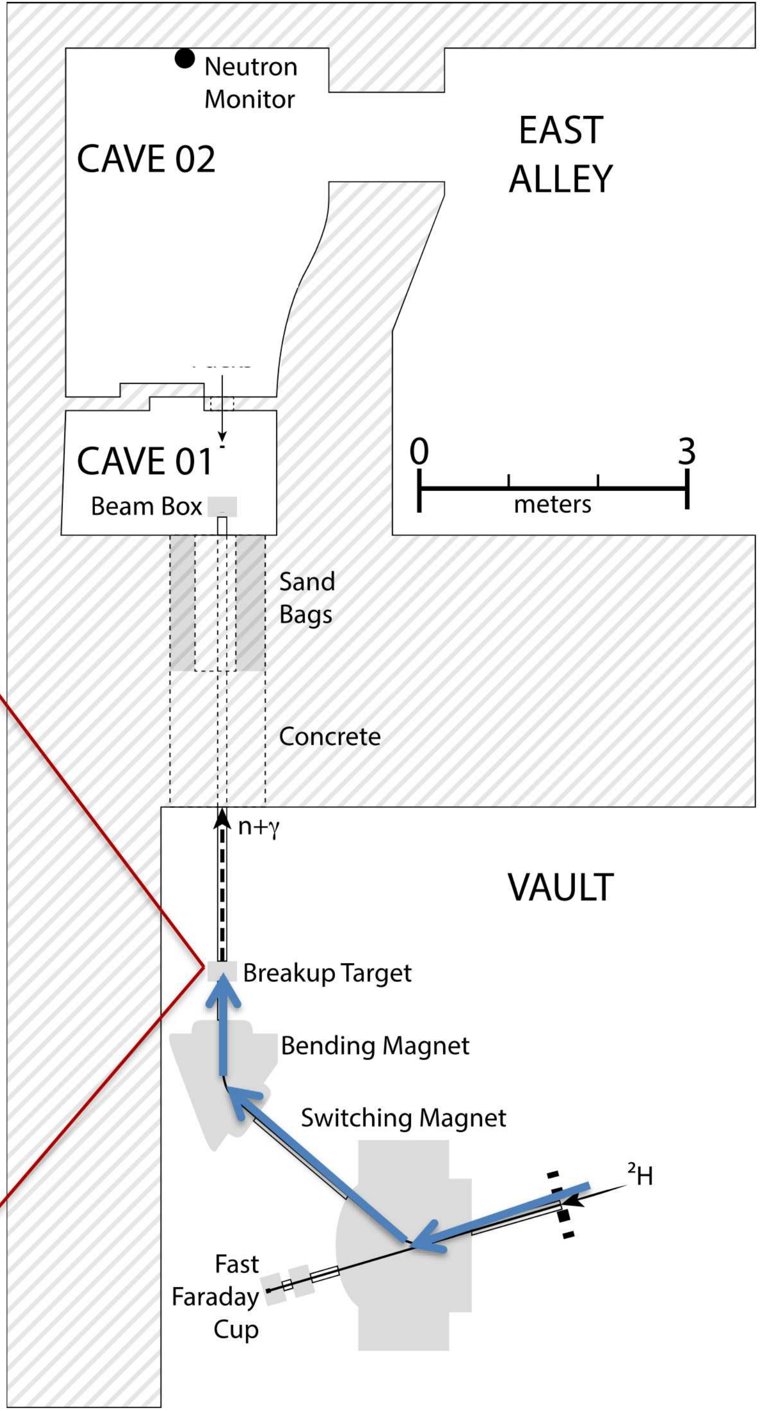

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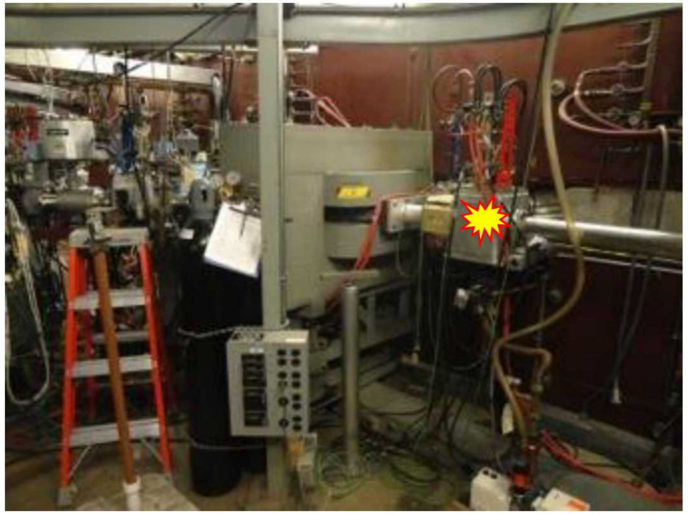

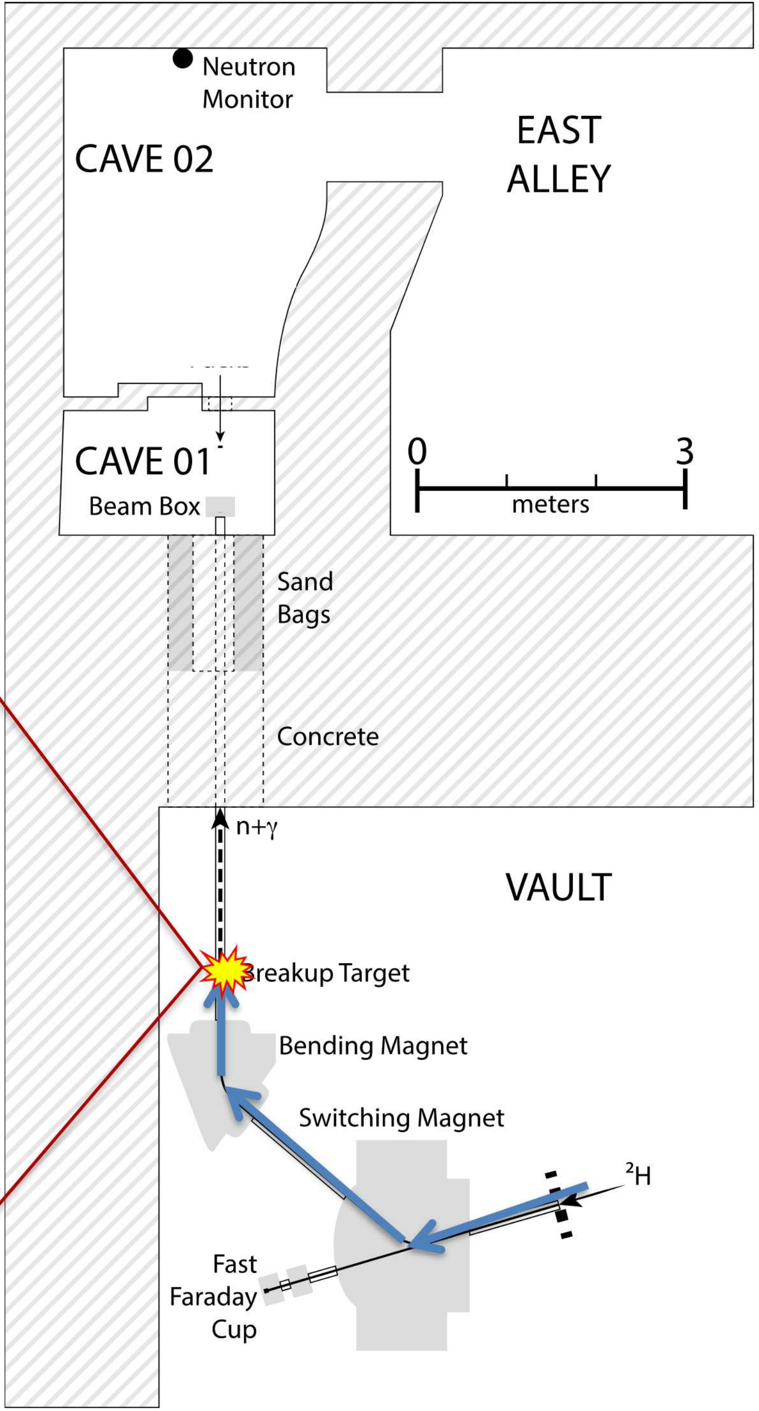

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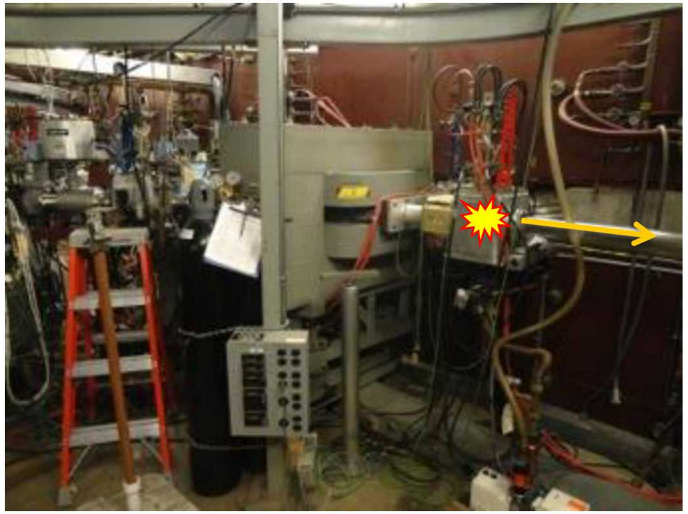

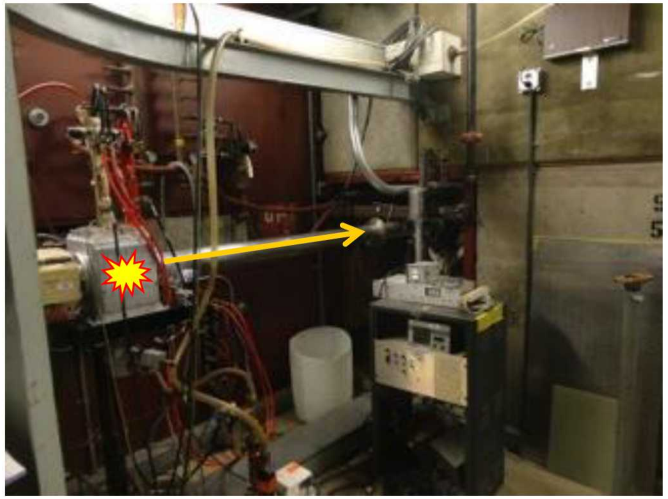

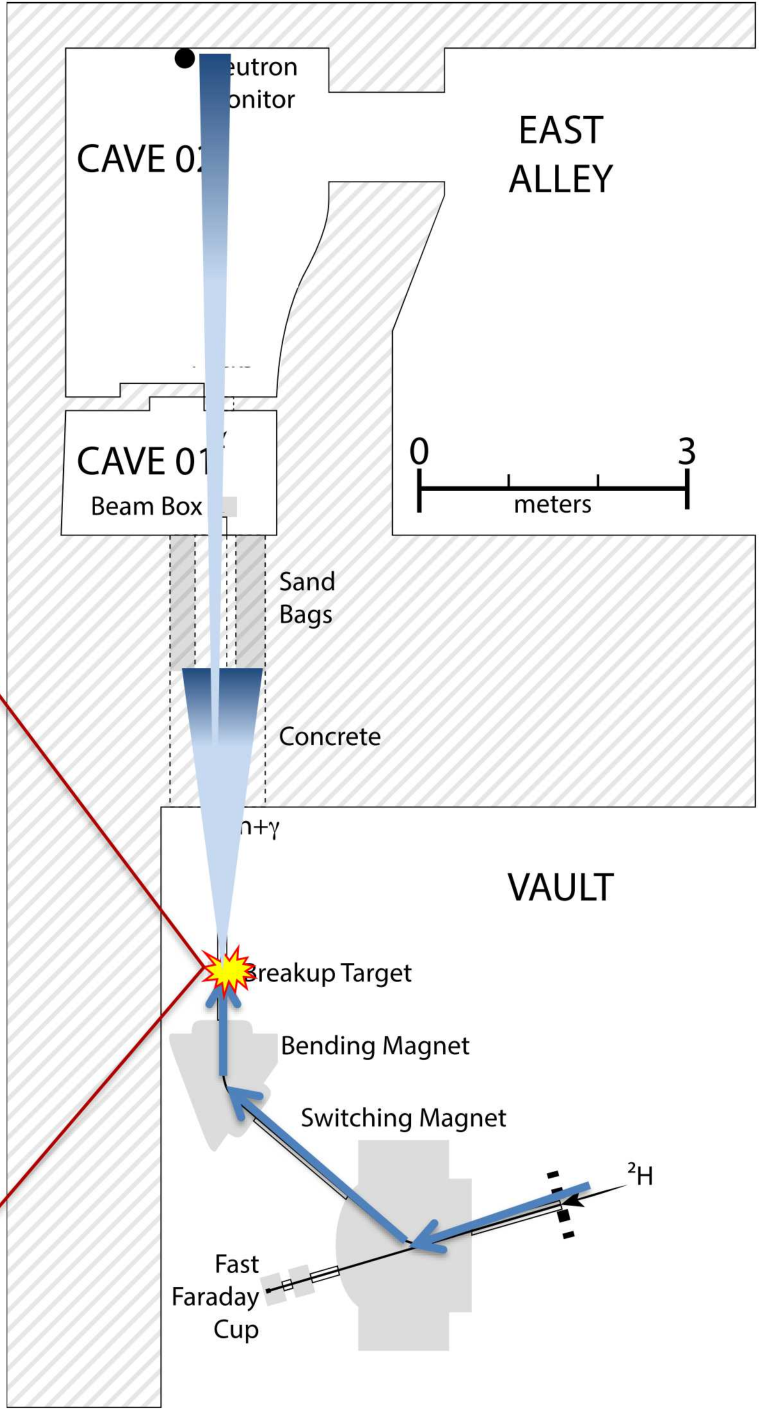

Light Yield measurements at the 88-Inch Cyclotron

- Kinematically over-constrained system
- Simultaneous proton and carbon light yield measurements
- Broad-spectrum neutron source

J.A. Brown, PhD Thesis, UC Berkeley 2017.
J.A. Brown, B.L. Goldblum, et al. Journal of Applied Physics 124, 045101 (2018).

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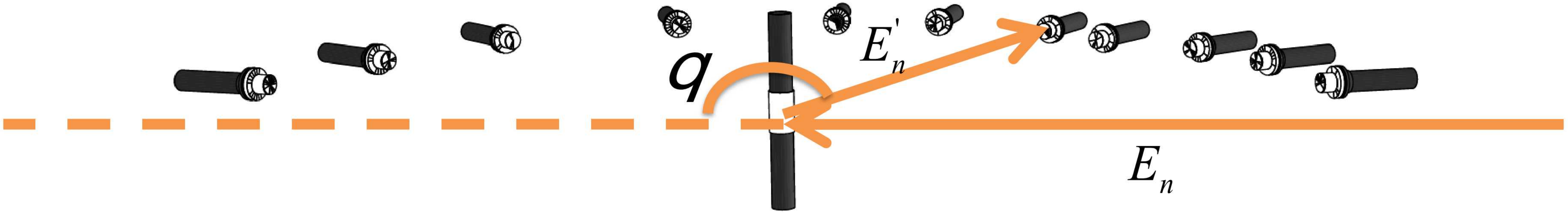

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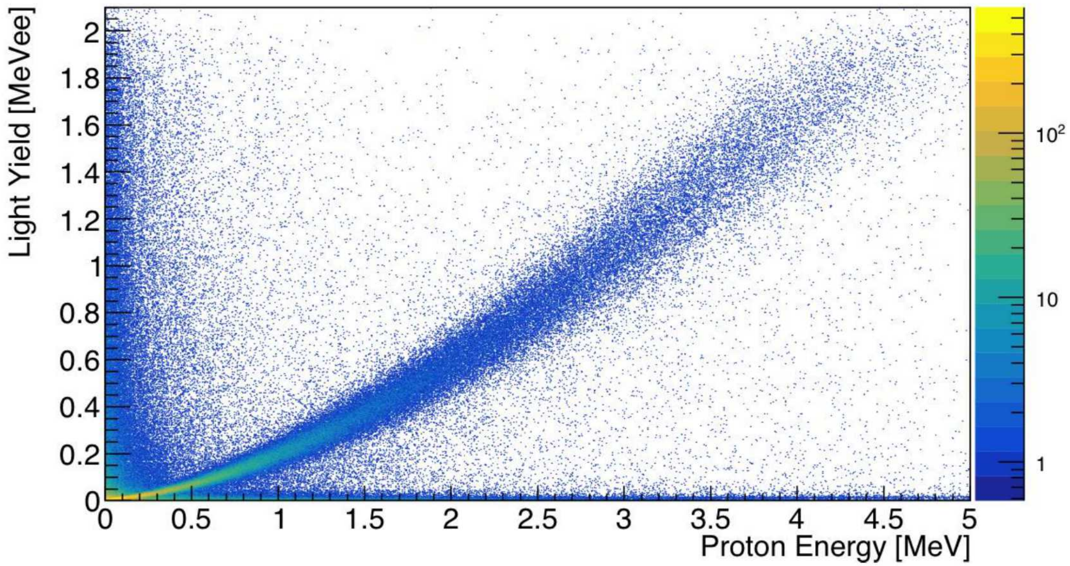

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Carbon Light Yield measurements

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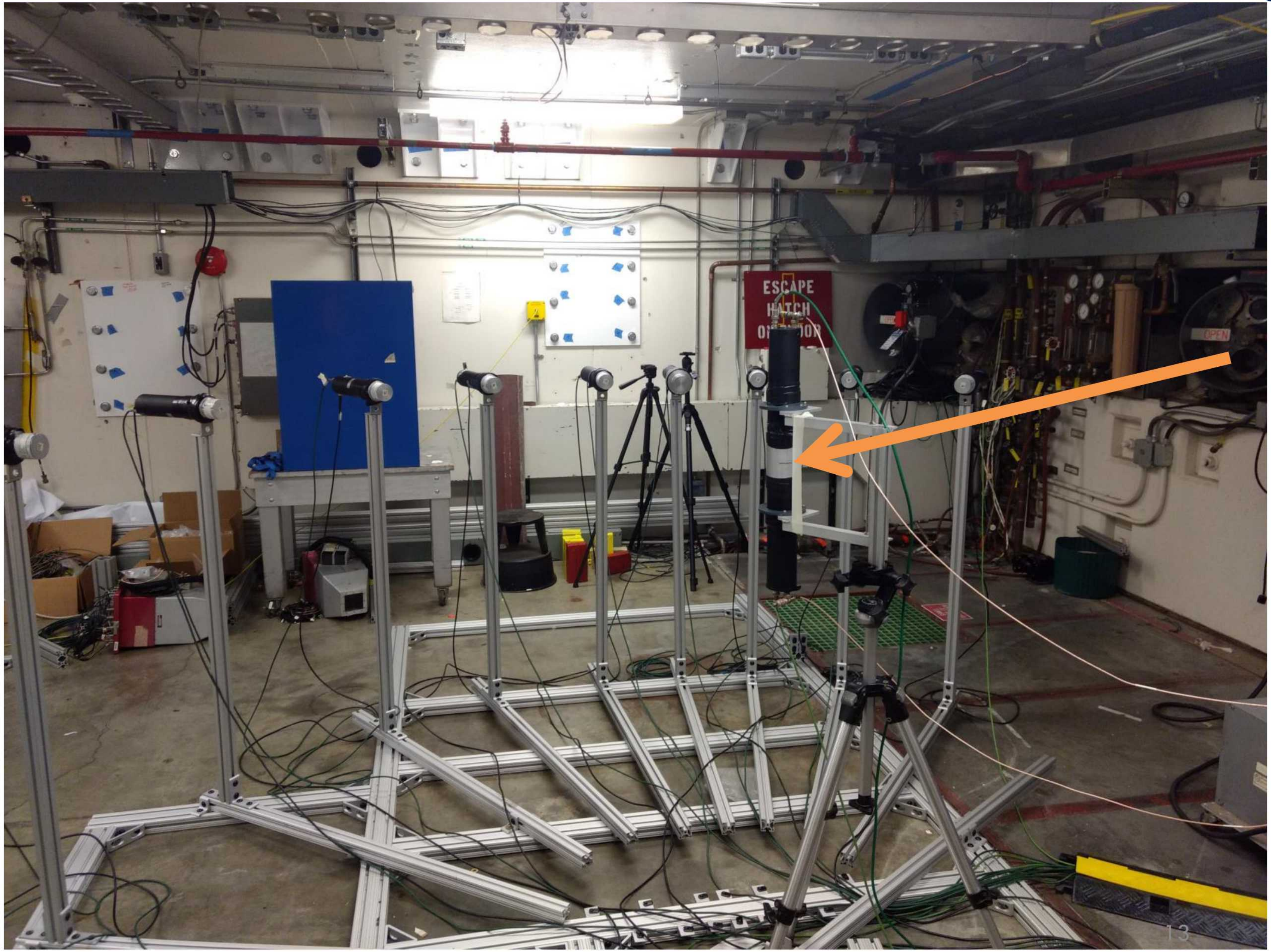

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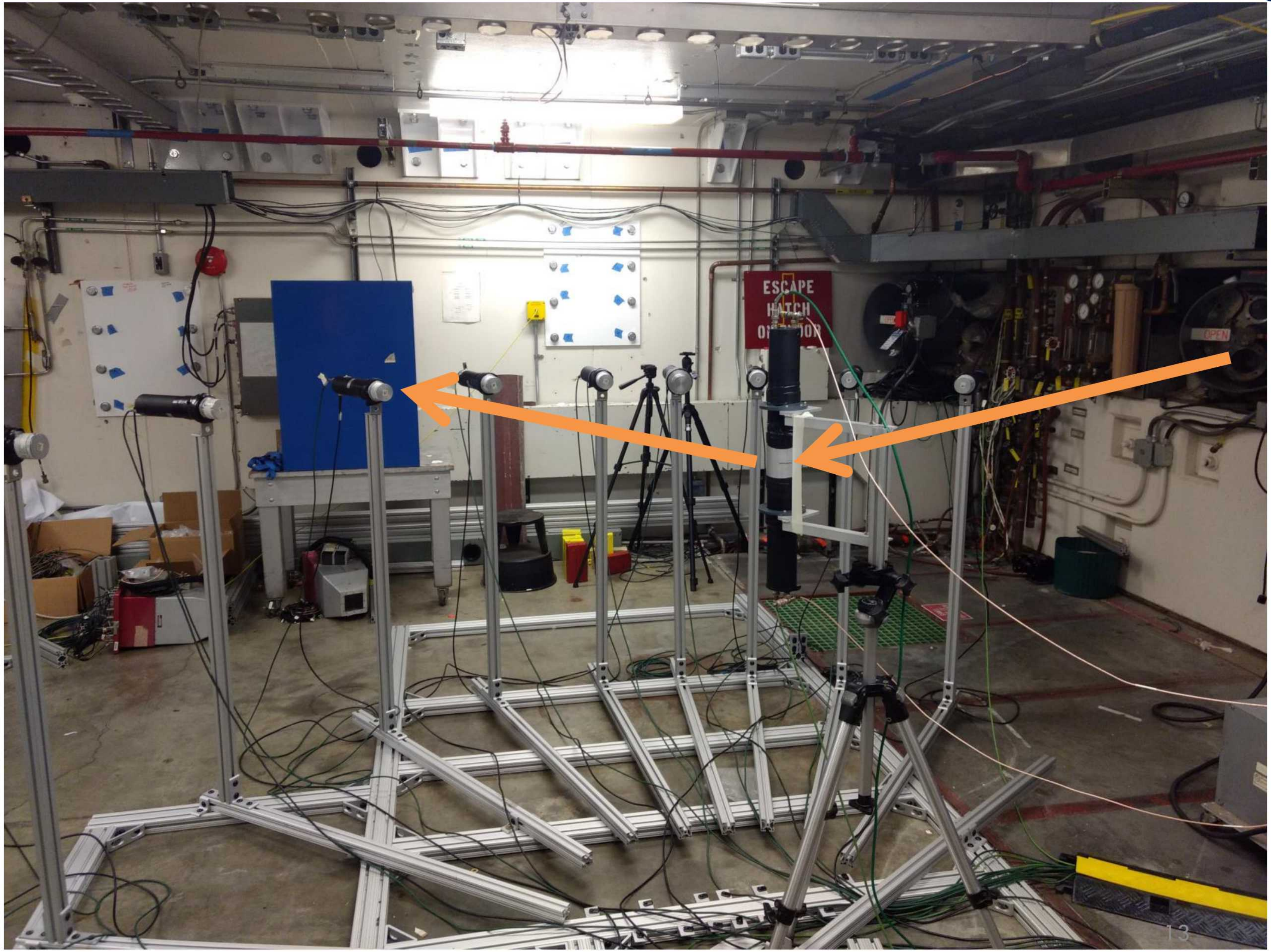
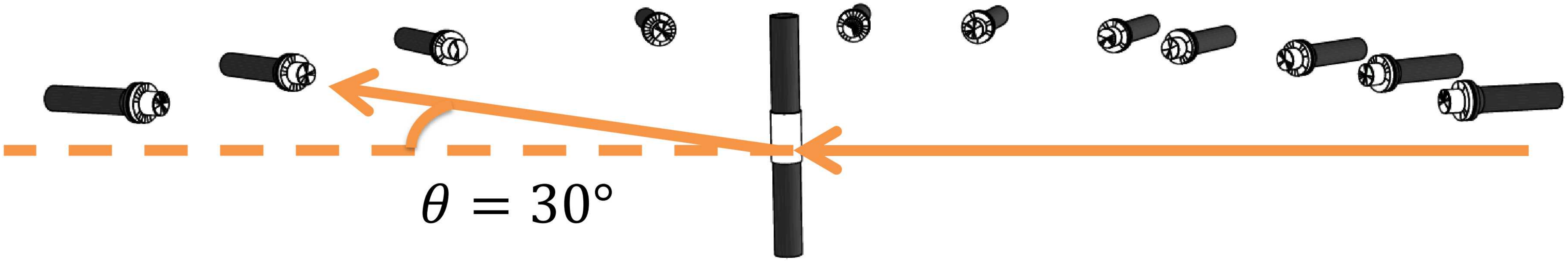


Forward Angle Measurement



$\theta = 30°$

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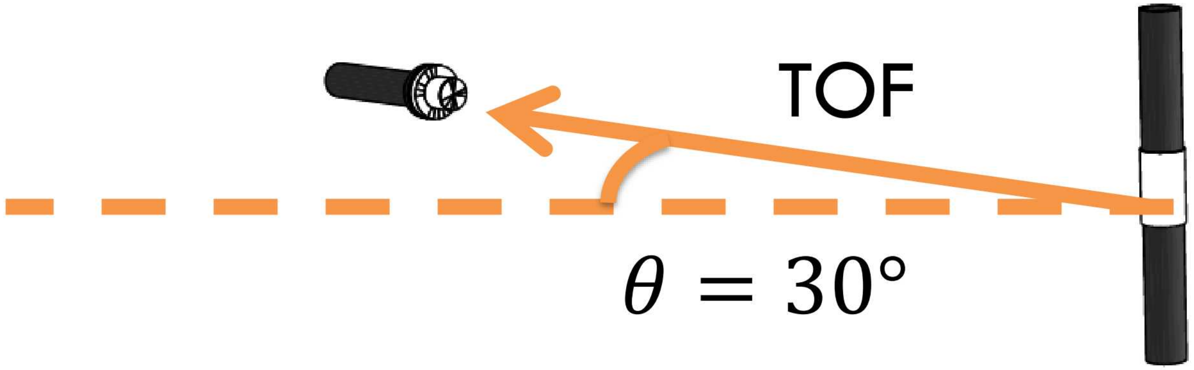

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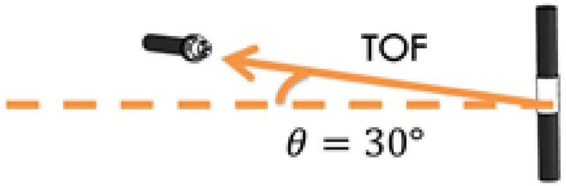

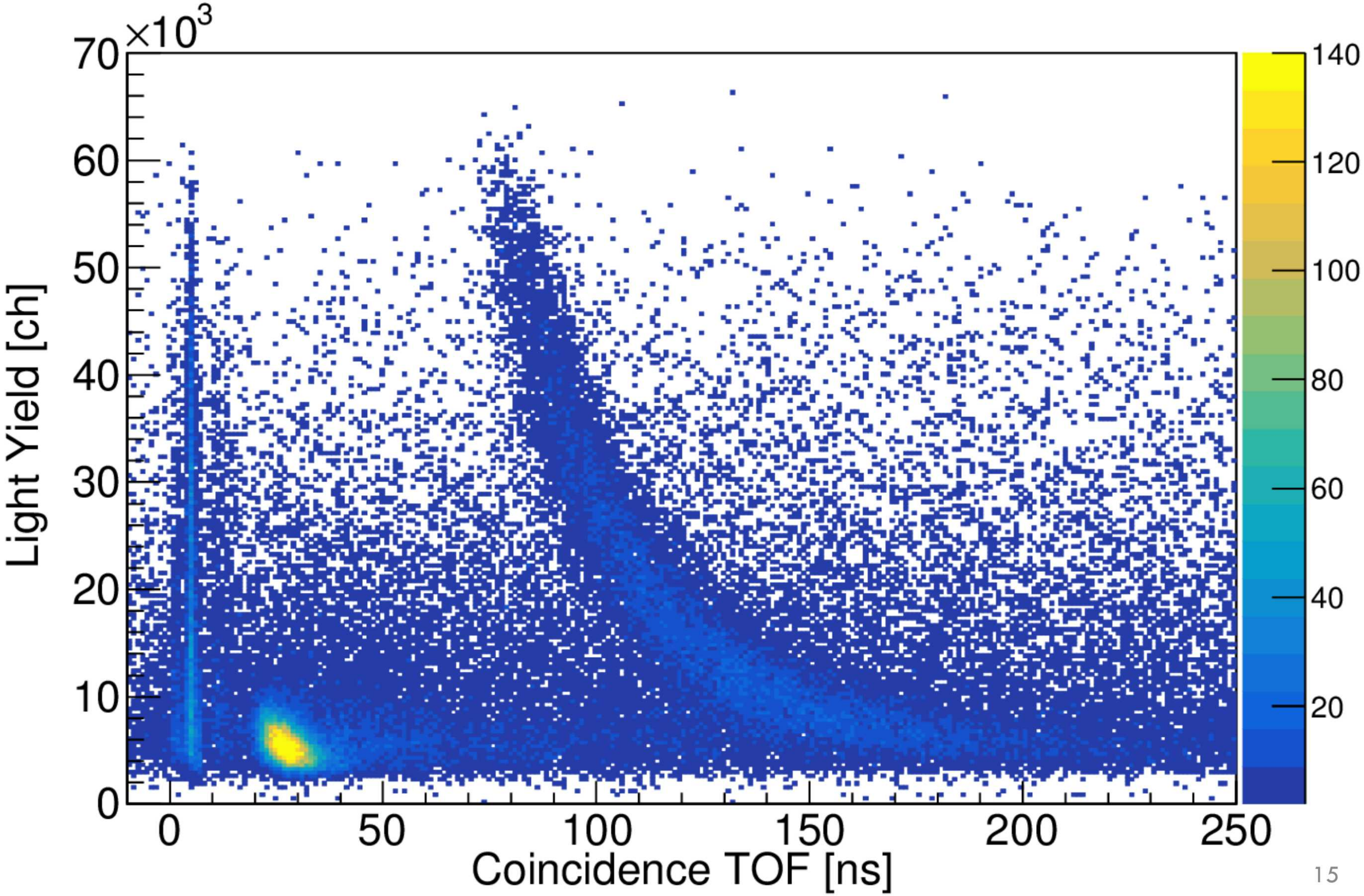

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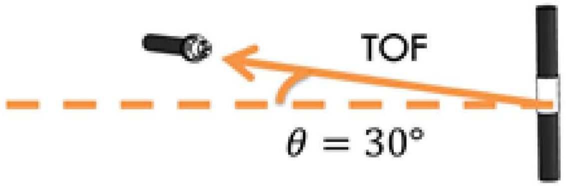
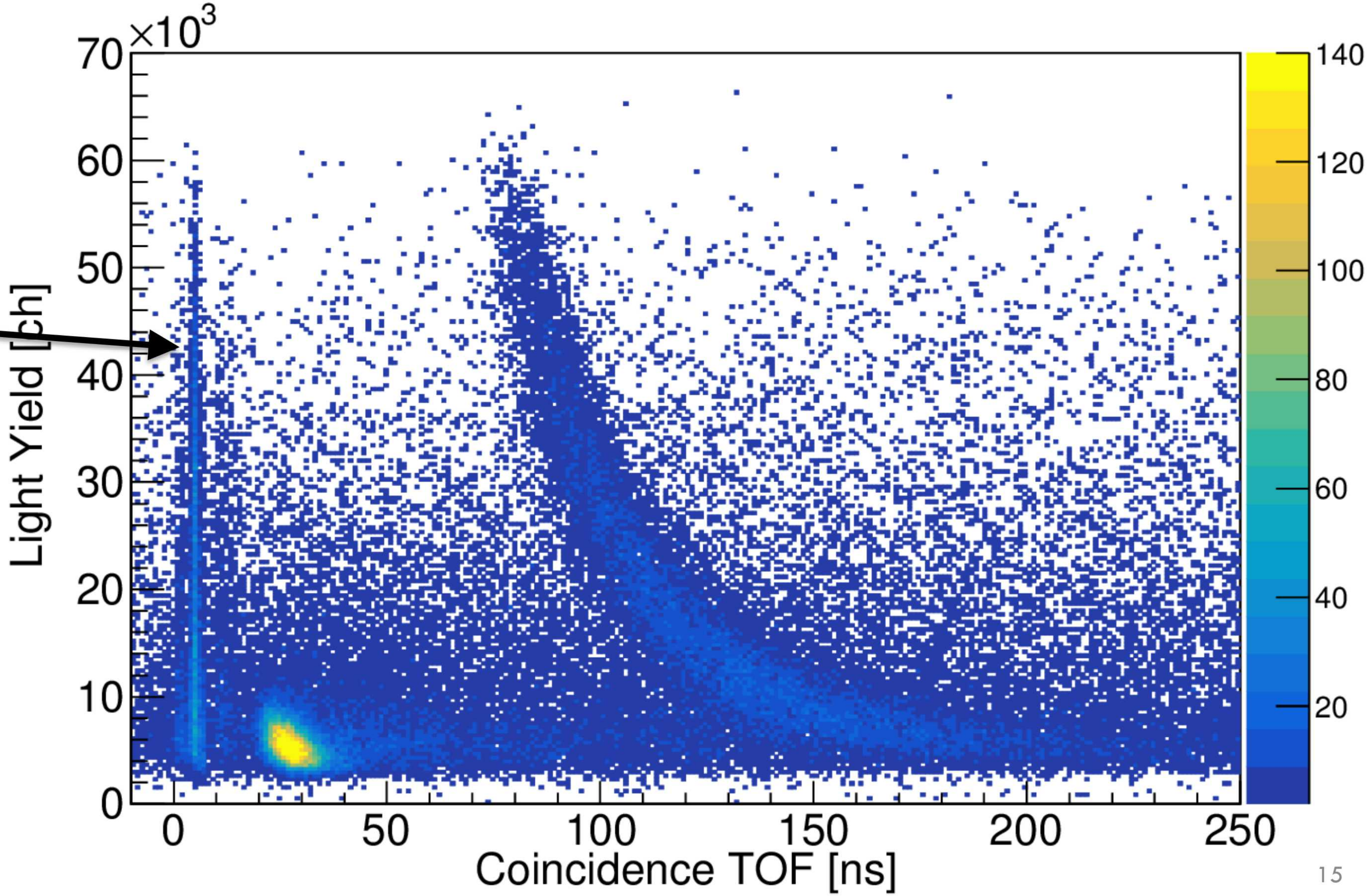


Photon
scatter



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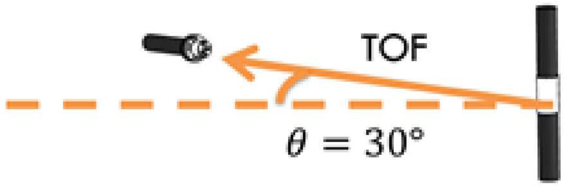
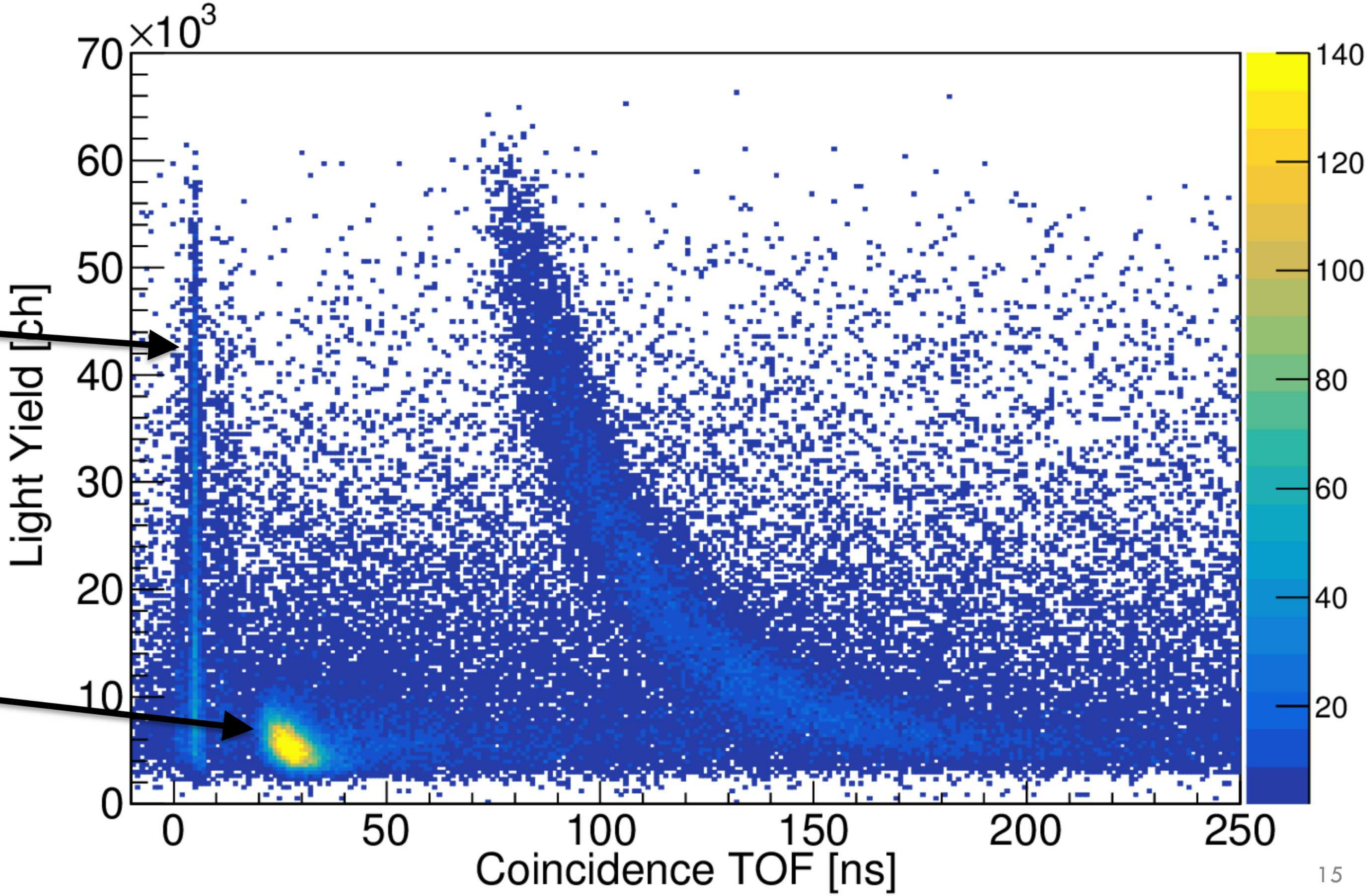


Photon scatter

(n,C) scatter



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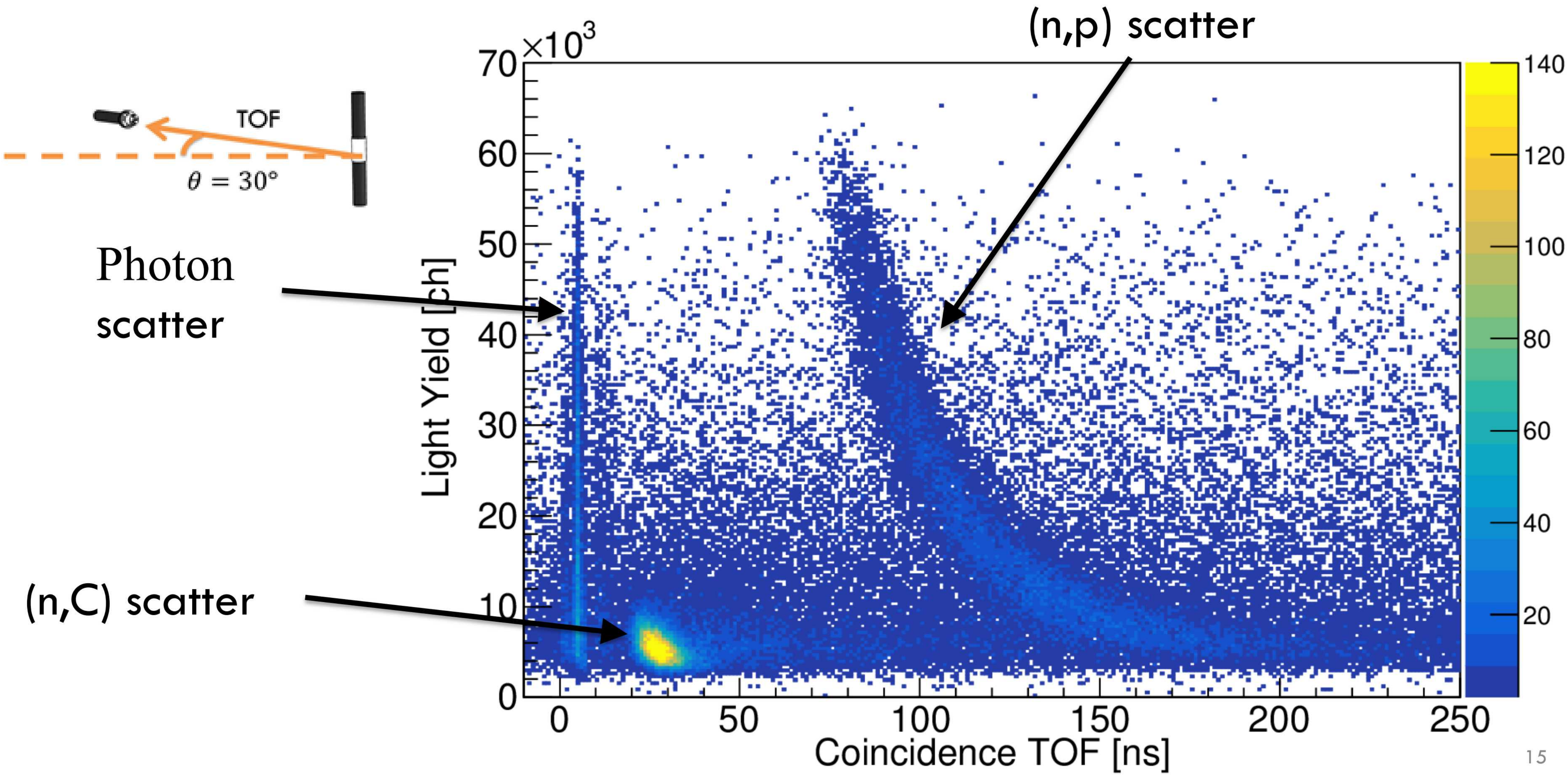

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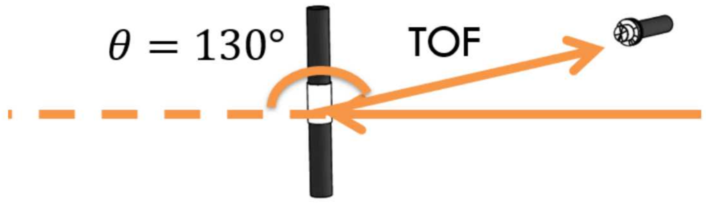
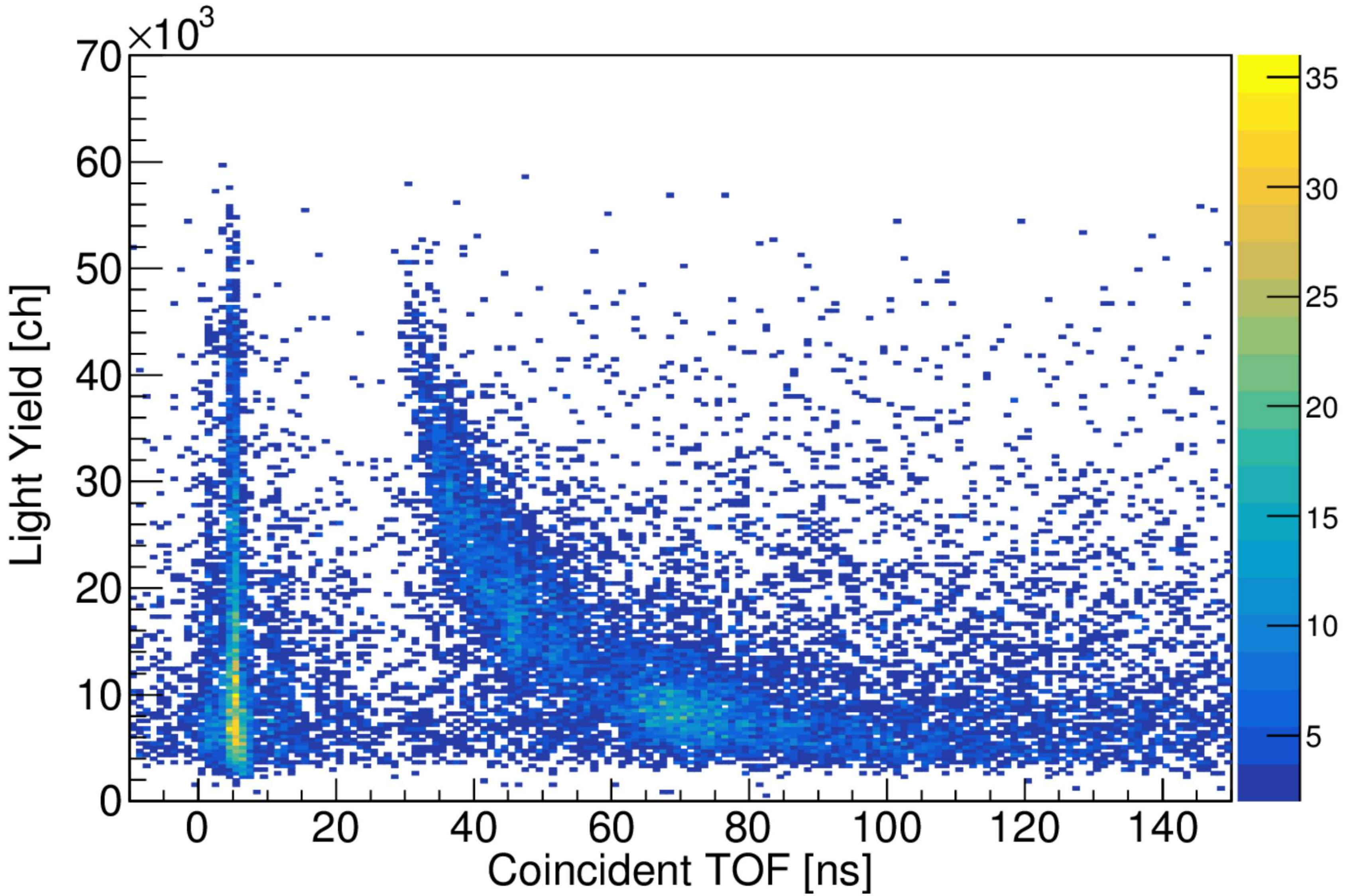
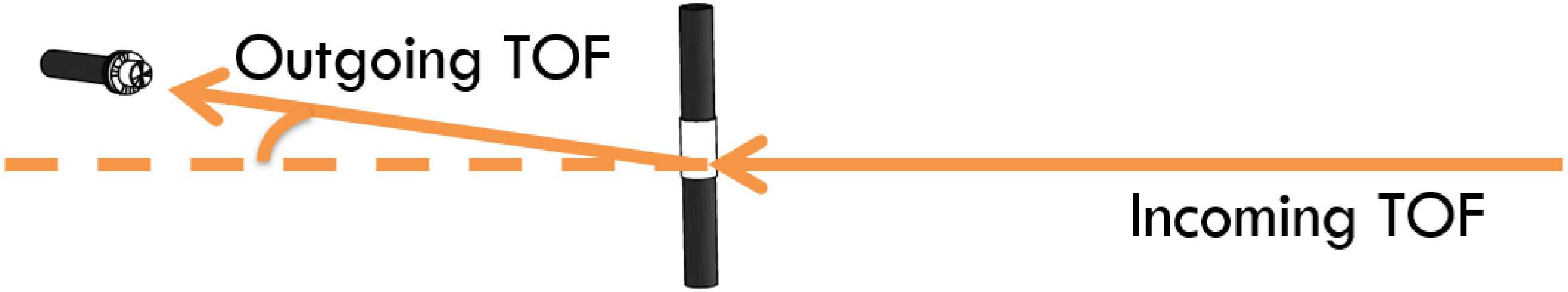


- (n,p) is kinematically forbidden at backward angles



Event Reconstruction – Carbon Light Yield

- Reconstruction on event by event basis
- PSD cuts on outgoing detector
- Cuts on reconstructed vs measured incoming TOF



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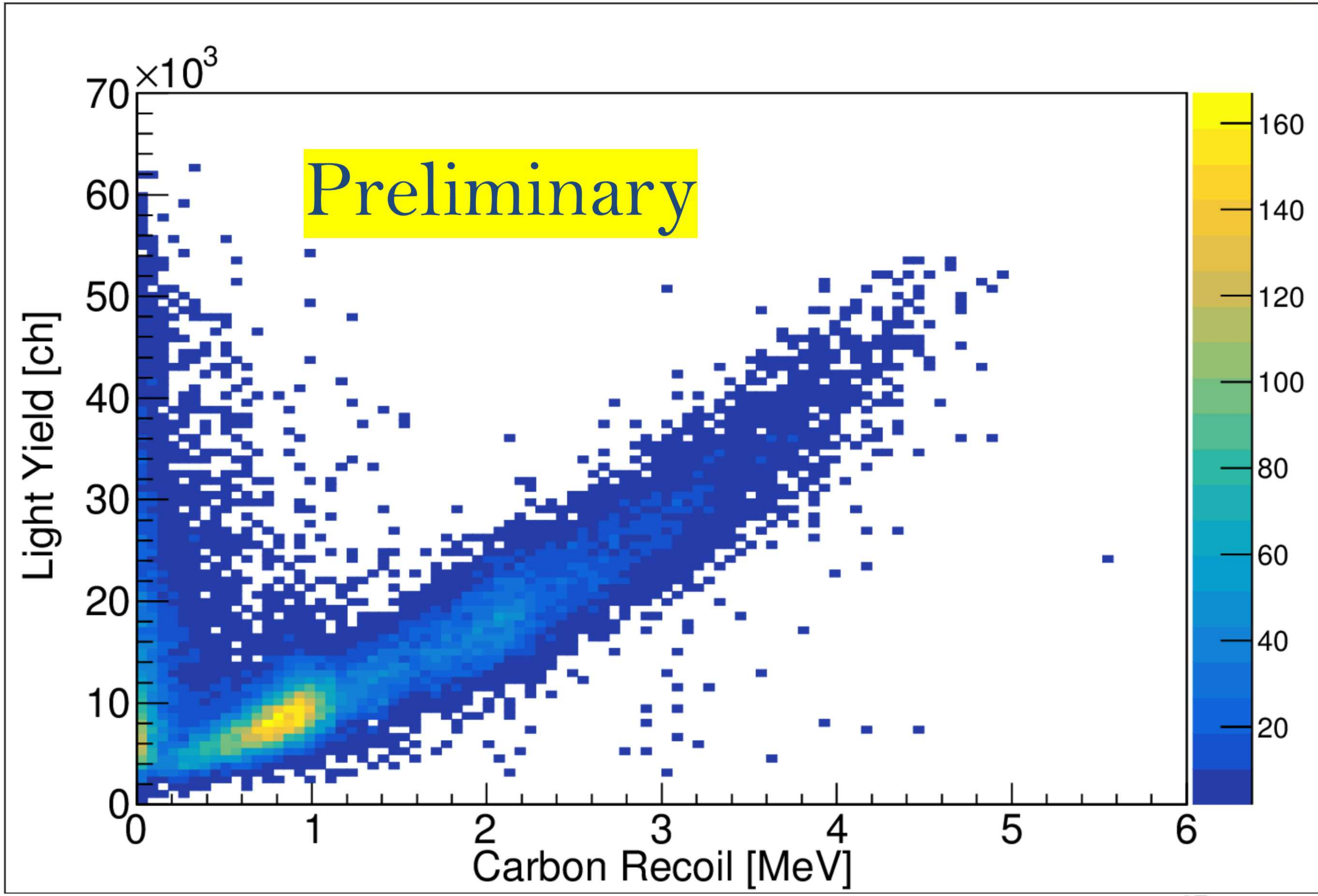
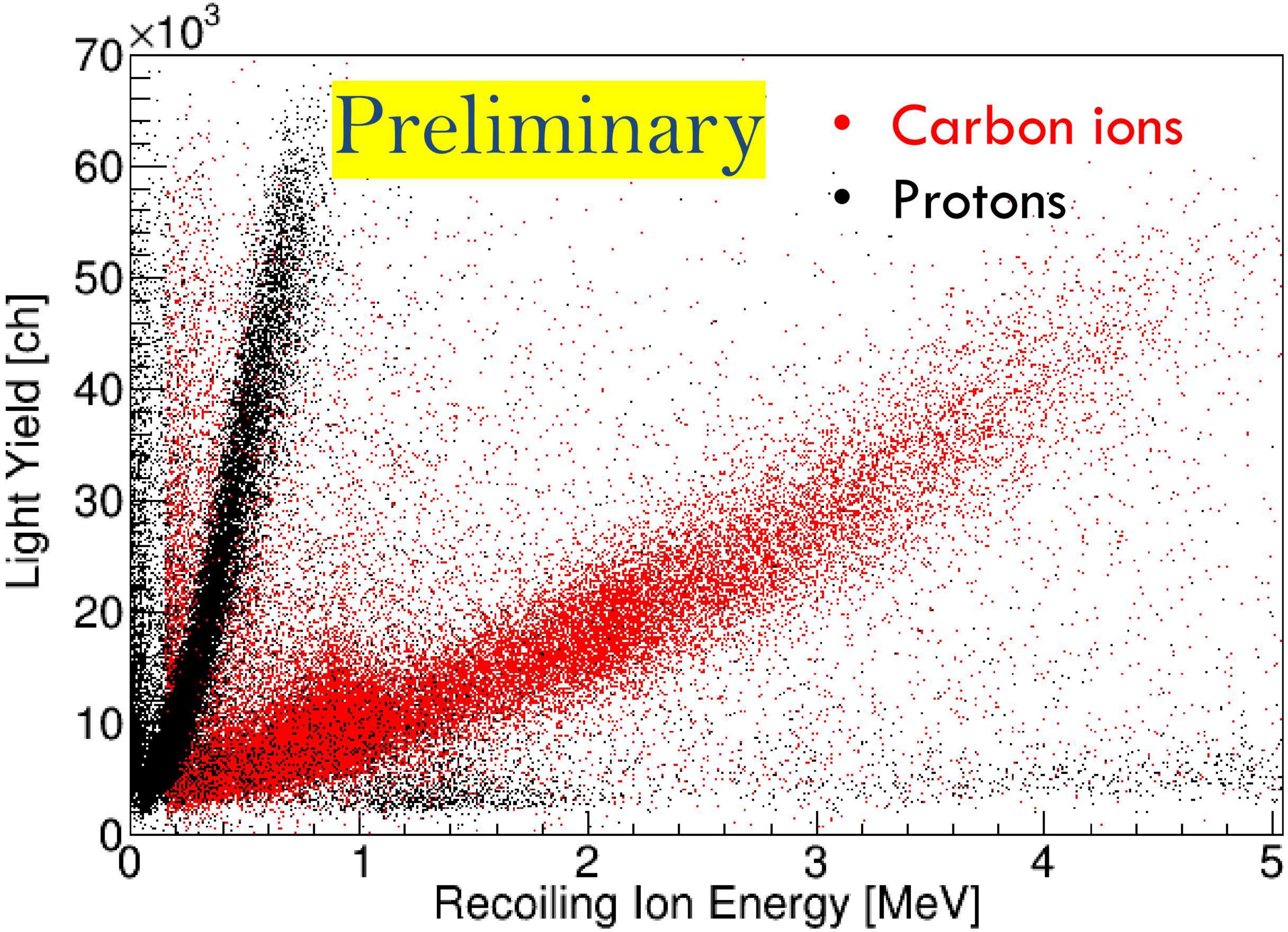


Simultaneous Proton & Carbon Light Yield Measurements

- Allows direct comparison of the light yield
- Example:
  0.5-0.7 MeV recoils:
  L(p) ≈ 7∗L(c)



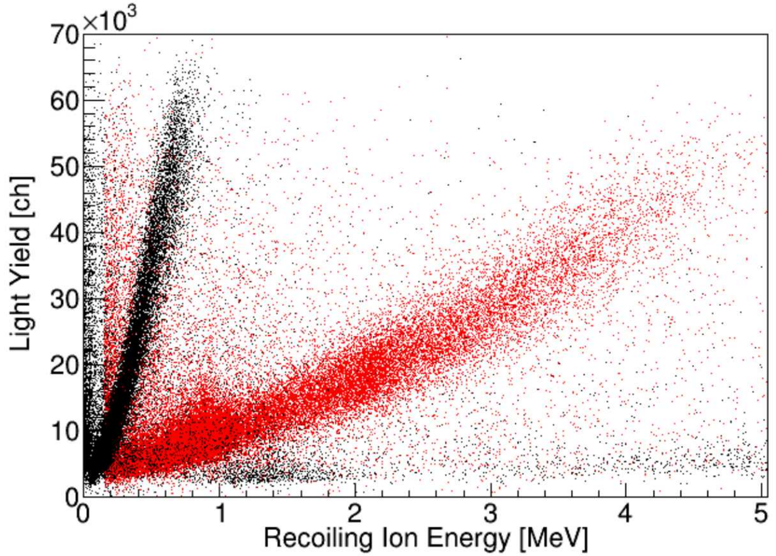
Summary & Impact

Summary:

- Simultaneous, continuous measurement of the carbon and proton light yield over a broad energy range in a single measurement

Impact:

- Carbon light yield enables benchmarking of physics-based models of the specific luminescence of organic scintillators
- Supports the development of advanced neutron-detection systems



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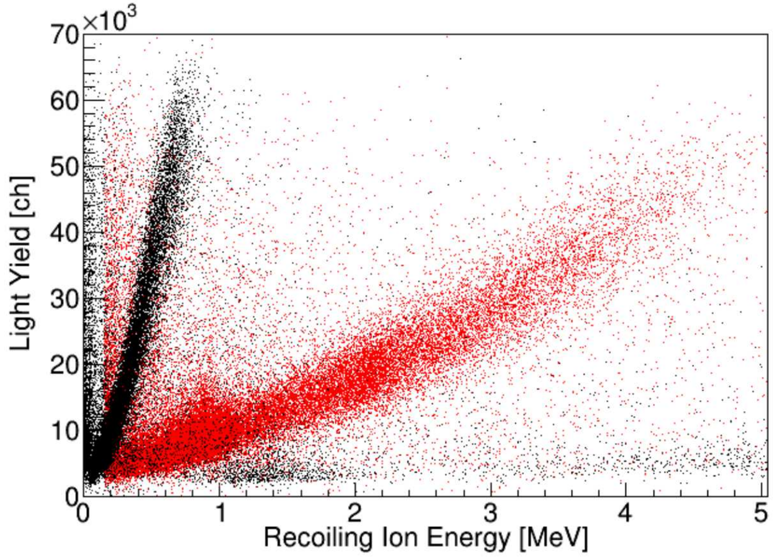
See also:

Poster N-05-249: Comparative scintillation performance of EJ-276, EJ-309 and a novel organic glass



Acknowledgements

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E. Bourret-Courchesne

D. Bleuel

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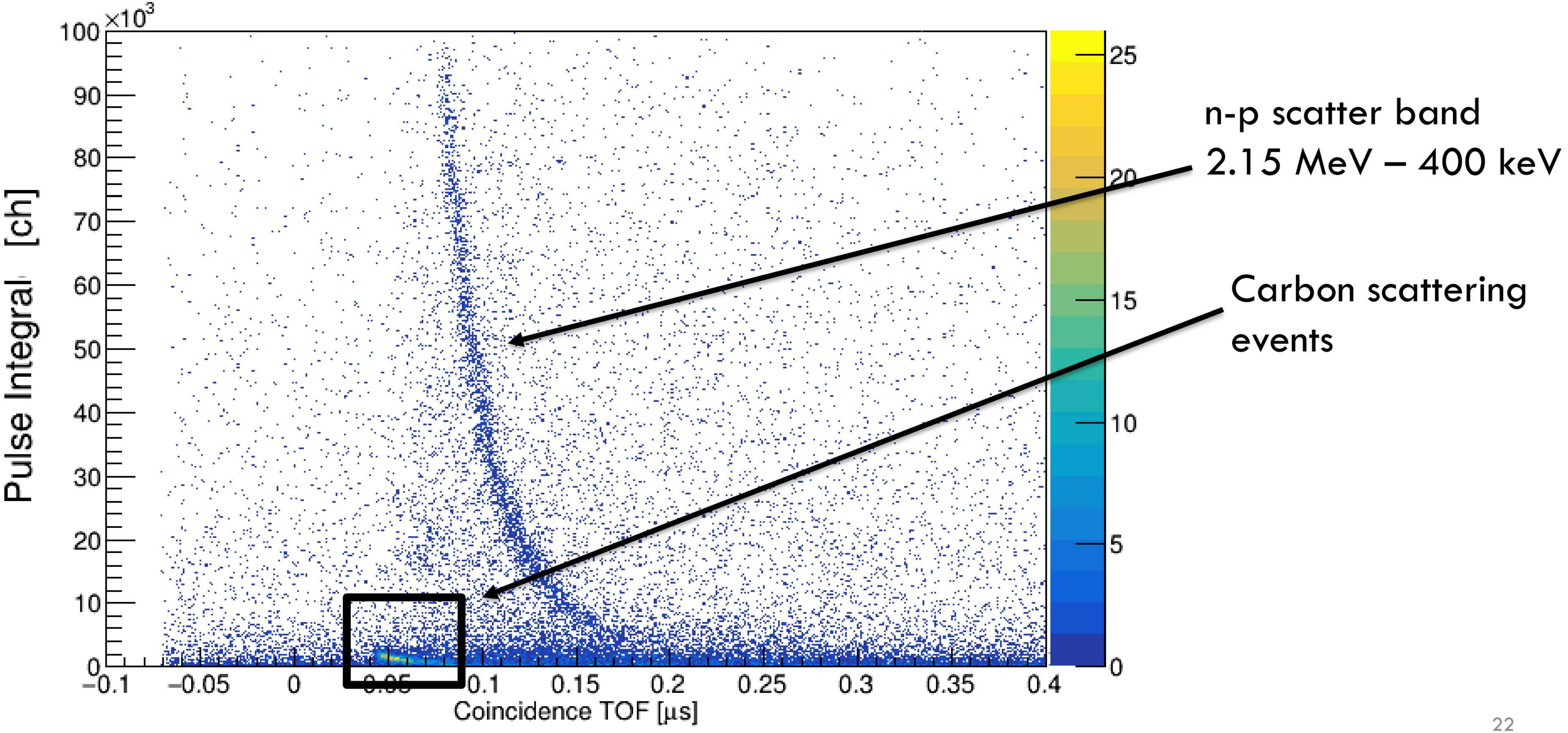
CAVE 0

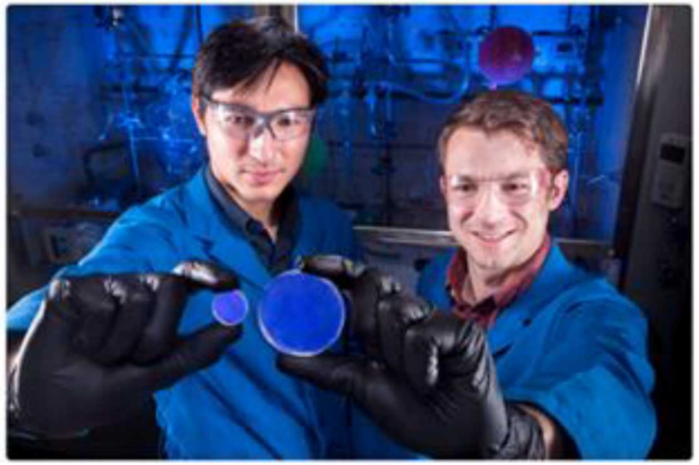
Forward Angle Measurement

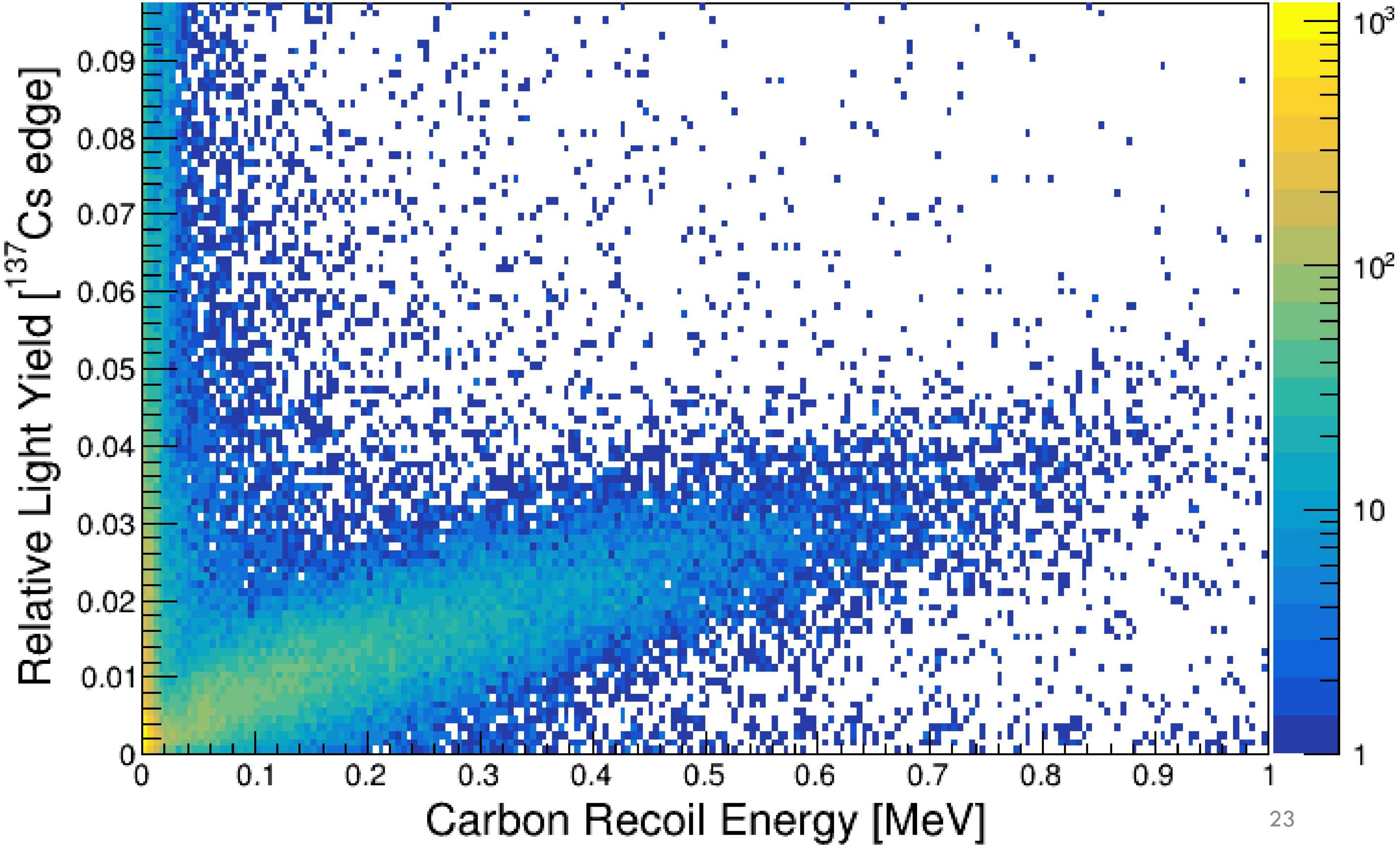


Combining all angles

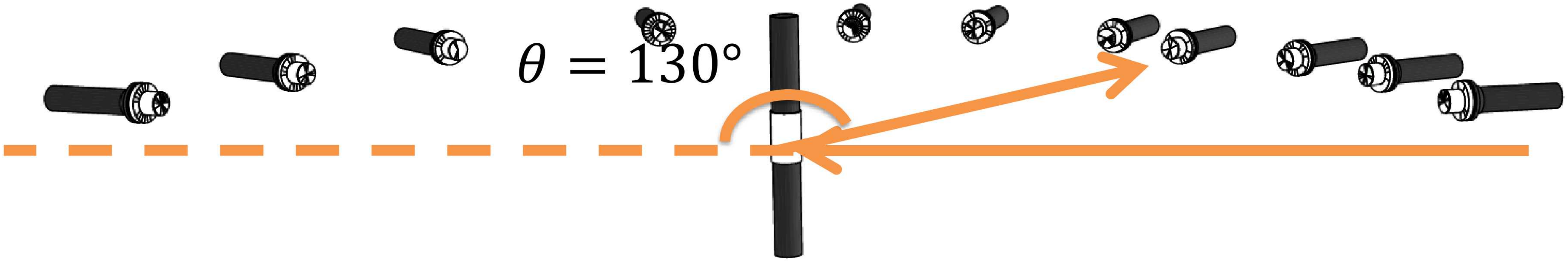
Organic glass scintillator

Forward angles





Backward Angle Measurement



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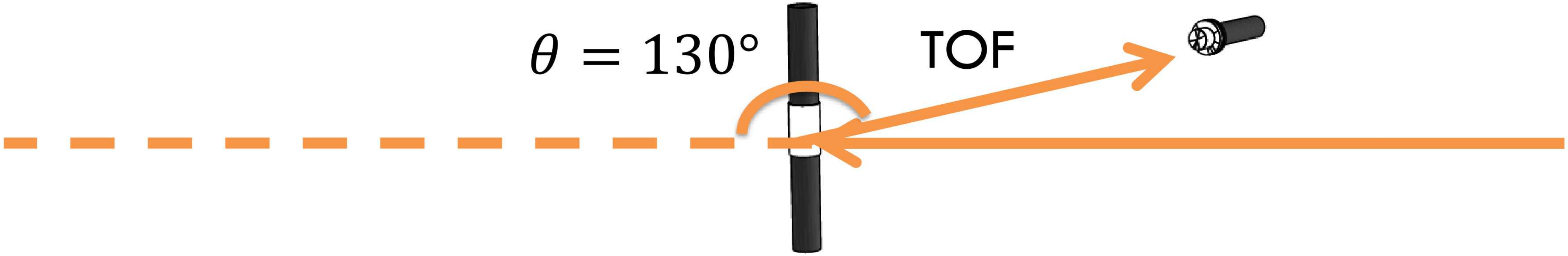

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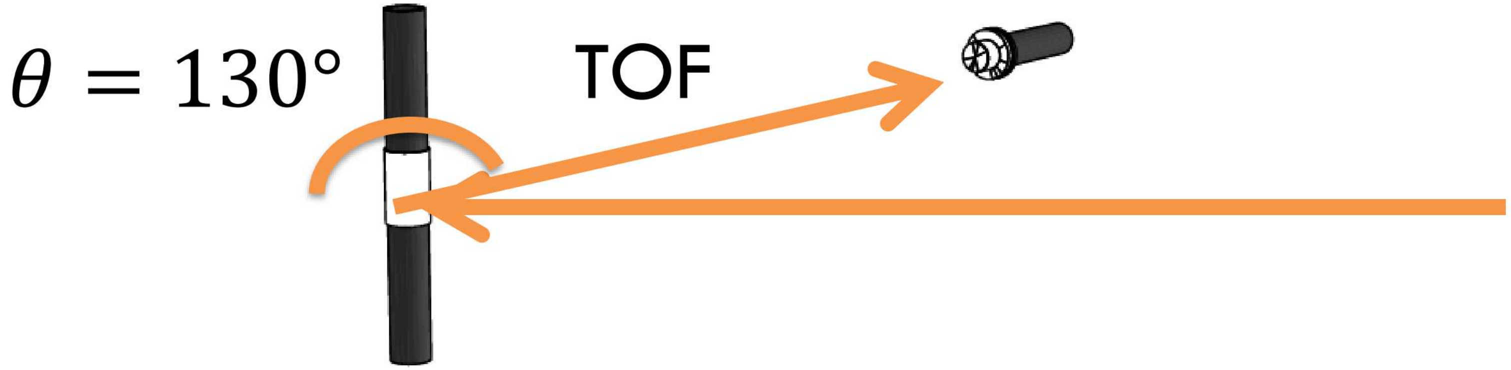

Light Yield measurements at the 88-Inch Cyclotron

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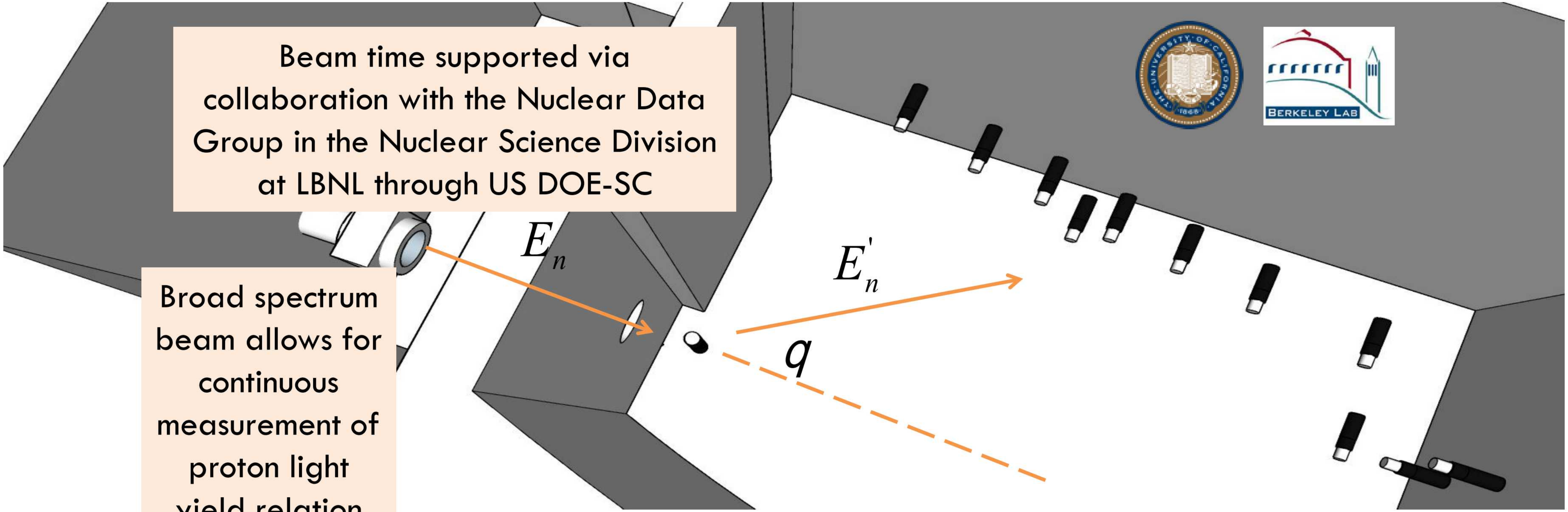
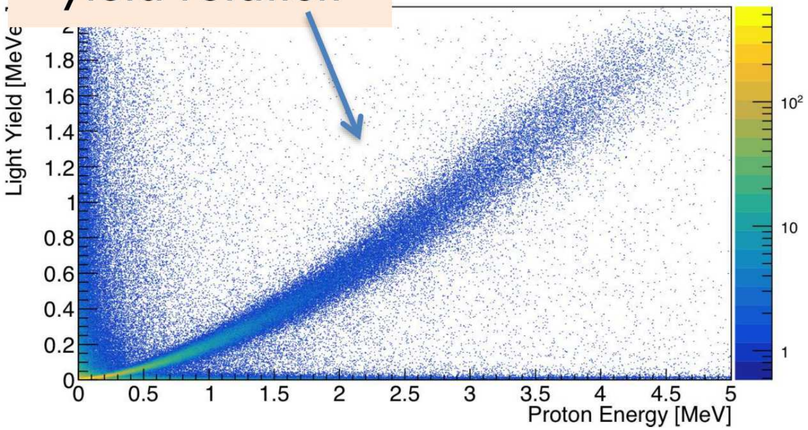


Broad spectrum beam allows for continuous measurement of proton light yield relation



Kinematically over-constrained system provides systematic check

$$E_p = E_n' \tan^2 q$$

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

$$E_p = E_n - E_n'$$

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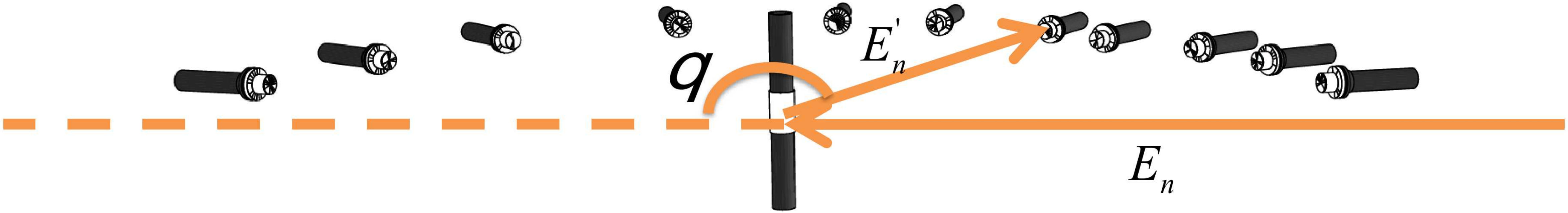
Carbon Light Yield measurements

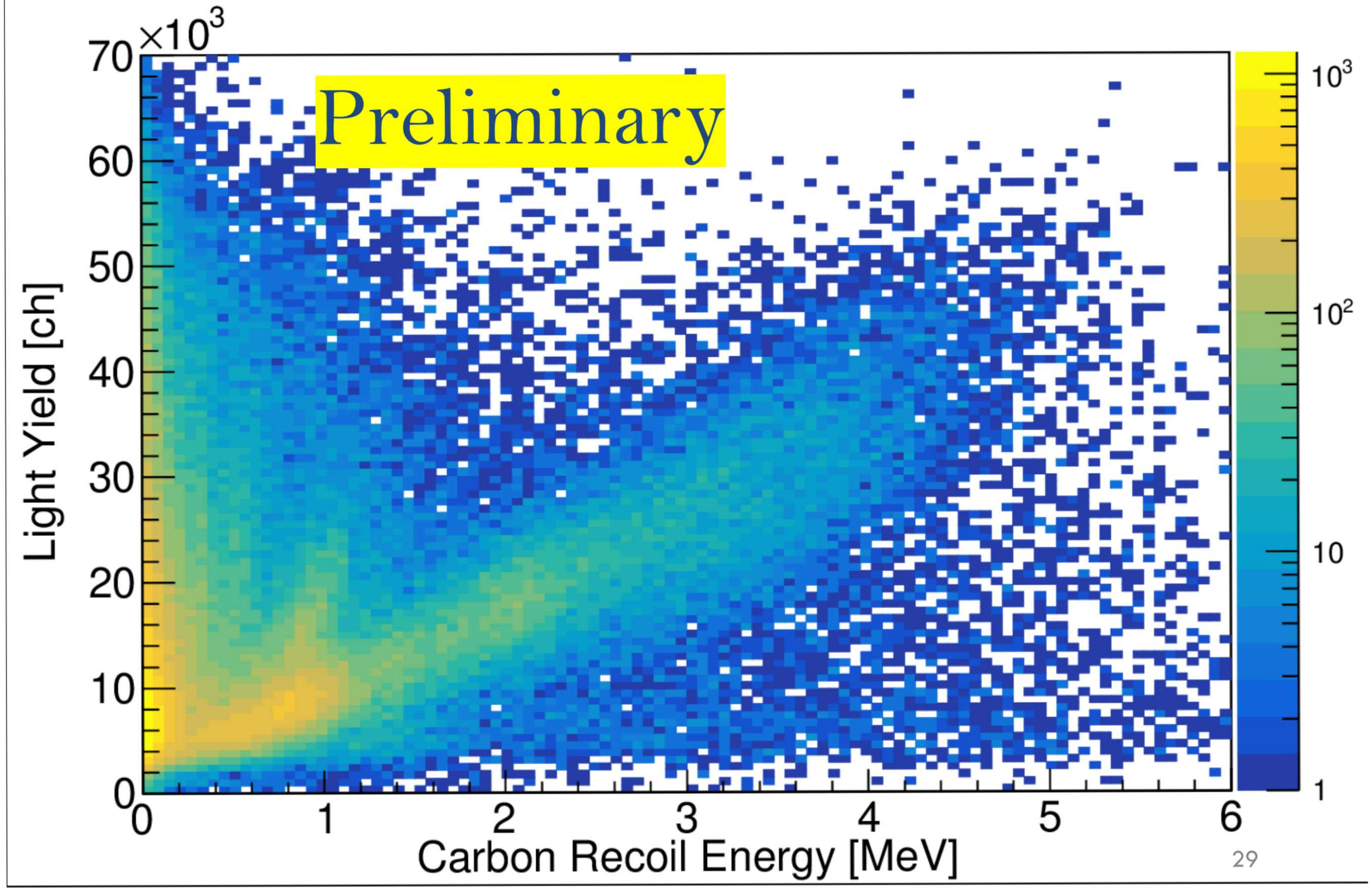


$$E_A^{recoil} = E_n \left\{ 1 - \frac{1}{(A+1)^2} \left[\cos(\theta) + \sqrt{\mathrm{A}^2 - \sin^2(\theta) + \frac{A(A+1)Q}{E_n}} \right]^2 \right\} - Q$$

- n-p elastic scattering is forward angle constrained
- For carbon, only other significant reaction for 4-20 MeV incoming neutrons is inelastic on the first excited state (Q=4.4 MeV) --double check n,3a

Event Reconstruction – Carbon Light Yield

- Reconstruction on event by event basis
- Assuming Carbon elastic scattering
- PSD cuts on outgoing detector



Event Reconstruction – Proton Light Yield

- Reconstruction on event-by-event basis
- Physics-based cuts