Quenching Measurements and Modeling for Organic Scintillators

Thibault Laplace

Department of Nuclear Engineering
University of California, Berkeley

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Overview

GOAL: predictive, reliable ionization quenching model

1. Response of organic scintillators – reported quantities

2. Challenges associated with different experimental techniques

3. Challenges in interpreting results – modeling

4. Stopping power data

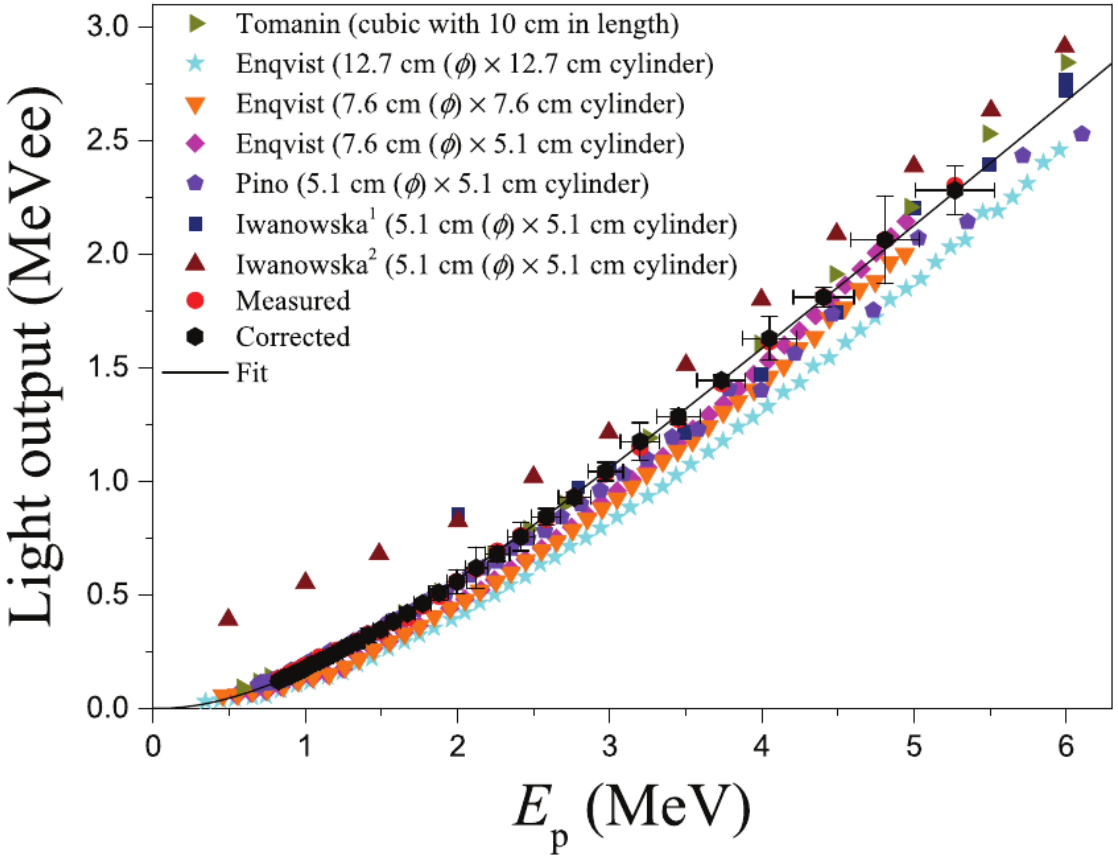
5. Recommendations

Response of organic scintillators

- Response of material to nuclear recoil is required to model an organic scintillator-based neutrino detection system but:

➔ No accurate physics-based model of ionization quenching

➔ Few measurements on most materials, highly discrepant

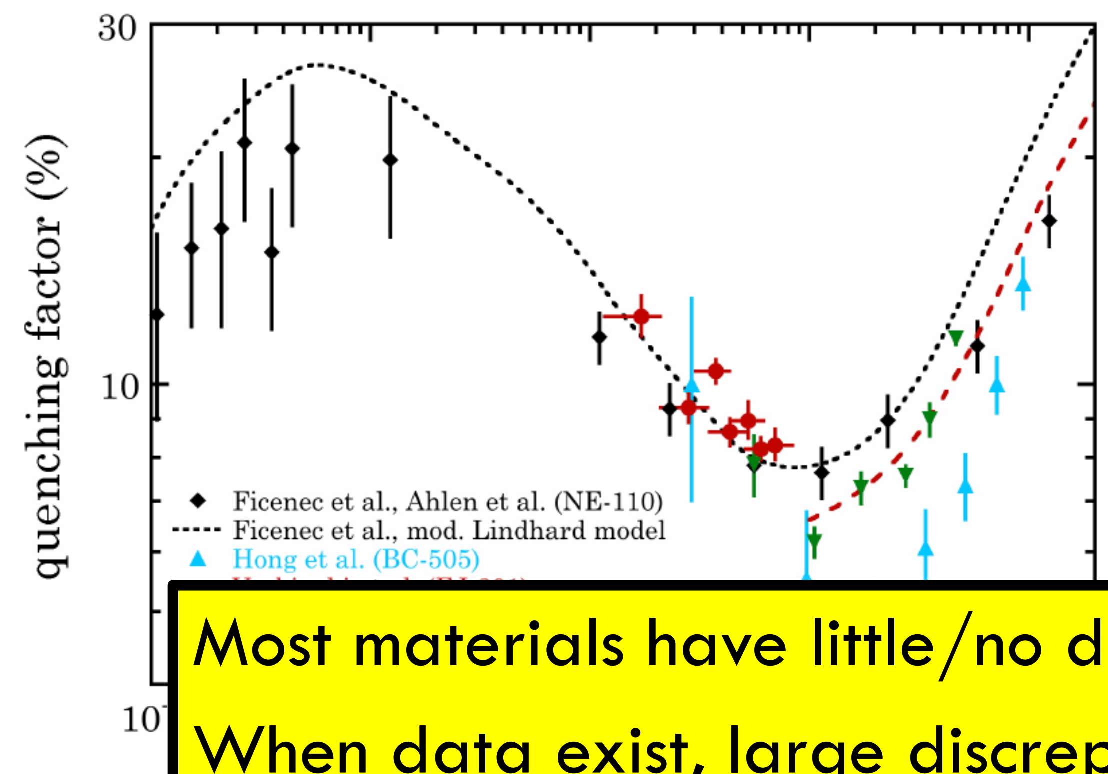


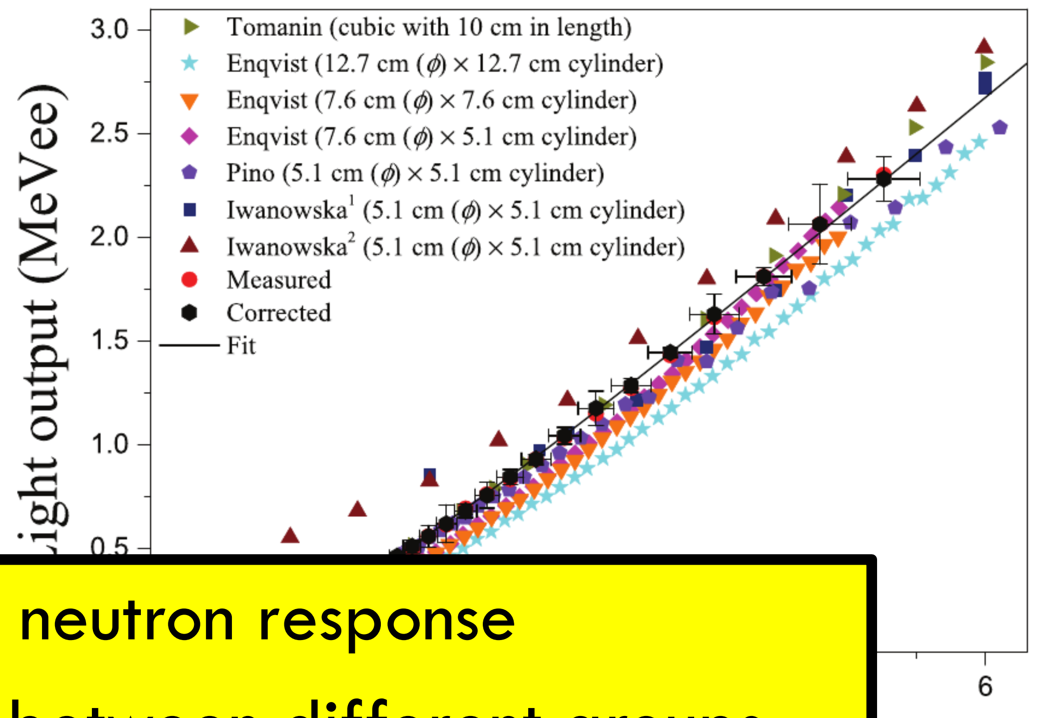
EJ-309 proton light yield. [Bai et al. NIMA 863 (2017)]

Response of organic scintillators in the literature

Quenching factors $QF(E) = \frac{L_i(E)}{L_{e^-}(E)}$

Light yield/ light output





Most materials have little/no data for neutron response

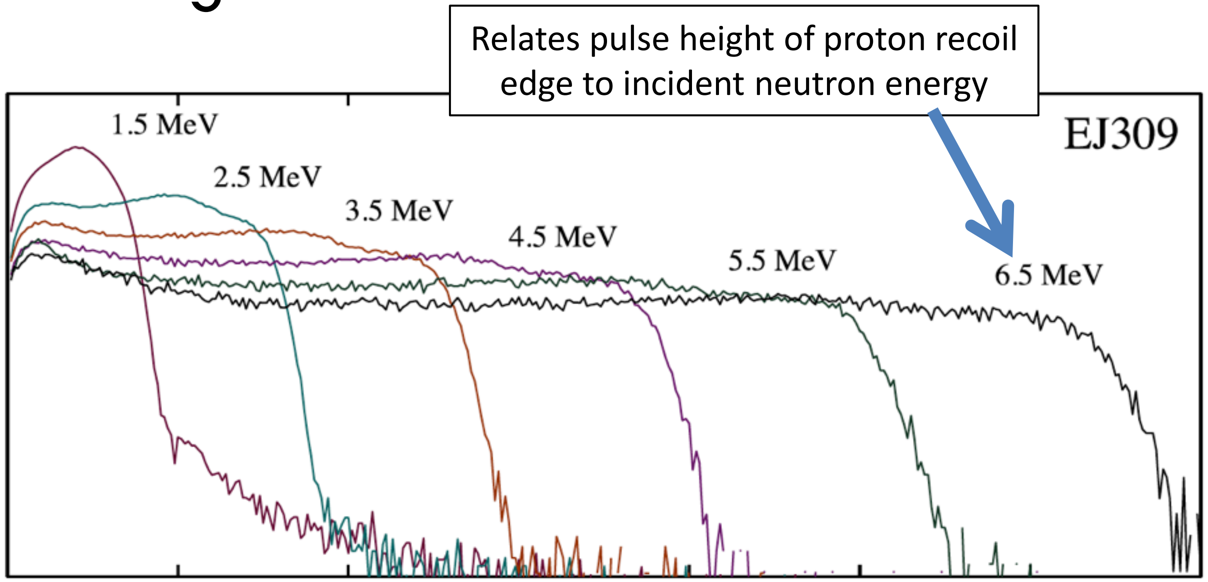
When data exist, large discrepancies between different groups

EJ-301 proton quenching factors. [Awe et al. PRC 98 (2018)]

EJ-309 proton light yield. [Bai et al. NIMA 863 (2017)]

Common Measurement techniques and potential biases

- Edge characterization

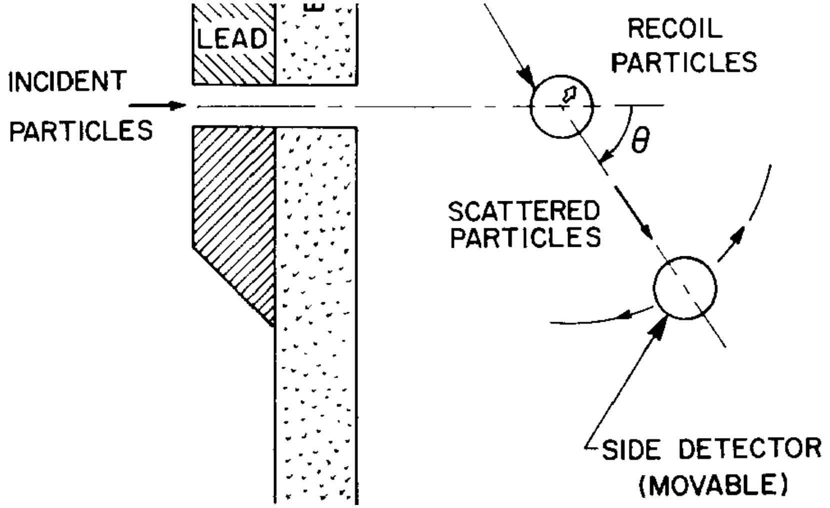


Bias if multiple scatters and energy dependence of the resolution function are not properly accounted for

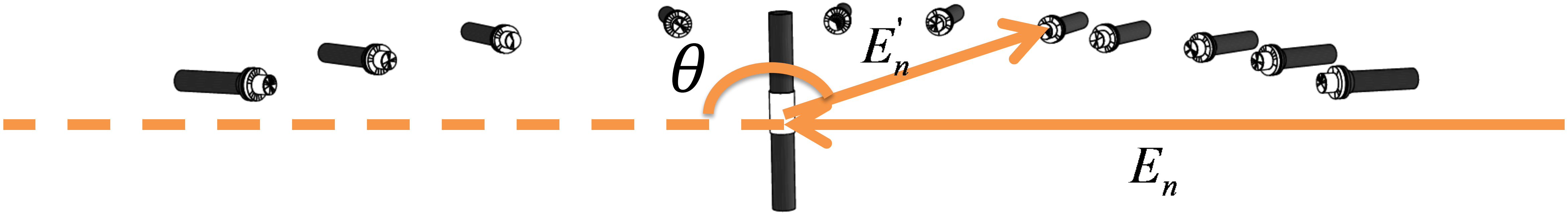
Extensive discussion in: Weldon et al. NIM A 953 (2020)

- Coincident scatter technique

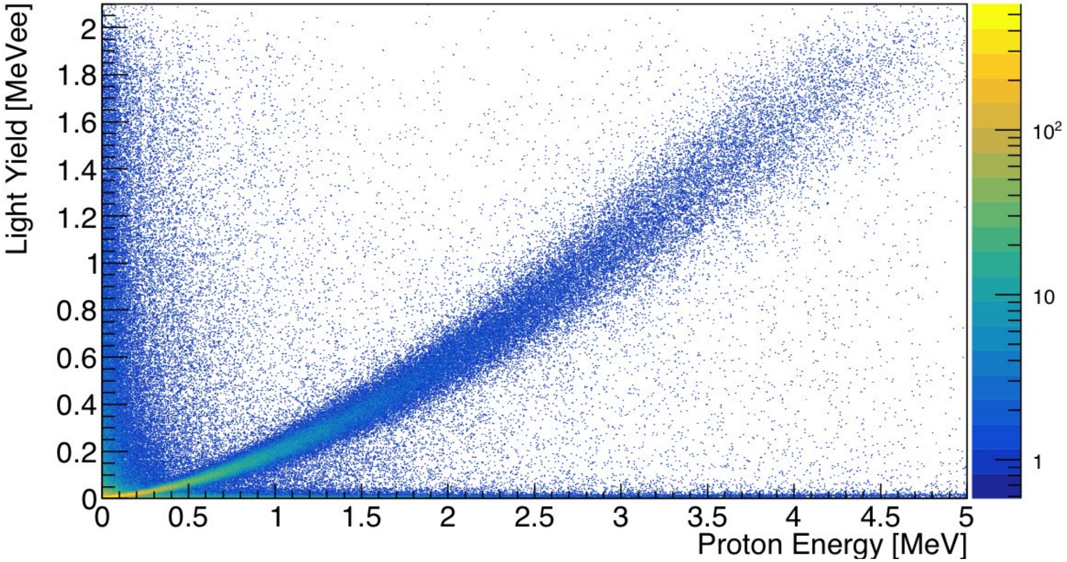
Uses multiple detectors and a series of mono-energetic neutron sources (e.g., DD, DT, TOF) to measure coincident events between detectors – ***Each detector pair yields a single data point***



Light Yield measurements at the 88-Inch Cyclotron



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



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

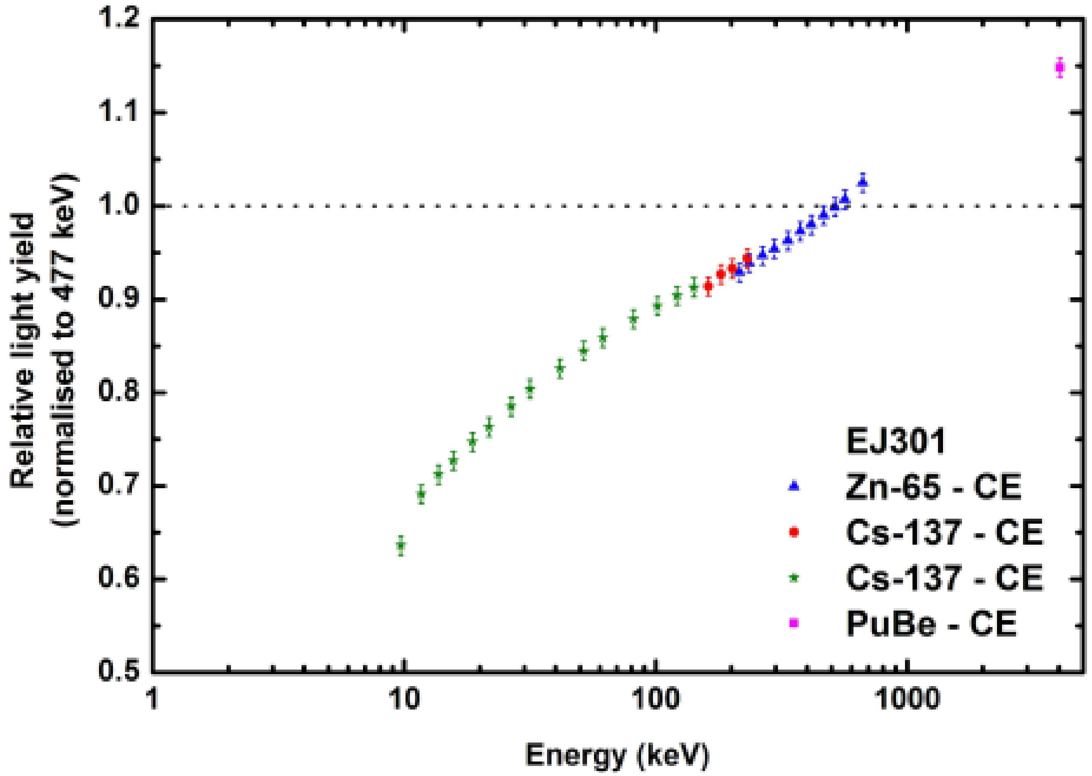
Impact of electron light nonproportionality on QF/light calibration

- Electron light nonproportionality is often neglected

For nonproportional materials:

➔Quenching factors do not provide a measure of ionization quenching (if defined as relative to electron light)

➔MeVee unit is not proportional to the number of photons



Swiderski et al JINST 7 (2012)

Problematic when comparing results from different experim to test ionization

Treatment of electron light nonproportionality is a source of bias between measurements

Models of ionization quenching

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

Birks Relation

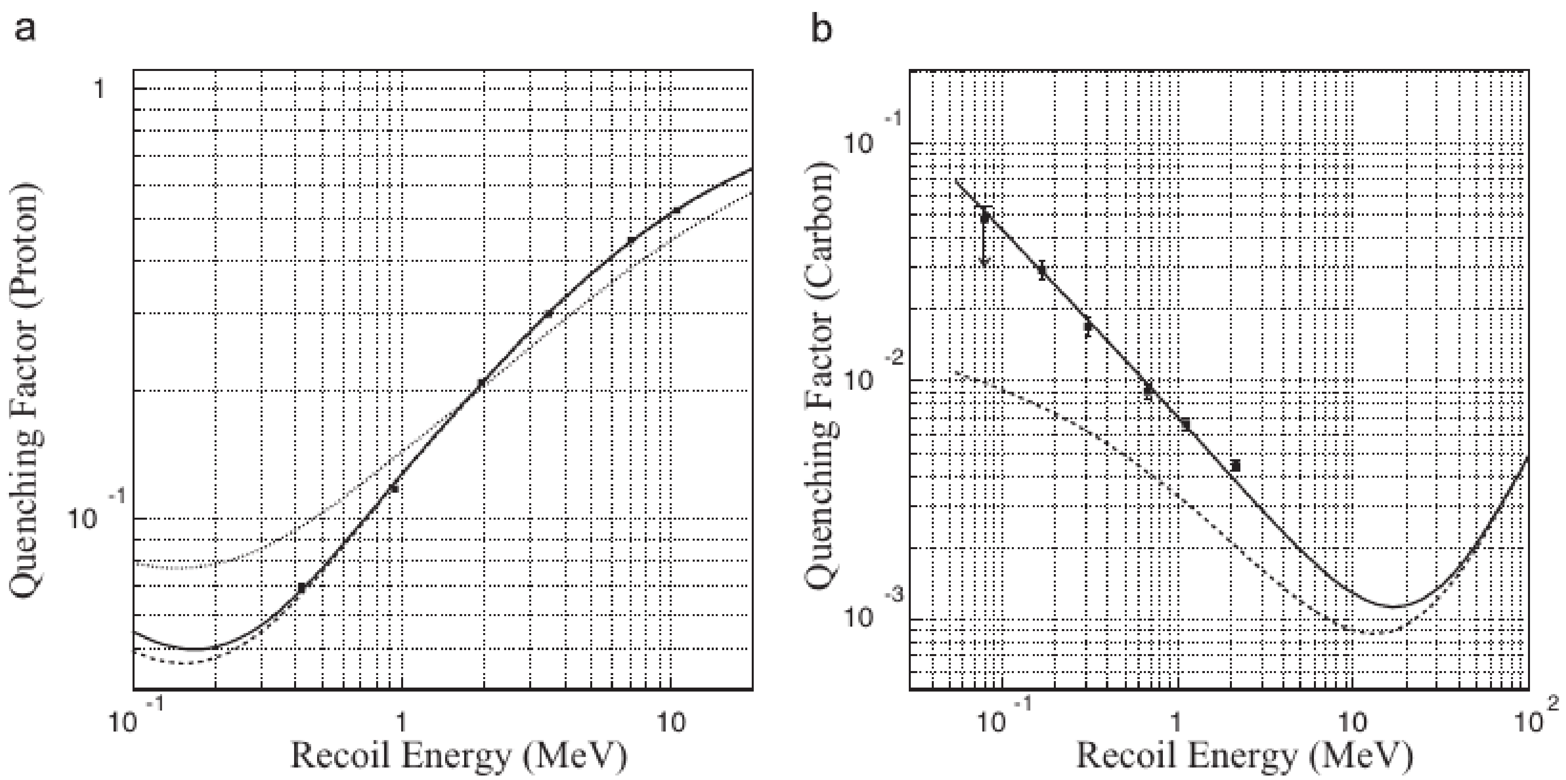
Model	Physics
Birks (1951)	Canonical quenching model
Chou (1952)	Second order quenching term
Voltz (1968)	Treats the prompt and delayed components of scintillation light independently Separate contribution from δ rays
Hong (2002)	Separate treatment of electronic and nuclear components of the stopping power
KamLAND (2010)	Extension of Hong with higher-order quenching

Model predicting both proton/carbon light

Hong et al.
Astroparticle Physics 16 (2002)

Yoshida et al. (KamLAND collaboration), NIMA 622 (2010)

Each group introduced a new model to fit their data



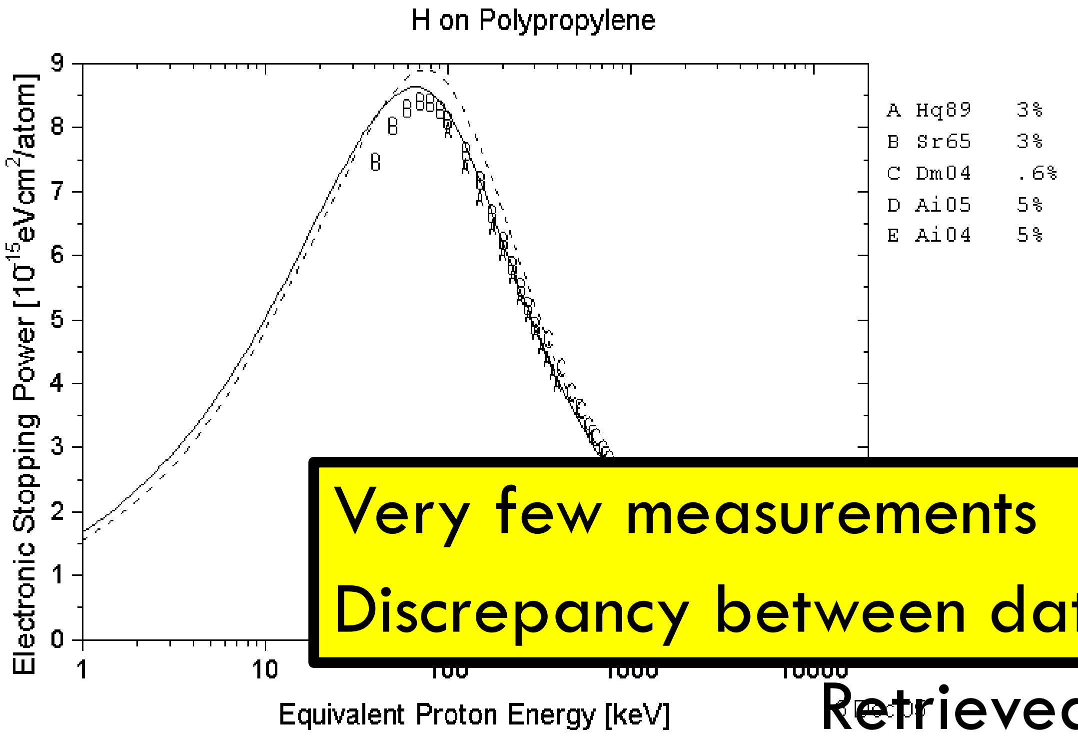
Scintillator understanding and development is generally the responsibility of a given project

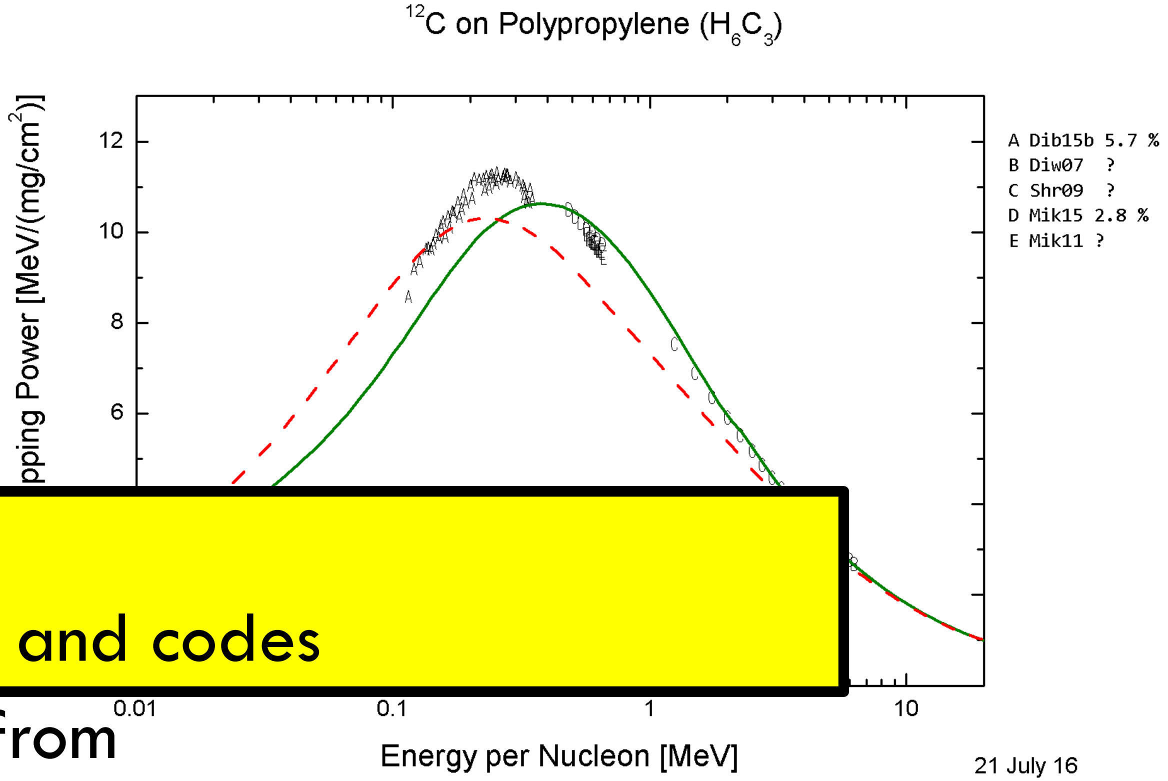
Stopping power data

Published measurements of stopping power on plastic scintillators:

Gooding T.S., Phys. Rev. 105 (1957) 37 MeV protons

Kloppenburg J., Z. Physik 181 (1964) 200-900 keV protons and deuterons





Very few measurements

Discrepancy between data and codes

Retrieved from IAEA website

Recommendations

- Issues with material development and understanding being tied to a project
  ➔ no core capability and knowledge – high variability of measurements

  ➔ understanding of basic mechanisms replaced by model/function that fits the measured data

Need a physical model of ionization quenching

- Need for a database compiling the different experimental measurements (similar to EXFOR for nuclear reaction data)

  ➔ Can be used as reference (saving researchers time and money)
  ➔ Facilitate benchmarking of models

  ➔ Help inform if more measurements are needed

  ➔ First step towards an "ENDF of scintillator response"

Recommendations

- Measure scintillator response for different materials of interest (informed by data deficiencies illuminated by compilation effort)

- Stopping power data

- Electron light yield measurements to inform quenching

Acknowledgements

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