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Modeling ionization quenching in organic scintillators

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Neutron detection with organic scintillators

Neutron interactions produce nuclear recoils

Ionization quenching: reduction in light production for particles with high stopping power resulting in nonlinear light output

Organic scintillators: limited data for proton light yield for few materials
almost no data for carbon, alpha recoils
➔ no reliable physics-based model covering a wide energy range and different recoiling ions

Light response to recoiling ions needed:

- for accurate simulation of detector performance
- to inform design of new detection systems

Our contribution:

- measurements of proton/carbon light yield in several materials
- test of ionization quenching models

EJ-309

EJ-276

Organic glass

EJ-204

Ionization Quenching Models

5 semi-empirical models were considered in this work

- **Birks** (canonical model -1951) and Chou (additional bi-molecular quenching)

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

dL/dx: specific light yield **dE/dx:** stopping power
S: scintillation efficiency **kB:** quenching parameter
C: bimolecular quenching parameter

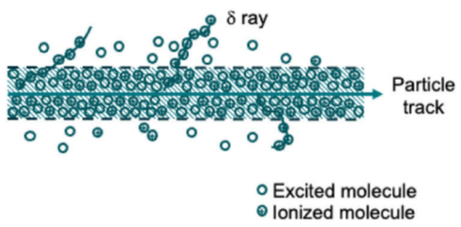
- **Hong** (separation of electronic and nuclear stopping power) and **Yoshid** (combines Hong and Chou):

$$\frac{dL}{dx}=\frac{S_e\left(\frac{dE}{dx}\right)_{\mathrm{e}}+S_n\left(\frac{dE}{dx}\right)_{\mathrm{n}}}{1+kB_e\left(\frac{dE}{dx}\right)_{\mathrm{e}}+C\left(\frac{dE}{dx}\right)_e^2+kB_n\left(\frac{dE}{dx}\right)_{\mathrm{n}}}$$

- **Voltz** (separate treatment of prompt and delayed light components and excitations in track vs from δ rays

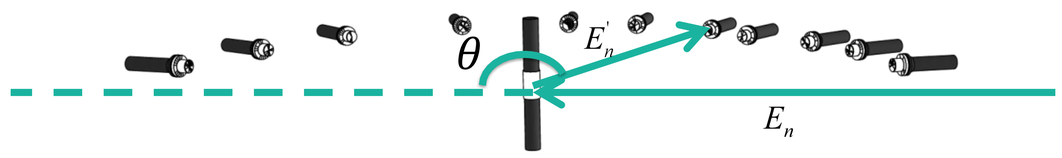
$$\frac{dL}{dx}=S_s\left[(1-F_s)\frac{dE}{dx}\exp\left(-kB_s(1-F_s)\frac{dE}{dx}\right)+F_s\frac{dE}{dx}\right]$$
$$+S_t\frac{dE}{dx}\exp\left(-kB_t\frac{dE}{dx}\right)$$

Fs: probability for an electron to escape particle track

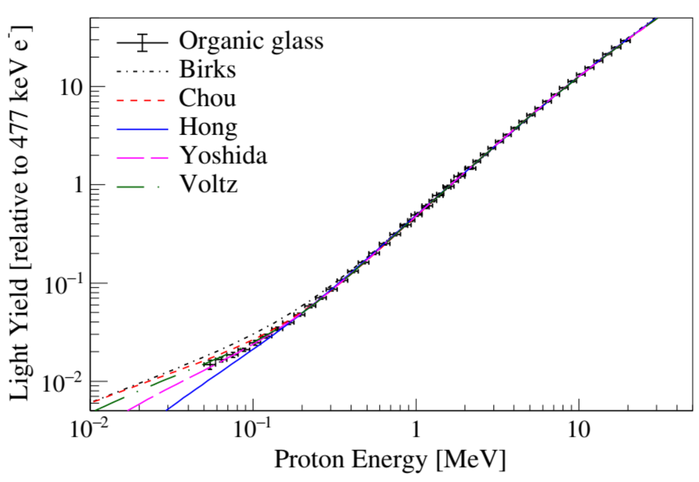


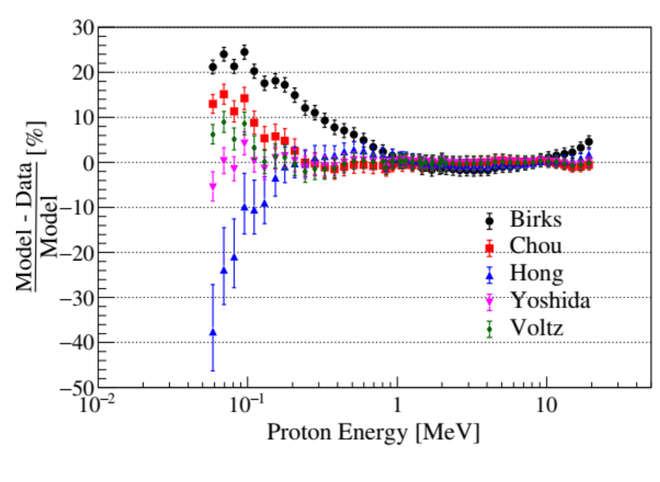
Measurements

- Pulsed ^{9}Be(d,n) beam at LBNL 88-Inch Cyclotron
- Coincidence between in-beam scintillator of interest and one of 11 out-of-beam PSD-capable scintillators
- Proton/carbon recoil energy obtained using kinematics on event-by-event basis
- Digital acquisition (CAEN V1730, 500 MS/s) recording full waveforms



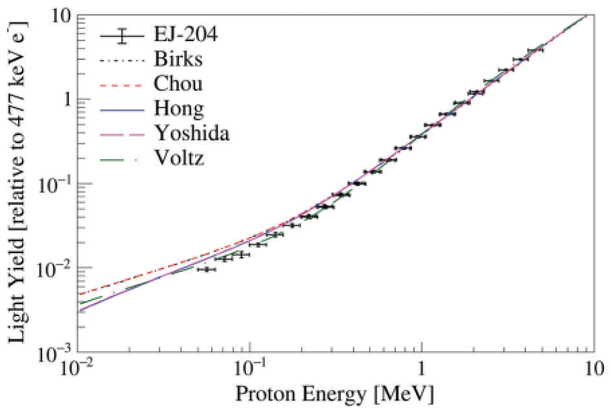
Results – Proton recoils

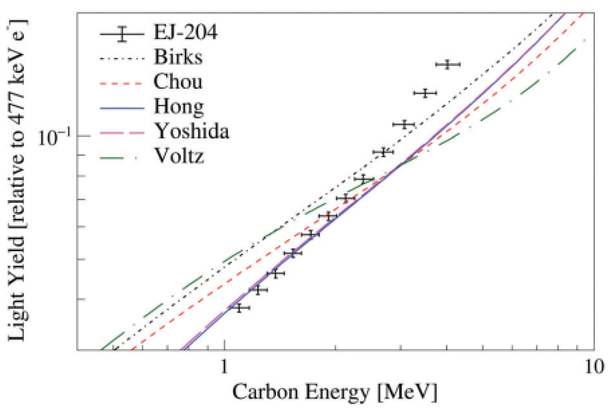




- Only the Yoshida and Voltz models reproduce proton light yield data over the full energy range for the Organic glass
- Similar observation for EJ-309, EJ-204 and EJ-276

Results – Simultaneous fit to proton and carbon





- None of the models provide a reasonable fit

Summary

- Model parameters with covariances matrices provided for four materials; Can be used to simulate detector response
- **Birks does not describe low energy light yield**
- Only Yoshida and Voltz models reproduce proton light yield data
- None of the models can reproduce proton and carbon light yield simultaneously
- Potential improvements for Voltz model and discussion on stopping power in published manuscript

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