Measurement of the relative proton light response of LAB based scintillators and its implication for supernova neutrino detection

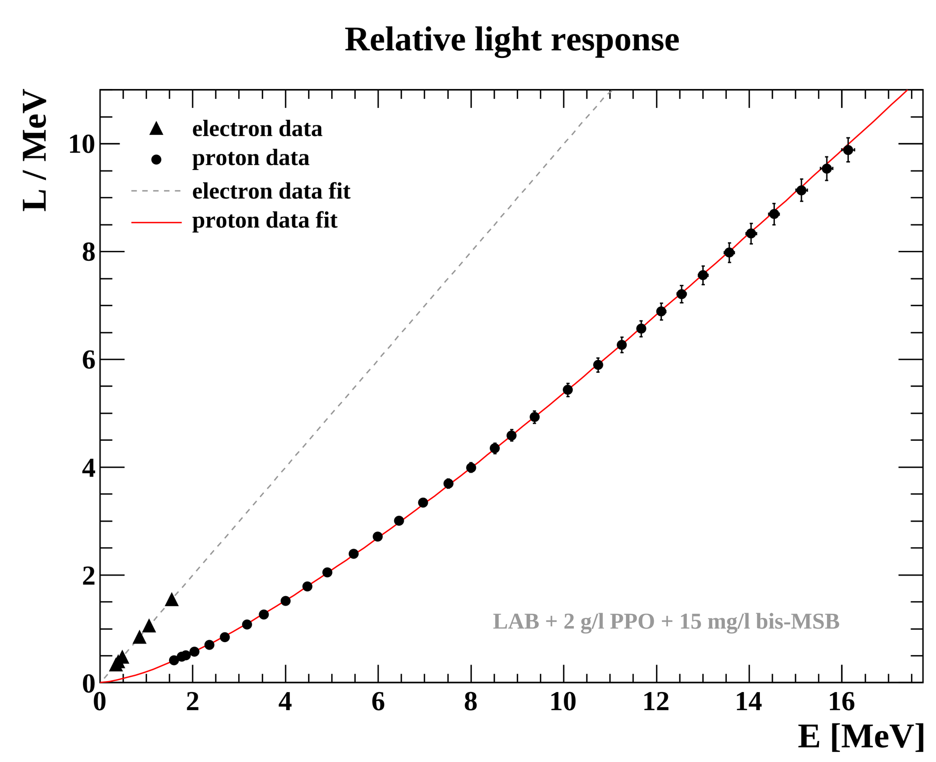
Motivation

The intense neutrino pulse, released in the final stages of a supernova (SN), may be observed by low energy neutrino detectors. It is of great interest to measure the flux of all flavors, since the shape of the overall spectrum can reveal new information about the supernova mechanism [1]. As the mean ν energy is below ~30 MeV, charged current interactions are only possible for electron type neutrinos, leaving only neutral current reactions as possible detection channel for all neutrinos. The only neutral current channel providing spectral information is ν–p elastic scattering [1], a viable channel for liquid scintillator detectors like SNO+. However only a fraction of the deposited kinetic energy of the highly ionizing protons is visible due to quenching effects. To reconstruct the true kinetic proton energy E_p from the visible energy E_p^{vis} in SNO+, the light response of the linear alkylbenzene (LAB) scintillator to protons has to be known.

Method

The light response function $L(E)$ for protons is measured relative to the electron response function $L_e(E)$, carried out at the neutron facility of the PTB in Braunschweig for a set of different LAB based scintillators. Free protons are intrinsic to the scintillator and accelerated due to n–p scattering induced by beam neutrons. Via time–of–flight selection the neutron energy is determined, which is identical to the maximum proton recoil energy. The resulting proton response data covers 1 MeV to 17 MeV and is fitted with Birks' law (2). The energy scale and electron response is defined with standard radioactive calibration sources with in total six gamma lines between 0.5 MeV and 1.8 MeV. For electrons of these energies, the electron data can be fitted to the linear approximation (3) of Birks' law due to their small stopping power dE/dX.

Data analysis



- The presented proton data points are measured by locating the maximum proton energy $E_p^{max} = E_n$ in the recoil spectrum after scattering with beam neutrons of selected energy E_n.
- The presented electron data is gained from locating the edge

$$E_e = \frac{2E_\gamma^2}{0.511 + 2E_\gamma} \quad (1)$$

in the Compton spectrum of the six γ's of ^{137}Cs, ^{22}Na and ^{207}Bi.

- Proton data is fitted with the response function after J. B. Birks:

$$L(E) = S \cdot \int_0^E d\epsilon \left[1 + kB\left(\frac{dE}{dX}\right) + C\left(\frac{dE}{dX}\right)^2\right]^{-1}. \quad (2)$$

- For the electron data fit, (2) is approximated, as $dE/dX \approx 0$:

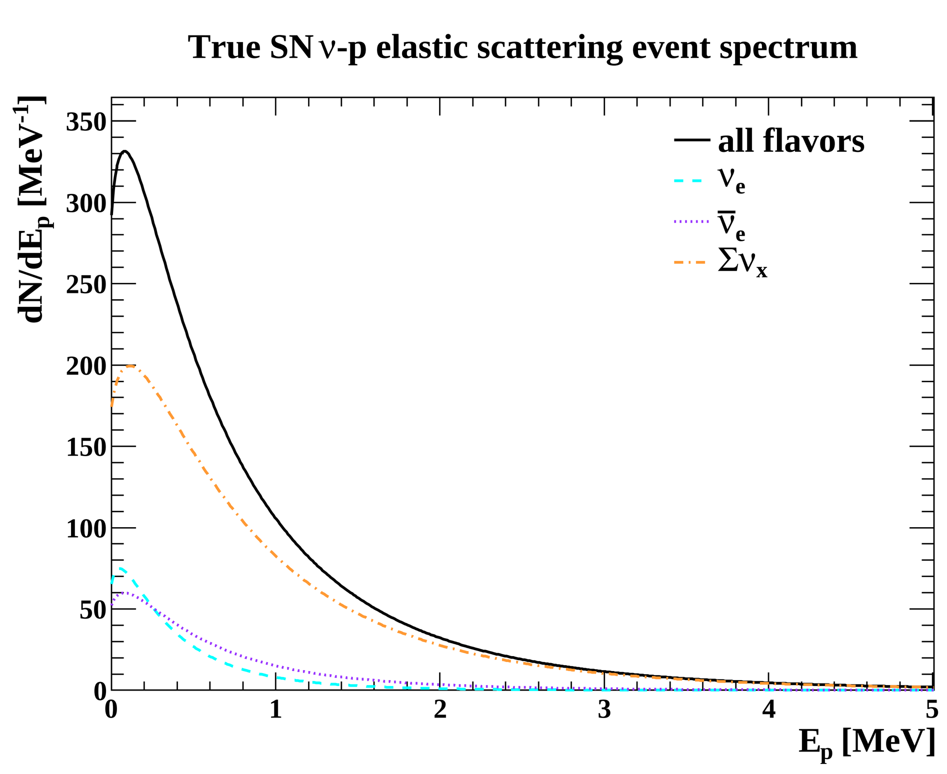
$$L_e(E) \approx S \cdot (E - E_0). \quad (3)$$

Ionization quenching is well-described by Birks' law (2) and can be quantified in terms of the parameter product kB, known as Birks' constant, and a quadratic correction parameter C [2]. Setting the scaling parameter $S = 1$ gives the light response in electron equivalent energy.

The measurement is performed for different LAB scintillators as listed in the table below together with the fitted quenching parameters. The uncertainties are at 1σ, the upper limits at 95% CL.

LAB admixture	kB [cm/MeV]	C [cm^2/MeV^2]
2g/l PPO, 15mg/l bis-MSB	0.0097 ± 0.0002	$\leq 5.0 \times 10^{-7}$
2g/l PPO	0.0098 ± 0.0003	$\leq 4.0 \times 10^{-7}$
3g/l PPO, 15mg/l bis-MSB	0.0098 ± 0.0003	$\leq 1.0 \times 10^{-7}$
3g/l PPO	0.0094 ± 0.0002	$\leq 6.5 \times 10^{-7}$

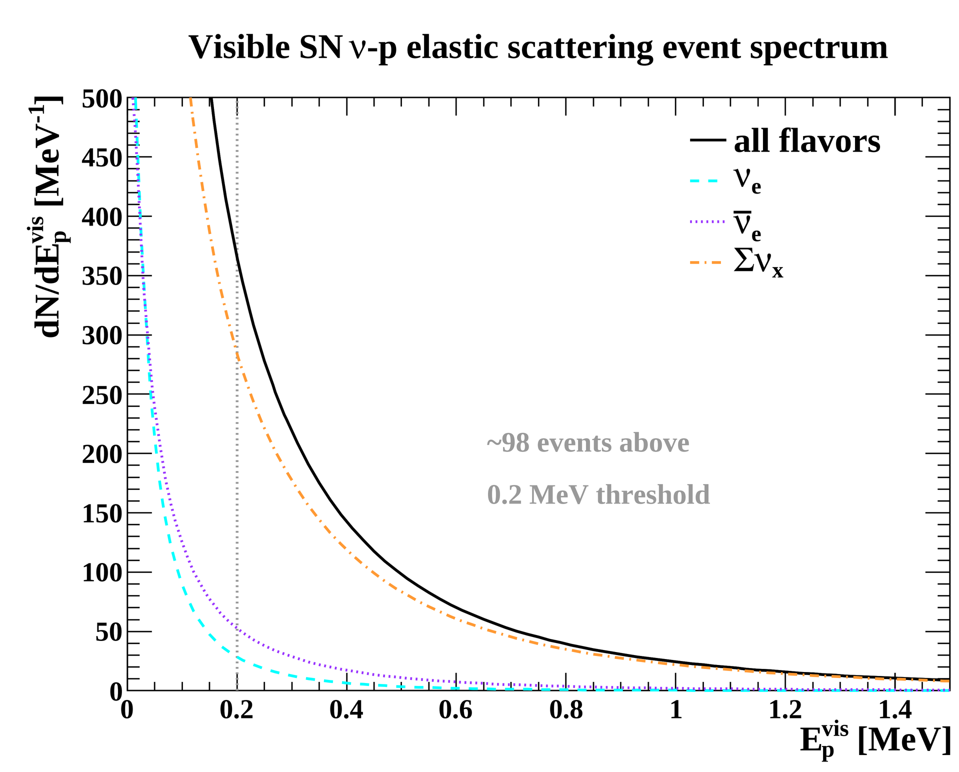
Discussion



SNO+ detector properties:

Target	N_p [10^{31}]	$\Delta E/E$ (E in MeV)	kB [cm/MeV]	C [cm^2/MeV^2]
LAB+2g/l PPO	5.9	$5.0\%/\sqrt{E}$	0.0098 ± 0.0003	0.0

The SN is assumed to occur at 10 kpc, releasing a total energy of 3×10^{53} erg equipartitioned among all flavors. The mean energy of the different flavors is set to 12 MeV for ν_e, 15 MeV for $\bar{\nu}_e$ and 18 MeV for the rest [1]. With N_p free protons in SNO+, the expected p energy spectrum (from ν–p elastic scattering) is shown on the left. The observed spectrum shown on the right, though, looks due to proton quenching markedly different. Regarding quenching and a threshold of 0.2 MeV, set by the intrinsic ^{14}C background, SNO+ is expected to observe ~98 SN ν–p elastic scattering events.



Selected Talks

- "The Sudbury Neutrino Observatory Scintillator Project", invited talk at the Neutrino Seminar of the University of Hamburg (29.10.2010)
- "The Sudbury Neutrino Observatory Scintillator Project", at the DPG conference, Karlsruhe (28.03.2011)
- "Neutrino oscillation studies in the upcoming SNO+ experiment", at the GK Block Course, Krippen (13.03.2012)
- "The Sudbury Neutrino Observatory Scintillator Project", at the DPG conference, Mainz (21.03.2012)
- "Status and Plans of SNO+", invited talk at the HQL–2012 conference, Prague (15.06.2012)

Collaboration

- SNO+ (Sudbury Neutrino Observatory)

Profit from the GK

- Biannual block course, giving an insight into scientific fields beyond the own
- Inhancement of contact to phd students outside the own working group
- Financial support for the attendance of schools and workshops
- Second supervisor, opening the possibility to get an independent opinion and additional support

Contact Details and further Information

PhD student: Belina von Krosigk, belina.von_krosigk@tu-dresden.de
PhD advisors: Prof. Dr. Kai Zuber, Dr. Elisa Bernardini

[1] J. F. Beacom et al., *Phys. Rev. D* **83**, 113006 (2011)
[2] J. B. Birks, The Theory and Practice of Scintillation Counting, Pergamon Press (1964)

January 14, 2013

Supported by DFG Deutsche Forschungsgemeinschaft