SAND2011-5218C

Light Output for EJ309 Liquid Scintillator in the Neutron Scatter Camera

Jeffrey Fein, Erik Brubaker, Pete Marleau — Radiation/Nuclear Detection Systems, Sandia National Labs, Livermore, CA

INTRODUCTION

The neutron scatter camera is a passive standoff fast neutron (1-10MeV) and gamma radiation detector/imager for use in nuclear nonproliferation applications. Neutrons and/or gamma photons (n,γ) incident from a special nuclear material source scatter in one (tagged single) or both (tagged double) of two planes of liquid scintillator elements. The source position, as well as neutron/gamma energy can be calculated from the measured time of flight (TOF) and the energy deposited in the scintillators. This energy measurement could help distinguish various neutron sources.

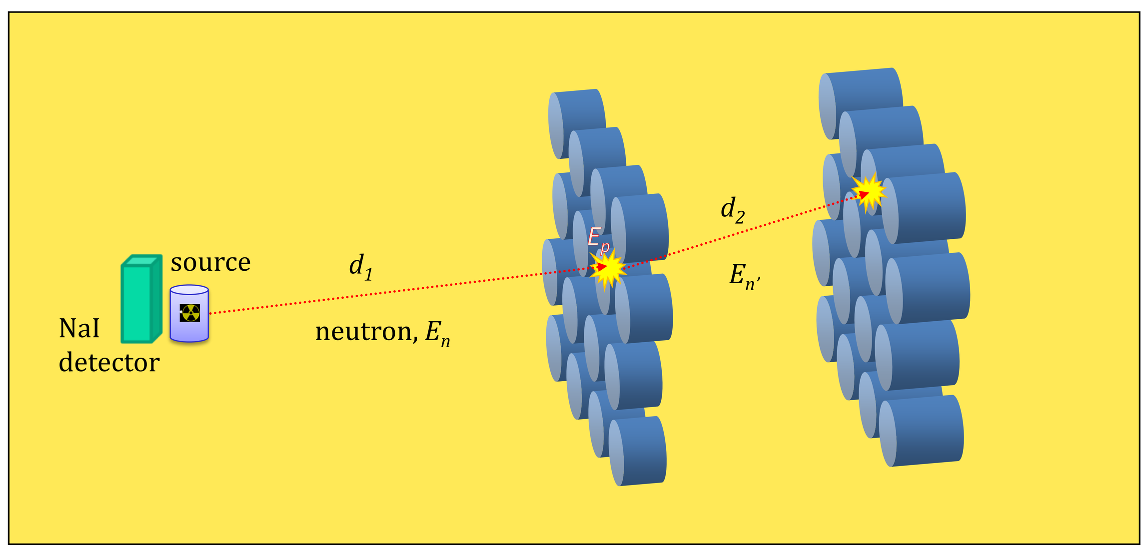


Fig. 1. Schematic of neutron scatter camera with a neutron double scatter event. d_1 and d_2 are the distances from source to the front detector and front detector to rear detector respectively. The nearby NaI detector records time $t=0$ from the gamma emitted simultaneously with a neutron.

Fig. 2. View of the photomultiplier tubes mounted to the back of the liquid scintillator elements

The neutron energy is calculated using conservation of energy, with τ as the TOF:

- Tagged single scatters (d is distance from source to a detector):

$$E_n = \tfrac{1}{2} m_n (d/\tau)^2$$

- Tagged double scatters:

$$E_n = E_p + E_{n'} = E_p + \tfrac{1}{2} m_n (d_2/\tau)^2$$

Edge Detection

An algorithm is developed to detect the edge of the MeVee-to-neutron source or proton recoil energy distribution. It works as follows:

- Iterate through x-bins,
  - iterate through y-bins,
    - compare means of two adjacent sets of y-bins to each other.
    - mark an edge where the difference between means is greater than twice the value of the lower of the two means.

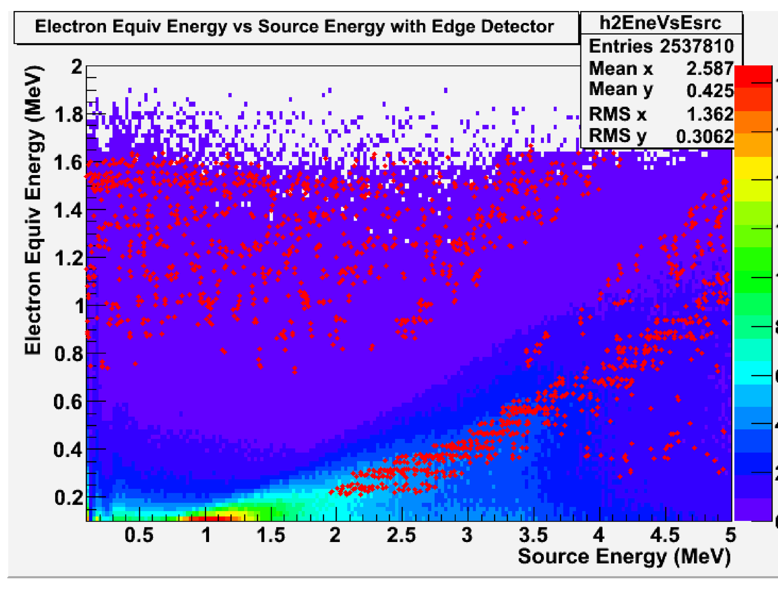


Fig. 7. Detected edge (red) for the tagged singles.

This algorithm is similar to taking a gradient of the distribution. Much improvement is needed since we only want one edge point per neutron energy bin.

Scintillator Physics

Neutrons and photons deposit their energy differently in the EJ309 liquid scintillator. This allows for pulse shape discrimination (PSD) between the two particles at the PMTs.

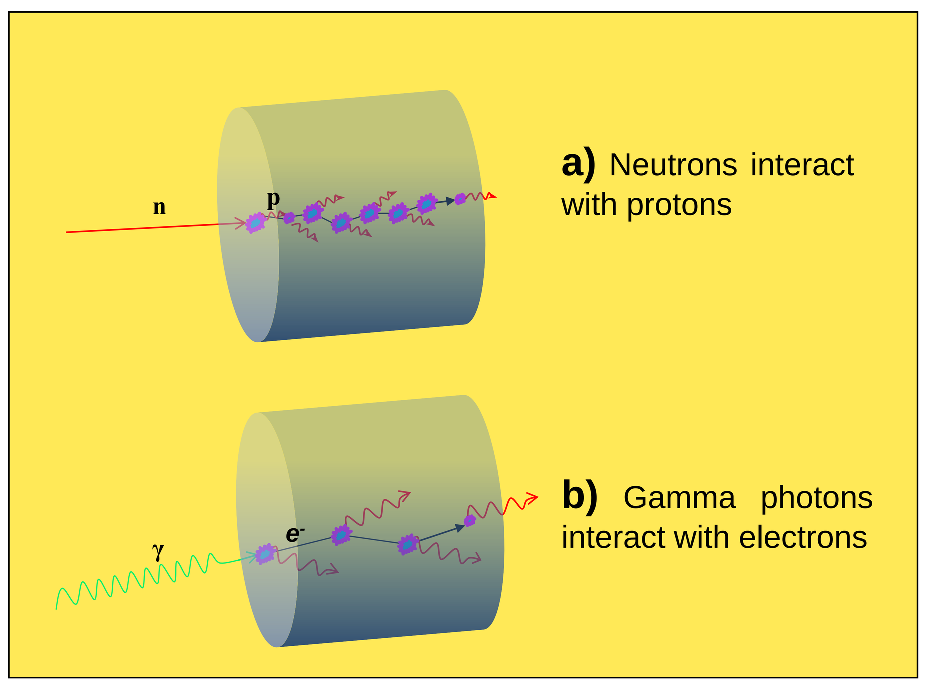


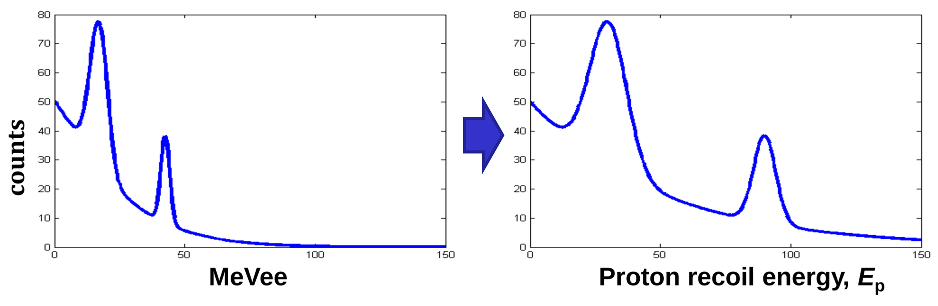
Fig. 3. Neutrons eject atomic nuclei (majority are protons from H) and gammas eject electrons in an EJ309 cell. Protons deposit energy (eject light) more densely than do electrons as they propagate through the cell.

The conversion of a gamma pulse shape in the PMT to the amount of energy an ejected electron deposits in the cell is well known. From this we define the parameter "electron equivalent energy" (MeVee) for gamma energy. The correlation between measured "proton recoil energy" (E_p) and corresponding signal in the PMT is not as well understood.

Objectives

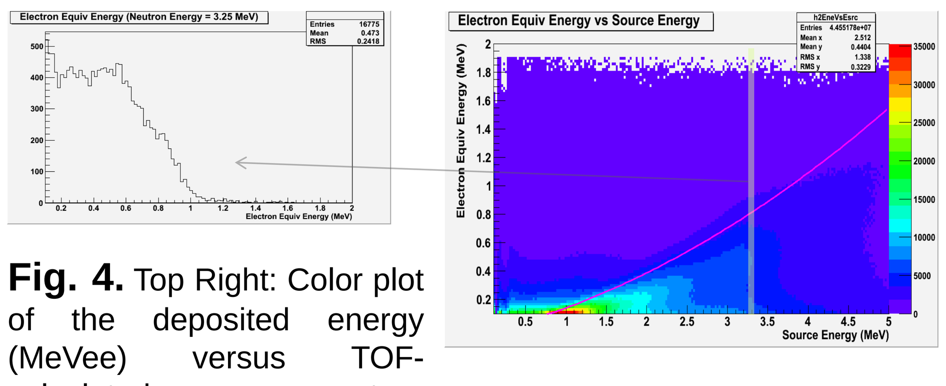
- Characterize the neutron light output in EJ309
- Find correlation between MeVee and E_p using:
  - MeVee for a neutron scatter,
  - TOF-calculated E_n from tagged singles, and
  - E_p from (E_n - $E_{n'}$) measured from d_1 and d_2 TOFs in tagged doubles.

Then we can convert a known MeVee scale to a proton recoil energy scale:



Light Output Analysis

The fraction of energy that a neutron deposits in a scintillator cell is not constant for a specific incoming neutron energy. Rather, there is a distribution of energies deposited for any incoming energy, with a maximum energy cutoff edge at 100% energy deposited in the cell.



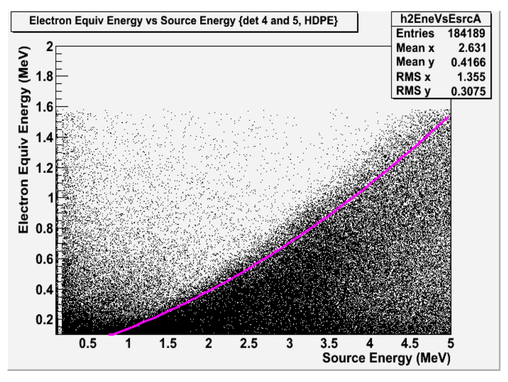


Fig. 4. Top Right: Color plot of the deposited energy (MeVee) versus TOF-calculated source neutron energy for all detectors for singles; Top left: MeVee for a single neutron energy Bottom: same plot but only for detectors 4 and 5, better demonstrating the maximum energy edge, ignoring the majority of the lower-energy events. The magenta line represents the quadratic Pozzi function.

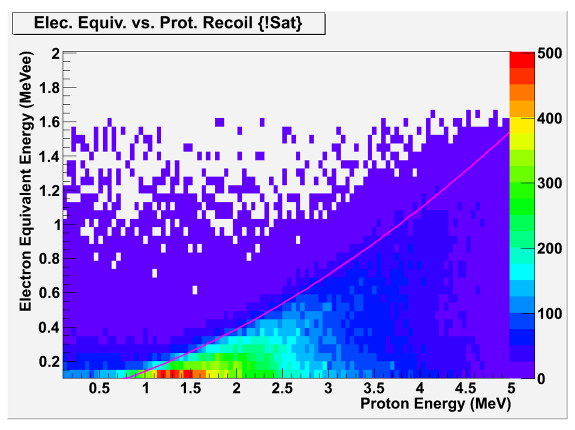


Fig. 5. Deposited energy versus proton recoil energy (MeVpe)

The maximum energy edge is the most interesting characteristic of the data. We want to know how this edge behaves. However, the spread of electron energies for a given neutron source energy or proton recoil energy tells us that the edge does not contain all the useful information.

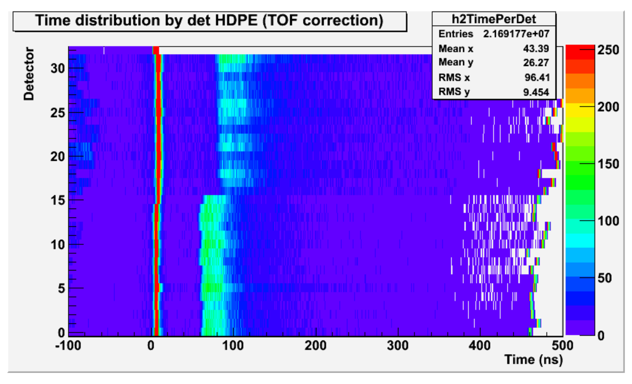


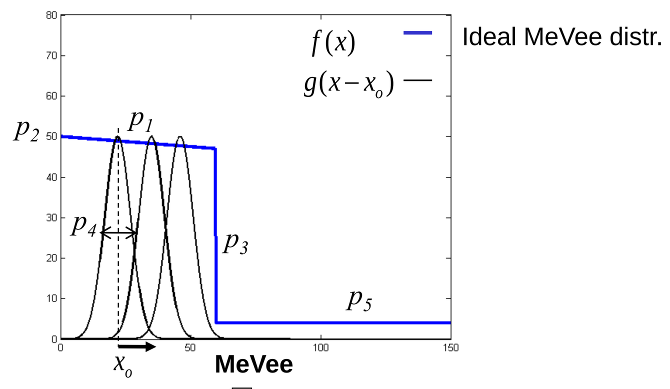
Fig. 6. The TOF distribution of events by detector (0-15 are front plane and 16-31 are rear). The red line indicates the gammas which travel at the speed of light. The greenish bands indicate neutrons.

Convolution

Another method to fit a curve to the edge in the MeVee-to-neutron source energy distribution is by performing a convolution of an energy deposition distribution with a Gaussian for each neutron energy value. This energy distribution has several important parameters,

- slope, p_1
- intercept on the y-axis, p_2
- estimated edge location, p_3

The Gaussian (width, p_4) accounts for the spread in MeVee values, due to unknowns such as scatter location within a cell, delay in TOF from electronics, etc.



$$(f*g) = \int_{-\infty}^{\infty} f(x_o)\, g(x_o - x)\, dx_o$$

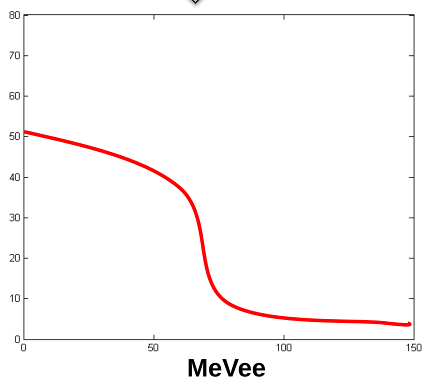


Fig. 8. Conceptualization of the convolution integral.

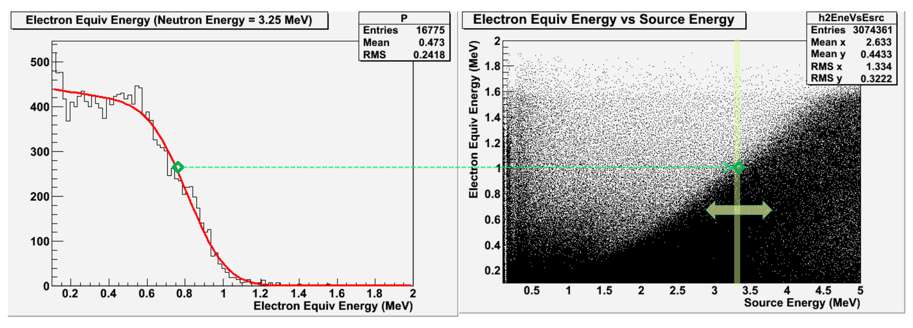


Fig. 9. Fit performed on an actual neutron energy slice.

Once the fit has been performed, we can pull out the estimated edge location. In future analysis, we will automate this for each slice and then create a fit over all edge locations. Final analysis will involve comparing the edge from convolution to the edge detector. If the two methods agree, we have increased confidence that both models describe the actual edge well.