0.1 Event Generator for Neutrinos on Deuterons

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COHERENT is a collaboration studying coherent elastic neutrino-nucleus scattering (CEvNS), a process with a well predicted but very small cross section. Several detectors are operated at the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory to study CEvNS. Currently there is ~10% uncertainty in neutrino flux at SNS. This uncertainty can be reduced with the addition of a heavy water detector which will measure neutrino flux. Simulations will be done to study the feasibility and efficacy of this detector. The purpose of this project is to create an event generator for these simulations. This involved constructing 2D histograms from tables of double differential cross section calculations for the $\nu_e + d \rightarrow e^- + p + p$ reaction. These cross sections have been weighted by the SNS flux, allowing for the random selection of events weighted by both the flux distribution and cross section information. This gives a sample of randomly generated electron events that are a realistic representation of reactions at SNS for input into a Monte Carlo simulation. Additionally, the code written to create these distributions will be made available for application to similar projects.

0.1.1 Introduction

Currently there is around 10% uncertainty in SNS neutrino flux. In order to reduce this uncertainty and therefore improve measurement of CEvNS, a heavy water detector is planned to measure the neutrino flux. Monte Carlo simulations will be done to determine the best design of this detector. To perform these simulations, it is necessary to create an event generator for neutrinos on deuterons to give event information.

0.1.2 Cross Section Tables

The reaction that will be used to measure flux is $\nu_e + d \rightarrow e^- + p + p$, where the electrons are the detected particles. This reaction has been studied, and theoretical calculations for these cross sections are available online [1]. Using Python's Beautiful Soup library, a web scraper was written to download these tables into readable text files.

0.1.3 Constructing Histograms

While the Gudkov tables give the double differential cross section with respect to electron momentum and solid angle, histograms for the event generator were constructed with even bins in electron energy and $\cos\theta$. This made the change of variables described in Eqn. 1 necessary.

$$
\begin{aligned}
\frac{d^2\sigma}{dE_e d\cos\theta} &= \left(\frac{dp_e}{dE_e}\right)\left(\frac{d\Omega_e}{d\cos\theta}\right)\frac{d^2\sigma}{dp_e d\Omega_e} \\
&= \left(\frac{E_e}{\sqrt{{E_e}^2 - {m_e}^2}}\right)\left(\frac{\sin\theta d\theta \int_0^{2\pi} d\phi}{d\cos\theta}\right)\frac{d^2\sigma}{dp_e d\Omega_e} \\
&= \left(\frac{E_e}{p_e}\right)(2\pi)\frac{d^2\sigma}{dp_e d\Omega_e}
\end{aligned} \tag{1}
$$

Because the tables covered a wide range of neutrino energies and had irregular intervals, a TH2Poly histogram was first constructed. The TH2Poly class in ROOT allows the user to define bins of any size and shape, so this method ensured all bins were correctly filled. A regularly binned TH2D histogram was then filled from each TH2Poly, and linear interpolation was used where multiple TH2D bins fell inside a single TH2Poly bin. Fig. 1 illustrates this.

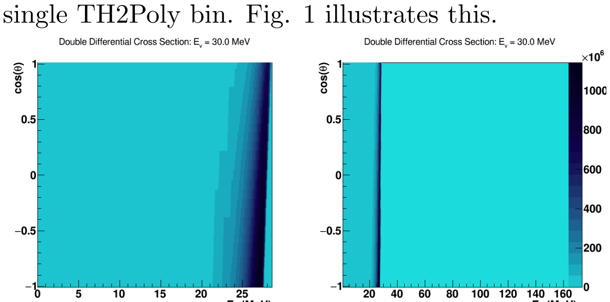

Figure 1: Left, TH2Poly; Right, TH2D

The tables gave cross section information for neutrino energies from 1.5 MeV to 170 MeV, which is an adequate range for the SNS flux, but for larger energies there are also larger gaps between calculated tables. To improve this resolution, interpolated histograms were created every 0.1 MeV using a linear interpolation algorithm that compared variably selected bins from the existing histograms. Fig. 2 shows an example of these interpolated histograms.

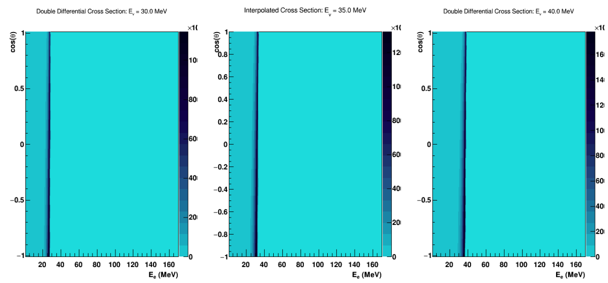

Figure 2: Left, 30 MeV; Center, Interpolated 35 MeV; Right, 40 MeV

0.1.4 Flux Weighting

A single TH2D histogram was created by weighting the cross section histograms over all neutrino energies to the SNS flux. Eqn. 2 gives the equation used to weight each bin. Fig. 3 shows the SNS flux distribution [2], and Fig. 4 shows this final flux-weighted histogram.

$$\sum_{E_\nu} \left(\frac{d^2\sigma}{dE_e d\cos\theta} \right)_{E_\nu} (\Phi)_{E_\nu} \left(\frac{binsize}{max} \right)_{E_\nu} \tag{2}$$

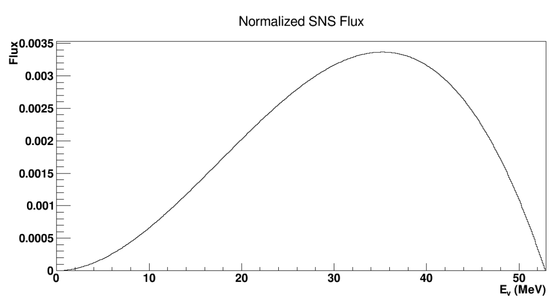

Figure 3: Normalized ν_e SNS flux distribution

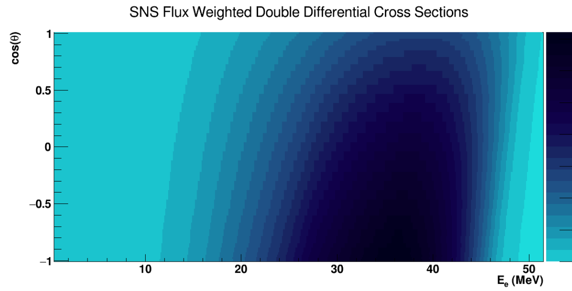

Figure 4: Flux-weighted distribution

0.1.5 Random Sampling

The output of the event generator is a list of electron event information. This process involves randomly sampling from the flux-weighted 2D histogram and outputting electron energy and cosθ for each of these sampled events.

0.1.6 Total Cross Section

The total flux weighted cross section is a useful number to know, and is also a good check of this process. Assuming everything has been done correctly, obtaining this number is as simple as integrating over the final 2D flux-weighted histogram. Doing this integral gives a flux weighted cross section of $1.056 * 10^{-43}$ cm^2. The Gudkov tables also provide calculated total cross sections by neutrino energy, so weighting these using the SNS flux should produce the same value. Performing this calculation give a cross section of $1.043 * 10^{-43}$ cm^2. Error propagation on this integral is unnecessary for event generation, but these two values agree reasonably well.

0.1.7 Code

All code written for this project is available at: https://github.com/jkoros/event-generator

0.1.8 Acknowledgments

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[1] Nakamura et al. (2001). *Tables of Neutrino (Anti-Neutrino) Deuteron Reactions Cross Sections.* [online] Available at: http://boson.physics.sc.edu/ gudkov/NU-D-NSGK/Netal/index.html [Accessed 26 Jul. 2018].

[2] code used to plot flux provided by Kate Scholberg