Extracting Neutron Yield From High Mass Background

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Jefferson National Laboratory

Started in 1984, Jefferson National Laboratory uses the Continuous Electron Beam Accelerator Facility (CEBAF), to study the quark-gluon structure of nucleons and nuclei. Two linear accelerators are connected by recirculation arcs to form the racetrack shape shown in *Figure 1*. After circling the track five times, the electron beam achieves an energy up to 12 GeV and is delivered to the different halls, also shown in *Figure 1*. The CLAS12 detector, shown in *Figure 2,* is housed in Hall B. The detector is split into two main regions; the Central and Forward Detectors, with the latter being the focus of this work.

Figure 1 Aerial view of Jefferson Lab, with each hall clearly indicated

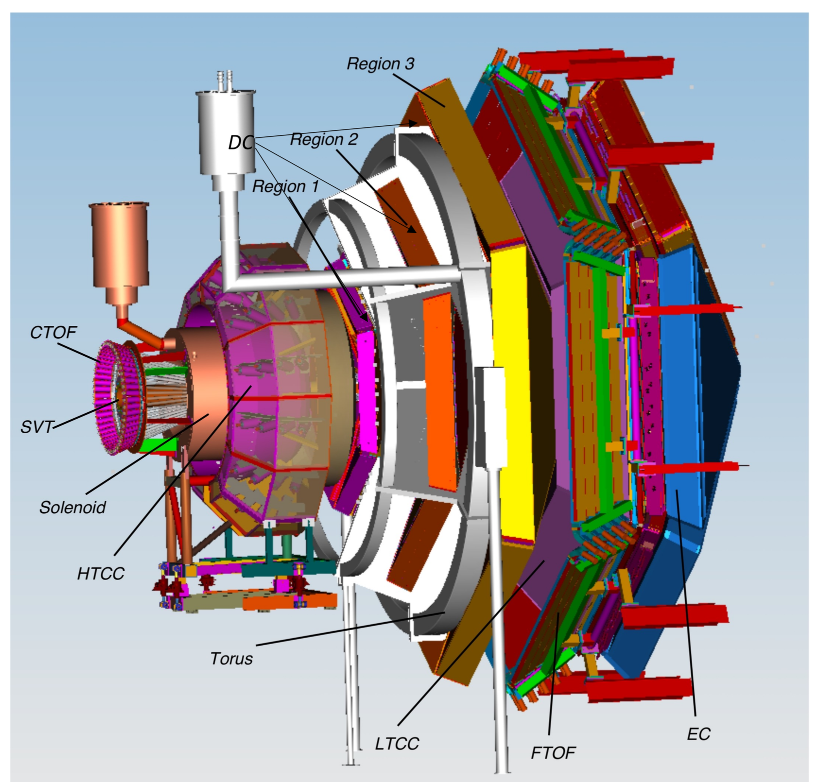


Figure 2 The CLAS12 detector, with its main subsystems labeled

CLAS12 Detector

CLAS12 is a large particle detector with more than 100,000 readouts. The Forward Detector is made up of several subsystems, see *Figures 2* and *3*.

- The Cherenkov Counters (in *Figure 3* and LTCC/HTCC in *Figure 2*) detect Cherenkov light emitted by near light-speed particles for particle identification.
- The Drift Chambers (in *Figure 3* and DC in *Figure 2*), cover three regions, measure particle trajectories as they bend in the toroidal magnetic field to determine the momenta.
- The Forward Time-of-Flight detectors (in *Figure 3* and FTOF in *Figure 2*) measure the time of flight to identify the particle.
- The Calorimeters (in *Figure 3* and PCAL and EC in *Figure 2*) measure charged particle energy and neutral particle TOF.

After data collection, the CLAS12 reconstruction software processes the data and extracts the 4-momenta and vertex (starting position) of the detected particles in a collision (yellow curve in *Figure 3*).

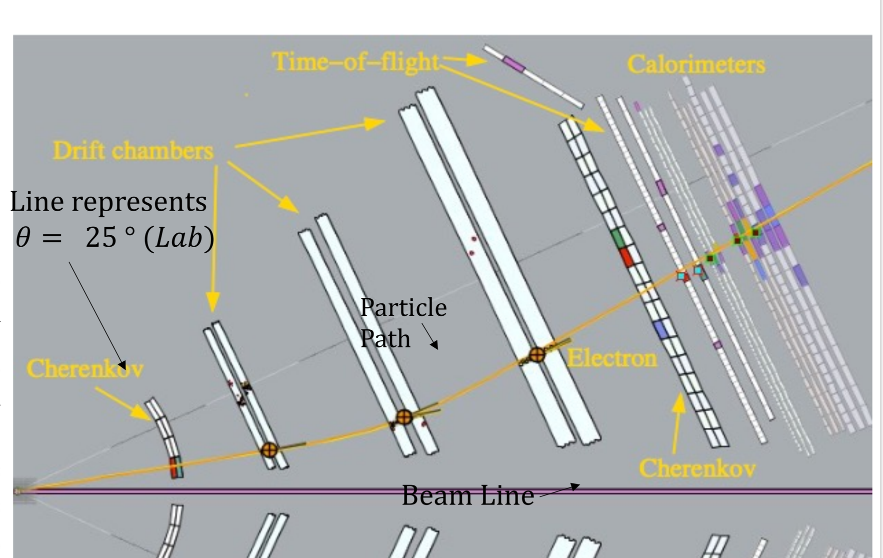


Figure 3 A CLAS12 event, generated by an event display simulator, showing each of the Forward Detector's main subsystems. The beam line (purple), the particle path (gold), and the line at $\theta = 25°$ (light grey) is also shown

Method

Our goal is to extract the Neutron Detection Efficiency (NDE), which is an essential property of CLAS12. We utilize the $e^1\text{H}\rightarrow e'\pi^+n$ reaction as a source of tagged neutrons and use the ratio of detected neutrons and expected neutrons to calculate the NDE. Expected neutrons are found by swimming the neutron track to the calorimeter using only the $e'\pi^+$ information and four-momentum conservation. Detected neutrons are neutrons near the expected neutrons. In order to find these, we must first separate neutron data from background data.

- ❑ Begin by extracting neutron tracks from the missing three-momentum from the $e^1\text{H}\rightarrow e'\pi^+x_n$ reaction, where x_n is any neutral particle.
- ❑ Create one dimensional missing mass spectra for 36 p_{mm} bins for both the detected neutrons and the expected neutrons.
- ❑ Use an iterative fitting process on the spectra, using the results of the previous fit at lower p_{mm} as the initial parameters for the current fit. We restrict the fit to the region where the neutron signal dominates the background. We expect the fit parameters to vary smoothly from each missing momentum bin to the next.
- ❑ The initial parameters for the first p_{mm} bin fit are chosen to be consistent with anticipated values.

Crystal Ball Function

The Crystal Ball function is a probability density function that we use to fit the mass peak for the neutron in the missing mass spectra. It consists of a Gaussian core and a power-law for the low-mass tail. Both the function and its first derivative are continuous. We found significantly better fit quality using this function versus a gaussian. The function is defined as:

$$f(x;\alpha,n,\bar{x},\sigma) = N\cdot\begin{cases} e^{-\frac{(x-\bar{x})^2}{2\sigma^2}} & \text{if } \frac{x-\bar{x}}{\sigma} > -\alpha \\ A\left(B-\frac{x-\bar{x}}{\sigma}\right)^{-n} & \text{if } \frac{x-\bar{x}}{\sigma} \leq -\alpha \end{cases}$$

$$N = \text{Amplitude} \quad A = \left(\frac{n}{|\alpha|}\right)^n \cdot e^{-\frac{|\alpha|}{2}} \quad B = \frac{n}{|\alpha|} - |\alpha|$$

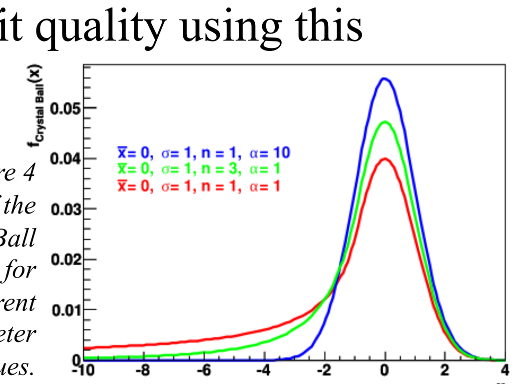
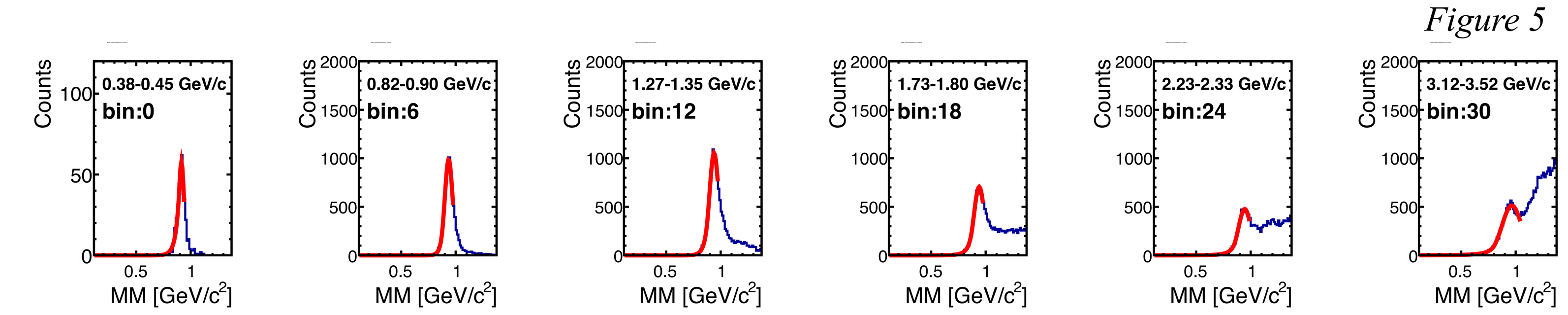


Figure 4 A plot of the Crystal Ball function for different parameter values.

Results

We present results of the fitting of the 36 missing mass spectra. We also present plots of the amplitude, μ, σ, α, and χ^2/ndf plotted over the full p_{mm} range to provide a set of plots that describe the accuracy of the fit. *Figure 5* shows a representative sample of the fits (the full set of 36 plots did not fit). In each case the data is in blue and the fit quality (red curve) is good. The missing momentum range and bin number are listed on each plot. *Figure 6* shows plots of the parameters. The average reduced χ^2 is near the ideal value. The average mean is consistent with neutron mass. The amplitude curve is normalized by dividing the amplitude by the bin size. Finally, we note that the near linear dependence of the widths on p_{mm} is consistent with simulation.

Figure 5



Results (cont.)

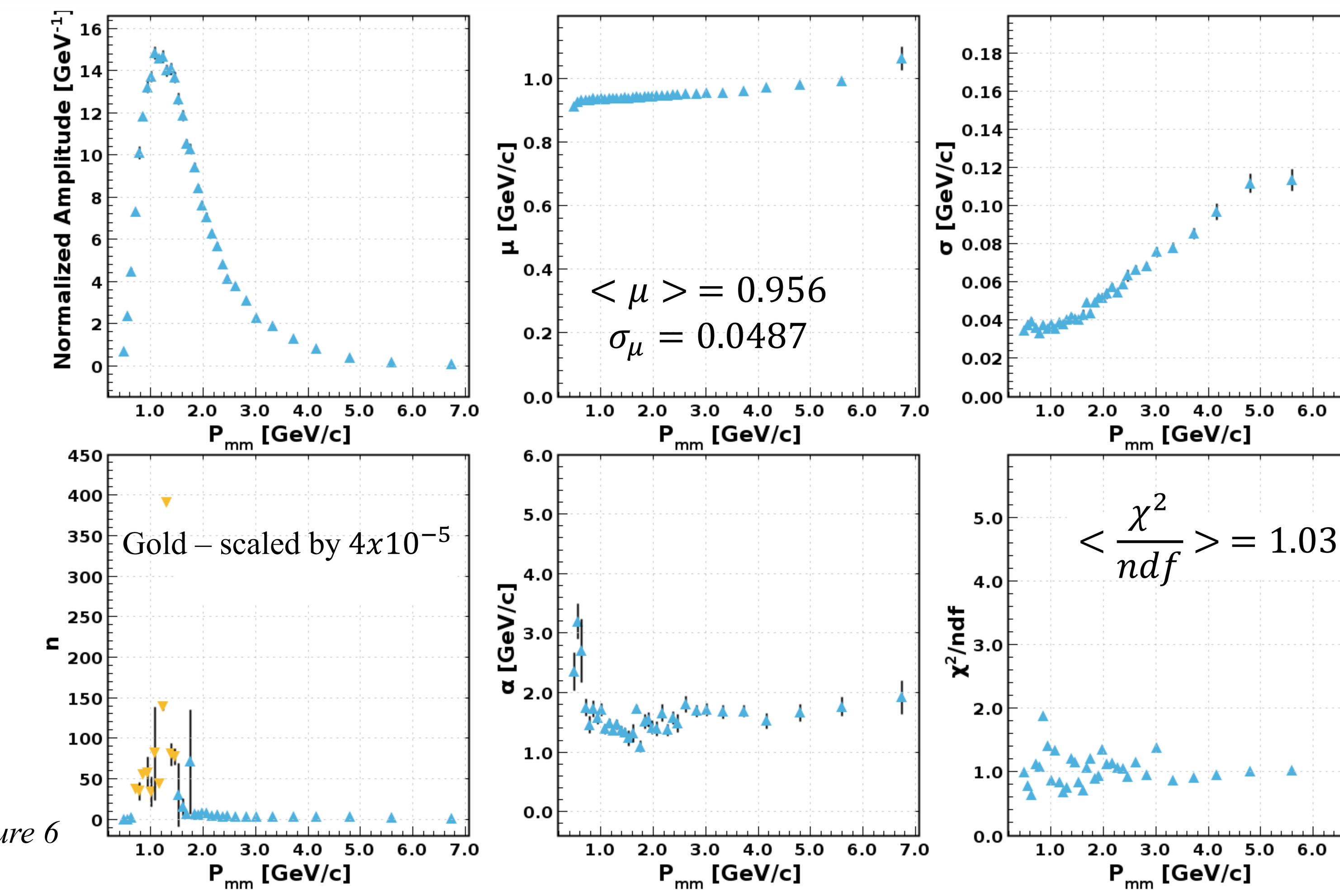
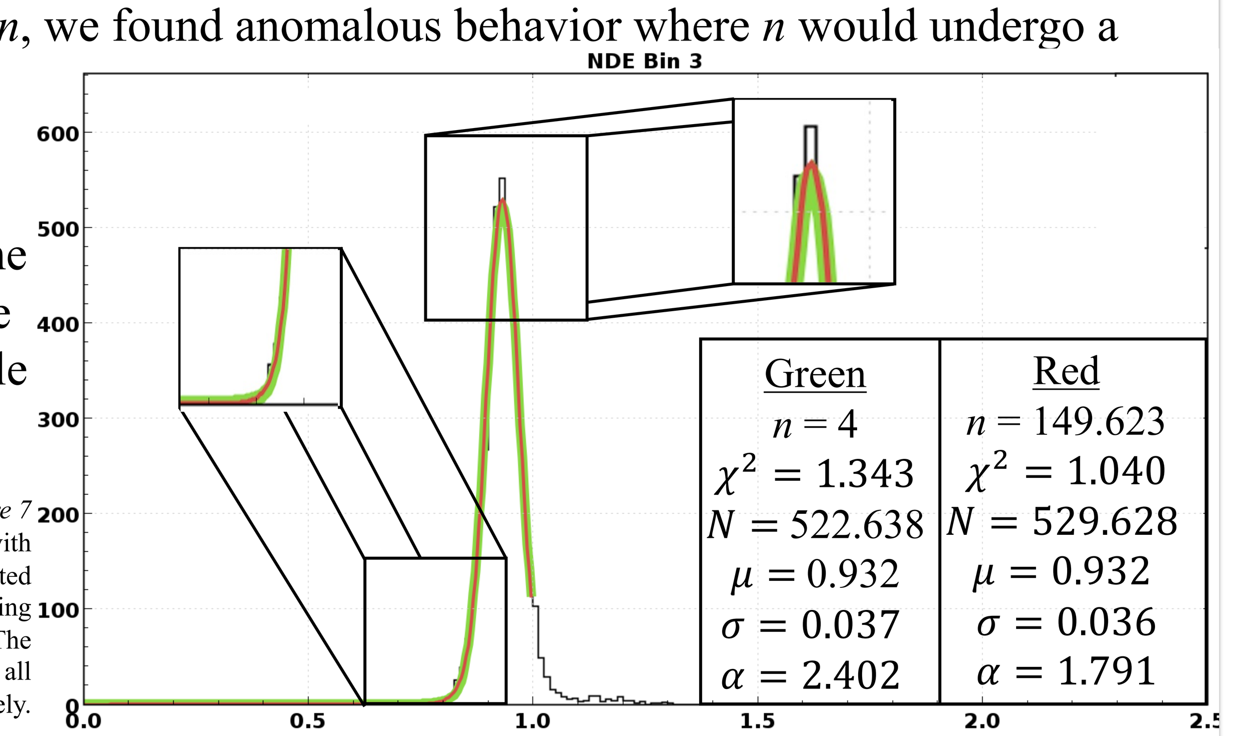


Figure 6

We found that the Crystal Ball Function has a weak dependence on its exponent parameter, 'n', for some p_{mm}. A change in n results in a minimal change in χ^2. Similarly, when studying the dependence on n, we found anomalous behavior where n would undergo a large change between fits accompanied by large error bars, shown in *Figure 6*. Demonstrated in *Figure 7*, the exponent parameter *'n'* in the Crystal Ball function has little impact on the overall fit.



Green	Red
$n = 4$	$n = 149.623$
$\chi^2 = 1.343$	$\chi^2 = 1.040$
$N = 522.638$	$N = 529.628$
$\mu = 0.932$	$\mu = 0.932$
$\sigma = 0.037$	$\sigma = 0.036$
$\alpha = 2.402$	$\alpha = 1.791$

Figure 7 A representative missing mass spectra with two fits. The first fit (Green) was created using the fixed value $n = 4.000$ and allowing all other parameters to vary freely. The second fit (Red) was created allowing all parameters vary freely.

Conclusions

From our results of the Crystal Ball fitting, we find that over the full momentum range, $p_{mm} = 0.4\,GeV - 7.0\,GeV$, the fit parameters vary smoothly. Similarly, the mean parameter agrees with the mass of the neutron, within the uncertainty. Over all 36 missing momentum bins, $< \frac{\chi^2}{ndf} > = 1.03$, demonstrating the accuracy of the Crystal Ball fit in general. This indicates our ability to confidently extract neutron yield utilizing the fit, and eventually to calculate the NDE.

References

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