Jefferson Lab

Neutron Detection Efficiency in the Forward Calorimeter

$$e\,p \longrightarrow e'\pi^{+}(n)$$

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FIU

clas
CEBAF Large Acceptance Spectrometer

Overview

Method to extract neutron detection efficiency (NDE).

Background Subtraction.

Calculate neutron efficiency for PCAL/ECAL.

NDE Results.

NDE Parameterization.

Data Set used:

Run Group A, inbending and outbending with beam energies 10.6 GeV and 10.2 GeV

Neutron Detection Efficiency (NDE)

Determine the neutron detection efficiency (NDE) by using:

$$e\,p \rightarrow e'\,\pi^{+}(n)$$

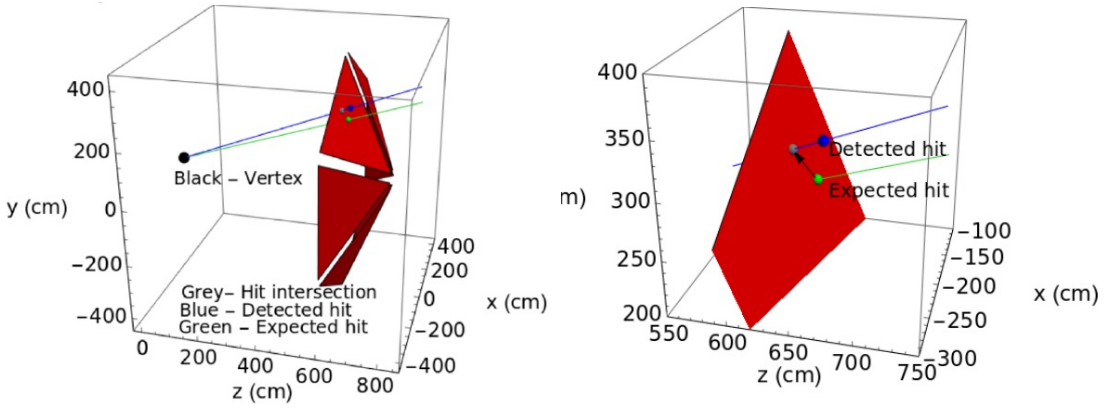
- Select $e'\,\pi^{+}$ final state with no other charged particles in CLAS12.
- Assume the missing particle is a single neutron and calculate the missing momentum of the neutron P_{mm} and it's trajectory through CLAS12 from the e' vertex.
- Check if the neutron's path intersects the front face of ECAL and is 10 cm away from the edge.

Yes → define as expected neutron

NO → skipped the event

- Loop over neutral ECAL hits (neutron candidates):
  - ✓ Get intersection of ray with the ECAL face by drawing a line from the e′ vertex to the actual neutral ECAL hit.
  - ✓ To identify neutrons :
    - ✓ Calculate the direction cosine from the electron vertex to the ECAL face for the expected neutron and the neutron candidates.
    - ✓ Cut on the difference between the expected neutron direction cosine and the neutron candidate (ΔCx ΔCy)
    - ✓ Select the smallest ΔCx ΔCy neutron candidate for multiple hits.

close-up view

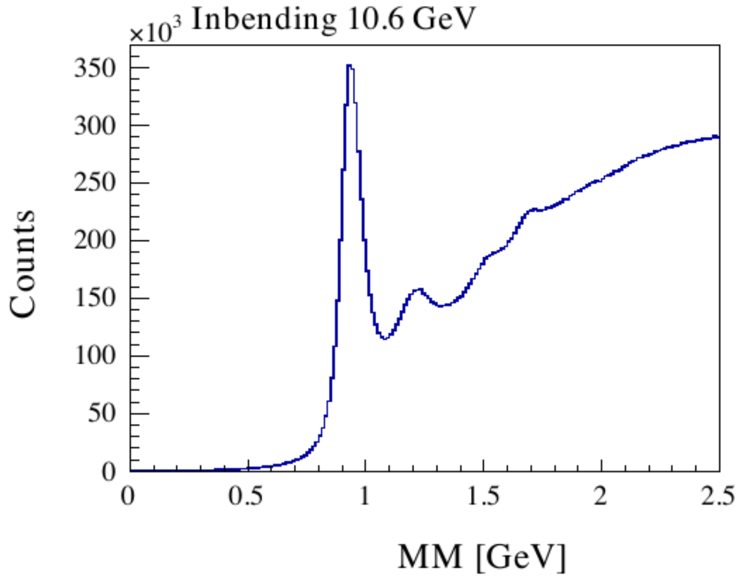


Red panels: ECAL front face

$$NDE = \frac{H(e,e'\pi^{+}n)}{H(e,e'\pi^{+})n}$$

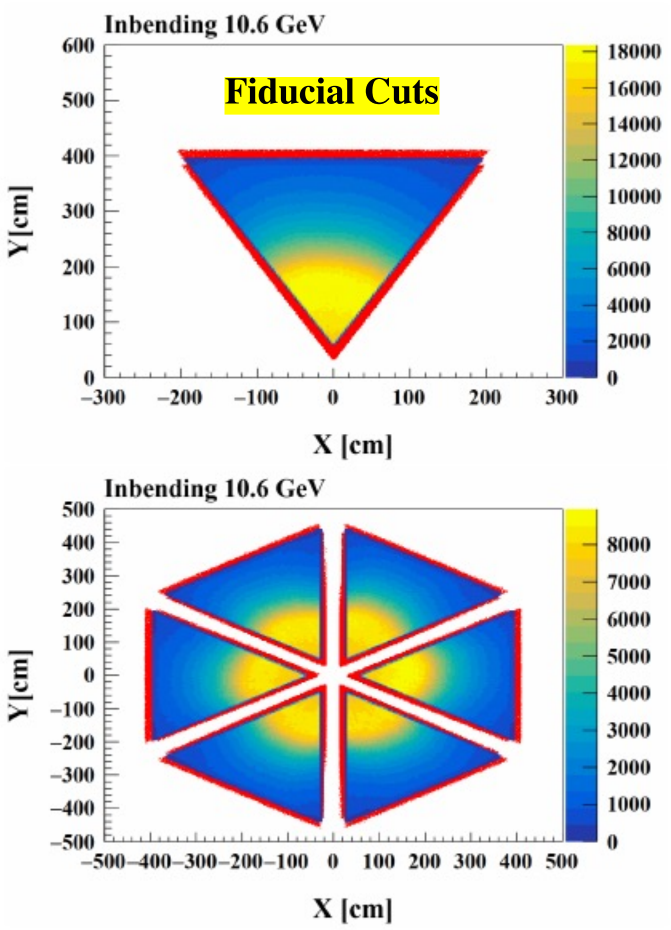
Missing Mass Distribution of $p(e,e'\pi^{+})n$

Missing Mass of neutron



Neutron can be in CD or FD

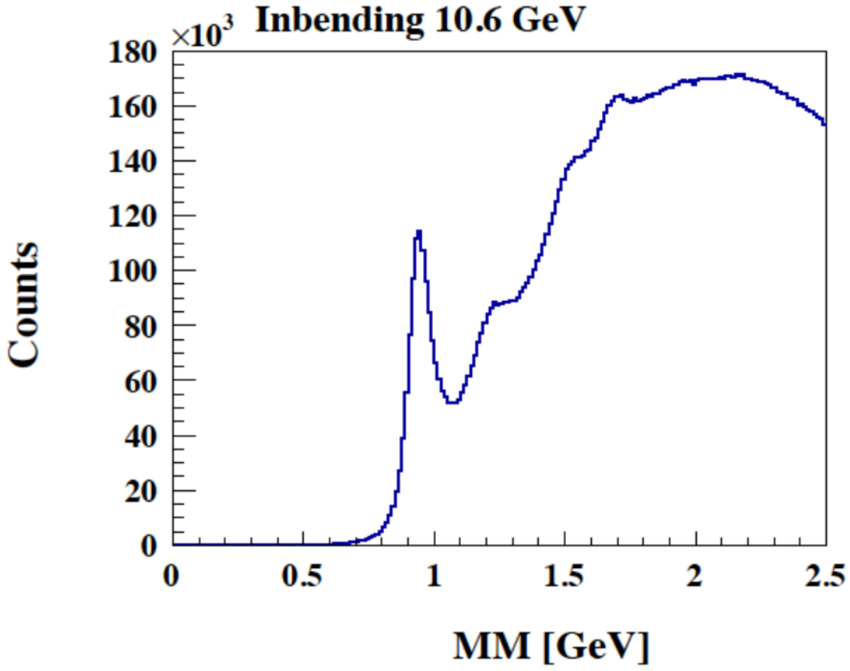
Swimming neutron to the PCAL/ECAL



Missing Mass of neutron after swimming and applying fiducial Cuts

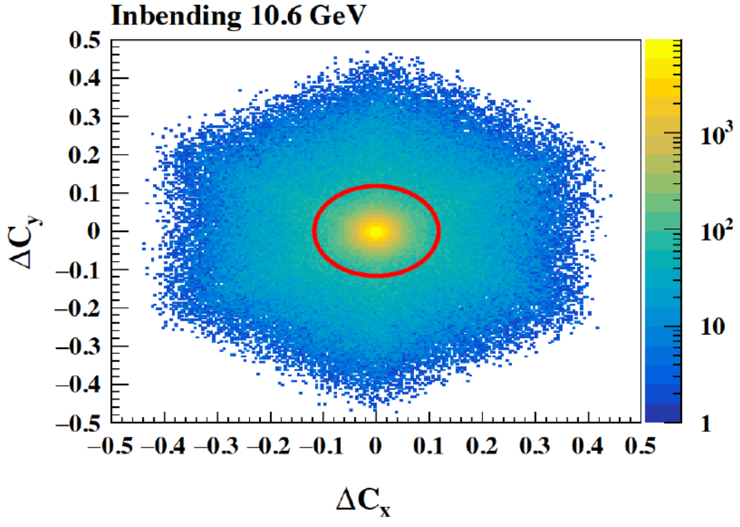
=

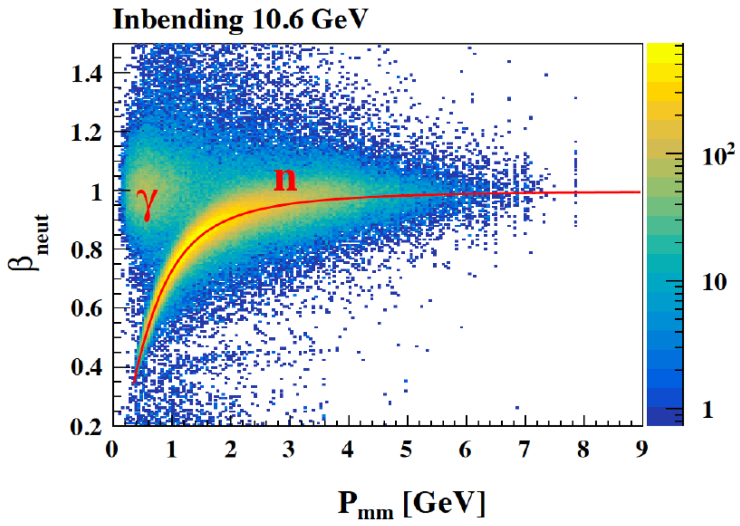
Expected Missing Mass of neutron



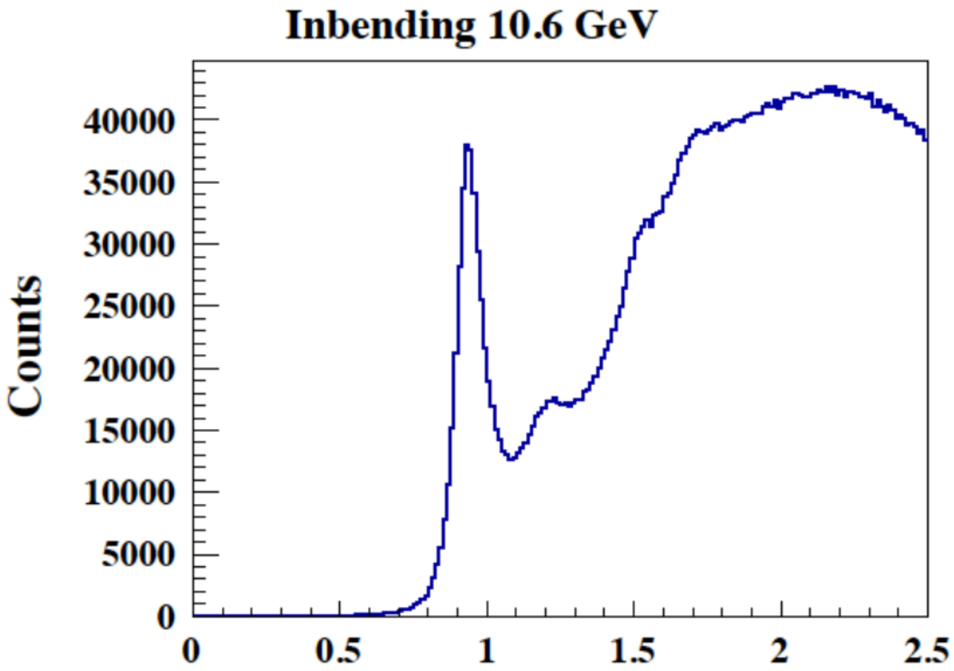
Neutron can be in FD

Neutral Particles Measured in PCAL/ECAL



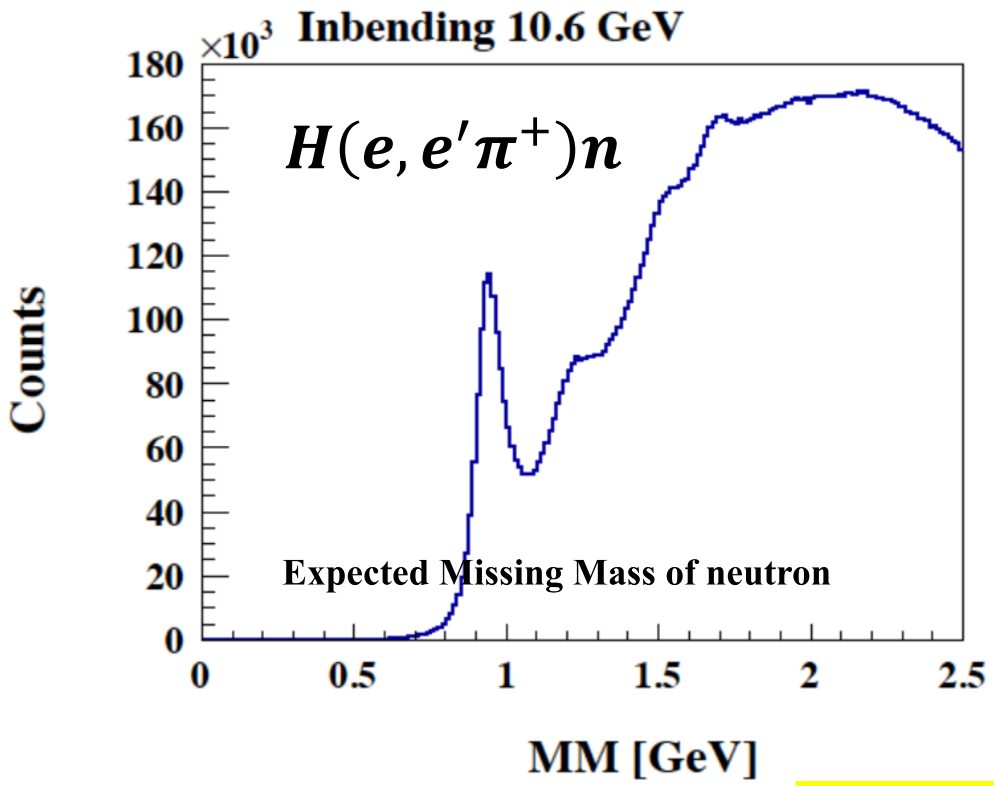


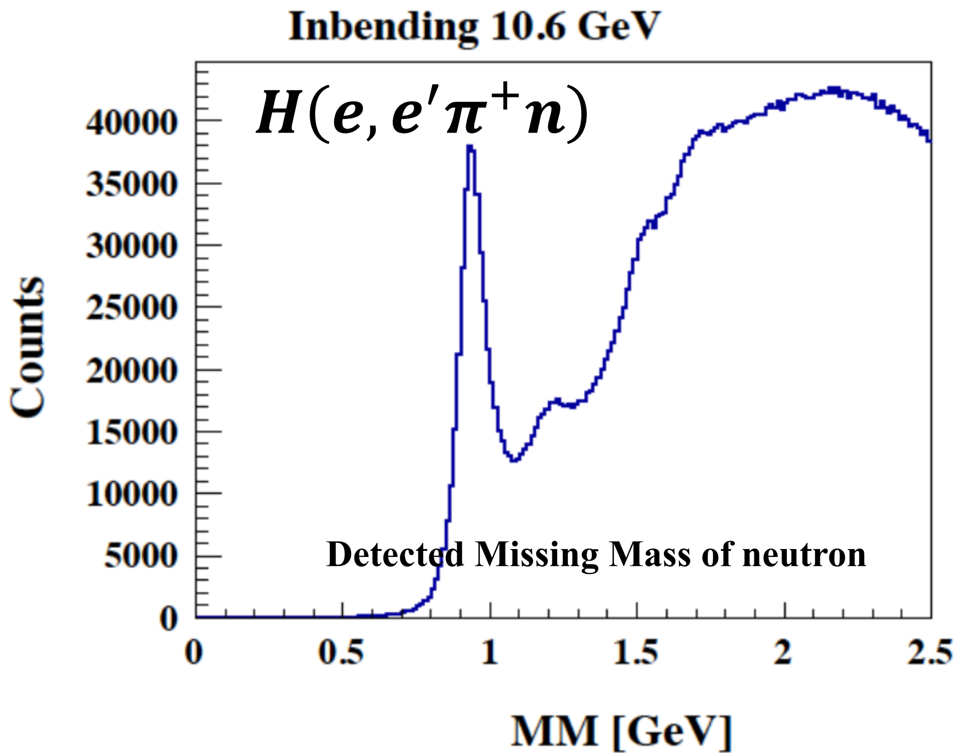
Detected Missing Mass of neutron pass ΔCx ΔCy cut



Most of the background under the detected missing mass of neutron due to photons contribution..

Missing Mass Distribution





Both the expected and detected missing mass of neutron have background events that must be subtracted.

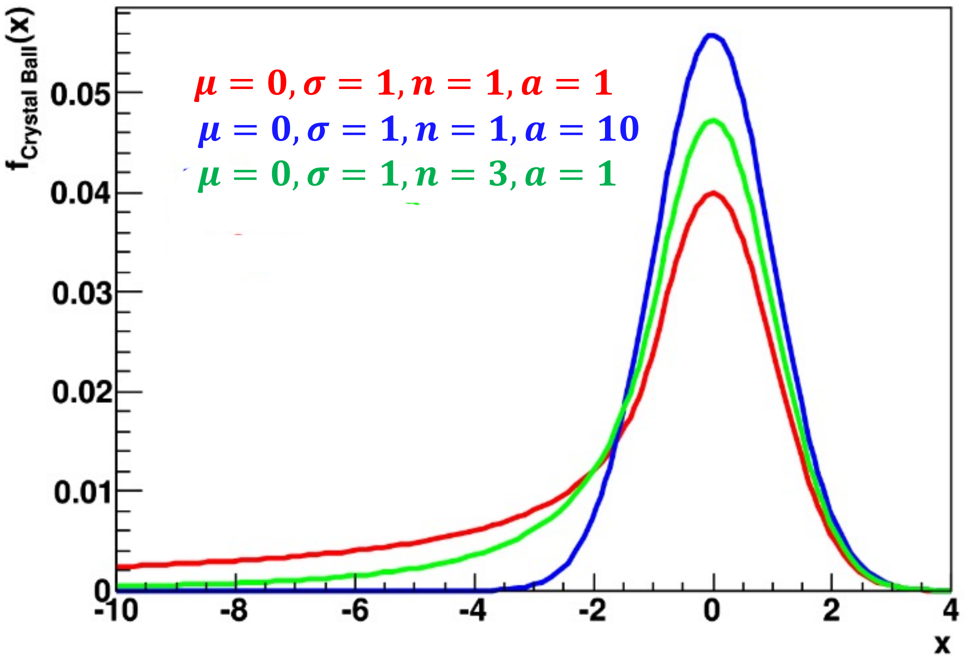
Background Subtraction

✓Fit both expected and detected neutrons at different P_{mm} Using two functions:

1- Gaussian Function

2- Crystal Ball Function

with Polynomial background



✓Crystal Ball Function defined as:

$$f_{CB}(x;\mu,\sigma,a,n) = e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} \quad \text{for} \quad \frac{x-\mu}{\sigma} > -a$$

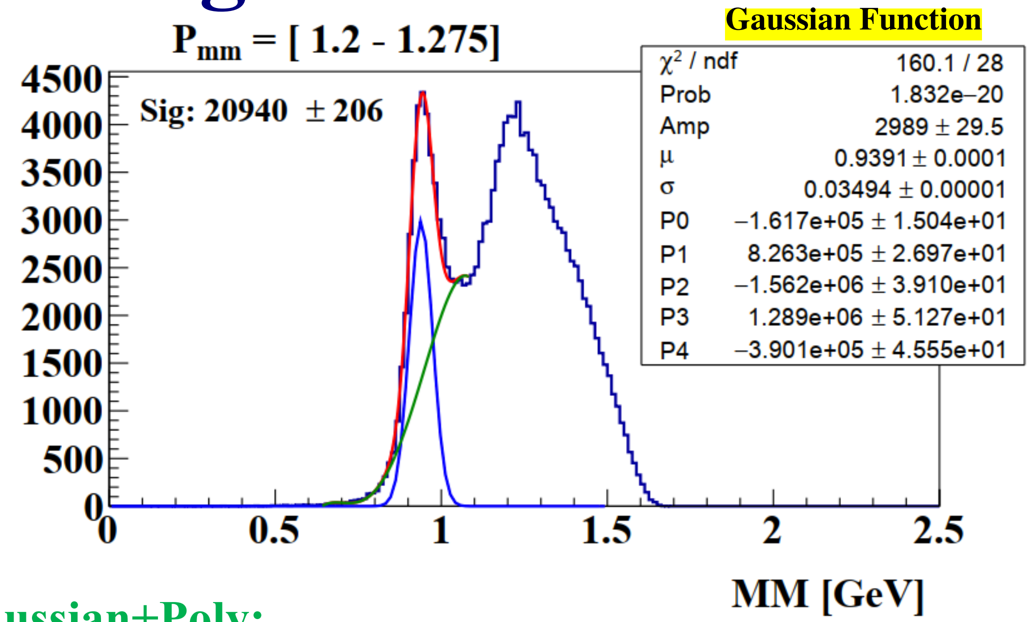
$$= \left(\frac{n}{|a|}\right)^n e^{-\frac{|a|^2}{2}} \left(\frac{n}{|a|} - |a| - \frac{x-\mu}{\sigma}\right)^{-n} \quad \text{for} \quad \frac{x-\mu}{\sigma} \leq -a.$$

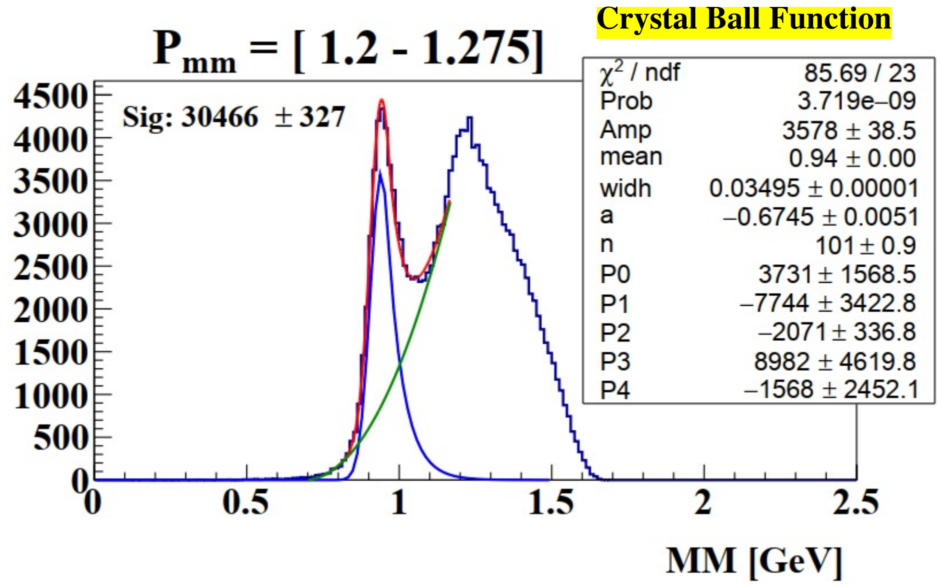
Where:

a: controls the location of the transition between the Gaussian and power-law parts of the function.

n: the steepness of the power-law tail.

Background Subtraction



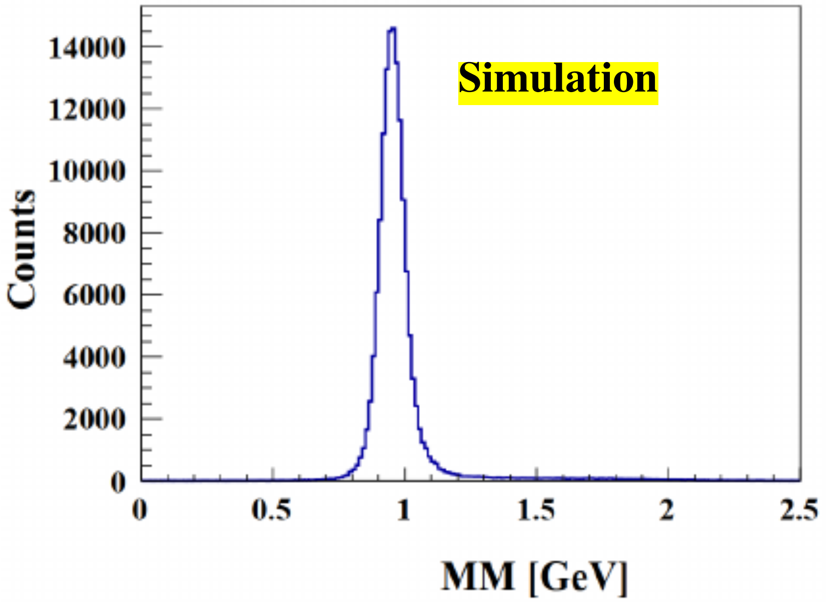


Gaussian+Poly:

- ✓ Fit limited range < 1.1GeV.
- ✓ Couldn't fit the dip region.

CB+Poly:

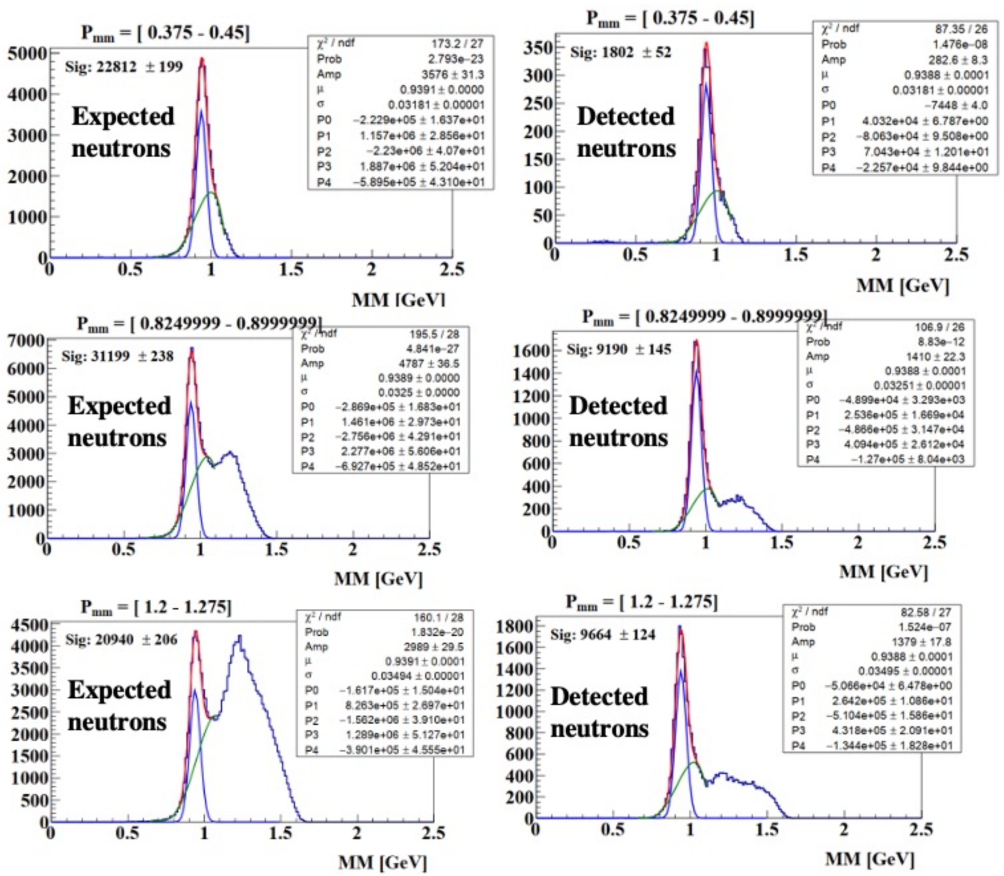
- ✓ CB has high-MM tail to fit the dip region.
- ✓ MC shows high-MM tail.



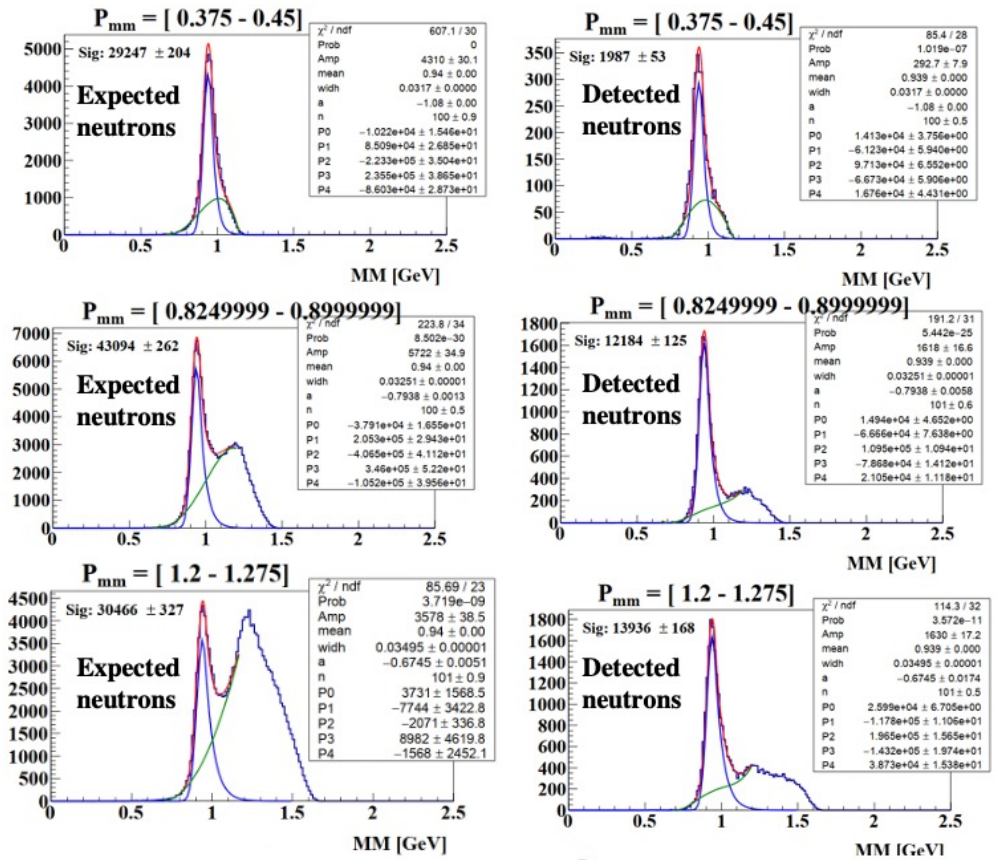
The high MM tail may be caused by:

- ✓ The radiative effects.

1- Fit Neutrons peaks using Gaussian Function



2- Fit Neutrons peaks using Crystal Ball Function



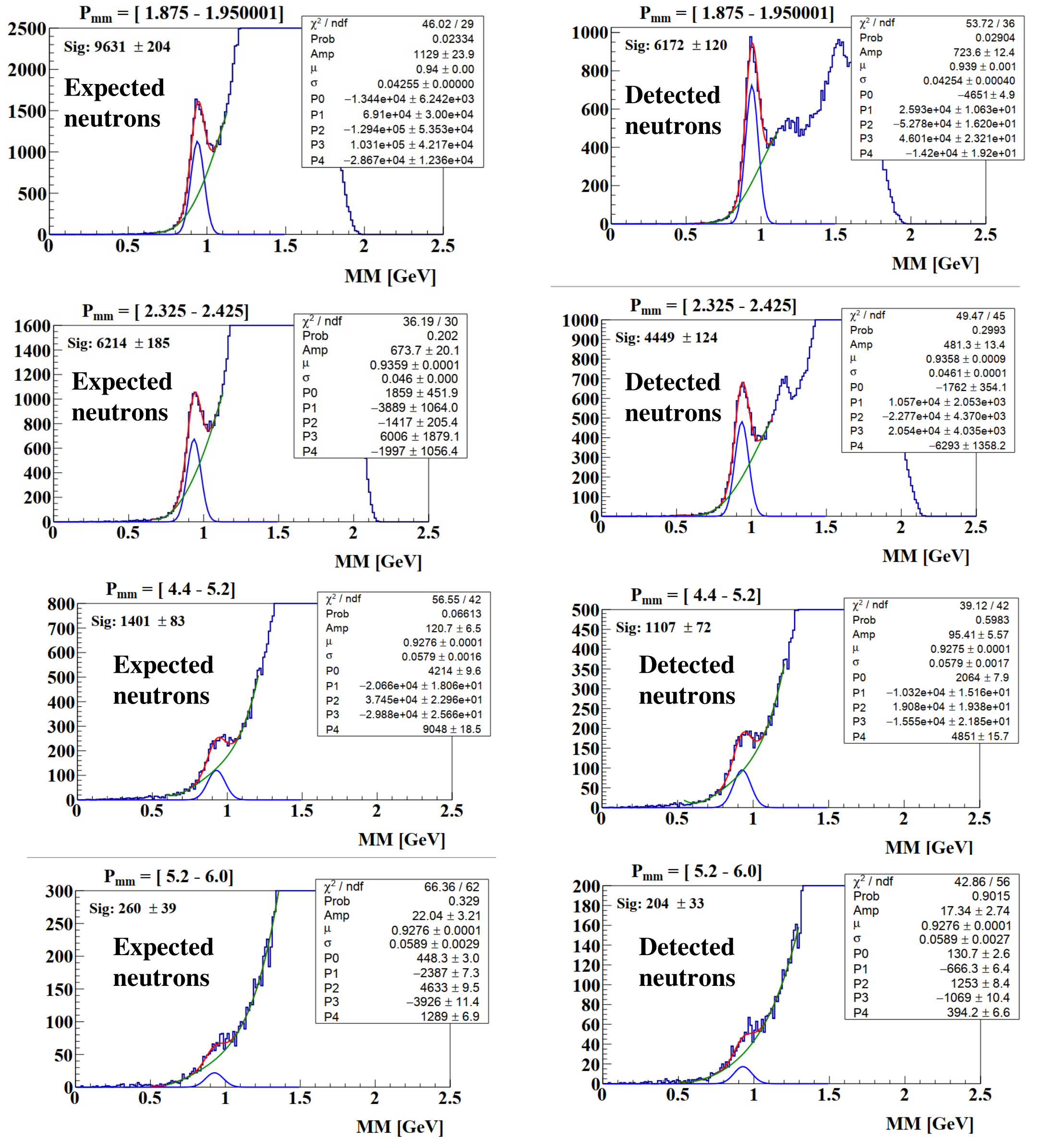
Gaussian Function:

1- First fit each detected neutron MM distribution using Gauss+Poly, allowing all parameters to vary. Range of the fit is limited to MM < 1.1 GeV where the neutron contribution is significant at P_{mm} < 2 GeV and then extend this range to MM < 1.2 GeV.
2- Use the same mean and width for each MM bin from step 1 and fit the expected neutron MM distribution with the Gaus+Poly function over the same range as step 1.
3- The Gaussian amplitude and the polynomial coefficients are allowed to vary for the expected neutron. The mean and width are fixed.

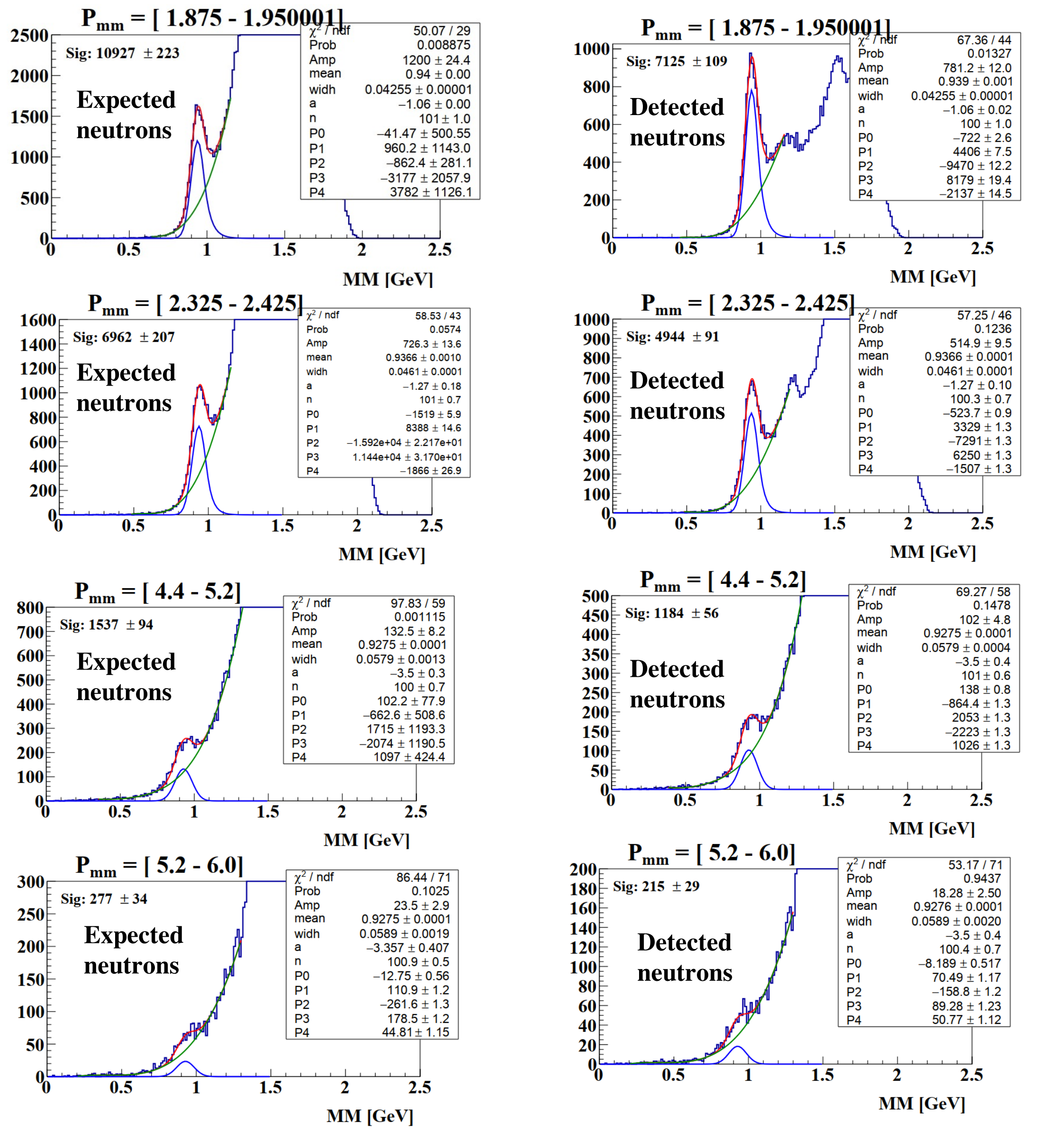
Crystal Ball Function (CB):

1- For each P_{mm} bin, use the same mean and width that were extracted from the detected neutron Gaussian fitting described in the left hand side.
2- The parameters of the CB, high-MM tail for both expected and detected neutrons are fixed at the same values that give the lowest chi2. Range of the fit is extended to MM < 1.2 GeV for all P_{mm} bins.
3- CB amplitude and the polynomial coefficients are allowed to vary for the expected neutron. The CB mean, width, and tail parameters are fixed.

1- Fit Neutrons peaks using Gaussian Function



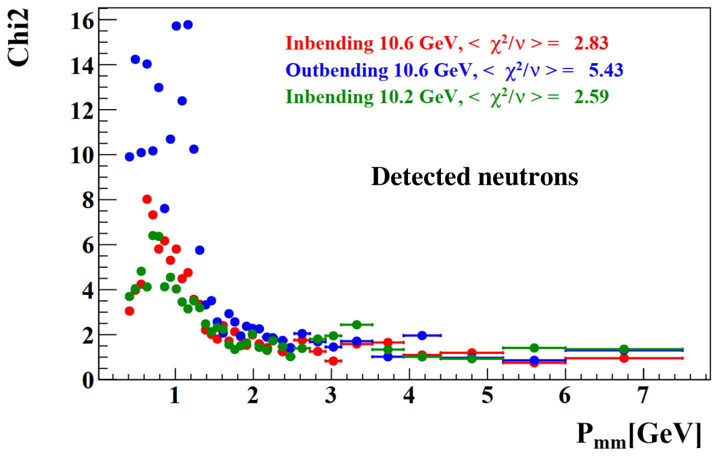
2- Fit Neutrons peaks using Crystal Ball Function

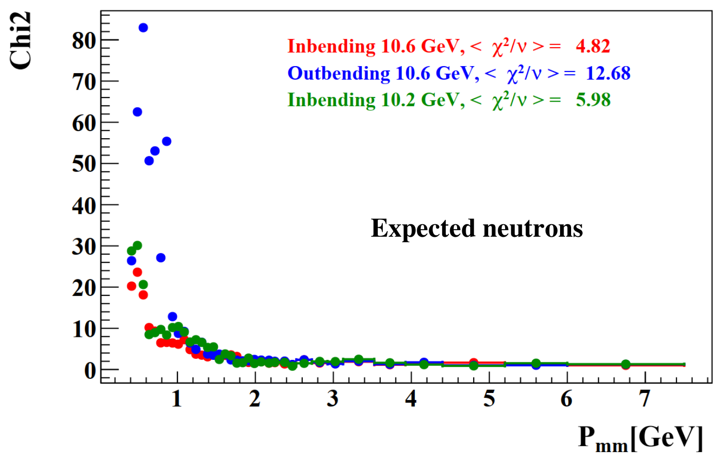


Parameters Fit Results

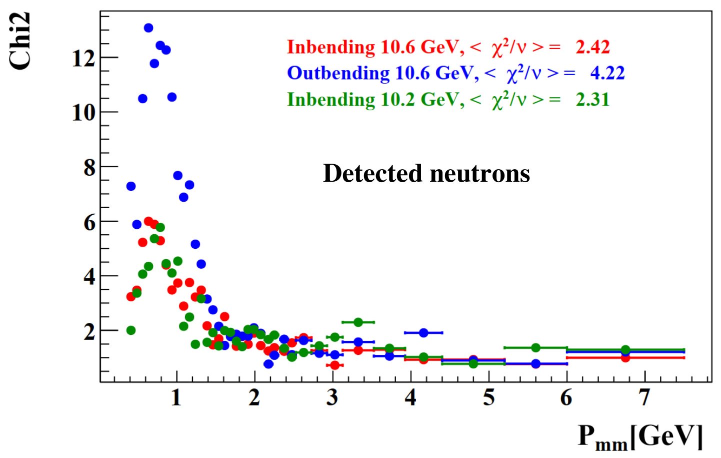
The fit quality is similar for Gauss and CB

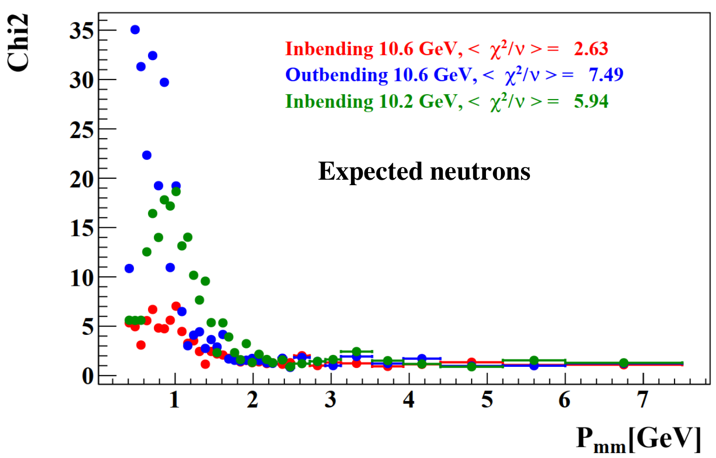
Crystal Ball Function



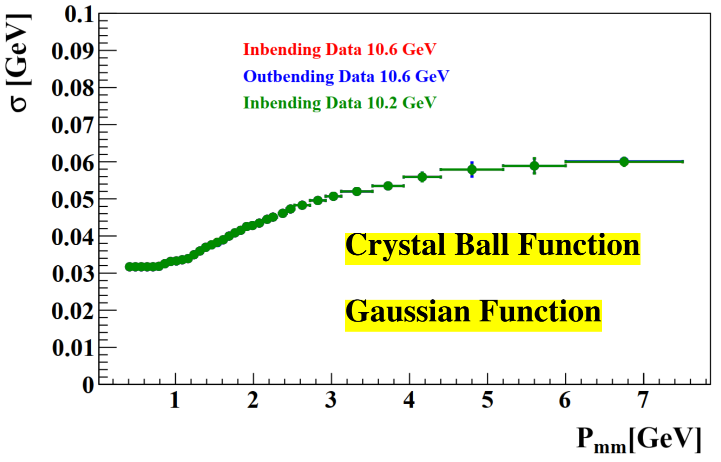


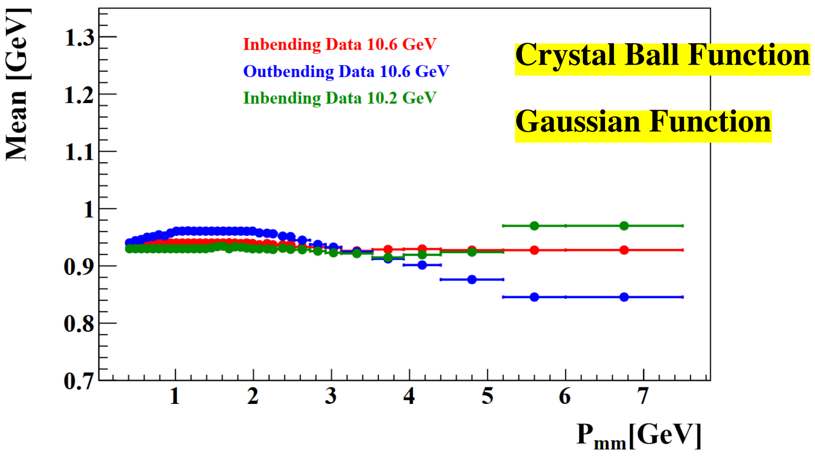
Gaussian Function



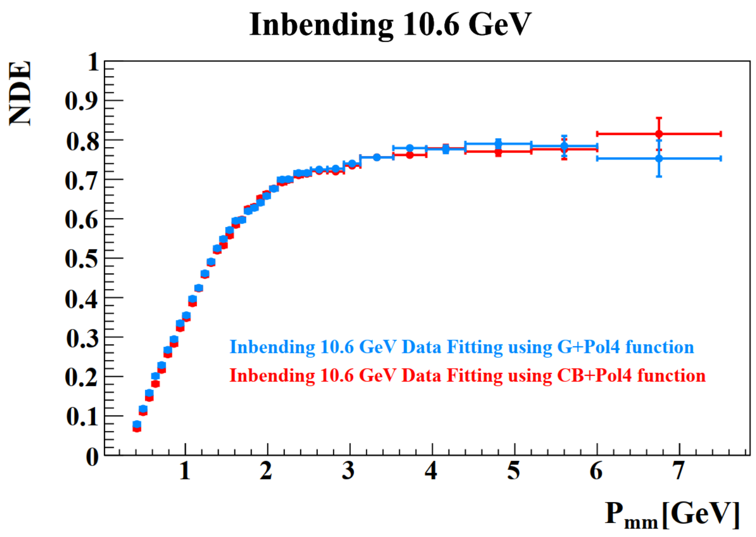


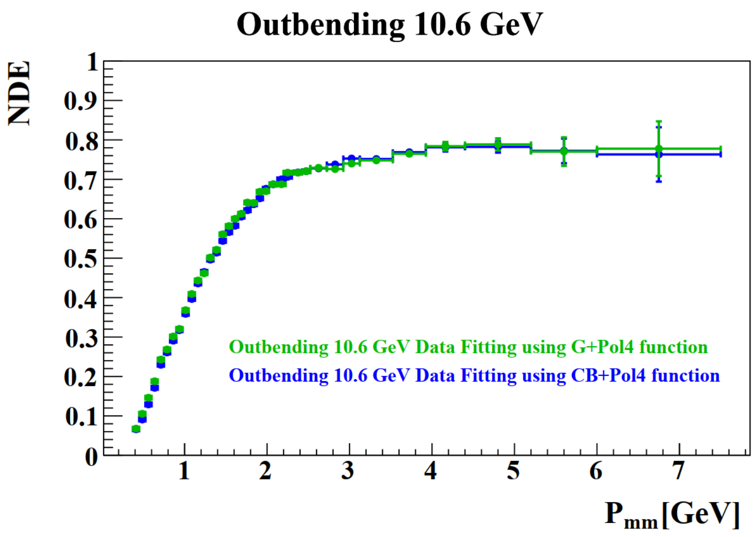
The mean and sigma vary smoothly with P_{mm}

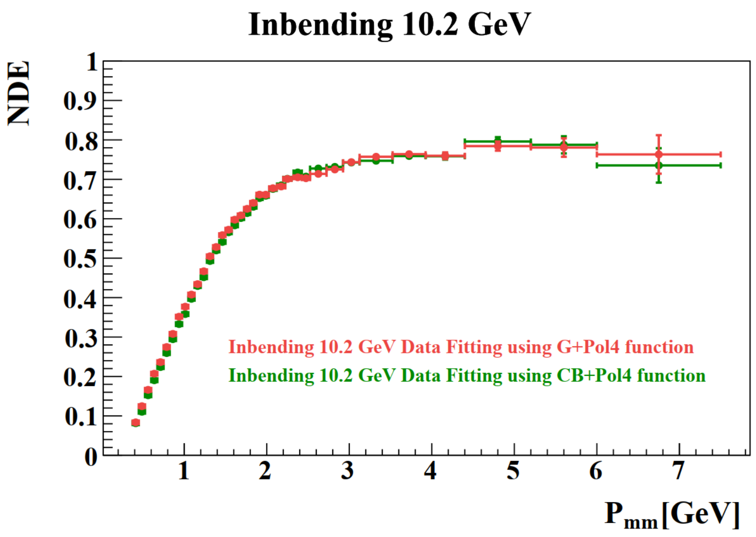


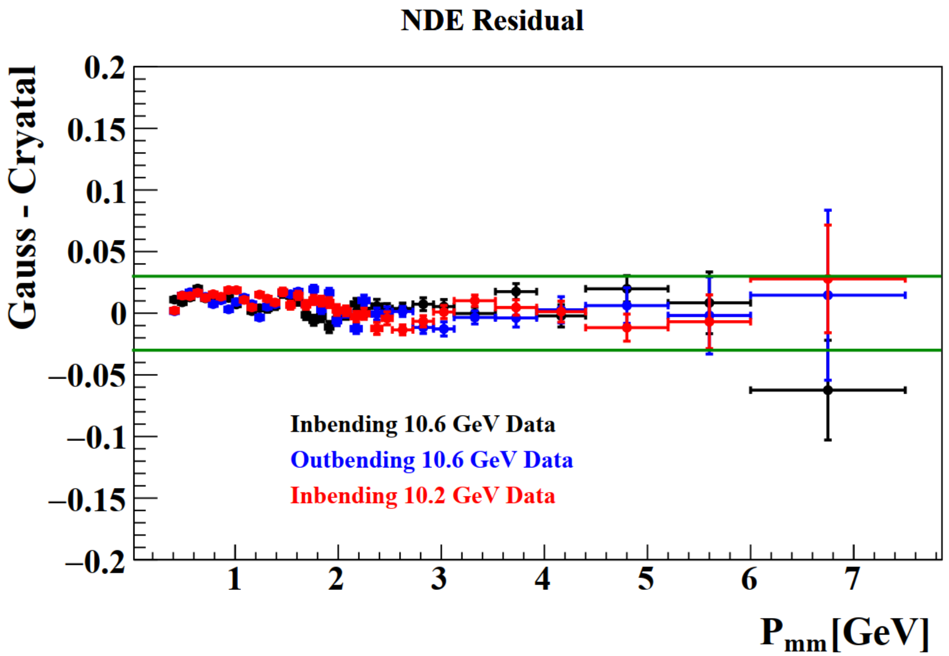


NDE Results



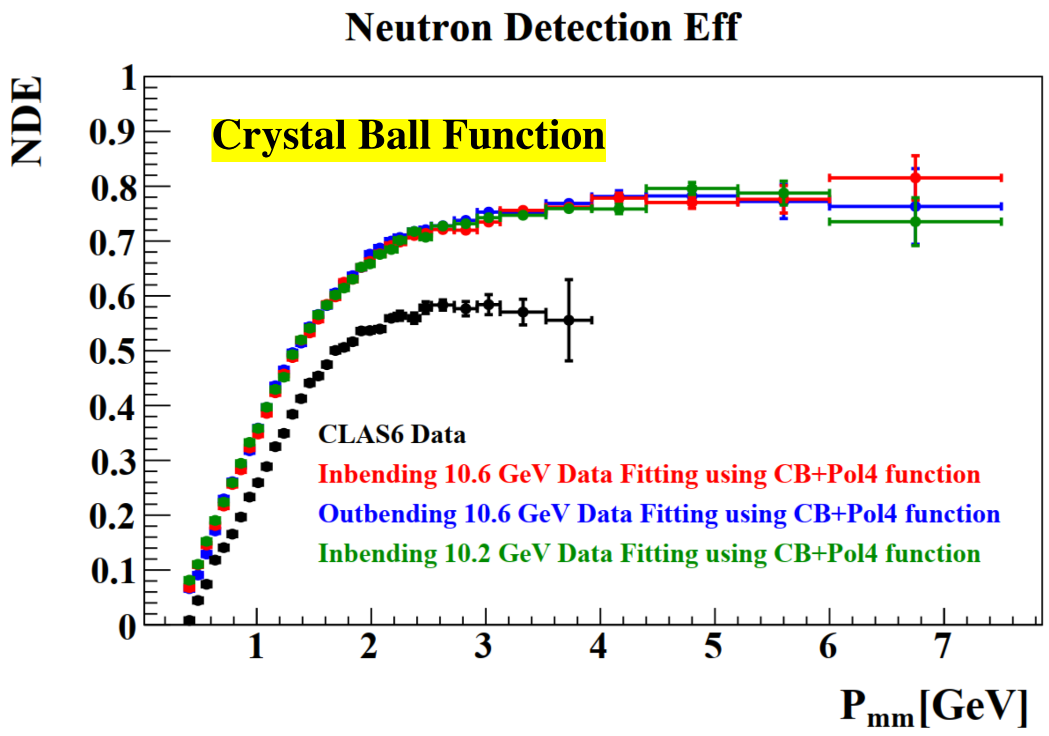


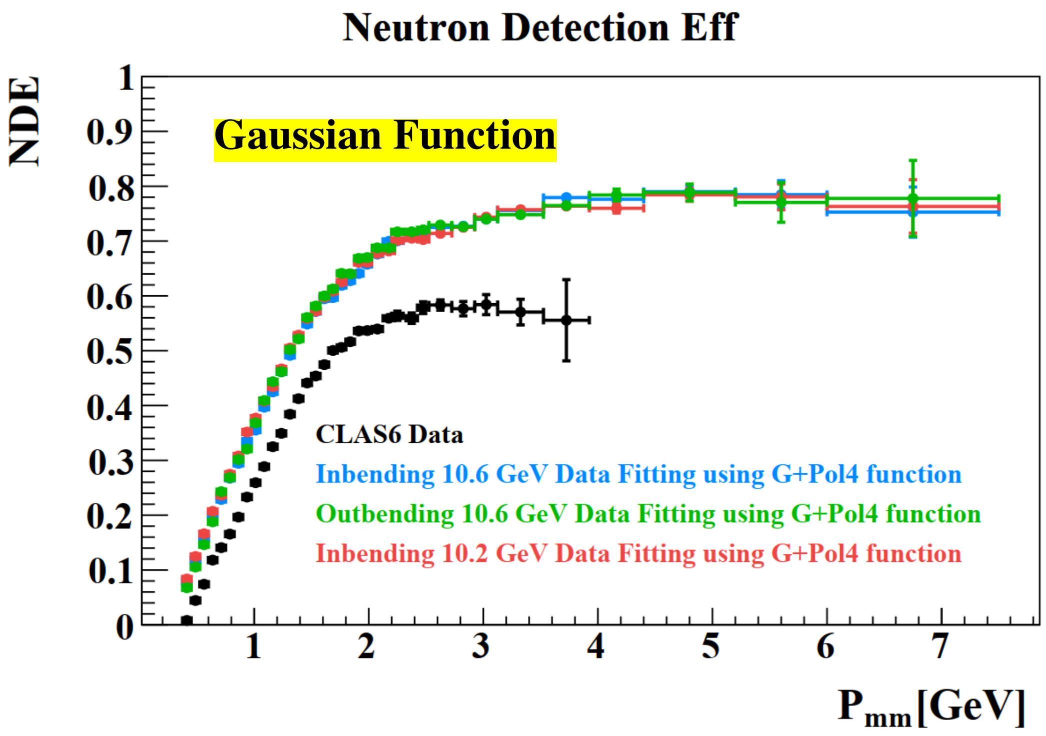




- ✓ NDE results show that below 2 GeV, the Gauss function is slightly higher compared to the CB function. However, above 2 GeV, the two functions provide consistent results within the uncertainty.
- ✓ Residual plot show the difference between Gauss and CB $< 3\%$

NDE Results

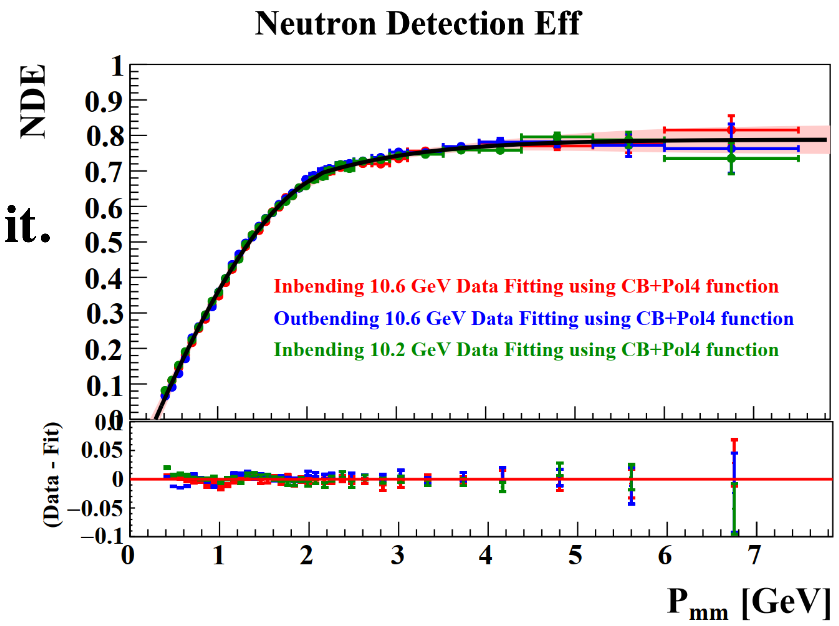




CLAS12 results shows all three data sets consistent to each other.
NDE ~ 0.77 at the plateau (pmm > 3.5 GeV) for outbending and inbending electrons.

Parameterized NDE

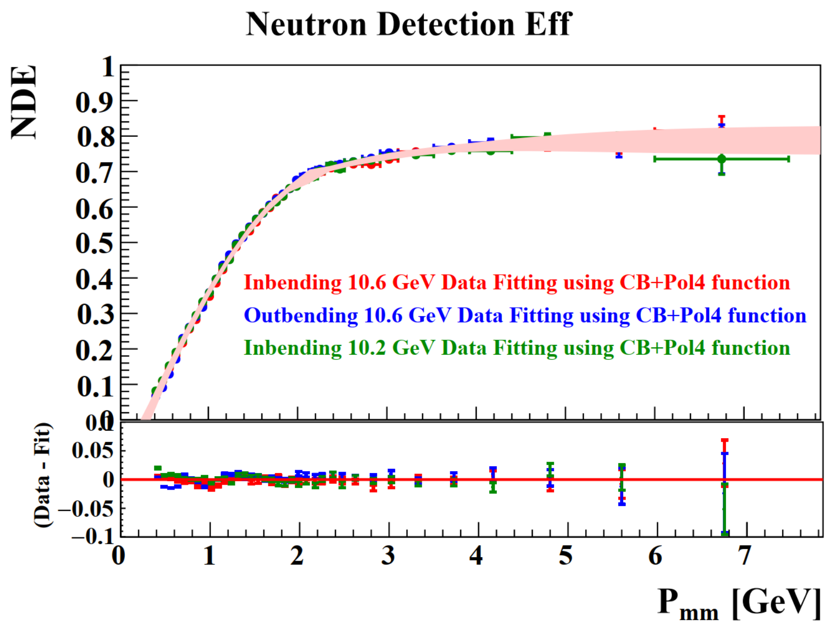
To use NDE results for Gnm, we need a function that can describe it.



Fit the neutron detection efficiency (NDE) with:

$$\eta(P_{mm}) = a_0 + a_1 P_{mm} + a_2 P_{mm}^2 + a_3 P_{mm}^3 \quad \text{for} \quad P_{mm} < p_t$$

$$= a_4\left(1 - \frac{1}{1 + e^{\frac{P_{mm} - a_5}{a_6}}}\right) \quad \text{for} \quad P_{mm} > p_t$$



The uncertainty on the fit can be calculate from the error matrix:

$$\sigma_\eta{}^2 = \sum_{i,j} \epsilon_{ij} \frac{\partial\eta}{\partial a_i} \frac{\partial\eta}{\partial a_j},$$

Summary

- NDE is necessary for G_M^n measurements in Run Group B and to other analyses/run groups.
- CLAS12 results show all three data sets are consistent to each other.
- NDE ~ 0.77 at the plateau ($P_{mm} > 3.5$ GeV) for outbending and inbending electrons.
- NDE results using Gauss function is slightly higher than Crystal Ball function below 2 GeV while above this value they are agreement within the uncertainty.

Thank you !!