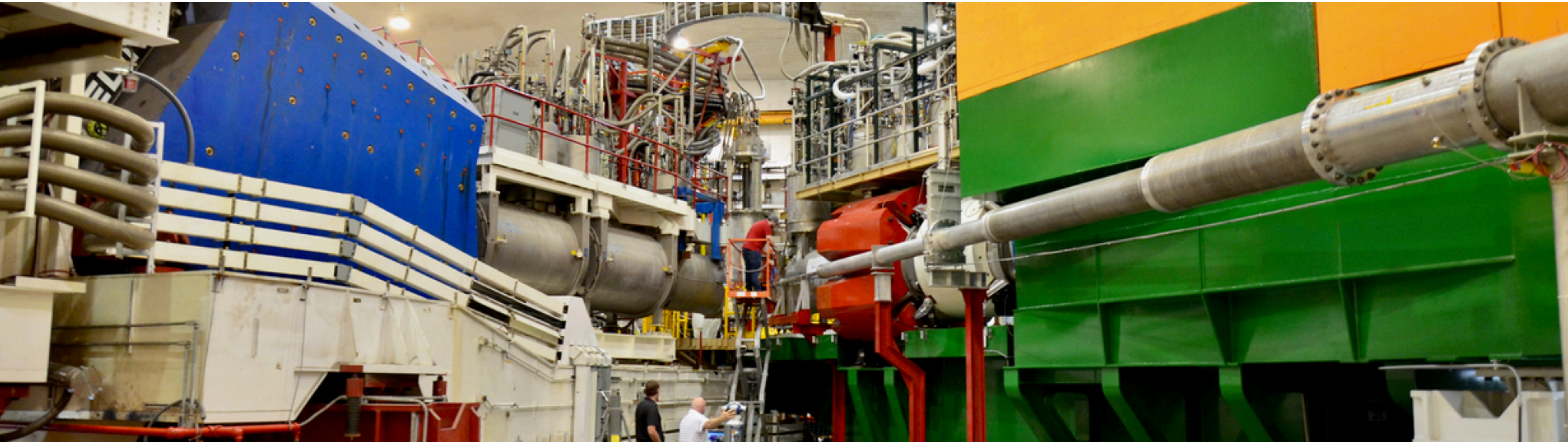


Update on the D(e,e'p)n Commissioning Experiment and Outlook

Hall A/C Joint Collaboration Meeting, June 27-28, 2019

Carlos Yero

Spokespeople: Drs. Werner Boeglin and Mark Jones

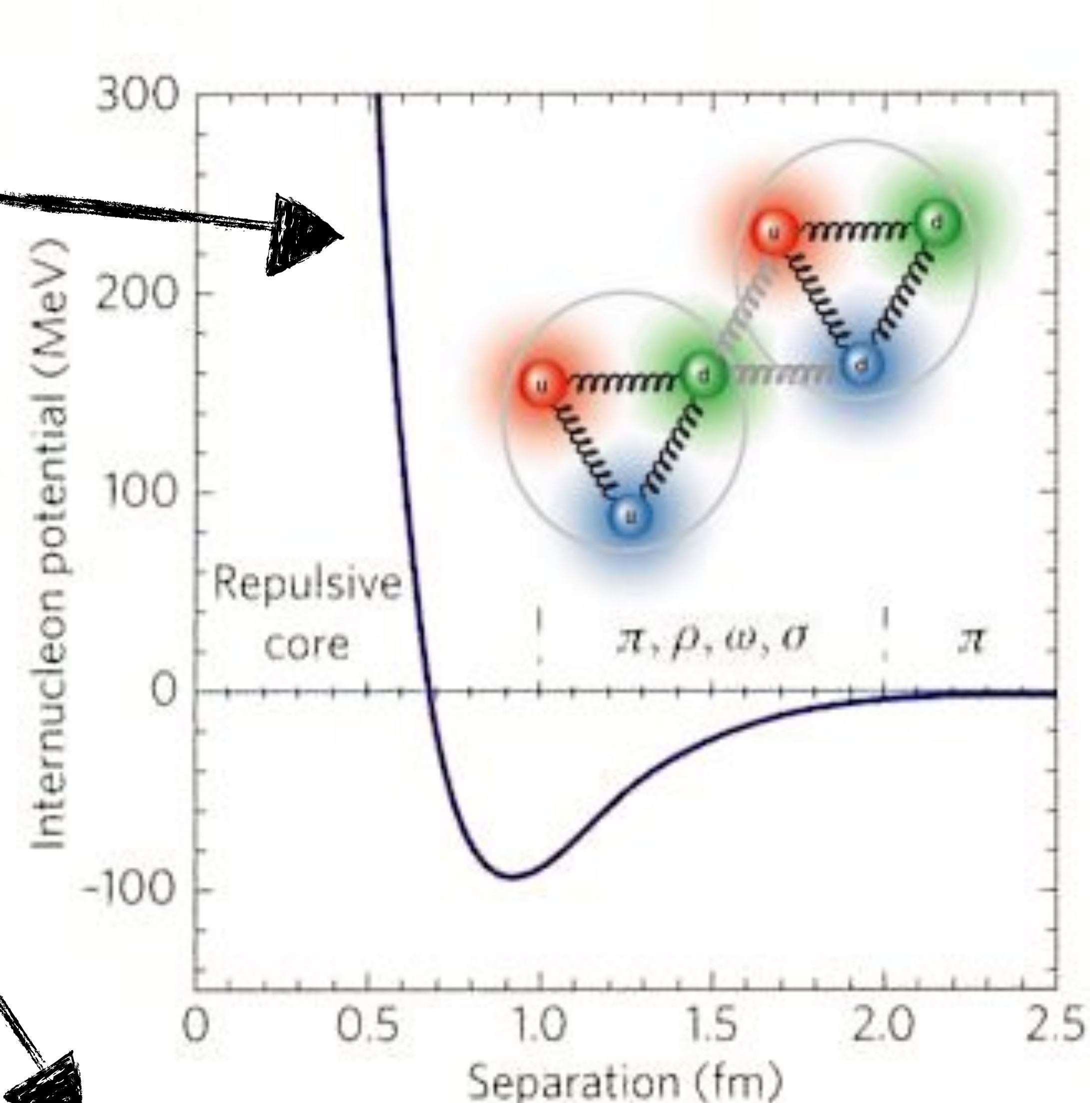
Jefferson Lab
Exploring the Nature of Matter

FIU

Hall-C

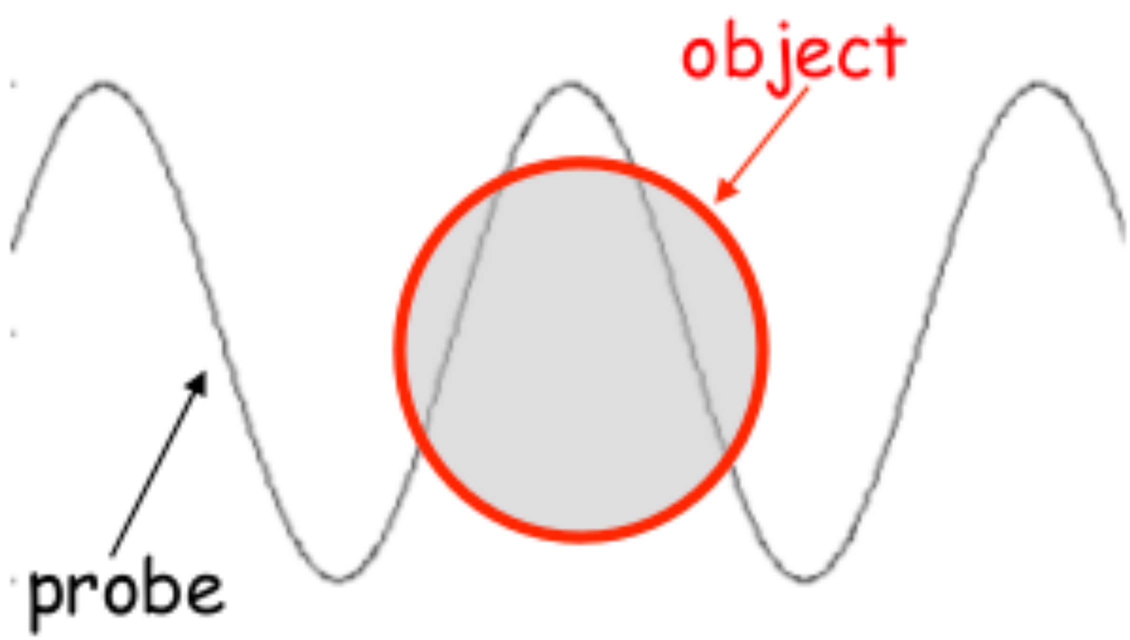
Motivation

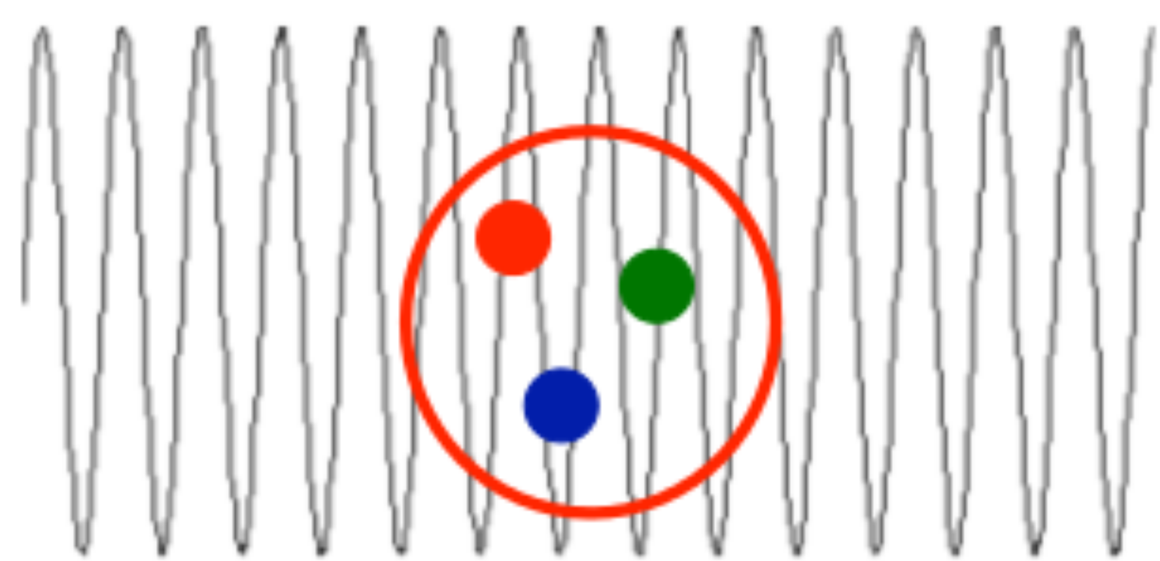
- ☑ **Understand the short range structure of the Deuteron by probing its high momentum tails**



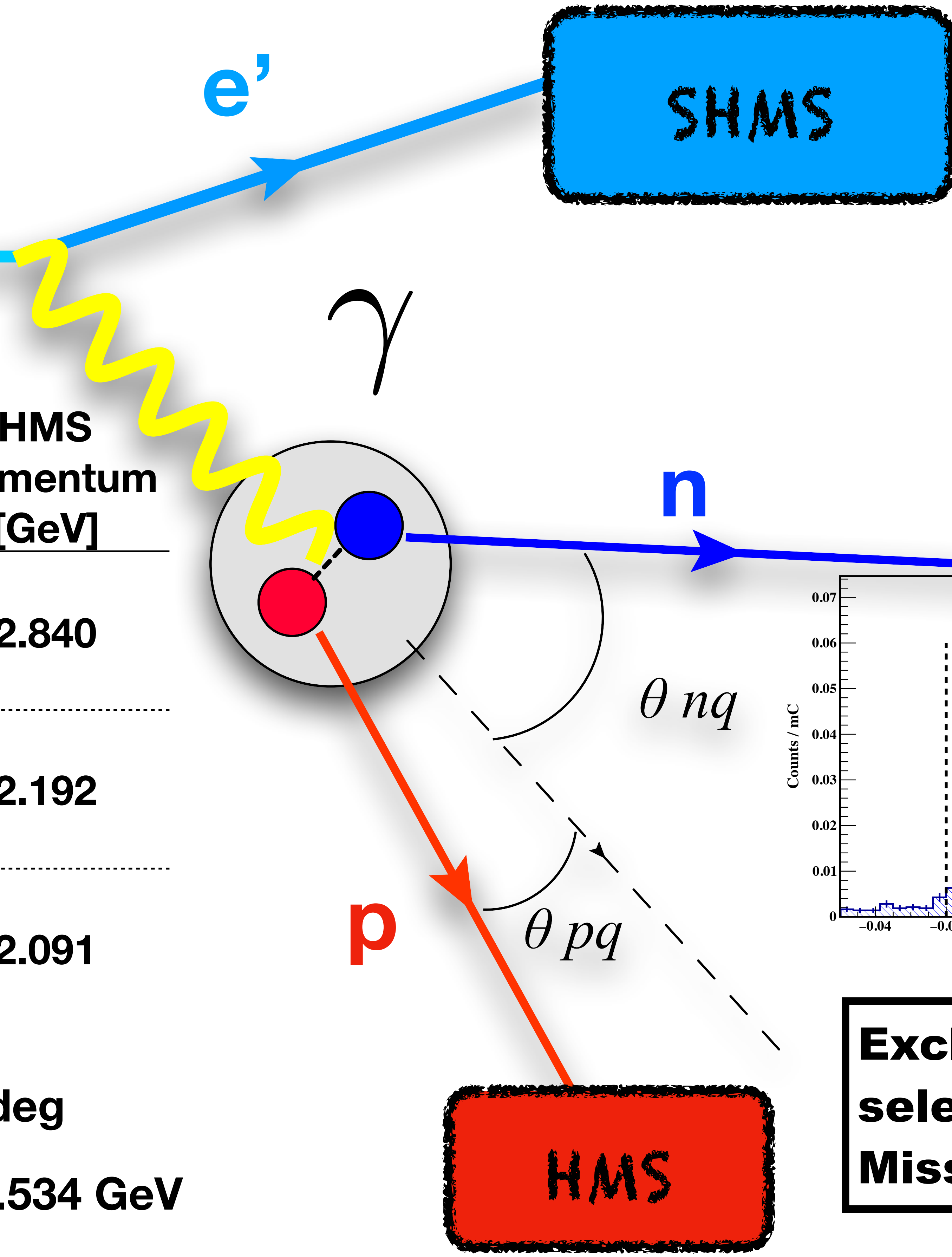
- ☑ **Use D(e,e'p)n reaction to probe sub-fermi distances using high momentum transfer (Q2)**

- ☑ **Extract momentum distributions beyond 500 MeV/c recoil momenta at PWIA kinematics**





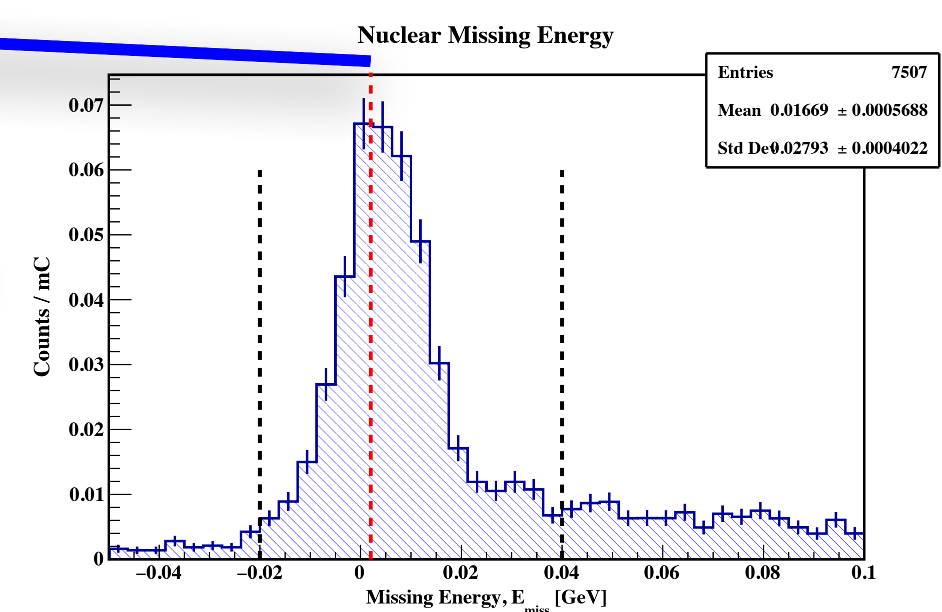
Kinematics



Pm [MeV]	HMS Angle [deg]	HMS Momentum [GeV]
80	~38.8	2.840
580	~55	2.192
750	~58.3	2.091

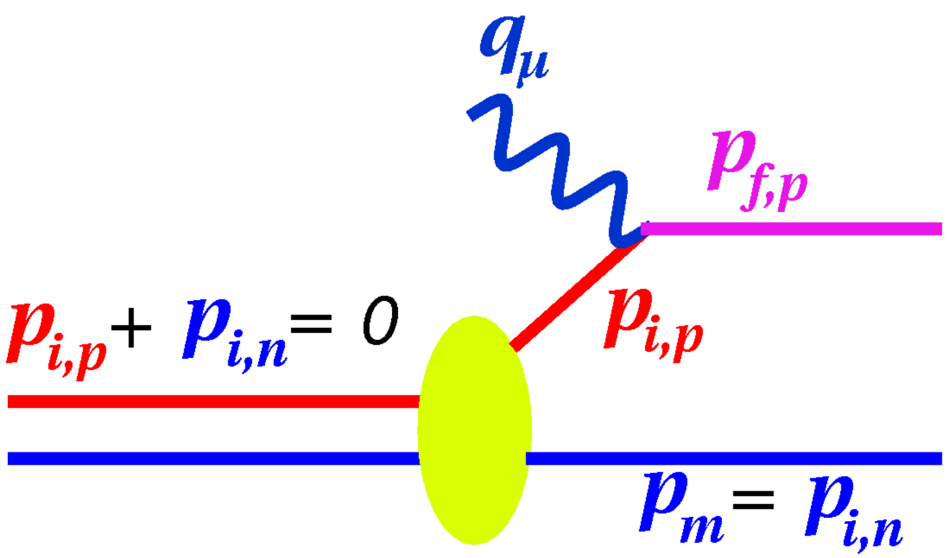
SHMS Angle: 12.194 deg

SHMS Momentum: -8.534 GeV

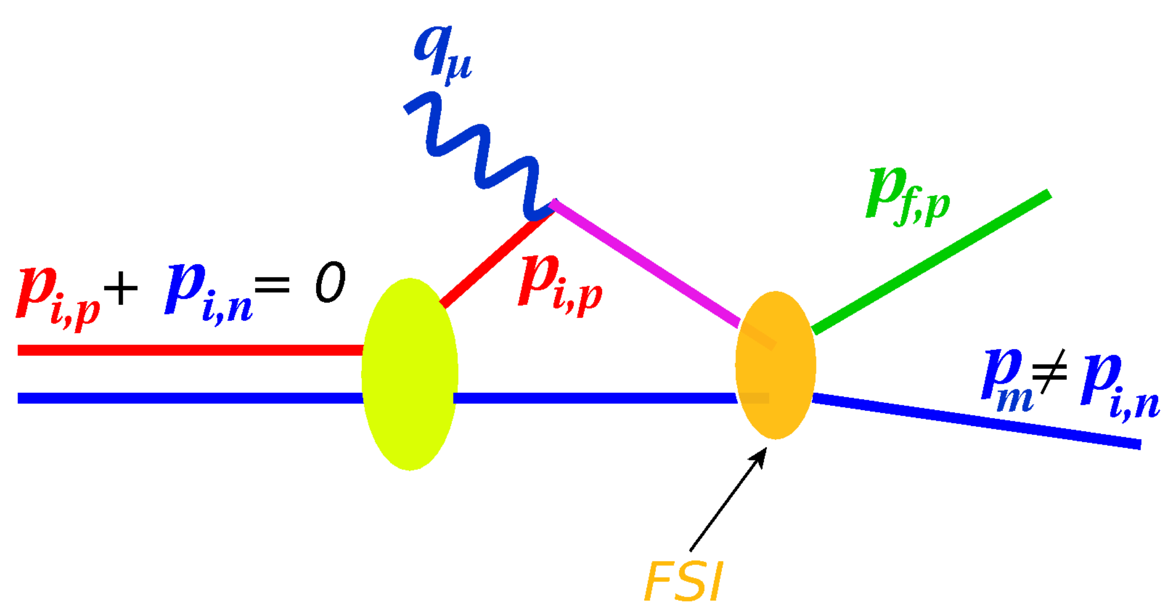


Exclusive reaction selected via Missing Energy Cut

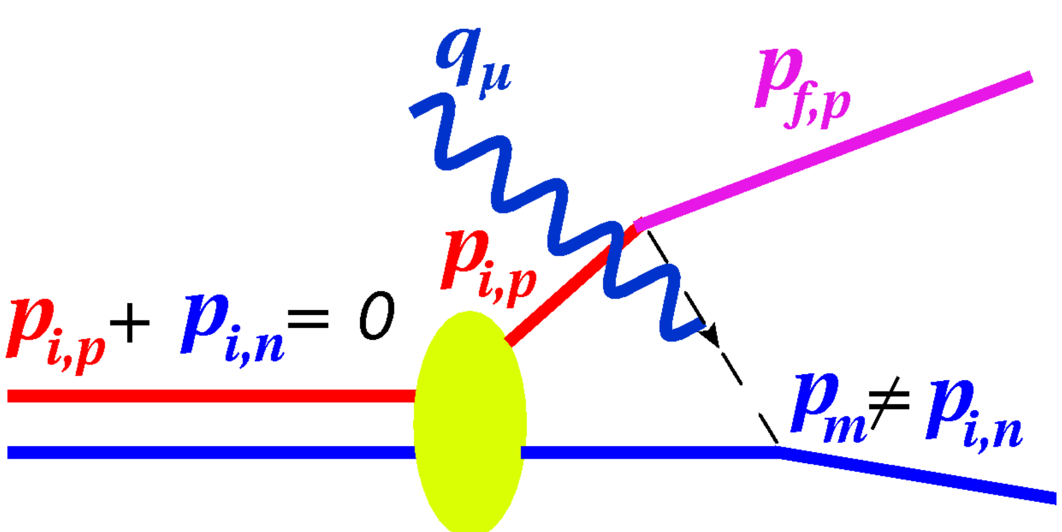
D(e,e'p)n Feynman Diagrams



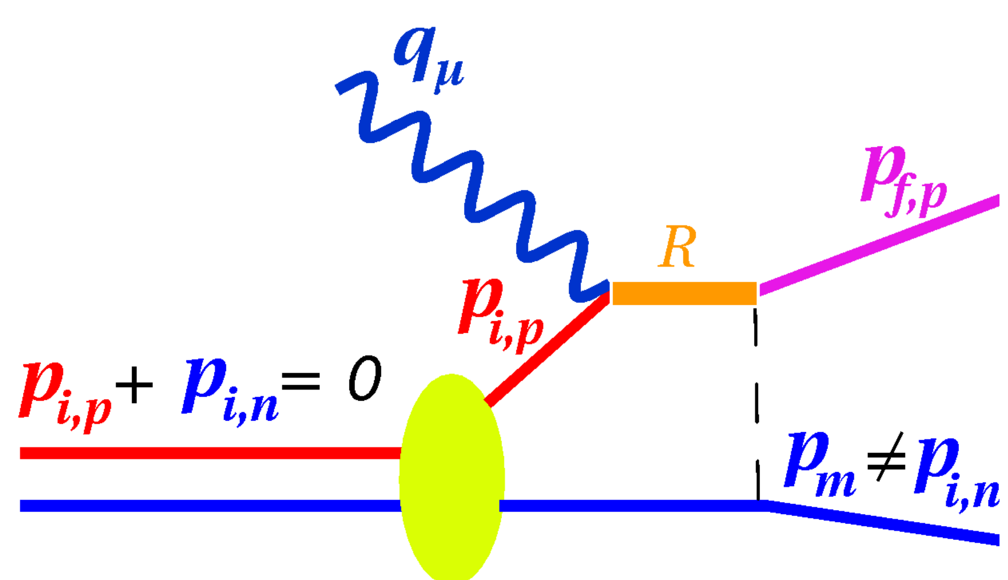
Plane Wave Impulse Approximation (PWIA)



Final State Interactions (FSI)



Meson-Exchange Currents (MEC)



Isobar Configurations (IC)

Deuteron Momentum Distribution

Experiment

$$\boxed{\sigma_{exp} \equiv \frac{d^5\sigma}{d\omega d\Omega_e d\Omega_p}} = \boxed{K \cdot \sigma_{ep} \cdot S(p_m)}$$

Theory

$$S(p_m) \approx \sigma_{red} \equiv \frac{\sigma_{exp}}{K\sigma_{ep}}$$

Factorization ONLY possible in PWIA

ep off-shell cross section

electron scatters off a bound proton within the nucleus; usually, de Forest σ_{cc1} or σ_{cc2} is prescribed

Spectral Function, $S(p_m)$

the momentum distribution inside the deuteron is interpreted as the probability density of finding a bound proton with momentum p_i

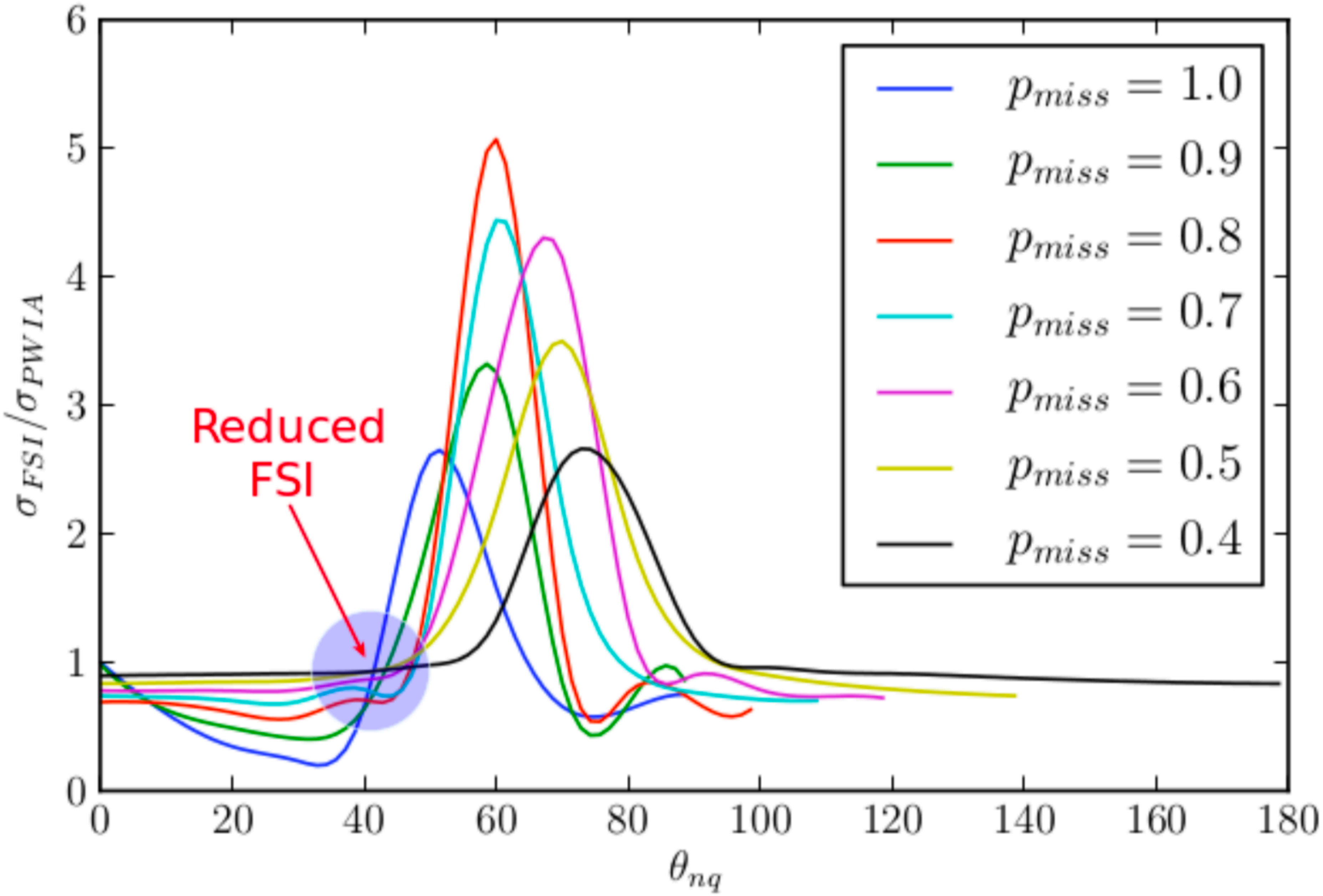
Theoretical Background for D(e,e'p)n

Kinematical Region where FSI are small was FOUND at ~ 40 deg !

D(e,e'p)n Kinematics

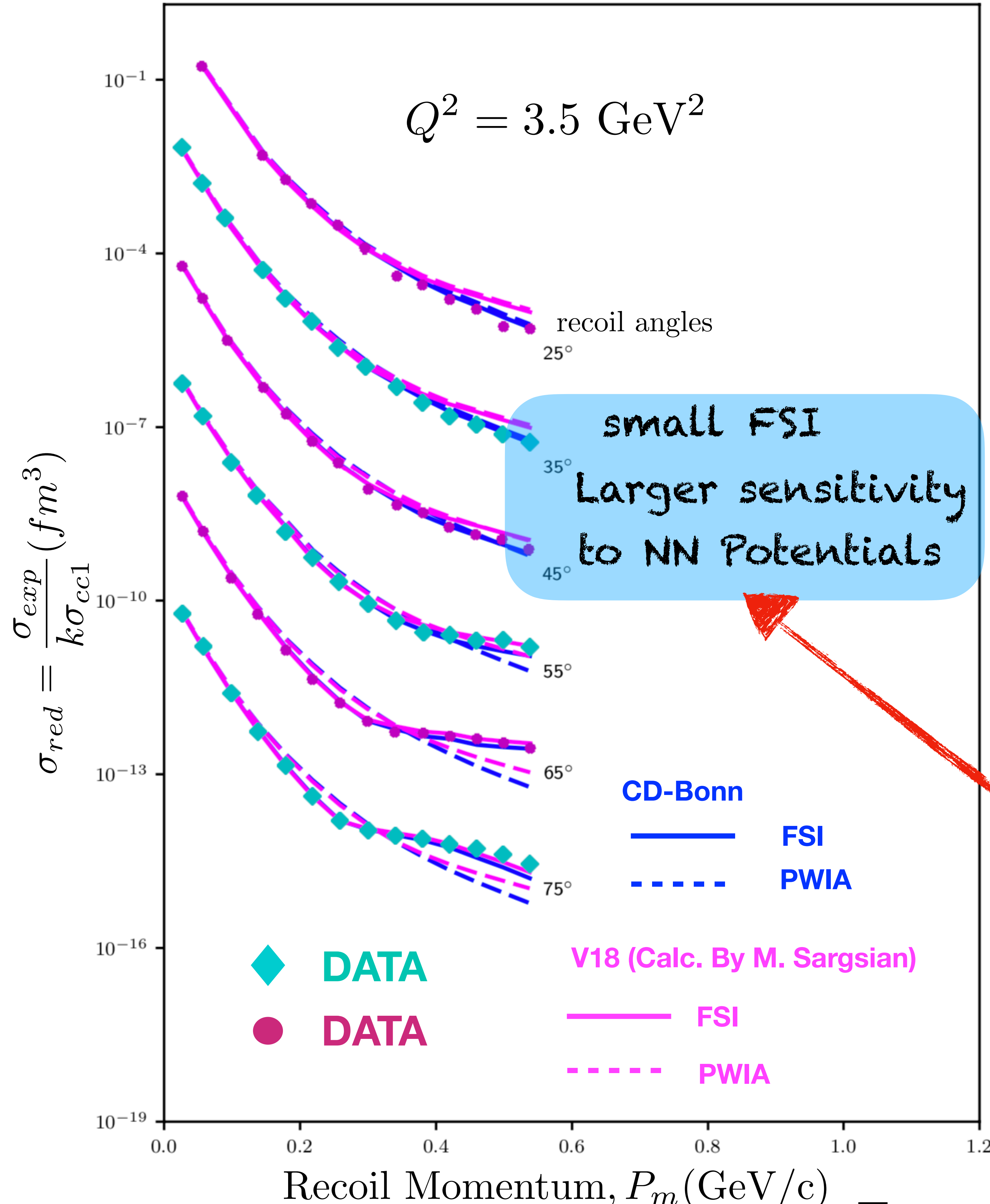
$E_e = 11$ GeV
$Q^2 = 4.25\ (\mathrm{GeV/c})^2$
$x_{B_j} = 1.35$
$p_m = 0.5 - 1.0$ GeV/c
$\theta_{nq} = 35° - 40°$

W.U. Boeglin *et. al*
Int.J.Mod.Phys. E24
(2015) no.03, 1530003



Theoretical Calculation by: M. Sargsian

Previous Hall A Measurement of D(e,e'p)n



- **Momentum Distribution at various recoil angles are scaled relative to the 25 deg. setting**
- **At recoil angles 40 +/- 5 deg, is a kinematic region of interest as FSI are suppressed**
- **Deuteron Momentum Distribution becomes accessible at small FSI**
- **This experiment focuses on recoil angles ~ 40 deg at recoil momenta beyond 500 MeV/c where FSI are small**

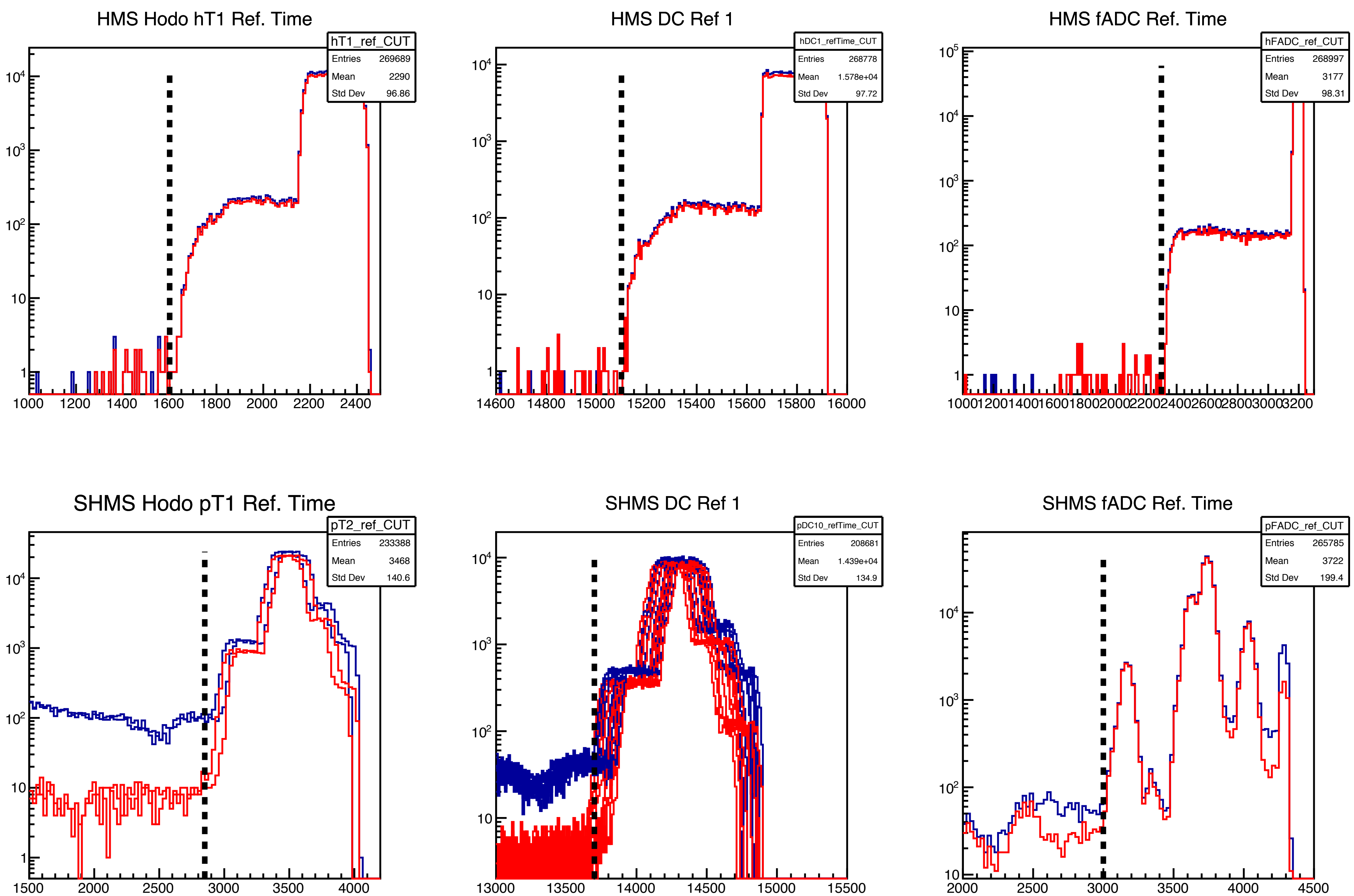
Experimental Analysis

on

D(e,e’p)n

Reference Time Cuts

☑ Correct reference time (copy of the trigger) must be chosen so that the ADCs/TDCs subtract the correct reference time (to the right of the cut dashed line)



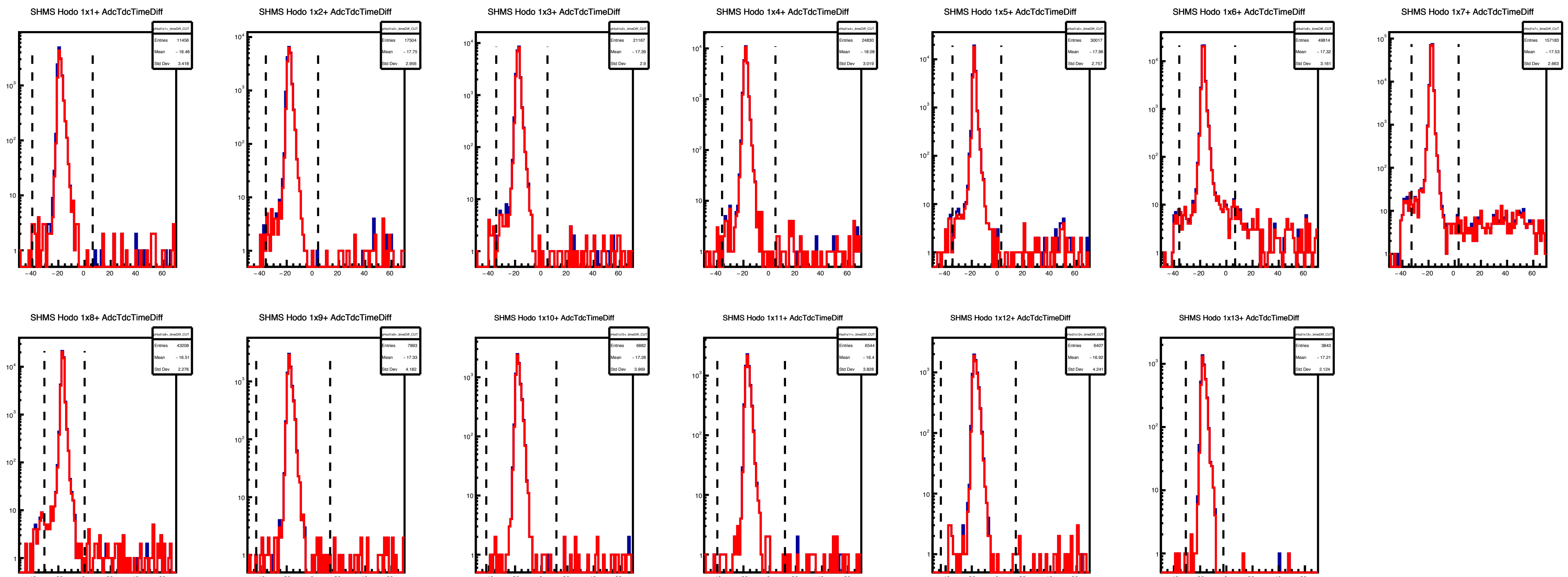
HMS Reference Times

SHMS Reference Times

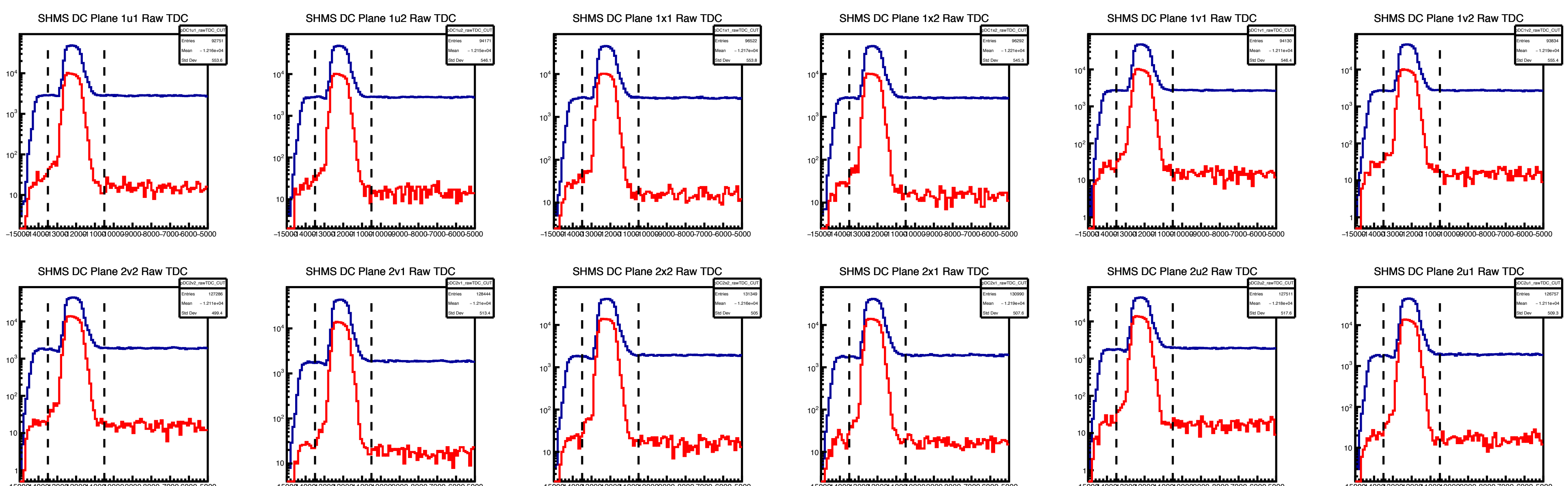
TDC Time Window Cuts

☑ **A time window cut MUST be made around the main signal peak to reduce background from possible out-of-time events.** **(Specially on the DCs)**

Legend: **No Mult. Cut** **Multiplicity==1**

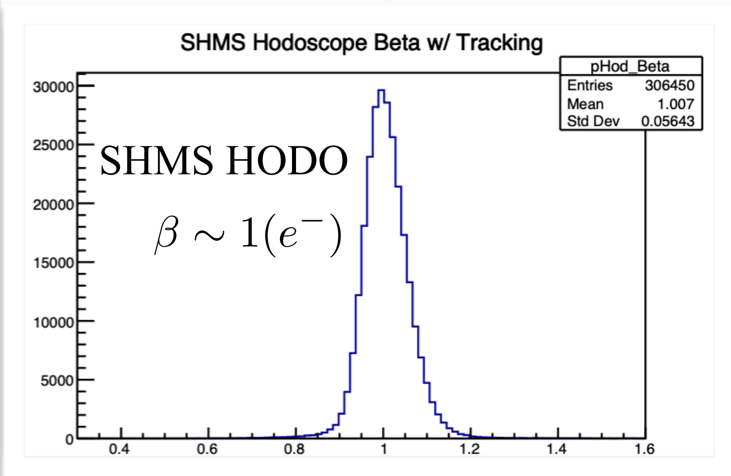


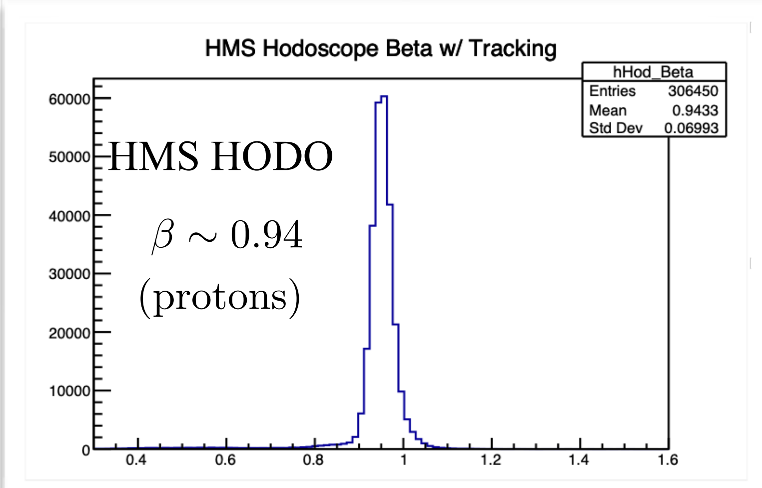
SHMS Hodoscope 1X+ (ADC-TDC) Time Difference

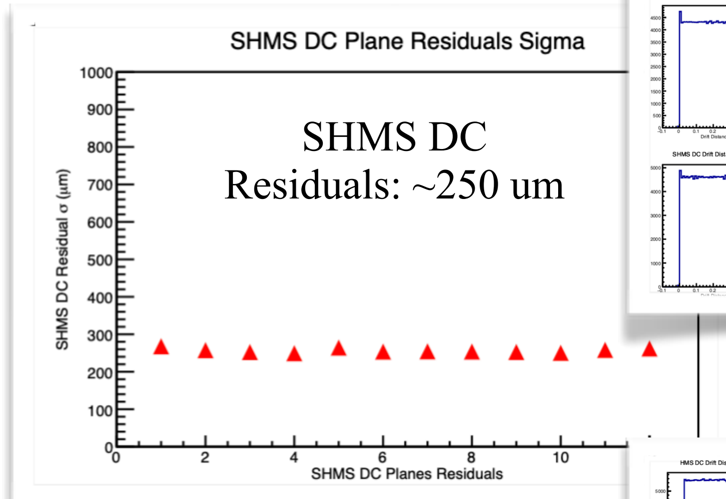


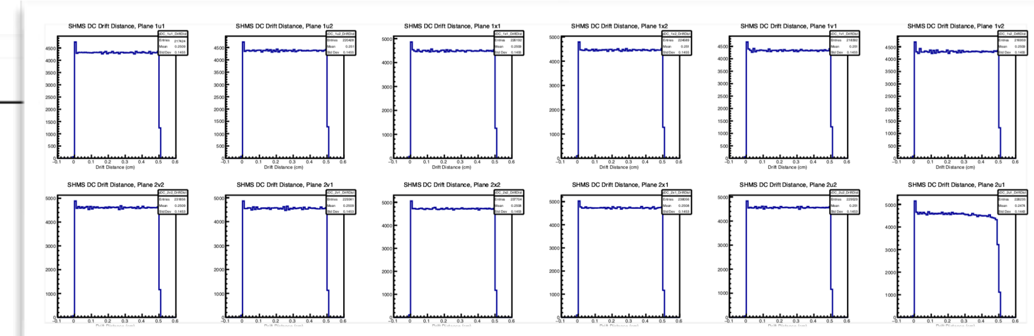
SHMS Drift Chambers Raw TDC Time

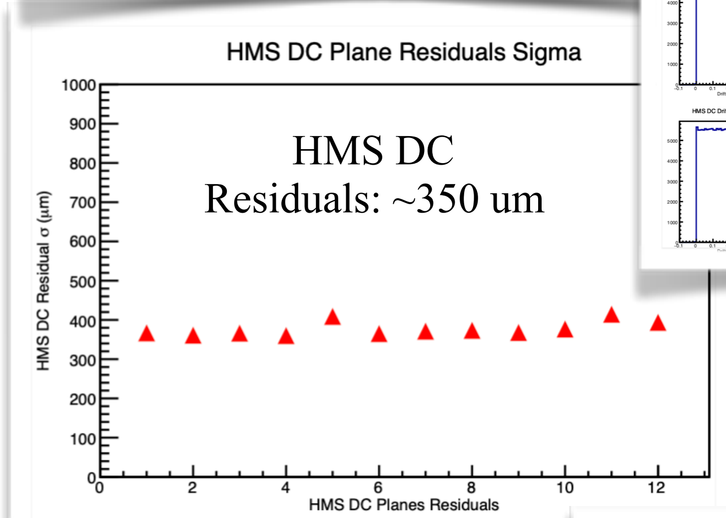
Detector Calibrations

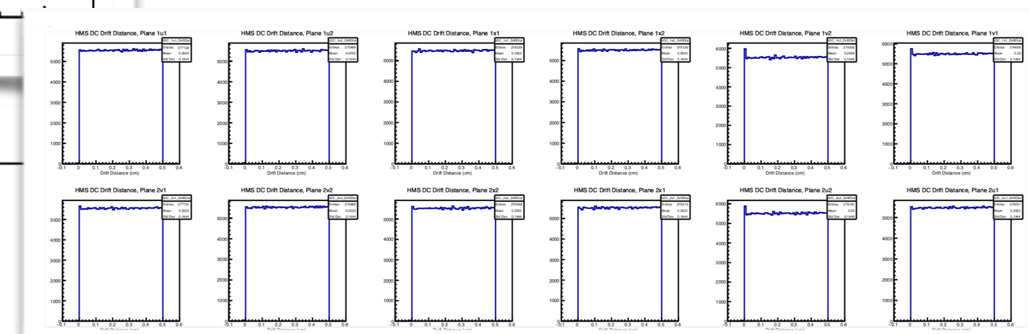


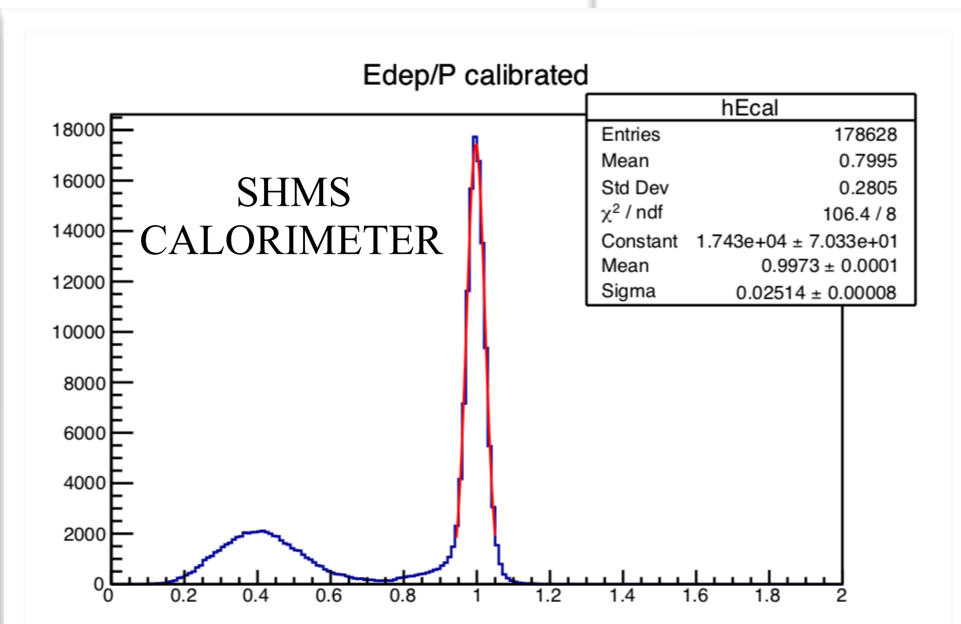


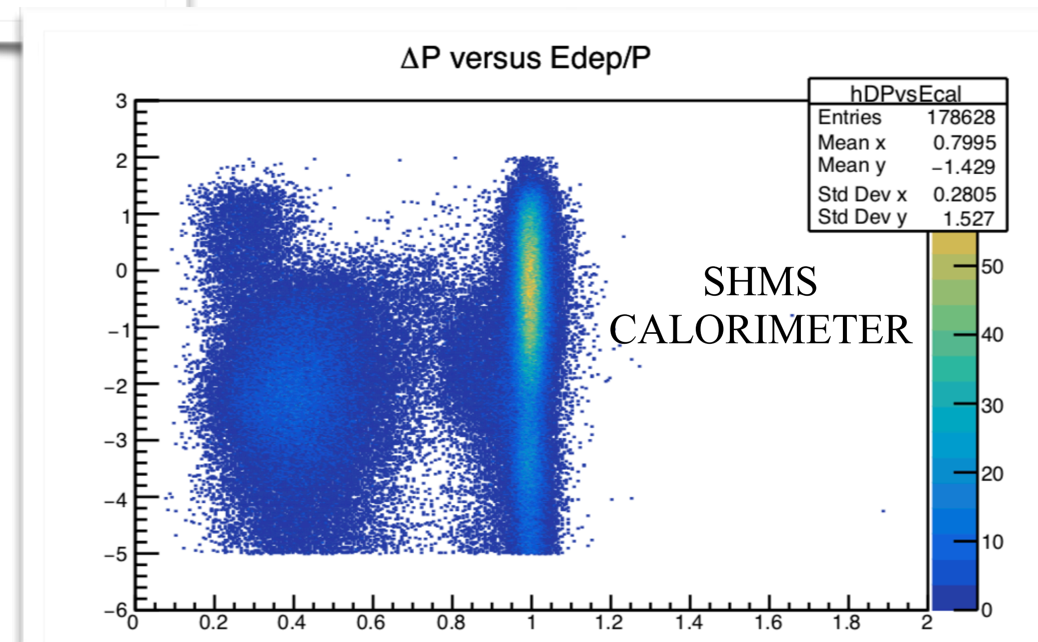




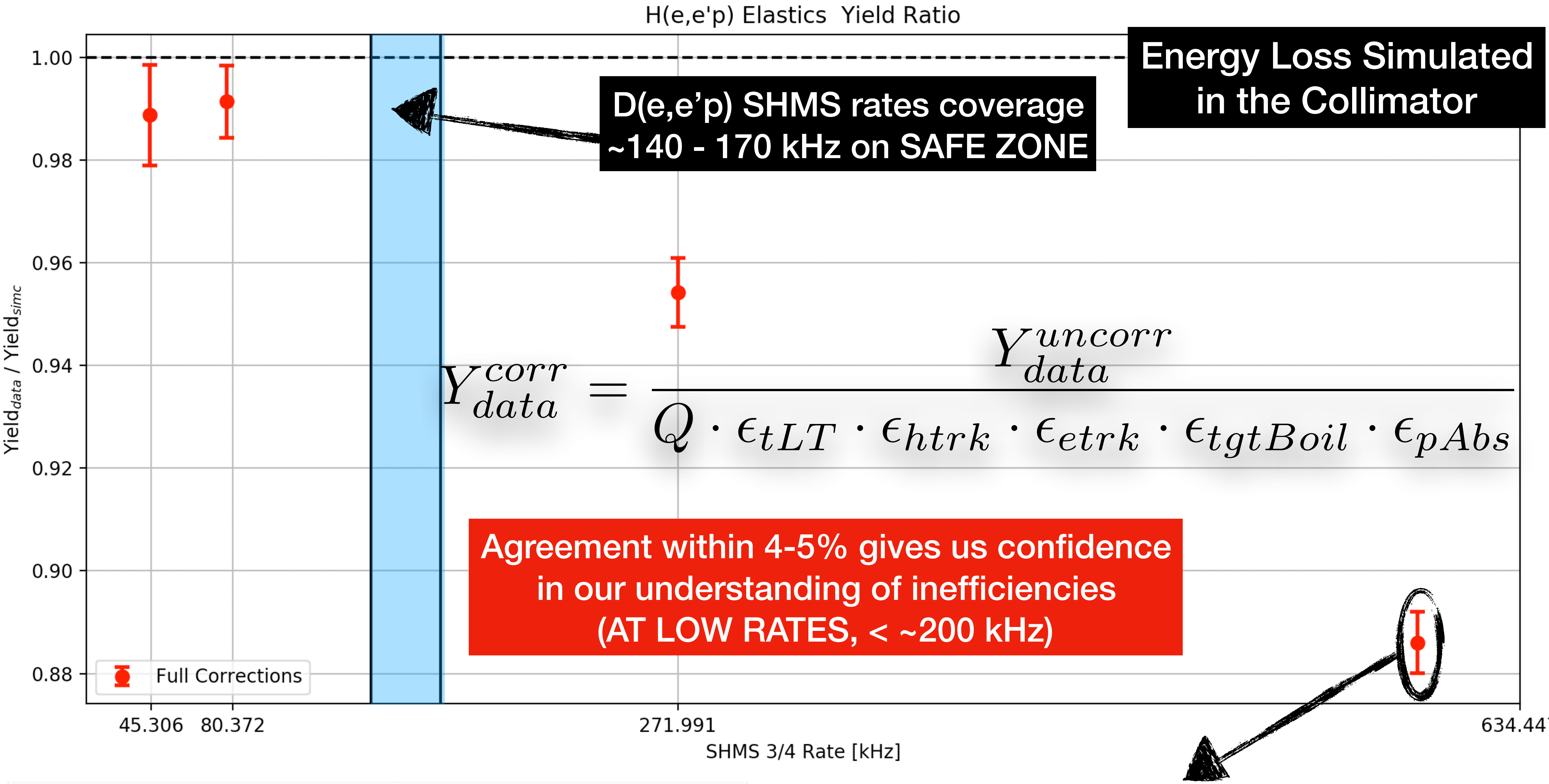








H(e,e'p) Yield Ratio Check



Energy Loss Simulated in the Collimator

D(e,e'p) SHMS rates coverage ~140 - 170 kHz on SAFE ZONE

$$Y_{data}^{corr} = \frac{Y_{data}^{uncorr}}{Q \cdot \epsilon_{tLT} \cdot \epsilon_{htrk} \cdot \epsilon_{etrk} \cdot \epsilon_{tgtBoil} \cdot \epsilon_{pAbs}}$$

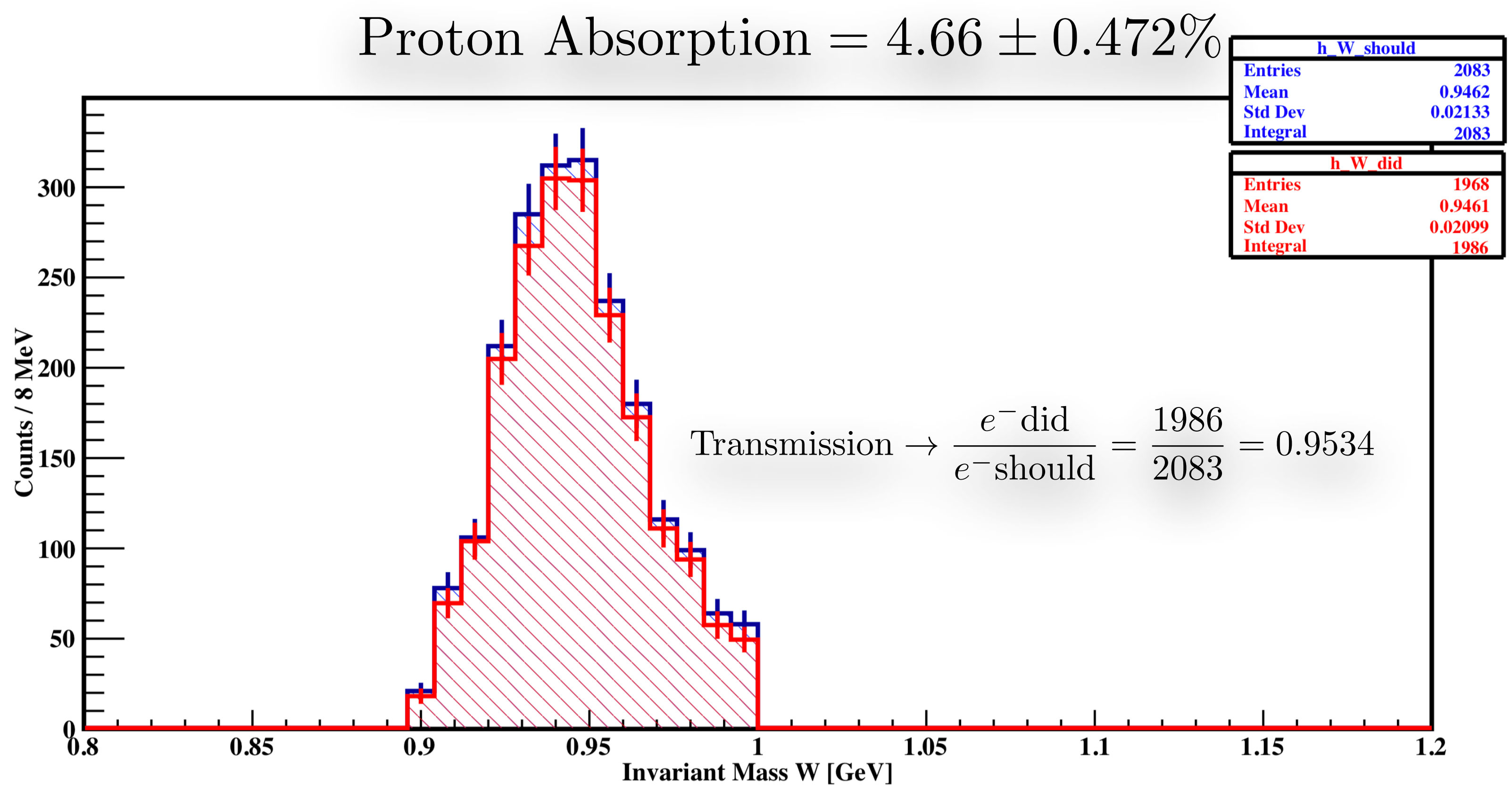
Agreement within 4-5% gives us confidence in our understanding of inefficiencies (AT LOW RATES, < ~200 kHz)

The general cuts applied were:
|HMS Delta| < 8 % SHMS Delta: (-10, 22) %
Inv. Mass W : (0.85, 1.05), HMS Coll. Cut

NOT Understood:

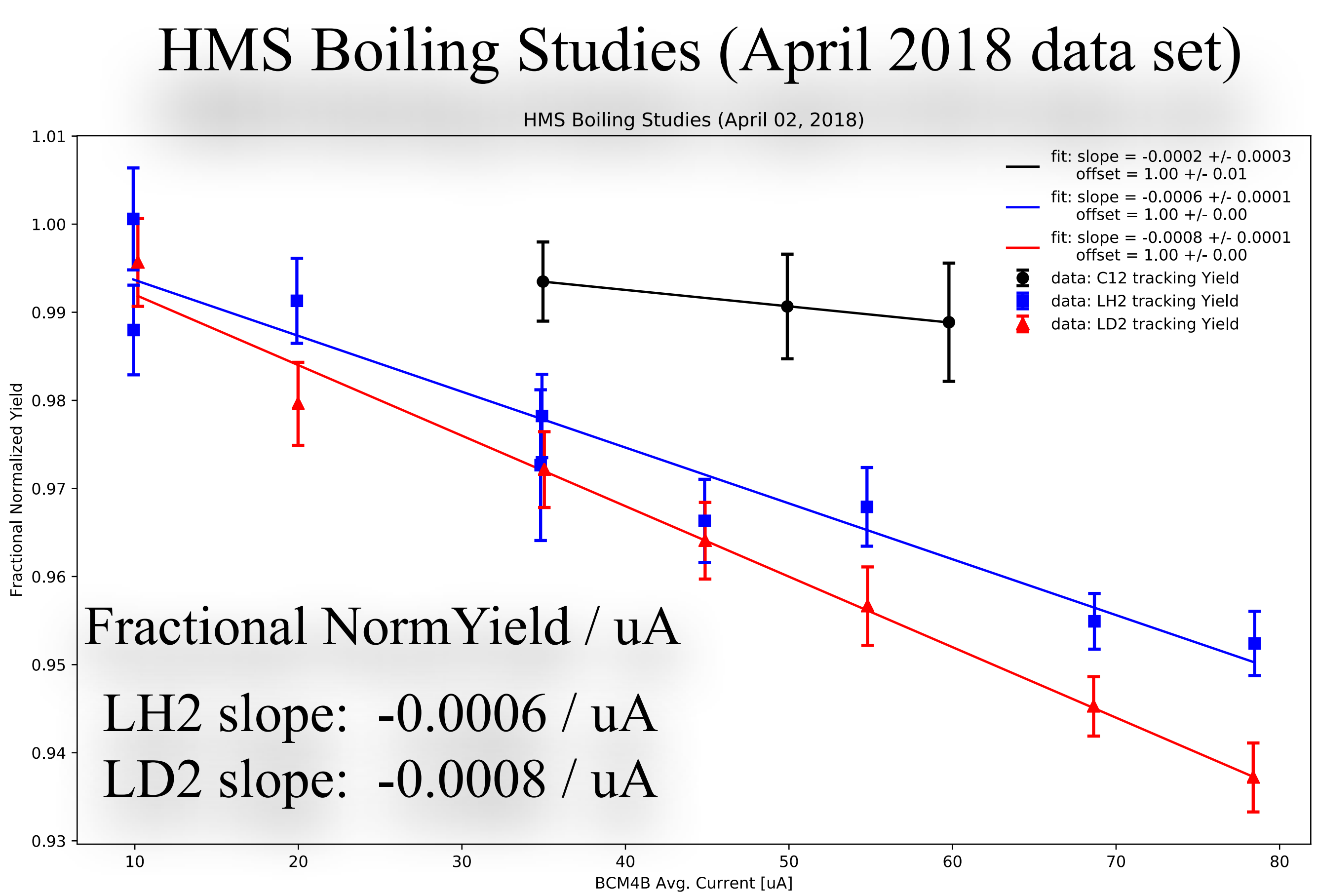
* How does the tracking algorithm perform at high rates?

Results of p-Absorption and Target Boiling Corrections to the Data Yield



For Full Description of Proton Absorption Analysis, See DOC DB Link HERE !

(ONLY relevant for coincidence experiments)



For Full Description of Target Boiling Corrections See DOC DB Link HERE !

Extraction of D(e,e'p)n Cross Section

- Corrected data Yield for inefficiencies and charge
  (explain basic definition of experimental cross section)

- Radiative Corrections

- Bin-Centering Corrections

(SEE BACK-UP SLIDES)

D(e,e'p) Momentum Distributions

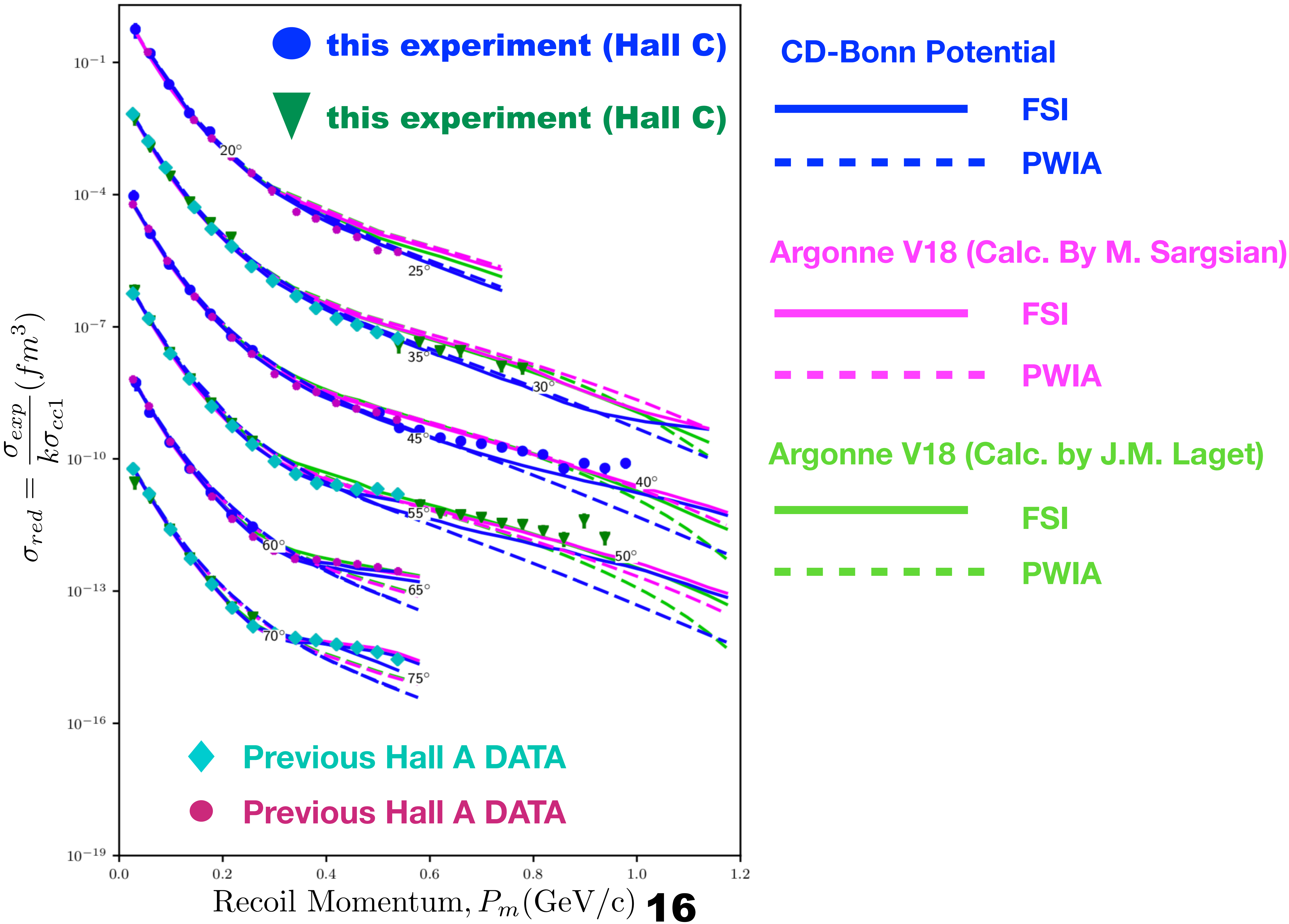
$$\boxed{\sigma_{red}} \equiv \frac{\boxed{\sigma_{bc}^{exp}}}{\boxed{k\sigma_{cc1}}}$$

Fully Corrected Experimental cross sections

Kinematic Factor times deForest e-N cross section

Reduced cross section (momentum distributions in PWIA)

Preliminary Results for this Experiment !



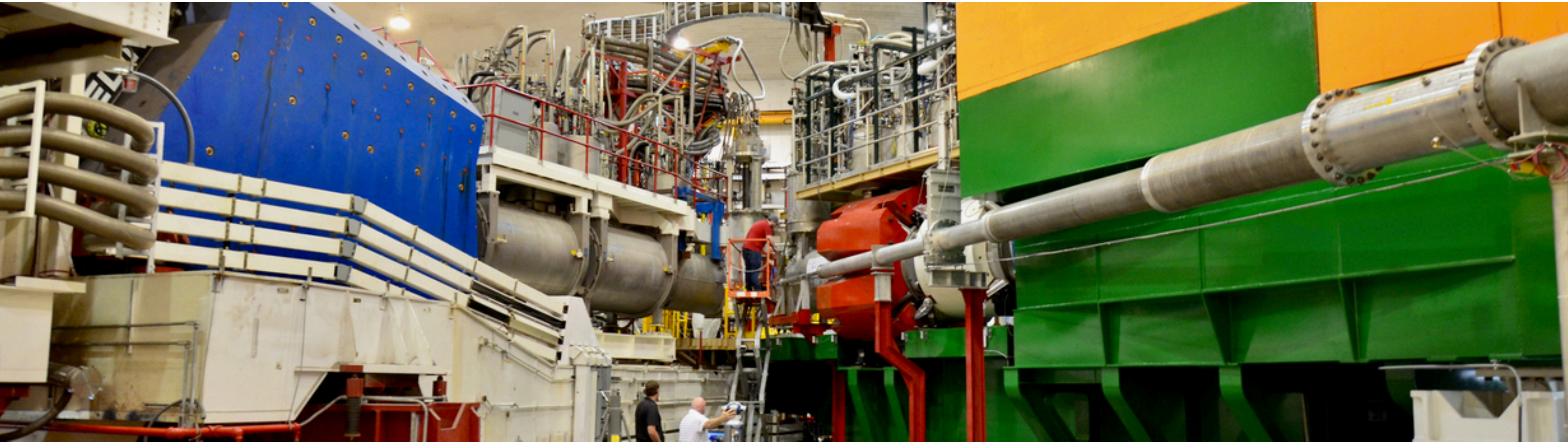
SUMMARY & OUTLOOK

- **This experiment (commissioning) ran for 3 PAC days (6 days total) out of the approved 21 PAC days.**

- **Preliminary results shows reasonable agreement with previous Hall A data at low recoil momenta**

- **At high recoil momenta, the data are NOT well described by either models.**

Very interesting results at high missing momentum with ONLY 6 days of beam time, as data does NOT seem to be well described by theory in small FSI region ! ! !



THANK YOU !

BACK-UP SLIDES

EXTRACTION OF CROSS SECTIONS:

BASIC CONCEPT

Extraction of the D(e,e'p)n Cross Section

$$\bar{\sigma}^{exp} \equiv \frac{Y^{corr}_{data}}{V^{P.S.}}$$

Corrected Data Yield

Phase Space Volume

$$Y^{corr}_{data} = \frac{Y^{uncorr}_{data} \cdot f_{rc}}{Q_{tot} \cdot \epsilon_{tLT} \cdot \epsilon_{htrk} \cdot \epsilon_{etrk} \cdot \epsilon_{tgtBoil} \cdot \epsilon_{pAbs}}$$

Radiative Correction

Normalize data by total charge

Correct for Inefficiencies

Extraction of the D(e,e'p)n Cross Section

$$V^{P.S.} = \frac{N_f}{N_{acc}}\mathcal{J}_{corr} \rightarrow \frac{N_f}{N_{acc}} \equiv \frac{\mathcal{L}}{N_{gen}} d\omega d\Omega_e d\Omega_p$$

Normalization Factor

Accepted Events within spec. Acceptance

Jacobian Correction to solid angles

Luminosity

Spectrometer "Solid Angles"

Generated Events

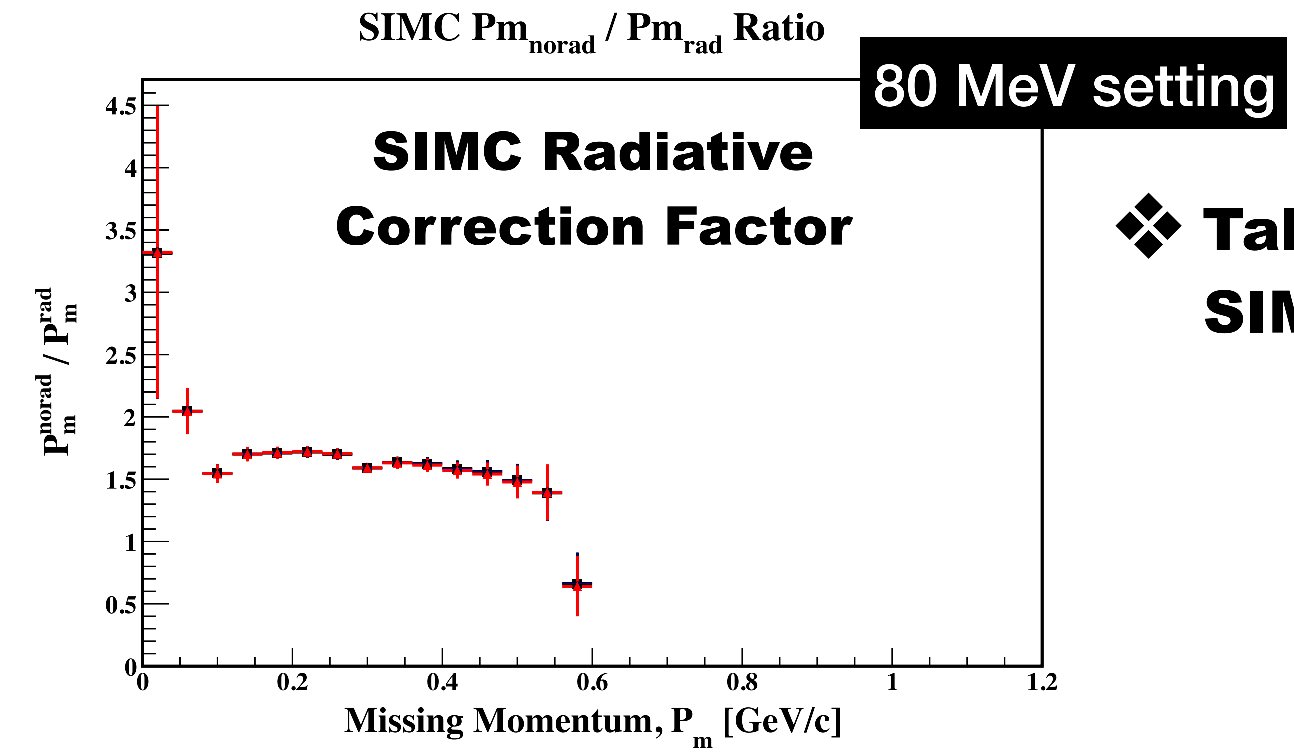
*(See simc.f in SIMC) for definition of normalization factor

RADIATIVE CORRECTIONS

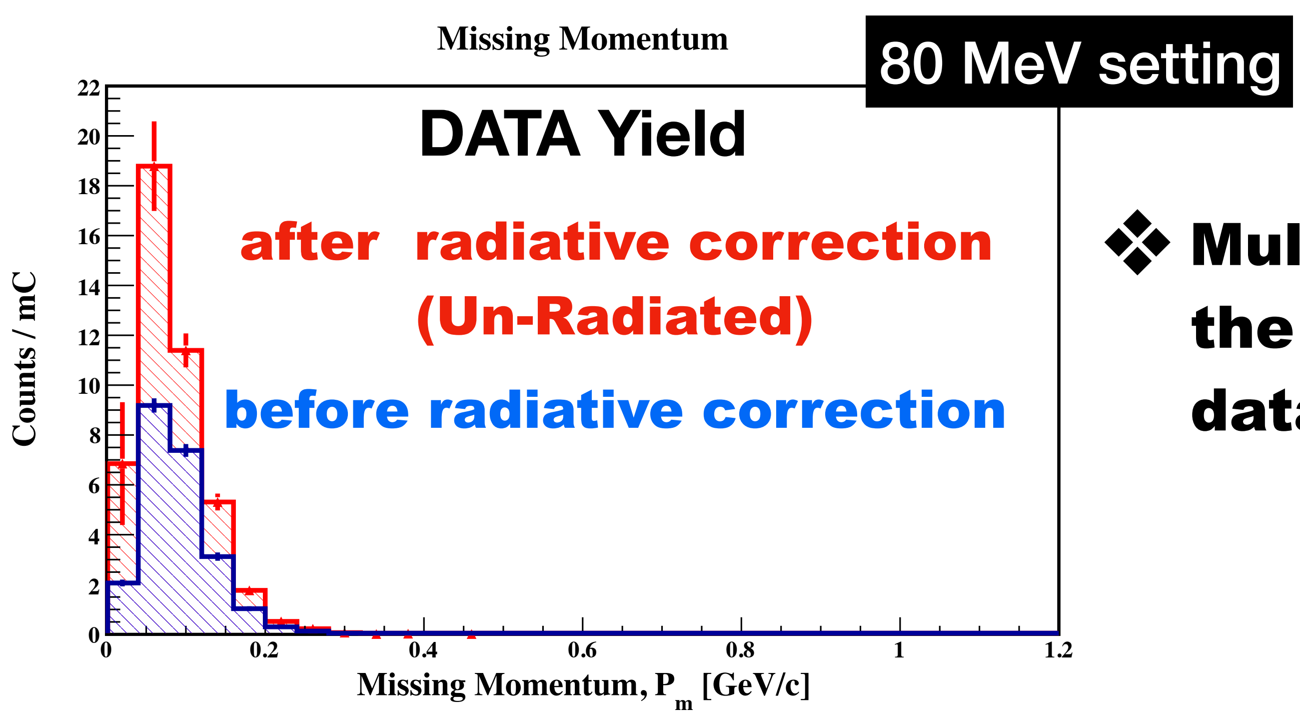
Extraction of the D(e,e'p)n Cross Section

❖ **Decide which kinematic variable to bin (or store) the cross section.**
(I choose to store the cross section in missing momentum bins)

❖ **Only apply radiative corrections to the relevant variable chosen**
(No need for unnecessary histograms)

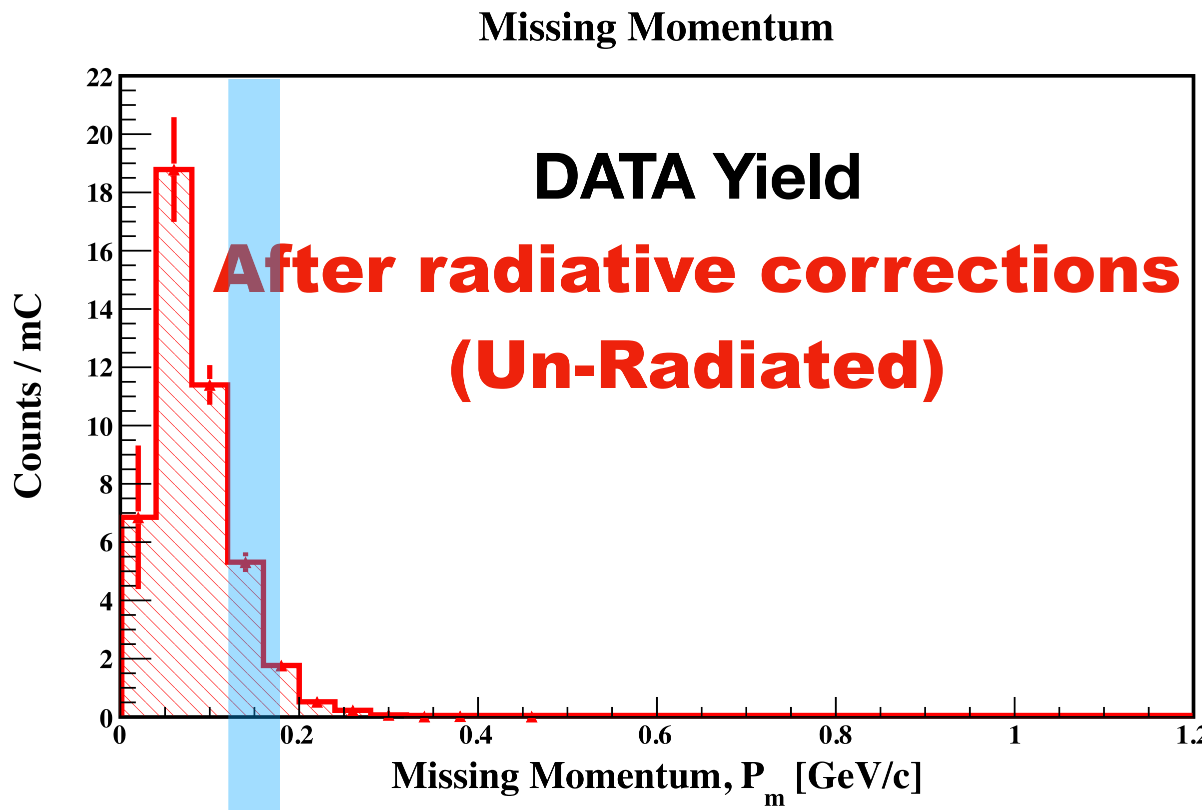


❖ **Take ratio between non-radiative to radiative SIMC Yield to get correction factor bin by bin.**

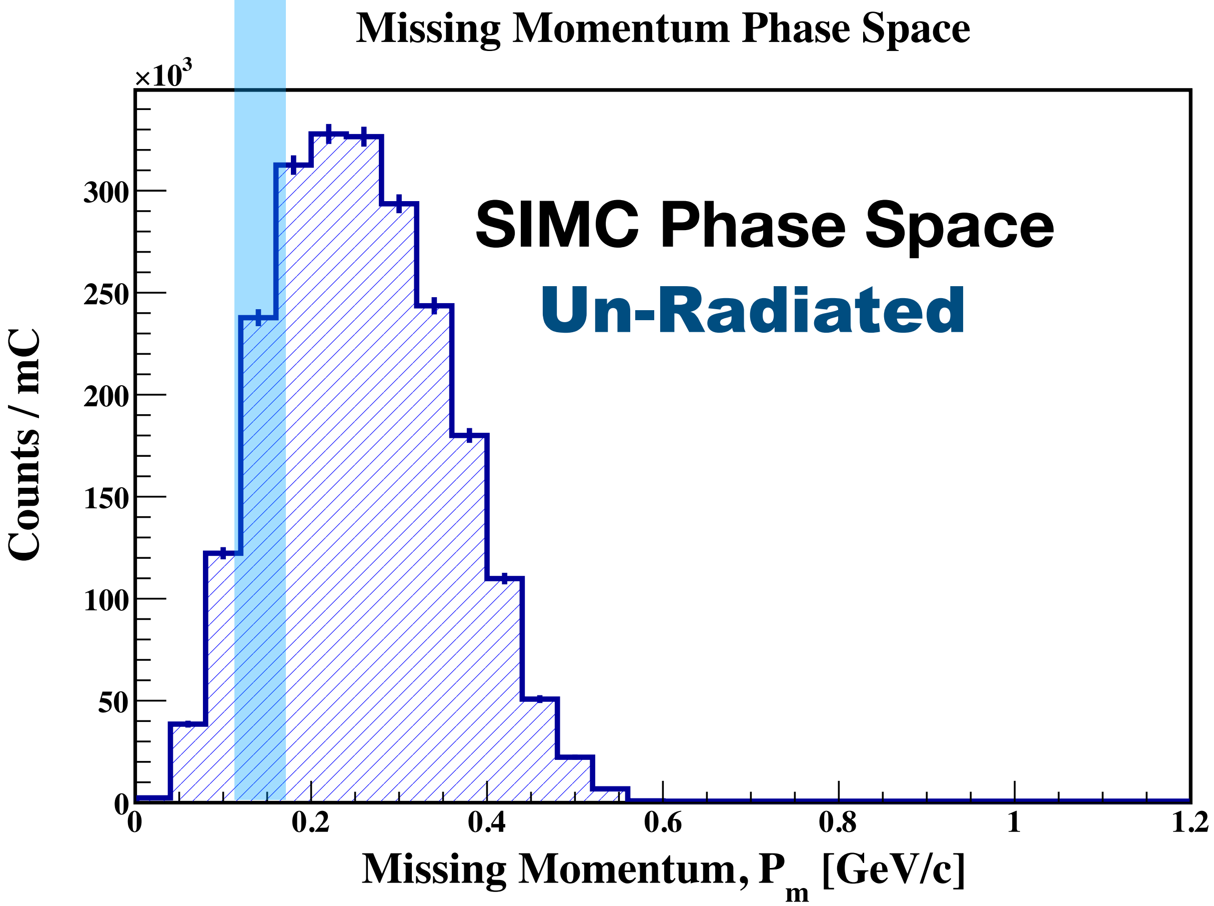


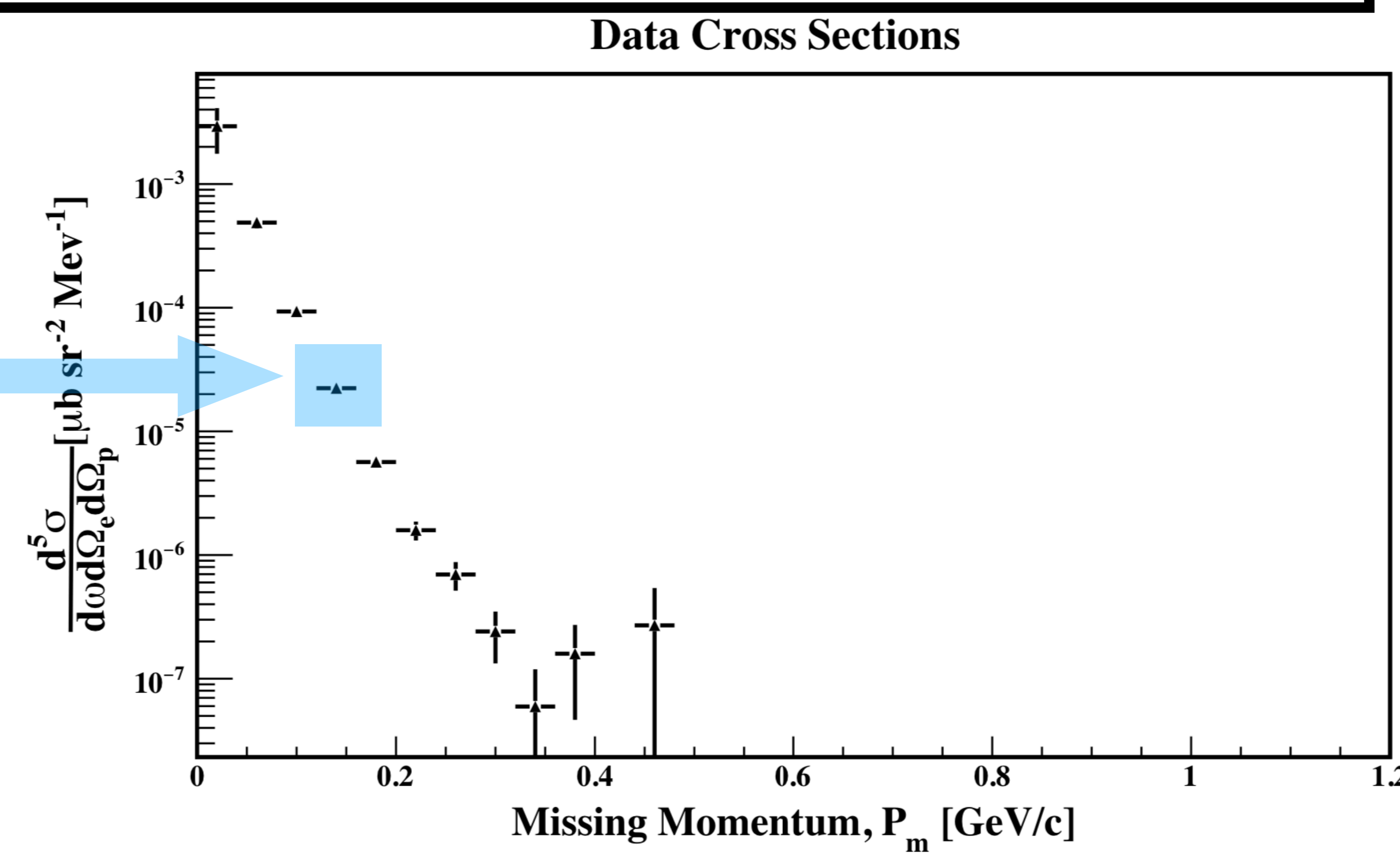
❖ **Multiply the radiative correction factor by the un-radiative data yield to get the corrected data yield bin-by-bin.**

Extraction of the D(e,e’p)n Cross Section



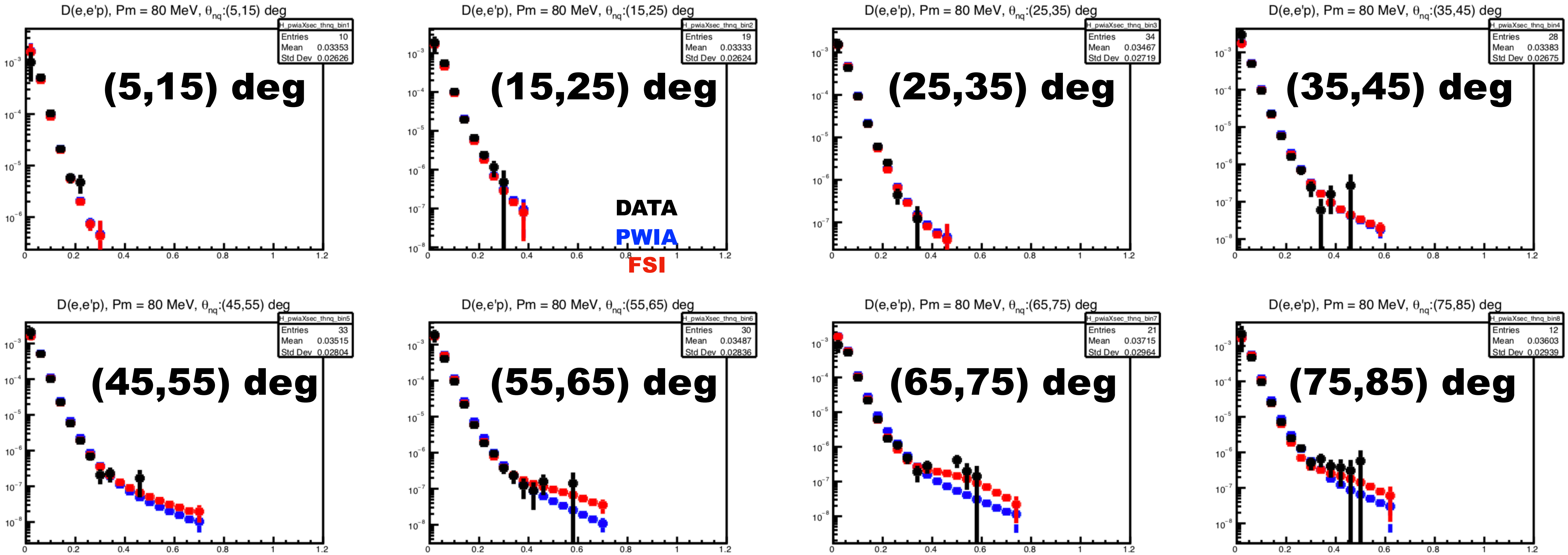
The ratio of the fully corrected data yield to the SIMC phase space will give the data cross section, bin-by-bin





Extraction of the D(e,e'p)n Cross Section

- ❖ **D(e,e'p)n 80 MeV setting Cross Section Binned in different recoil neutron angles.**

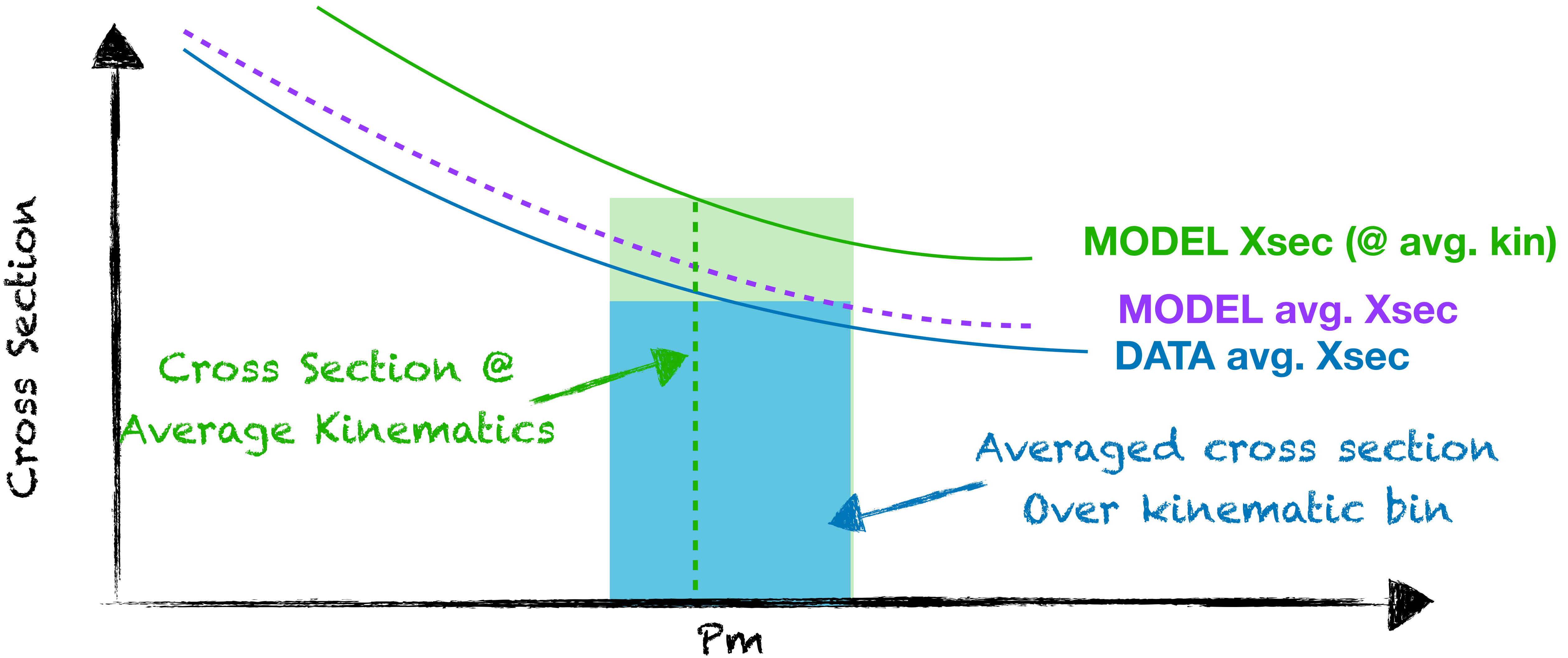


BIN-CENTERING

CORRECTIONS

Bin Centering Corrections

❖ **In reality, the measured data cross section is an average over the kinematic bin in which it is stored.**



Model cross section at the averaged kinematic variables

Model average cross section -> simcYield / PhaseSpace

(SIMC Yield does NOT have to be corrected for efficiencies or charge, as it is assumed all efficiencies are 100% and a 1 mC charge is assumed in the input file)

$$f_{bc} = \frac{\sigma^{model}(\bar{E}_b, \bar{Q}^2, \bar{\omega}, \bar{\theta}^{cm}_{pq}, \bar{\phi}_{pq})}{\bar{\sigma}^{model}}$$

Bin-centering correction

Bin Centering Corrections

- Currently, Hall C software does **NOT** do energy loss corrections, therefore, the average kinematics were calculated from vertex quantities in simulation.

Kinematic bin (e.g. Pm bin
where cross section is stored)

$$\bar{x}_k = \left(\frac{\sum_i w_i x_i}{\sum_i w_i} \right)_k$$

(blue)	**Averaged kinematic variable x over kinematic bin k**
(red)	**Weight times kinematic variable summed over all events**
(green)	**Sum of the weights over all events**

Bin Centering Corrections

❖ **Once the averaged kinematics have been calculated, . . .**

$\bar{x}$: avg. kinematics $\xrightarrow{\text{IN}}$ Theoretical Model (usually a code that takes the input) $\xrightarrow{\text{OUT}}$ $\sigma^{model}(\bar{E}_b, \bar{Q}^2, \bar{\omega}, \bar{\theta}_{pq}^{cm}, \bar{\phi}_{pq})$

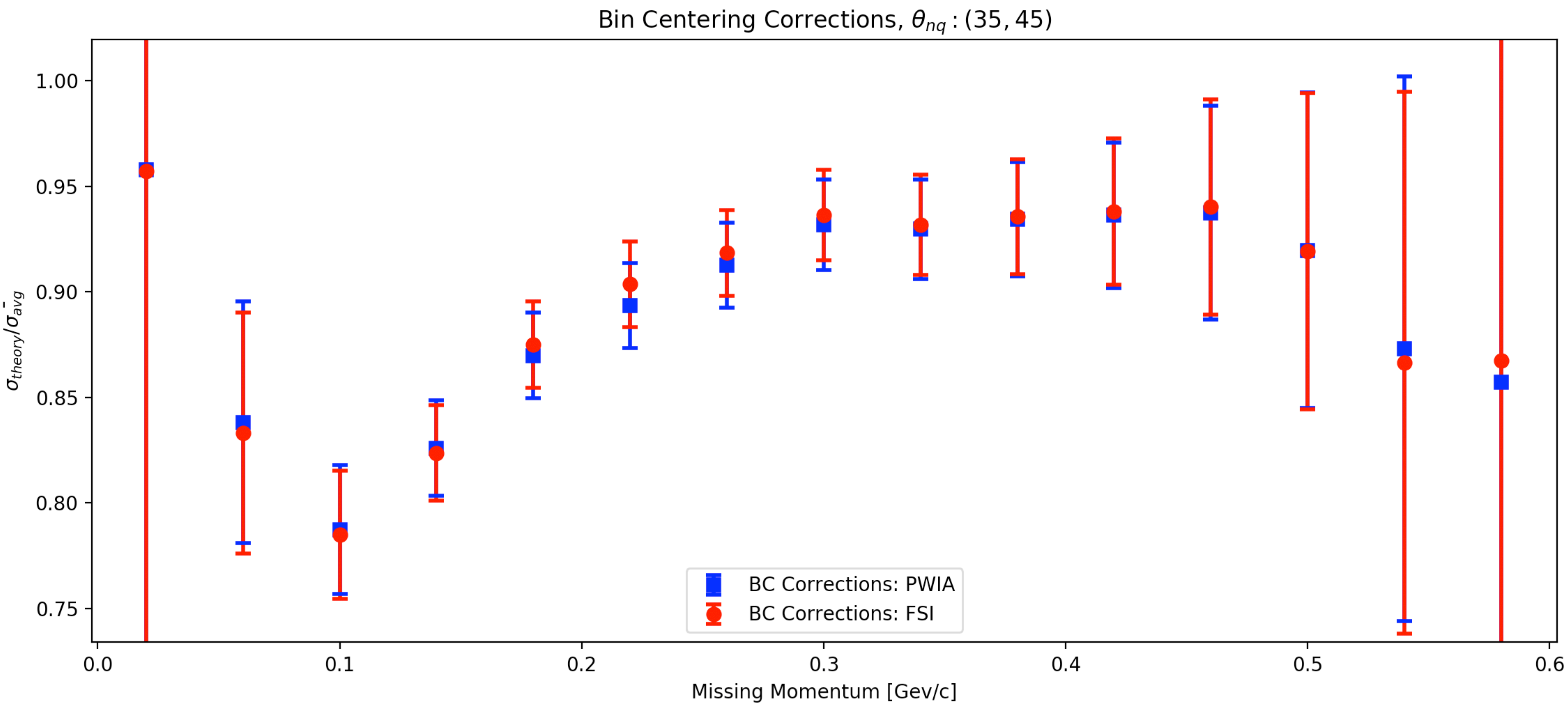
$\bar{\sigma}^{model} \equiv \dfrac{Y^{\mathrm{SIMC}}}{V^{P.S.}}$ $\longrightarrow$ **Averaged Model Cross Section**
(See Slide 21 for reference)

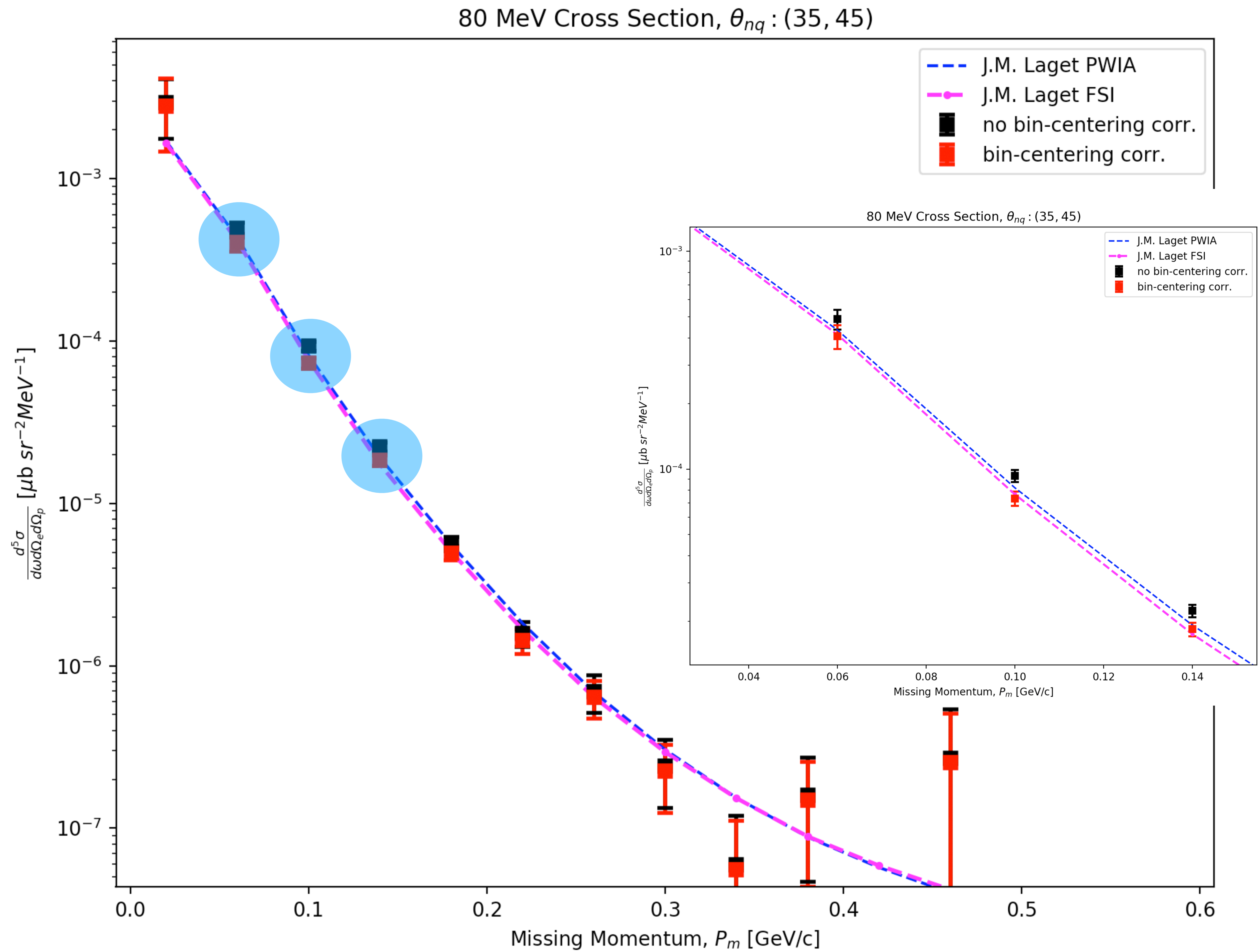
❖ **Correct the data bin-by-bin using the model cross sections ratio . . .**

$$\sigma_{bc}^{exp} = \bar{\sigma}^{exp} \cdot \frac{\sigma^{model}(\bar{E}_b, \bar{Q}^2, \bar{\omega}, \bar{\theta}_{pq}^{cm}, \bar{\phi}_{pq})}{\bar{\sigma}^{model}}$$

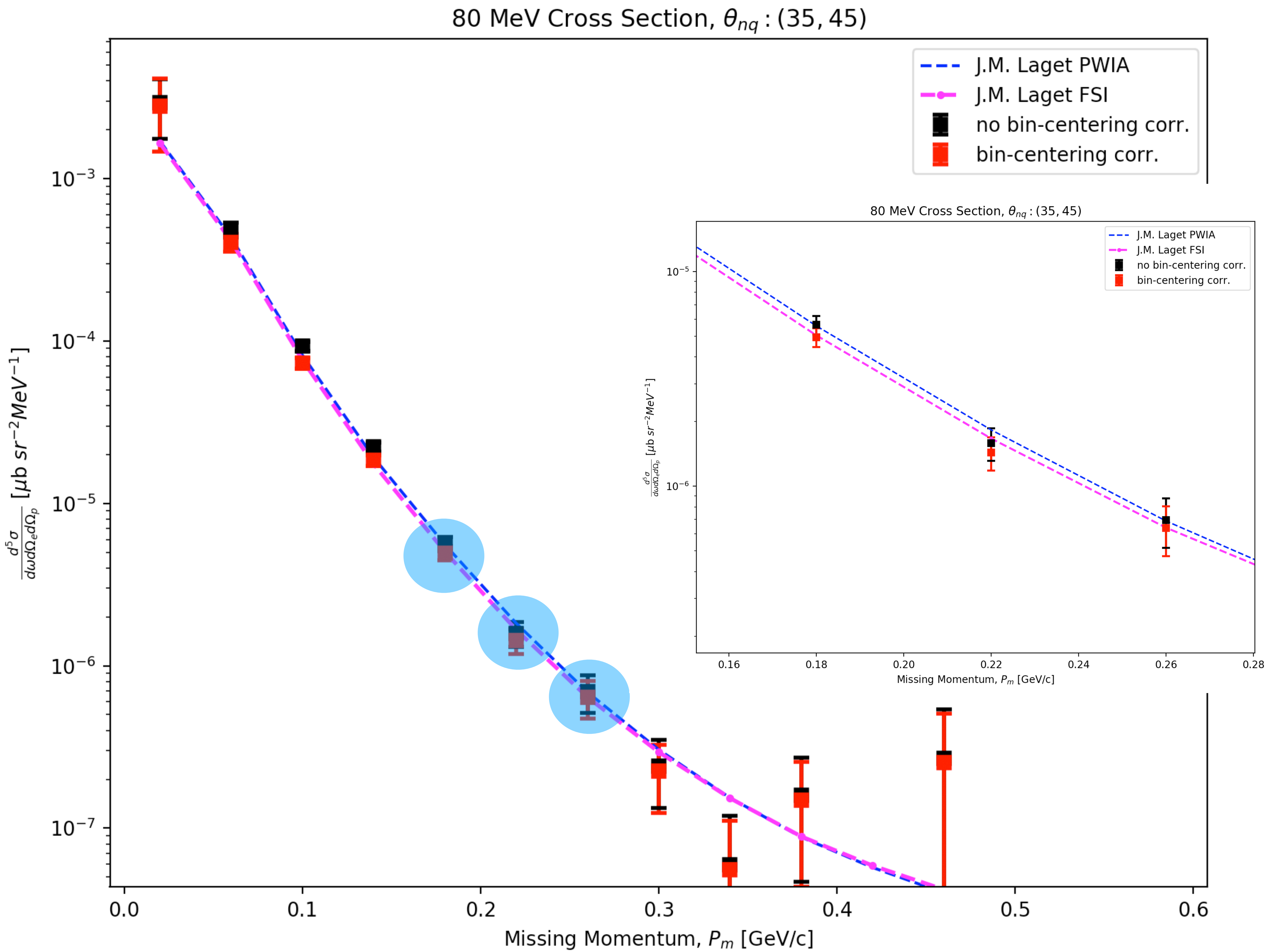
Bin Centering Corrections

❖ **Bin-centering correction factor for the 80 MeV setting**

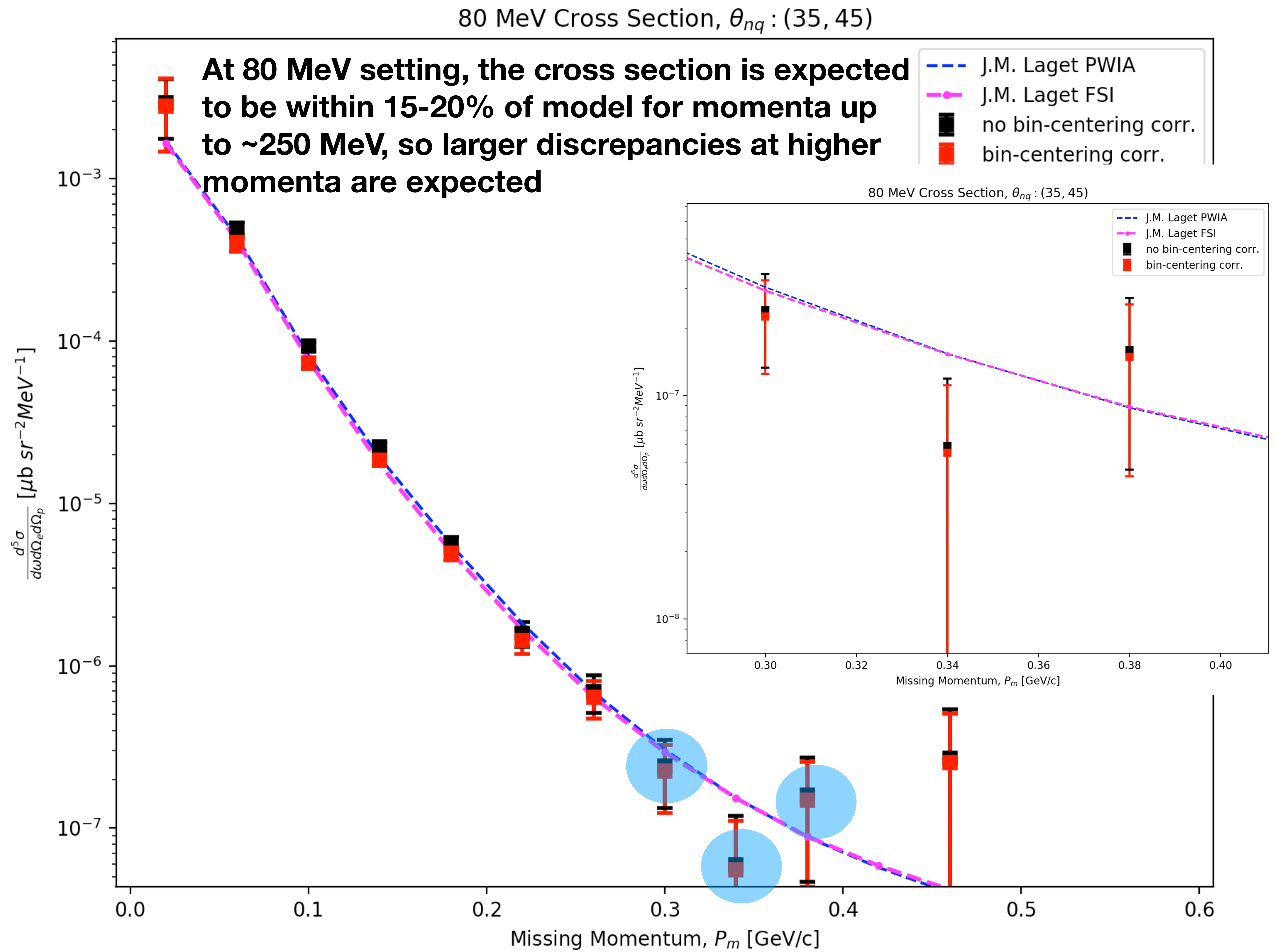




80 MeV Cross Section, $\theta_{nq}:(35,45)$
J.M. Laget PWIA
J.M. Laget FSI
no bin-centering corr.
bin-centering corr.
$\frac{d^5\sigma}{d\omega d\Omega_e d\Omega_p}$ [$\mu b\ sr^{-2} MeV^{-1}$]
Missing Momentum, P_m [GeV/c]
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.04
0.06
0.08
0.10
0.12
0.14



80 MeV Cross Section, $\theta_{nq}: (35, 45)$
J.M. Laget PWIA
J.M. Laget FSI
no bin-centering corr.
bin-centering corr.
$\frac{d^5\sigma}{d\omega d\Omega_e d\Omega_p}$ [$\mu b\ sr^{-2} MeV^{-1}$]
Missing Momentum, P_m [GeV/c]
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.16
0.18
0.20
0.22
0.24
0.26
0.28


80 MeV Cross Section, $\theta_{nq}:(35,45)$
At 80 MeV setting, the cross section is expected to be within 15-20% of model for momenta up to ~250 MeV, so larger discrepancies at higher momenta are expected
J.M. Laget PWIA
J.M. Laget FSI
no bin-centering corr.
bin-centering corr.
$\frac{d^5\sigma}{d\omega d\Omega_e d\Omega_p}$ $[\mu b\ sr^{-2} MeV^{-1}]$
Missing Momentum, P_m [GeV/c]
80 MeV Cross Section, $\theta_{nq}:(35,45)$
Missing Momentum, P_m [GeV/c]