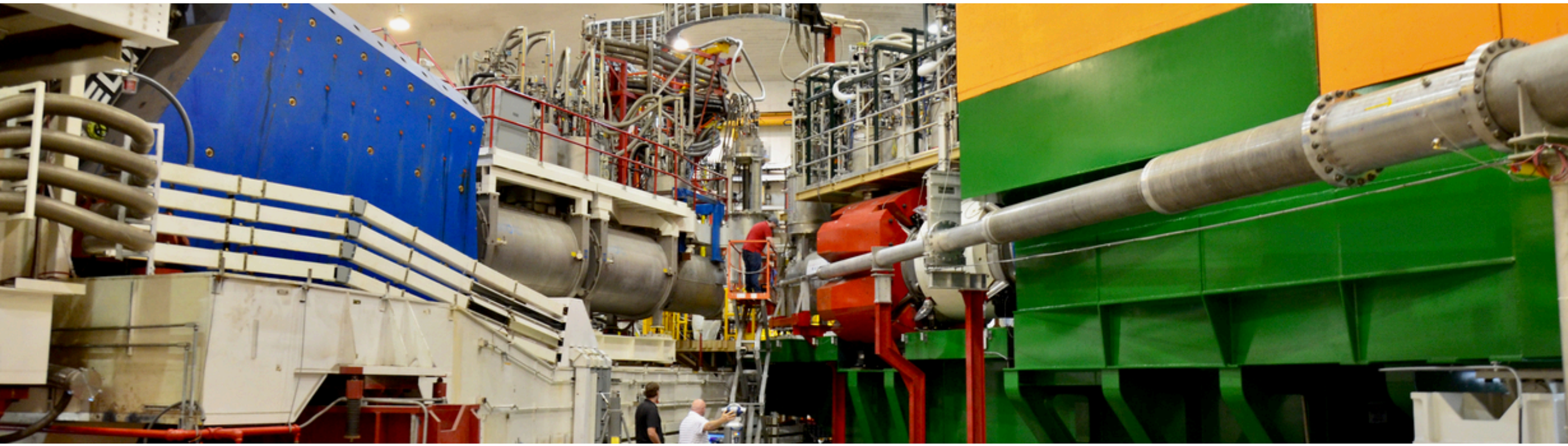


Deuteron Electro-Disintegration Experiment at Hall C (E12-10-003)

Carlos Yero

Spokespeople: Drs. Werner Boeglin and Mark Jones

March 21, 2019

Jefferson Lab
Exploring the Nature of Matter

FIU

Hall C

Motivation

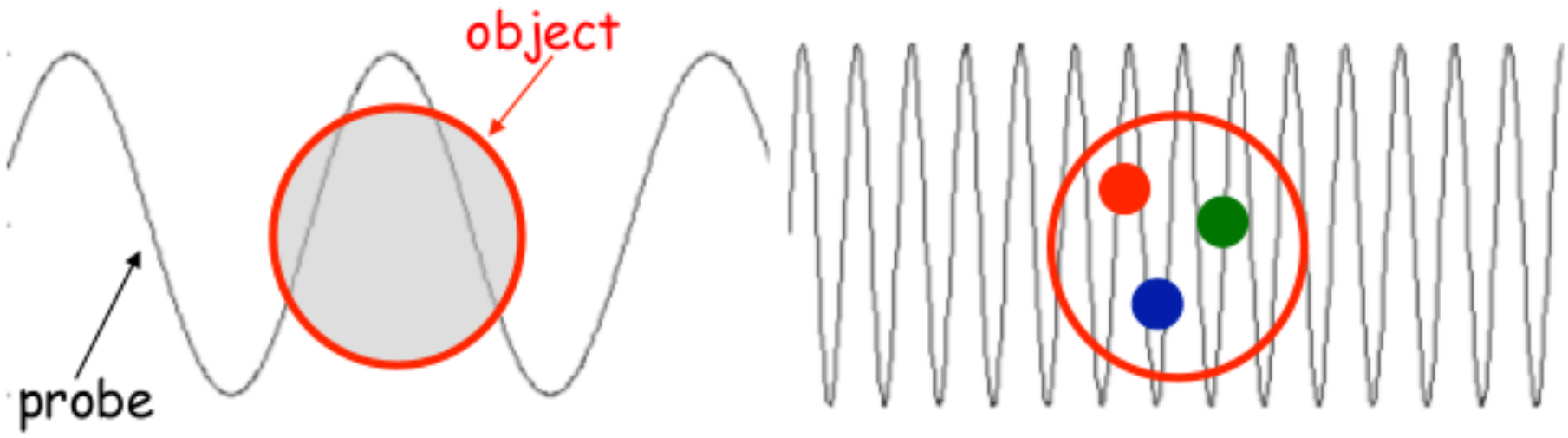
☑ Study Deuteron at short ranges (< 1fm).

High momentum transfers probe the Deuteron at smaller distances.
Smaller inter-nucleon distances enables one to access the high momentum components of nucleons

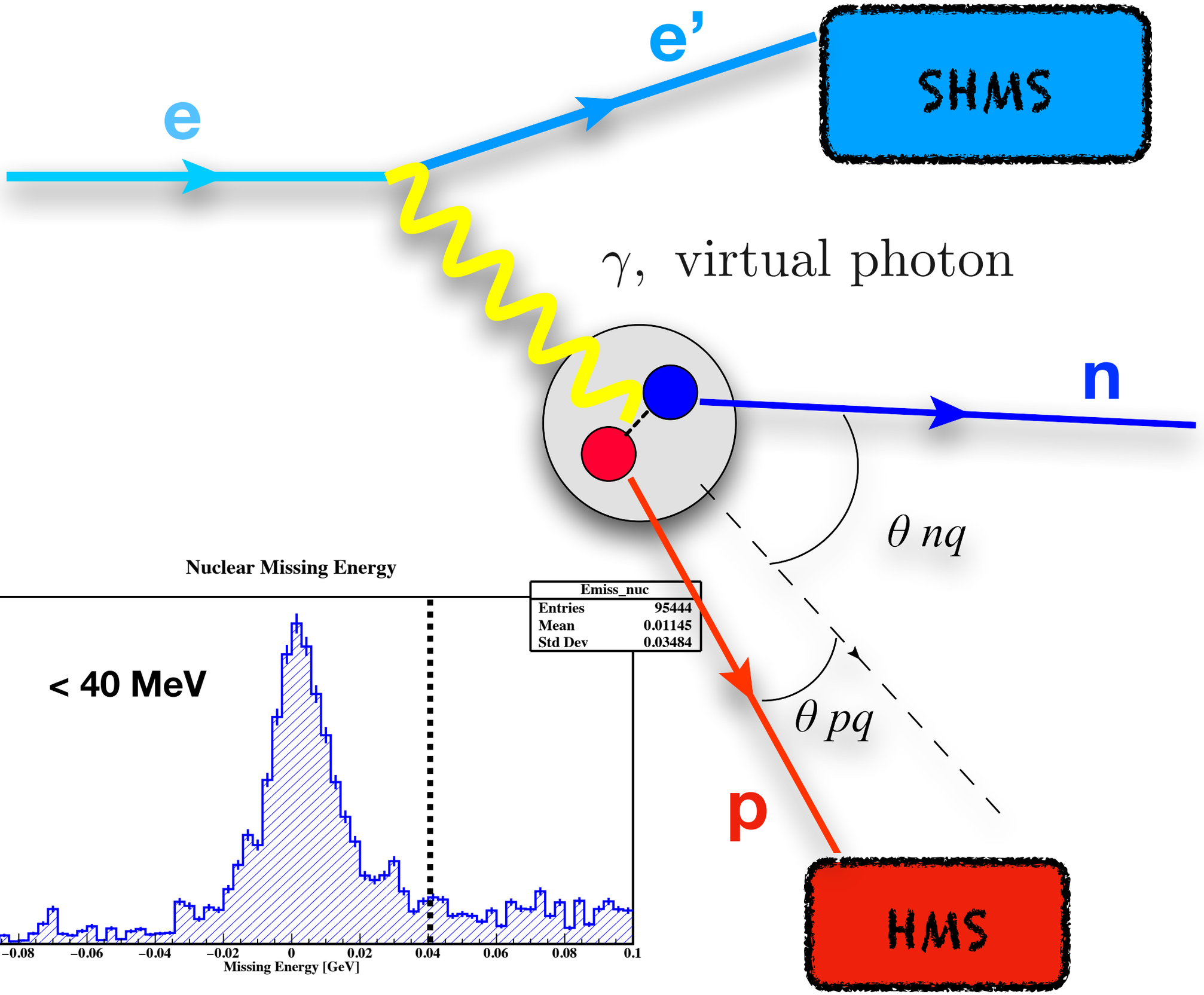
☑ **First time measurements of high missing momentum at large Q2**

☑ Extract D(e,e'p)n cross-section beyond 500 MeV/c missing momentum at high Q2

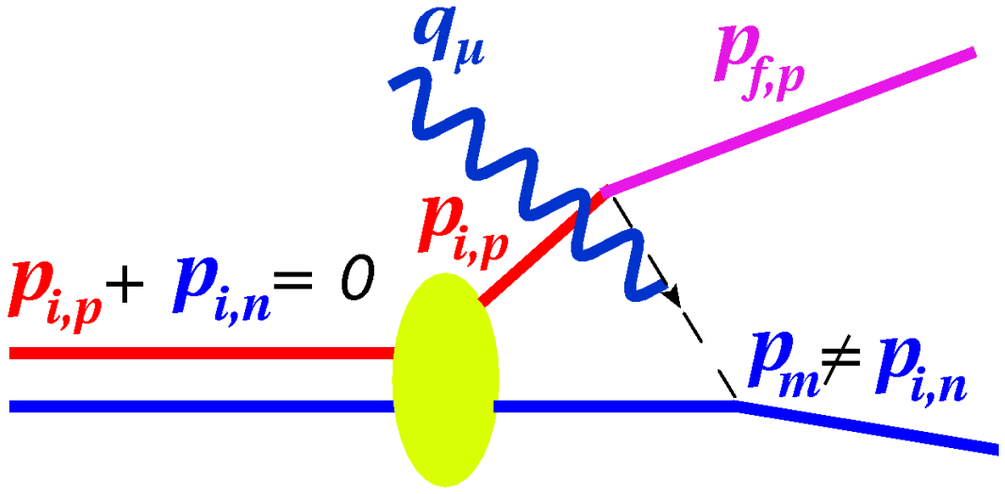
☑ Extract momentum distributions (not an observable) from cross sections.



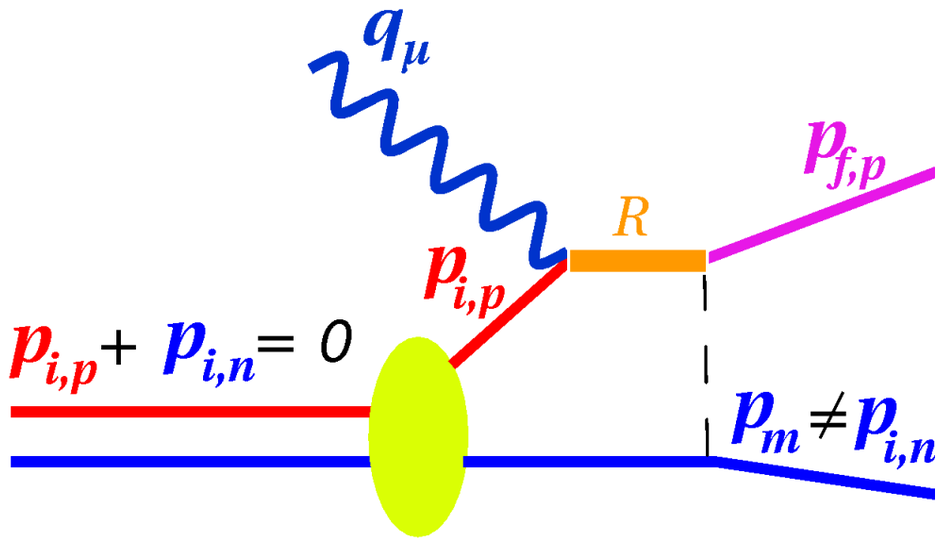
D(e,e'p)n Reaction Kinematics



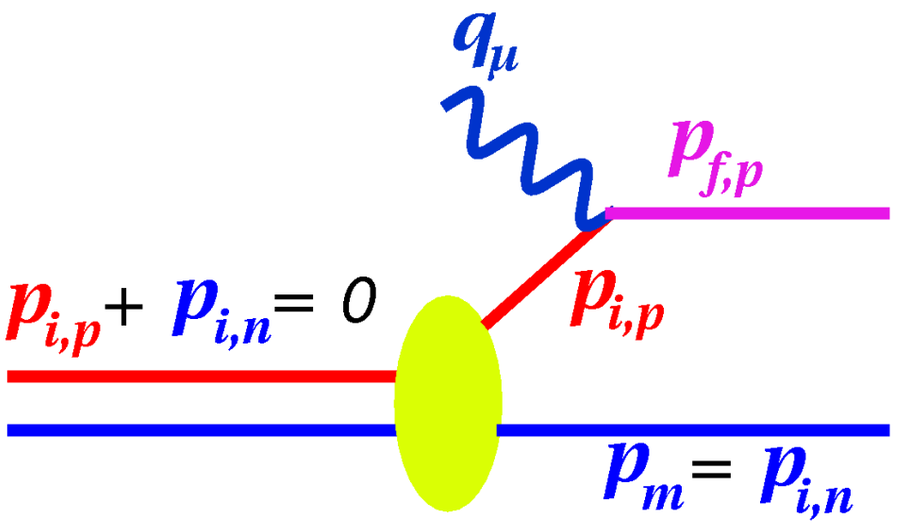
D(e,e'p)n Interactions



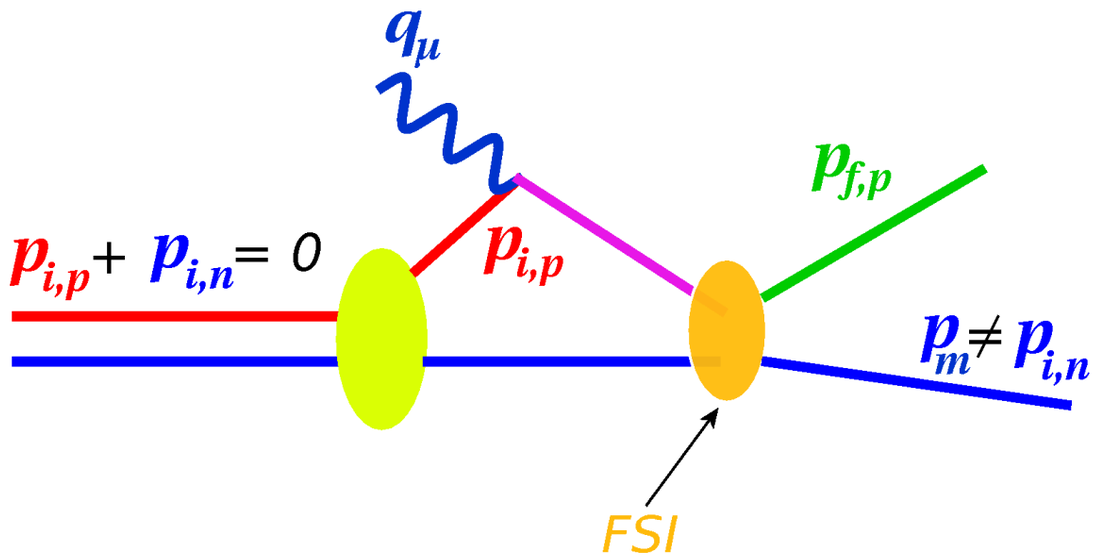
Meson-Exchange Currents (MEC)



Isobar Configurations (IC)



Plane Wave Impulse Approximation (PWIA)



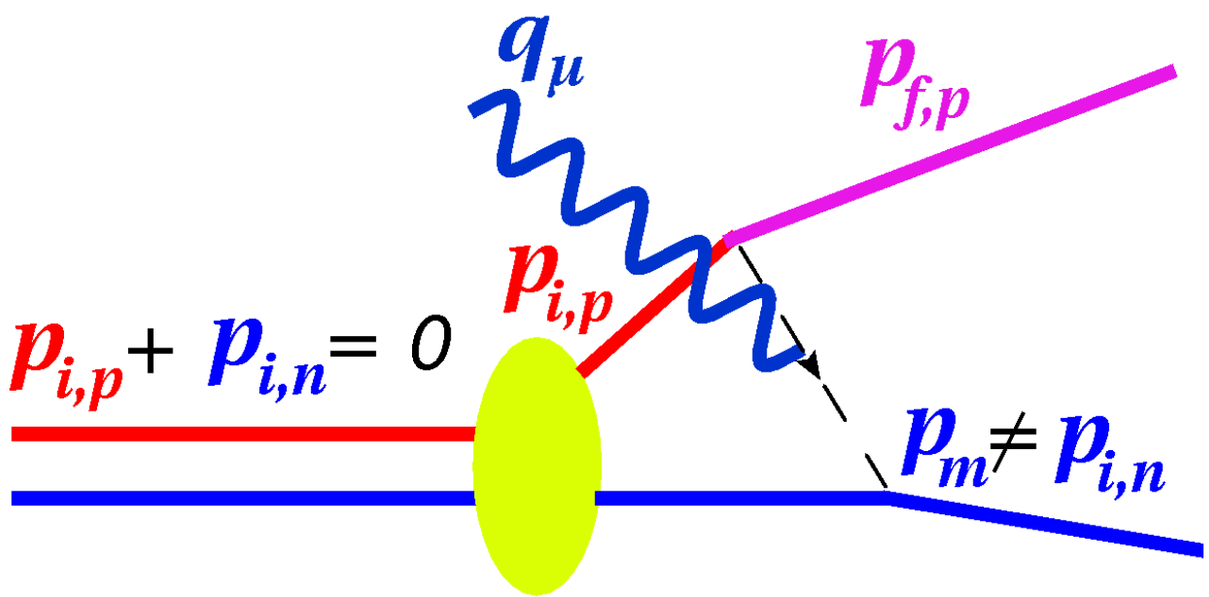
Final State Interactions (FSI)

Meson-Exchange Currents (MEC)

- ☑ Virtual photon couples with exchange meson between nucleons.
- ☑ Virtual meson may become real after photon absorption.
- ☑ Meson exchange propagator is proportional to

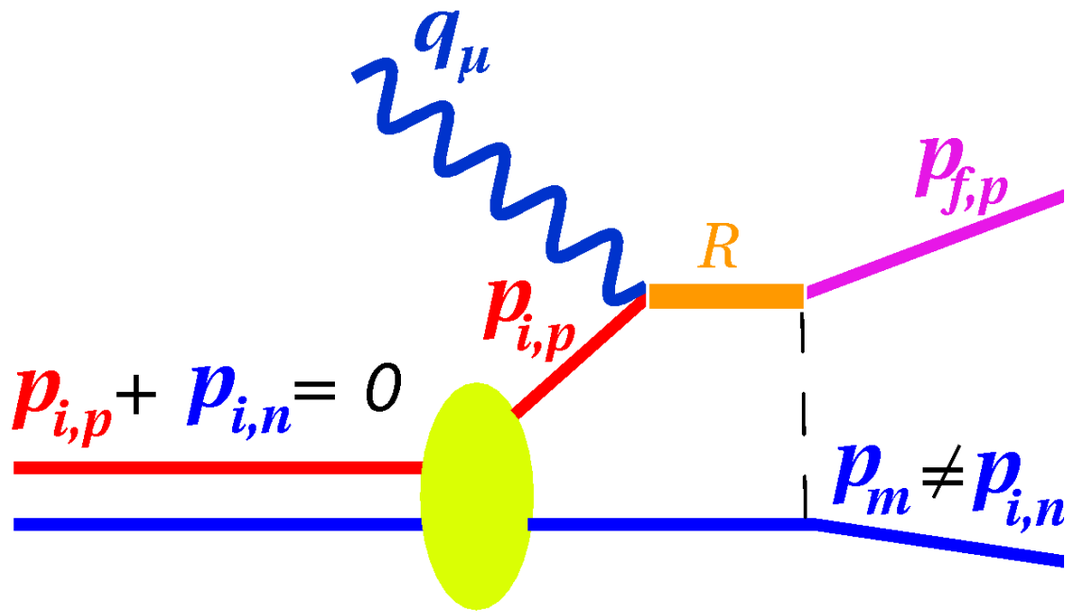
$$(1 + \frac{Q^2}{m^2_{meson}})^{-1}$$

$\Longrightarrow$ MEC suppressed for $Q^2 \gg m^2_{meson}$

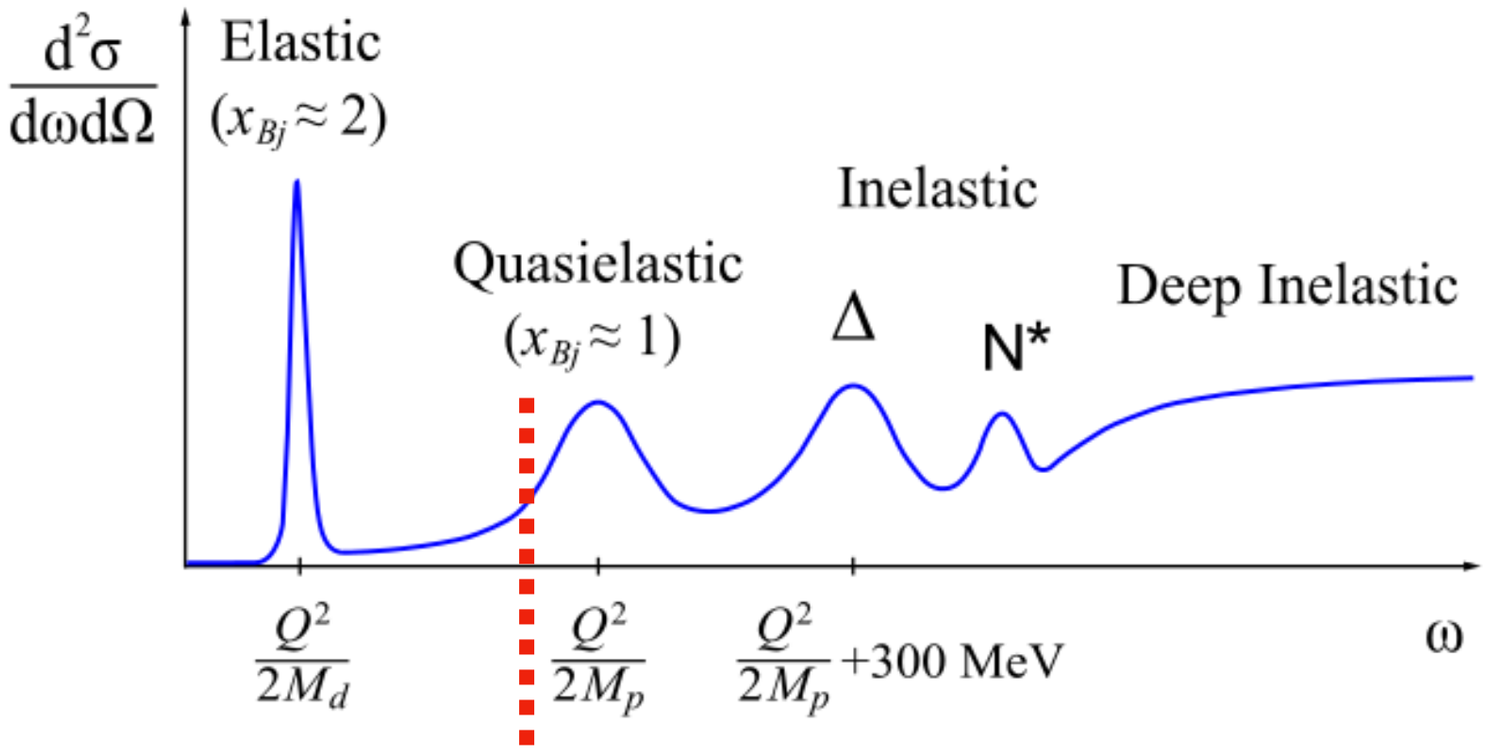


Isobar Configurations (IC)

- ☑ Virtual photon excites nucleon into resonance.
- ☑ Resonance de-excites through meson exchange with spectator nucleon.



- ☑ For high Q^2 and $x_{Bj} > 1$ ($x_{Bj} \equiv \dfrac{Q^2}{2M_p\omega}$) one is able to probe the lower ω region of the quasi-elastic peak to suppress Δ or N^* resonance



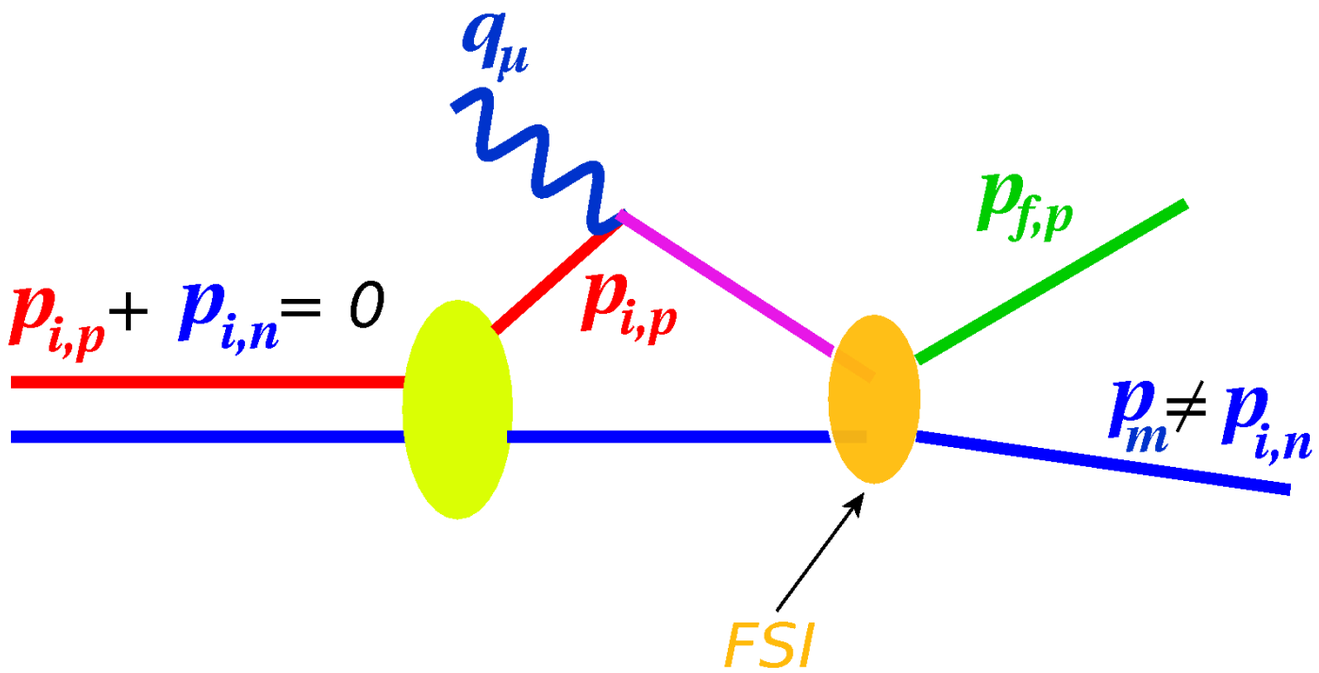
x = 1.35 (E12-10-003)

Final State Interactions (FSI)

- ☑ In final state, the nucleons are at short enough distances (~ 2 fm) and continue to interact

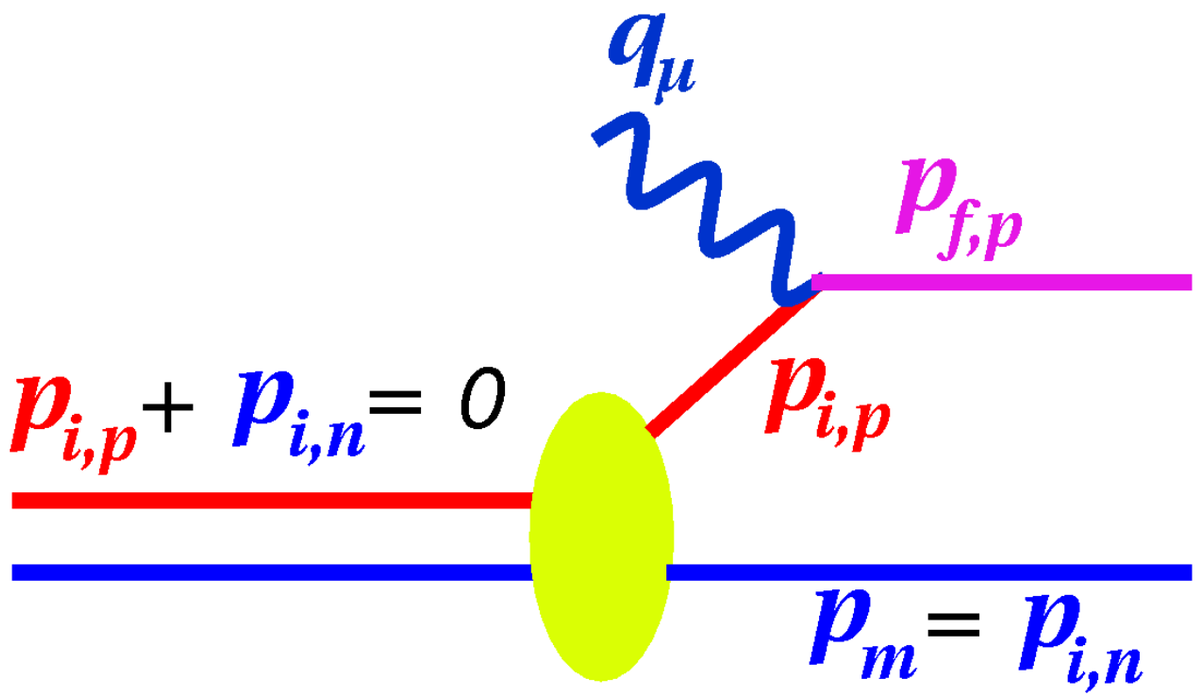
- ☑ Neutron re-scatters with a final momentum different than inside the deuteron

- ☑ FSI are still dominant, even at high momentum transfers and x > 1.
  Certain kinematics must be chosen to suppress this process



Plane Wave Impulse Approximation (PWIA)

- ☑ Virtual photon couples to proton
- ☑ The other nucleon is a spectator
- ☑ Final state particles treated as plane waves (free particles)
- ☑ Direct access to the deuteron momentum distribution (factorization)



Deuteron Momentum Distribution

$$\sigma_{exp} \equiv \frac{d^6\sigma}{d\omega d\Omega_e dT_p d\Omega_p} = K \cdot \sigma_{ep} \cdot S(E_m, p_m)$$

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

ep off-shell cross section

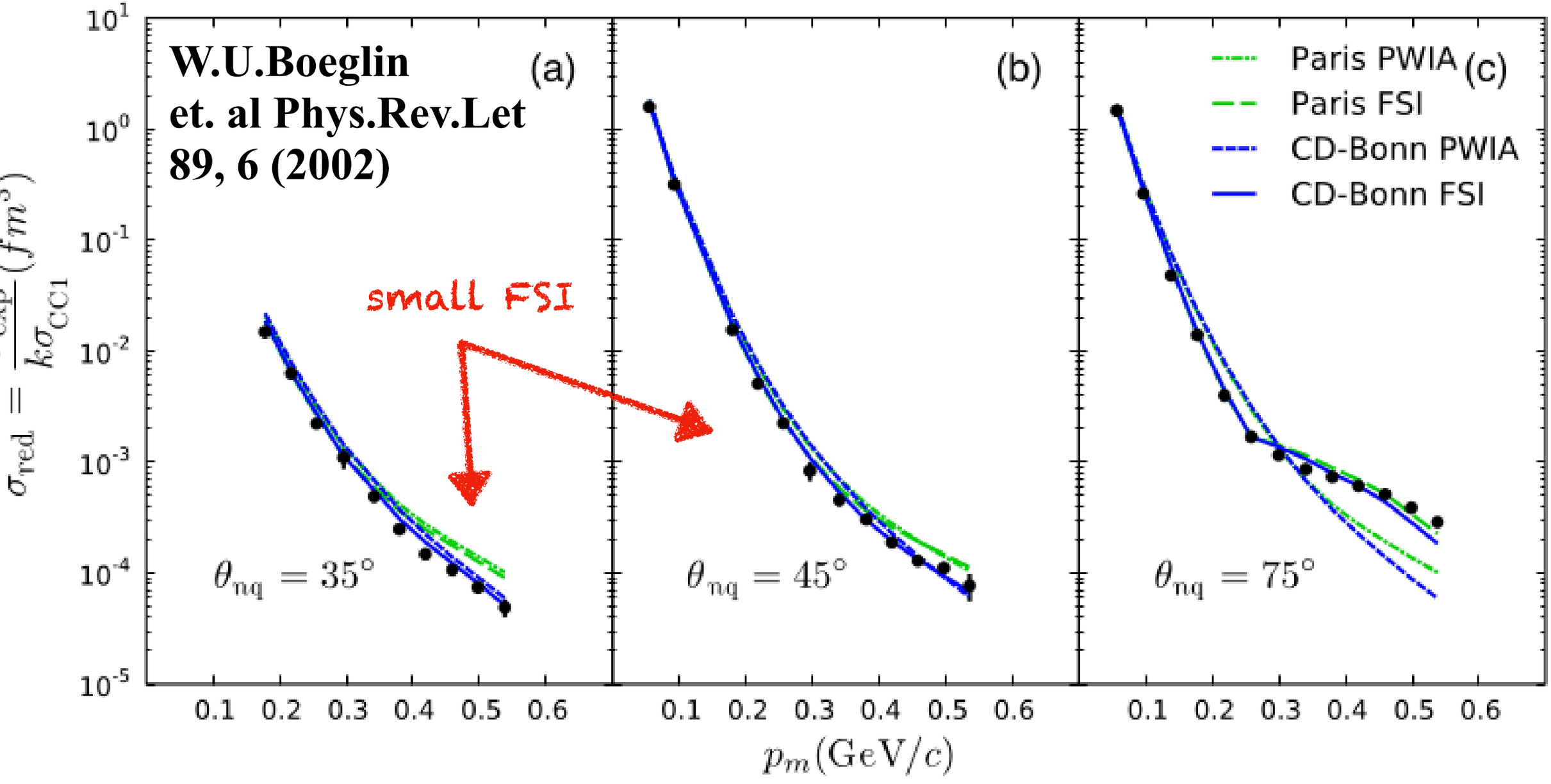
electron scatters off a bound proton within the nucleus; usually, de Forest σ_{cc1} or σ_{cc2} is prescribed

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

Experimental Support for D(e,e'p)n at Hall C

Previous D(e,e'p)n data from Hall A at $Q^2 = 3.25$ GeV^2



- ☑ E12-10-003 Experiment at Hall C focused at $\theta_{nq} \sim 40^o$ and $p_m \geq 500$ MeV/c at $Q^2 = 4.25$ GeV^2

- ☑ Greater sensitivity of deuteron momentum distribution to different NN potential models (e.g. CD-Bonn, Paris, Laget, etc.)

D(e,e'p)n (E12-10-003) Theoretical Background

D(e,e'p)n Kinematics

$E_e = 11$ GeV

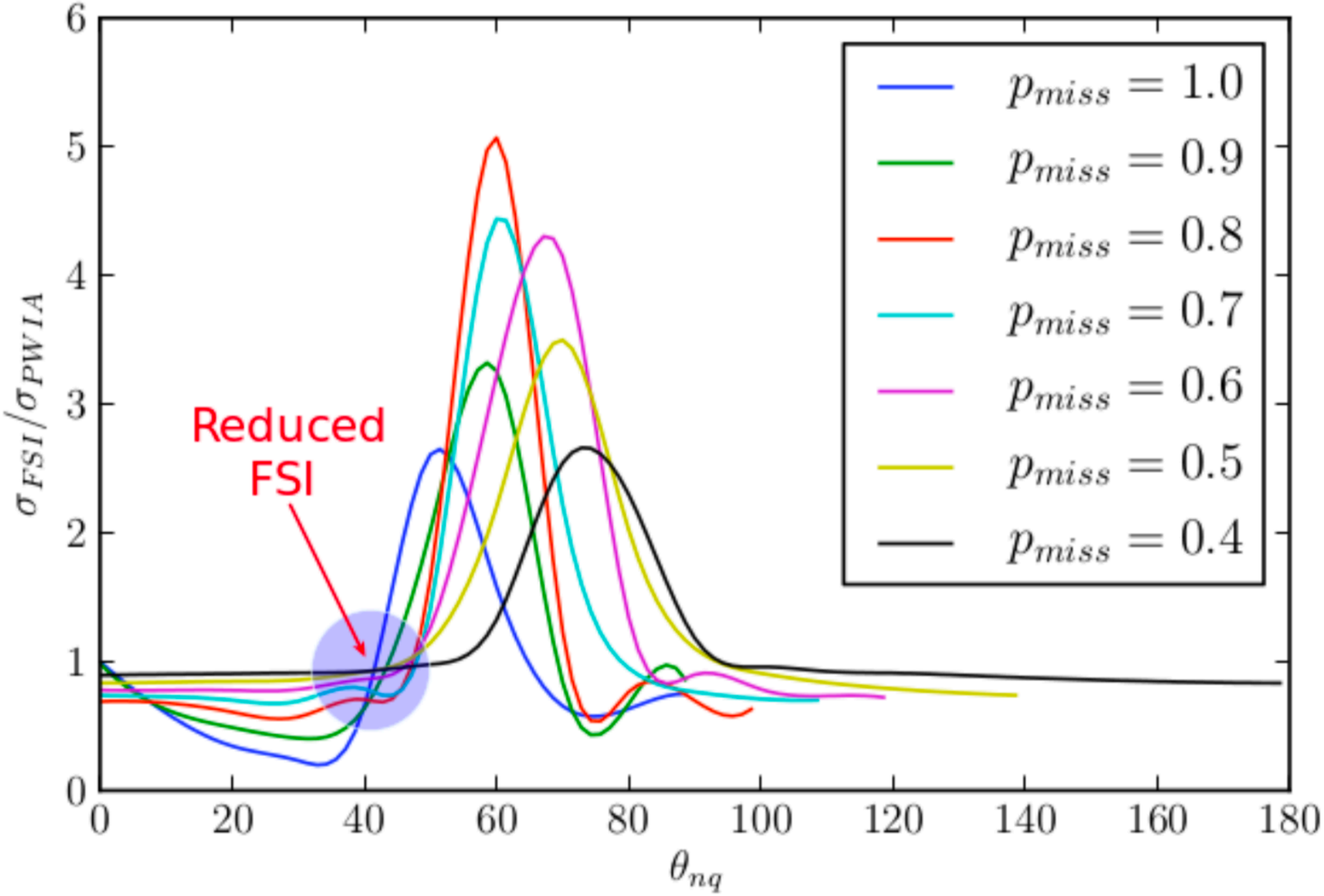
$Q^2 = 4.25$ (GeV/c)^2

$x_{B_j} = 1.35$

$p_m = 0.5 - 1.0$ GeV/c

$\theta_{nq} = 35^\circ - 40^\circ$

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

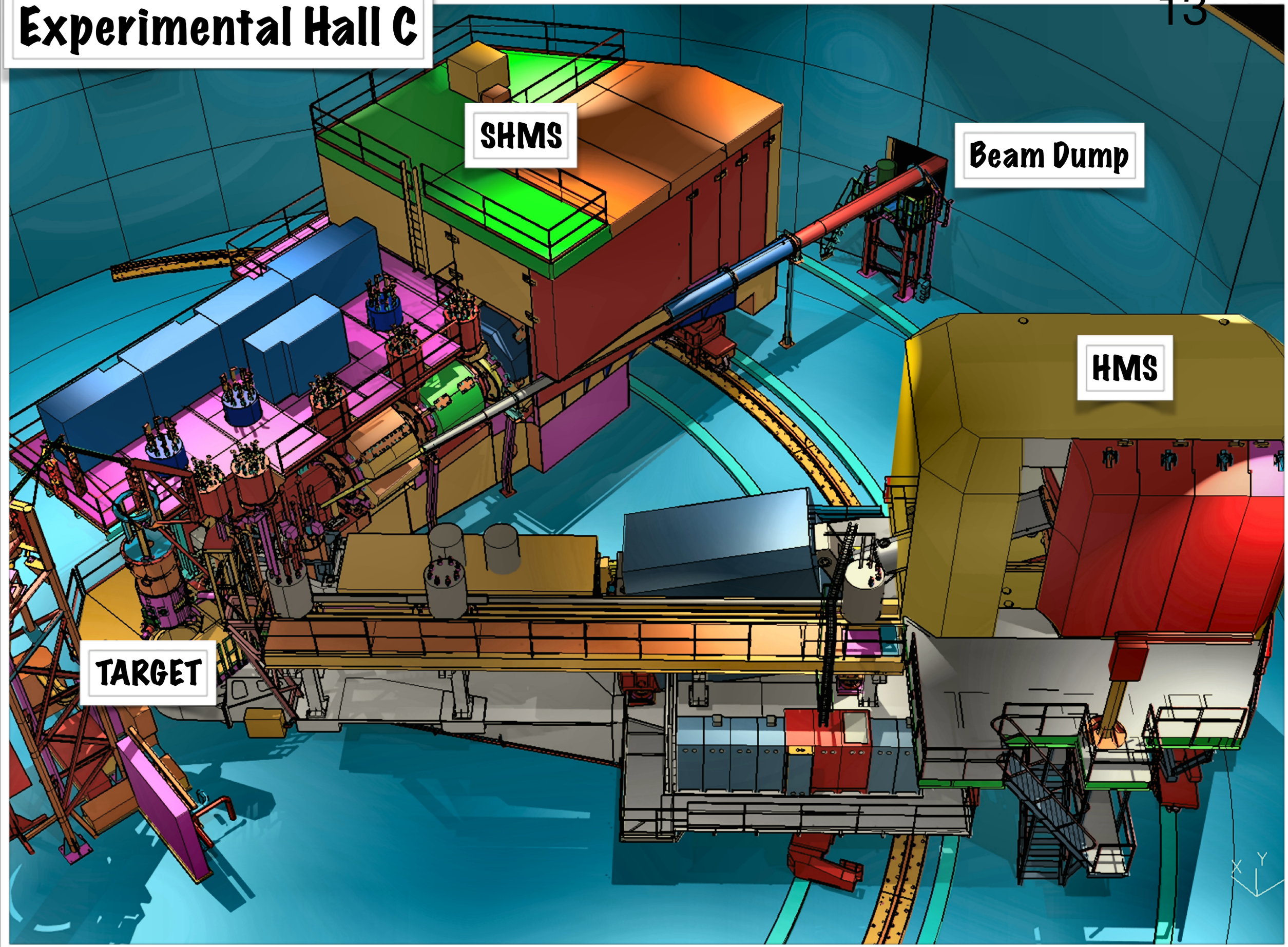


Theoretical Calculation by: M. Sargsian

E12-10-003

Deuteron Break-Up Experiment Background

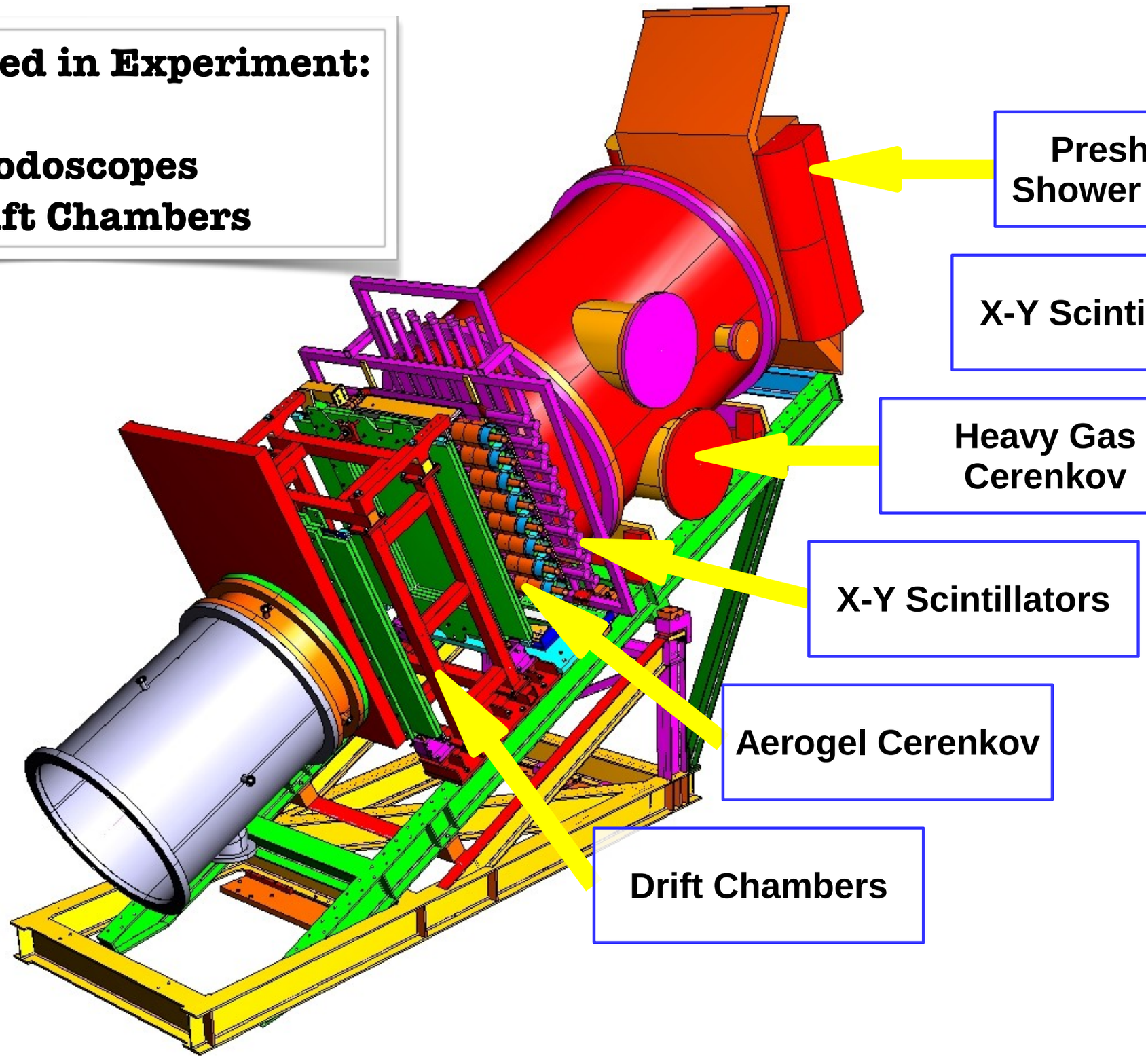
Experimental Hall C



Particle Detectors inside the HMS

Detector Used in Experiment:

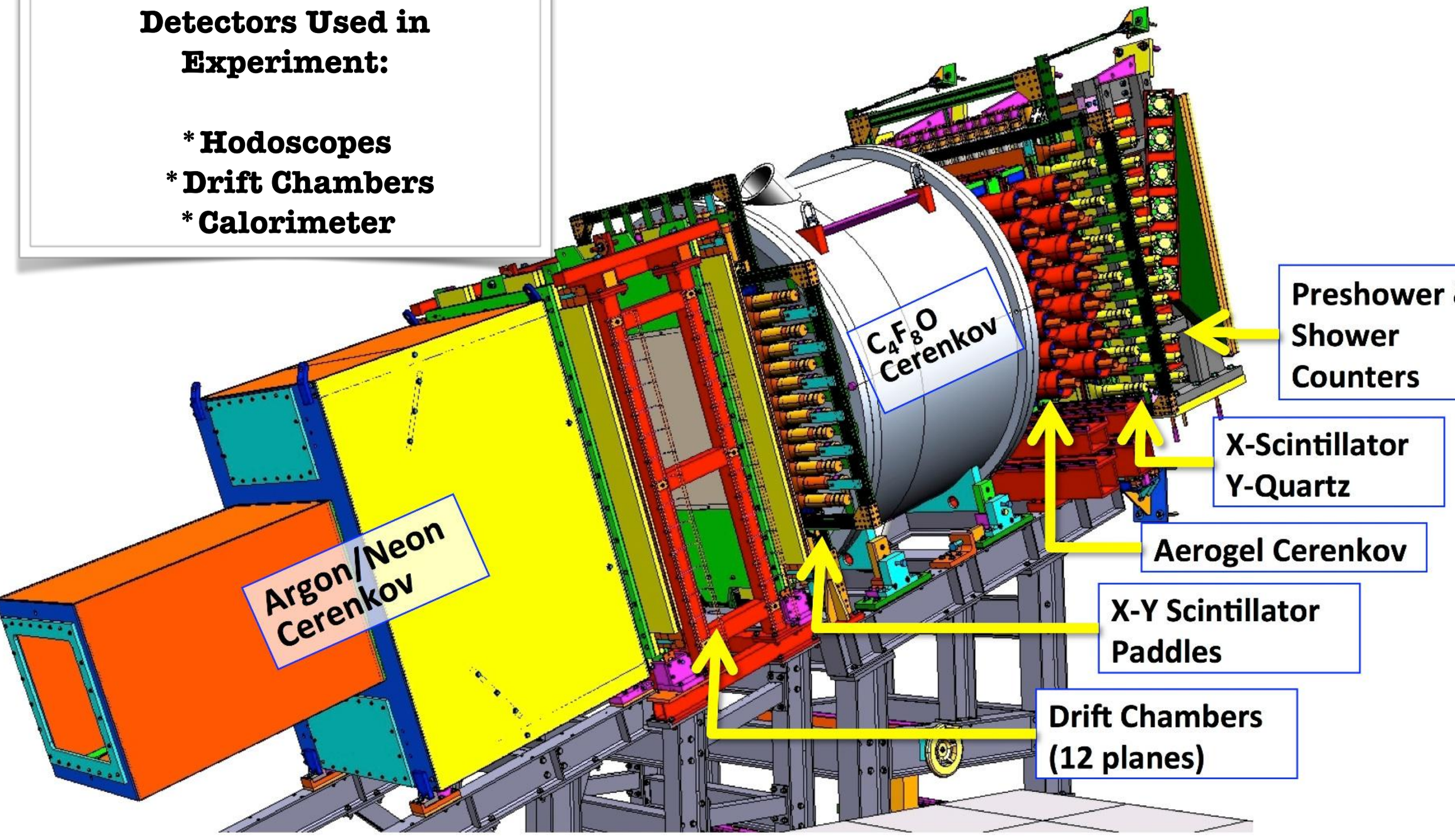
* **Hodoscopes**
* **Drift Chambers**



Particle Detectors inside the SHMS

Detectors Used in Experiment:

* **Hodoscopes**
* **Drift Chambers**
* **Calorimeter**



Experiment Time Line (Year 2018)

April 3 — April 5 — April 9

Carbon Hole
1 H(e,e'p) Elastic
Proton Absorption
Al. Dummy

D(e,e'p)n: Pm=80 MeV
D(e,e'p)n: Pm=580 MeV

NOT YET ANALYZED!

1 H(e,e'p) Elastic
1 D(e,e'p)n : 80 MeV

D(e,e'p)n : 580 MeV
D(e,e'p)n : 750 MeV

D(e,e'p)n : 580 MeV
D(e,e'p)n : 750 MeV

H(e,e'p) Elastics

D(e,e'p)n : 750 MeV

Spectrometer Moved!

Analyze data sets separately

SHMS Q3 Un-Necessary Optics Correction Removed.

ANALYZED

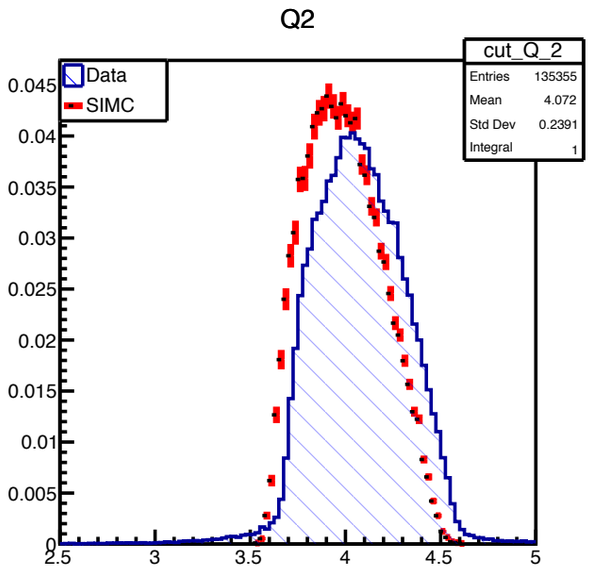
H(e,e'p) Elastics Kinematics

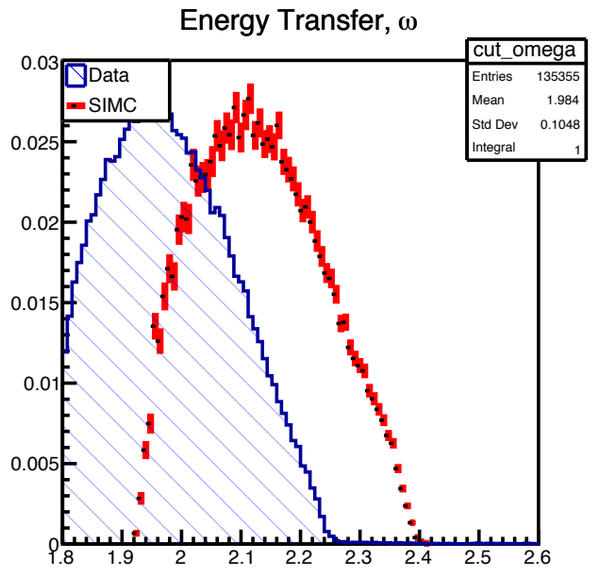
RUN	SHMS Momentum [GeV]	SHMS Angle [deg]	HMS Momentum [GeV]	HMS Angle [deg]	SHMS Delta Range [%]	HMS Delta Range [%]
3288	-8.7	12.194	2.938	37.338	(-6, 2)	(-12,10)
3371	-8.7	13.93	3.480	33.545	(-12, 4)	(-12,10)
3374	-8.7	9.928	2.31	42.9	(3, 8)	(-12,10)
3377	-8.7	8.495	1.8899	47.605	(8, 12)	(-12,10)

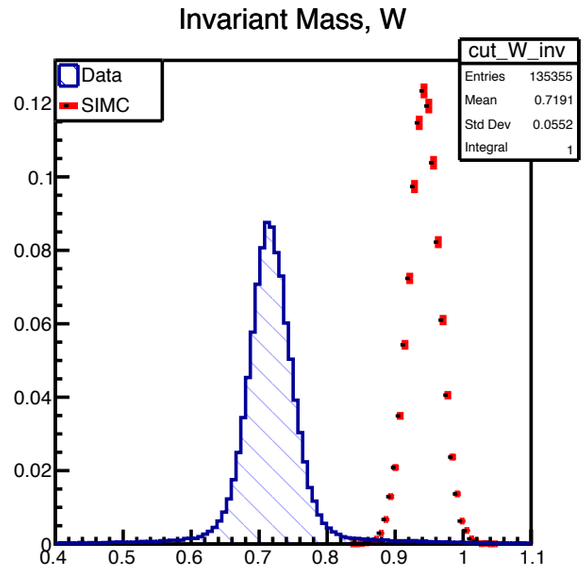
Cover Entire HMS Momentum Range of D(e,e'p)n

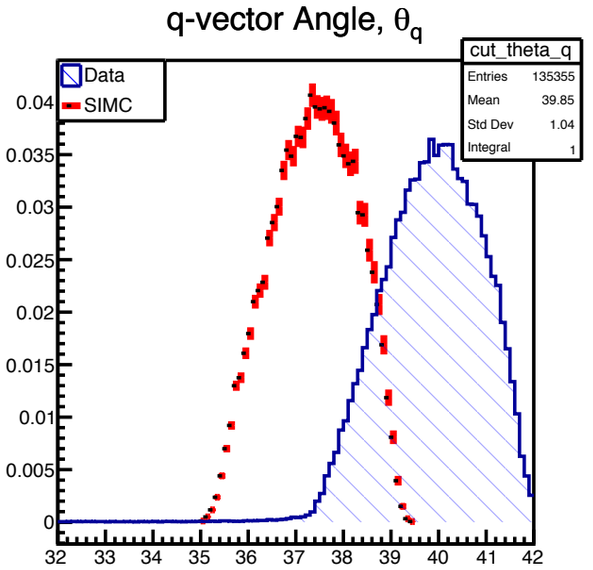
Spectrometers Momentum Corrections / Optimization Using H(e,e')p Elastics

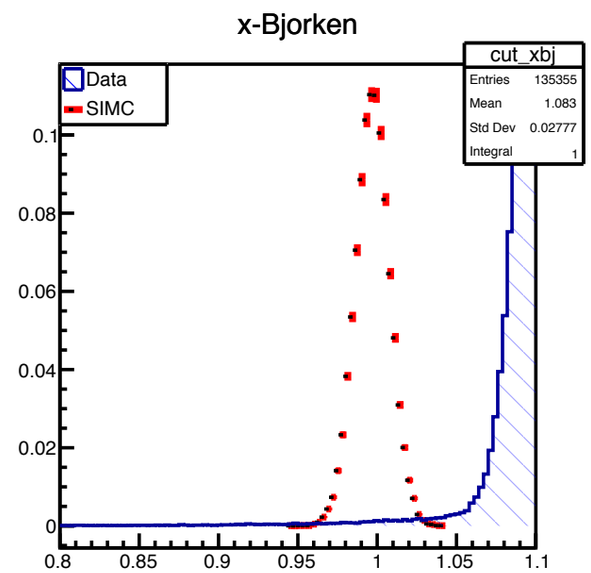
SIMC/DATA COMPARISONS BEFORE CORRECTIONS:

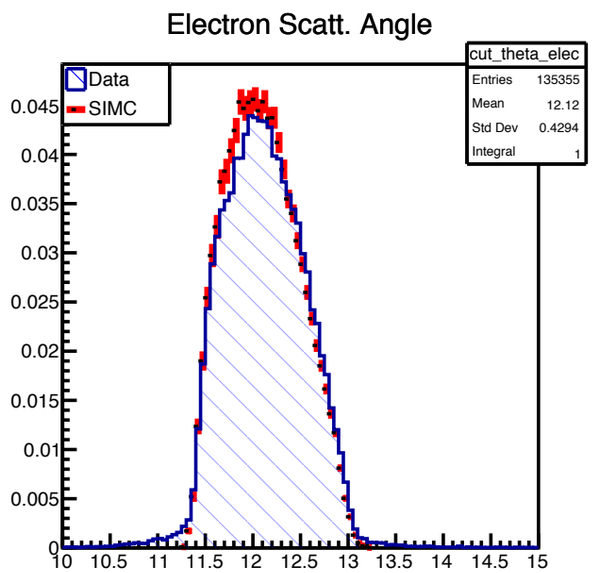


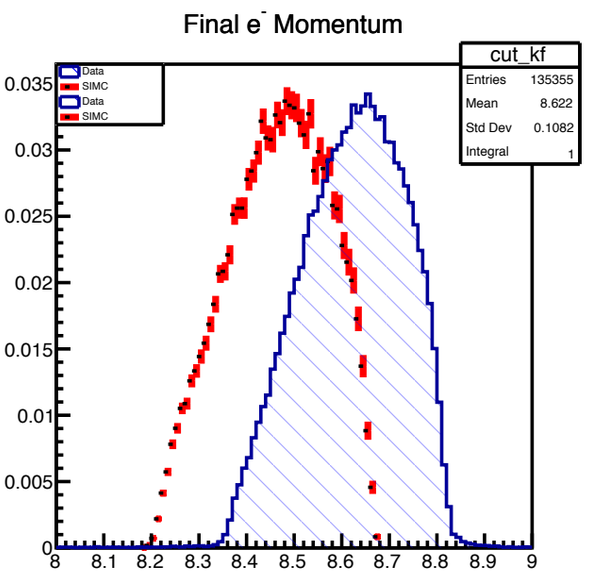


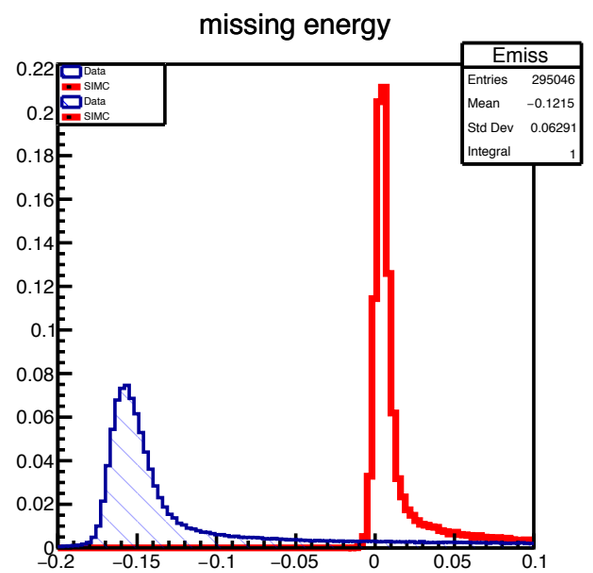








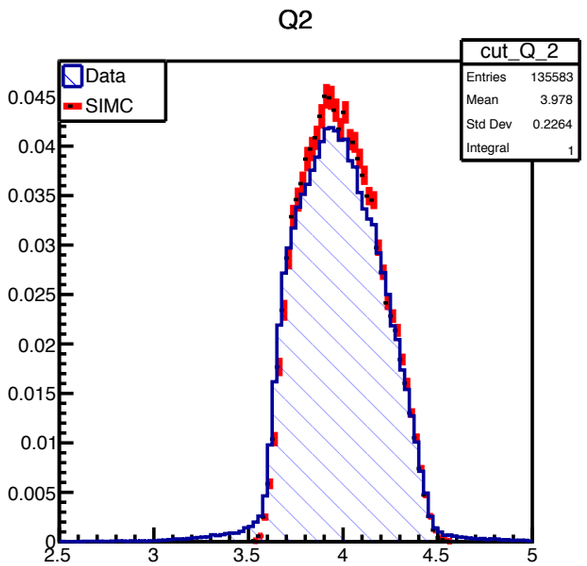


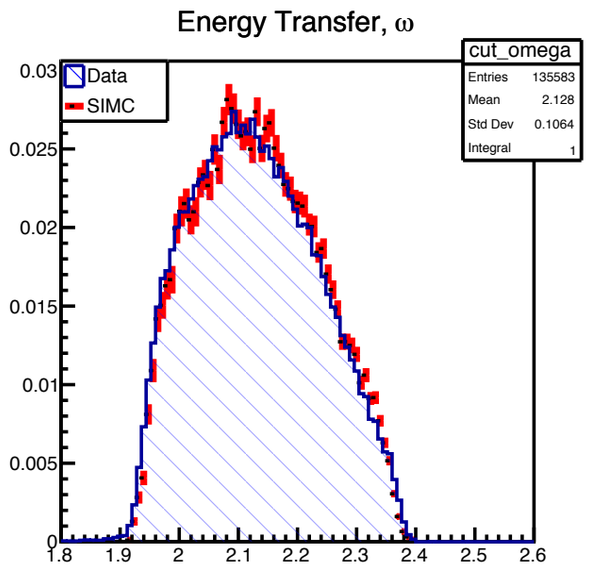


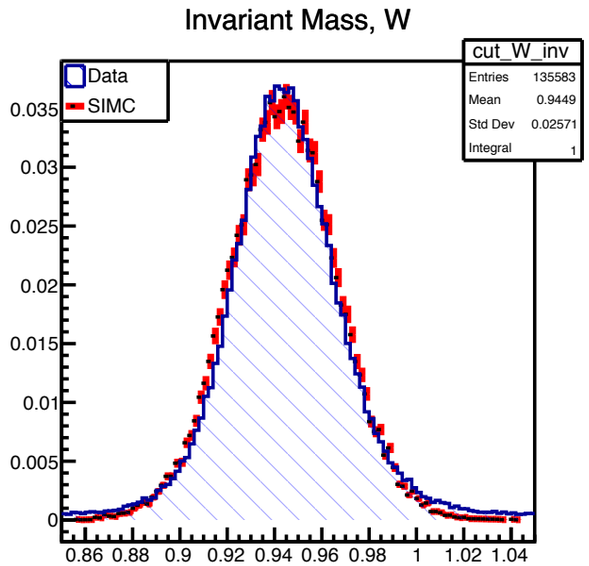
Kinematics for one (run 3288) of the four elastic points analyzed.

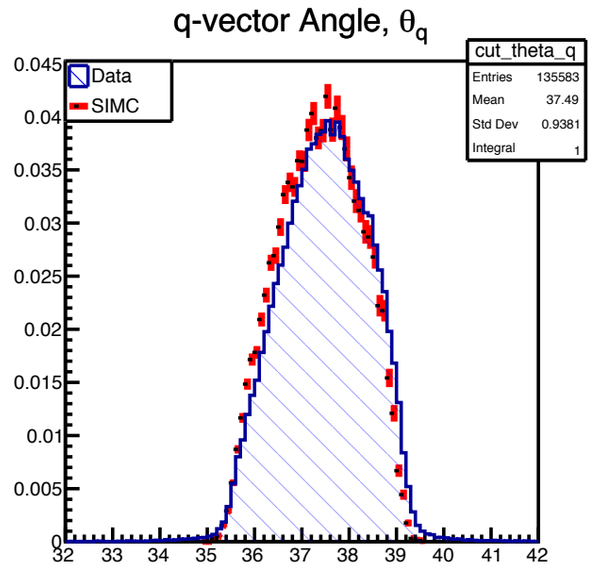
Spectrometers Momentum Corrections / Optimization Using H(e,e')p Elastics

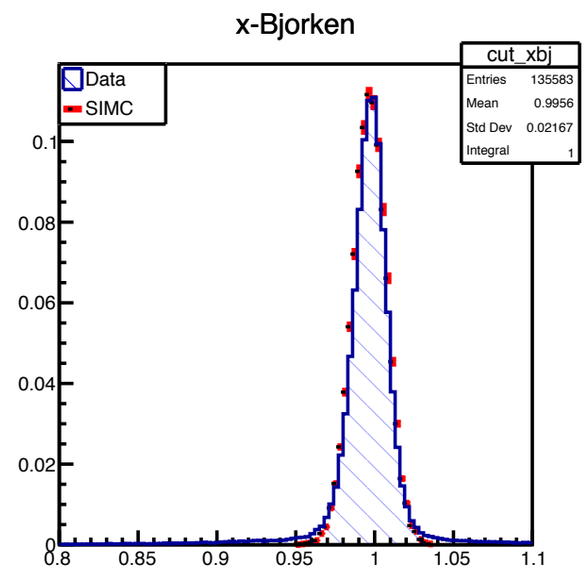
SIMC/DATA COMPARISONS AFTER CORRECTIONS:

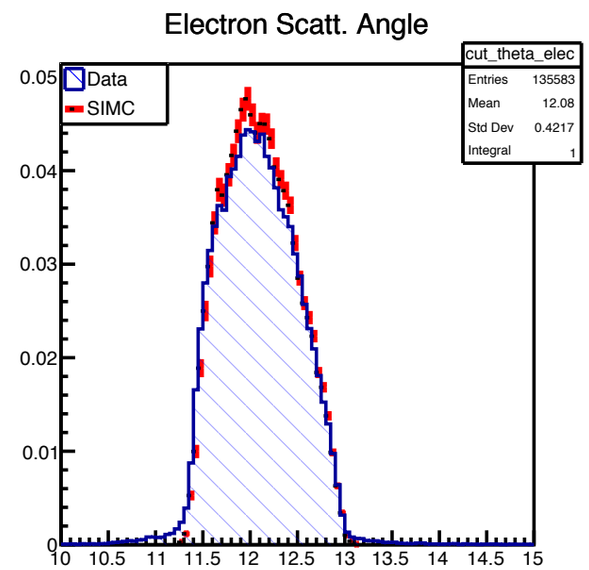


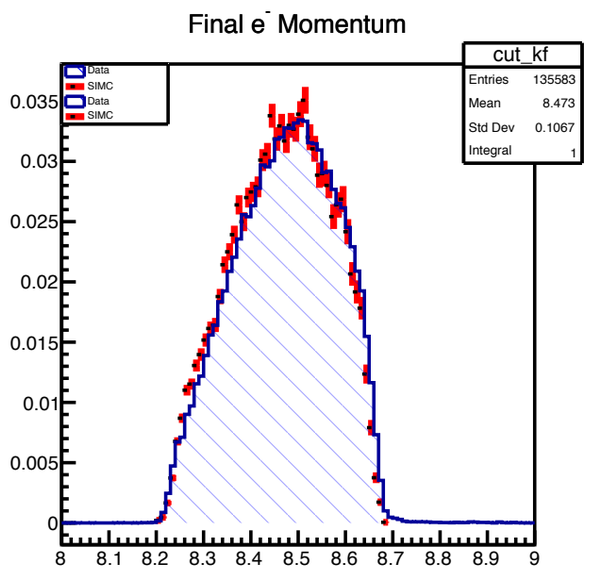


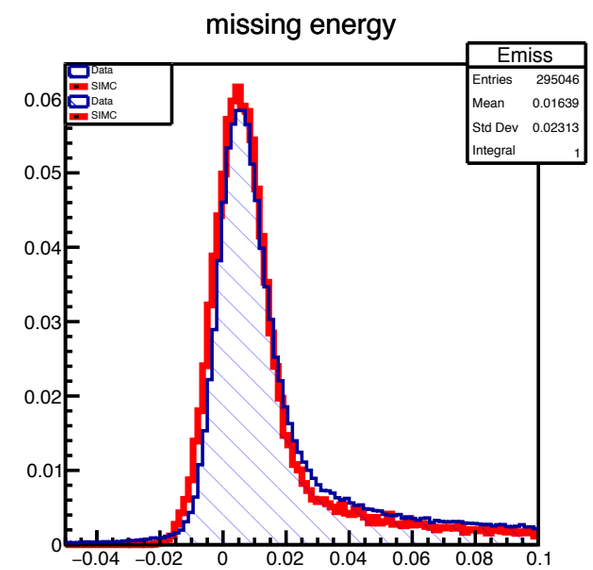






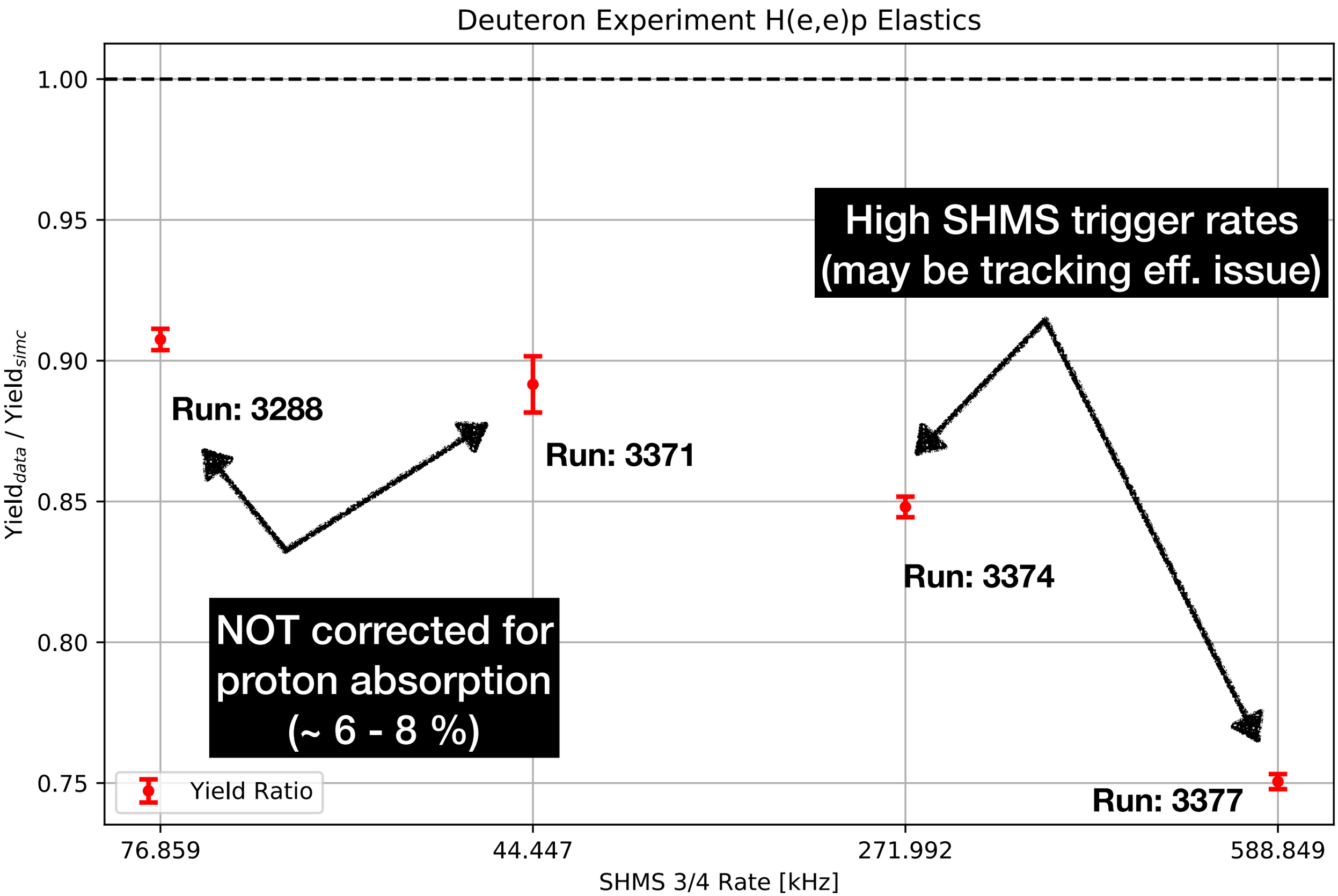






Kinematics for one (run 3288) of the four elastic points analyzed.

H(e,e'p) Check: DATA/SIMC Yield Ratio

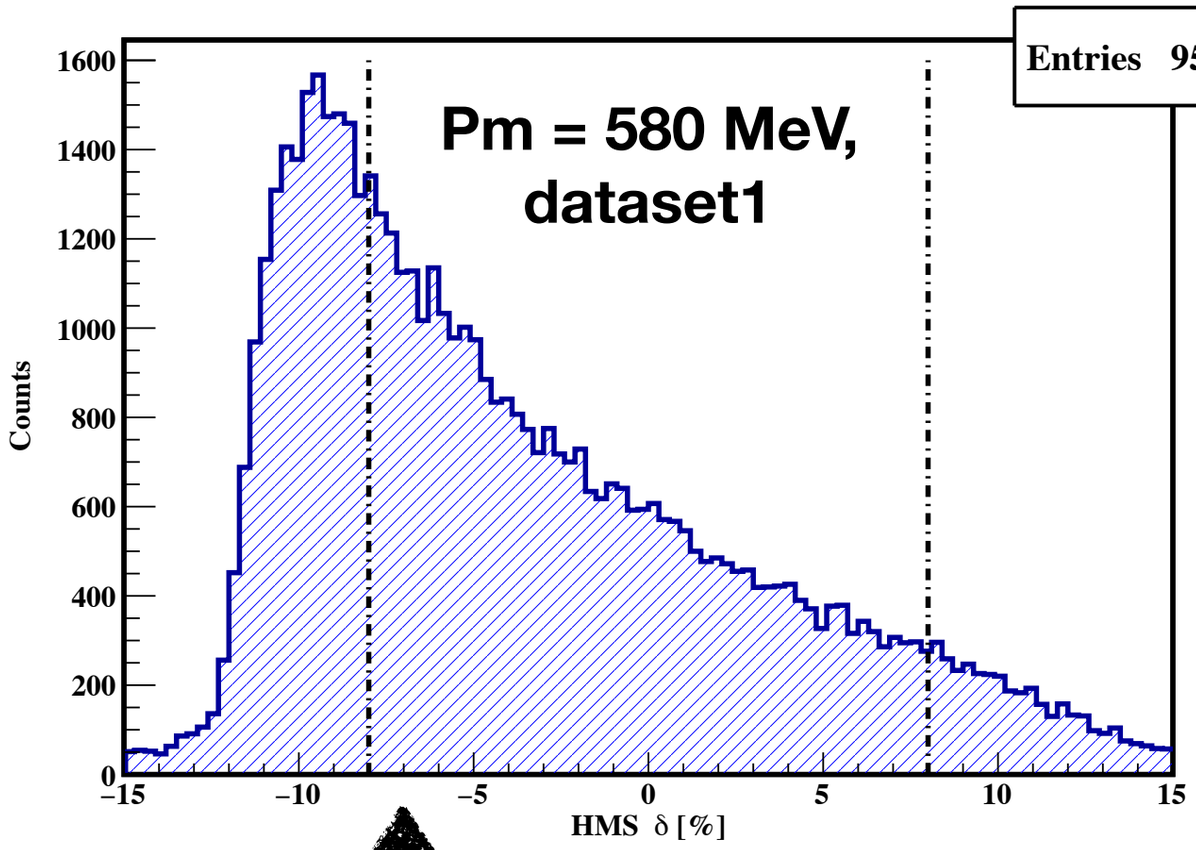


D(e,e'p)n Kinematics

Pmiss [MeV]	SHMS Momentum [GeV]	SHMS Angle [deg]	HMS Momentum [GeV]	HMS Angle [deg]
80	-8.7	~12.2	2.844	~37.3
580	-8.7	~12.2	2.194	~55
750	-8.7	~12.2	2.091	~58.4

Spectrometer Acceptance Cuts

- ☑ General cuts to select reliable event reconstruction region
- ☑ Spectrometer Optics is well known in this region



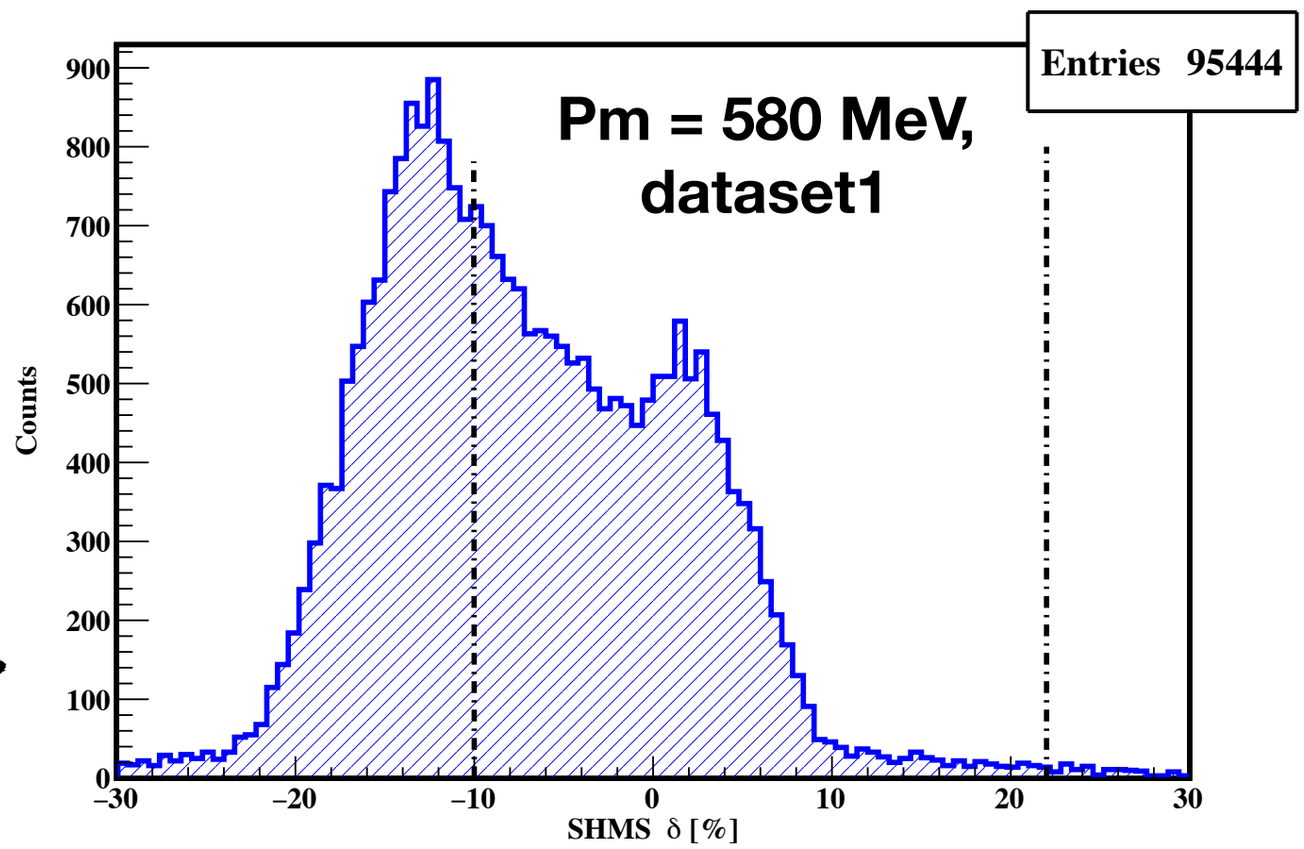
Particle momentum

Central momentum

$$\delta \equiv \frac{P - P_{cent}}{P_{cent}}$$

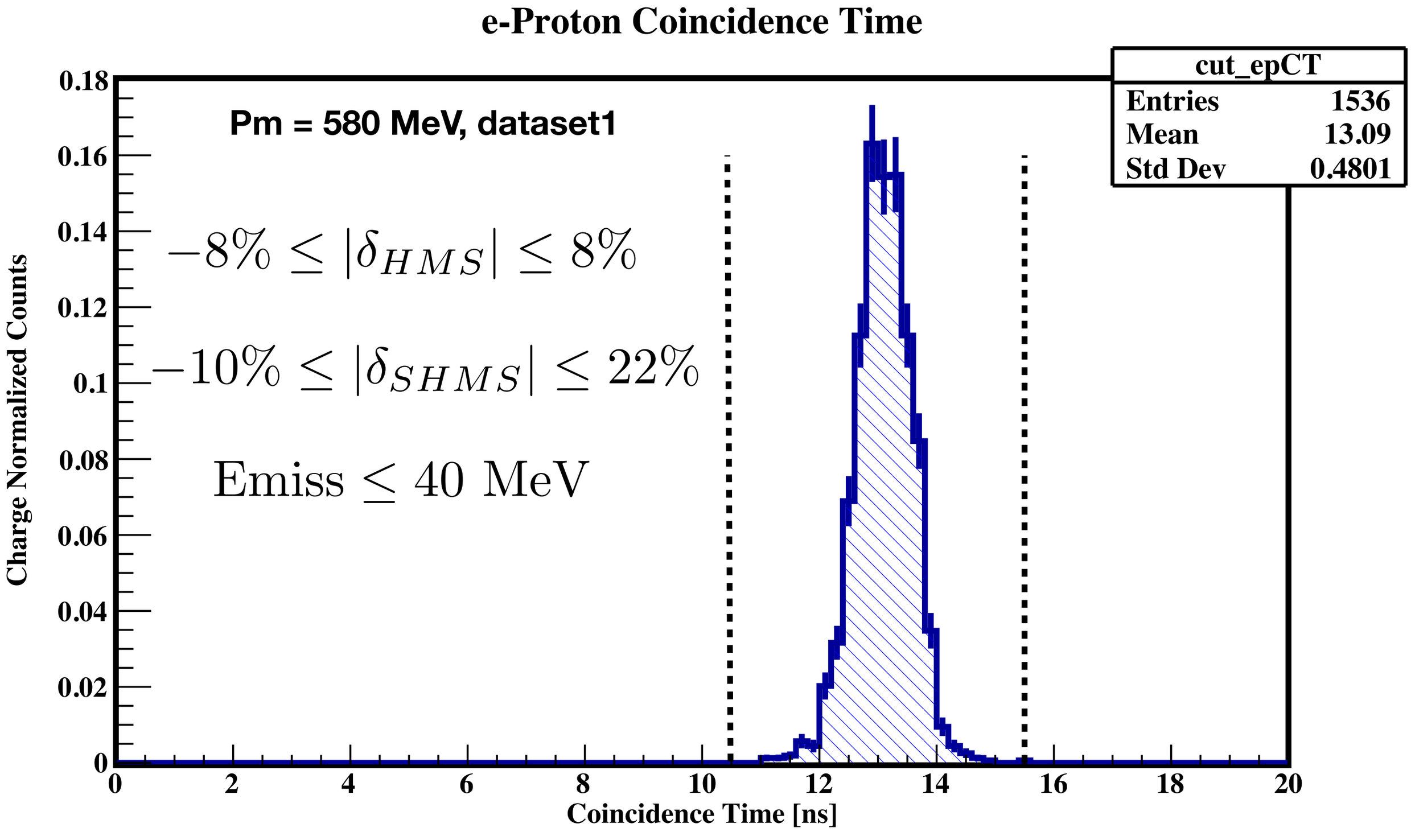
$$-8\% \leq |\delta_{HMS}| \leq 8\%$$

$$-10\% \leq |\delta_{SHMS}| \leq 22\%$$



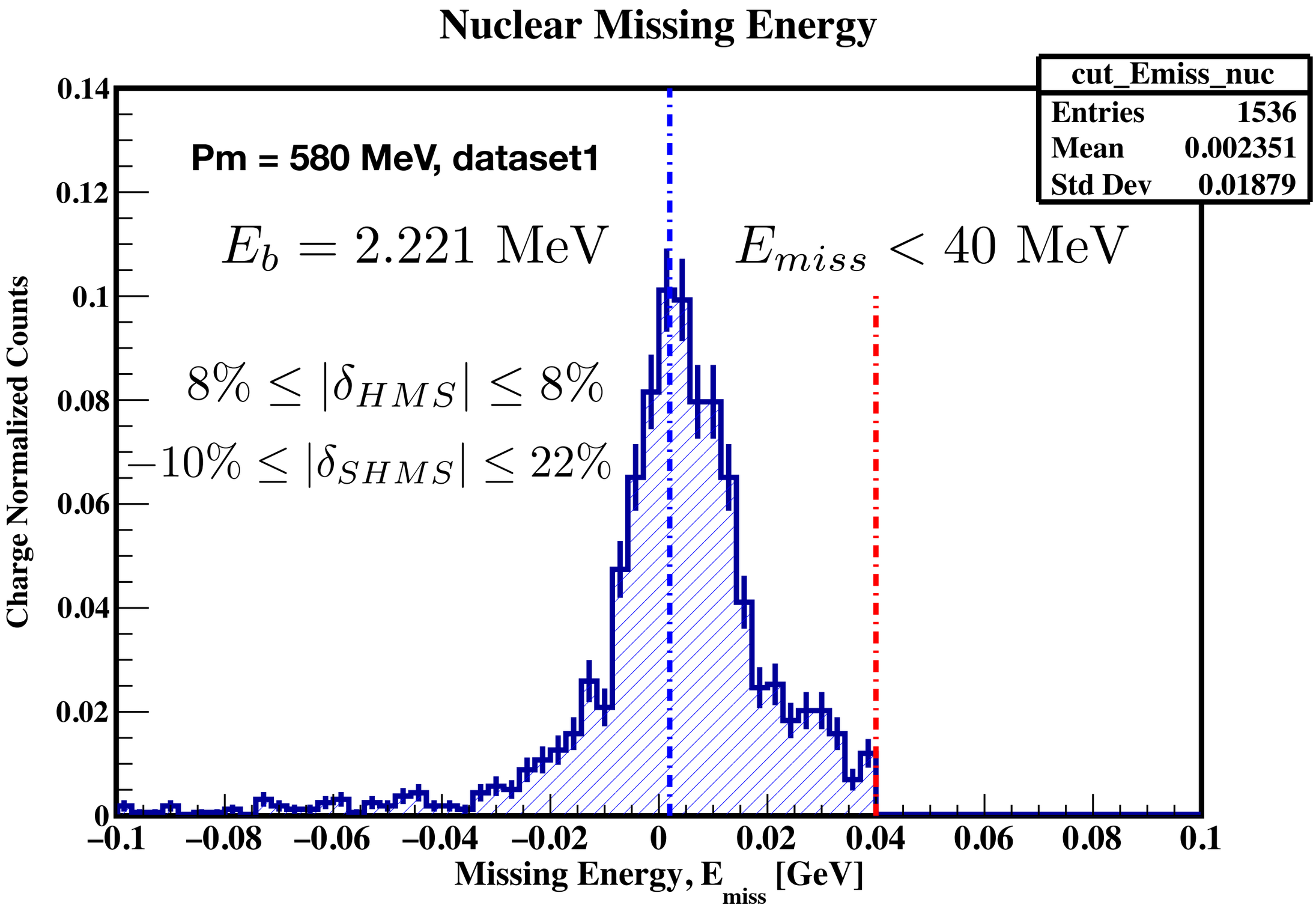
D(e,e'p)n Particle Identification

- ☑ Coincidence rates were low due to small cross sections at higher missing momentum tail.



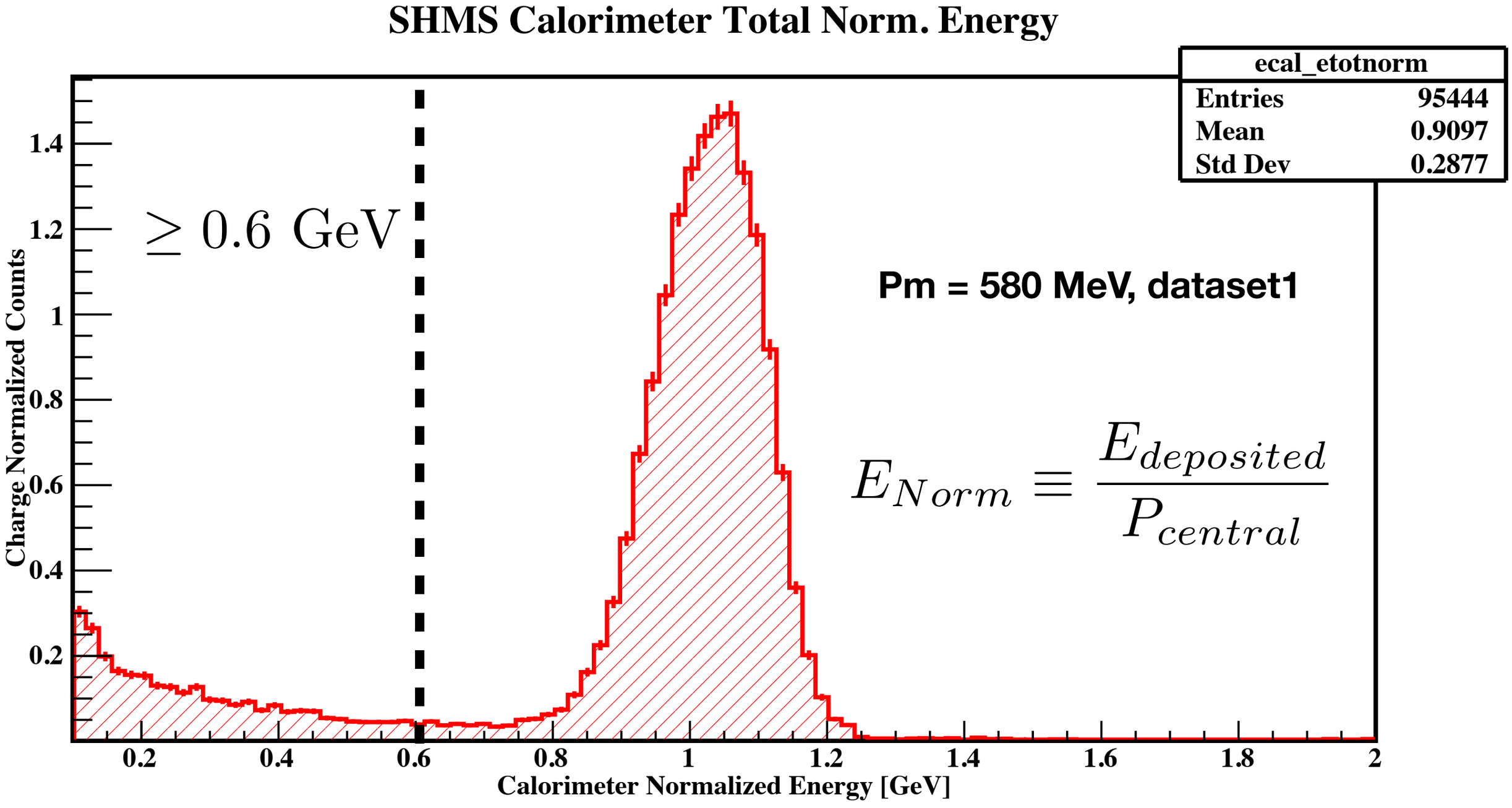
D(e,e'p)n Particle Identification

☑ For the HMS (protons), Missing Energy Cut was made.



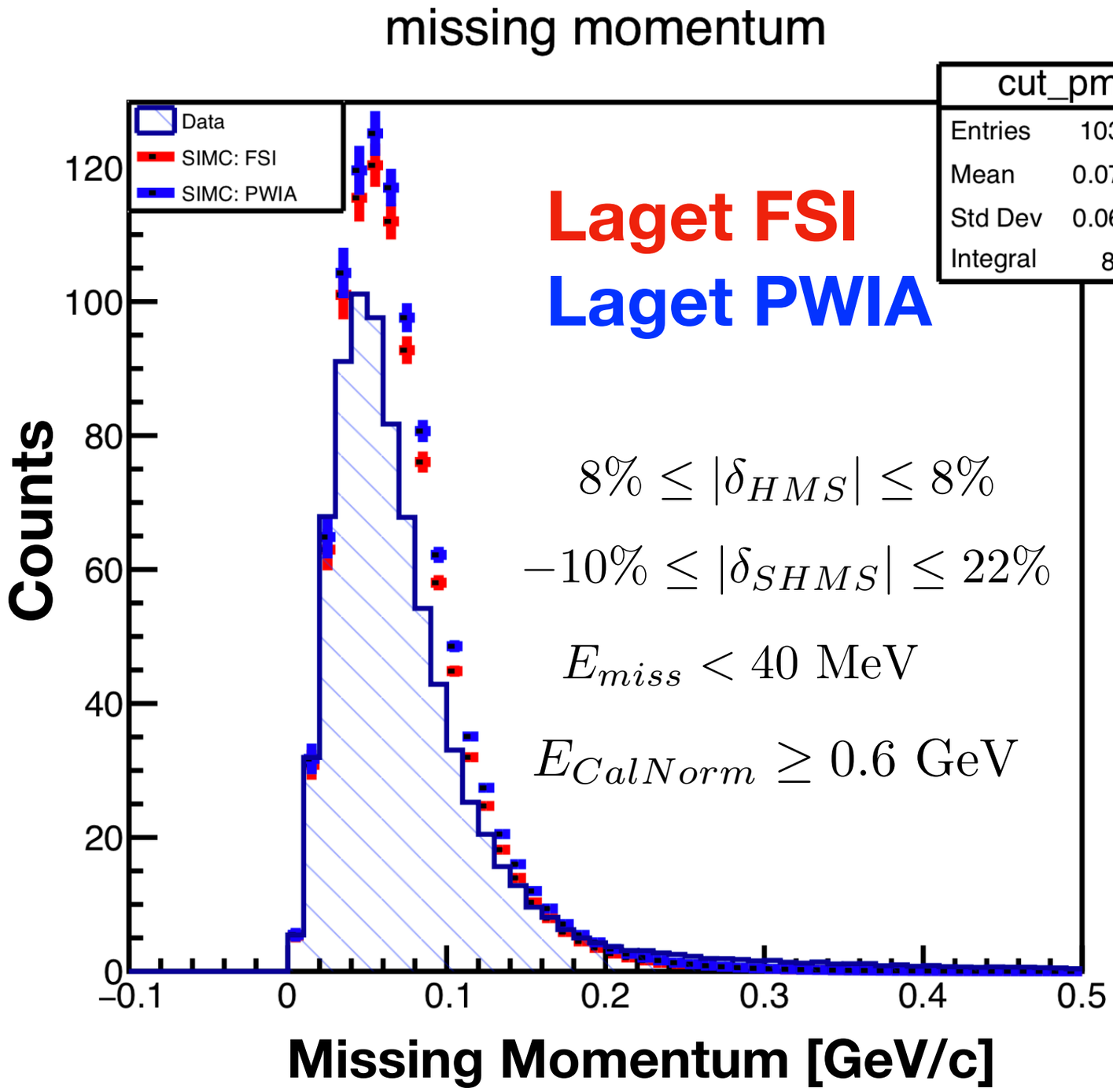
D(e,e'p)n Particle Identification

☑ SHMS Calorimeter Cut to select electrons.



D(e,e'p)n: 80 MeV Setting

This low missing momentum setting serves as the control for the 580 / 750 MeV settings.



☑ **Existing Data @ 80 MeV**

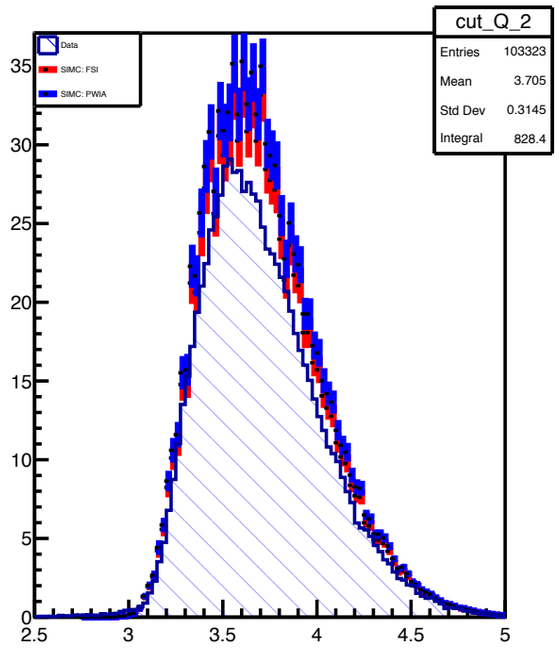
☑ **Small FSI**

☑ **Existing models are in good agreement with data at low missing momentum**

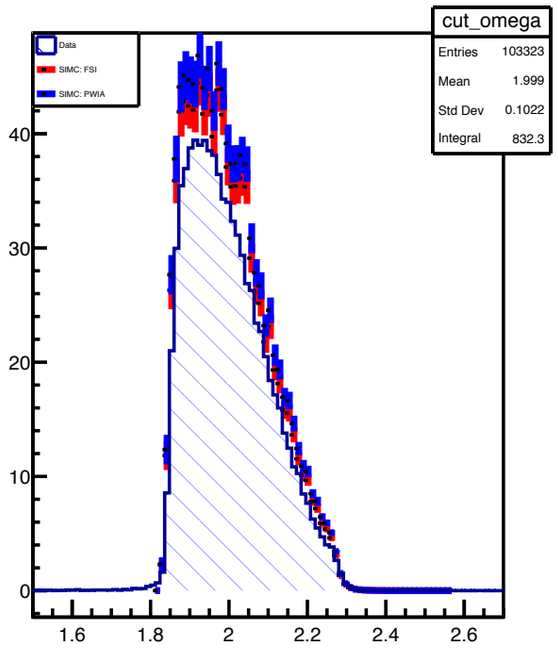
D(e,e'p)n: 80 MeV Setting Additional Kinematics

Laget FSI
Laget PWIA

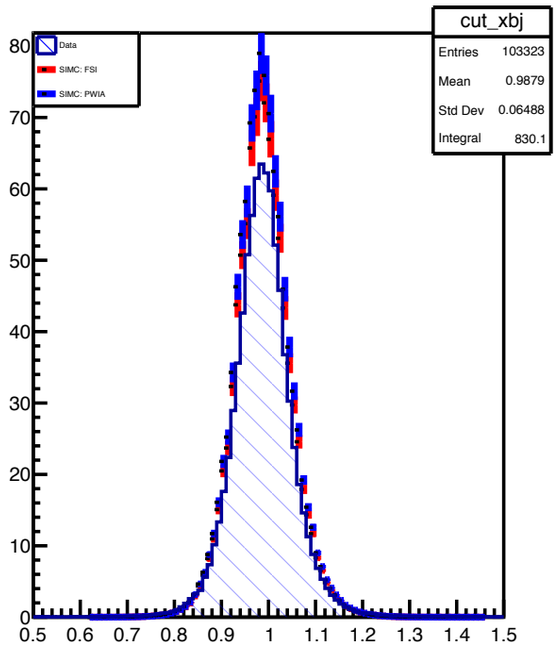
Q2



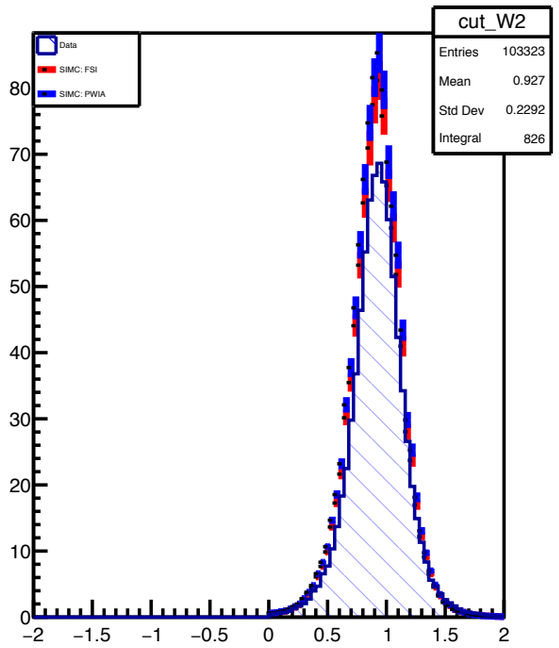
Energy Transfer, ω



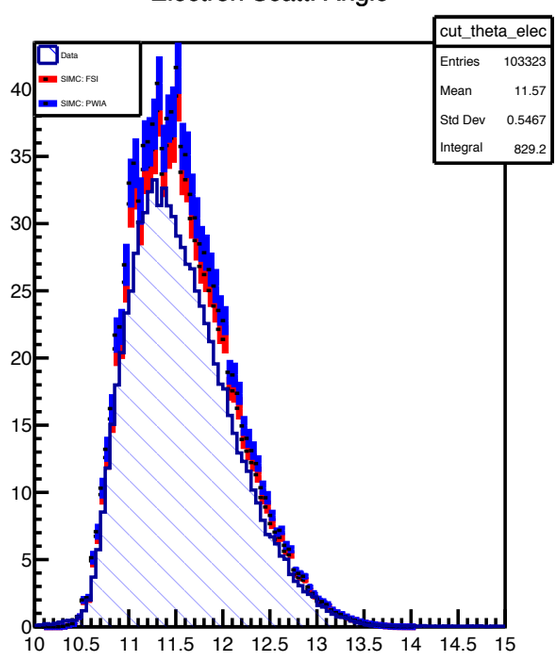
x-Bjorken



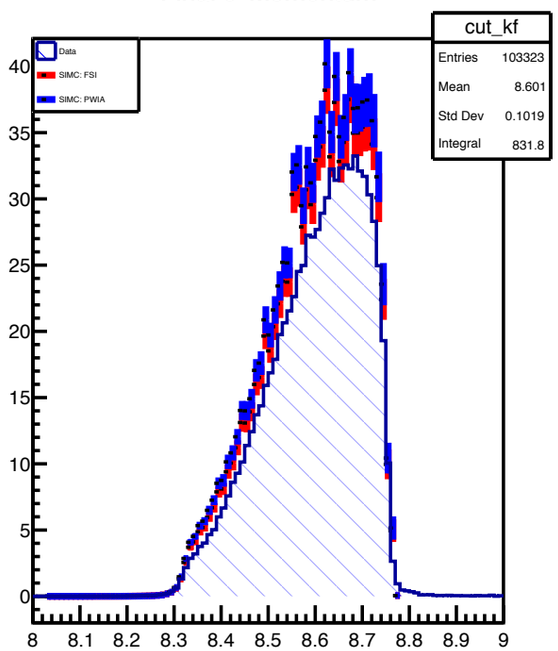
Invariant Mass W2



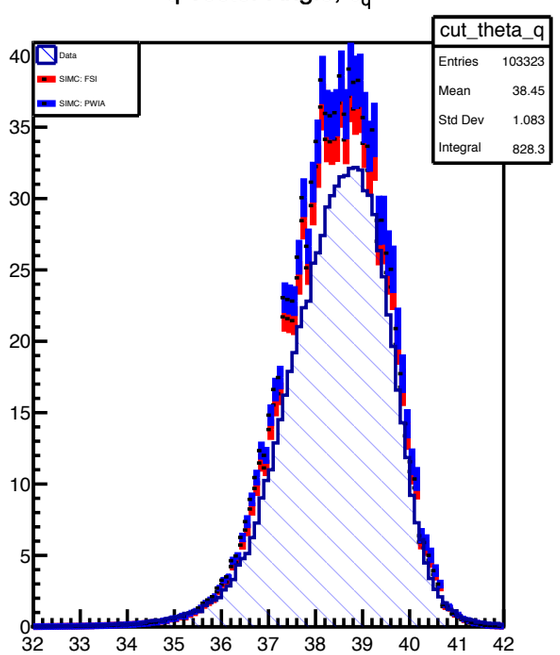
Electron Scatt. Angle



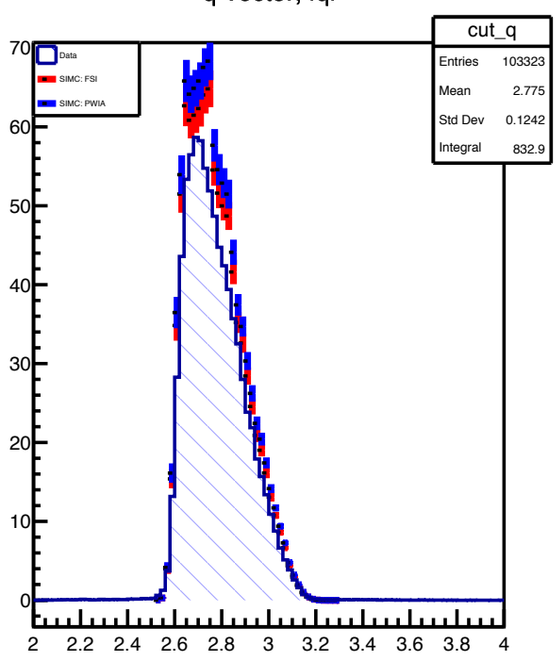
Final e⁻ Momentum



q-vector Angle, θ_q



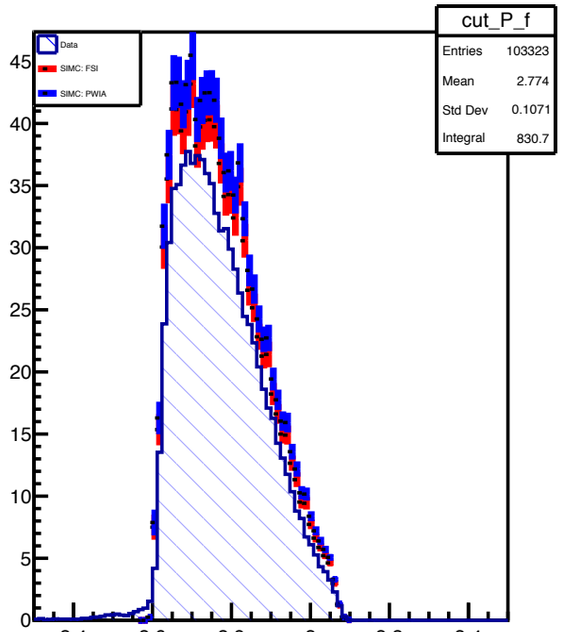
q-vector, |q|



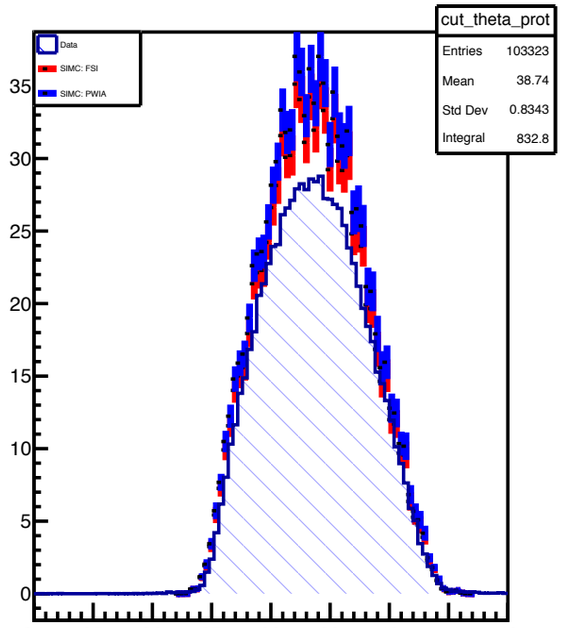
D(e,e'p)n: 80 MeV Setting Additional Kinematics

Laget FSI
Laget PWIA

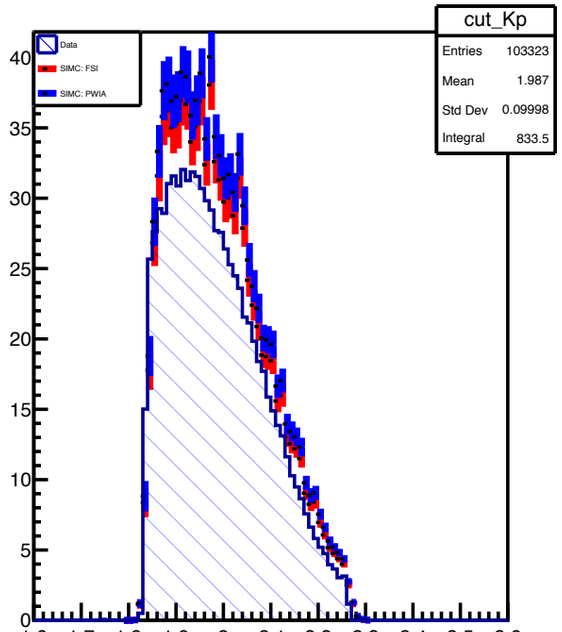
Final Proton Momentum



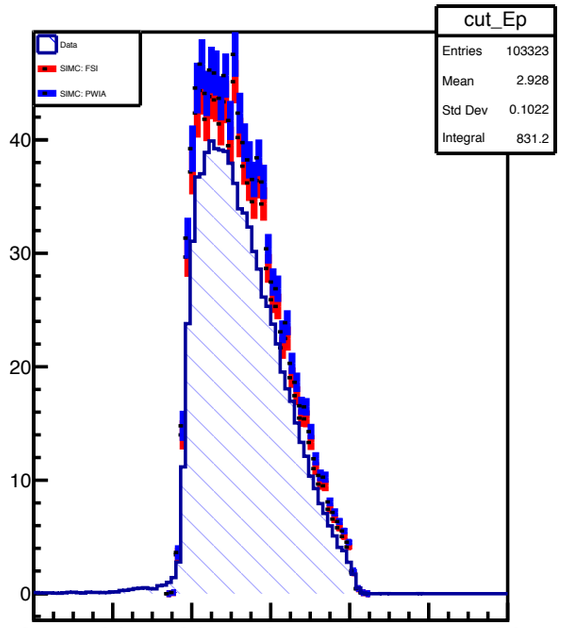
Proton Scatt. Angle



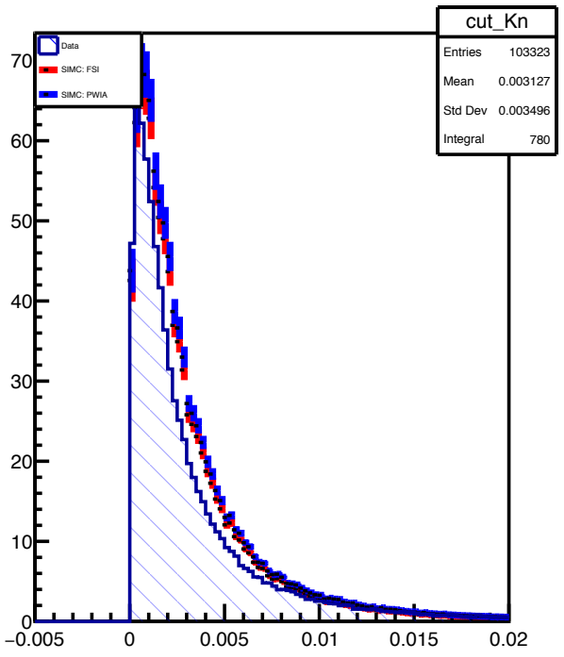
Proton Kin. Energy



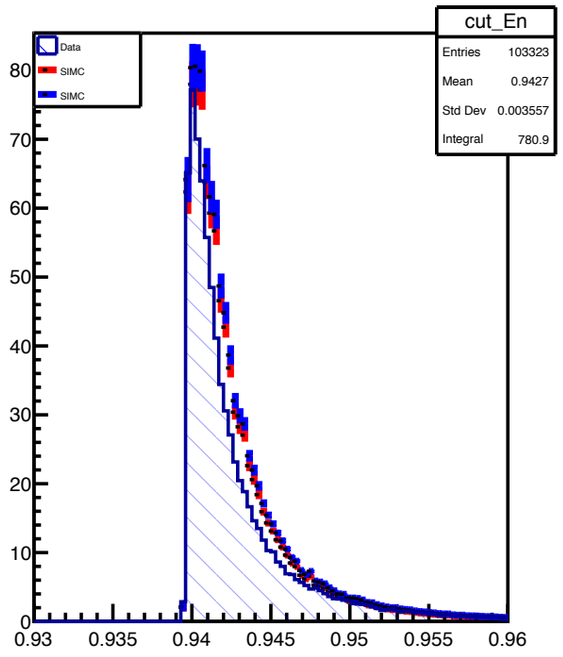
Proton Final Energy



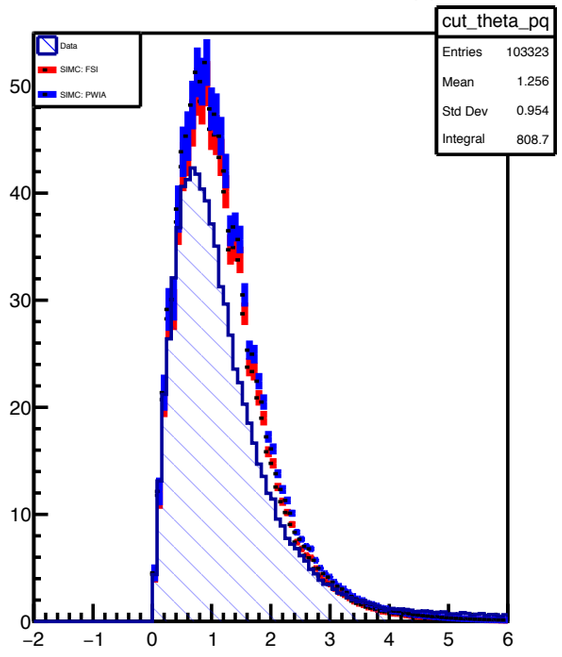
Neutron Kin. Energy



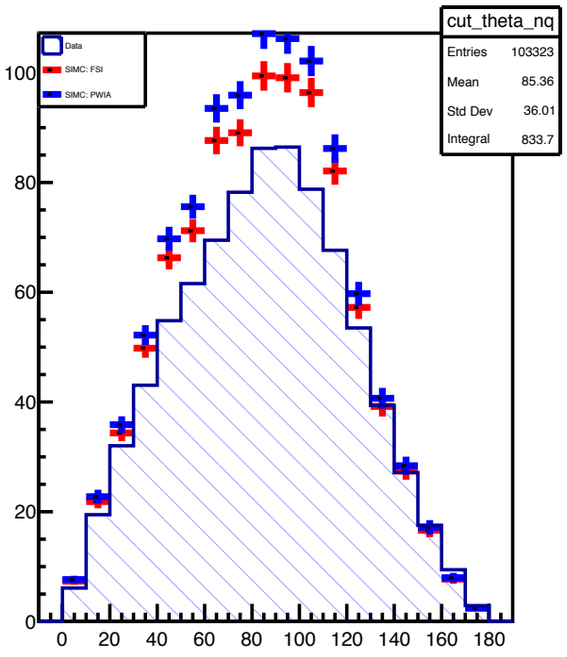
Neutron Final Energy



(Proton, q-vector) Angle, θ_{pq}



(q-vector, Neutron) Angle, θ_{nq}



D(e,e'p)n: 580 / 750 MeV Settings

☑ Spectrometer was moved in between data sets of the same setting.

☑ Pm = 580 MeV has 2 data sets

☑ Pm = 750 MeV has 3 data sets

- Can the data sets be combined ?
- How do the cross-sections for each data set compare ?
- How sensitive are cross sections to spectrometer motion?

Extracting the Cross Sections

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

Determined from simulation

$$Y^{data}_{corr.} = \frac{Y^{data}_{uncorr.}}{Q_{tot.} * \epsilon_{LT} * \epsilon^{hms}_{trk} * \epsilon^{shms}_{trk}}$$

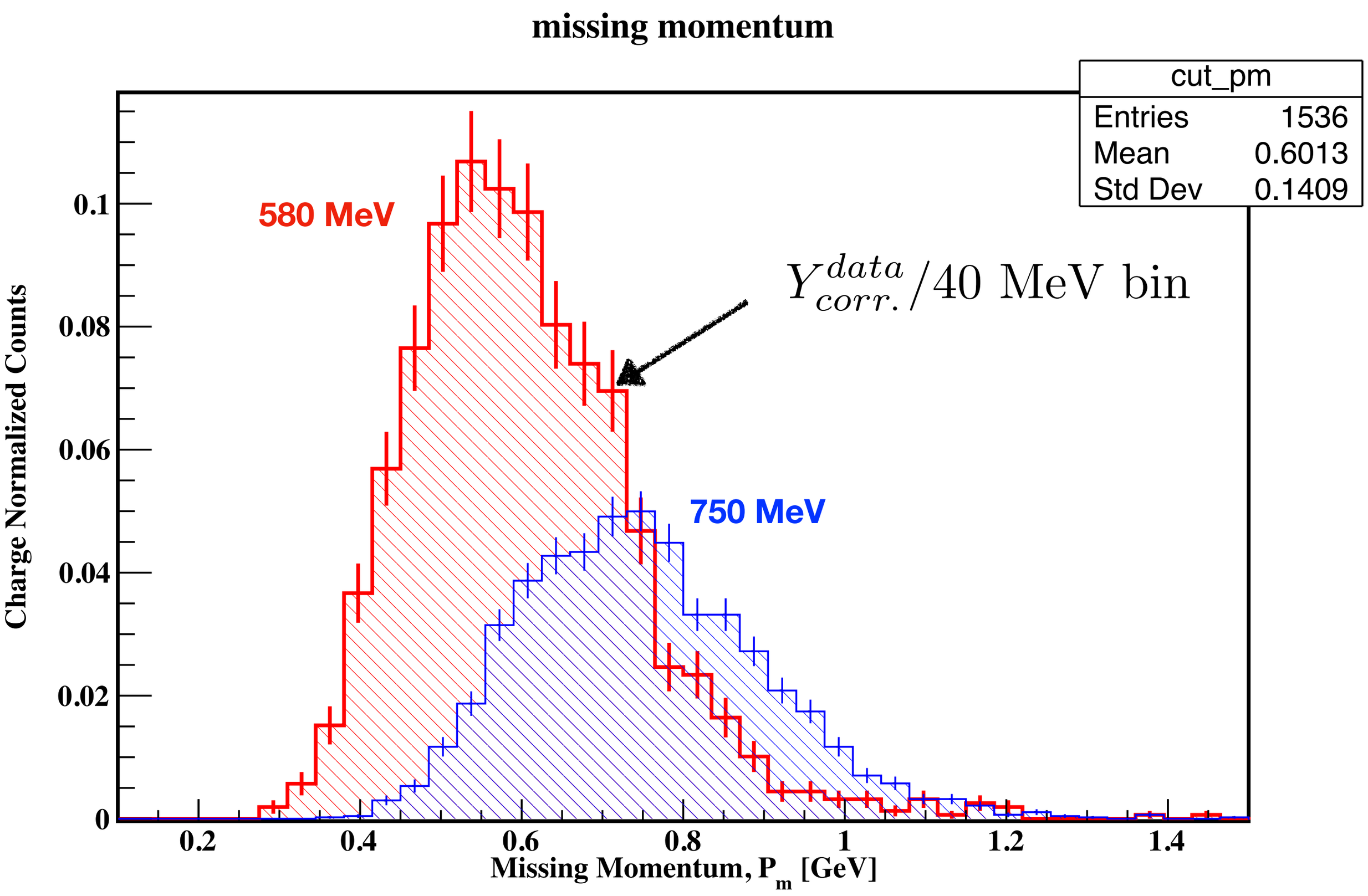
Other corrections still need to be applied...
* Target Boiling
* Radiative corr.

$$V^{P.S.} = \frac{N_{acc.}}{N_{gen.}} \Delta V \text{ , where } \Delta V = \Delta\omega \Delta\Omega_e \Delta\Omega_p$$

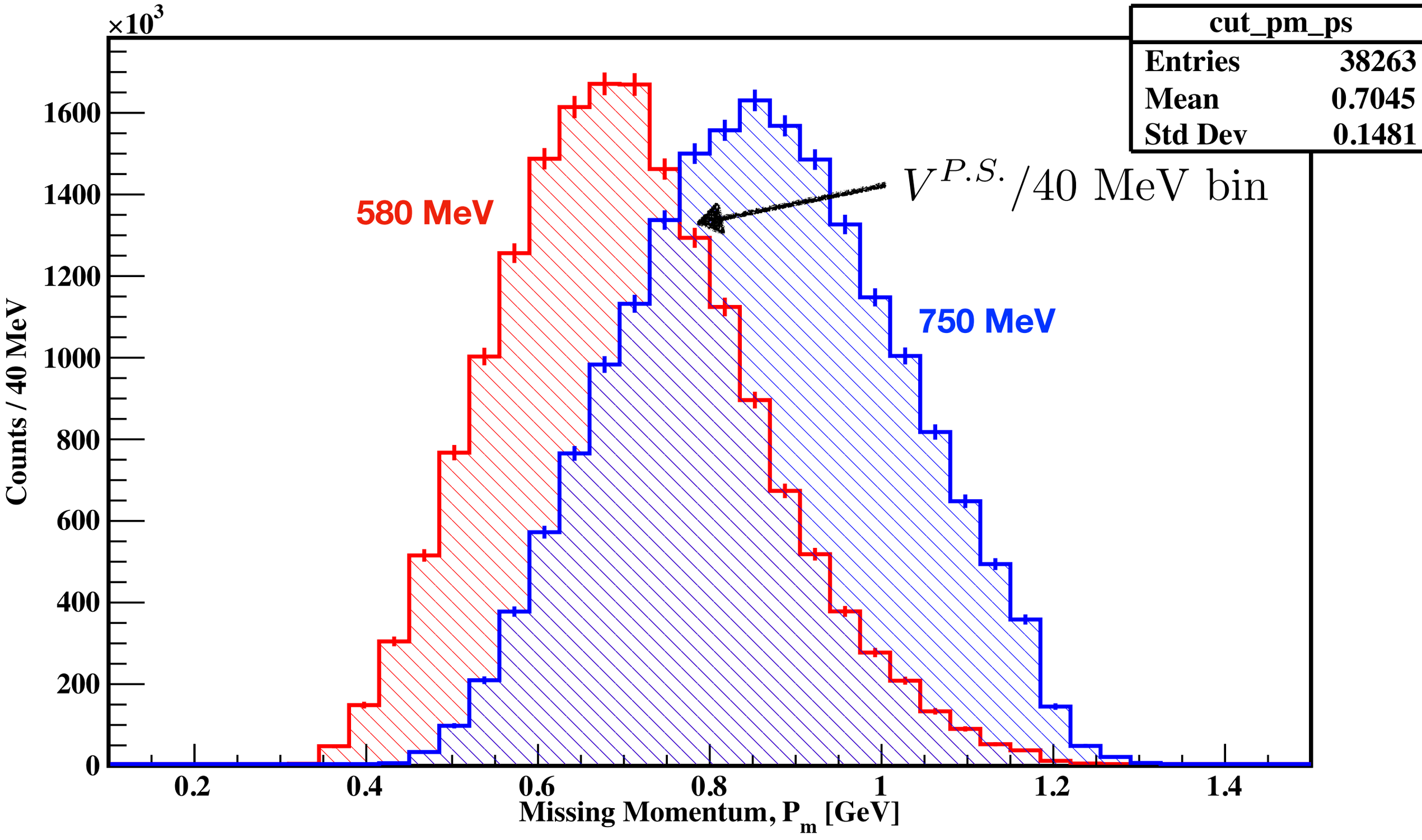
Ratio of accepted to thrown events in spectrometers

Spectrometers Phase Space Volume

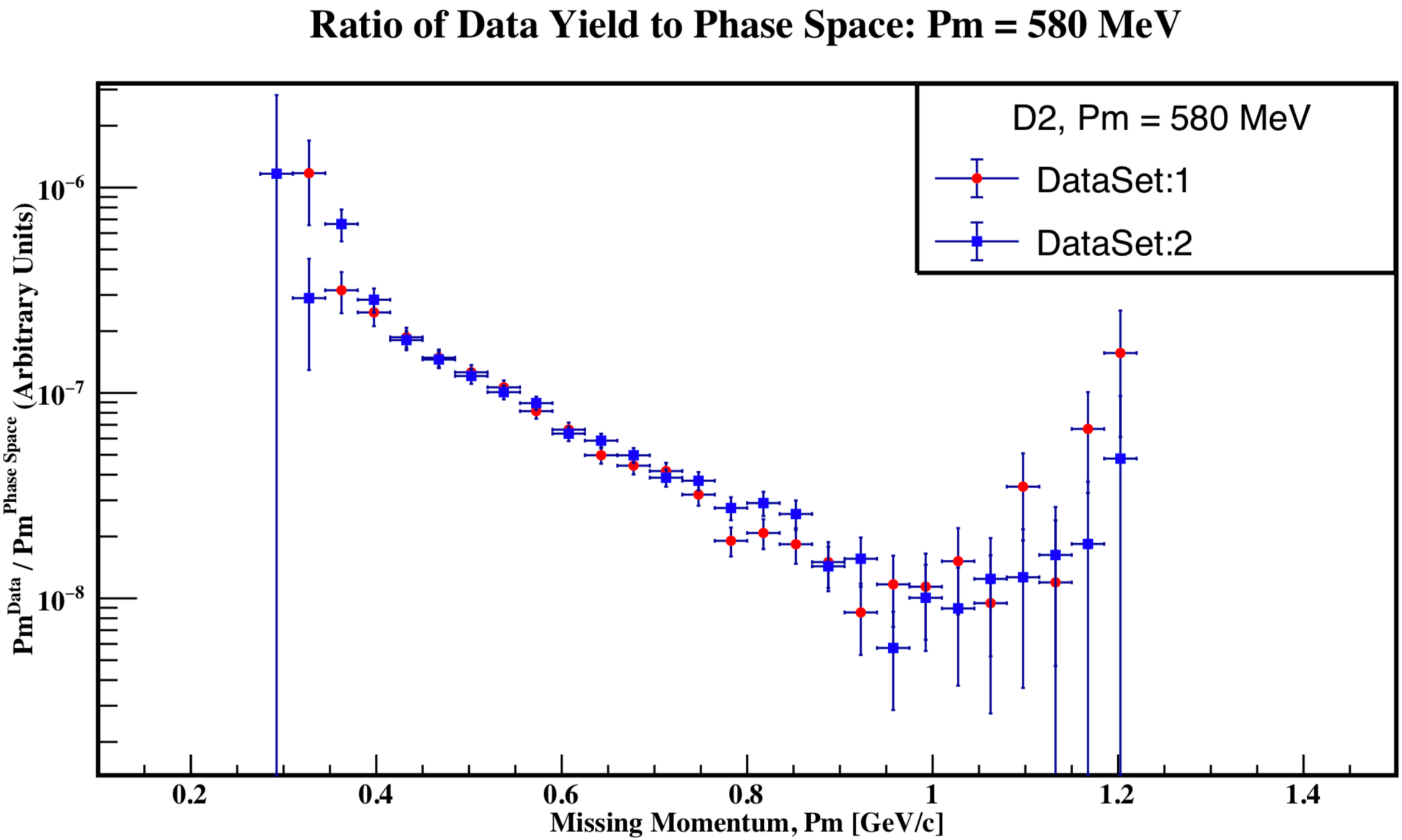
Data Set Charge Normalized Missing Momentum Yield



Missing Momentum Phase Space from SIMC

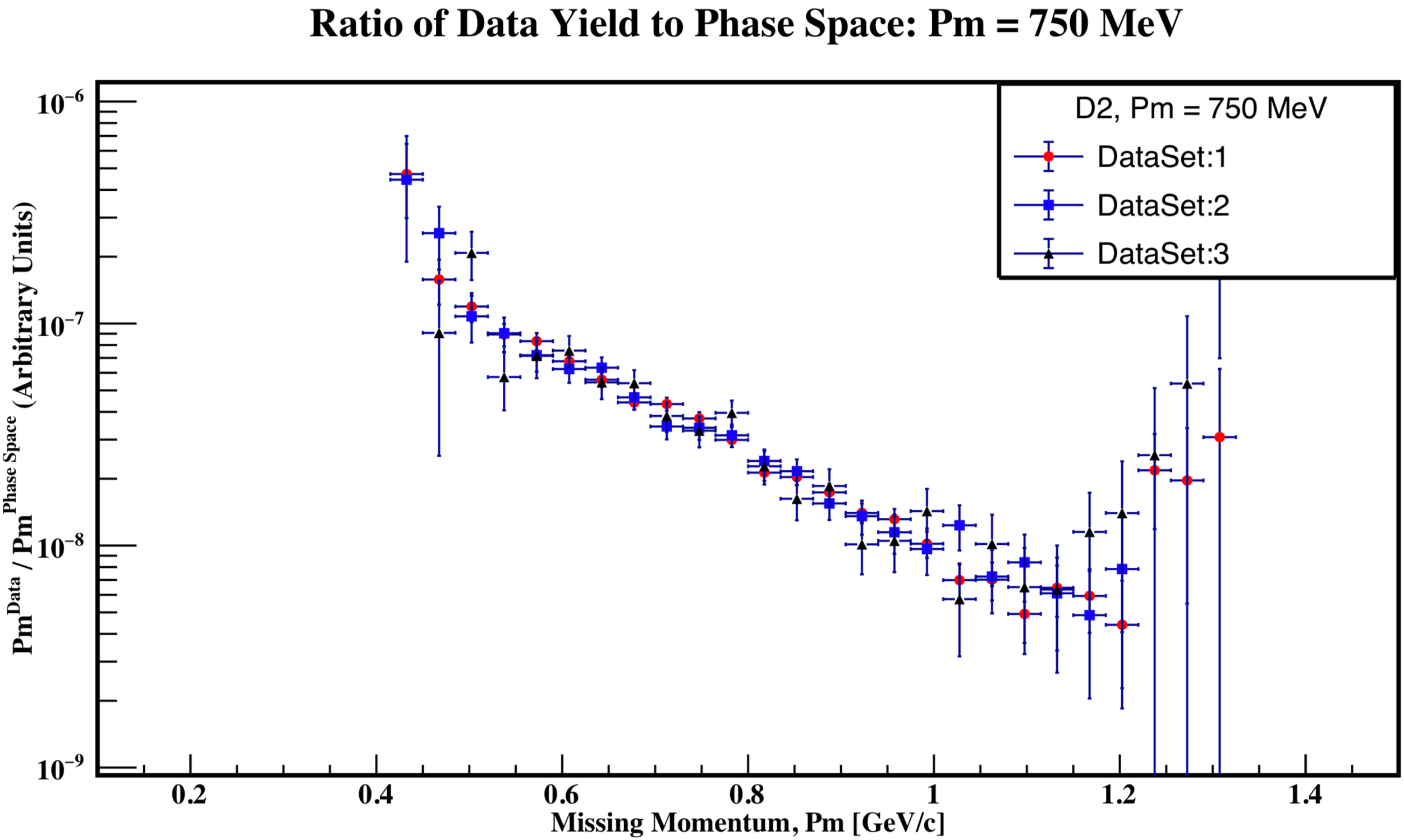


- ☑ Good agreement between the two 580 MeV data sets
- ☑ Data sets can be combined



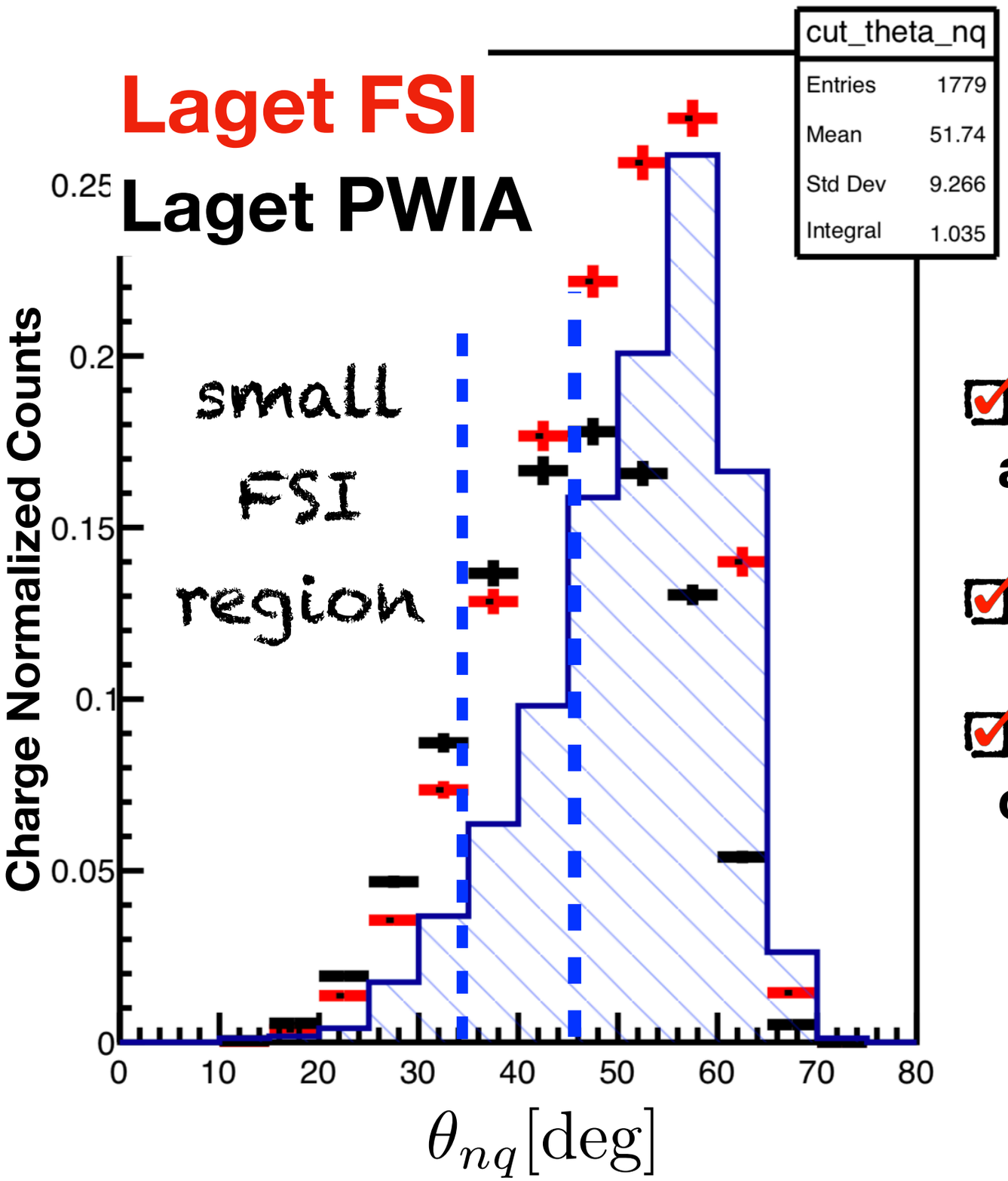
☑ Good agreement between the three 750 MeV data sets

☑ Data sets can be combined



Selecting Small FSI Region

(q-vector, Neutron) Angle, θ_{nq}



FSI ~ PWIA at:

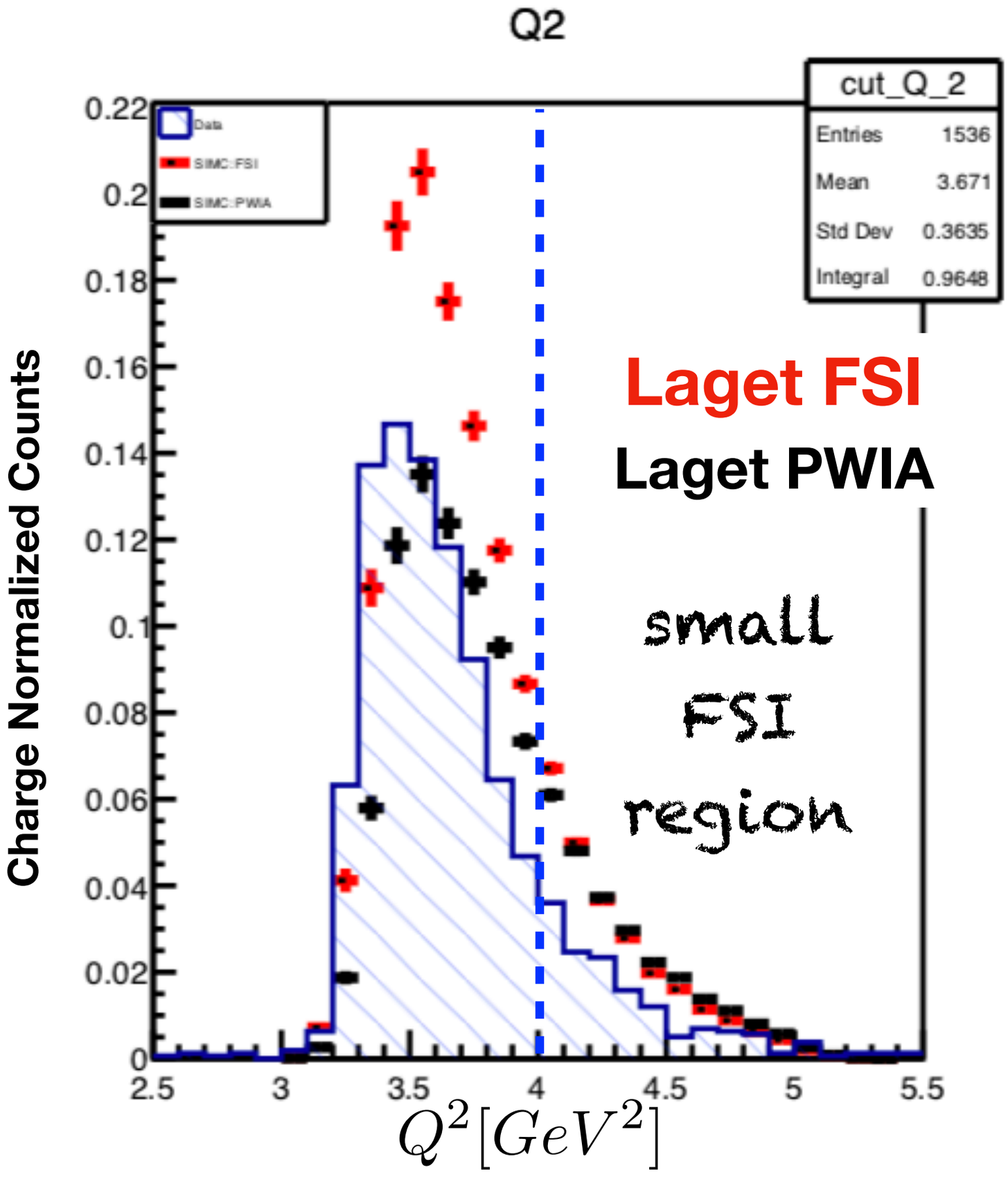
$$35^o \leq \theta_{nq} \leq 45^o$$

☑ **Kinematic region of interest at high missing momentum**

☑ **FSI contributions are small**

☑ **Deuteron Momentum Distribution can be extracted**

Selecting Small FSI Region

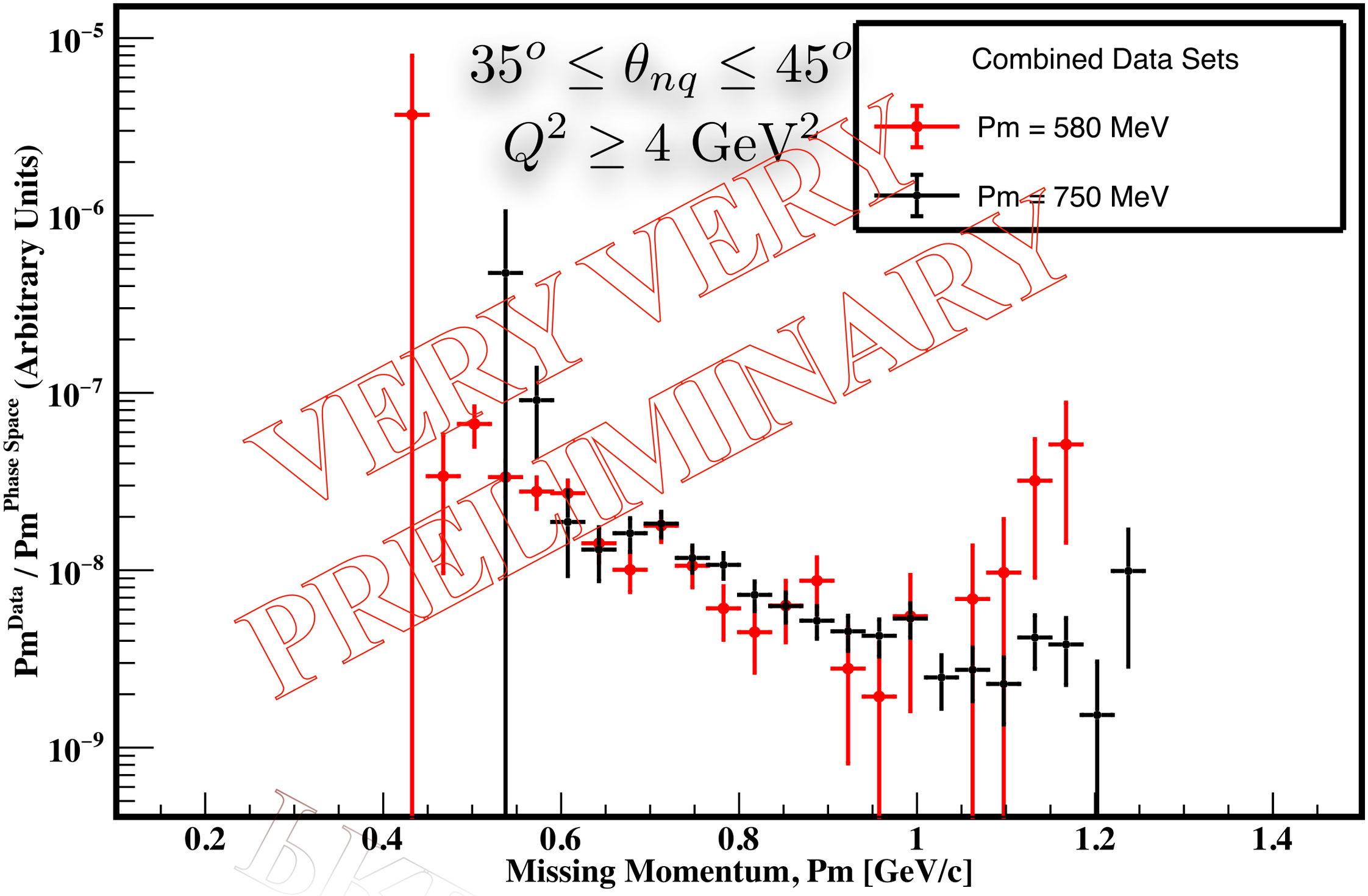


FSI ~ PWIA at:

$$Q^2 \geq 4\ \mathrm{GeV}^2$$

Selecting Small FSI Region

Ratio of Corrected Data Yield to SIMC Phase Space



Extraction of Momentum Distributions

$$\sigma_{exp} \equiv \frac{d^6\sigma}{d\omega d\Omega_e dT_p d\Omega_p} = K \cdot \sigma_{ep} \cdot S(E_m, p_m)$$

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

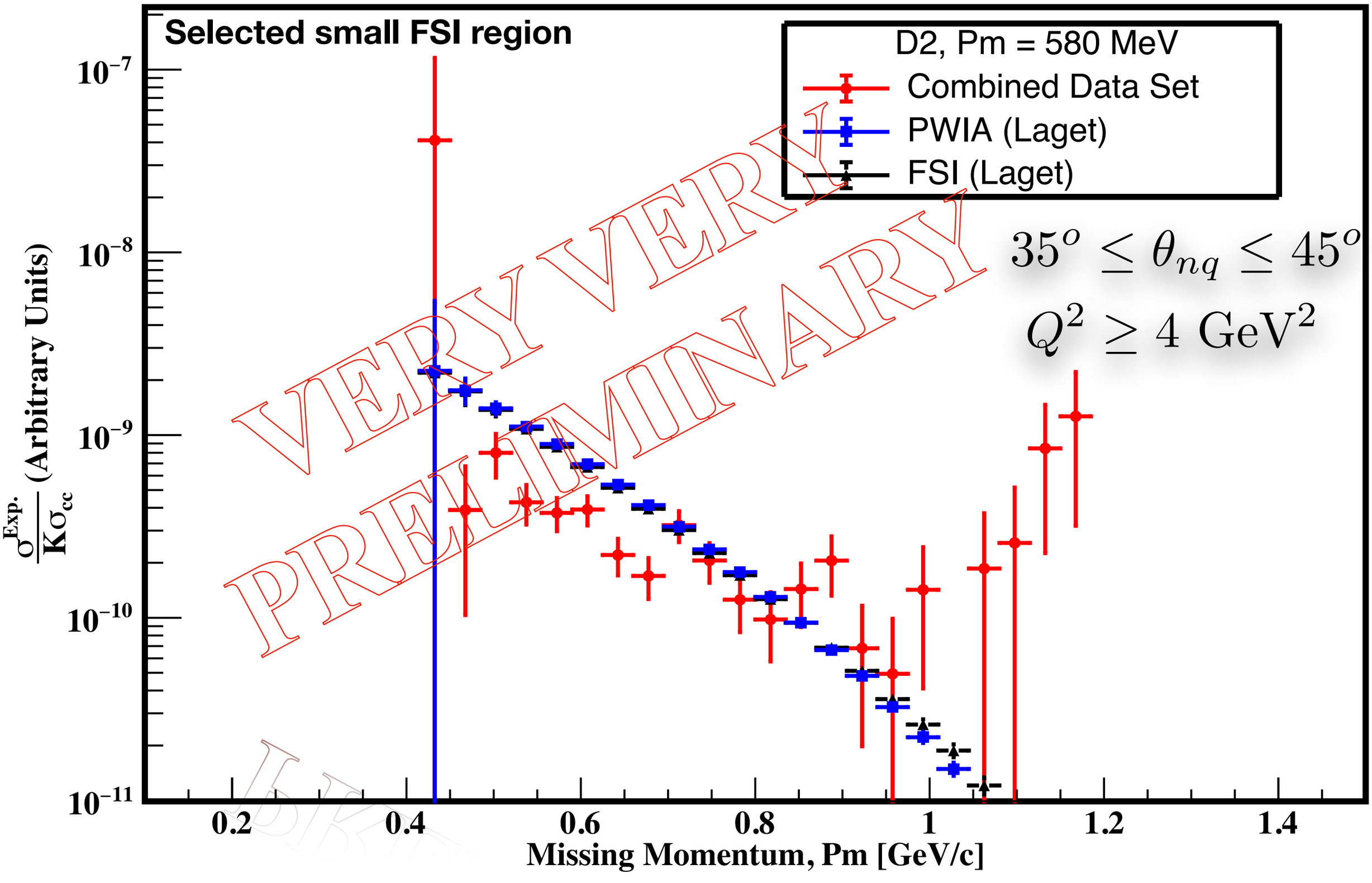
$K = \frac{E_p P_p}{(2\pi)^3}$ **Kinematic Factor. (See Hari Khanal's Thesis)**

$\sigma_{ep} \rightarrow \sigma_{\mathrm{cc1\ or\ cc2}}$ **Off-shell proton cross-section (from SIMC)**

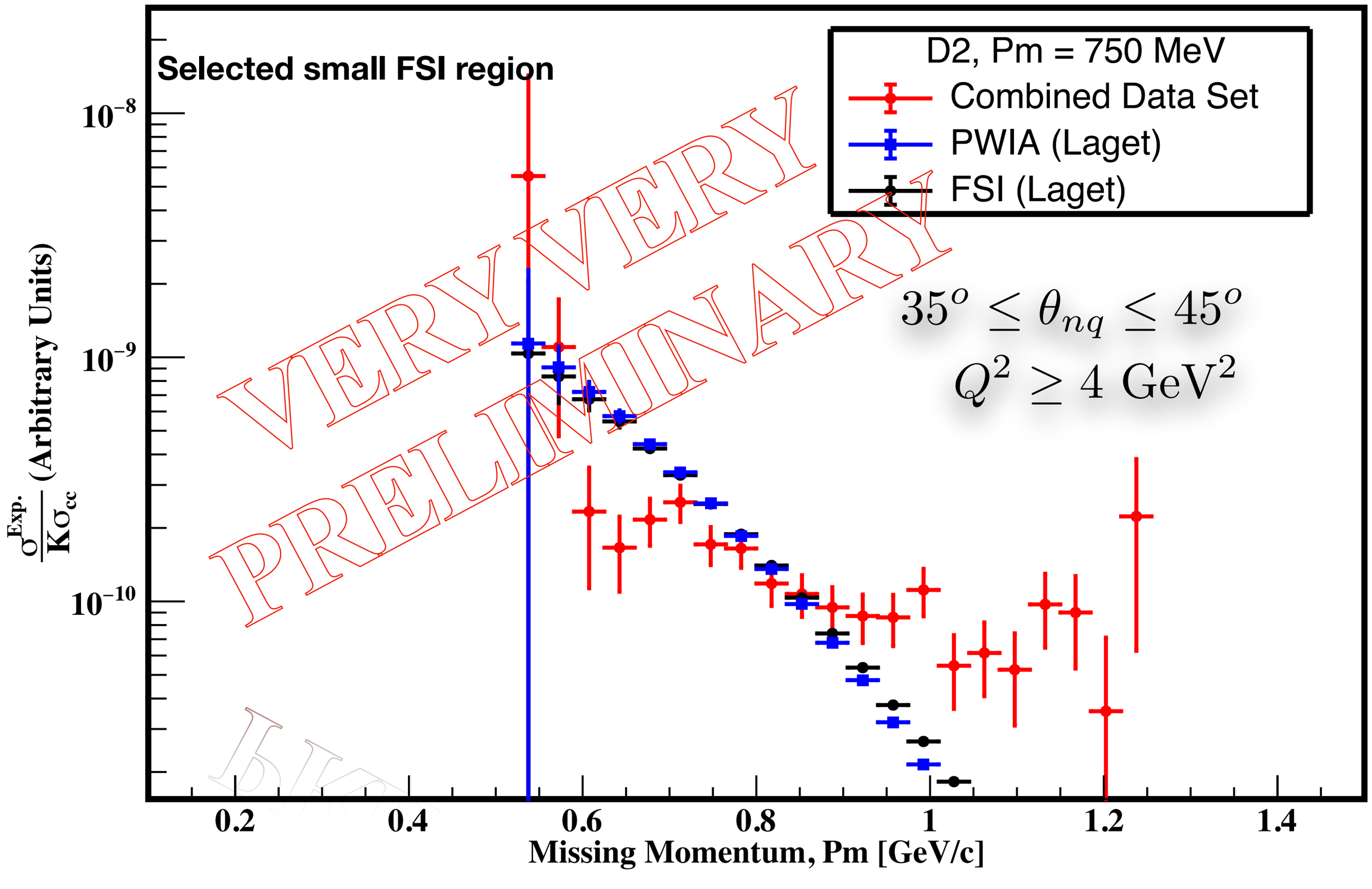
☑ **Only in PWIA (small FSI) is factorization possible**

☑ **Small FSI region has been selected in experiment (See previous slides)**

Reduced Cross Sections: Pm = 580 MeV

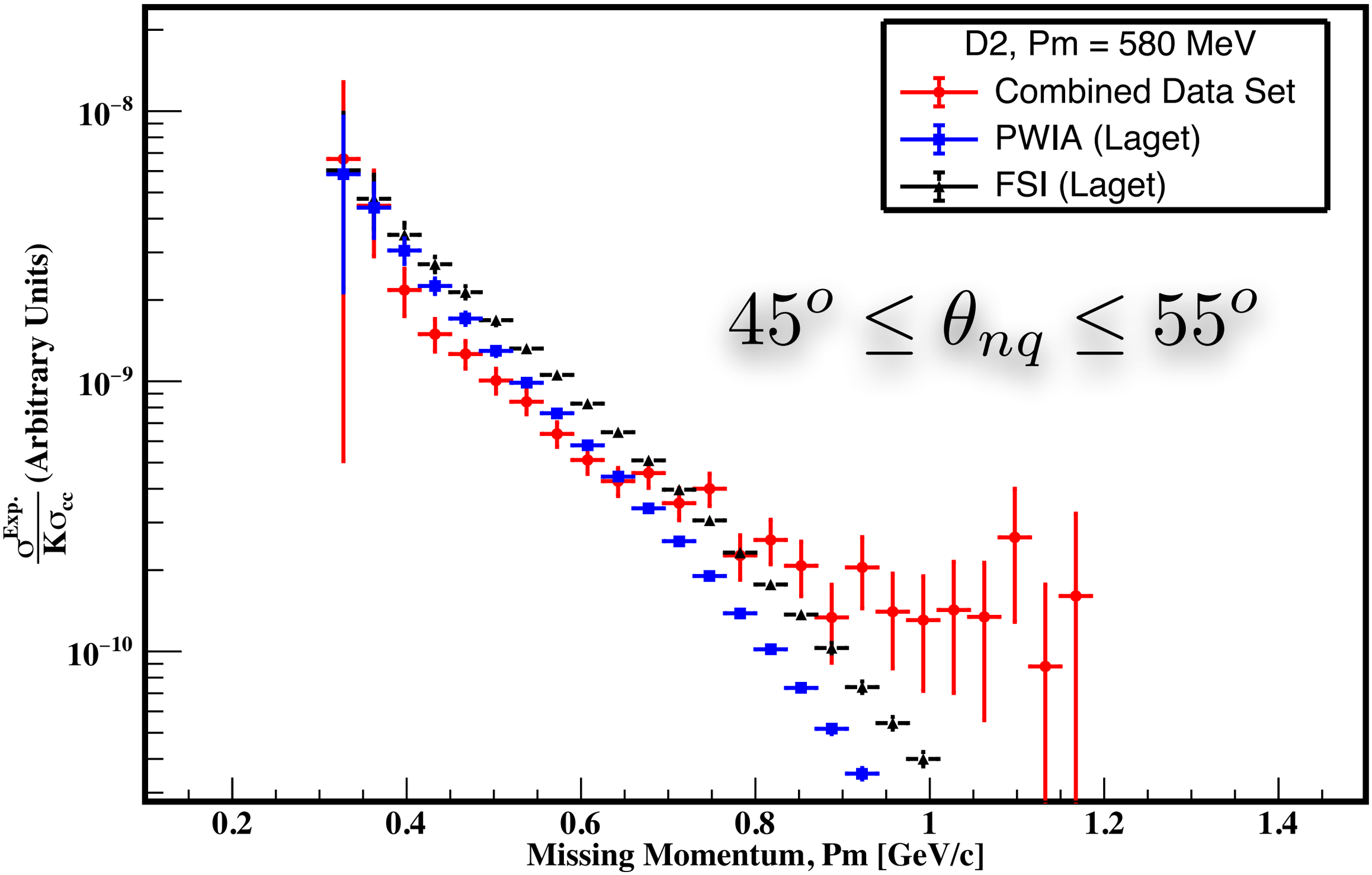


Reduced Cross Sections: Pm = 750 MeV



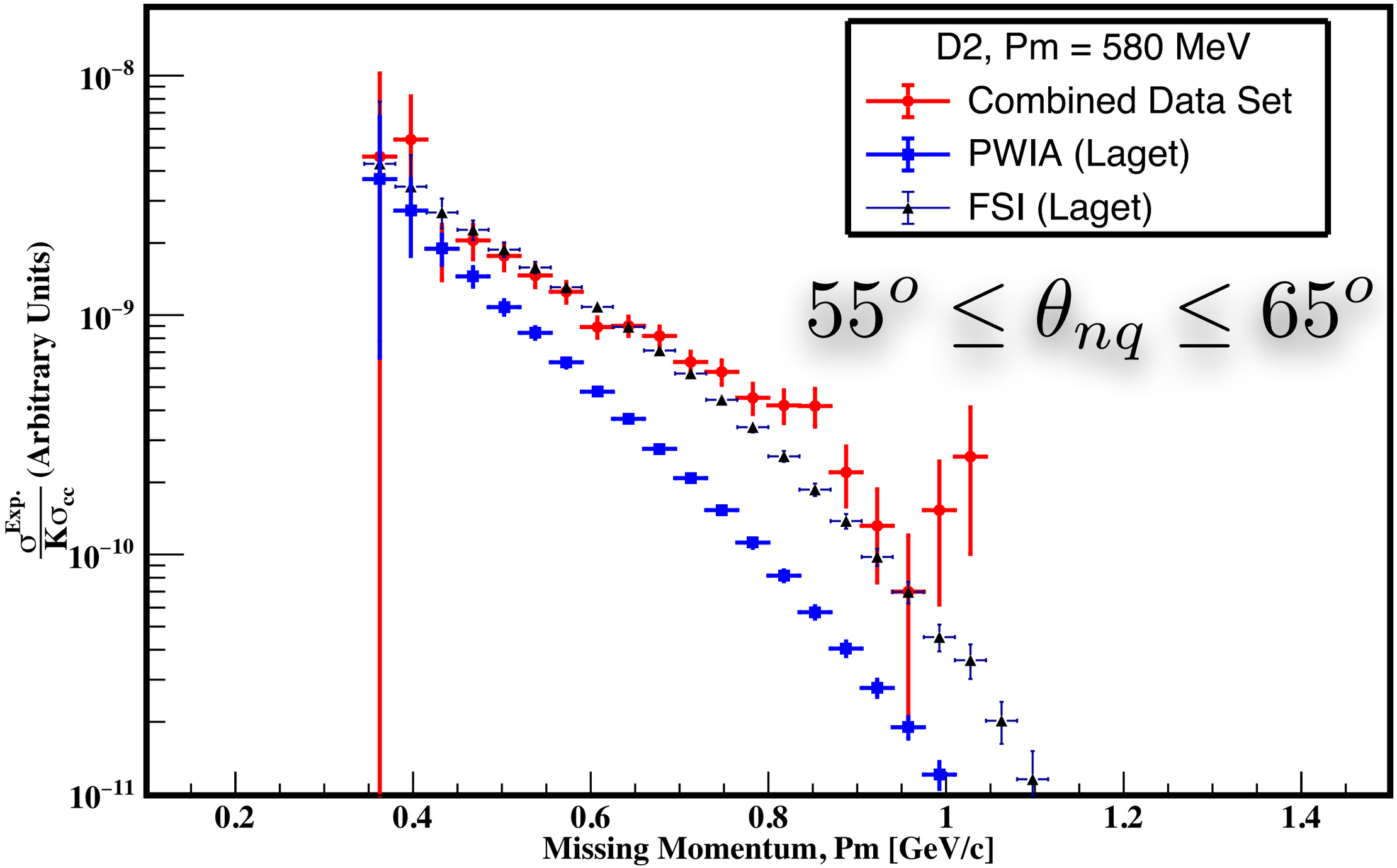
Selecting Angle Bins for: $\theta_{nq} \geq 45^o$

Reduced Cross Sections: Pm = 580 MeV



Selecting Angle Bins for: $\theta_{nq} \geq 45^o$

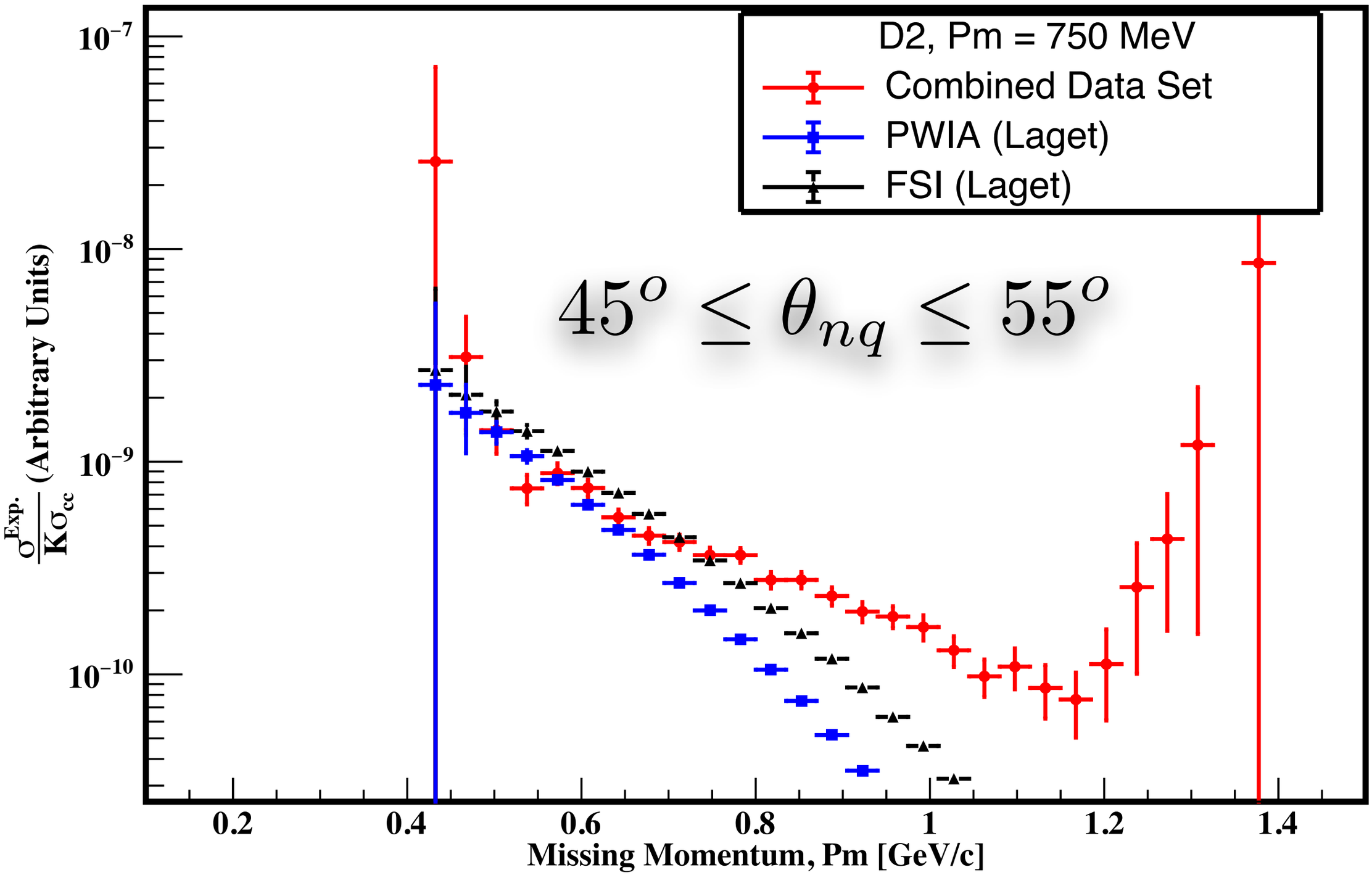
Reduced Cross Sections: Pm = 580 MeV



Selecting Angle Bins for:

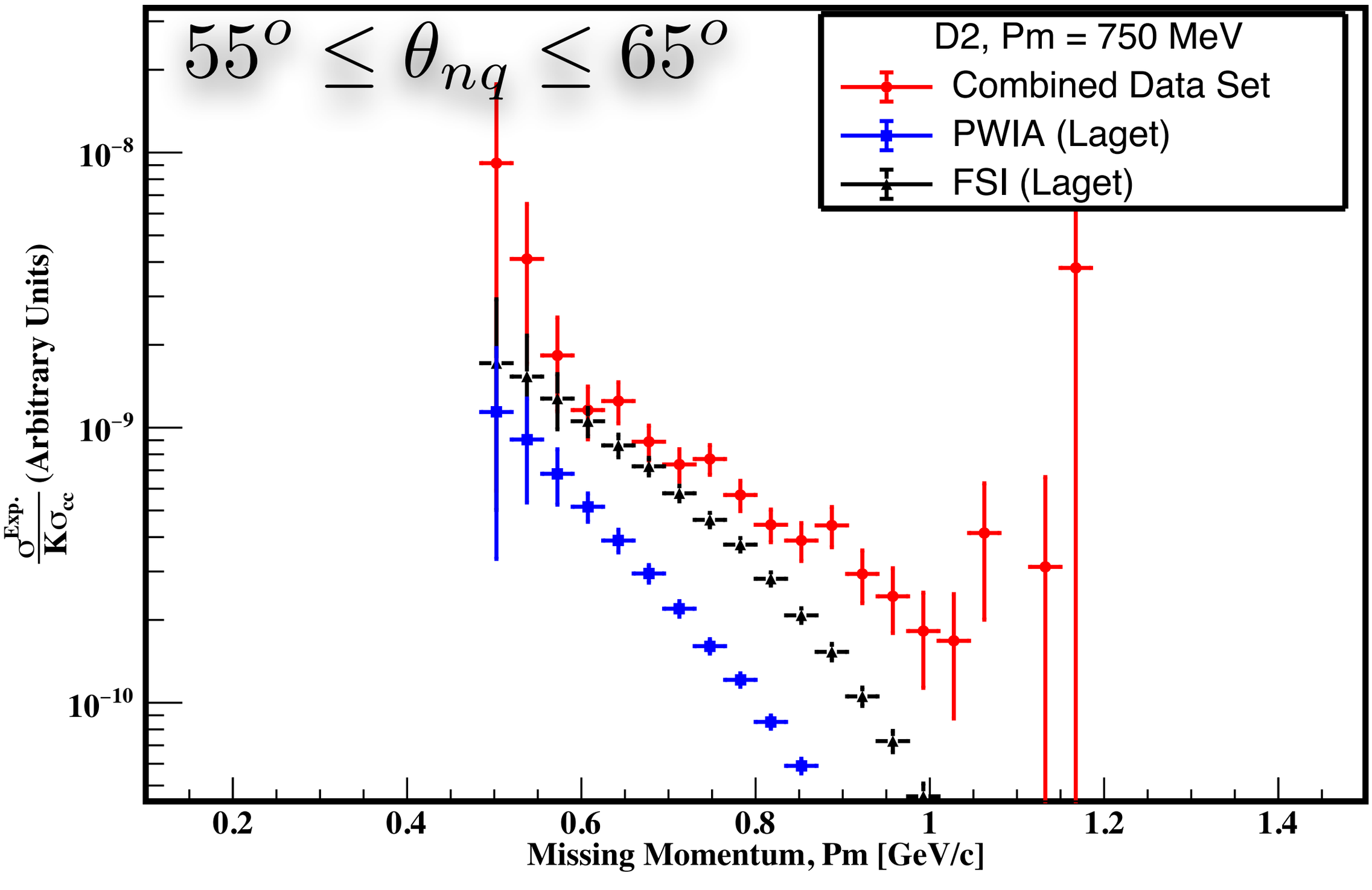
$$\theta_{nq} \geq 45^o$$

Reduced Cross Sections: Pm = 750 MeV



Selecting Angle Bins for: $\theta_{nq} \geq 45^o$

Reduced Cross Sections: Pm = 750 MeV



Summary

- ☑ H(e,e’p) Elastic Check looks OK
- ☑ Deuteron 80 MeV Setting SIMC/DATA looks OK
- ☑ First Look at Deuteron High Missing Momentum Components
- ☑ Agreement of 580 / 750 MeV data in the overlap region
- ☐ Data need further corrections
- ☐ Systematic Uncertainties need to be studied

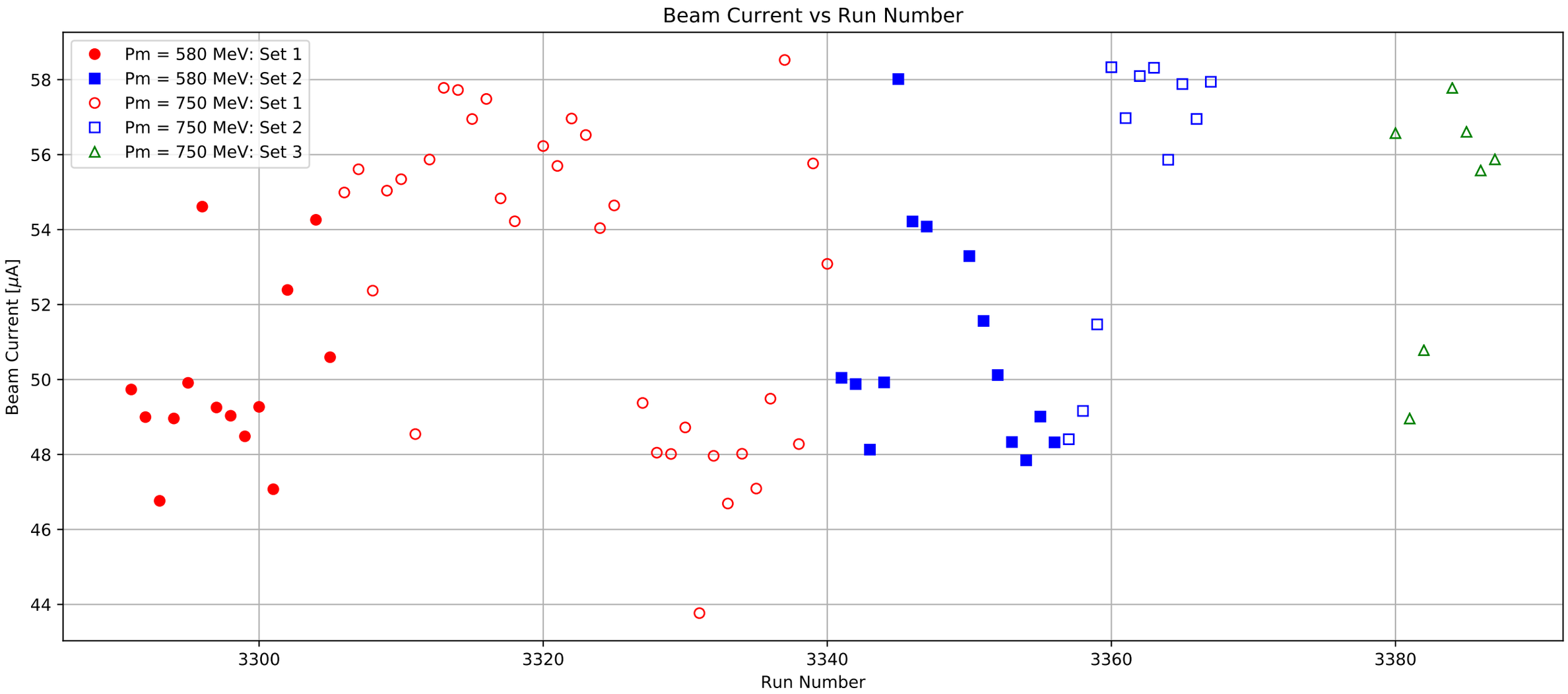
Thank You !

Any Questions ?

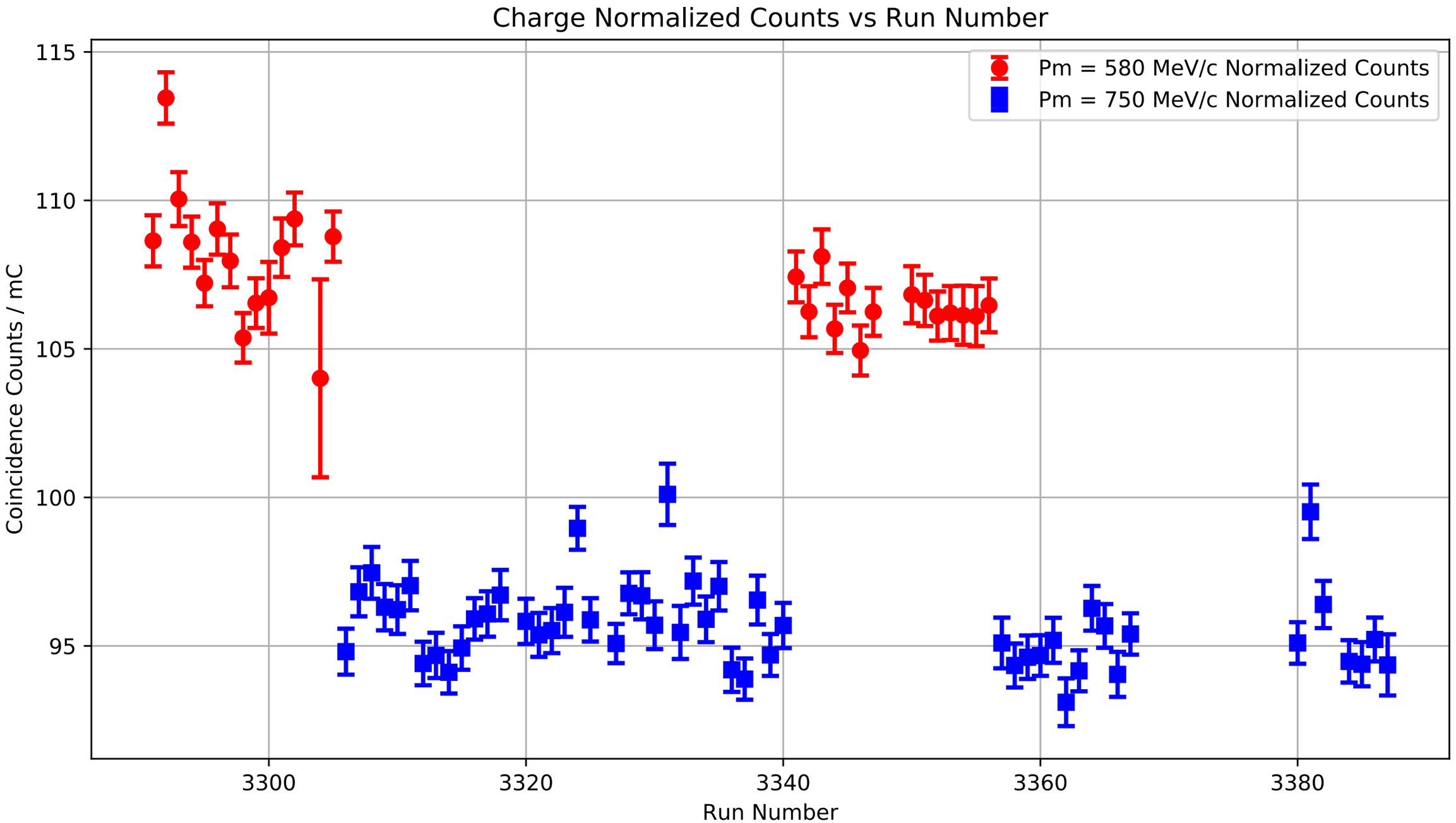
Back-Up Slides

Beam Current

☑ Beam Current ranged from 45 - 60 uA

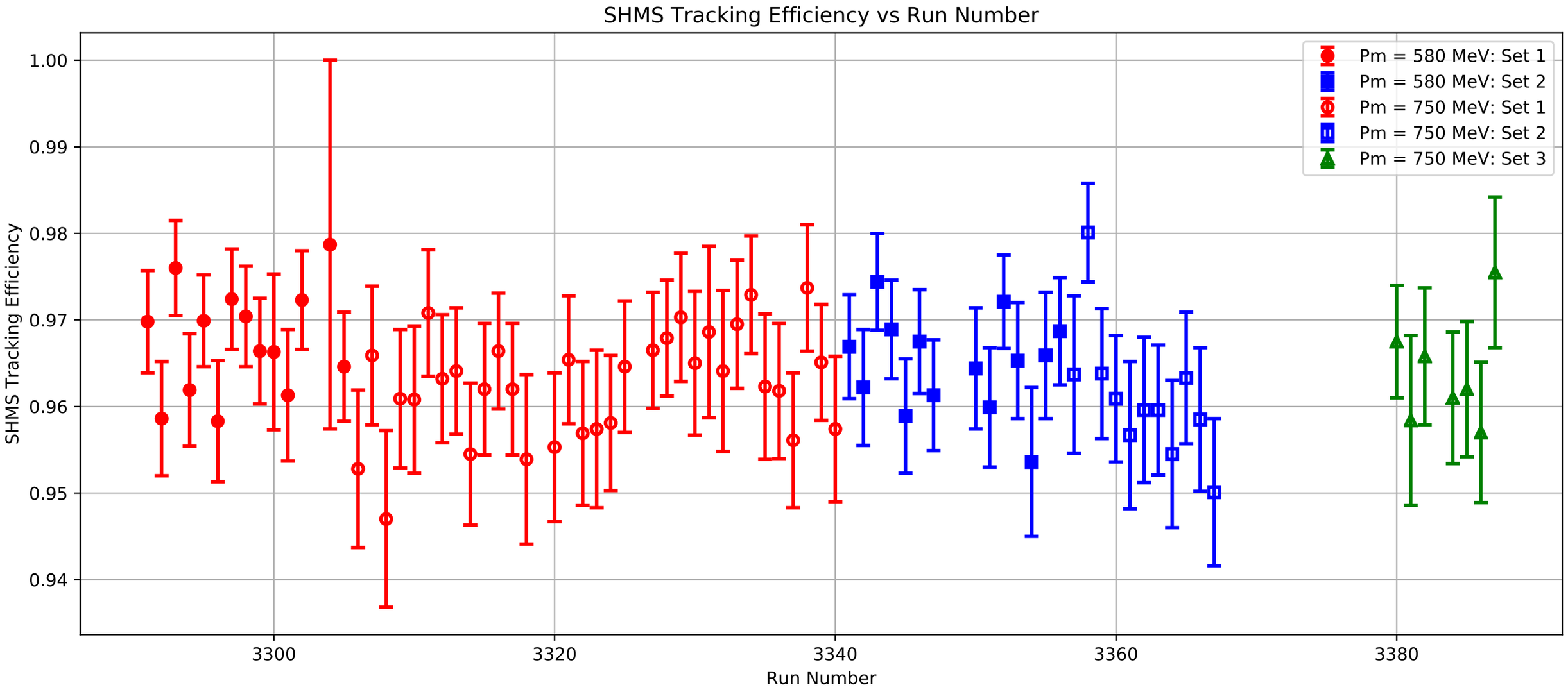


Charge Normalized Counts



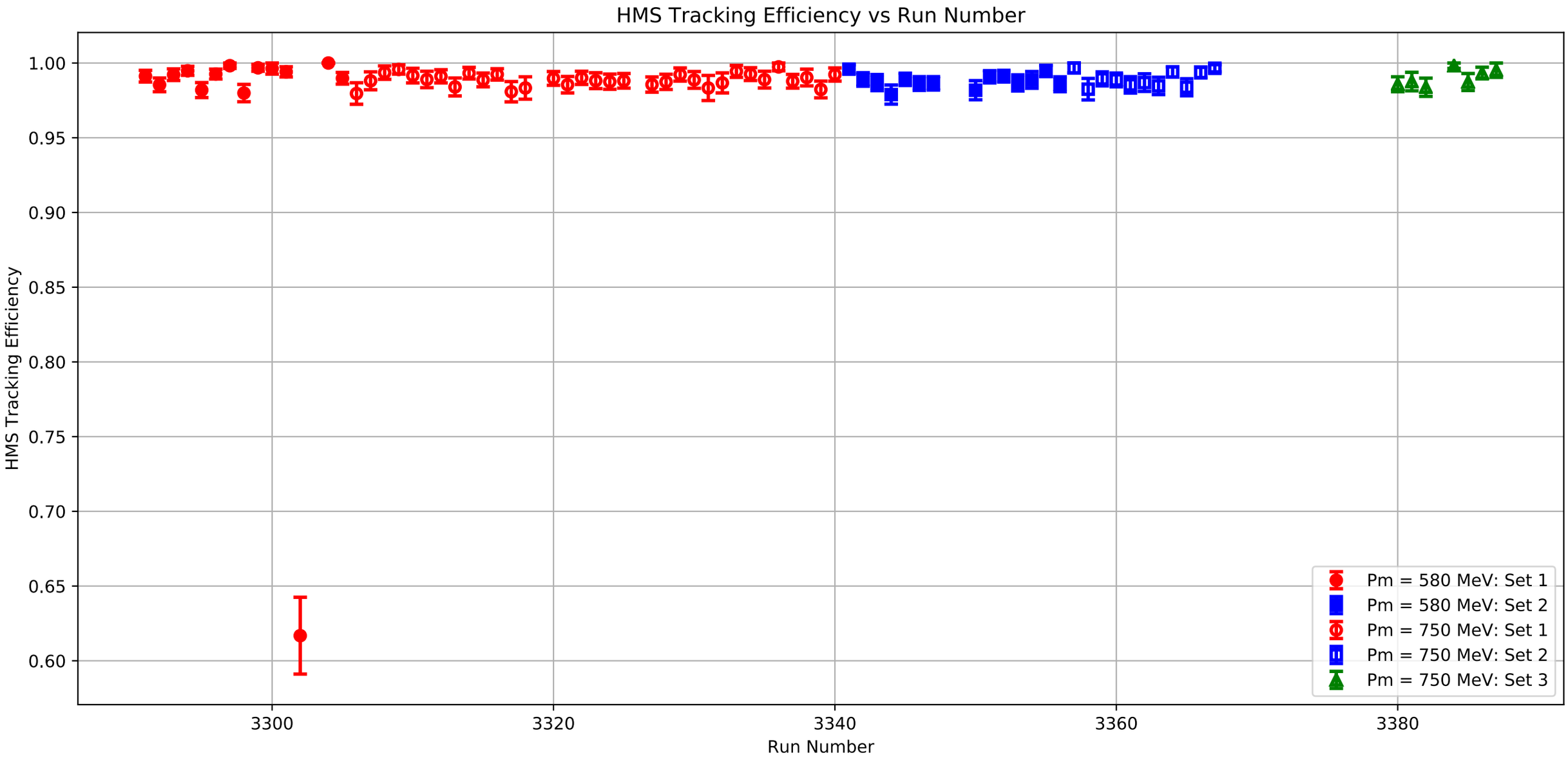
SHMS Tracking Efficiencies

☑ **SHMS electron tracking efficiencies ranged from 95-98 %**



HMS Tracking Efficiencies

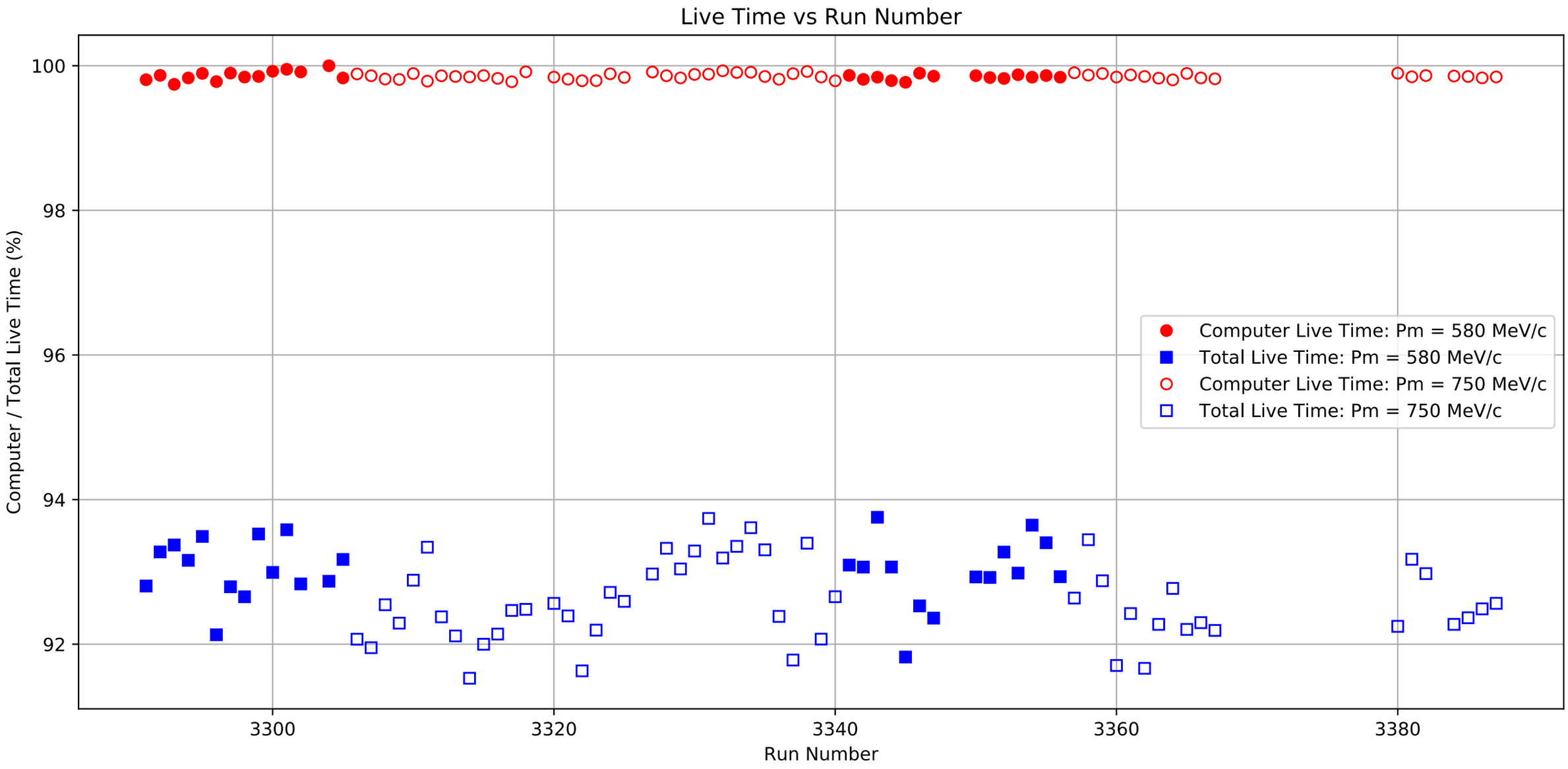
☑ **HMS electron tracking efficiencies ranged from 98-99 %**



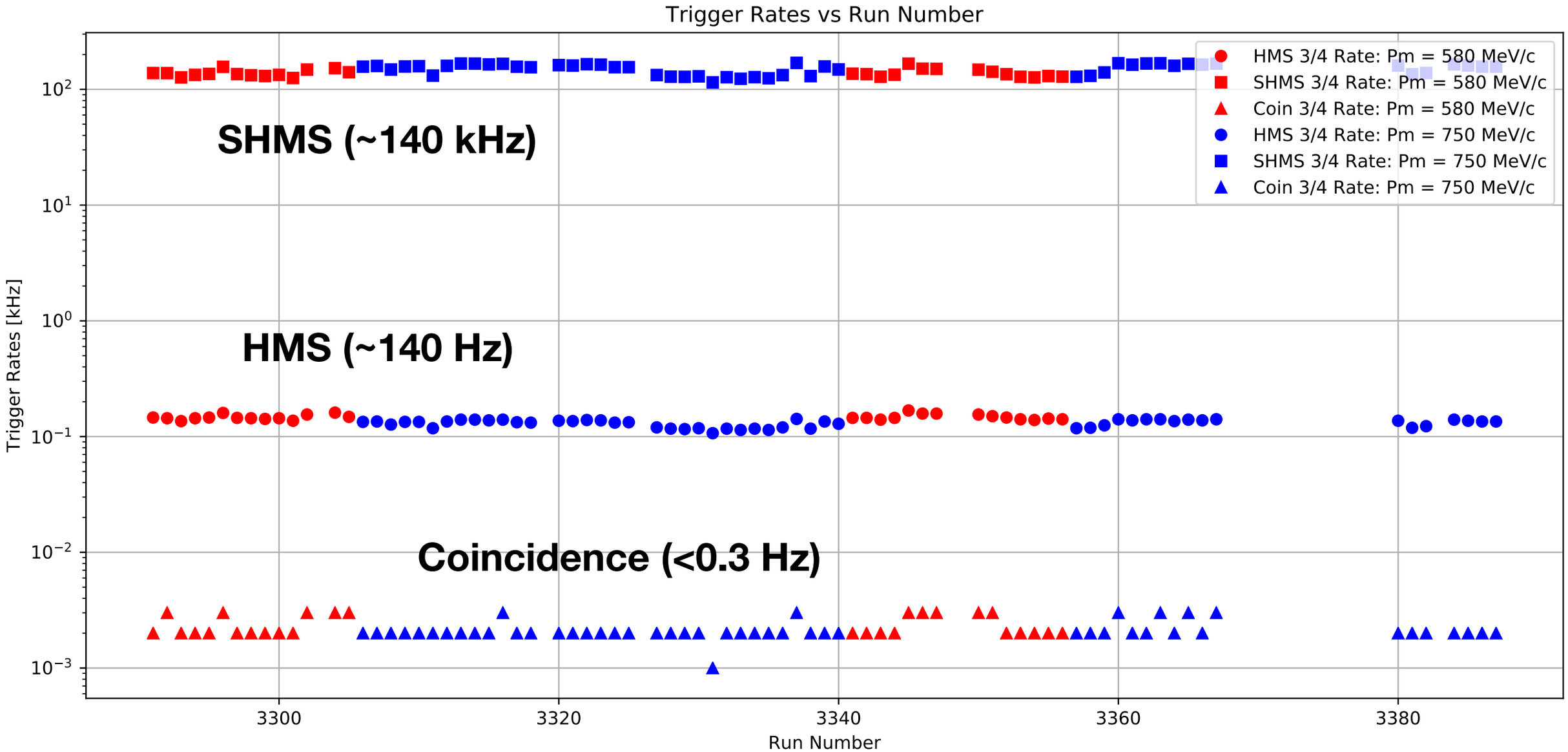
Computer / Total Live Time

☑ **Computer Live Time was ~ 98-99%**

☑ **Total Live Time was ~92-94% (Due to electronics pile-up at high rates)**



Trigger Rates



Beam Positions (BPMs)