A Measurement of the Nuclear Dependence of the Separated Longitudinal and Transverse Structure Functions in the Resonance Region

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Physics Overview

(Basics)

$$\left(\frac{d^2\sigma}{dE'd\Omega}\right)_{ep\to eX} = \frac{\alpha^2}{4E^2 sin^4(\theta/2)}\Big(W_2(\nu,Q^2)cos^2(\theta/2) + 2W_1(\nu,Q^2)sin^2(\theta/2)\Big)$$

$$\boxed{\sigma_R = \frac{1}{\Gamma}\frac{d^2\sigma}{dE'd\Omega} = \frac{4\pi^2\alpha}{x(W^2-M^2)}\left[2xF_1 + \epsilon F_L\right]}$$

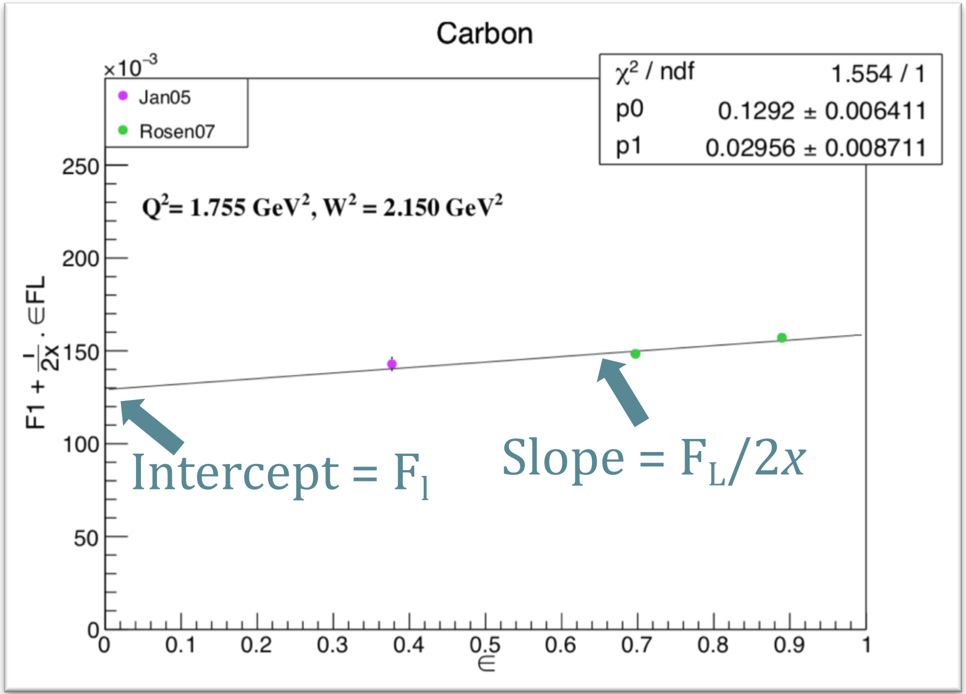
$$\epsilon = [1 + 2(1+\nu^2/Q^2)tan^2(\theta/2)]^{-1}$$

$$\Gamma = \frac{\alpha K E'}{2\pi^2 Q^2 E(1-\epsilon)}$$

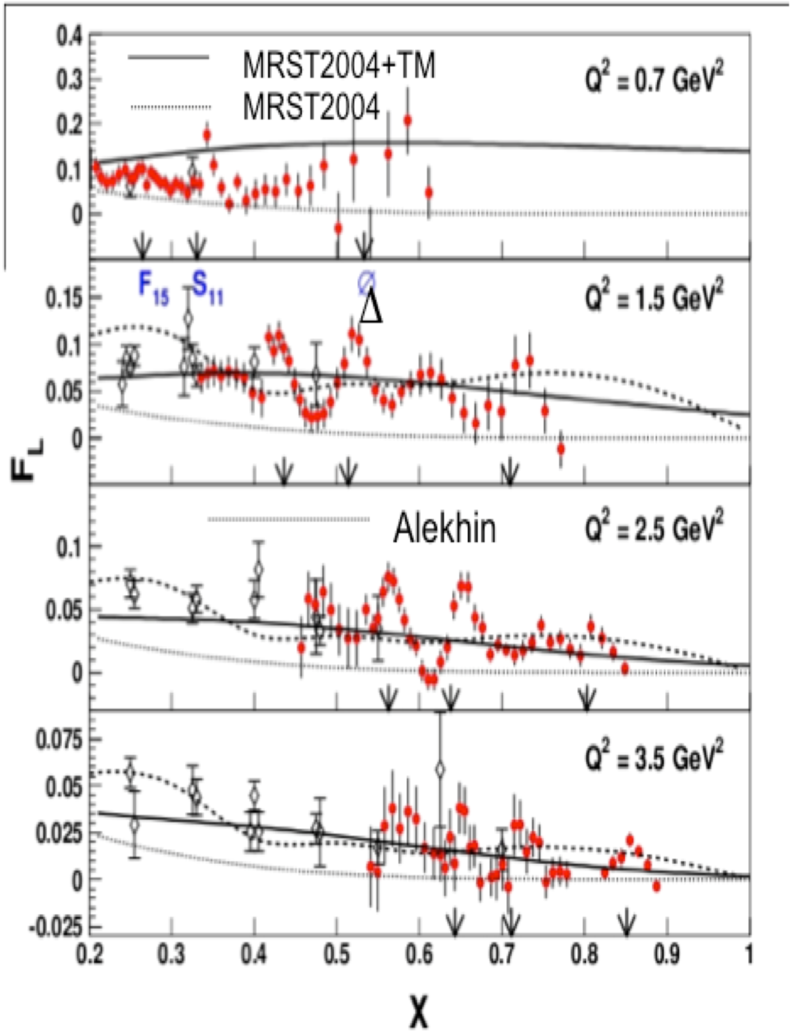
Linear in ε

$$F_2 = (1+\frac{\nu^2}{Q^2})\left[F_L + 2xF_1\right]$$

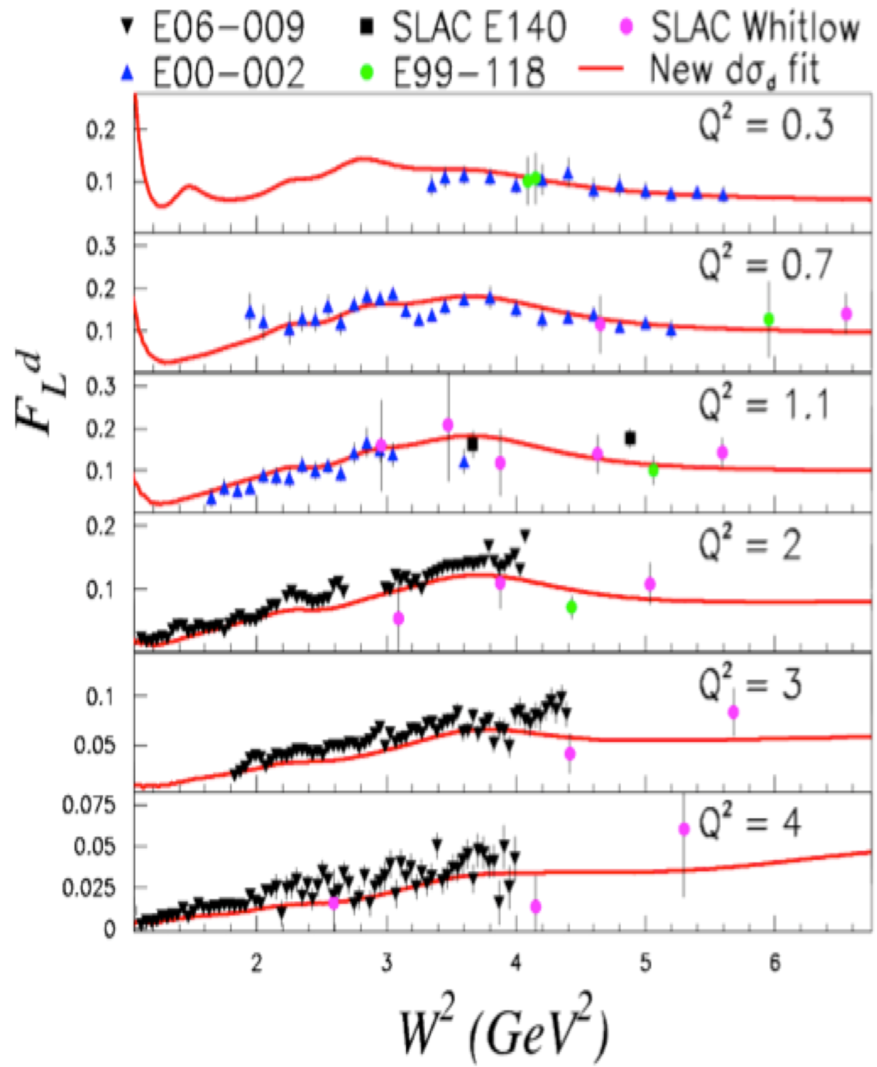
Rosenbluth Separation



Proton: E94-110 + SLAC



Deuteron



Previous Hall C results

Physics Overview

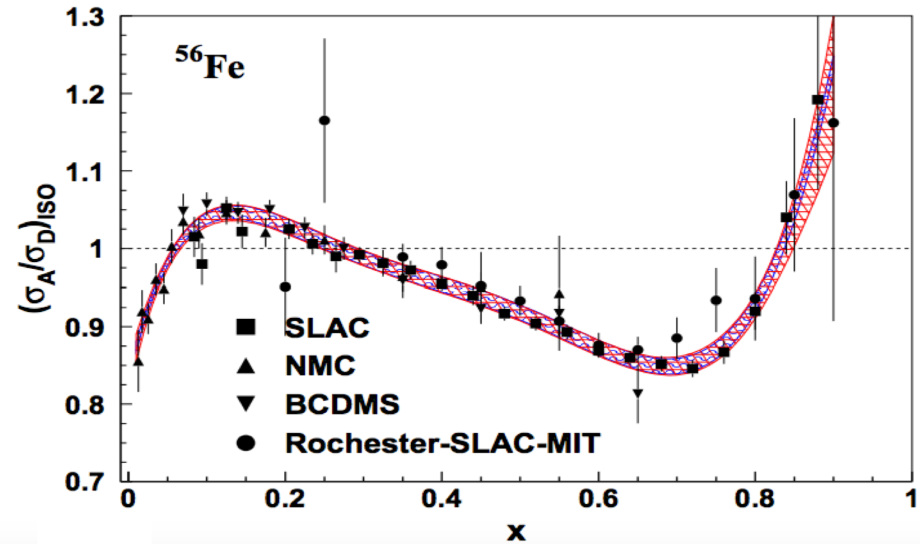
(A-dependence of structure functions)

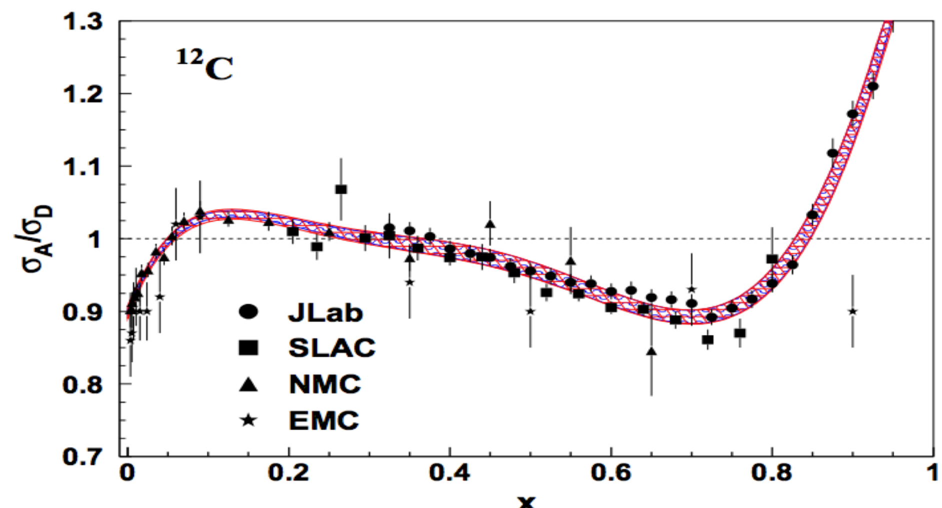
Structure functions of bound nucleons are different from free nucleons

The nuclear environment influences the internal structure of the nucleon (need to study the nuclear medium modifications of structure function)

F_2^A / F_2^D	F_L^A / F_L^D	F_1^A / F_1^D
(✓ in DIS)	(No evidence)	(No evidence)

Does A-dependence effect is the same for F_L and F_1 ?





Physics Overview

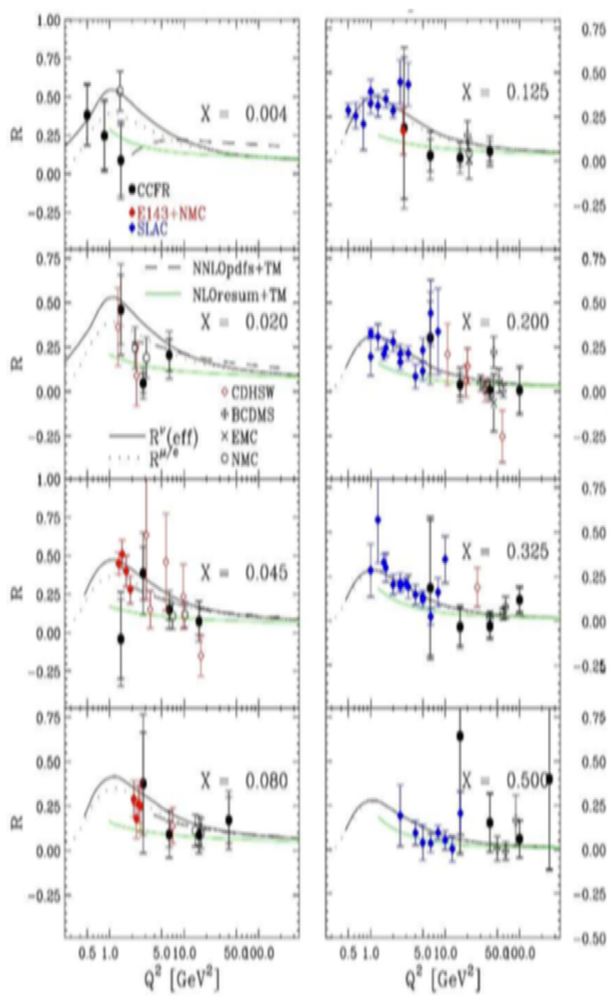
(A-dependence of R)

Useful quantity:

$$R = \frac{\sigma_L}{\sigma_T} = \frac{F_L}{2xF_1}$$

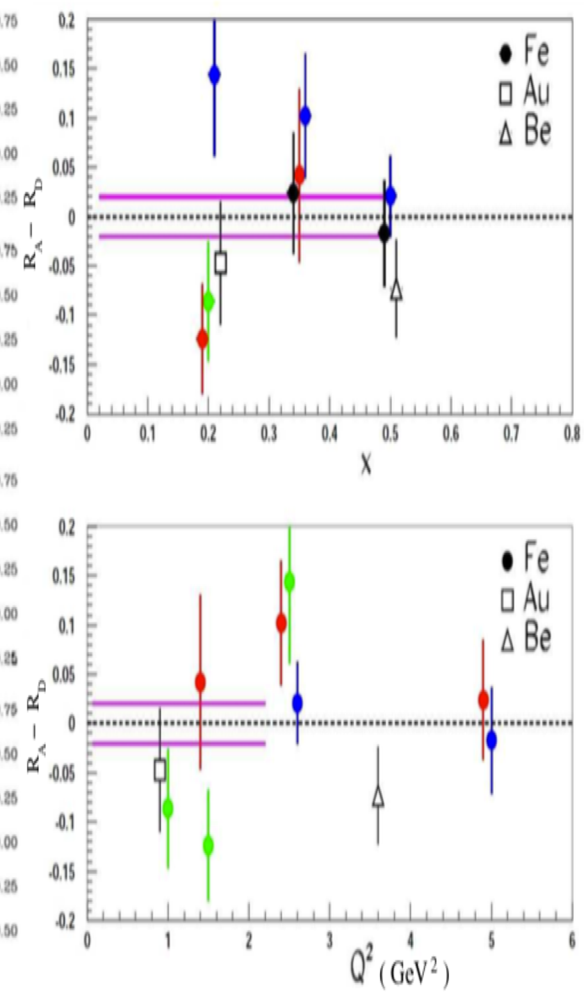
The nuclear dependence of R can be studied in the form ($R_A - R_D$)

World Data on R



- Only DIS region (no results for resonance region)
- Big Error bars
- Coulomb correction was **NOT** applied

SLAC E140



R is typically a small value (< 1), even a small value of $R_A - R_D$ in absolute value could imply a non-negligible nuclear medium modifications of R

Physics Overview

(A-dependence of R)

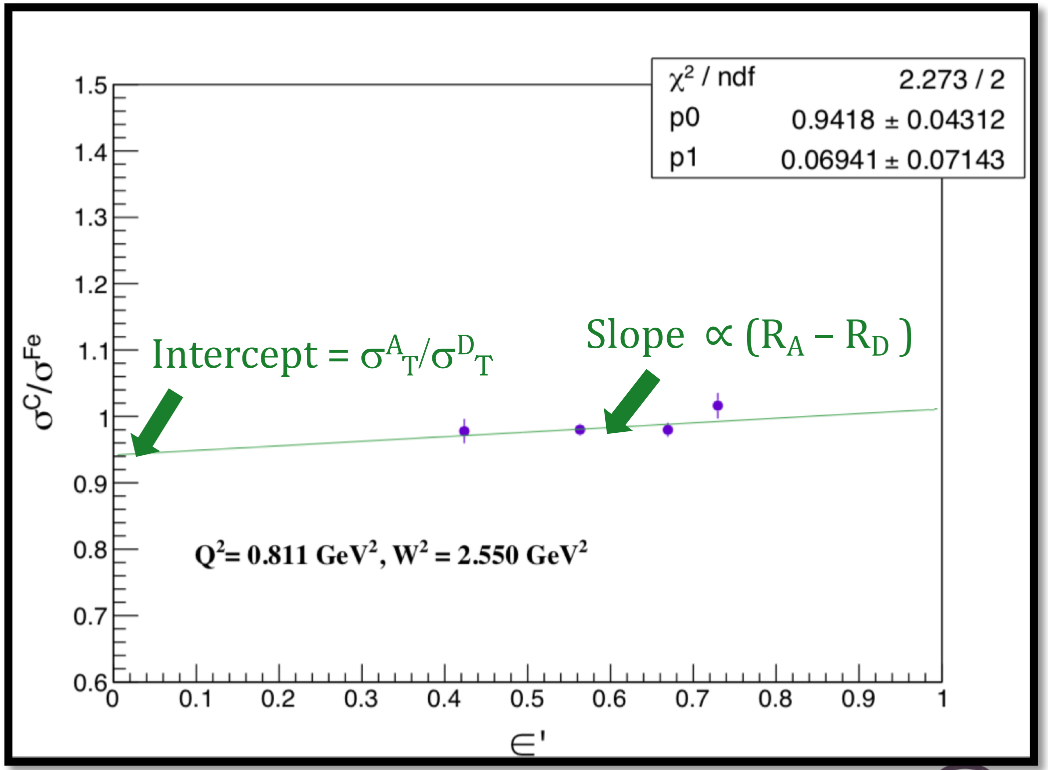
$$\left(\frac{d^2\sigma}{dE'd\Omega}\right) = \Gamma\left(\sigma_T + \epsilon\sigma_L\right)$$

$$\frac{\sigma_A/\Gamma}{\sigma_D/\Gamma} = \frac{\sigma_T^A}{\sigma_T^D}\left(\frac{1+\epsilon R_A}{1+\epsilon R_D}\right)$$

$$\frac{\sigma_A}{\sigma_D} = \frac{\sigma_T^A}{\sigma_T^D}\left(1+\epsilon'(R_A - R_D\right)$$

Linear in ε`

$$\epsilon' = \frac{\epsilon}{1+\epsilon R_D}$$



Physics Overview

(Search for Nuclear Pions)

- Pions are believed to be the carrier of the nuclear force (Yukawa's theory)
- One way to verify pion existence arises from the measurement of $R = \sigma_L/\sigma_T$
  - Small value of R → spin ½ partons
  - Big value of R → indication of bosonic constituents
- Pions (spin 0) contribute to the longitudinal structure function (helicity 0) :

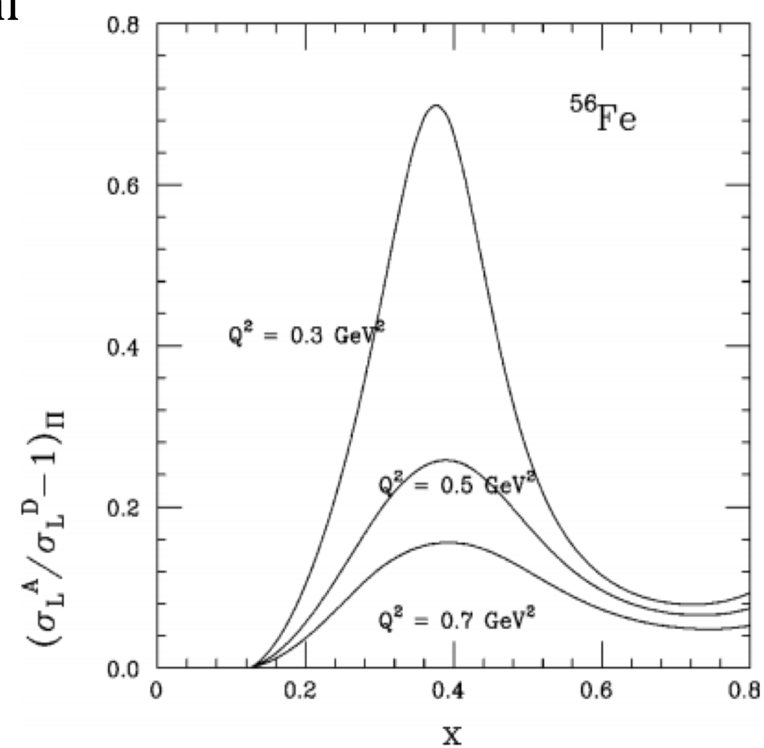
$$\sigma_L(A) = \sigma_L(D) + \delta^{\pi}\sigma_L$$

- The pionic enhancement is given by:

$$\frac{\sigma_L(A)}{\sigma_L(D)} = 1 + x\frac{2}{3}f_\pi(\xi)\frac{\nu^2}{(Q^2+\nu^2)}\frac{F_\pi^2(Q^2)}{F_2^D R_D}(1+R_D)$$

Pion form factor (drops at high Q^2)

G. A Miller, Phys. ReV. C 64, 022201



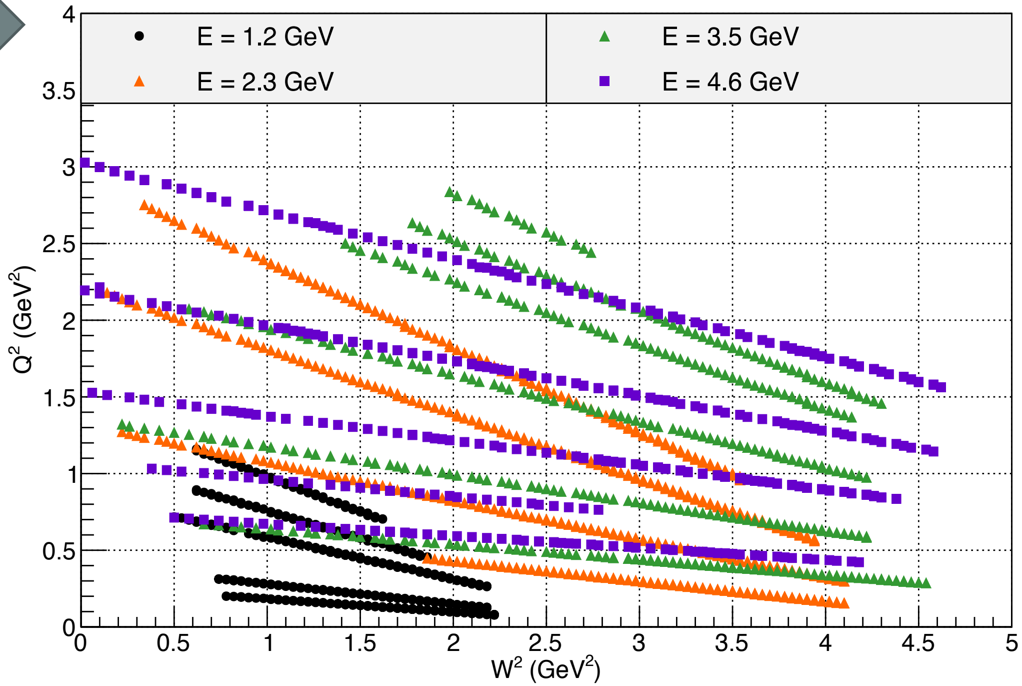
Experiment E04-001

- Measure F_L and F_1 from nuclei in the resonance region
- Investigate quark-hadron duality in nuclei
- Neutrino cross section model development in collaboration with the neutrino community
- Provide information of medium modifications of separated F_1 and F_L and R.
- look for nuclear pions

6 GeV L/T Separation Program in Hall C

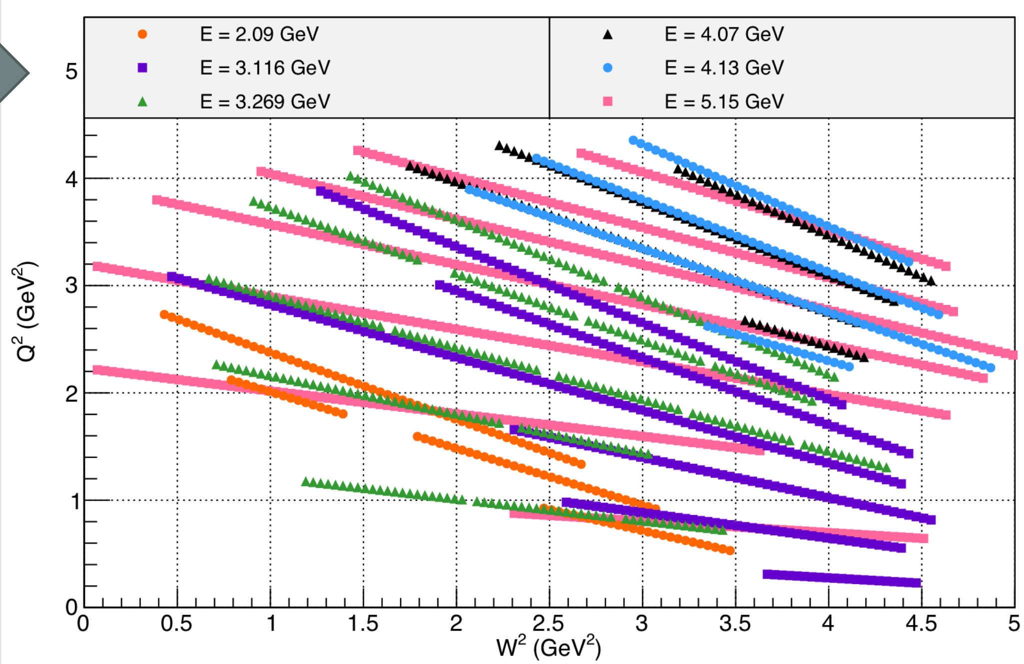
Experiment	target(s)	W range	Q^2 range	Status
E94-110	p	RR	0.3 - 4.5	nucl-ex/041002
E99-118	p,d	DIS+RR	0.1 - 1.7	PRL98:14301
E00-002	p,d	DIS+RR	0.25 - 1.5	Analysis finalized/Published **Phys.Rev. C97 (2018) no.4, 045204**
E02-109	d	RR+QE	0.2 - 2.5	Finalizing dσ analysis
E06-009	d	RR+QE	2.0 - 4.0	Cross section, F_L finalized Non-singlet moments paper in collaboration review
E04-001 - I	C,Al,Fe	RR+QE	0.2 - 2.5	Finalizing dσ analysis
E04-001 - II	C,Al,Fe	RR+QE	2.0 - 4.0	Cross section, RA-Rd finalized for most targets

Different Q^2 Scale



E04-001 (phase I)

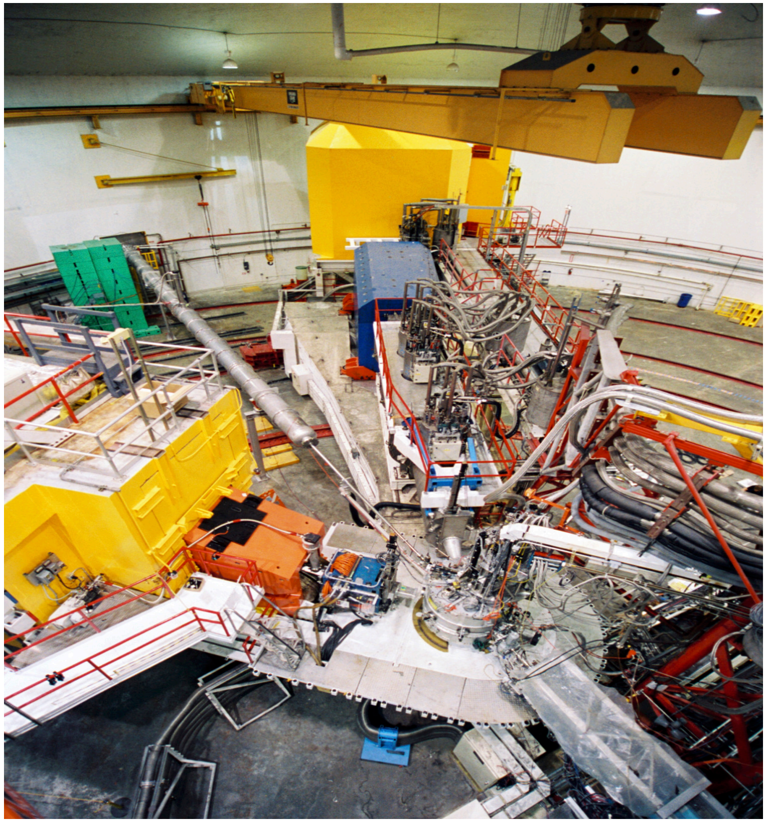
Jan05

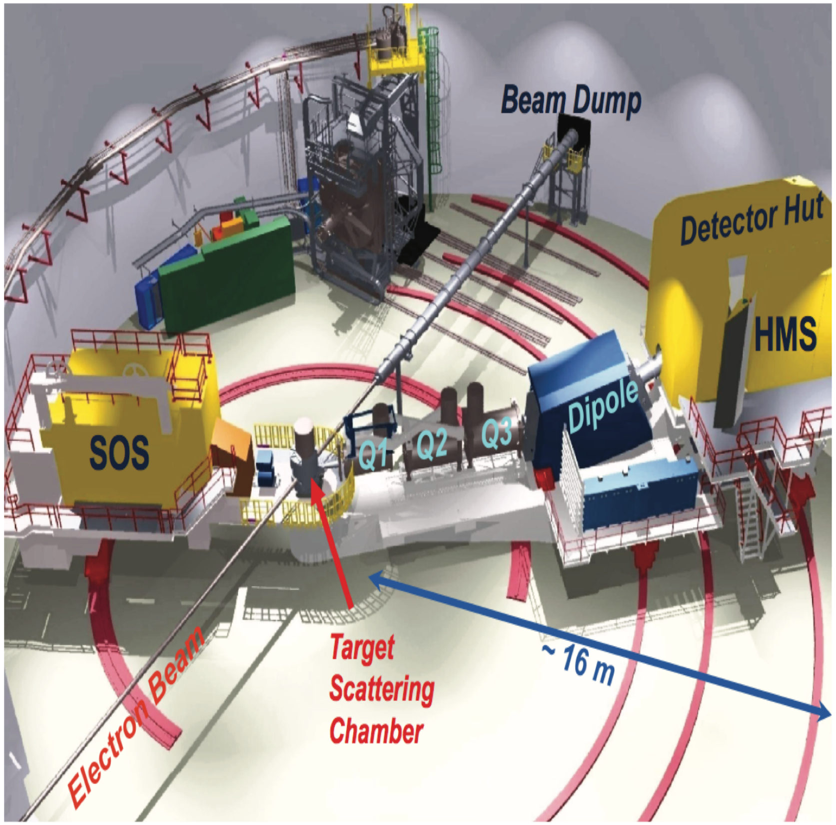


E04-001 (phase II)

Rosen07

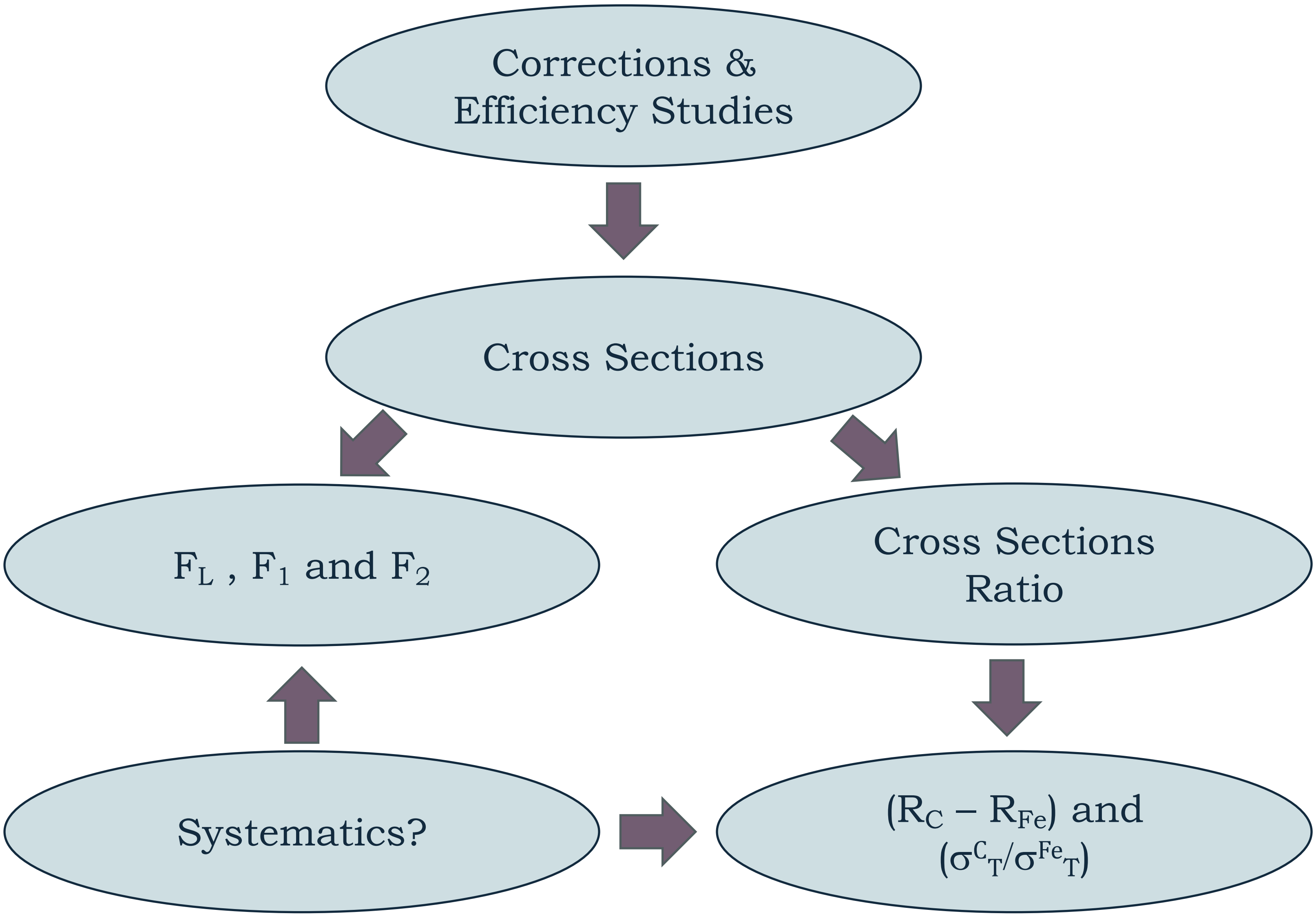
Experimental Setup





Hall C top view (6 GeV era). High Momentum Spectrometer (HMS) was used to detect scattered electrons, whereas the Short Orbit Spectrometer (SOS) was used largely for charge symmetric background rejection.

Analysis Steps



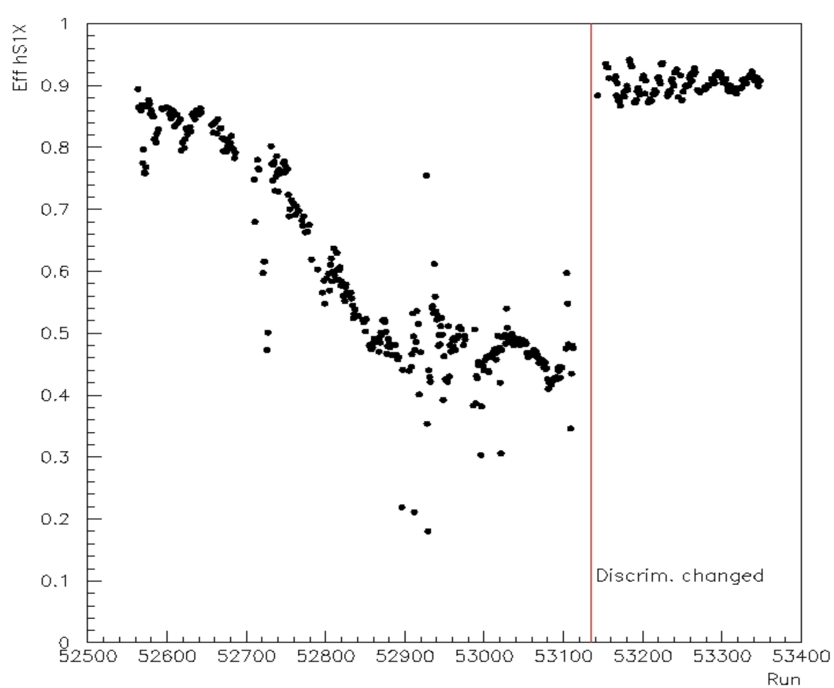
Corrections and Efficiency studies

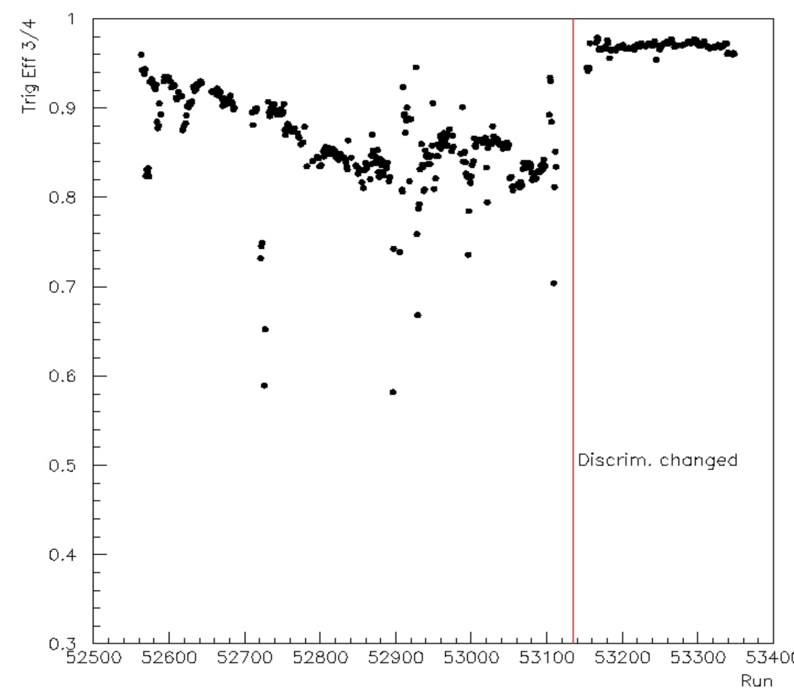
Trigger Efficiency

$$\epsilon_{trg} = \epsilon_{PRLO} \times \epsilon_{STOF} + (1 - \epsilon_{PRLO}) \times \epsilon_{3/4}$$

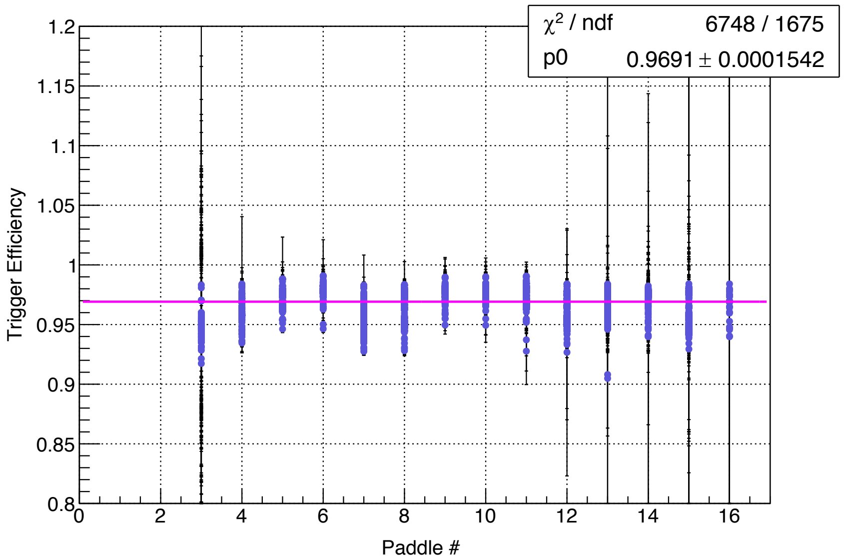
During the data taking, a discriminator connected to S1X scintillator paddles went bad => the average trigger efficiency dropped

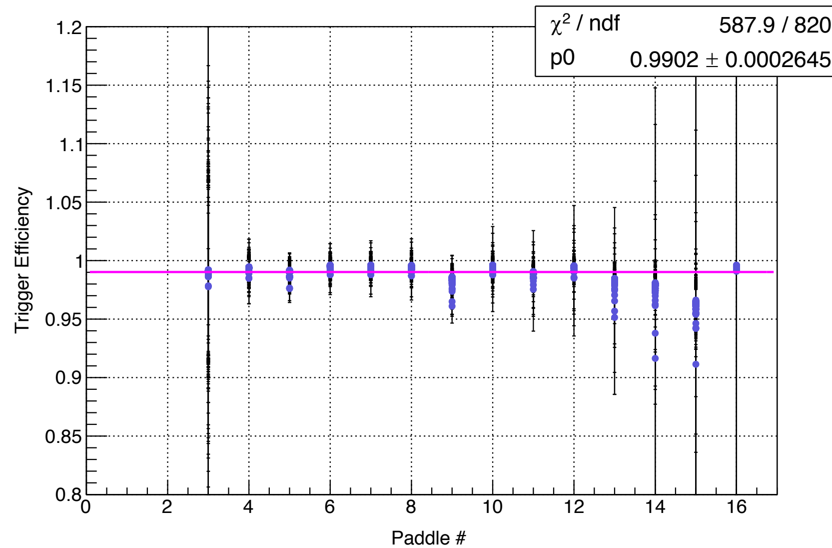
Alternative of average trigger eff. → trigger efficiency per paddle





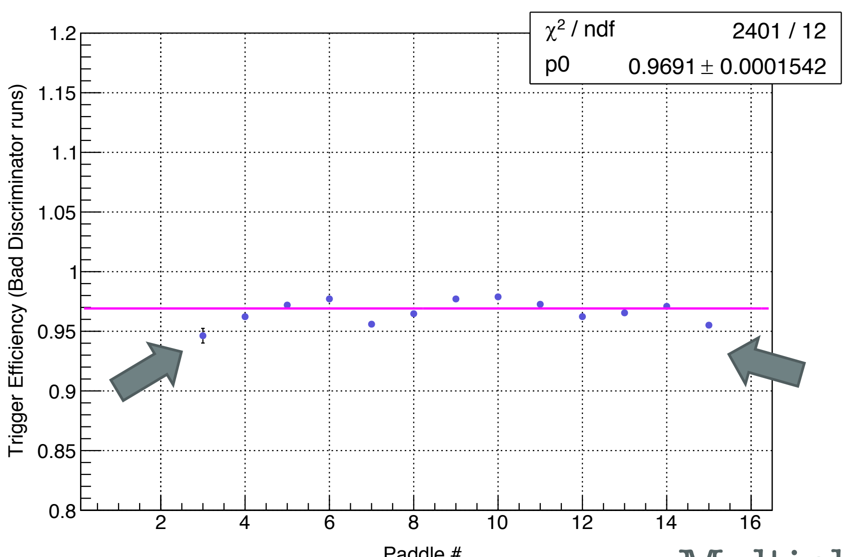
Corrections and Efficiency studies

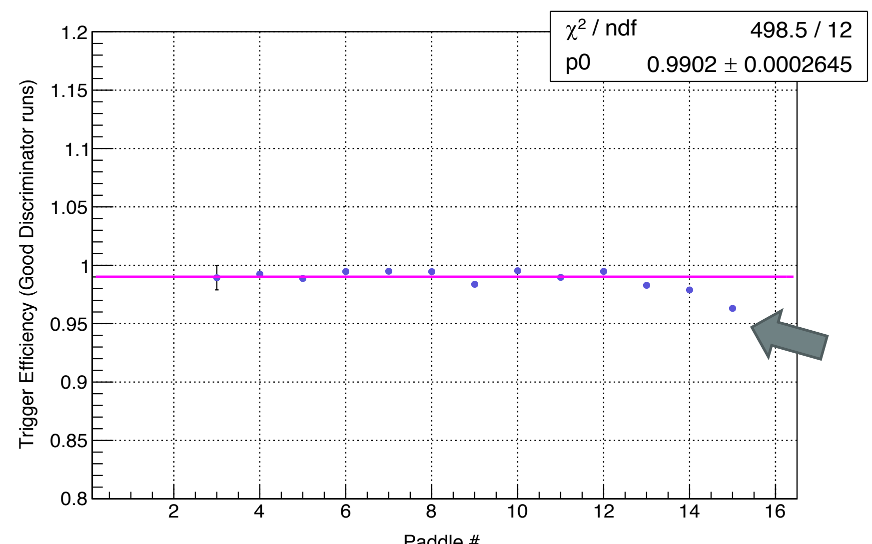




Before replacing the discriminator

After replacing the discriminator



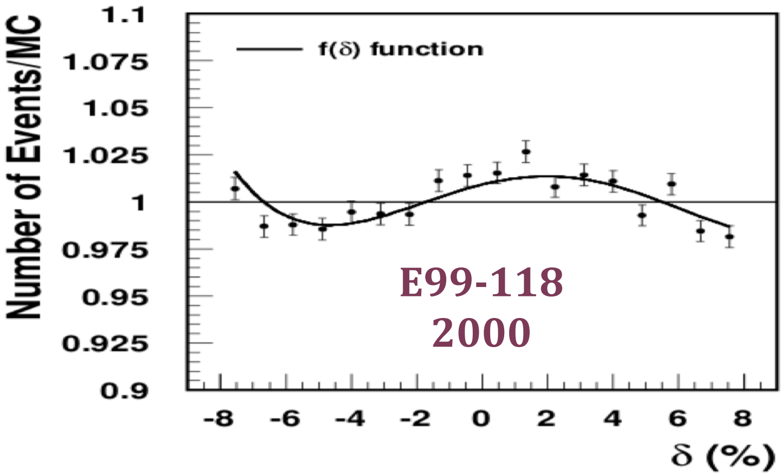


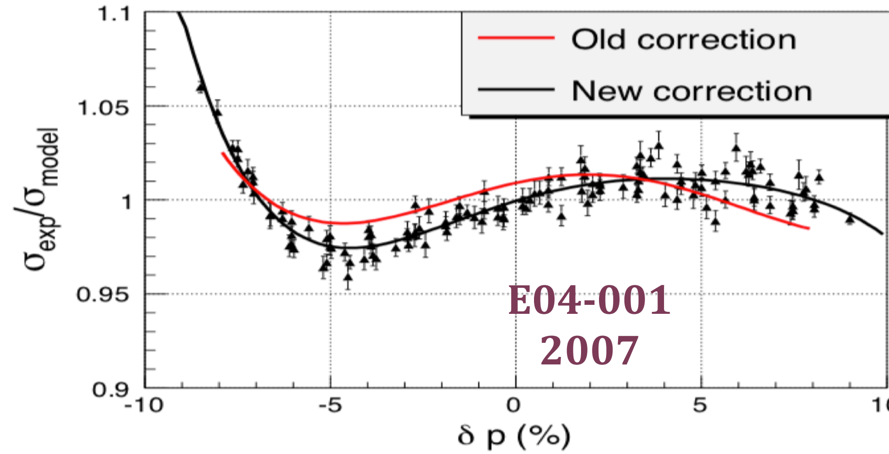
Multiple scattering?

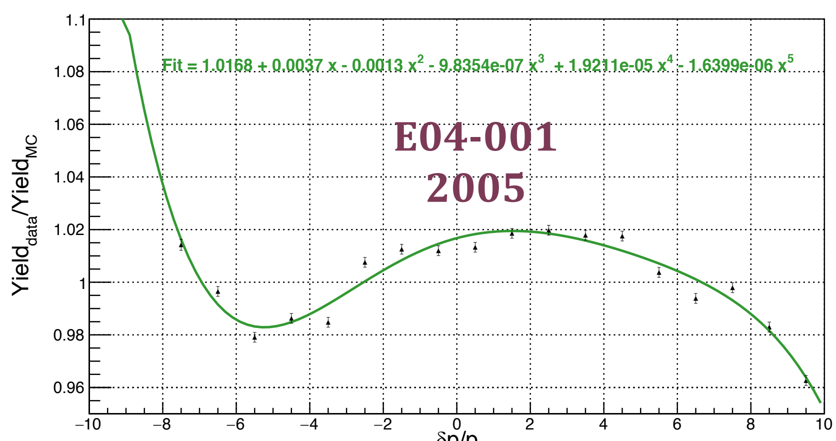
Corrections and Efficiency studies

δp/p Correction

A common issue when comparing Data to Monte Carlo, the Data/MC yield ratio vs δp/p has always similar shape (overfit?)

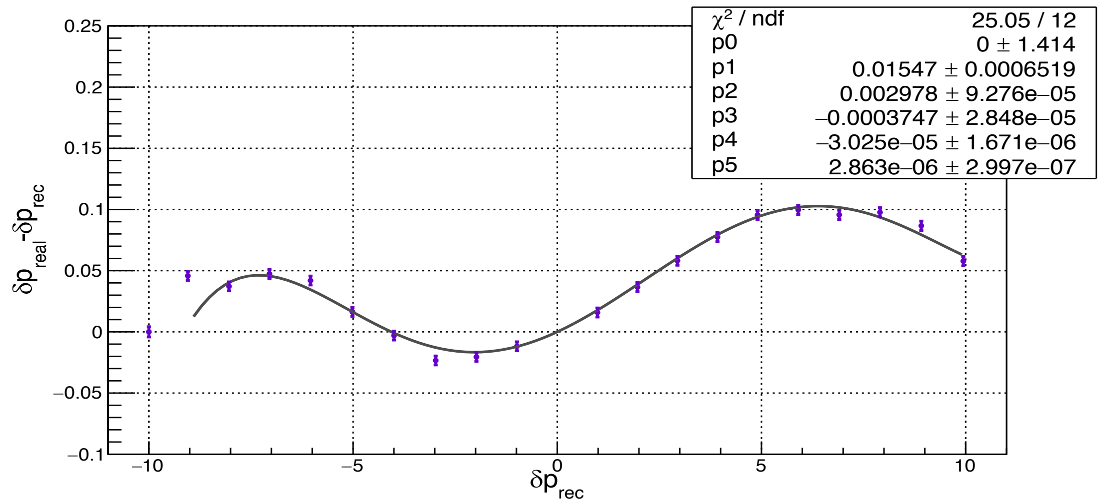


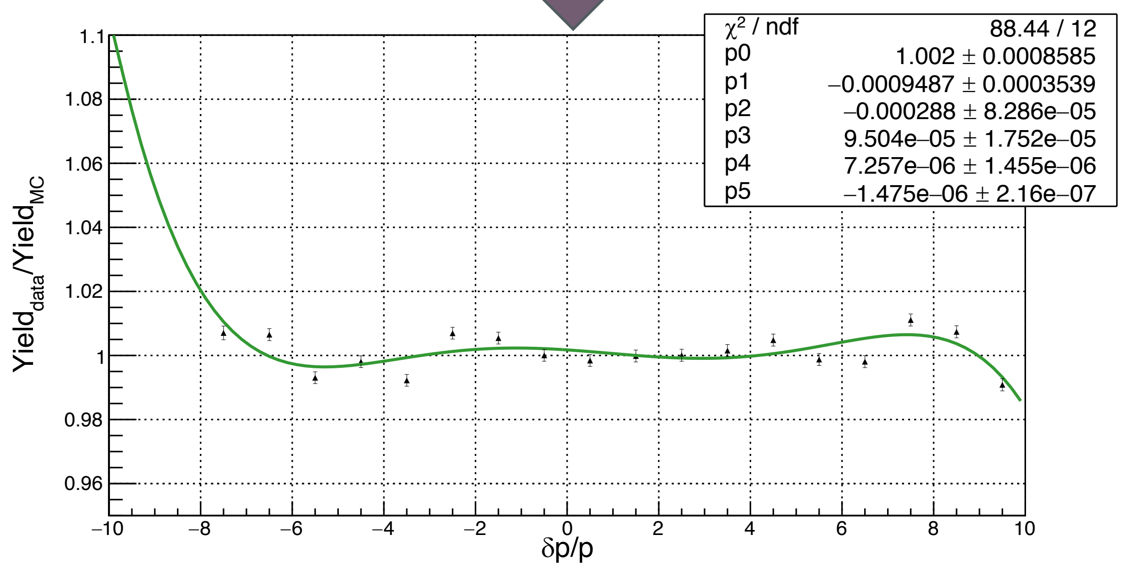




Corrections and Efficiency studies

δp/p Correction





Cross Section

In order to extract the inclusive cross section, some necessary pieces of information are needed:

Data: Number of good electrons

Monte Carlo: Number of good electrons

Model: Model cross section

$\text{Yield}_{\text{Data}}$

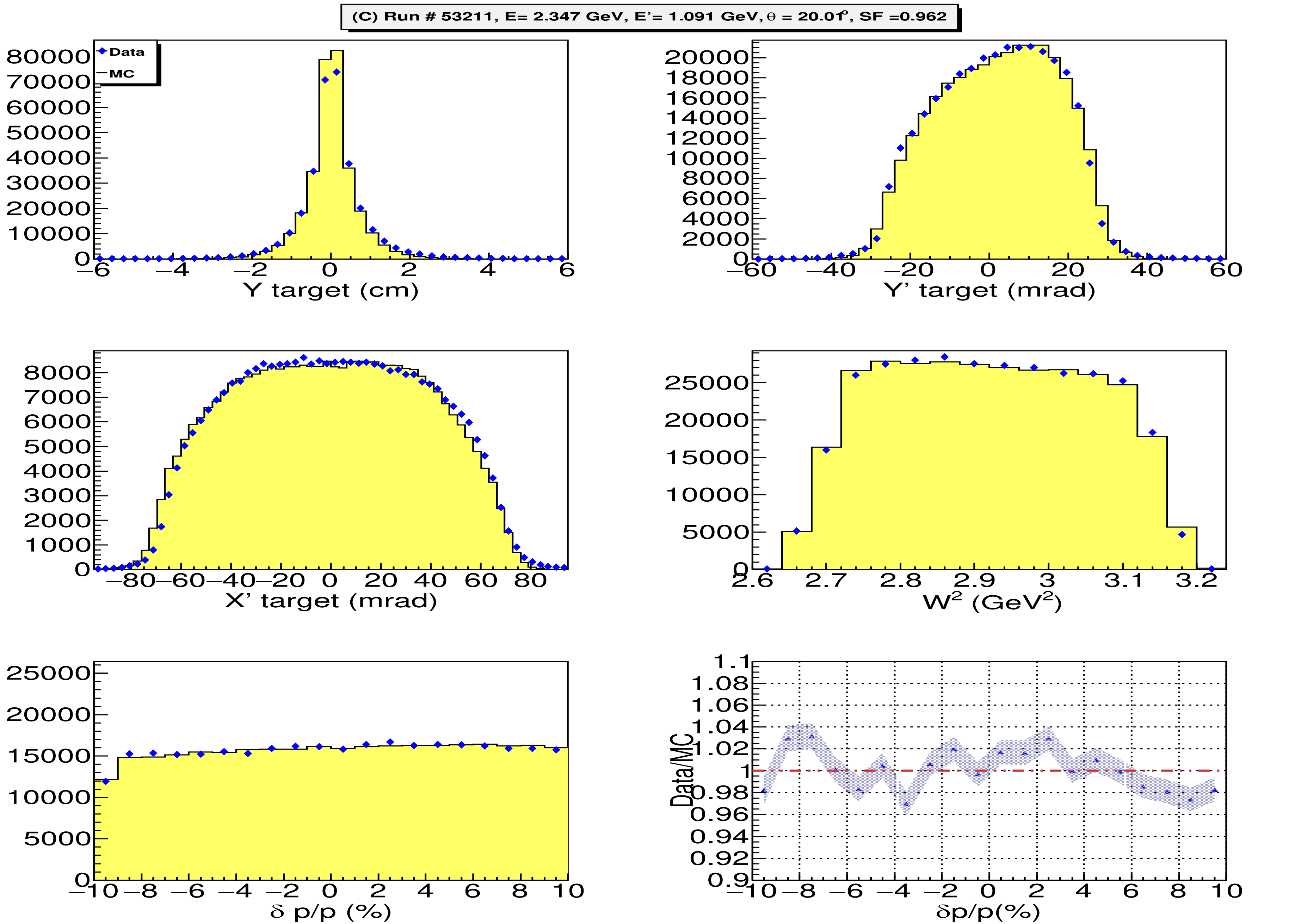
Yield_{MC}

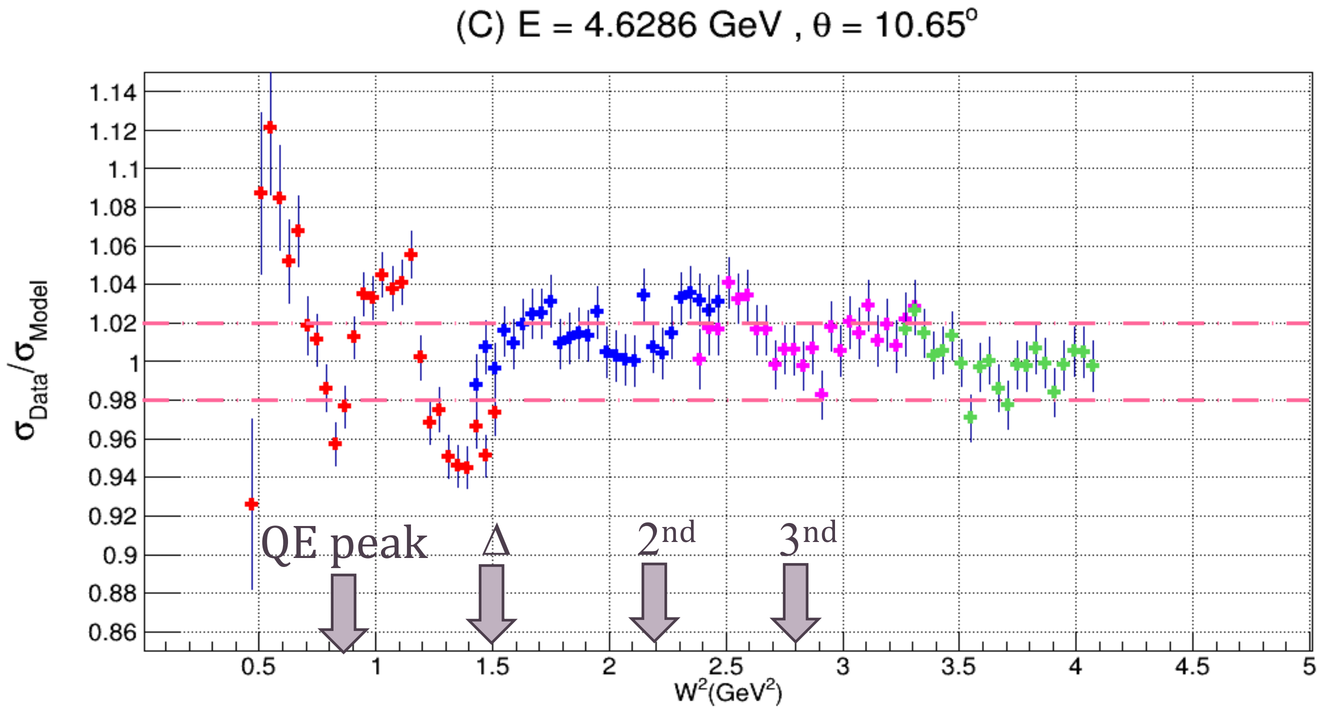
weighting

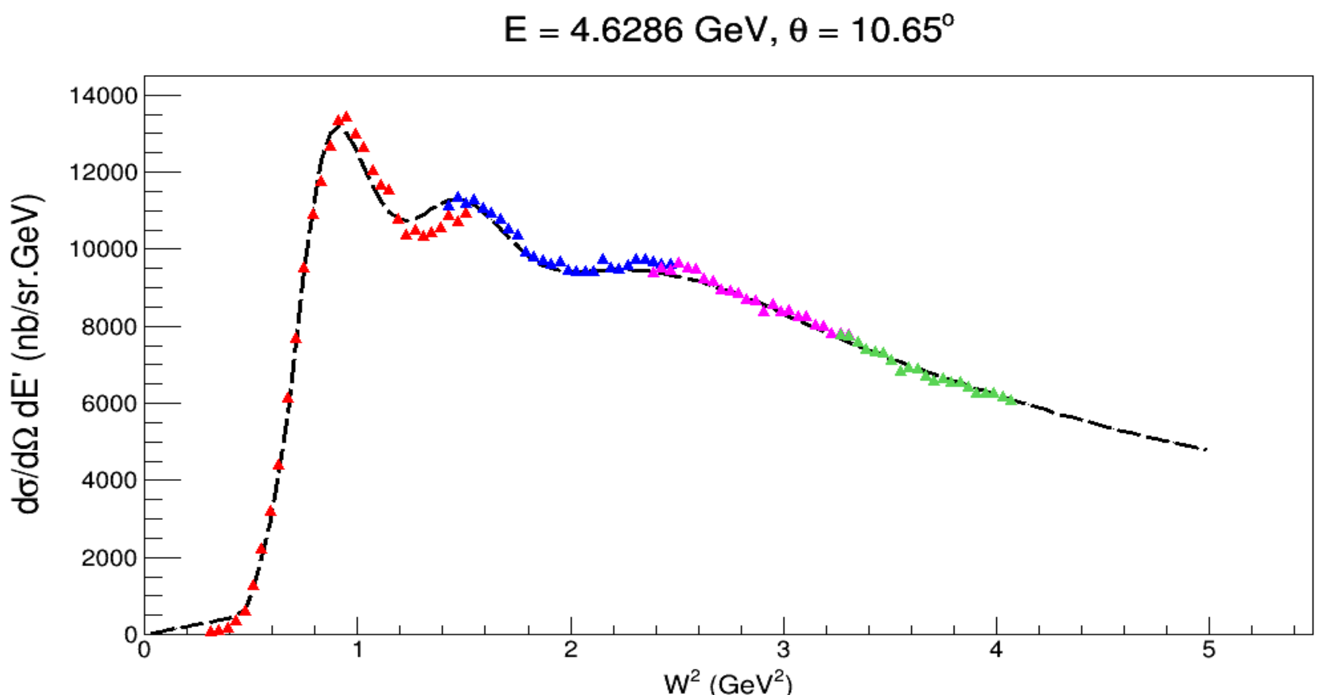
σ_{mod}

$$\frac{d\sigma}{dW^2 d\Omega} = \frac{Y_{data}}{Y_{mod}} \cdot \frac{d\sigma_{mod}}{dW^2 d\Omega}$$

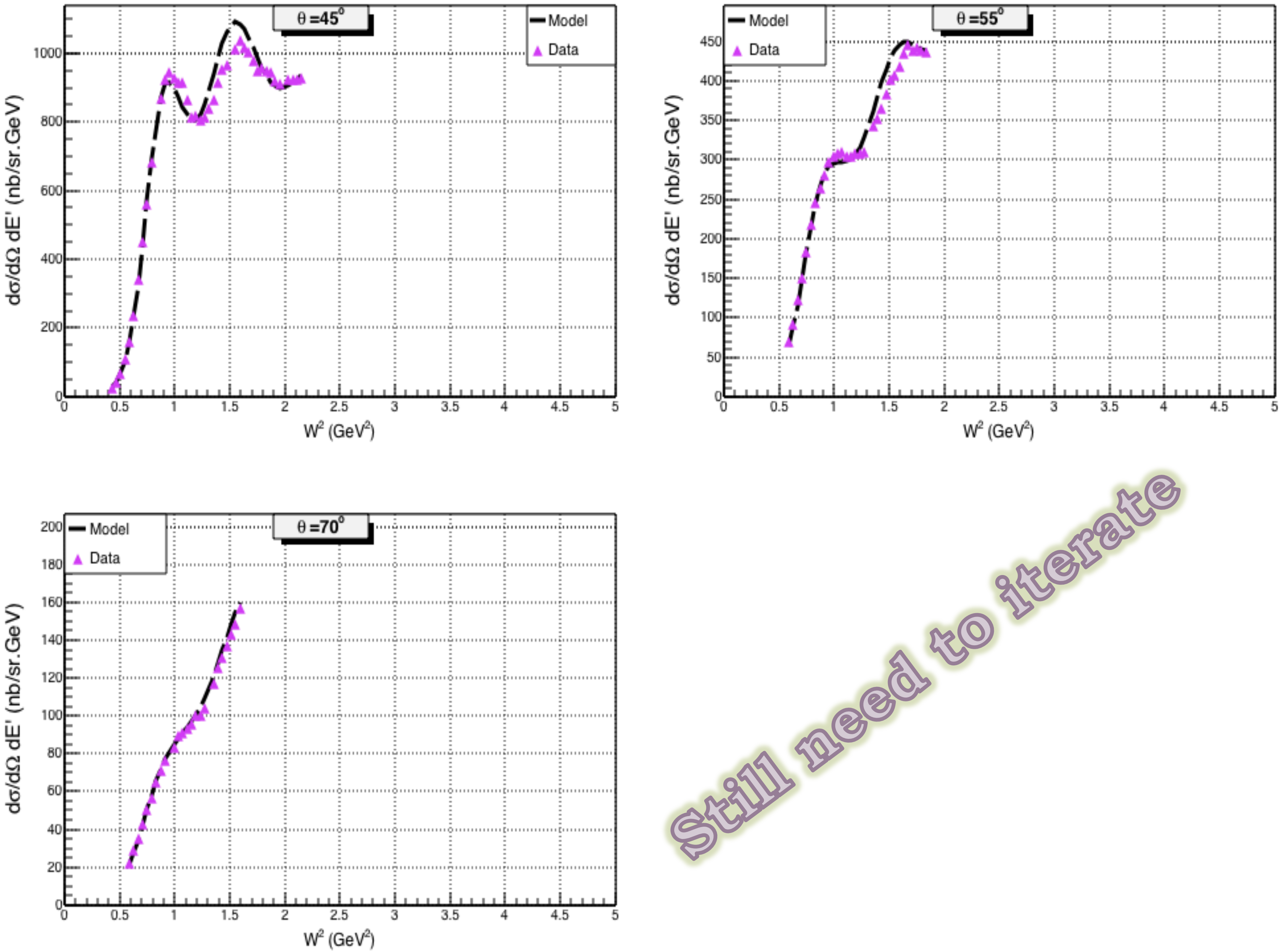
The model is a global fit to existing data by M.E. Christy, A Bodek, T. Gautam (paper in preparation). Still need to iterate.


(C) Run # 53211, E= 2.347 GeV, E'= 1.091 GeV, θ = 20.01°, SF =0.962
Data
MC
Y target (cm)
Y' target (mrad)
X' target (mrad)
W² (GeV²)
δ p/p (%)
Data/MC
δp/p(%)

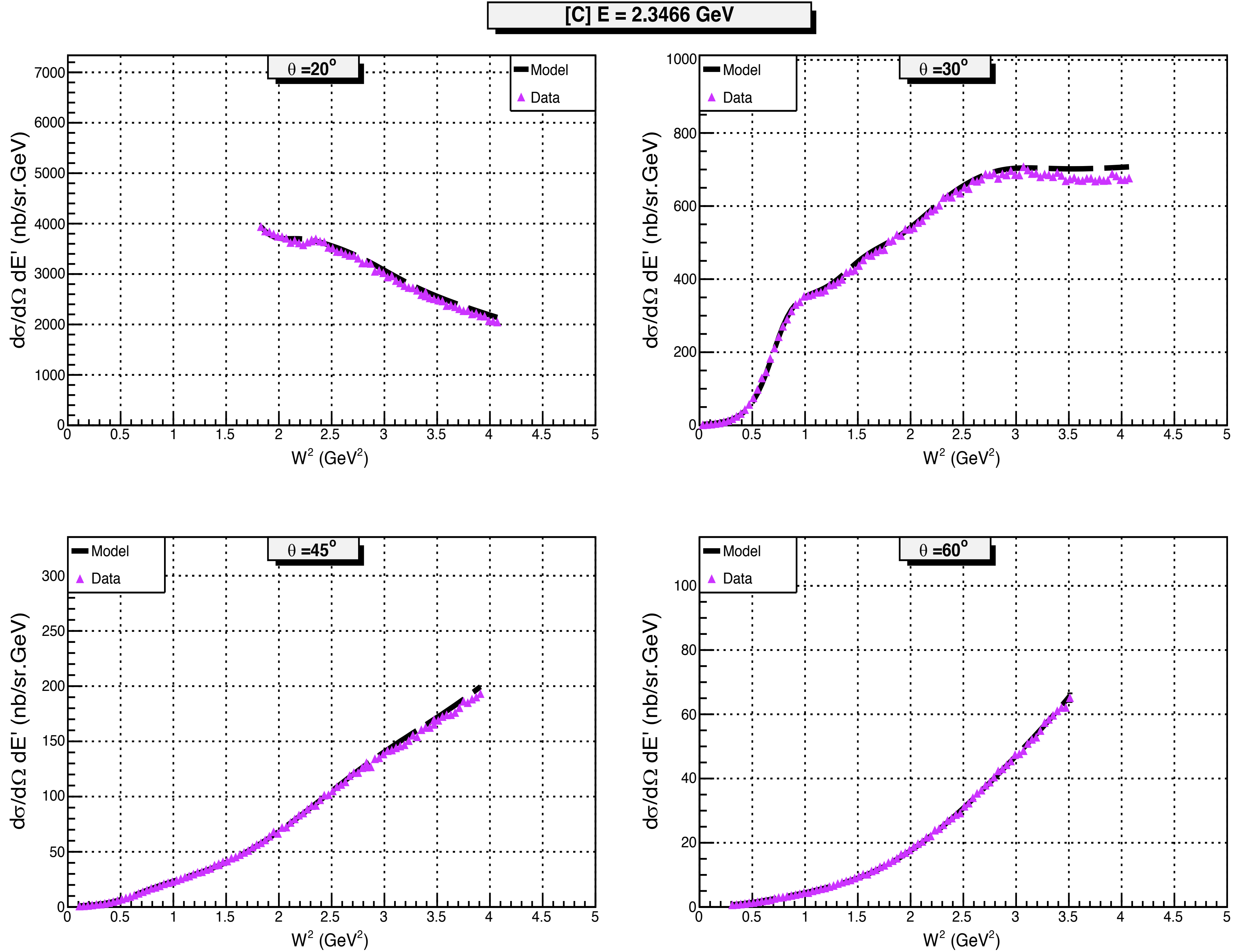

(C) E = 4.6286 GeV , θ = 10.65°
σData/σModel
W²(GeV²)
QE peak
Δ
2nd
3nd

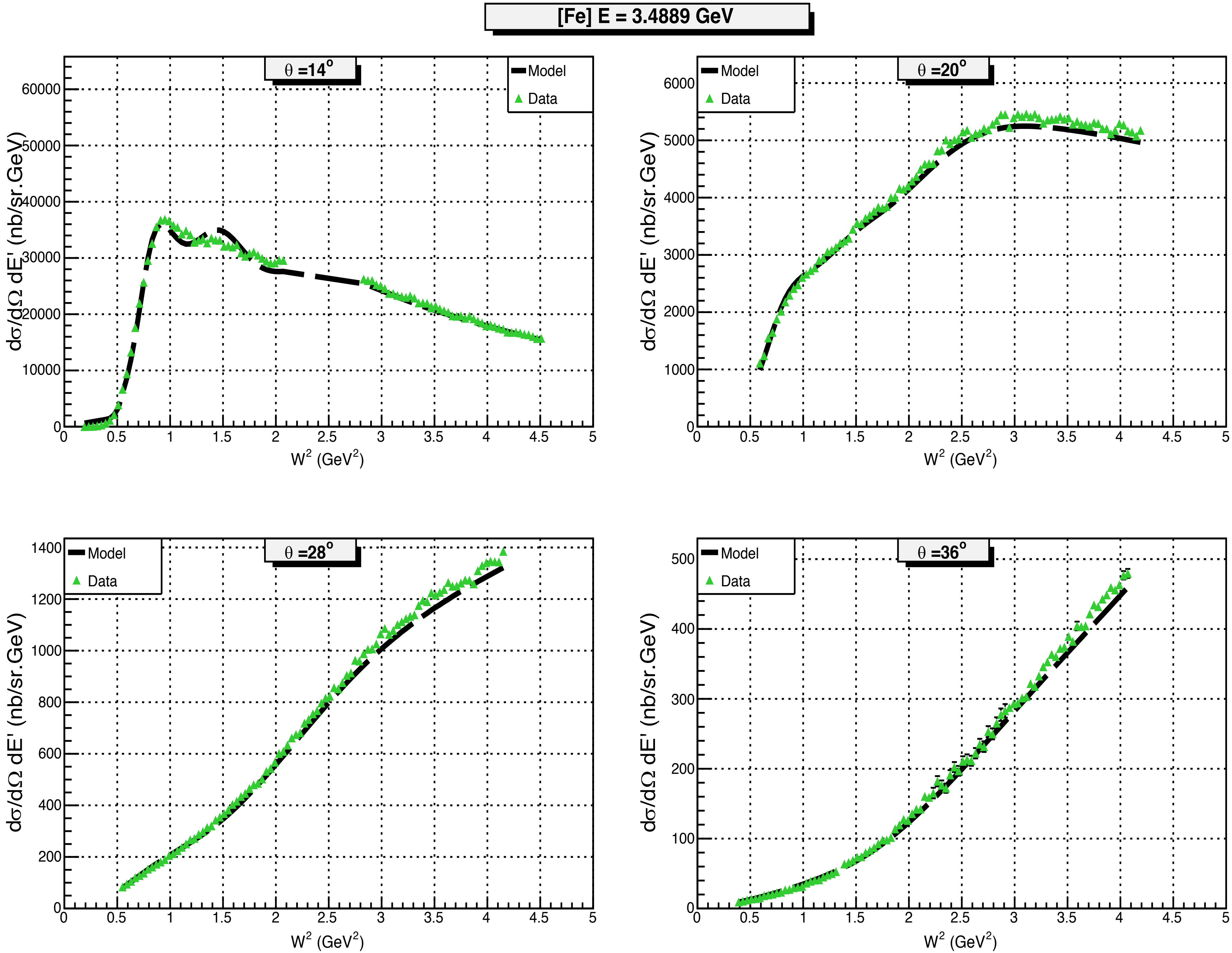

E = 4.6286 GeV, θ = 10.65°
dσ/dΩ dE' (nb/sr.GeV)
W² (GeV²)

[C] E = 1.2044 GeV

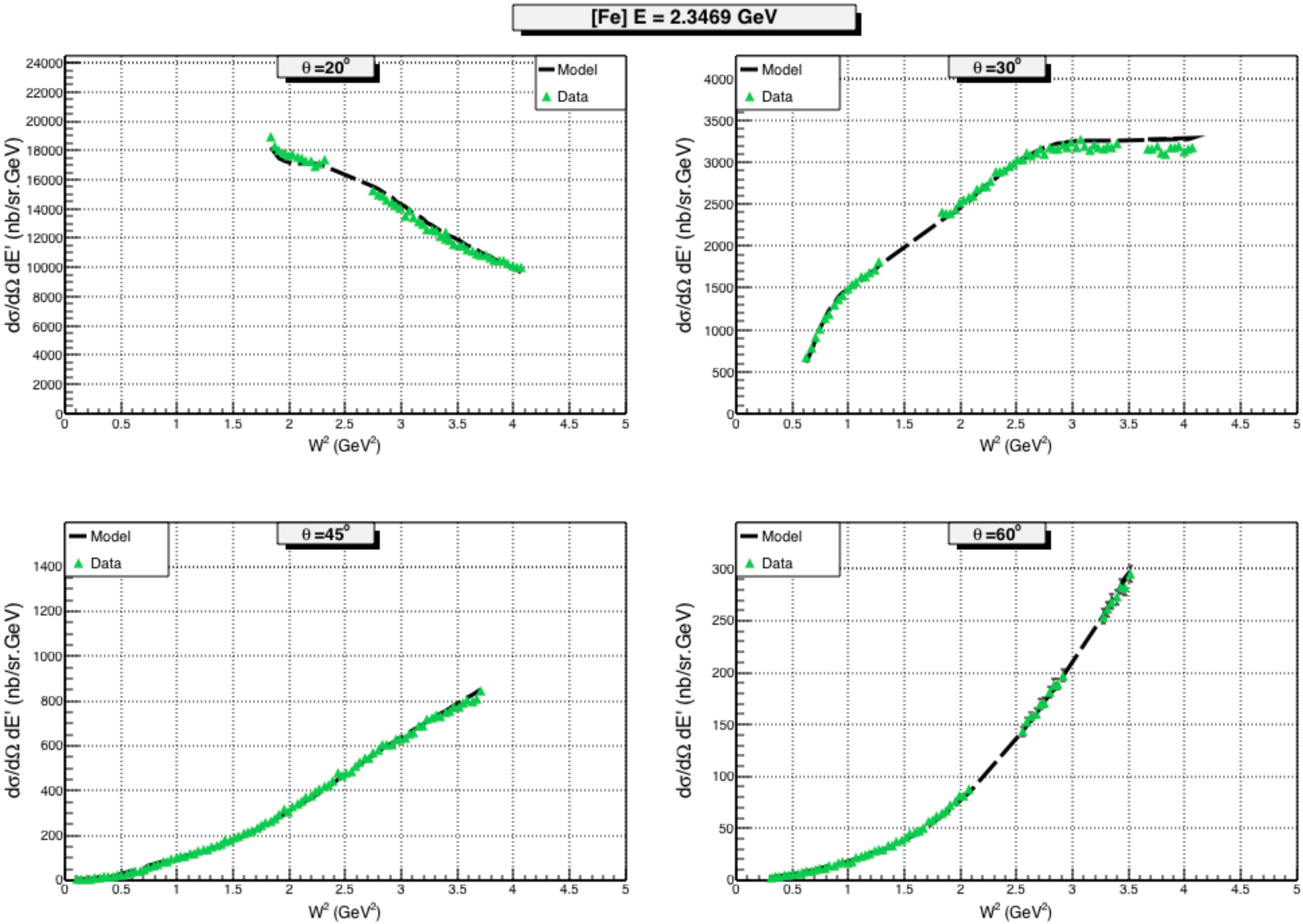


Still need to iterate


[C] E = 2.3466 GeV
θ =20°
θ =30°
θ =45°
θ =60°
Model
Data
dσ/dΩ dE' (nb/sr.GeV)
W² (GeV²)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
1000
2000
3000
4000
5000
6000
7000
200
400
600
800
50
100
150
250
300
20
40
60
80



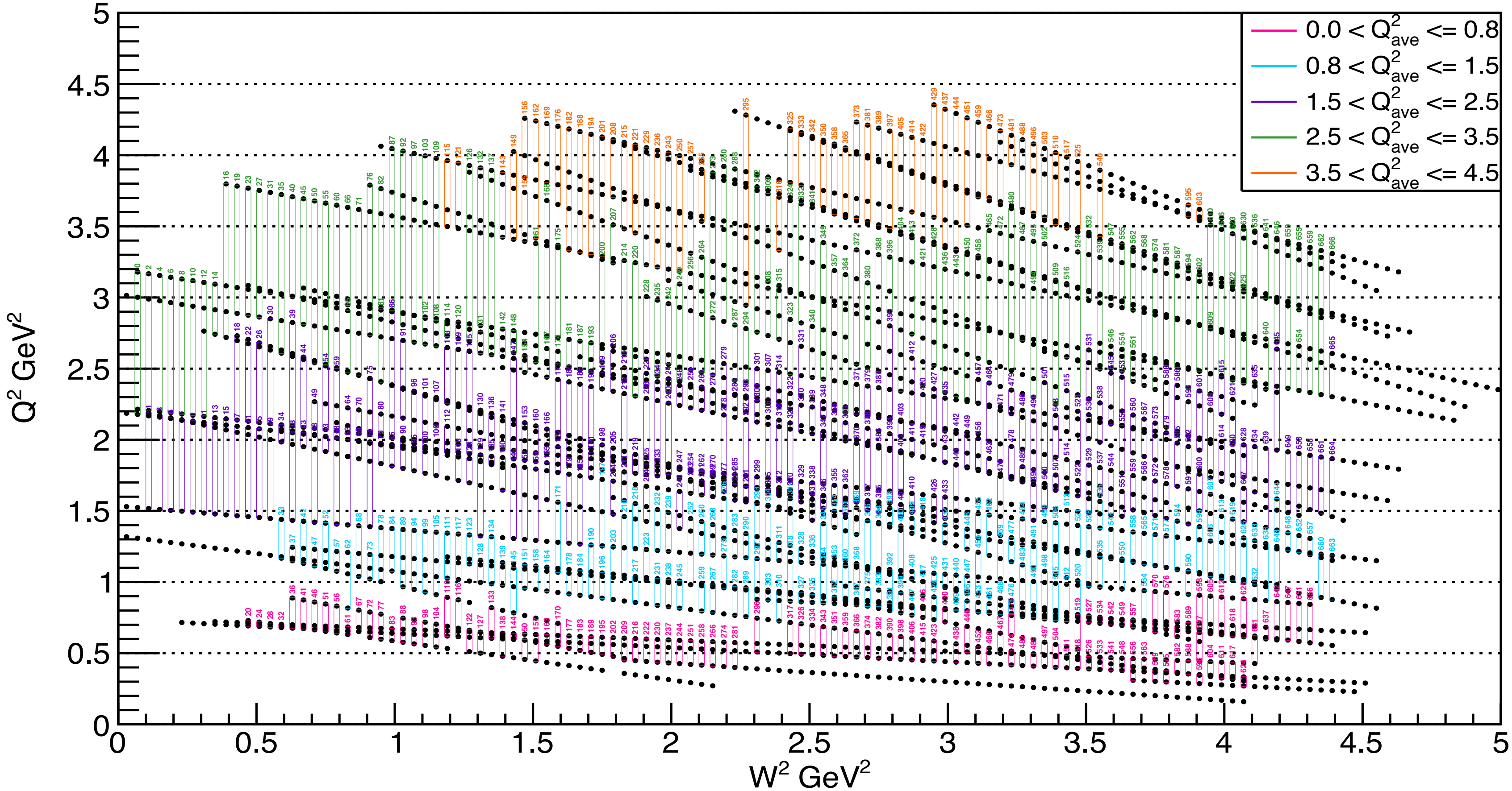
[Fe] E = 3.4889 GeV
θ =14°
Model
Data
dσ/dΩ dE' (nb/sr.GeV)
W² (GeV²)
θ =20°
Model
Data
dσ/dΩ dE' (nb/sr.GeV)
W² (GeV²)
θ =28°
Model
Data
dσ/dΩ dE' (nb/sr.GeV)
W² (GeV²)
θ =36°
Model
Data
dσ/dΩ dE' (nb/sr.GeV)
W² (GeV²)



[Fe] E = 2.3469 GeV
θ =20°
θ =30°
θ =45°
θ =60°
Model
Data
dσ/dΩ dE' (nb/sr.GeV)
W² (GeV²)

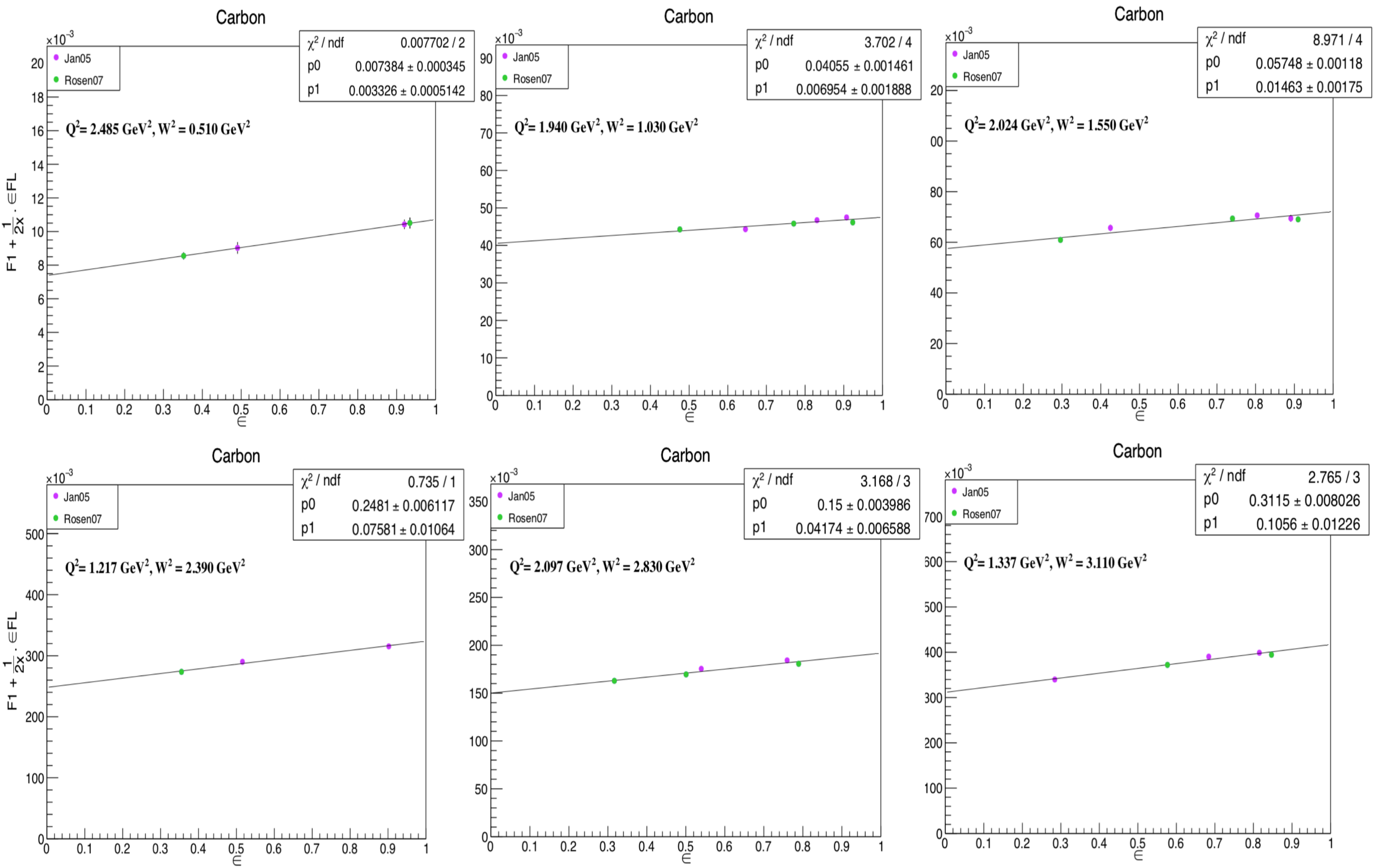
Rosenbluth Separation

LT Data

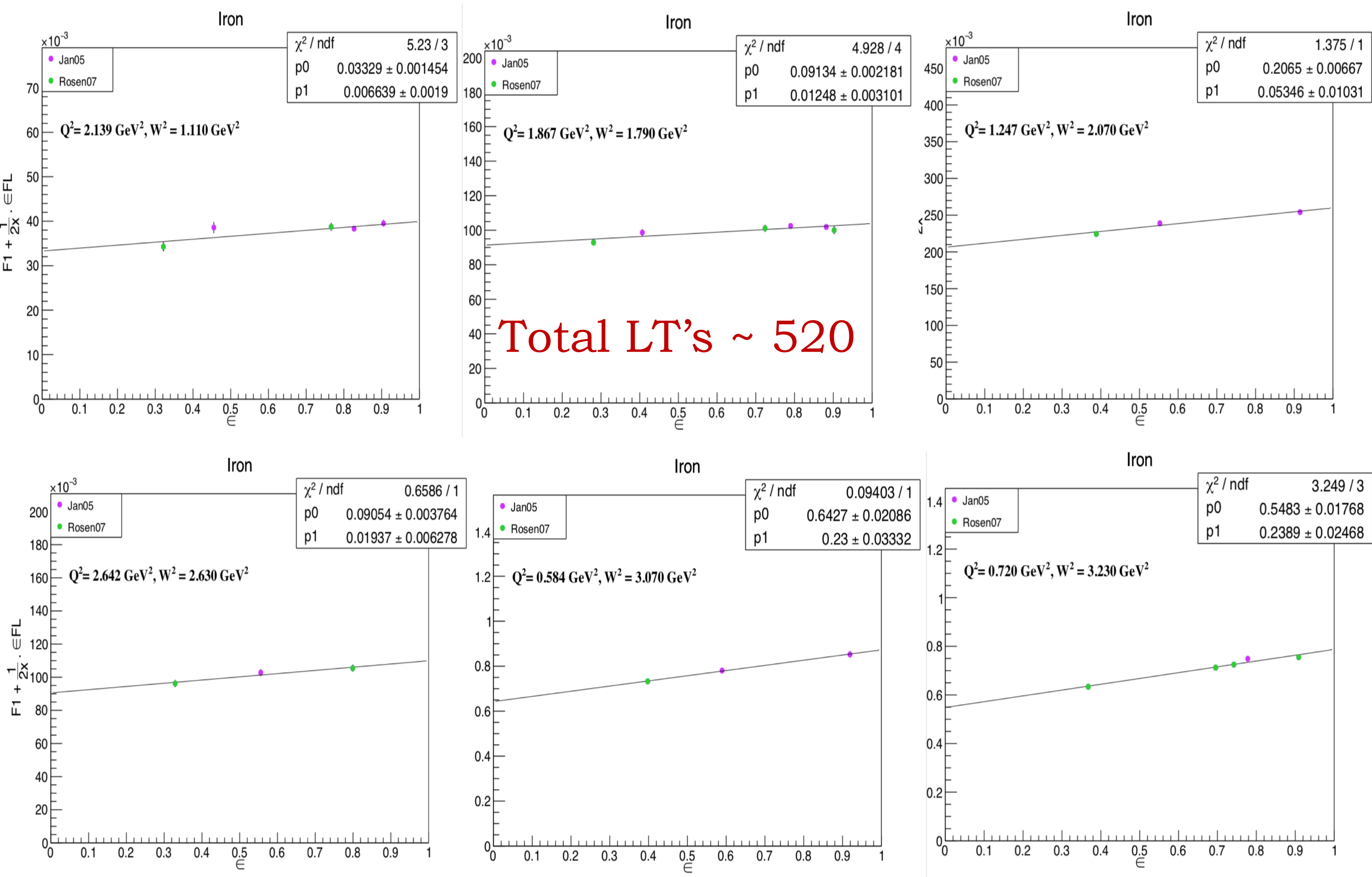


Fixed W^2 , Q^2 range = Q^2 +/- 20 %

Rosenbluth Separation

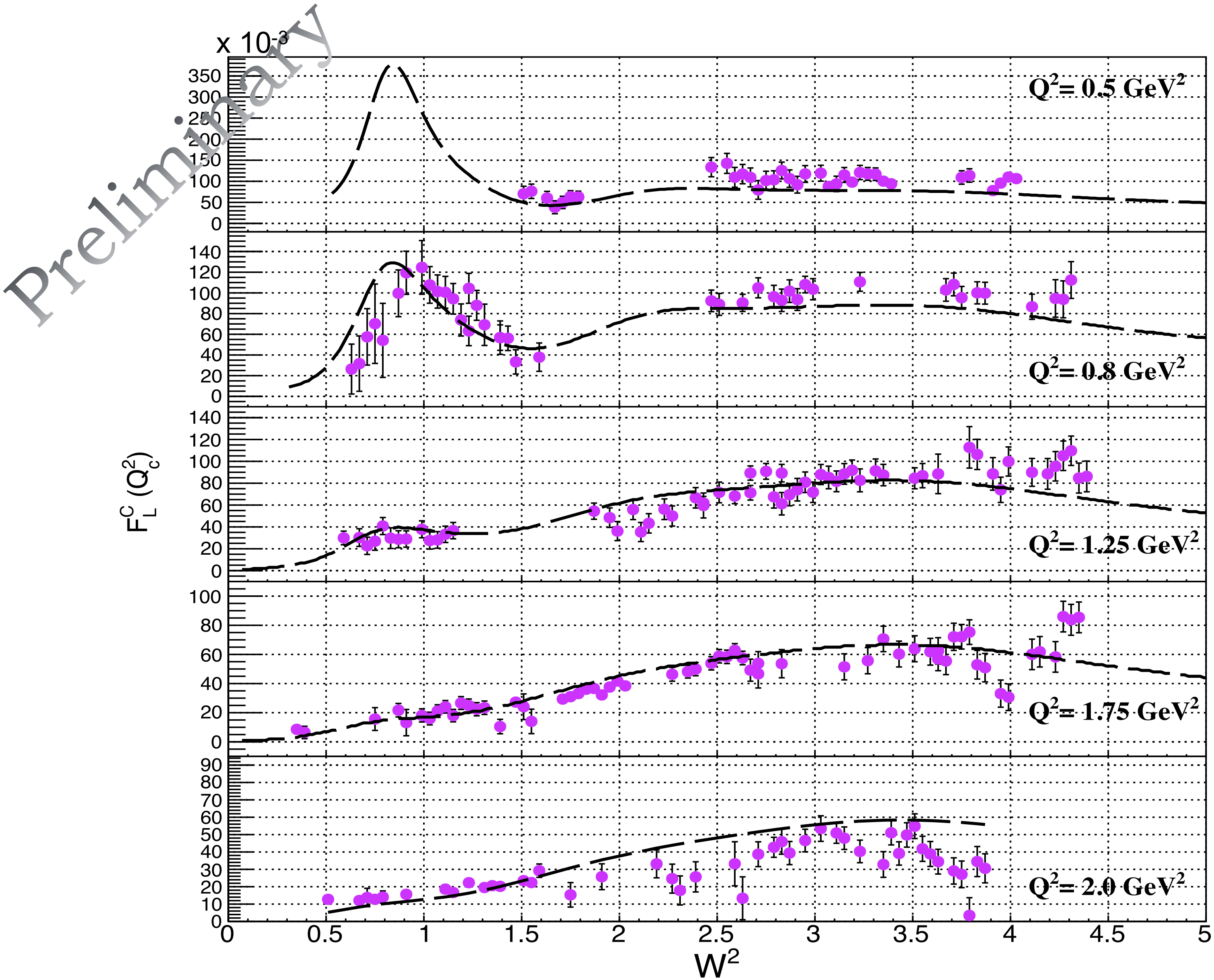


Rosenbluth Separation

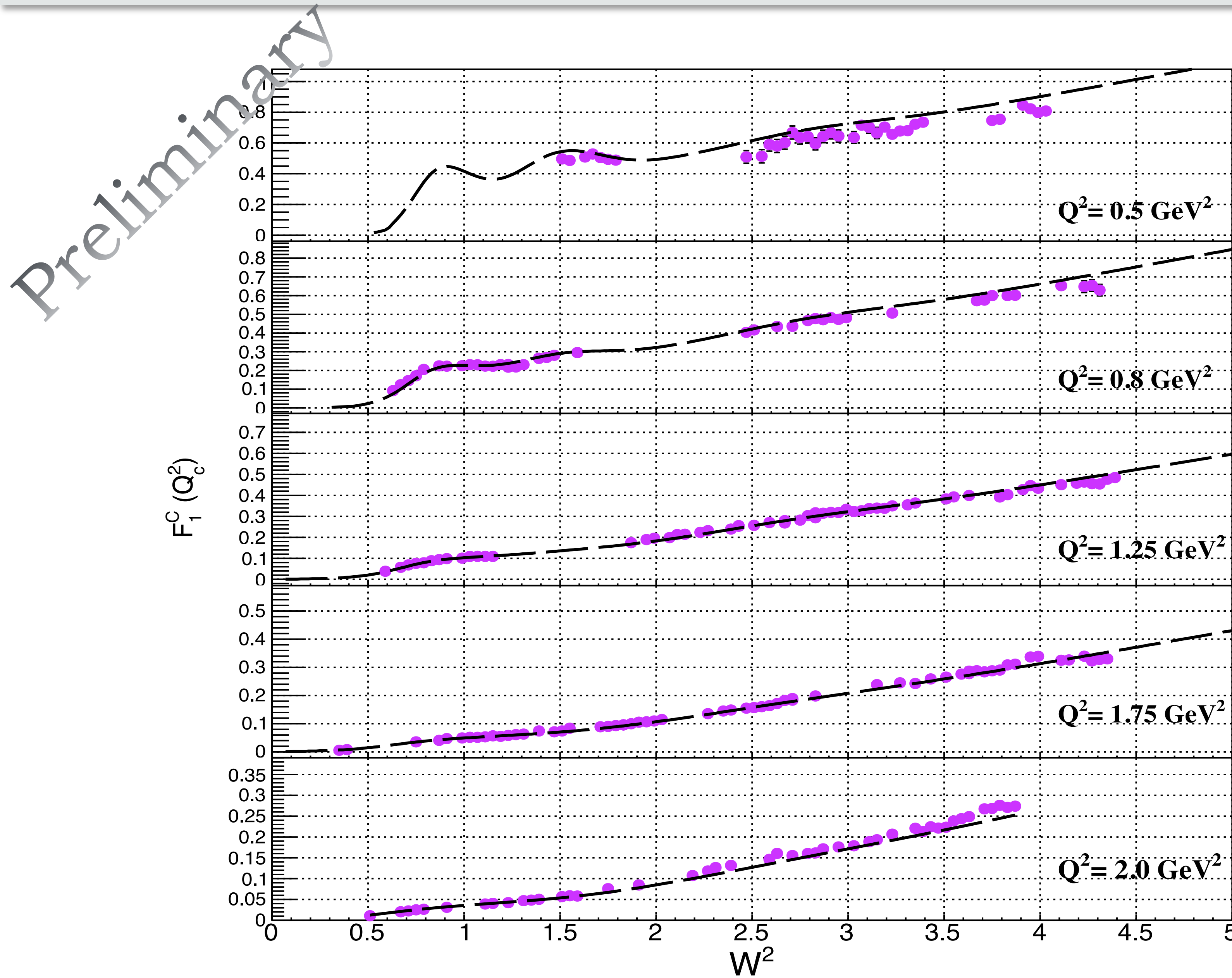


Total LT's ~ 520

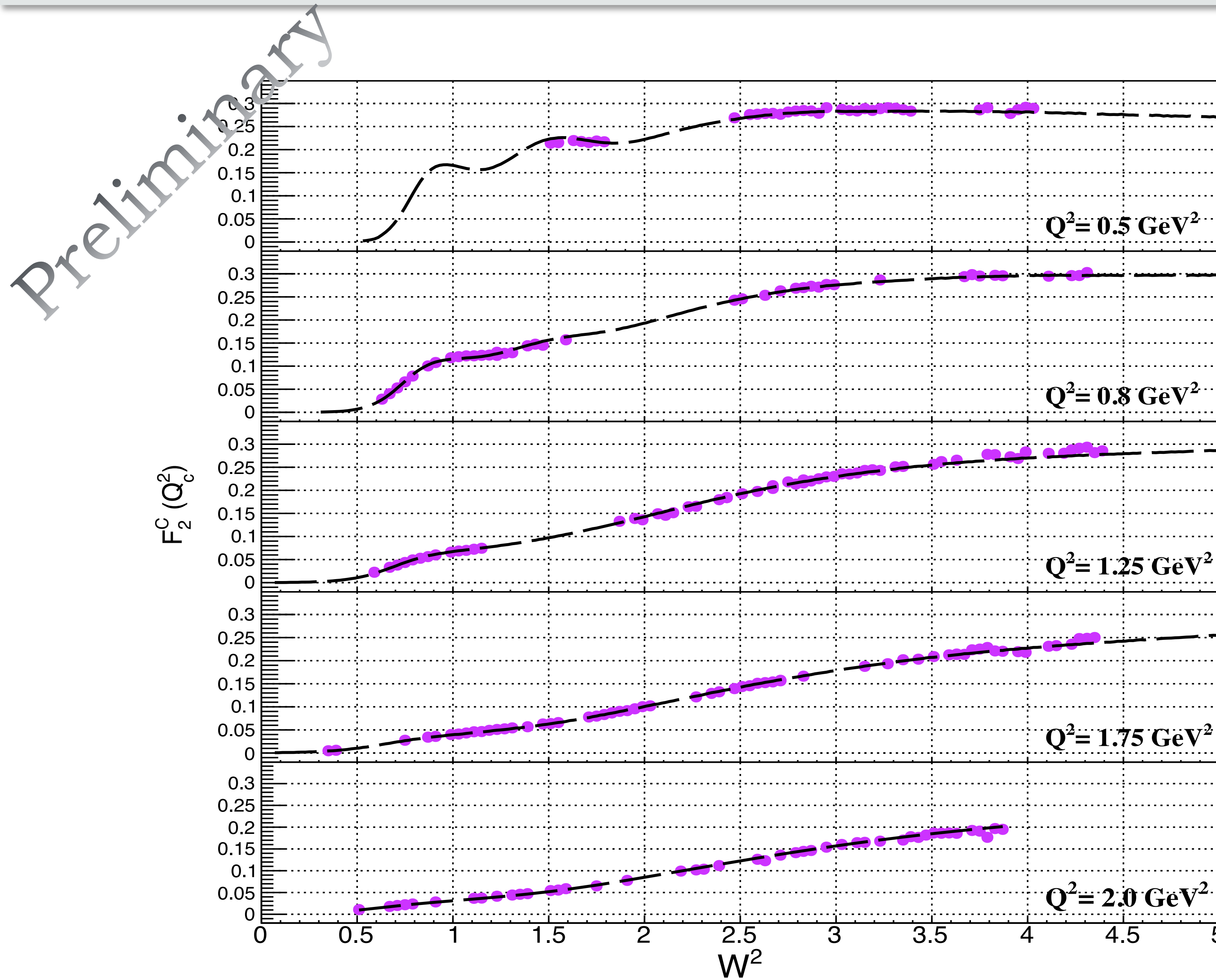
Structure Functions (F_L , F_1 and F_2)



Structure Functions (F_L , F_1 and F_2)

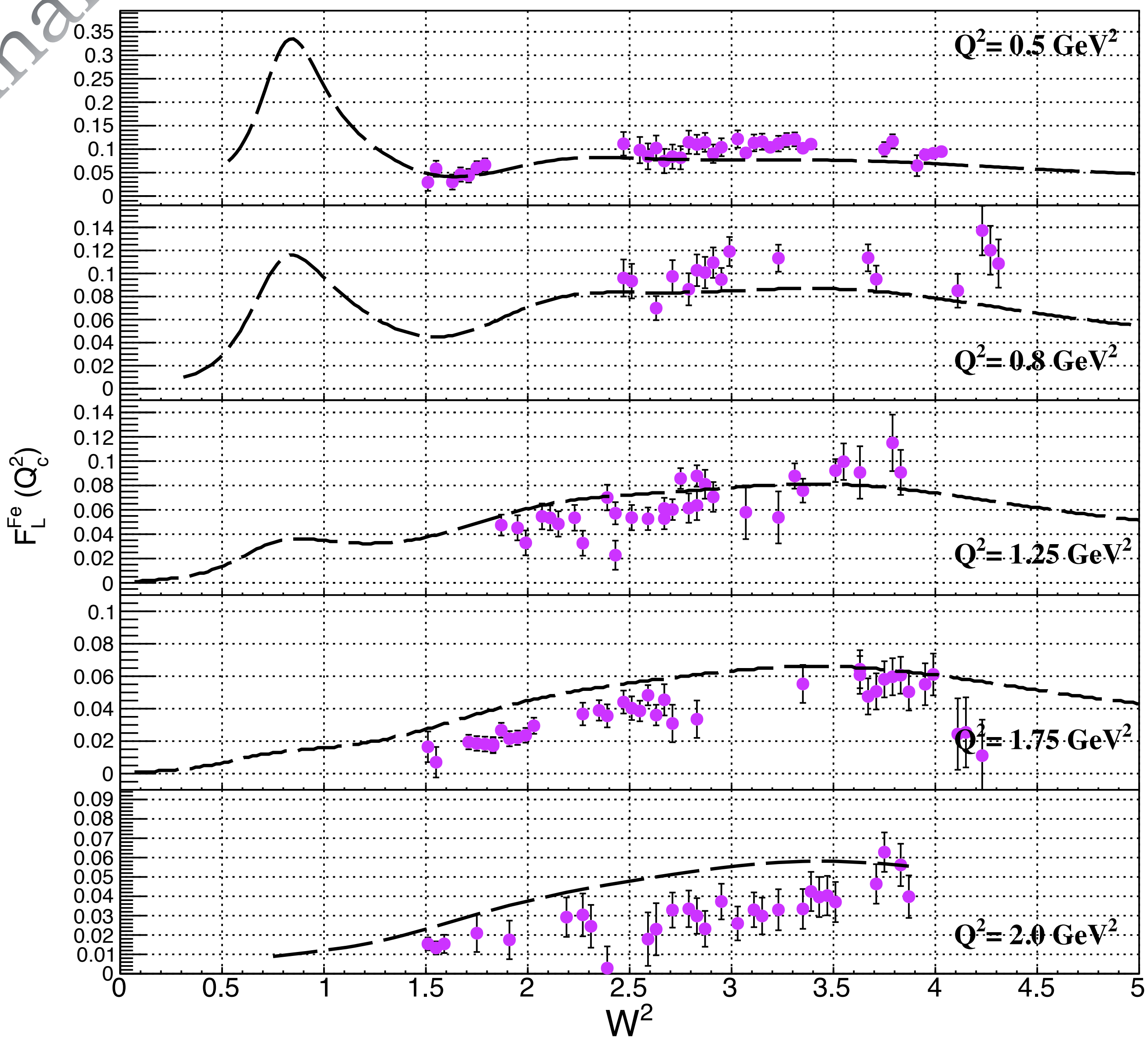


Structure Functions (F_L , F_1 and F_2)

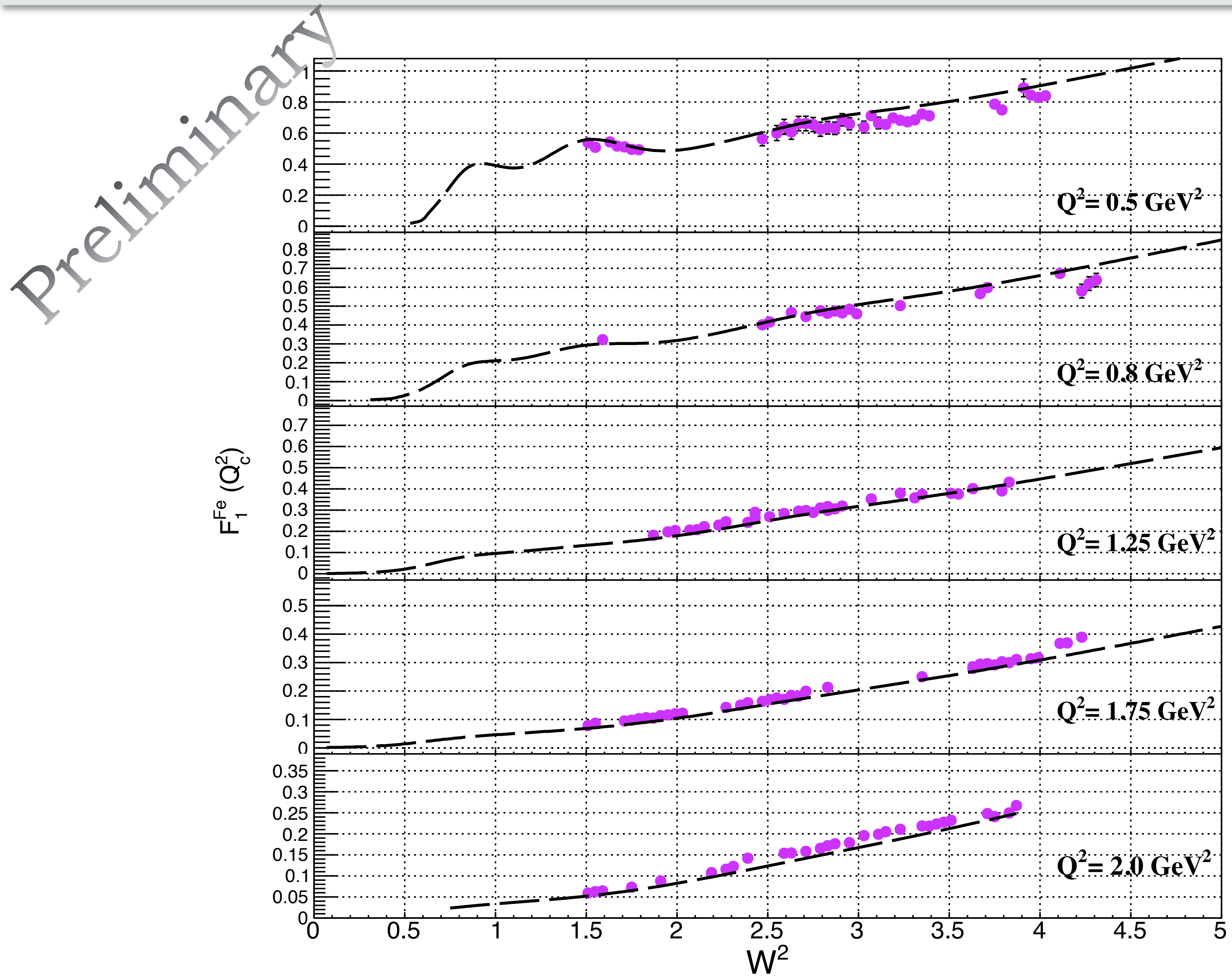


Structure Functions (F_L , F_1 and F_2)

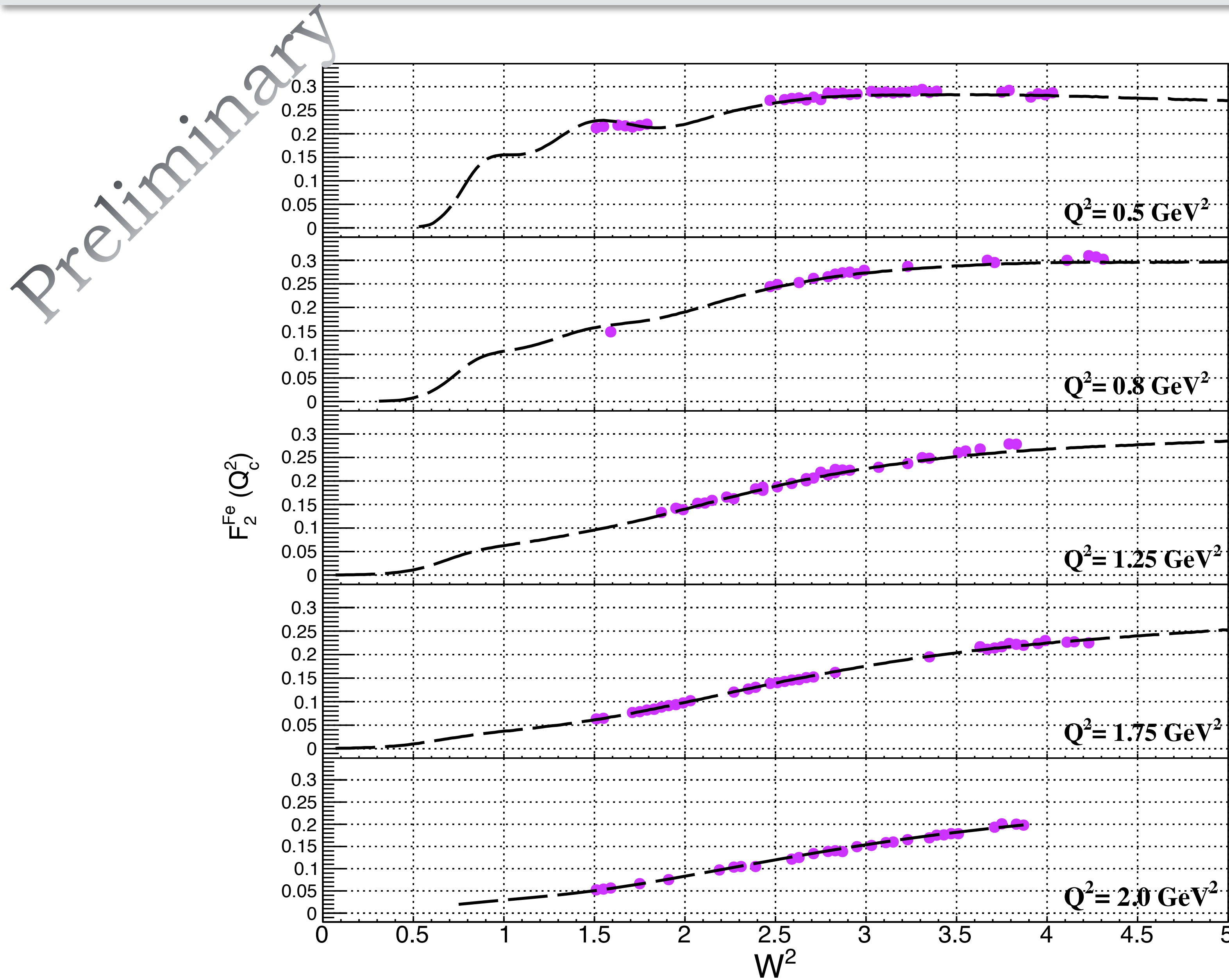
Preliminary



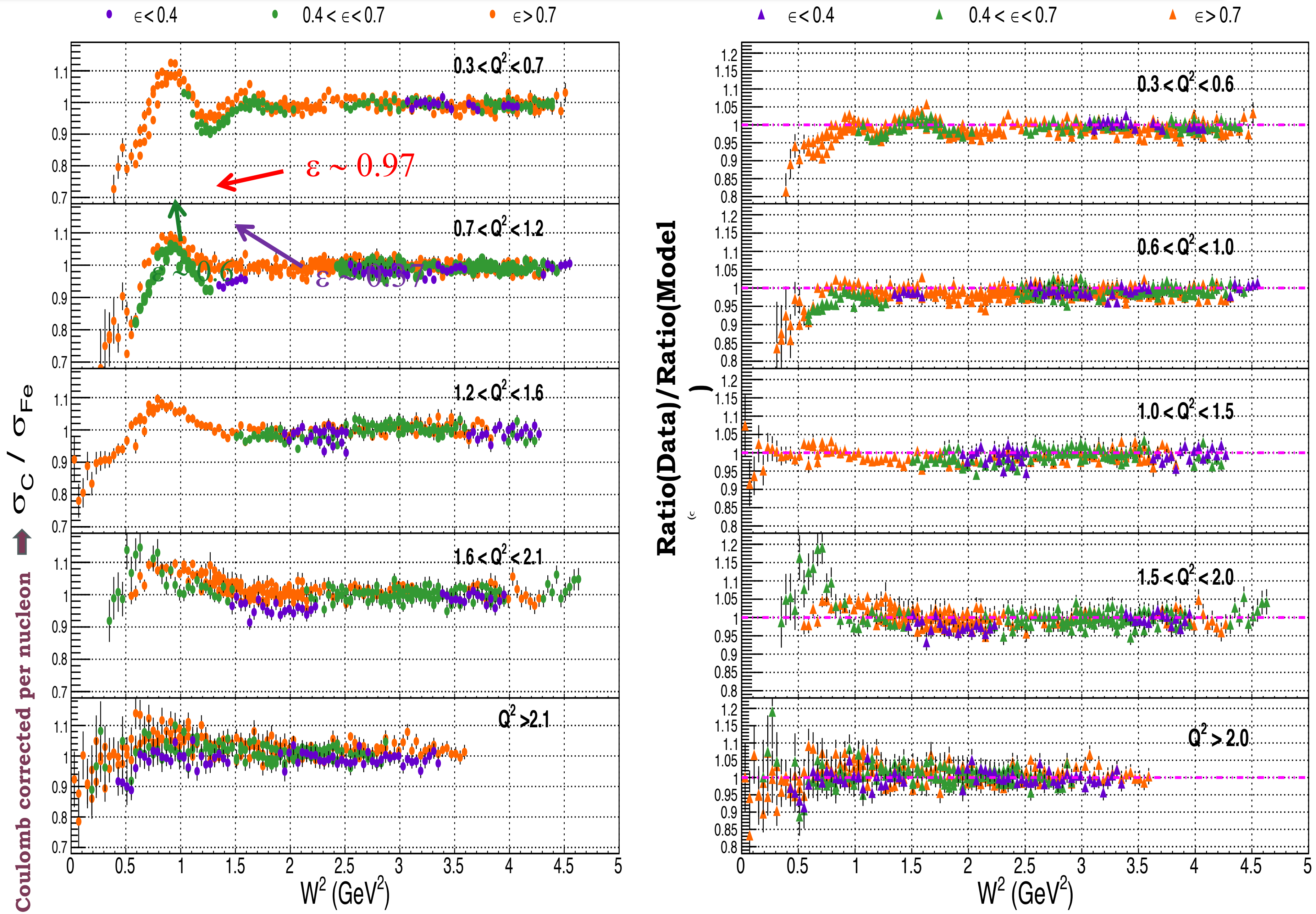
Structure Functions (F_L , F_1 and F_2)



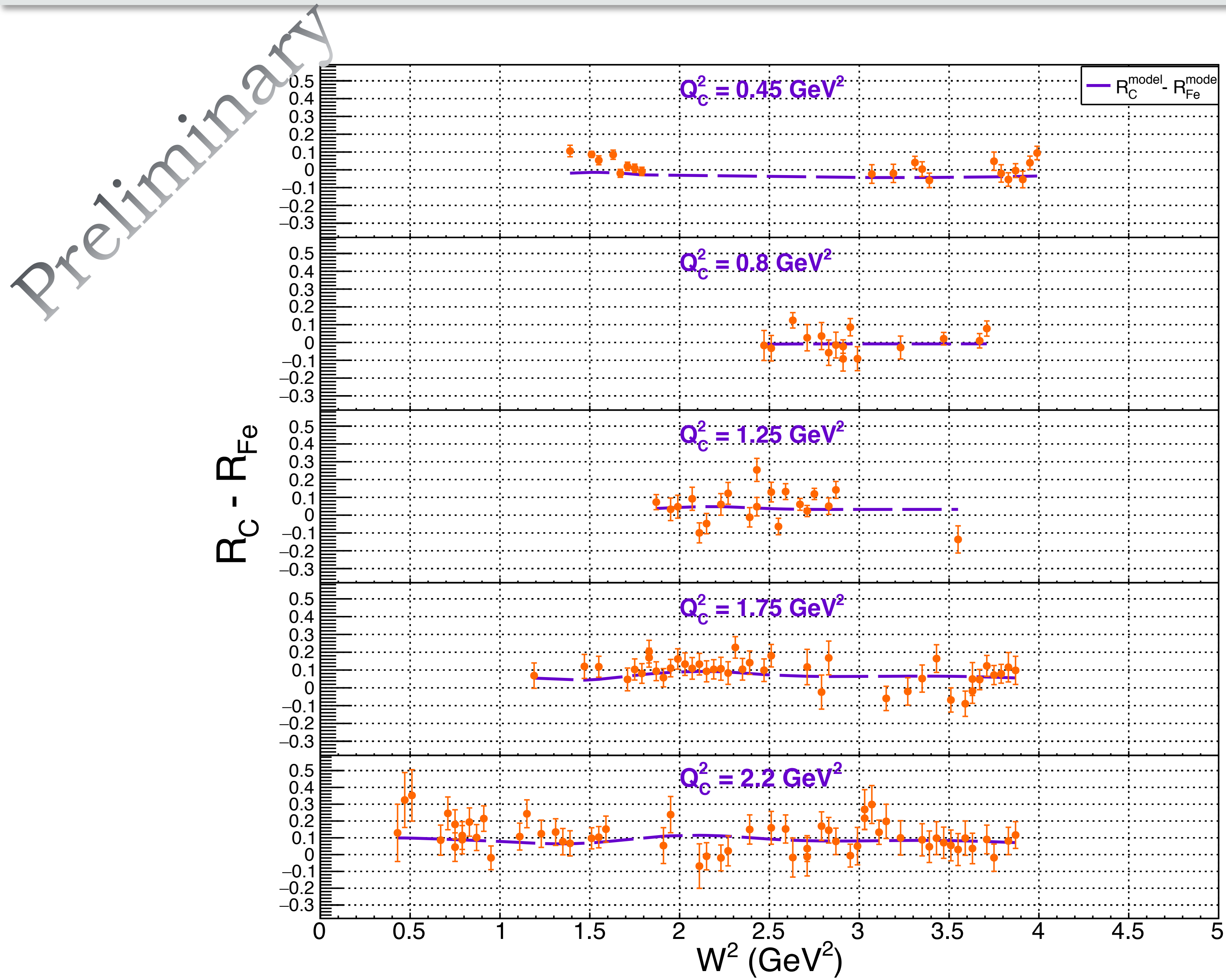
Structure Functions (F_L , F_1 and F_2)



Cross Section Ratio

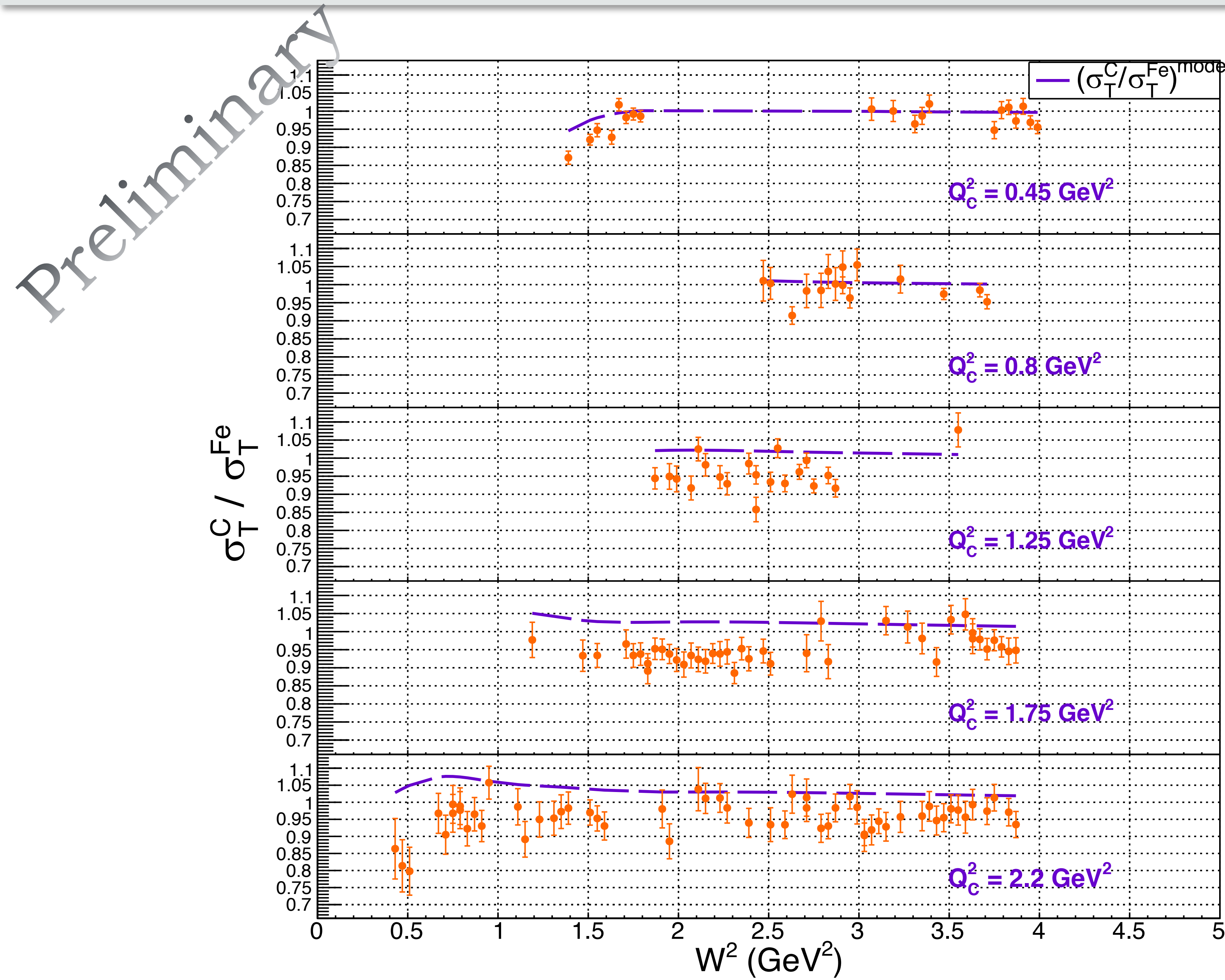


R_C - R_{Fe}



Preliminary
Q_C^2 = 0.45 GeV^2
Q_C^2 = 0.8 GeV^2
Q_C^2 = 1.25 GeV^2
Q_C^2 = 1.75 GeV^2
Q_C^2 = 2.2 GeV^2
R_C^{model} - R_{Fe}^{mode}
R_C - R_{Fe}
W^2 (GeV^2)
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

σ_T ratio



Systematics

Quantity	Uncertainty
Scattering Angle Offset q	0.35 mrad
Scattering Energy Offset E'	4×10^{-4} GeV^2
Charge Symmetric Background	(0.05% - 2%)
Calorimeter Efficiency	0.05 – 0.12%
Cerenkov Efficiency	0.04 %
Trigger Efficiency	0.3%
Optics	0.6 %
Acceptance	0.4%

To-Do List

- Fully estimate the systematics (correlated)
- Finalize $R_C - R_{Fe}$
- Search for nuclear pions
- Iterate the model to agree with data, and evaluate the model dependency

Thank You!

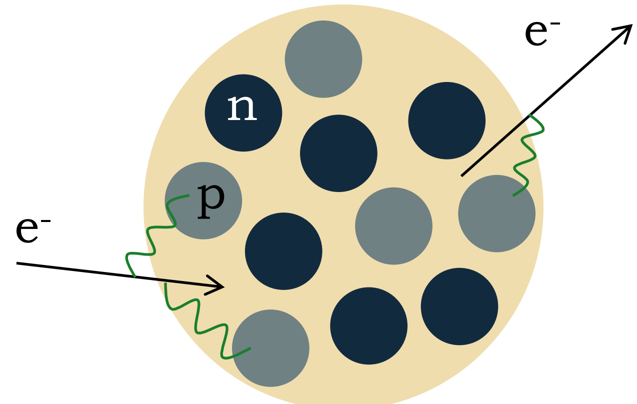
Backup slides

Coulomb Correction

* When approaching the target, the electron's energy will be affected by the Coulomb field generated by the target nucleus.

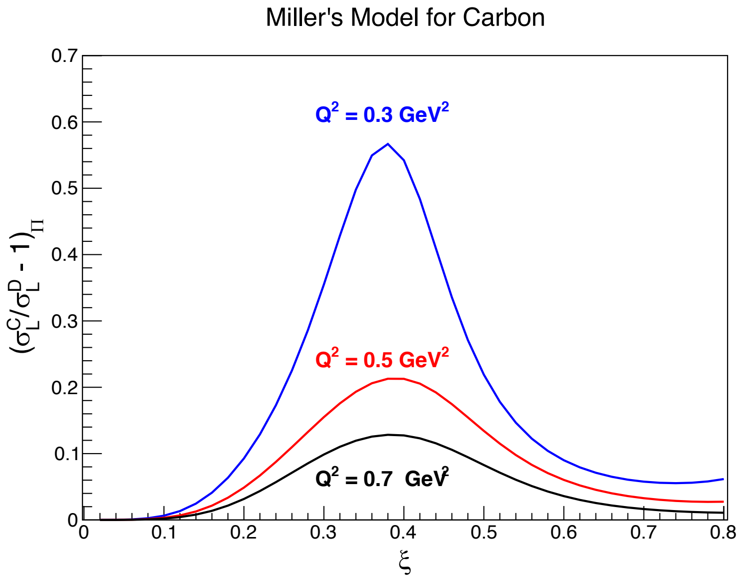
* The incoming electron will accelerate (decelerate) as it gets close to (far from) the nucleus

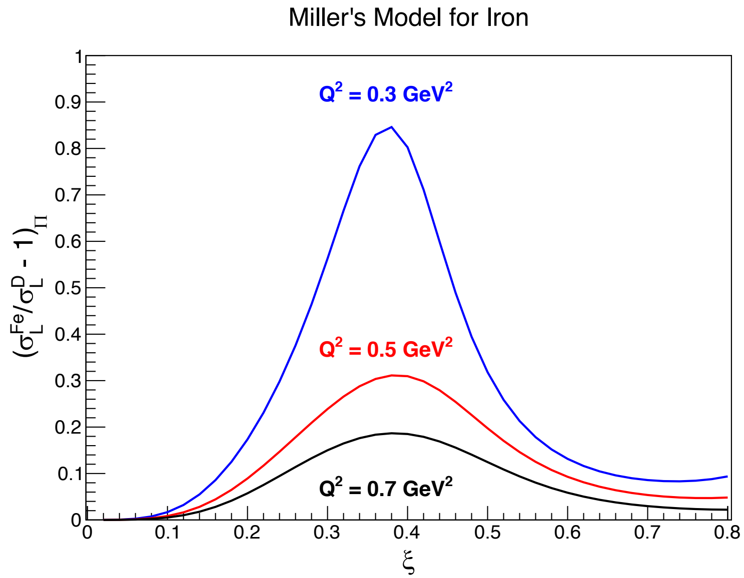
* One efficient method to approximate the Coulomb correction to the exact calculation is the Effective Momentum Approximation (EMA)



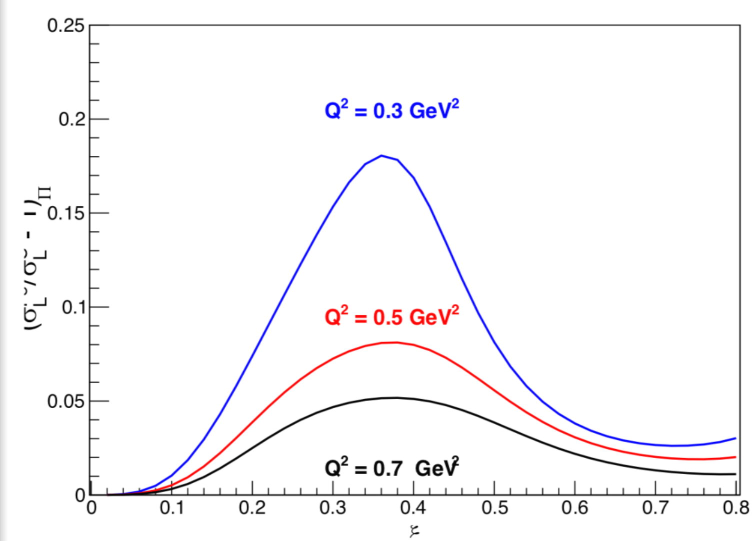
$$E \rightarrow E + V_{eff}$$

$$E_p \rightarrow E_p + V_{eff}$$





What we “might’ see



taking the measured σ_L’s to search for nuclear pions requires dealing/ estimating carefully the correlated systematics. (can be done, but is there a faster / easier way?)

Measured $R_C - R_{Fe}$ ← Miller's predictions

$$R_C - R_{Fe} = \frac{\sigma_L^C}{\sigma_T^C} - \frac{\sigma_L^{Fe}}{\sigma_T^{Fe}}$$

$$= \frac{\sigma_L^C}{\sigma_T^C}\left(1 - \frac{\sigma_L^{Fe}/\sigma_T^{Fe}}{\sigma_L^C/\sigma_T^C}\right)$$

$$R_C - R_{Fe} = R_C\left(1 - \frac{\sigma_T^C}{\sigma_T^{Fe}} \times r^{miller}\right)$$

Measured