A measurement of the differential cross section for the exclusive π^- Electro-production from the Neutron

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for the BoNuS Collaboration

Sep. 26, 2012

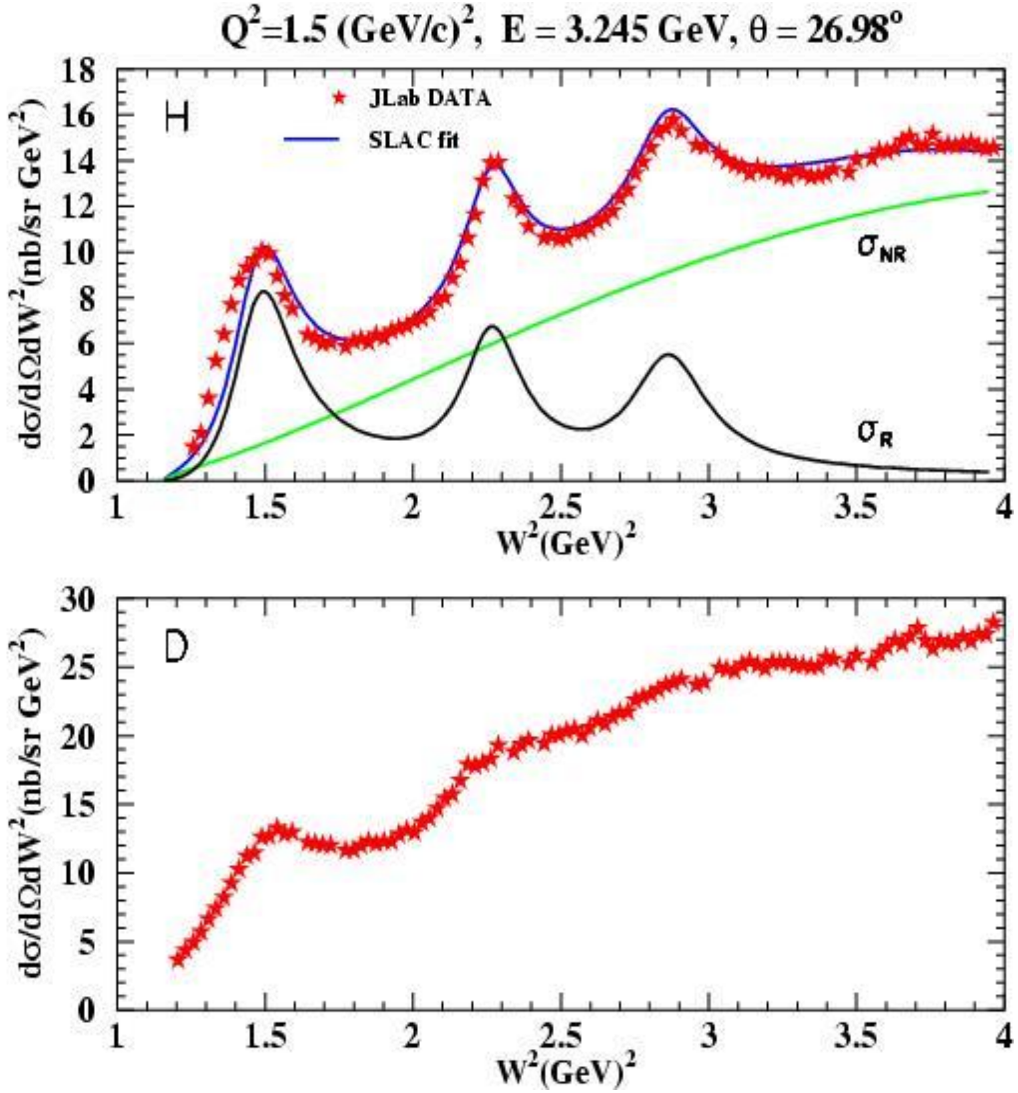
Outline

- Motivation
- Theory Background
- BoNus Experiment
- Data Analysis
- Result
- Outlook

Cross Section in the Resonance Region

- Data on the Proton: Clear resonant structure, separation from the non-resonant background is possible

- Data on the deuteron: Kinematically smeared due to binding, off-shell, final state interactions (FSI), etc.



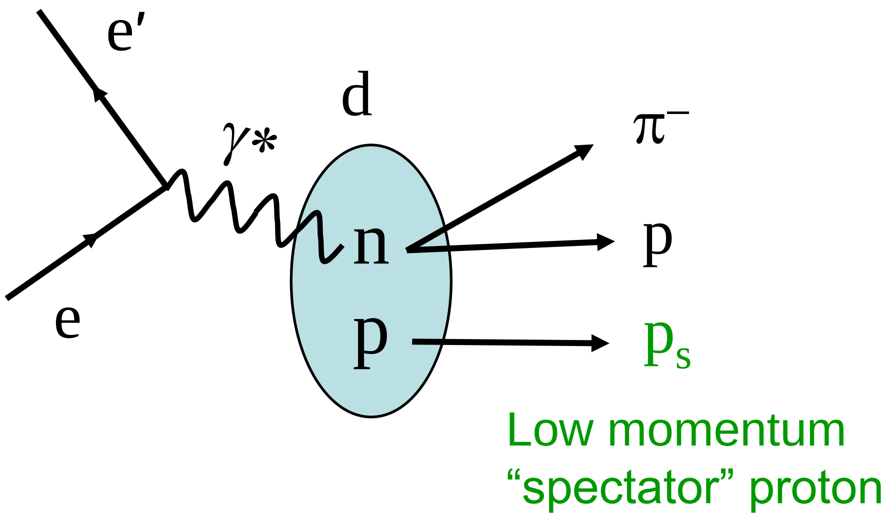
L.W. Whitlow *et al.*, Phys. Lett. **B282**, 475 (1992).

P. Amaudruz *et al.*, Phys. Lett. **B295**, 159 (1992).

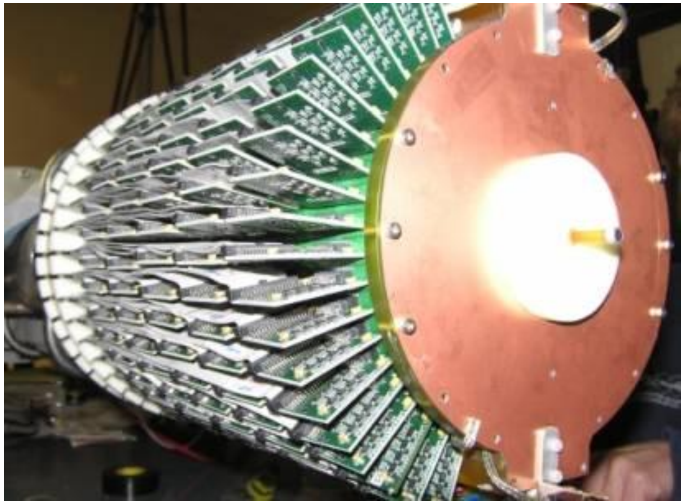
Exclusive π^- electro-production

D(e,e`π^-p)p

Detect e′, π^- and at least ONE of the two final state protons in D(e,e`π^-p)p to ensure exclusivity and select events where the “spectator” proton has low, backwards momentum. Conservation of energy and momentum allows to determine the initial state of the neutron.

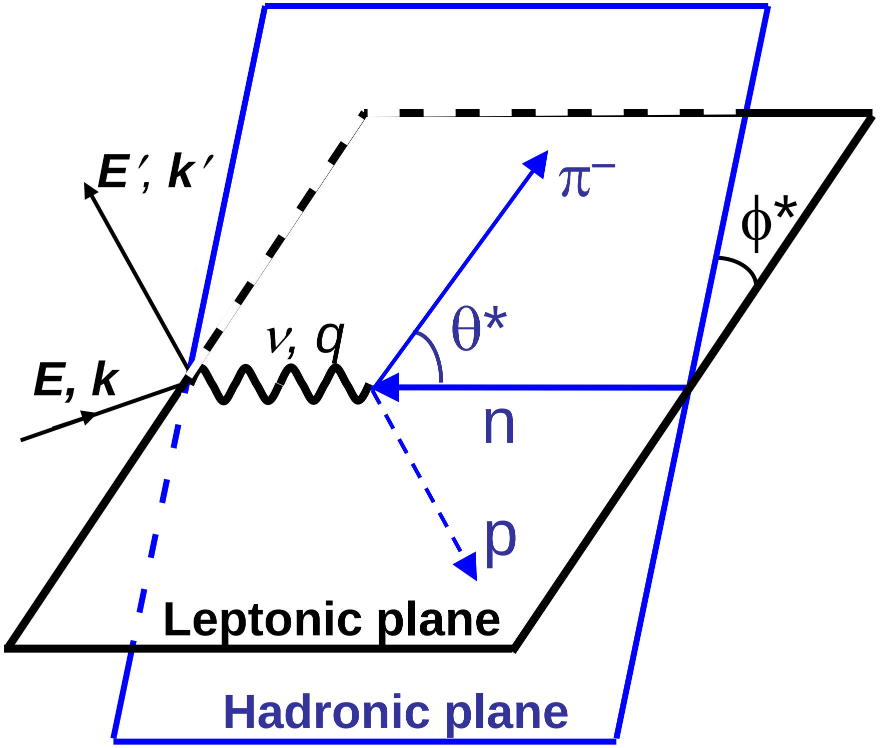


Novel approach by the BoNuS collaboration: detect the spectator proton directly.



π^- Production Kinematics

$$\gamma^* n \rightarrow \pi^- p$$



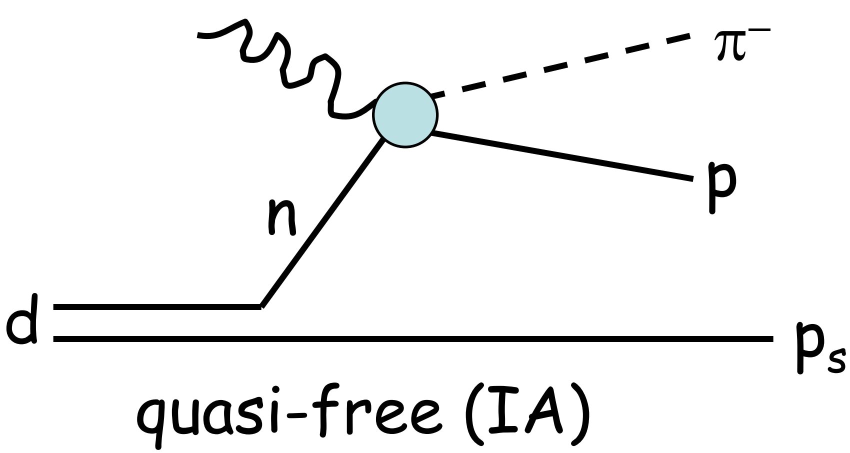
$Q^2 = -(q^\mu)^2$
$= 4EE' \sin^2(\theta_e/2)$

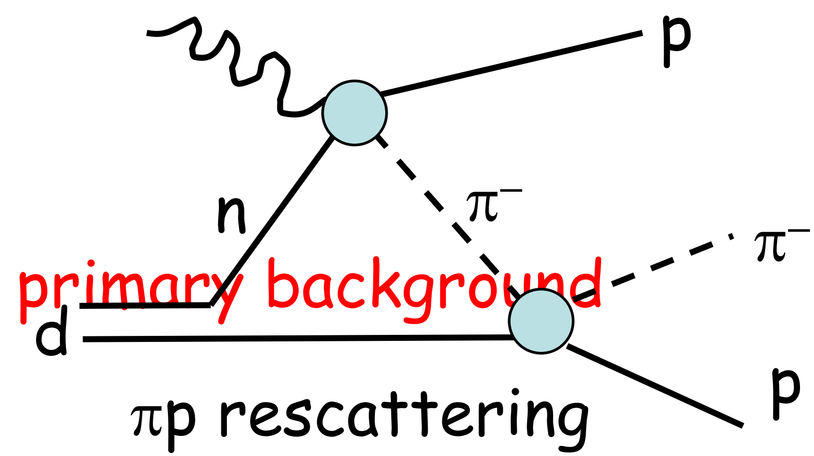
$W'^2 = (q^\mu + n^\mu)^2$
$= (q^\mu + d^\mu - p_s{}^\mu)^2$
$= (\pi^\mu + p^\mu)^2$

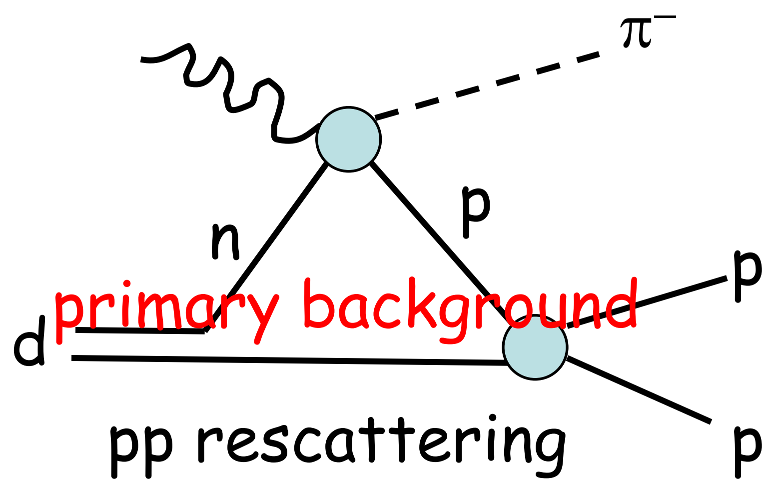
θ^* = polar angle of the outgoing π^- in C.M. frame

ϕ^* = Azimuthal angle of the outgoing π^- in C.M. frame

Final State Interations



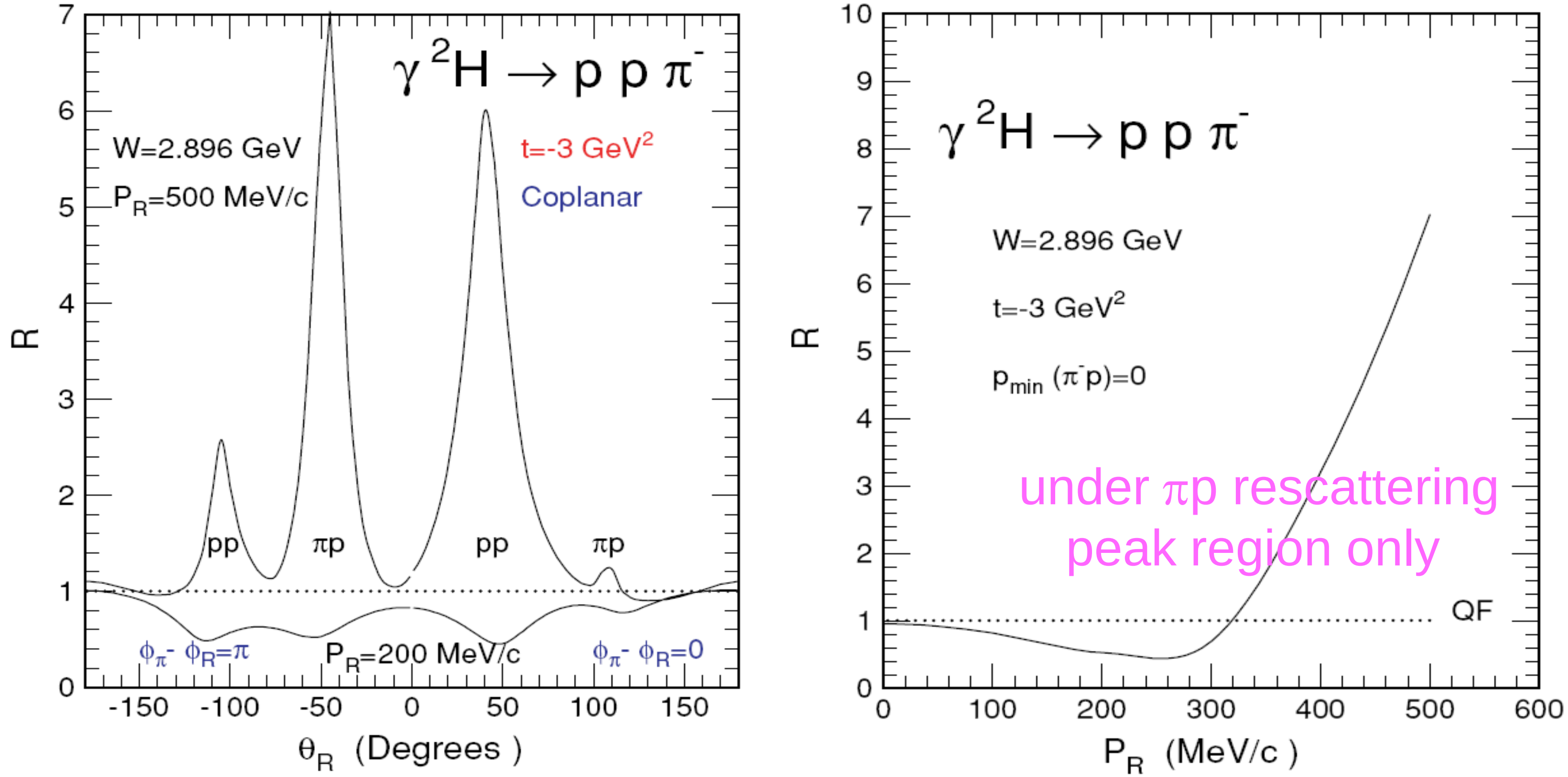




No theory calculation for γ^* n → π^- p FSI yet. Try to estimate this from FSI of γn → π^- p ....

V. Tarasov, A. Kudryavtsev, W. Briscoe, H. Gao, IS, arXiv: 1105.0225

FSI Prediction for D(γ,π^-p)p, by Laget



J. M. Laget, Phys. Rev. C. **73**, 044003 (2006).

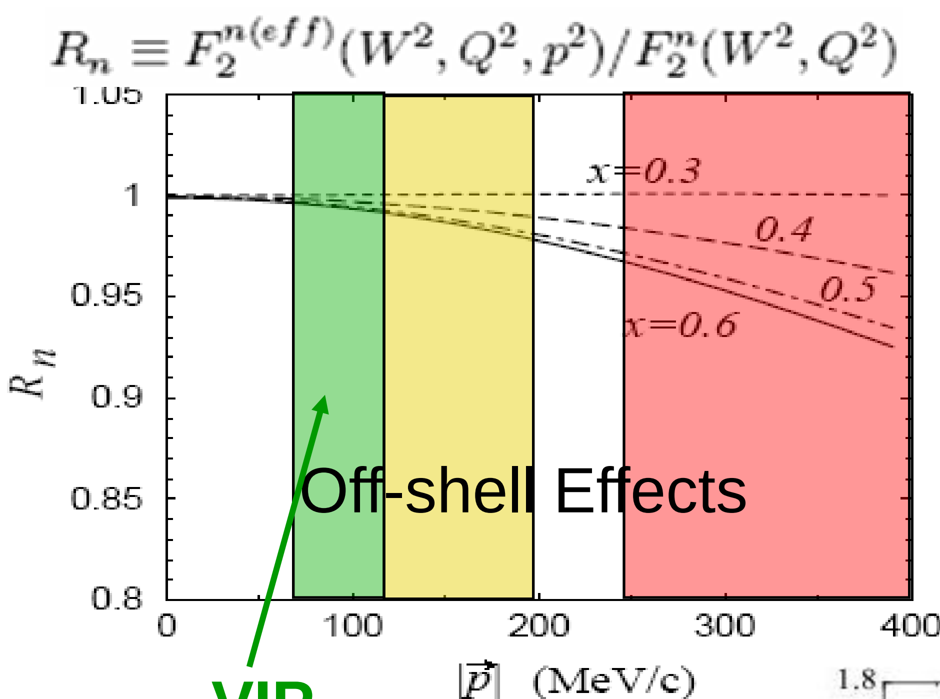
R = ratio of the total to the quasi-free cross section

θ_R = polar angle between photon and spectator proton

P_R = momentum of the spectator proton

Strong momentum and anglular dependence

Off-Shell and FSI for $D(e,e'p_s)X$



VIP$_s$

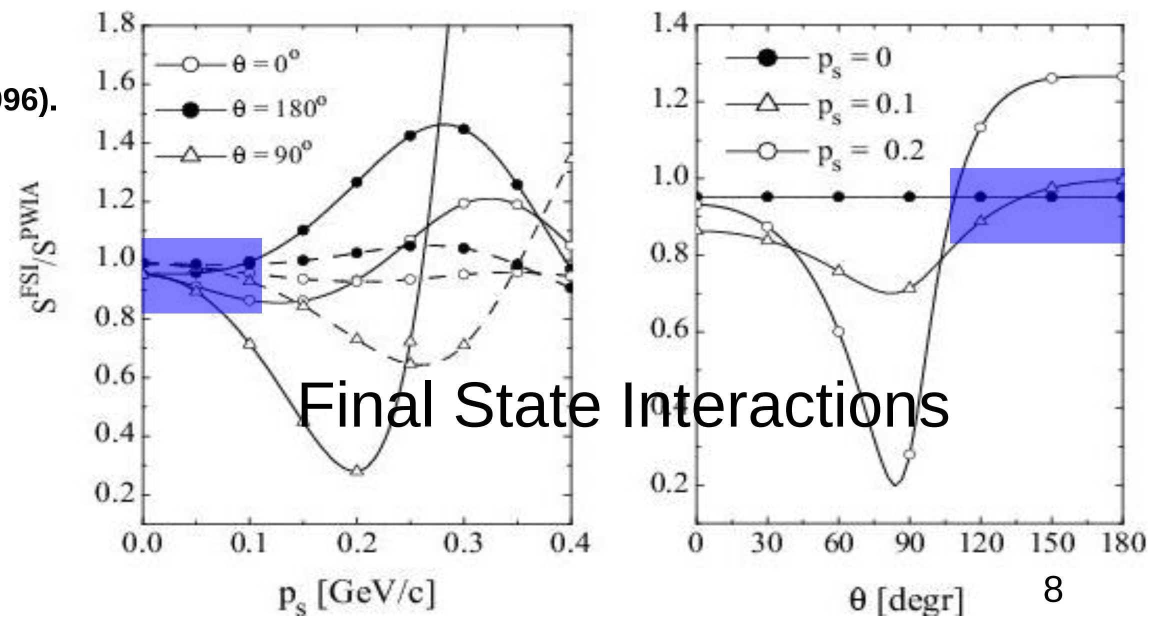
W. Melnitchouk *et al*, Phys. Lett. B377, 11 (1996).

↑

Off-shell effects are negligible for small P_s. Choose P_s<120 MeV/c as Very Important Spectator Protons (VIP)

Select low P_s (<120 MeV/c) and large backward θ_{pq} (>100º), angle between Ps and virtual photon, to minimize FIS.

↓



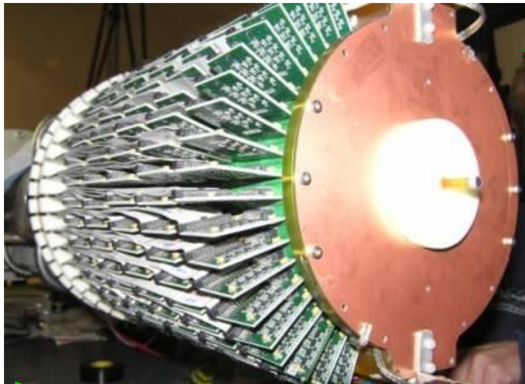
C. Atti *et al*, Eur. Phys. J. A 19,133-137 (2004).

Jefferson Lab Experiment E03-012

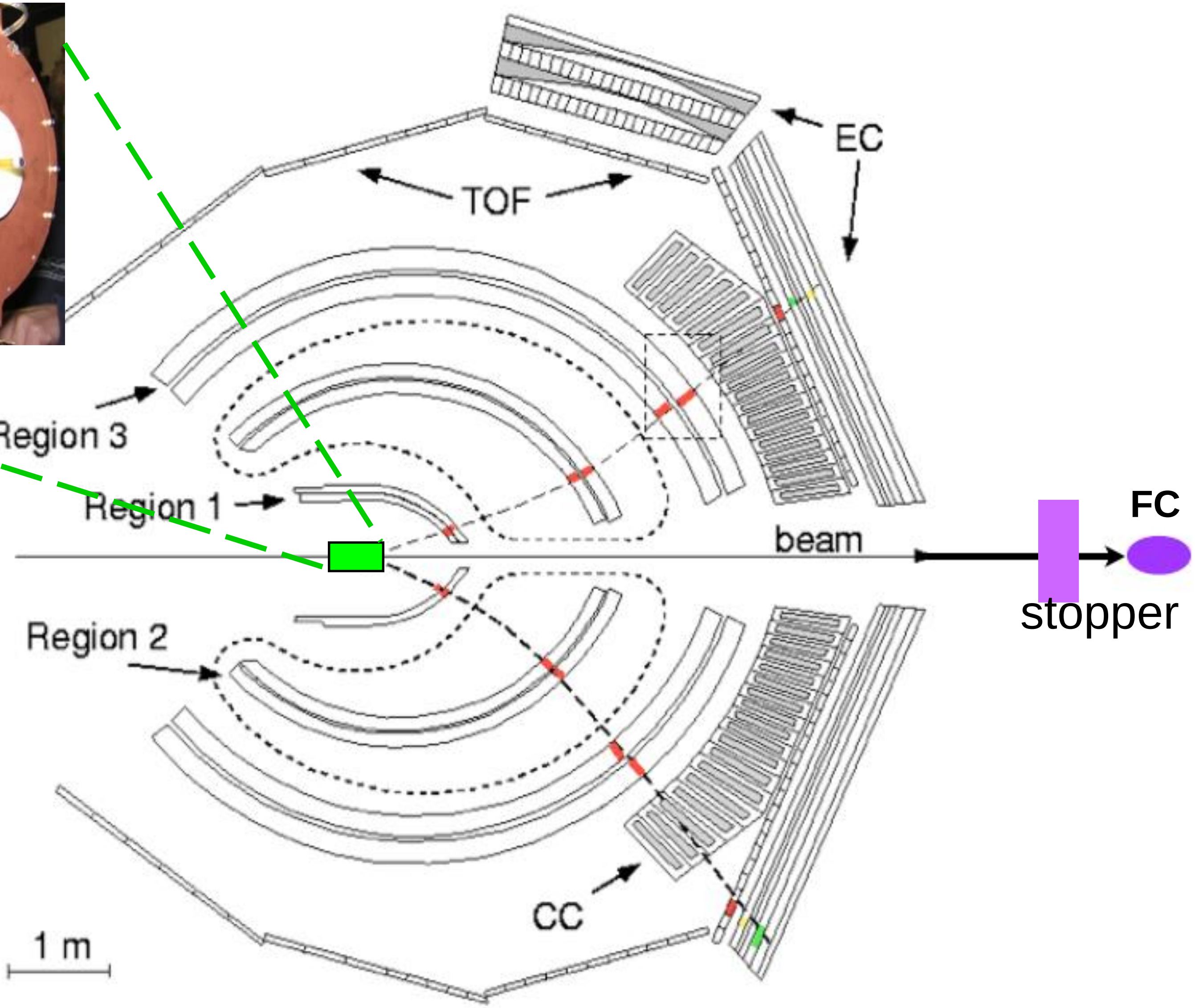
Barely off-shell Nucleon Structure (BoNuS)

- Electron beam energies: 2.1, 4.2, 5.3 GeV
- Spectator protons were detected by the newly built Radial Time Projection Chamber (RTPC)
- Scattered electrons and other final state particles were detected by CEBAF Large Acceptance Spectrometer (CLAS)
- Target: 7 atm D_2 gas, 20 cm long
- Data were taken from Sep. to Dec. in 2005

RTPC Sits in the Center of CLAS



BoNuS RTPC



CLAS

Radial Time Projection Chamber (RTPC)

Sensitive to protons with momenta of 67-250 Mev/c

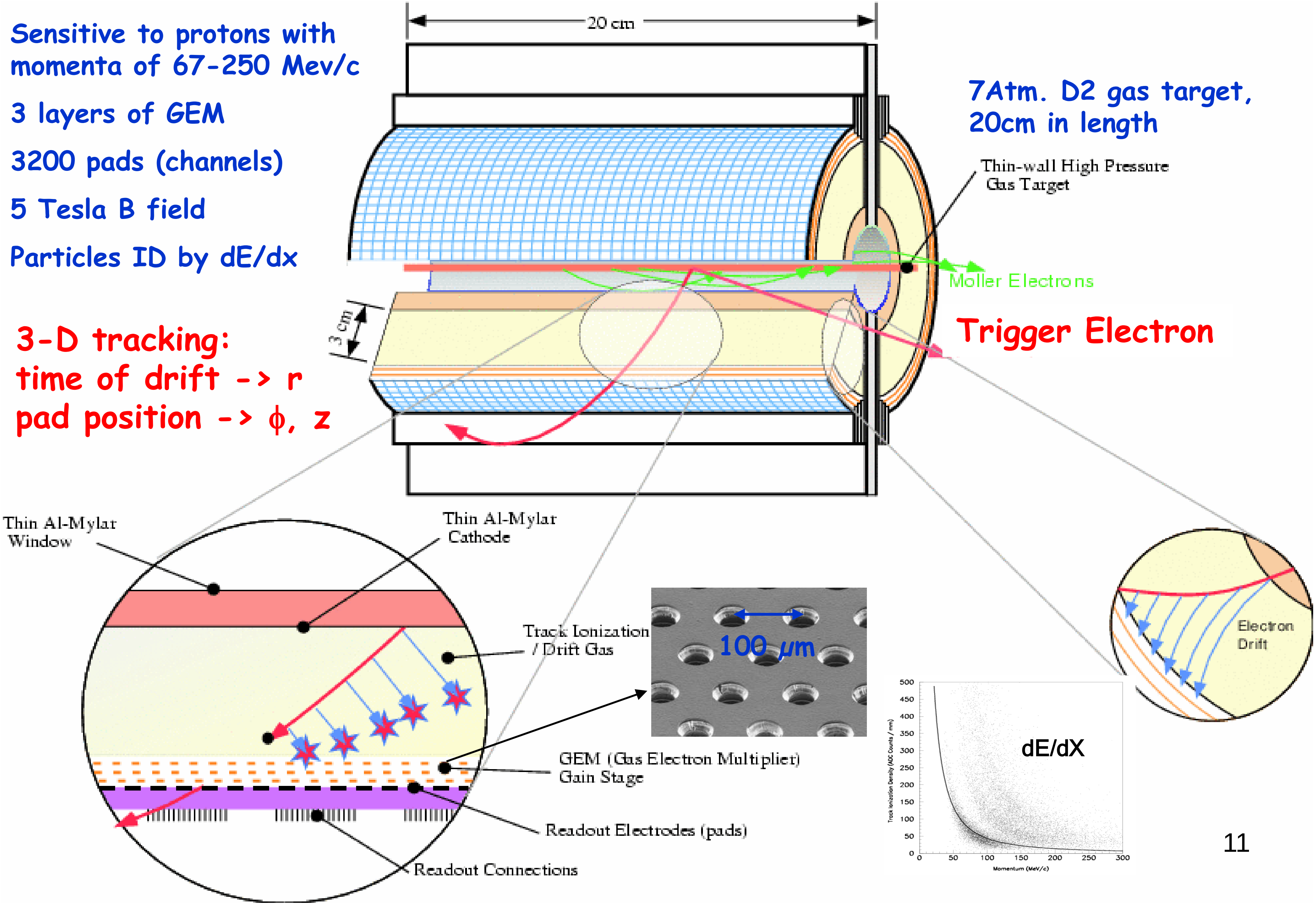
3 layers of GEM

3200 pads (channels)

5 Tesla B field

Particles ID by dE/dx

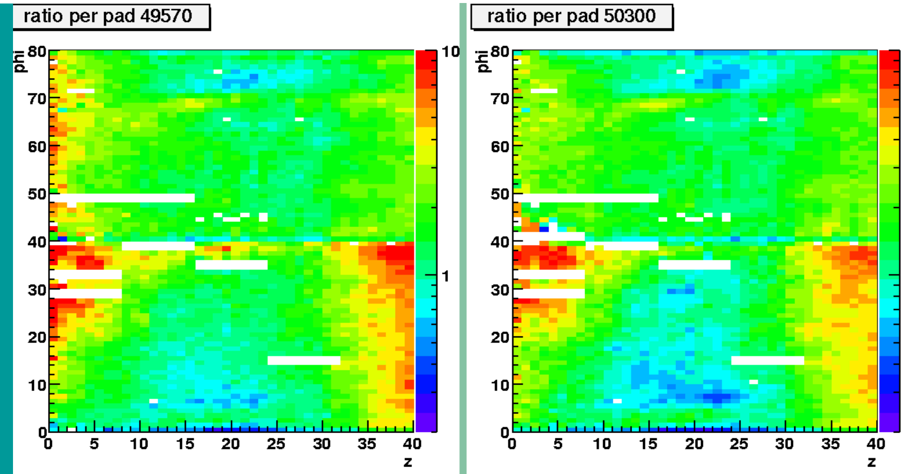
3-D tracking:
time of drift -> r
pad position -> ϕ, z



RTPC Gain Calibration

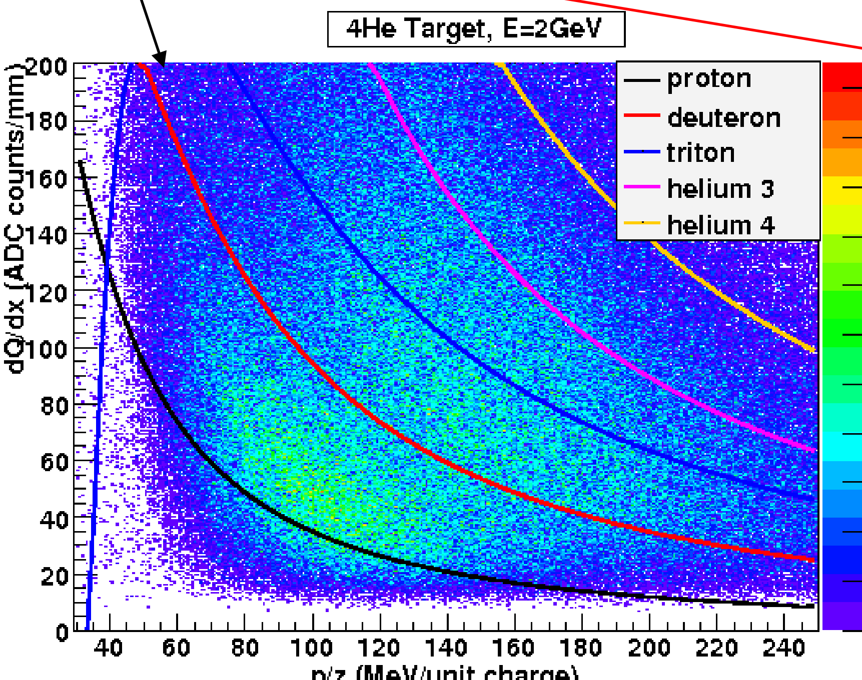
Channel by Channel gain multipliers can be determined for each run by comparing the track's expected energy loss to the measured value.

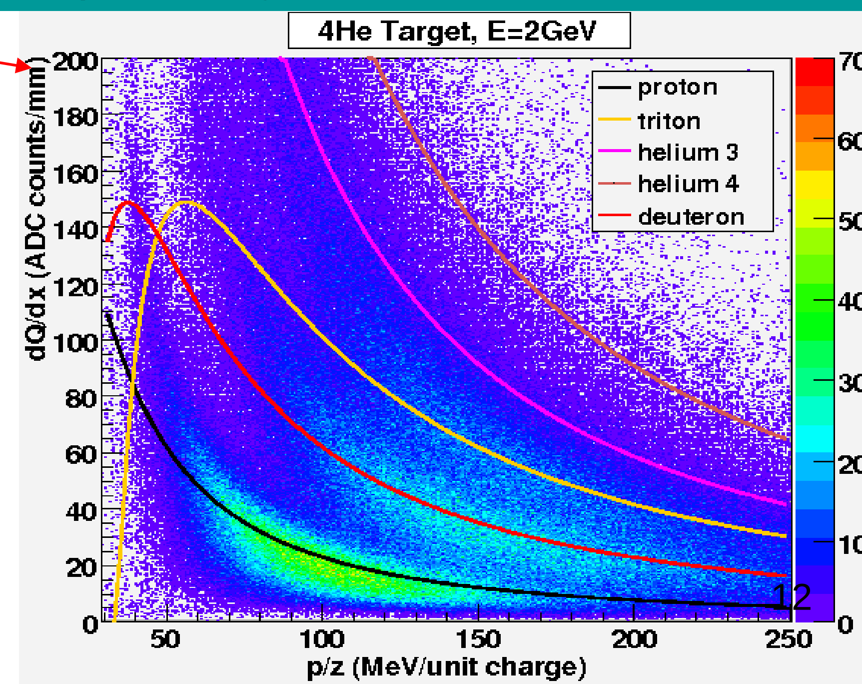
After applying the gain corrections, a clear separation of protons and heavier particles through dE/dx has been achieved.



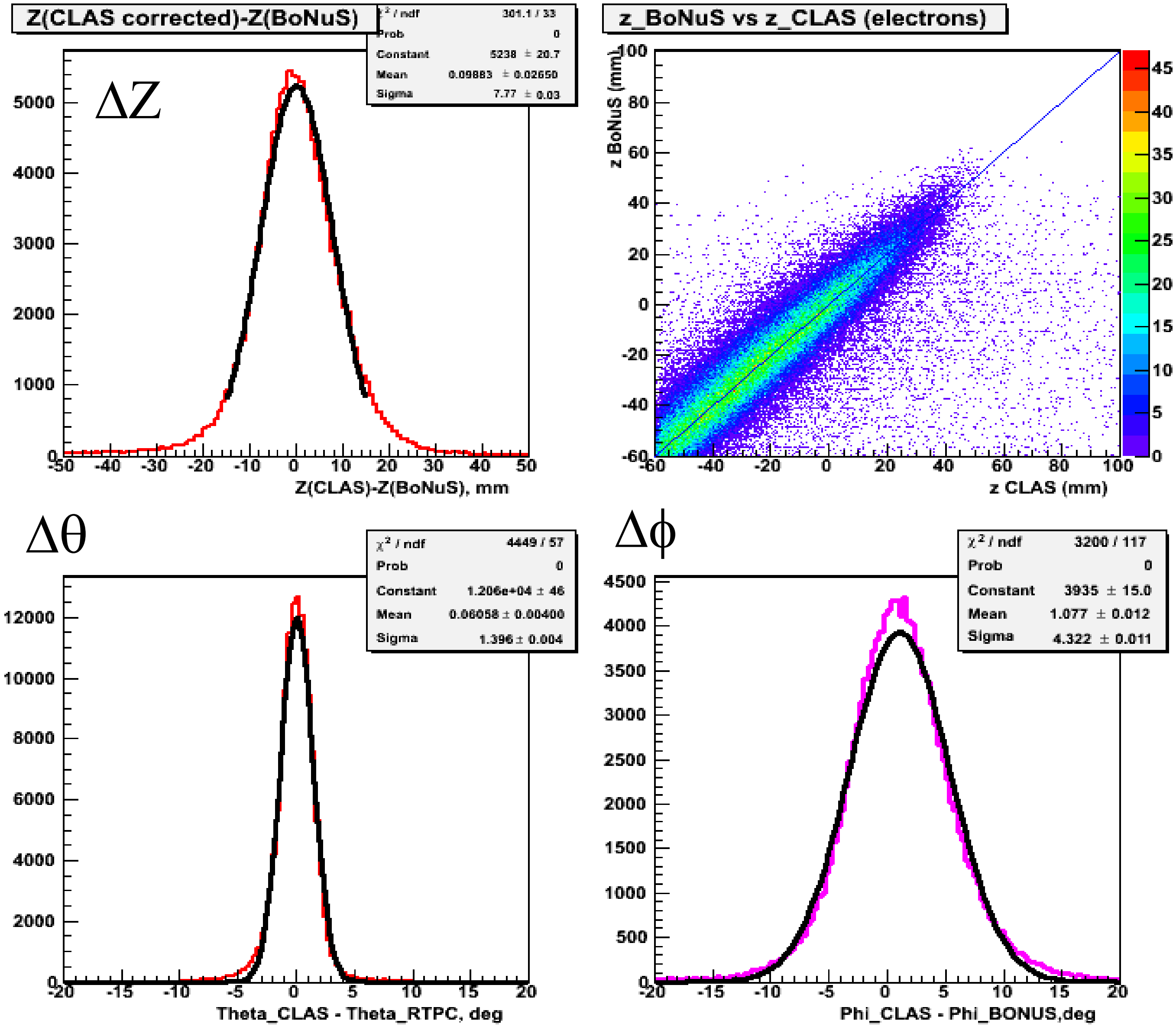
Gain constants (vs phi and z) determined independently for two different runs.

Before and After Gain Calibration





RTPC Resolution



Trigger electrons measured by CLAS are compared to the same electrons measured in BoNuS during High Gain Calibration runs.

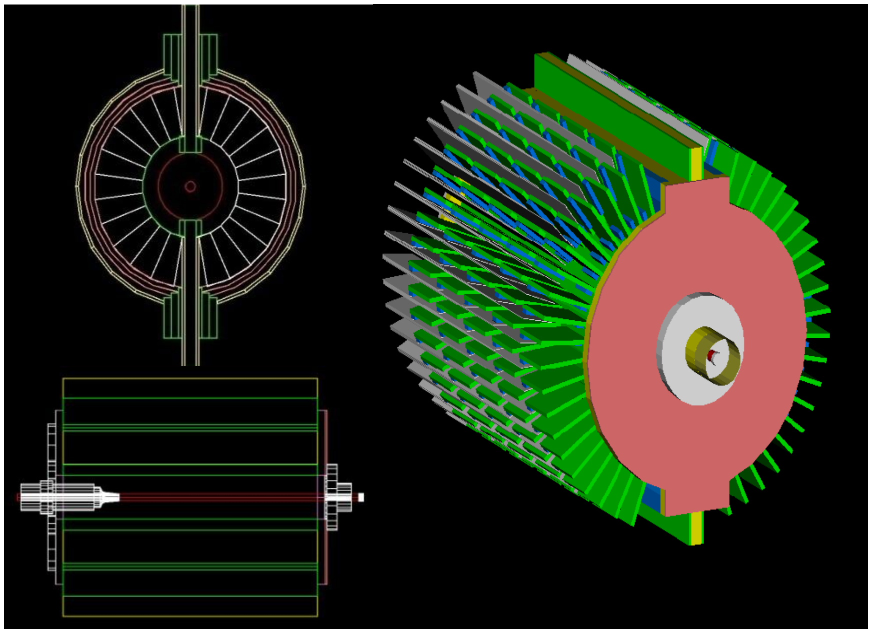
H. Fenker, et.al. **Nucl.Instrum. Meth. A592:273-286,2008**

Analysis Outline

1. Quality Checks
2. Vertex correction and vertex z cuts
3. Particle identifications (electron, π^- and proton)
4. Fiducial cut for trigger electron, π^- and proton
5. Energy loss correction for electron, π^- and proton
6. Exclusive cut (2-σ Missing Mass cut)
7. Acceptance cut and acceptance correction
8. Background subtraction
9. Trigger efficiency correction, CLAS proton and RTPC proton detection efficiency correction
10. Radiation correction
11. Luminosity analysis
12. Extract the cross section and structure functions
13. Systematic error estimation

Simulation Overview

RTPC(Geant4) → CLAS(geant3) → Reconstruction → Analysis



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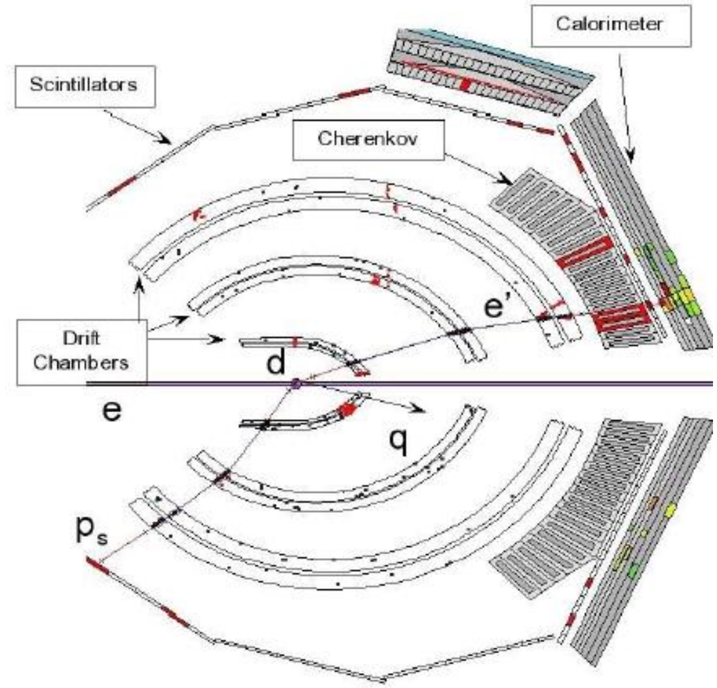
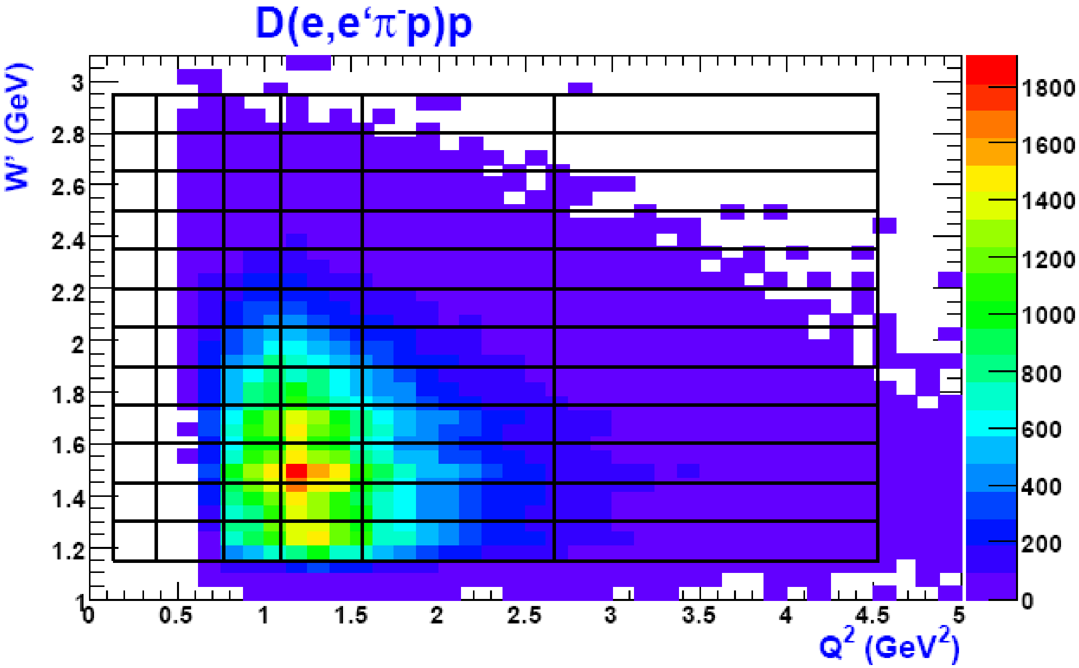


What have been done with simulation?

- Debug/optimize RTPC reconstruction packages
- Generate energy loss correction tables, radiation length tables
- Study Detector's acceptance for $D(e,e`\pi^- p_{CLAS})p$ and $D(e,e`\pi^- p_{RTPC})p$
- Study particle detection efficiency
- Model the background…

Kinematic coverage and binning, 5 GeV

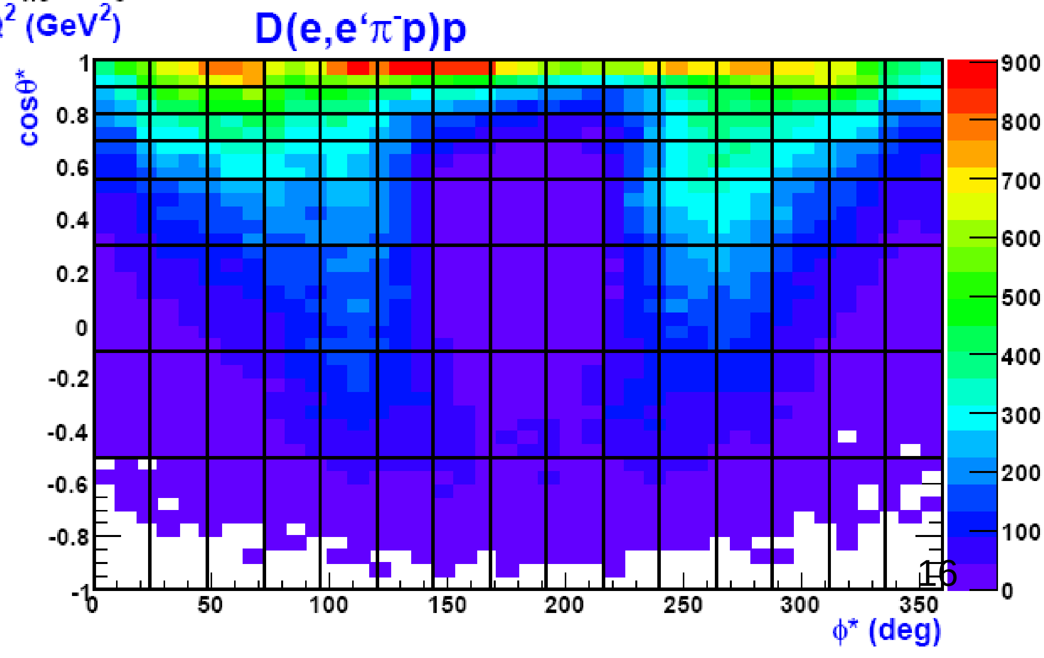


W′: 150 MeV each bin, [1.15,2.95)

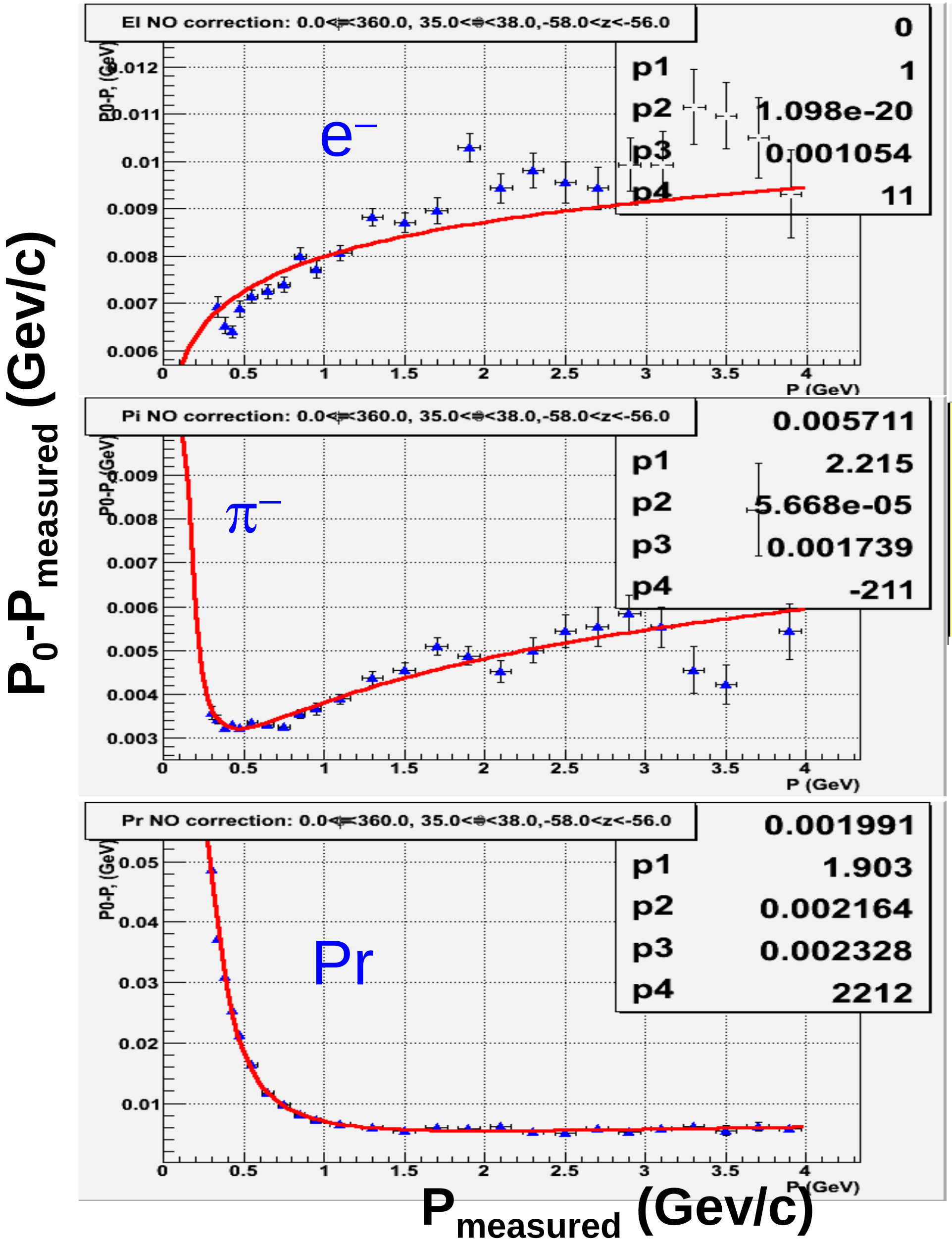
Q^2 : 6 bins with boundaries at 0.1309, 0.3790, 0.7697, 1.0969, 1.5632, 2.6594, 4.5243

cosθ*: 8 bins with boundaries at -1.0, -0.5, -0.1, 0.3, 0.55, 0.7, 0.8, 0.9,1.0

ϕ*: 15 bins, 24 degrees each bin, [0.0,360.0)



Energy Loss Correction for CLAS Particles



Particles loss energy when going through matter;

Binned by measured ϕ, θ, z, p;

Based on simulation, fit 'P_0-P vs P' with an integral Bethe-Bloch function for all particles

$$p_i = \sqrt{E_i^2 - m^2}$$

$$E_i = m + K_i$$

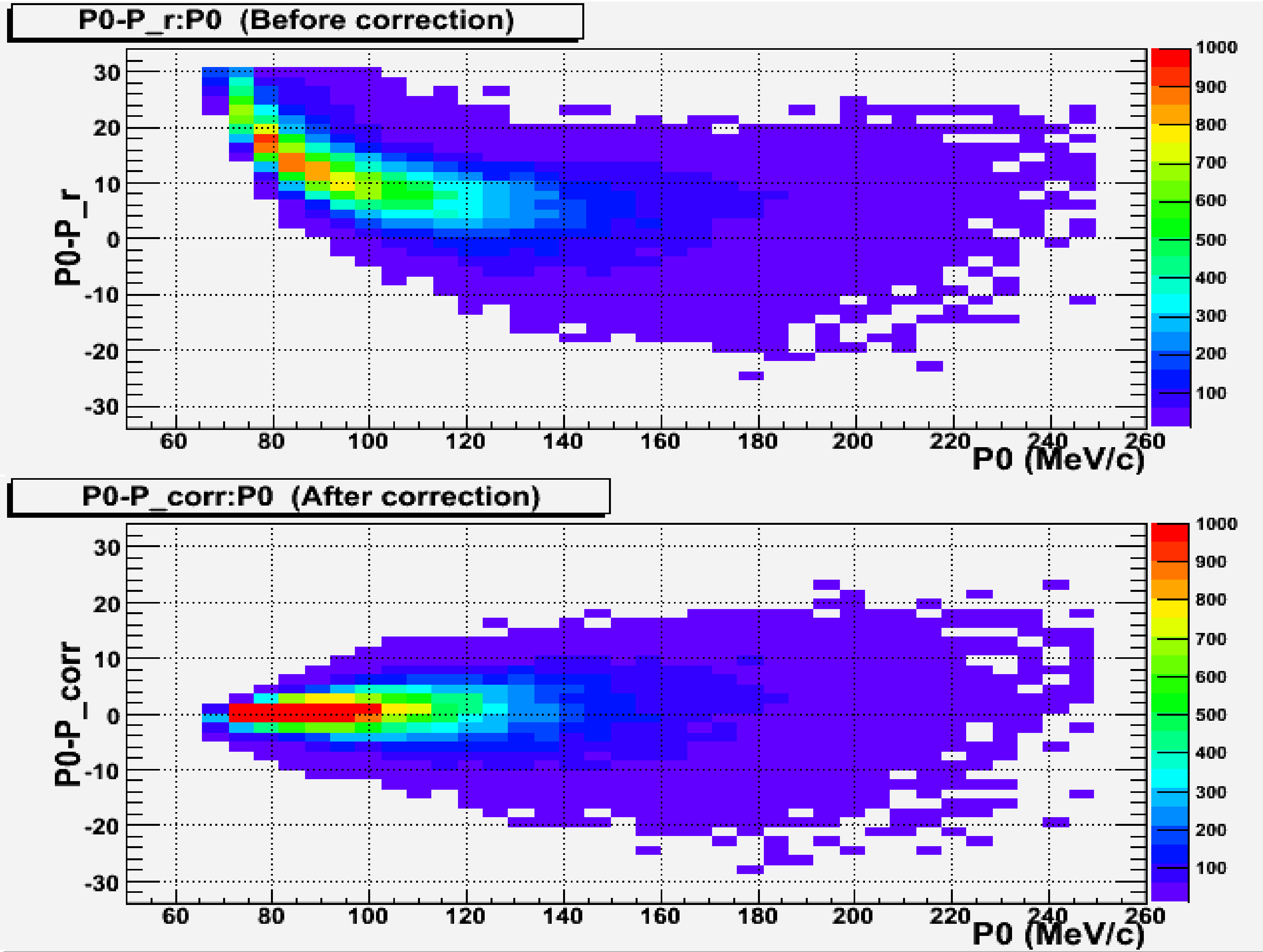
$$K_i = (K_f^b + a m^{b-1})^{1/b} + c + d \ln \gamma$$

$$K_f = E_f - m = \sqrt{p_f^2 + m^2} - m$$

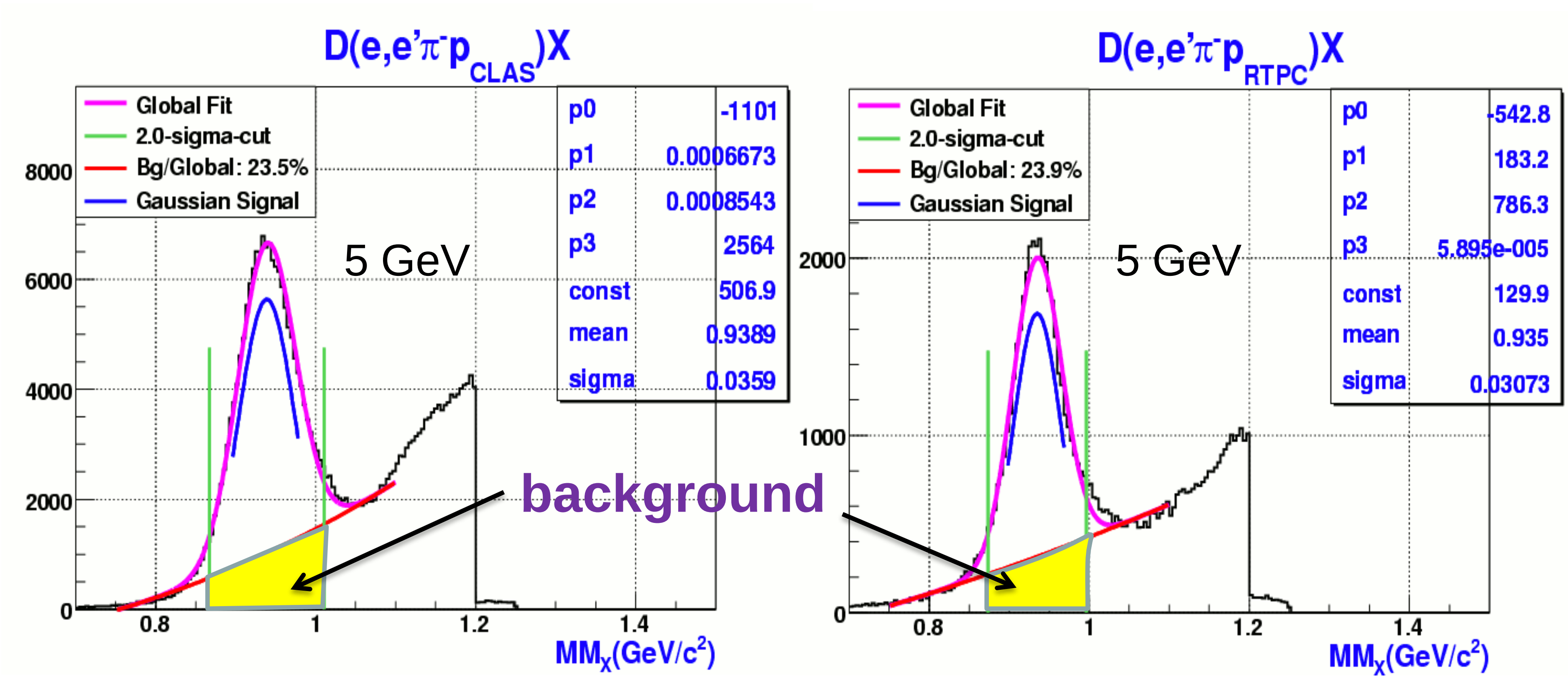
$$\gamma = \frac{1}{\sqrt{1-\beta^2}} = \frac{\sqrt{m^2 + p_f^2}}{m}.$$

$$\delta p \equiv p_i - p_f = f(a, b, c, d, m, p_f)$$

Energy Loss Correction for RTPC Proton



Missing Mass Cut: 2σ from Gaussian Center



Beam Energy	MM Cut of $D(e,e`\pi^- p_{CLAS})p$	MM Cut of $D(e,e`\pi^- p_{RTPC})p$
2.x	0.9436 +/- 0.0509	0.9374 +/- 0.0400
4.x	0.9401 +/- 0.0605	0.9356 +/- 0.0501
5.x	0.9389 +/- 0.0718	0.9350 +/- 0.0615

Background Subtraction

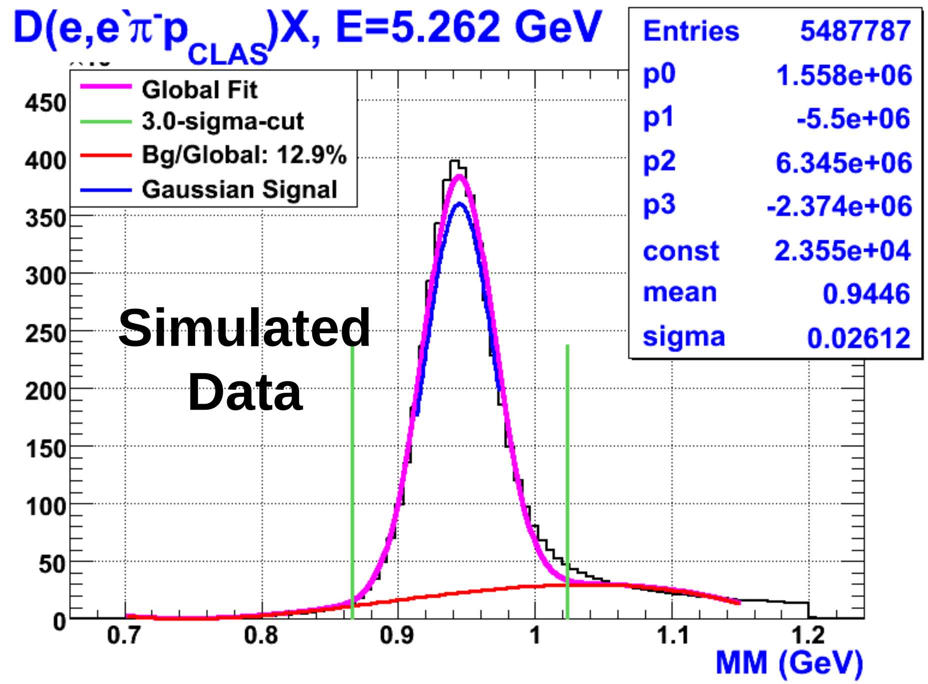
average

$$f(W', Q^2, \theta^*, \phi^*) = f_3(\theta^*) * \frac{f_1(W')}{< f_1(W') >} * \frac{f_2(Q^2)}{< f_2(Q^2) >} * \frac{f_4(\phi^*)}{< f_4(\phi^*) >}$$

$$f^{sim}(W', Q^2, \theta^*, \phi^*) = f_3^{sim}(\theta^*) * \frac{f_1^{sim}(W')}{< f_1^{sim}(W') >} * \frac{f_2^{sim}(Q^2)}{< f_2^{sim}(Q^2) >} * \frac{f_4^{sim}(\phi^*)}{< f_4^{sim}(\phi^*) >}$$

f_1, f_2, f_3 and f_4 are the fitted background fraction functions for real data.

f_1^{sim}, f_2^{sim}, f_3^{sim} and f_4^{sim} are the fitted background fraction functions for simulated data.

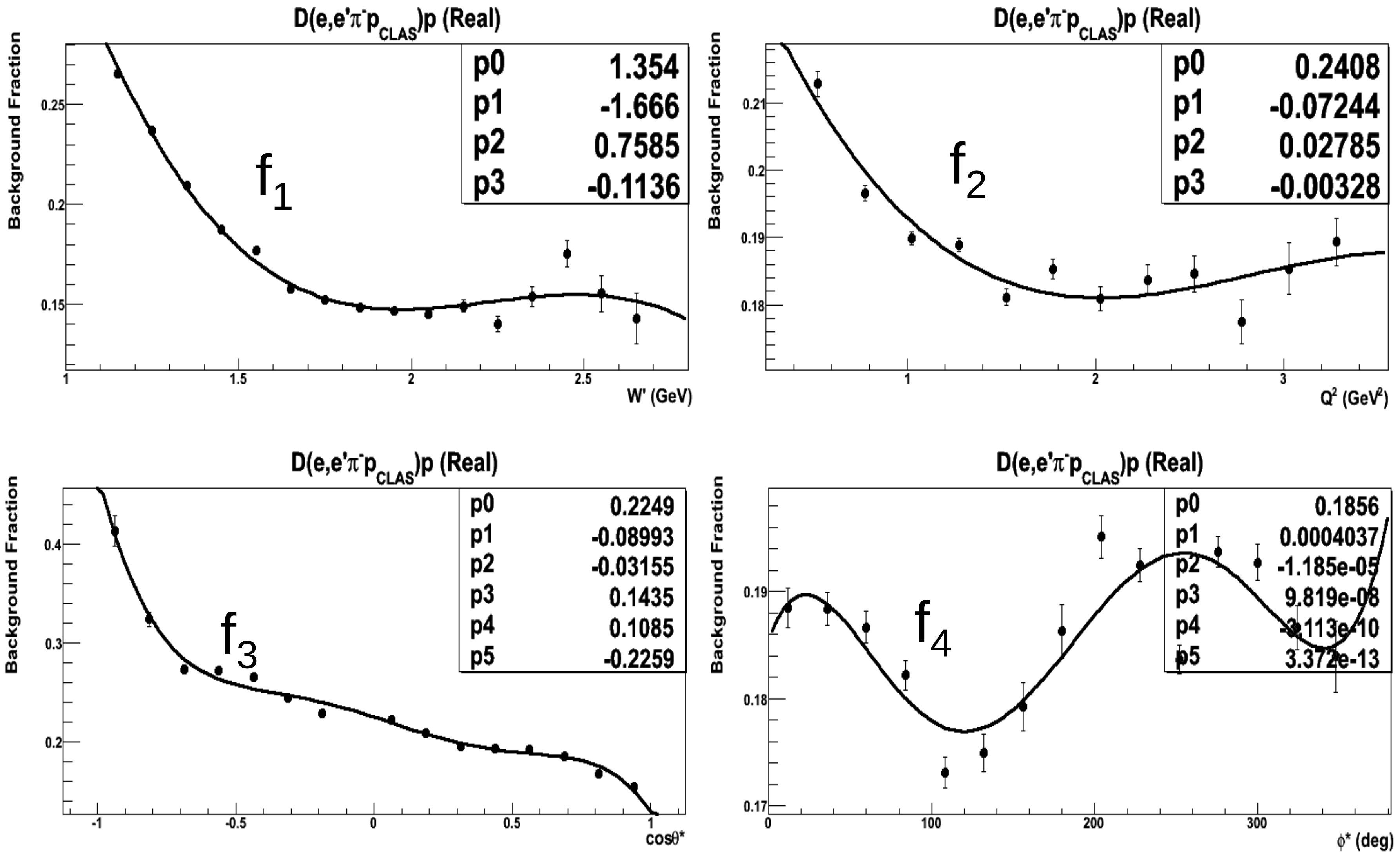


Final background correction factor:

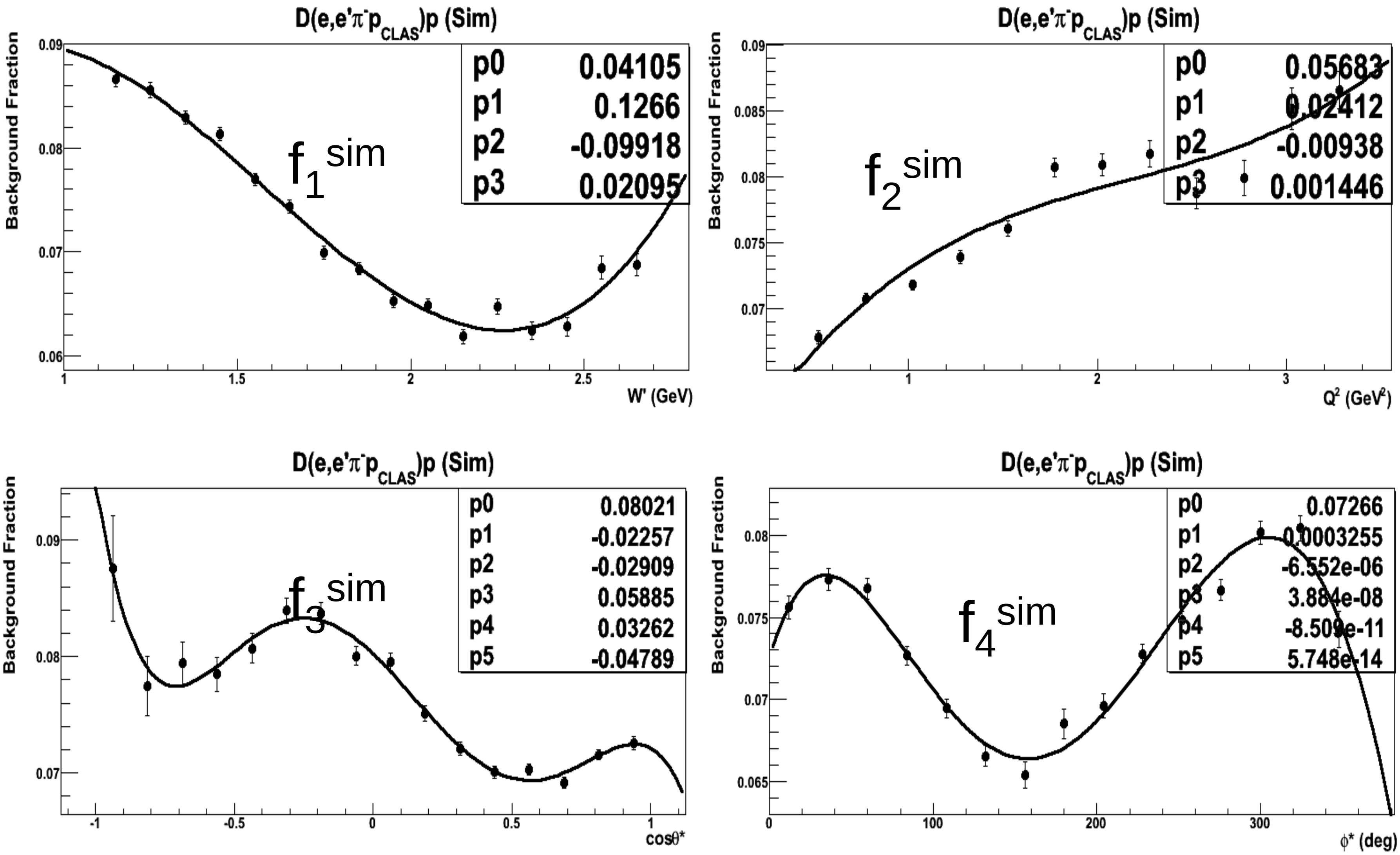
$$\frac{GoodData}{Total} = (1.0 - f(W', Q^2, \theta^*, \phi^*) + f^{sim}(W', Q^2, \theta^*, \phi^*))/0.9545$$

where 0.9545 is the coverage of 2σ in a gaussian distribution.

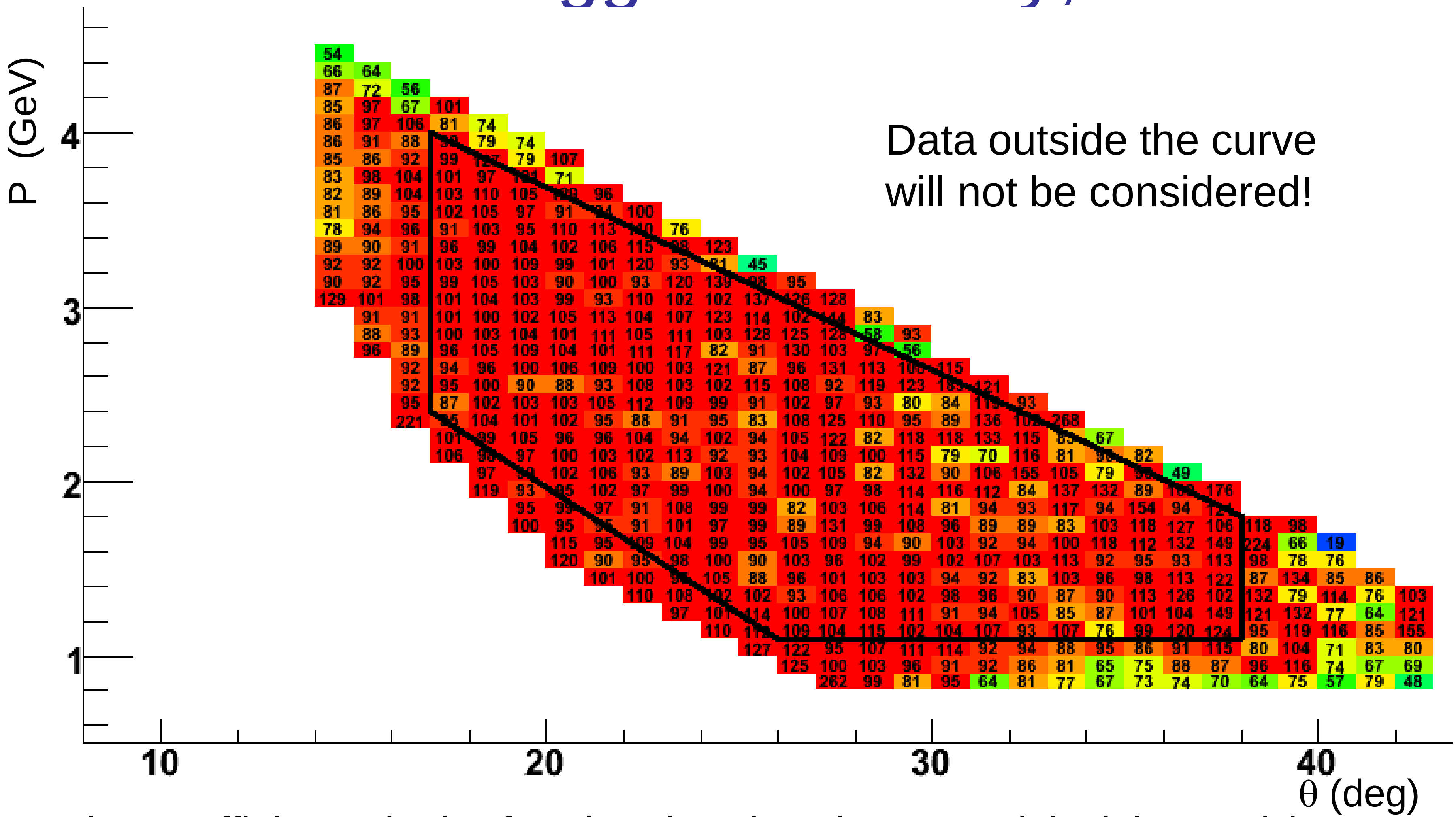
Background of $D(e,e`\pi^- p_{CLAS})p$, 5G Real



Background of D(e,e`π^-p_{CLAS})p, 5G Sim.

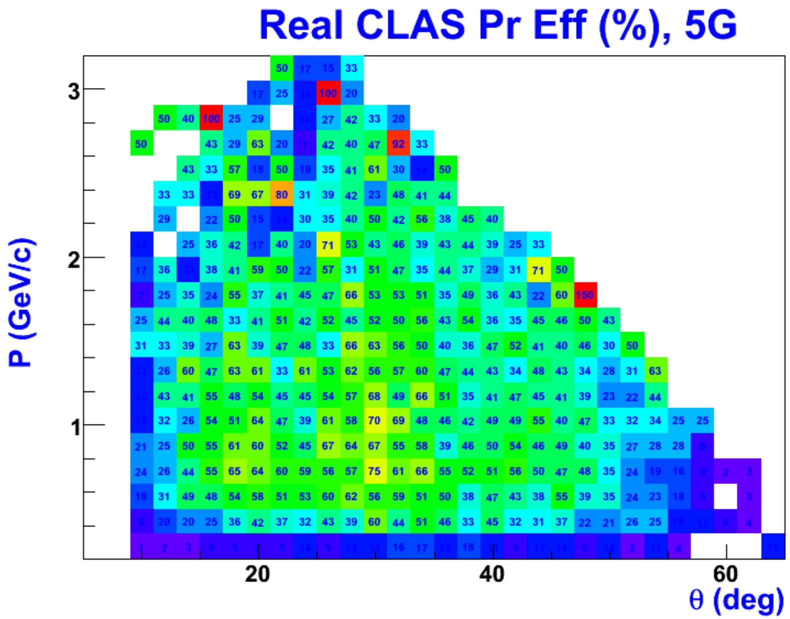


CLAS trigger efficiency, 5G

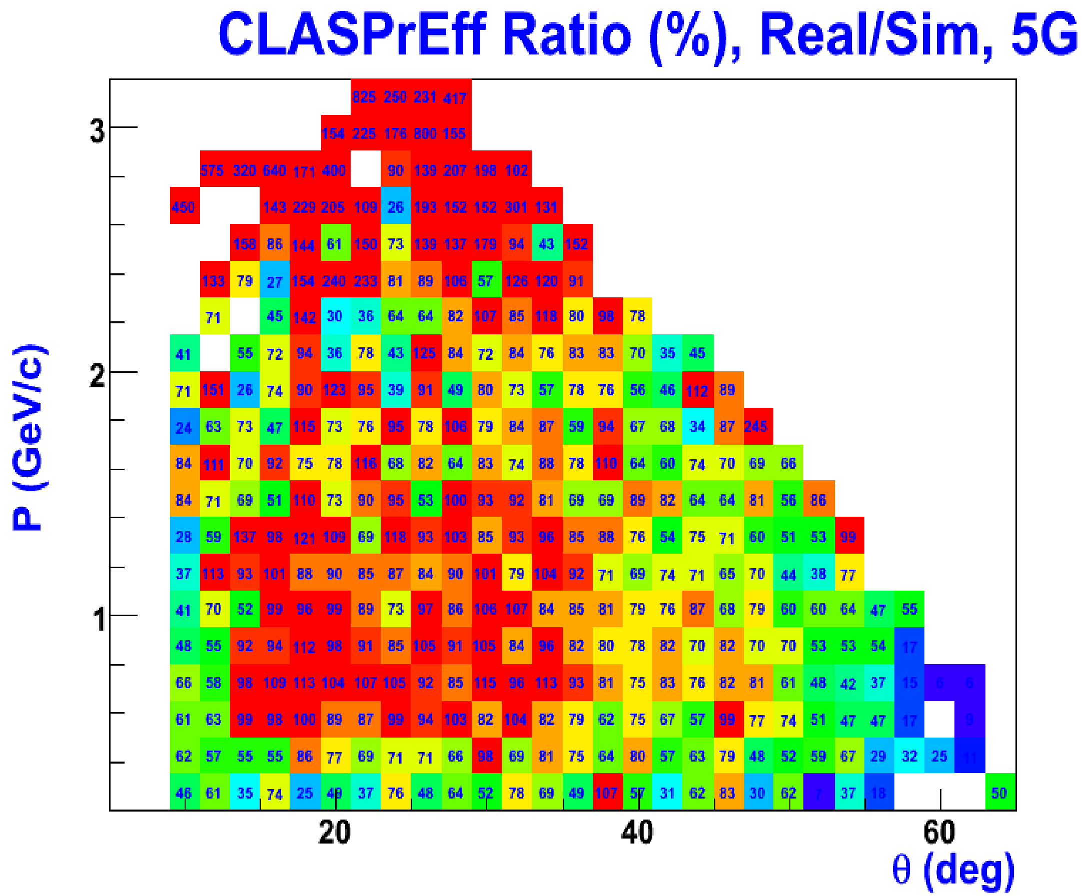


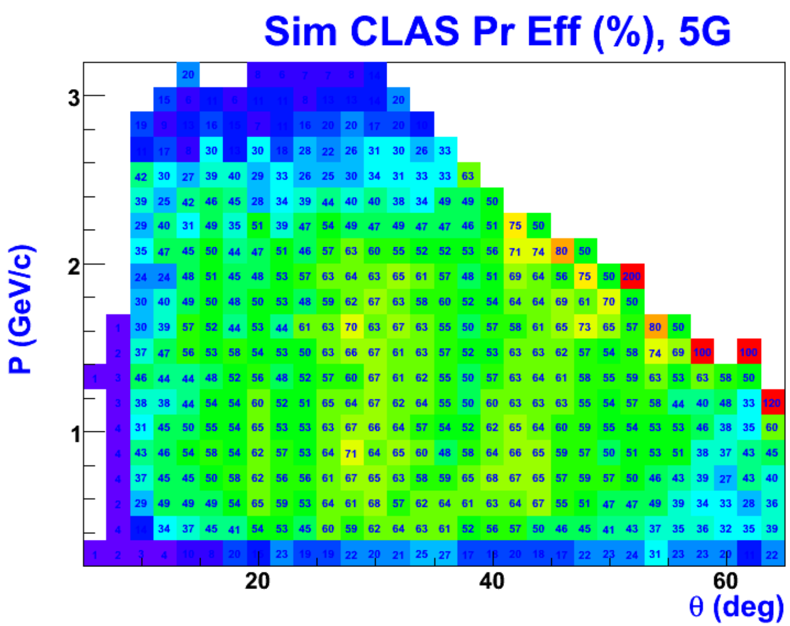
Trigger efficiency is the fraction that the trigger particle (electron) is detected. It is obtained by scaling the simulation data to the real data, then calculating the ratio of real event counts in each p-θ grid to the simulated event counts in the same grid.

CLAS proton efficiency

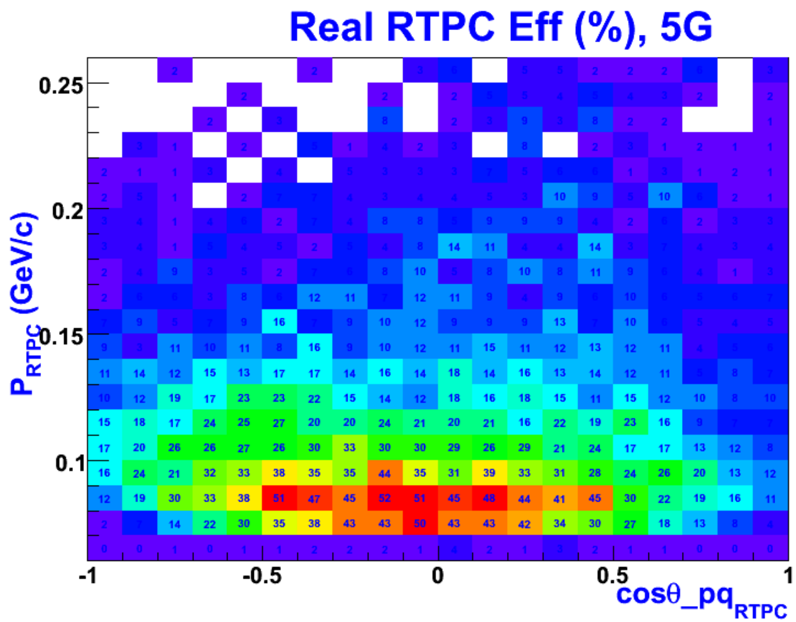


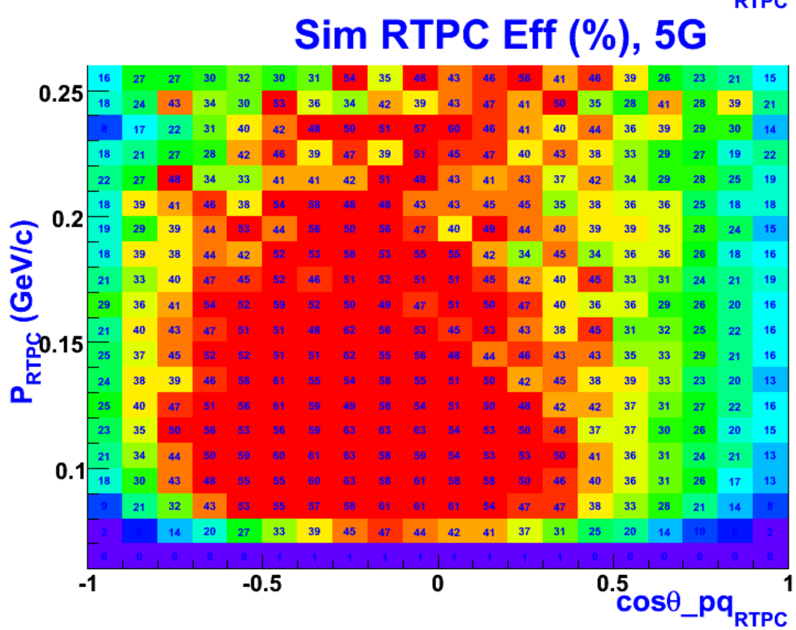
$$\eta_p = \frac{D(e, e'\pi^- p_{CLAS} p_{RTPC})}{D(e, e'\pi^- p_{RTPC}) p}$$



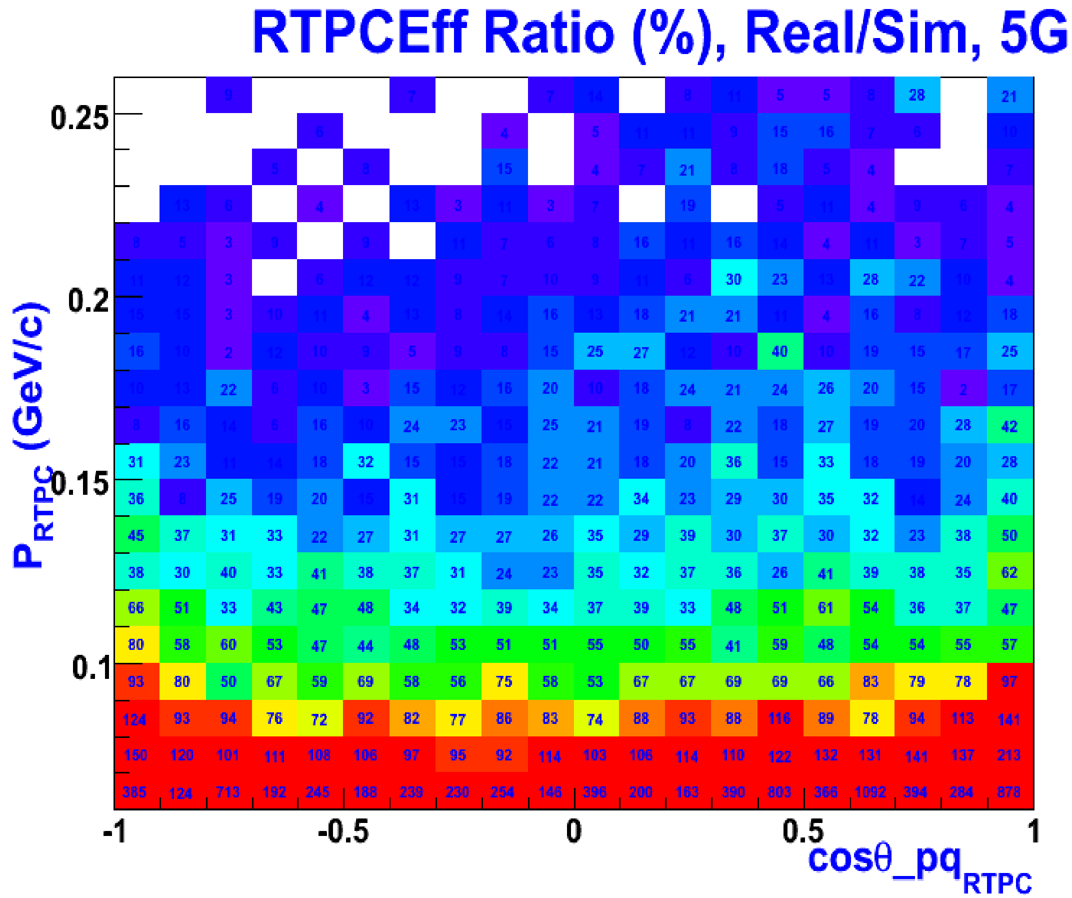


RTPC proton efficiency

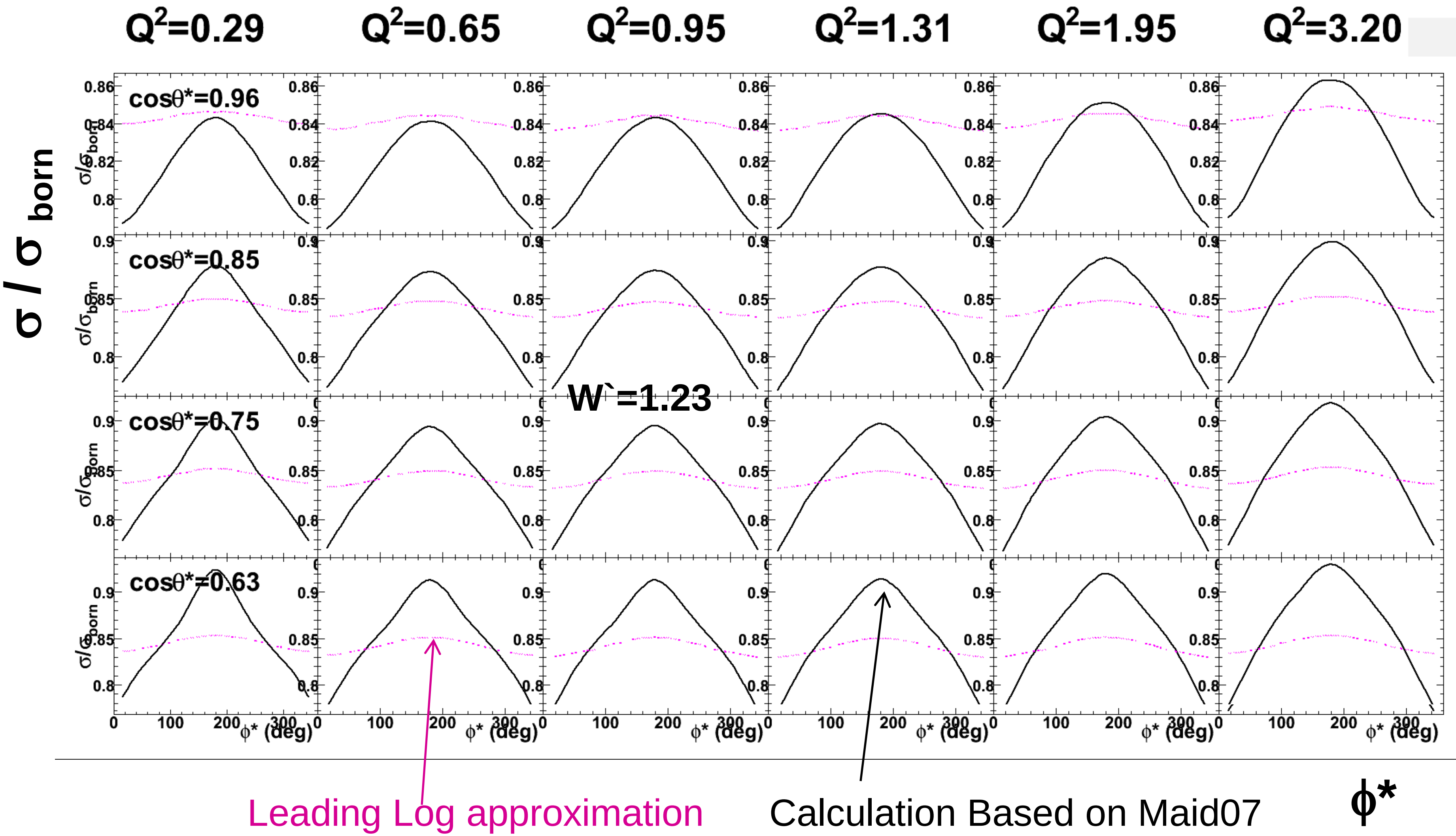




$$\eta_{RTPC} = \frac{D(e, e'\pi^- p_{CLAS} p_{RTPC})}{D(e, e'\pi^- p_{CLAS})p}$$



Radiation Correction, E=5.3 GeV



Using upraded “Exclurad”. Updated with MAID07 multipole model for both neutron and proton. A dedicate clas-note will be vesy soon.

Cross Section Calculations

1. Select exclusive events
2. Apply corrections: acceptance, trigger, π^-, CLAS proton and RTPC proton efficiency, radiative and background correction.

$$\frac{\partial^5\sigma}{\partial E'\partial\Omega_e\partial\Omega_\pi^*} = \int \Gamma_v dE' d\Omega_e \int \frac{\partial^2\sigma}{\partial\Omega_\pi^*} d\Omega_\pi^*$$

$$\lambda_{CLAS} = \frac{B}{R\cdot\eta_e\cdot\eta_\pi\cdot\eta_p^{r2s}\cdot A};$$

$$\lambda_{RTPC} = \frac{B}{R\cdot\eta_e\cdot\eta_\pi\cdot\eta_{RTPC}^{r2s}\cdot A};$$

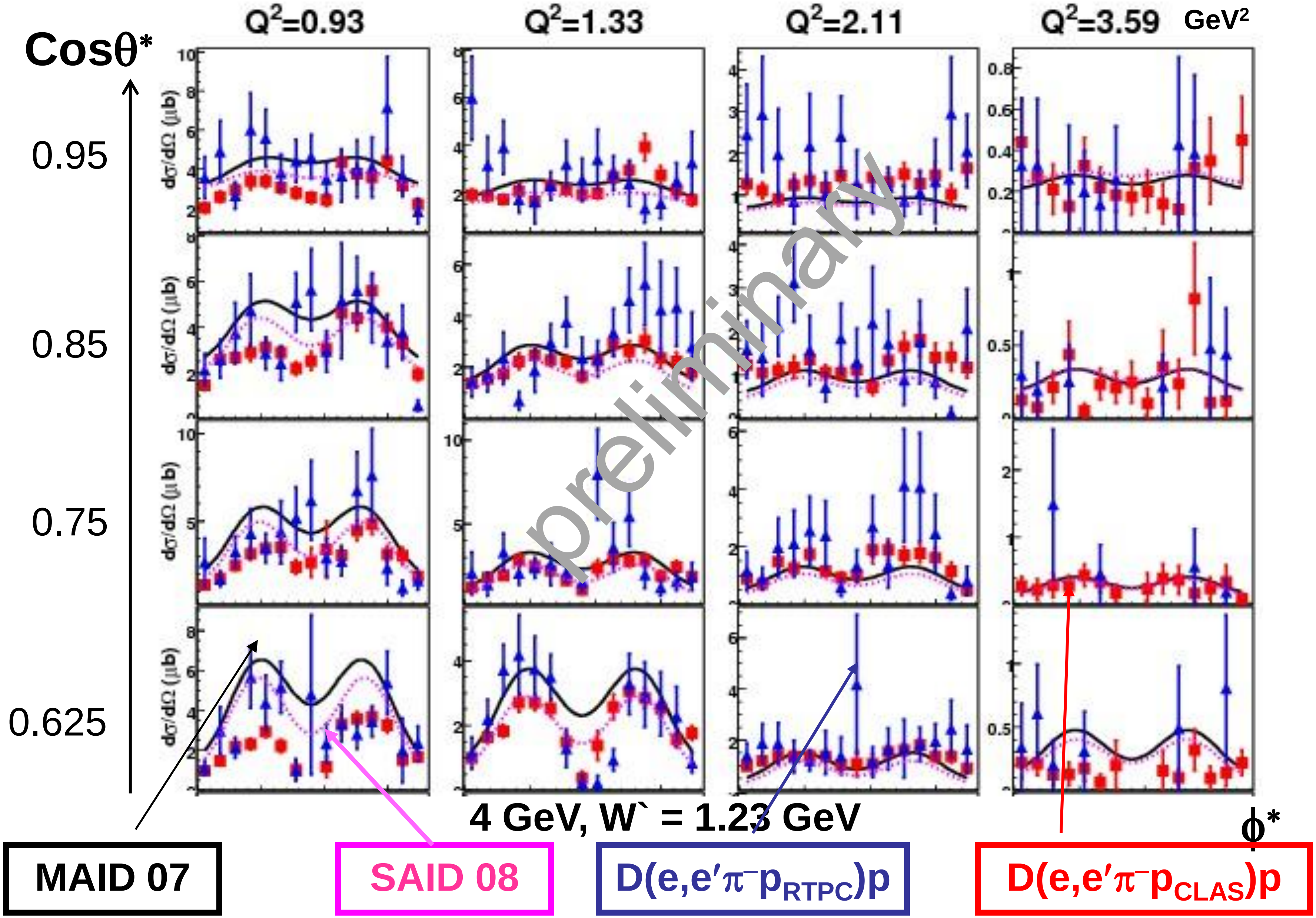
$$\begin{aligned}
\tau &= \int \Gamma_v \frac{\pi W'}{EE'M_n} dW' dQ^2 \\
&= \int \frac{\alpha}{2\pi^2}\frac{E'}{E}\frac{W'^2 - M_n^2}{2M_n Q^2}\frac{1}{1-\varepsilon}\frac{\pi W'}{EE'M_n} dW' dQ^2 \\
&= \frac{\alpha}{4\pi E^2 M_n^2}\int \frac{(W'^2 - M_n^2)W'}{Q^2(1-\varepsilon)} dW' dQ^2 \\
&= \frac{\alpha}{8\pi E^2 M_n^2}\int \frac{W'^2 - M_n^2}{Q^2(1-\varepsilon)} dW'^2 dQ^2.
\end{aligned}$$

$$\sum_{events}(1\cdot\lambda) = L\tau\Delta(cos\theta_\pi^*)\Delta\phi_\pi^*\frac{\partial^2\sigma}{\partial\Omega_\pi^*}$$

$$\frac{\partial^2\sigma}{\partial\Omega_\pi^*} = \frac{\sum_{events}(1\cdot\lambda)}{L\tau\Delta(cos\theta_\pi^*)\Delta\phi_\pi^*}.$$

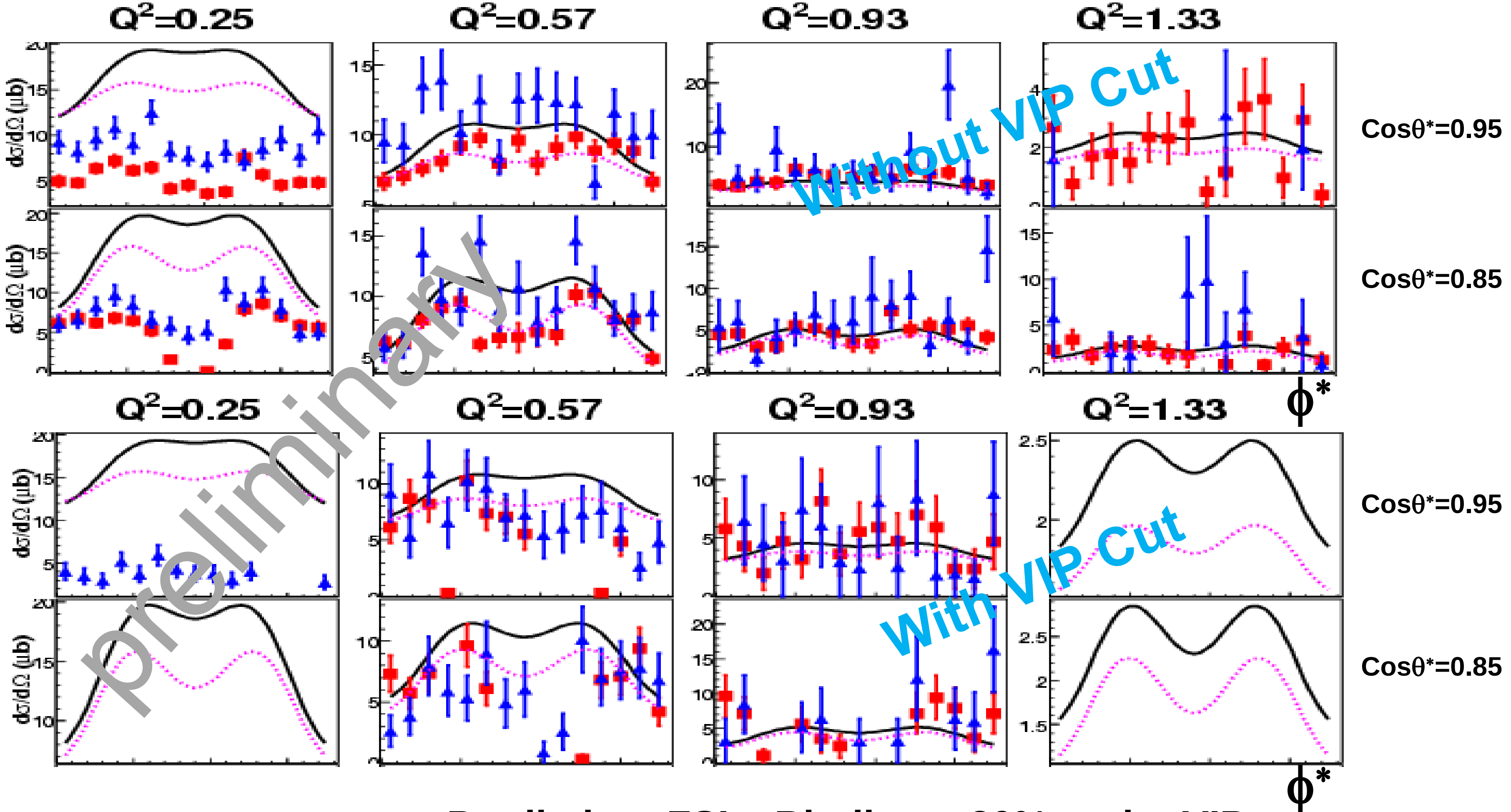
$$L = \frac{N_B\times N_{target}}{A} = \frac{N_B\times 2PVN_A}{ART} = \frac{2N_B PlN_A}{RT}$$

Cross Section: BoNuS Vs MAID and SAID



Minimizing Final State Interactions

2 GeV, W` = 1.23 GeV

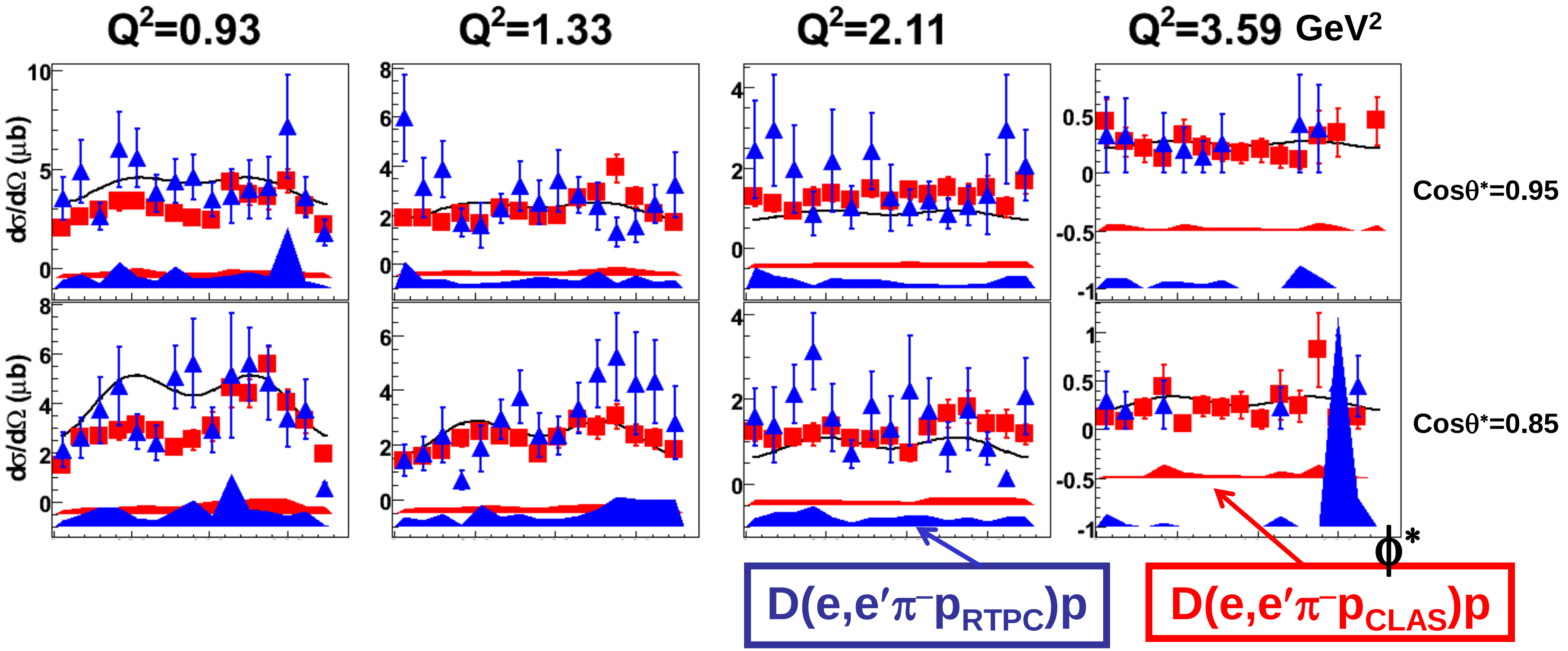


VIP Cut= θ_{pq}>100°
and 70<p_s<120 MeV

Prediction: FSI + Binding < 20% under VIP cut

Data: 1)Better agreement between CLAS and RTPC channel for low Q^2; 2) No obvious change other than removing data points to the results with larger Q^2

Systematic Error 4 GeV, W` = 1.23 GeV

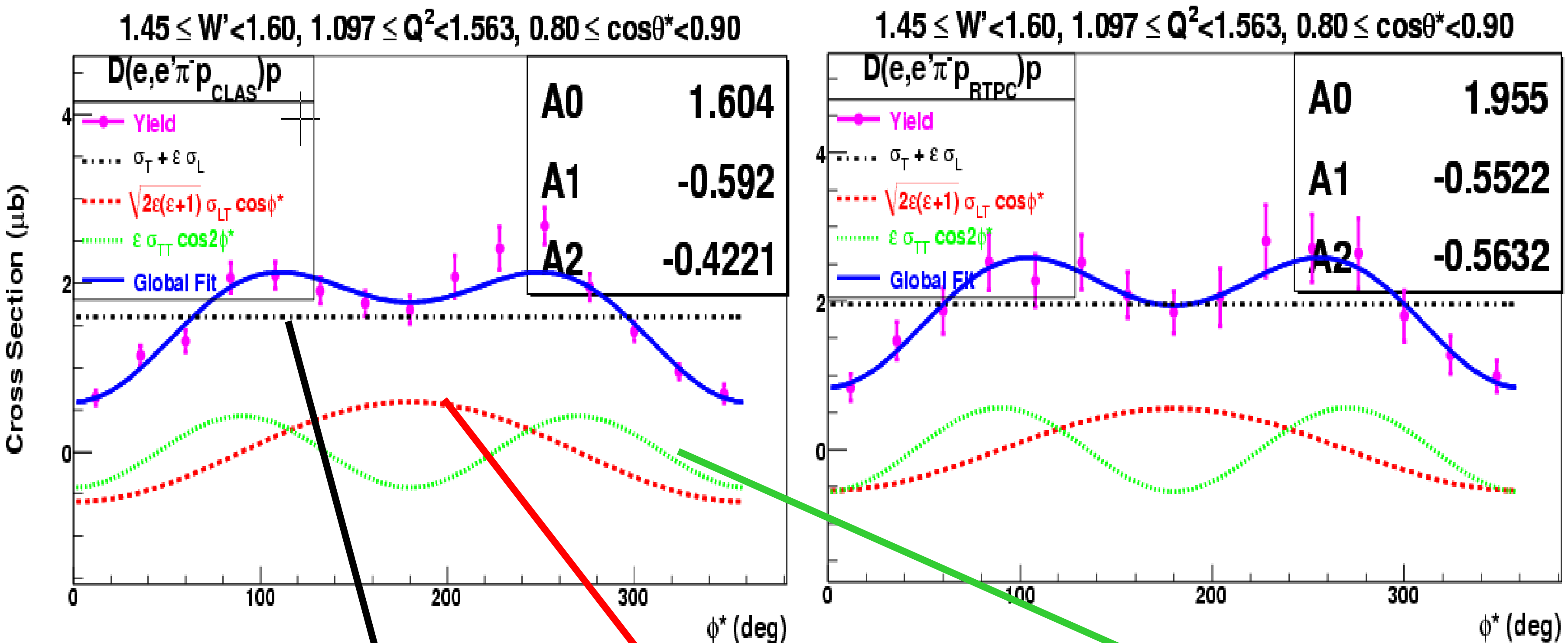


15% in average, mainly come from the following (values are all in average):

Rad. corr.	~5%	Background corr.	5%
Acceptance cut	10%	Missing mass cut	5%
PID and Detection eff.	8%	Luminosity	2%

FSI is estimated to be 15%, not included in the figure yet

Fit for Structure Functions

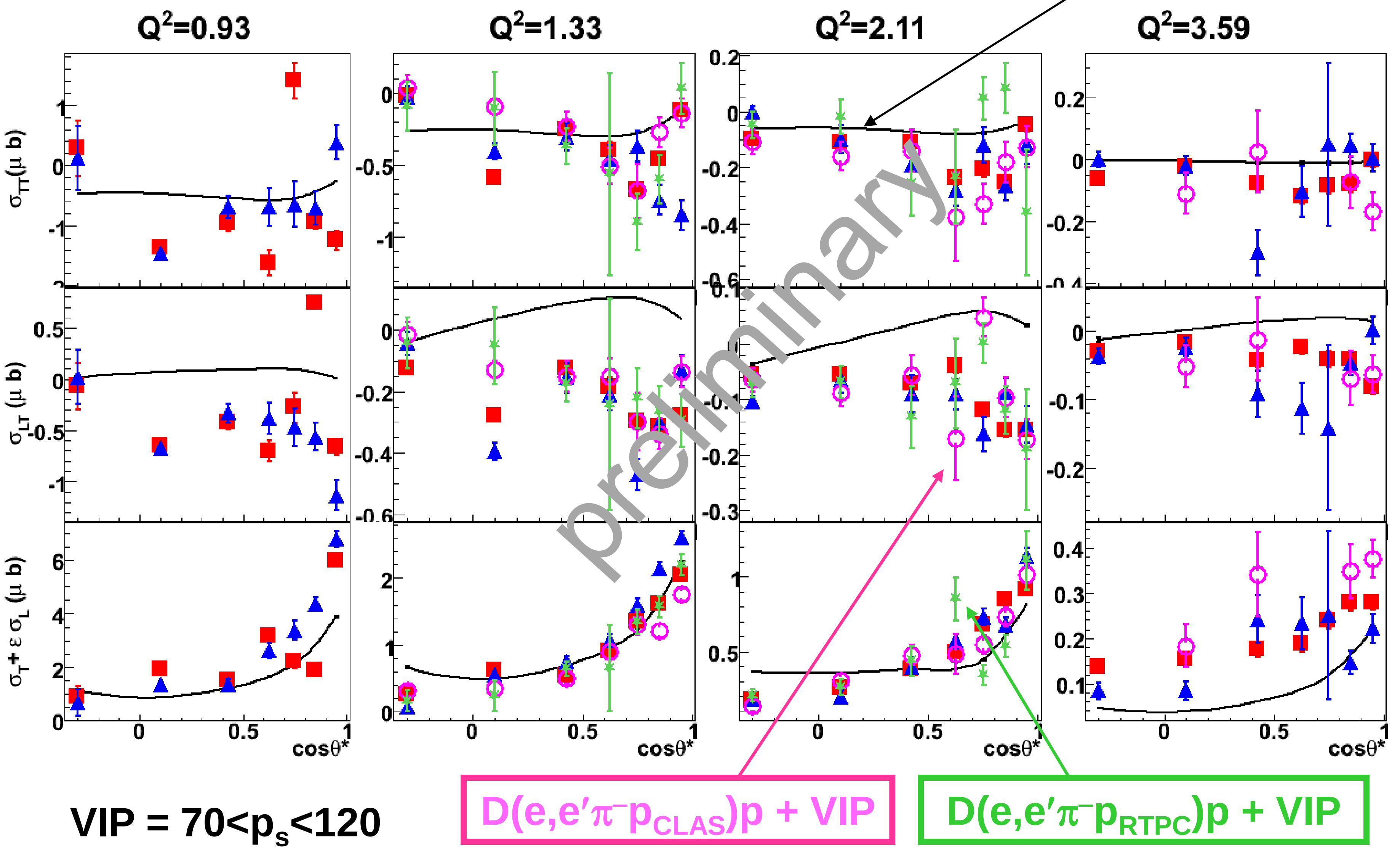


$$\frac{\partial^2 \sigma}{\partial \Omega_\pi^*} = \boxed{\sigma_T + \varepsilon \sigma_L} + \boxed{\sqrt{2\varepsilon(1+\varepsilon)}\sigma_{LT} cos\phi_\pi^*} + \boxed{\varepsilon \sigma_{TT} cos2\phi_\pi^*}$$

$$= \boxed{\text{A0}} + \boxed{\text{A1 Cos}\phi^*} + \boxed{\text{A2 Cos2}\phi^*}$$

Structure Functions: BoNuS Vs MAID

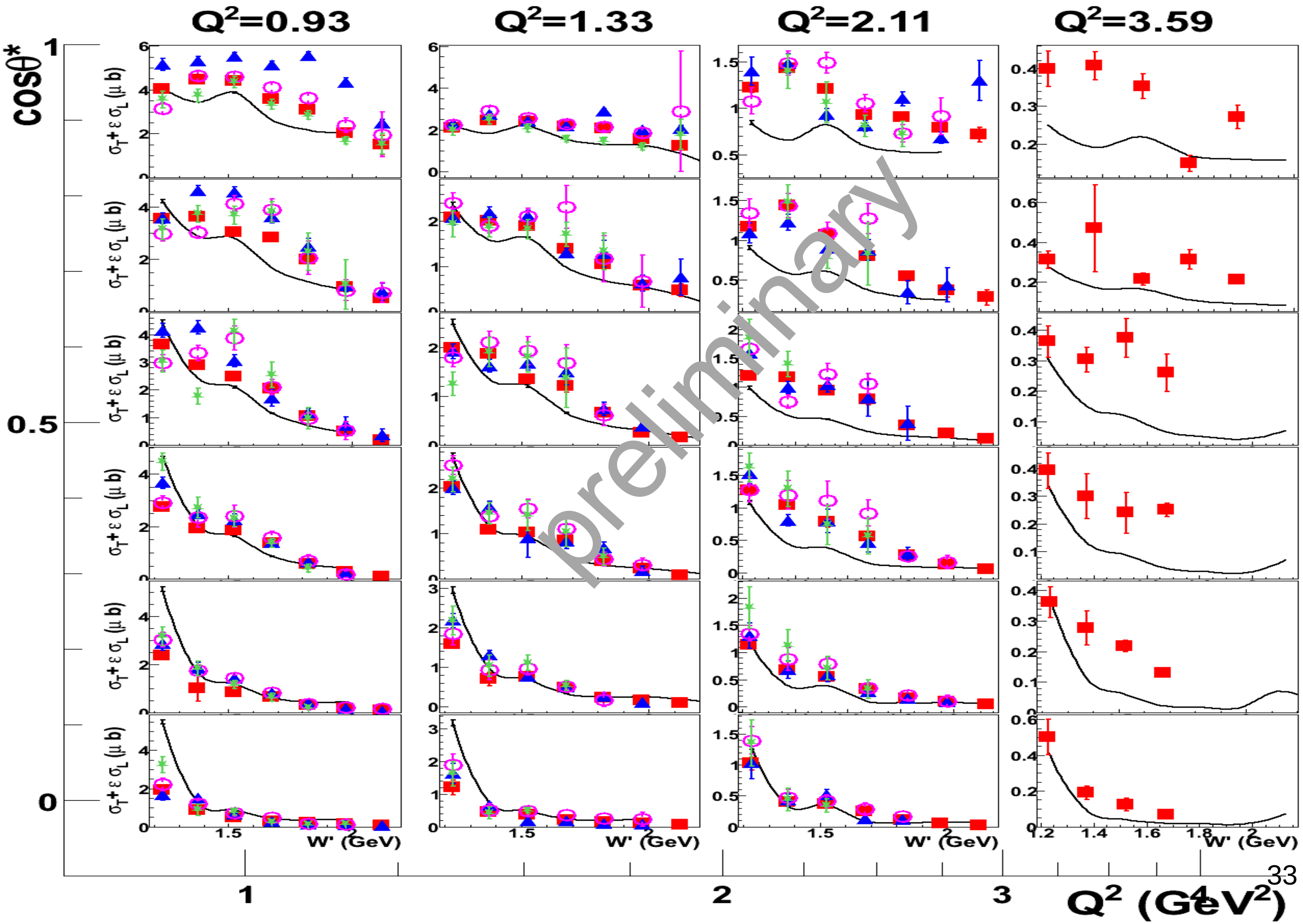
5 GeV, W` = 1.525 GeV



VIP = 70<p_s<120 MeV/c, and θ_{pq}>100°

FSI + Binding < 20% under VIP cut

A_0: BoNuS Vs MAID, 4 GeV with VIP cut



Summary and Outlook

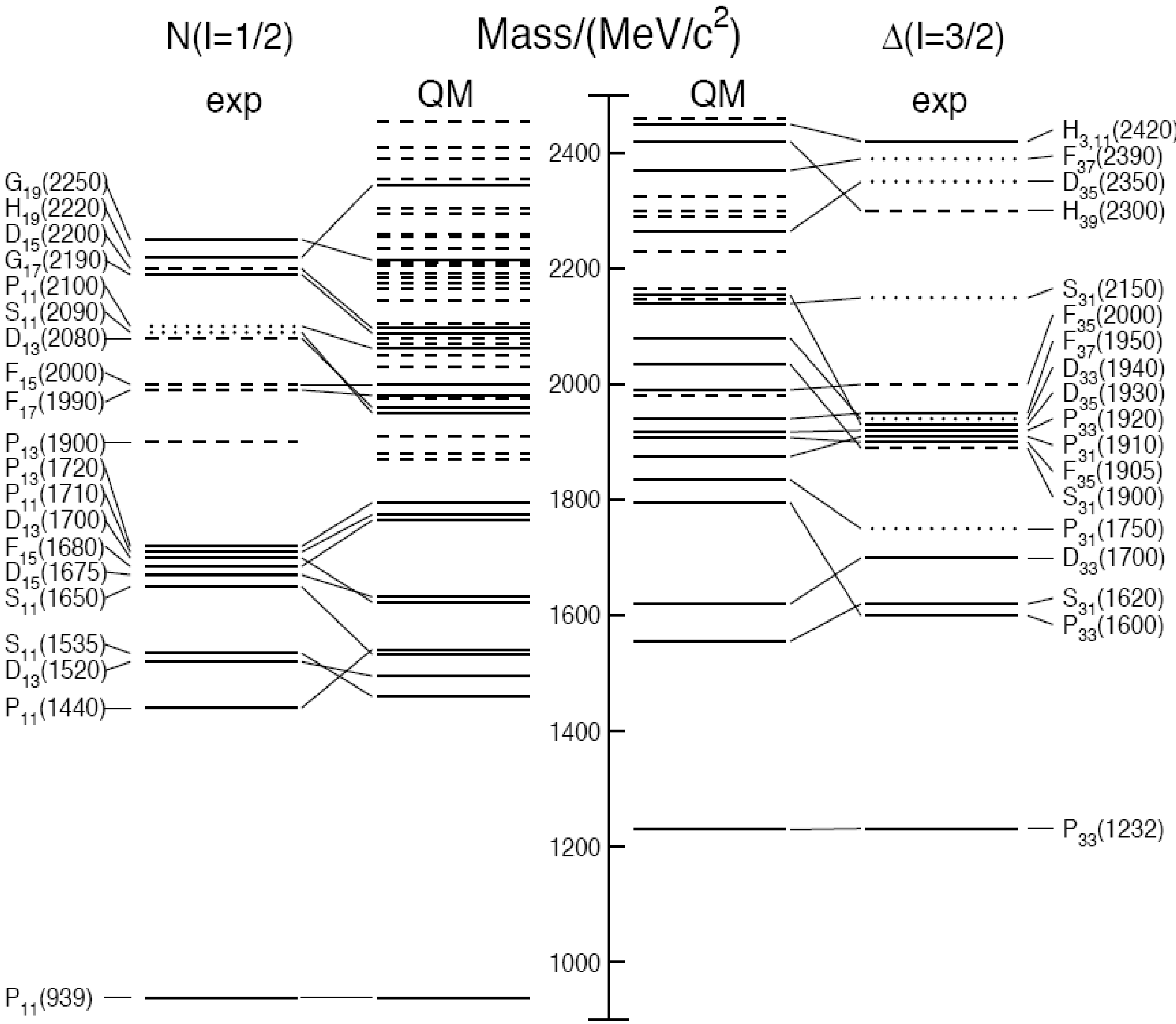
- Measured absolute cross sections for $D(e,e'\pi^{-}p)p$ reaction over a wide kinematic range, $1.1<W`<2.8$ GeV, $0.13<Q^2<4.5$ GeV^2, full range of $\cos\theta^*$ and ϕ^*.
- We see qualitative consistency in most bins between our results and model predictions.
- In most bins, the p_{RTPC} and p_{CLAS} channels are consistent.
- Huge increase in available data points (about 5000) for $\gamma^* n \rightarrow \pi^- p$. Currently only ~900 points available in the world database. BoNuS data will be used to improve our understanding of neutron structure, as part of fits to world data (SAID, MAID…).
- Systematic error is about 15%.
- Include the FSI correction in future.
- Plan to repeat this analysis using other deuteron data, i.e. CLAS E6 data.

Backup Slices

Motivation

- Purpose: In order to understand the structure of the nucleon (neutron and proton) we need to study the excited states (resonances).
- We have a lot of data on the proton but almost nothing on the neutron – both are needed for a complete understanding.
- Strategy is to use pion production: $\gamma^* + n \rightarrow p\ \pi^-$
- We have some real photon data, almost no electroproduction (virtual photon)
- Difficulty: No free neutron target, need to use deuteron instead.

Resonances predicted by Quark Model vs. experimental measurements



Full lines: tentative assignment to observed states

Dashed lines: so far no observed counterparts.

From http://pdg.lbl.gov/2009/reviews/rpp2009-rev-quark-model.pdf

Resonances

6 families, depending on quark content (Isospin):

N*(1/2), Δ(3/2), Λ(0), Σ(1), Ξ(1/2), Ω(0)

Heisenberg Uncertainty Principle:

$$\Delta x \Delta p \geq \frac{\hbar}{2}$$

short life time → wide energy

$$\Delta A \Delta B \geq \left| \frac{\langle [A,B] \rangle}{2i} \right|$$

Measured from the decay products

N*, Δ Resonance, combination of u and d only

Notation: $\mathbf{L_{2I2J}}$

L: orbital angular momentum

I: Isospin

J: total angular momentum J = L+S

S,P,D,F,G,H → L= 0,1,2,3,4,5

γ+N → π + N

I=1 I=1/2

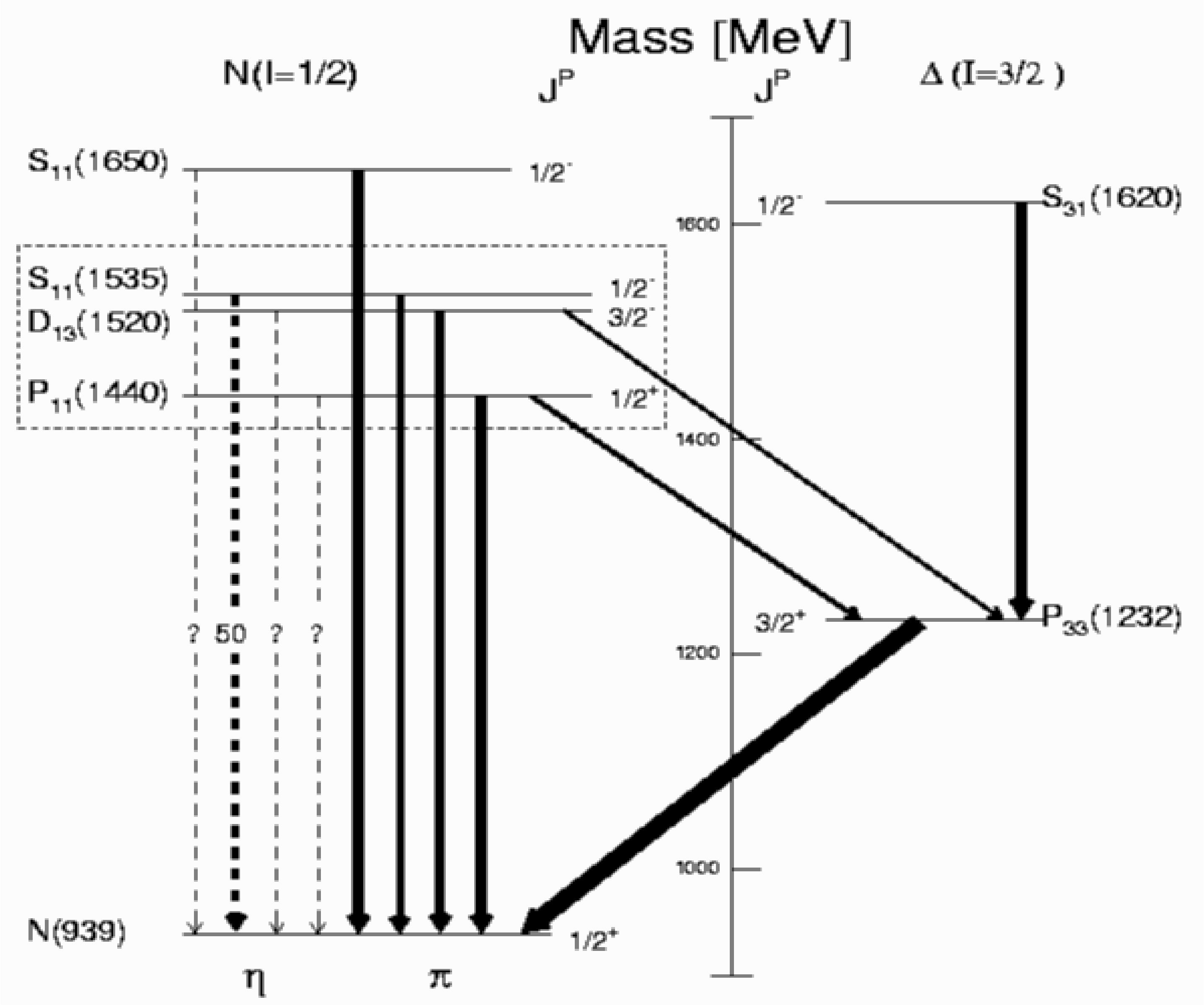
Possible for both N and Δ

γ+N → η + N

I=0 I=1/2

Possible for N not Δ

Resonances examples



Exclusive π^- Cross Section

$$\frac{\partial^5\sigma}{\partial E'\partial\Omega_e\partial\Omega_\pi^*} = \Gamma_v \cdot \frac{\partial^2\sigma}{\partial\Omega_\pi^*}$$

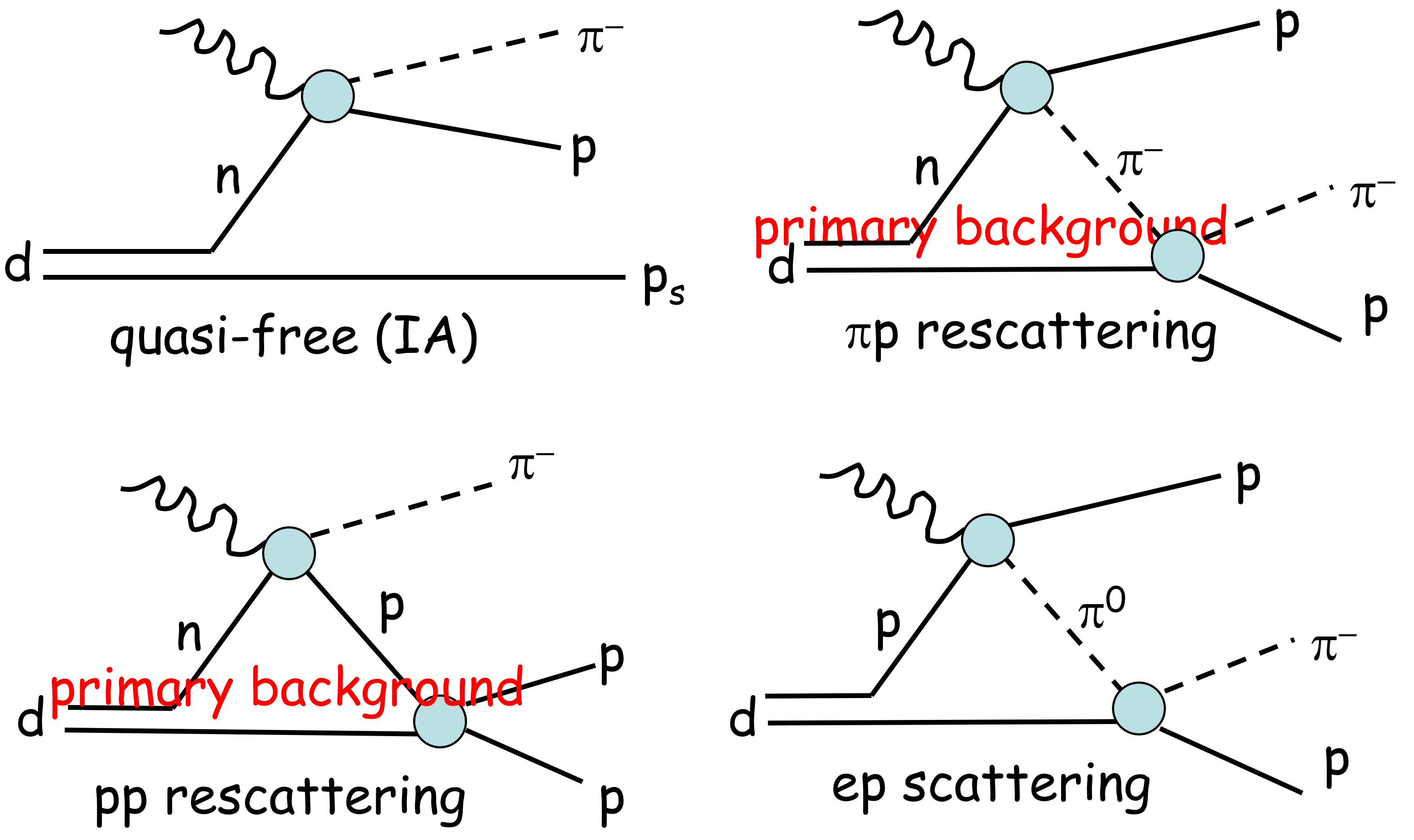
$$\Gamma_v = \frac{\alpha}{2\pi^2}\,\frac{E'}{E}\,\frac{K_\gamma}{Q^2}\,\frac{1}{1-\varepsilon}\quad , \qquad K_\gamma = (W^2 - M_n^2)/2M_n$$

$$\frac{\partial^2\sigma}{\partial\Omega_\pi^*} = \sigma_T + \varepsilon\sigma_L + \sqrt{2\varepsilon(1+\varepsilon)}\sigma_{LT}cos\phi_\pi^* + \varepsilon\sigma_{TT}cos2\phi_\pi^*$$

Unpolarized virtual photon cross-section of $\gamma^*+n \rightarrow \pi^-+p$

Degree of transverse polarization: $\varepsilon = (1 + \frac{2|\overrightarrow{\mathbf{q}}|^2}{Q^2}tan^2\frac{\theta_e}{2})^{-1}$

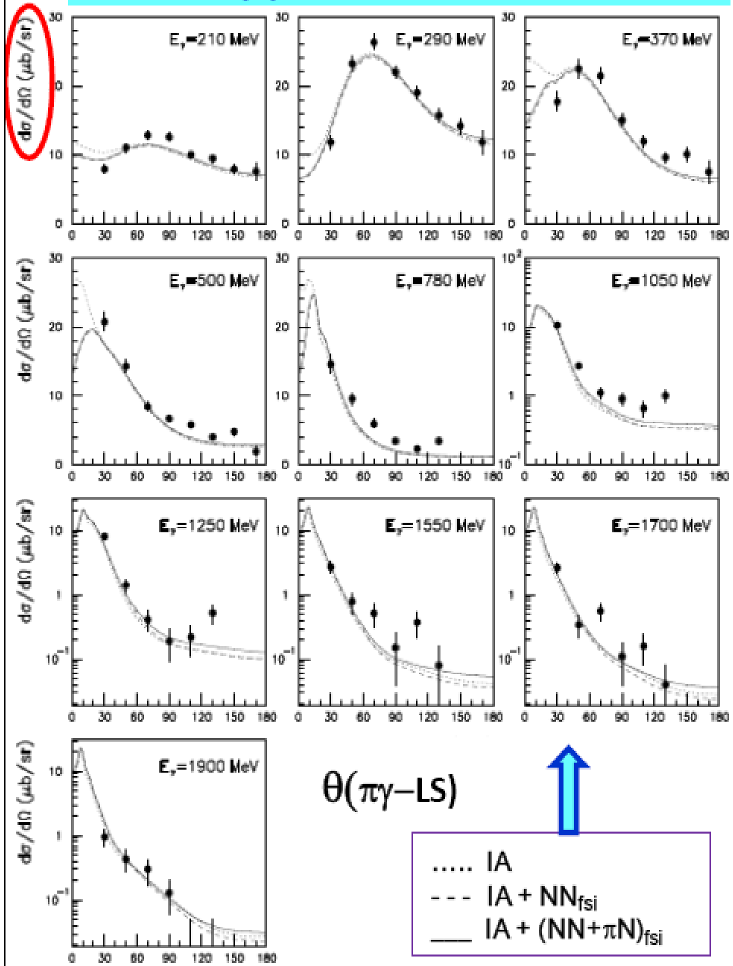
Final State Interations



FSI & $\gamma d \rightarrow \pi^- pp \Longrightarrow \gamma n \rightarrow \pi^- p$

[V. Tarasov, A. Kudryavtsev, W. Briscoe, H. Gao, IS, arXiv: 1105.0225]

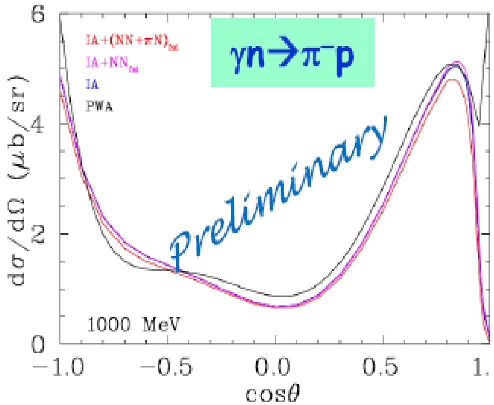
$\gamma d \rightarrow \pi^- pp$ – No fit to the data



$\theta(\pi\gamma\text{–LS})$

..... IA
- - - IA + NN_{fsi}
—— IA + $(NN+\pi N)_{fsi}$

DESY [Bubble Chamber data]:
P. Benz *ea* Nucl Phys **B65**, 158 (1973)

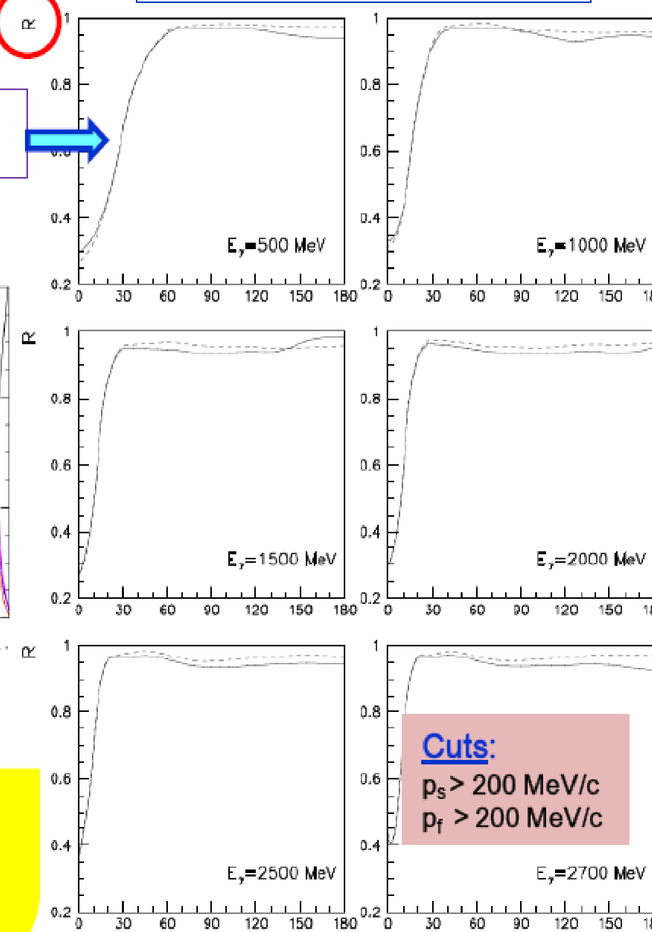


There is a sizeable FSI effect R < 1 from S- wave part of pp-FSI at small angles
This region narrows as the E_γ increases

$\gamma n \rightarrow \pi^- p$

$$R_{FSI} = (d\sigma/d\Omega_{\pi p})/(d\sigma^{IA}/d\Omega_{\pi p})$$

- - - $[IA + NN_{fsi}] / IA$
—— $[IA + (NN+\pi N)_{fsi}] / IA$

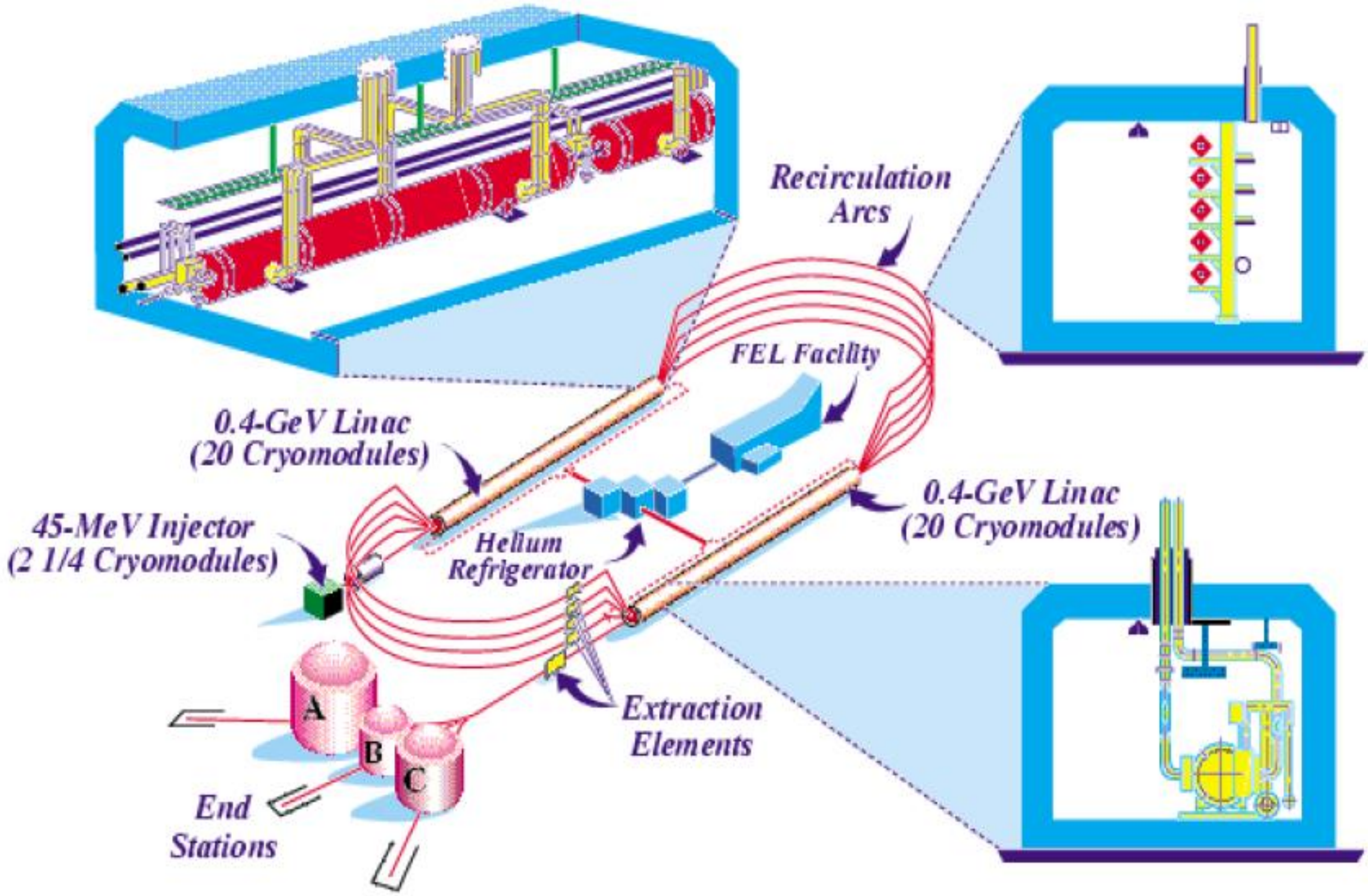


Cuts:
p_s > 200 MeV/c
p_f > 200 MeV/c

$\theta(\pi p\text{–CM})$

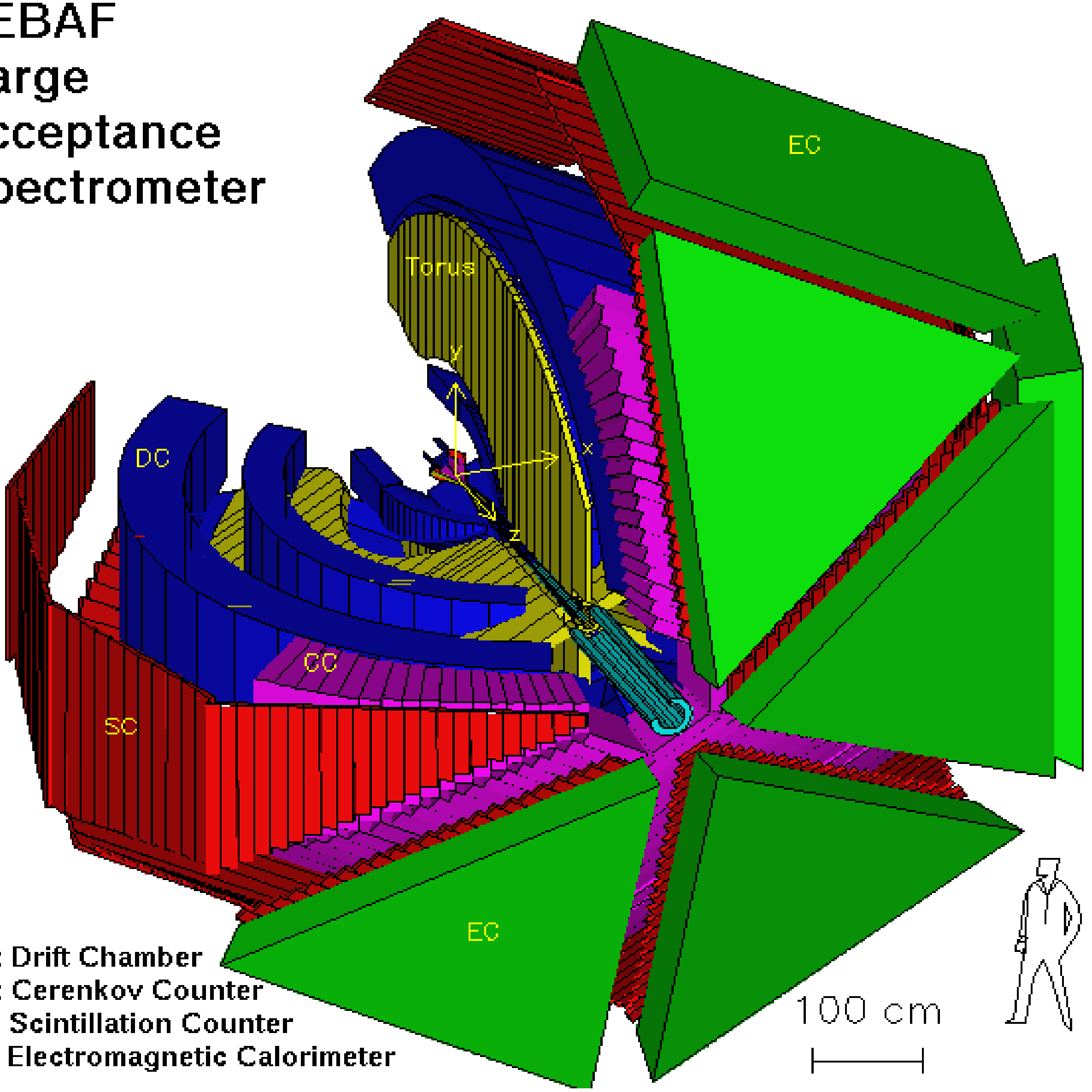
Fermi motion included

Continuous Electron Beam Accelerator Facility (CEBAF)



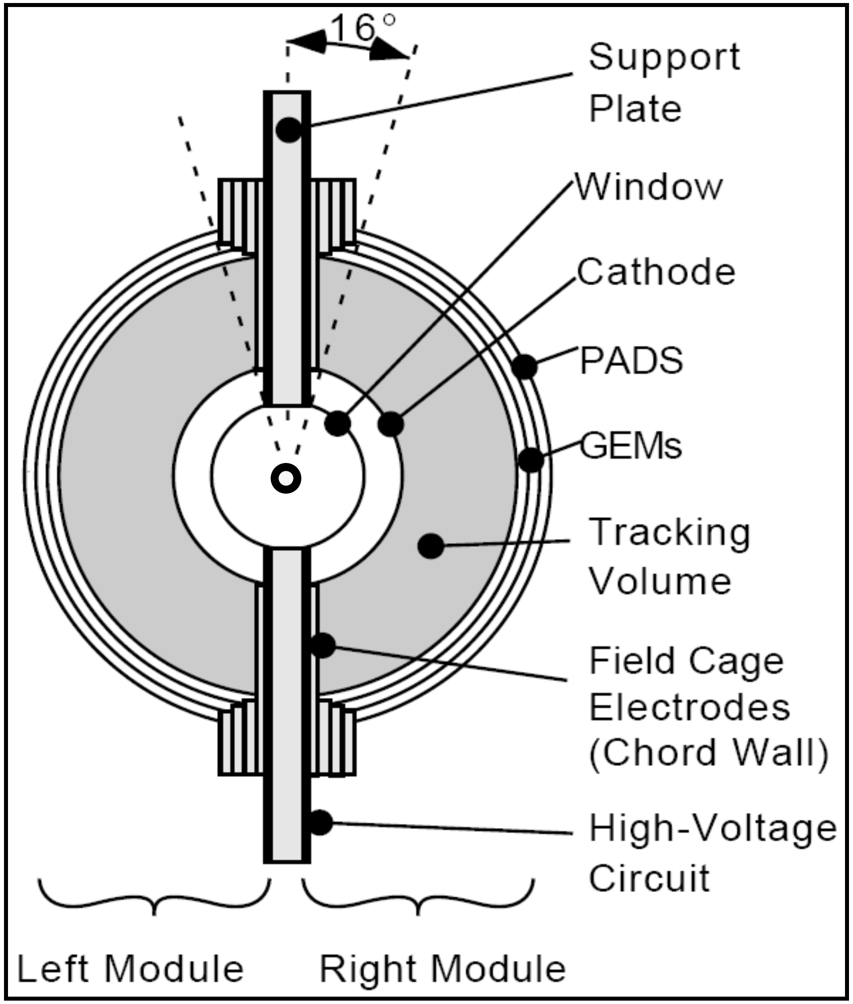
CLAS in Jefferson Lab, Hall B

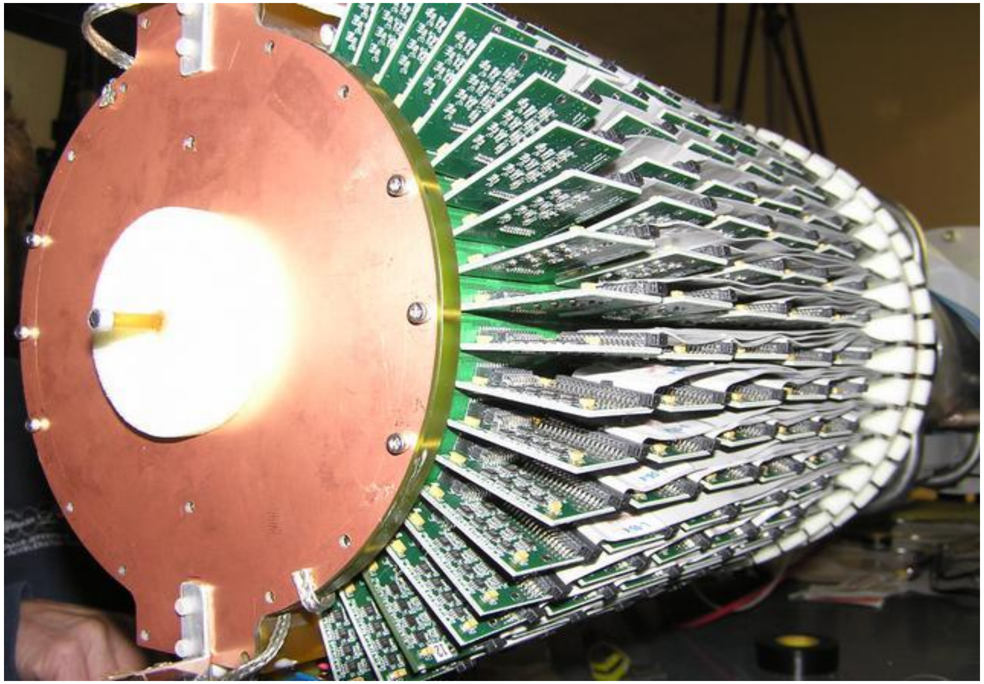
CEBAF
Large
Acceptance
Spectrometer



DC: Drift Chamber
CC: Cerenkov Counter
SC: Scintillation Counter
EC: Electromagnetic Calorimeter

Radial Time Projection Chamber (RTPC)

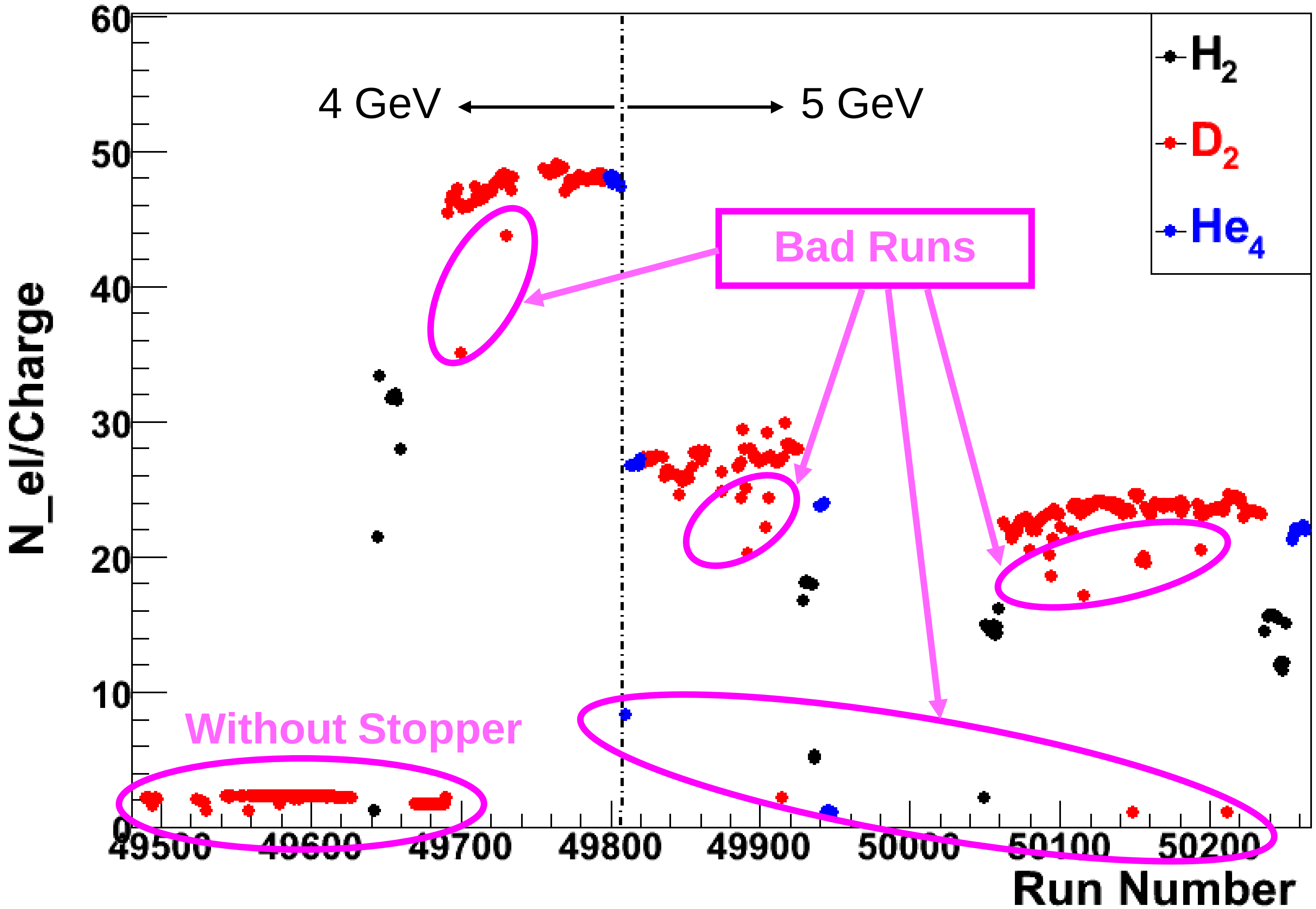




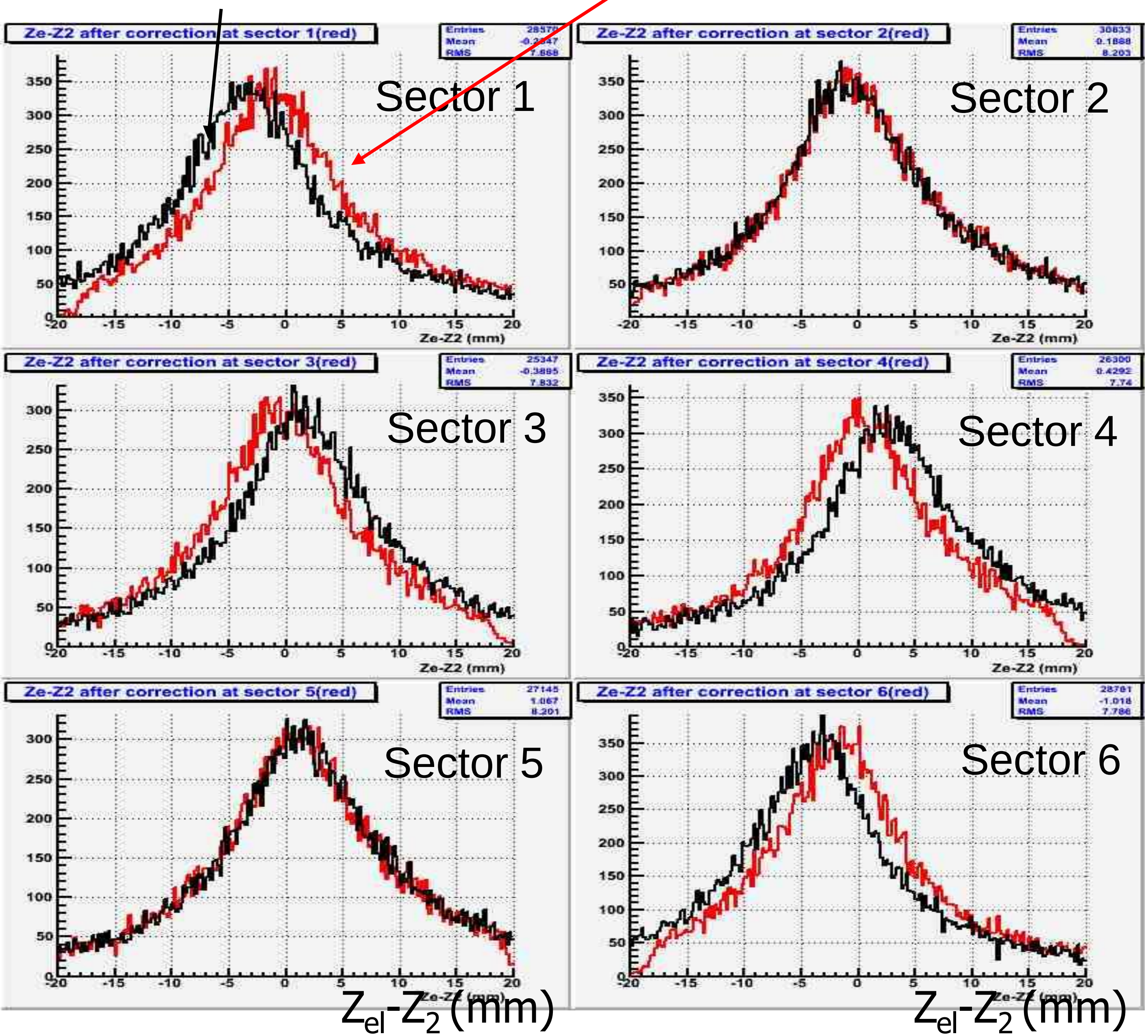
Analysis Procedure

1. Quality Checks
2. Vertex correction and cuts
3. Particle identification (electron, π^- and proton)
4. Fiducial cut for trigger electron, π^- and protons
5. Energy loss correction
6. Exclusive cut (Missing Mass cut)
7. Acceptance correction
8. Background subtraction
9. Radiation correction
10. Particle detection efficiency for e^-, proton and RTPC proton
11. Extract cross section and structure functions

Run Selection: Quality Checks

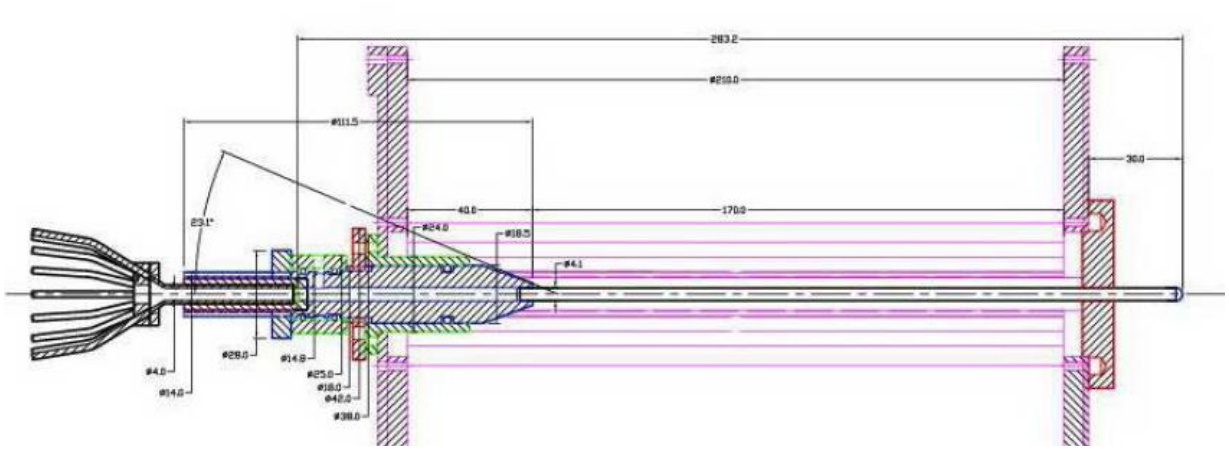


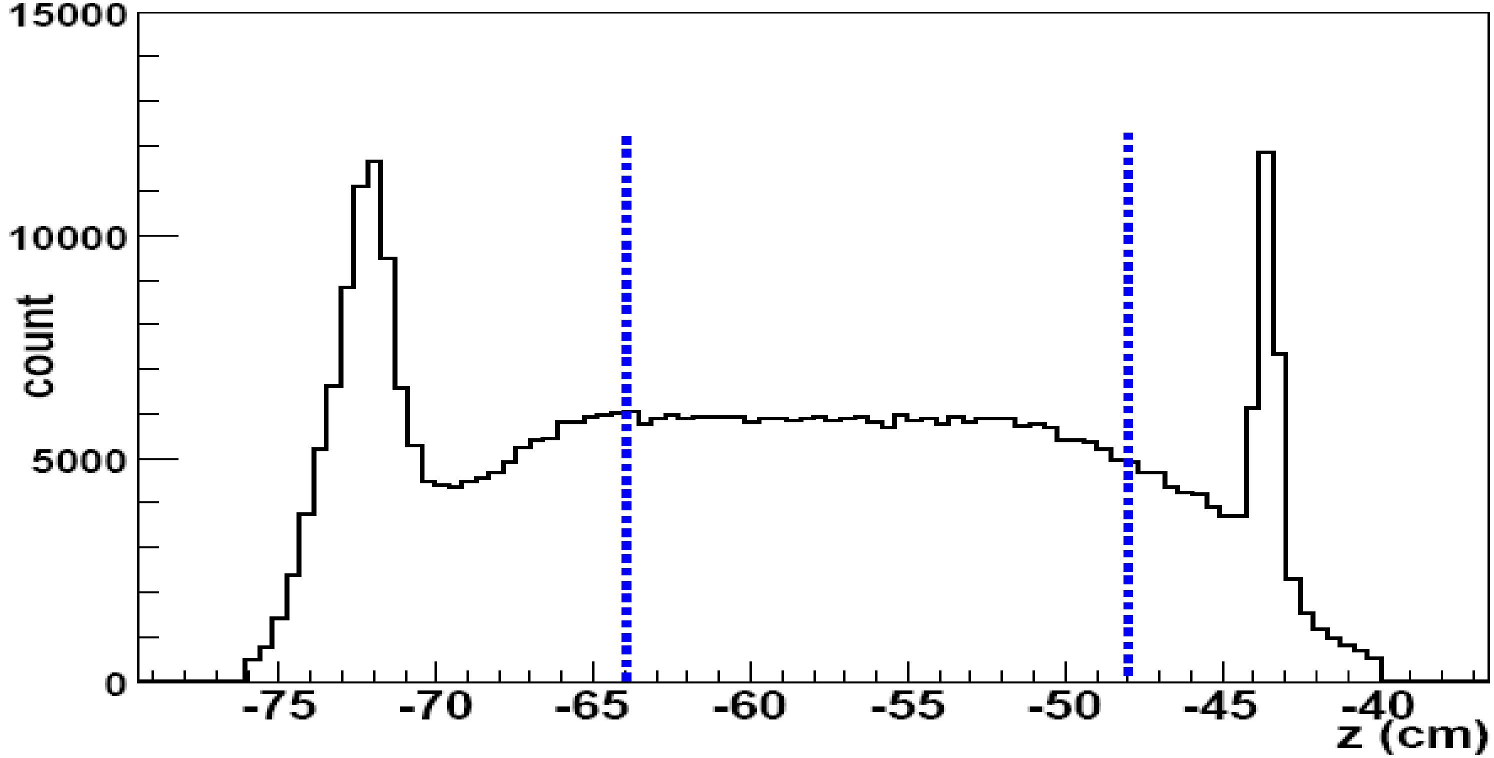
Before and After Vertex Correction



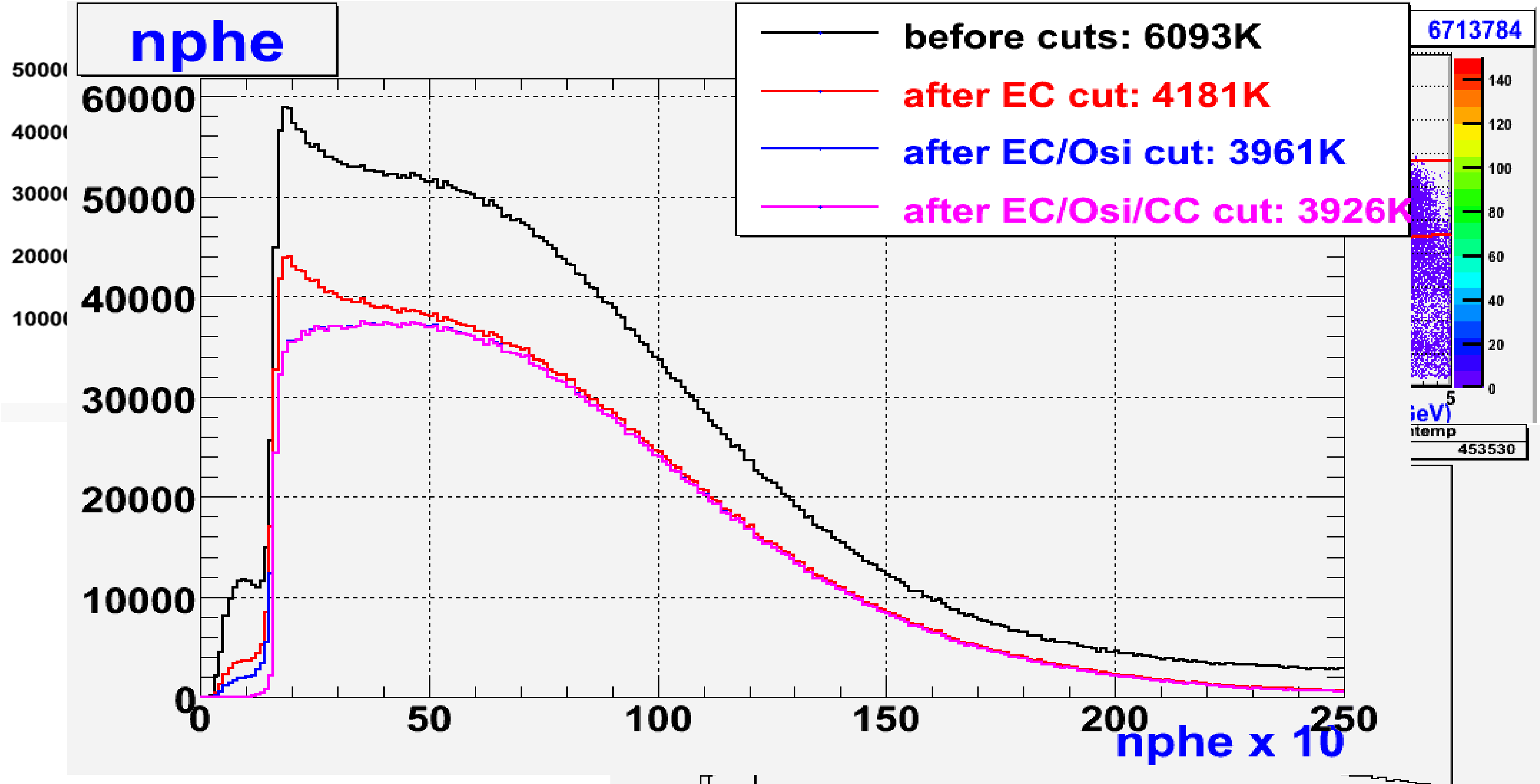
Using real data, find the best beam position to minimize the vertex difference among coincident particles

Vertex Cut





Electron Identification



1. Negative charge.
2. Number of photo electrons (Nphe) > 1.5
3. E_inner > 0.06 and 0.016*P+0.15 < E_total/P < 0.34
4. Pass Osipenko cut (geometry matching between SC and CC)

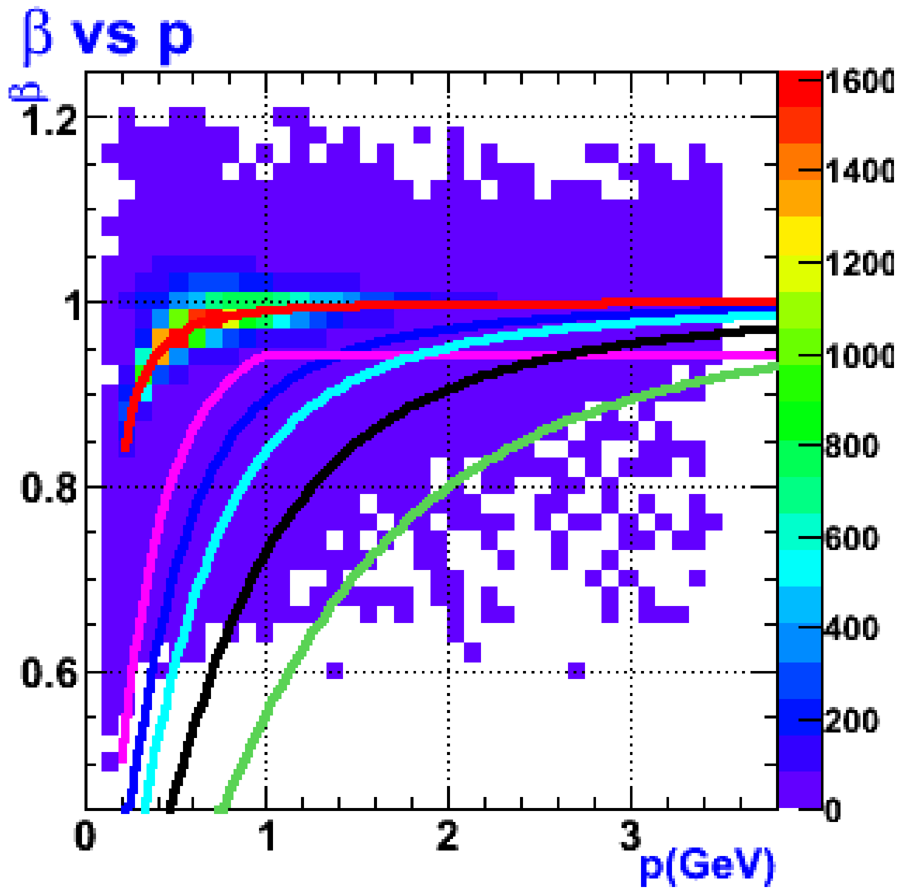
CLAS Particle Identifications

Negative non-trigger particles:

(1) β above purple curve π^-

(2) Among the rest, β between purple and light blue curve K^-

(3) Among the rest, β below light blue curve anti-proton



Positive particles:

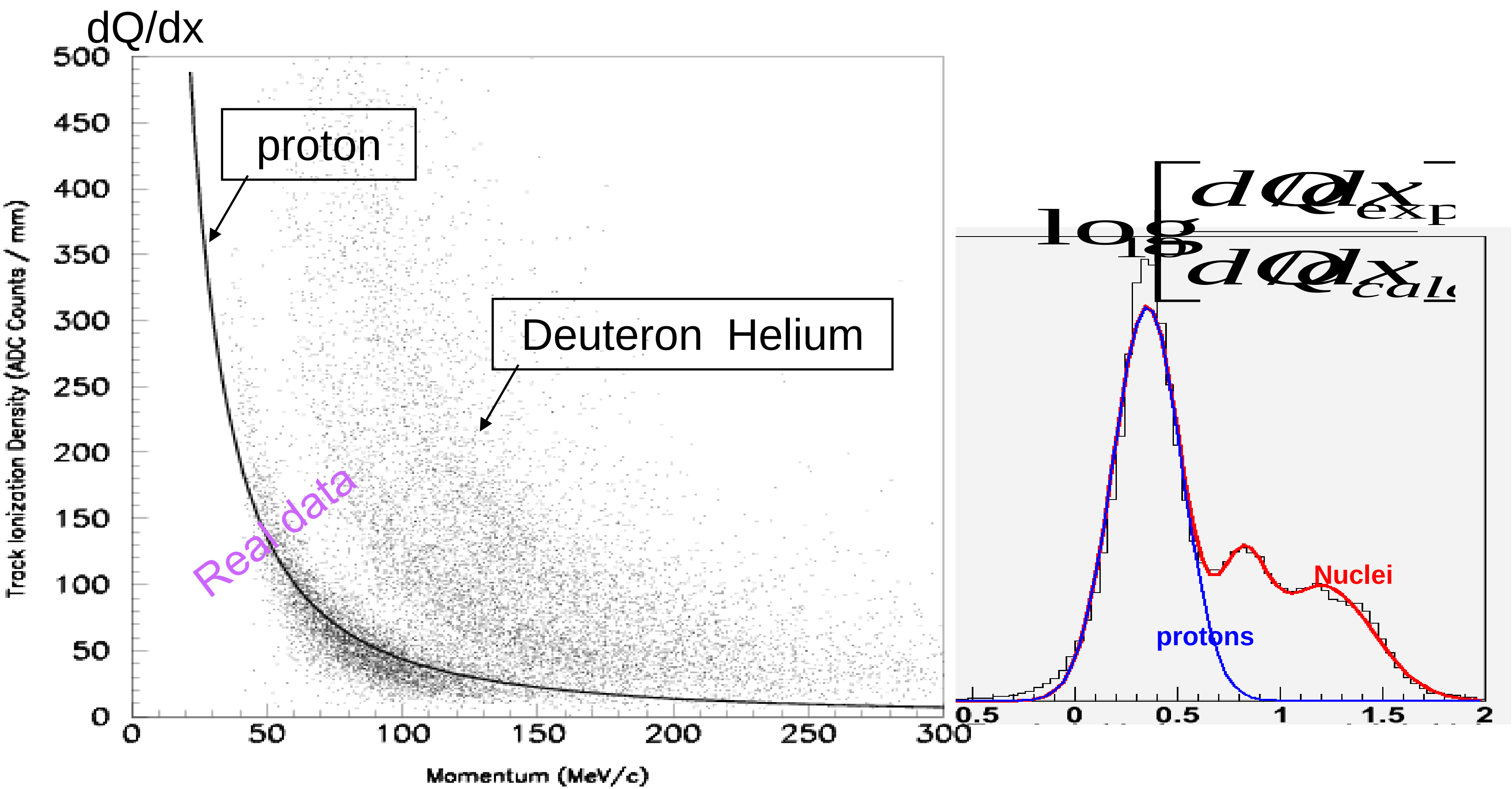
(1) β between light blue and green curve proton

(2) β below green curve Deuteron

(3) Among the rest, β above purple curve π^+

(4) Among the rest, β between purple and light blue curve K^+

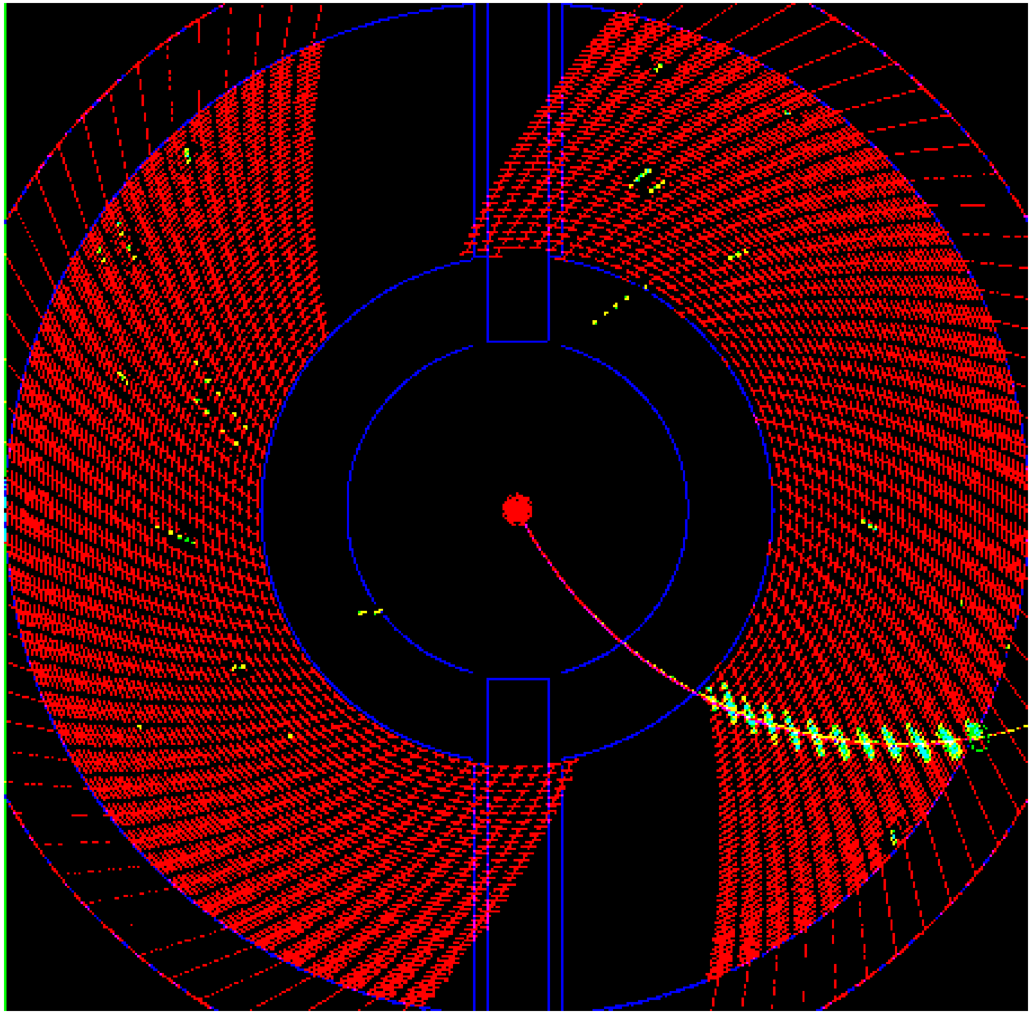
RTPC Proton Identification



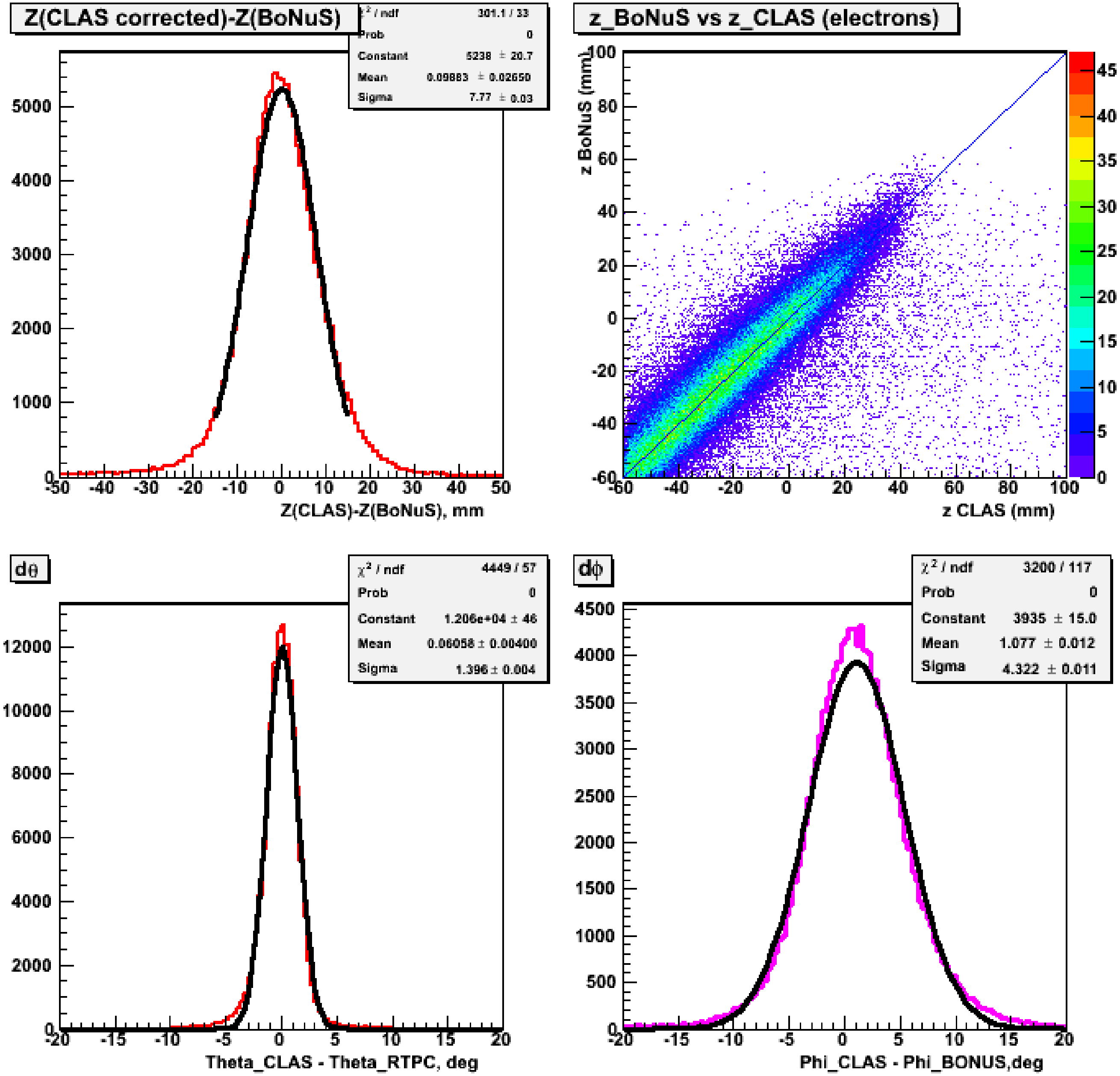
The Drift Path of An Ionized Electron

A MAGBOLTZ simulation of the crossed E and B fields, together with the drift gas mixture, determines the drift path and the drift velocity of the electrons.

- The red lines show the drift path of each ionization electron that would appear on a given channel.
- In green is the spatial reconstruction of where the ionization took place.
- In reconstruction, hits which are close to each other in space are linked together and fit to a helical trajectory.
- This resulting helix tells us the vertex position and the initial three momentum of the particle.



RTPC Drift Velocity Calibration



H. Fenker, et.al.
Nucl.Instrum.Meth. A592:273-286,2008

Trigger electrons measured by CLAS are compared to the same electrons measured in BoNuS during High Gain Calibration runs.

The drift velocity parameters are chosen which best improve the centroid and width of the dz, dθ, and dϕ distributions.

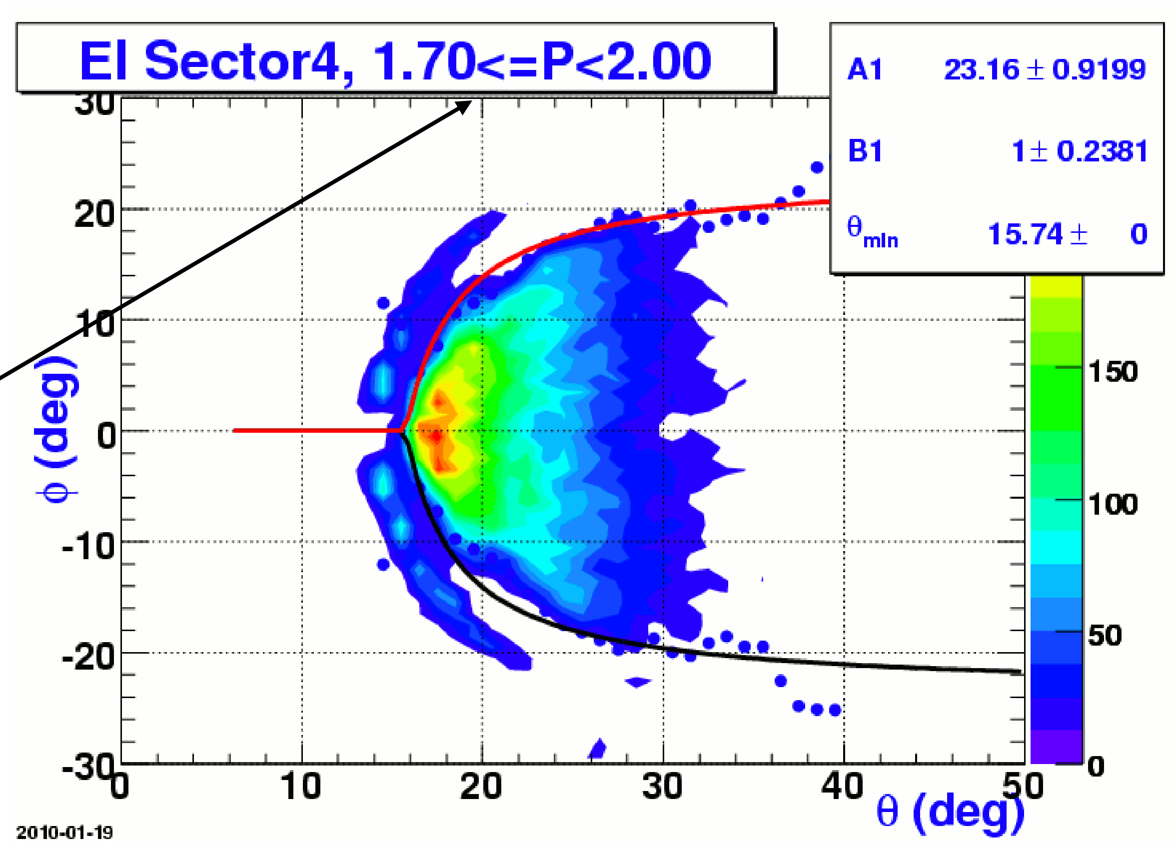
Fiducial Cut Fitting Function

$$\phi^{s}_{dc1} = (\phi_{dc1}) - 60 \times (sector - 1)$$

Fitting function: $$\phi^{s}_{dc1}(\theta_{dc1}) = a[1.0 - (1.0 + \lambda(\theta_{dc1} - c)^{b})^{-1}]$$

Fiducial cut is the geometry cut which is used to remove inefficiency part of the detector.

Momentum dependent

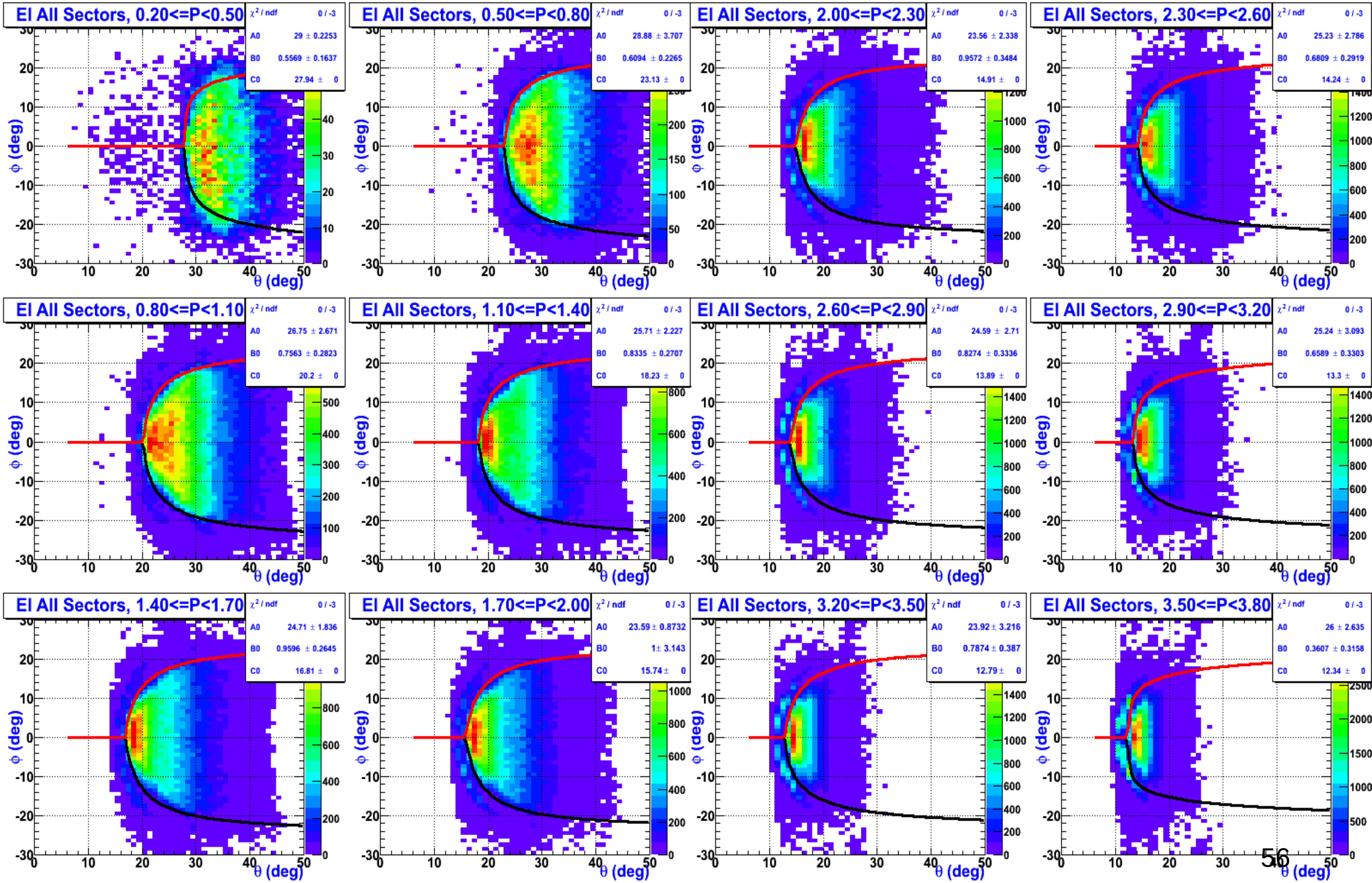


Electron: λ = 0.35,

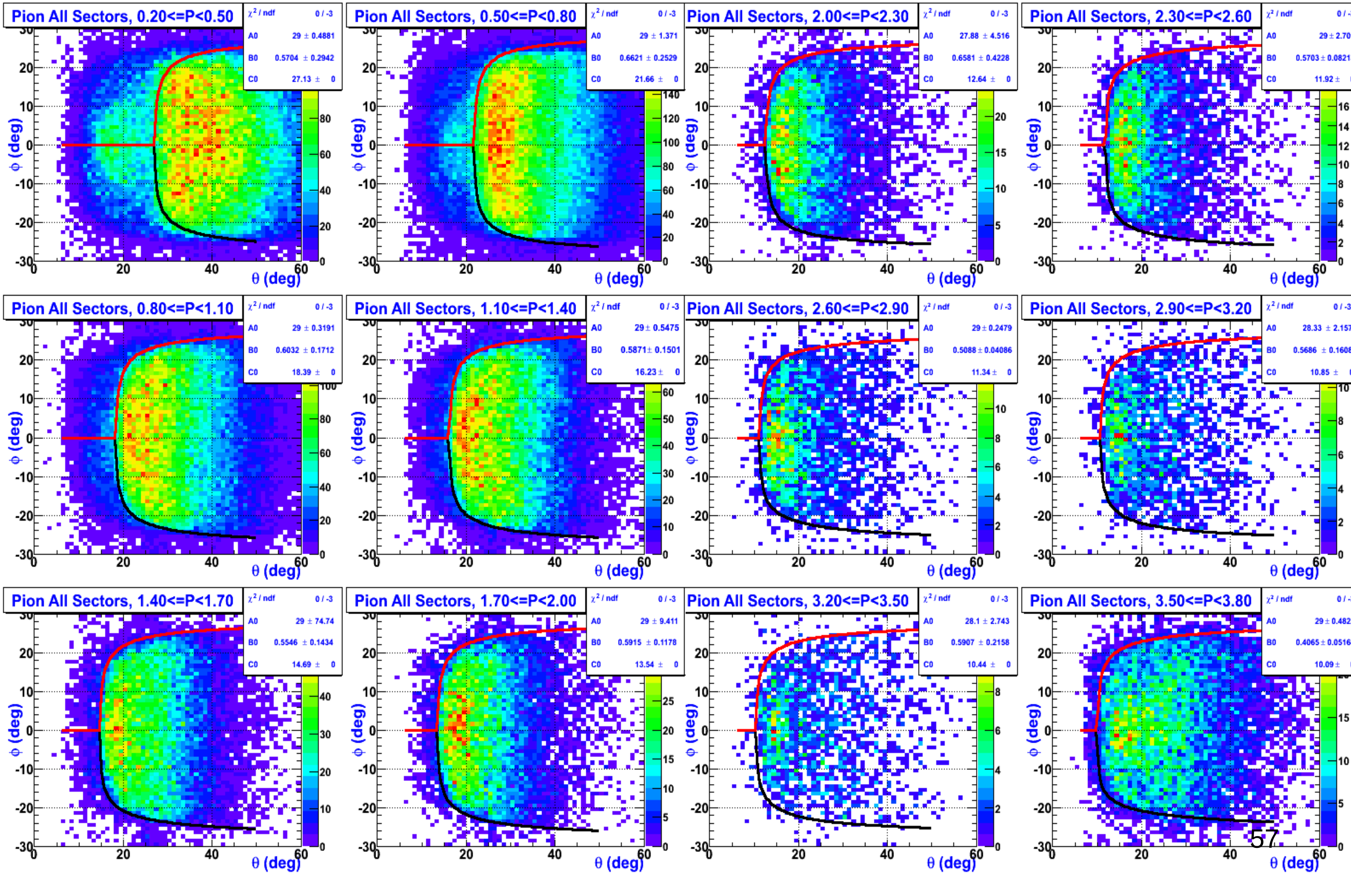
Pion: λ = 1.0

Ptoton : λ = 3.0

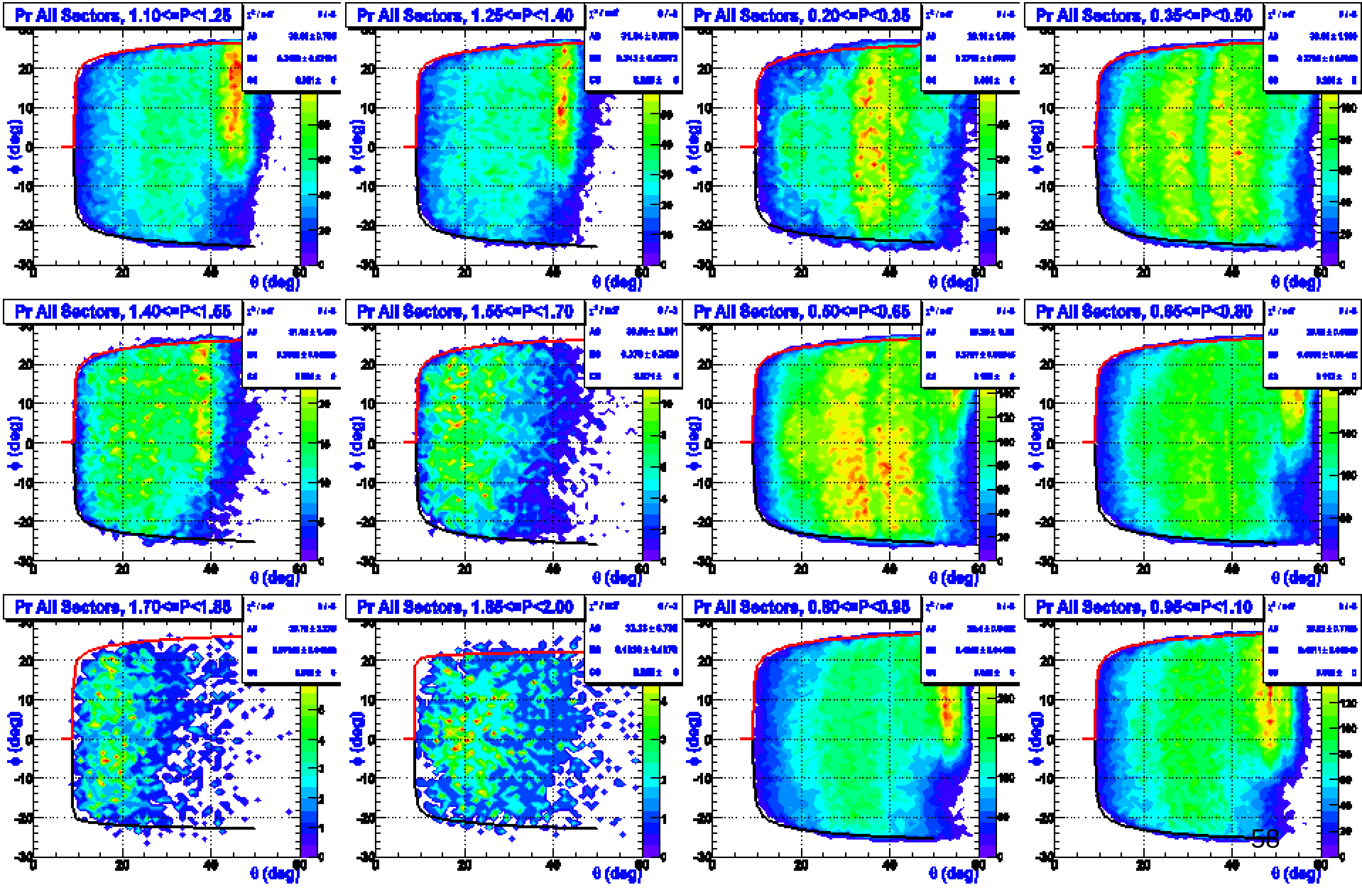
New Fiducial cut for e^-



Fiducial cut for π^-



Fiducial cut for proton



Exclusive π^- Events Selection

1. Select good trigger (scattered electron)
   q<0 ,
   CC + Osipenko (CC geometry match cut)
   EC (Ein>0.06, without Etot/p Cut)
   Theta_Z_Cut
2. Vertex Z correlation cut
   |z_el –Z_i| < 2.71 cm, i could be π^-, fast proton or RTPC proton.
3. Identify the π^-, if not found, use a negative non-trigger particle as π^-
4. Identify protons, if not found, use a positive particle as proton
5. Apply vertex and energy loss corrections
6. Apply 2-σ missing mass cut

$D(e,e'\pi^- p)p$ Acceptance Correction

- Binning information:

  W': 150 MeV each bin, [1.15,3.10);

  Q^2 : 6 bins, {0.1309, 0.3790, 0.7697, 1.0969, 1.5632, 2.6594, 4.5243 };

  $\cos\theta^*$: 8 bins, 0.25 each bin, [-1.0,1.0);

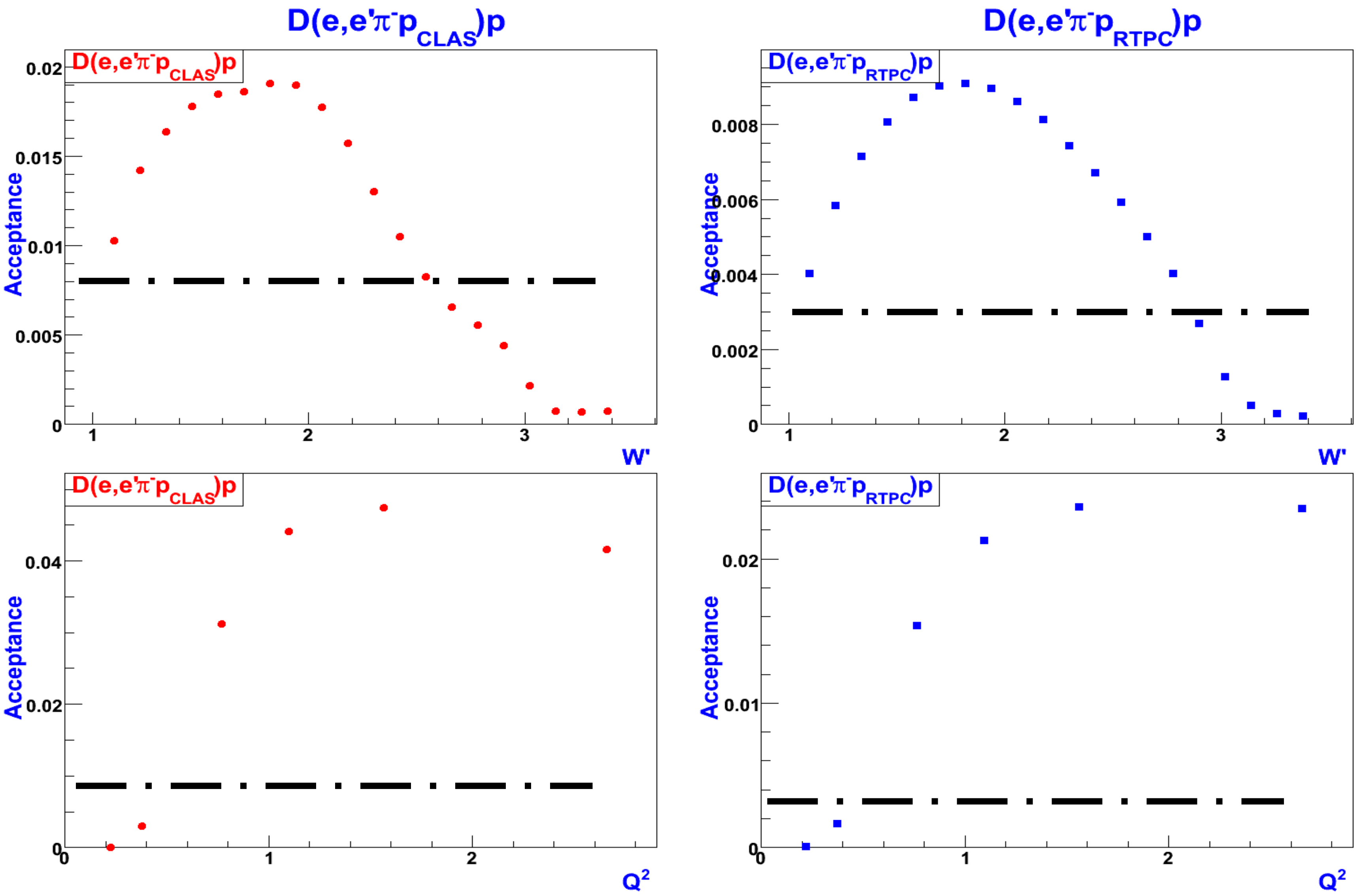
  ϕ^*: 15 bins, 24 degrees each bin, [0.0,360.0).

- Acceptance is the ratio of the number of events detected in a given bin to the number of generated events in the same bin.
- Need to generate tables for $D(e,e'\pi^- p_{RTPC})p$ and $D(e,e'\pi^- p_{CLAS})p$ reaction separately.
- Applied event by event
- Need to have acceptance cut to ensure the reliabilities

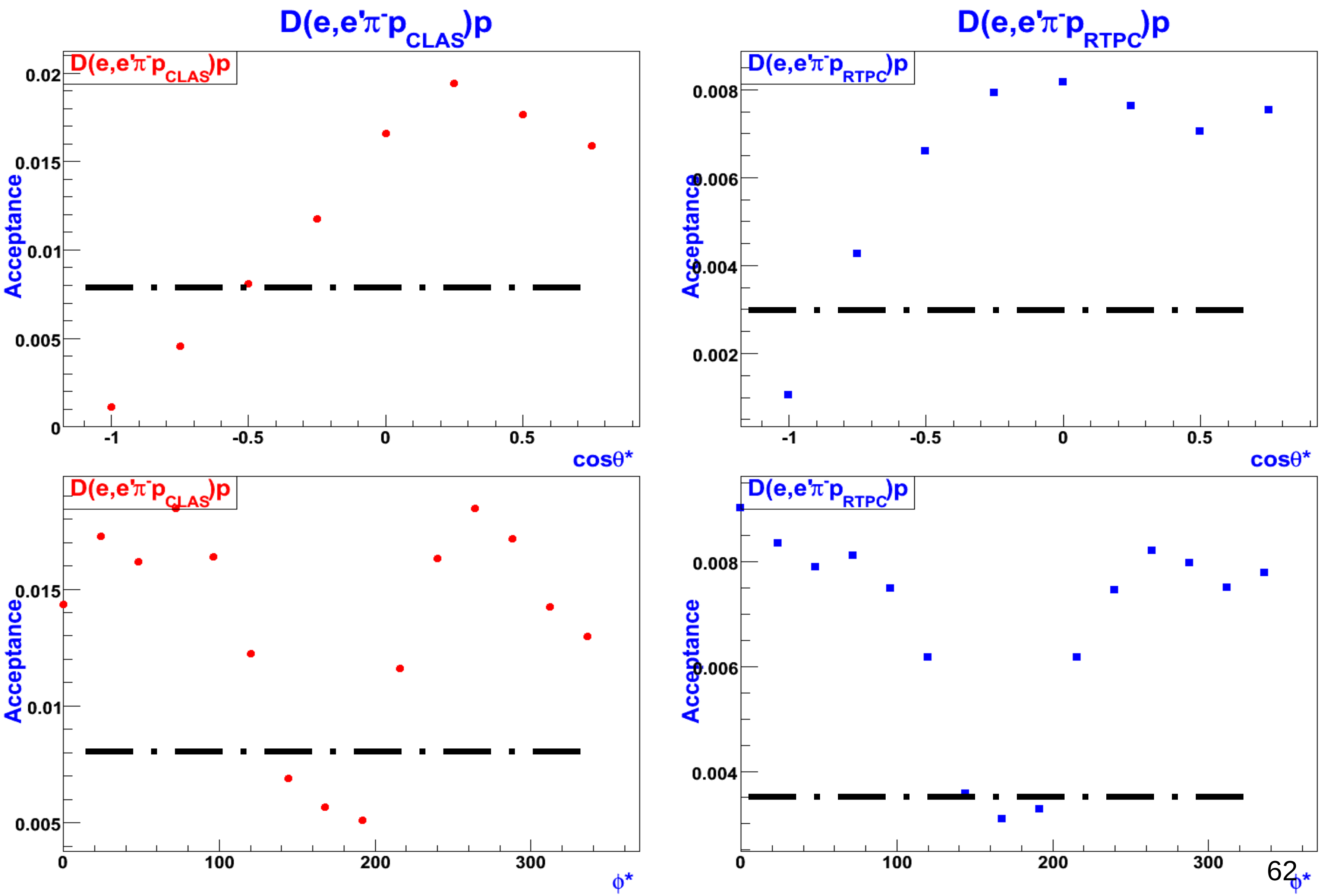
  For CLAS channel: 0.008 and less than 10% uncertainty (> 100 detected events)

  For RTPC channel: 0.003 and less than 15% uncertainty (> 40 detected events)

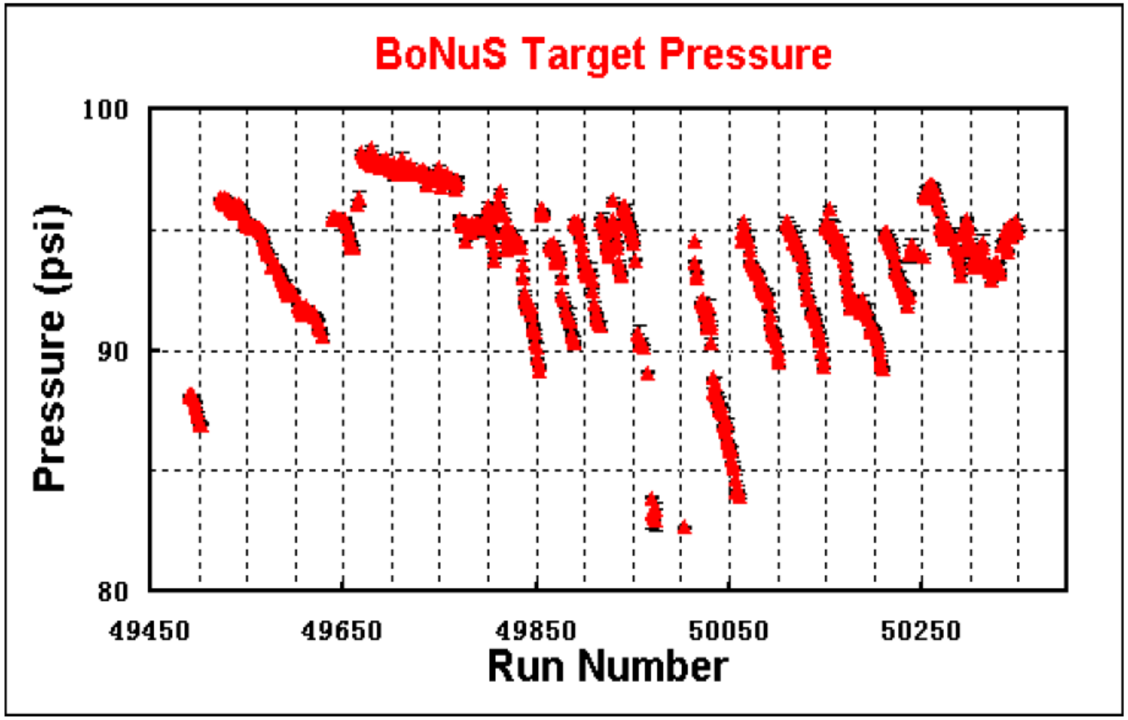
Acceptance Correction, E=5.3 GeV



Acceptance Correction, E=5.3 GeV



Target Thickness



Target	Beam(GeV)	P_{eff} (psi)
H_2	1.X	95.350
D_2	1.X	96.041
H_2	2.X	95.156
D_2	2.X	95.104
He	2.X	95.721
H_2	4.X	95.542
D_2	4.X	95.874
He	4.X	95.596
H_2	5.X	92.531
D_2	5.X	93.635
He	5.X	96.693

Calculate the effective target pressure, P_{eff} , for a data set by weighting the pressure of each run with the number of good electrons in that run.

$$P_{eff} = \sum_{run=begin}^{end} \frac{P_{run} N_{run}^{el}}{\sum_{run=begin}^{end} N_{run}^{el}}$$

Time integrated Luminosity

$$L = \frac{N_B \times N_{target}}{A} = \frac{N_B \times 2PVN_A}{ART} = \frac{2N_B P l N_A}{RT}$$

coefficient 2 represent the fact that a deuterium molecular contains 2 atoms;
N_B is the total number of incident electrons;
P is the effective pressure of the gaseous target;
l is the valid length of the target (l=16.0 cm);
N_A is Avogadro's number (6.022×10^{23});
R is the gaseous constant ($8.314 J \cdot K^{-1} \cdot mol^{-1}$);
T is the effective temperature ($293.0K$).

Beam (GeV)	Luminosity ($10^{34}/\mathrm{cm}^2$)
2.1	10158.4
4.2	59060.0
5.3	113031.0

Cross Section Calculations

1. Select exclusive events
2. Apply corrections: acceptance, trigger, π^-, CLAS proton and RTPC proton efficiency, radiative and background correction.

$$\frac{\partial^5\sigma}{\partial E'\partial\Omega_e\partial\Omega_\pi^*} = \int \Gamma_v dE' d\Omega_e \int \frac{\partial^2\sigma}{\partial\Omega_\pi^*} d\Omega_\pi^*$$

$$\lambda_{CLAS} = \frac{B}{R\cdot\eta_e\cdot\eta_\pi\cdot\eta_p^{r2s}\cdot A};$$

$$\lambda_{RTPC} = \frac{B}{R\cdot\eta_e\cdot\eta_\pi\cdot\eta_{RTPC}^{r2s}\cdot A};$$

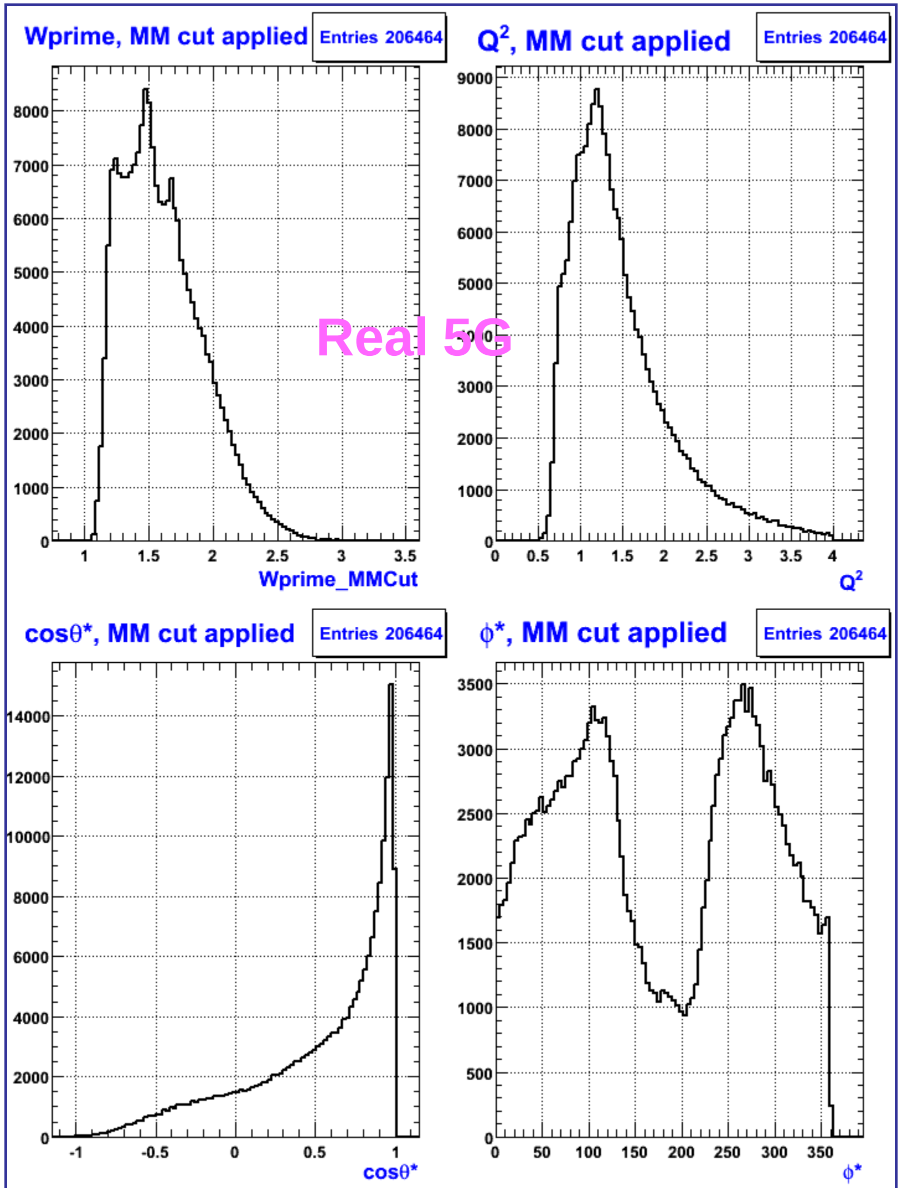
$$\begin{aligned}\tau &= \int \Gamma_v \frac{\pi W'}{EE'M_n} dW' dQ^2 \\ &= \int \frac{\alpha}{2\pi^2}\frac{E'}{E}\frac{W'^2-M_n^2}{2M_nQ^2}\frac{1}{1-\varepsilon}\frac{\pi W'}{EE'M_n} dW' dQ^2 \\ &= \frac{\alpha}{4\pi E^2 M_n^2}\int \frac{(W'^2-M_n^2)W'}{Q^2(1-\varepsilon)} dW' dQ^2 \\ &= \frac{\alpha}{8\pi E^2 M_n^2}\int \frac{W'^2-M_n^2}{Q^2(1-\varepsilon)} dW'^2 dQ^2.\end{aligned}$$

$$\sum_{events}(1\cdot\lambda) = L\tau\Delta(\cos\theta_\pi^*)\Delta\phi_\pi^*\frac{\partial^2\sigma}{\partial\Omega_\pi^*}$$

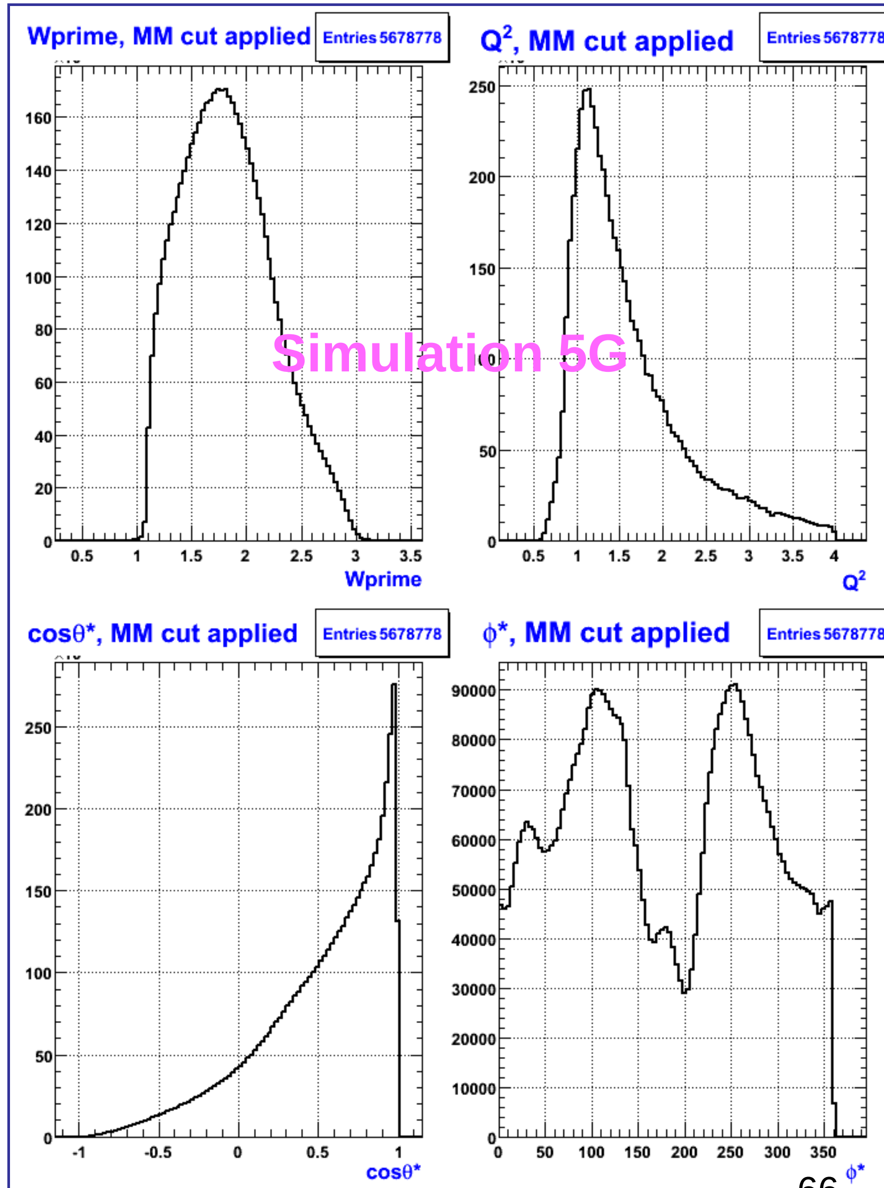
$$\frac{\partial^2\sigma}{\partial\Omega_\pi^*} = \frac{\sum_{events}(1\cdot\lambda)}{L\tau\Delta(\cos\theta_\pi^*)\Delta\phi_\pi^*}.$$

$$L = \frac{N_B\times N_{target}}{A} = \frac{N_B\times 2PVN_A}{ART} = \frac{2N_B P l N_A}{RT}$$

Sim Vs Real

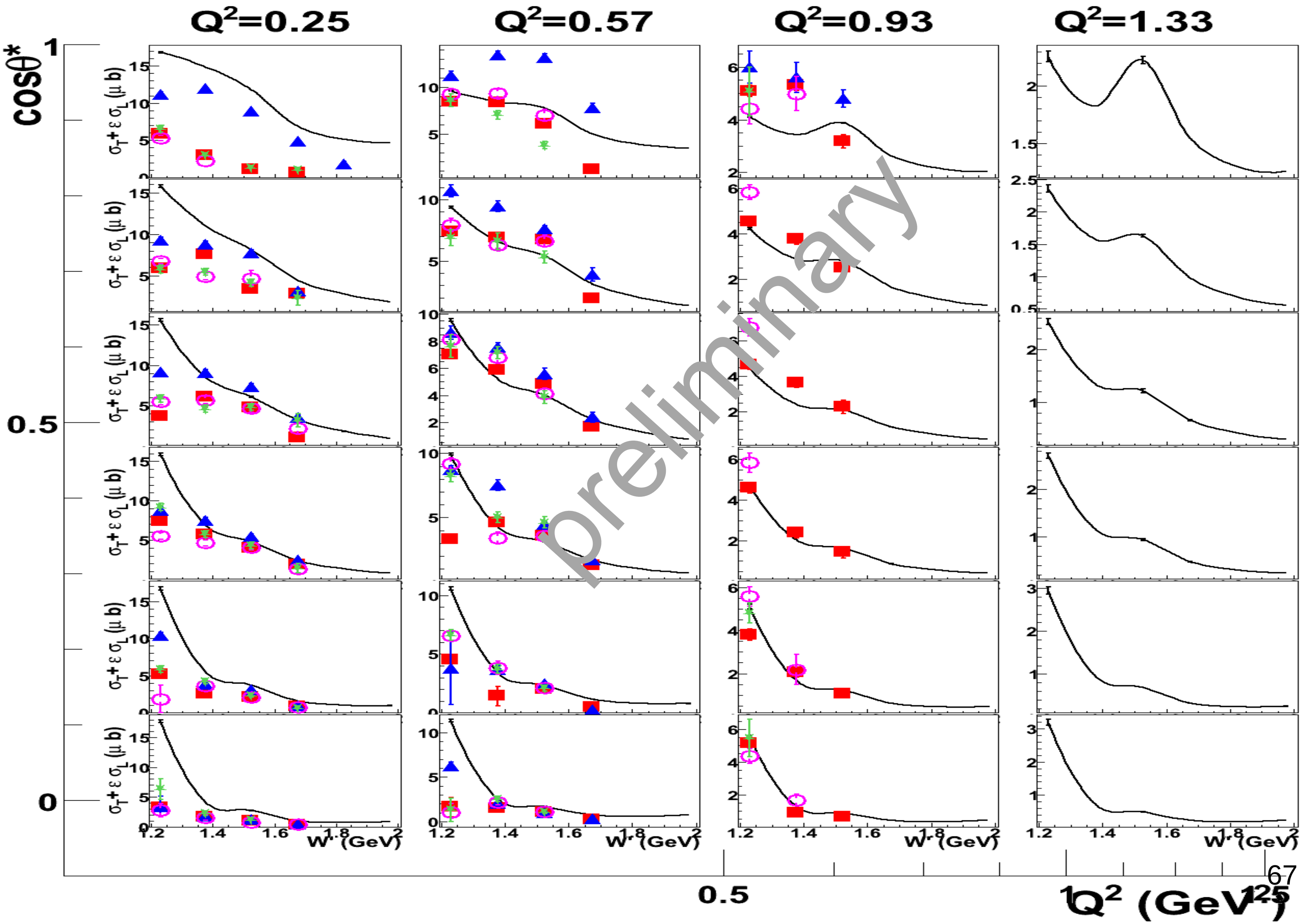


Wprime, MM cut applied
Entries 206464
Wprime_MMCut
Q², MM cut applied
Entries 206464
Q²
Real 5G
cosθ*, MM cut applied
Entries 206464
cosθ*
φ*, MM cut applied
Entries 206464
φ*

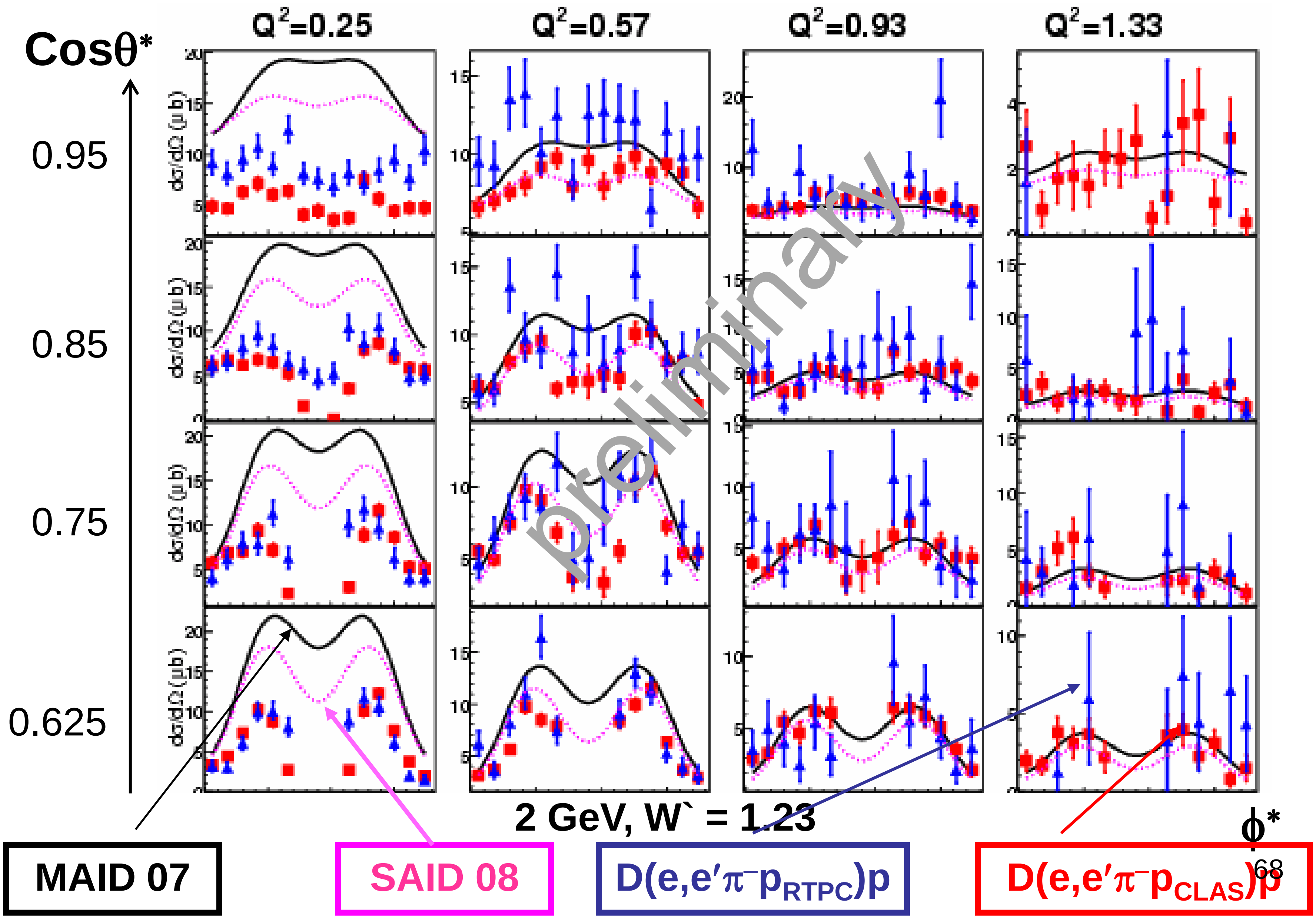


Wprime, MM cut applied
Entries 5678778
Wprime
Q², MM cut applied
Entries 5678778
Q²
Simulation 5G
cosθ*, MM cut applied
Entries 5678778
cosθ*
φ*, MM cut applied
Entries 5678778
φ*

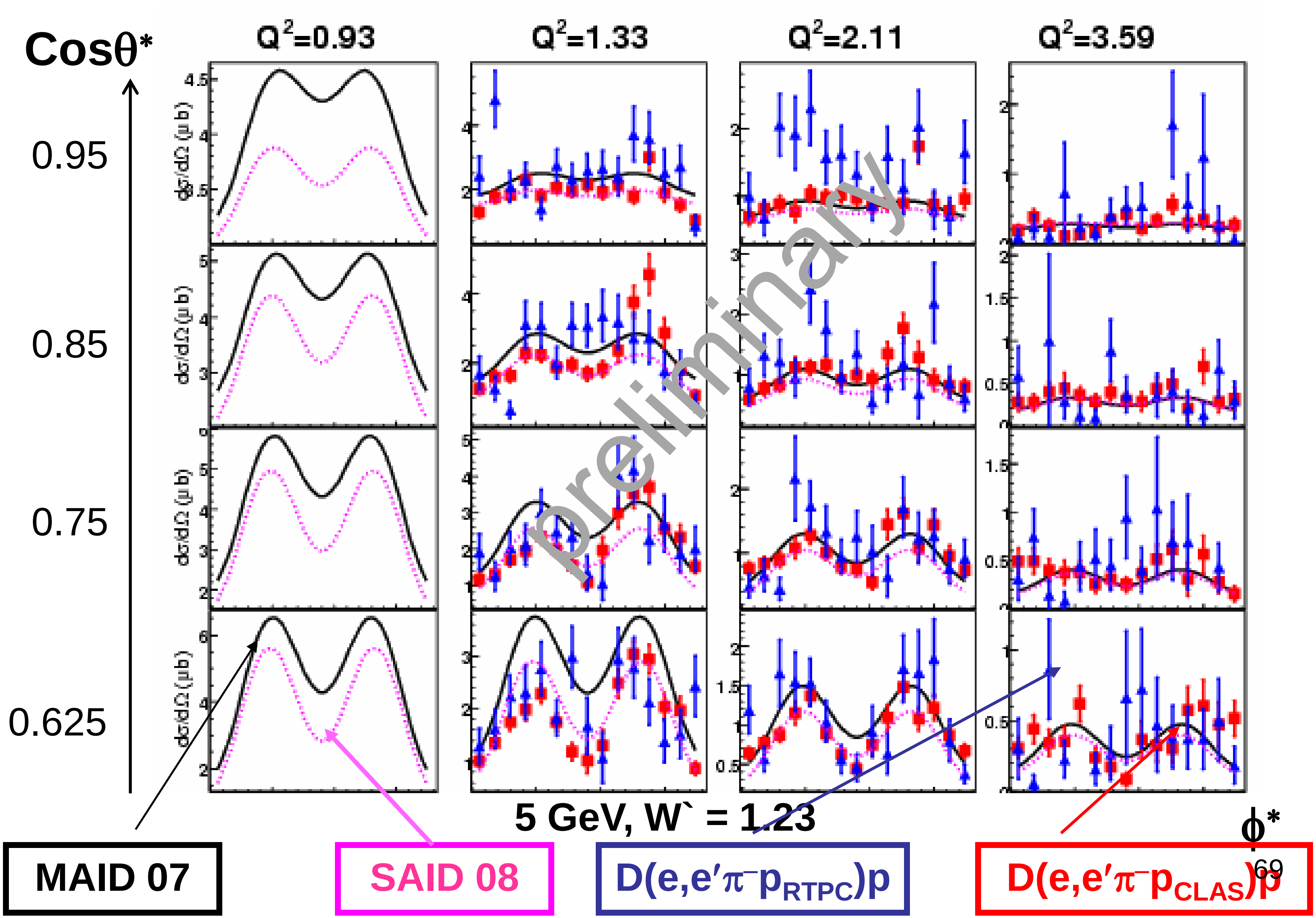
A_0: BoNuS VIP Vs MAID, 2 GeV



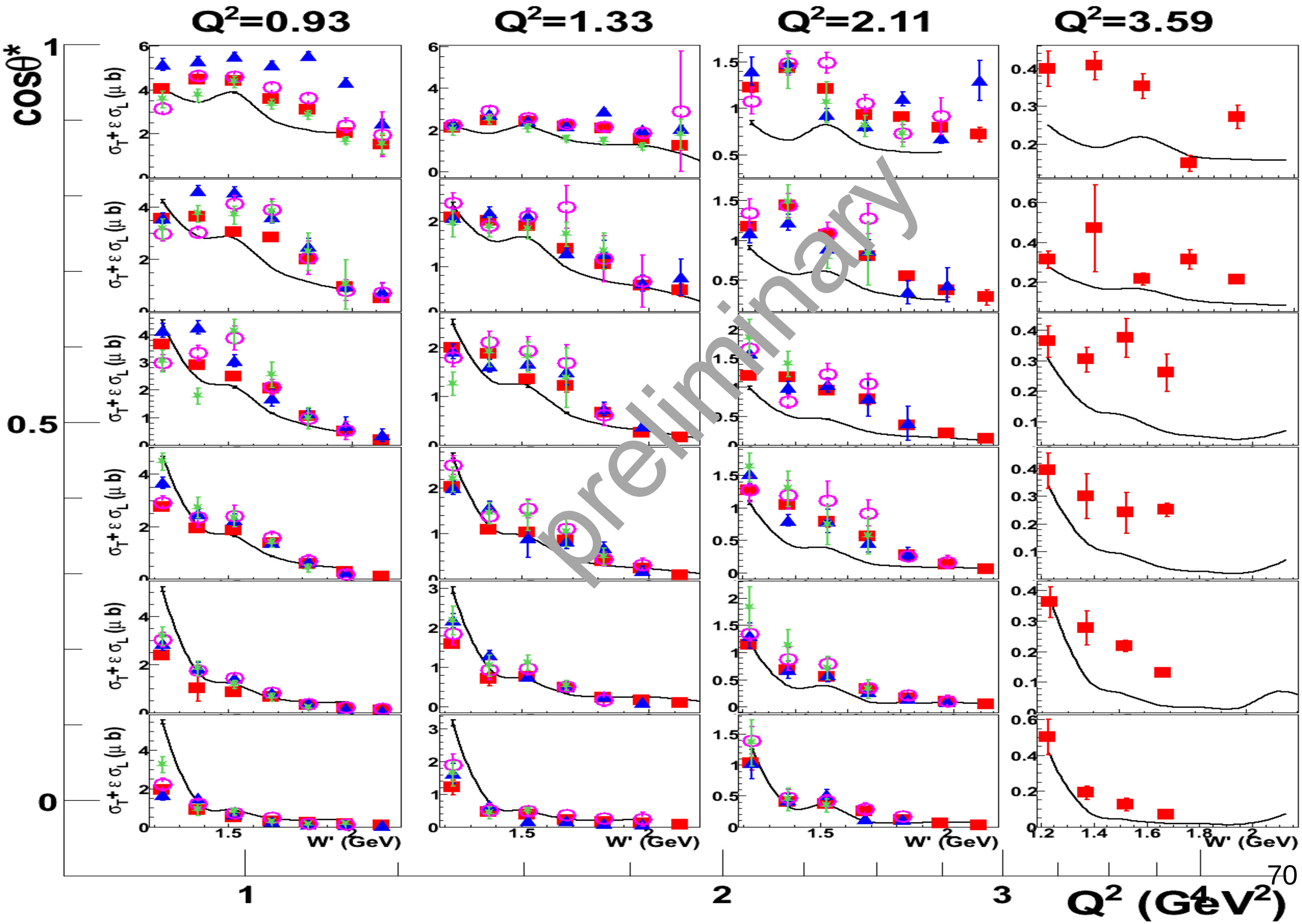
Cross Section: BoNuS Vs MAID and SAID



Cross Section: BoNuS Vs MAID and SAID



A_0: BoNuS VIP Vs MAID, 4 GeV



A_0: BoNuS VIP Vs MAID, 5 GeV