Cross Section of Exclusive π^{-} Electro-production from Neutron

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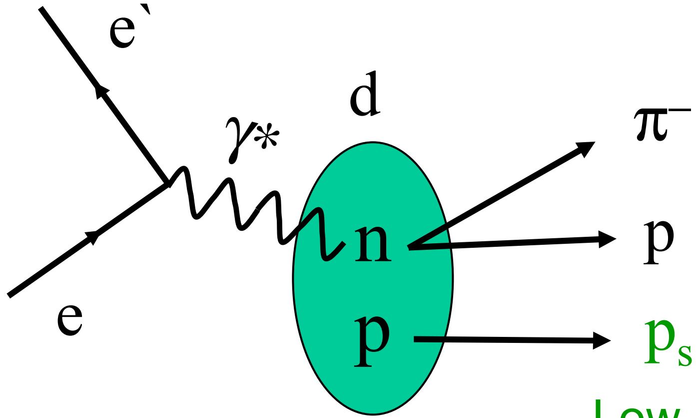
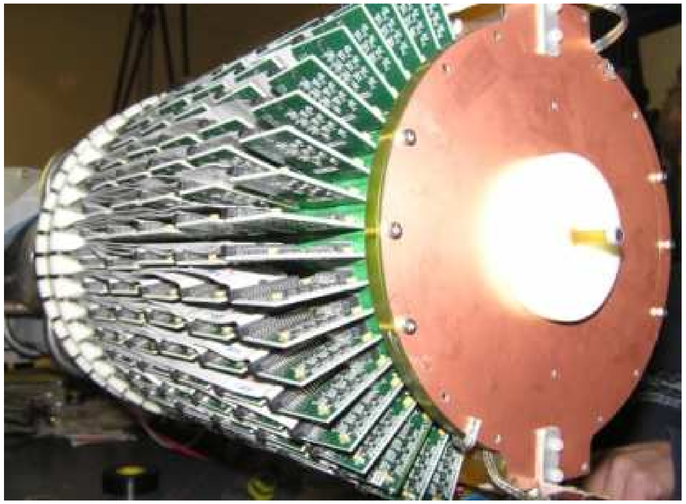
Exclusive π^- electro-production

Detect e\`, $\pi^-$ 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.



Low momentum spectator proton



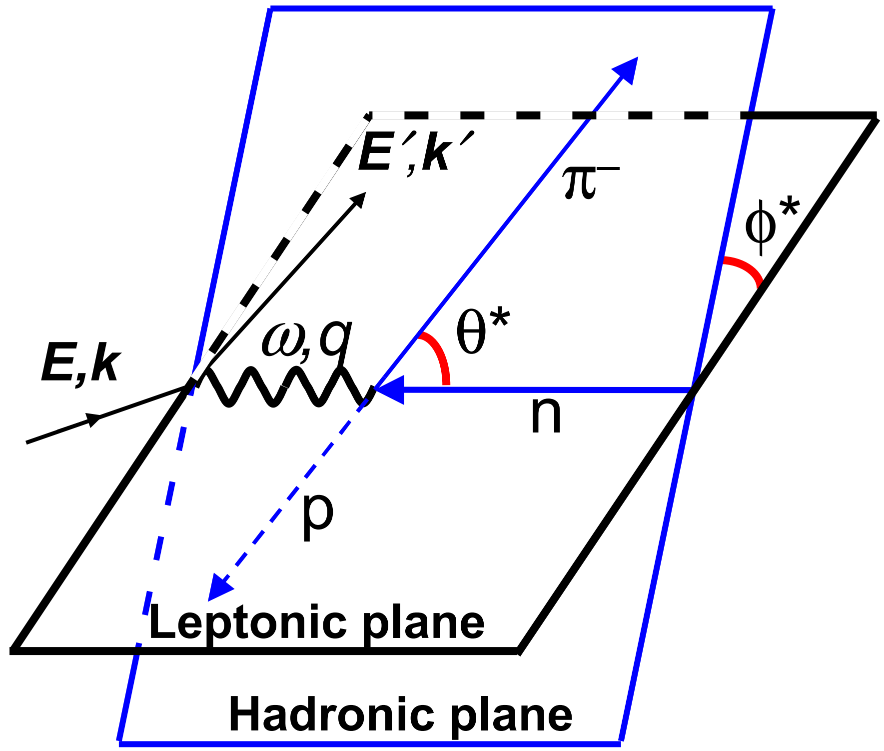
Novel approach by the BoNuS collaboration: detect the spectator proton directly.

Exclusive 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 emitted negative pion in C.M. frame

ϕ^* = Azimuth angle of the emitted negative pion in C.M. frame

Exclusive π^- Cross Section

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

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

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

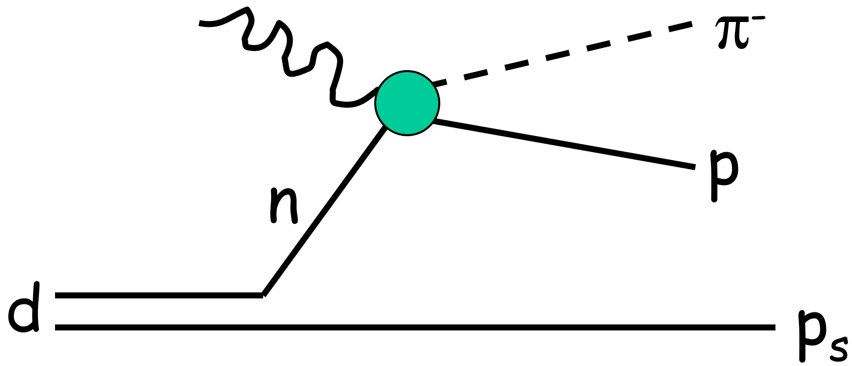
Unpolarized virtual photon cross-section of n → π^-+p

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

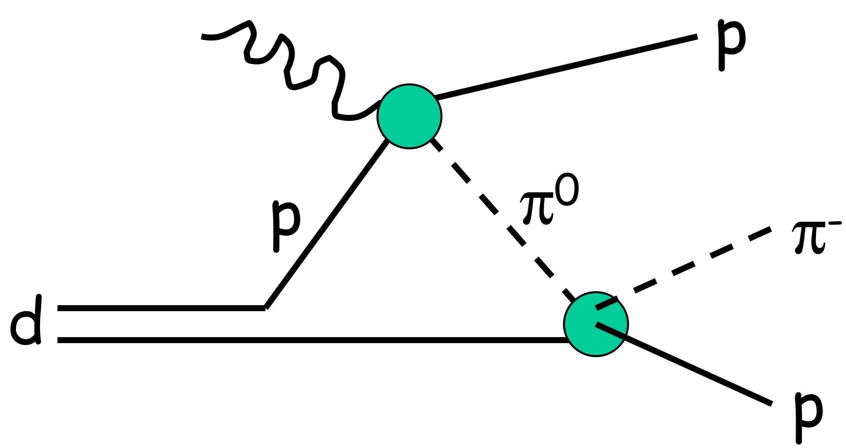
Converted to W', Q^2 frame:

$$dE' d\Omega_e = \begin{vmatrix} \frac{\partial E'}{\partial W'} & \frac{\partial E'}{\partial Q^2} \\ \frac{\partial \Omega_e}{\partial W'} & \frac{\partial \Omega_e}{\partial Q^2} \end{vmatrix} dW' dQ^2 = \frac{\pi W'}{E E' M_n} dW' dQ^2$$

Primary Background



quasi-free

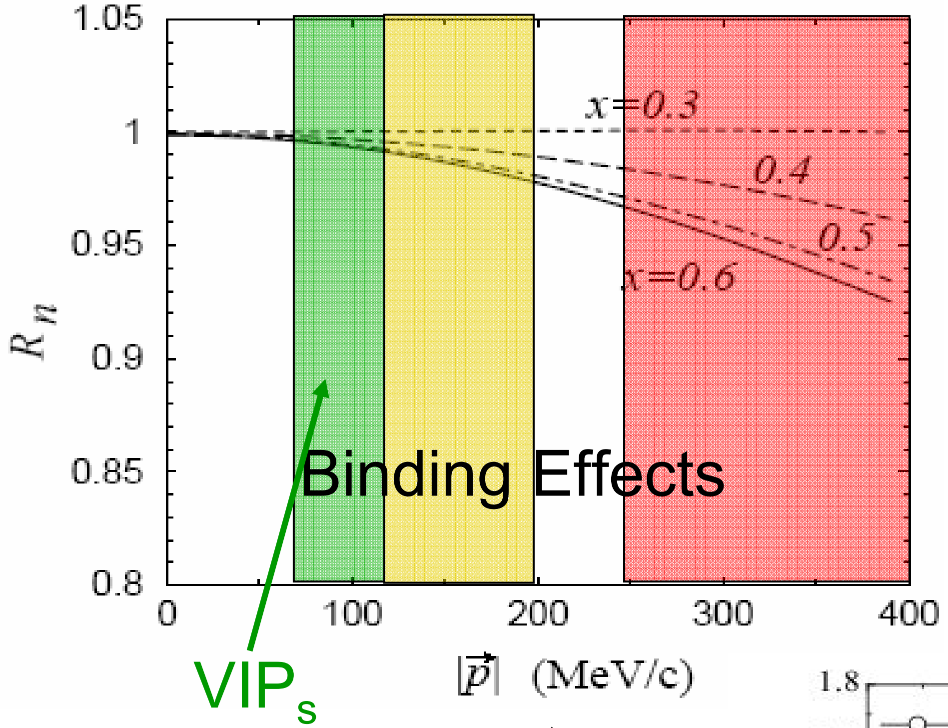


primary background

This final state interaction is small for low momentum p_s and has a very strong angular dependence.

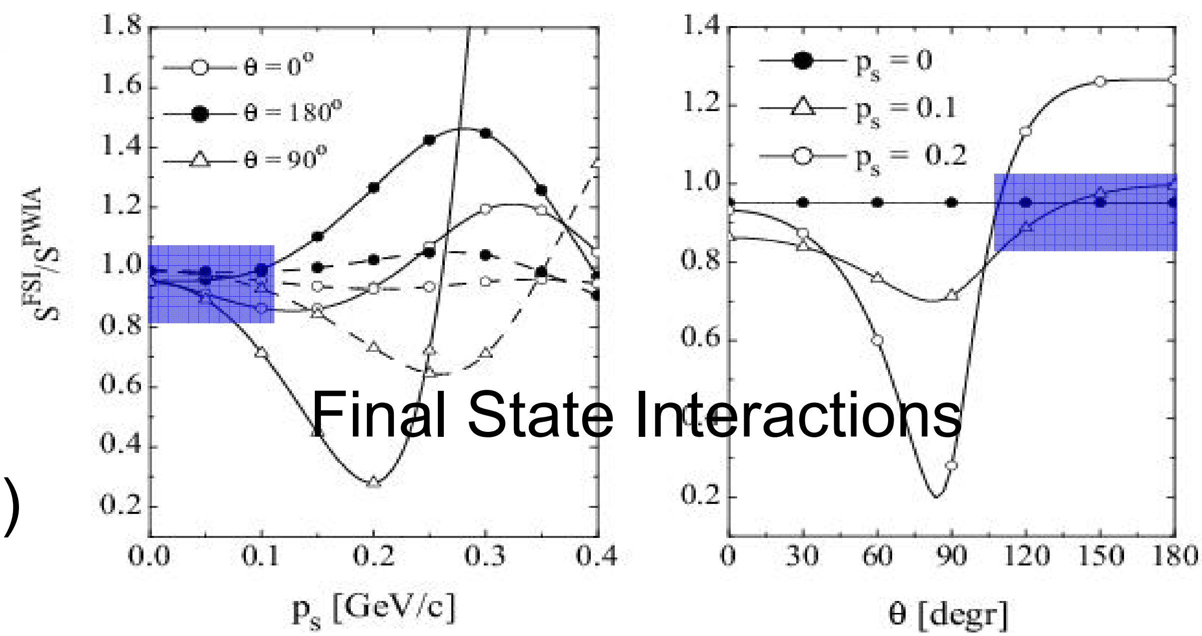
Model Independence?! How?

$$R_n \equiv F_2^{n(eff)}(W^2, Q^2, p^2)/F_2^n(W^2, Q^2)$$



Select low P_s and large backward θ_{pq} (angle between Ps and virtual photon) to minimize FIS.

Binding effect is negligible for small P_s. Choose P_s<120 MeV/c as Very Important Spectator Protons (VIP_s)



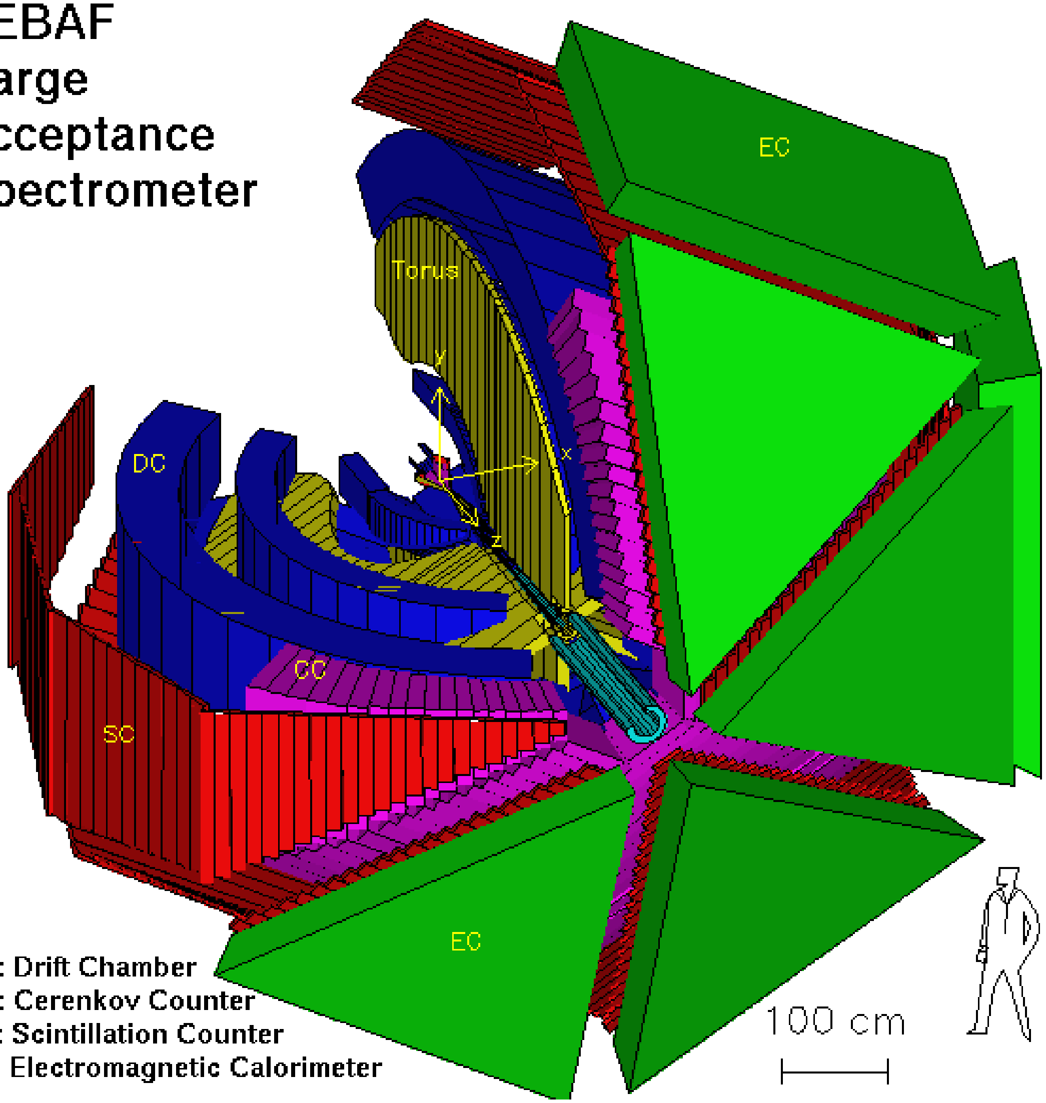
Jefferson Lab Experiment E03-012

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

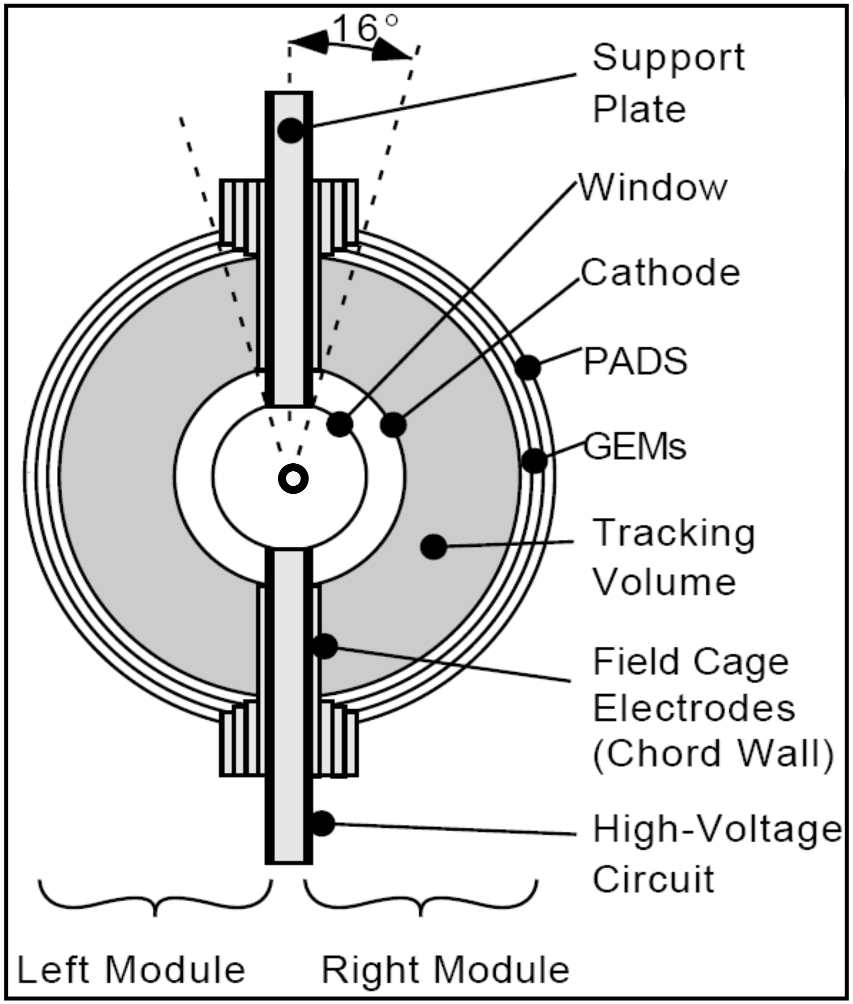
CLAS in Jefferson Lab, Hall B

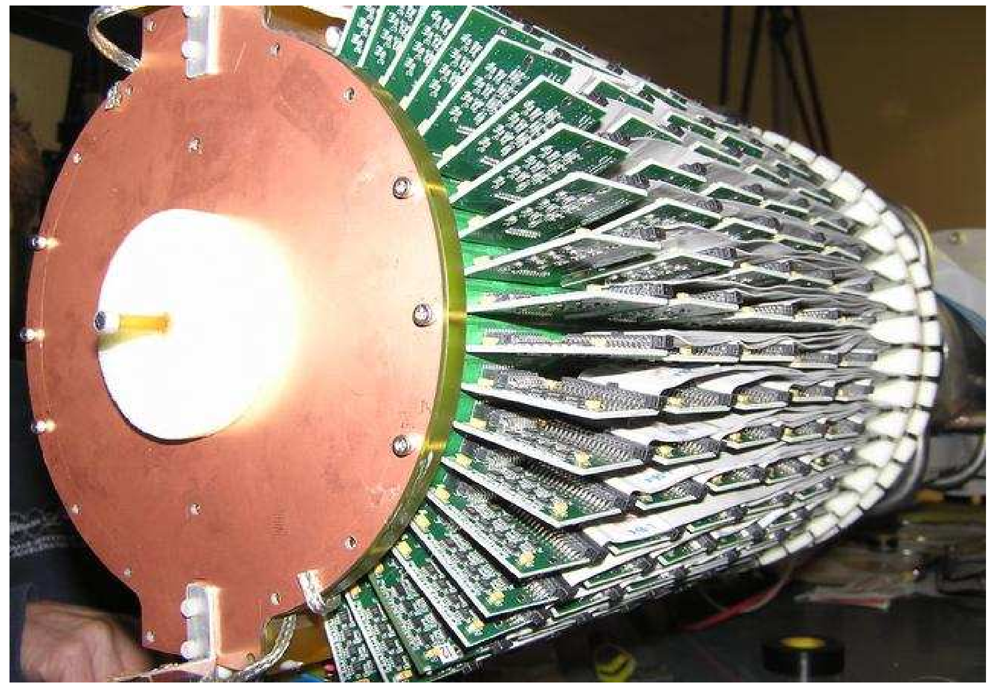
CEBAF
Large
Acceptance
Spectrometer



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

Radial Time Projection Chamber (RTPC)





BoNuS RTPC Detector

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

3 layers of GEM foils

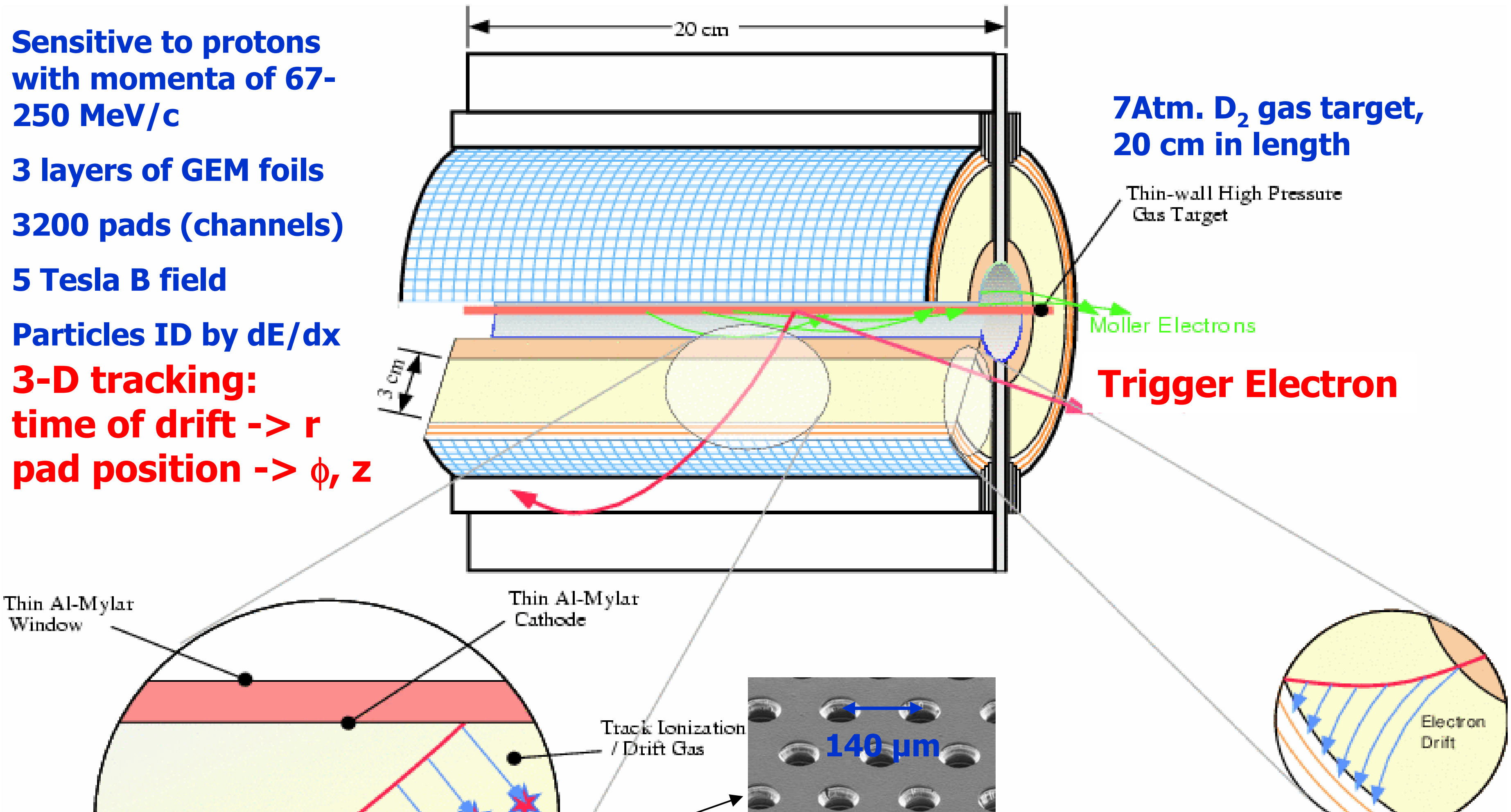
3200 pads (channels)

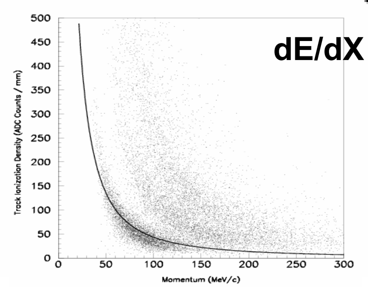
5 Tesla B field

Particles ID by dE/dx

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

7Atm. D_2 gas target, 20 cm in length

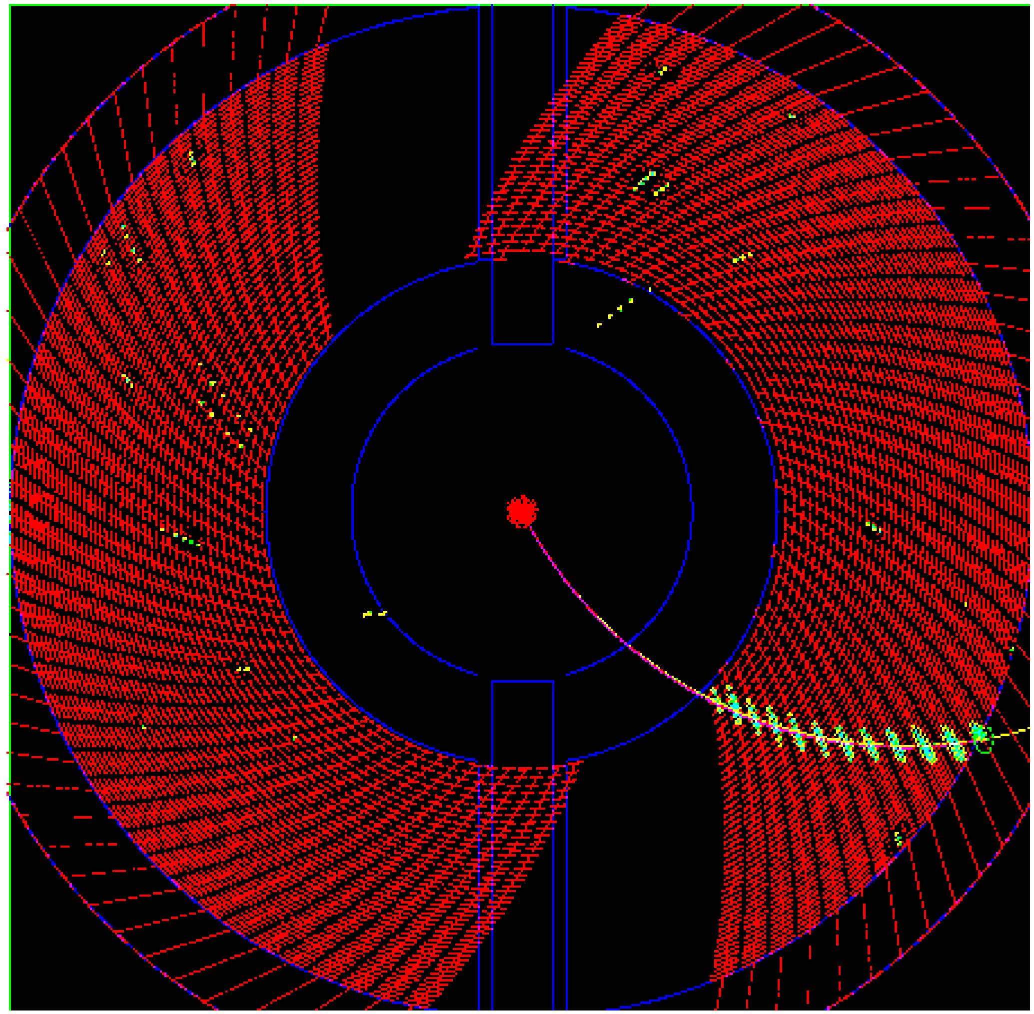




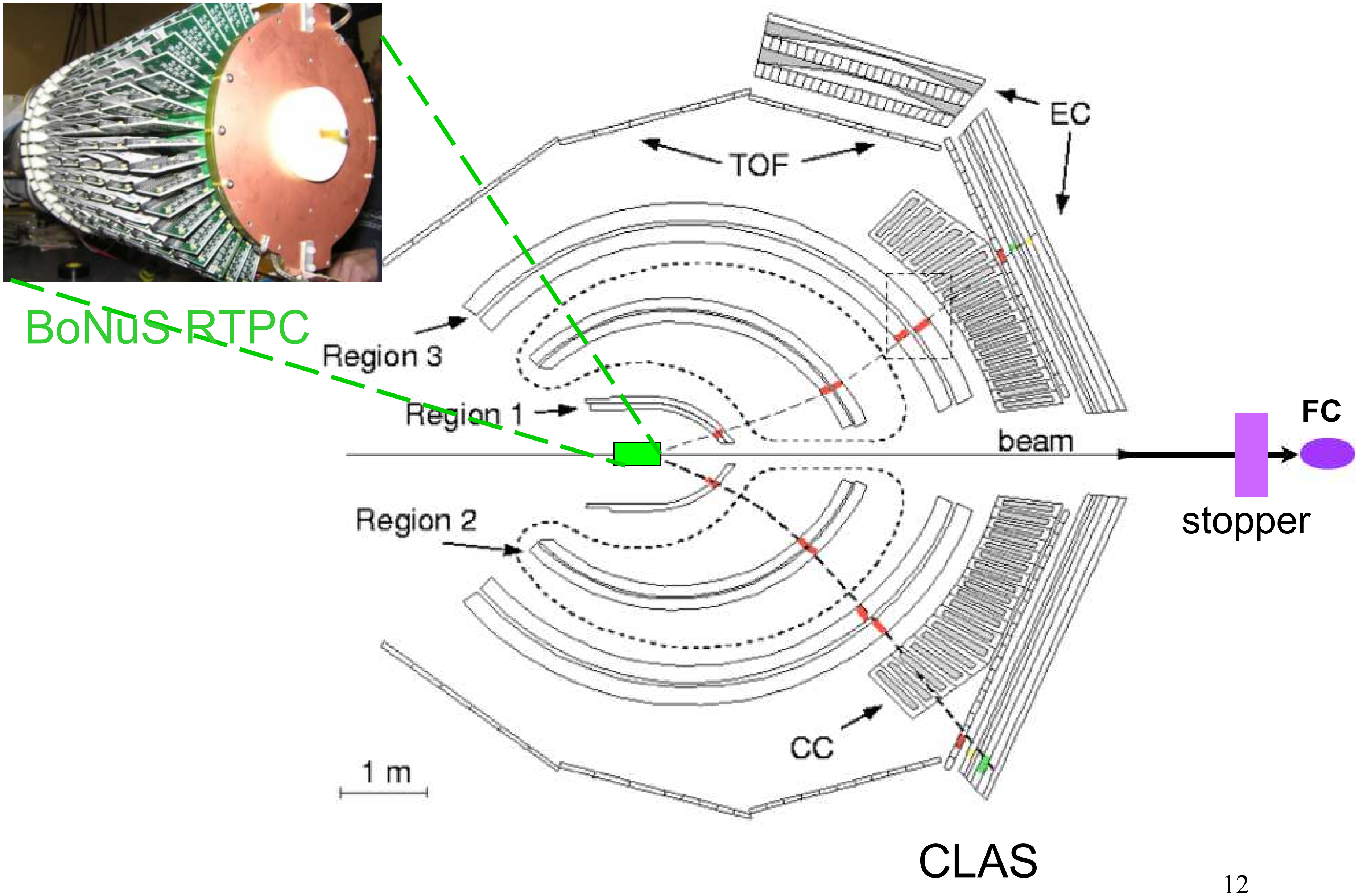
The Drift Path of An Ionized Electron

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.



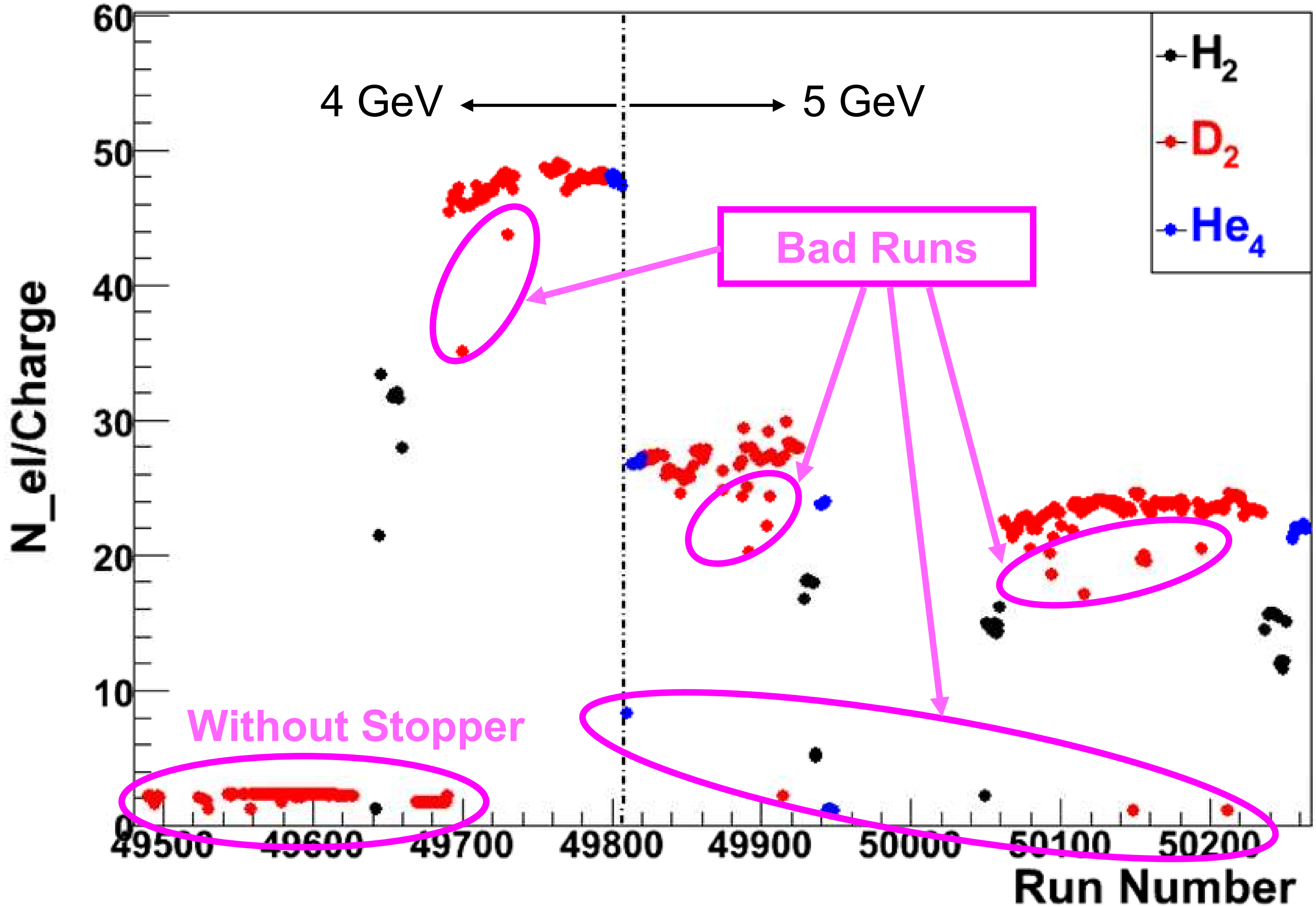
RTPC Sits in the Center of CLAS



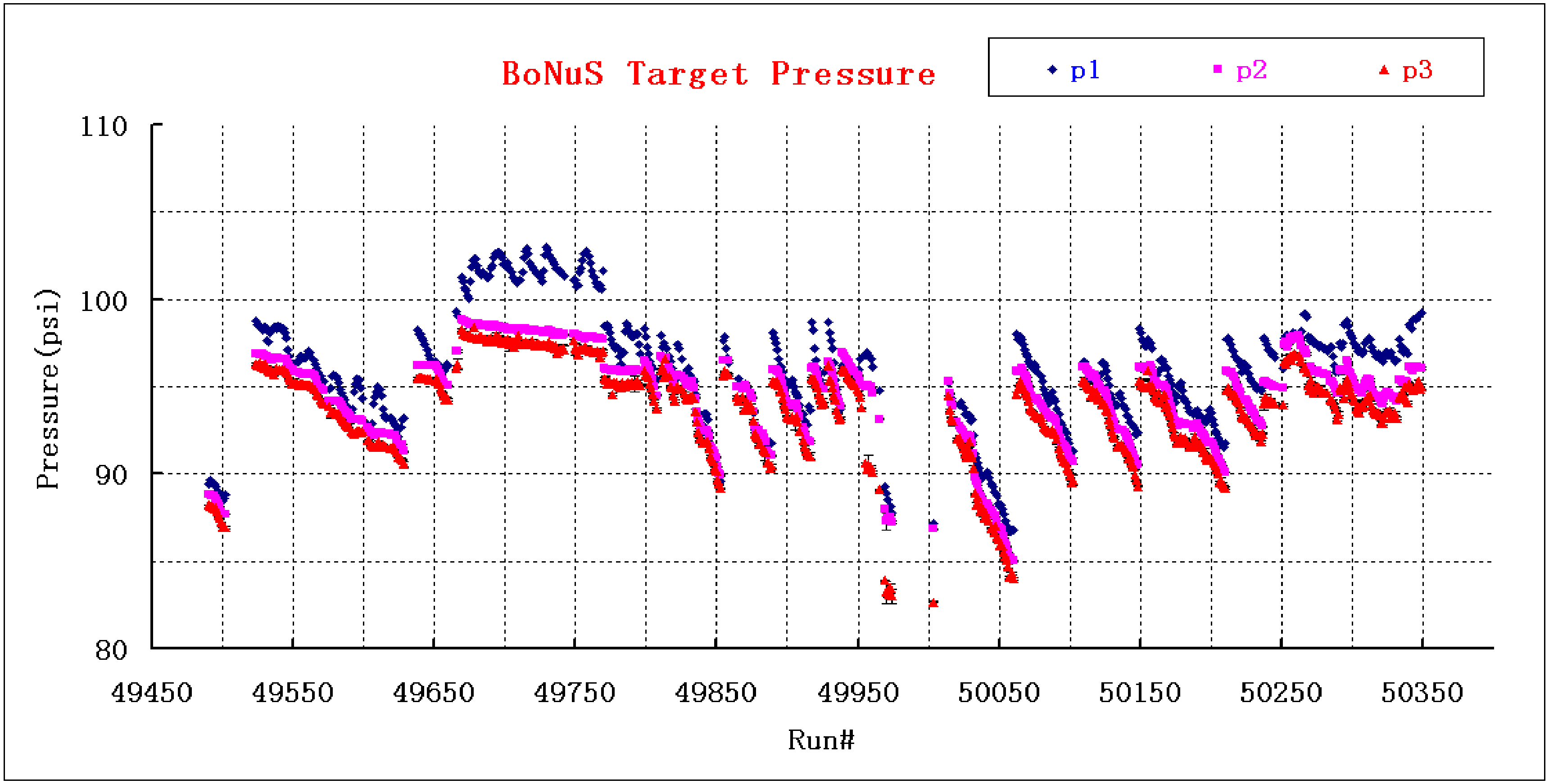
Analysis Outline

1. Quality checks
2. Target thickness analysis (N_b)
3. Beam charge analysis (q)
4. Kinematic corrections
    - •CLAS and RTPC PID,
    - •RTPC Gain Calibration and Drift Velocity Calibration
    - •RTPC Energy Loss Correction
    - •CLAS Energy Loss Correction
    - •Beam Line and Vertex Correction
5. Simulation Overview
6. Acceptance and efficiency analysis
7. Background subtraction
8. Cross section (σ)

Run Selection: Quality Checks

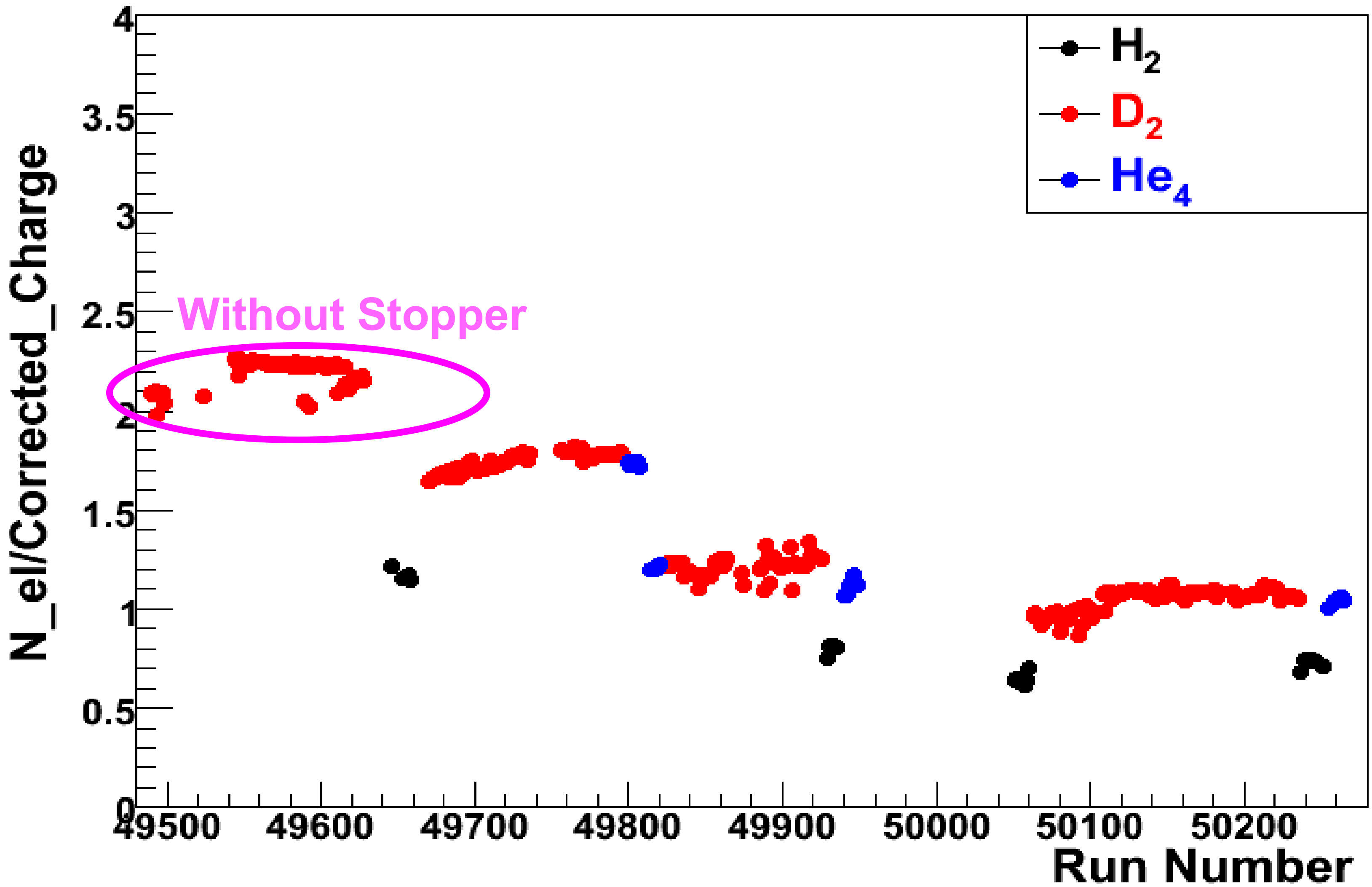


Target Thickness



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

Charge After Stopper Correction



CLAS Particle Identification

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

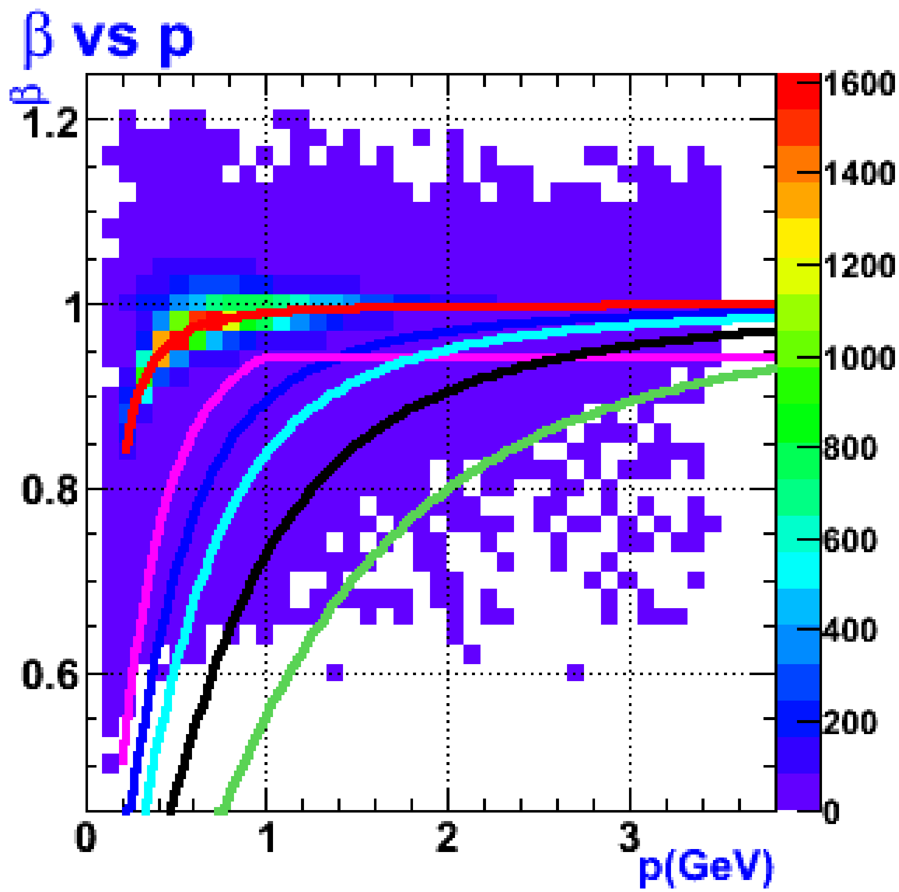
Positive particles:

(1) β between light blue and green curve proton

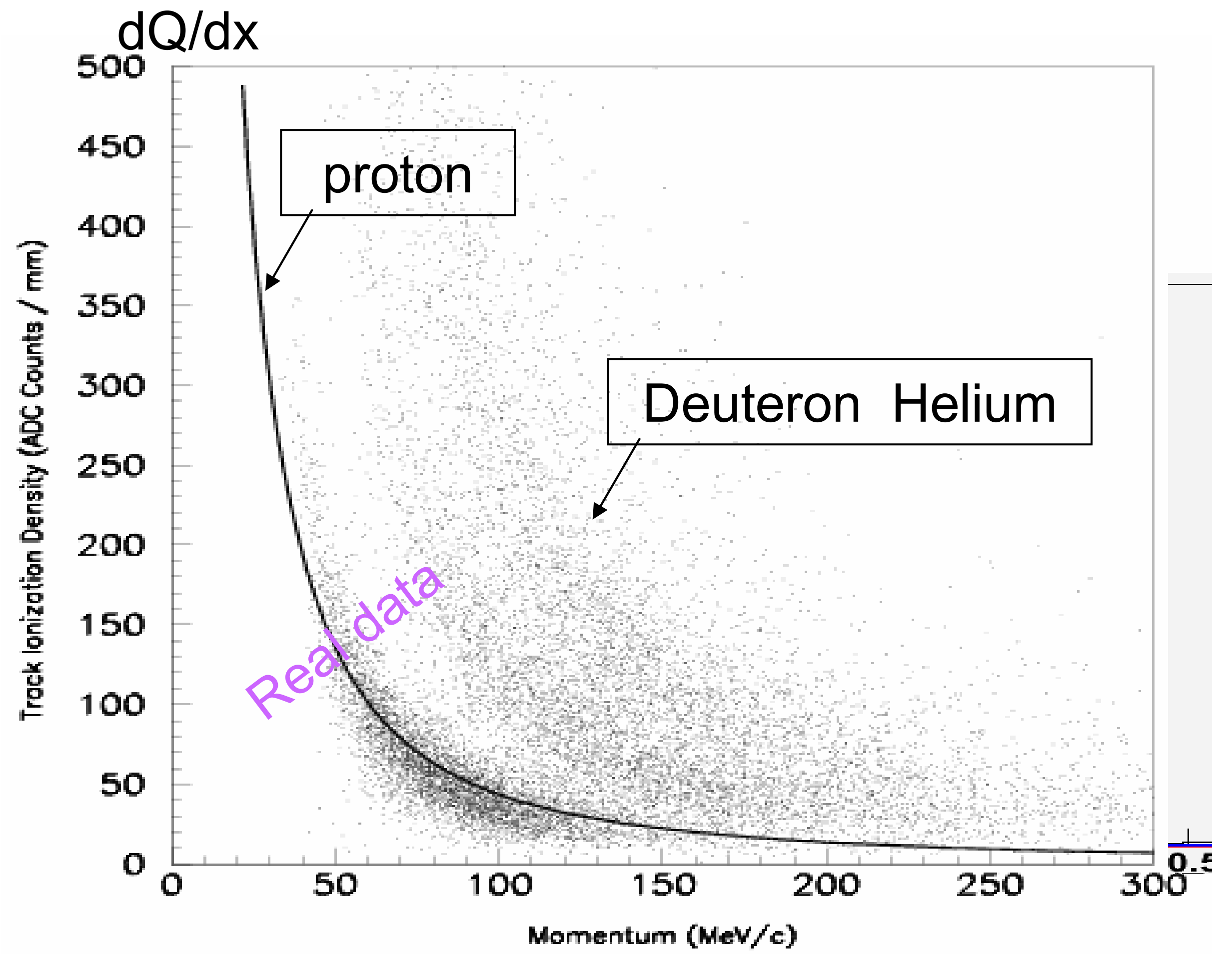
(2) β below green curve Deuteron

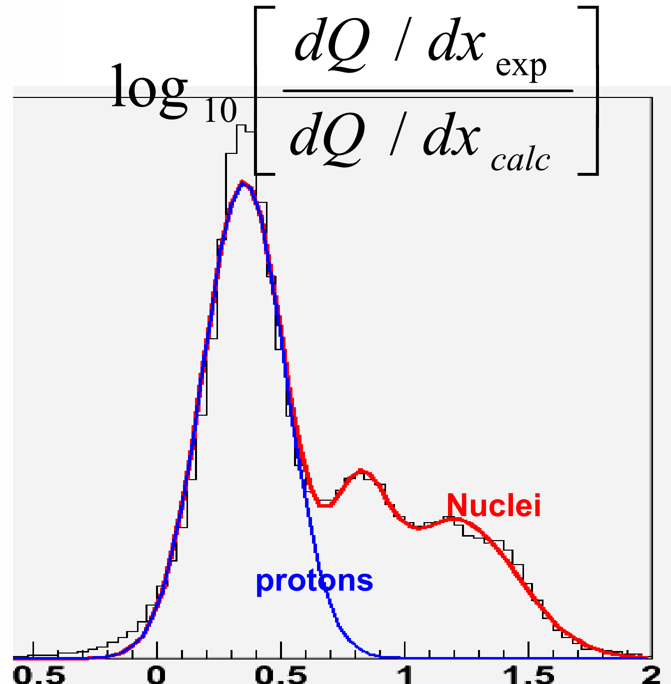
(3) Among the rest, β above purple curve π^+

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



RTPC Proton Identification

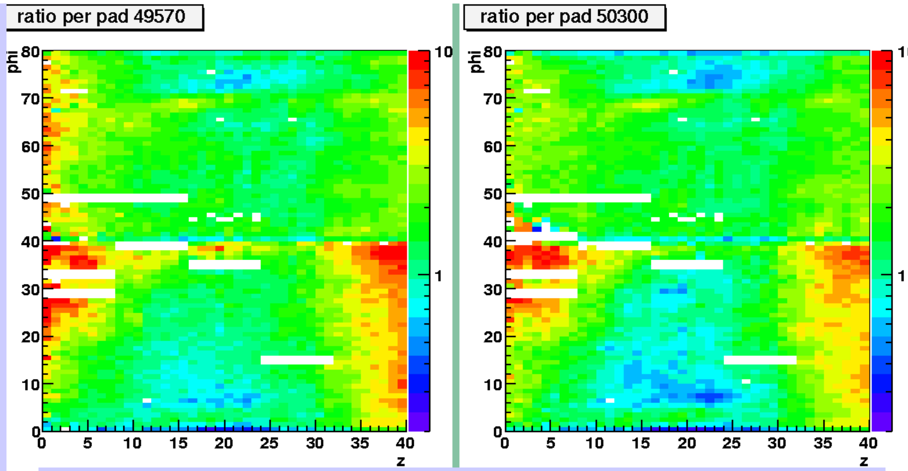




RTPC Gain Calibration

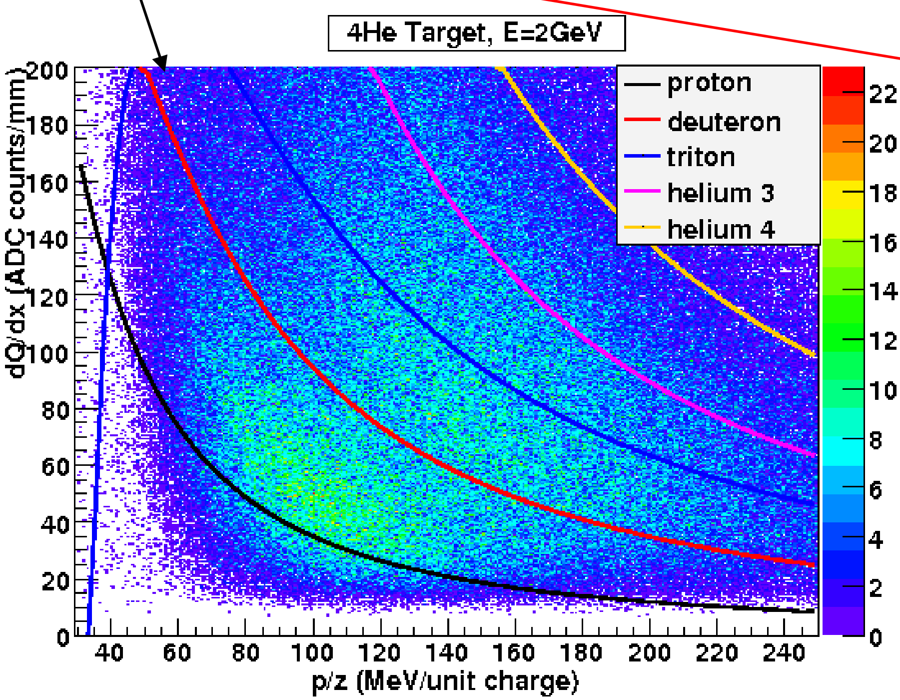
Channel by Channel gain multipliers can be determined for each run by comparing the track's expected energy loss to the measured value.

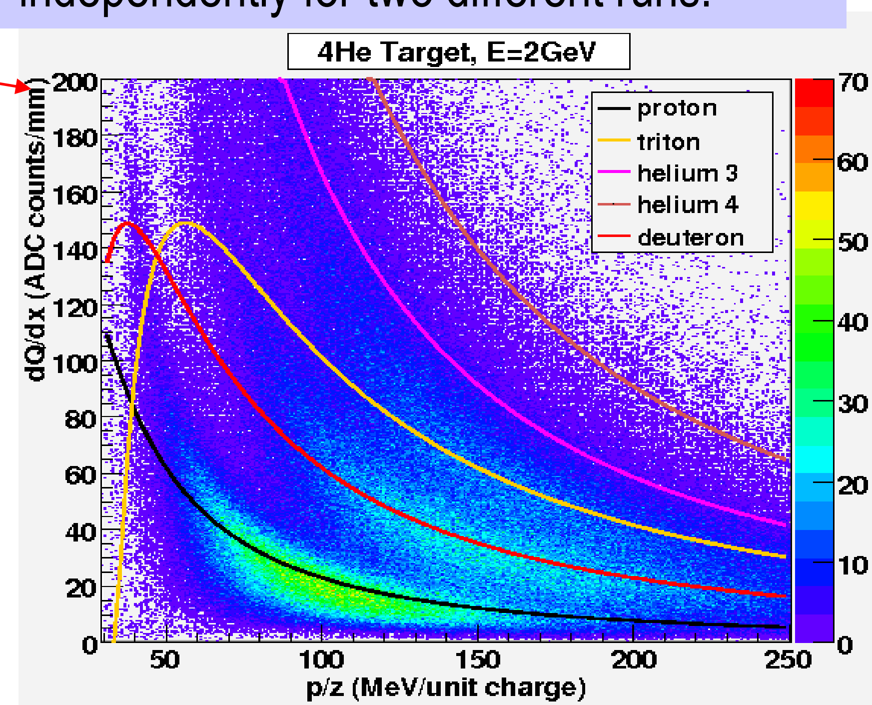
After applying the gain corrections, a clear separation of protons and heavier particles through dE/dx has been achieved.



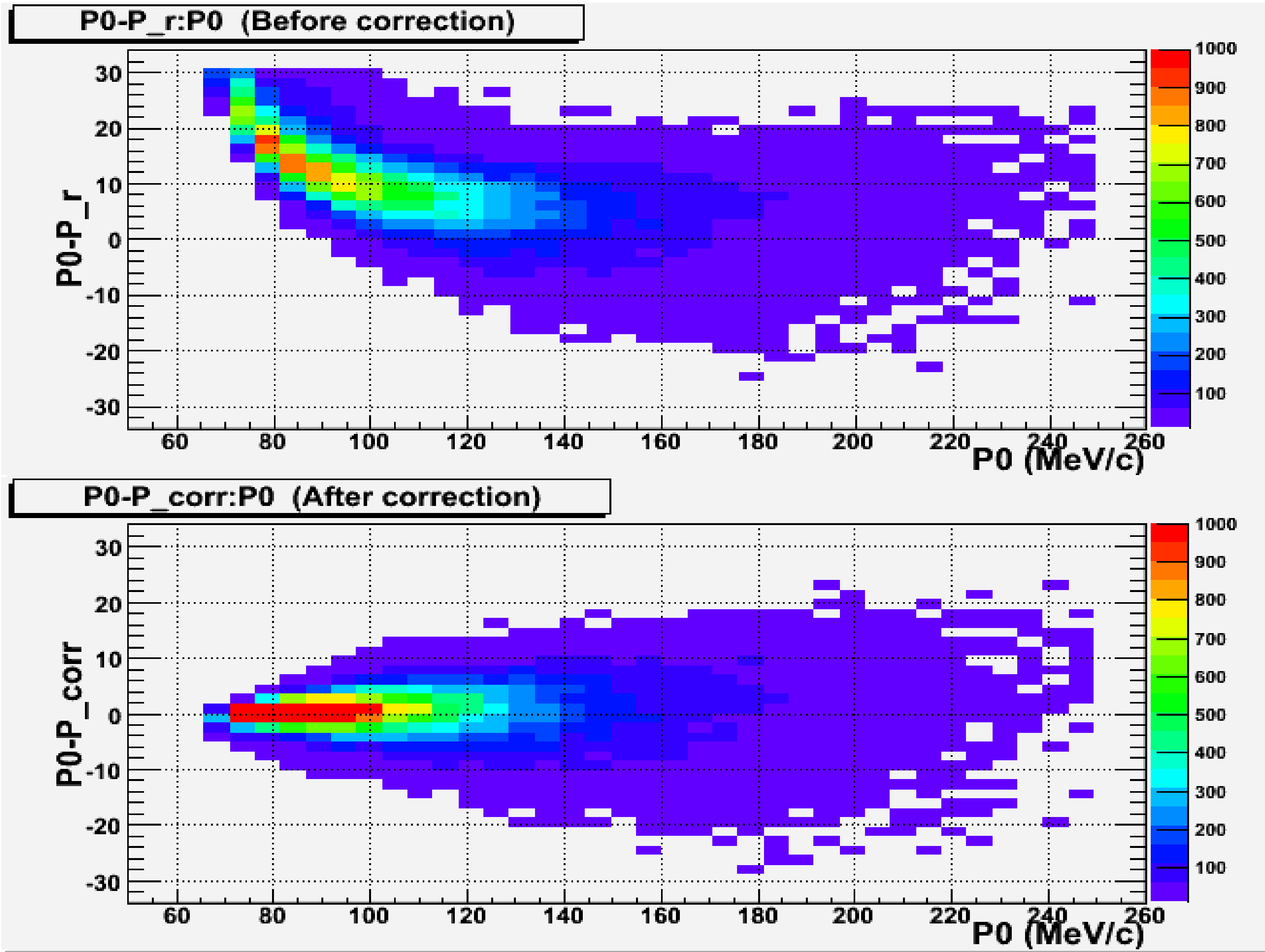
Gain constants (vs phi and z) determined independently for two different runs.

Before and After Gain Calibration

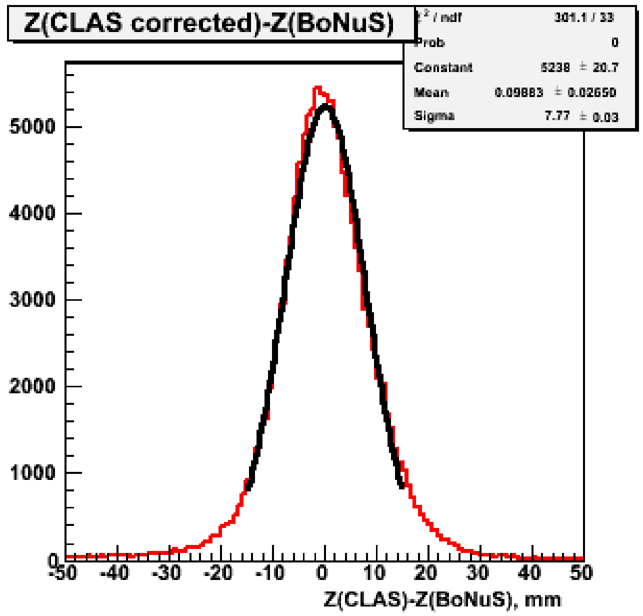


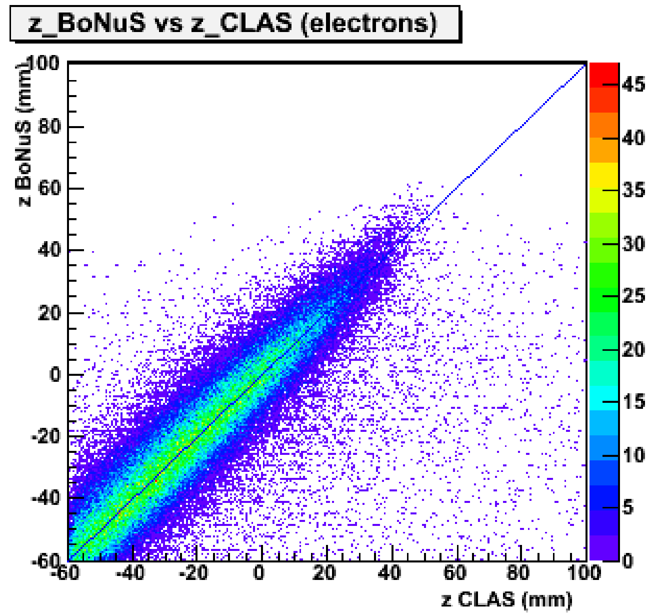


Energy Loss Correction for RTPC Proton

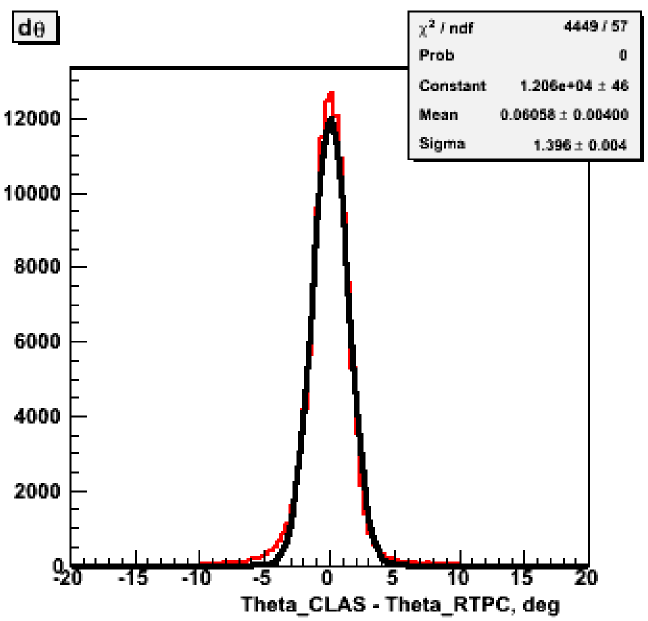


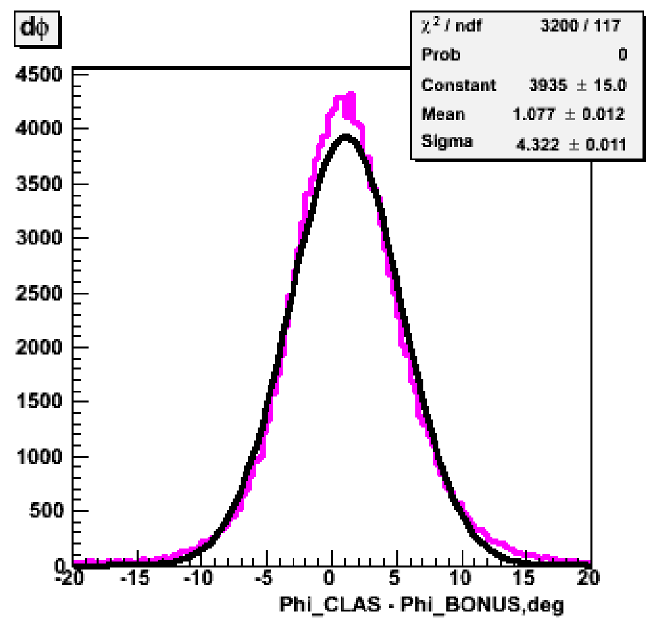
RTPC Drift Velocity Calibration





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

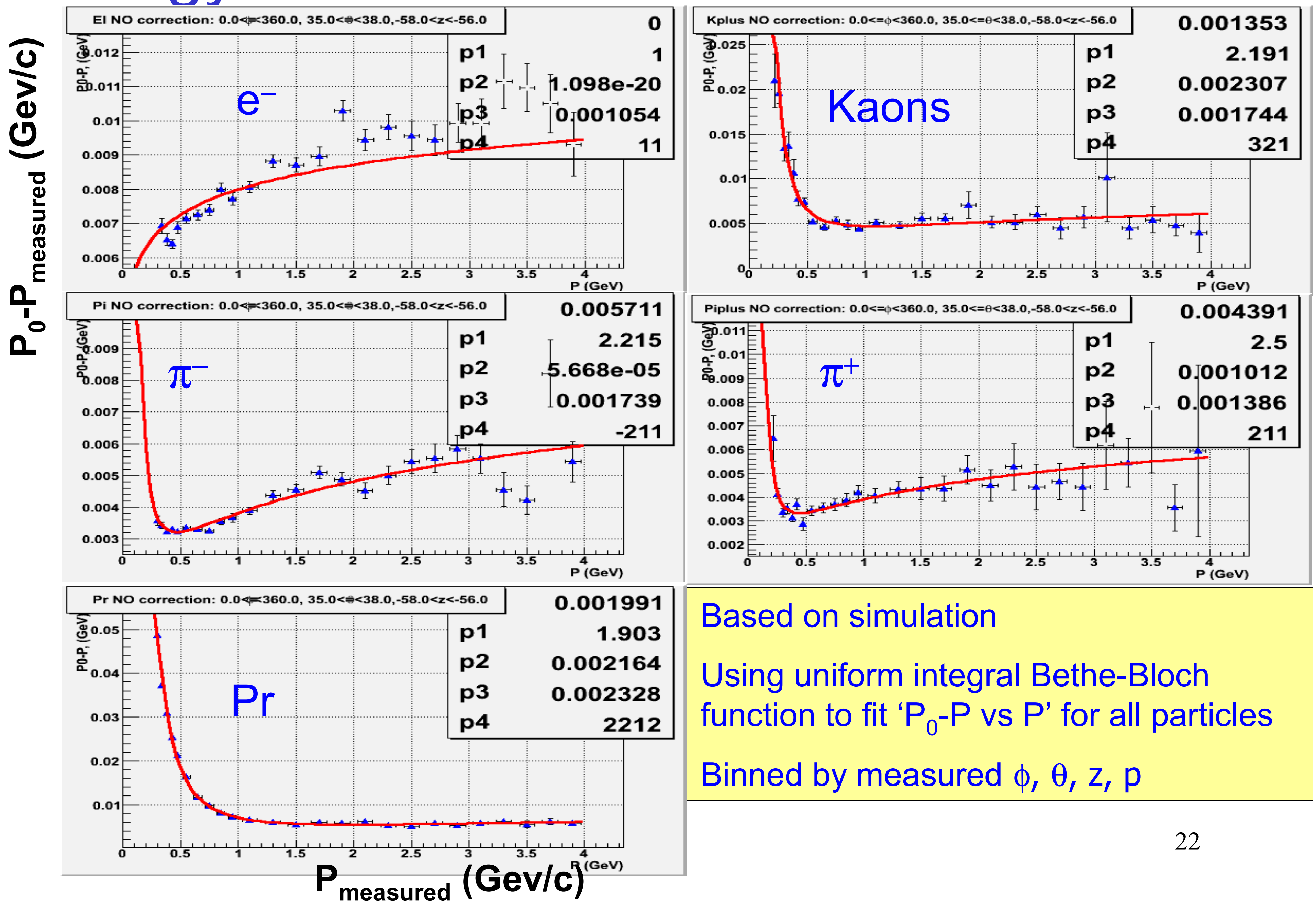




Trigger electrons measured by CLAS are compared to the same electrons measured in BoNuS during High Gain Calibration runs.

The drift velocity parameters are chosen which best improve the centroid and width of the dz, d θ , and d ϕ distributions.

Energy Loss Correction for CLAS Particles

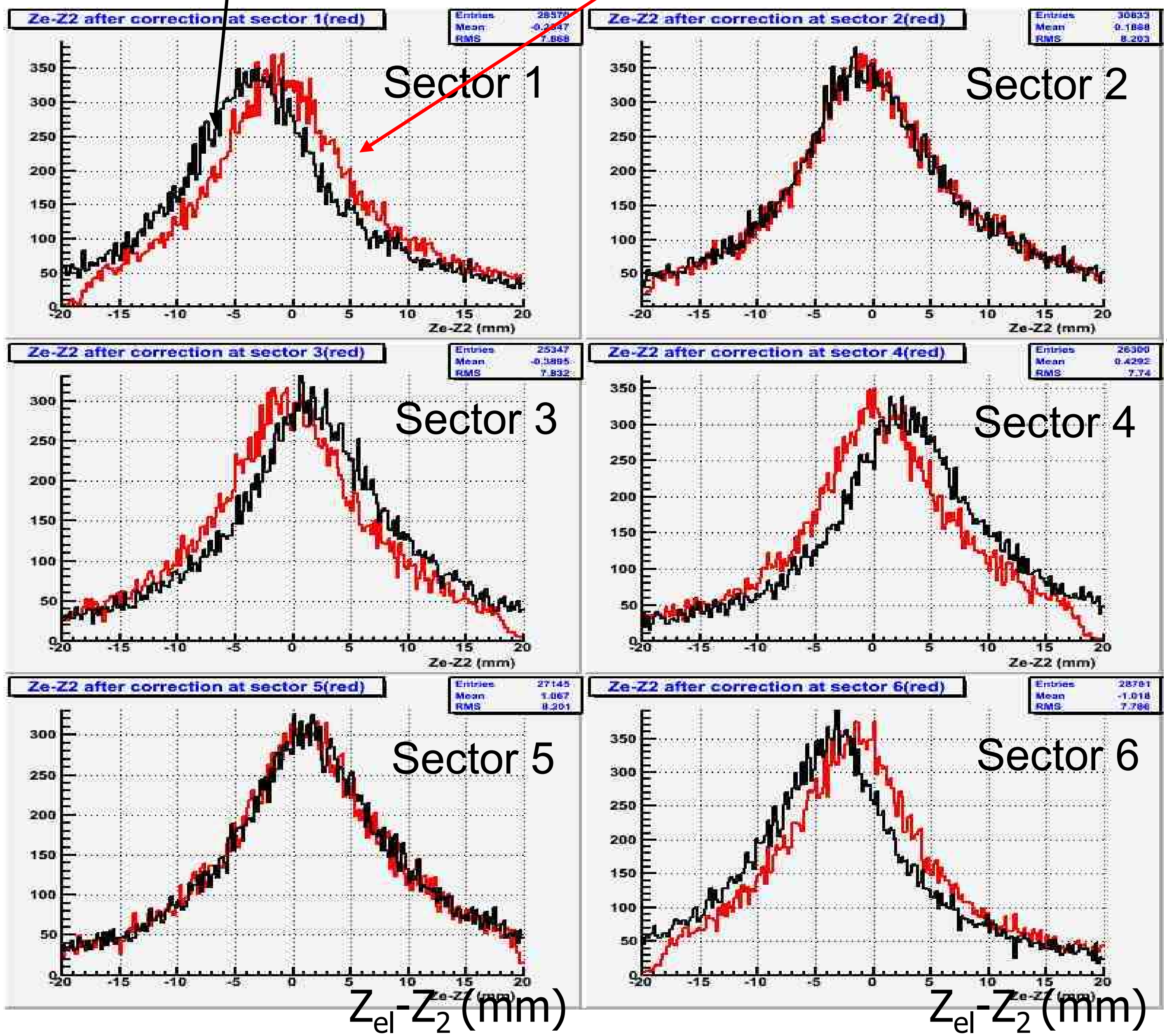


Based on simulation

Using uniform integral Bethe-Bloch function to fit 'P_0-P vs P' for all particles

Binned by measured φ, θ, z, p

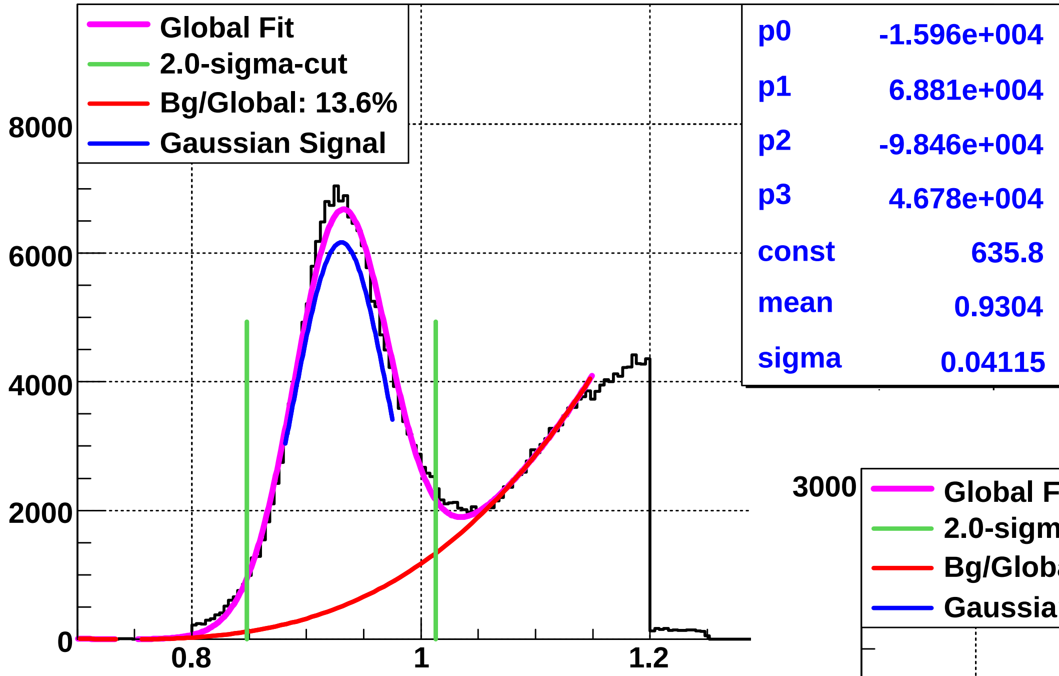
Before and After Vertex Correction



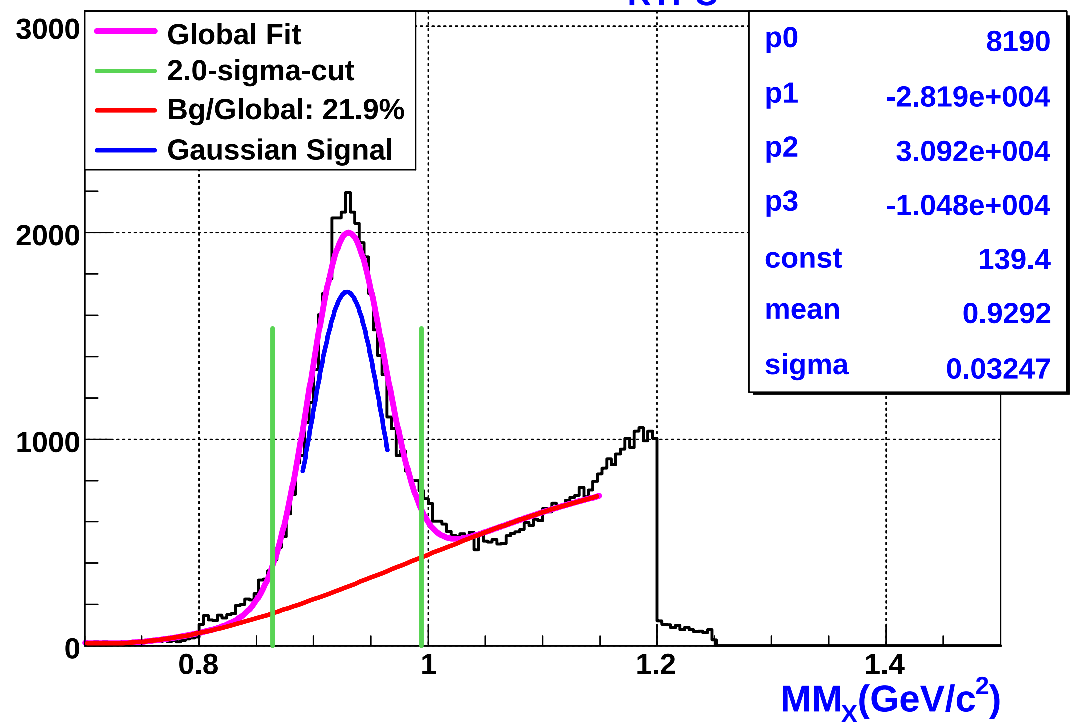
Using real data, find the best beam position to minimize the vertex difference among coincident particles

Missing Mass Cut

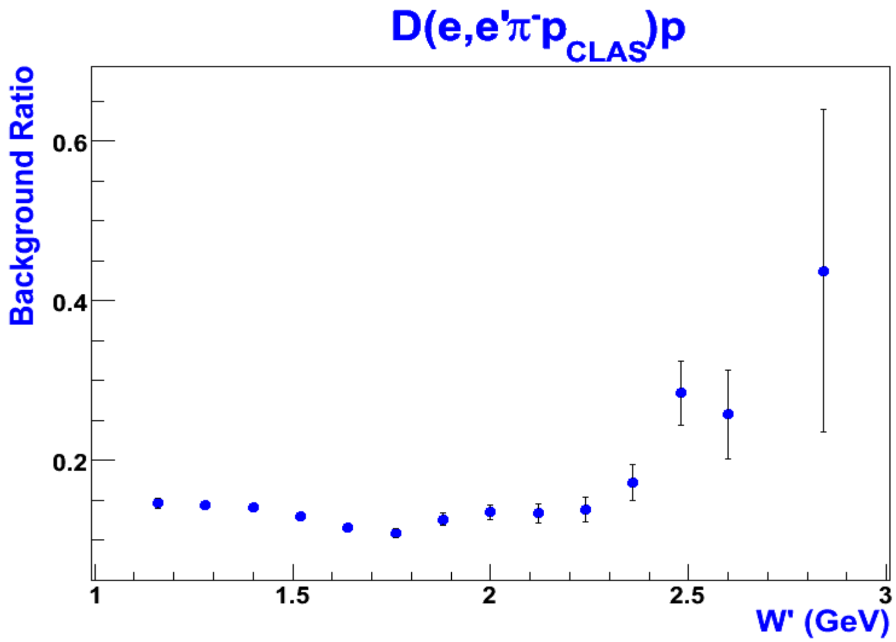
$D(e,e'\pi^- p_{CLAS})X$

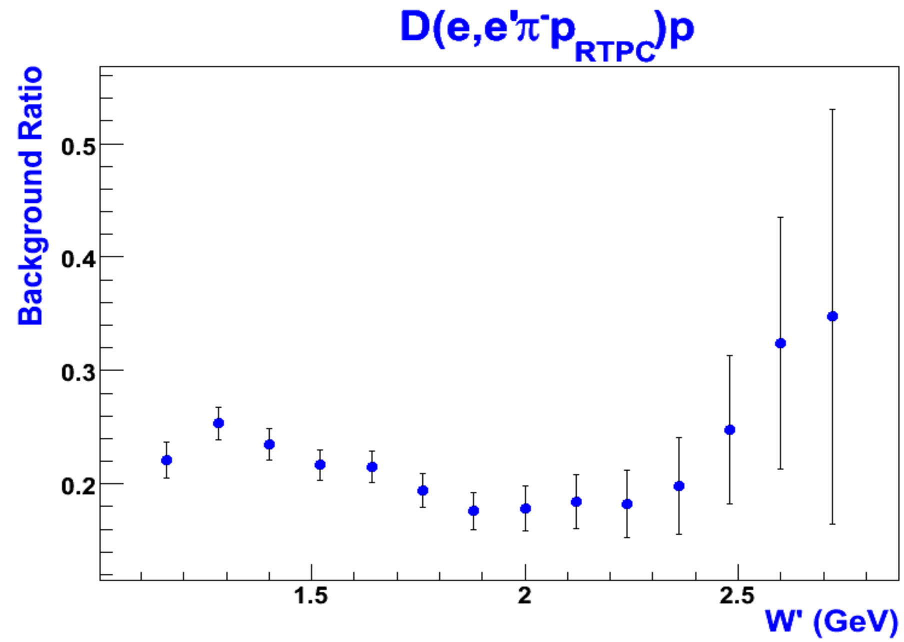


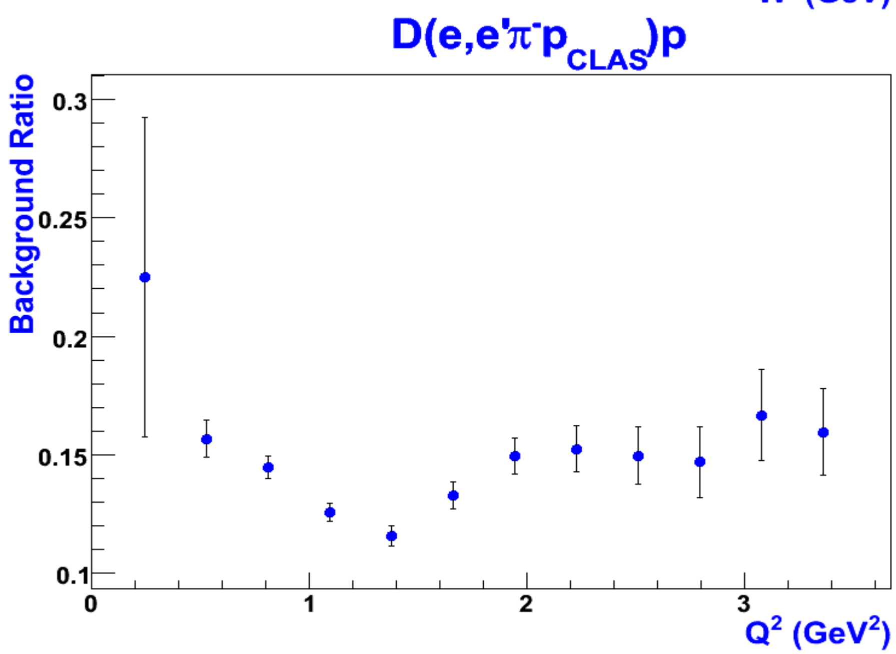
$D(e,e'\pi^- p_{RTPC})X$

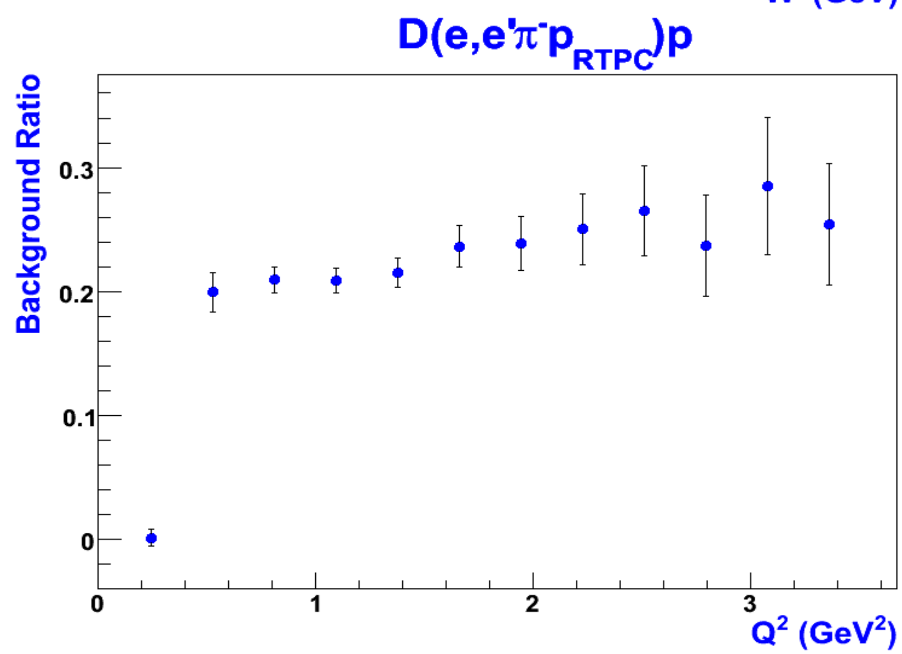


Background Subtraction (1)

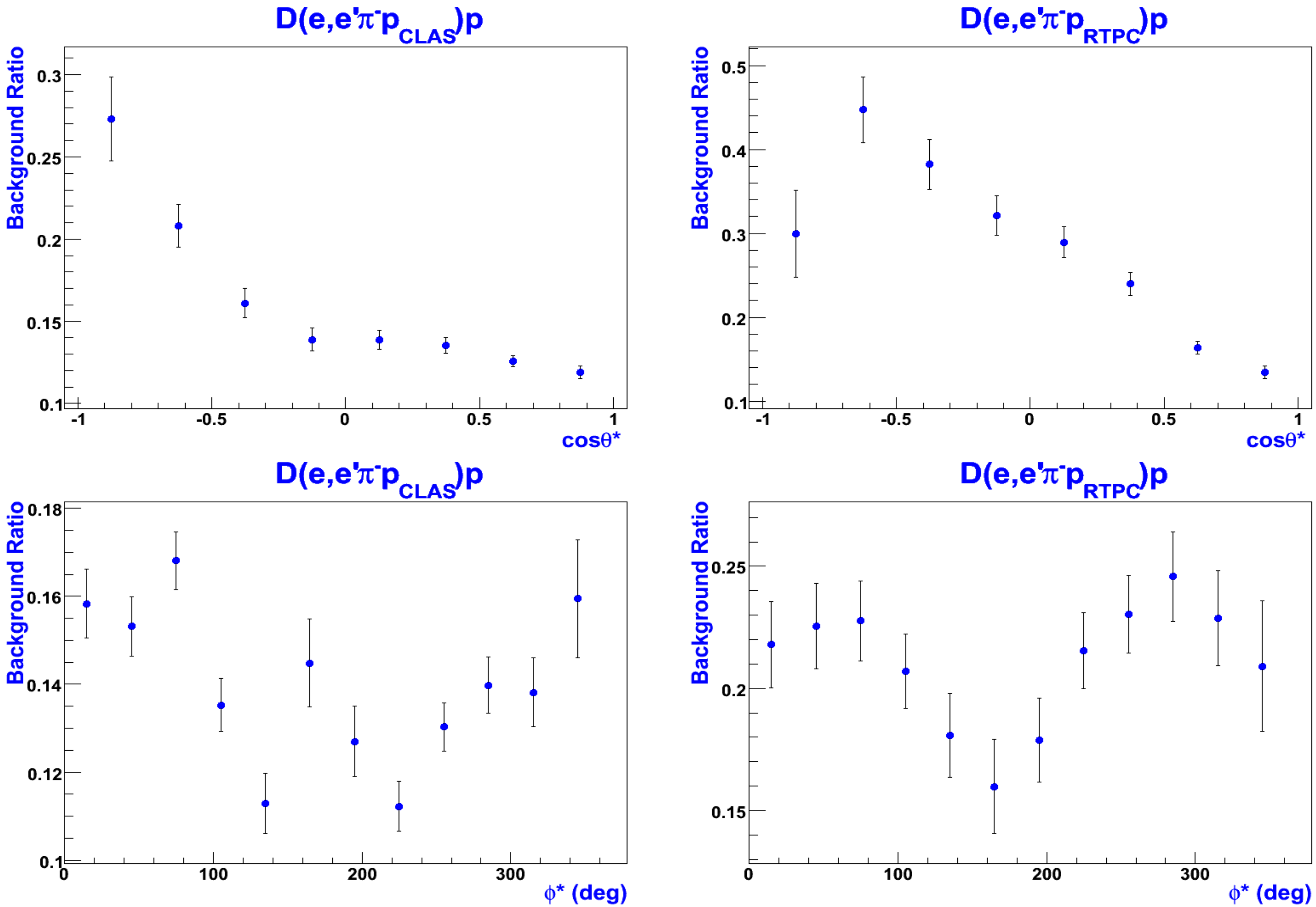






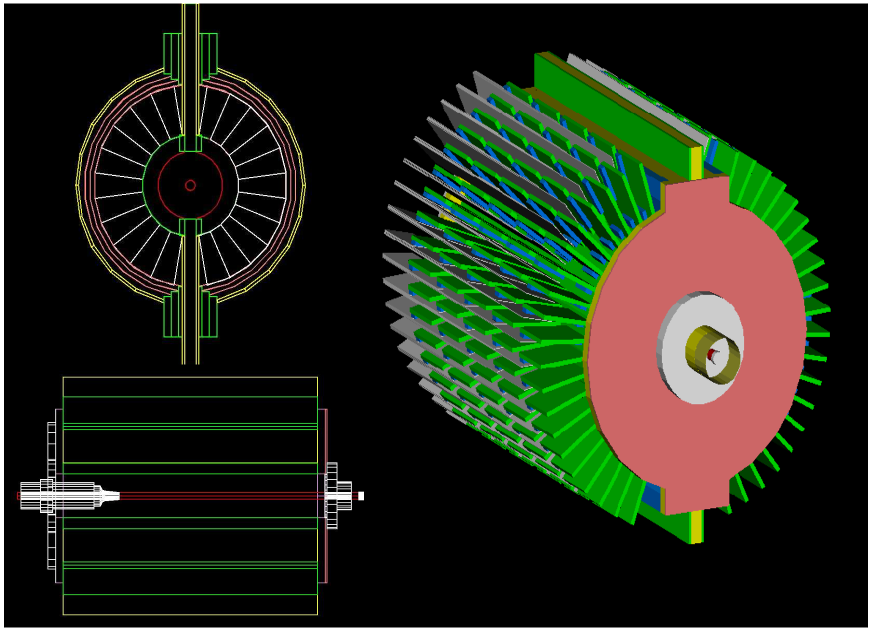


Background Subtraction (2)



Simulation Overview

Evgen (fsgen or other event generators) → RTPC (BONUS) CLAS(gsim) → Gsim Post Processing (gpp) → Reconstruction (user_ana) → Skim → Higher Level Simulation Ntuple



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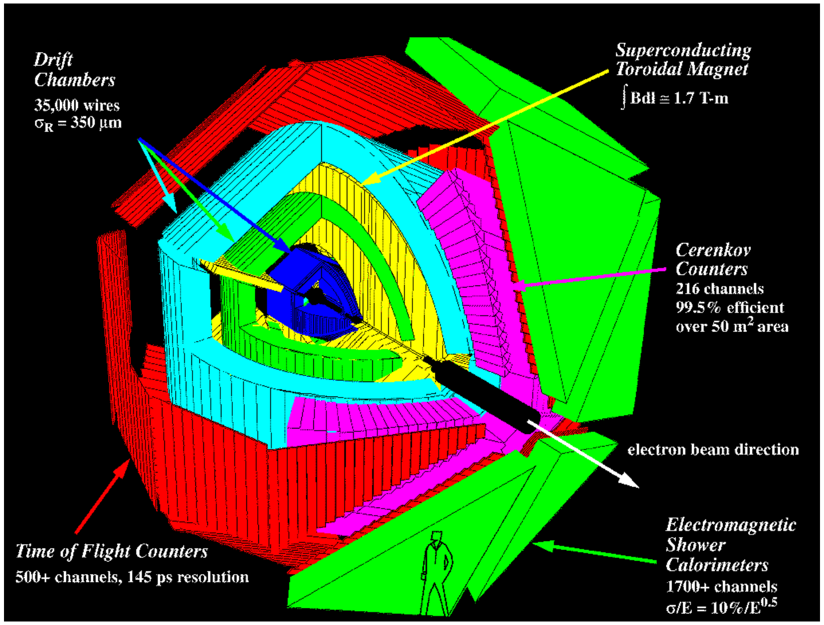
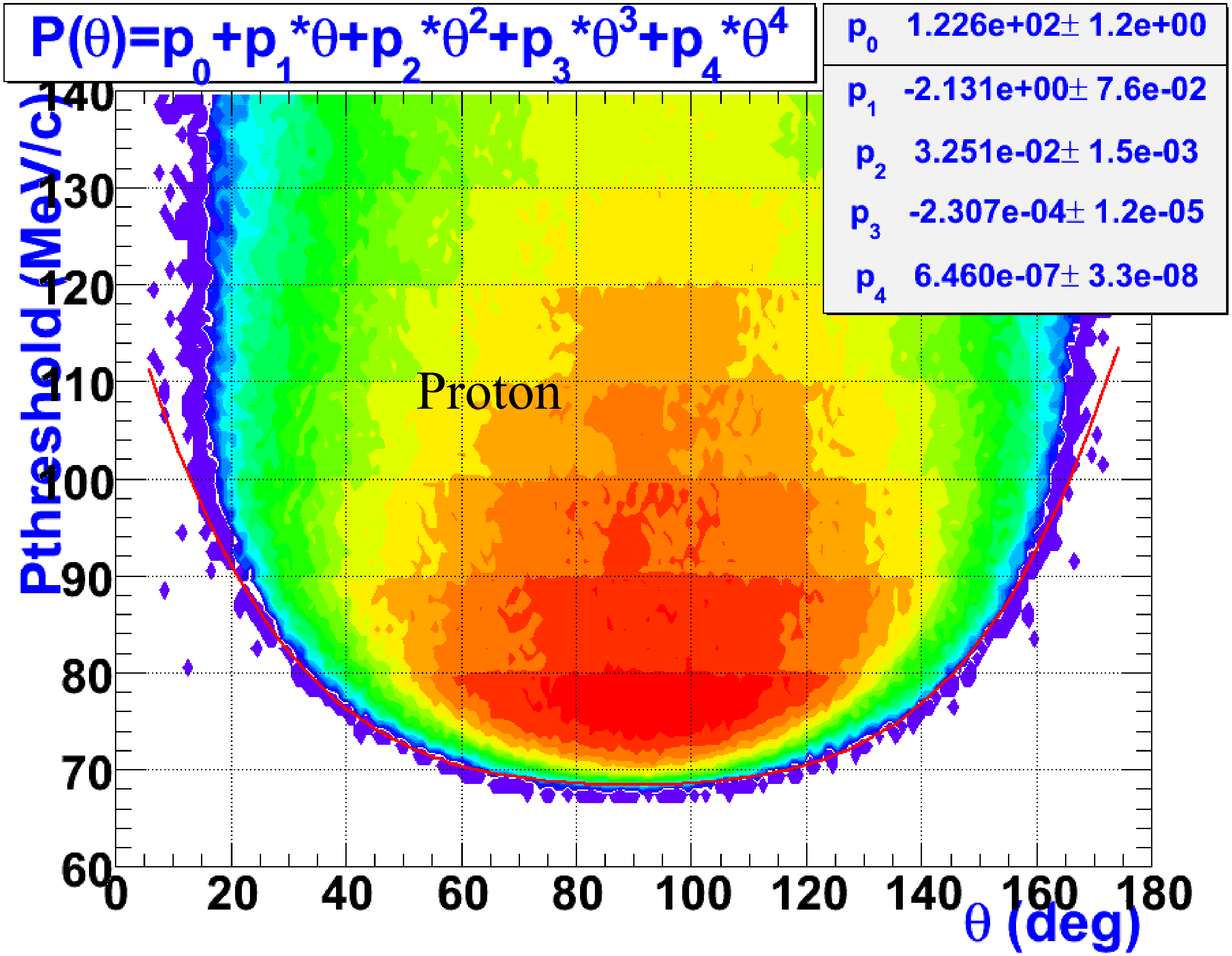


What I have done using simulation?

- Help to design the detector and choose the best configurations of HV and Drift Gas
- Debug/optimize reconstruction code of RTPC
- Generate energy loss correction tables, radiation length tables
- Detector's acceptance and efficiency study

RTPC Proton Threshold Momentum

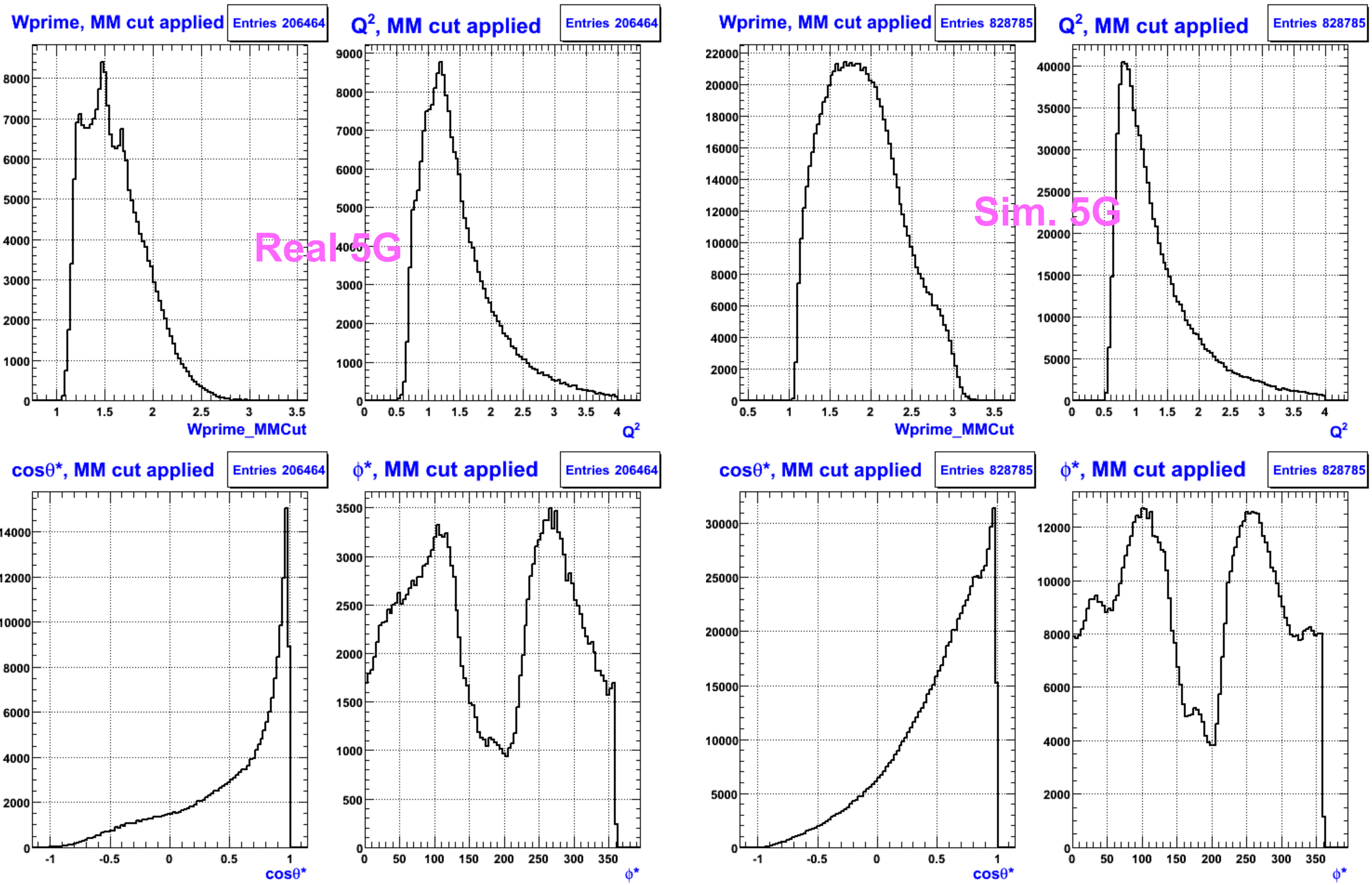


Exclusive Simulation Status

Simulation status									
	5 GeV		4 GeV		2 GeV		1 GeV		
Channel	Sim(k)	Data(k)	Sim(k)	Data(k)	Sim(k)	Data(k)	Sim(k)	Data(k)	
$D(e, e'\pi^- P_{CLAS})P_{RTPC}$	5257	118	6432	132	3000	55.2	435	1.4	50X
$D(e, e'\pi^- P_{RTPC})P_{CLAS}$	2673	27.5	2750	33.5	1230	17.7	367	0.67	100X
$D(e, e'\pi^- P_{RTPC}P_{CLAS})$	1420	14.7	1791	15.7	688	6.1	71.1	0.87	100X
$D(e, e'\pi^- P_{CLAS})X$	7612	1440	9386	1088	4376	130	557	1.8	5X
$D(e, e'\pi^- P_{RTPC})X$	4146	340	4302	269	1901	36.9	482	0.92	13X
$D(e, e'\pi^- P_{RTPC}P_{CLAS})X$	1771	98.2	2189	79.3	1041	11.1	129	0.16	17X

Generated 5 GeV exclusive events with the following distribution:
Flat W′
Q^2 with shape $1/x^{2.7}$
t with shape $-1/e^{1.3}$
Flat ϕ^*

Sim. Vs Real



Wprime, MM cut applied
Entries 206464
Wprime_MMCut
Q2, MM cut applied
Entries 206464
Q2
Real 5G
Wprime, MM cut applied
Entries 828785
Wprime_MMCut
Q2, MM cut applied
Entries 828785
Q2
Sim. 5G
cosθ*, MM cut applied
Entries 206464
cosθ*
φ*, MM cut applied
Entries 206464
φ*
cosθ*, MM cut applied
Entries 828785
cosθ*
φ*, MM cut applied
Entries 828785
φ*

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

- Binning information:

  W': 120 MeV each bin, [1.10,3.5);

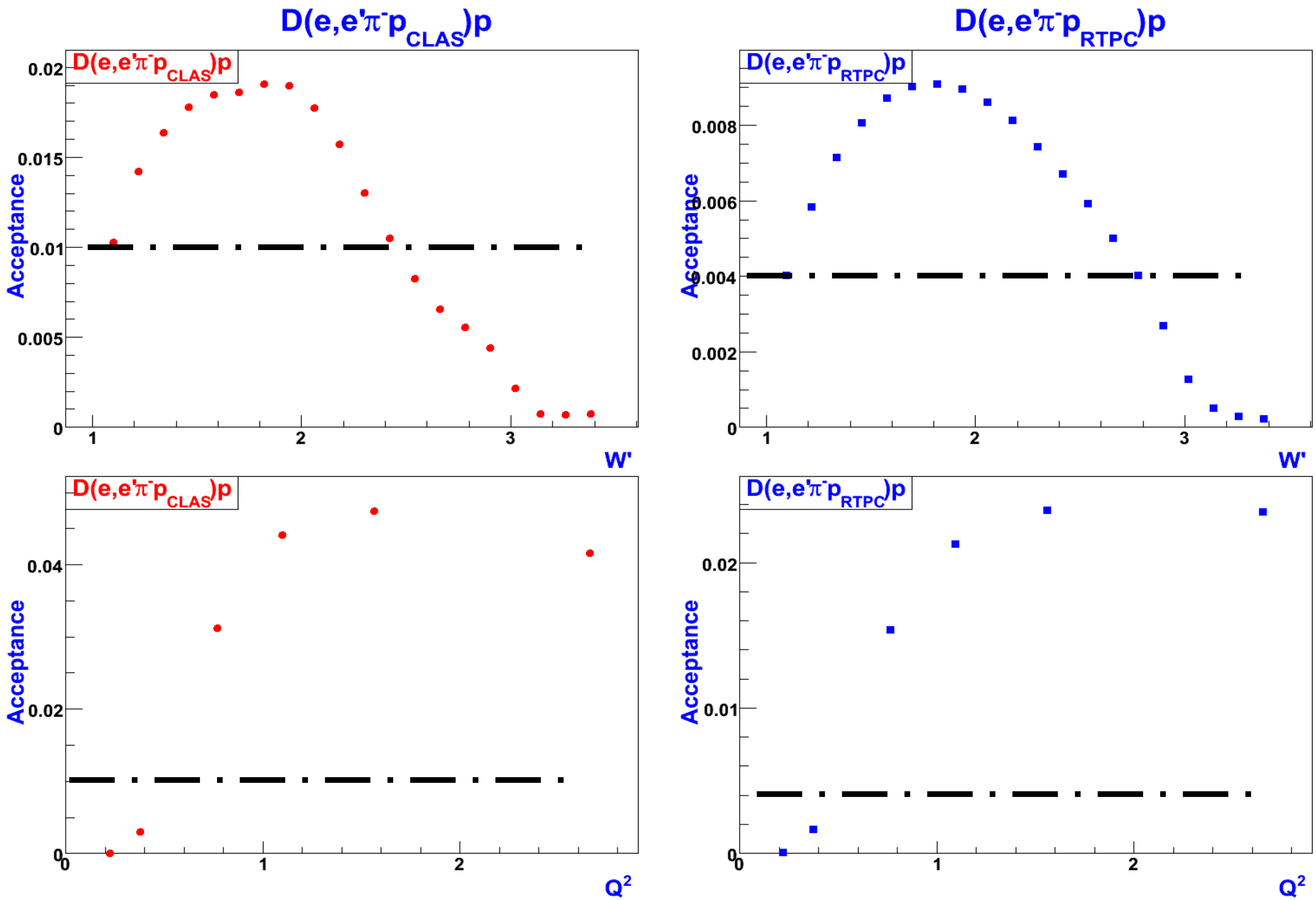
  Q^2 : 6 bins, { 0.2228, 0.3790, 0.7697, 1.0969, 1.5632, 2.6594, 4.5243 };

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

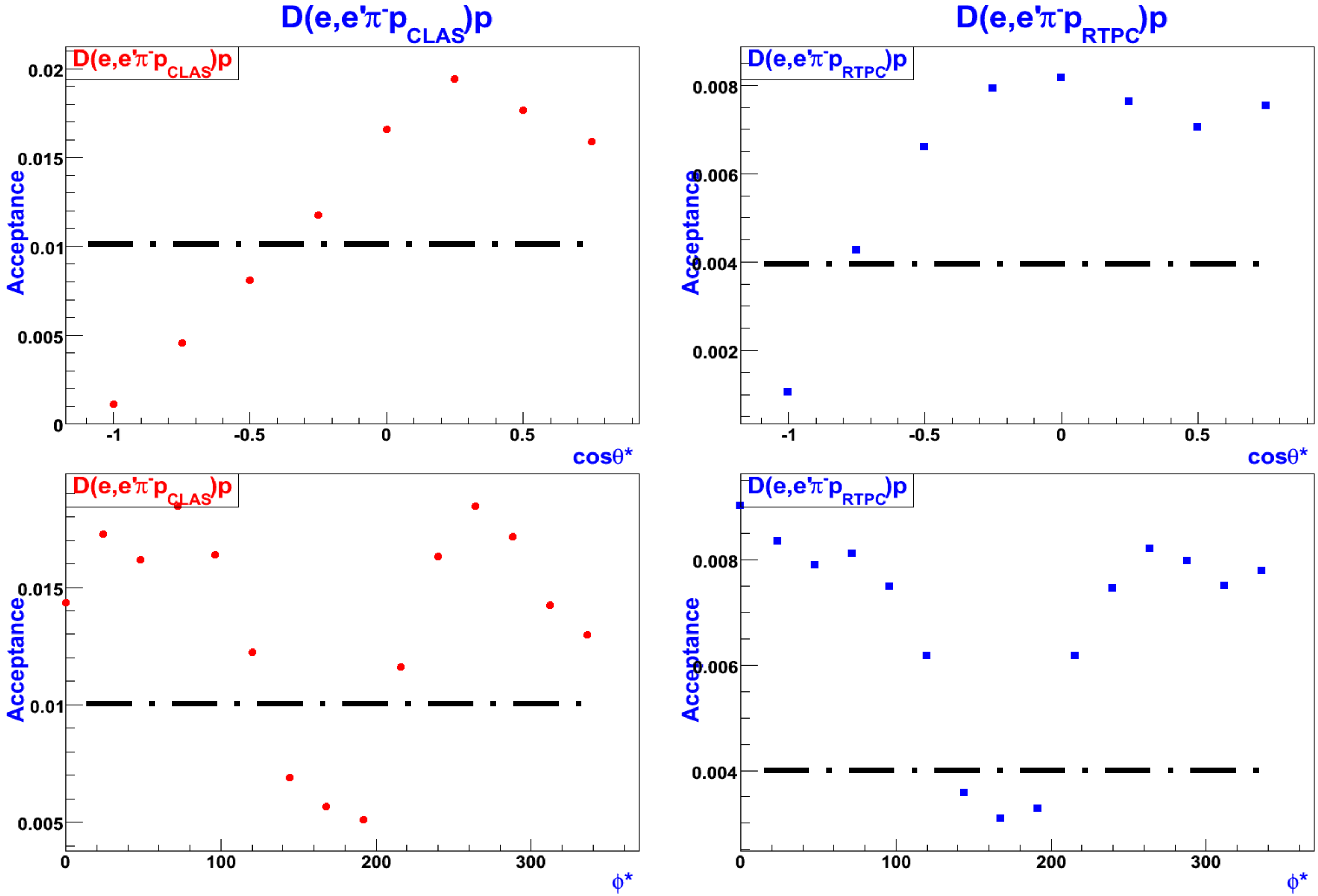
  ϕ^*: 15 bins, 24 degrees each bin, [0.0,360.0).

- Acceptance is the ratio of the number of events detected in a given bin to the number of simulated events in the same bin.
- Need to generate tables for $D(e,e'\pi^- p_{RTPC})p$ reaction and $D(e,e'\pi^- p_{CLAS})p$ reaction separately.
- Applied event by event, or bin by bin if data analysis binning is identical to acceptance binning.

Acceptance Correction, E=5.3 GeV



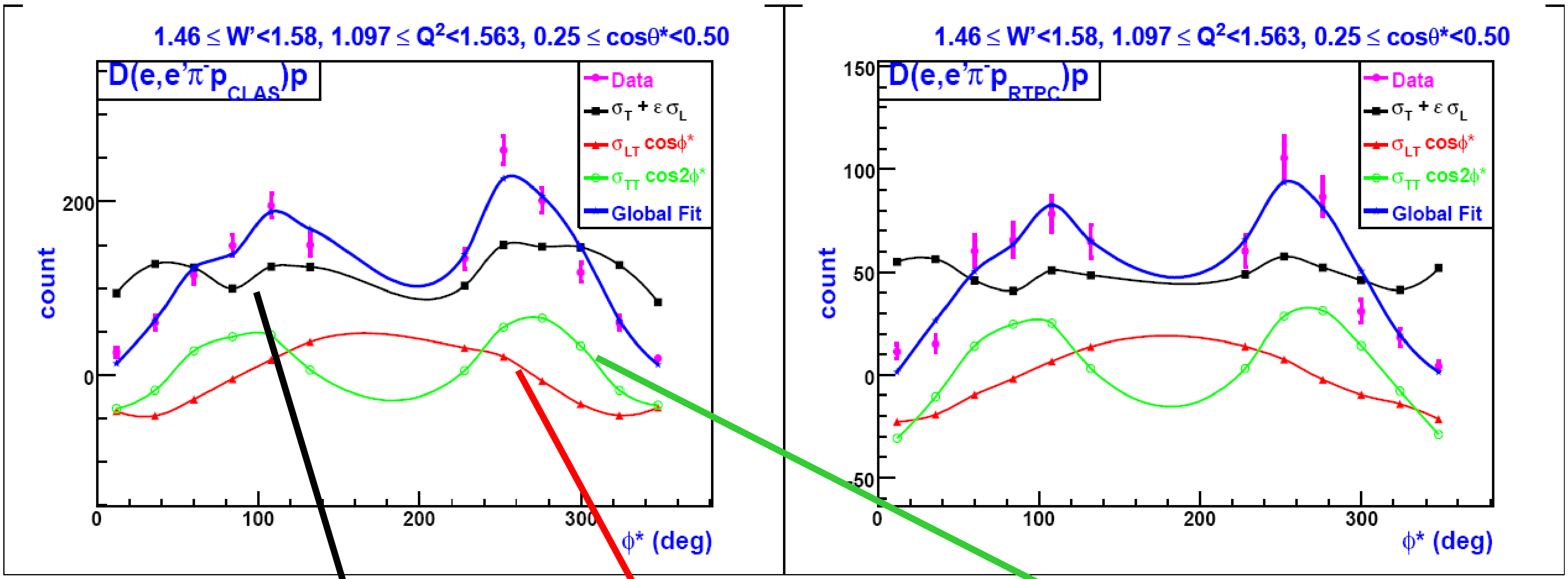
Acceptance Correction, E=5.3 GeV



Exclusive π^- Events Selection

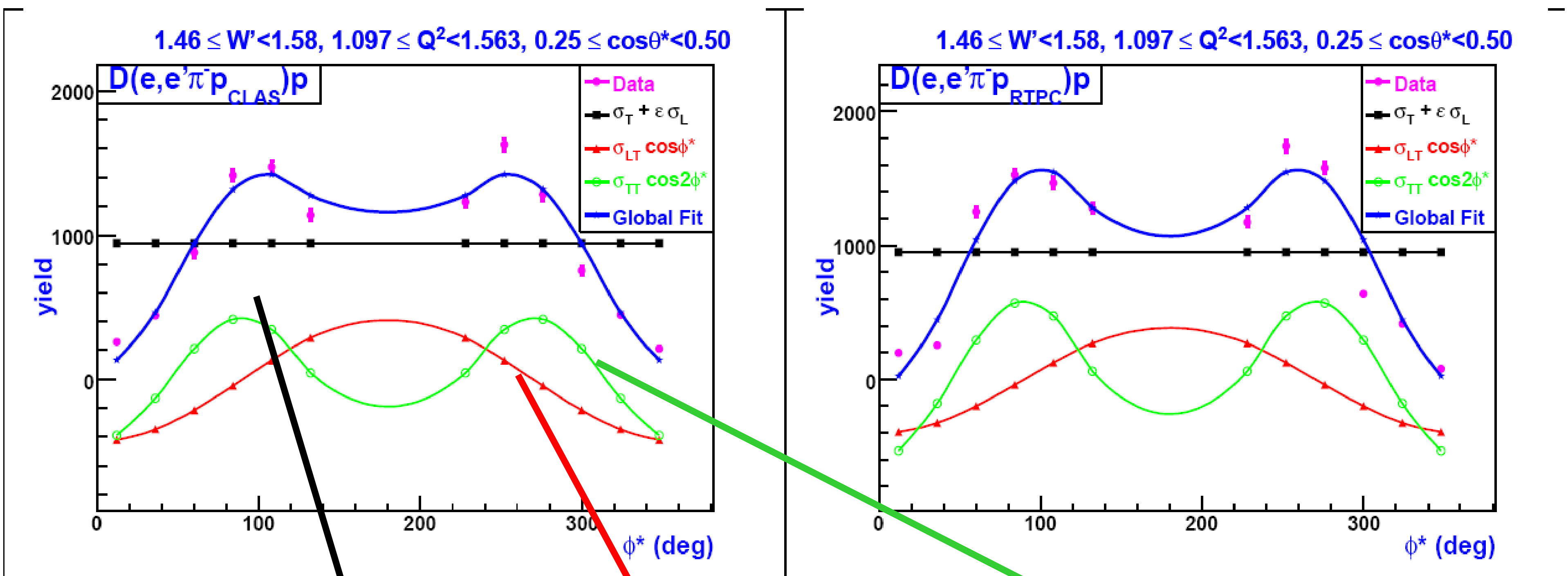
1. Select good trigger (scattered electron)
   q<0 ,
   CC + Osipenko (CC geometry match cut)
   EC (Ein>0.06, without Etot/p Cut)
   Theta_Z_Cut
2. Vertex Z correlation cut
   |z_el –Z_i| < 2.71 cm, I could be π^-, fast proton or RTPC proton.
3. By default using my PID routines to identify pions, if no pion found, use a negative non-trigger particle as π^-
4. Using my PID routines to identify protons, if no proton found, use a positive particle as proton
5. Apply kinematics corrections
6. Apply 2-σ missing mass cut
7. Apply background subtraction
8. Apply acceptance and efficiency correction

Cross Section Fitting



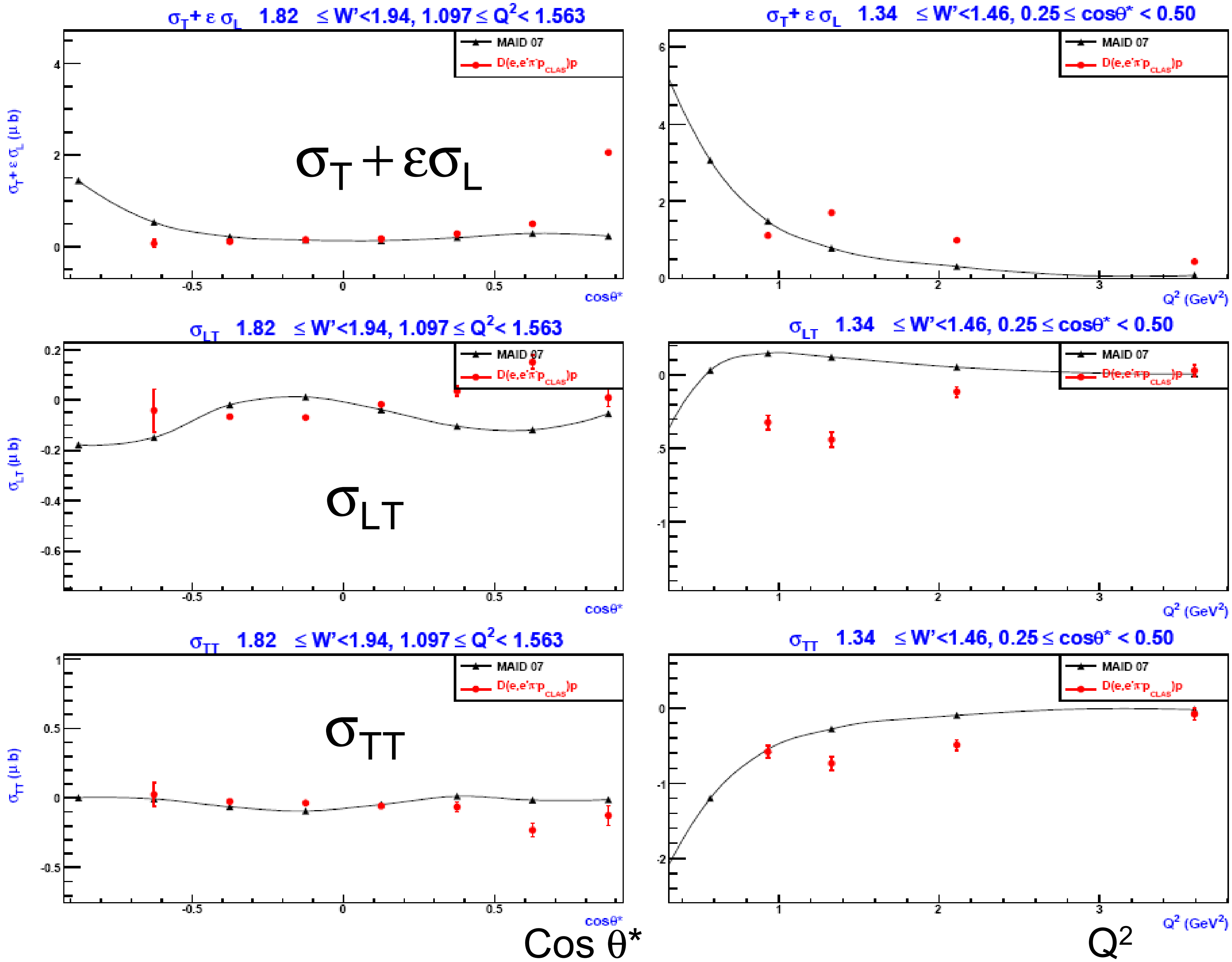
$$\frac{\partial^2 \sigma}{\partial \Omega_\pi^*} = \boxed{\sigma_T + \varepsilon \sigma_L} + \boxed{\sqrt{2\varepsilon(1+\varepsilon)}\sigma_{LT} cos\phi_\pi^*} + \boxed{\varepsilon \sigma_{TT} cos2\phi_\pi^*}$$

Cross Section Fitting

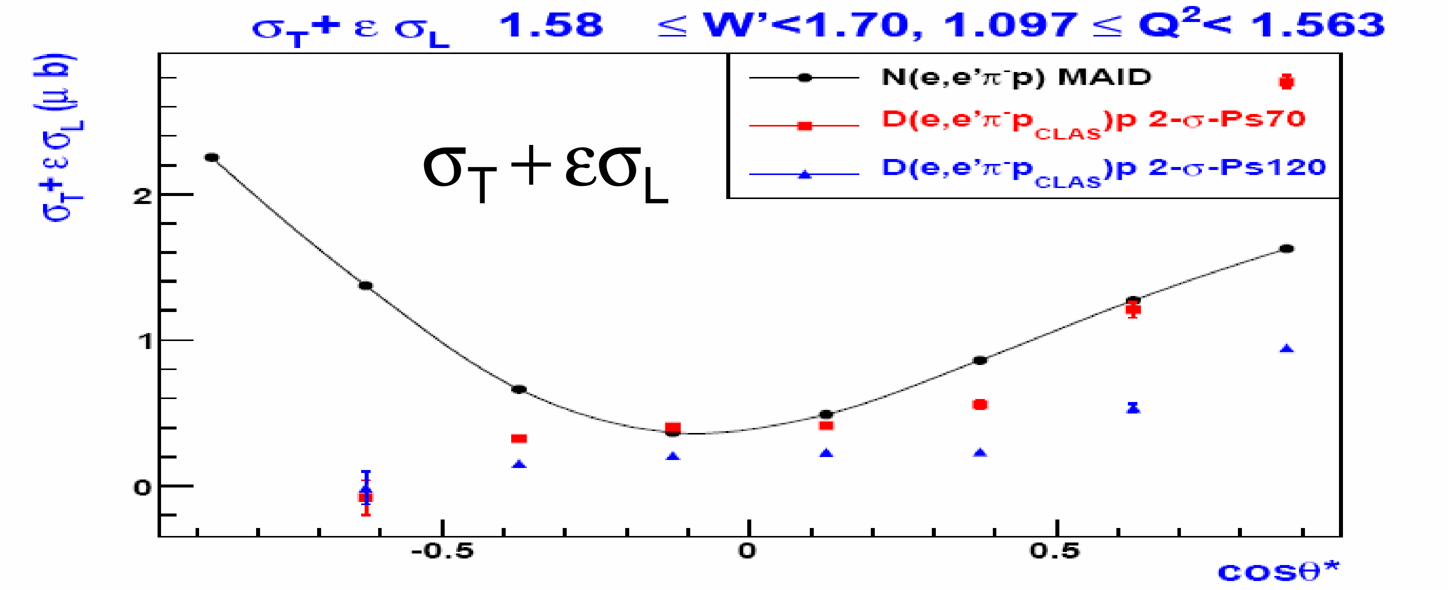


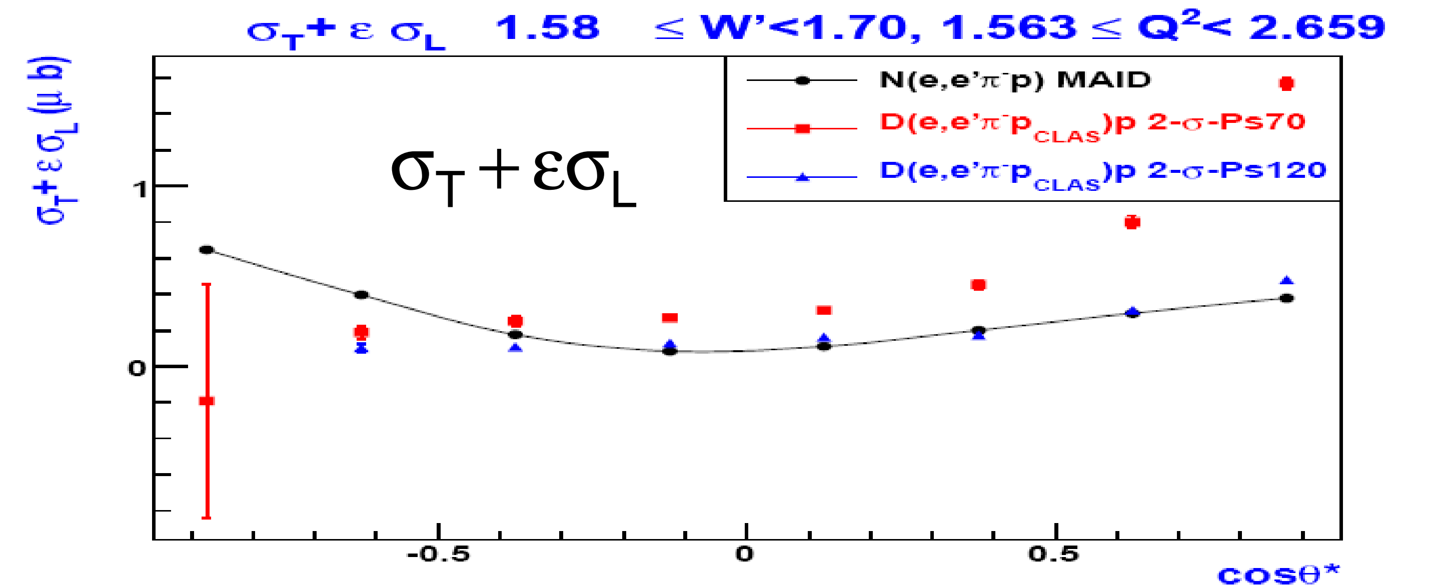
$$\frac{\partial^2\sigma}{\partial\Omega_\pi^*} = \boxed{\sigma_T + \varepsilon\sigma_L} + \boxed{\sqrt{2\varepsilon(1+\varepsilon)}\sigma_{LT}cos\phi_\pi^*} + \boxed{\varepsilon\sigma_{TT}cos2\phi_\pi^*}$$

Cross Section: BoNuS Vs MAID



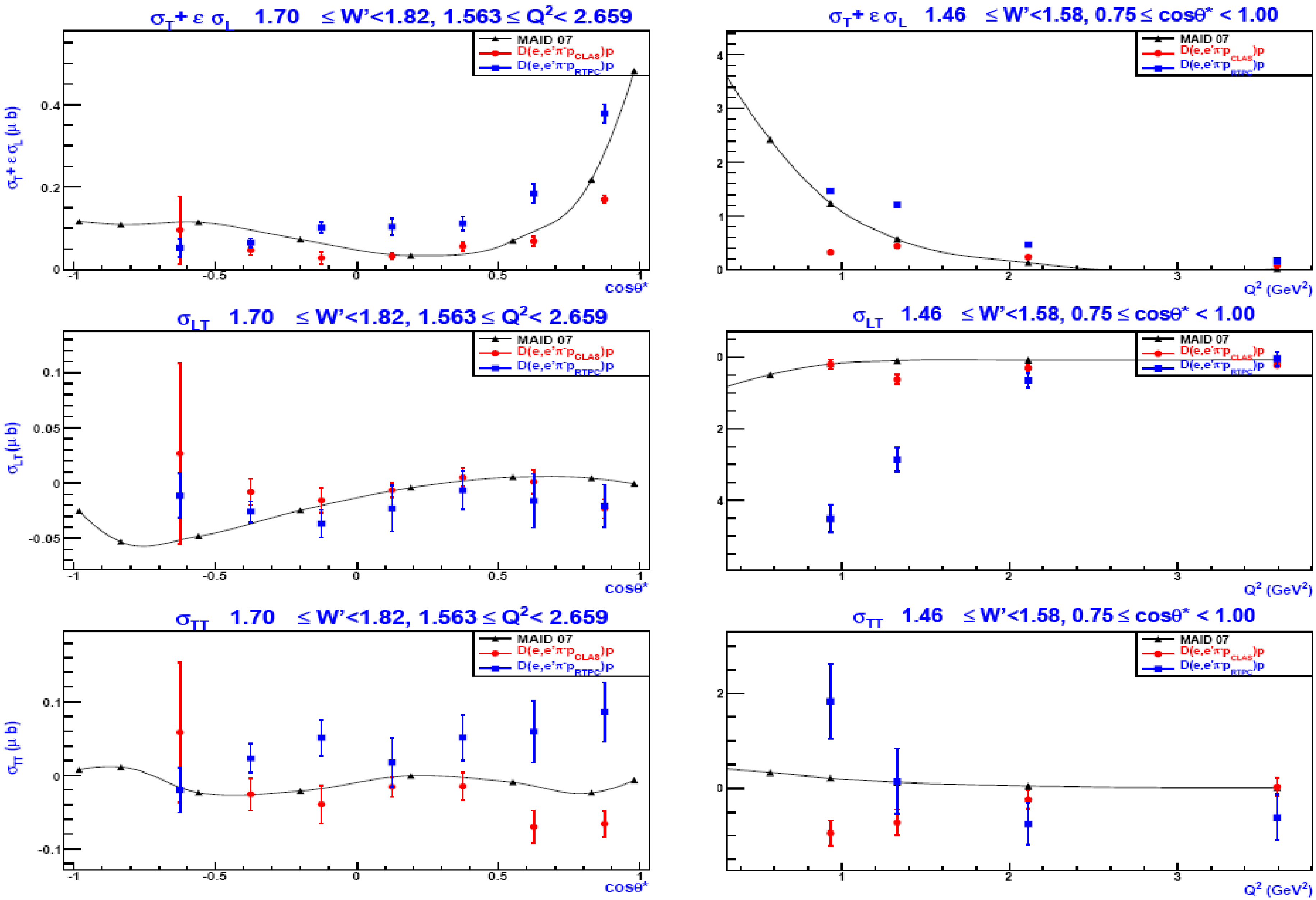
Cross Section: Ps<120 Vs Ps>120





Thank you!

Cross Section: BoNuS Vs MAID



Cross Section: Ps<120 Vs Ps>120