Exclusive π^- Electro-production from the Neutron in the Resonance Region

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for the CLAS Collaboration

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Outline

- Motivation
- Theory background
- Experiment setup
- Data Analysis
- Result
- Outlook

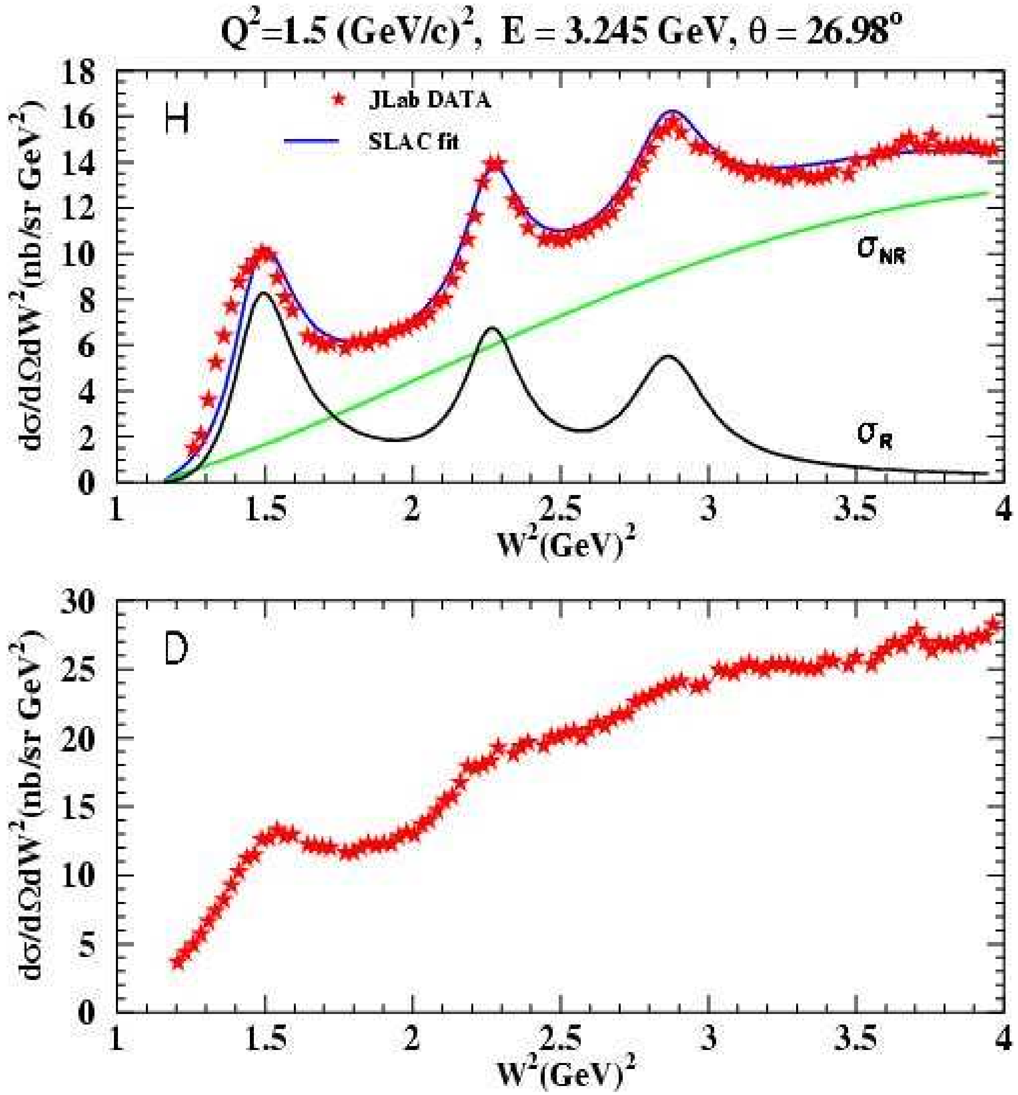
Motivation

- 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.

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.

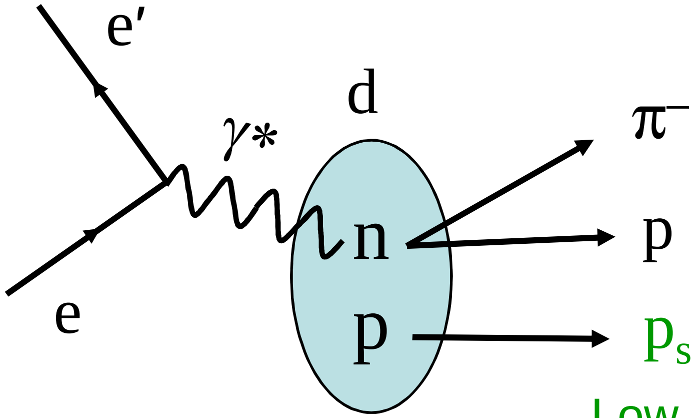


L.W. Whitlow *et al.*, Phys. Lett. **B282**, 475 (1992).

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

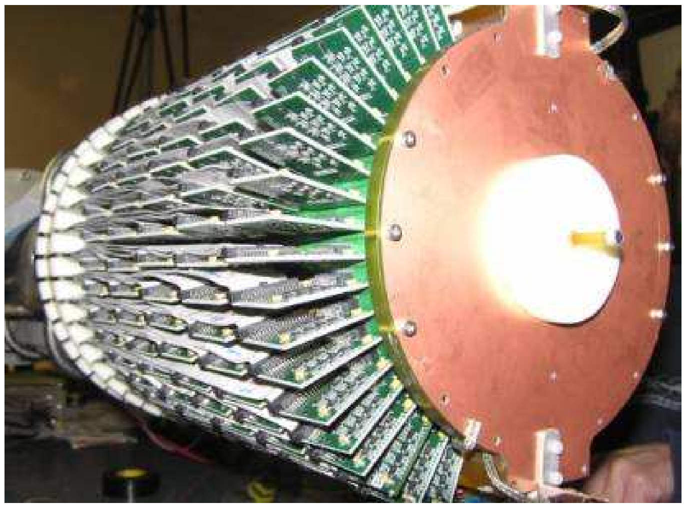
Exclusive π^- electro-production

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.



Low momentum spectator proton

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

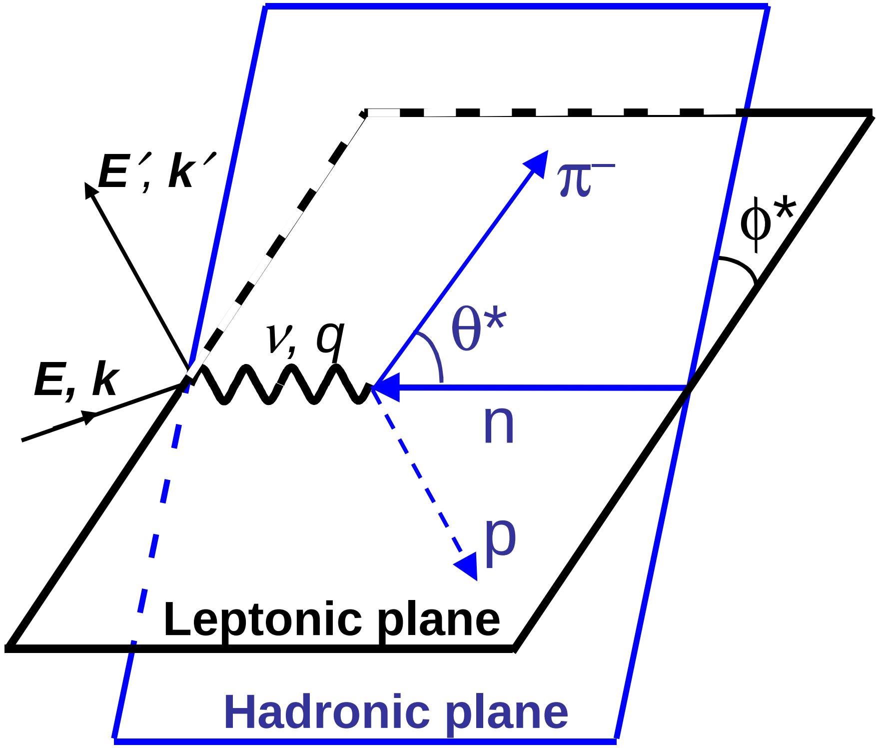


π^- Production Kinematics

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

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

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



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

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

Exclusive π^- Cross Section

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

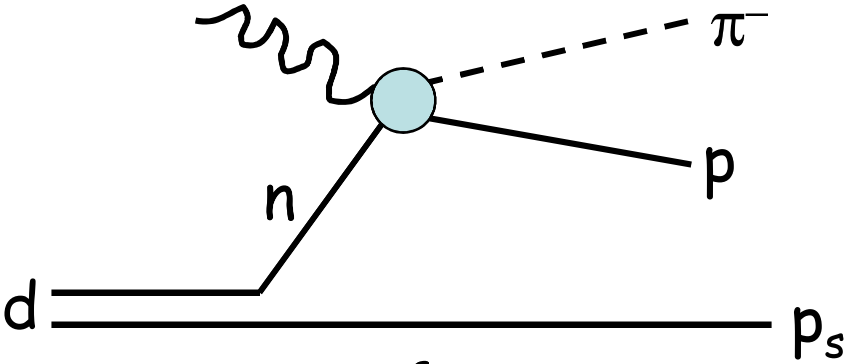
$$\Gamma_v = \frac{\alpha}{2\pi^2}\,\frac{E'}{E}\,\frac{K_\gamma}{Q^2}\,\frac{1}{1-\varepsilon}\quad , \qquad K_\gamma = (W^2 - M_n^2)/2M_n$$

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

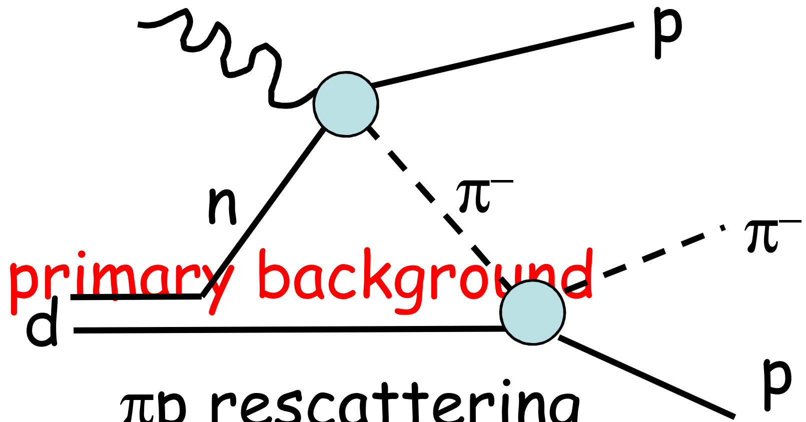
Unpolarized virtual photon cross-section of $\gamma^*+n \rightarrow \pi^-+p$

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

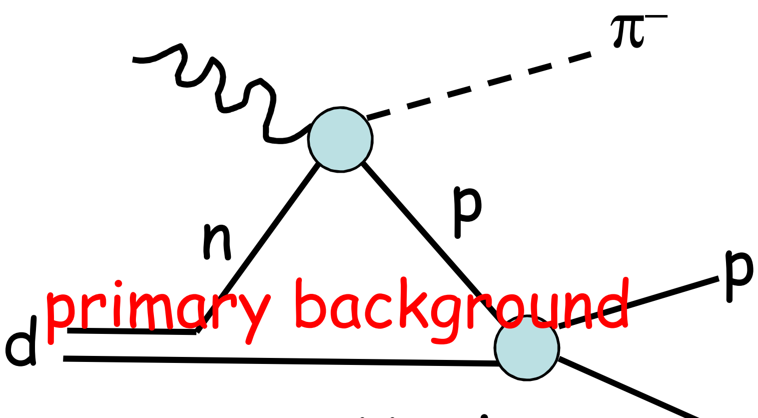
Final State Interations



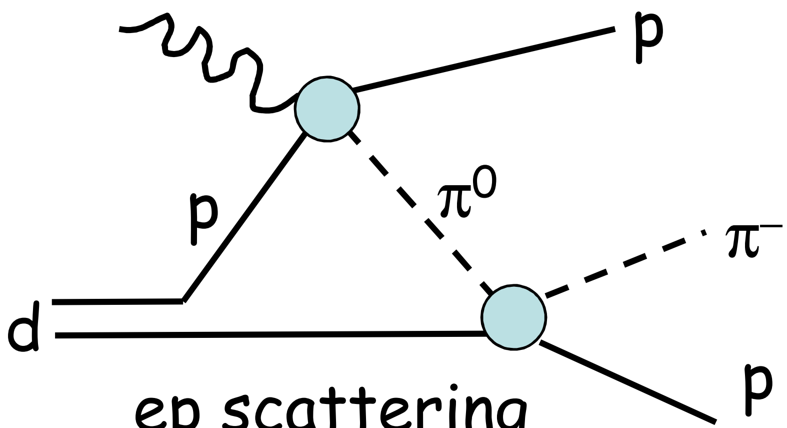
quasi-free



πp rescattering

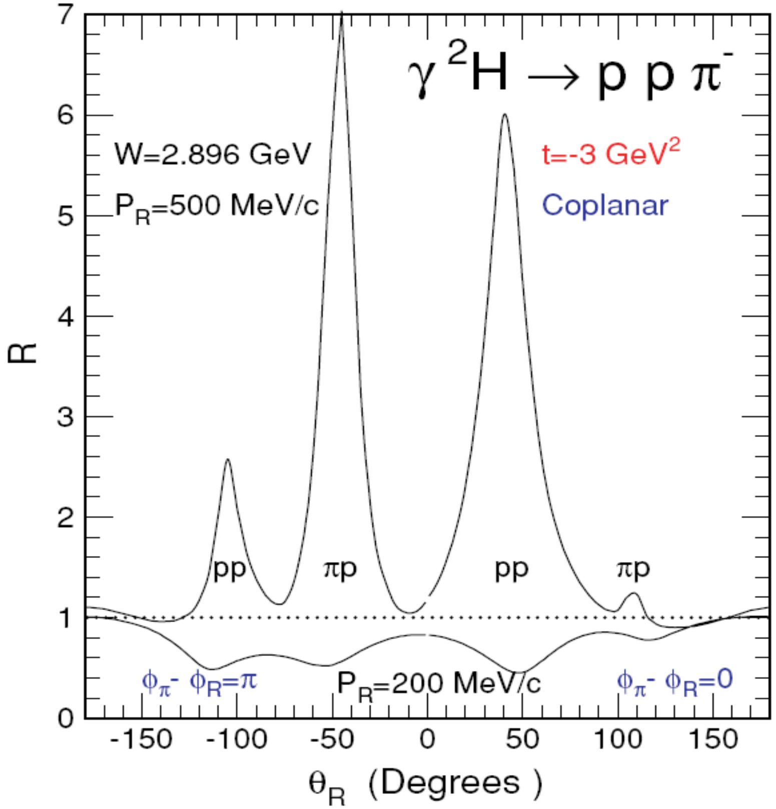


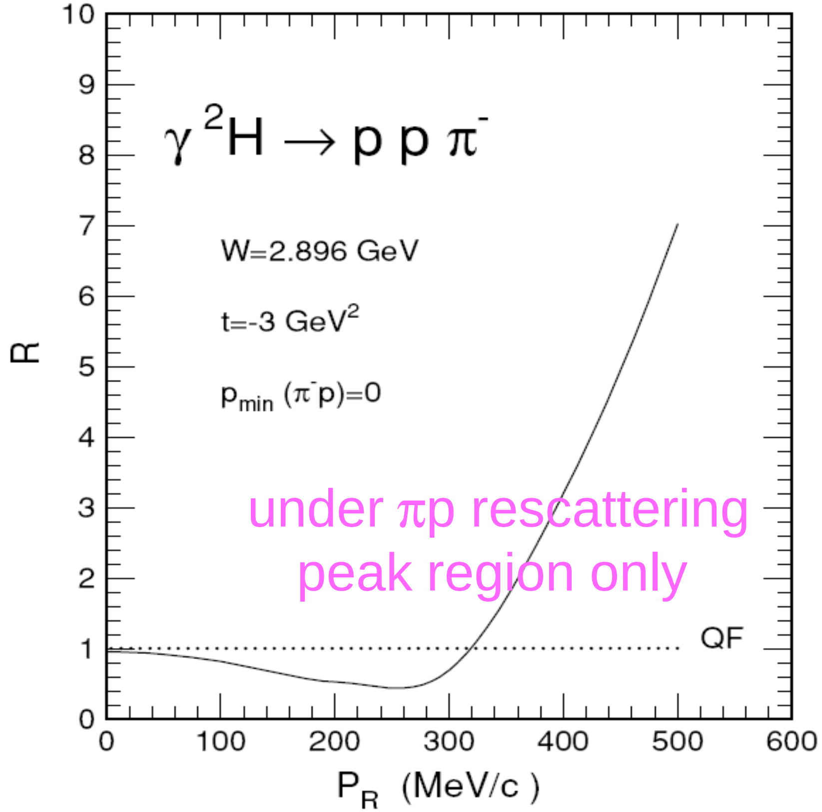
pp rescattering



ep scattering

FSI Prediction for $D(\gamma,\pi^{-}p)p$, by Laget



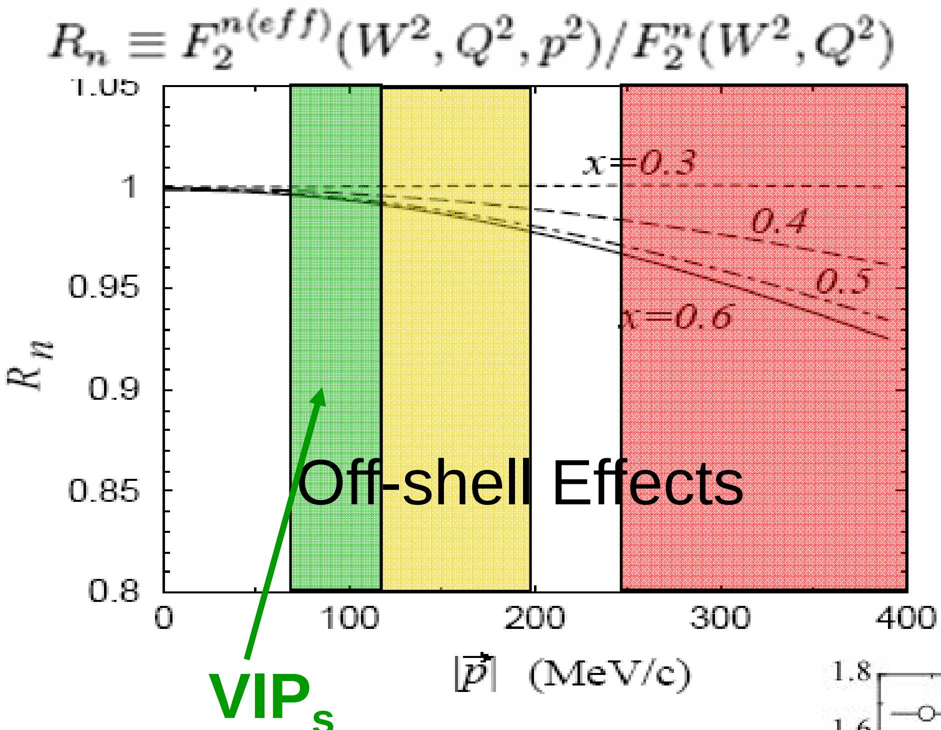


J. M. Laget, Phys. Rev. C. **73**, 044003 (2006).

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 $D(e,e'p_s)X$



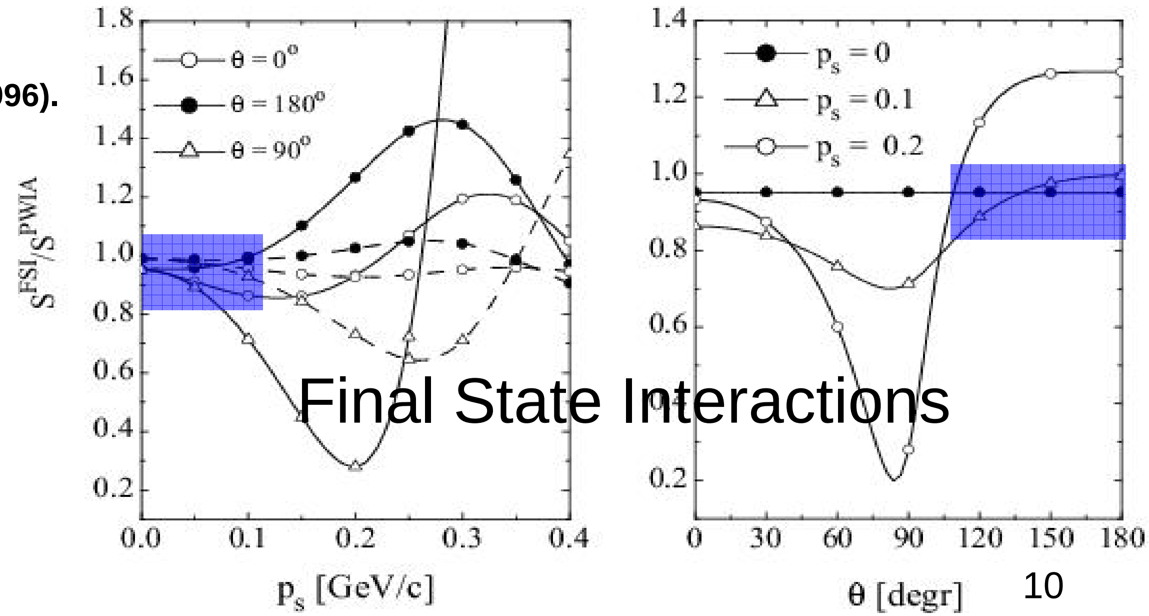
W. Melnitchouk *et al*, Phys. Lett. B377, 11 (1996).

↑

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} (>100°), angle between Ps and virtual photon, to minimize FIS.

↓



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

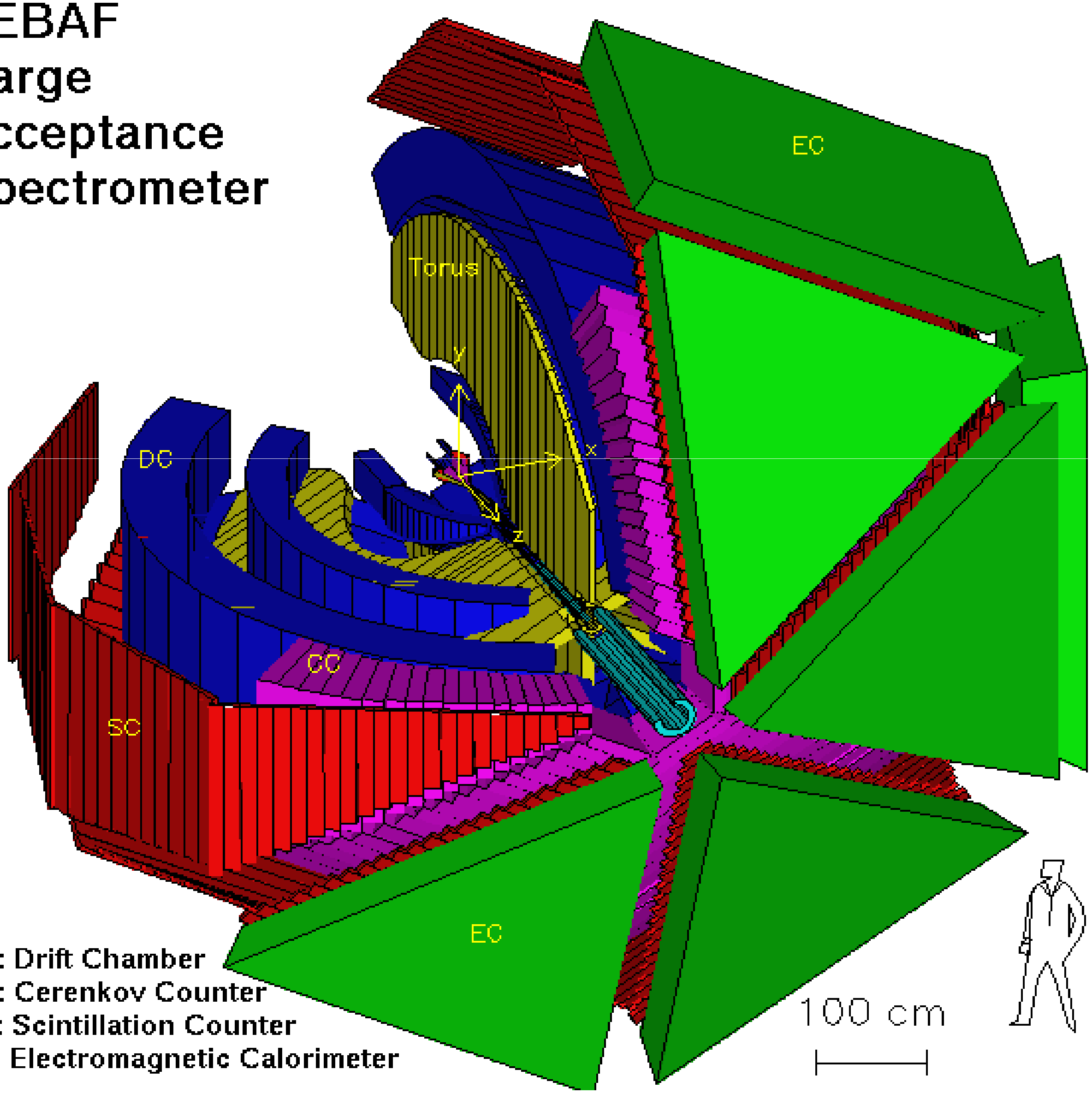
Jefferson Lab Experiment E03-012

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

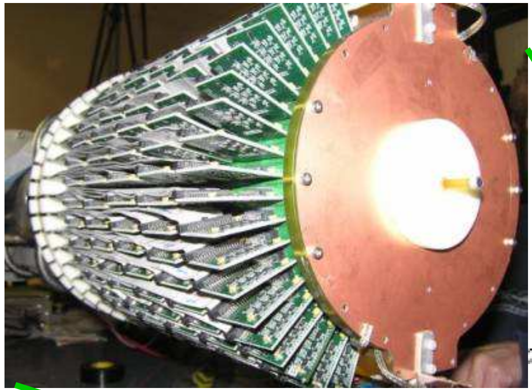
CLAS in Jefferson Lab, Hall B

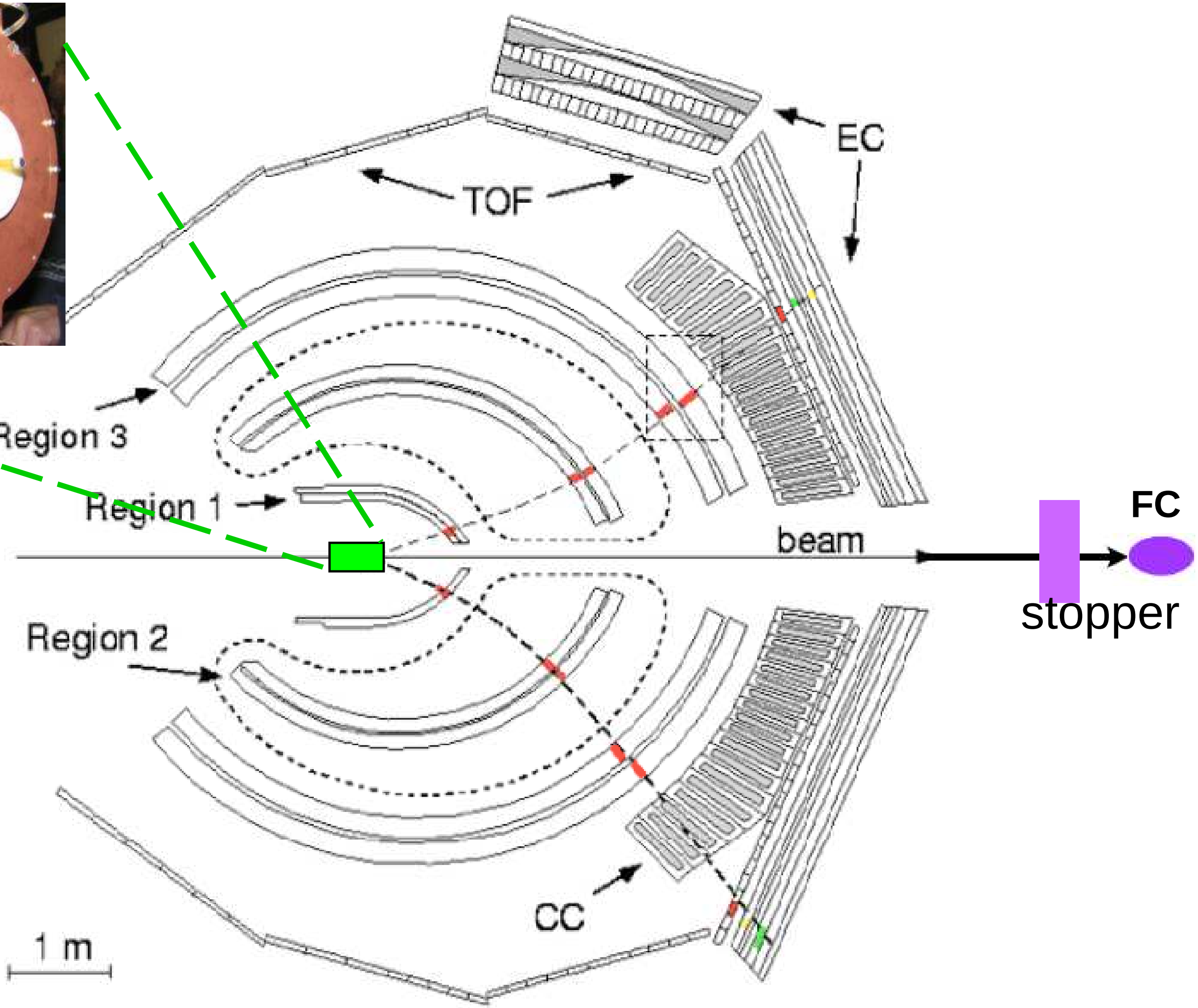
CEBAF
Large
Acceptance
Spectrometer



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

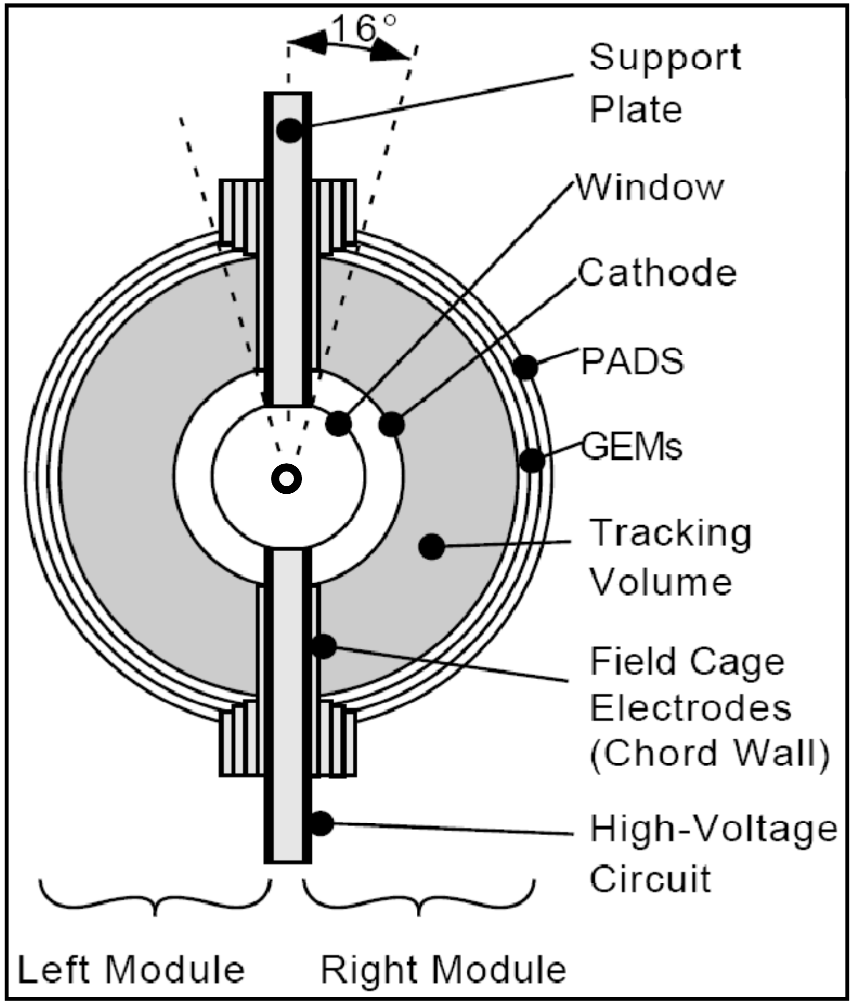
RTPC Sits in the Center of CLAS

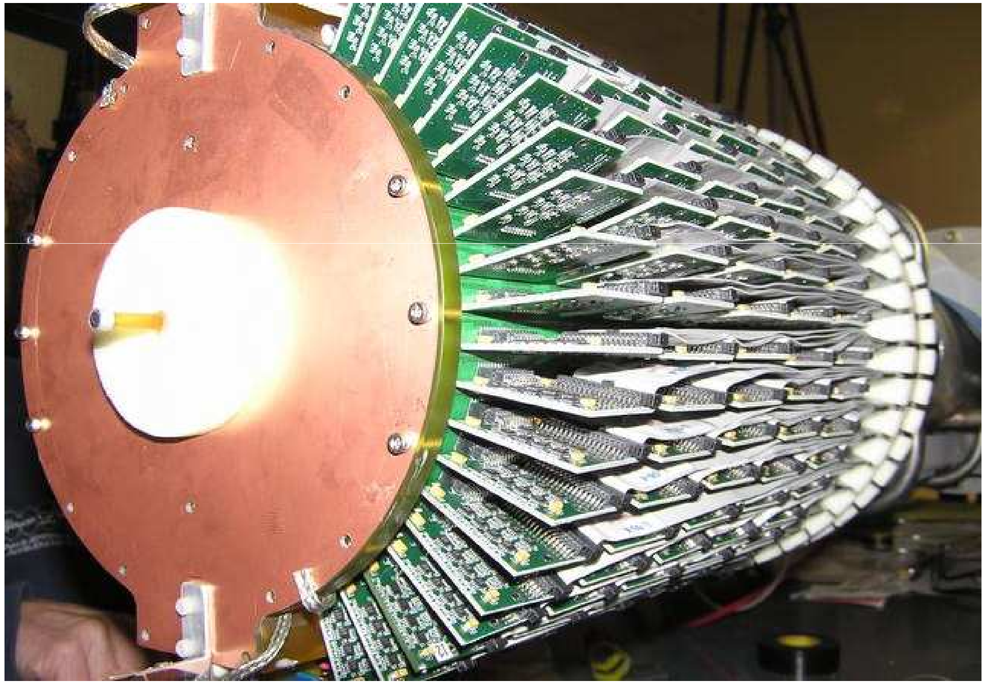




CLAS

Radial Time Projection Chamber (RTPC)





Radial Time Projection Chamber (RTPC)

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

3 layers of GEM

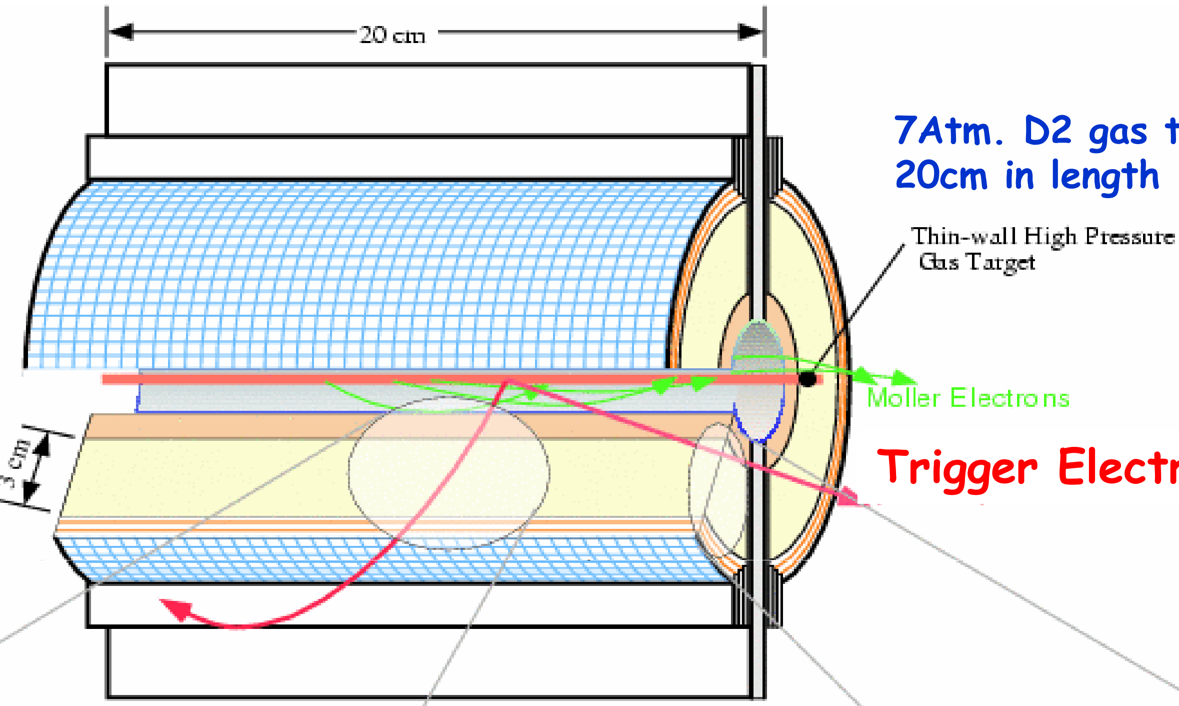
3200 pads (channels)

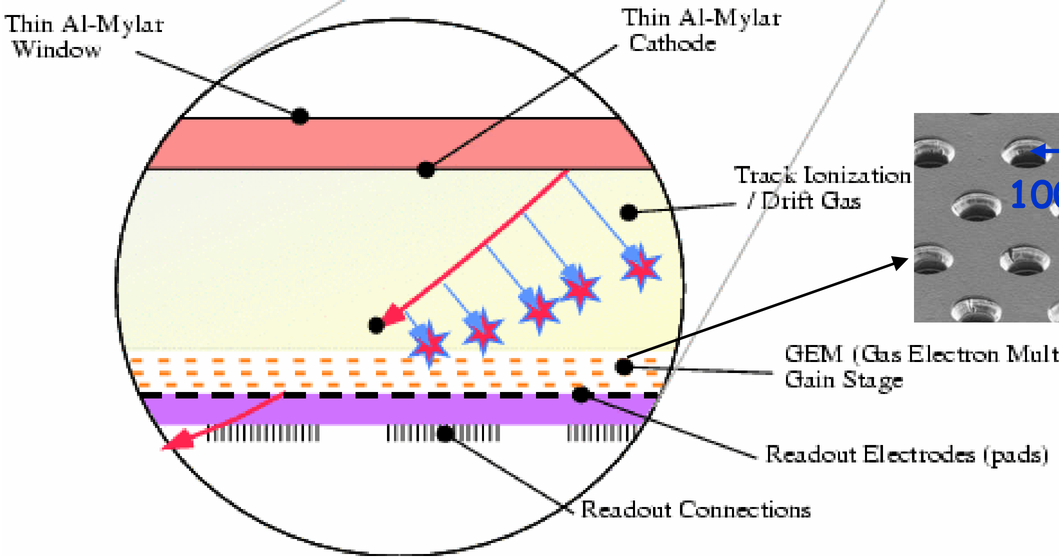
5 Tesla B field

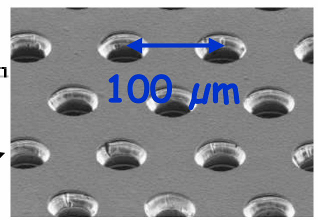
Particles ID by dE/dx

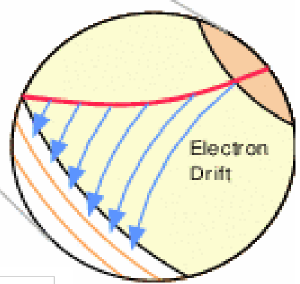
3-D tracking:
time of drift -> r
pad position -> ϕ, z

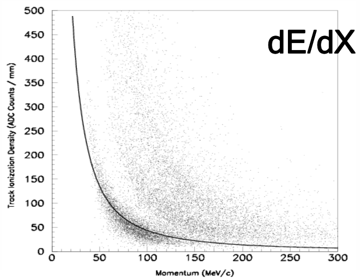
7Atm. D2 gas target, 20cm in length



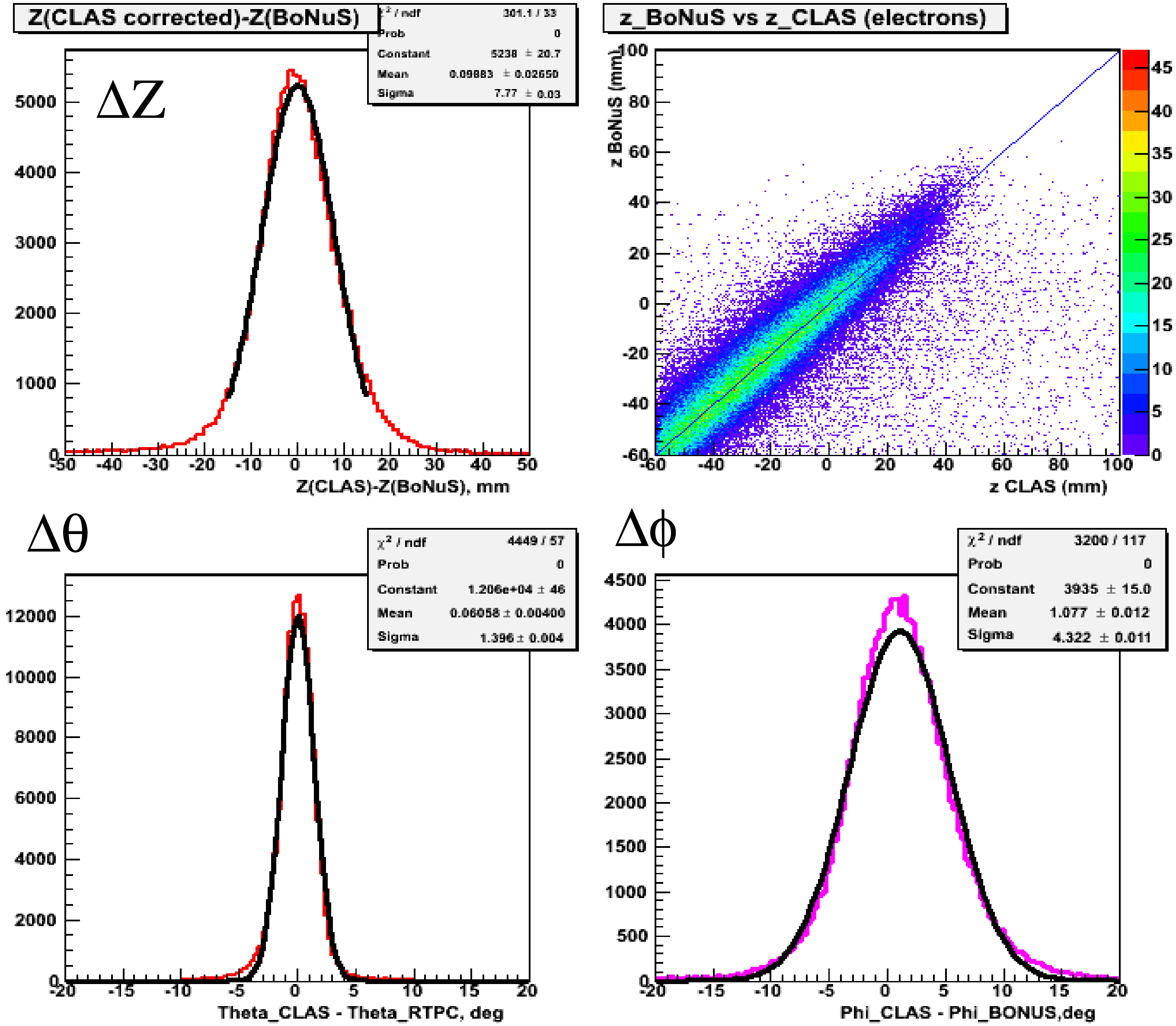








RTPC Resolution



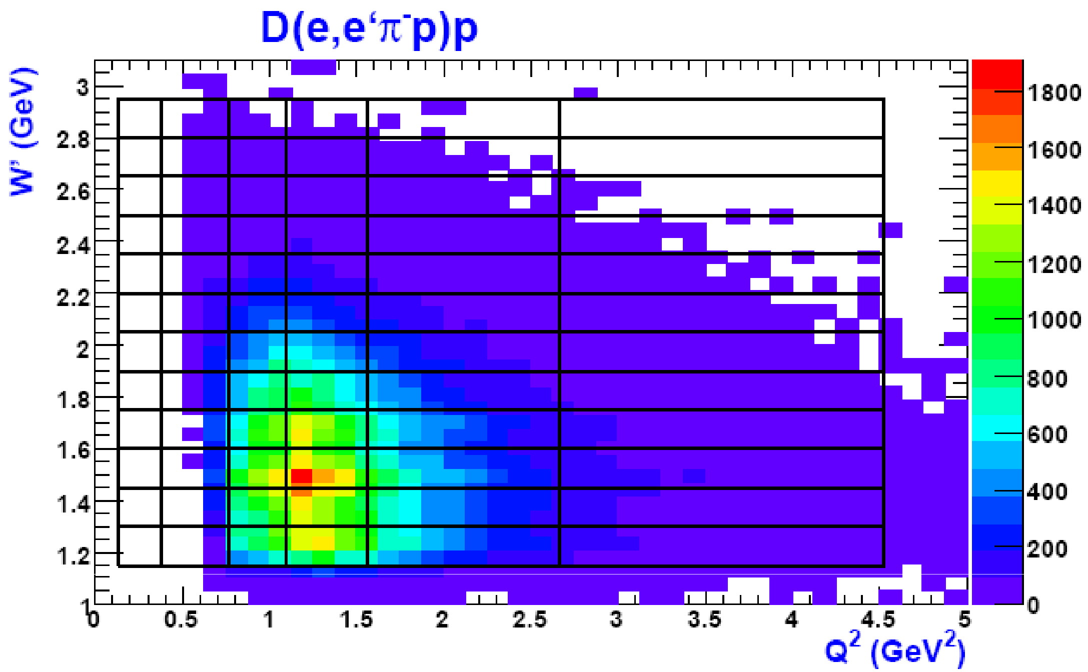
Trigger electrons measured by CLAS are compared to the same electrons measured in BoNuS during High Gain Calibration runs.

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

Analysis outline

1. Quality Checks
2. Vertex correction and 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

Kenematic coverage and binning, 5 GeV

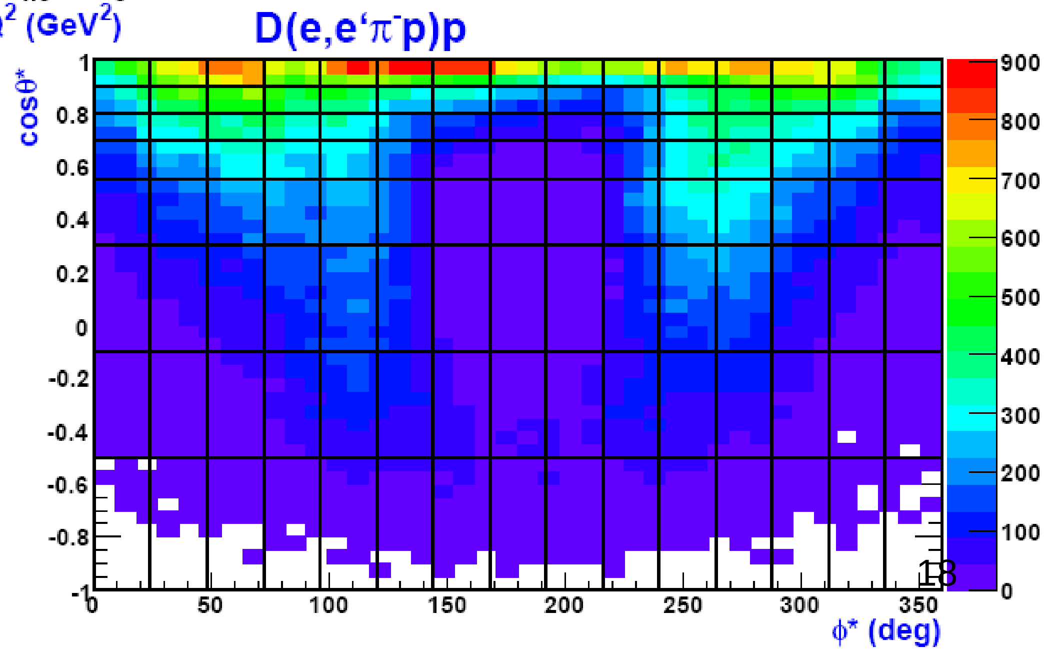


W′: 150 MeV each bin, [1.15,2.95)

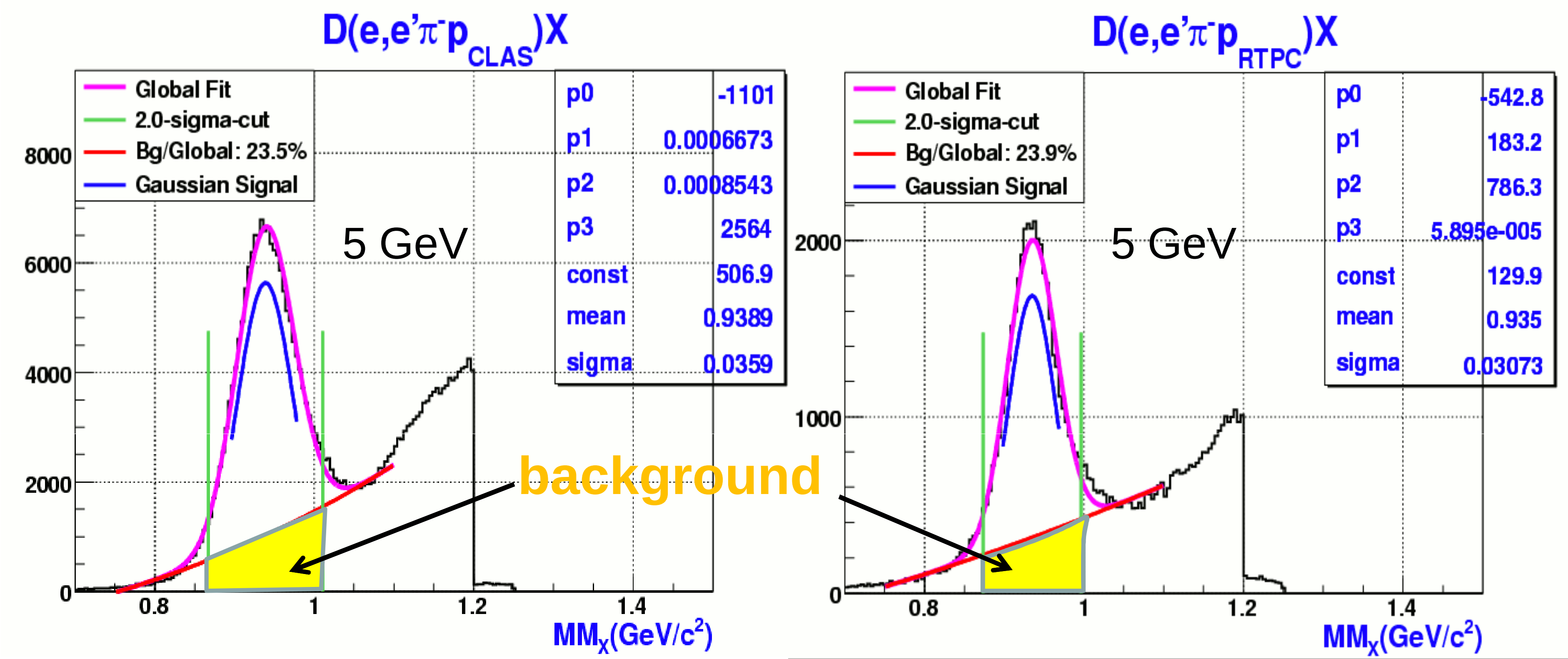
Q^2 : 6 bins with boundaries at 0.1309, 0.3790, 0.7697, 1.0969, 1.5632, 2.6594, 4.5243

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)



Missing Mass Cut: 2σ



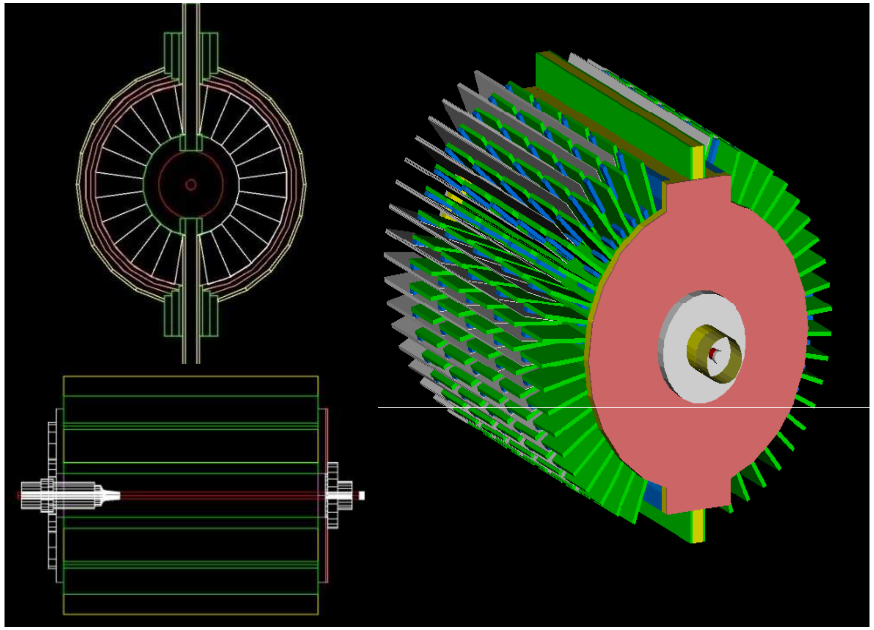
$\gamma^* + n \rightarrow \pi^- + X \Rightarrow X = \gamma^* + n - \pi^-$

$E_x = E\gamma + E_n - E_\pi ; \quad P_x = P\gamma + P_n - P_\pi$

$\longrightarrow \quad M_x^2 = E_x^2 - P_x^2$

Simulation Overview

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



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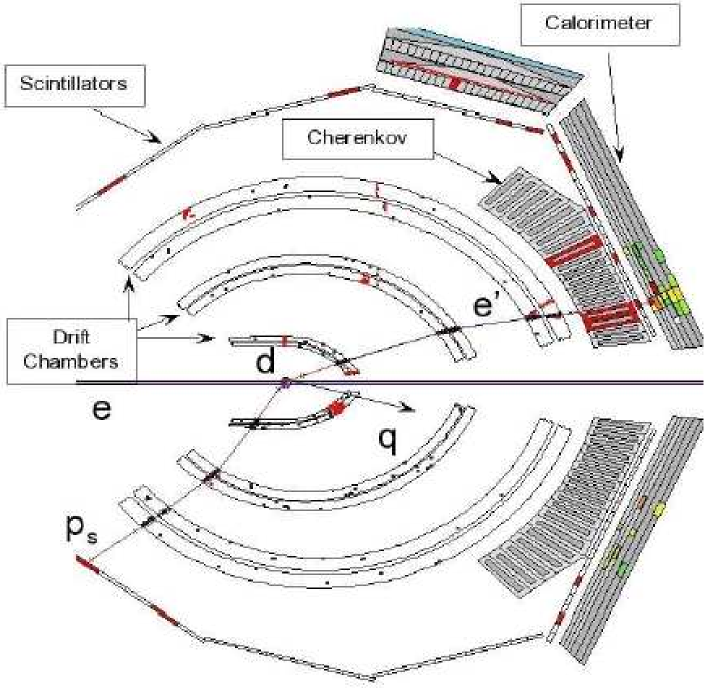
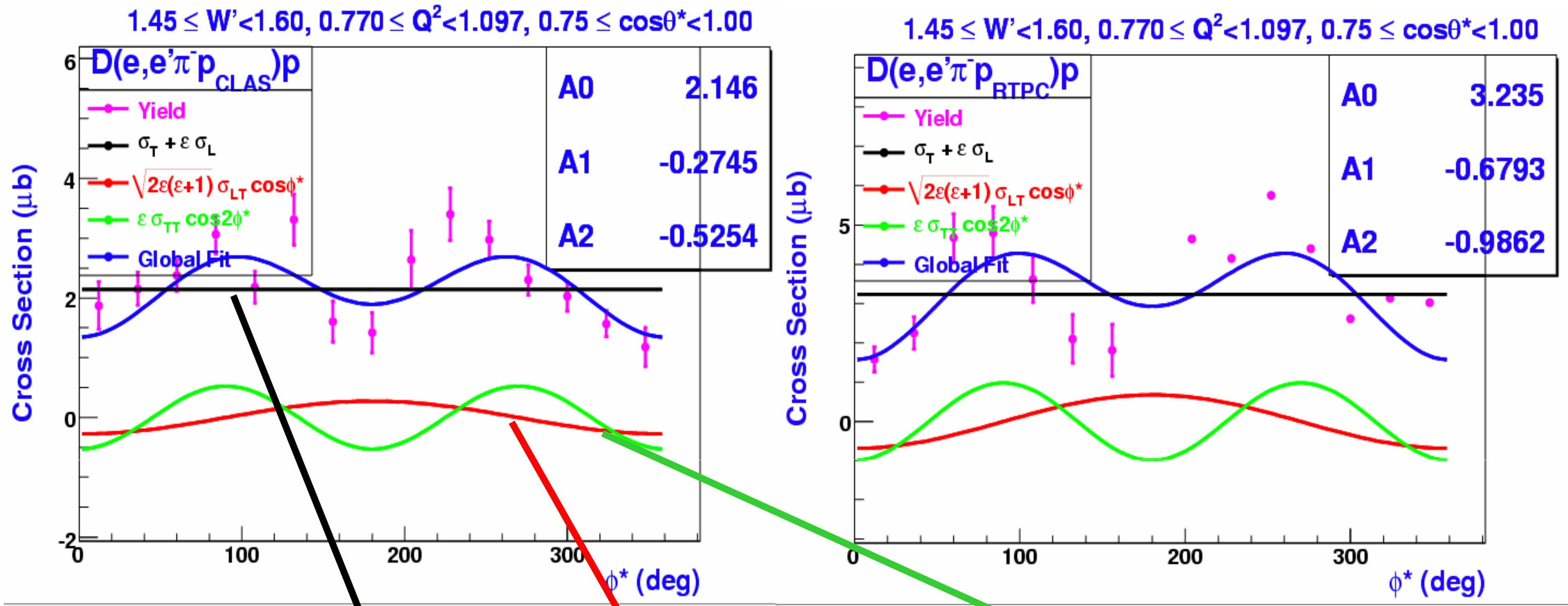


What have been done with simulation?

- 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\`π^-p_{RTPC})p
- Study particle detection efficiency
- Model the background…

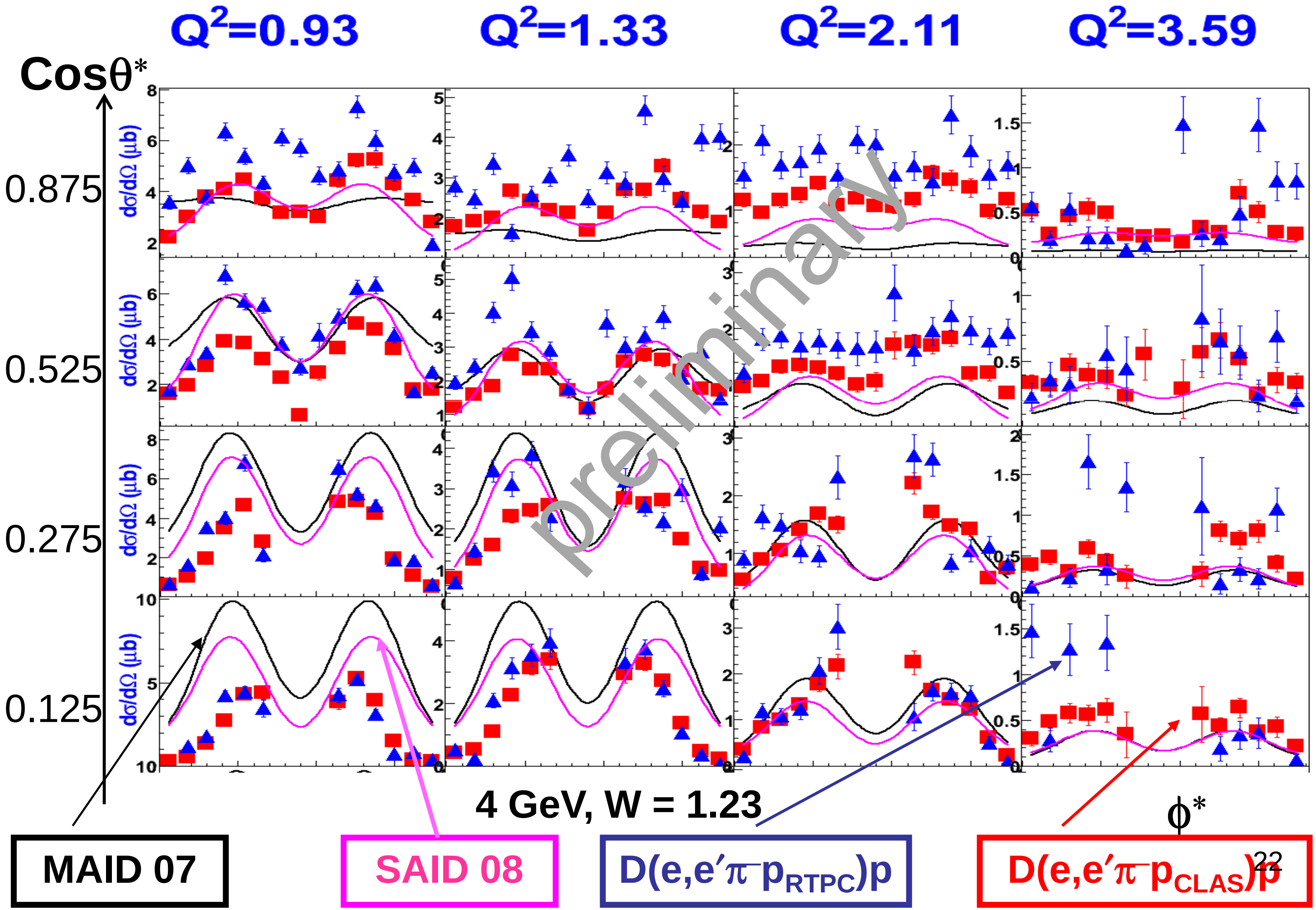
Cross Section Fitting



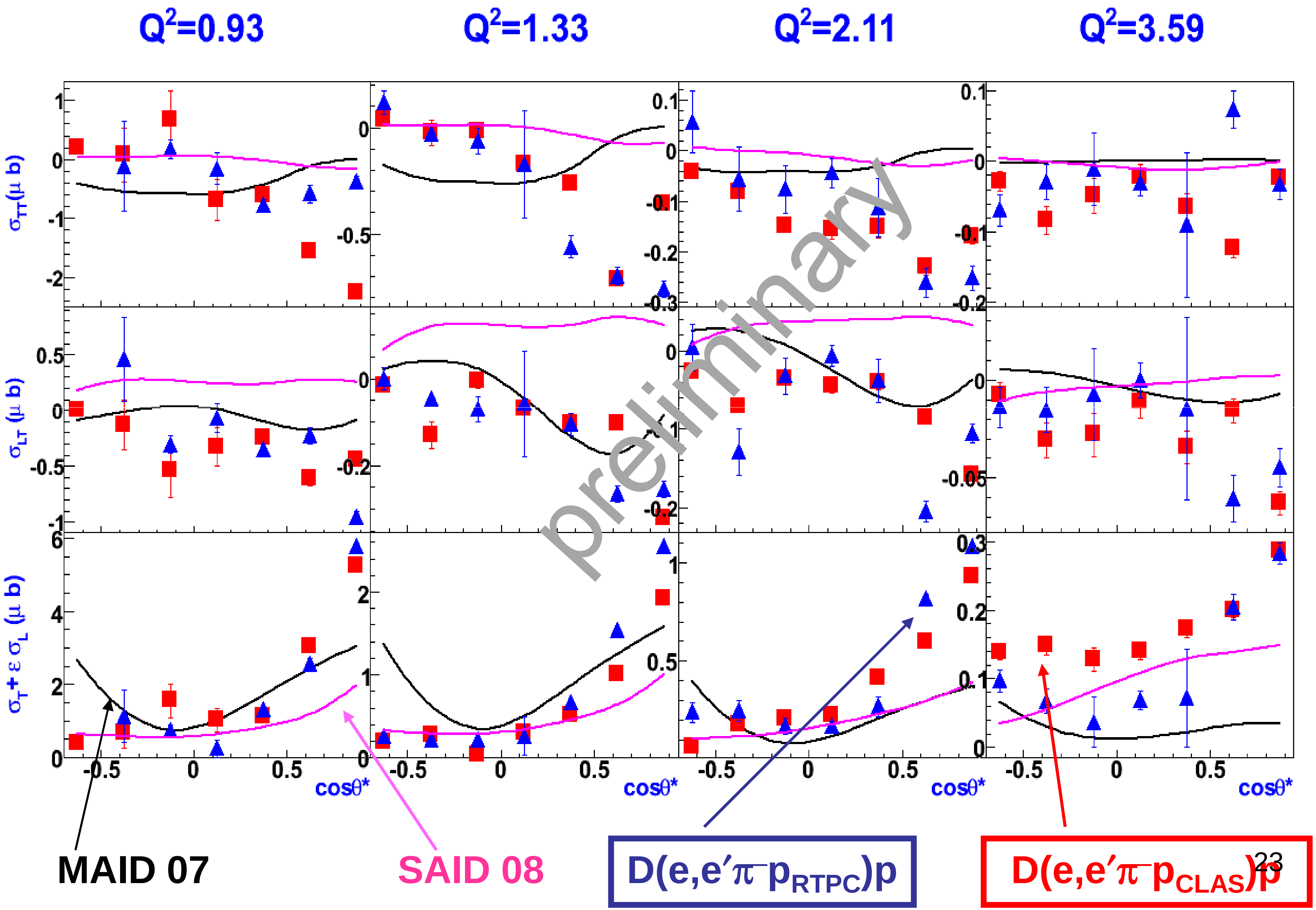
$$\frac{\partial^2\sigma}{\partial\Omega_\pi^*} = \boxed{\sigma_T + \varepsilon\sigma_L} + \boxed{\sqrt{2\varepsilon(1+\varepsilon)}\sigma_{LT}cos\phi_\pi^*} + \boxed{\varepsilon\sigma_{TT}cos2\phi_\pi^*}$$

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

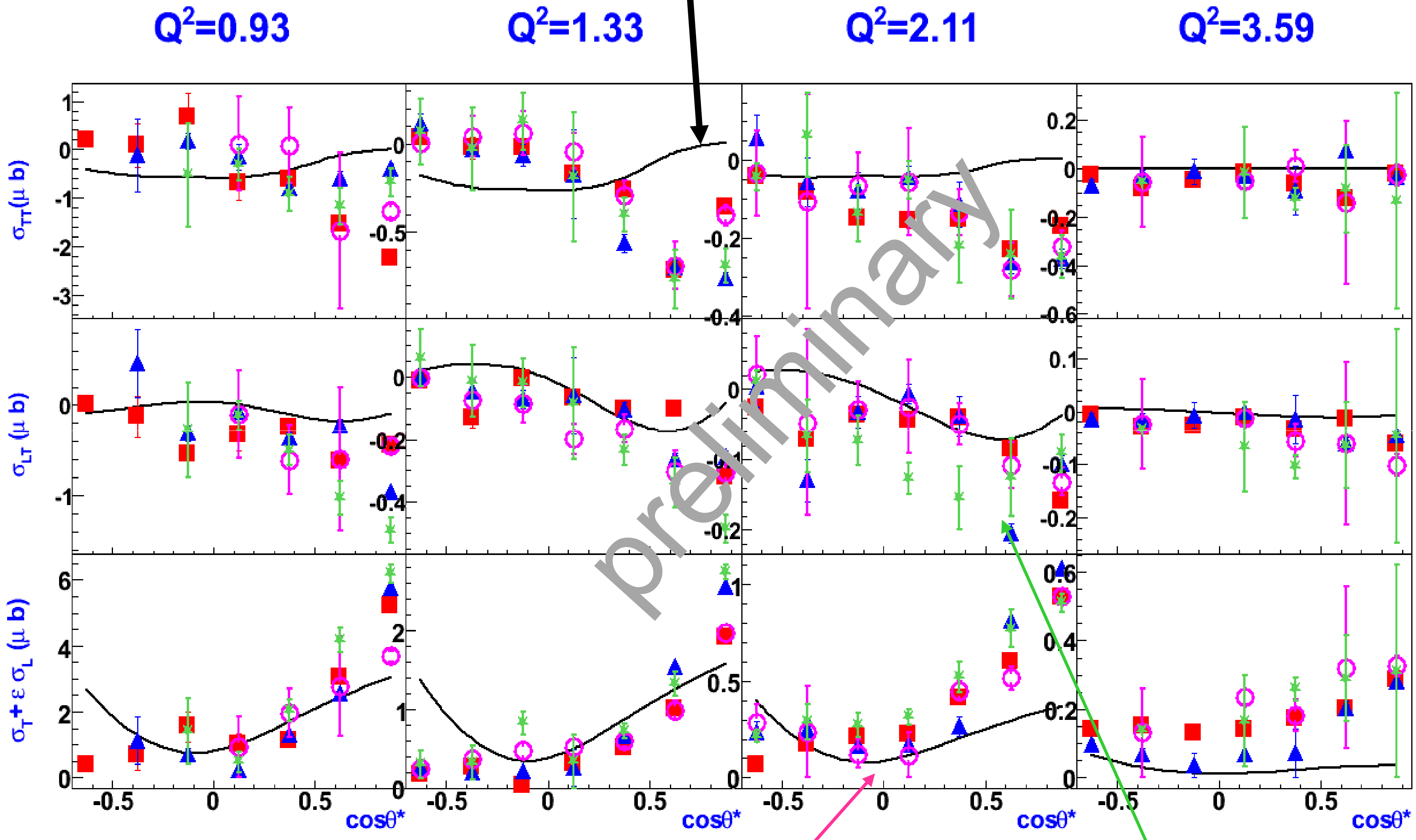
Cross Section: BoNuS Vs MAID and SAID



BoNuS Vs Models, 5 GeV, W = 1.525



BoNuS VIP Vs MAID, 5 GeV, W = 1.525

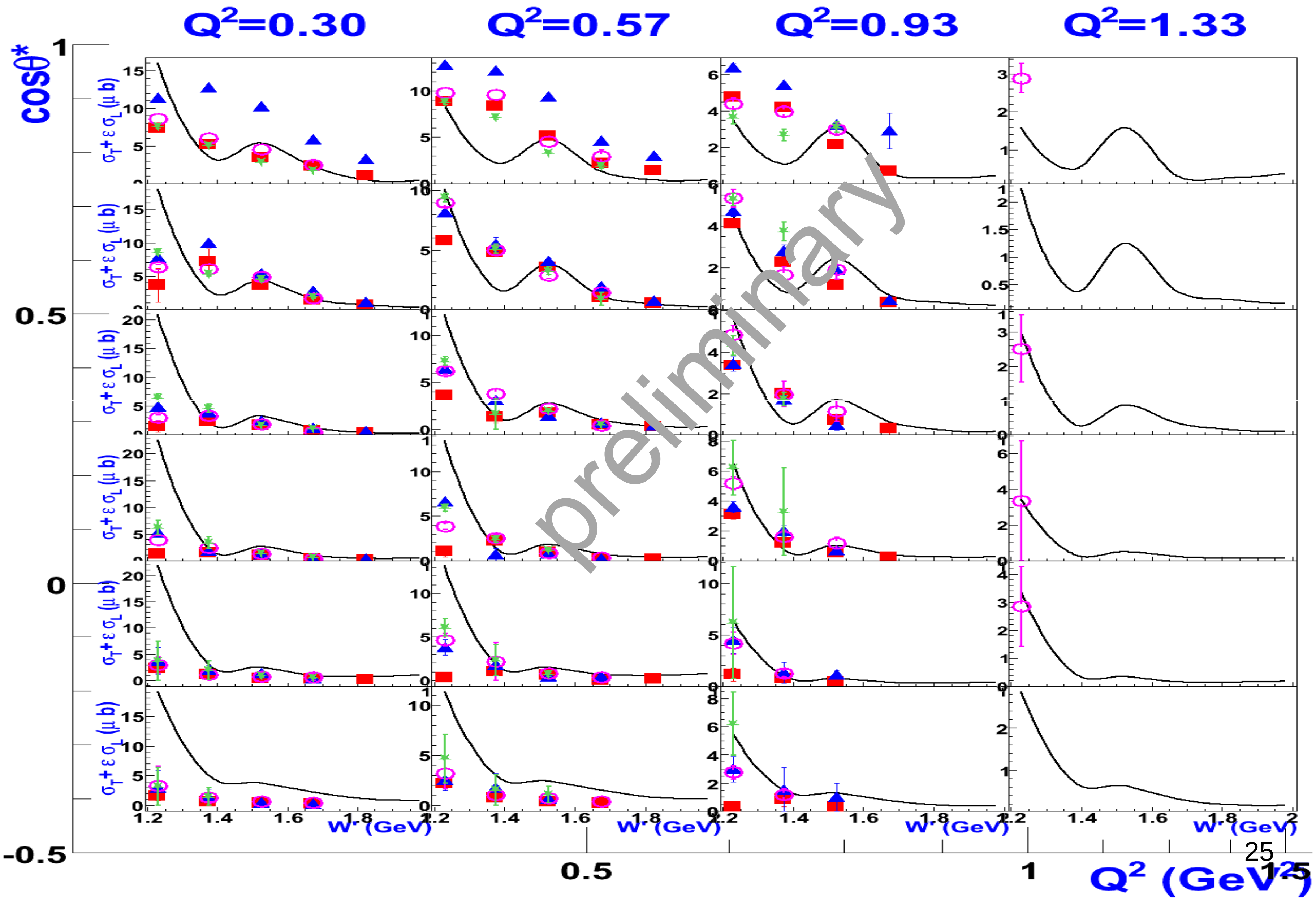


VIP = 70<p_s<120 and MeV/c, θ_{pq}>100°

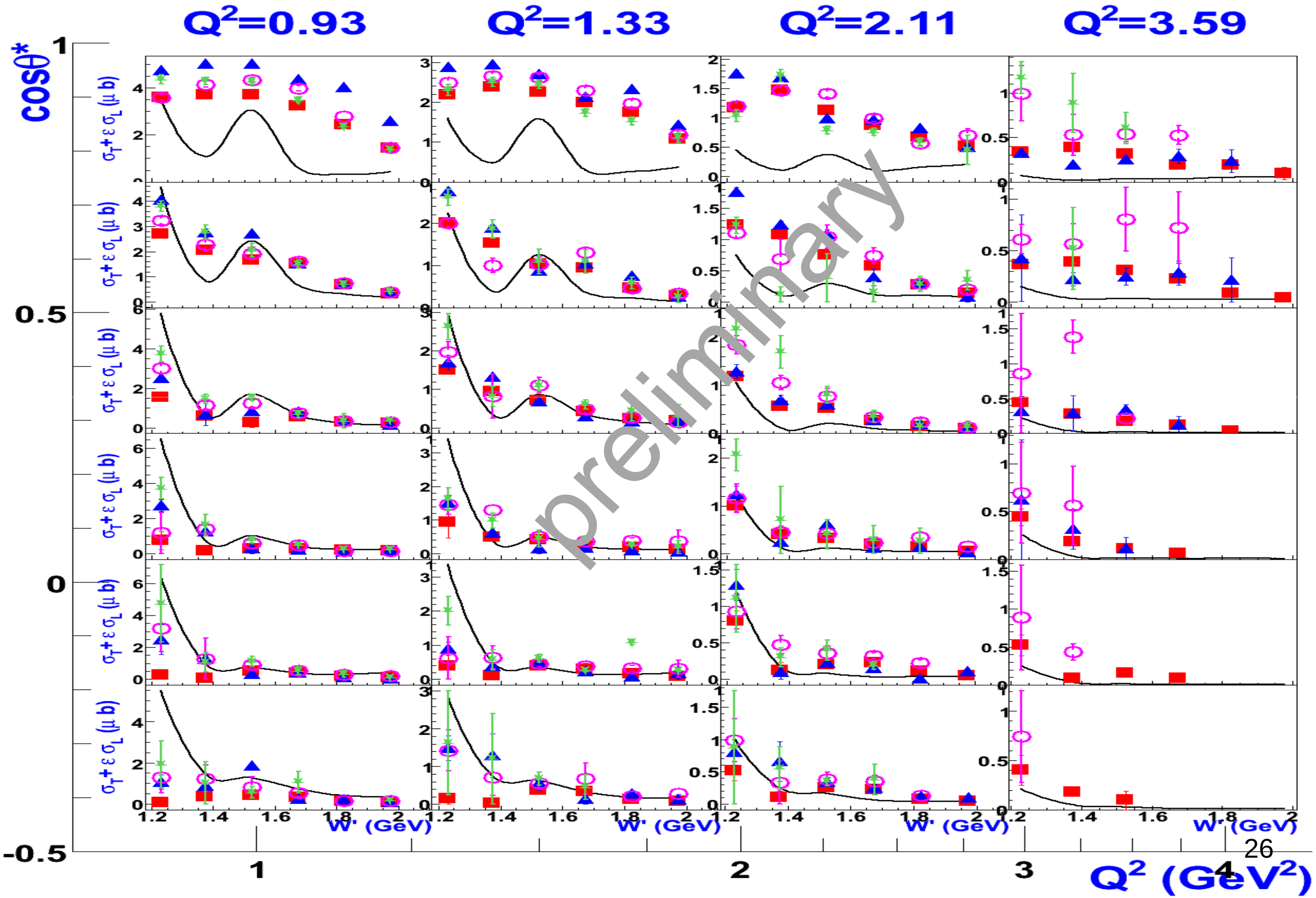
D(e,e′$\pi^-$$p_{CLAS}$)p VIP

D(e,e′$\pi^-$$p_{RTPC}$)p VIP

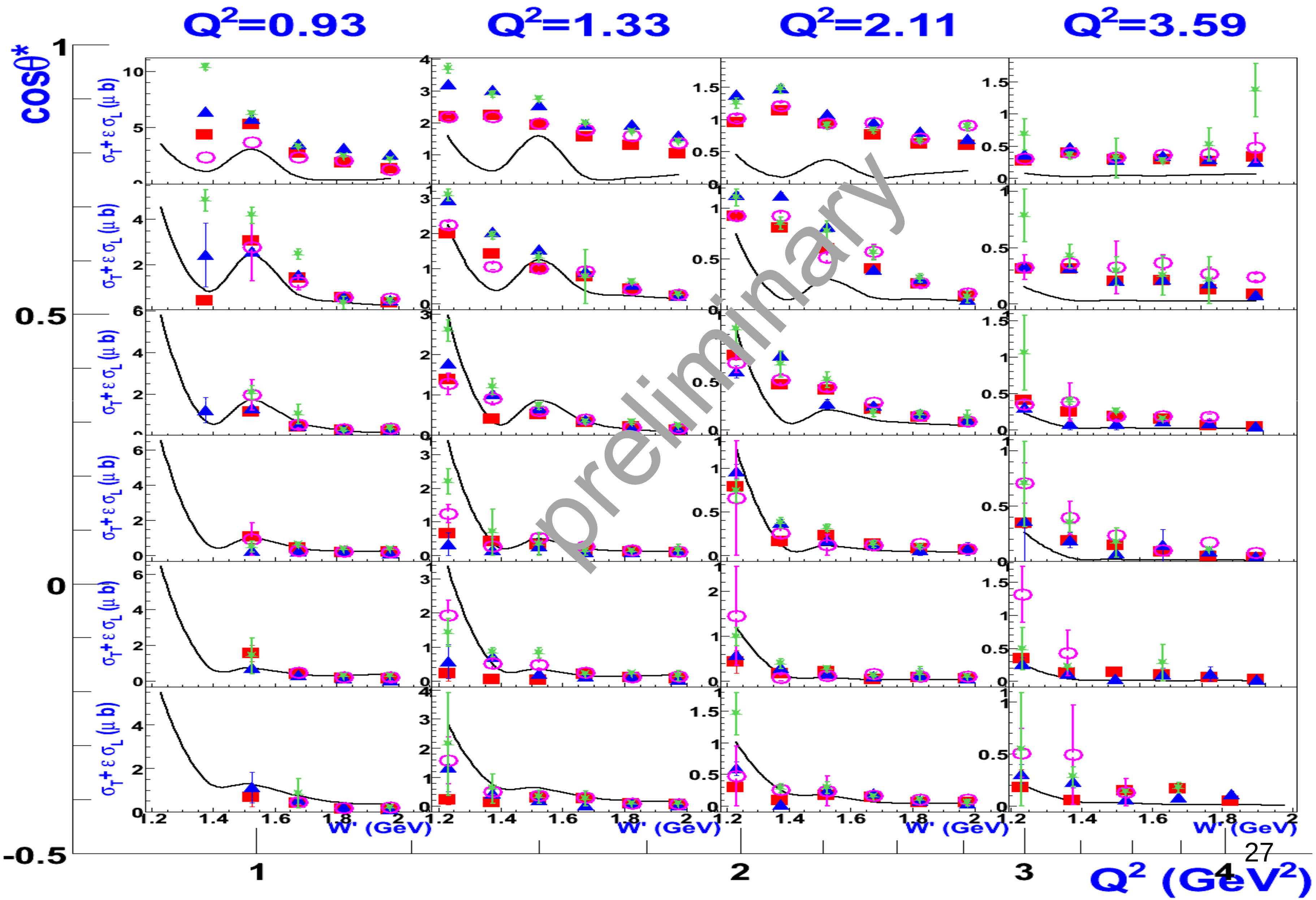
A_0: BoNuS VIP Vs MAID, 2 GeV



A_0: BoNuS VIP Vs MAID, 4 GeV



A_0: BoNuS VIP Vs MAID, 5 GeV



Summary and outlook

- Measured absolute cross sections for $D(e,e'\pi^{-}p)p$ reaction over a wide kinematic range.
- Huge increase in available data for neutron channel.
- These data will be used to improve our understanding of neutron structure, as part of fits to world data (SAID, MAID…)
- Our results are very sensitive to the acceptance correction, which must be carefully checked.
- In most bins, the p_{RTPC} and p_{CLAS} channels are consistent.
- We see qualitative consistency in most bins between our results and model predictions.
- The VIP data (low p_s and large θ_{pq}) are mostly consistent with the full data set.
- Include the FSI correction in future.
- We look forward to incorporate these data into the world database. We may repeat this analysis using other deuteron data.

Thank you!