# $\pi^-/\pi^+$ Separated Response Function Ratios in Forward Pion Electroproduction

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UNIVERSITY OF REGINA

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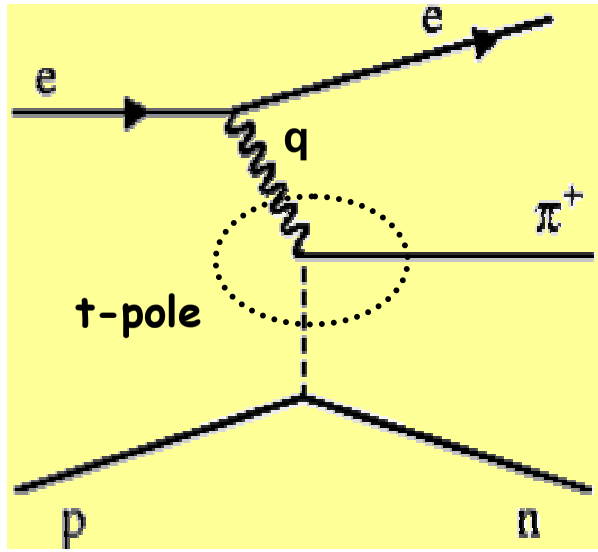
# Motivation

$^2H(e,e'\pi^+)nn$, $^2H(e,e'\pi^-)pp$ reactions




- Testing the t-pole dominance – key factor in the extraction of the pion form factor $F_\pi$.

- Pion $\pi^\pm$ electroproduction can proceed via isovector and isoscalar photons.

- The experimental ratio $R = \dfrac{\sigma(\gamma_V n \to \pi^- p)}{\sigma(\gamma_V p \to \pi^+ n)} = \dfrac{|A_V - A_S|^2}{|A_V + A_S|^2}$ evolution with -t gives a good indication of the presence of isoscalar processes.

- Separated ratios $R_L$ and $R_T$ tests the t-pole contribution to $\sigma_L$.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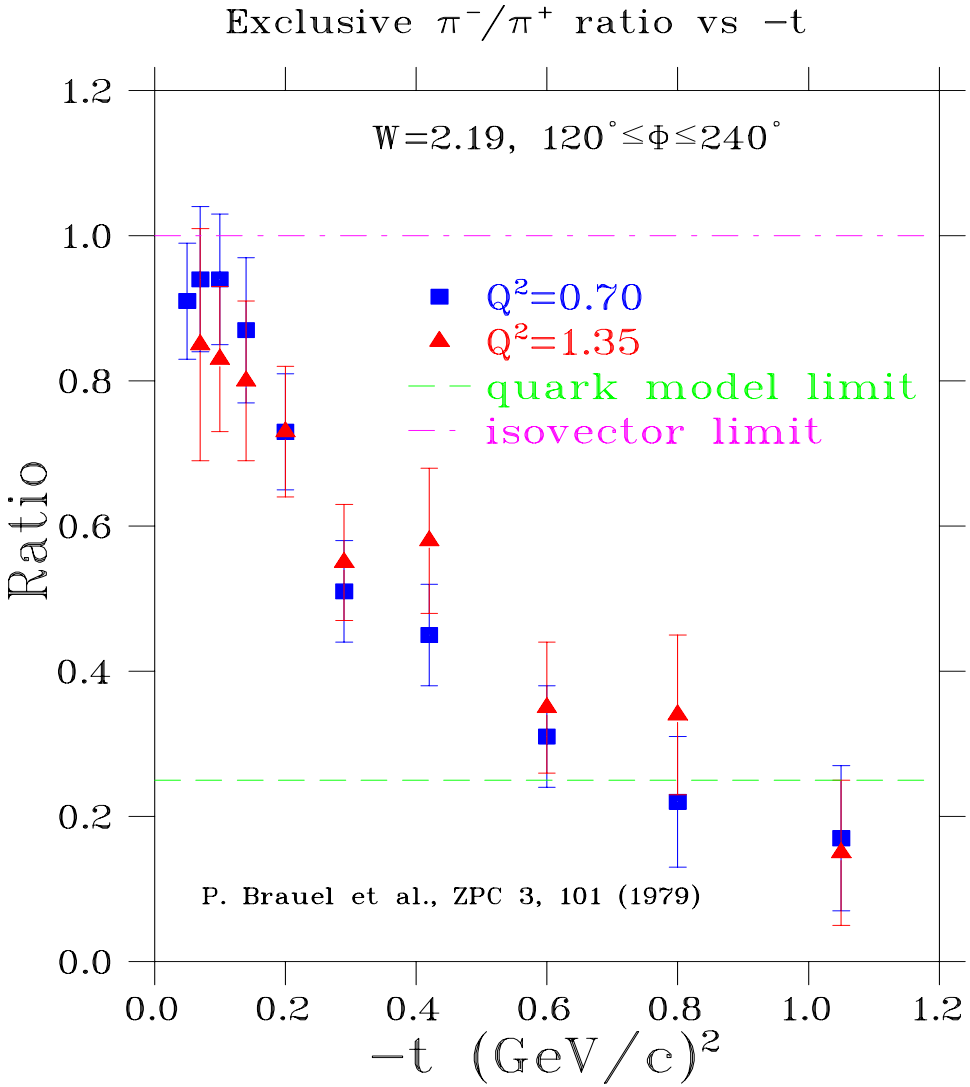
# Previous Studies




Unseparated cross section ratios

- At low -t

$$R \rightarrow R_L = \frac{Q^2_{\pi^-}}{Q^2_{\pi^+}} = 1$$

- At high -t

$$R \rightarrow R_T = \frac{2Q^2_d}{2Q^2_u} = 1/4$$

A. Nachtmann, Nucl. Phys. B 115 (1976) 61



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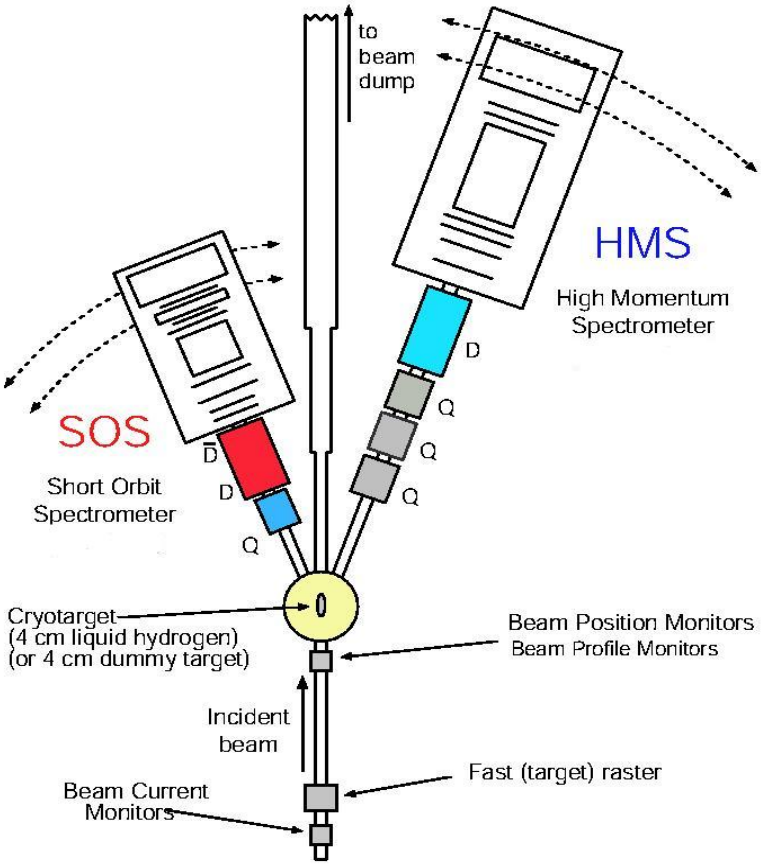
# Experimental Setup

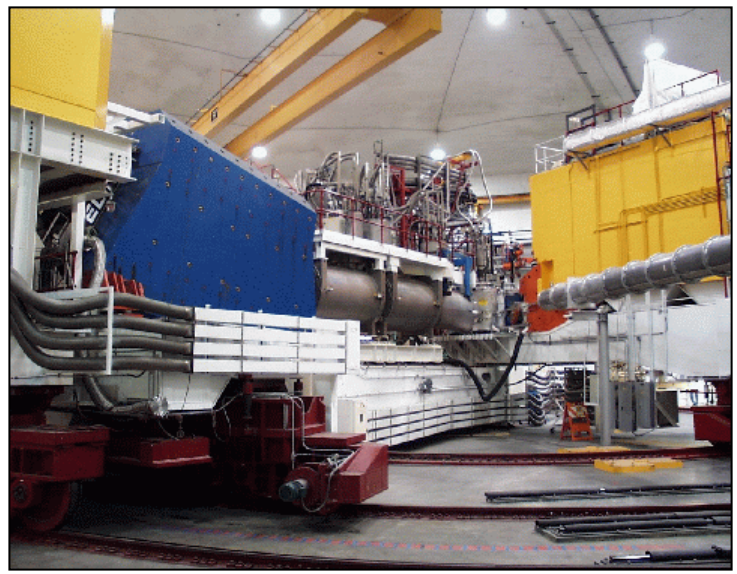



## Hall C spectrometers:

- Coincidence measurement.
- SOS detects $e^-$.
- HMS detects $\pi^+$ and $\pi^-$.

## Targets:

- Liquid 4-cm H/D cells.
- Al (dummy) target for background measurement.
- $^{12}C$ solid targets for optics calibration.



| Exp | Q2 $(GeV/c)^2$ | W (GeV) | $\lvert t_{min} \rvert$ $(Gev/c)^2$ | $E_e$ (GeV) |
|---|---|---|---|---|
| Fπ-1 | 0.6-1.6 | 1.95 | 0.03-0.150 | 2.445-4.045 |
| Fπ-2 | 1.6,2.5 | 2.22 | 0.093,0.189 | 3.779-5.246 |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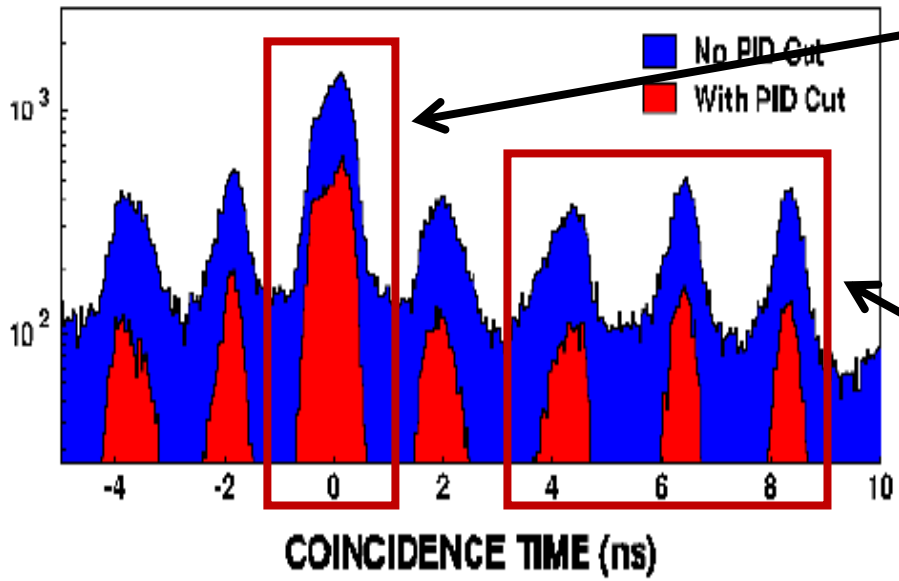
# Event selection

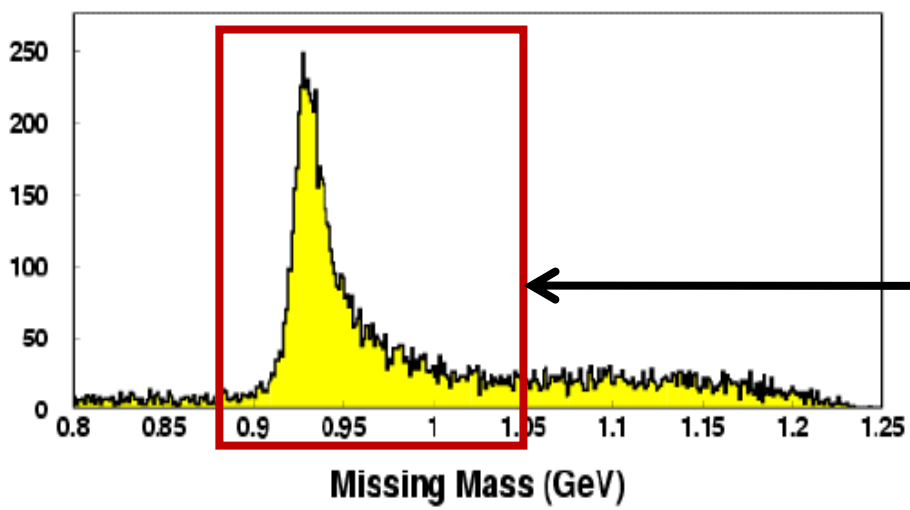



Electron-pion coincidences

Pions detected in HMS – Cerenkov & Coincidence time for PID

Electrons detected in SOS – Cerenkov & Lead Glass Calorimeter

Random coincidences




Exclusivity assured via 0.875<MM<1.05 GeV cut



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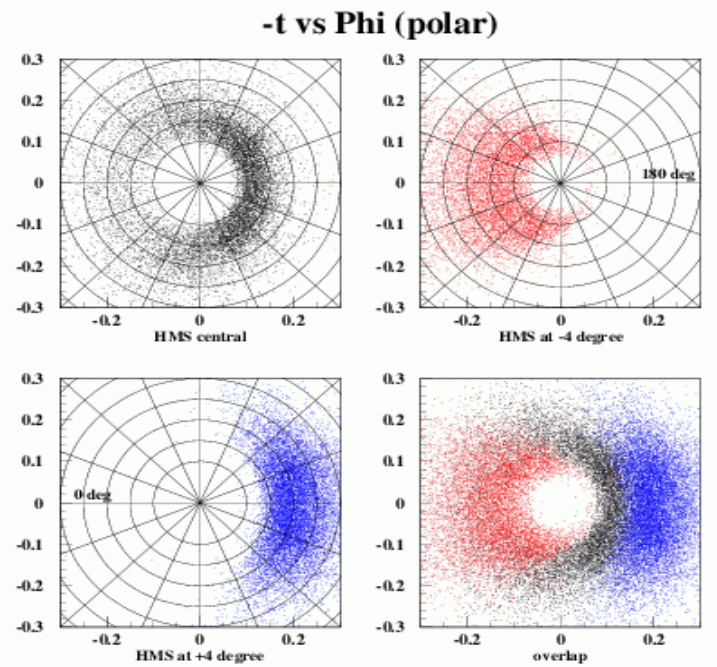
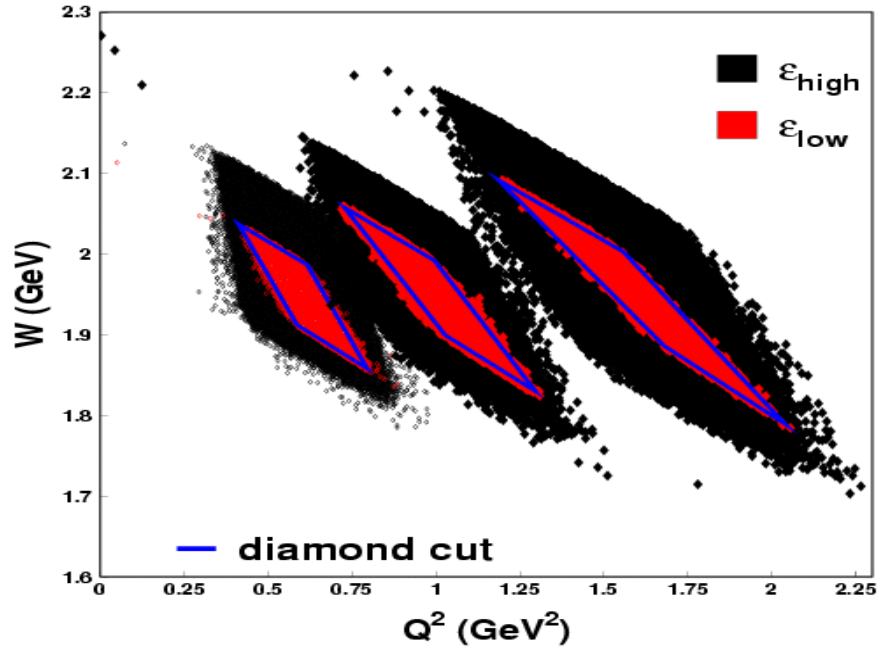
# Kinematics Coverage

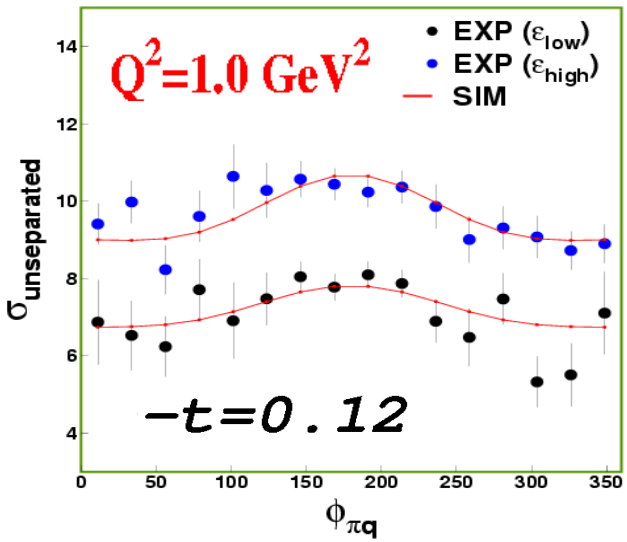



$Q^2$=1 GeV$^2$, $\pi^+$

Take data at three angles: $\theta_{\pi q}$=0°, +4°, -4°. → $\sigma_{TT}, \sigma_{LT}$




Diamond cuts define common $(W, Q^2)$ coverage at both ε.




**Extract $\sigma_L$ by simultaneous fit** of L,T,LT,TT

$$2\pi\frac{d\sigma}{dtd\phi}=\varepsilon\frac{d\sigma_L}{dt}+\frac{d\sigma_T}{dt}+\sqrt{2\varepsilon(\varepsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi+\varepsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi$$



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# Data Analysis

- **Magnetic Calibrations**

  Over-constrained *p(e,e'p)* and elastic *e* + $^{12}C$ reactions were used to calibrate spectrometer acceptances, momenta and angular offsets.

  SOS & HMS Delta/xpfp correlations were corrected with a linear dependent function of form $\delta' = \delta + C_{\delta} \cdot x'_{fp}$ .

- **Corrections to the high rate $\pi^-$ data set**

  $\pi^-$ data were taken at high rates while $\pi^+$ data were taken at low rates. Understanding the rate dependent corrections is very important with respect to the final $\sigma_{\pi^-}/\sigma_{\pi^+}$ ratios.

  - New high rate tracking algorithm.
  - Better high rate tracking efficiencies (2-9%).
  - $\pi^-$ HMS Cerenkov blocking correction (2-20%).
  - High current ($\pi^+$ data set) target boiling correction (2-13%).


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# EXISTING MODELS (VGG & VGL)

## VGL Regge Model

Pion electroproduction in terms of exchange of $\pi$ and $\rho$ Regge trajectories.

[VGL, PRC 57(1998)1454]

Model parameters fixed from pion photoproduction.

Free parameters: $\Lambda_\pi^2$ and $\Lambda_\rho^2$ (from $^2$H data).

$$F_{\pi,\rho}(Q^2) = [1 + Q^2/\Lambda^2_{\pi,\rho}]^{-1}$$

$\rho$ exchange does not significantly influence $\sigma_L$ at small $-t$.

## VGG GPD Model

Pion electroproduction in terms of generalized skewed quark distributions (OFPD).

[VGG,PRD 60(1999)094017]

Include power corrections due to:

intrinsic transverse momentum of the active quark

soft overlap type contributions (no gluon exchange)

Free parameters: $\Lambda_\pi^2$ and $\Lambda_\rho^2$ (from $^2$H data).



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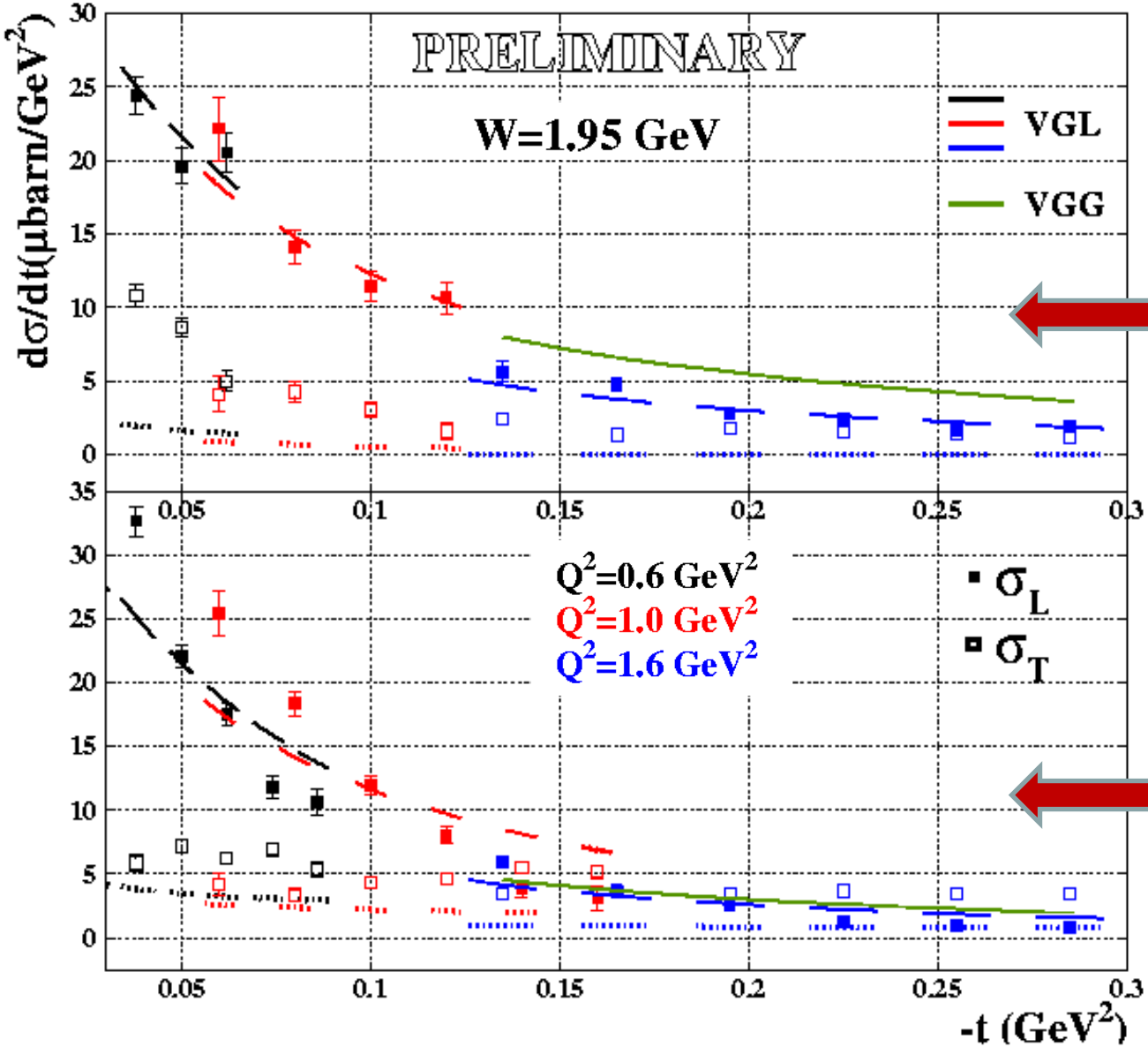
# Separated Response Functions




$^2H(e,e'\pi^-)pp$

$\Lambda_\pi^2, \Lambda_\rho^2$ - 0.410, 1.5

$\Lambda_\pi^2, \Lambda_\rho^2$ - 0.503, 1.5

$\Lambda_\pi^2, \Lambda_\rho^2$ - 0.428, 1.5

$\Lambda_\pi^2, \Lambda_\rho^2$ - 0.428, 1.5

$^2H(e,e'\pi^+)nn$

$\Lambda_\pi^2, \Lambda_\rho^2$ - 0.418, 1.5

$\Lambda_\pi^2, \Lambda_\rho^2$ - 0.494, 1.5

$\Lambda_\pi^2, \Lambda_\rho^2$ - 0.397, 1.5

$\Lambda_\pi^2, \Lambda_\rho^2$ - 0.397, 1.5



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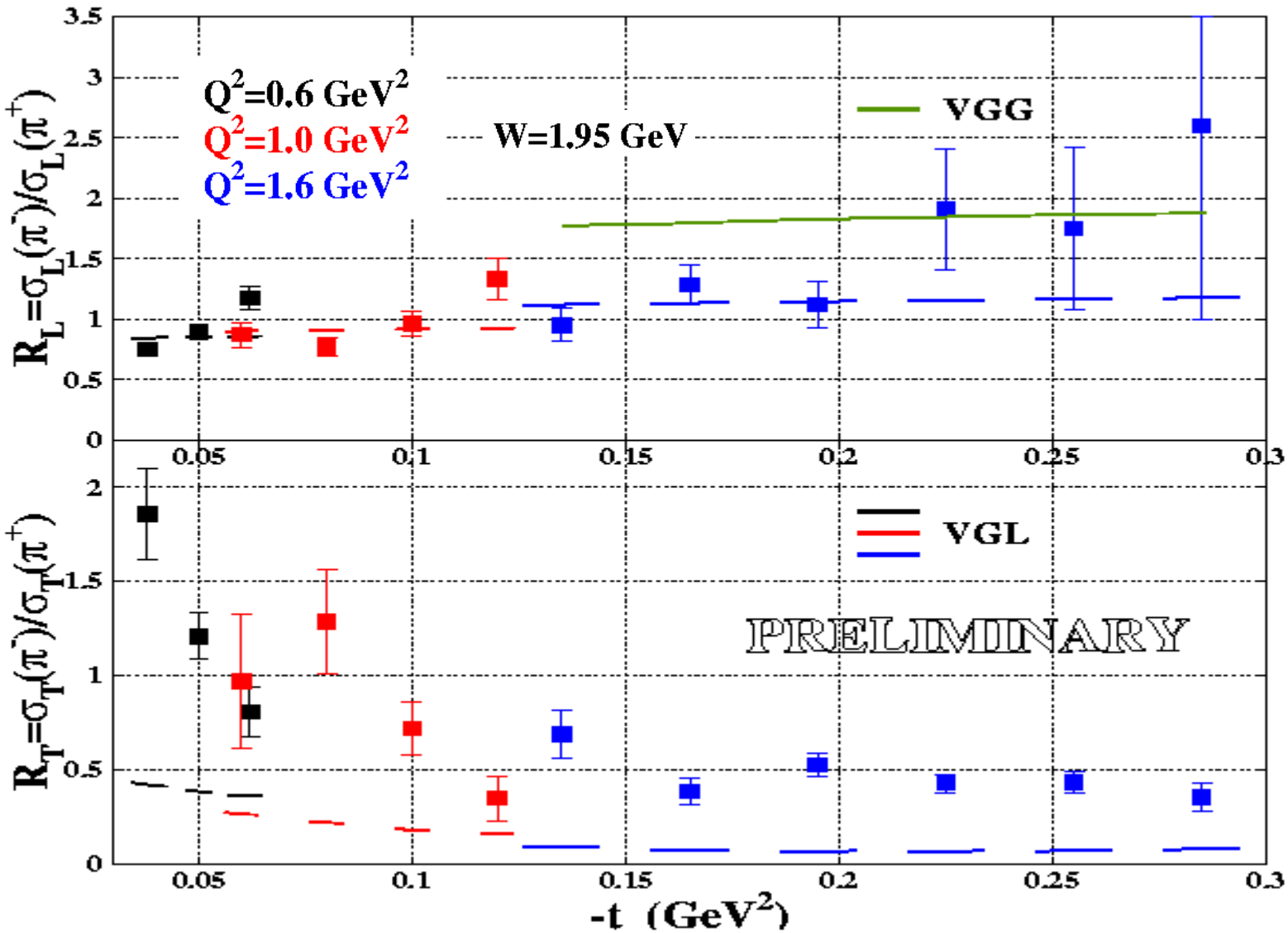
# Separated Response Functions Ratios



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# Summary

- Separated $\sigma_L$, $\sigma_T$, $\sigma_{LT}$, $\sigma_{TT}$ cross sections were extracted using Rosenbluth L/T separation technique.

- Ratios $R = \frac{\sigma_{\pi^-}}{\sigma_{\pi^+}}$ were extracted as a function of -t.

- Preliminary results show that $R_L$ is consistent with 1 over the whole range in –t indicating a dominance of isovector processes at low –t in the longitudinal response function $\sigma_L$ .

- These findings confirm the expectation that $\sigma_L$ is indeed dominated by the t-pole term.

- In the kinematic region studied here both ratios $R_L$ and $R_T$ present a very slight dependence of $Q^2$ .

- The evolution of $R_T$ with –t shows a rapid fall off which is consistent with earlier theoretical predictions, expected to approach $\frac{1}{4}$, the square of the ratio of the quark charges involved.


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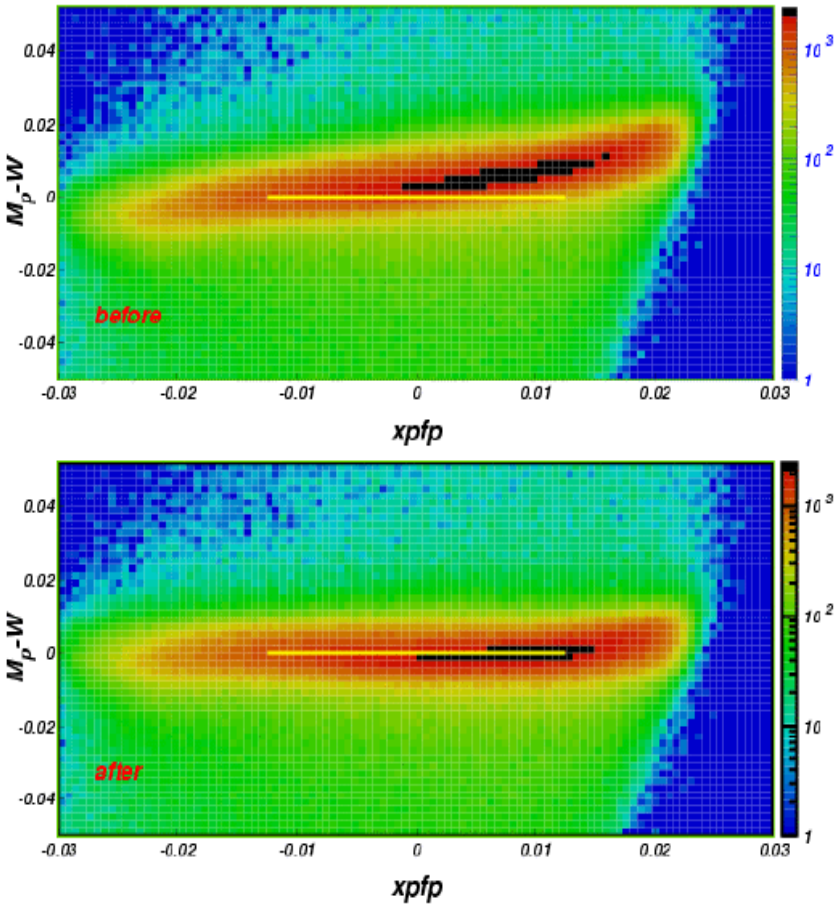
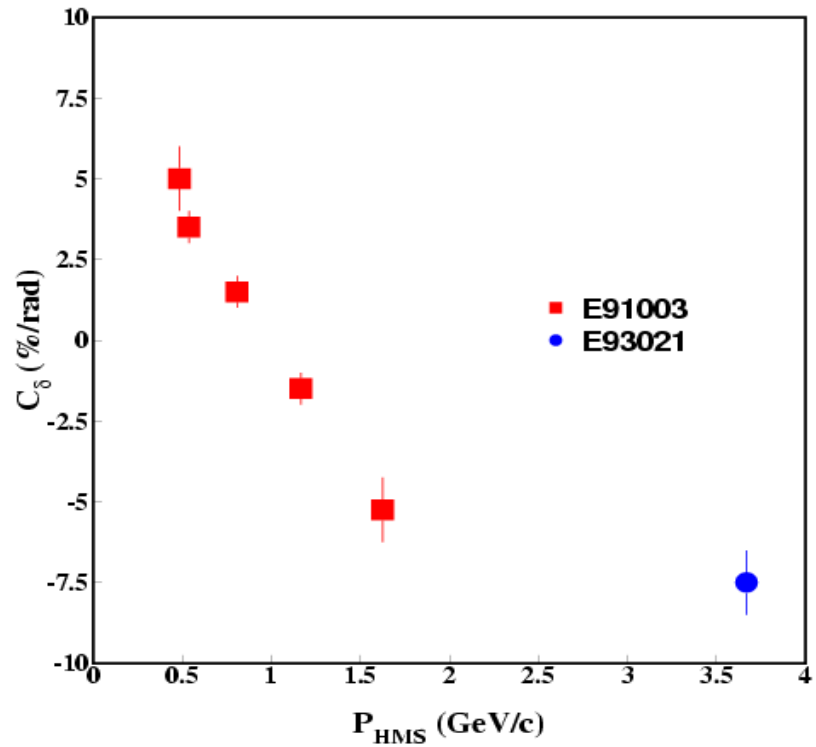
# HMS Q3 Corrections




Old Q3/Dipole ratio

$$\delta_{HMS} = \delta_{HMS} + C_\delta * x'_{fp}$$

$$\delta_{HMS} = \frac{P - P_{HMS}}{P_{HMS}} * 100$$



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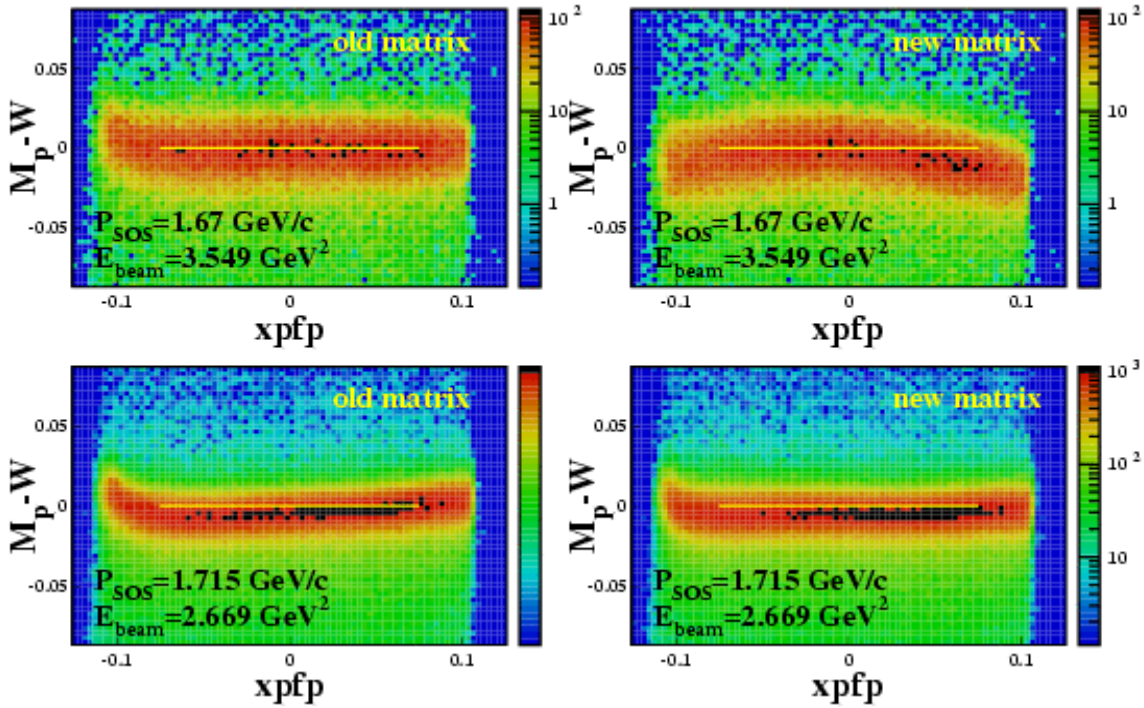
# SOS Optics Calibration




For low momentum (<1.6 GeV/c) we used the Fpi1 (1999) optics matrix & delta/xpfp correction.

For high momentum (>1.6 GeV/c) we used the Fpi2 (2003) new optics matrix & delta/xpfp correction.



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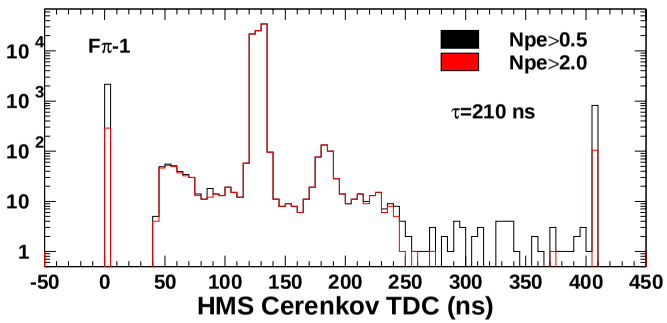
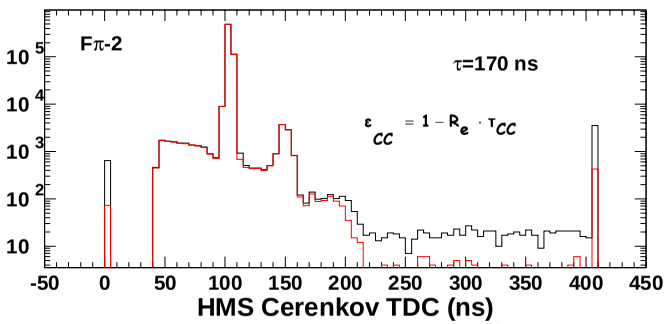
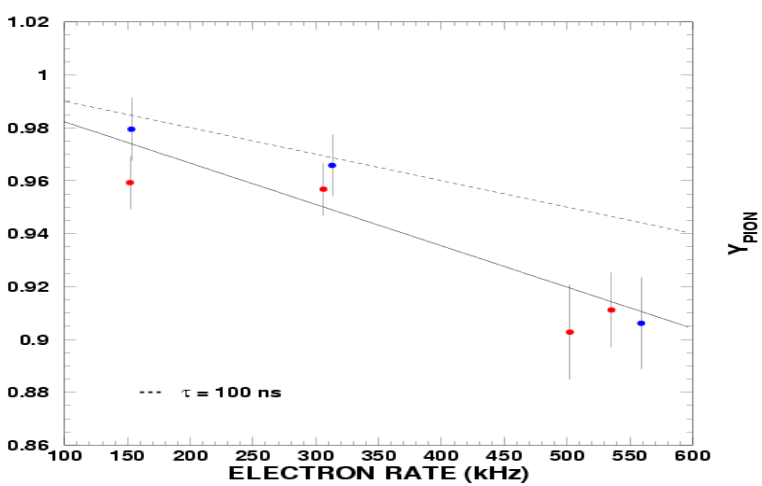
# HMS Cerenkov Blocking




HMS CC TDC spectrum for e

as identified by the HMS CC ADC




- Used data taken with open trigger (el. & pions) to fit the effective time window.
- The TDC time window in Fpi1 is 23% larger than in Fpi2.
- Used the Fpi2 data to fit the effective TDC gate (for the same CC cut).
- For a CC cut of npe<1.5 the effective TDC gate for Fpi1 set is ~184 ns.
- Implies a larger correction for Fpi1 data (18-20 % at 1MHz).
- Significant impact in pi- (high rate) data.

$$\varepsilon_{CC} = 1 - R_e \cdot \tau_{CC}$$

$$\tau_{CC} = 184 \pm 5 \text{ ns}$$

- Uncertainties associated with this correction are of the order of 1.6% at 1MHz.



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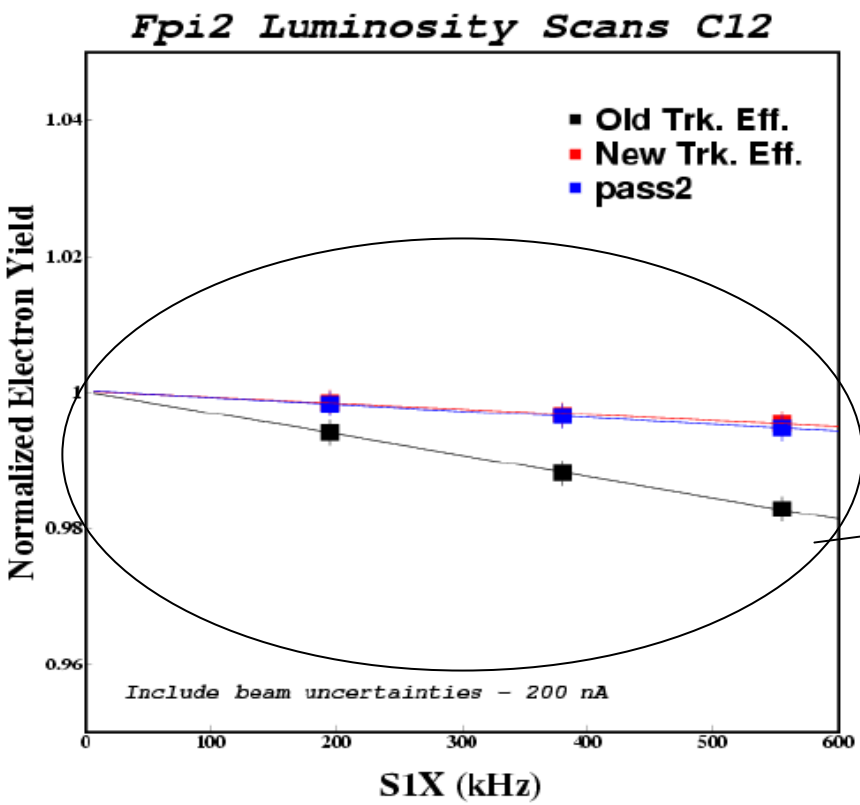
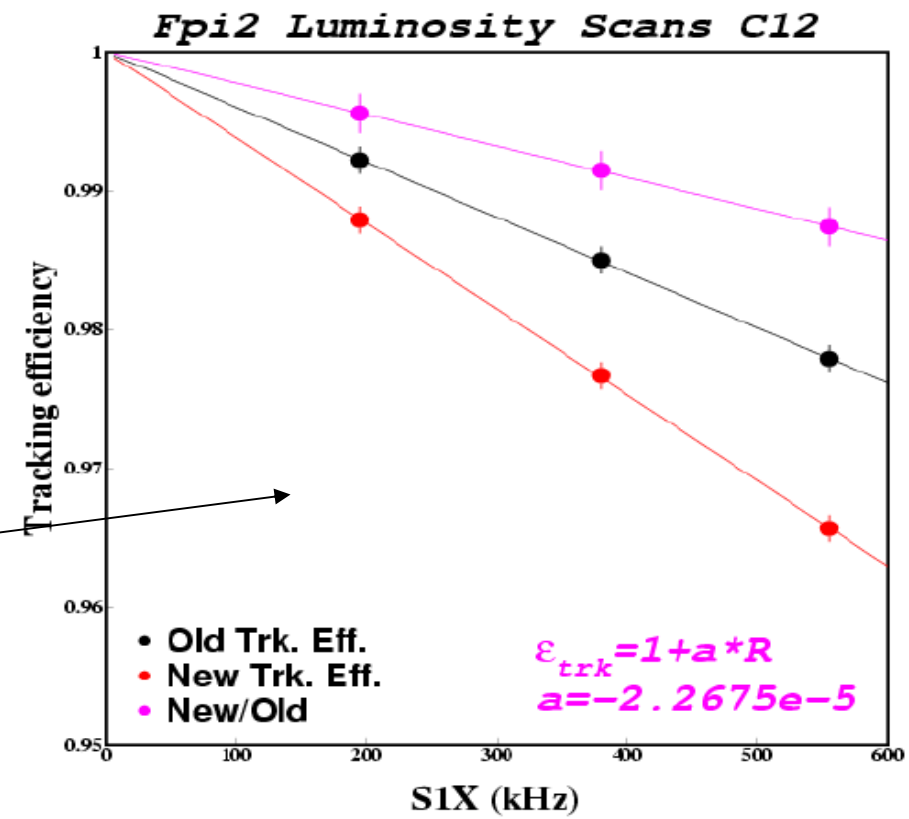
# Corrected Tracking Efficiencies




A ~8% correction to the tracking efficiencies at 1.4MHz was applied to the high rate data (pi-).



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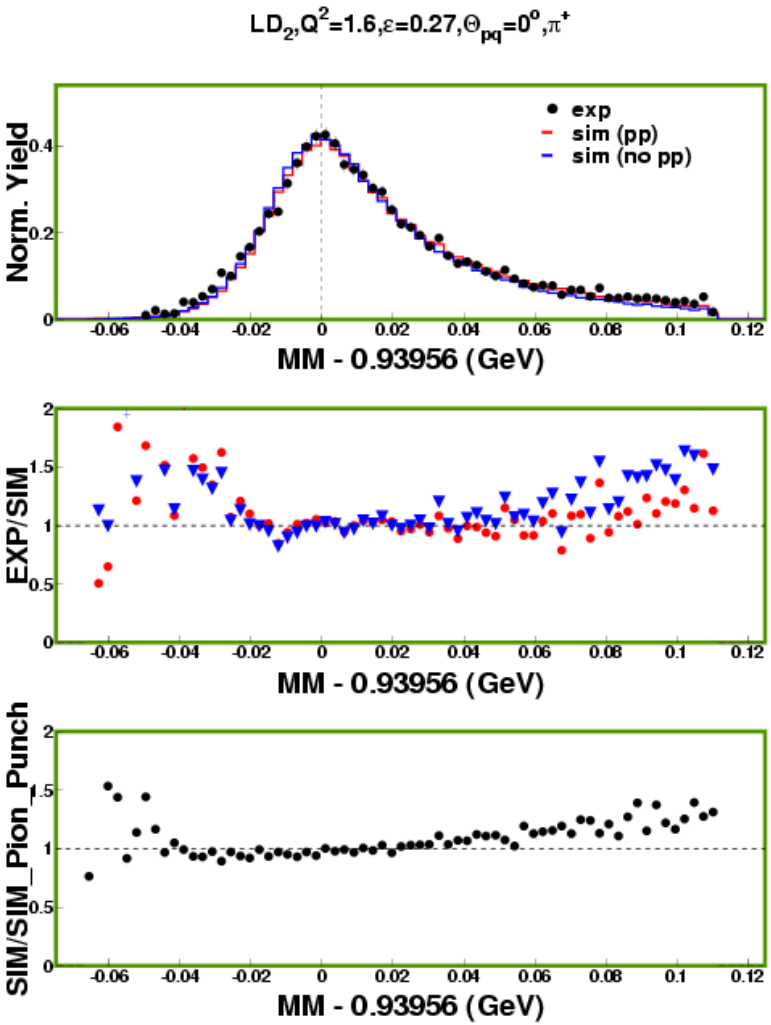
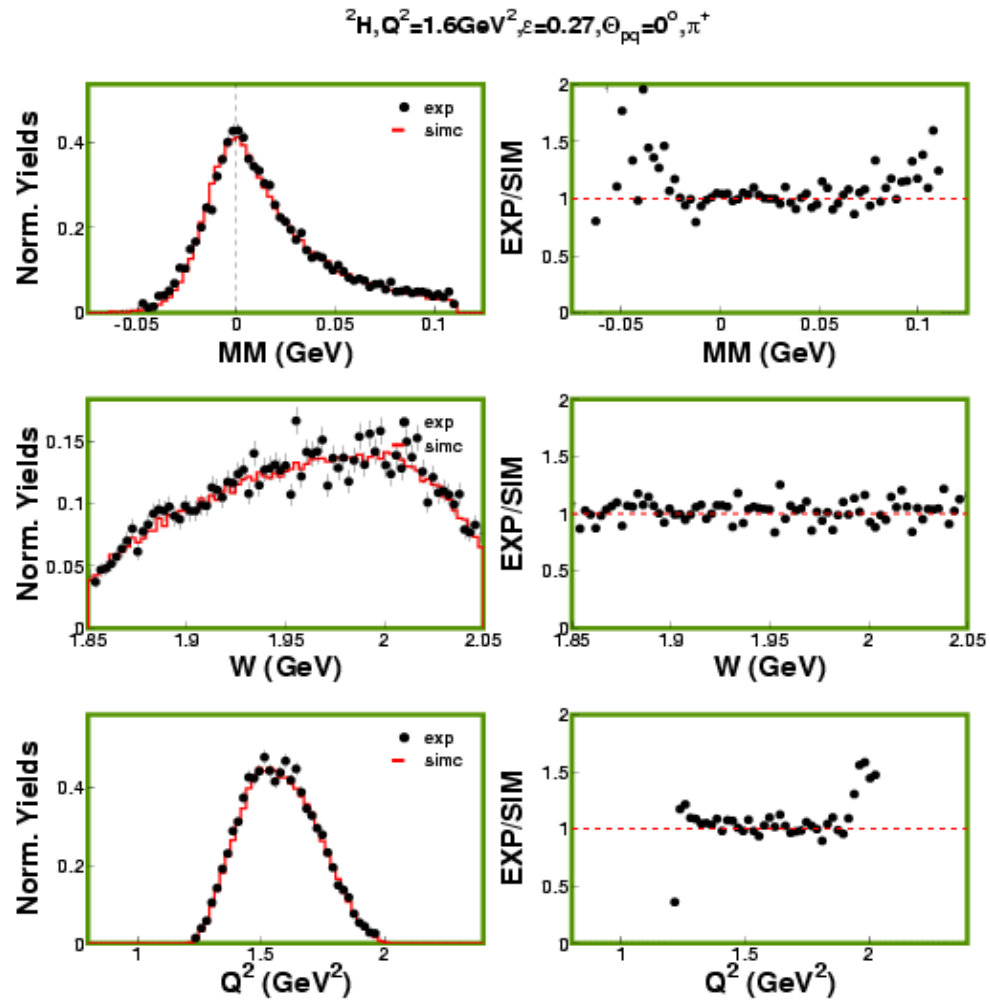
# Simulations vs Experimental data




Simulated Missing Mass spectrum was improved by implementing pions that were penetrating the collimator.

Pion Punchthrough Implementation resulted in an overall improved simulated kinematic variables (W,Q2,-t).



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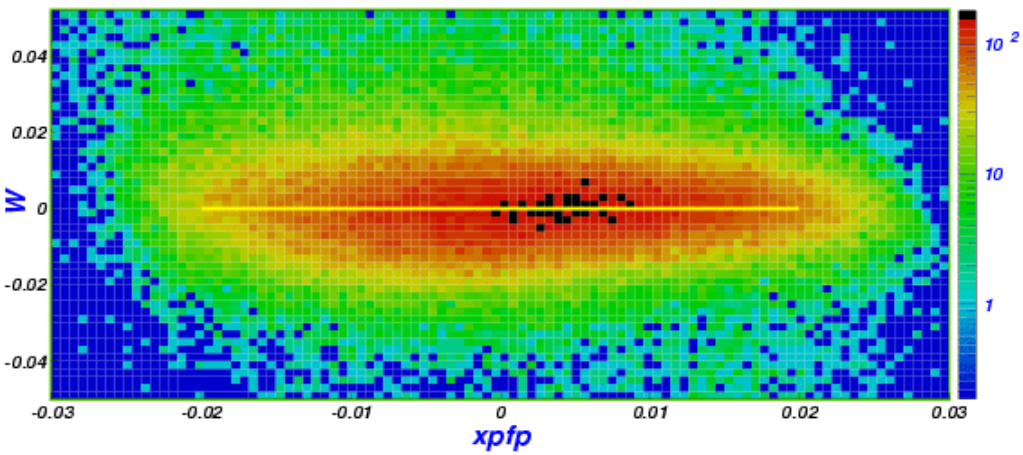
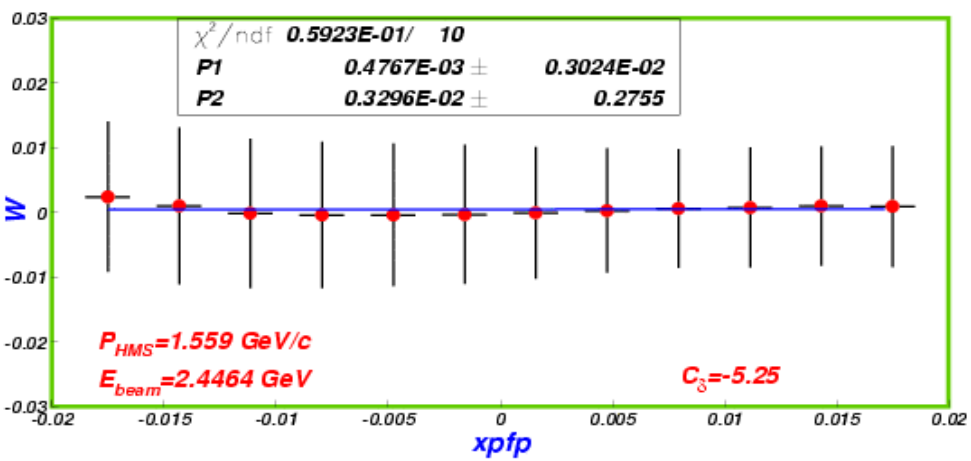
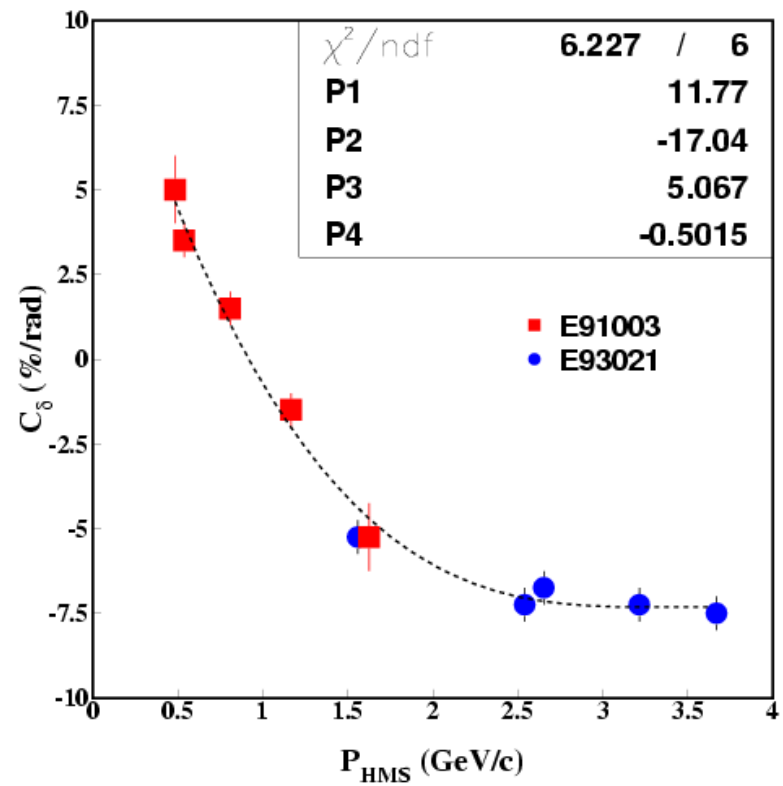
# HMS Q3 corrections



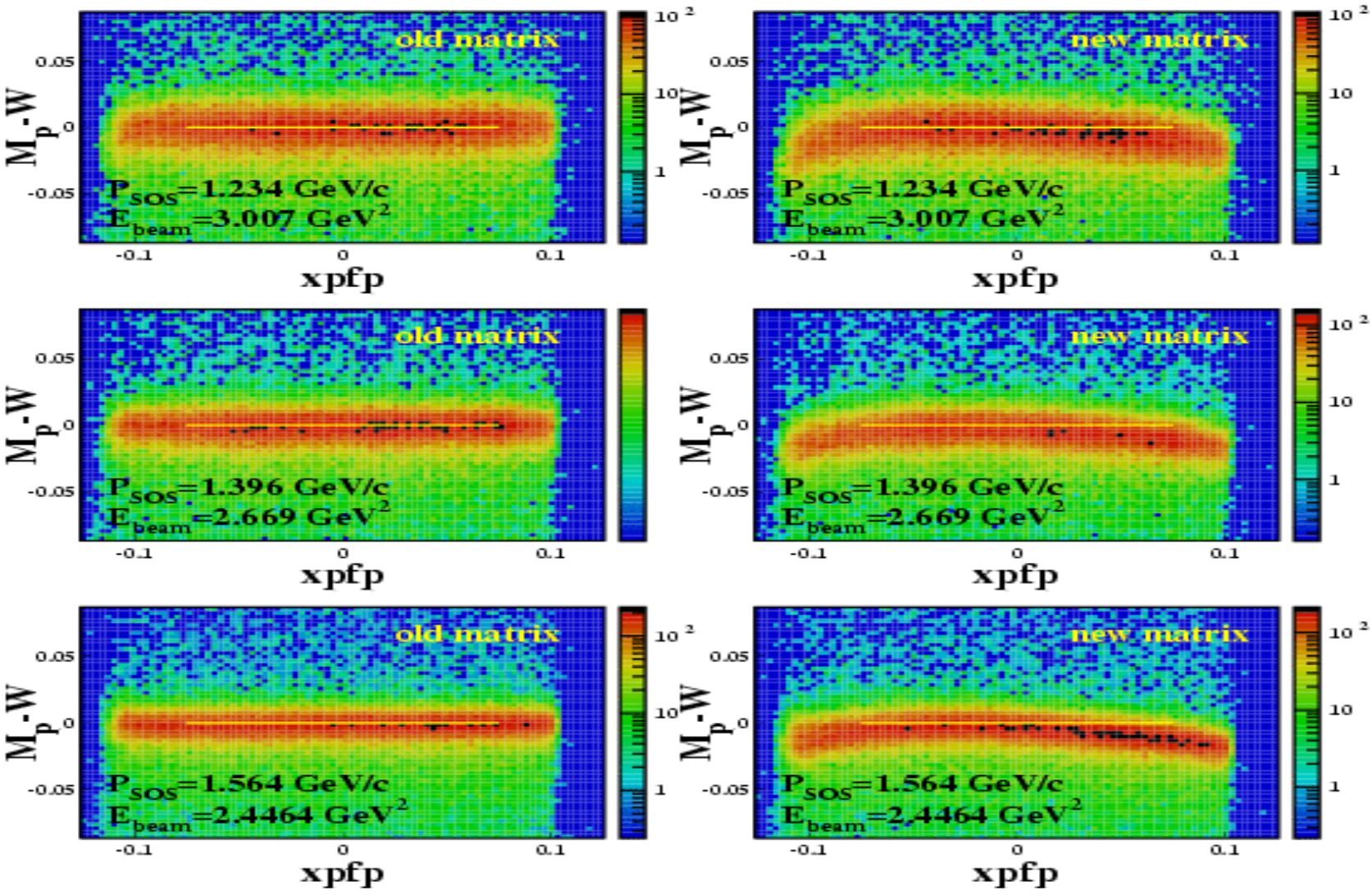

Using central HMS kinematics and detected proton momentum we reconstruct the invariant mass W (electron mass).




The W vs X' distribution was fitted with 1 degree polynomial.



# SOS Q3 Corrections




2003 SOS optics matrix



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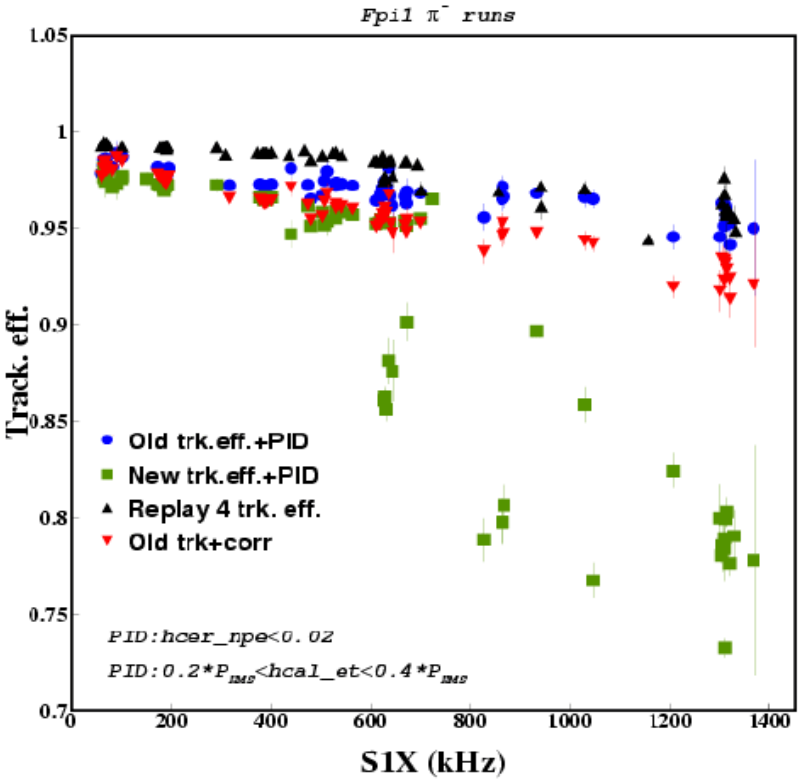
# Tracking efficiency

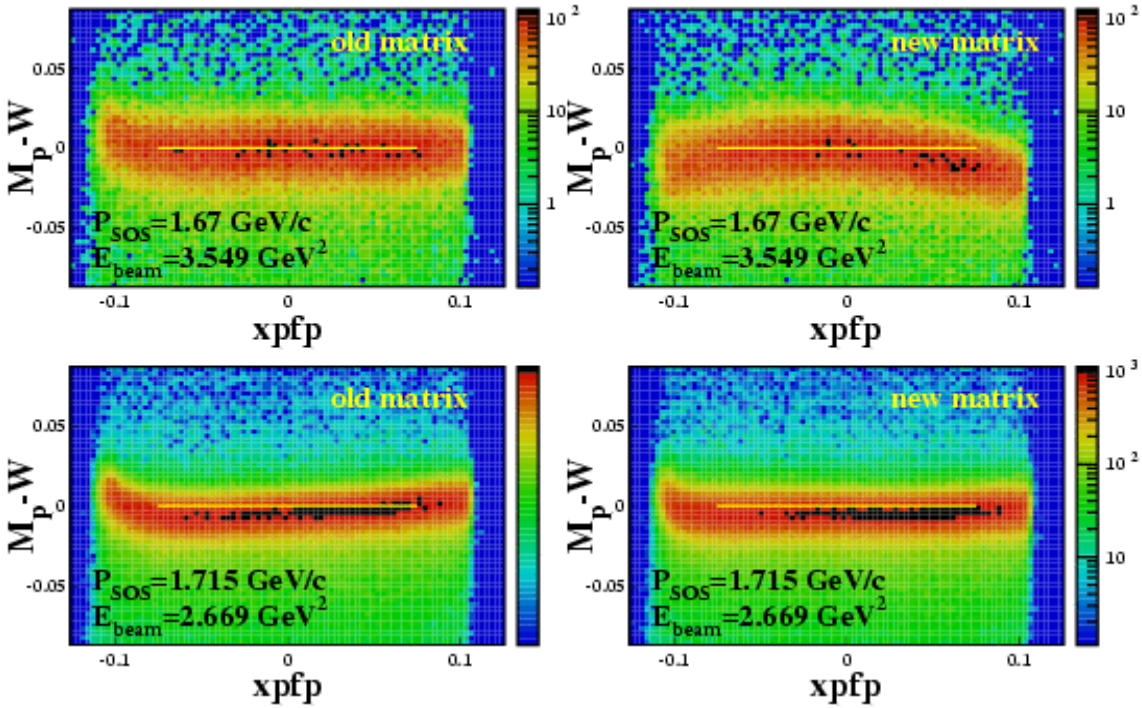



Two issues:

1. The Fpi1 version of the Trk. Eff. algorithm used a "cleaner" data sample by removing the multiple hits events resulting in overevaluated trk. eff.
2. The Fpi2 version used a "dirty" data sample by including the multiple hits events resulting in subevaluated trk. eff.

- The high rate data (pi-) is the most sensitive to the tracking efficiency correction (~10% at 1.4 MHz).
- A linear correction dependent of event rate was applied to the tracking efficiencies of pi- data.

# SOS Q3 Corrections




Low momentum (<1.6 GeV/c) – old settings & corrections works fine.

High momentum (>1.6 GeV/c) – use of new SOS optic matrix & new delta/xpfp correction.



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# Tracking Efficiency

$$\varepsilon_{tracking} = P_1 \cdot \varepsilon_1 + P_2 \cdot \varepsilon_2$$

$$P_2 \approx R \cdot \tau_{DC}$$

$$P_1 = 1 - P_2$$

$$\varepsilon_1 = 0.984$$

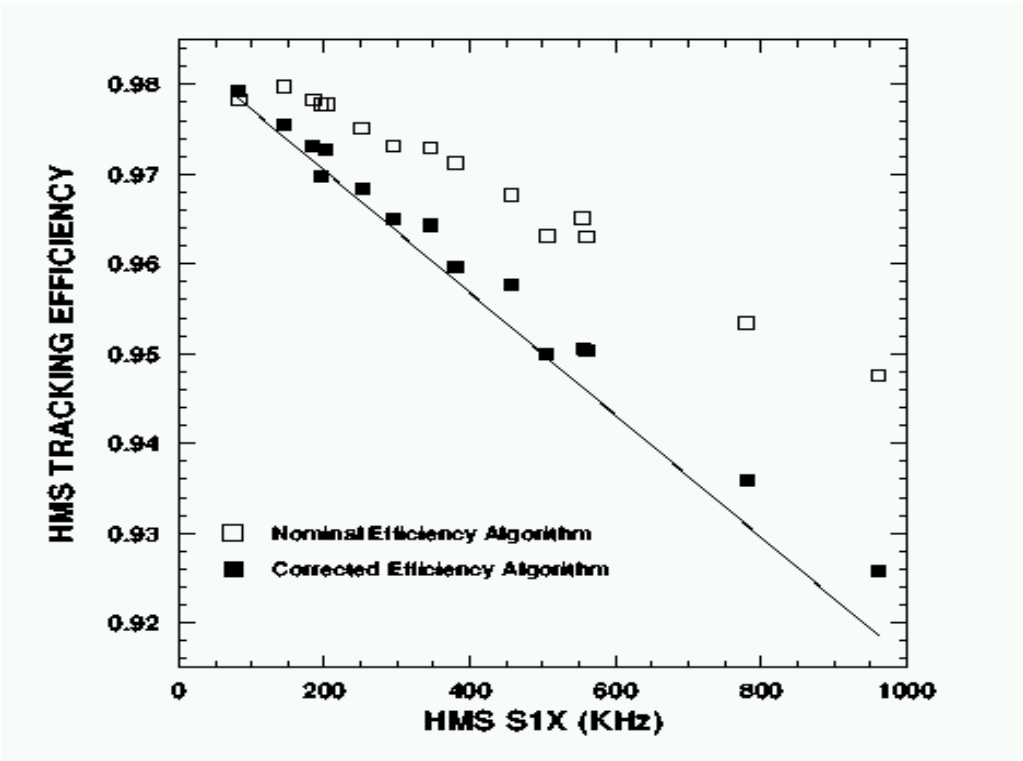
$$\varepsilon_2 = 0.71$$

$\tau_{DC}$ - DC gate width

R – DC rate

$P_1$ -single hit probability

$P_2$ - multiple hits probability



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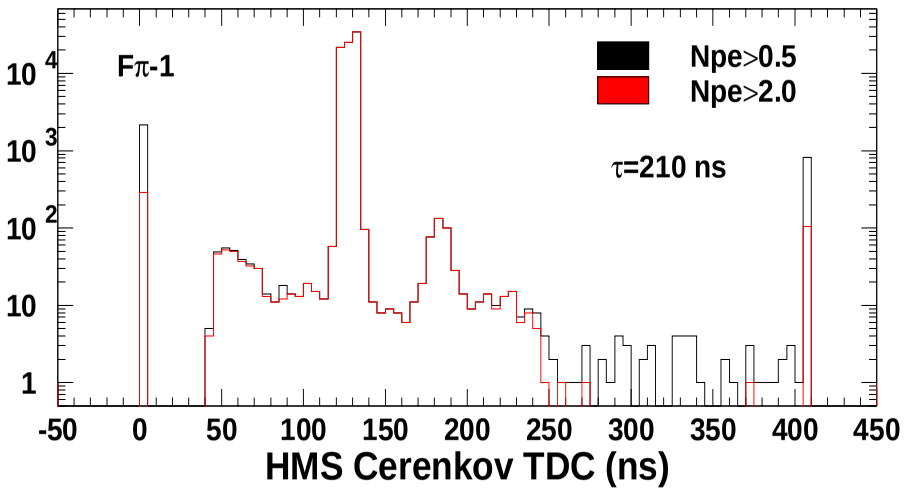
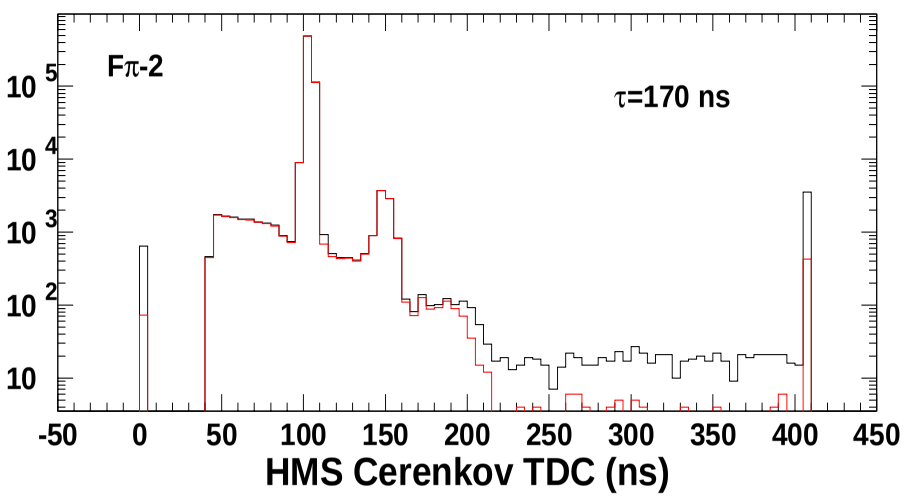
# HMS Cerenkov Blocking




HMS CC TDC spectrum for e as identified by the HMS CC ADC

Using data taken with open trigger (el. & pions).

The TDC time window in Fpi1 is 23% larger than in Fpi2.

Use the Fpi2 data to fit the effective gate (same CC cut).

For npe<2.0 gate width – 190 ns.

Implies a larger correction in Fpi1 (18-20 % at 1MHz).

Significant impact in pi- (high rate) data.

$$\varepsilon_{CC} = 1 - R_e \cdot \tau_{CC}$$



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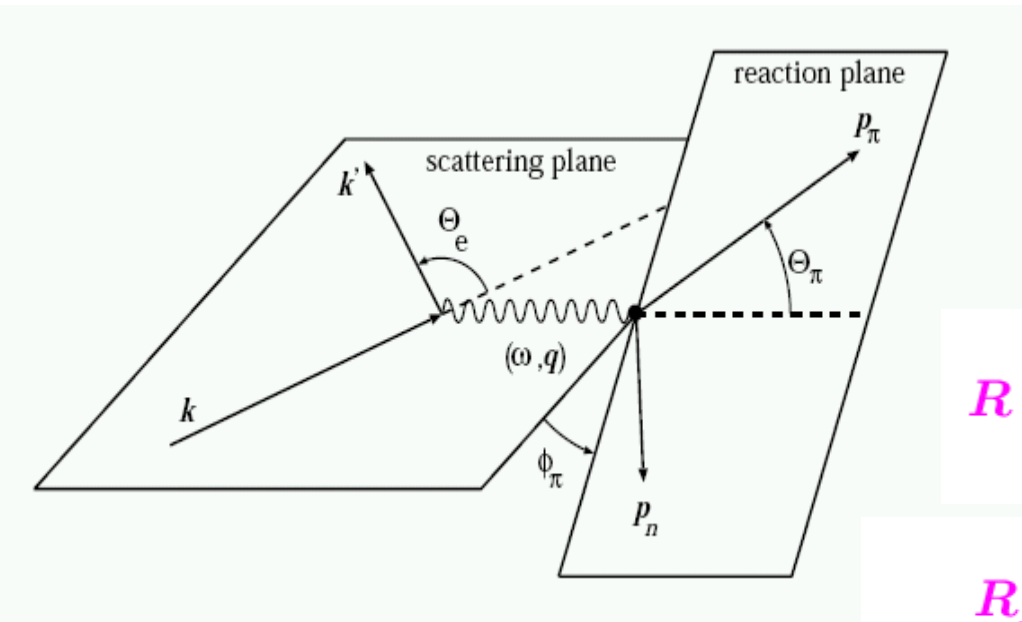
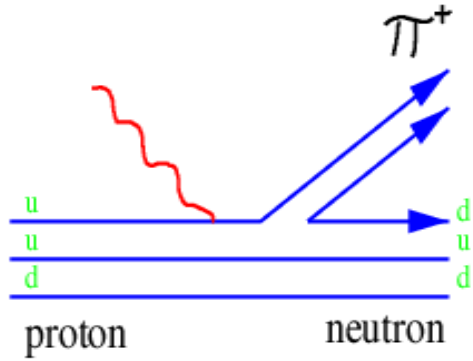
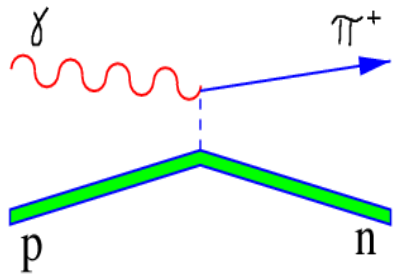
# Kinematic Variables




$$R \simeq \frac{2Q_d^2}{2Q_u^2} = \frac{(-1/3)^2}{(+2/3)^2} = 1/4$$

$$R_L \simeq \frac{Q_{\pi^-}^2}{Q_{\pi^+}^2} = 1$$




$$t \equiv (\gamma_v - \pi)^2 = -Q^2 + m_\pi^2 - 2\nu E_\pi + 2\nu p_\pi cos\theta_{q\pi}$$

$$\frac{d\sigma}{dt} = \sigma_T + \epsilon\,\sigma_L + \epsilon\cos 2\phi\,\sigma_{TT} + \sqrt{2\epsilon(1+\epsilon)}\cos\phi\,\sigma_{LT}$$

$$\sigma_L \propto \frac{-2tQ^2}{(t-m_\pi^2)^2} \cdot g_{\pi NN}^2(t) \cdot F_\pi^2$$



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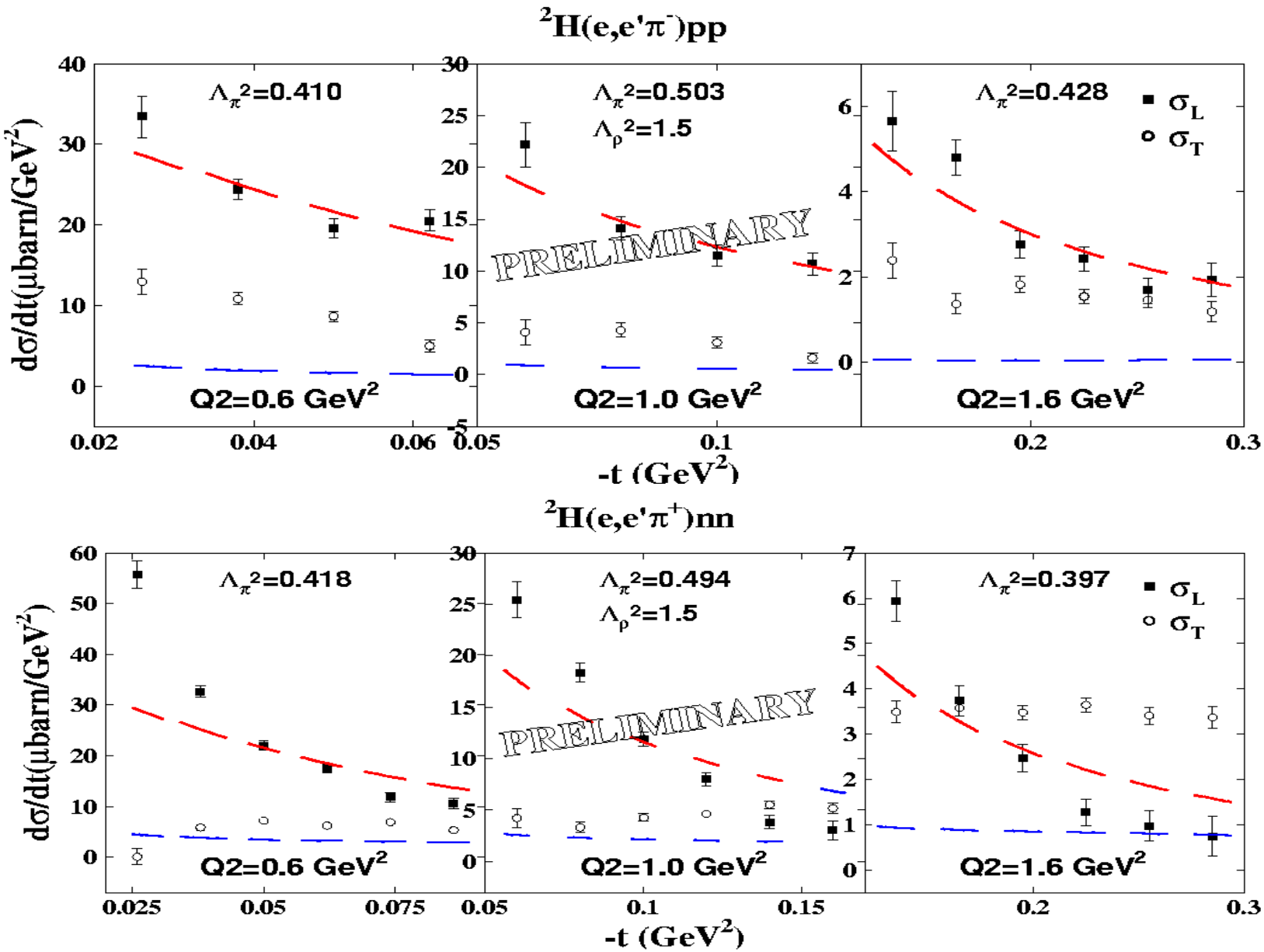
# Separated Response Functions



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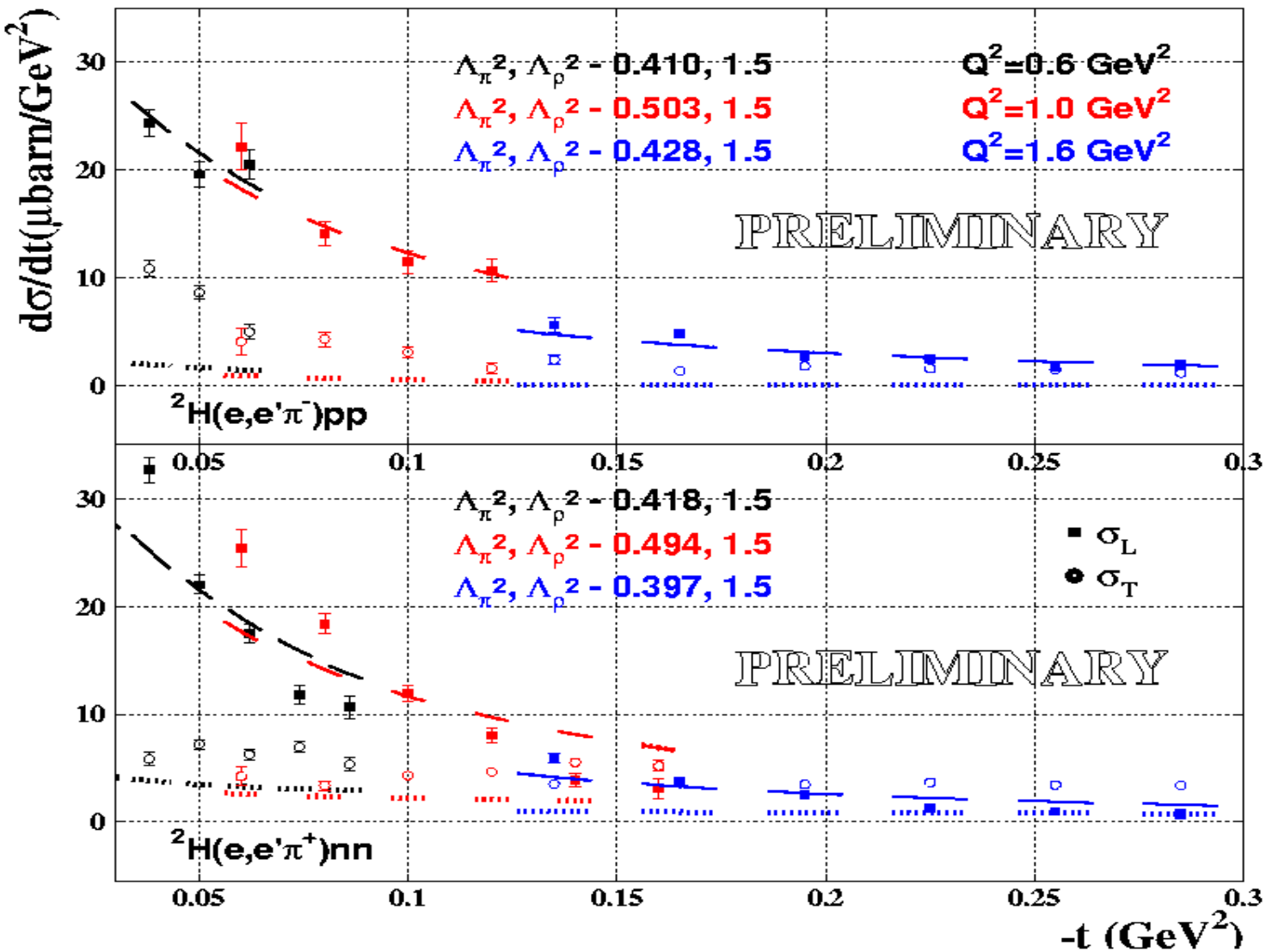
# Separated Response Functions



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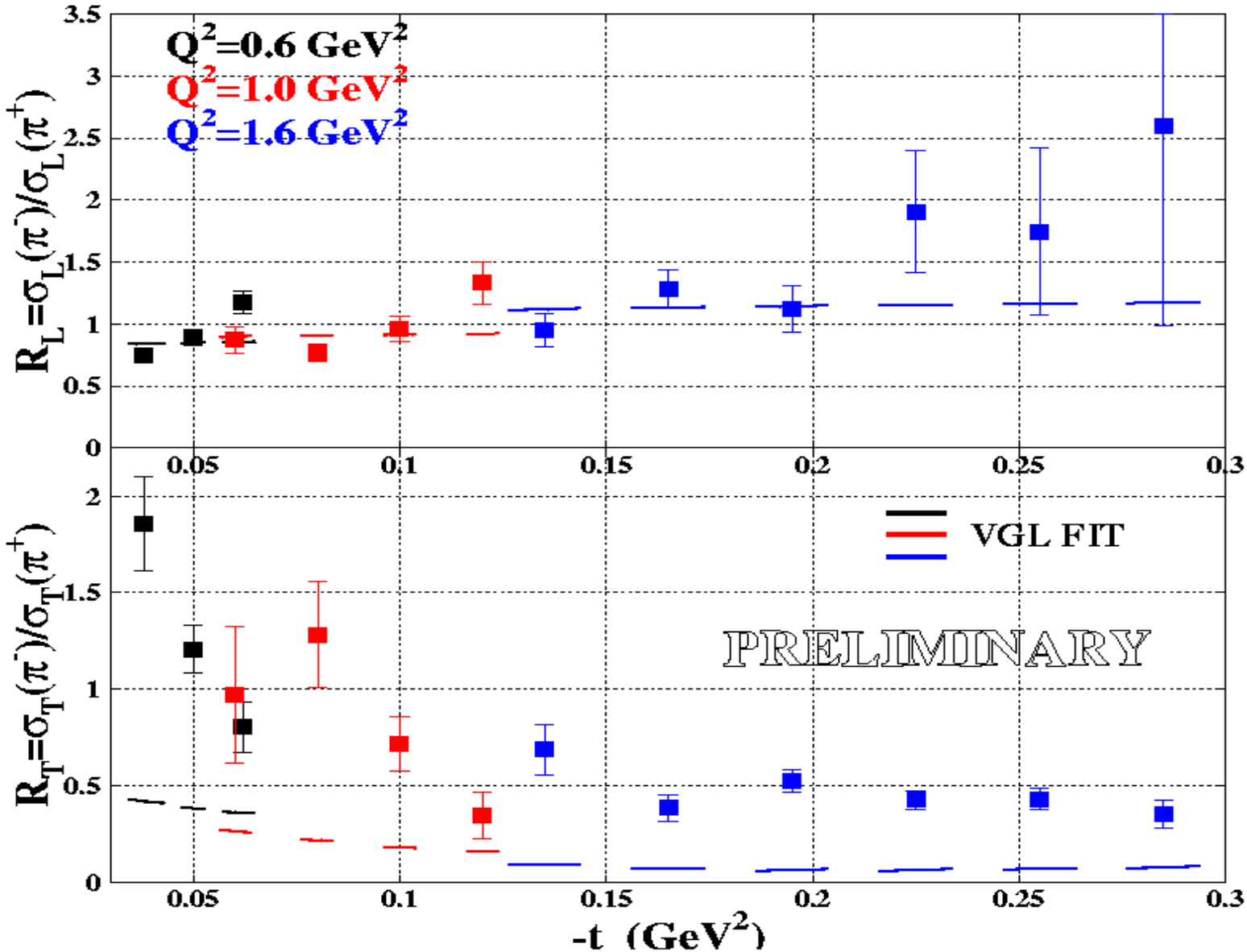
# Separated Response Functions Ratios



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