π^-/π^+ Exclusive Pion Electroproduction Results from Jefferson Lab

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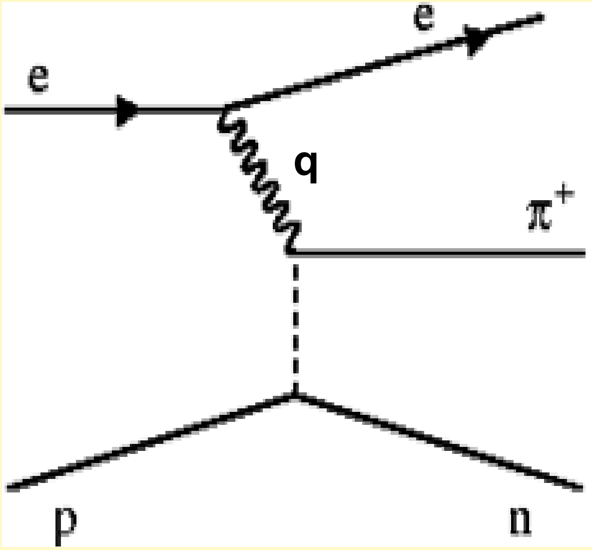
Deep Exclusive Meson Production

- **Single π^+ produced from proton, or π^- from neutron at high momentum transfer.**
- Probes the relevant degrees of freedom within nucleon at different distance scales.
- Use the virtual photon's longitudinal and transverse polarizations to act as a filter on the details of the probing interaction.



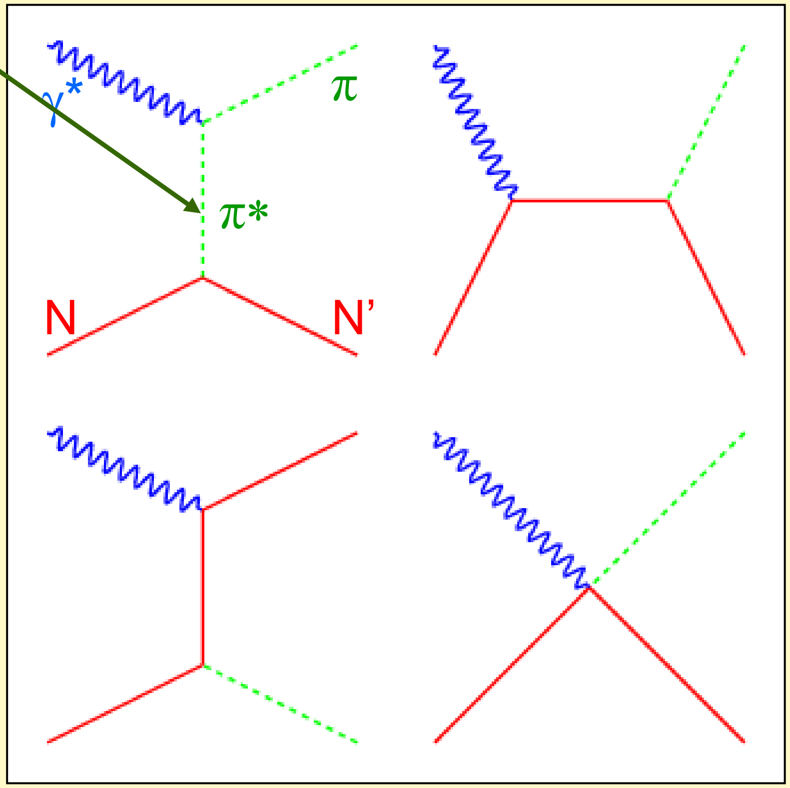
$$R_T = \frac{\gamma_T^* n \to \pi^- p}{\gamma_T^* p \to \pi^+ n} \xrightarrow[high\ -t]{} \frac{2Q_d^2}{2Q_u^2} = \frac{(-1/3)^2}{(+2/3)^2} = \frac{1}{4}$$

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

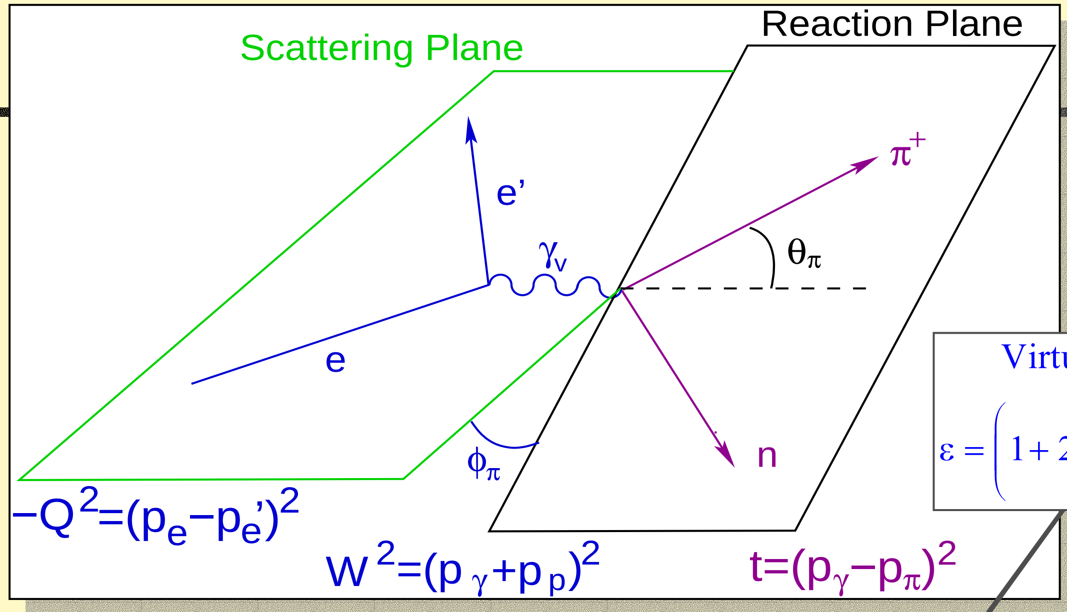
At low –t, Meson-Nucleon Degrees of Freedom

- $\pi^{\pm}$ *t*-channel diagram is purely isovector (G-parity conservation).

$$R_L = \frac{\sigma_L[n(e,e'\pi^-)p]}{\sigma_L[p(e,e'\pi^+)n]} = \frac{|A_V - A_S|^2}{|A_V + A_S|^2}$$



- A significant deviation of R_L from unity would indicate the presence of Isoscalar backgrounds (such as $b_1(1235)$ contributions to *t*-channel).
- Relevant for the extraction of the pion form factor from $p(e,e'\pi^+)n$ data, which uses a model including some isoscalar background.



Virtual-photon polarization:

$$\varepsilon = \left(1 + 2\frac{(E_e - E_{e'})^2 + Q^2}{Q^2}\tan^2\frac{\theta_{e'}}{2}\right)^{-1}$$

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

1. At small $-t$, σ_L has maximum contribution from the π pole.
   - $t=(p_{target}-p_{recoil})^2$ used in this analysis.
   - not necessarily equivalent to $t=(p_\gamma-p_\pi)^2$ due to Fermi momentum and radiation.
2. Only three of Q^2, W, t, θ_π are independent.
   - Vary θ_π to measure t dependence.
   - Since non-parallel data needed, LT and TT must also be determined.

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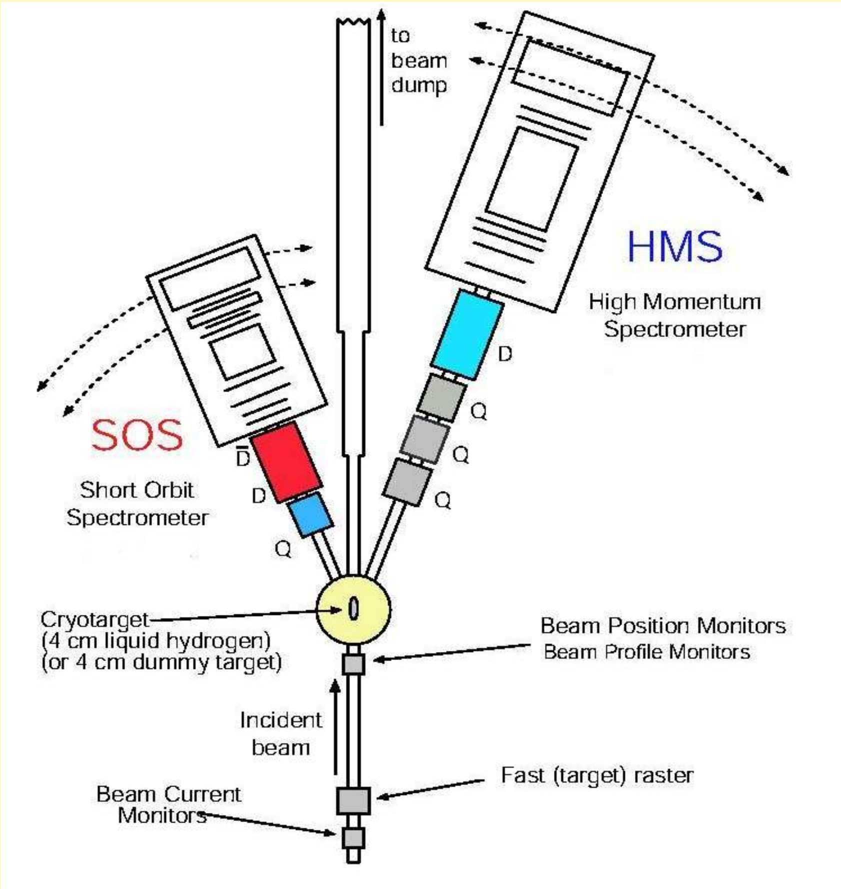
Jefferson Lab Hall C Experimental Setup



Exp	Q^2 $(GeV/c)^2$	W (GeV)	$\|t_{min}\|$ $(Gev/c)^2$	E_e (GeV)
Fπ-1	0.6-1.6	1.95	0.03-0.150	2.445-4.045
Fπ-2	2.45	2.22	0.189	4.210-5.246

Hall C spectrometers:

- Coincidence measurement.
- SOS detects e^-.
- HMS detects π^+ and π^-.

Targets:

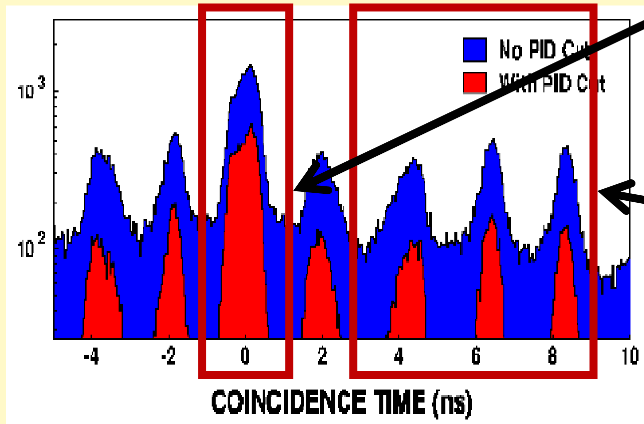
- Liquid 4-cm H/D cells.
- Al target for empty cell measurement.
- ^{12}C solid targets for optics calibration.

$^2H(e,e'\pi^{\pm})NN$ Event selection

Pions detected in HMS – Cerenkov & Coincidence time for PID

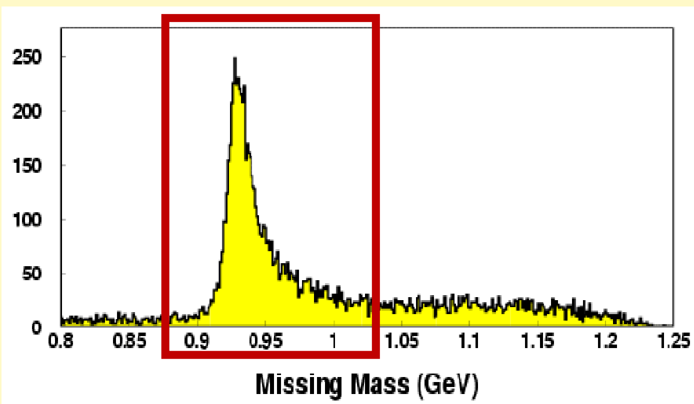
Electrons detected in SOS –Cerenkov & Lead Glass Calorimeter

Coincidence time resolution ~200-230 ps. Cut value ±1 ns.



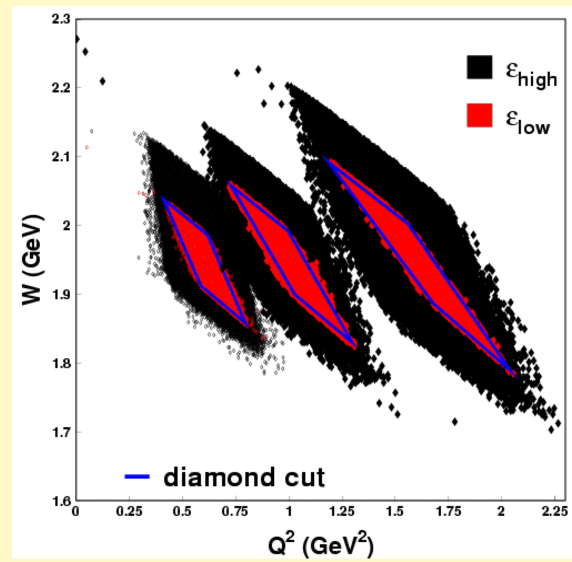
Electron-pion coincidences

Random coincidences



Exclusivity assured via 0.875<MM<1.03 GeV cut

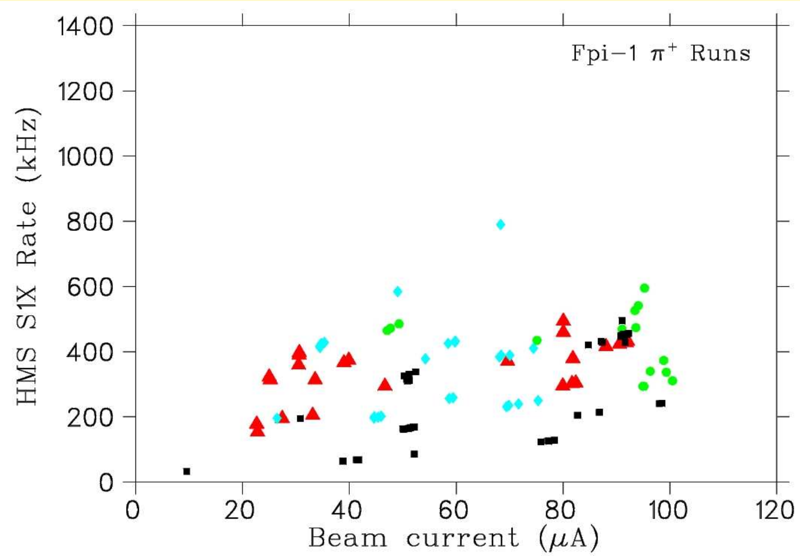
After PID & MM cuts, almost no random coincidences remain.

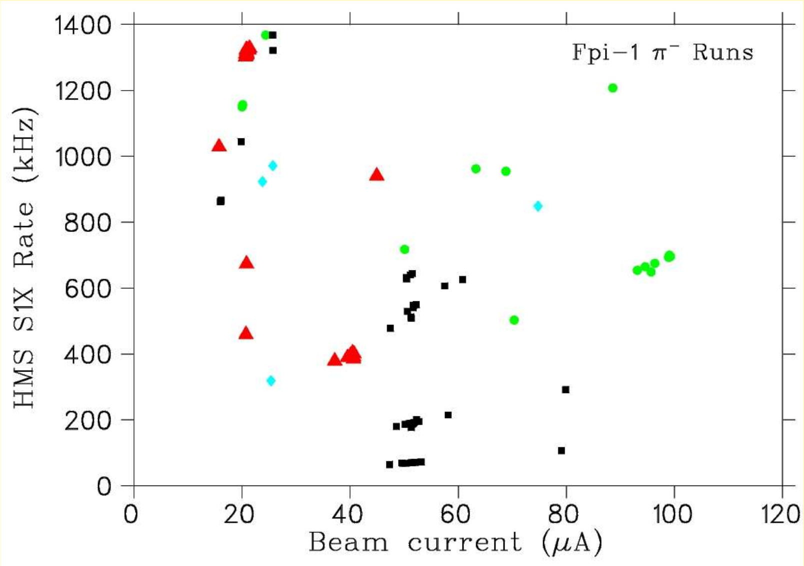


Diamond cuts define common (W,Q^2) coverage at both ε.

Corrections to π^-, π^+ Data

- **Negative polarity of HMS field for $^2H(e,e'\pi^-)pp$ means these runs have high electron rates not shared by $^2H(e,e'\pi^+)nn$ runs.**
- **Understanding rate dependent corrections very important with respect to final π^-/π^+ ratios.**
  - Improved high rate HMS tracking algorithm.
  - More accurate high rate tracking efficiencies (91-98%).
  - HMS π^- misidentification correction due to e^- pileup in Cerenkov (13%/MHz e^-).
  - High current ^2H target boiling correction (4.7%/100μA).

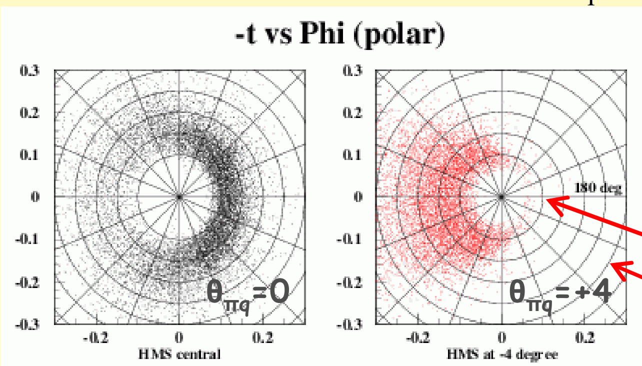




Q^2=0.60, 0.75, 1.0, 1.6 GeV^2

Extract response functions through iterative procedure

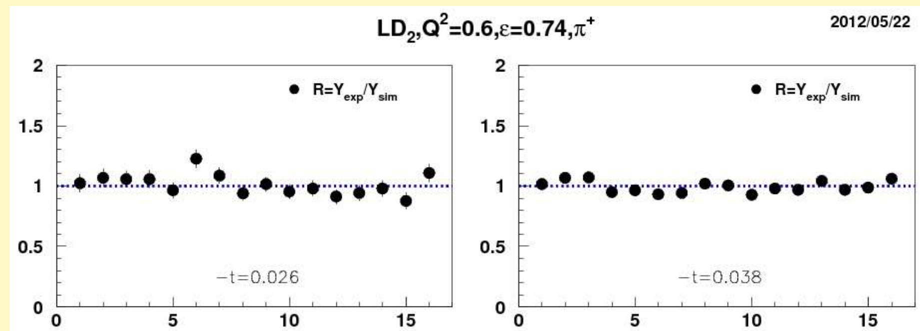
Improve φ coverage by taking data at multiple π (HMS) angles, $-4^o<\theta_{\pi q}<4^o$.

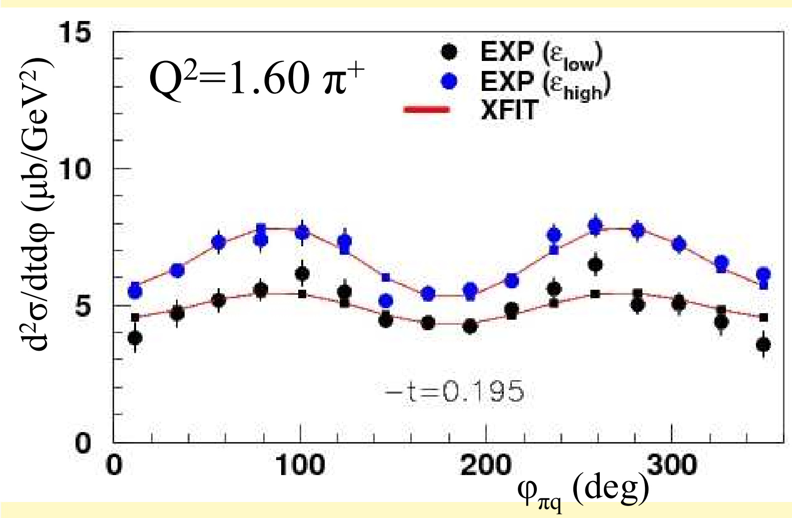


For each π HMS setting, form ratio:

$$R=\frac{Y_{EXP}}{Y_{SIMC}}$$

Combine ratios for π settings together, propagating errors accordingly.



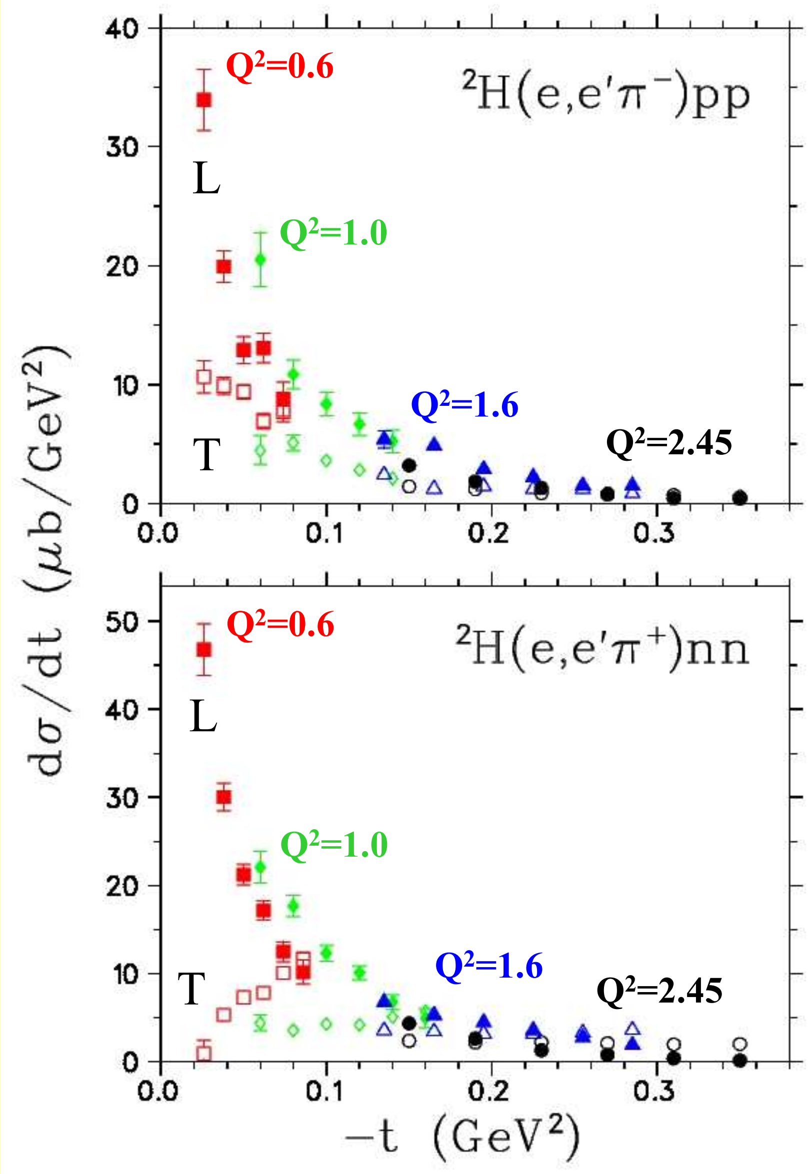


Extract via simultaneous fit of L,T,LT,TT

$$\left(\frac{d^2\sigma}{dtd\phi}\right)_{EXP}=\left(\frac{Y_{EXP}}{Y_{SIMC}}\right)\left(\frac{d^2\sigma}{dtd\phi}\right)_{SIMC}$$

$$2\pi\frac{d\sigma}{dtd\phi}=\varepsilon\frac{d\sigma_L}{dt}+\frac{d\sigma_T}{dt}+\sqrt{2\varepsilon(\varepsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi+\varepsilon\frac{d\sigma_{TT}}{dt}\cos2\phi$$

^{2}H(e,e'$\pi^{\pm}$)NN Separated dσ/dt

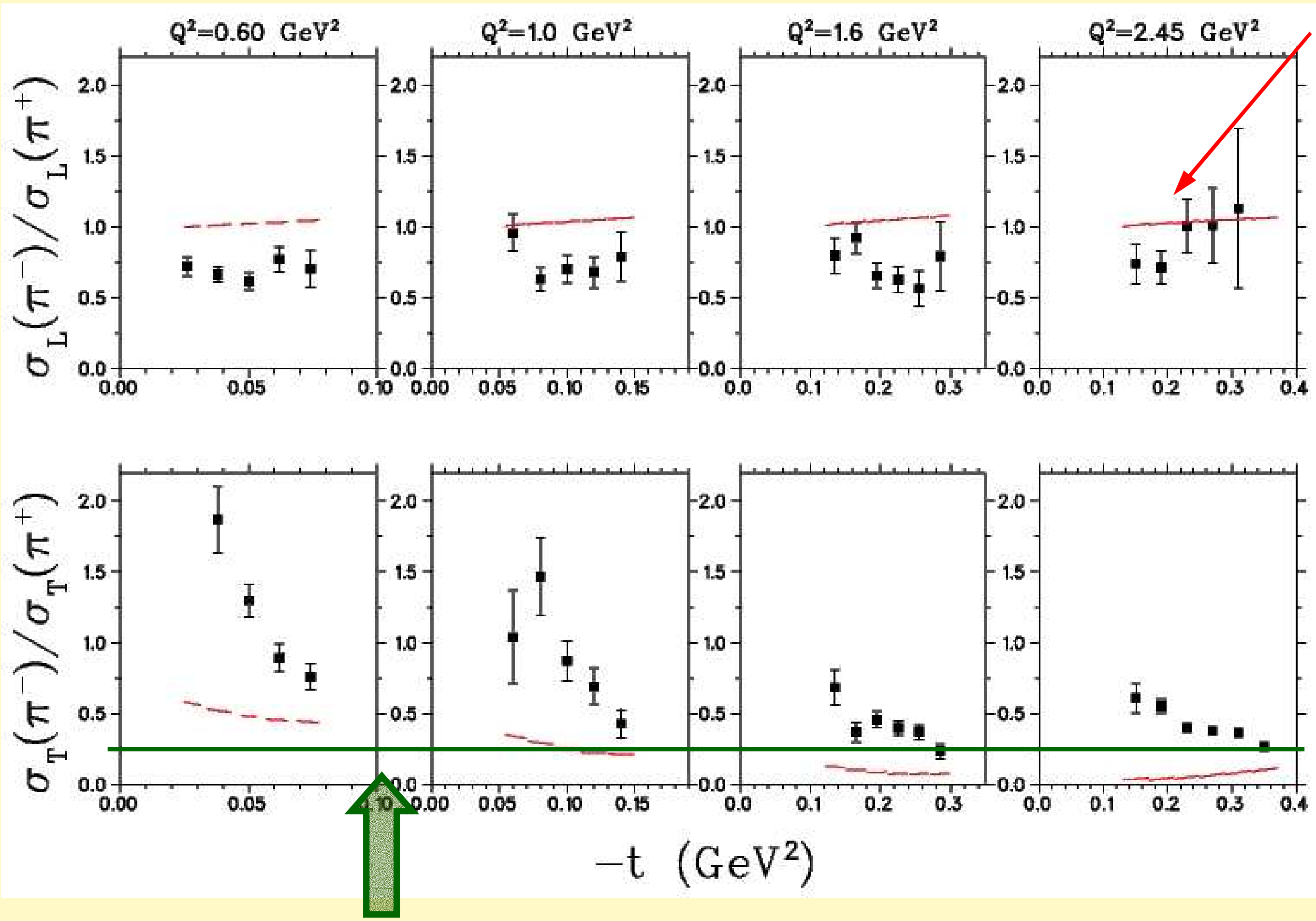


- Data points have slightly different $\overline{W}, \overline{Q}^2$
- All data scaled to W=2.0 GeV assuming $1/(W^2-M^2)$ dependence, M=free nucleon mass.
- No scaling applied in Q^2.

- **Longitudinal cross-section shows steep rise due to π pole at small –t.**
- **Transverse cross-section much flatter, generally smaller for π^-.**
- **Both follow nearly universal curves vs –t, with only a weak Q^2-dependence.**

Error bars indicate statistical and pt-pt systematic uncertainties in quadrature.

π^-/π^+ Separated Response Function Ratios



VGL Regge Model:

- π electroproduction in terms of exchange of π and ρ Regge trajectories.
  [PRC **57**(1998)1454]
- Model parameters fixed from pion photoproduction.
- Free parameters: Λ_π^2 and Λ_ρ^2 (from ^1H data).

R_L=0.8 consistent with $|A_S/A_V|$<6%.

- Transverse Ratios tend to ¼ as –t increases:
  → Is this an indication of Nachtmann's quark charge scaling?
- -t=0.3 GeV^2 seems too low for this to apply. Might indicate the partial cancellation of soft QCD corrections in the formation of the ratio.

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Summary

- **Separated σ_L, σ_T, σ_{LT}, σ_{TT} cross sections for the $^2H(e,e'\pi^{\pm})NN$ reactions were extracted using the Rosenbluth L/T separation technique.**
  - Fπ-1: W=1.95 GeV: Q^2=0.6, 1.0, 1.6 GeV^2.
  - Fπ-2: W=2.2 GeV: Q^2=2.45 GeV^2.

- **π^-/π^+ ratios for σ_L, σ_T extracted as a function of -t.**
  - $R_L \approx 0.8$, trending towards unity at low –t.
    - Indicates the dominance of isovector processes at low –t in the longitudinal response function.
  - The evolution of R_T with –t shows rapid fall off consistent with earlier theoretical predictions, expected to approach ¼, the square of the ratio of the quark charges involved.
    - Further theoretical work needed re. alternate explanations.