Separated Response Functions in Exclusive, Forward $\pi^{\pm}$ Electroproduction on ^{2}H

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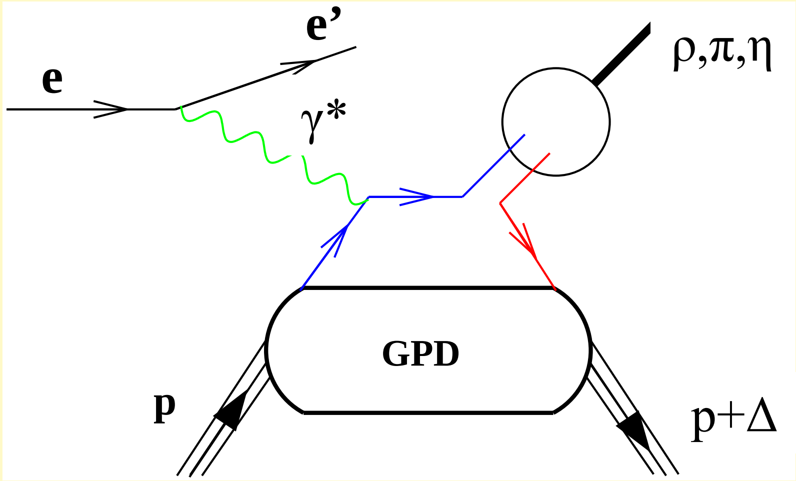
GPDs in Deep Exclusive Meson Production

Four GPDs at leading twist:

→ Unpolarized: $H(x, \xi, t)$, $E(x, \xi, t)$

→ Polarized: $\tilde{H}(x, \xi, t)$, $\tilde{E}(x, \xi, t)$



Second set of four GPDs at twist-3: $\tilde{H}_T$, H_T, $\tilde{E}_T$, E_T

→ Dominant twist-3 contribution from H_T contributes to $M_{0-,++}$ amplitude

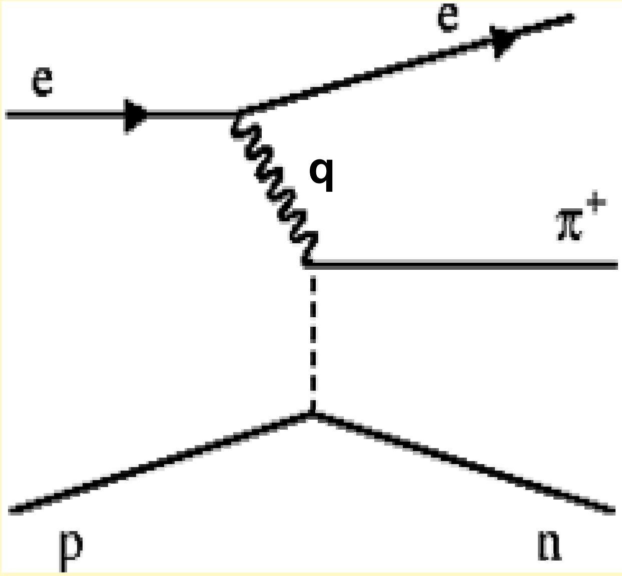
→ Manifested in the transverse cross section or interference terms:

σ_T, σ_{TT}, σ_{LT}, and various single spin asymmetries.

In the forward limit, H_T reduces to the transversity distribution $h_1(x)$.

Deep Exclusive $\pi^{\pm}$ Production

- **Single π^{+} produced from proton, or π^{-} from neutron at high momentum transfer.**
- **Can form ratios of separated cross-sections for which non-perturbative corrections may partially cancel, yielding insight into soft-hard factorization at modest Q^2.**



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

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

- **Pseudoscalar meson production has been identified as especially sensitive to chiral-odd transverse GPDs.**

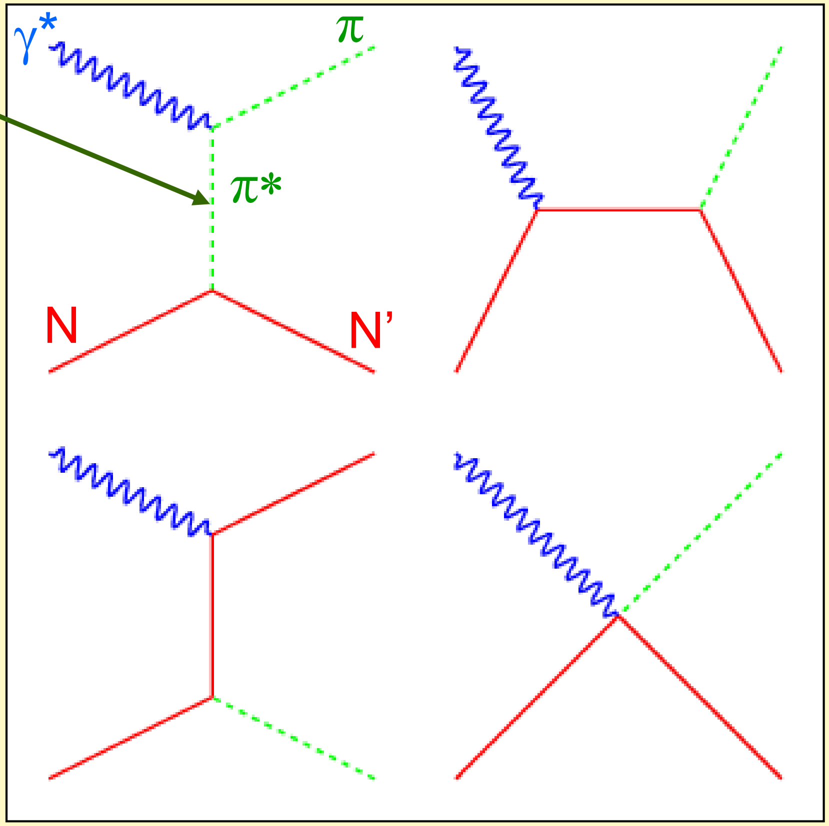
  → R_T is not complicated by the π–pole term.

At low $-t$, Meson-Nucleon Degrees of Freedom

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

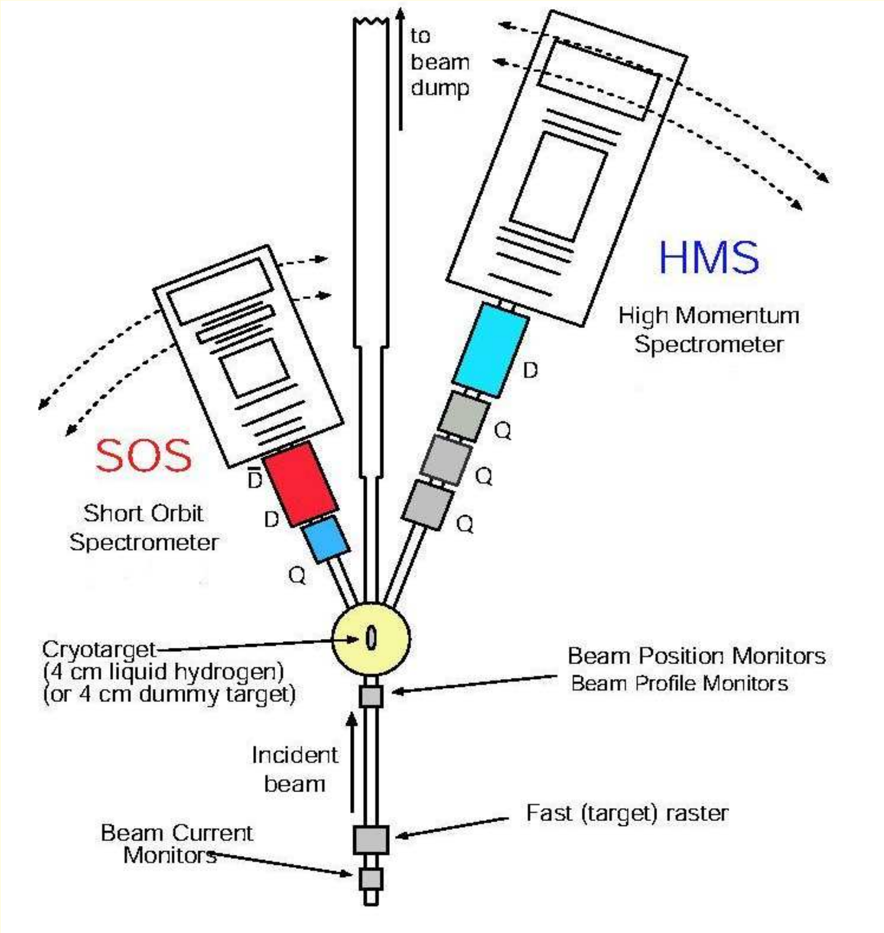
$$R_L = \frac{\sigma_L[n(e,e'\pi^-)p]}{\sigma_L[p(e,e'\pi^+)n]} = \frac{|A_V - A_S|^2}{|A_V + A_S|^2}$$

- 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 extraction of pion form factor from $p(e,e'\pi^+)n$ data, which uses model including some isoscalar background.

Jefferson Lab Hall C Experimental Setup



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.

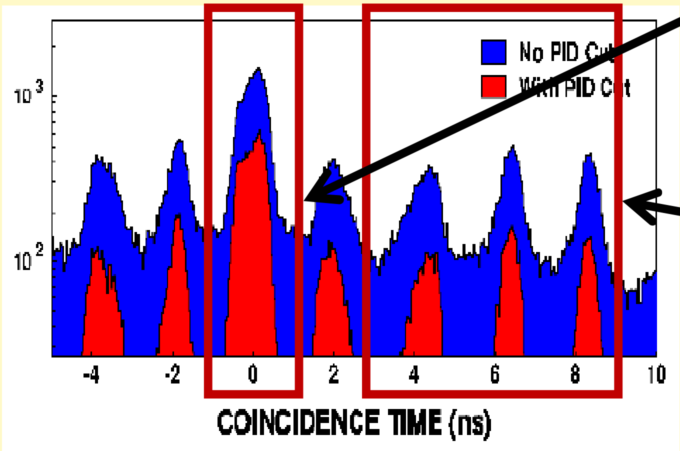
Exp	Q^2 (GeV/c)^2	W (GeV)	$\|t_{min}\|$ (Gev/c)^2	E_e (GeV)
Fπ-1	0.6-1.6	1.95	0.03-0.150	2.445-4.045
Fπ-2	2.45	2.22	0.189	4.210-5.246

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

Pions detected in HMS – Cerenkov & Coincidence time for PID

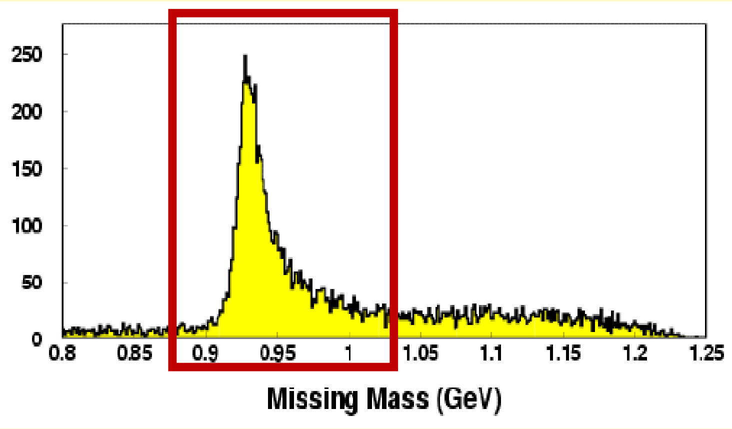
Electrons detected in SOS –Cerenkov & Lead Glass Calorimeter

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



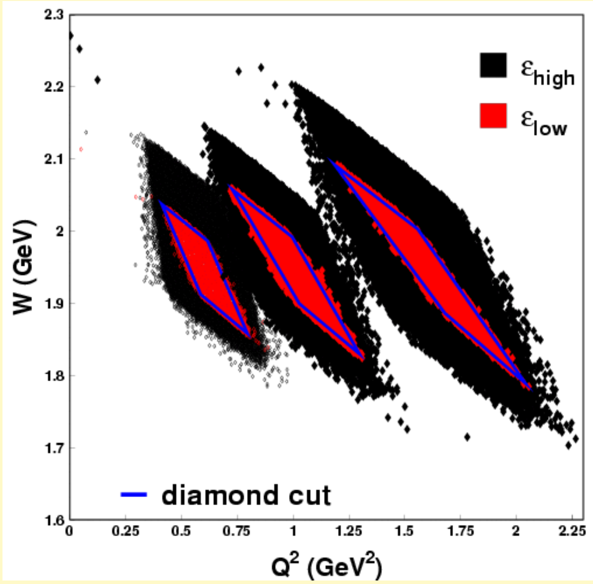
Electron-pion coincidences

Random coincidences



Exclusivity assured via 0.875<MM<1.03 GeV cut

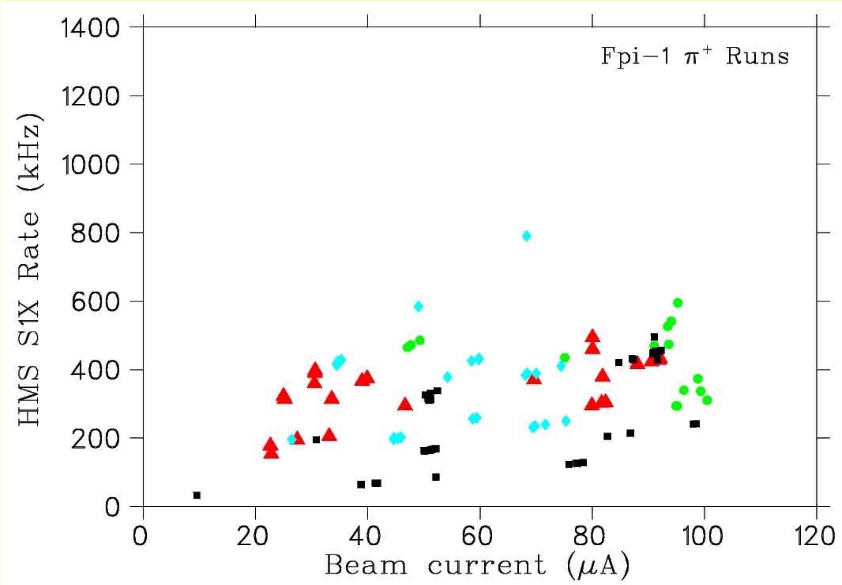
After PID & MM cuts, almost no random coincidences remain.

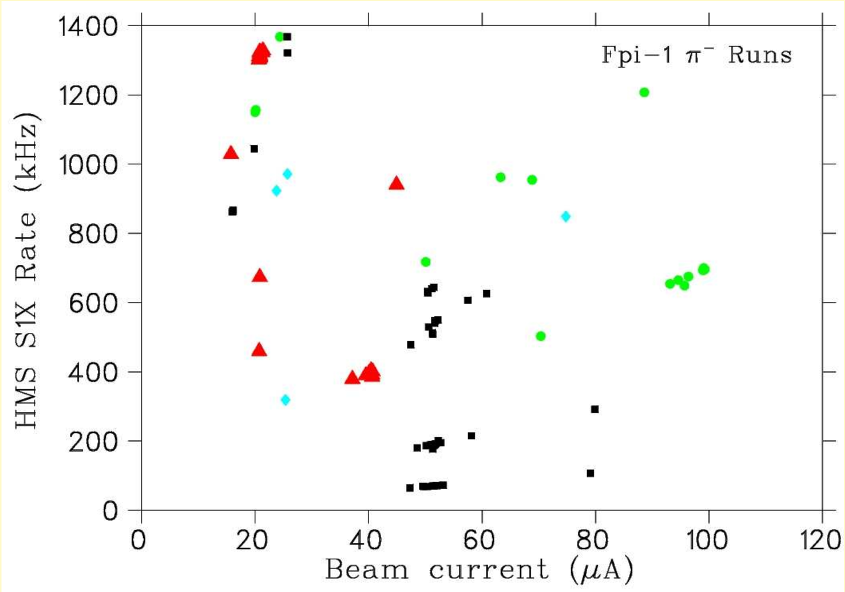


Diamond cuts define common (W,Q^{2}) coverage at both ε.

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).

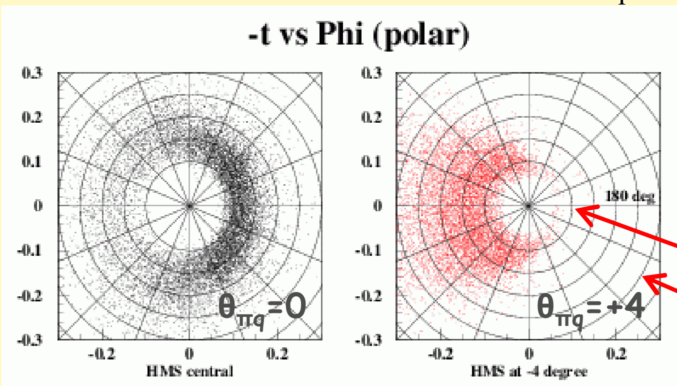




Q^2=0.60, 0.75, 1.0, 1.6 GeV^2

Extract Response Functions through Iterative Procedure

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



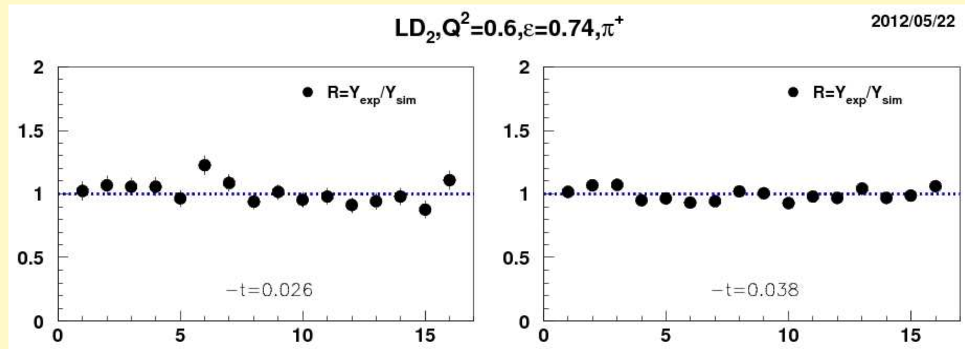
-t=0.1

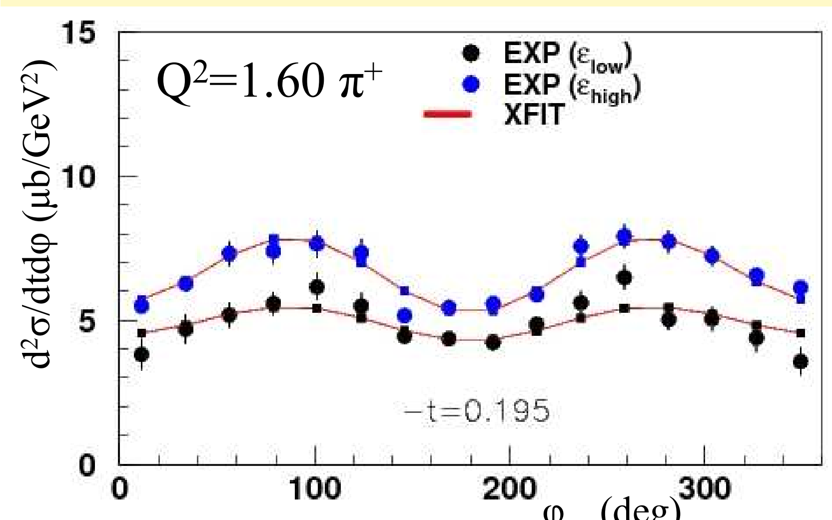
-t=0.3

For each π HMS setting, form ratio:

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

Combine ratios for π settings together, propagating errors accordingly.



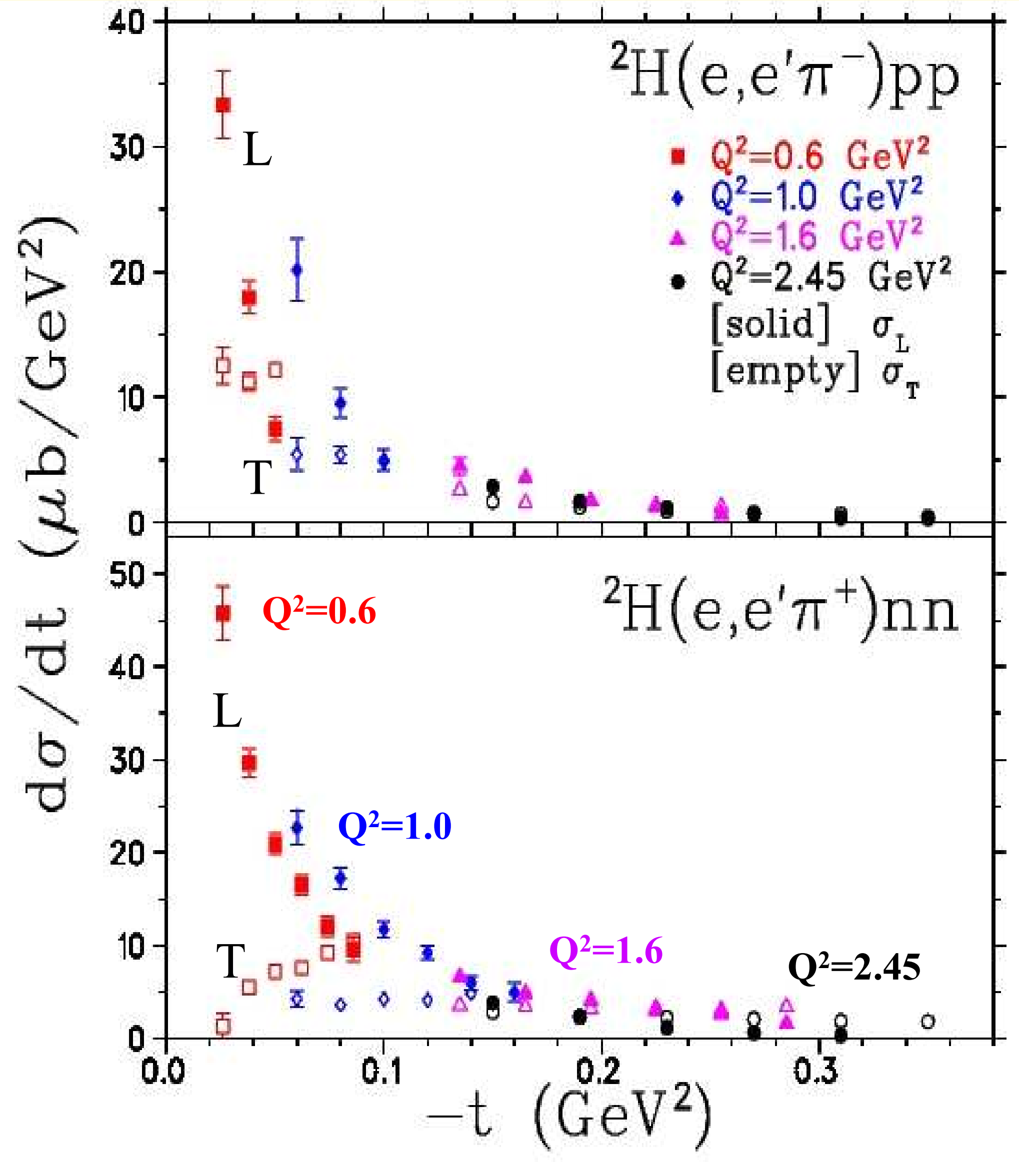


Extract via simultaneous fit of L,T,LT,TT

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

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

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

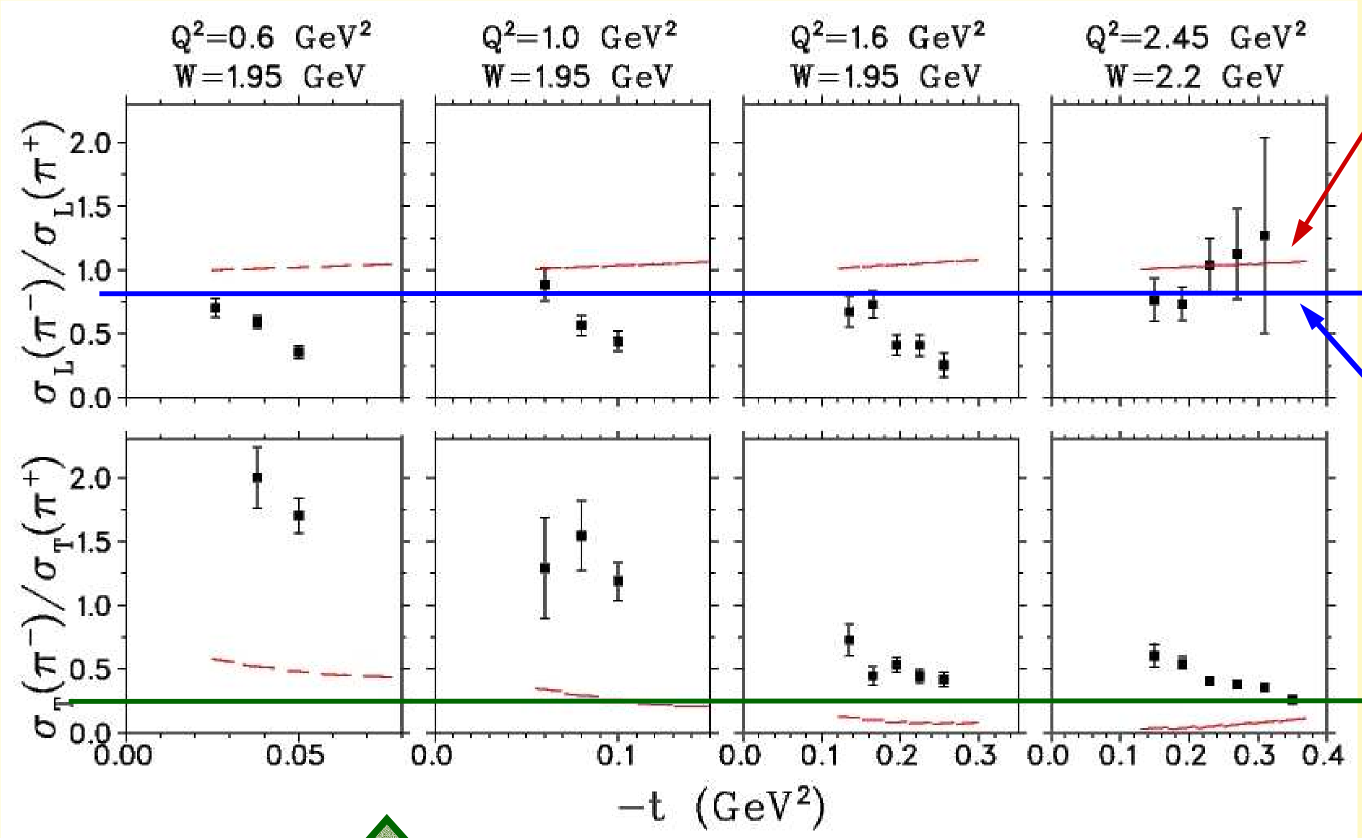


- Data points have slightly different $\overline{W}, \overline{Q}^2$
- All data scaled to W=2.0 GeV assuming $1/(W^2-M^2)$ dependence, M=free nucleon mass.
- No scaling applied in Q^2.

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

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

π^-/π^+ Separated Response Function Ratios



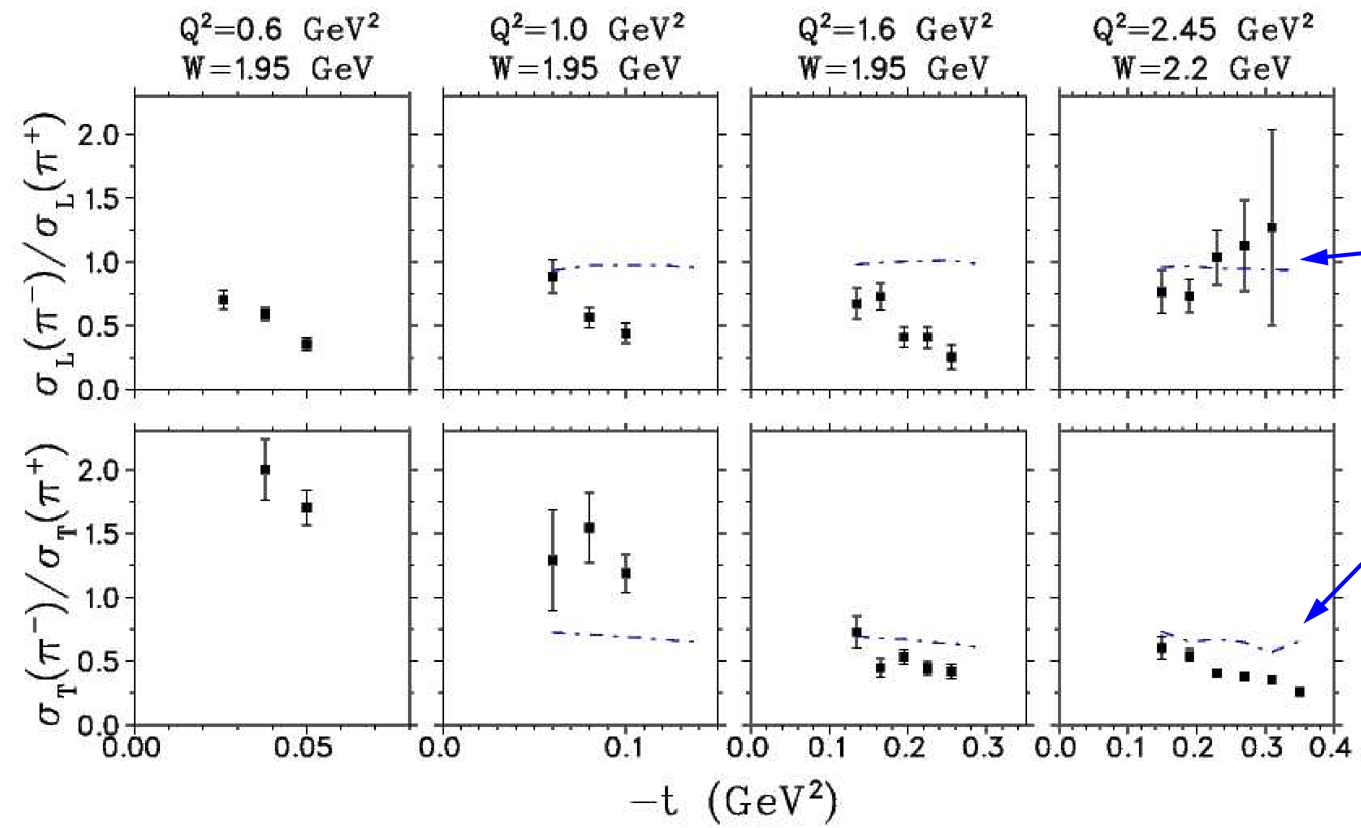
VGL Regge Model:

- Free parameters: Λ_π^2 and Λ_ρ^2 (from ^{1}H data).
  [PRC **57**(1998)1454]

***R_L*≈0.8 near *$-t_{min}$* at each *Q^2*.**
Predicted in large *N_c* limit calculation.
Frankfurt, et al.
PRL **84**(2000)2589.

- **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.**

Comparison with Goloskokov-Kroll GPD model



- $\pi^{\pm}$ electroproduction in a handbag framework.
- Modified perturbative approach with full $F_{\pi}(Q^2)$.
- Substantial contributions from transverse photons as twist-3 effect (H_T) [Eur.Phys.J.A**47**(2011)112]

- Model parameters optimized for small skewness ($\xi<0.1$) and W>4 GeV.
- Application to our kinematics requires substantial extrapolation in W, ξ.
  → Please be cautious in the comparison.
- Although model does reasonable job at predicting ratios, agreement of model with our σ_T is not good.
- Model optimized for JLab kinematics should be sensitive to transverse GPD, $\boldsymbol{H_T}$

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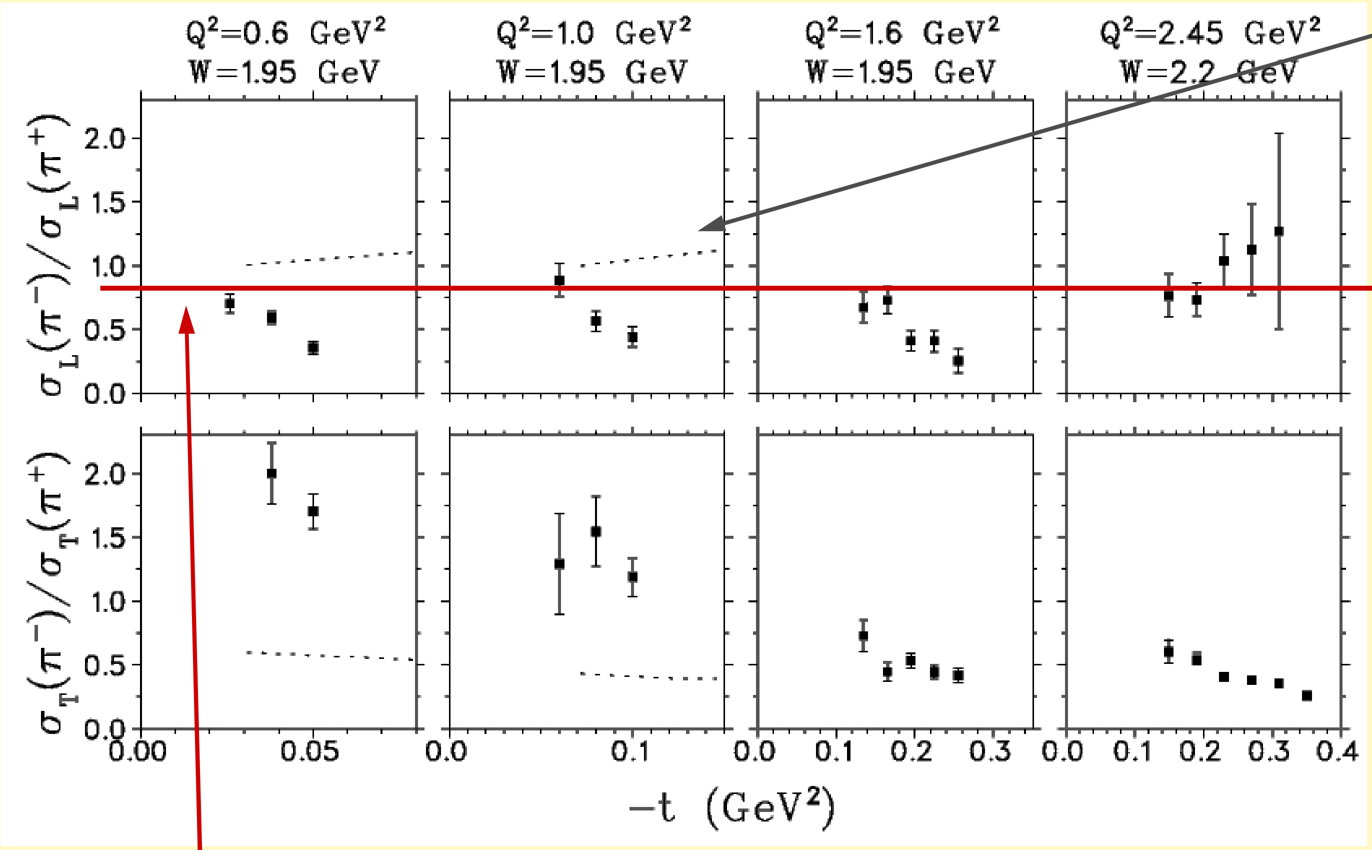
Relevance to Pion Form Factor Extraction



Kaskulov-Mosel Model:

- VGL Regge Model underpredicts σ_T by large factor.
- KM extend VGL with hard DIS process of virtual photons off nucleons.

[PRC **81**(2010)045202]

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

- Qualitatively in agreement with our Fπ-1 analysis:
  - We found evidence for small additional contribution to σ_L at W=1.95 GeV not taken into account by the VGL model.
- We found little evidence for this contribution in Fπ-2 analysis at W=2.2 GeV.

Summary

- **Separated σ_L, σ_T, σ_{LT}, σ_{TT} cross sections for the ^{2}H(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.