π^-/π^+ Separated Response Function Ratios in Forward, Exclusive Pion Electroproduction

Garth Huber

UNIVERSITY OF REGINA

CAP Congress, Calgary, AB. June 13, 2012.

Jefferson Lab F_π Collaboration

R. Ent, D. Gaskell, M.K. Jones, D. Mack, D. Meekins, J. Roche, G. Smith, W. Vulcan, G. Warren, S.A. Wood
Jefferson Lab, Newport News, VA , USA

C. Butuceanu, E.J. Brash, G.M. Huber, V. Kovaltchouk, G.J. Lolos, S. Vidakovic, C. Xu
University of Regina, Regina, SK, Canada

H.P. Blok, V. Tvaskis
V.U. University, Amsterdam, Netherlands

E. Beise, H. Breuer, C.C. Chang, T. Horn, P. King, J. Liu, P.G. Roos
University of Maryland, College Park, MD, USA

W. Boeglin, P. Markowitz, J. Reinhold
Florida International University, FL, USA

J. Arrington, R. Holt, D. Potterveld, P. Reimer, X. Zheng
Argonne National Laboratory, Argonne, IL, USA

H. Mkrtchyan, V. Tadevosyan
Yerevan Physics Institute, Yerevan, Armenia

S. Jin, W. Kim
Kyungook National University, Taegu, Korea

M.E. Christy, C. Keppel, L.G. Tang
Hampton University, Hampton, VA, USA

J. Volmer
DESY, Hamburg, Germany

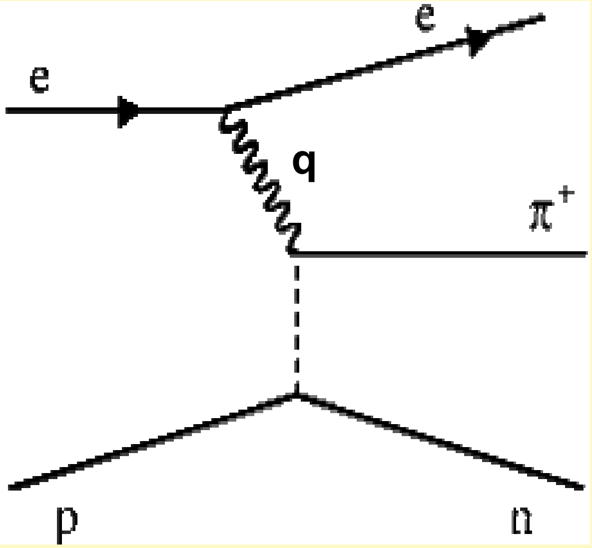
A. Matsumura, T. Miyoshi, Y. Okayasu
Tohuku University, Sendai, Japan

B. Barrett, A. Sarty
St. Mary's University, Halifax, NS, Canada

K. Aniol, D. Margaziotis
California State University, Los Angeles, CA, USA

L. Pentchev, C. Perdrisat
College of William and Mary, Williamsburg, VA, USA

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.

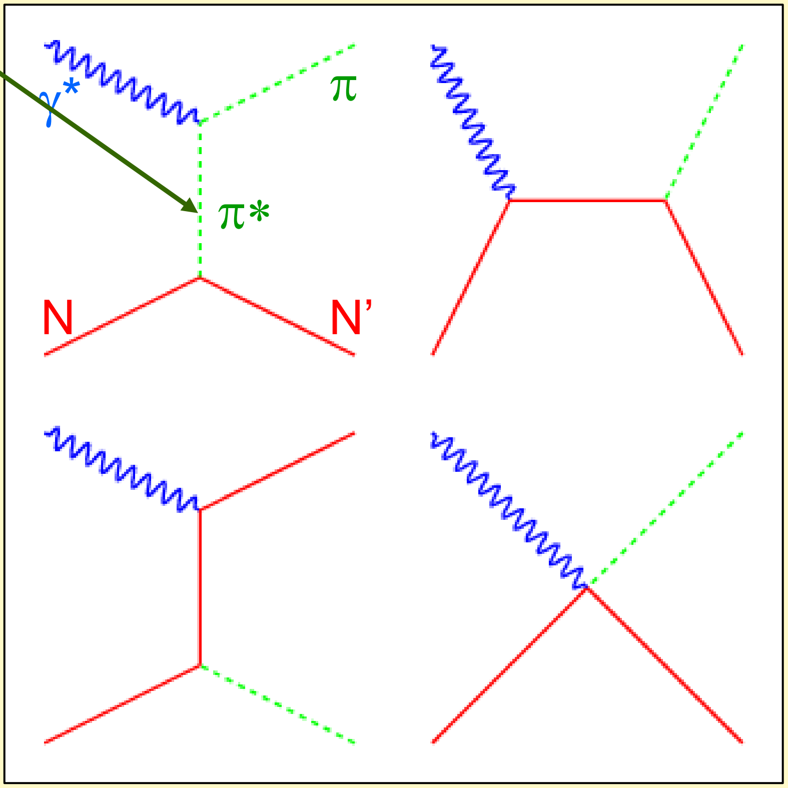
$$R_T = \frac{\gamma_T^* n \to \pi^- p}{\gamma_T^* p \to \pi^+ n} \xrightarrow[high\ -t]{} \frac{2Q_d^2}{2Q_u^2} = \frac{(-1/3)^2}{(+2/3)^2} = \frac{1}{4}$$

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

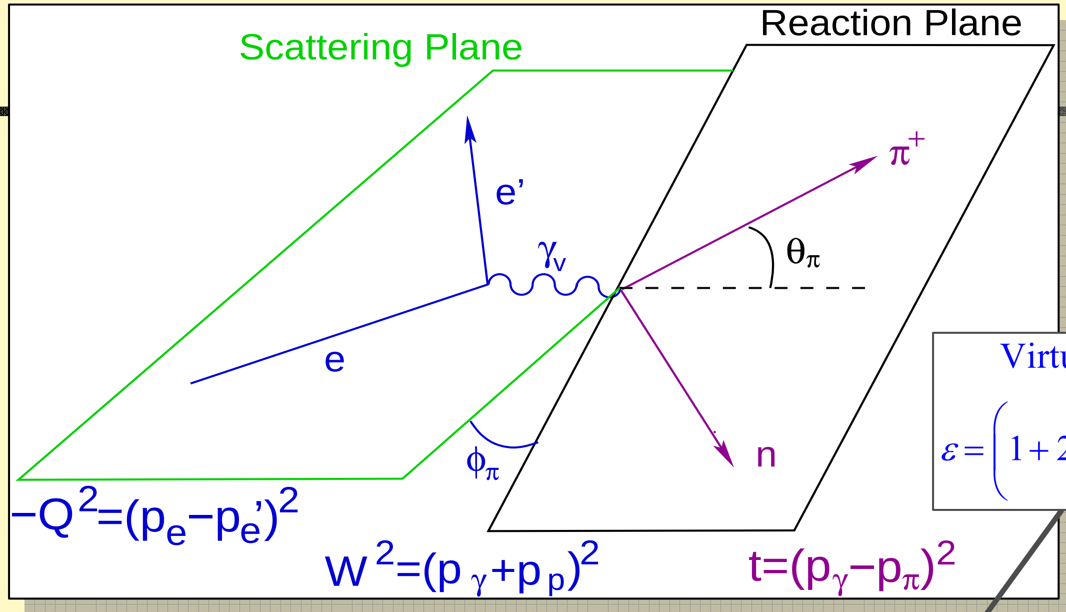
At low –t, Meson-Nucleon Degrees of Freedom

- π^+ *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.



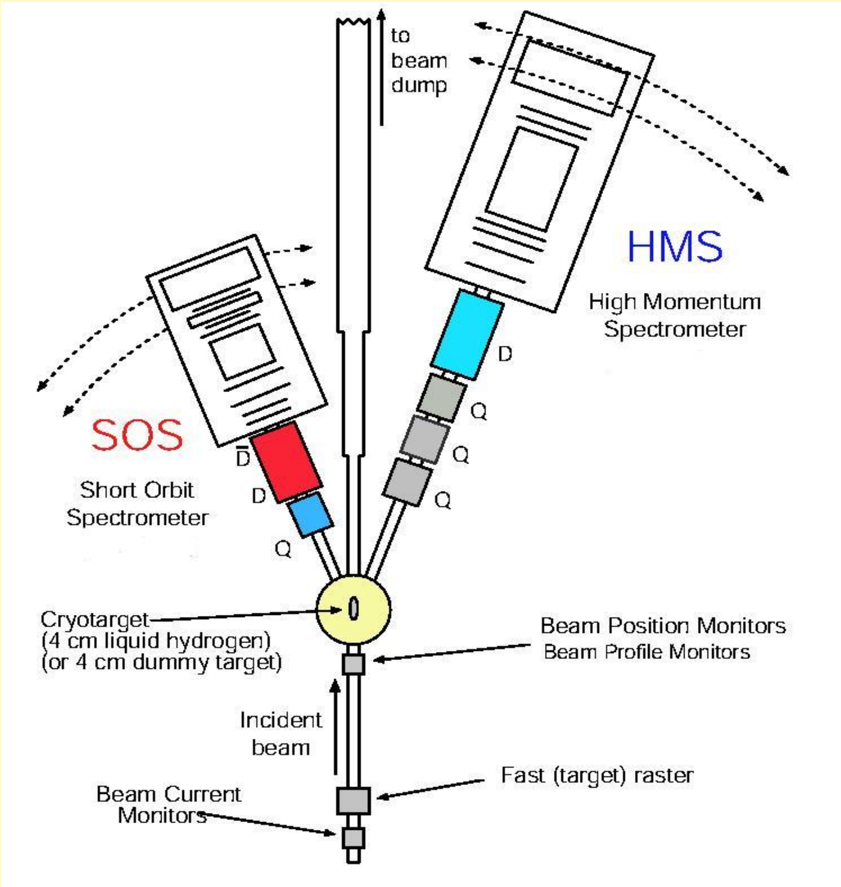
Virtual-photon polarization:

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

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

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 $(p_\gamma-p_\pi)^2$ 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.

Experimental Setup



Exp	Q2 $(GeV/c)^2$	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	1.6,2.5	2.22	0.093,0.189	3.779-5.246

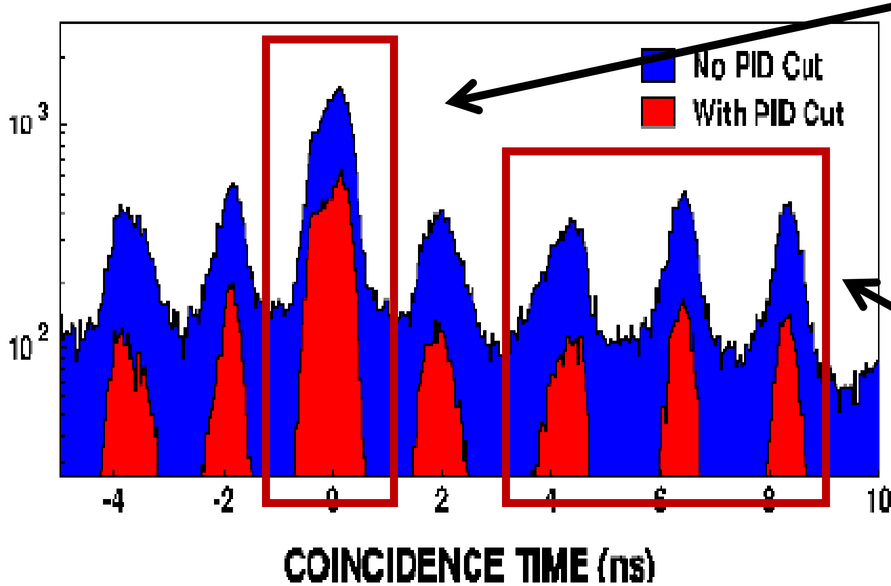
Hall C spectrometers:

- 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



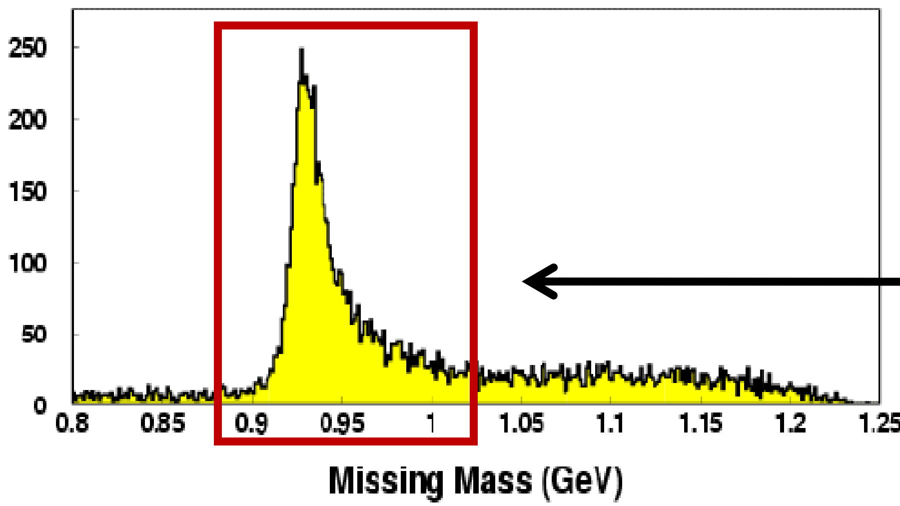
Electron-pion coincidences

Random coincidences

Pions detected in HMS – Cerenkov & Coincidence time for PID

Coincidence time resolution ~200-230 ps.

Cut value ±1 ns.



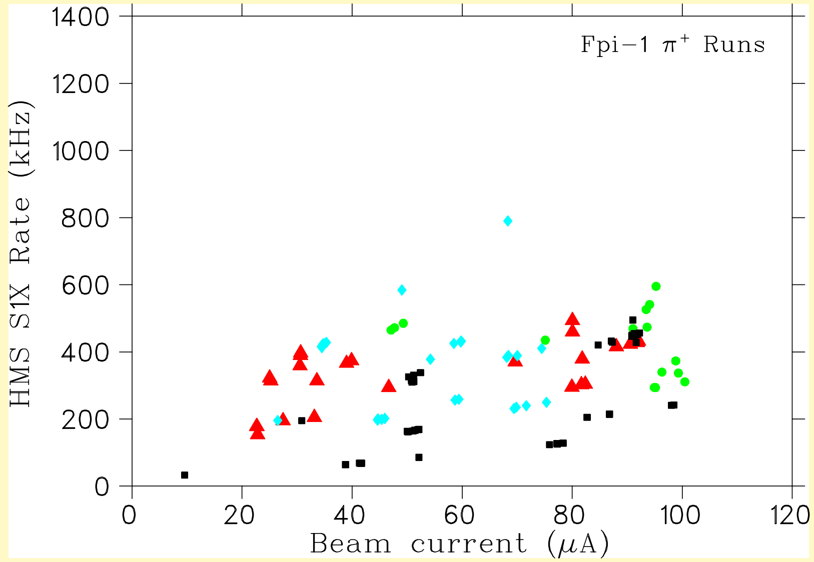
Electrons detected in SOS – Cerenkov & Lead Glass Calorimeter

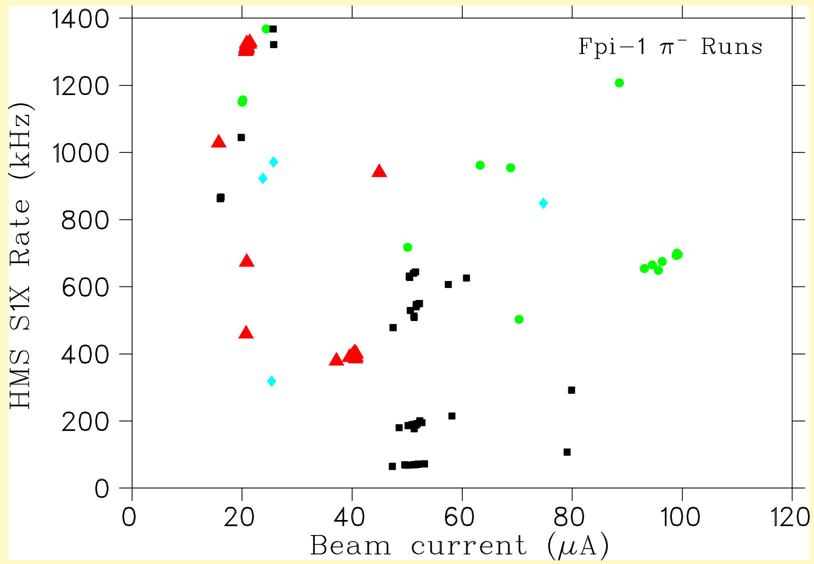
Exclusivity assured via 0.875<MM<1.03 GeV cut

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

Corrections to π-, π+ Data

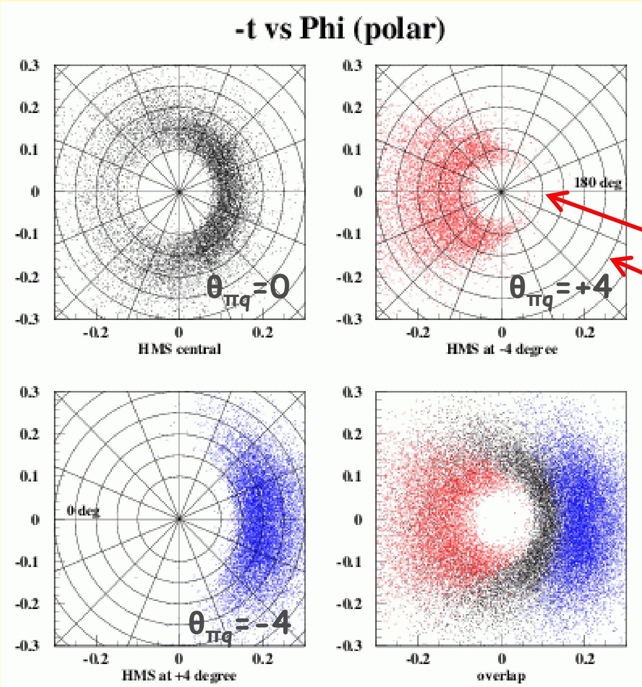
- **Negative polarity of HMS field for ^{2}H(e,e'π-)pp means these runs have high electron rates not shared by ^{2}H(e,e'π+)nn runs.**
- Understanding rate dependent corrections very important with respect to final π-/π+ ratios.
  - Better high rate HMS tracking algorithm.
  - More accurate high rate tracking efficiencies (91-98%).
  - HMS Cerenkov π- blocking correction (13%/MHz e^-).
  - High current ^{2}H target boiling correction (7%/100µA).





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

Kinematic Coverage

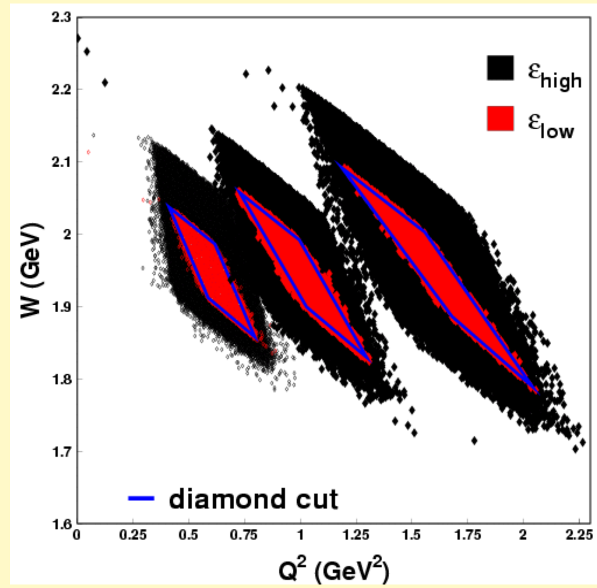


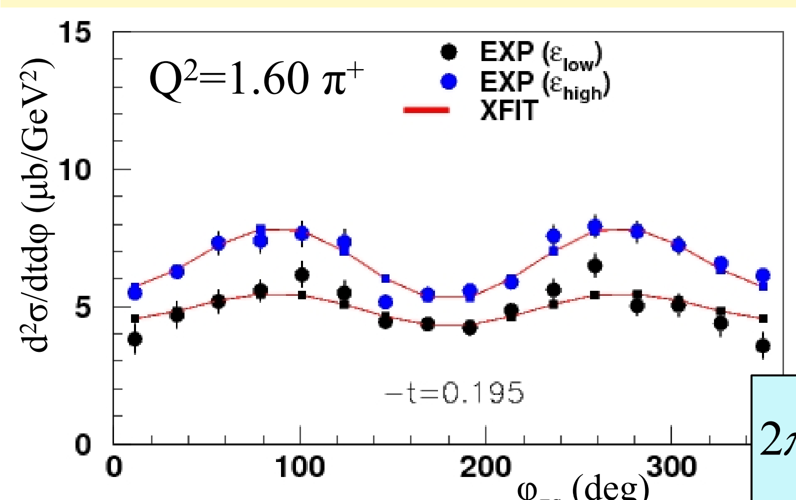
Measure σ_{TT} and σ_{LT} by taking data at three π^+ angles: $\boldsymbol{\theta_{\pi q}}$=0°, +4°, -4°.

-t=0.1

-t=0.3

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





Extract σ_L by simultaneous fit of L,T,LT,TT

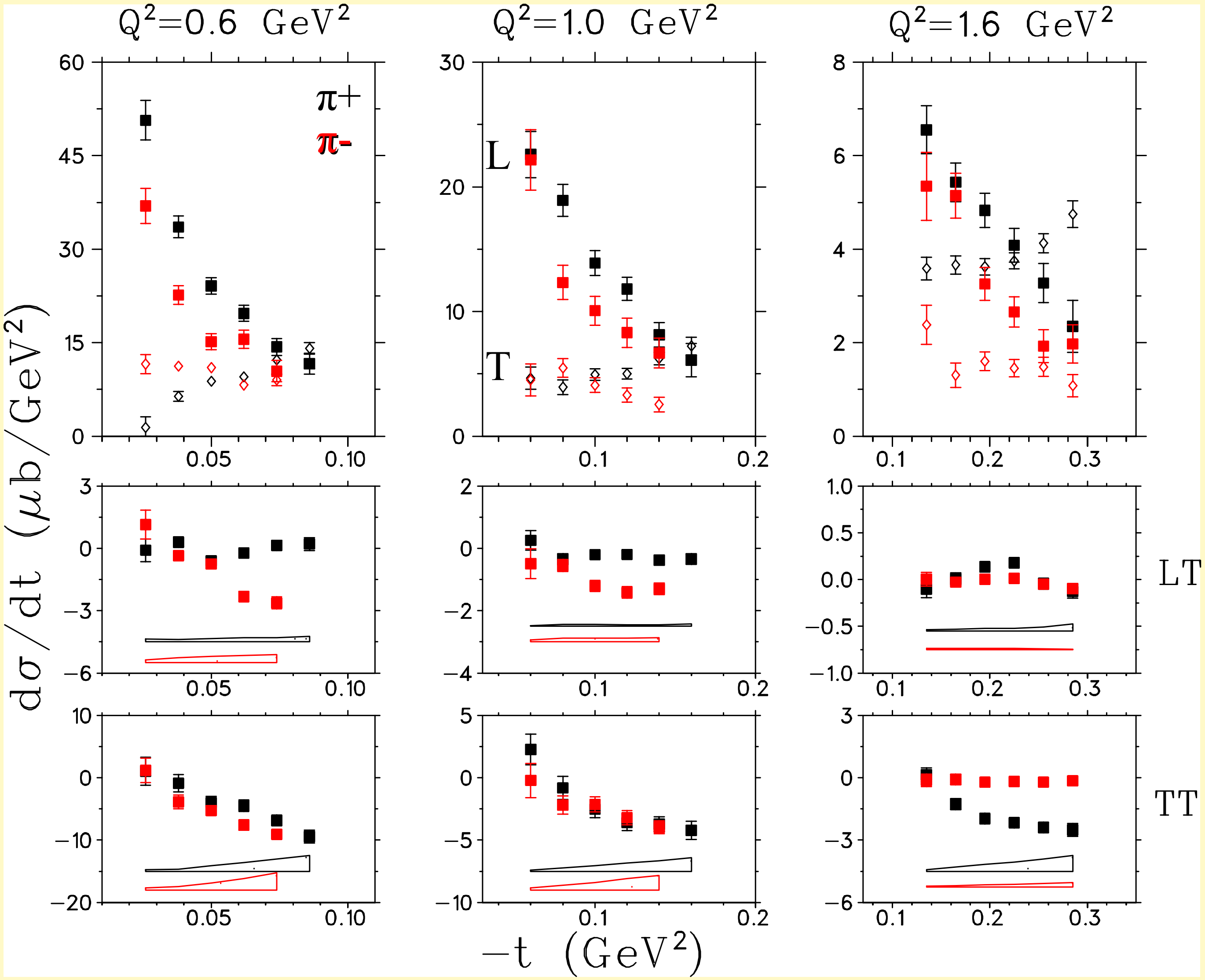
$$2\pi\frac{d\sigma}{dtd\phi}=\varepsilon\frac{d\sigma_L}{dt}+\frac{d\sigma_T}{dt}+\sqrt{2\varepsilon(\varepsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi+\varepsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi$$

Magnetic Spectrometer Calibrations

- Over-constrained *p(e,e'p)* reaction and elastic *e*+^{12}C reactions used to calibrate spectrometer acceptances, momenta, offsets, etc.
- Spectrometers well-understood after careful comparison with MC simulations.
  - Beam energy and spectrometer momenta determined to <0.1%.
  - Spectrometer angles to <1 mrad.
- **Agreement with published *p+e* elastics cross sections <2%.**

Source	Pt-Pt	ε uncorr. t corr,	Scale
Beam and Spectrometer Kinematic Offsets	0.2%	0.8-1.1%	
HMS β-cut corrections	0.4%		
Particle ID		0.2%	
Pion Absorption Correction			1.0%
Pion Decay Correction	0.03%		1.0%
HMS Tracking		0.4% (π+) 1.3% (π-)	1.0% (π+) 1.0% (π-)
SOS Tracking		0.2%	0.5%
Integrated Beam Charge	0.3%		0.5%
Target Thickness		0.3%	1.0%
CPU and Trigger Dead time		0.3%	
HMS Cerenkov Veto Correction (π-)	0.7%		2.0%
Missing Mass Cut	0.8%		1.3%
Spectrometer Acceptance	1.0%	0.6%	1.0%
MC Model Dependence (L,T)	0.4%	0.7-3.5%	0.3-2.0%
Radiative Corrections		0.4%	2.0%
TOTAL (π+)	**1.4%**	**1.4-3.6%**	**3.1-3.5%**
TOTAL (π-)	**1.6%**	**2.3-4.4%**	**3.7-4.2%**
Typical Statistical Uncertainty (per t-bin)	**5-10%**		

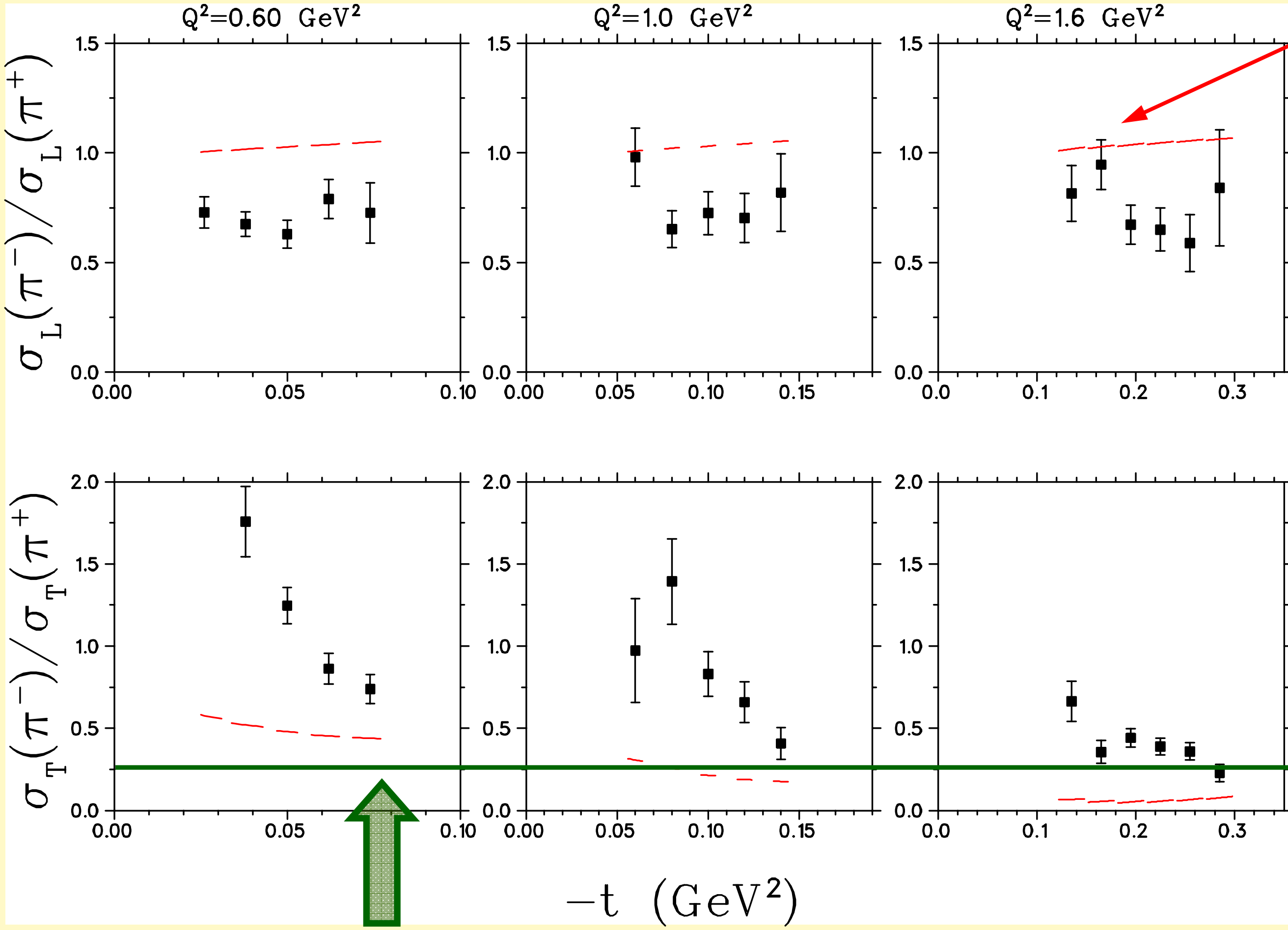
$^2H(e,e'\pi^{\pm})NN$ Separated dσ/dt



- W=1.95 GeV, above most of the resonance region.
- Longitudinal cross-section shows steep rise due to π pole at small –t.
- Transverse cross-section much flatter, generally smaller for π-.
- Negative TT.
- LT nearly zero.

Error bars indicate statistical and pt-pt systematic uncertainties in quadrature.
Bands indicate LT,TT MC model dependence systematic uncertainty.

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 ^{1}H data).

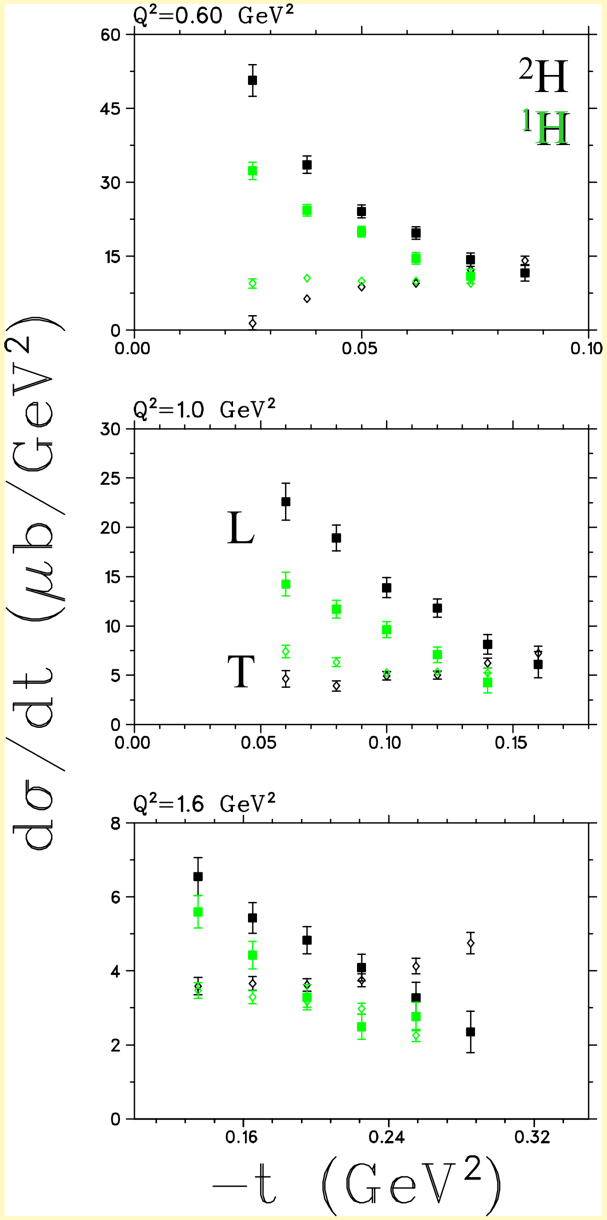
R_L=0.8 consistent with $|A_S/A_V|$<6%.

- Transverse Ratios tend to ¼ as –t increases:
  → Is this an indication of Nachtmann's quark charge scaling?
- -t=0.3 GeV² seems too low for this to apply. Might indicate the partial cancellation of soft QCD corrections in the formation of the ratio.

Summary

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

Comparison of π+ from ^{1}H and ^{2}H

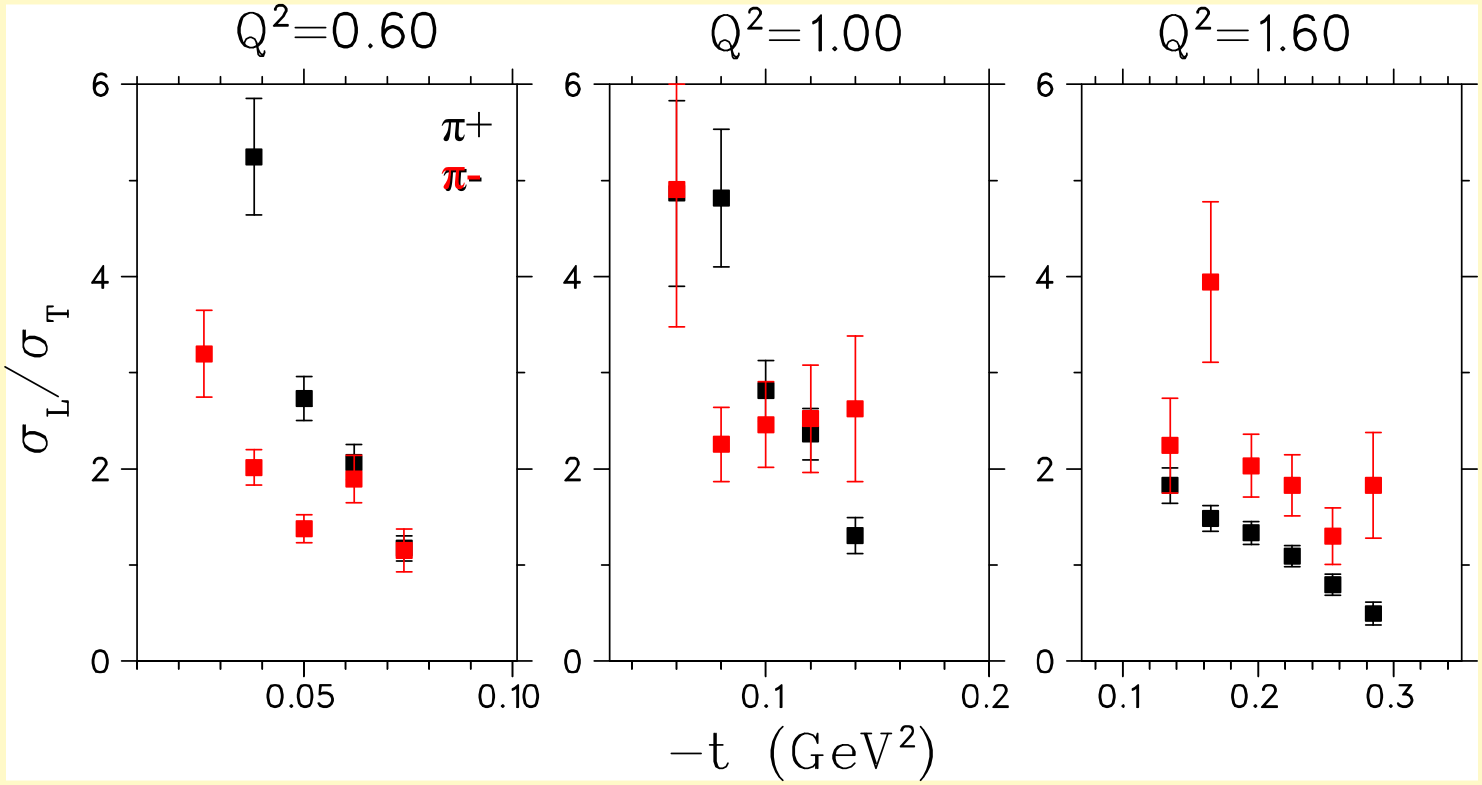


- **Intriguing differences between π+ production from hydrogen and deuterium.**
- σ_L consistently larger from ^{2}H than ^{1}H.
- σ_T t-dependences different as well.
- Are these due to off-shell effects in ^{2}H?
- Role of Fermi momentum in ^{2}H?

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

σ_L/σ_T Ratios for $\pi+$, $\pi-$

- L/T ratio becomes more favorable for $\pi-$ production from quasi-free neutron as Q^2 increases.



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