Pseudoscalar Meson Production at 12 GeV

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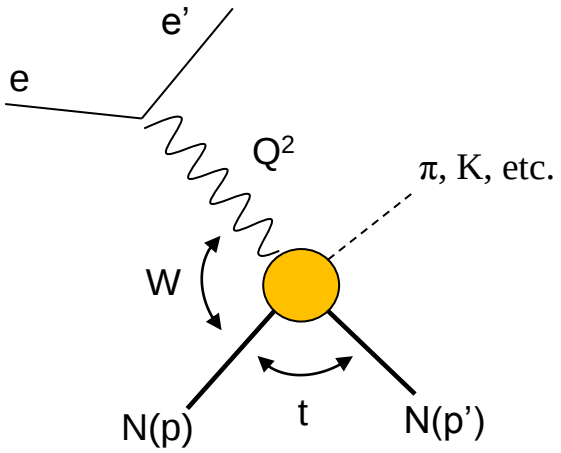
THE CATHOLIC UNIVERSITY of AMERICA

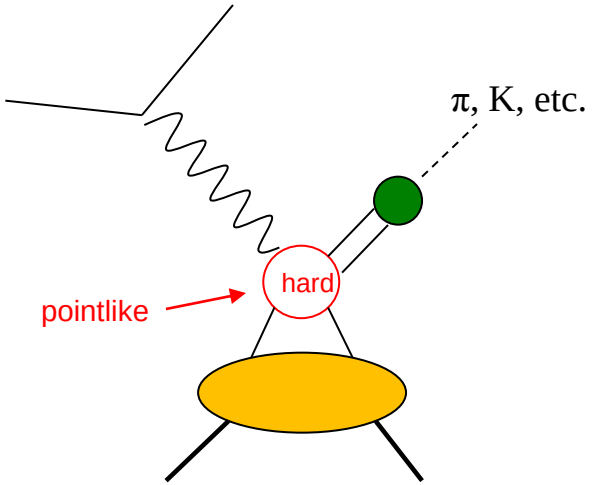
Hall C Summer Workshop

20 August 2011

Meson Reaction Dynamics



t-channel process



handbag

- Meson production can be described by the t-channel exchange meson pole term in the limit of small –t and large W
  - Pole term is dominated by longitudinally polarized photons
  - Meson form factor describes the spatial distribution of the nucleon

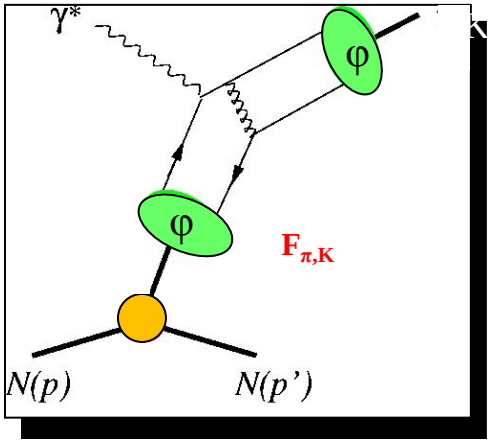
- At sufficiently high Q^2, the process should be understandable in terms of the "handbag" diagram
  - The non-perturbative (soft) physics is represented by the GPDs
    - Shown to factorize from QCD perturbative processes for longitudinal photons *[Collins, Frankfurt, Strikman, 1997]*

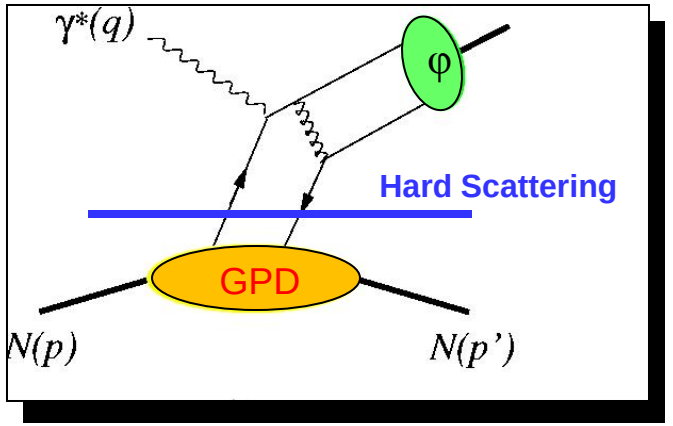
Form Factors and GPDs

- Form factors and GPDs are essential to understand the structure of hadrons

- But measurements of form factors and GPDs have certain prerequisites:
  - *Before looking at form factors*, we must make sure that σ_L is dominated by the meson pole term at low –t
  - *Before we can learn about GPDs*, we must demonstrate that factorization applies

- Need to understand relative importance of "pole" and "nonpole" contributions to access spin structure of nucleon (e.g., $\tilde{H}$)

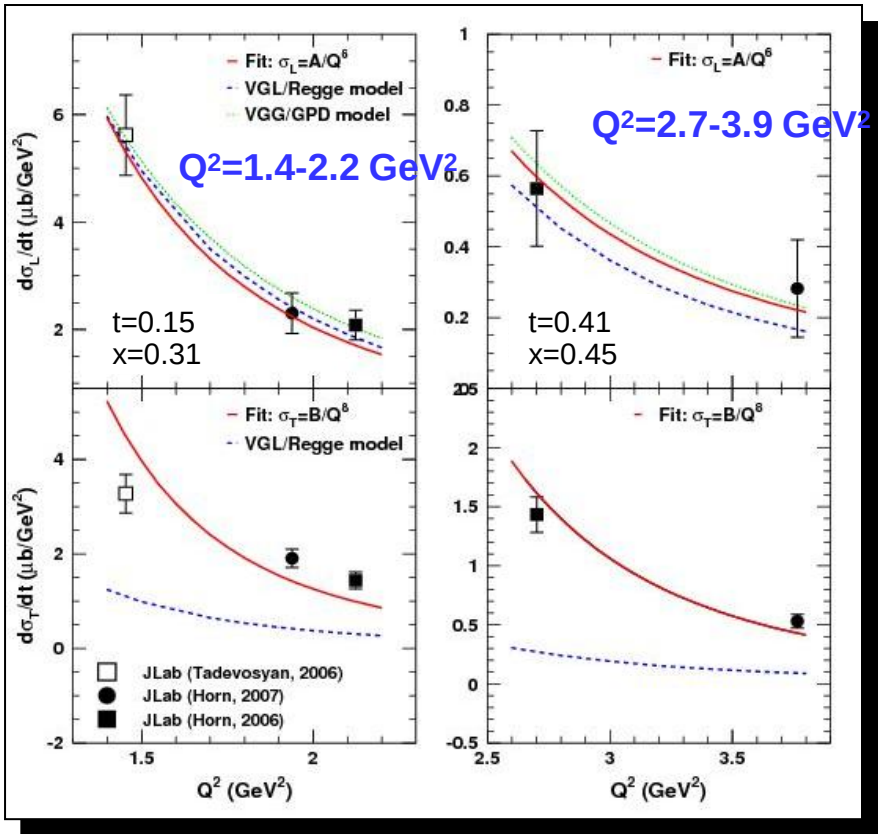




JLab 6 GeV: Q^2 dependence of σ_L and σ_T

- Measurements of GPDs are limited to kinematics where *hard-soft factorization* applies
- A test is the Q^2 dependence of the polarized cross section:
  - $\sigma_L \sim Q^{-6}$
  - $\sigma_T \sim Q^{-8}$
  - For large Q^2: $\sigma_L >> \sigma_T$
- The QCD scaling prediction is reasonably consistent with recent 6 GeV JLab π^+ σ_L data, *but* σ_T does not follow the scaling expectation

T. Horn et al., Phys. Rev. C78, 058201 (2008)

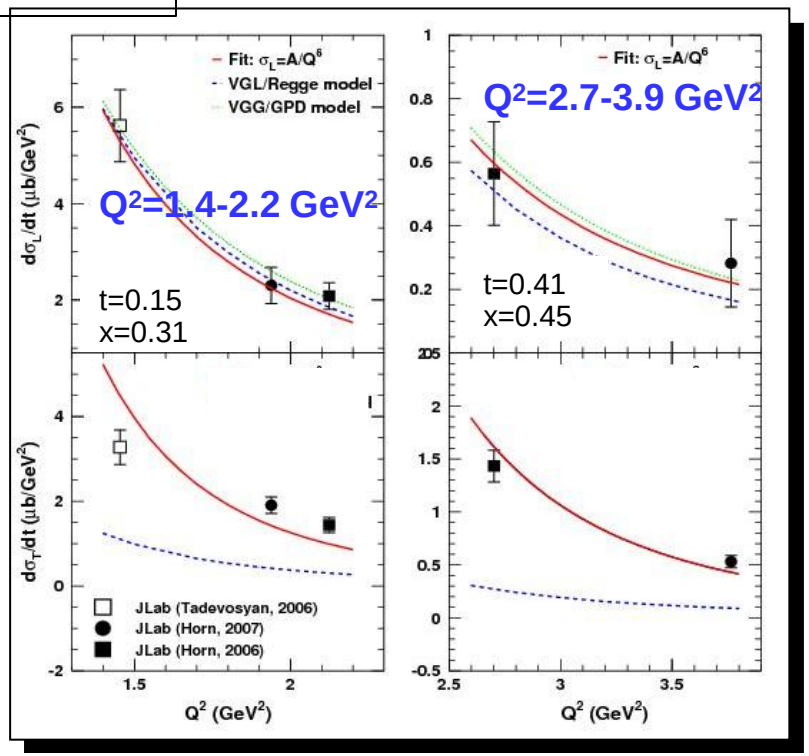


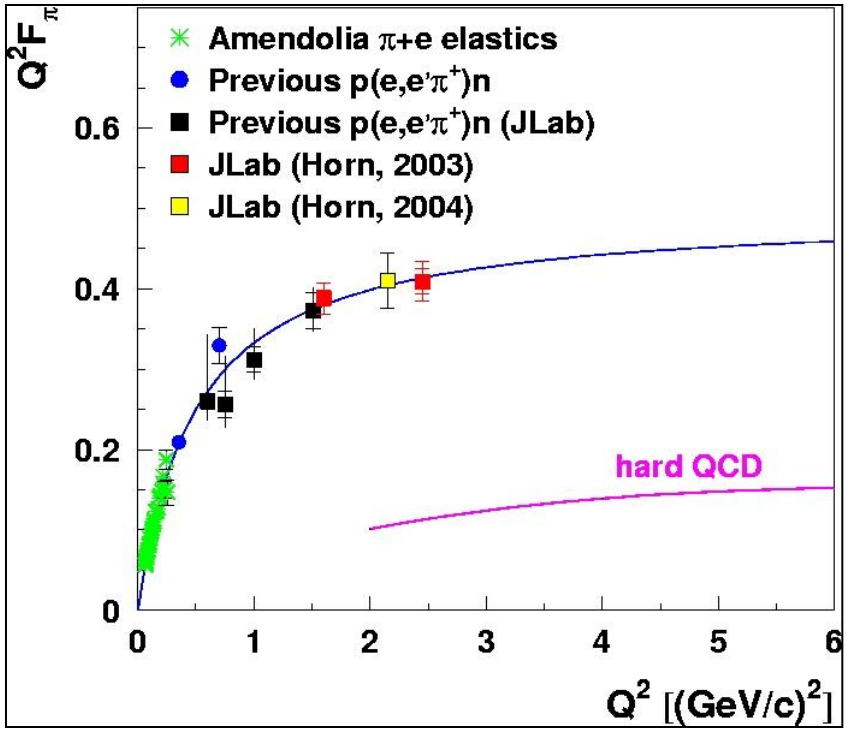
Full understanding of the onset of factorization requires an extension of the kinematic reach

Pion Form Factor – a puzzle?

$ep \rightarrow e'\pi^+n$

T. Horn et al., Phys. Rev. C78, 058201 (2008)





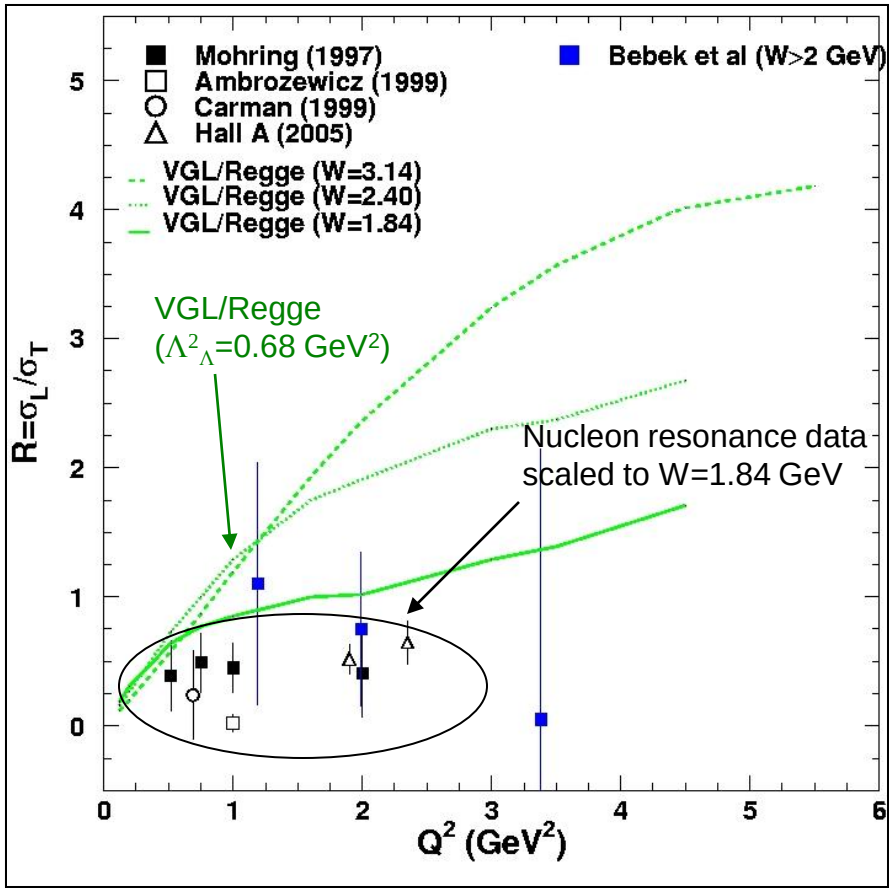
- The QCD scaling prediction is reasonably consistent with recent 6 GeV JLab π^+ σ_L data, *but* σ_T does not follow the scaling expectation

- Q^2 dependence of the pion form factor (F_π) follows prediction from perturbative QCD, suggests factorization holds
- Different magnitudes imply that factorization does not hold or something is missing in calculation

Further information on the pion puzzle through varying the system

$R=\sigma_L/\sigma_T$: Kaon form factor prerequisite

- Meson form factor extraction requires a good reaction model
  - Need high quality data to develop these models
- Current knowledge of σ_L and σ_T *above* the resonance region is insufficient
  - Role of the t-channel kaon exchange in amplitude unclear
- Not clear how to understand reaction mechanism through current models



L/T separations above the resonance region are essential for building reliable models, which are also needed for form factor extractions

So what about $R = \sigma_L/\sigma_T$?

"Semi-inclusive DIS": $\Sigma e_q^2 q(x)\, D_q^{\pi}(z)$

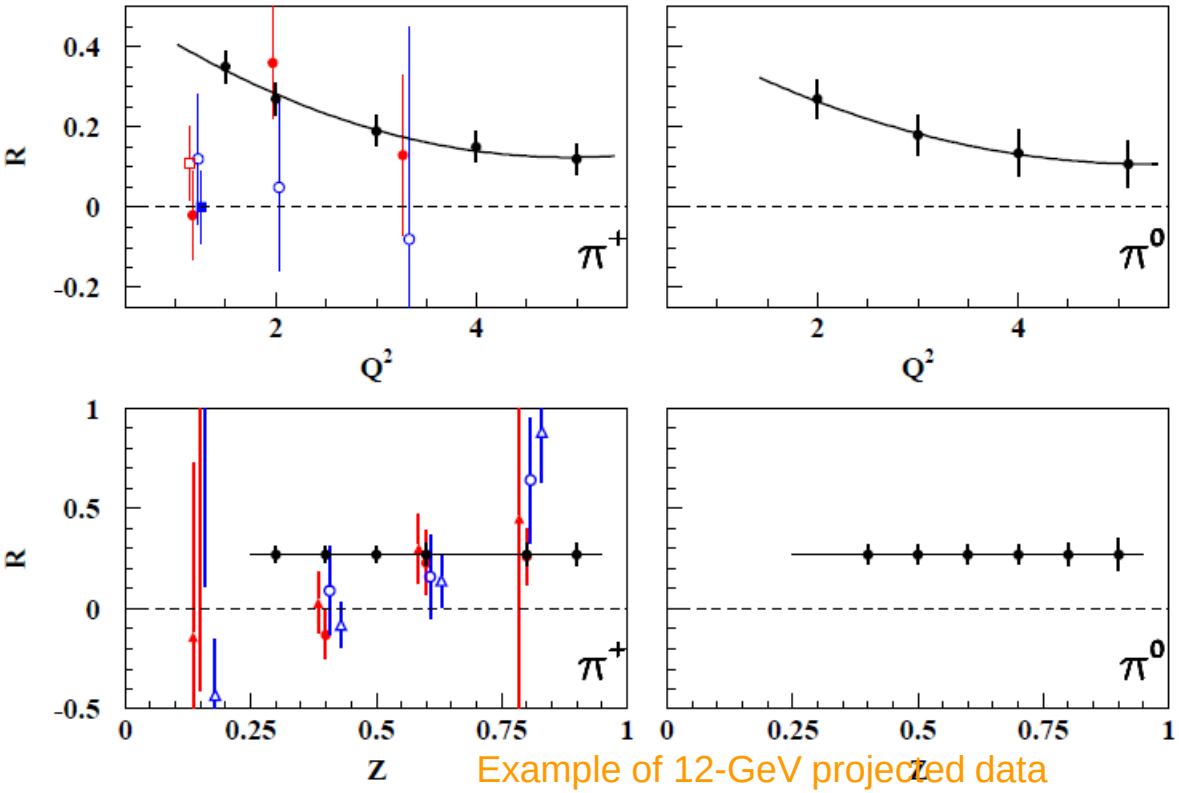
"Deep exclusive scattering" is the $z \rightarrow 1$ limit of this "semi-inclusive DIS" process

$R_{SIDIS} \rightarrow R_{DIS}$ disappears with Q^2! (?)

Here, $R = \sigma_L/\sigma_T \sim Q^2$ (at fixed x)

Charged pions:

Pole @ z = 1



Neutral pions:

No pole @ z = 1

No data exist!

Conclusion:

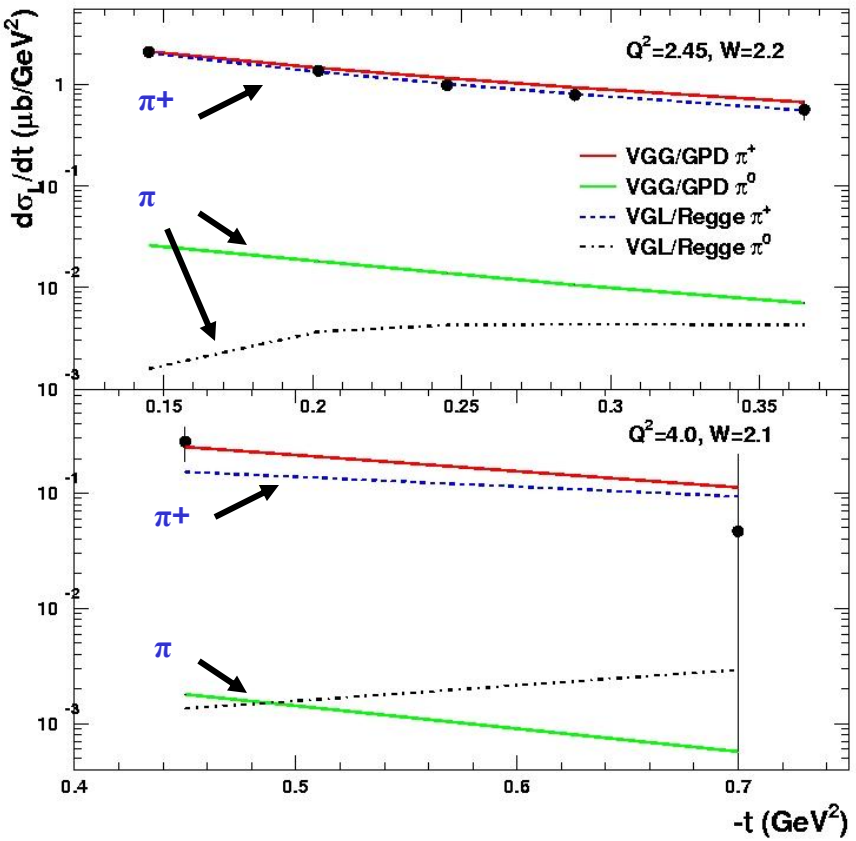
There **should** be differences between $R(\pi^+)$ (and $R(\pi^-)$) & $R(\pi^0)$ at intermediate energies → we must know these for a *proper analysis and interpretation* of TMD measurements and corresponding angular asymmetries

Example of 12-GeV projected data assuming $R_{SIDIS} = R_{DIS}$

Longitudinal pion cross sections in the exclusive limit

- GPD studies with pions requires understanding of σ_L
- Is the relative contribution of σ_L in π production significant?
  - Would indicate non-pole contributions in π^+
  - Current data have limited range in t, x_B, Q^2, W
- Unseparated π data from Hall A suggest that σ_L may be larger than predicted by either model and shows no t-dependence
  - VGL and VGG predictions for σ_L differ by an order of magnitude at $t=t_{min}$

Separated σ_L data and predictions



Separated σ_L data for both π^+ and π^0 production would provide important information for understanding the pion reaction mechanism

Pseudoscalar Meson Program in Hall C

Experiment	Goal	Comment
Pion Factorization	Check if the conditions of factorization apply at JLab, and if they do, study the 3-dimensional image of the nucleon	Approved JLab experiment (E12-07-105)
Kaon Electroproduction	Test the reaction mechanism with a heavier quark system. This may also help solving the form factor puzzle.	Approved JLab experiment (E12-09-011)
Neutral Pion L/T	Understanding the neutral pion reaction mechanism would allow a more reliable interpretation of the charged pion data	Proposal to PAC38 (PR12-11-102)

Rosenbluth Technique to access σ_L and σ_T

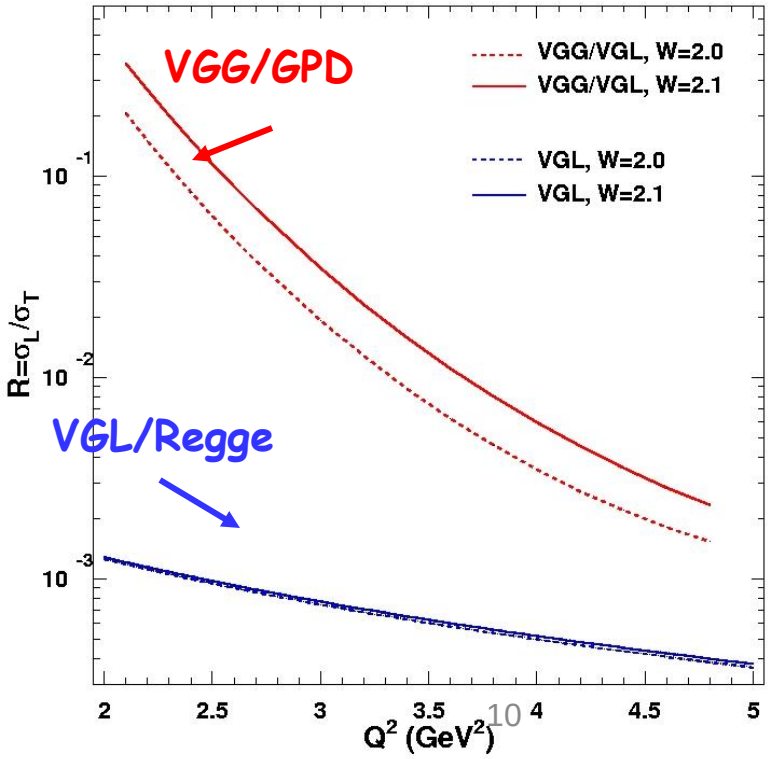
$$\frac{d^2\sigma}{dtd\varphi} = \varepsilon \frac{d\sigma_L}{dtd\varphi} + \frac{d\sigma_T}{dtd\varphi} + \sqrt{2\varepsilon(\varepsilon+1)} \frac{d\sigma_{LT}}{dtd\varphi} \cos\varphi_\pi + \varepsilon \frac{d\sigma_{TT}}{dtd\varphi} \cos 2\varphi_\pi$$

- Pseudoscalar cross section separation in non-perturbative regime requires using Rosenbluth technique
  - Compare data at two different beam energies and isolate σ_L, by varying photon polarization, ε

- L/T separations for pseudo-scalar mesons need systematic error control to minimize amplification

$$\rightarrow \quad d\sigma_L = \frac{d\sigma}{\varepsilon_1 - \varepsilon_2} \sqrt{\left(R^{-1} - \varepsilon_1\right)^2 + \left(R^{-1} - \varepsilon_2\right)^2}$$

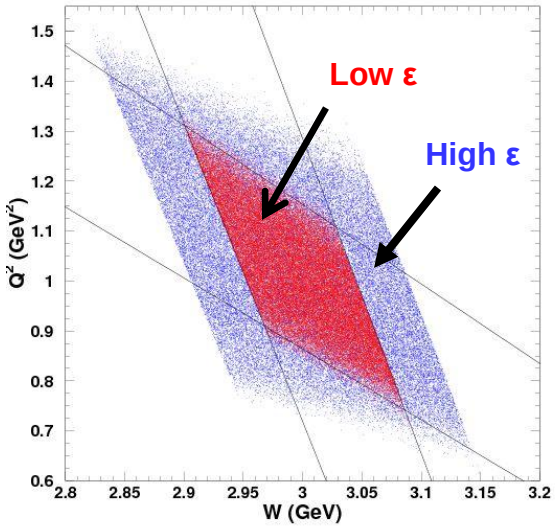
- *Small σ_L can also make Rosenbluth separation difficult due to large error amplification for small $R=\sigma_L/\sigma_T$*

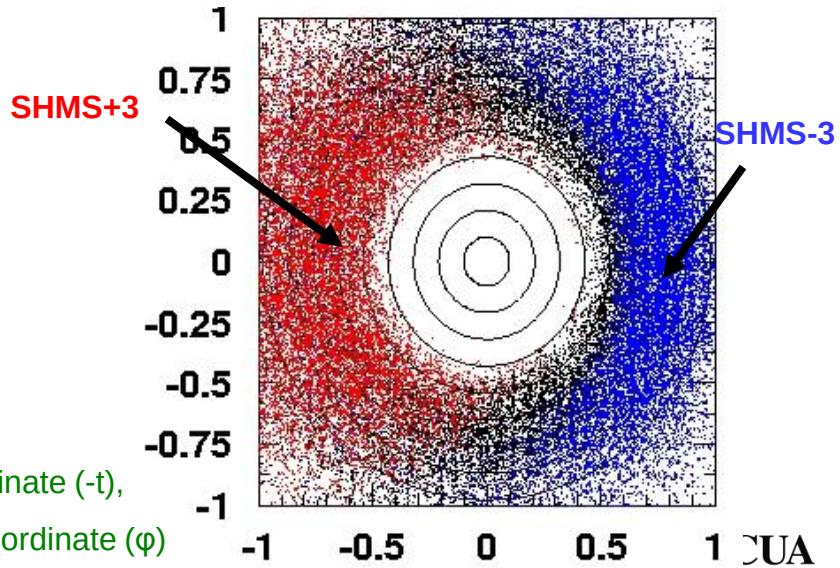


Separation in a Multi-Dimensional Phase Space

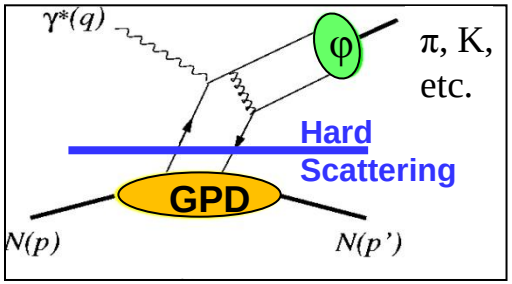
- Cuts are placed on the data to equalize the Q^2-W range measured at the different ε-settings

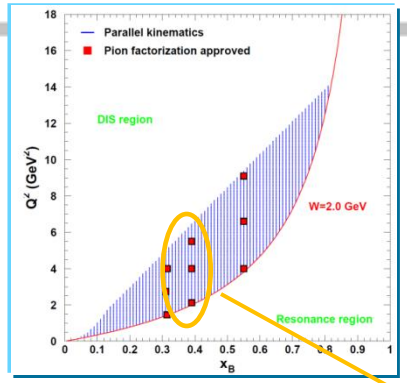
- Multiple SHMS settings (3 left and right of the **q** vector) are used to obtain good φ coverage over a range of –t
  - Measuring $0<\varphi<2\pi$ allows to determine L, T, LT and TT



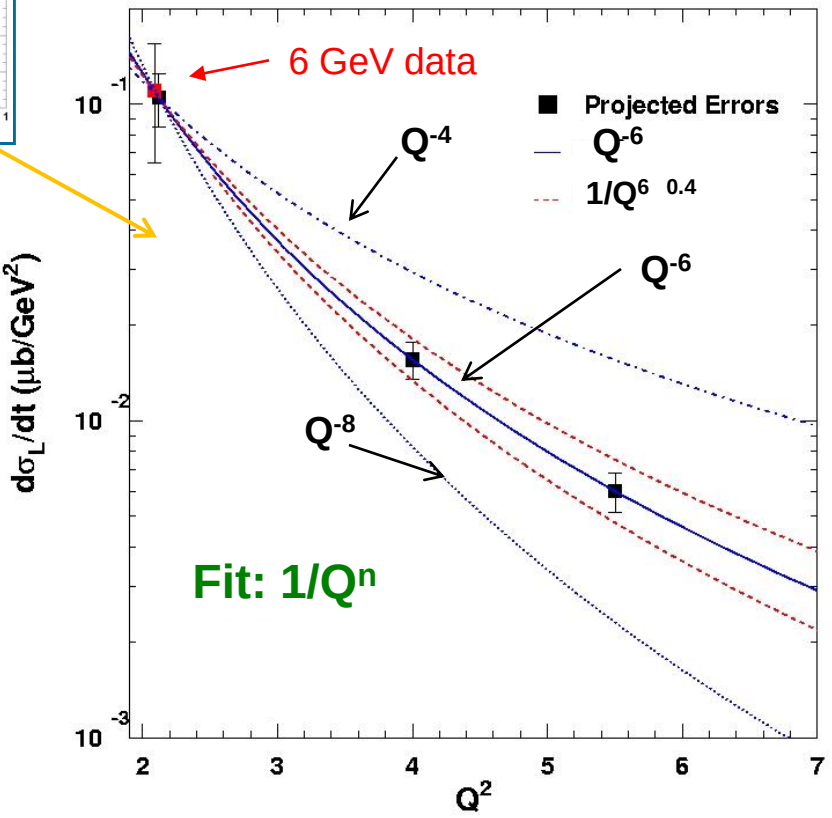


Factorization Tests in π^+ Electroproduction





E12-07-105 will search for the onset of factorization



- One of the most stringent tests of factorization is the Q^2 dependence of the π electroproduction cross section
  - σ_L scales to leading order as Q^{-6}
- Q^2 coverage is 2-3 times larger than at 6 GeV at smaller t
- Factorization essential for reliable interpretation of results from the JLab GPD program at both 6 GeV and 12 GeV

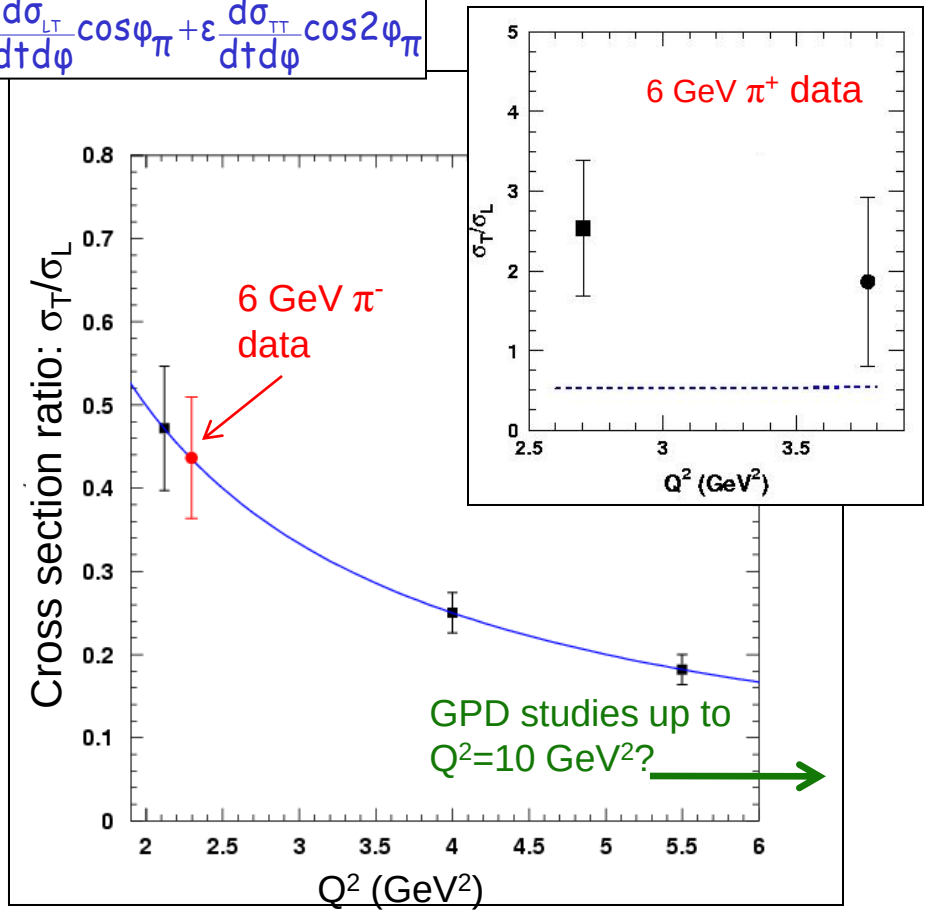
Is the partonic description applicable at JLab?

Can we extract GPDs from pion production?

Explore opportunities in π^- production

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

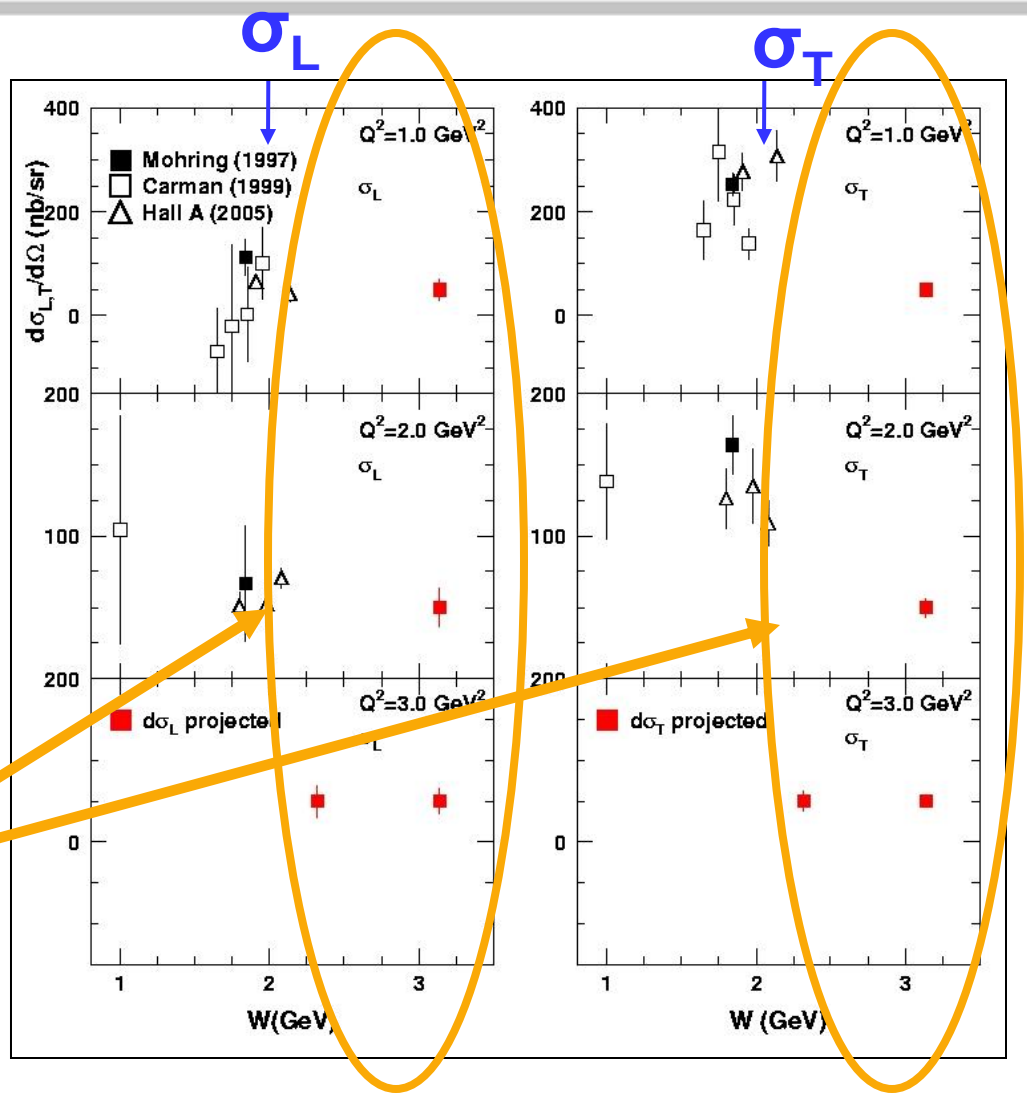
- The L/T ratios will provide valuable information for π cross section measurements with large acceptance detectors
- Earlier data suggest that σ_L is larger for π^- than for π^+ production
  - If this holds, one can extract σ_L from unseparated cross sections
  - Could extend kinematic reach for GPD studies beyond Q^2=6 GeV^2



E12-07-105 will compare π^+ and π^- production to check possibilities of extracting GPDs without explicit L/T

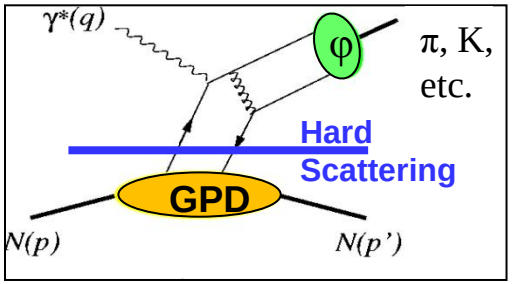
Kaon cross sections: σ_L and σ_T

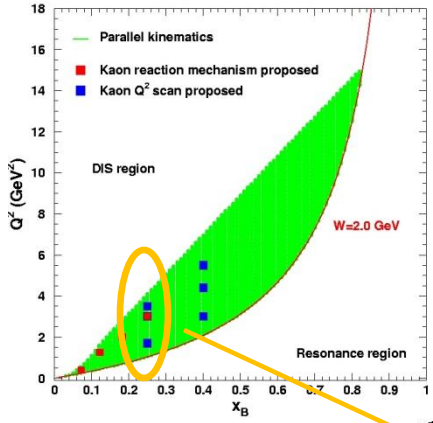
- E12-09-011 will provide first L/T separated **kaon** data above the resonance region
- Onset of factorization
- Understanding of hard exclusive reactions
  - QCD model building
  - Coupling constants

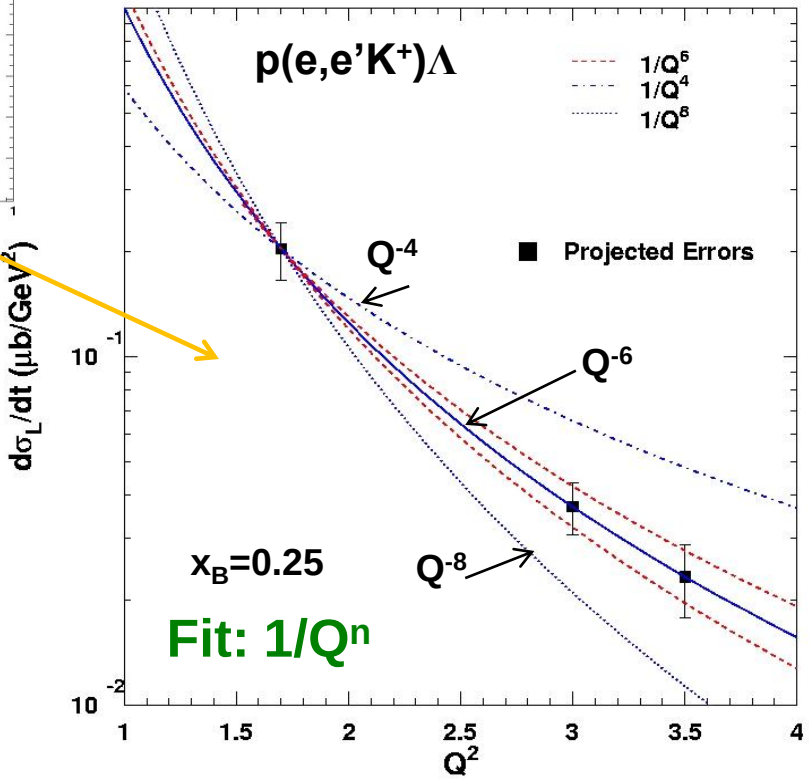


E12-09-011: Precision data for W > 2.5 GeV

Factorization Tests in K^+ Electroproduction







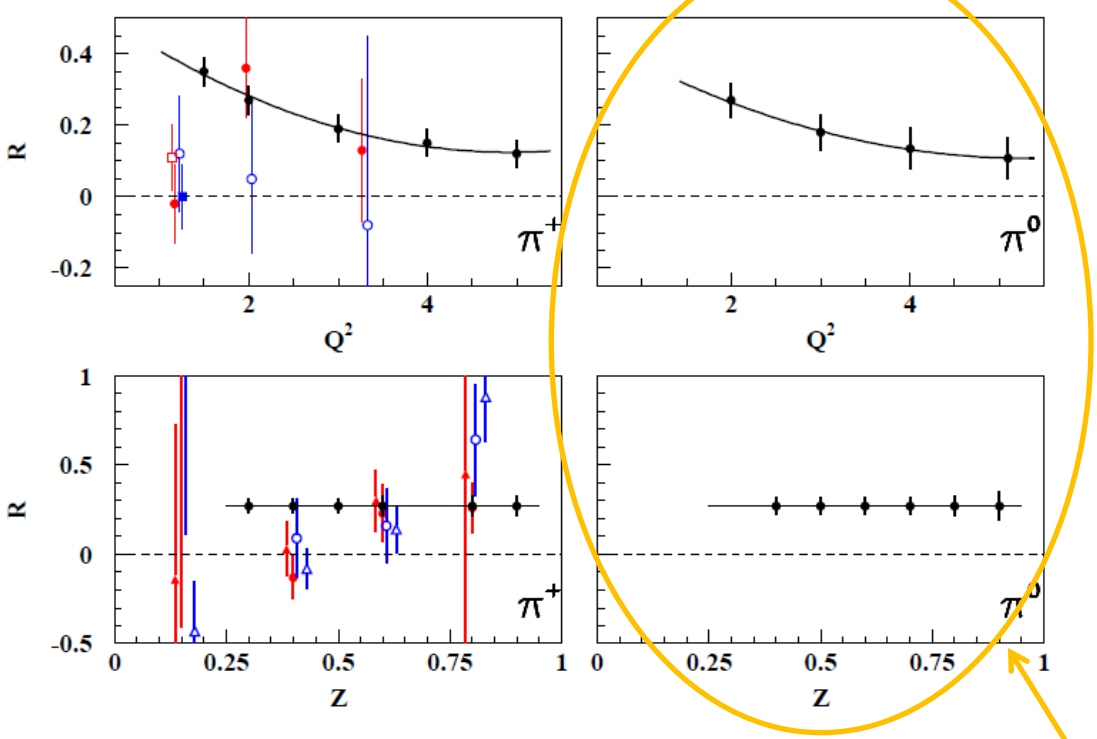
- Compare the Q^2 dependence and magnitude of separated π^+ and K^+ cross sections, and if possible, the form factors
- Will the analogy in the Q^2-scaling of the pion cross section and form factor also manifest itself for kaons?

Is onset of scaling different for kaons than pions?

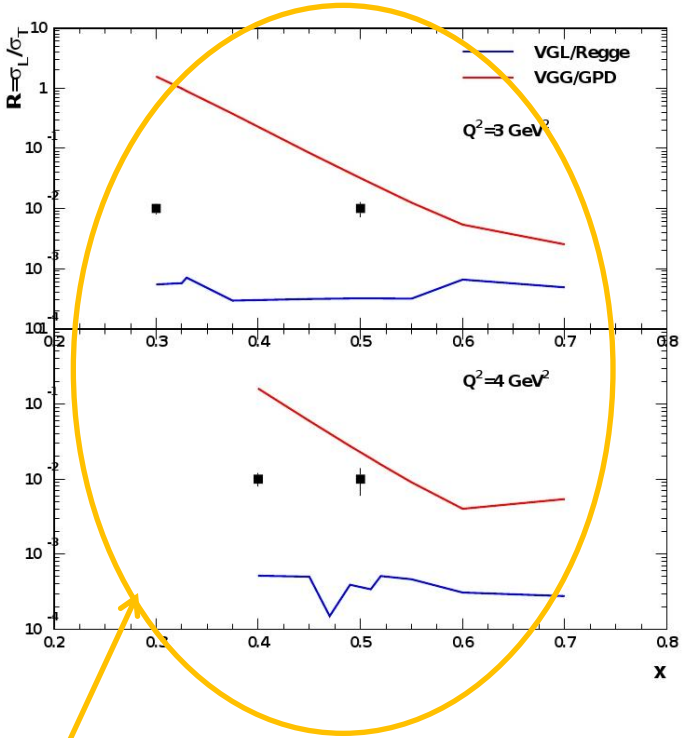
Kaons and pions together provide quasi model-independent study

Projections for $R=\sigma_L/\sigma_T$

"Semi-inclusive DIS": $\Sigma e_q^2 q(x)\, D_q^{\pi}(z)$



"Deep exclusive scattering" is the z → 1 limit of this "semi-inclusive DIS" process



- Well known parameterizations were used for PDFs and fragmentation functions in the rate estimates
  - Assumes $R_{SIDIS}=R_{DIS}$

PR12-11-102:

Precision L/T π data

- Average of VGL/VGG models used for rate estimates
  - Projected Δ(L/T)=5-10%

Summary

- L/T separated cross sections will be essential for understanding the meson reaction mechanism at 12 GeV
  - Relative contribution of σ_L and σ_T are needed for GPD studies

- Our theoretical understanding of hard (partonic?) reactions will benefit from L/T separated π , K^+, and π data over a wide kinematic range
  - Comparison of pion and kaon data would allow for better understanding of onset of factorization
  - Constrain size of pole and non-pole contributions by comparing π and π°

- Comprehensive pseudo-scalar program in Hall C at 12 GeV
  - Magnetic spectrometers ideally suited for challenging L/T