Transverse Target Asymmetry in Exclusive Charged Pion Production at 12 GeV

Dipangkar Dutta
Mississippi State University
(with Dave Gaskell & Garth Huber)

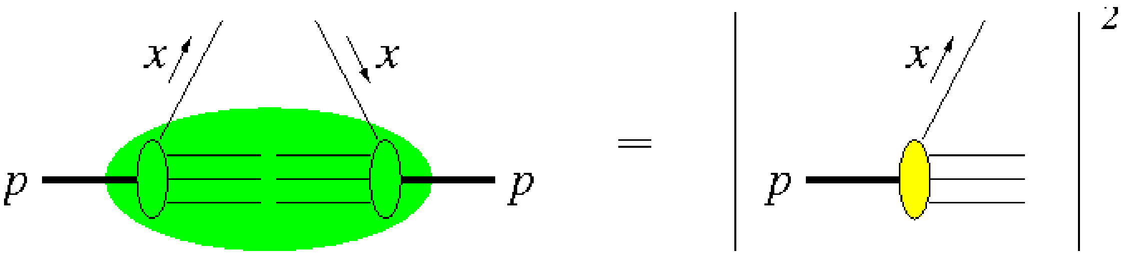
Polarized Target Workshop: June 17-18, 2010

Outline

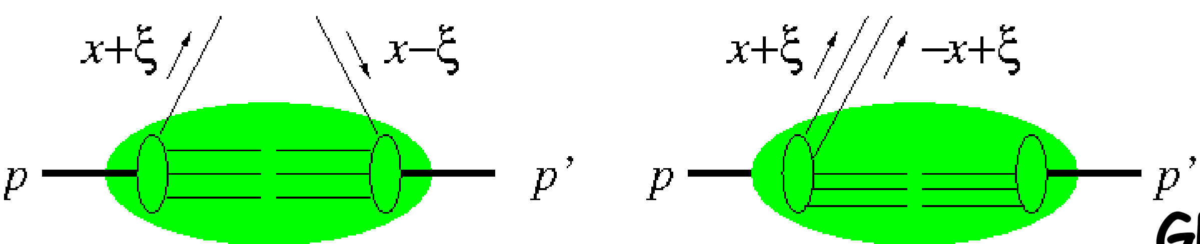
- Motivations
  - GPDs
  - Factorization Studies
- Transverse Target Asymmetry
- Possible Measurements
- Rate Estimates
- Summary

Generalized Parton Distribution

Over the last decade tremendous progress has been made on the theory of generalized parton distributions (GPD).



PDFs : Squared hadronic wavefunctions = probability of finding a parton with specified longitudinal momentum fraction and polarization in a fast moving hadron

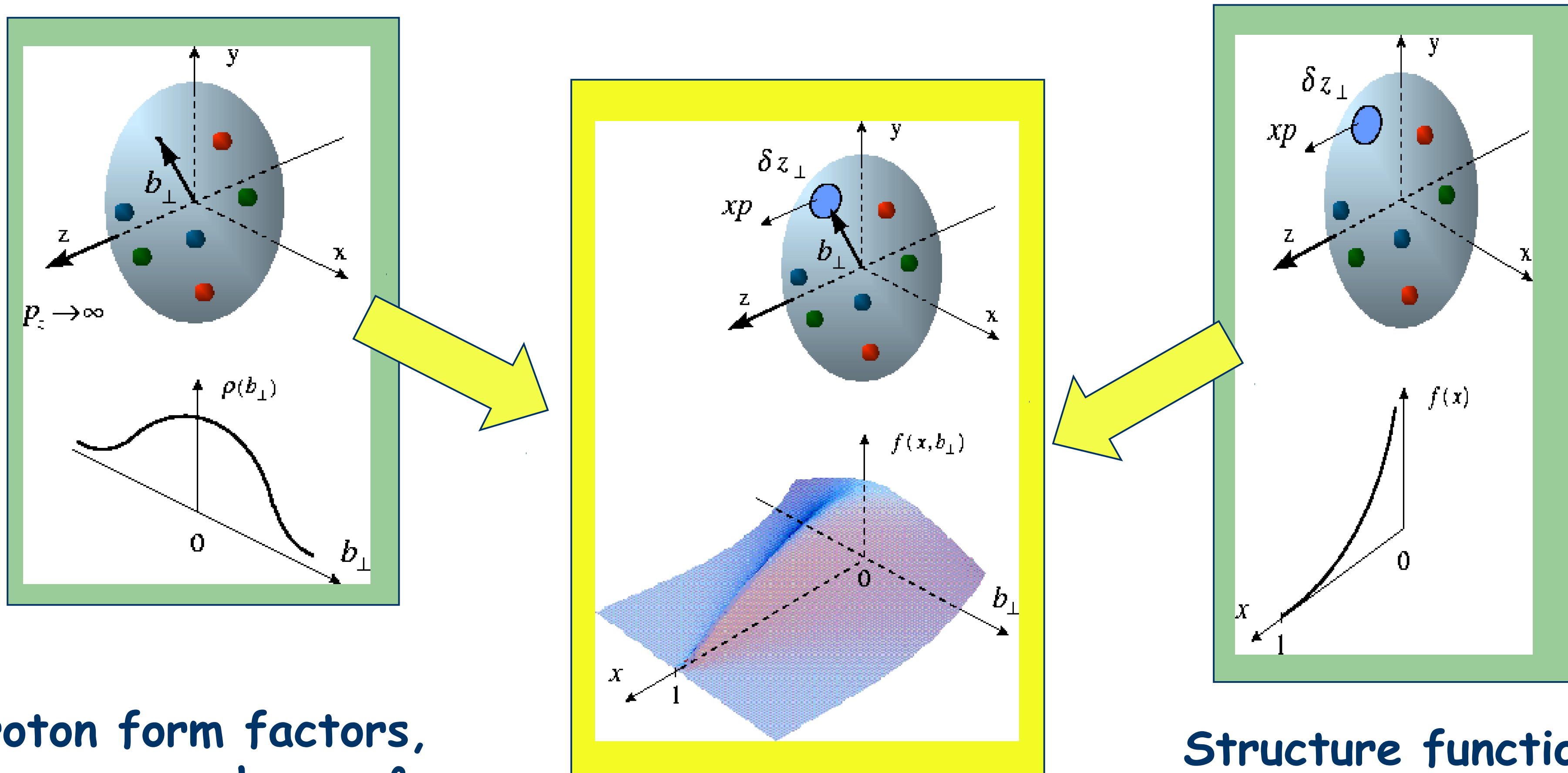


GPDs : interference between wavefns. of parton with momentum fraction x+ξ and parton with momentum fraction x-ξ

- GPDs may give us access to:
  - Orbital angular momentum in the nucleon
  - 3D pictures of the nucleon

Generalized Parton Distribution

GPDs allow simultaneous determination of longitudinal momentum and transverse position of partons, they correlate different quark-gluon configurations in the hadron



Proton form factors, transverse charge & current densities

Correlated quark momentum and helicity distributions in transverse space - GPDs

Structure functions, quark longitudinal momentum & helicity distributions

Leading Twist GPDs

- At leading twist, 4 independent GPDs for each quark, gluon type
- x is the light cone momentum fraction of struck parton($x \neq x_{Bj}$)
- $t=\Delta^2$, momentum transfer to nucleon
- ξ , defined by

  $\Delta^+ = -2\xi(p+\Delta/2)^+$

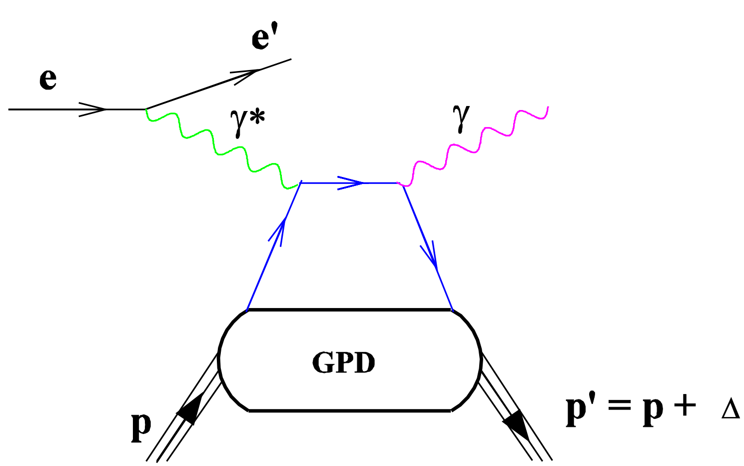
  Parametrizes skewedness, or the Longitudinal fraction of the momentum transfer, t

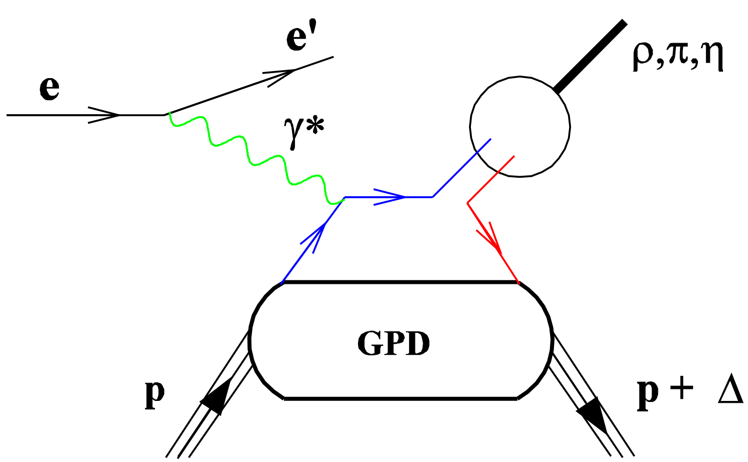
$H^{q,g}(x,\xi,t)$ spin avg no hel. flip	$E^{q,g}(x,\xi,t)$ spin avg helicity flip
$\tilde{H}^{q,g}(x,\xi,t)$ spin diff no hel. flip	$\tilde{E}^{q,g}(x,\xi,t)$ spin diff helicity flip

Access to GPDs

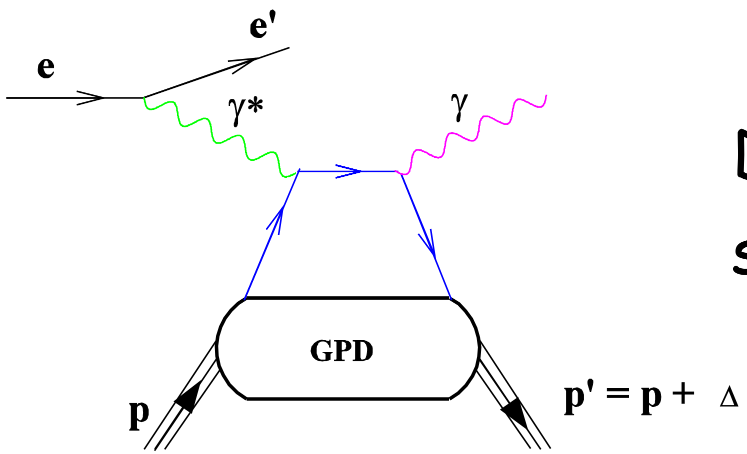
- GPDs are not observables – but, they are constrained by
  - DIS: $H(x,0,0) = q(x)$ and $\tilde{H}(x,0,0) = \Delta q(x)$ (PDFs, at vanishing t,ξ)
  - Elastic scattering: $\int dx\, x\, H(x,\xi,t) = F_1(t)$, (Form Factor, from model independent sum rules)

- To access GPDs, we need a program that will measure …
  - a variety of **hard exclusive processes** (vector mesons, DVCS, pseudo-scalar mesons)
  - a broad range of phase space (t, x_B)





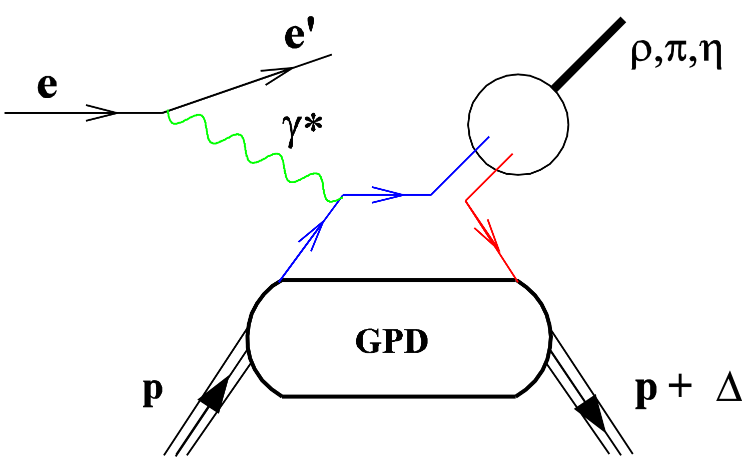
Access to GPDs



Deeply Virtual Compton Scattering sensitive to a combination of all 4 GPDs

Vector mesons (ρ,ω,ϕ) sensitive to H and E

Pseudo scalar mesons sensitive to $\tilde{H}$ and $\tilde{E}$



$$\tilde{E}^{ud}(x,\xi,t) = F_\pi(t)\frac{\theta(\xi > |x|)}{2\xi}\phi_\pi(\frac{x+\xi}{2\xi}),$$

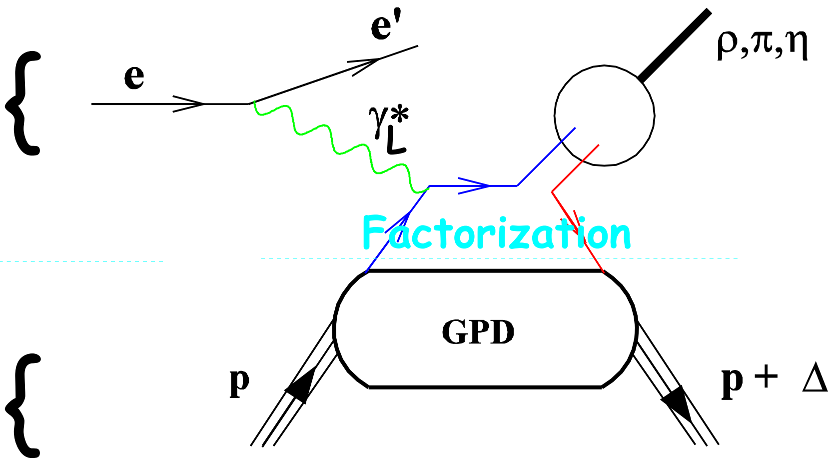
$\tilde{E}$ via hard pion electroproduction can provide new information on nucleon structure which is available from any other source.

- **An extensive program of Hard Exclusive Measurements to constrain GPDs is a major part of the 12 GeV upgrade.**

Factorization in Hard Exclusive Reactions

- Hard probe creates creates a small size configuration, its interactions can be described by pQCD (applies to longitudinally polarized virtual photon only)

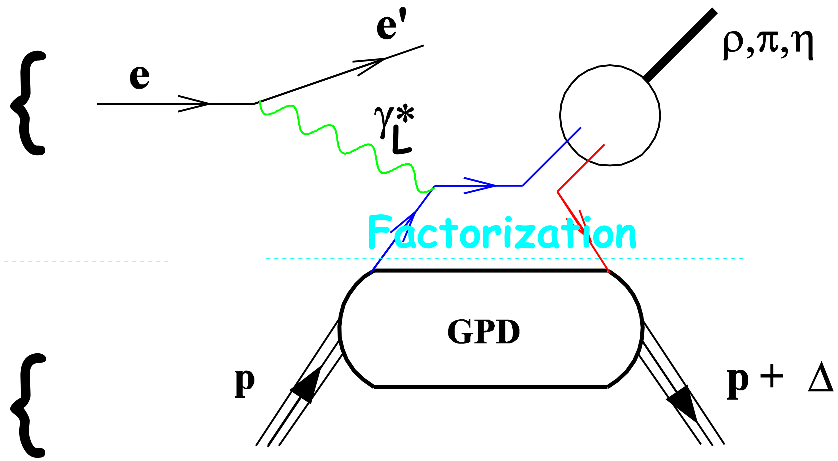
- How the probe is transformed into the hadron etc can only be described non-perturbatively (parametrized by GPDs)



Factorization in Hard Exclusive Reactions

- Hard probe creates creates a small size configuration, its interactions can be described by pQCD (applies to longitudinally polarized virtual photon only)

- How the probe is transformed into the hadron etc can only be described non-perturbatively (parametrized by GPDs)



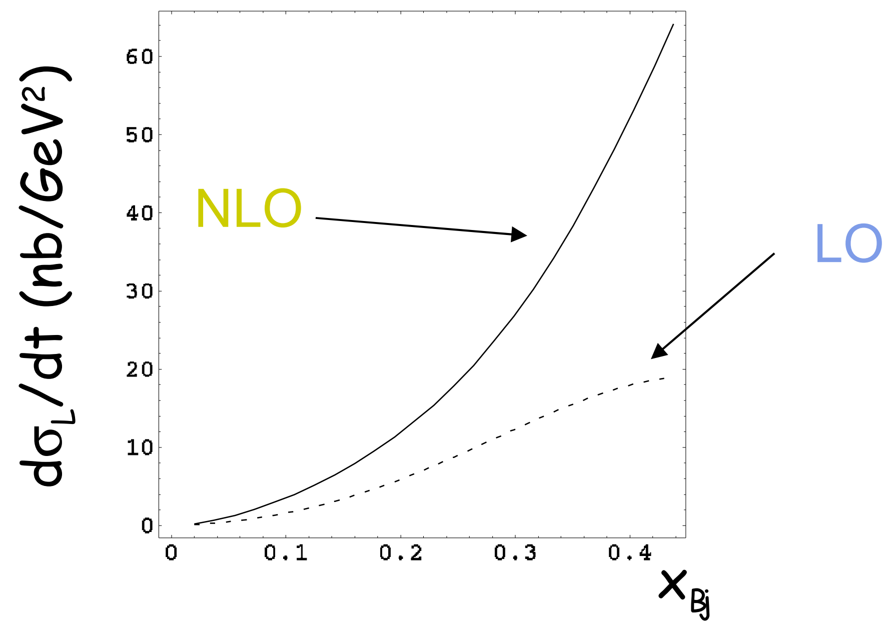
- To say anything about GPDs, we must be confident we are in a regime where soft-hard factorization applies (large Q^2)

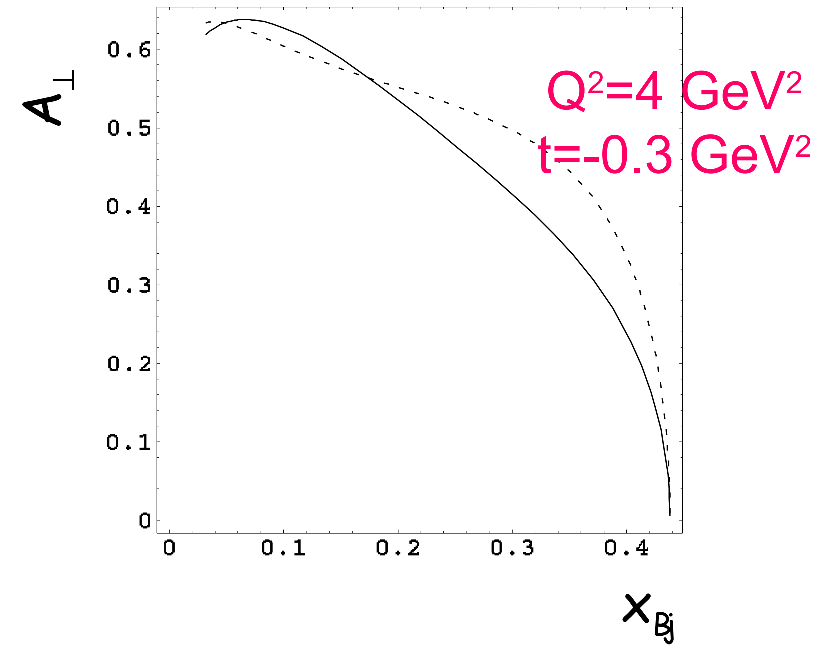
- Higher order corrections may be large for absolute cross sections for $Q^2 < 10$ GeV^2

- Ratios have a better chance of exhibiting precocious factorization – higher order effects in numerator and denominator "cancel"

Exclusive π^+ Production at NLO

- **Belitsky and Müller GPD based calc. of π+ production to NLO (Phys Lett B 513, 349)**
  - **Even at Q^2=10 GeV^2, NLO effects can be large, but cancel in the asymmetry, $A_\perp$**
  - **At Q^2=4, higher twist effects even larger in σ_L, but still cancel in asymmetry (CIPANP 2003)**
- **This cancellation of higher order effects known as precocious factorization**





Exclusive π^+ Production with Target (or Recoil) Polarization

Unpolarized Cross section

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

Exclusive π^+ Production with Target (or Recoil) Polarization

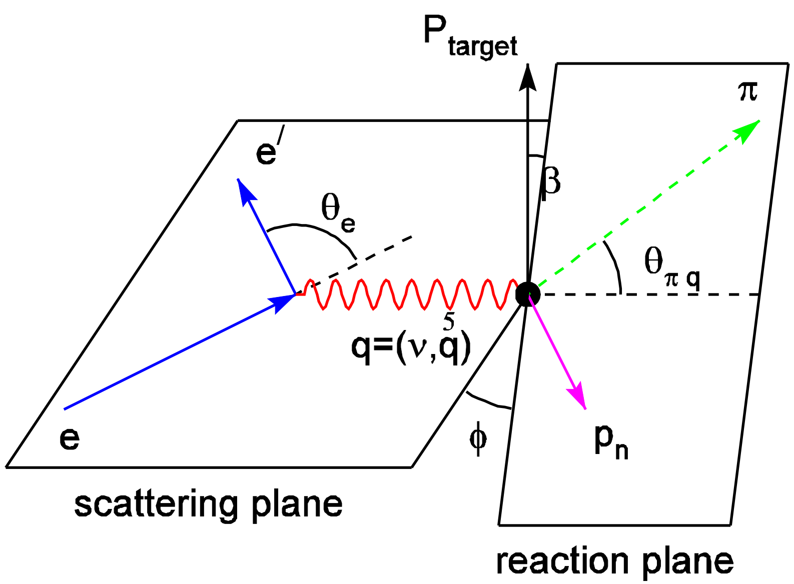
Unpolarized Cross section

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

Polarized cross section has additional components

$$\sigma_t = P_x\left[-\sqrt{2\epsilon(1+\epsilon)}\sin\phi\,\sigma^x_{LT} - \epsilon\sin 2\phi\,\sigma^x_{TT}\right]$$
$$- P_y\left[\sigma^y_{TT} + \epsilon\cos 2\phi\,\sigma^y_{TT'} + 2\epsilon\,\sigma^y_L + \sqrt{2\epsilon(1+\epsilon)}\cos\phi\,\sigma^y_{LT}\right]$$
$$+ P_z\left[\epsilon\sin 2\phi\,\sigma^z_{TT} + \sqrt{2\epsilon(1+\epsilon)}\sin\phi\,\sigma^z_{LT}\right]$$

- Target polarization components (P_x, P_y) are defined relative to the reaction plane
- β = azimuthal angle between (transverse) target polarization and reaction plane
  $P_x = P_\perp\cos\beta$ and $P_y = P_\perp\sin\beta$



π^+ Transverse Target Asymmetry

- Setting all transverse amplitudes to zero, the pion electroproduction cross section (with polarized target) is:

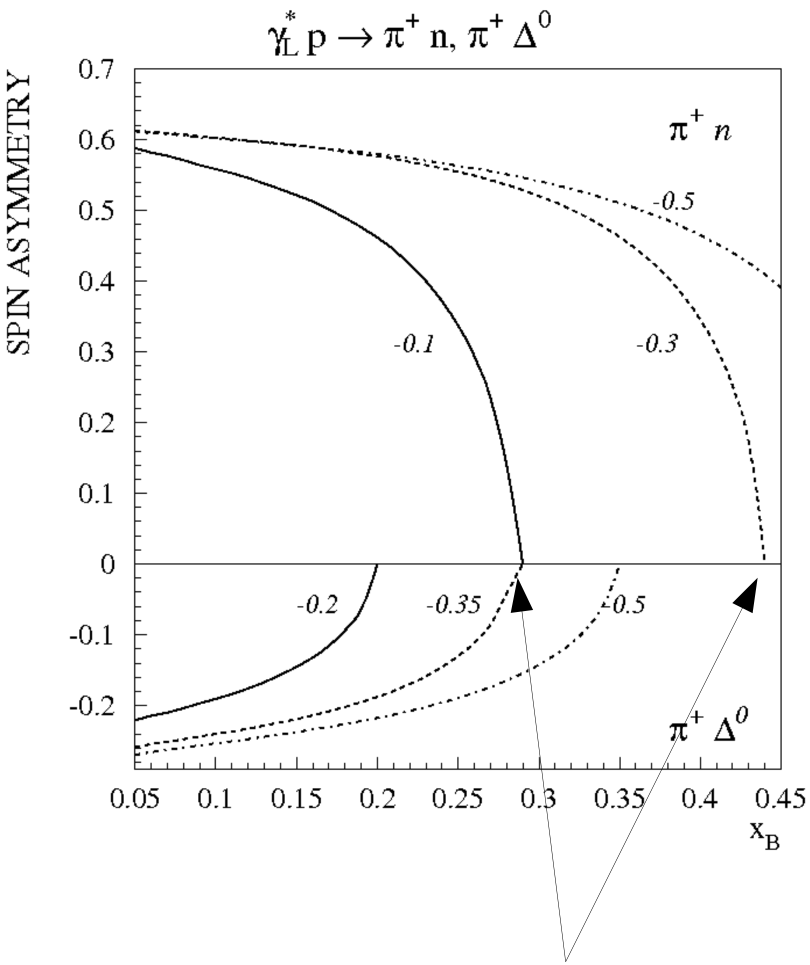
$$\sigma = \varepsilon\, \sigma_L - 2\, \varepsilon\, \sigma_L^y\, P_\perp \sin\beta \qquad (P_y = P_\perp \sin\beta)$$

- The transverse target asymmetry is typically defined [Frankfurt et al, PRD 60, 014010 (1999)]

$$A_\perp = \frac{\int_0^{\pi} d\beta \frac{d\sigma_L^{\pi}}{d\beta} - \int_{\pi}^{2\pi} d\beta \frac{d\sigma_L^{\pi}}{d\beta}}{\int_0^{2\pi} d\beta \frac{d\sigma_L^{\pi}}{d\beta}}$$

- The transverse target asymmetry then involves the ratio of two longitudinal cross sections

$$A_\perp = \frac{2}{\pi}\frac{2\sigma_L^y}{\sigma_L}$$



A_T =0 at parallel kinematic limit, where P_y is not well defined.

PRL84, 2589 (2000)

Measurement of $A_\perp$

- At JLab energies, cannot ignore contributions from transverse photons (σ_T suppressed by $1/Q^2$ compared to σ_L)

Two alternatives to get "separated asymmetry"

$$A_\perp = \frac{2}{\pi}\frac{2\sigma_L^y}{\sigma_L}$$

1. Two Rosenbluth separations and ratio of longitudinal cross sections

   $\sigma_A = \sigma_T^\perp + \varepsilon\,\sigma_L^\perp$ where $\sigma(\varepsilon) = \sigma_U + \sigma_A \sin\beta + \ldots$

   $\sigma_U = \sigma_T + \varepsilon\,\sigma_L$

2. Rosenbluth separation of the asymmetry

   $A = A_T + \varepsilon\,A_L$

Measurement of $A_\perp$

- To cleanly extract $A_\perp$, we need
  - target polarized transverse to virtual photon direction
  - Large acceptance in π^+ azimuthal angle (i.e. ϕ and β)
  - Measurements at multiple beam energies and electron scattering angles -> ε dependence (L/T separation)

    (advantage of focusing spectrometers in Hall-C)

for $r = \sigma_T/\sigma_L$, uncertainty in longitudinal cross sections is

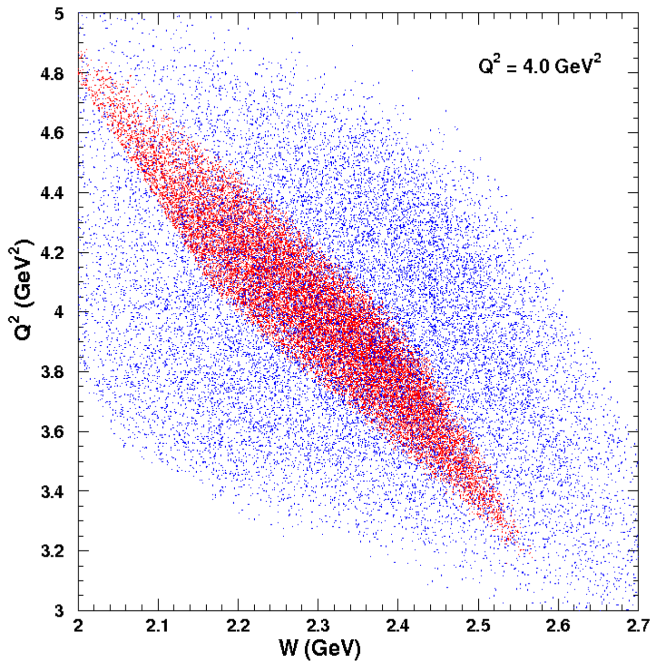
$$\Delta\sigma_L/\sigma_L = 1/(\varepsilon_1-\varepsilon_2)\ \Delta\sigma/\sigma\ [(r+\varepsilon_1)^2 + (r+\varepsilon_2)^2]^{1/2}$$

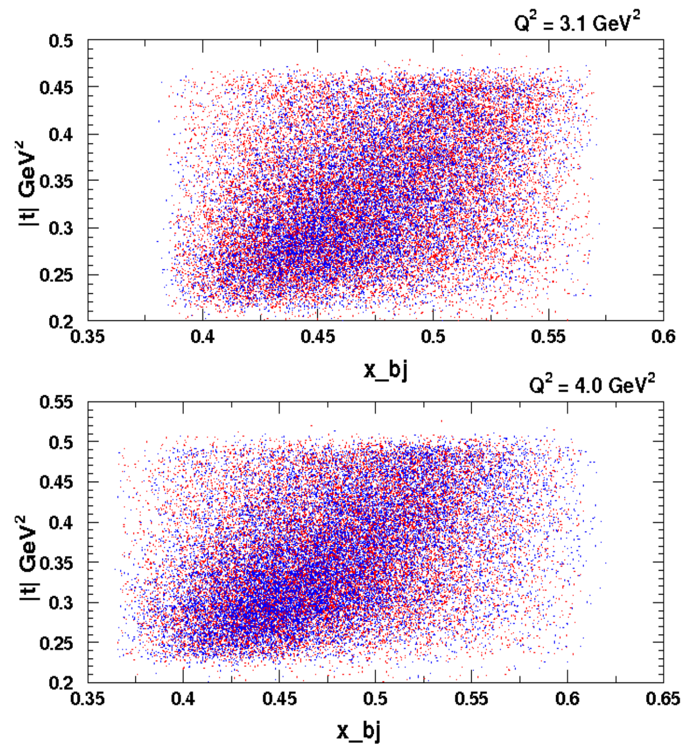
Ratio of two L/T separations will have larger uncertainties than separated asymmetry method.

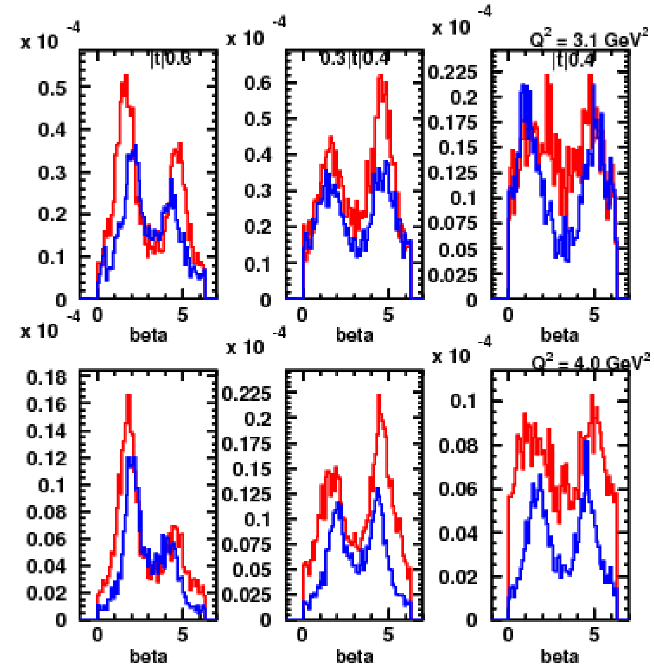
- Need $\Delta\varepsilon$ as large as possible

HMS-SHMS Possible Kinematics

n(e,e'π^-)p or p(e,e'π^+)n



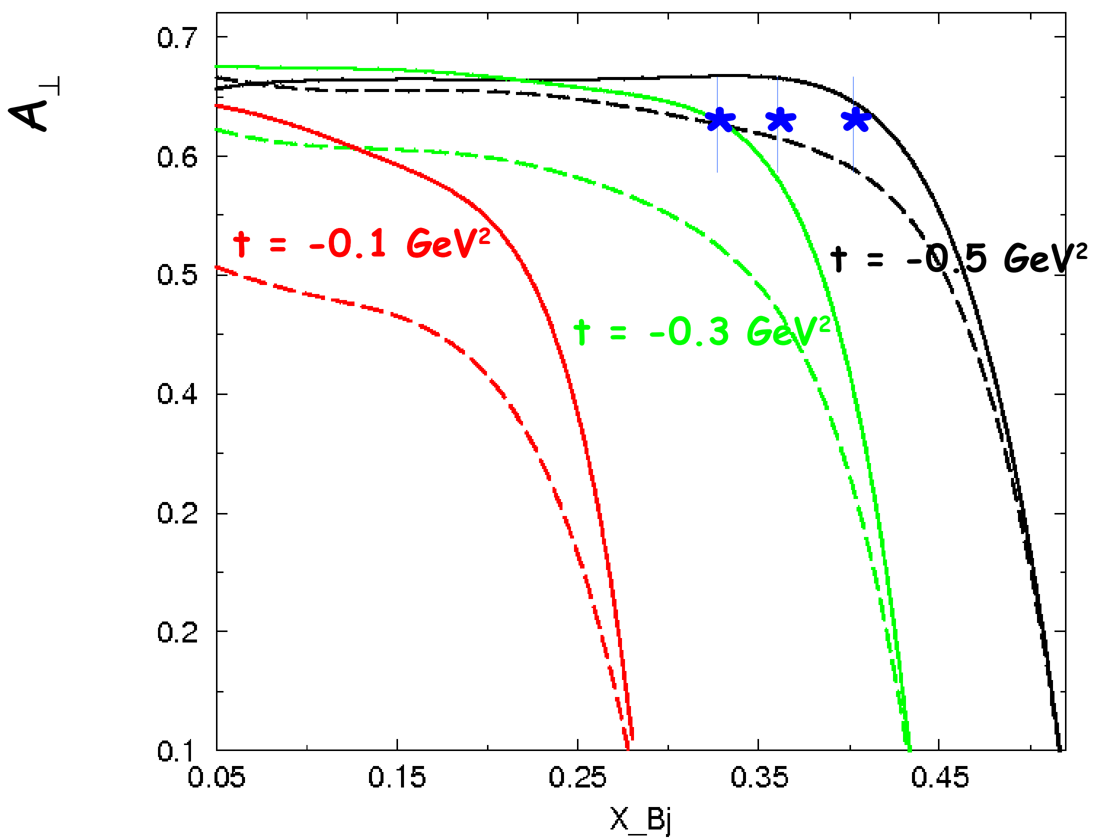




high ε   low ε   Δε = 0.3

Estimated Rates

Assuming a luminosity of 5×10^{37} /cm²/s, using SIMC and the VGL model for the value of r and $A_\perp$ etc, we estimate that a ~6% (stat) measurement of the transverse asymmetry can be performed in 500 hours.
(this rules out any measurement with the UVa NH_3 target.)



Solid: asymptotic pion distribution amp.
Dashed: CZ pion dist. amp.

Issues to be Studied

- Compare figure of merit for recoil polarization measurement (with LD_2 target) vs high luminosity transverse pol. ^3He target...

- Compare backgrounds for different pol. target options

- Explore large acceptance devices BigCal, SBB etc

Summary

JLab 12 GeV upgrade will open the doors to a rich program of "measuring" GPDs

Deep Exclusive Pion Production (large Q^2, low $-t$), will provide unique insight into certain class of GPDs and also on soft-hard factorization.

The transverse asymmetry in exclusive pion production is one of the important observables in these studies.

It is very important to separate the longitudinal cross-section and asymmetry.

High luminosity transversely polarized targets are critical for these type of experiments.