Probing Hadron Structure Using Meson Electroproduction

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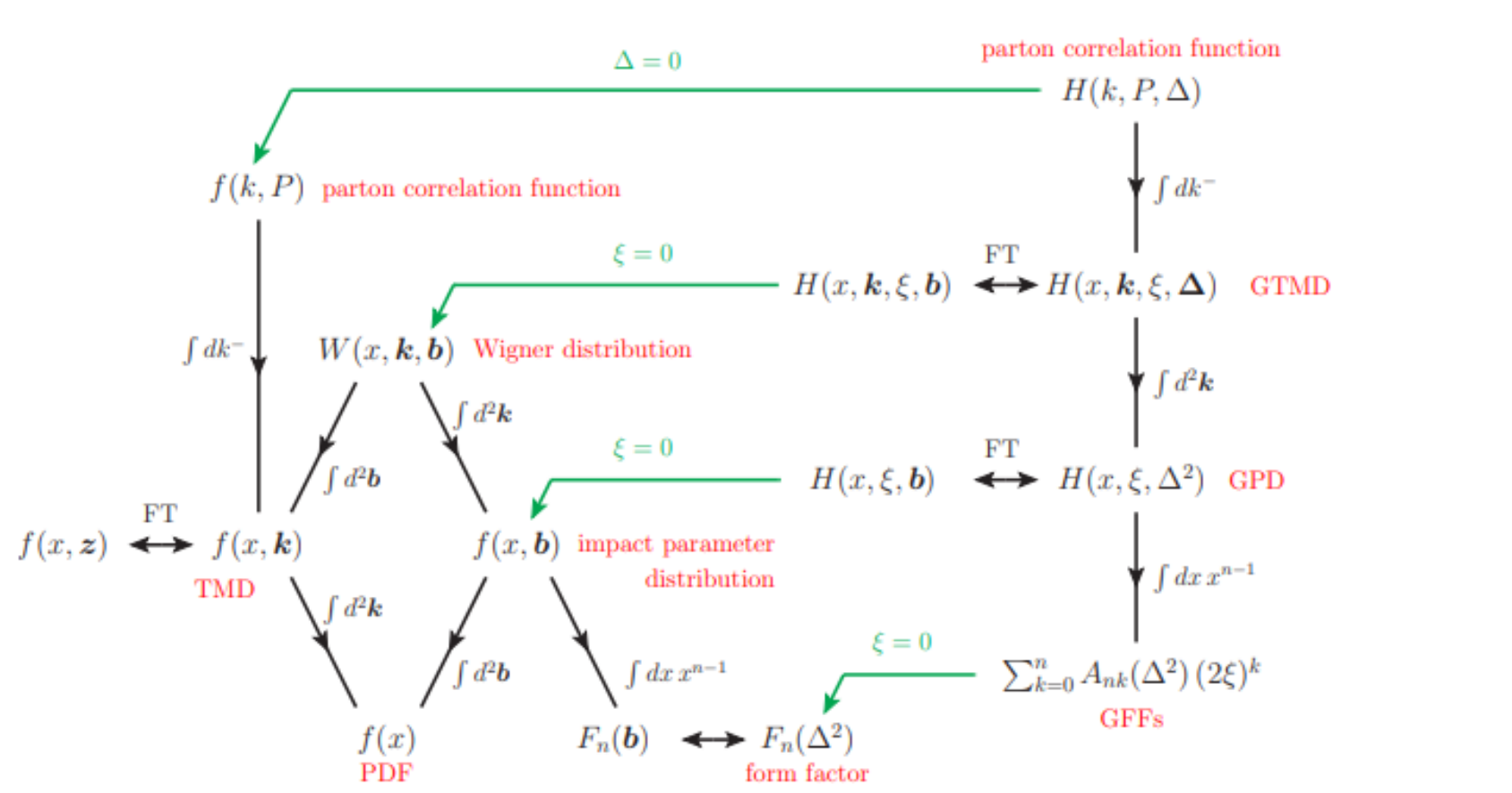
Flow of the talk

1. What is Hadron ”structure”?
2. Distributions; Generalized Parton Distribution (GPD)
3. How do we see them?; DVCS, DVMP, etc.
4. Let’s make pions!; DVMP shallow waters
5. L/T intro; Aysmptotic limit doesn’t work :(
6. Past and Current experiments; Neutral Particle Spectrometer
7. What now...? Ideas..? GPDs...? Something else...?

Hadron Structure

1. Simply adding the individual ”partons” doesn’t give the whole picture.
2. Many ways to look at the nucleon
   - Charge distribution
   - Mass distribution
   - Spin distribution
   - Pressure distribution
   - 2-Dimensional vs. 3-Dimensional structure
   - Longitudinal vs. Transverse structure
3. Interestingly enough, two structures needn’t be the same. For example, the charge radius of the proton $\neq$ the mass radius of the proton.

Distributions



arXiv:1512.01328

Light Cone Variables

1. Introduction to new variables: For a four-vector V^μ, its light cone components are defined as:

$$V^+ = \frac{V^0 + V^3}{\sqrt{2}}, \qquad V^- = \frac{V^0 - V^3}{\sqrt{2}}, \qquad \mathbf{V}^T = \left(V^1, V^2\right) \tag{1}$$

2. Why introduce new variables? Consider a boost:

$$V'^+ = V^+ e^{\psi}, \qquad V'^- = V^- e^{-\psi}, \qquad \mathbf{V}'_T = \mathbf{V}_T \tag{2}$$

   where the *hyperbolic angle* $\psi = \frac{1}{2} \ln \frac{1+v}{1-v}$.

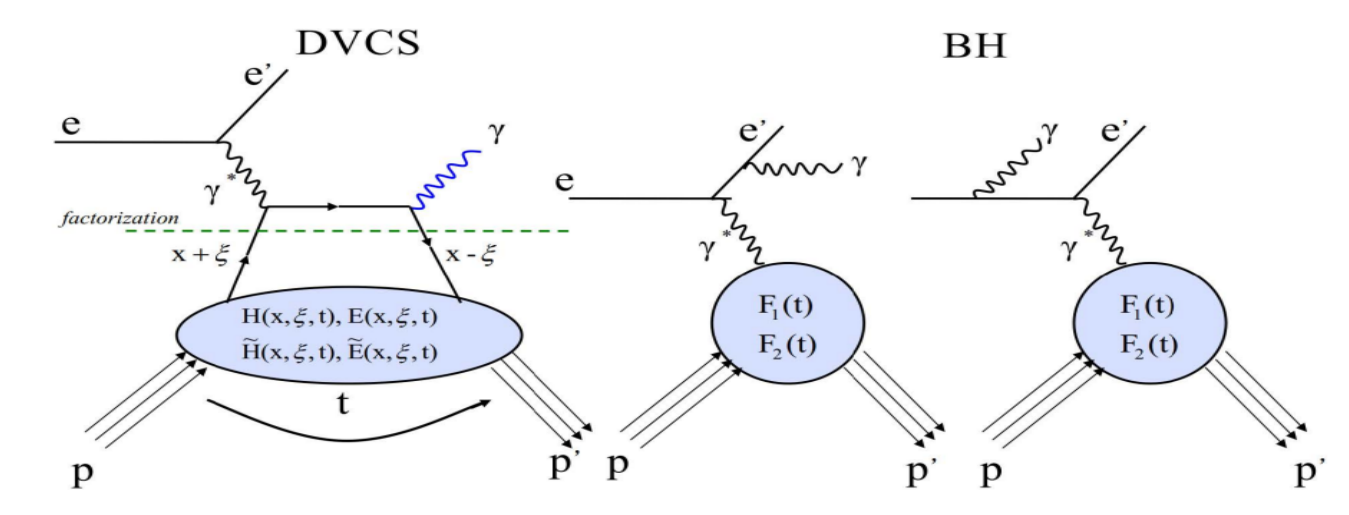
3. Notice the simplicity in boost transformations.

Generalized Parton Distributions (GPDs)

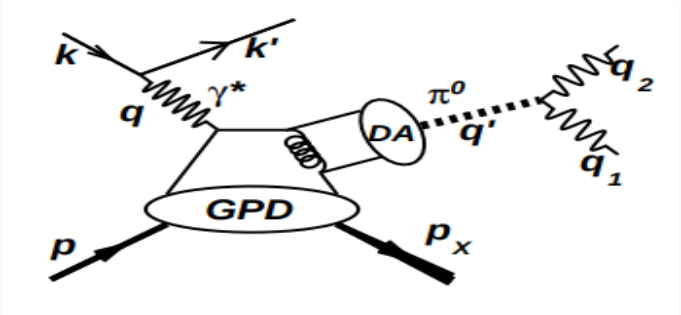
- **Definition:**
  - GPDs describe the correlation between the longitudinal momentum and the transverse position of partons.
- **Key Variables:**
  - x: Longitudinal momentum fraction.
  - ξ: Skewness parameter.
  - t: Momentum transfer squared.
- **An example of GPD equation:**

$$\int \frac{dz^-}{4\pi} e^{ixP^+z^-} \left\langle p', \lambda'_N \right| \bar{\psi}_q \left(-\frac{1}{2}z\right) \gamma^+ \psi_q \left(\frac{1}{2}z\right) \left| p, \lambda_N \right\rangle \Big|_{z^+=0, \mathbf{z}_T=0}$$
$$= \frac{1}{2P^+} \bar{u}\left(p', \lambda'_N\right) \left[H^q \gamma^+ + E^q \frac{i\sigma^{+\alpha}\Delta_\alpha}{2M_N} \right] u\left(p, \lambda_N\right) \tag{3}$$

How to see them? Just squint your eyes!



(a) Deeply Virtual Compton Scattering (DVCS)



(b) Deeply Virtual Meson Production (DVMP) arxiv:1608.01003

Deeply Virtual Meson Production: Adding flavor to GPDs

- DVMP more sensitive for probing flavours.
- Gives access to the transversity GPDs at leading-twist: $H_T, \tilde{H}_T, E_T, \tilde{E}_T$.
- DVMP (vector mesons) gives access to gluon-GPDs at leading-twist while DVCS only gives that at higher order making it harder to extract.
- At leading twist, pseudoscalar meson production also gives polarized GPDs ($\tilde{H}_q$ and $\tilde{E}_q$), which can be accessed without the need for a polarized target or beam.

Experimental Access

- The handbag mechanism is applicable in the asymptotic limit ($Q^2 \to \infty$) and for longitudinal photons.
- The cross section can be expressed as:

$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi} = \frac{1}{2\pi}\frac{d^2\Gamma}{dx_B dQ^2}\left(Q^2, x_B, E\right) \times \left[\frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt} + \sqrt{2\epsilon(1+\epsilon)}\frac{d\sigma_{TL}}{dt}\cos\phi + \epsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi + h\sqrt{2\epsilon\left(11-\epsilon\right)}\frac{d\sigma_{LT'}}{dt}\sin\phi\right] \tag{4}$$

where E is the incident lepton energy in the target rest frame and ϕ is the angle between the leptonic and hadronic planes.

Visualization of Data: Understanding Trends and Patterns

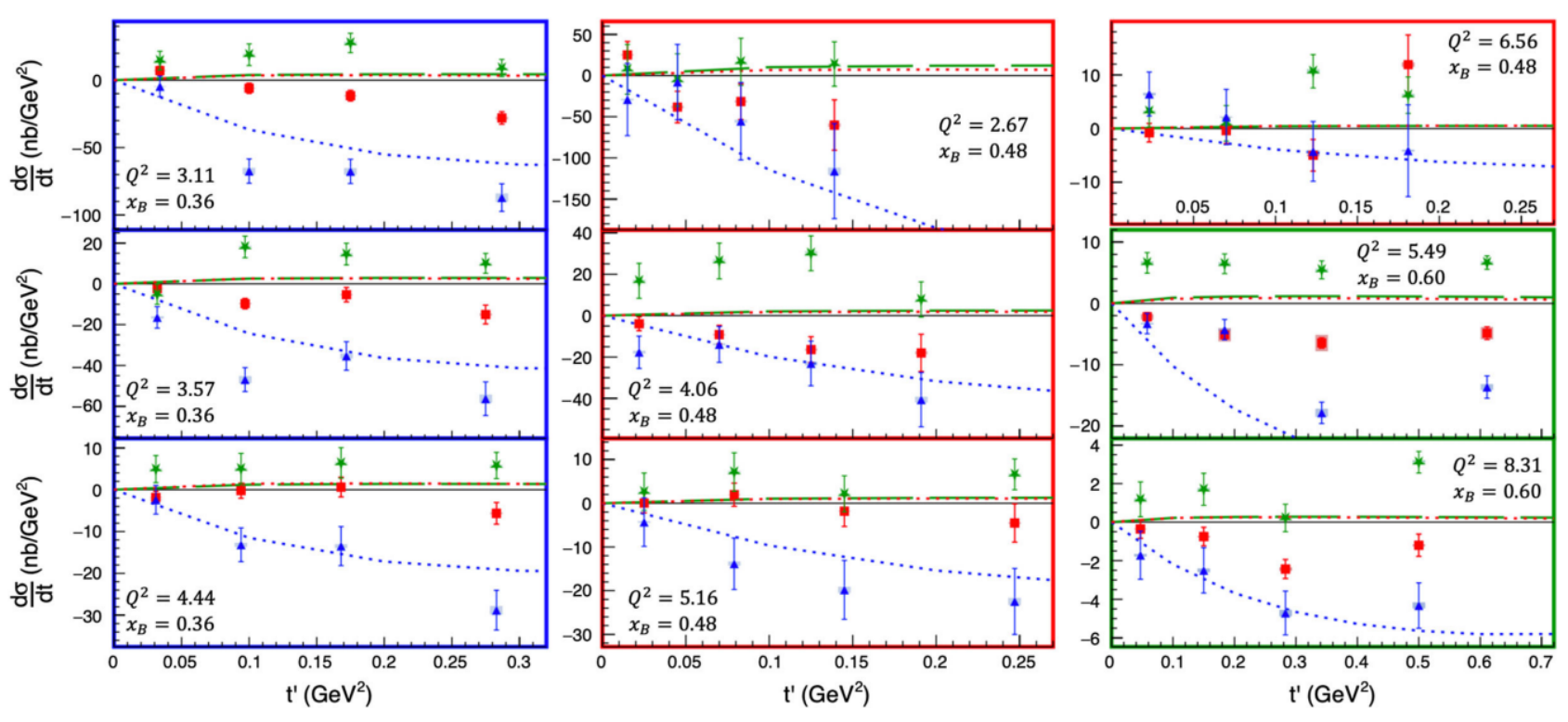


Figure 2: $d\sigma_{TT}$ (blue triangles), $d\sigma_{LT}$ (red squares), and $d\sigma_{LT'}$ (green stars). https://doi.org/10.1103/PhysRevLett.127.152301

Visualization of Data: Understanding Trends and Patterns

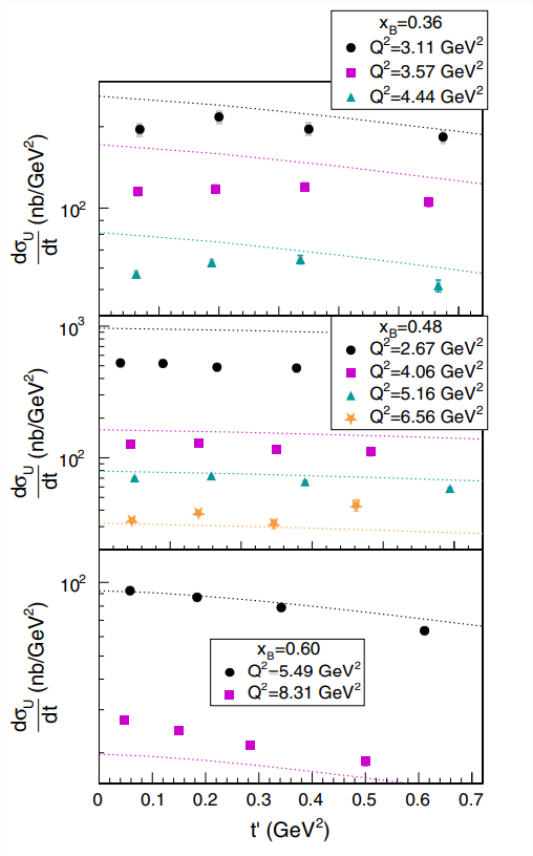


Figure 3: Unpolarized and unseparated data for $d\sigma_U = d\sigma_T + \epsilon d\sigma_L$.
https://doi.org/10.1103/PhysRevLett.127.152301

Visualization of Data: Understanding Trends and Patterns

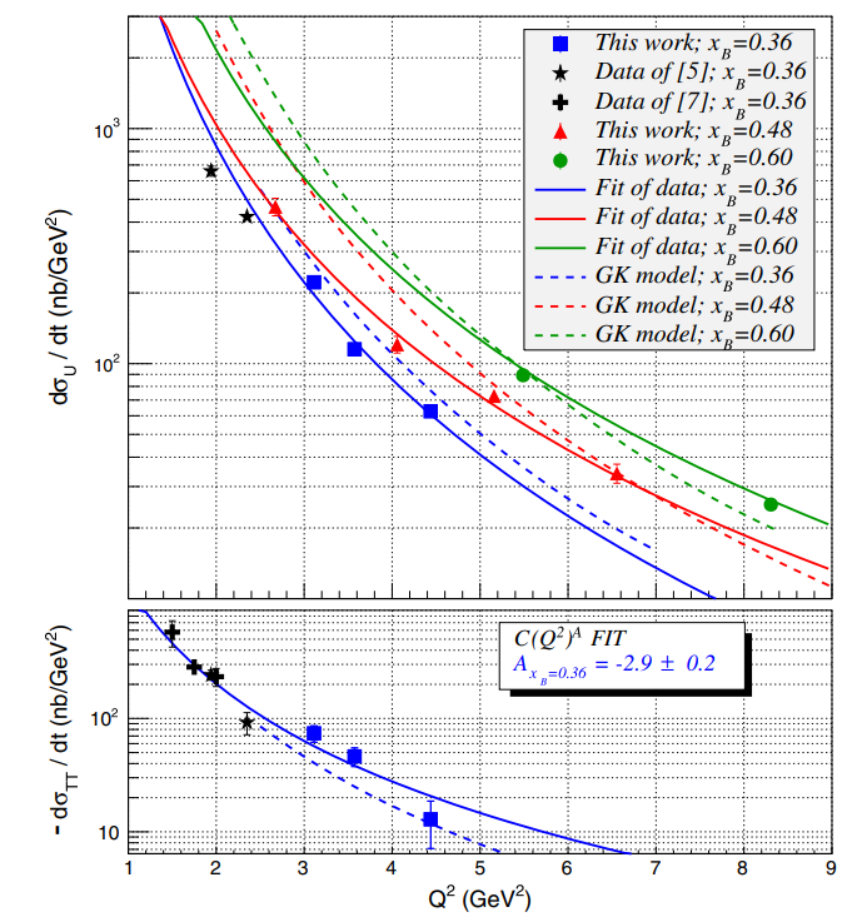
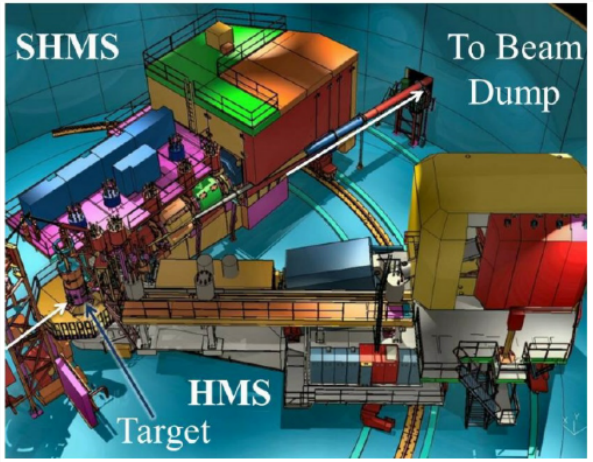


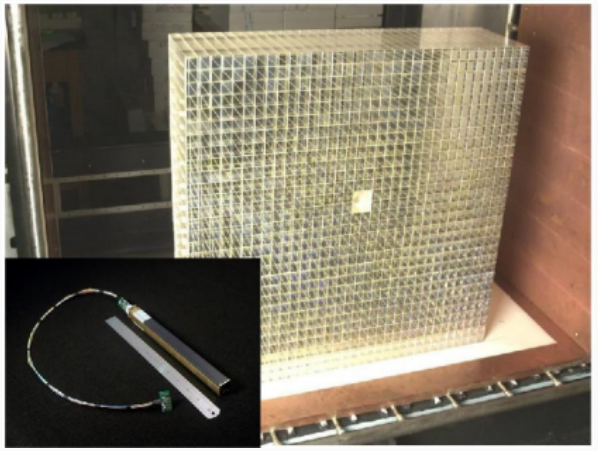
Figure 4: Fits to the analytic form $(Q^2)^A$

https://doi.org/10.1103/PhysRevLett.127.152301

Let's Go! Neutral Particle Spectrometer

1. Run Group 1 experiments were completed in Hall-C recently on May 20^{th}.
2. Utilized HMS (High Momentum Spectrometer) and NPS (Neutral Particle Spectrometer) in coincidence.
3. For π^0 DVMP, the decay $\pi^0 \rightarrow \gamma + \gamma$ (observed by NPS) in coincidence with e^- (observed by HMS) is under study.





Closing Remarks

- Testing the limits of factorization with Q^2.
- Insights into the GPDs with better access to the flavors.
- Separation of the longitudinal and transverse contributions necessary.
- Lots of data! $\rightarrow$ Lots of analysis! $\rightarrow$ Exciting models and theories to explore! $\rightarrow$ Many sleepless nights ahead!

Thank You!

” Questions? Comments? Concerns? ”

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