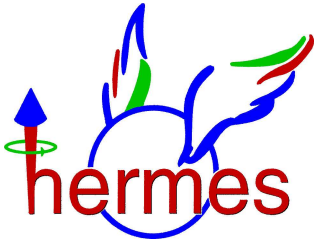
Exclusive Processes at HERMES

Arne Vandenbroucke

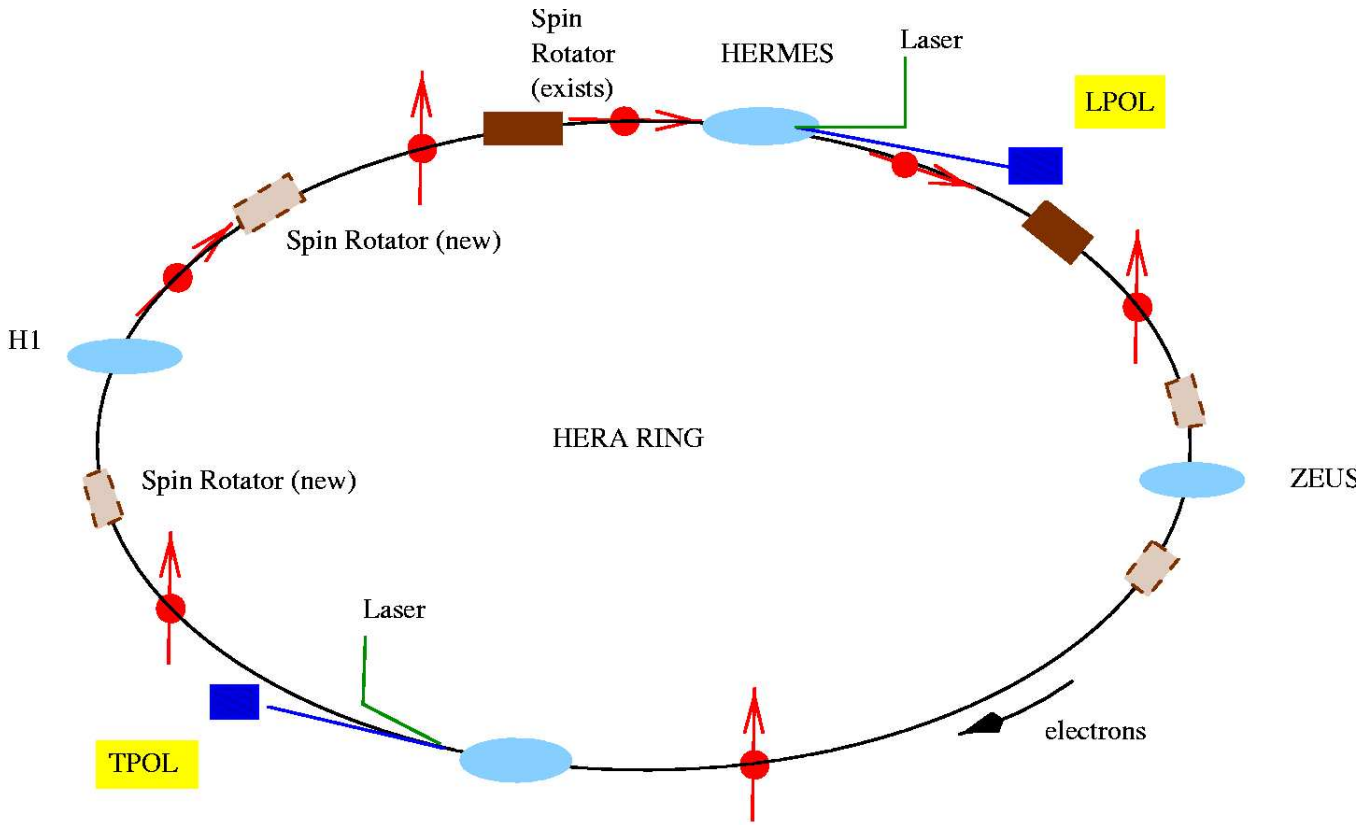
Gent University, Belgium
On behalf of the HERMES Collaboration

22nd Winter Workschop on Nuclear Dynamics
La Jolla, California, USA
March 17th, 2006



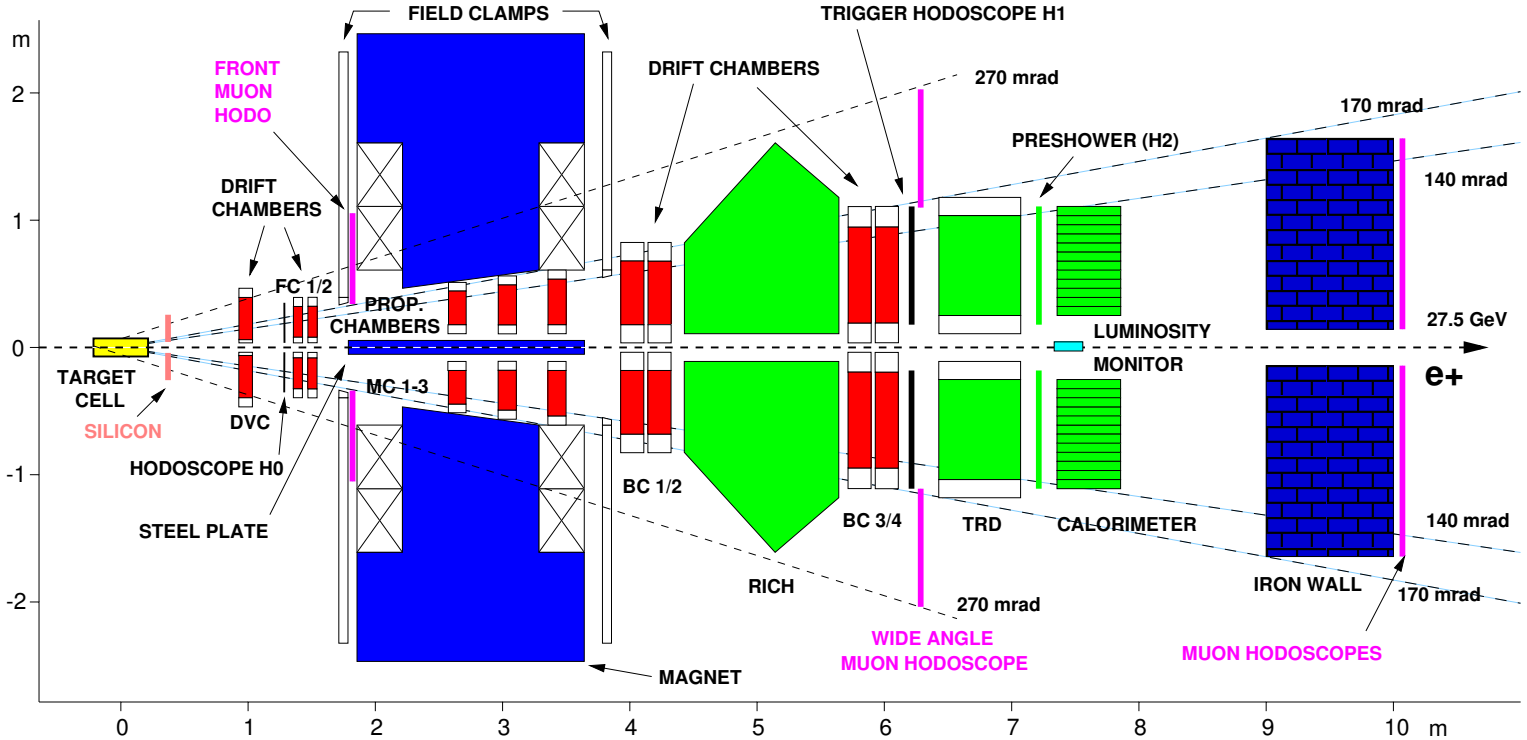
Outline

HERA Lepton Beam



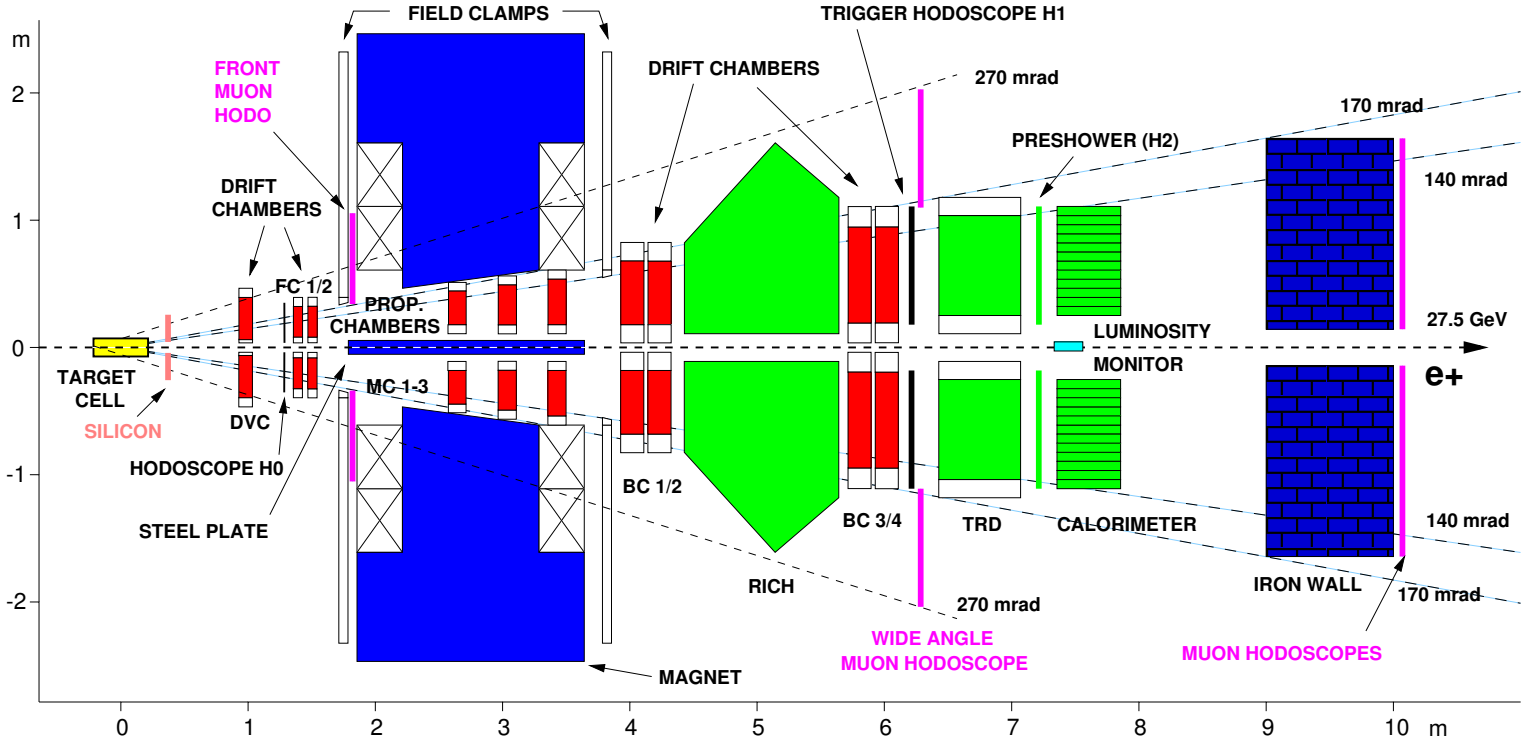
- Polarized beam with polarization around 50 %
- Possibility of both electron and positron beams

The HERMES Spectrometer



- Internal Polarized Gas Target
- Magnet Momentum measurement
- Tracking Chambers $\Delta P/P \sim 2\%$
- Lepton/Hadron Separation with $\epsilon > 99\%$
- RICH to separate pion,kaon,proton
- Calorimeter $\Delta E_\gamma / E_\gamma \sim 5\%$

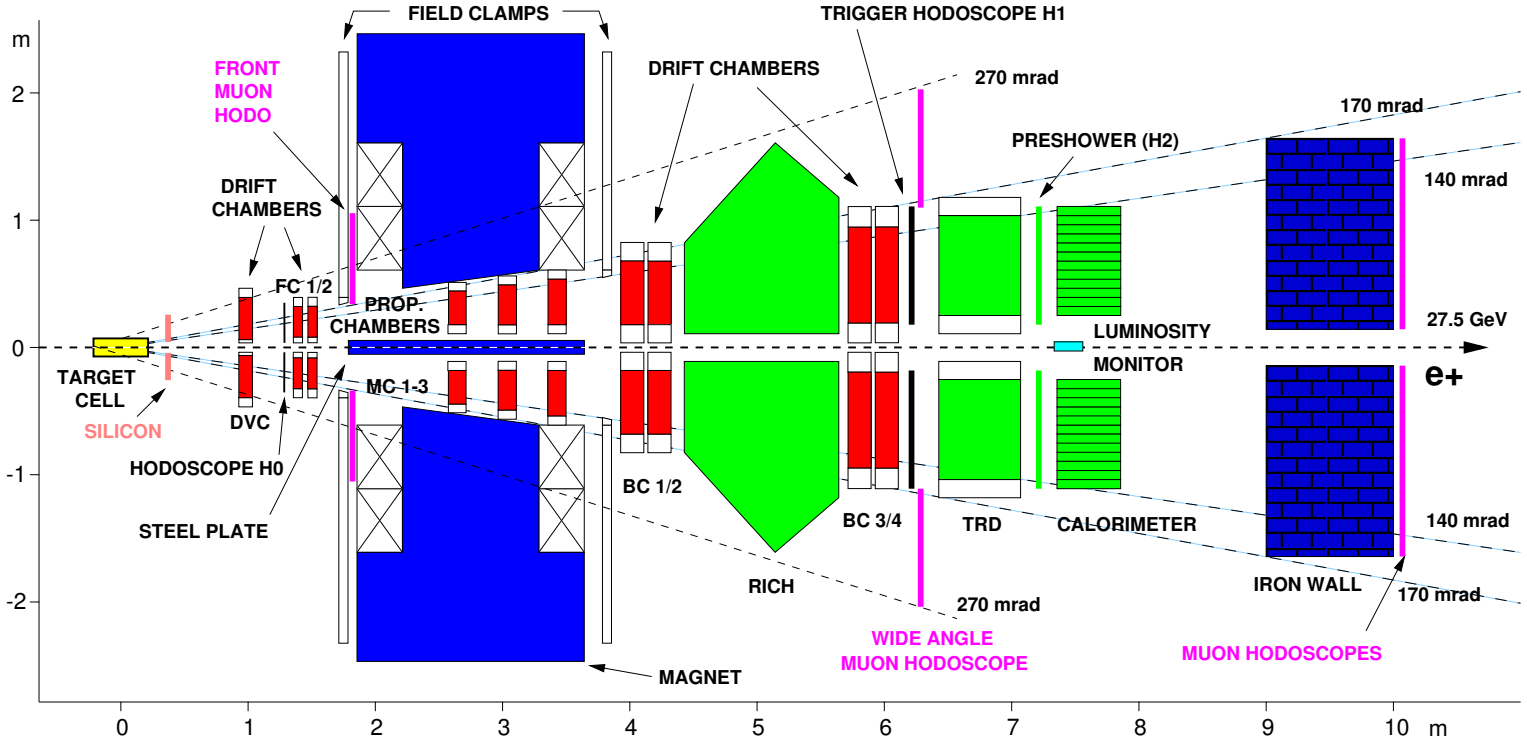
The HERMES Spectrometer



- Internal Polarized Gas Target
- Magnet Momentum measurement
- Tracking Chambers $\Delta P/P \sim 2\%$

- Lepton/Hadron Separation with $\epsilon > 99\%$
- RICH to separate pion,kaon,proton
- Calorimeter $\Delta E_\gamma / E_\gamma \sim 5\%$

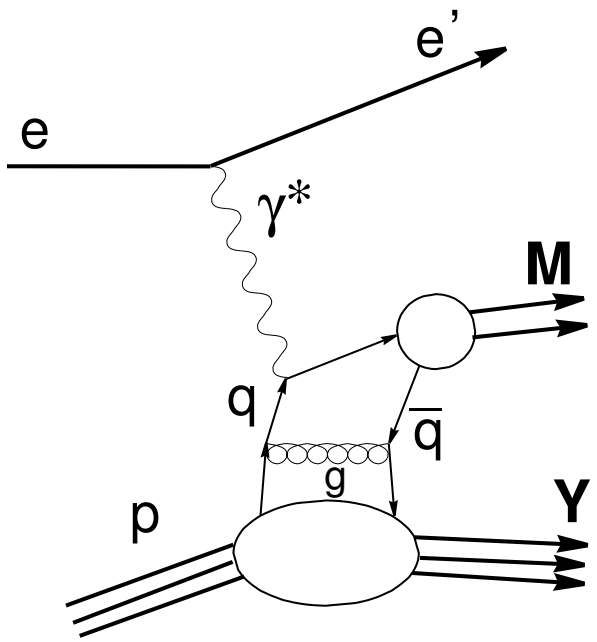
The HERMES Spectrometer



- Internal Polarized Gas Target
- Magnet Momentum measurement
- Tracking Chambers $\Delta P/P \sim 2\%$
- Lepton/Hadron Separation with $\epsilon > 99\%$
- RICH to separate pion,kaon,proton
- Calorimeter $\Delta E_\gamma / E_\gamma \sim 5\%$

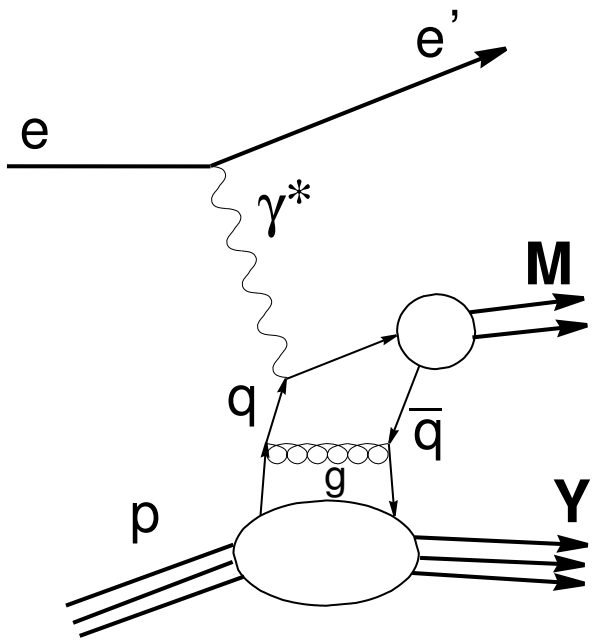
Exclusive processes

- Initial and Final State *fully* known
- HERA Lepton Beam with fixed internal gas target.
- Scattered Lepton and produced meson in Hermes acceptance
- Select Exclusive reactions by putting *constraints* on the missing mass, or missing energy



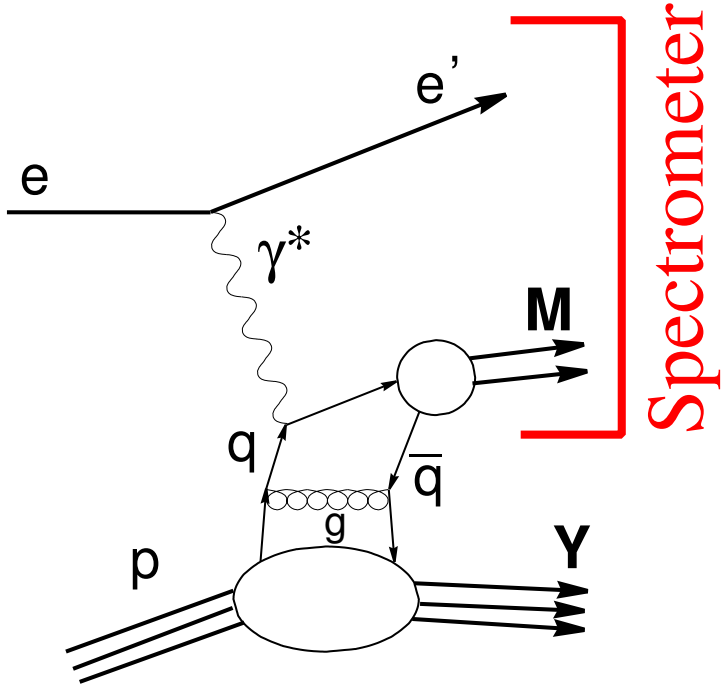
Exclusive processes

- Initial and Final State *fully* known
- HERA Lepton Beam with fixed internal gas target.
- Scattered Lepton and produced meson in Hermes acceptance
- Select Exclusive reactions by putting *constraints* on the missing mass, or missing energy



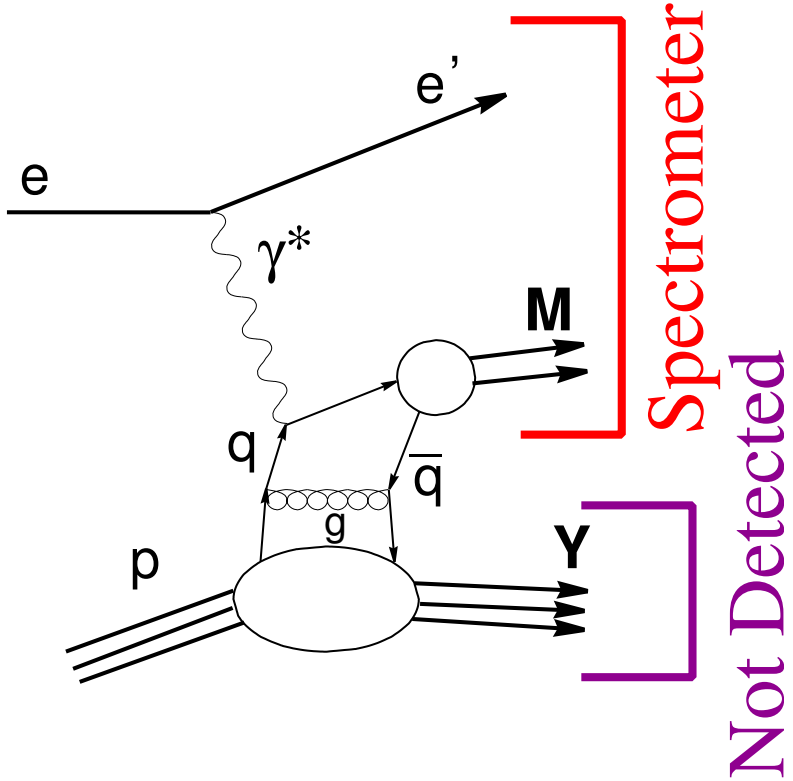
Exclusive processes

- Initial and Final State *fully* known
- HERA Lepton Beam with fixed internal gas target.
- Scattered Lepton and produced meson in Hermes acceptance
- Select Exclusive reactions by putting *constraints* on the missing mass, or missing energy



Exclusive processes

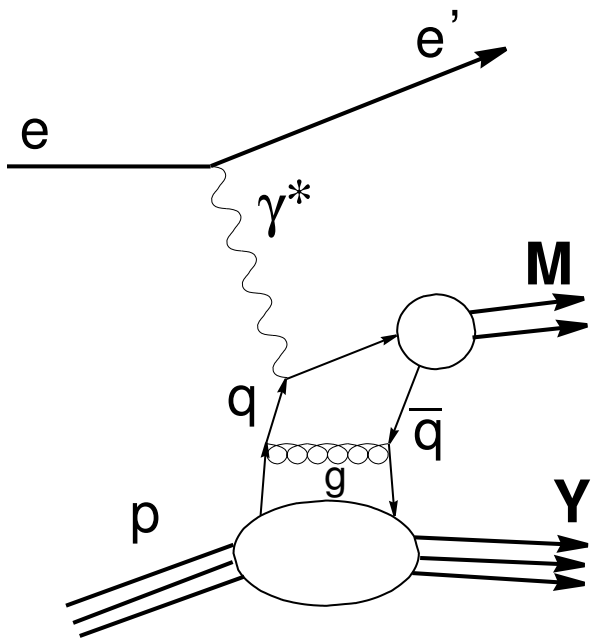
- Initial and Final State *fully* known
- HERA Lepton Beam with fixed internal gas target.
- Scattered Lepton and produced meson in Hermes acceptance
- Select Exclusive reactions by putting *constraints* on the missing mass, or missing energy



Exclusive Leptoproduction of Mesons/Photons

- Collins, hep-ph/9907513 -
- Collins, Frankfurt, Strikman, hep-ph/9709336 -

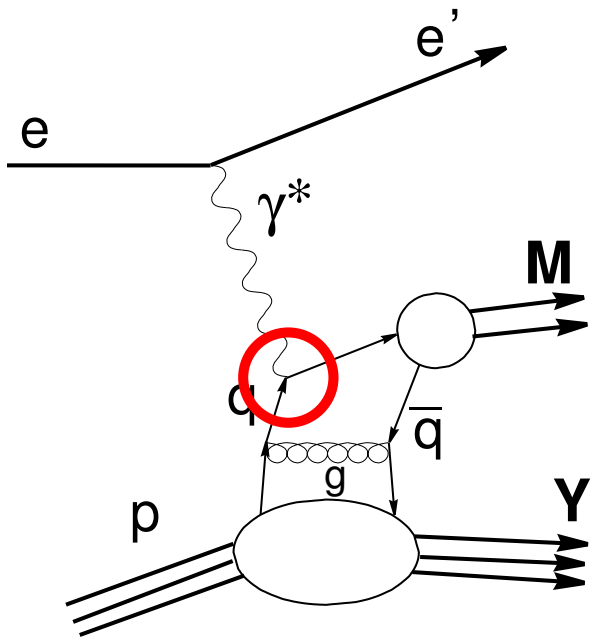
- **Factorization** can be applied for exclusive processes:
  - a hard part
  - a meson distribution amplitude
  - a soft part providing information about the nucleon in terms of Generalized Parton Distributions
  - Factorization valid for large Q^2, low t (and γ^*_L)



Exclusive Leptoproduction of Mesons/Photons

- Collins, hep-ph/9907513 -
- Collins, Frankfurt, Strikman, hep-ph/9709336 -

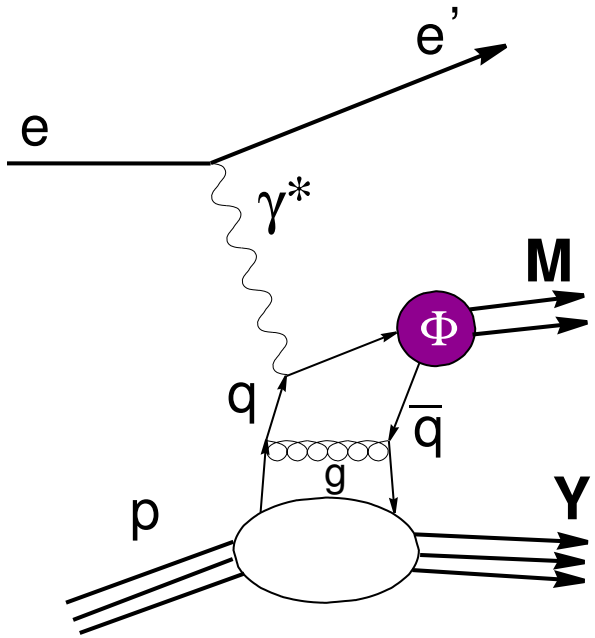
- Factorization can be applied for exclusive processes:
- a hard part
- a meson distribution amplitude
- a soft part providing information about the nucleon in terms of Generalized Parton Distributions
- Factorization valid for large Q^2, low t (and γ^*_L)



Exclusive Leptoproduction of Mesons/Photons

- Collins, hep-ph/9907513 -
- Collins, Frankfurt, Strikman, hep-ph/9709336 -

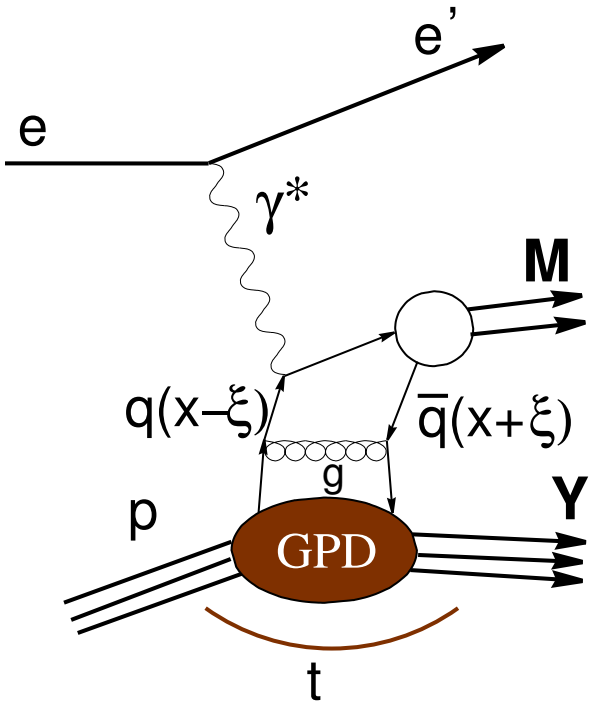
- Factorization can be applied for exclusive processes:
- a hard part
- a meson distribution amplitude
- a soft part providing information about the nucleon in terms of Generalized Parton Distributions
- Factorization valid for large Q^2, low t (and γ_L^*)



Exclusive Leptoproduction of Mesons/Photons

- Collins, hep-ph/9907513 -
- Collins, Frankfurt, Strikman, hep-ph/9709336 -

- Factorization can be applied for exclusive processes:
- a hard part
- a meson distribution amplitude
- a soft part providing information about the nucleon in terms of Generalized Parton Distributions
- Factorization valid for large Q^2, low t (and γ_L^*)

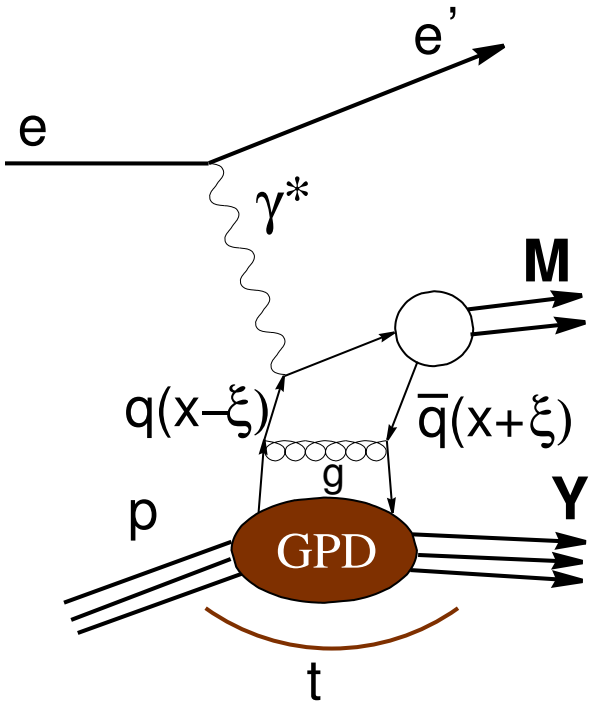


GPD(x,ξ,t)

Exclusive Leptoproduction of Mesons/Photons

- Collins, hep-ph/9907513 -
- Collins, Frankfurt, Strikman, hep-ph/9709336 -

- Factorization can be applied for exclusive processes:
- a hard part
- a meson distribution amplitude
- a soft part providing information about the nucleon in terms of Generalized Parton Distributions
- Factorization valid for large Q^2, low t (and γ_L^*)

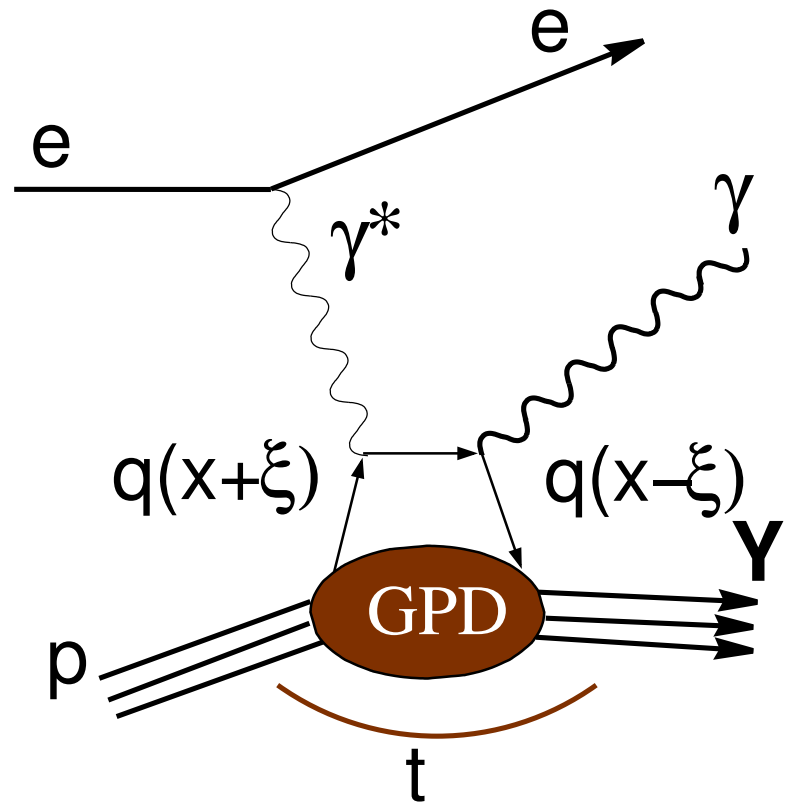


GPD(x,ξ,t)

Generalized Parton Distribution Functions

- 4 GPD's for every quark flavor q: $H^q, E^q, \tilde{H}^q, \tilde{E}^q$
- Functions of x, ξ, and t
- Contain the standard Form Factors and Distribution functions
- Combining Transverse position and Longitudinal Momentum
- Access to the Total Spin J^q via Ji's Sum Rule:

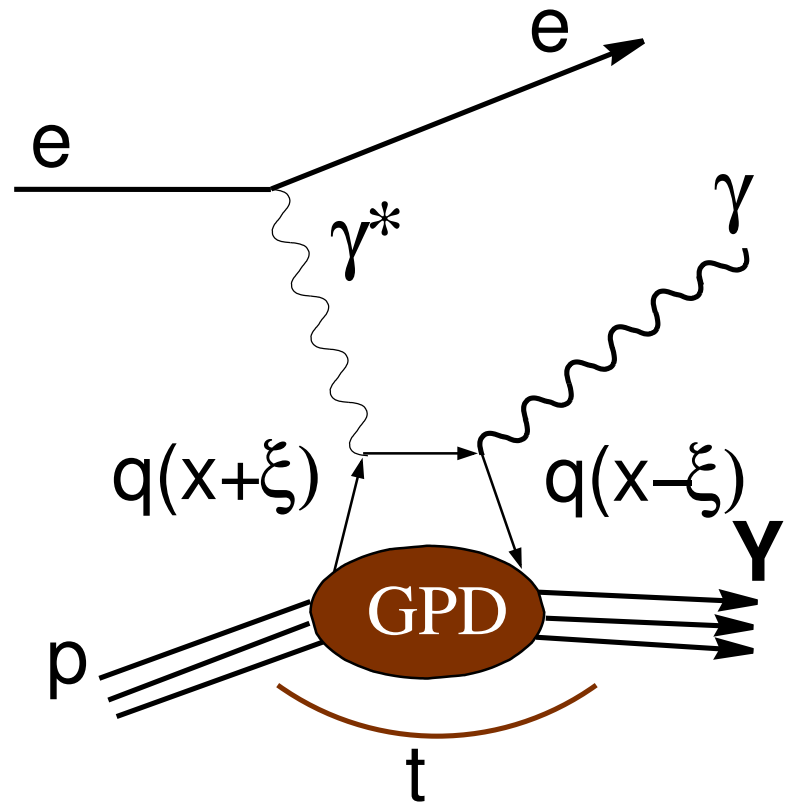
$$J^q = \frac{1}{2}\lim_{t\to 0}\int_{-1}^{1}(H^q + E^q)x\,dx$$
$$= \frac{1}{2}(\Delta u + \Delta d + \Delta s) + L^q$$



Generalized Parton Distribution Functions

- 4 GPD's for every quark flavor q: $H^q, E^q, \tilde{H}^q, \tilde{E}^q$
- Functions of x, ξ, and t
- Contain the standard Form Factors and Distribution functions
- Combining Transverse position and Longitudinal Momentum
- Access to the Total Spin J^q via Ji's Sum Rule:

$$J^q = \frac{1}{2}\lim_{t\to 0}\int_{-1}^{1}(H^q + E^q)x\,dx$$
$$= \frac{1}{2}(\Delta u + \Delta d + \Delta s) + L^q$$

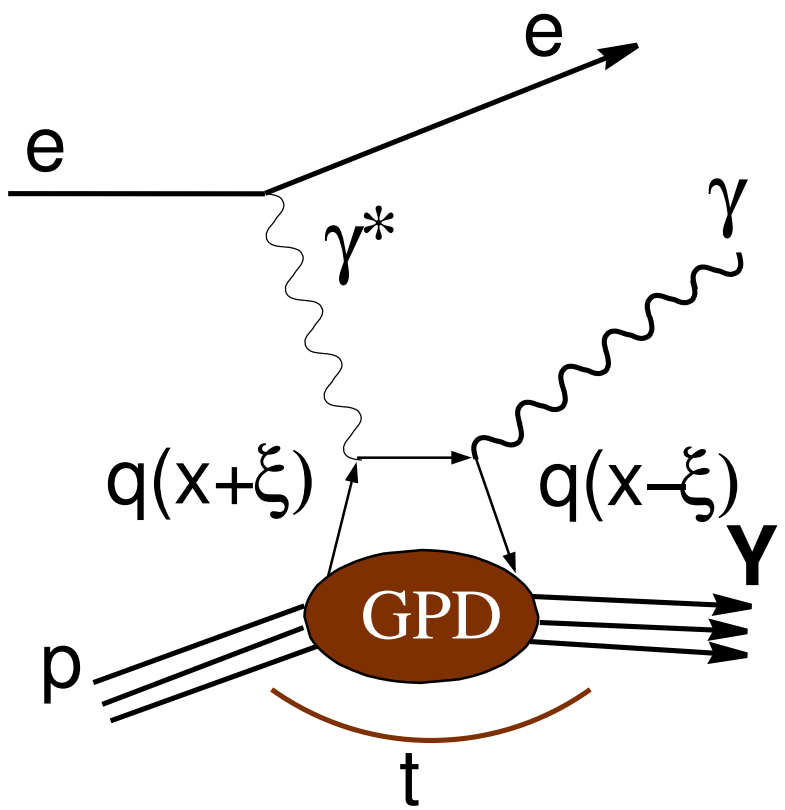


Generalized Parton Distribution Functions

- 4 GPD's for every quark flavor q: $H^q, E^q, \tilde{H}^q, \tilde{E}^q$
- Functions of x, ξ, and t
- Contain the standard Form Factors and Distribution functions

$$\int_{-1}^{1} dx H^q(x,\xi,t) = F_1^q(t)$$
$$\int_{-1}^{1} dx E^q(x,\xi,t) = F_2^q(t)$$
$$\int_{-1}^{1} dx \tilde{H}^q(x,\xi,t) = G_A^q(t)$$
$$\int_{-1}^{1} dx \tilde{E}^q(x,\xi,t) = G_P^q(t)$$

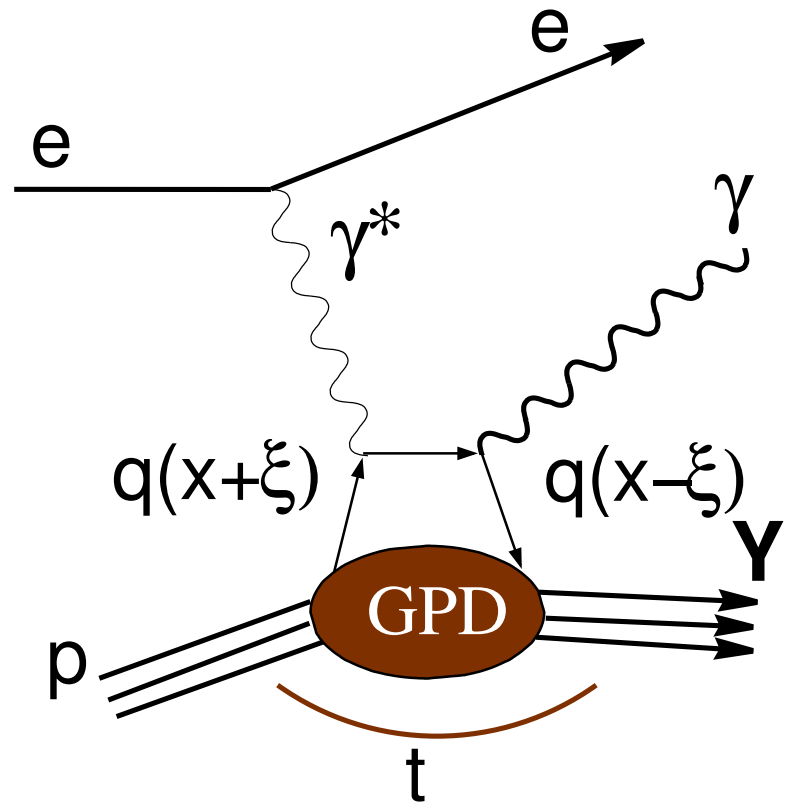
$$H^q(x,0,0) = q(x)$$
$$\tilde{H}^q(x,0,0) = \Delta q(x)$$



Generalized Parton Distribution Functions

- 4 GPD's for every quark flavor q: $H^q, E^q, \tilde{H}^q, \tilde{E}^q$
- Functions of x, ξ, and t
- Contain the standard Form Factors and Distribution functions
- Combining Transverse position and Longitudinal Momentum
- Access to the Total Spin J^q via Ji's Sum Rule:

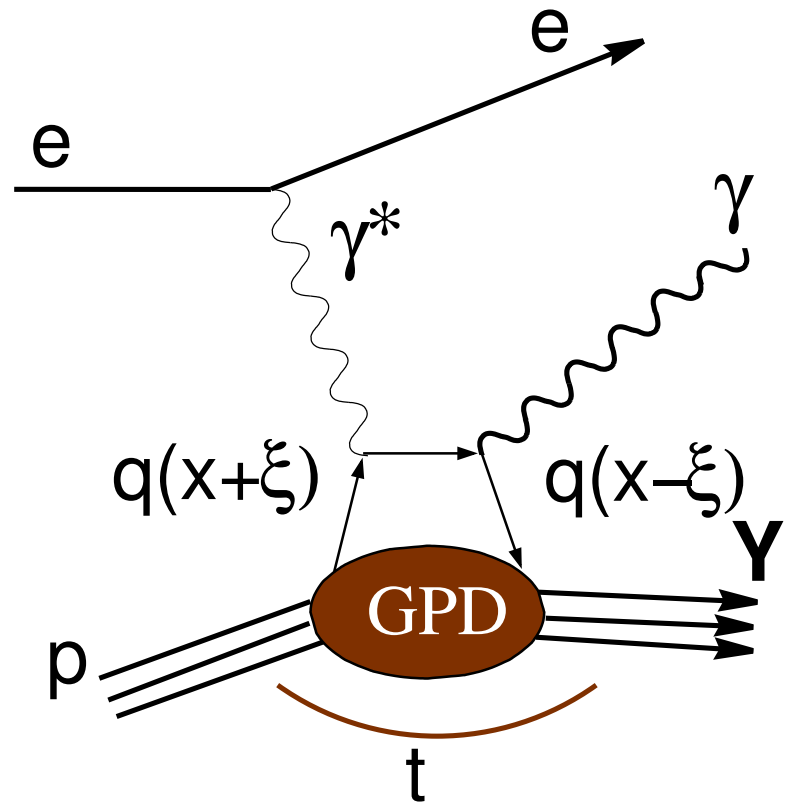
$$J^q = \frac{1}{2}\lim_{t\to 0}\int_{-1}^{1}(H^q + E^q)x\,dx$$
$$= \frac{1}{2}(\Delta u + \Delta d + \Delta s) + L^q$$



Generalized Parton Distribution Functions

- 4 GPD's for every quark flavor q: $H^q, E^q, \tilde{H}^q, \tilde{E}^q$
- Functions of x, ξ, and t
- Contain the standard Form Factors and Distribution functions
- Combining Transverse position and Longitudinal Momentum
- Access to the Total Spin J^q via Ji's Sum Rule:

$$J^q = \frac{1}{2}\lim_{t\to 0}\int_{-1}^{1}(H^q + E^q)x\,dx$$
$$= \frac{1}{2}(\Delta u + \Delta d + \Delta s) + L^q$$



Observing Generalized Parton Distributions

- Both different final states and different observables select different combinations of GPD's:
  - Exclusive Pseudoscalar Meson Production: $\tilde{H}, \tilde{E}$
  - Exclusive Vector Meson Production: H, E
  - Deeply Virtual Compton Scattering: $H, E, \tilde{H}, \tilde{E}$
  - Target or Beam related asymmetries access a product of GPD's.
  - Cross Section Measurements give access to quadratic combination.

Observing Generalized Parton Distributions

- Both different final states and different observables select different combinations of GPD's:
  - Exclusive Pseudoscalar Meson Production: $\tilde{H}, \tilde{E}$
  - Exclusive Vector Meson Production: H, E
  - Deeply Virtual Compton Scattering: $H, E, \tilde{H}, \tilde{E}$
  - Target or Beam related asymmetries access a product of GPD's.
  - Cross Section Measurements give access to quadratic combination.

Observing Generalized Parton Distributions

- Both different final states and different observables select different combinations of GPD's:
  - Exclusive Pseudoscalar Meson Production: $\tilde{H}, \tilde{E}$
  - Exclusive Vector Meson Production: H, E
  - Deeply Virtual Compton Scattering: $H, E, \tilde{H}, \tilde{E}$
  - Target or Beam related asymmetries access a product of GPD's.
  - Cross Section Measurements give access to quadratic combination.

Observing Generalized Parton Distributions

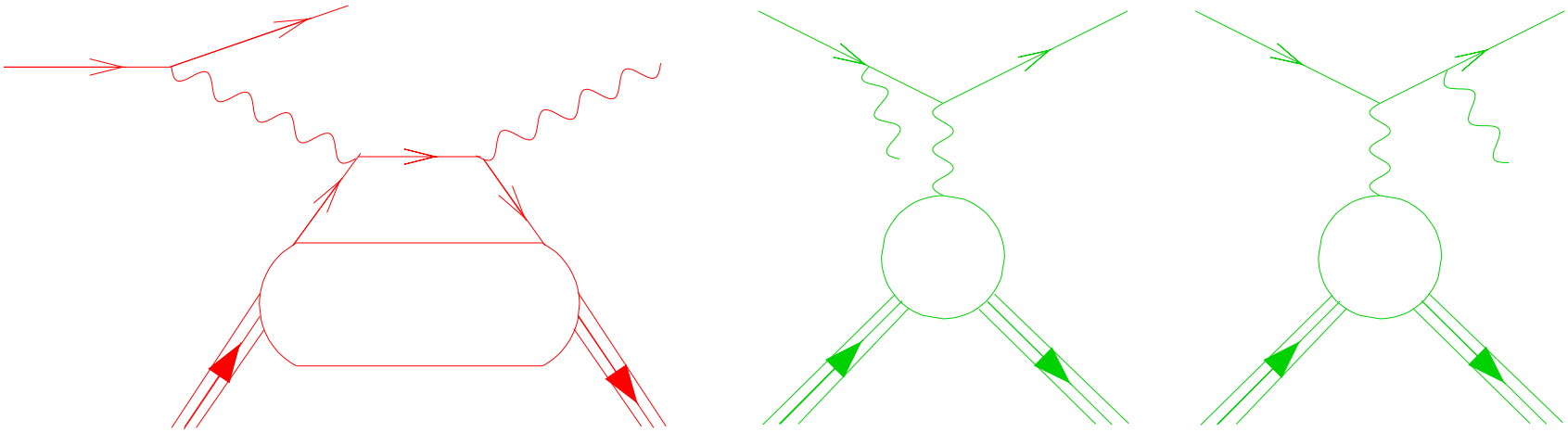
- Both different final states and different observables select different combinations of GPD's:
  - Exclusive Pseudoscalar Meson Production: $\tilde{H}, \tilde{E}$
  - Exclusive Vector Meson Production: H, E
  - Deeply Virtual Compton Scattering: $H, E, \tilde{H}, \tilde{E}$
  - Target or Beam related asymmetries access a product of GPD's.
  - Cross Section Measurements give access to quadratic combination.

Deeply Virtual Compton Scattering

$\Rightarrow$ *Probe E and H (and $\tilde{E}$,$\tilde{H}$)*

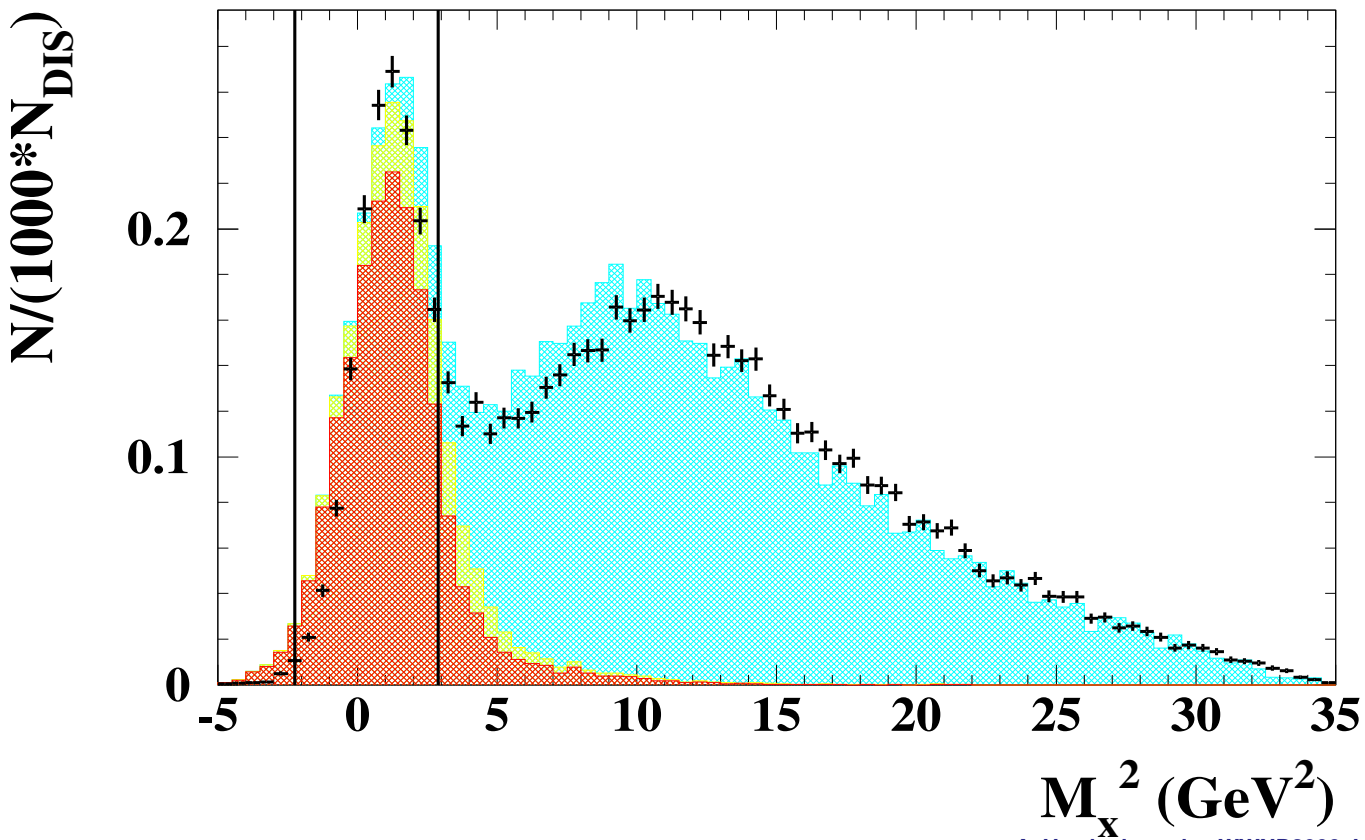
$e + p \rightarrow e + p + \gamma$

- DVCS final state indistinguishable from the Bethe-Heithler final state, where a Brehmsstrahlung photon is created.



$e + p \rightarrow e + p + \gamma$

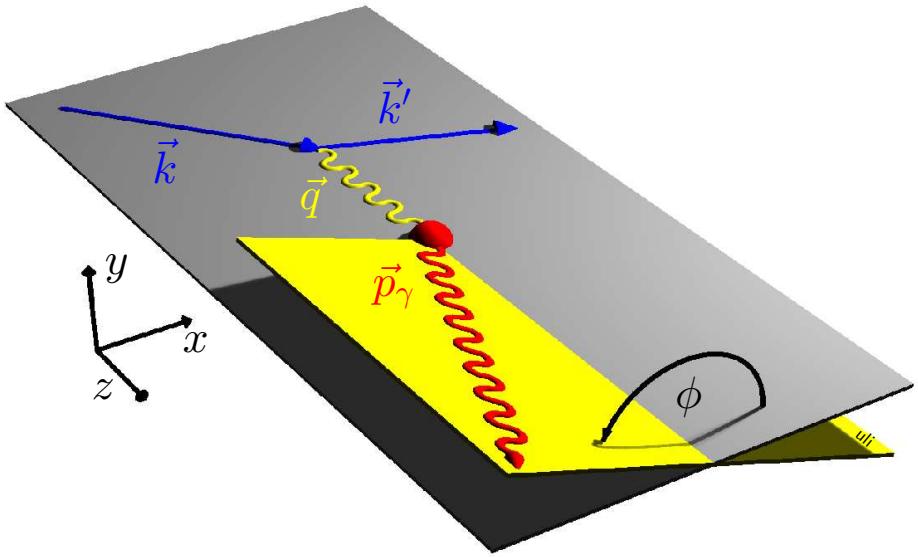
- DVCS final state indistinguishable from the Bethe-Heithler final state, where a Brehmsstrahlung photon is created.
- Select final state by putting constraints on the Missing Mass



$e + p \rightarrow e + p + \gamma$

- DVCS final state indistinguishable from the Bethe-Heithler final state, where a Brehmsstrahlung photon is created.
- Select Final state by putting constraints on the Missing Mass
- Amplitudes add up coherently:

$$\begin{aligned} d\sigma &= |\tau_{BH} + \tau_{DVCS}|^2 \\ &= |\tau_{BH}|^2 + |\tau_{DVCS}|^2 + \underbrace{(\tau_{BH}\tau^*_{DVCS} + \tau^*_{BH}\tau_{DVCS})}_{\propto c_0 + \Sigma_n c_n \cos(n\phi) + \lambda \Sigma_n s_n \sin(n\phi)} \end{aligned}$$



$e + p \rightarrow e + p + \gamma$

- DVCS final state indistinguishable from the Bethe-Heithler final state, where a Brehmsstrahlung photon is created.
- Select Final state by putting constraints on the Missing Mass
- Amplitudes add up coherently:

$$\begin{aligned} d\sigma &= |\tau_{BH} + \tau_{DVCS}|^2 \\ &= |\tau_{BH}|^2 + |\tau_{DVCS}|^2 + \underbrace{(\tau_{BH}\tau^*_{DVCS} + \tau^*_{BH}\tau_{DVCS})}_{\propto c_0 + \Sigma_n c_n \cos(n\phi) + \lambda \Sigma_n s_n \sin(n\phi)} \end{aligned}$$

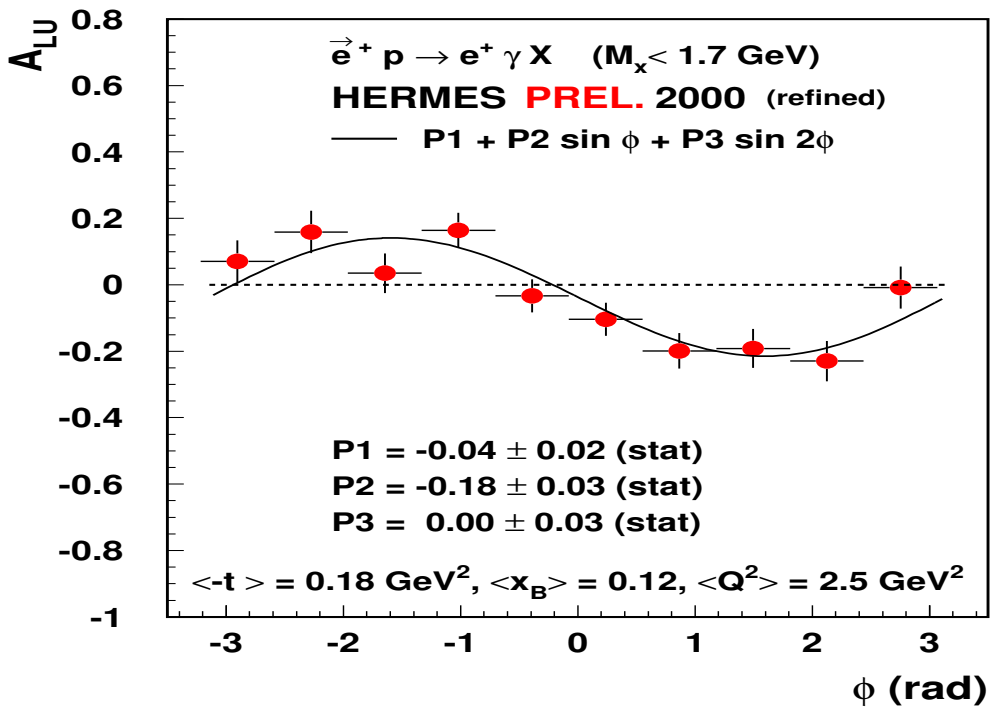
Beam Related Asymmetries:

BSA: $d\sigma(\overrightarrow{e^+}p) - d\sigma(\overleftarrow{e^+}p) \sim \sin(\phi) \times \mathrm{Im} M^{1,1}_{\mathrm{unp}}$

BCA: $d\sigma(e^+p) - d\sigma(e^-p) \sim \cos(\phi) \times \mathrm{Re} M^{1,1}_{\mathrm{unp}}$

Beam Spin Asymmetry

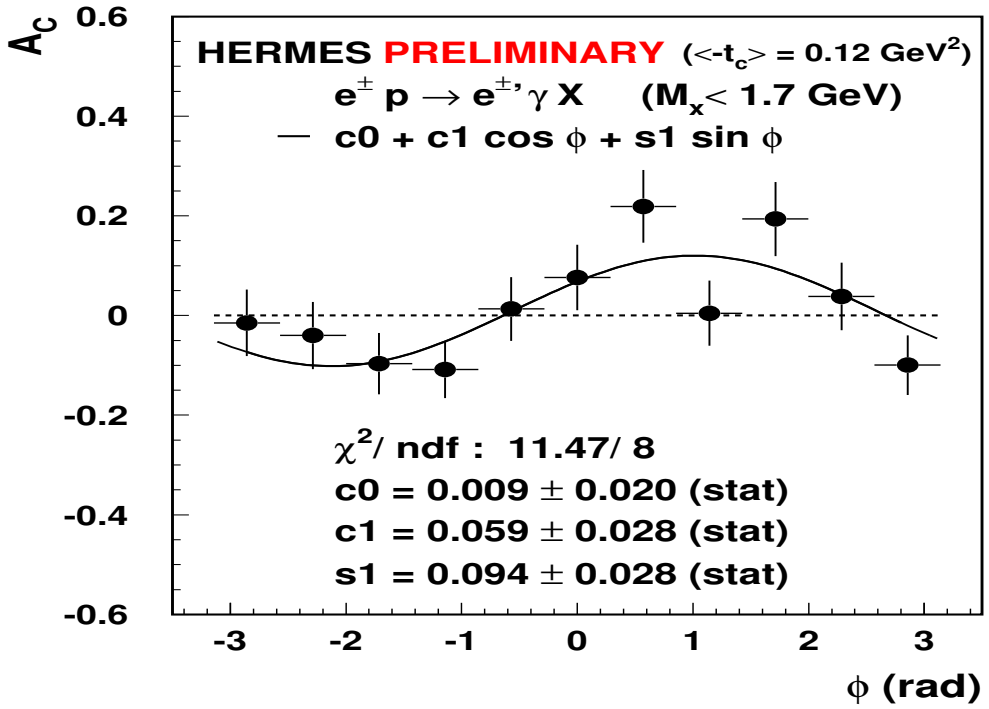
$$A_{LU} = \frac{1}{<|P_B|>} \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)} \propto \Sigma_n s_n \sin(n\phi)$$



- expected $\sin(\phi)$ behavior !

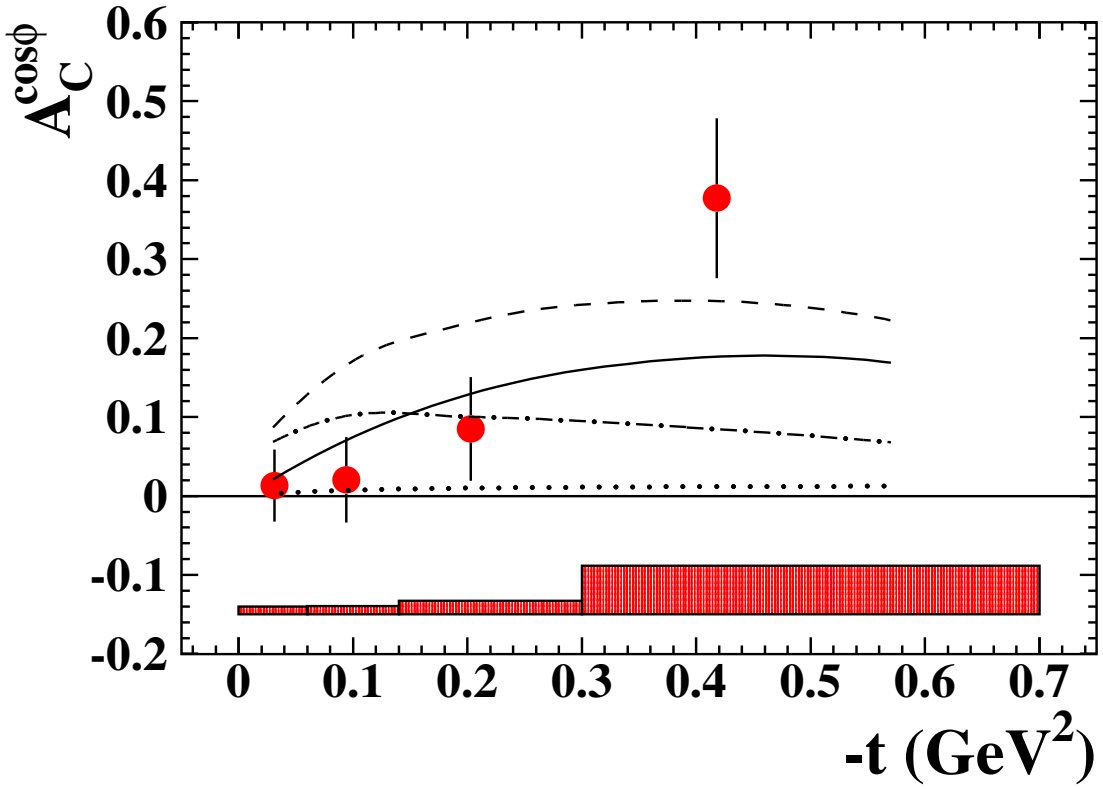
Beam Charge Asymmetry

$$A_C = \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)} \propto c_0 + \Sigma_n c_n \cos(n\phi) + \lambda \Sigma_n s_n \sin(n\phi)$$



- expected $\cos(\phi)$ behaviour
- $\sin(\phi)$ moment due to polarized beam

Beam Charge Asymmetry



- $A_C(t)$ can distinguish between models
  - GPD model with factorized t-dependence (dotted) with D-term (dash-dotted)
  - GPD model with Regge-inspired t-dependence (solid) with D-term (dashed)

From Asymmetries to GPD's

$$M_{\mathrm{unp}}^{1,1} = F_1(t)\mathcal{H}_1(\xi,t) + \frac{x_B}{2-x_B}\left(F_1(t)+F_2(t)\right)\tilde{\mathcal{H}}_1(\xi,t) - \frac{t}{4M_p^2}F_2(t)\mathcal{E}_1(\xi,t)$$

- $F_1(t)$ and $F_2(t)$ Dirac and Pauli Form Factors
- $\mathcal{H}_1, \tilde{\mathcal{H}}_1$ and $\mathcal{E}_1$ Compton Form Factors

From Asymmetries to GPD's

$$M^{1,1}_{\text{unp}} = F_1(t)\mathcal{H}_1(\xi,t) + \frac{x_B}{2-x_B}\left(F_1(t)+F_2(t)\right)\tilde{\mathcal{H}}_1(\xi,t) - \frac{t}{4M_p^2}F_2(t)\mathcal{E}_1(\xi,t)$$

- $F_1(t)$ and $F_2(t)$ Dirac and Pauli Form Factors
- $\mathcal{H}_1, \tilde{\mathcal{H}}_1$ and $\mathcal{E}_1$ Compton Form Factors

$< x_B > \sim 0.1$ and $< -t > \sim 0.1\,\text{GeV}^2$

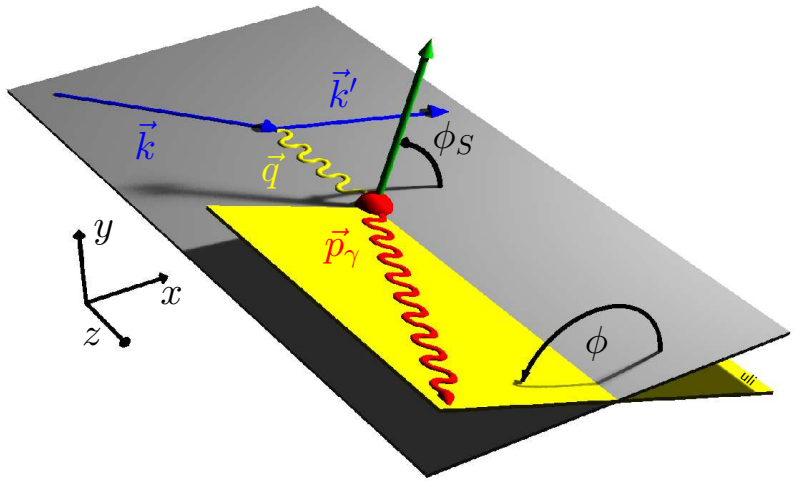
$$\textit{BSA} : \propto \text{Im}\mathcal{H}_1 \quad \propto \sum_q e_q^2 \left(H^q(\xi,\xi,t) - H^q(-\xi,\xi,t)\right)$$

$$\textit{BCA} : \propto \text{Re}\mathcal{H}_1 \quad \propto \sum_q e_q^2 \left(P\int_{-1}^{1} H^q(x,\xi,t)\left(\frac{1}{x-\xi}+\frac{1}{x+\xi}\right)dx\right)$$

$\Rightarrow$ Access to GPD H !

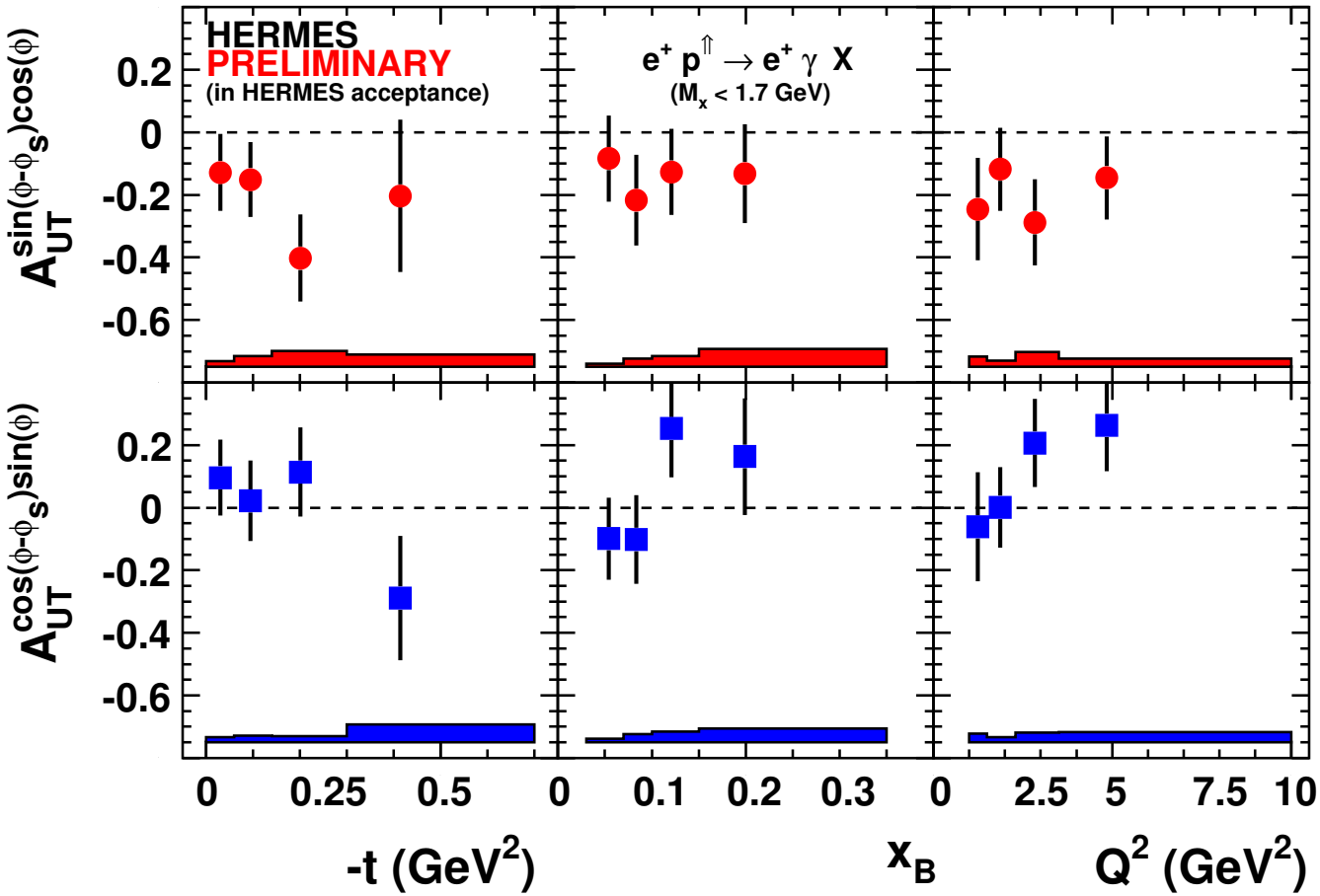
Transverse Target Asymmetry

- During 2002-2005 Hermes run with a transversily polarised target: $< |P_T| > \sim 75\%$

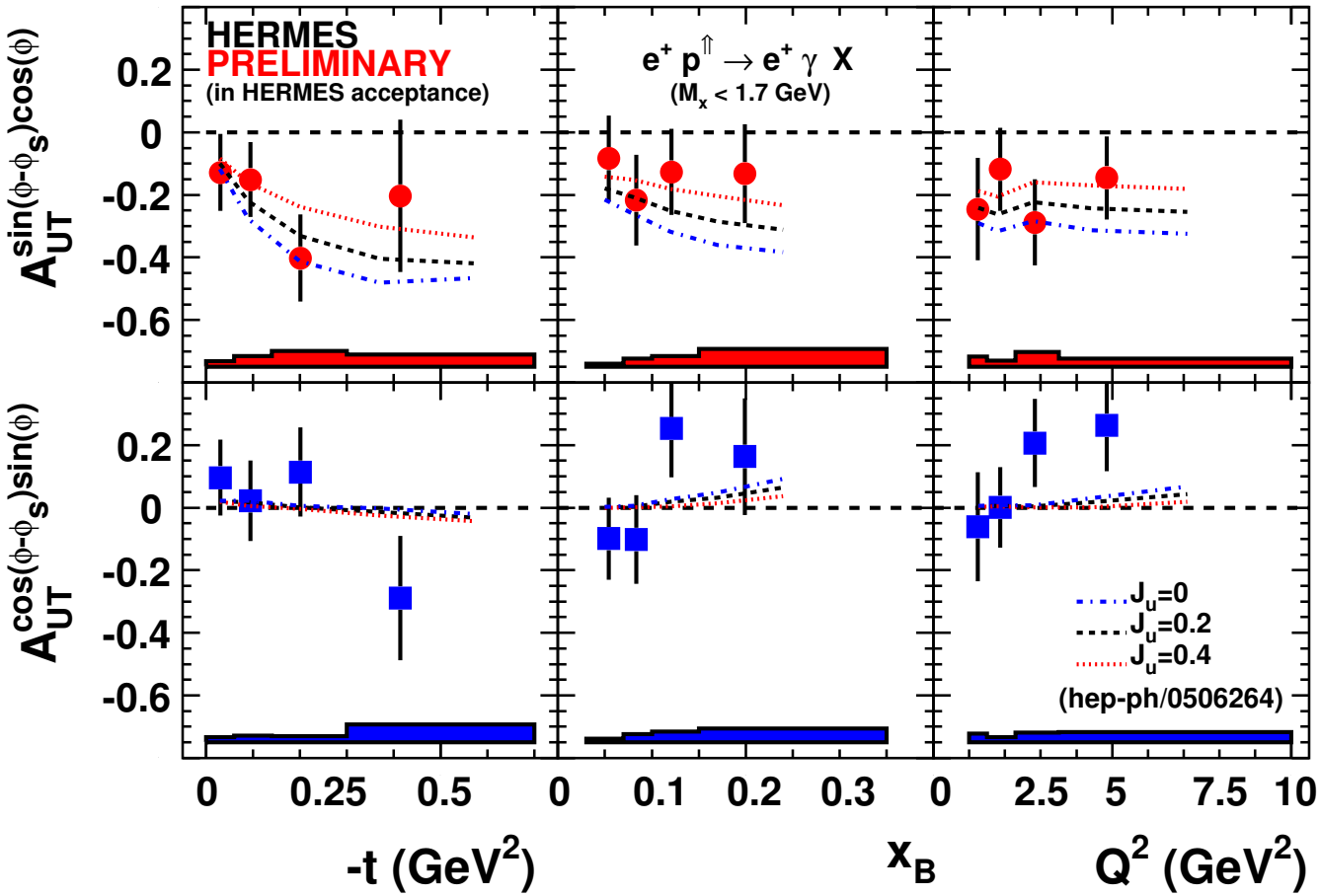


$$A_{UT}(\phi,\phi_S) = \frac{1}{|P_T|}\cdot\frac{N^{\uparrow}(\phi,\phi_S)-N^{\downarrow}(\phi,\phi_S)}{N^{\uparrow}(\phi,\phi_S)+N^{\downarrow}(\phi,\phi_S)}$$
$$\propto \mathrm{Im}(F_2\mathcal{H}-F_1\mathcal{E})\sin(\phi-\phi_S)\cos(\phi)+$$
$$\mathrm{Im}(F_2\tilde{\mathcal{H}}-F_1\xi\tilde{\mathcal{E}})\cos(\phi-\phi_S)\sin(\phi)$$

Transverse Target Asymmetry



Transverse Target Asymmetry



$$A_{UT}^{\sin(\phi-\phi_S)\cos(\phi)} \propto \mathrm{Im}(F_2\mathcal{H} - F_1\mathcal{E}) \Rightarrow \text{Access to GPD E !}$$

Pseudoscalar Mesons

$\Rightarrow$ *Probe* $\tilde{E}$ *and* $\tilde{H}$

$$e + p \rightarrow e + n + \pi^+$$

Cross Section:

$$\sigma^{\gamma^* p \rightarrow n + \pi^+}(x, Q^2) = \frac{N^{\pi^+}_{\text{excl}}}{L \cdot \Delta x \Delta Q^2 \cdot \kappa(x, Q^2) \cdot \Gamma(< x >, < Q^2 >)}$$

- L: Integrated luminosity 1996-2000 : 283 pb^{-1}
- $\kappa(x, Q^2)$: Detection probability (estimated from MC)
- $\Gamma(< x >, < Q^2 >)$: virtual photon flux factor

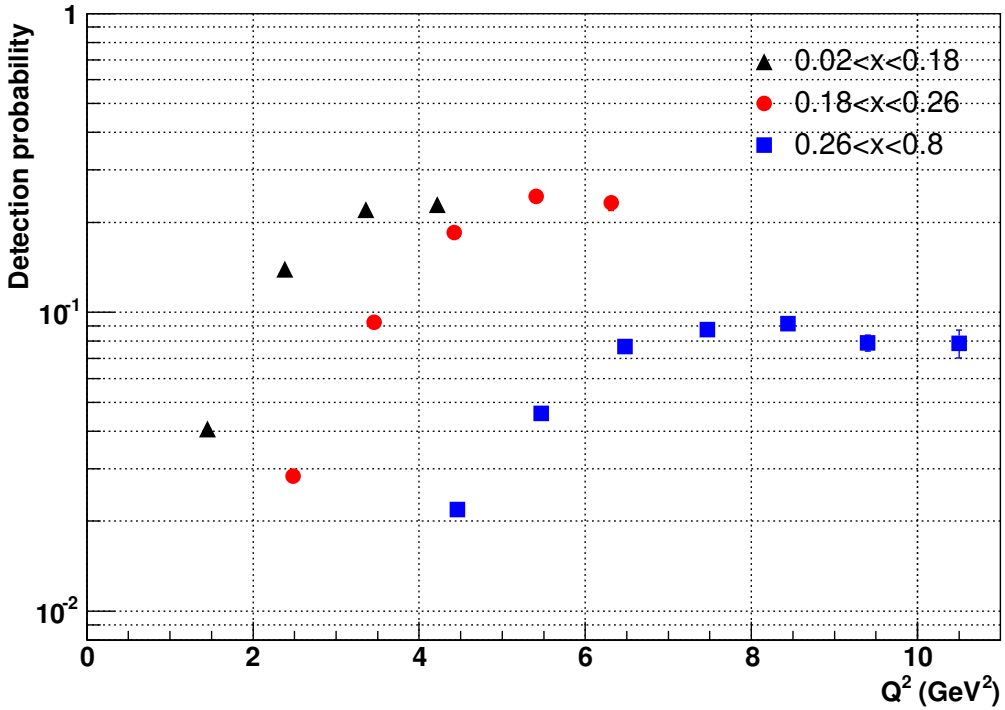
$$\sigma^{\pi^+} \sim (\tilde{H} + \tilde{E})^2$$

Extracting a Cross Section

- Acceptance correction is model dependent, therefore a comparison with 2 different GPD models was made
  - Mankiewicz, Piller & Radyushkin (1999)
  - Vanderhaeghen, Guichon & Guidal (1999)

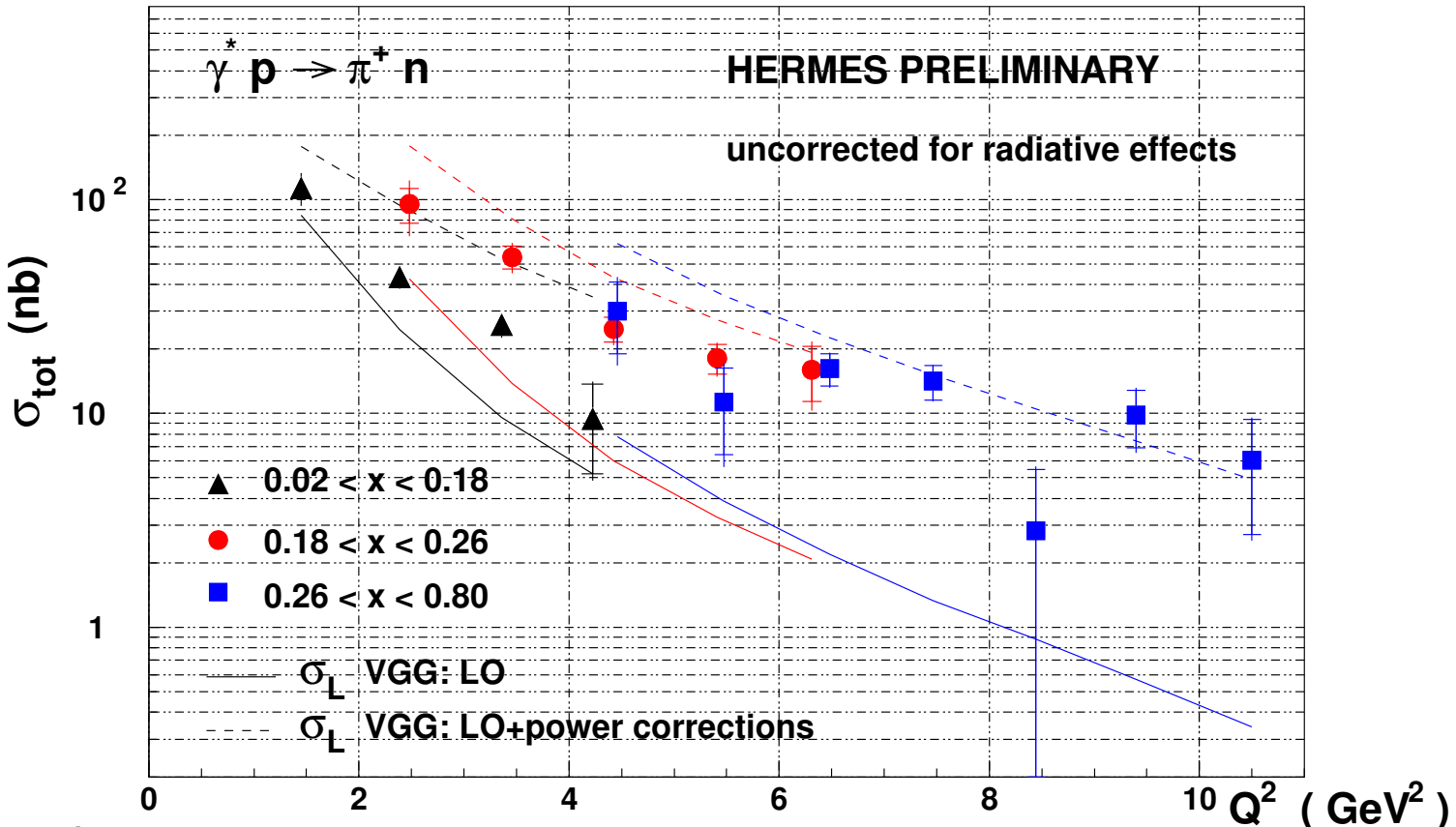
Extracting a Cross Section

- Acceptance correction is model dependent, therefore a comparison with 2 different GPD models was made
- Detection probability has to be taken into account



σ_{tot} : Q^2 dependence in x bins: $\sim (\tilde{H} + \tilde{E})^2$

- Q^2 behavior with respect to $\sigma_L - \sigma_T$



- Q^2 dependence is consistent with LO expectations, however Vanderhaeghen, Guidal, Guichon model too small
- Power corrections (k_T, soft overlap) overestimate data

Testing factorisation theorem predictions σ_{red}

- Factorization theorem predicts a $\frac{1}{Q^6}$ dependence for σ_L at fixed x and t

Testing factorisation theorem predictions σ_{red}

- Factorization theorem predicts a $\frac{1}{Q^6}$ dependence for σ_L at fixed x and t
- Cross Section can be written as

$$\sigma = \underbrace{\frac{1}{16\pi}\frac{x^2}{1-x}\frac{1}{Q^4}\frac{1}{\sqrt{1+\frac{4m^2x^2}{Q^2}}}}_{\text{Kinematical Factor}} \sum_{\text{spin}} |\mathcal{A}(\gamma^* p \to pM)|^2$$

Testing factorisation theorem predictions σ_{red}

- Factorization theorem predicts a $\frac{1}{Q^6}$ dependence for σ_L at fixed x and t
- Cross Section can be written as

$$\sigma = \underbrace{\frac{1}{16\pi}\frac{x^2}{1-x}\frac{1}{Q^4}\frac{1}{\sqrt{1+\frac{4m^2x^2}{Q^2}}}}_{\text{Kinematical Factor}} \underbrace{\sum_{\text{spin}} |\mathcal{A}(\gamma^* p \to pM)|^2}_{\sigma_{reduced}}$$

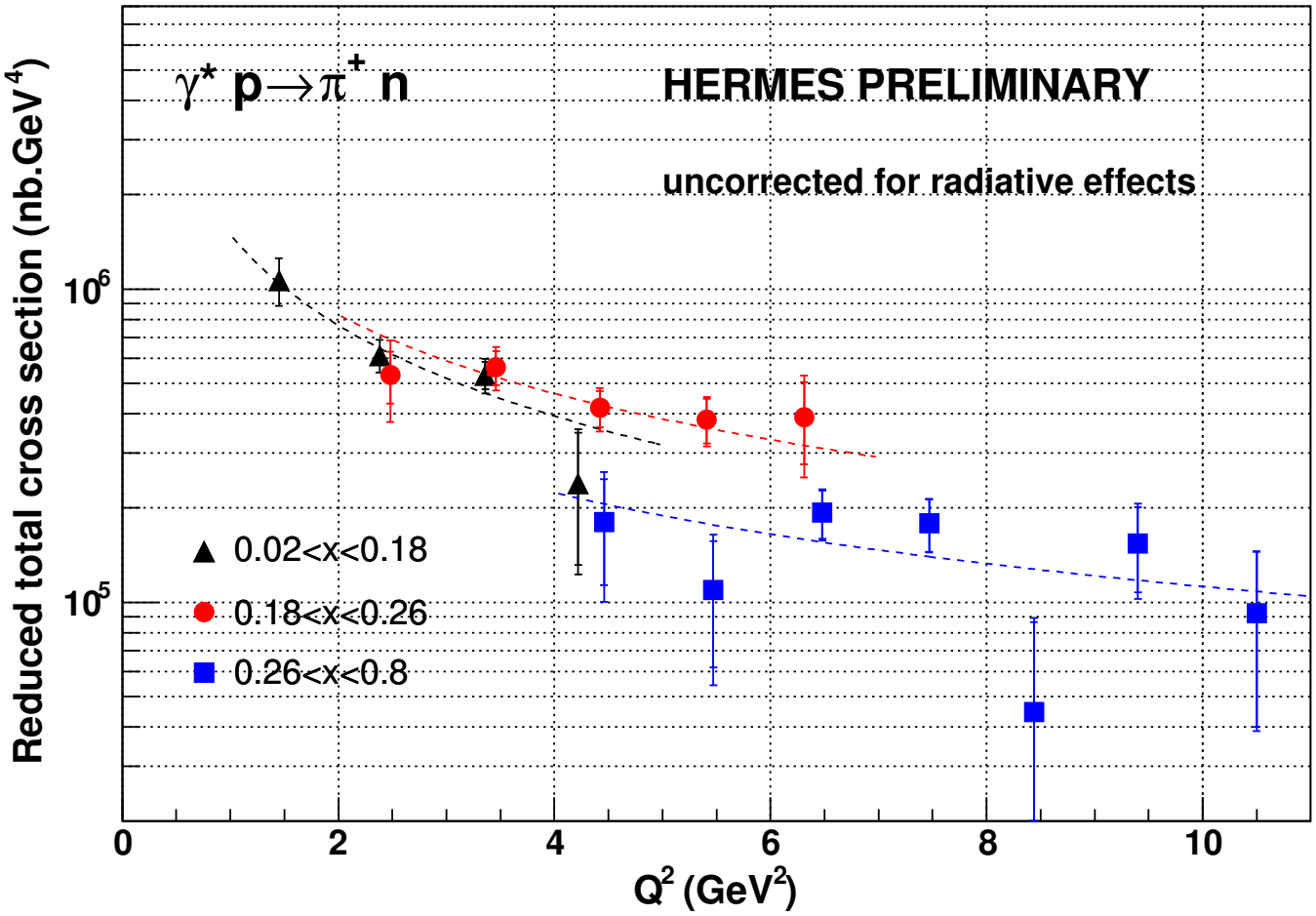
Testing factorisation theorem predictions σ_{red}

- Factorization theorem predicts a $\frac{1}{Q^6}$ dependence for σ_L at fixed x and t
- Cross Section can be written as

$$\sigma = \underbrace{\frac{1}{16\pi}\frac{x^2}{1-x}\frac{1}{Q^4}\frac{1}{\sqrt{1+\frac{4m^2x^2}{Q^2}}}}_{\text{Kinematical Factor}} \underbrace{\sum_{\text{spin}} |\mathcal{A}(\gamma^* p \to pM)|^2}_{\sigma_{reduced}}$$

pure γ_L^* + LO $\Rightarrow$ d$\sigma_{\mathrm{red}} \sim \frac{1}{Q^2}$

Testing factorisation theorem predictions σ_{red}



Fit To data of a $\frac{1}{Q^p}$ function:

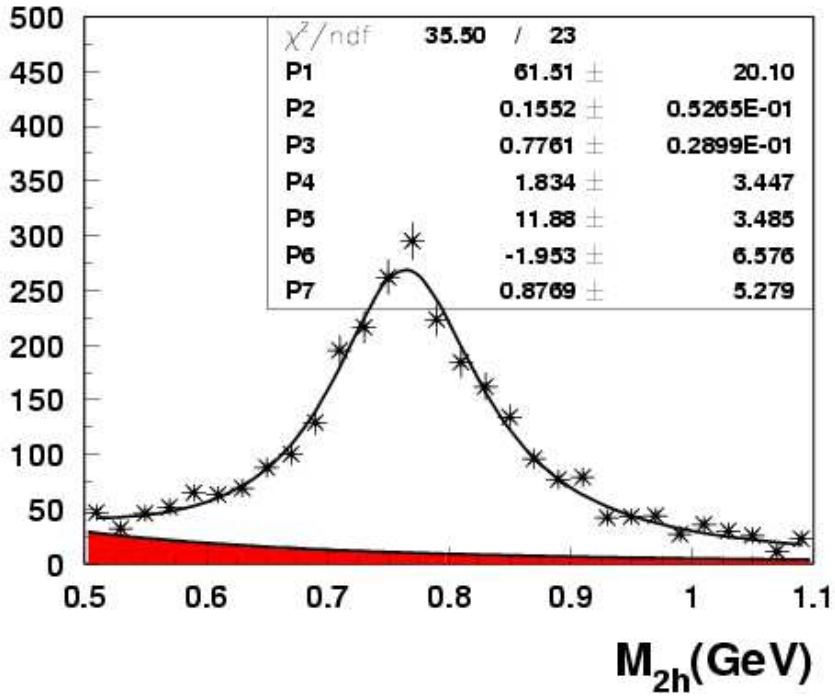
$p = 1.9 \pm 0.5$ $p = 1.7 \pm 0.6$ $p = 1.5 \pm 1.0$

Vector Mesons

$\Rightarrow$ *Probe E and H*

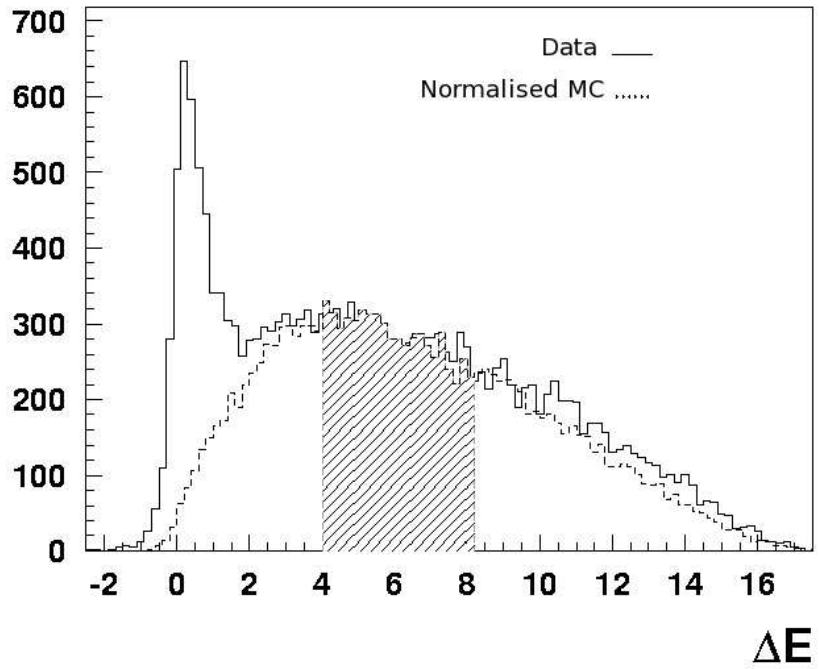
$e+ p \rightarrow e + p + \rho^0$

- ρ^0 reconstructed from h^+h^- pairs
- Exclusivity constraints by requiring *Missing Energy* ΔE to be 0, describe background shape by MC
- Evidence of exclusive ρ^0 production



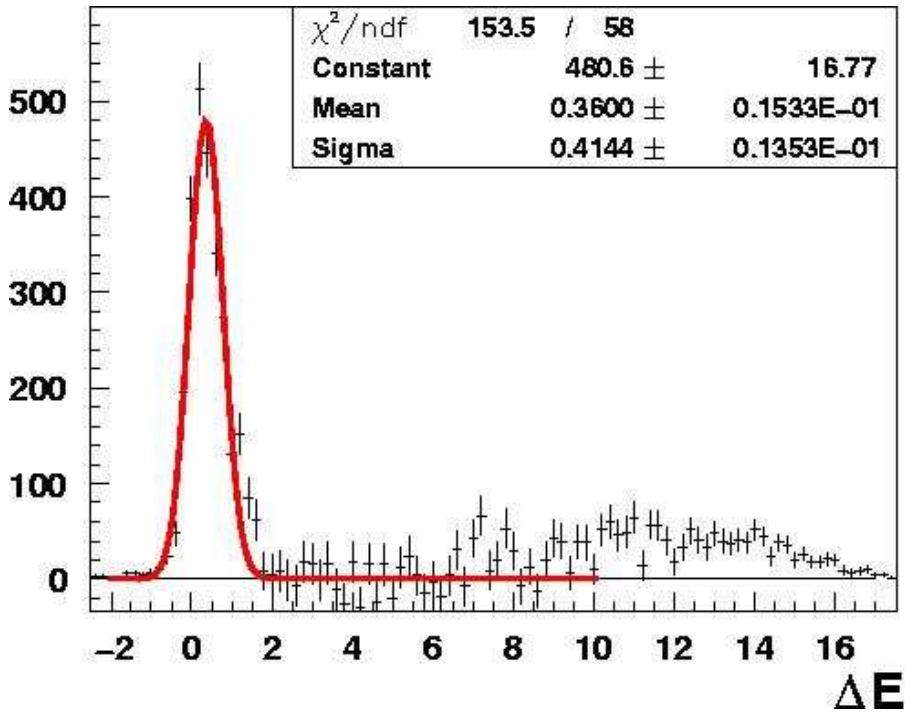
$e+ p \rightarrow e + p + \rho^0$

- ρ^0 reconstructed from h^+h^- pairs
- Exclusivity constraints by requiring *Missing Energy* ΔE to be 0, describe background shape by MC
- Evidence of exclusive ρ^0 production



$e+ p \rightarrow e + p + \rho^0$

- ρ^0 reconstructed from h^+h^- pairs
- Exclusivity constraints by requiring *Missing Energy* ΔE to be 0, describe background shape by MC
- Evidence of exclusive ρ^0 production

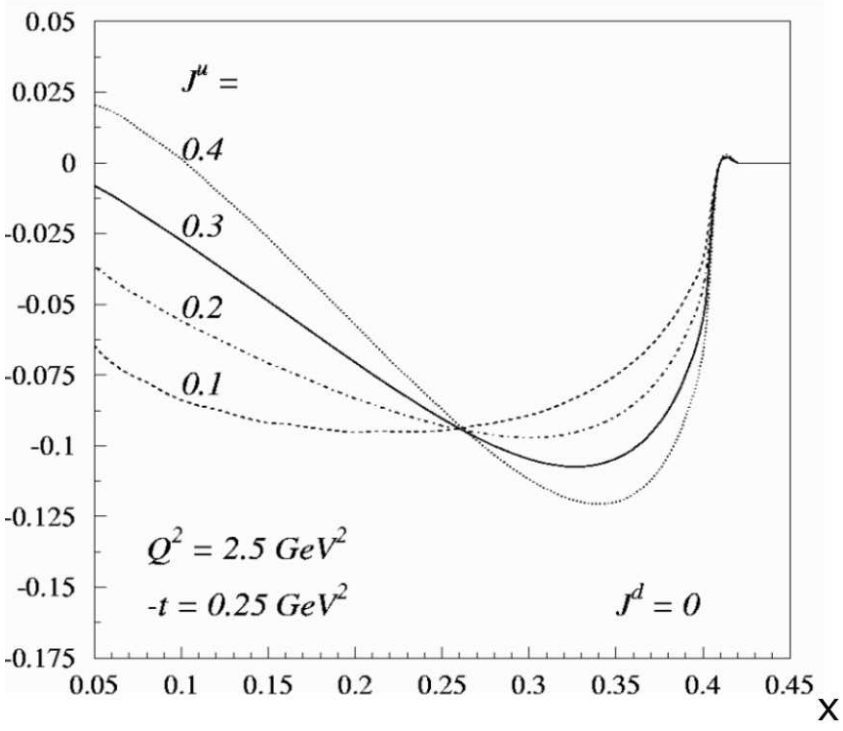


Target Spin Asymmetry A_{UT} for e+ p $\rightarrow$ e + p + ρ^0

$$\mathcal{A} = \frac{1}{|S_\perp|} \frac{\int_0^\pi \sigma(\beta)\mathrm{d}\beta - \int_\pi^{2\pi} \sigma(\beta)\mathrm{d}\beta}{\int_0^{2\pi} \sigma(\beta)\mathrm{d}\beta}$$

- Sensitivity to J^u
- At Hermes asymmetry slope predicted to be positive

Goeke et al., Prog. Part. Nucl. Phys. 47 (2001)

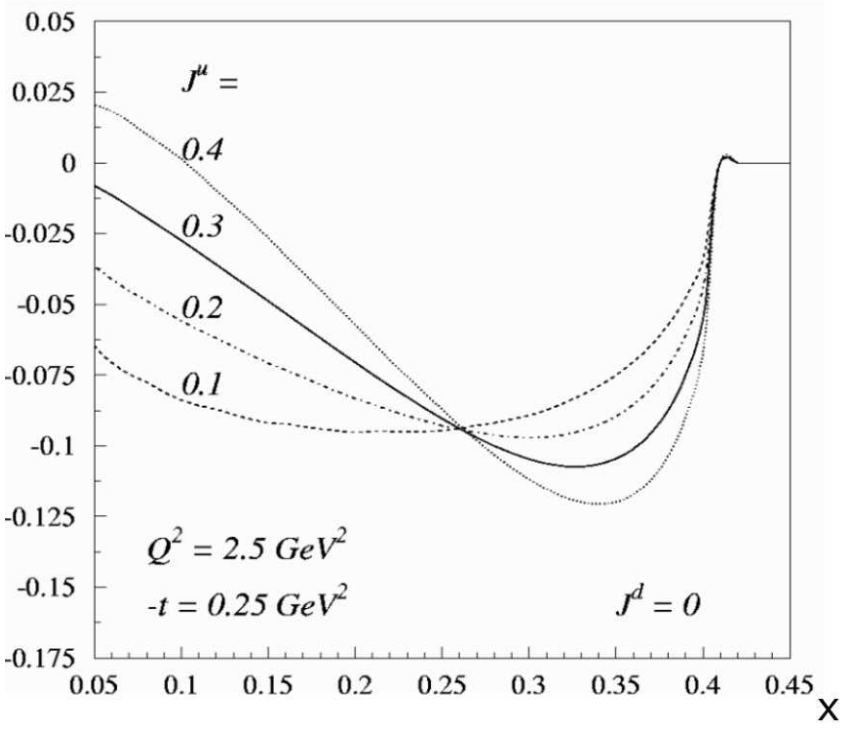


Target Spin Asymmetry A_{UT} for e+ p $\rightarrow$ e + p + ρ^0

$$\mathcal{A} = \frac{1}{|S_\perp|} \frac{\int_0^\pi \sigma(\beta)\mathrm{d}\beta - \int_\pi^{2\pi} \sigma(\beta)\mathrm{d}\beta}{\int_0^{2\pi} \sigma(\beta)\mathrm{d}\beta}$$

- Sensitivity to J^u
- At Hermes asymmetry slope predicted to be positive

Goeke et al., Prog. Part. Nucl. Phys. 47 (2001)



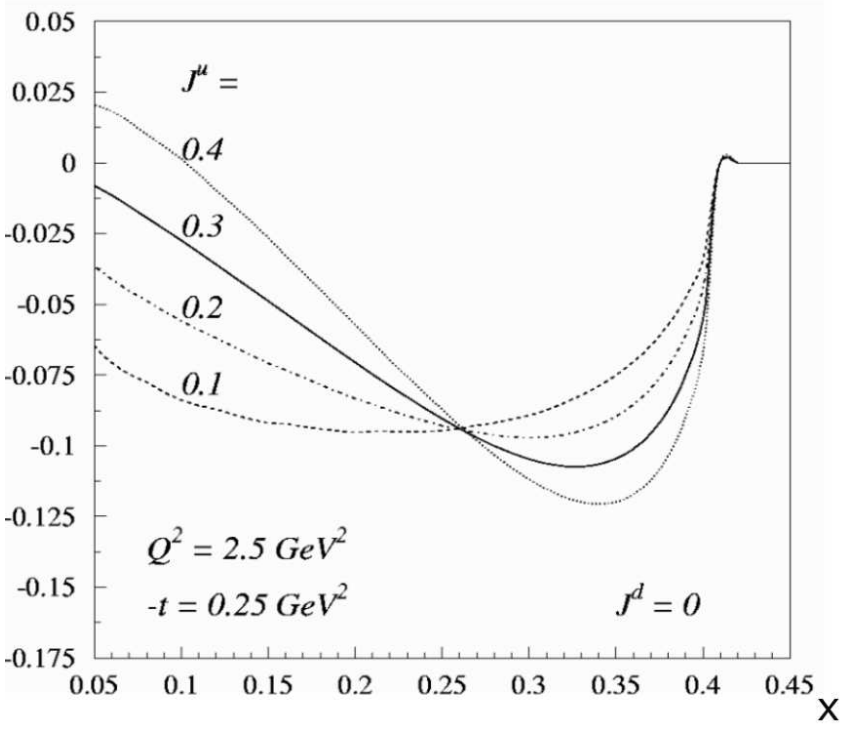
sin($\phi - \phi_S$) amplitude of asymmetry: $A_{UT}^{\sin(\phi-\phi_S)} \sim -\mathcal{A} \propto E \cdot H$

Target Spin Asymmetry A_{UT} for e+ p $\rightarrow$ e + p + ρ^0

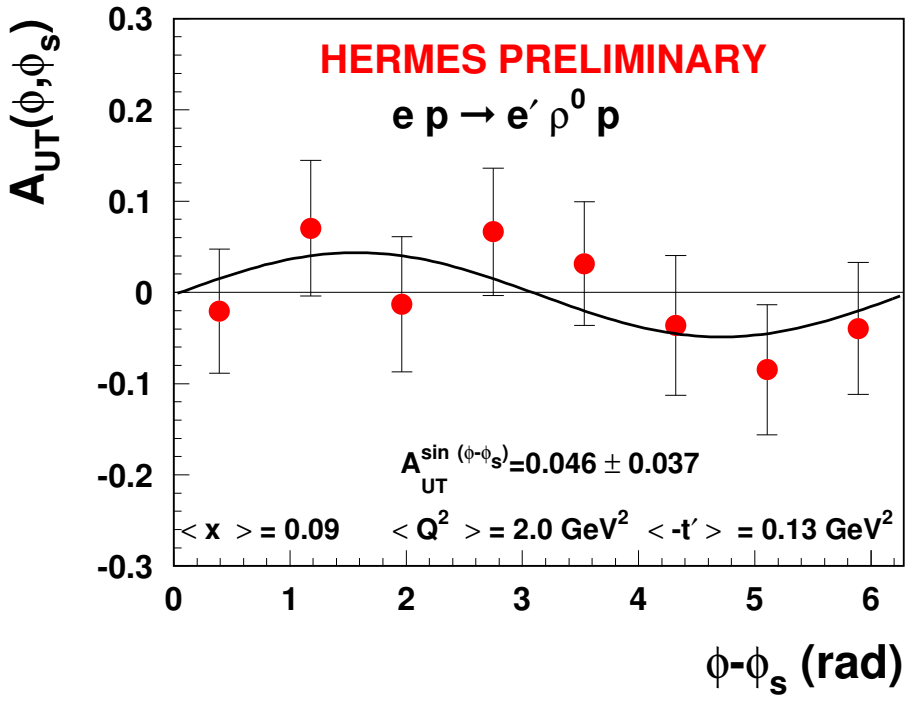
$$\mathcal{A} = \frac{1}{|S_\perp|} \frac{\int_0^\pi \sigma(\beta)\mathrm{d}\beta - \int_\pi^{2\pi} \sigma(\beta)\mathrm{d}\beta}{\int_0^{2\pi} \sigma(\beta)\mathrm{d}\beta}$$

- Sensitivity to J^u
- At Hermes asymmetry slope predicted to be positive

Goeke et al., Prog. Part. Nucl. Phys. 47 (2001)

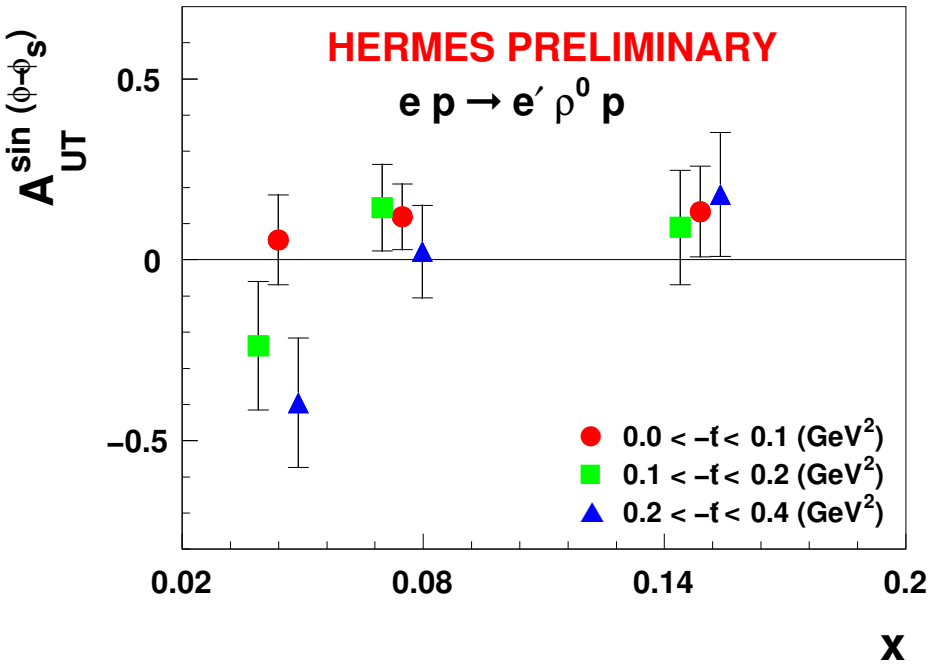


A_{UT} for exclusive ρ^0 production



- Increasing statistics by including all transverse data will allow for an $\sigma_L - \sigma_T$ separation

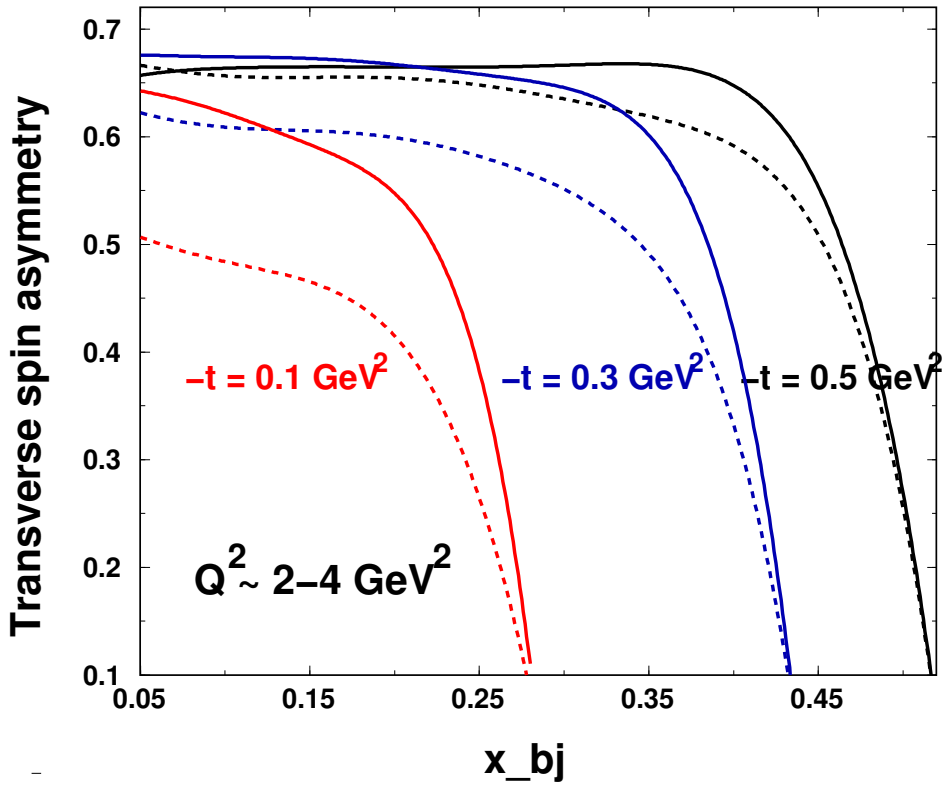
A_{UT} for exclusive ρ^0 production



- Increasing statistics by including all transverse data will allow for an $\sigma_L - \sigma_T$ separation
- Data consistent with theory predictions

Stay Tuned !

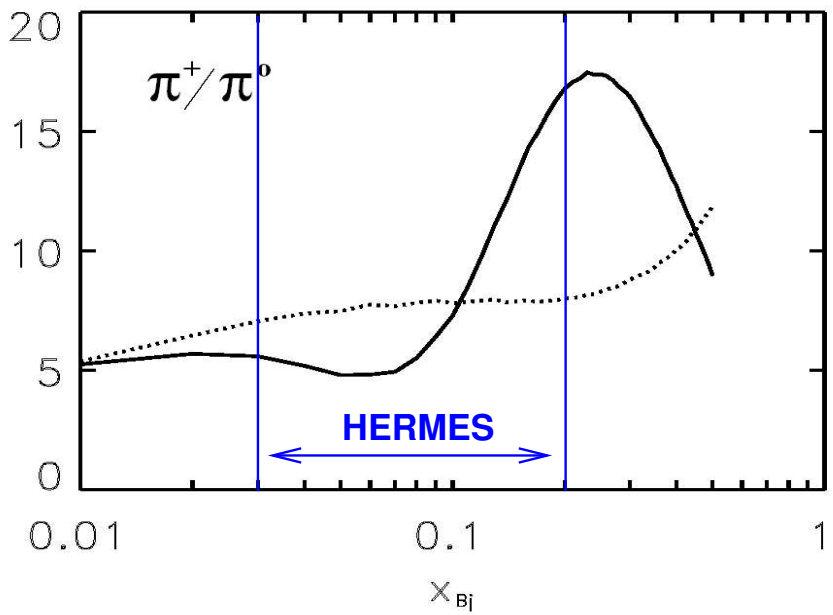
- Transverse Target Asymmetry for exclusive π^+
  - Theoretical prediction – Frankfurt et Al., Phys. Rev. D60 (1999), 2 models with different pion form factor
  - Data under analysis !



Stay Tuned !

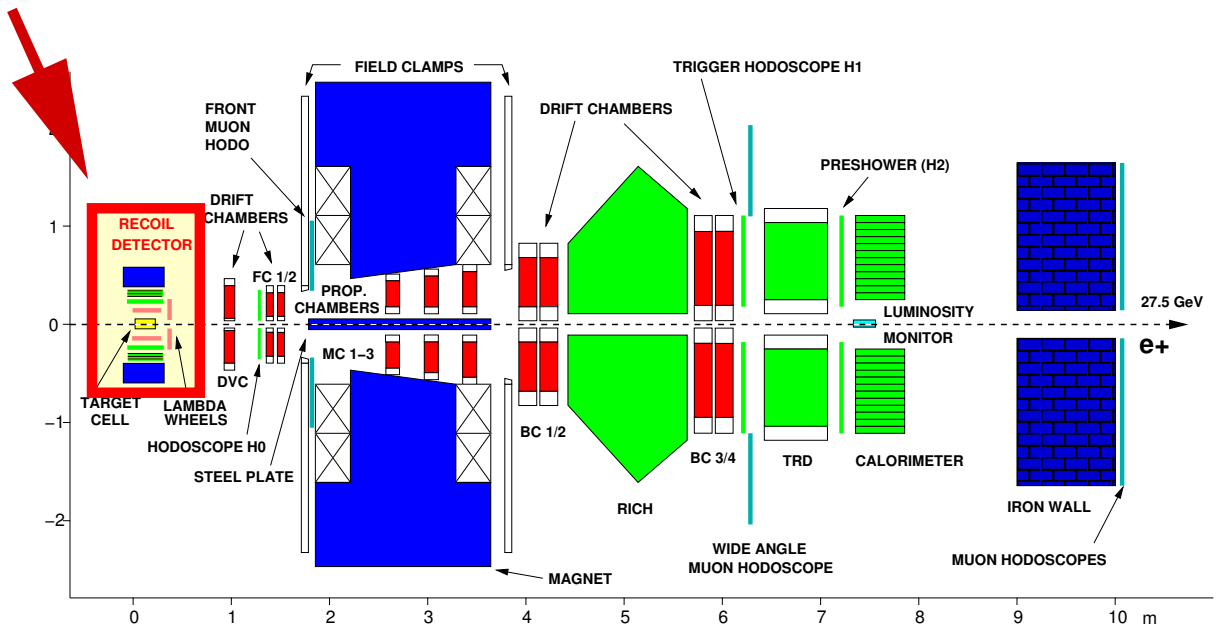
- Transverse Target Asymmetry for exclusive π^+
- Exclusive π^0 production analysis ongoing
  - no pion-pole contribution
  - information about $\tilde{H}$ only

Mankiewicz et. al.
Eur. Phys. J. C10 (1999)



Stay Tuned !

- Transverse Target Asymmetry for exclusive π^+
- Exclusive π^0 production analysis ongoing
- A Recoil Detector surrounding the target cell is currently being commissioned, and will allow a direct measurement of exclusive reactions.



Summary

1. Factorization theorem for hard exclusive processes allows GPD's to be probed
2. DVCS probes the GPD's H and E via asymmetries
   - BCA and BSA give access to H
   - A_{UT} allows E to be parametrized, giving access to J^q
3. Cross Section for exclusive π^+ production
   - Comparison with GPD based model
   - Q^2 dependence in agreement with theory
4. A_{UT} for exclusive ρ^0 production gives additional constraints on H and E

Summary

1. Factorization theorem for hard exclusive processes allows GPD's to be probed
2. DVCS probes the GPD's H and E via asymmetries
   - BCA and BSA give access to H
   - A_{UT} allows E to be parametrized, giving access to J^u
3. Cross Section for exclusive π^+ production
   - Comparison with GPD based model
   - Q^2 dependence in agreement with theory
4. A_{UT} for exclusive ρ^0 production gives additional constraints on H and E

Summary

1. Factorization theorem for hard exclusive processes allows GPD's to be probed
2. DVCS probes the GPD's H and E via asymmetries
   - BCA and BSA give access to H
   - A_{UT} allows E to be parametrized, giving access to J^u
3. Cross Section for exclusive π^+ production
   - Comparison with GPD based model
   - Q^2 dependence in agreement with theory
4. A_{UT} for exclusive ρ^0 production gives additional constraints on H and E

Summary

1. Factorization theorem for hard exclusive processes allows GPD's to be probed
2. DVCS probes the GPD's H and E via asymmetries
   - BCA and BSA give access to H
   - A_{UT} allows E to be parametrized, giving access to J^u
3. Cross Section for exclusive π^+ production
   - Comparison with GPD based model
   - Q^2 dependence in agreement with theory
4. A_{UT} for exclusive ρ^0 production gives additional constraints on H and E

Summary

1. Factorization theorem for hard exclusive processes allows GPD's to be probed
2. DVCS probes the GPD's H and E via asymmetries
   - BCA and BSA give access to H
   - A_{UT} allows E to be parametrized, giving access to J^u
3. Cross Section for exclusive π^+ production
   - Comparison with GPD based model
   - Q^2 dependence in agreement with theory
4. A_{UT} for exclusive ρ^0 production gives additional constraints on H and E

Last Word:

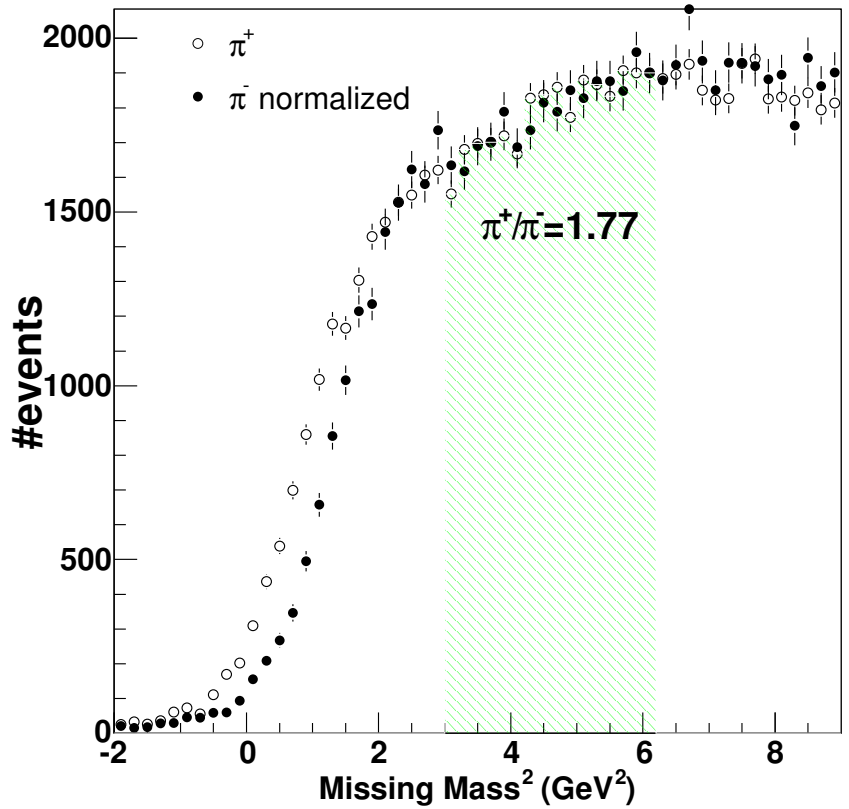
Thanks for Listening !

$$e + p \rightarrow e + X + \pi^+$$

- $M_X^2 = (P_e + P_p - (P_{e'} + P_h))^2$ doesn't allow separation of exclusive events from the non-exclusive background

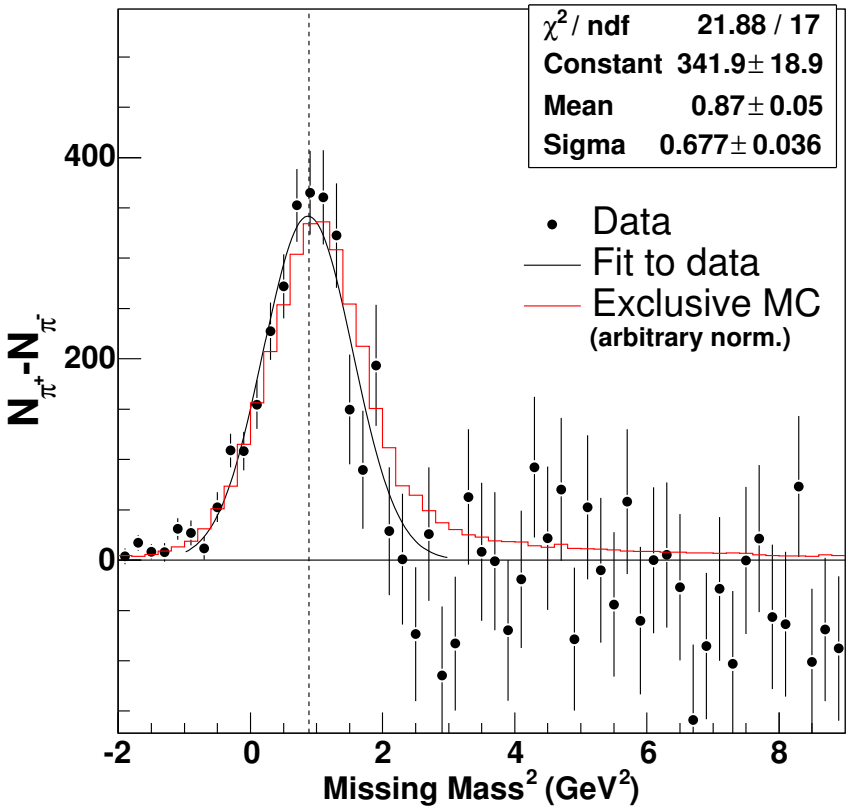
$e + p \rightarrow e + X + \pi^+$

- $M_X^2 = (P_e + P_p - (P_{e'} + P_h))^2$ doesn't allow separation of exclusive events from the non-exclusive background
- Solution: Use the normalised π^- yield as an estimate for the background ($e + p \not\rightarrow e + n + \pi^-$).

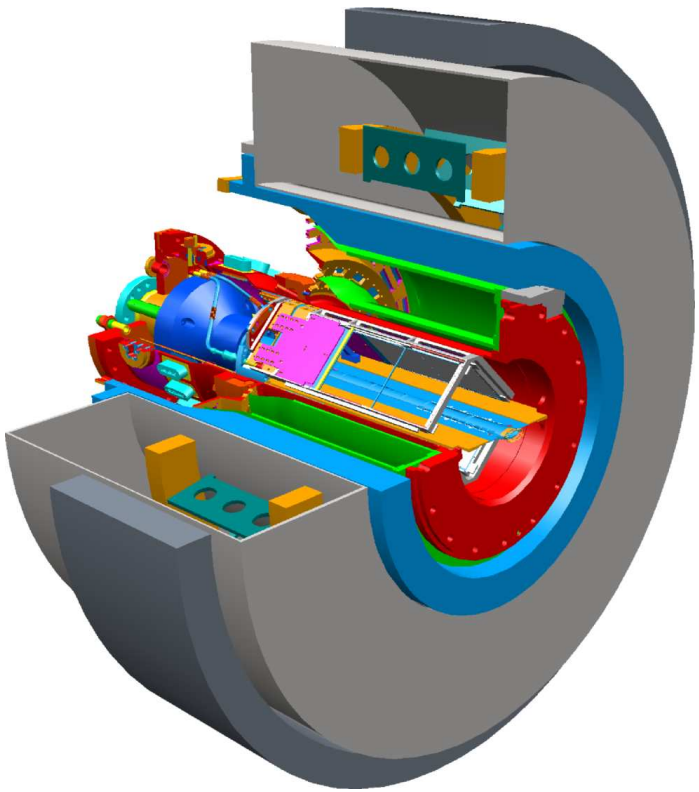


$e + p \rightarrow e + n + \pi^+$

- $M_X^2 = (P_e + P_p - (P_{e'} + P_h))^2$ doesn't allow separation of exclusive events from the non-exclusive background
- Solution: Use the normalised π^- yield as an estimate for the background ($e + p \not\rightarrow e + n + \pi^-$).
- Exclusive Peak at nucleon mass, mean and width like exclusive Monte Carlo, based on a GPD model



A Recoil Detector for HERMES



- Silicon measuring low momenta protons
- SciFi for momentum and tracking
- Photon detector to improve exclusivity
- Superconducting Magnet providing field for SciFi
- A new collimator to reduce background hits