Exclusive Meson Production at hermes

Riccardo Fabbri

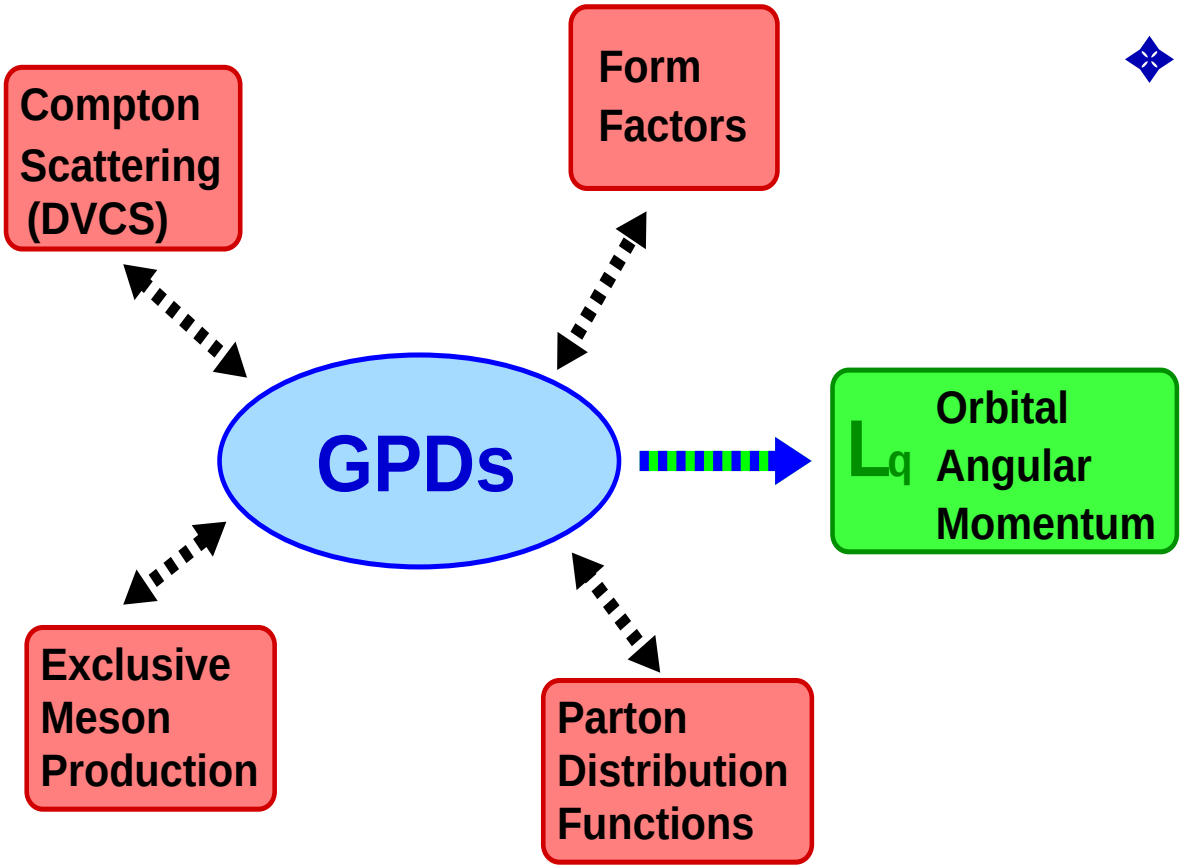
on behalf of the *HERMES* Collaboration

SIR 2005

JLab, May 2005

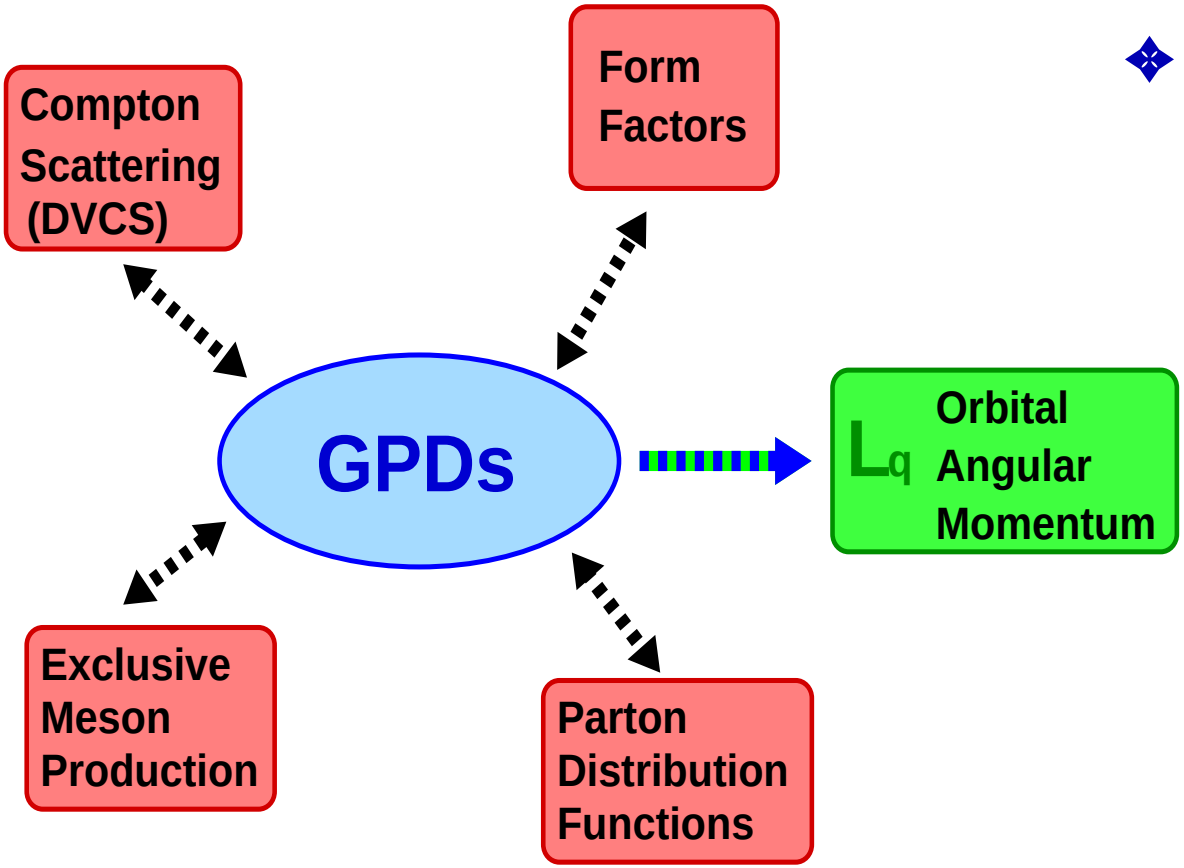
- ✔ Exclusive Reactions and GPDs
- ✔ Exclusive π^+ production
- ✔ Exclusive ρ^0 and ϕ production
- ✔ Exclusive $\pi^+\pi^-$ production
- ✔ Summary and Outlook

Exclusive Reactions & GPDs



- GPDs offer most complete description of quark-gluon structure of hadrons

Exclusive Reactions & GPDs

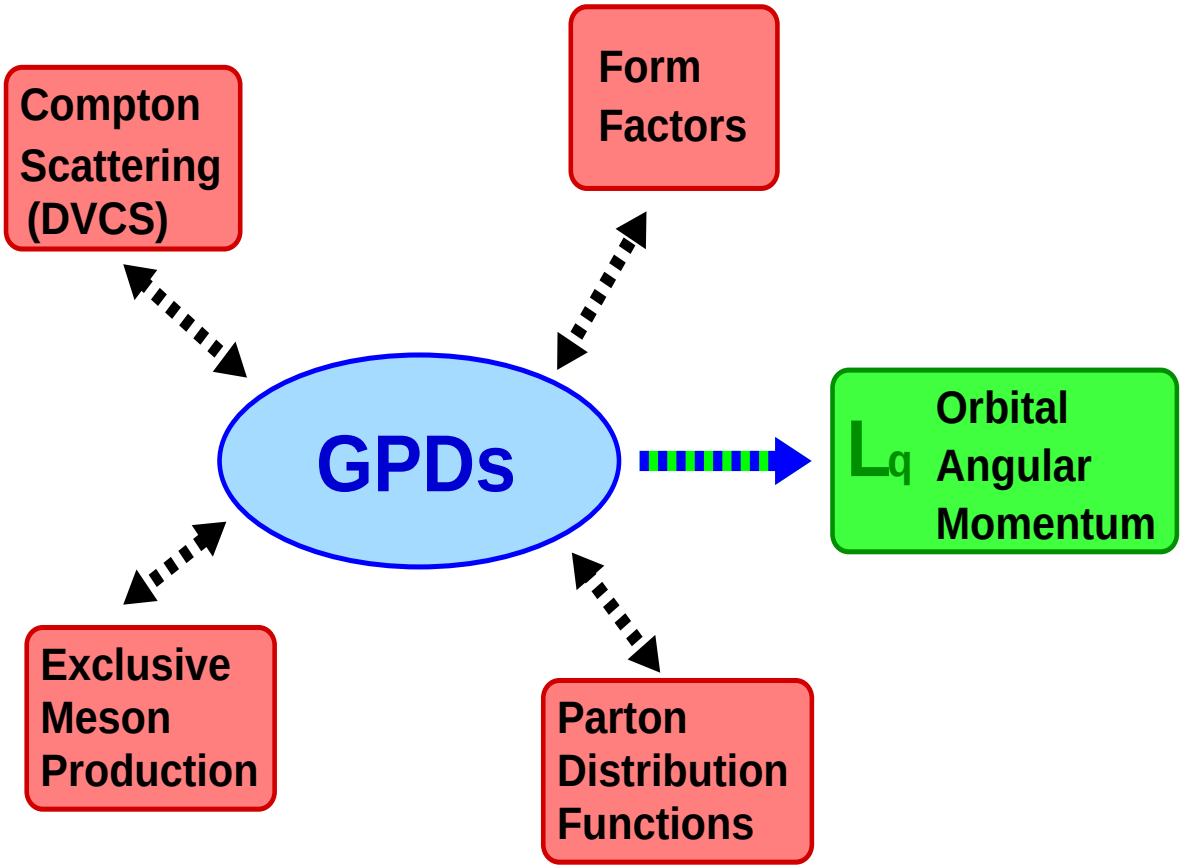


- GPDs offer most complete description of quark-gluon structure of hadrons

Ji sum rule

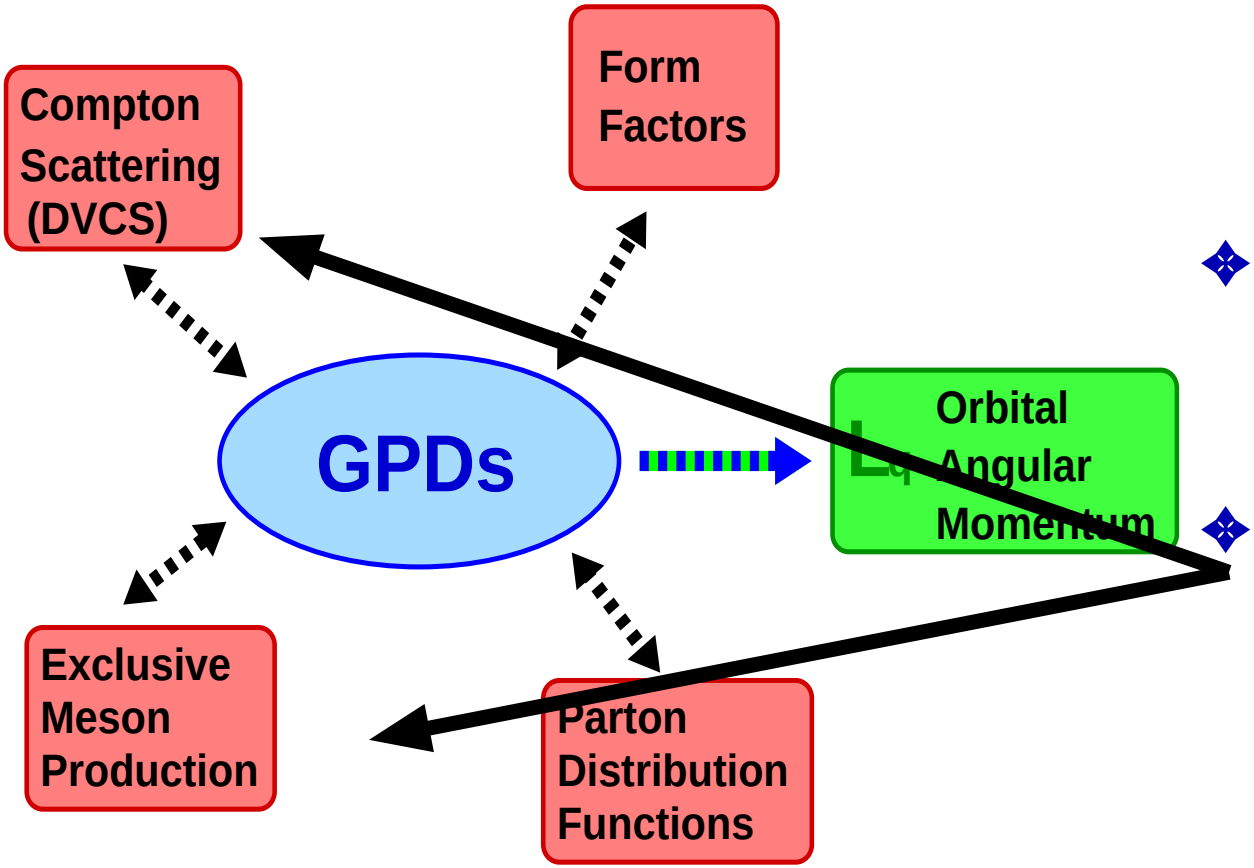
$$J_q = \lim_{t\to 0} \int_{-1}^{+1} x dx \left[H_q(x,\xi,t) + E_q(x,\xi,t) \right]$$

Exclusive Reactions & GPDs



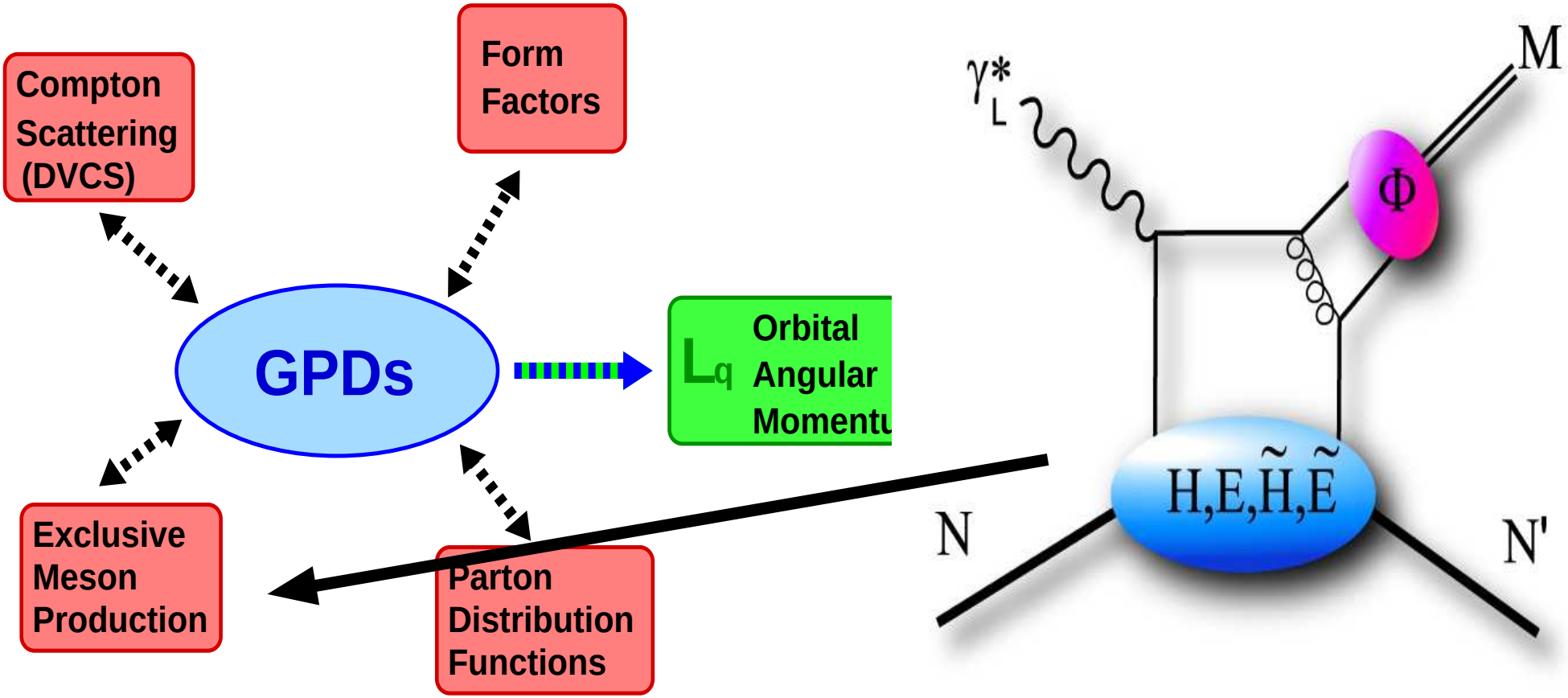
- **Hard Exclusive Processes interpreted in GPD framework!**

Exclusive Reactions & GPDs



- Hard Exclusive Processes interpreted in GPD framework!
- Analysed at HERMES

Exclusive Reactions & GPDs



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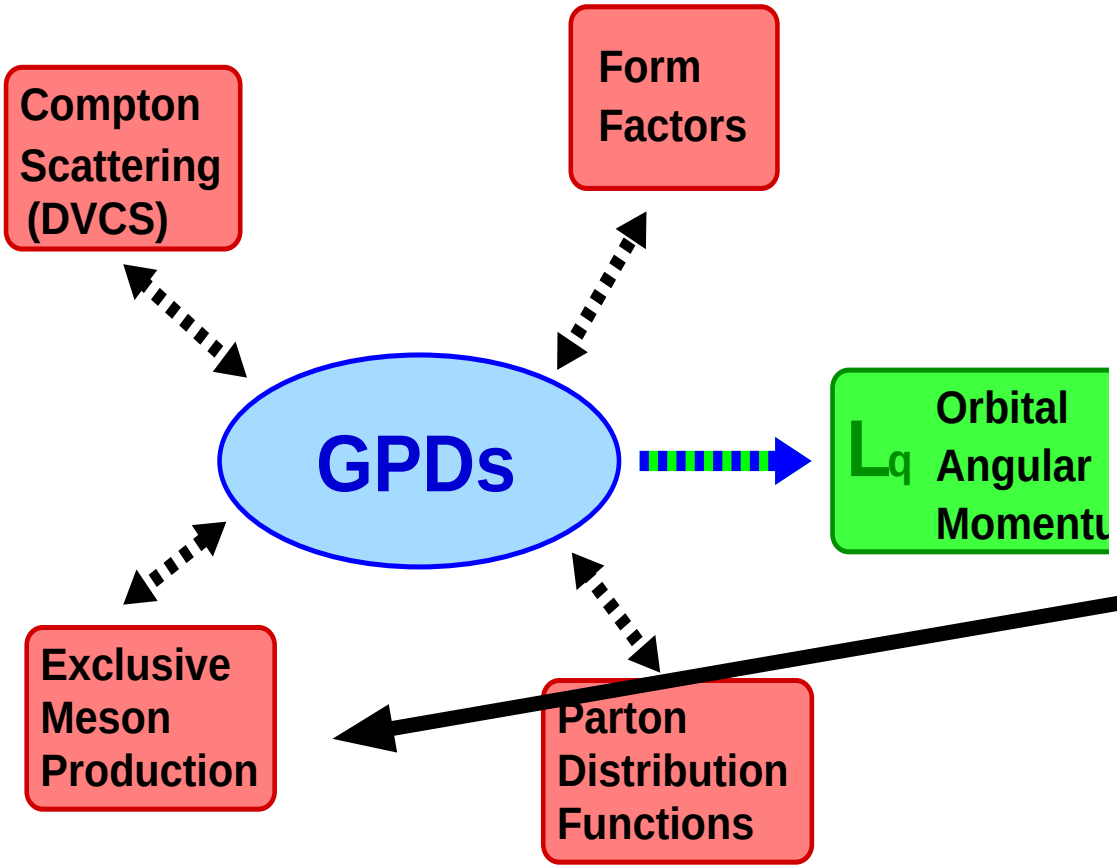
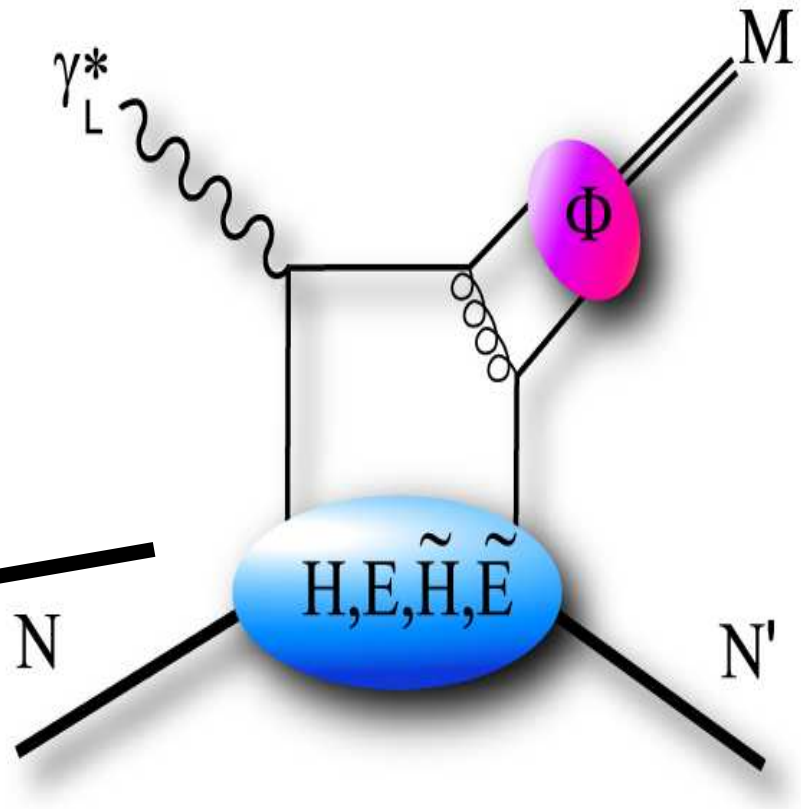




☞ Quantum numbers of final meson state select different $GPDs$

- ❖ **Pseudoscalar mesons ($\pi, \eta \ldots$):** $\tilde{H}, \tilde{E}$
- ❖ **Vector mesons ($\rho, \omega, \phi \ldots$):** H, E **(flavour singlet)**
- ❖ f**-meson family ($f_0, f_2, \ldots$):** H, E **(flavour non-singlet)**

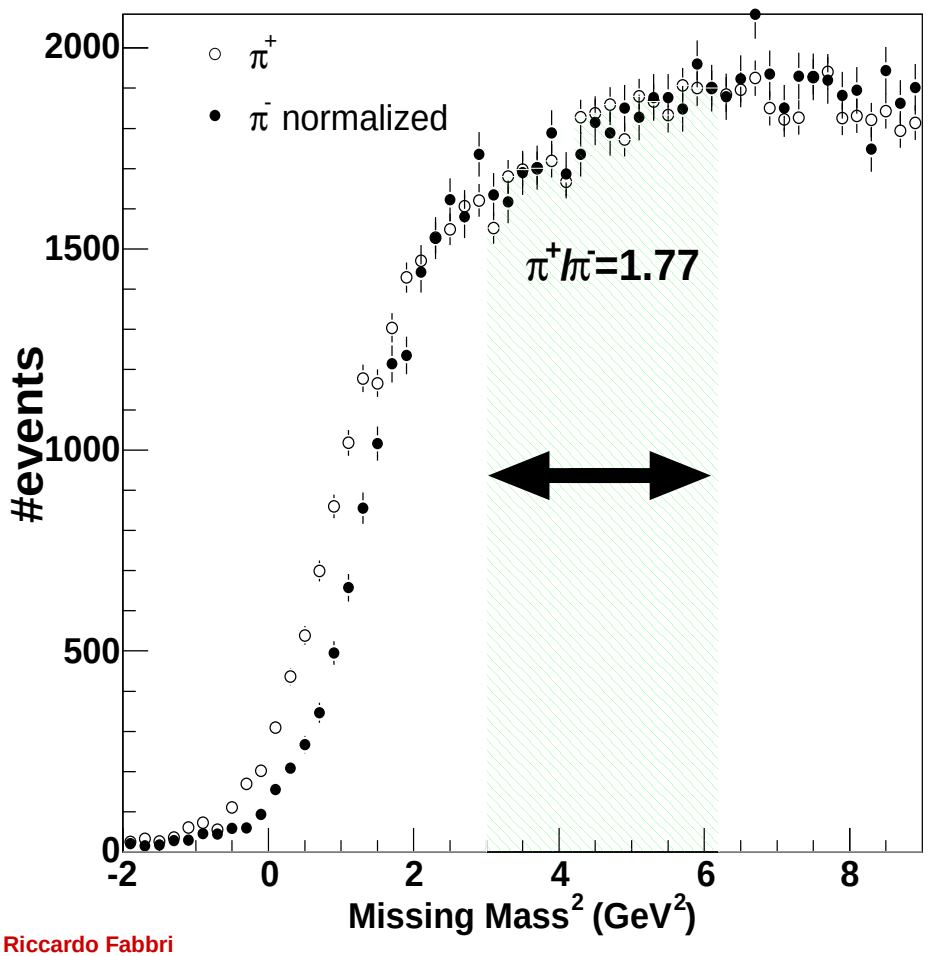
Pseudoscalar Mesons

Sensitivity to $\tilde{H}$ and $\tilde{E}$

Hard Exclusive π^+ Production

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

Extraction of the exclusive sample



- **Detection:** e^+, π^+
- **Recoil neutron reconstructed via Missing Mass**
- **Use of π^- to subtract the non-exclusive bg**

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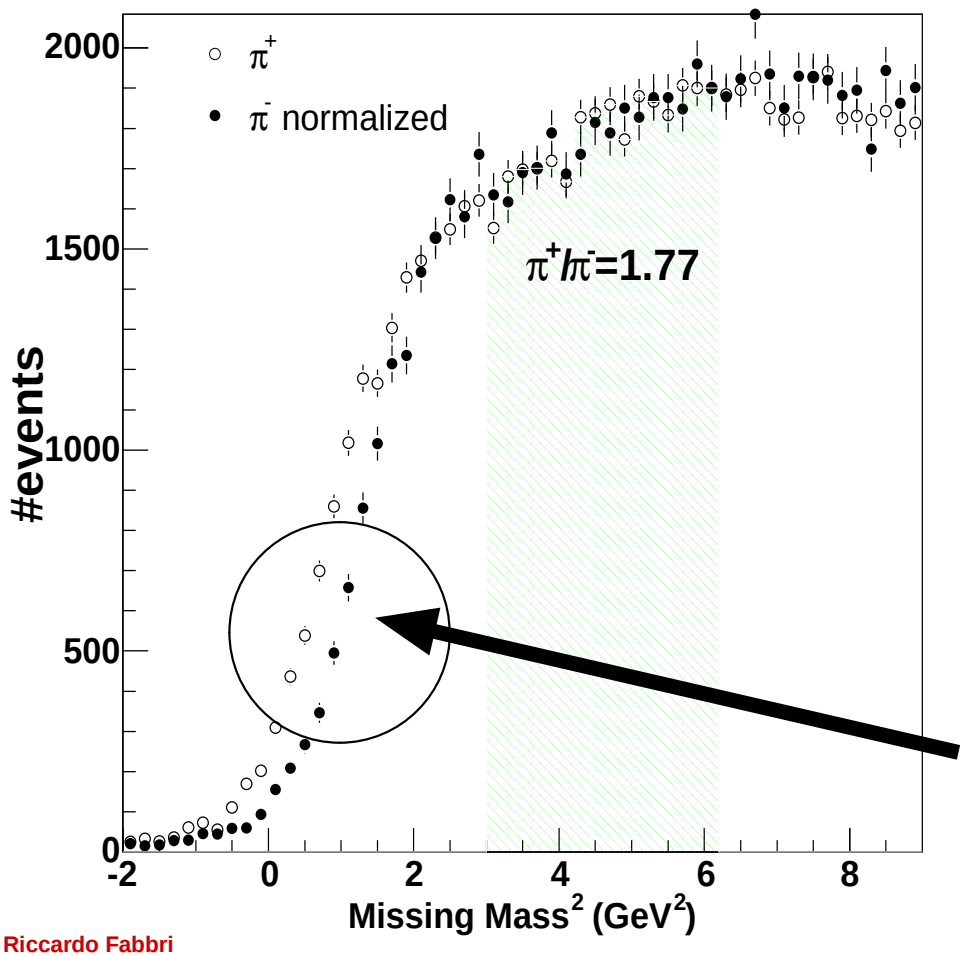


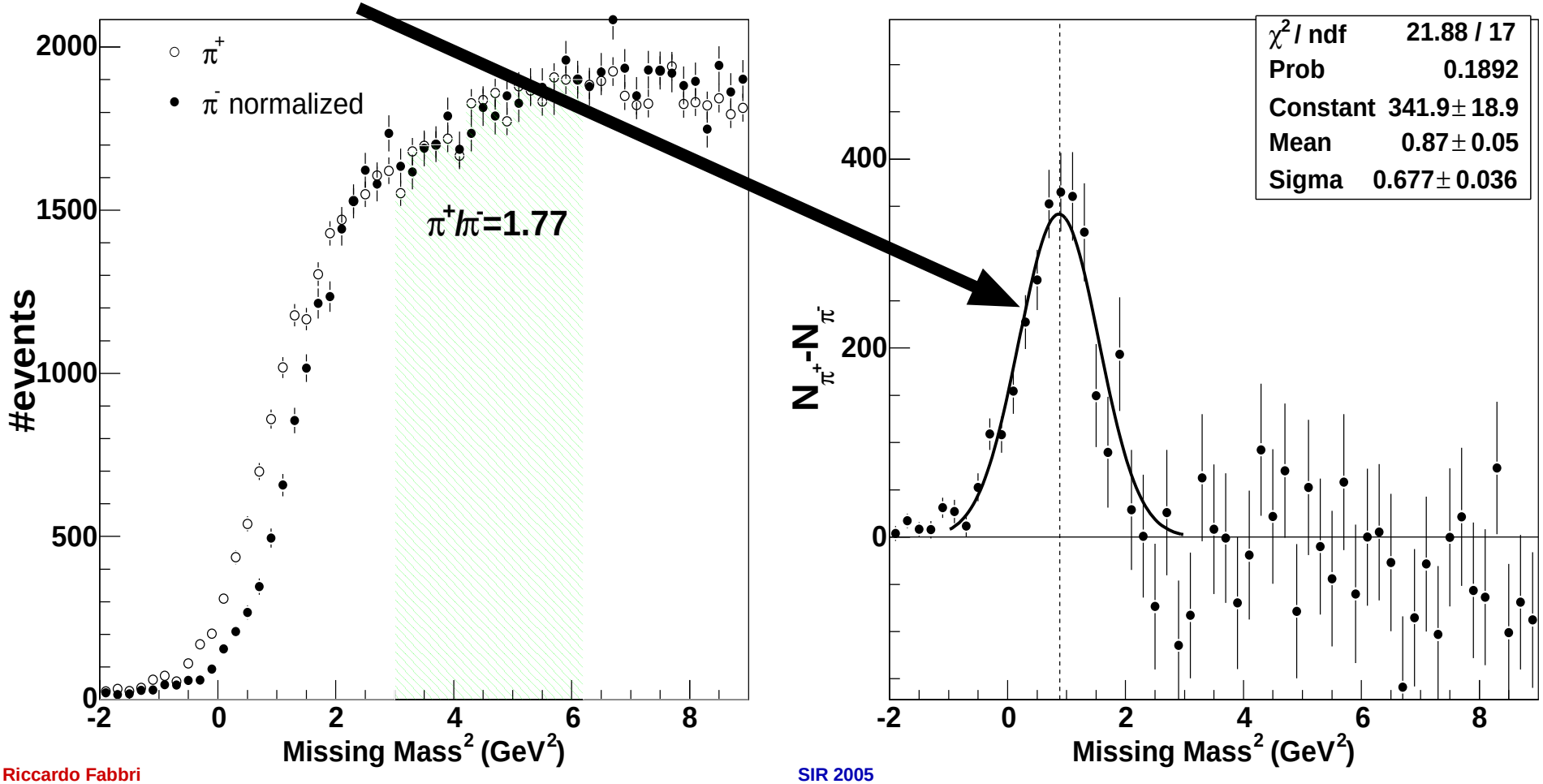
- **Detection:** e^+, π^+
- **Recoil neutron reconstructed via Missing Mass**
- **Use of π^- to subtract the non-exclusive bg**
- **π^+ enhancement**

Hard Exclusive π^+ Production

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

Extraction of the exclusive sample

Exclusive peak clearly centered at the neutron mass



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Measurement of the cross-section: $\sim (\tilde{H} + \tilde{E})^2$

- X_section extracted after proper tuning of exclusive MC in the HERMES acceptance

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$GPDs$ framework

- Vanderhaeghen, Guichon & Guidal (1999) -

in terms of: $\tilde{H}$ & $\tilde{E}$

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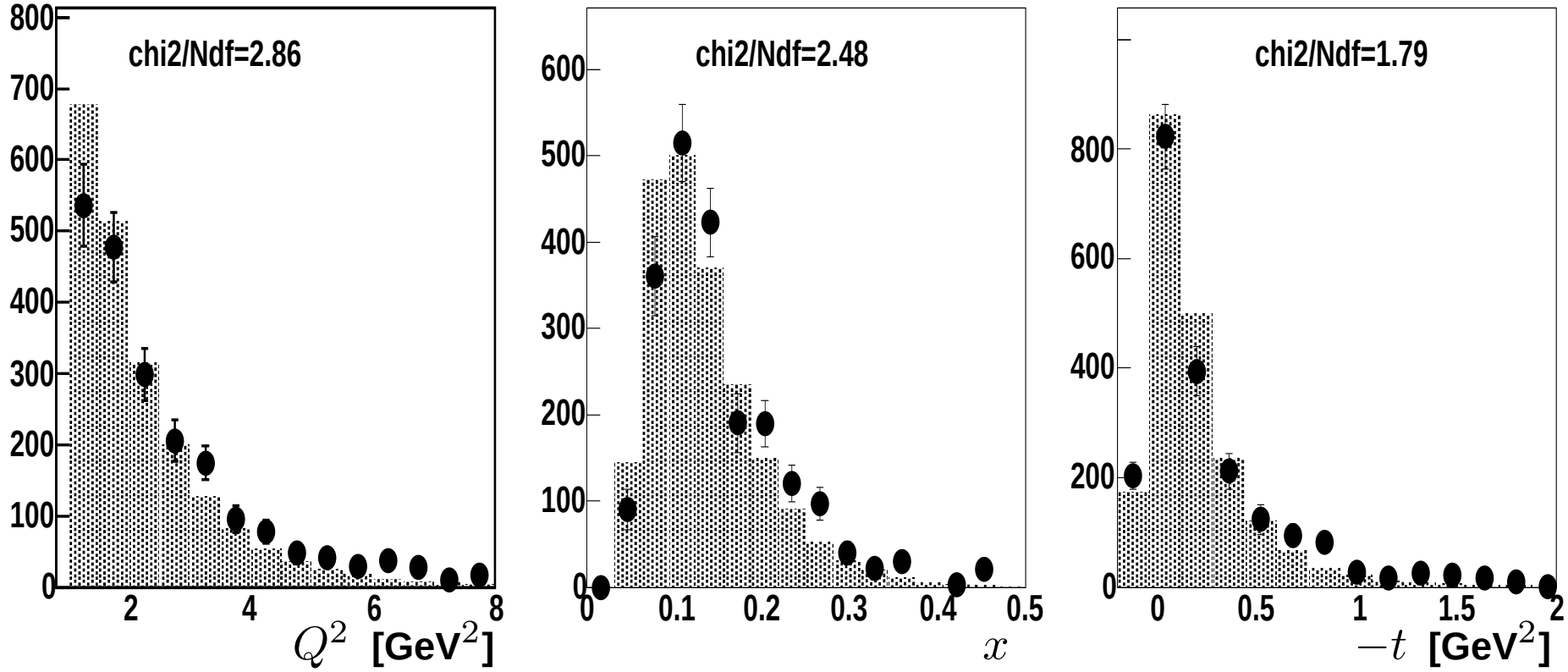

Hard Exclusive π^+ Production

Measurement of the cross-section

$$\sigma^{\gamma^\star p \longrightarrow \pi^+ n}(x, Q^2) = \frac{N_{\pi^+}^{excl}}{L \Delta x \Delta Q^2 \Gamma(x,Q^2) \kappa(x,Q^2)}$$

Hard Exclusive π^+ Production

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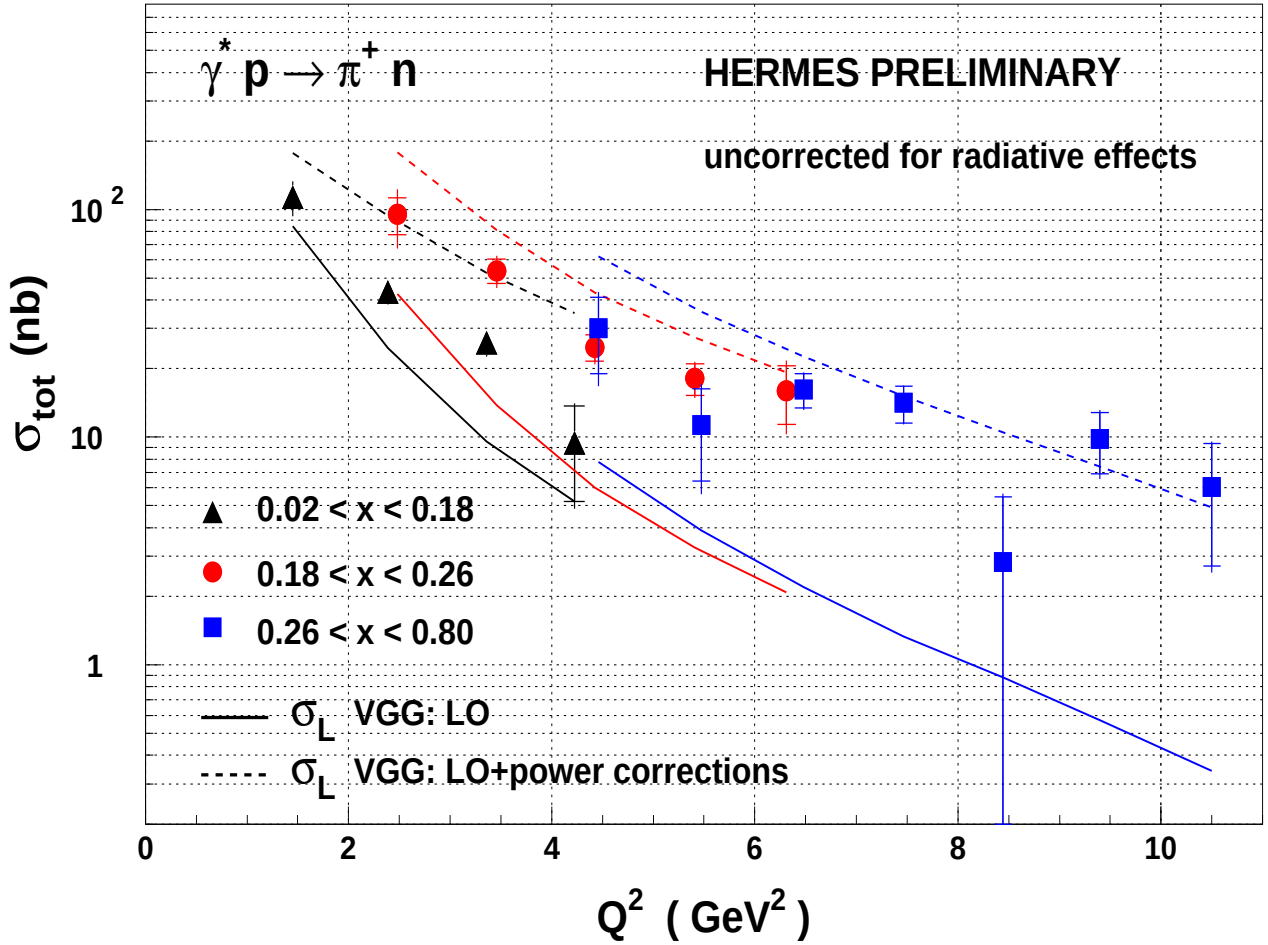

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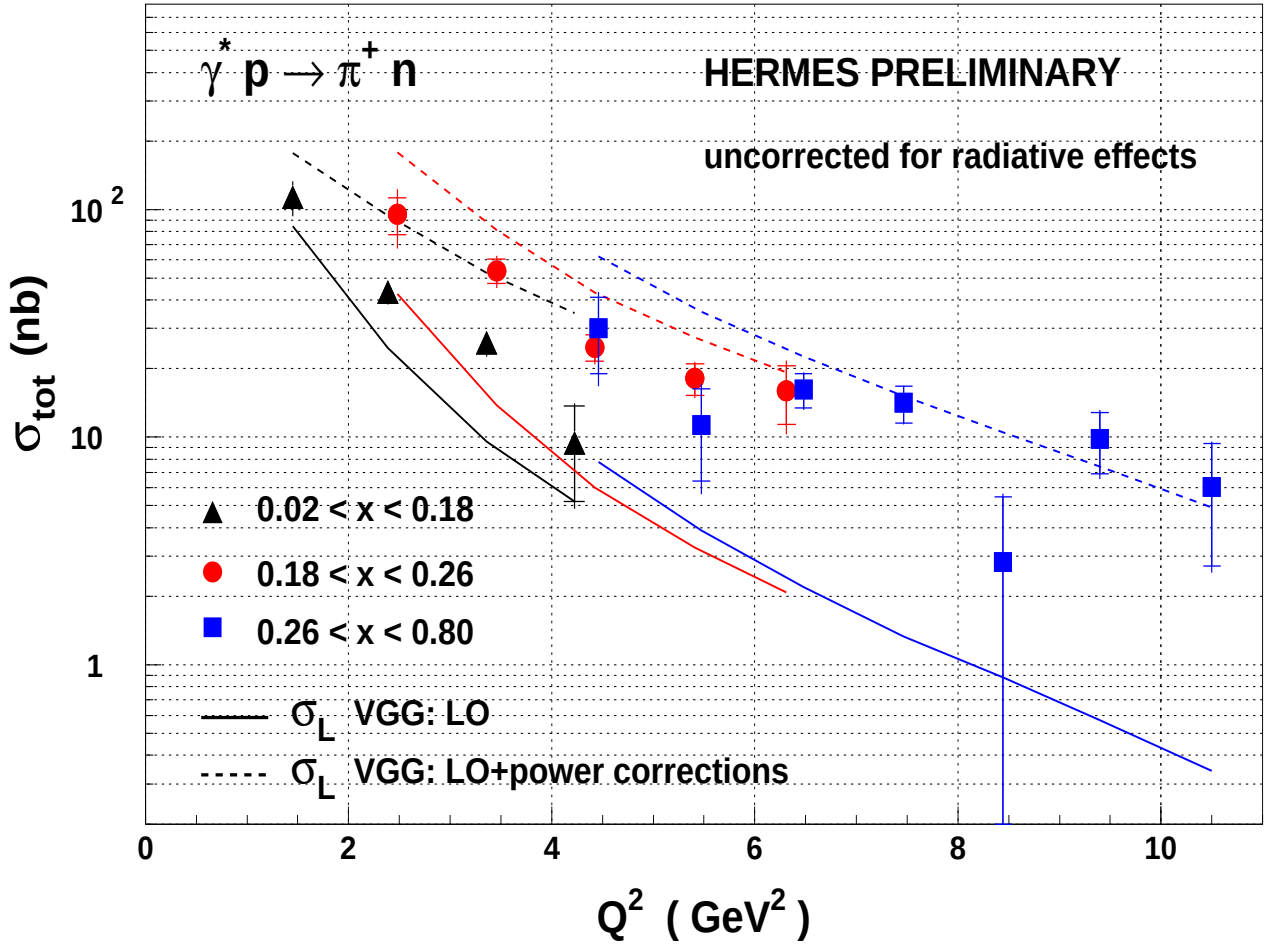
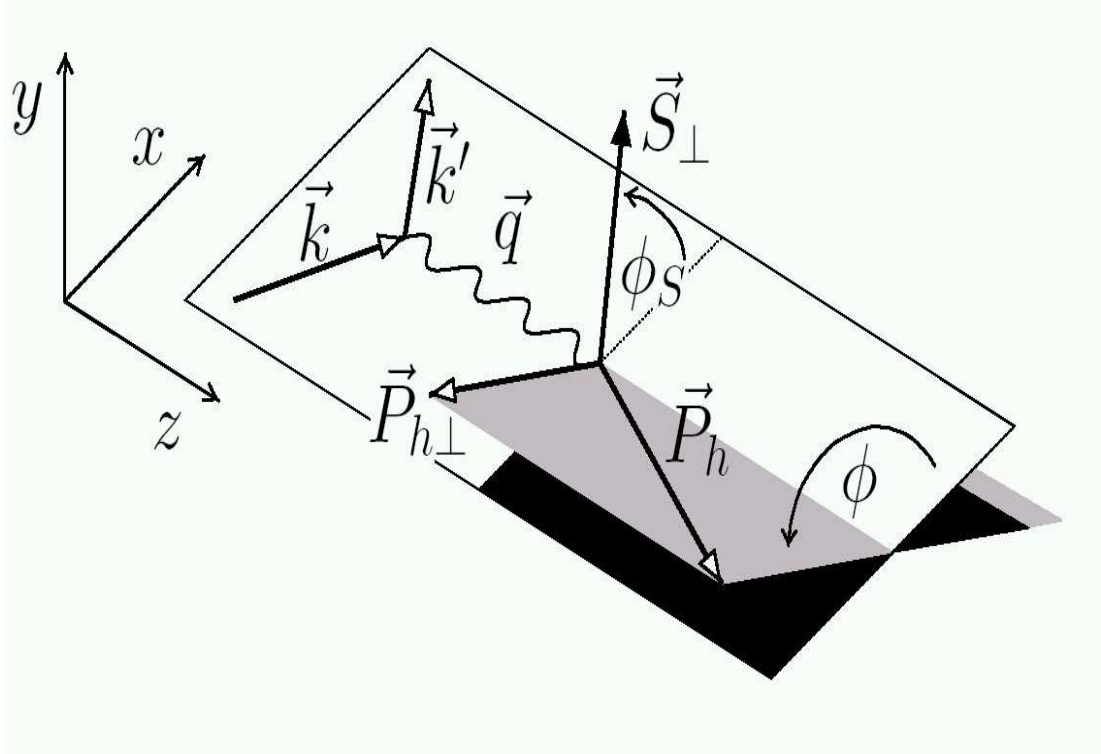


- ☞ Q^2 dependence qualitatively in agreement with the data
- ☞ leading order calculations underestimate data
- ☞ Power correction calculations overestimate the data

Hard Exclusive π^+ Production

Transverse Target Spin Asymmetry: $\sim \tilde{E} \cdot \tilde{H}$

$$A_{UT}(\phi - \phi_S) \propto \frac{N^{\uparrow}_{excl}(\phi-\phi_S) - N^{\downarrow}_{excl}((\phi-\phi_S)}{N^{\uparrow}_{excl}((\phi-\phi_S) + N^{\downarrow}_{excl}((\phi-\phi_S)}$$



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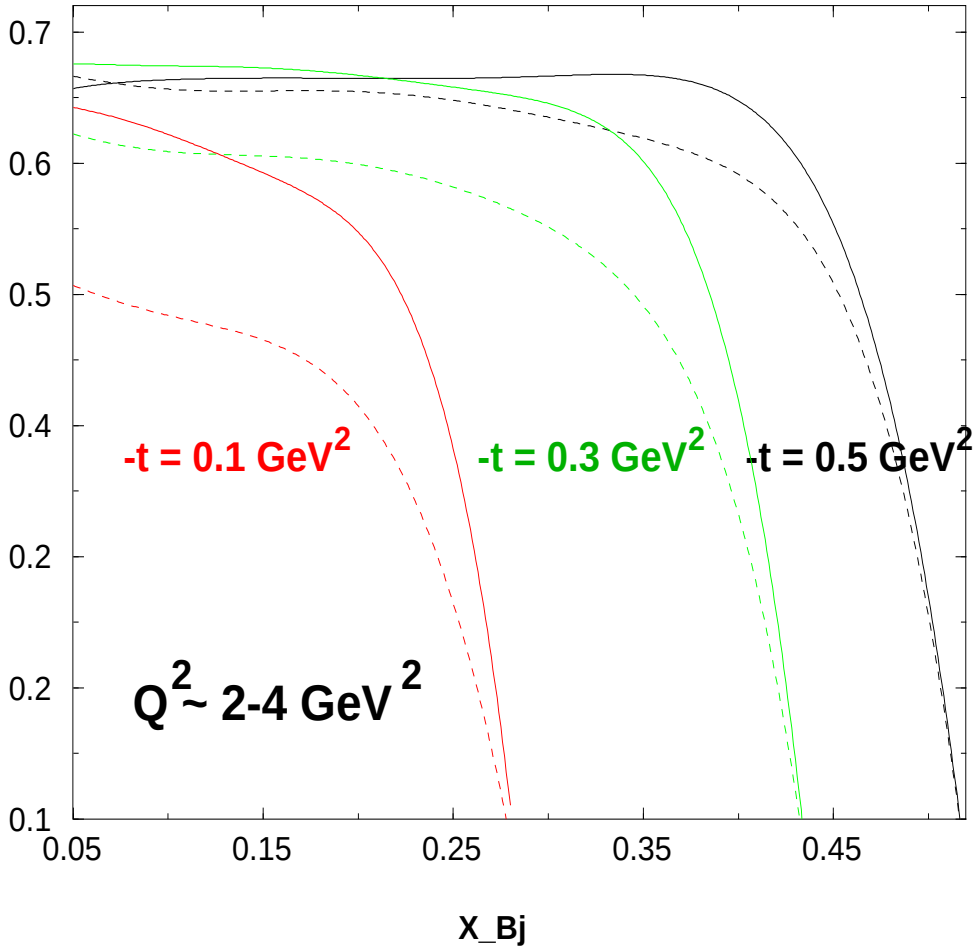

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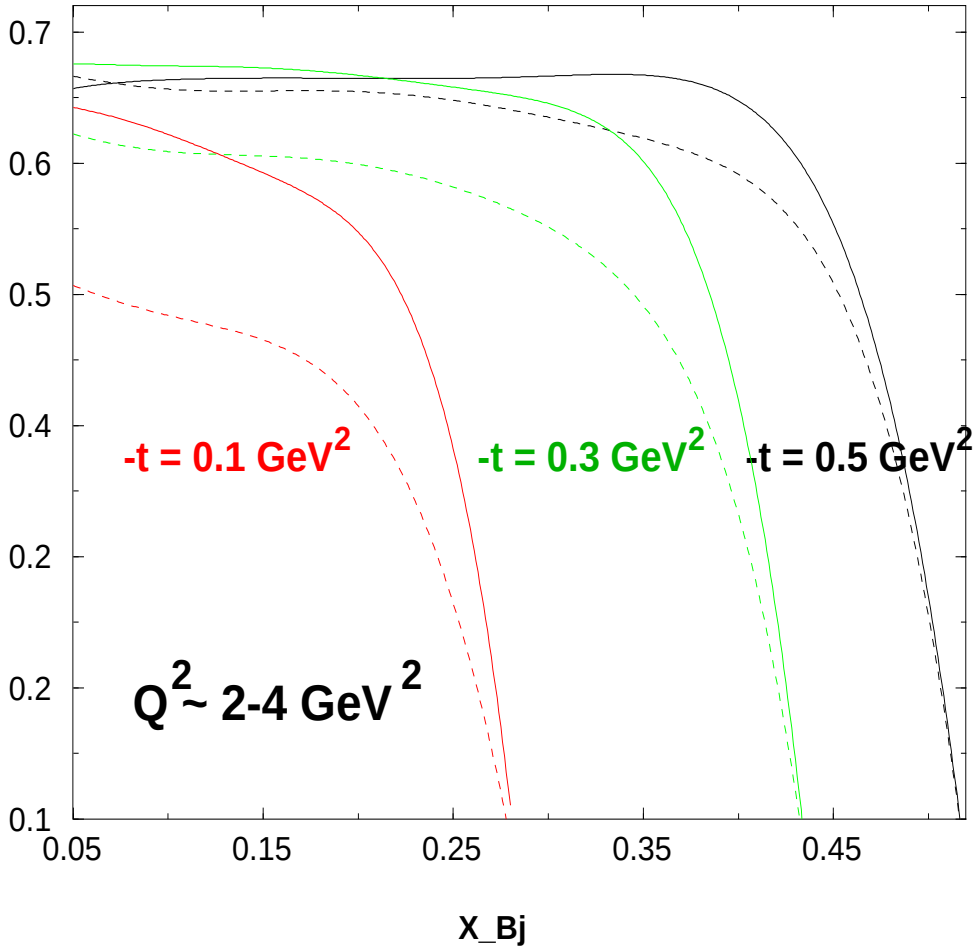

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☞ $GPDs$ framework

❖ Sizable asymmetry predicted!

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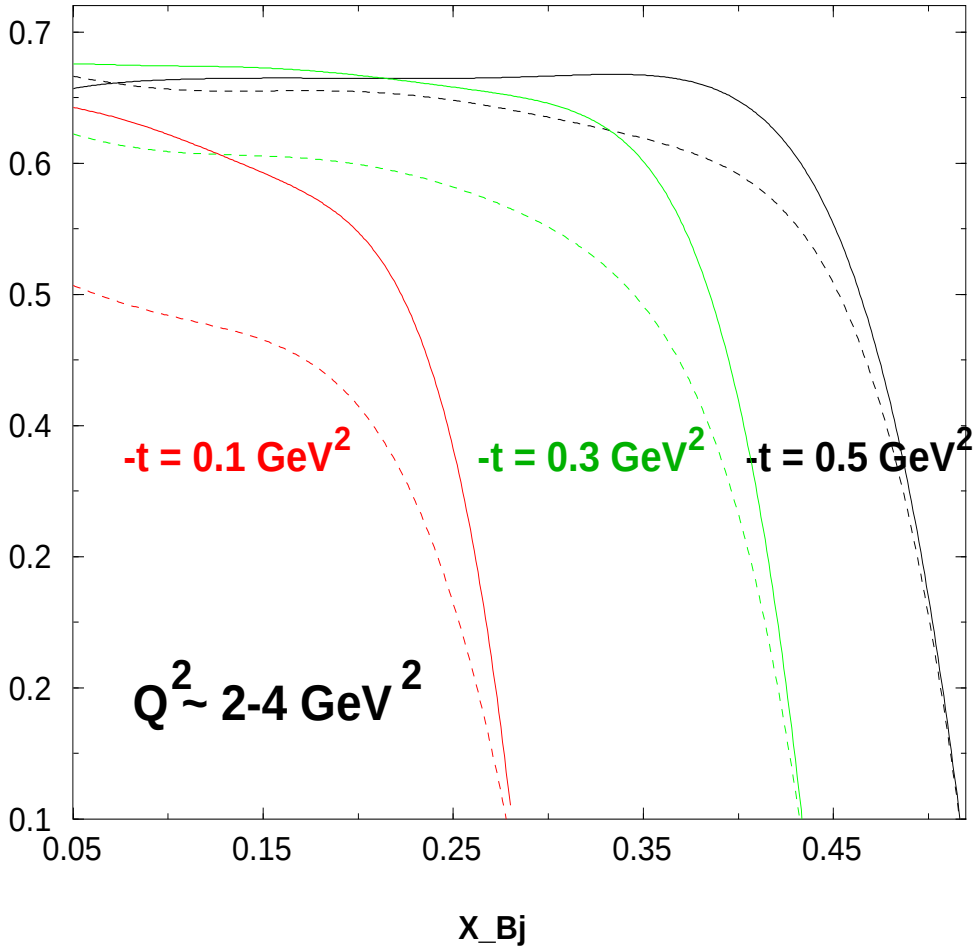

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☞ $GPDs$ framework

❖ Sizable asymmetry predicted!

☞ Analysis from proton target in progress!

Hard Exclusive π^o Production

- **Analysis of exclusive π^o production on unpolarized proton target ongoing**
  - ☞ **no pion-pole contribution in $\tilde{E}$**
  - ☞ **predicted sensitivity to $\tilde{E}$**

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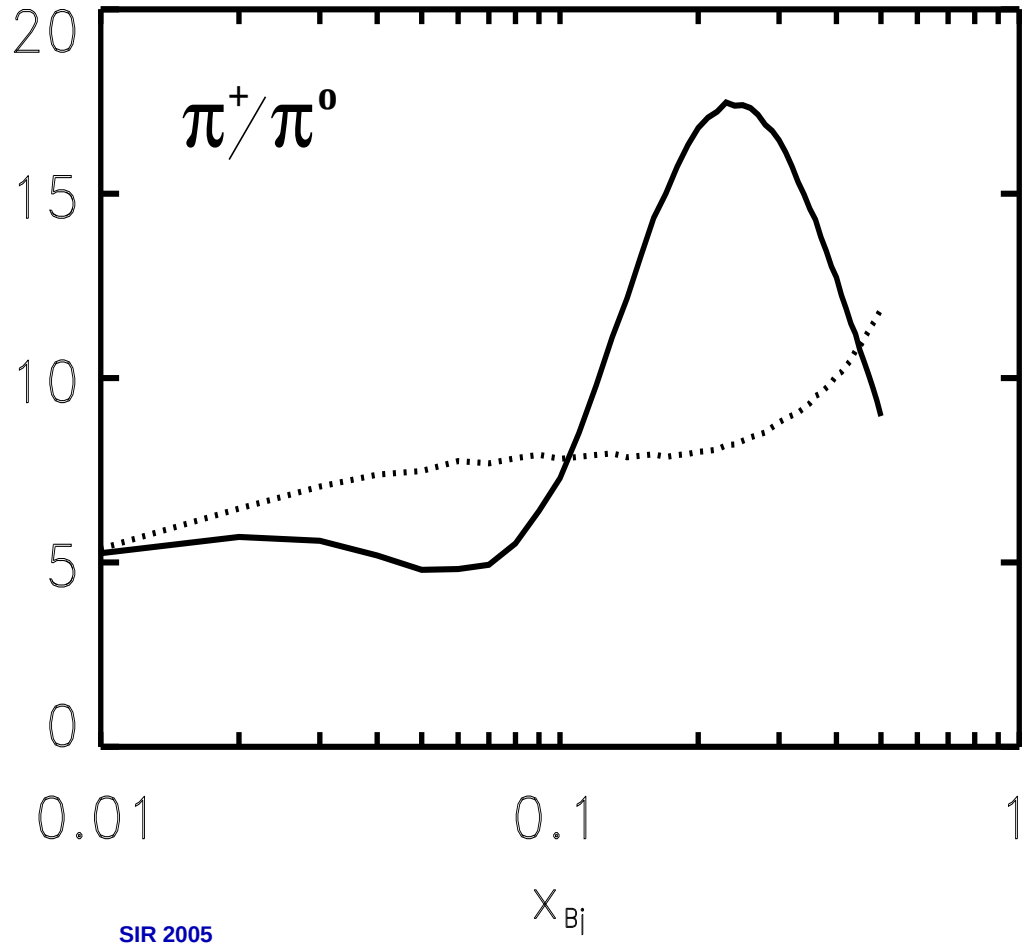
- Mankiewicz et. al. (1999) -



Vector Mesons

Sensitivity to H and E

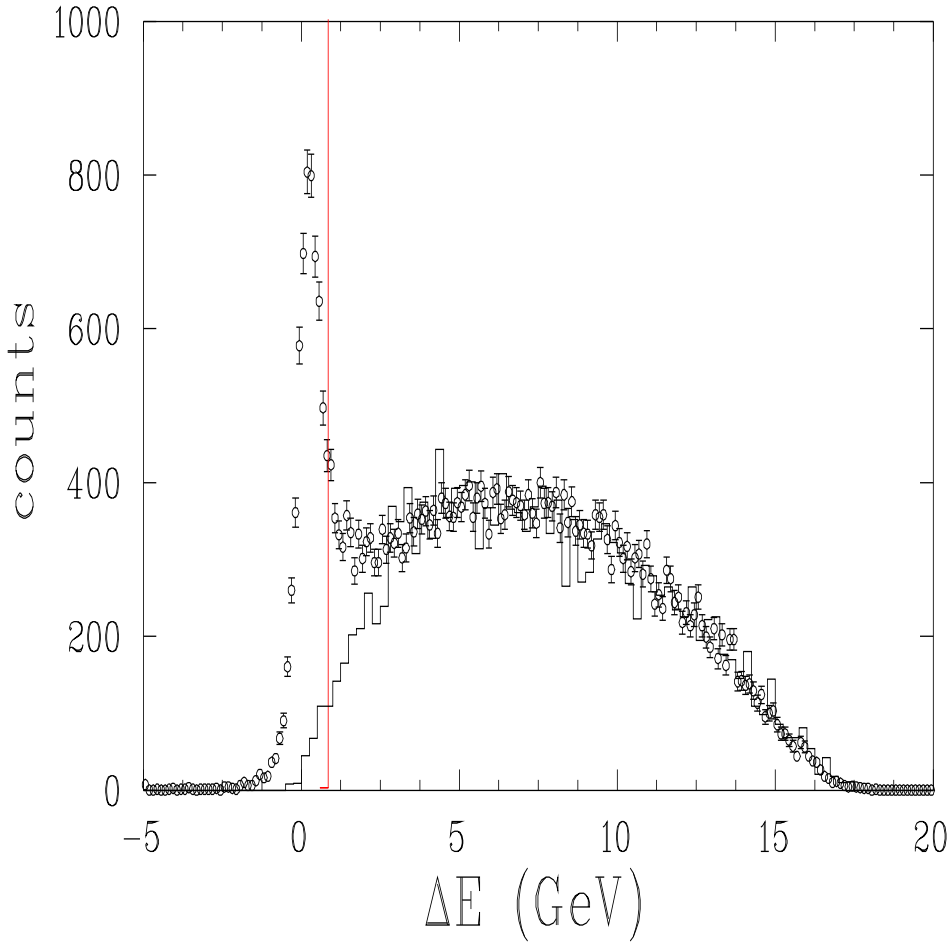
in flavour singlet state

$$\Longrightarrow C = +1$$

Hard Exclusive ρ^o Production

$$e^+p \longrightarrow e^+p\rho^o \longrightarrow e^+p\pi^+\pi^-$$

Extraction of the exclusive sample



- **Detection:** $e^+, \pi^+\pi^-$
- **Recoil proton reconstructed via Missing Energy** ΔE
- **Use of SIDIS MC to subtract the non-exclusive bg**

Hard Exclusive ρ^o Production

Measurement of the cross-section σ_L

$$\gamma_L^\star p \longrightarrow p\rho^o$$

Hard Exclusive ρ^o Production

Measurement of the cross-section σ_L

- σ_L extraction from decomposition of decay-angle distributions:

$$R = \frac{\sigma_L}{\sigma_T} = \frac{1}{\epsilon}\frac{r_{00}^{04}}{1-r_{00}^{04}}$$

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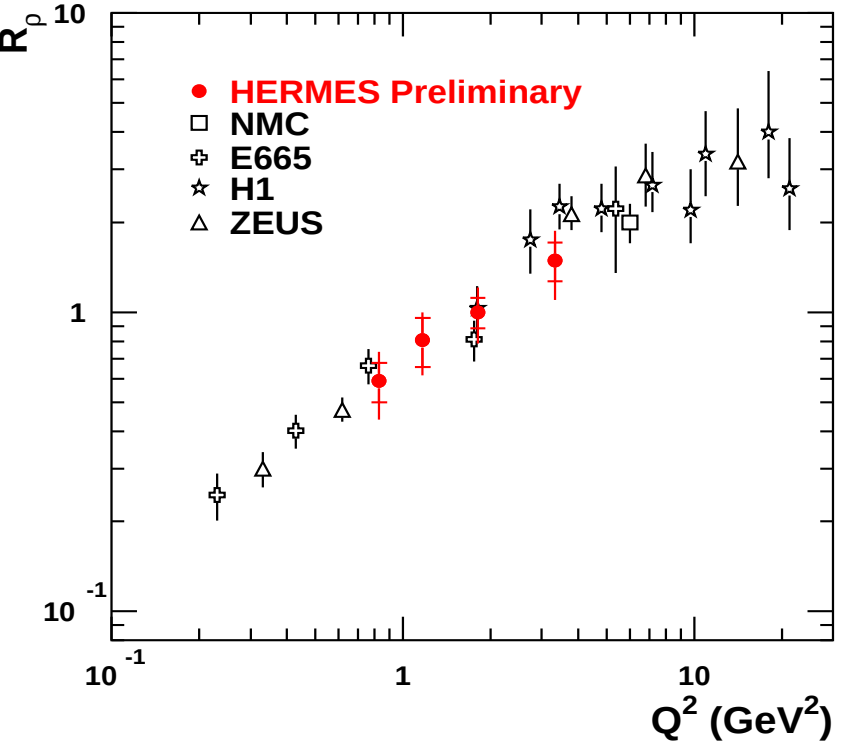

☞ agreement with proton world data

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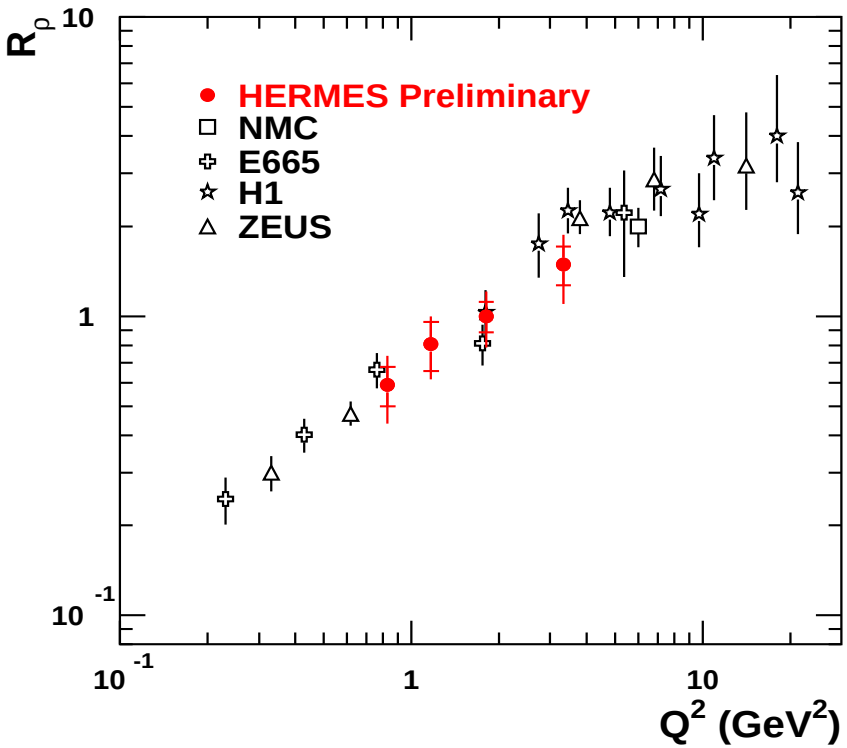

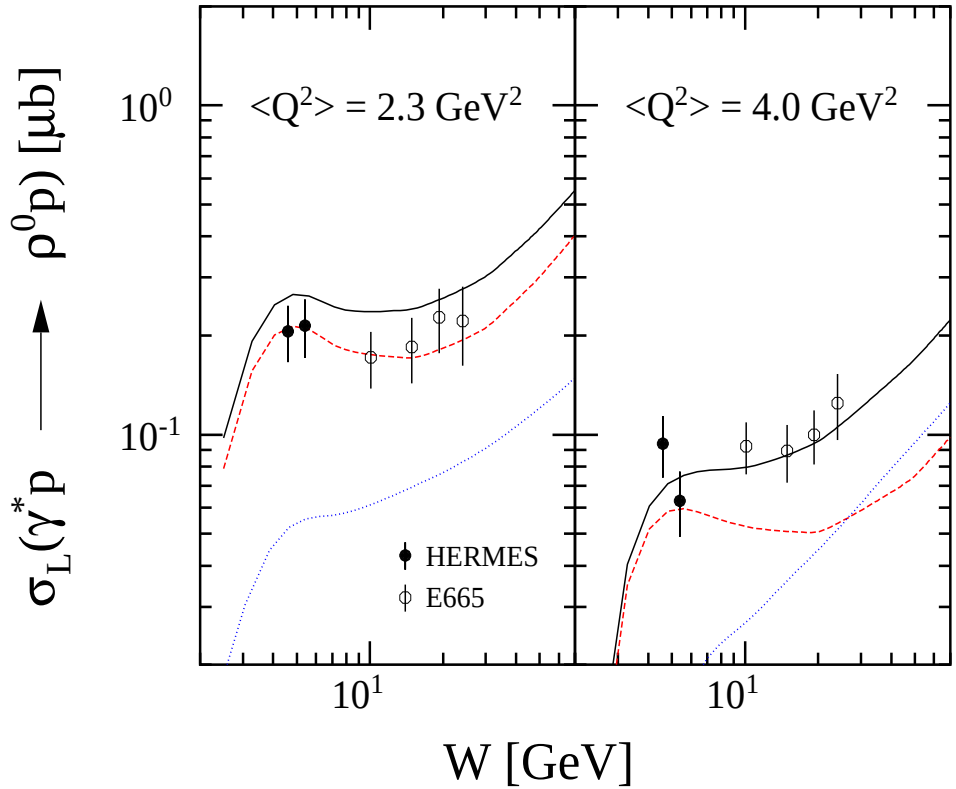

- GPD calculations in terms of H & E

  - Vanderhaeghen, Guichon & Guidal -

- $q\bar{q}$-exchange
- gluon-exchange

} mechanisms considered

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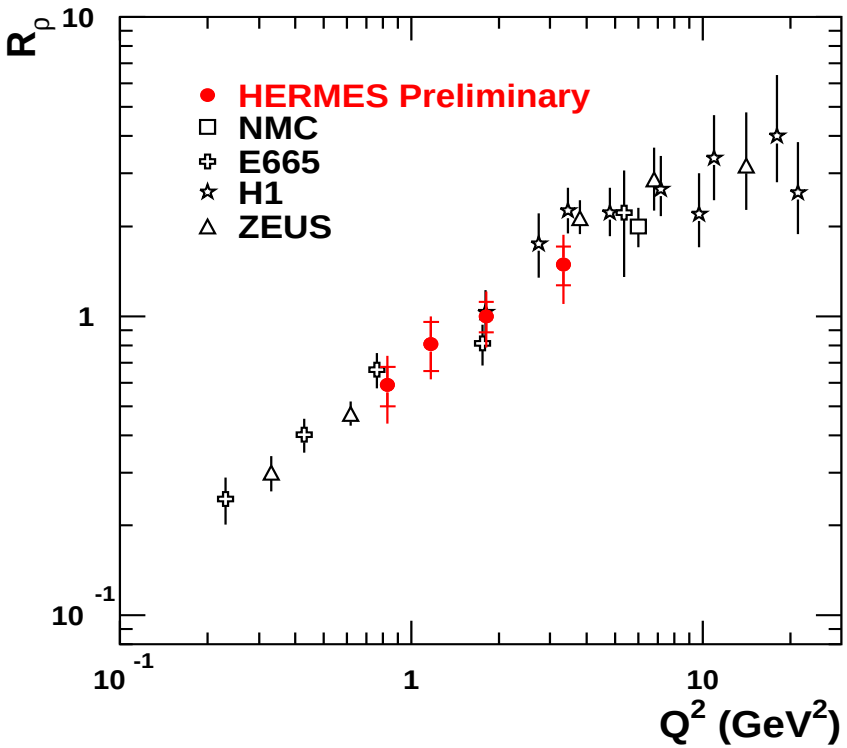

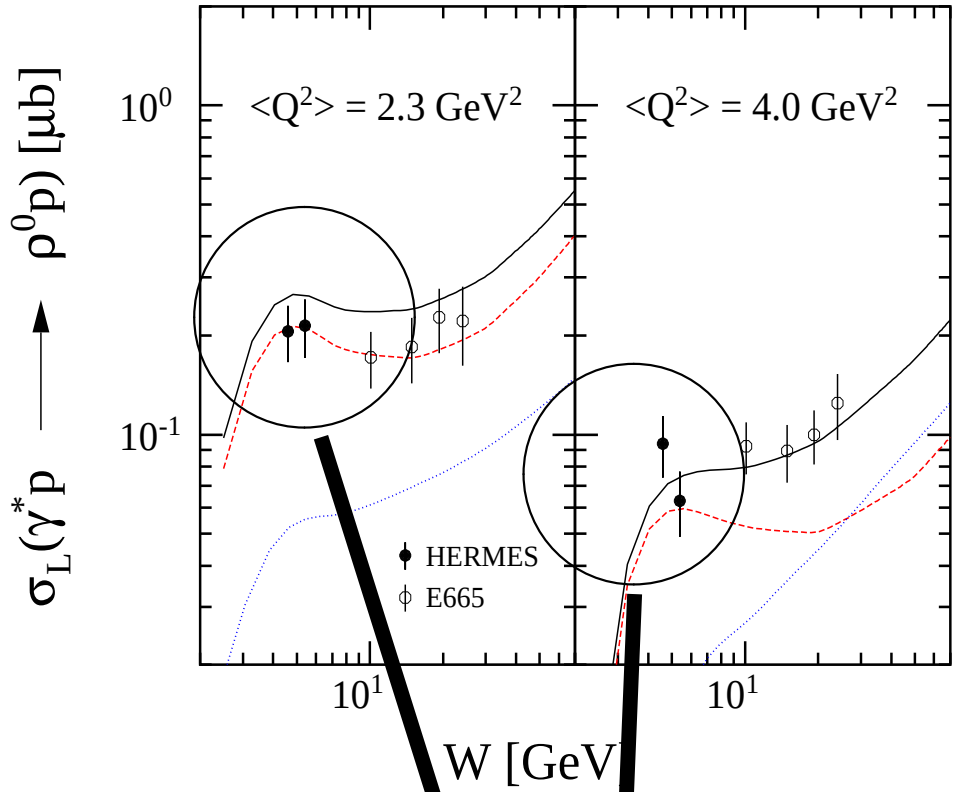

- GPD calculations in terms of H & E
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might dominate at HERMES ✔

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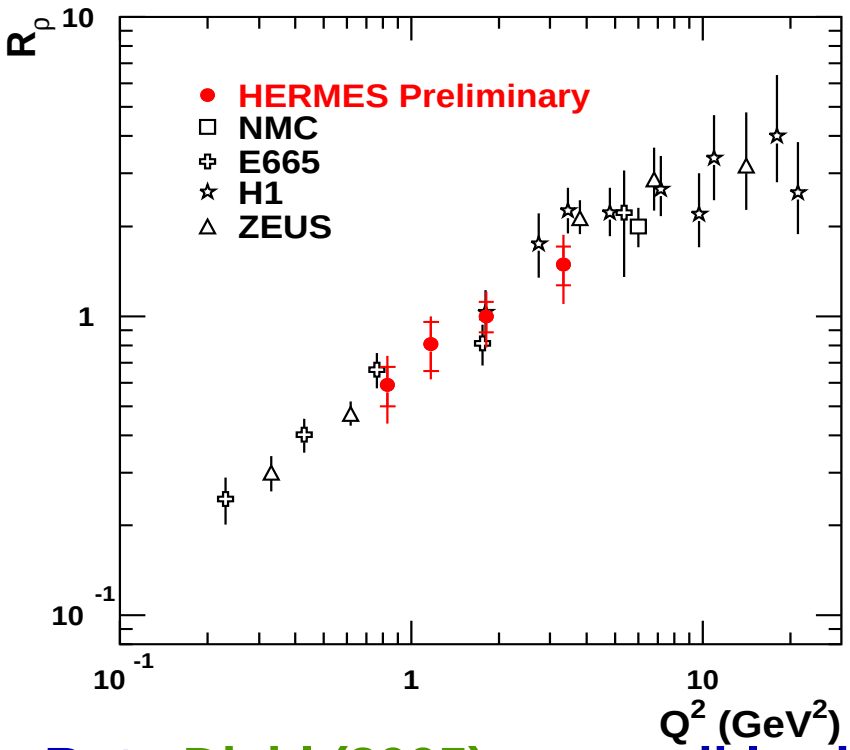

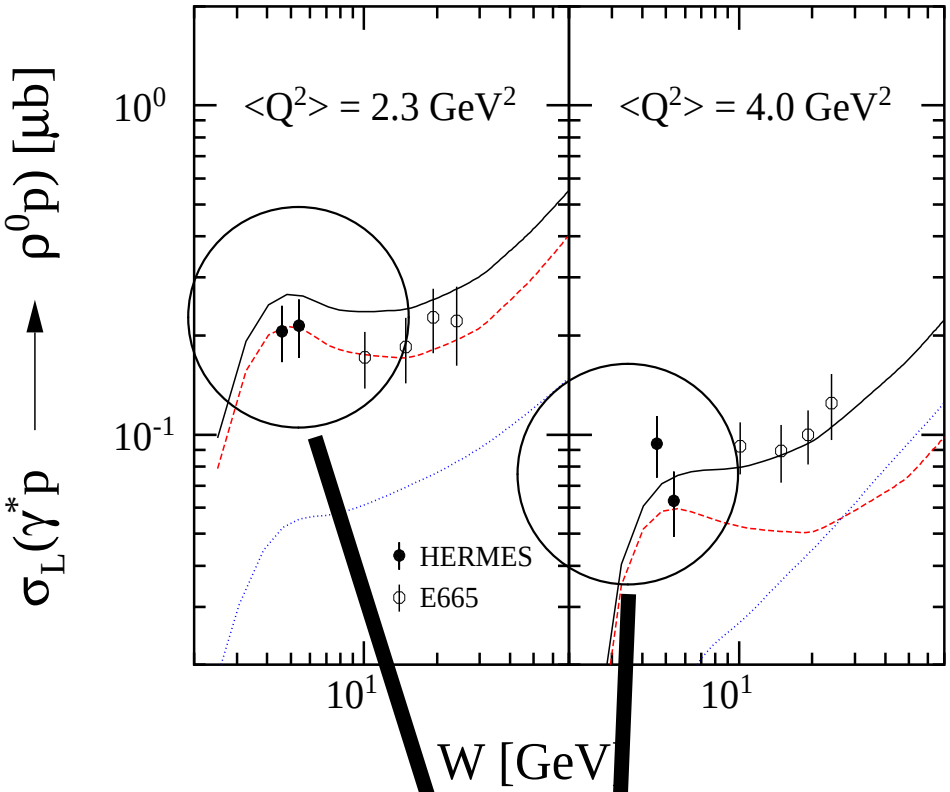

- GPD calculations in terms of H & E
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might dominate at HERMES ✔

☞ But - Diehl (2005) - : possibly sizable contribution from gluons in HERMES

Hard Exclusive ρ^o Production

Transverse Target Spin Asymmetry A_{UT}

Hard Exclusive ρ^o Production

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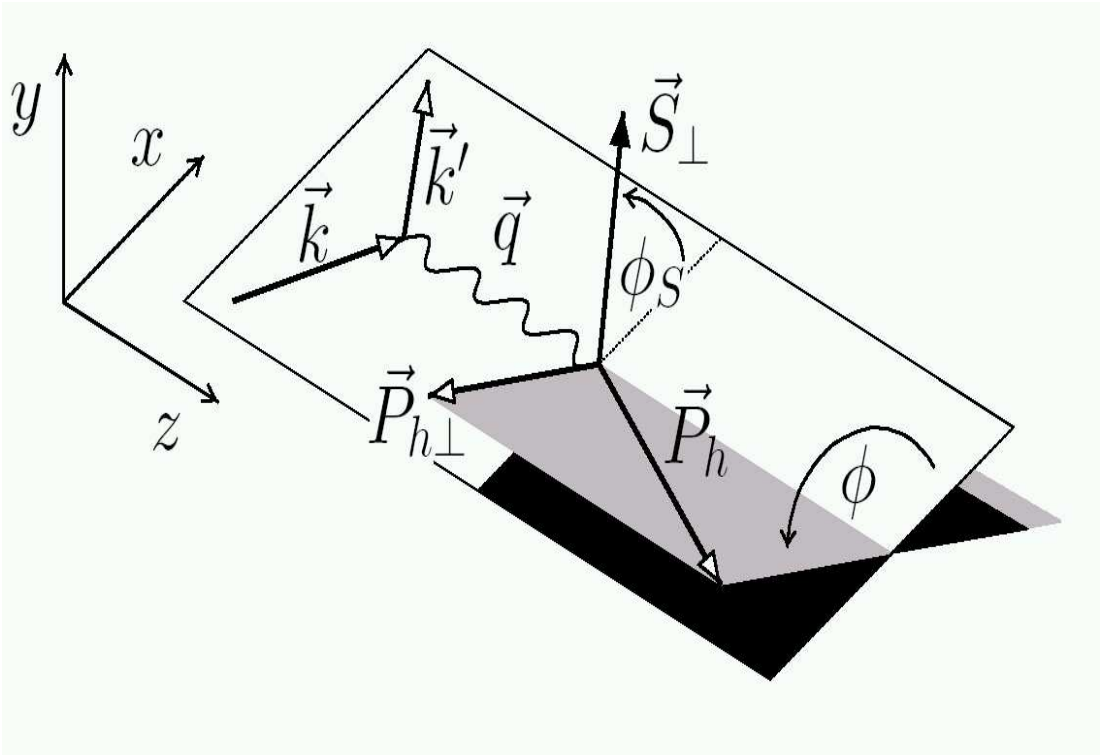

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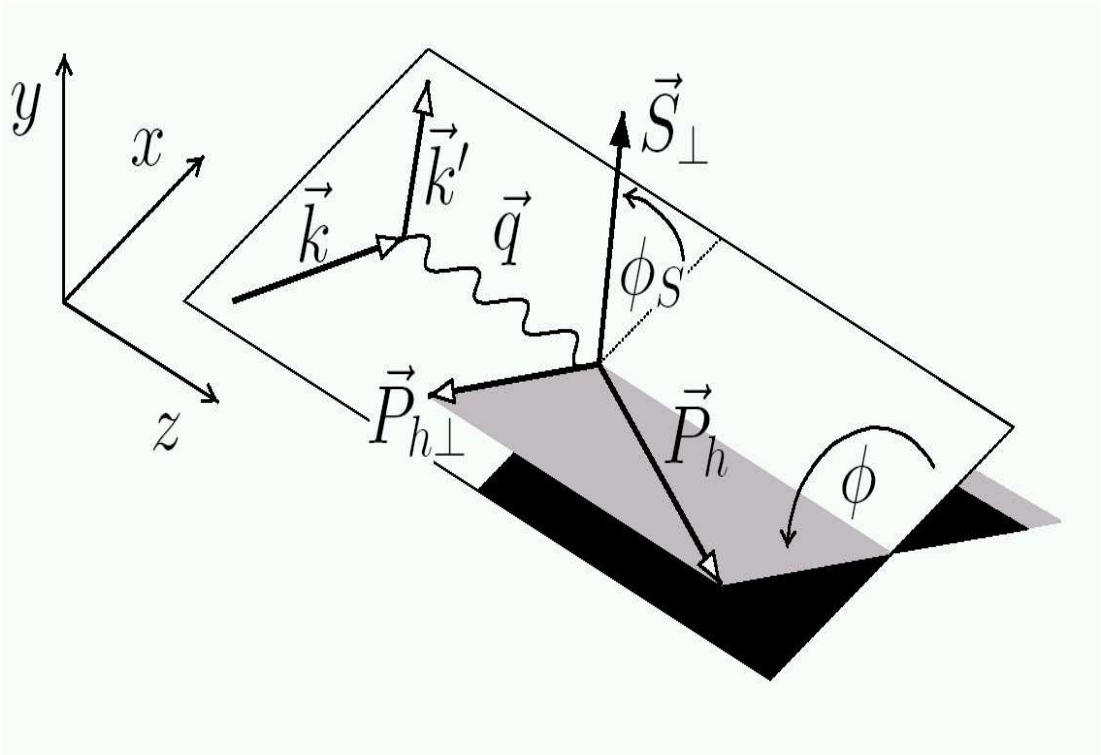

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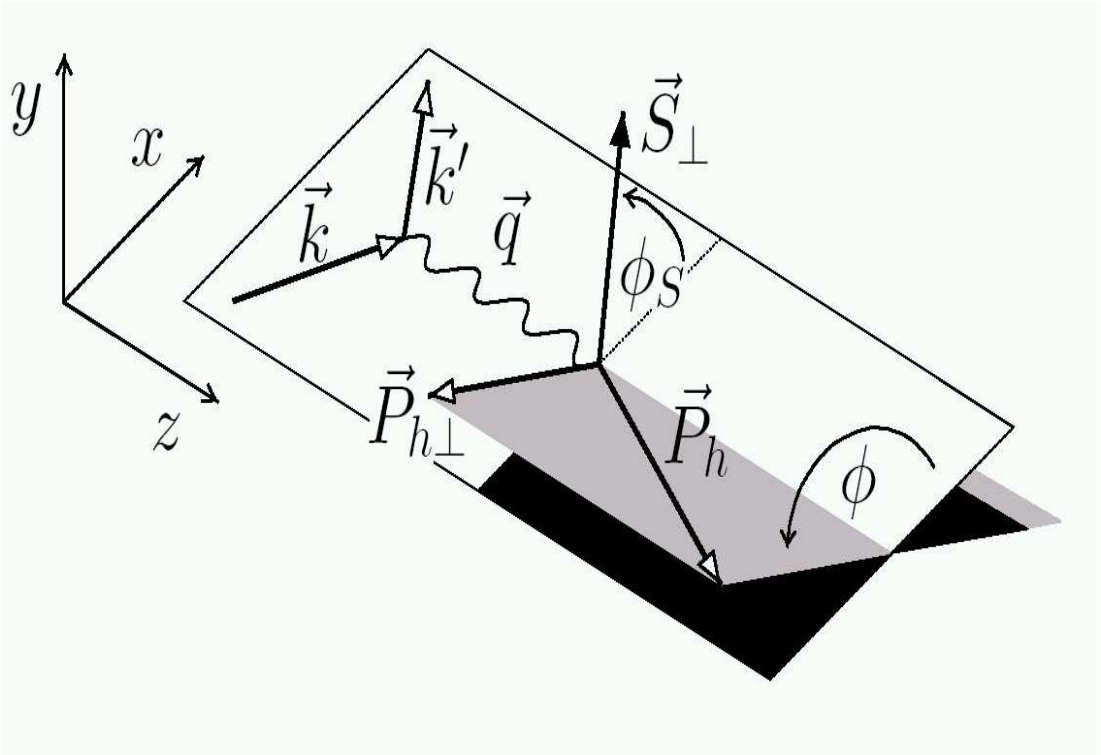

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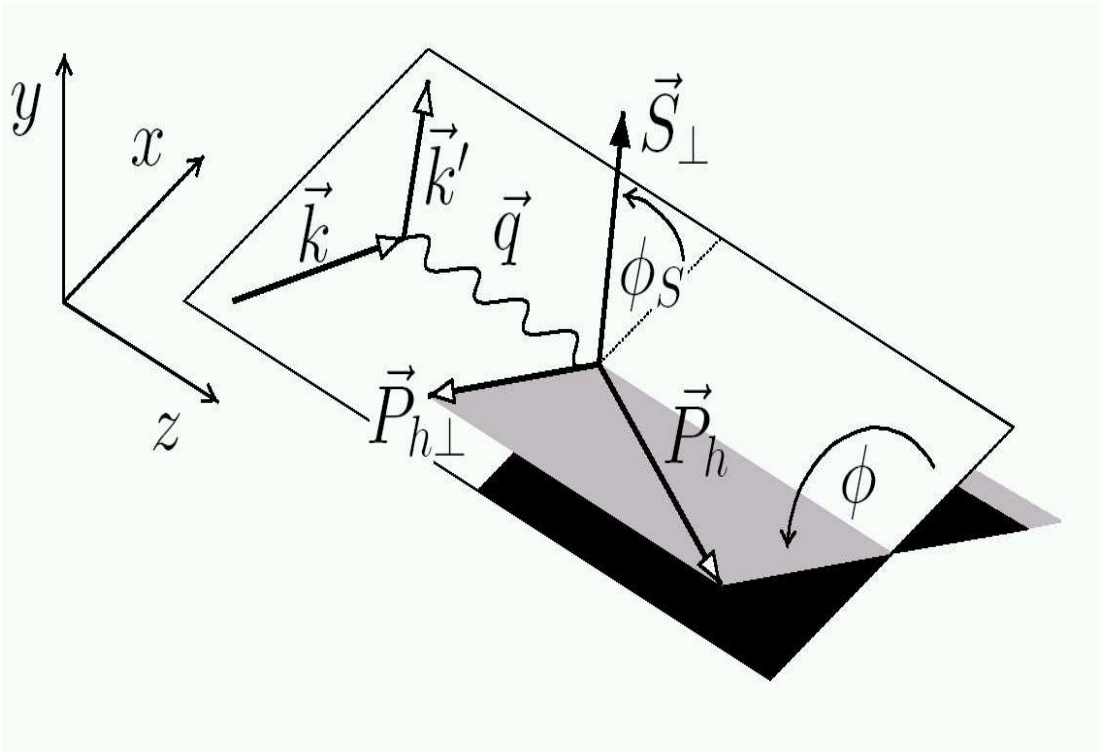

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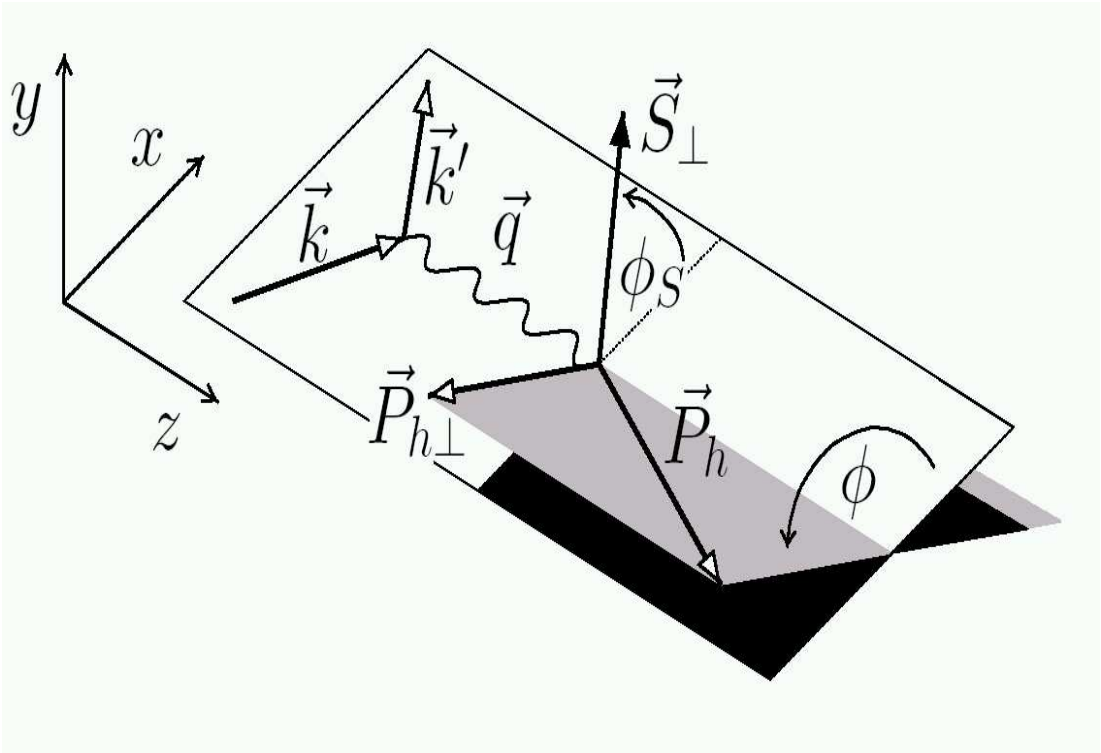

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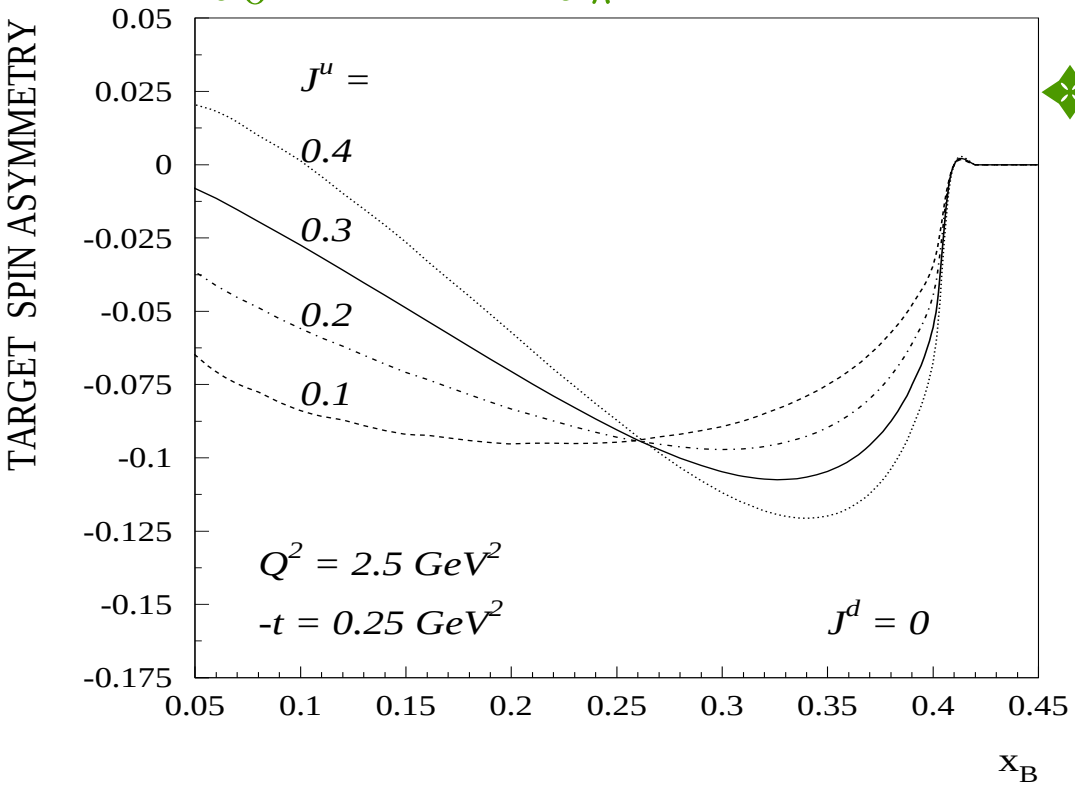

- **GPD calculations for proton**
  - Goeke et al. (2001) -

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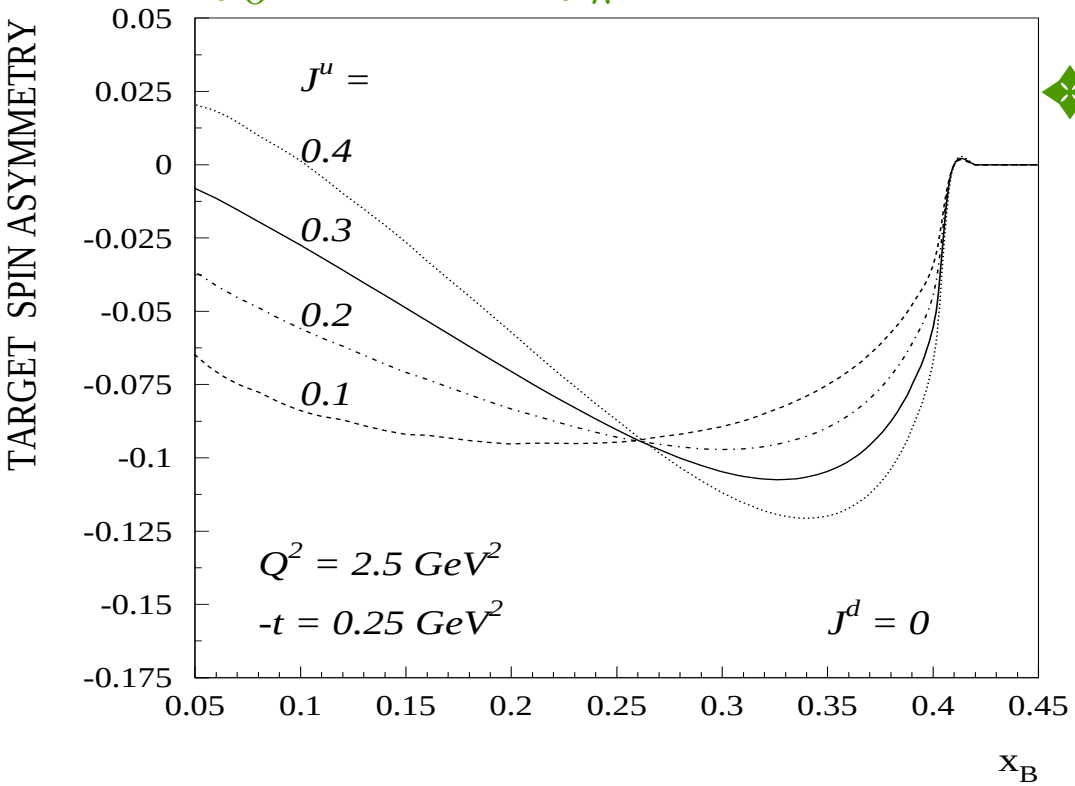

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- **Accessing $\mathcal{A}$ by measuring**

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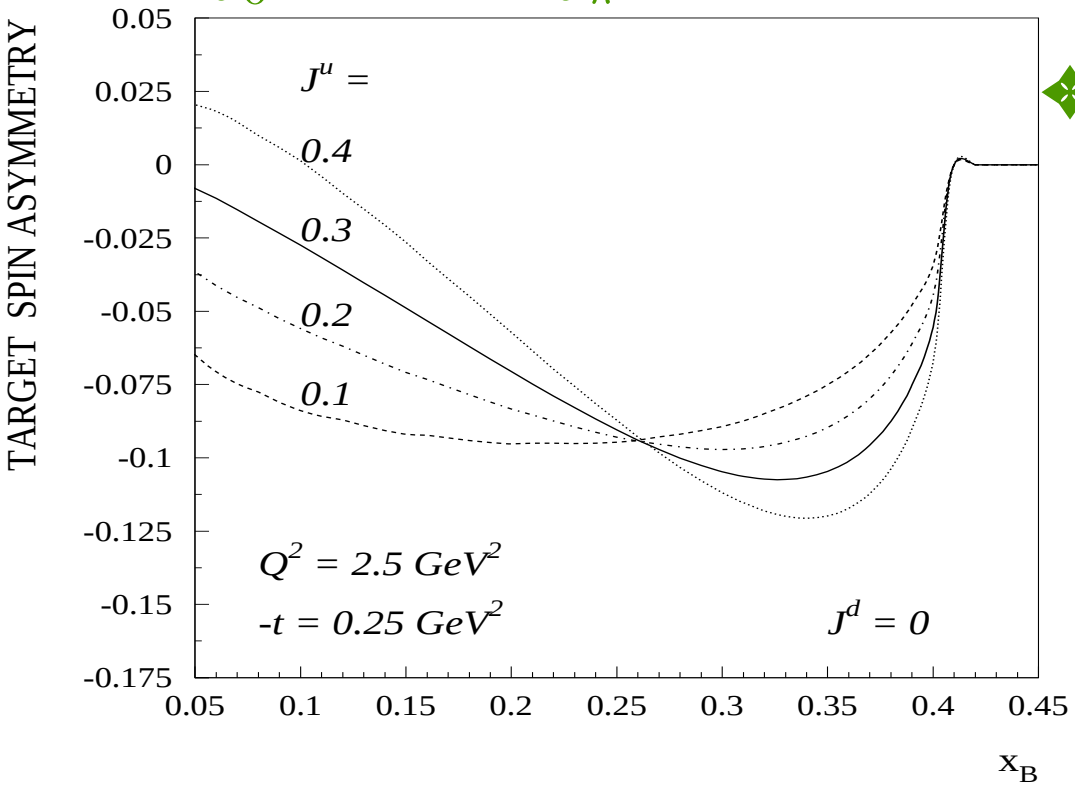

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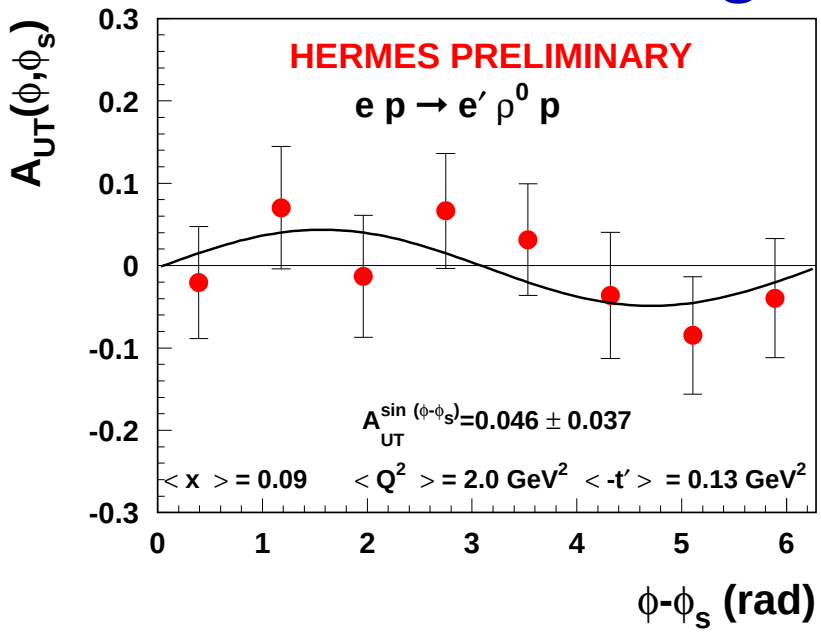
- **Accessing $\mathcal{A}$ by measuring**

$$A_{UT}{}^{sin(\phi-\phi_S)}$$

$$\mathcal{A} \propto - A_{UT}{}^{sin(\phi-\phi_S)}$$

Hard Exclusive ρ^o Production

Transverse Target Spin Asymmetry A_{UT}



- No σ_L separation yet!

Hard Exclusive ρ^o Production

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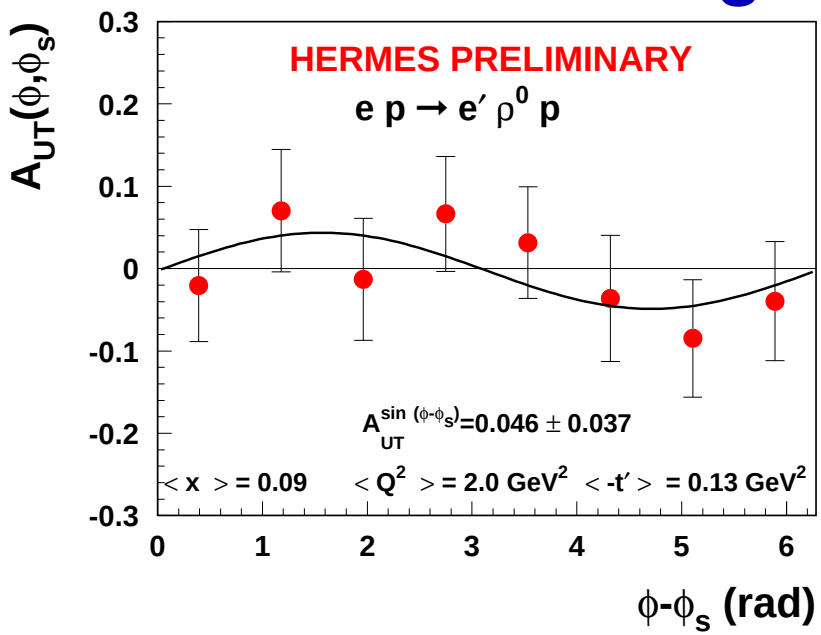

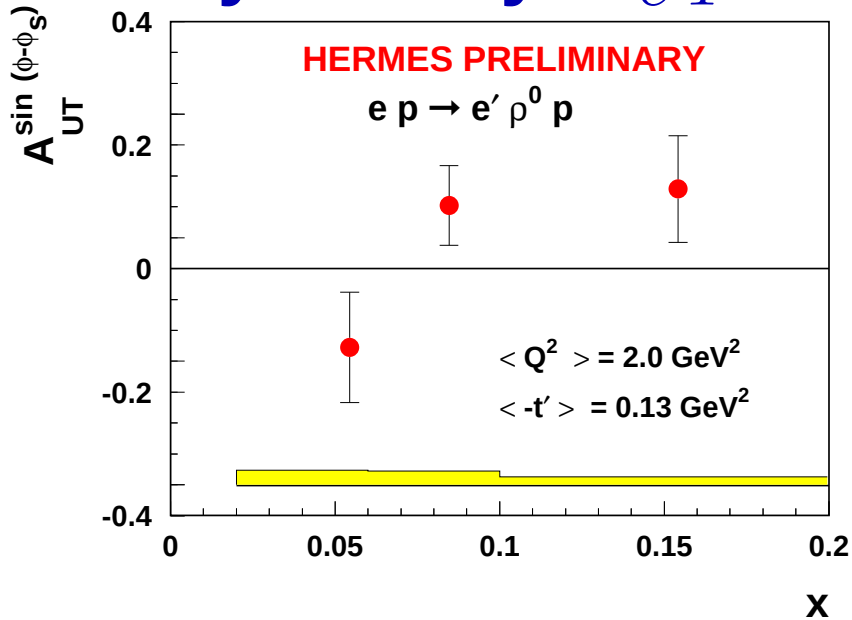

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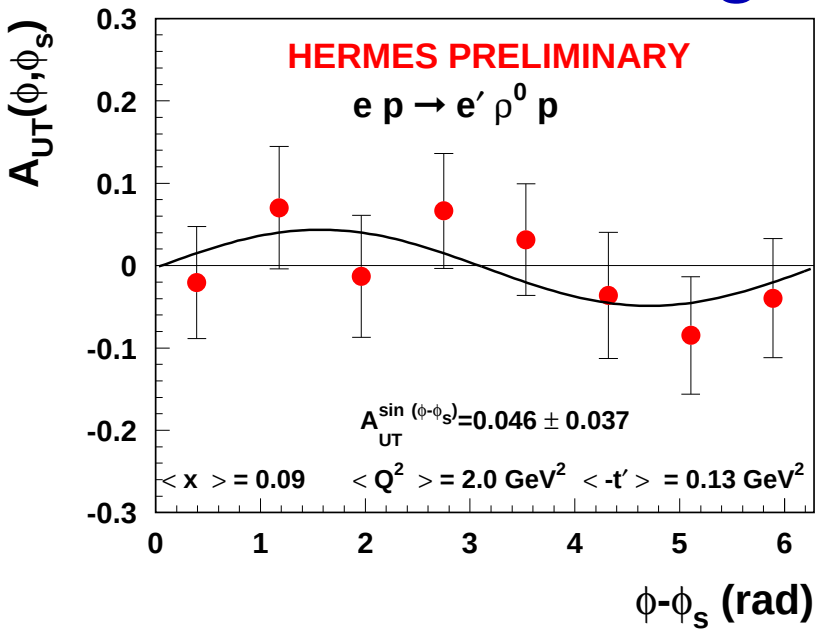

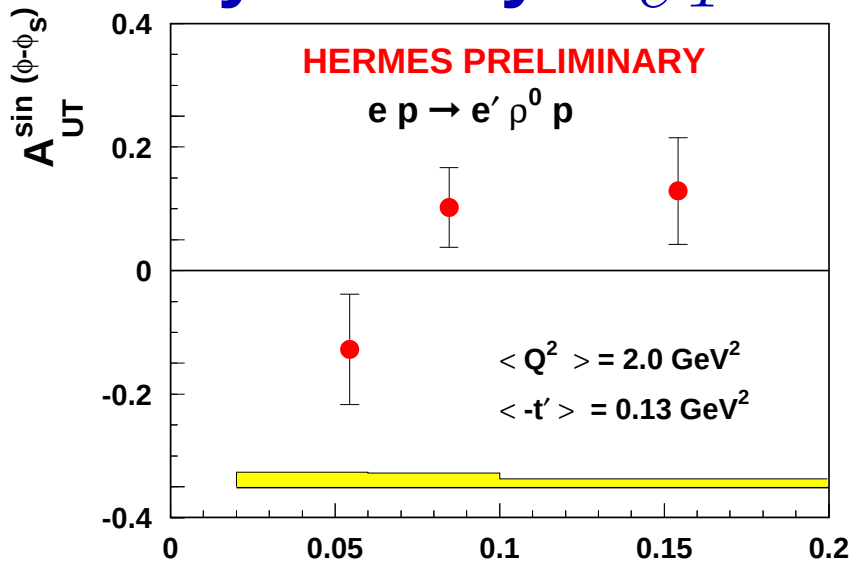

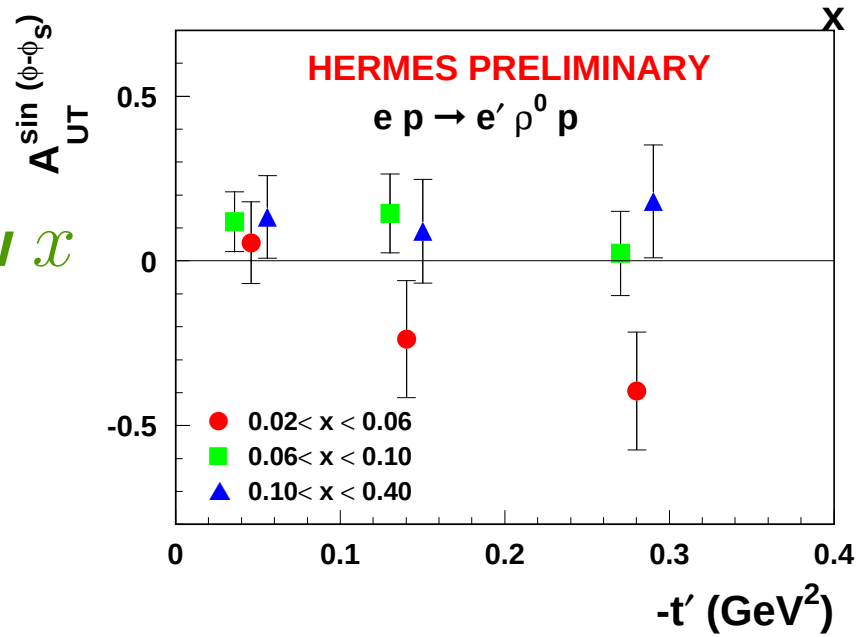

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- Indication of t-depend. at low x

Hard Exclusive ρ^o Production

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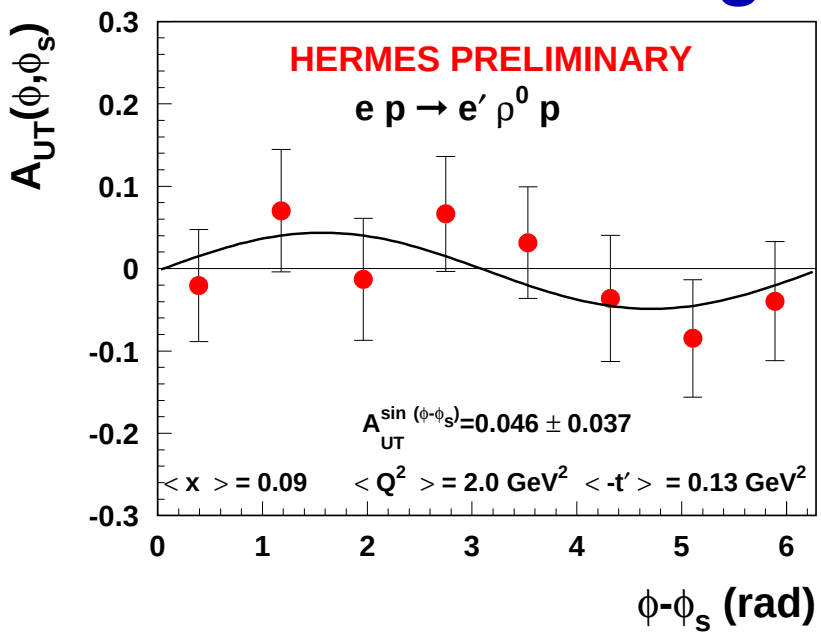
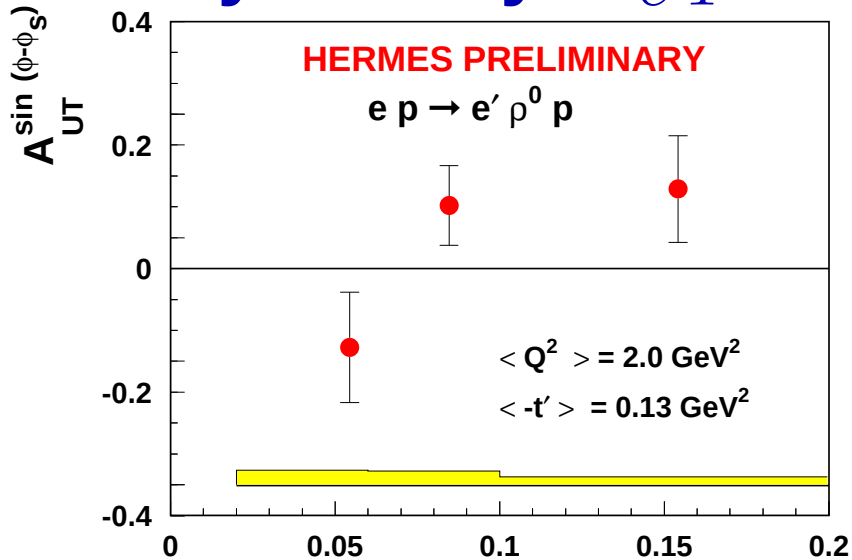
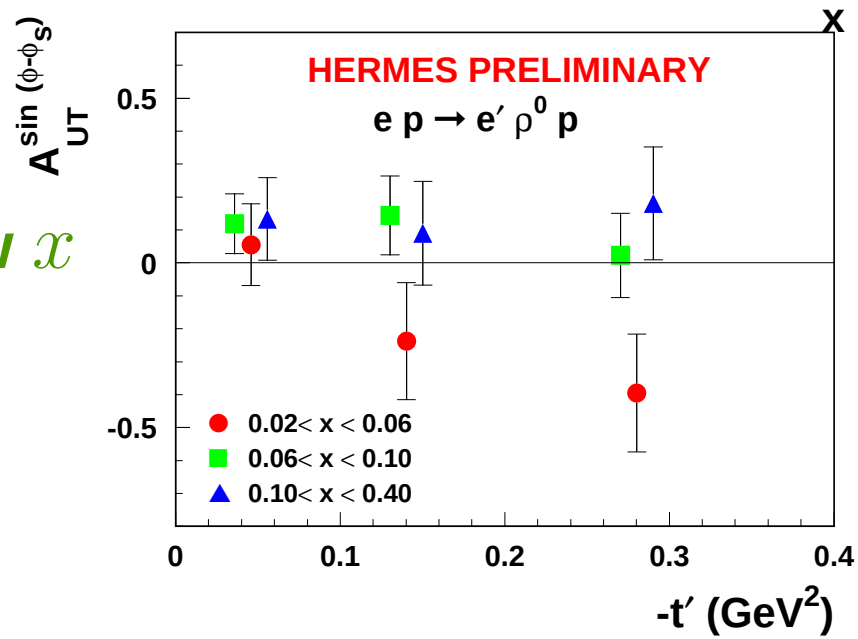






- No σ_L separation yet!
- Indication of t-depend. at low x

☞ possibly doubled statistics at end 2005

☞ σ_L/σ_T separation possible

Hard Exclusive ϕ Production

Measurement of the cross-section σ_L

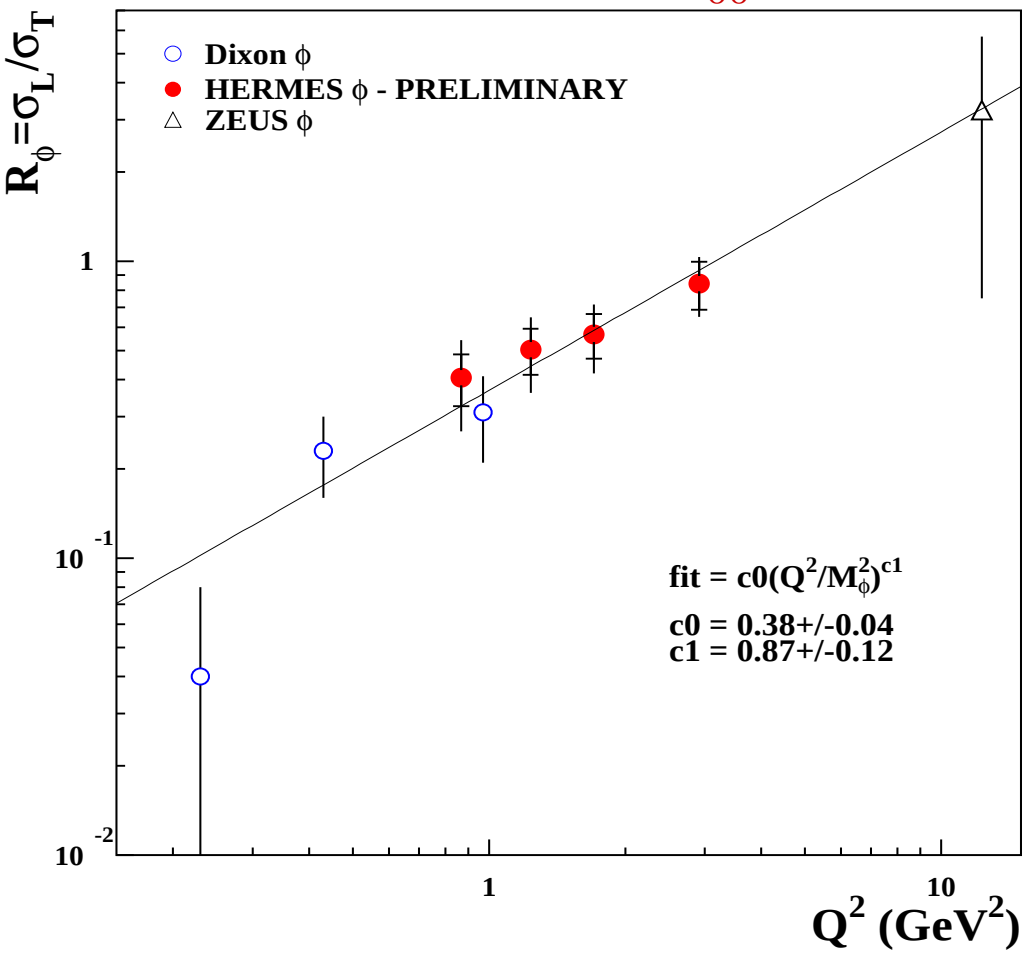
$$\gamma_L^\star p \longrightarrow p\phi \longrightarrow pK^+K^-$$

- analysis procedure as for ρ^o

Hard Exclusive ϕ Production

Measurement of the cross-section σ_L

$$R = \frac{\sigma_L}{\sigma_T} = \frac{1}{\epsilon}\frac{r_{00}^{04}}{1-r_{00}^{04}}$$



☞ agreement with world data

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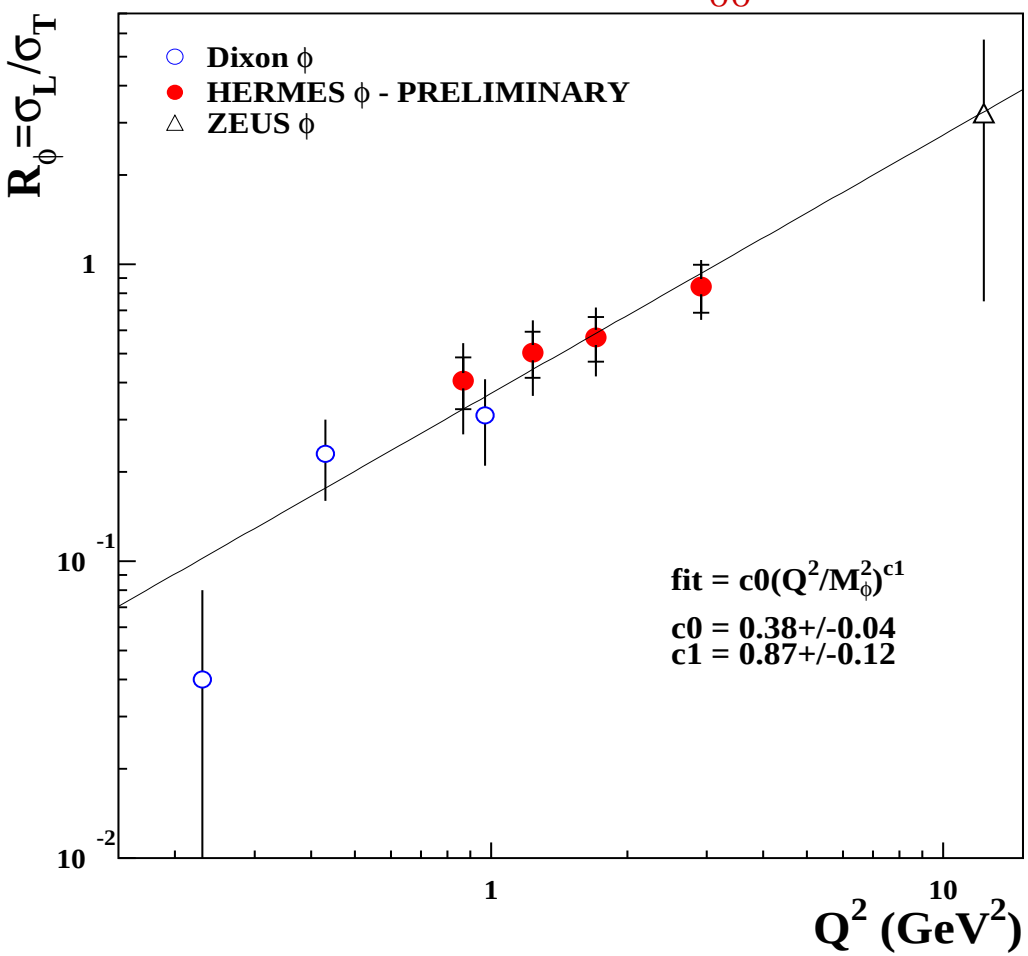

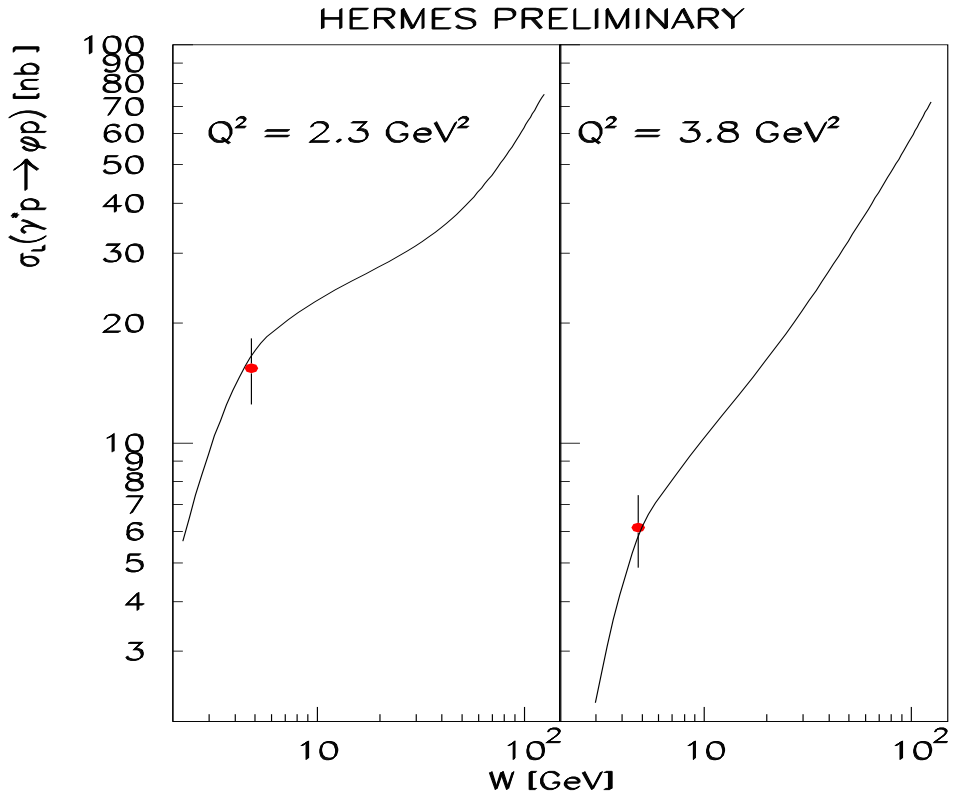

- GPD calculations in terms of gluon H & E

  - Guidal -

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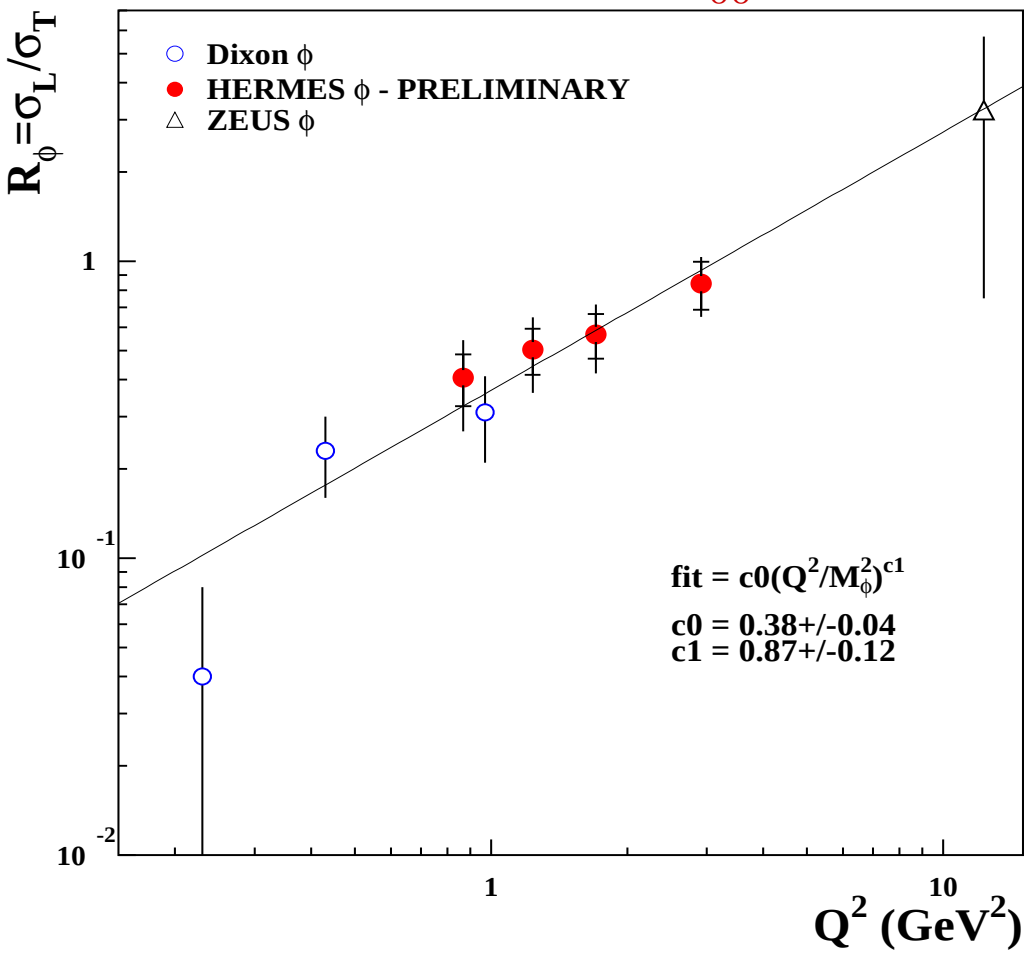

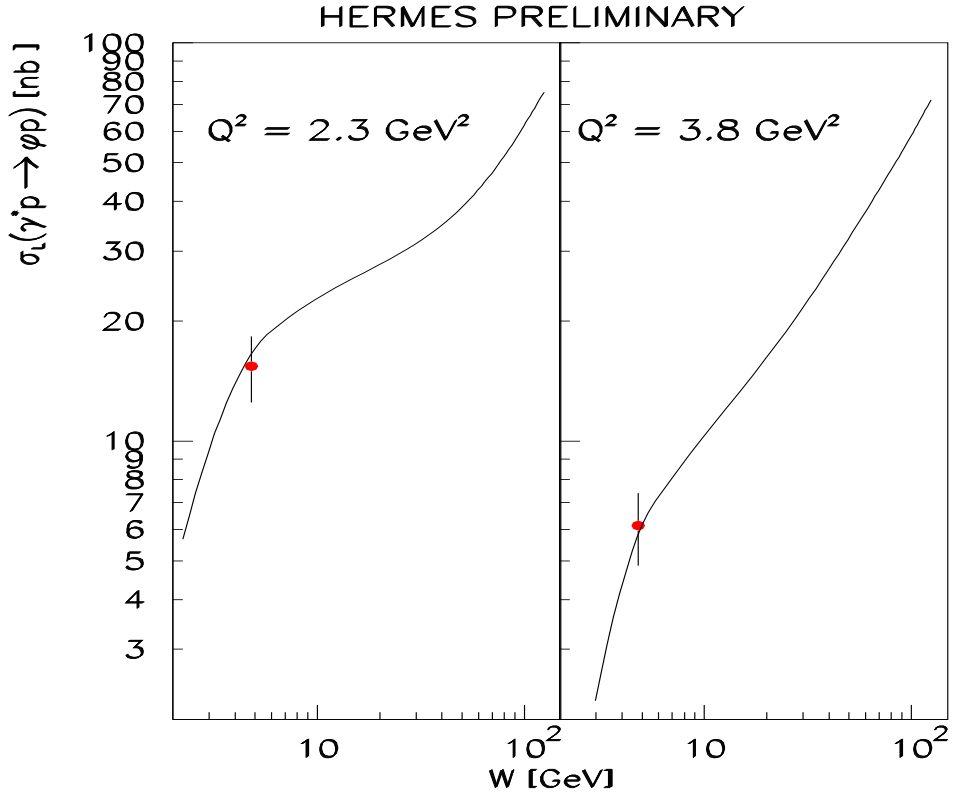

- GPD calculations in terms of gluon H & E

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- gluon-exchange DOMINATES ✔

☞ agreement with world data

Exclusive Meson Production: X_Section Ratios

$$\sigma_\phi / \sigma_\rho$$

Exclusive Meson Production: X_Section Ratios

$$\sigma_\phi / \sigma_\rho$$

$$\frac{2}{9} \sim \frac{\sigma_\phi(2g\ exchange)}{\sigma_\rho(2g\ exchange)}$$

☞ **with only 2g-exchange mechanism for ρ^o**

Exclusive Meson Production: X_Section Ratios

$$\sigma_\phi / \sigma_\rho$$

$$\frac{2}{9} \sim \frac{\sigma_\phi(2g\ exchange)}{\sigma_\rho(2g\ exchange)} \geq \frac{\sigma_\phi(2g\ exchange)}{\sigma_\rho(2g\ exchange + q\bar{q}\ exchange)}$$

☞ **with only 2g-exchange mechanism for ρ^o**

☞ **with $q\bar{q}$-exchange mechanism included for ρ^o**

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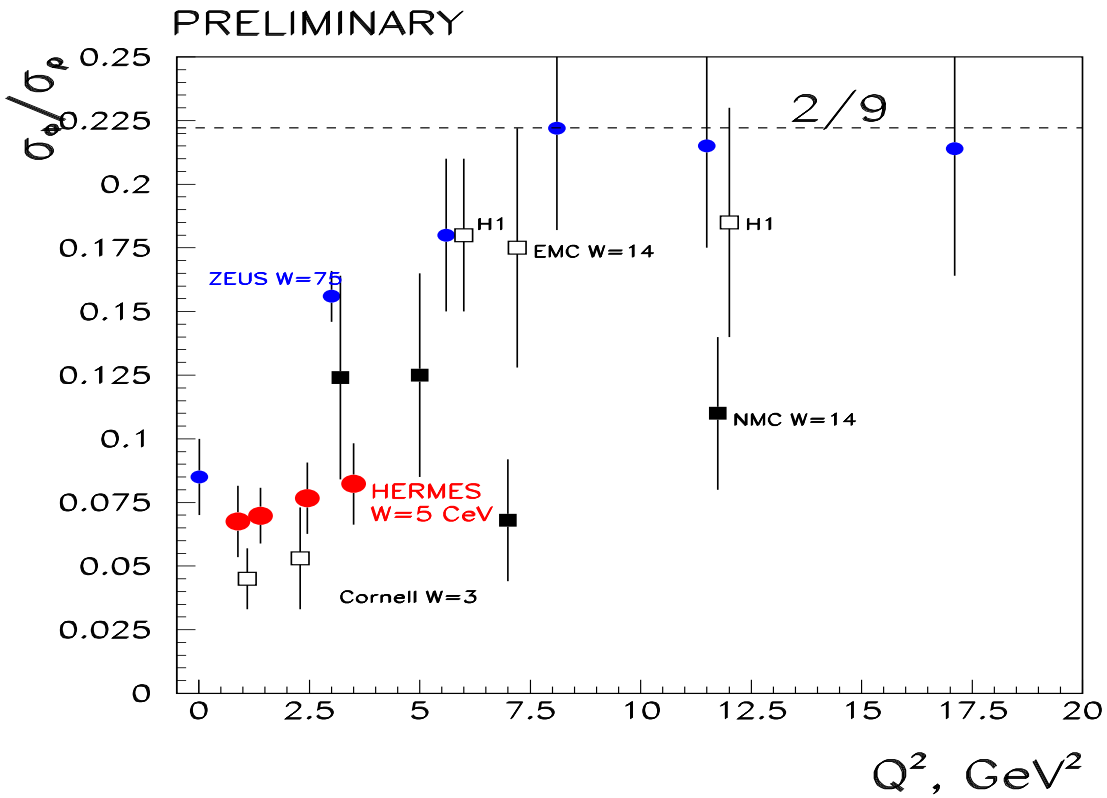

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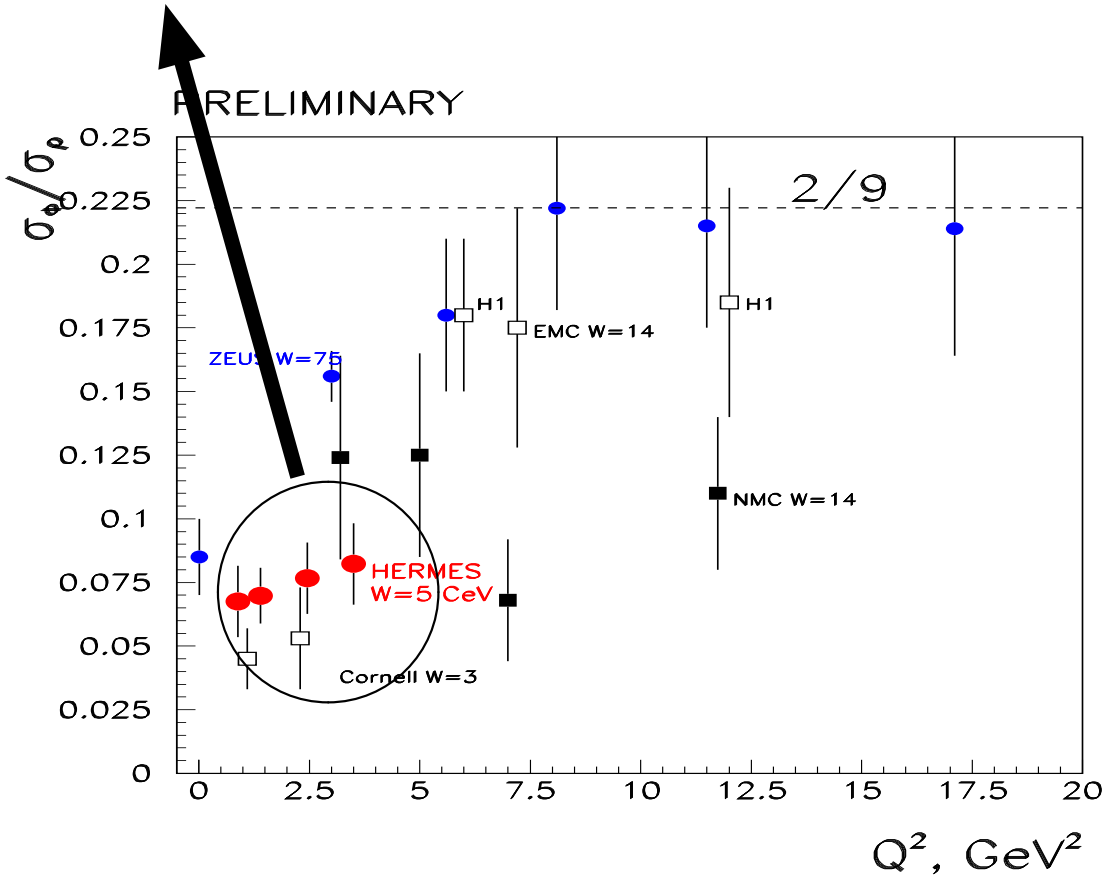

- **HERMES data** $\ll \frac{2}{9}$

Exclusive Meson Production: X_Section Ratios

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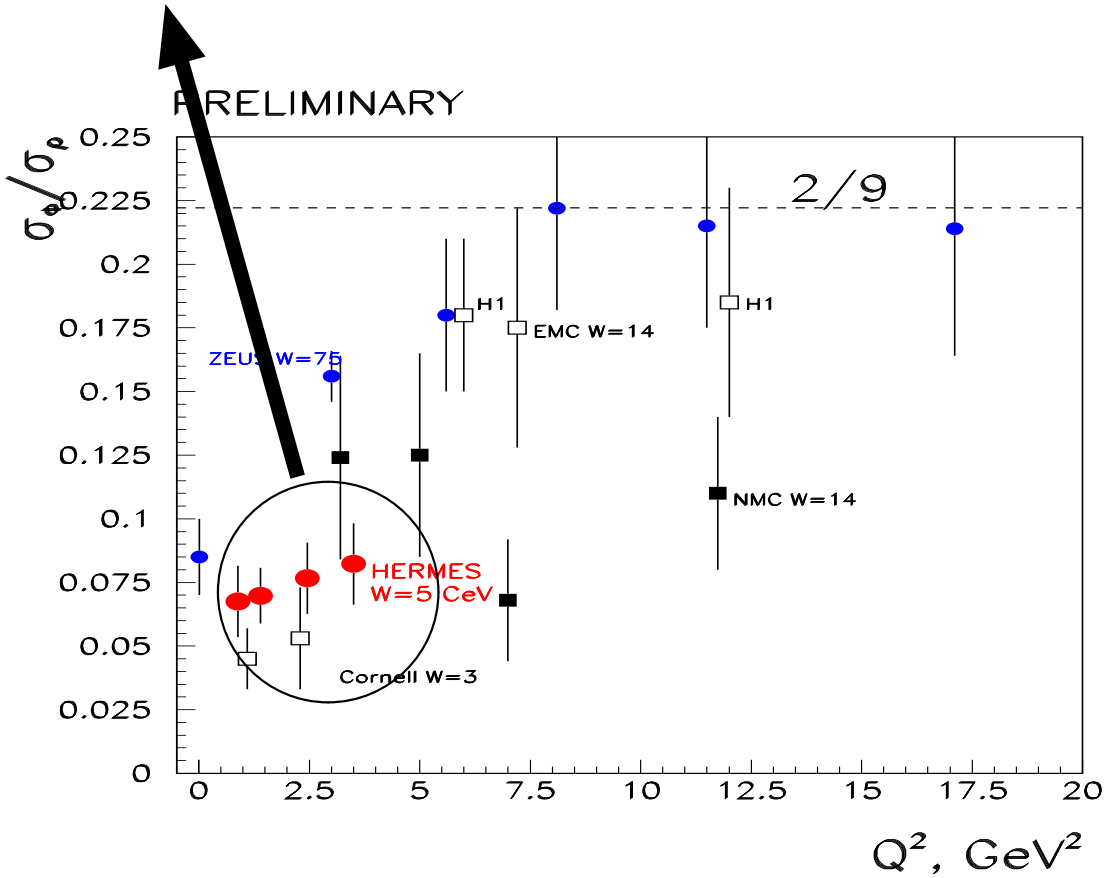

- **HERMES data** $\ll \frac{2}{9}$
- **indication that**

$$H_q \ \& \ E_q$$

play a role in ρ^o **production**

in the HERMES kinematics

Pion Pairs and f-meson Family

Sensitivity to H and E

in flavour non-singlet state

$$\Longrightarrow C = -1$$

Hard Exclusive Production of $\pi^+\pi^-$

$$\gamma_L^\star p \longrightarrow p\pi^+\pi^-$$

$$\gamma_L^\star d \longrightarrow d\pi^+\pi^-$$

Hard Exclusive Production of $\pi^+\pi^-$

$$\gamma_L^\star p \longrightarrow p\pi^+\pi^-$$

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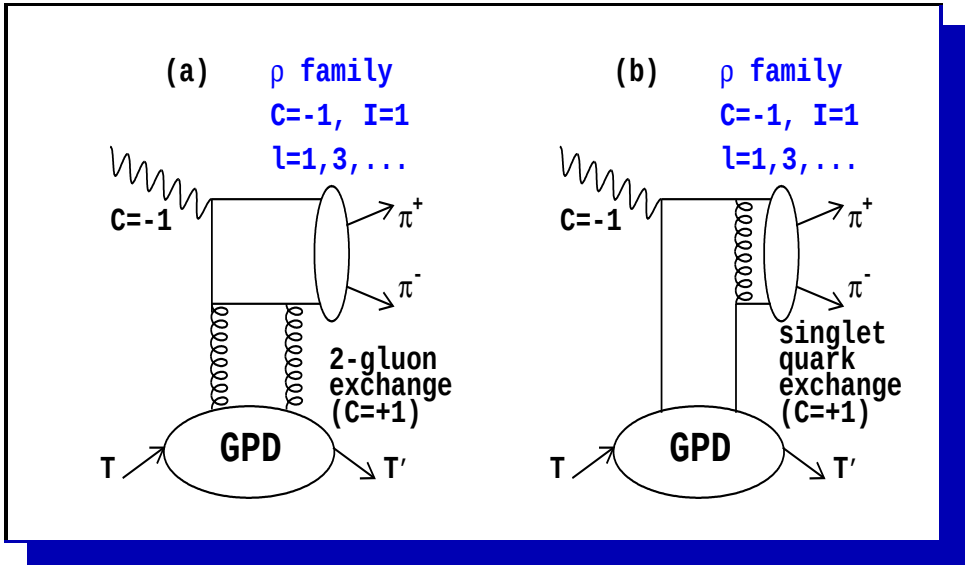
Which channels may contribute?



Example:

- ρ^0: $I(J^{PC})$=$1(1^{--})$

Hard Exclusive Production of $\pi^+\pi^-$

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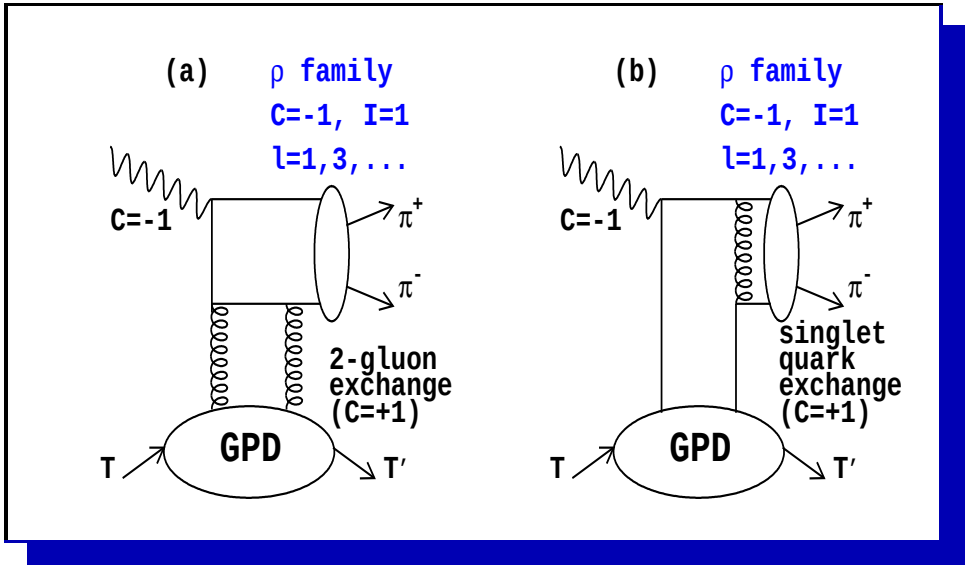

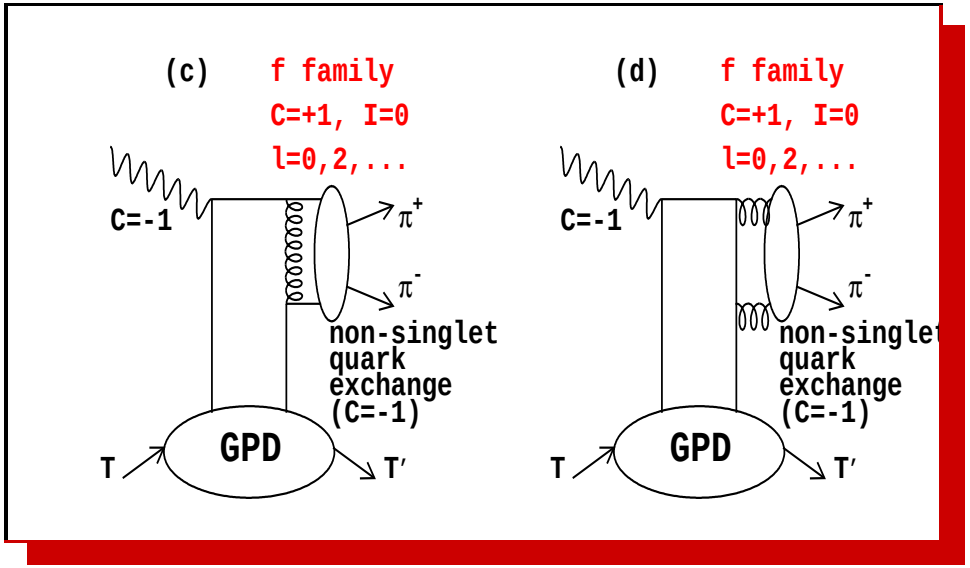

Example:

- ρ^0: $I(J^{PC})$=$1(1^{--})$

Example:

- non-resonant S-wave & f_0:

  $I(J^{PC})$=$0(0^{++})$
- f_2: $I(J^{PC})$=$0(2^{++})$

Legendre Moments

- How to highlight the elusive *f*-meson family channel?

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Spin Density Matrix:

$$\boxed{\rho^{JJ'}_{\lambda\lambda'}}$$

Legendre Moments

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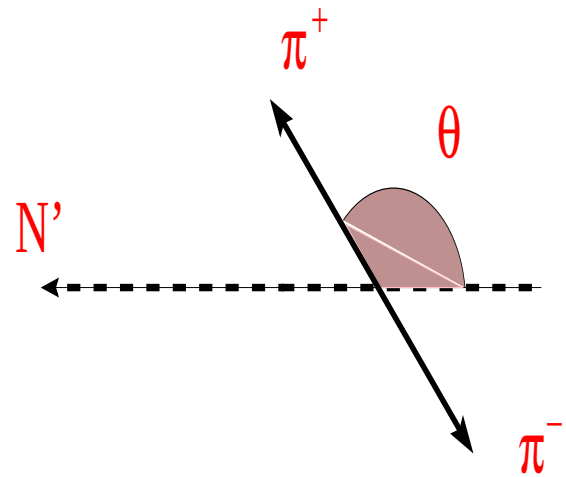
Legendre Moments:

$$\langle P_l(cos\theta)\rangle^{\pi^+\pi^-} = \frac{\int_{-1}^{1} dcos\theta\, P_l(cos\theta)\, \frac{d\sigma^{\pi^+\pi^-}}{dcos\theta}}{\int_{-1}^{1} dcos\theta\, \frac{d\sigma^{\pi^+\pi^-}}{dcos\theta}}$$



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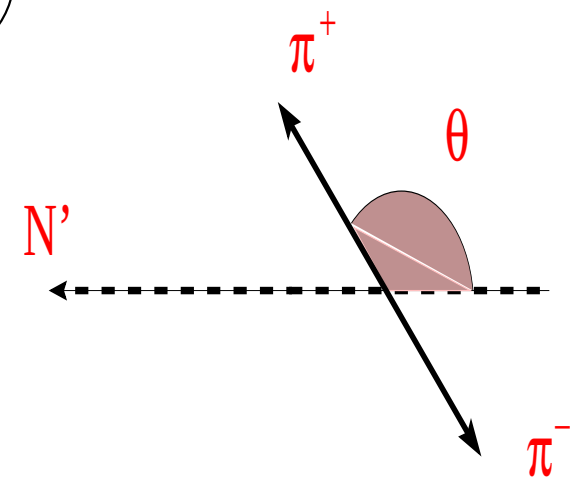

Legendre Moments

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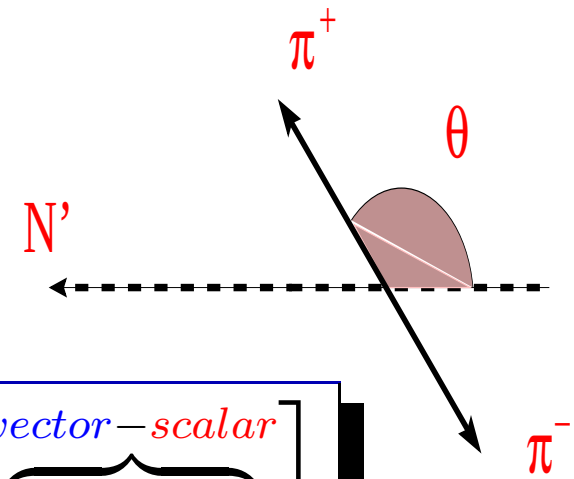
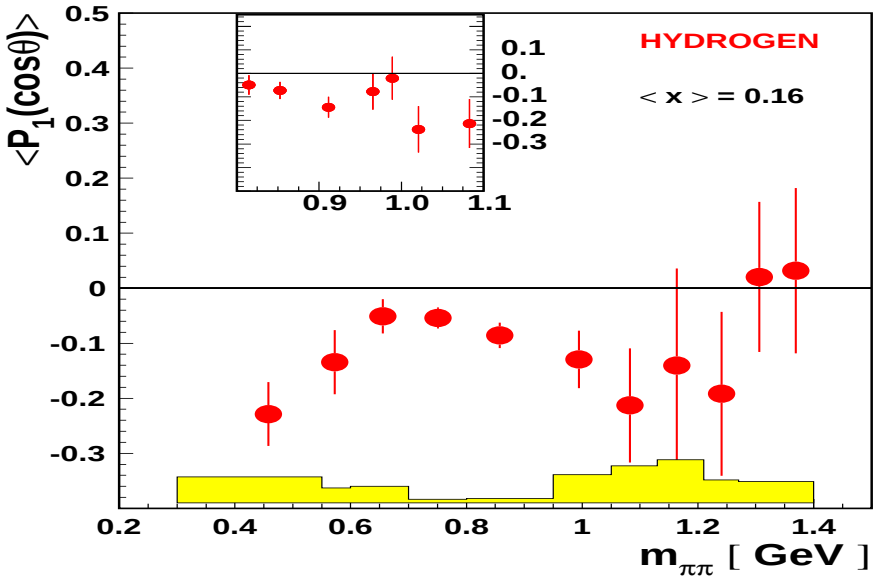


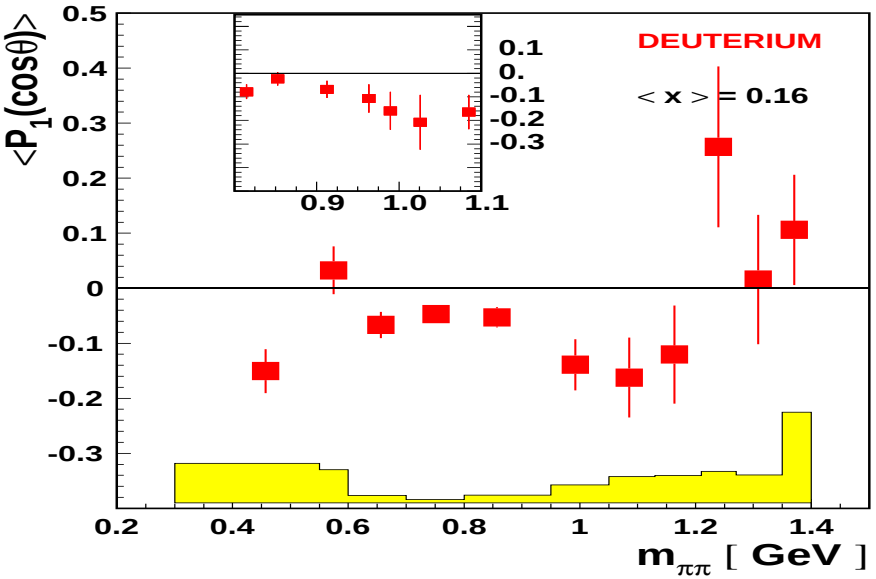
$$\langle P_1(\cos\theta)\rangle = \frac{1}{\sqrt{15}} \left[\underbrace{4\sqrt{3}\rho^{21}_{11} + 4\rho^{21}_{00}}_{tensor-vector} \overbrace{+2\sqrt{5}\rho^{10}_{00}}^{vector-scalar} \right]$$

☞ **highlighting elusive *f*-meson family channel through its interference with dominating ρ^o-meson**

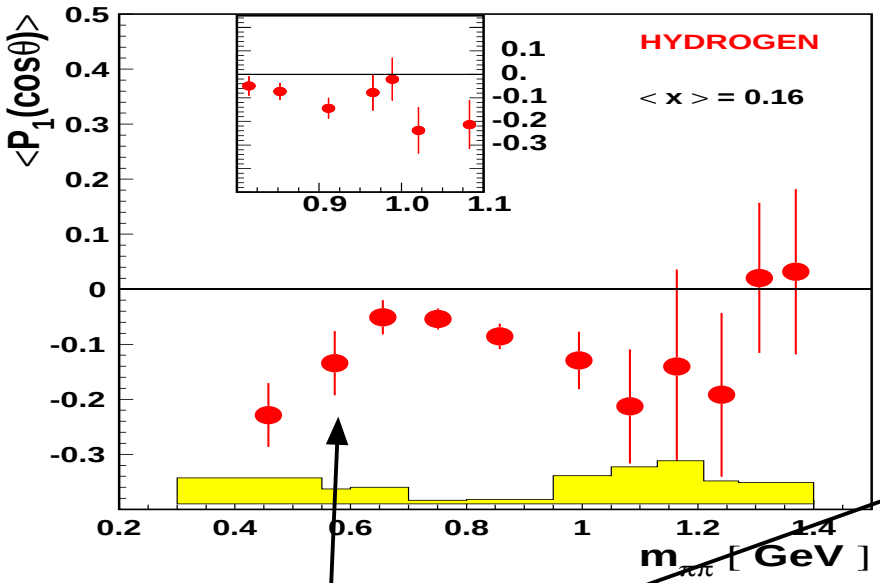
☞ **Sensitivity to the interference by measuring $\langle P_1(\cos\theta)\rangle$**

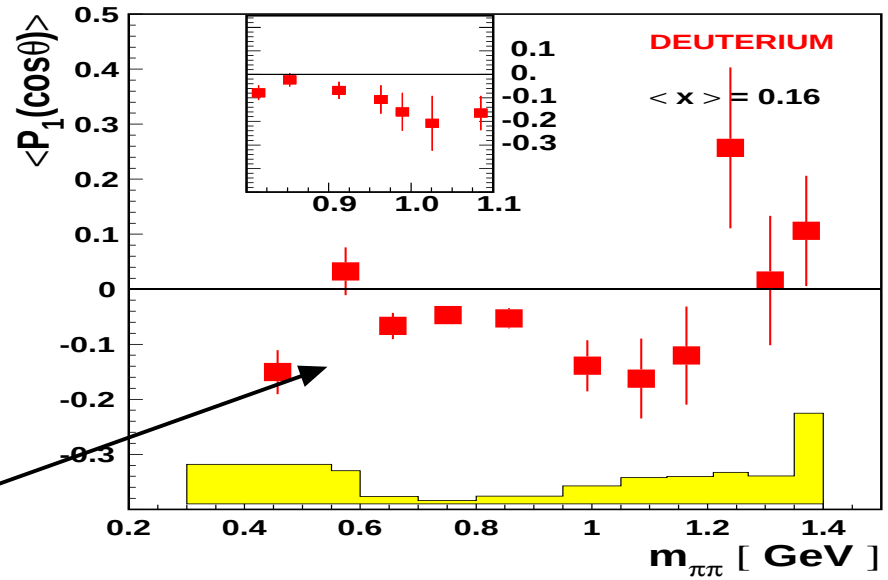
$m_{\pi\pi}$-dependence of $\langle P_1(cos\theta)\rangle$





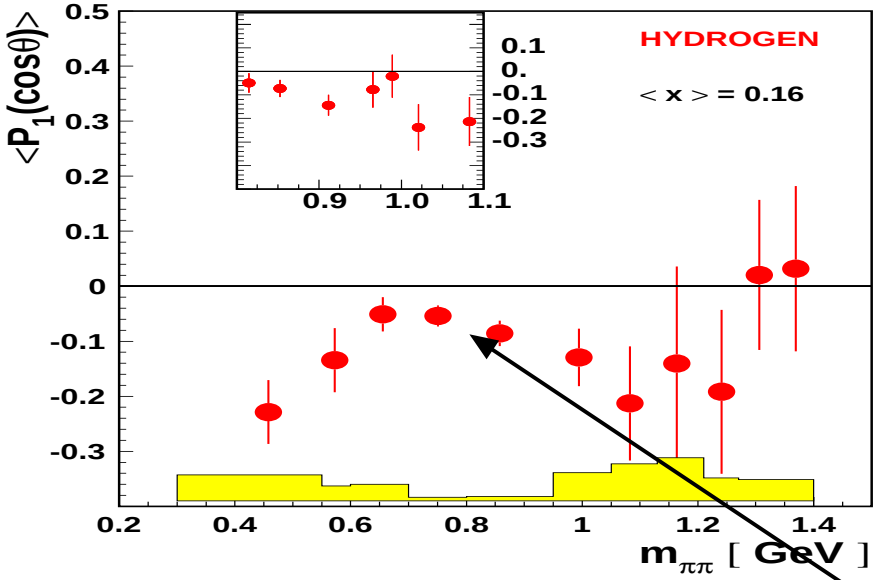
$m_{\pi\pi}$-dependence of $\langle P_1(cos\theta)\rangle$

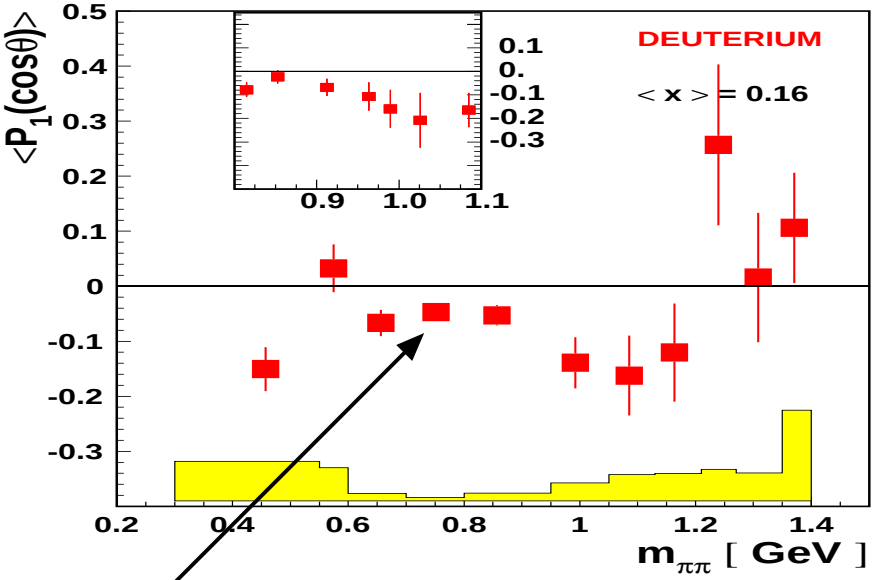




Interference between non-resonant S-wave and lower ρ^0 tail $m_{\pi\pi} < 0.6$ GeV

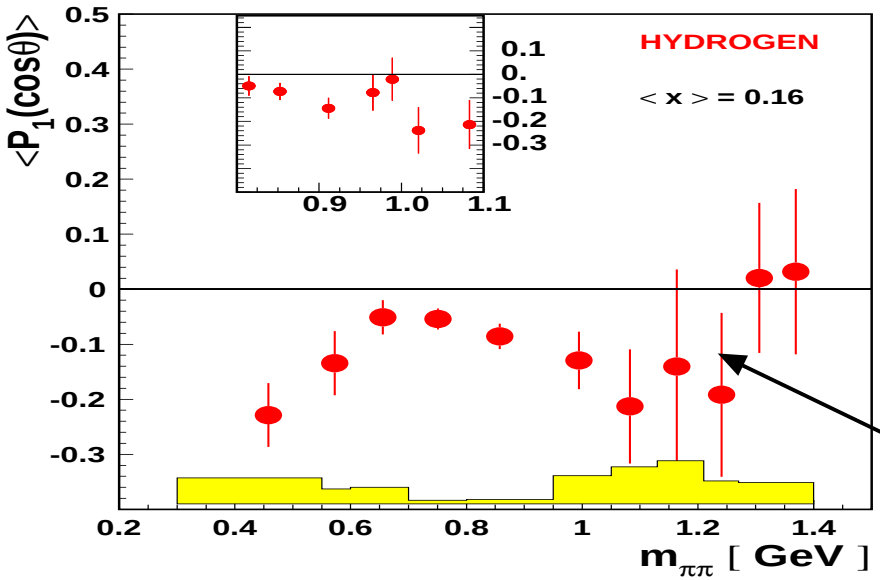
$m_{\pi\pi}$-dependence of $\langle P_1(cos\theta)\rangle$

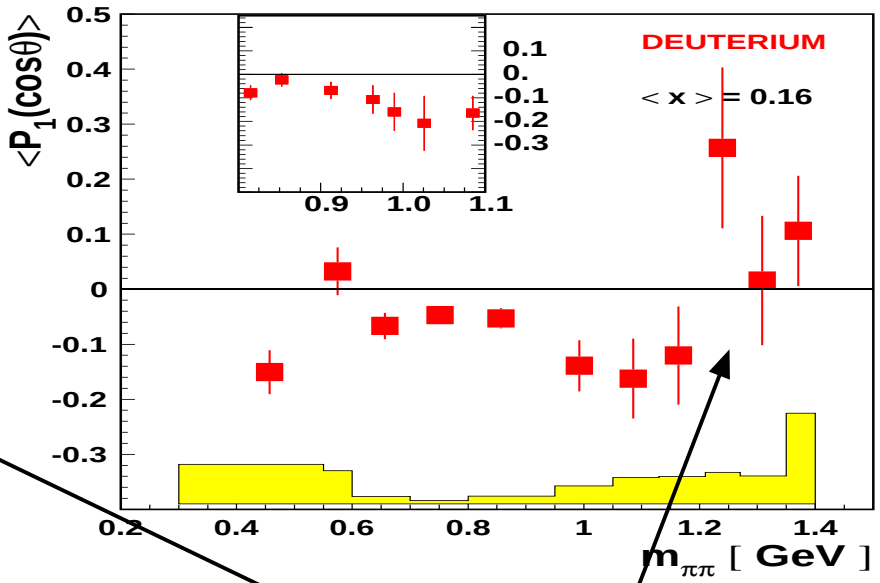




Minimum interference between S-P waves $m_{\pi\pi} \sim 0.77$ GeV

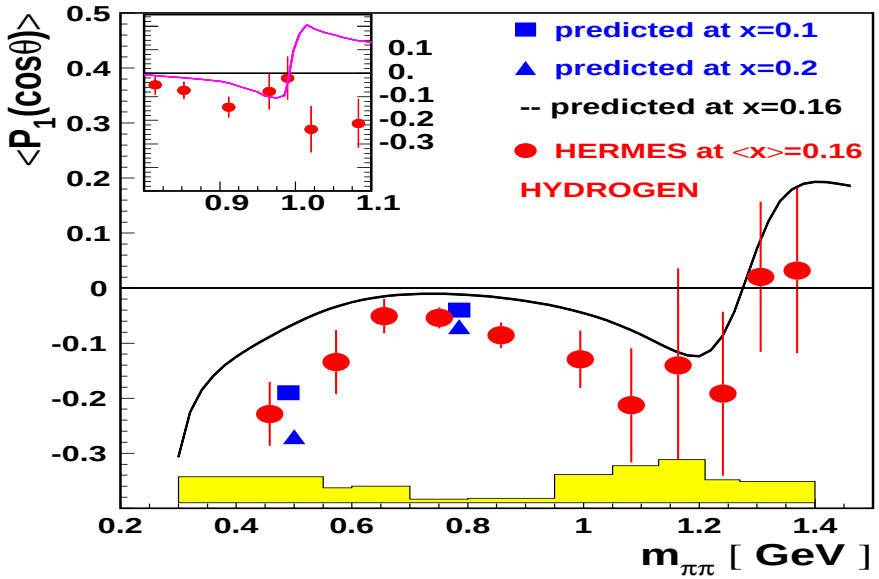
$m_{\pi\pi}$-dependence of $\langle P_1(cos\theta)\rangle$

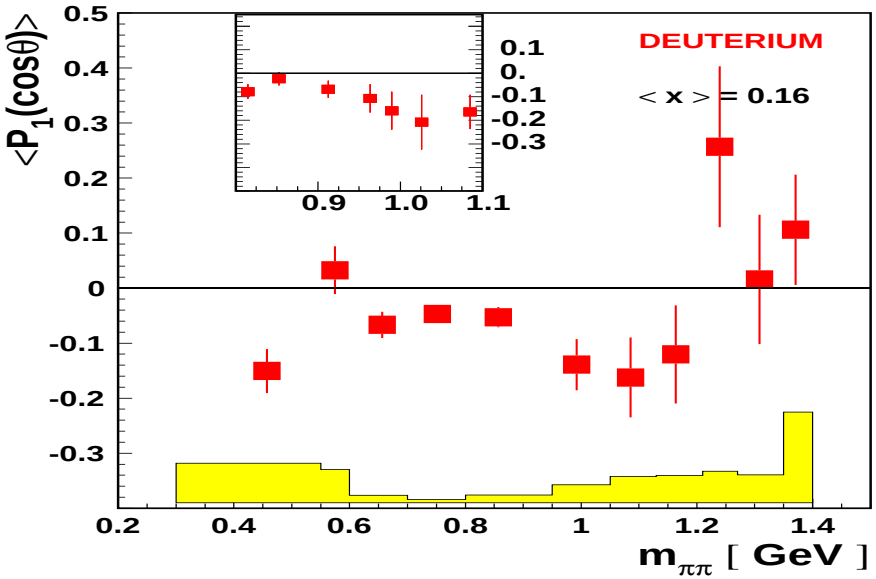




Indication of ρ^0-f_2 interference $m_{\pi\pi} \sim 1.3$ GeV

$m_{\pi\pi}$-dependence of $\langle P_1(cos\theta)\rangle$





- B.Lehmann-Dronke, P.V.Pobylitsa, M.V.Polyakov, A.Schäfer, K.Goeke:
  - Phys. Lett. B **475**, (2000) 147, $\Rightarrow$ **gluon *GPD* neglected**
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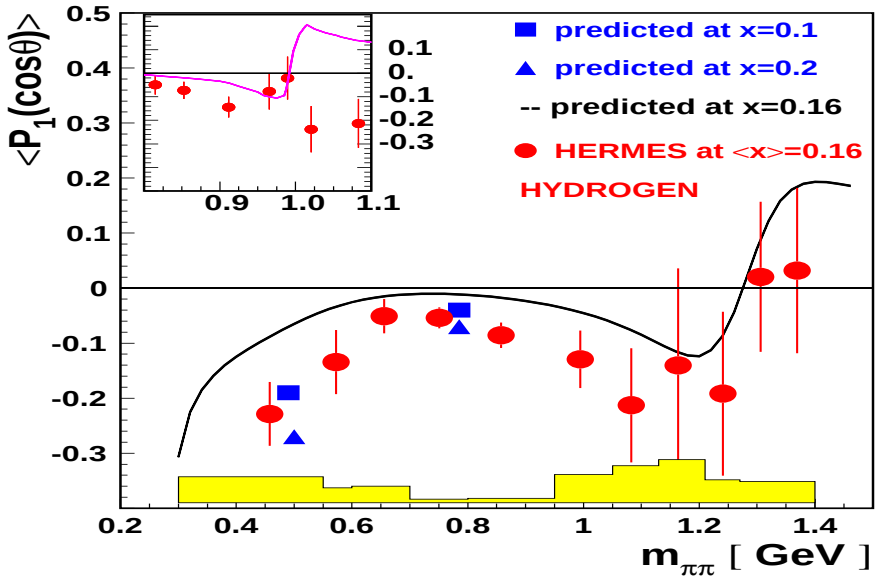
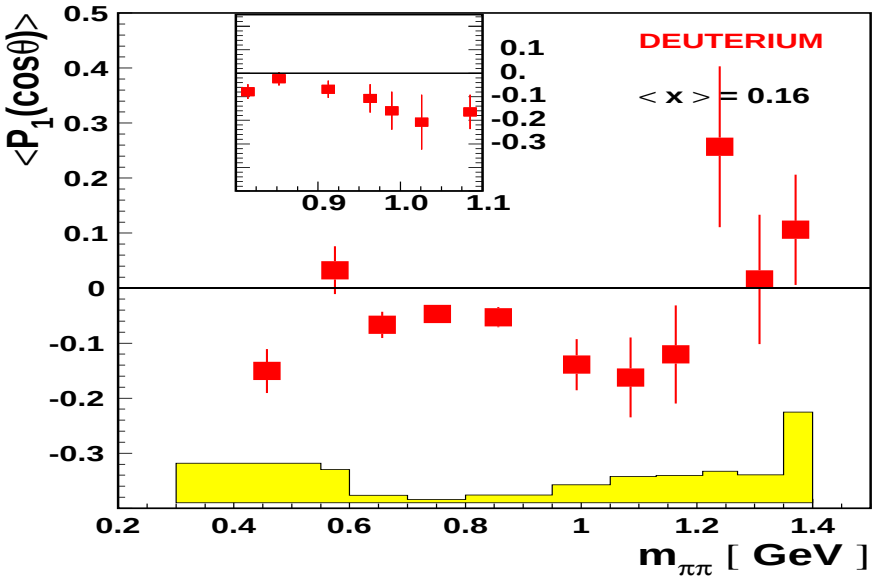
$m_{\pi\pi}$-dependence of $\langle P_1(cos\theta)\rangle$





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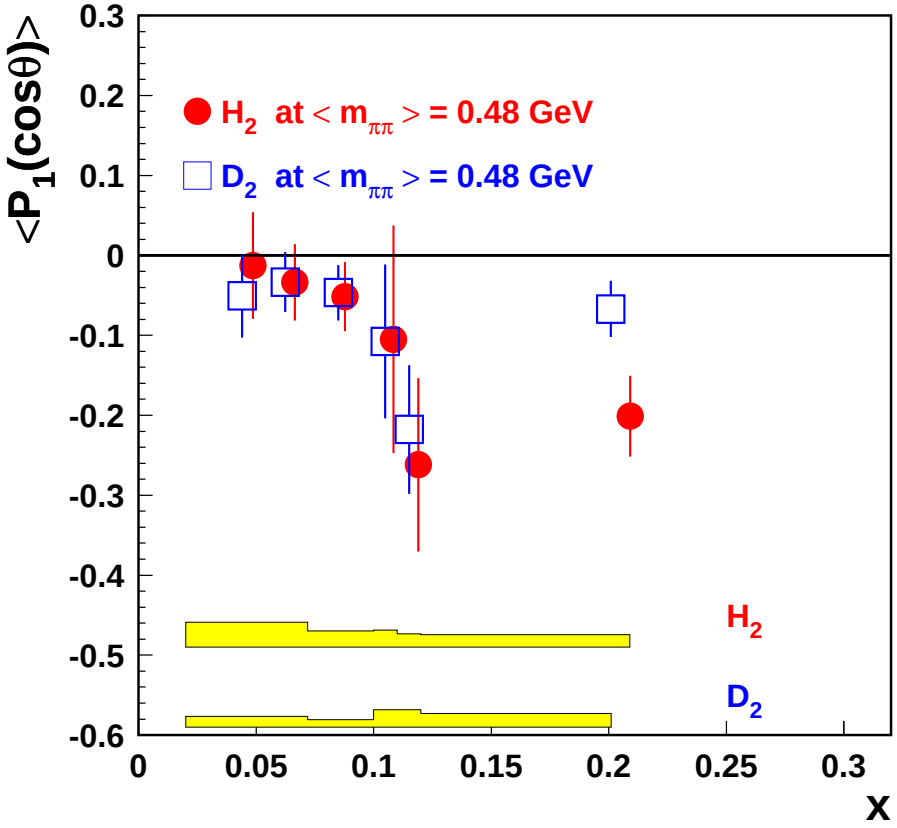
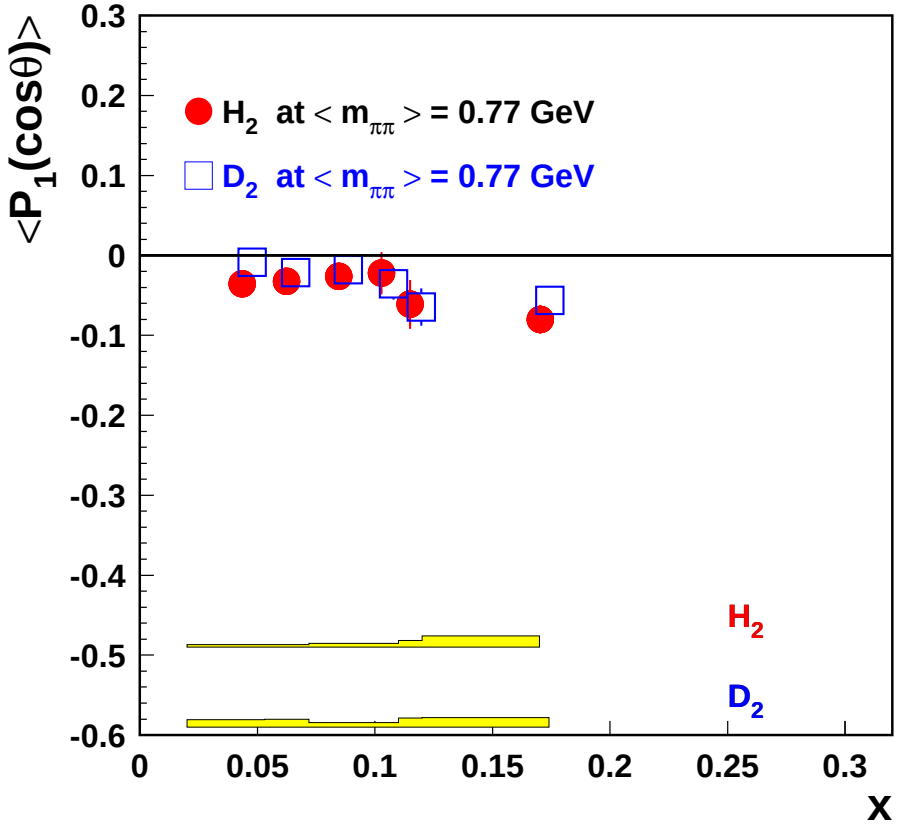
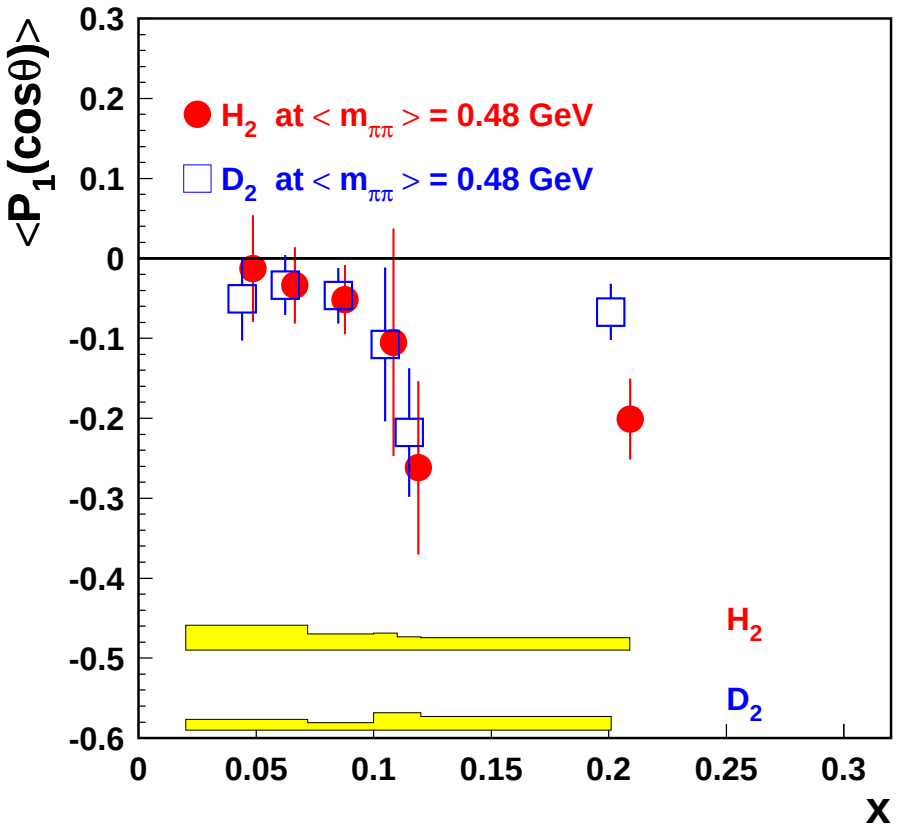
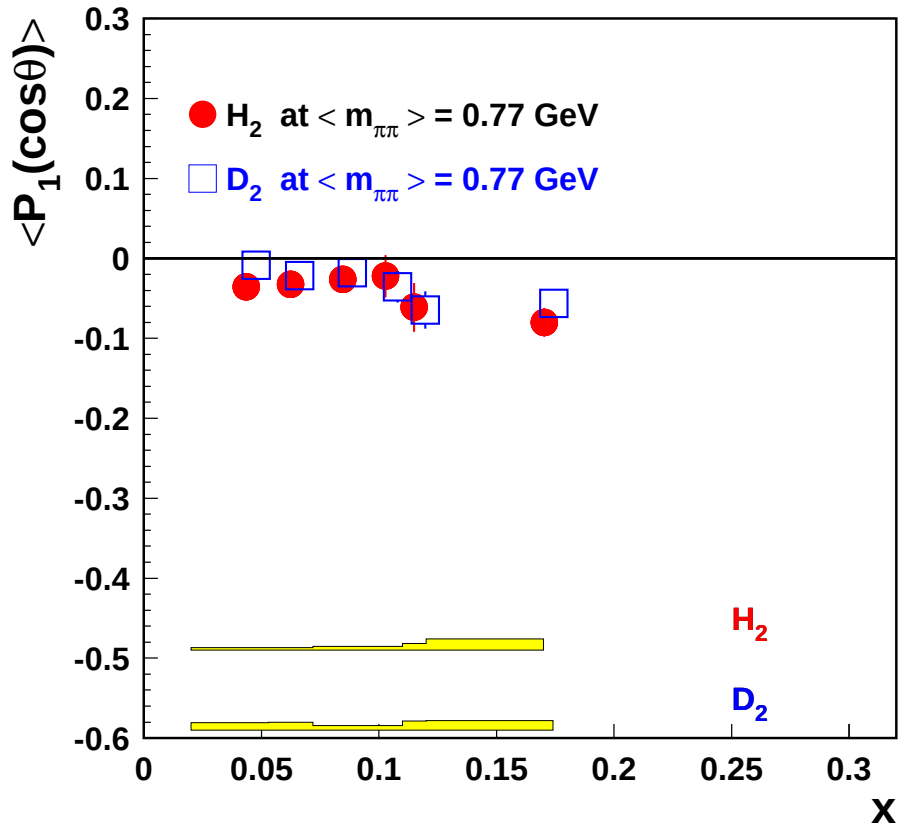
x-dependence of $\langle P_1(cos\theta)\rangle$





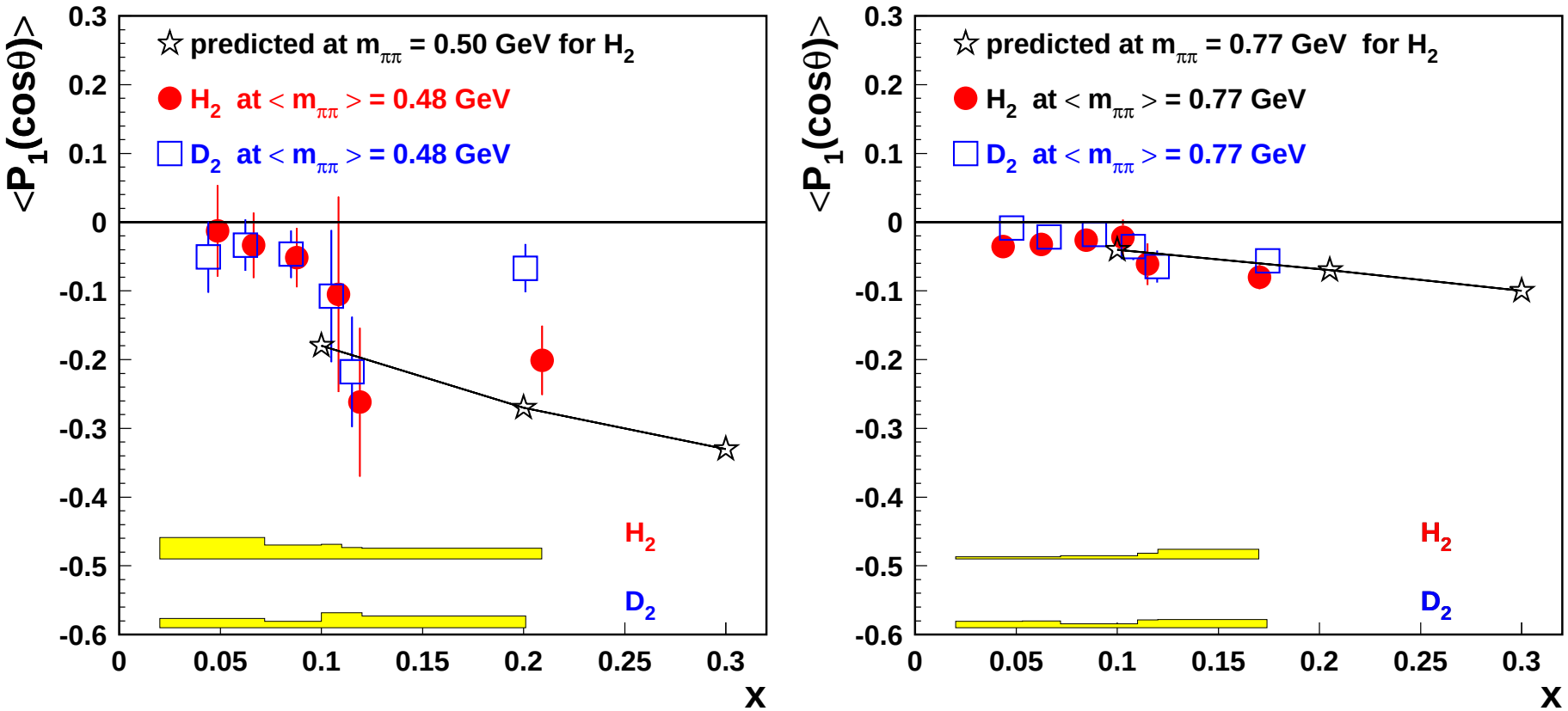
x-dependence of $\langle P_1(cos\theta)\rangle$





Increasing interference vs increasing x
between non-resonant S-wave and ρ^0
$\Rightarrow$ **increased contribution of non-singlet $q\bar{q}$ exchange**

x-dependence of $\langle P_1(cos\theta)\rangle$



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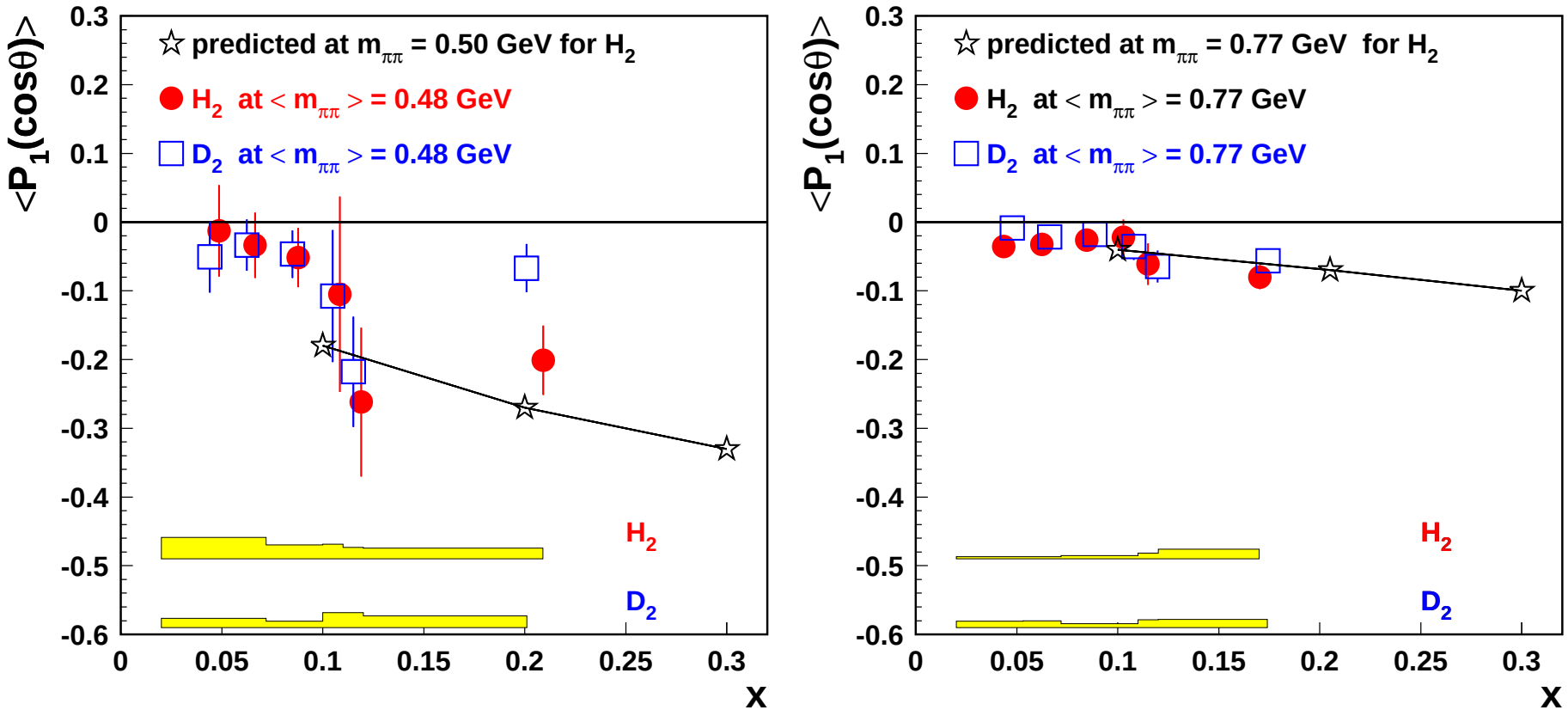
x-dependence of $\langle P_1(cos\theta)\rangle$



- B.Lehmann-Dronke, P.V.Pobylitsa, M.V.Polyakov, A.Schäfer, K.Goeke:
  - ☞ Phys. Lett. B **475**, (2000) 147 $\Rightarrow$ **gluon** *GPD* **neglected**

Reasonable agreement of theory with data

Conclusions (1)

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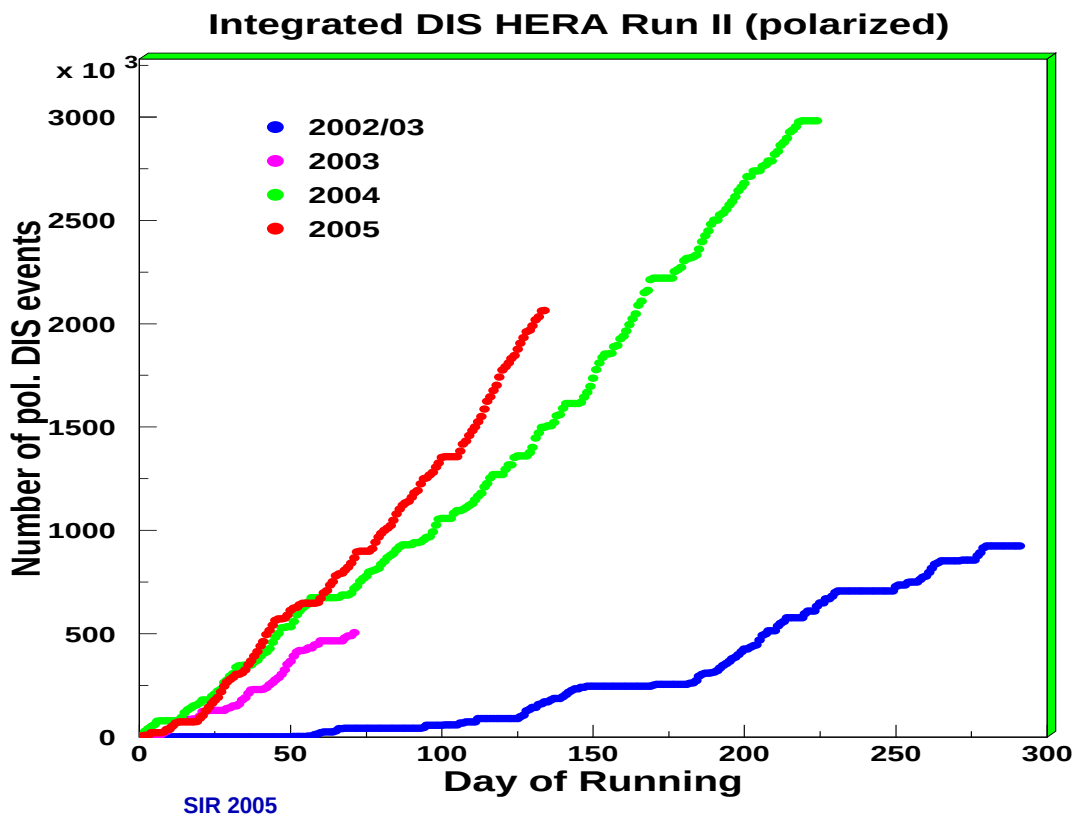
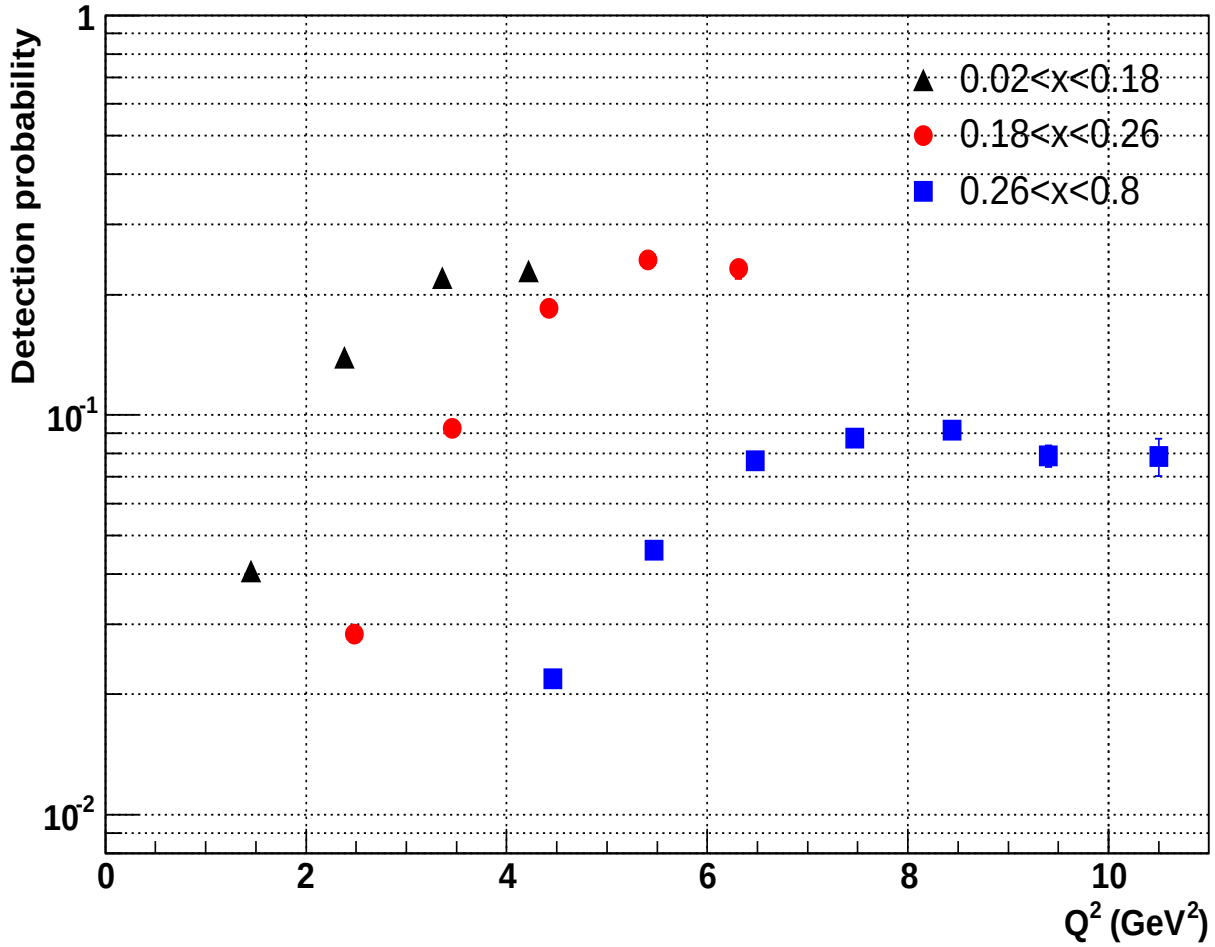
Near future:

☞ **Interesting results expected from all data including 2005 running**



Exclusive π^+: Acceptance Correction

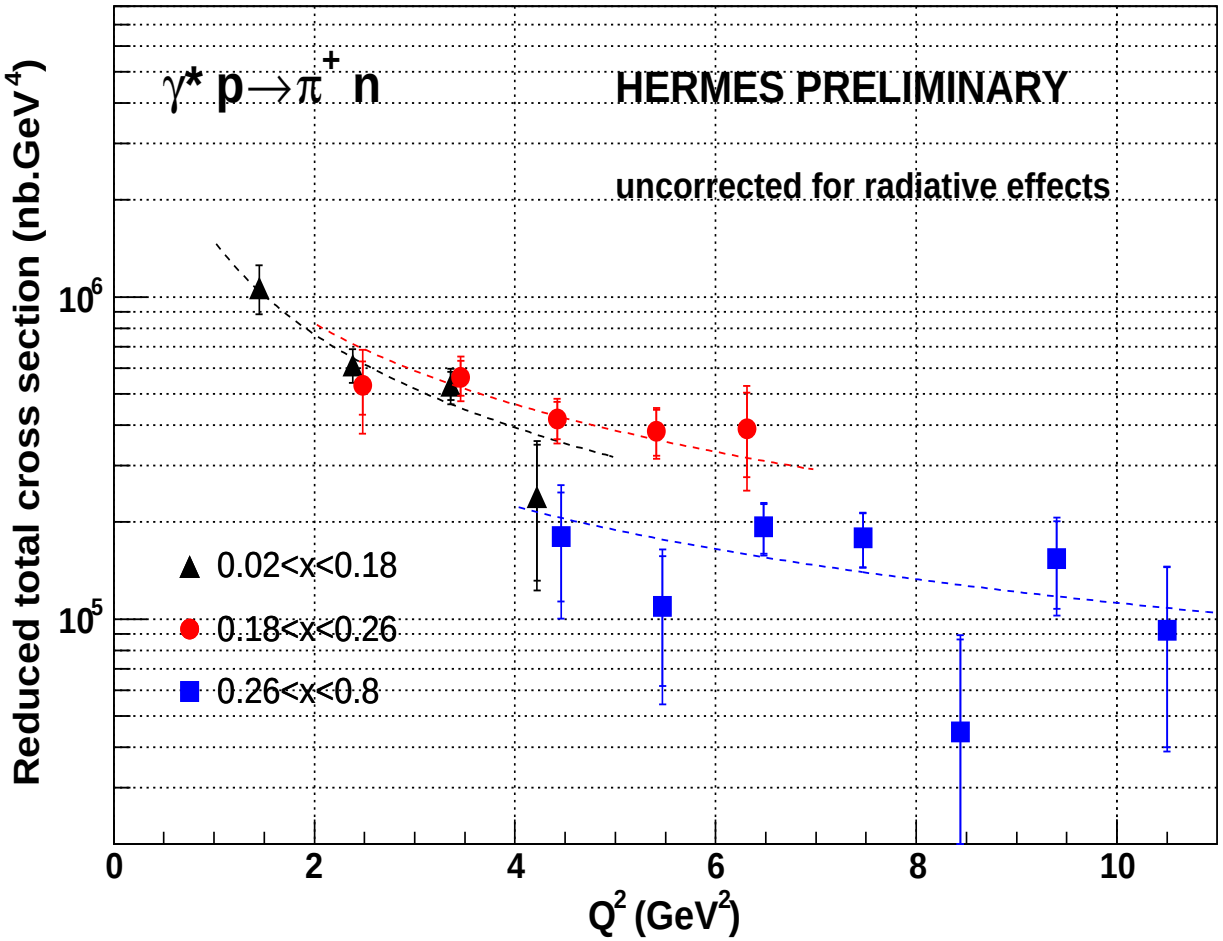
- Acceptance correction found to be model dependent
- Comparison with two different models made and included in the systematics



Exclusive π^+: Reduced X_section

- **Reduced X_section σ_{red} defined as**

$$\sigma_{tot} = \frac{1}{16\pi}\frac{x^2}{1-x}\frac{1}{Q^4}\frac{1}{\sqrt{(1+\frac{4x^2M_p^2}{Q^2})}}\cdot\sigma_{red}$$



Fit of the form: $1/Q^p$:

$$p = 1.9 \pm 0.5$$

$$p = 1.7 \pm 0.6$$

$$p = 1.5 \pm 1.0$$

- agreement with theoretical expectation $1/Q^2$ at fixed x and t