Exclusive electro-production of pions and vector mesons at HERMES

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On behalf of HERMES collaboration

- √ Hard exclusive π^+ production
- √ Exclusive $\pi^+\pi^-$ pair production
- √ Exclusive ρ^0 and ϕ production

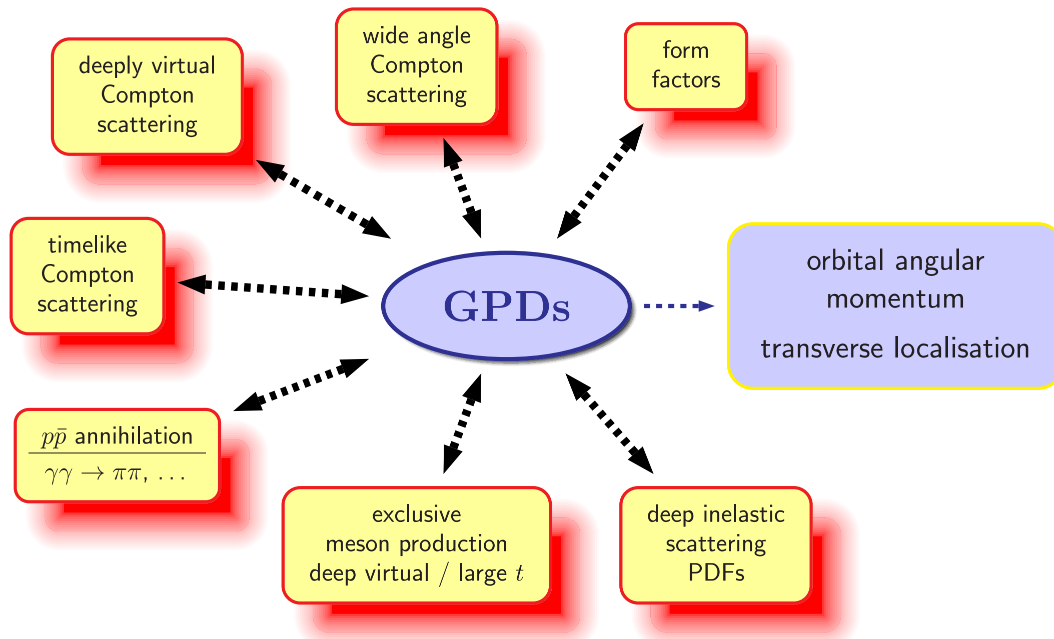
World of GPDs

QCD factorization theorem was proved in the case of $\gamma_L^* N \rightarrow M N'$ reaction at large Q^2 and low t.

At leeding twist nucleon is parametrized by E, H, $\tilde{E}$, $\tilde{H}$ - four Generalized Parton Distributions.

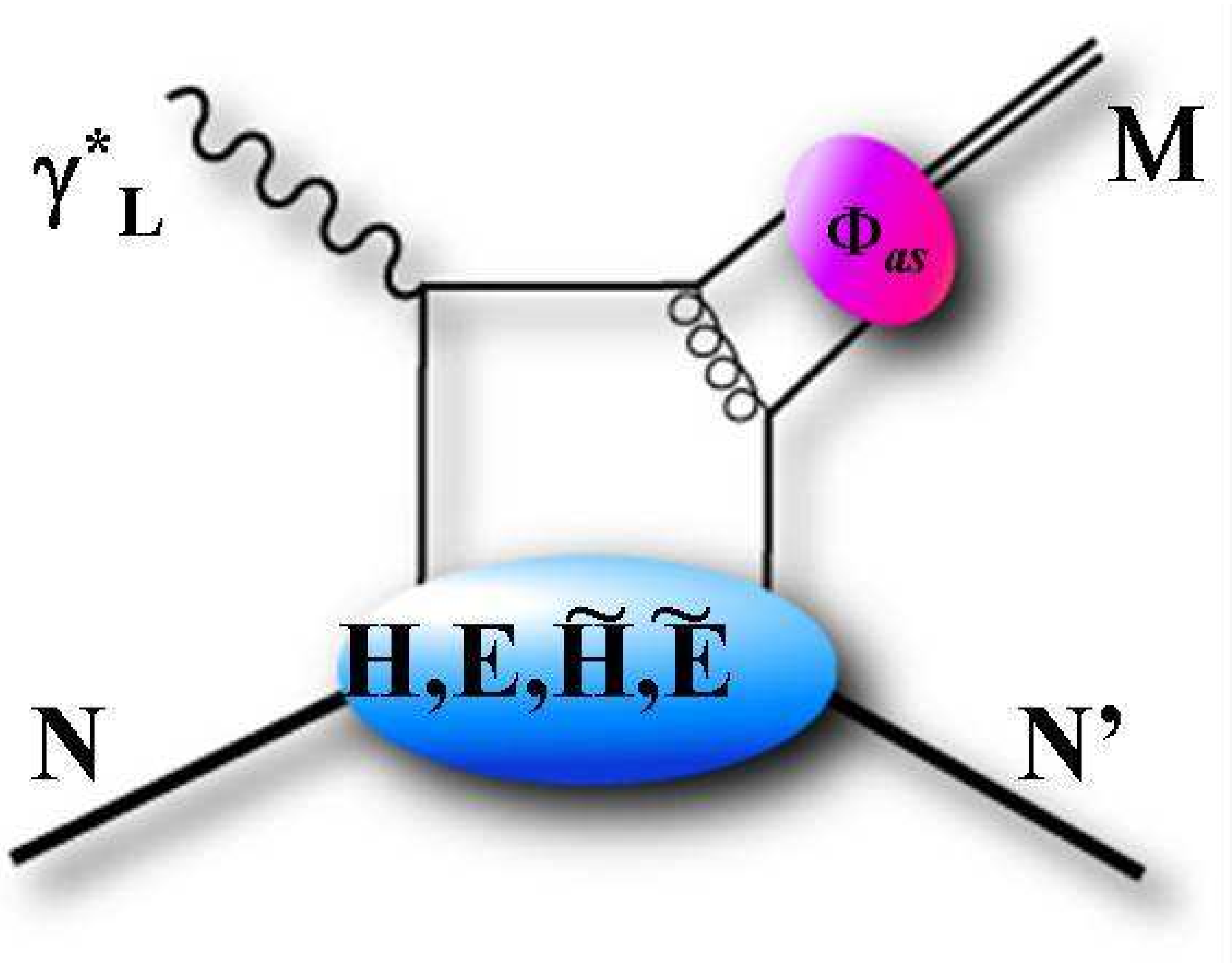
Quantum numbers of the produced mesons and different observables, like cross section and SSA select different combinations of GPDs.

HERMES

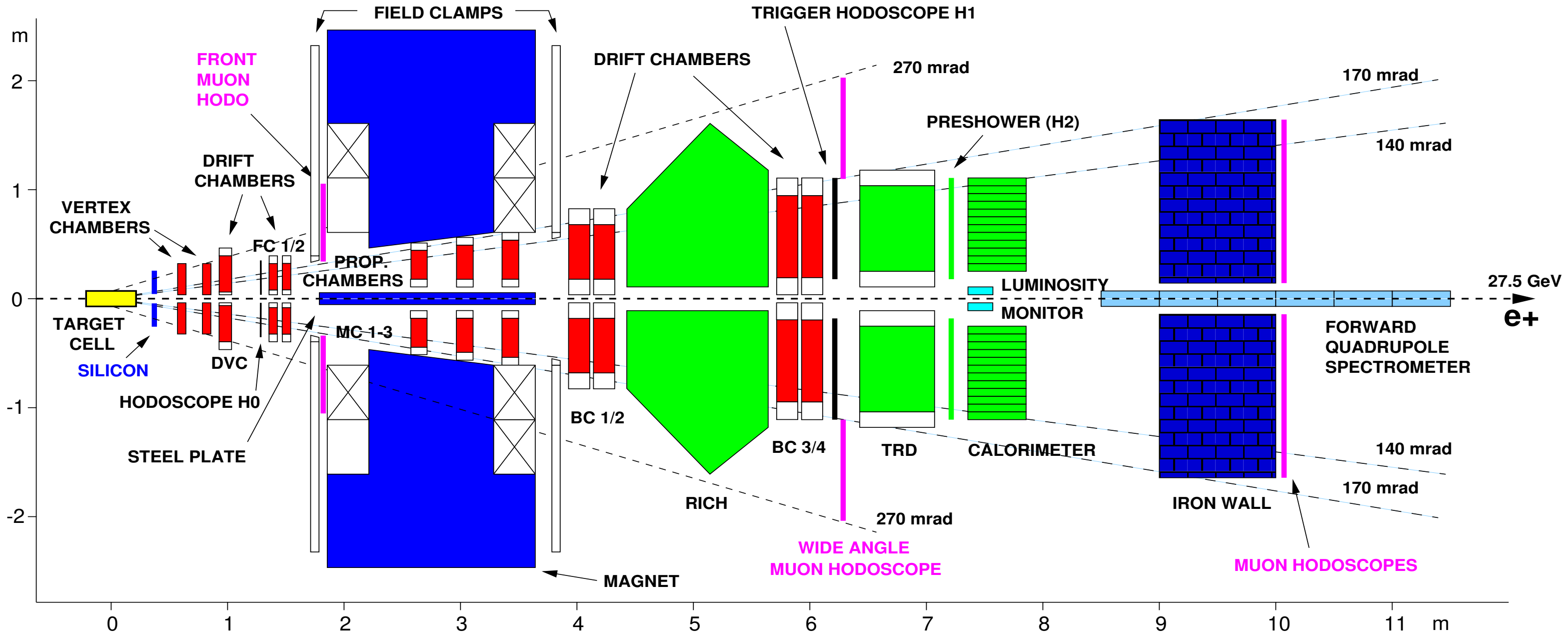


HERMES

Hard exclusive meson production



HERMES



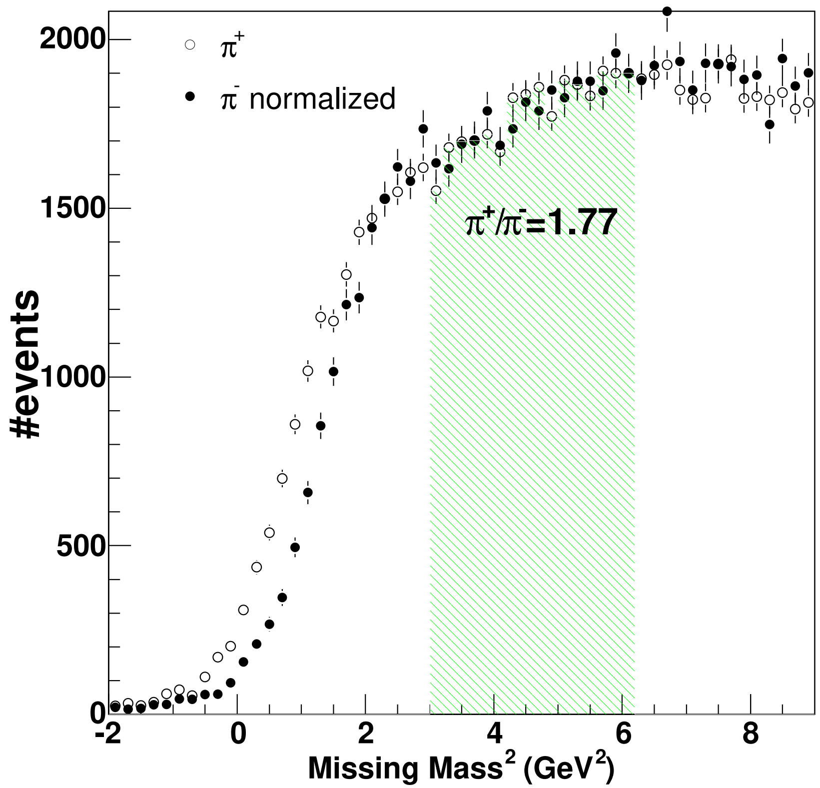
Exclusive π^+ cross section : data from 1996 to 2000 on H and $\vec{H}$ targets.

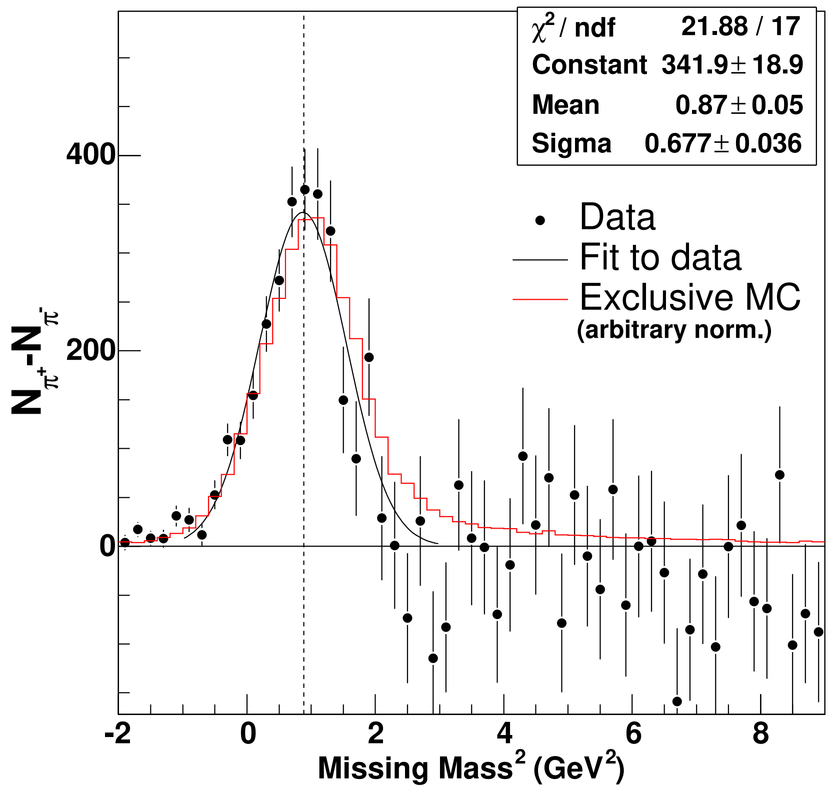
Exclusive π^+ target SSA: 1997 year data on $\vec{H}$ target.

Exclusive ρ^0, ϕ and $\pi^+\pi^-$: data from 1996 to 2000 on H, $\vec{H}$ and $\vec{D}$ targets.

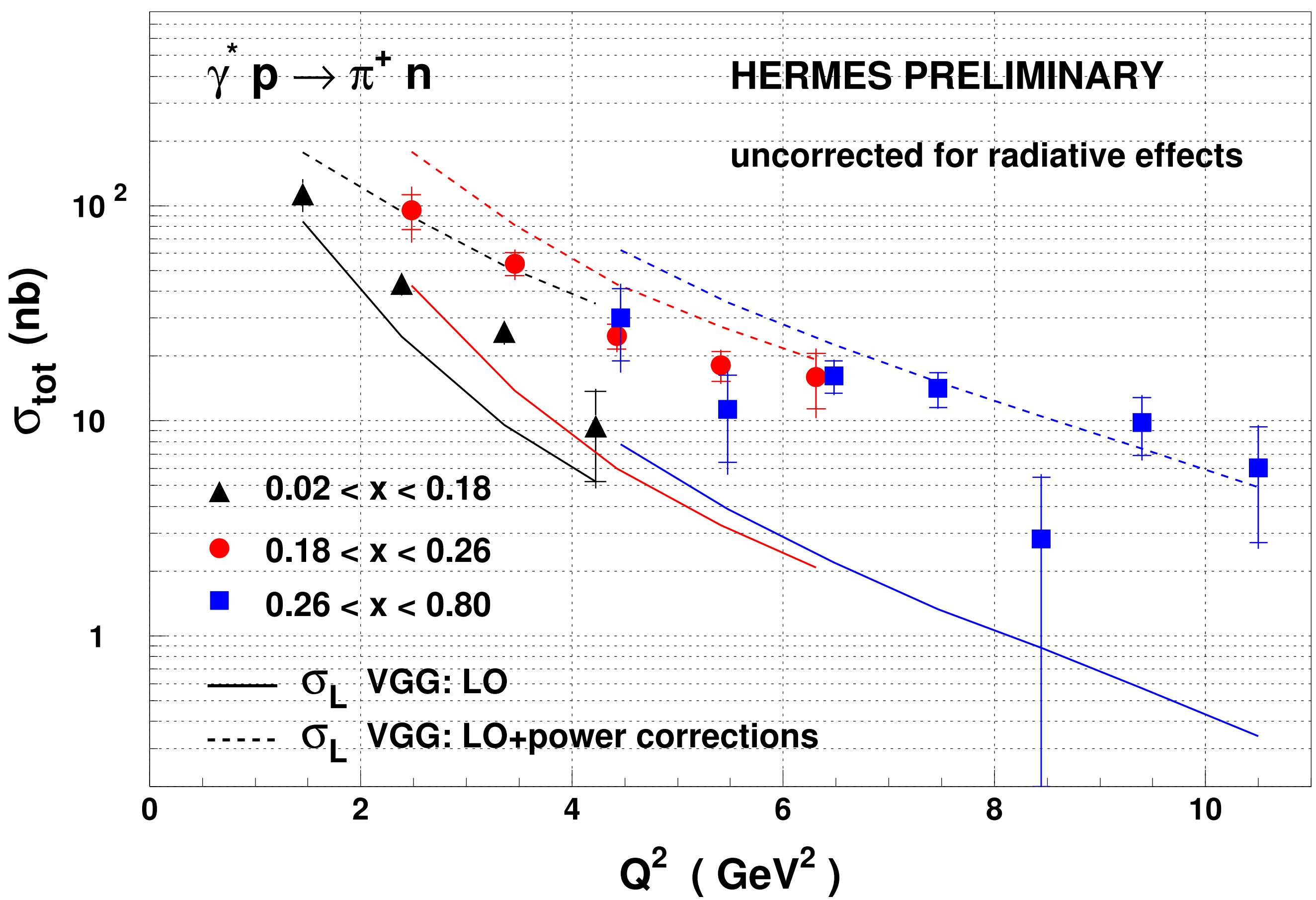
Exclusivity for $ep \rightarrow e\pi^+(n)$

The recoiling neutron was not detected, and so exclusive production was selected by requiring that the missing mass M_X corresponds to the nucleon mass, the process $ep \rightarrow e\pi^- X$ being used to subtract non-exclusive channels.





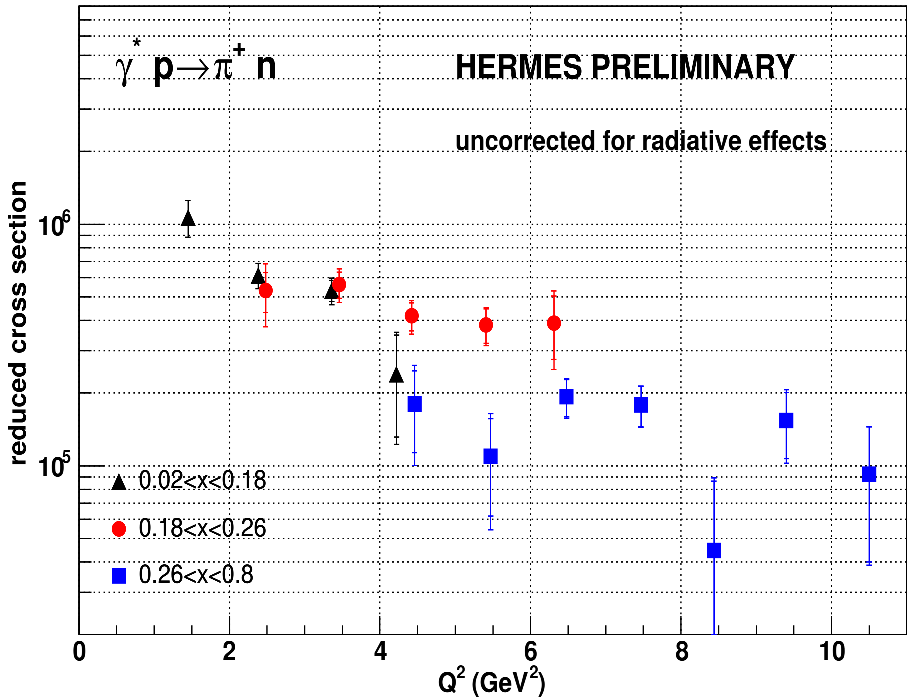
π^+ production cross section



Calculations for the longitudinal part of the cross section computed from GPD model by Vanderhaegen, Guichon and Guidal [Phys.Rev.Lett. 80(1998)5064].

$$\sigma = \sigma_T + \epsilon\sigma_L \; , \qquad \frac{\sigma_T}{\sigma_L} = O(\frac{1}{Q^2}) \; , \qquad \epsilon = 0.8 \div 0.95$$

Reduced cross section for π^+ production



σ_L =Kin factor * $\sum_i |M_i|^2$

Kin factor = $O(\frac{1}{Q^4})$,

$\Leftarrow \sum_i |M_i|^2 = O(\frac{1}{Q^2})$

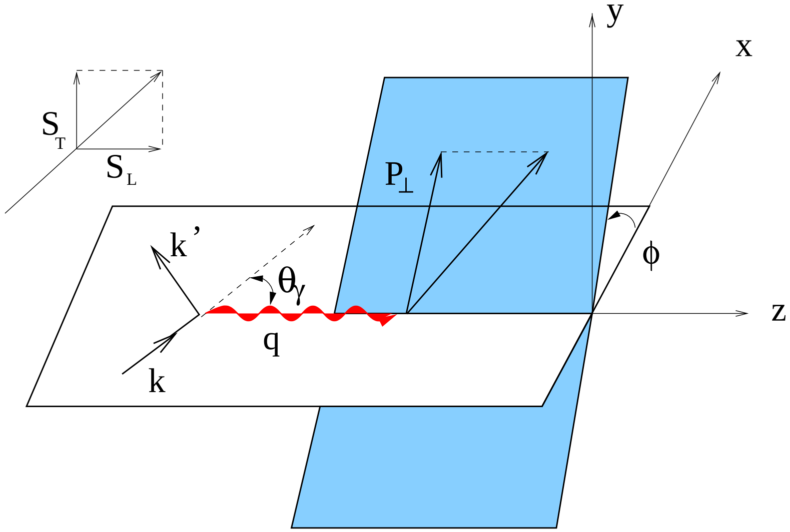
A fit of the form $\frac{1}{Q^p}$ leads to

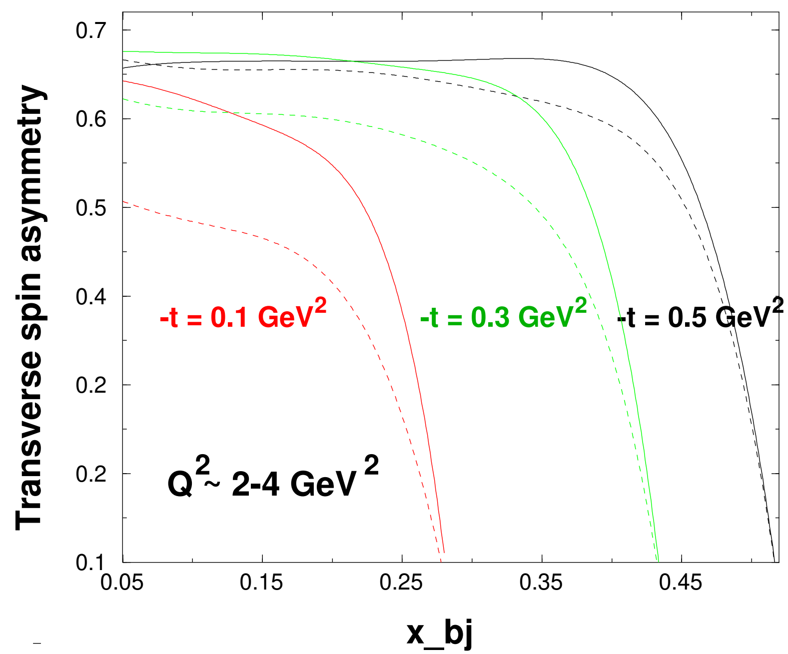
$$p = 1.9 \pm 0.5\ , \qquad p = 1.7 \pm 0.6\ , \qquad p = 1.5 \pm 1.0$$

respectively for the black, red and blue graphs.

Large single-spin asymmetries in reaction $\gamma_L^* + \vec{p} \rightarrow \pi^+ + n$ have been predicted by Frankfurt, Polyakov, Strikman, Vanderhaegen [Phys.Rev.Lett. 84(2000)2589] for transversely polarized nucleon from interference of pseudo-scalar ($\tilde{E}$) and pseudo-vector ($\tilde{H}$) amplitudes.

$$\sigma_S \sim S_\perp \tilde{E}\tilde{H} \sin(\phi - \phi_s) \rightarrow A(\phi) = \frac{1}{\langle S_\perp \rangle} \frac{\overrightarrow{N} - \overleftarrow{N}}{\overrightarrow{N} + \overleftarrow{N}} = A_{\mathrm{UT}}^{\sin\phi} \cdot \sin\phi \,.$$



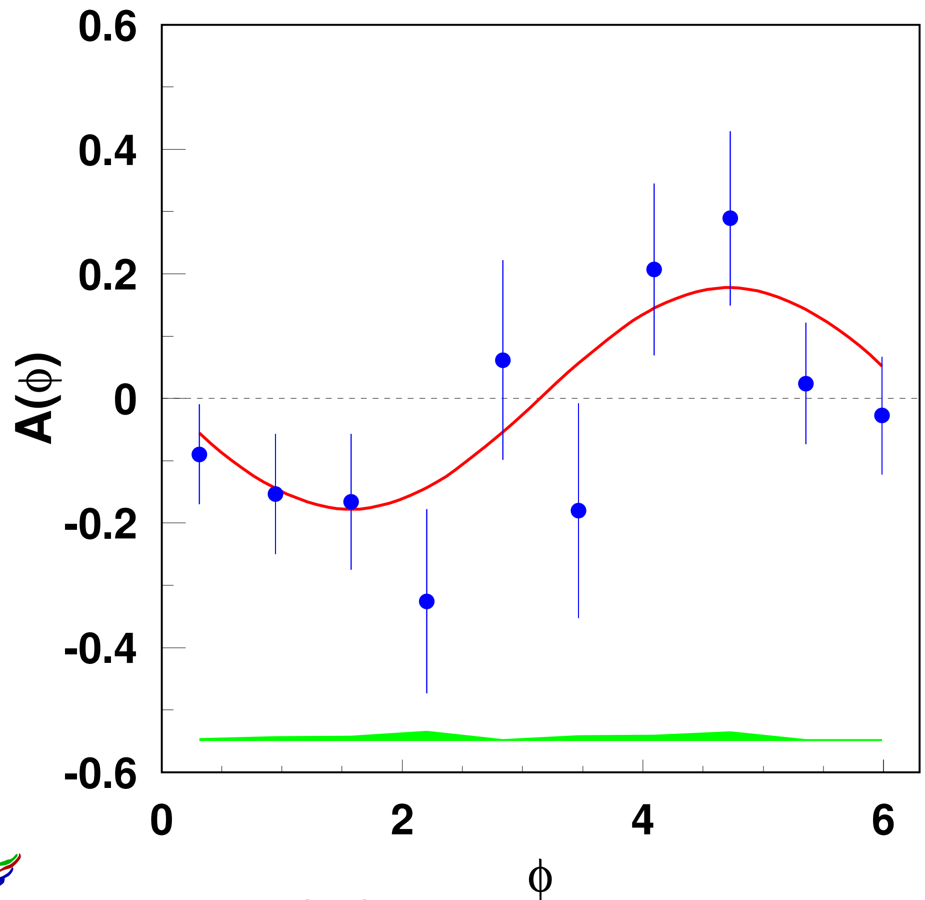


Target ($\vec{H}$) SSA of π^+

For a longitudinally polarized target and a longitudinally-transversely mixed virtual photon beam:

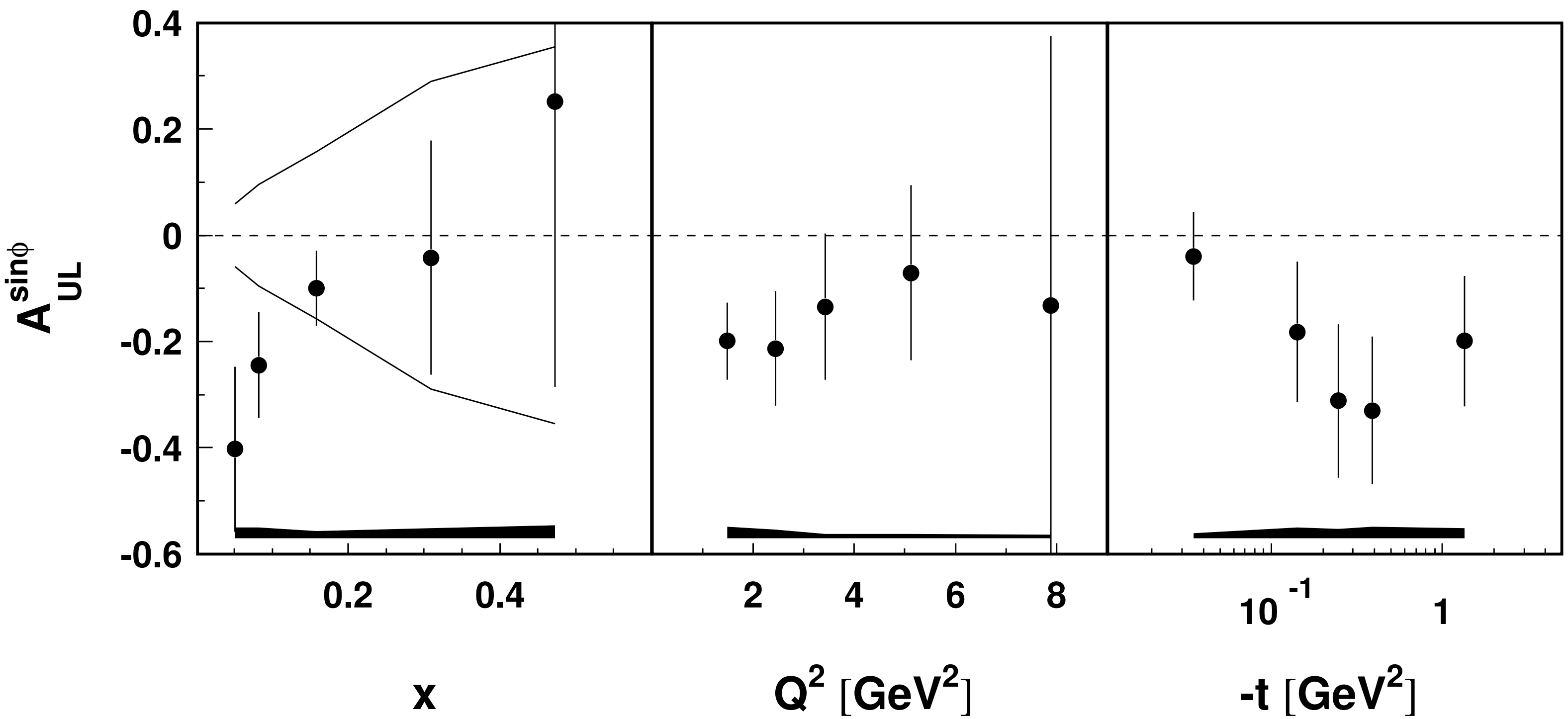
$$\boxed{\sigma_S \sim [S_\perp \sigma_{\mathcal{L}} + S_{\|} \sigma_{\mathcal{LT}}] \sin\phi \ .}$$

For HERMES kinematics : $\langle \frac{S_\perp}{|S|} \rangle = 0.17.$



Curve is the fit to the data by

$$A_{\mathrm{UL}}^{\sin\phi} = -0.18 \pm 0.05$$



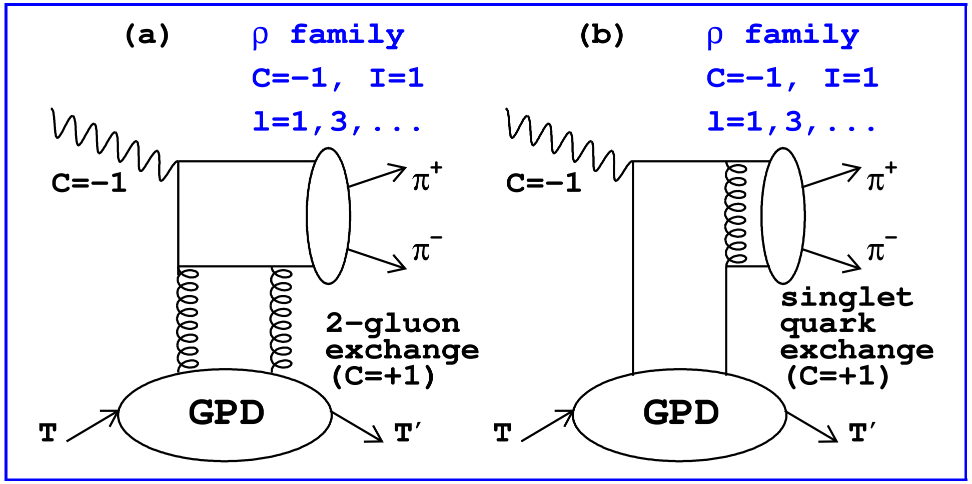
Lines indicate limits for any asymmetry due to *transverse* target polarization component.

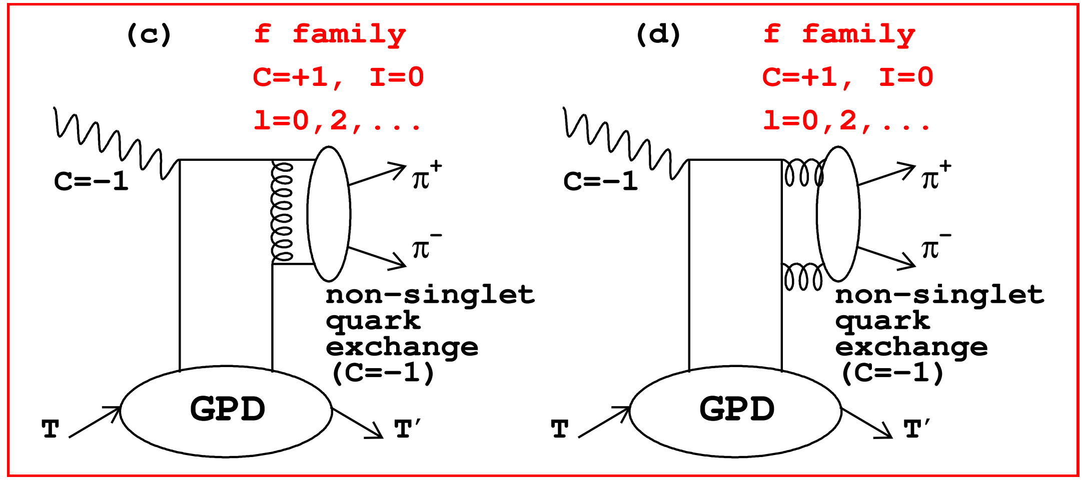
$$\boxed{\sigma_S \sim [S_\perp \sigma_{\mathcal{L}} + S_\parallel \sigma_{\mathcal{LT}}] \sin\phi \qquad \Rightarrow}$$

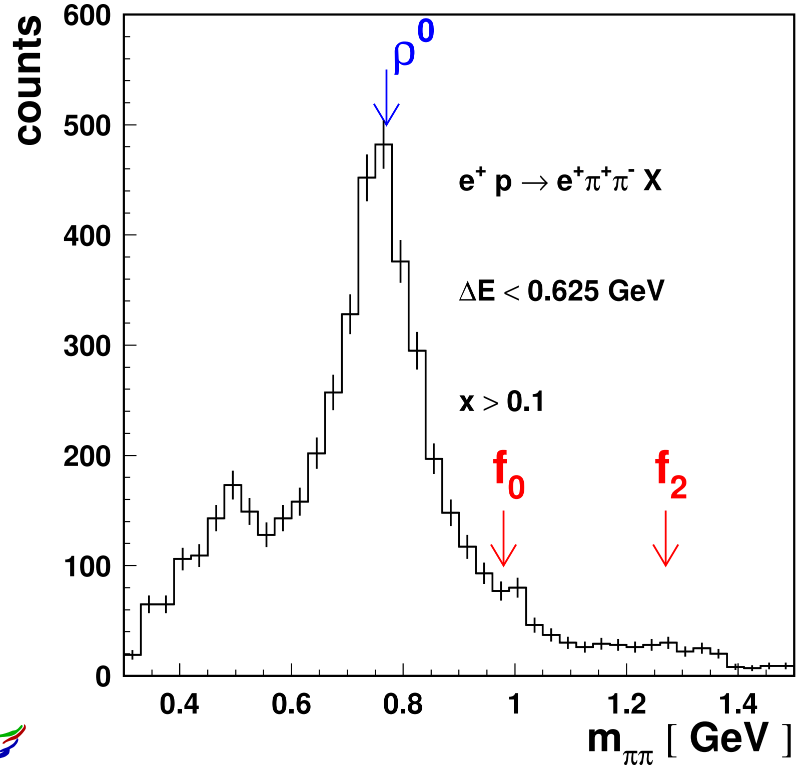
asymmetry at low x is due to *longitudinal* target polarization component

$$(\langle \frac{S_\parallel}{|S|} \rangle = 0.83\ )$$

Exclusive $\pi^+\pi^-$ pair production







Which channels may contribute?

- ρ^0: $I(J^{PC}) = 1(1^{--})$
- non-resonant S-wave & f_0: $I(J^{PC}) = 0(0^{--})$
- f_2: $I(J^{PC}) = 0(2^{--})$

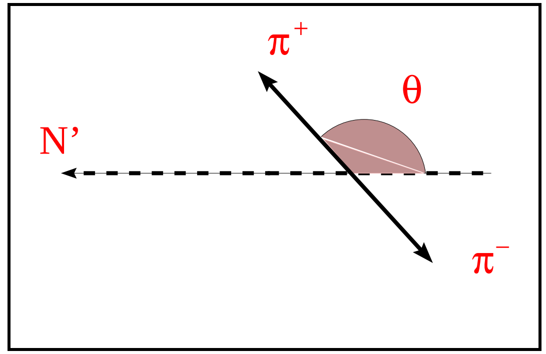
$\Leftarrow$ $m_{\pi\pi}$ region accessed at HERMES

Legendre Moments

Weak f-family channels can be highlighted via its interference with the dominated ρ-family

Legendre moment of order n of the angular distribution of π^+ mesons in the centre-of-mass frame is given by:

$$\langle P_n(\cos\theta)\rangle \equiv \frac{\int_{-1}^{1} d\cos\theta \frac{d\sigma^{\pi^+\pi^-}}{d\cos\theta} P_n(\cos\theta)}{\int_{-1}^{1} d\cos\theta \frac{d\sigma^{\pi^+\pi^-}}{d\cos\theta}}$$

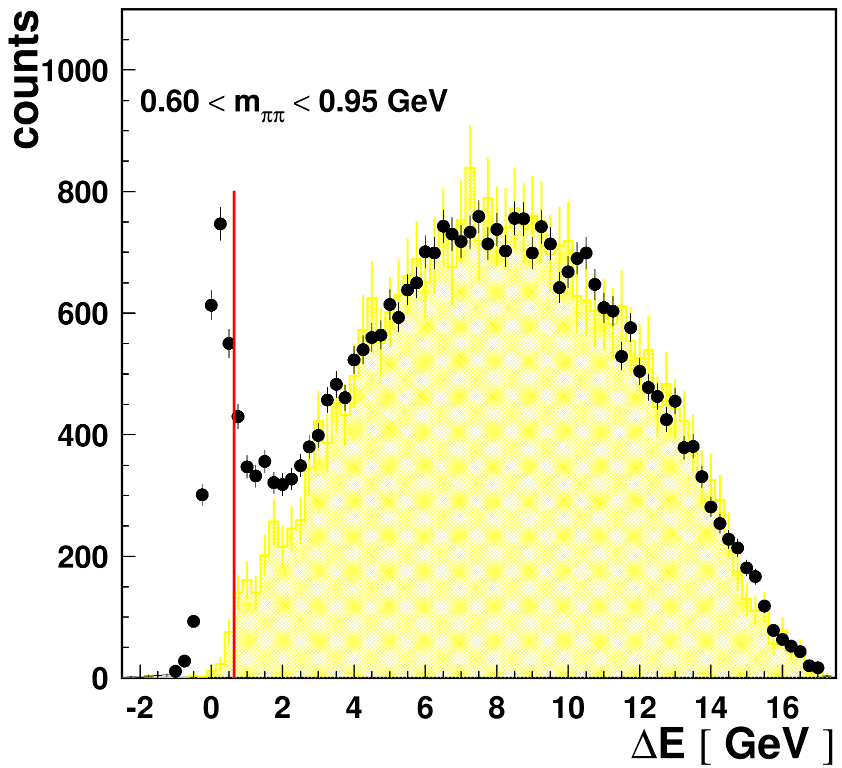


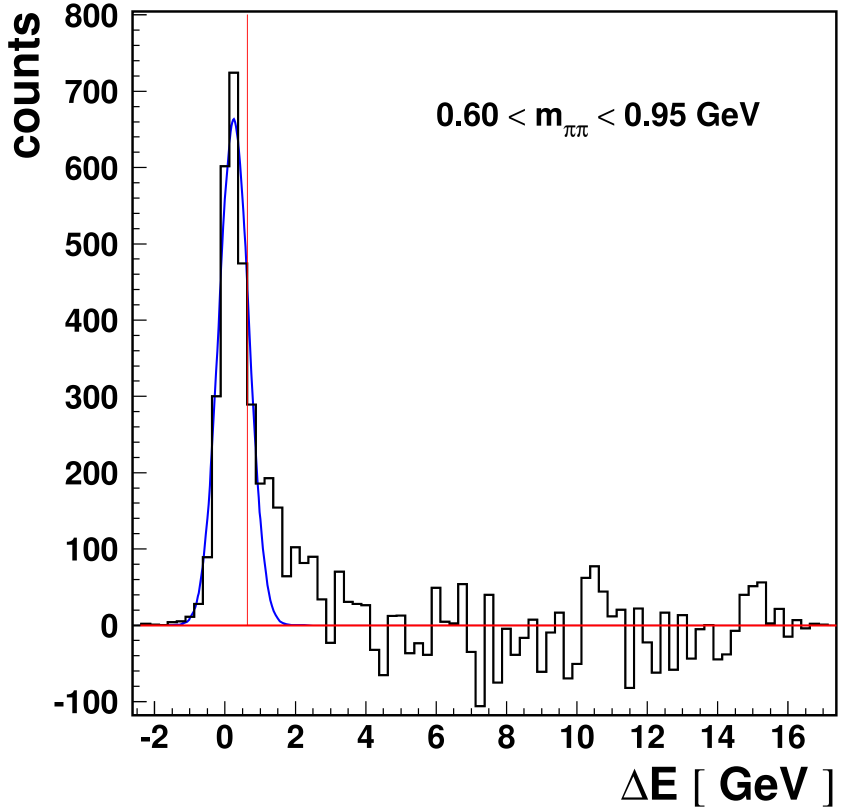
$$\frac{d\sigma^{\pi^+\pi^-}}{d\cos\theta} \propto \sum_{JJ'\lambda\lambda'} \rho^{JJ'}_{\lambda\lambda'} \Upsilon_{J\lambda}(\theta,\phi)\Upsilon^*_{J'\lambda'}(\theta,\phi)$$

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

Exclusive $\pi^+\pi^-$ pair production

Exclusive events: $\Delta E \equiv \frac{M_X^2 - M_P^2}{2M_p} \approx 0$

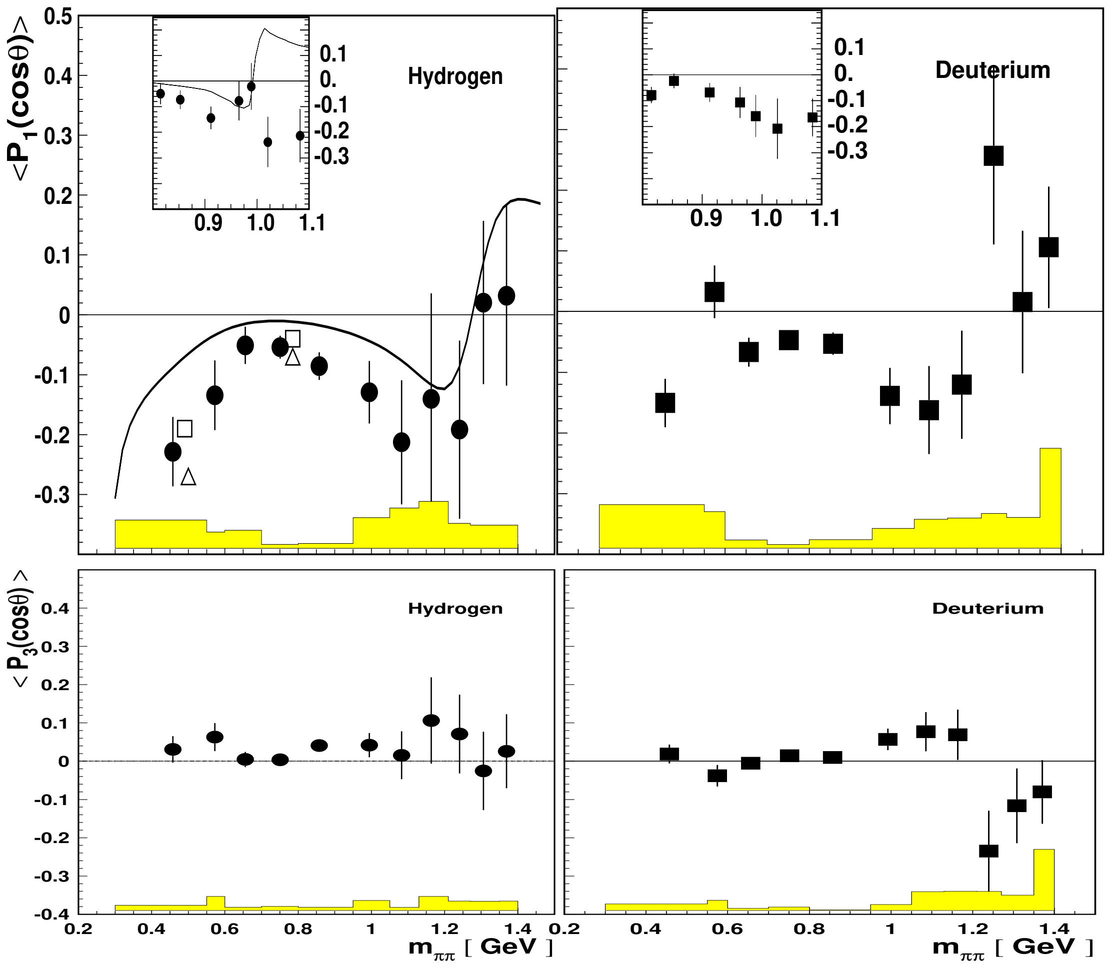




Solid circles - the data.
The simulated (SIDIS) background represented by the histogram.

Yields of the exclusive events as obtained by subtracting the normalized Monte Carlo events from the data

$m_{\pi\pi}$-dependence of $\langle P_1 \rangle$ and $\langle P_3 \rangle$



$$\langle P_1 \rangle = \frac{1}{\sqrt{15}} \left[4\sqrt{3}\rho_{11}^{21} + 4\rho_{00}^{21} + 2\sqrt{5}\rho_{00}^{10} \right]$$

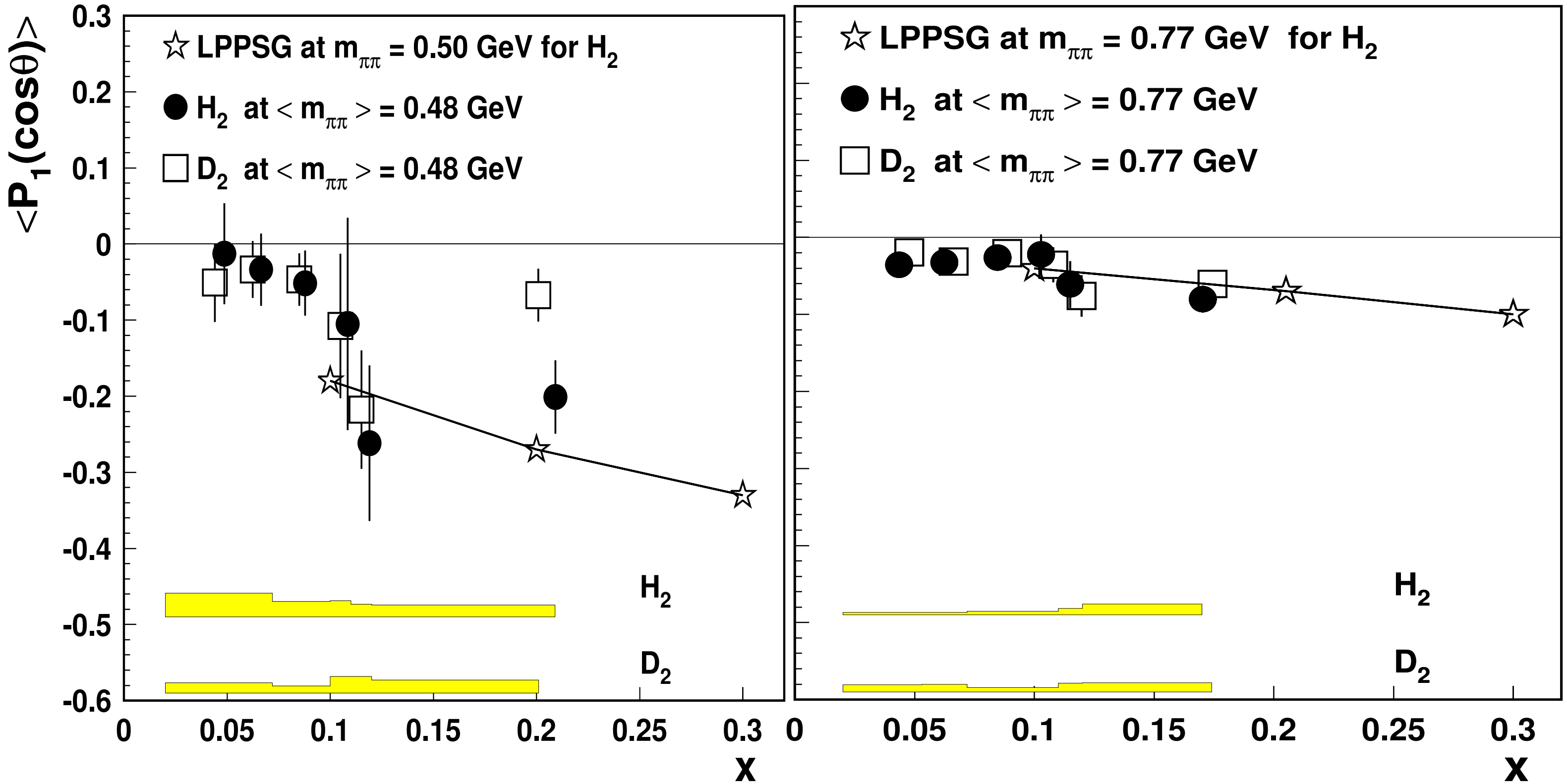
P-wave $\leftrightarrow$ S,D-waves

$$\langle P_3 \rangle = \frac{1}{7\sqrt{5}} \left[-12\rho_{11}^{21} + 6\sqrt{3}\rho_{00}^{21} \right]$$

P-wave $\leftrightarrow$ D-wave

$m_{\pi\pi} < 0.6$ GeV: interference of non-resonant S-wave and lower ρ^0 tail
$m_{\pi\pi} \sim 0.77$ GeV: minimum interference of $S - P$ waves
$m_{\pi\pi} \sim 1.3$ GeV: $\rho^0 - f_2$ interference
Curve: leading twist predictions including 2g exchange contribution.
Lehmann-Dronke, Pobylitsa, Polyakov, Schaefer, Goeke [Phys.Rev. D63(2001)114001-1].

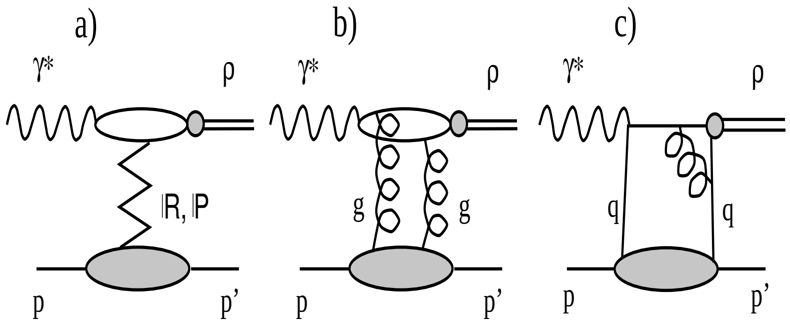
x_{Bj}-dependence of $\langle\cos\theta\rangle$

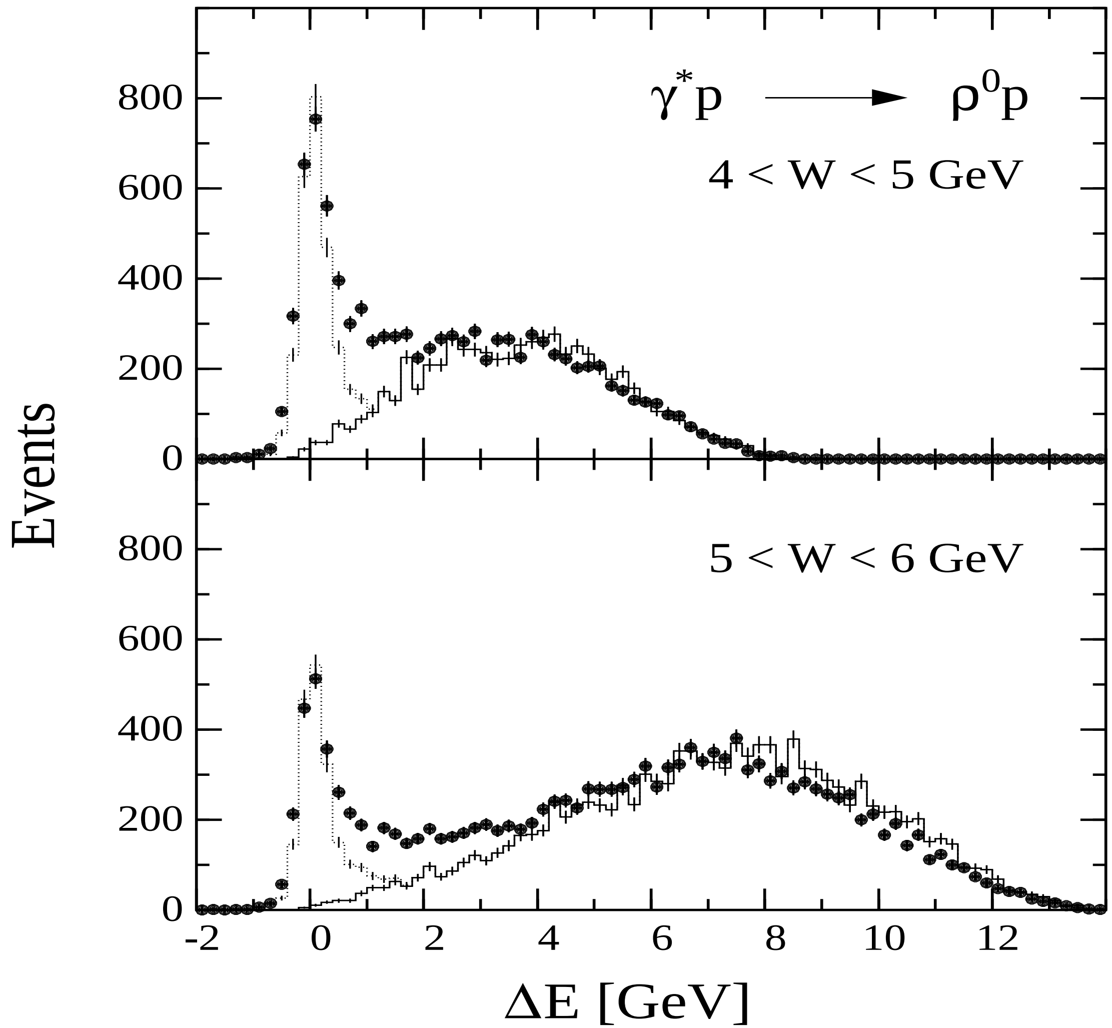


Increasing interference vs x_{Bj} between non-resonant S-wave and lower ρ^0 tail
$\Rightarrow$ increased contribution of non-singlet $q\bar{q}$ exchange.

Curve: predictions with only the quark exchange in the GPD framework,
LPPSG [Phys.Lett. B475(2000)1147]

Exclusive ρ^0 and ϕ production

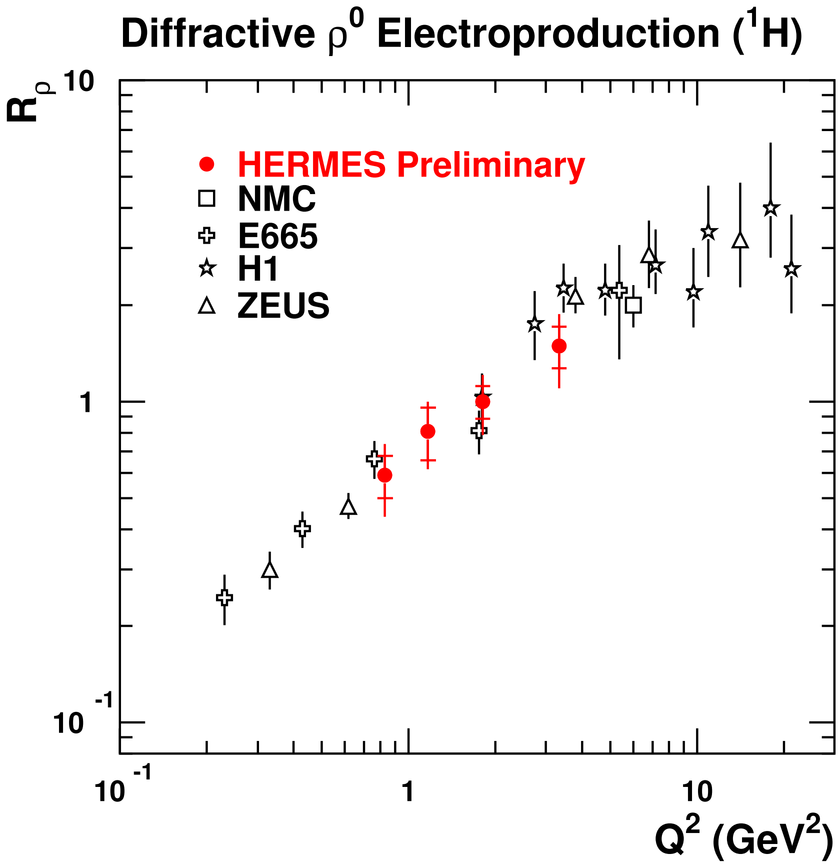


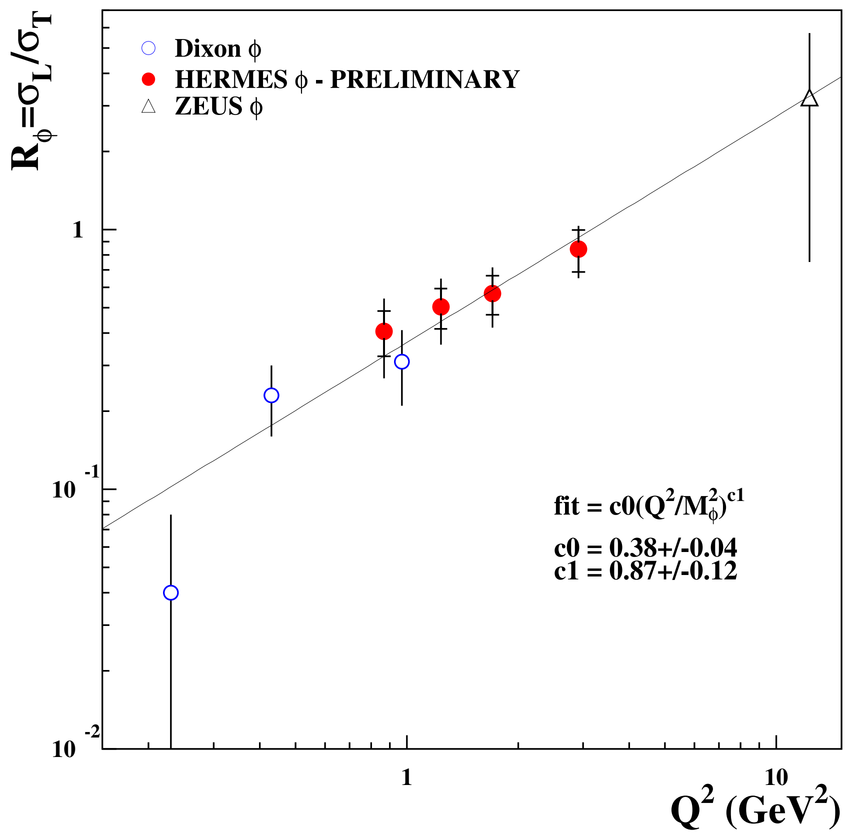


Good determination of exclusive channel DIS-"background" well described by MC

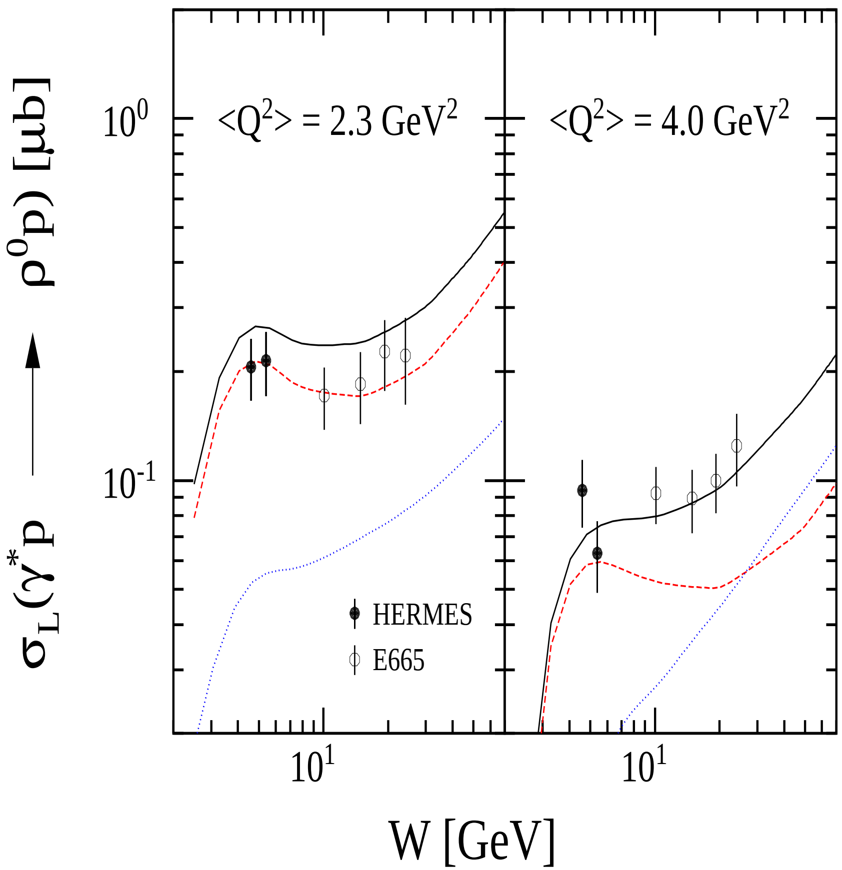
Longitudinal cross section is deduced from measured total cross section and from decay angular distributions

Assuming SCHC + knowledge of γ^* polarization: $R = \frac{\sigma_L}{\sigma_T} = \frac{1}{\epsilon}\frac{r^{04}_{00}}{1-r^{04}_{00}}$

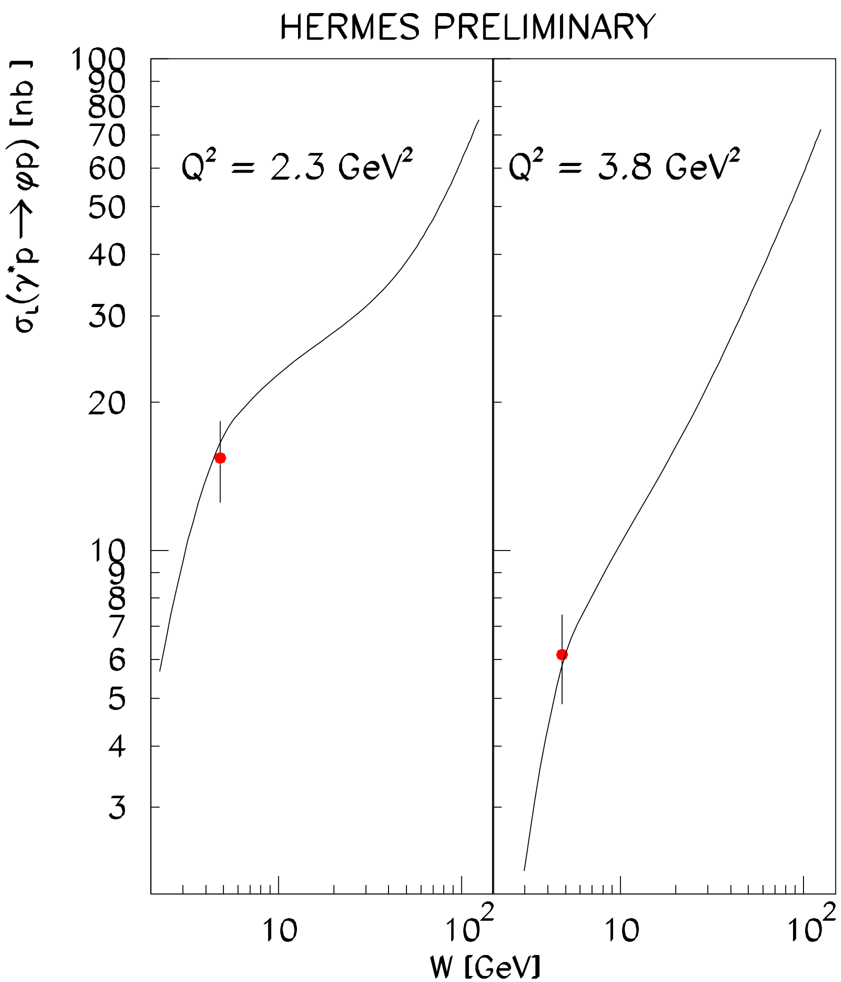




Total longitudinal cross section

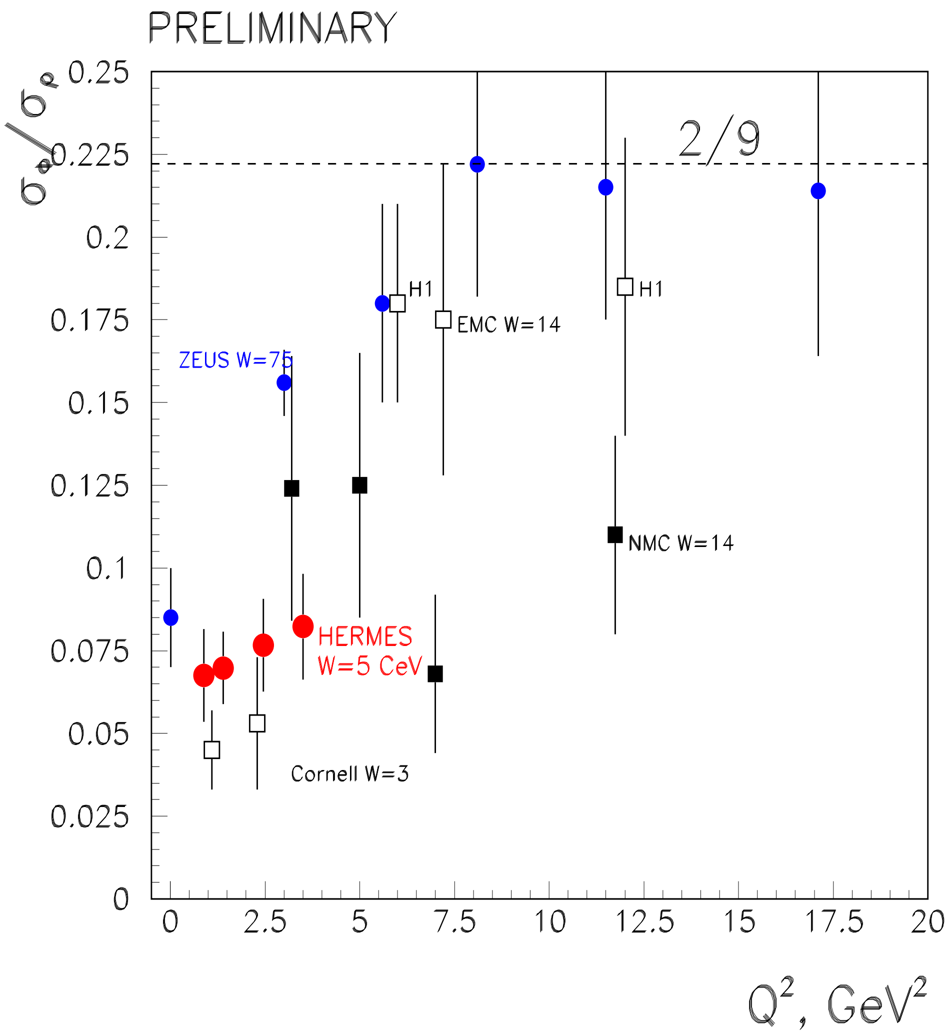


Solid lines - GPD model (VGG) =
red lines - quark exchange +
blue lines - two-gluon exchange.



Solid lines - two-gluon exchange

Cross section ratios



Increase both with Q^2 and W;

$$\frac{\sigma_\phi(\text{ 2g-exchange })}{\sigma_\rho(\text{q-exchange })+\sigma_\rho(\text{2g-exchange })} \leqslant \frac{\sigma_\phi(\text{ 2g-exchange })}{\sigma_\rho(\text{2g-exchange })} = \frac{2}{9}$$

$\Rightarrow$ Confirmation of
2g-exchange dominance of ϕ and
q-exchange dominance of ρ
productions at low W and Q^2

DSA of ρ^0 production

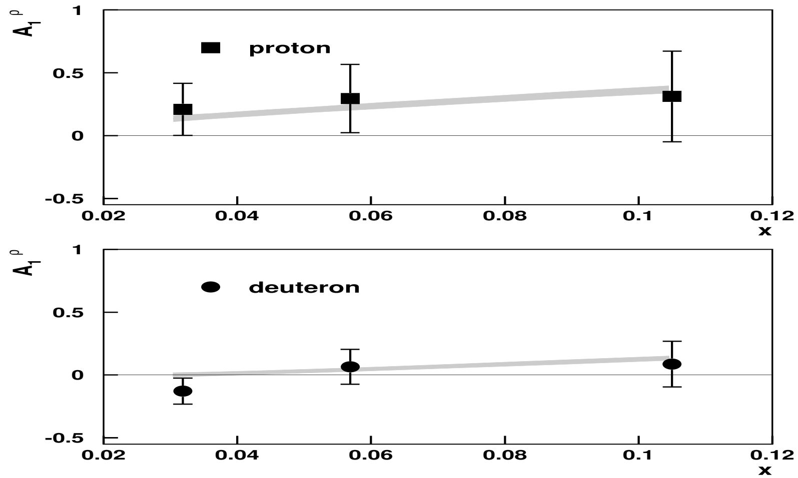
$$\vec{\gamma}^*_T + \vec{N} \to \rho + N$$

$$\boxed{A_1^\rho = \frac{\sigma_{1/2}-\sigma_{3/2}}{\sigma_{1/2}+\sigma_{3/2}}} = \frac{A_\parallel}{D} - \eta\sqrt{R}$$

$$A_\parallel = \frac{\sigma^{\overleftarrow{\rightarrow}} - \sigma^{\overrightarrow{\rightarrow}}}{\sigma^{\overleftarrow{\rightarrow}} + \sigma^{\overrightarrow{\rightarrow}}}$$

$D \simeq 0.4$ - γ^*_T effective polarization,

$R = \frac{\sigma_L}{\sigma_T} \simeq 0.62, < \eta > \simeq 0.06$

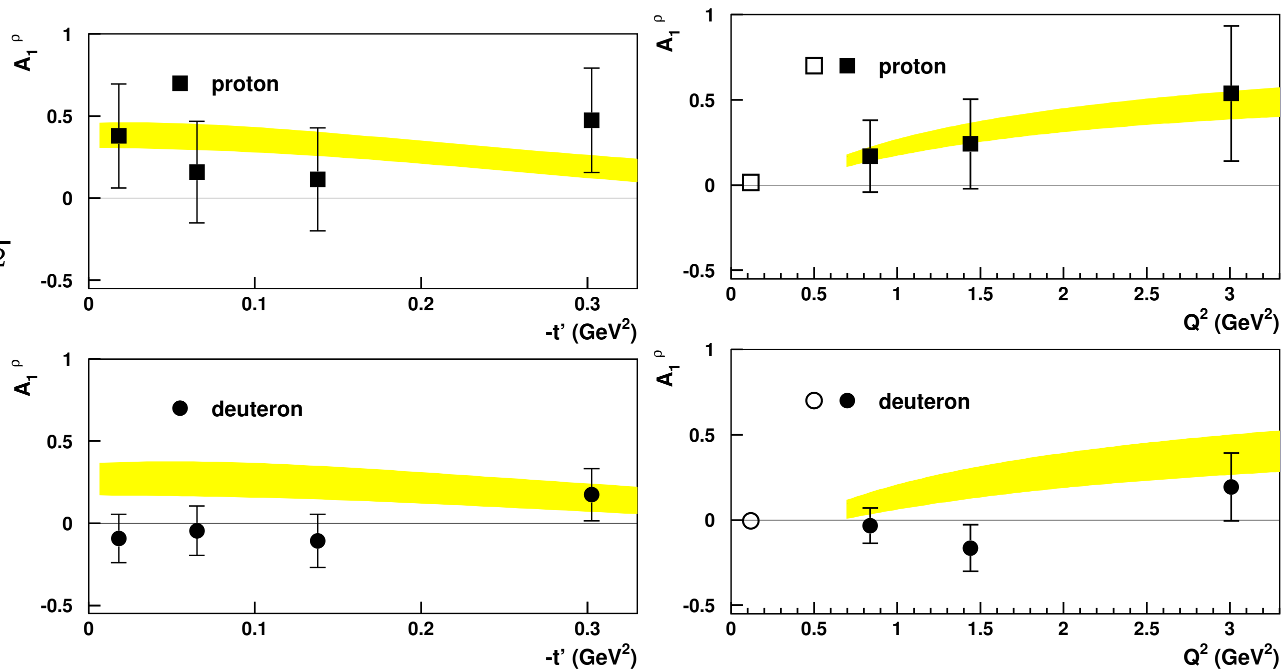


Expectations:
Fraas, 1976:

$$A_1^\rho = \frac{2A_1^N}{1+(A_1^N)^2}$$

A_1^N - DSA in inclusive DIS.

Redge model (Kochelev, Oh)



Summary and Outlook

√ Exclusive π^+:

- Cross section: measurements for Q^2 dependence at different x_{Bj}. Comparison with GPD-based model;
- SSA: large longitudinal target spin asymmetry ;
- Outlook: transverse target spin asymmetry (2004 - end of transverse target runs).

√ Exclusive $\pi^+\pi^-$:

- First measurement of angular asymmetry in $\pi^+\pi^-$ hard exclusive electro-production;
- $\langle\cos\theta\rangle$ asymmetry shows signature of $I = 1$ and $I = 0$ interference $\longrightarrow f$-family channel is highlighted;
- Good agreement with GPD-based theory ;

√ Exclusive ρ^0 and ϕ:

- Total cross section has been measured and $R = \sigma_L/\sigma_T$ was determined from the decay-angle distributions $\Rightarrow$ longitudinal cross section σ_L has been obtained and compared to GPD-based model;
- Positive tendency of the DSA in ρ^0 production on H $\Rightarrow$ supports domination of quark exchange mechanism.
- Outlook: 2005 - run with the recoil detector