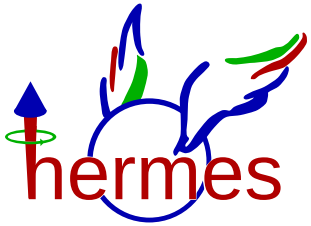
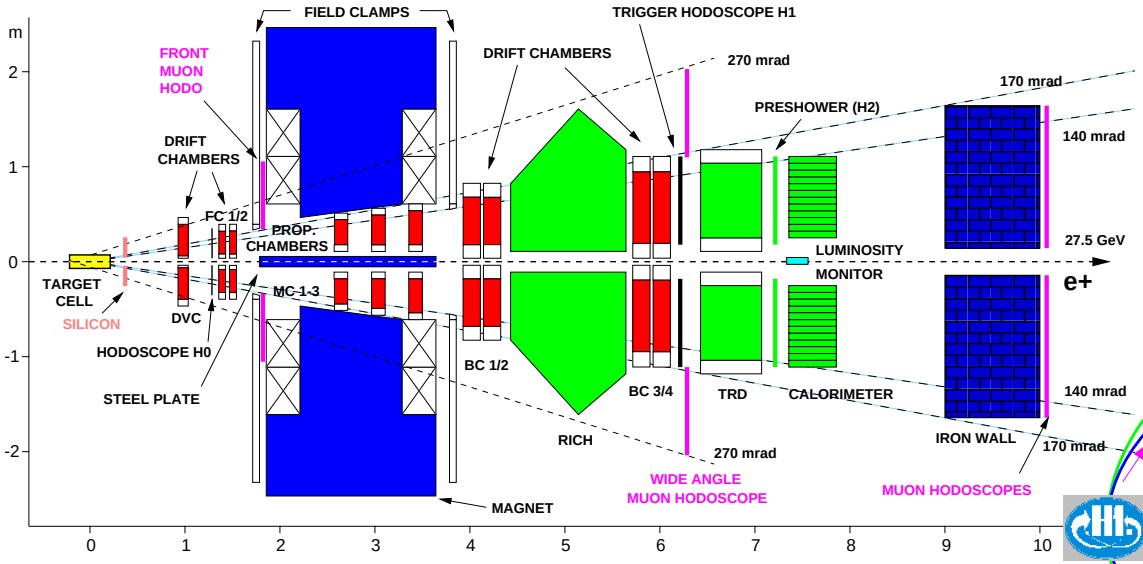
Exclusive Meson Production
at
HERMES

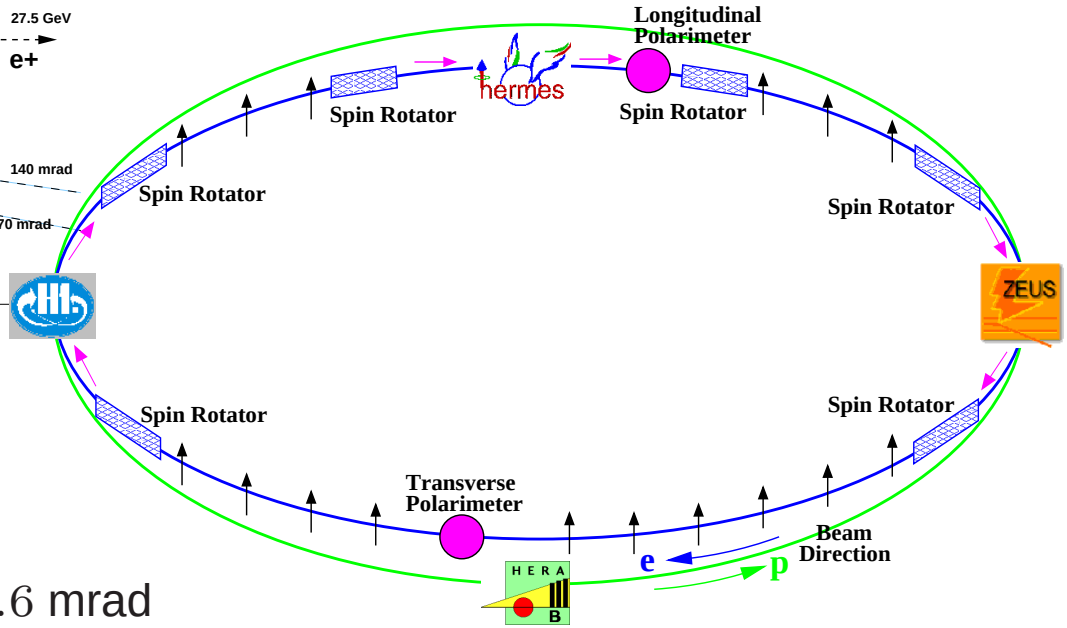
$\Rightarrow$ Exclusive π^+ Production Cross Section
$\Rightarrow$ Exclusive ρ^0 Target Single Spin Asymmetry
$\Rightarrow$ Exclusive ρ^0 Spin Density Matrix Elements
$\Rightarrow$ Hard Exclusive $\pi^+\pi^-$ Pair Production

Michael Tytgat
University of Gent
on behalf of the HERMES Collaboration



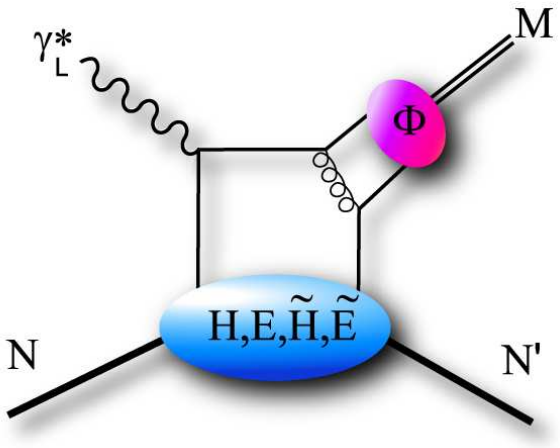
The HERMES Experiment @ DESY





- 27.6 GeV HERA $\vec{e}$-beam
- Internal, pure gas target : $\vec{\text{He}}$, $\vec{\text{H}}$, $\vec{\text{D}}$, H↑;
  unpol : H_2, D_2, He, N, Ne, Kr, Xe
- Resolution : $\Delta p/p = 1.4 - 2.5$ %, $\Delta\theta < 0.6$ mrad
- Lepton/hadron separation : TRD, Preshower, Calorimeter, Cherenkov (1995-97)
- Hadron ID : Cherenkov (1995-97) - RICH (1998- ...)
- Target polarization : longitudinal (1996-2000) $\langle P_t \rangle \sim 85$ %
  & transverse (2002-2005) $\langle P_t \rangle \sim 75$ % ; flipping every 90s
- HERA beam polarization $\langle P_b \rangle = 53$ % longitudinal

Generalized Parton Distributions



- For $Q^2 >>$ and $t << Q^2$, factorization for longitudinal γ^* in meson production [Collins *et al.*, PRD56 (1997) 2982]
- 4 GPDs in leading twist :
  $H^q(x,\xi,t)$, $E^q(x,\xi,t)$ unpolarized;
  $\tilde{H}^q(x,\xi,t)$, $\tilde{E}^q(x,\xi,t)$ polarized

  H^q, $\tilde{H}^q$ conserve nucleon helicity;
  E^q, $\tilde{E}^q$ flip nucleon helicity

$\Rightarrow$ New observables in hard exclusive scattering; related to standard PDF and form factors :

$$H^q(x,0,0) = q(x), \qquad \tilde{H}^q(x,0,0) = \Delta q(x),$$
$$\int_{-1}^{+1} \mathrm{d}x\, H^q(x,\chi,t) = F_1^q(t), \qquad \int_{-1}^{+1} \mathrm{d}x\, E^q(x,\chi,t) = F_2^q(t), \qquad \ldots$$

- Ji's sum rule :

$$J_q = \frac{1}{2}\Delta q + L_q = \frac{1}{2}\int_{-1}^{+1} \mathrm{d}x\, x\, [H^q + E^q]$$

$\Rightarrow$ access to orbital angular momentum

- Unpolarized cross section contain quadratic combinations of GPDs; new information from polarized measurements

Accessing Generalized Parton Distributions

Final state quantum numbers select different GPDs :

- Deeply Virtual Compton Scattering : H, E, $\tilde{H}$, $\tilde{E}$ (*See talk M. Kopytin*)
  - $\Rightarrow$ Beam charge asymmetry ($e^+ \leftrightarrow e^-$) : H [A. Airapetian *et al.*, hep-ex/0605108]
  - $\Rightarrow$ Beam-spin Azimuthal Asymmetry : H [A. Airapetian *et al.*, Phys. Rev. Lett. 87 (2001) 182001]
  - $\Rightarrow$ Longitudinal Target Spin Asymmetry : $\tilde{H}$
  - $\Rightarrow$ Transverse Target Spin Asymmetry : E, J_q

- Pseudoscalar meson production (π, η ...) : $\tilde{H}$, $\tilde{E}$
  - $\Rightarrow$ Cross section exclusive π^+ production
  - $\Rightarrow$ Transverse single spin asymmetries

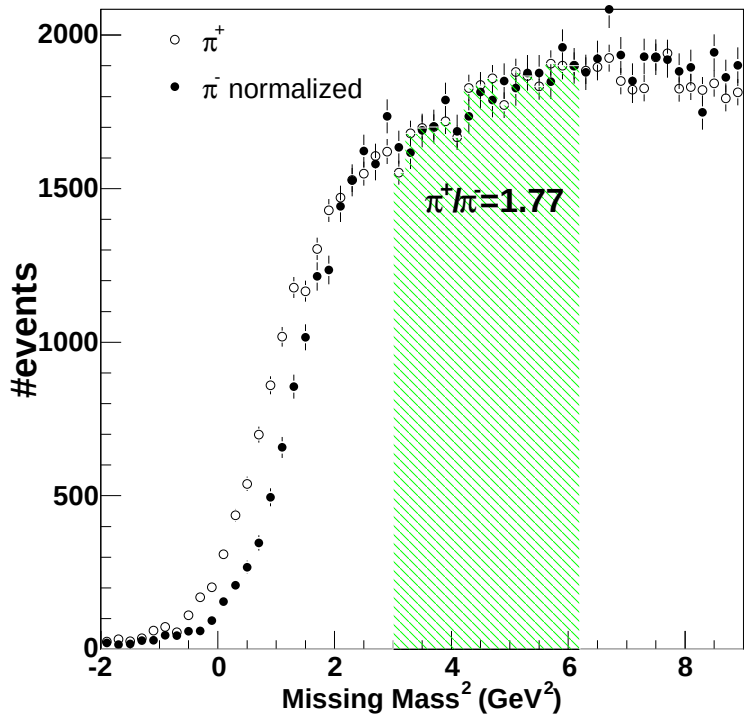
- Vector meson production (ρ, ω, ϕ ...) : H, E
  - $\Rightarrow$ Cross section exclusive ρ^0 (ω, ϕ) production [A. Airapetian *et al.*, Eur. Phys. J. C17 (2000) 389]
  - $\Rightarrow$ Transverse single spin asymmetries

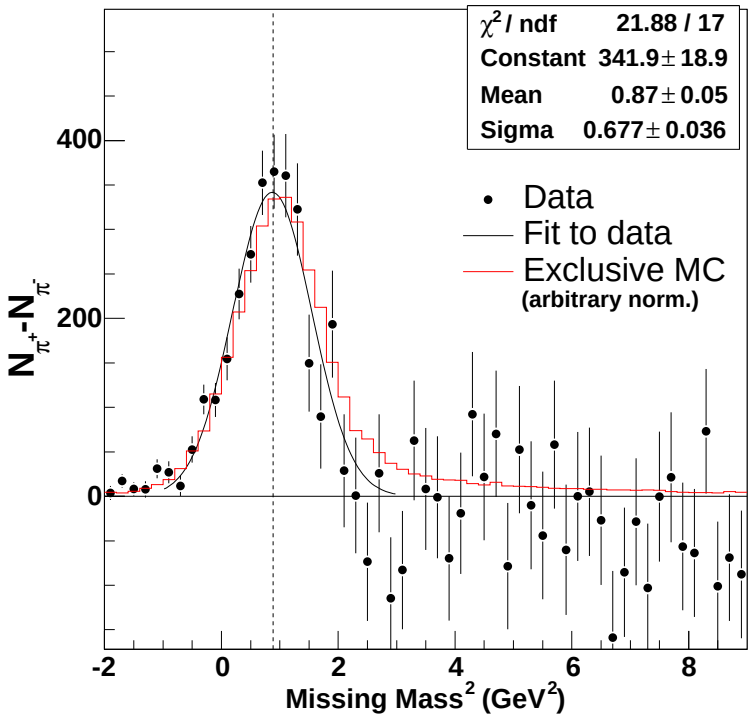
- Pion pair production : H, E
  - $\Rightarrow$ Angular distributions [A. Airapetian *et al.*, Phys. Lett. B599 (2004) 212]

Exclusive π^+ Production

$e + p \rightarrow e + n + \pi^+$ sensitive to $\tilde{H}$ and $\tilde{E}$

No detection of recoiling neutron ☞ use missing mass for $e + p \rightarrow e + \pi^+ + X$





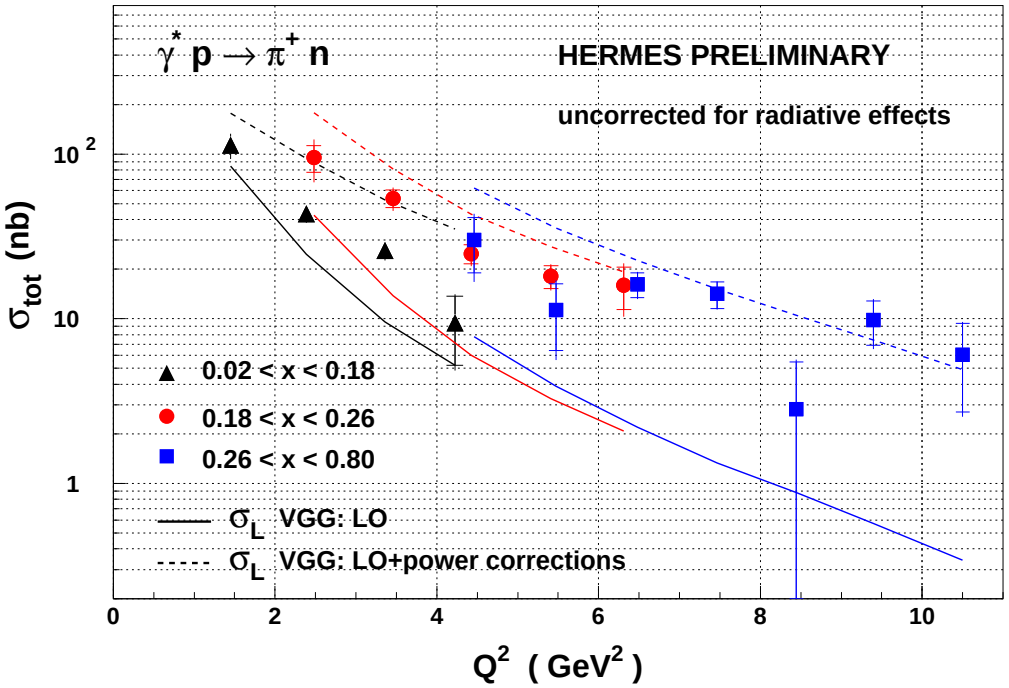
Subtract non-exclusive background via $e + p \rightarrow e + \pi^- + X$

method cross-checked with GPD based Monte Carlo

π^+ Cross Section Measurement

$$\sigma_{\text{tot}} = \sigma_T + \epsilon\sigma_L$$

no LT-separation, but σ_T suppressed by $1/Q^2$ and $0.80 < \epsilon < 0.96$ for HERMES



☞ Q^2 dependence consistent with LO expectations, however

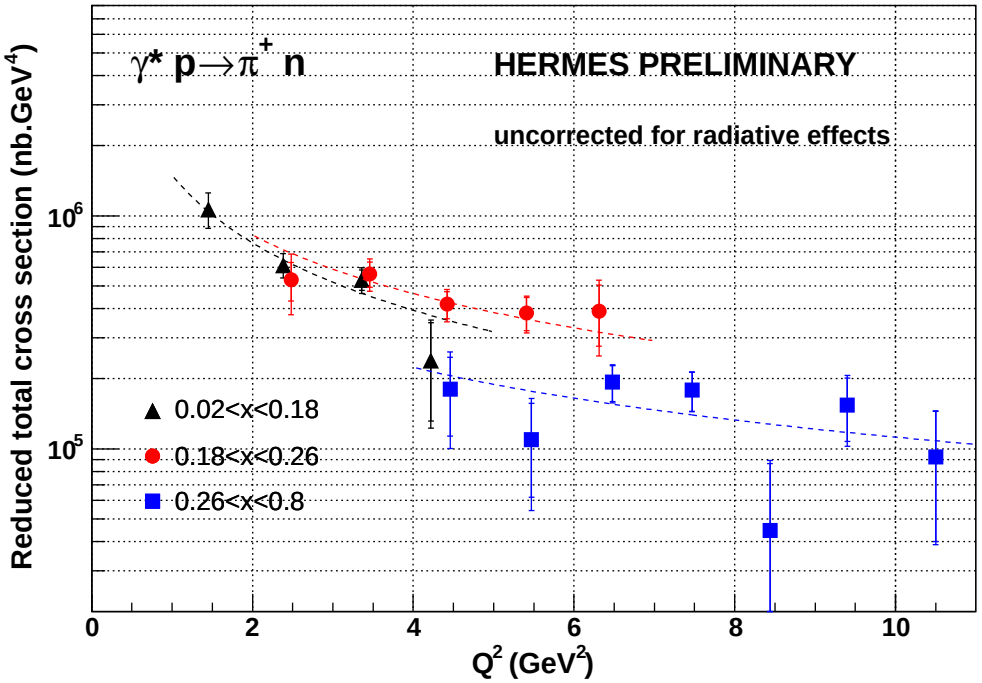
. GPD model underestimates data [Vanderhaeghen *et al.*, PRD60 (1999) 094017]

. Power corrections ($k_\perp$ and soft overlap) overestimate data

π^+ Cross Section Measurement

Factorization theorem predicts $\sigma_L \propto 1/Q^6$ at fixed x and t

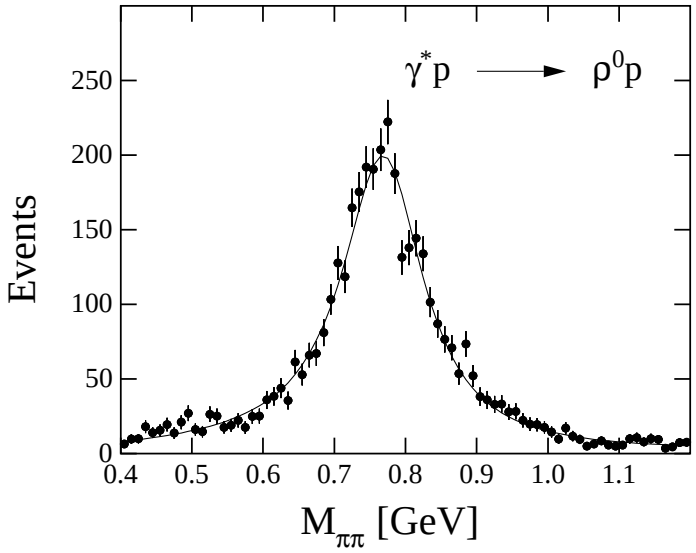
$$\sigma_{tot} = \underbrace{\frac{1}{16\pi}\frac{1}{Q^4}\frac{1}{\sqrt{1+4M_p^2x_B^2/Q^2}}}_{\text{phase space factor}} \underbrace{\sum_{\text{spin}} |A(\gamma^* p \to p\pi|^2}_{\sigma_{reduced}} \quad \text{☞} \quad \sigma_{reduced} \propto 1/Q^2 \ ?$$



$1/Q^p$-fit yields : $p = 1.9 \pm 0.5$ $p = 1.7 \pm 0.6$ $p = 1.5 \pm 1.0$

Exclusive ρ^0 Production

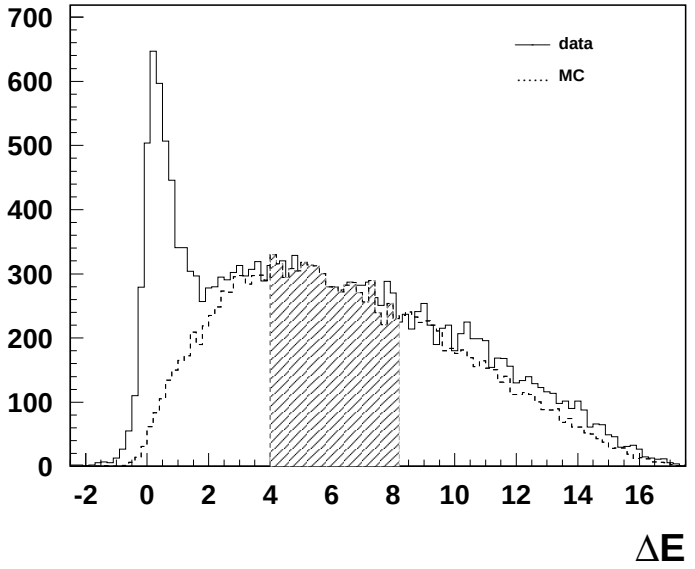
$e + p \rightarrow e + p + \rho^0$ sensitive to H and E



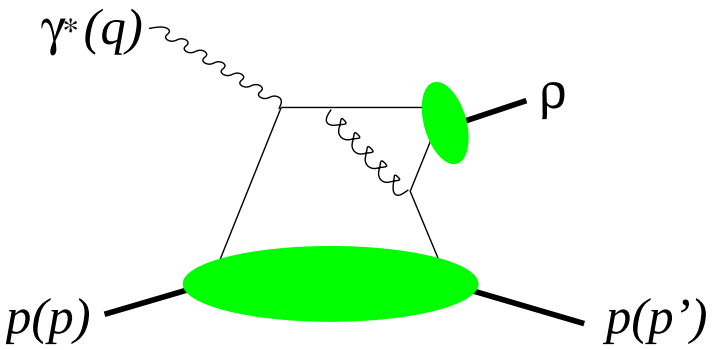
- ρ^0 reconstructed from its 2 pion decay

- Exclusivity through $\Delta E = \dfrac{(M_X^2 - M_p^2)}{2M_p}$ cut

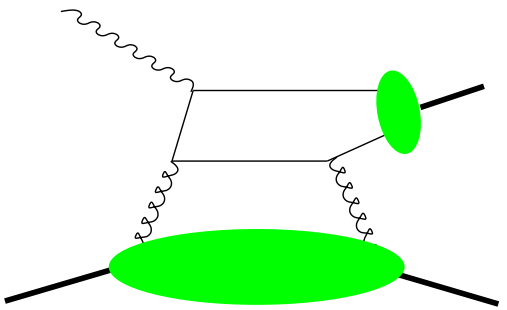
- Non-exclusive background described by Monte Carlo



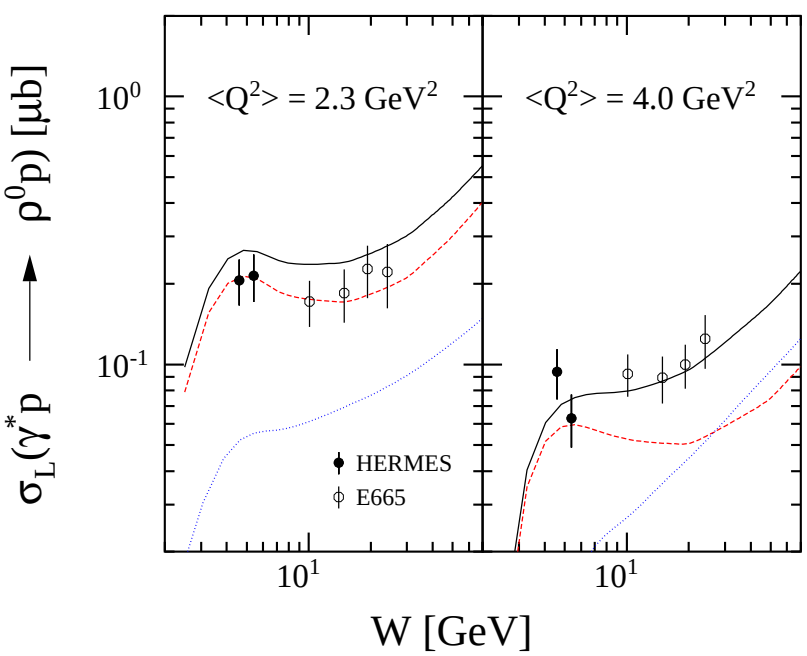
Quark vs. Gluon Exchange in ρ^0 Production @ HERMES

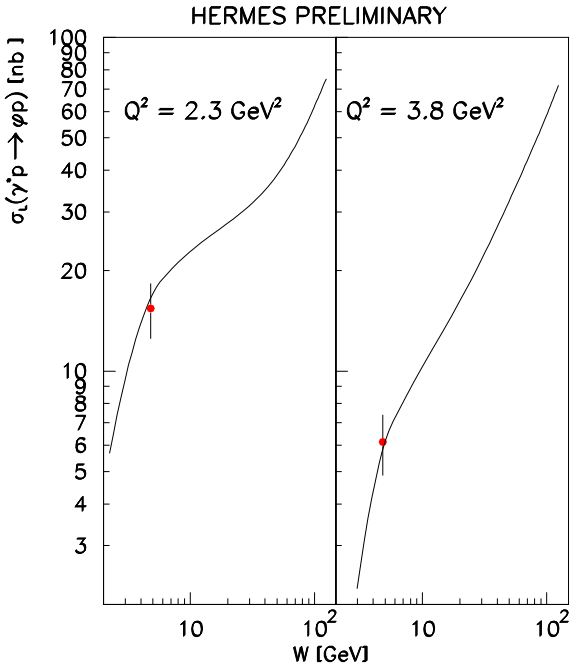


Quark exchange



gluon exchange

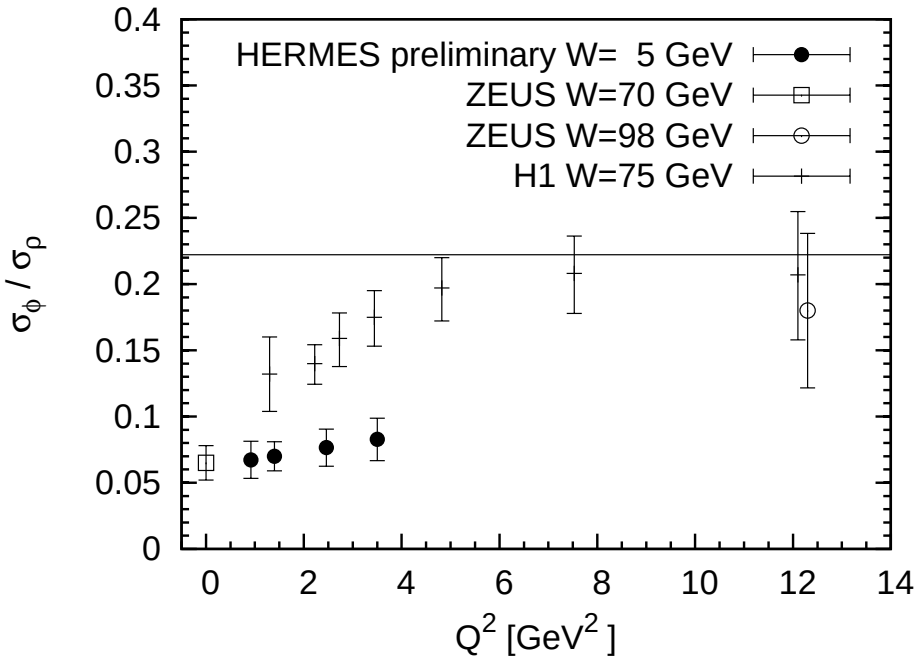




GPD model calculations : [Vanderhaeghen *et al.*, PRD60 (1999) 094017]

Quark vs. Gluon Exchange in ρ^0 Production @ HERMES

Use $\sigma_\phi/\sigma_{\rho^0}$ measurements



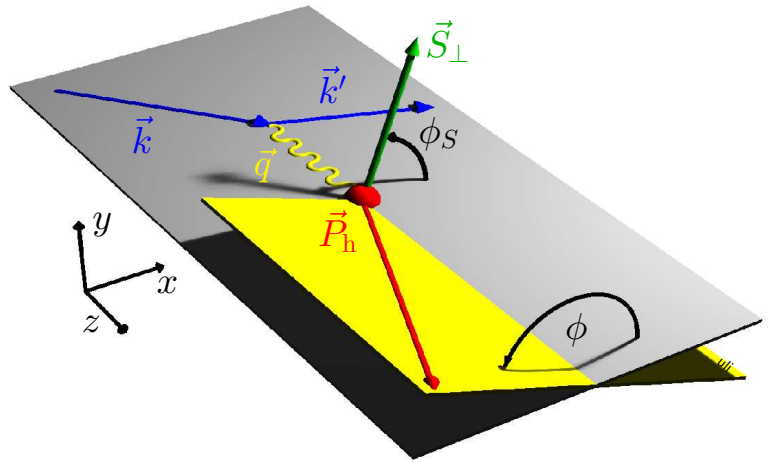
GPD model : [Diehl and Vinnikov, PLB609 (2005) 286]

$$\frac{\sigma_\phi}{\sigma_{\rho^0}} \simeq \frac{2}{9}\frac{|g_{\rho^0}|^2}{|g_{\rho^0}|^2 + 2|q_{\rho^0}|g_{\rho^0}|\cos\alpha + |q_{\rho^0}|^2}$$

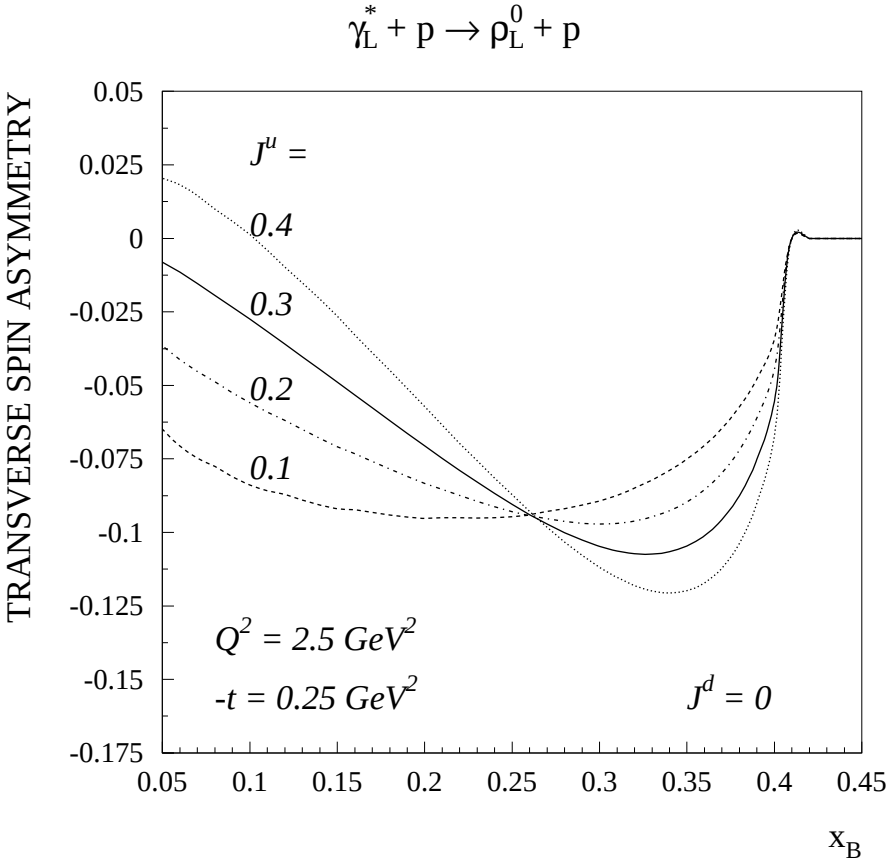
$0.38 \leq |g_{\rho^0}/q_{\rho^0}| \leq 1.5$ for HERMES @ $< x_B > \approx 0.1$

☞ Substantial contribution from gluon exchange to ρ^0 production

Target Single Spin Asymmetry in Exclusive ρ^0 Production



$$A_{UT}(\phi,\phi_S) = \frac{1}{|S_\perp|}\frac{\sigma^\uparrow(\phi,\phi_S)-\sigma^\downarrow(\phi,\phi_S)}{\sigma^\uparrow(\phi,\phi_S)+\sigma^\downarrow(\phi,\phi_S)} = A_{UT}^{\sin(\phi-\phi_S)}\sin(\phi-\phi_S)$$



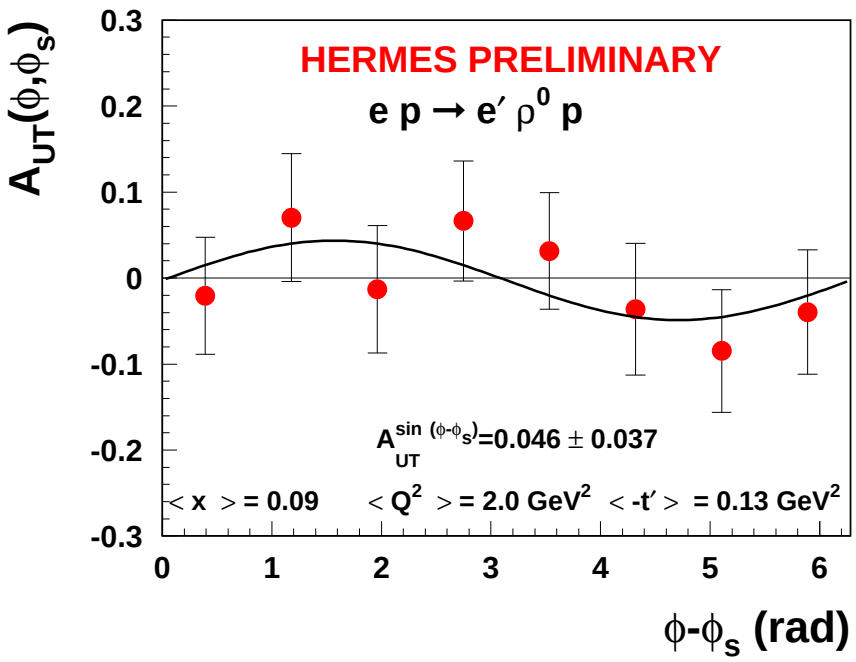
[Goeke *et al.*, PPNP47 (2001) 401]

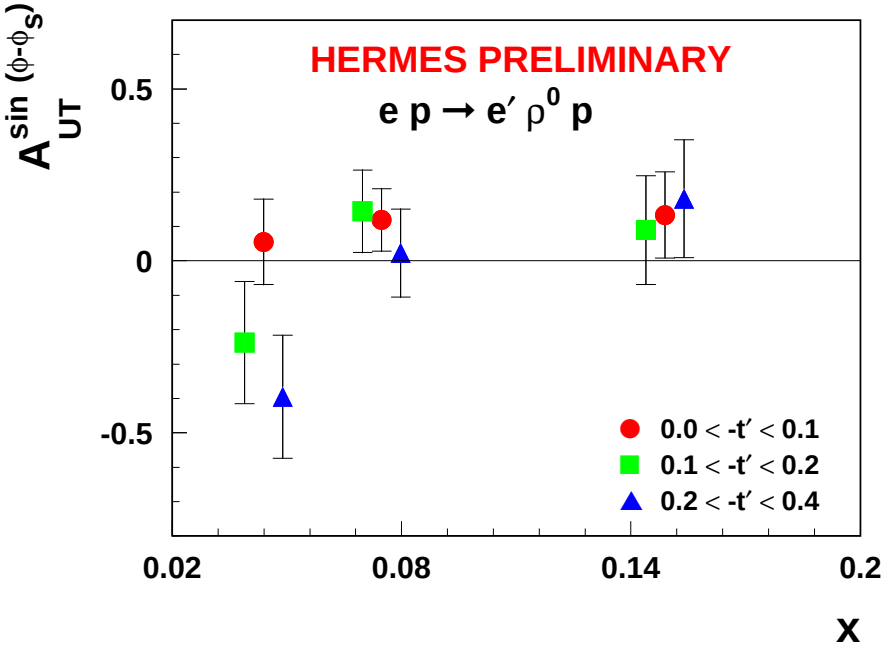
☞ $A_{UT}^{\sin(\phi-\phi_S)}$ sensitive to interference of H and E and to J^u, total angular momentum u quarks

Positive slope wrt. x_B expected at HERMES

$$\mathcal{A}_{theory} \sim -A_{UT}^{\sin(\phi-\phi_S)} \propto E \cdot H$$

Target Single Spin Asymmetry in Exclusive ρ^0 Production



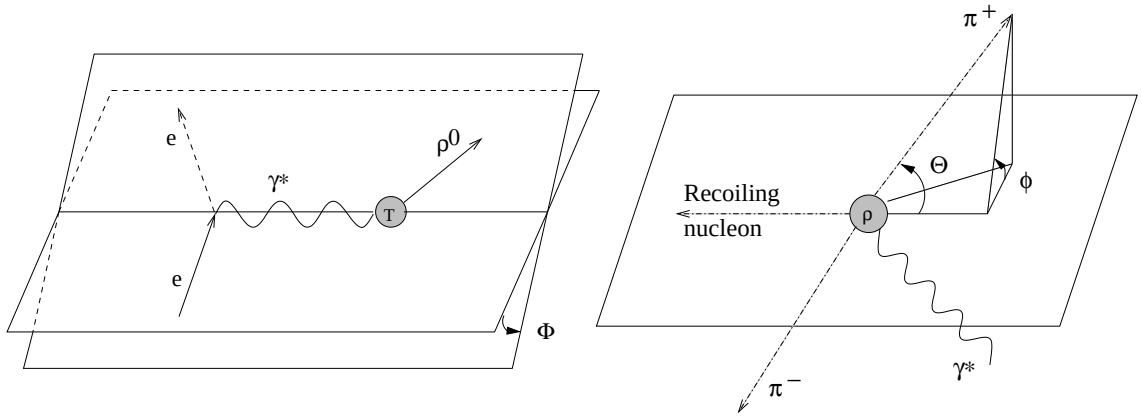


☞ Data consistent with theory expectations

$\sigma_L - \sigma_T$ separation underway ...

ρ^0 Spin Density Matrix Elements

ρ^0 spin state reflected in orbital angular momentum of 2-pion decay system



☞ $W(\cos\theta, \phi, \Phi) = W_{unpol}(\cos\theta, \phi, \Phi) + P_b \cdot W_{pol}(\cos\theta, \phi, \Phi)$

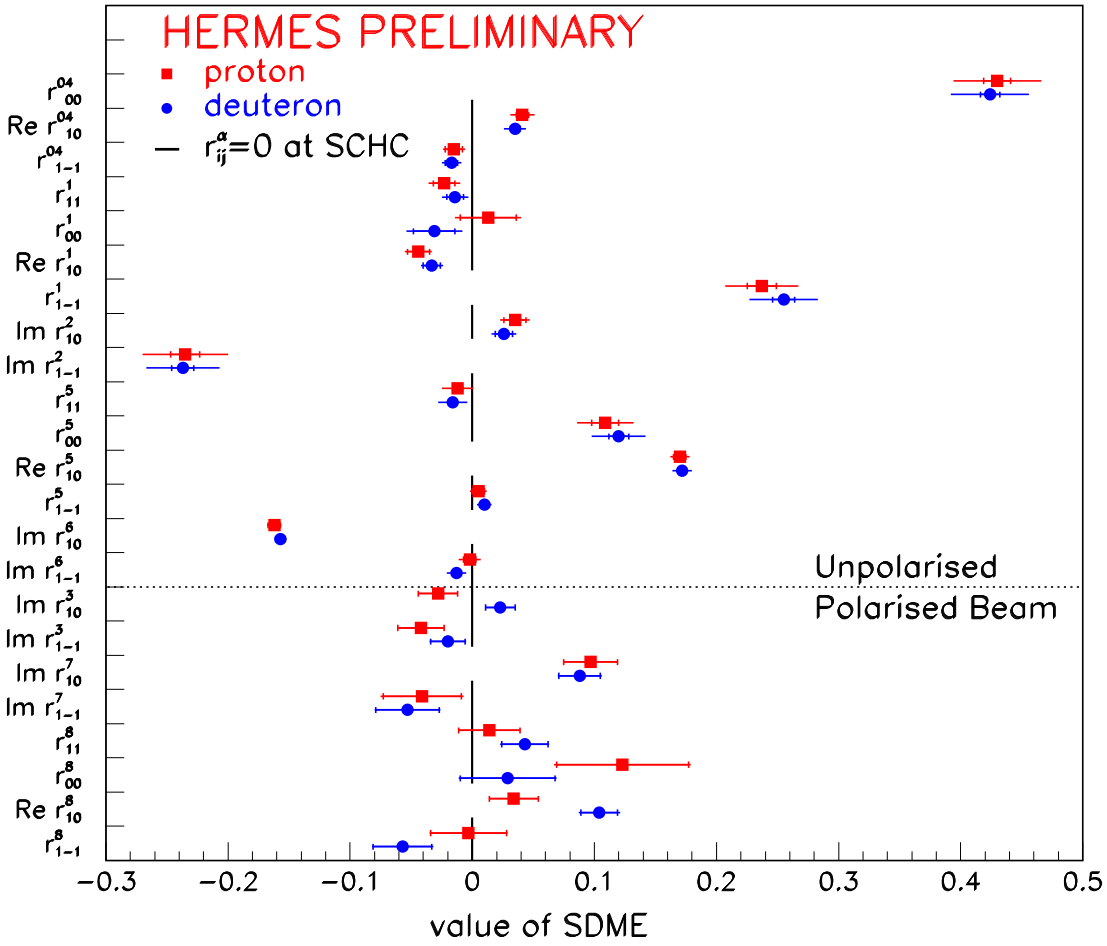
= function of 15 “unpolarized” + 8 “polarized” SDME related to helicity amplitudes $T_{\lambda_V \lambda_\gamma}$

Measure helicity transfer from virtual photon to vector meson

☞ Check assumptions :

- s-channel helicity conservation : $T_{\lambda_V \lambda_{N'}, \lambda_\gamma \lambda_N} = T_{\lambda_V \lambda_{N'}, \lambda_\gamma \lambda_N} \delta_{\lambda_V \lambda_\gamma} \delta_{\lambda_{N'} \lambda_N}$
- t-channel natural parity exchange ($P = (-1)^J$) : $T_{-\lambda_V \lambda_{N'}, -\lambda_\gamma \lambda_N} = (-1)^{(\lambda_V - \lambda_\gamma)} T_{\lambda_V \lambda_{N'}, \lambda_\gamma \lambda_N}$

ρ^0 Spin Density Matrix Elements



Determine SDME from fit of 3D $(\cos\theta, \phi, \Phi)$ event matrix of isotropic Monte Carlo to data in maximum likelihood procedure

☞ Significant violation of SCHC, eg. r^5_{00} ($\propto$ interf. of T_{00} and T_{01})

☞ Significant contribution of unnatural parity exchange

$$1 - r^{04}_{00} + 2r^{04}_{1-1} - 2r^1_{11} - 2r^1_{1-1} \neq 0$$

ρ^0 Spin Density Matrix Elements

Kinematic dependence of 15 unpol SDME

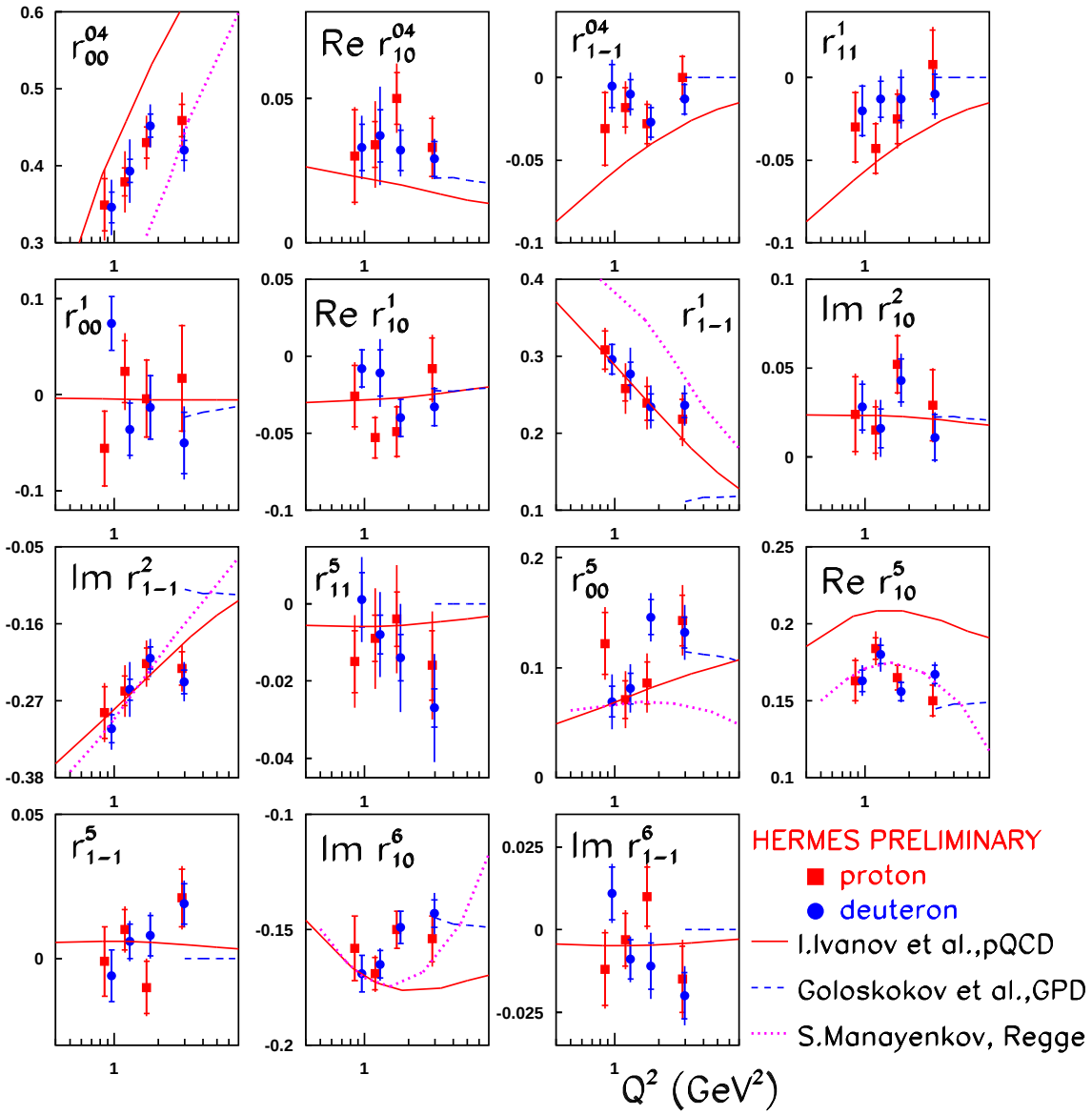
Model calculations :

Ivanov *et al.*, hep-ph/0501034 : pQCD

Manayenko, EPJC33 (2004) 397 : Regge

Goloskokov *et al.*, EPJC42 (2005) 281 : GPD (only gluon exchange)

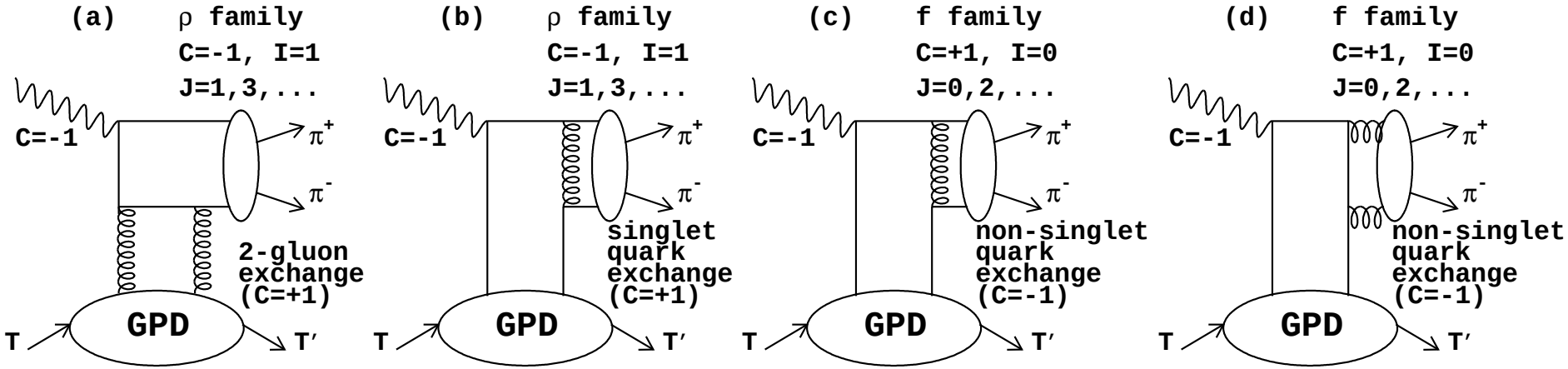
☞ Need to include quark exchange contributions at HERMES kinematics. . .



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

$$e + p/d \rightarrow e + p/d + \pi^+ + \pi^-$$ sensitive to H and E

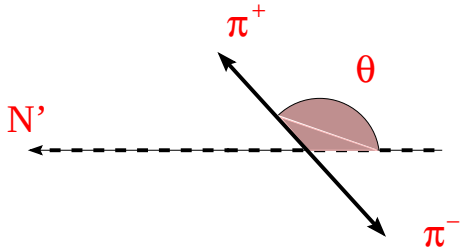
Gluon exchange (isovector pairs) or quark exchange (isovector + isoscalar pairs) :



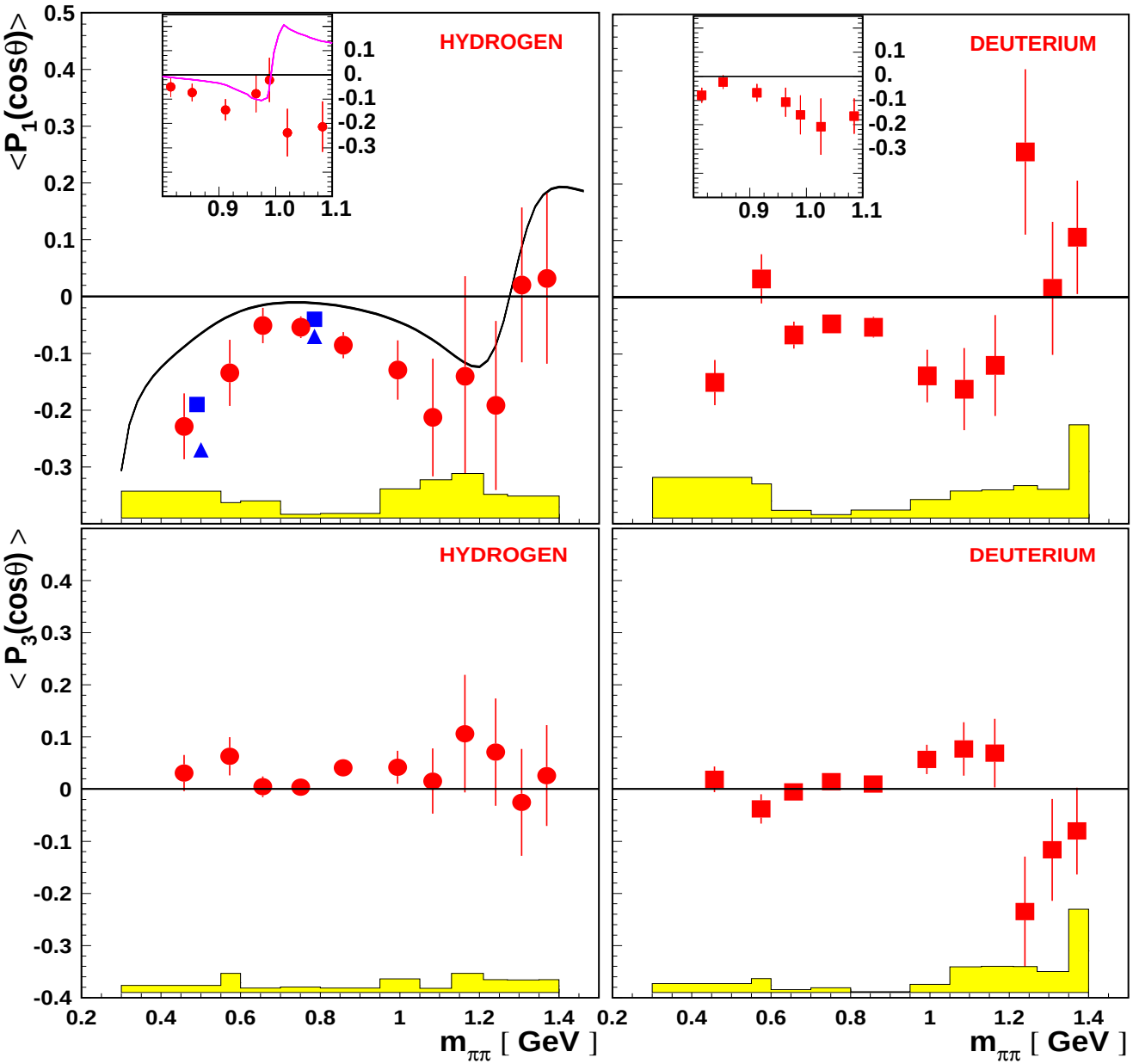
☞ study interference between $I = 1$ (ρ-family) and $I = 0$ (f-family) channels to get information on small isoscalar channel

Intensity densities (Legendre moments) :

$$< P_l(\cos\theta) >^{\pi\pi} = \frac{\int_{-1}^{+1} \mathrm{d}\cos\theta \, P_l(\cos\theta) \frac{\mathrm{d}\sigma^{\pi\pi}}{\mathrm{d}\cos\theta}}{\int_{-1}^{+1} \mathrm{d}\cos\theta \frac{\mathrm{d}\sigma^{\pi\pi}}{\mathrm{d}\cos\theta}}$$



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



$\langle P_1 \rangle$ sensitive to interference of P-wave with S and D-waves

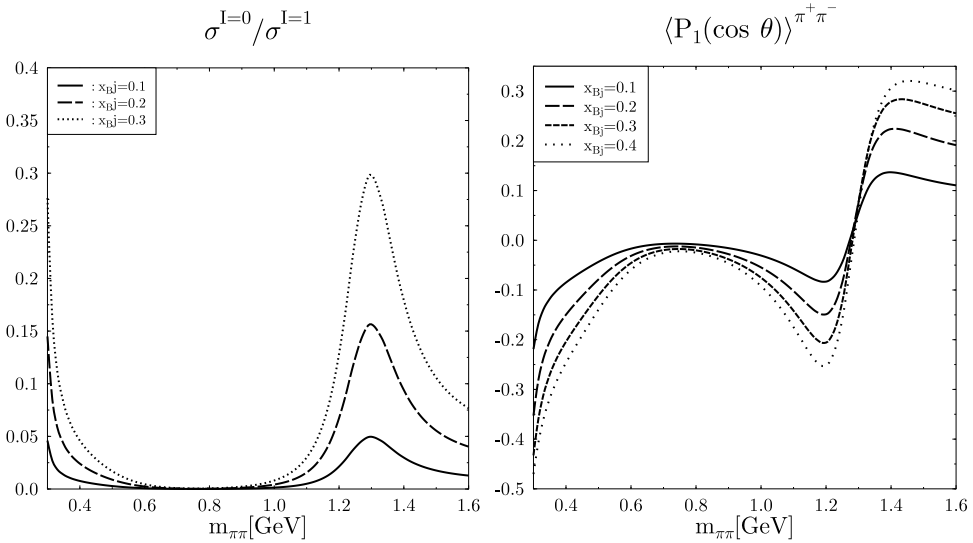
☞ Interference of ρ^0 P-wave with non-resonant $\pi\pi$ S-wave, $f_0(980)$ S-wave and $f_2(1270)$ D-wave

$\langle P_3 \rangle$ sensitive to interference of P-wave with D-wave

Agreement with GPD calculations

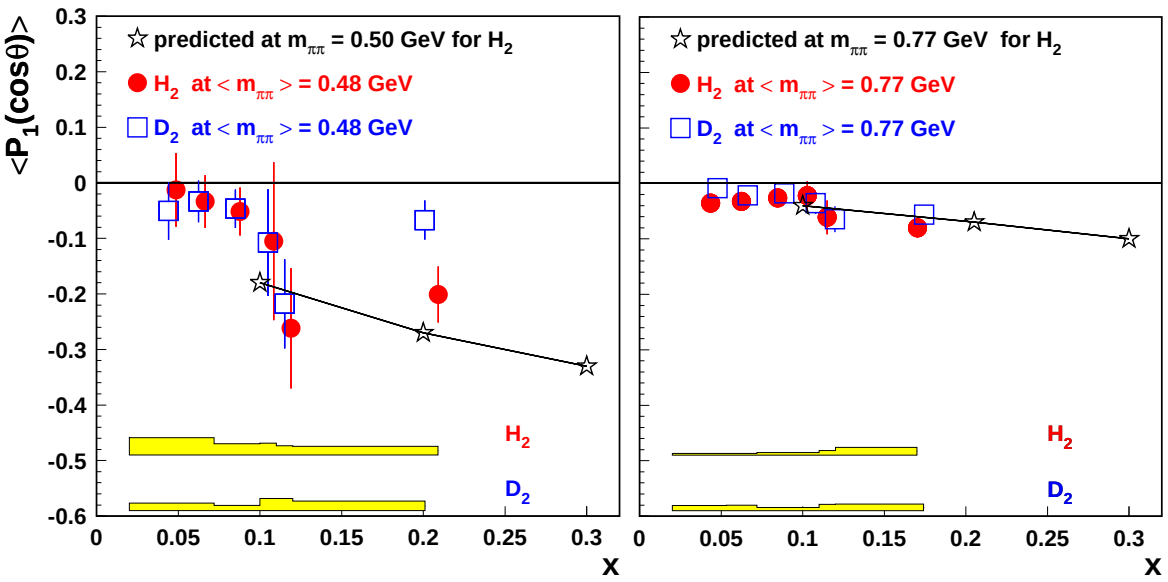
[B. Lehmann-Dronke *et al.*]

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



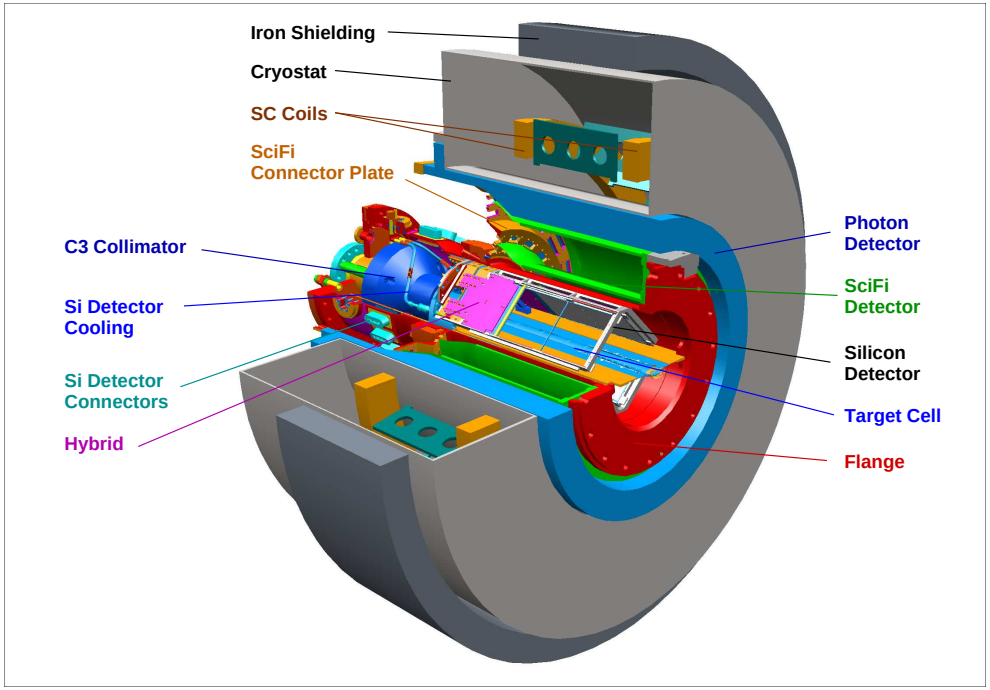
[B. Lehmann-Dronke *et al.*, PLB475 (2000) 147] (without gluon GPD)

☞ Exchange of flavor non-singlet ($C = -1$) quark combinations becomes competitive with dominant singlet ($C = +1$) exchange



Summary & Outlook

- Hard exclusive pseudo-scalar and vector meson production provides access to GPDs
- Exclusive π^+ production cross section : Q^2 dependence in agreement with GPD calculations
- Exclusive ρ^0 production : first measurement of target single spin asymmetry, sensitive to J^u; new extraction of SDME
- Exclusive 2-pion production gives additional constraints on GPDs
- More data analysis underway . . .



- HERMES Recoil Detector was installed beginning of this year

☞ HERMES is focussing on exclusive reactions during running with high density unpolarized target; expect 1 fb^{-1} of recoil data on H and D (*See poster W. Yu*)