Study of Spin Density Matrix in Exclusive Diffractive ρ^0 Meson Production at HERMES

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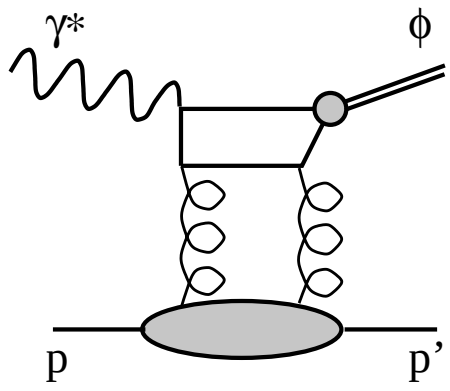
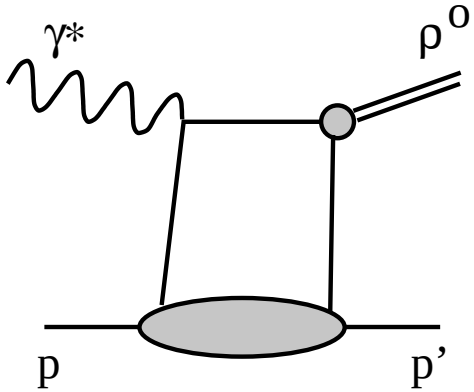
CONTENTS

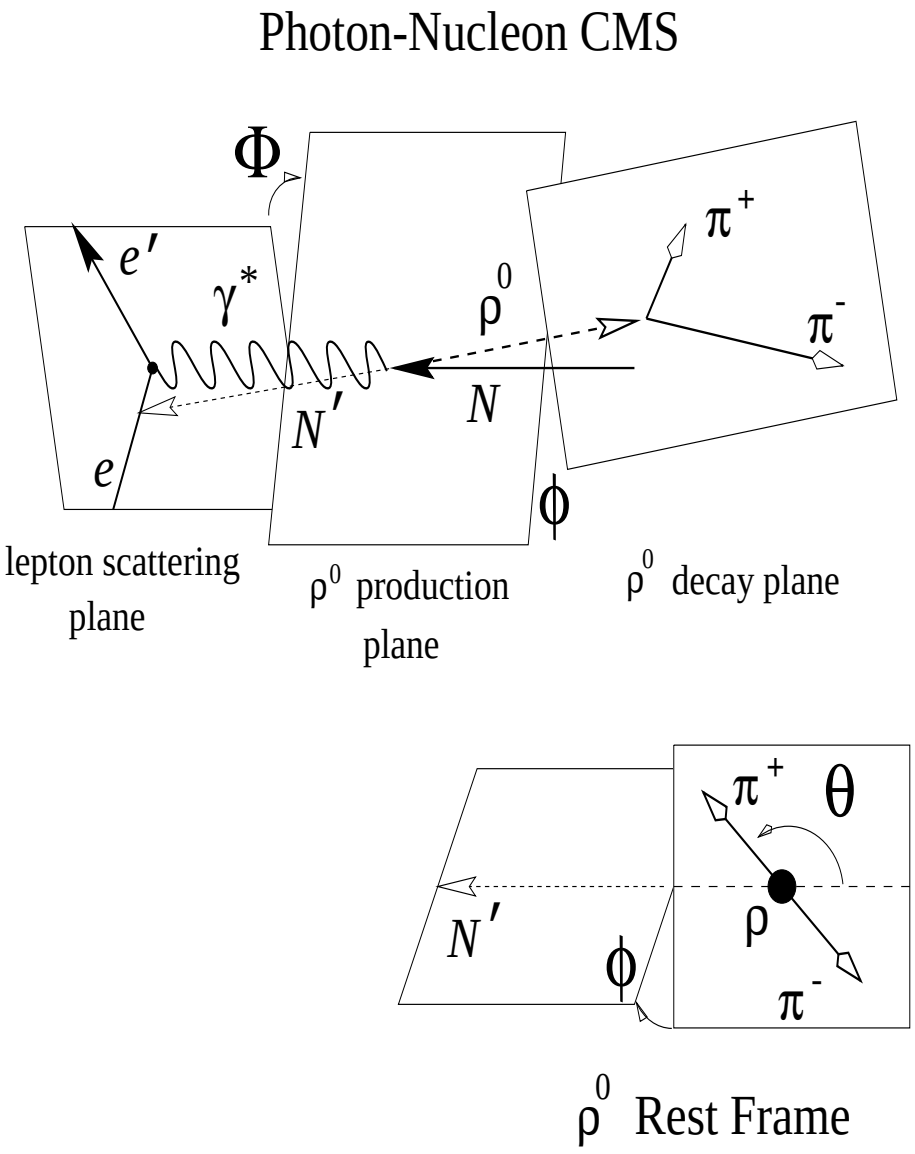
Physics Motivation

- $\gamma^* + N \rightarrow \rho^0 + N'$
  is a perfect reaction to study the spin structure of ρ^0 QCD production mechanism: spin state of γ^* is known; decay $\rho^0 \rightarrow \pi^+ + \pi^-$ is self-analysing.
- Measurement of s-channel helicity violation shows itself in spin-flip amplitudes.
- Hierarchy of spin non-flip amplitudes is measured via σ_L/σ_T ratio. For spin-flip amplitudes it can be estimated via SCHC violating spin density matrix elements (SDMEs).
- ρ^0 production mechanisms can be tested by comparing resulting SDMEs with calculations, where two-gluon (Pomeron) exchange dominates.
- $q\bar{q}$-exchange with isospin 1 can be observed in case of difference between proton and deuteron data.
- Observation of unnatural parity ($P = -(-1)^J$) exchange points to importance of $q\bar{q}$-exchange mediated by pion.





Reaction $e + N \to e' + \rho^0 + N'$



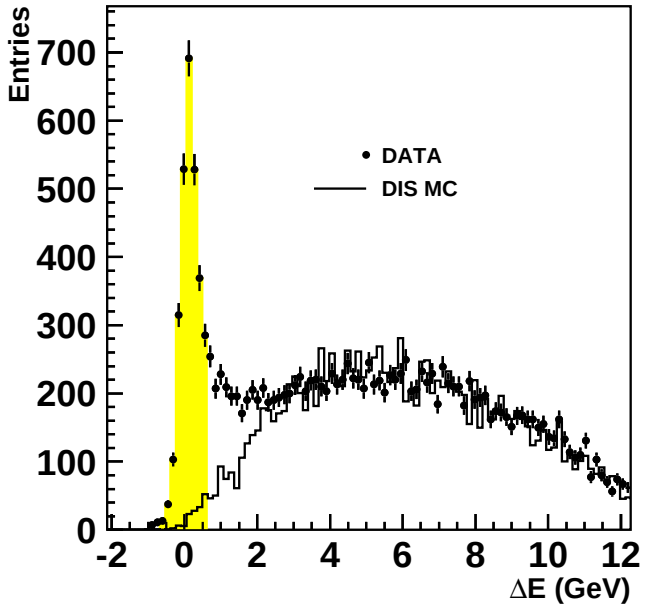
- First: $e \to e' + \gamma^*$ (QED)
  Spin-density matrix of the virtual photon $\rho(\gamma^*)$
- Second: $\gamma^* + N \to \rho^0 + N$ (QCD)
  Helicity amplitudes in CMS of $\gamma^* N$
  $T_{\lambda_\rho \lambda'_N; \lambda_\gamma \lambda_N} = T_{\lambda_\rho \lambda_\gamma}$
  Vector-meson (VM) spin-density matrix
  $\rho(V) = T\ \rho(\gamma^*)\ T^+$
  Free parameters $\rho^\alpha(V) = T\ \Sigma^\alpha\ T^+$
  If contributions of transverse and longitudinal photons are not distinguished $\rho^\alpha(V) \Rightarrow r^\alpha(V)$
- Third: $|\rho^0; 1m > \to |\pi^+\pi^-; 1m > \Rightarrow Y_{1m}(\theta, \phi)$

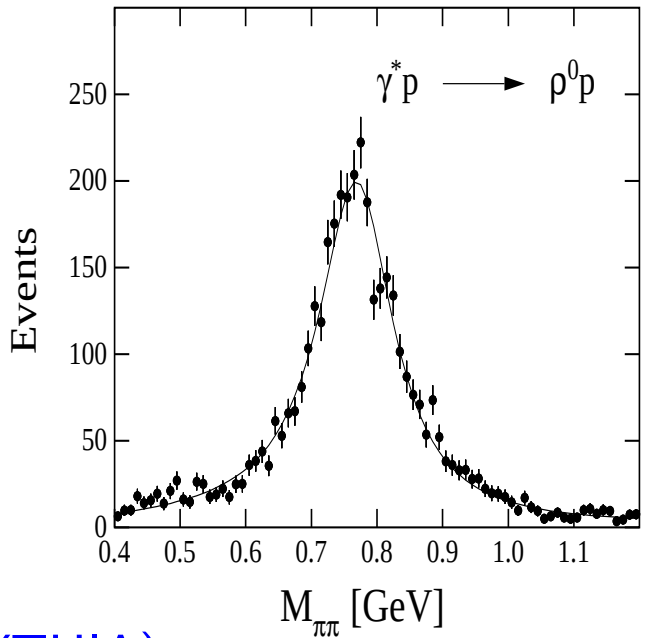
Kinematics of Exclusive ρ^0 Production

- $\nu = 5 \div 24$ GeV, $< \nu >= 13.3$ GeV
- $Q^2 = 1.0 \div 5.0$ GeV^2, $< Q^2 >= 2.3$ GeV^2
- $W = 3.0 \div 6.5$ GeV, $< W >= 4.9$ GeV
- $x_{Bj} = 0.01 \div 0.35$, $< x_{Bj} >= 0.07$

$\Delta E = \frac{M_X^2 - M_p^2}{2M_p}$ with $M_X^2 = (p + q - v)^2$

Clean exclusive peak

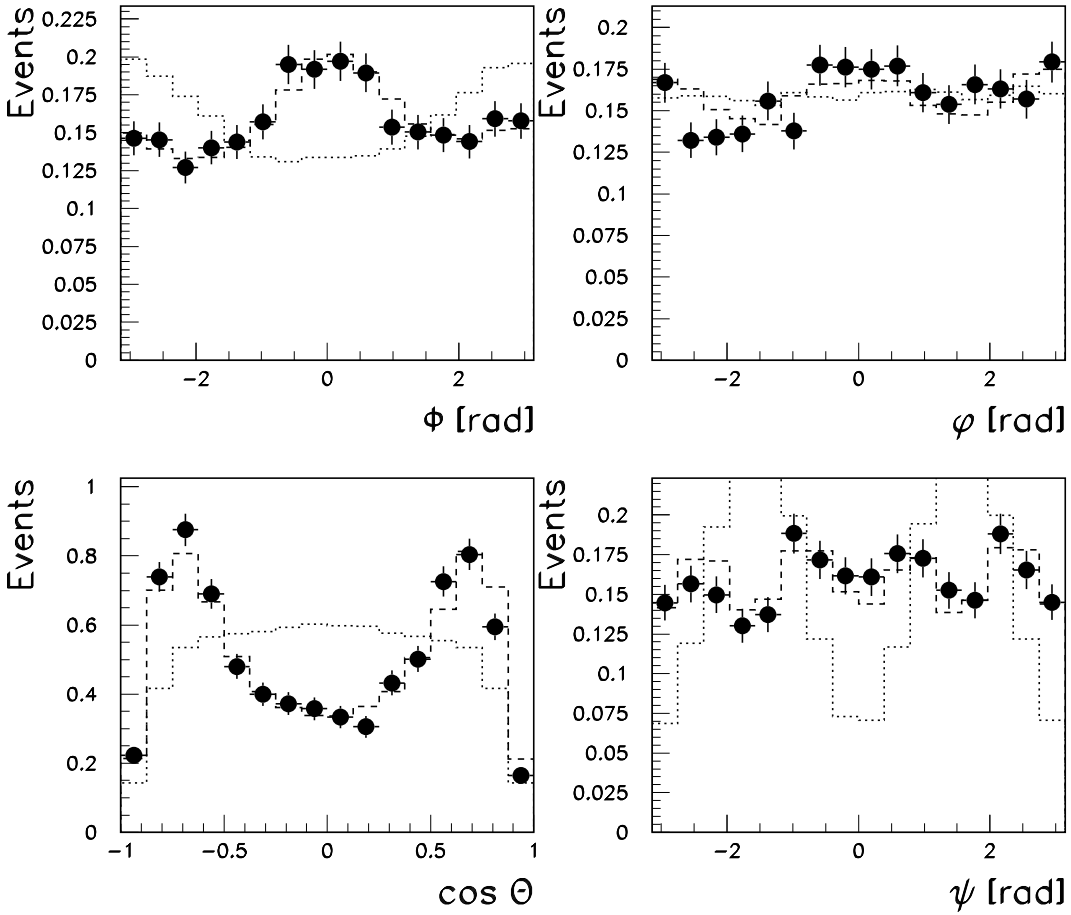




Background is subtracted with the help of MC (PYTHIA)

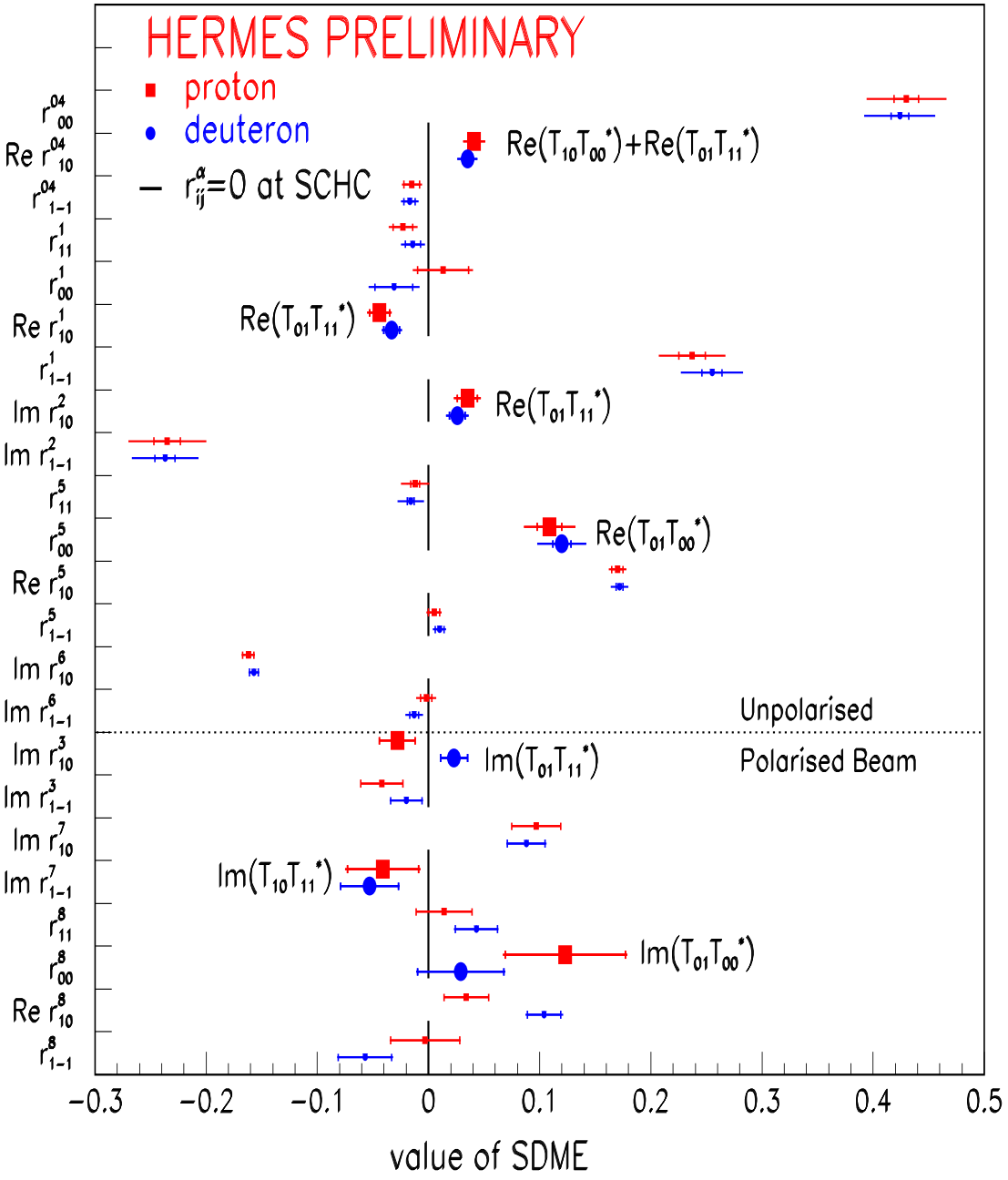
Data Processing using Maximum Likelihood Method in MINUIT

- Monte Carlo Events: 3-dimensional matrix of fully reconstructed MC events at initial uniform angular distribution.
- Binned Maximum Likelihood Method: $8 \times 8 \times 8$ bins of $\cos(\Theta), \phi, \Phi$. Simultaneous fit of 23 SDMEs for data with negative and positive beam helicity ($< P_b >= 53.5\%$).



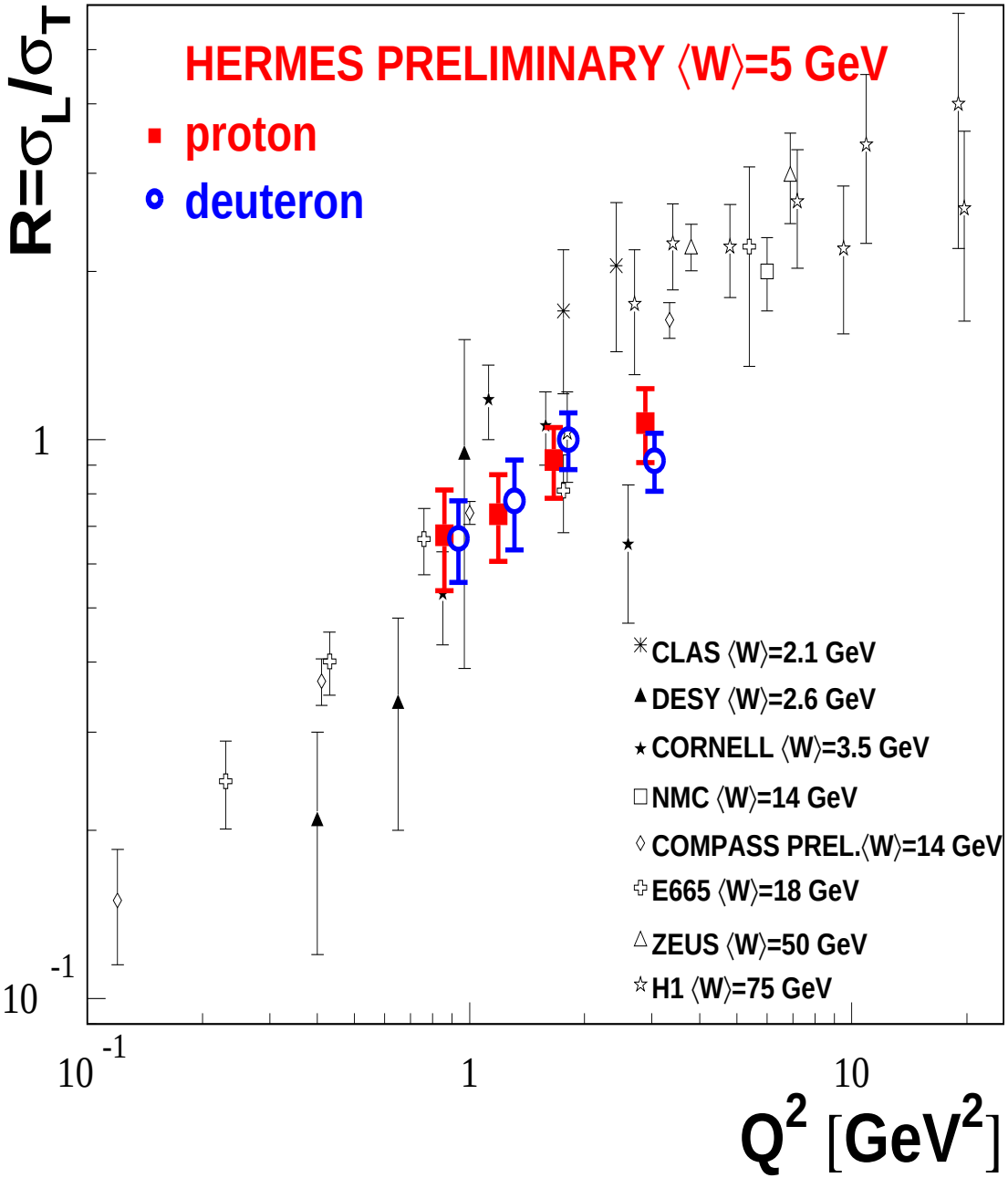
$\longrightarrow$ agreement of fitted angular distributions with data

RESULTS: Spin Density Matrix Elements $r^{\alpha}_{\lambda_\rho \lambda'_\rho}$



- No statistically significant difference between proton and deuteron.
- S-Channel Helicity Conservation (SCHC): Non-zero: T_{11}, T_{-1-1}, T_{00}.
- Violation of SCHC: enlarged points $(2 \div 5\,\sigma)$.
  Linear contribution of spin-flip amplitudes T_{01}, T_{10}, T_{1-1}.
- Indication on hierarchy of amplitudes:
  $T_{00} \sim T_{11} \gg T_{01} > T_{10} \sim T_{1-1}$

Longitudinal-to-Transverse Cross-section Ratio



$$R = \sigma_L/\sigma_T$$

$$\sigma_L = \tfrac{1}{2}\sum_{\lambda_N\lambda'_N}[|T_{00}|^2+|T_{10}|^2+|T_{-10}|^2]$$

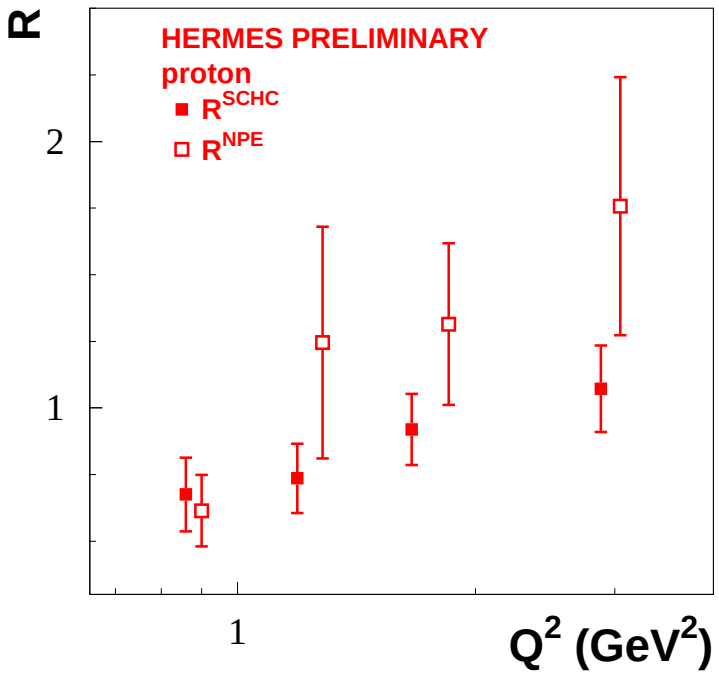
$$\sigma_T = \tfrac{1}{2}\sum_{\lambda_N\lambda'_N}[|T_{11}|^2+|T_{01}|^2+|T_{-11}|^2]$$

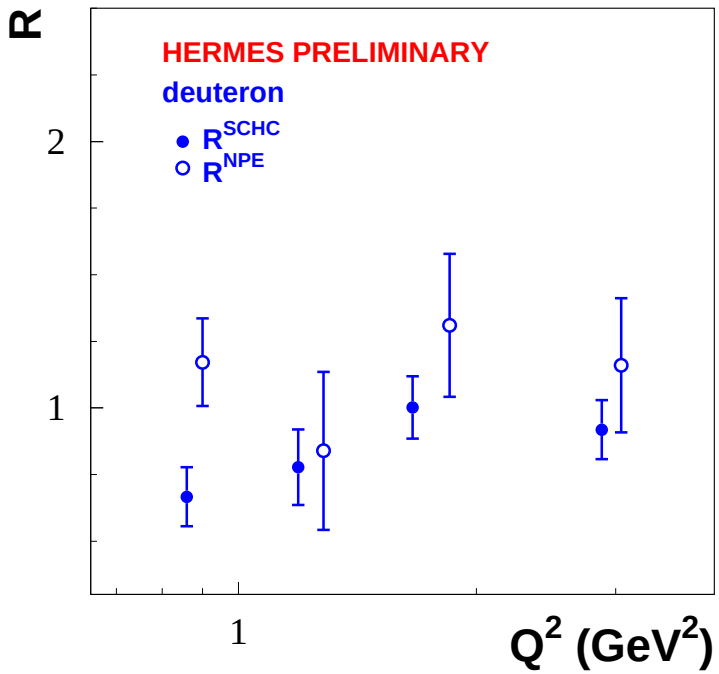
Second order contribution of spin-flip amplitudes (violating SCHC).

SCHC approximation

$$R^{SCHC} = |T_{00}|^2/|T_{11}|^2 \approx \frac{r_{00}^{04}}{\epsilon(1-r_{00}^{04})}$$

L-T Cross-Section Ratio at SCHC and NPE





- SCHC approximation: $R^{SCHC} = \frac{1}{\epsilon}\left\{\frac{1}{1-r^{04}_{00}} - 1\right\}$
- Natural Parity Exchange Dominance: $R^{NPE} = \frac{1}{\epsilon}\left\{\frac{1}{2r^{1}_{1-1}-r^{1}_{00}} - 1\right\}$

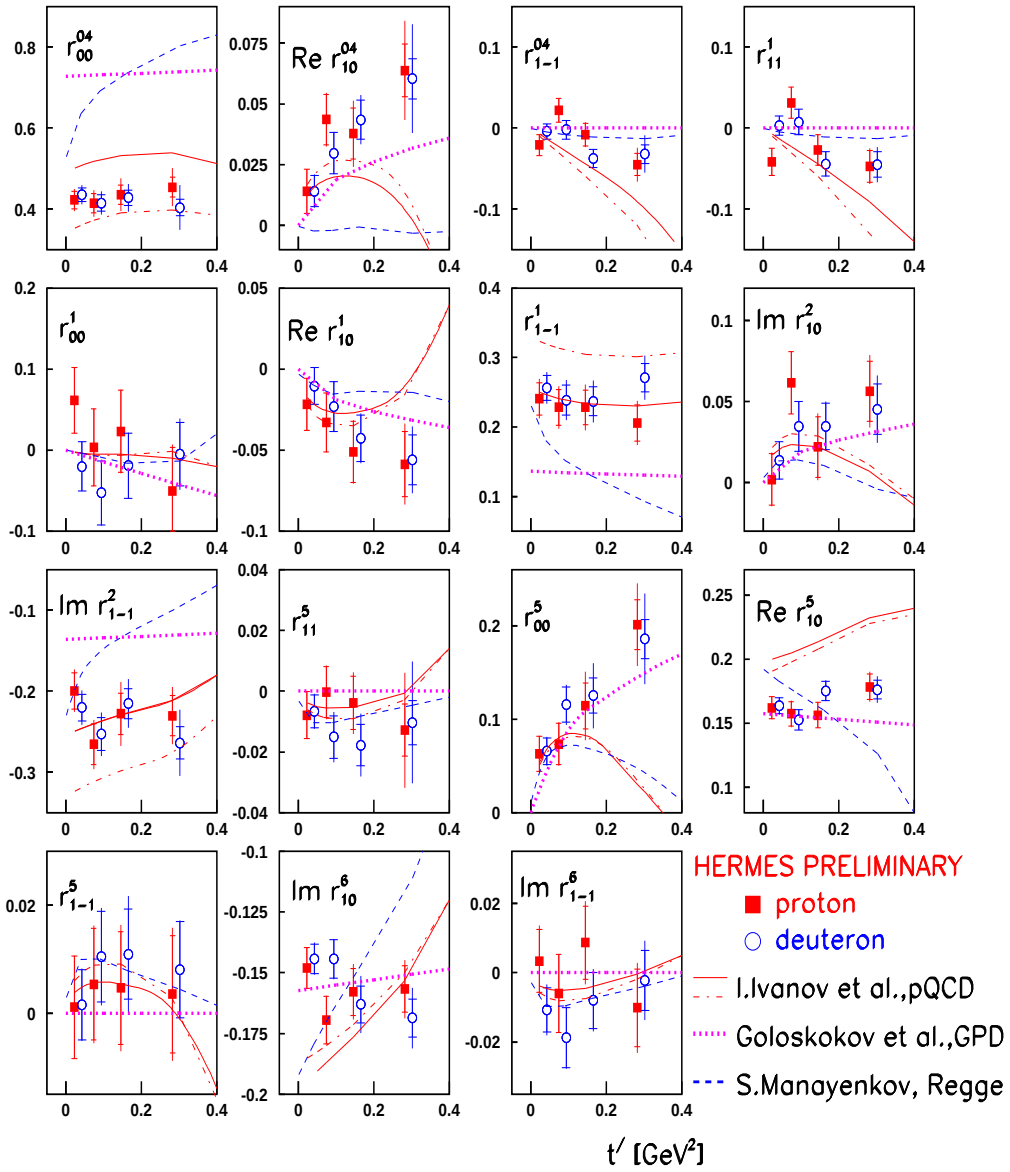
  R^{NPE} has statistical errors greater than R^{SCHC}
- R^{NPE} is the upper limit for R ($R \leq R^{NPE}$)

Calculations of Kinematic Dependences

- Model 1. (I. P. Ivanov and N. N. Nikolaev, JETP Lett. **69** (1999) 294; I. P. Ivanov, PhD thesis, Bonn University, 2003, hep-ph/0303053)
  pQCD. Two-gluon (Pomeron) exchange, ρ-meson wave function with S- and D-waves (Coulomb-like and Gaussian functions). Amplitudes: T_{00}, T_{11}, T_{01}, T_{10}, T_{1-1}.
- Model 2. (S. V. Goloskokov and P. Kroll, Eur.Phys.J. C **42** (2005) 281; hep-ph/0501242)
  Generalized Parton Distributions (GPD), Gaussian ρ-meson wave function (S-wave). Amplitudes: T_{00}, T_{11}, T_{01}.
- Model 3. (S.Manayenkov, Eur.Phys.J. C **33** (2004) 397)
  Regge Phenomenology. Exchanges with Pomeron, ρ, ω, f, A_2. Parton-hadron duality. Amplitudes: T_{00}, T_{11}, T_{01}, T_{10}, T_{1-1}.

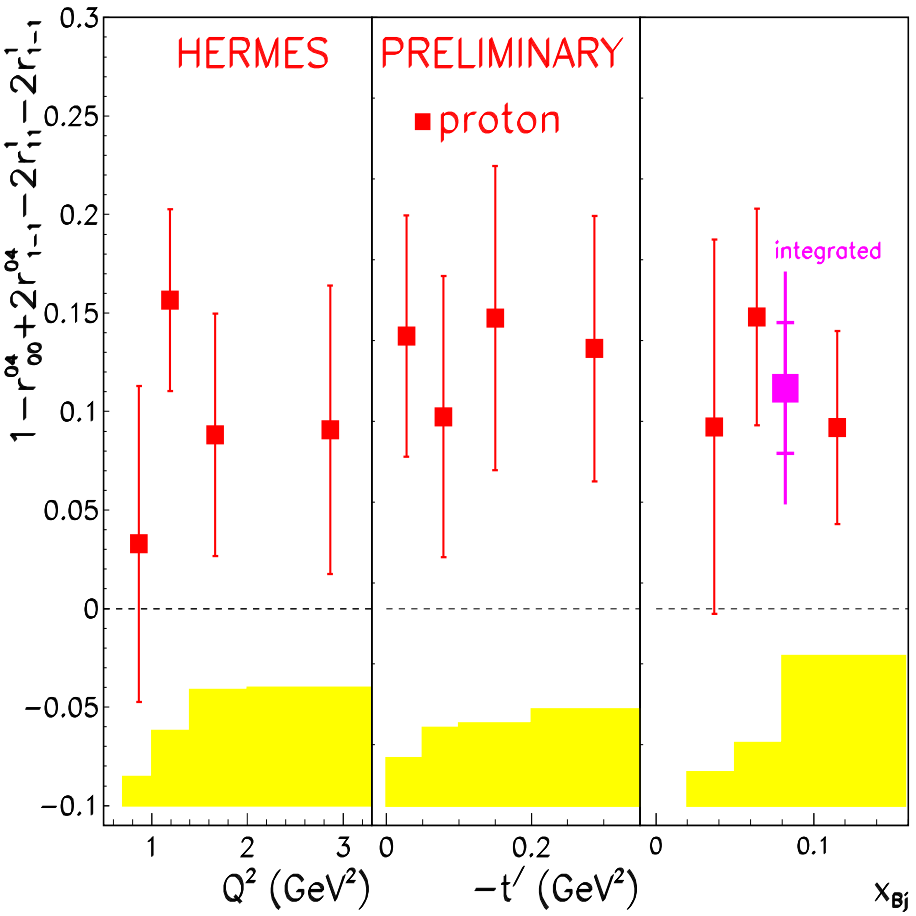
- Special calculations for the HERMES kinematics.

t'-Dependence of SDMEs Compared with Calculations



- Reasonable agreement for a majority of SDMEs at low t'.
- The most crucial disagreement with data for Models 2, 3: r^{04}_{00}, r^{1}_{1-1}, $\mathrm{Im}\{\mathrm{r}^{2}_{1-1}\}$, and for Model 1 $\mathrm{Re}\{\mathrm{r}^{5}_{10}\}$, $\mathrm{Im}\{\mathrm{r}^{6}_{10}\}$.
- No model describes well all unpolarized SDMEs.
- Quark-exchange or/and many-Pomeron exchanges are probably important.
- Extraction of amplitudes from the data is needed.

Test of Unnatural-Parity Exchange



$U_1 = 0.112 \pm 0.033_{stat} \pm 0.049_{syst}$ (H),

$U_1 = 0.059 \pm 0.026_{stat} \pm 0.047_{syst}$ (D)

- Natural and Unnatural Parity Exchanges
  NPE: $P = (-1)^J$
  UPE: $P = -(-1)^J$
  NPE in the t-channel (Pomeron, ρ, ω, f_2, A_2, ...) dominate and UPE (π, A_1, ...) are suppressed at high energies
- $T_{\lambda_\rho \lambda'_N;\lambda_\gamma \lambda_N} = T^N_{\lambda_\rho \lambda'_N;\lambda_\gamma \lambda_N} + T^U_{\lambda_\rho \lambda'_N;\lambda_\gamma \lambda_N}$
  No interference between NPE and UPE contributions to SDMEs $r^\alpha_{\lambda_\rho \lambda'_\rho}$ for unpolarized target
- $U_1 = 1 - r^{04}_{00} + 2r^{04}_{1-1} - 2r^1_{11} - 2r^1_{1-1}$
  $U_1 = \sum_{\lambda_N \lambda'_N} (2\epsilon |T^U_{10}|^2 + |T^U_{11} + T^U_{-11}|^2)/(\sigma_T + \epsilon \sigma_L)$

Summary

- 15 unpolarized and, for the first time, 8 polarized SDMEs are obtained.
- Violation of SCHC is observed both for proton and deuteron data with $2 \div 5\,\sigma$.
- Kinematic dependences of SDMEs are measured for 4 bins in Q^2 and t'.
  No statistically significant difference between proton and deuteron data is found.
  No noticeable natural-parity $q\bar{q}$-exchange with $I = 1$ is observed.
- $R = \sigma_L/\sigma_T$ is obtained under assumption of SCHC and NPE, and is in agreement with world data.
- t'-dependence of SDMEs is compared to theoretical models. Agreement is found for the majority of the unpolarized matrix elements, but no model describes well all SDMEs.
- Unnatural parity exchange is seen for the proton with $2\,\sigma$.

Outlook

- Extraction of helicity amplitudes from the data is in progress.
- Factor of ~ 4 in the experimental statistics is expected.