New Results on Spin Density Matrix Elements for ρ^0 at Hermes

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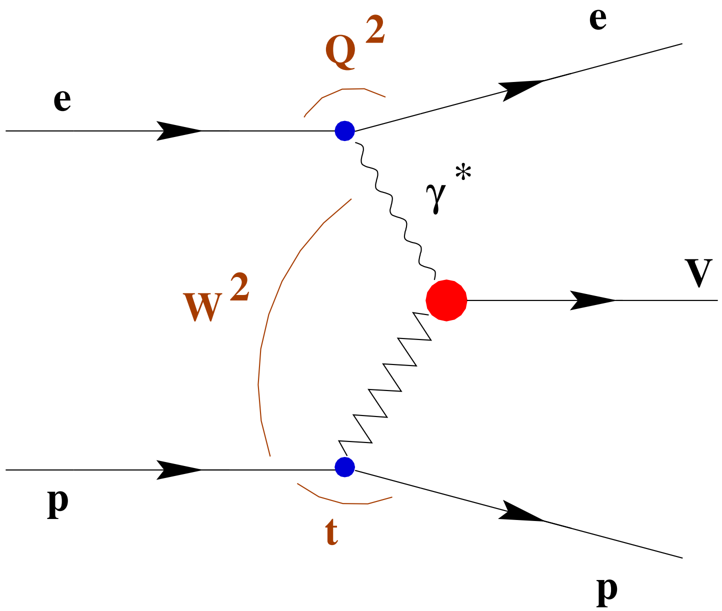
Outline

- Definition of Spin Density Matrix Elements (SDMEs)
- Angular Distribution of Vector Meson Decay
- The Hermes Data
- Method of SDMEs extraction
- 23 Extracted SDMEs
- Kinematical dependences of the SDMEs
- Summary

Exclusive, Diffractive Electroproduction of ρ^0

$$e+N \rightarrow e' + N + \rho^0$$



- Two gluon exchange mechanism at higher energies
- Quark exchange mechanism at intermediate energies
- Spin structure of the ρ^0 production

(How the helicity of the of the ρ^0 meson is related to the helicity of the virtual photon)

$Q^2 = -q^2 = -(k - k')^2$
$W^2 = (q+p)^2$
$t = (q+v)^2$

- Spin Density Matrix Elements
  SDMEs

Spin-Density Matrix of the Vector Meson

- $\rho(\mathrm{V}) = \frac{1}{2}\mathrm{T}\rho(\gamma)\mathrm{T}^{+}$ – Spin-density matrix of the vector meson ρ(V) in terms of the photon spin density matrix ρ(γ) and helicity amplitude T

- $\rho^{\alpha}_{\lambda_{\mathrm{V}}\lambda_{\mathrm{V}'}} = \frac{1}{2N_{\alpha}} \sum_{\lambda_{\gamma}\lambda'_{\gamma}} T_{\lambda_{\mathrm{V}}\lambda_{\gamma}} \Sigma^{\alpha}_{\lambda_{\gamma}\lambda'_{\gamma}} T^{*}_{\lambda'_{\mathrm{V}}\lambda'_{\gamma}}$ – spin-density matrix elements of the vector meson

$T_{\lambda_{\mathrm{V}}\lambda'_{N},\lambda_{\gamma}\lambda_{\mathrm{N}}} = \left\langle \lambda_{\mathrm{V}}\lambda'_{N} \left| \mathrm{J}^{(\mathrm{em})} e^{(\lambda_{\gamma})} \right| \lambda_{\mathrm{N}} \right\rangle$ – helicity amplitudes

where λ_{V}, λ_{γ}, λ_{N} – helicity of the vector meson, photon and proton
$\mathrm{J}^{(\mathrm{em})}$ – electromagnetic current, $\mathrm{e}^{(\lambda)}$ – photon polarization vector
$\lambda_{\gamma} = 0$ – longitudinal polarization, $\lambda_{\gamma} = \pm 1$ – transverse polarization

$\Sigma^{\alpha}_{\lambda_{\gamma}\lambda'_{\gamma}}$ – (α=0,…8) nine hermitian matrices representing states of photon polarization

α = 0 – unpolarized transverse photon   α = 1,2 – linear polarization
α = 3 – circularly polarized photon   α = 4 – longitudinal photon
α = 5,6,7,8 – longitudinal- transverse interference terms

Spin Density Matrix Elements (SDMEs)

- It is not possible to separate contributions from longitudinal and transverse photon at constant beam energy.
- We measure SDMEs – $r^{\alpha}_{\lambda\lambda'_V}$

$$r^{04}_{\lambda_V\lambda'_V} = \frac{\rho^{0}_{\lambda_V\lambda'_V} + \varepsilon R \rho^{4}_{\lambda_V\lambda'_V}}{1+\varepsilon R} \qquad R = \frac{\sigma_L}{\sigma_T} \qquad \varepsilon \text{ – polarization parameter}$$

$$r^{\alpha}_{\lambda_V\lambda'_V} = \frac{\rho^{a}_{\lambda_V\lambda'_V}}{1+\varepsilon R} \qquad \alpha = 1, 2, 3$$

$$r^{\alpha}_{\lambda_V\lambda'_V} = \sqrt{R}\,\frac{\rho^{a}_{\lambda_V\lambda'_V}}{1+\varepsilon R} \qquad \alpha = 5, 6, 7, 8$$

- SCHC – s-channel helicity conservation

helicity of the virtual photon = helicity of the vector meson

$T_{01} = T_{10} = T_{-10} = T_{0-1} = T_{-11} = T_{1-1} = 0$

$T_{00} \neq 0$, $T_{11} \neq 0$ $T_{-1-1} \neq 0$

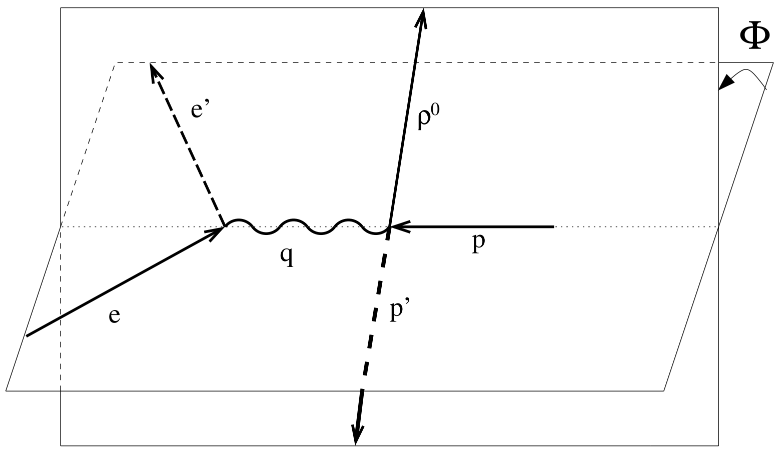
$r^{04}_{00}, \mathrm{Re}\{r^{1}_{1-1}\}, \mathrm{Im}\{r^{2}_{1-1}\}, \mathrm{Re}\{r^{5}_{10}\}, \mathrm{Im}\{r^{6}_{10}\}, \mathrm{Im}\{r^{7}_{10}\}, \mathrm{Re}\{r^{8}_{10}\} \neq 0$

- NPE - Natural Parity Exchange process dominance

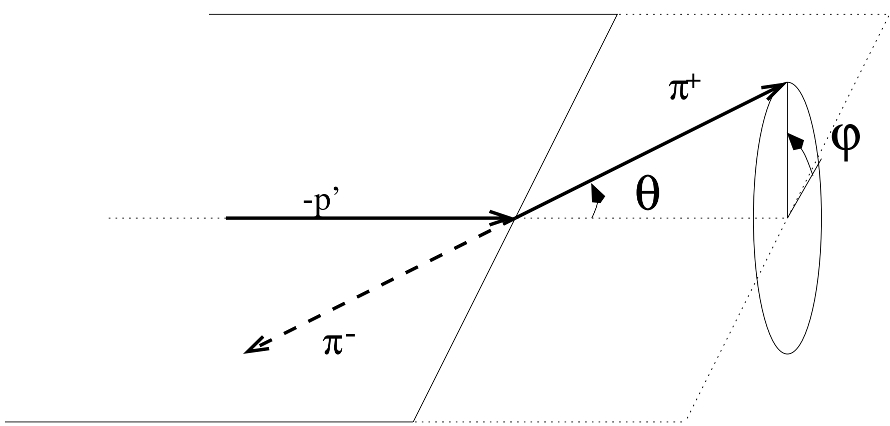
the exchange particle have quantum numbers ($J^P = 0^+, 1^-, 2^+ \ldots$)

T_{00}, $T_{11} = T_{-1-1}$, $T_{01} = -T_{0-1}$, $T_{10} = -T_{-10}$, $T_{1-1} = T_{-11}$

Decay Angles Definition



$\gamma^{*}p$ – center - of momentum frame
Φ - the azimuthal production angle of ρ^0 meson



ρ^0 – rest frame
θ, φ – polar and azimuthal decay angle of the meson π^+ relative to the ρ^0 spin quantization axis, which is along the direction oposite the direction of the recoiling target $-p'$

Decay Angular Distribution in terms of SDMEs

$$\mathrm{W}(\cos\Theta,\phi,\Phi) = W^{unpol} + W^{long.pol.}$$

$$\mathrm{W}^{unpol}(\cos\Theta,\phi,\Phi) = \tfrac{3}{4\pi}\Bigg[\tfrac{1}{2}(1-r^{04}_{00}) + \tfrac{1}{2}(3r^{04}_{00}-1)\cos^2\Theta$$

$$-\ \sqrt{2}Re(r^{04}_{10})\sin 2\Theta\cos\phi - r^{04}_{1-1}\sin^2\Theta\cos 2\phi$$

$$-\ \epsilon\cos 2\Phi\Big(r^{1}_{11}\sin^2\Theta + r^{1}_{00}\cos^2\Theta - r^{1}_{1-1}\sin^2\Theta\cos 2\phi\Big)$$

$$-\ \epsilon\sin 2\Phi\Big(\sqrt{2}Im(r^{2}_{10})\sin^2\Theta\sin\phi + Im(r^{2}_{1-1})\sin 2\Theta\sin 2\phi\Big)$$

$$+\ \sqrt{2\epsilon(1+\epsilon)}\cos\Phi\Big(r^{5}_{11}\sin^2\Theta + r^{5}_{00}\cos^2\Theta - \sqrt{2}Rer^{5}_{10}\sin 2\Theta\cos\phi - r^{5}_{1-1}\sin^2\Theta cos2\phi\Big)$$

$$+\ \sqrt{2\epsilon(1+\epsilon)}\sin\Phi\Big(\sqrt{2}Im(r^{6}_{10})\sin 2\Theta\sin\phi + Im(r^{6}_{1-1})\sin^2\Theta\sin 2\phi\Big)\Bigg]$$

15 unpolarized SDMEs

$$\mathrm{W}^{long.pol.}(\cos\Theta,\phi,\Phi) = \tfrac{3}{4\pi}P_{beam}\Bigg[$$

$$\sqrt{1-\epsilon^2}\Big(\sqrt{2}Im(r^{3}_{10})\sin 2\Theta\sin\phi + Im(r^{3}_{1-1})\sin^2\Theta\sin 2\phi\Big)$$

$$+\ \sqrt{2\epsilon(1-\epsilon)}\cos\Phi\Big(\sqrt{2}Im(r^{7}_{10})\sin 2\Theta\sin\phi + Im(r^{7}_{1-1})\sin^2\Theta\sin 2\phi\Big)$$

$$+\ \sqrt{2\epsilon(1-\epsilon)}\sin\Phi\Big(r^{8}_{11}\sin^2\Theta + r^{8}_{00}\cos^2\Theta - \sqrt{2}Re(r^{8}_{10})\sin 2\Theta\cos\phi - r^{8}_{1-1}\sin^2\Theta\cos 2\phi\Big)\Bigg]()$$

8 polarized SDMEs

Information about Hermes Experimental Data

- Polarized positron (electron) beam of energy E=27.6 GeV
- The average lepton beam polarization was 0.53 for both positive and negative beam helicities
- Targets: Hydrogen, Deuterium
- Data collected in years 1996-2000

Selection of Diffractive Exlusive ρ^0 Events

- Event has only 3 tracks, scattered lepton and two pions $\pi+ \pi-$
- The ρ^0 meson is selected by mass constraints

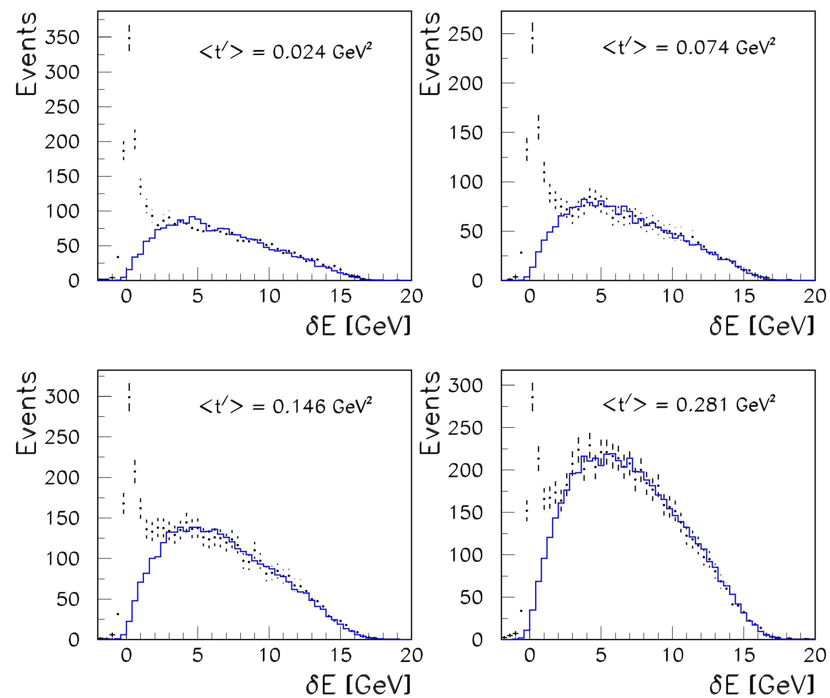
$$0.6 < M_{\pi+\pi-} < 1.0 \text{ GeV}$$

and veto constraints $M_{K+\,K-} > 1.06$ GeV
- Diffractive events were selected by requiring $-t' = t - t_{min} < 0.6$ GeV

- Exlusive events $-1 < \delta E = \dfrac{M_x^2 - M_{targ}^2}{2M_{targ}} < 0.6\,\text{GeV}$

- 9600 – events H, 16000 – events D

SIDIS background subtraction



δE distributions for exlusive diffractive ρ^0 production for different kinematical bins (circles), compared to SIDIS background calculated by PYTHIA MC (histogram)

Extraction of SDMEs

- SDMEs were determined by minimizing the difference between 3-dimesional matrix of data and a sample of MC events.

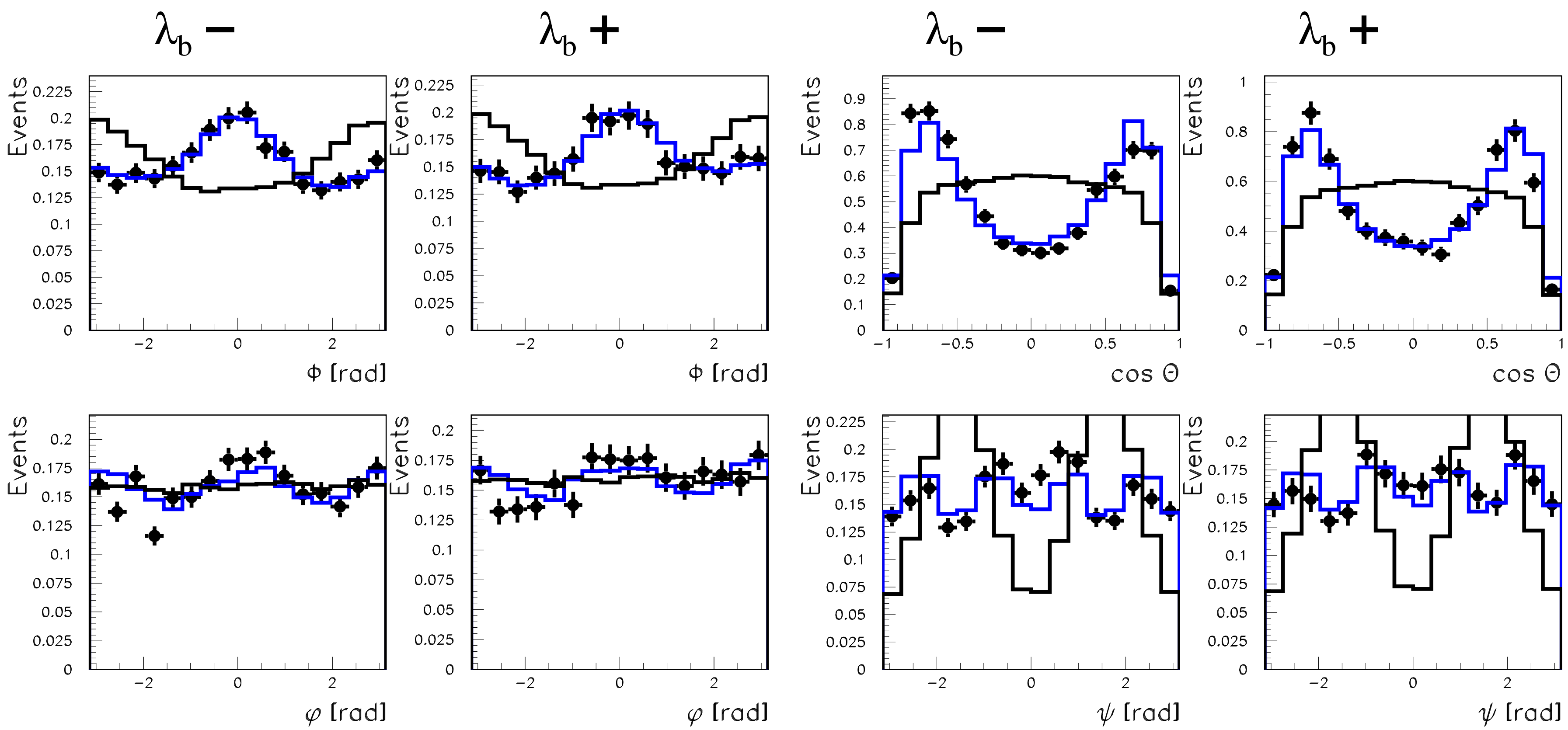
(1) 3-dimensional matrix of data in variables $(\cos(\theta), \varphi, \Phi)$ binned in (8, 8, 8) bins

(2) 3-dimensional matrix of background events

(3) 3-dimensional matrix of MC events generated with uniform angular distribution, reweighted with angular distribution function $W(\cos(\theta), \varphi, \Phi)$ which depends on the SDMEs

(1) – (2) was fitted by (3) with a binned Maximum Likelihood Method where SDMEs were treated as free parameters.

Fitted Angular Distribution



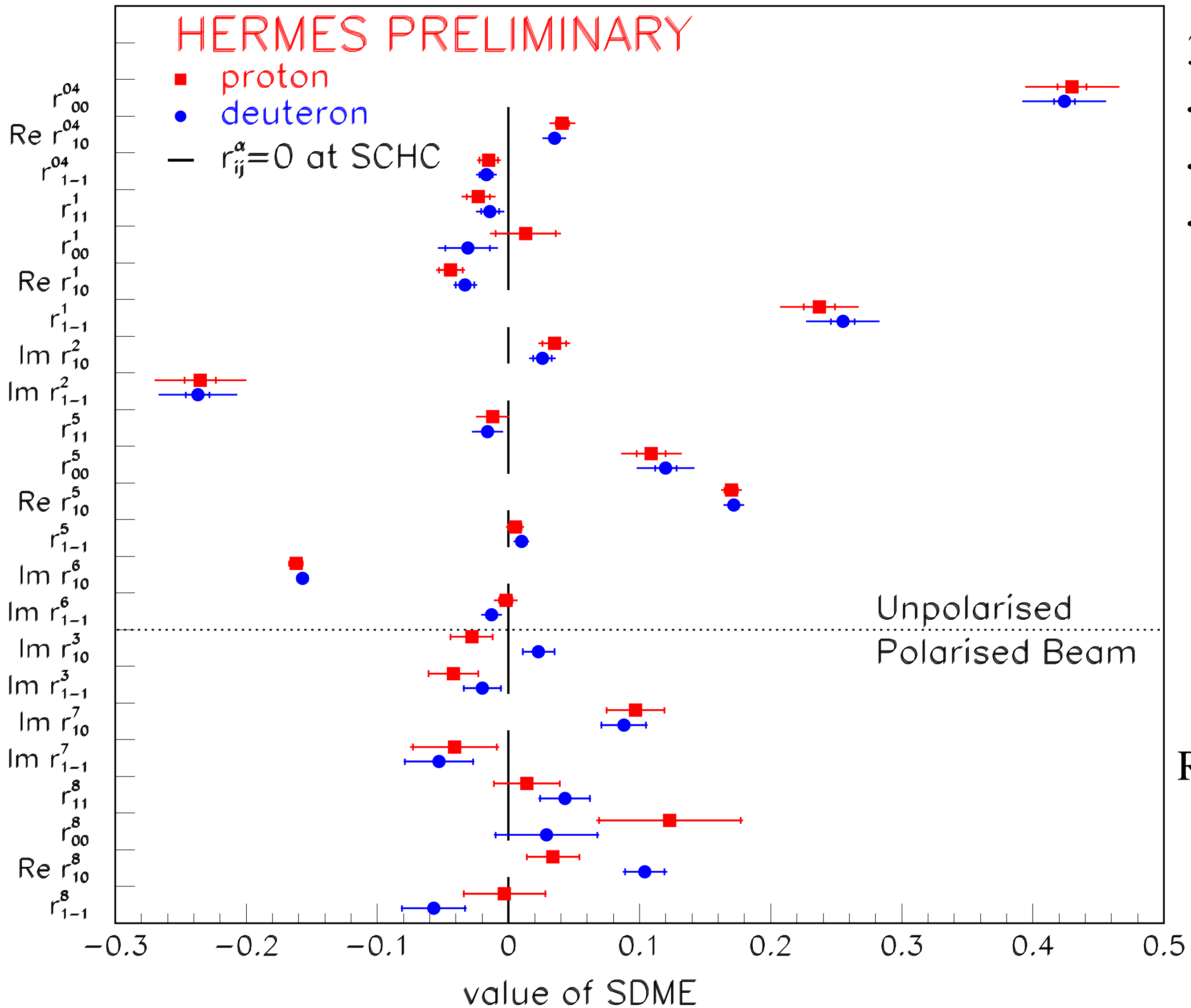
- Closed circles represent measured data

MC distribution fitted to the data

isotropically genereted events used as an input for the fits

$\psi = \varphi - \Phi$

23 Unpolarized and Polarized SDME on Hydrogen and Deuterium



$1.0 < Q^2 < 5.0$ GeV^2

$3.0 < W < 6.3$ GeV

$\langle Q^2 \rangle = 1.86$ GeV^2

$\langle W \rangle = 5.0$ GeV

$\langle t' \rangle = 0.130$ GeV^2

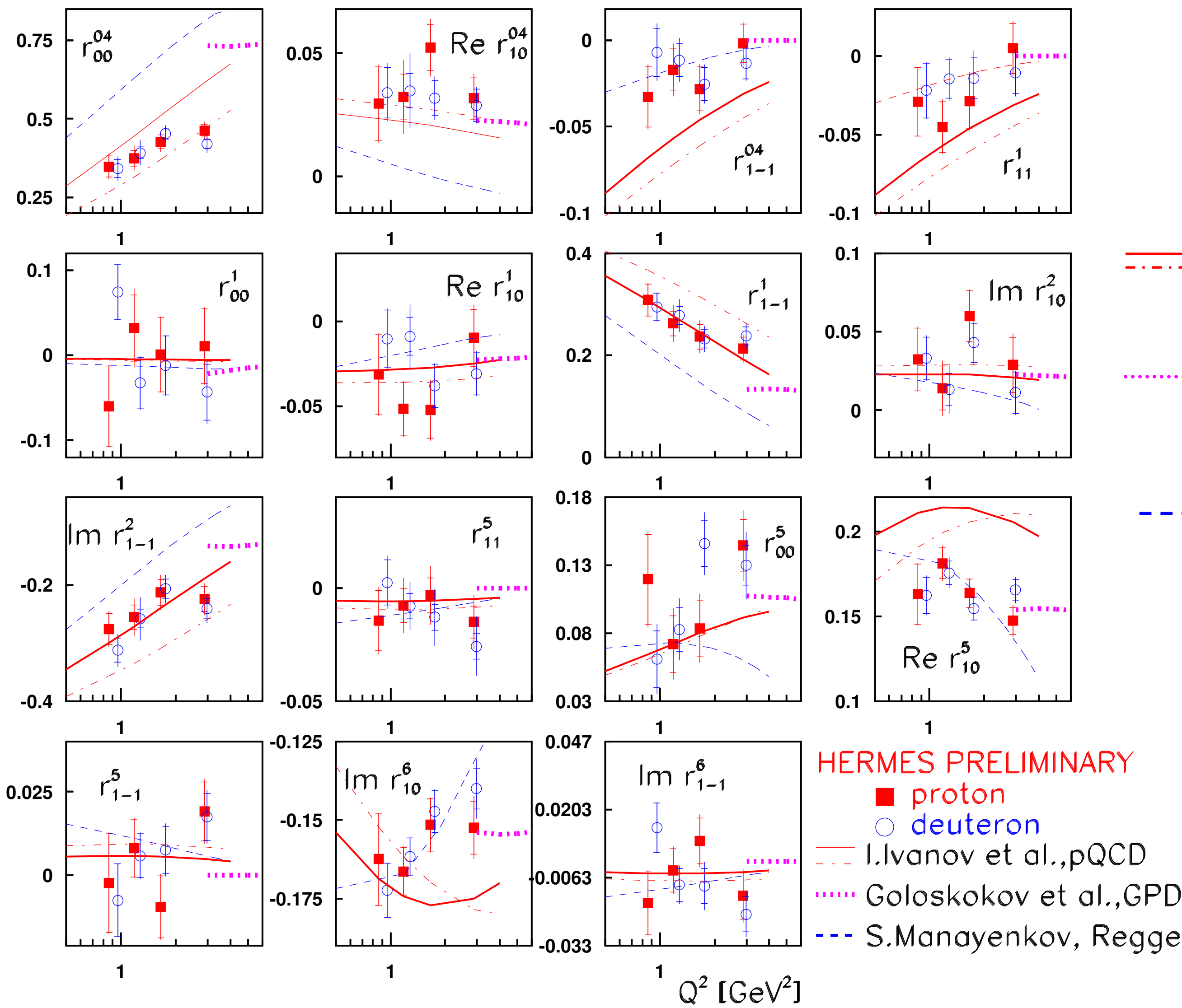
Inner error bar - statistical

outer – total

Elements which violate SCHC

$\mathrm{Re}\{r^{04}_{10}\}, \mathrm{Re}\{r^{1}_{10}\}, \mathrm{Im}\{r^{2}_{10}\}, r^{5}_{00}$

The Q^2- dependence of the 15 upolarized SDMEs



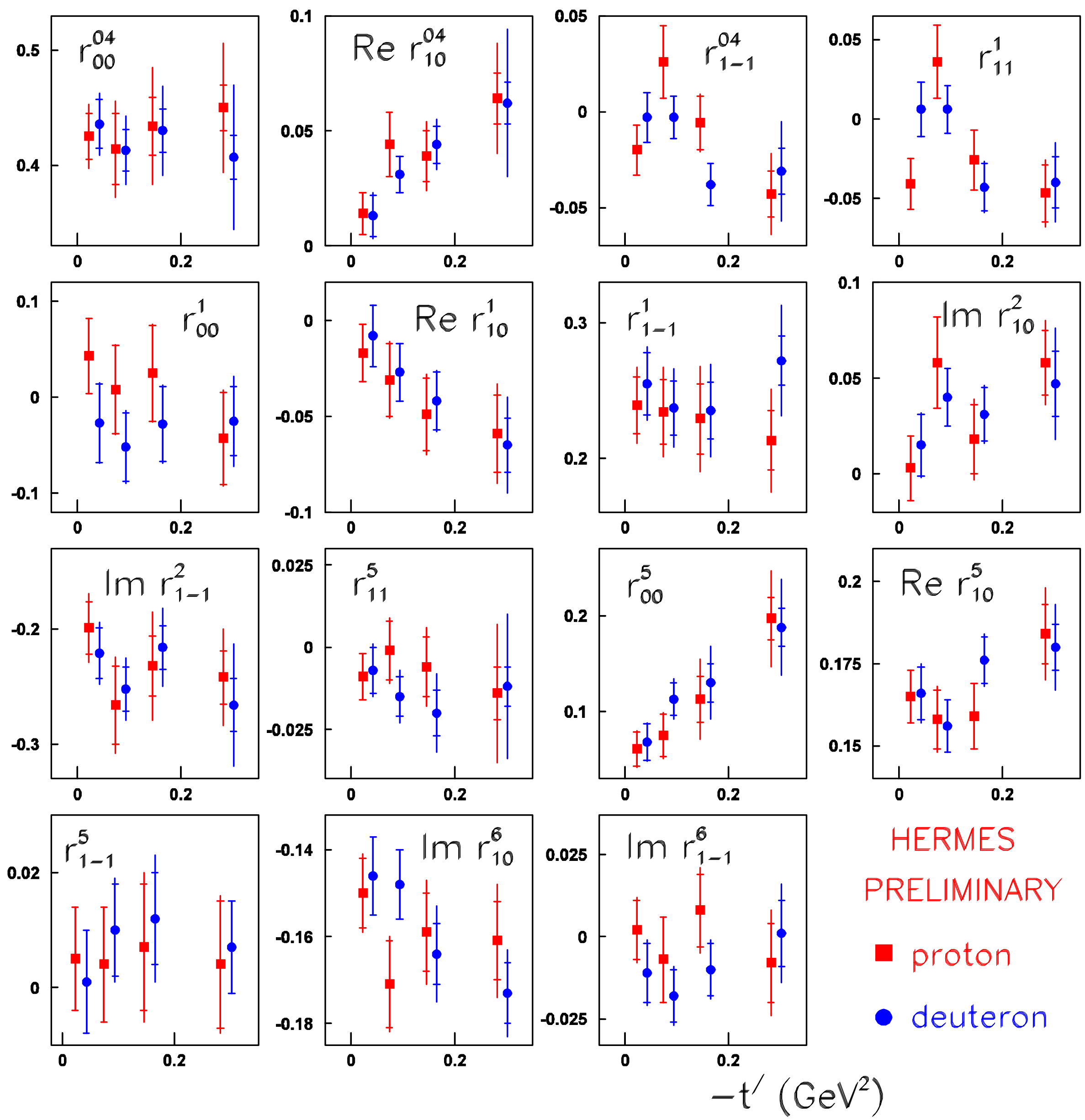
four Q^2 bins
(0.7 – 1.0 – 1.4 – 2.5 –5.0) GeV^2

Perturbative QCD
2 gluon exchane only

Generalized parton distribution

Regge model

The -t'- dependence of the 15 unpolarized SDME



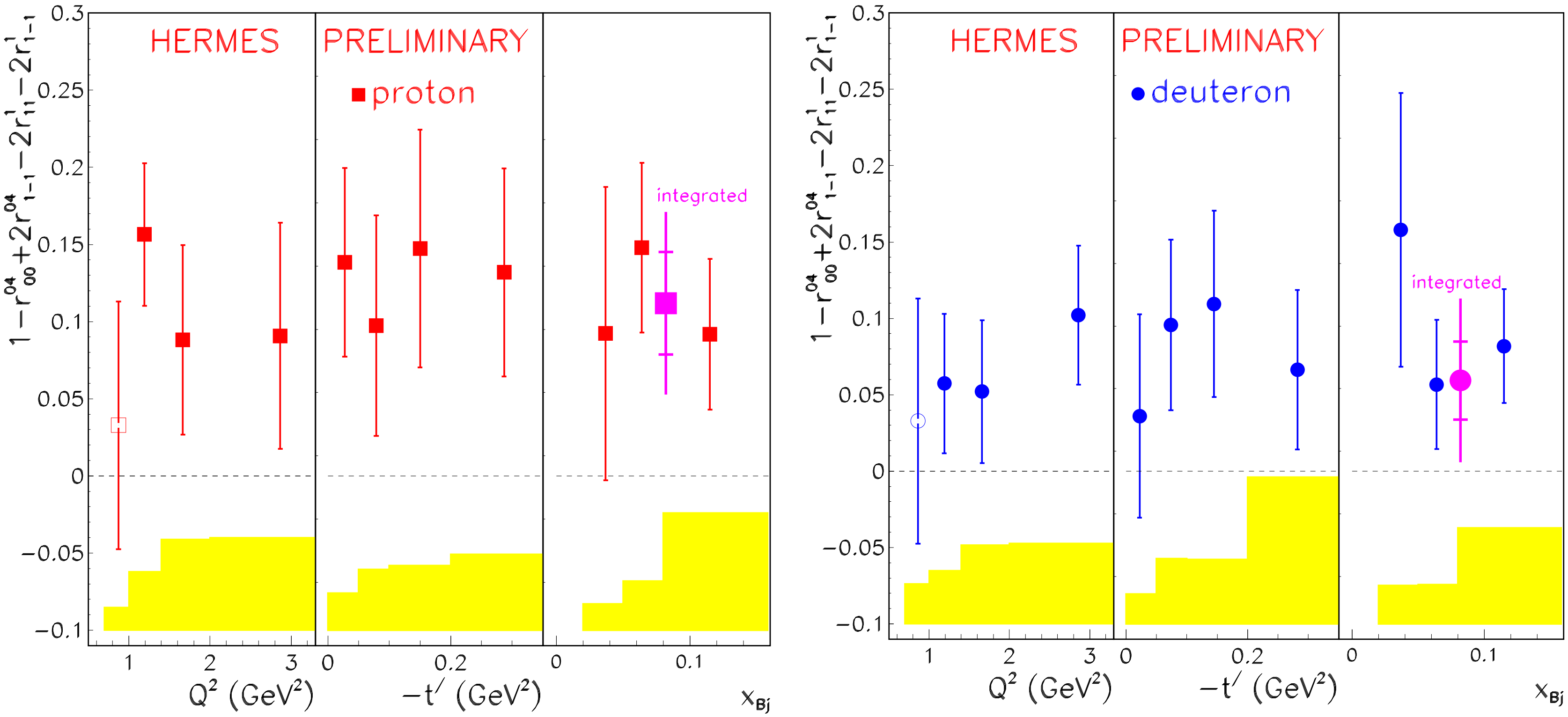
four –t' bins
(0.0 – 0.05 – 0.10
– 0.2 – 0.4) GeV^2
$1.0 < Q^2 < 5.0$ GeV

-t' dependence
observed for:

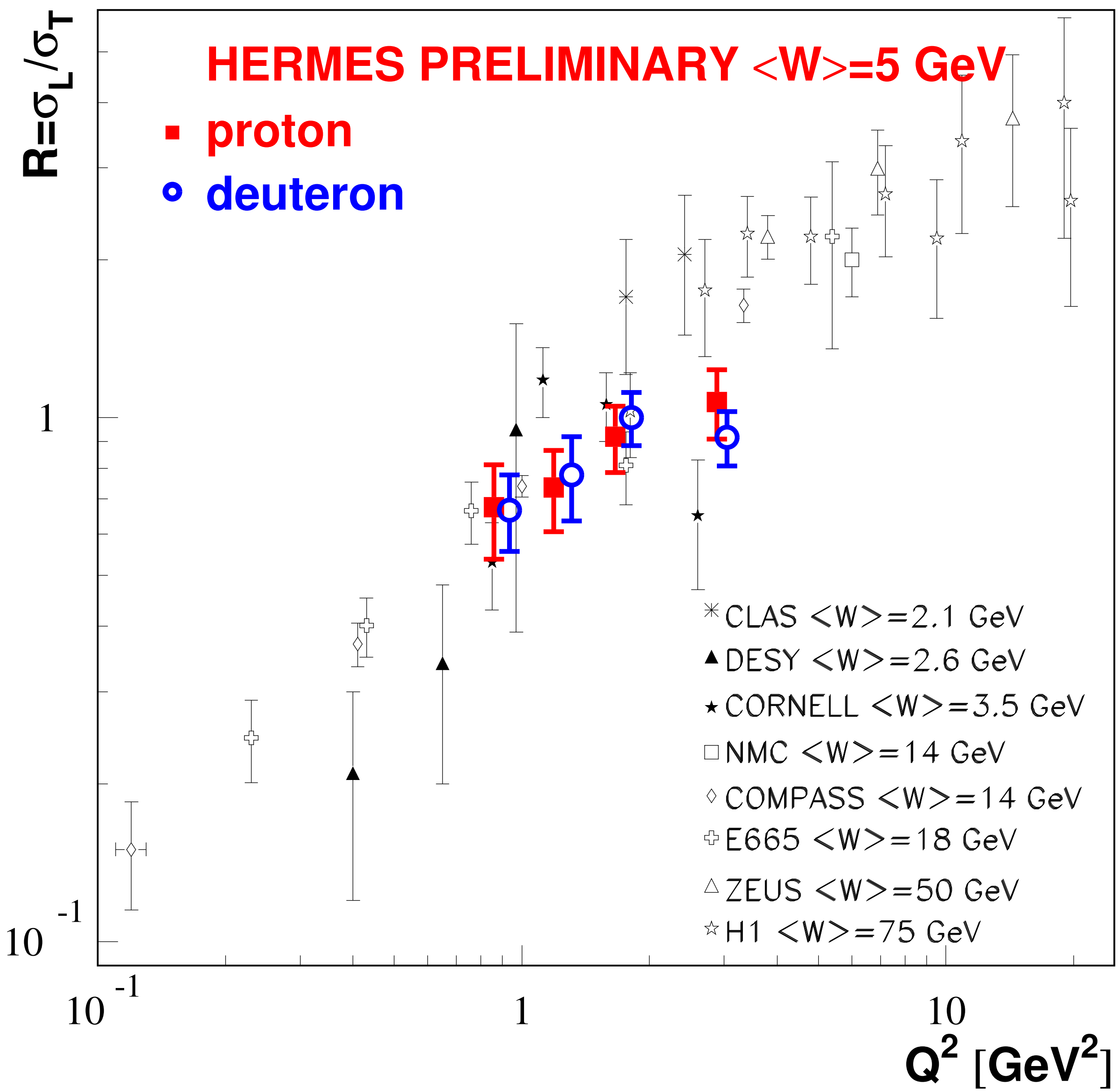
$\mathrm{Re}\{r^{04}_{10}\}, r^{04}_{1\text{-}1}, \mathrm{Re}\{r^{1}_{10}\},$
$\mathrm{Im}\{r^{2}_{10}\}, r^{5}_{00}$

Test of NPE dominance

$$1 - r_{00}^{04} + 2r_{1-1}^{04} - 2r_{11}^{1} - 2r_{1-1}^{1} = 0 \qquad \text{For NPE}$$



Longitudinal-to-Transverse Cross-Section Ratio



$$R_{\rho}^{SCHC} = \frac{1}{\varepsilon} \times \frac{r_{00}^{04}}{1 - r_{00}^{04}}$$

Summary

- 23 SDMEs were obtained with the Likelihood method for ρ^0 production on proton and deuteron targets.
- No significant deviation is seen between the SDMEs from proton and deuteron data and their kinematic dependences.
- Violation of SCHC was shown for non-zero values of several SDMEs on hydrogen and deuterium.
- 15 unpolarized SDMEs were extracted for four Q^2 bins and four $-t'$ bins for proton and deuteron. Several clean kinematic dependences of SDMEs on Q^2 and $-t'$ are observed.
- Test of Natural Parity Exchange was performed for different kinematic bins. An indication of unnatural parity exchange amplitudes is seen in the proton data.
- R^{SCHC} was obtained for four Q^2 bins under the assumption of SCHC