Study of helicity amplitudes in hard exclusive electroproduction of ρ^0 meson on proton and deuteron at HERMES

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1.Introduction

- Exclusive electroproduction of ρ^0 in the process $\gamma^* + N \rightarrow \rho + N^{'}$ provides information on reaction mechanism and nucleon structure.
- Study of exclusive vector meson production offers the possibility of constraining Generalized Parton Distribution(GPD).
- The present work is a continuation of the Spin Density Matrix Elements (SDME) analysis published at **EPJ C62(2009) 659**.
- SDME can be expressed through helicity amplitudes ratio which can be directly extracted from the experimental angular distribution of π^+ and π^- from the decay of the ρ^0 meson.
- The amplitude ratios can be used to check s-Channel Helicity Concervation (SCHC) and contribution of N(U)natural Parity Exchange(NPE,UPE) amplitudes. For this aim, an amplitude ratio is more convenient than SDMEs as any SDME depends on all amplitude ratios.

2. Exclusive ρ^0-Meson Production at HERMES

$\Delta E = \frac{M_X^2 - M_p^2}{2M_p}$ with $M_X^2 = (p + q - p_{\pi^+} - p_{\pi^-})^2$ and M_X being missing mass, p, q, p_{π^+}, p_{π^-} are 4-momenta of proton γ^* and pions.

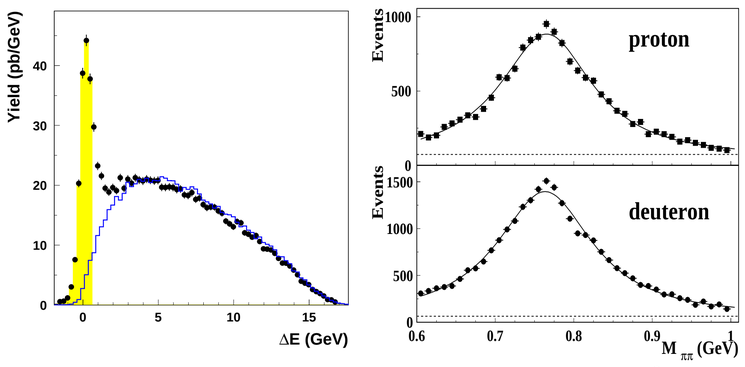

Fig. 1 Distribution of ΔE and invariant mass of two pions (ρ^0). Blue line in the left panel is SIDIS background calculated with the help of MC(PYTHIA).

3.Helicity amplitudes formalism

- Differential cross section of hard exclusive electroproduction of mesons(V) on nucleons(N), $eN \rightarrow e^{'}VN^{'}$, $\gamma^* + N \rightarrow V + N^{'}$, is described by Spin Density Matrix Elements(SDMEs).
- For longitudinally polarized beam and unpolarized target we have 23 SDMEs.
- The SDMEs are expressed in terms of helicity amplitudes $T_{\lambda_V \lambda^{'}_N \lambda_\gamma \lambda_N}$ and $U_{\lambda_V \lambda^{'}_N \lambda_\gamma \lambda_N}$ where T and U correspond to natural and unnatural - parity exchange, $\lambda_V, \lambda\gamma$ are helicities of vector meson and virtual photon, respectively, while $\lambda_N(\lambda^{'}_N)$ describes spin states of the initial (scattered) nucleon.
- The amplitudes obey the following symmetry relation:
  $T_{\lambda_V \lambda^{'}_N \lambda_\gamma \lambda_N} = (-1)^{-\lambda_V + \lambda_\gamma} T_{-\lambda_V \lambda^{'}_N - \lambda_\gamma \lambda_N}$
  $= (-1)^{-\lambda^{'}_N + \lambda_N} T_{\lambda_V - \lambda^{'}_N - \lambda_\gamma - \lambda_N}$
  $U_{\lambda_V \lambda^{'}_N \lambda_\gamma \lambda_N} = -(-1)^{-\lambda_V + \lambda_\gamma} U_{-\lambda_V \lambda^{'}_N - \lambda_\gamma \lambda_N}$
  $= -(-1)^{-\lambda^{'}_N + \lambda_N} U_{\lambda_V - \lambda^{'}_N - \lambda_\gamma - \lambda_N}$
- Due to these symmetry relations production of vector meson is described by 10 NPE and 8 UPE amplitudes.
- The SDMEs are expressed by 18 complex helicity amplitudes, 34 parameters (real and imaginary parts).
- NPE amplitudes with nucleon spin flip are suppressed in comparison to amplitudes describing diagonal transition with $\lambda_N = \lambda^{'}_N$ We neglect NPE amplitudes with nucleon spin flip.
- From SDME analysis it has been found that for UPE transition s-Channel Helicity Concervation (SCHC) is fulfilled at small $t^{'}$. $|U_{01}|^2, |U_{10}|^2, |U_{1-1}|^2 \ll |U_{11}|^2$, we only keep $|U_{11}| = \sqrt{|U_{1\frac{1}{2}1\frac{1}{2}}|^2 + |U_{1-\frac{1}{2}1\frac{1}{2}}|^2}$.
- Finally, we can aproximate the SDMEs through 9 real parameters, namely: $Re\{T_{11}/T_{00}\}$, $Im\{T_{11}/T_{00}\}$, $Re\{T_{01}/T_{00}\}$, $Im\{T_{01}/T_{00}\}$, $Re\{T_{10}/T_{00}\}$, $Im\{T_{10}/T_{00}\}$, $Re\{T_{1-1}/T_{00}\}$, $Im\{T_{1-1}/T_{00}\}$, $|U_{11}/T_{00}|$ where $|U_{11}/T_{00}|$ is the module of U_{11}/T_{00}. W use shorthand notation $T_{\lambda_V \lambda_\gamma} = T_{\lambda_V \frac{1}{2} \lambda_\gamma \frac{1}{2}}$

4. Determination of amplitudes ratios

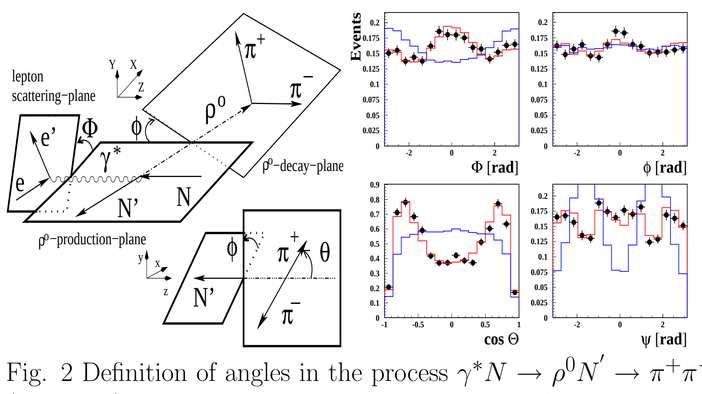

Fig. 2 Definition of angles in the process $\gamma^* N \rightarrow \rho^0 N^{'} \rightarrow \pi^+\pi^- N^{'}$ (left panel). An example of fitted angular distribution. The blue lines represent isotropic input Monte Carlo distribution as modified by the HERMES acceptance, while the red lines are the results of the fit (right panel).

- Amplitude ratios are extracted directly from the measured angular distribution.
- Angular distribution $\mathcal{W}(\Phi, \phi, \cos\Theta)$ depends linearly on SDMEs $r^{\alpha}_{\lambda_V \lambda^{'}_V}$ and beam polarization P_b.
- SDMEs are expressed through 5 amplitude ratios, i.e. 9 real parameters. The amplitudes ratios are free parameters in fitting procedure. The amplitudes ratios were extracted for 4×4 of Q^2 and $-t^{'}$ bins.
- The amplitude ratios are extracted with the same binned maximum likelihood method as SDMEs **EPJ C62(2009) 659**.

5.Kinematic Dependences of Ratios of T_{11} Helicity Amplitudes

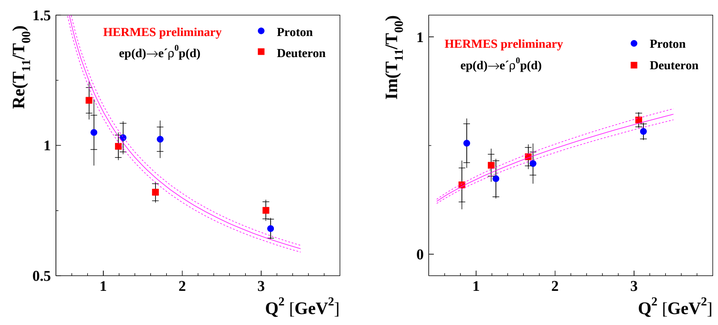

Fig. 3 The Q^2 dependence of $Re\{T_{11}/T_{00}\}$ and $Im\{T_{11}/T_{00}\}$ for proton and deutron data.

- No difference between proton and deuteron for amplitude ratio T_{01}/T_{00}.
- pQCD predicts the folowing dependence: $T_{11}/T_{00} \propto M_\rho/Q$.
- The Q depenence of T_{11}/T_{00} is fitted with
  $\mathrm{Re}\{T_{11}/T_{00}\} = a/Q$, $\mathrm{Im}\{T_{11}/T_{00}\} = b$.
  Combined data on proton and deuteron: $a = 1.129 \pm 0.024$ GeV, $\chi^2/N_{df} = 1.02$; $b = 0.344 \pm 0.014$ GeV^{-1}, $\chi^2/N_{df} = 0.87$.
- Behaviour of $\mathrm{Im}\{T_{11}/T_{00}\}$ is in contradiction with high-Q asymptotics in pQCD.
- The Q^2 dependence of the phase difference δ_{11} between the amplitudes T_{11} and T_{00} is given by
  $\tan\delta_{11} = \mathrm{Im}\{T_{11}/T_{00}\}/\mathrm{Re}\{T_{11}/T_{00}\} = bQ^2/a$.
  Phase difference is $\delta_{11} \sim 30^\circ$ at $< Q^2 = 1.95 GeV^2$ and grows with Q^2 in disagreement with pQCD calculation.

6.Kinematic Dependences of Ratios of T_{01} Helicity Amplitudes

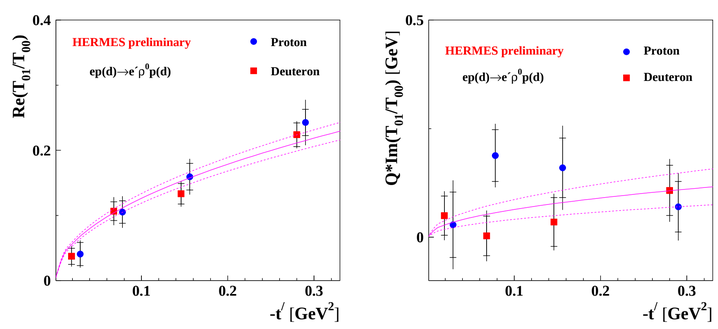

Fig. 4 The $t^{'}$ dependence of $Re\{T_{01}/T_{00}\}$ and $Q * Im\{T_{01}/T_{00}\}$ for proton and deutron data.

- The amplitude $T_{01} = T_{0\frac{1}{2}1\frac{1}{2}}$ describing the transition $\gamma^* N \rightarrow \rho^0_L$ is the largest SCHC-violating amplitude.
- There is no difference between proton and deuteron for amplitude ratio T_{01}/T_{00}.
- pQCD predicts the folowing dependence: $\frac{T_{01}}{T_{00}} \propto \frac{\sqrt{-t'}}{Q}$.
- the t' dependence of T_{01}/T_{00} is fitted with
  $\mathrm{Re}(T_{01}/T_{00}) = a\sqrt{-t'}$, $\mathrm{Im}(T_{01}/T_{00}) = b\sqrt{-t'}/Q$.
  Combined proton and deuteron data: $a = 0.399 \pm 0.023$ GeV^{-1}, $\chi^2/N_{df} = 0.72$;
  $b = 0.20 \pm 0.07$, $\chi^2/N_{df} = 1.09$.

7.Kinematic Dependences of Ratios of U_{11} Helicity Amplitudes

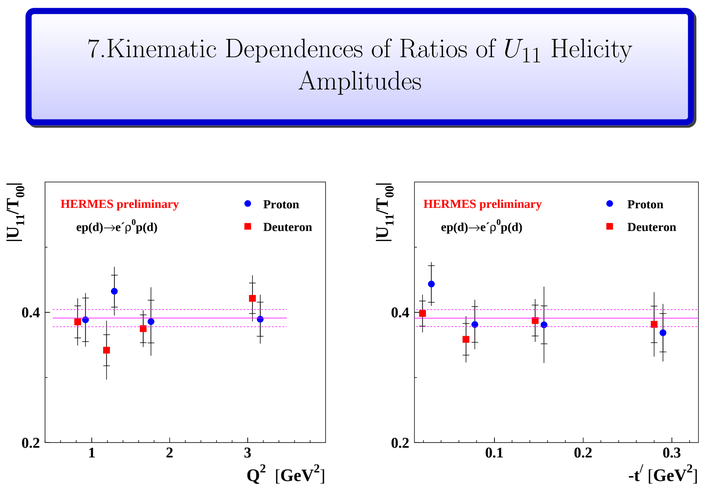

Fig. 5 The dependence of $|U_{11}/T_{00}|$ on Q^2 and $t^{'}$ for proton and deutron data.

- No difference between proton and deuteron for amplitude ratio $|U_{11}/T_{00}|$.
- pQCD predicts the folowing dependence: $U_{11}/T_{00} \propto M_\rho/Q$.
- we do not see either Q^2 or t' dependence: $|U_{11}|/|T_{00}| = a$, $a = 0.391 \pm 0.013$, $\chi^2/N_{df} = 0.44$
- Contradiction with both high-Q asymptotic and one-pion-exchange dominance.
- Unnatural Parity Exchange is seen here much better than in SDME method.

Comparison of Hermes and H1 results.

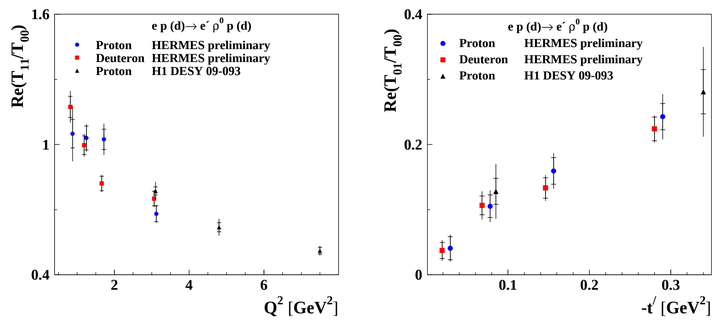

Fig.6 Comparison of T_{11}/T_{00} and T_{01}/T_{00} amplitude ratios of HERMES and H1 proton and deutron data.

- H1: Unpolarized beam and unpolarized target (15 SDMEs), $< Q^2 >= 3.3$ GeV^2.
- Additional assumption: all amplitudes are imaginary, all amplitude ratios are real.
- HERMES: Longitudinally polarized beam and unpolarized target (23SDMEs).
- Both real and imaginary parts of ratios of helicity amplitudes are extracted.
- Excellent agreement of amplitude ratios extracted by H1 and HERMES.

8.Summary

- Study of electroproduction of ρ^0 vector meson on proton and deutron enables to obtain ratios of helicty amplitudes, and investigate their kinematic dependences.
- The kinematic dependence of $Im\{T_{11}/T_{00}\}$, $Re\{U_{11}/T_{00}\}$ are in contradiction with high-Q asymptotics behavior predicted in pQCD.
- The amplitude ratios for deuterons are compatible with those for protons.
- The UPE signal is seen here with very high significance for both proton and deuteron data and with higher precision than that obtained in SDME method.