Hard exclusive electro-production of vector mesons at HERMES

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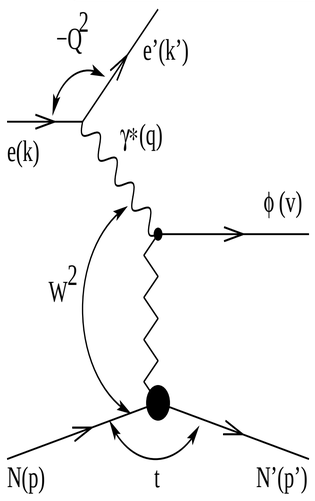
What can we learn from electro-production of vector mesons.

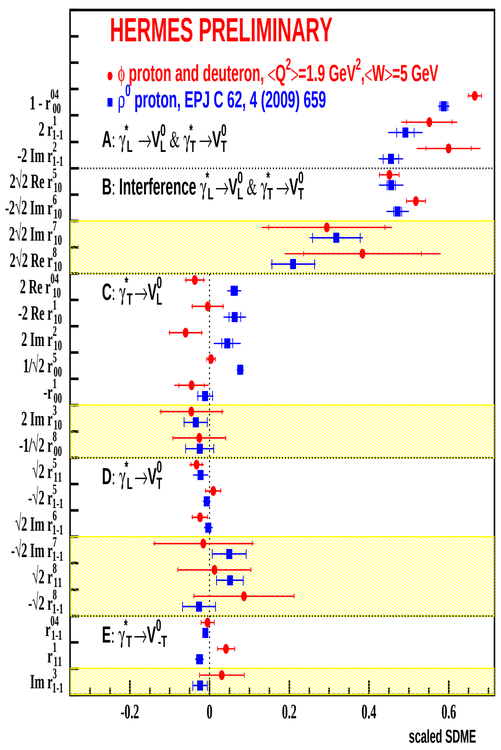
- Exclusive electroproduction of vector mesons in the process $\gamma^* + N \rightarrow V + N'$ (V=ρ^0, ϕ, ω) provides information on reaction mechanism and nucleon structure.
- Test of S-channel Helicity Conservation hypothesis (SCHC).
- Possibility to distinguish between contribution of N(U)natural Parity Exchange(NPE,UPE).
- Direct extraction of helicity amplitudes ratios of the reaction.
- Study of exclusive vector meson production offers the possibility of constraining Generalized Parton Distribution(GPD).

Experimental observables. Spin Density Matrices in reaction $e + N \rightarrow e' + V + N$



- $e \rightarrow e' + \gamma^*$ (QED). Spin-density matrix of the virtual photon : $\varrho^{U+L}_{\lambda_\gamma\lambda'_\gamma}(\gamma) = \varrho^{U}_{\lambda_\gamma\lambda'_\gamma} + P_{beam}\varrho^{L}_{\lambda_\gamma\lambda'_\gamma}$ (U - unpolarized, L - polarized beam)
- $\gamma^* + N \rightarrow \rho^0(\phi) + N \rightarrow \pi^+(K^+) + \pi^-(K^-) + N$ (QCD).
- Spin Density Matrix Elements (SDMEs): $r^{\alpha}_{\lambda_\rho\lambda'_\rho} \sim \rho(V) = \frac{1}{2}F\rho(\gamma)F^+$ Vector meson spin-density matrix $\rho(V)$ so and SDMEs are expressed in terms of the photon matrix $\rho(\gamma)$ and helicity amplitude $F_{\lambda_V\lambda_\gamma}$.
- α=0$\div$3 - transverse photons , 4 - longitudinal photons, 5$\div$8 - interference terms.
- $F_{\lambda_V\lambda_\gamma} = T_{\lambda_V\lambda_\gamma} + U_{\lambda_V\lambda_\gamma}$ amplitudes, $T_{\lambda_V\lambda_\gamma}$ - natural- parity exchange (NPE), $U_{\lambda_V\lambda_\gamma}$ - unatural-parity exchange (NPE) amplitudes.
- SDMEs are bilinear combination of helicity amplitudes.
- For longitudinally polarized beam and unpolarized target there are 23 SDMEs,(15 unpolarized and 8 polarized) which are determined from the fit of angular distribution of kaons from decay $\phi \Rightarrow K^+K^-$ or pions from $\rho^0 \Rightarrow \pi^+\pi^-$.

Comparison of SDMEs for the integrated data on exclusive ρ^0 and ϕ production



- A, $\gamma^*_L \rightarrow \phi_L$ and $\gamma^*_T \rightarrow \phi_T$
  $|T_{11}|^2 \propto 1 - r^{04}_{00} \propto r^1_{1-1} \propto -Im\{r^2_{1-1}\}$

- B, Interference: γ^*_L, ϕ_T
  $Re\{T_{00}T^*_{11}\} \propto Re\ \{r^5_{10}\} \propto -Im\{r^6_{10}\}$
  $Im\{T_{11}T^*_{00}\} \propto Im\{r^7_{10}\} \propto Re\{r^8_{10}\}$

- C, Spin Flip: $\gamma^*_T \rightarrow \phi_L$
  $Re\{T_{11}T^*_{01}\} \propto Re\{r^{04}_{10}\} \propto Re\{r^1_{10}\} \propto Im\{r^2_{10}\}$
  $Re\{T_{01}T^*_{00}\} \propto r^5_{00}$
  $|T_{01}|^2 \propto r^1_{00}$
  $Im\{T_{01}T^*_{11}\} \propto Im\{r^3_{10}\}$
  $Im\{T_{01}T^*_{00}\} \propto r^8_{00}$

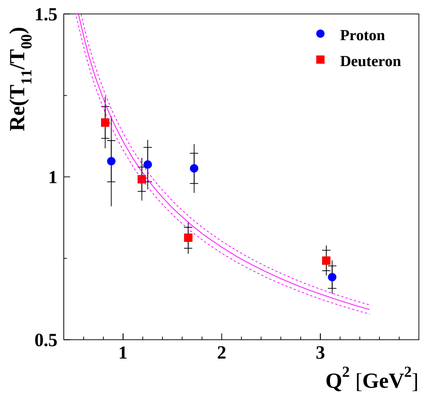
- D, Spin Flip: $\gamma^*_L \rightarrow \phi_T$
  $Re\{T_{10}T^*_{11}\} \propto r^5_{11} \propto r^5_{1-1} \propto Im\{r^6_{1-1}\}$
  $Im\{T_{10}T^*_{11}\} \propto Im\{r^7_{1-1}\} \propto r^8_{11} \propto r^8_{1-1}$

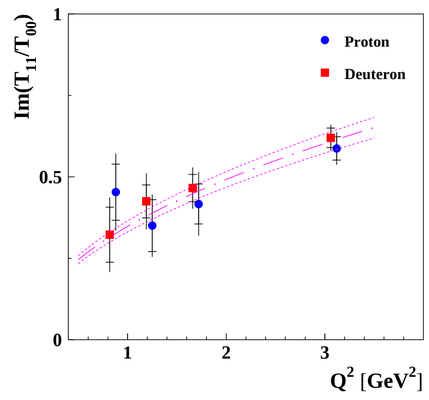
- E, Spin Flip: $\gamma^*_T \rightarrow \phi_{-T}$
  $Re\{T_{1-1}T^*_{11}\} \propto r^{04}_{1-1} \propto r^1_{11}$
  $Im\{T_{1-1}T^*_{11}\} \propto Im\{r^3_{1-1}\}$

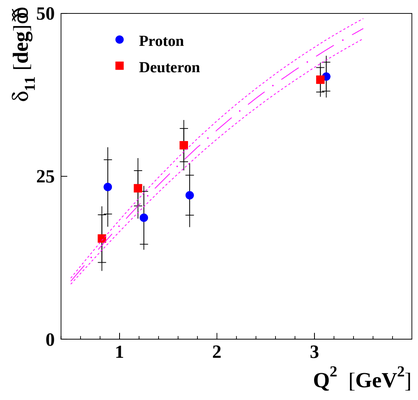
Hierarchy of the ρ^0 amplitudes:
$|T_{00}| \sim |T_{11}| \gg |T_{01}| > |T_{10}| > |T_{1-1}|$,

- class A and B - helicity conserving SDMEs
- A, $\gamma^*_L \rightarrow \phi_L$ and $\gamma^*_T \rightarrow \phi_T$ SDMEs(ϕ) larger by 10% -20% than SDMES(ρ^0)
  $|T_{11}/T_{00}|(\phi) > |T_{11}/T_{00}|(\rho_0)$
- if SCHC holds:
  $r^1_{1-1} = -Im\{r^2_{1-1}\}$, $Re\ \{r^5_{10}\} = -Im\{r^6_{10}\}$, $Im\{r^7_{10}\} = Re\{r^8_{10}\}$ Approximately fulfilled
- Phase difference between T_{11} and T_{00} $\tan\delta = (Im\{r^7_{10}\} + Re\{r^8_{10}\})/(Re\ \{r^5_{10}\} - Im\{r^6_{10}\})$
  $\delta^\rho = 30.0 \pm 5.0 \pm 2.4$ deg $\delta^\phi = 33.0 \pm 7.4$ deg
- C, Spin Flip: $\gamma^*_T \rightarrow \phi_L$ ϕ meson SDMEs are consistent with SCHC
- Pronounced differences for r^5_{00} and Re $\{r^{04}_{10}\}$ between ρ and ϕ
  $r^5_{00} \propto Re(T_{11}T^*_{01}) = |T_{01}||T_{11}|cos\delta_{01}$
  $r^8_{00} \propto Im(T_{11}T^*_{01}) = |T_{01}||T_{11}|sin\delta_{01}$
  $|T_{01}|(\phi) < |T_{01}|(\rho^0)$
  T_{01} close to 0 in the absence of longitudinal quark motion in meson.E.V. Kuraev, N. Nikolaev.and B.G.Zakharov JETP. Lett.68,696 (1998)
  smaller longitudinal quark motion in the ϕ meson as compared to the ρ^0

Q^2 depedence of $Re(Im)\{T_{11}/T_{00}\}$ and phase diference δ_{11}

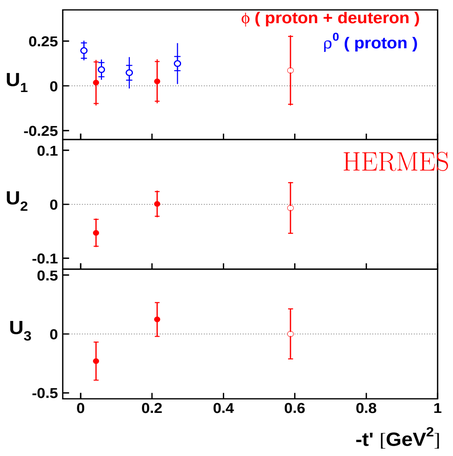


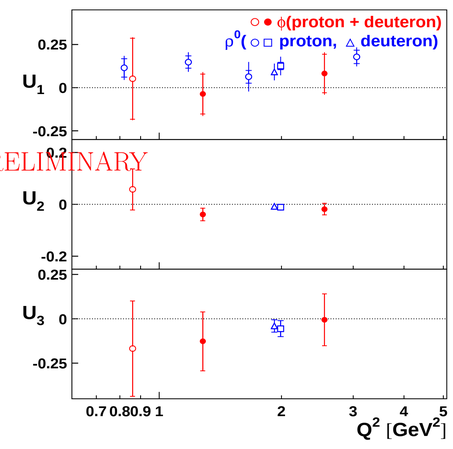




- The real parts of T_{11}/T_{00} follows $\mathrm{Re}\{T_{11}/T_{00}\} = a/Q$ with $a = 1.11 \pm 0.03$ GeV as expected from pQCD.
- Imaginary part follows $\mathrm{Im}\{T_{11}/T_{00}\} = b \cdot Q$. in contradiction to pQCD.
- The Q^2 dependence of the phase difference δ_{11} between the amplitudes 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. Large value of δ_{11} contradicts GPD-based model.

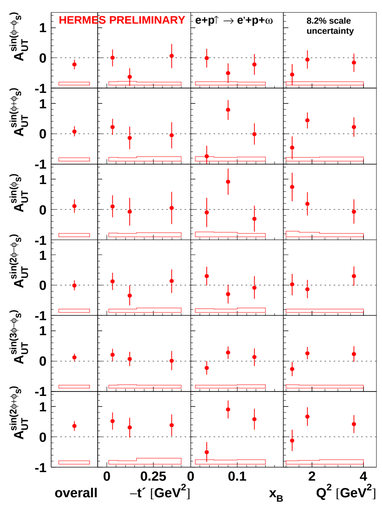
Test of Unnatural-Parity contribution in vector meson production





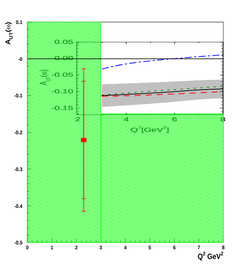
- Signal of UPE in SDME method $u_1 = 1 - r^{04}_{00} + 2r^{04}_{1-1} - 2r^1_{11} - 2r^1_{1-1}$, $u_1 = \sum_{\lambda_N\lambda'_N} \frac{2\epsilon|U_{10}|^2 + |U_{11}+U_{-11}|^2}{N}$
- $u_1(\phi)$=0.021 $\pm 0.071_{stat} \pm 0.159_{syst}$, $u_1(\rho^0)$=0.106 $\pm 0.036_{tot}$(H+D)
- Signal of UPE was observed in ρ production - existence of quark-anti-quark echange. **(HERMES, Eur. Phys. J. C62 (09) 659.)**
- No signal in ϕ production - small content of strangeness in the nucleon and also light $q\bar{q}$ pairs in the ϕ meson.

Asymmetry moments of ω meson produced on transversely polarized proton



- $e + p \rightarrow e' + p' + \omega \rightarrow (\pi^+\pi^-\pi^0(\rightarrow 2\gamma))$ $BR = 89.1\%$
- $A^l_{UT}(\phi, \phi_s) = \frac{1}{P_T}\frac{\sigma(\phi,\phi_s) - \sigma(\phi,\phi_s+\pi)}{\int[\sigma(\phi,\phi_s)+\sigma(\phi,\phi_s+\pi)]d\phi/2\pi}$
  $= \sum_{m,n} A^{sin(m\phi+n\phi_s)}_{UT} sin(m\phi + n\phi_s)$
  $\phi = 2\pi - \Phi$ - angle between lepton scattering and vector-meson production planes.
  ϕ_s - angle between lepton scattering plane and transverse target spin vector S_T.
- $A^{sin(\phi-\phi_s}_{UT} \propto \frac{\sqrt{t_0 - t}}{m_p} \propto Im[\frac{2E^u - E^d}{2H^u - H^d}]$

Asymmetry moments for overall bin and their kinematical dependences for t'(0.0 - 0.6) GeV, x_B(0.0 - 0.35), q^2(1 - 7) GeV^2 bins.



Comparison of exprimental value of $A^{sin(\phi-\phi_s)}_{UT}$ with theoretical predictions based on handbag model of S. V.Goloskokov and P.Kroll. (arXiv:0809.4126[hep-ph]) The solid, dashed, dotted and dash-dotted lines represent the results for different variants. The shaded band indicates the theoretical uncertainty for one variant. The other variants have similar uncertainties.