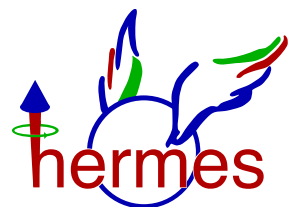


EXCLUSIVE VECTOR MESON PRODUCTION AT HERMES

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INFN Ferrara

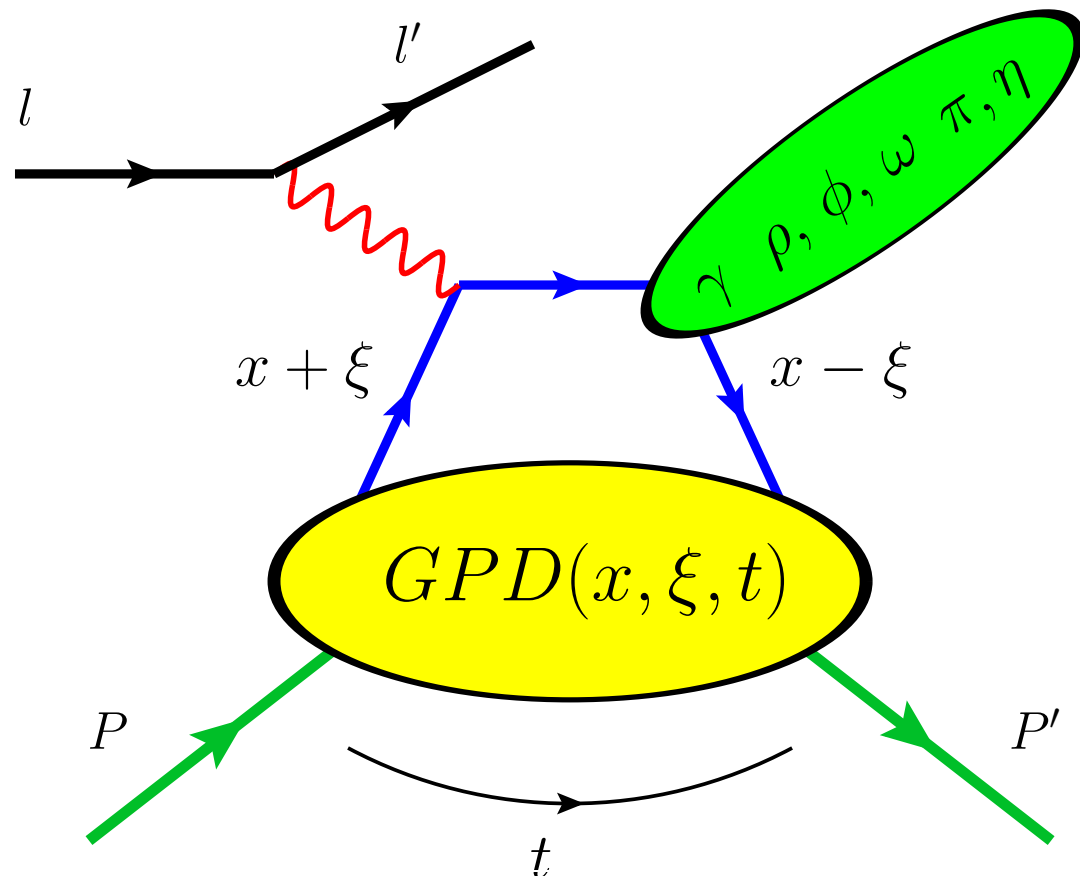


for the HERMES collaboration
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Introduction

Experimental probe of GPDs $\longrightarrow$ Hard exclusive Processes



Deeply Virtual Compton Scattering

- Theoretically the cleanest probe of GPDs
- Theoretical accuracy at NNLO
- GPDs are accessed through convolution integrals with hard scattering amplitude
- Experimental observables: Azimuthal asymmetries, cross sections, cross section differences.
- Amplitudes depend on all GPDs $H, E, \tilde{H}, \tilde{E}$

Vector Mesons

- Factorization for σ_L (to ρ_L, ϕ_L, ω_L) only
- σ_L to σ_T suppressed by $1/Q$
- σ_T suppressed by $1/Q^2$
- Experimental observables: cross sections, SDMEs, azimuthal asymmetries, Helicity amplitude ratios
- At leading twist $\rightarrow$ sensitive to GPDs H and E
- Observables for different mesons provide a possibility of flavor tagging.

Pseudoscalar mesons

- Experimental observables: Cross sections, azimuthal asymmetries
- At leading twist $\rightarrow$ sensitive to GPDs $\tilde{H}$ and $\tilde{E}$

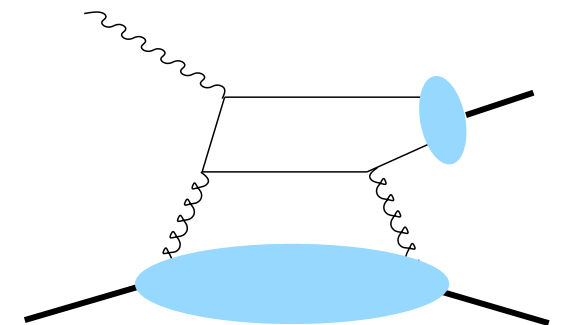
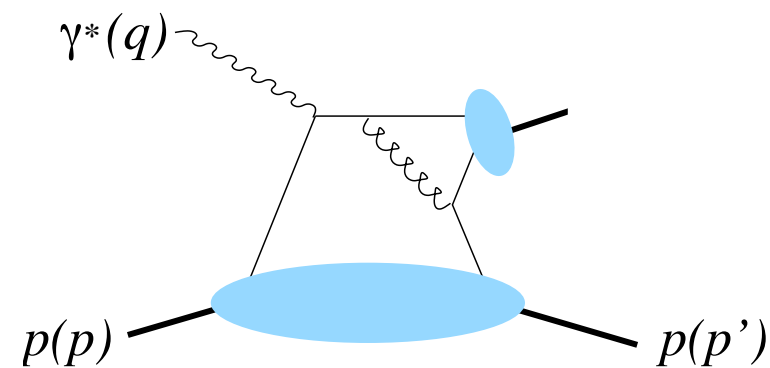
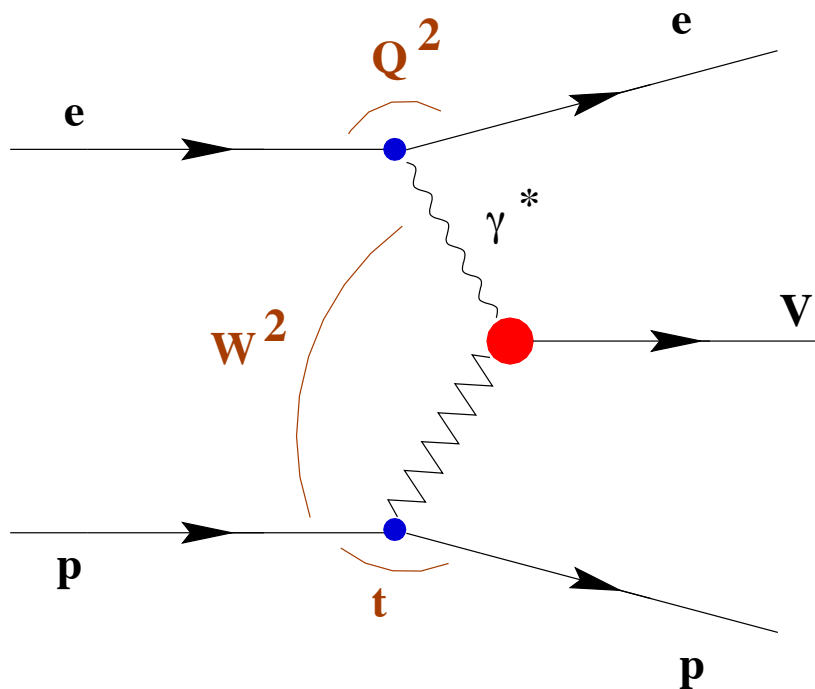
Exclusive Vector Meson Production

Vector Meson Dominance

pQCD

$$0 < Q^2 < \text{few } \text{GeV}^2$$

$$Q^2 \gg 1 \text{ GeV}^2$$



pQCD description of the process.

- I) dissociation of the virtual photon into quark-antiquark pair
- II) scattering of the pair on a nucleon
- III) formation of the observed vector meson

Natural Parity Exchange - described by GPDs H and E

Unnatural Parity Exchange - described by GPDs $\tilde{H}$ and $\tilde{E}$

Experimental Observables

Cross Section

$$\frac{d\sigma}{dx_B dQ^2 dt d\Phi d\cos\theta d\phi} \propto \frac{d\sigma}{dx_B dQ^2 dt} W(x_B, Q^2, t, \Phi, \cos\theta, \phi)$$

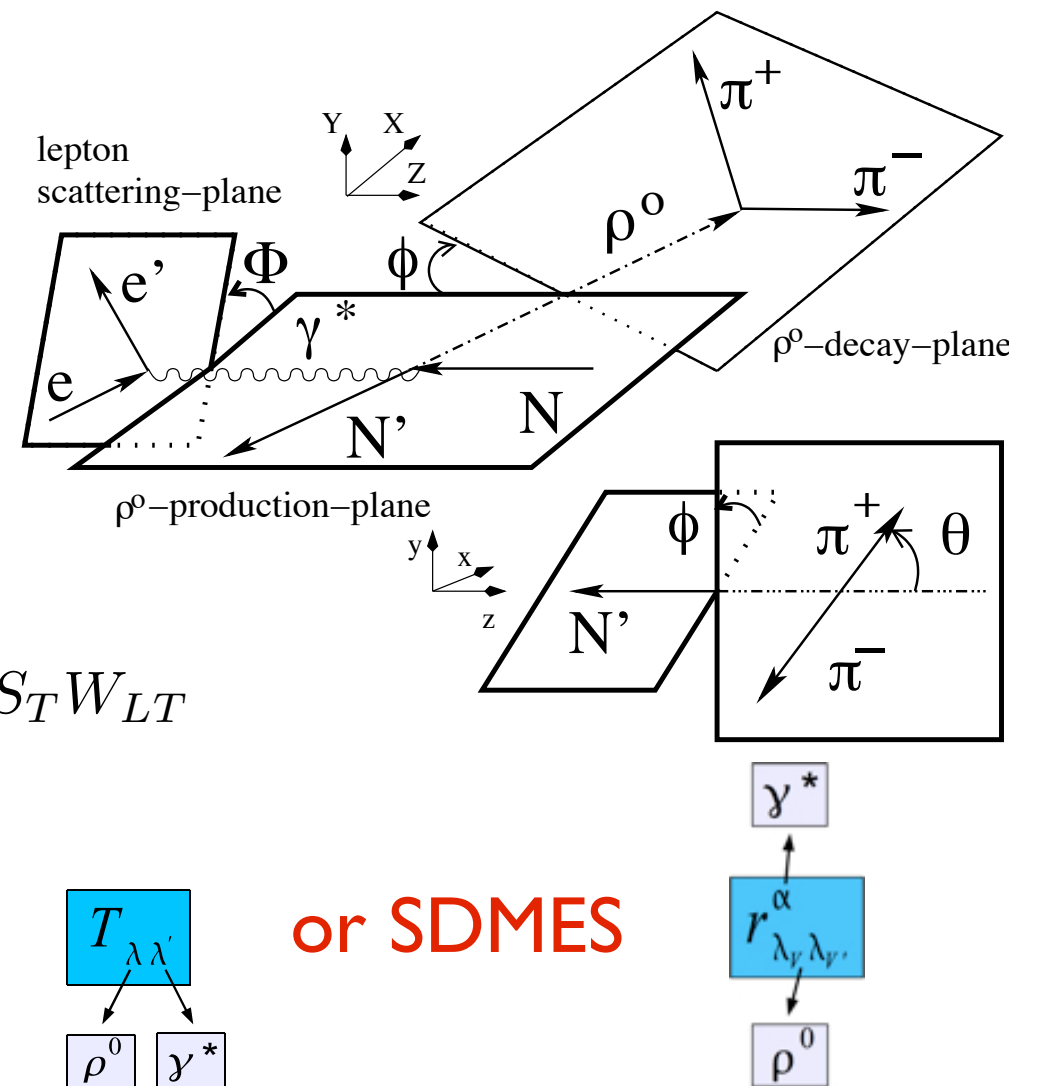
production and decay angular distribution

$$W = W_{UU} + P_\ell W_{LU} + S_L W_{UL} + P_\ell S_L W_{LL} + S_T W_{UT} + P_\ell S_T W_{LT}$$

parameterization in terms of helicity amplitudes

-Schilling, Wolf (1973)

-Diehl (2007)



parameterization in terms of helicity amplitudes or SDMES

-Schilling, Wolf (1973)

-Diehl (2007)

$$W = W_{UU} + P_\ell W_{LU} + S_L W_{UL} + P_\ell S_L W_{LL} + S_T W_{UT} + P_\ell S_T W_{LT}$$

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SDMEs

8

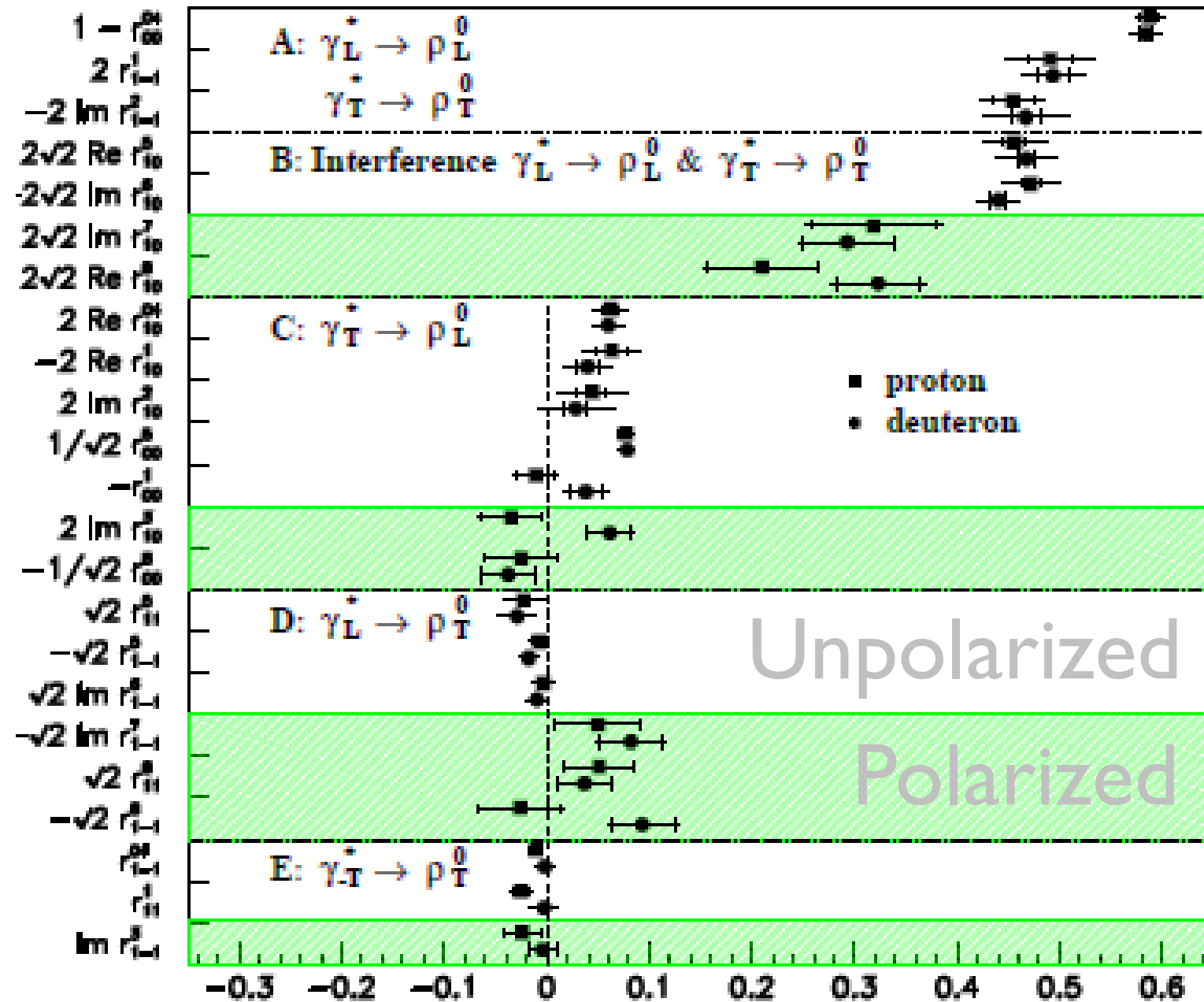
SDMEs

30

SDMEs

SDME's ρ^0

$$|T_{00}| \sim |T_{11}| \gg |T_{01}| > |T_{10}| \geq |T_{1-1}|$$



- Selected hierarchy of NPE helicity amplitudes is confirmed
- No differences between proton and deuteron

$$\gamma^*_L \rightarrow V_L \text{ \&\& } \gamma^*_T \rightarrow V_T \text{ (Class A \& B)}$$

- SDMEs are significantly different from zero
- SDMEs of Class B are smaller than SDMEs of Class A

$$\gamma^*_T \rightarrow V_L \text{ (Class C)}$$

- some SDMEs are significantly different from zero (up to 10σ)
- Violation from SCHC

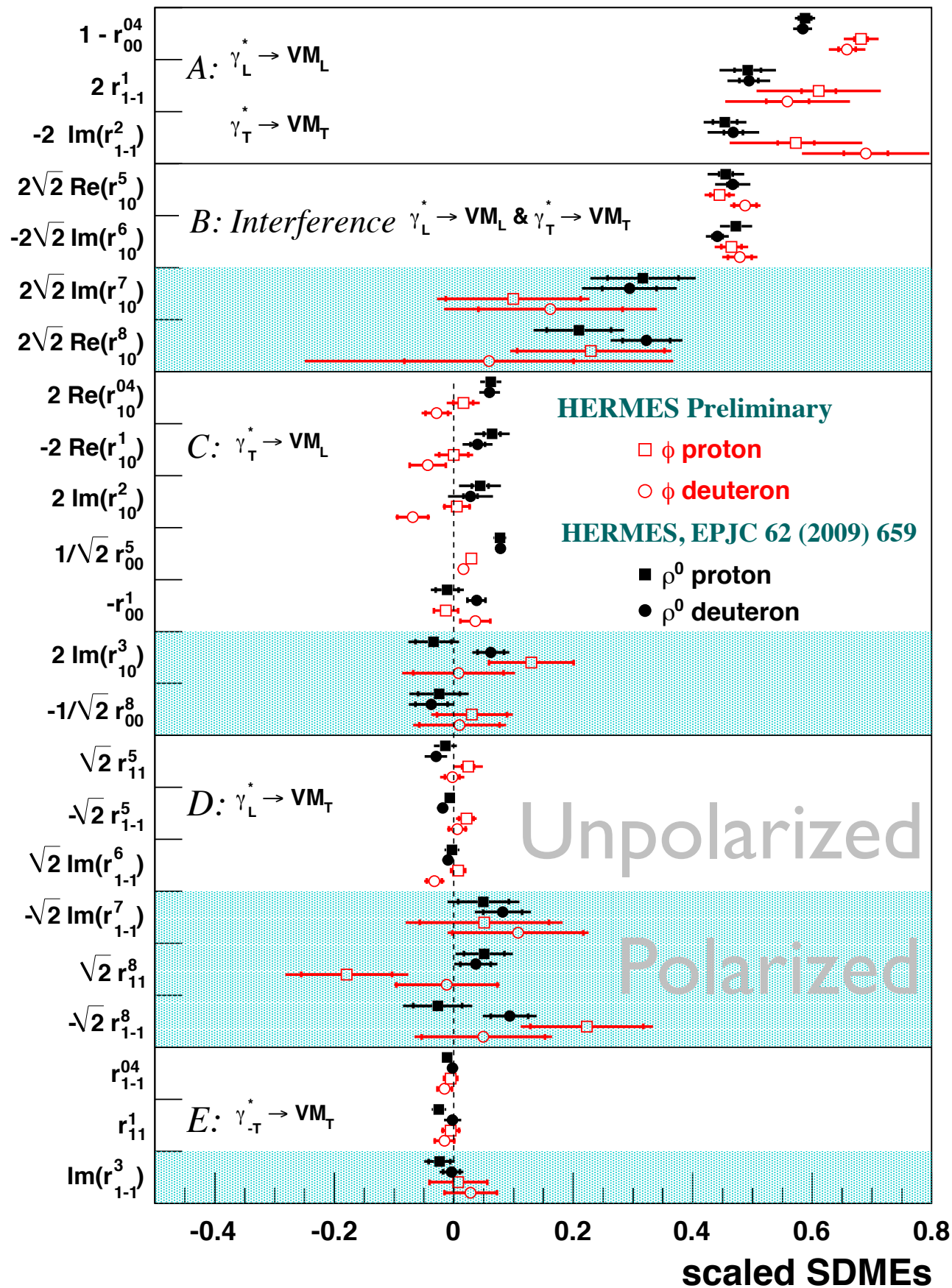
$$Y^*_L \rightarrow V_T \text{ (Class D)}$$

- Unpolarized SDMEs are slightly negative
- Polarized SDMEs are slightly positive

$$\gamma^*_{-T} \rightarrow V_T \text{ (Class E)}$$

- SDMEs on Deuteron are consistent with zero
- Small deviation from zero for SDMEs on hydrogen

SDMEs Φ



- Selected hierarchy of NPE helicity amplitudes is confirmed
- No significant differences between proton and deuteron

$\gamma_L^* \rightarrow V_L$ & $\gamma_T^* \rightarrow V_T$ (Class A & B)

- SDMEs are significantly different from zero
- 10-20% difference between ρ and Φ SDMEs

$\gamma_T^* \rightarrow V_L$ (Class C)

- SDMEs are consistent with zero
- SDMEs on deuteron are slightly negative
- No strong indication of violation from SCHC

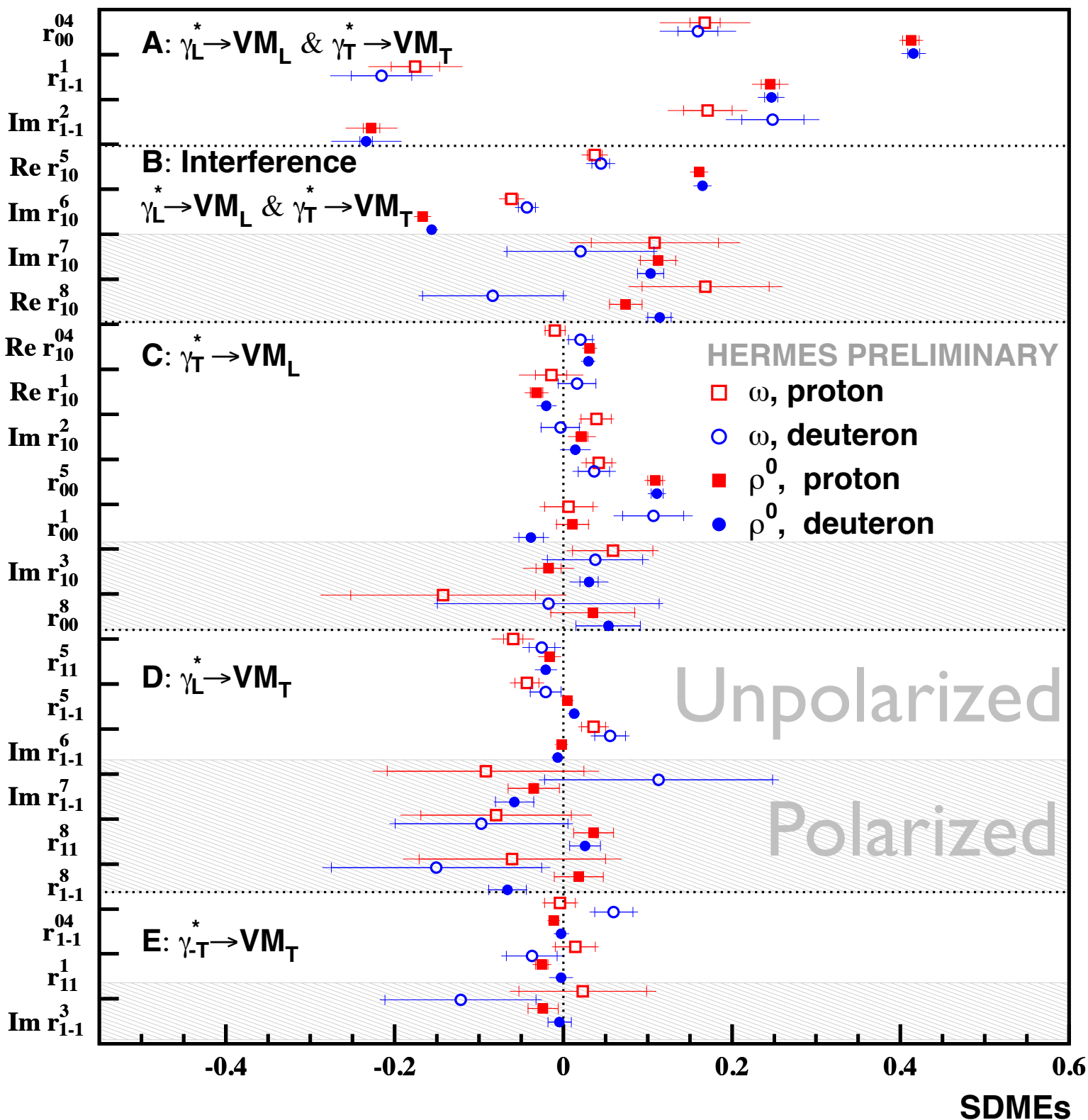
$\gamma_L^* \rightarrow V_T$ (Class D)

- Unpolarized and Polarized SDMEs are consistent with zero for both hydrogen and deuteron

$\gamma_{-T}^* \rightarrow V_T$ (Class E)

- Unpolarized and Polarized SDMEs are consistent with zero for both hydrogen and deuteron

SDMEs ω



- Selected hierarchy of NPE helicity amplitudes is not confirmed
- No differences between proton and deuteron

$\gamma_L^* \rightarrow V_L$ & $\gamma_T^* \rightarrow V_T$ (Class A & B)

- SDMEs are significantly different from zero
- Significant differences between ρ and ω SDMEs

$\gamma_T^* \rightarrow V_L$ (Class C)

- SDMEs are consistent with zero on both targets

$\gamma_L^* \rightarrow V_T$ (Class D)

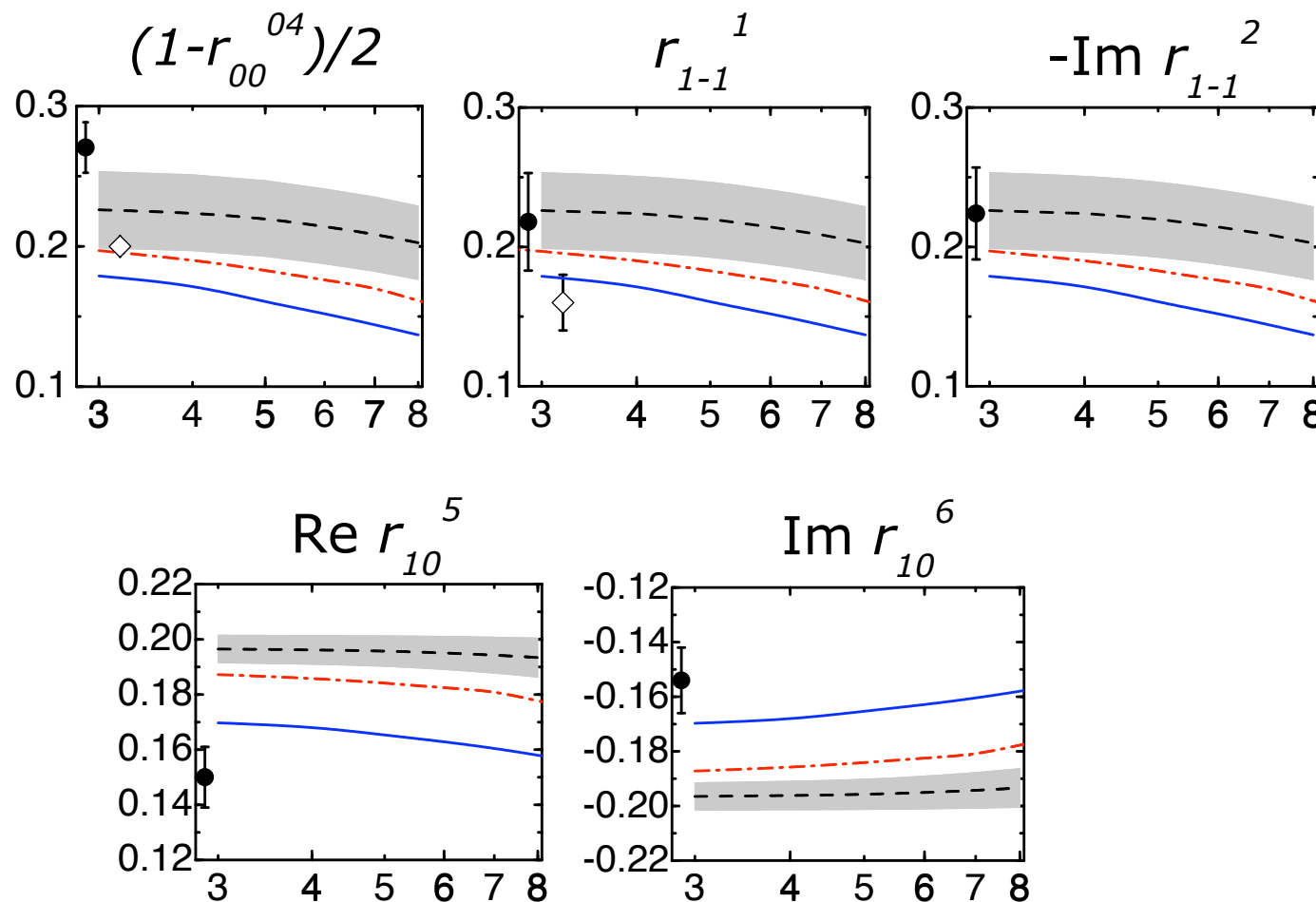
- Unpolarized SDMEs differ from zero
- Small evidence for violation from SCHC

$\gamma_{-T}^* \rightarrow V_T$ (Class E)

- Unpolarized and Polarized SDMEs are consistent with zero for both hydrogen and deuteron

Comparison with GPD models

GPD model: [S.Goloskokov, P. Kroll \(2007\)](#)



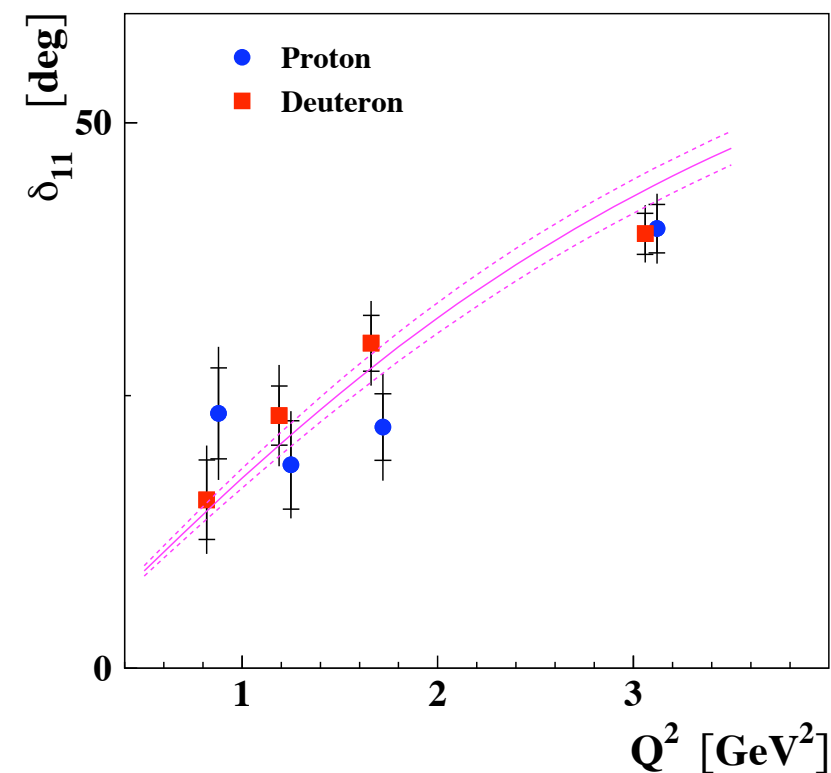
$$\tan \delta_{11} = \frac{\text{Im}(T_{11}/T_{00})}{\text{Re}(T_{11}/T_{00})}$$

HERMES result $\delta_{11}=31.5 \pm 1.4$ deg.

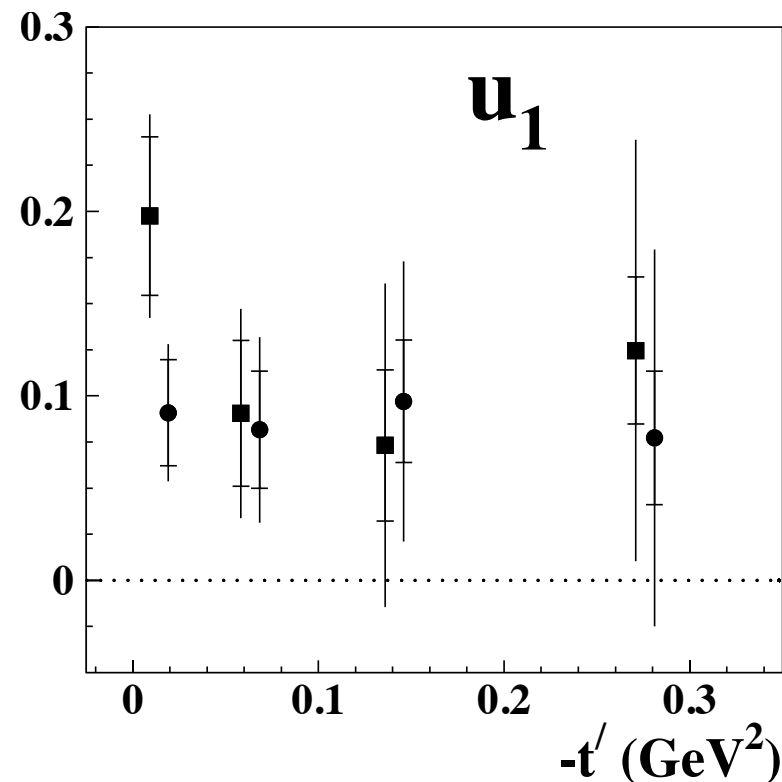
Large phase difference was observed also by H1 ($\delta_{11}=20$)

W=5 GeV (HERMES)
W=10 GeV (COMPASS)
W=90 GeV (H1, ZEUS)

$\gamma^*_L \rightarrow \rho^0_L$ & $\gamma^*_T \rightarrow \rho^0_T$
 $1 - r_{00}^{04}, r_{1-1}^1, -\text{Im } r_{1-1}^2 \propto T_{11}$
 model is in agreement with data
interference $\gamma^*_L \rightarrow \rho^0_L$ & $\gamma^*_T \rightarrow \rho^0_T$
 model dose not describe the data
 model uses phase difference
 between T_{00} and T_{11} , $\delta_{11}=3.1$ deg.



UPE Contribution ρ^0



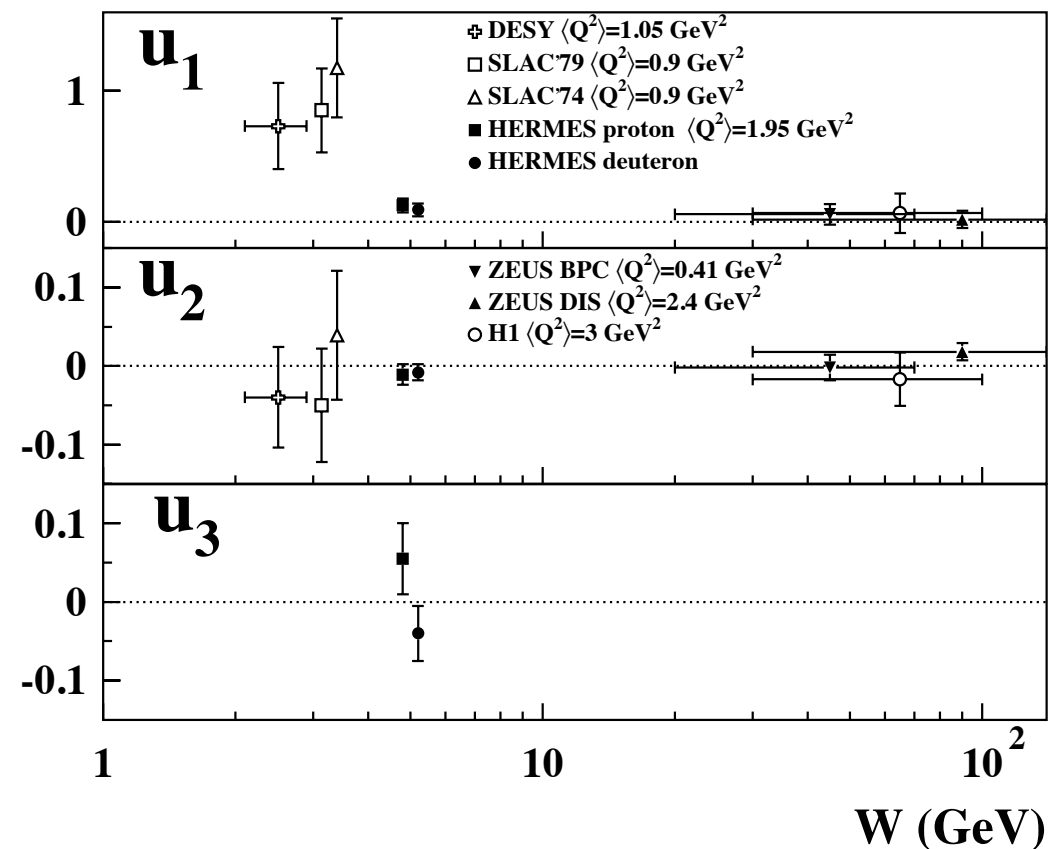
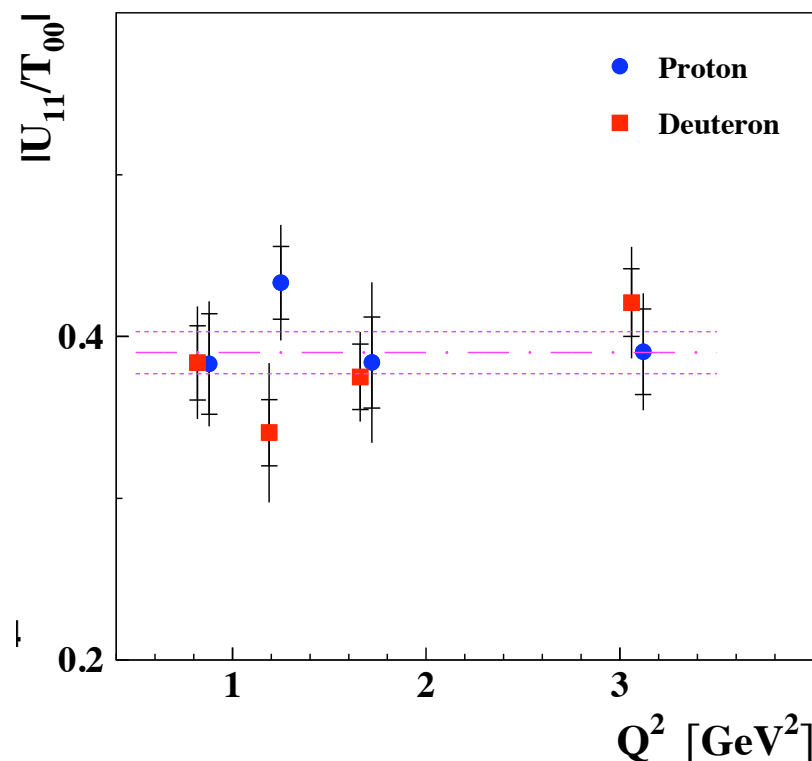
At large W^2 and Q^2 the transition should be suppressed by M/Q

- direct helicity amplitude ratio analysis: U_{11}/T_{00}
- the combination of SDMEs is expected to be zero in case of NPE

$$u_1 = 1 - r_{00}^{04} + 2r_{1-1}^{04} - 2r_{11}^1 - 2r_{1-1}^1$$

$$u_2 = r_{11}^5 + r_{1-1}^5$$

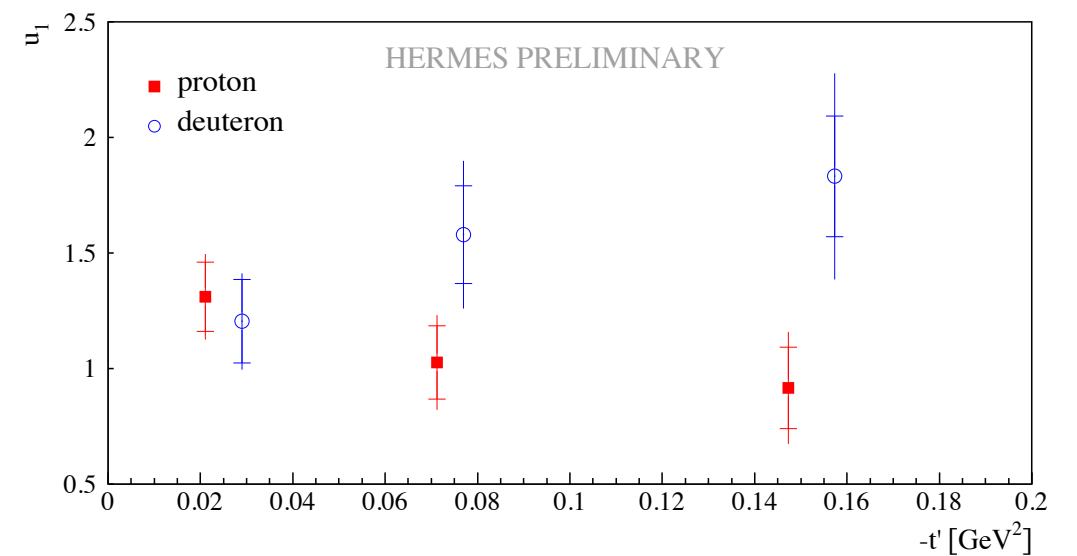
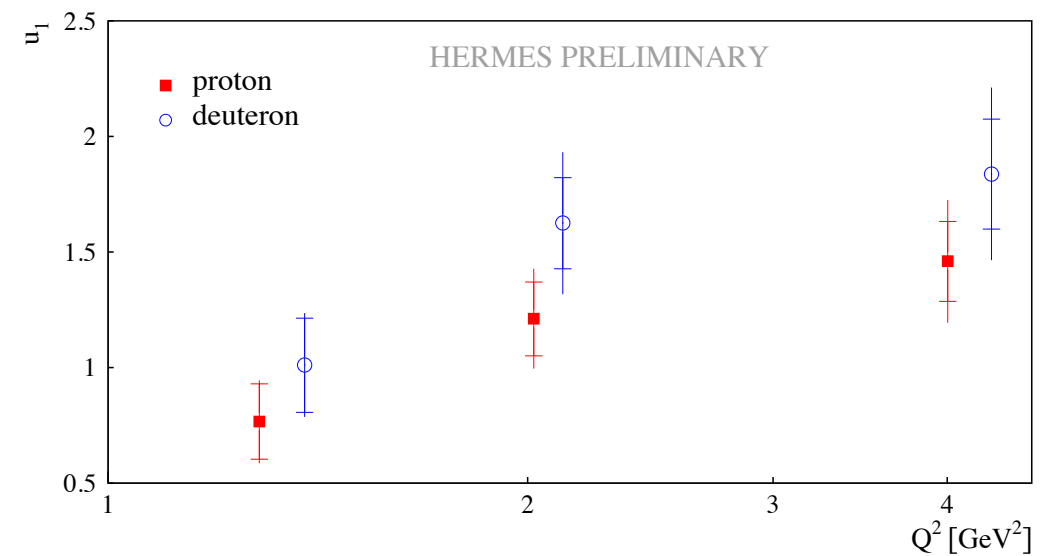
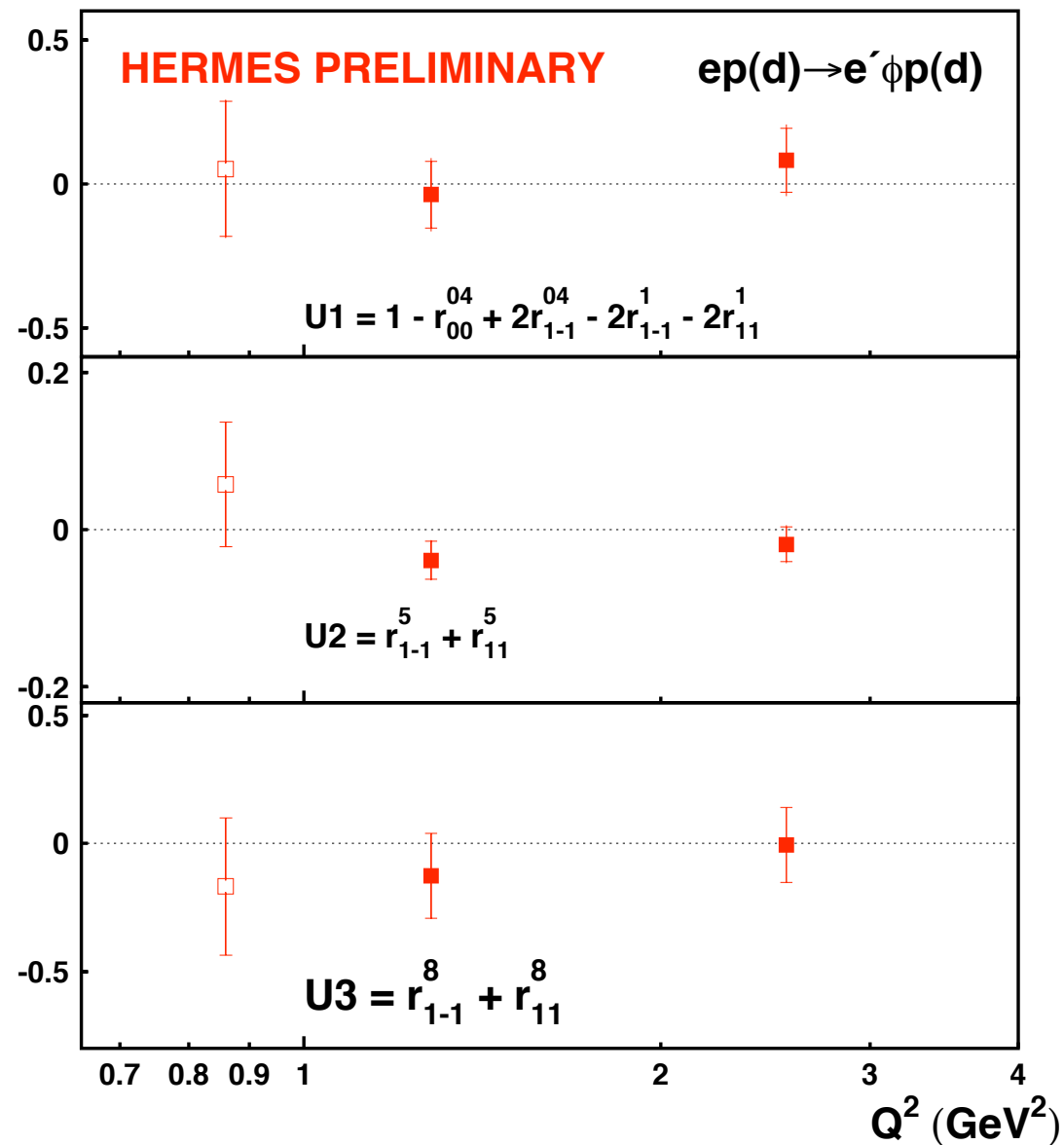
$$u_3 = r_{11}^8 + r_{1-1}^8$$



UPE Contribution Φ and ω

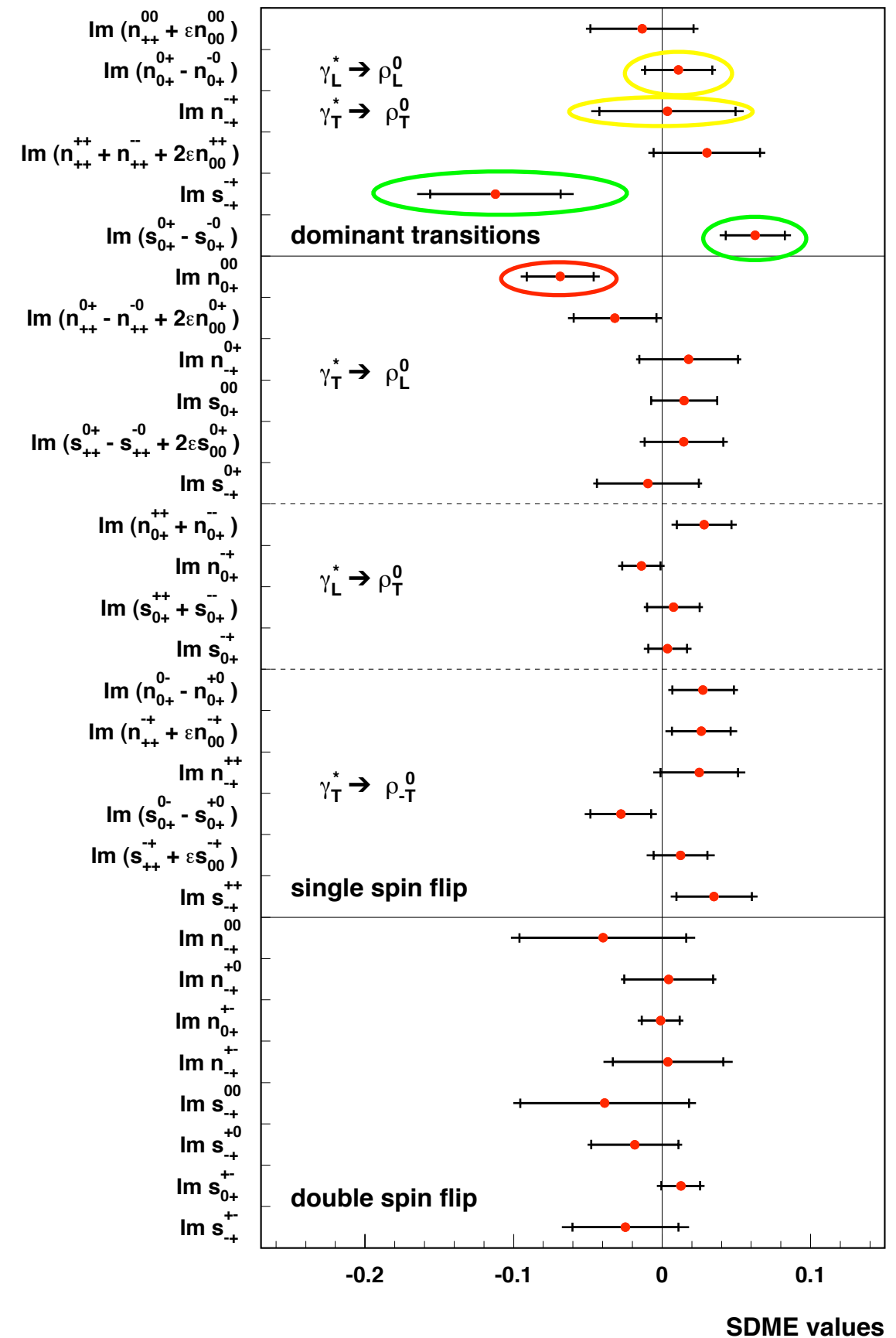
- u values are consistent with zero.
- Process dynamics is dominated by two-gluon exchange mechanism.

- Significantly large value for u_1
- Process dynamics is dominated by quark exchange mechanism.



Transverse SDMEs of ρ^0

- Most of the SDMEs are consistent with zero within 1.5σ
- SDMEs $\text{Im}(s_{0+}^{0+} - s_{0+}^{-0})$, $\text{Im} s_{-+}^{+-}$ and $\text{Im} n_{0+}^{00}$ differ from zero by 2.5σ
- Non - zero value for SDME $\text{Im} n_{0+}^{00}$ - violation from SCHC
- In case of NPE - expected $s_{\mu\mu'}^{\nu\nu'} < n_{\mu\mu'}^{\nu\nu'}$
- Non - zero values for SDMEs $\text{Im}(s_{0+}^{0+} - s_{0+}^{-0})$ and $\text{Im} s_{-+}^{+-}$ indicate a large contribution of UPE



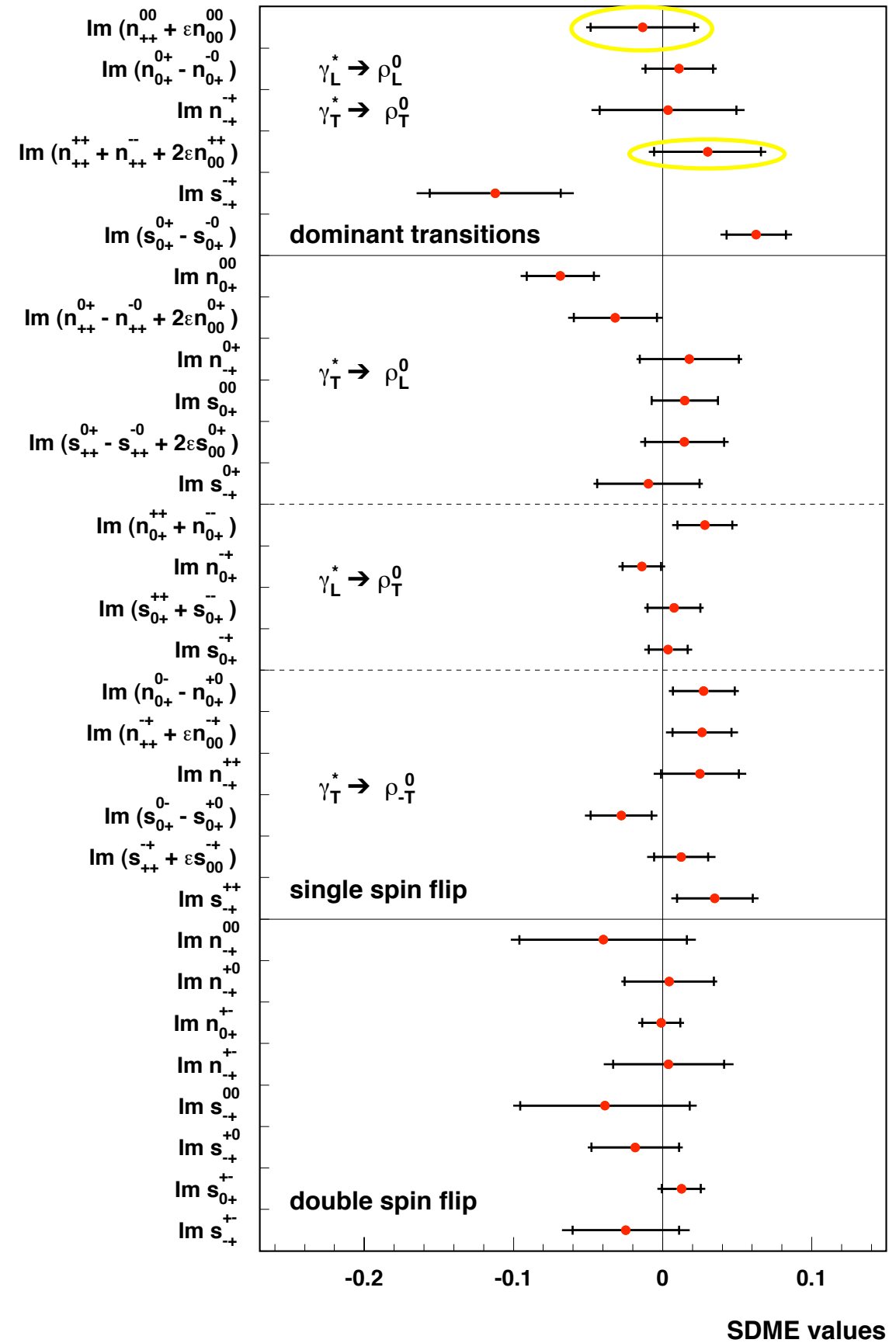
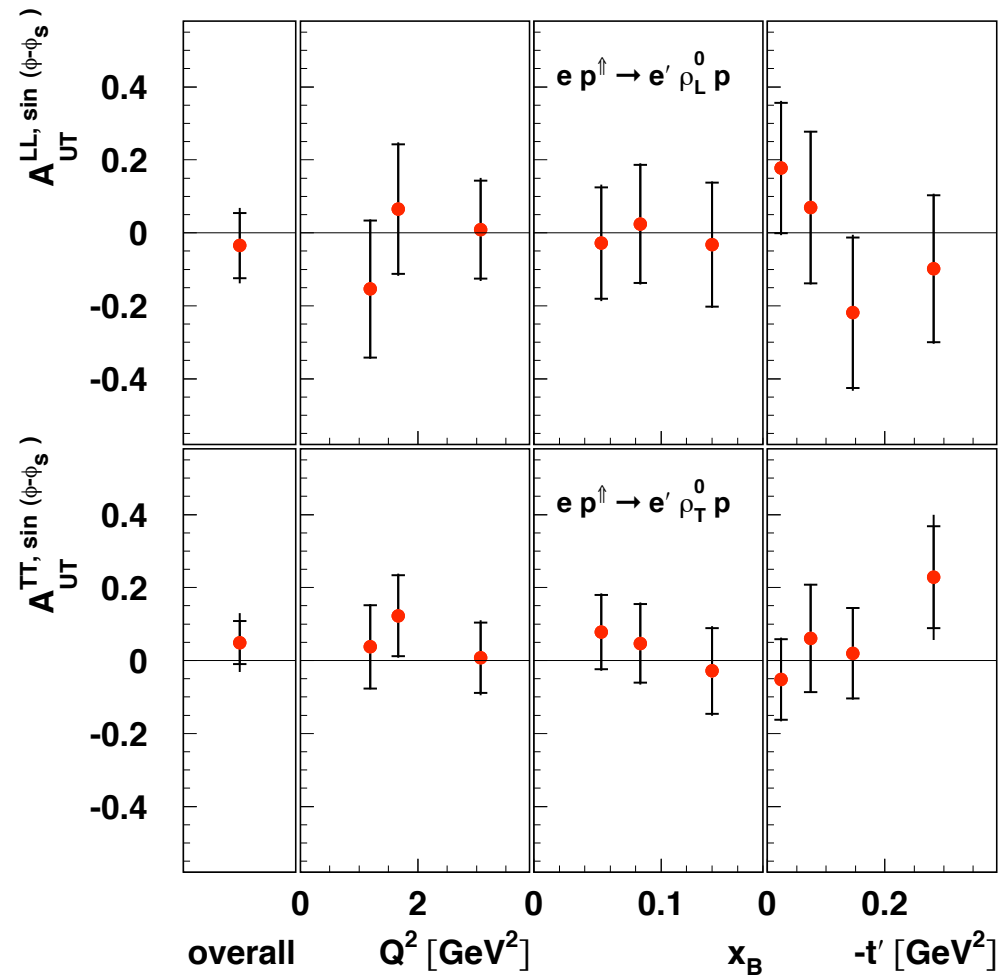
Transverse SDMEs of ρ^0

Transverse Target-Spin Asymmetry : $\sim$ GPD E
for L - L

$$A_{UT}^{LL, \sin(\phi - \phi_s)} = \frac{\text{Im}(n_{00}^{++} + \epsilon n_{00}^{00})}{u_{++}^{00} + \epsilon u_{00}^{00}}$$

and T - T

$$A_{UT}^{TT, \sin(\phi - \phi_s)} = \frac{\text{Im}(n_{++}^{++} + n_{++}^{--} + 2\epsilon n_{00}^{++})}{1 - (u_{++}^{00} + \epsilon u_{00}^{00})}$$



Results for R

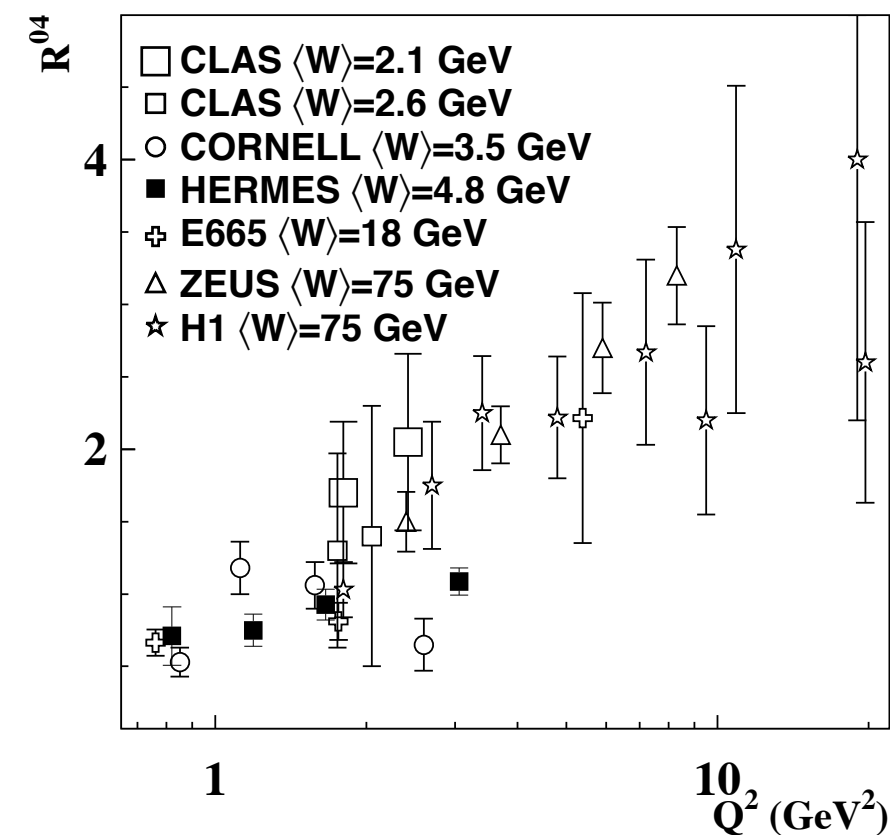
Commonly used observable $R^{04} = \frac{1}{\epsilon} \frac{r_{00}^{04}}{1 - r_{00}^{04}}$

In case of SCHC and NPE $R^{04} = R = \sigma_L / \sigma_T$

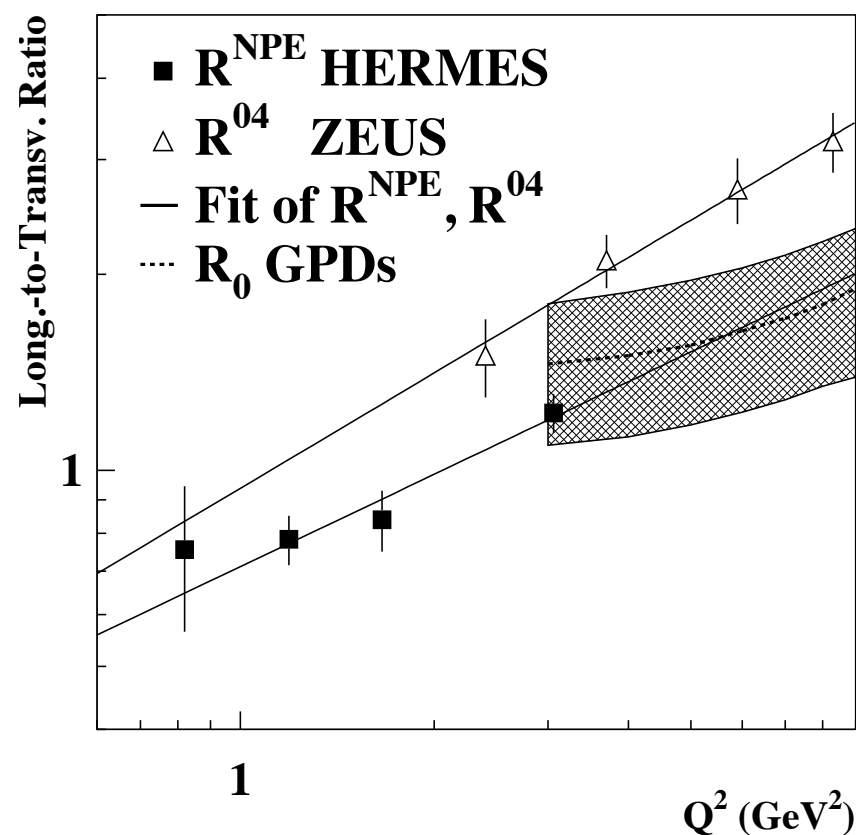
Strong W dependence for both - UPE contribution and ratio R

W dependence of the Q^2 slope can be studied $R(Q^2) = c_0 \left(\frac{Q^2}{M_V^2} \right)^{c_1}$

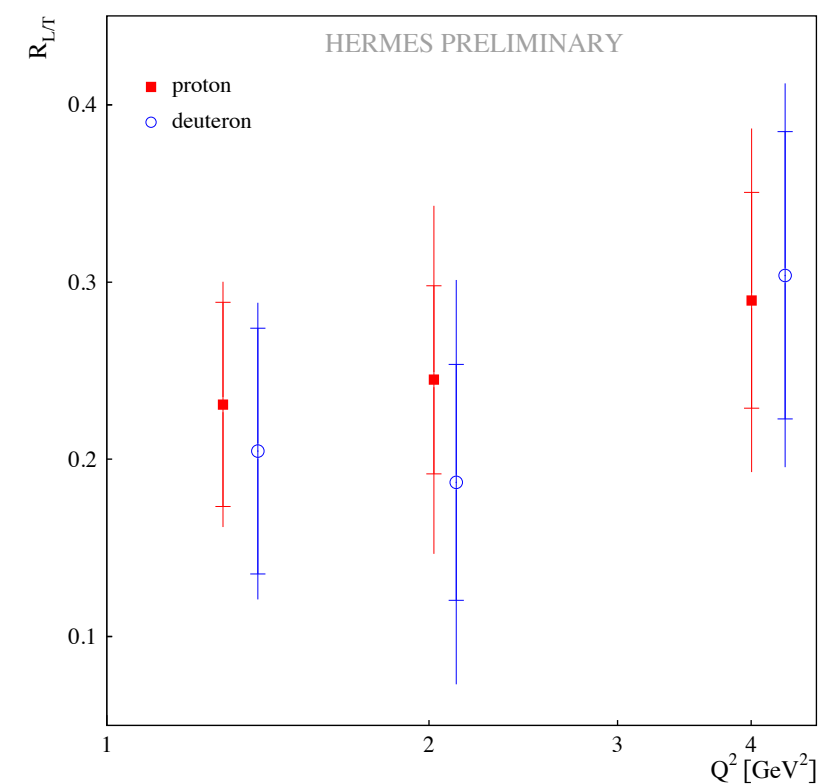
ρ^0



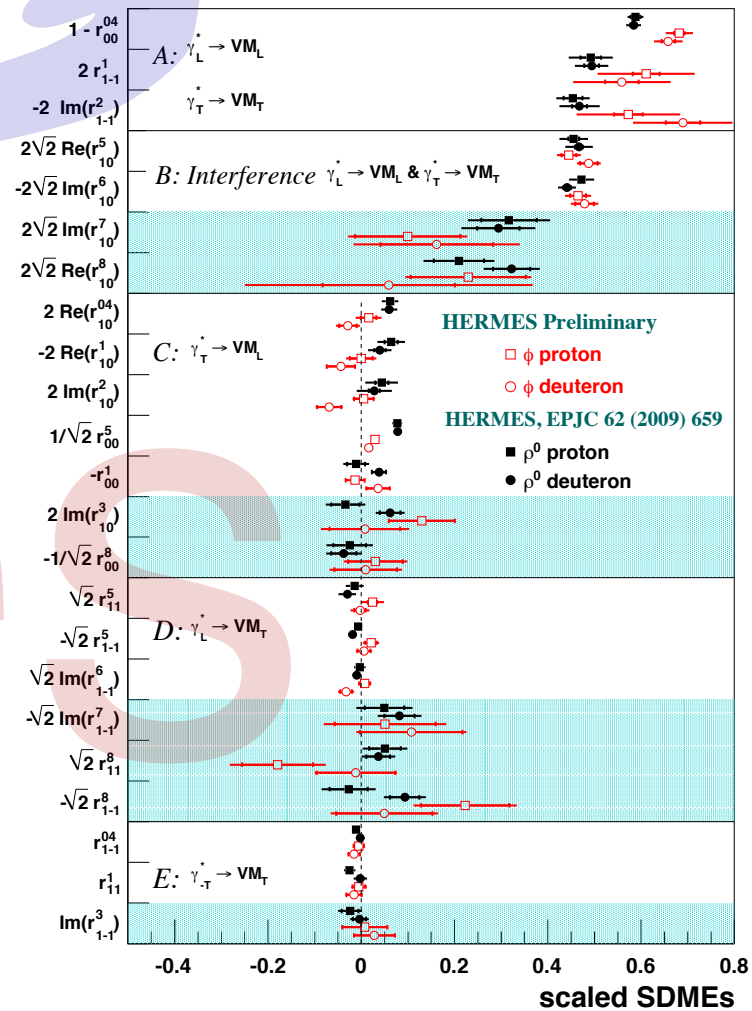
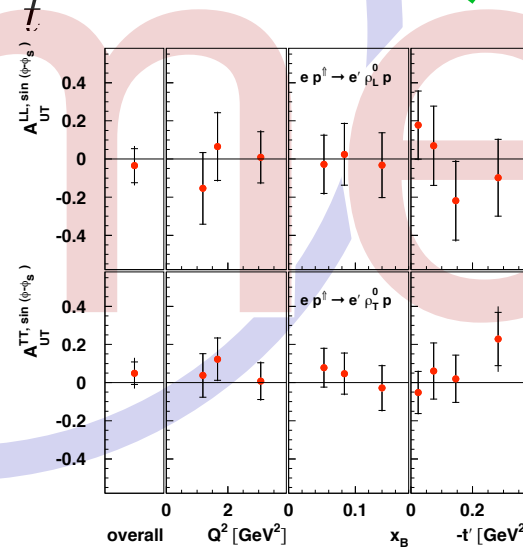
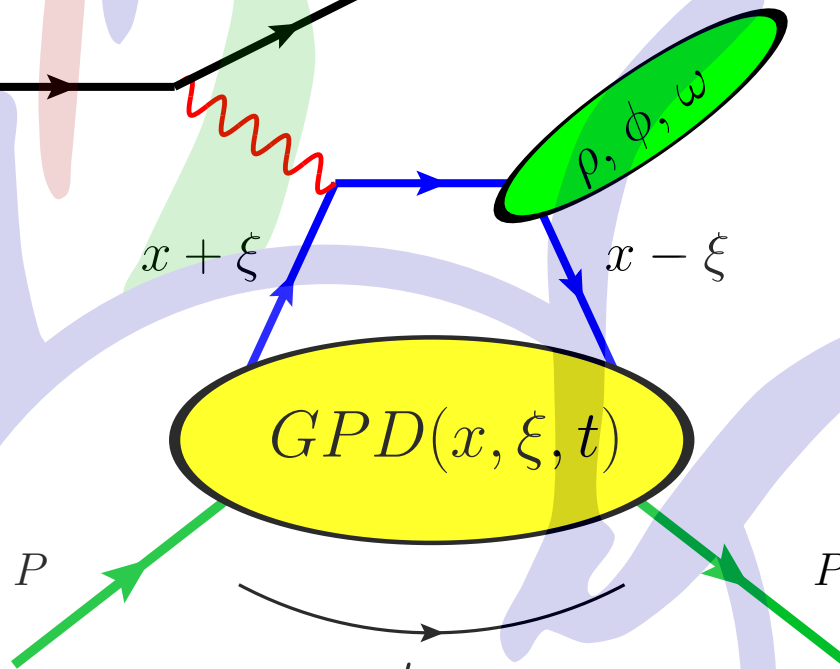
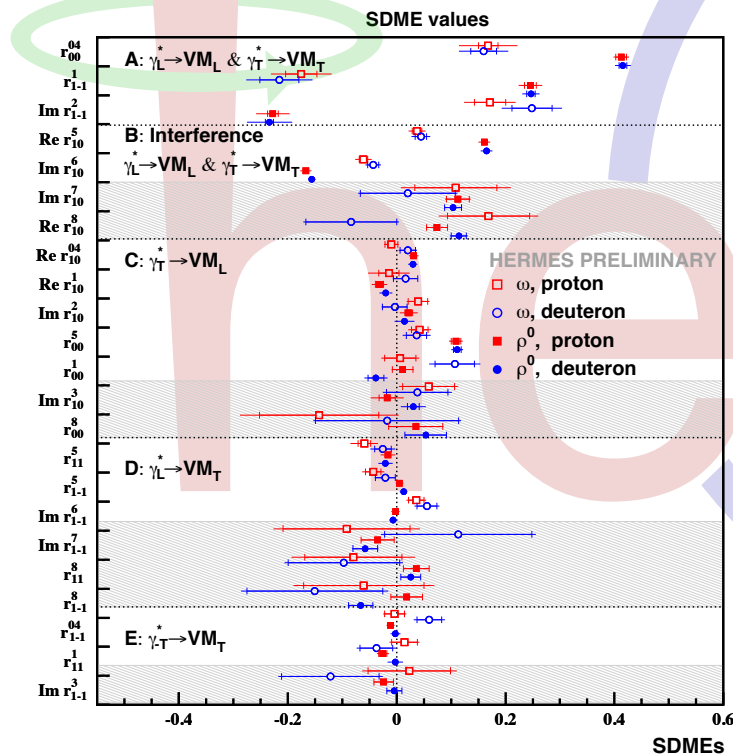
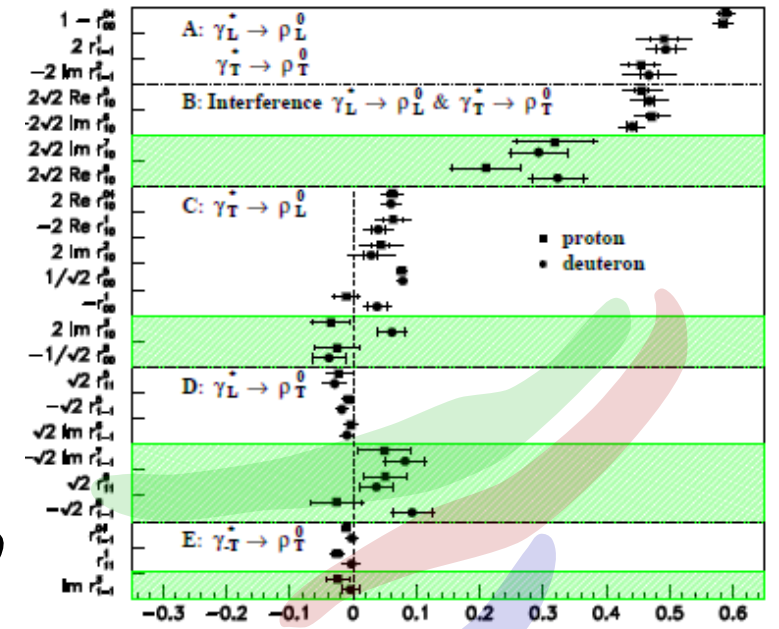
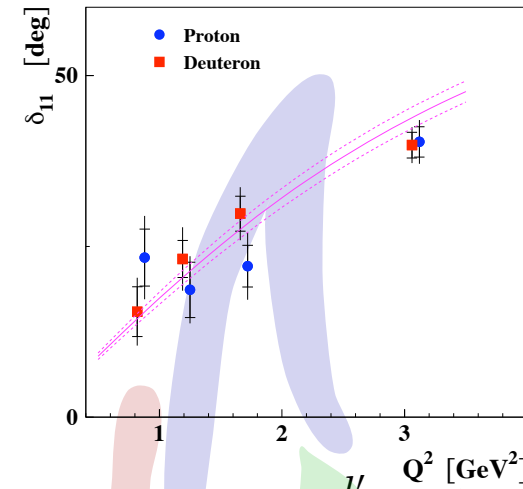
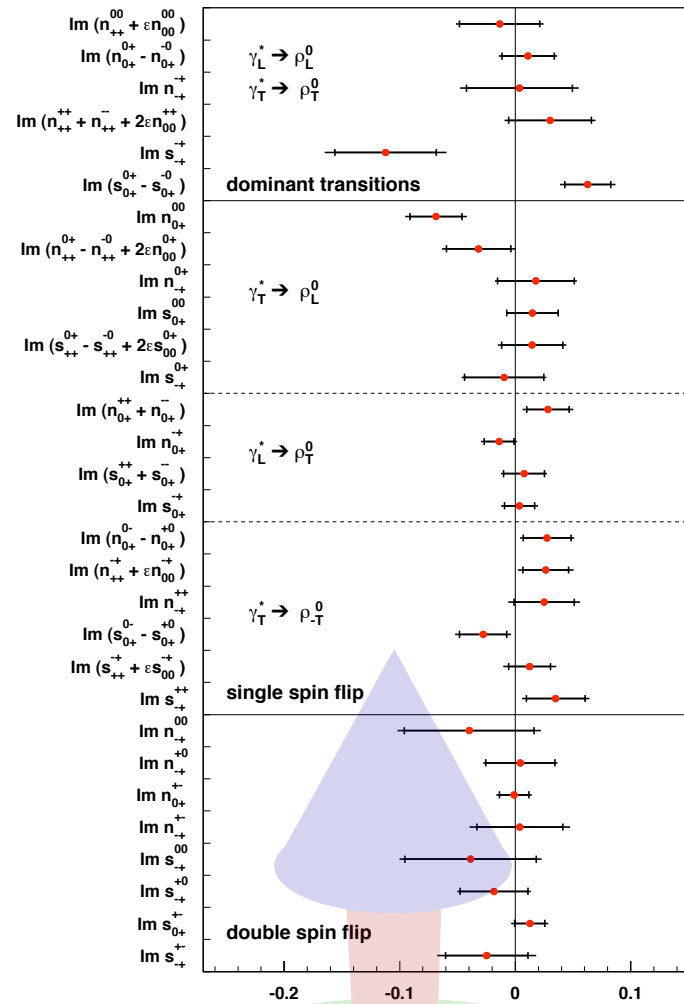
ρ^0



ω



Conclusion



backup

Event Selection

No recoil detection

Small missing energy

$$\Delta E = \frac{M_x^2 - M^2}{2M} \approx 0$$

Small energy transfer to the target nucleon

$$t = (q - v)^2$$

Kinematic requirements

$$1 < Q^2 < 7 \text{ GeV}^2$$

$$-t' < 0.4 \text{ GeV}^2$$

$$3 < W < 6.3 \text{ GeV}$$

$$-1.0 < \Delta E < 0.6 \text{ GeV}$$

Invariant mass of hadronic system

$$\rho^0 \quad 0.6 < M_{\pi\pi} < 1.0 \text{ GeV}$$

$$\Phi \quad 1.012 < M_{KK} < 1.028 \text{ GeV}$$

$$\omega \quad 0.71 < M_{\pi\pi\pi} < 0.87 \text{ GeV}$$

