Latest results of exclusive meson production at HERMES

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hermes

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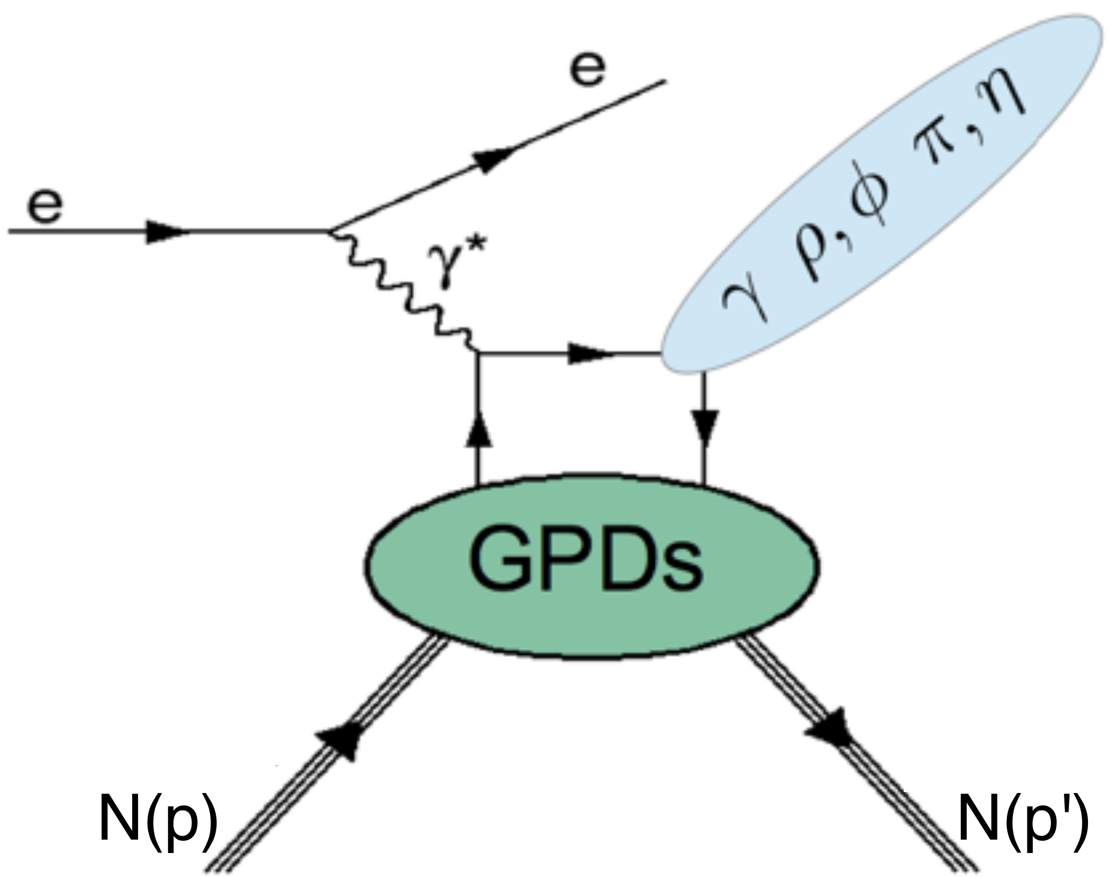
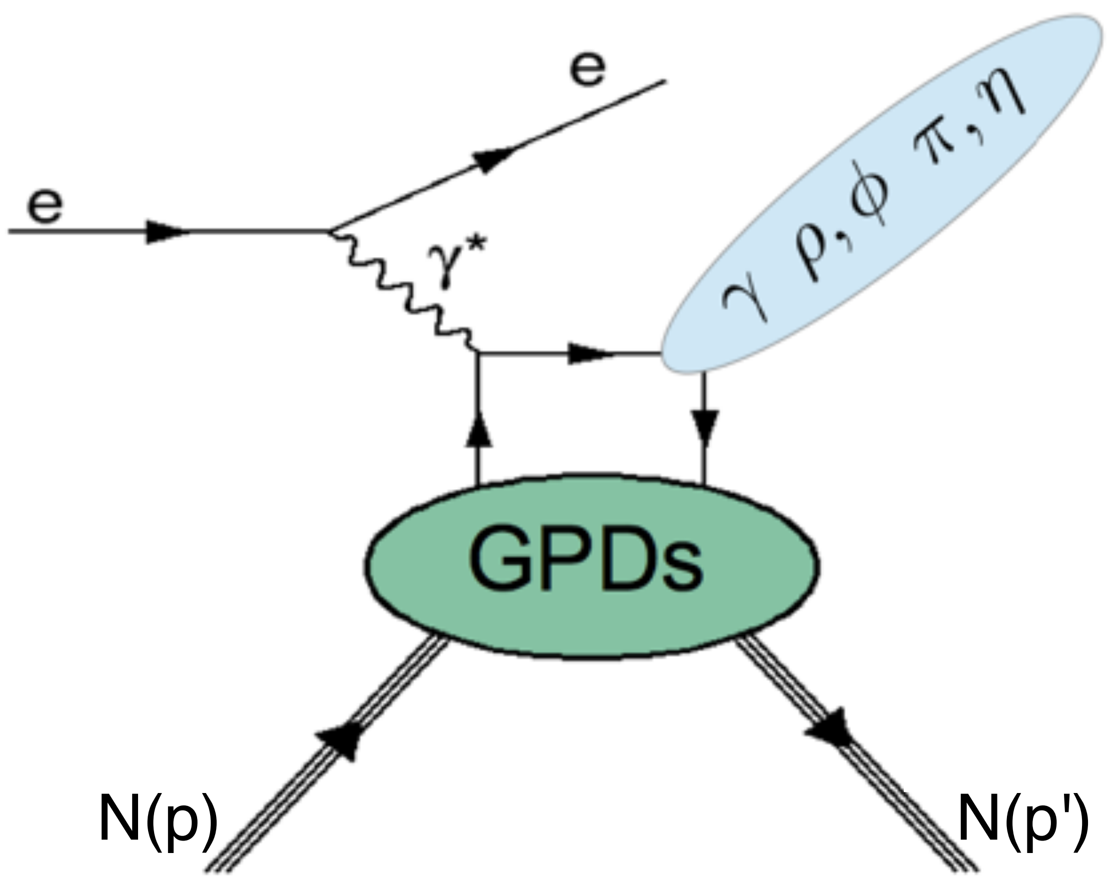
Exclusive ρ^0 and ω production



Exclusive meson production

- probe various types of GPDs with different sensitivity and different flavour combinations
- complementary to DVCS

Exclusive ρ^0 and ω production



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- probe various types of GPDs with different sensitivity and different flavour combinations
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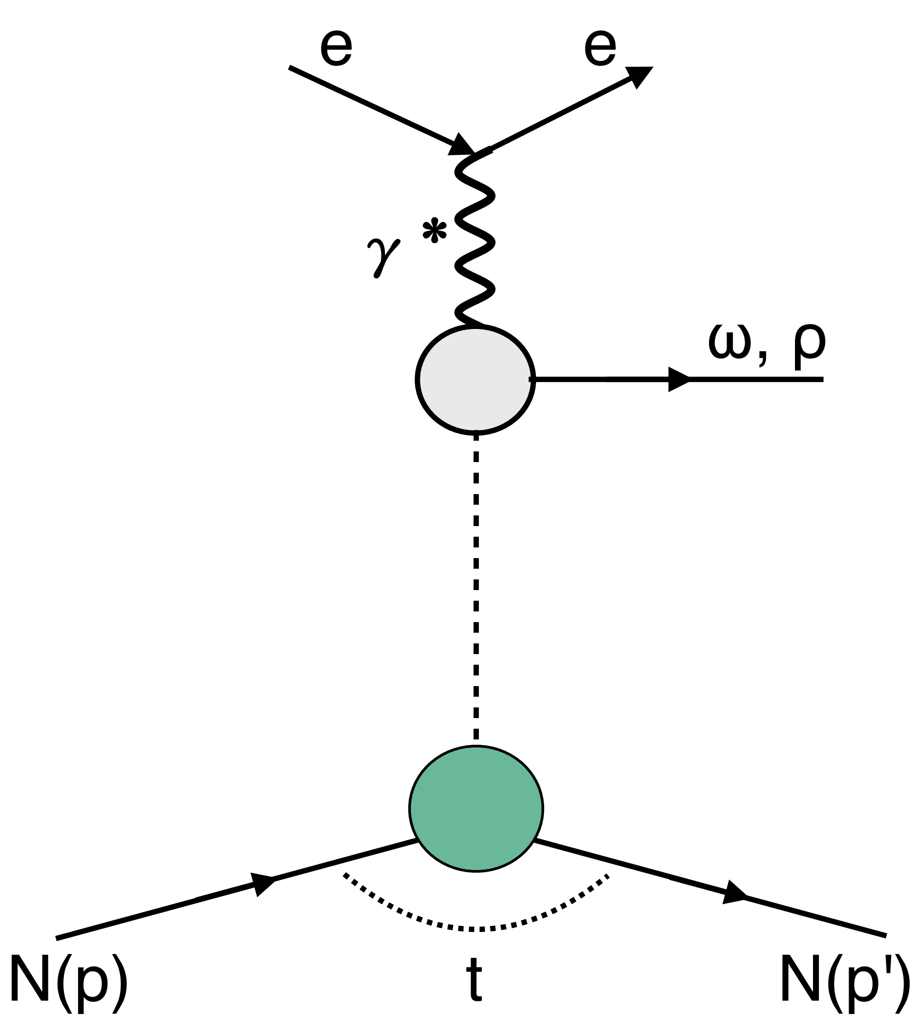
Target polarization state

- unpolarized target: nucleon-helicity-non-flip GPDs H and $\tilde{H}$
- transversely polarized target: nucleon-helicity-flip GPDs E and $\tilde{E}$

Exclusive ρ^0 and ω production



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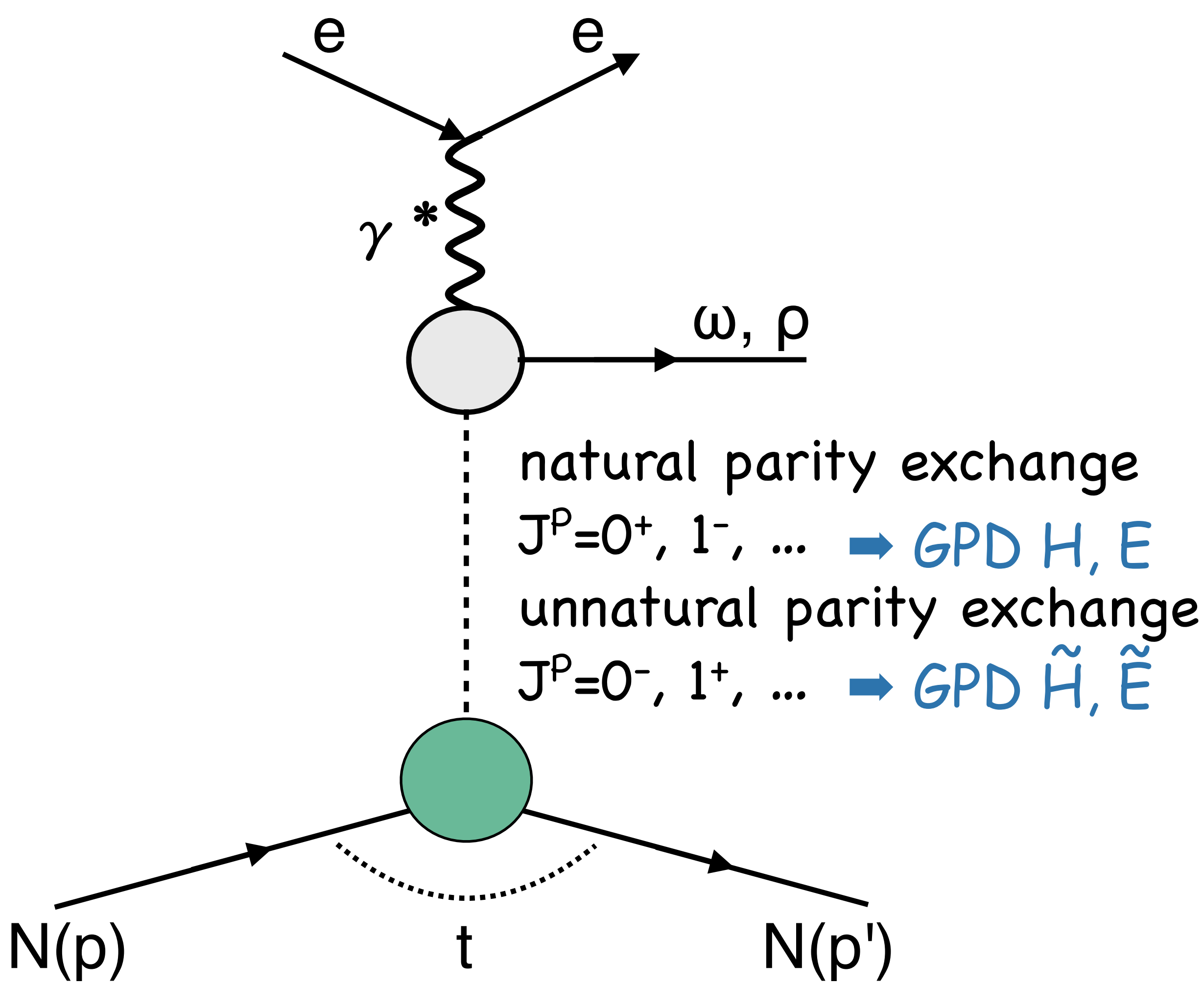

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Exclusive ρ^0 and ω production: angular distribution

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

$$\rho^0 \to \pi^+ + \pi^-$$

$$e + N \to e + N + \omega$$

$$\omega \to \pi^+ + \pi^- + \pi^0(2\gamma)$$

Exclusive ρ^0 and ω production: angular distribution

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$$\rho^0 \rightarrow \pi^+ + \pi^-$$

$$e + N \rightarrow e + \cancel{N} + \omega$$

$$\omega \rightarrow \pi^+ + \pi^- + \pi^0(2\gamma)$$

$$3.0 \text{ GeV} \leq W \leq 6.3 \text{ GeV}$$

$$1.0 \text{ GeV}^2 \leq Q^2 \leq 7.0 \text{ GeV}^2$$

$$0.0 \text{ GeV}^2 \leq -t' \leq 0.4 \text{ GeV}^2$$

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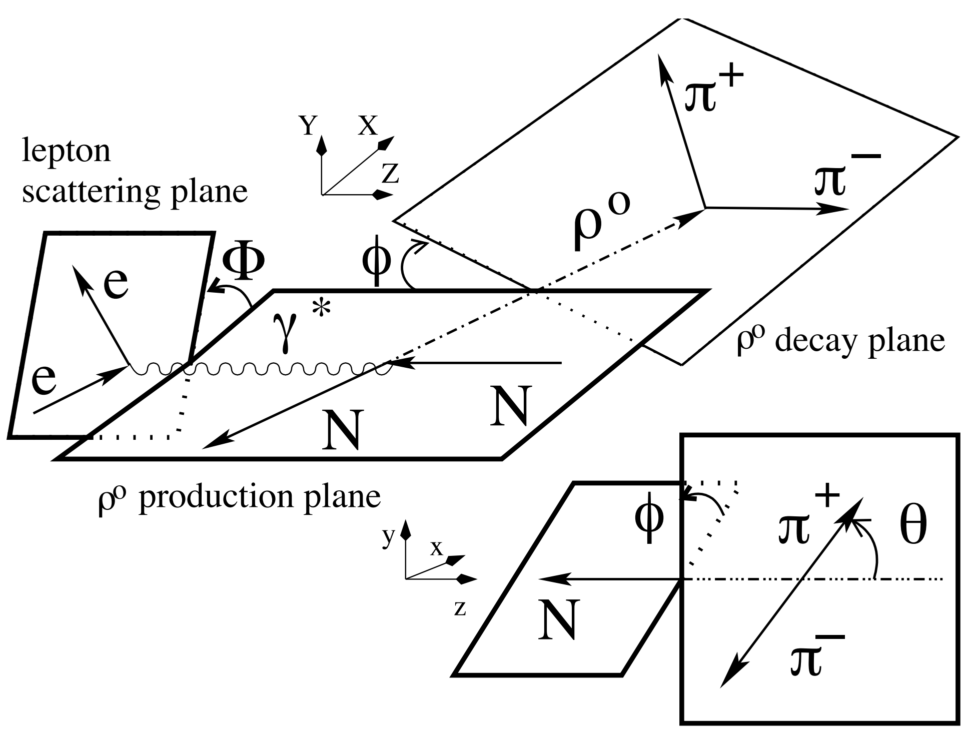

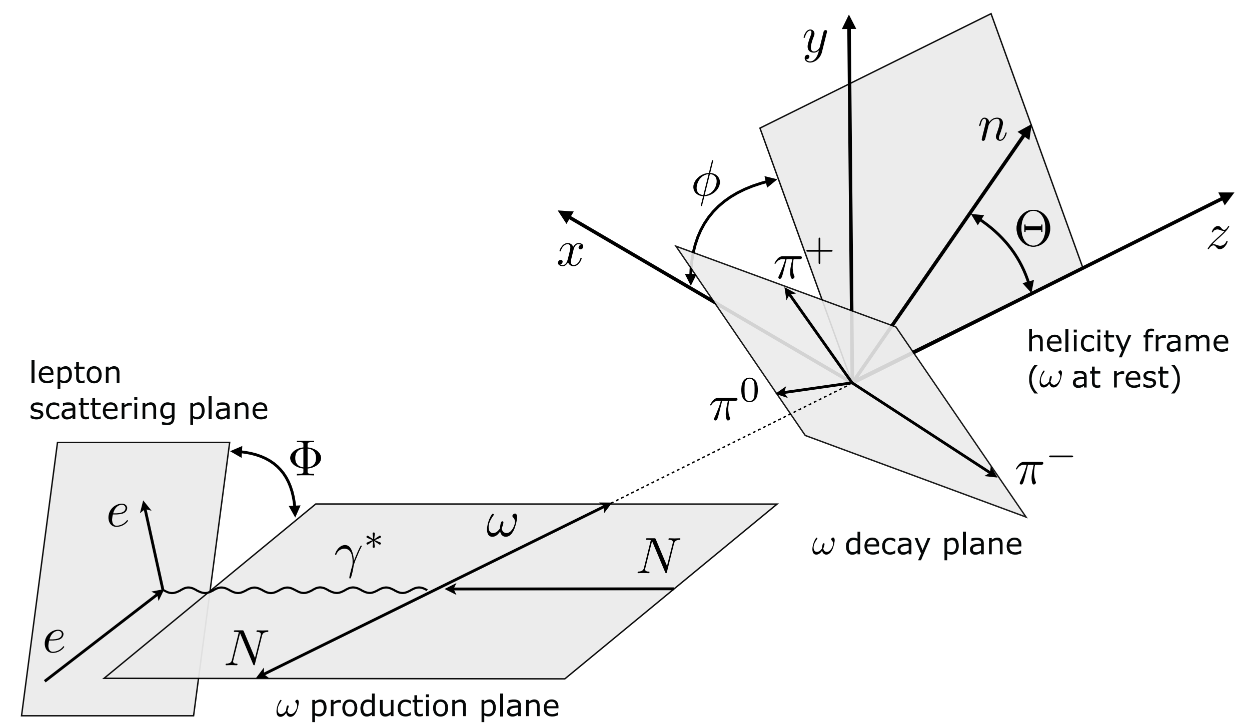

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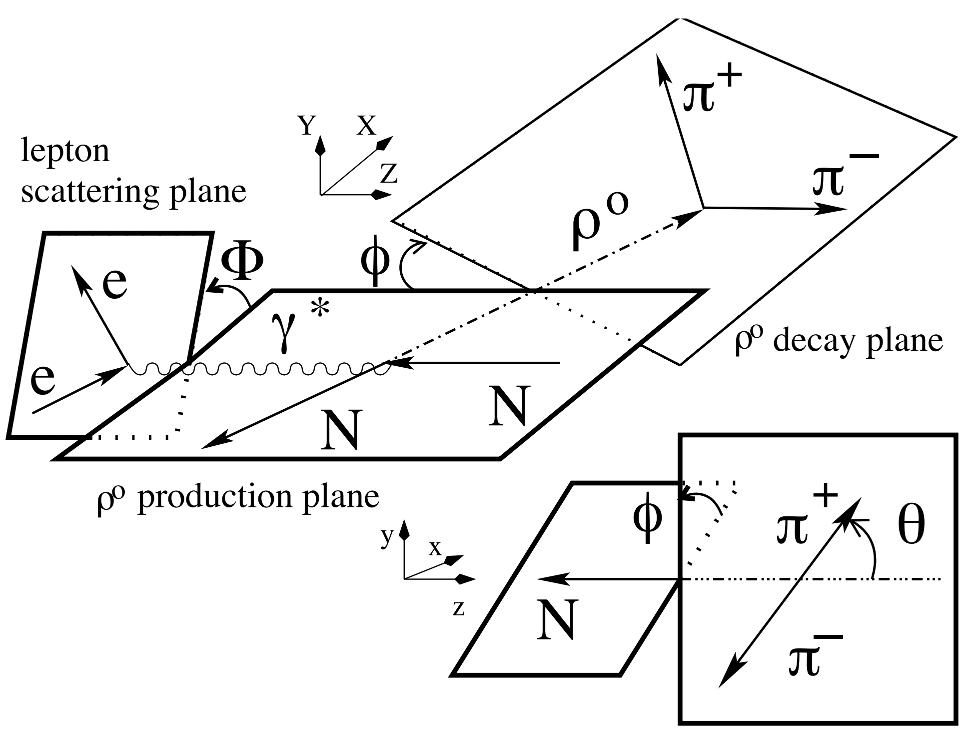
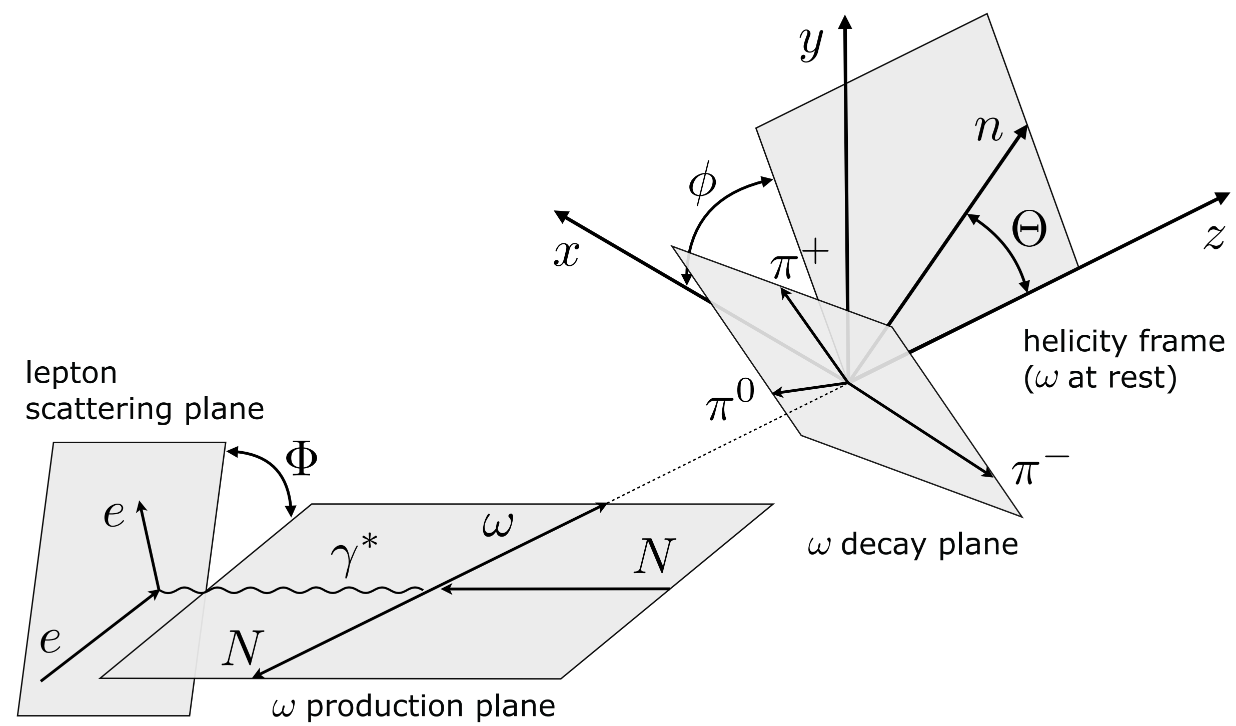




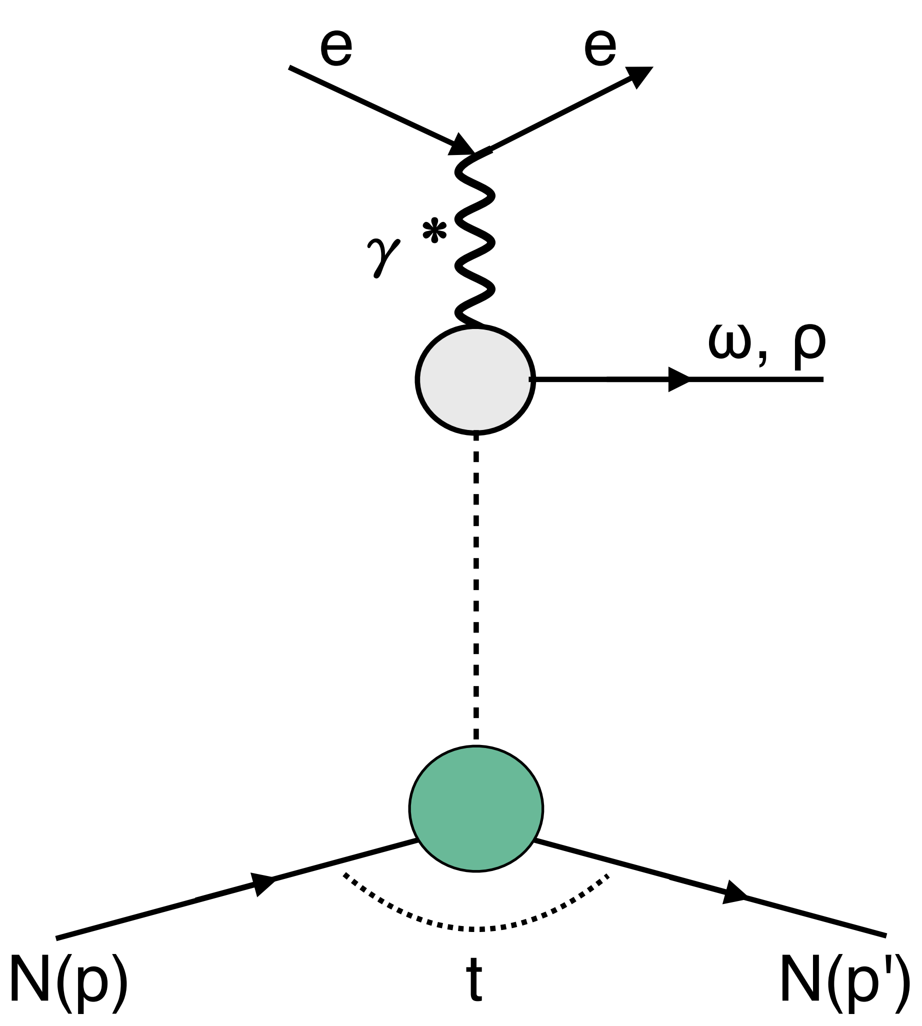
Fit angular distribution of decay pions $\mathcal{W}(\Phi, \phi, \Theta, \Psi)$ and extract either

- Spin Density Matrix Elements (SDMEs)

or

- helicity amplitude ratios

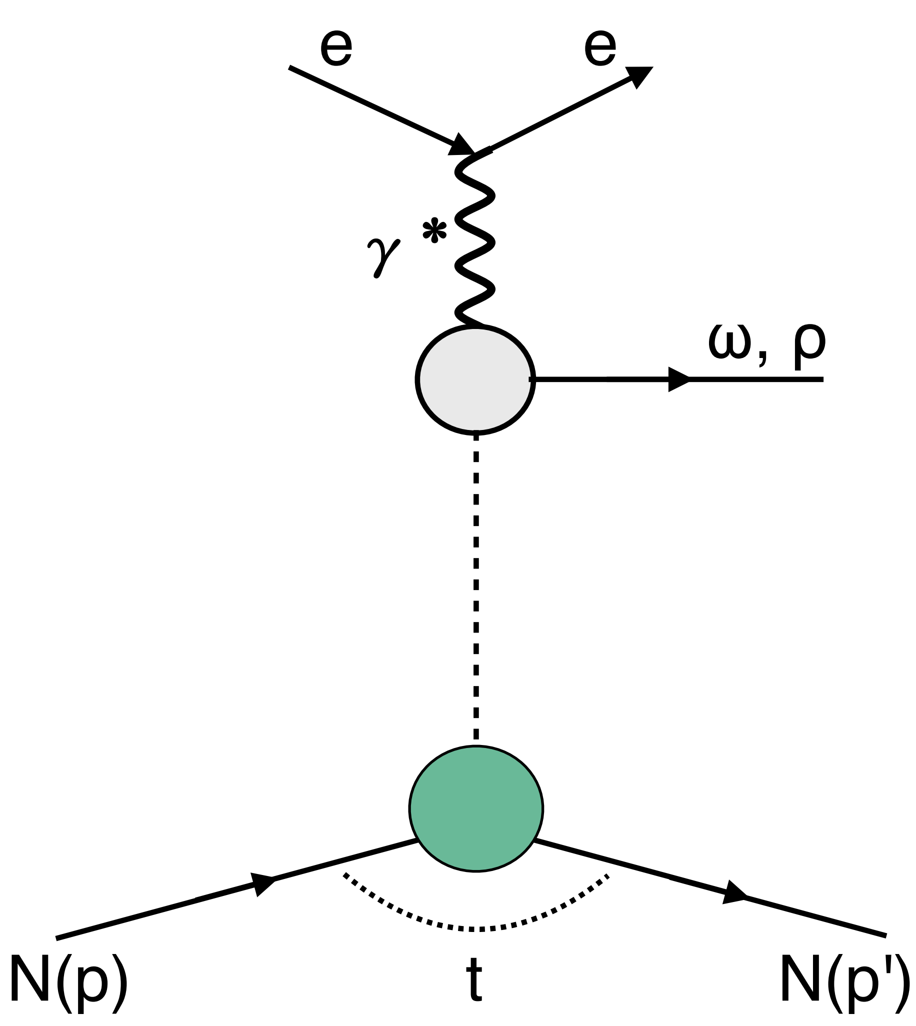
Helicity amplitude ratios and SDMEs



$$\gamma^*(\lambda_\gamma) + N(\lambda_N) \to V(\lambda_V) + N(\lambda'_N)$$

- Helicity amplitude $F_{\lambda_V \lambda'_N \lambda_\gamma \lambda_N}$

Helicity amplitude ratios and SDMEs



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- Helicity amplitude $F_{\lambda_V \lambda'_N \lambda_\gamma \lambda_N}$

$$F_{\lambda_V \lambda'_N \lambda_\gamma \lambda_N} = T_{\lambda_V \lambda'_N \lambda_\gamma \lambda_N} + U_{\lambda_V \lambda'_N \lambda_\gamma \lambda_N}$$

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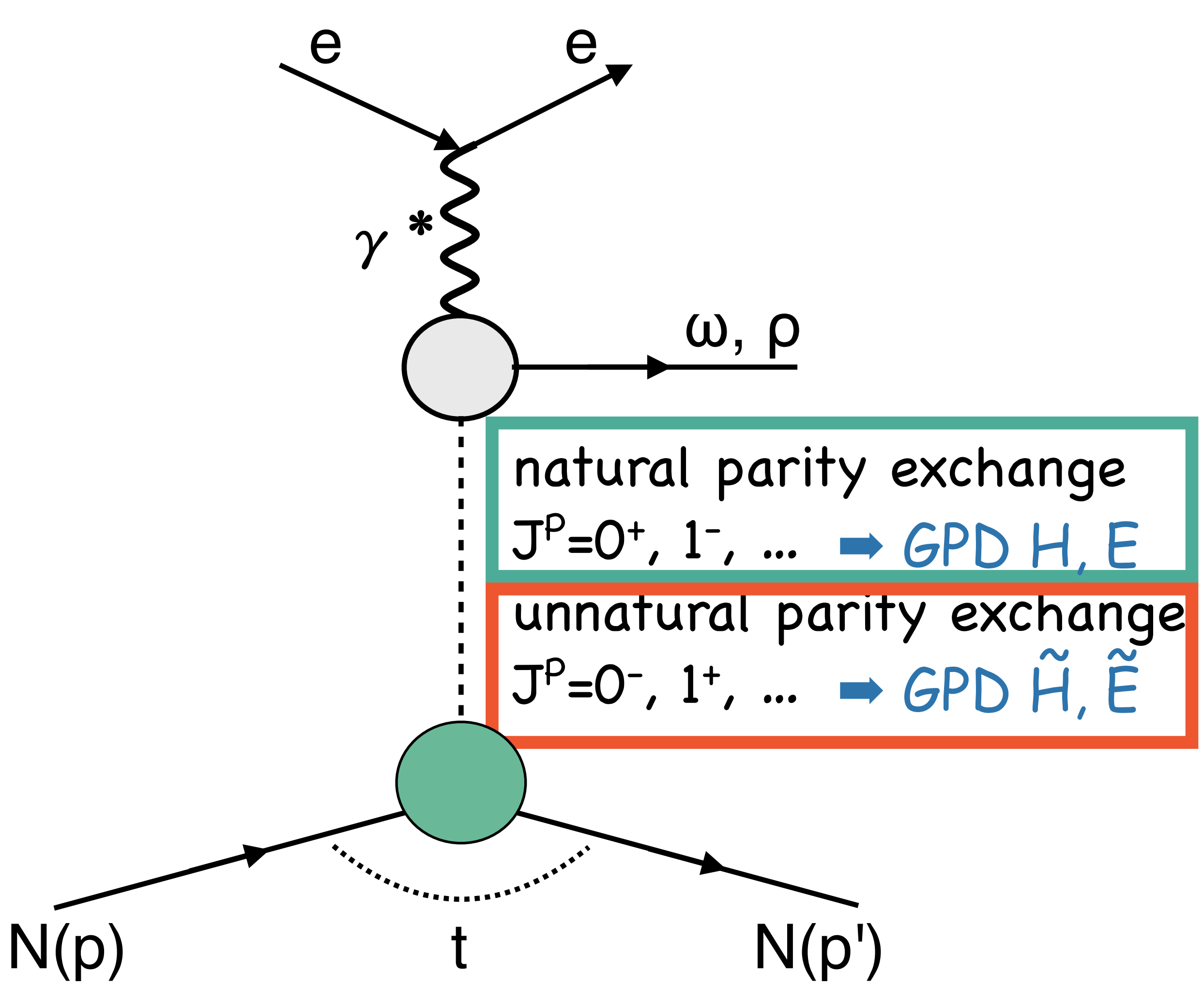

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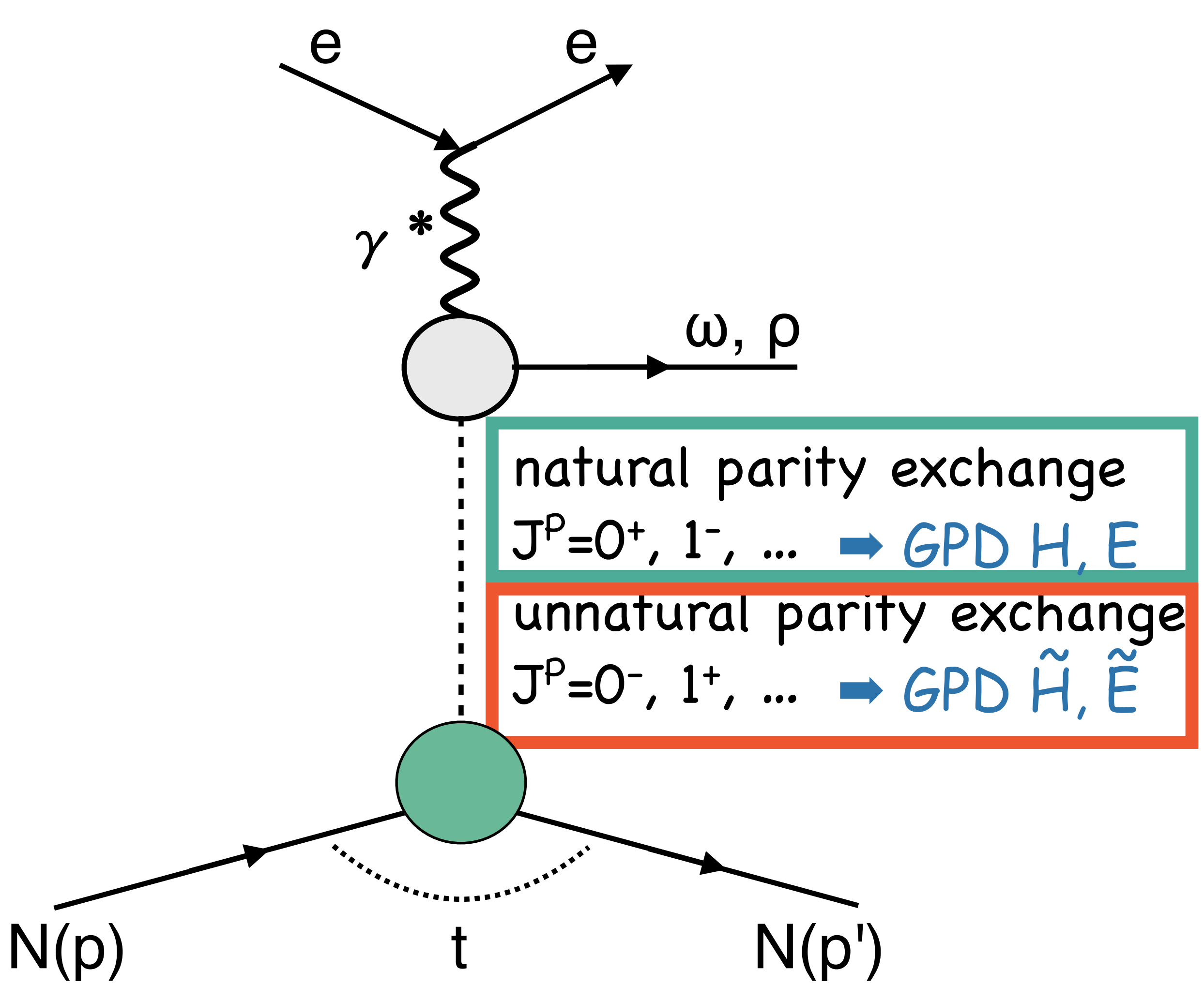
natural parity amplitude | unnatural parity amplitude

Helicity amplitude ratios and SDMEs



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$$F_{\lambda_V \lambda'_N \lambda_\gamma \lambda_N} = T_{\lambda_V \lambda'_N \lambda_\gamma \lambda_N} + U_{\lambda_V \lambda'_N \lambda_\gamma \lambda_N}$$

natural parity amplitude (T); unnatural parity amplitude (U)

- Helicity amplitude ratios

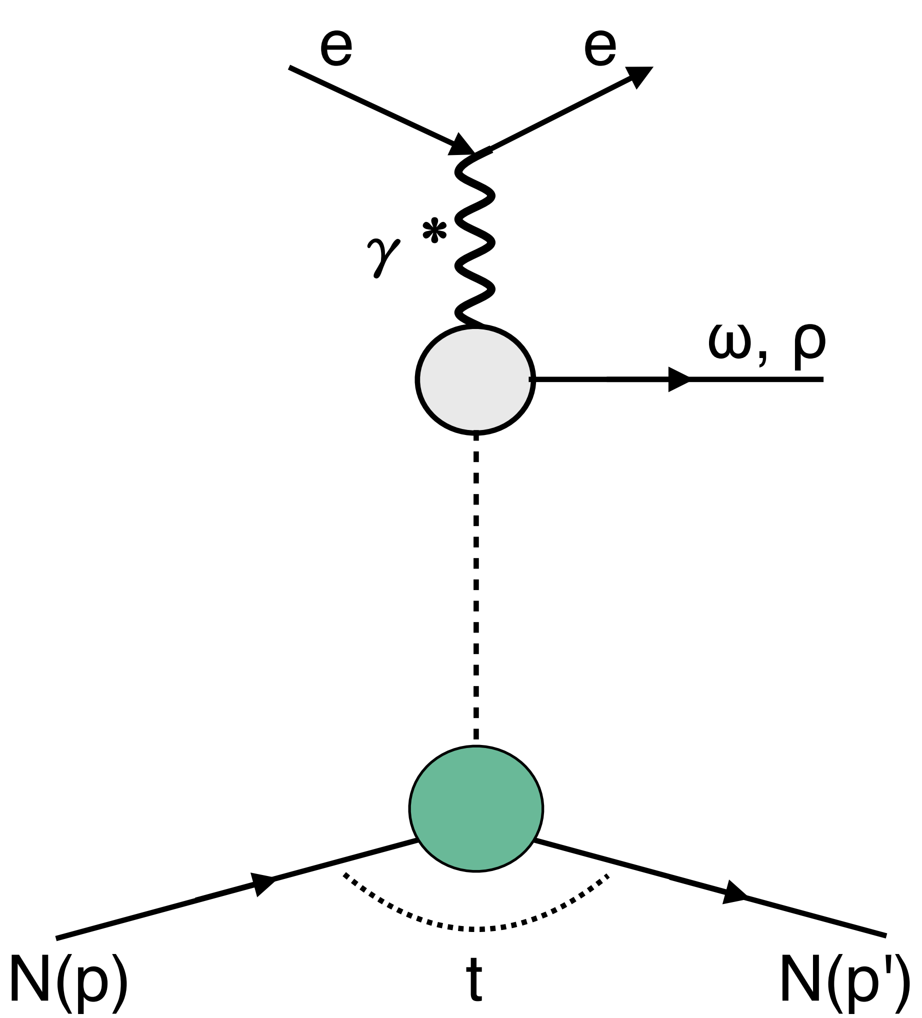
$$t^{(n)}_{\lambda_V \lambda_\gamma} = T^{(n)}_{\lambda_V \lambda_\gamma} / T_{0\frac{1}{2}0\frac{1}{2}}$$

$$u^{(n)}_{\lambda_V \lambda_\gamma} = U^{(n)}_{\lambda_V \lambda_\gamma} / T_{0\frac{1}{2}0\frac{1}{2}}$$

$n = 1 \quad \lambda_N = \lambda'_N$

$n = 2 \quad \lambda_N \neq \lambda'_N$

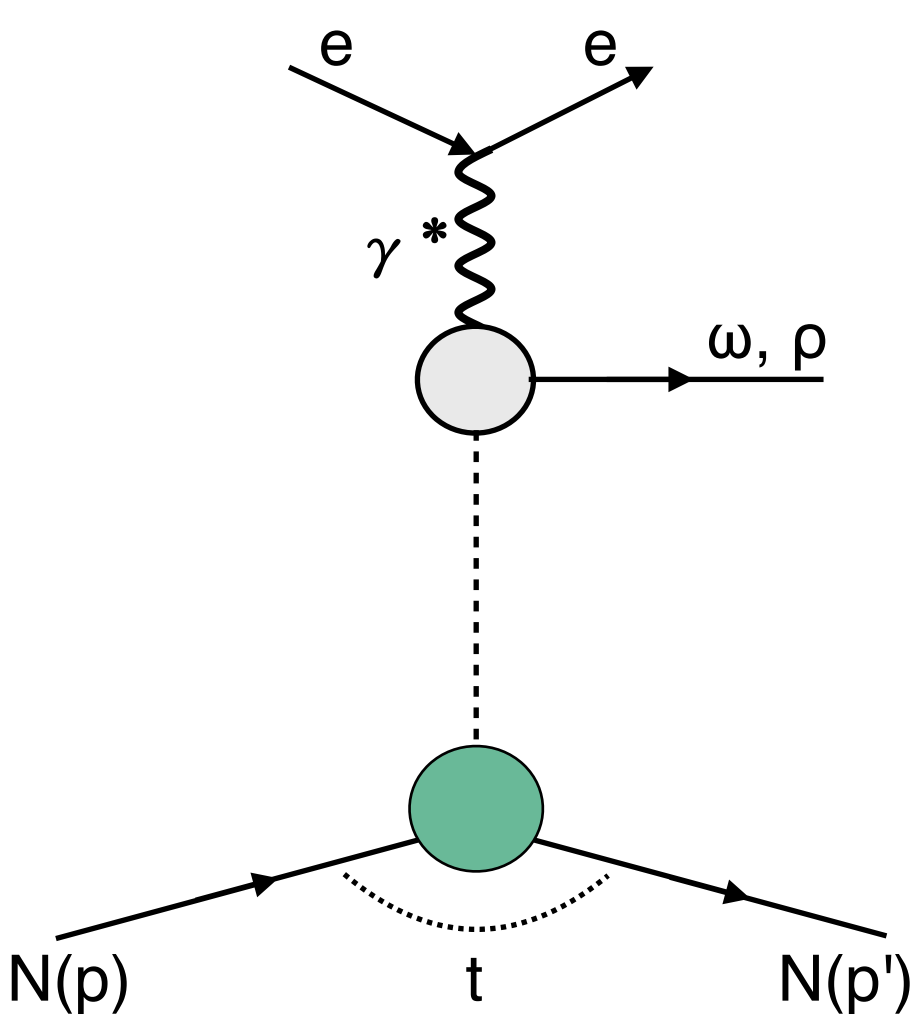
Helicity amplitude ratios and SDMEs



$$\gamma^*(\lambda_\gamma) + N(\lambda_N) \to V(\lambda_V) + N(\lambda'_N)$$

- SDMEs

Helicity amplitude ratios and SDMEs

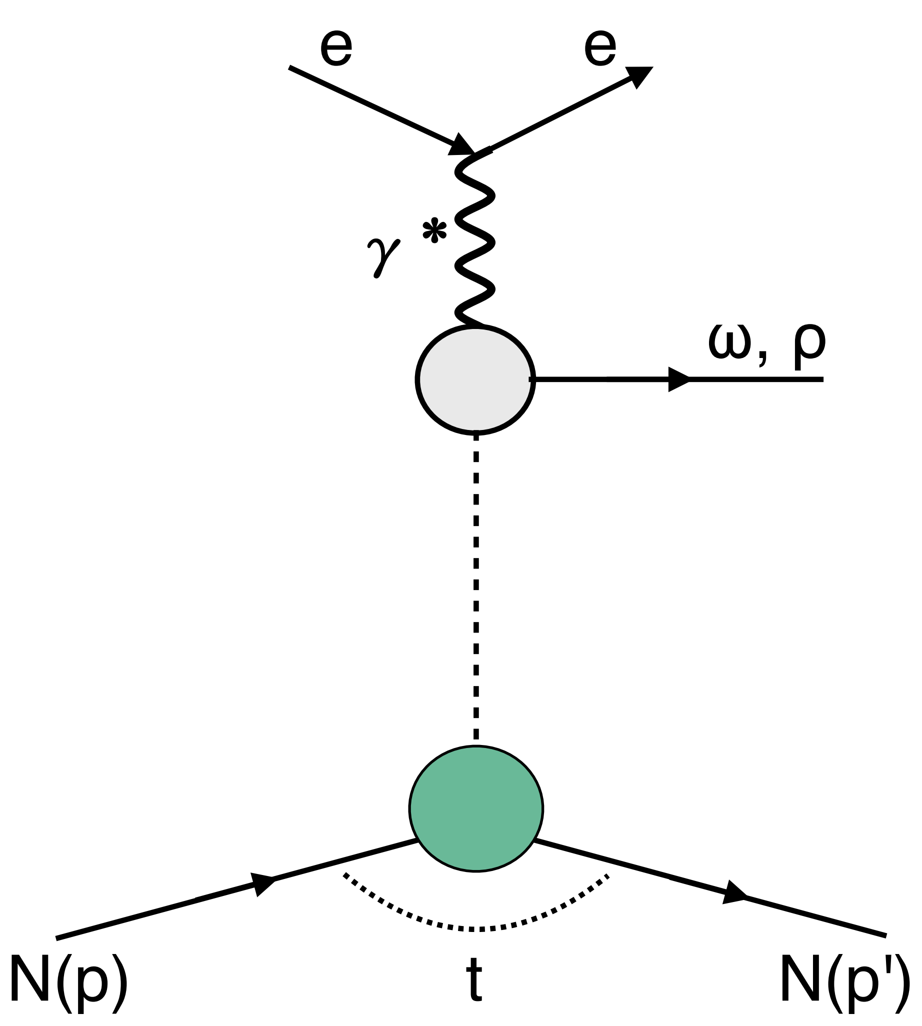


$$\gamma^*(\lambda_\gamma) + N(\lambda_N) \to V(\lambda_V) + N(\lambda'_N)$$

- SDMEs

$$\propto F_{\lambda_V \lambda'_N \lambda_\gamma \lambda_N} \Sigma^{\alpha}_{\lambda_\gamma \lambda'_\gamma} F^*_{\lambda'_V \lambda'_N \lambda'_\gamma \lambda_N}$$

Helicity amplitude ratios and SDMEs



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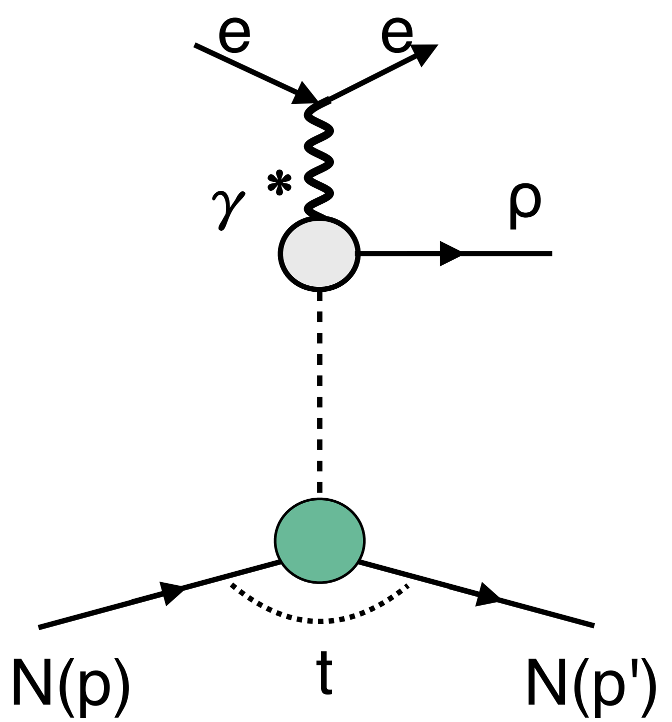
- SDMEs

$$\propto F_{\lambda_V \lambda'_N \lambda_\gamma \lambda_N} \Sigma^{\alpha}_{\lambda_\gamma \lambda'_\gamma} F^*_{\lambda'_V \lambda'_N \lambda'_\gamma \lambda_N}$$

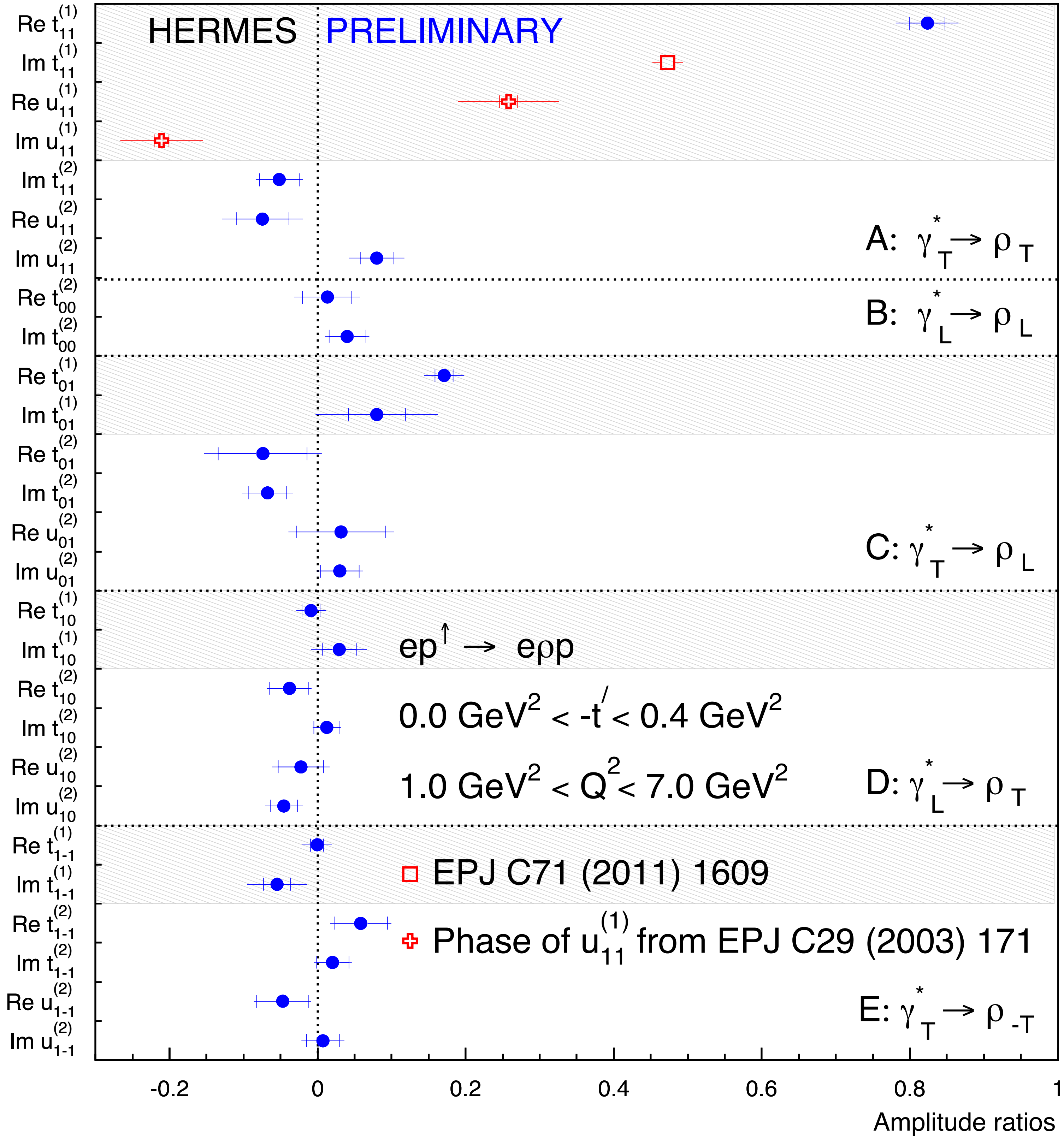
- SDMEs
  - unpolarized target
    $u^{\lambda_V \lambda'_V}_{\lambda_\gamma \lambda'_\gamma}$
  - longitudinally polarized target
    $l^{\lambda_V \lambda'_V}_{\lambda_\gamma \lambda'_\gamma}$
  - transversely polarized target
    $n^{\lambda_V \lambda'_V}_{\lambda_\gamma \lambda'_\gamma}$ and $s^{\lambda_V \lambda'_V}_{\lambda_\gamma \lambda'_\gamma}$

Helicity amplitude ratios for exclusive ρ^0



- transversely polarized H target
- 8741 exclusive-ρ events
- 25-parameter fit

Results helicity ρ^0 amplitude ratios



already obtained in EPJ C71 (2011) 1609

extracted for first time

- 5 classes of helicity amplitude ratios

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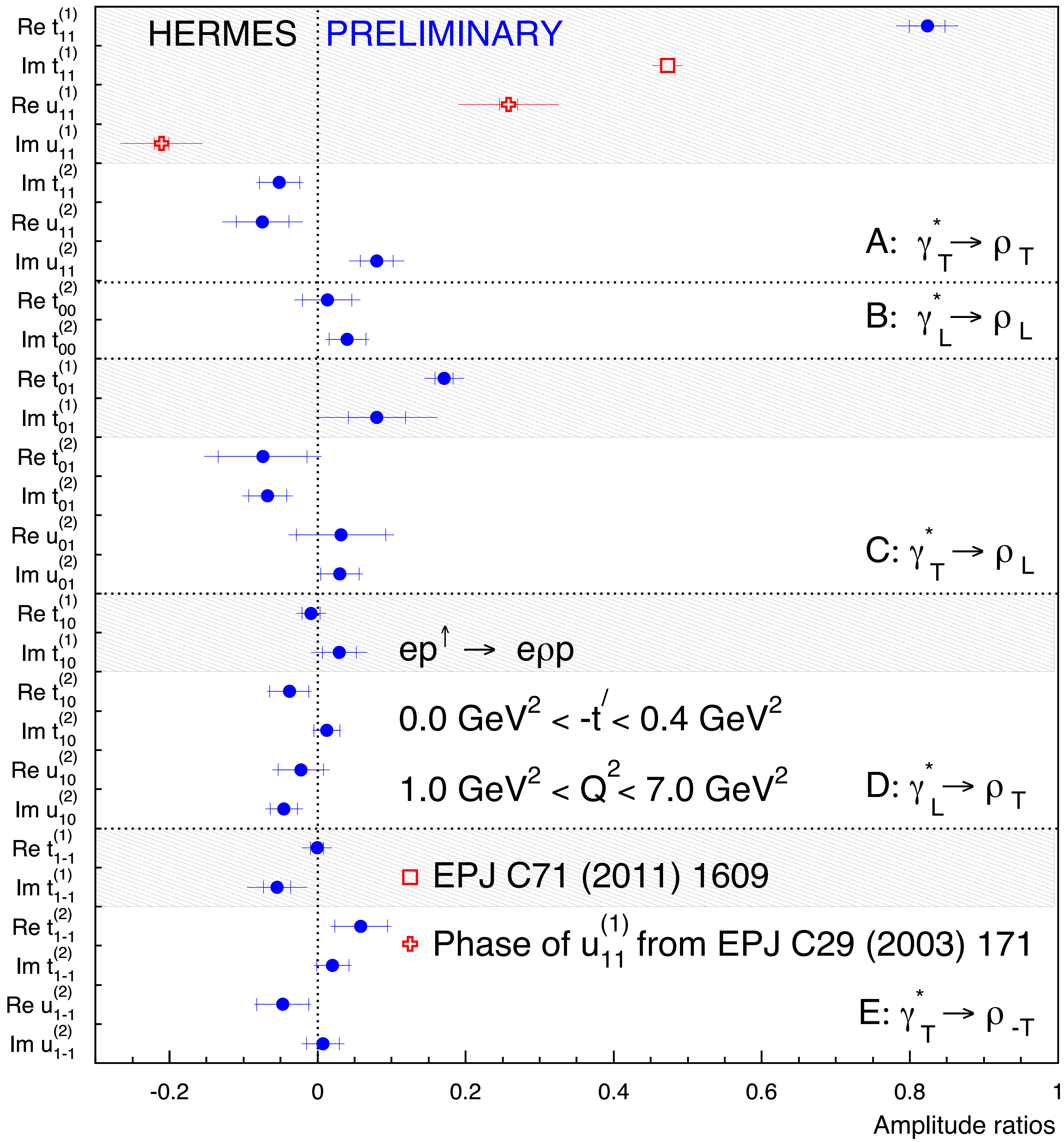

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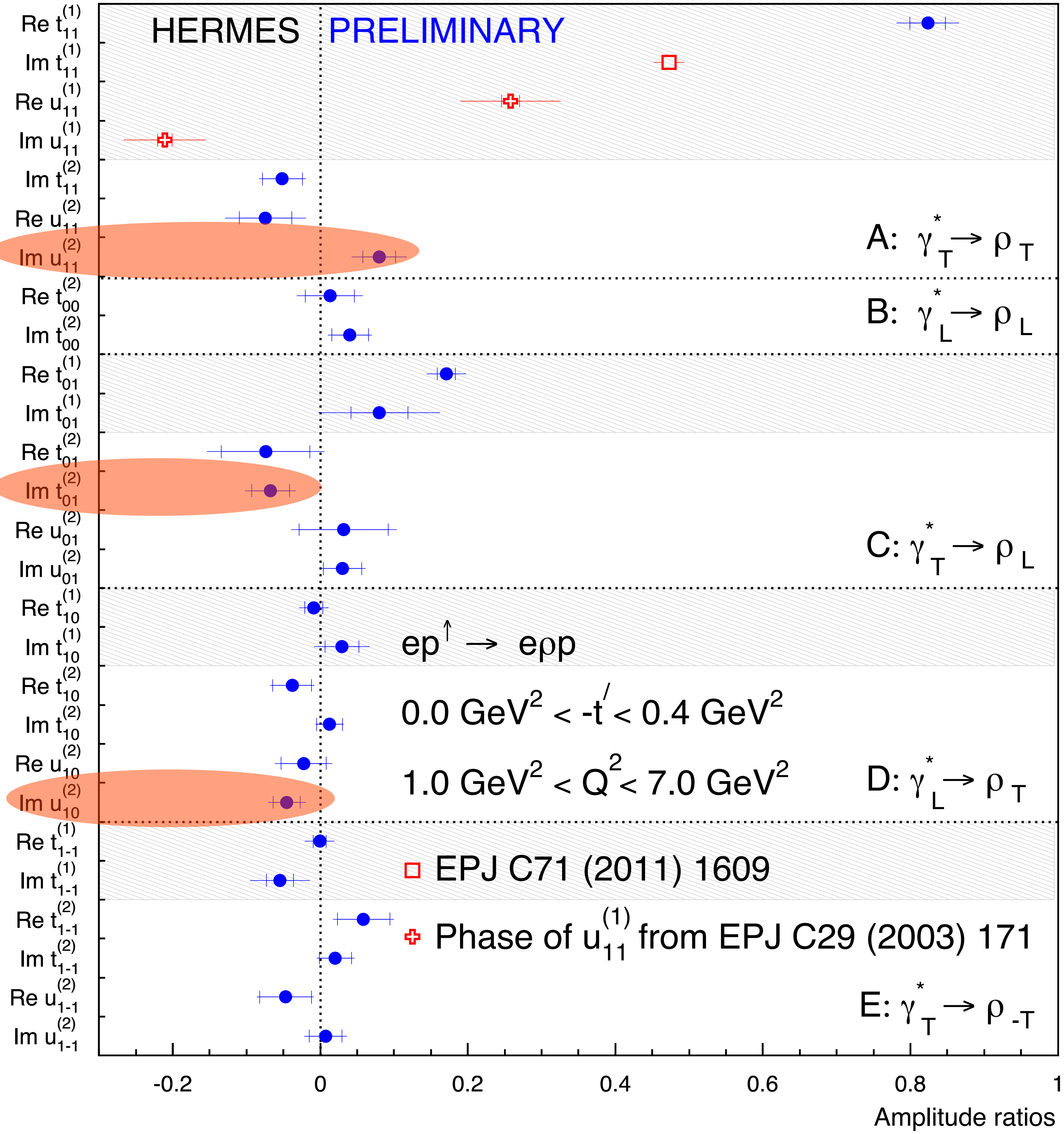
- 5 classes of helicity amplitude ratios
- dominant amplitudes: natural parity nucleon-helicity non-flip $t_{11}^{(1)}$
- also unnatural parity nucleon-helicity non-flip $u_{11}^{(1)}$ ≠ 0 by 4σ

Results helicity ρ^0 amplitude ratios



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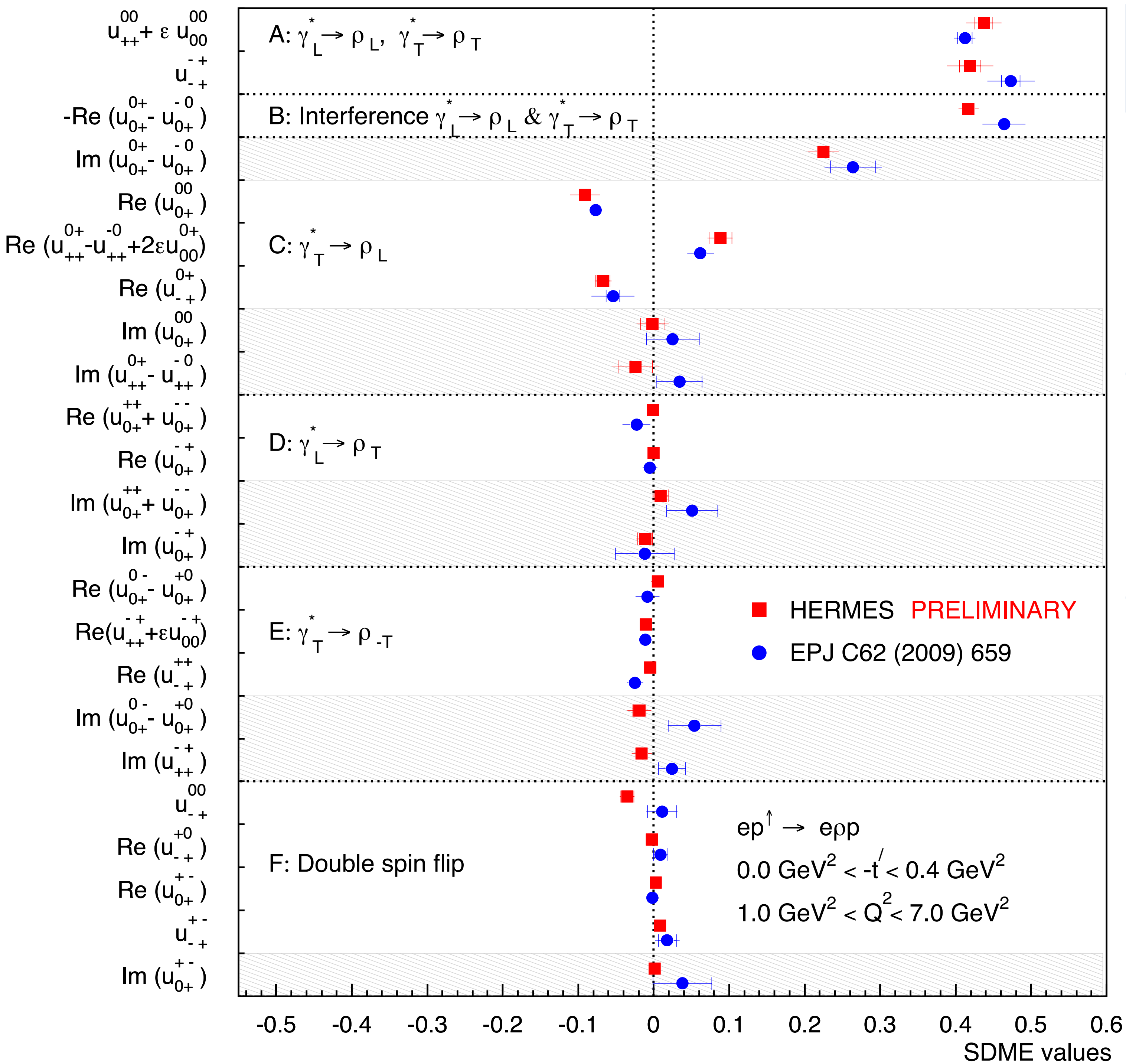
extracted for first time

- 5 classes of helicity amplitude ratios
- dominant amplitudes: natural parity nucleon-helicity non-flip $t_{11}^{(1)}$
- also unnatural parity nucleon-helicity non-flip $u_{11}^{(1)} \neq 0$ by 4σ
- nucleon-helicity-flip amplitudes: small, consistent with 0

Comparison with SDMEs: unpolarized target

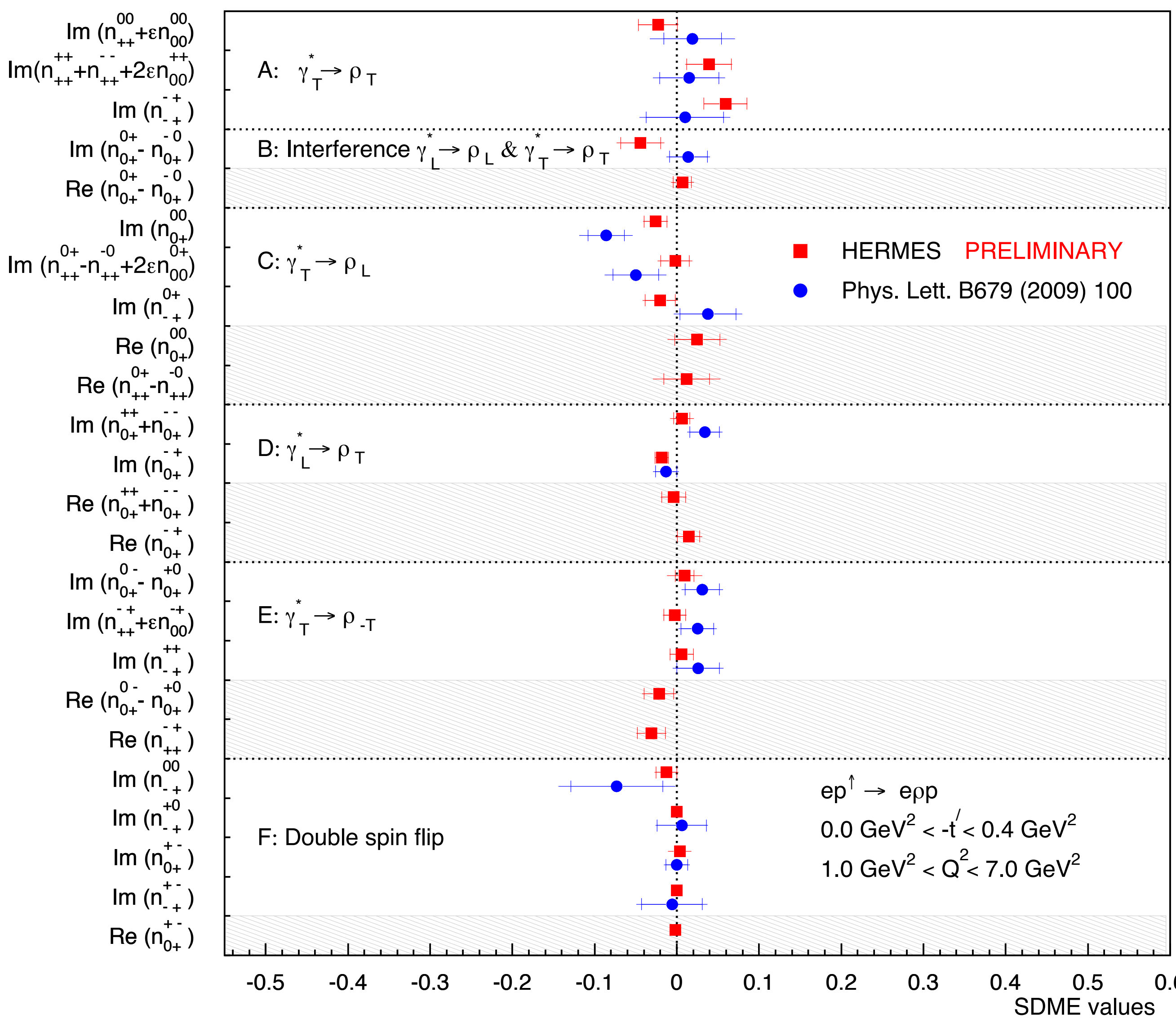


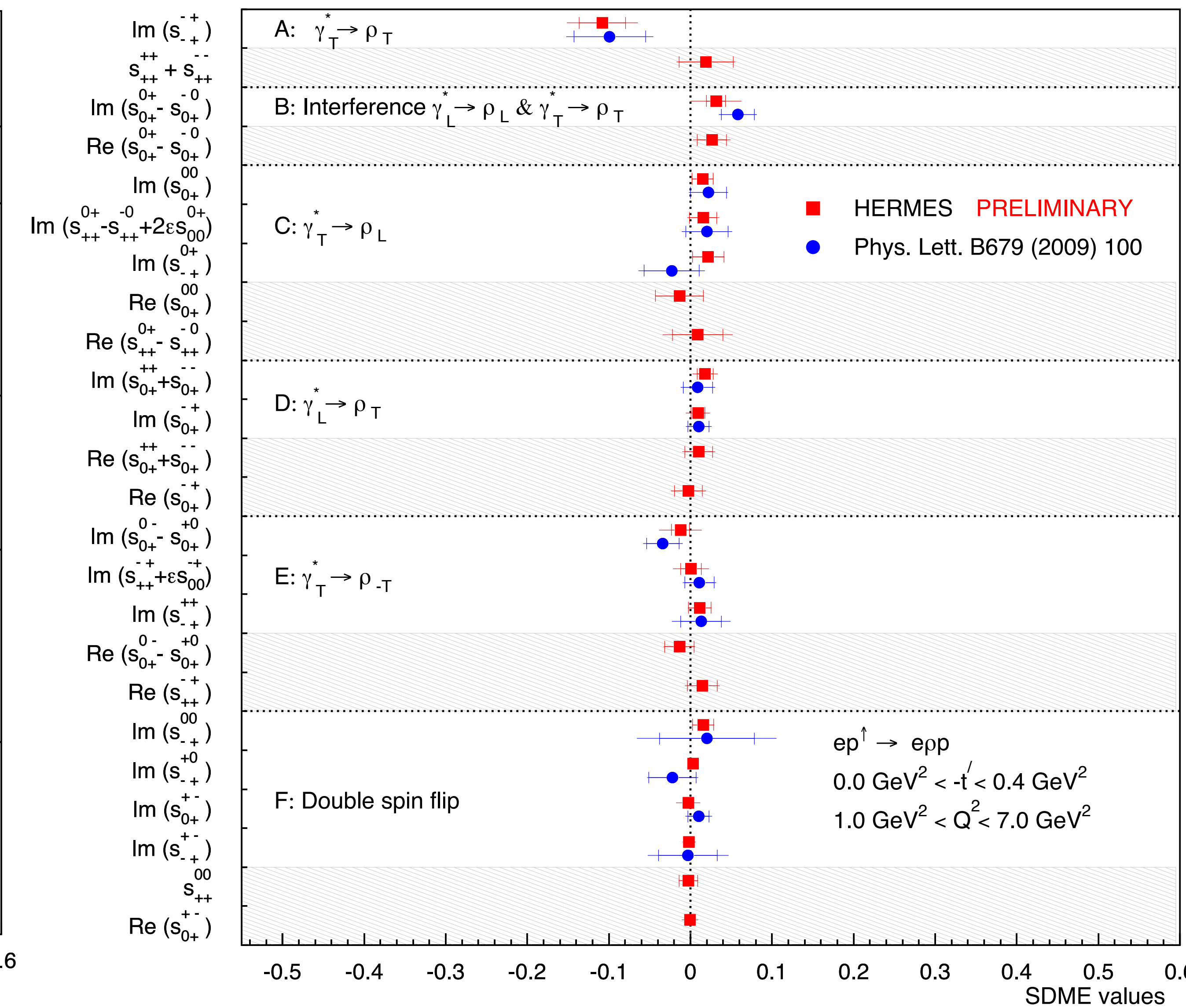
unpolarized beam

longitudinally polarized beam

- Overall good agreement between direct extraction of SDMEs and SDMEs via helicity amplitude ratios
- Parameter space in two methods are ≠ → methods do not necessarily coincide

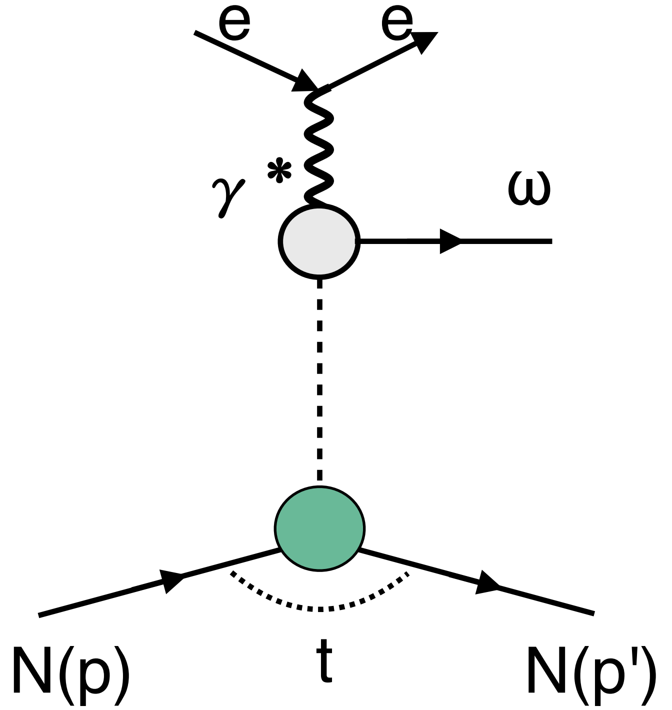
Comparison with SDMEs: transversely polarised target





- Overall good agreement between two methods
- Newly obtained SDMEs

Spin density matrix elements from exclusive ω



- unpolarized H and D targets
- 2260/1332 exclusive-ω events from H/D
- 23-parameter fit

Results ω SDMEs

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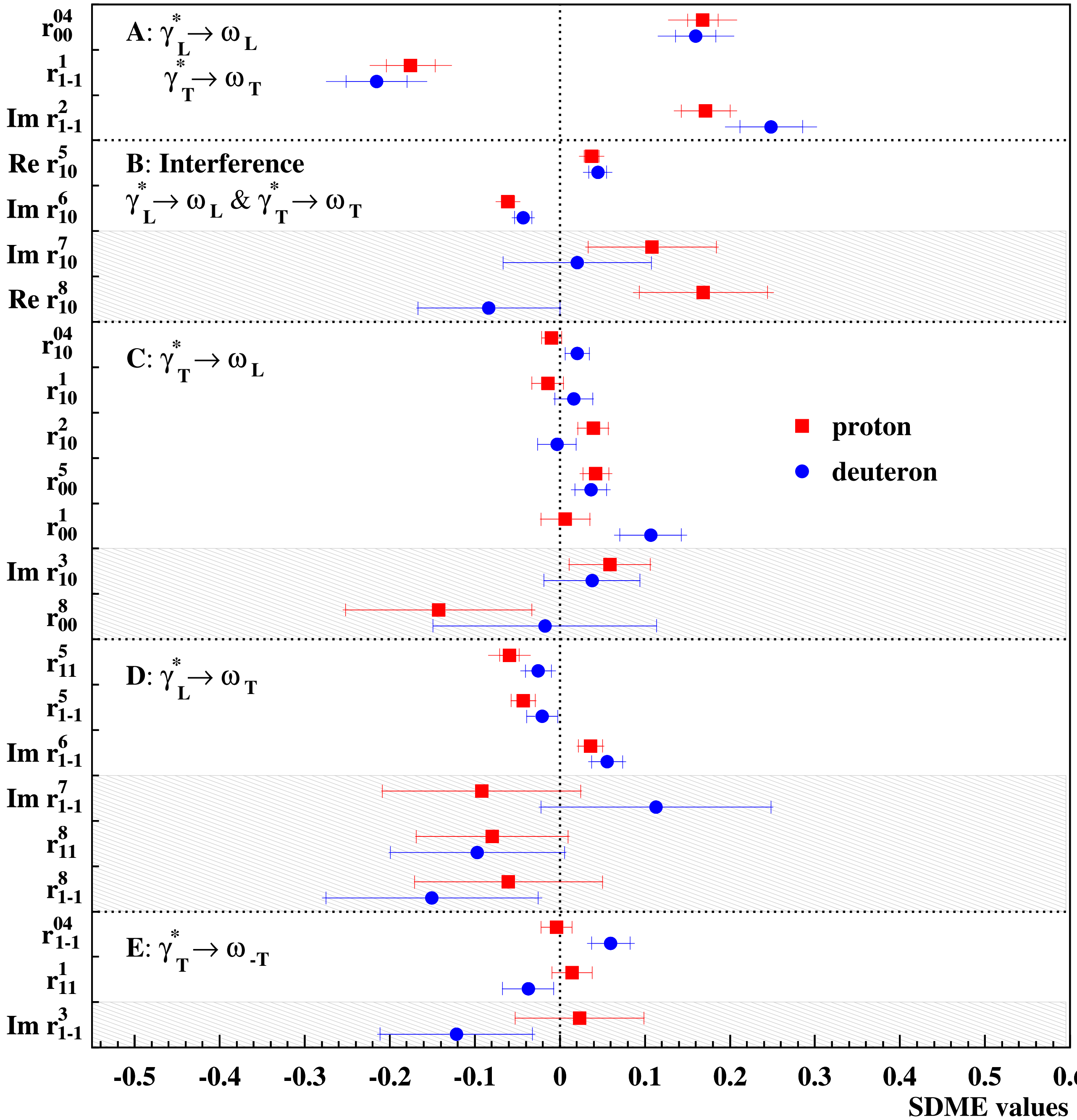

- 5 classes of SDMEs
- unpolarized and polarized SDMEs
- proton & deuteron similar

Results ω SDMEs

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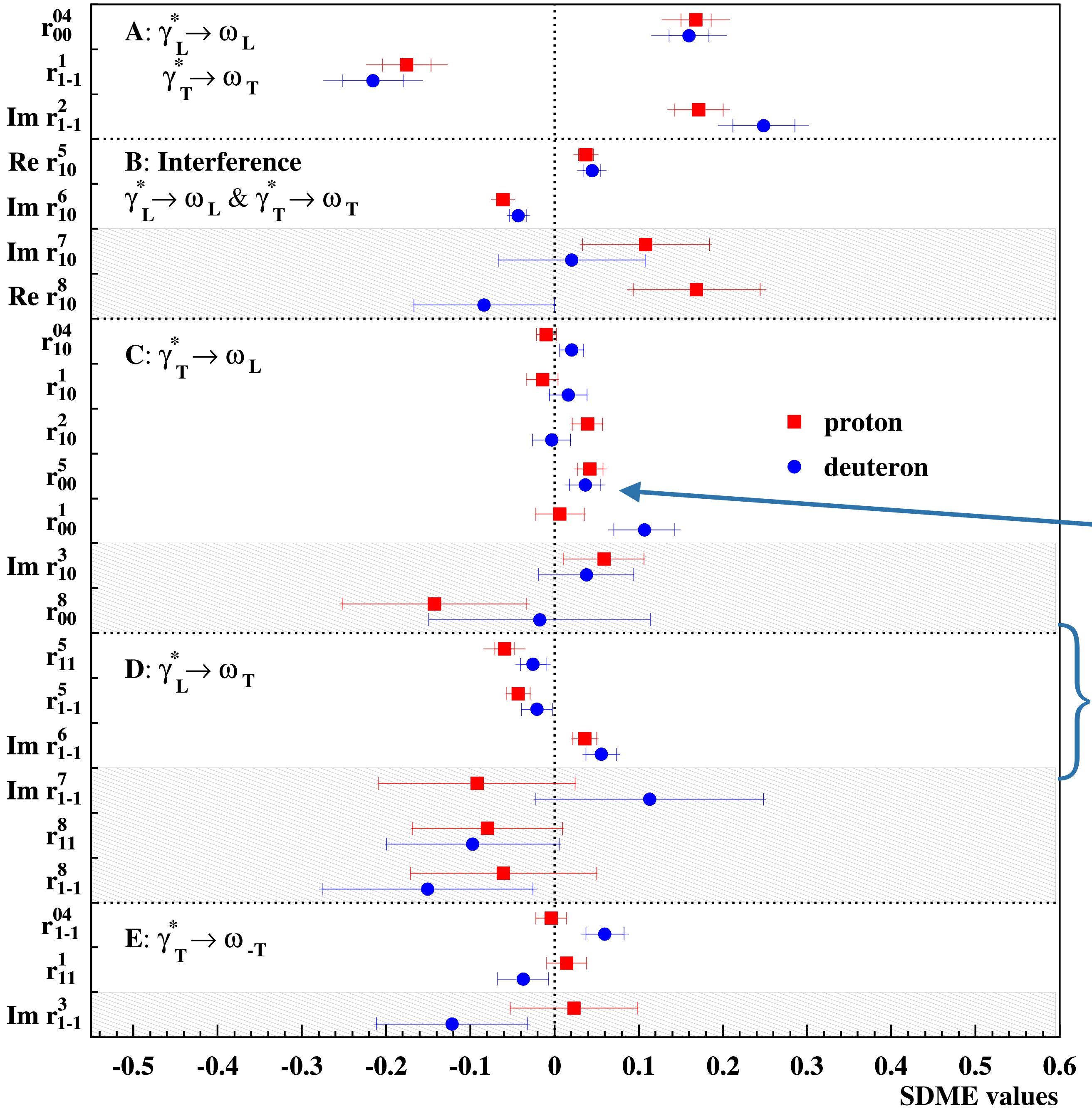

- 5 classes of SDMEs
- unpolarized and polarized SDMEs
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- s-channel helicity conservation ($\lambda_{\gamma^*} = \lambda_\omega$):
  - fulfilled for class A & B
  - class C - slight violation:

    $r^5_{00} \neq 0$ by $3(2)\,\sigma$ for p(d)
  - class D - slight violation:

    $r^5_{11} + r^5_{1-1} - \Im r^6_{1-1} \neq$

    by $3(2.5)\,\sigma$ for p(d)

Results ω and ρ SDMEs

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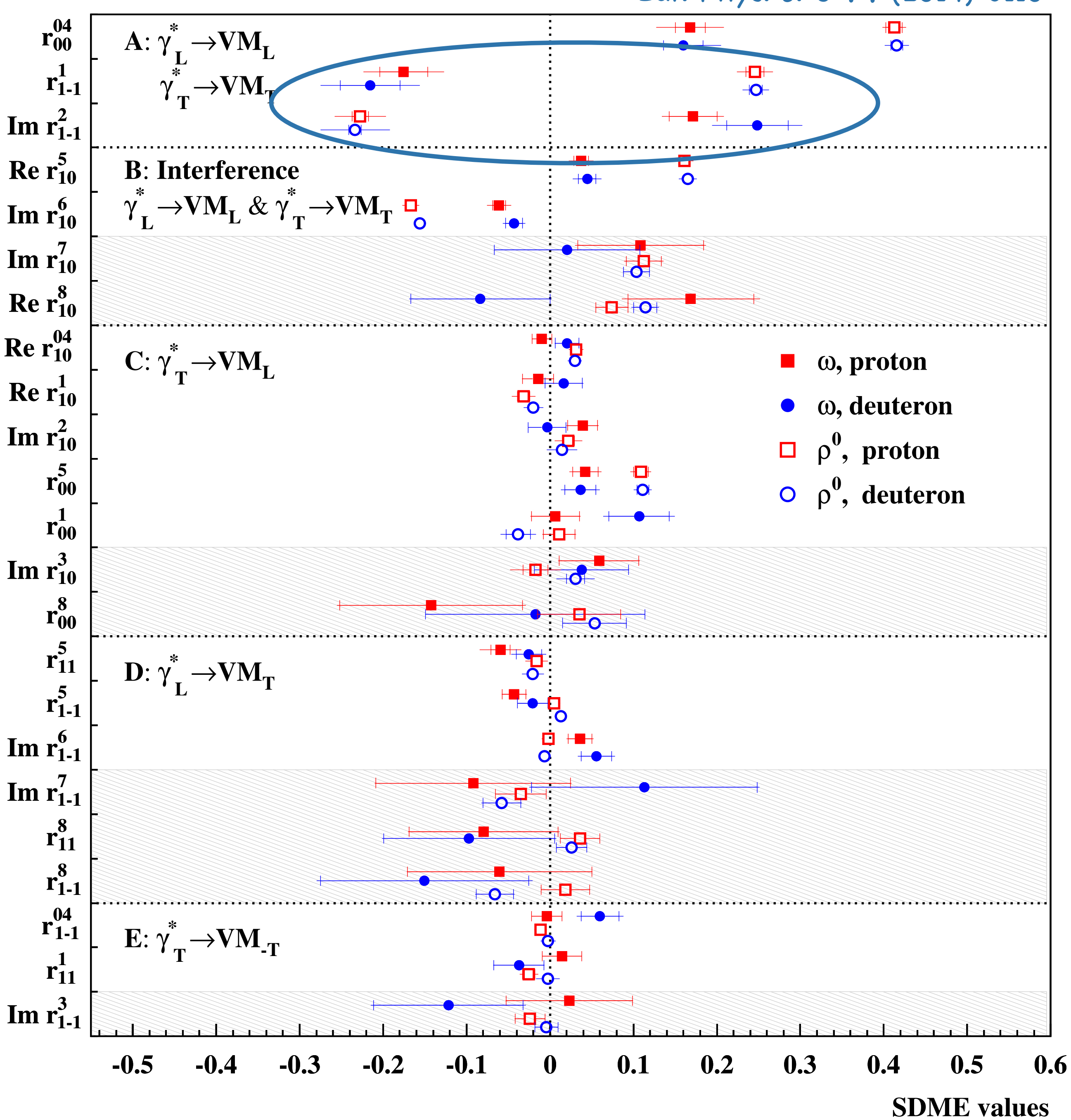


- ω: $r^1_{1-1} < 0$ and $\Im r^2_{1-1} > 0$
- ρ: $r^1_{1-1} > 0$ and $\Im r^2_{1-1} < 0$

⇩

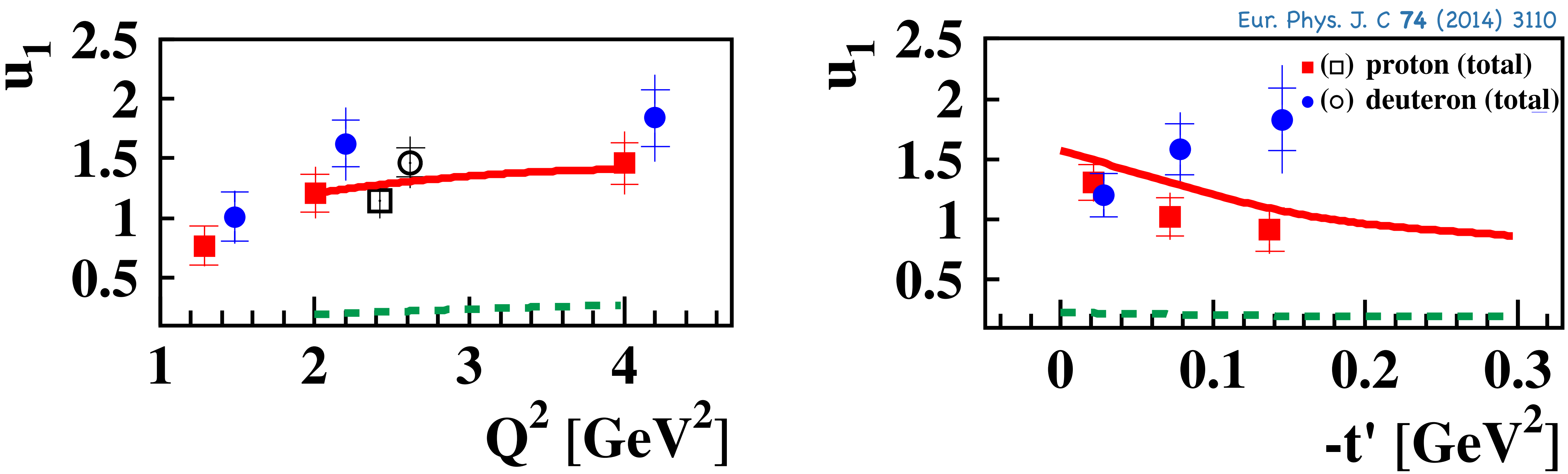
- ω: large unnatural parity exchange
- ρ: large natural parity exchange

exclusive ρ^0: Eur. Phys. J. C **62** (2009) 659

Test of unnatural-parity exchange

$$u_1 = 1 - r^{04}_{00} + 2\,r^{04}_{1-1} - 2\,r^1_{11} - 2\,r^1_{1-1}$$

$$\propto 2\,\epsilon |U_{10}|^2 + |U_{11} + U_{-11}|^2$$ (U=unnatural-parity amplitude)



- large unnatural parity exchange seen

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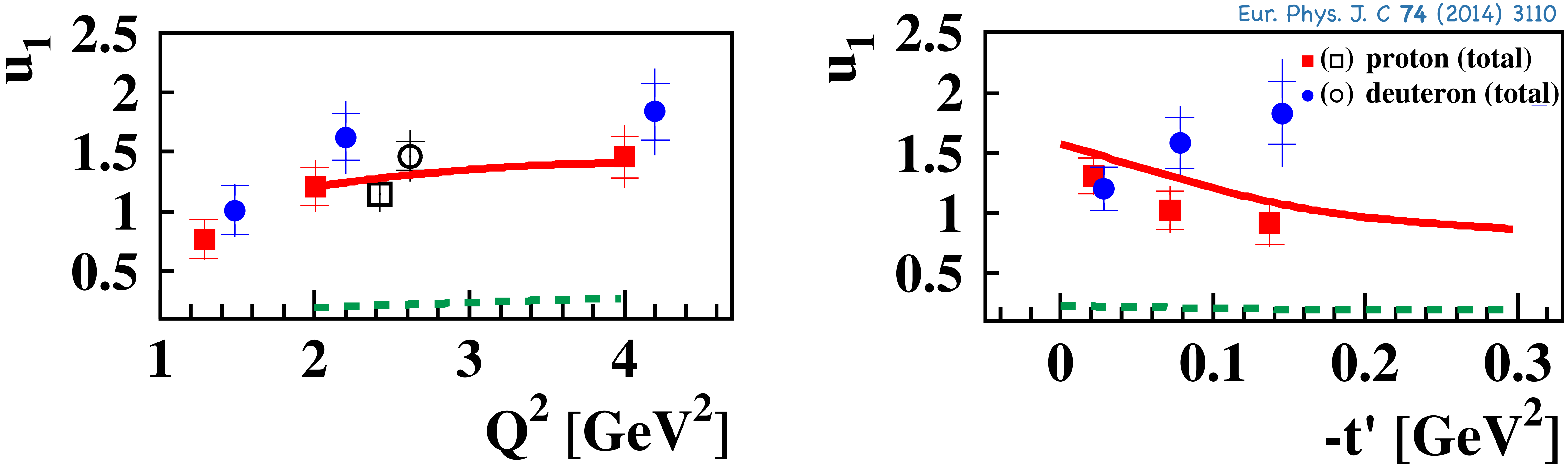

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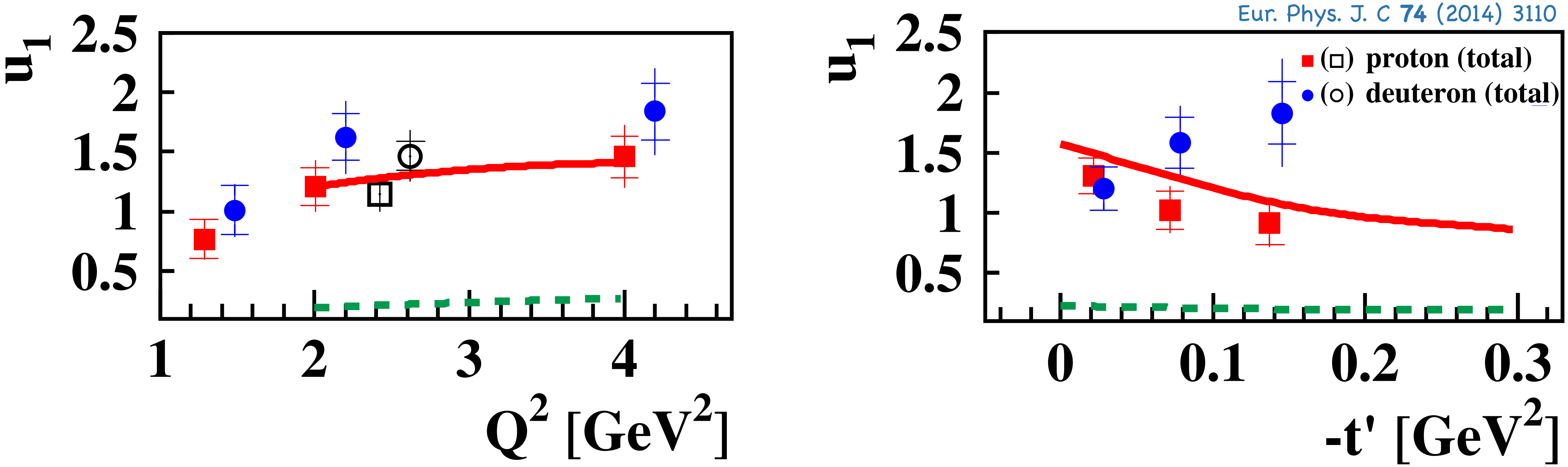

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$$F_{\lambda_V \frac{1}{2} \lambda_{\gamma=V} \frac{1}{2}} \propto \sum_{q,g} \mathcal{I} \left[\mathcal{A} \times \left(H^a, \frac{\xi^2}{1-\xi^2} E^a \right) + \mathcal{A}' \times \left(\tilde{H}^a, \frac{\xi^2}{1-\xi^2} \tilde{E}^a \right) \right)$$

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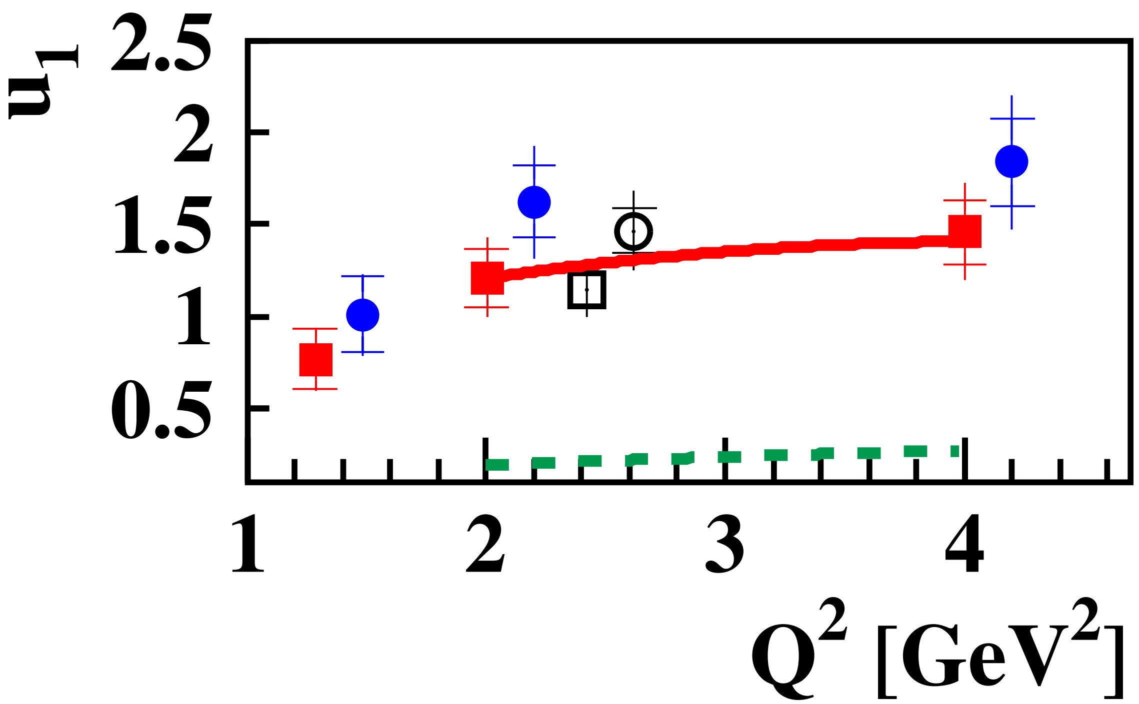
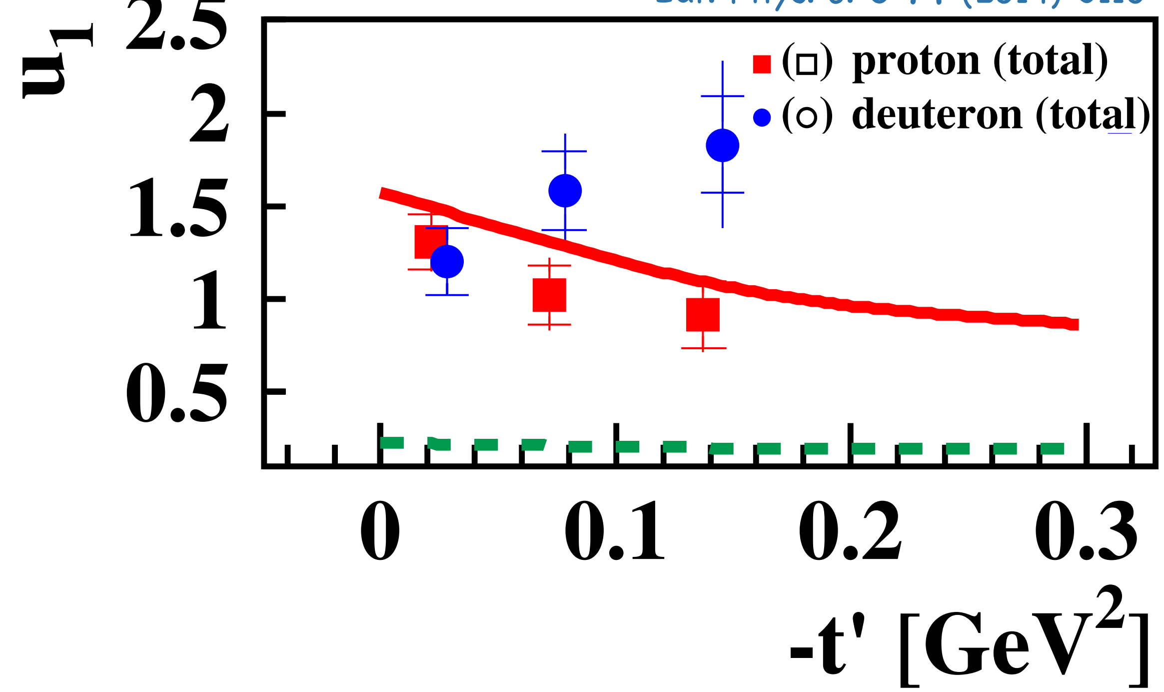
Test of unnatural-parity exchange

Eur. Phys. J. C **74** (2014) 3110





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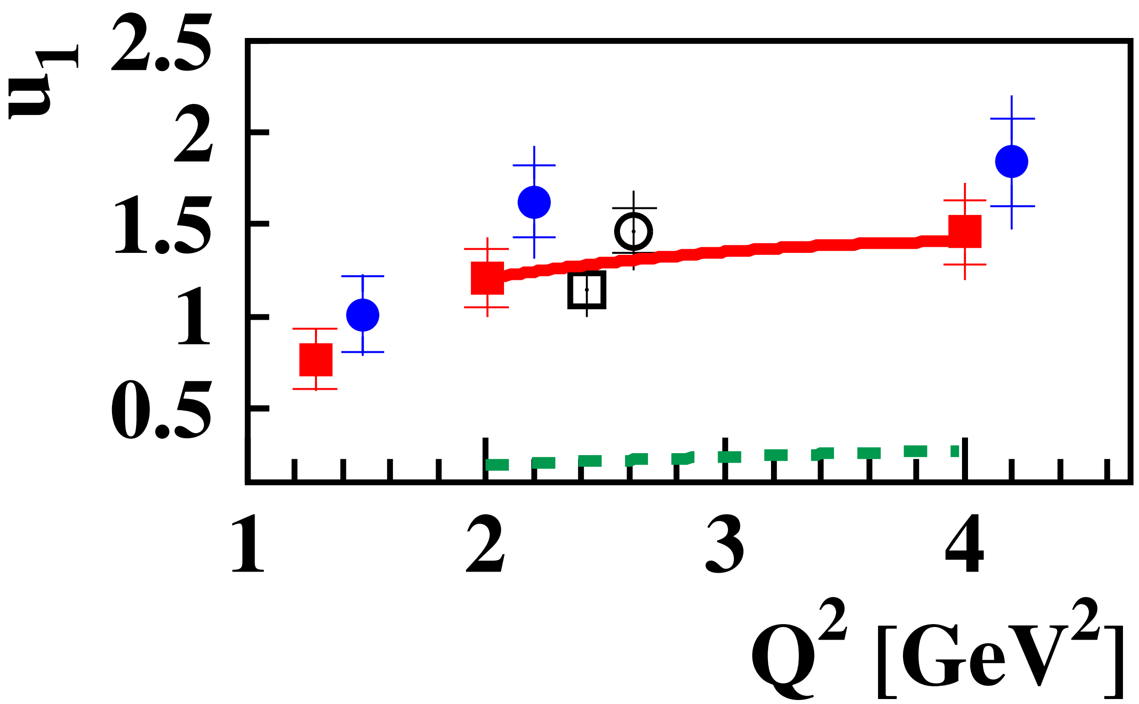

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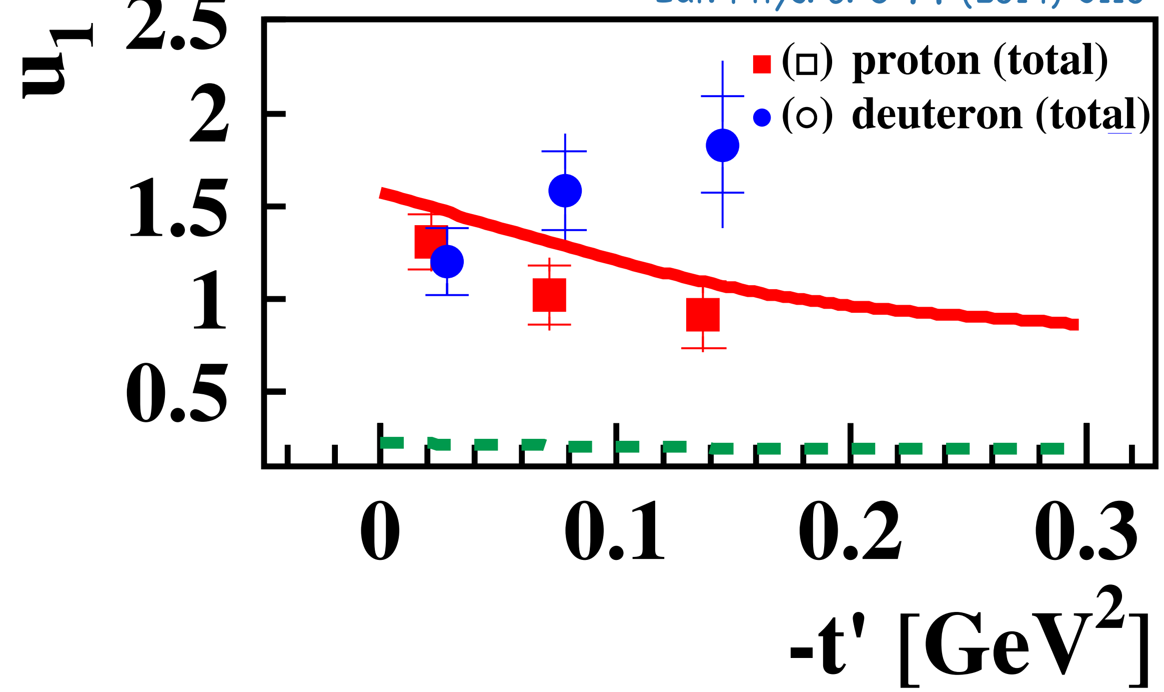

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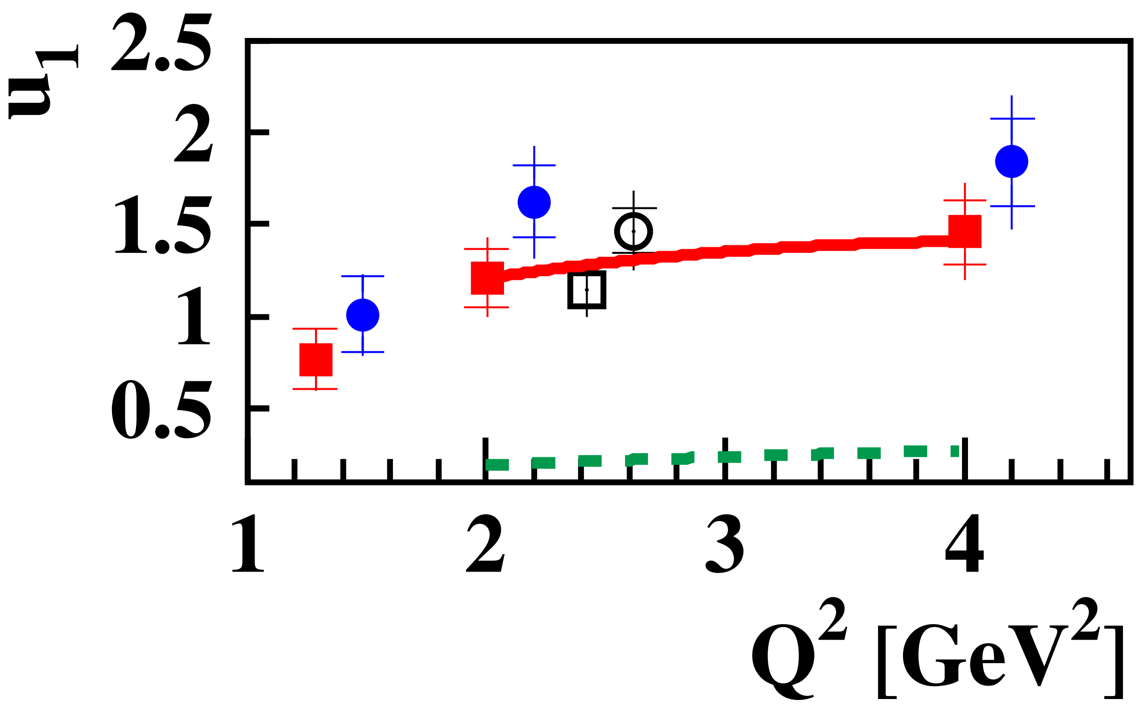
Factorization only proven for $\gamma_L^* \to V_L$
Assumed for $\gamma_T^* \to V_T, V_L$
IR singularities regularised by modified perturbative approach

Test of unnatural-parity exchange



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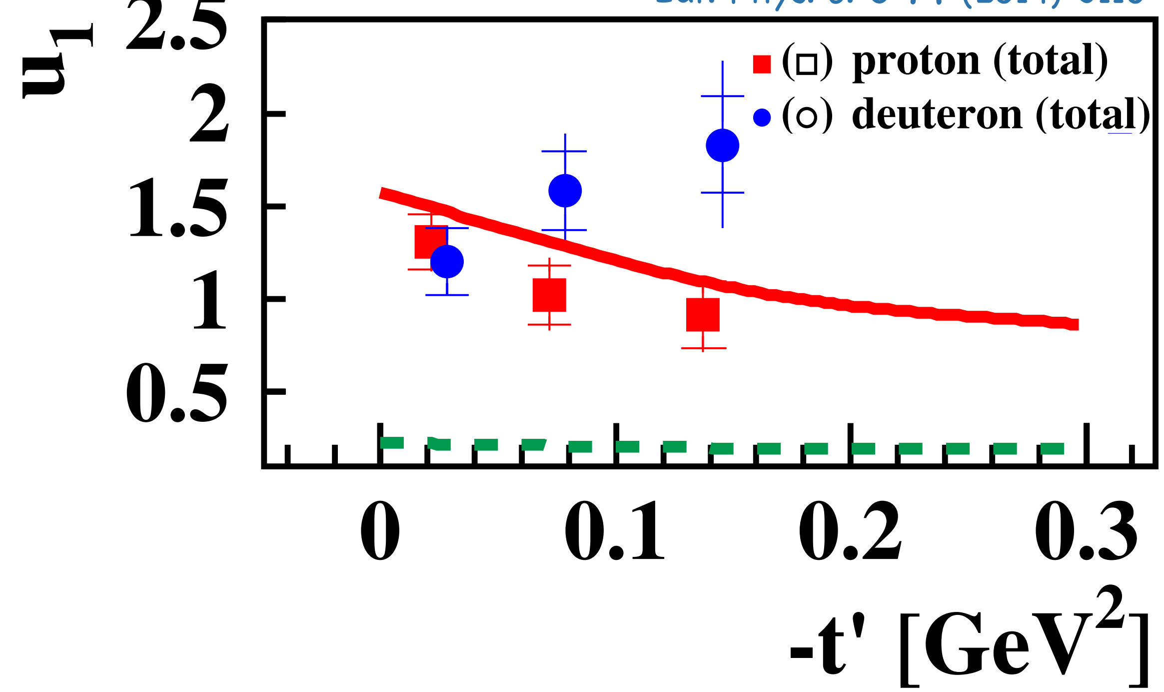

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natural parity
unnatural parity

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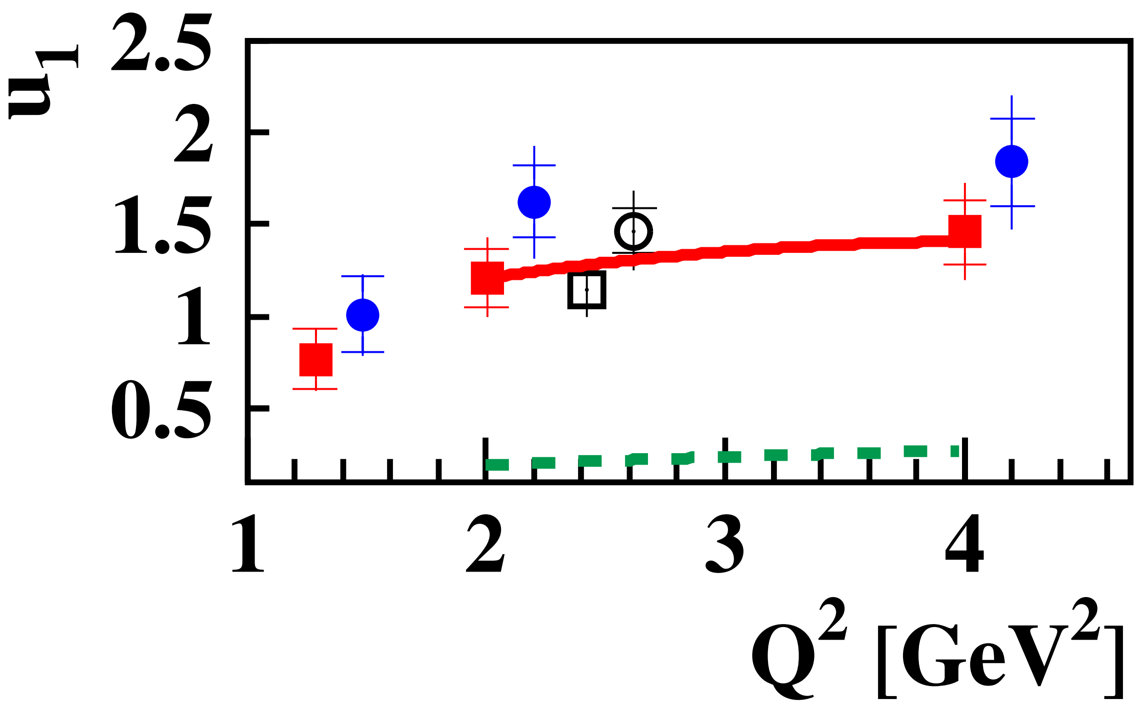

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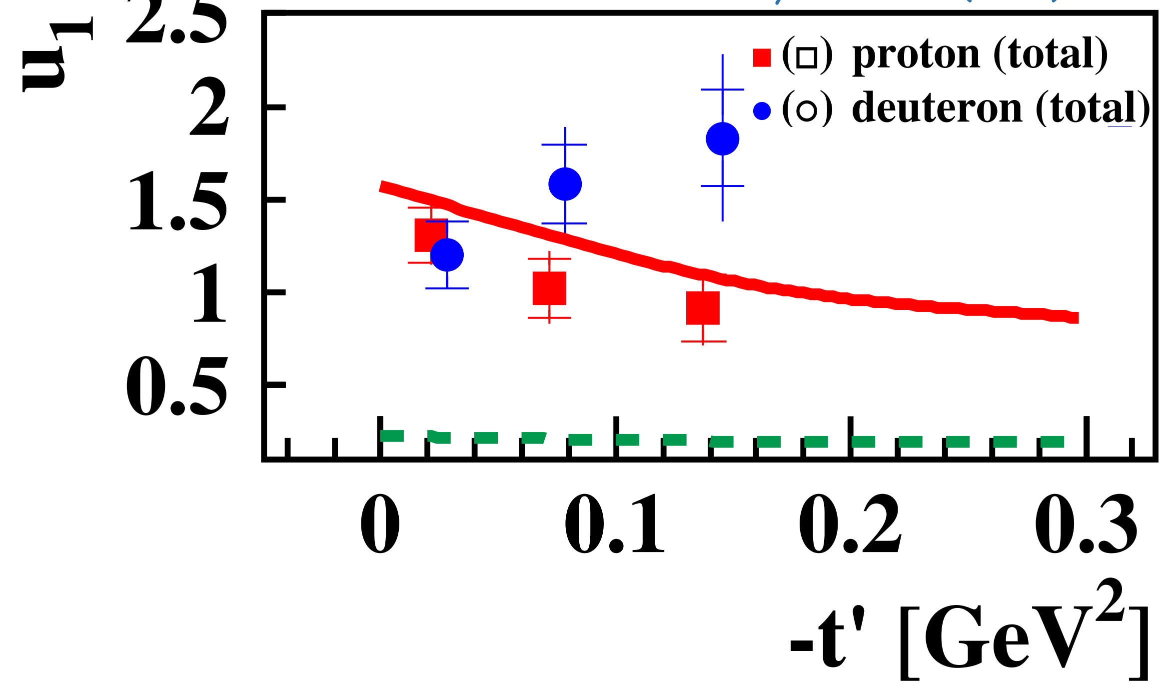

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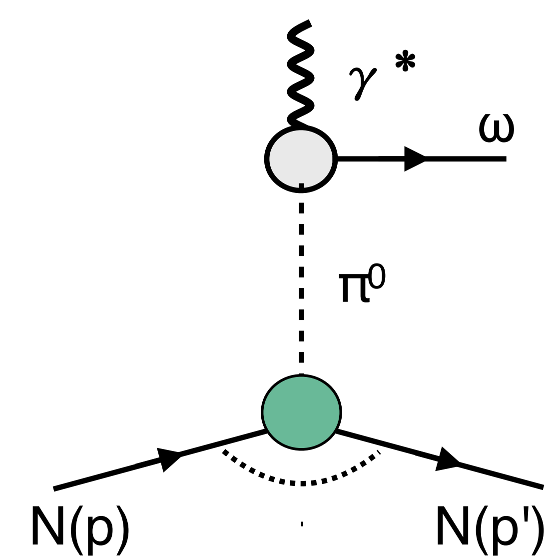
natural parity

unnatural parity



without pion-pole contribution

with pion-pole contribution

pion-pole contribution seems to account completely for unnatural-parity exchange

Kinematic dependencies

class A: $\gamma_L^* \to \omega_L$ and $\gamma_T^* \to \omega_T$

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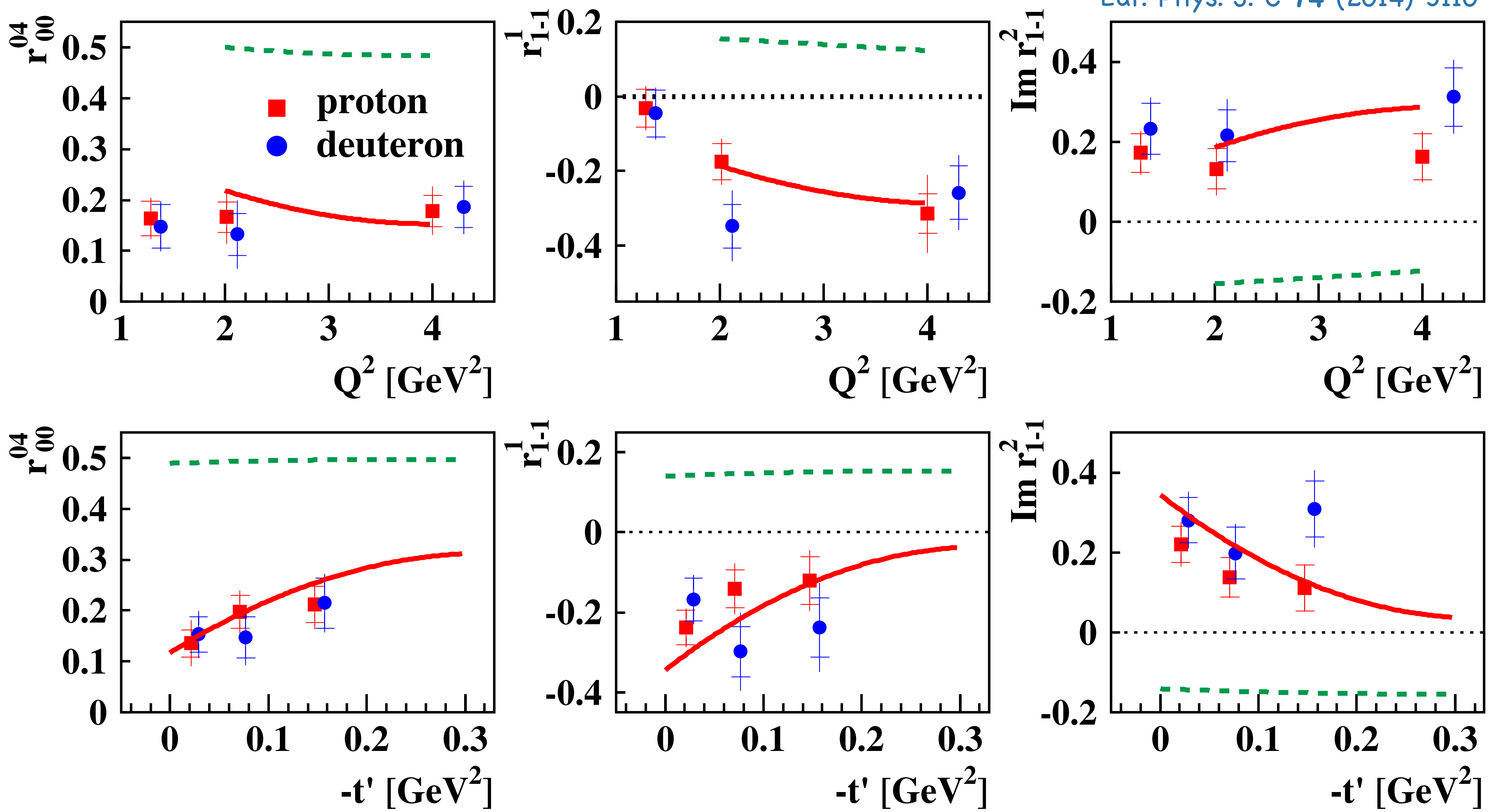

- no pronounced kinematic dependence observed
- again, need for pion-pole contribution observed

Kinematic dependencies

class B: interference $\gamma^*_L \to \omega_L$ and $\gamma^*_T \to \omega_T$

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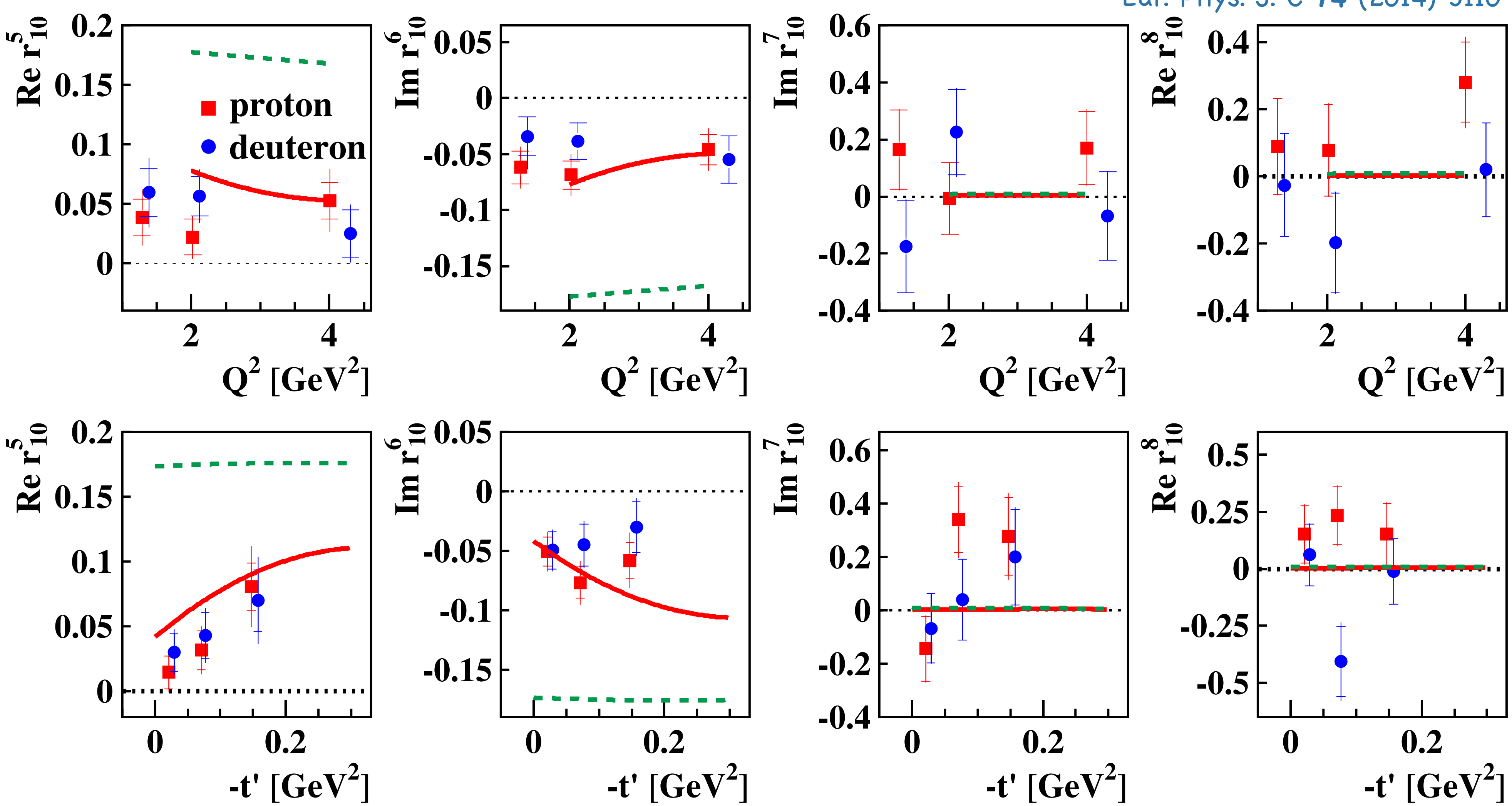

- no pronounced kinematic dependence observed
- need for pion-pole contribution observed for unpolarized SDMEs

Longitudinal-to-transverse cross-section ratio

$$R = \frac{d\sigma(\gamma_L^* \to \omega)}{d\sigma(\gamma_T^* \to \omega)} \approx \frac{1}{\epsilon}\frac{r_{00}^{04}}{1 - r_{00}^{04}}$$

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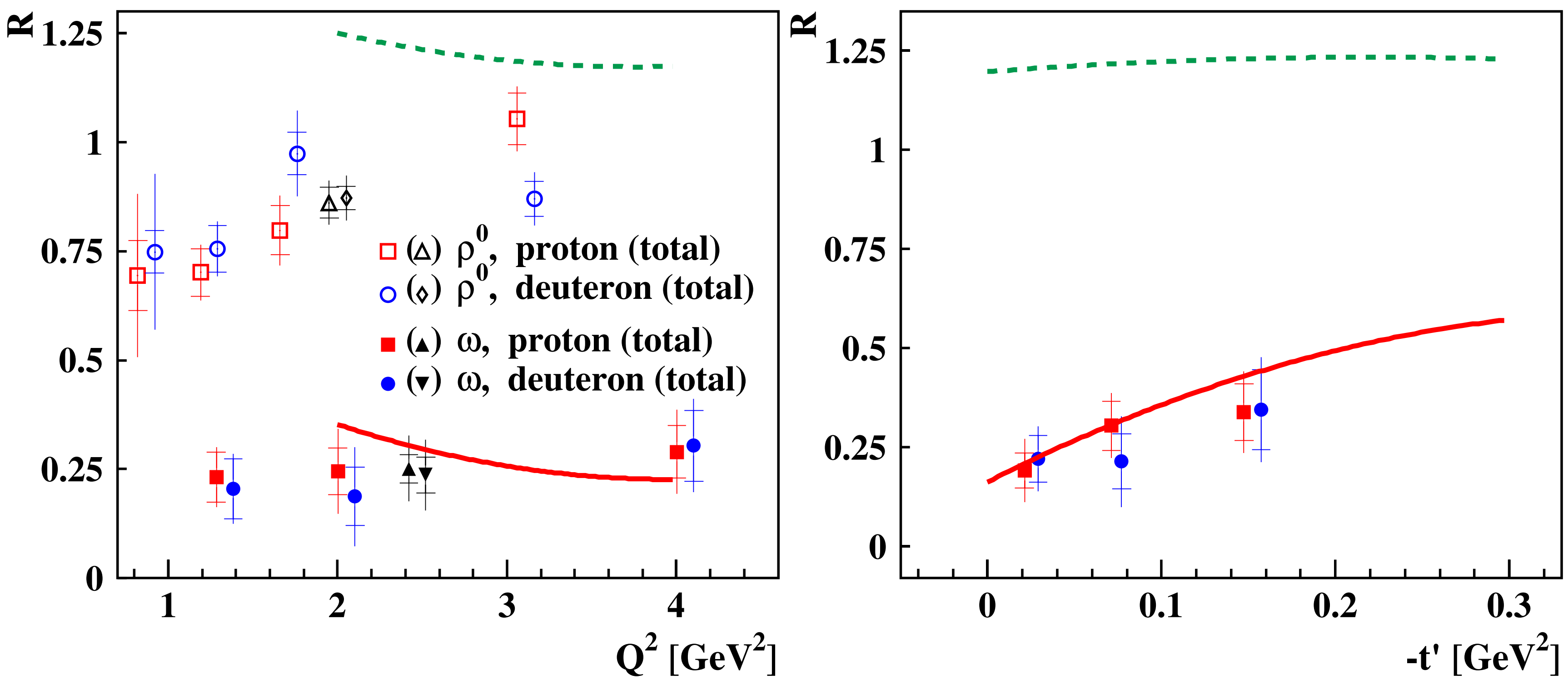
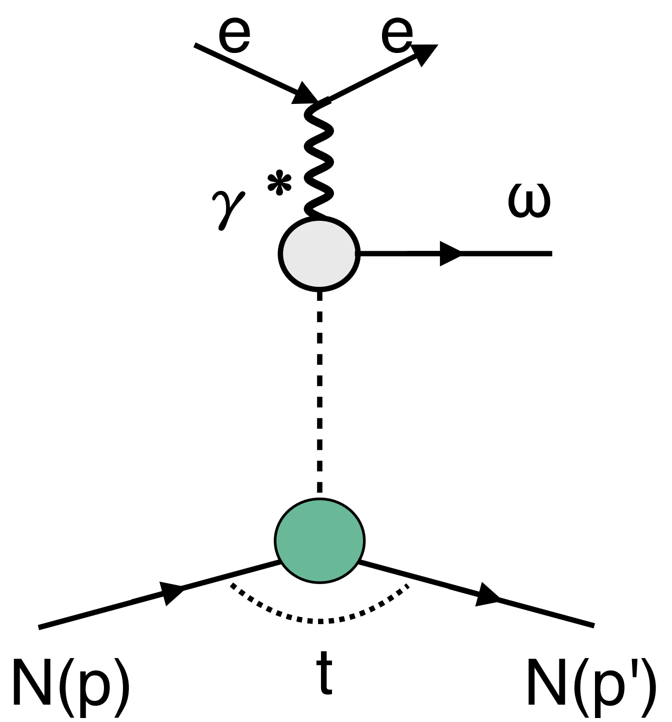


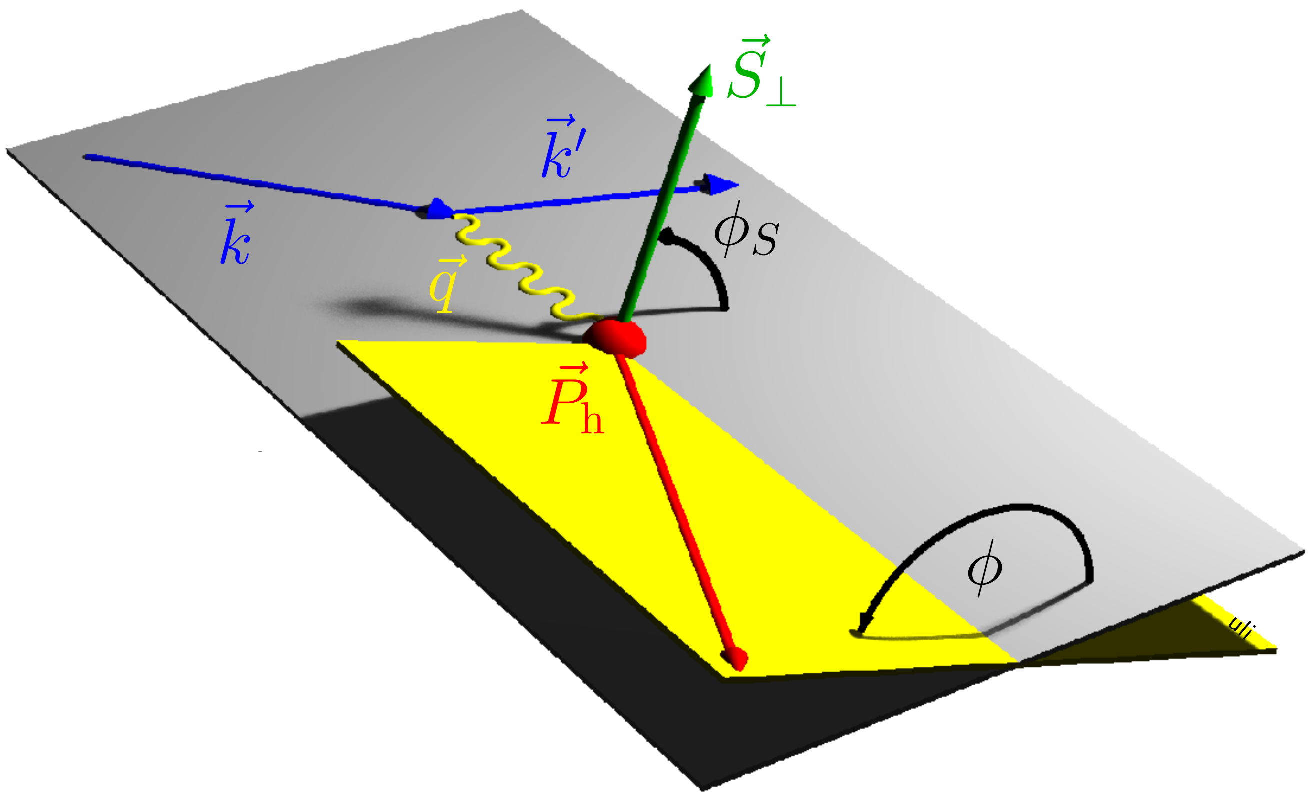
- R(ω) 4 times smaller than R(ρ)
- no pronounced kinematic dependence observed
- need for pion-pole contribution

Transverse-target spin asymmetry in exclusive ω production



- transversely polarized H target
- 279 exclusive-ω events

Transverse target-spin asymmetry A_{UT} in exclusive ω production



$$\mathcal{W}(\phi,\phi_S) = 1 + A_{UU}^{\cos(\phi)}\cos(\phi) + A_{UU}^{\cos(2\phi)}\cos(2\phi)$$
$$+S_\perp\left[A_{UT}^{\sin(\phi+\phi_S)}\sin(\phi+\phi_S) + A_{UT}^{\sin(\phi-\phi_S)}\sin(\phi-\phi_S) + A_{UT}^{\sin(\phi_S)}\sin(\phi_S)\right.$$
$$\left.+\,A_{UT}^{\sin(2\phi-\phi_S)}\sin(2\phi-\phi_S) + A_{UT}^{\sin(3\phi-\phi_S)}\sin(3\phi-\phi_S)\right]$$

Results ω A_{UT}

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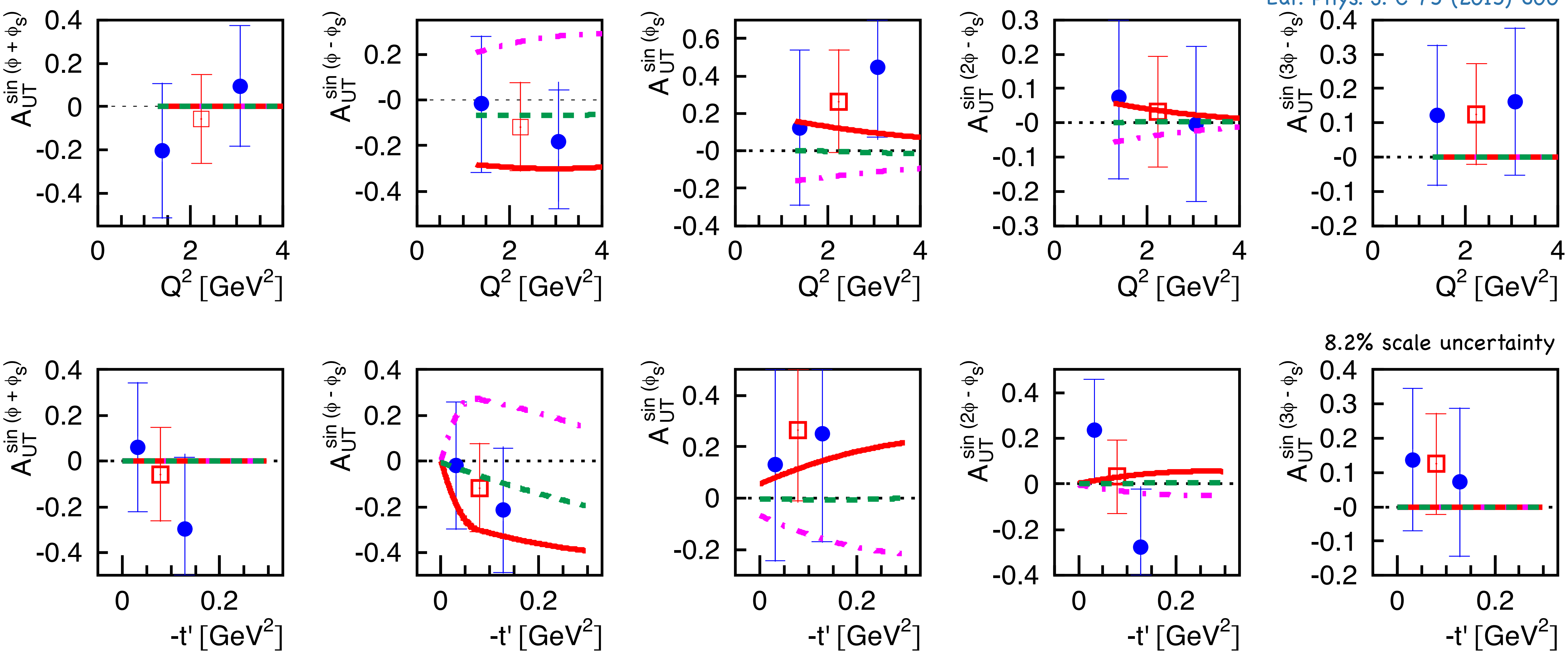
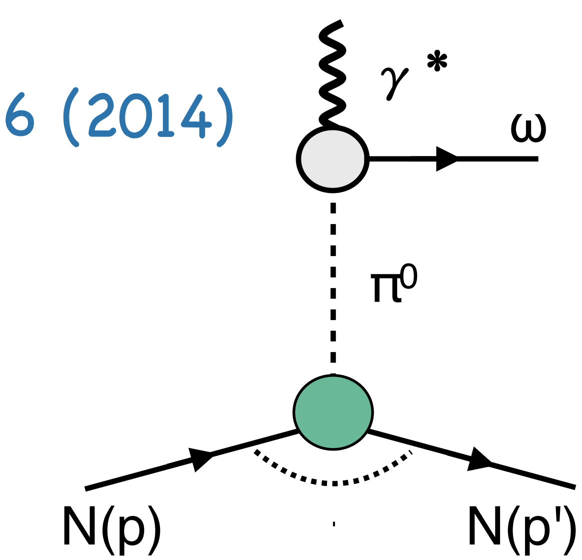


- large unnatural parity exchange seen
- model for protons - S. Goloskokov and P. Kroll, Eur. Phys. J A **50** 146 (2014)
  without pion-pole contribution
  with pion-pole contribution: πω transition FF > 0
  with pion-pole contribution: πω transition FF < 0
  Positive πω transition FF favoured



Results ω A_{UT}: transversely polarized ω

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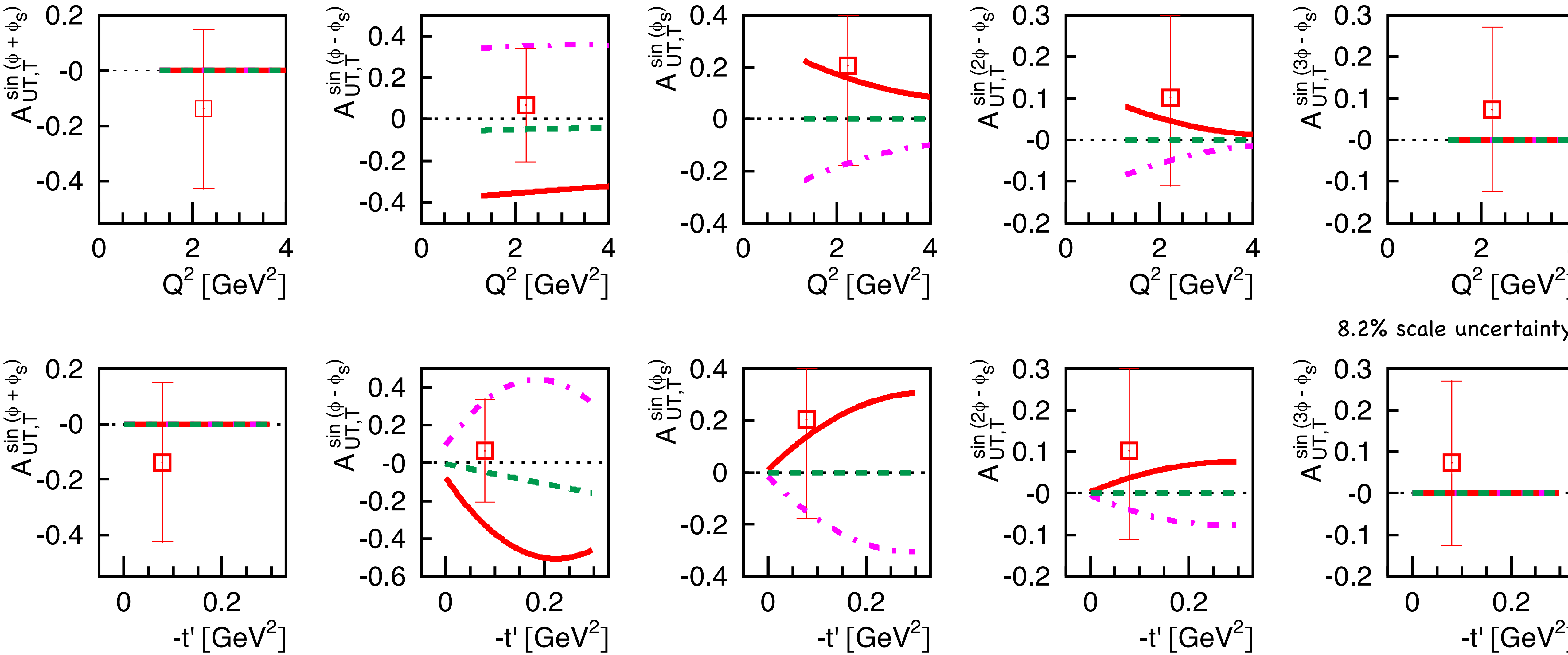

Summary

- ρ^0 helicity amplitude ratios:
  - New: nucleon-helicity-flip amplitudes. They are consistent with zero
  - Good agreement with direct extraction of SDMEs
- ω SDMEs:
  - Large unnatural parity contribution.
  - Importance of pion pole
- ω A_{UT}:
  - positive sign for $\pi\omega$ form factor favoured