Ratios of helicity amplitudes for hard exclusive ρ^0 electroproduction on transversely polarized protons at HERMES

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University of the Basque Country UPV/EHU, Spain

hermes

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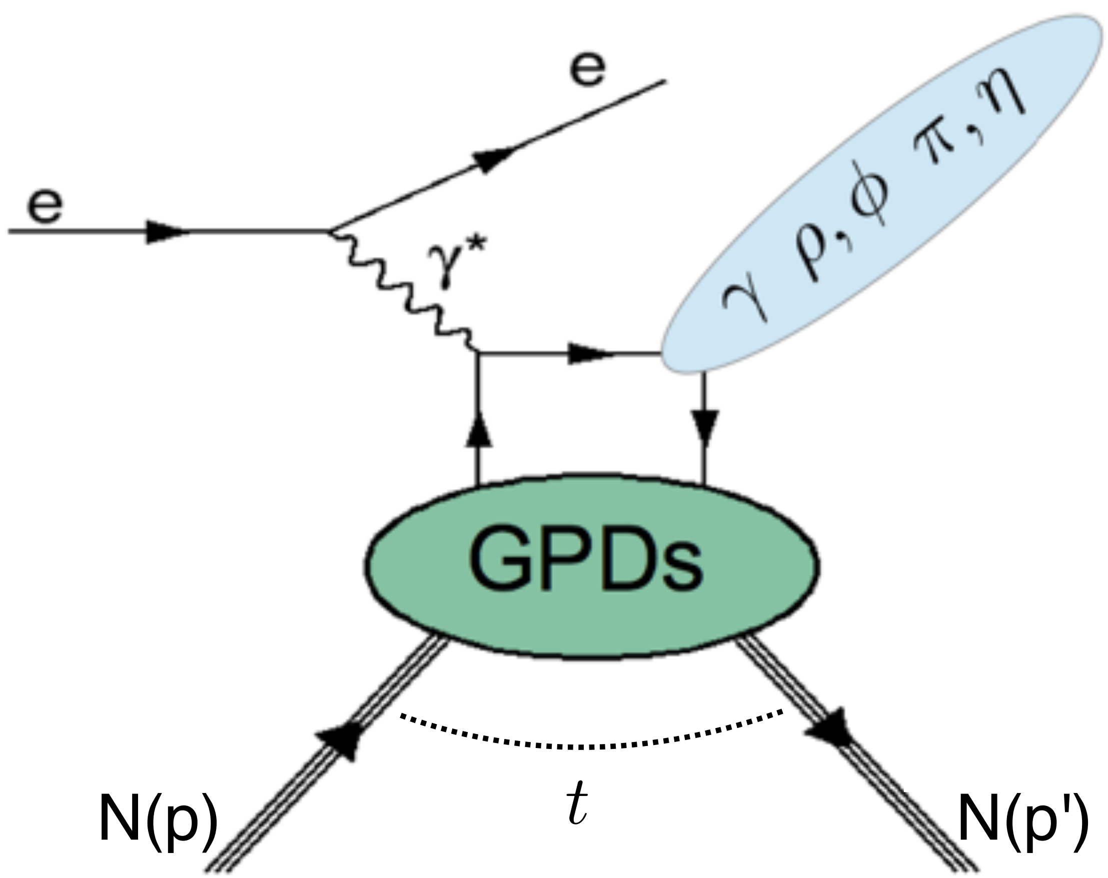
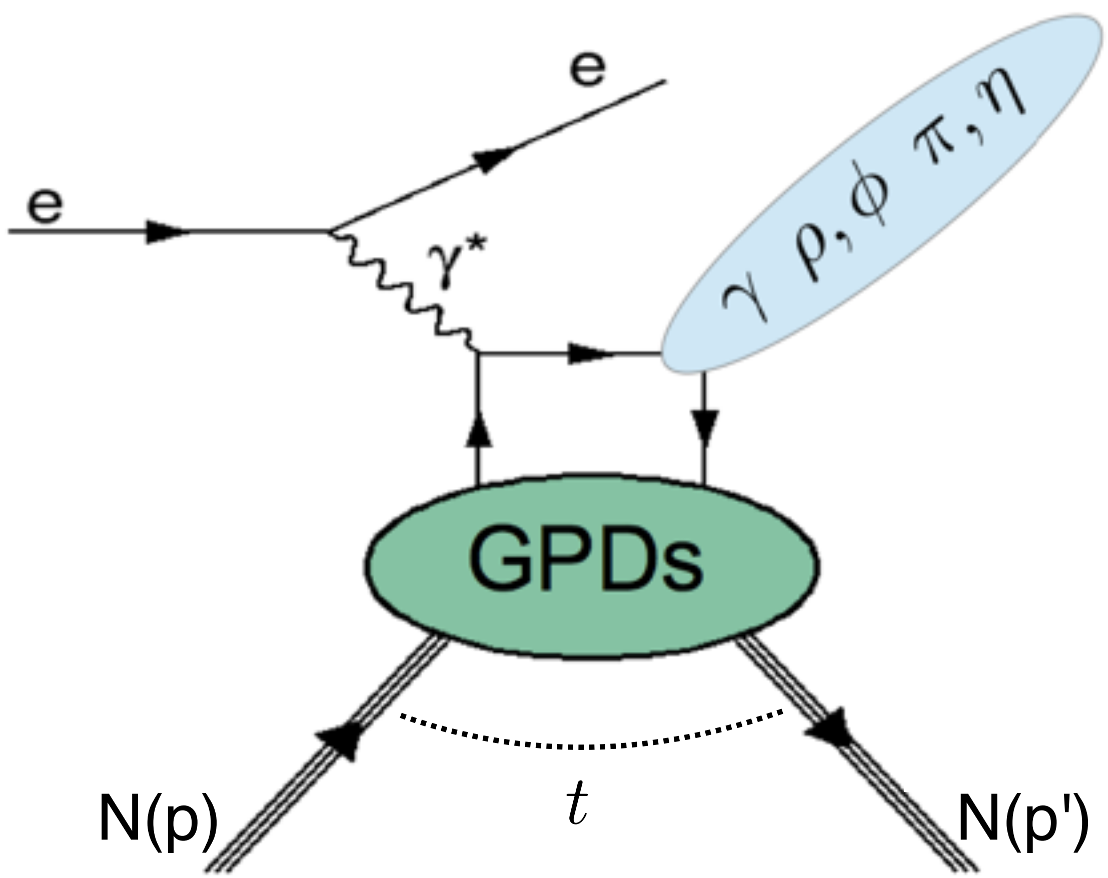
Exclusive ρ^0 production



Exclusive meson production

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

Exclusive ρ^0 production



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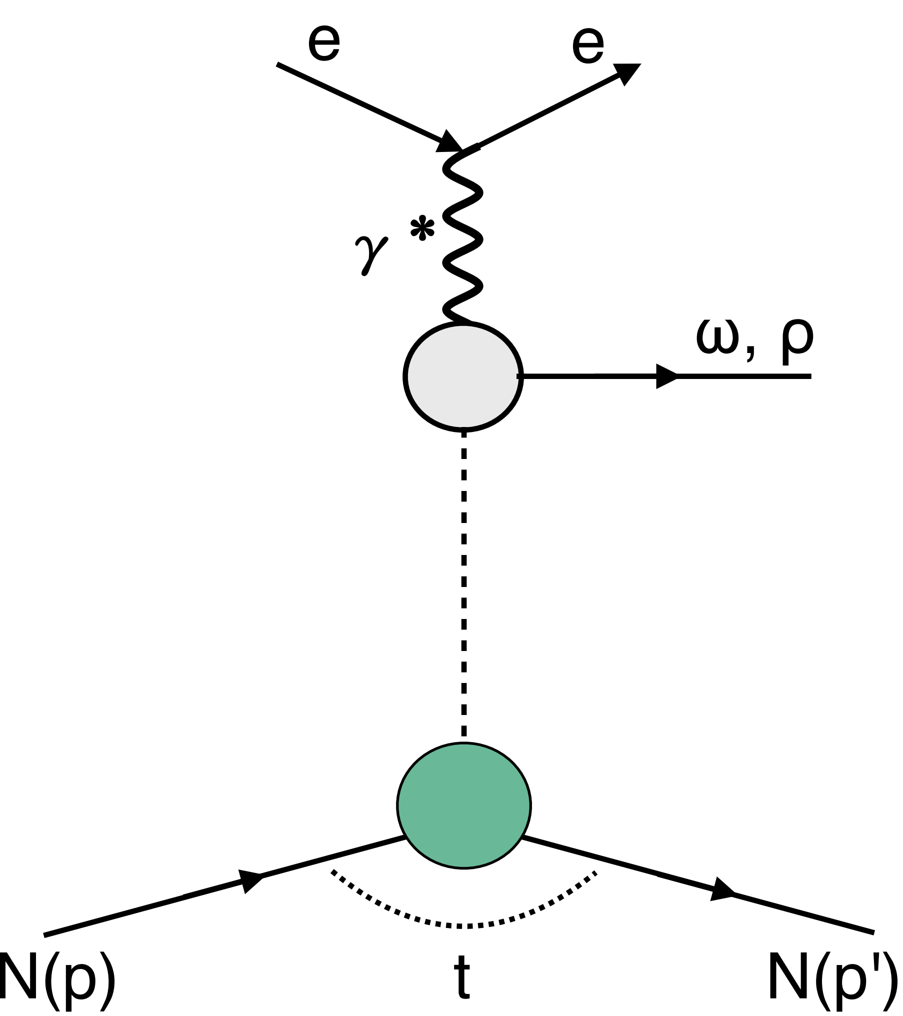
Target polarization state

- unpolarized target: nucleon-helicity-non-flip GPDs H, $\tilde{H}$ and $\bar{E}_T = 2\tilde{H}_T + E_T$.
- transversely polarized target: nucleon-helicity-flip GPDs E, $\tilde{E}$ and H_T.

Exclusive ρ^0 production



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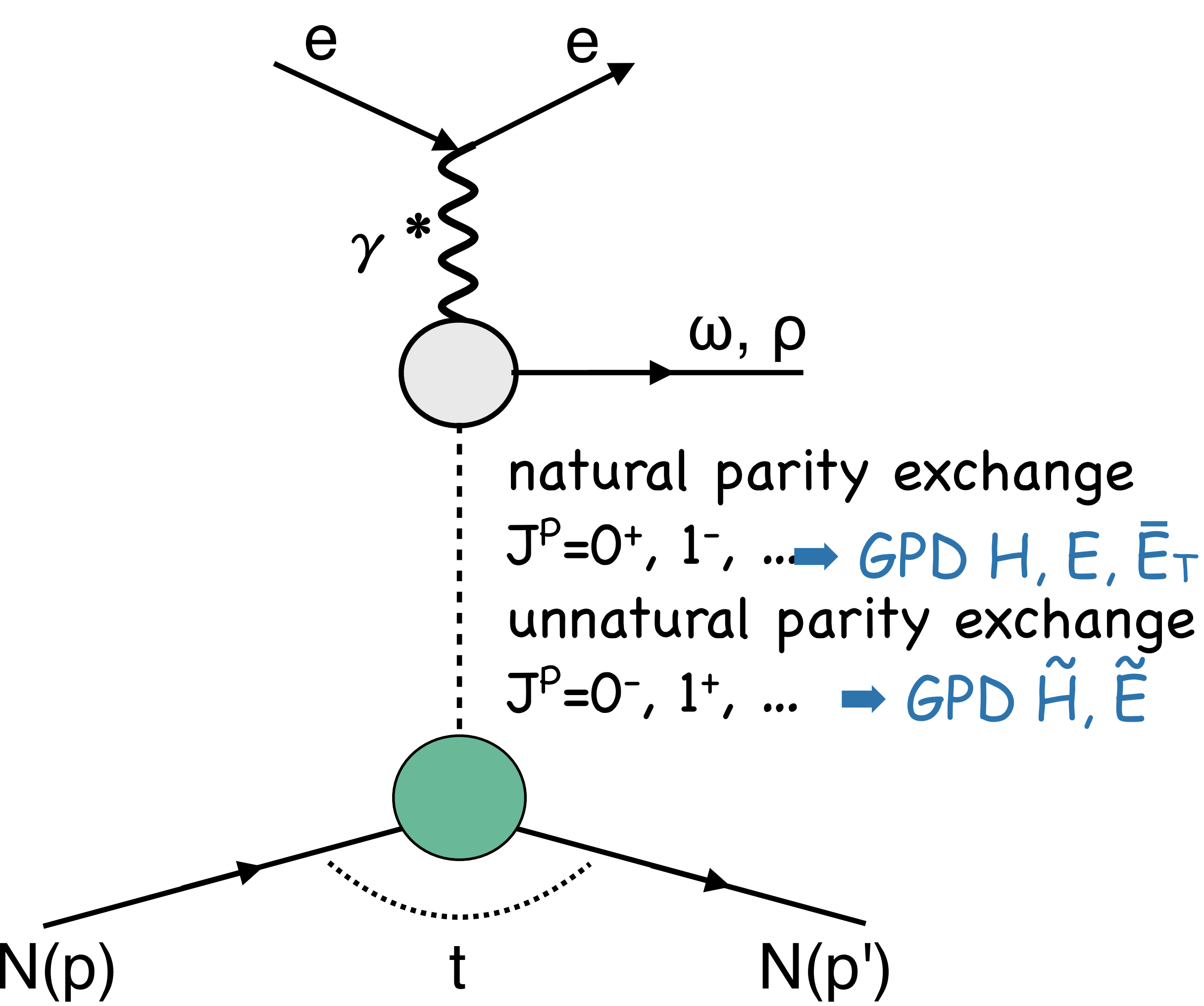

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Exclusive ρ^0 production: angular distribution

$$\vec{e} + p^{\uparrow} \rightarrow e + p + \rho^0$$

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$$\vec{e} + p^{\uparrow} \to e + p + \rho^0$$

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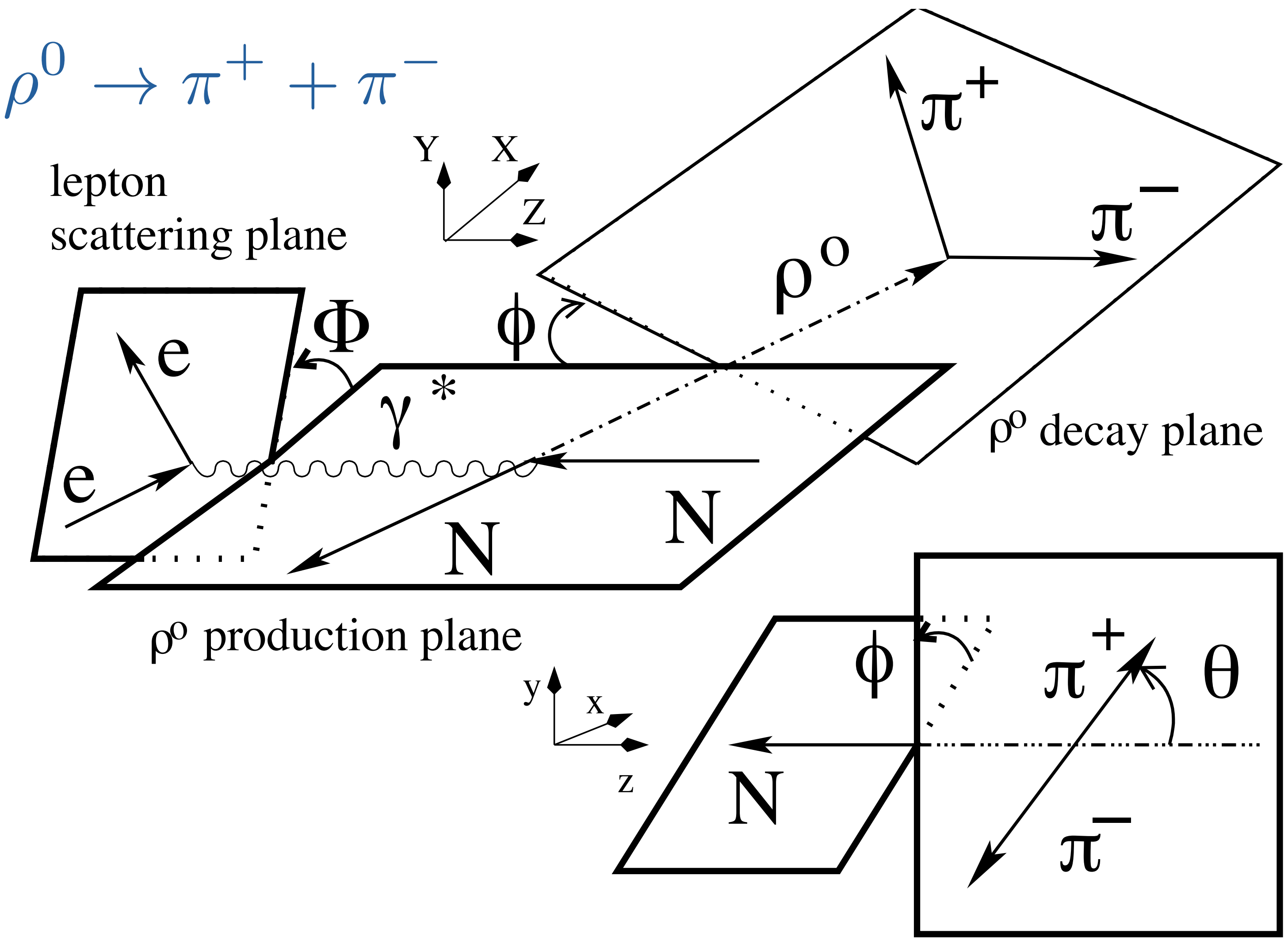

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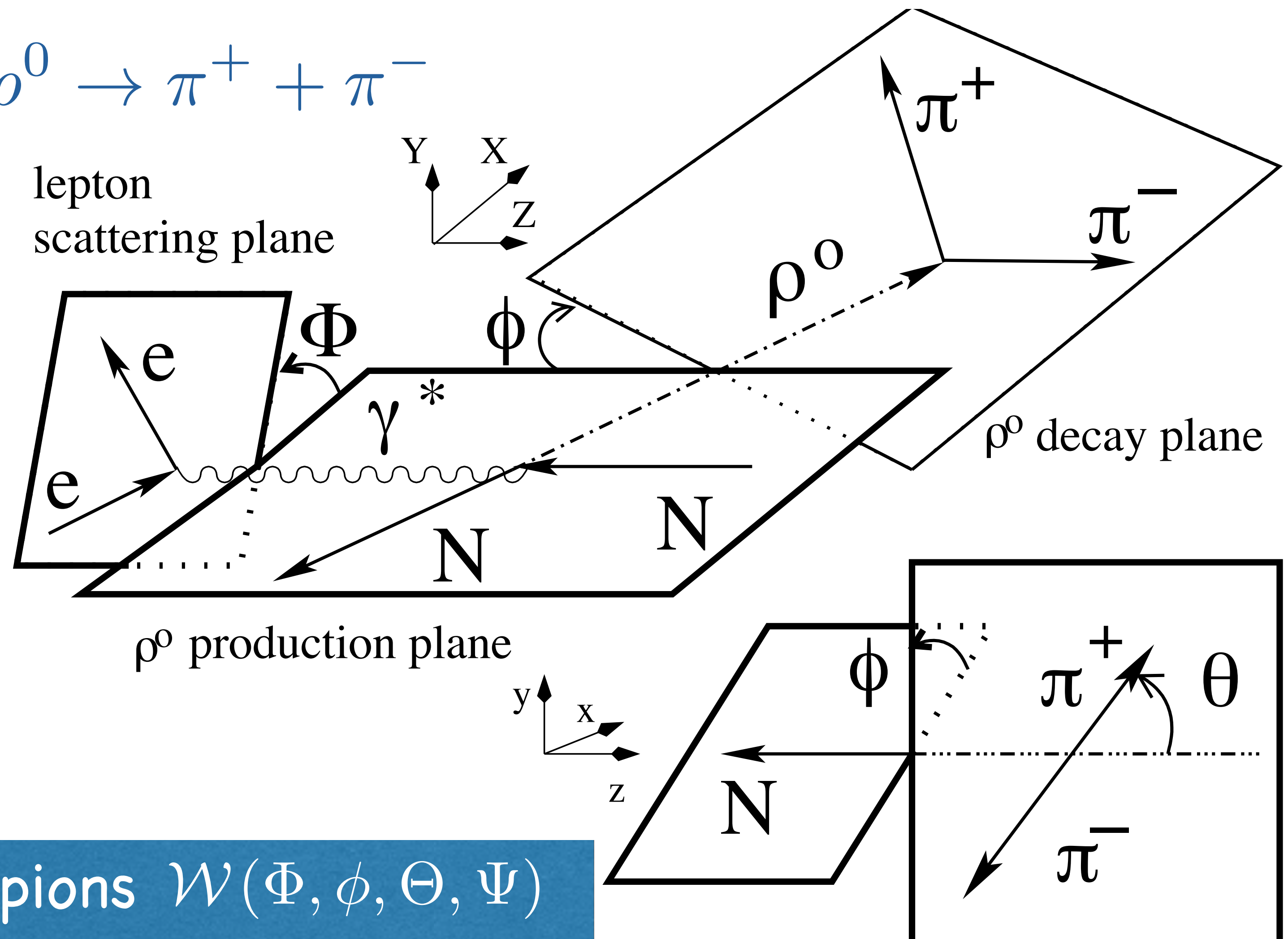


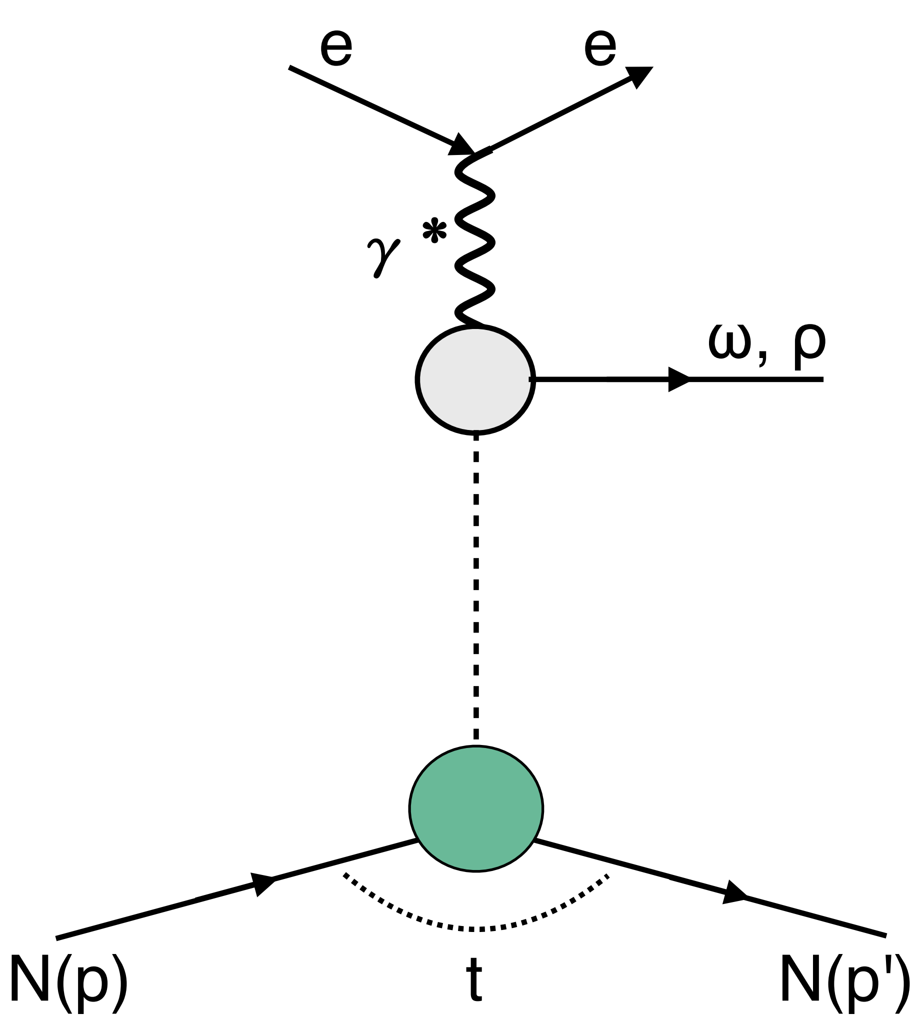
Fit angular distribution of decay pions $\mathcal{W}(\Phi, \phi, \Theta, \Psi)$

- Spin Density Matrix Elements (SDMEs)

or

- helicity amplitude ratios

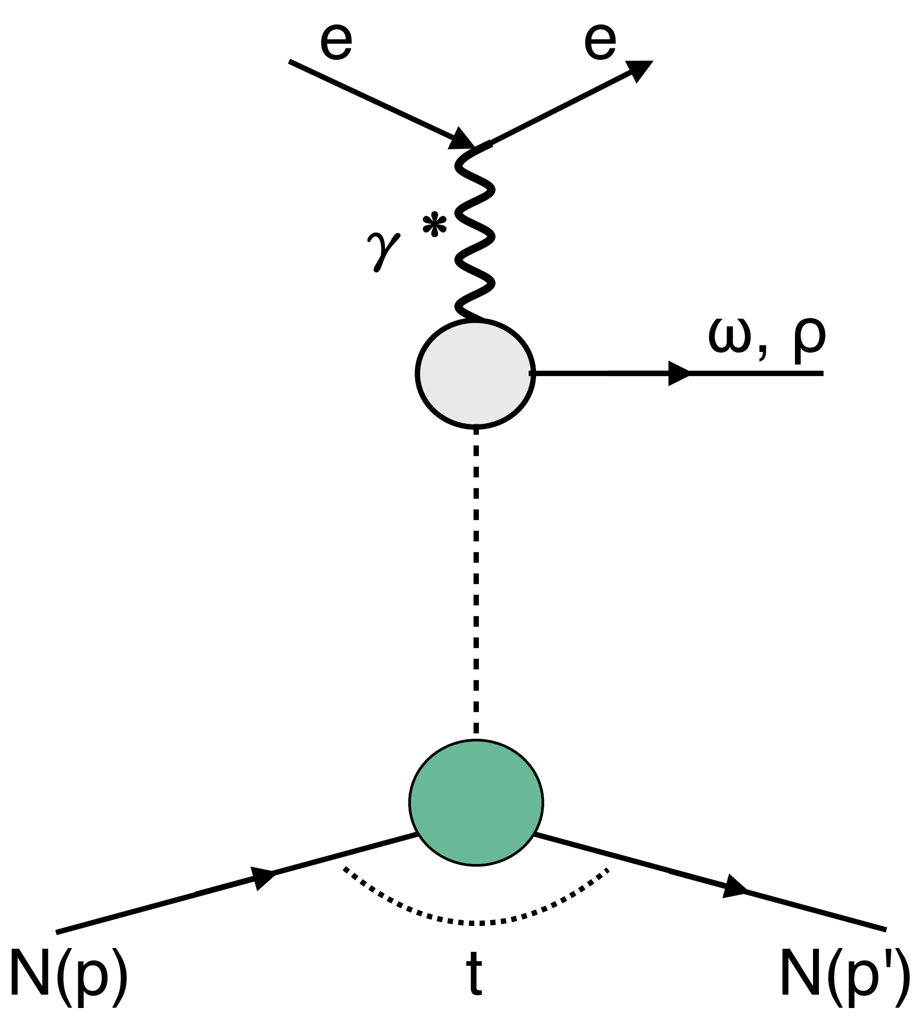
Helicity amplitude ratios and SDMEs



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

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

Helicity amplitude ratios and SDMEs



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

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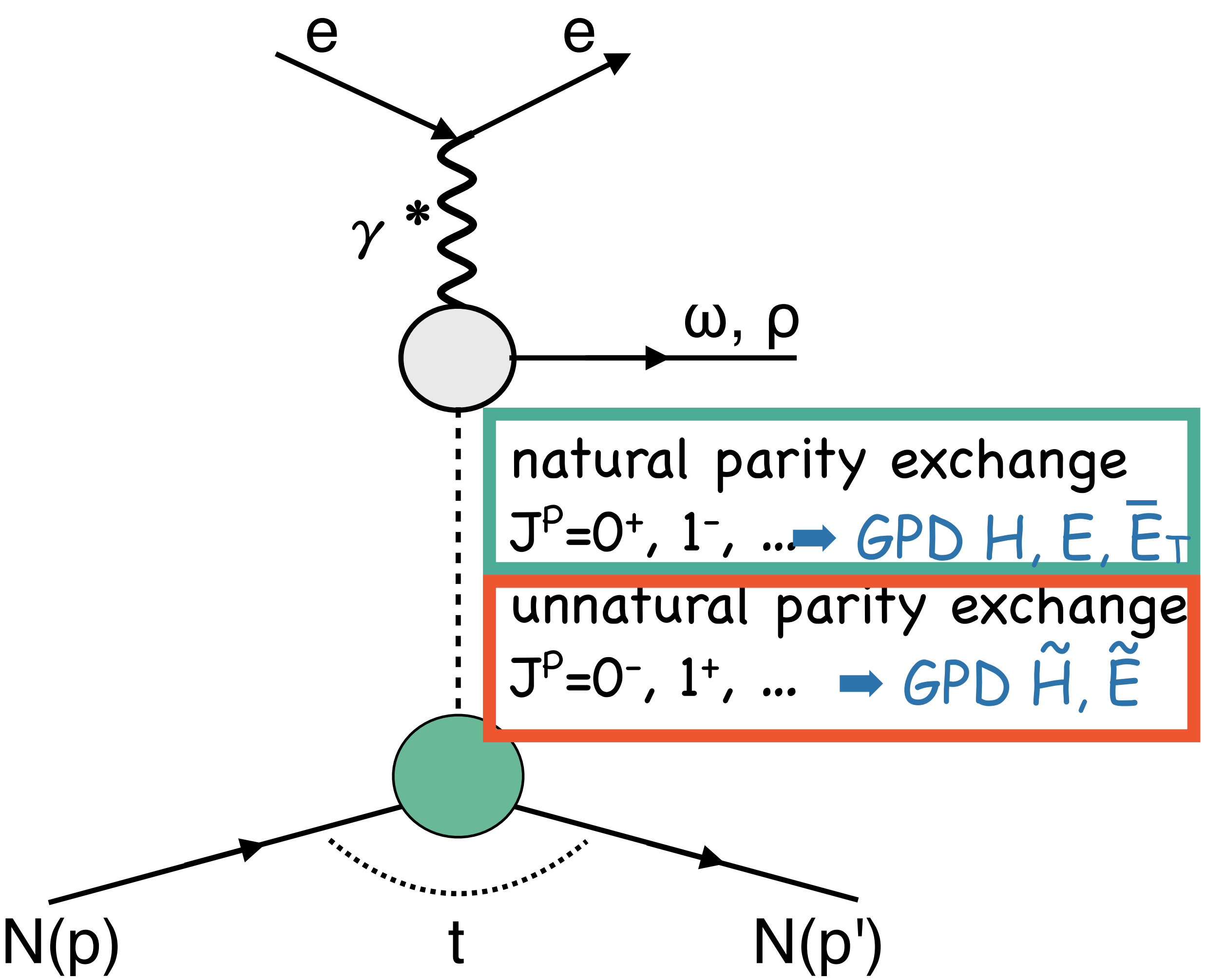

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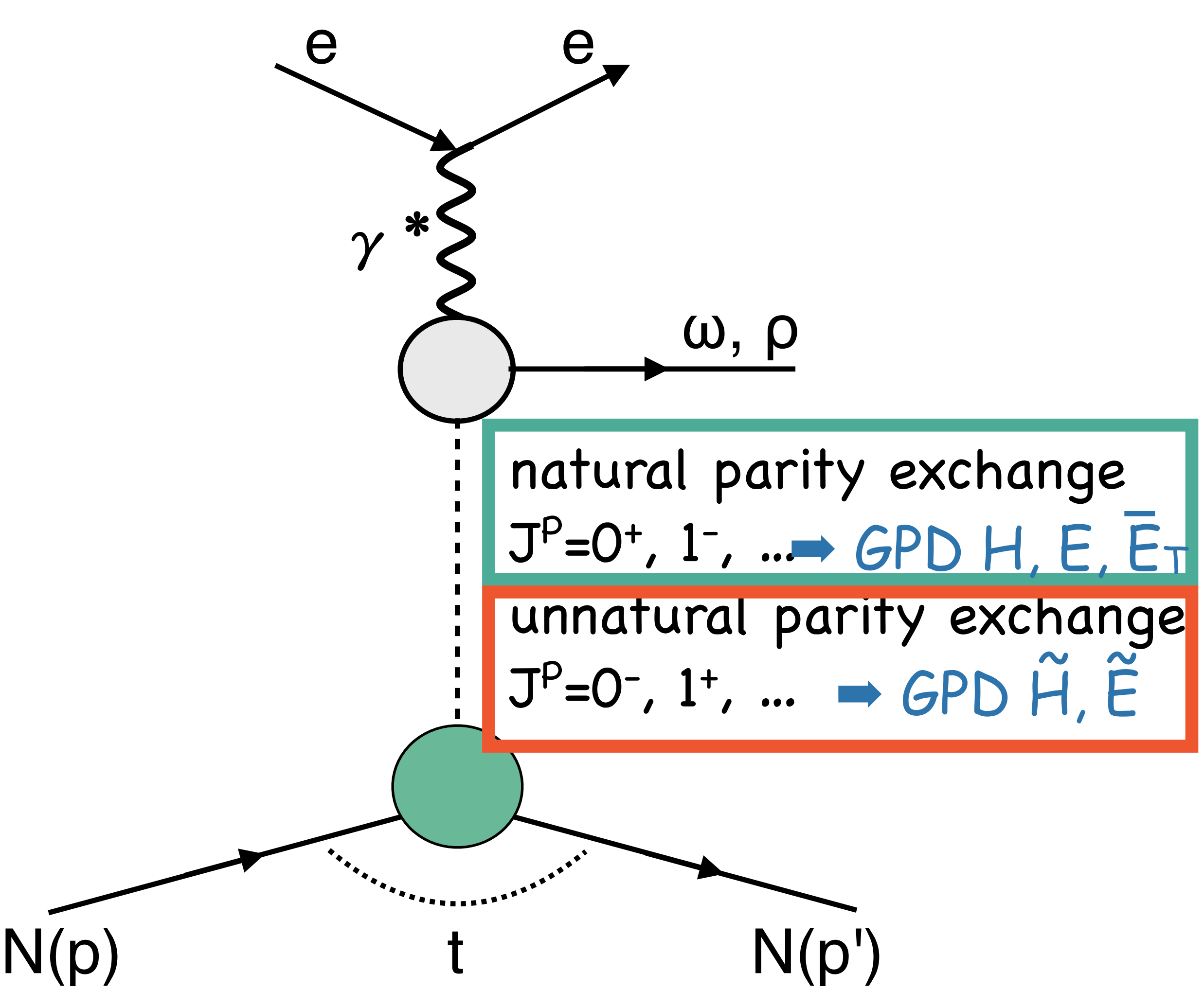
T: natural parity amplitude

U: unnatural parity amplitude

Helicity amplitude ratios and SDMEs



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T: natural parity amplitude

U: unnatural parity amplitude

- Helicity amplitude ratios

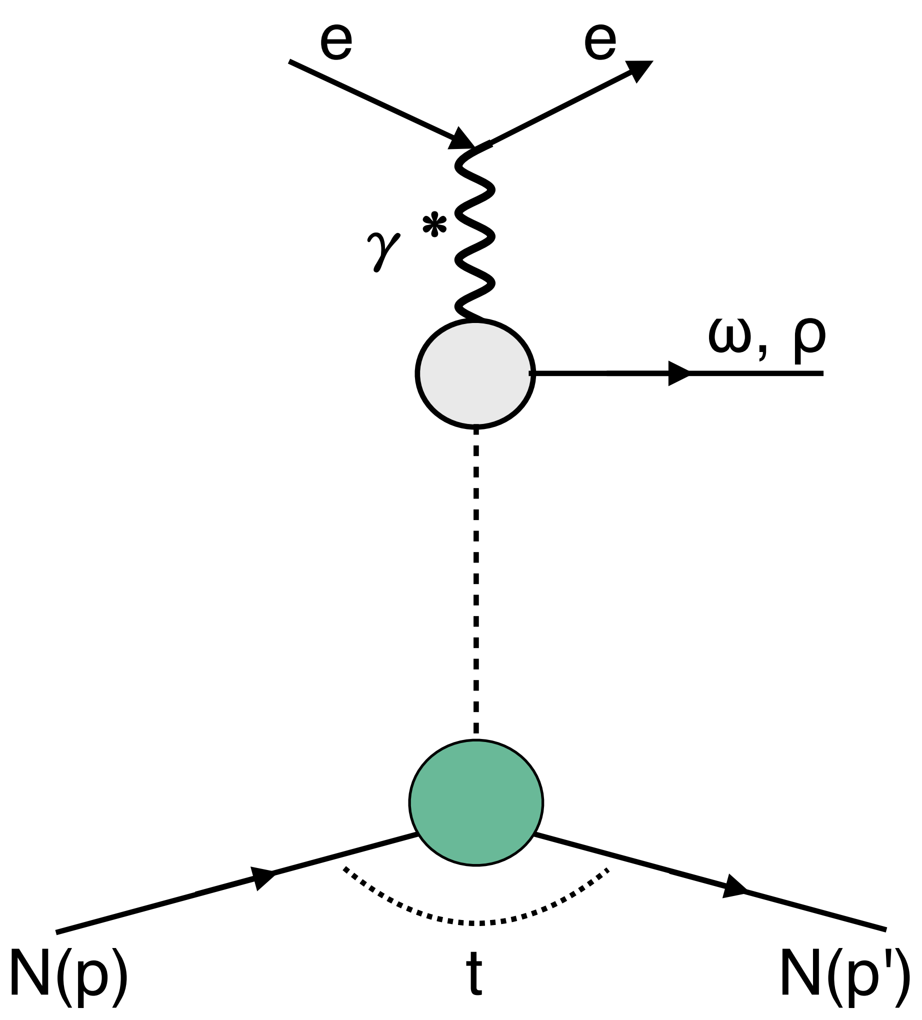
$$t^{(n)}_{\lambda_V \lambda_\gamma} = T^{(n)}_{\lambda_V \lambda_\gamma} / T_{0\frac{1}{2}0\frac{1}{2}}$$

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

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

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

Helicity amplitude ratios and SDMEs



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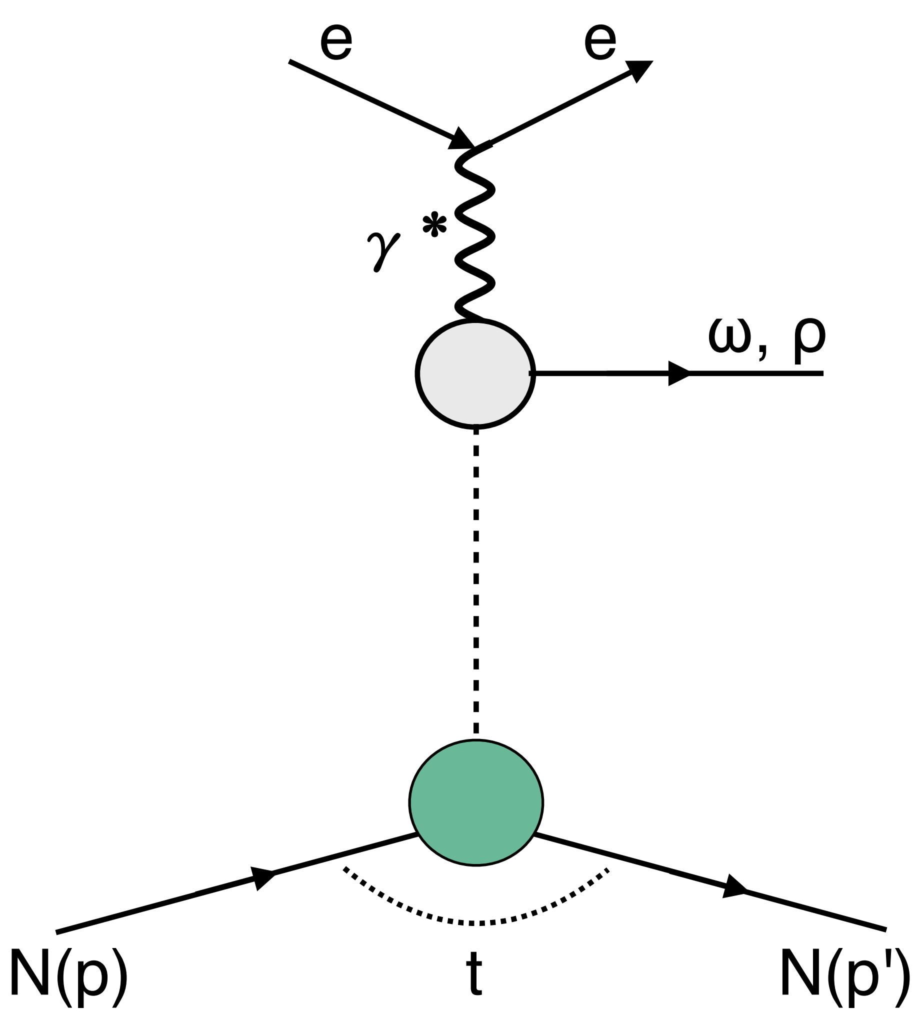
Helicity amplitude ratios and SDMEs

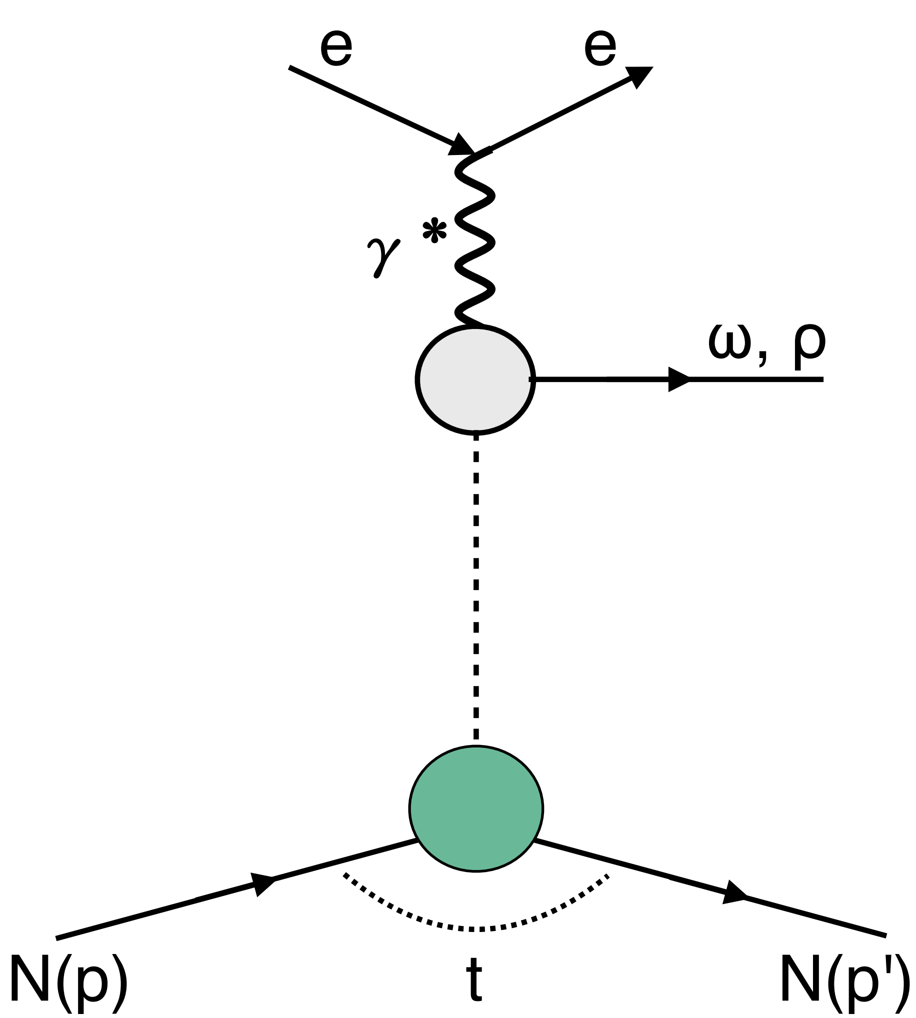


$$\gamma^*(\lambda_\gamma) + N(\lambda_N) \to V(\lambda_V) + N(\lambda'_N)$$

- 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 $s^{\lambda_V \lambda'_V}_{\lambda_\gamma \lambda'_\gamma}$

Extraction of helicity amplitude ratios for exclusive ρ⁰

$$\vec{e} + p^{\uparrow} \rightarrow e + p + \rho^0$$

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

- transversely polarized H target
- longitudinally polarized $e^{\pm}$

Extraction of helicity amplitude ratios for exclusive ρ^0

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- longitudinally polarized $e^{\pm}$
- 8741 hard exclusive ρ events

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$$3.0\ \mathrm{GeV} \leq W \leq 6.3\ \mathrm{GeV}$$
$$1.0\ \mathrm{GeV}^2 \leq Q^2 \leq 7.0\ \mathrm{GeV}^2$$
$$0.0\ \mathrm{GeV}^2 \leq -t' \leq 0.4\ \mathrm{GeV}^2$$

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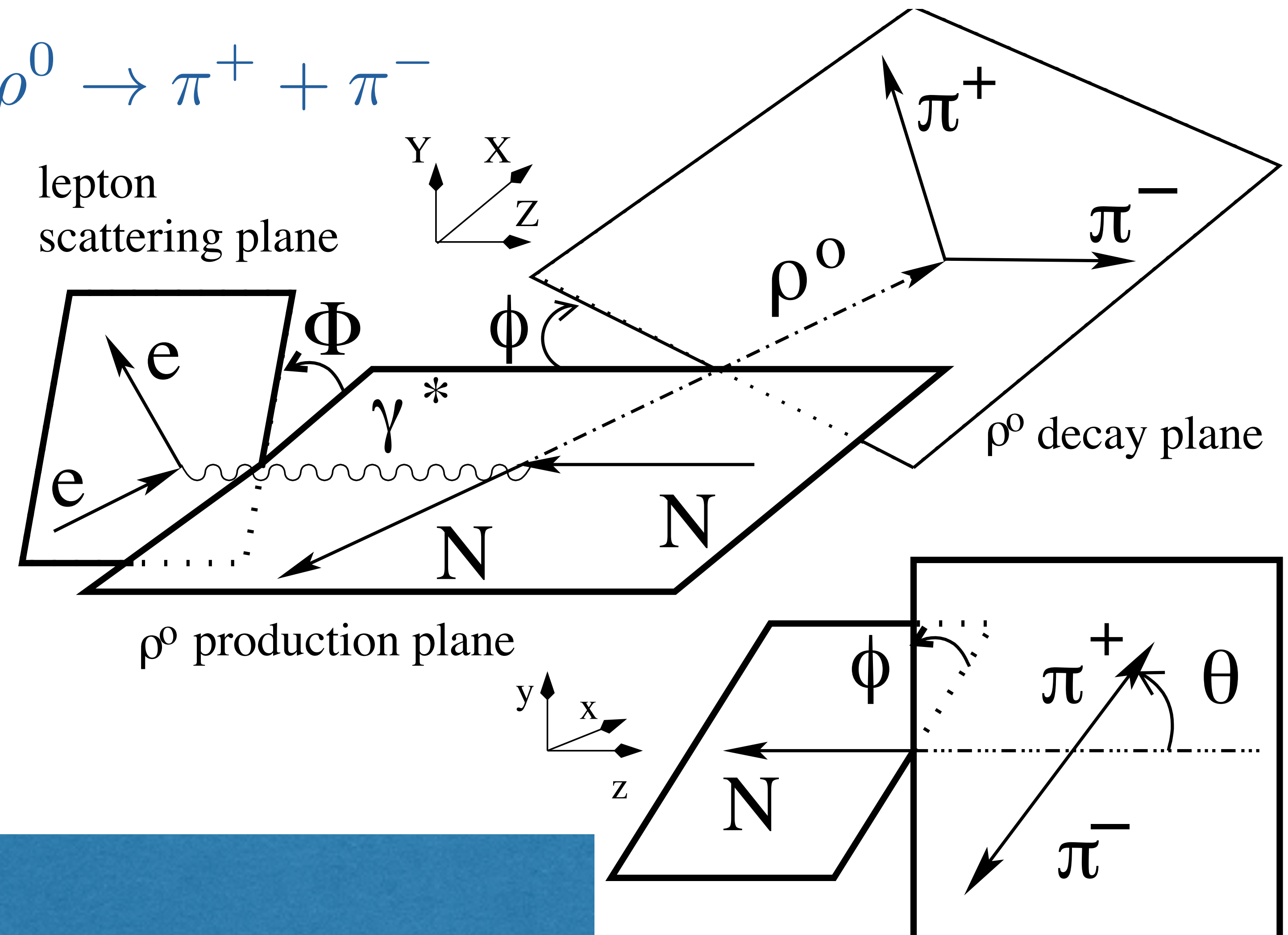


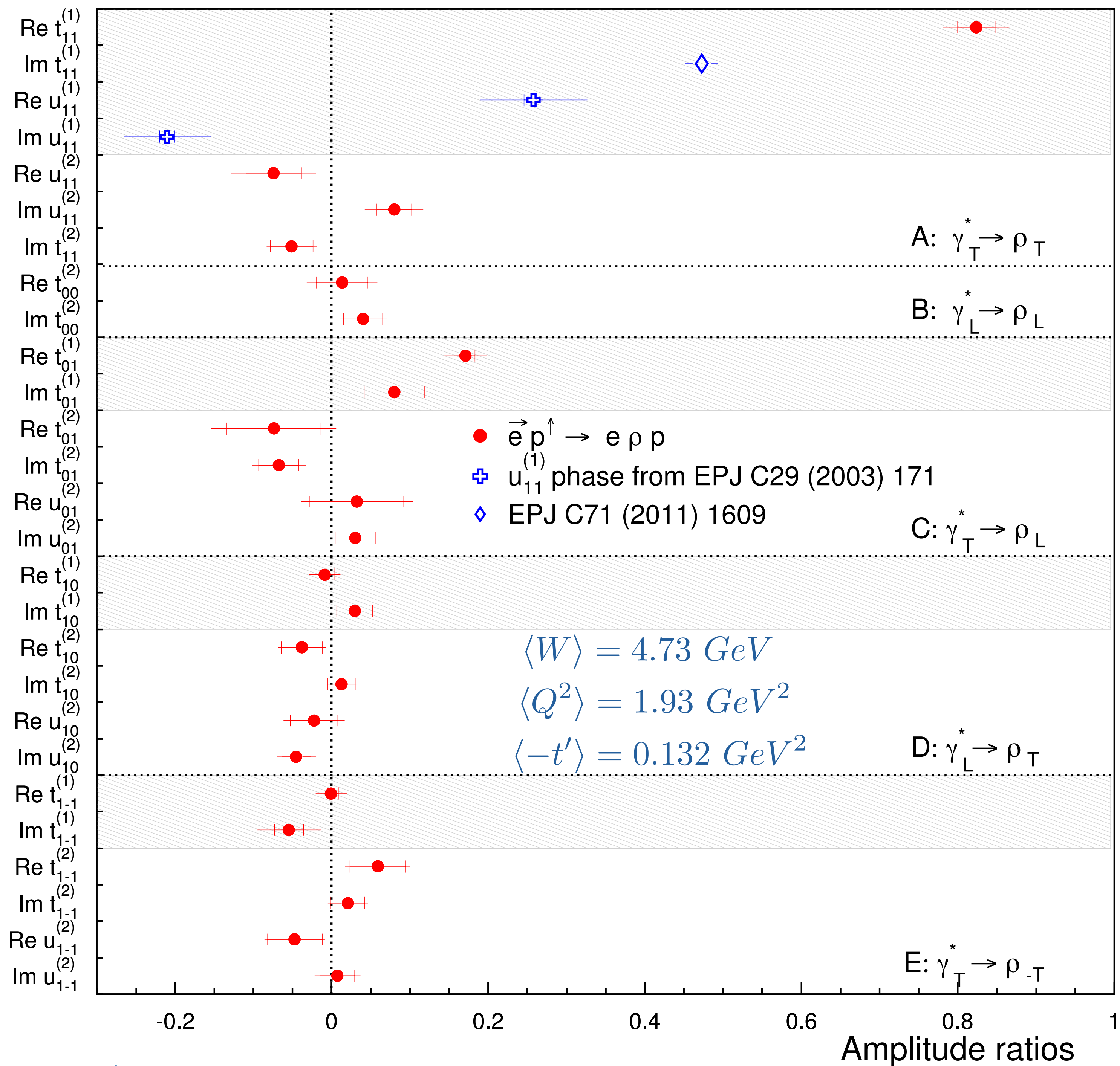
Fit angular distribution of decay pions $\mathcal{W}(\Phi,\phi,\Theta,\Psi)$ extract 25 parameters. Use 4x3 cells in (Q^2,-t').

Parametrisation of helicity amplitudes

Parametrization	value of parameter	statistical uncertainty	total uncertainty
$\mathrm{Re}\{t_{11}^{(1)}\} = b_1/Q$	$b_1 = 1.145$ GeV	0.033 GeV	0.081 GeV
$\lvert u_{11}^{(1)}\rvert = b_2$	$b_2 = 0.333$	0.016	0.088
$\mathrm{Re}\{u_{11}^{(2)}\} = b_3$	$b_3 = -0.074$	0.036	0.054
$\mathrm{Im}\{u_{11}^{(2)}\} = b_4$	$b_4 = 0.080$	0.022	0.037
$\xi = b_5$	$b_5 = -0.055$	0.027	0.029
$\zeta = b_6$	$b_6 = -0.013$	0.033	0.044
$\mathrm{Im}\{t_{00}^{(2)}\} = b_7$	$b_7 = 0.040$	0.025	0.030
$\mathrm{Re}\{t_{01}^{(1)}\} = b_8\sqrt{-t'}$	$b_8 = 0.471$ GeV^{-1}	0.033 GeV^{-1}	0.075 GeV^{-1}
$\mathrm{Im}\{t_{01}^{(1)}\} = b_9\frac{\sqrt{-t'}}{Q}$	$b_9 = 0.307$	0.148	0.354
$\mathrm{Re}\{t_{01}^{(2)}\} = b_{10}$	$b_{10} = -0.074$	0.060	0.080
$\mathrm{Im}\{t_{01}^{(2)}\} = b_{11}$	$b_{11} = -0.067$	0.026	0.036
$\mathrm{Re}\{u_{01}^{(2)}\} = b_{12}$	$b_{12} = 0.032$	0.060	0.072
$\mathrm{Im}\{u_{01}^{(2)}\} = b_{13}$	$b_{13} = 0.030$	0.026	0.033
$\mathrm{Re}\{t_{10}^{(1)}\} = b_{14}\sqrt{-t'}$	$b_{14} = -0.025$ GeV^{-1}	0.034 GeV^{-1}	0.063 GeV^{-1}
$\mathrm{Im}\{t_{10}^{(1)}\} = b_{15}\sqrt{-t'}$	$b_{15} = 0.080$ GeV^{-1}	0.063 GeV^{-1}	0.118 GeV^{-1}
$\mathrm{Re}\{t_{10}^{(2)}\} = b_{16}$	$b_{16} = -0.038$	0.026	0.030
$\mathrm{Im}\{t_{10}^{(2)}\} = b_{17}$	$b_{17} = 0.012$	0.018	0.019
$\mathrm{Re}\{u_{10}^{(2)}\} = b_{18}$	$b_{18} = -0.023$	0.030	0.039
$\mathrm{Im}\{u_{10}^{(2)}\} = b_{19}$	$b_{19} = -0.045$	0.018	0.026
$\mathrm{Re}\{t_{1-1}^{(1)}\} = b_{20}\frac{(-t')}{Q}$	$b_{20} = -0.008$ GeV^{-1}	0.096 GeV^{-1}	0.212 GeV^{-1}
$\mathrm{Im}\{t_{1-1}^{(1)}\} = b_{21}\frac{(-t')}{Q}$	$b_{21} = -0.577$ GeV^{-1}	0.196 GeV^{-1}	0.428 GeV^{-1}
$\mathrm{Re}\{t_{1-1}^{(2)}\} = b_{22}$	$b_{22} = 0.059$	0.036	0.047
$\mathrm{Im}\{t_{1-1}^{(2)}\} = b_{23}$	$b_{23} = 0.020$	0.022	0.026
$\mathrm{Re}\{u_{1-1}^{(2)}\} = b_{24}$	$b_{24} = -0.047$	0.035	0.039
$\mathrm{Im}\{u_{1-1}^{(2)}\} = b_{25}$	$b_{25} = 0.007$	0.022	0.029

Results helicity ρ^0 amplitude ratios

arXiv:1702.00345



8% uncertainty target polarization

2% uncertainty beam polarization

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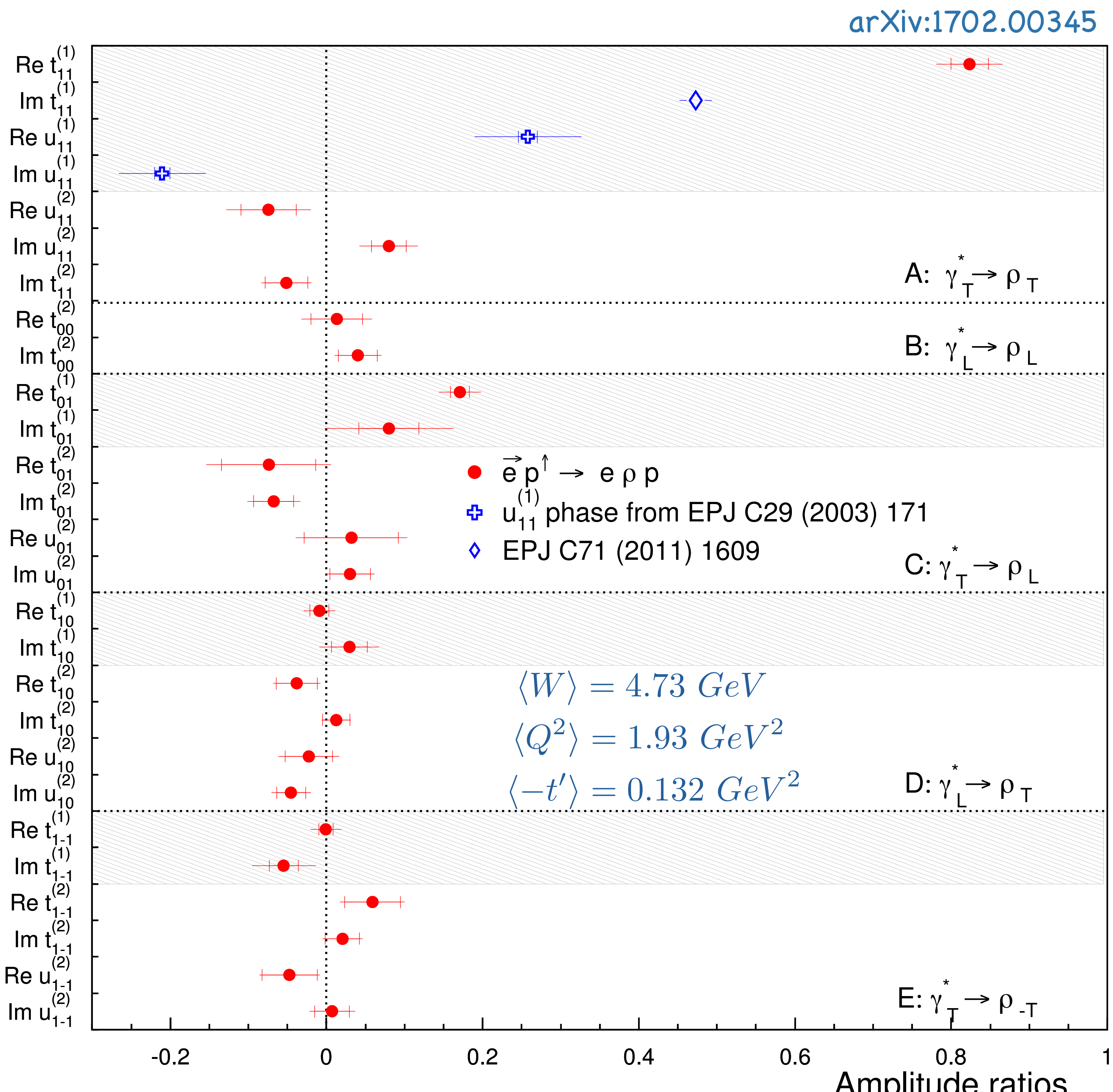

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already obtained in EPJ C71 (2011) 1609

extracted for first time

- 5 classes of helicity amplitude ratios

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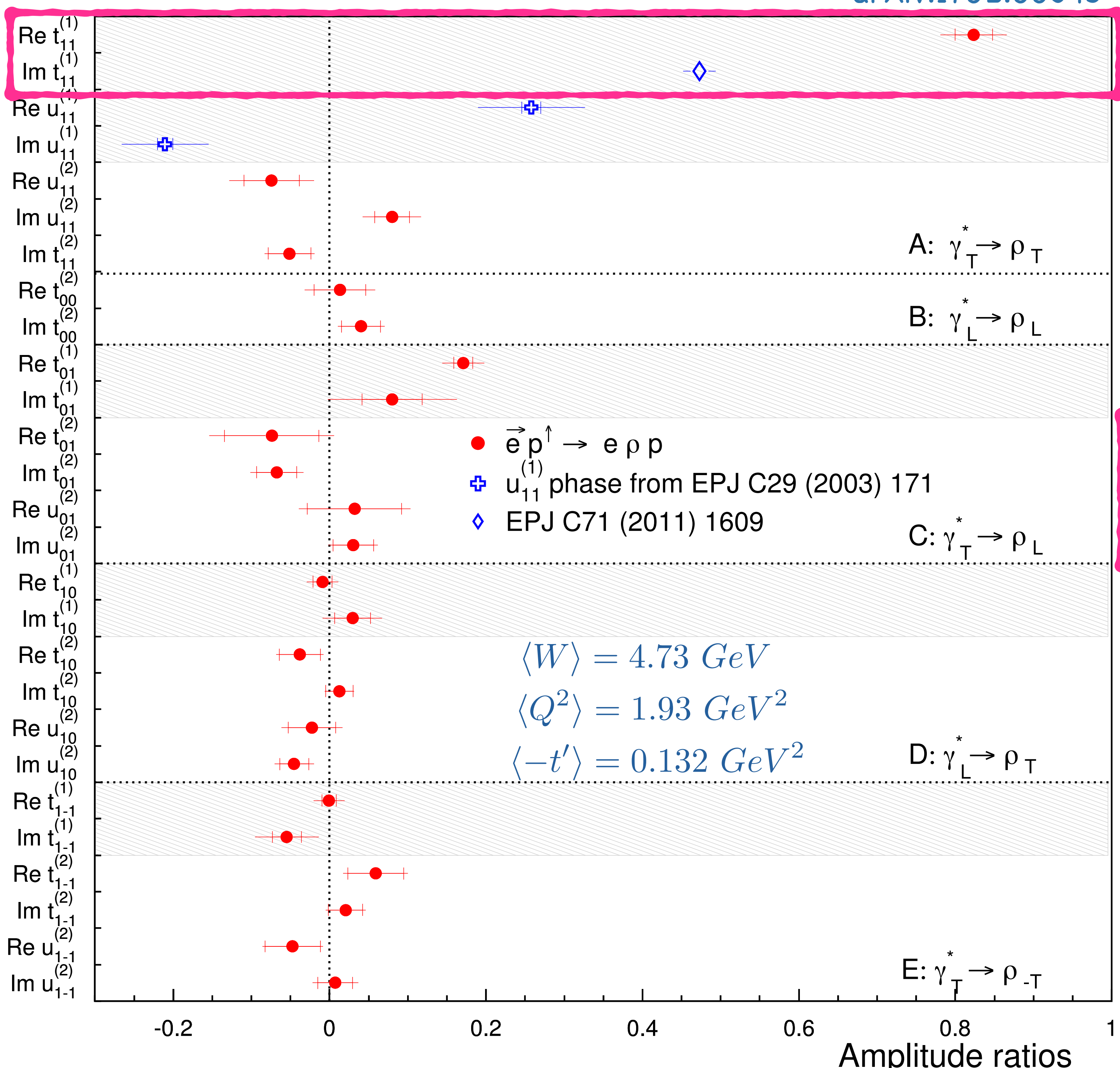

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- dominant amplitude: natural parity nucleon-helicity non-flip $t_{11}^{(1)}$ (≠0 by >5σ)

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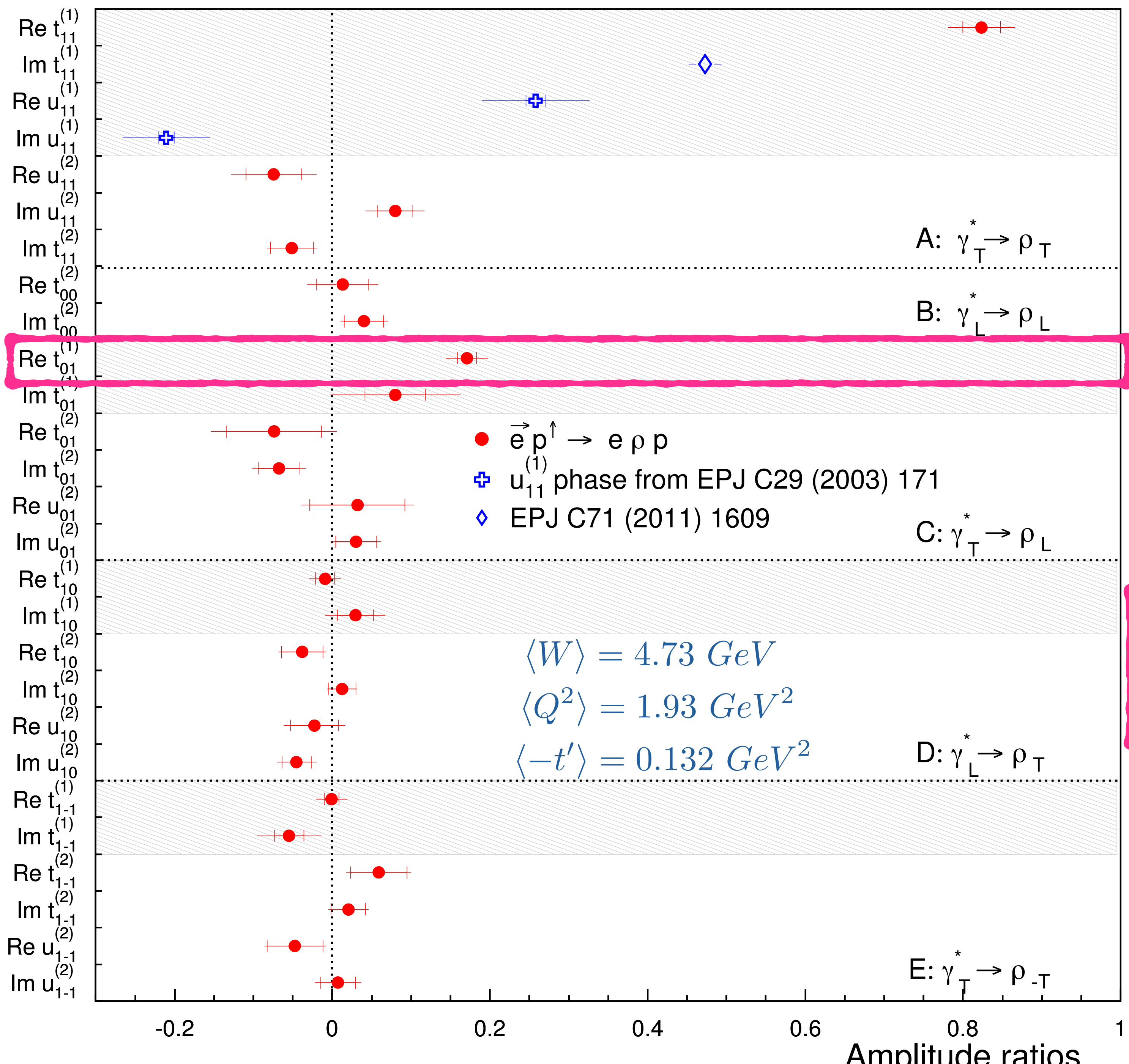

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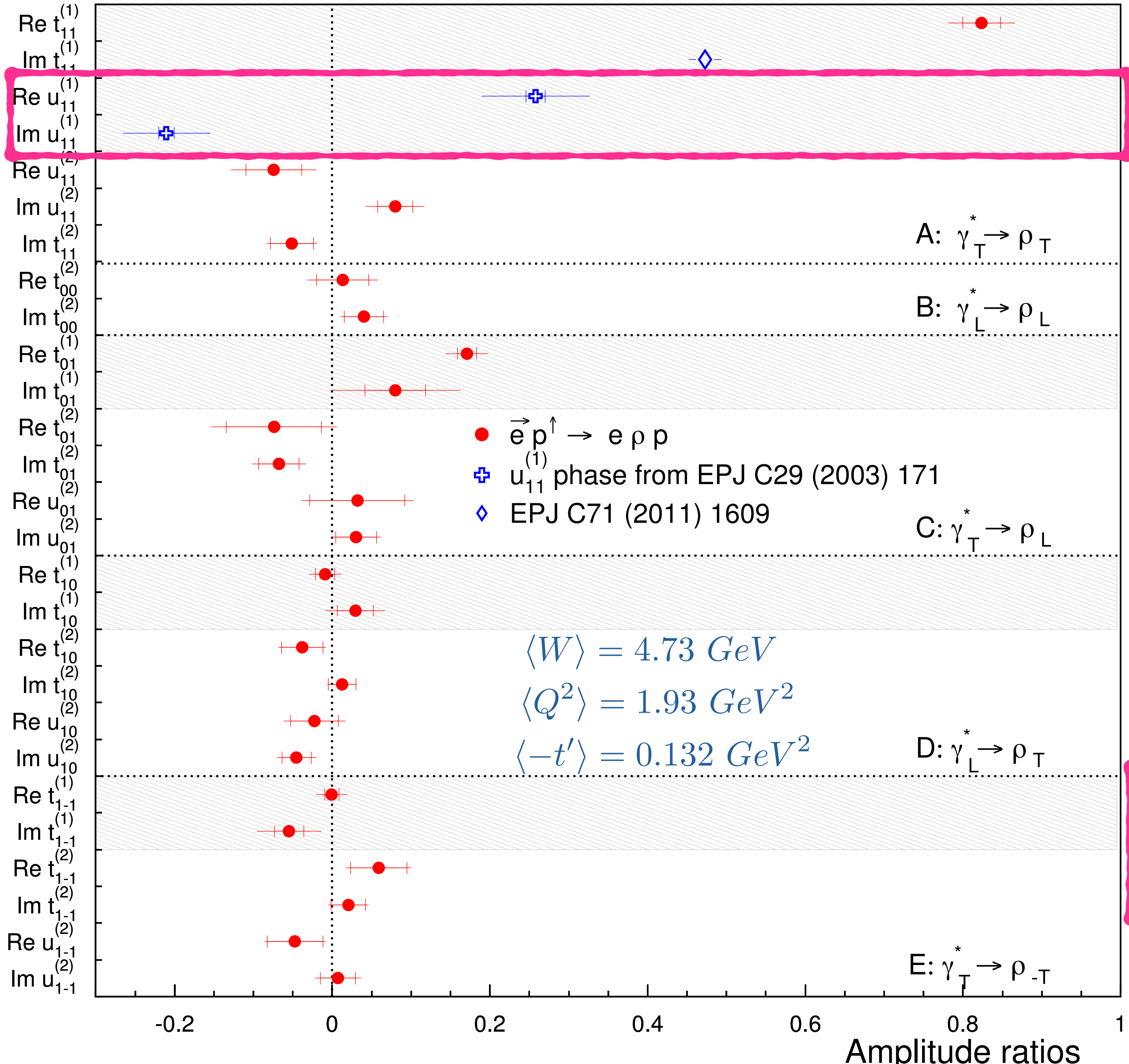

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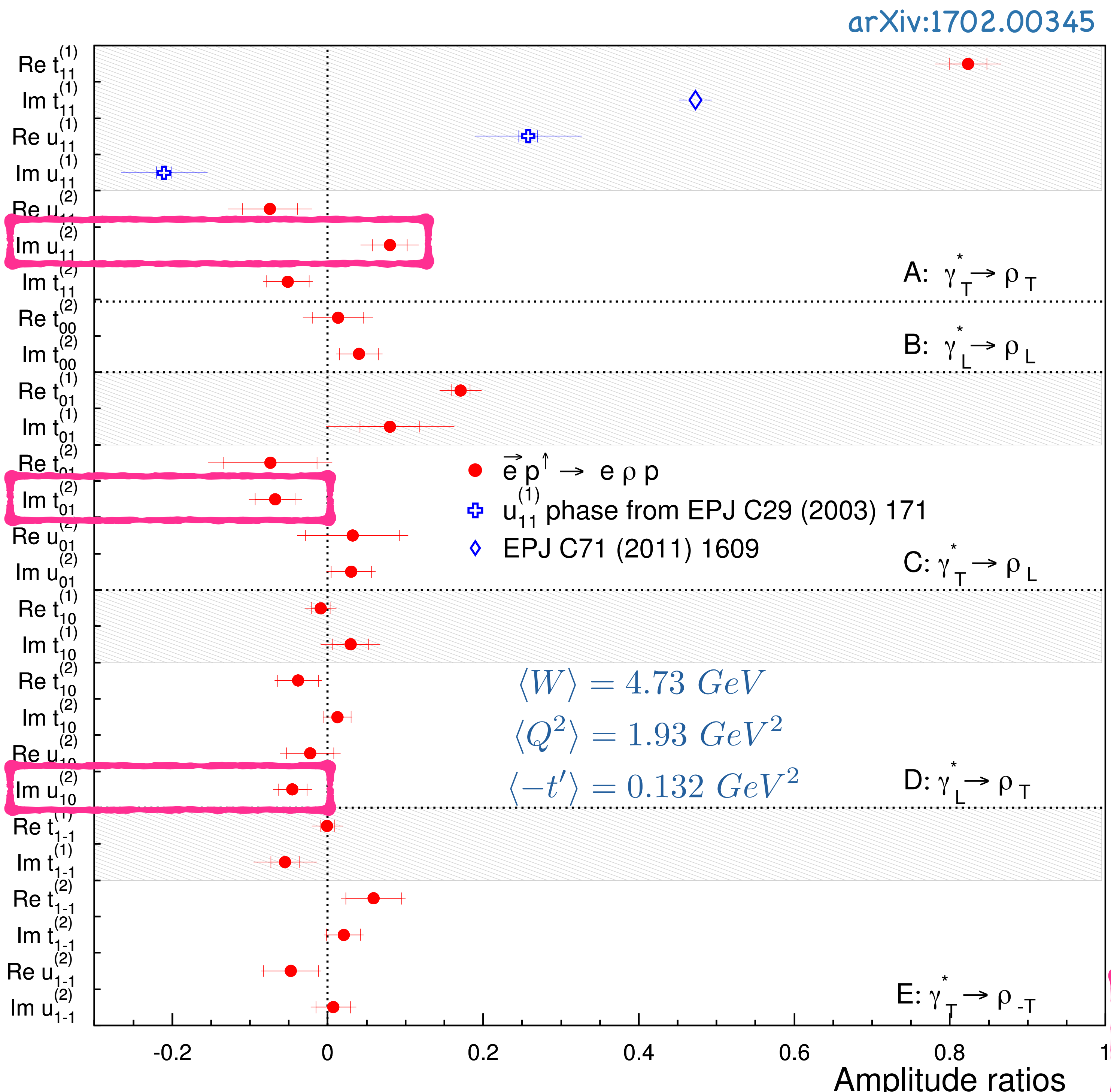

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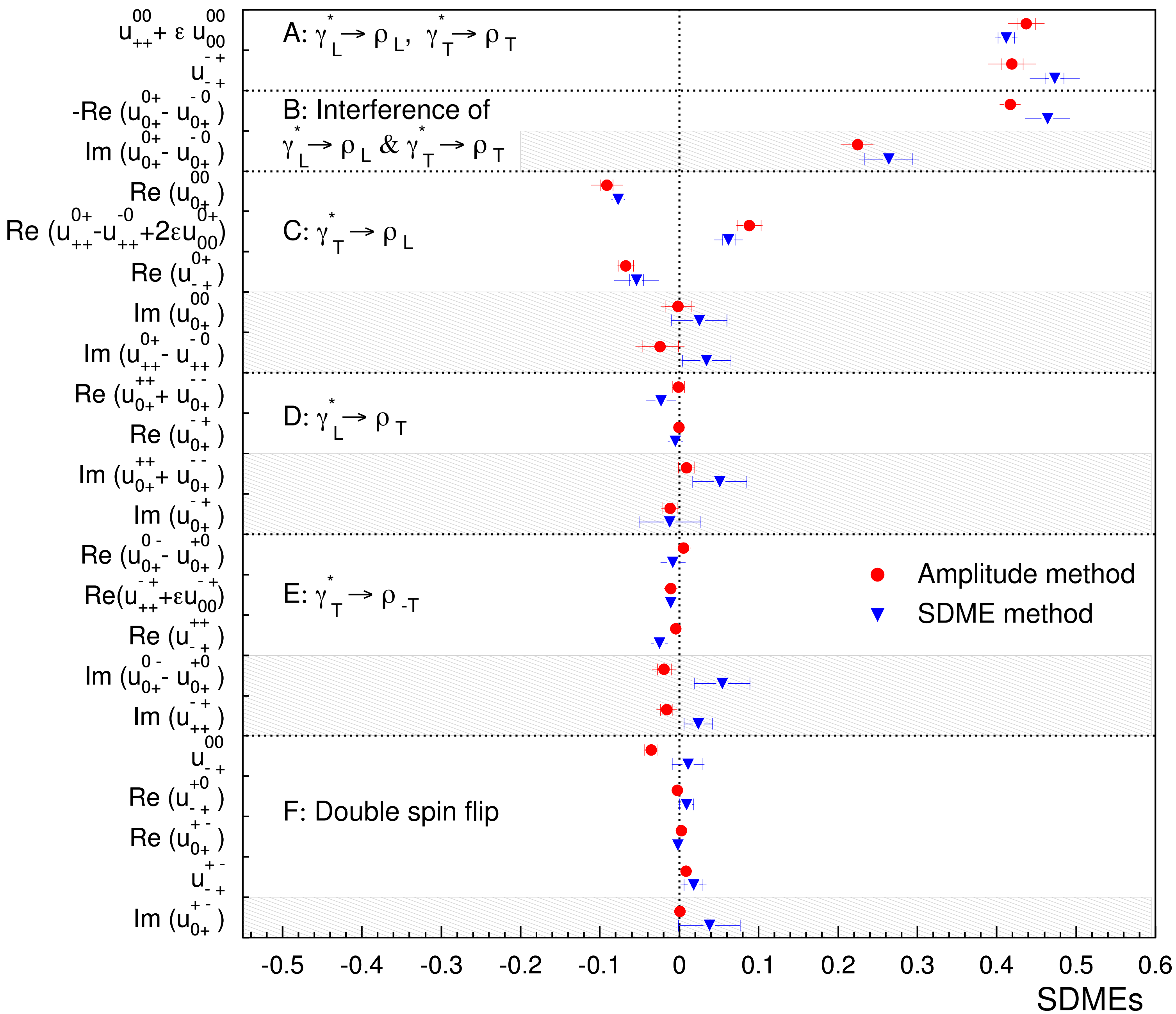
- Significant nucleon-helicity non-flip $\mathrm{Re}\, t_{01}^{(1)}$ (≠0 by 5σ)
- unnatural parity nucleon-helicity non-flip $u_{11}^{(1)}$ ≠ 0 by 4σ
- nucleon-helicity flip $\mathrm{Im}\ t_{01}^{(2)}, \mathrm{Im}\ u_{11}^{(2)}, \mathrm{Im}\ u_{10}^{(2)}$ ≠ 0 by 2σ

Comparison with SDMEs: unpolarized target

arXiv:1702.00345

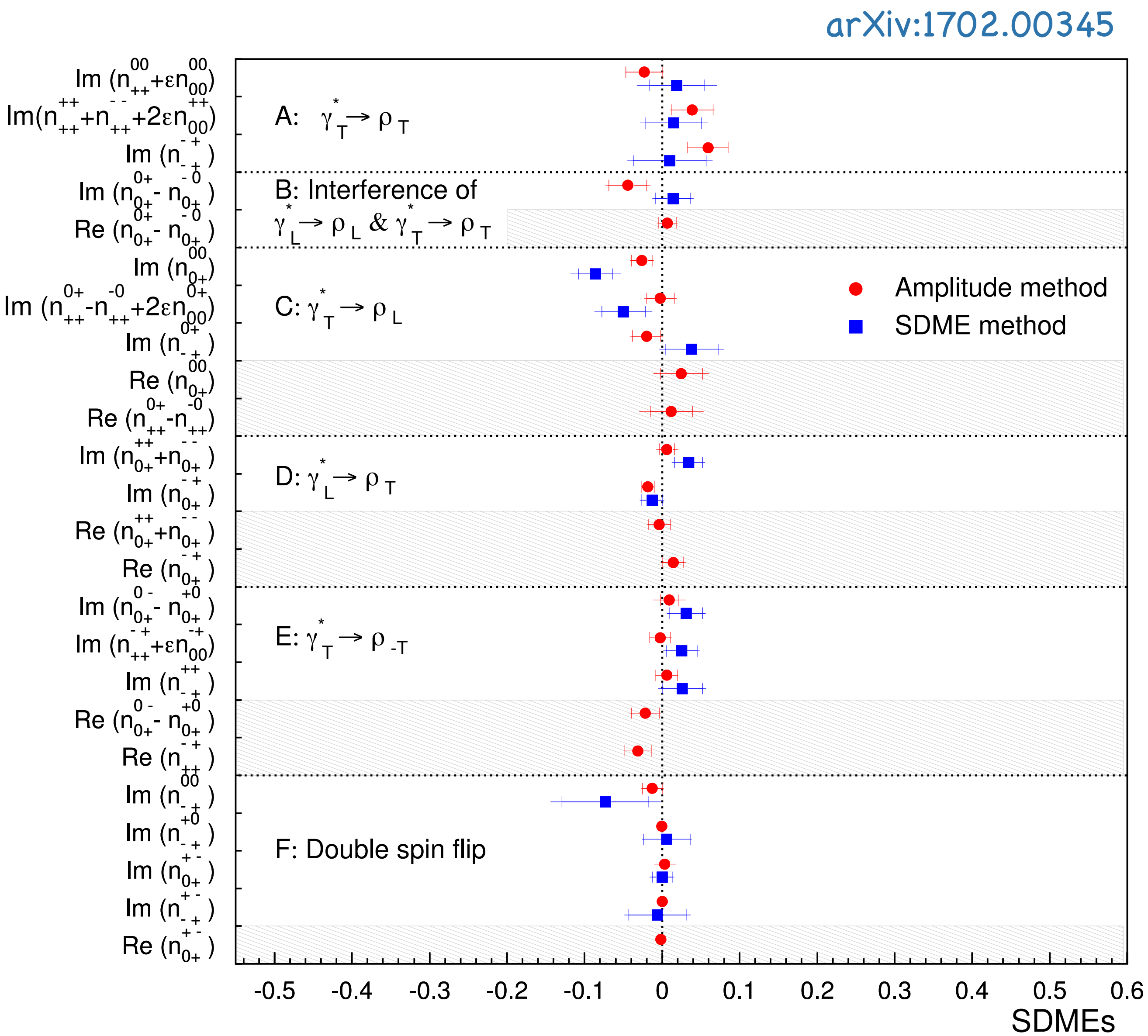


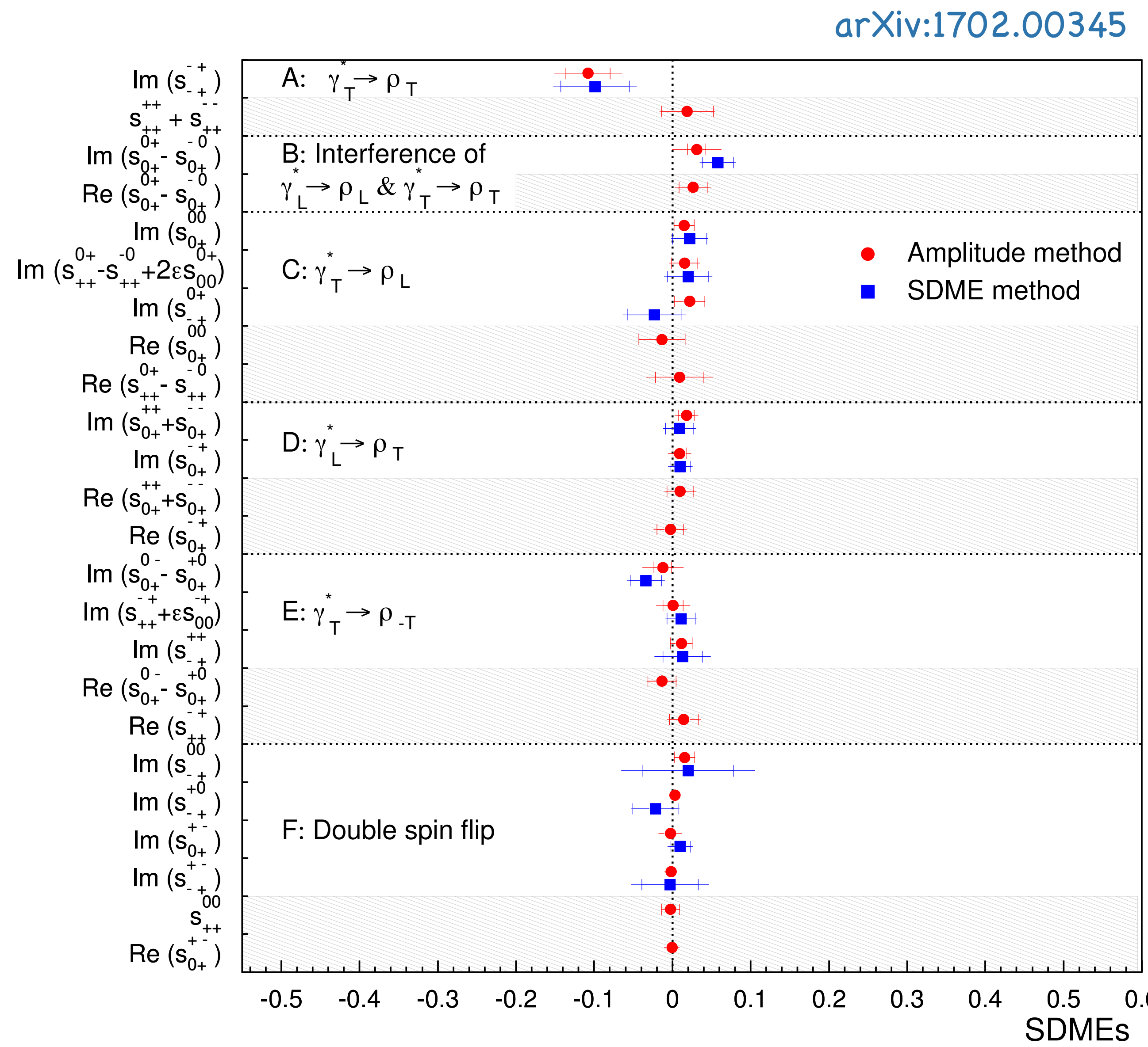
unpolarized beam

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

GK model

model for protons - S. Goloskokov and P. Kroll,

Eur. Phys. J. C **50** (2007) 829; **53** (2008) 367, Eur. Phys. J. A **50** (2014) 146

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

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

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natural parity

unnatural parity

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natural parity

unnatural parity

Factorization only proven for $\gamma^*_L \to V_L$

Assumed for $\gamma^*_T \to V_T, \gamma^*_L \to V_T$. Other transitions neglected.

IR singularities regularised by modified perturbative approach.

GK model

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

natural parity

unnatural parity

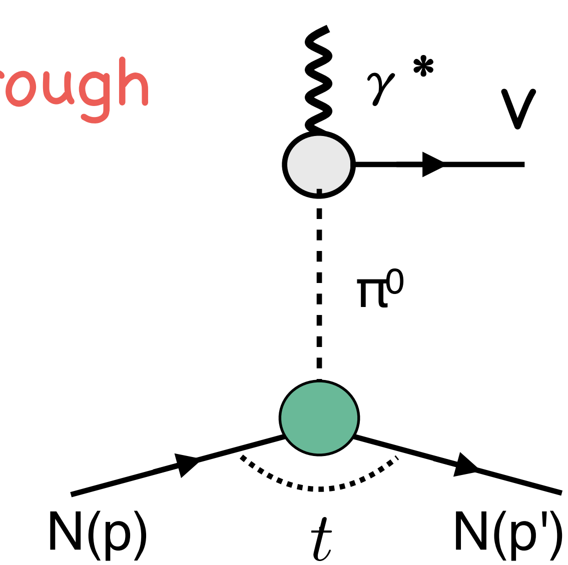
Factorization only proven for $\gamma_L^* \to V_L$

Assumed for $\gamma_T^* \to V_T, \gamma_L^* \to V_T$. Other transitions neglected.

IR singularities regularised by modified perturbative approach.

Pion pole $\left(\propto \frac{1}{t - m_\pi^2}\right)$ through

one-particle exchange



$$g_{\gamma^* \pi V}(Q^2, t) \simeq g_{\pi V}(Q^2)$$

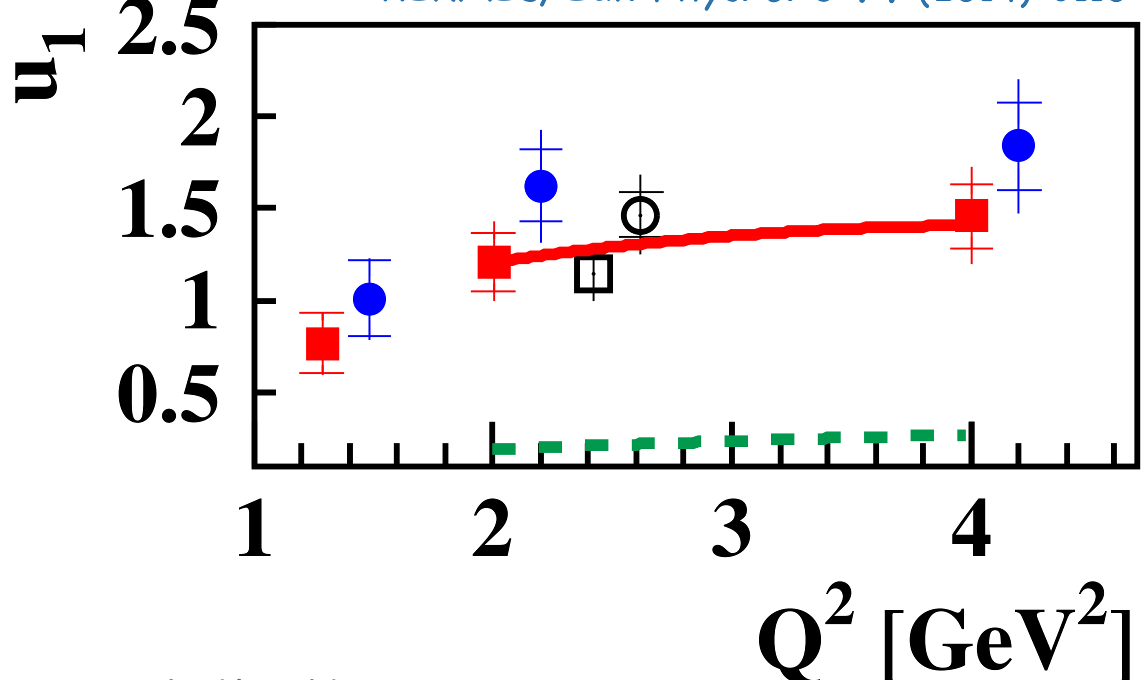
at small t

πω transition form factor extraction: ω SDMEs

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

GK, Eur. Phys. J. A **50** (2014) 146

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



without pion-pole contribution

with pion-pole contribution

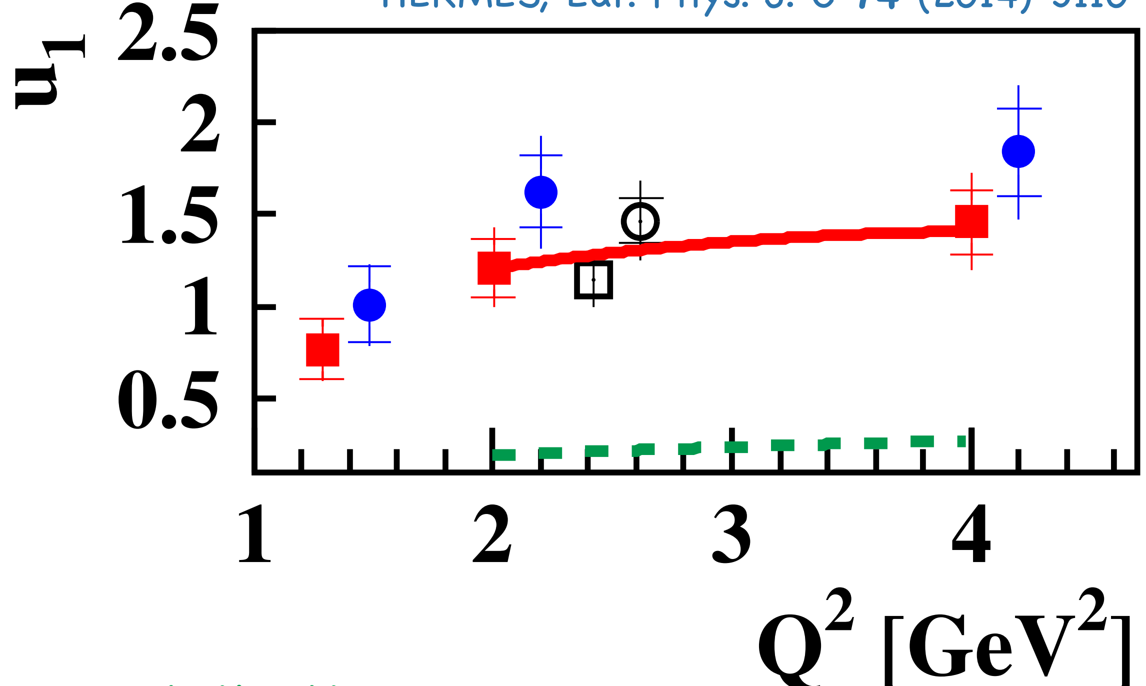
pion-pole contribution seems to account completely for unnatural-parity exchange

πω transition form factor extraction: ω SDMEs

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

GK, Eur. Phys. J. A **50** (2014) 146

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



Only magnitude of transition form factor, not sign

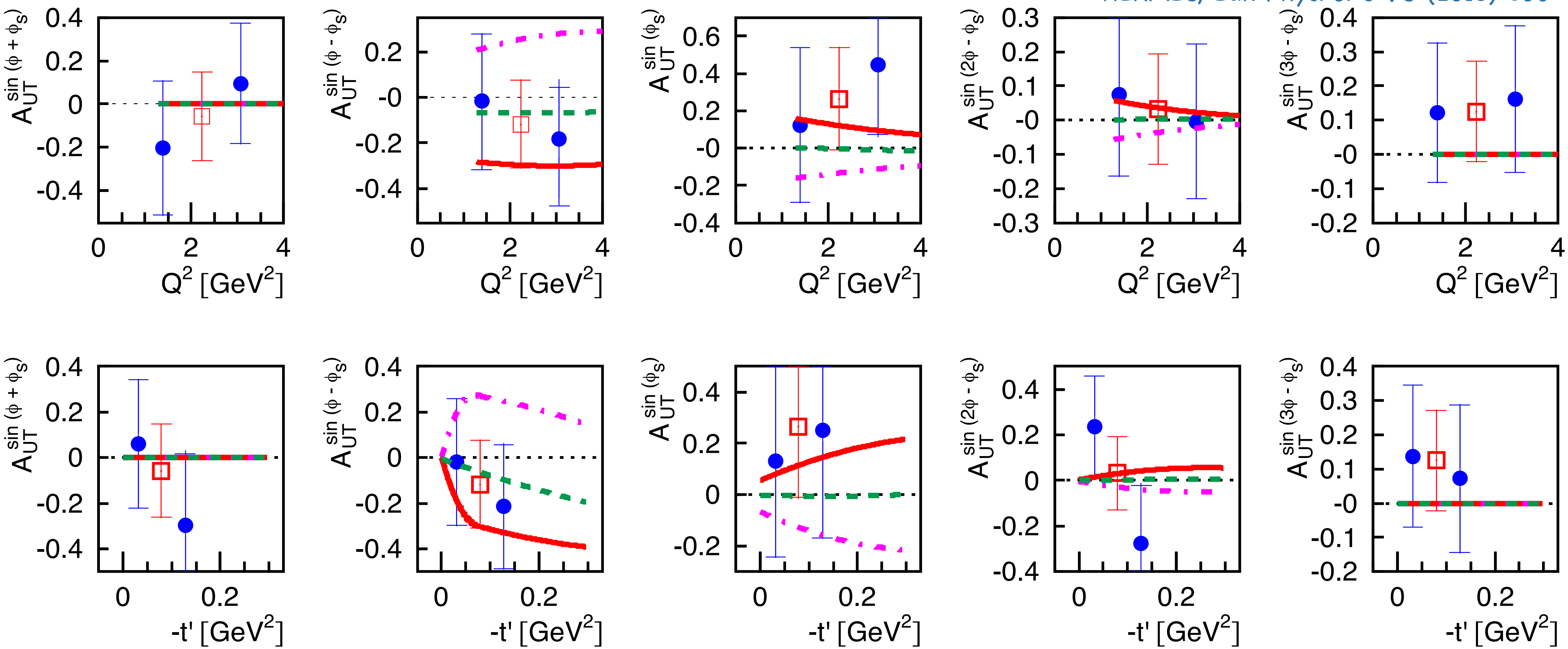
without pion-pole contribution

with pion-pole contribution

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

Sign of $\pi\omega$ transition form factor extraction: ω A_{UT}

HERMES, Eur. Phys. J. C **75** (2015) 600



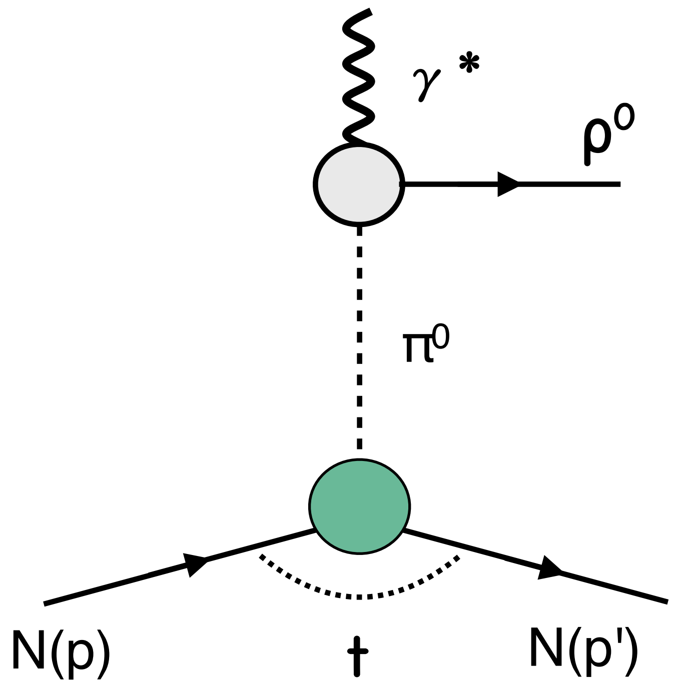
without pion-pole contribution

with pion-pole contribution: $\pi\omega$ transition FF > 0

with pion-pole contribution: $\pi\omega$ transition FF < 0

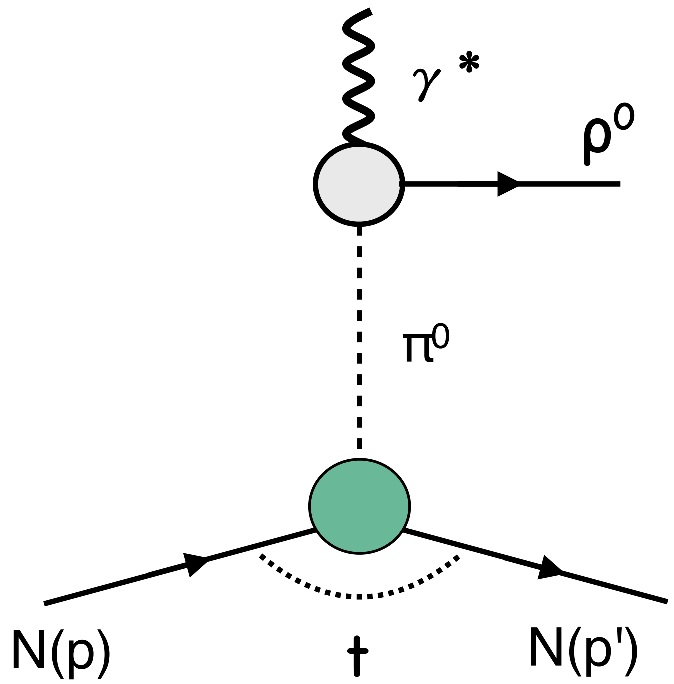
Positive $\pi\omega$ transition FF favoured

$\pi\rho^0$ transition form factor



$$g_{\pi\rho} \simeq \frac{e_u + e_d}{e_u - e_d} g_{\pi\omega}$$

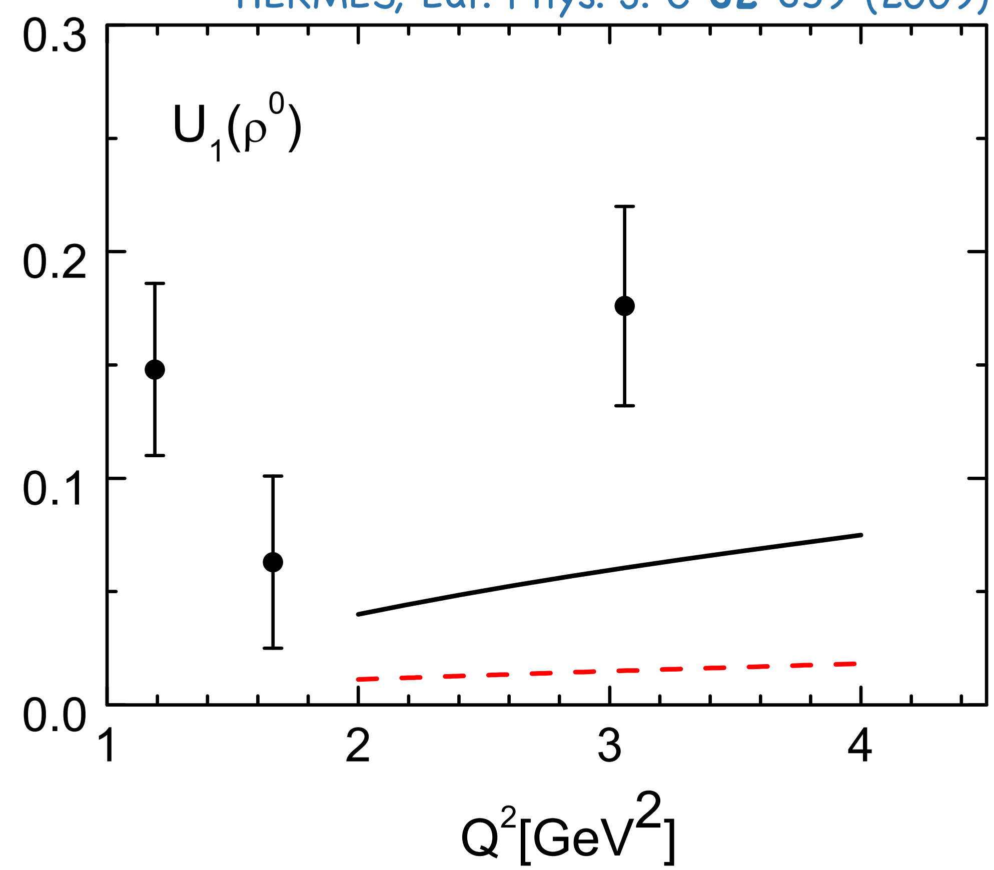
$\pi\rho^0$ transition form factor



$$g_{\pi\rho} \simeq \frac{e_u + e_d}{e_u - e_d} g_{\pi\omega}$$

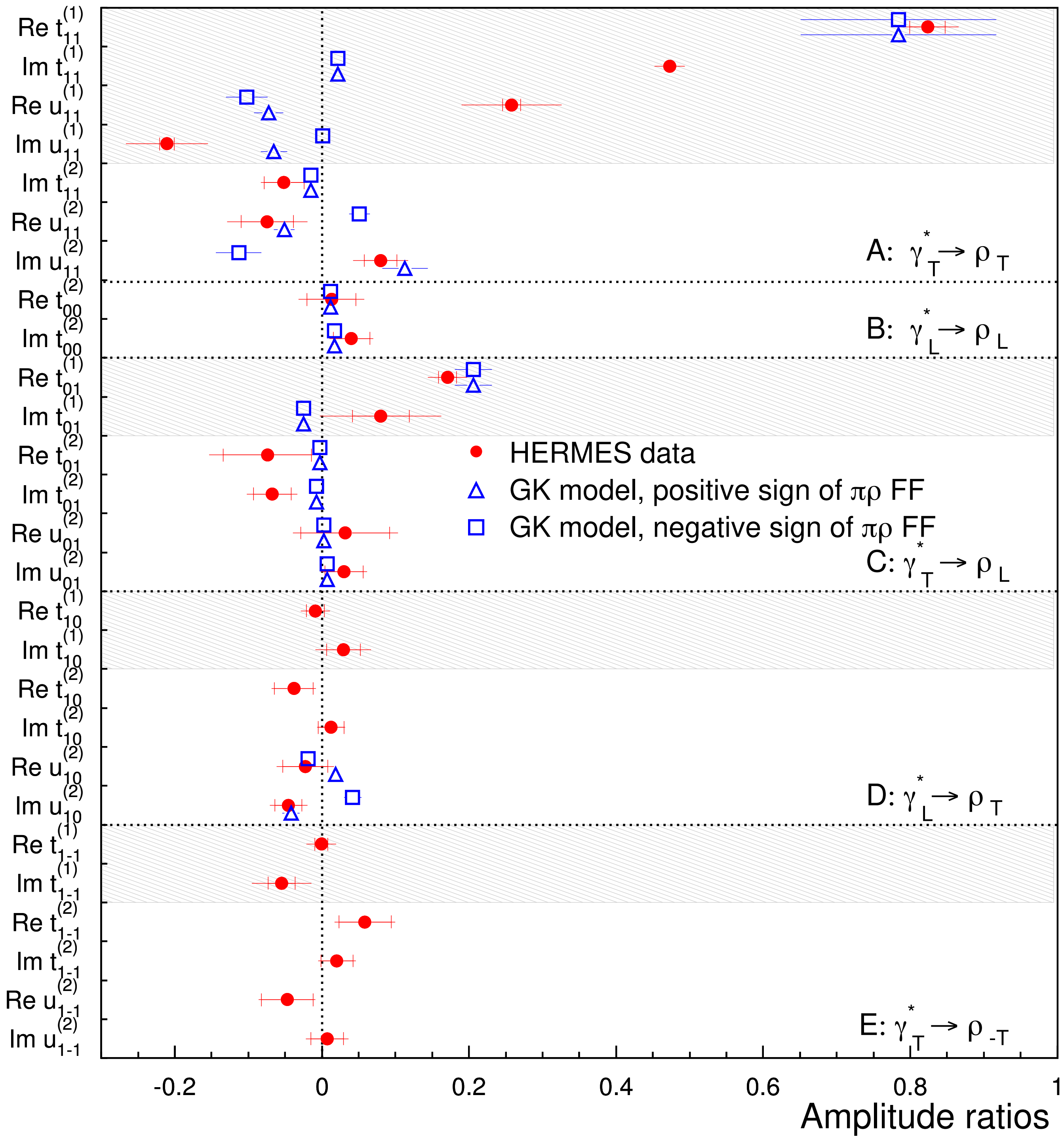
Cross section: 2% effect @ HERMES

GK, Eur. Phys. J. A **50** 146 (2014)
HERMES, Eur. Phys. J. C **62** 659 (2009)



Comparison ρ^0 helicity amplitude ratios with GK model

arXiv:1702.00345



Comparison ρ^0 helicity amplitude ratios with GK model

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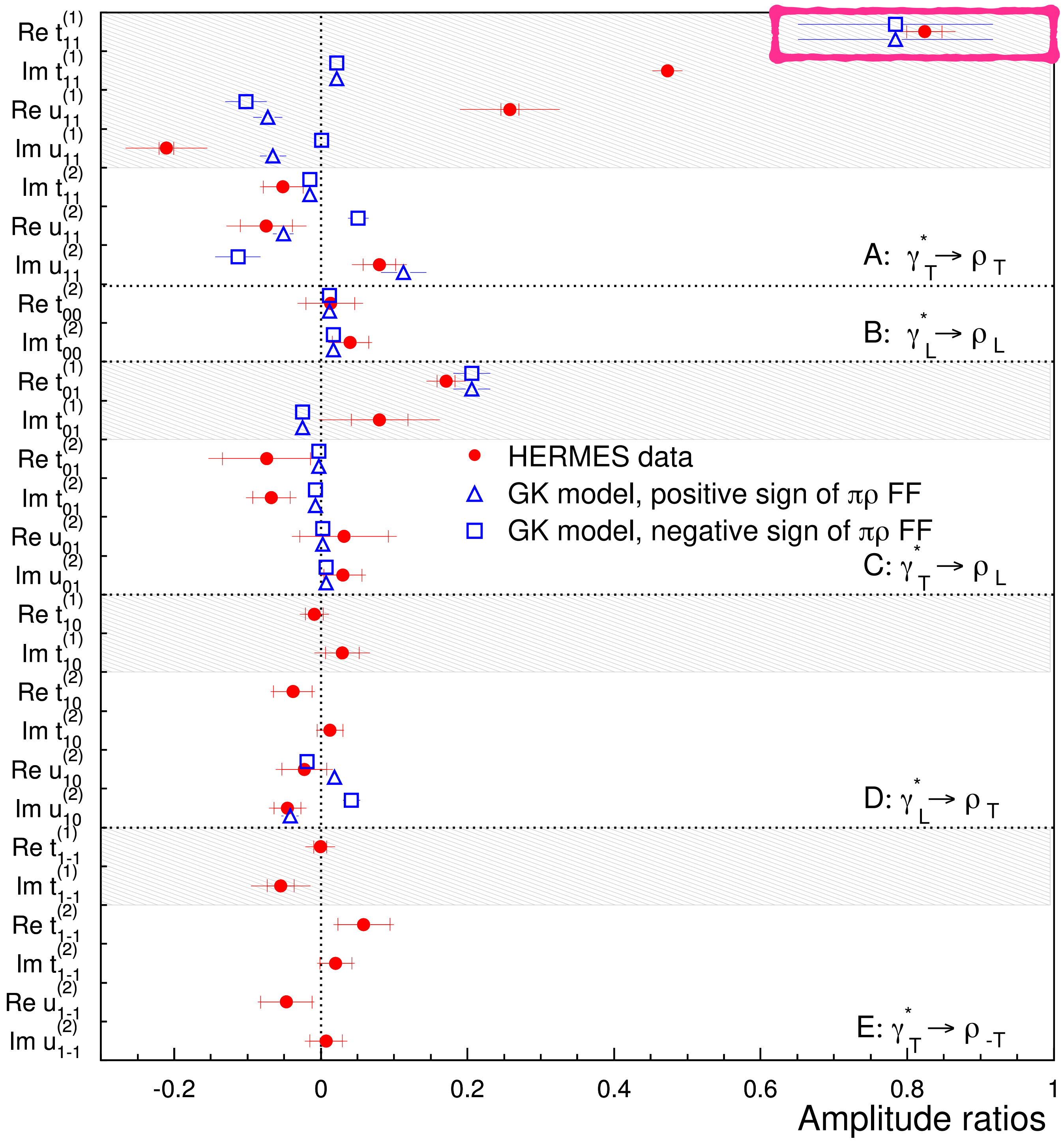
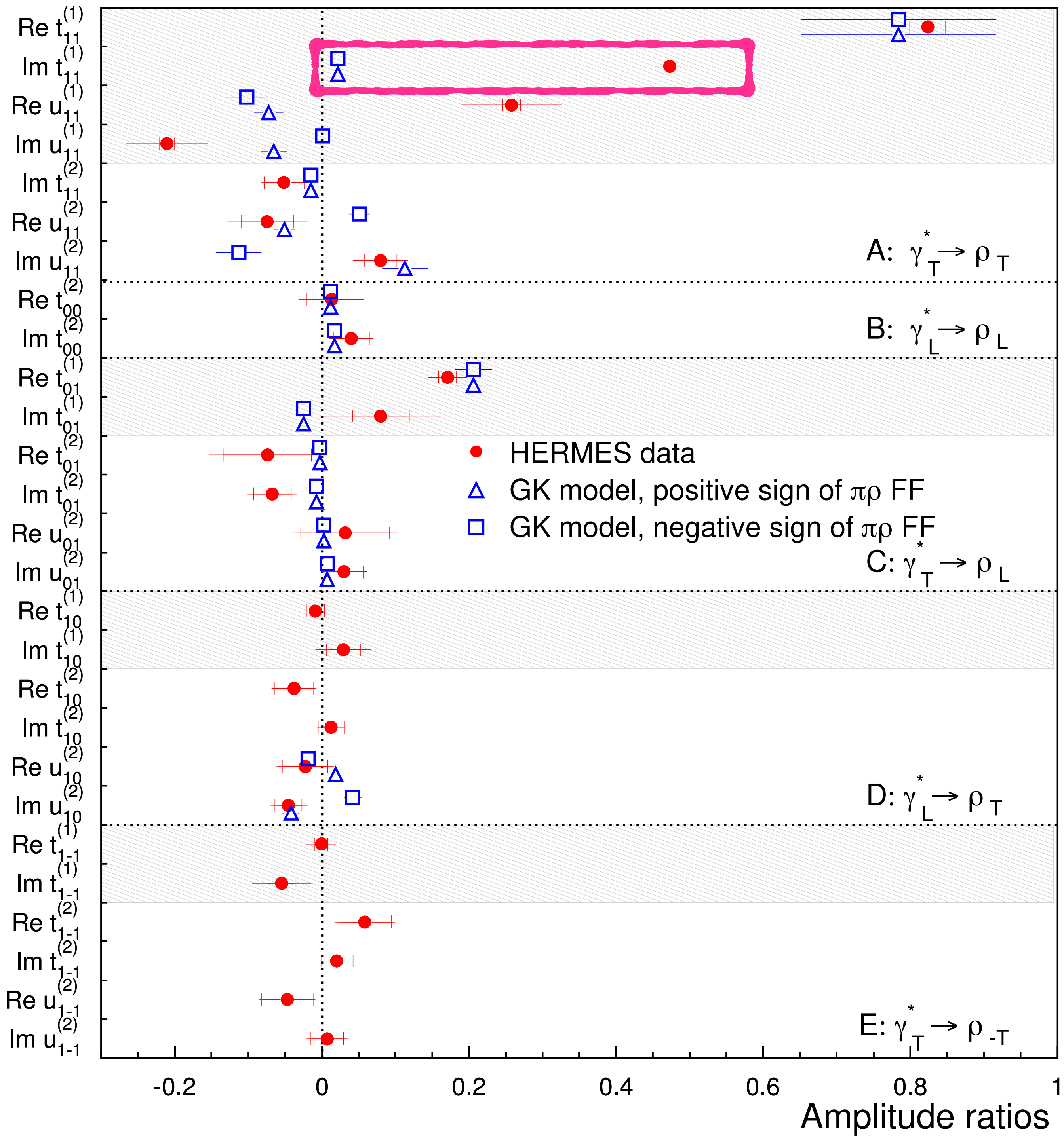


- GPD H. Agreement.

Comparison ρ^0 helicity amplitude ratios with GK model

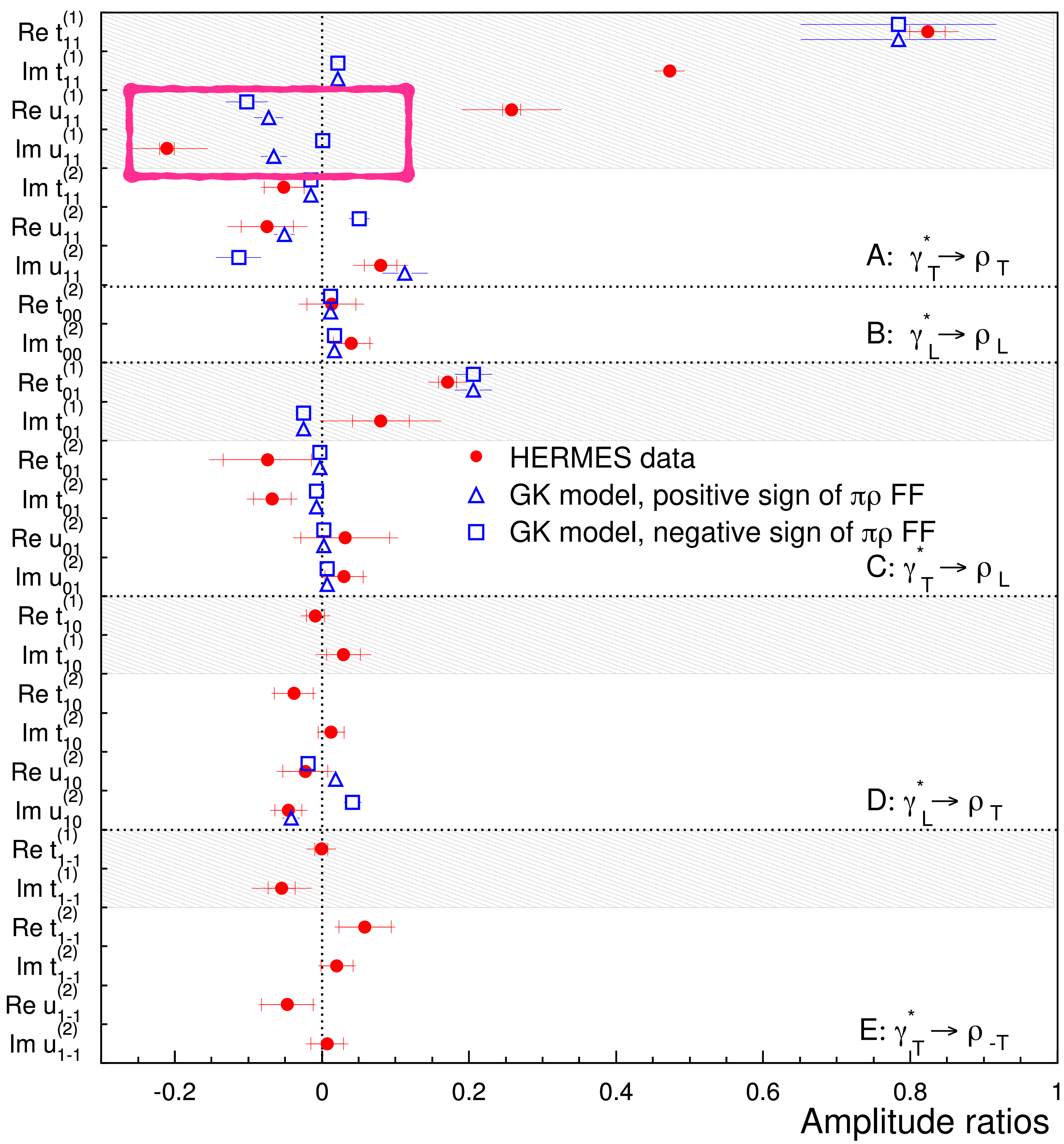
arXiv:1702.00345



- GPD H. Disagreement.

Comparison ρ^0 helicity amplitude ratios with GK model

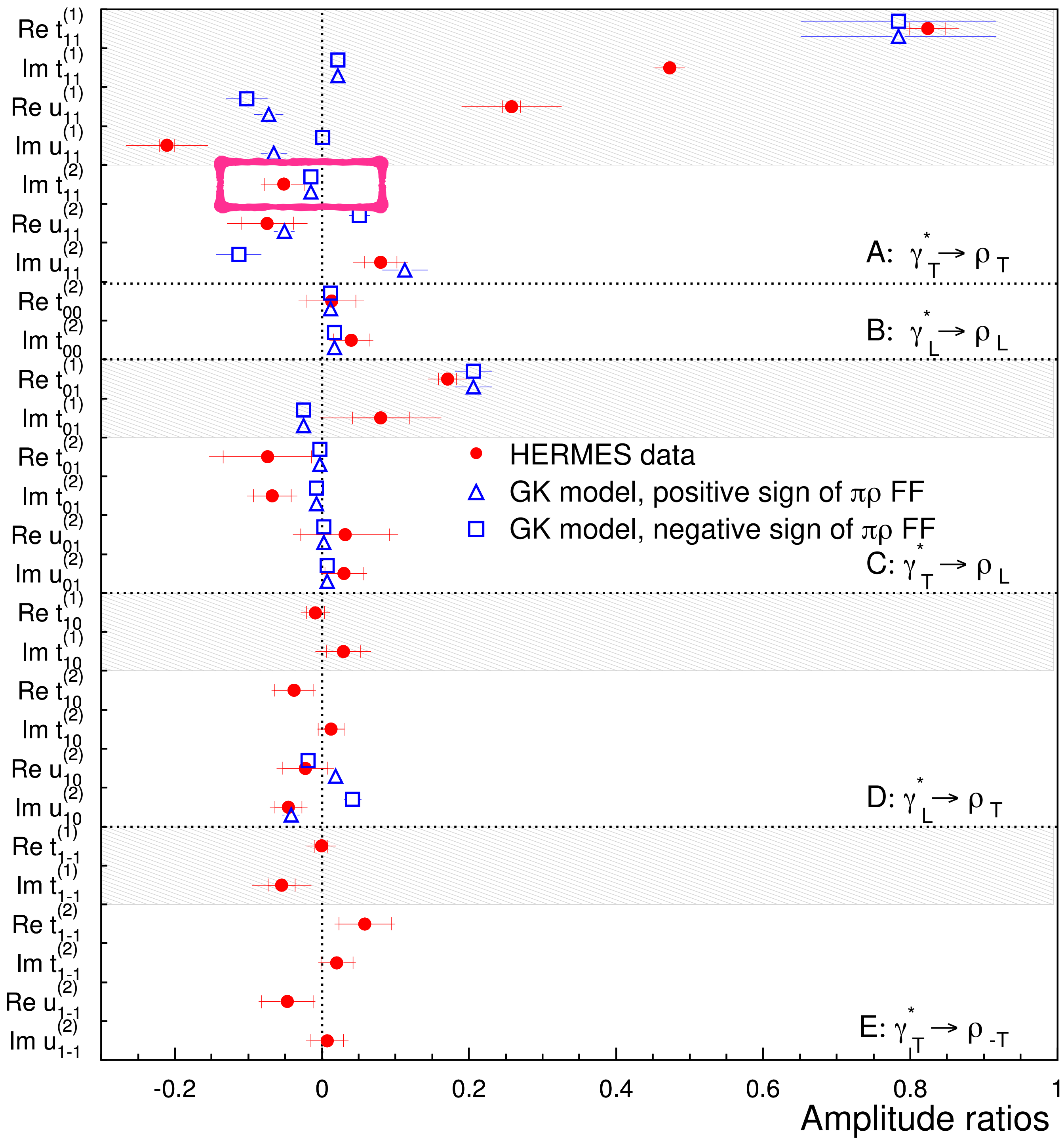
arXiv:1702.00345



- GPD $\tilde{H}$ + pion pole. Disagreement.

Comparison ρ^0 helicity amplitude ratios with GK model

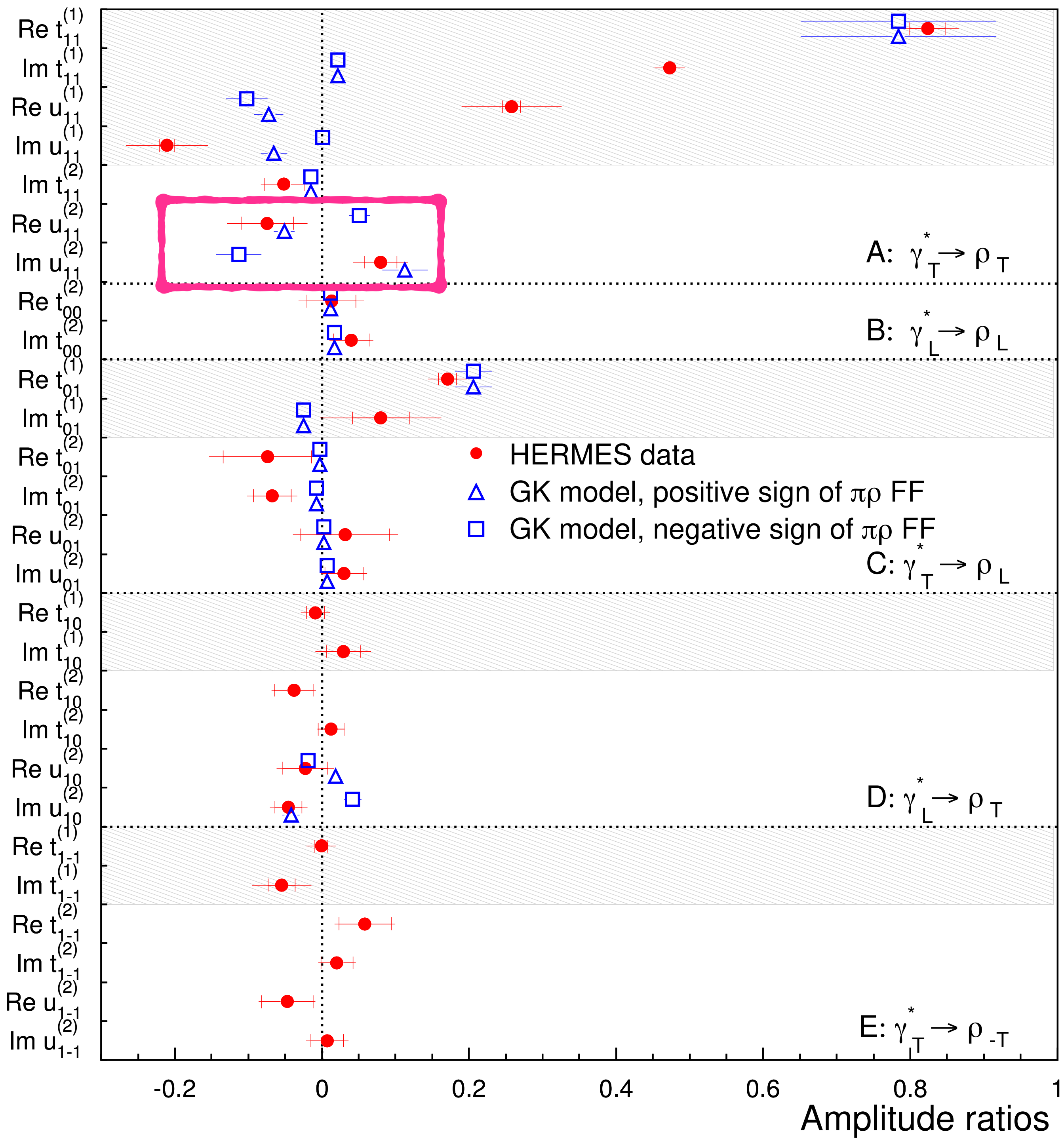
arXiv:1702.00345



- GPD E. Agreement.

Comparison ρ^0 helicity amplitude ratios with GK model

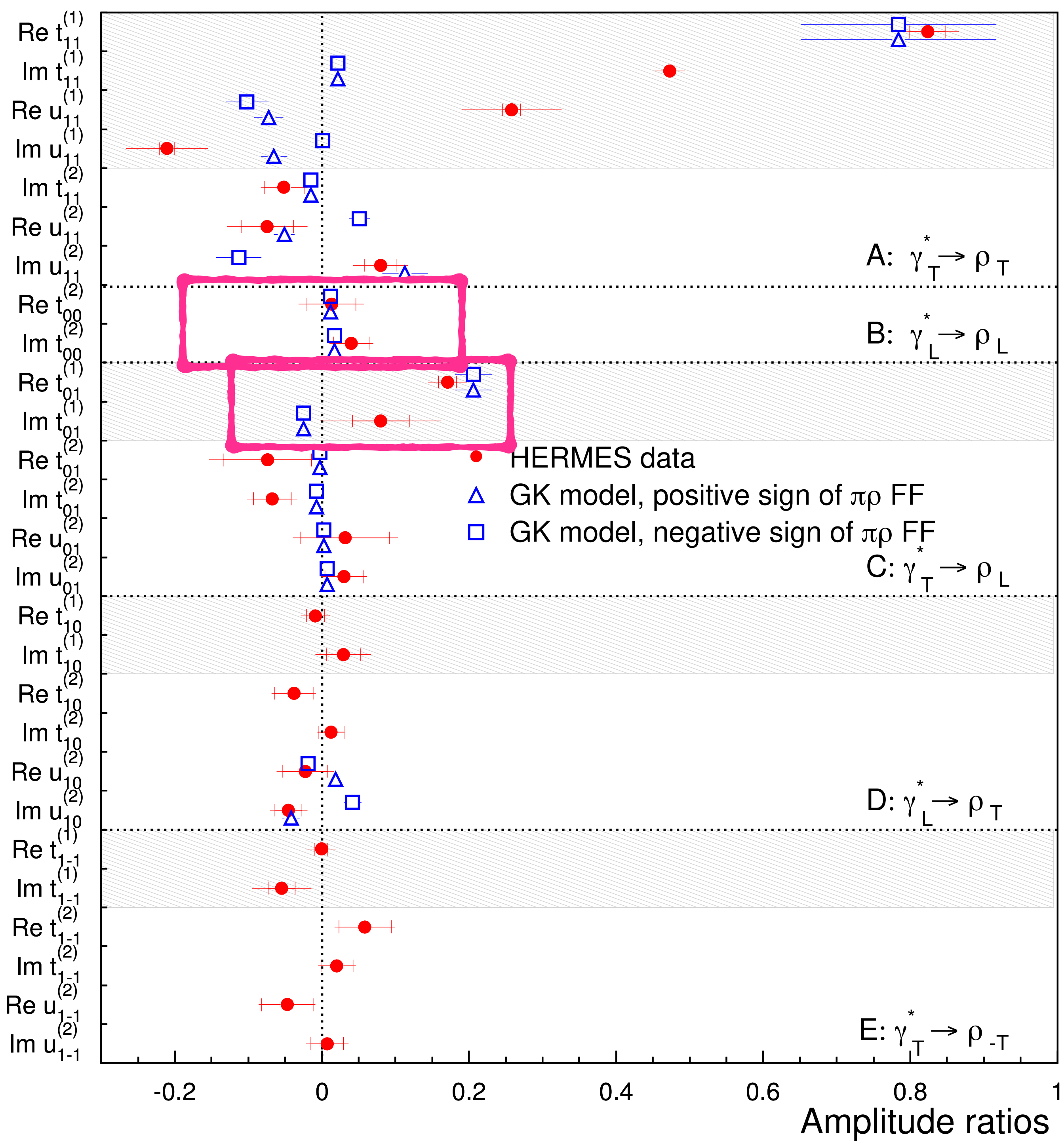
arXiv:1702.00345



- Only pion pole. Positive form factor.

Comparison ρ^0 helicity amplitude ratios with GK model

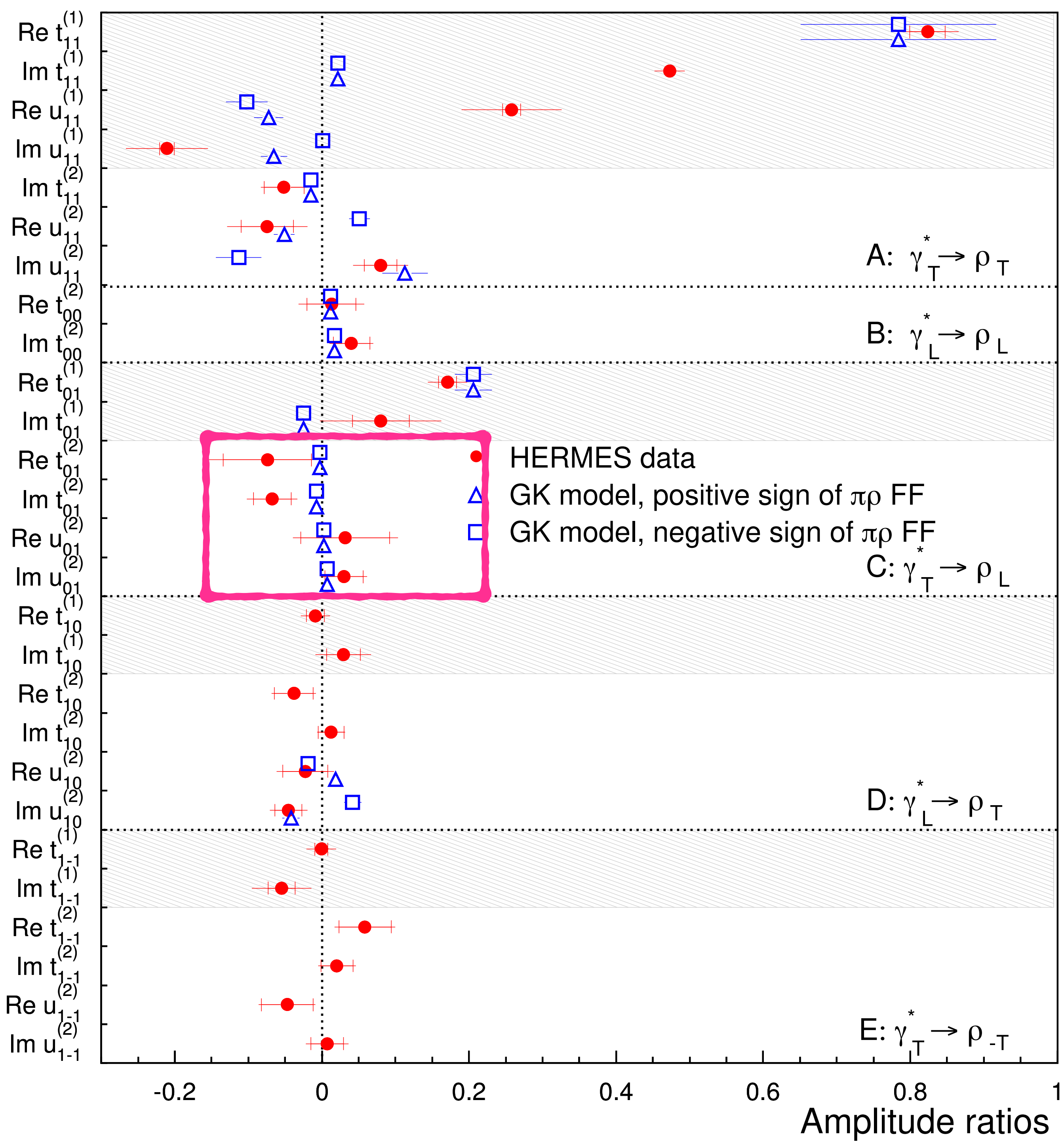
arXiv:1702.00345



- GPD E. Agreement.
- GPD $\bar{E}_T$. Agreement.

Comparison ρ^0 helicity amplitude ratios with GK model

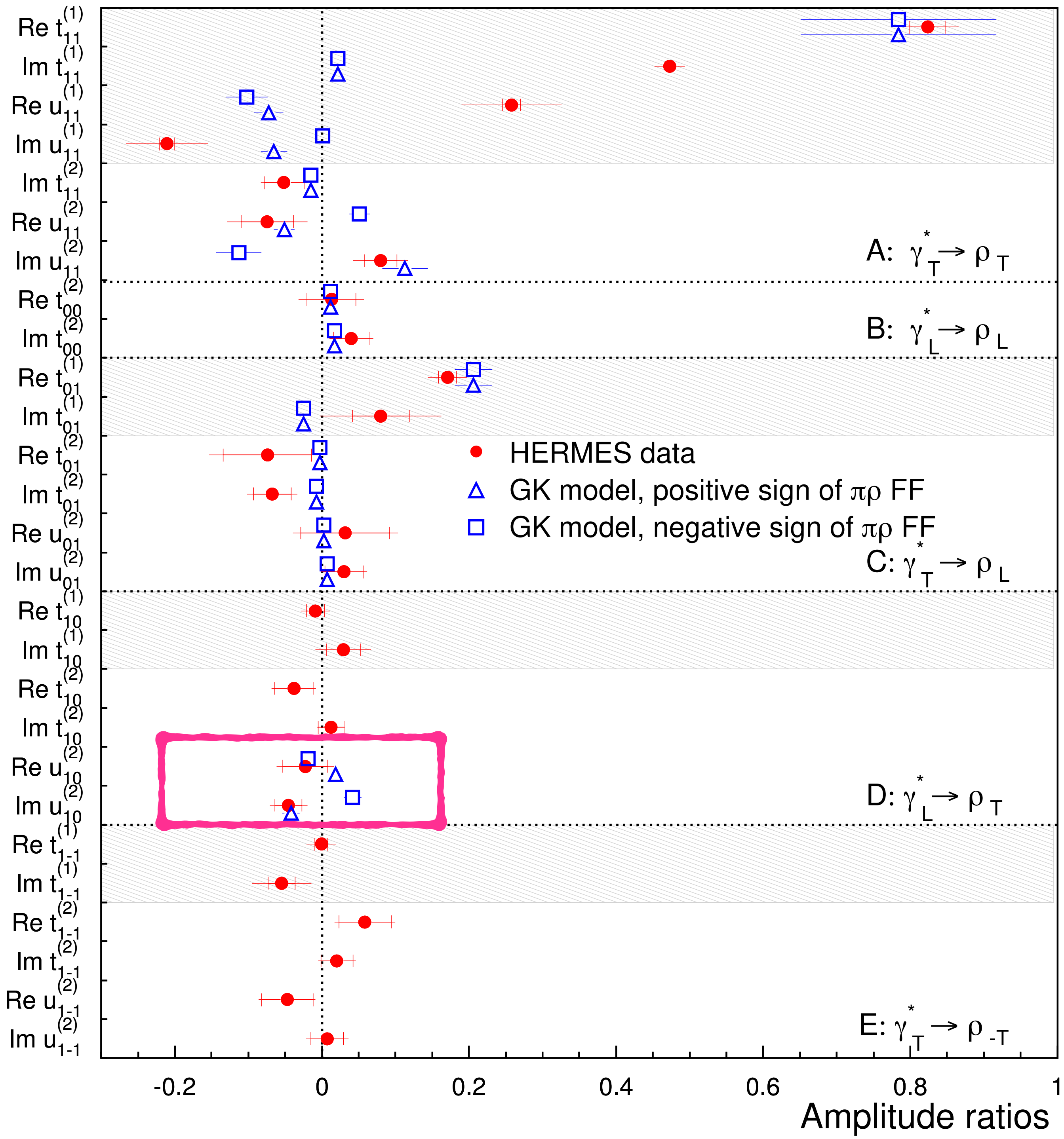
arXiv:1702.00345



- GPD H_T.

Comparison ρ⁰ helicity amplitude ratios with GK model

arXiv:1702.00345



- Only pion pole. Positive form factor.

Summary

- New: nucleon-helicity-flip ρ^0 helicity amplitude ratios.

  Small/Consistent with zero.

- Good agreement with direct extraction of SDMEs.

- New SDMEs from ρ^0 helicity amplitude ratios.

- Partial agreement with GK model.

  Positive $\pi\rho$ transition form factor.

Summary

- New: nucleon-helicity-flip ρ^0 helicity amplitude ratios.

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