Exclusive meson production at HERMES

Pan-Pacific Symposium on High Energy Spin Physics, 2007.

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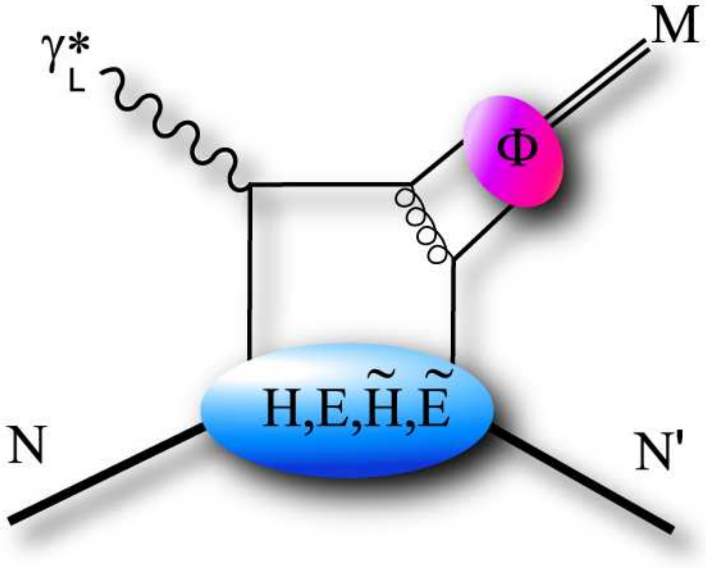
on behalf of the HERMES collaboration

- Cross section of exclusive π^+ production
- Spin Density Matrix Elements (SDMEs) for exclusive ρ^0 and ϕ production
- Transverse target spin asymmetry in excl. ρ^0 production, ρ_L-ρ_T separated

GPDs & Exclusive Meson Production

Factorization of Amplitudes

Proven for Mesons in case of Longitudinal γ^* Polarization *(Collins, Frankfurt, Strikman: Phys. Rev. D 56 (1997) 2982)*



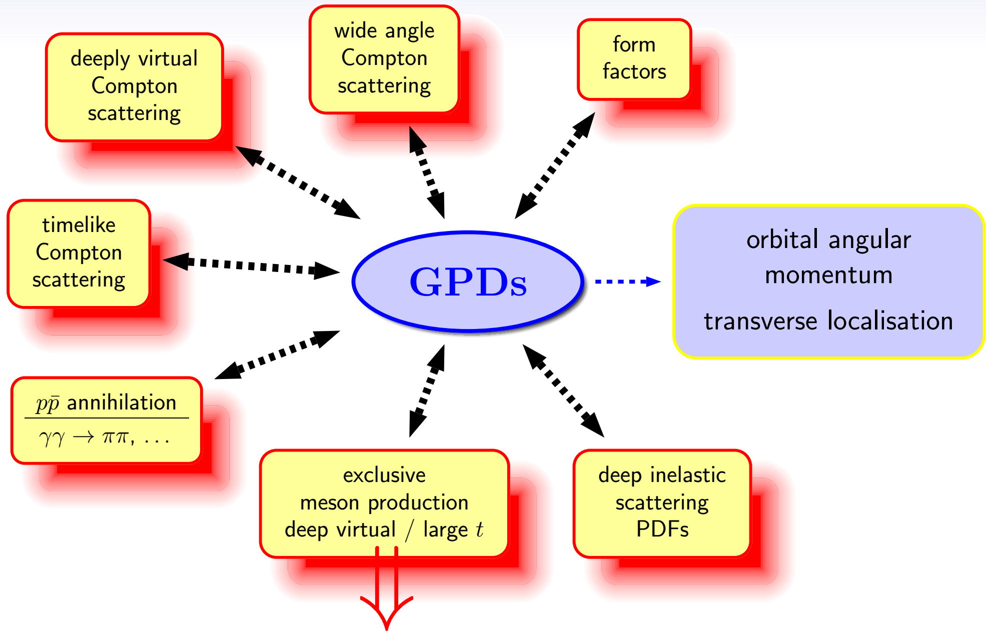
At leading twist:

- Only transitions allowed with both meson and γ^* longitudinally polarized
- Amplitudes can be expressed in terms of GPDs $H, E, \widetilde{H}, \widetilde{E}$

$\Rightarrow$ *Final state determines sensitivity to different GPDs*

$$\begin{cases} H, E: & \text{vector mesons } (\rho, \phi, \omega) \\ \tilde{H}, \tilde{E}: & \text{pseudoscalar mesons } (\pi, \eta) \end{cases}$$

Access to GPDs

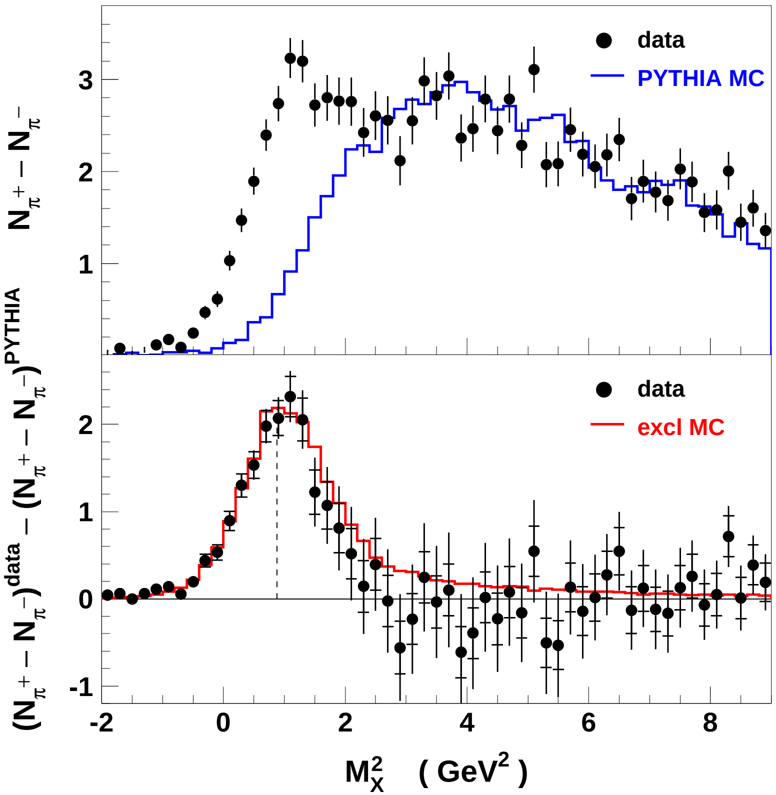


- GPD $\tilde{E}$: t-channel pion-pole contribution
- GPDs H, E : Ji sum rule

$$\frac{1}{2}\int_{-1}^{1} dx\; x\; [H(x,\zeta,t) + E(x,\zeta,t)] \overset{t\to 0}{=} J_q = \frac{1}{2}\Delta\Sigma + \Delta L_q$$

- ...

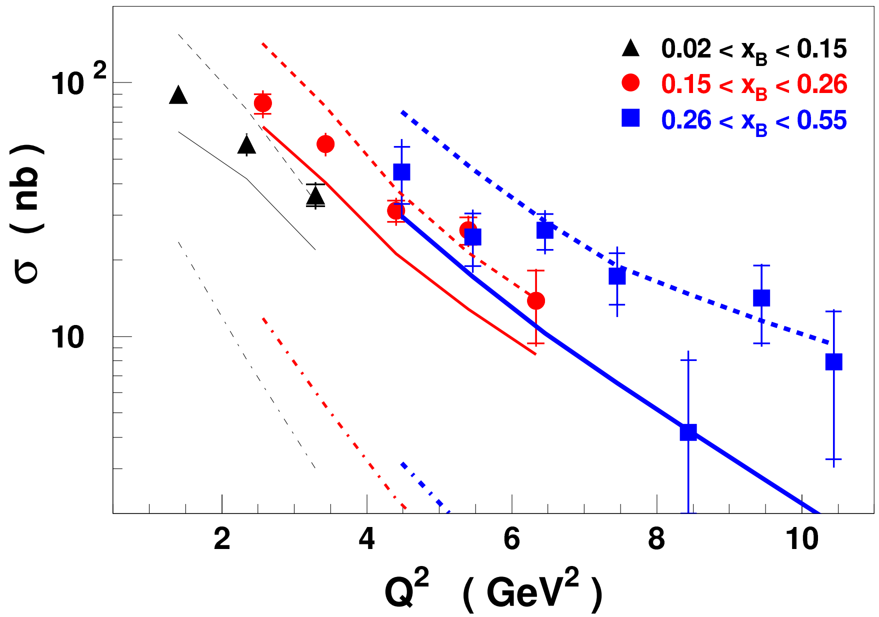
Exclusive π^+ Production



$\gamma^* p \rightarrow \pi^+ n$ Event selection

- Determine missing mass $M_X^2 = (P_{\gamma^*} + P_p - P_{\pi^+})^2$ for $\gamma^* p \rightarrow \pi^+ X$
- Non-exclusive background estimated with PYTHIA
- After background subtraction: *M_X centered around M_n*

Measured Cross Section $\gamma^* p \to \pi^+ n$ *vs* Q^2



$\cdots\cdots$ σ_L: VGG, LO

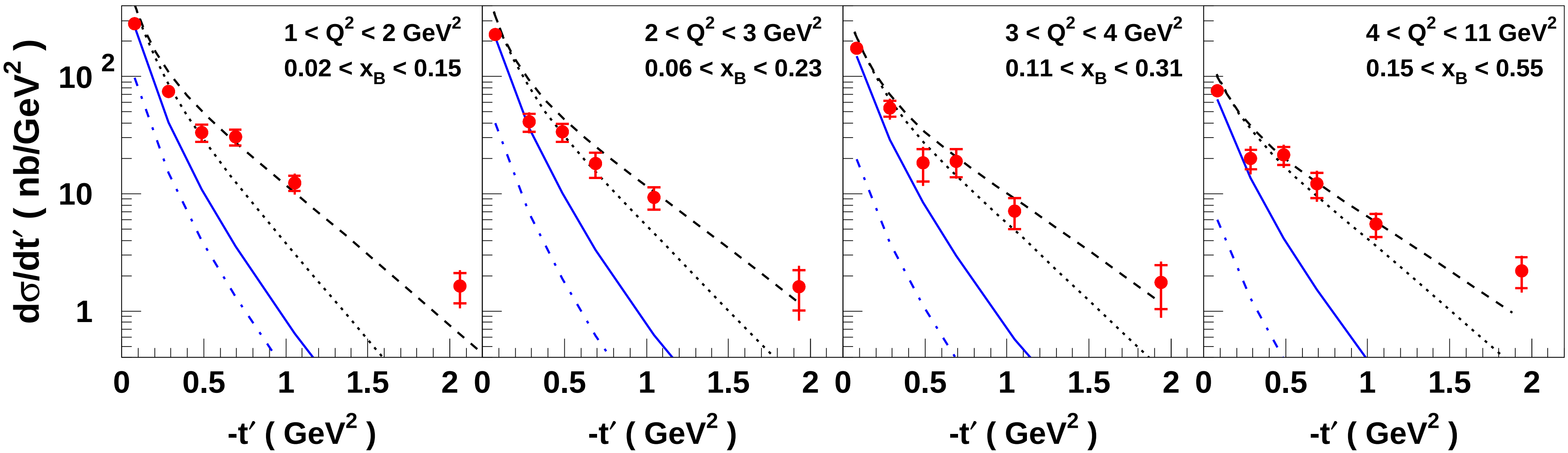
——— σ_L: VGG, LO + power corr.

- - - - - Regge model

- $\sigma_{tot} = \sigma_T + \epsilon\sigma_L$
- Regge model: dominance of σ_L over σ_T *(Laget: PRD 70 (2004) 054023)*
- Shape Q^2 dependence agrees with GPD model calculations

  (Vanderhaegen, Guichon, Guidal: PRD 60 (1999) 094017)

Measured Cross Section $\gamma^* p \rightarrow \pi^+ n$ *vs* $-t'$



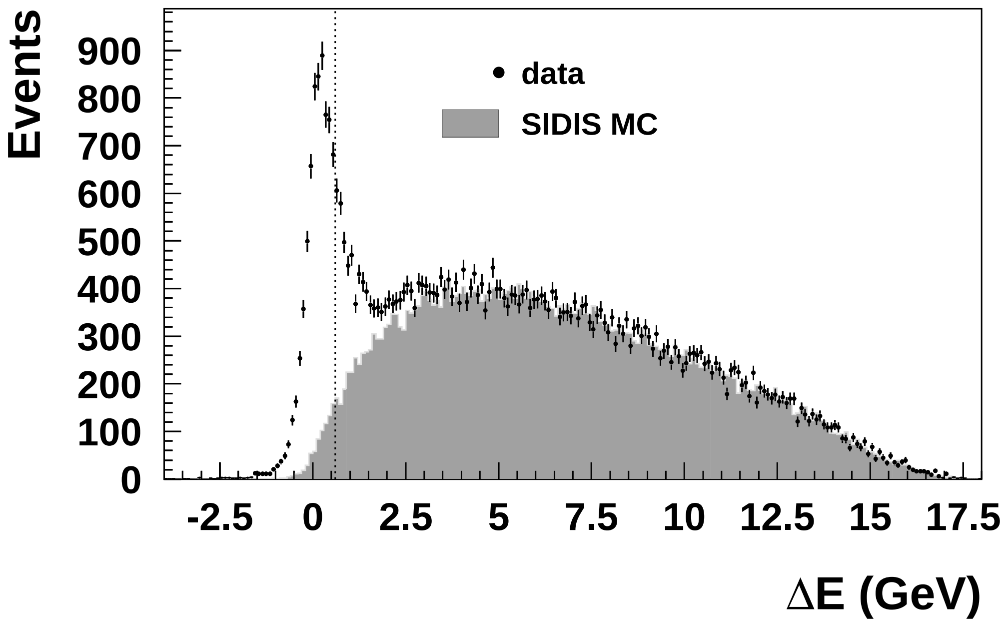
- - - - - $\frac{d\sigma_L}{dt'}$: VGG, LO — - - - - $\frac{d\sigma}{dt}$: Regge model

——— $\frac{d\sigma_L}{dt'}$: VGG, LO + power corr. — .... $\frac{d\sigma_L}{dt}$: Regge model

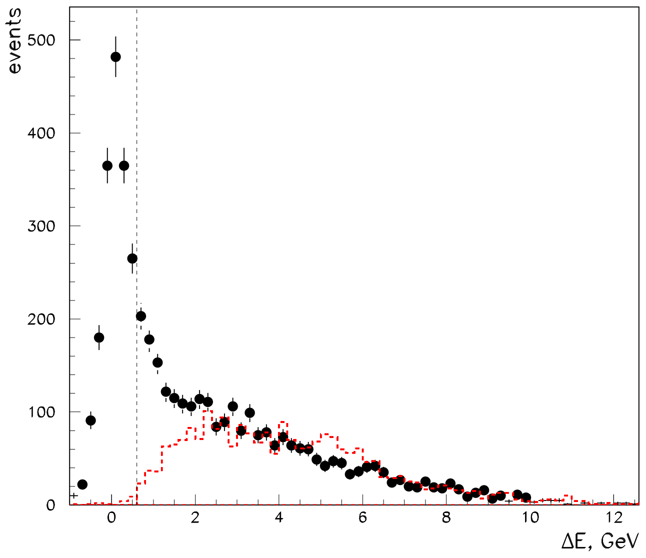
- Power corrected GPD calculations in fair agreement with data at low values of $-t'$ (note: GPD model requires $-t' \ll Q^2$)
- Order of magnitude of power corrections is supported by data

Exclusive ρ^0 and ϕ production

$\gamma^* p \to \rho^0 X$



$\gamma^* p \to \phi X$



Exclusive ρ^0 and ϕ meson selection

- $\Delta E = \frac{M_X^2 - M_p^2}{2M_p}$ peaked around zero for exclusive production
- Non-exclusive contributions estimated by using Monte Carlo

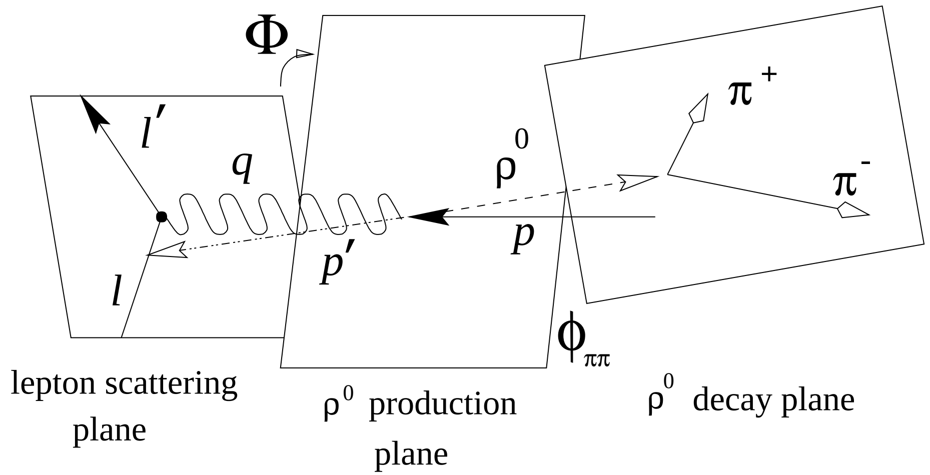
SDMEs for Exclusive ρ^0 and ϕ Production

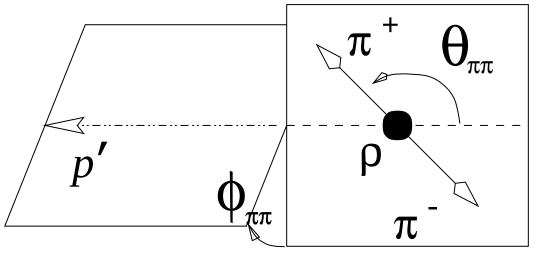
- Spin Density Matrix Elements (SMDEs)
  (Schilling, Wolf: Nucl. Phys. B 61, 381)
  - $\gamma^* \to VM$ helicity transfer:
    s-channel helicity conservation (SCHC)?
  - parity exchange
- SDMEs extracted by measuring the angular distribution of decay products:

$$\rho^0 \quad \to \quad \pi^+\pi^-$$
$$\phi \quad \to \quad K^+K^-$$

- Exclusive ρ^0 vs ϕ production
  - ρ^0: both quark exchange and gluon exchange mechanisms contribute
  - ϕ: gluon exchange mechanism dominates

Photon-Nucleon CMS



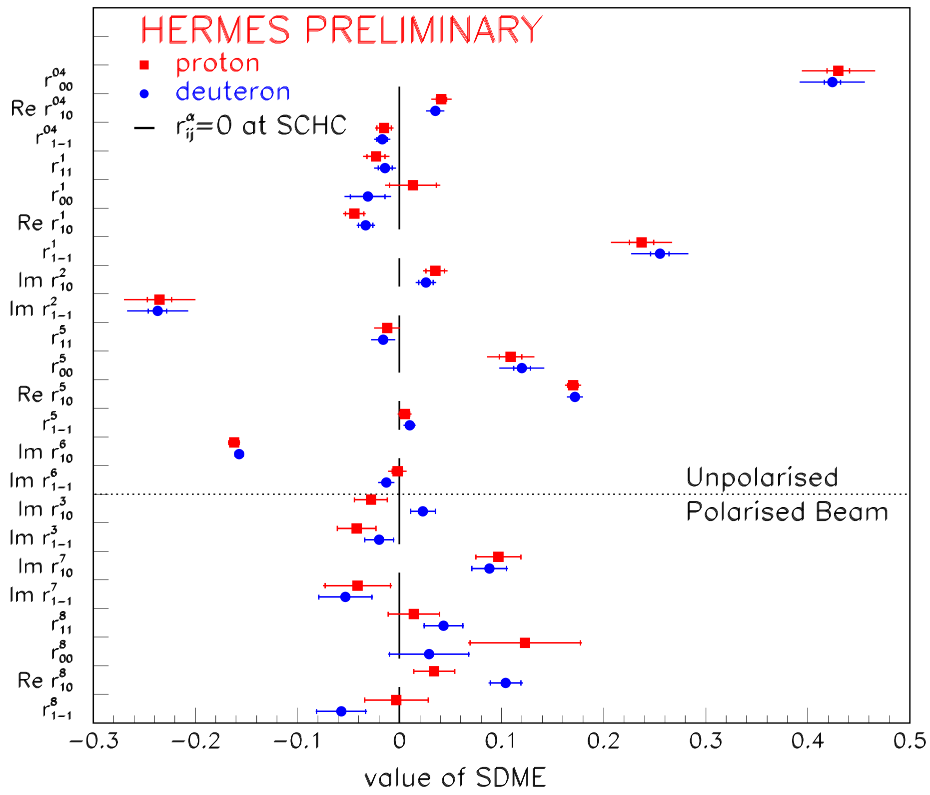


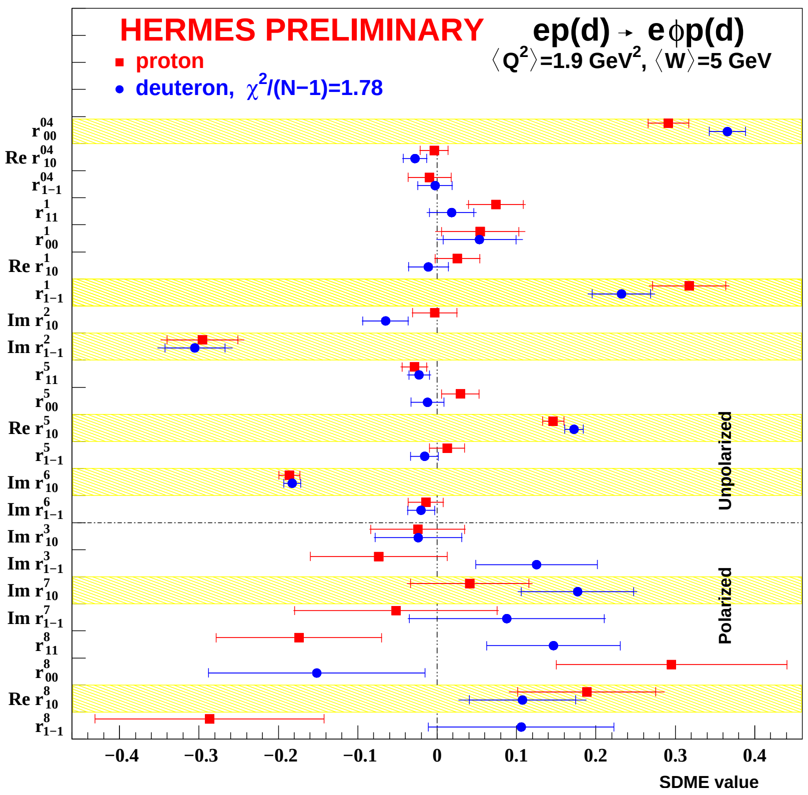
ρ^0 Rest Frame

Measured SDMEs

- In case of SCHC: only 7 non-zero SDMEs

$$\gamma^* p(d) \to \rho^0 p(d) \qquad \gamma^* p(d) \to \phi p(d)$$





- Violations of SCHC observed
- Results consistent with SCHC

$\gamma^* \rightarrow$ *VM Helicity Transfer*

Hierarchy of Amplitudes

- ρ^0 meson: $|T_{00}| \sim |T_{11}| \gg |T_{01}| > |T_{10}| \gtrsim |T_{1,-1}|$
- ϕ meson SDMEs consistent with SCHC ($|T_{00}| \sim |T_{11}|$)

Assuming SCHC

- $V_L - V_T$ separation is equivalent to $\gamma^*_L - \gamma^*_T$ separation
- $R = \frac{\sigma_L}{\sigma_T} = \frac{1}{\epsilon} \frac{r^{04}_{00}}{1 - r^{04}_{00}}$,

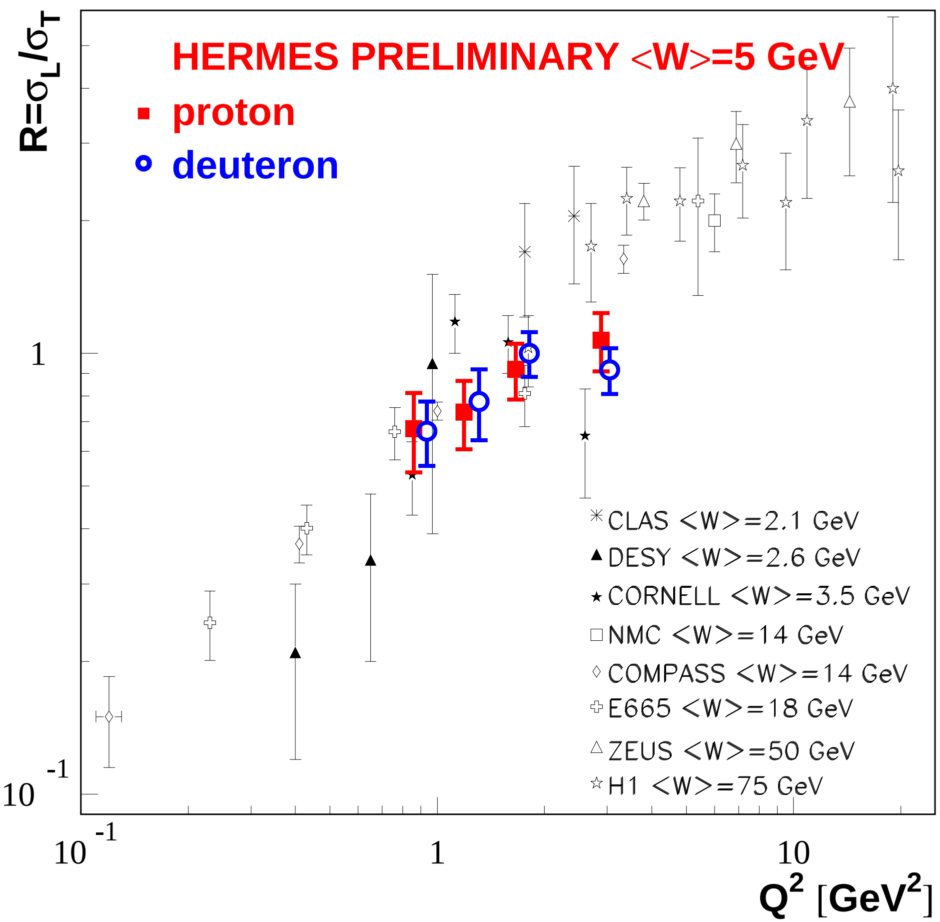
  Here

  - r^{04}_{00} represents the longitudinal VM polarization
  - $\sigma_{\gamma^* p \rightarrow V p} = \sigma_T + \epsilon \sigma_L$

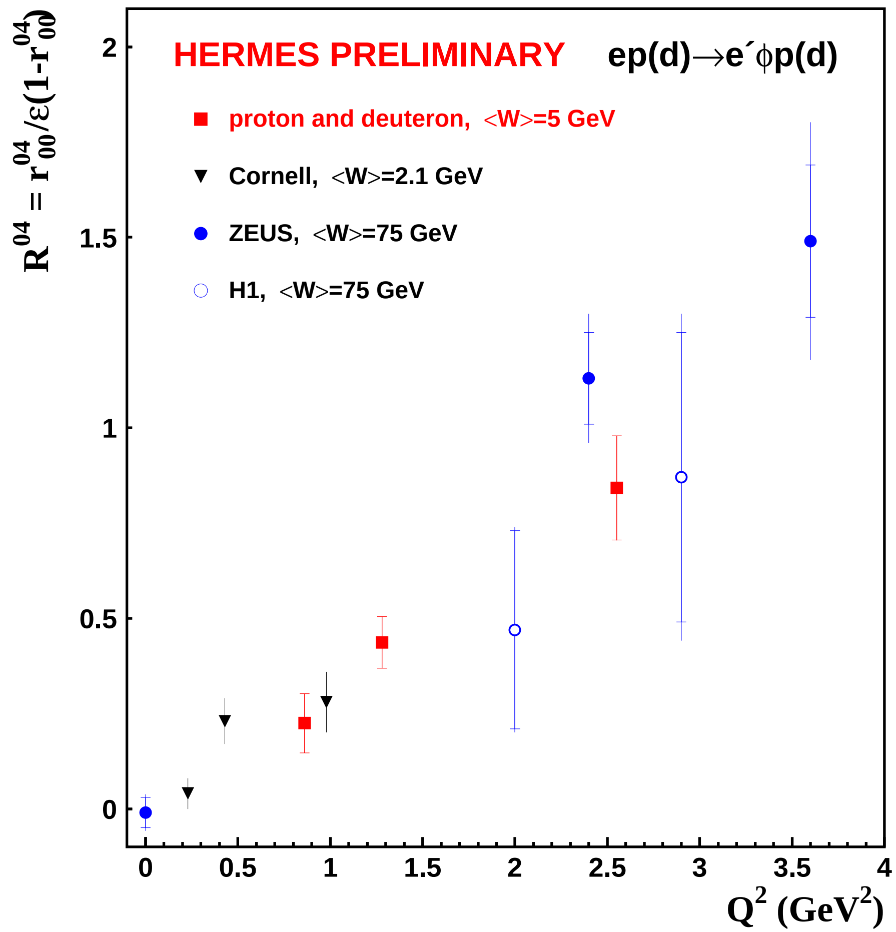
hermes

Results for $R = \sigma_L/\sigma_T$

$\gamma^* p(d) \to \rho^0 p(d)$



$\gamma^* p(d) \to \phi p(d)$



- R determined under the assumption of SCHC

Transverse Target Spin Asymmetry

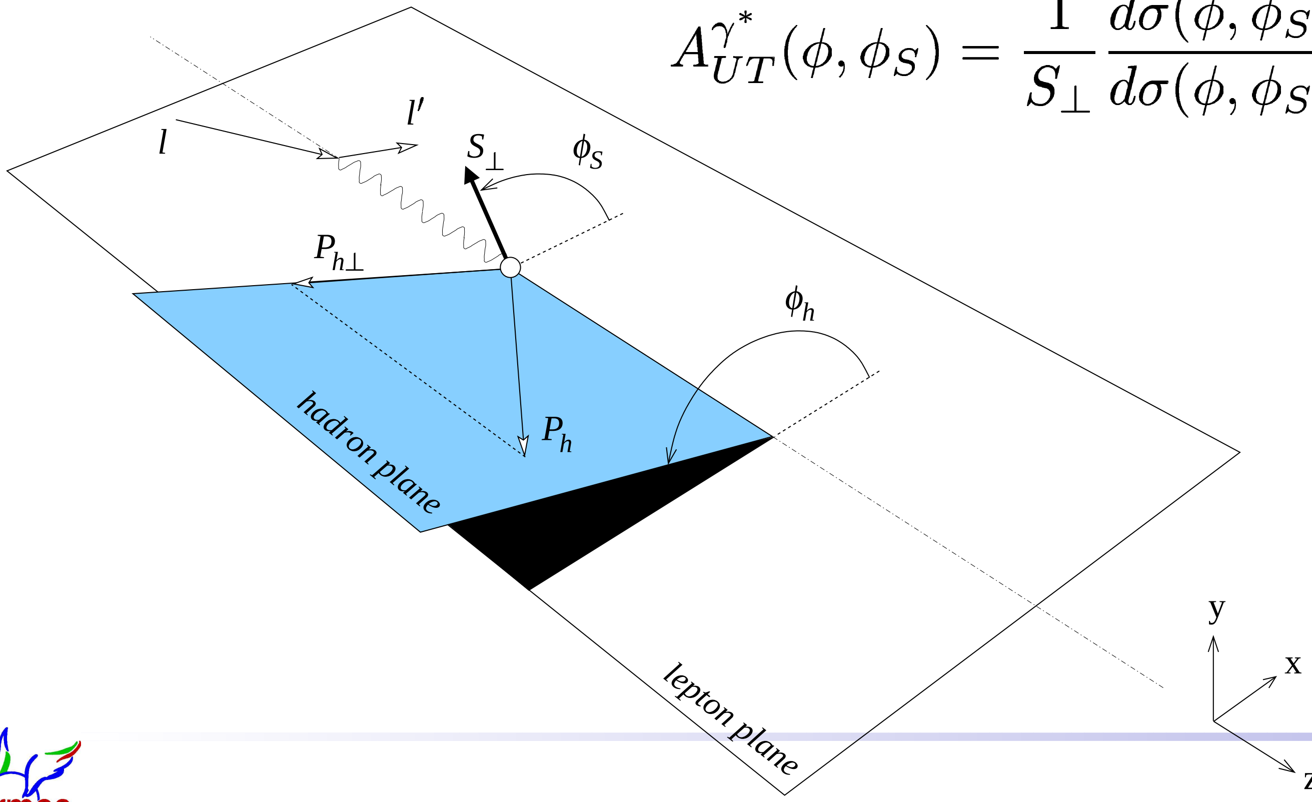
- Angular distribution for polarized target (unpol. beam)

$$W(\phi, \phi_S, \boldsymbol{S}) = W_{UU}(\phi) + S_{||} W_{UL}(\phi) + S_{\perp} W_{UT}(\phi, \phi_S)$$

- Sensitivity to $S_{\perp}$ dependence: Transverse Target Spin Asymmetry

(Trento Convention: Phys. Rev. D70 (2004) 117504)

$$A_{UT}^{\gamma^*}(\phi, \phi_S) = \frac{1}{S_{\perp}} \frac{d\sigma(\phi, \phi_S) - d\sigma(\phi, \phi_S + \pi)}{d\sigma(\phi, \phi_S) + d\sigma(\phi, \phi_S + \pi)}$$



GPD Calculations for A_{UT} ($\gamma_L^* p \to \rho_L^0 p$)

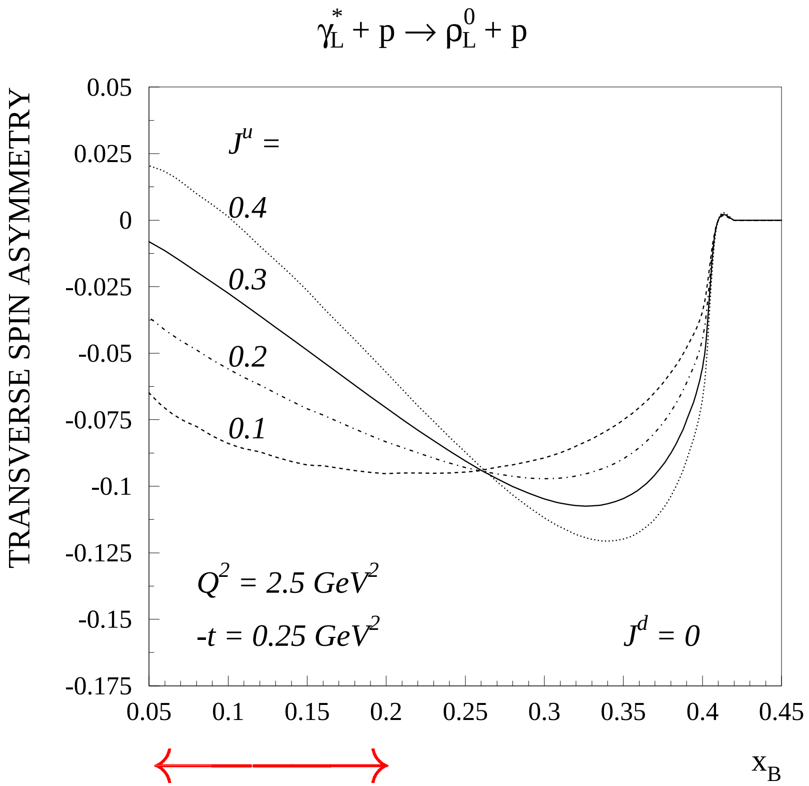
At leading twist:

- Longitudinally polarized γ^* and ρ^0
- Sensitivity to E, H interference term

$$A_{UT} \sim \sin(\phi - \phi_s) \mathcal{I}_{EH}$$

- Dependence on J^u $\Longrightarrow$ (quark GPDs)
- Calculations including gluon contribution available

(Ellinghaus et al.: Eur. Phys. J. C46 (2006) 729-739.)



Goeke, Polyakov, Vanderhaeghen: Prog. Part. Nucl. Phys. 47 (2001) 401

- $$\mathcal{A}_{GPV} = -\frac{2}{\pi} A_{UT}^{\sin(\phi-\phi_s)}$$

$\rho_L - \rho_T$ Separation of A_{UT}

Using the ρ^0 decay angle $\theta_{\pi\pi}$:

$$\frac{d\sigma^{ij}_{mn}}{d(\cos\theta_{\pi\pi})} = \frac{3\cos^2\theta_{\pi\pi}}{2}\,\sigma^{ij}_{mn}(\gamma^* p \to \rho_L\, p) + \frac{3\sin^2\theta_{\pi\pi}}{4}\,\sigma^{ij}_{mn}(\gamma^* p \to \rho_T\, p)$$

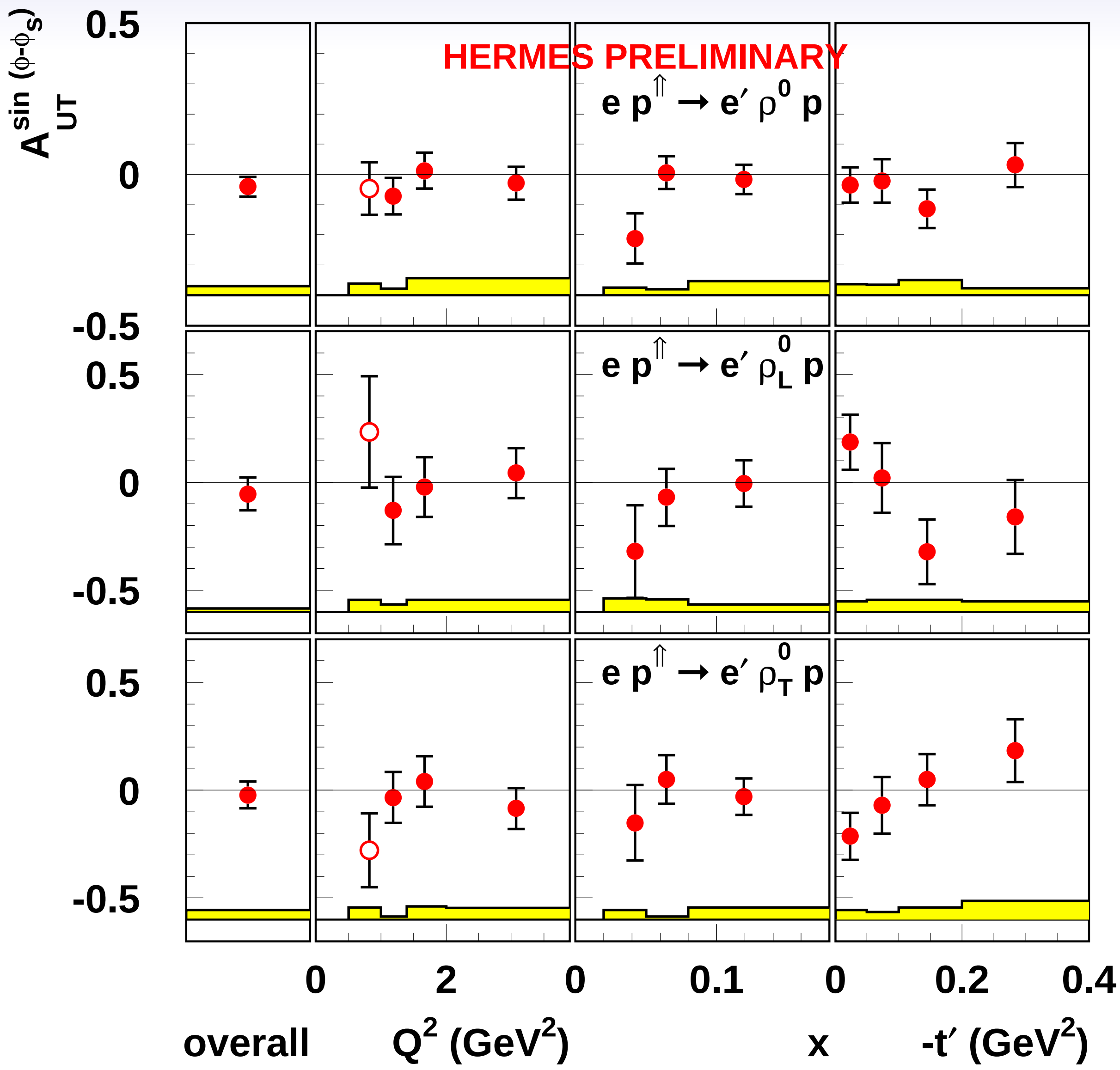
- Expressed in terms of $\gamma^* p$ cross sections / interference terms σ^{ij}_{mn} $(\gamma^* p \to \rho^0 p)$ *(Diehl, Sapeta: hep-ph/0503023)*
  - virtual photon helicity: $m, n = 0, \pm 1$
  - proton spin state: $i, j = \pm(\frac{1}{2})$
- To be used: SDMEs for a polarized target *(Diehl: hep-ph arXiv:0704.1565)*

Angular $(\theta_{\pi\pi}, \phi, \phi_s)$ distribution can be written as:

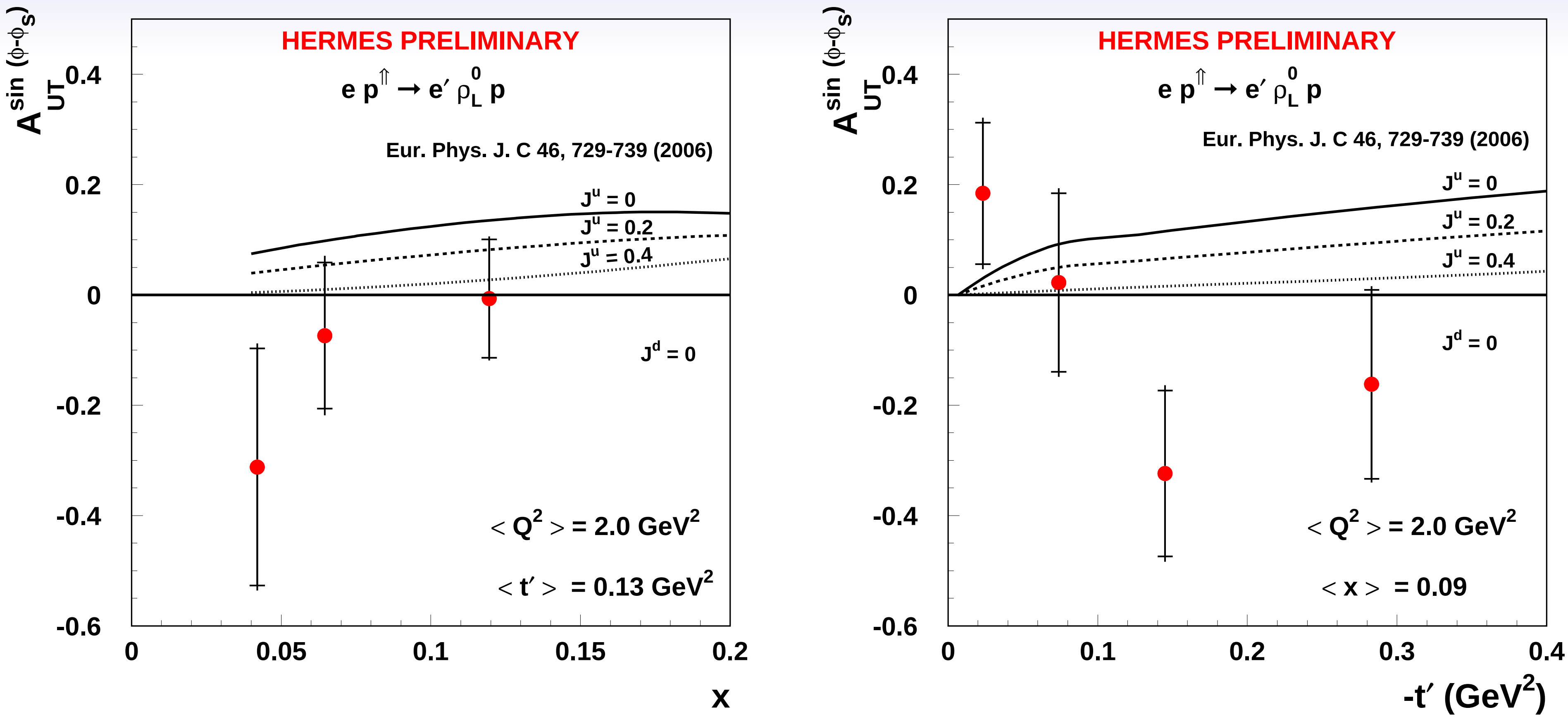
$$W(\theta_{\pi\pi}, \phi, \phi_s) \propto \Big[\cos^2\theta_{\pi\pi}\; r^{04}_{00} \Big(1 + A_{UU,\rho_L}(\phi) + P_\perp A^l_{UT,\rho_L}(\phi,\phi_s)\Big) + \frac{1}{2}\sin^2\theta_{\pi\pi}\,(1 - r^{04}_{00})\Big(1 + A_{UU,\rho_T}(\phi) + P_\perp A^l_{UT,\rho_T}(\phi,\phi_s)\Big) \Big]$$

$P_\perp$ defined w.r.t. beam direction: $P_\perp \approx S_\perp$, $|S_{||}/P_\perp| \lesssim 0.15$, $\langle S_{||}\rangle \approx 0$

Results $A_{UT}^{\sin(\phi-\phi_s)}$ Separately for ρ_L and ρ_T



Comparison with Theoretical Calculations



- Results favour positive value of J^u
- Model dependent determination of J^u requires more effort

Conclusions

- Cross section of exclusive π^+ production measured
  - Results in agreement with GPD based calculation at low values of $-t'$
  - Paper submitted to PLB *(arXiv: 0707.0222)*
- Unpolarized SDMEs measured for both exclusive ρ^0 and ϕ production
- A_{UT} in exclusive ρ^0 production extracted for the first time separately for ρ_L and ρ_T
  - Results allow model dependent estimate of the value of J^u
  - Analysis will be updated using the new SDME formalism for a transversely polarized target