Probing the 3D nucleon structure using the polarized high energy muon beam at CERN ***with polarized target and recoil detection*** between 2018 and 2025

Nicole d'Hose, GDR PH-QCD, Saclay Nov 27, 2013

Until 2016-17: LH2 target + recoil proton detection

cross-sections on proton for $\mu^{+\downarrow}$, $\mu^{-\uparrow}$ beam with opposite charge & spin (e_μ& P_μ)

Ex DVCS:

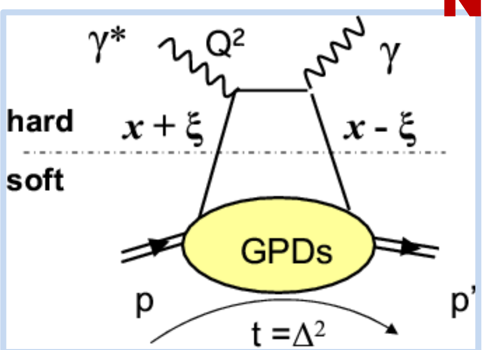
$$d\sigma_{(\mu p \to \mu p \gamma)} = d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + P_\mu\, d\sigma^{DVCS}_{pol} + e_\mu\, a^{BH}\, \mathcal{Re}\, A^{DVCS} + e_\mu\, P_\mu\, a^{BH}\, \mathcal{Im}\, A^{DVCS}$$

Charge & Spin Difference and Sum **with LH2 target:**

$$\mathcal{D}_{CS,U} \equiv d\sigma(\mu^{+\downarrow}) - d\sigma(\mu^{-\uparrow}) \propto c_0^{Int} + c_1^{Int} \cos\phi \quad \text{and} \quad c_{0,1}^{Int} \sim F_1\, \mathcal{Re}\, \mathcal{H}$$

$$\mathcal{S}_{CS,U} \equiv d\sigma(\mu^{+\downarrow}) + d\sigma(\mu^{-\uparrow}) \propto d\sigma^{BH} + c_0^{DVCS} + K.s_1^{Int} \sin\phi \quad \text{and} \quad s_1^{Int} \sim F_1\, \mathcal{Im}\, \mathcal{H}$$

Note: dominance of H at COMPASS kinematics



$\xi \sim x_B / (2-x_B)$

$$\mathcal{Im}\, \mathcal{H}(\xi,t) = H(x=\xi,\xi,t)$$

$$\mathcal{Re}\, \mathcal{H}(\xi,t) = \mathcal{P}\int dx \frac{H(x,\xi,t)}{x-\xi} = \mathcal{P}\int dx \frac{H(x,x,t)}{x-\xi} + \mathcal{D}(t)$$

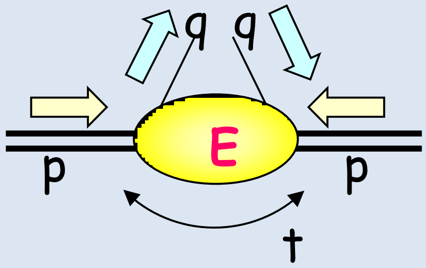
Re part of the *Compton Form Factors* linked to the *D term*

After 2018: with a transversely polarized target?

Constraints on the 'elusive' chiral-even GPD E

the GPD E allows nucleon helicity flip

so it is related to the angular momentum

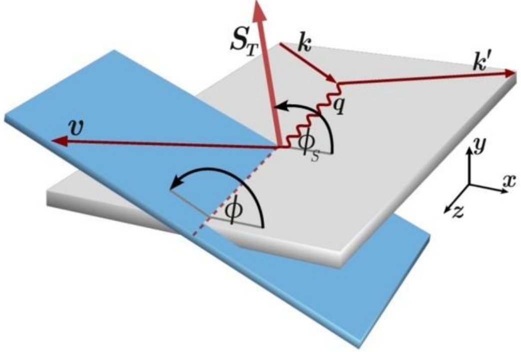


Ji sum rule: $2J^q = \int x \, (H^q(x,\xi,0) + E^q(x,\xi,0)) \, dx$

The GPD E is the 'Holy-Grail' of the GPD quest

And also constraints on the chiral-odd GPDs H_T and $\bar{E}_T$

exclusive ρ^0 production



$$\left[\frac{\alpha_{em}}{8\pi^3}\frac{y^2}{1-\varepsilon}\frac{1-x_B}{x_B}\frac{1}{Q^2}\right]^{-1}\frac{d\sigma}{dx_{Bj}\,dQ^2\,dt\,d\phi\,d\phi_s}$$

$$= \frac{1}{2}\left(\sigma_{++}^{++}+\sigma_{++}^{--}\right)+\varepsilon\sigma_{00}^{++}-\varepsilon\cos(2\phi)\,\mathrm{Re}\,\sigma_{+-}^{++}-\sqrt{\varepsilon(1+\varepsilon)}\cos\phi\,\mathrm{Re}\left(\sigma_{+0}^{++}+\sigma_{+0}^{--}\right)$$

$$-P_\ell\sqrt{\varepsilon(1-\varepsilon)}\sin\phi\,\mathrm{Im}\left(\sigma_{+0}^{++}+\sigma_{+0}^{--}\right)$$

transv. polar. target

$$-S_T\left[\sin(\phi-\phi_S)\,\mathrm{Im}\left(\sigma_{++}^{+-}+\varepsilon\sigma_{00}^{+-}\right)+\frac{\varepsilon}{2}\sin(\phi+\phi_S)\,\mathrm{Im}\,\sigma_{+-}^{+-}+\frac{\varepsilon}{2}\sin(3\phi-\phi_S)\,\mathrm{Im}\,\sigma_{+-}^{-+}\right.$$

$$\left.+\sqrt{\varepsilon(1+\varepsilon)}\sin\phi_S\,\mathrm{Im}\,\sigma_{+0}^{+-}+\sqrt{\varepsilon(1+\varepsilon)}\sin(2\phi-\phi_S)\,\mathrm{Im}\,\sigma_{+0}^{-+}\right]$$

transv. polar. target + long. Polar. beam

$$+S_T P_\ell\left[\sqrt{1-\varepsilon^2}\cos(\phi-\phi_S)\,\mathrm{Re}\,\sigma_{++}^{+-}\right.$$

$$\left.-\sqrt{\varepsilon(1-\varepsilon)}\cos\phi_S\,\mathrm{Re}\,\sigma_{+0}^{+-}-\sqrt{\varepsilon(1-\varepsilon)}\cos(2\phi-\phi_S)\,\mathrm{Re}\,\sigma_{+0}^{-+}\right]$$

σ : $i\,j$ for nucleon helicity; mn for photon helicity

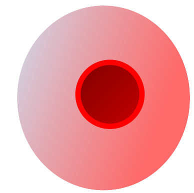
exclusive ρ^0 production with transv. polarized target

Chiral-even GPDs

σ

$$H \rightarrow q$$

$$p^{\uparrow} + \gamma^*_L \rightarrow p^{\uparrow} + \rho_L$$

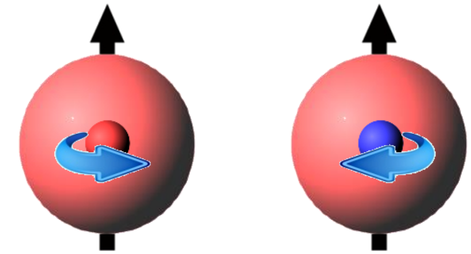


$A_{UT}^{\sin(\phi - \phi_S)}$

$$E \longleftrightarrow f_{1T}^{\perp}$$

$$p^{\uparrow} + \gamma^*_L \rightarrow p^{\downarrow} + \rho_L$$

Sivers correlates
quark k_T and nucleon spin (transv. pol. N)



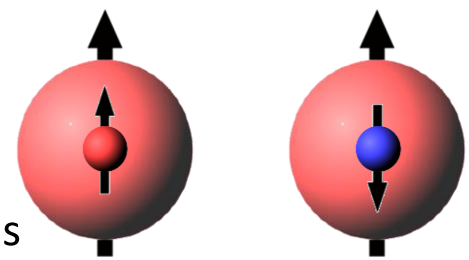
Chiral-odd GPDs

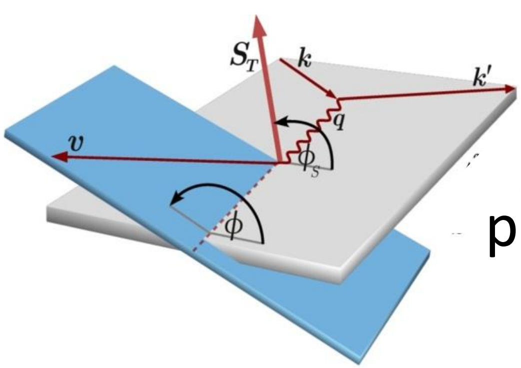
$A_{UT}^{\sin(\phi_S)}$

$$H_T \longleftrightarrow h_1$$

$$p^{\uparrow} + \gamma^*_T \rightarrow p^{\downarrow} + \rho_L$$

Transversity correlates
quark spin and nucleon spin (transv. pol. N)

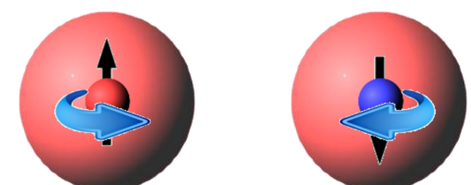




$$\bar{E}_T = 2\tilde{H}_T + E_T \longleftrightarrow h_1^{\perp}$$

$$p^{\uparrow} + \gamma^*_T \rightarrow p^{\uparrow} + \rho_L$$

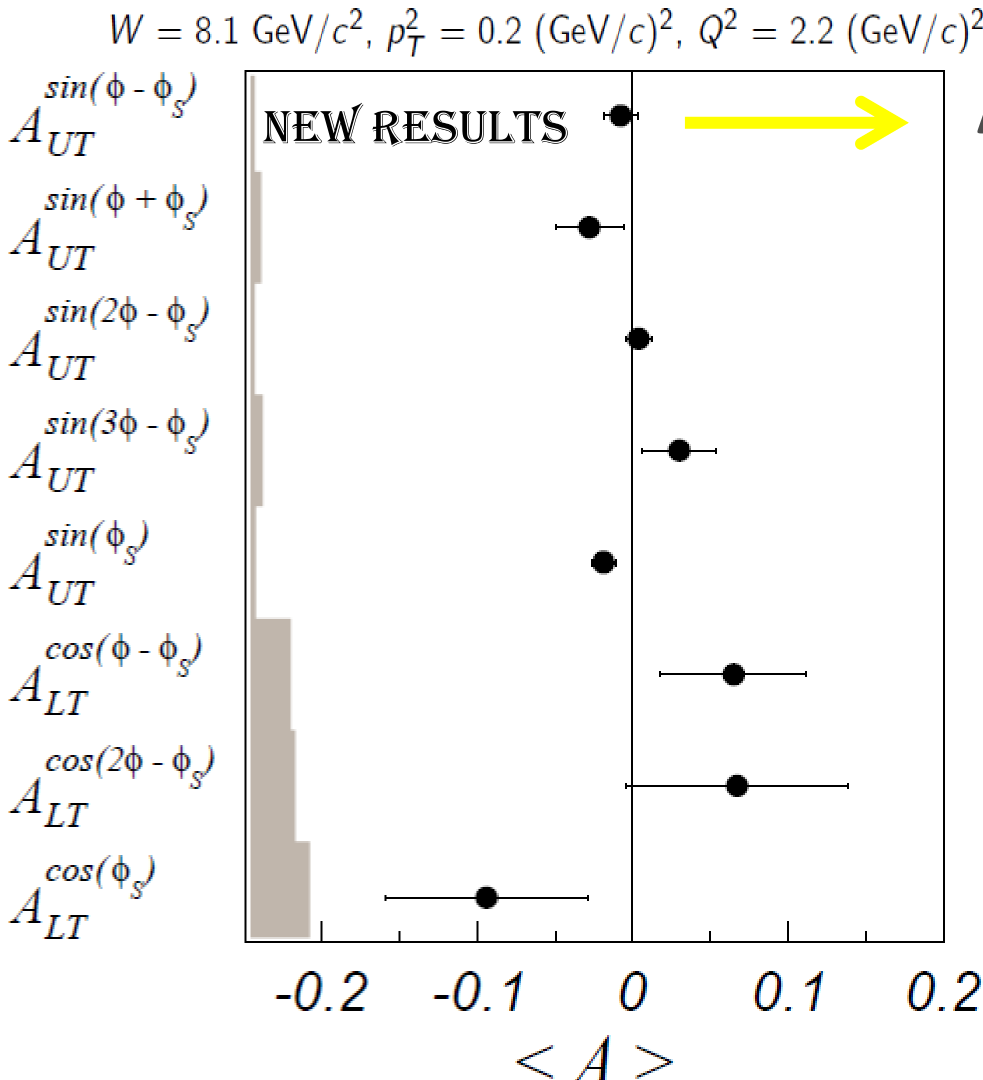
Boer-Mulders correlates
quark k_T and quark transverse spin (unpol N)



exclusive ρ^0 production –Transv. Polar. Target

$\mu\ p \rightarrow \mu' + \rho^0 + p_{\text{non détecté}}$
$\hookrightarrow \pi^+\pi^-$

COMPASS 2007-2010,without recoil detector



$$A_{UT}^{\sin(\phi-\phi_S)} \propto Im(\mathcal{E}^* \mathcal{H})$$

$E\rho^0 \propto 2/3\ E^u + 1/3\ E^d + 3/8\ E^g$
Cancellation between gluon and sea contributions and **$E^{u\ val} \sim -E^{d\ val}$**

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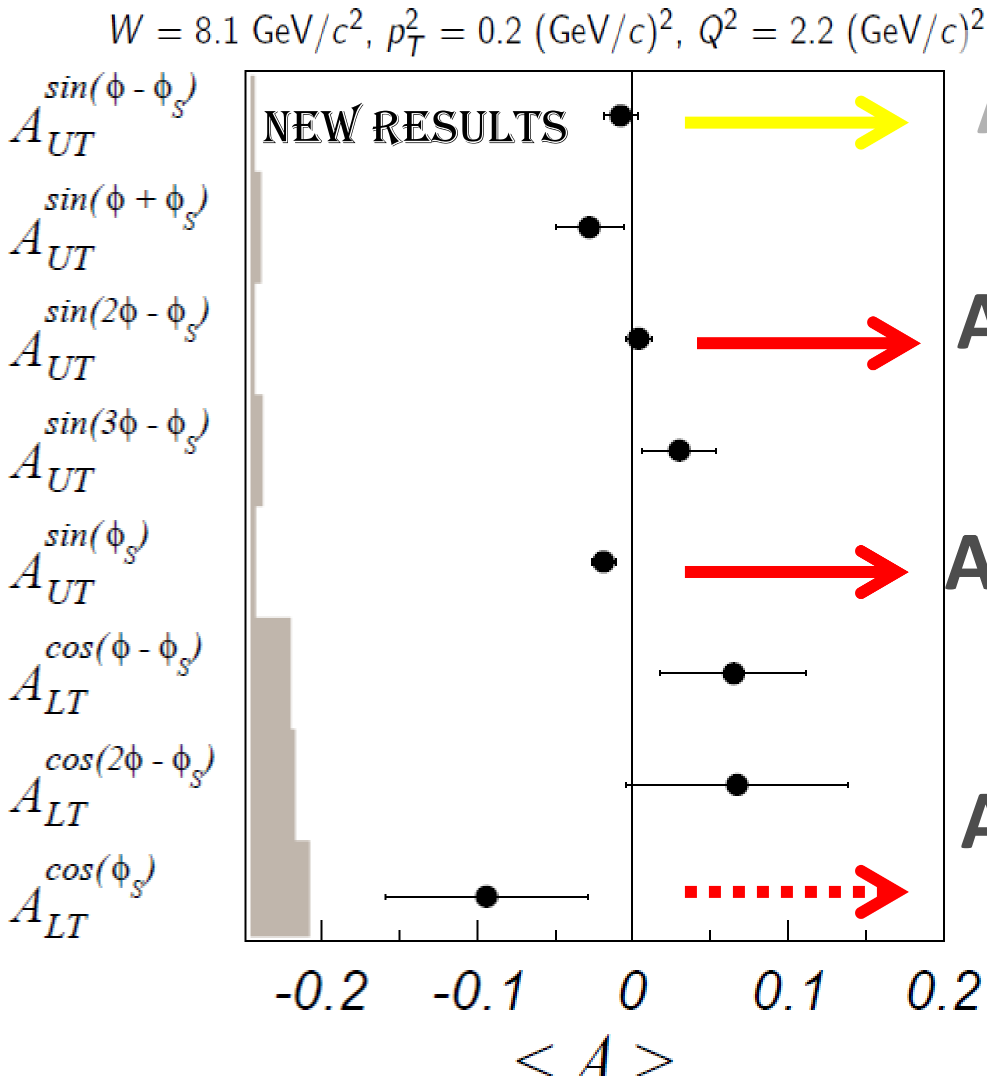
ω Production would be more promising

exclusive ρ^0 production –Transv. Polar. Target

$\mu\ p \rightarrow \mu' + \rho^0 + p_{\text{non détecté}}$

$\hookrightarrow \pi^+\pi^-$

COMPASS 2007-2010,without recoil detector



$A_{UT}^{\sin(\phi - \phi_S)} \propto Im(\mathcal{E}^* \mathcal{H})$

$A_{UT}^{\sin(2\phi - \phi_S)} \propto Im(\mathcal{E}^* \bar{\mathcal{E}}_T)$

$A_{UT}^{\sin(\phi_S)} \propto Im(\mathcal{E}^* \bar{\mathcal{E}}_T - \mathcal{H}^* \mathcal{H}_T)$

$A_{LT}^{\cos(\phi_S)} \propto Re(\mathcal{E}^* \bar{\mathcal{E}}_T - \mathcal{H}^* \mathcal{H}_T)$

➔ H_T should be not small

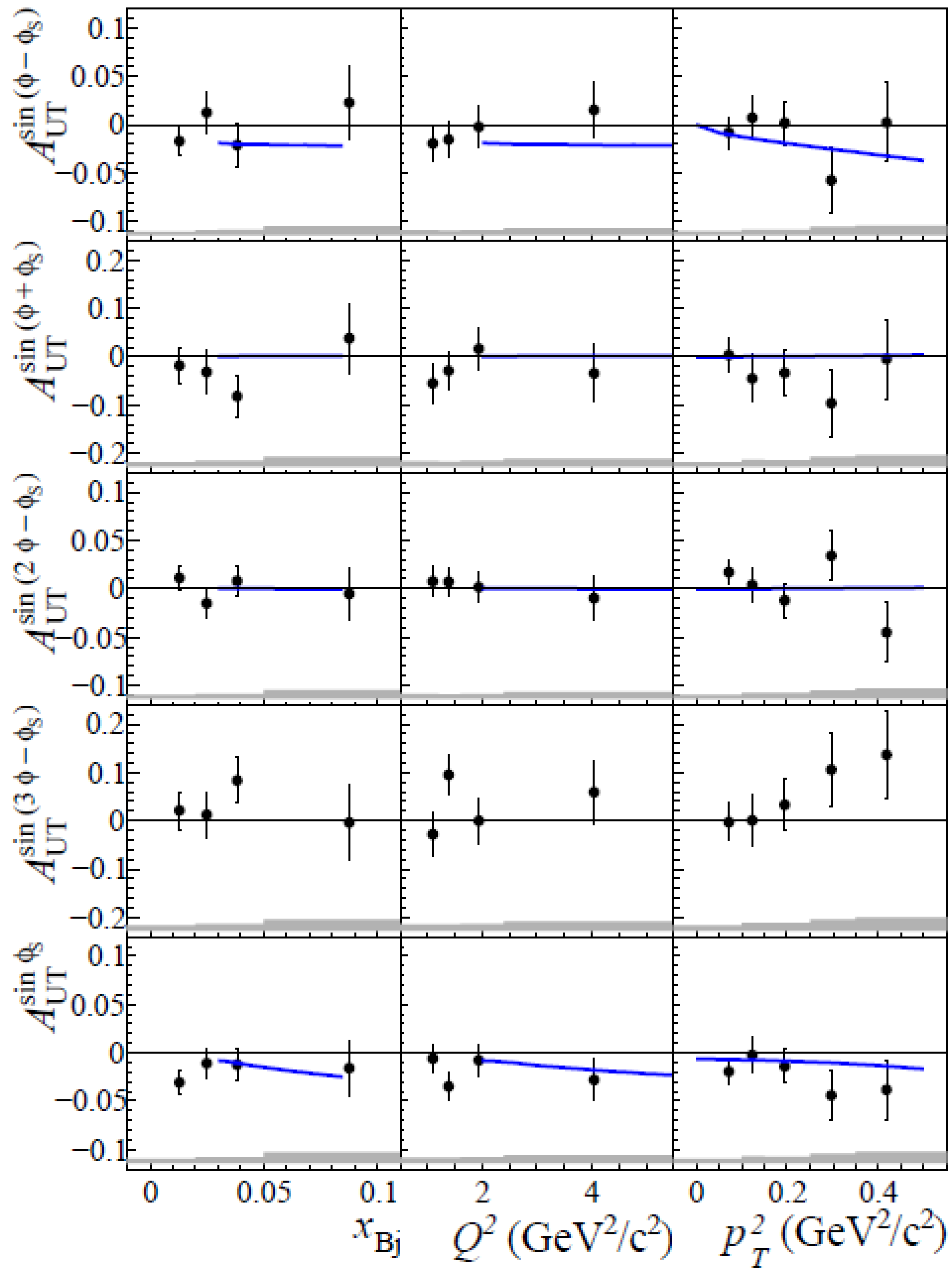
Submited to PLB

$\mu \; p \rightarrow \mu' + \rho^0 + p_{\text{non détecté}}$

$\hookrightarrow \pi^+\pi^-$

COMPASS 2007-2010,without recoil detector

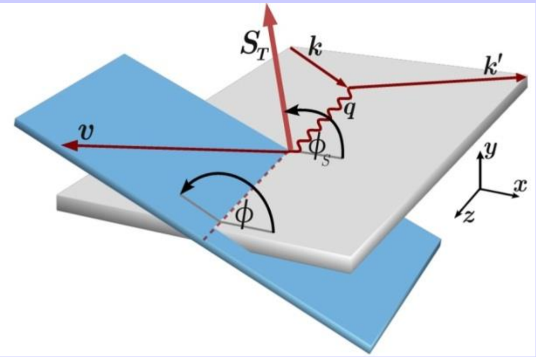
Submited to PLB



Plan for DVCS : Transv. Polarized target

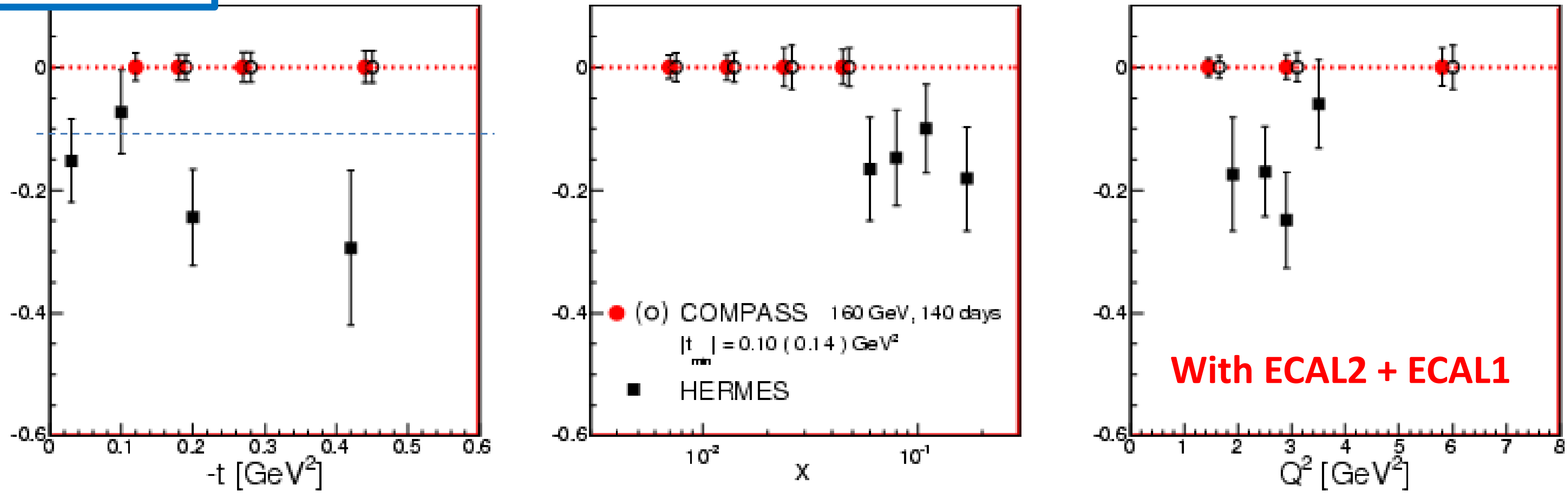
with $\mu^{+\downarrow}$, $\mu^{-\uparrow}$ **beam** and **transversely** polarized NH3 (proton) target

$$\mathcal{D}_{CS,T} \equiv d\sigma_T(\mu^{+\downarrow}) - d\sigma_T(\mu^{-\uparrow})$$
$$\propto Im(F_2\mathcal{H} - F_1\mathcal{E})\sin(\phi-\phi_S)\cos\phi$$



$A_{CS,T}^{\sin(\phi-\phi_s)\cos\phi}$ **related to H and E**

2 years of data 160 GeV muon beam
1.2 m polarised NH_3 target ε_{global} = 10%



Requirements for an ideal experiment:

- a polarized target inserted inside a recoil proton (neutron) detector
- a target as long as 1 or 2m
- with polarization: longitudinal and transverse
- with the minimum of material budget
  to reach low proton (neutron) momentum
- with the minimum of displacement of the setup, of lost of time…

→ A review of polarized target projects for 4π detectors at MAMI
by Andreas Thomas, Univ. of Mainz