Transverse target spin asymmetries in exclusive ρ^0 muoproduction

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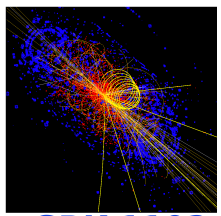
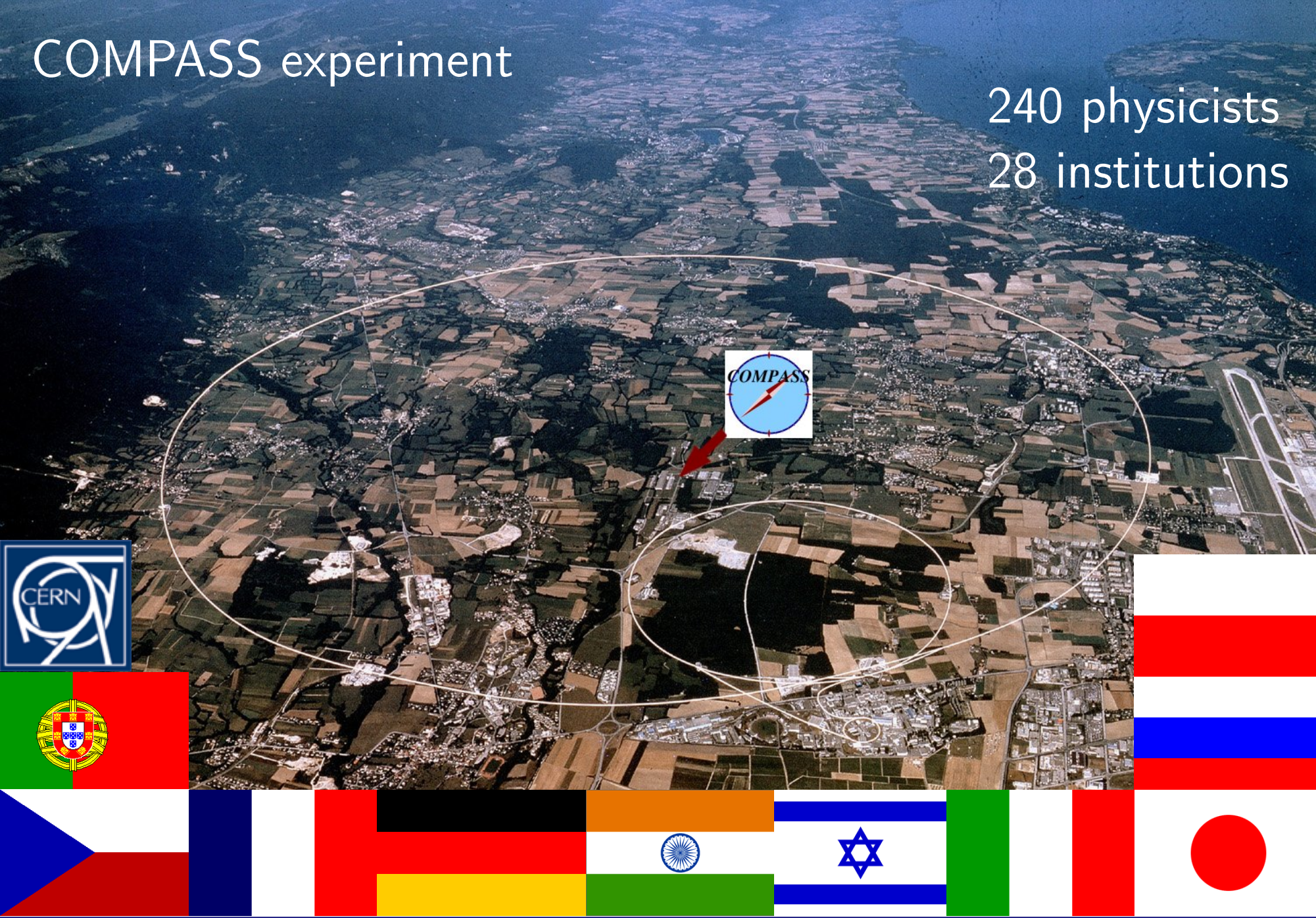
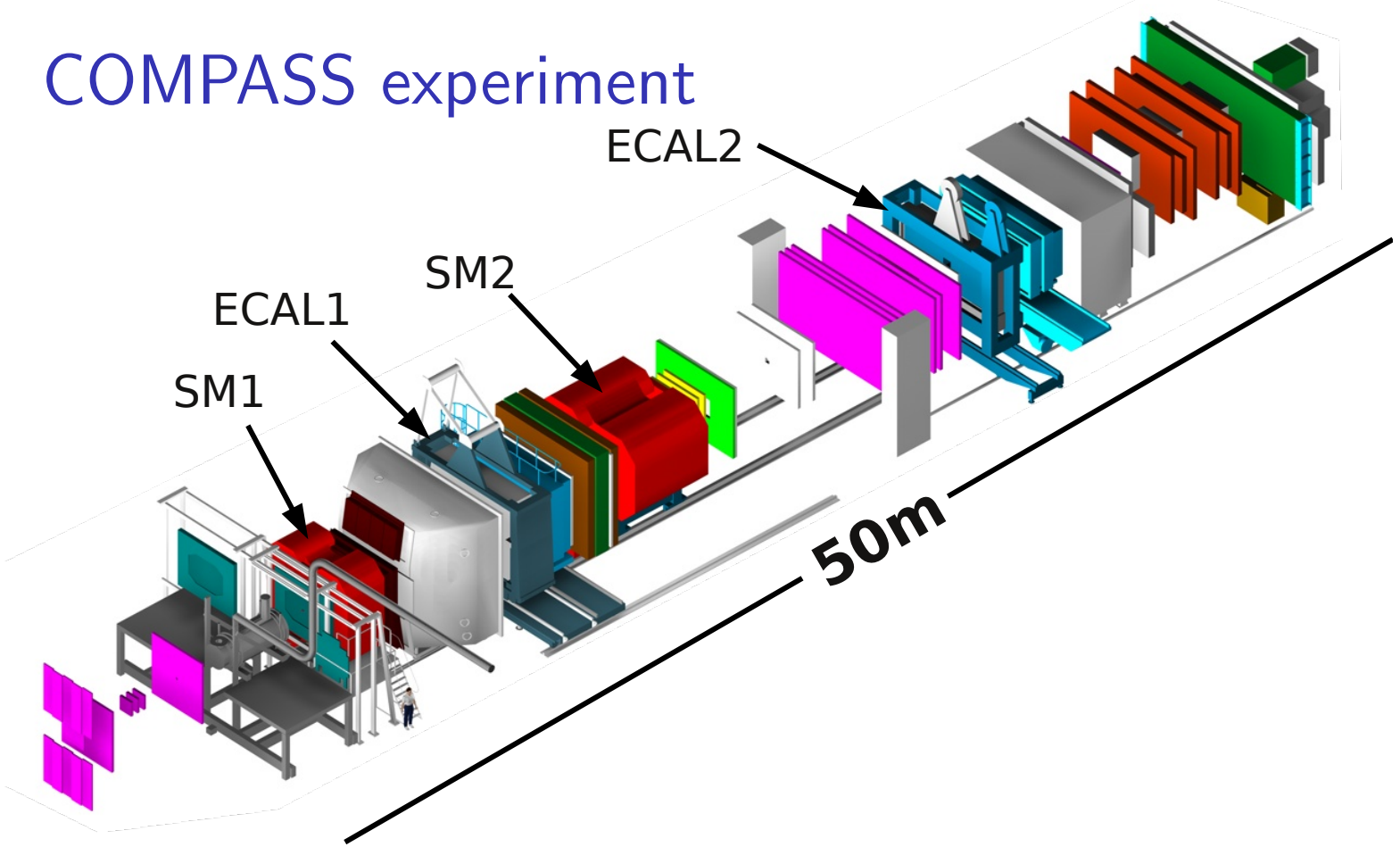


COMPASS experiment

240 physicists
28 institutions

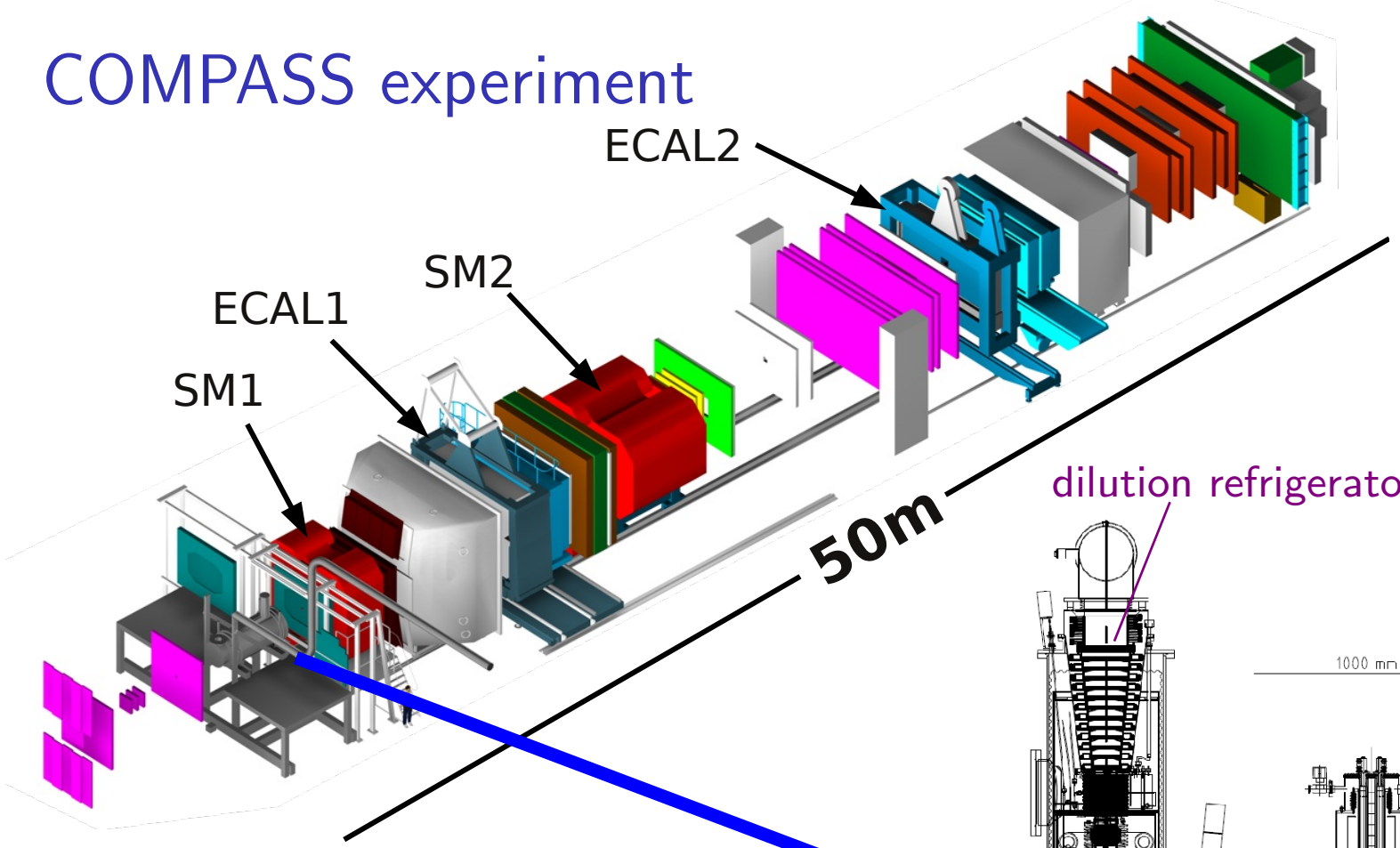


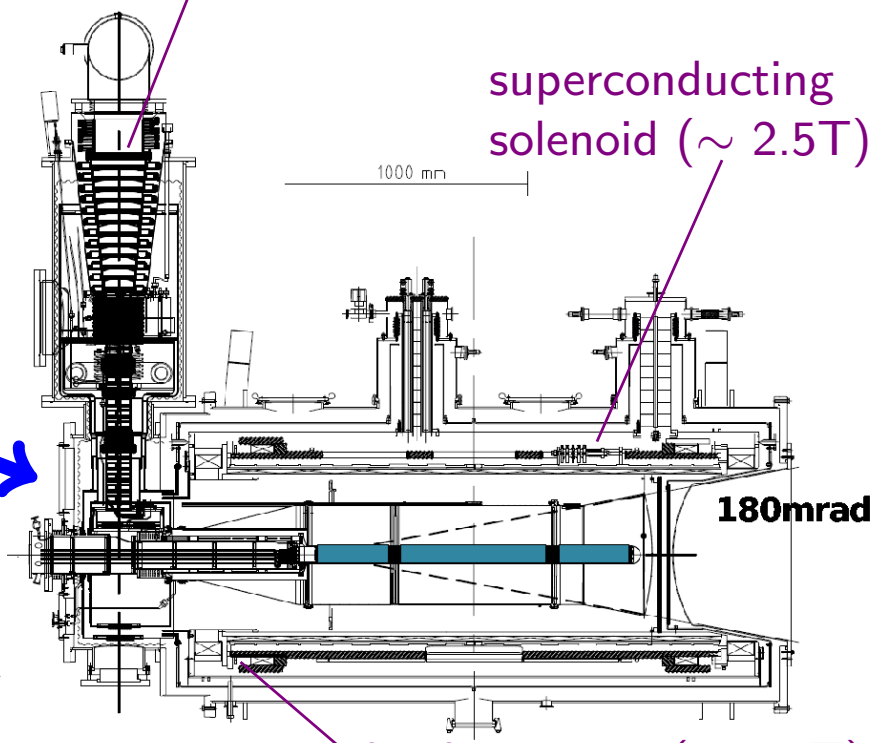
COMPASS experiment



- μ^+ 160 GeV beam from CERN SPS
- Transversely polarized solid state target

COMPASS experiment





- μ^+ 160 GeV beam from CERN SPS
- Transversely polarized solid state target

Hard exclusive ρ^0 production

$$\left[\frac{\alpha_{\rm em}}{8\pi^3}\,\frac{y^2}{1-\varepsilon}\,\frac{1-x_B}{x_B}\,\frac{1}{Q^2}\right]^{-1}\frac{d\sigma}{dx_B\,dQ^2\,d\phi\,d\psi} = \frac{1}{2}\left(\sigma_{++}^{++}+\sigma_{++}^{--}\right)+\varepsilon\sigma_{00}^{++}-\varepsilon\cos(2\phi)\mathrm{Re}\,\sigma_{+-}^{++}$$

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

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

$$+S_L P_\ell\left[\sqrt{1-\varepsilon^2}\,\frac{1}{2}\left(\sigma_{++}^{++}-\sigma_{++}^{--}\right)-\sqrt{\varepsilon(1-\varepsilon)}\,\cos\phi\,\mathrm{Re}\,(\sigma_{+0}^{++}-\sigma_{+0}^{--})\right]$$

transversely polarized target

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

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

transversely polarized target + longitudinally polarized beam

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

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

Diehl & Sapeta
Eur.Phys.J.C 41 (2005)

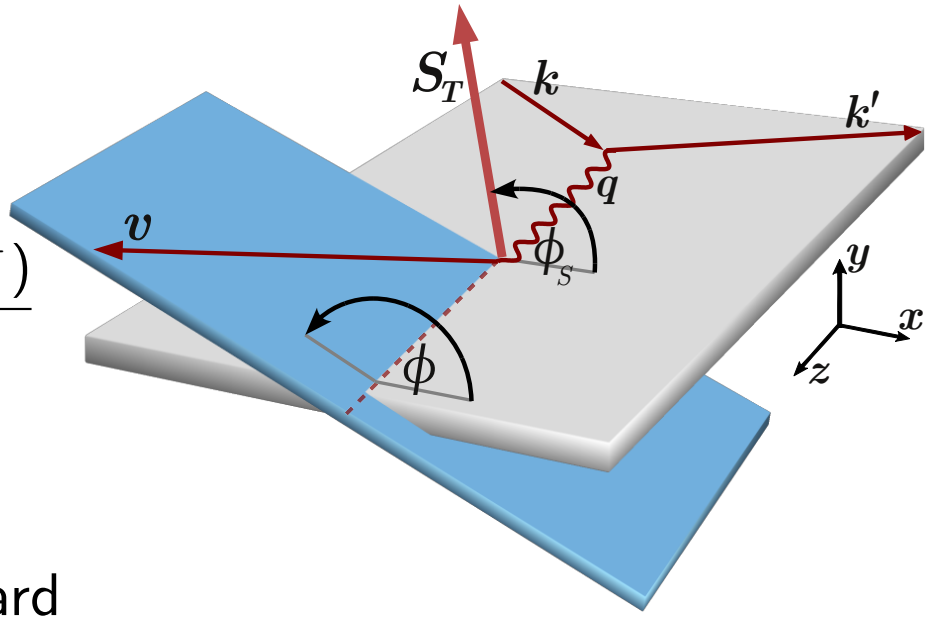
ϵ = virtual photon polarization parameter
σ_{mn}^{ij} = spin dependent photoabsorption cross sections, interference terms
m,n = virtual-photon helicity
i,j = target nucleon helicity

Hard exclusive ρ^0 production

- Factorisation valid for σ_L
- Leading twist term σ_{00}^{+-} sensitive to

$$A_{\mathrm{UT}}^{\sin(\phi-\phi_s)} = -\frac{\mathrm{Im}\,(\sigma_{++}^{+-} + \varepsilon\,\sigma_{00}^{+-})}{\sigma_0}$$

$$\mathrm{Im}\,\frac{d\sigma_{00}^{+-}}{dt} \sim \mathrm{Im}\,(\mathcal{E}^{\star}\mathcal{H})$$



- $\mathcal{E}$ & $\mathcal{H}$ are convolution integrals of hard scattering kernels and the ρ^0 distribution amplitude with GPDs E & H where:

$$E_{\rho^0} = \frac{1}{\sqrt{2}}\left(\frac{2}{3}E^u + \frac{1}{3}E^d + \frac{3}{4}E^g\right)$$

- Additional asymmetries contain higher twist terms

$\rightarrow$ Constrain GPD E

Exclusive ρ^0 production at COMPASS

All measurements done with μ^+ 160 GeV beam with polarization $\langle P_B \rangle \sim 80\%$ and a transversely polarized target

^{6}LiD target (polarized deuterons) 2003&2004

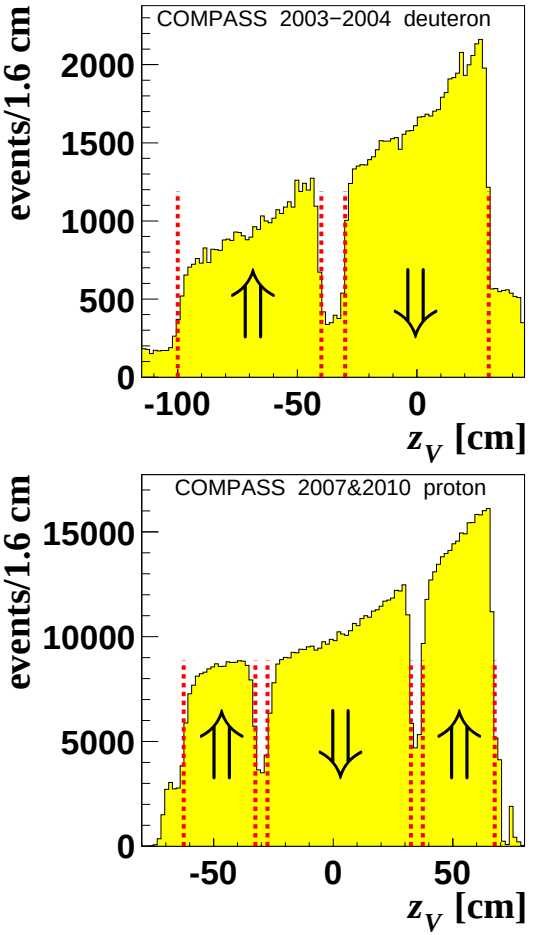
$\rightarrow$ Dilution factor $\langle f \rangle \sim 0.45$

$\rightarrow$ Polarization $\langle P_T \rangle \sim 50\%$

NH_3 target (polarized protons) 2007&2010

$\rightarrow$ Dilution factor $\langle f \rangle \sim 0.25$

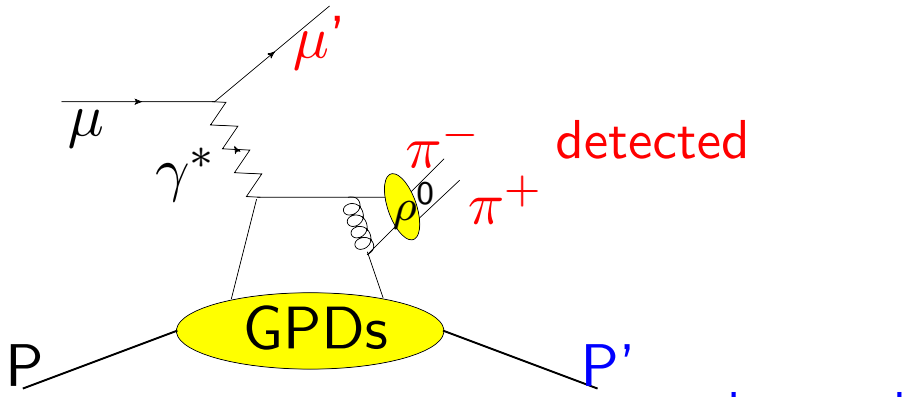
$\rightarrow$ Polarization $\langle P_T \rangle \sim 80\%$

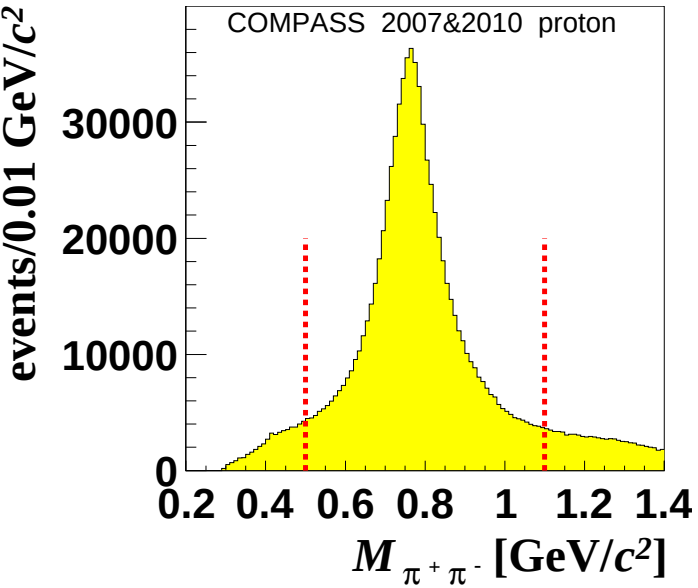


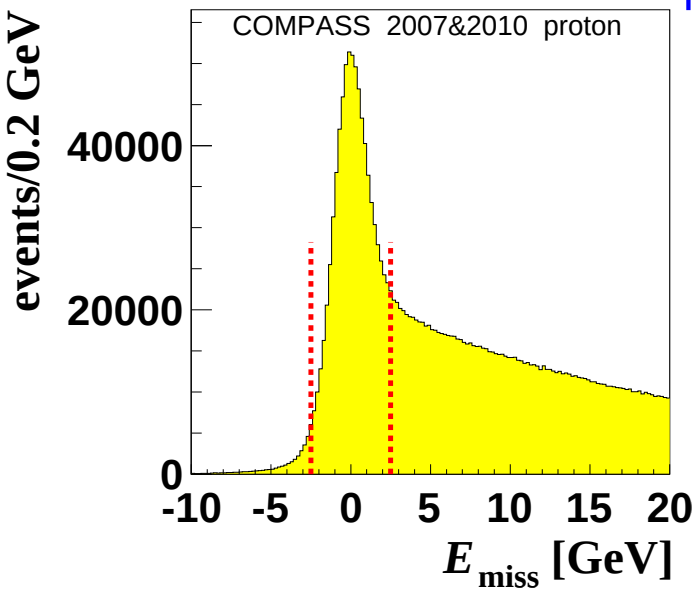
change of polarization $\sim$ weekly

Exclusive ρ^0 production - event selection

$$\mu + N^{\uparrow} \rightarrow \mu' + N' + \rho^0$$
$$\rho^0 \rightarrow \pi^+ + \pi^-$$







- Peak at ρ^0 mass ~ 0.775 GeV/c^2
- Signature for exclusivity $E_{miss} \sim 0$

$$E_{\text{miss}} = \frac{(p+q-\rho)^2 - p^2}{2 \cdot M_p} = \frac{M_X^2 - M_p^2}{2 \cdot M_p}$$

Semi-inclusive background estimation

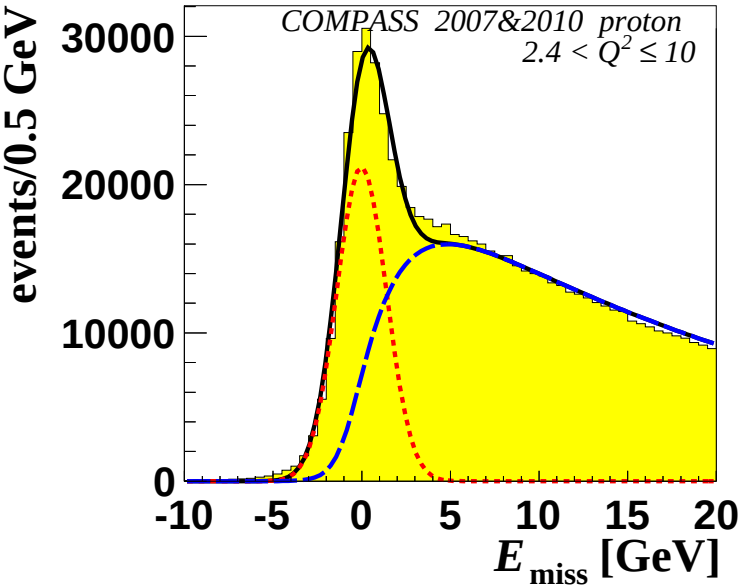
- LEPTO MC (COMPASS tuning)

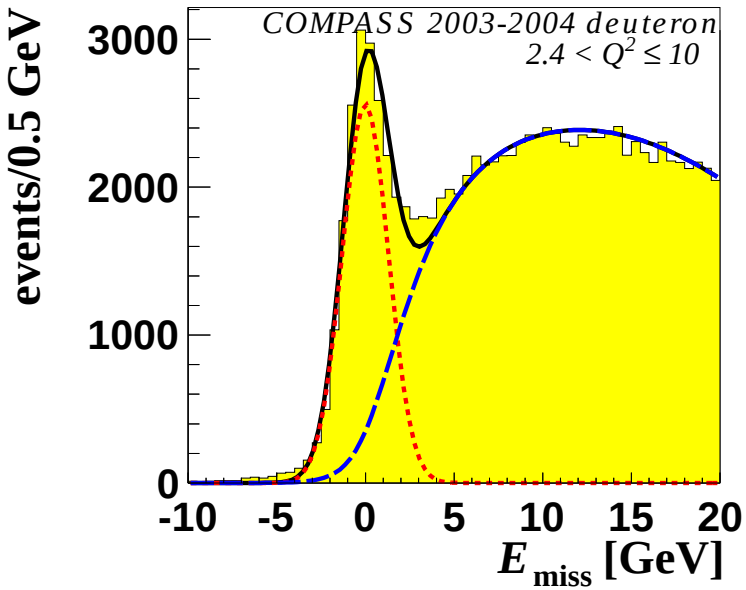
1.) Parameterization of MC:

- MC weighted with the like sign sample

$$w = \frac{N^{h^+h^+}_{\text{data}}(E_{\text{miss}}) + N^{h^-h^-}_{\text{data}}(E_{\text{miss}})}{N^{h^+h^+}_{\text{MC}}(E_{\text{miss}}) + N^{h^-h^-}_{\text{MC}}(E_{\text{miss}})}$$

- Parameterize the E_{miss} shape of weighted MC
- Binning appropriate for asymmetry extraction (x_{Bj}, Q^2 or p_T^2, target cell)





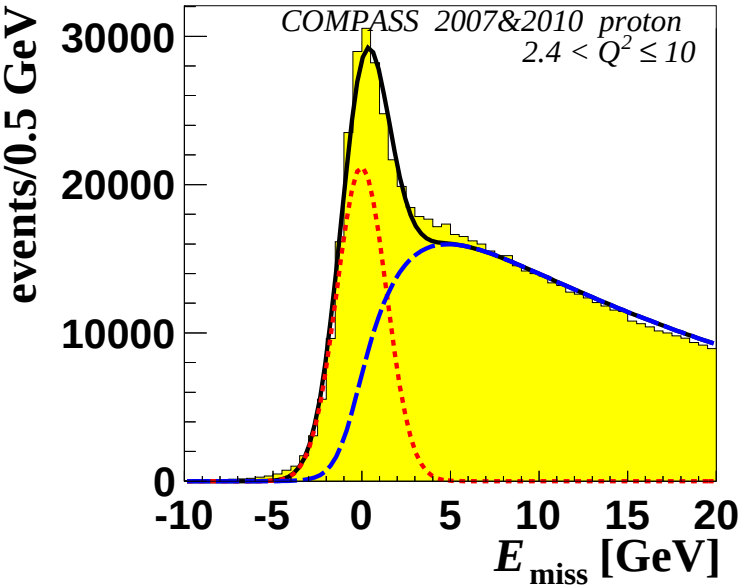
Semi-inclusive background estimation

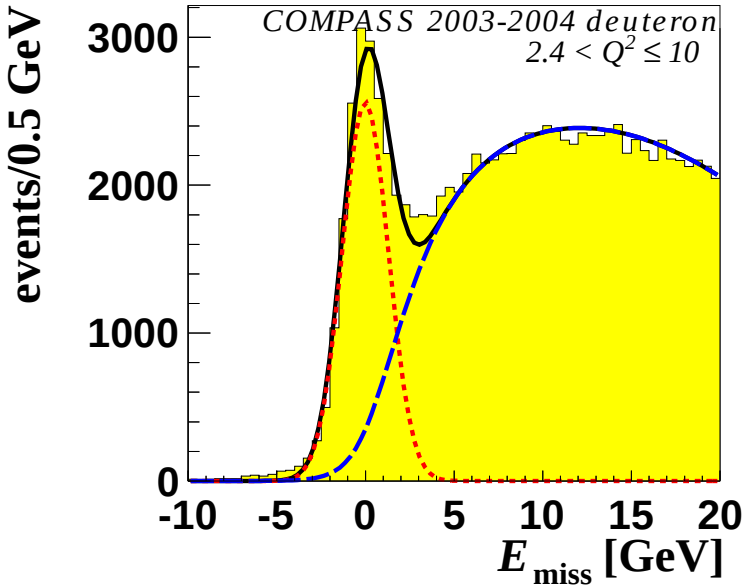
- LEPTO MC (COMPASS tuning)

2.) Fit to data:

- Normalize MC E_{miss} shape to data by performing a two component signal (gauss) + background fit
- ϕ, ϕ_S distribution for $7 < E_{\text{miss}} < 20$ GeV scaled with the number of background events and subtracted from ϕ, ϕ_S distribution in signal range $-2.5 < E_{\text{miss}} < 2.5$ GeV
- Asymmetry extraction with corrected ϕ, ϕ_S distribution

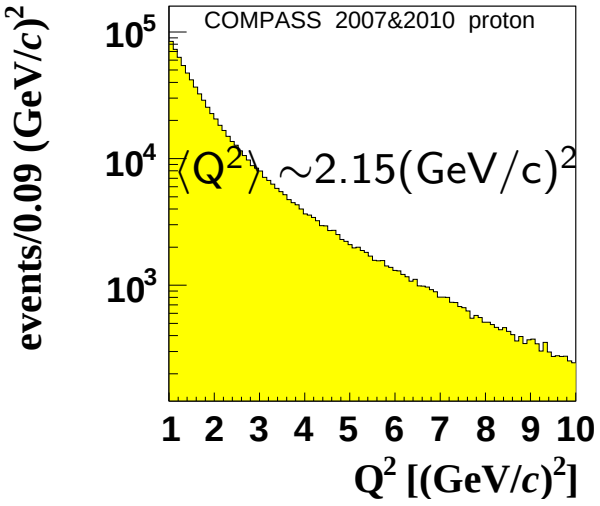
$\rightarrow$ Total amout of SIDIS background: 18% (^{6}LiD), 22% (NH_3)

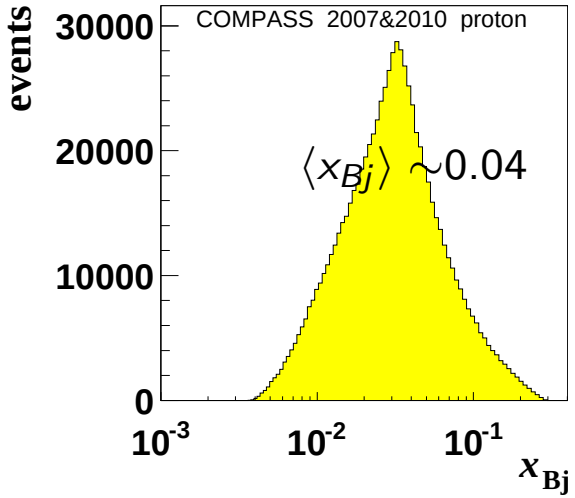


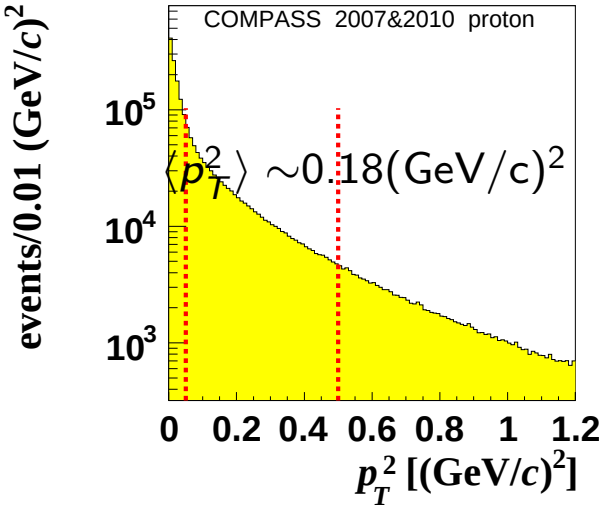


Exclusive ρ^0 production - kinematical distributions

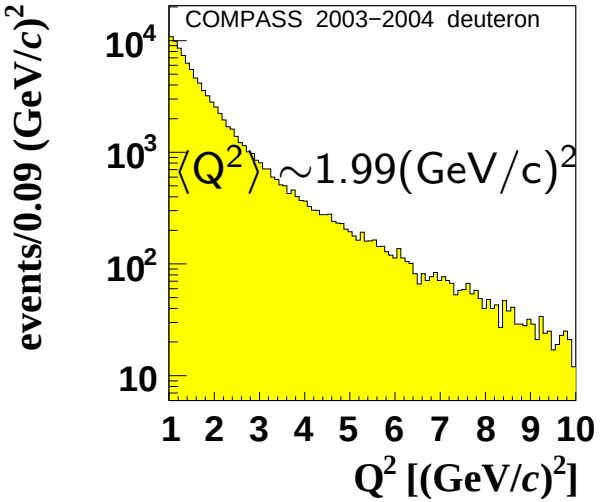
protons

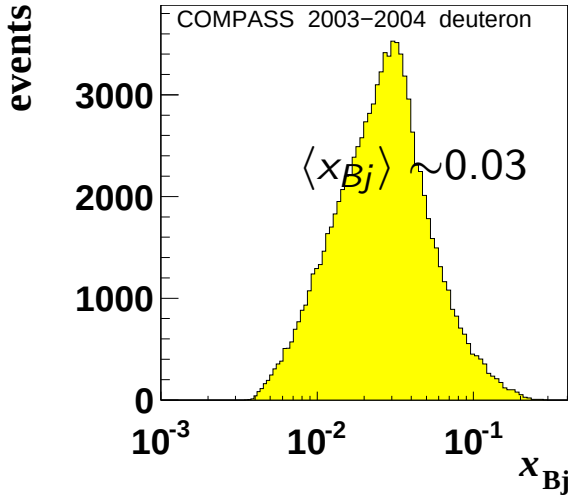


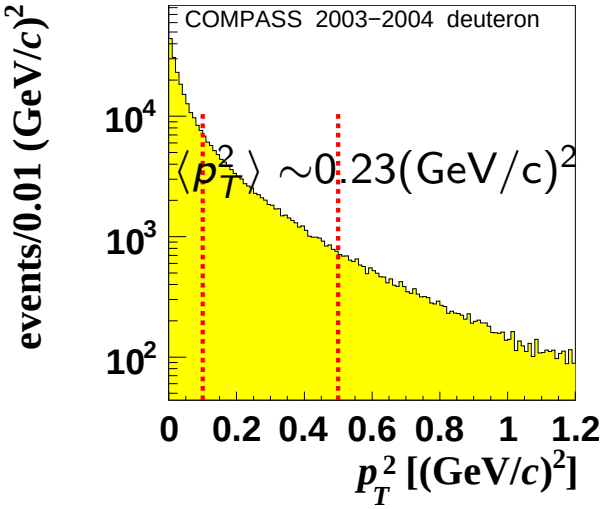




deuterons

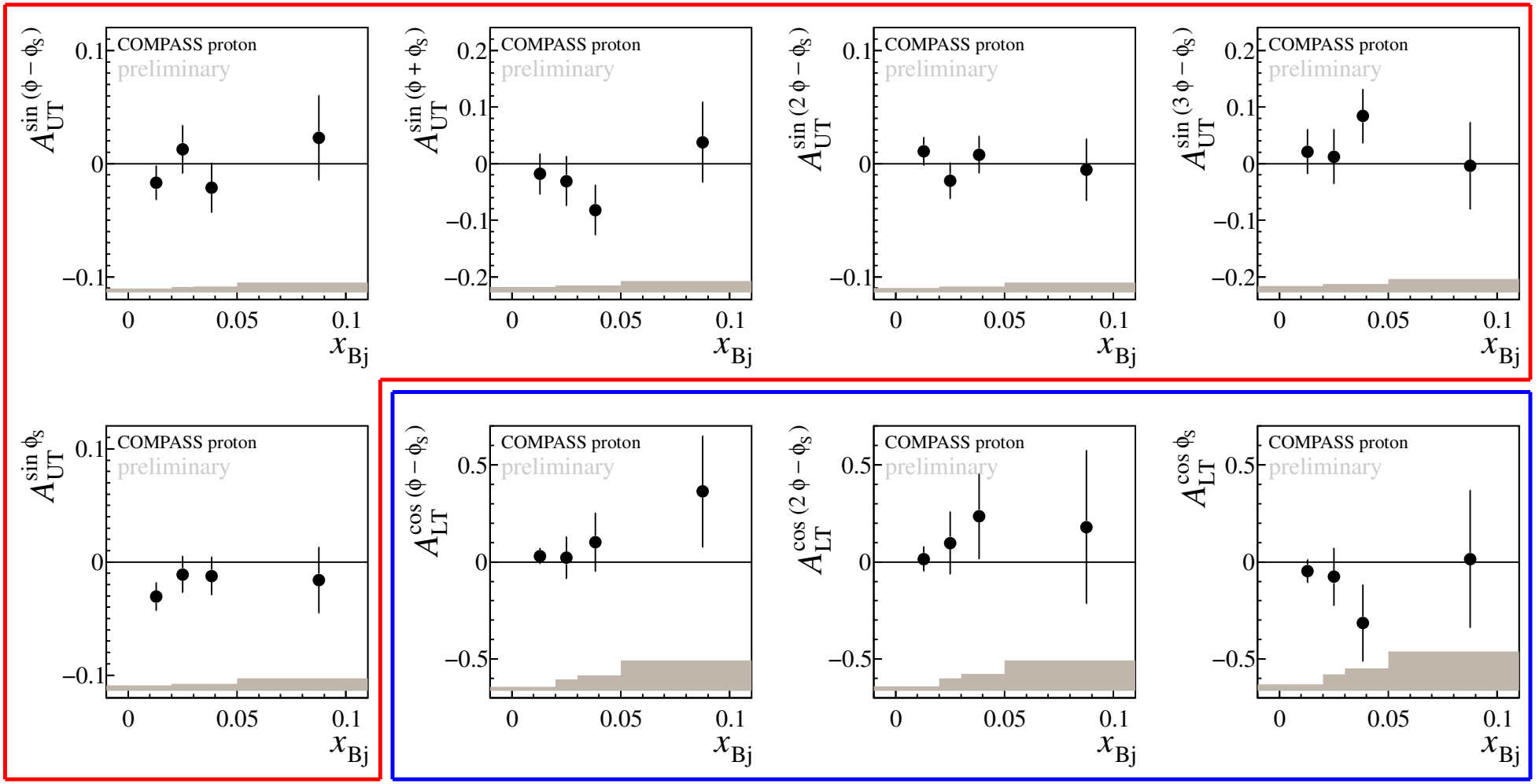






Asymmetry $A_{UT,LT}$ - NH_3 target (2007&2010)

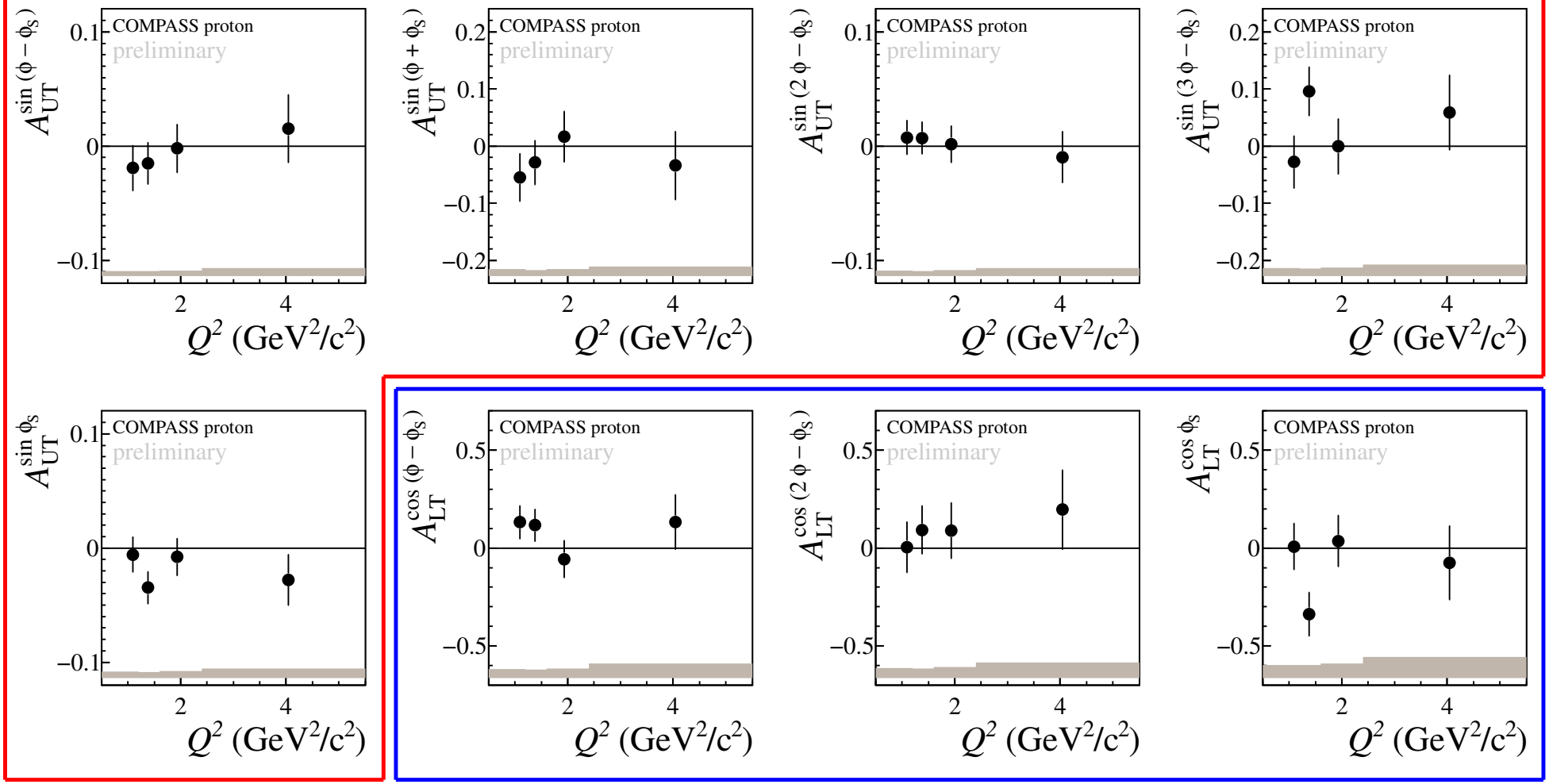
as a function of x_{Bj}



- Asymmetry extraction using a 2D binned maximum likelihood fit after subtracting the SIDIS background

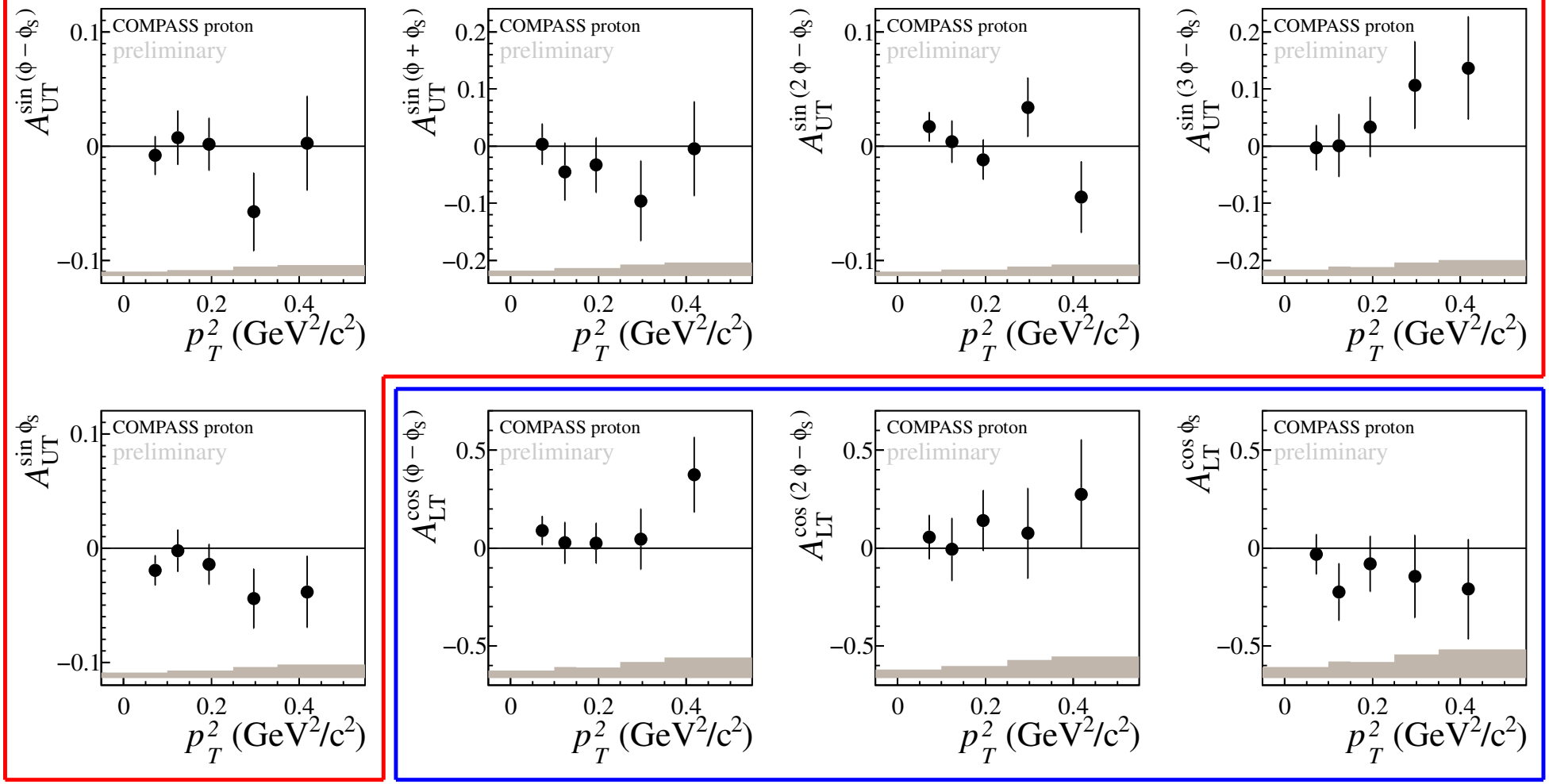
Asymmetry $A_{UT,LT}$ - NH_3 target (2007&2010)

as a function of Q^2

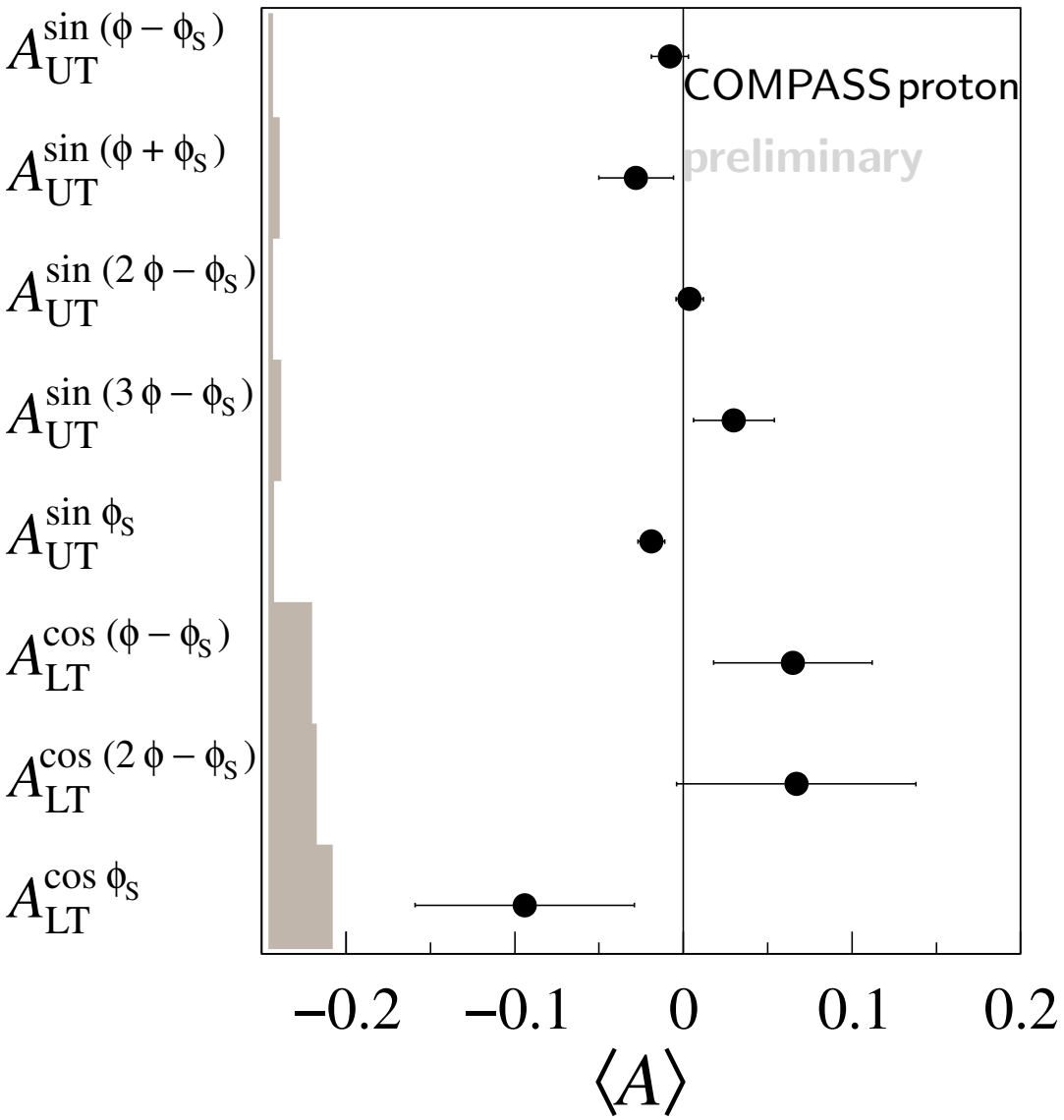


Asymmetry $A_{UT,LT}$ - NH_3 target (2007&2010)

as a function of p_T^2



Mean asymmetries - NH_3 target (2007&2010)



Comparison with a phenomenological GPD-based model

- phenomenological 'handbag' approach
- based on $k_\perp$ factorisation
- includes twist-3 meson wave functions
- includes contributions from γ^*_L and γ^*_T

Goloskokov & Kroll
Eur.Phys.J.C 59 (2009)

$$\sigma^{\nu\lambda}_{\mu\sigma} = \sum \mathcal{M}^*_{\mu'\nu',\mu\nu}\mathcal{M}_{\mu'\nu',\sigma\lambda}$$

$$A_{UT}^{\sin(\phi-\phi_s)}\sigma_0 = -2\mathrm{Im}\left[\epsilon\mathcal{M}^*_{0-,0+}\mathcal{M}_{0+,0+} + \mathcal{M}^*_{+-,++}\mathcal{M}_{++,++} + \frac{1}{2}\mathcal{M}^*_{0-,++}\mathcal{M}_{0+,++}\right]$$

$$A_{UT}^{\sin(\phi_s)}\sigma_0 = -\mathrm{Im}\left[\mathcal{M}^*_{0-,++}\mathcal{M}_{0+,0+} - \mathcal{M}^*_{0+,++}\mathcal{M}_{0-,0+}\right]$$

$$A_{UT}^{\sin(2\phi-\phi_s)}\sigma_0 = -\mathrm{Im}\left[\mathcal{M}^*_{0+,++}\mathcal{M}_{0-,0+}\right]$$

$$A_{LT}^{\cos(\phi_s)}\sigma_0 = -\mathrm{Re}\left[\mathcal{M}^*_{0-,++}\mathcal{M}_{0+,0+} - \mathcal{M}^*_{0+,++}\mathcal{M}_{0-,0+}\right]$$

$\mathcal{M}_{\delta\gamma,\beta\alpha}$ = helicity amplitudes
α = initial-state proton helicity
β = virtual-photon helicity
γ = final-state proton helicity
δ = meson helicity

Comparison with a phenomenological GPD-based model

Up to now mainly used to describe DVCS and HEMP:
chiral-even GPDs

$\gamma_L^* \to \rho_L^0 \quad \mathcal{M}_{0+,0+} \sim H;\ \mathcal{M}_{0-,0+} \sim E$ dominant

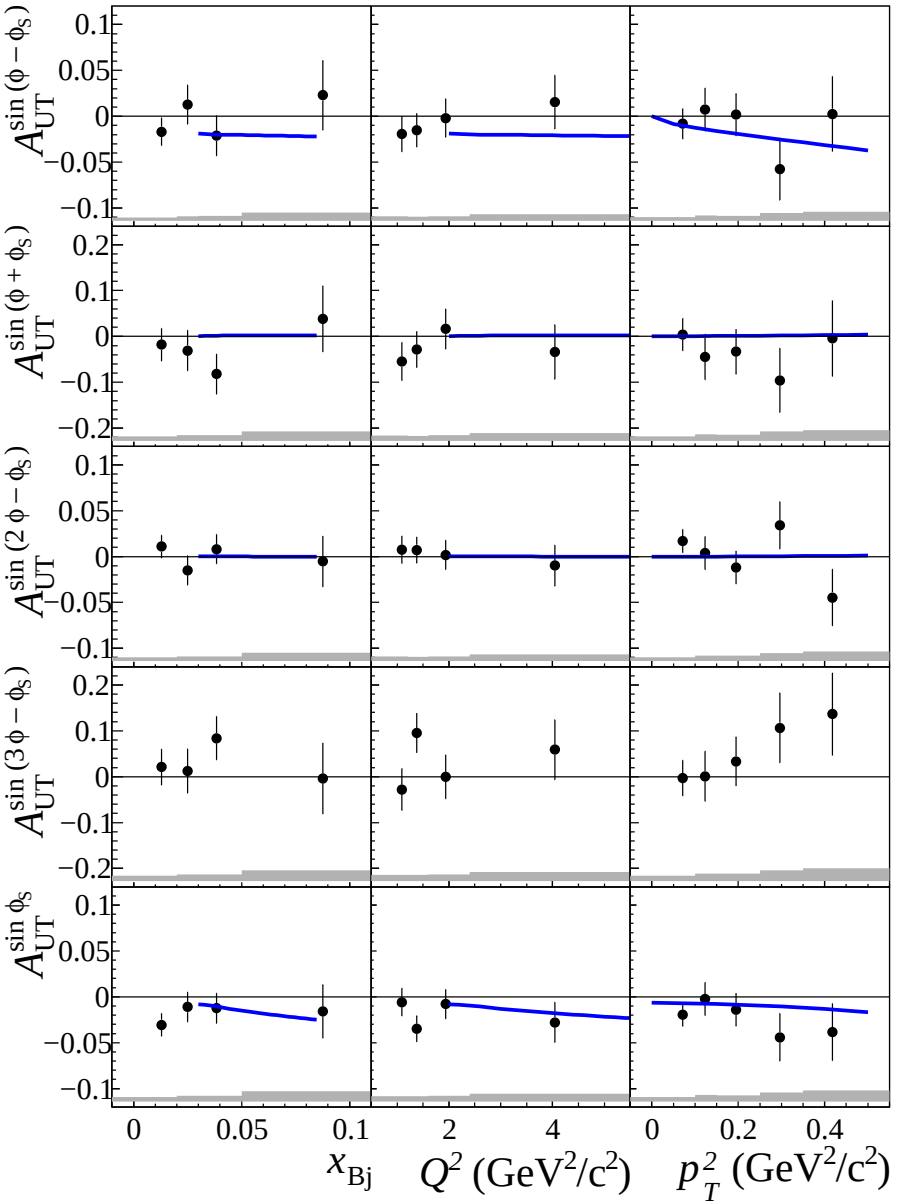
$\gamma_T^* \to \rho_T^0 \quad \mathcal{M}_{++,++} \sim H;\ \mathcal{M}_{+-,++} \sim E$ suppressed

Recently introduced: chiral-odd (transverse) GPDs

$$\gamma_T^* \to \rho_L^0 \quad \mathcal{M}_{0-,++} \sim H_T;\ \mathcal{M}_{0+,++} \sim \bar{E}_T = 2\tilde{H}_T + E_T$$

$\gamma_L^* \to \rho_T^0$, $\gamma_T^* \to \rho_{-T}^0$ known to be suppressed, neglected in the model

Asymmetry $A_{UT,p}$ - NH_3 target (2007&2010)

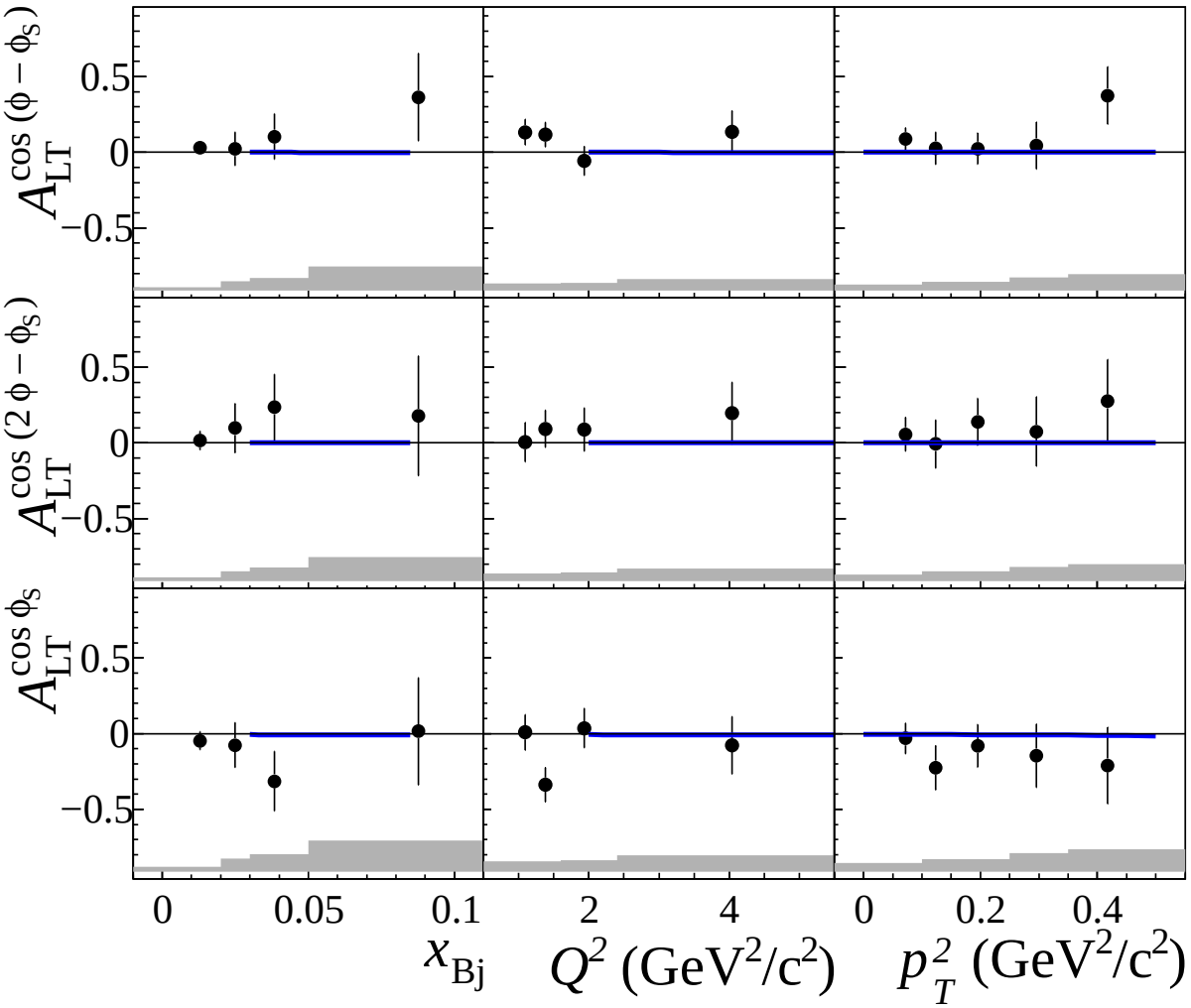


COMPASS proton

preliminary

- Blue line: Model from Goloskokov and Kroll
- Predictions for COMPASS kinematic
  $W = 8.1$ GeV/c^2,
  $p_T^2 = 0.2$ (GeV/c)^2,
  $Q^2 = 2.2$ (GeV/c)^2

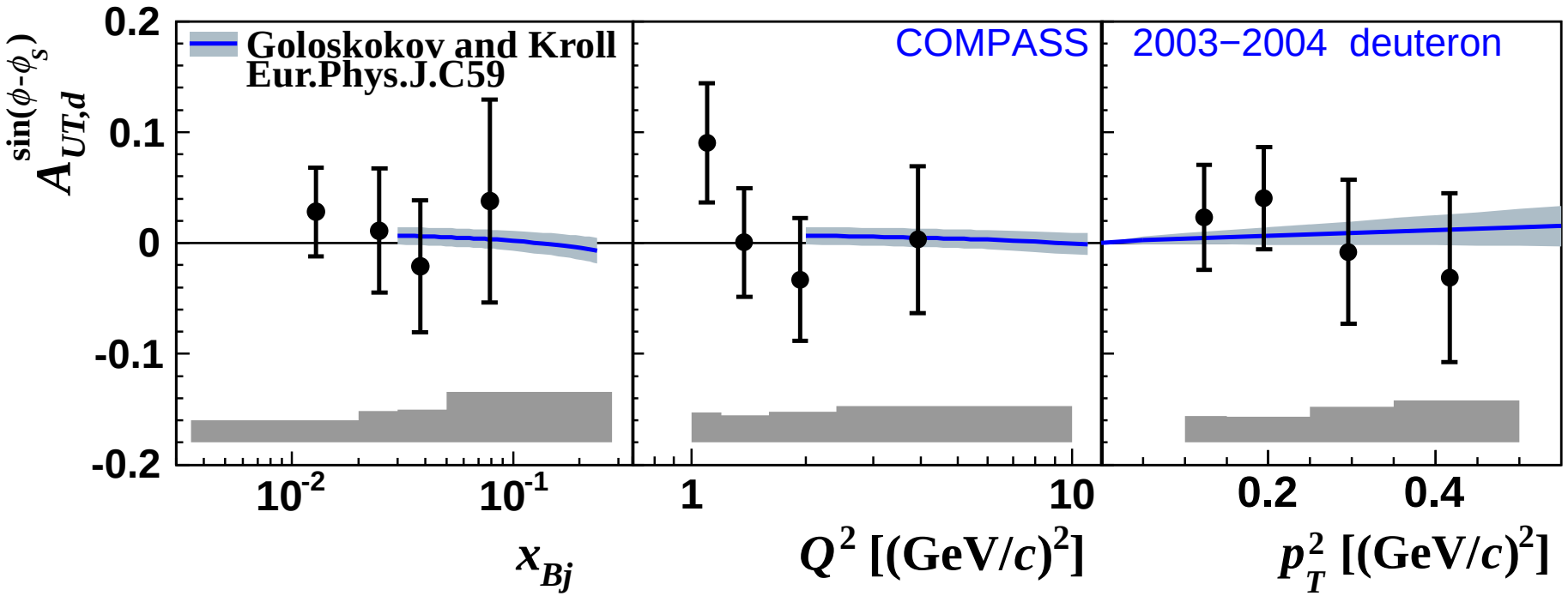
Asymmetry $A_{LT,p}$ - NH_3 target (2007&2010)



COMPASS proton

preliminary

Asymmetry $A_{UT,d}^{sin(\phi-\phi_S)}$ - ^{6}LiD target (2003&2004)



- Contribution from GPDs E^u and E^d approx. cancel in exclusive ρ^0 production (different in exclusive ω production)

Nucl.Phys. B865 (2012)

Summary

- Exclusive ρ^0 production in high energy muon scattering off transversely polarized protons and deuterons was studied
- Results for 5 transverse target single-spin asymmetries $A_{\mathrm{UT,p}}$ and 3 transverse target double-spin asymmetries $A_{\mathrm{LT,p}}$ for transversely polarized protons were presented
- Most of the modulations are small, consistent with zero within experimental uncertainties
- $A_{\mathrm{UT,p}}^{\sin(\phi_S)} = \text{-}0.019 \pm 0.008 \pm 0.003$ evidence for existence of chiral-odd GPD H_T