Exclusive ρ^0 production off transversely polarized protons and deuterons

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XIV WORKSHOP ON HIGH ENERGY SPIN PHYSICS (DSPIN-2011)
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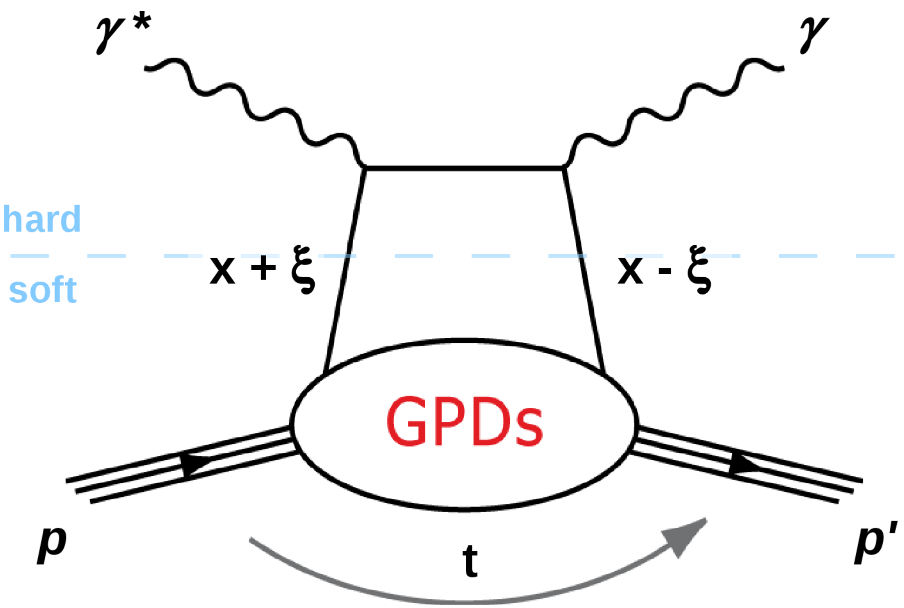
Outline

- Motivation
- Theoretical framework (GPD formalism)
- COMPASS experiment
- Event selection and experimental method
- Results
- Recent development of the analysis
- Summary and outlook

Motivation

Measurement of exclusive ρ^0 production off transversely polarized target provides constraints of GPDs, in particular of GPD E which is sensitive to orbital momentum

Deeply Virtual Coulomb Scattering
$\gamma^* p \rightarrow \gamma p'$



factorization for large Q^2 and $-t < 1$ (GeV/c)^2

GPDs (Generalized Parton Distributions):

$H^{q,g}(x,\xi,t)$	$E^{q,g}(x,\xi,t)$	*for sum over parton helicities*
$\widetilde{H}^{q,g}(x,\xi,t)$	$\widetilde{E}^{q,g}(x,\xi,t)$	*for difference over parton helicities*
for retained proton helicity	*for changed proton helicity*	

where:

x: average longitudinal momentum fraction of the parton

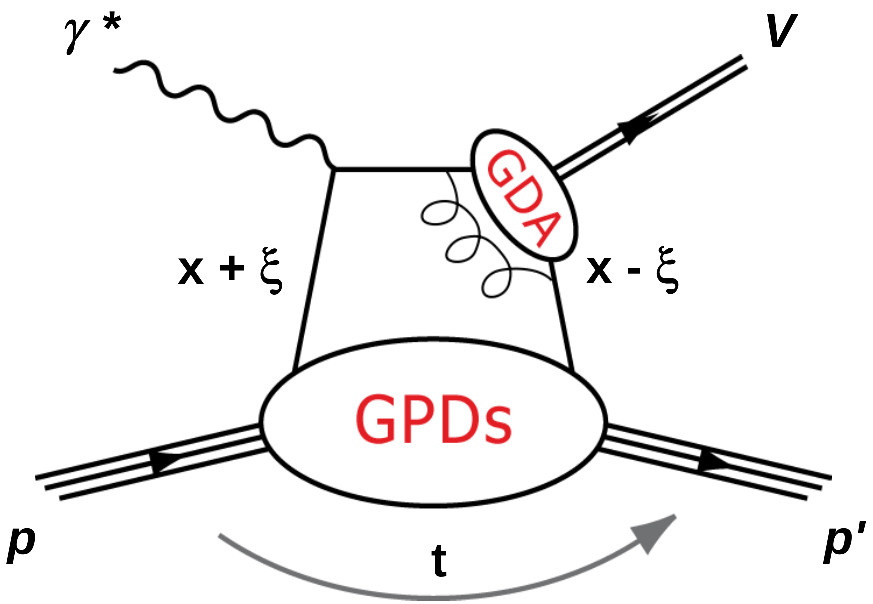
2ξ: longitudinal momentum fraction transferred by the parton

$$\xi \approx \frac{x_B}{2 - x_B}$$ (in the Bjorken limit)

t: squared momentum transferred to the target nucleon

Deeply Virtual Meson Production

$\gamma^* p \rightarrow V p'$



Production meson dependence on different GPDs:

$H^{q,g}(x,\xi,t)$	$E^{q,g}(x,\xi,t)$	*for vector mesons*
$\widetilde{H}^{q,g}(x,\xi,t)$	$\widetilde{E}^{q,g}(x,\xi,t)$	*for pseudoscalar mesons*

for example:

$$H_{\rho^0} = \frac{1}{\sqrt{2}}\left(\frac{2}{3}H^u + \frac{1}{3}H^d + \frac{3}{8}H^g\right)$$

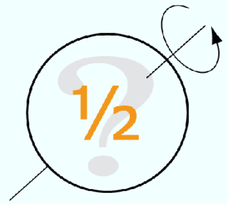
$$H_{\omega} = \frac{1}{\sqrt{2}}\left(\frac{2}{3}H^u - \frac{1}{3}H^d + \frac{1}{8}H^g\right)$$

$$H_{\phi} = -\frac{1}{3}H^s - \frac{1}{8}H^g$$

- *contribution from gluons at the same order of α_s as from quarks*
- *factorization is strictly proven only for longitudinal γ^**

Important feature of GPDs

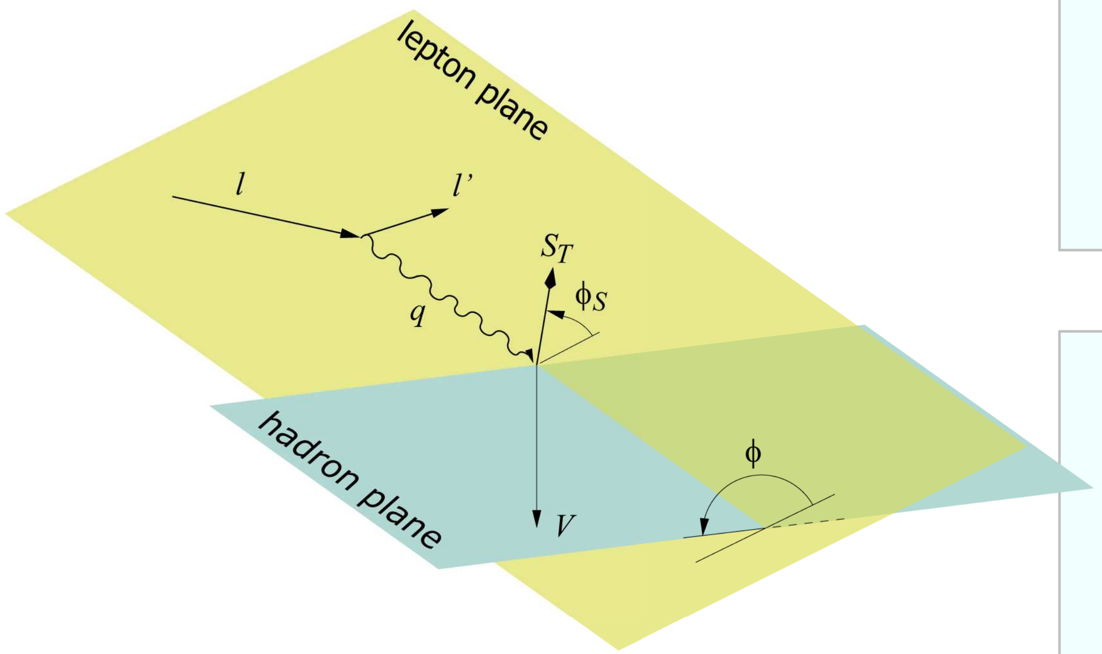
Total angular momentum:



$$\int_{-1}^{1} dx\, x\left[H^q(x,\xi,0)+E^q(x,\xi,0)\right]=2J^q$$ (Ji's sum rule)

where:

$$J^q = L^q + S^q$$



Considered reaction:

$$\mu^{+} + p \rightarrow \mu^{+}{}' + p' + \rho^{0}$$

Relevant angles:

ϕ: azimuthal angle between lepton plane and hadron plane

ϕ_s: azimuthal angle between target spin vector and lepton plane

Spin-dependent photoabsorption cross sections and interference terms σ^{ij}_{mn} :

$$\sigma^{ij}_{mn}\left(x_B, Q^2, t\right) \propto \sum_{spins} (A^i_m)^* A^j_n$$

where:

A^i_m: amplitude for subprocess $\gamma^* p \rightarrow V p'$ with photon helicity *m* and target proton helicity *i*

General formula for cross-section including beam and target polarization

$$\left[\frac{\alpha_{\rm em}}{8\pi^3}\,\frac{y^2}{1-\varepsilon}\,\frac{1-x_B}{x_B}\,\frac{1}{Q^2}\right]^{-1}\frac{d\sigma}{dx_B\,dQ^2\,d\phi\,d\phi_S}$$

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

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

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

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

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

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

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

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

$$\epsilon=\frac{1-y-\frac{1}{4}y^2\gamma^2}{1-y+\frac{1}{2}y^2+\frac{1}{4}y^2\gamma^2} \qquad \gamma=2x_{Bj}M_P/Q$$

For vector mesons:

$$\frac{1}{\Gamma'}\frac{d\sigma_{00}^{++}}{dt} = (1-\xi^2)|\mathcal{H}_M|^2 - \left(\xi^2+\frac{t}{4M_p^2}\right)|\mathcal{E}_M|^2 - 2\xi^2 Re(\mathcal{E}_M^* \mathcal{H}_M)$$

unpolarized cross section

$$\sigma_0 = \frac{1}{2}\left(\sigma_{++}^{++} + \sigma_{++}^{--}\right) + \epsilon\sigma_{00}^{++} \equiv \sigma_T + \epsilon\sigma_L$$

$$\frac{1}{\Gamma'} Im \frac{d\sigma_{00}^{+-}}{dt} = -\sqrt{1-\xi^2}\frac{\sqrt{t_0-t}}{M_p} Im(\mathcal{E}_M^* \mathcal{H}_M)$$

transverse target spin asymmetry

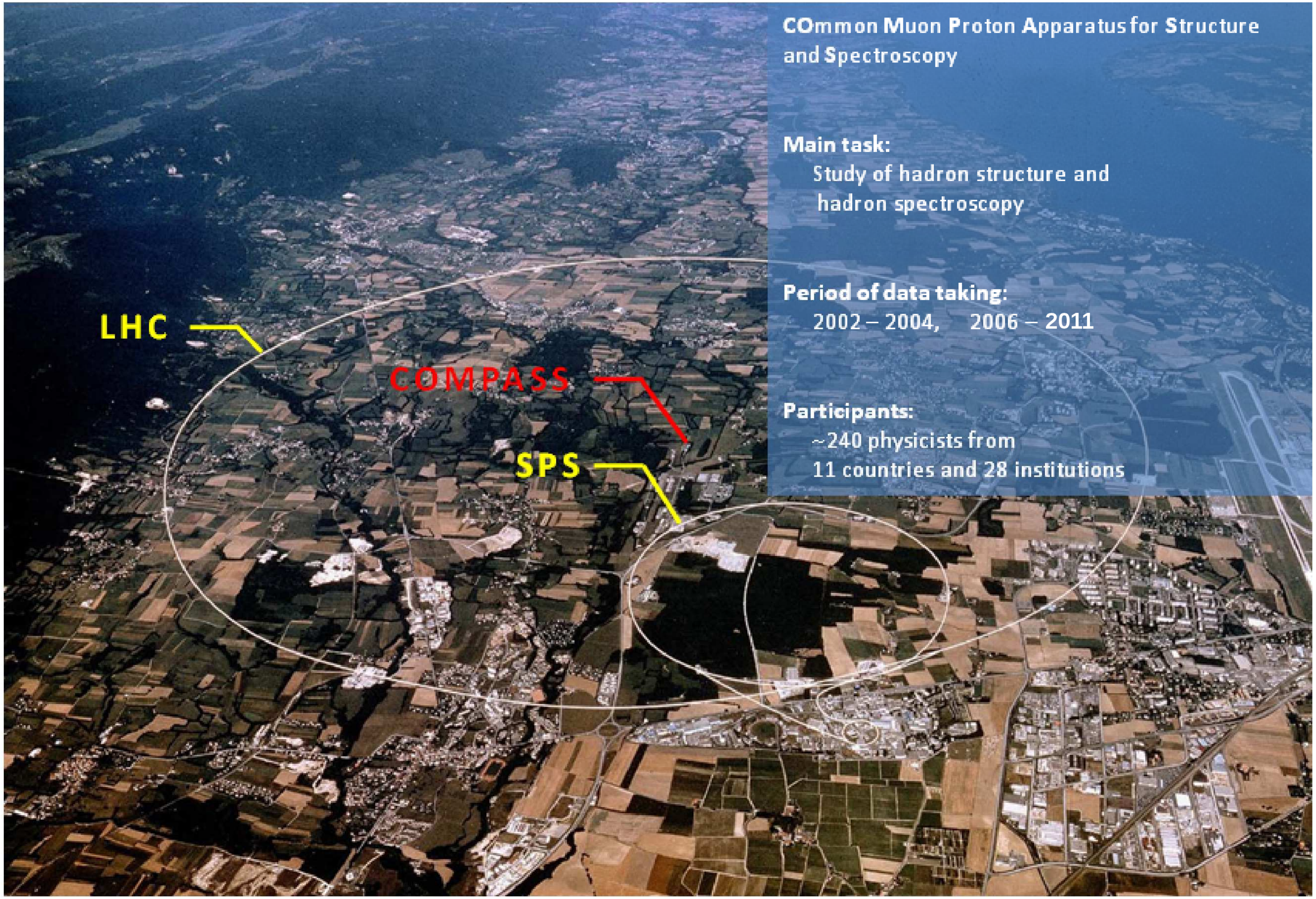
$$A_{UT} = -\frac{Im\left(\sigma_{++}^{+-} + \epsilon\sigma_{00}^{+-}\right)}{\sigma_0}$$

where:

$\mathcal{H}_M, \mathcal{E}_M$ are convolutions of the GPDs $H^{q,g}, E^{q,g}$ with hard scattering kernel and meson GDA

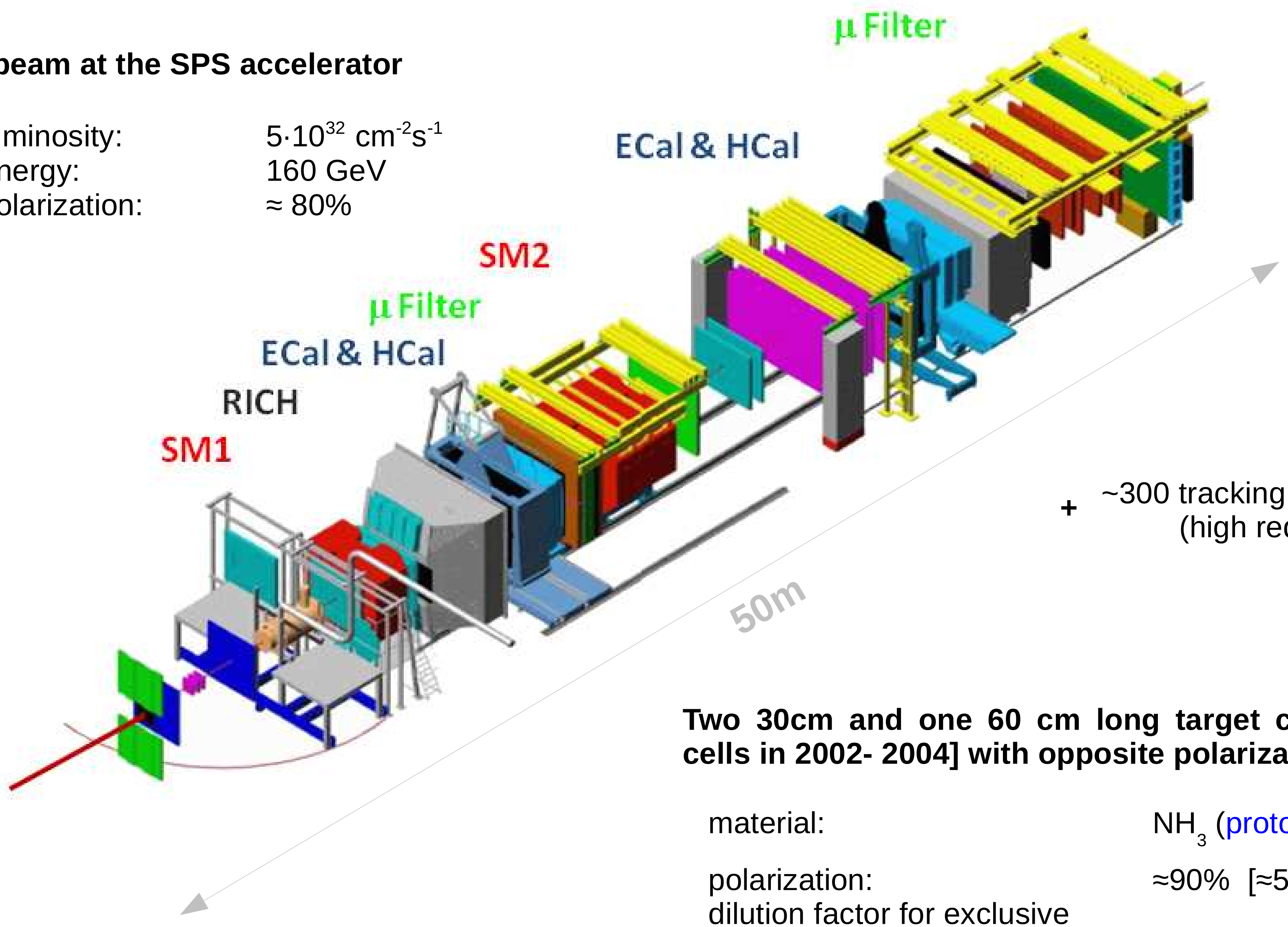
$$\Gamma' = \frac{\alpha_{em}}{Q^6}\frac{x_B^2}{1-x_B} \qquad -t_0 = \frac{4\xi^2 M_P^2}{1-\xi^2} \qquad \xi \approx \frac{x_B}{2-x_B}$$

COMPASS experiment



μ^+ beam at the SPS accelerator

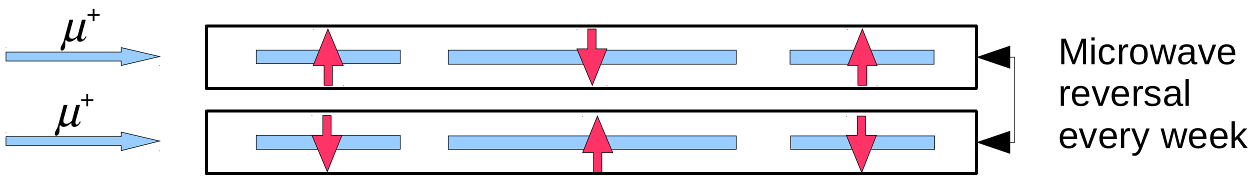
luminosity:	$5 \cdot 10^{32}$ cm^{-2}s^{-1}
energy:	160 GeV
polarization:	≈ 80%



+ ~300 tracking detector planes (high redundancy)

Two 30cm and one 60 cm long target cells [two 60cm long cells in 2002- 2004] with opposite polarization

material:	NH_3 (protons) [^{6}LiD (deuterons)]
polarization:	≈90% [≈50%]
dilution factor for exclusive ρ^0 production:	≈25% [≈44%]



Used data and event selection

Used data:

2002 – 2004 (deuterons)
2007 (protons)
} for transverse target polarization

Analyzed decay channel:

$\rho^0 \rightarrow \pi^+ + \pi^-$ $BR \sim 100\%$

Topology:

- one incident and one scattered muon
- two charged hadron tracks with opposite signs

Vertex in the target

Kinematics domain:

- $Q^2 > 1$ [(GeV/c)^2]
- $W > 5$ [GeV]
- $0.1 < y < 0.9$
- $0.003 < x_{Bj} < 0.35$

where:

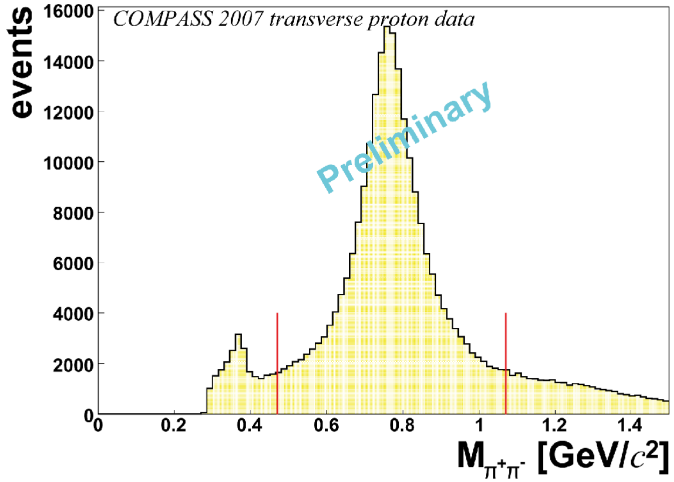
Q^2: negative four-momentum squared of γ^*

W: total energy in γ^* - N system

y: fraction of the lepton energy lost in the LAB

x_{Bj}: Bjorken scaling variable

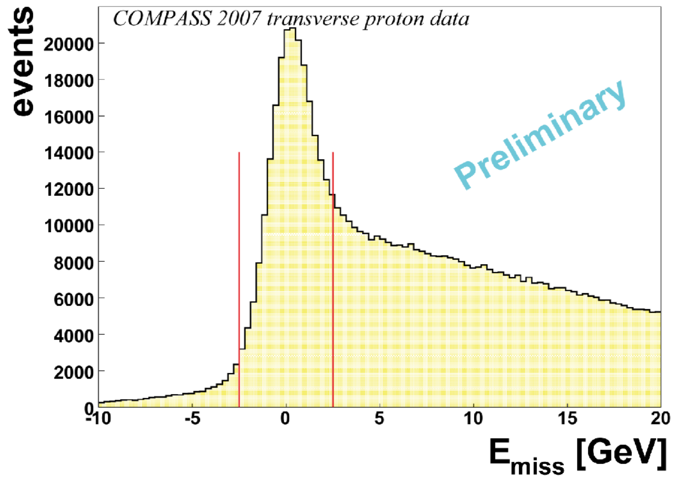
Event selection – cuts on hadron variables



Invariant mass

Pion mass is assumed for each outgoing hadron track

$$-0.3 < M_{\pi\pi} - M_{\rho}^{PDG} < 0.3\ [GeV/c^2]$$

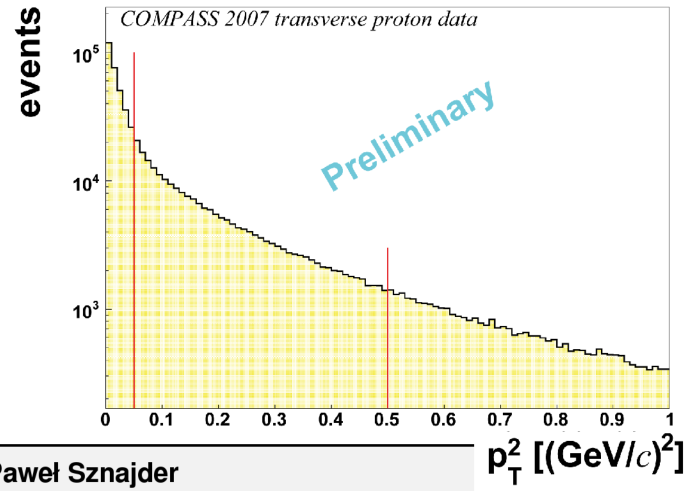


Missing energy

Recoil proton is not detected - check if the proton is intact

$$E_{miss} = \frac{M_x^2 - M_p^2}{2M_p} \in [-2.5,\ 2.5]\ GeV$$

$E_{miss} = 0$ is the signature of the exclusivity



Squared transverse momentum of ρ^0 candidate w.r.t. virtual photon direction

To remove coherent production off target nuclei

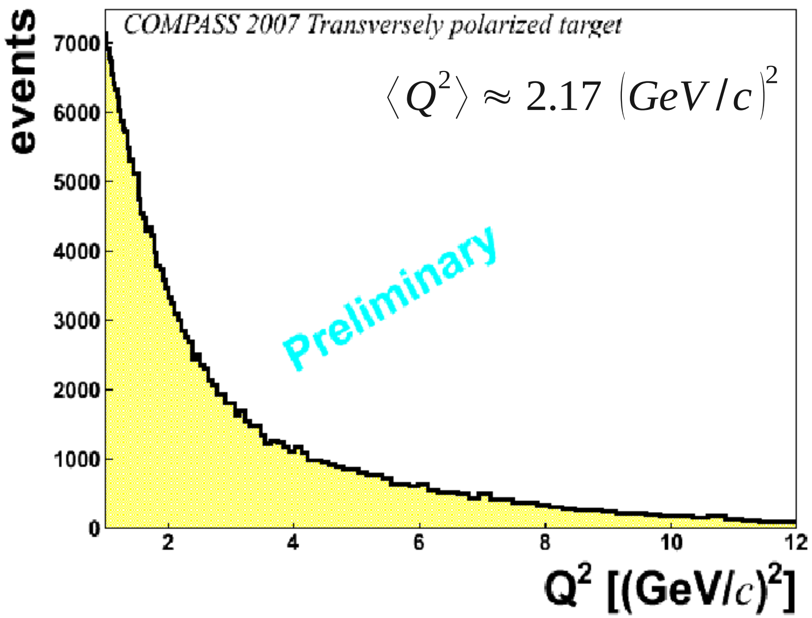
$0.05 < p_t^2\ [(GeV/c)^2]$ for protons

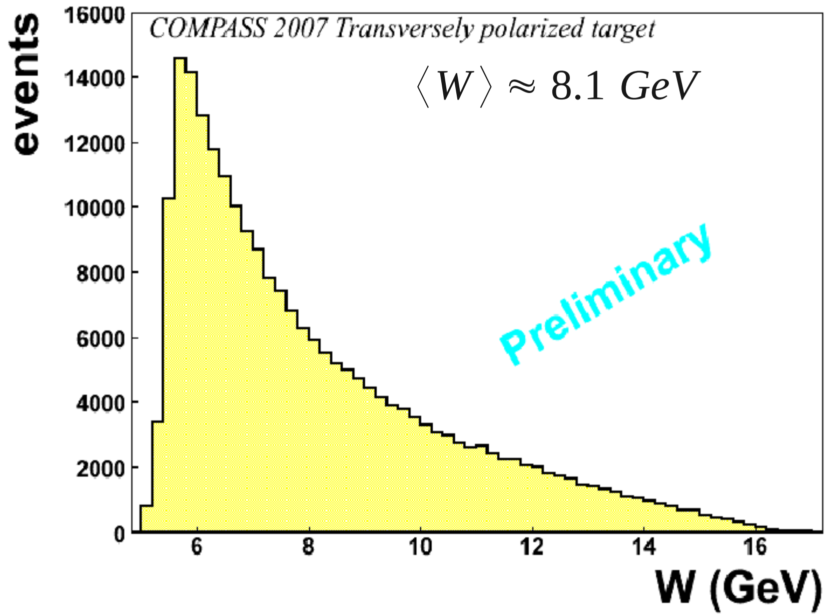
To remove inefficient region of azimuthal angle reconstruction

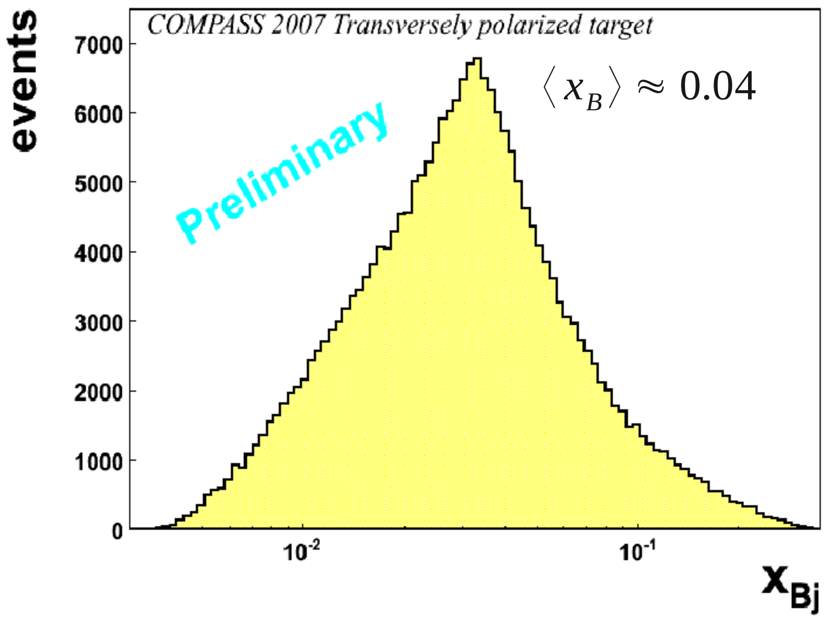
$0.01 < p_t^2\ [(GeV/c)^2]$ for deuterons

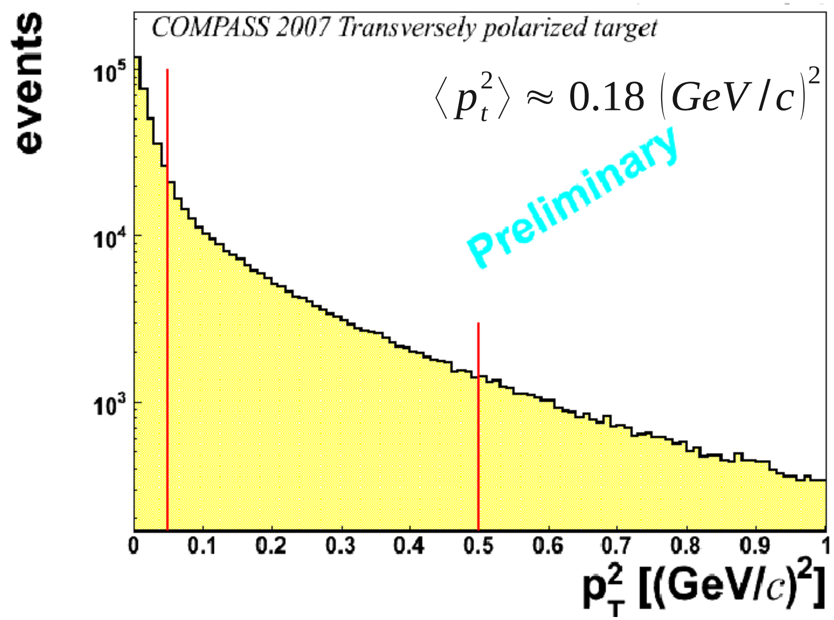
To suppress non-exclusive background

$p_t^2 < 0.5\ [(GeV/c)^2]$ for protons and deuterons


COMPASS 2007 Transversely polarized target
$\langle Q^2 \rangle \approx 2.17\ (GeV/c)^2$
Preliminary
events
0
1000
2000
3000
4000
5000
6000
7000
2
4
6
8
10
12
Q^2 [(GeV/c)^2]


COMPASS 2007 Transversely polarized target
$\langle W \rangle \approx 8.1\ GeV$
Preliminary
events
0
2000
4000
6000
8000
10000
12000
14000
16000
6
8
10
12
14
16
W (GeV)


COMPASS 2007 Transversely polarized target
$\langle x_B \rangle \approx 0.04$
Preliminary
events
0
1000
2000
3000
4000
5000
6000
7000
10^{-2}
10^{-1}
x_{Bj}


COMPASS 2007 Transversely polarized target
$\langle p_t^2 \rangle \approx 0.18\ (GeV/c)^2$
Preliminary
events
10^3
10^4
10^5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
p_T^2 [(GeV/c)^2]

Double ratio method for extraction of transverse target spin asymmetry

Acceptance

Number of observed events — Flux — Dilution factor

$$N(\phi-\phi_s) = F\ n\ a(\phi-\phi_s)\ \sigma_0 \cdot \left(1 \pm f \langle P_T \rangle A_{UT} \sin(\phi-\phi_s)\right)$$

Number of target nucleons — Mean target polarization

$$A_{UT} = -\frac{Im\left(\sigma_{++}^{+-} + \epsilon\sigma_{00}^{+-}\right)}{\sigma_0}$$

$$DR(\phi-\phi_s) = \frac{N^{\uparrow}_{Up/Down}(\phi-\phi_s)}{N^{\downarrow}_{Center}(\phi-\phi_s)} \cdot \frac{N^{\uparrow}_{Center}(\phi-\phi_s)}{N^{\downarrow}_{Up/Down}(\phi-\phi_s)}$$

$$= \frac{F^{\uparrow}_{Up/Down} F^{\uparrow}_{Center}}{F^{\downarrow}_{Center} F^{\downarrow}_{Up/Down}} \frac{a^{\uparrow}_{Up/Down}(\phi-\phi_s) a^{\uparrow}_{Center}(\phi-\phi_s)}{a^{\downarrow}_{Center}(\phi-\phi_s) a^{\downarrow}_{Up/Down}(\phi-\phi_s)} \frac{\left(1+f\langle P_T\rangle A_{UT}\sin(\phi-\phi_s)\right)^2}{\left(1-f\langle P_T\rangle A_{UT}\sin(\phi-\phi_s)\right)^2}$$

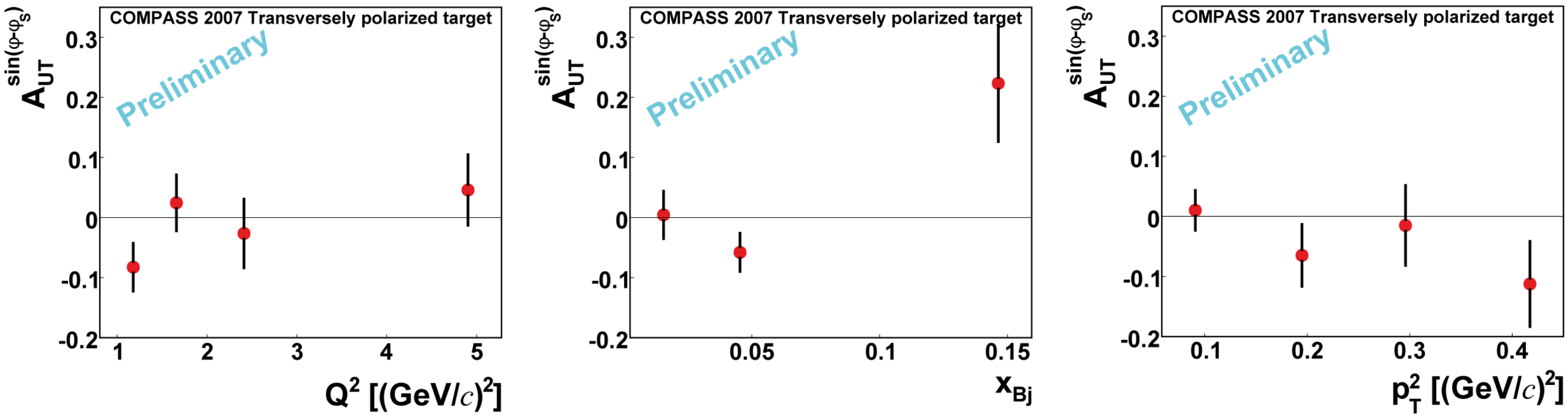
Number of target nucleons, flux and σ_0 cancel

Acceptance cancel with reasonable assumption $\frac{a^{\uparrow}_{Up/Down}}{a^{\downarrow}_{Center}} = \frac{a^{\downarrow}_{Up/Down}}{a^{\uparrow}_{Center}}$

A_{UT} from a fit to the $DR(\phi-\phi_s)$

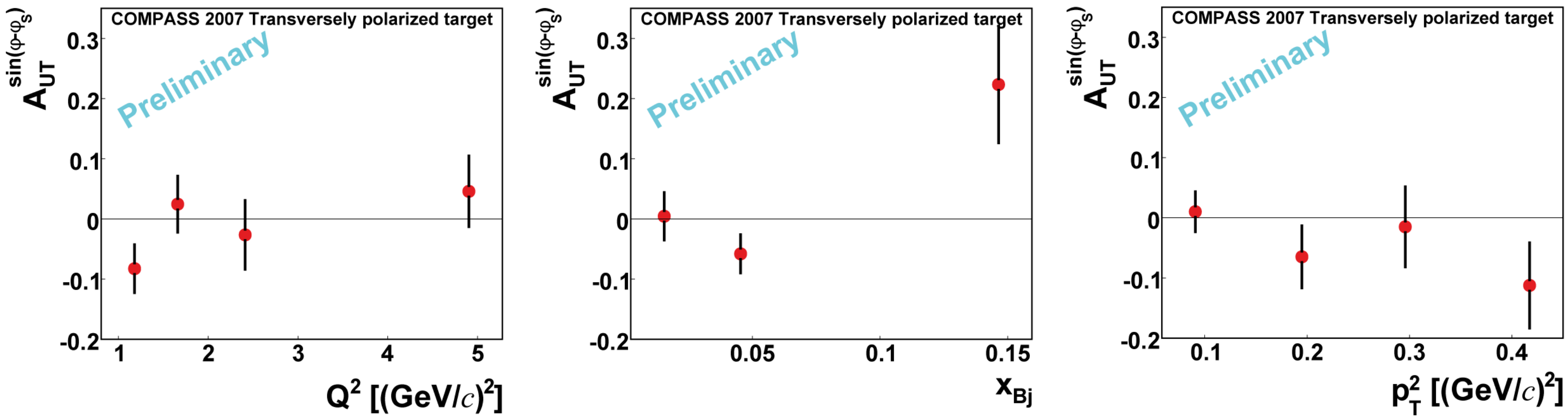
Results for the proton target

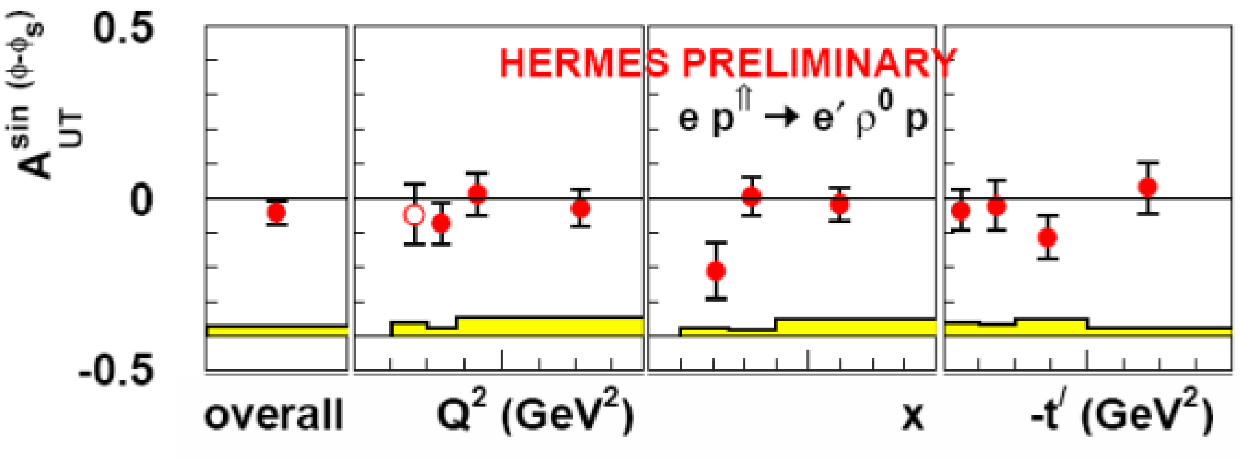
$\langle Q^2 \rangle \approx 2.2\ (GeV/c)^2$ $\langle x_B \rangle \approx 0.04$ $\langle p_t^2 \rangle \approx 0.18\ (GeV/c)^2$



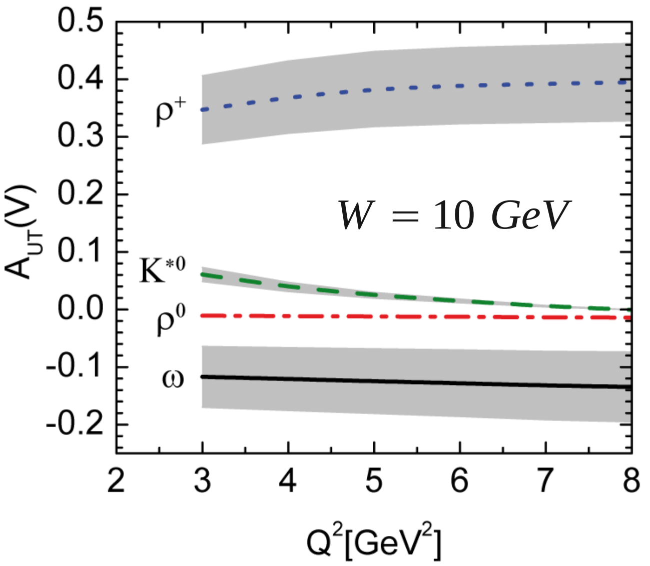
$A_{UT}^{\sin(\phi-\phi_s)}$ compatible with 0

$\langle Q^2 \rangle \approx 2.2\ (GeV/c)^2$ $\langle x_B \rangle \approx 0.04$ $\langle p_t^2 \rangle \approx 0.18\ (GeV/c)^2$





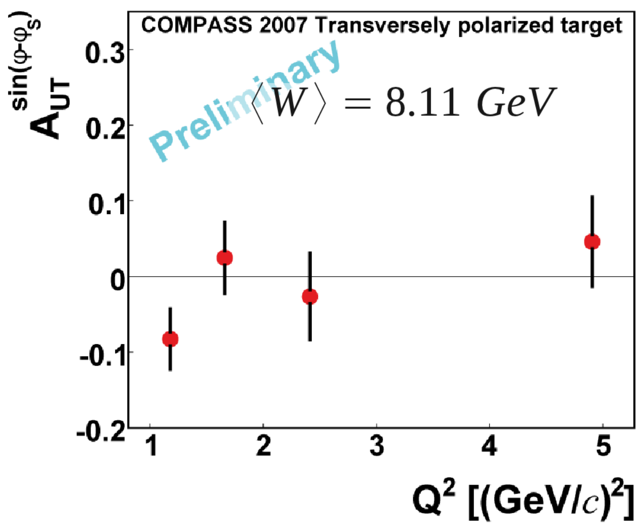
Both results are in good agreement

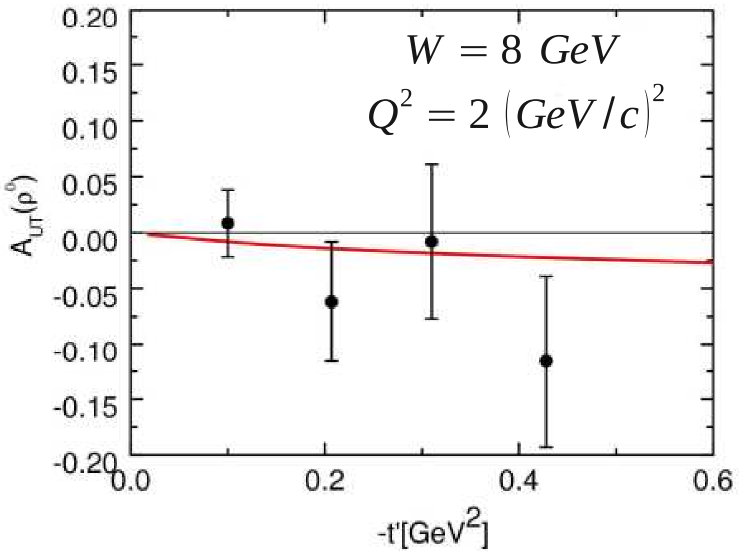


Model given by S. V. Goloskokov and P. Kroll (see Eur. Phys. J. C 59 4 (2009))

- "handbag model"
- GPDs constrained by CTEQ6 parametrization and nucleon form factors
- power corrections due to transverse quarks momenta
- predictions both for γ^*_L and γ^*_T

$$A_{UT}(\rho^0) \approx -0.02$$
$$A_{UT}(\omega) \approx -0.10$$
for protons



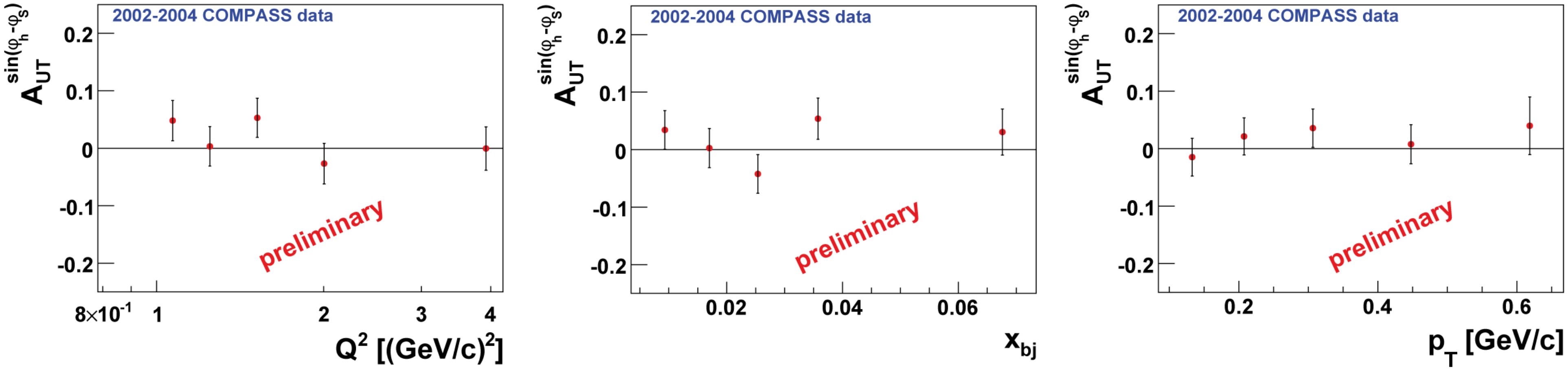


Results are in good agreement with the model

Results for the deuteron target

without coherent/incoherent scattering separation ($0.01 < p_t^2 < 0.5 \; [(GeV/c)^2]$)

$\langle Q^2 \rangle \approx 2.0 \; (GeV/c)^2$ $\langle x_B \rangle \approx 0.03$ $\langle p_t \rangle \approx 0.11 \; (GeV/c)^2$



$A_{UT}^{\sin(\phi-\phi_s)}$ compatible with 0

Recent development of the analysis

Main features of the new analysis

- background subtraction
- new method of asymmetry extraction → binned likelihood method
- detailed systematic studies → impact of false asymmetries, background subtraction, etc.

New release and publication of the paper expected soon

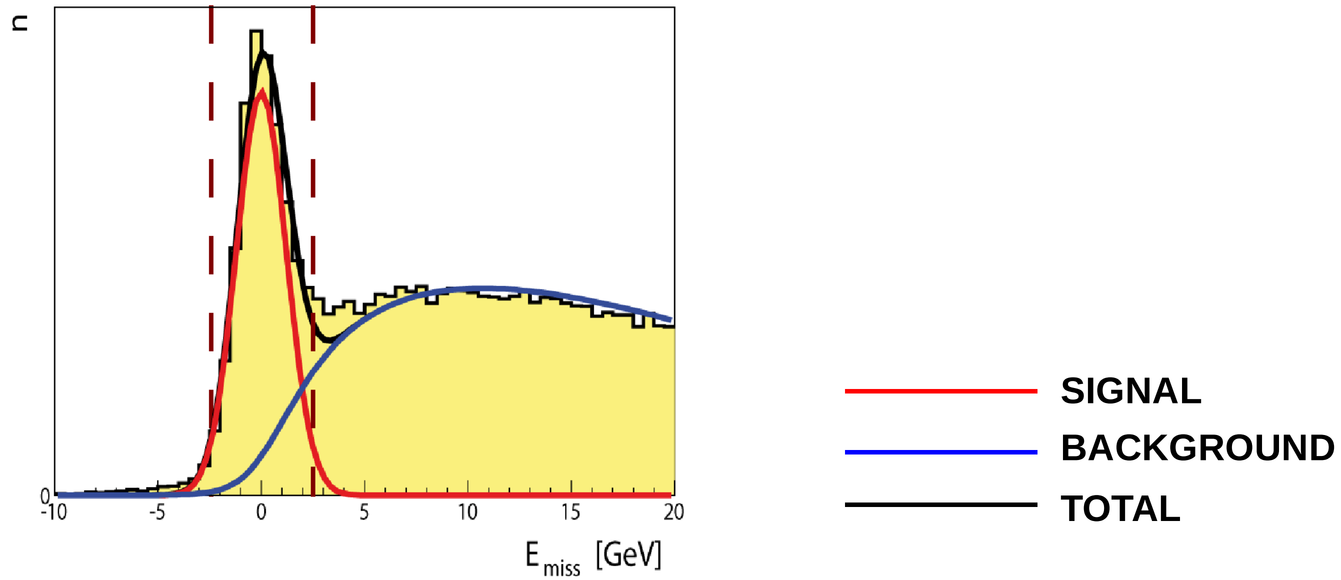
No significant changes of final results compared with the ones presented today

Background subtraction

- fraction of background measured from fit to E_{miss} distribution
- shape of exclusive distribution fitted directly to data
- shape of semi-inclusive distribution taken from MC

  → LEPTO generator
- fraction of background extracted from data as a function of ϕ-ϕ_s modulation

  → background asymmetry



Summary and outlook

- **Summary**
  - Transverse target spin asymmetry A_{UT} was measured both for protons and deuterons
  - Asymmetries are small, compatible with 0
  - Results are compatible with HERMES experiment and with GPD predictions by S. V. Goloskokov and P. Kroll

- **In progress**
  - new analysis with background subtraction
  - no significant changes of final results compared with the ones presented today
  - release of results and dedicated paper expected soon

- **Outlook**
  - 2010 data with transversely polarized proton target → increase of statistics for ρ^0 with 2010 data (≈ 3 times)
  - γ^* transverse/longitudinal separation
  - extraction of non-leading twist asymmetries
  - possible analysis of ϕ and ω mesons
  - measurement with transversely polarized protons considered using GPD setup at COMPASS-II experiment (with Recoil Proton Detector)