Exclusive processes in leptoproduction at COMPASS

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Present analyses of exclusive channels in leptoproduction at COMPASS

- Physics analyses for ρ^0 and φ channels
  - transverse target spin asymmetry — ρ^0 on p, d
  - double spin asymmetry — ρ^0, φ on d
  - SDMEs — ρ^0, φ on p, d
  - cross sections, R(=σ_L/σ_T), t-slopes — ρ^0, φ on p, d

- Searches for signals of exclusive $J/\psi(\rightarrow\mu^+\mu^-)$, ω^0, π^0 production

- Feasibility study to detect exclusive single photon events from 'DVCS 2008 test run'

COMPASS setup

as in μ run
NIM A 577(2007) 455

- **high energy beam**
- **large angular acceptance**
- **broad kinematical range**

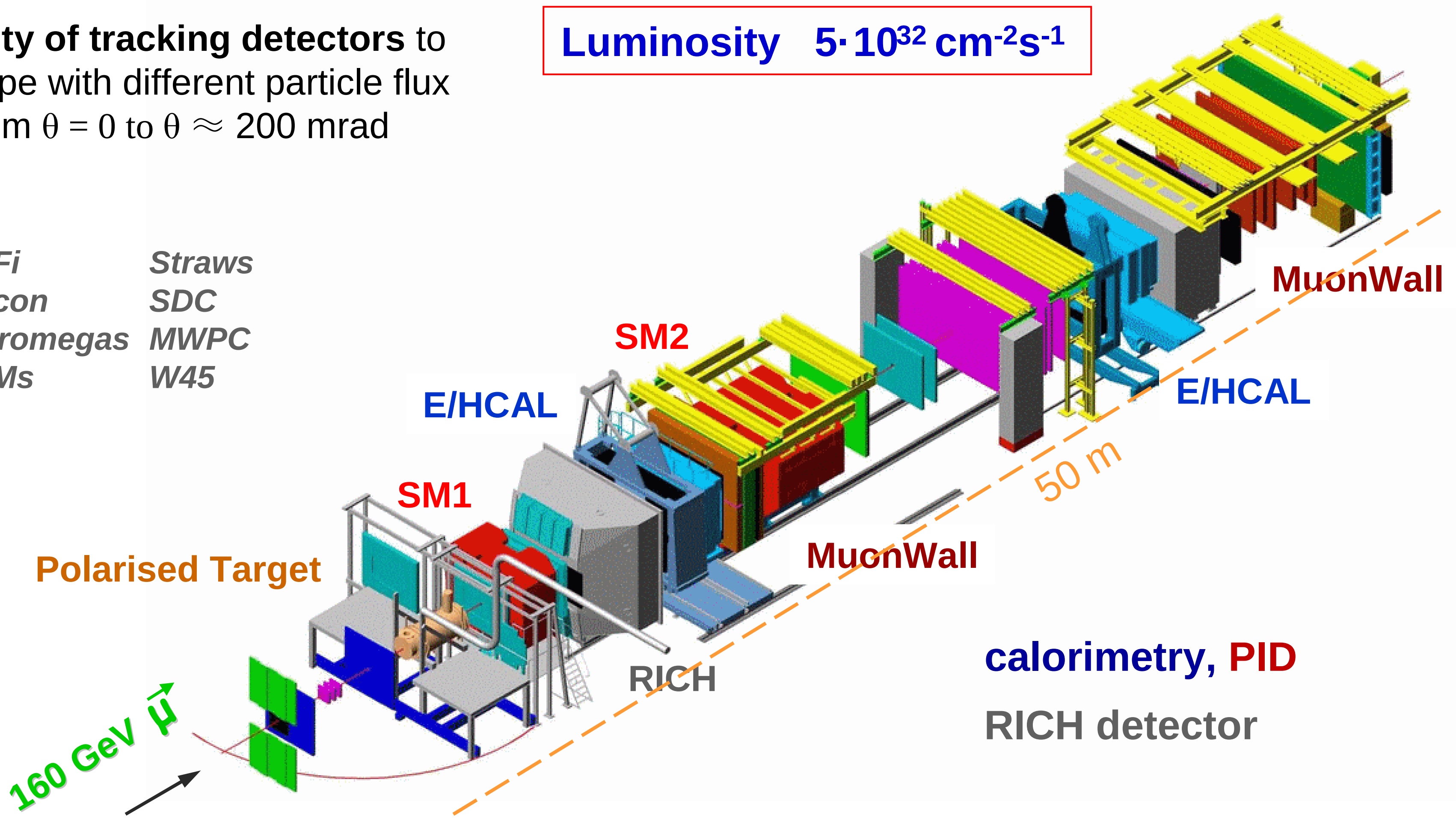
two stages spectrometer

Large Angle Spectrometer (SM1)

Small Angle Spectrometer (SM2)

variety of tracking detectors to cope with different particle flux from $\theta = 0$ to $\theta \approx 200$ mrad

SciFi	*Straws*
Silicon	*SDC*
Micromegas	*MWPC*
GEMs	*W45*



calorimetry, PID

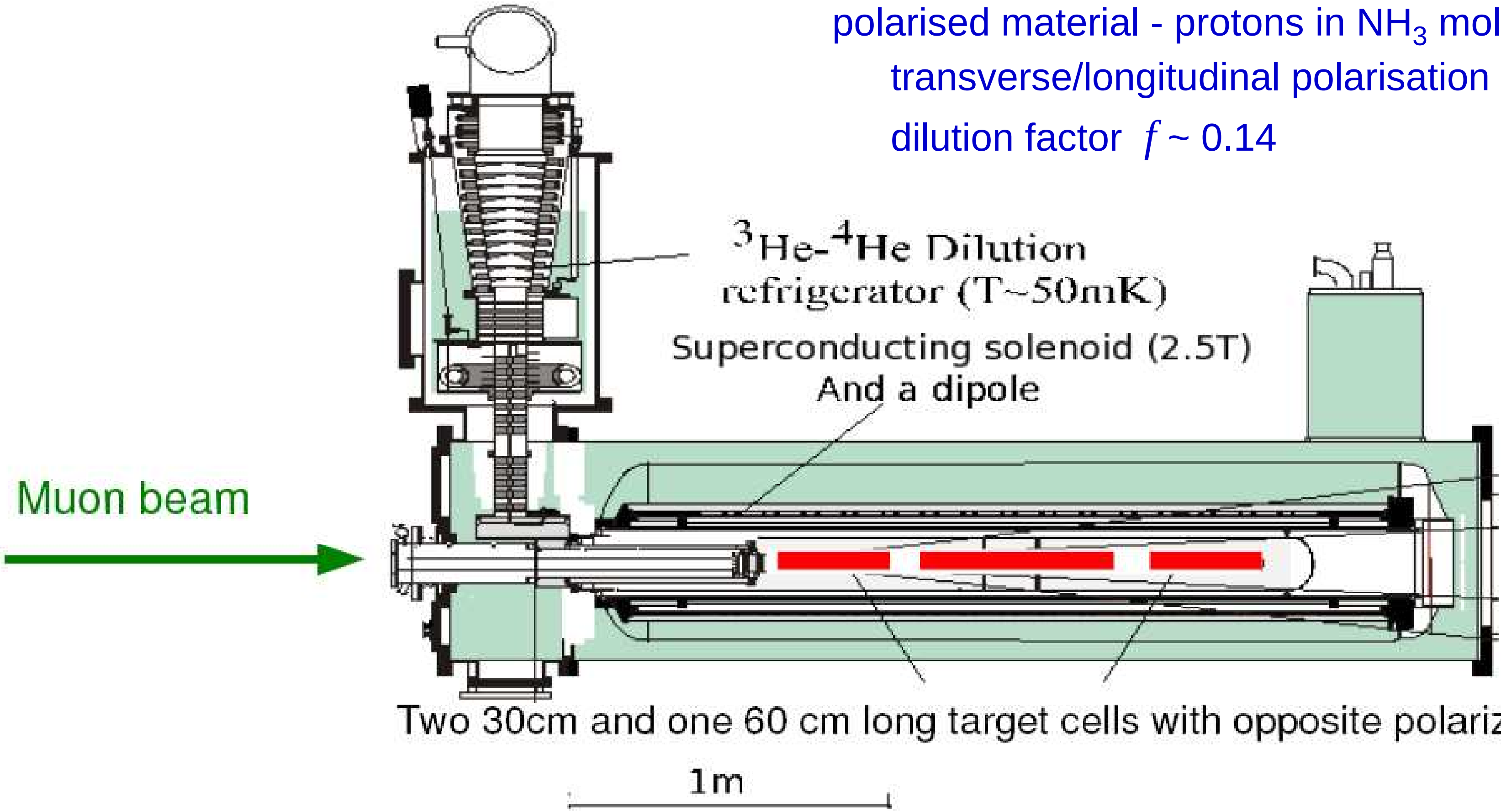
RICH detector

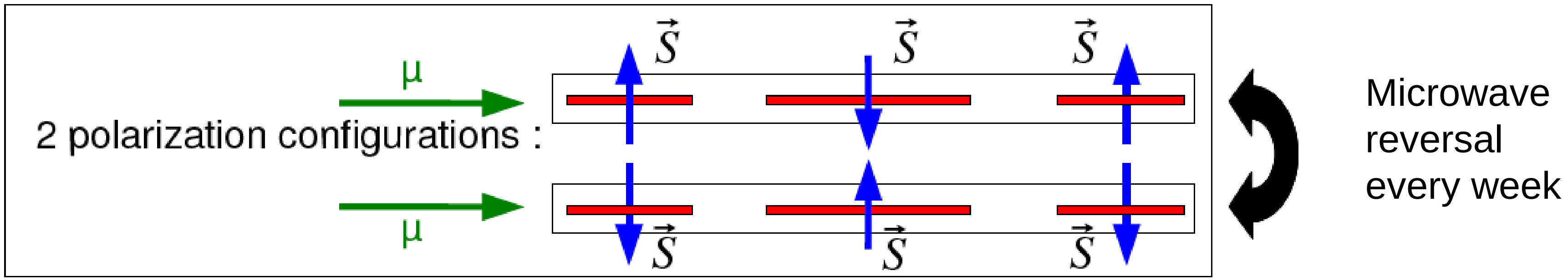
COMPASS polarised ammonia target (2007)

polarised material - protons in NH_3 molecule

transverse/longitudinal polarisation ~90%

dilution factor $f \sim 0.14$

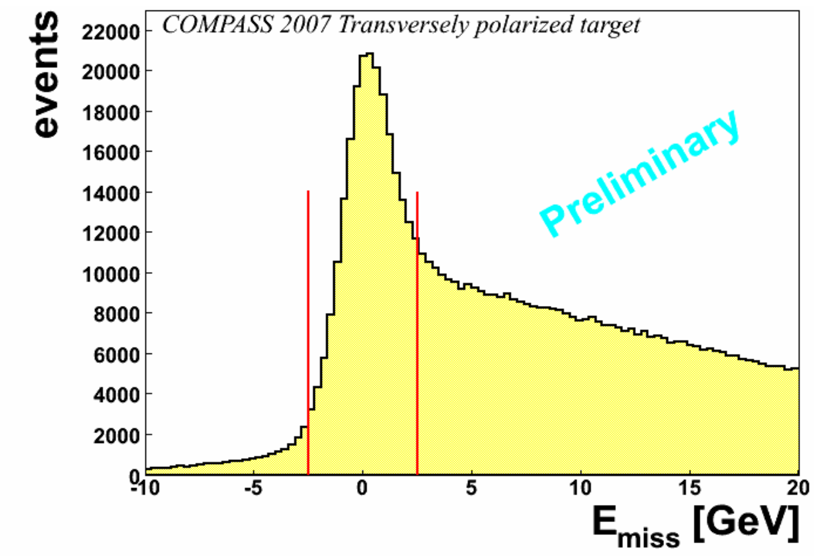




Selections of exclusive ρ^0 events

$Q^2 > 1$ GeV^2
W > 5 GeV
$0.005 < x_{Bj} < 0.1$
$0.05 < p_t^2 < 0.5$ GeV^2

Transversely polarised proton target (NH_3), $P_T \approx 90\%$, 2007 data



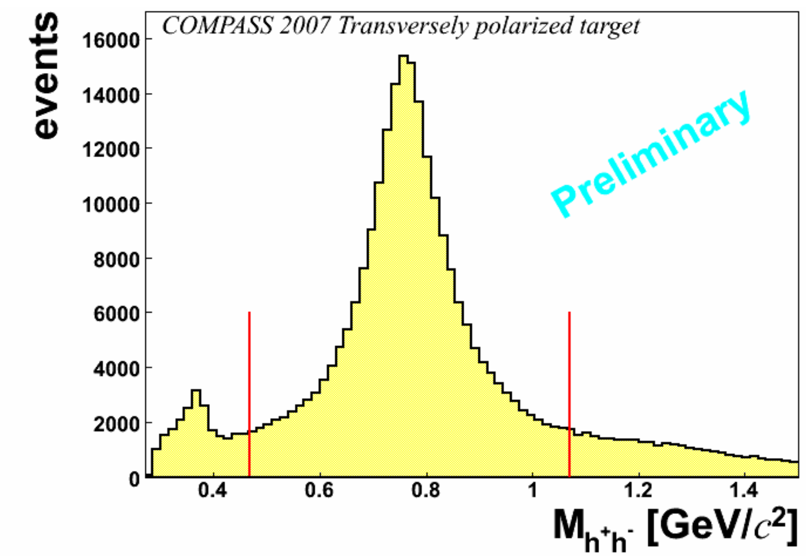
- recoil proton (recoiling system) not detected

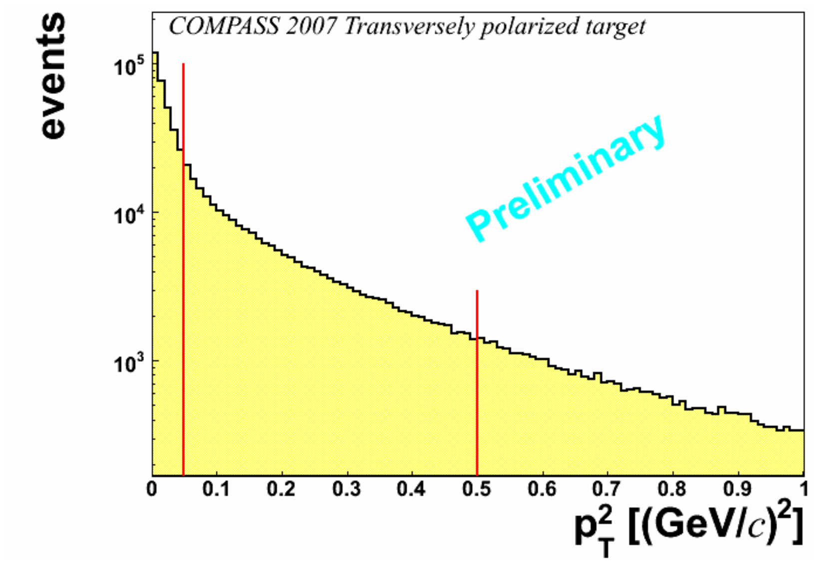
$$E_{miss} = \frac{M_X^2 - M_{proton}^2}{2M_{proton}} \in [-2.5, 2.5]\,GeV$$

- charged pion mass assumed for $h^+(h^-)$

$$-0.3 < M_{\pi\pi} - M_{\rho(\mathrm{PDG})} < 0.3\ \mathrm{GeV}/c^2$$

- cuts on p_t^2 to remove coherent production from N and further suppress non-exclusive background





Observables in hard exclusive meson production relevant for GPDs

for vector mesons

unpolarised cross section ($\sigma_{00}^{++} \equiv \sigma_L$)

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

transverse target spin asymmetry

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

⟸ **access to GPD E**

related to orbital momentum

$\mathcal{H}_\mathcal{M}, \mathcal{E}_\mathcal{M}$ are weighted sums of integrals of the GPDs $H_{q,g}$, $E_{q,g}$

weights depend on contributions of various quark flavours
and of gluons to the production of meson M

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

(large Q^2 approximation)

Give access to the orbital angular momentum of quarks

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

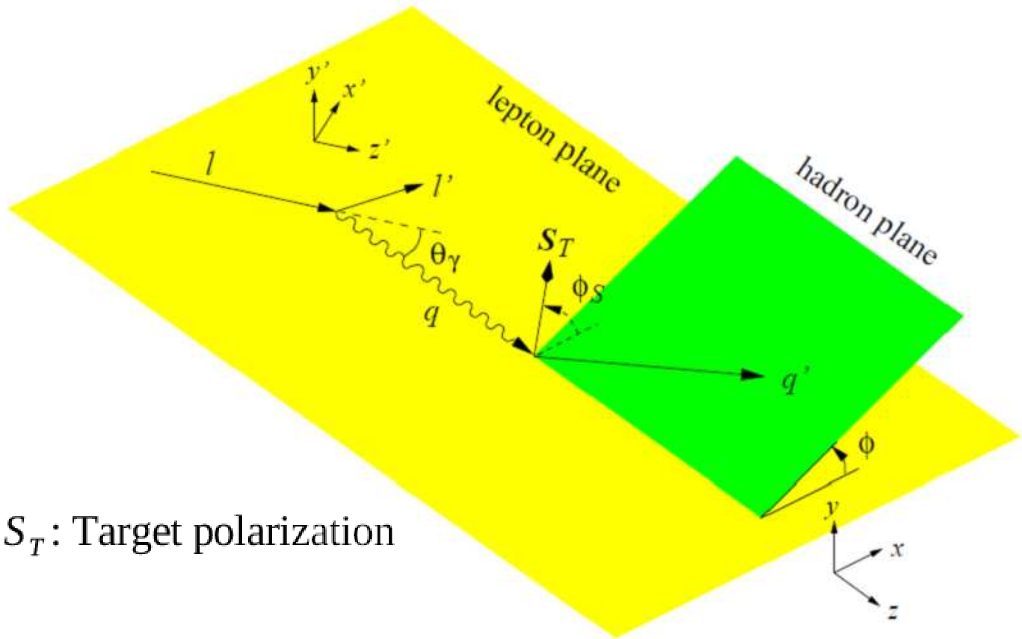
Ji's sum rule

So far GPD E poorly constrained by data (mostly by Pauli form factors)

Transverse target spin asymmetry for exclusive ρ^0 production

$$\mu + P^{\uparrow} \rightarrow \mu' + P' + \rho^0$$

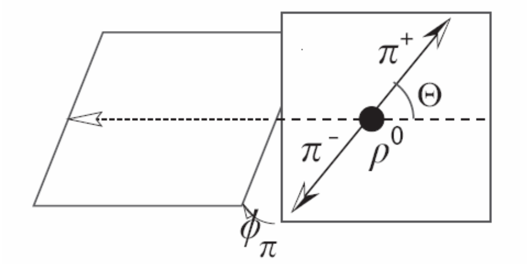
definitions



S_T: Target polarization

to disentangle contributions from γ_L and γ_T the distribution of ρ^0 decay polar angle needed in addition

Diehl and Sapeta (2005)



ρ^0 Rest Frame

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

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

A^i_m amplitudes for subprocess $\gamma^* p \rightarrow \rho^0 p$
with proton polarisation ***i*** and photon polarisation ***m***

- Virtual photon polarisation parameter $\varepsilon = \dfrac{1 - y - \frac{1}{4}y^2\gamma^2}{1 - y + \frac{1}{2}y^2 + \frac{1}{4}y^2\gamma^2}$,

(if m_l can be neglected)

Cross sections in terms of target polarisation wrt virtual photon

(in deep inelastic kinematics)

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

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

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

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

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

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

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

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

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

Extraction of transverse target spin asymmetry

Flux — Acceptance — Dilution factor — Mean target polarisation

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

Numer of target nucleons

$$\sigma_0 = \frac{1}{2}(\sigma_{++}^{++} + \sigma_{++}^{--}) + \varepsilon\, \sigma_{00}^{++} \equiv \sigma_T + \varepsilon\, \sigma_L$$

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

Asymmetry extraction from double ratio method using 3 targets with two polarisations each

$$DR(\phi-\phi_s) = \frac{N_{Up/Down}^{\uparrow}(\phi-\phi_s) N_{Center}^{\uparrow}(\phi-\phi_s)}{N_{Center}^{\downarrow}(\phi-\phi_s+\pi) N_{Up/Down}^{\downarrow}(\phi-\phi_s+\pi)}$$

$$= \frac{F_{Up/Down}^{\uparrow} F_{Center}^{\uparrow}}{F_{Center}^{\downarrow} F_{Up/Down}^{\downarrow}} \; \frac{a_{Up/Down}^{\uparrow}(\phi-\phi_s) a_{Center}^{\uparrow}(\phi-\phi_s)}{a_{Center}^{\downarrow}(\phi-\phi_s+\pi) a_{Up/Down}^{\downarrow}(\phi-\phi_s+\pi)} \; \frac{(1+ f \langle P_T \rangle A_{UT} \sin(\phi-\phi_s))^2}{(1- f \langle P_T \rangle A_{UT} \sin(\phi-\phi_s))^2}$$

in the double ratio Flux and σ_0 cancel

also Acceptance cancels provided no changes between spin reversals

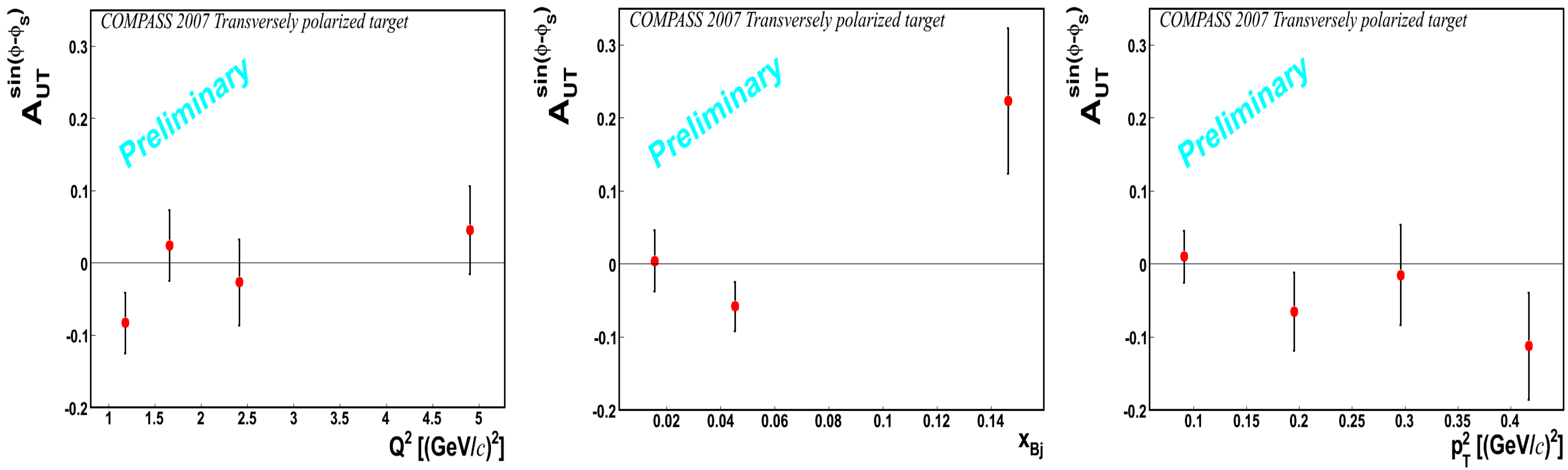
A_{UT} from a fit to $DR\ (\phi\text{-}\phi s)$

Transverse target spin asymmetry: polarised protons (2007)

new

NH_3 target

$< Q^2 > \approx 2.2\ (\mathrm{GeV}/c)^2$ $< x_{Bj} > \approx 0.04$ $< p_t^2 > \approx 0.18\ (\mathrm{GeV}/c)^2$



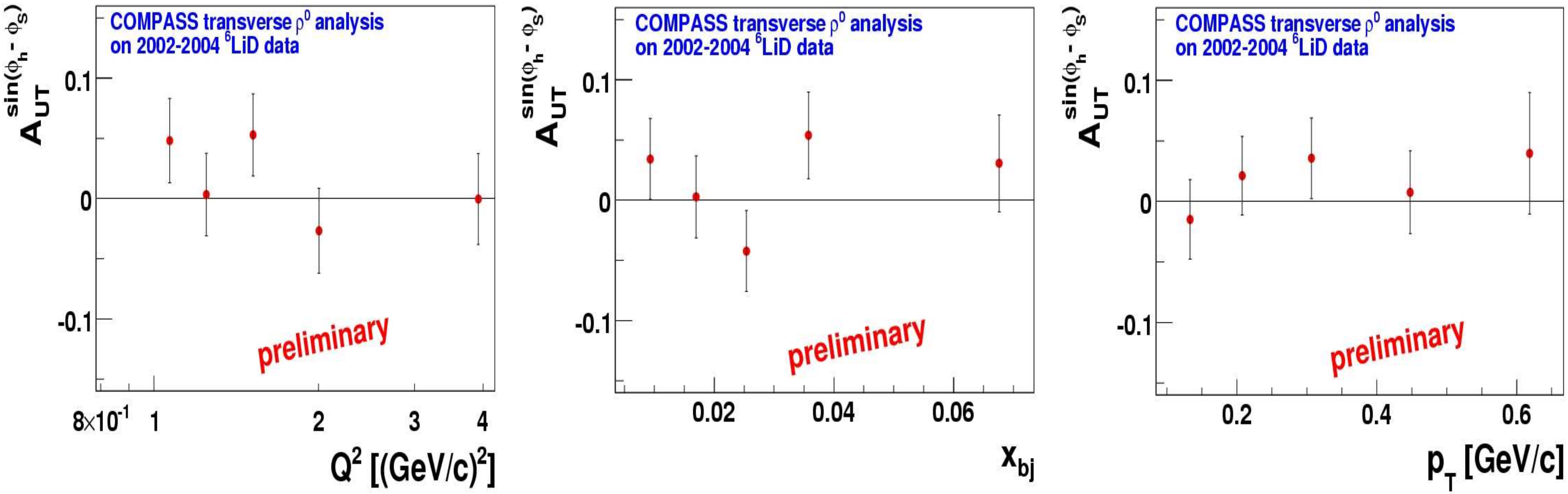
$A_{UT}^{\sin(\phi-\phi_s)}$ compatible with 0

In progress: L/T γ^* separation (using ρ^0 decay angular distribution)

Transverse target spin asymmetry: polarised deuterons (2002-2004)

^{6}LiD target

$< Q^2 > \approx 2.0\ (\mathrm{GeV}/c)^2$ $< x_{Bj} > \approx 0.03$ $< p_t > \approx 0.11\ \mathrm{GeV}/c$



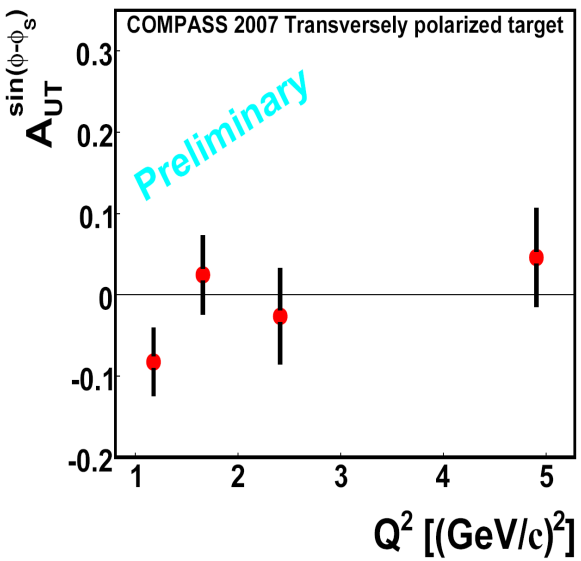
$A_{UT}^{\sin(\phi-\phi_s)}$ compatible with 0

In progress: L/T γ^* separation (using ρ^0 decay angular distribution)

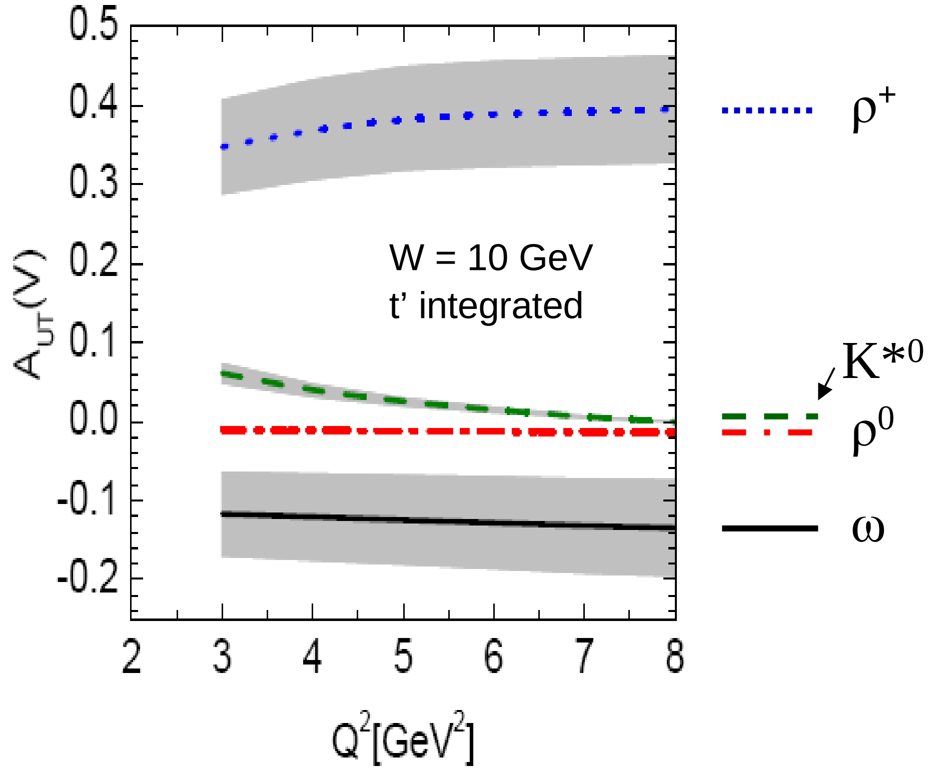
and coherent / incoherent separation for deuteron

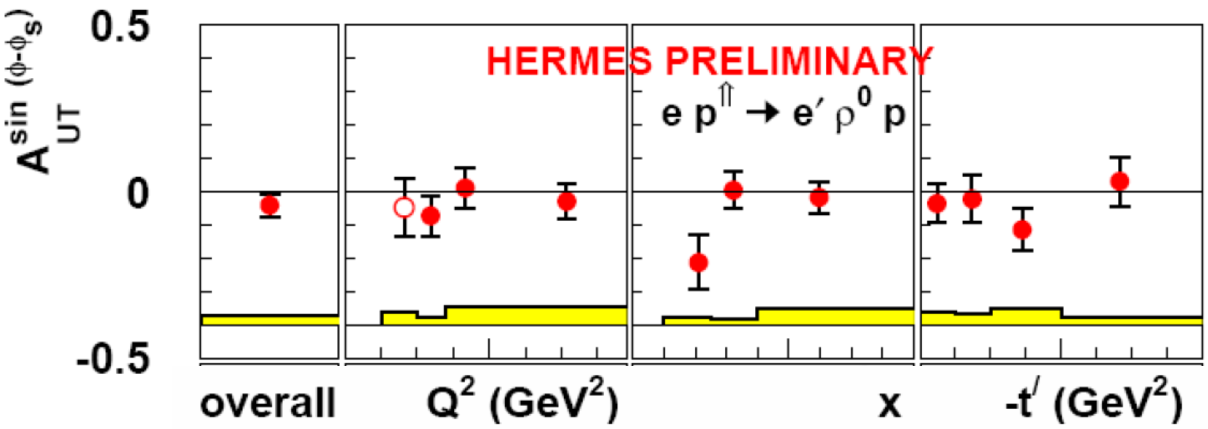
Comparison to a GPD model and to HERMES

COMPASS $p^{\uparrow}$



GPD model:
Goloskokov, Kroll
2008





predictions for protons

$A_{UT}(\rho) \approx -0.02$

$A_{UT}(\omega) \approx -0.10$

similar for both experiments

HERMES extracted also ρ^0 TTSA separately for γ^*_L and γ^*_T **!** → compatible with 0

Longitudinal double-spin asymmetry for exclusive ρ^0 production

EPJ C 52 (2007)

$<P_B>$ = -0.76   longitudinally polarised deuteron target (^{6}LiD) $P_T \approx 50\%$ $f \approx 0.37$

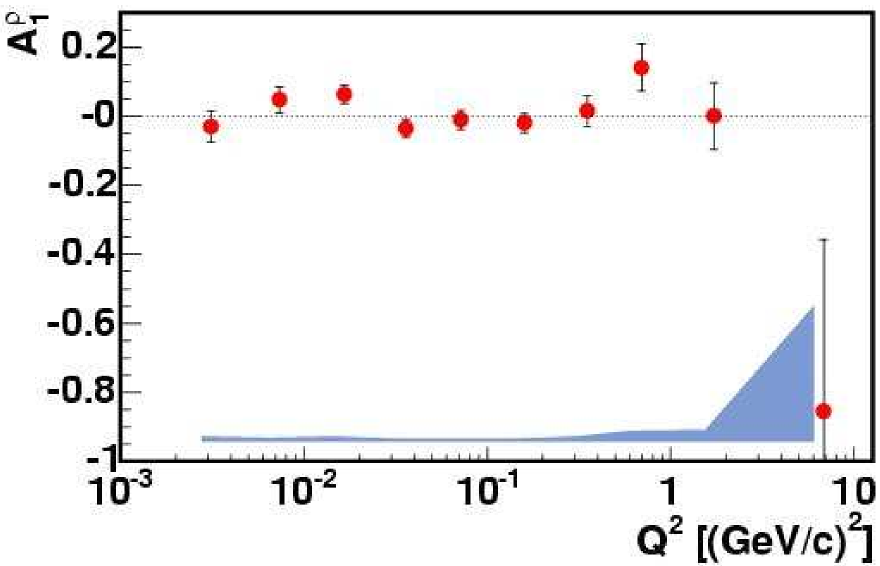
wide range of Q^2 and x ,   W > 7.5 GeV , $0.15 < p_t^2 < 0.5$ GeV^2

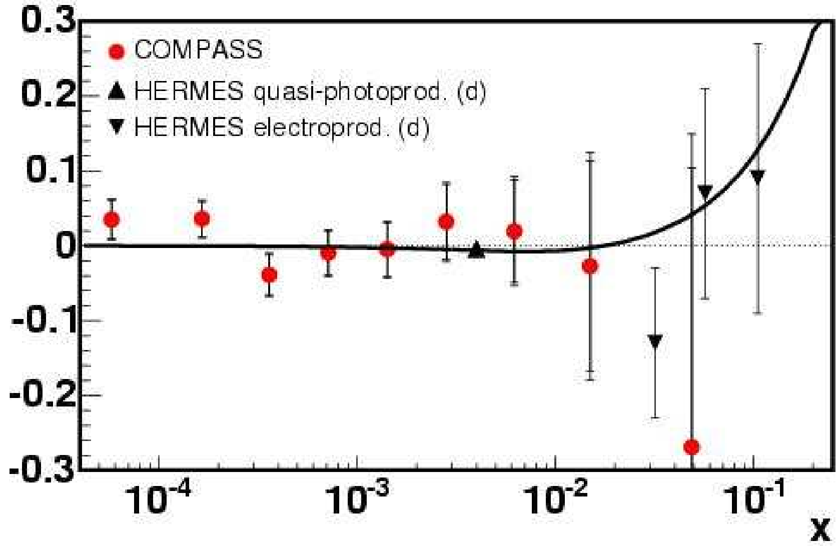
$$A_{LL}(\mu N \to \mu N \rho^0) = \frac{\sigma(\mu N)_{\uparrow\Downarrow} - \sigma(\mu N)_{\uparrow\Uparrow}}{\sigma(\mu N)_{\uparrow\Downarrow} + \sigma(\mu N)_{\uparrow\Uparrow}} = \frac{1}{f} \cdot \frac{1}{P_b} \cdot \frac{1}{P_t} \cdot A_{LL}^{raw}$$

$$A_1^{\rho}(\gamma^* N \to \rho^0 N) \approx \frac{1}{D} A_{LL}(\mu N \to \mu N \rho^0)$$

curve: $A_1^{\rho} = \frac{2\,A_1}{1 + (A_1)^2}$

where A_1 – inclusive asymmetry (d)





A_1^{ρ} on polarised deuterons consistent with 0

Longitudinal double-spin asymmetry for exclusive ρ^0 production (cont.d)

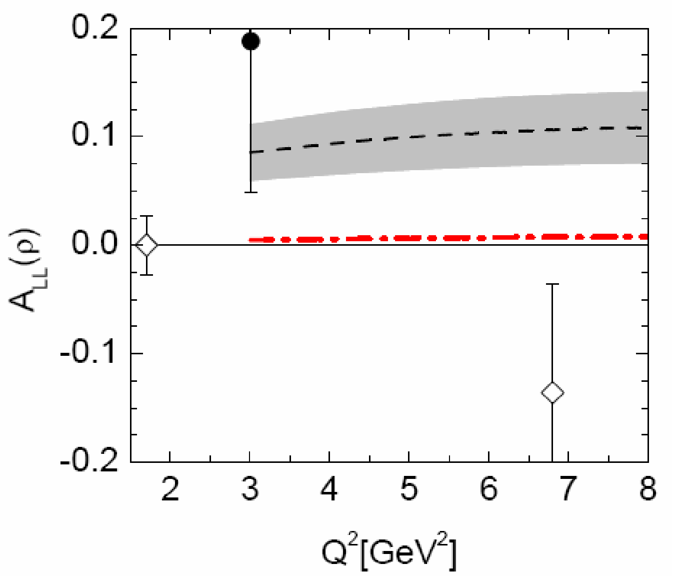
estimate of contribution of unnatural exchanges (π, a_1)

$$A_1^{\rho} = \frac{\sum_{\lambda_\rho \lambda_{N'}} 2Re\,\{T^N_{\lambda_\rho \lambda_{N'},++} \cdot T^{*U}_{\lambda_\rho \lambda_{N'},++}\}}{\sum_{\lambda_\rho \lambda_{N'}} \{|T^N_{\lambda_\rho \lambda_{N'},++}|^2 + |T^U_{\lambda_\rho \lambda_{N'},++}|^2\}} \Rightarrow \frac{2Re\,\{T^N_{++,++} \cdot T^{*U}_{++,++}\}}{|T^N_{++,++}|^2 + |T^U_{++,++}|^2}$$

if SCHC

The asymmetry is a sensitive probe of unnatural parity exchanges

- at small Q^2 and x data provides precise limits on their contribution
- at large Q^2 A_1^{ρ} related to GPDs (higher-twist) $\propto k_T^2\, \tilde{H}_{g(sea)} / (Q^2 H_{g(sea)})$



Goloskokov, Kroll (2007)

W = 5 GeV
W = 10 GeV
HERMES
COMPASS

small value of A_1^{ρ} at W ≥ 10 GeV due to approximate cancellation of gluon and sea contributions

Spin Density Matrix Elements

VM angular distributions W(cosθ, φ_π, ϕ) depend on the spin density matrix elements (SDME) ⇨ 23 (15) observables with polarized (unpolarized) beam

SDMEs are bilinear combinations of the helicity amplitudes $T_{\lambda m\, \lambda\gamma}(\gamma^* N \longrightarrow mN)$

$\lambda\gamma = \pm 1, 0 \quad \lambda m = \pm 1, 0$

(averaged over nucleon spins)

- describe helicity transfer from γ^* to VM

  s-channel helicity conservation (SCHC)

- describe parity of t-channel exchange

  (NPE vs. UPE)

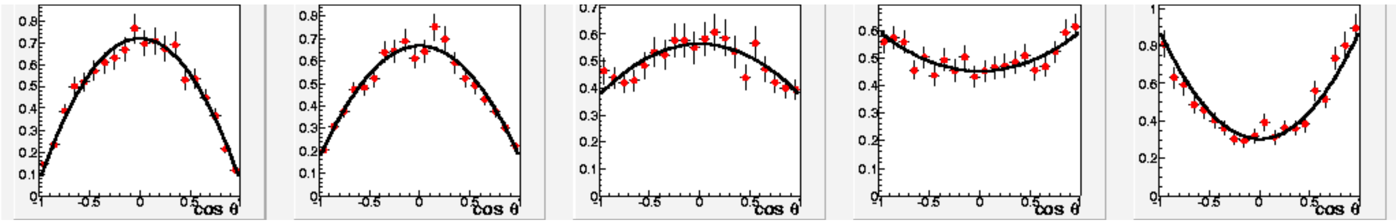
- impact on GPD studies – determination of σ_L

  SDME $r^{04}_{00} \xrightarrow{SCHC} R = \frac{\sigma_L}{\sigma_T}$

Measurement of r_{00}^{04} and determination of $R = \sigma_L/\sigma_T$

0.01 < Q^2 < 0.05 < Q^2 < 0.3 < Q^2 < 0.6 < Q^2 < 2.0 < Q^2 < 10 GeV^2

W(cos θ)



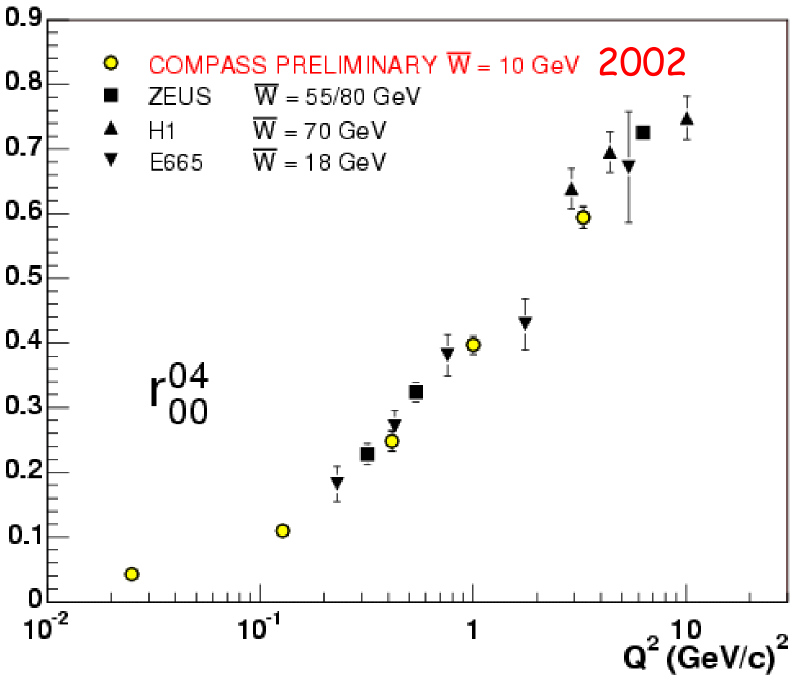
$$W(\cos\theta) = \frac{3}{4}\left[(1 - r_{00}^{04}) + (3r_{00}^{04} - 1)\cos^2\theta\right]$$

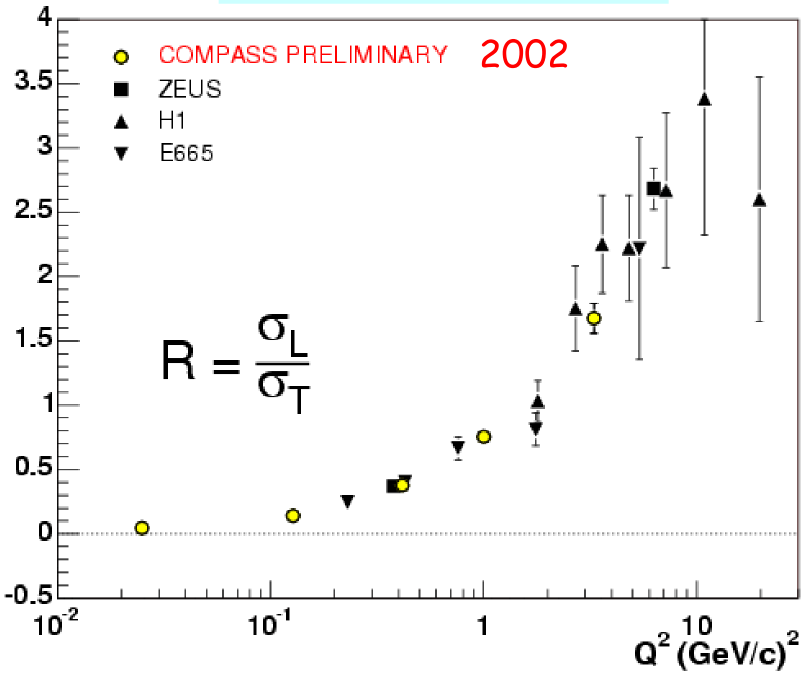
$$r_{00}^{04} \sim \frac{|T_{01}|^2 + (\varepsilon + \delta)|T_{00}|^2}{\sigma_T + (\varepsilon + \delta)\sigma_L}$$

$T_{\lambda\rho\,\lambda\gamma}$ helicity amplitudes

meson photon

$$r_{00}^{04} \xrightarrow{\text{SCHC}} R = \frac{\sigma_L}{\sigma_T}$$



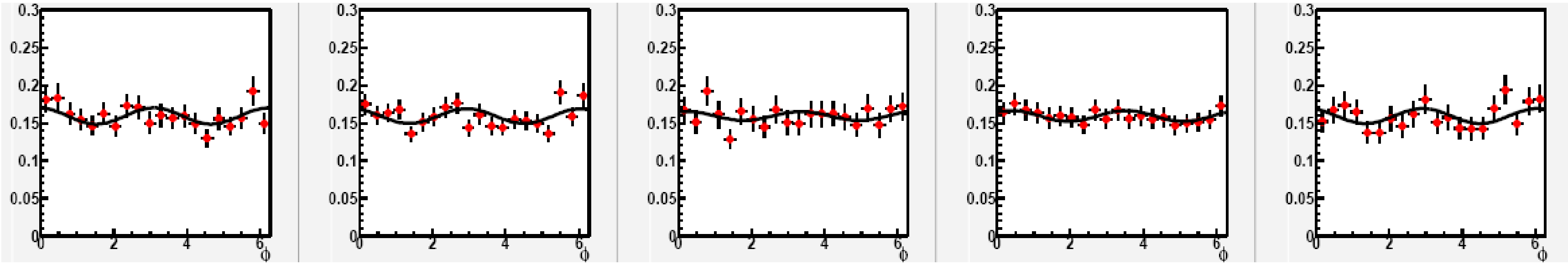


- High statistics from quasi-photoproduction to hard production
- Impact on GPD studies; determination of σ_L

Measurement of r^{04}_{1-1} and Im r^{3}_{1-1}

0.01 < Q² < 0.05 < Q² < 0.3 < Q² < 0.6 < Q² < 2.0 < Q² < 10 GeV²

W(φ)



($\varphi \equiv \varphi_\pi$)

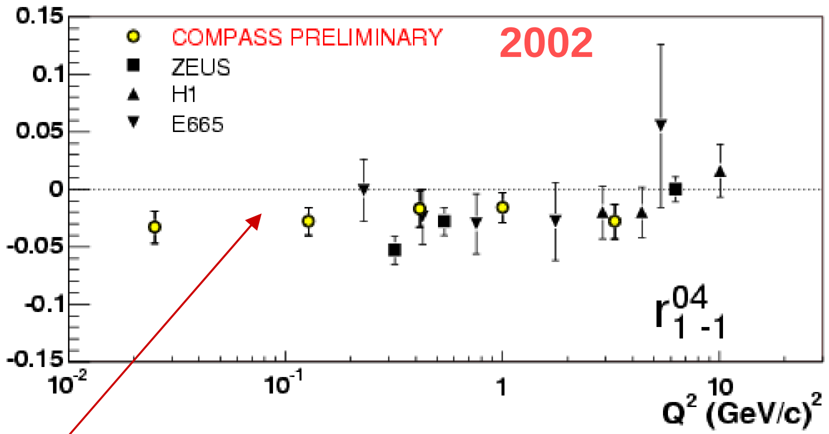
$$W(\varphi) = \frac{1}{2\pi}\left[1 - 2r^{04}_{1-1}\cos 2\varphi + 2\,\mathrm{Im}\,r^{3}_{1-1} P_\mu \sqrt{1-\varepsilon^2}\,\sin 2\varphi\right]$$

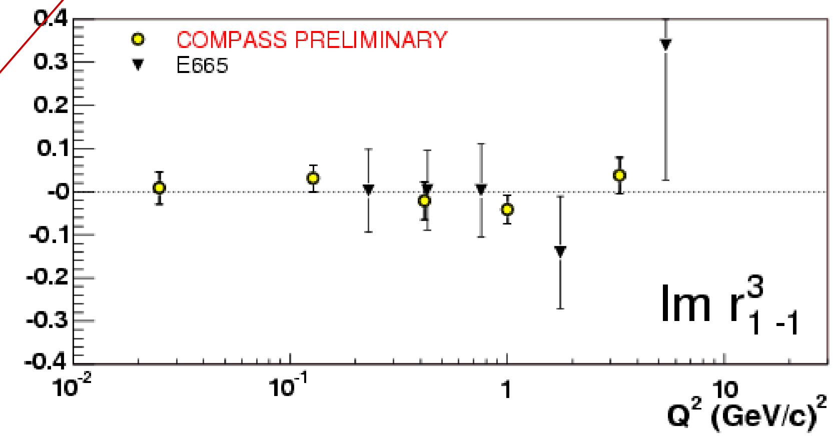
beam polarisation

$$r^{04}_{1-1} = \frac{\mathrm{Re}(T_{11}T^{*}_{-11}) - (\varepsilon+\delta)|T_{10}|^2}{N_T(1+(\varepsilon+\delta)R)} = 0$$

$$\mathrm{Im}\,r^{3}_{1-1} = \ldots = 0$$

if SCHC holds





weak violation of SCHC

Future GPD program @ COMPASS

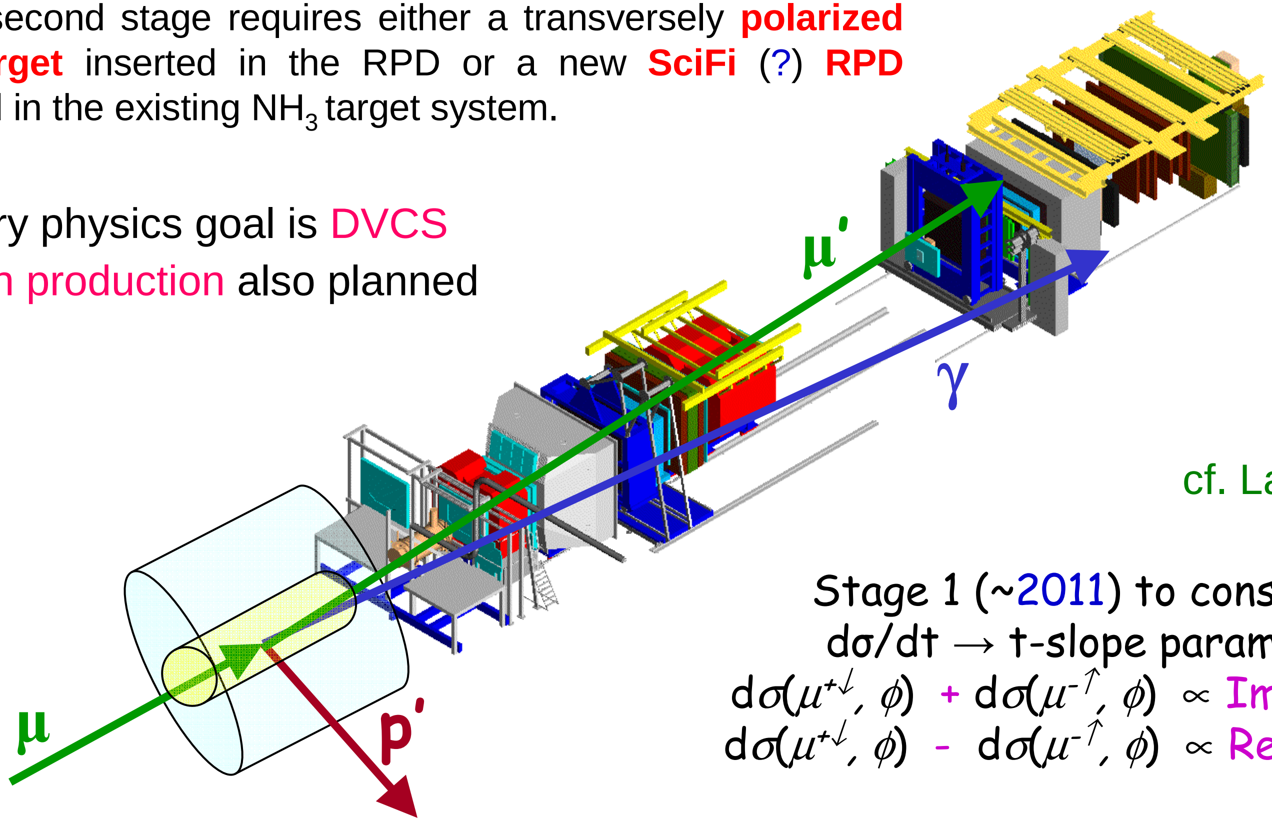
- The GPDs program is part of the **COMPASS Phase II** (2010-2015) proposal to be submitted to CERN in 2009.

- The first stage of this program requires a 4 m long recoil proton detector (**RPD**) together with a 2.5 m long **LH_2 target**. Upgrades of electromagnetic calorimeters to enlarge coverage at large x_B and reduce bkg.

- The second stage requires either a transversely **polarized NH_3 target** inserted in the RPD or a new **SciFi** (?) **RPD** inserted in the existing NH_3 target system.

primary physics goal is DVCS

meson production also planned



cf. Laurent Schoeffel talk

Stage 1 (~2011) to constrain H

$d\sigma/dt \rightarrow$ t-slope parameter b

$$d\sigma(\mu^{+\downarrow}, \phi) + d\sigma(\mu^{-\uparrow}, \phi) \propto \mathrm{Im}(F_1 H) \sin\phi$$

$$d\sigma(\mu^{+\downarrow}, \phi) - d\sigma(\mu^{-\uparrow}, \phi) \propto \mathrm{Re}(F_1 H) \cos\phi$$

Stage 2 (~2013) to constrain E

$$d\sigma(\phi, \phi_S) - d\sigma(\phi, \phi_S+\pi) \propto \mathrm{Im}(F_2 H - F_1 E) \sin(\phi-\phi_S) \cos\phi$$

100 – 190 GeV $\mu^{+\downarrow,-\uparrow}$ 80%

2008 DVCS test run

Goal: evaluate feasibility to detect DVCS/BH in the COMPASS setup

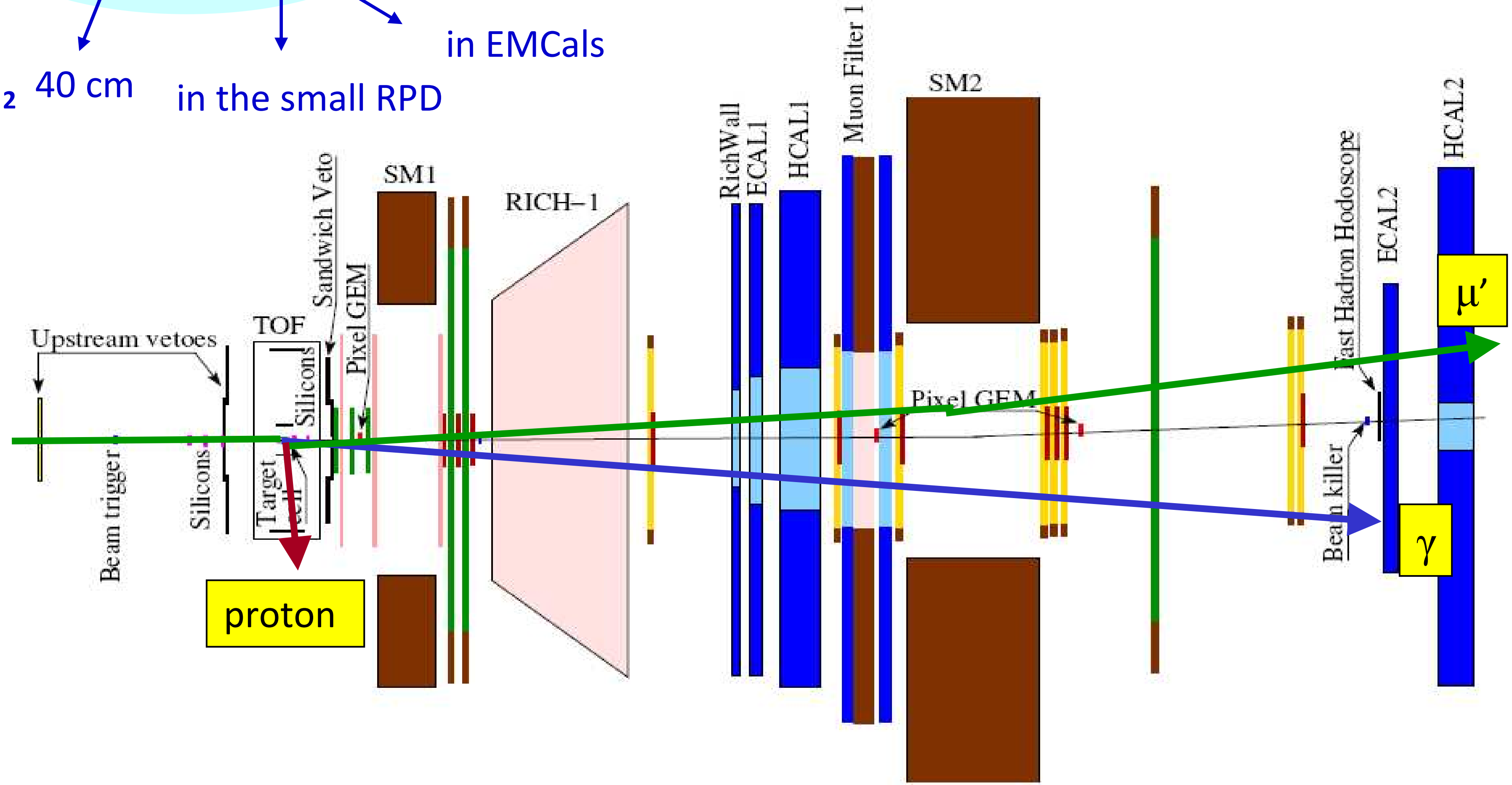
$\mu \, p \rightarrow \mu \, p \, \gamma$

LH_2 40 cm

in the small RPD

in EMCals

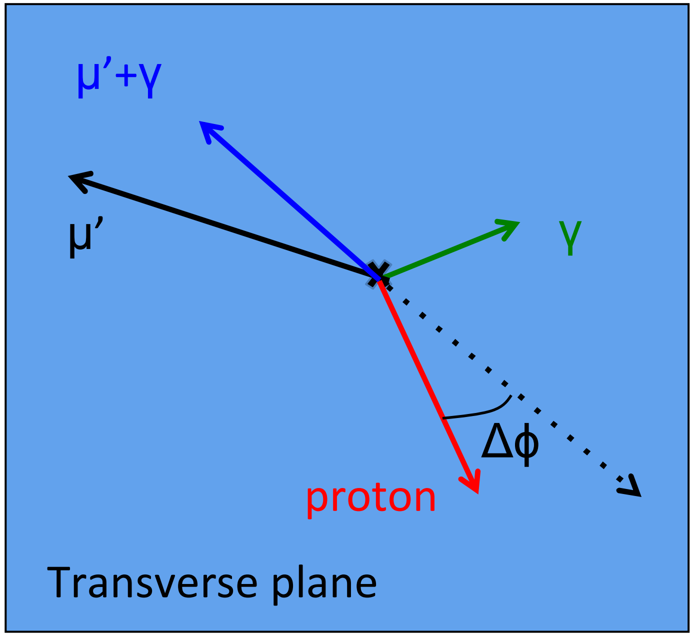
Use COMPASS 'hadron' set-up

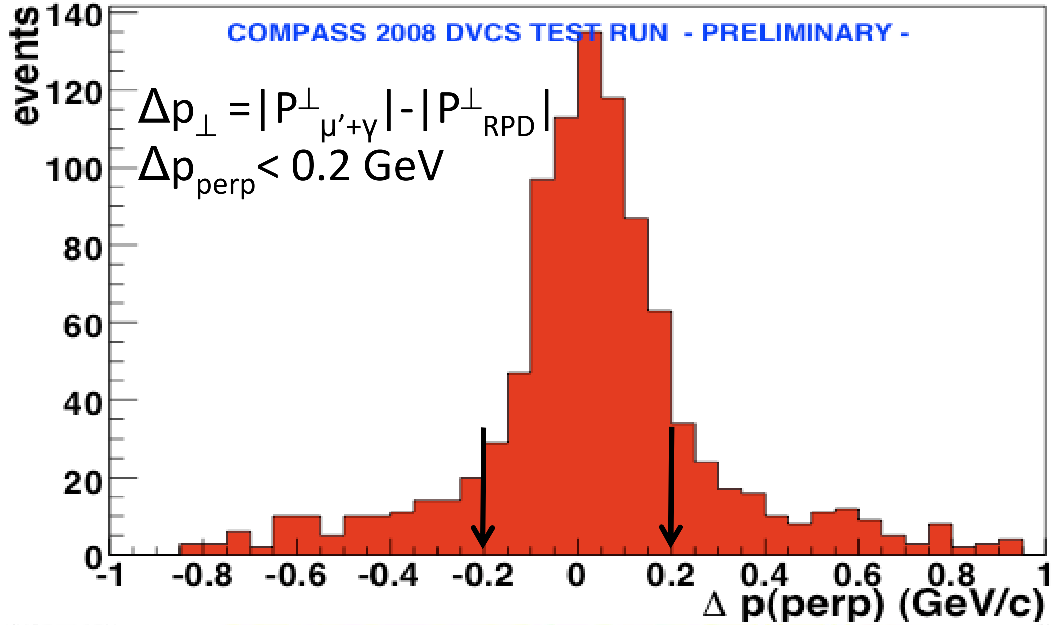


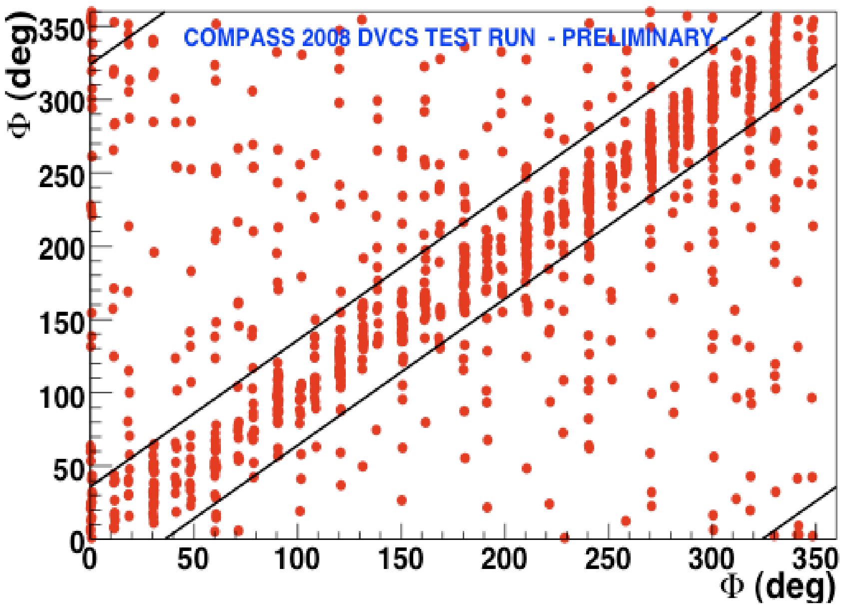
2 days of 160 GeV muon beam (μ^+ and μ^-)

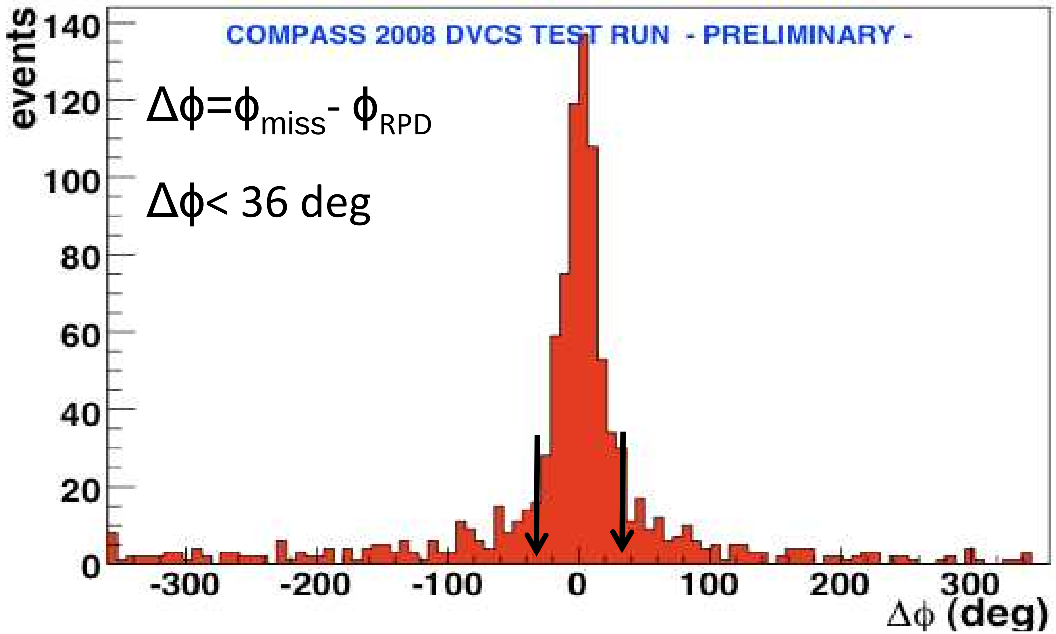
Kinematic constraints in the transverse plane

$$\vec{p}_{miss} = \vec{p}_{\mu} - \vec{p}_{\mu'} - \vec{p}_{\gamma}$$

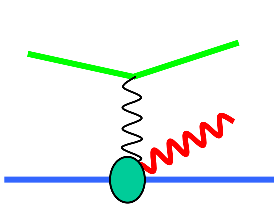


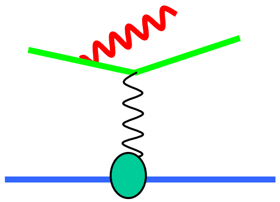


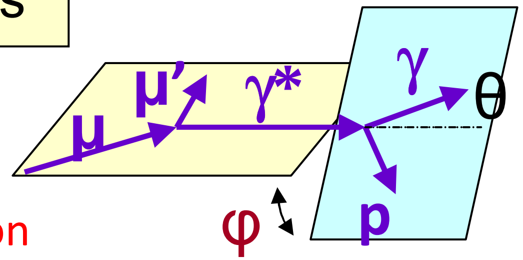




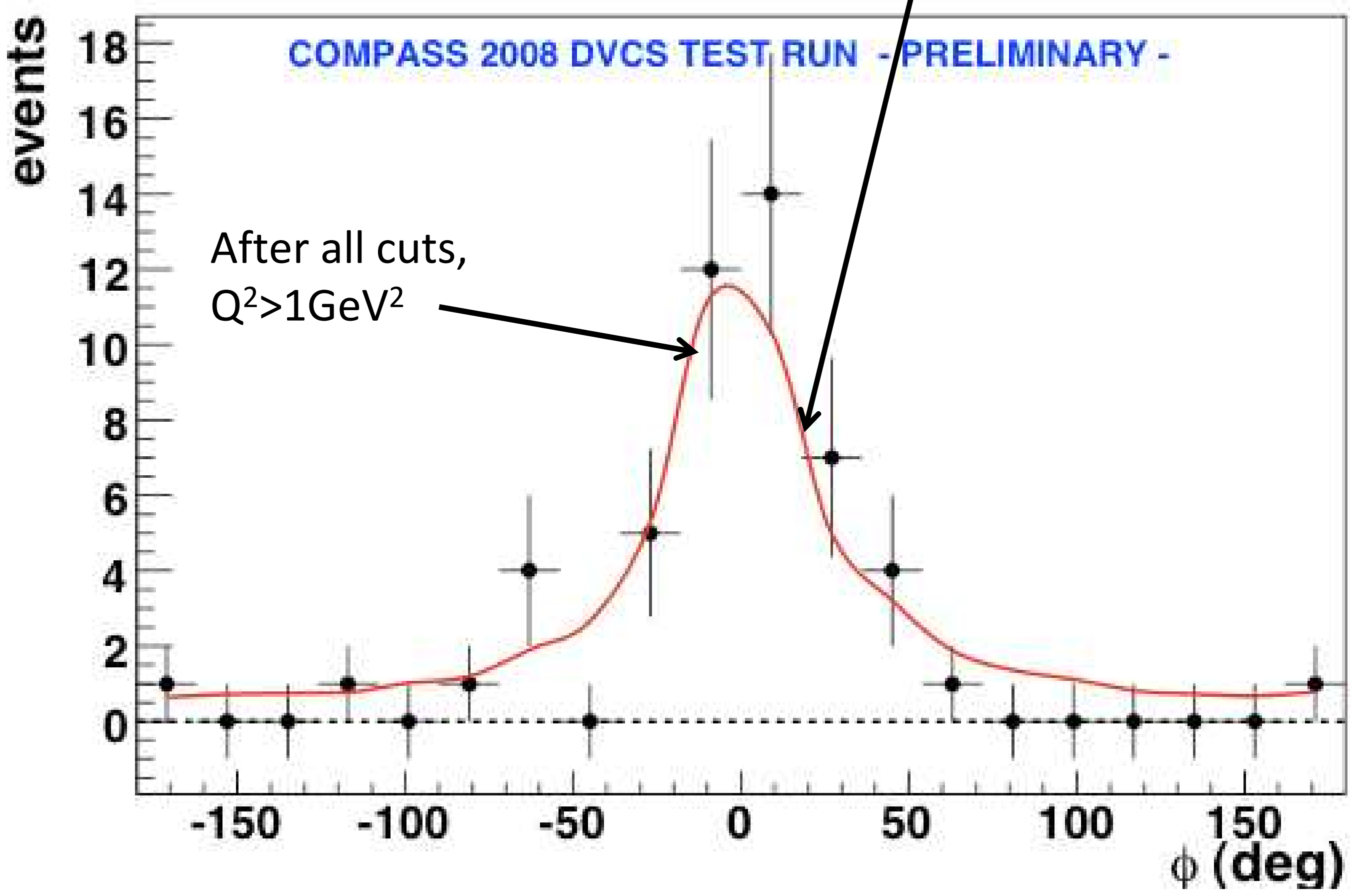
Azimuthal distribution for exclusive single photon events


DVCS


Bethe-Heitler



Monte-Carlo simulation
of BH (dominant) and DVCS



Clear signature of dominant BH events

Conclusions and outlook

- New results on transverse target spin asymmetries for ρ^0 production

  compatible with 0 both for the proton and the deuteron targets
  ongoing work on L/T separation, and coh./incoh. separation for d

- Published results on double spin asymmetry for ρ^0 production on d

  compatible with 0 in a wide x and Q^2 range
  precise upper limits on contribution of unnatural parity exchanges

- Expected high precision results on ρ^0 and φ SDMEs and cross sections

- In preparation proposal aiming at the GPD physics

  equipment needed: 4m long RPD, 2.5m LH_2 target, extented calorimetry
  RPD with polarised target

- 'DVCS test' runs: 2 days in 2008, 2 weeks in 2009

  muon beam and 'hadron setup' including 40cm LH_2 and the small RPD