Exclusive ρ^o production at COMPASS

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On behalf of the COMPASS *Collaboration*

- longitudinal double-spin asymmetry A_1^ρ
- ρ^o spin density matrix elements and $R = \sigma_L / \sigma_T$

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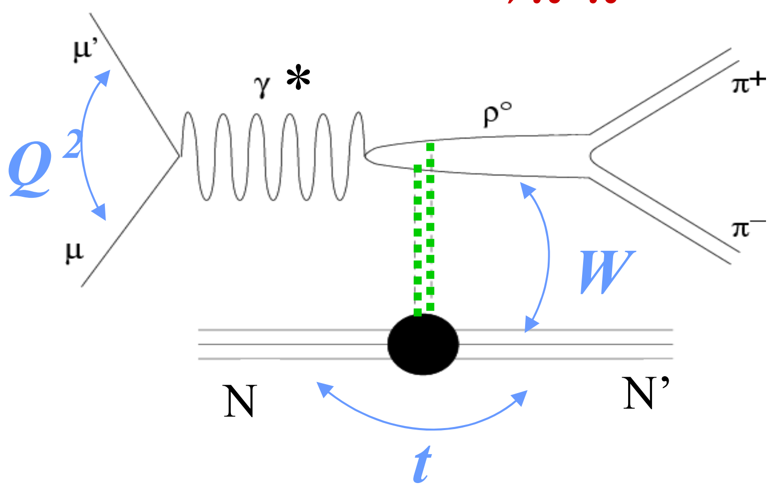
Physics of exclusive ρ^0 production

$\mu N \rightarrow \mu' N' \rho$
$\rightarrow \pi^+ \pi^-$



pQCD calculations or pQCD-inspired models with exchange of 2 quarks or 2 gluons (at large Q^2)

Diffraction

Regge theory:

at low energy (W < 5 GeV) exchange of Reggeons ρ, ω, a_2, f_2

at higher energies exchange of Pomeron

aim of the present analysis:

spin structure of cross section / helicity amplitudes for $\gamma^* N \rightarrow \rho^0 N$

- natural/unnatural parity of exchanged object
- is γ^* helicity retained by ρ^0 (SCHC) ?
- $R = \sigma_L/\sigma_T$ vs. Q^2

⇒ better understanding of Pomeron's nature

Properties of helicity amplitudes (1)

$$T_{\lambda_\rho \lambda_{N'};\lambda_\gamma \lambda_N} = \langle \lambda_\rho \lambda_{N'} | j_{\lambda_\gamma} | \lambda_N \rangle$$

Wick and Jacob

assume $\gamma^* N \to \rho^0 N$ with t-channel exchanges of natural and unnatural parities

$$T_{\lambda_\rho \lambda_{N'},\lambda_\gamma \lambda_N} = T^N_{\lambda_\rho \lambda_{N'},\lambda_\gamma \lambda_N} + T^U_{\lambda_\rho \lambda_{N'},\lambda_\gamma \lambda_N}$$

$$T^N_{-\lambda_\rho \lambda_{N'},-\lambda_\gamma \lambda_N} = (+1) \cdot (-1)^{\lambda_\rho - \lambda_\gamma} T^N_{\lambda_\rho \lambda_{N'},\lambda_\gamma \lambda_N}$$

natural: P, ρ, ω, a_2, f

$$T^U_{-\lambda_\rho \lambda_{N'},-\lambda_\gamma \lambda_N} = (-1) \cdot (-1)^{\lambda_\rho - \lambda_\gamma} T^U_{\lambda_\rho \lambda_{N'},\lambda_\gamma \lambda_N}$$

unnatural: π, a_1

How to assess contribution of unnatural exchanges ?

=> use longitudinal double spin asymmetries

$$A_1^\rho = \frac{\sigma^\rho_{1/2} - \sigma^\rho_{3/2}}{\sigma^\rho_{1/2} + \sigma^\rho_{3/2}} = \frac{\sum_{\lambda_\rho \lambda_{N'}} \{|T_{\lambda_\rho \lambda_{N'},++}|^2 - |T_{\lambda_\rho \lambda_{N'},-+}|^2\}}{\sum_{\lambda_\rho \lambda_{N'}} \{|T_{\lambda_\rho \lambda_{N'},++}|^2 + |T_{\lambda_\rho \lambda_{N'},-+}|^2\}}$$

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

if SCHC

Properties of helicity amplitudes (2)

if a) nucleon unpolarized (or average over nucleon spins ≈ 0)

b) assume only natural parity exchanges contribute

⇨ only 5 independent helicity amplitudes $T_{\lambda_V \lambda_\gamma}$

helicity conserving T_{00}, T_{11} , single helicity-flip T_{10}, T_{01} , double helicity-flip T_{1-1}

hierarchy of helicity amplitudes

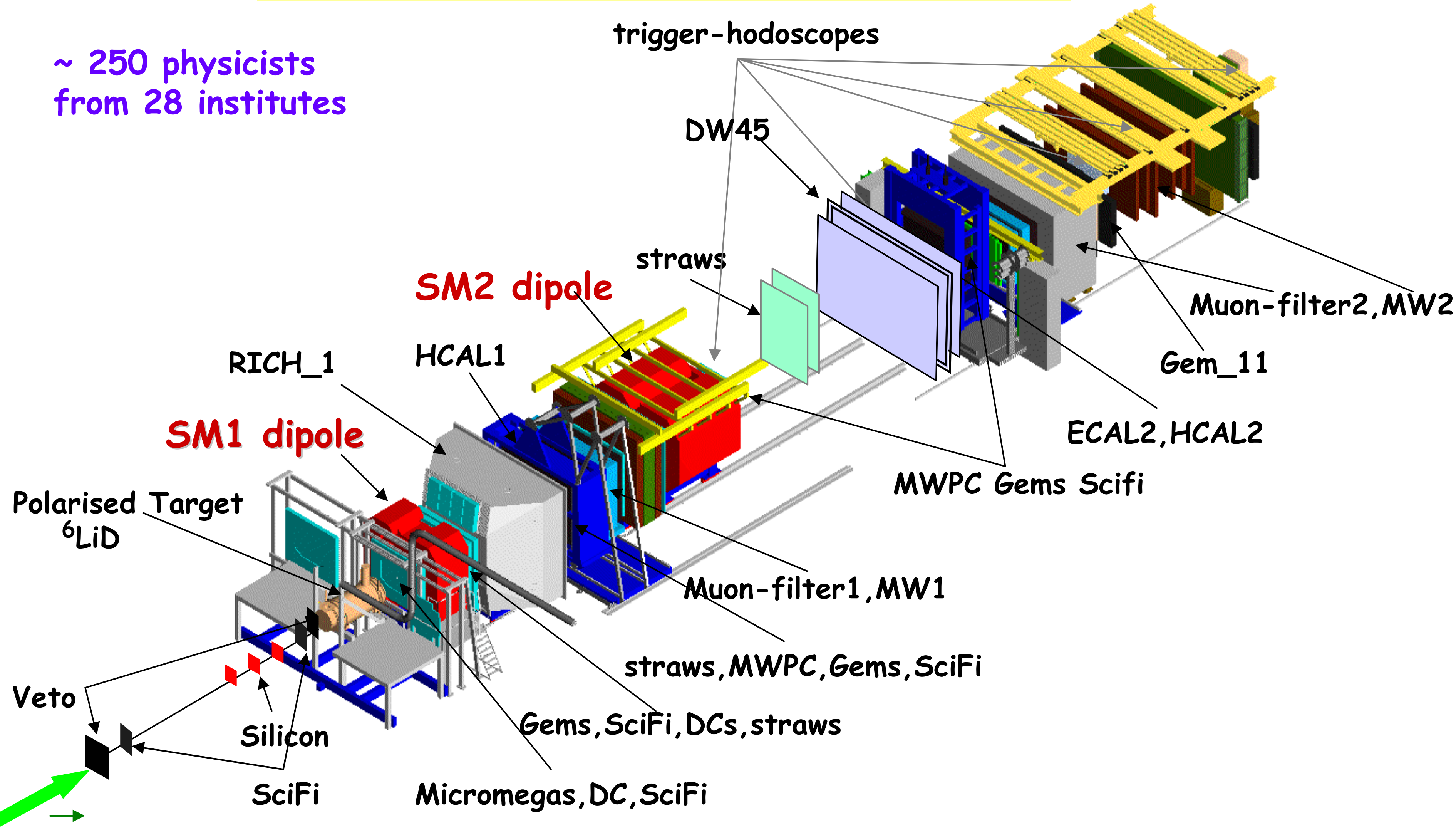
T_{00} , T_{11} > T_{01} > T_{1-1} > T_{10}

due to the angular momentum conservation
all helicity-flip amplitudes vanish at t = 0

st small t	T_{01} , T_{10}	T_{1-1}
	$\sim \sqrt{\lvert t \rvert}$	$\sim t$

COMPASS experiment

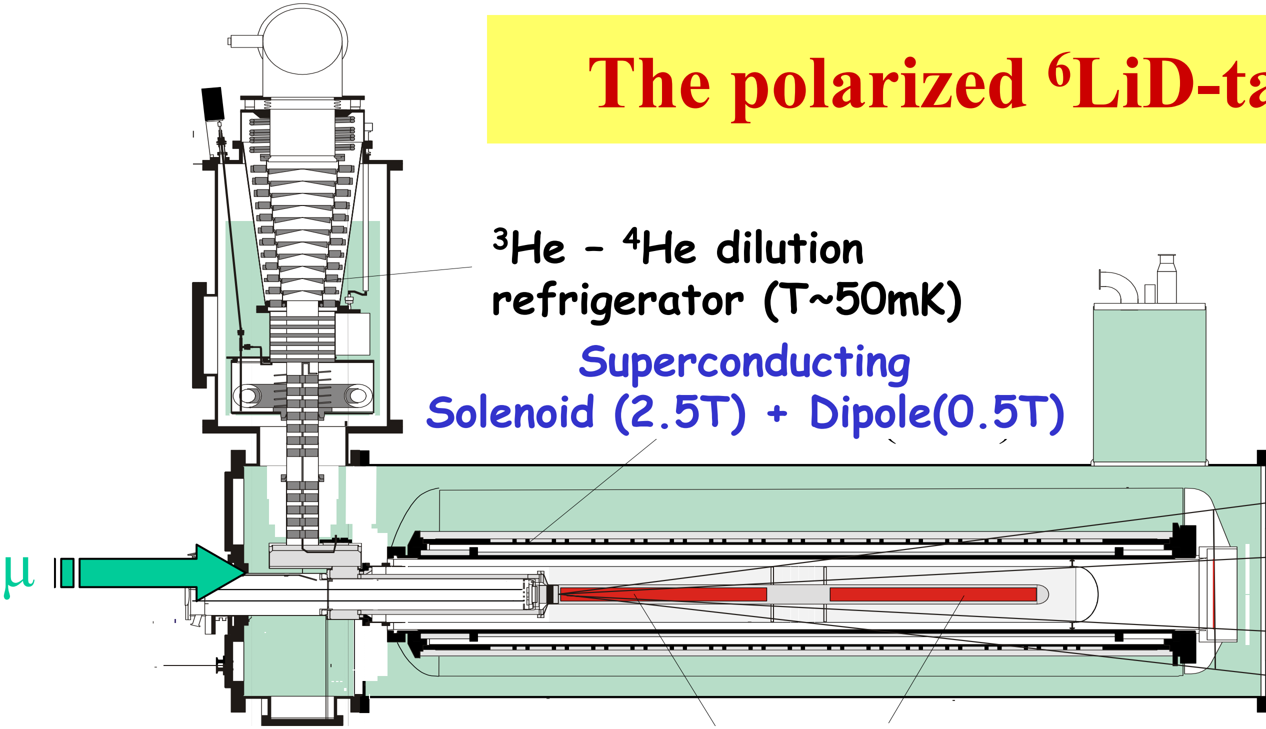
~ 250 physicists
from 28 institutes



$\vec{\mu}$ 160 GeV
from CERN SPS
Beam Polarization ~ -76%

Beam intensity $2 \cdot 10^8$ μ^+/spill (4.8 s / 16.2 s)
Luminosity ~ $5 \cdot 10^{32}$ cm^{-2}s^{-1}

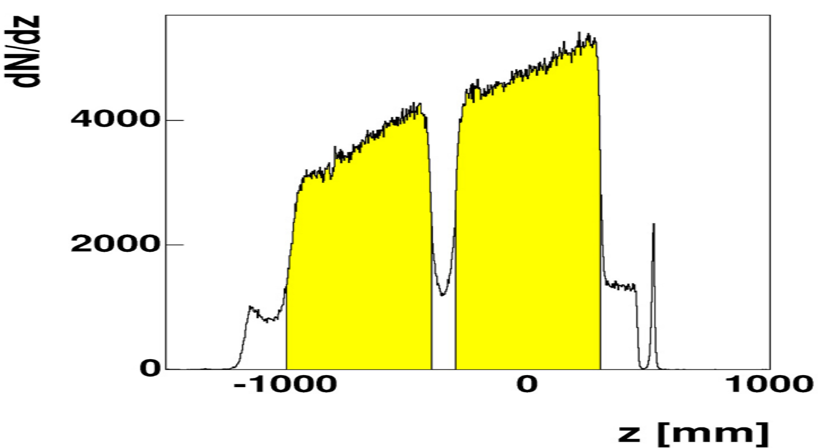
The polarized ^{6}LiD-target



Two 60cm long target cells with opposite polarizations

Target Polarization ~ 50%

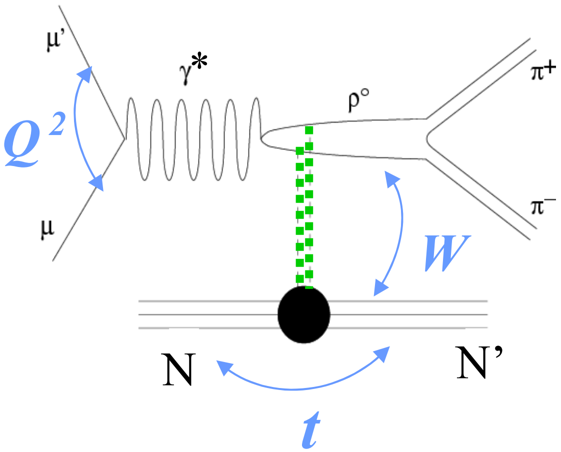
Dilution factor f ~ 0.36



4 possible spin combinations:

longitudinal	transverse
❶ → ←	❸ ↑ ↓
❷ ← →	❹ ↓ ↑
Reversed every 8 hours	Reversed once a week

Incoherent exclusive ρ^0 production



^{6}LiD polarized target

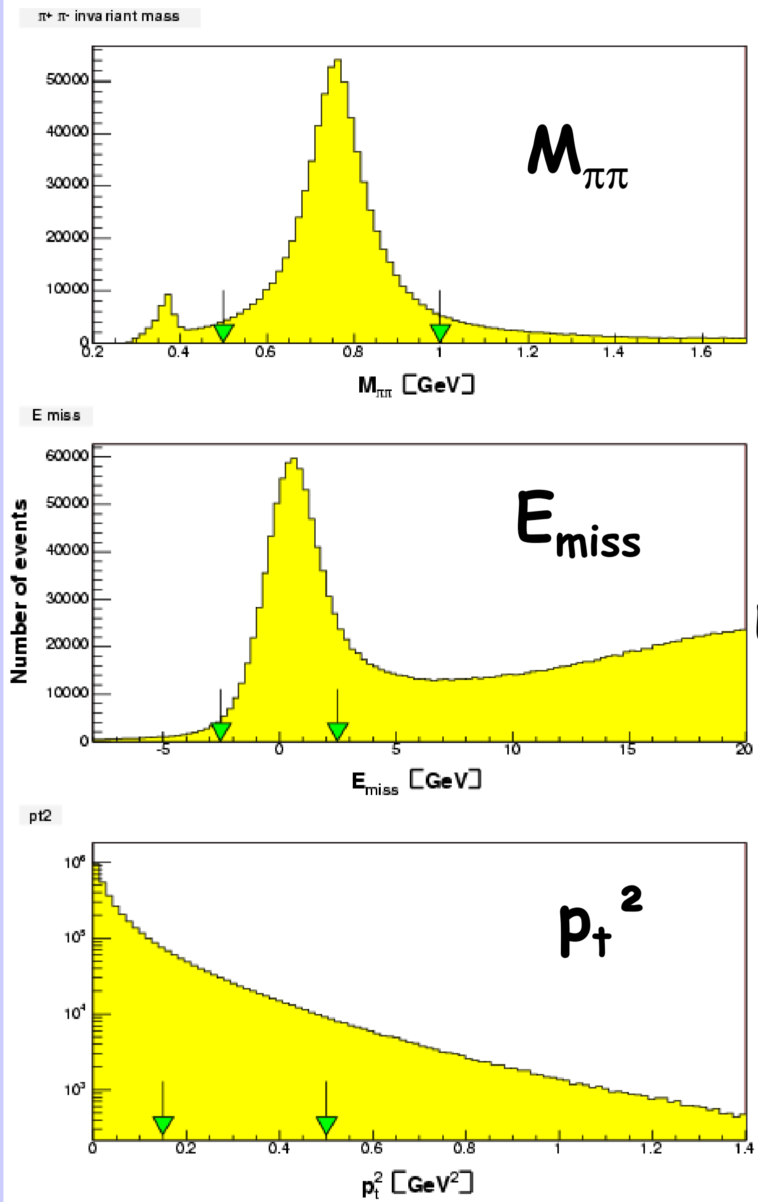
Kinematics:

ν > 30 GeV

$E_{\mu'}$ > 20 GeV

Q^2 > 0.01 GeV^2

(Q^2 cut applied only in SDME analysis)



Assuming both hadrons are π

$0.5 < M_{\pi\pi} < 1$ GeV

Exclusivity of the reaction

$E_{miss} = (M^2_X - M^2_N) / 2M_N$

$-2.5 < E_{miss} < 2.5$ GeV

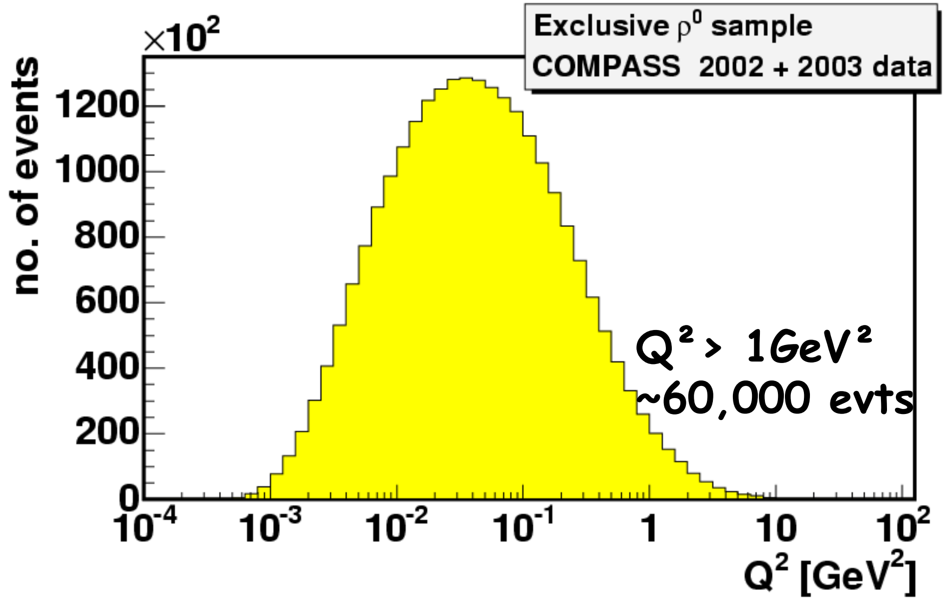
Incoherent production

$0.15 < p_t^2 < 0.5$ GeV^2

scattering off a quasi-free nucleon

Background ~12%

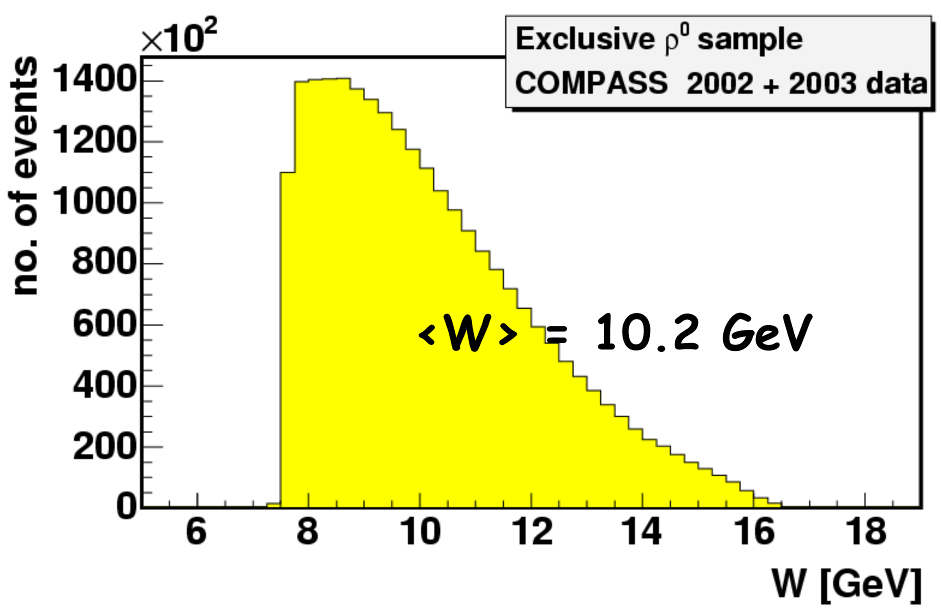
Kinematical domain of the final sample

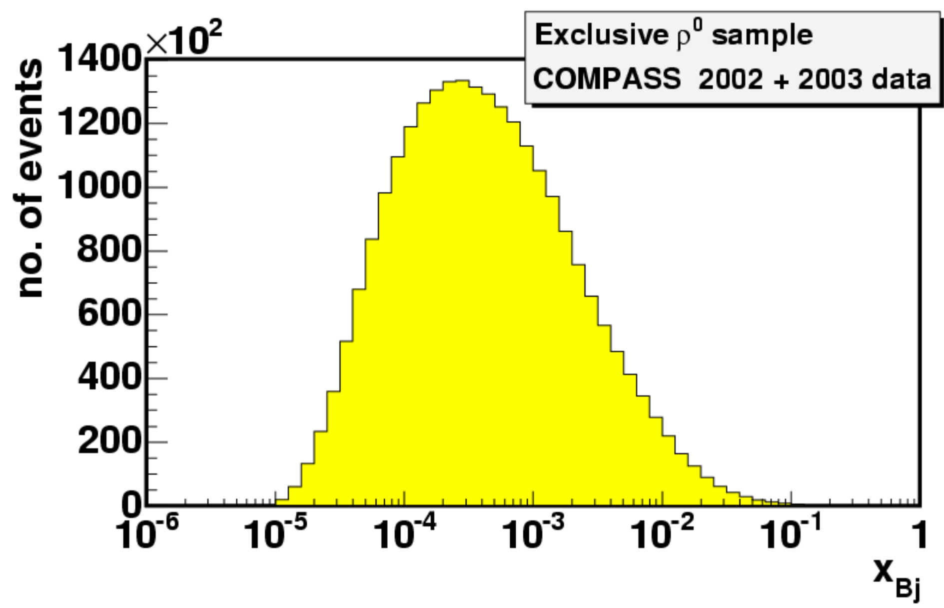


2002 : 800,000 evts
2003 : 1,600,000 evts

+ 2004 : not yet analyzed
~ will double the data sample

$\langle p_t^2 \rangle = 0.27\ GeV^2$





Longitudinal double-spin asymmetry for exclusive ρ^0 production

Both muon beam and target have to be polarized along the beam direction

in COMPASS polarized d from ^{6}LiD

Ultimately one determines

$$A_1^{\rho} = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$

$\sigma_{1/2}$ ($\sigma_{3/2}$) cross section for $\gamma^* N \to \rho^0 N$ for antiparallel (parallel) spin orientation of γ^* and target N

- can arise from exchange of $a_1(1260)$ trajectory in t-channel (small at 160 GeV)
- from interference of amplitudes for exchange in t-channel of Reggeons

  with natural parity: ρ, ω, f, $a_2(1320)$, P(pomeron) and unnatural parity: π, $a_1(1260)$

  (sensitivity even to small contributions of the latter ones)

- if only non-perturbative P $A_1^{\rho} \approx 0$
- in pQCD-inspired models possible $A_1^{\rho} \neq 0$ => access to spin dependent GPDs

Ryskin Goloskokov and Kroll

Evaluation of A_1^{ρ} $(\gamma^* N \rightarrow \rho^0 N)$ for incoherent exclusive ρ^0 production

$$A_{LL}^{raw} = \frac{1}{2}\left(\frac{N_{+-}^{u} - N_{++}^{d}}{N_{+-}^{u} + N_{++}^{d}} - \frac{N_{++}^{u'} - N_{+-}^{d'}}{N_{++}^{u'} + N_{+-}^{d'}}\right)$$

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

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

to minimize systematic effects '2nd order weighted method' used

- each event assigned weight $w = f\,D\,P_b$
- 2nd order equation for A1

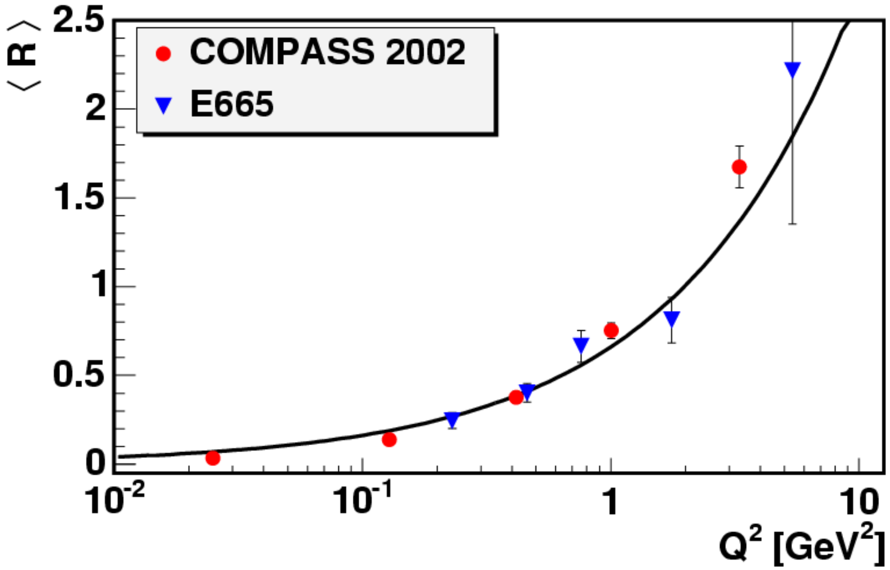
with coefficients depending on weights w, P_b and acceptance ratios for u and d cells

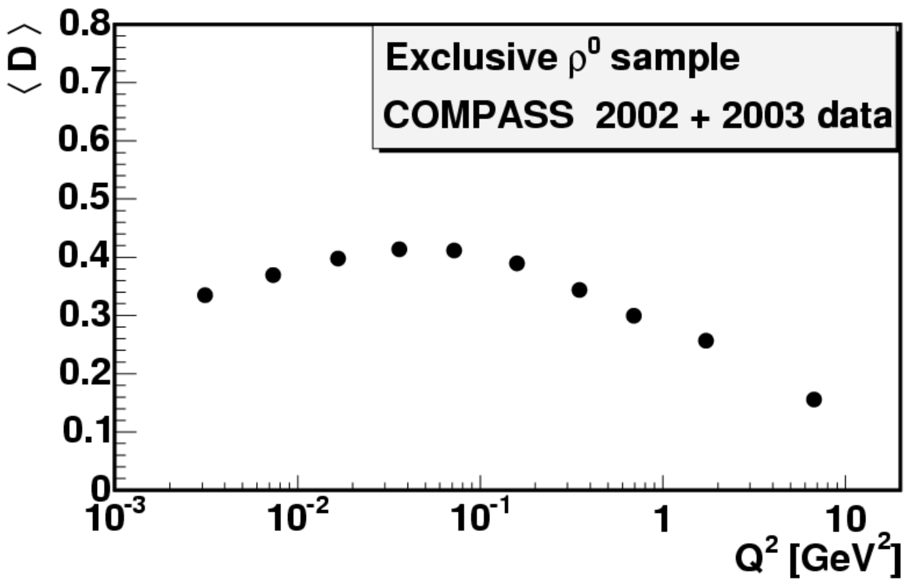
values of A-dependent cross sections (for f) and ratio R (for D)
specific for incoherent exclusive ρ^0 production

Depolarization factor D for incoherent exclusive ρ° production

$$D(y,Q^2) = \frac{y[(1+\gamma^2 y/2)(2-y) - 2y^2 m_\mu^2/Q^2]}{y^2(1-2m_\mu^2/Q^2)(1+\gamma^2) + 2(1+R)(1-y-\gamma^2 y^2/4)}$$

$$\gamma^2 = Q^2/\nu^2$$





R: E665 parametrization

Dilution factor f for incoherent exclusive ρ° production

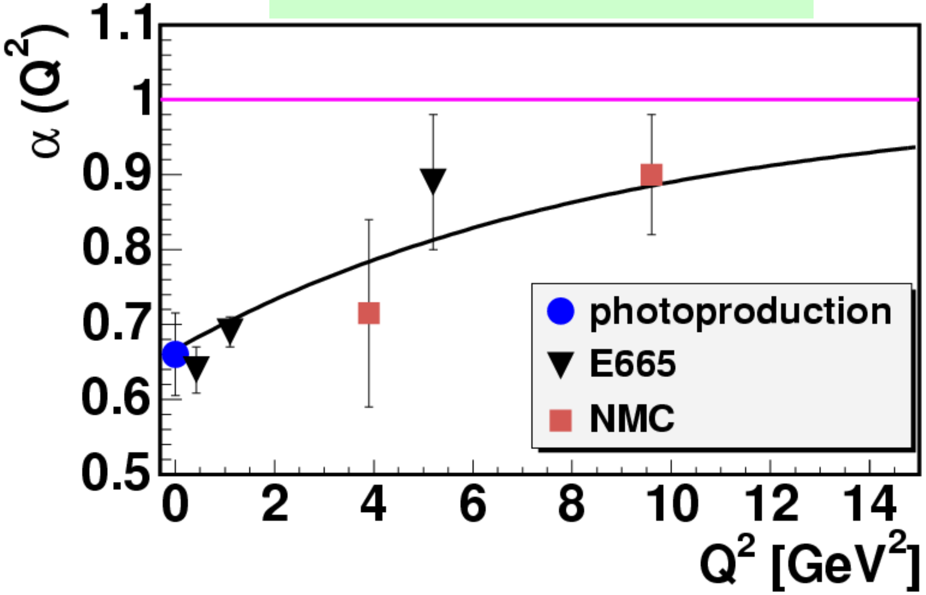
$$f_0 = \frac{n_d}{n_d + \Sigma_A\, n_A(\tilde{\sigma_A}/\tilde{\sigma_d})}$$

n_D, n_A: numbers of nucleons from deuteron and nucleus A in the target

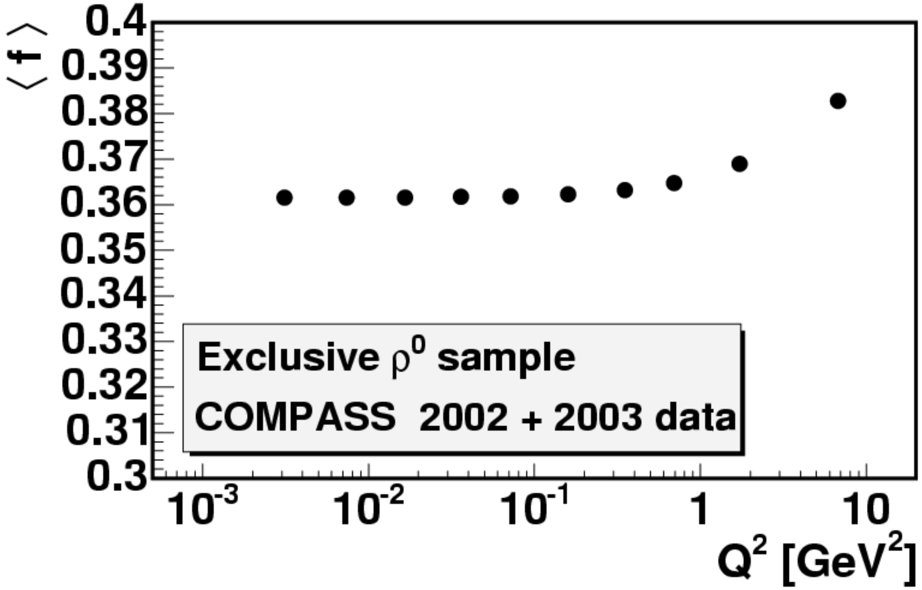
$\tilde{\sigma}_A$ $\tilde{\sigma}_D$: cross sections per nucleon for incoherent exclusive ρ° production on deuteron and nucleus A

finally used $f = C_1 \cdot f_0$, where C_1 takes into account that there are 2 deuterons in ^{6}LiD molecule

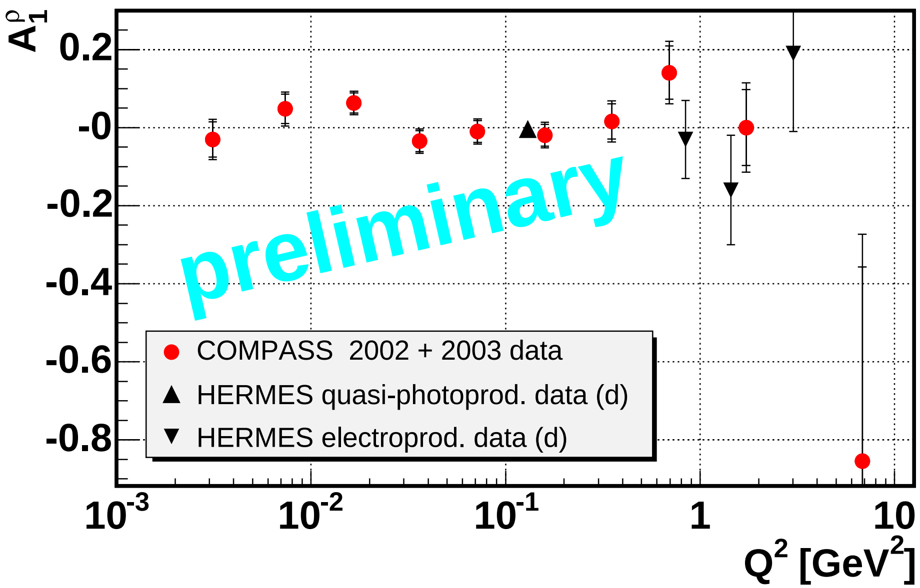
$$\tilde{\sigma_A} = \sigma_p \cdot A^{\alpha(Q^2)-1}$$

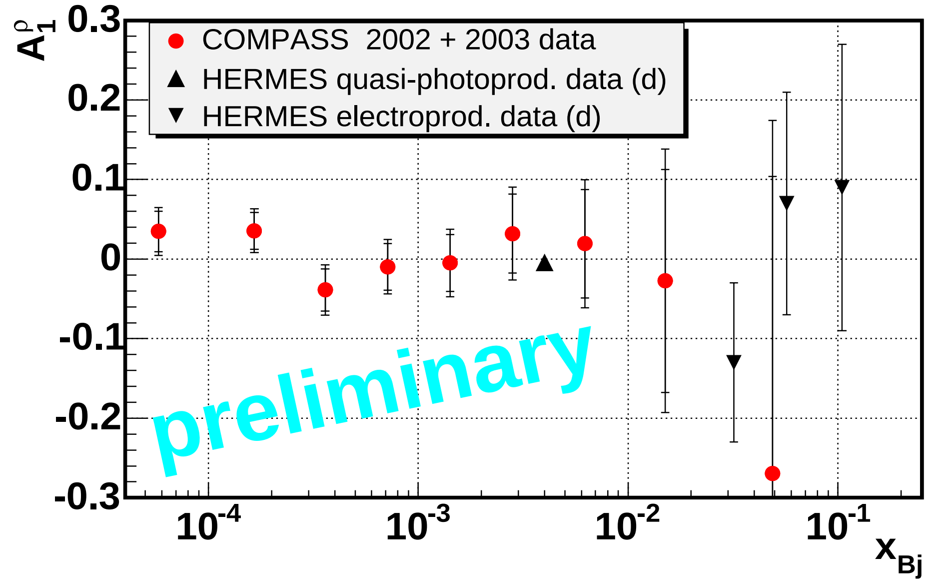


f calculated event by event



COMPASS preliminary and HERMES results on A_1^ρ (d)





COMPASS results on A_1^ρ on polarized deuteron target consistent with 0

Extended kinematical range of COMPASS by almost 2 decades down both in Q^2 and x

COMPASS : inner bars –stat. outer – total errors
HERMES: total errors

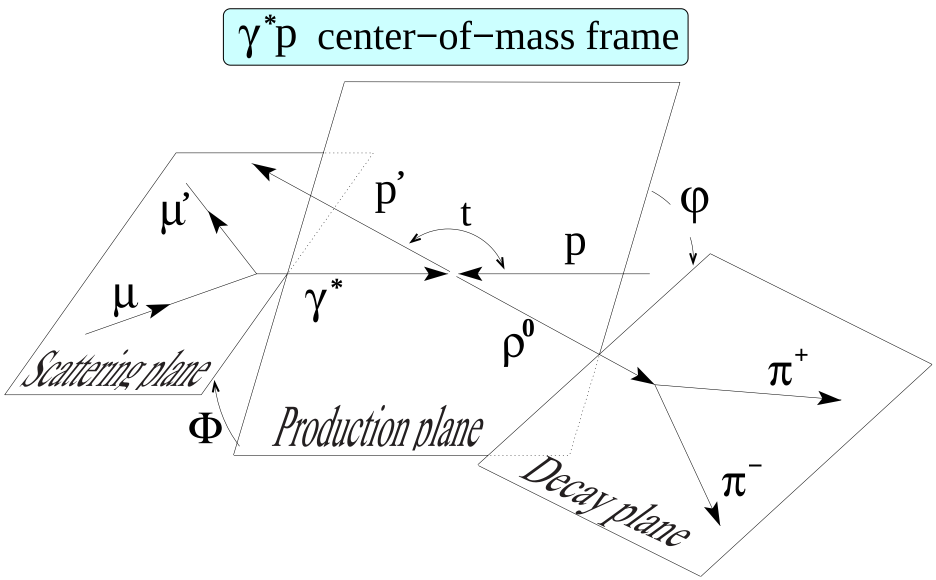
⇨ at small *x* (< 0.01) contribution of unnatural parity exchanges small

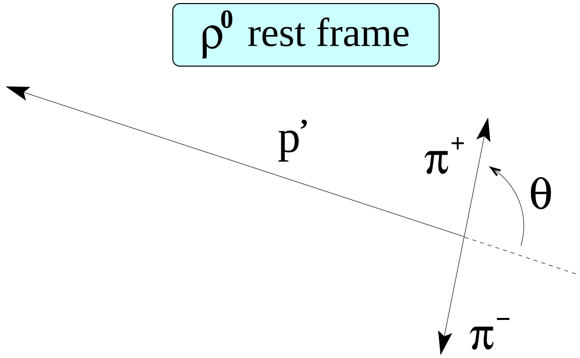
for exclusive ρ^0 production

$\rho°$ angular distributions $W(\cos\theta, \varphi, \Phi)$

depend on the spin density matrix elements (SDME)

⇨ 23 (15) observables with polarized (unpolarized) beam





SDMEs are bilinear combinations of the helicity amplitudes

$$A(\gamma^*(\lambda_\gamma) \longrightarrow \rho(\lambda_\rho)) \equiv T_{\lambda\rho,\,\lambda\gamma}$$

$$\lambda_\gamma = \pm 1, 0 \qquad \lambda_\rho = \pm 1, 0$$

This analysis:

only one-dimensional angular distributions

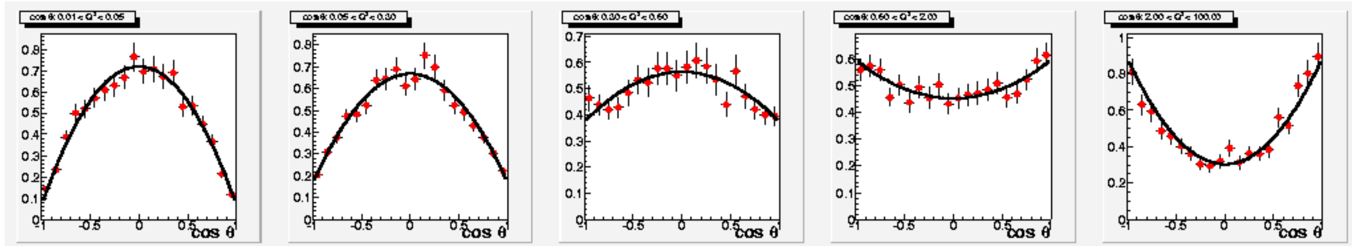
also used:

$\psi = \varphi - \Phi$

Measurement of r_{00}^{04}

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

cos θ



Distribution :

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

Spin density matrix element:

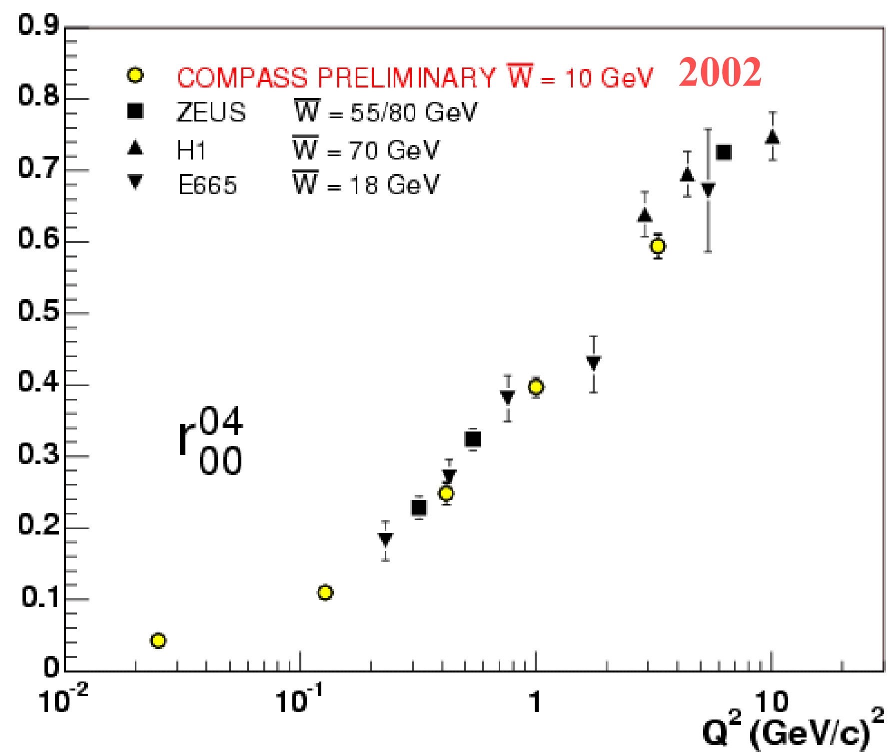
$$r_{00}^{04} = \frac{|T_{01}|^2 + (\varepsilon+\delta)|T_{00}|^2}{N_T(1+(\varepsilon+\delta)R)} \xrightarrow{\text{SCHC}} \frac{\sigma_L}{\sigma_T}$$

$$R = \sigma_L/\sigma_T \qquad N_T = |T_{11}|^2 + |T_{-11}|^2 + |T_{01}|^2$$

$$\Gamma_L/\Gamma_T = \varepsilon + \delta$$

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

meson photon



Determination of $R = \sigma_L/\sigma_T$

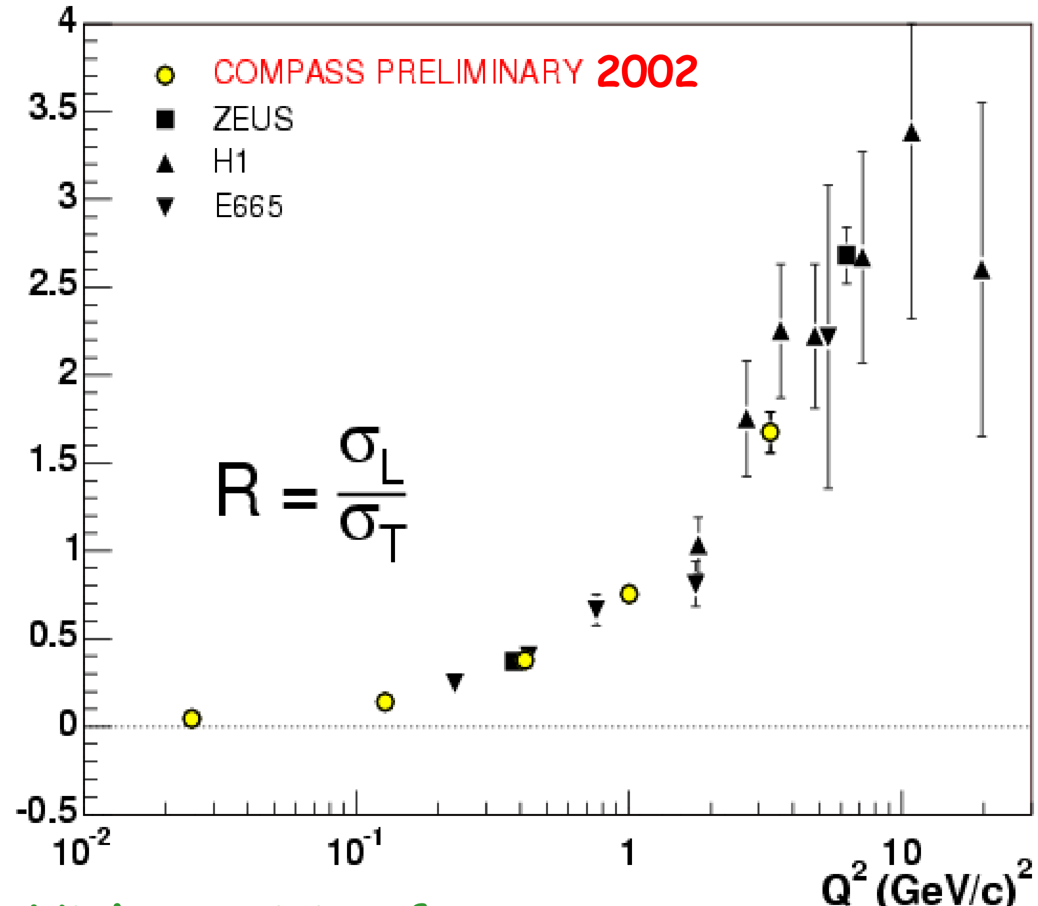
If SCHC holds :

only $T_{00} \neq 0$

$T_{11} \neq 0$

Then :

$$R = \frac{\sigma_L}{\sigma_T} = \frac{1}{(\varepsilon + \delta)} \frac{r_{00}^{04}}{1 - r_{00}^{04}}$$



Impact on GPD study:

determination of σ_L

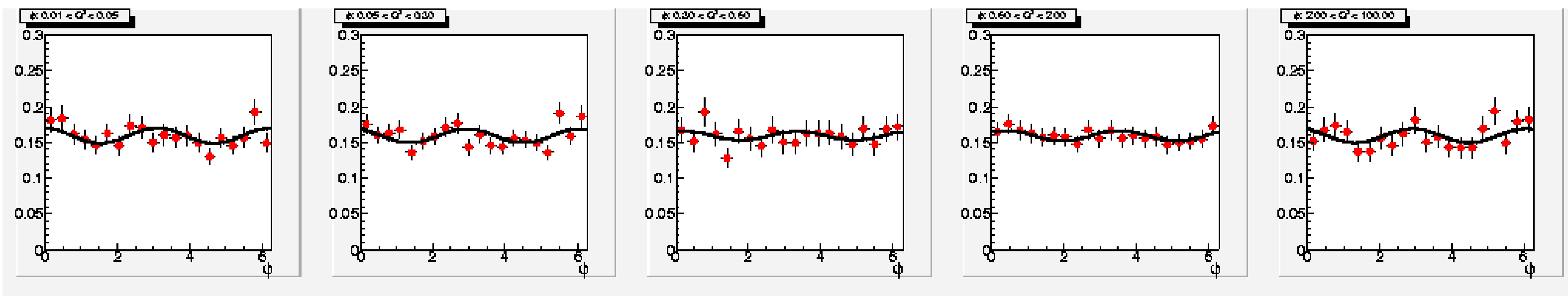
σ_L is dominant at $Q^2 > 2$ GeV^2

- High statitics from quasi-photoproduction to hard production

- Better coverage at high Q^2 with 2003 and 2004 data

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

φ

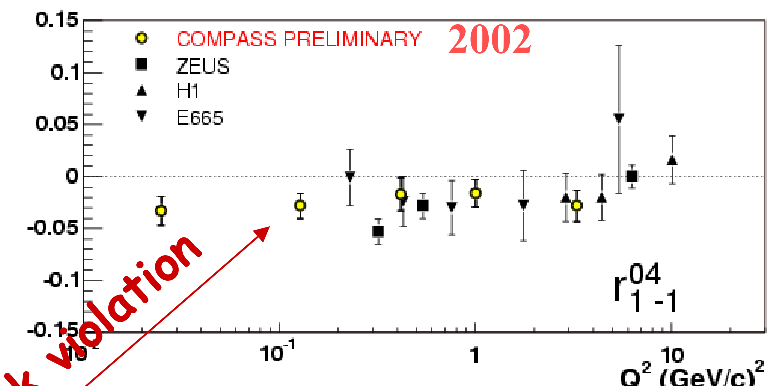


Distribution :

$$W(\varphi) = \frac{1}{2\pi}[1 - 2r^{04}_{1-1}\cos 2\varphi$$

$$+ 2\,\mathrm{Im}\,r^{3}_{1-1} P_{\mu}\sqrt{1-\varepsilon^{2}}\,\sin 2\varphi]$$

beam polarisation



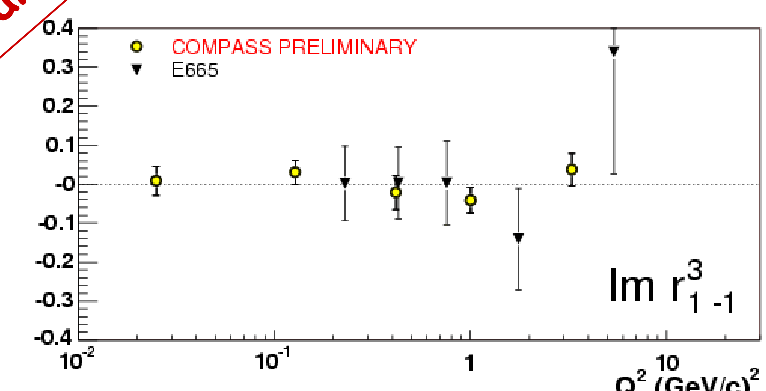
weak violation

Spin density matrix elements:

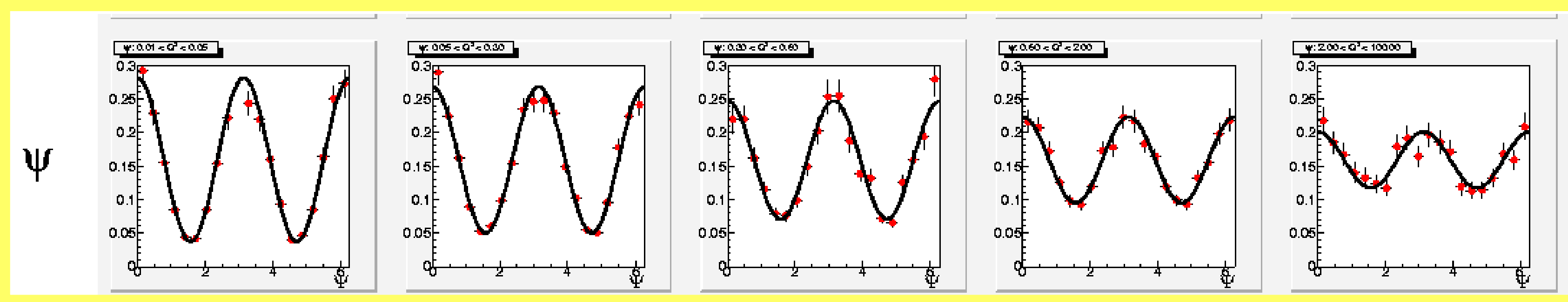
$$r^{04}_{1-1} = \frac{\mathrm{Re}(T_{11}T^{*}_{-11}) - (\varepsilon+\delta)|T_{10}|^{2}}{N_T(1+(\varepsilon+\delta)R)} = 0$$

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

If SCHC holds



Measurement of r^1_{1-1}



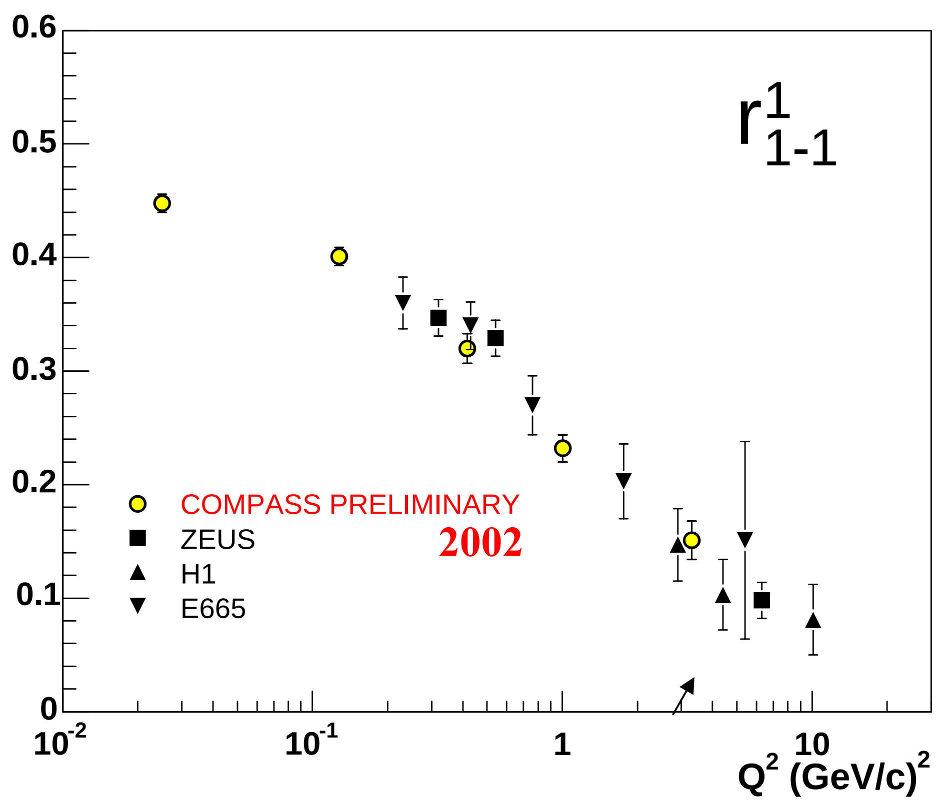
If SCHC holds

$$W(\psi) = \frac{1}{2\pi}[1 + 2r^1_{1-1}\varepsilon\cos 2\psi]$$

general expression for r^1_{1-1} :

$$r^1_{1-1} = \frac{1}{2}\frac{|T_{11}|^2 + |T_{1-1}|^2}{N_T(1+(\varepsilon+\delta)R)}$$

in future independent of SCHC determination of 23 SDMEs including r^1_{1-1} from 3D distributions



Summary and outlook

- Asymmetry A_1^ρ (d) consistent with zero over wide range of Q^2 and x
  - small contribution of unnutaral parity exchanges at x < 0.01
  - first measurement at small Q^2 and small x
- High-statistics data on SDM elements and R for incoherent exlusive ρ^0 production
  - in a wide Q^2 range (including small Q^2 not covered previously)
  - weak violation of SCHC observed
- Significant improvement of accuracy expected after including 2004 (and 2003 data)
  - extraction of 23 SDMEs under way
- Studies of coherent exclusive ρ^0 production foreseen
- Single spin asymmetry for transversely polarized target → E/H GPDs
- Analysis of exlusive φ and J/ψ production in progress