Double–spin asymmetry in exclusive ρ^0 meson production at COMPASS experiment

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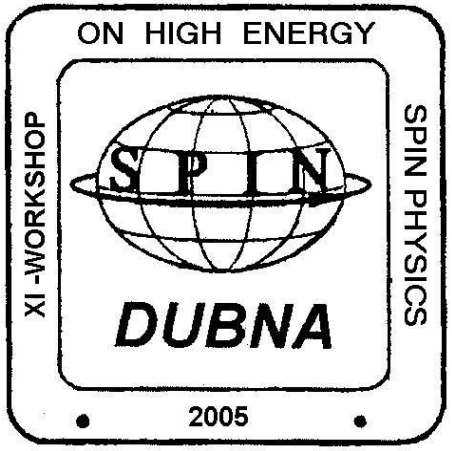
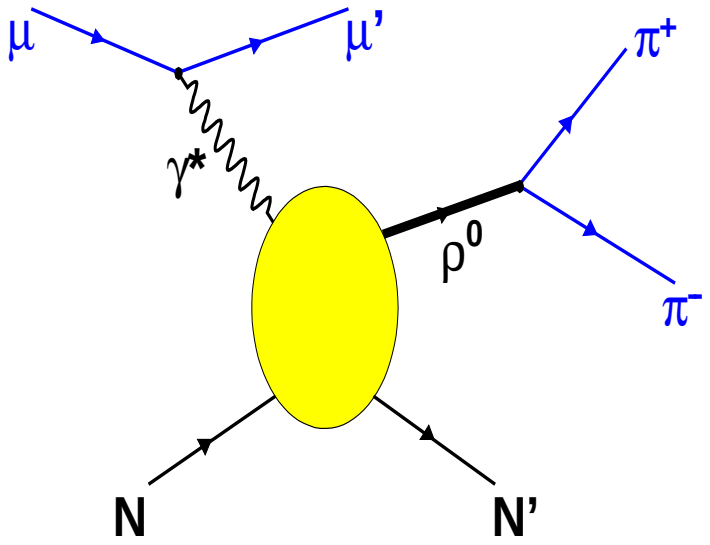
Outline:



- reaction of exclusive vector meson production
- physics & motivation
- data sample
- double–spin asymmetry
- results
- summary

Exclusive ρ^0 meson production



In blue particles (tracks) detected at COMPASS spectrometer.

BR($\rho^0 \to \pi^+\pi^-$) $\approx$ 100%

$$Q^2 = -q^2 = -(k - k')^2$$

$$x_{\mathrm{Bj}} = Q^2/(2\,\nu\,m_{\mathrm{p}})\,, \quad \nu = p \cdot q/m_{\mathrm{p}}$$

$$W^2 = (p+q)^2 \qquad y = \nu/E_{\mathrm{beam}}$$

$$t = (p - p')^2 = (q - v)^2$$

$$p_t^2 \approx |\, t - t_{\mathrm{min}}\,|$$

$k,\ k',\ q,\ v,\ p,\ p'$ — four-momenta of $\mu,\ \mu',\ \gamma^*,\ \rho^0,\ N,\ N'$ respectively

- exchange of reggeons in the t-channel
- at COMPASS energies pomeron exchange dominates $\Longrightarrow$ diffractive process
- allows to test both perturbative and non-perturbative aspects of strong interactions
- this analysis $\Longrightarrow$ incoherent production on COMPASS polarized ^{6}LiD target

Motivation for studying EVMP & spin effects in it

- probing of hadronic structure of the virtual photon
- diffractive process
  - $\Rightarrow$ at large W exchange of the pomeron ($\mathbb{P}$) in the t-channel dominates
  - $\Rightarrow$ studying of $\mathbb{P}$ physical nature, couplings etc.
- exclusive process
  - $\Rightarrow$ possible access to generalized parton distributions (GPDs), and particularly to generalized gluon distribution $\boldsymbol{G}$ (within Q^2 range where pQCD is applicable)
- spin effects in EVMP
  - spin density matrix of VM:
    - defined for the case of unpolarized or polarized beam and unpolarized (spin–averaged) target
    - related to helicity structure of the reaction $\gamma^* \boldsymbol{N} \to \boldsymbol{V N}$
    - if all 23 elements determined $\Longrightarrow$ helicity structure of EVMP known completely
  - double spin asymmetries of cross sections $\Longrightarrow$ next transparencies

Double–spin longitudinal asymmetry in exclusive ρ^0 production

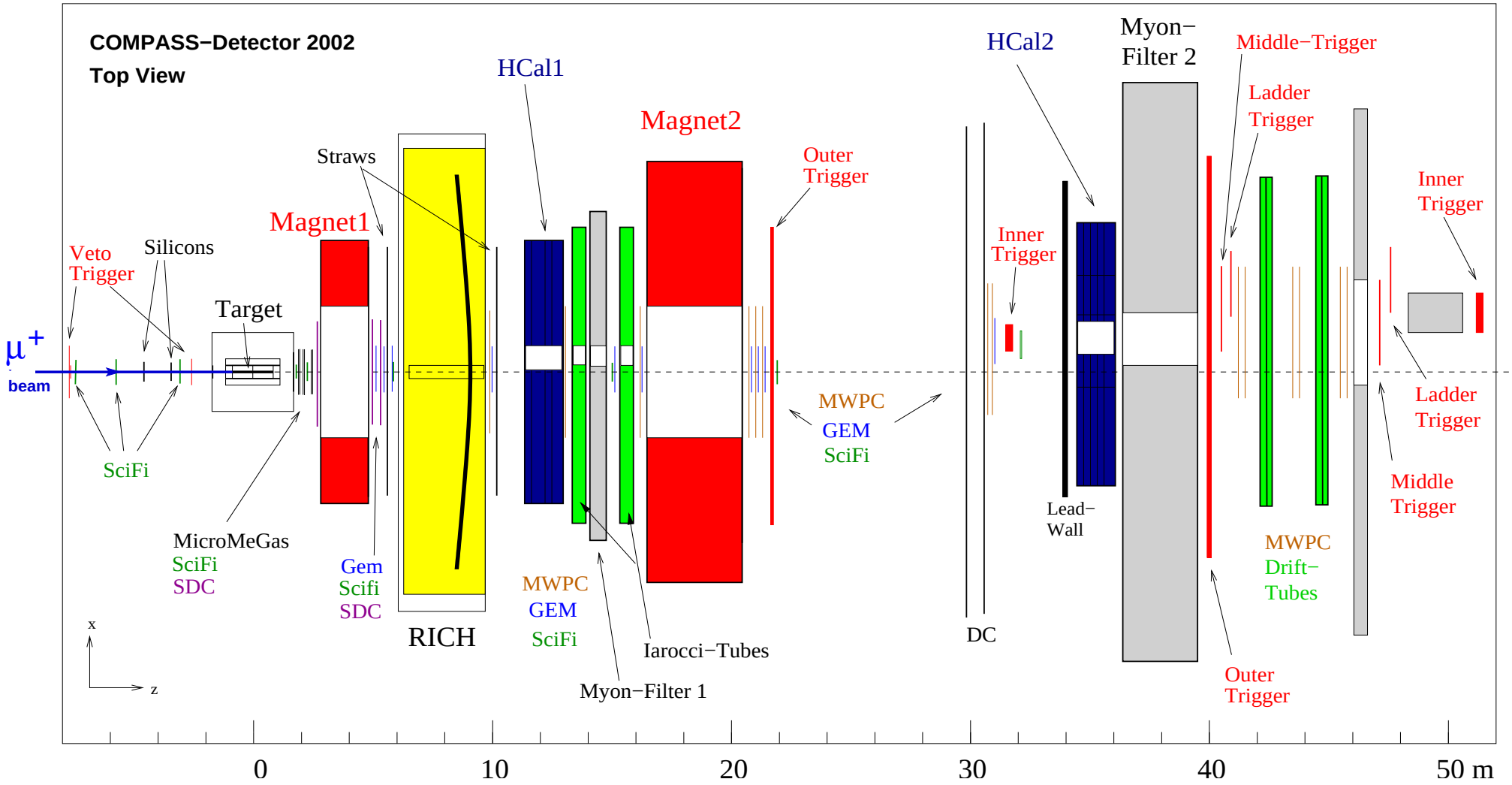
- defined for the case of polarized beam and polarized target
- we are concerned with double–spin longit. asymmetry for $\gamma^* N \to \rho^0 N$ reaction
- definition

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

	$\longrightarrow \vec{q}$		$\longrightarrow \vec{q}$	quantization axis
$1/2$	$\vec{s}_\gamma \Rightarrow \Leftarrow \vec{s}_N$	or	$\vec{s}_\gamma \Leftarrow \Rightarrow \vec{s}_N$	
$3/2$	$\vec{s}_\gamma \Rightarrow \Rightarrow \vec{s}_N$	or	$\vec{s}_\gamma \Leftarrow \Leftarrow \vec{s}_N$	

- can arise from exchange of $a_1(1260)$ trajectory in the t-channel or...
- ...from interference of amplitudes for exchange in the t-channel of reggeons with natural and unnatural parity
  - natural ($P = (-1)^J$): $\rho,\ \omega,\ f,\ a_2(1320)$, $\mathbb{P}$ (pomeron) trajectories
  - unnatural ($P = (-1)^{J+1}$): $\pi,\ a_1(1260)$ trajectories
- if non-perturbative $\mathbb{P}$ $\Longrightarrow$ $A_1^\rho \approx 0$
- if pQCD $\mathbb{P}$ $\Longrightarrow$ maybe $A_1^\rho \neq 0$
  $\Longrightarrow$ possible access to generalized ΔG (GPDs) (M.G. Ryskin, 1999)

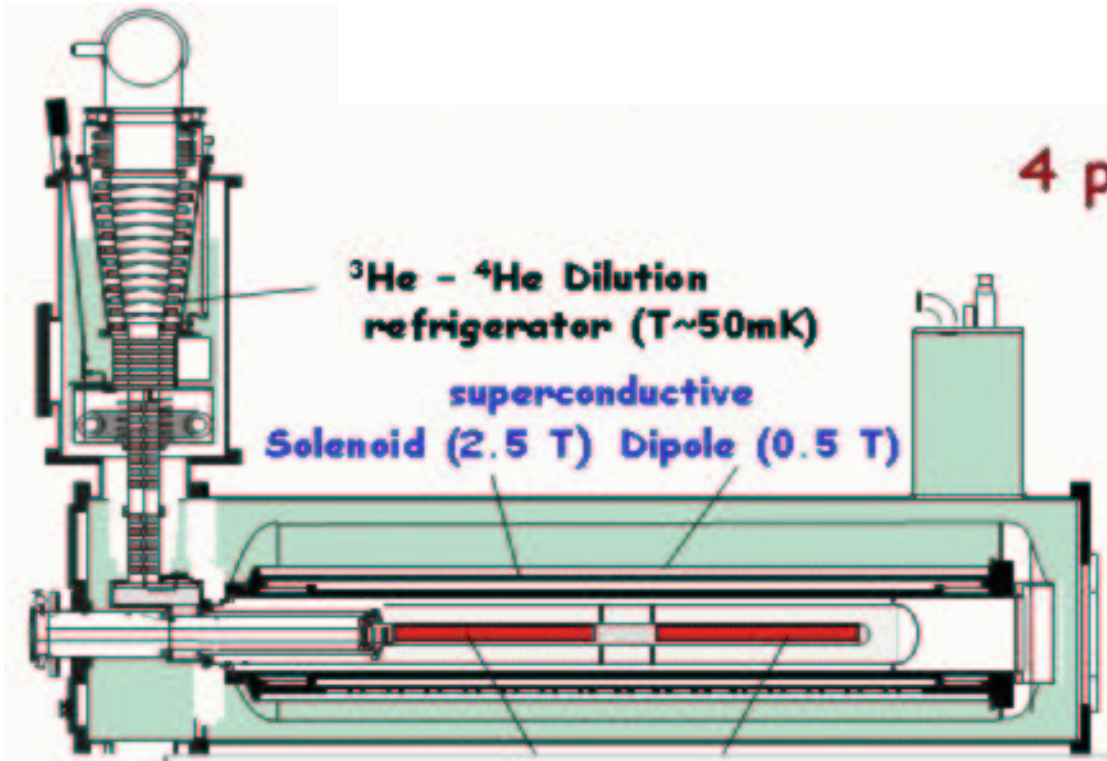
COMPASS (NA-58) experiment at CERN



Beam $2 \cdot 10^8\ \mu^+$/spill (4.8s / 16.2s) **Beam momentum** 160 GeV/c

Luminosity $\sim 5 \cdot 10^{32}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ **Beam polarization** −76%

COMPASS — polarized ^{6}LiD target



4 possible spin combinations:

1 → ←

2 ← →

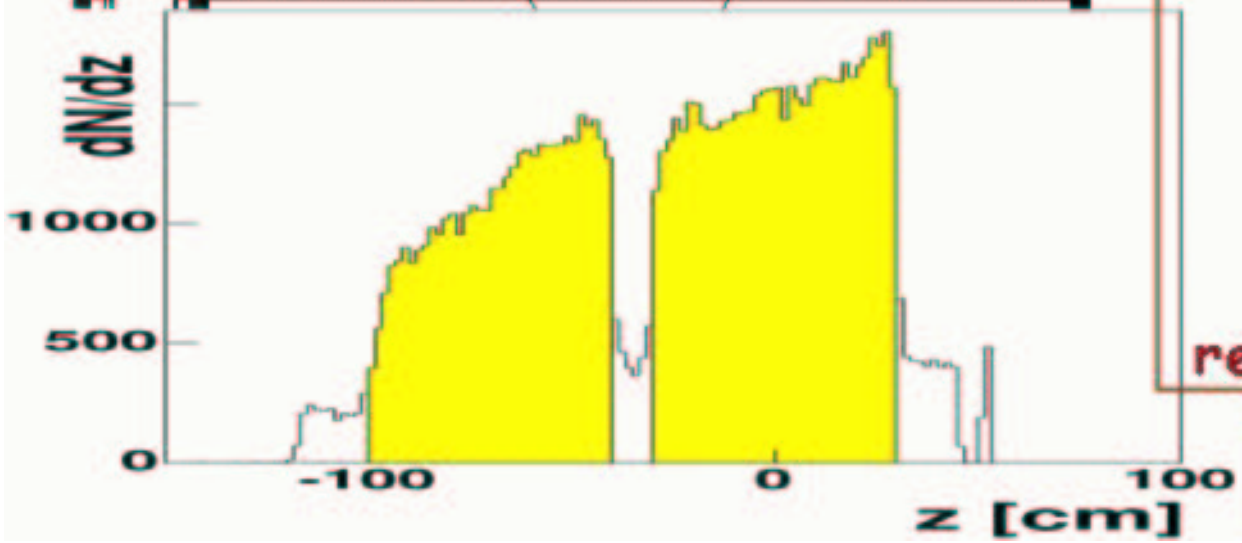
reversed every 8 hours

or:

3 ↑ ↓

4 ↓ ↑

reversed once a week



Polarization: ~50%

Selection of the exclusive incoherent ρ^0 sample

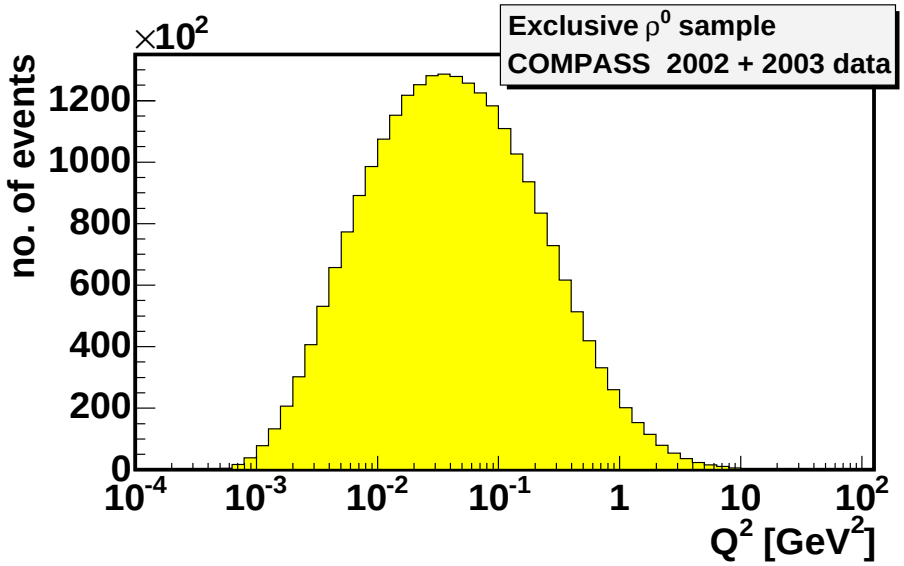
2002 + 2003 data taken with deuteron target used in this analysis

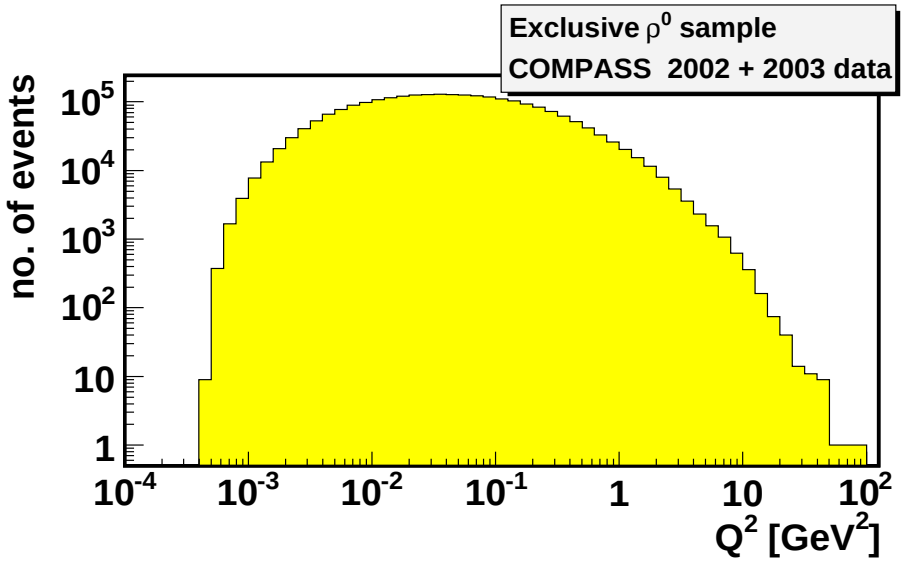
- primary vertex, caused by beam–muon interaction, must be present within target volume
- only events with exactly 3 tracks outgoing from primary vertex selected
- one of 3 tracks has to be μ', remaining 2 have to be hadrons with opposite charges
- RICH not used for PID $\Longrightarrow$ $m_{\pi^\pm}$ & $m_{K^\pm}$ hypotheses assigned to hadronic tracks
  $\Longrightarrow$ $m_{\pi\pi}$ & m_{KK} invariant masses determined
- $\nu > 30$ GeV $\wedge$ $E_{\mu'} > 20$ GeV
- $0.5 < m_{\pi\pi} < 1$ GeV
- $-2.5 < E_{\rm miss} < 2.5$ GeV

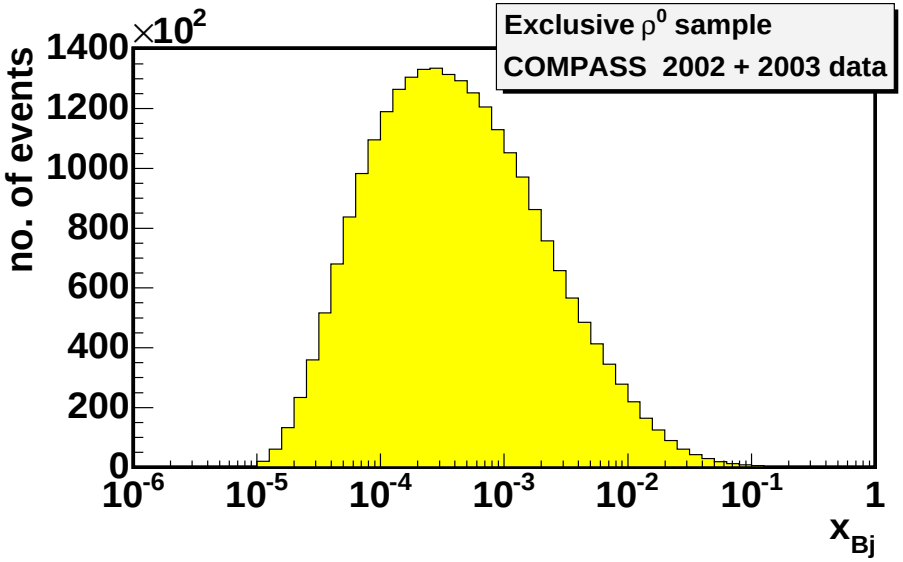
  where $E_{\rm miss} = (m_X^2 - m_{\rm p}^2) \,/\, 2\, m_{\rm p}\,, \quad m_X^2 = (p + q - v)^2$
- $0.15 < p_t^2 < 0.5$ GeV^2

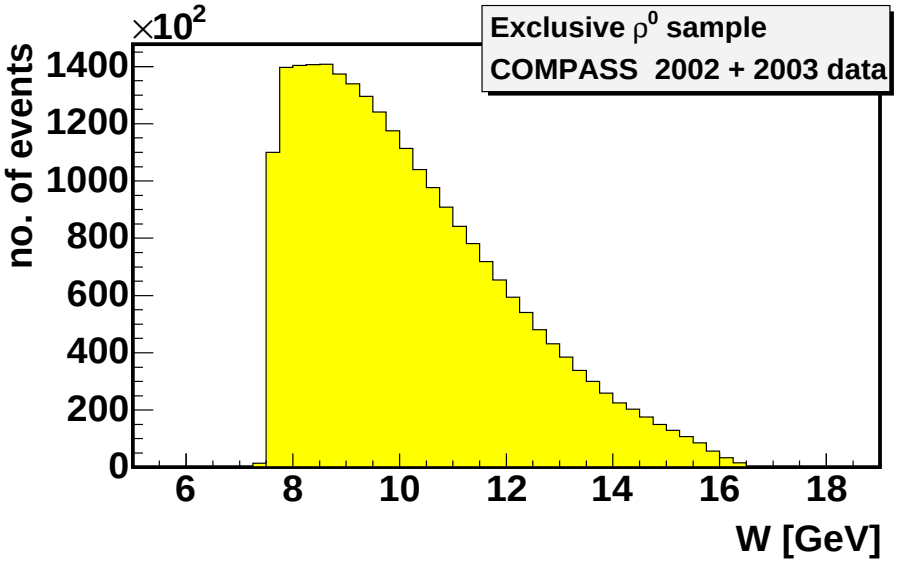
COMPASS exclusive ρ^0 sample — selected kinematical plots

Muon variables







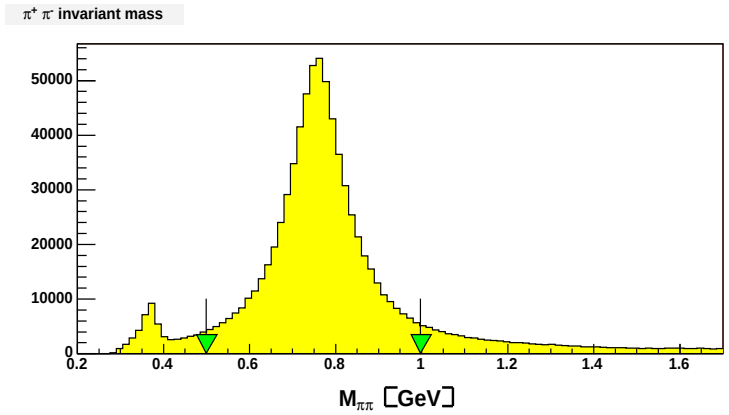


$$\langle W \rangle = 10.2 \text{ GeV}$$

COMPASS exclusive ρ^0 sample — selected kinematical plots

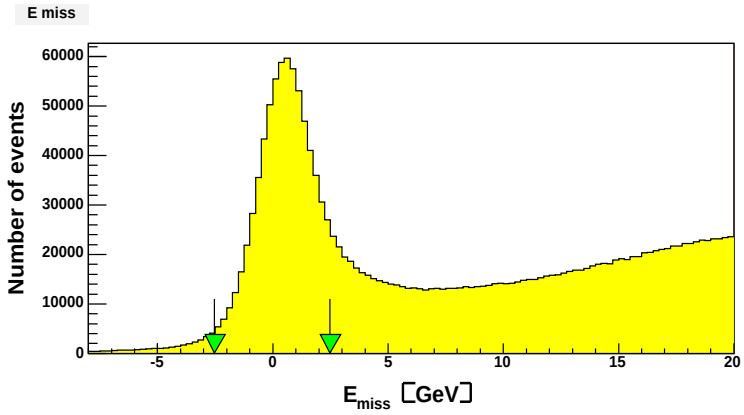
Hadron variables

$m_{\pi\pi}$ [GeV]



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

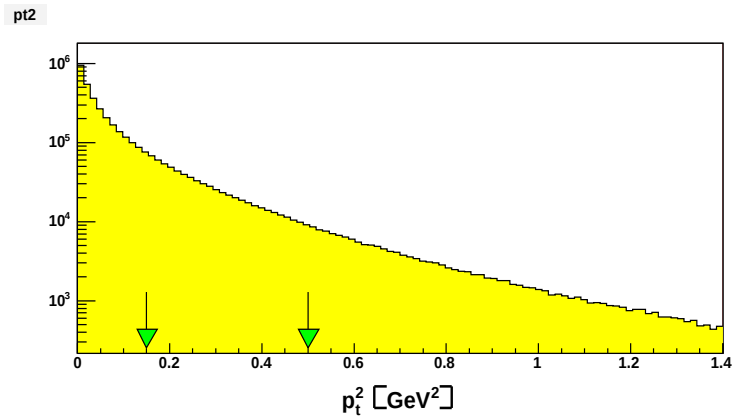
$E_{\rm miss}$ [GeV]



Altogether

2.44 M events selected from 2002 + 2003 data

p_t^2 [GeV^2]



Double–spin longitudinal asymmetries in exclusive ρ^0 production [1]

- Asymmetry *measured* in muon–nucleon interaction $\boldsymbol{\mu N \to \mu' N \rho^0}$:

$$\mathcal{A}_{LL}^{\text{meas}} = \frac{\mathbf{1}}{\mathbf{2}} \left(\frac{\mathcal{N}^{\text{u}}_{+-} - \mathcal{N}^{\text{d}}_{++}}{\mathcal{N}^{\text{u}}_{+-} + \mathcal{N}^{\text{d}}_{++}} - \frac{\mathcal{N}^{\text{u}\,\prime}_{++} - \mathcal{N}^{\text{d}\,\prime}_{+-}}{\mathcal{N}^{\text{u}\,\prime}_{++} + \mathcal{N}^{\text{d}\,\prime}_{+-}} \right)$$

- Asymmetry for muon–nucleon cross sections $\boldsymbol{\sigma(\mu N \to \mu' N \rho^0)}$:

$$\mathcal{A}_{LL}(\mu N \to \mu' N \rho^0) = \frac{\sigma(\mu N)_{\uparrow\Downarrow} - \sigma(\mu N)_{\uparrow\Uparrow}}{\sigma(\mu N)_{\uparrow\Downarrow} + \sigma(\mu N)_{\uparrow\Uparrow}} = \frac{1}{f} \cdot \frac{1}{P_{\text{b}}} \cdot \frac{1}{P_{\text{t}}} \cdot \mathcal{A}_{LL}^{\text{meas}}$$

- Asymmetry for photon–nucleon cross sections $\boldsymbol{\sigma(\gamma^* N \to \rho^0 N)}$:

$$\mathcal{A}_1^{\rho}(\gamma^* N \to \rho^0 N) \approx \frac{1}{D} \mathcal{A}_{LL}(\mu N \to \mu' N \rho^0) \,,$$

where:

$+$, $+$, $-$ — polarizations of beam (const.) and target (reversed)

$\uparrow$, $\Uparrow$, $\Downarrow$ — directions of spins of beam and target

P_{b}, P_{t} — polarizations of beam and target

f — dilution factor

D — depolarization factor

Double–spin longitudinal asymmetries in exclusive ρ^0 production [2]

- To minimize systematic effects the 2nd order weighted method has been used to obtain A_1^ρ
  - each event is assigned a weight $w = fDP_{\rm b}$
  - 2nd order equation for A_1^ρ is constructed:

$$a(A_1^\rho)^2 \; + \; bA_1^\rho \; + \; c \; = \; 0$$

    $a,\ b,\ c$ being functions of weights w, $P_{\rm t}$ and acceptances $a_{\rm u},\ a_{\rm d},\ a'_{\rm u},\ a'_{\rm d}$
  - physical solution for A_1^ρ is one of two obtained (second is rejected):

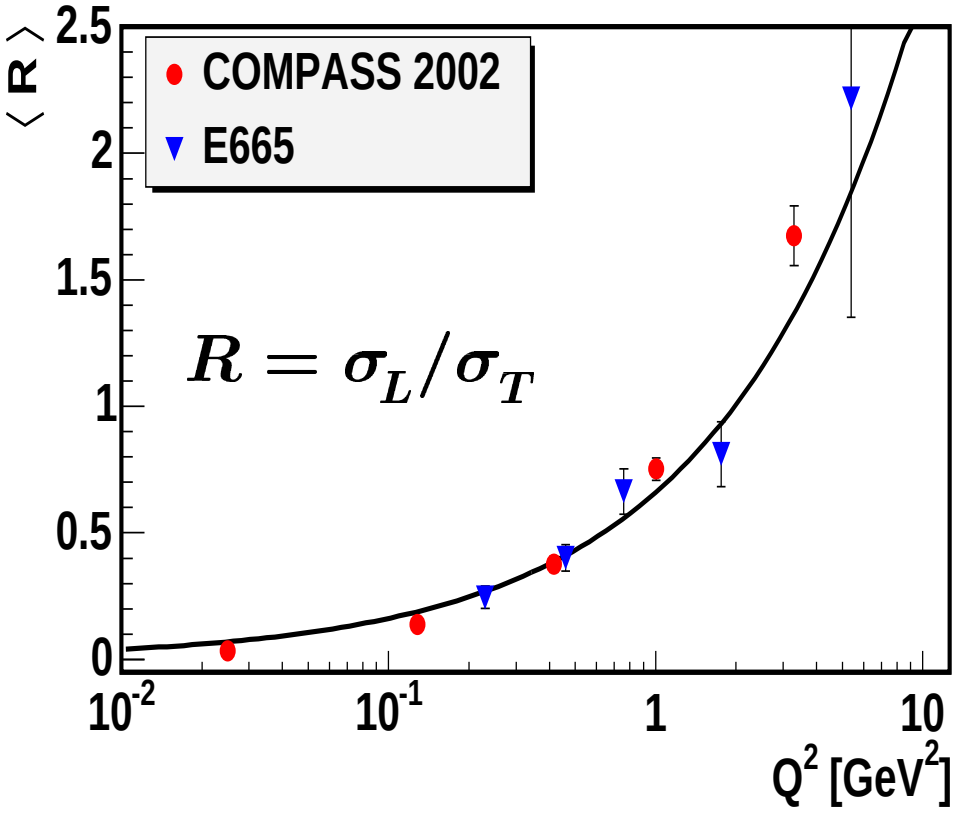
$$A_1^\rho \; = \; (-b \; \pm \; \sqrt{b^2 \; - \; 4ac}) \; / \; 2a$$

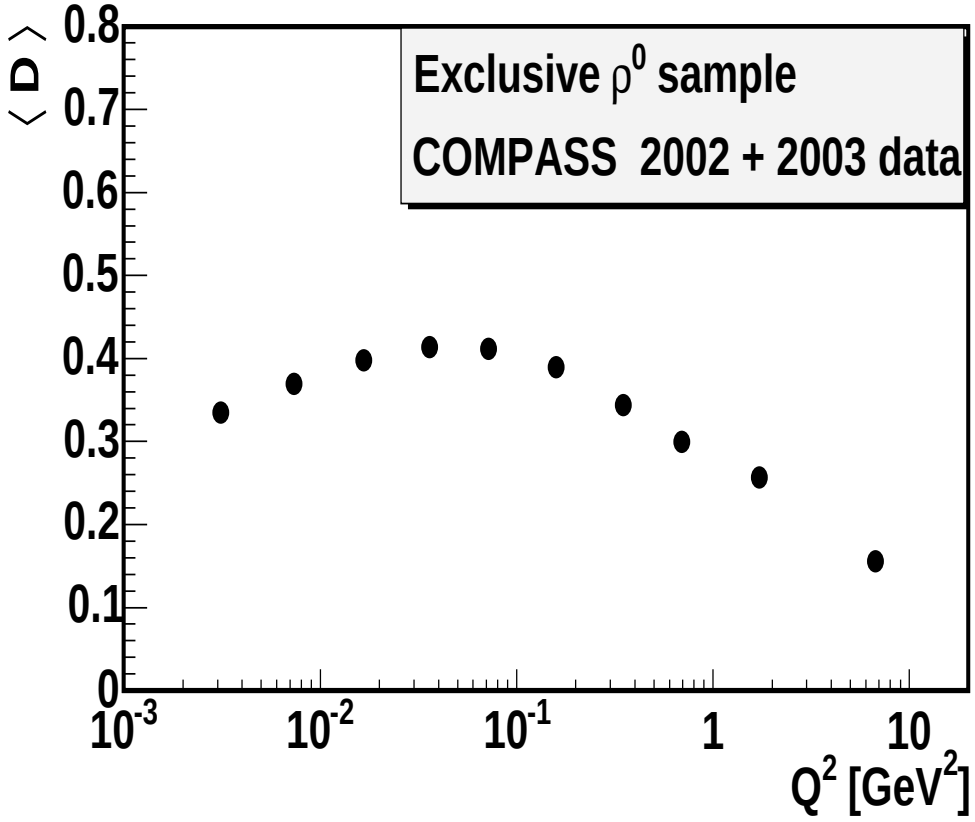
- Exact relation between A_{LL} and A_1^ρ is:

$$A_{LL} \; = \; D \; (A_1^\rho \; + \; \eta \, A_2^\rho \,) \quad (*)$$

  - $A_2^\rho \; = \; 2\,\sigma_{LT} \, / \, (\sigma_{1/2} \; + \; \sigma_{3/2})$
  - positivity limit $|A_2^\rho| \; < \; \sqrt{R}$ holds for A_2^ρ, $\qquad R = \sigma_L/\sigma_T$
  - $\eta \; \sim \; 10^{-4} \div 10^{-2}$ in COMPASS kinematical range
  - so ηA_2^ρ term in $(*)$ neglected $\Rightarrow$ effect of this included in systematic error; contribution to the total syst. error negligible

Depolarization factor D for exclusive ρ^0 production at COMPASS





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

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

Dilution factor f for exclusive ρ^0 production at COMPASS

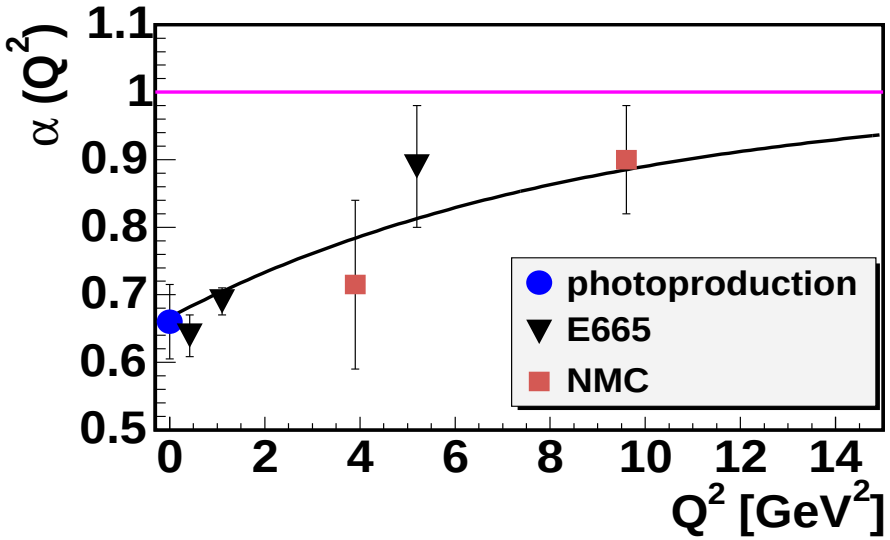
- Definition

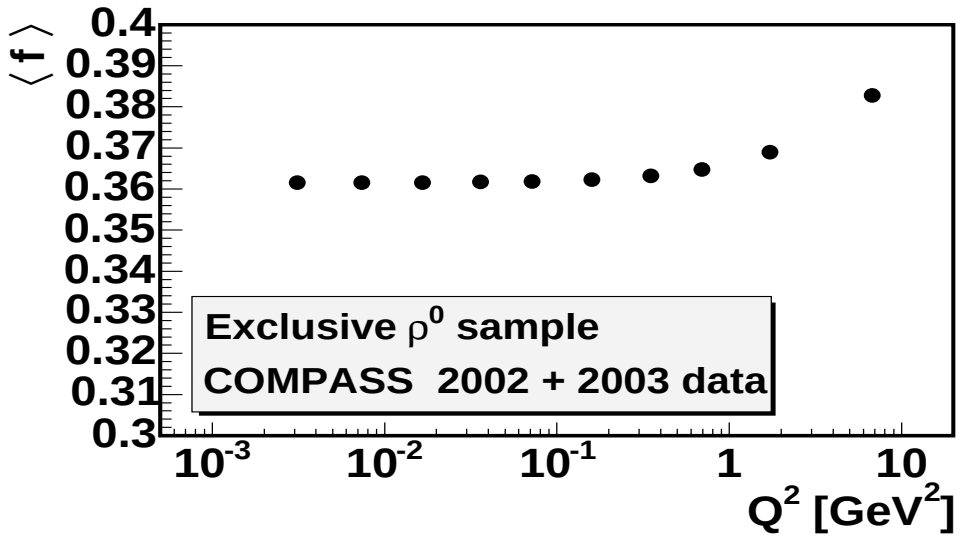
$$f_0 = \frac{n_D}{n_D + \Sigma_A n_A (\tilde{\sigma}_A / \tilde{\sigma}_D)}$$

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

$\tilde{\sigma}_D$, $\tilde{\sigma}_A$ — cross sections *per nucleon* for exclusive incoherent ρ^0 production on deuteron and nucleus A

- We use $f = C_1 \cdot f_0$ quantity, where C_1 factor takes account of the fact that there are 2 polarized deuterons in ^{6}LiD molecule
- f is calculated event by event

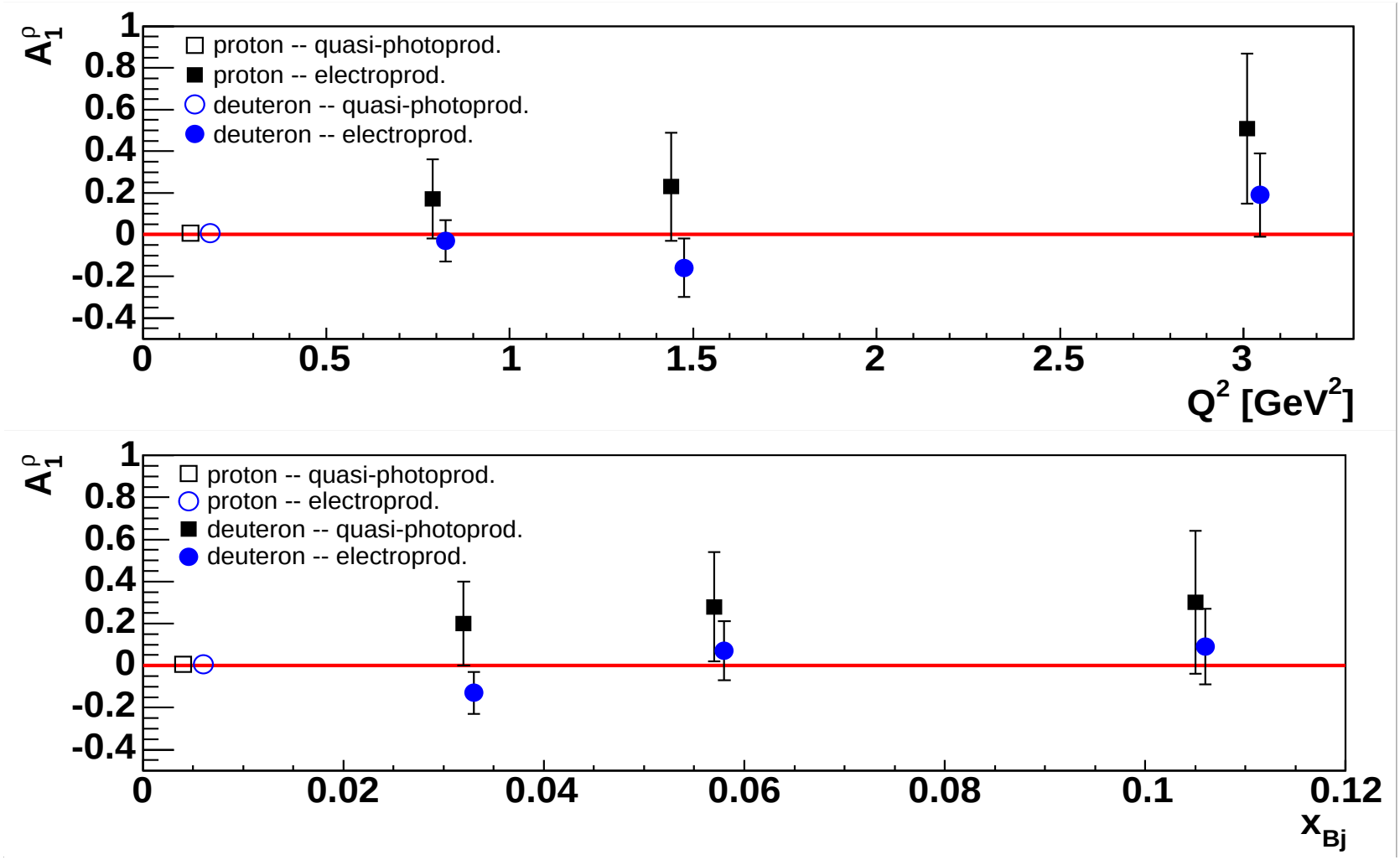




$$\tilde{\sigma}_A = \sigma_p \cdot A^{\alpha(Q^2)-1}$$

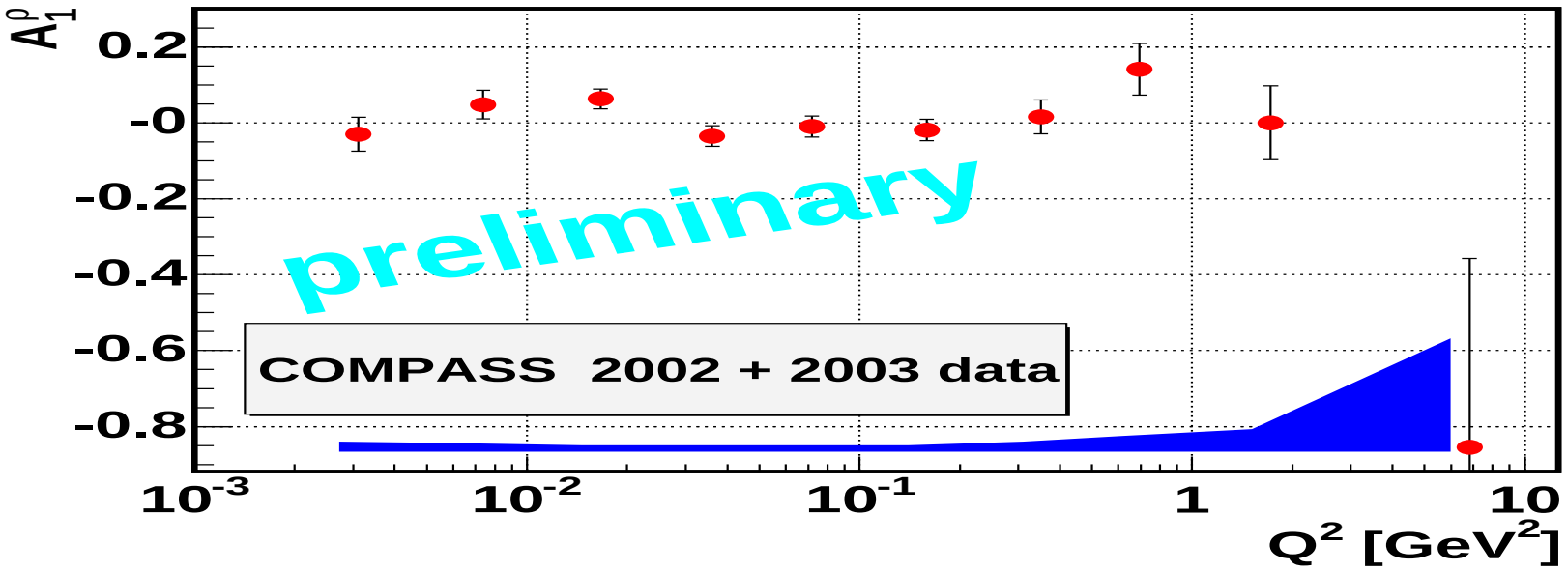
Experimental situation prior to COMPASS — HERMES results

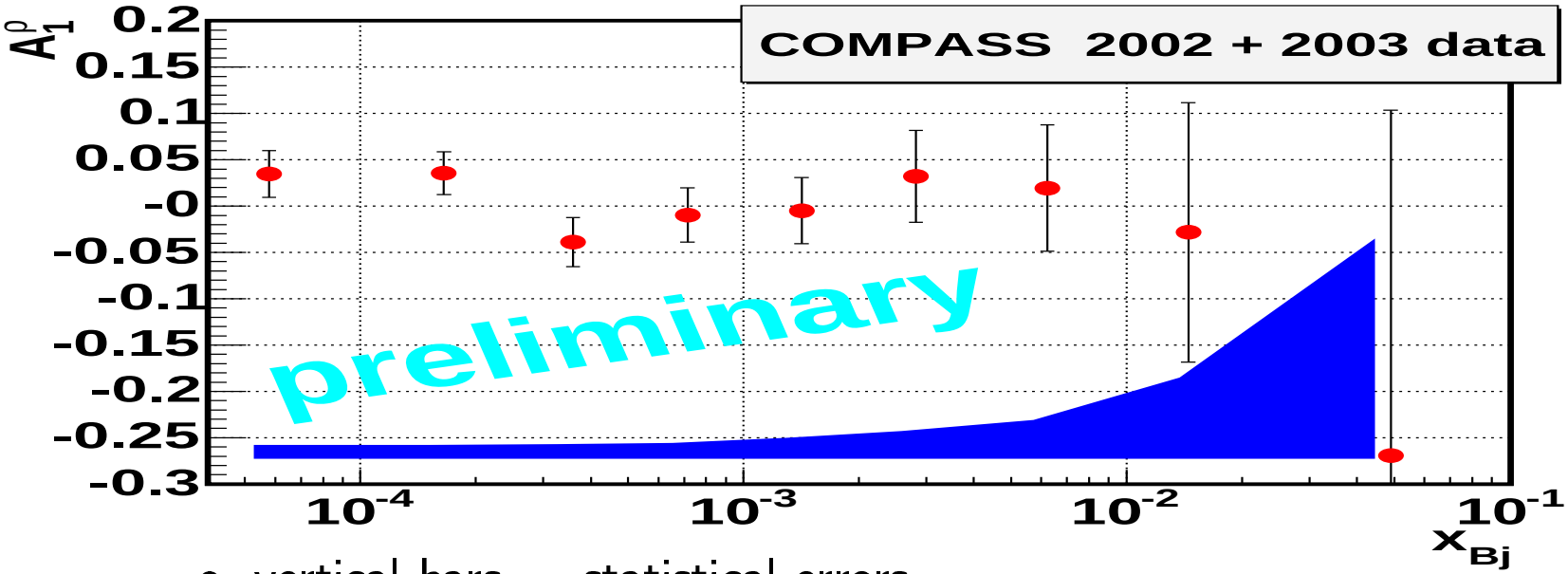
Results published in Eur. Phys. J. C 29 (2003) 171



- proton and deuteron targets
- $E_{\rm beam} = 27.5$ GeV $\Longrightarrow$ $\langle W \rangle \approx 5$ GeV

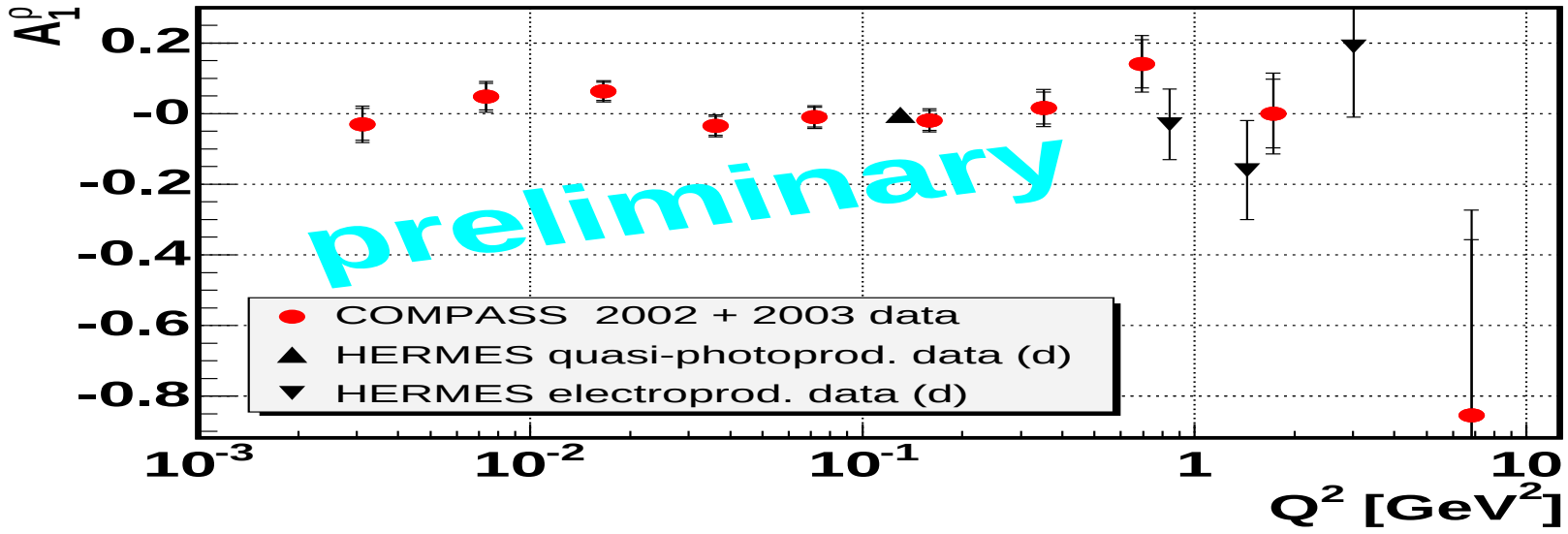
COMPASS results for A_1^p from 2002 + 2003 data

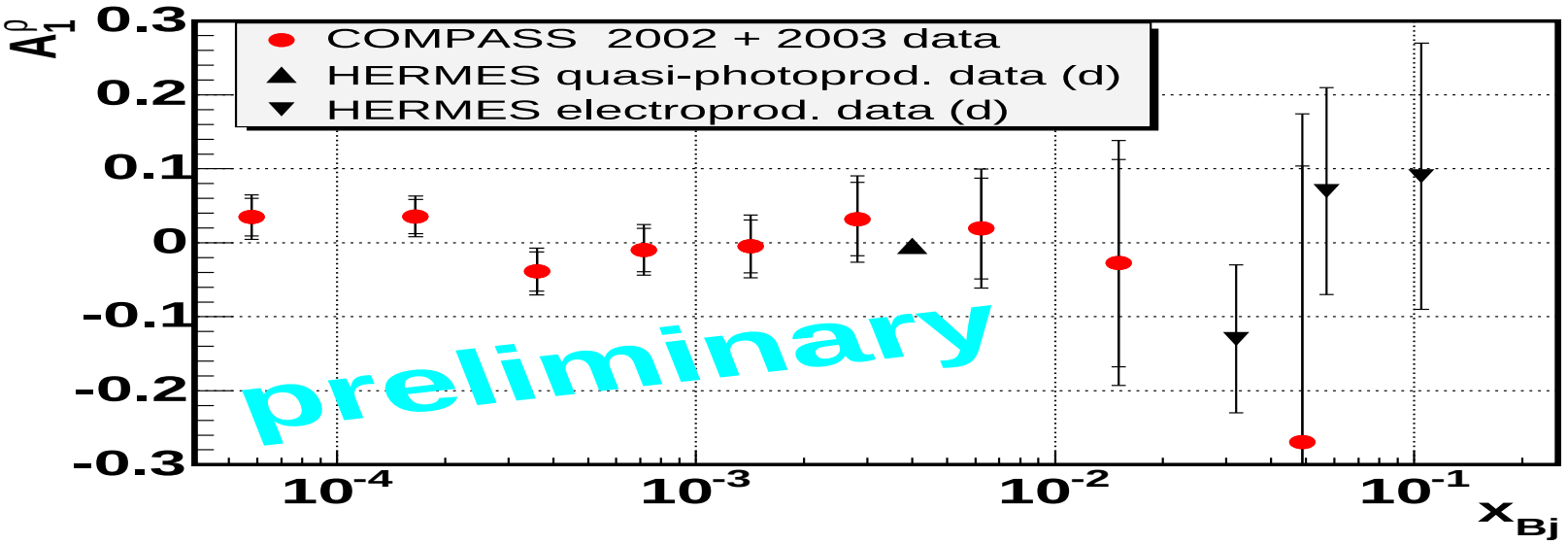




- vertical bars — statistical errors
- blue bands — total systematic errors

Comparison of COMPASS & HERMES results for $A_1^{\rho\,(\mathrm{d})}$





- COMPASS error bars — stat. errors (inner), quadratic sum of stat. & syst. ones (outer)
- HERMES error bars — quadratic sum of stat. & syst. errors

Summary

- preliminary results for the asymmetry A_1^ρ from COMPASS 2002 + 2003 data on exclusive incoherent ρ^0 meson production on deuteron target obtained
- these results cover wide kinematical ranges $3 \times 10^{-3} < Q^2 < 7$ GeV^2 and $5 \times 10^{-5} < x_{\rm Bj} < 0.05$ at $\langle W \rangle \approx 10$ GeV
- asymmetry A_1^ρ as function of both Q^2 and $x_{\rm Bj}$ compatible with 0
- results not background corrected so far, but this correction is expected to increase total error by 7% on average
- COMPASS results consistent with results of HERMES and SMC on deuteron targets
- errors dominated by statistics, $\sigma_{\rm syst} \approx 60\% \, \sigma_{\rm stat}$
- including 2004 data in analysis looks promising, as it will double data sample