COMPASS results: new measurements of transverse-spin asymmetries in two-hadron inclusive production

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on behalf of the COMPASS collaboration

Miniworkshop on Dihadron Fragmentation Functions (DiFF)
5 - 7 September 2011
Pavia - Italy

GEFÖRDERT VOM

Bundesministerium
für Bildung
und Forschung

COMPASS

Friedrich-Alexander-Universität
Erlangen-Nürnberg

Outline

The COMPASS experiment at CERN

The COMPASS experiment

COMPASS setup 2007

50 m

SM2

E/HCAL

SM1

E/HCAL

Polarized NH₃ Target

RICH

μ beam

- Beam: $160\,GeV/c$
- Intensity: $2 \times 10^{8}\mu^{+}/$spill
- Luminosity: $5 \times 10^{32}\,cm^{-2}s^{-1}$

- Two stage spectrometer
- Longitudinal polarized μ^{+}-beam
- 2002-2004 polarized ^{6}LiD (deuterium) target
- 2007 & 2010 polarized NH₃ (proton) target

- Tracking
- Calorimetry
- PID (RICH)
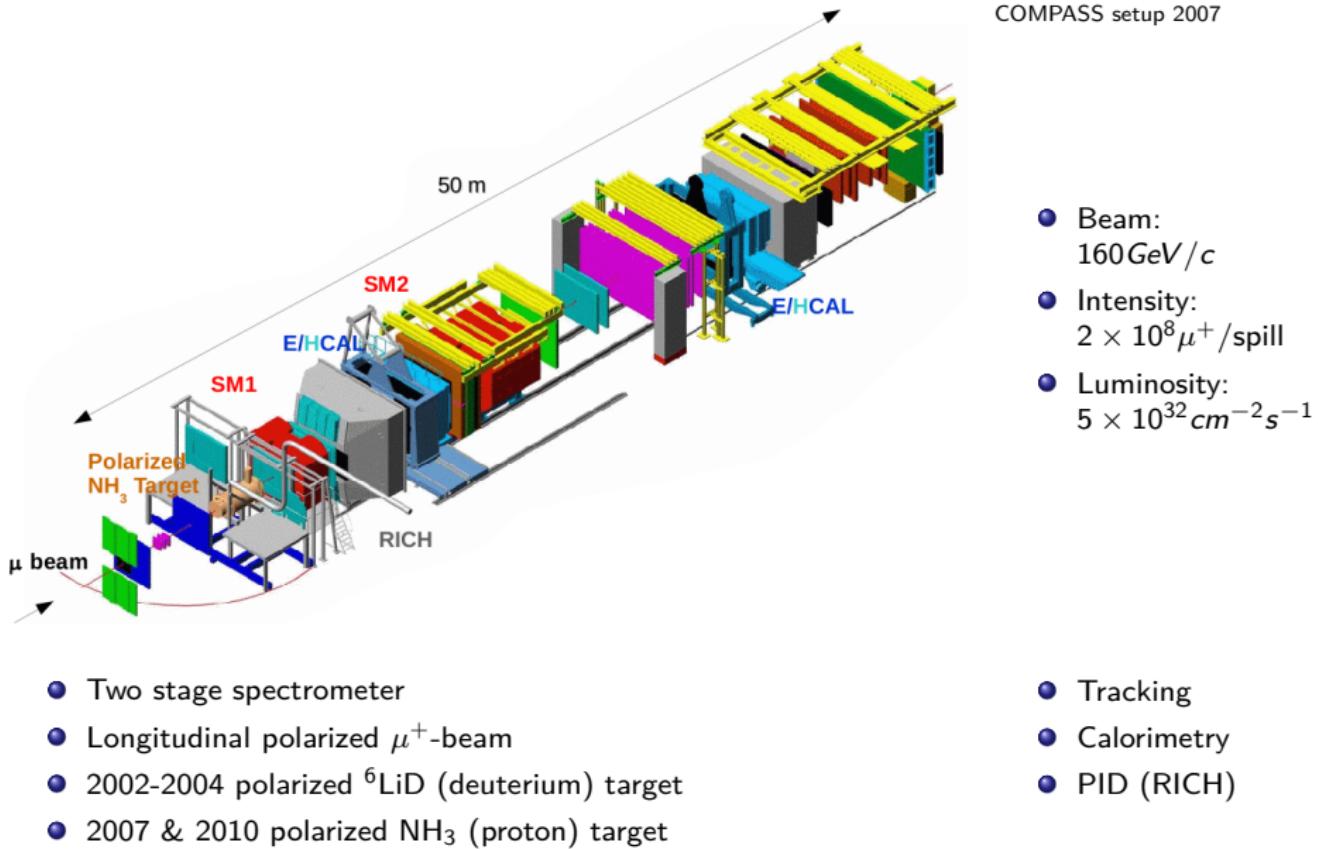
The COMPASS target system
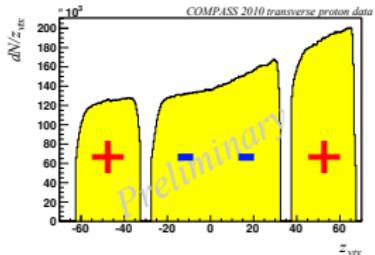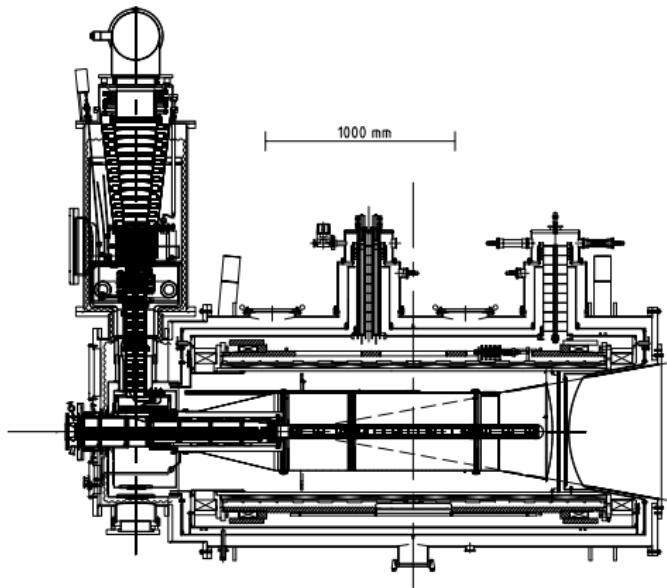
- Upgrade of target system in 2005
- Three cells with opposite polarization
- 180 mrad geometrical acceptance
- Transverse polarization reversed every week via microwave

- ^{6}LiD (deuteron):
  - polarization $\approx 48\%$
  - dilution factor ≈ 0.38
- NH_3 (proton):
  - polarization $\approx 90\%$
  - dilution factor ≈ 0.15

The COMPASS RICH
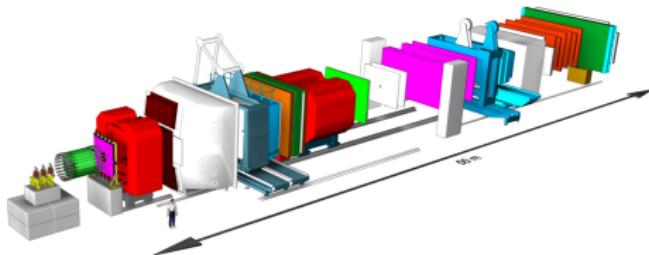

COMPASS setup 2008-09

COMPASS 2007 proton data

COMPASS 2007 proton data
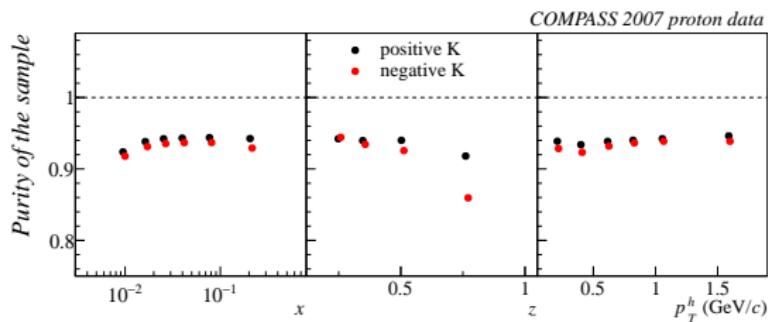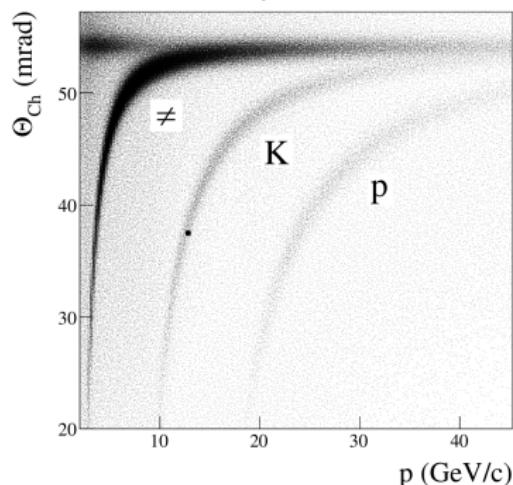
purity of $\pi^{\pm}$ sample $> 99\%$

Spin structure → Transversity

Three distribution functions are necessary to describe the spin structure of the nuclean in LO:

	U	L	T
U	$f_1(x)$		
L		$g_1(x)$	
T			$h_1(x)$

nucleon

Quark distribution
$f_1(x) = q^+(x) + q^-(x)$

Helicity distribution
$g_1(x) = q^+(x) - q^-(x)$

Transversity distribution
$h_1(x) = q^{\uparrow\uparrow}(x) - q^{\uparrow\downarrow}(x)$
$lN^\uparrow \to l'hX$ Collins FF
$lN^\uparrow \to l'hhX$ Interference FF
$lN^\uparrow \to l'\Lambda X$ FF of $q^\uparrow \to \Lambda$

Theoretical motivations: angle definitions
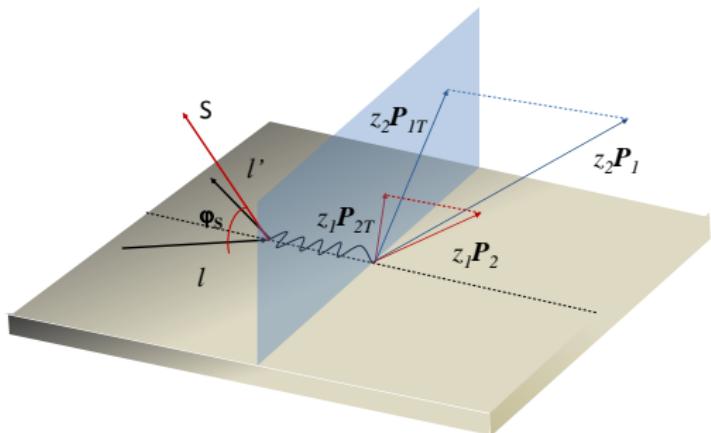
$lP^\uparrow \to l' h_1 h_2$

Fragmentation of transversely polarized quark into two unpolarized hadrons
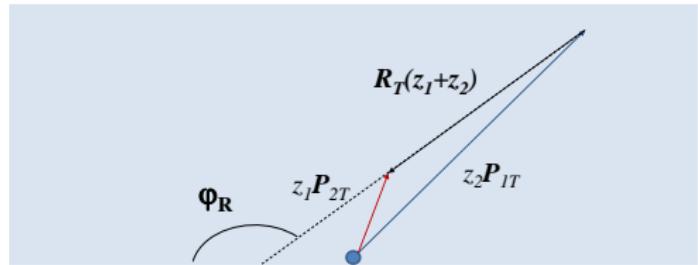
- $z_i = \dfrac{\mathbf{P_i}}{\mathbf{P_{tot}}}$
- $\mathbf{R_T} = \dfrac{z_1 \mathbf{P_{2,T}} - z_2 \mathbf{P_{1,T}}}{z_1 + z_2}$
- $\hat{\mathbf{q}} = \hat{\mathbf{z}}$
- Azimuthal angle of $\mathbf{R_T}$:
  $\cos \Phi_R = \dfrac{\hat{\mathbf{q}} \times \mathbf{l}}{|\hat{\mathbf{q}} \times \mathbf{l}|} \cdot \dfrac{\hat{\mathbf{q}} \times \mathbf{R_T}}{|\hat{\mathbf{q}} \times \mathbf{R_T}|}$
- Φ_S azimuthal angle of the spin of the fragmenting quark

Theoretical motivations: two-hadron cross section

While integrating over $\mathbf{P_{h,T}}$ ($\mathbf{P_h = P_1 + P_2}$) the two-hadron cross section is:

$$\frac{d^7}{d\zeta dM_h^2 d\Phi_R dz dx dy d\Phi_S} = \frac{2\alpha^2}{4\pi sxy^2} A(y)q(y)D_1^{\triangleleft q}(z, M_h^2)$$
$$+B(y)|S_\perp|\frac{|R_T|}{M_h}\sin(\Phi_R + \Phi_S - \pi)h_1(x)H_1^{\triangleleft q}(z, M_h^2)$$

Where $h_1(x)$ is the Transversity PDF and $H_1^{\triangleleft q}(z, M_h^2)$ is the two-hadron Interference FF, which describes the Fragmentation of a transversely polarized quark into two unpolarized hadrons (results from BELLE *talk of A.Vossen*, models from Radici et al. & Ma et al.).

Theoretical motivations: asymmetries extraction

$$N_{2h}^{\pm}(\Phi_{RS}) = N_{2h}^0(1 \pm fP_T D_{NN} A_{2h} \sin \Phi_{RS} \sin \Theta)$$

with $\sin \Phi_{RS} = \sin(\Phi_R + \Phi_S - \pi)$

$$A_{2h} = \frac{\sum\limits_q e_q^2 h_1(x) H_1^{\triangleleft q}(z, M_h^2)}{\sum\limits_q e_q^2 q(x) D_1^{\triangleleft q}(z, M_h^2)}$$

$\pm$ indicates nucleon spin orientation
f = target dilution factor
P_T = target polarization
$D_{NN} = \frac{1-y}{1-y+\frac{y^2}{2}}$ = transv. spin transfer coef.

$h^+ h^-$ center of mass frame
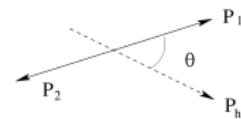
Data selection

- Vertex with at least **3** outgoing tracks:
  $\hookrightarrow$ All $h^+ h^-$ pair combinations are taken into account
- $Q^2 > 1$ GeV^2
- $0.1 < y < 0.9$
- $W > 5$ GeV

Specific cuts for two-hadron analysis:

- $z > 0.1$ for each hadron
- $x_F > 0.1$ for each hadron
- $E_{miss} > 3$ GeV for each pair
- $R_T > 0.07$ GeV for each pair
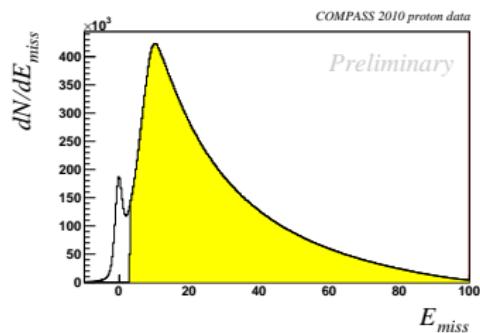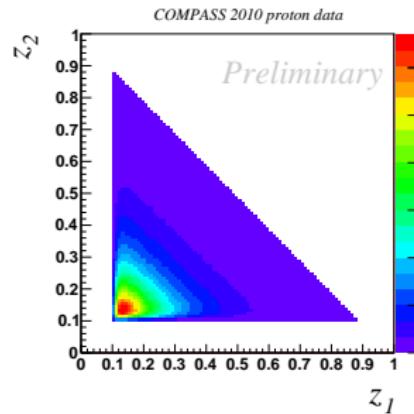
COMPASS 2010 proton data

Preliminary

COMPASS 2010 proton data

Preliminary

two-hadron asymmetries:

deuteron data 2002 - 2004

two-hadron asymmetries: deuteron data 2002 - 2004
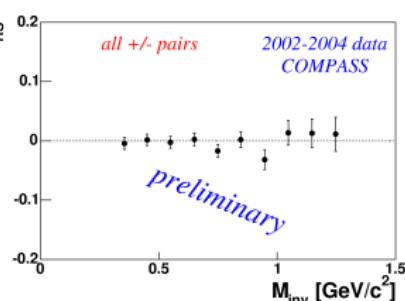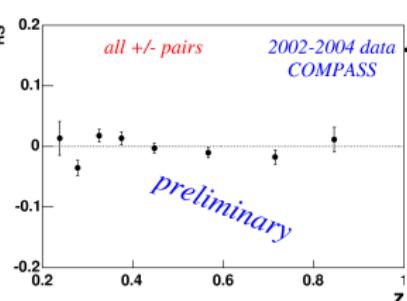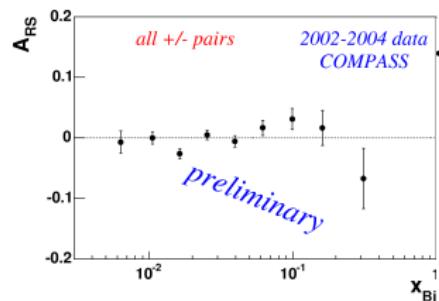
2002 - 2004 deuteron data two-hadron asymmetries of $h^+ h^-$ pairs:

$\hookrightarrow$ all asymmetries are small, compatible with zero

deuteron data 2002 - 2004: $\pi^+\pi^-$ pairs
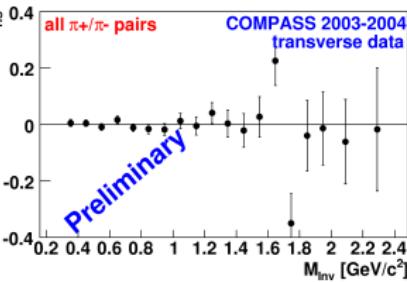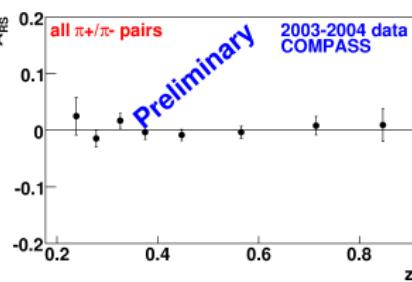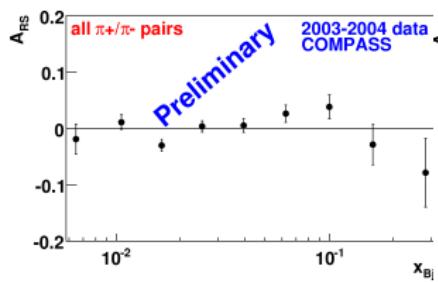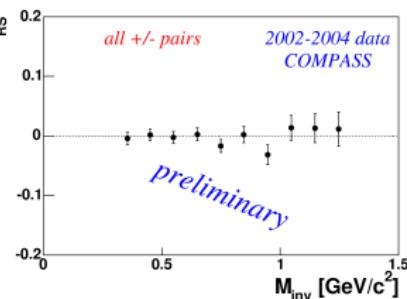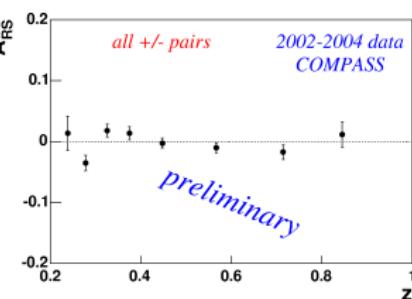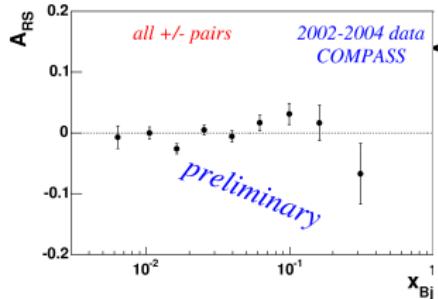
2002 - 2004 deuteron data two-hadron asymmetries: all h^+h^- pairs (top), $\pi^+\pi^-$ pairs (bottom)

$\hookrightarrow \pi^+\pi^-$ signal determines most of the unidentified asymmetries

deuteron data 2002 - 2004: $\pi^+ K^-$ pairs

2002 - 2004 deuteron data two-hadron asymmetries: all h^+h^- pairs (top), π^+K^- pairs (bottom)

deuteron data 2002 - 2004: $K^+\pi^-$ pairs
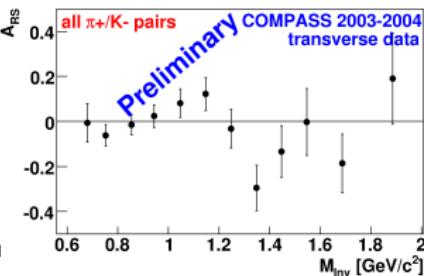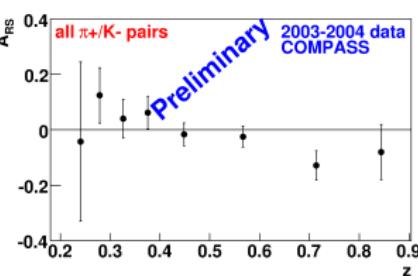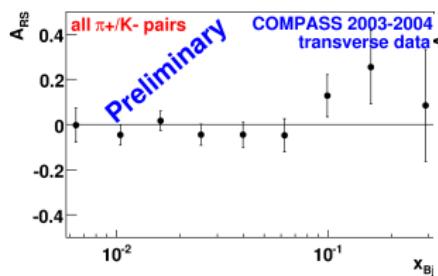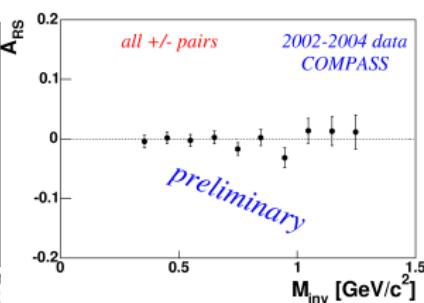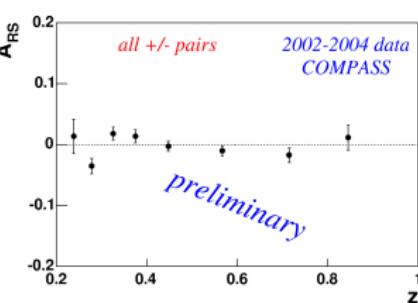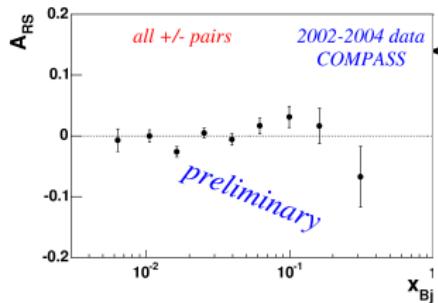
2002 - 2004 deuteron data two-hadron asymmetries: all h^+h^- pairs (top), $K^+\pi^-$ pairs (bottom)

deuteron data 2002 - 2004: K^+K^- pairs
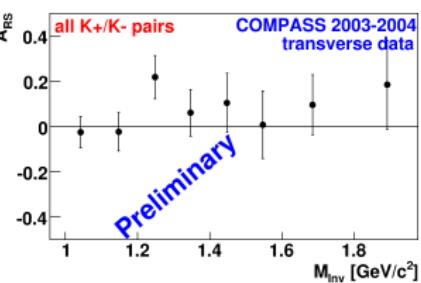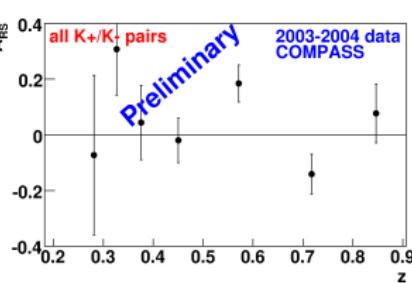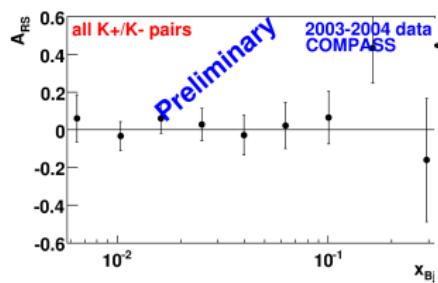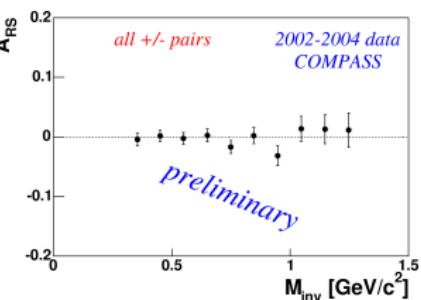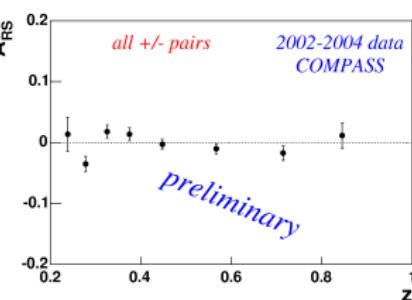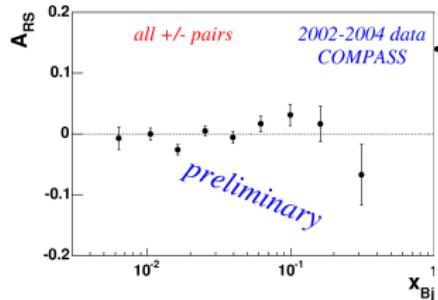
2002 - 2004 deuteron data two-hadron asymmetries: all h^+h^- pairs (top), K^+K^- pairs (bottom)

two-hadron asymmetries: deuteron data 2002 - 2004
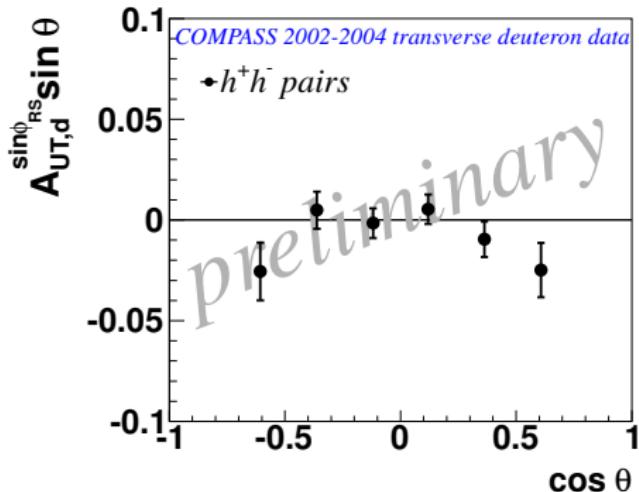
two-hadron asymmetrie deuteron data as a function of cos(Θ)

deuteron data 2002 - 2004 comparison with model predictions
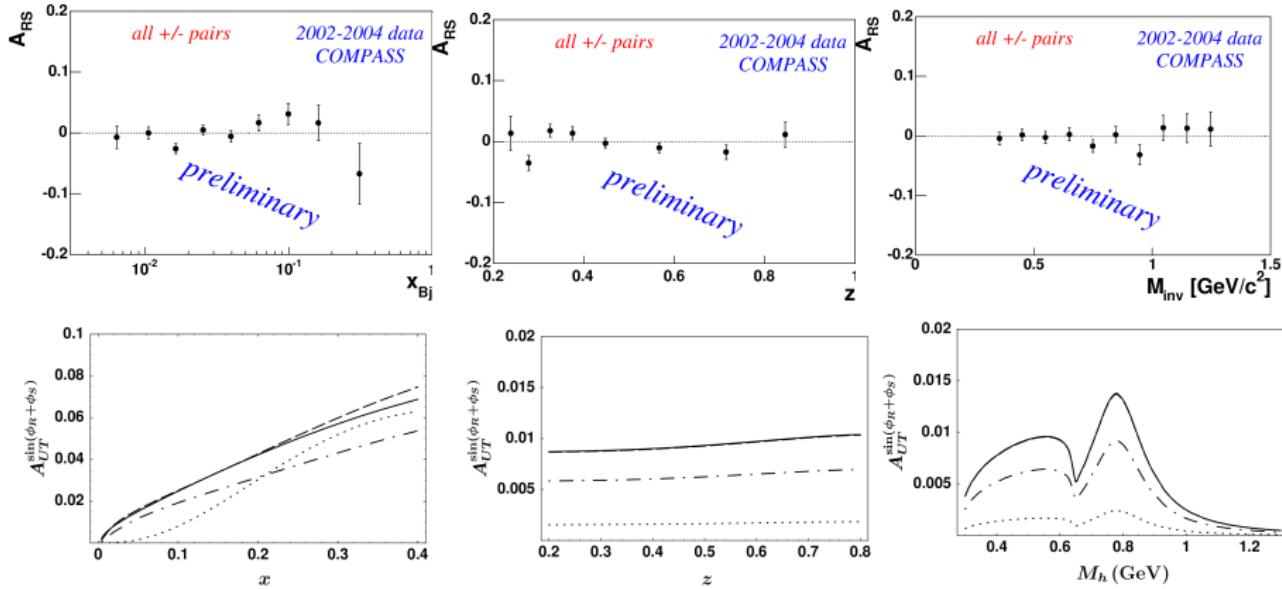
A. Bacchetta, hep-ph/0708037

Different lines correspond to different models of $h_1(x)$.

Different definition of Φ_S w.r.t. COMPASS

$\hookrightarrow$ rather agreement with model predictions

two-hadron asymmetries:

proton data 2007
unidentified hadron pairs

two-hadron asymmetries: proton data 2007

sin(Θ) (top), cos(Θ) (bottom)
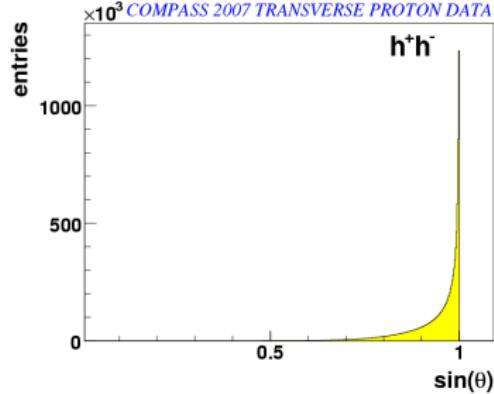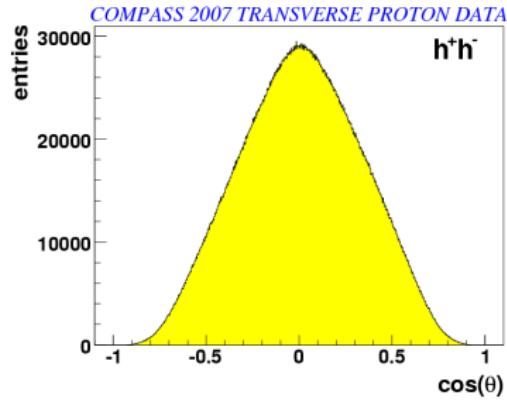
# two-hadron asymmetries: proton data 2007
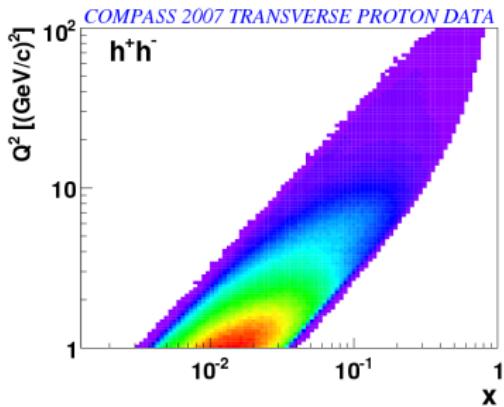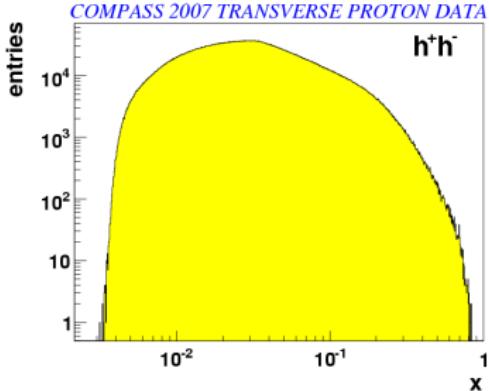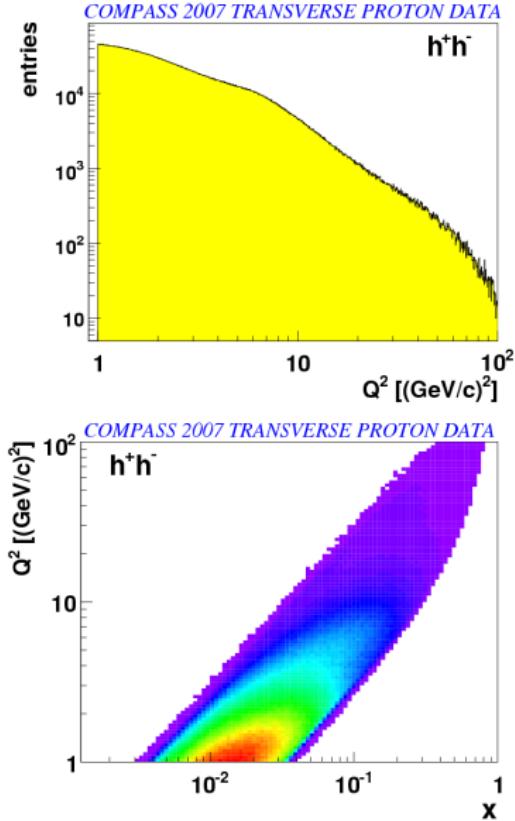
Q^2 (top left), x (top right) and $Q^2(x)$ distribution (bottom left) of proton data selection

two-hadron asymmetries: proton data 2007
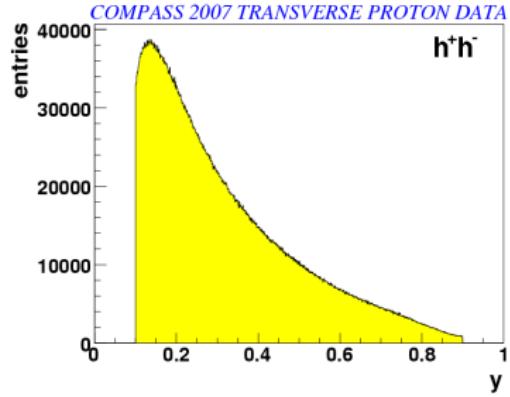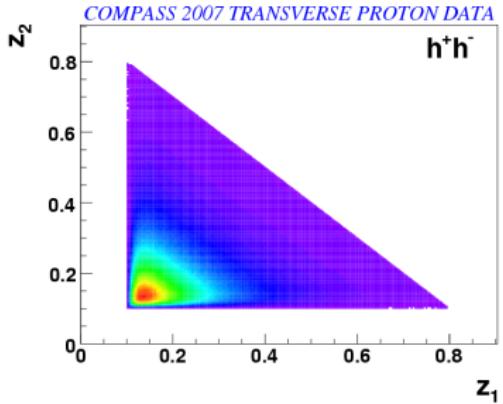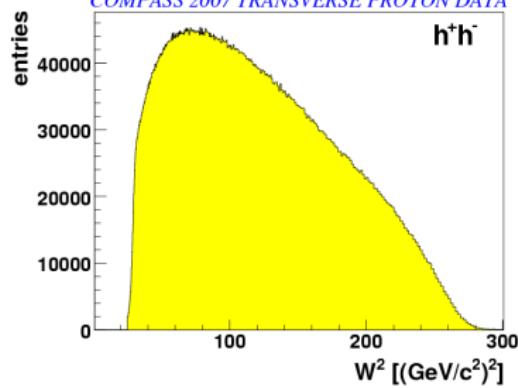
W^2 (top left), z_2 vs. z_1 (top right) and y distribution (bottom left) of proton data selection

two-hadron asymmetries: proton data 2007
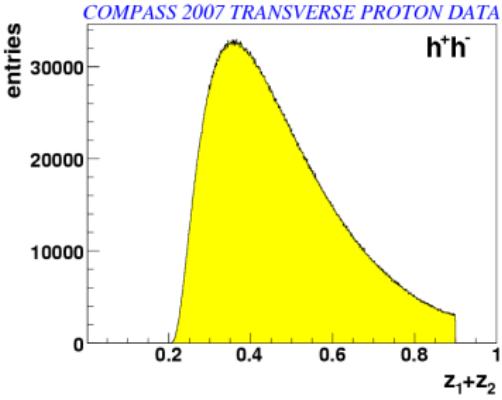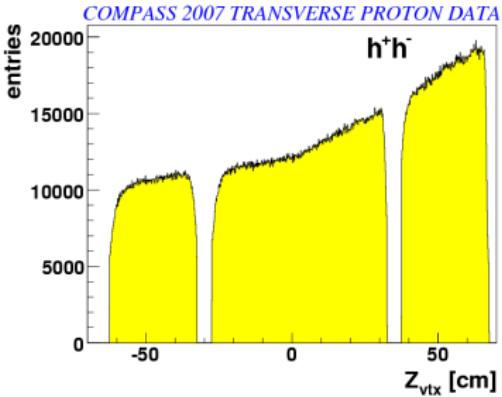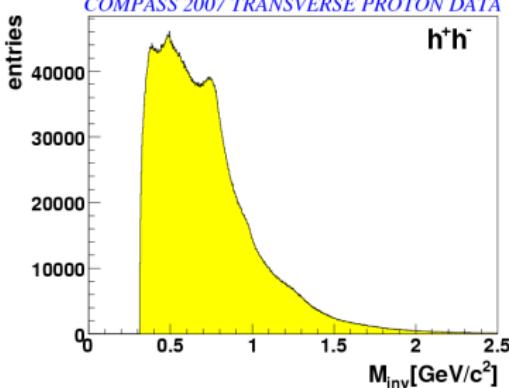
M_{inv} (top left), z-coordinate of the vertex (top right) and $z_1 + z_2$ distribution (bottom right) for proton 2007 data

two-hadron asymmetries: proton data 2007
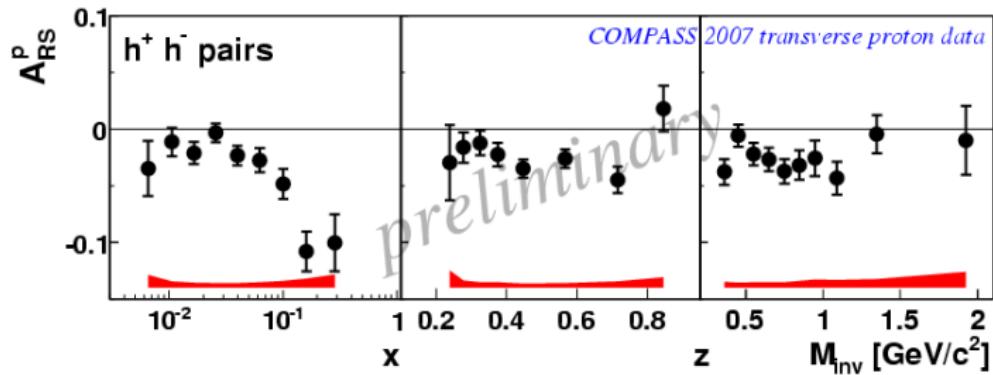
2007 proton data two-hadron asymmetries of h^+h^- pairs.

↪ Large asymmetries for proton up to $5 - 10\%$

proton data 2007: $x > 0.032$
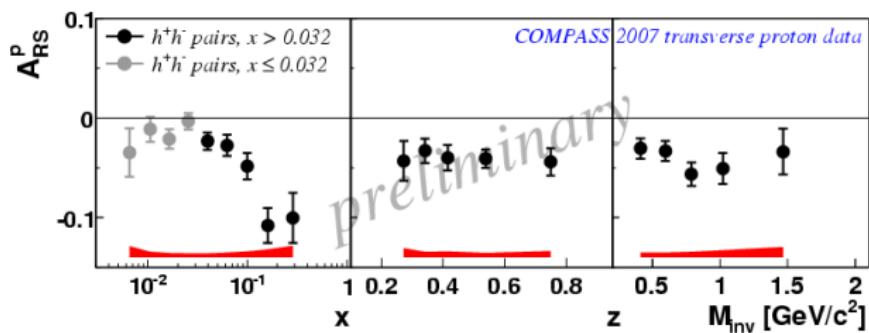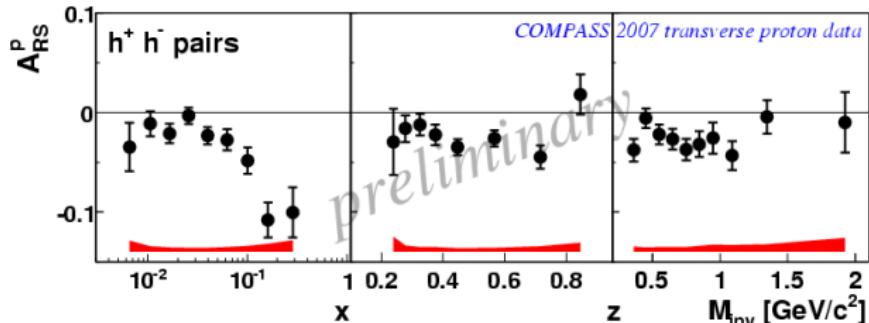
$\hookrightarrow$ Asymmetries in z and M_{inv} increase for $x > 0.032$ sample

**proton data 2007:** $M_{inv} < 1.5$
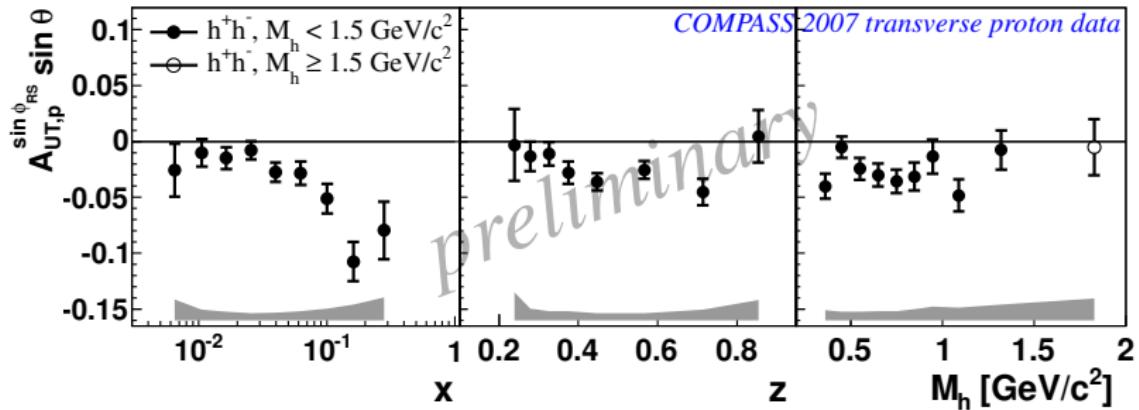
## proton data 2007: comparison with HERMES data
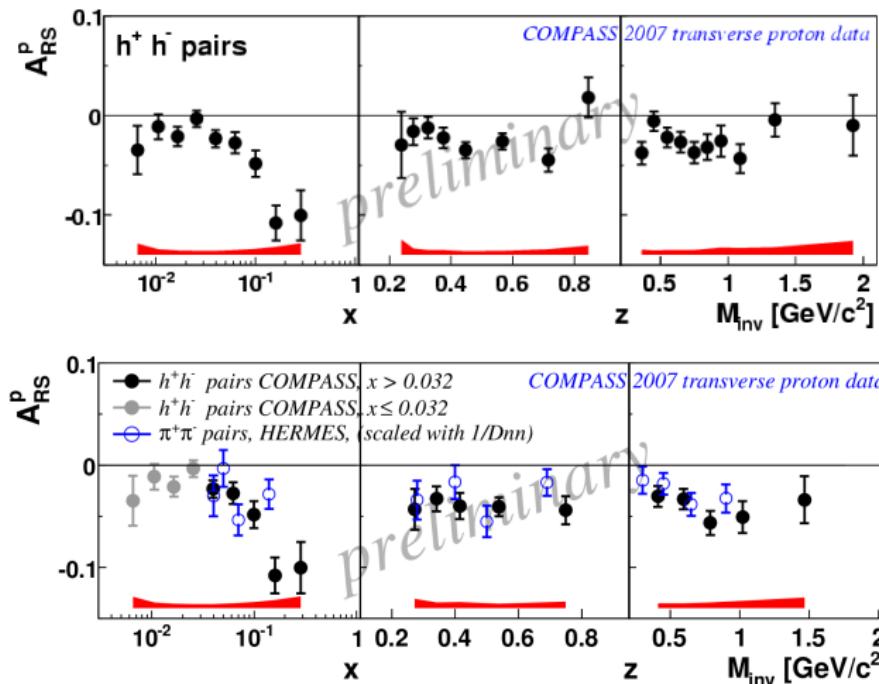
HERMES data scaled with $1/D_{nn}$

$\hookrightarrow$ Good agreement with HERMES data within the error bars

proton data 2007: comparison with model predictions
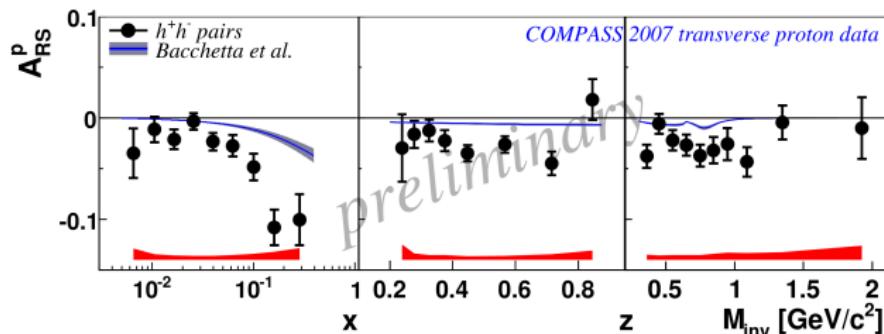

Bachetta & Radici, hep-ph/0608037
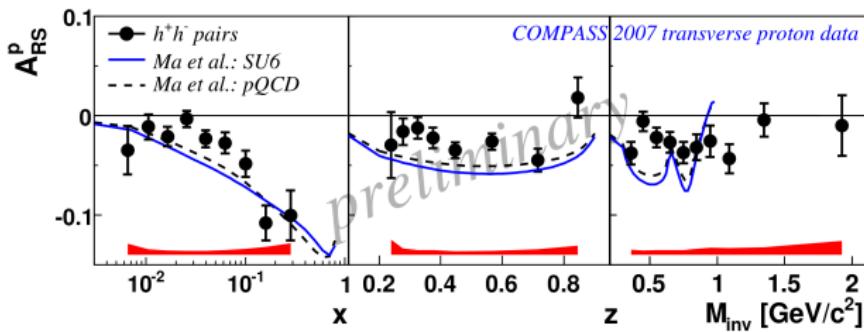
Ma et al., arXiv:0711.0817

↪ Model predictions in agreement with data

two-hadron asymmetries:

proton data 2010
unidentified hadron pairs

proton data 2010: kinematics (a)
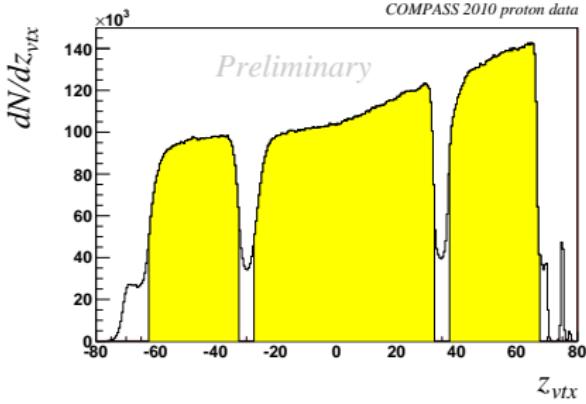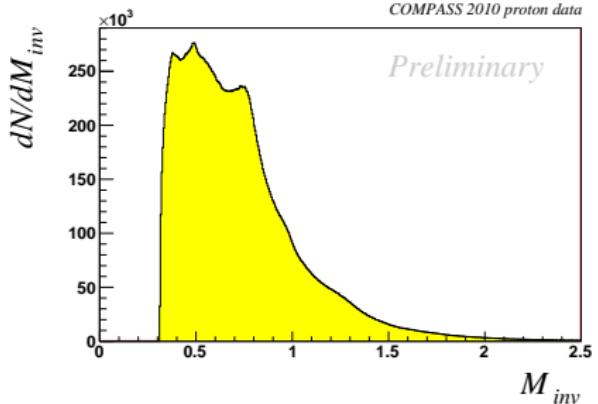
M_{inv} (top left), z-coordinate of the vertex (top right) and $z_1 + z_2$ distribution (bottom right) for proton 2007 data
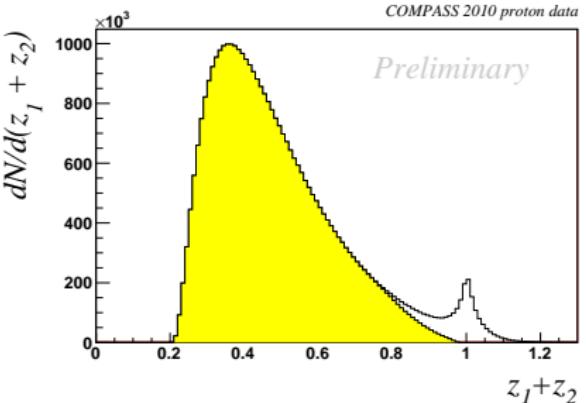
proton data 2010: kinematics (b)
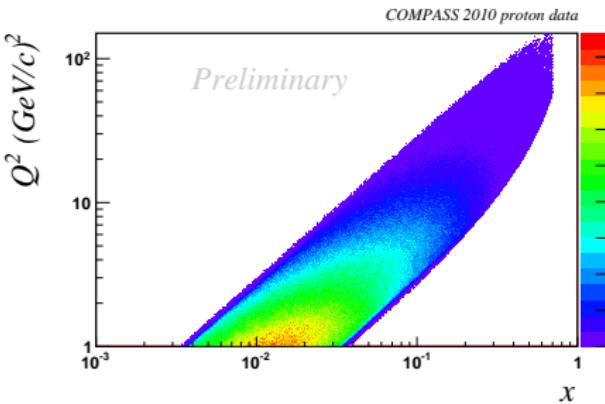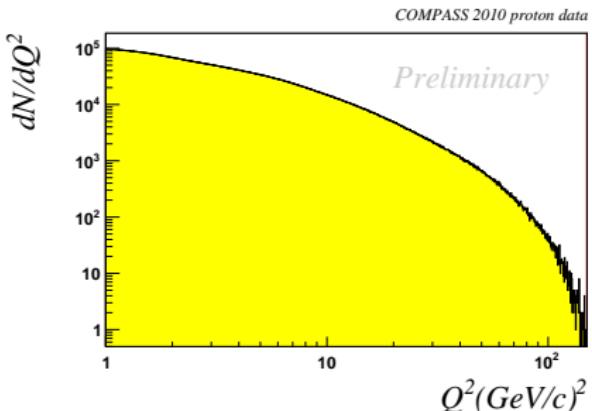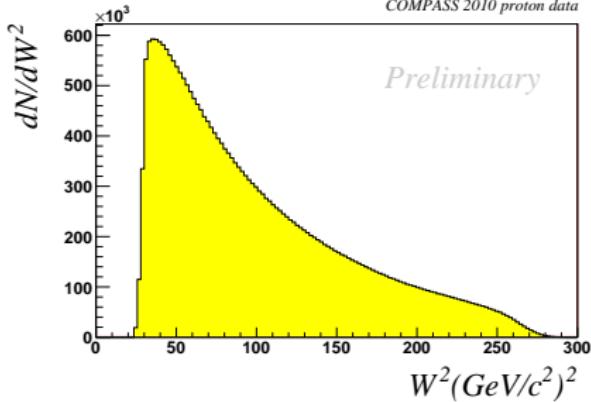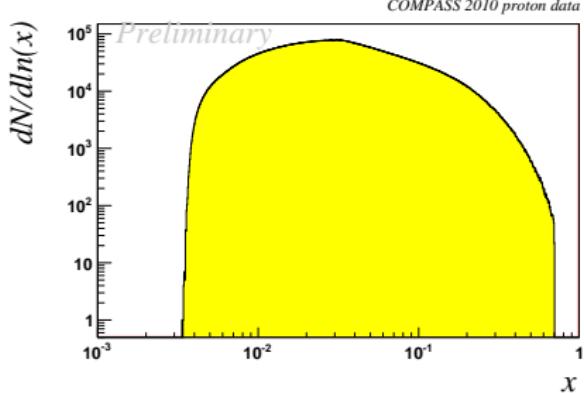
proton data 2010: kinematics (c)


COMPASS 2010 proton data
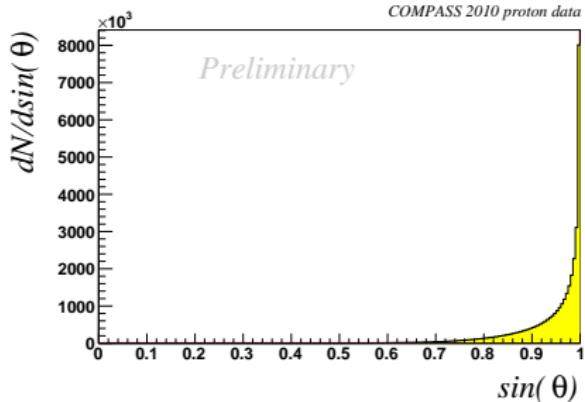
$\langle\sin\Theta\rangle = 0.943$

$\hookrightarrow \sin\Theta$ can be neglected.
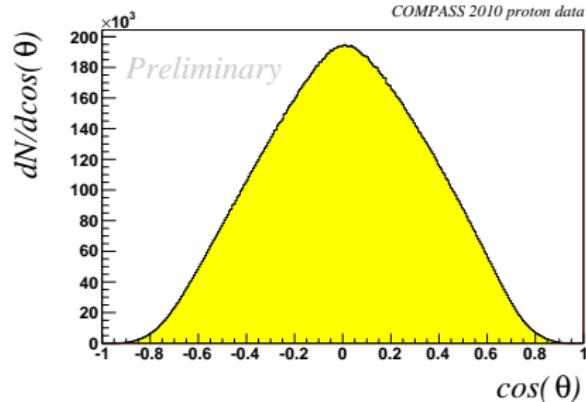
$H_1^{\sphericalangle}(z, \cos\Theta, M_{inv}^2) =$
$H_{1,0t}^{\sphericalangle}(z, M_{inv}^2) + H_{1,lt}^{\sphericalangle}(z, M_{inv}^2)\cos\Theta$

A. Bacchetta, hep-ph/0708037

$\langle\cos\Theta\rangle = 0.01$
$\langle\cos^2\Theta\rangle = 0.1$
But not for pairs including Kaon(s)!

**two-hadron asymmetries: proton data 2010**

COMPASS 2010 proton data

preliminary
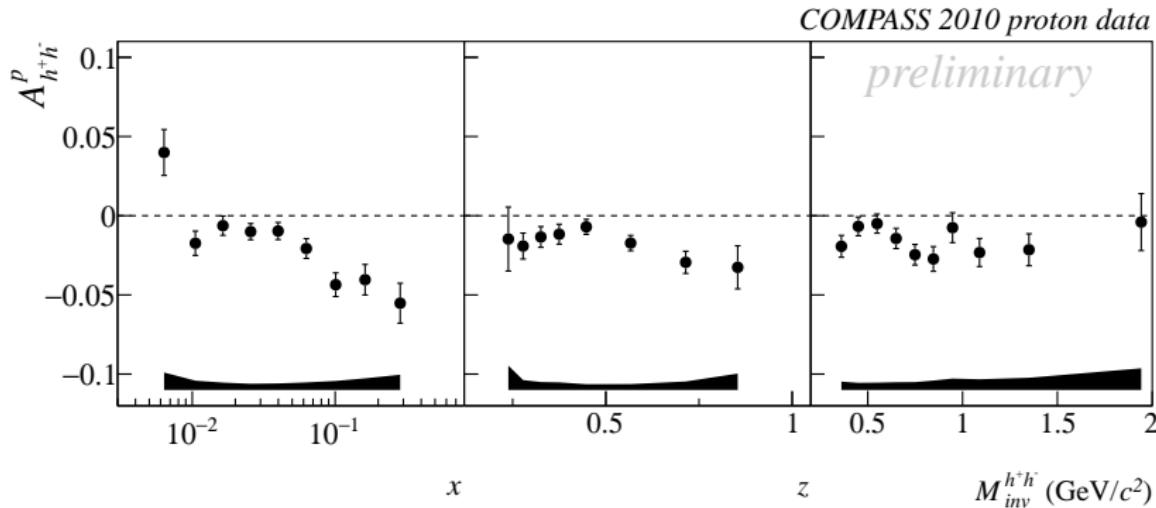
**NEWS:** The 2010 two-hadron asymmetries of h^+h^- pairs.

$\hookrightarrow$ Clear asymmetries for proton with improved errors

two-hadron asymmetries: comparison 2010 and 2007 proton data

COMPASS 2010 proton data

preliminary
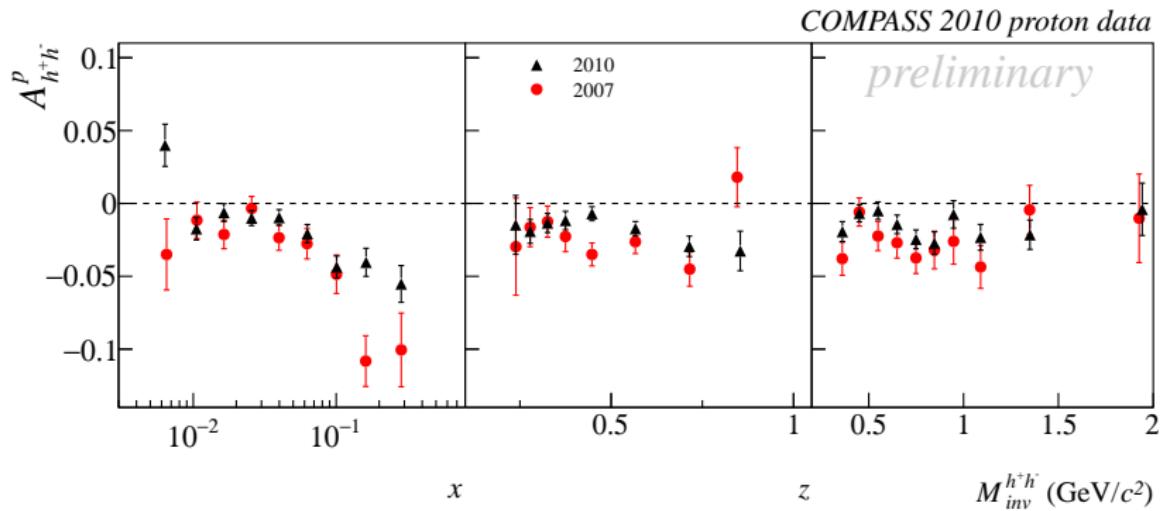
↪ Good agreement between 2007 and 2010 results within the error bars. Factor of gain in statistical err. ~ 1.7 & $\sigma_{sys}/\sigma_{stat} = 0.8$

two-hadron asymmetries: proton data 2010 $x_{bj} > 0.032$
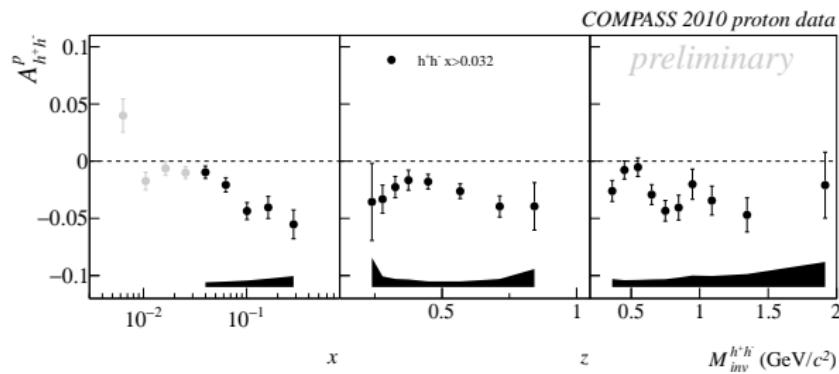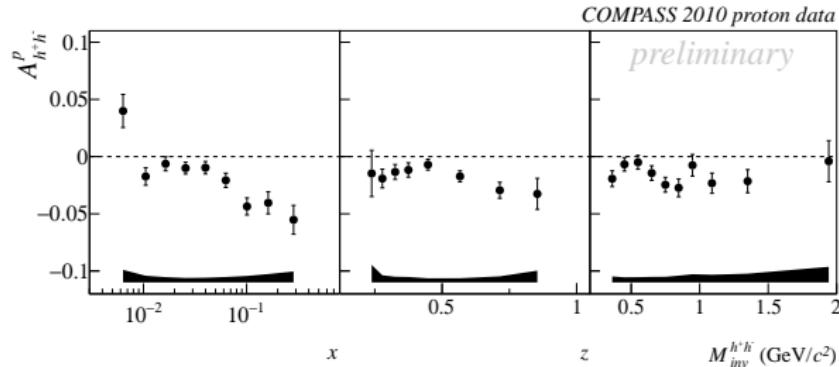
$\hookrightarrow$ Asymmetries in z and M_{inv} increase for $x > 0.032$ sample

Comparison with results from HERMES

COMPASS 2010 proton data

preliminary

COMPASS 2010 proton data

- h⁺h⁻ COMPASS 2010, x>0.032
- h⁺h⁻ COMPASS 2010, x<0.032
- pi⁺pi⁻ HERMES (scaled with 1/Dnn)

preliminary
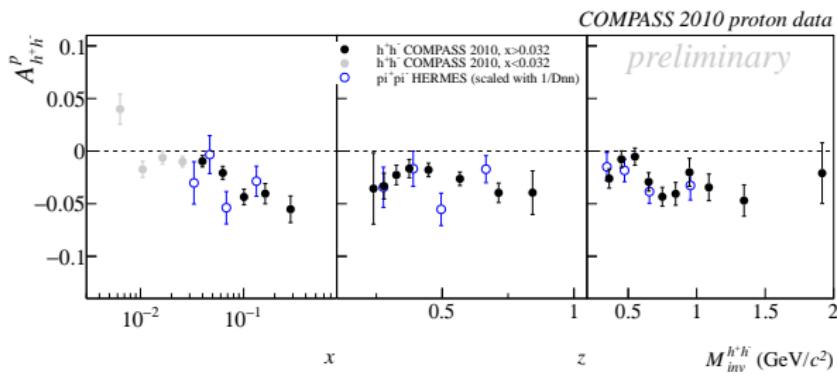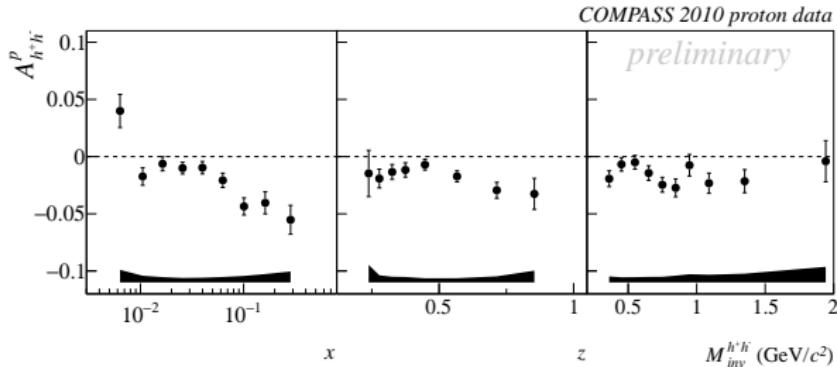
HERMES data scaled with $1/D_{nn}$

$\hookrightarrow$ Good agreement with HERMES data within the error bars

2010 proton data comparison with model predictions

Bachetta & Radici

Ma et al.
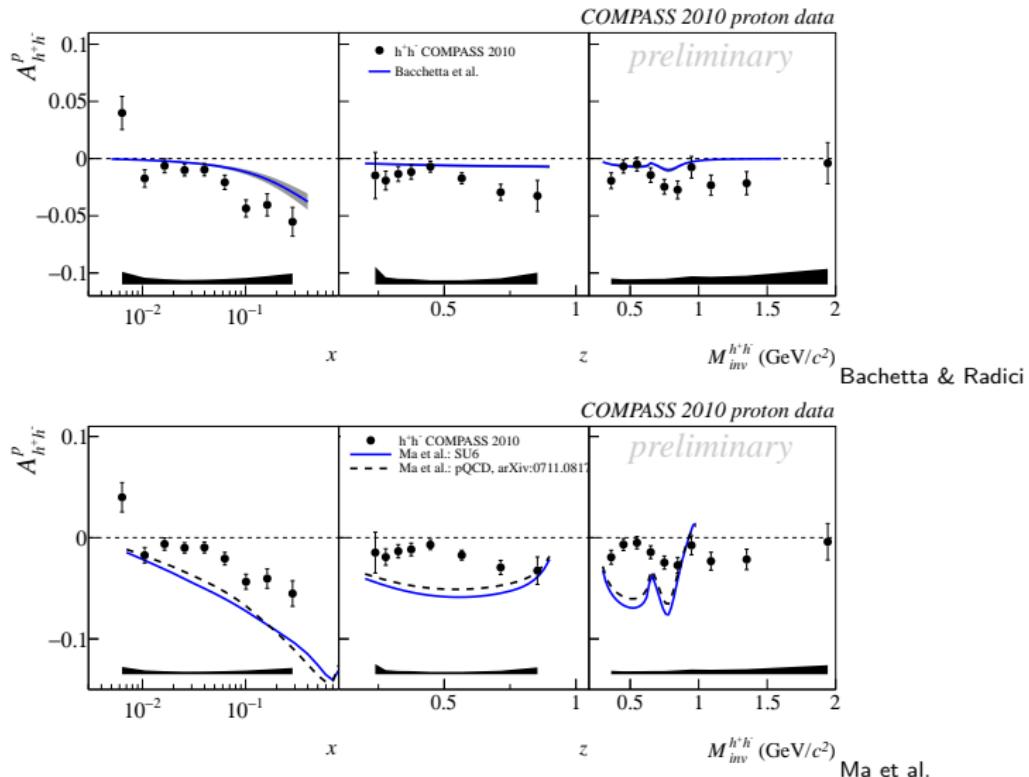
$\hookrightarrow$ level of agreement differs for x, z and M_{inv}

2010 proton data comparison with model predictions
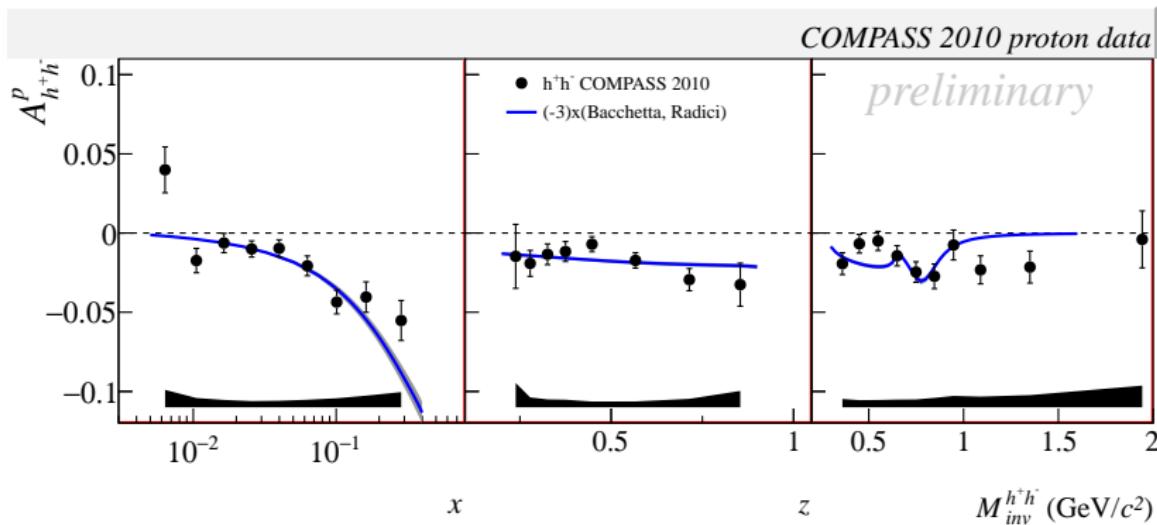
$\hookrightarrow (-3) \cdot$ (Bachetta & Radici's prediction)

two-hadron asymmetries: proton data 2010 $M_{inv} < 1.5 \, GeV/c^2$
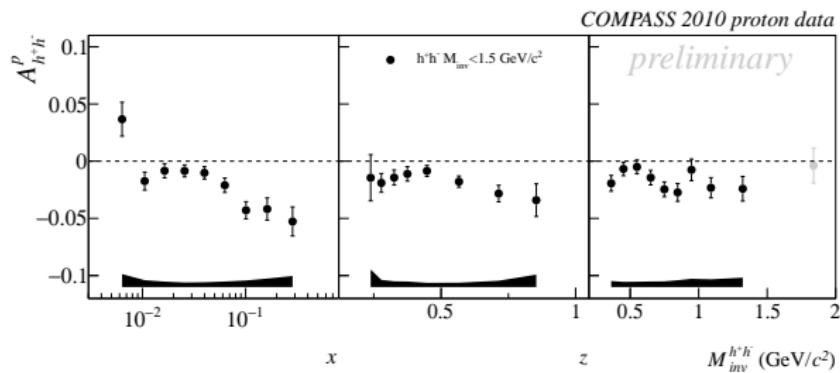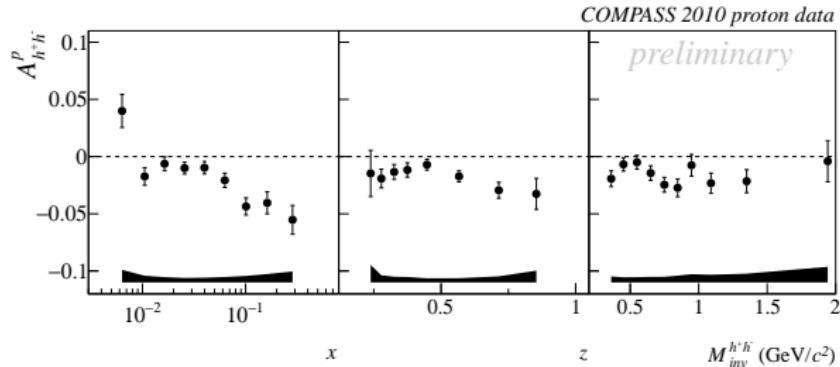
$\hookrightarrow$ Asymmetries for $M_{inv} < 1.5 \, GeV/c^2$

Conclusions & Outlook

- Complete analysis of COMPASS deuteron data available
- COMPASS 2007 proton data available

$\hookrightarrow$ paper to be published soon

- **NEWS:** preliminary results for 2010 COMPASS proton data available:

1. Small statistical and systematic uncertainty
2. Agreement of independent COMPASS 2010 and 2007 proton measurements within the error bars
3. COMPASS data, with it's higher precision, is in agreement with HERMES data
4. **Good** agreement with model predictions of Bacchetta & Ma

Outlook:

- Asymmetries for identified hadron pairs: charged and maybe also uncharged

Thank You!

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