

COMPASS results on tranverse spin asymmetries in two-hadron production in SIDIS

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on behalf of the COMPASS collaboration

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HK 23.6



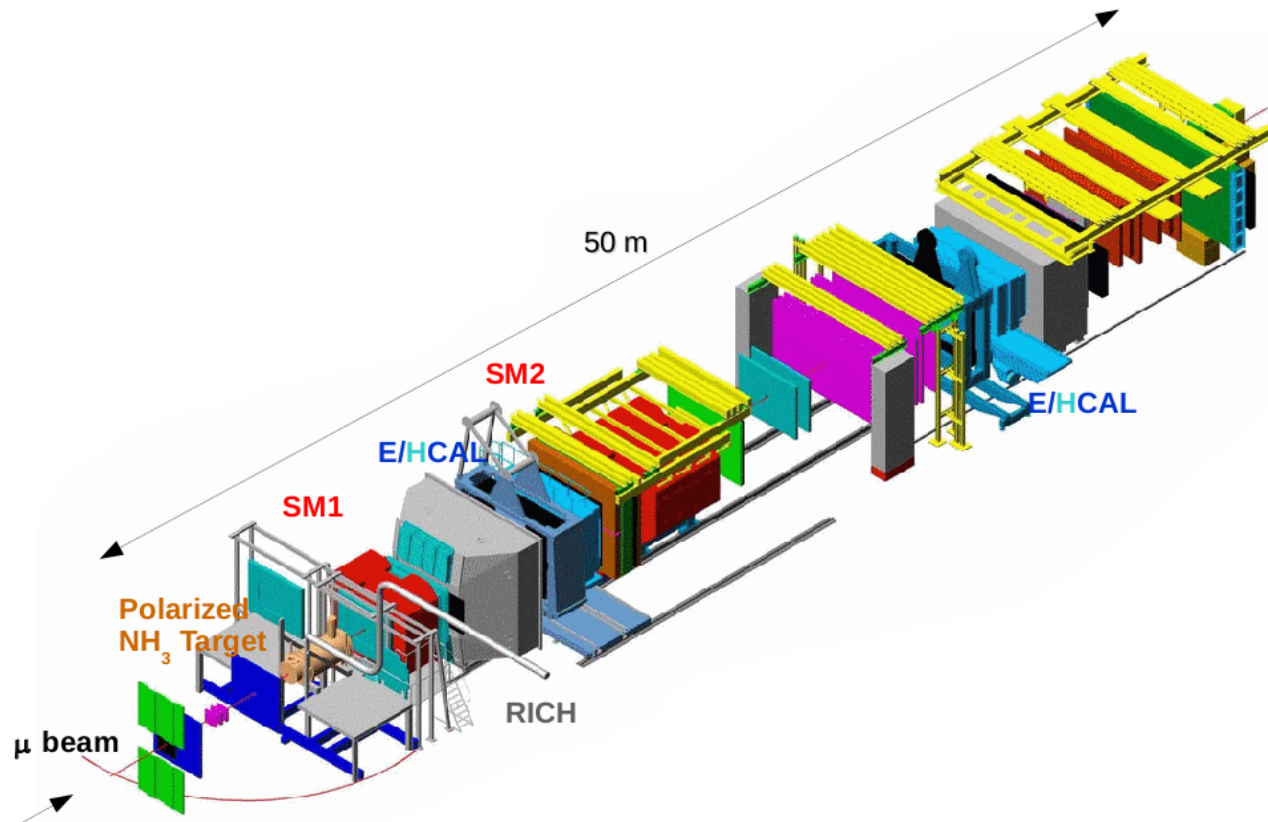
Outline

- 1 The COMPASS experiment
- 2 Theoretical framework
- 3 Data selection 2010
- 4 Two-hadron asymmetries: deuteron data 2002-04
- 5 Two-hadron asymmetries: proton data 2007
- 6 Two-hadron asymmetries: proton data 2010
- 7 Conclusions & outlook

The COMPASS experiment at CERN



The COMPASS experiment



e.g.

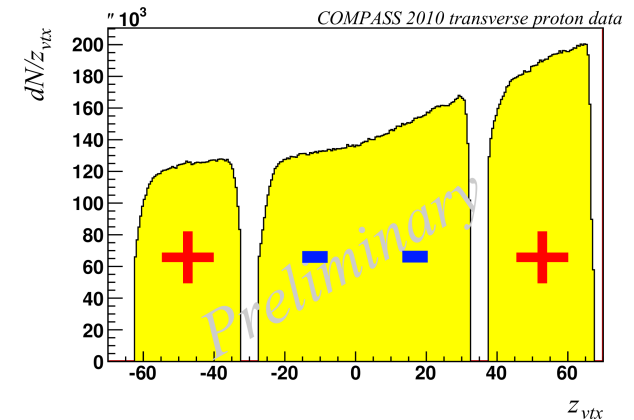
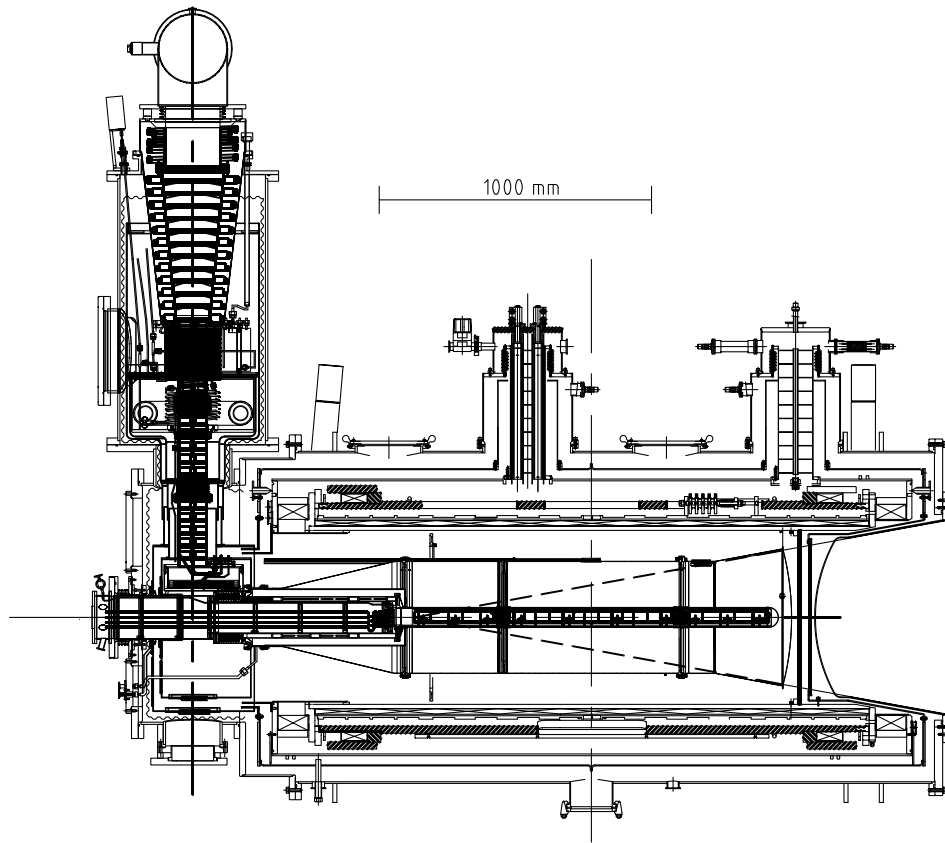
COMPASS setup 2007

- Two stage spectrometer
- Longitudinal polarized μ^+ -beam
- 2002-04 polarized deuterium (^6LiD) target
- 2007 & 2010 polarized proton (NH_3) target

- Beam:
 $160 \text{ GeV}/c$
- Intensity:
 $3.0 - 3.5 \cdot 10^8 \mu^+/\text{spill}$
- Luminosity:
 $5 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$

- Tracking
- Calorimetry
- PID (RICH)



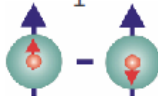
The COMPASS target system



- Upgrade of target system in 2005
 - Three cells with opposite polarization
 - ± 180 mrad geometrical acceptance
 - Transverse polarization reversed every week via microwave
- deuteron ${}^6\text{LiD}$:
 - ▶ polarization $\approx 48\%$
 - ▶ dilution factor ≈ 0.38
 - proton NH_3 :
 - ▶ polarization $\approx 90\%$
 - ▶ dilution factor ≈ 0.15

Theoretical framework: from spin structure to Transversity

Three independent parton distribution functions (PDF) are necessary to describe the spin structure of the nucleon in leading order:

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

Quark distribution:

$$f_1(x_{bj}) = q^+(x_{bj}) + q^-(x_{bj})$$

Helicity distribution:

$$g_1(x_{bj}) = q^+(x_{bj}) - q^-(x_{bj})$$

Transversity distribution:

$$h_1(x_{bj}) = q^{\uparrow\uparrow}(x_{bj}) - q^{\uparrow\downarrow}(x_{bj})$$

Collins FF $lN^\uparrow \rightarrow l'hX$

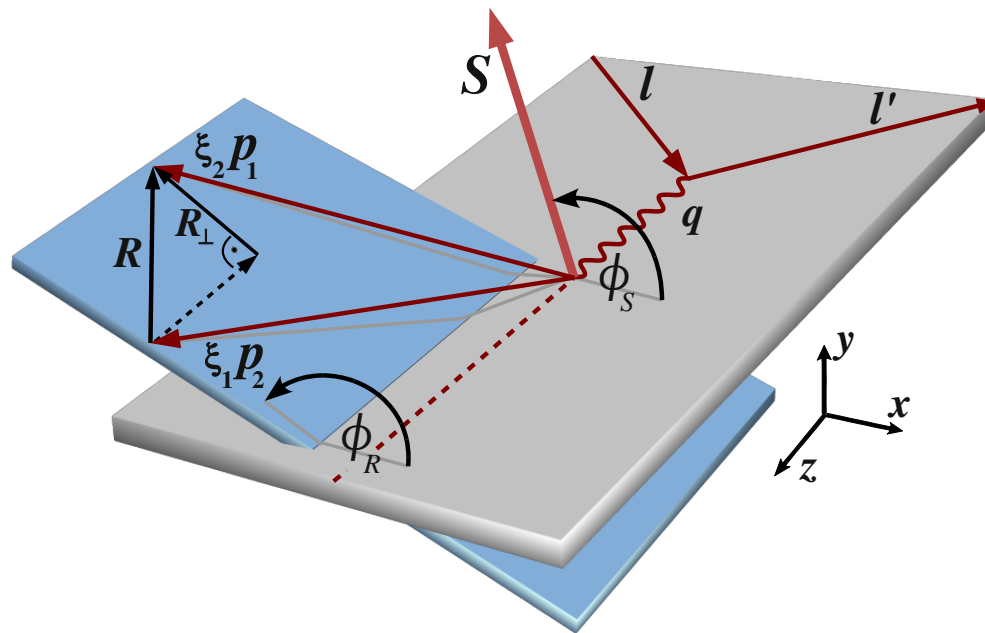
Interference FF $lN^\uparrow \rightarrow l'hhX$

FF of $q^\uparrow \rightarrow \Lambda$ $lN^\uparrow \rightarrow l'\Lambda X$

Theoretical framework: angle definitions

$$l p^\uparrow \rightarrow l' h_1 h_2$$

Fragmentation of transversely polarized quark into two unpolarized hadrons



- l, l' and q are 3-momenta of incoming, scattered lepton and virtual photon
- Φ_S azimuthal angle of the spin of the fragmenting quark S
- $z_i = \frac{\mathbf{p}_i}{\mathbf{p}}$
- $\mathbf{R} = \frac{z_2 \mathbf{p}_1 - z_1 \mathbf{p}_2}{z_1 + z_2} = \xi_2 \mathbf{p}_1 - \xi_1 \mathbf{p}_2$
- \mathbf{R}_T is the component of \mathbf{R} perpendicular to \mathbf{q}
- Azimuthal angle of \mathbf{R} :

$$\Phi_R = \frac{(\mathbf{q} \times \mathbf{l}) \cdot \mathbf{R}}{|(\mathbf{q} \times \mathbf{l}) \cdot \mathbf{R}|} \arccos \left(\frac{(\mathbf{q} \times \mathbf{l}) \cdot (\mathbf{q} \times \mathbf{R})}{|\mathbf{q} \times \mathbf{l}| |\mathbf{q} \times \mathbf{R}|} \right)$$

Theoretical framework: two-hadron cross section

The differential two-hadron cross section is:

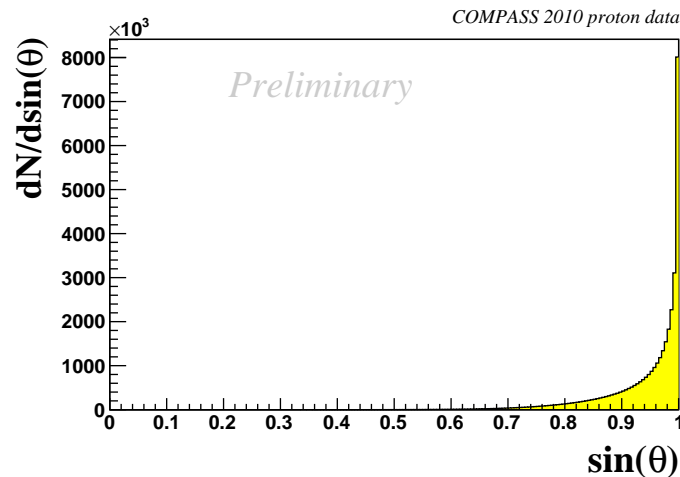
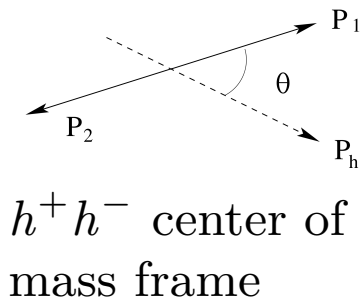
$$\frac{d^7\sigma}{d\cos\theta dM_h^2 d\Phi_R dz dx dy d\Phi_S} =$$
$$\frac{\alpha^2}{2\pi Q^2 y} \left(\left(1 - y + \frac{y^2}{2}\right) \sum_q e_q^2 f_1^q(x) D_{1,q}^{2h}(z, M_h^2, \cos\theta) \right.$$
$$\left. + (1 - y) S_\perp \sum_q e_q^2 \frac{|\mathbf{p}_1 - \mathbf{p}_2|}{2M_h} \sin(\theta) \sin(\Phi_{RS}) h_1^q(x) H_{1,q}^\triangleleft(z, M_h^2, \cos\theta) \right)$$

$$\text{with } \Phi_{RS} = \Phi_R + \Phi_S - \pi$$

Where $h_1(x)$ is the Transversity PDF and $H_{1,q}^\triangleleft$ is the two-hadron Interference FF, which describes the Fragmentation of a transversely polarized quark into two unpolarized hadrons. $D_{1,q}^{2h}$ is the unpolarized two-hadron fragmentation function which is measured at *e.g.* BELLE.

Theoretical framework: asymmetries extraction

$$N_{2h}(x, y, z, M_h^2, \cos(\theta), \Phi_{RS}) \propto \sigma_{UU} (1 \pm f P_T D_{NN} A_{UT}^{\sin \Phi_{RS}} \sin \theta \sin \Phi_{RS})$$



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

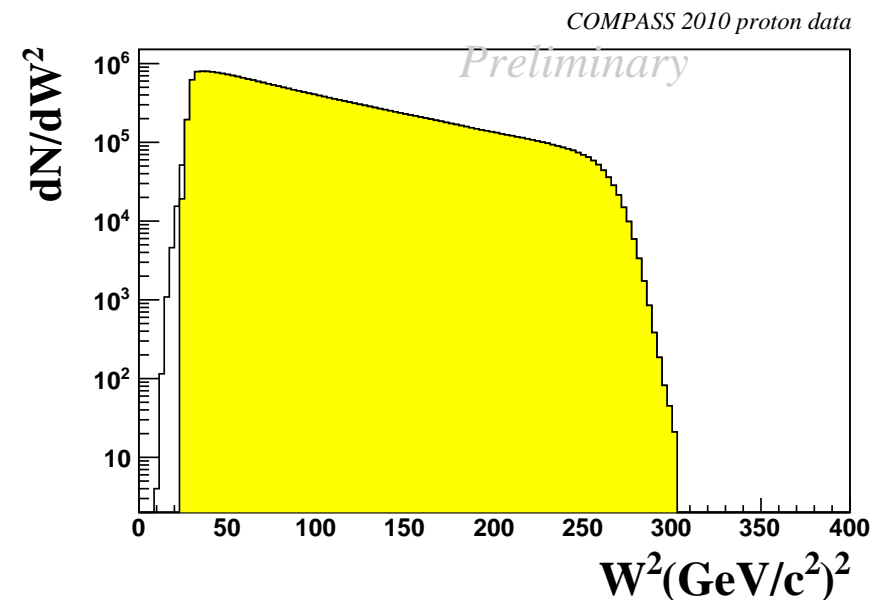
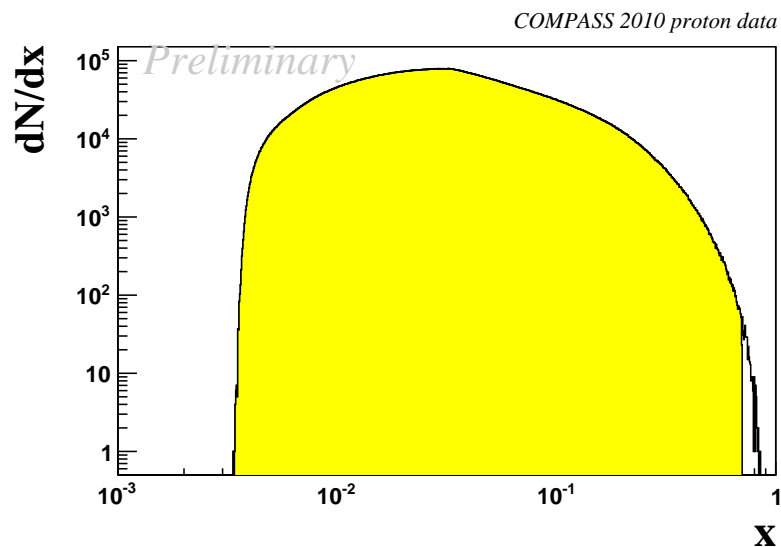
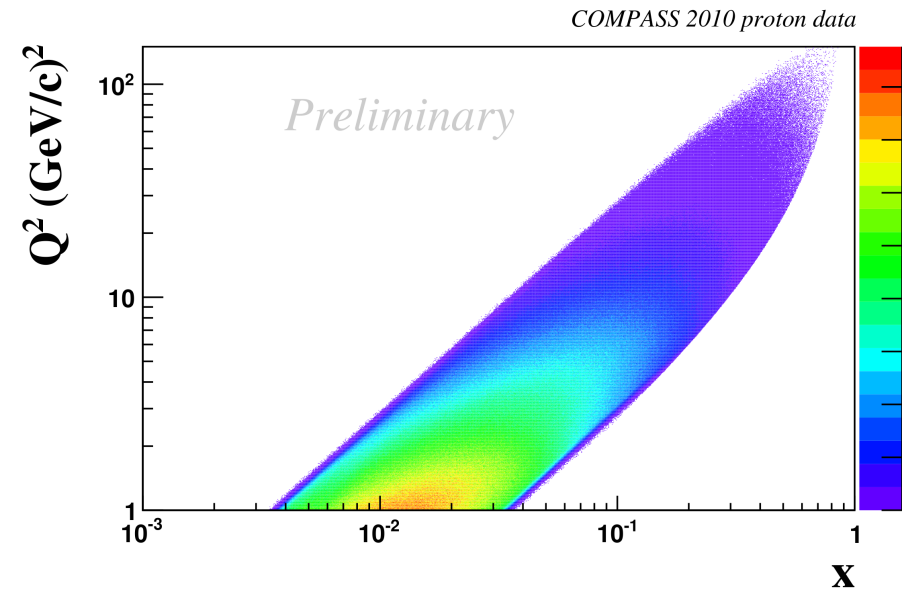
$\langle \sin \theta \rangle = 0.943$
 \Rightarrow can be neglected

$$A_{UT}^{\sin \Phi_{RS}} = \frac{|\mathbf{p}_1 - \mathbf{p}_2|}{2M_h} \frac{\sum_q e_q^2 \cdot h_1^q(x) \cdot H_{1,q}^{\leftarrow}(z, M_h^2, \cos \theta)}{\sum_q e_q^2 \cdot f_1^q(x) \cdot D_{1,q}^{2h}(z, M_h^2, \cos \theta)}$$

Data selection 2010: DIS cuts

DIS cuts are in common with single hadron analysis:

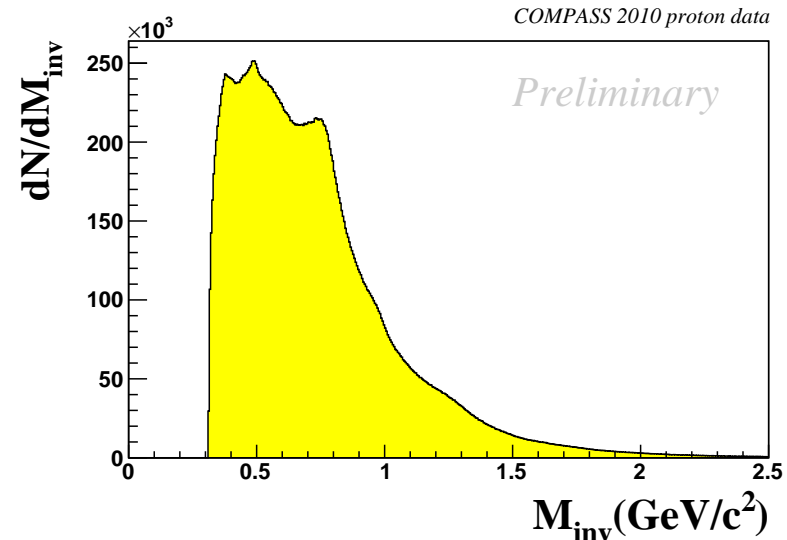
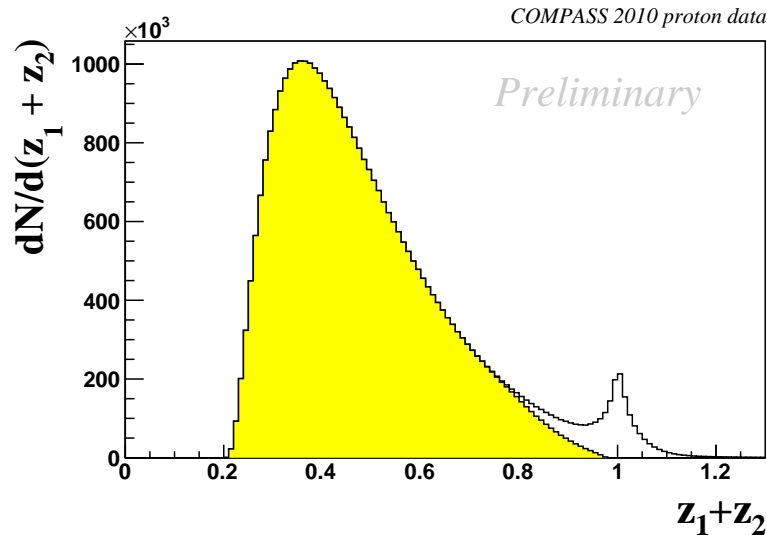
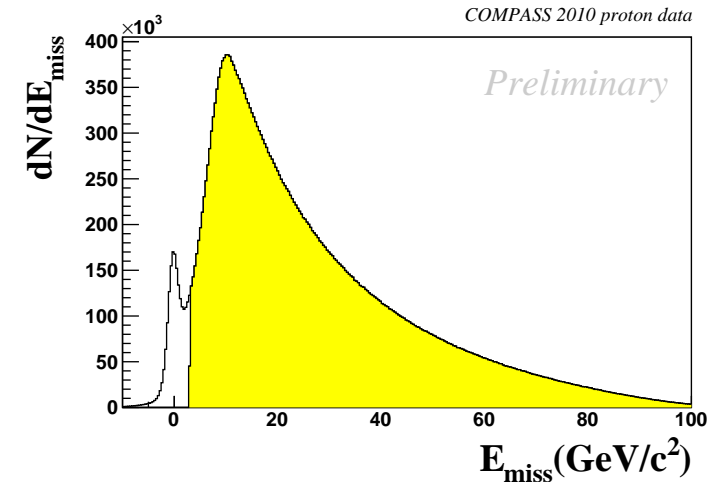
- $Q^2 > 1 \text{ (GeV/c)}^2$
 - $0.1 < y < 0.9$
 - $W > 5 \text{ GeV/c}^2$
-
- spectrometer acceptance:
 $0.003 < x_{bj} < 0.7$



Data selection 2010: hadron & pair cuts

Specific cuts for 2-hadron analysis:

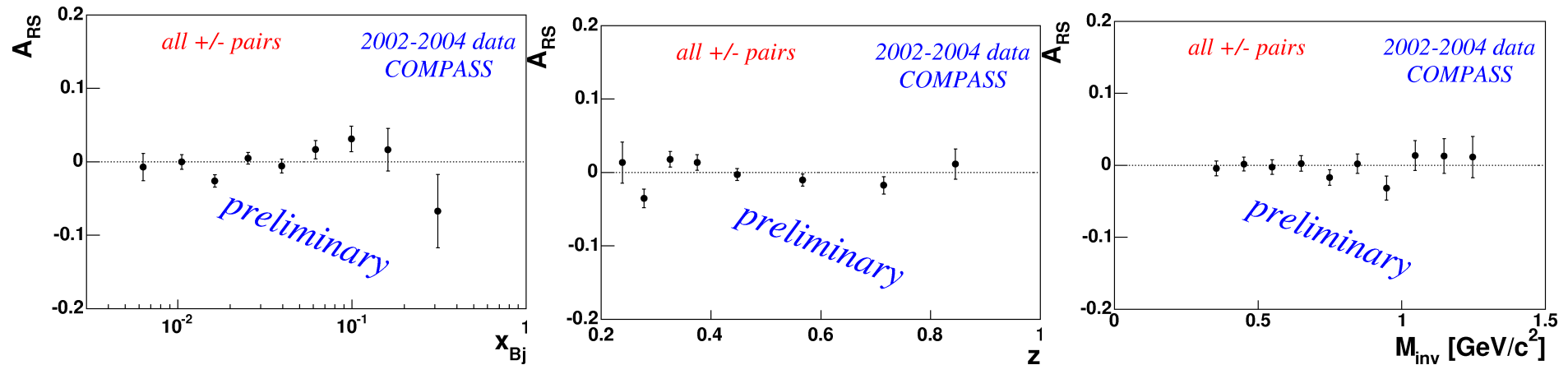
- Vertex with at least **3** outgoing tracks.
↪ All h^+h^- pair combinations are taken into account
- $z > 0.1$ for each hadron
- $x_F > 0.1$ for each hadron
- $E_{miss} > 3$ GeV for each pair
- $R_T > 0.07$ GeV/ c for each pair



two-hadron asymmetries:

deuteron data 2002-04

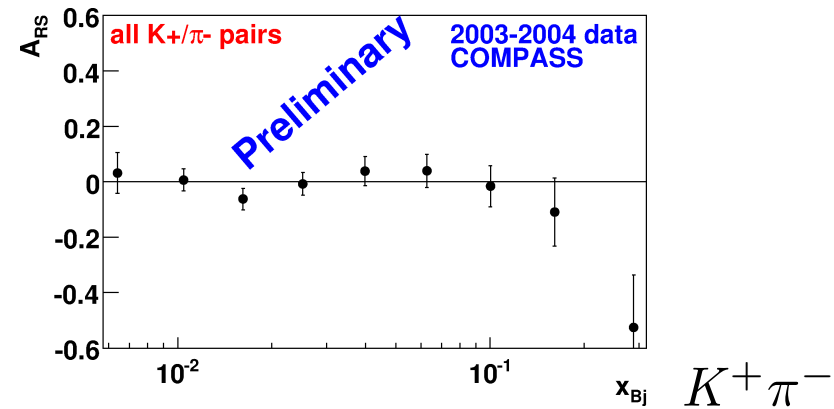
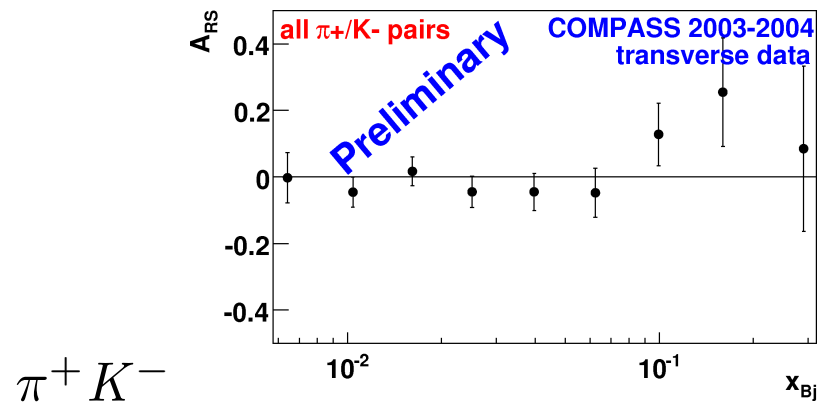
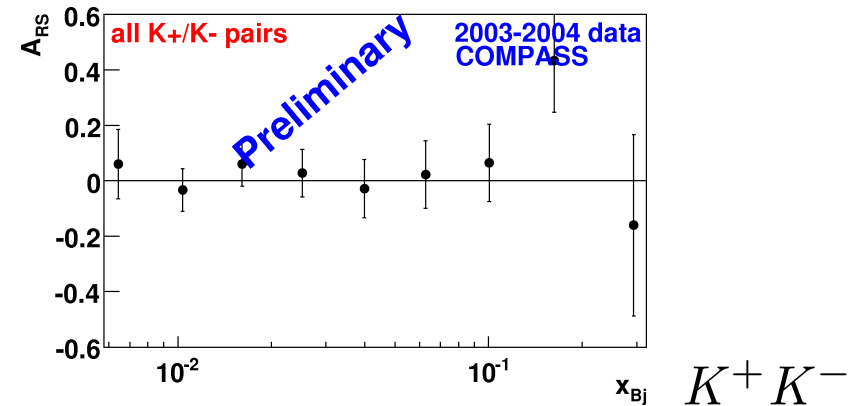
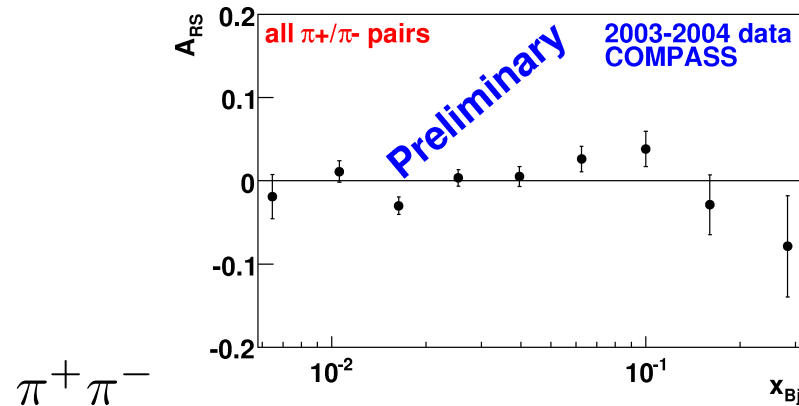
deuteron data 2002-04: all h^+h^- pairs



2002-04 deuteron data 2-hadron asymmetries of h^+h^- pairs:

↪ all asymmetries are small and compatible with zero

deuteron data 2002-04: identified pairs

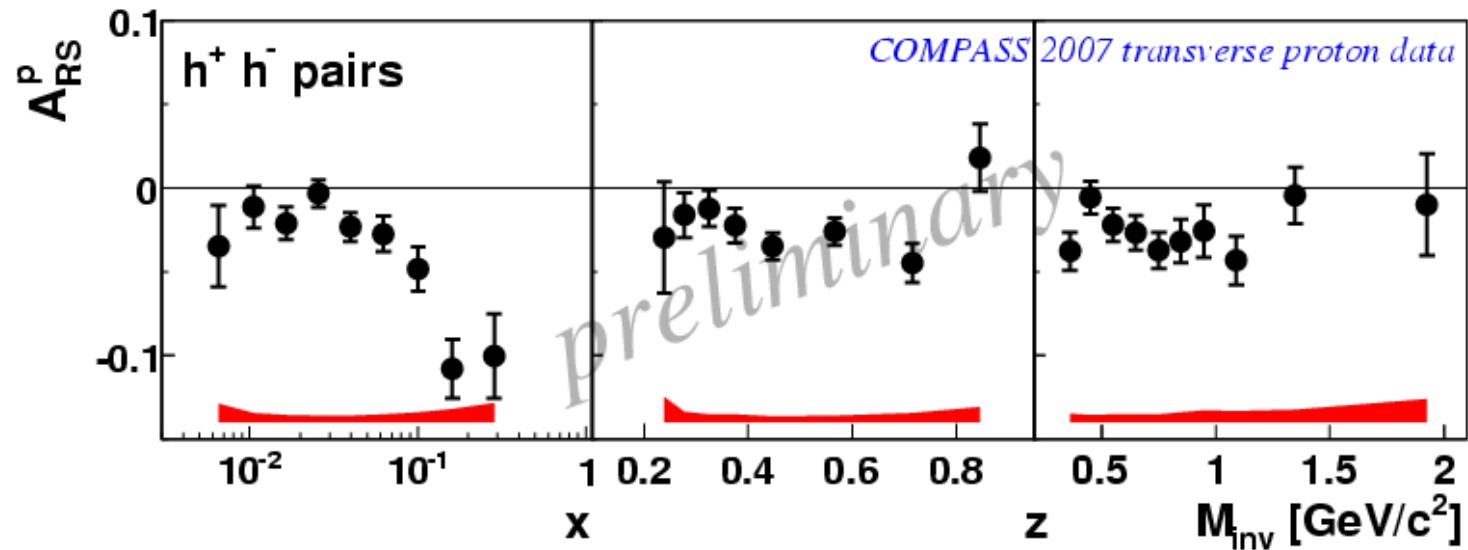


- ↪ signal is compatible with zero \forall pairs
- ↪ opposite signs of mean value in x_{bj} for $\pi^+ K^- / K^+ \pi^-$ pairs

two-hadron asymmetries:

proton data 2007

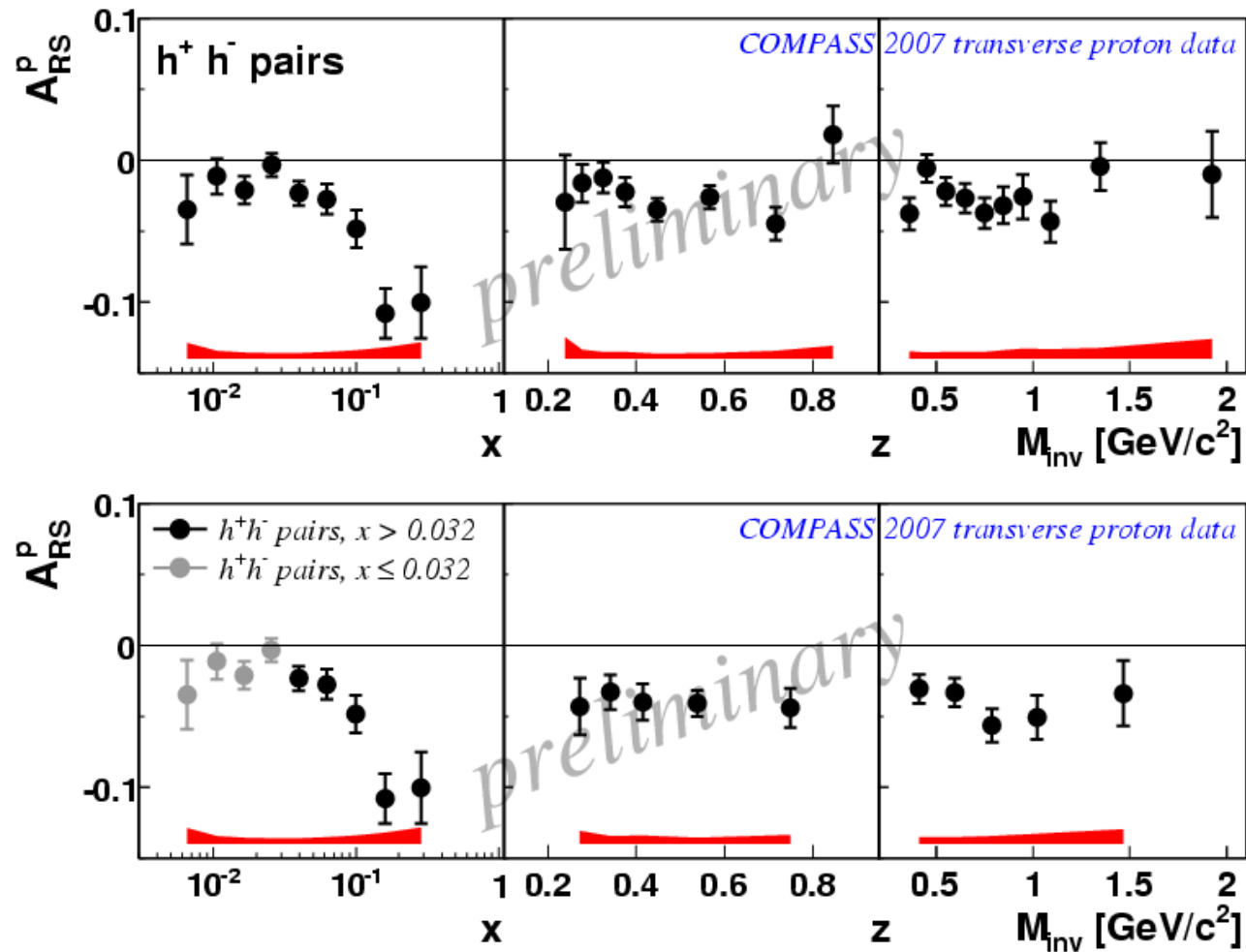
two-hadron asymmetries: proton data 2007



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

↪ Large asymmetries for proton up to 5 – 10%

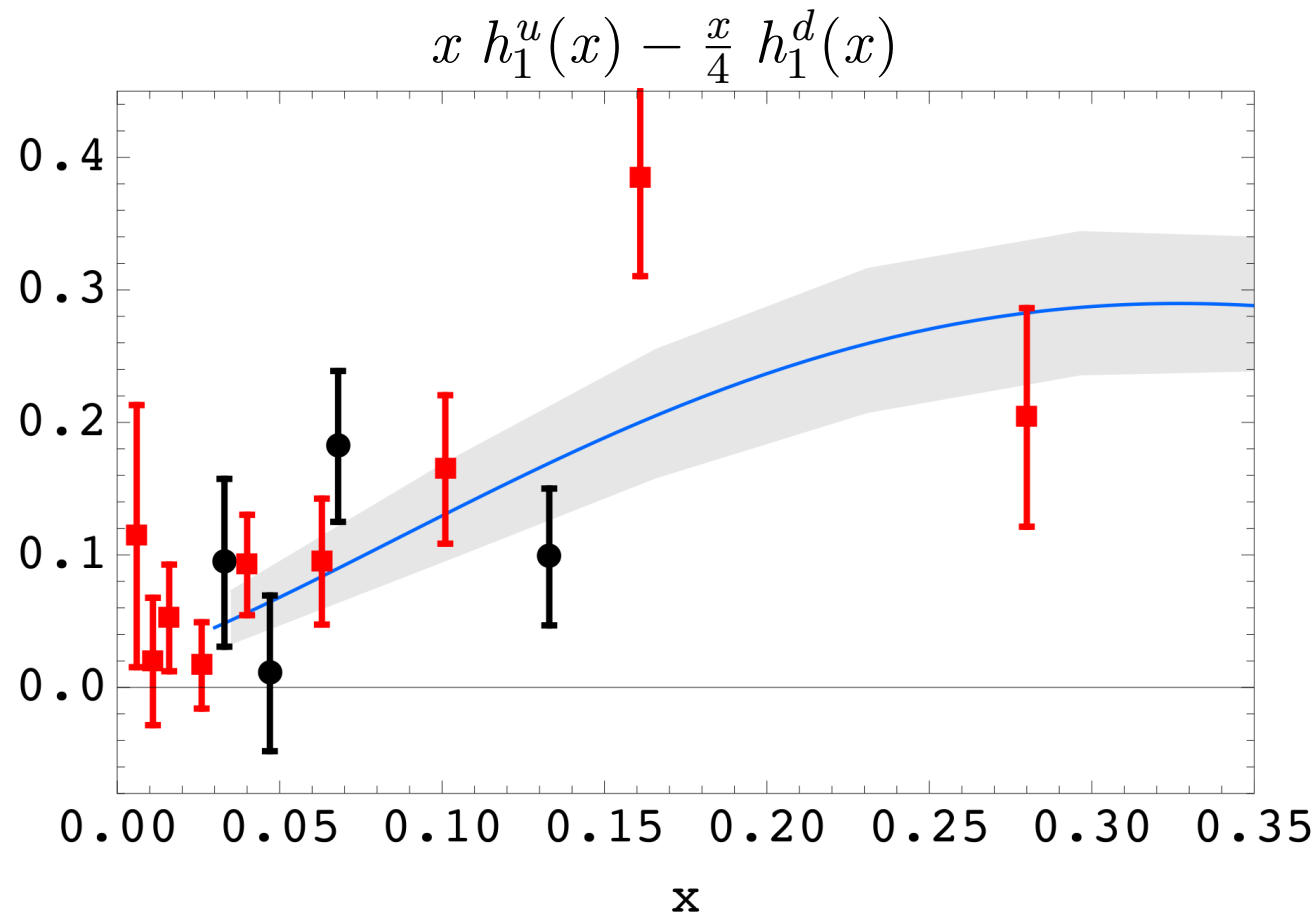
proton data 2007: $x > 0.032$ (valence region)



↪ Asymmetries in z and M_{inv} increase for $x_{bj} > 0.032$ sample

proton data 2007: 1st extraction of transversity in collinear framework via DiFF

Bachetta *et al.*, PRL **107** (11)



Combination of valence u , d flavors for the transversity distribution from:

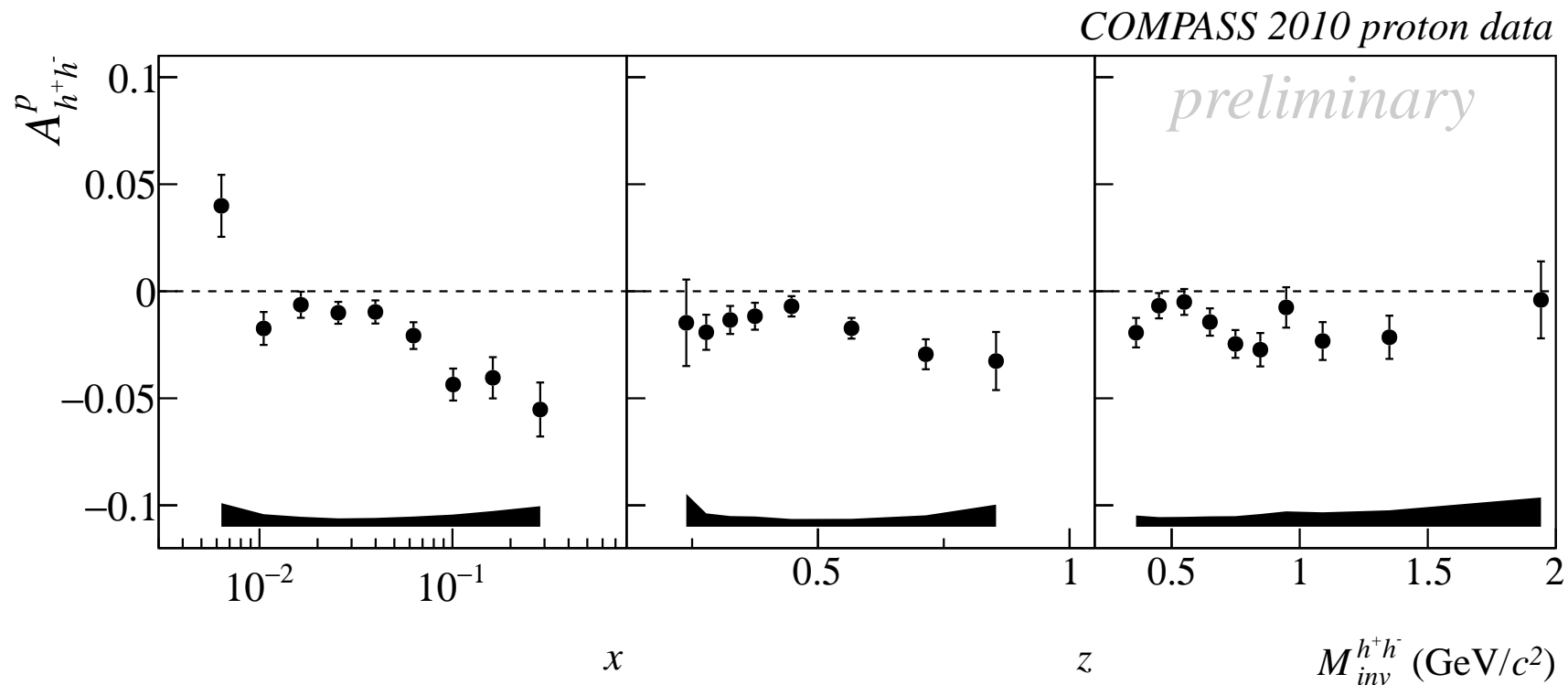
black:
HERMES Airapetian *et al.*, JHEP, **06** (2008) 017

red:
COMPASS Wollny *et al.*, arXiv:0907.0961

two-hadron asymmetries:

proton data 2010

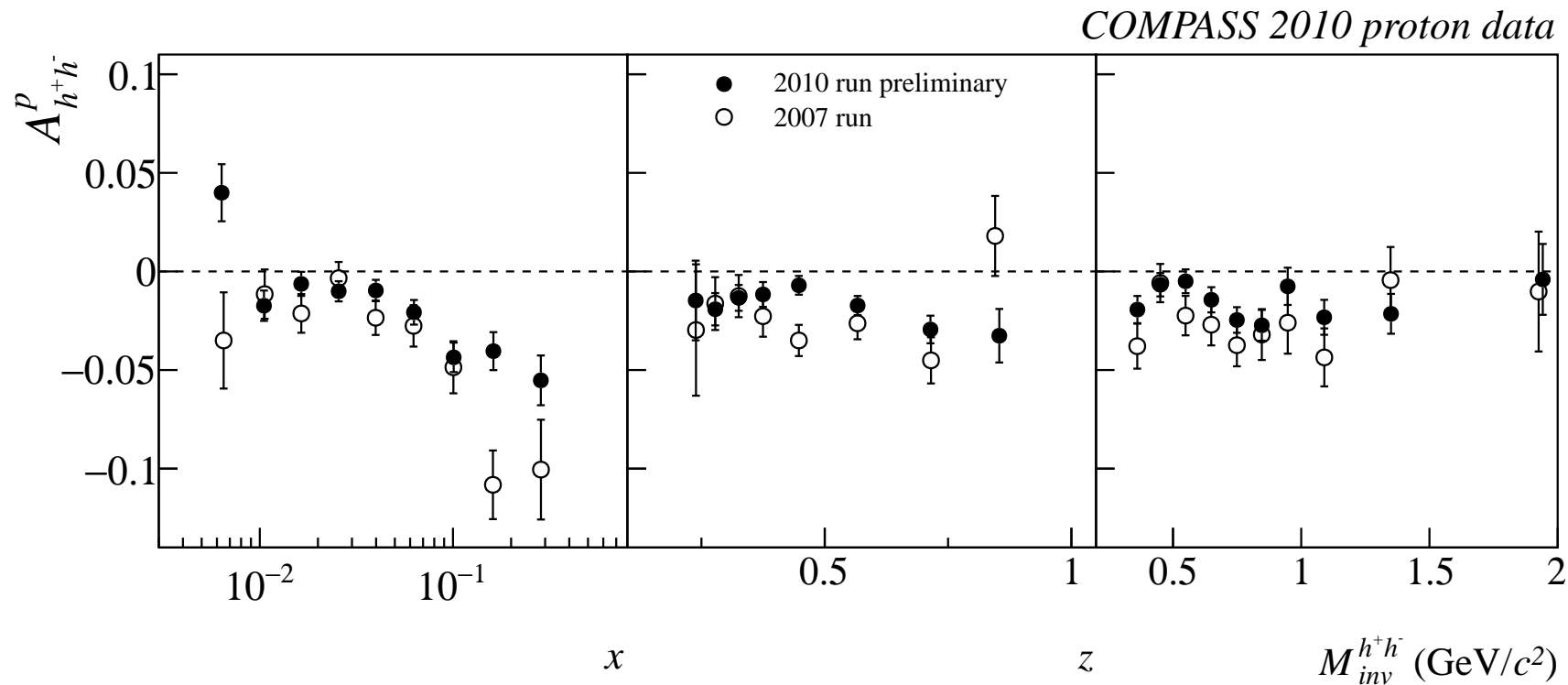
two-hadron asymmetries: proton data 2010



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

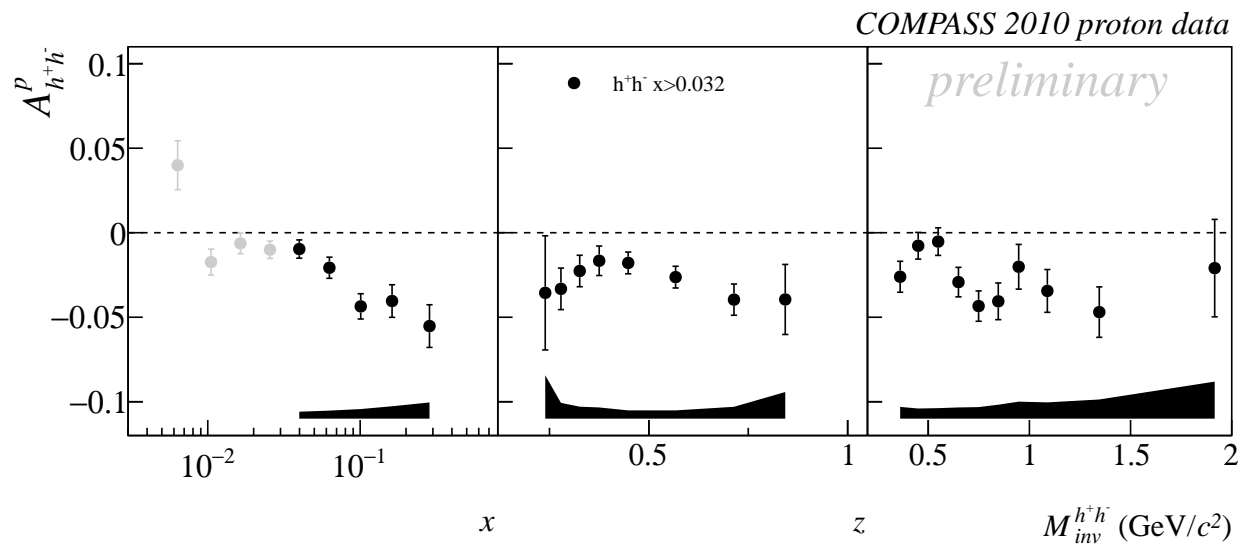
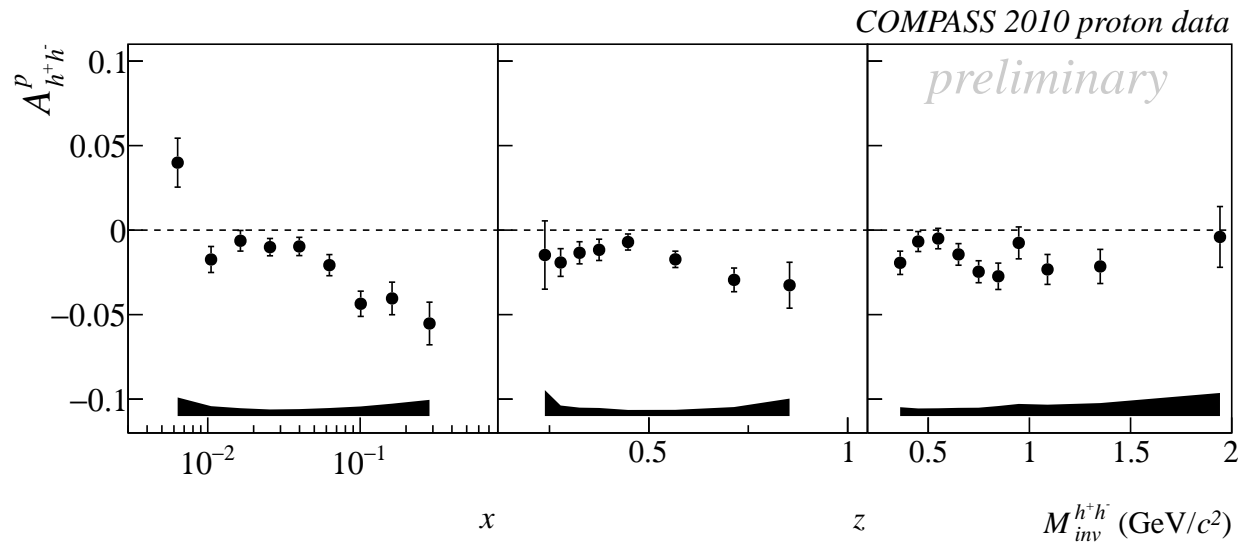
↪ Clear asymmetries for proton target with improved errors

two-hadron asymmetries: comparison 2010 and 2007 proton data



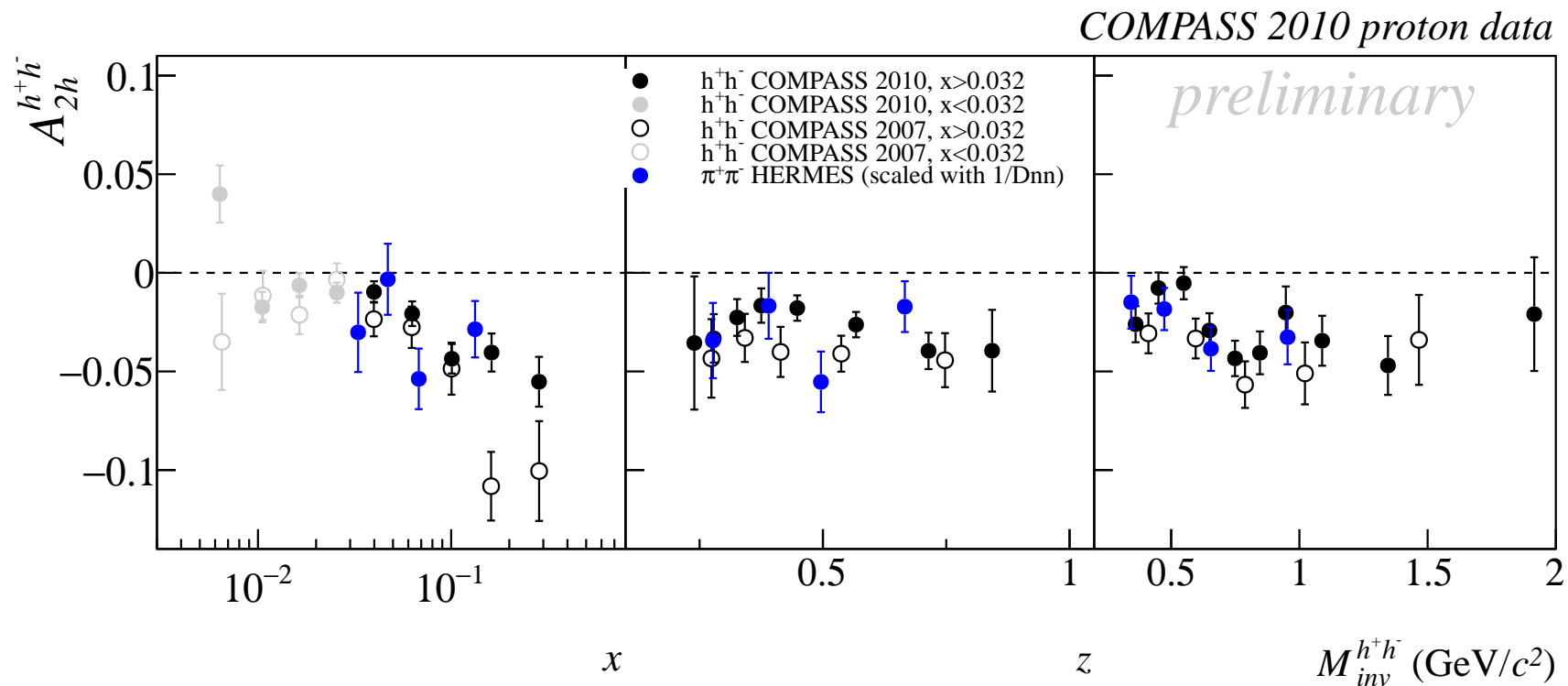
↪ Good agreement between 2007 and 2010 results within the error bars. Factor of gain in statistical err. ~ 1.7 & $\sigma_{sys}/\sigma_{stat} = 0.8$

two-hadron asymmetries: proton data 2010 $x_{bj} > 0.032$



↪ Asymmetries in z and M_{inv} increase for $x > 0.032$ sample

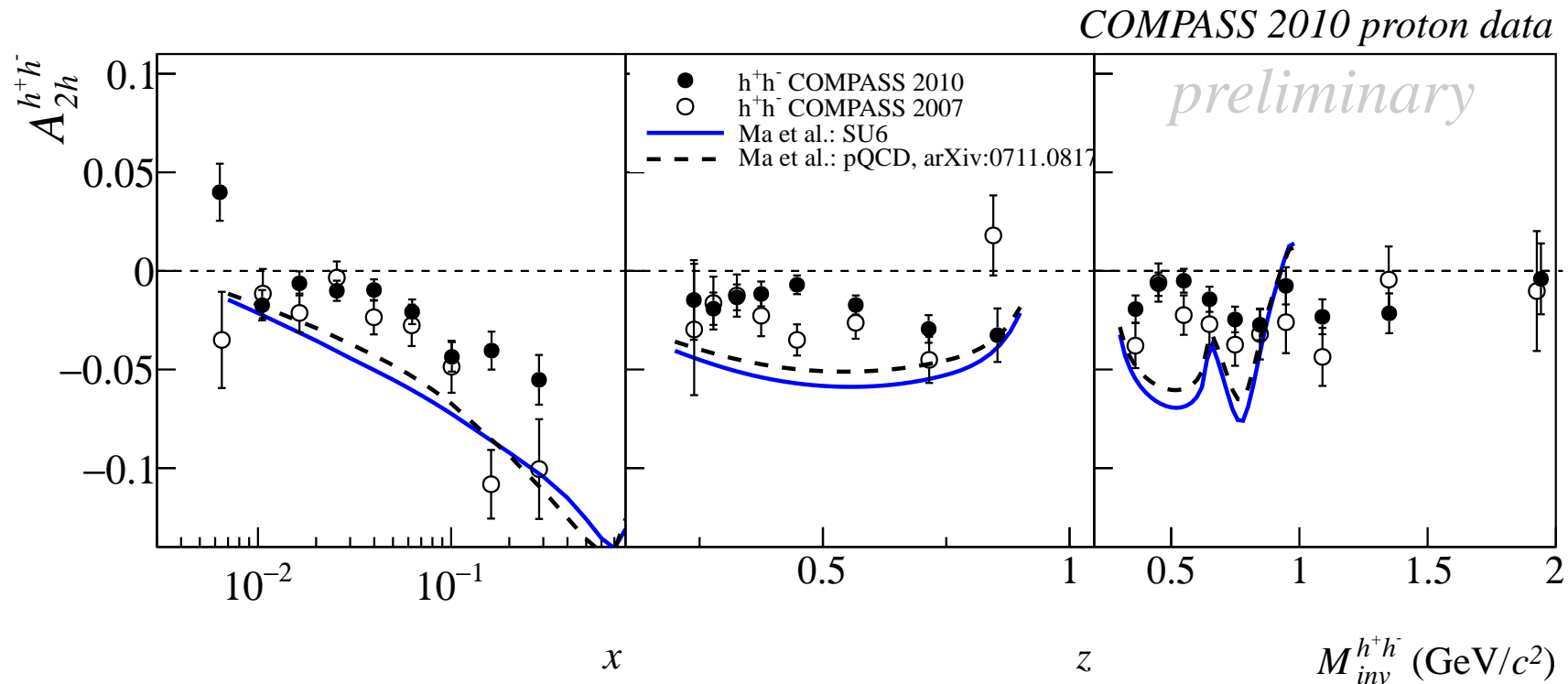
Comparison with results from HERMES



Airapetian *et. al.*, JHEP, **06** (2008) 017 scaled with $\frac{1}{D_{nn}}$

↪ Good agreement with HERMES data within the error bars

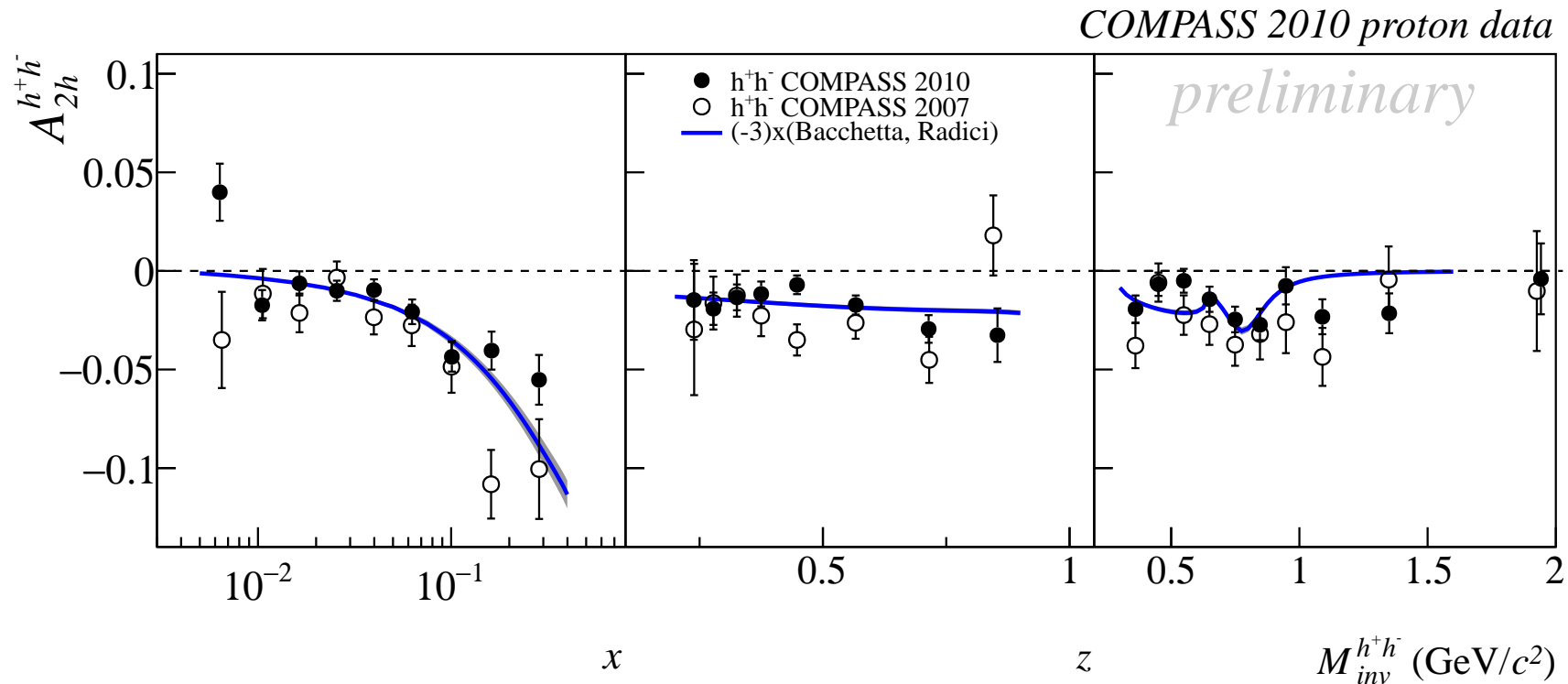
2010 proton data comparison with model predictions



Ma *et al.*, arXiv:0711.0817

- ↪ trend in x confirmed
- ↪ rather agreement for z and M_{inv}

2010 proton data comparison with model predictions



Bacchetta *et al.*, hep-ph/0608037

- ↪ good agreement for x and z
- ↪ ρ_0 signal in M_{inv} confirmed

Conclusions & Outlook

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

↪ paper to be published soon

- **NEWS:** preliminary results for 2010 COMPASS proton data available:
 - 1 Extensive **new** data
 - 2 Small statistical and systematic uncertainty
 - 3 Strong improvement with 2010 data
 - 4 Agreement of independent COMPASS 2010 and 2007 proton measurements within the error bars
 - 5 COMPASS data, with it's higher precision, is in agreement with HERMES data
 - 6 Reasonable agreement with model predictions of Bacchetta & Ma

Outlook:

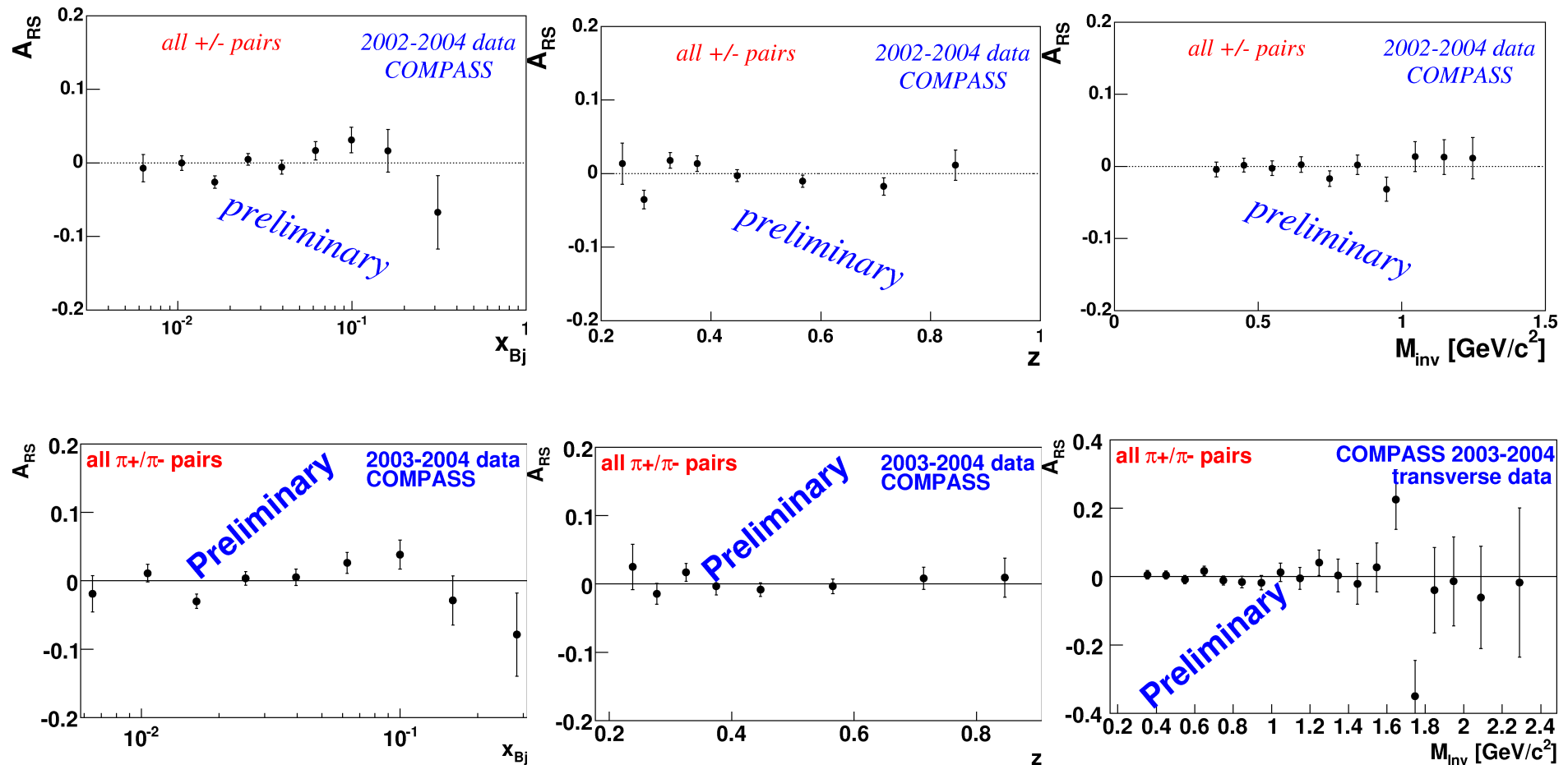
- Asymmetries for identified hadron pairs:
 $\pi^+ \pi^-, K^+ K^-, \pi^+ K^-, K^+ \pi^-$

Thank you for your attention!

electronic address: `christopher.braun@cern.ch`

Back Up

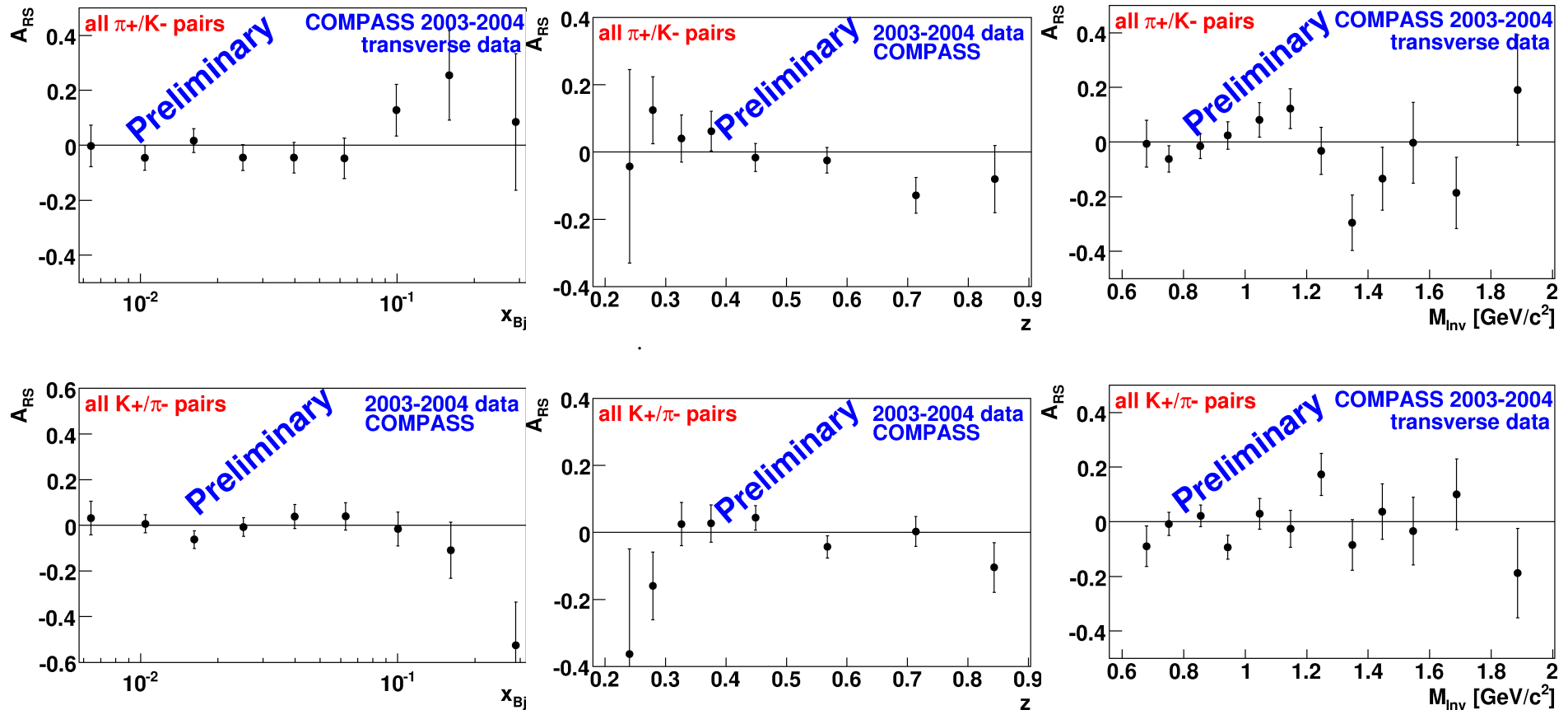
deuteron data 2002-04: $\pi^+\pi^-$ pairs



2002-04 deuteron data 2-hadron asymmetries: all h^+h^- pairs (top), $\pi^+\pi^-$ pairs (bottom)

↪ signal determines most of the h^+h^- asymmetries

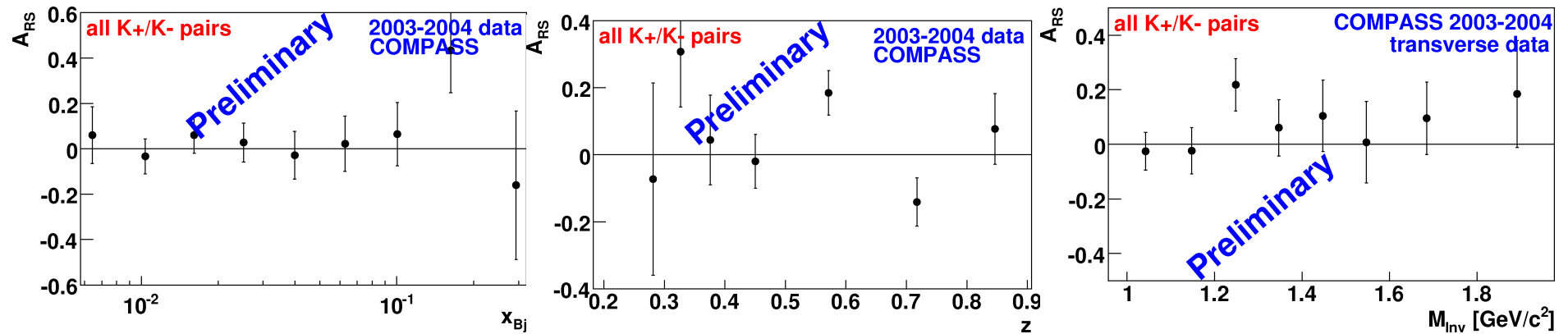
deuteron data 2002-04: $\pi^+ K^-$ & $K^+ \pi^-$ pairs



2002-04 deuteron data 2-hadron asymmetries: all $\pi^+ K^-$ pairs (top), $K^+ \pi^-$ pairs (bottom)

$\hookrightarrow \pi^+ K^-$ & $K^+ \pi^-$ signal compatible with zero
 \hookrightarrow opposite signs of mean values in x_{bj}

deuteron data 2002-04: $K^+ K^-$ pairs

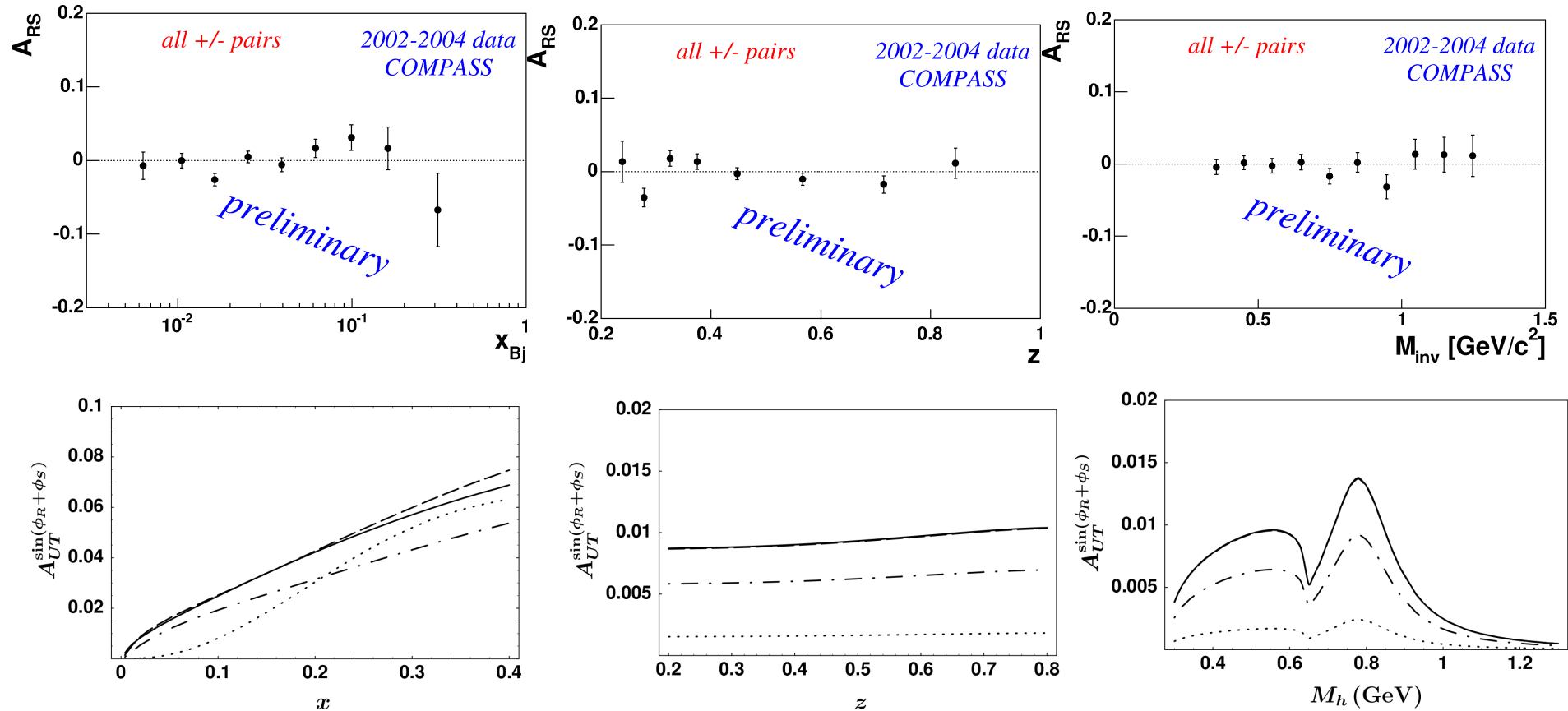


2002-04 deuteron data 2-hadron asymmetries: $K^+ K^-$ pairs

↪ $K^+ K^-$ no signal & low statistics

deuteron data 2002-04: comparison with model predictions

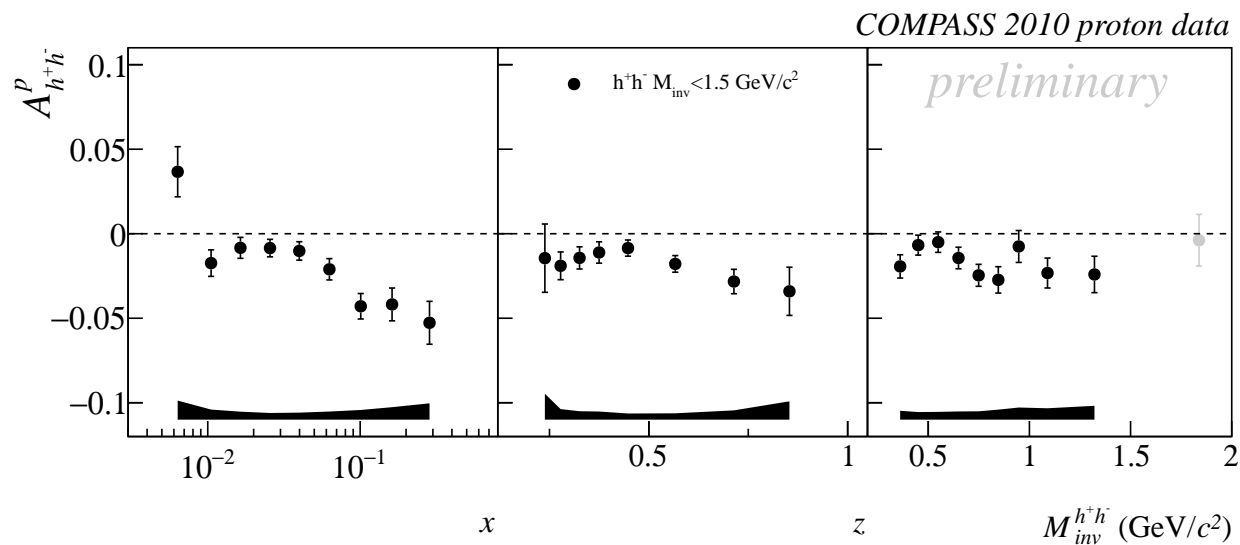
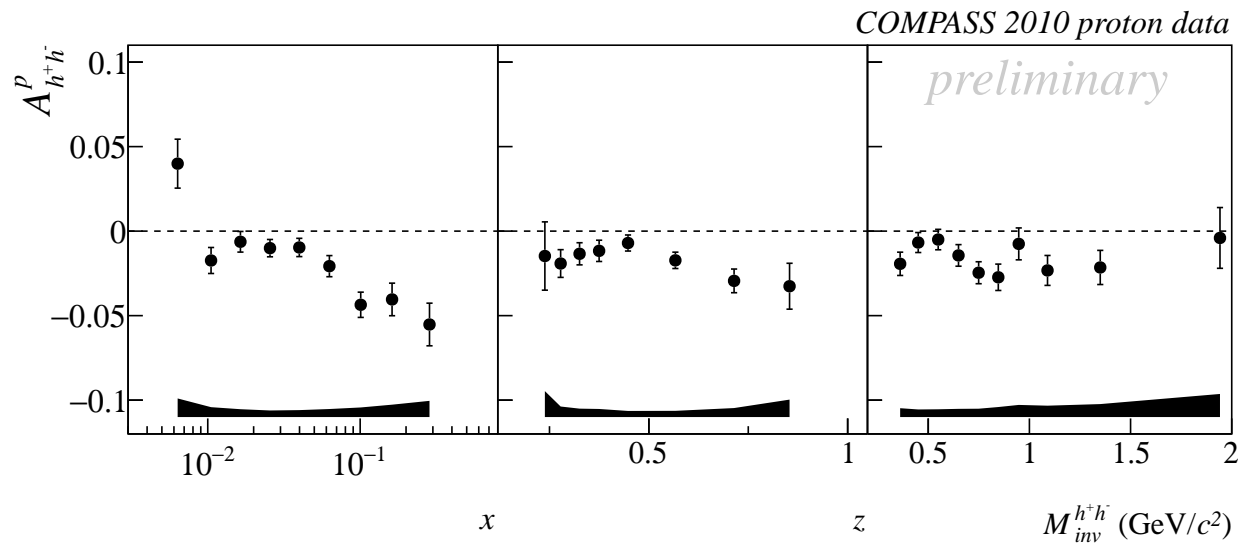
Bacchetta *et. al.* hep-ph/0708037



Different lines correspond to different models of $h_1(x)$.
 Different definition of Φ_S w.r.t. COMPASS

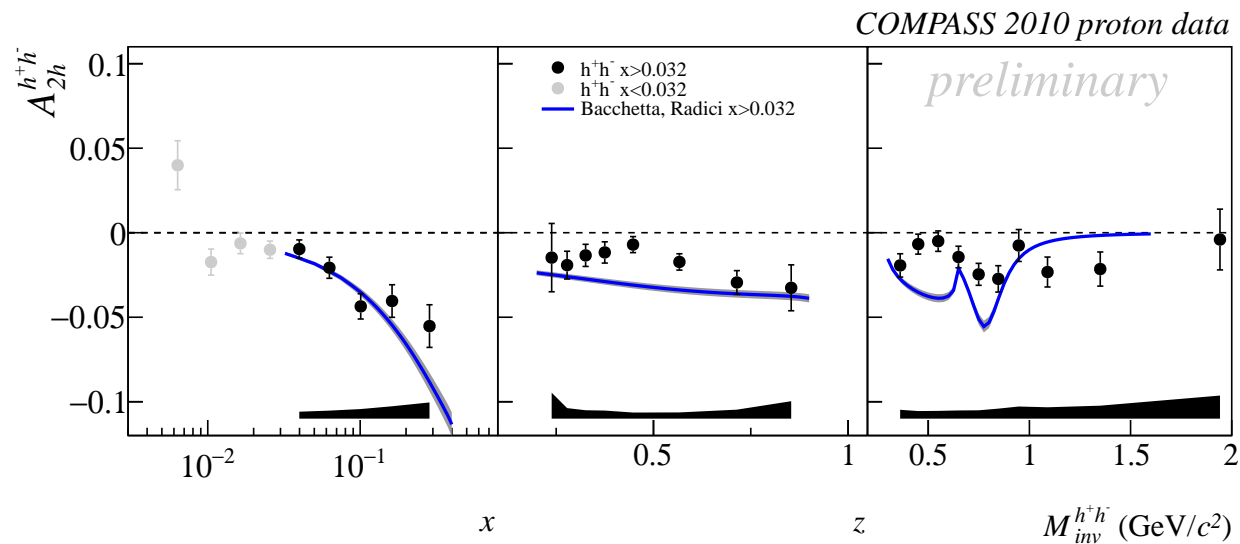
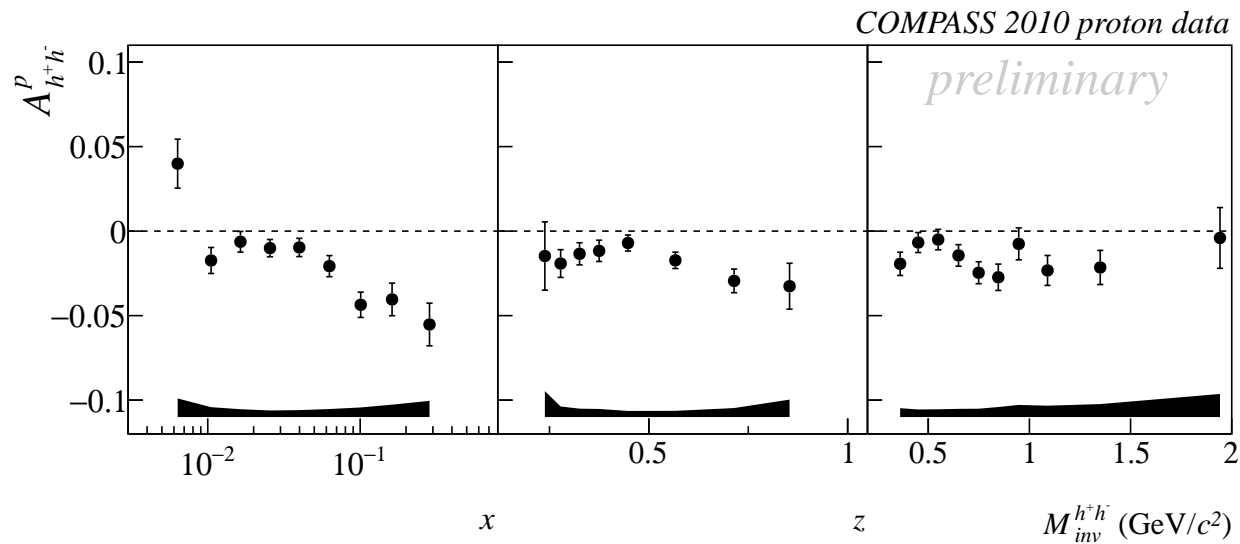
↪ Rather agreement with model predictions

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



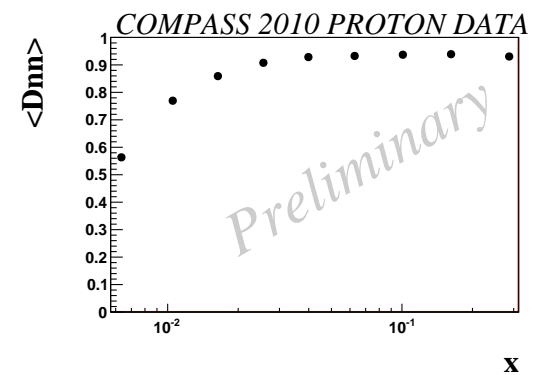
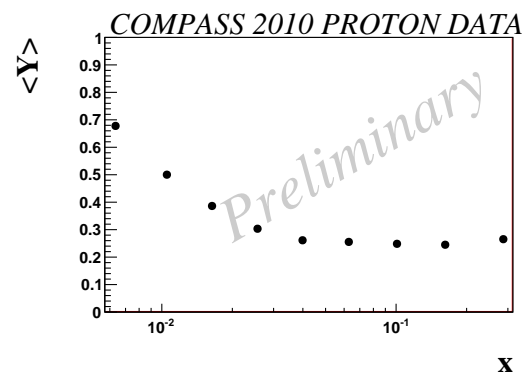
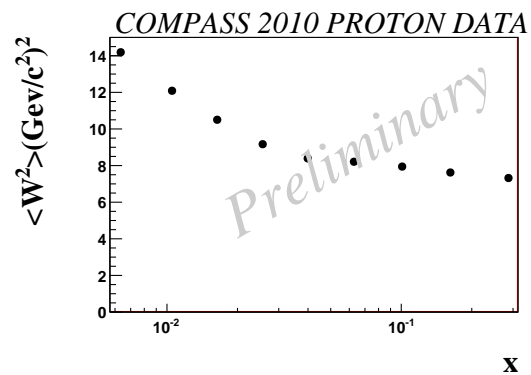
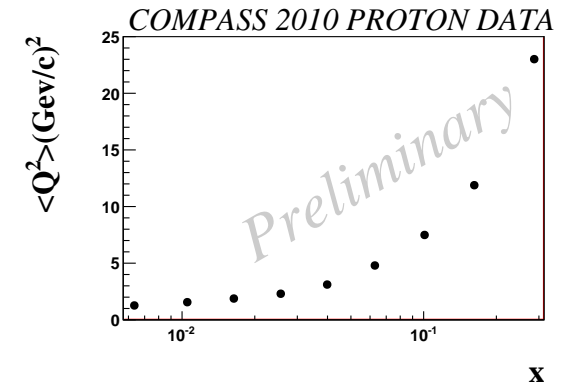
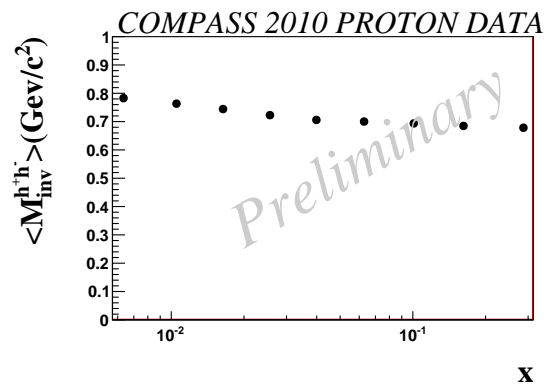
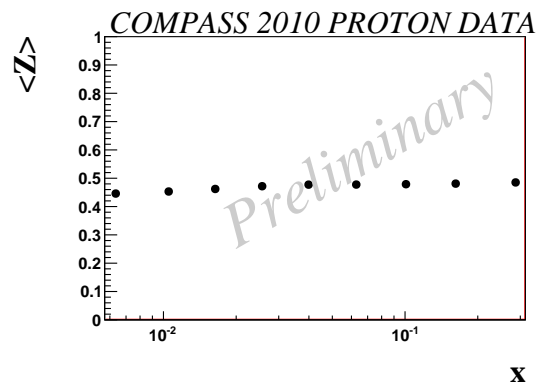
↪ No change in the asymmetries for $M_{inv} < 1.5 \text{ GeV}/c^2$

2010 proton data comp. with Bacchetta et al. $x_{bj} > 0.032$

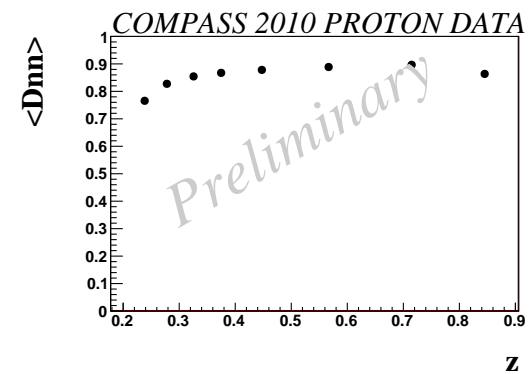
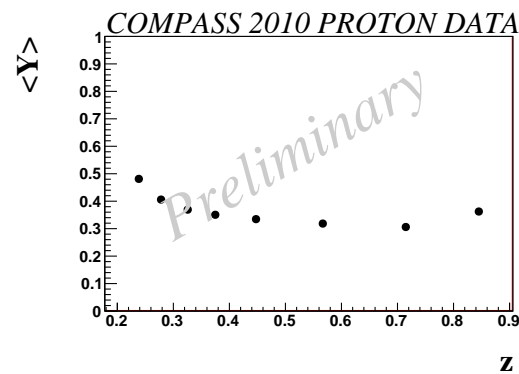
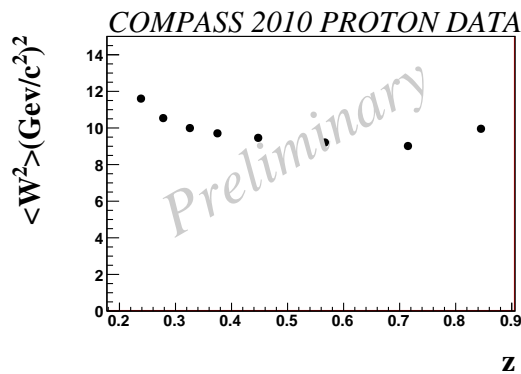
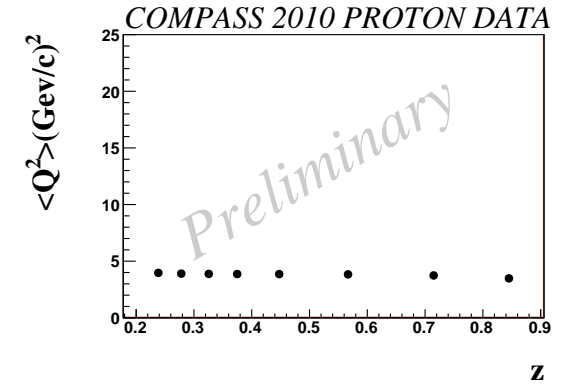
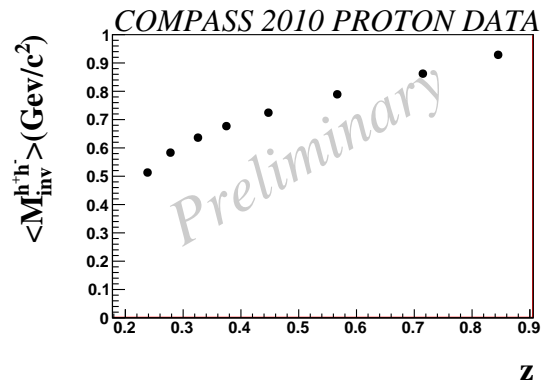
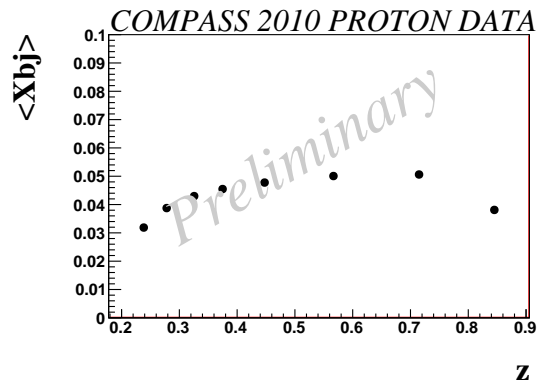


↪ data and model prediction increase for $x > 0.032$

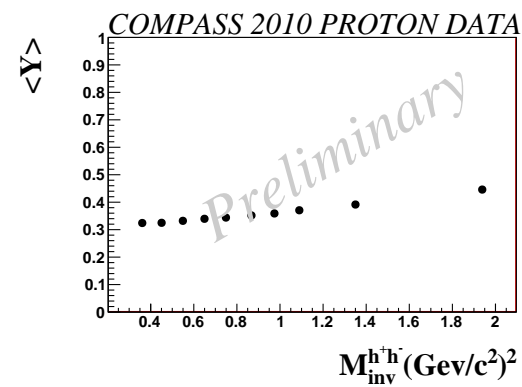
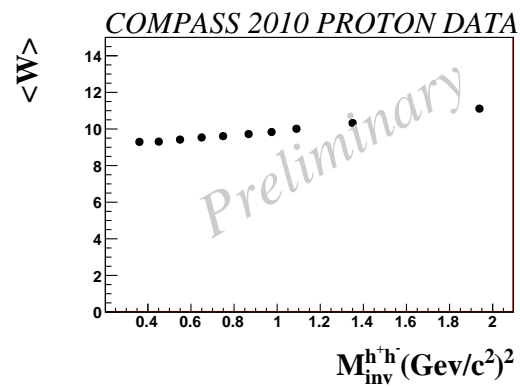
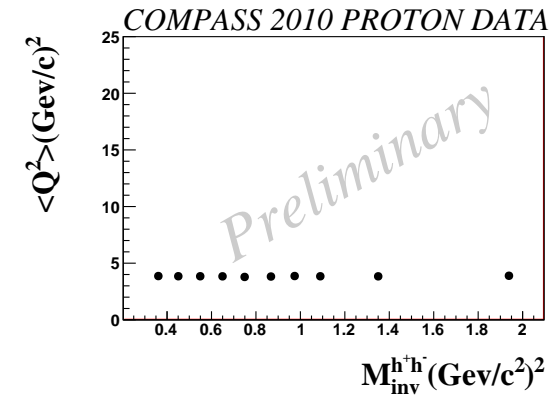
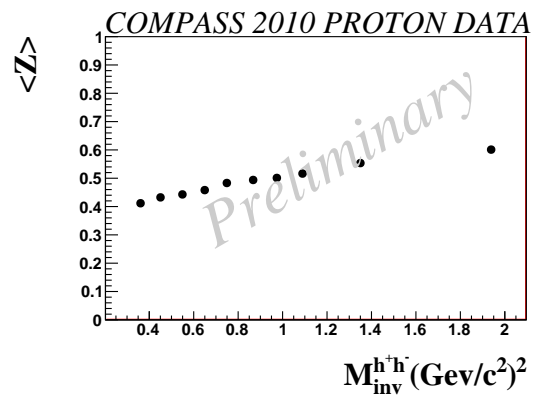
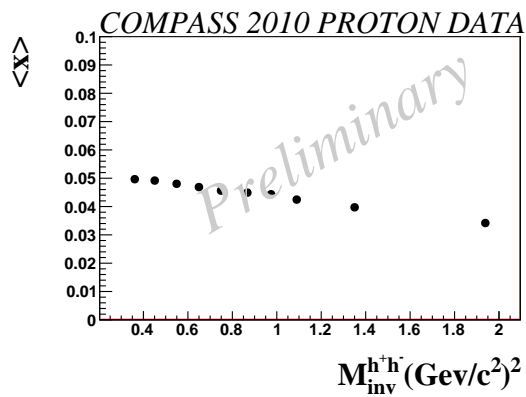
2010 proton data: kinematic mean values in x_{bj}



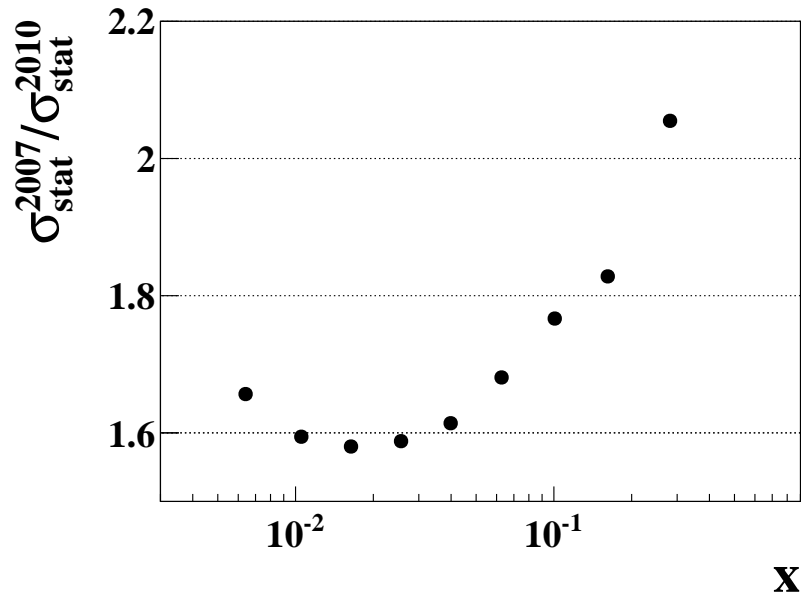
2010 proton data: kinematic mean values in x_{bj}



2010 proton data: kinematic mean values in x_{bj}



Comparison of statistical errors 2007/2010



The ratio between the statistical error of 2007 on 2010 analysis, as a function of x bins. The overall gain is around a factor of 1.7

deuteron data: data Selection

- μ' -recovery is used as a veto
- Wrong combinations of ECAL1, HCAL1 and HCAL2 clusters (ECAL2)
- 2002-04:
 - ▶ HCAL1: $P_{had} > 4.0 \text{ GeV}/c$ && $E_{hcal1} < 0.3 \cdot P_{had}$
 - ▶ HCAL2: $E_{hcal2} < 0.24 \cdot P_{had} + 1 \text{ GeV}$
- 2007:
 - ▶ HCAL1: $P_{had} > 5.0 \text{ GeV}/c$ && $E_{hcal1} < 0.2 \cdot P_{had}$
 - ▶ HCAL2: $E_{hcal2} < 0.25 \cdot P_{had}$
- 2010: no calorimeter cuts

Comparison of systematic errors 2002-04/2007/2010

	2002-2004	2007	2010
	$\sigma_{sys}/\sigma_{stat}$	$\sigma_{sys}/\sigma_{stat}$	$\sigma_{sys}/\sigma_{stat}$
estimator	0.04	0.04	0.15
false asymmetrie	0.32	0.66	0.71
left/right and top/bottom	0.84	0.75	0.77
target ploarization	5.4%	2.2%	5.0%
total	0.90	1.00	0.76