

COMPASS results on transverse spin asymmetries in identified two-hadron production in SIDIS

Christopher Braun¹

on behalf of the **COMPASS** collaboration

¹Physikalisches Institut IV der Universität Erlangen-Nürnberg

The 20th INTERNATIONAL SYMPOSIUM on Spin Physics,
September 18th 2012, JINR, Dubna, Russia



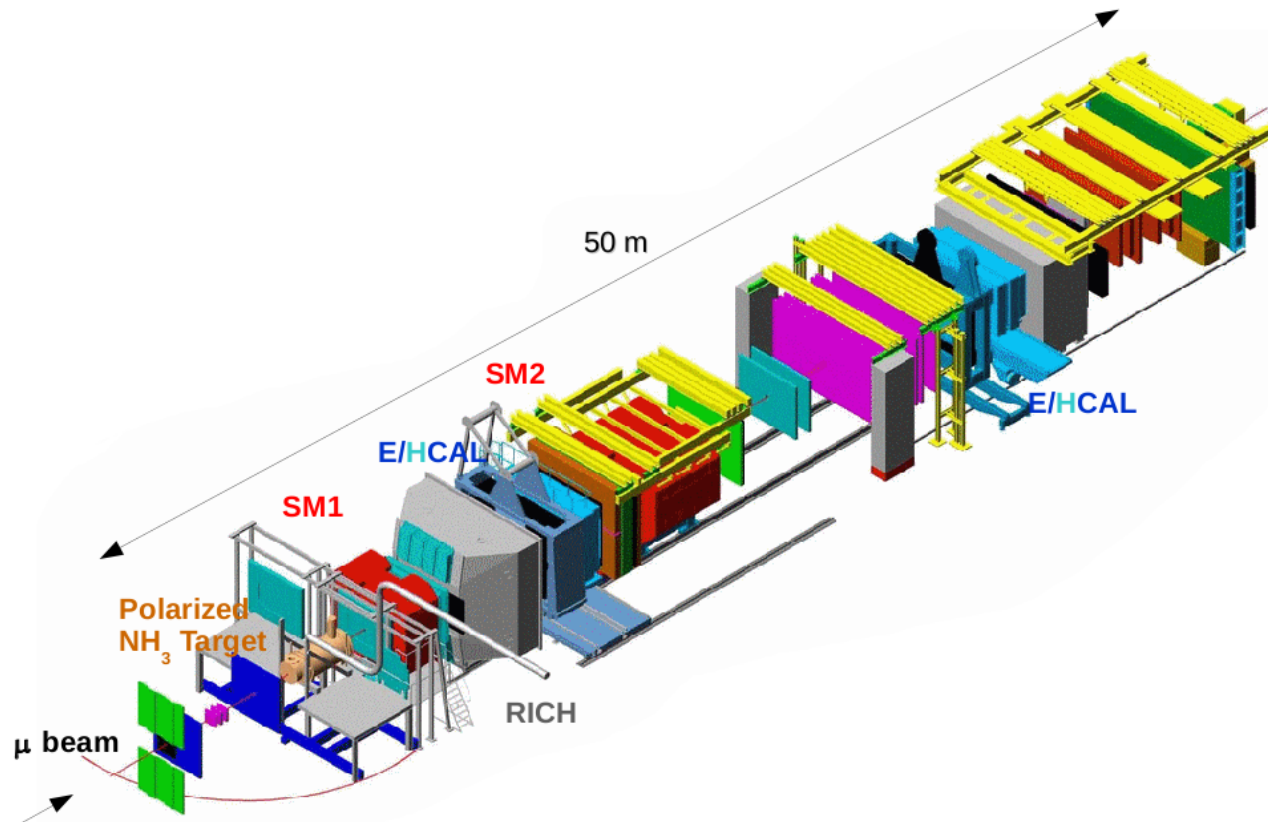
Outline

- 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.

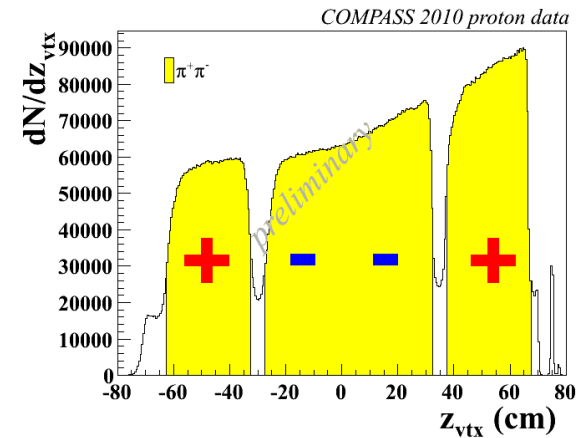
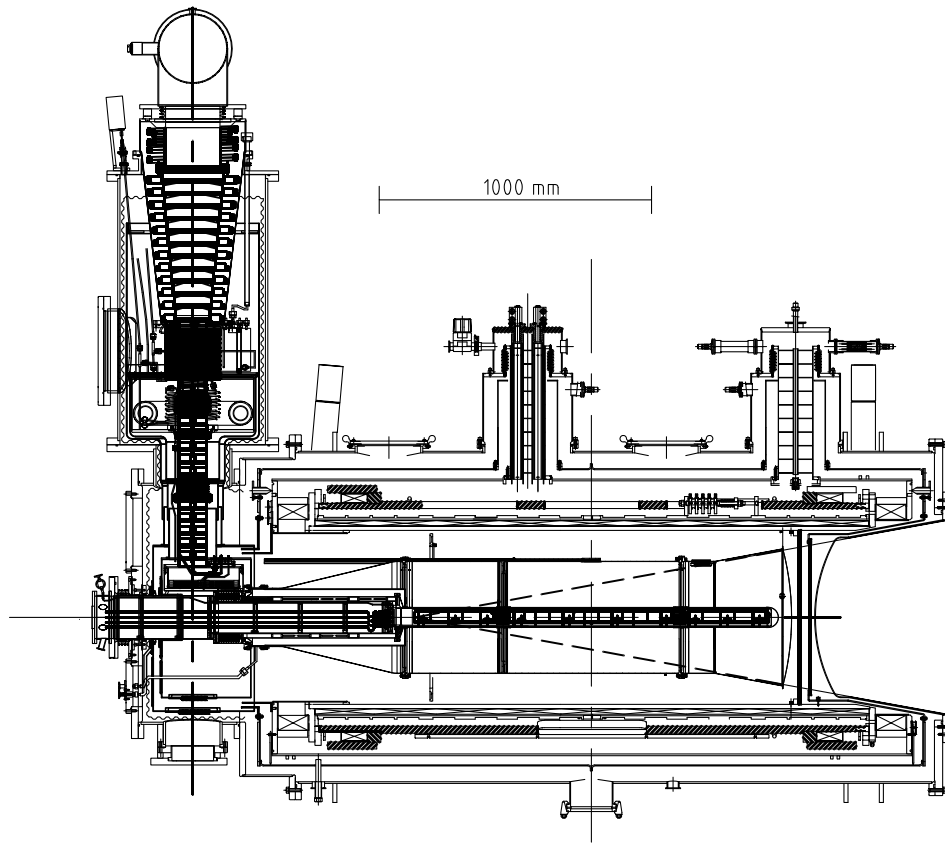
COMPASS setup 2007

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

- Two stage spectrometer
- Longitudinally polarized μ^+ -beam
- 2002 & '04 transversely polarized deuterium (^6LiD) target
- '07, '10 & '11 transversely polarized proton (NH_3) target

- Tracking
- Calorimetry
- PID (RICH)

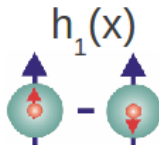
The COMPASS target system



- Upgrade of target system in 2005
 - Three cells with opposite polarization
 - ± 180 mrad geometrical acceptance
 - Transverse polarization reversed every week via microwave
- deuteron ^6LiD :
 - ▶ polarization $\approx 47\%$
 - ▶ 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 in the collinear case:

		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 FF¹ $lN^\uparrow \rightarrow l'hX$

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

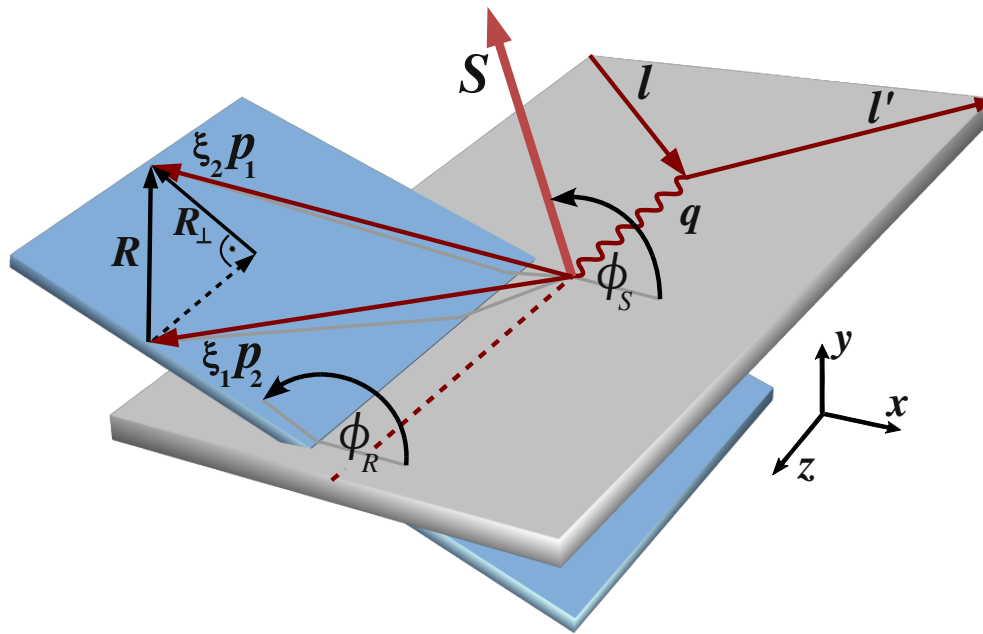
FF of $q^\uparrow \rightarrow \Lambda$ $lN^\uparrow \rightarrow l'\Lambda X$

¹ see Anna Martin's talk

Theoretical framework: angle definitions

$$lp^\uparrow \rightarrow l'h_1h_2$$

Fragmentation of transversely polarized quark into two unpolarized hadrons



in courtesy of H. Wollny

- 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
- $z_i = \frac{\mathbf{p}_i \cdot \mathbf{q}}{q^2}$
- $\mathbf{R} = \frac{z_2 \mathbf{p}_1 - z_1 \mathbf{p}_2}{z_1 + z_2} = \xi_2 \mathbf{p}_1 - \xi_1 \mathbf{p}_2$
- $\mathbf{R}_T$ is the component of $\mathbf{R}$ perpendicular to $\mathbf{q}$
- Azimuthal angle of $\mathbf{R}$:

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

Theoretical framework: two-hadron cross section

The differential two-hadron cross section is:

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

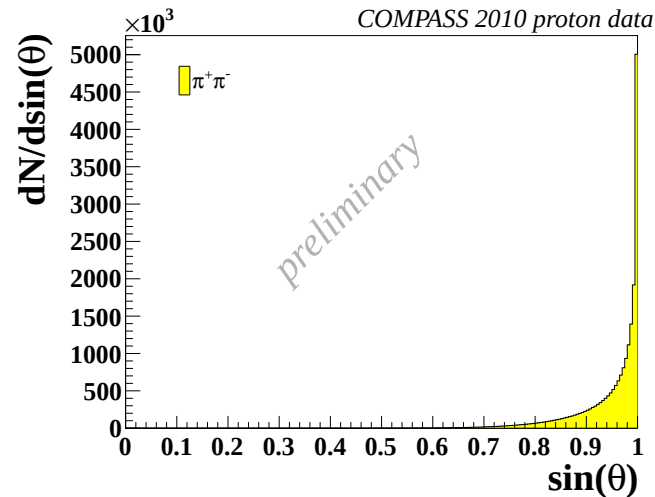
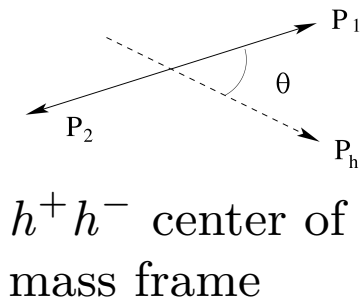
$$\text{with } \Phi_{RS} = \Phi_R + \Phi_S - \pi$$

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. $D_{1,q}$ is the unpolarized two-hadron fragmentation function².

² see Nour Makke's talk on hadron multiplicities

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.

$$D_{NN} = \frac{1-y}{1-y+\frac{y^2}{2}}$$

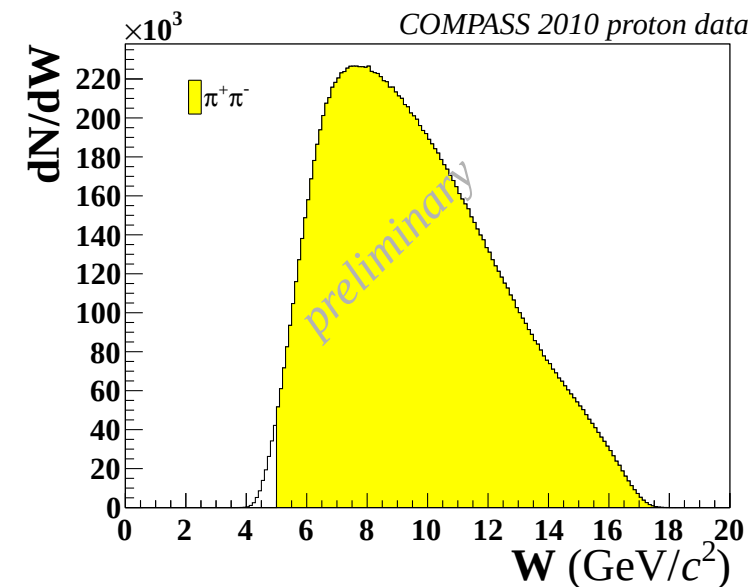
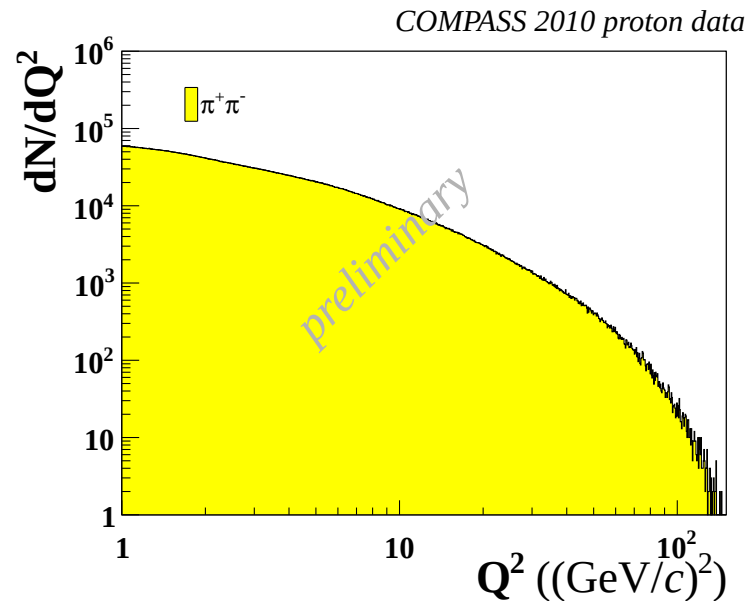
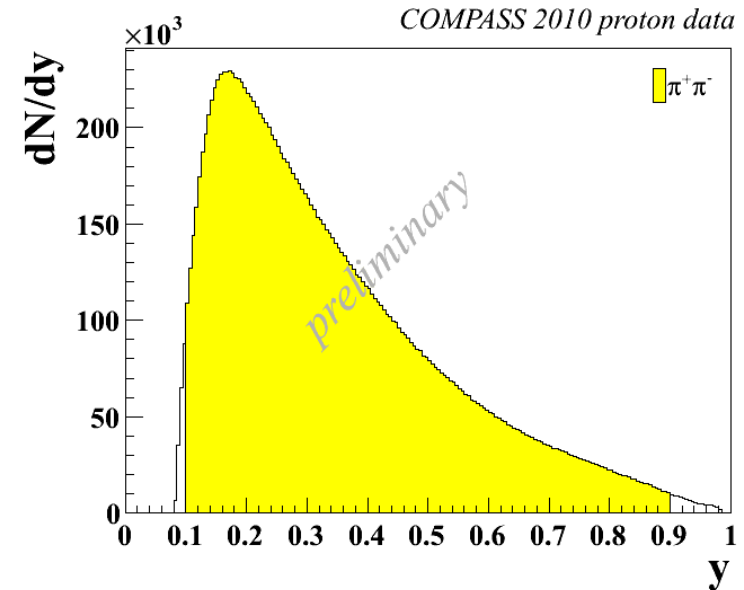
$\langle \sin \theta \rangle = 0.943$
 $\Rightarrow$ can be neglected

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

Data selection 2010: DIS cuts

DIS cuts on events:

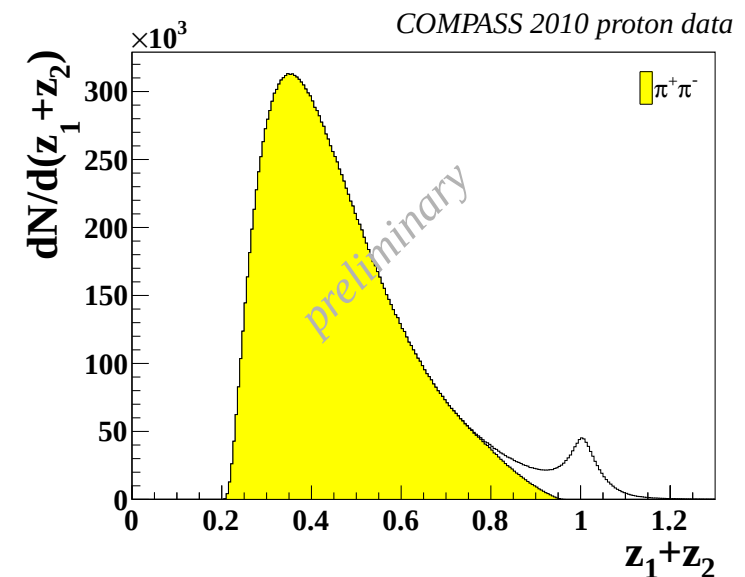
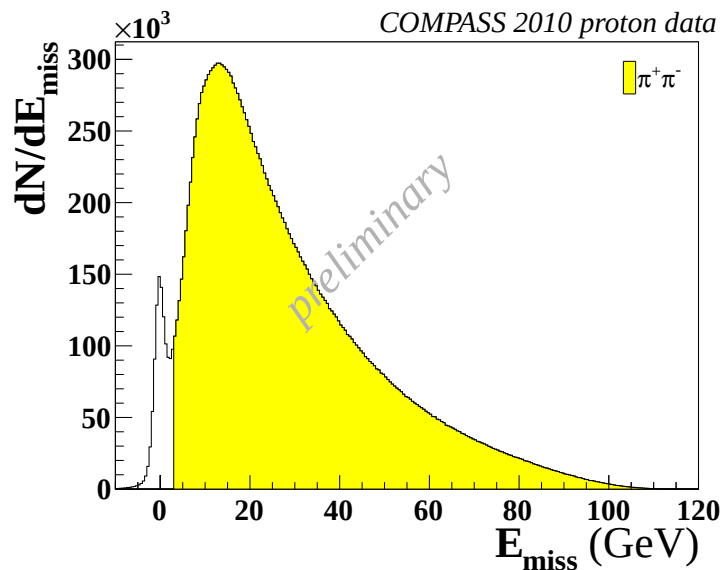
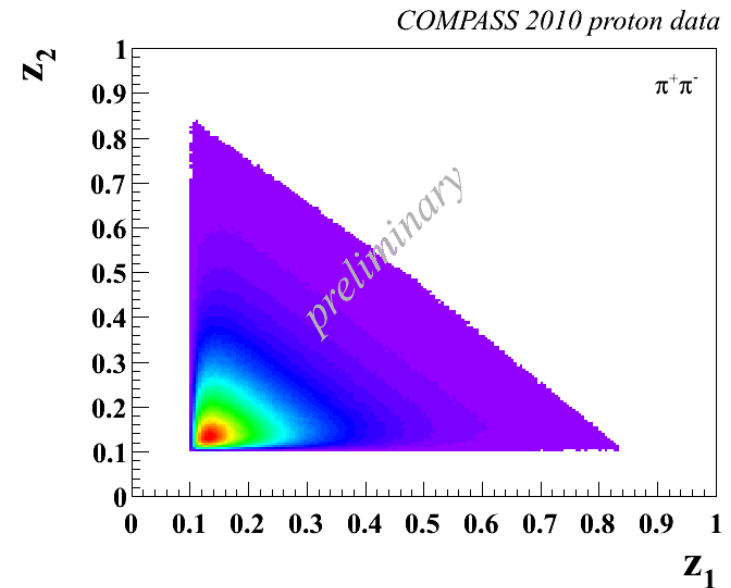
- $Q^2 > 1 \text{ (GeV/c)}^2$
 - $0.1 < y < 0.9$
 - $W > 5 \text{ GeV/c}^2$
- spectrometer acceptance:
 $0.003 < x < 0.7$



Data selection 2010: hadron & hadron pair cuts

hadron & hadron pair cuts:

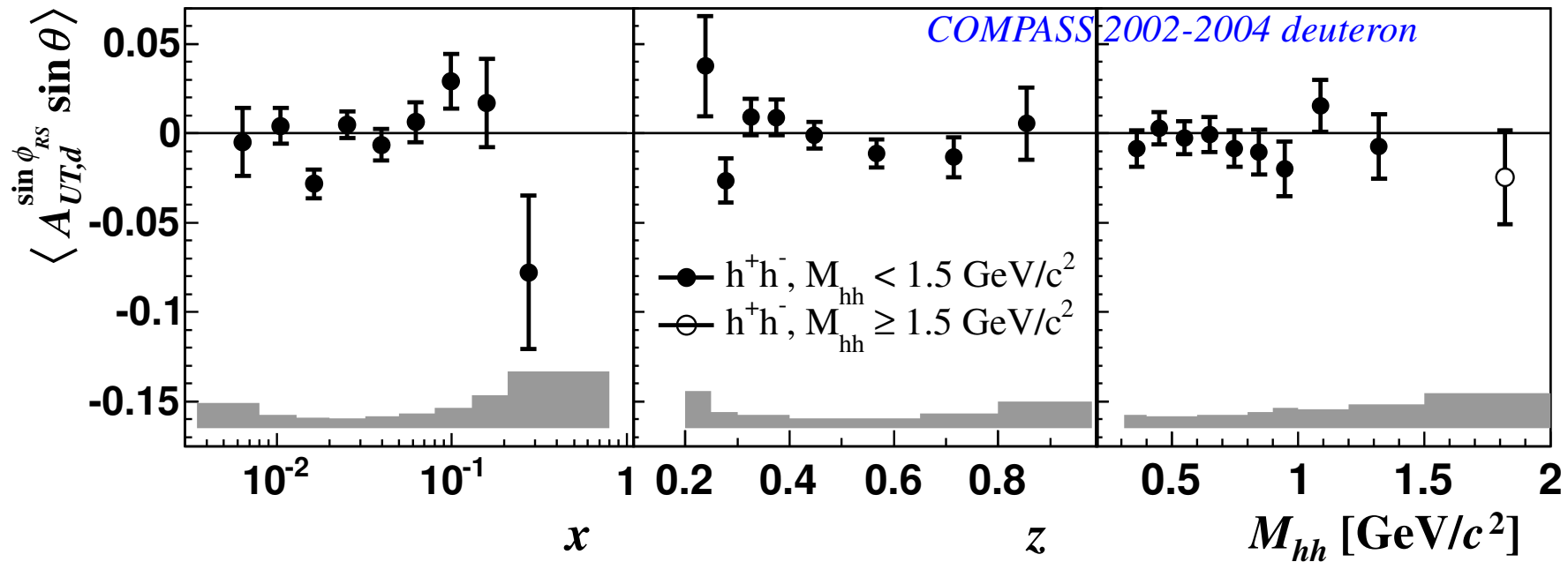
- at least 2 outgoing hadrons with opposite charge
- $z > 0.1$ for each hadron
- $x_F > 0.1$ for each hadron
- $E_{miss} > 3 \text{ GeV}/c^2$ for each pair
- $R_T > 0.07 \text{ GeV}/c$ for each pair



two-hadron asymmetries:

deuteron data 2002-04

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



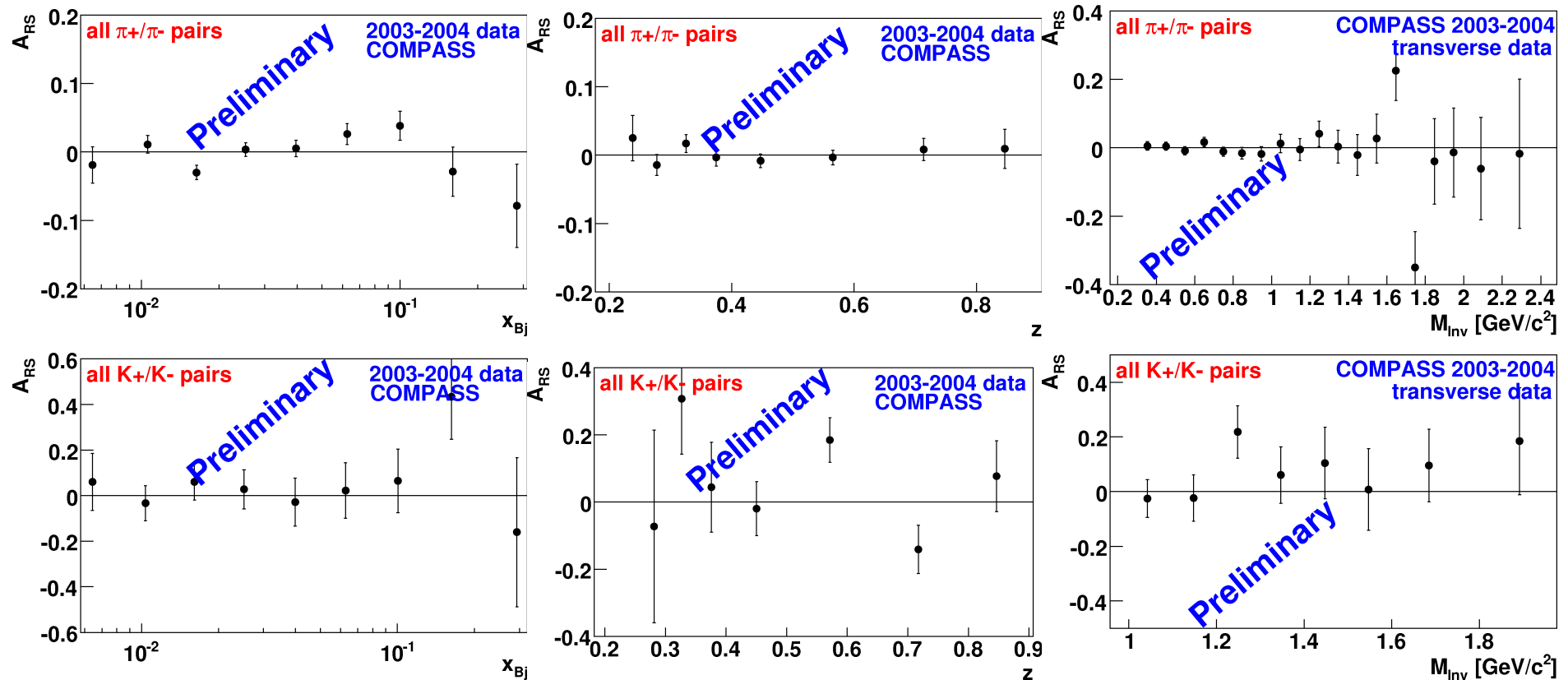
COMPASS Collaboration C. Adolph *et. al.*, Phys. Lett. B **713** (2012) 10-16, arXiv:1202.6150

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

cf. Collins asymmetry on deuteron target is also compatible with zero

COMPASS Collaboration M. Alekseev *et. al.*, Phys.Lett.B **673** 127-135 (2009), arXiv:0802.2160

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



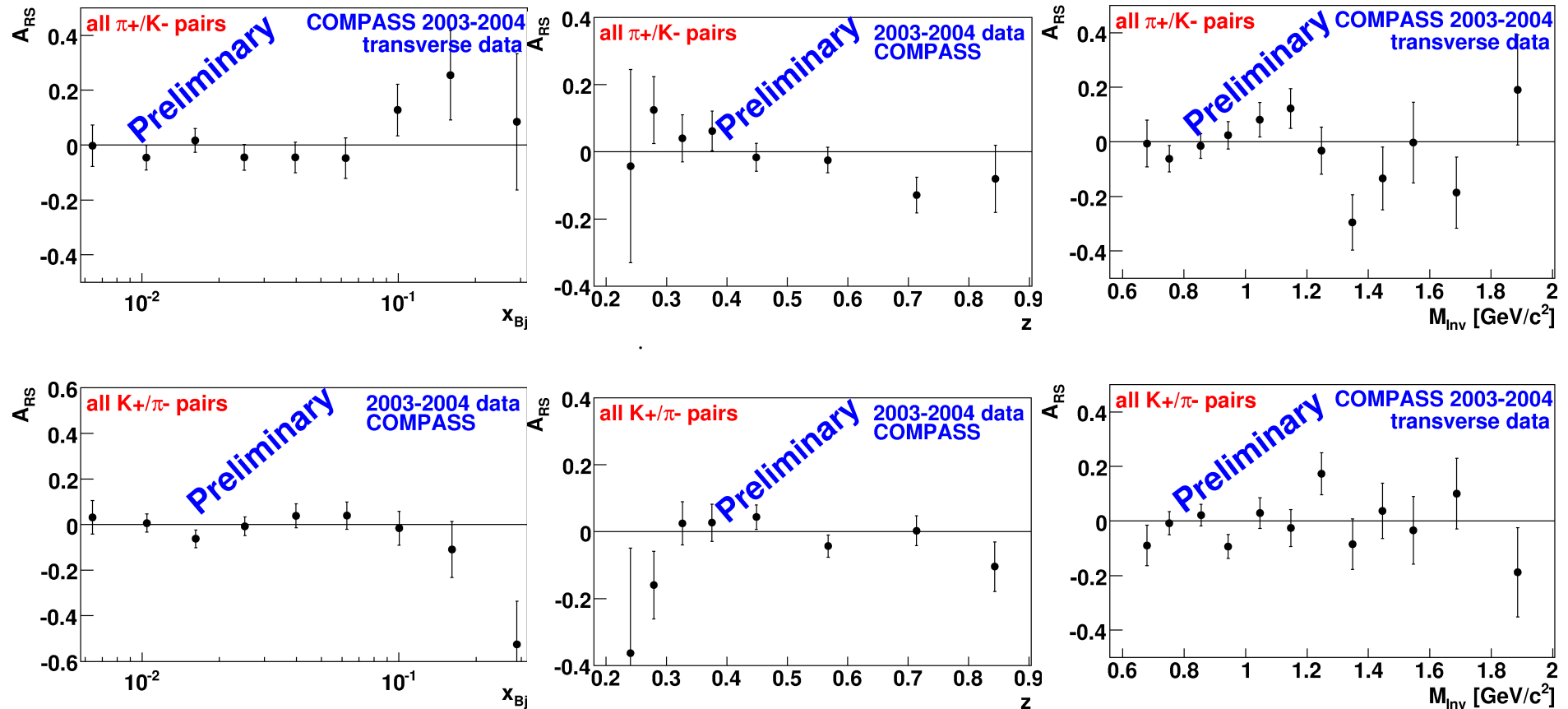
2002-04 deuteron data 2-hadron asymmetries: $\pi^+\pi^-$ pairs (top), K^+K^- pairs (bottom)

$\hookrightarrow h^+h^-$ asymmetries dominated by $\pi^+\pi^-$ signal

$\pi^+\pi^-$ asymmetries are small and compatible with zero

K^+K^- no signal & low statistics

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

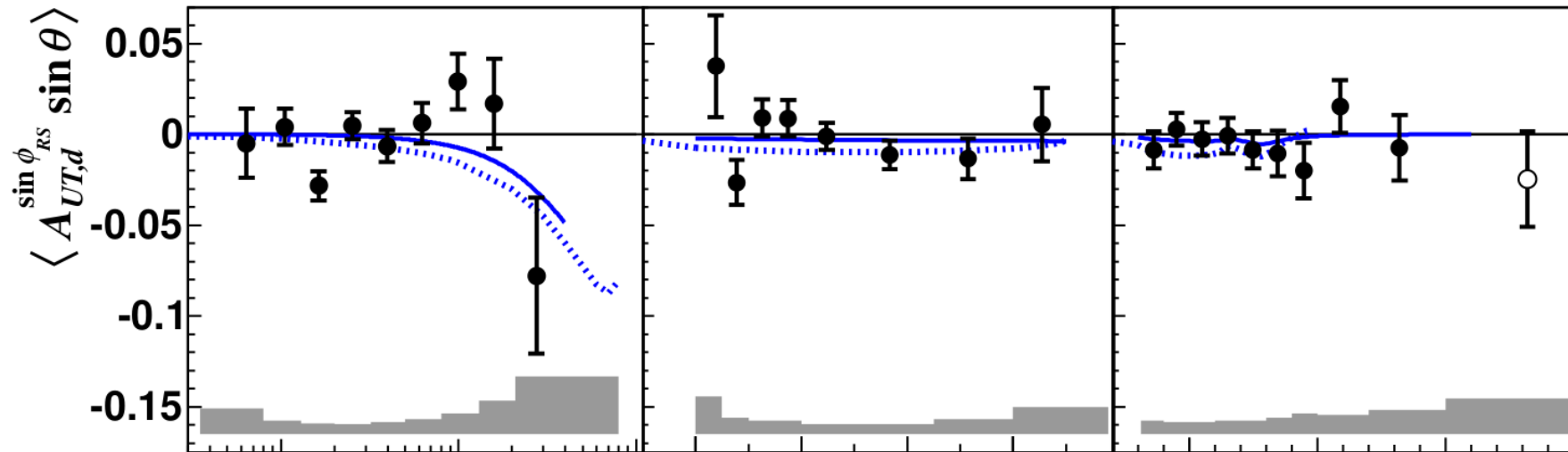


2002-04 deuteron data 2-hadron asymmetries: all $\pi^+ K^-$ pairs (top), $K^+ \pi^-$ pairs (bottom)

$\hookrightarrow \pi^+ K^-$ & $K^+ \pi^-$ signal compatible with zero

weak indication of opposite sign of the signal in x_{bj} dependence

deuteron data 2002-04: comparison with model predictions



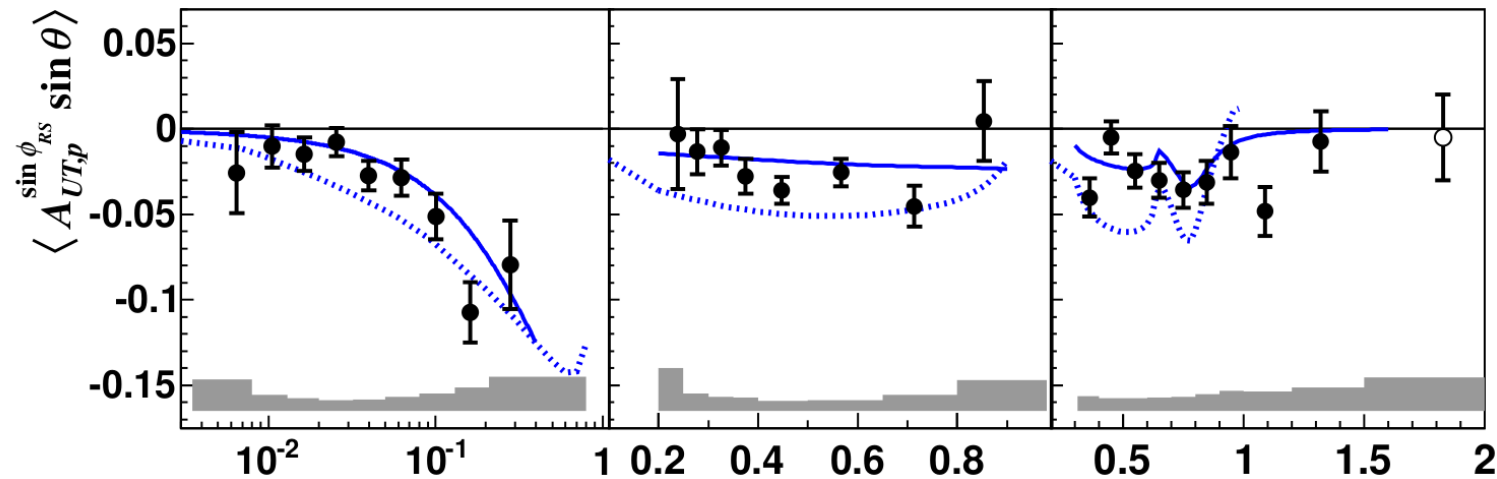
↪ Good agreement with model predictions

Bacchetta *et al.* hep-ph/0708037

two-hadron asymmetries:

proton data 2007

proton data 2007: all h^+h^- pairs

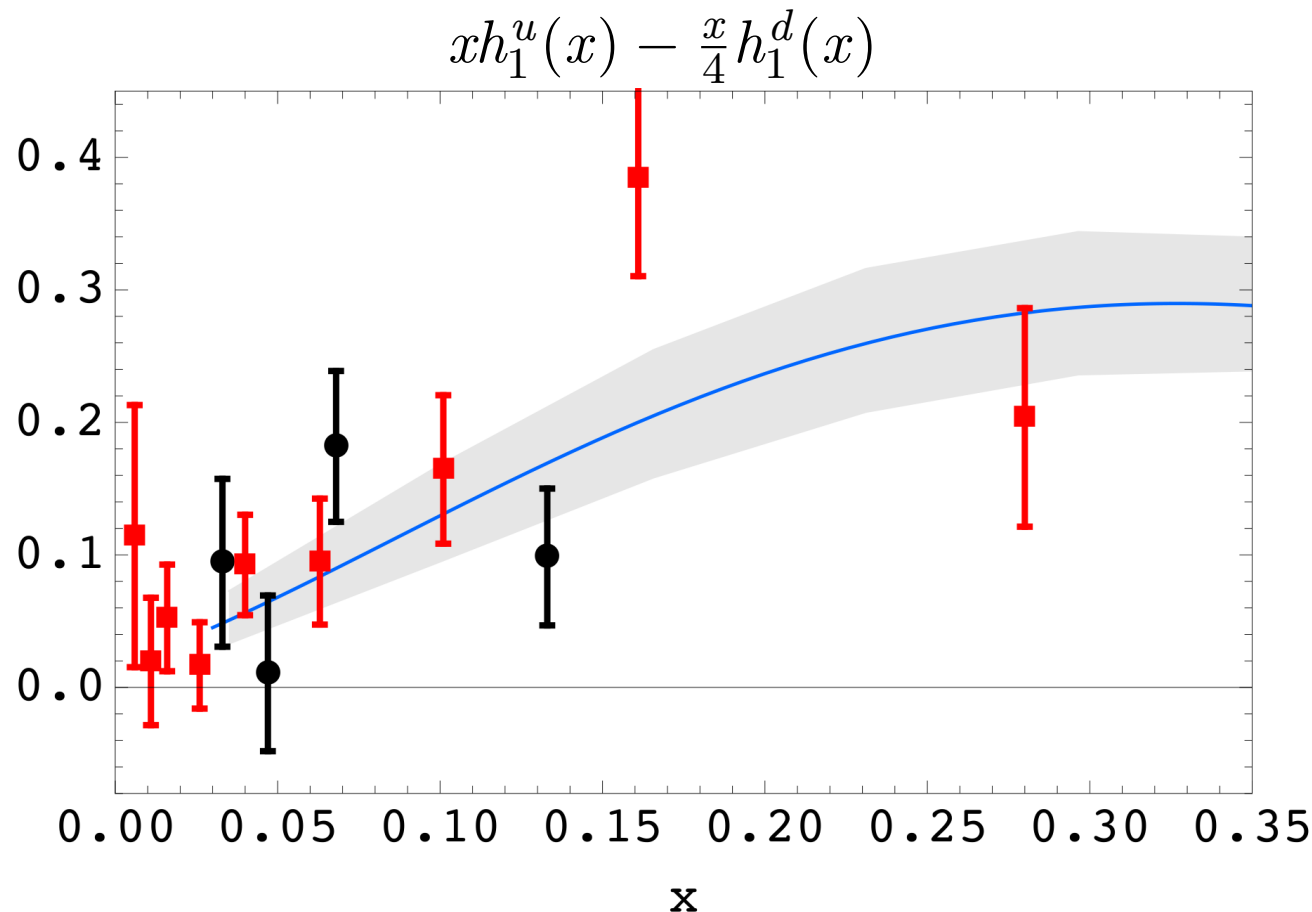


↪ Large asymmetries for proton up to 5 – 10%

COMPASS Collaboration C. Adolph *et. al.*, Phys. Lett. B **713** (2012) 10-16, arXiv:1202.6150

proton data 2007: 1st extraction of “a linear combination” of transversity ”PDFs“ via DiFF

A. Bachetta, A. Courtoy and M. Radici, PRL **107** (11), arXiv:1206.1836



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

black:

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

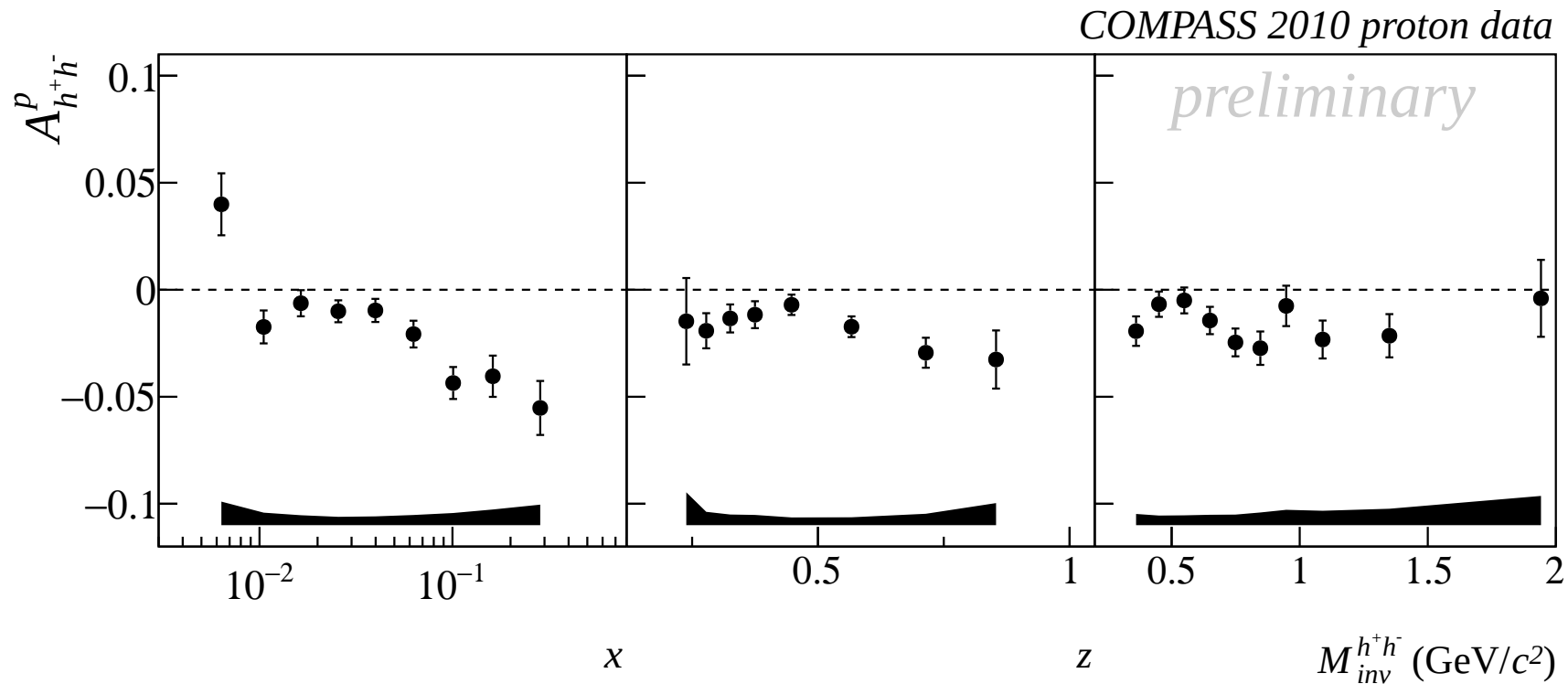
red:

COMPASS Adolph *et. al.*, Phys. Lett. B **713** (2012) 10-16, arXiv:1202.6150

two-hadron asymmetries:

proton data 2010

proton data 2010: all h^+h^- pairs



→ Clear asymmetries of h^+h^- with improved errors w.r.t. 2007 data

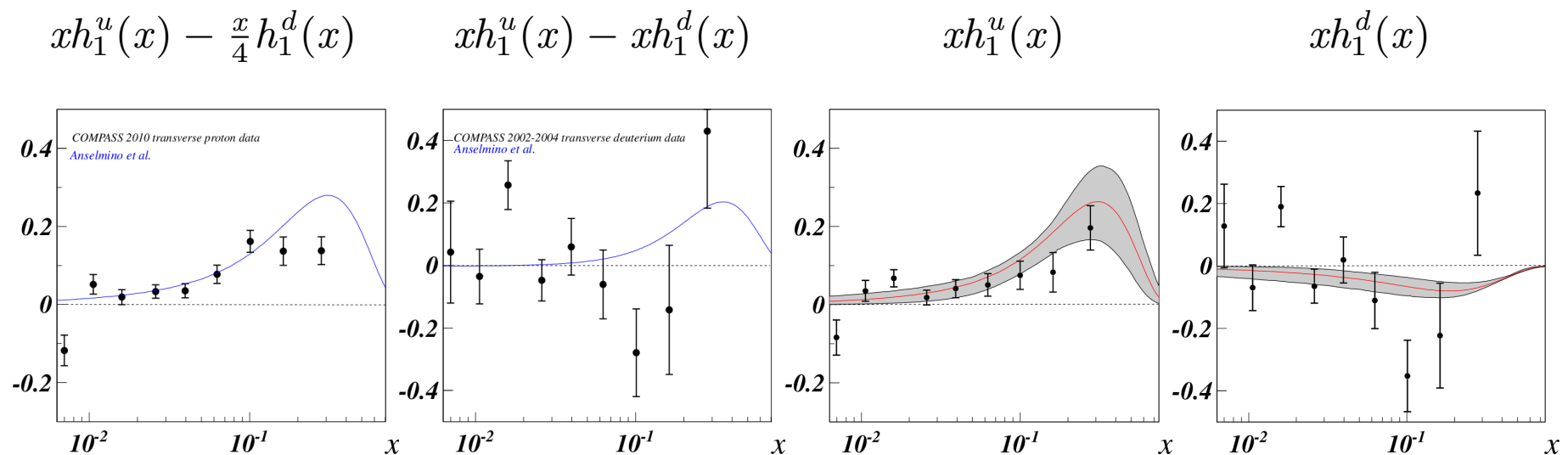
TRANSVERSITY 2011 proceedings:

Braun C. *o.b.o.* the COMPASS Collab. Nuovo Cimento C **035** (2012) 02

1st extraction of u and d transversity from 2010 proton data

Extract information on DiFF from BELLE data as in "Bacchetta, Courtoy, Radici, PRL 107:012001,2011"

→ u and d transversity PDFs can be extracted using COMPASS deuterium and 2010 proton data



PhD thesis C. Elia, Trieste 2011 & F. Sozzi at IWHSS 2012

See also DIS2012 proceeding by

A. Courtoy, A. Bacchetta & M. Radici, arXiv:1206.1836

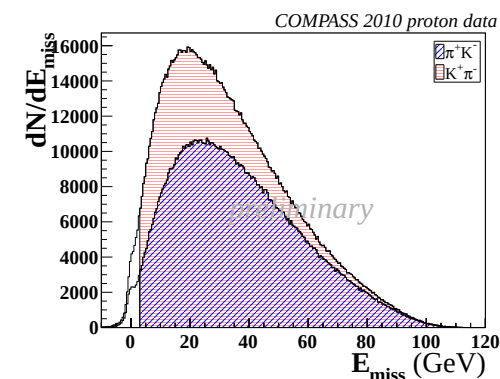
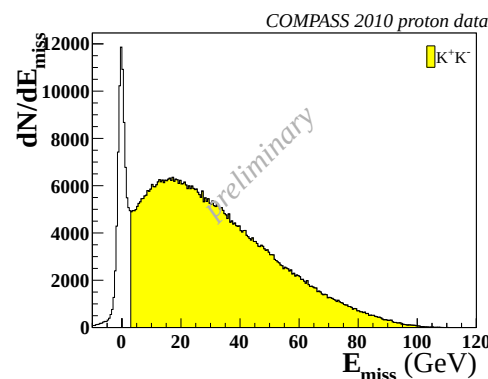
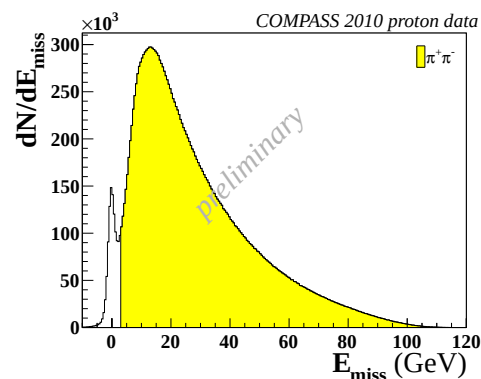
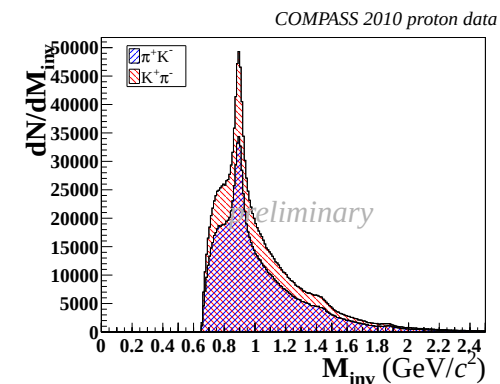
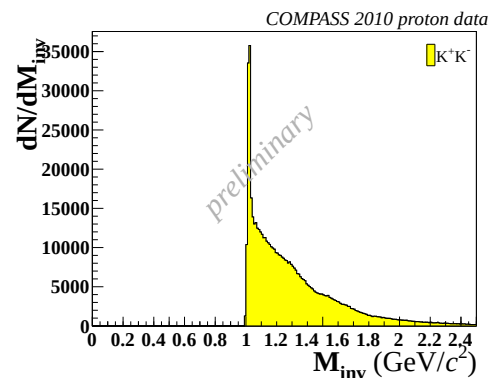
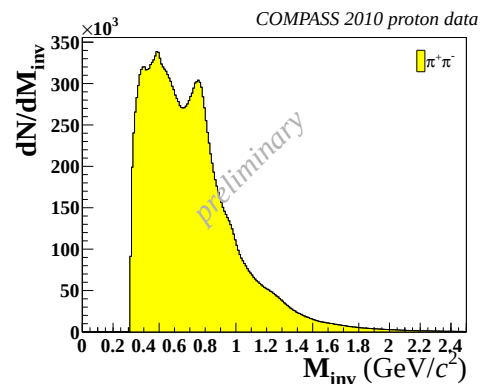
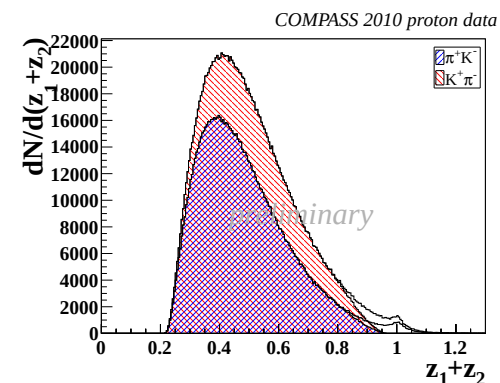
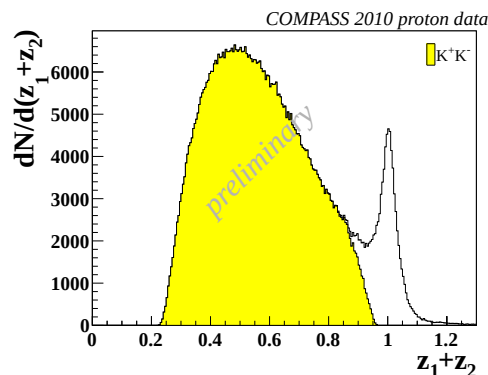
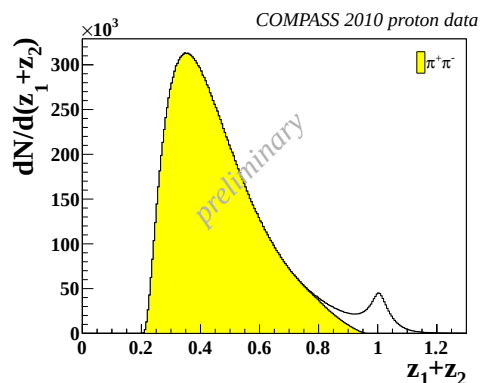
Identified hadron pairs: kin. distributions $z_1 + z_2$, M_{inv} and E_{miss}

NEW:

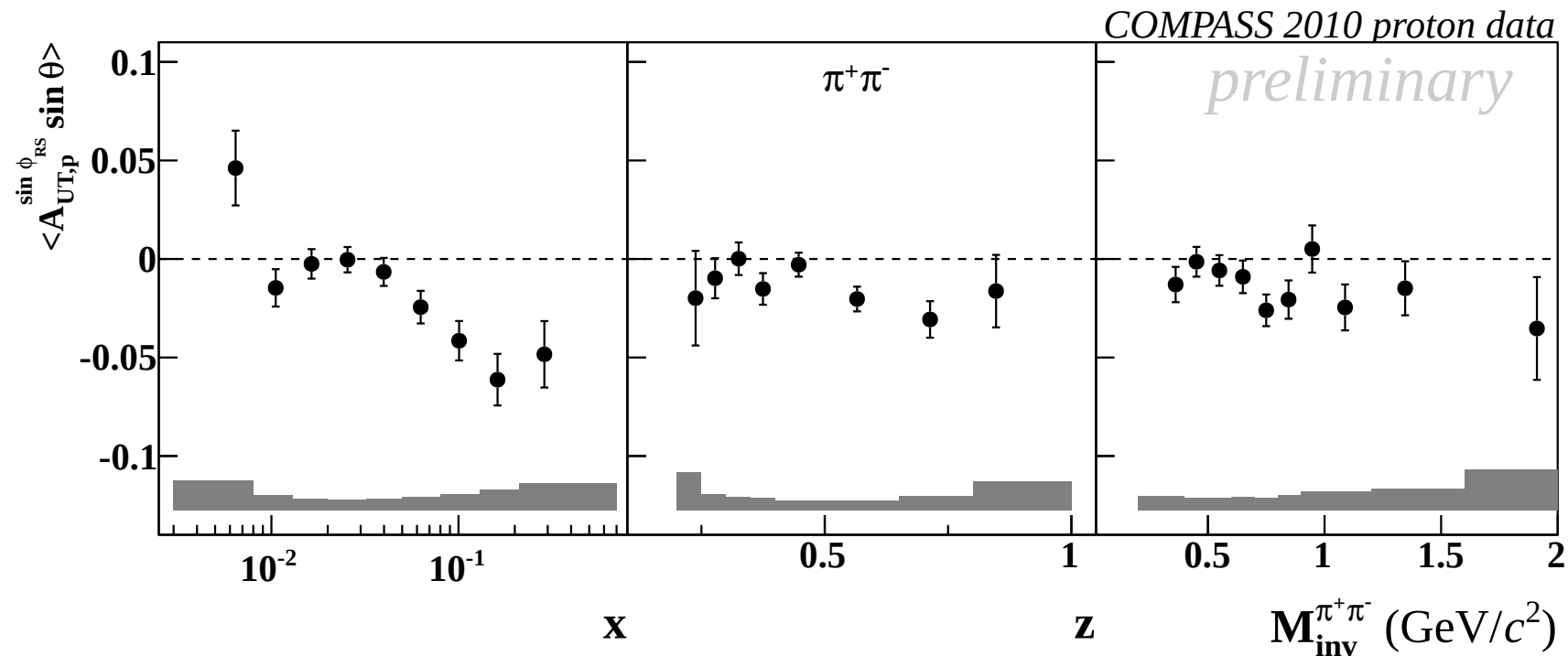
$\pi^+ \pi^-$

$K^+ K^-$

$\pi^+ K^-$ & $K^+ \pi^-$



identified two-hadron asymmetries: proton data 2010 $\pi^+\pi^-$



NEW: The 2010 $\pi^+\pi^-$ pair asymmetries

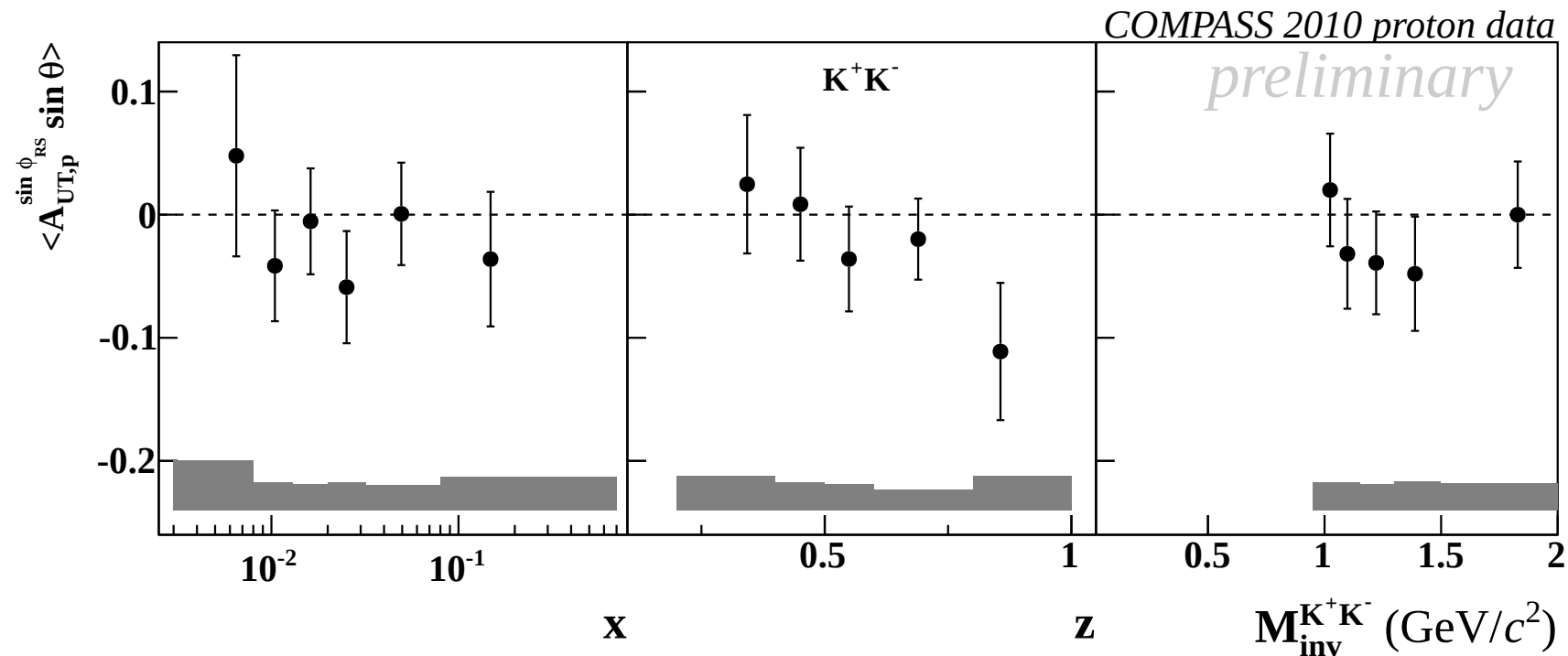
↪ Clear asymmetries of $\pi^+\pi^-$ pairs

x up to 6 %

z compatible with a constant function

M_{inv} peak around ρ^0 mass

identified two-hadron asymmetries: proton data 2010 $K^+ K^-$



NEW: The 2010 $K^+ K^-$ pair asymmetries

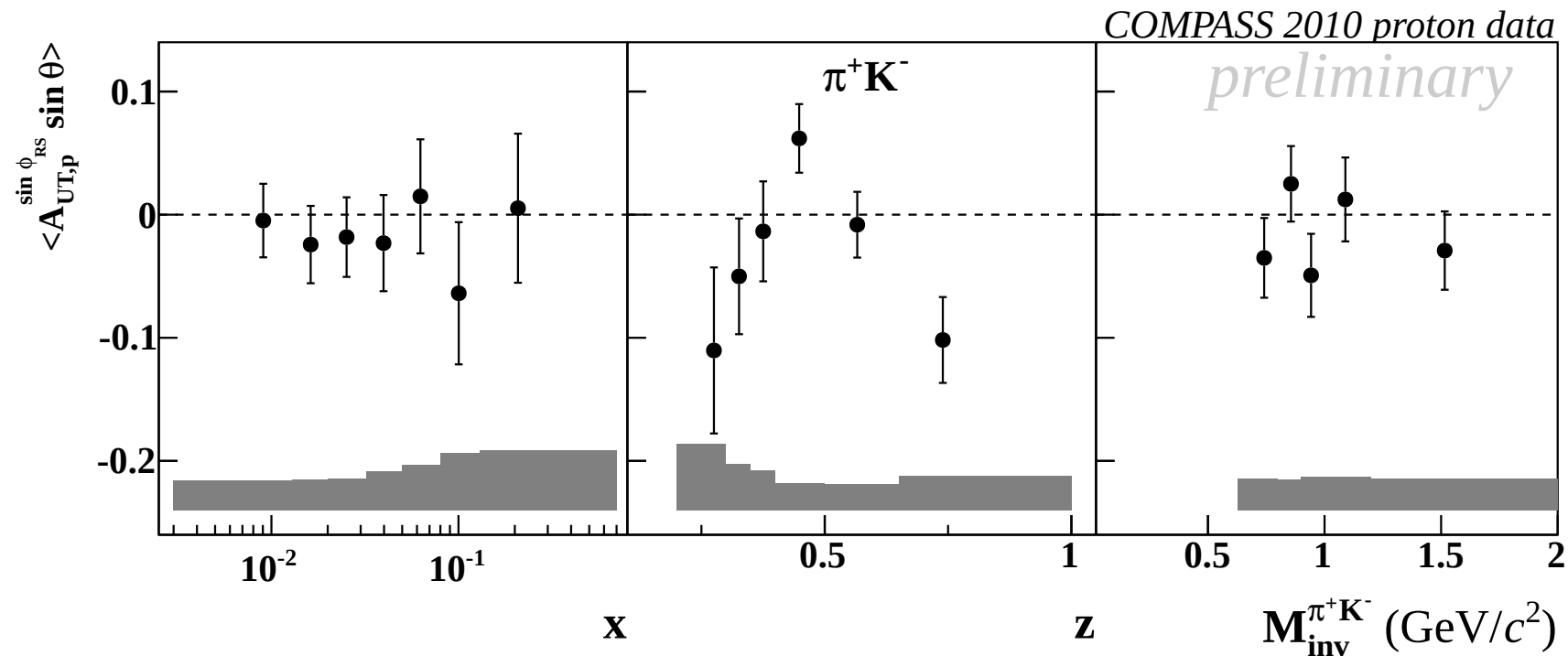
↪ no clear trend & compatible with 0 within the statistical errors

x no signal

z no signal

M_{inv} negative mean value

identified two-hadron asymmetries: proton data 2010 $\pi^+ K^-$



NEW: The 2010 $\pi^+ K^-$ pair asymmetries

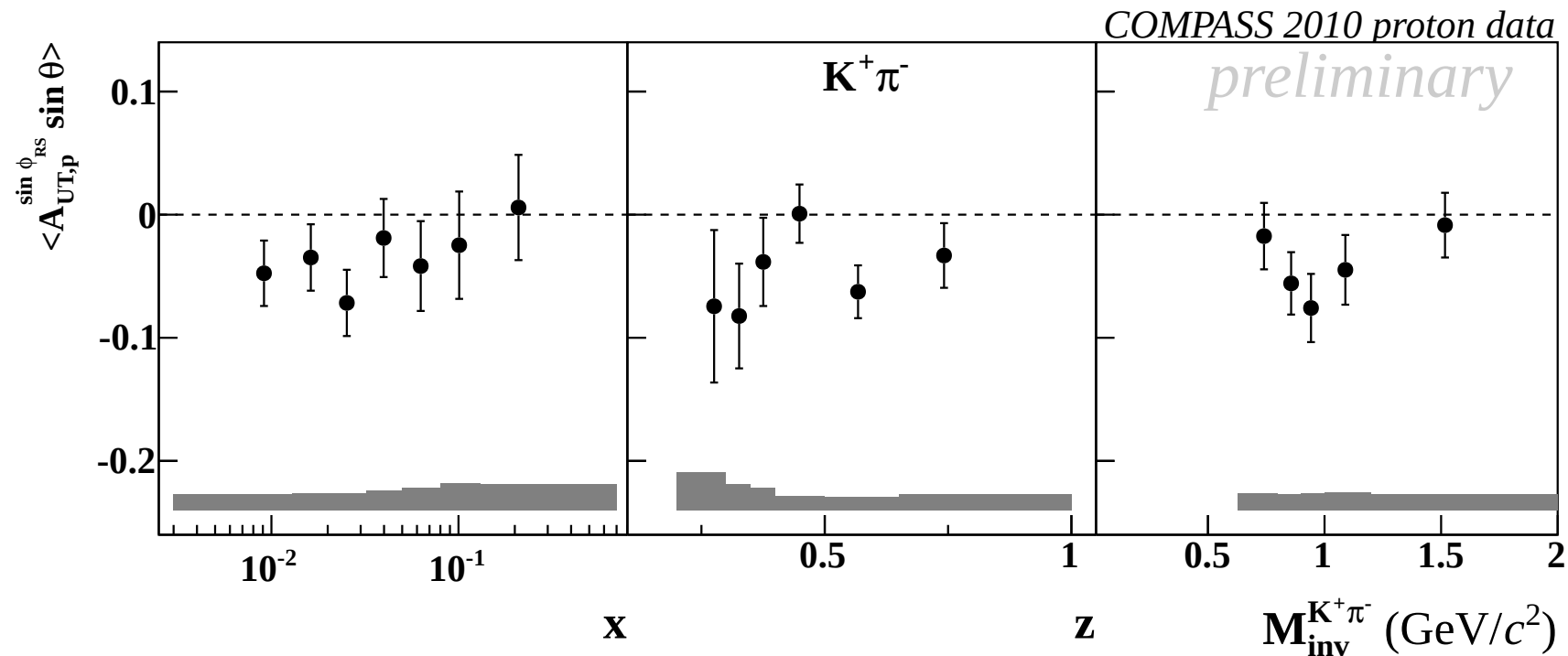
↪ no clear trend & compatible with 0 within the statistical errors

x no signal

z negative mean value with positive peak around 0.45

M_{inv} no signal

identified two-hadron asymmetries: proton data 2010 $K^+\pi^-$



NEW: The 2010 $K^+\pi^-$ pair asymmetries

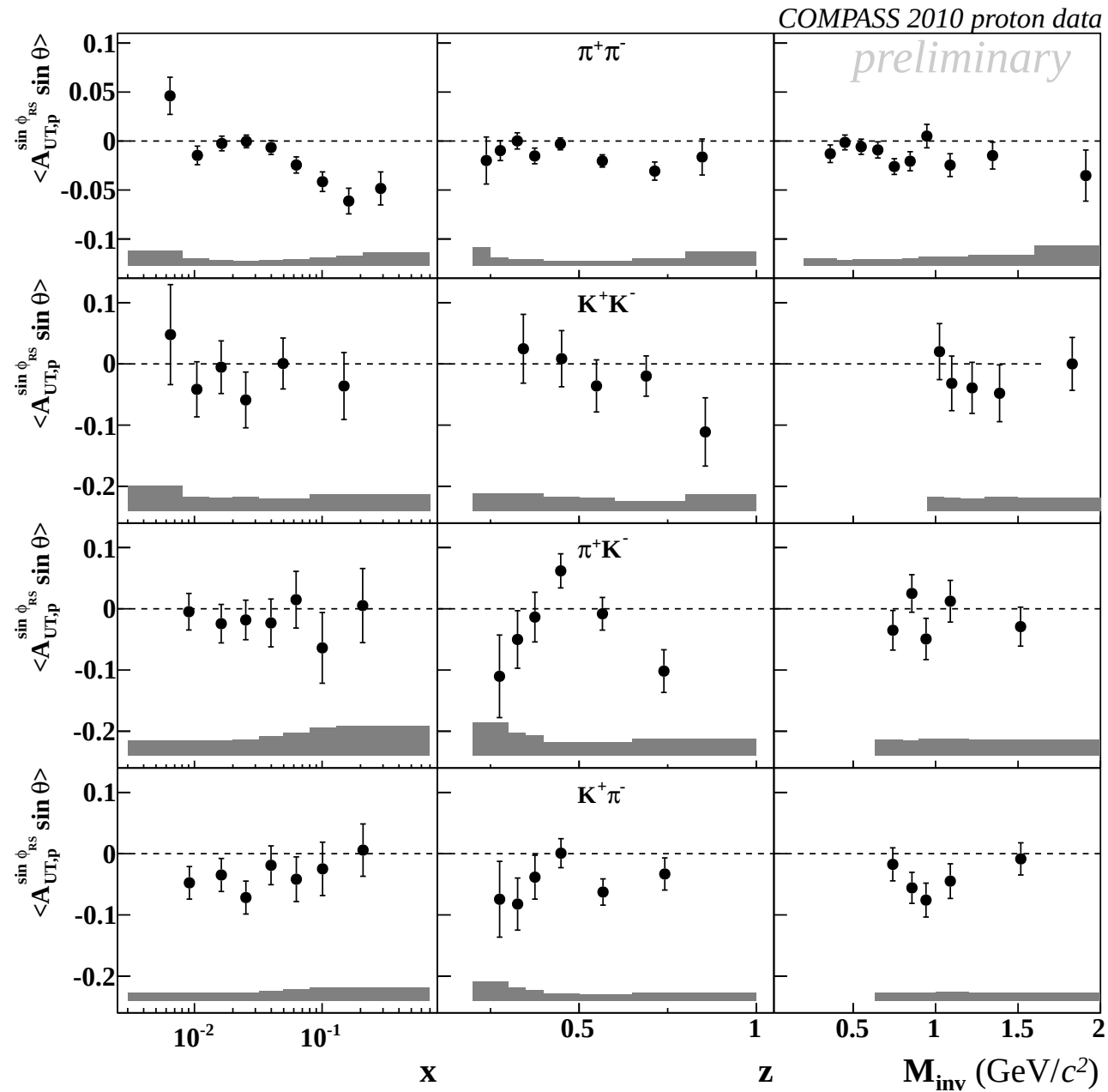
↪ compatible with 0 within the statistical errors

x negative mean value

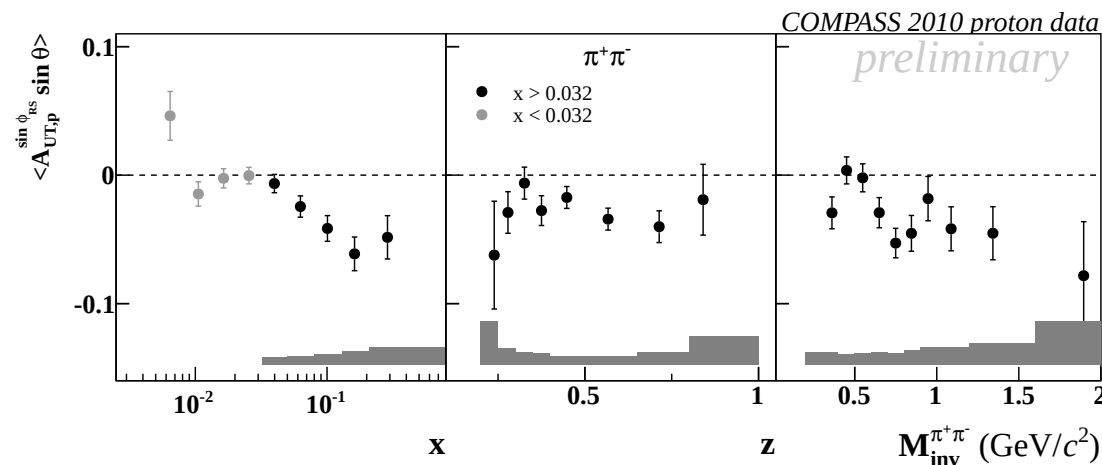
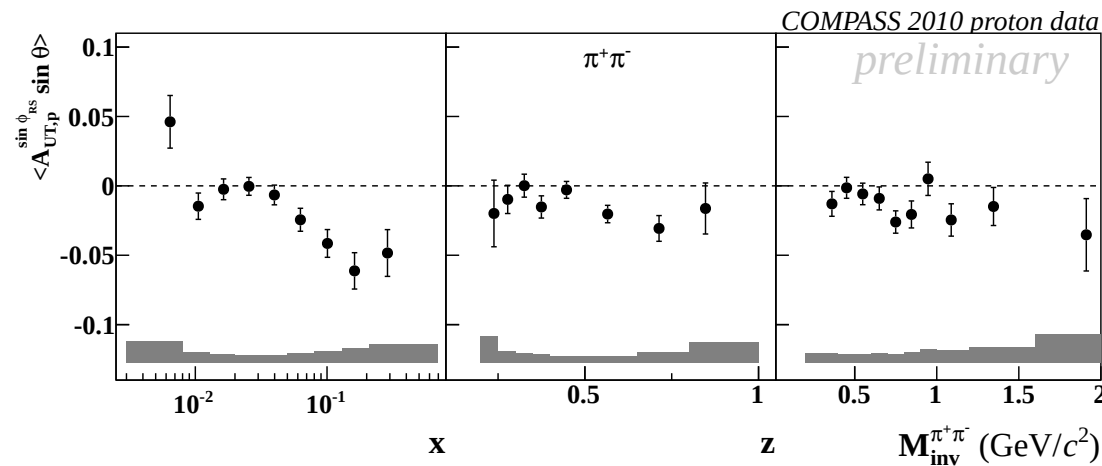
z negative mean value

M_{inv} negative peak peak around 0.9 GeV/ c^2

NEW: identified two-hadron asymmetries: proton data 2010



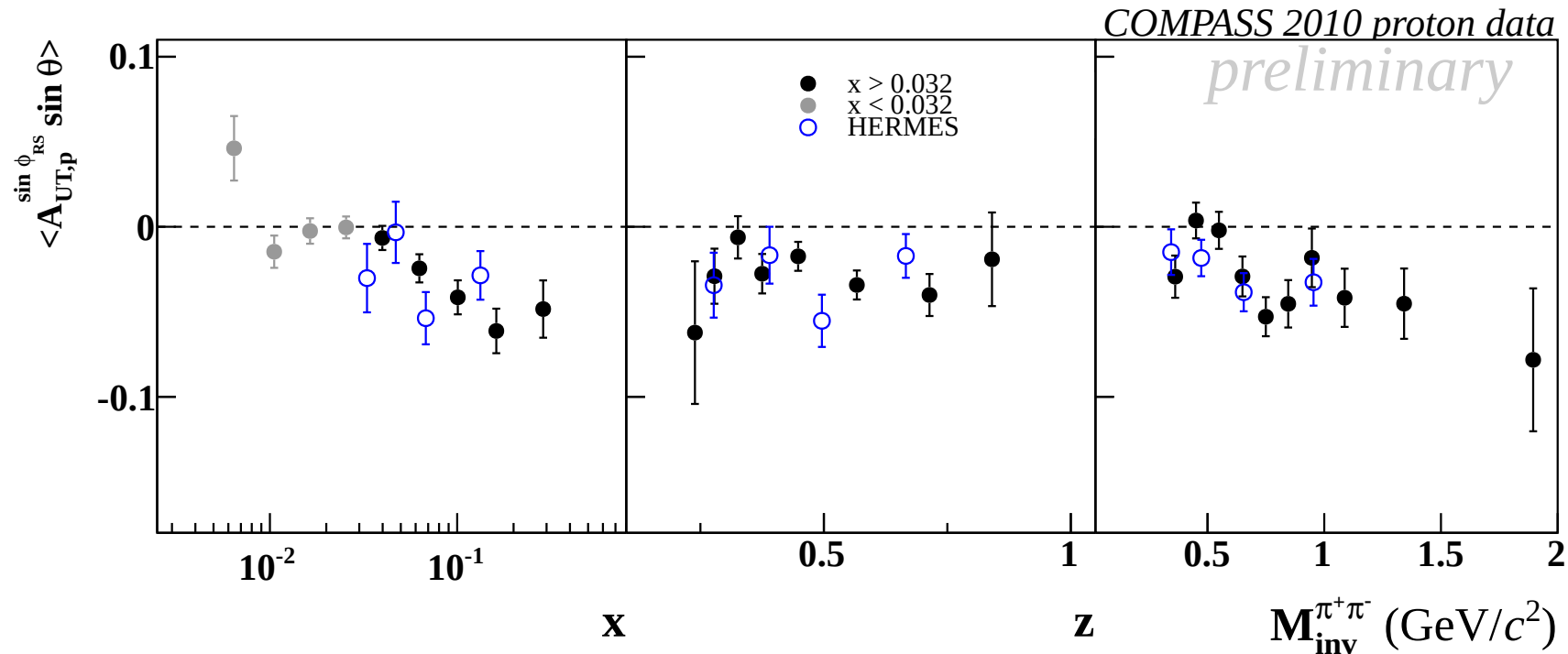
NEW: proton data 2010 $\pi^+\pi^-$ valence region



$\hookrightarrow \pi^+\pi^-$ valence region $x_{bj} > 0.032$

clear signal around ρ^0 mass is pronounced in valence region sample

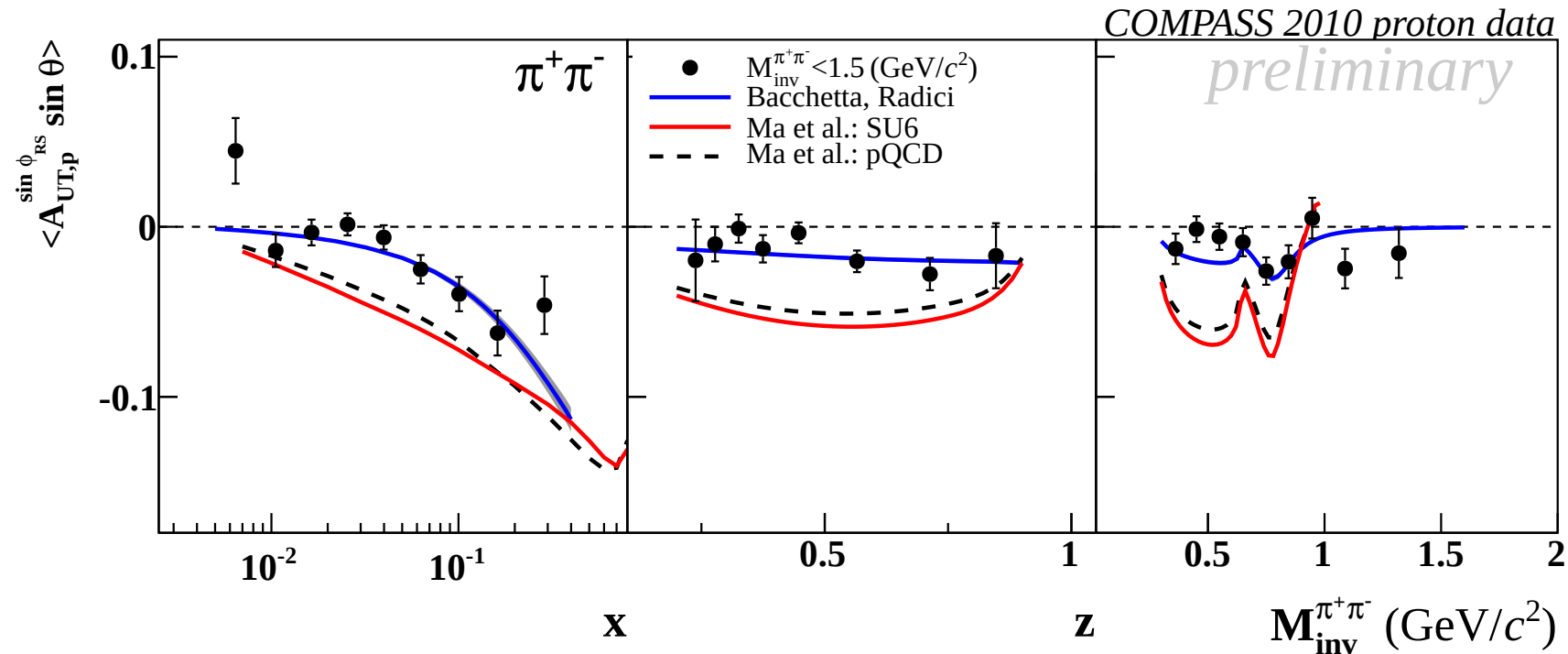
NEW: Comparison of $\pi^+\pi^-$ with results from HERMES



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

↪ Good agreement of COMPASS $\pi^+\pi^-$ data, with its higher precision, with HERMES $\pi^+\pi^-$ data within the error bars

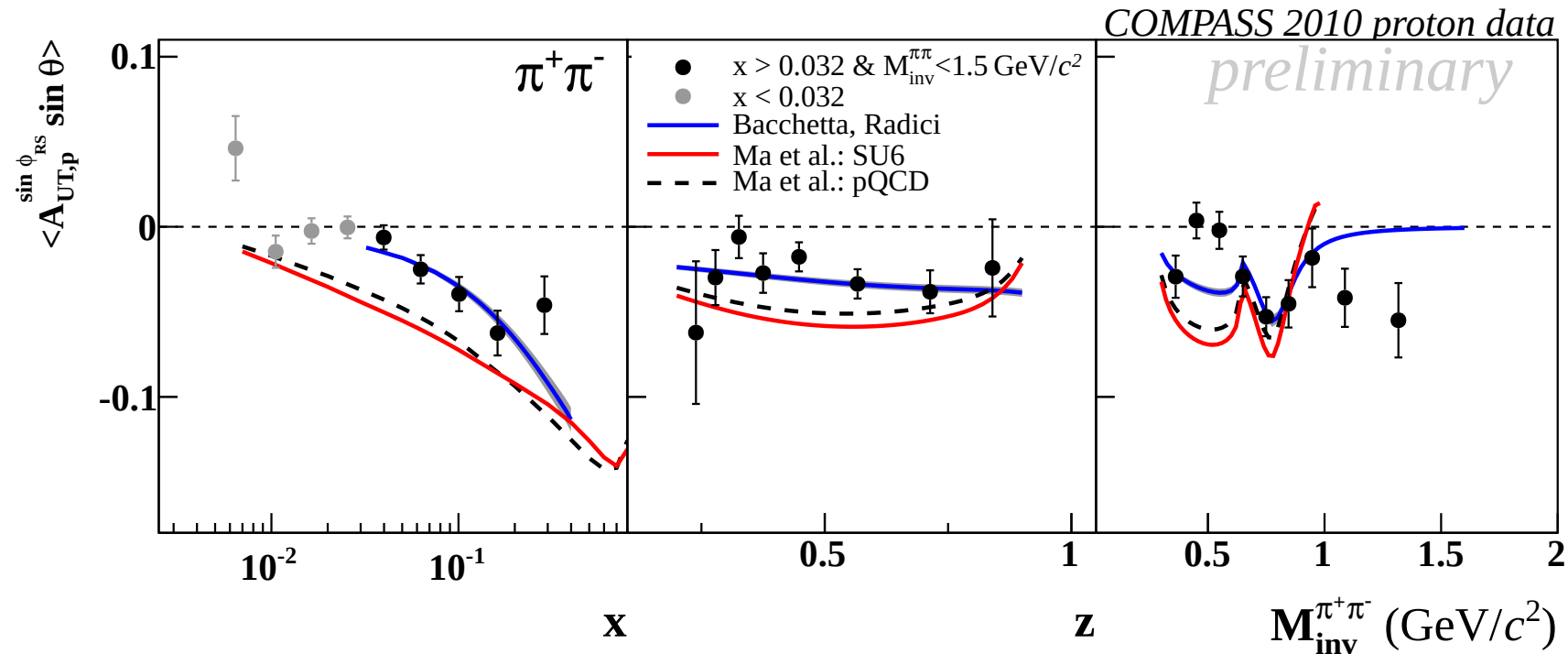
NEW: 2010 proton data comparison with model predictions



Bacchetta *et al.*, hep-ph/0608037
Ma *et al.*, arXiv:0711.0817

- ↪ x_{bj} : Ma trend confirmed | Bacchetta good agreement
- ↪ z : Ma too large | Bacchetta compatible
- ↪ M_{inv} : Ma too large | Bacchetta good agreement around ρ^0 mass

NEW: comparison with model predictions in valence region



Bacchetta *et al.*, hep-ph/0608037
Ma *et al.*, arXiv:0711.0817

- ↪ x_{bj} : Ma trend confirmed | Bacchetta good agreement
- ↪ z : compatible within the errors
- ↪ M_{inv} : good agreement around ρ^0 mass

Conclusions & Outlook

- COMPASS deuteron data available
 - COMPASS 2007 proton data available
 - preliminary results for 2010 COMPASS proton data :
- ① For the **FIRST TIME: COMPASS proton** data on transverse spin asymmetries in **identified** two-hadron production
 - ▶ $\pi^+\pi^-$ also measured by HERMES
 - ▶ K^+K^- , π^+K^- and $K^+\pi^-$ never measured before!
 - ② COMPASS $\pi^+\pi^-$ data is in good agreement with HERMES data
 - ③ Reasonable agreement with available model predictions
 - ④ Important new input for the extraction of transversity

Outlook:

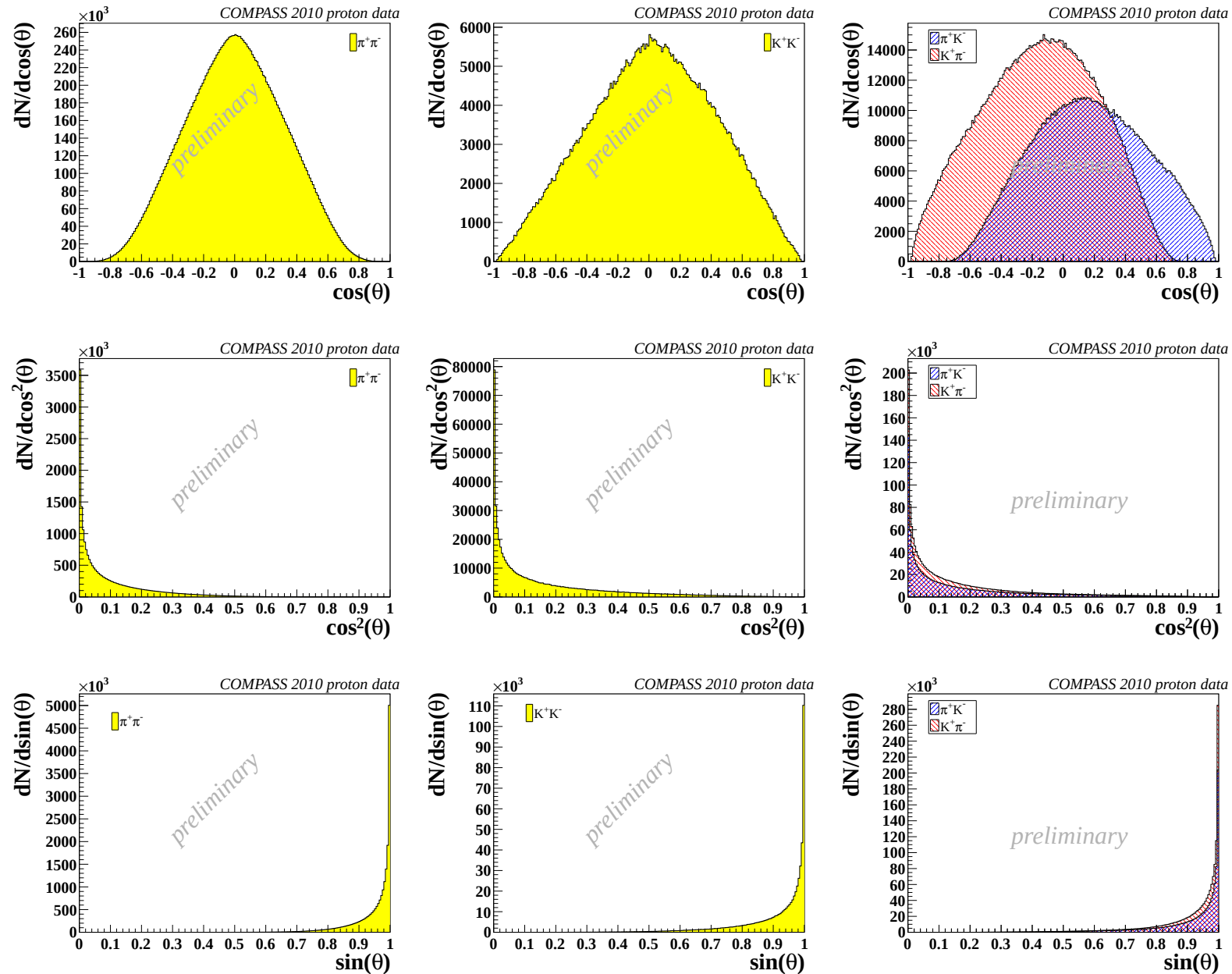
- COMPASS combined 2007/2010 results on identified two-hadron asymmetries

Thank you for your attention!

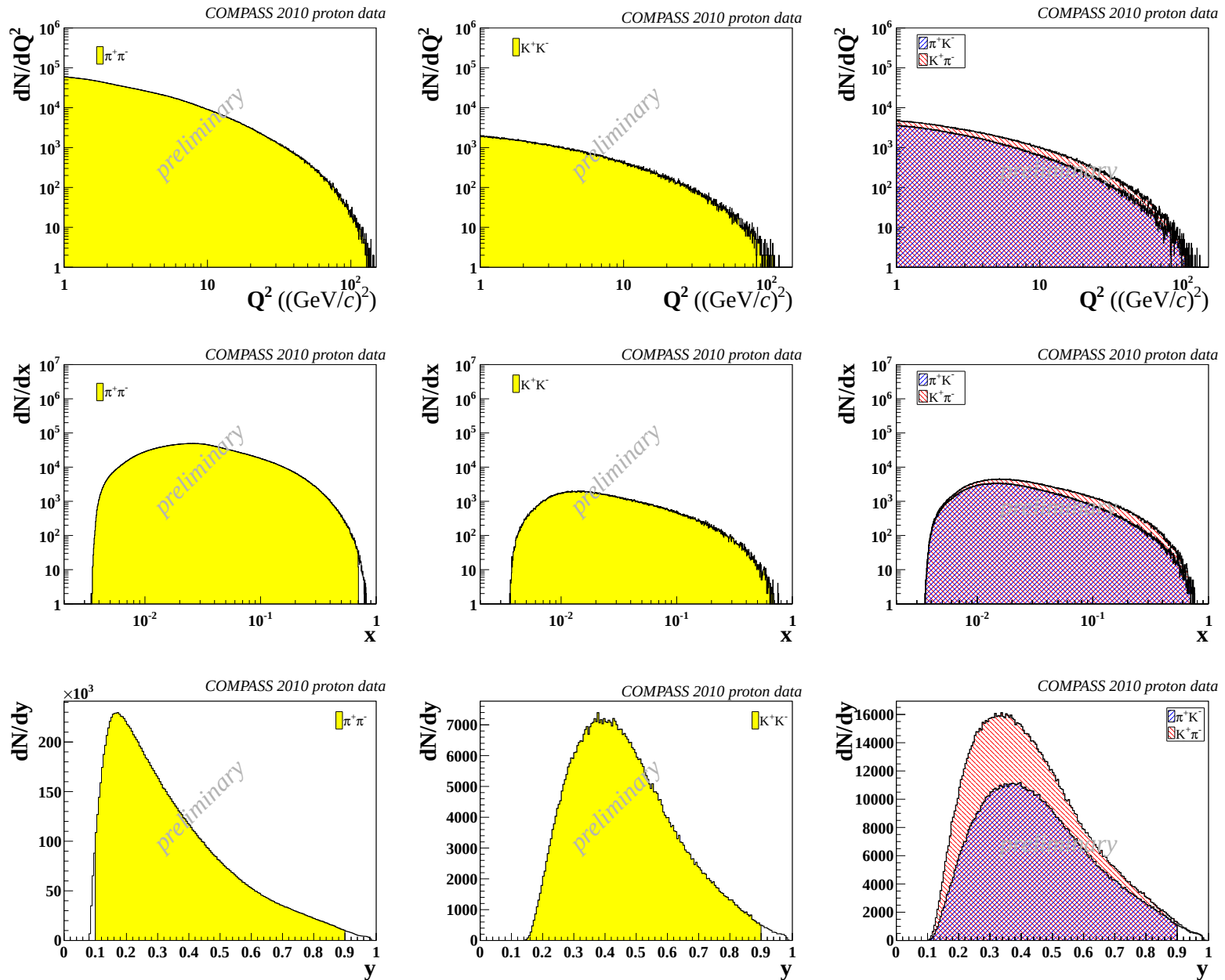
electronic address: `christopher.braun@cern.ch`

Back up

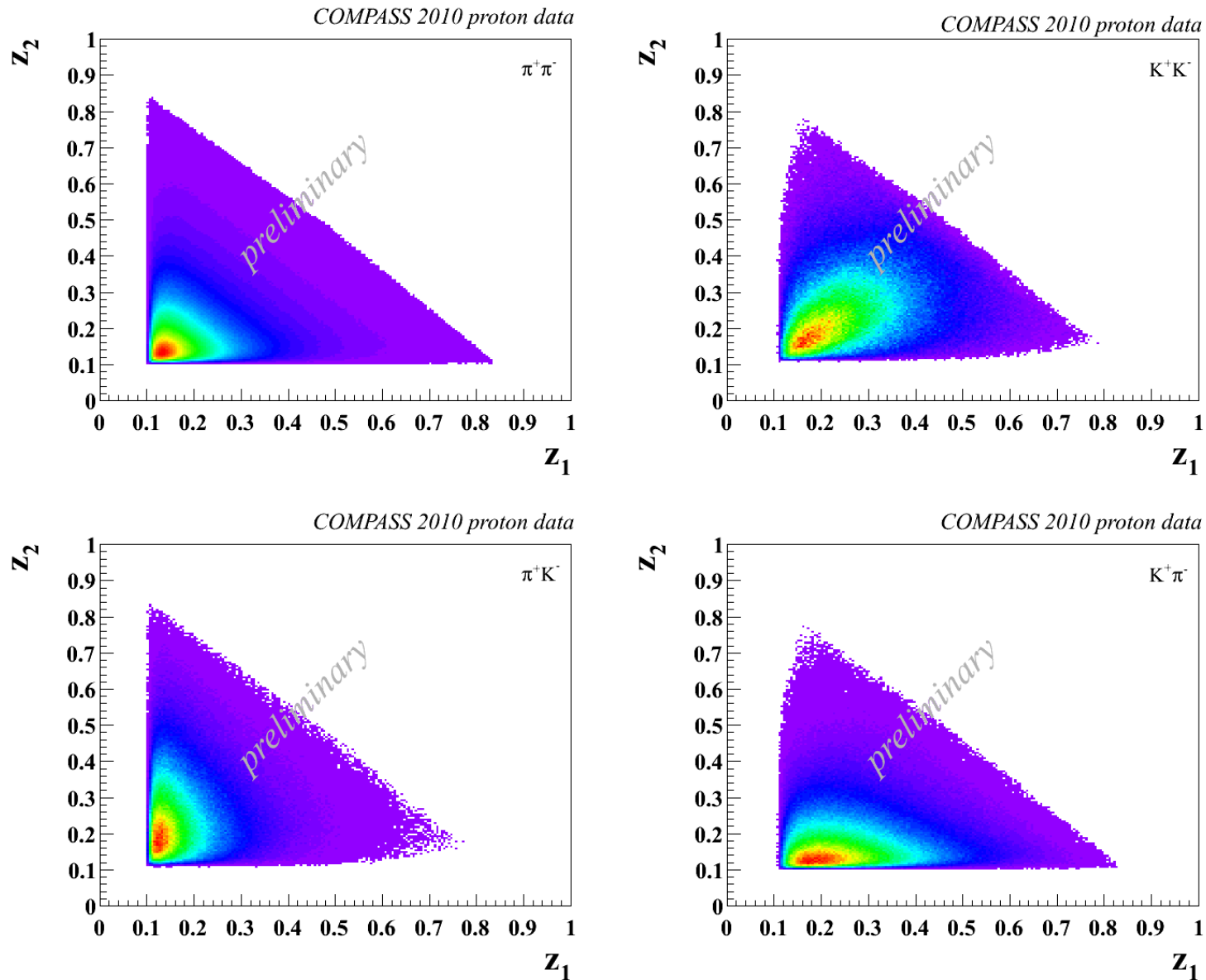
Kinematic distributions of DIS events: $\cos \Theta$, $\cos^2 \Theta$ and $\sin \Theta$



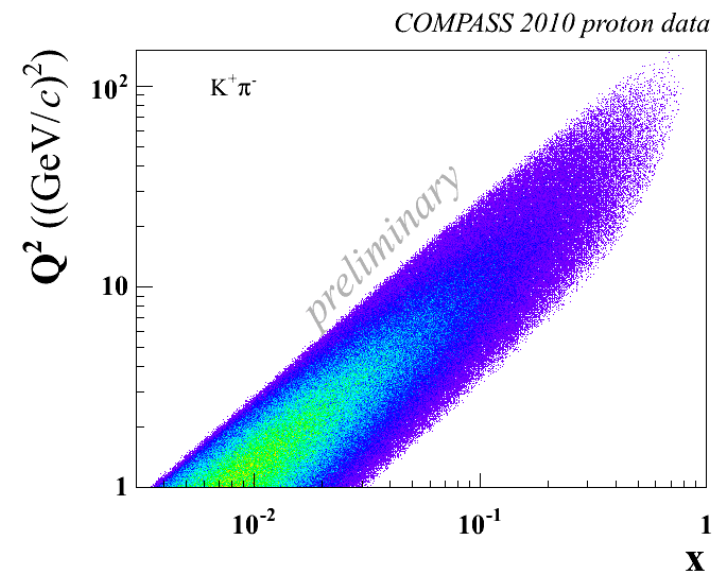
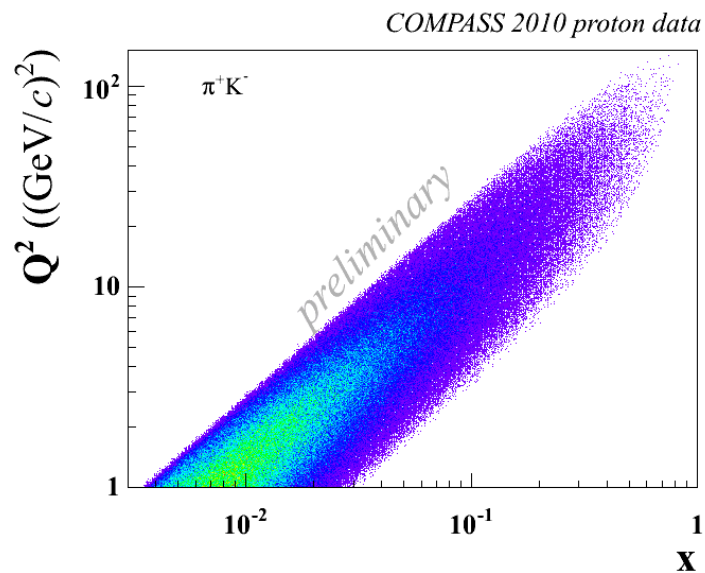
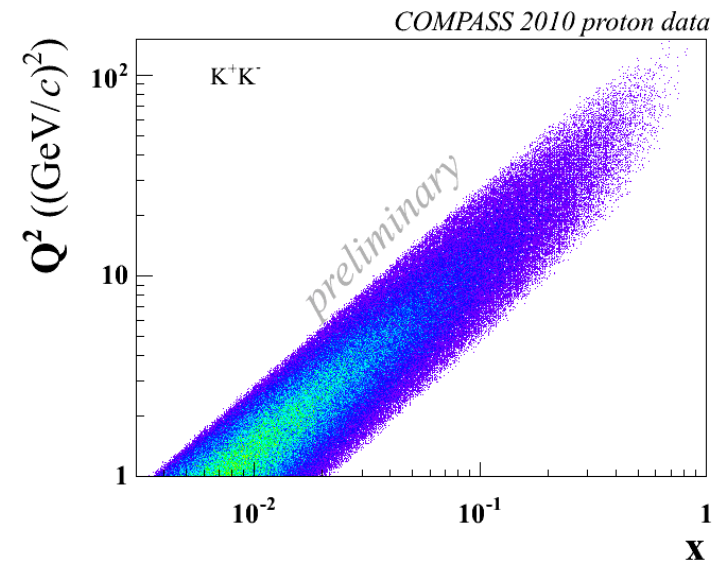
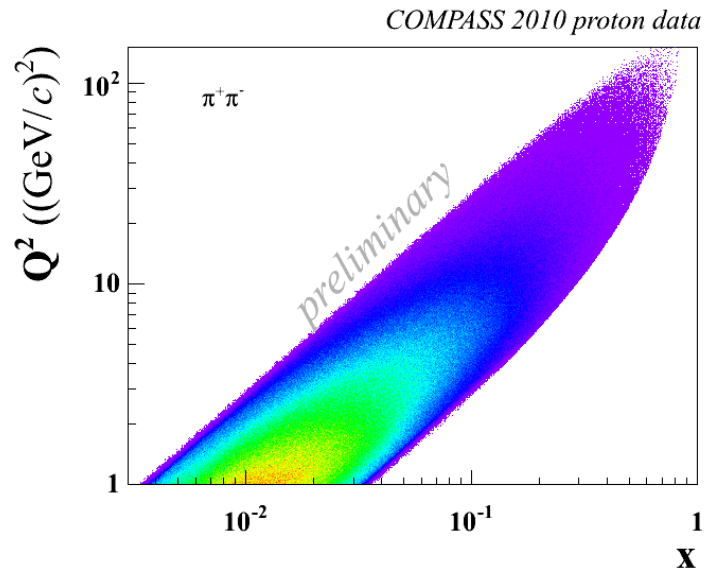
Kinematic distributions of DIS events: Q^2 , x_{bj} and y



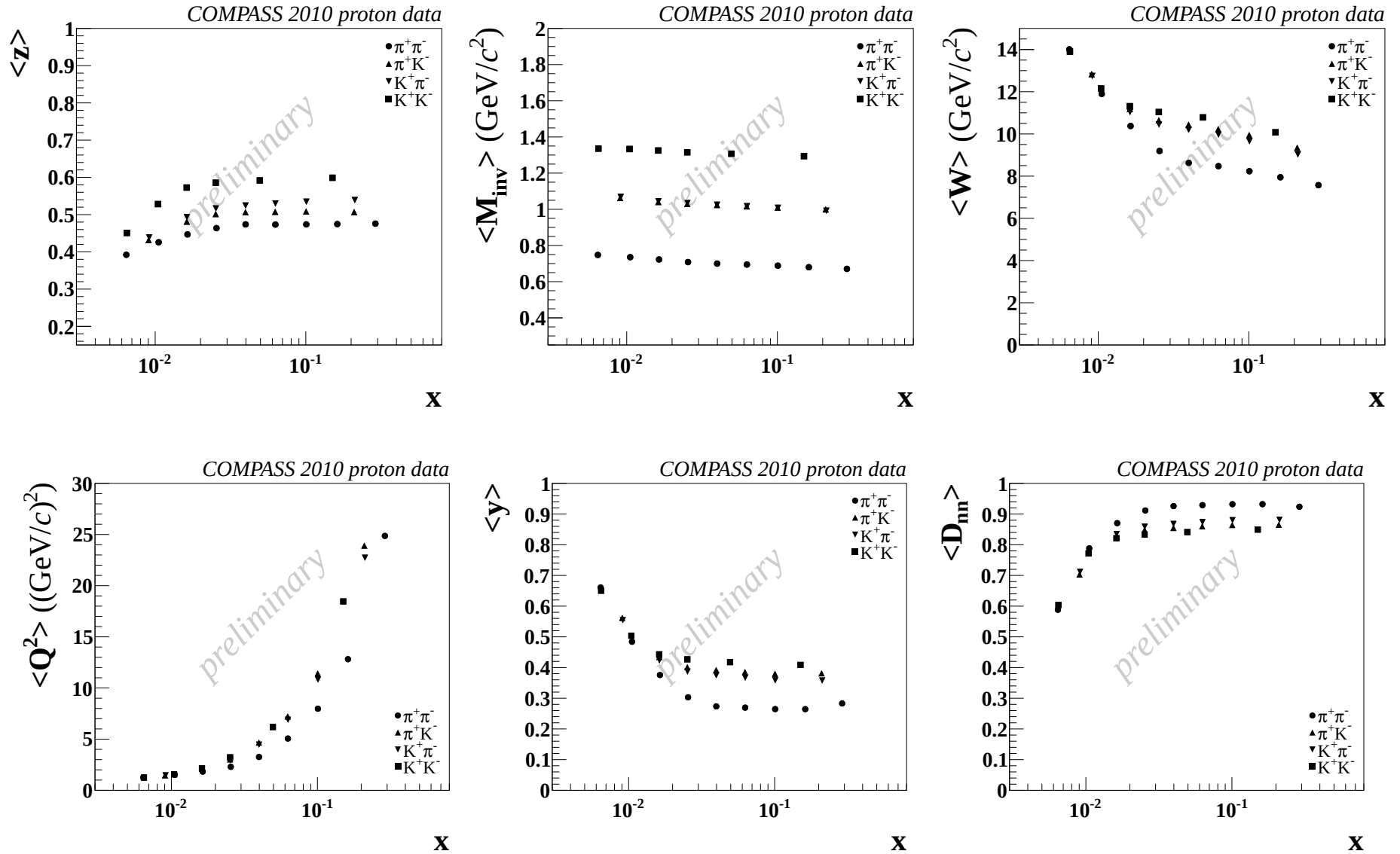
Kinematic distributions of DIS events: z_1 vs. z_2



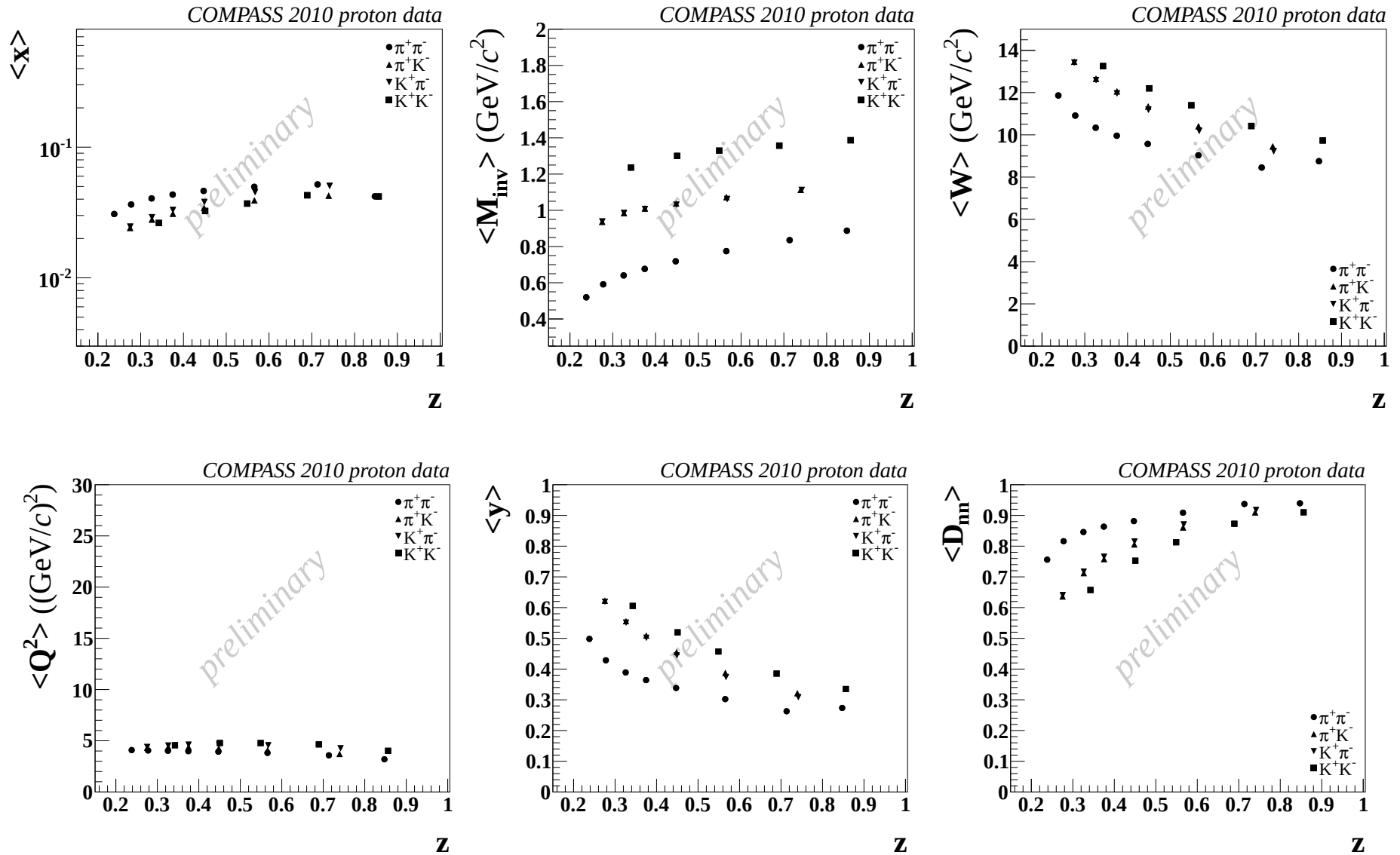
Kinematic distributions of DIS events: Q^2 vs. x_{bj}



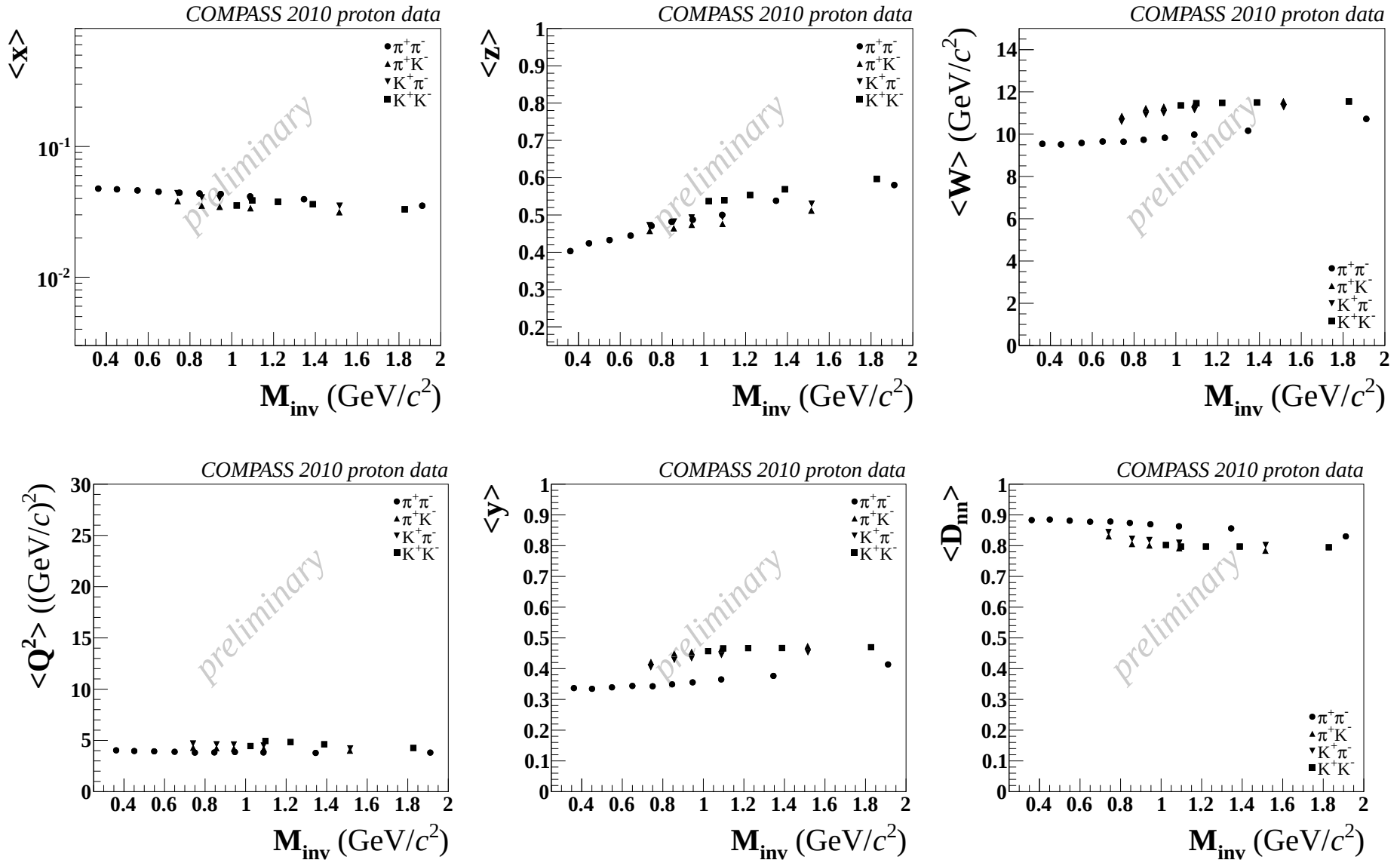
2010 proton data: kinematic mean values in x_{bj}



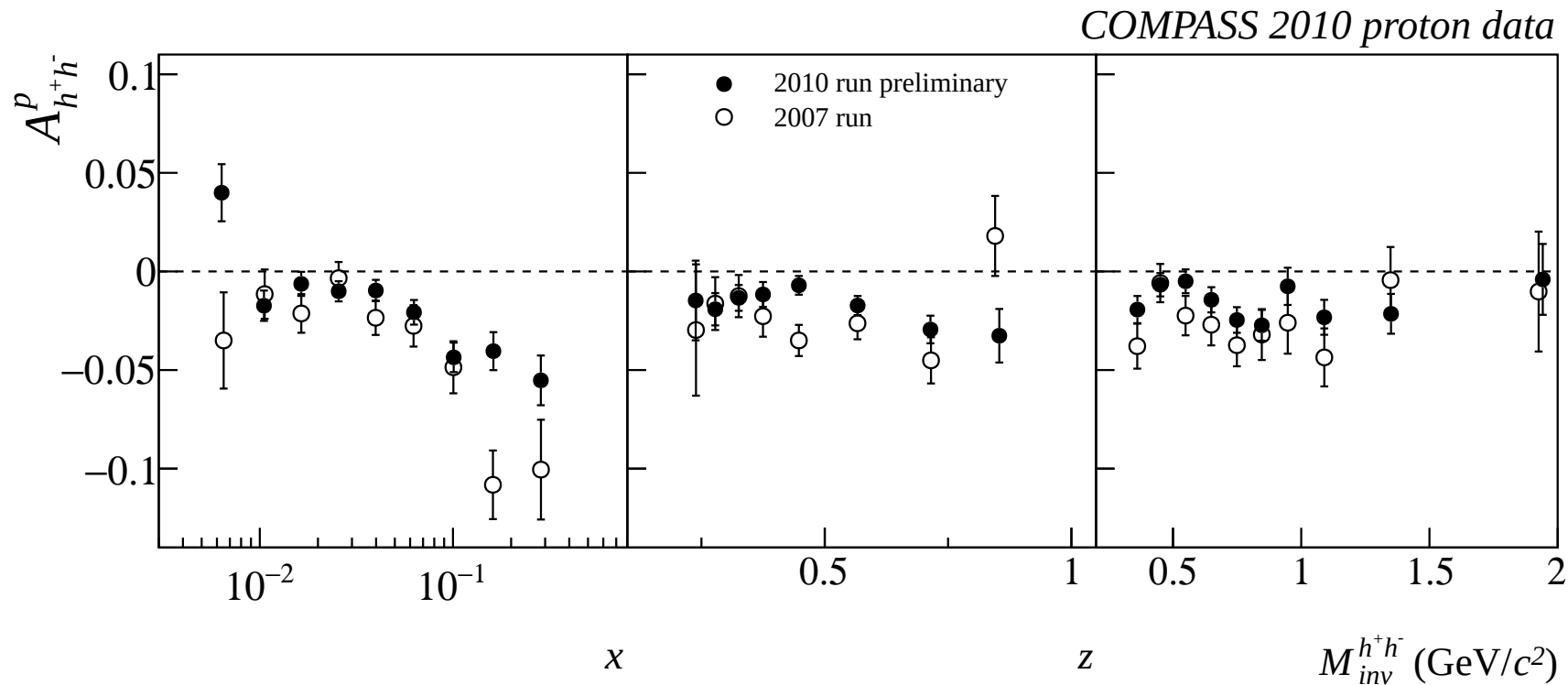
2010 proton data: kinematic mean values in z



2010 proton data: kinematic mean values in M_{inv}

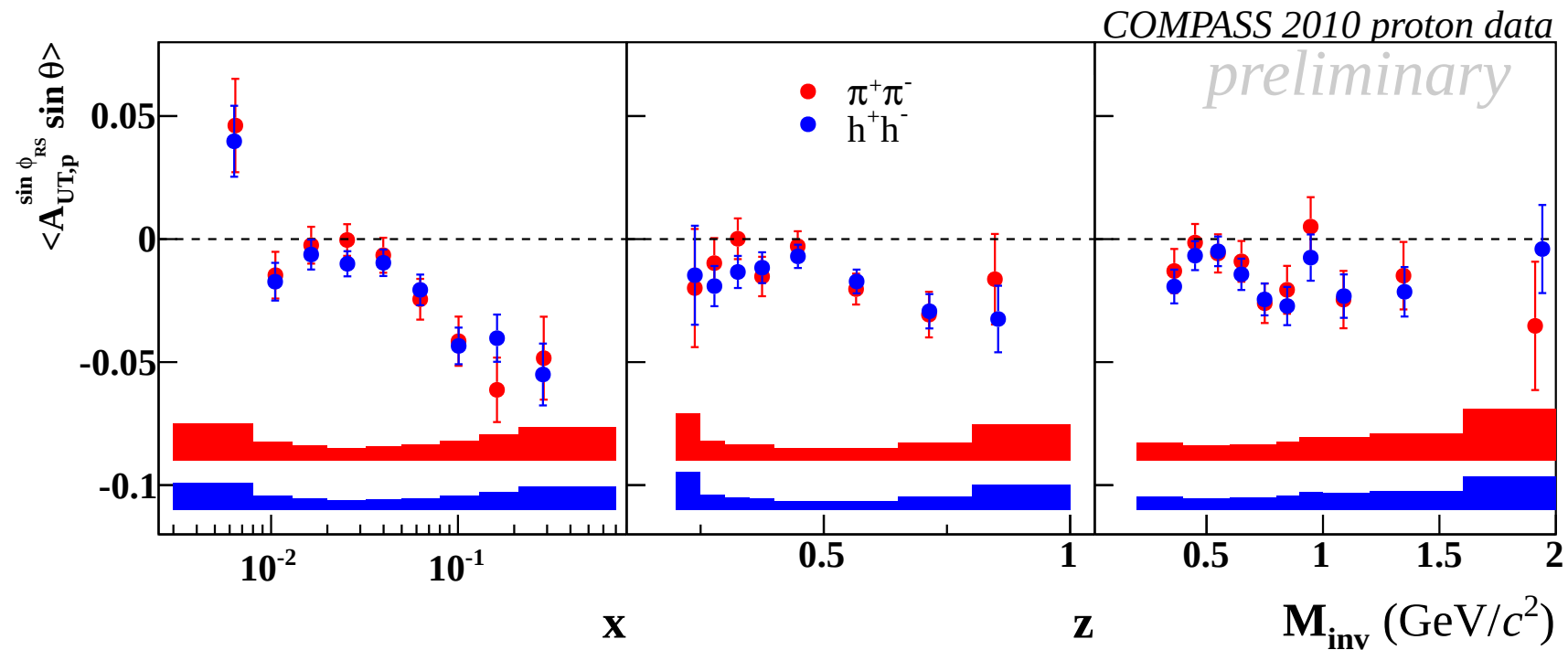


two-hadron asymmetries: comparison 2010 and 2007 proton data



↪ 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: comparison 2010 h^+h^- vs. $\pi^+\pi^-$



$\hookrightarrow h^+h^-$ follows mostly $\pi^+\pi^-$ signal