

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

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on behalf of the **COMPASS** collaboration

<sup>1</sup>Physikalisches Institut IV der Universität Erlangen-Nürnberg

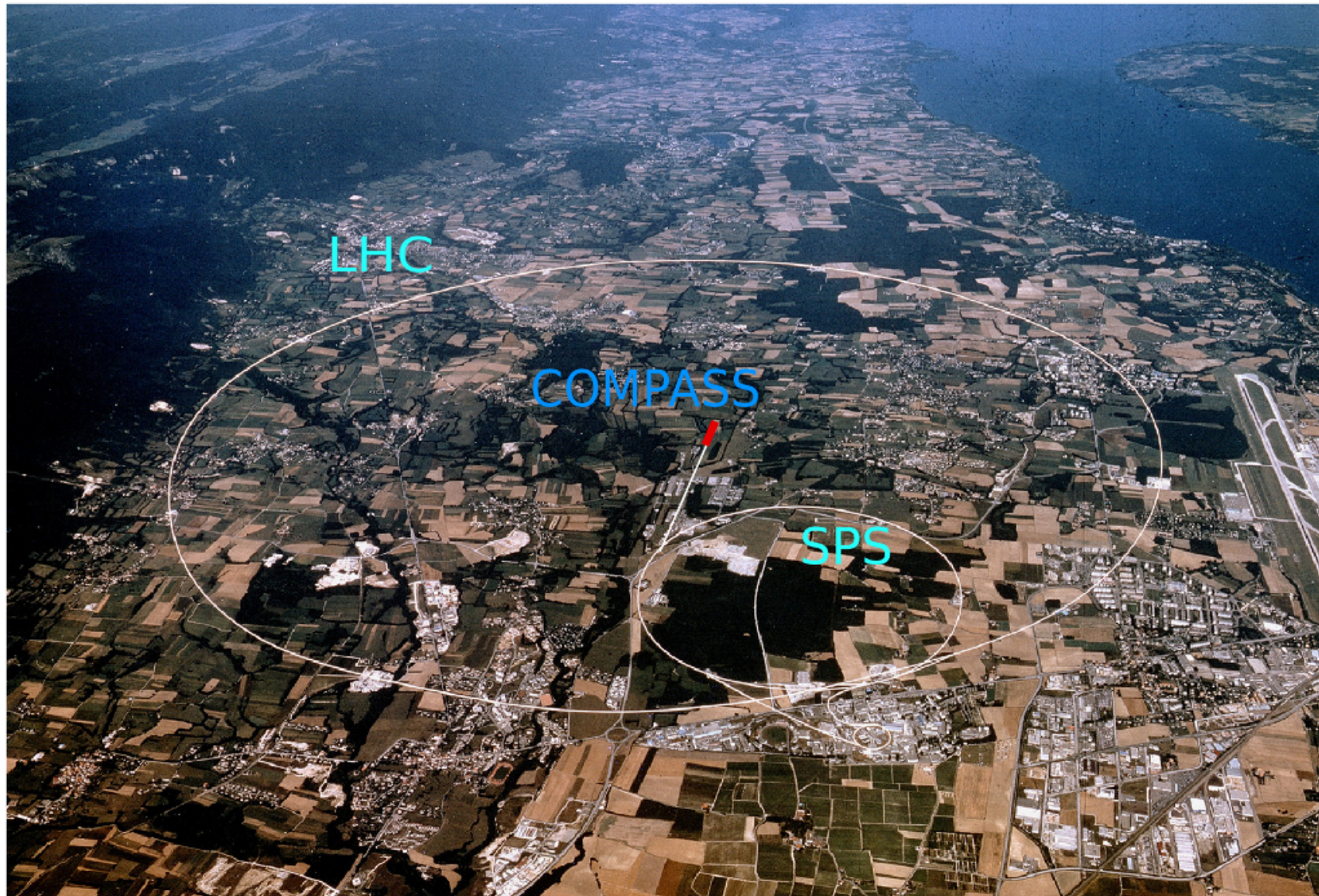
The 20<sup>th</sup> INTERNATIONAL SYMPOSIUM on Spin Physics,  
September 18<sup>th</sup> 2012, JINR, Dubna, Russia



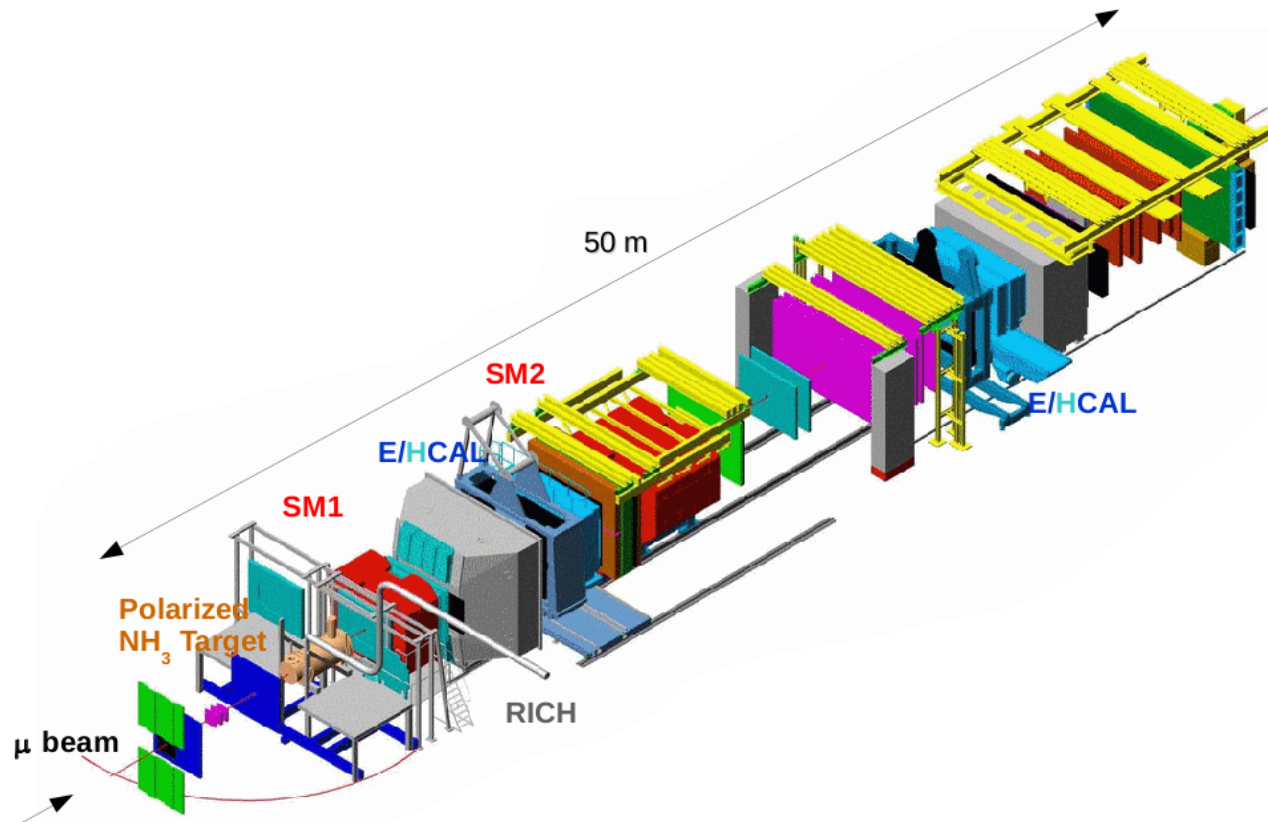
# Outline

- 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

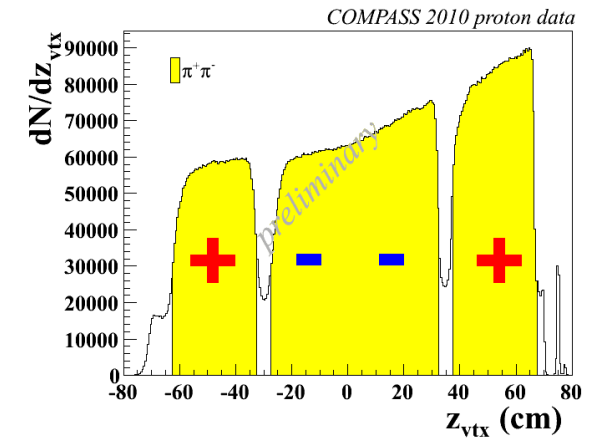
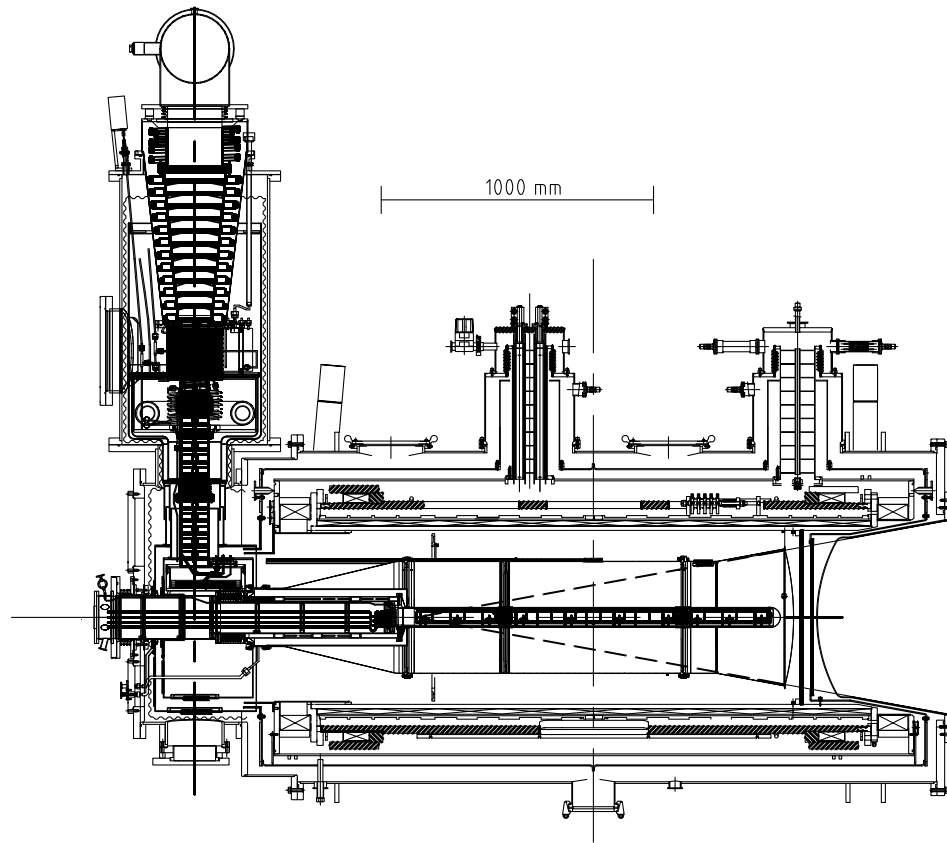


*e.g.*

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  $\mu^+$ -beam
- 2002 & '04 transversely polarized deuterium ( $^6\text{LiD}$ ) target
- '07, '10 & '11 transversely polarized proton ( $\text{NH}_3$ ) target
- Tracking
- Calorimetry
- PID (RICH)



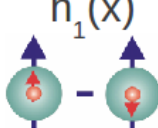
# The COMPASS target system



- Upgrade of target system in 2005
- Three cells with opposite polarization
- $\pm 180$  mrad geometrical acceptance
- Transverse polarization reversed every week via microwave
- deuteron  ${}^6\text{LiD}$ :
  - ▶ polarization  $\approx 47\%$
  - ▶ dilution factor  $\approx 0.38$
- proton  $\text{NH}_3$ :
  - ▶ polarization  $\approx 90\%$
  - ▶ dilution factor  $\approx 0.15$

# 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 FF<sup>1</sup>  $lN^\uparrow \rightarrow l'hX$

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

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

<sup>1</sup> see Anna Martin's talk



## Theoretical framework: two-hadron cross section

The differential two-hadron cross section is:

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

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

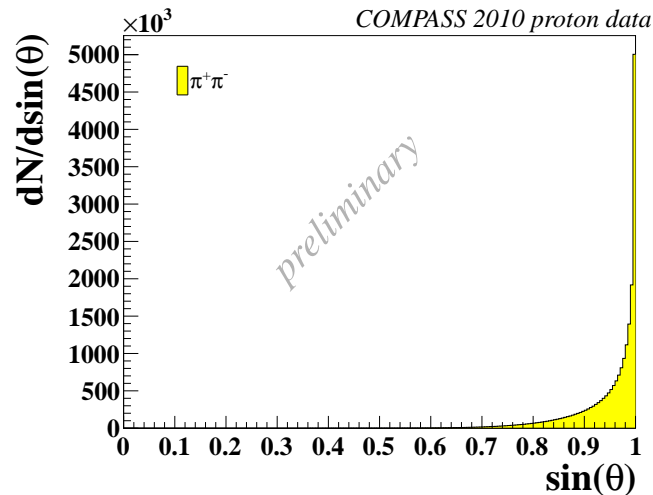
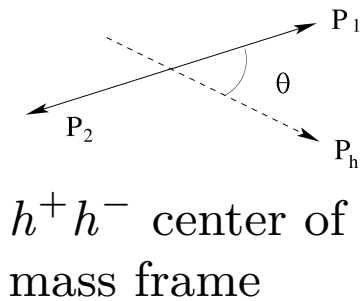
Where  $h_1(x)$  is the Transversity PDF and  $H_{1,q}^{\triangleleft}$  is the two-hadron Interference FF, which describes the Fragmentation of a transversely polarized quark into two unpolarized hadrons.  $D_{1,q}$  is the unpolarized two-hadron fragmentation function<sup>2</sup>.

<sup>2</sup> see Nour Makke's talk on hadron multiplicities



# Theoretical framework: asymmetries extraction

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



$\sigma_{UU}$  = unpolarized cross section  
 $\pm$  indicates nucleon spin orientation  
 $f$  = target dilution factor  
 $P_T$  = target polarization  
 $D_{NN}$  = transv. spin transfer coef.  

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

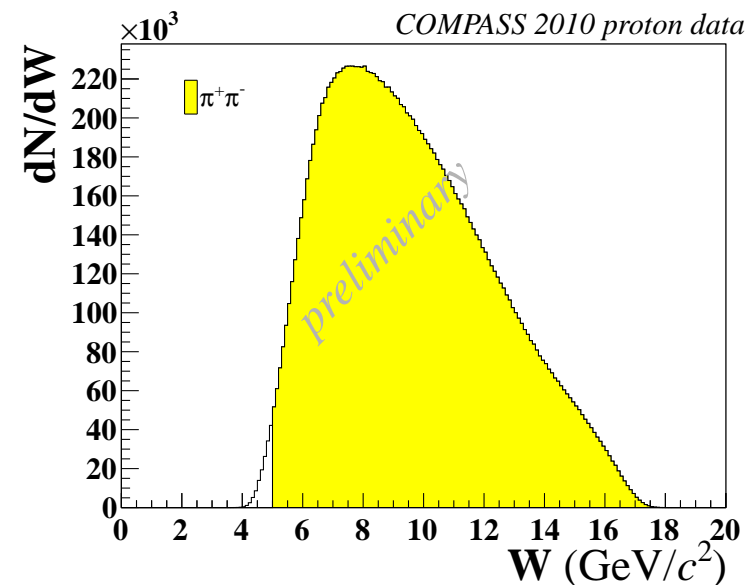
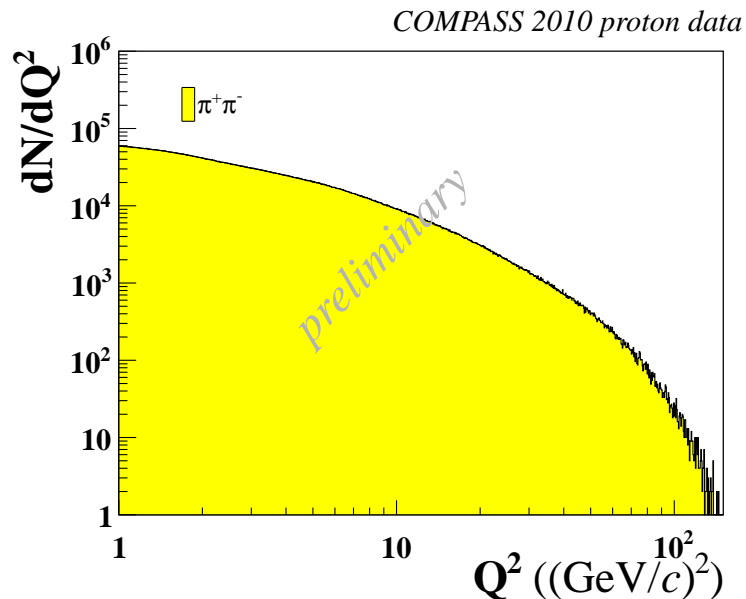
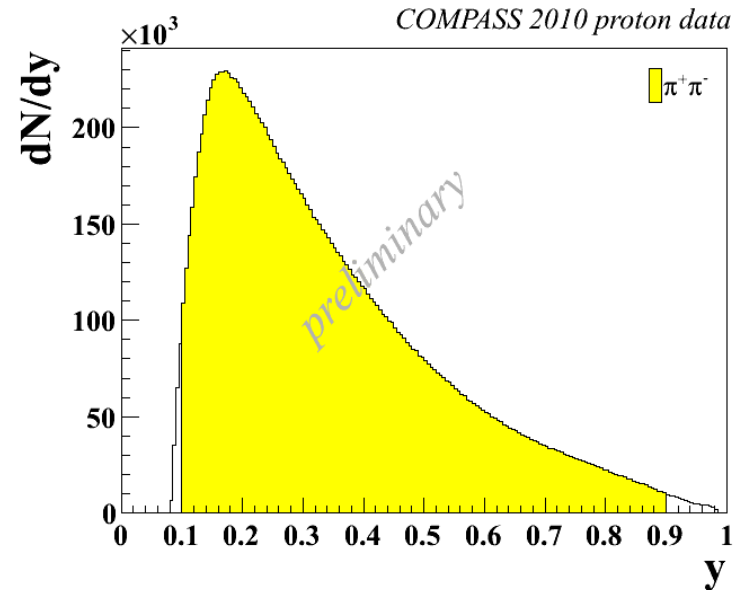
$\langle \sin \theta \rangle = 0.943$   
 $\Rightarrow$  can be neglected

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

# Data selection 2010: DIS cuts

## DIS cuts on events:

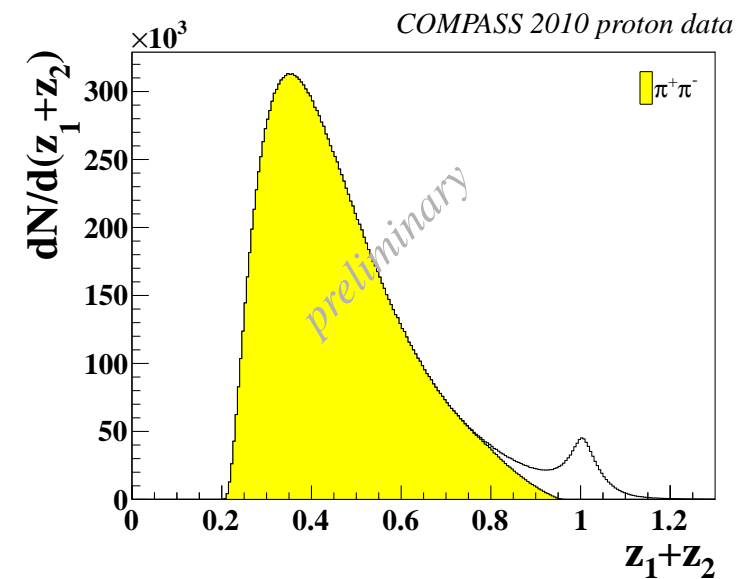
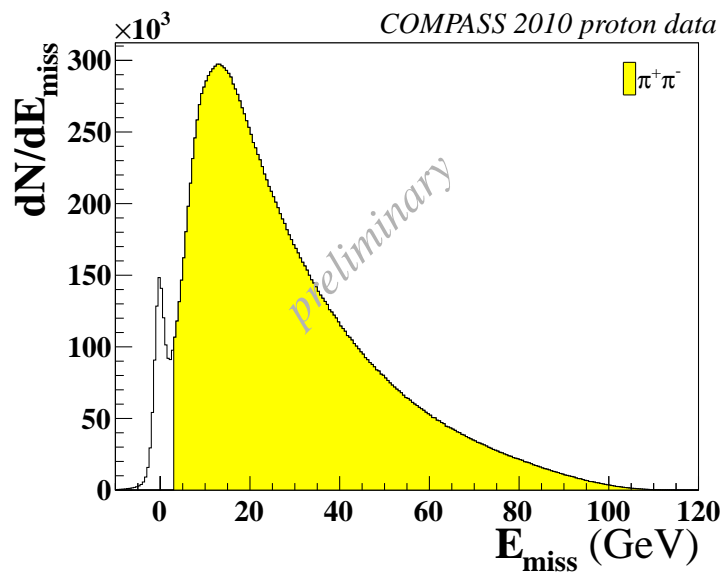
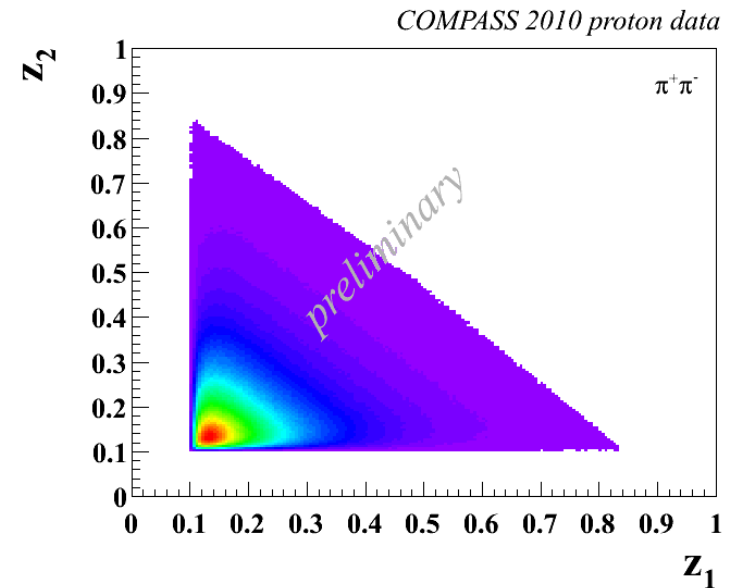
- $Q^2 > 1 \text{ (GeV/c)}^2$
  - $0.1 < y < 0.9$
  - $W > 5 \text{ GeV/c}^2$
- spectrometer acceptance:  
 $0.003 < x < 0.7$



# Data selection 2010: hadron & hadron pair cuts

## hadron & hadron pair cuts:

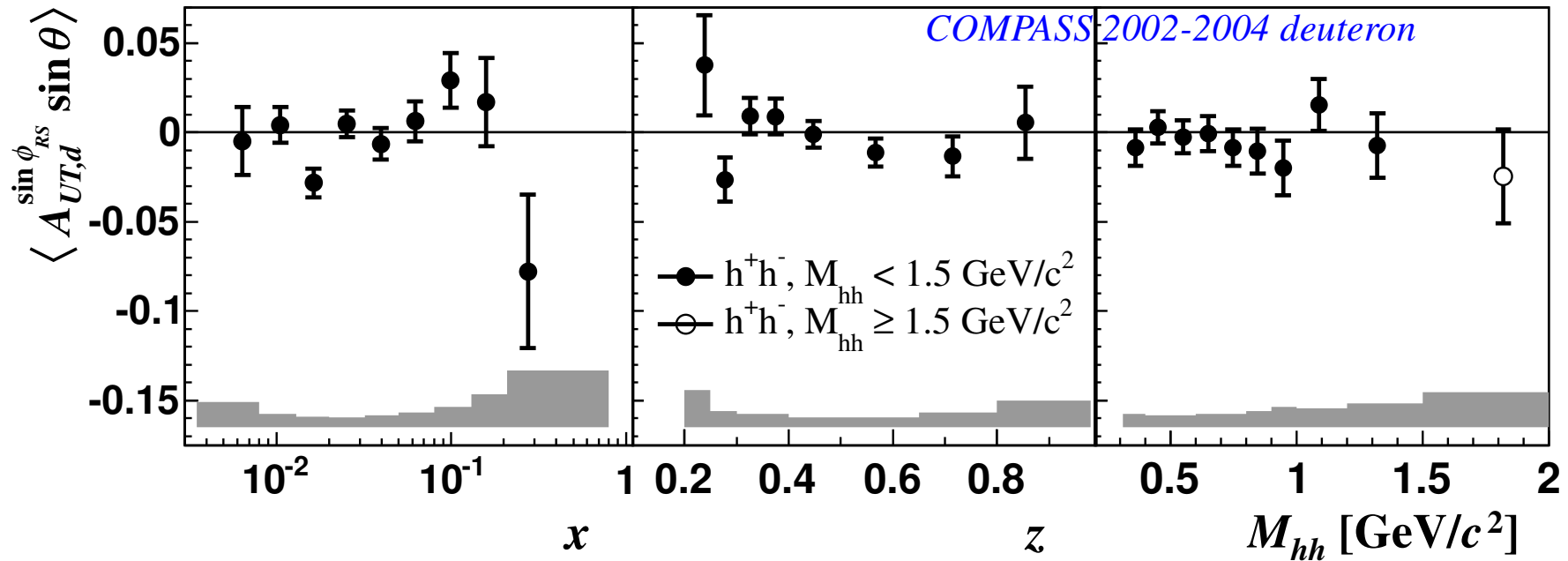
- at least 2 outgoing hadrons with opposite charge
- $z > 0.1$  for each hadron
- $x_F > 0.1$  for each hadron
- $E_{miss} > 3 \text{ GeV}/c^2$  for each pair
- $R_T > 0.07 \text{ GeV}/c$  for each pair



two-hadron asymmetries:

deuteron data 2002-04

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



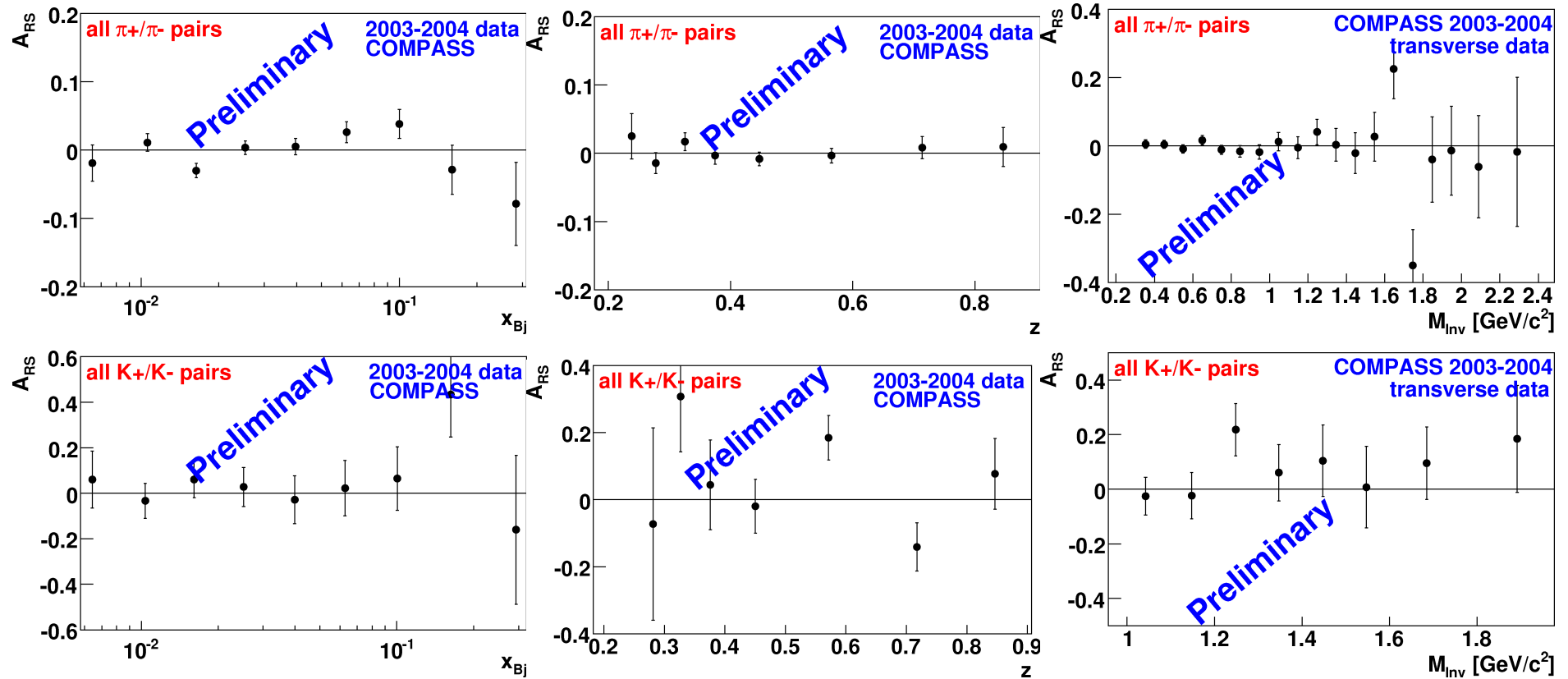
COMPASS Collaboration C. Adolph *et. al.*, Phys. Lett. B **713** (2012) 10-16, arXiv:1202.6150

↪ 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



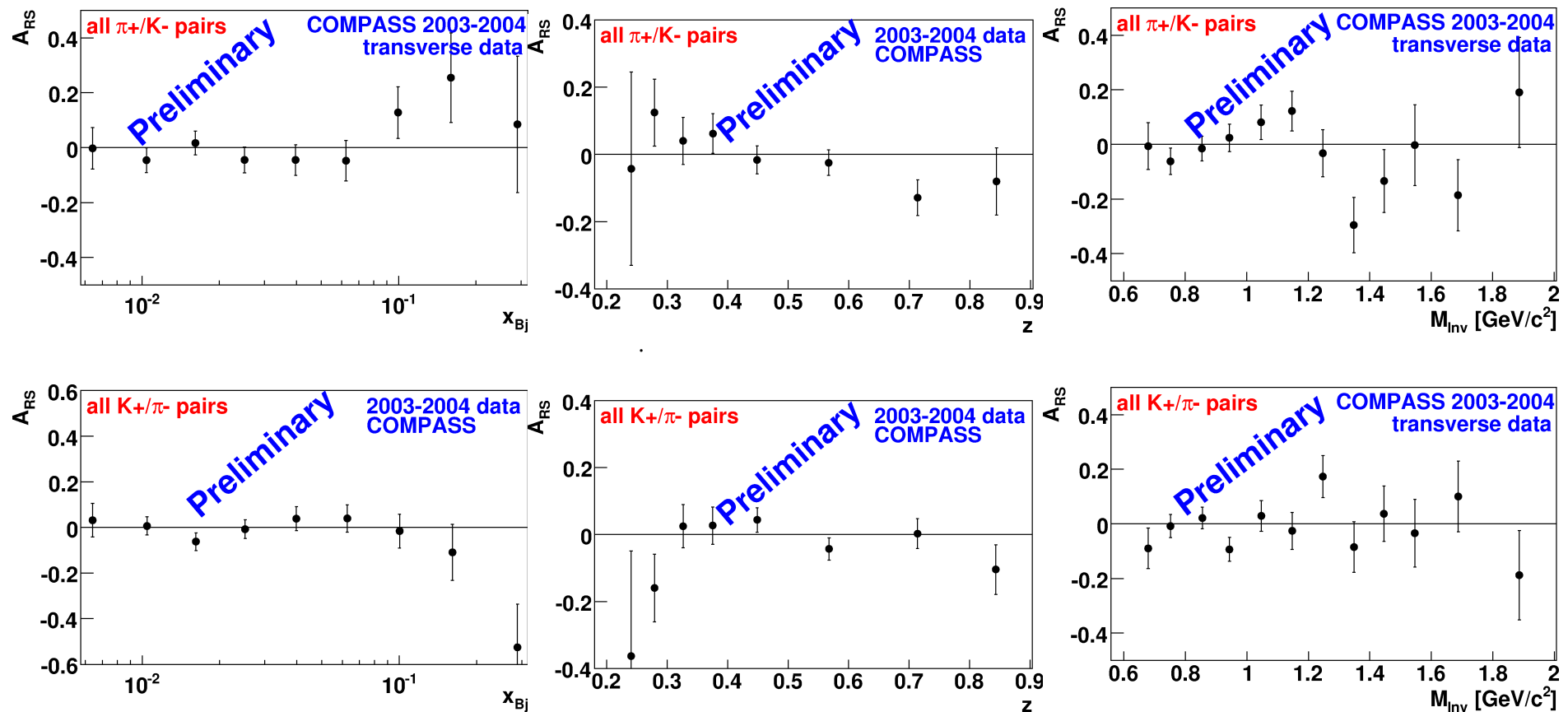
2002-04 deuteron data 2-hadron asymmetries:  $\pi^+\pi^-$  pairs (top),  $K^+K^-$  pairs (bottom)

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

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

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

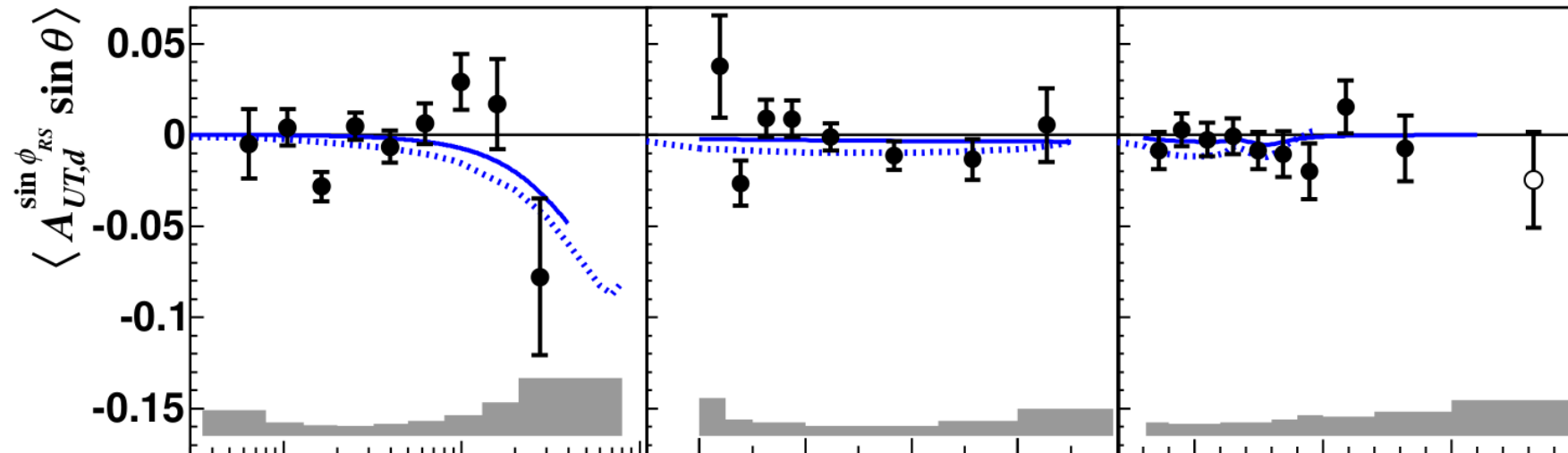
# deuteron data 2002-04: $\pi^+ K^-$ & $K^+ \pi^-$ pairs



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

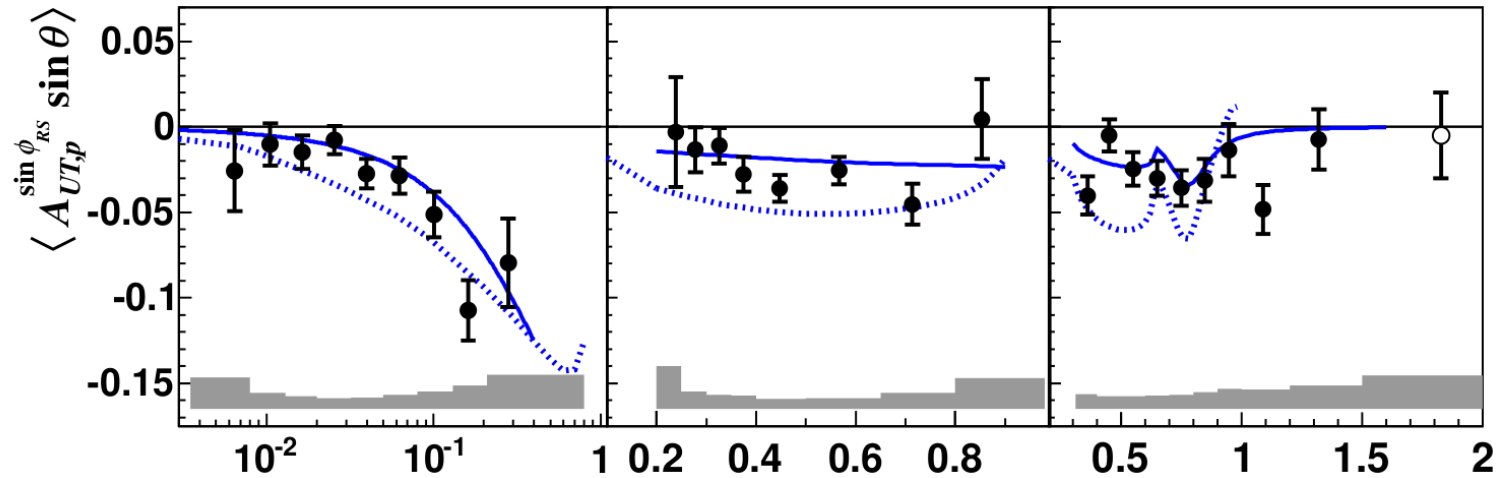
Bacchetta *et al.* hep-ph/0708037



two-hadron asymmetries:

proton data 2007

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

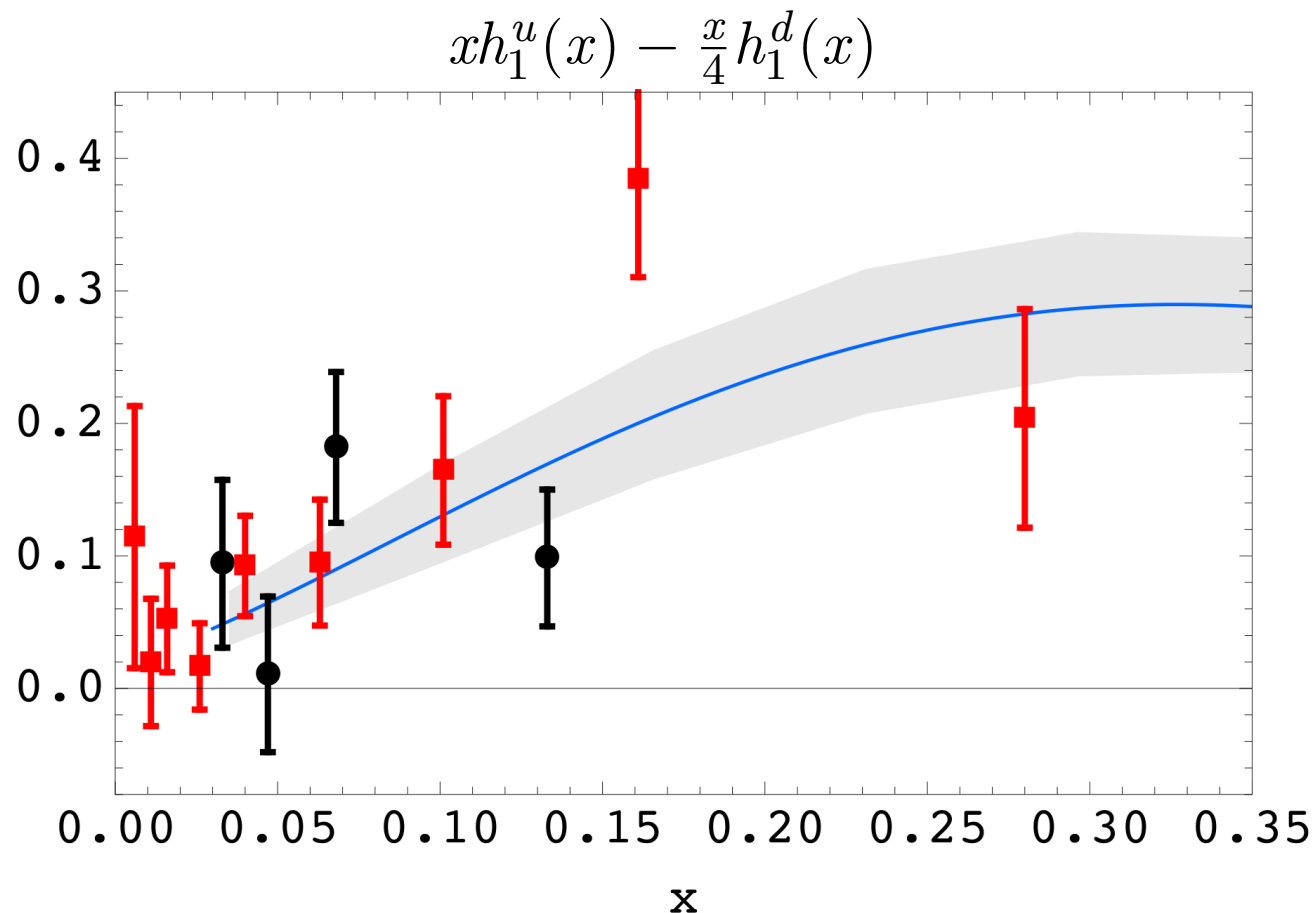


↪ Large asymmetries for proton up to 5 – 10%

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

# proton data 2007: 1<sup>st</sup> extraction of “a linear combination“ of transversity ”PDFs“

A. Bacchetta, 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



# 1<sup>st</sup> 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"

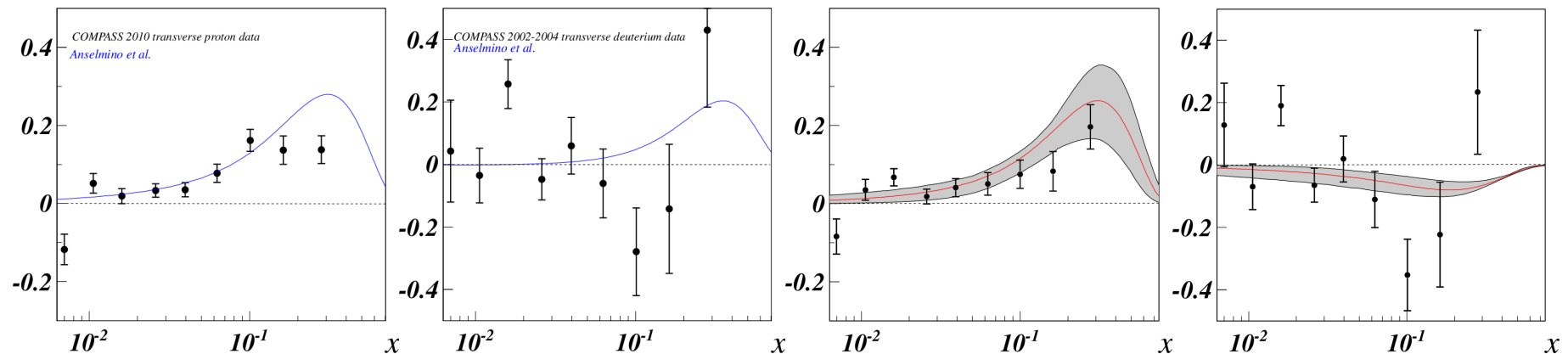
→  $u$  and  $d$  transversity PDFs can be extracted using COMPASS deuterium and 2010 proton data

$$xh_1^u(x) - \frac{x}{4}h_1^d(x)$$

$$xh_1^u(x) - xh_1^d(x)$$

$$xh_1^u(x)$$

$$xh_1^d(x)$$



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

See Alessandro Bacchetta's talk and

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

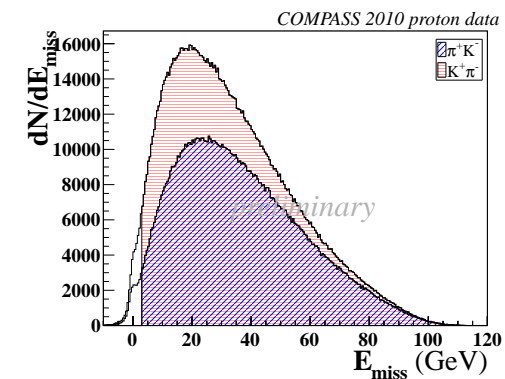
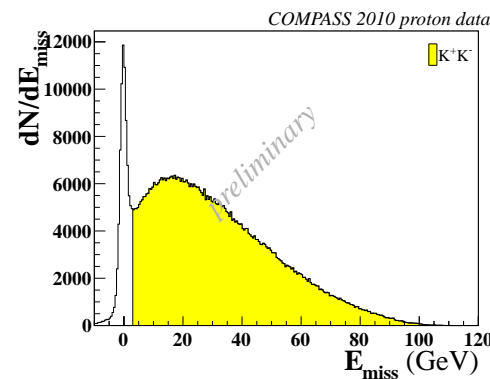
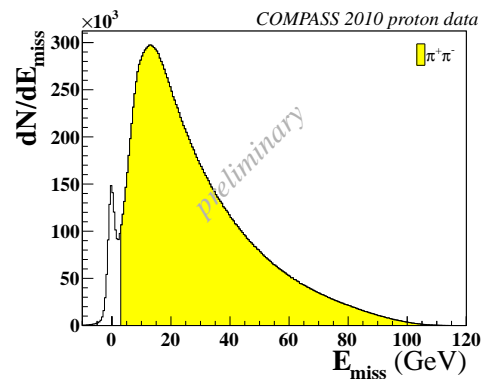
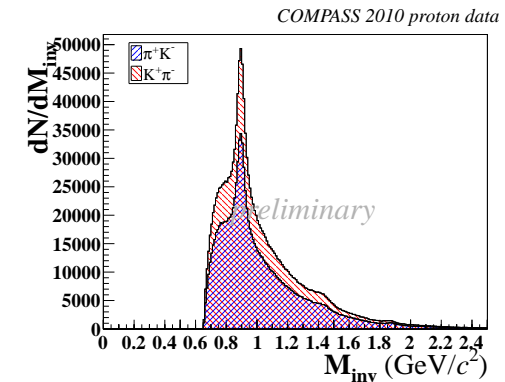
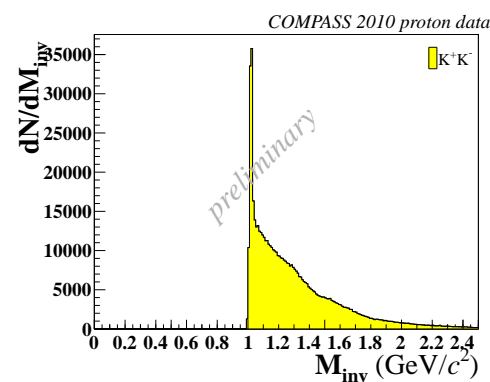
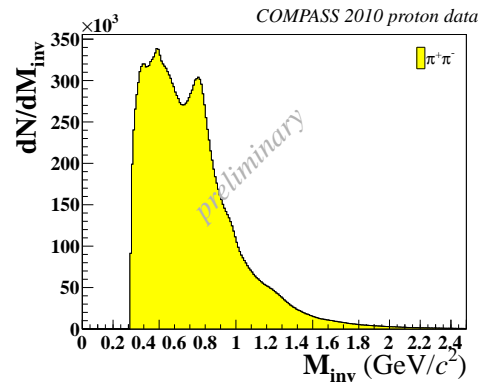
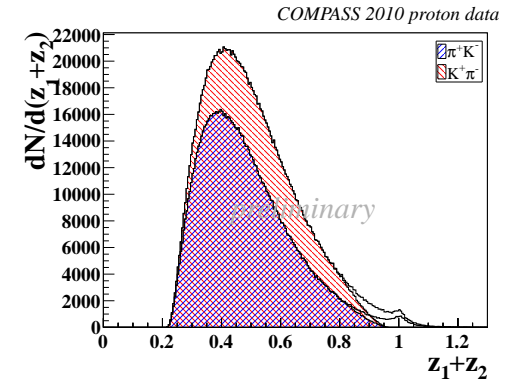
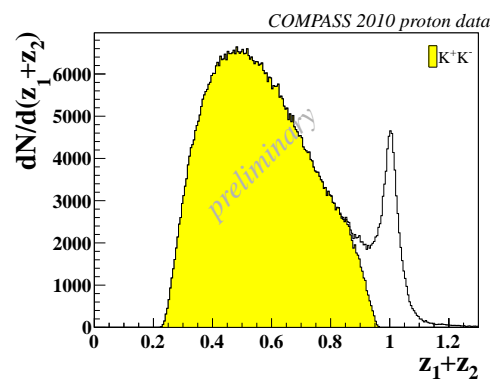
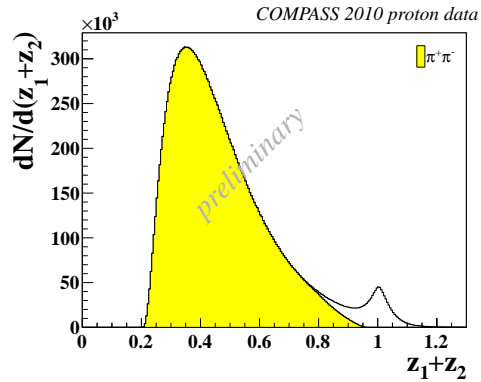
# Identified hadron pairs: kin. distributions $z_1 + z_2$ , $M_{inv}$ and $E_{miss}$

**NEW:**

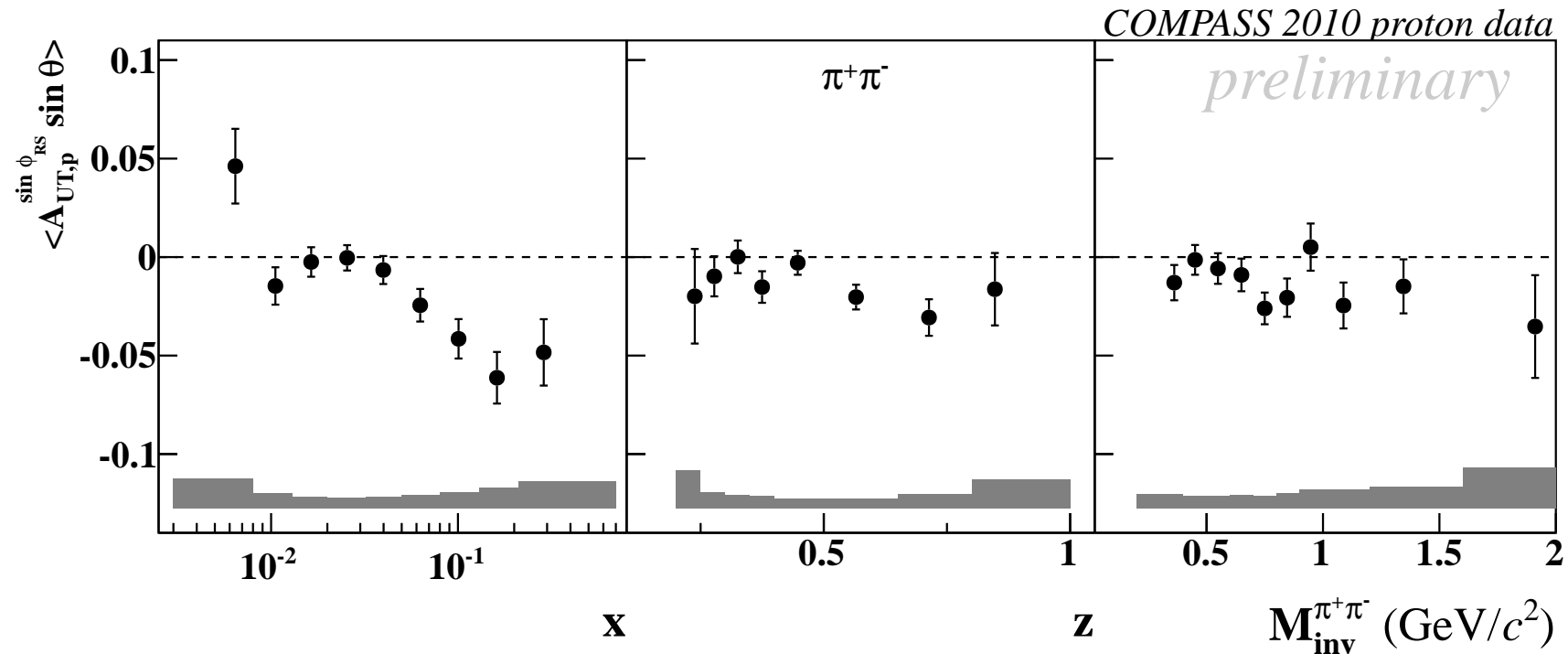
$\pi^+ \pi^-$

$K^+ K^-$

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



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



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

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

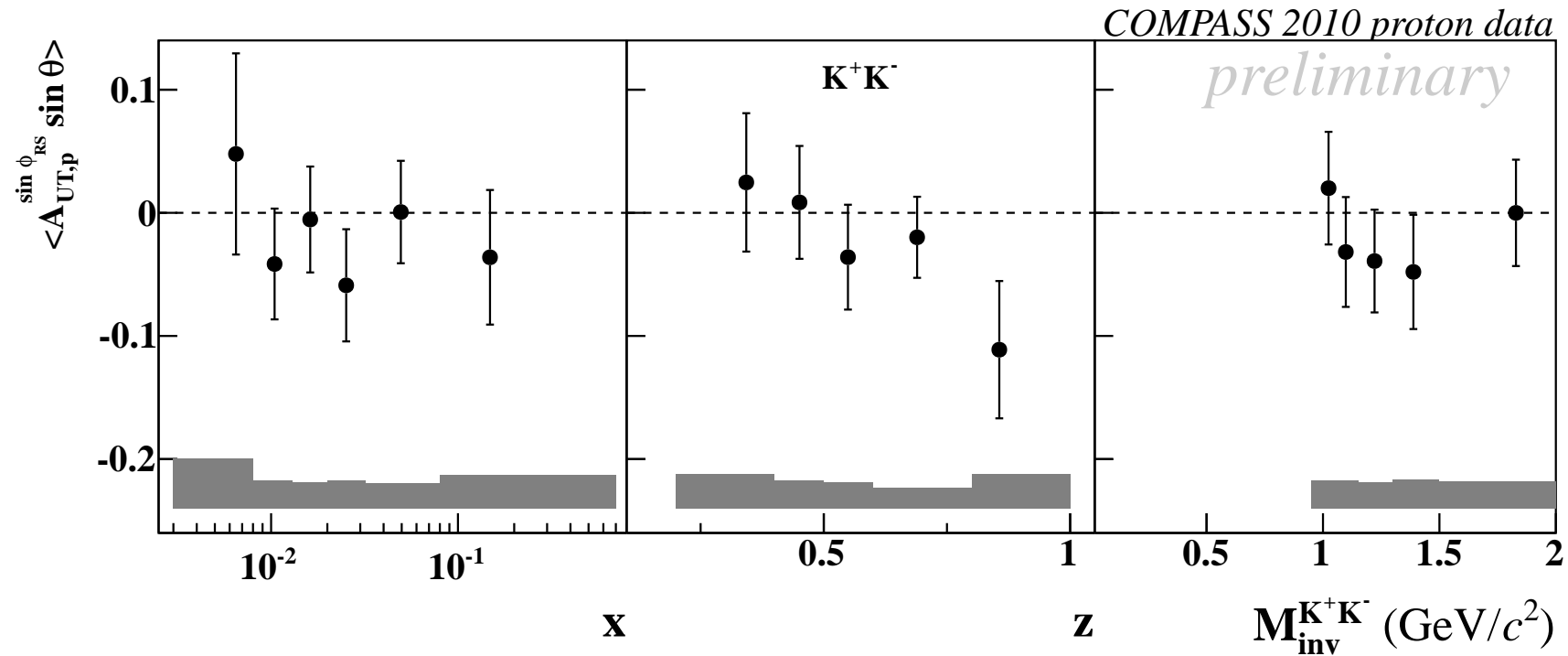
$x$  up to 6 %

$z$  compatible with a constant function

$M_{inv}$  peak around  $\rho_0$  mass



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



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

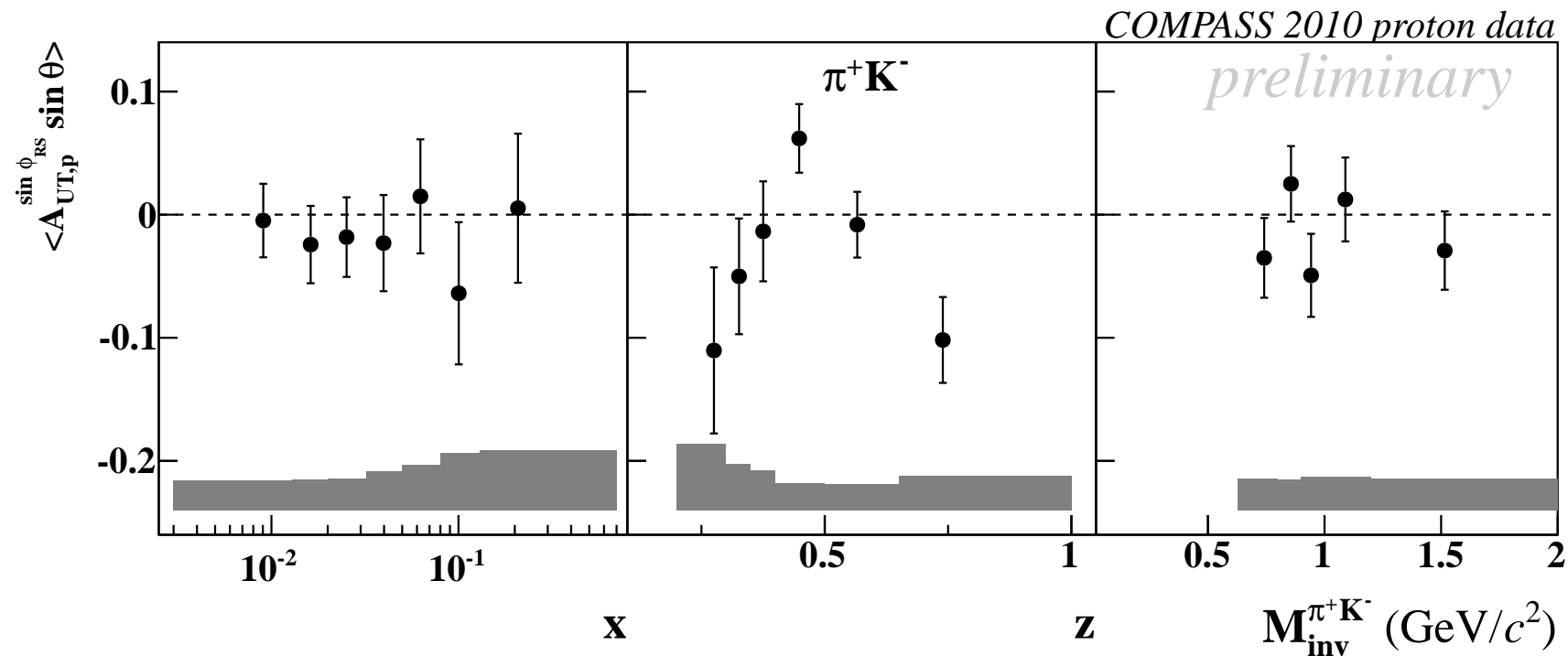
↪ no clear trend & compatible with 0 within the statistical errors

$x$  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

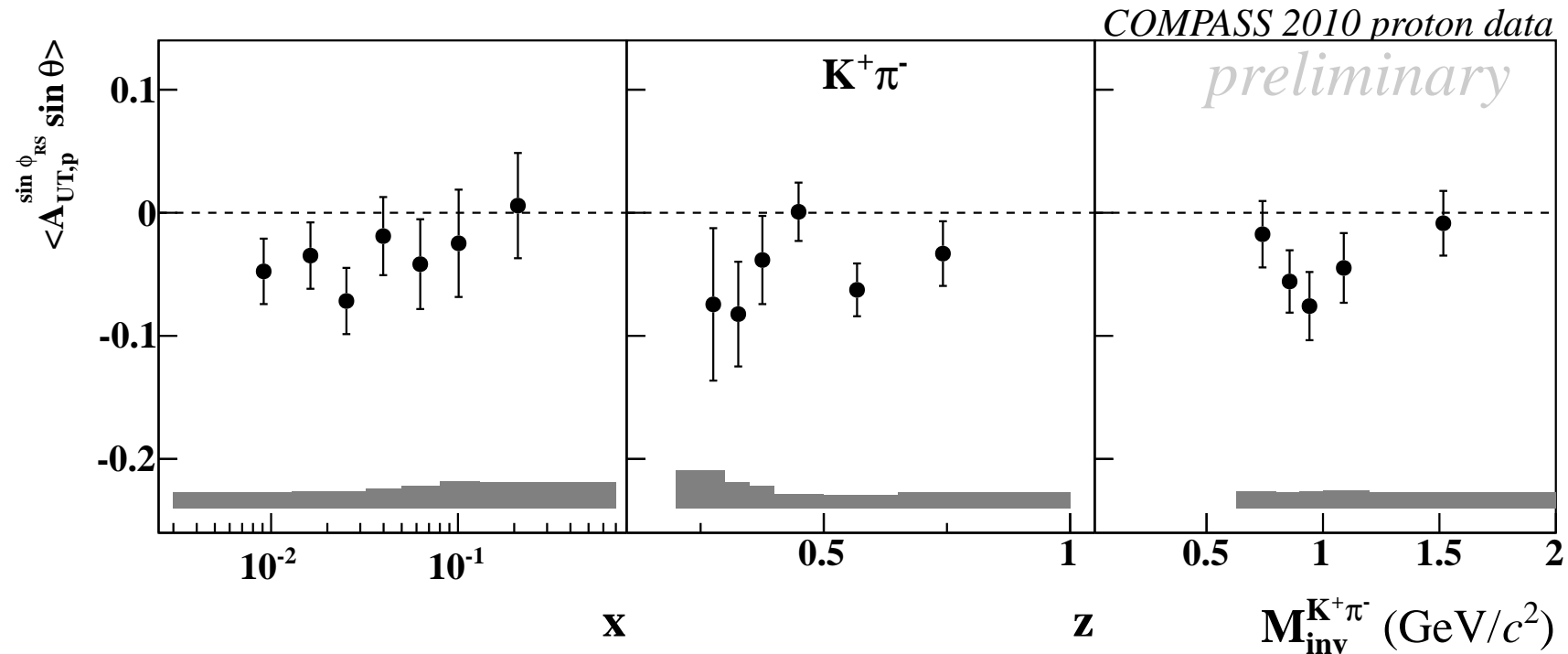
$\hookrightarrow$  no clear trend & compatible with 0 within the statistical errors

$x$  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

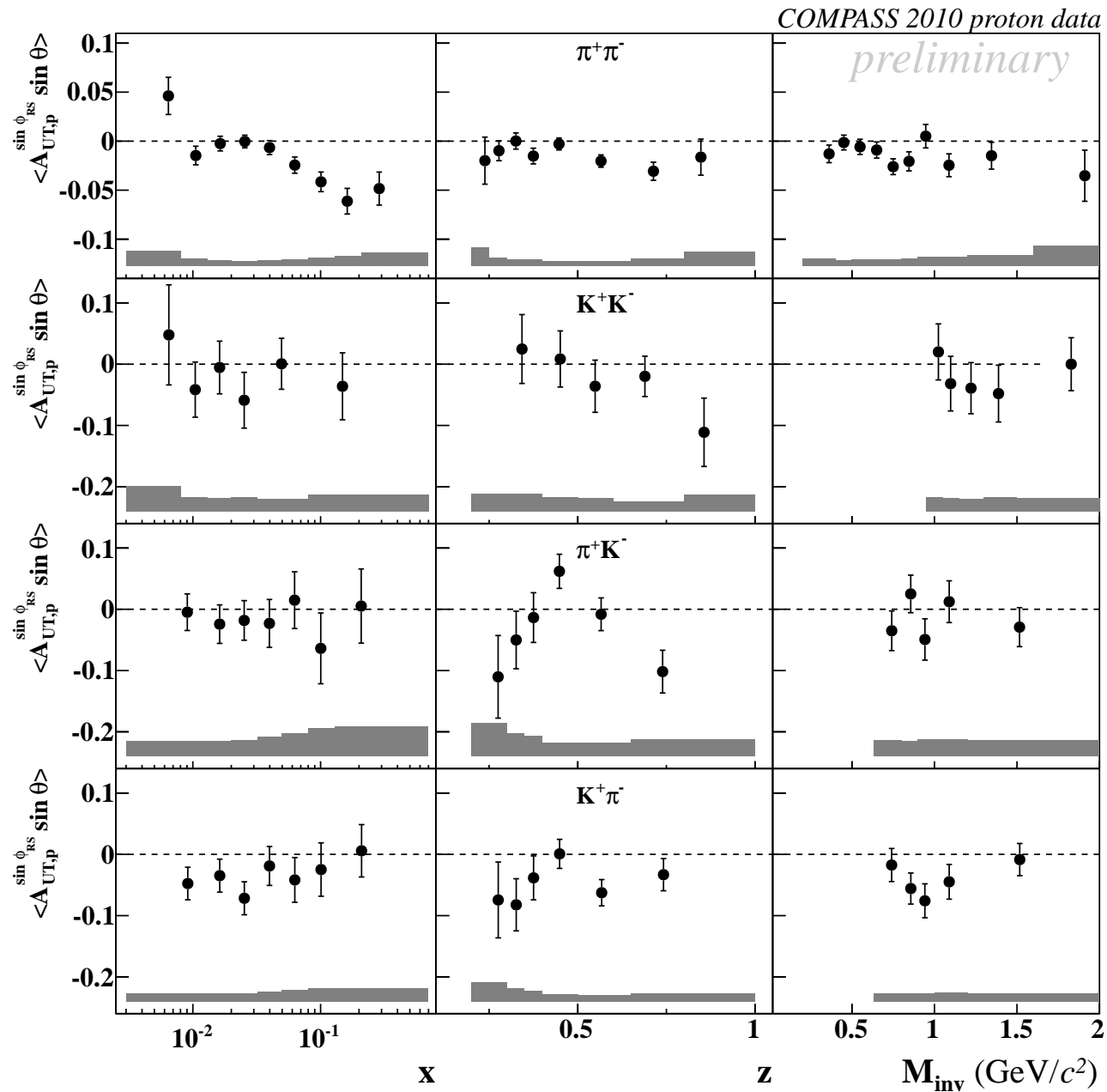
↪ compatible with 0 within the statistical errors

$x$  negative mean value

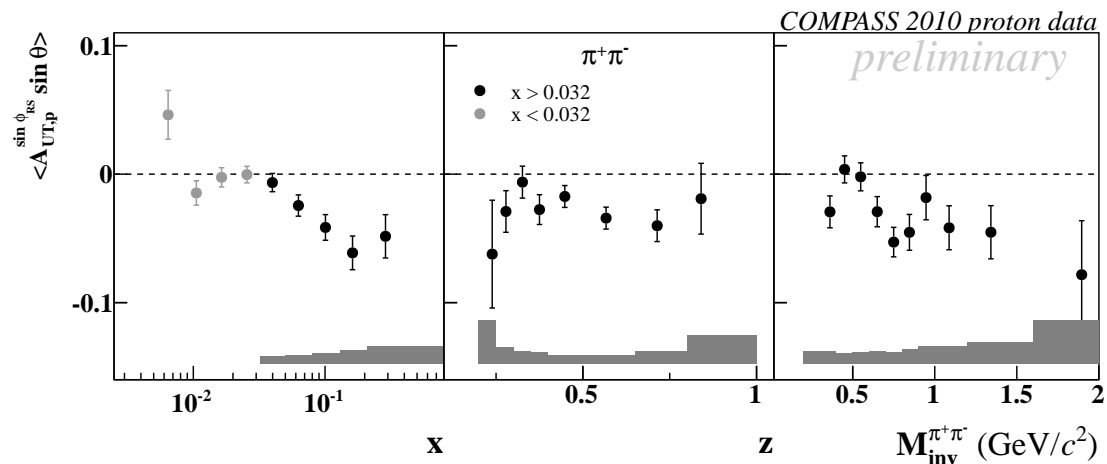
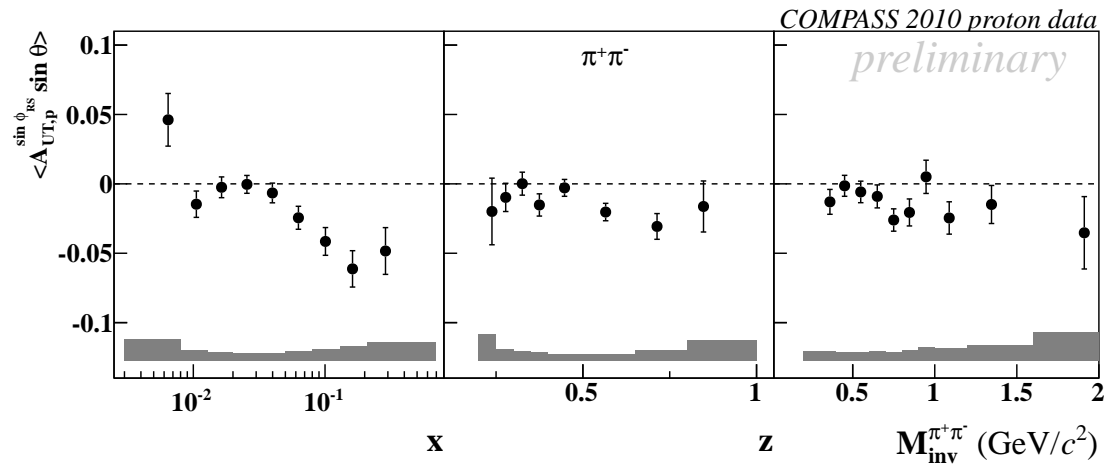
$z$  negative mean value

$M_{inv}$  negative peak peak around 0.9 GeV/c<sup>2</sup>

# NEW: identified two-hadron asymmetries: proton data 2010



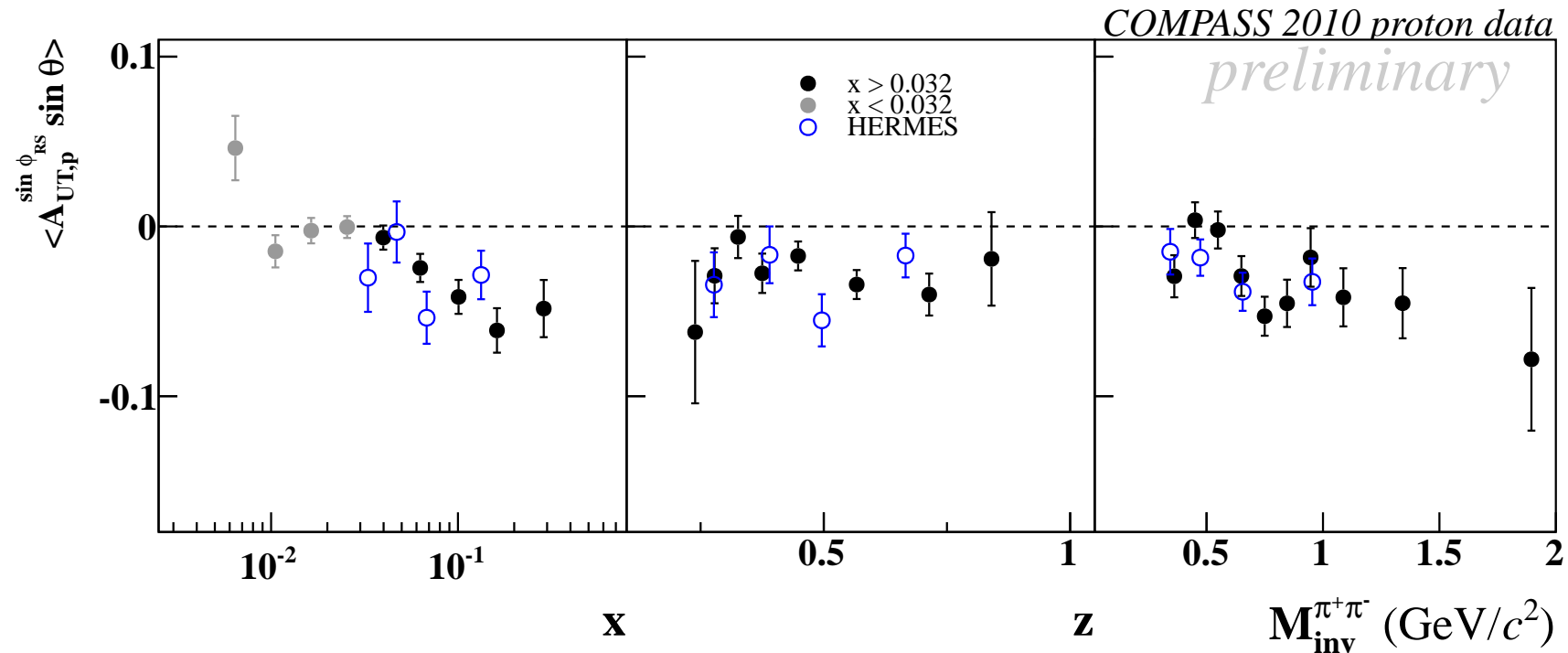
# NEW: proton data 2010 $\pi^+\pi^-$ valence region



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

clear signal around  $\rho_0$  mass is pronounced in valence region sample

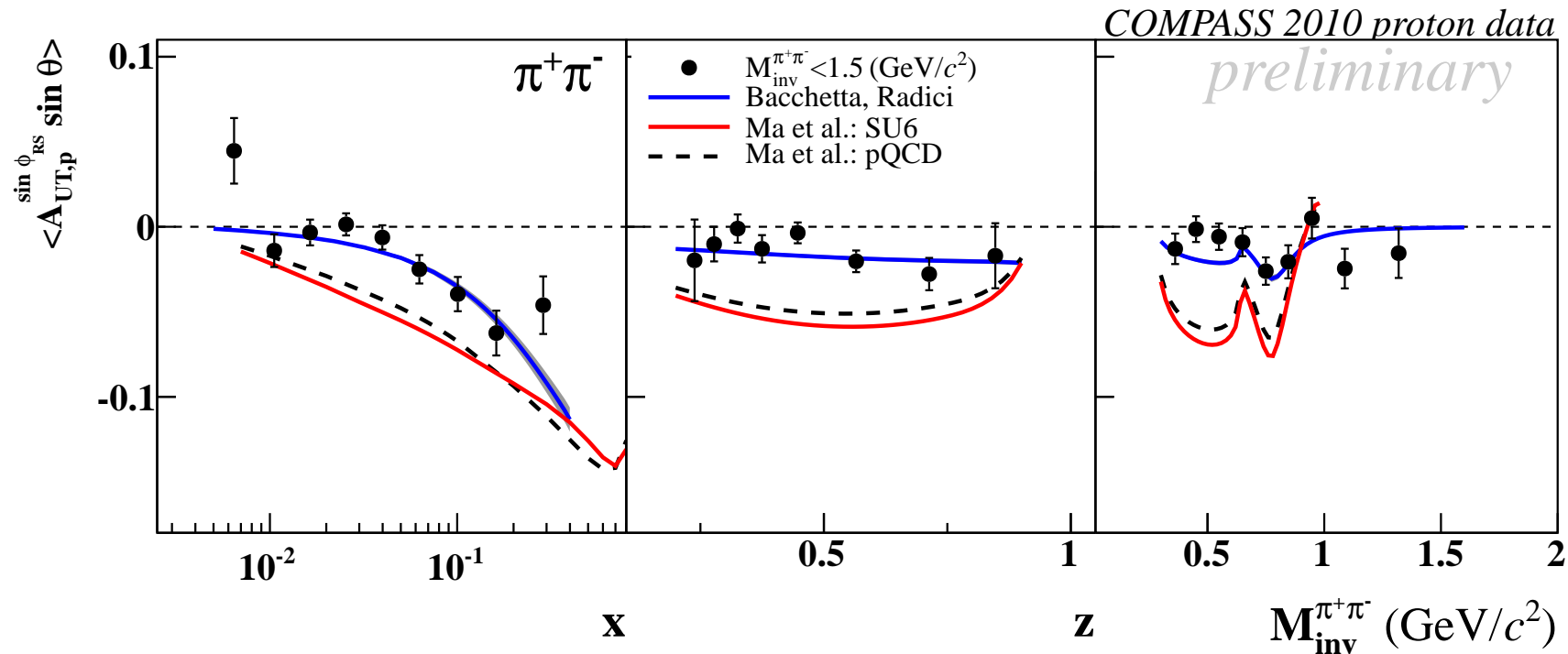
# NEW: Comparison of $\pi^+\pi^-$ with results from HERMES



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

↔ Good agreement of COMPASS  $\pi^+\pi^-$  data, with it's higher precision, with HERMES  $\pi^+\pi^-$  data within the error bars

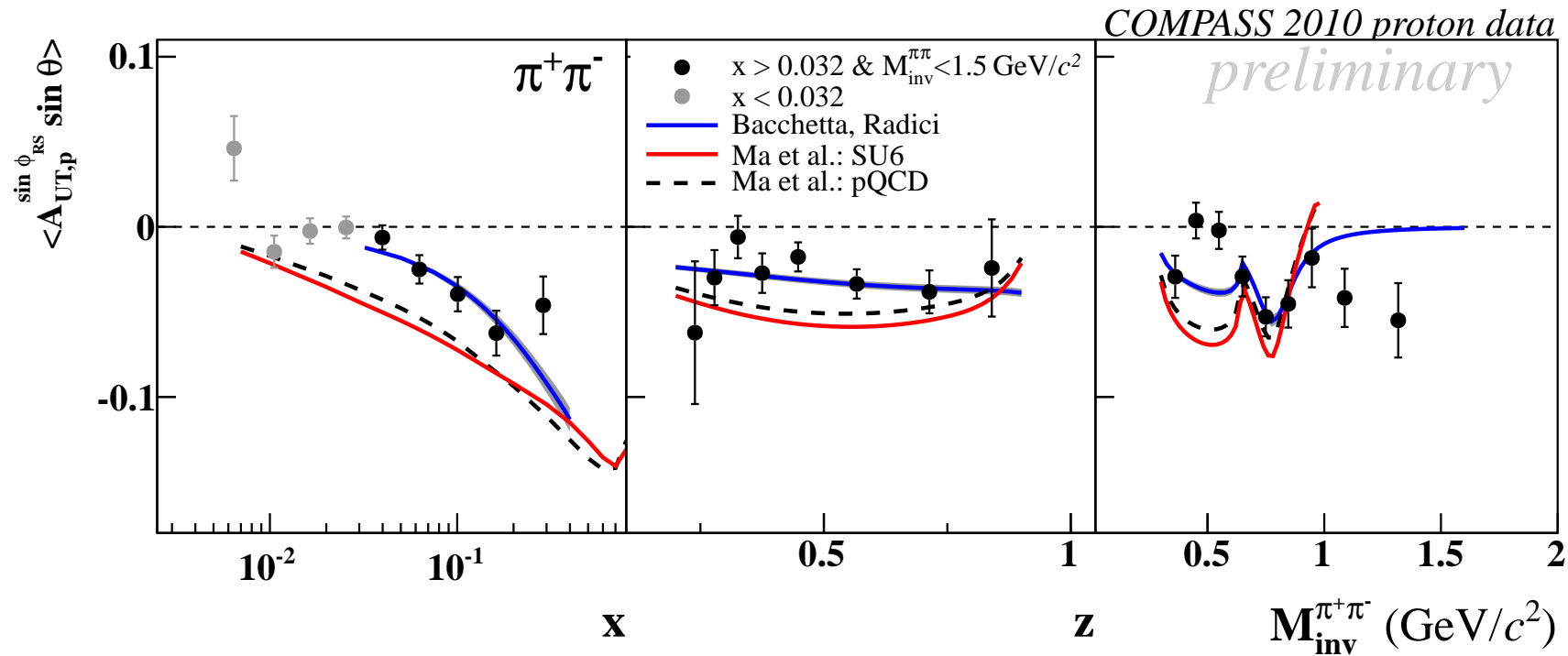
# NEW: 2010 proton data comparison with model predictions



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

- ↪  $x_{bj}$ : *Ma* trend confirmed | *Bachetta* good agreement
- ↪  $z$ : *Ma* too large | *Bachetta* compatible
- ↪  $M_{inv}$ : *Ma* too large | *Bachetta* good agreement around  $\rho_0$  mass

# NEW: comparison with model predictions in valence region



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

- ↪  $x_{bj}$ : Ma trend confirmed | Bachetta good agreement
- ↪  $z$ : compatible within the errors
- ↪  $M_{inv}$ : good agreement around  $\rho_0$  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
    - ▶  $K^+K^-$ ,  $\pi^+K^-$  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:

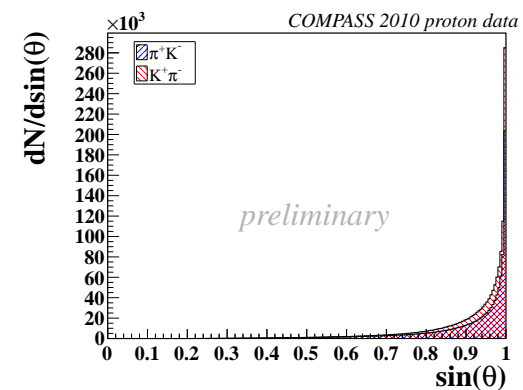
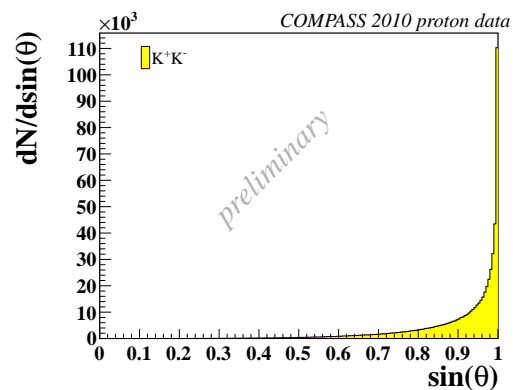
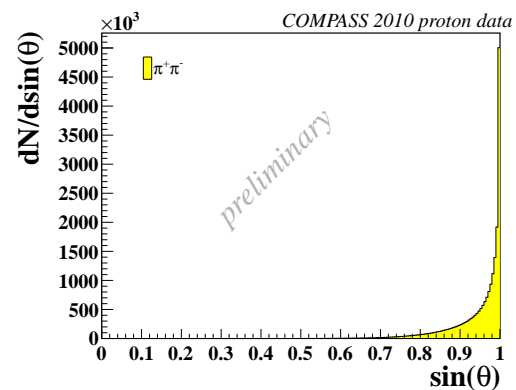
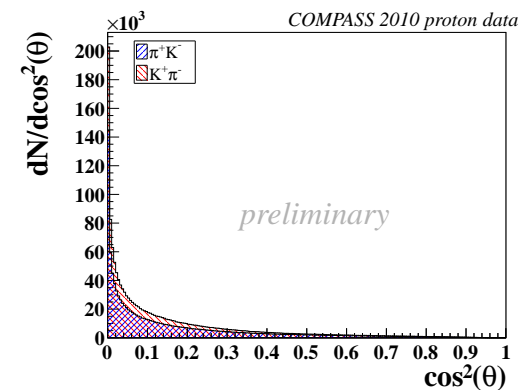
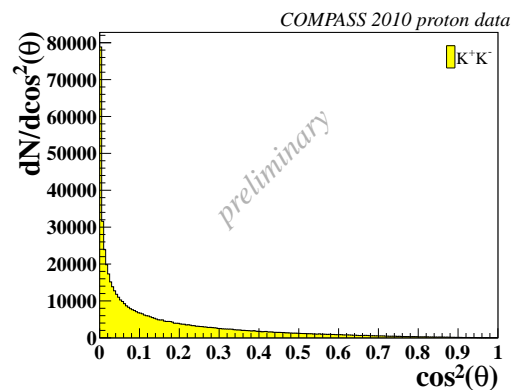
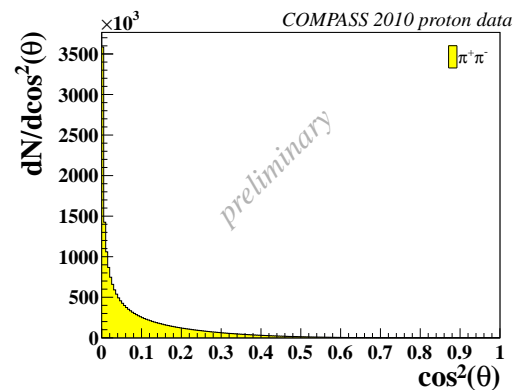
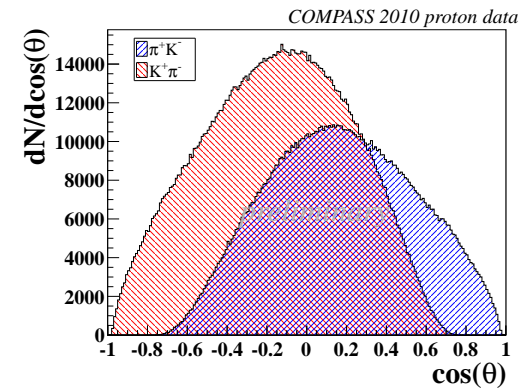
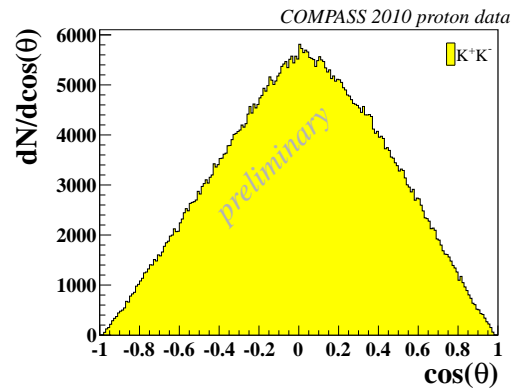
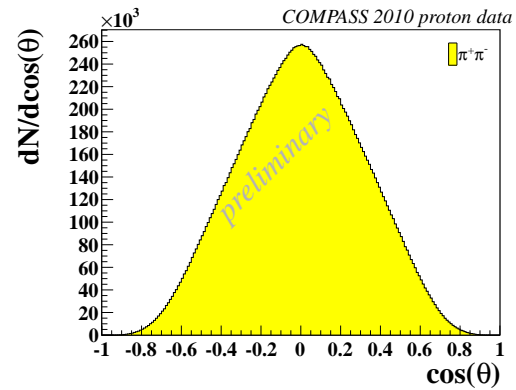
- COMPASS combined 2007/2010 results on identified two-hadron asymmetries

Thank you for your attention!

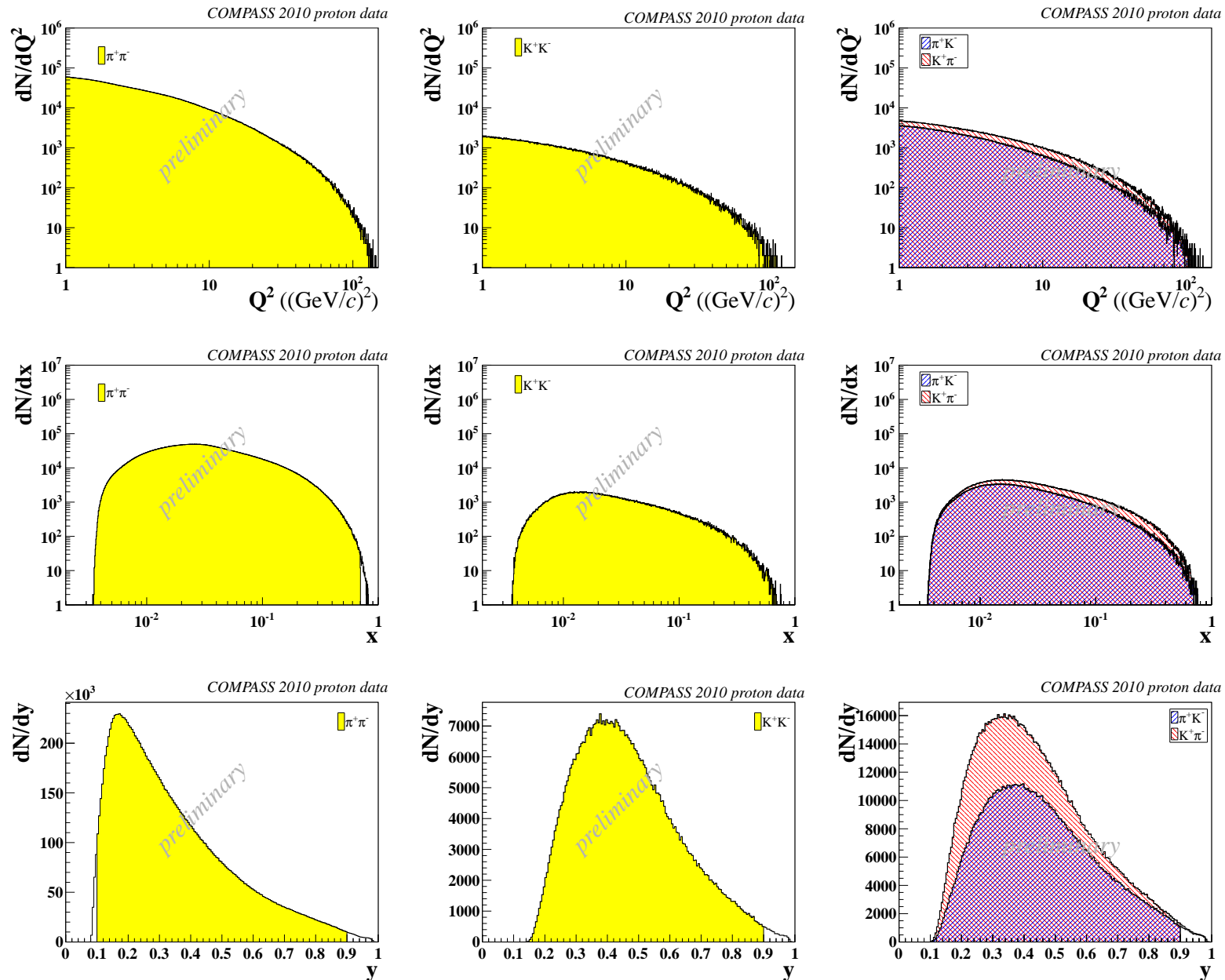
electronic address: [christopher.braun@cern.ch](mailto:christopher.braun@cern.ch)

Back up

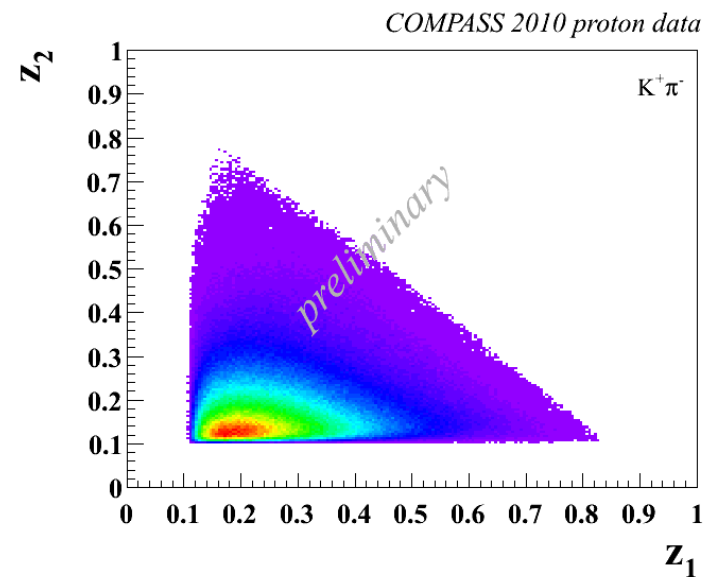
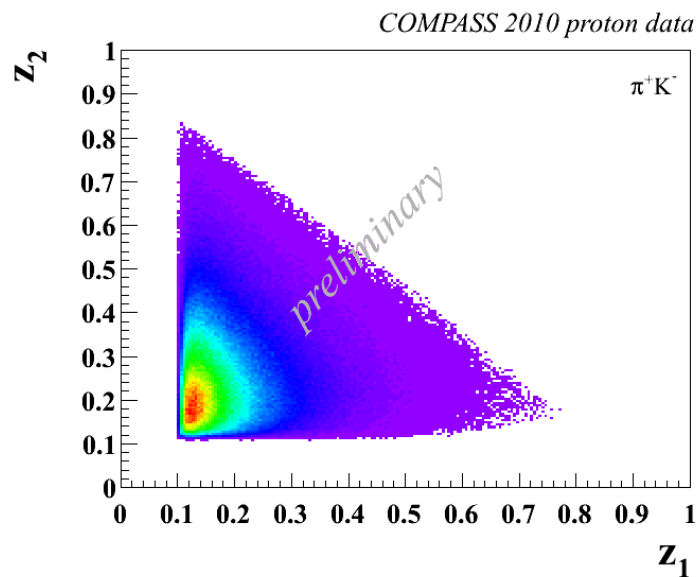
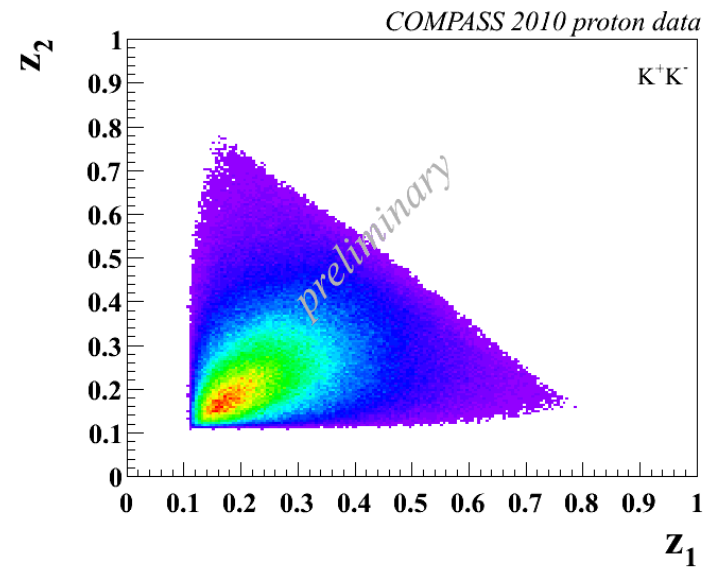
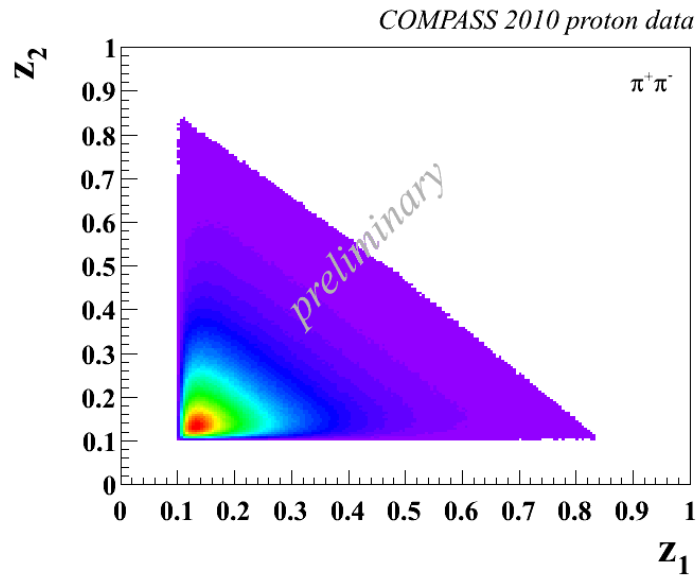
# Kinematic distributions of DIS events: $\cos \Theta$ , $\cos^2 \Theta$ and $\sin \Theta$



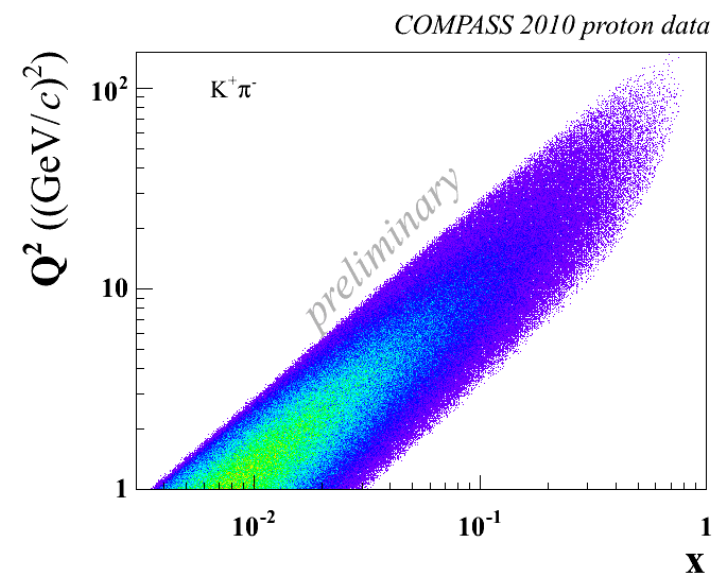
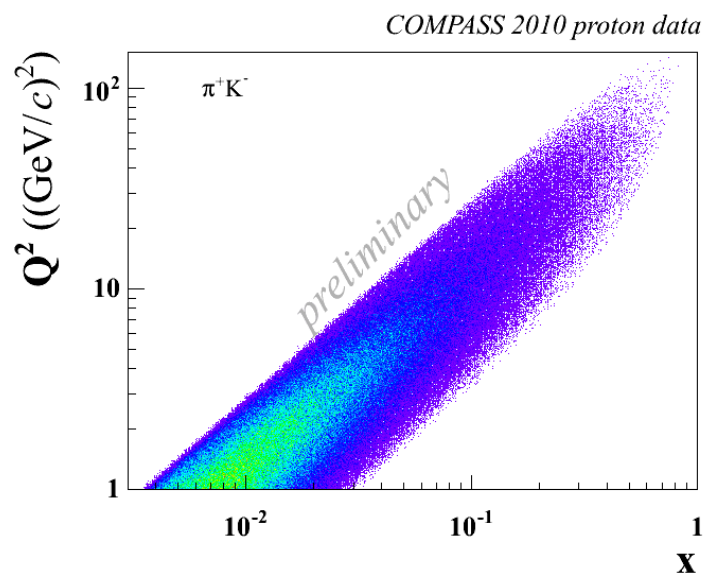
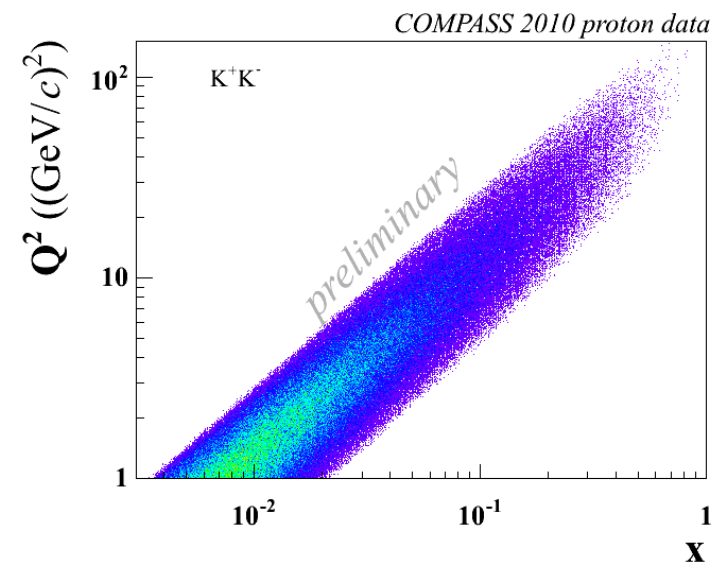
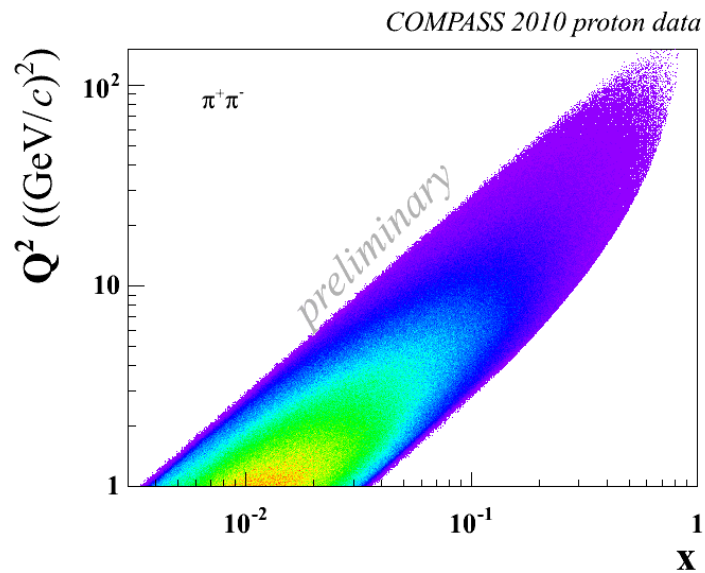
# Kinematic distributions of DIS events: $Q^2$ , $x_{bj}$ and $y$



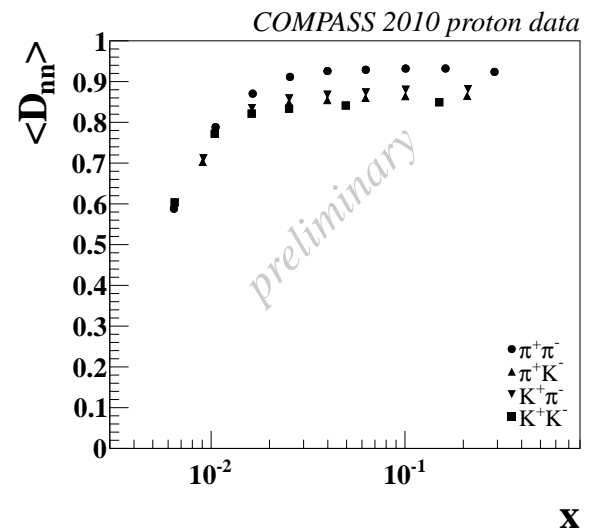
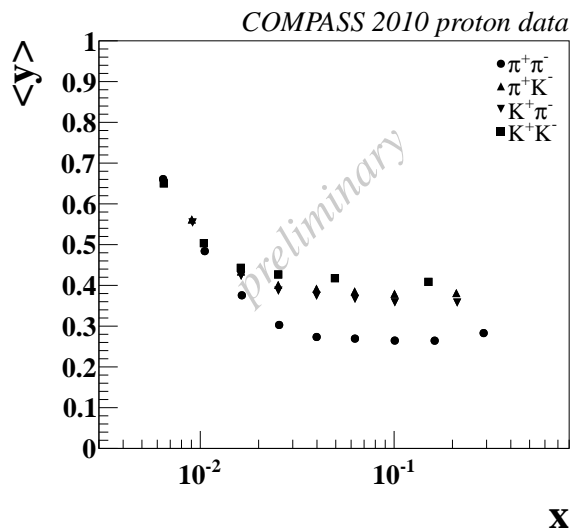
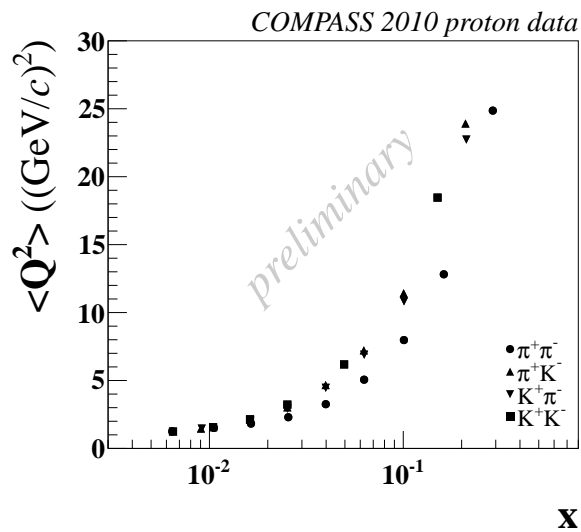
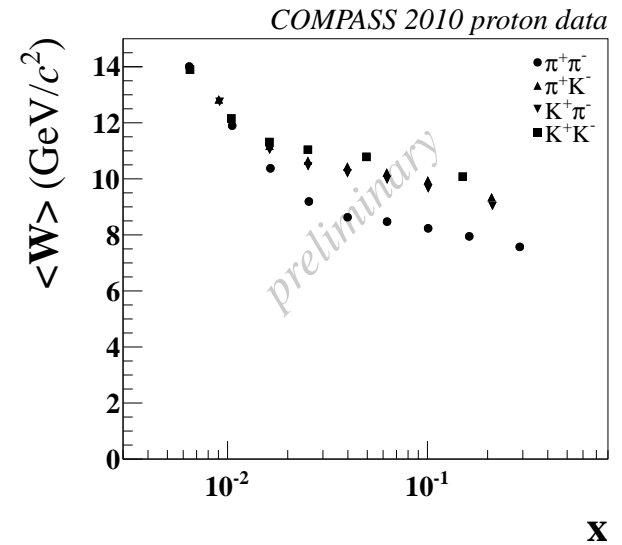
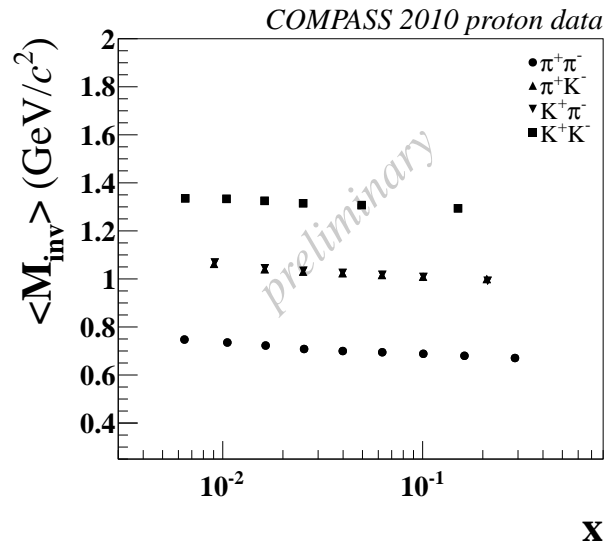
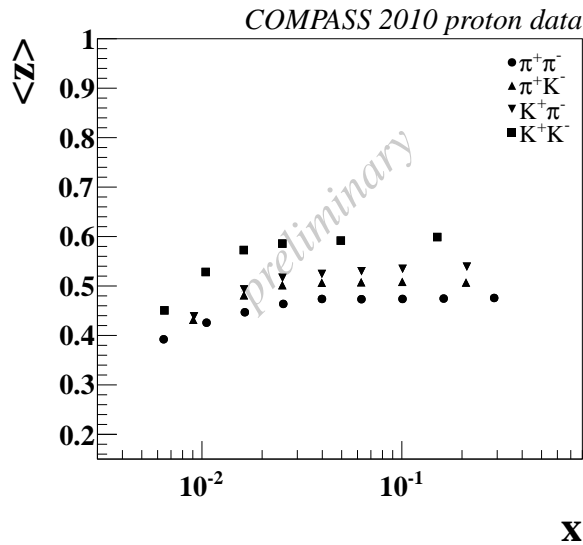
# Kinematic distributions of DIS events: $z_1$ vs. $z_2$



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

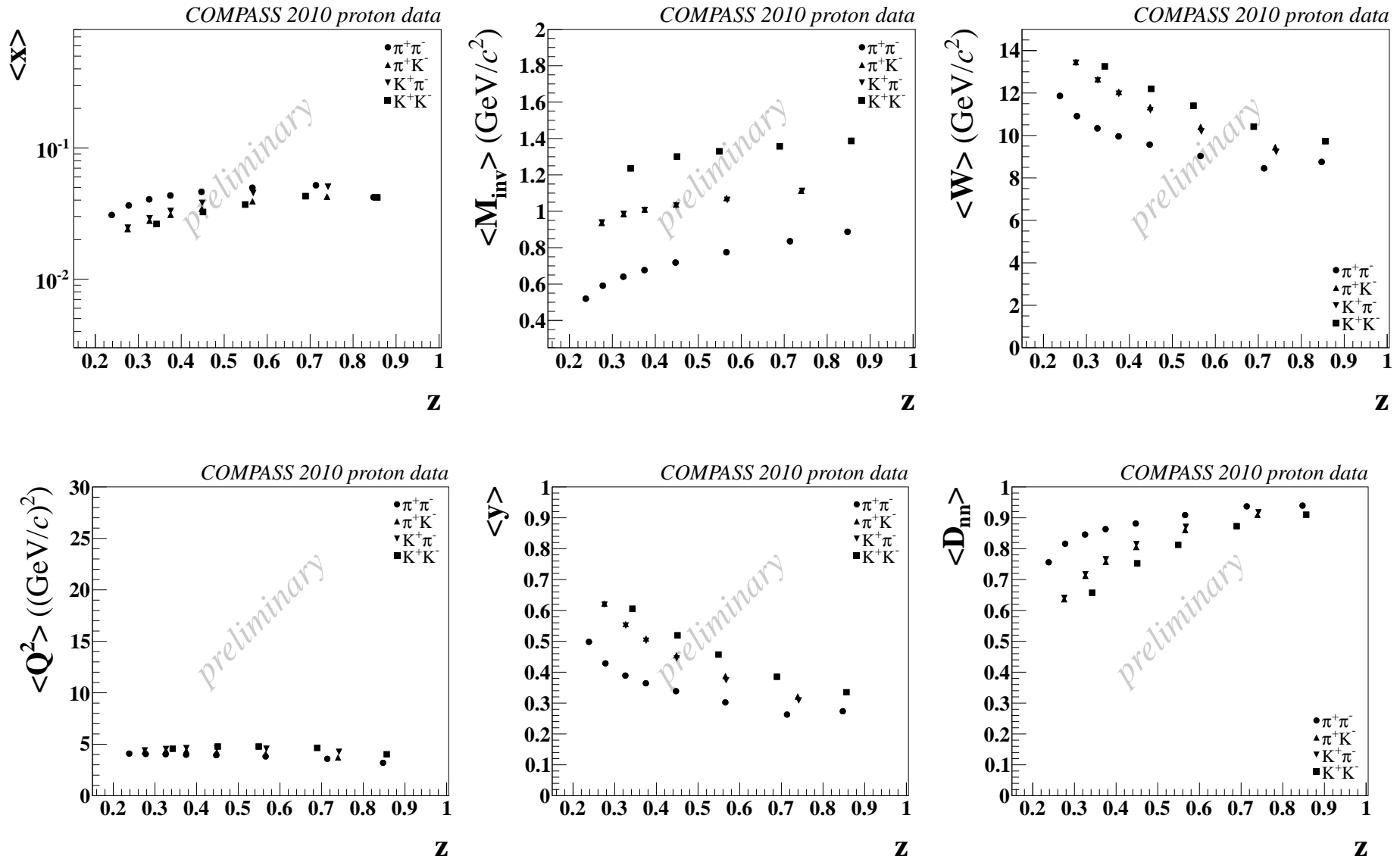


# 2010 proton data: kinematic mean values in $x_{bj}$

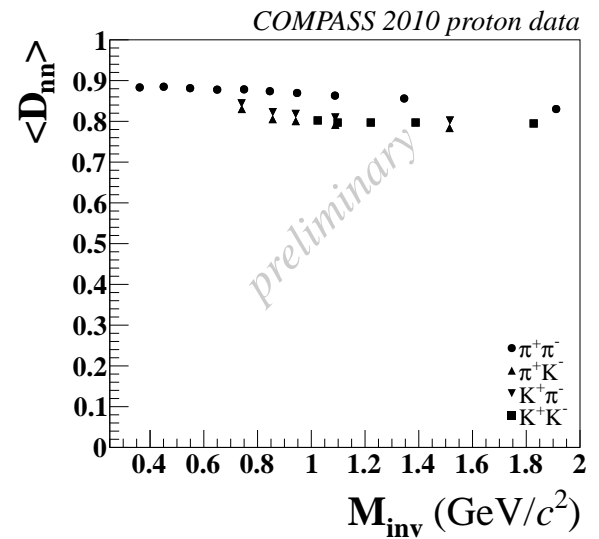
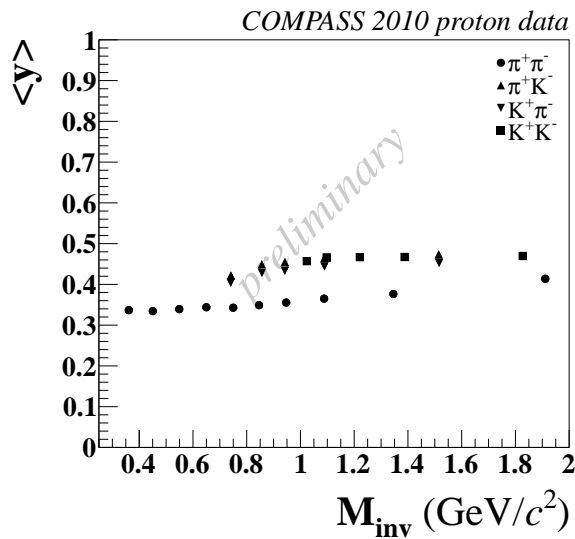
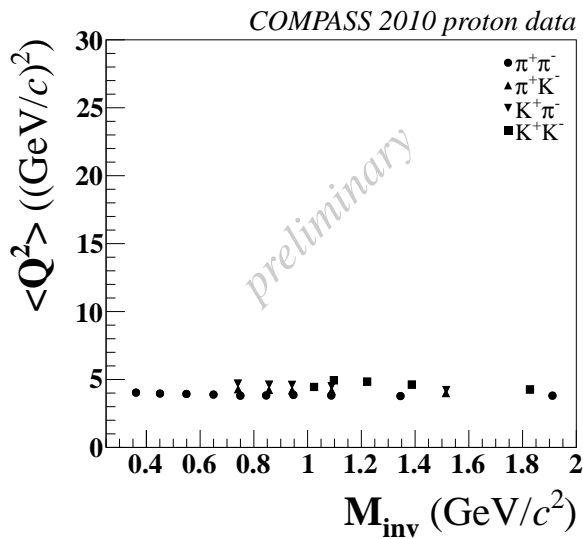
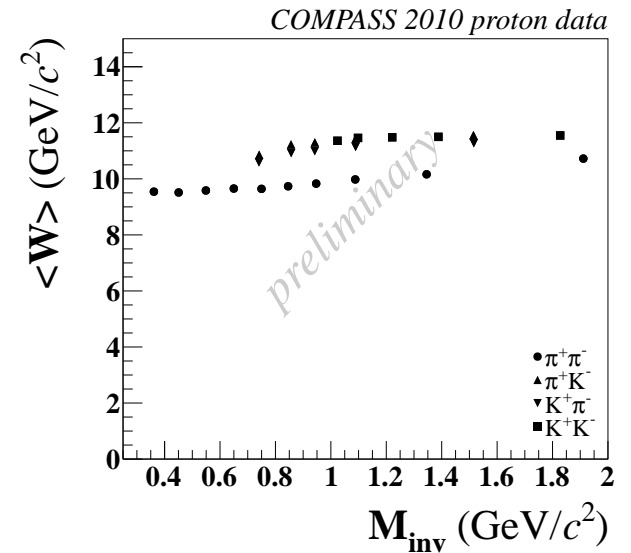
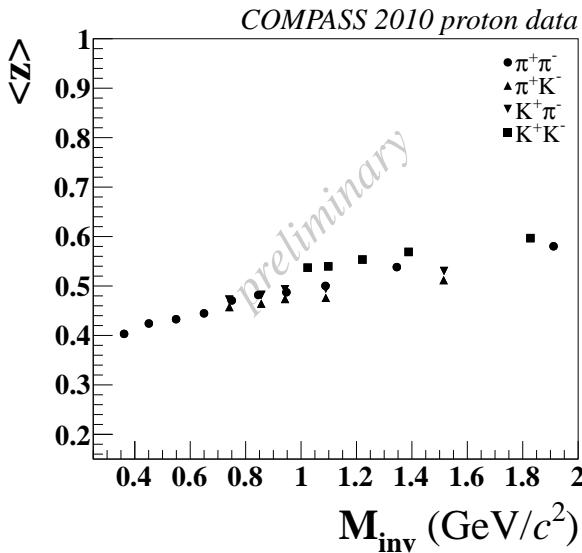
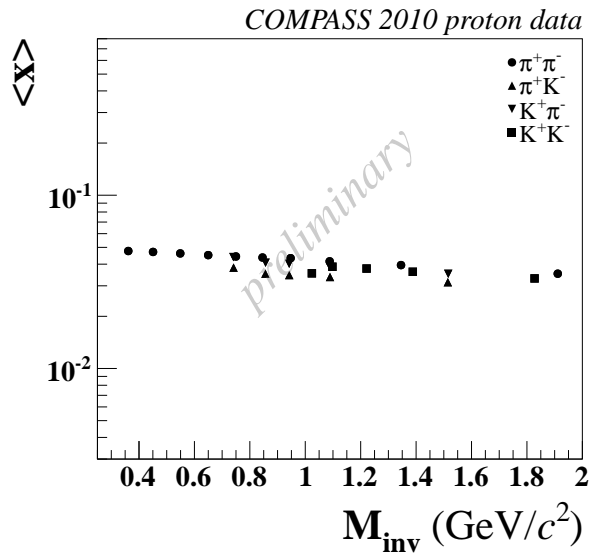




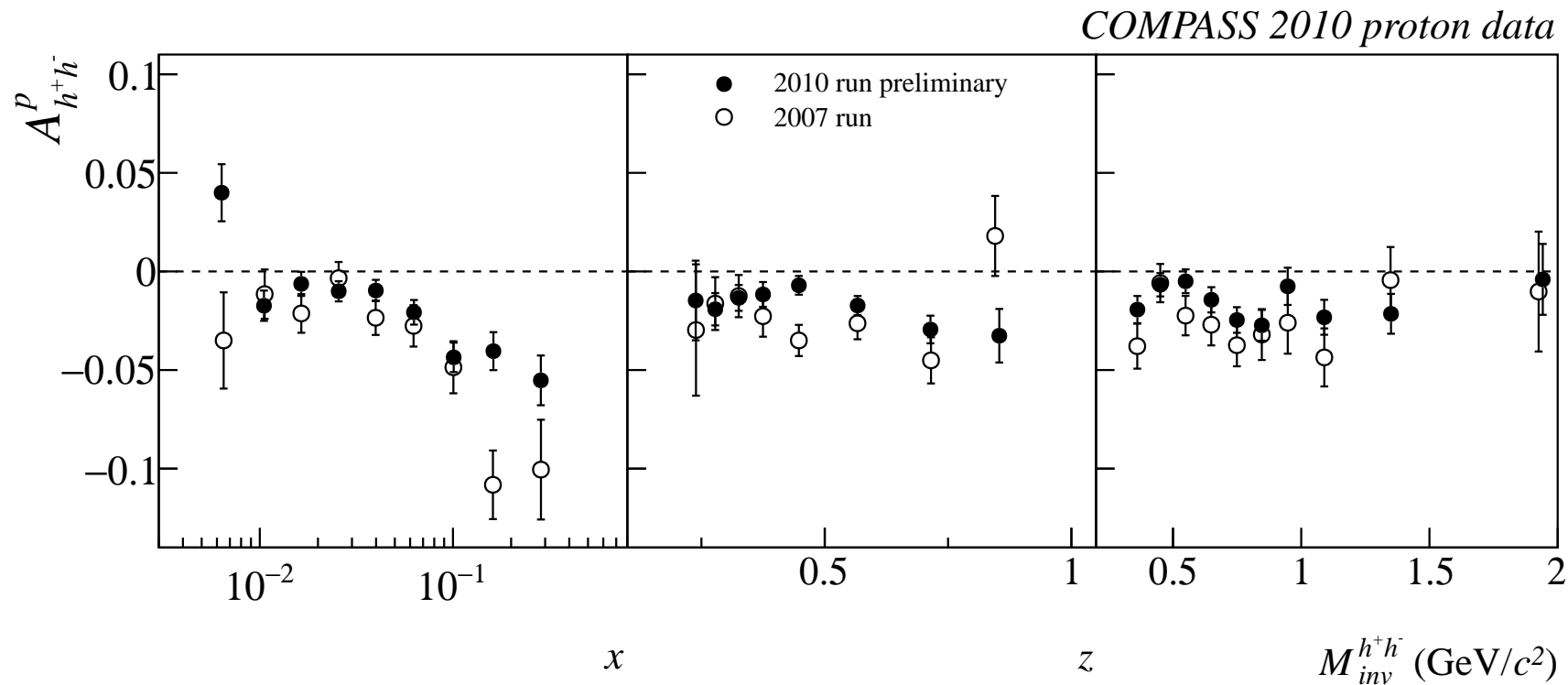
# 2010 proton data: kinematic mean values in $z$



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

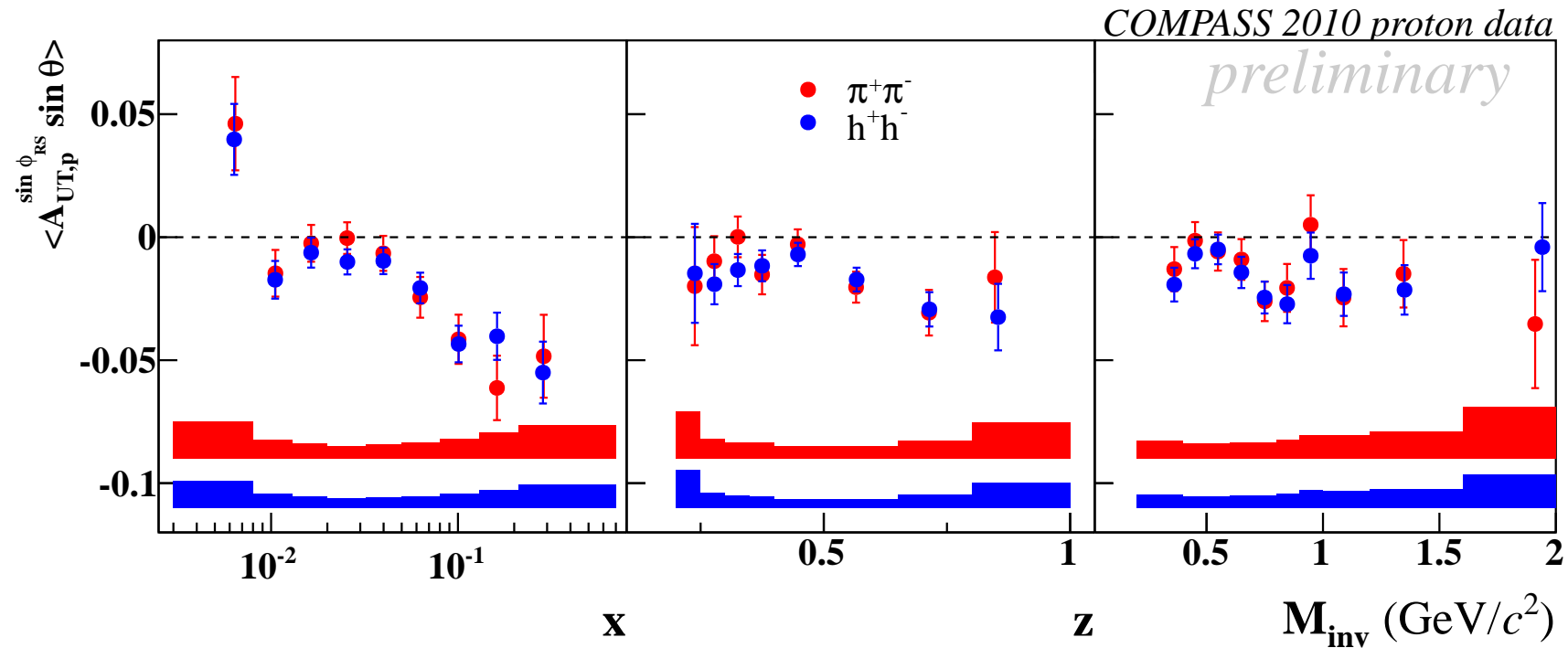


# two-hadron asymmetries: comparison 2010 and 2007 proton data



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

# two-hadron asymmetries: comparison 2010 $h^+h^-$ vs. $\pi^+\pi^-$



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