COMPASS results for dihadron single spin asymmetries

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COMPASS collaboration

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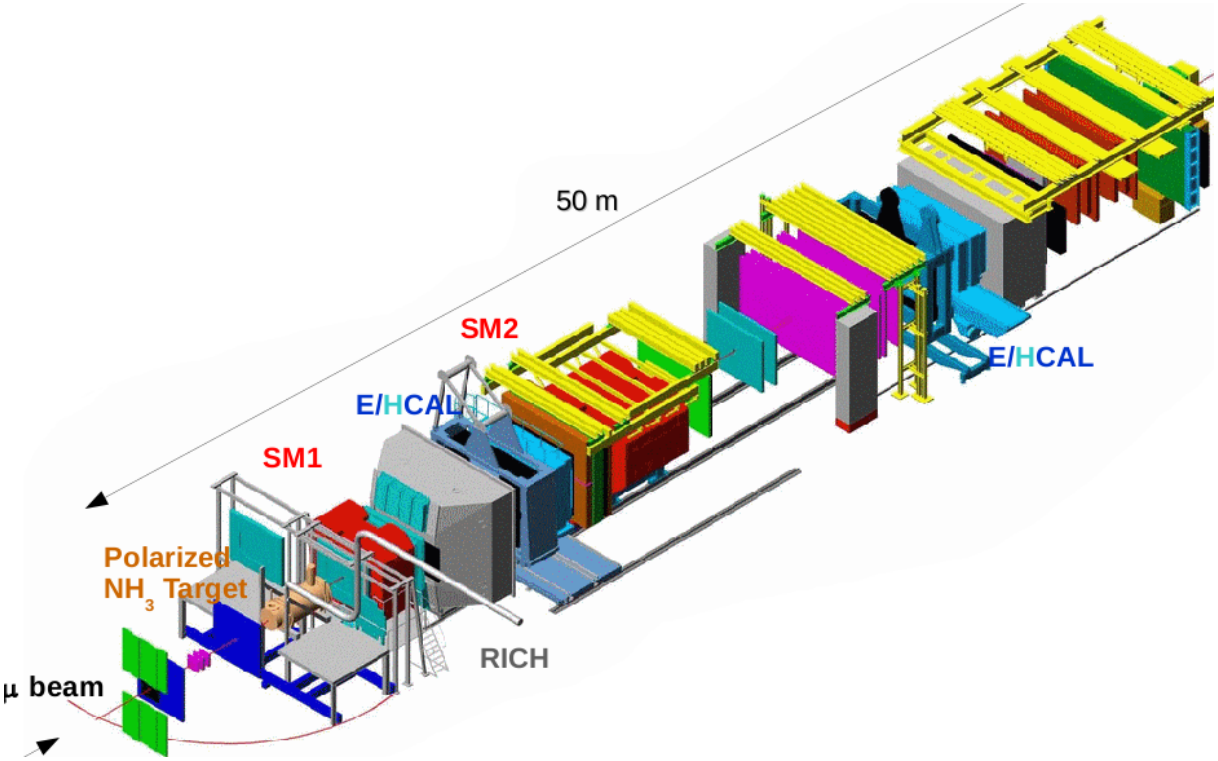
Structure of Nucleons and Nuclei 2013
June 12th 2013, Como, Italy

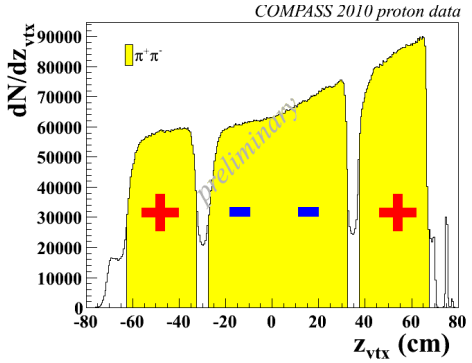
GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Outline

The COMPASS experiment



e.g. COMPASS setup 2007



deuteron (^{6}LiD):

- polarization $\langle P_T \rangle \approx 0.47$
- dilution factor $\langle f \rangle \approx 0.38$

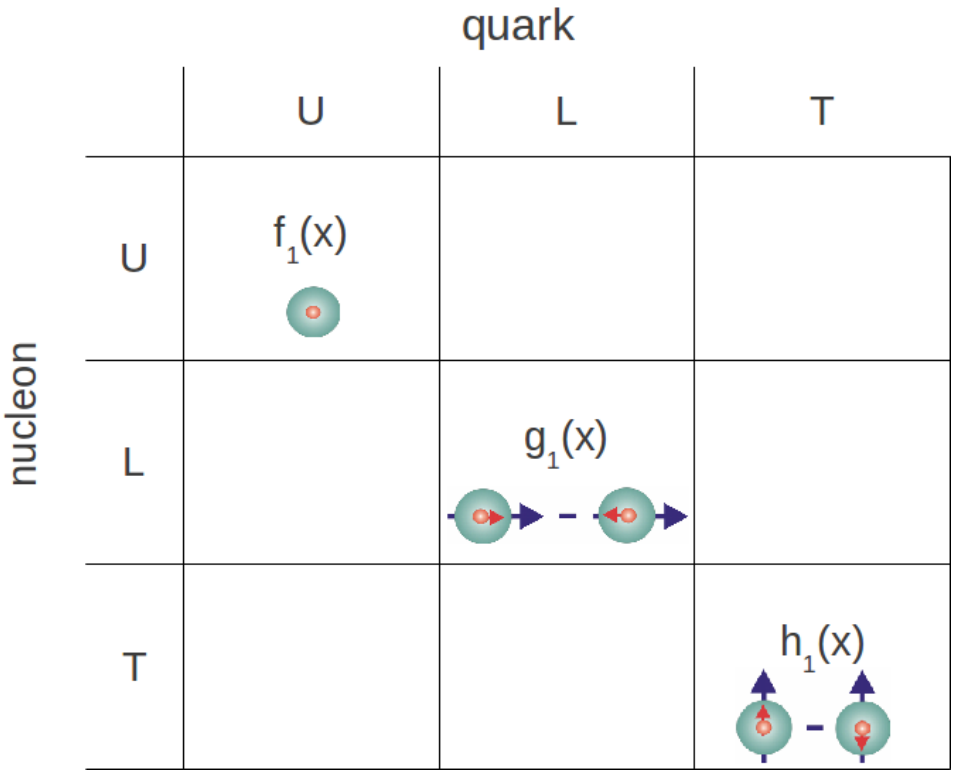
proton (NH_3):

- $\langle P_T \rangle \approx 0.90$
- $\langle f \rangle \approx 0.15$

- 2-stage spectrometer with tracking, calo and PID (RICH)
- Longitudinally polarized 160 GeV/c μ^+-beam
- 2002-04 transversely polarized deuterium 2-cell target
- 2007 & 2010 transversely polarized ammonia 3-cell target
- Polarization reversed every week via microwave

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 twist in the collinear case:



number density:
$f_1(x) = q^+(x) + q^-(x)$

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

Transversity distribution:
$h_1(x) = q^{\uparrow\uparrow}(x) - q^{\uparrow\downarrow}(x)$

Collins FF $\quad \ell N^\uparrow \to \ell' h X$

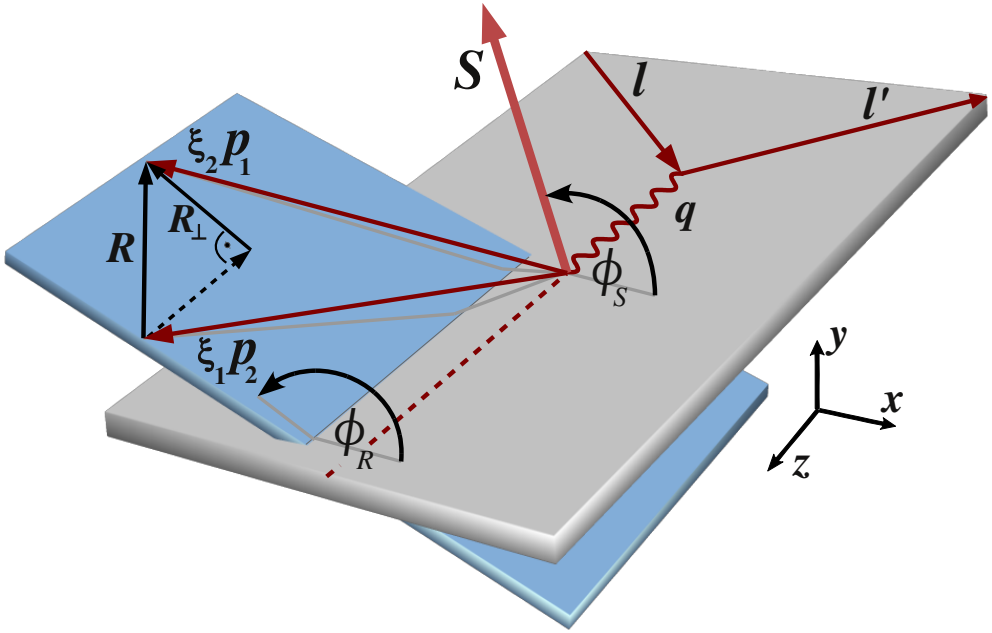
Interference FF $\quad \ell N^\uparrow \to \ell' h h X$

cf. L. L. Pappalardo, A. Martin, A. Bressan, B. Parsamyan

Theoretical framework: angle definitions

$$\ell + N^{\uparrow} \to \ell' + h_1 + h_2 + X$$

Fragmentation of a transversely polarized quark into a pair of unpolarized hadrons



- ℓ, ℓ' and $\mathbf{q}$ are 3-momenta of incoming, scattered lepton and virtual photon
- ϕ_S azimuthal angle of the spin $\boldsymbol{S}$ of the fragmenting quark
- $\mathbf{p_i}$ is the 3-momenta of h_i
- z_i is the fraction of the virtual-photon energy carried by h_i
- $\mathbf{R} = \frac{z_2\mathbf{p_1} - z_1\mathbf{p_2}}{z_1+z_2} = \xi_2\mathbf{p_1} - \xi_1\mathbf{p_2}$
- $\mathbf{R_T}$ is the component of $\mathbf{R}$ perpendicular to $\mathbf{q}$
- Azimuthal angle of $\mathbf{R}$:

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

cf. F. Bradamante

Theoretical framework: dihadron cross section

The differential dihadron cross section is:

$$\frac{\mathrm{d}^7\sigma}{\mathrm{d}\cos\theta\,\mathrm{d}M_{inv}^2\,\mathrm{d}\phi_R\,\mathrm{d}z\,\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}\phi_S} =$$
$$\frac{\alpha^2}{2\pi Q^2 y}\Big(\big(1-y+\tfrac{y^2}{2}\big)\sum_q e_q^2 f_1^q(x) D_1^q(z, M_{inv}^2, \cos\theta)$$
$$+S_\perp(1-y)\times\sum_q e_q^2 \tfrac{|\mathbf{p_1}-\mathbf{p_2}|}{2M_{inv}} \sin(\theta)\sin(\phi_{RS}) h_1^q(x) H_1^{\sphericalangle,q}(z, M_{inv}^2, \cos\theta)\Big)$$

with $\phi_{RS} = \phi_R + \phi_S - \pi$

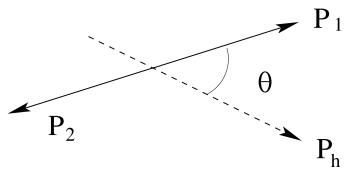
Where $h_1(x)$ is the Transversity PDF and $H_1^{\sphericalangle,q}$ is the dihadron Interference FF.
D_1^q is the unpolarized dihadron fragmentation function,
which is measured at *e.g.* BELLE.

cf. A. Vossen

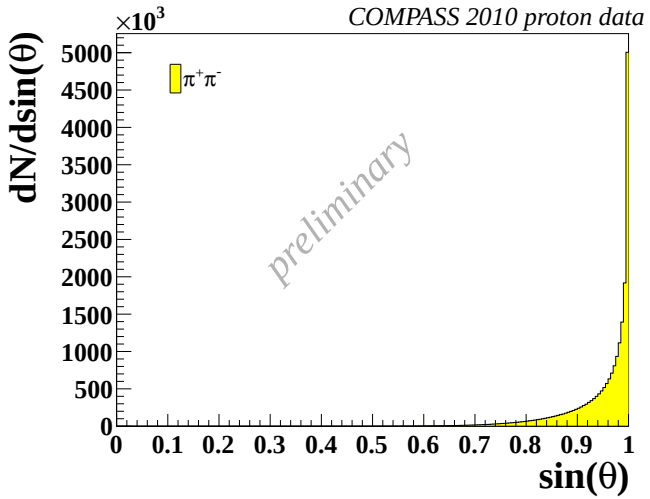
A. Vossen *et al.* [BELLE Collaboration], Phys. Rev. Lett. **107** (2011) 072004
arXiv:1104.2425v3.

Theoretical framework: asymmetries extraction

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



h^+h^- center of mass frame



σ_{UU} = unpolarized cross section

$\pm$ indicates nucleon spin orientation

f = target dilution factor

P_T = target polarization

D_{NN} = transv. spin transfer coef.

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

$\langle \sin\theta \rangle = 0.94$

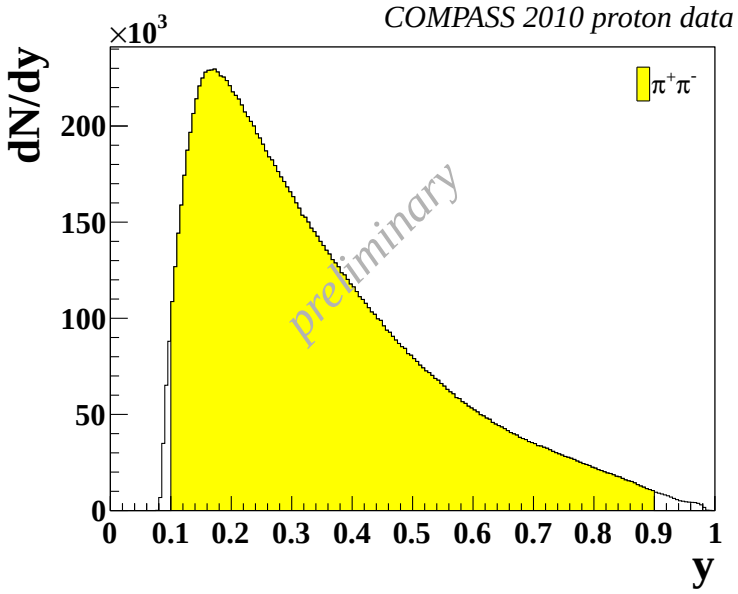
$$A_{UT}^{\sin\phi_{RS}} = \frac{|\mathbf{p_1}-\mathbf{p_2}|}{2M_{inv}} \frac{\sum_q e_q^2 h_1^q(x) H_1^{\sphericalangle,q}(z, M^2_{inv}, \cos\theta)}{\sum_q e_q^2 f_1^q(x) D_1^q(z, M^2_{inv}, \cos\theta)}$$

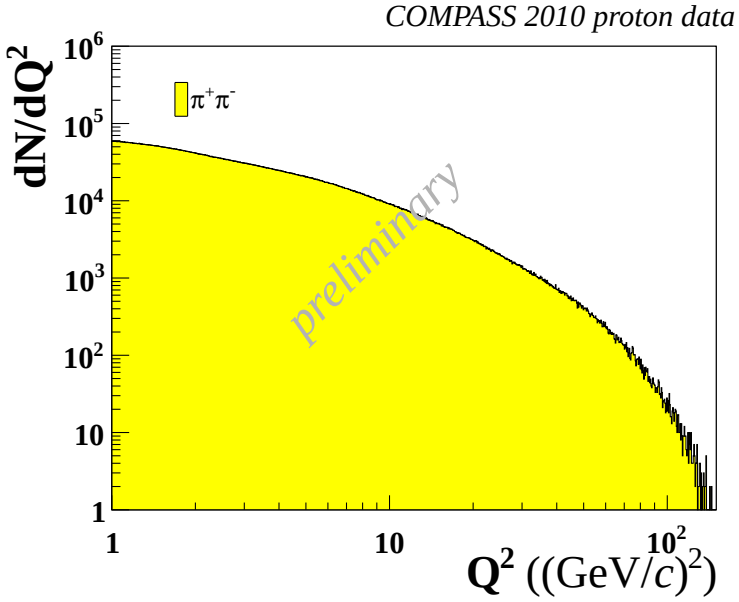
Data selection: DIS cuts

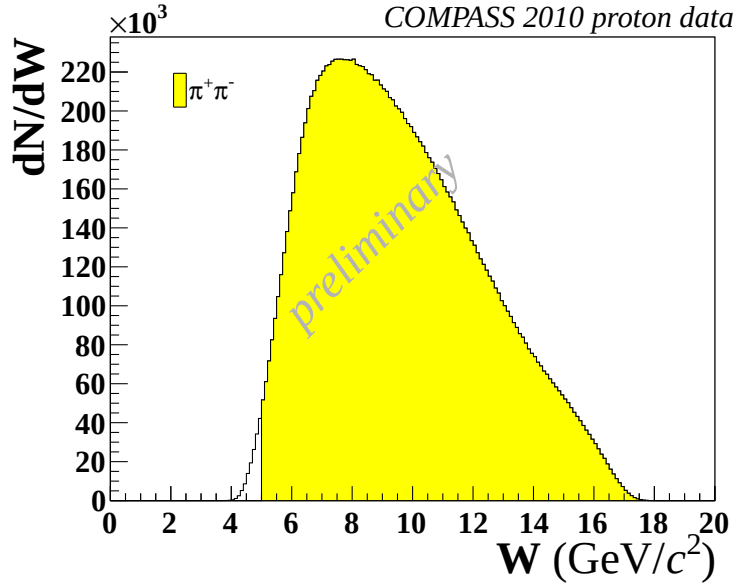
DIS cuts on events:

- $Q^2 > 1\,(\mathrm{GeV}/c)^2$
- $0.1 < y < 0.9$
- $W > 5\ \mathrm{GeV}/c^2$

- spectrometer acceptance:
  $0.003 < x < 0.7$



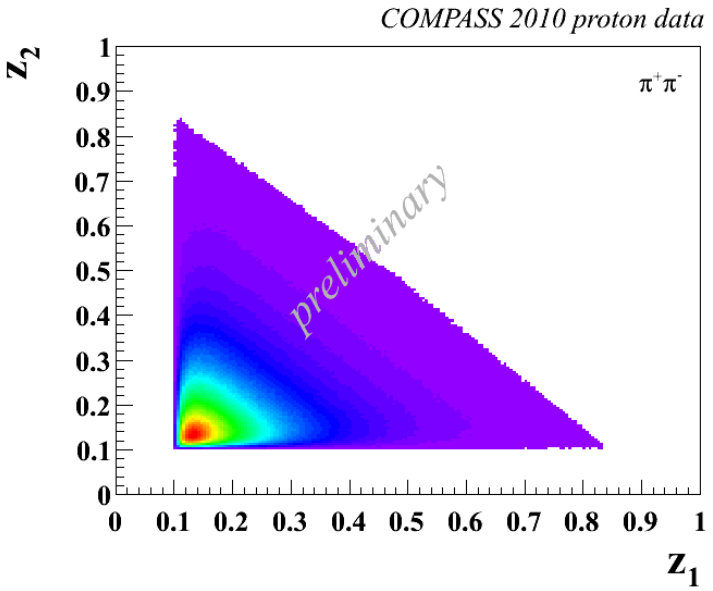


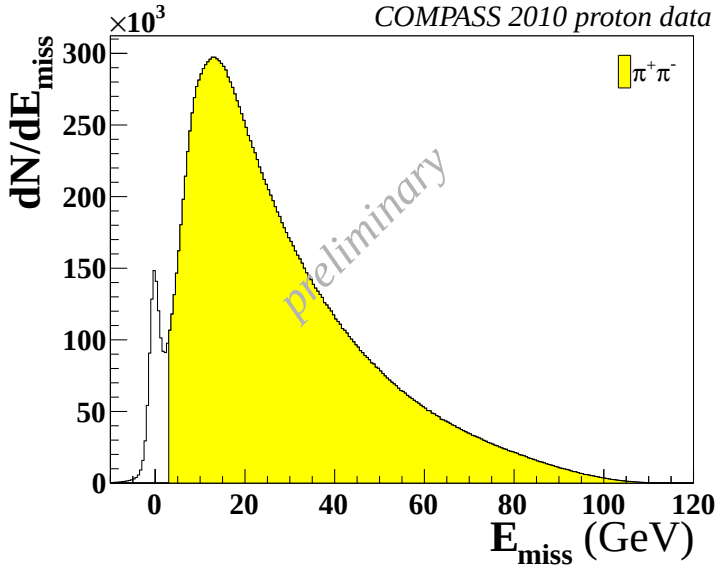


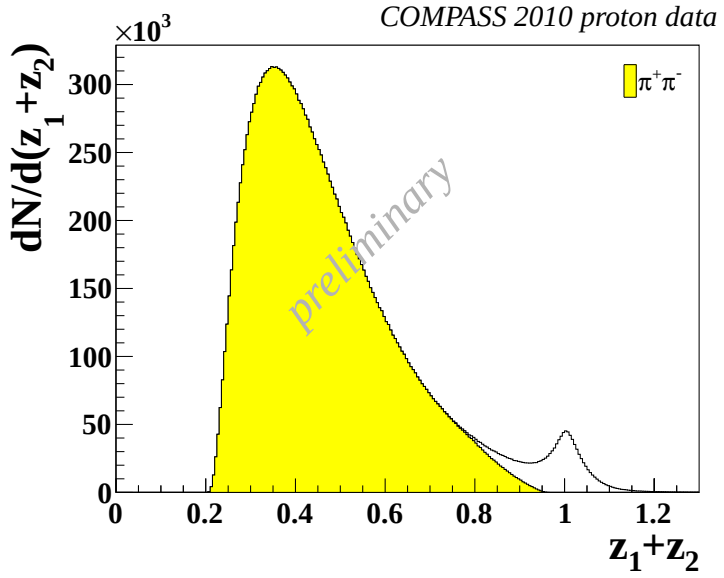
Data selection: hadron & hadron pair cuts

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
- $E_{miss} > 3$ GeV for each pair
- $R_T > 0.07$ GeV/c for each pair



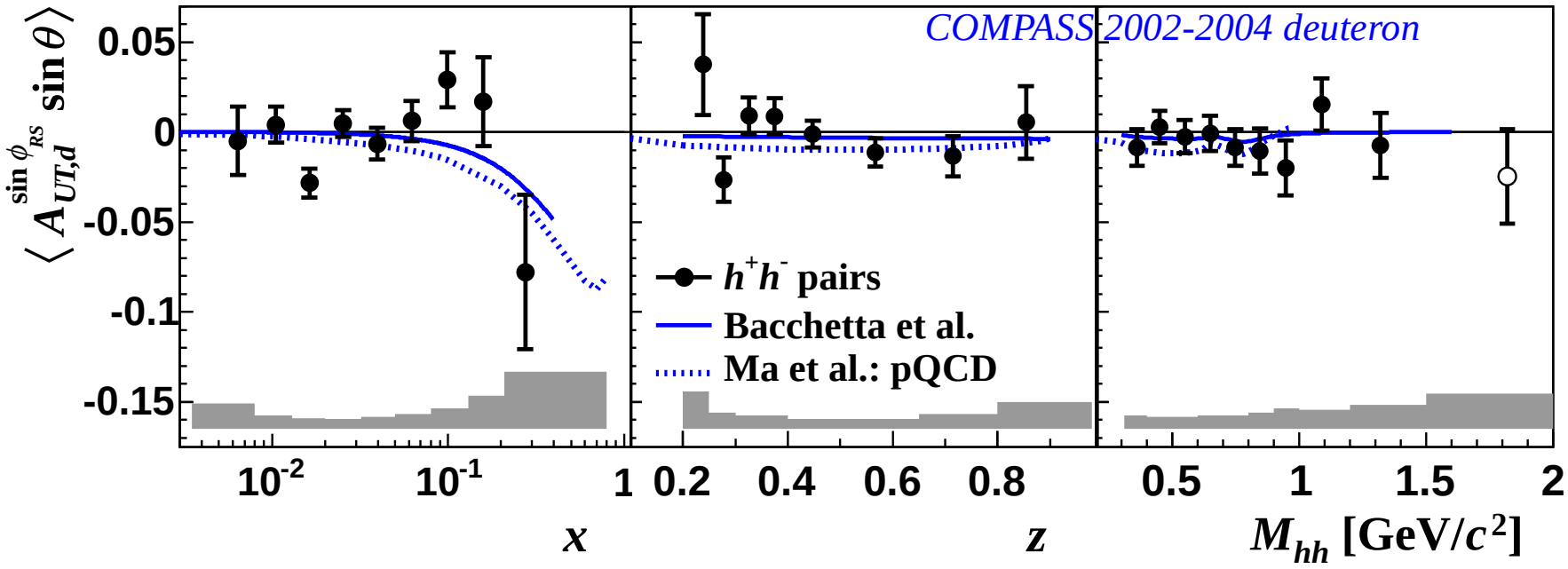




dihadron asymmetries:

deuteron 2002-04 and proton 2007 data

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

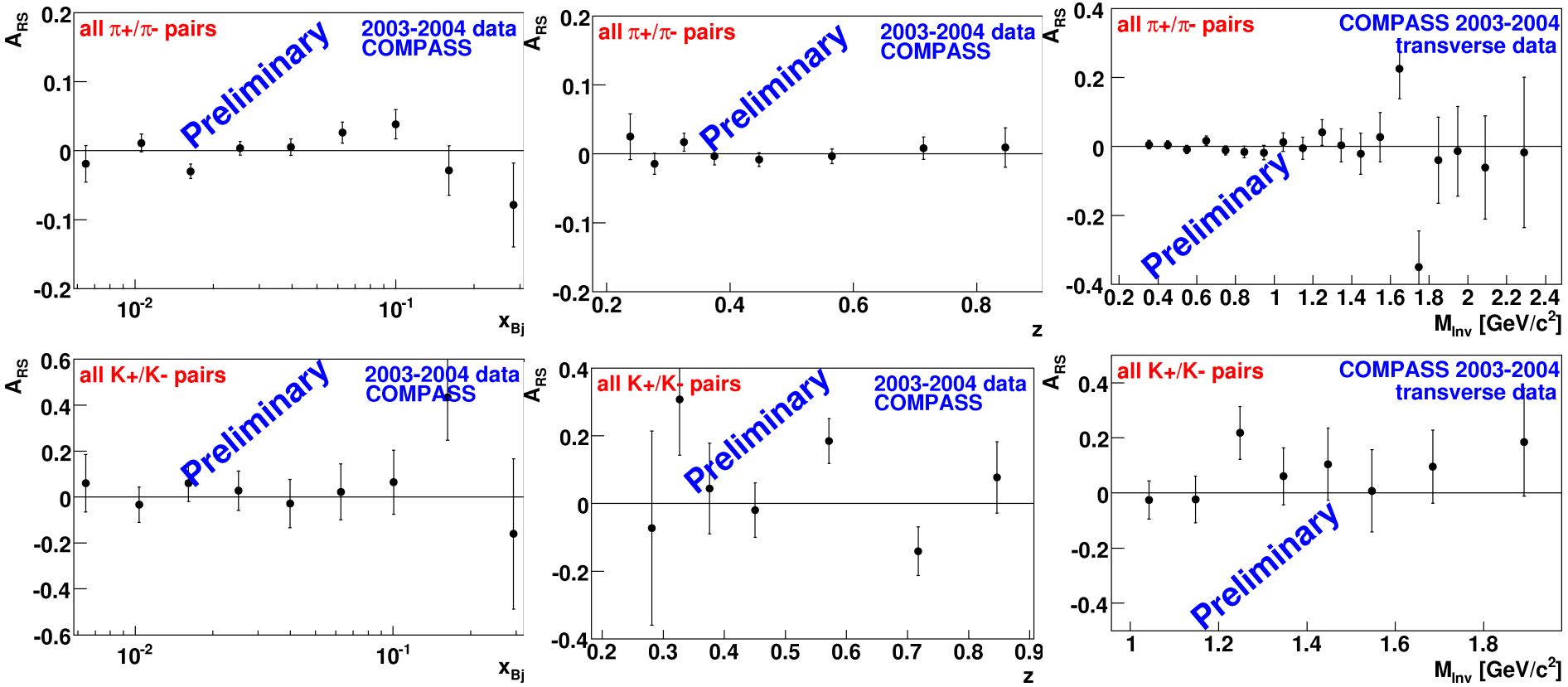


Adolph C. *et al.* [COMPASS Collaboration], Phys. Lett. B **713** (2012) 10
Bacchetta A. and Radici M., Phys. Rev. D **74** (2006) 114007
Ma B.-Q. *et al.*, Phys. Rev. D **77** (2008) 014035

↪ Asymmetries for deuteron target compatible with zero within the uncertainties

The models also predict a cancellation of the u and d quark transversity on the deuteron.

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

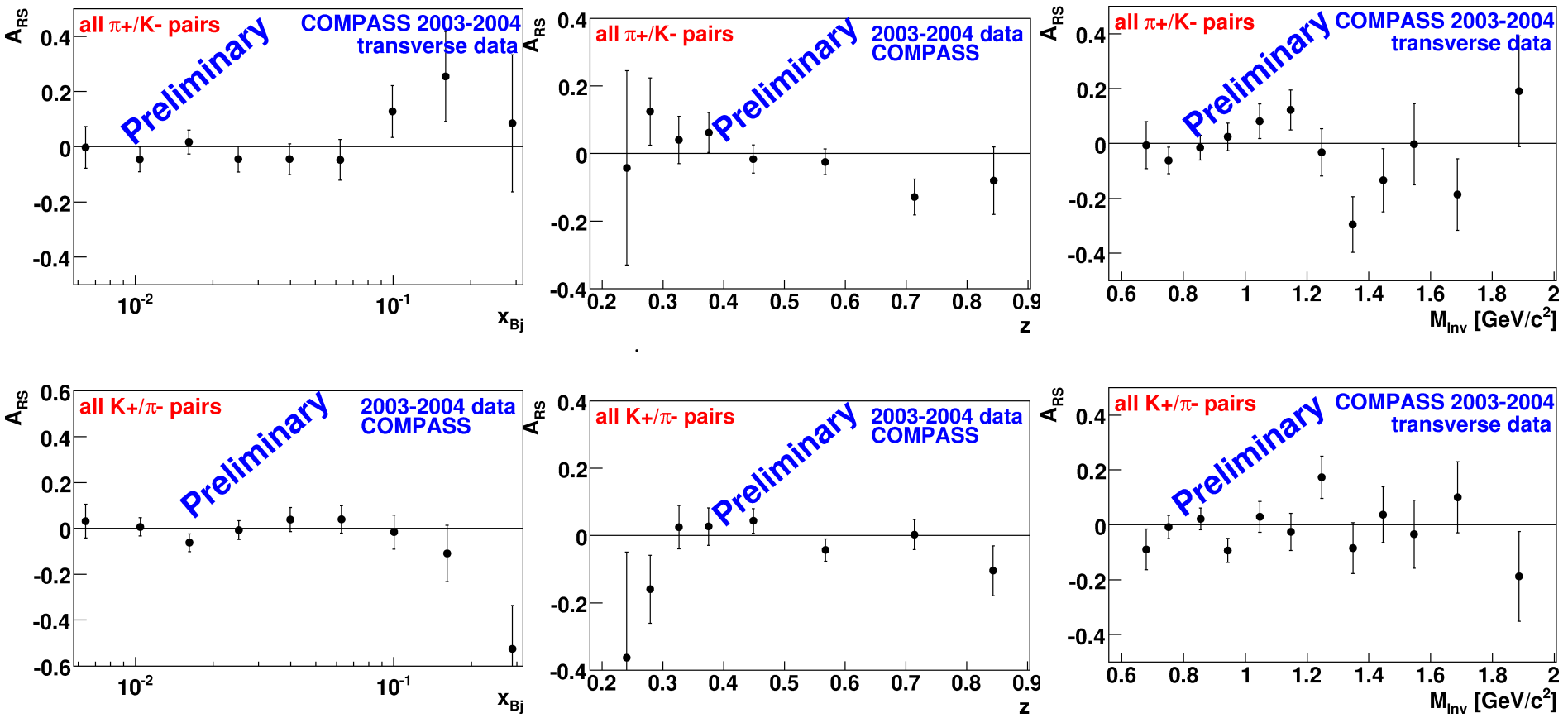


2002-04 deuteron data 2-hadron asymmetries: $\pi^+\pi^-$ pairs (top), K^+K^- pairs (bottom)

$\hookrightarrow$ h^+h^- asymmetries follow mostly $\pi^+\pi^-$ signal

$\pi^+\pi^-$ asymmetries are small and compatible with zero
K^+K^- no signal & low statistics

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

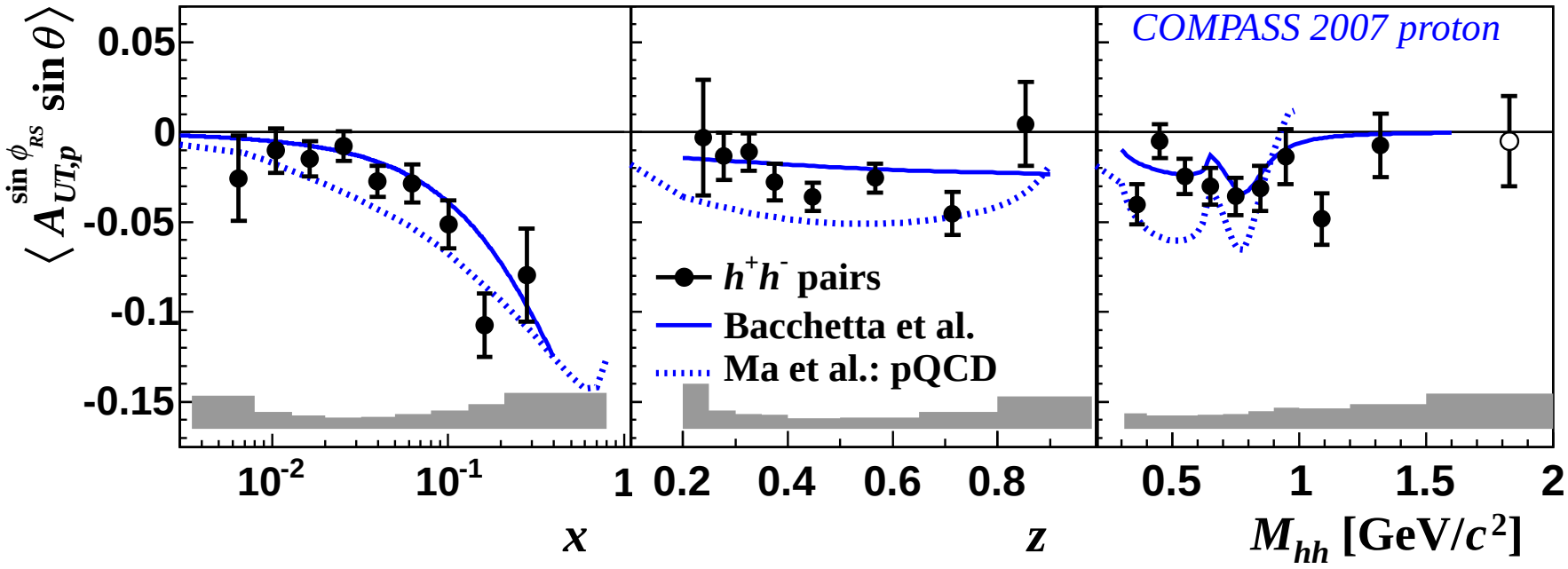


2002-04 deuteron data 2-hadron asymmetries: all π^+K^- pairs (top), $K^+\pi^-$ pairs (bottom)

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

weak indication of opposite sign of the signal in x dependence

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



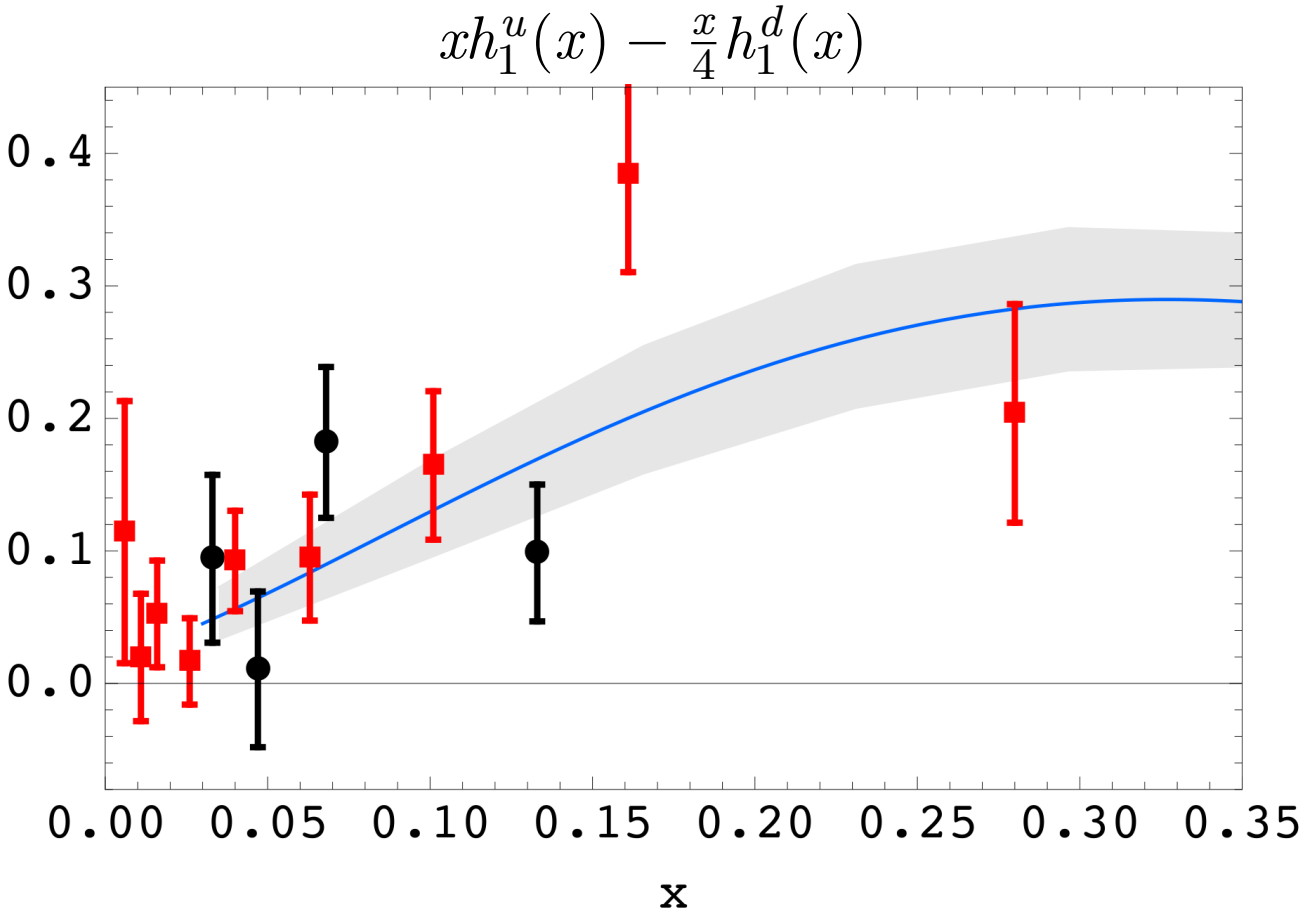
Adolph C. *et al.* [COMPASS Collaboration], Phys. Lett. B **713** (2012) 10
Bacchetta A. and Radici M., Phys. Rev. D **74** (2006) 114007
Ma B.-Q. *et al.*, Phys. Rev. D **77** (2008) 014035

↪ Large asymmetries in x dependence up to -10 %

Good agreement with the model predictions

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



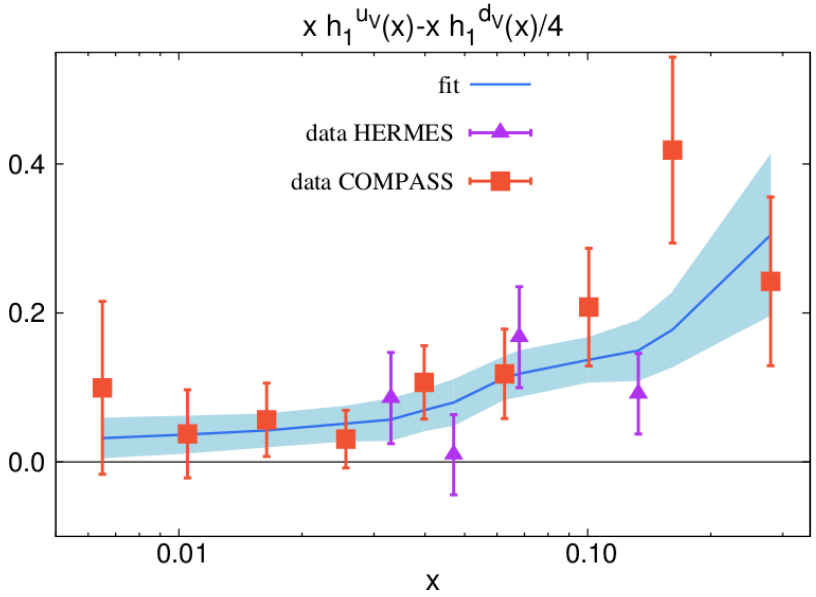
Combination of valence u, d flavors for the transversity distribution from:

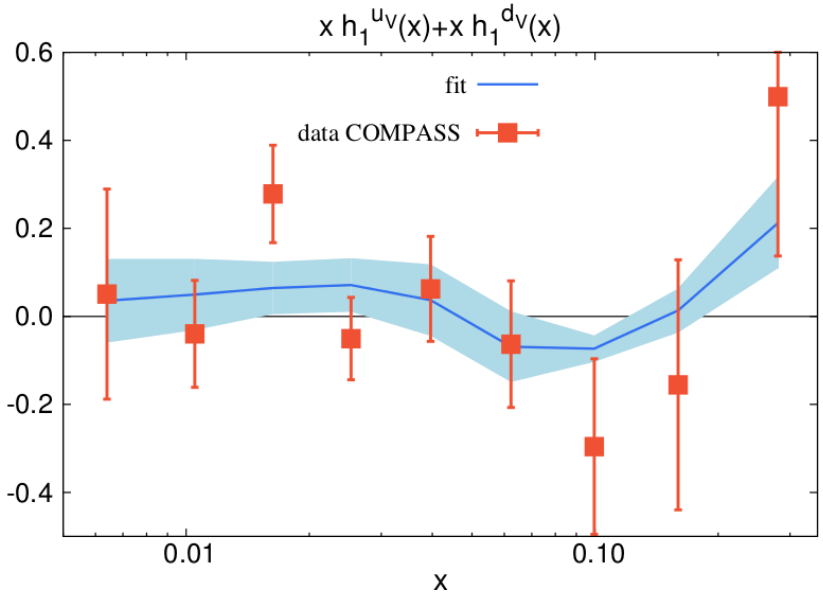
black:
HERMES Airapetian *et. al.*, JHEP, **06** (2008) 017

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

proton data 2007: extraction of u and d transversity 1

$\rightarrow$ h_1^u & h_1^d were extracted using **HERMES** proton and **COMPASS** 2007 proton & 2002-04 deuteron data

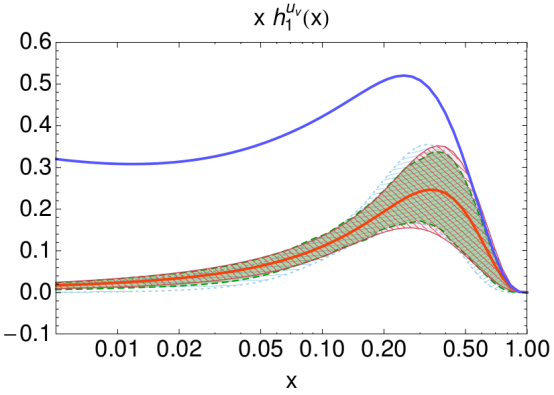


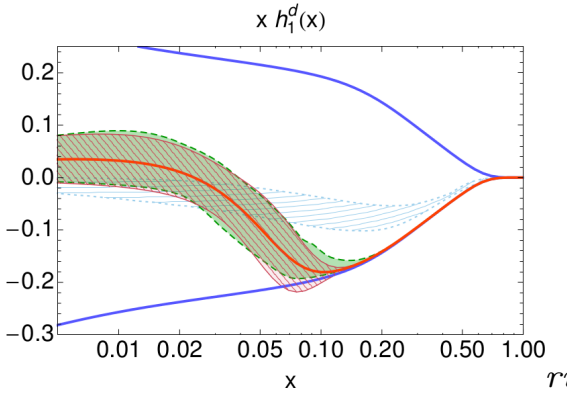


Bacchetta A., Courtoy A. and Radici M., JHEP **1303** (2013) 119

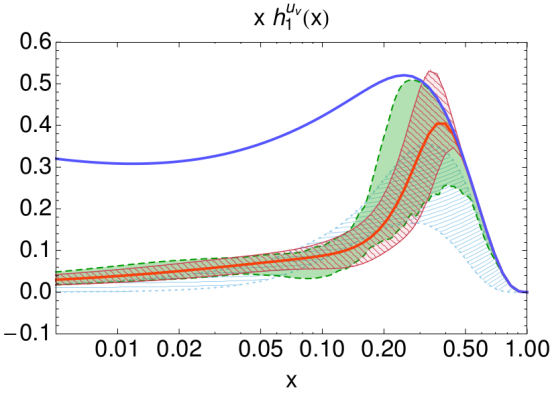
proton data 2007: extraction of u and d transversity 2

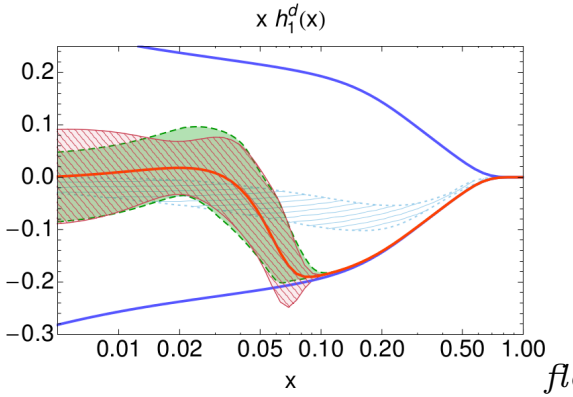
Fit function: $$x\,h_1^{qV}(x;Q_0^2) = \tanh\left[x^{1/2}\left(A_q + B_q\,x + C_q\,x^2 + D_q\,x^3\right)\right]\left[x\,\mathrm{SB}^q(x;Q_0^2) + x\,\mathrm{SB}^{\bar{q}}(x;Q_0^2)\right]$$



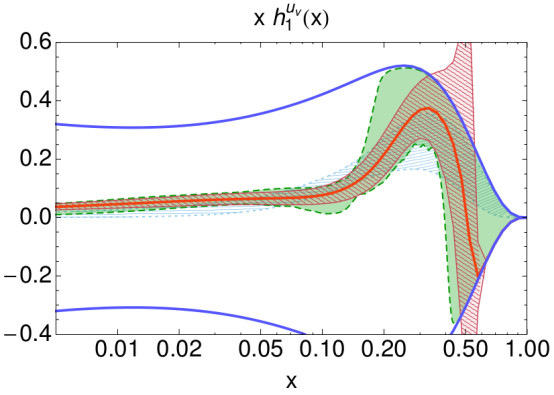


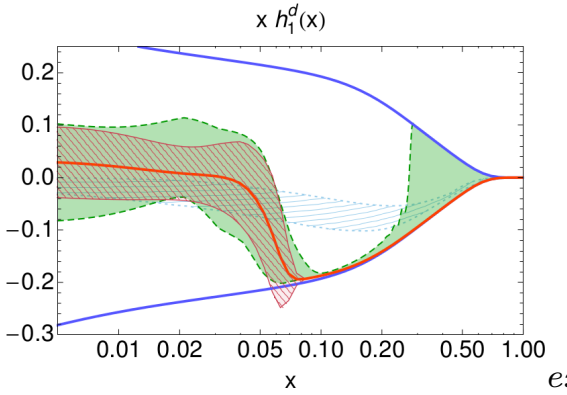
rigid scenario: $C_u = C_d = D_u = D_d = 0$





flexible scenario: $D_u = D_d = 0$



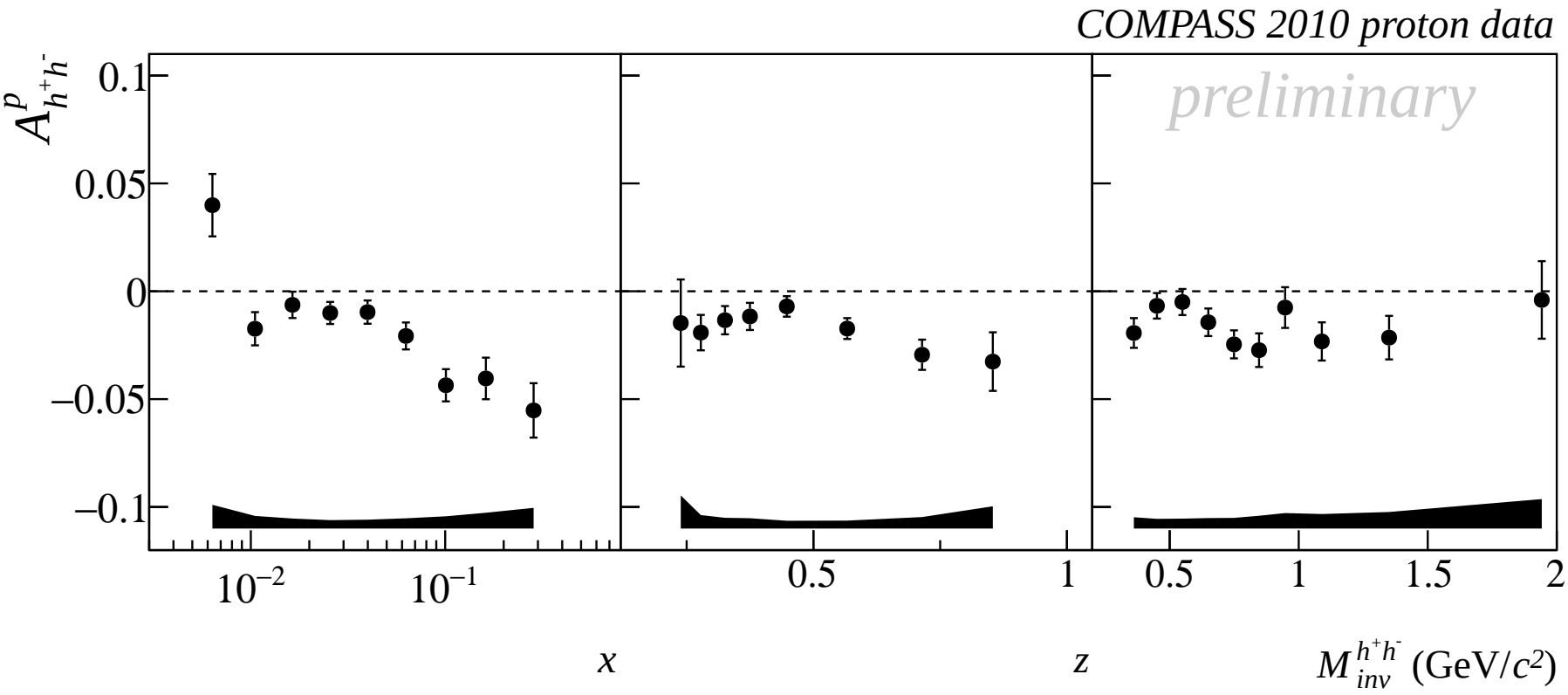


extra-flexible scenario

dihadron asymmetries:

proton 2010 data

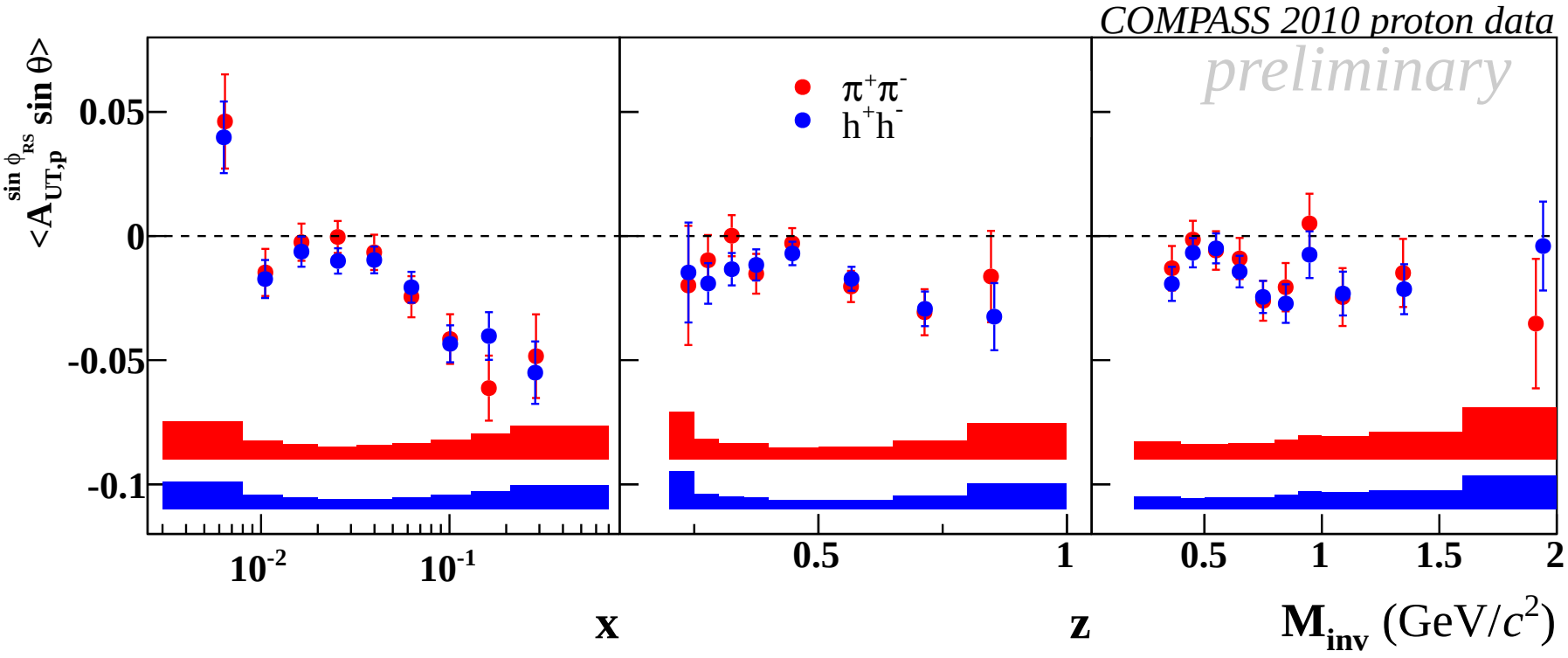
proton 2010 data: all h^+h^- pairs



CB, Nuovo Cimento C **035** (2012) 02

↪ Clear asymmetries of all hadron h^+h^- pairs

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



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

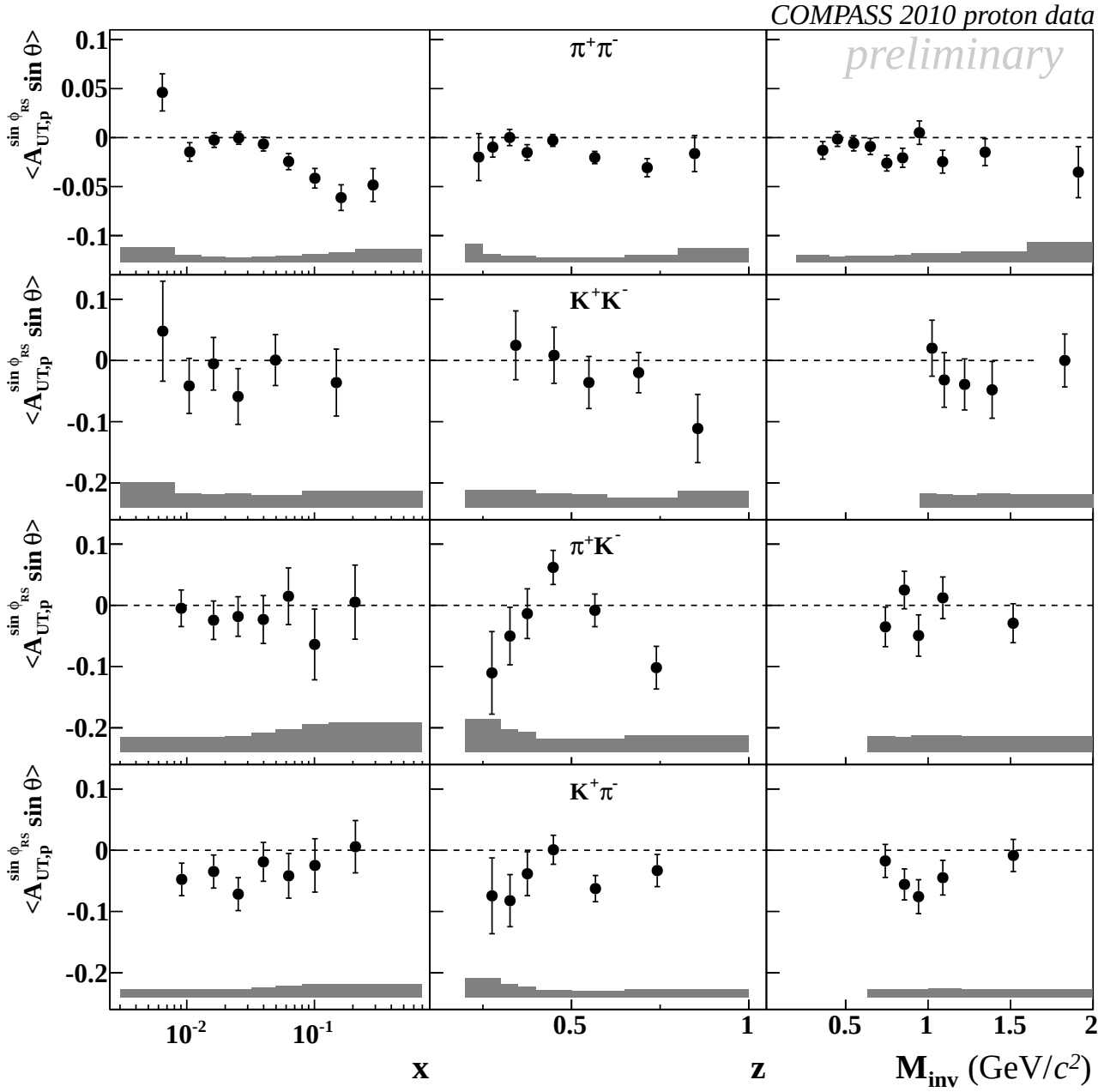
x up to -6 %

z no clear trend (compatible with a constant slope)

M_{inv} clear dip around ρ^0 mass

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

2010 proton data: identified dihadron asymmetries all pairs

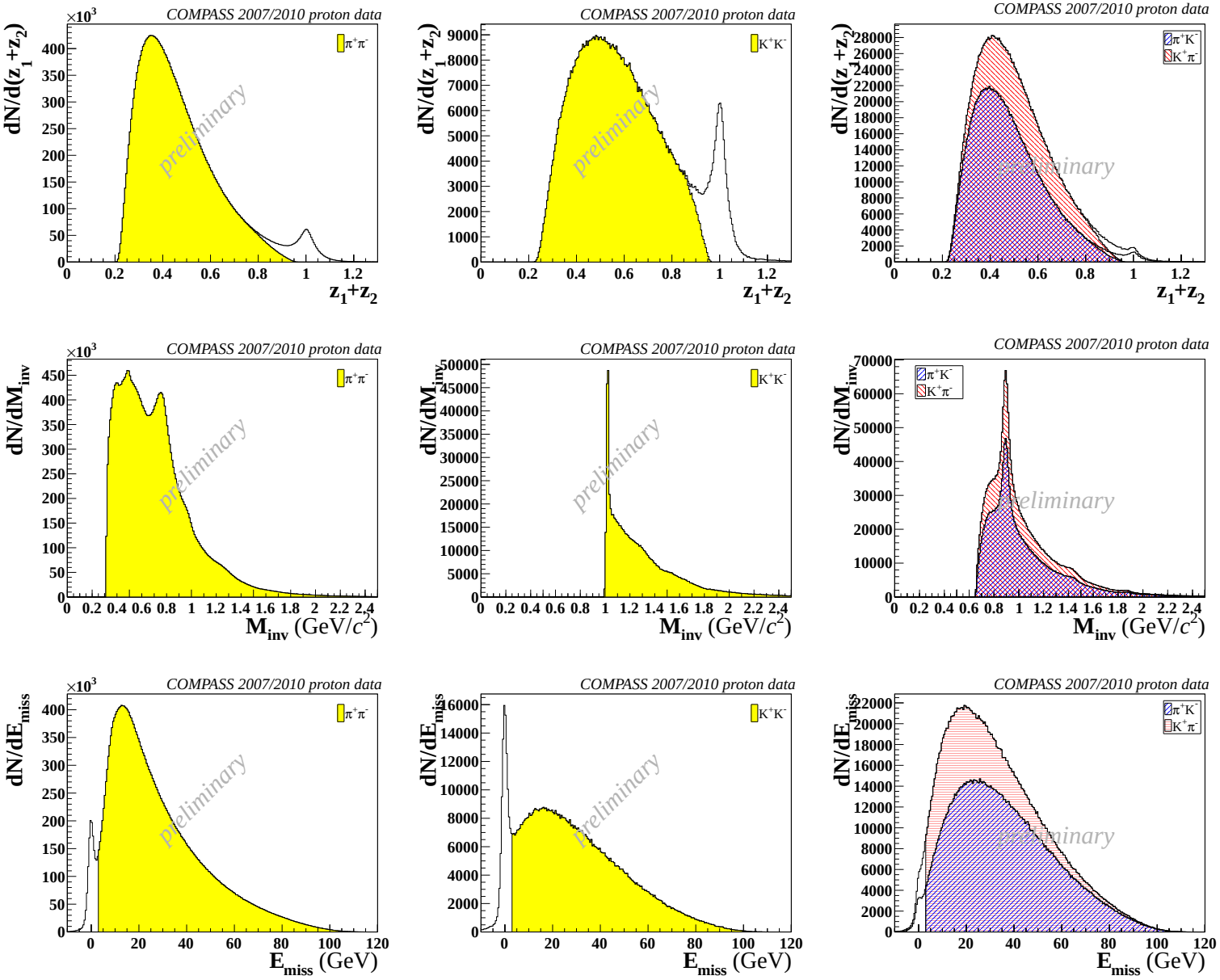


dihadron asymmetries:

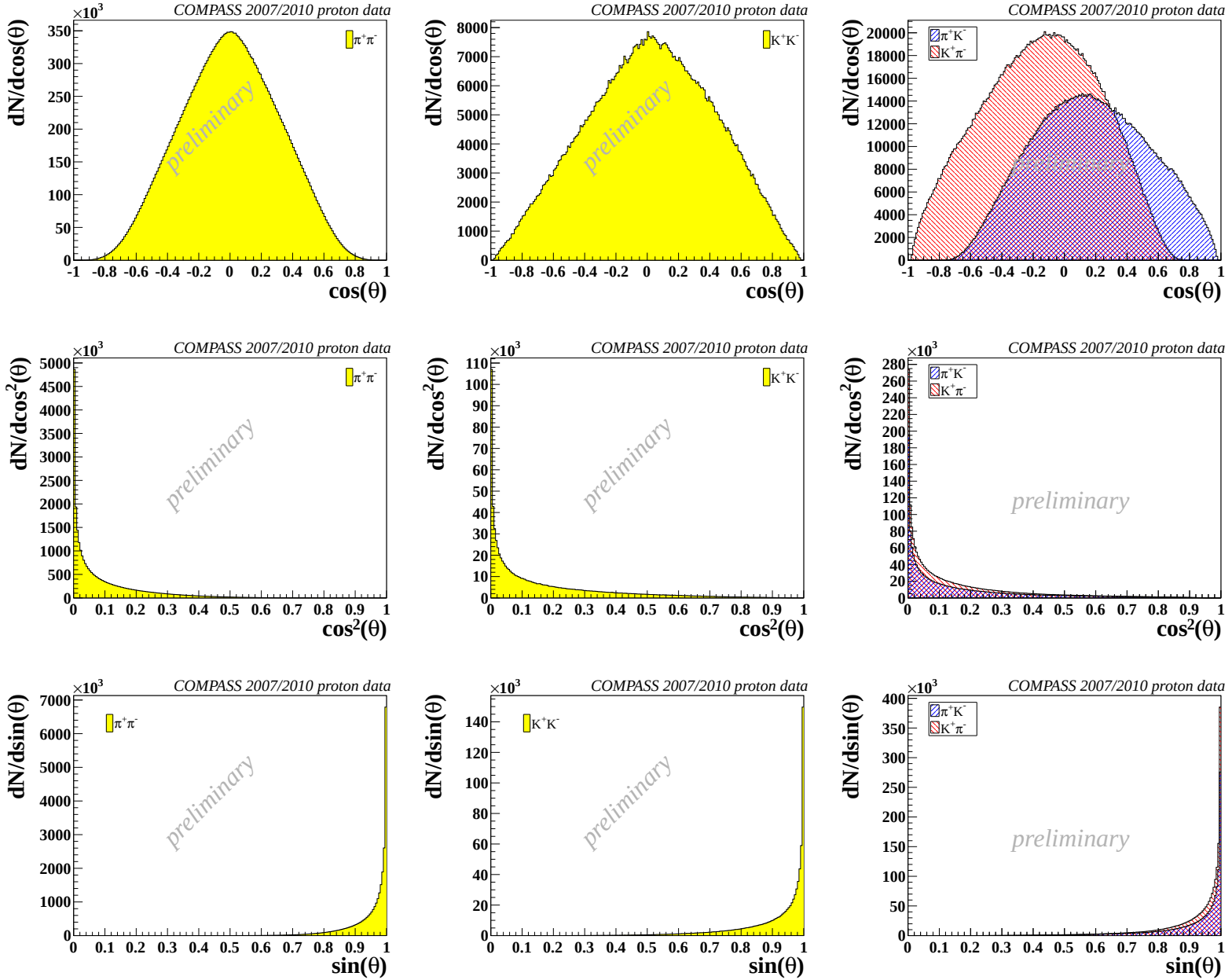
combined 2007/2010 data

combined 2007/2010 data: $z_1 + z_2$, M_{inv} and E_{miss} distributions

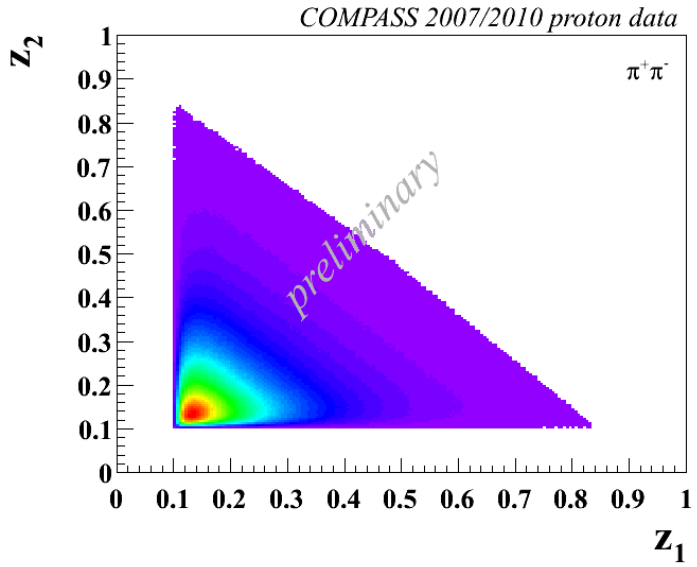
$\pi^+\pi^-$ | K^+K^- | $\pi^+K^- \,\&\, K^+\pi^-$

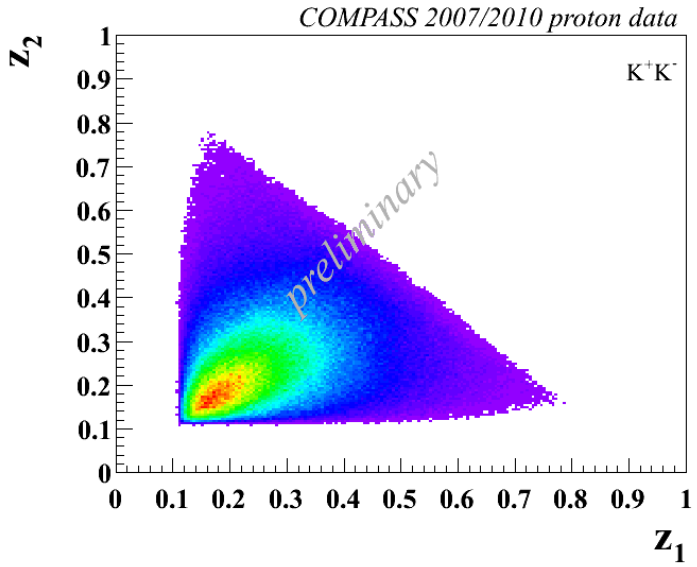


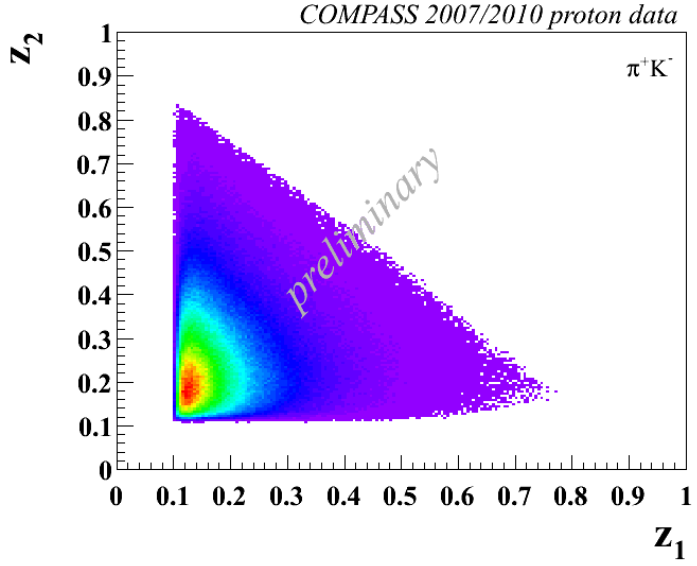
combined 2007/2010 data: $\cos\Theta$, $\cos^2\Theta$ and $\sin\Theta$ distributions

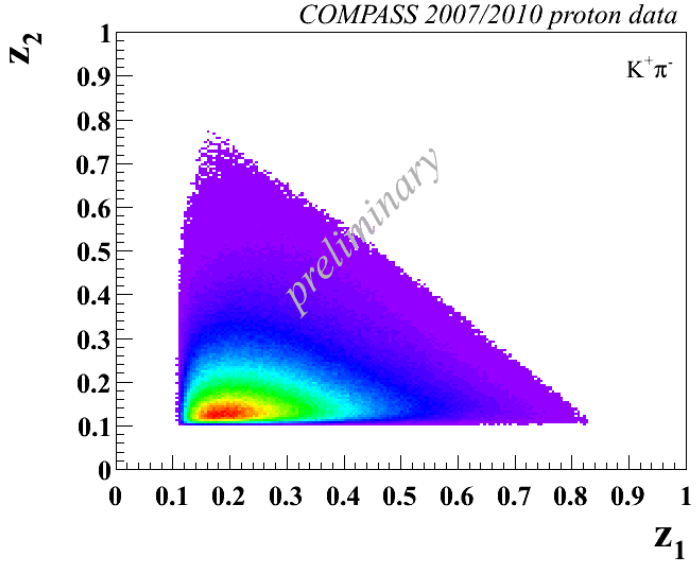


combined 2007/2010 data: z_1 vs. z_2 distributions

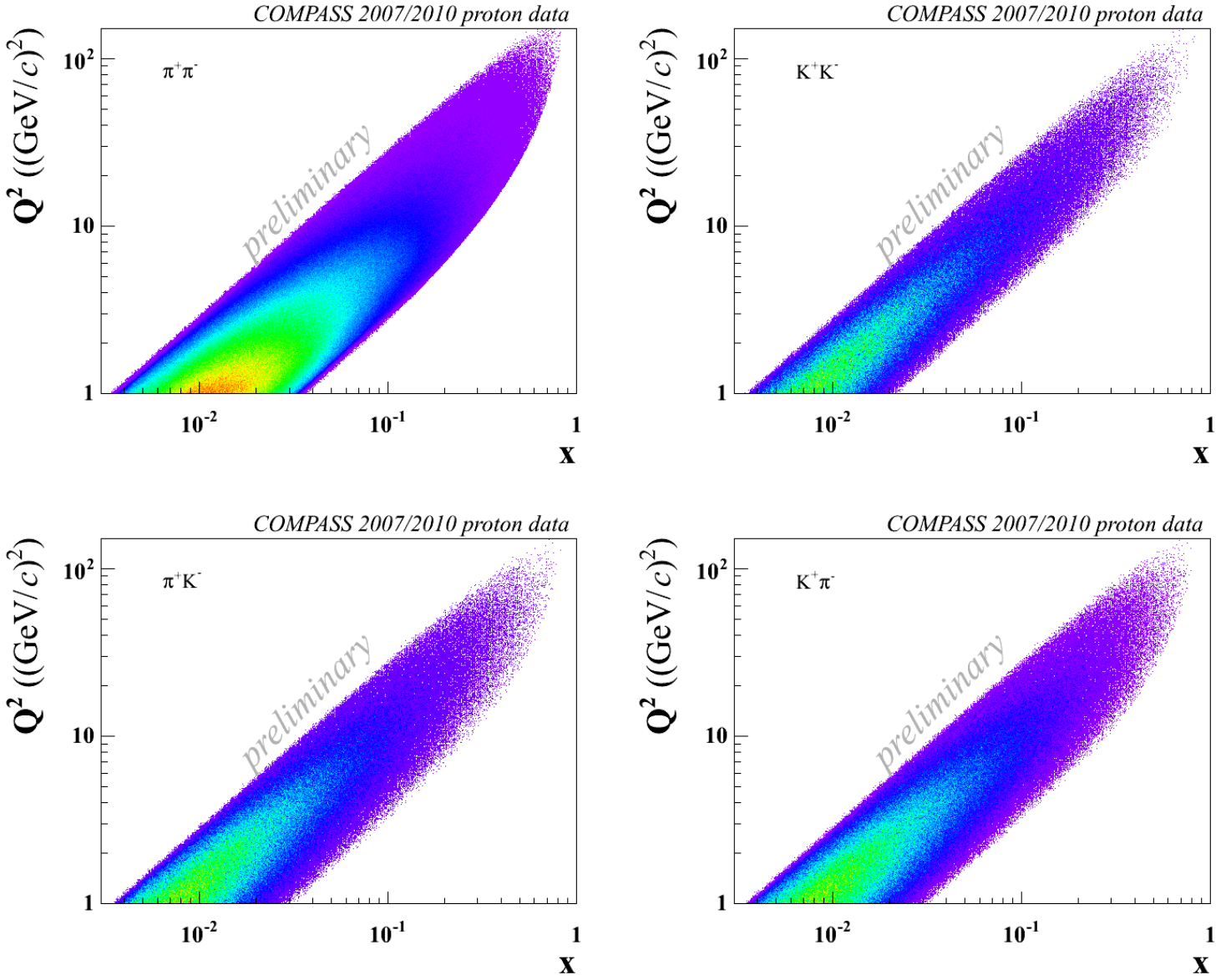




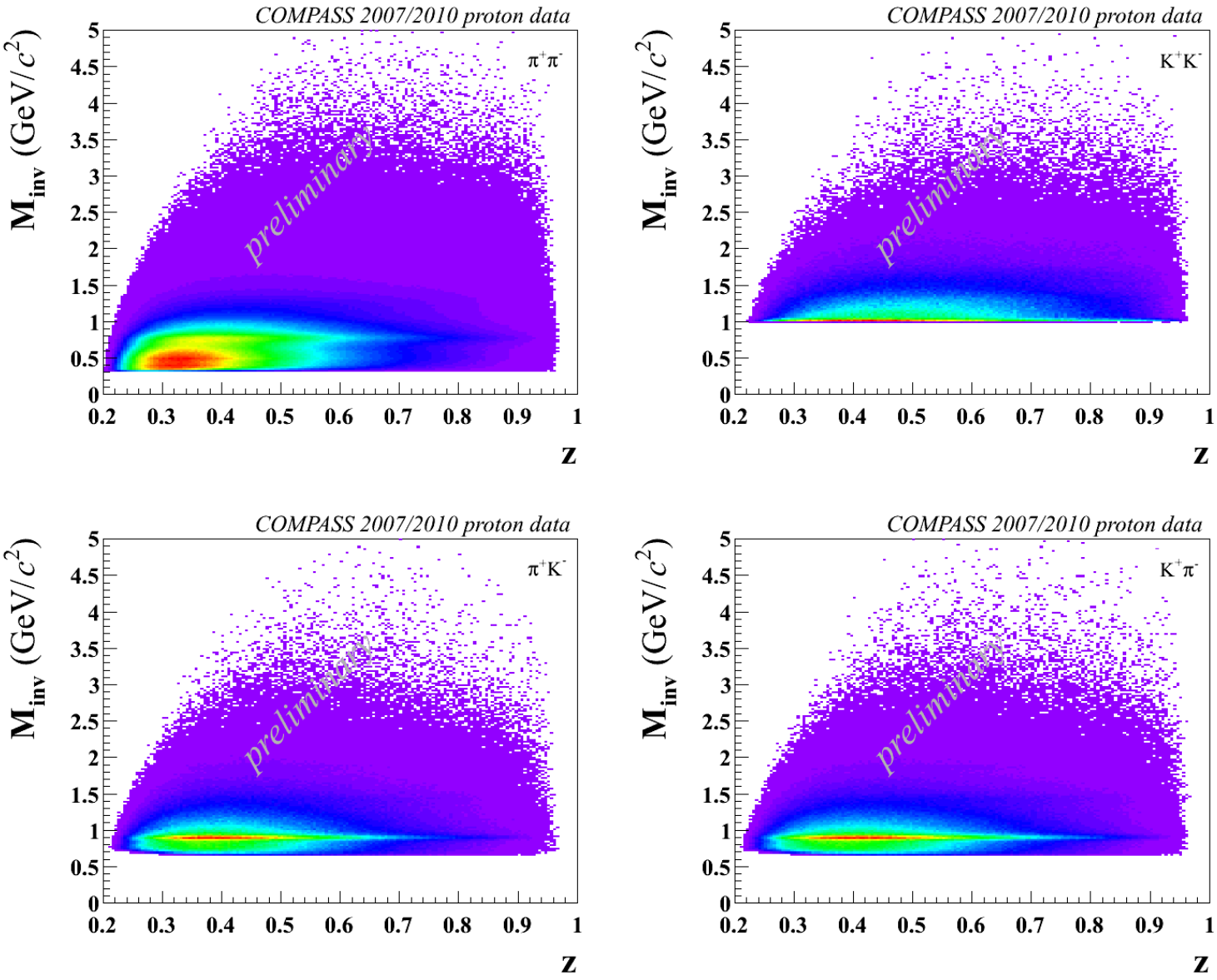




combined 2007/2010 data: Q^2 vs. x distributions

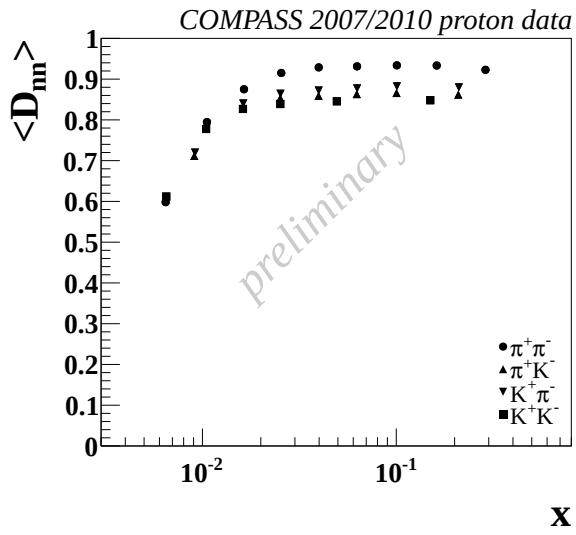


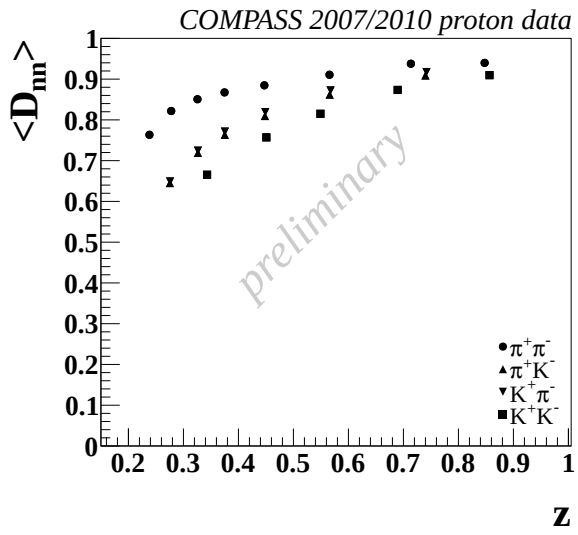
combined 2007/2010 data: M_{inv} vs. z distributions

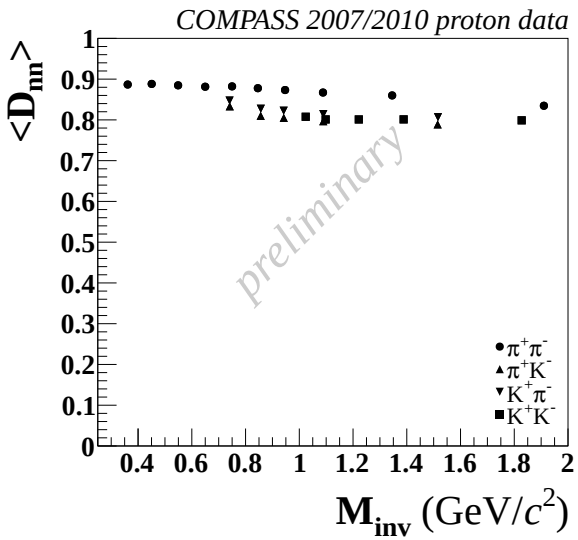


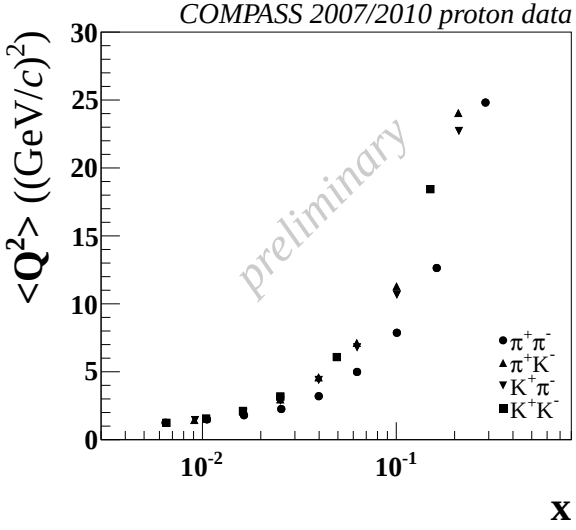
cf. Matevosyan

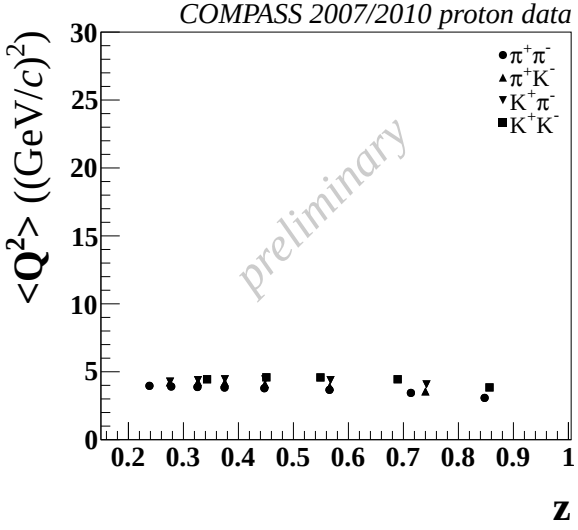
combined 2007/2010 data: mean D_{nn} & Q^2 in x, z and M_{inv} bins

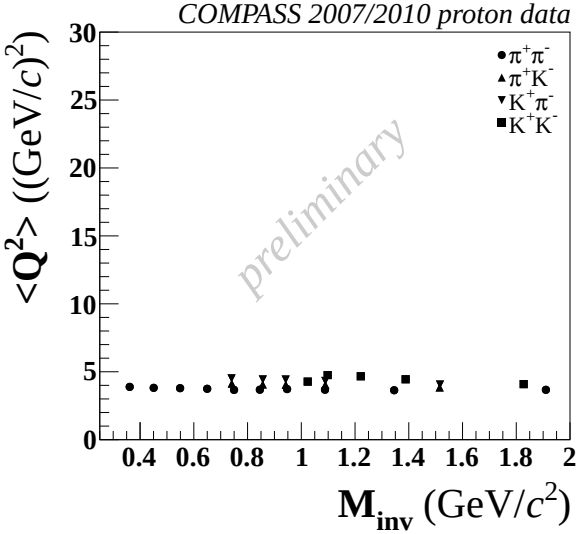






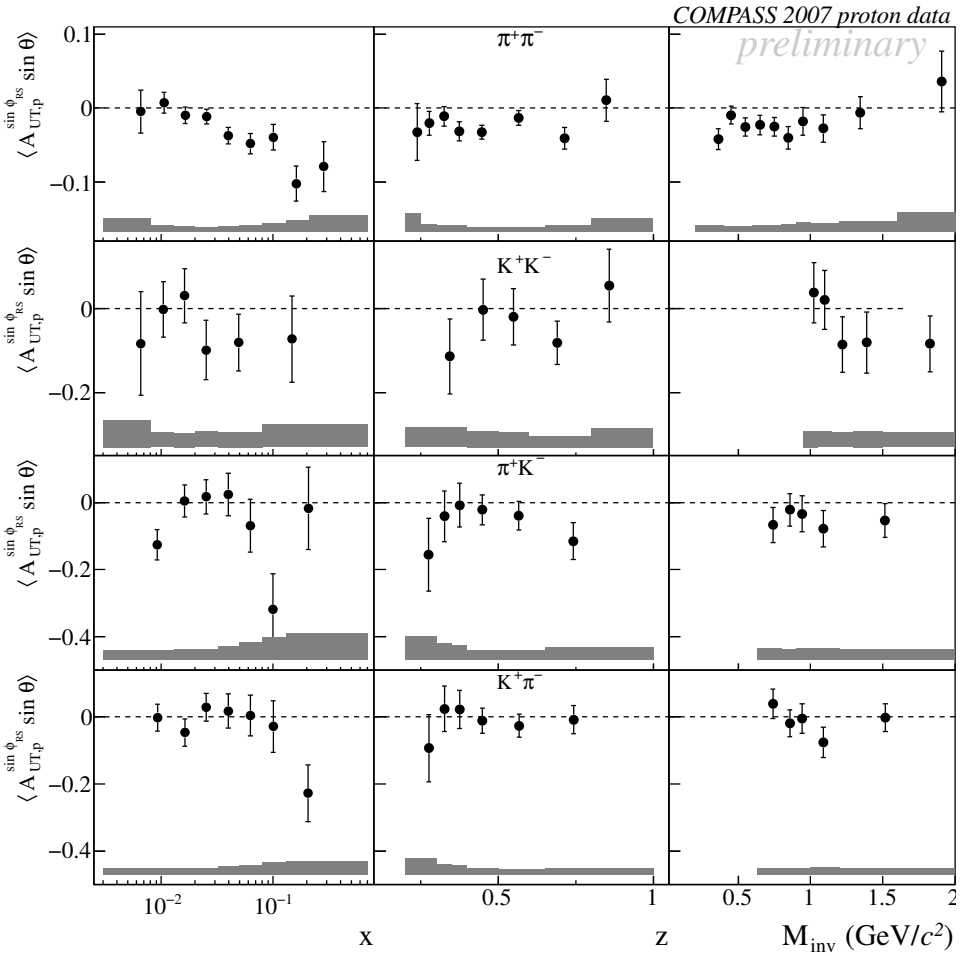




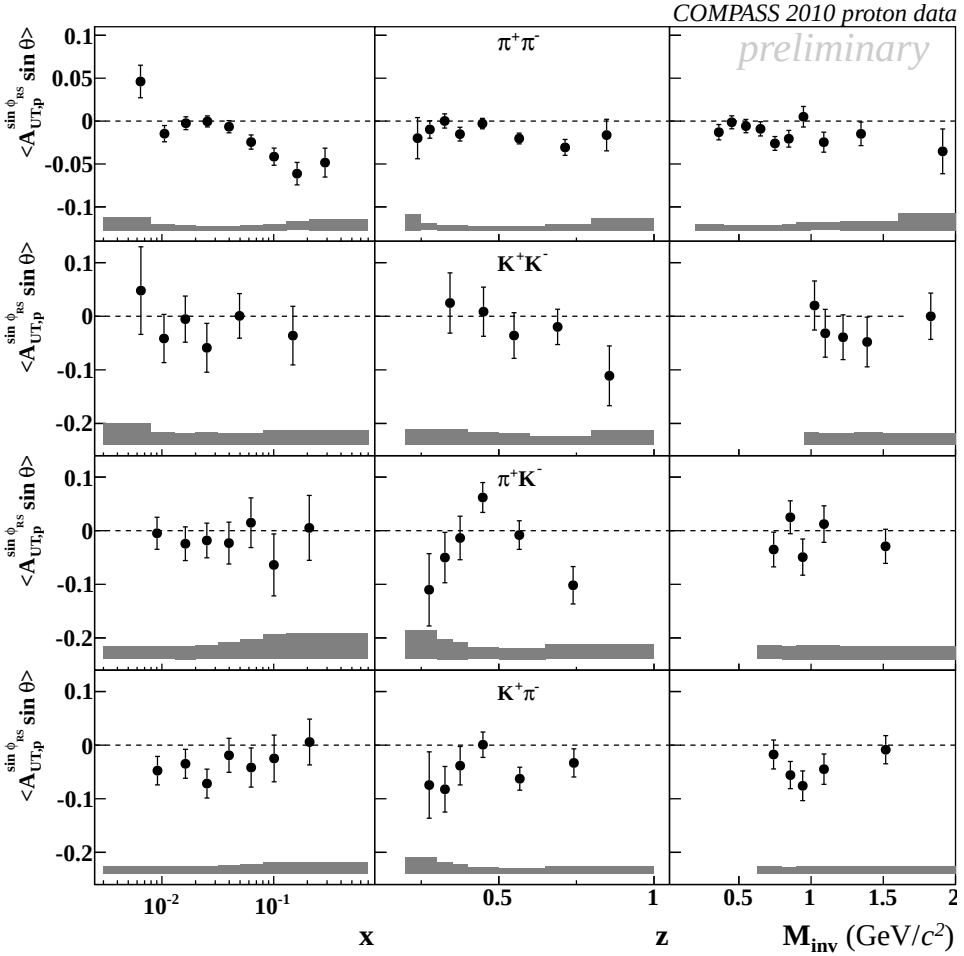


NEW: 2010 and 2007 proton data: all identified pairs

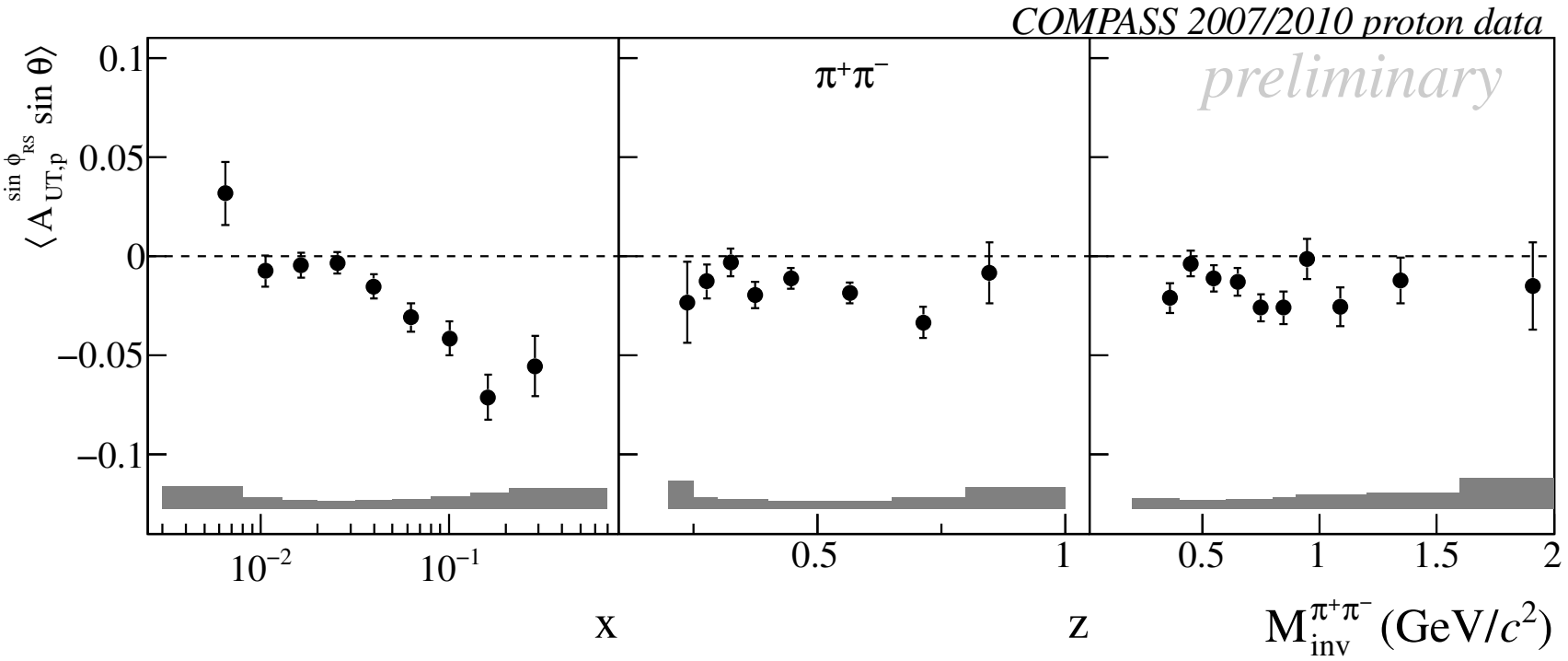
2007 data



2010 data



NEW: combined 2007/2010 data: $\pi^+\pi^-$ asymmetries



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

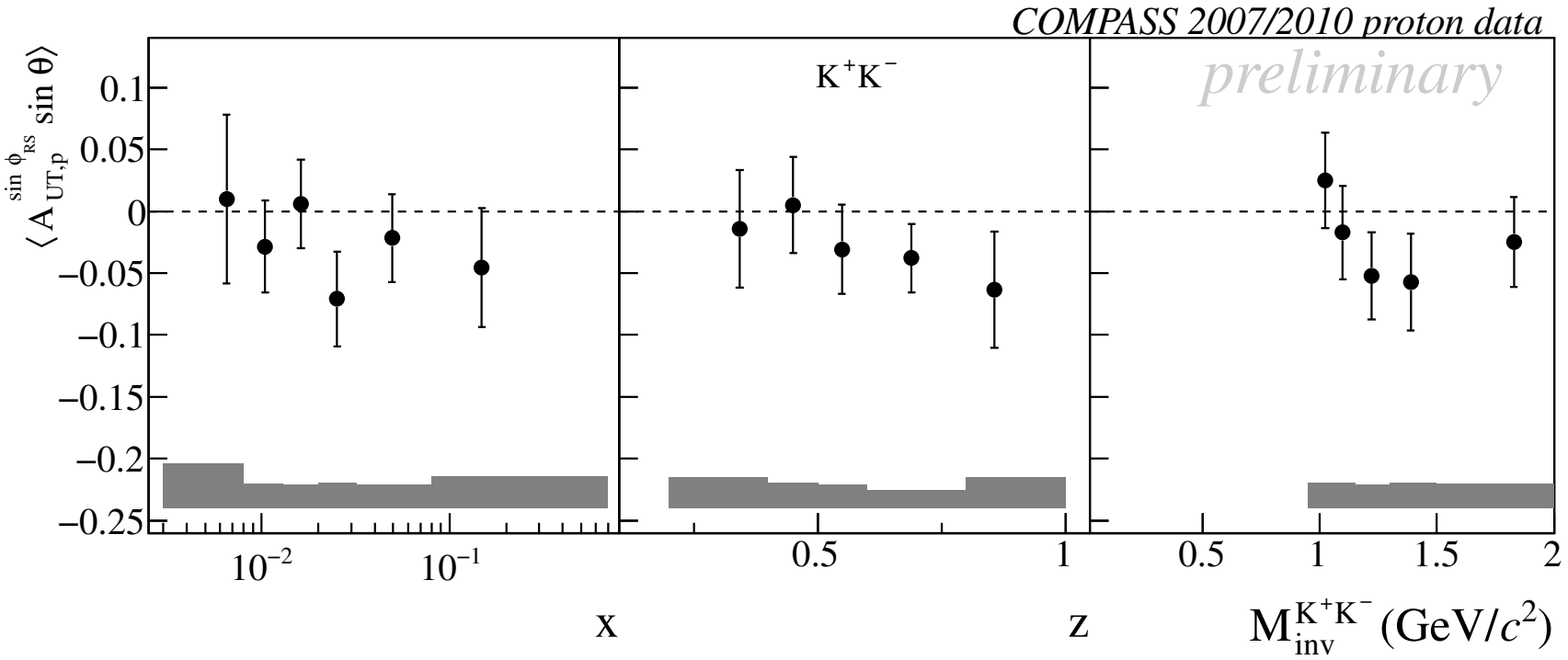
x up to $-6\,\%$

z no clear trend (compatible with a constant slope)

M_{inv} clear dip around ρ^0 mass

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

NEW: combined 2007/2010 data: K^+K^- asymmetries



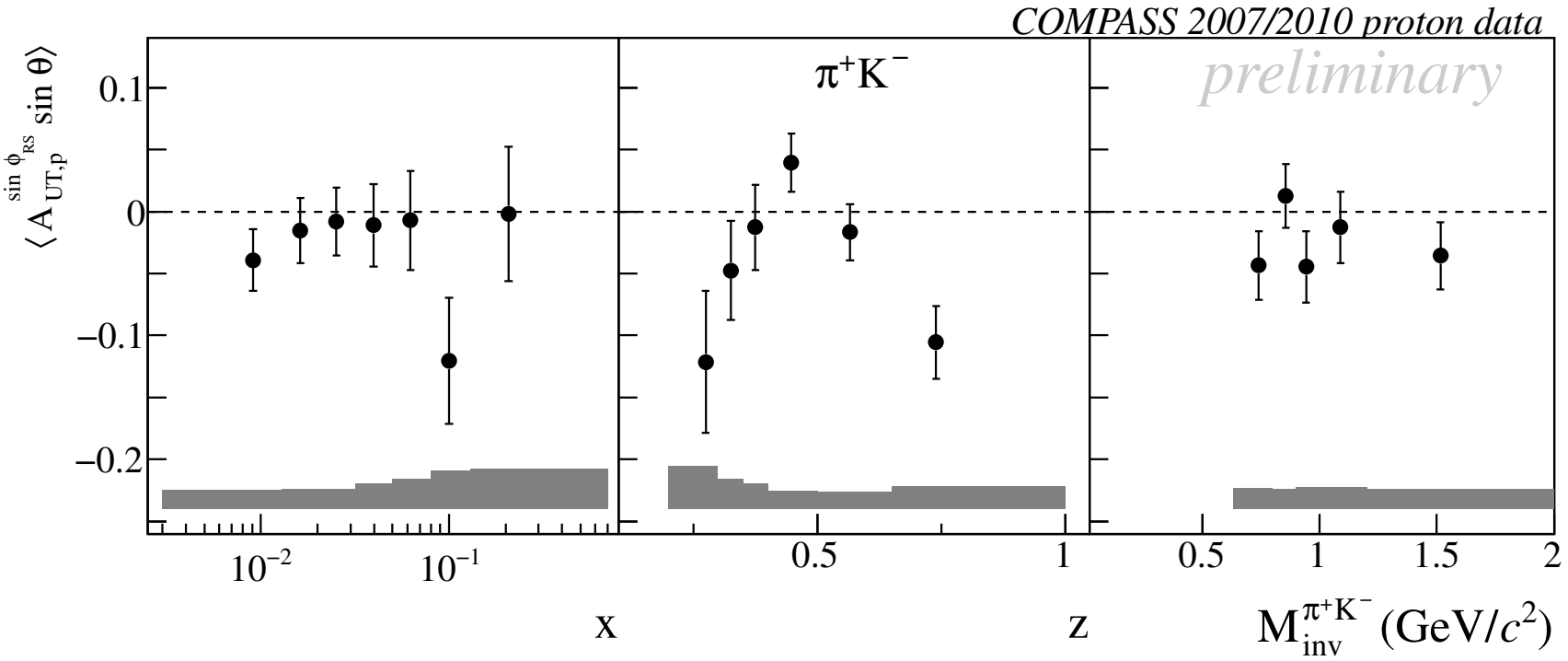
↪ no clear trend & compatible with zero within the statistical uncertainties

x no significant signal

z no significant signal

M_{inv} no significant signal

NEW: combined 2007/2010 data: π^+K^- asymmetries



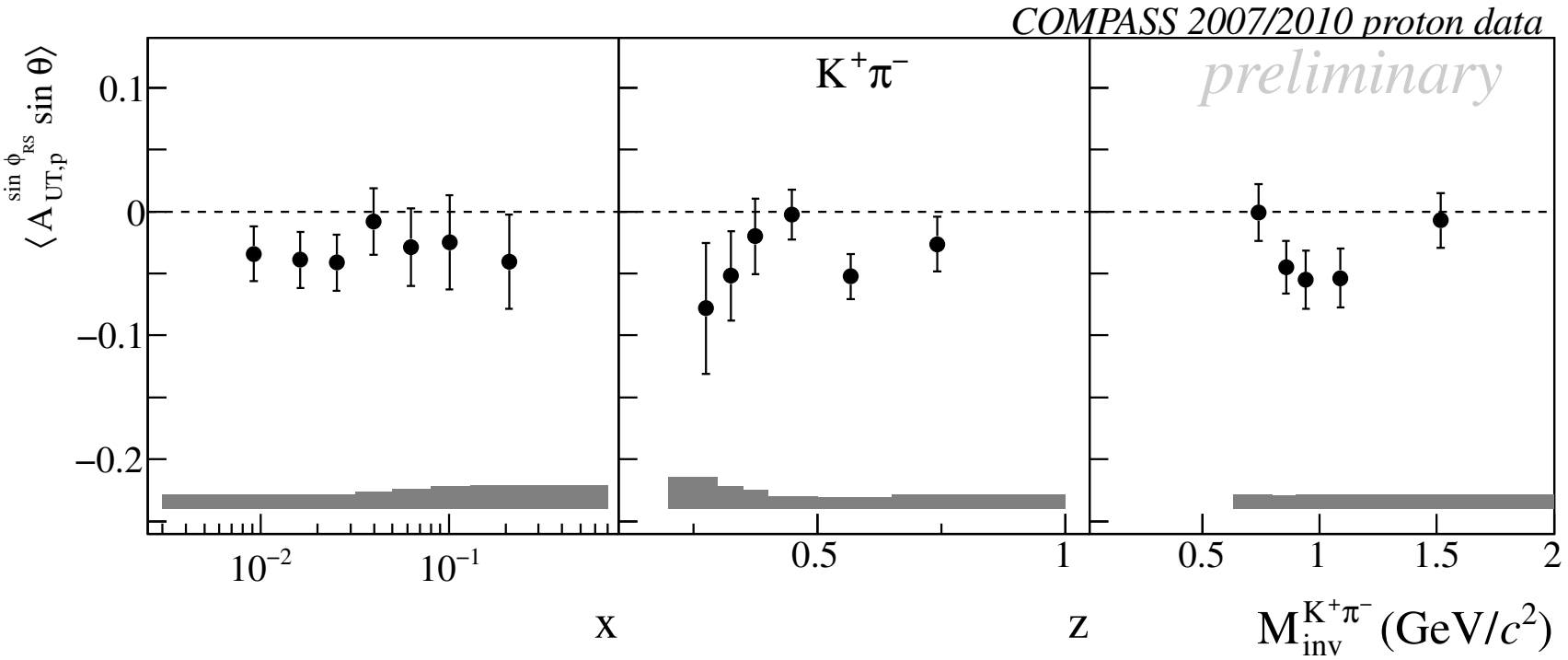
↪ compatible with zero within the statistical uncertainties

x no signal

z significant slope with a relative maximum around 0.45

M_{inv} no clear signal

NEW: combined 2007/2010 data: $K^+\pi^-$ asymmetries



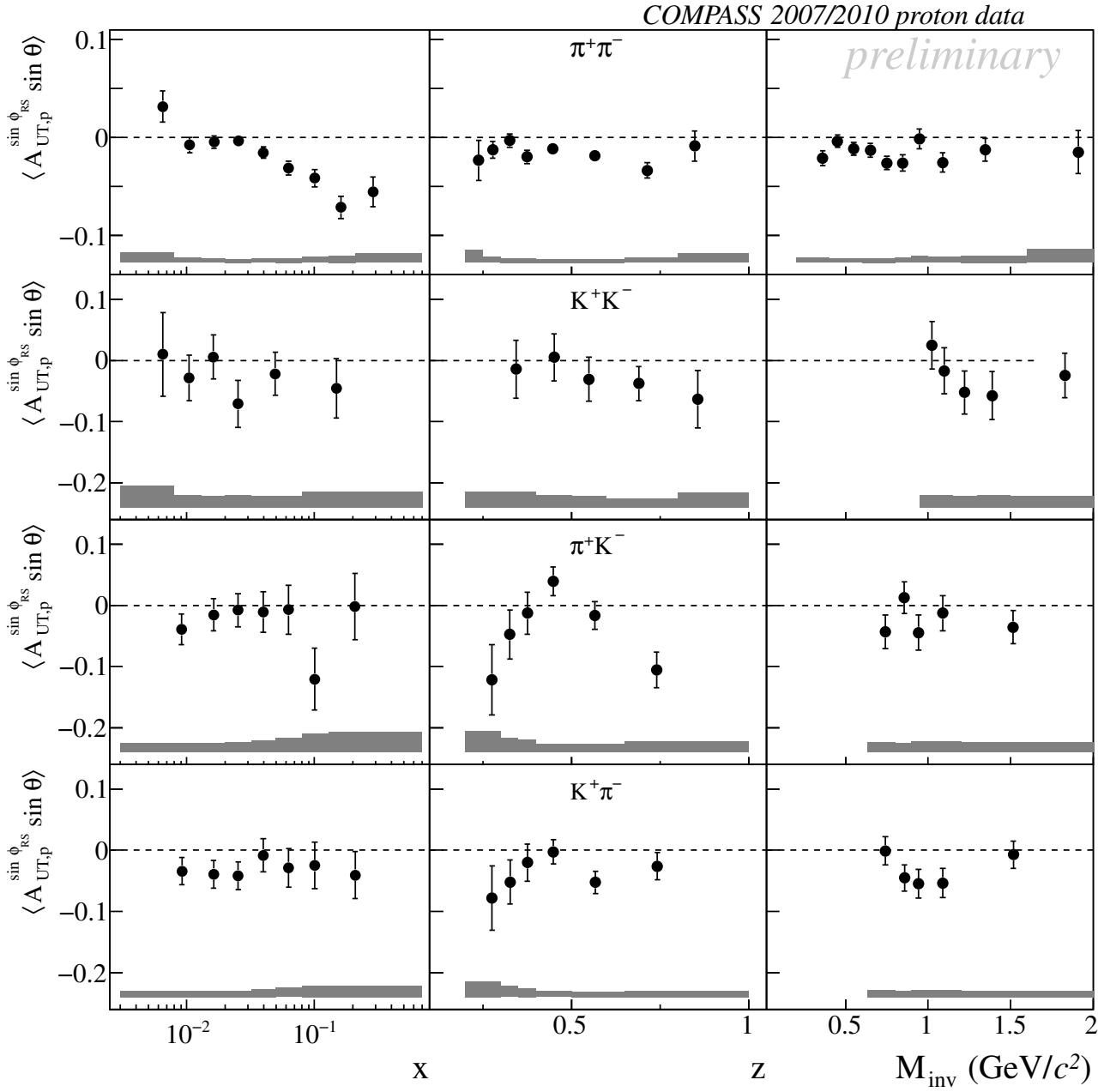
↪ compatible with zero within the statistical uncertainties

x no clear signal & negative mean value

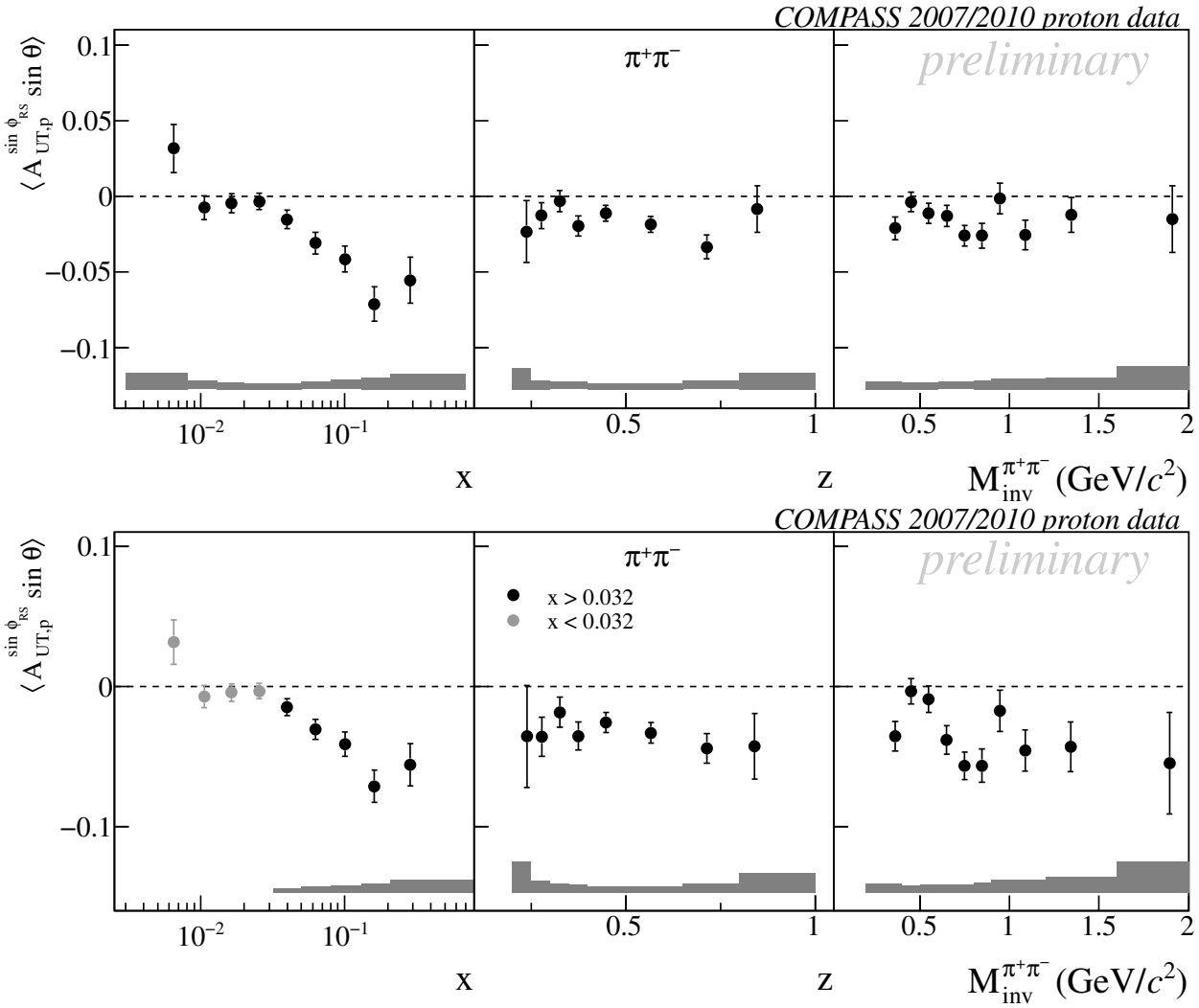
z no clear signal & negative mean value

M_{inv} minimum around 0.9 GeV/c^2

NEW: combined 2007/2010 data: all identified asymmetries



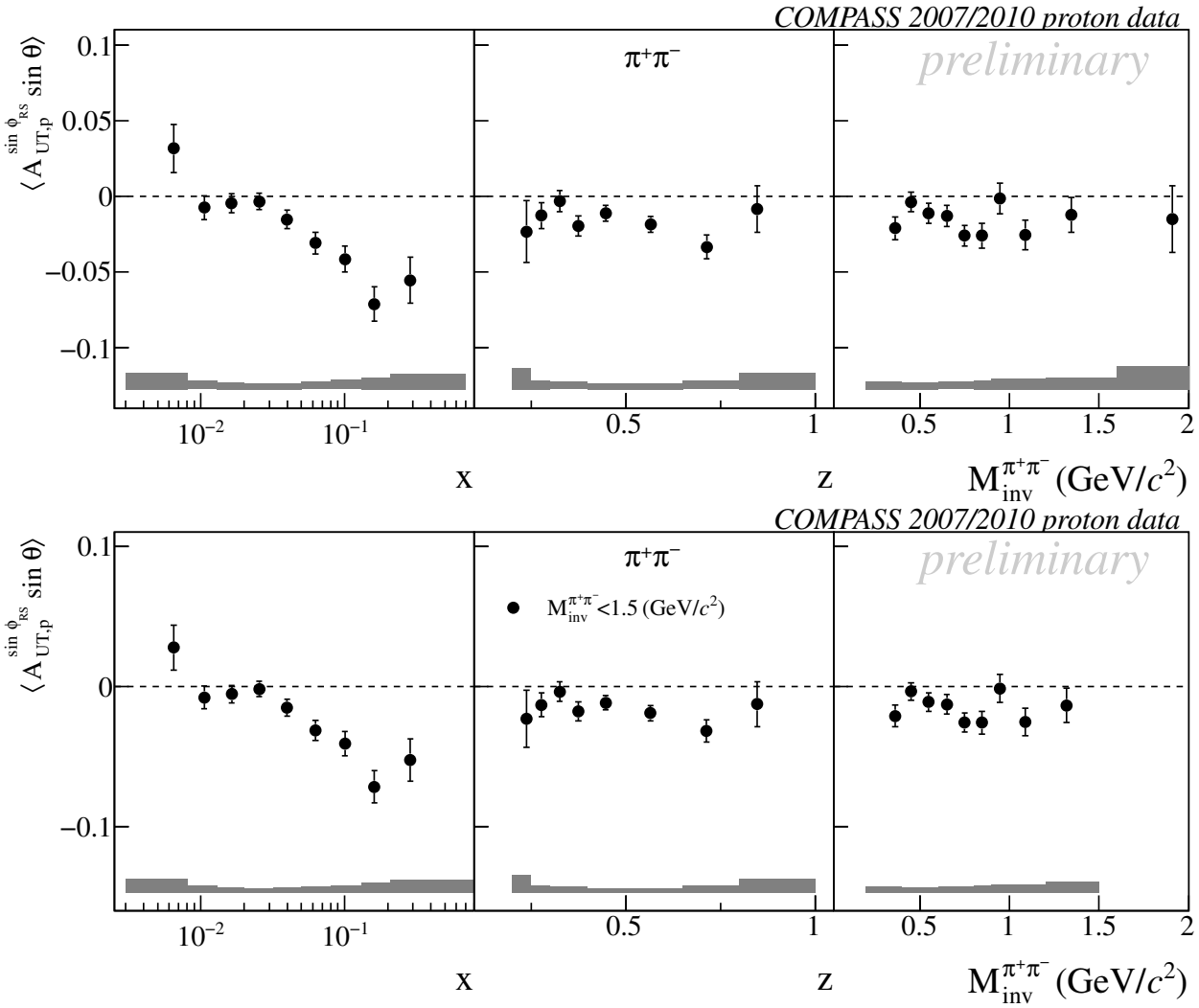
NEW: combined 2007/2010 data: $\pi^+\pi^-$ in valence region



$\hookrightarrow$ $\pi^+\pi^-$ valence region $x > 0.032$

Dip around the ρ^0 mass is pronounced in the valence region sample

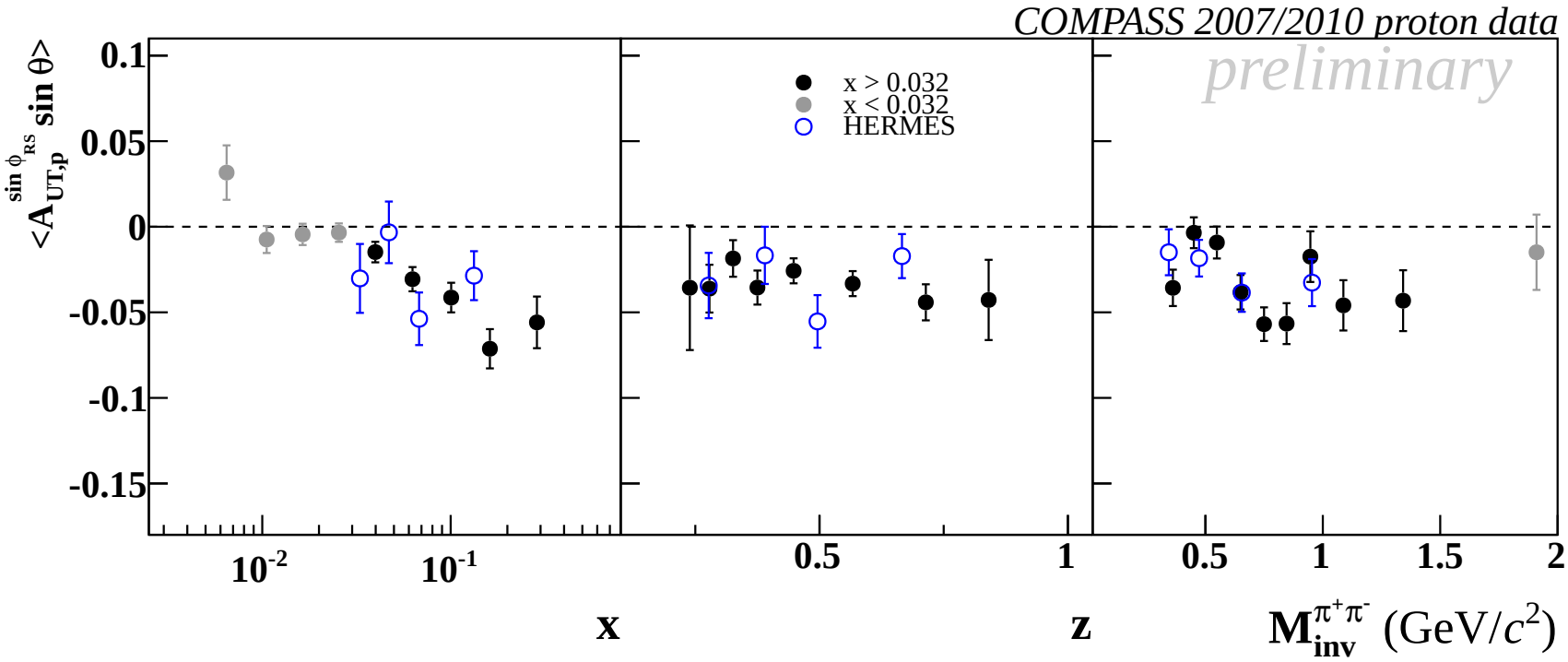
NEW: combined 2007/2010 data: $\pi^+\pi^-$ with M_{inv} cut



$\hookrightarrow$ $\pi^+\pi^-$ with M_{inv} <1.5 GeV/c^2

No change.

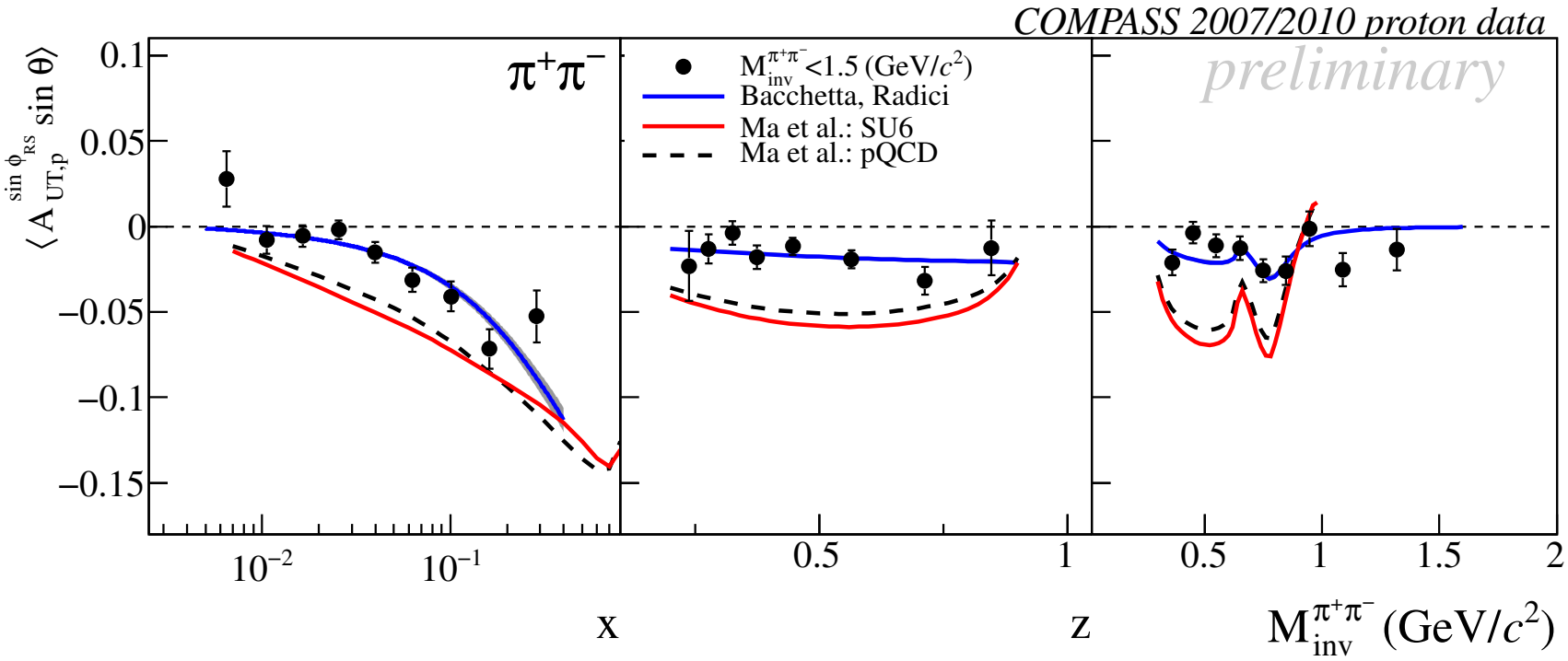
NEW: combined 2007/2010 data: comparison of $\pi^+\pi^-$ with results from HERMES



Airapetian A. et al. *et al.* [HERMES collaboration], J. High Energ. Phys. **06** (2008) 017
scaled with $\frac{1}{D_{nn}}$ and sign changed

↪ Good agreement within the uncertainties, bearing in mind the larger kinematic range of COMPASS

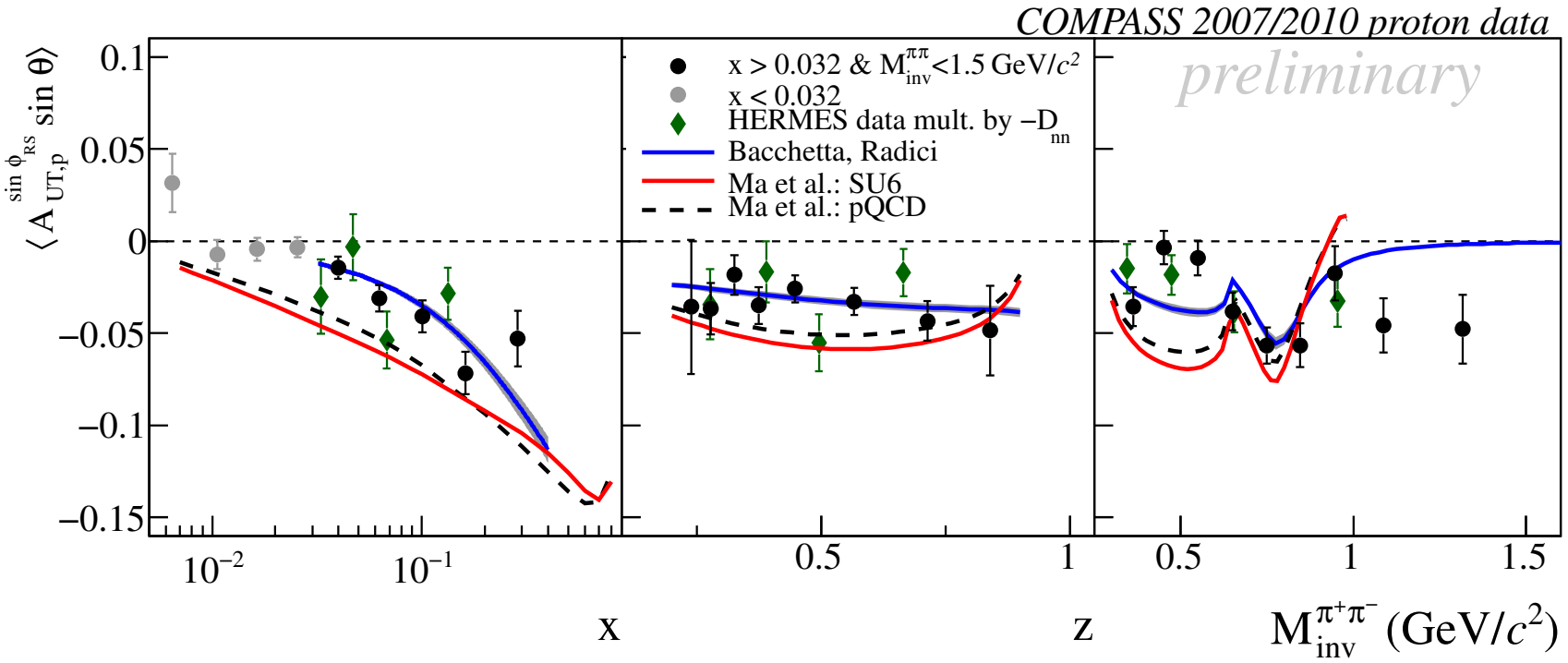
NEW: combined 2007/2010 data: comparison with model predictions



Bacchetta A. and Radici M., Phys. Rev. D **74** (2006) 114007
Ma B.-Q. *et al.*, Phys. Rev. D **77** (2008) 014035

↪ x: *Ma* trend confirmed | *Bachetta* good agreement
↪ z: *Ma* too large | *Bachetta* compatible
↪ M_{inv}: *Ma* too large | *Bachetta* good agreement around ρ^0 mass

NEW: combined 2007/2010 data: comparison with model predictions and HERMES



Airapetian A. et al. *et al.* [HERMES collaboration], J. High Energ. Phys. **06** (2008) 017
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Ma B.-Q. *et al.*, Phys. Rev. D **77** (2008) 014035

↪ Good agreement of the two measurements and model predictions

Conclusions & Outlook

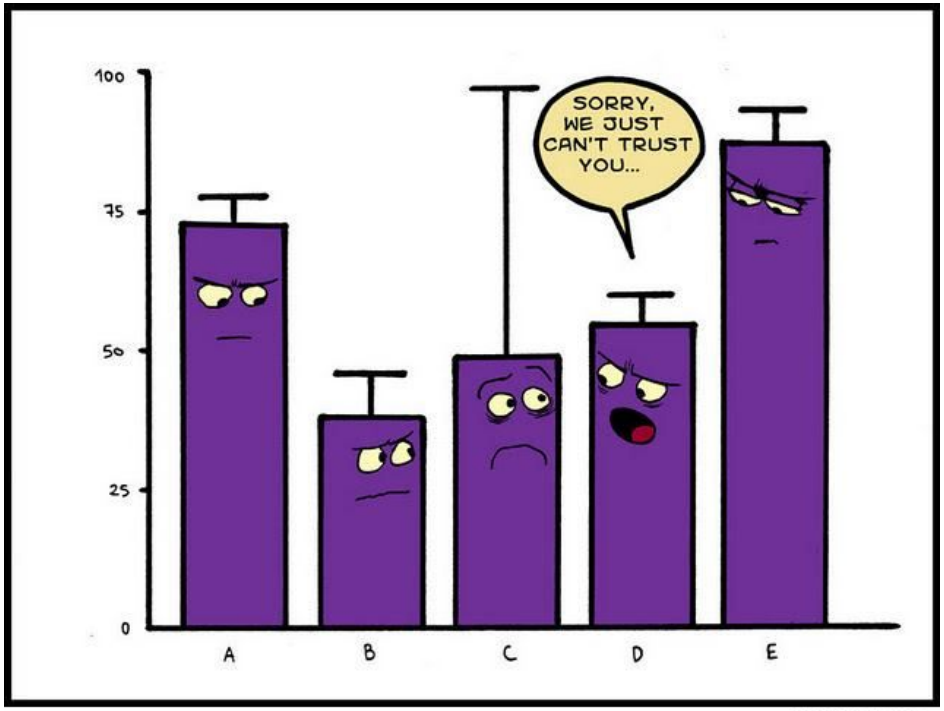
- COMPASS 2002-04 h^+h^- deuteron data published
- COMPASS 2007 proton data published
- preliminary results for 2010 COMPASS proton data
- preliminary combined results 2007/2010 COMPASS proton data

1. Recently: COMPASS **proton** data on transverse spin asymmetries in **identified** dihadron production
   - $\pi^+\pi^-$ (also measured by HERMES)
   - K^+K^-, π^+K^- and $K^+\pi^-$ to improve flavour separation
2. COMPASS $\pi^+\pi^-$ data is in good agreement with HERMES data
3. Reasonable agreement with available model predictions
4. Important input for the extraction of transversity h_1

Outlook:

- Paper on proton 2010 data: h^+h^- asymmetries
- Paper on combined proton 2007 & 10 and deuteron 2002-04 data (re-analysis): all identified pairs

Thank you for your attention!



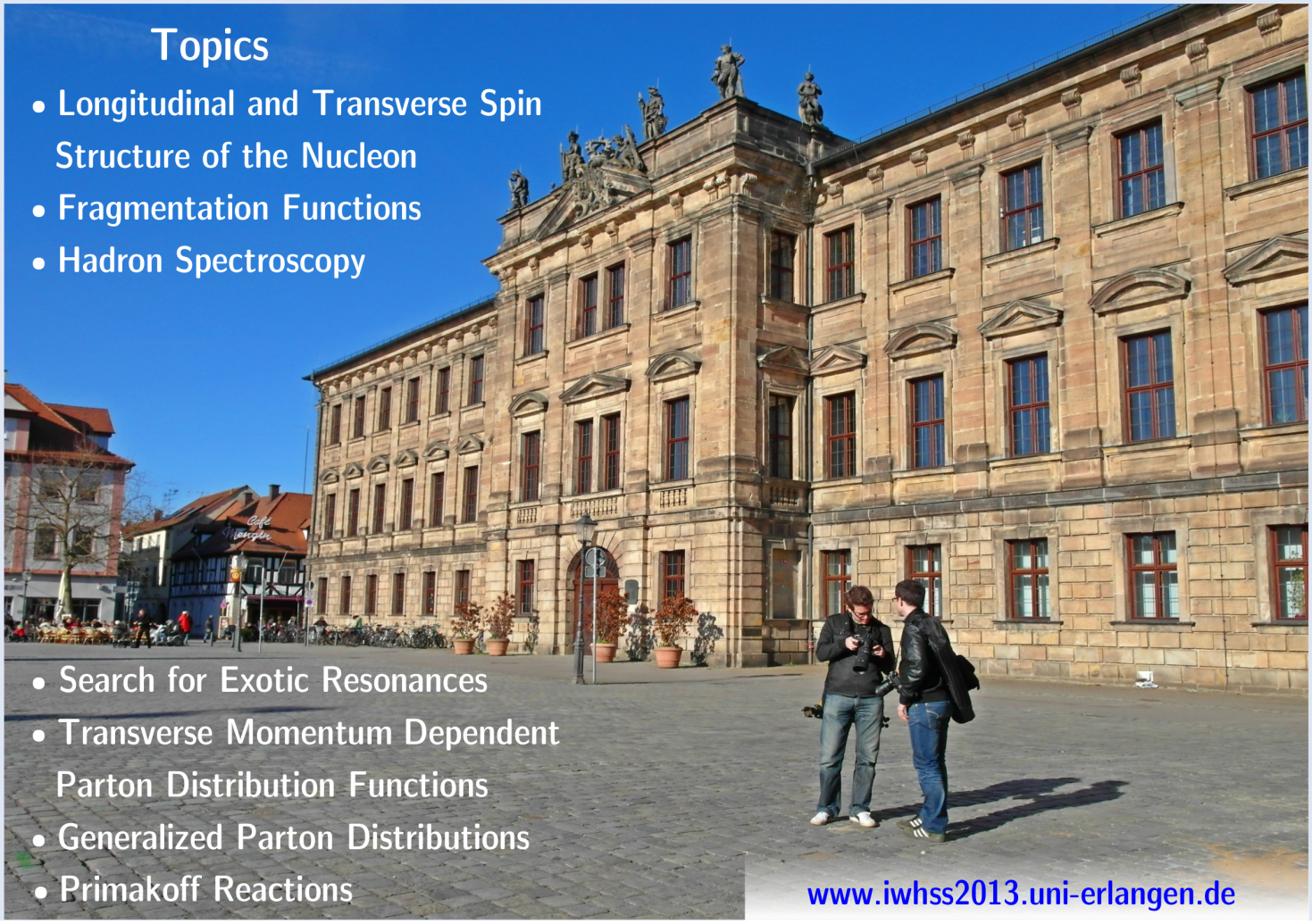
electronic address: christopher.braun@cern.ch

You are warmly invited to the IWHSS 2013

IWHSS 2013

International Workshop on Hadron Structure and Spectroscopy,

Erlangen, 22-24 July 2013



Invitation to IWHSS2013: Preliminary list of speakers and topics

E.-C. Aschenauer	Experimental review of hadron multiplicities and fragmentation functions
M. Boglione	Transverse momentum distributions – Q^2 evolution
F. Bradamante	Highlights of the workshop
V. Burkert	The JLAB 12 GeV project
V. Drach	Recent progress in Lattice QCD
A. Ferrero	COMPASS II: experiment and physics case
B. Grube	Spectroscopy at COMPASS and related Experiments
A. Guskov	Experimental review of Primakoff reactions
M. Kreps	Meson spectroscopy at LHCb
K. Kurek	Review of longitudinal spin physics
C. Lorcé	The proton spin decomposition: observability and physical interpretation
H. Moutarde	Review of some recent developments on Deeply Virtual Compton Scattering
B. Parsamyan	Unpolarized azimuthal asymmetries in SIDIS
M. Pennington	Directions in Spectroscopy: COMPASS points the way
K. Peters	The FAIR project
M. Radici	Theoretical overview of transverse spin physics in SIDIS and Drell-Yan
C. Riedl	Review of Drell-Yan experiments
F. Ringer	QCD resummation for semi-inclusive hadronproduction processes
K. Rith	Deep inelastic scattering – an overview
G. Schnell	Experimental review of transverse spin physics
M. Stratmann	Theoretical review of fragmentation functions