Measuring Transversity at COMPASS and RHIC with Spin Dependent Fragmentation Functions

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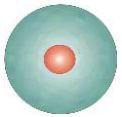
Workshop on Fragmentation Functions and QCD 2012 (Fragmentation 2012)

9-11 November 2012 RIKEN Wako, Nishina Hall

Parton Distribution Functions

The three leading order, collinear PDFs

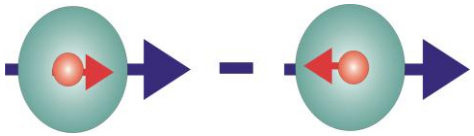
q(x)
$f_1^q(x)$



unpolarized PDF
quark with momentum $x=p_{quark}/p_{proton}$ in a nucleon

well known – unpolarized DIS

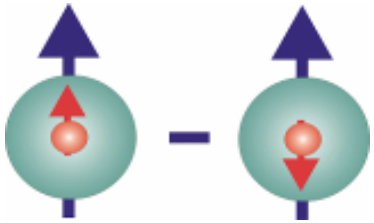
$\Delta q(x)$
$g_1^q(x)$



helicity PDF
quark with spin parallel to the nucleon spin in a longitudinally polarized nucleon

known – polarized DIS

$\Delta_T q(x)$
$h_1^q(x)$

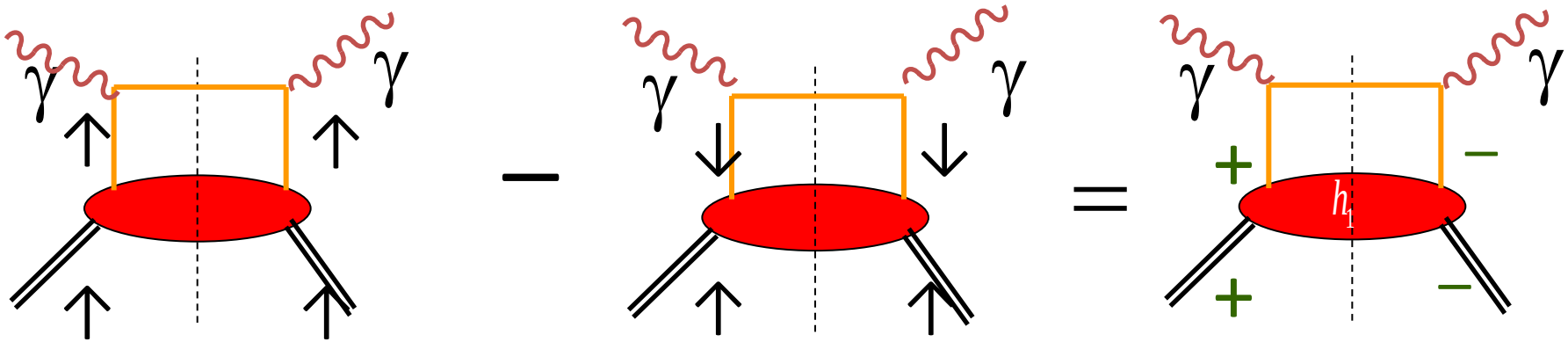


transversity PDF
quark with spin parallel to the nucleon spin in a transversely polarized nucleon

chiral odd, poorly known
Cannot be measured inclusively

Transversity is Chiral Odd

- Transversity base:



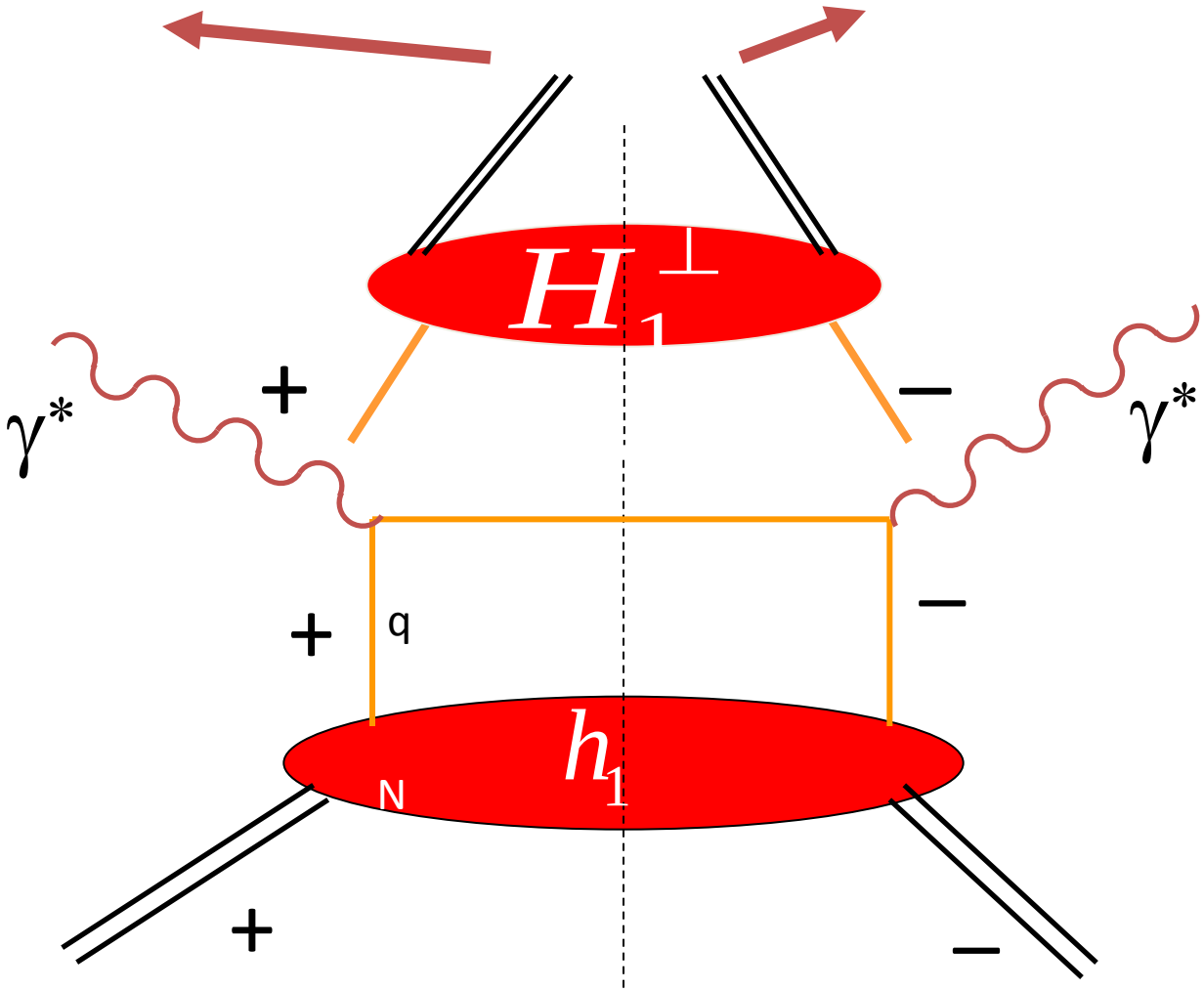
Difference in densities for ↑, ↓ quarks
in ↑ nucleon

- **Helicity base**: chiral odd
- Needs chiral odd partner ➔ Fragmentation Function
- Does not couple to gluons ⇨ different QCD evolution than $g_1(x)$
- Valence dominated ⇨ **Tensor charge comparable to Lattice calculations**

- **We want to extract tensor charge** $g_T = \int_{-1}^{1} h_1(x)dx$

Chiral odd FFs

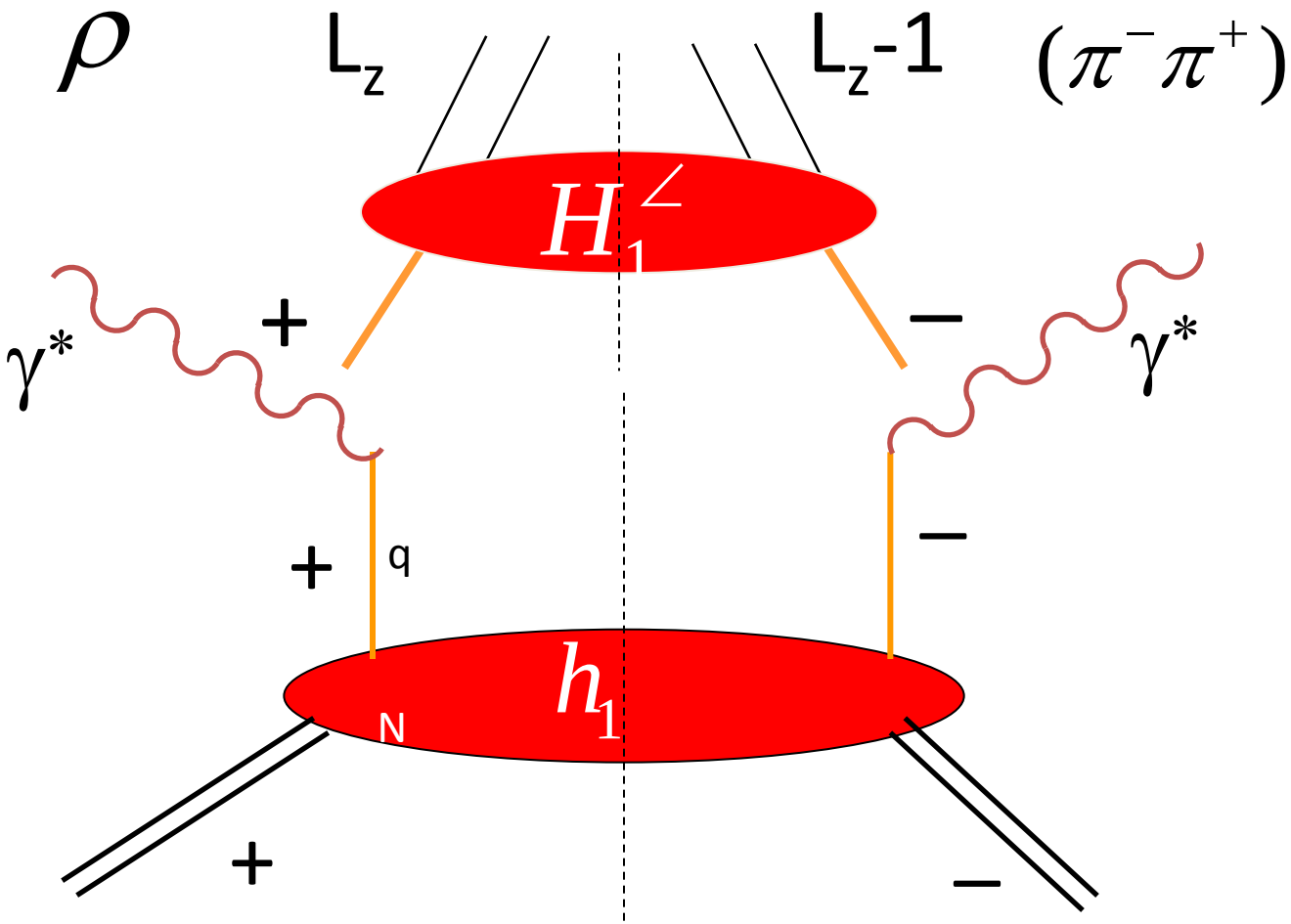
Collins effect



$H_1^\perp$ **: Collins FF**

Chiral odd FFs

Interference Fragmentation Function



Azimuthal Asymmetries for single Hadrons with transversal polarized target in SIDIS

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} = \quad \ldots$$

Collins asymmetry

$$+ |\boldsymbol{S}_\perp| \Big[\sin(\phi_h - \phi_S) \left(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \varepsilon\, F_{UT,L}^{\sin(\phi_h-\phi_S)} \right)$$

$h_1 H_1^\perp$

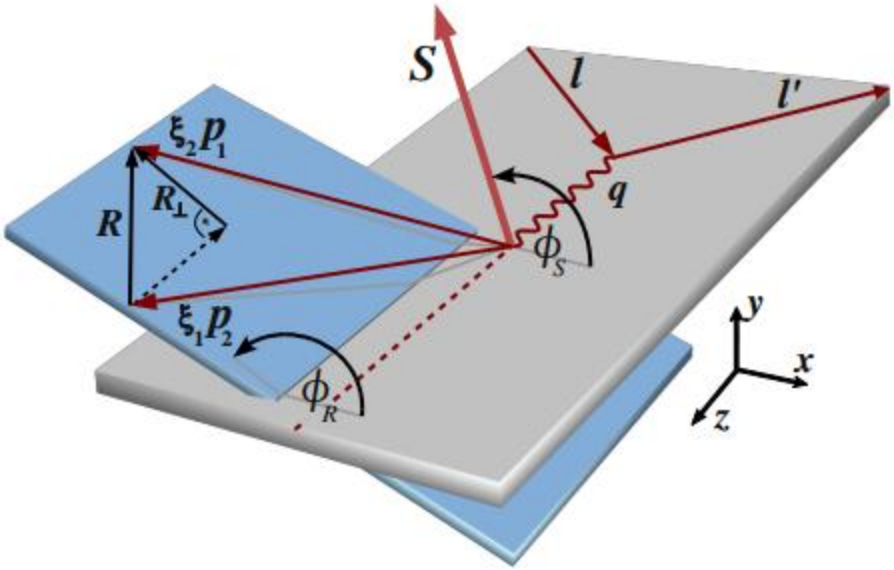
$$+ \varepsilon \sin(\phi_h + \phi_S)\, F_{UT}^{\sin(\phi_h+\phi_S)} + \varepsilon \sin(3\phi_h - \phi_S)\, F_{UT}^{\sin(3\phi_h-\phi_S)}$$

$$+ \sqrt{2\,\varepsilon(1+\varepsilon)} \sin\phi_S\, F_{UT}^{\sin\phi_S} + \sqrt{2\,\varepsilon(1+\varepsilon)} \sin(2\phi_h - \phi_S)\, F_{UT}^{\sin(2\phi_h-\phi_S)} \Big]$$

$$+ |\boldsymbol{S}_\perp| \lambda_e \Big[\sqrt{1-\varepsilon^2} \cos(\phi_h - \phi_S)\, F_{LT}^{\cos(\phi_h-\phi_S)} + \sqrt{2\,\varepsilon(1-\varepsilon)} \cos\phi_S\, F_{LT}^{\cos\phi_S}$$

$$+ \sqrt{2\,\varepsilon(1-\varepsilon)} \cos(2\phi_h - \phi_S)\, F_{LT}^{\cos(2\phi_h-\phi_S)} \Big] \Big\}$$

Di-hadron FF measurements



- Polarized di-hadron x-section ~ $\sin(\theta)h_1(x)H_1(z,M)\sin(\phi_R+\phi_S-\pi)$
- Compass does not fit $\sin(\theta)$ separately

COMPASS Setup

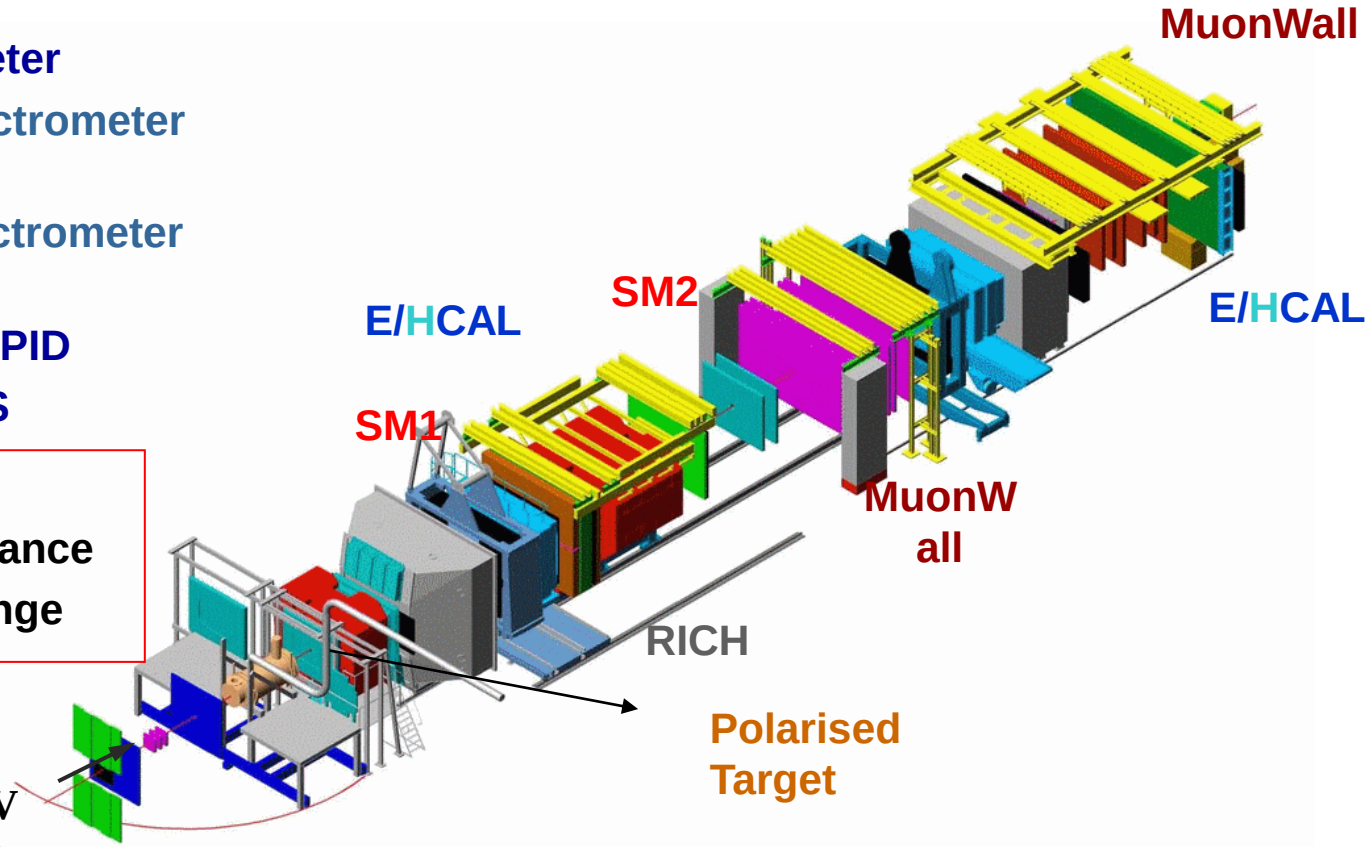
two stages spectrometer

- **Large Angle Spectrometer (SM1),**
- **Small Angle Spectrometer (SM2)**

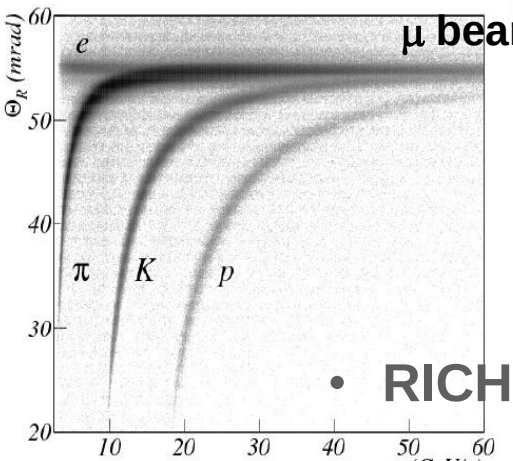
tracking, calorimetry, PID

NEW TECHNOLOGIES

- **high energy beam**
- **Large angular acceptance**
- **Broad kinematical range**



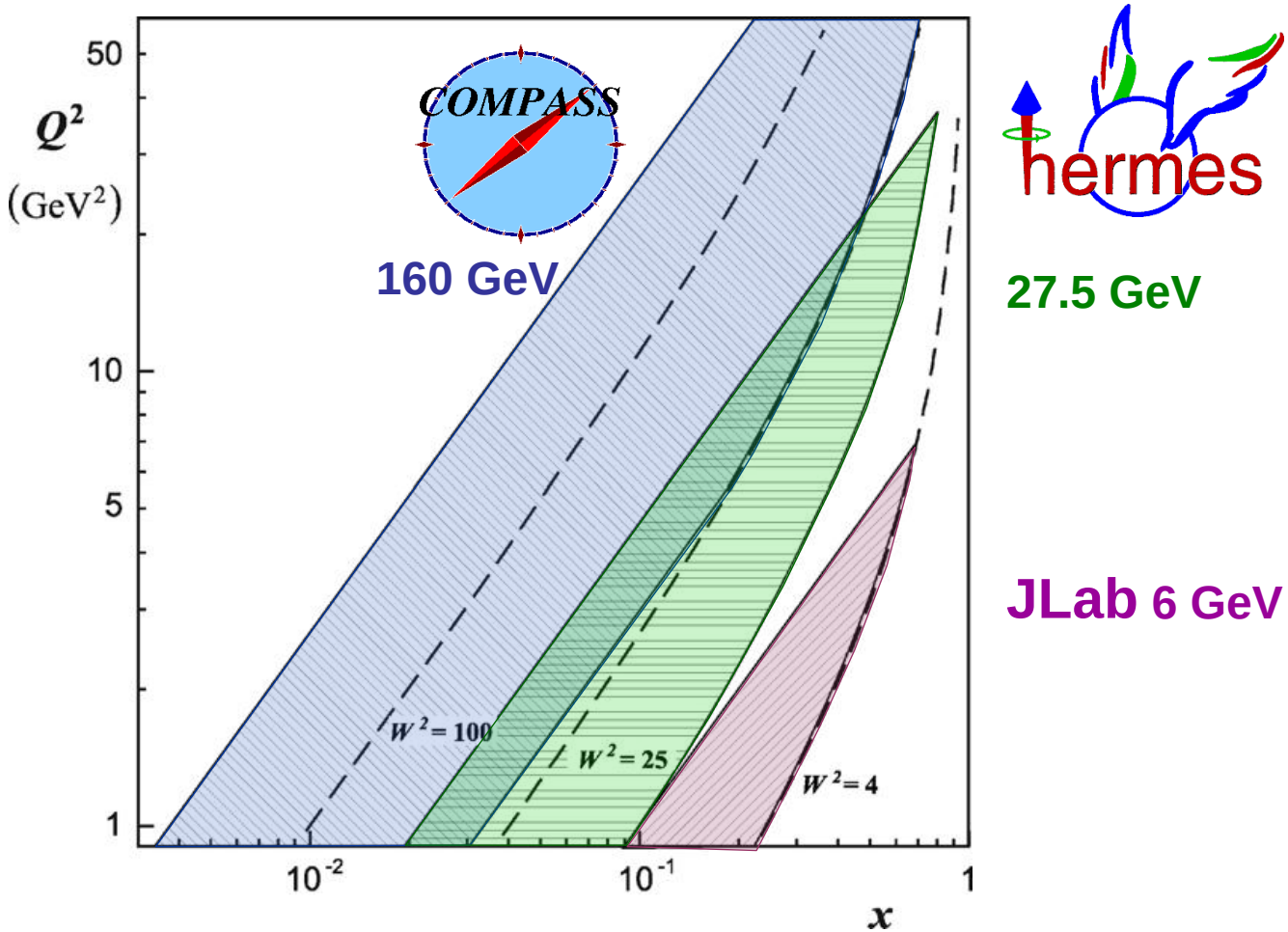
160 GeV
μ beam



- **RICH PID 9-50 GeV**

2002-2004: 6LiD (Deuteron)
dilution factor f = 0.38 polarization PT =50%
>2005 NH3 (proton)
3 target cells with opposite polarization,90% polarization, 16% dilution

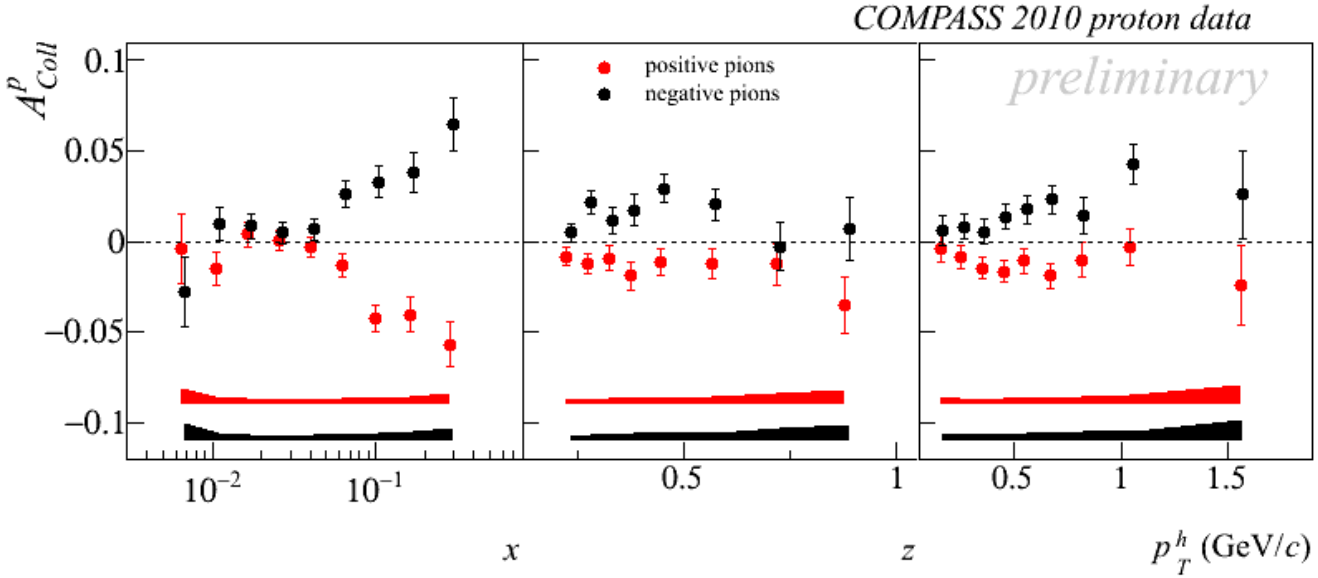
COMPASS Kinematic Reach vs. Hermes and Jlab @ 12GeV

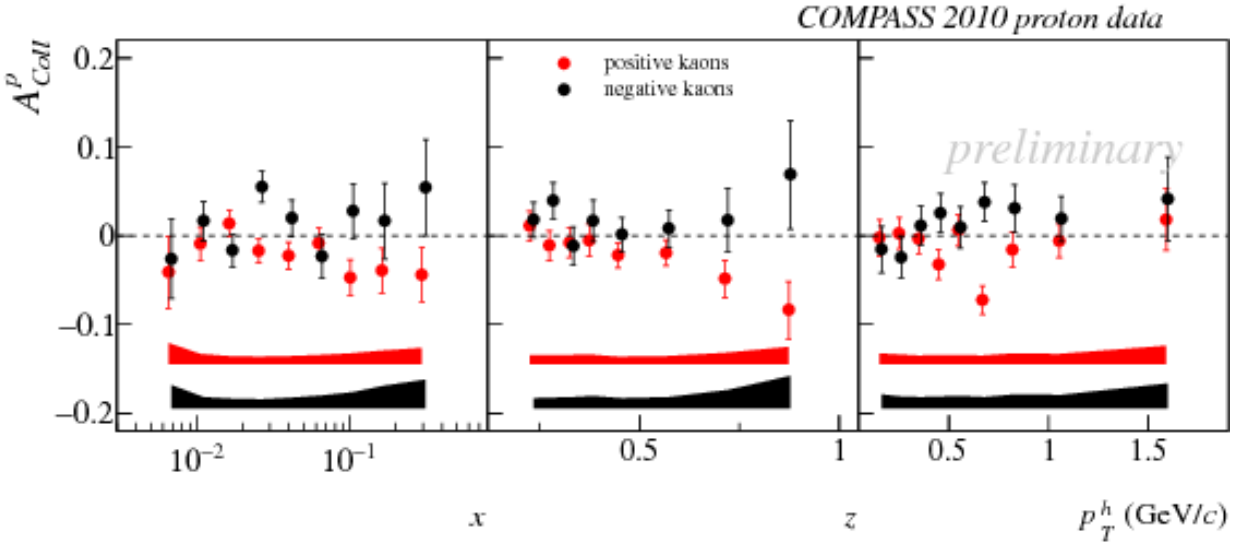


Compass Data taking

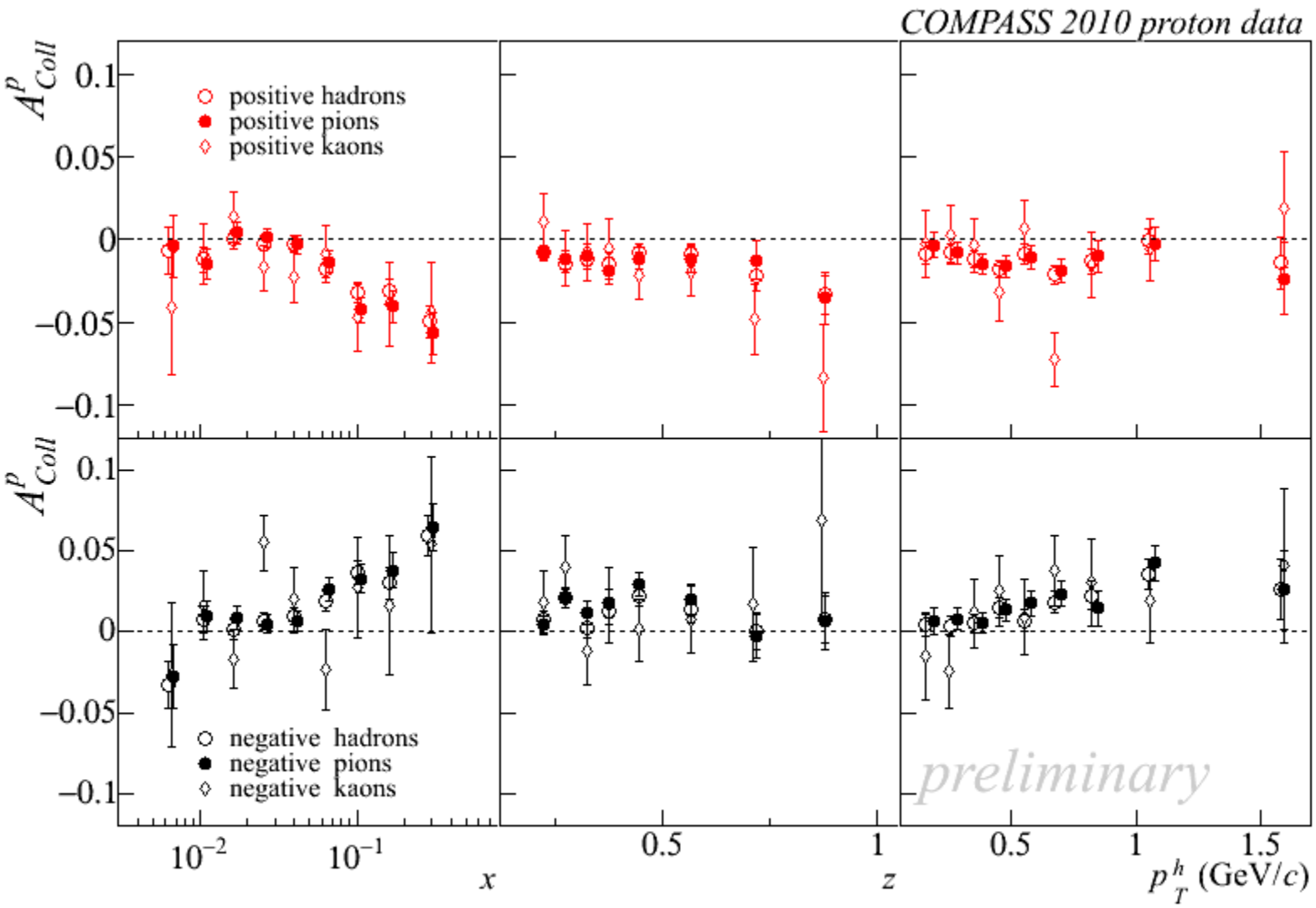
- **Deuteron: 2002-2004**
- **Proton 2007 and 2010**
- **Publications:**
  - **Unidentified Dihadrons: Phys.Lett. B713 (2012) 10-16, 2002-2004 (deuteron), 2007 proton**
  - **Unidentifed Hadrons Collins:**
    - **Deuteron:NP B765 (2007) 31–70 (uident) PLB 673 (2009) 127–135,**
    - **Proton: PLB 692 (2010) 240–246**
- **Identified proton 2010 preliminary:**

Results Collins

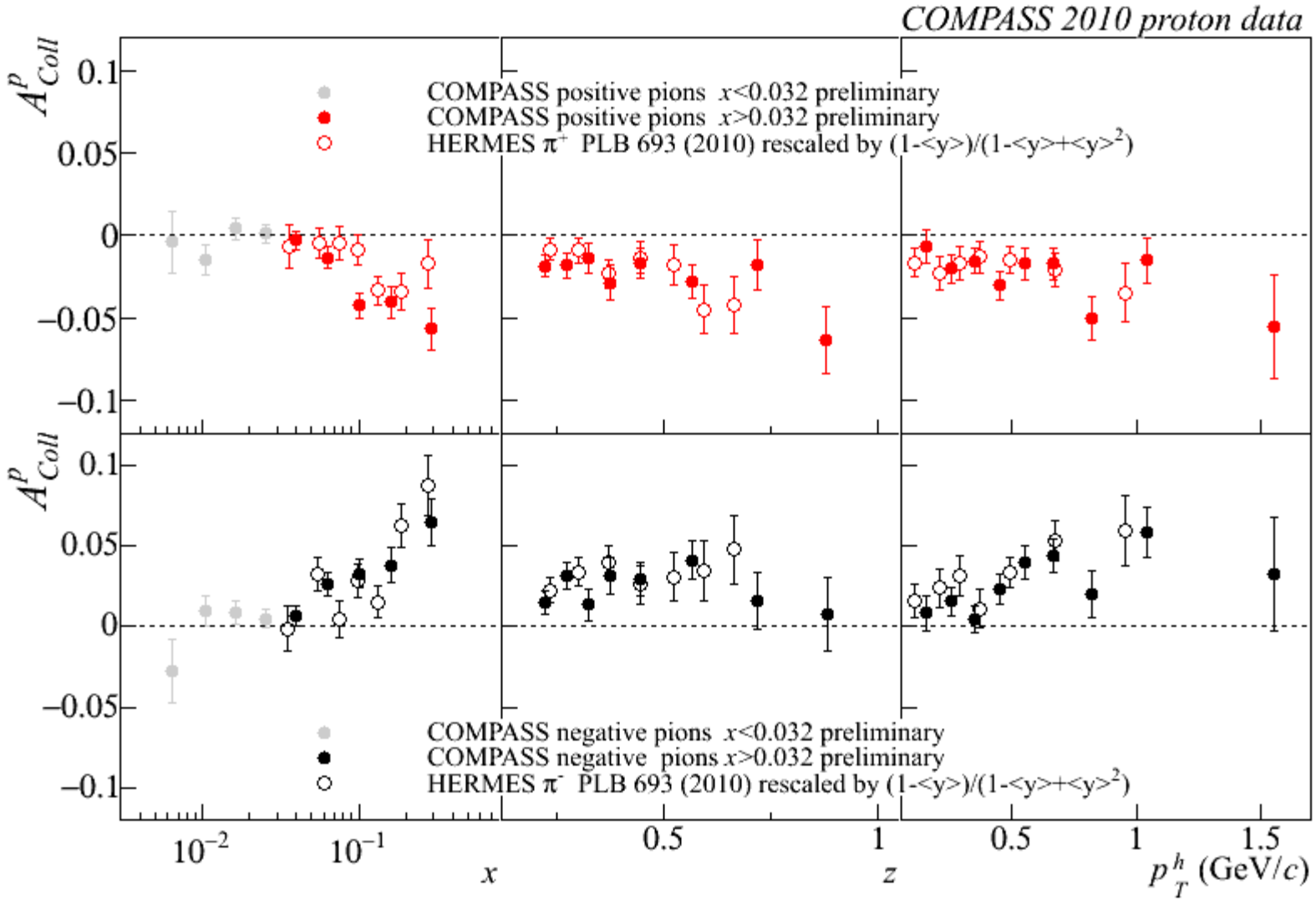




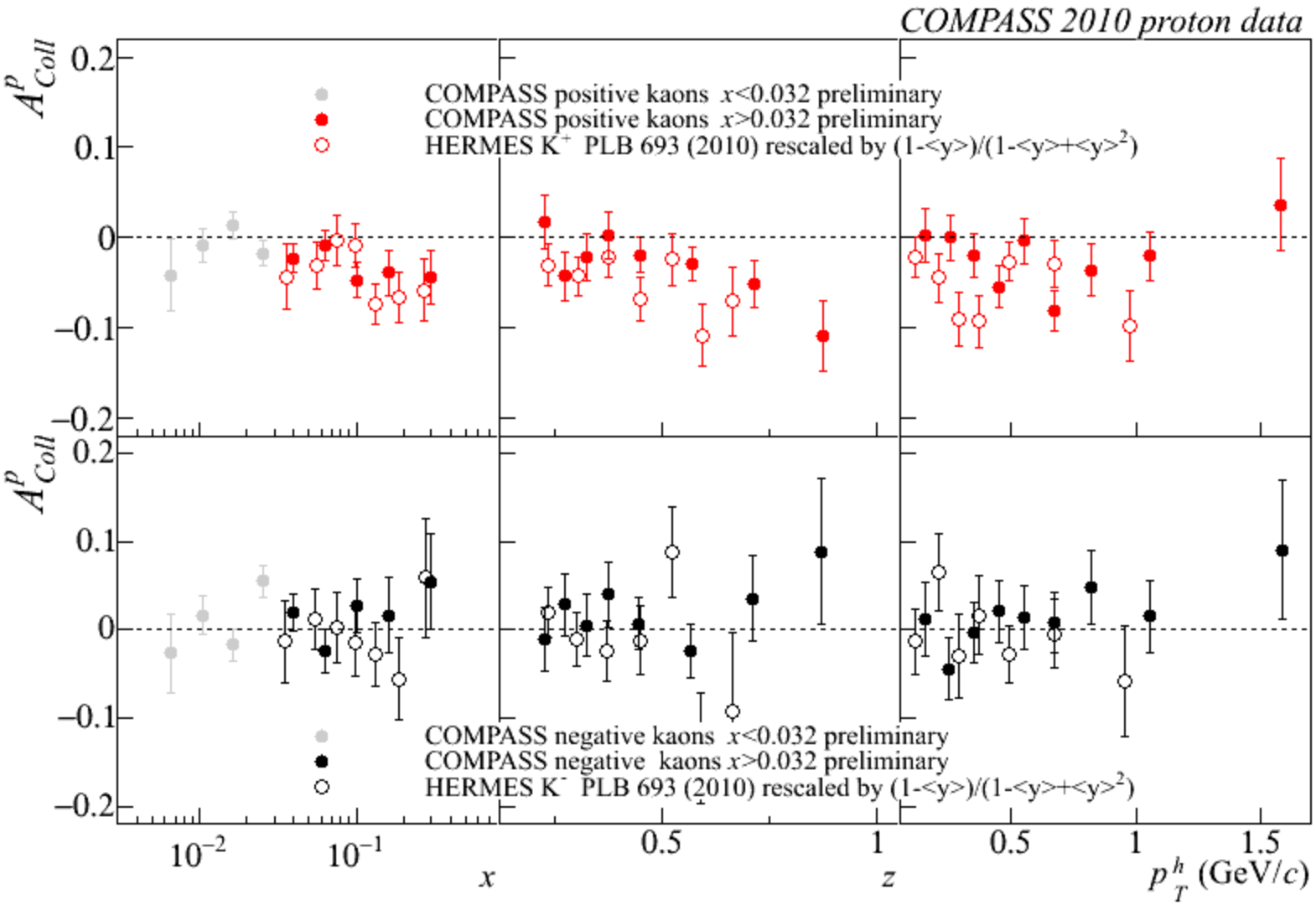
Pions Asymmetries similar to Kaons



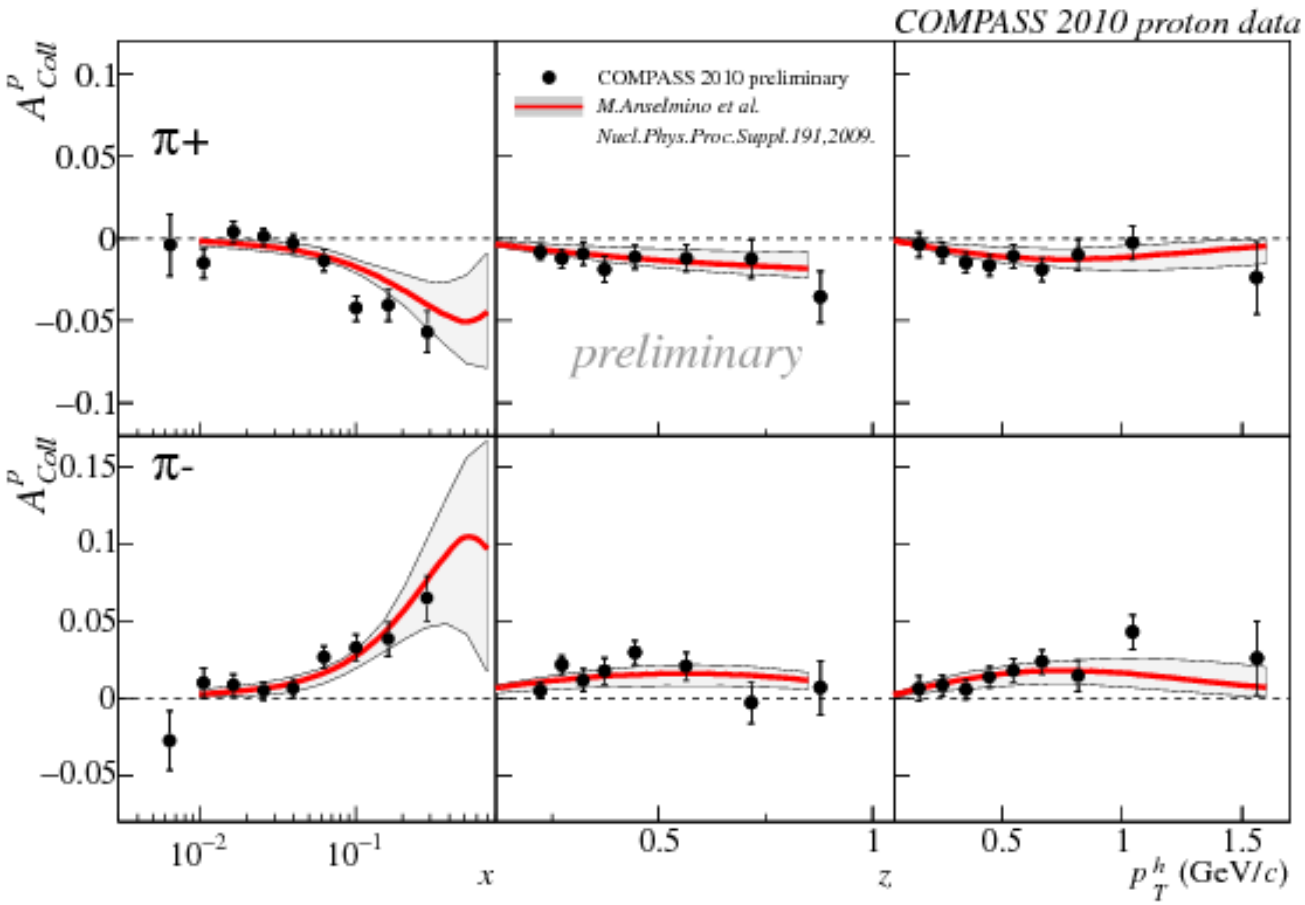
Compass is consistent with Hermes



Compass/Hermes Kaons

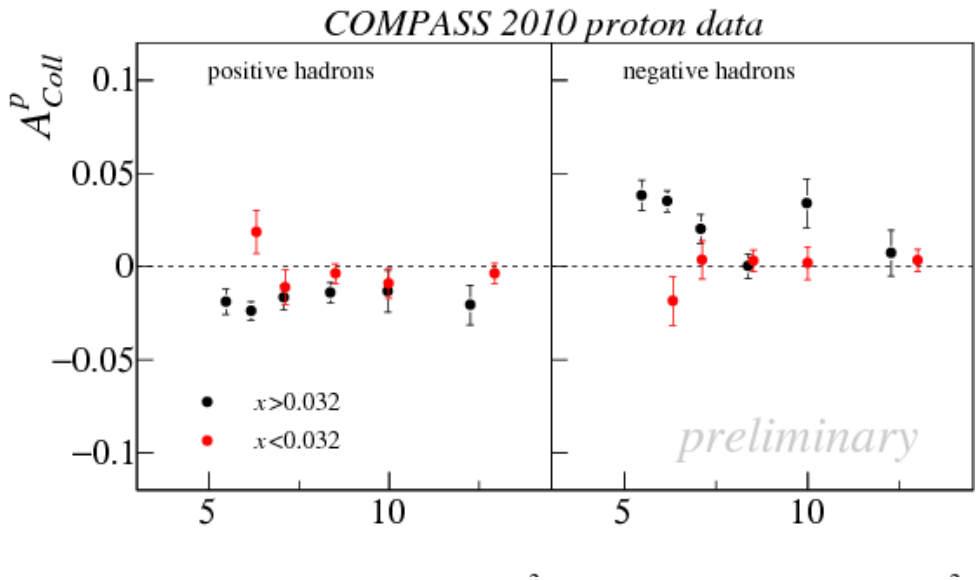


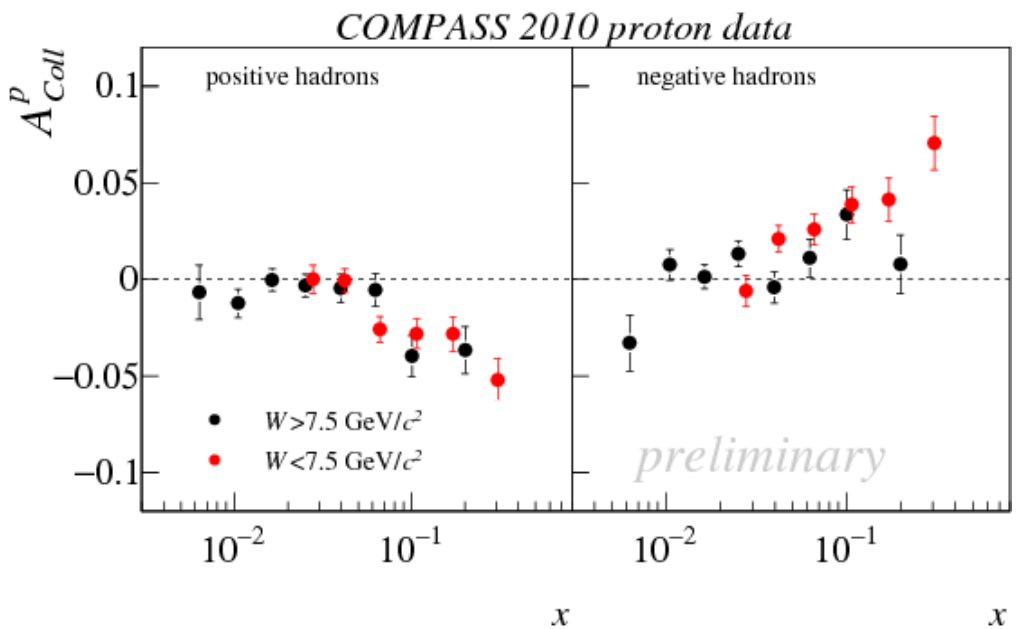
Comparison with Theory Predictions



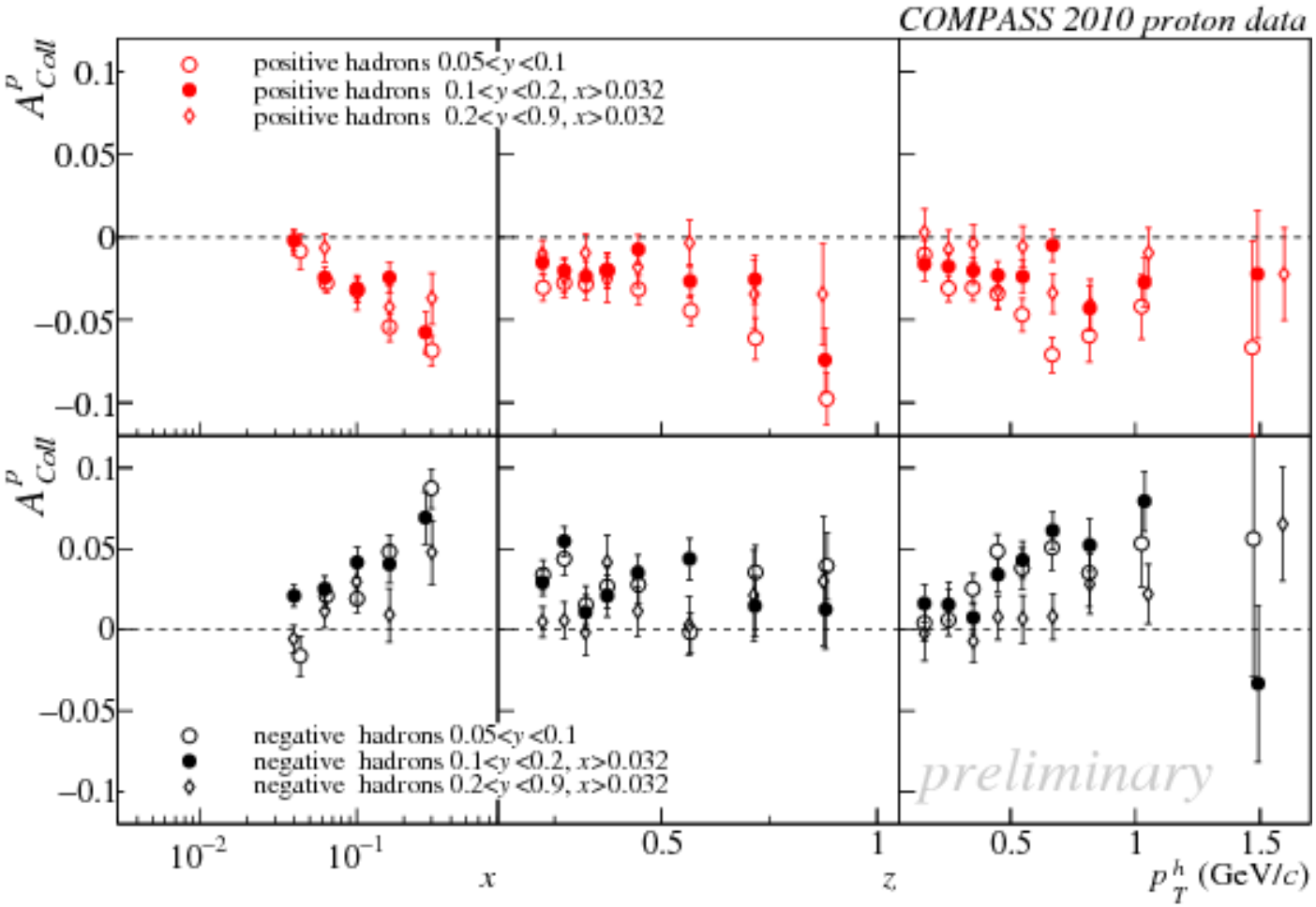
See talk by Elena Boglione

Very weak W dependence

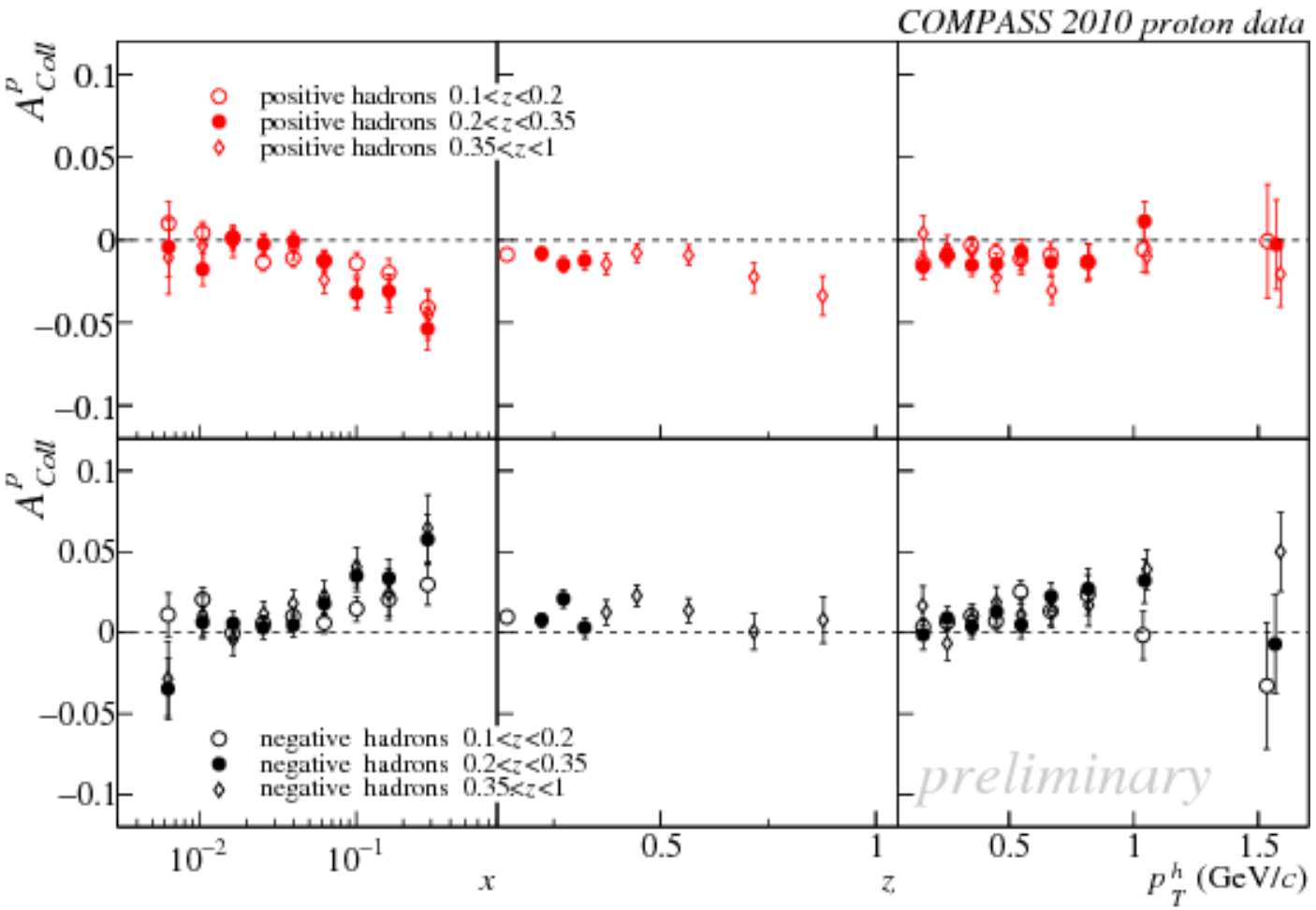




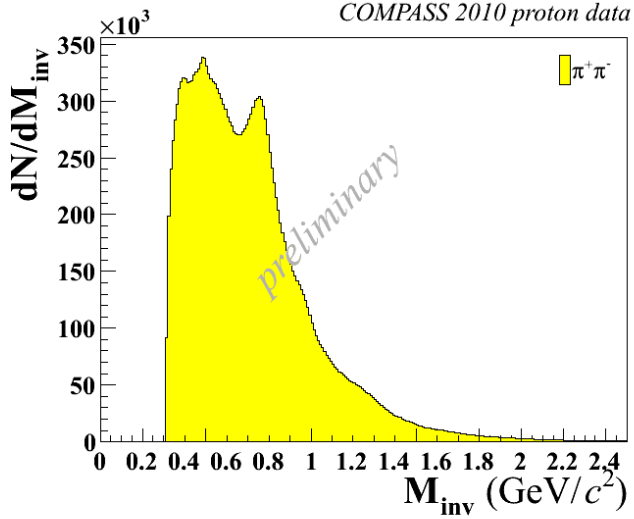
y “binning”: Some effect from Q^2 evolution?

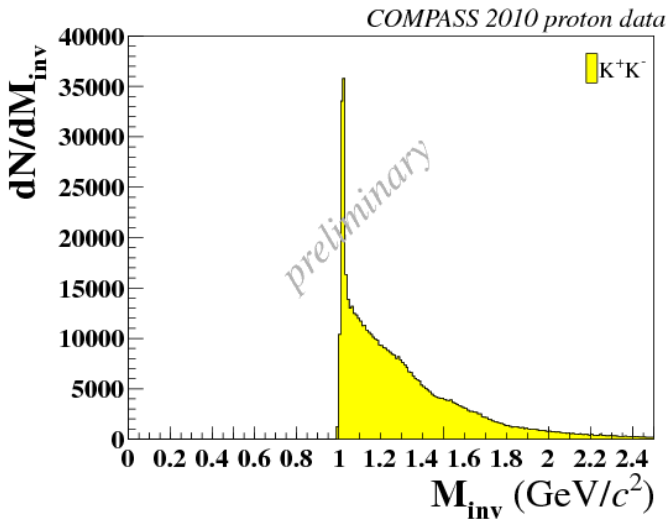


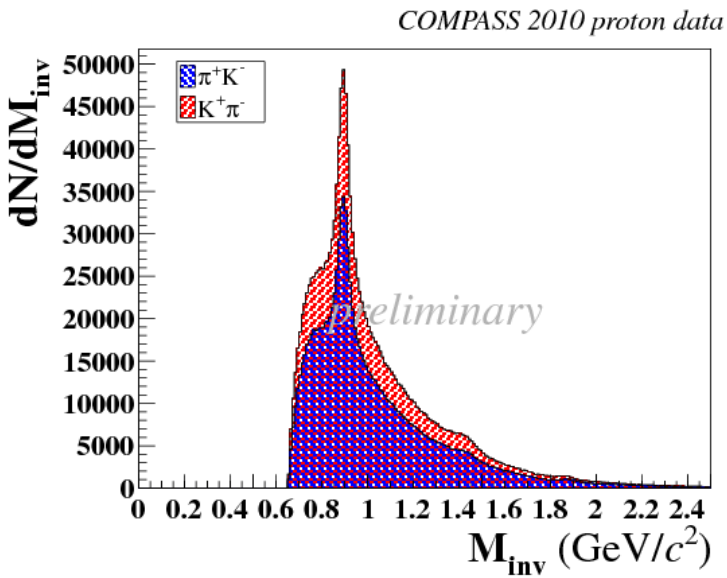
z “binning”


COMPASS 2010 proton data
A^p_{Coll}
positive hadrons 0.1<z<0.2
positive hadrons 0.2<z<0.35
positive hadrons 0.35<z<1
negative hadrons 0.1<z<0.2
negative hadrons 0.2<z<0.35
negative hadrons 0.35<z<1
preliminary
0.1
0.05
0
−0.05
−0.1
10^{-2}
10^{-1}
x
0.5
1
z
0.5
1
1.5
p_T^h (GeV/c)

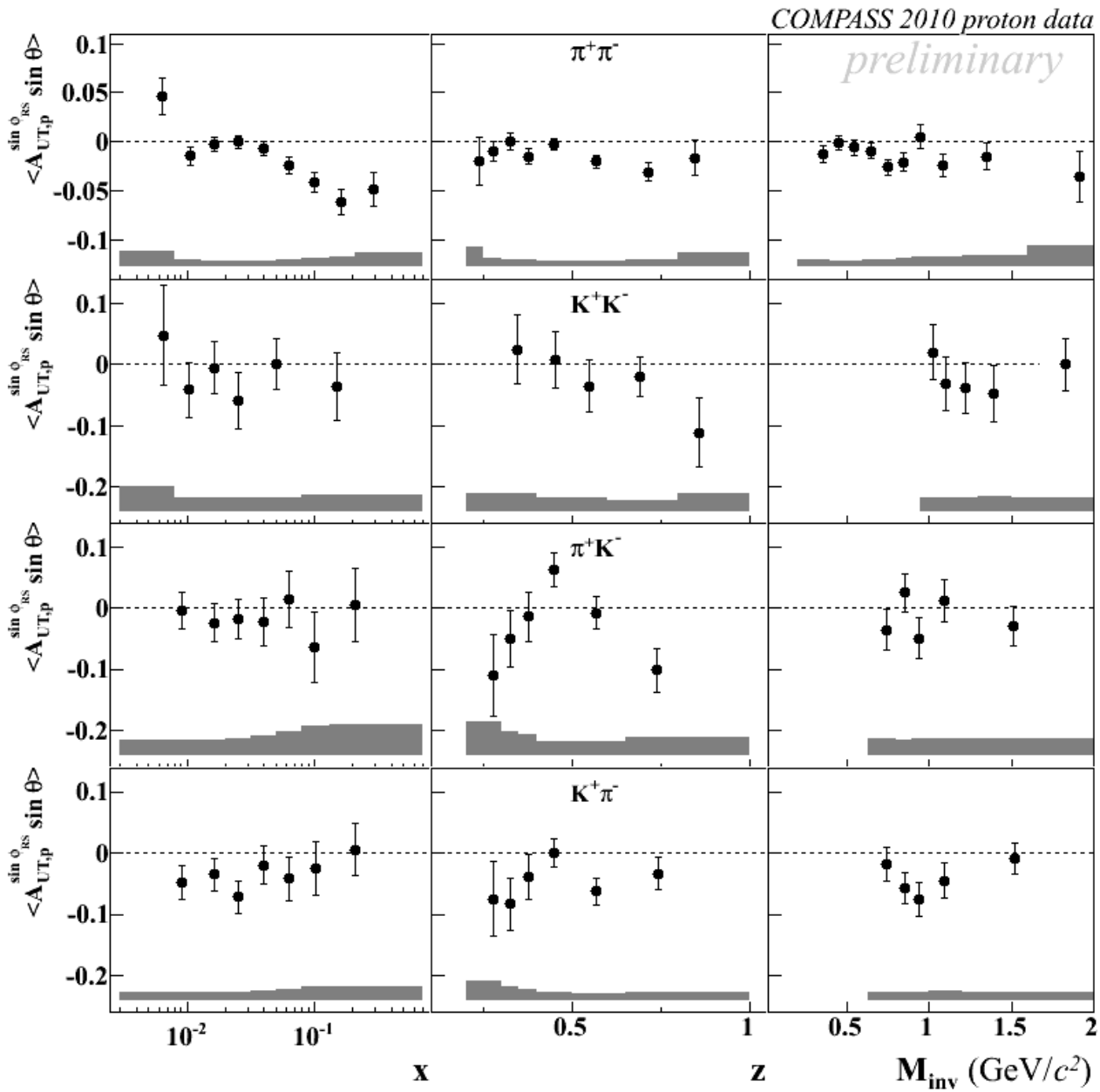
Compass IFF


COMPASS 2010 proton data
×10³
dN/dM_inv
π⁺π⁻
preliminary
M_inv (GeV/c²)

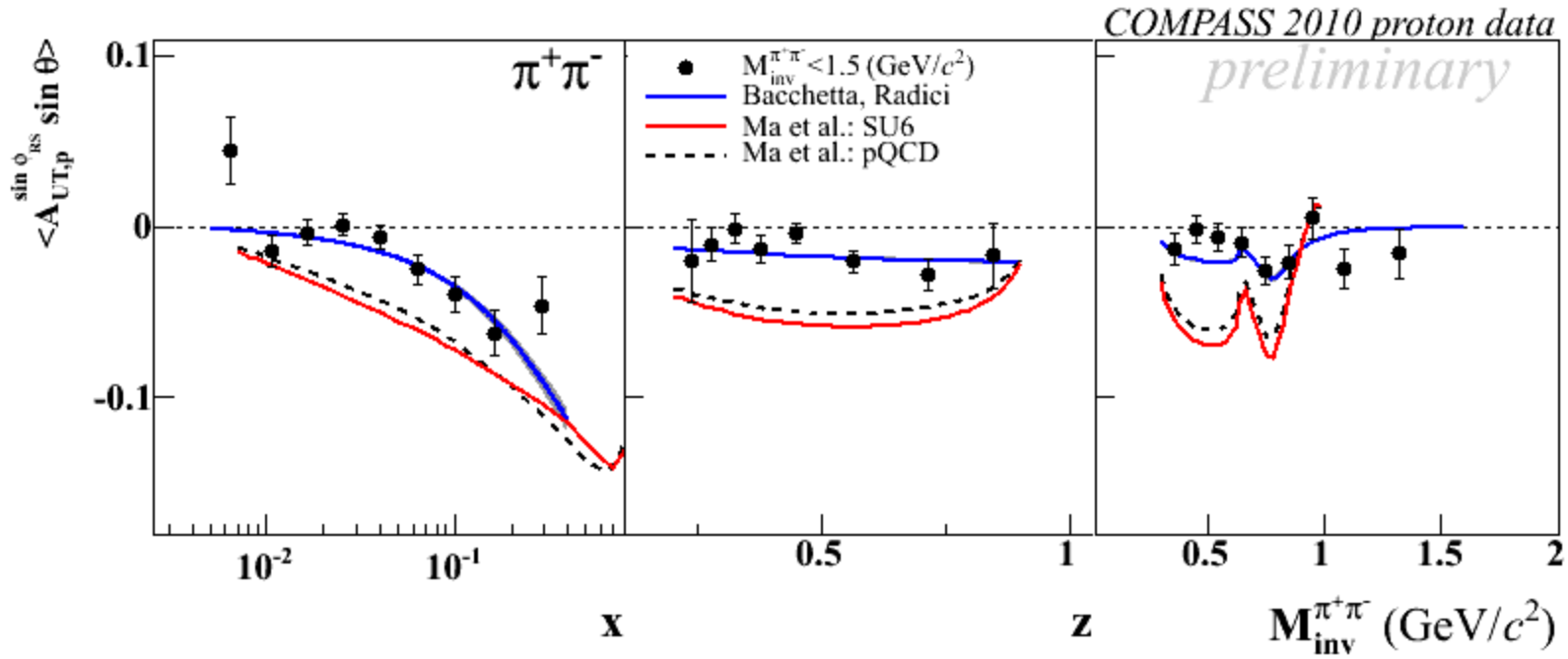

COMPASS 2010 proton data
dN/dM_inv
K⁺K⁻
preliminary
M_inv (GeV/c²)


COMPASS 2010 proton data
dN/dM_inv
π⁺K⁻
K⁺π⁻
preliminary
M_inv (GeV/c²)

Di-hadron Asymmetries

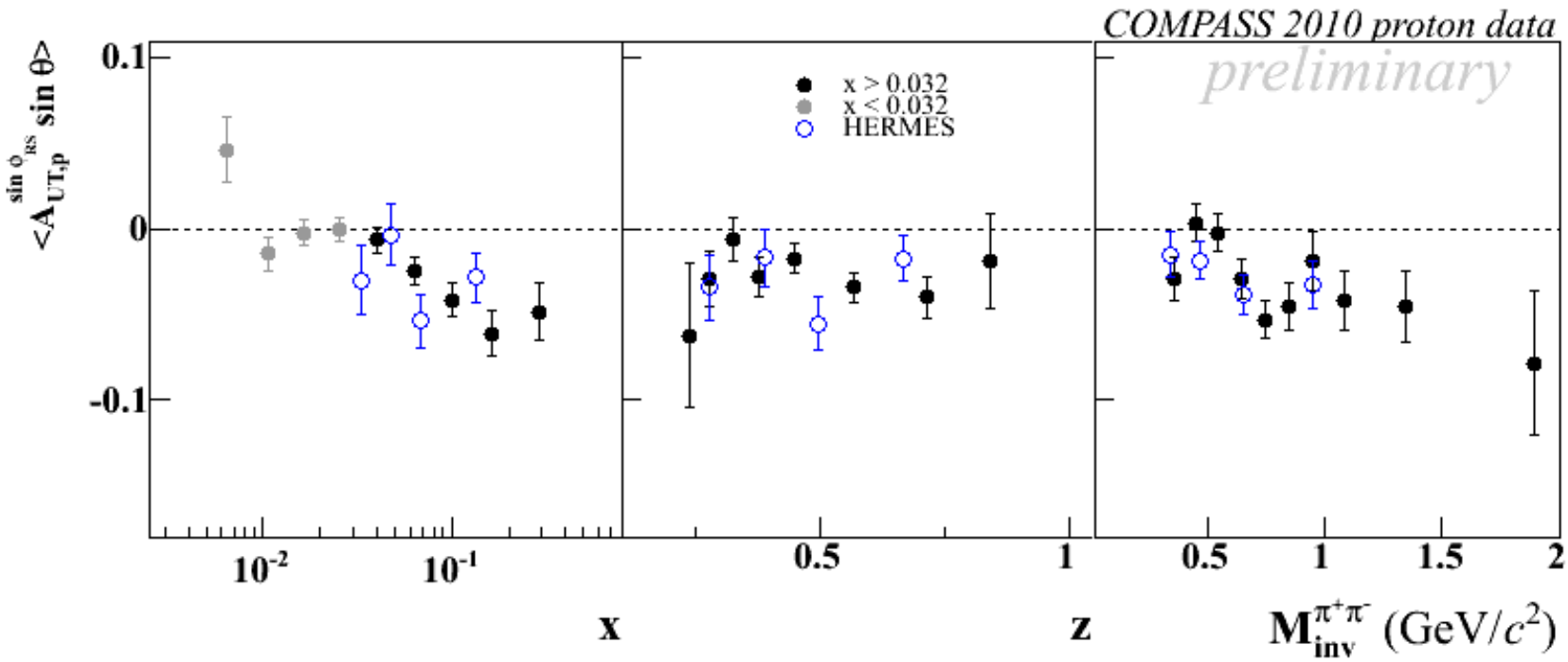


Di-hadron Asymmetries

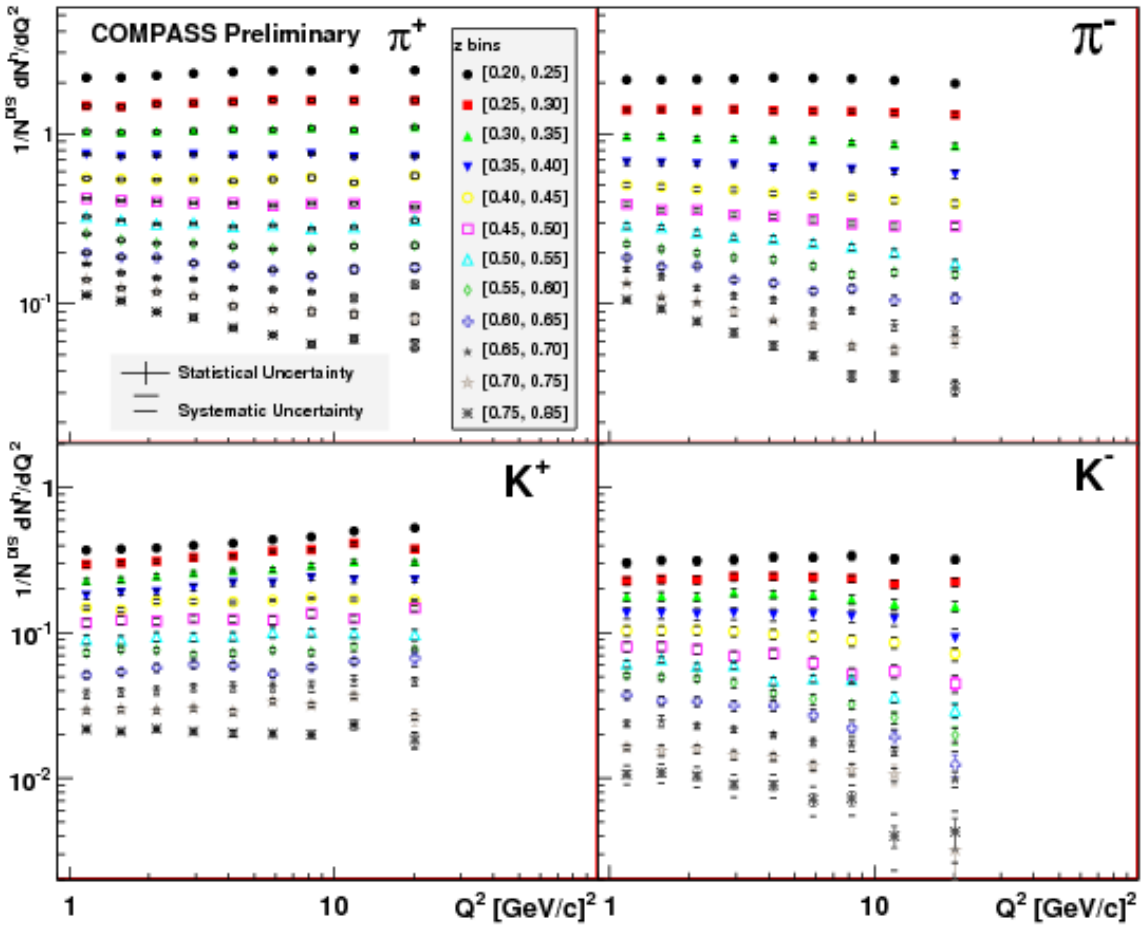


See Marco's talk

Comparison with Hermes

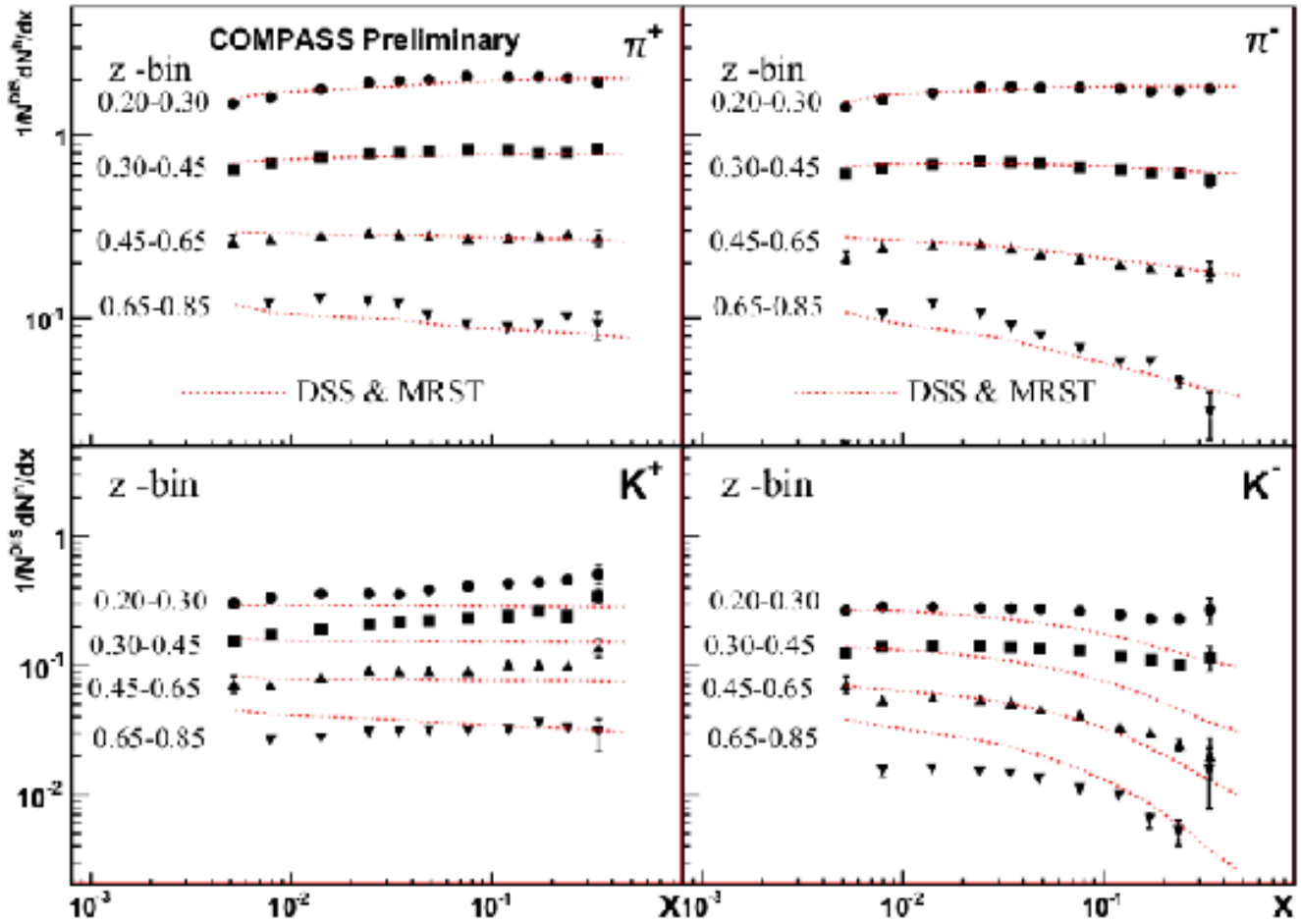


Single Hadron Multiplicities



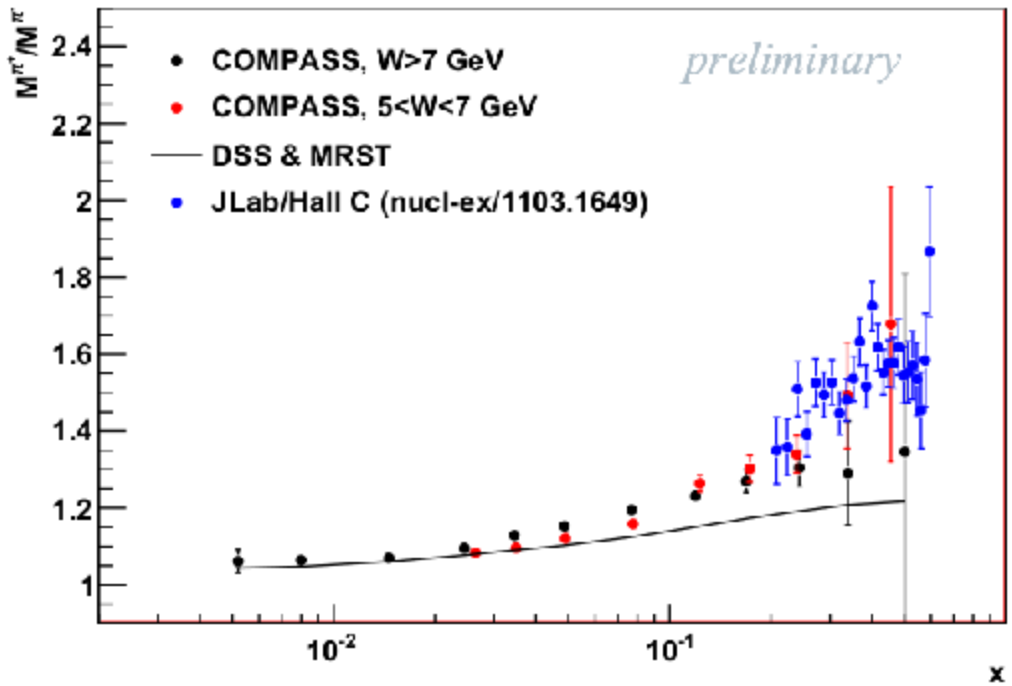
See Marco's talk

Single Hadron Multiplicities

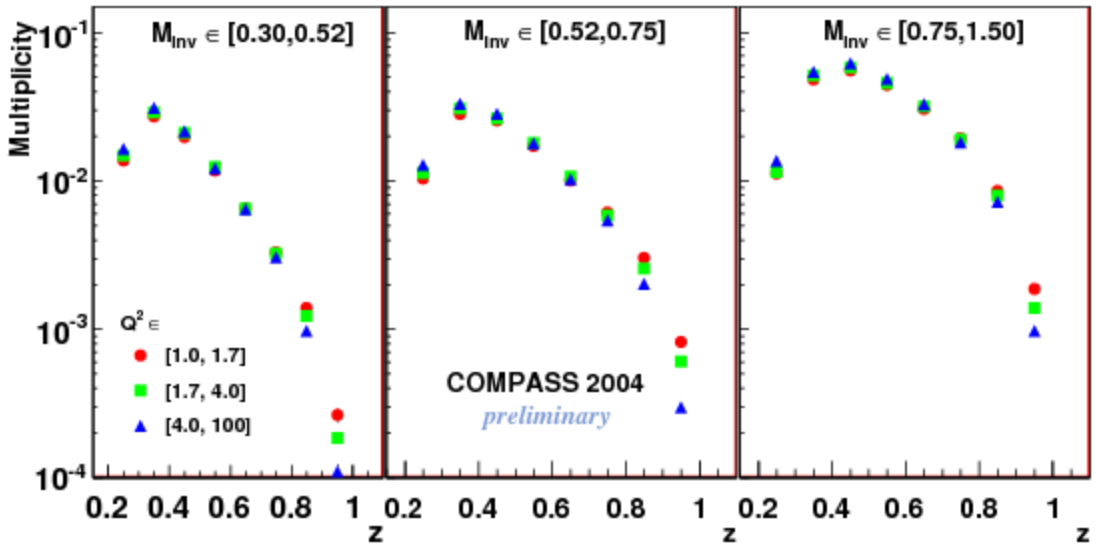


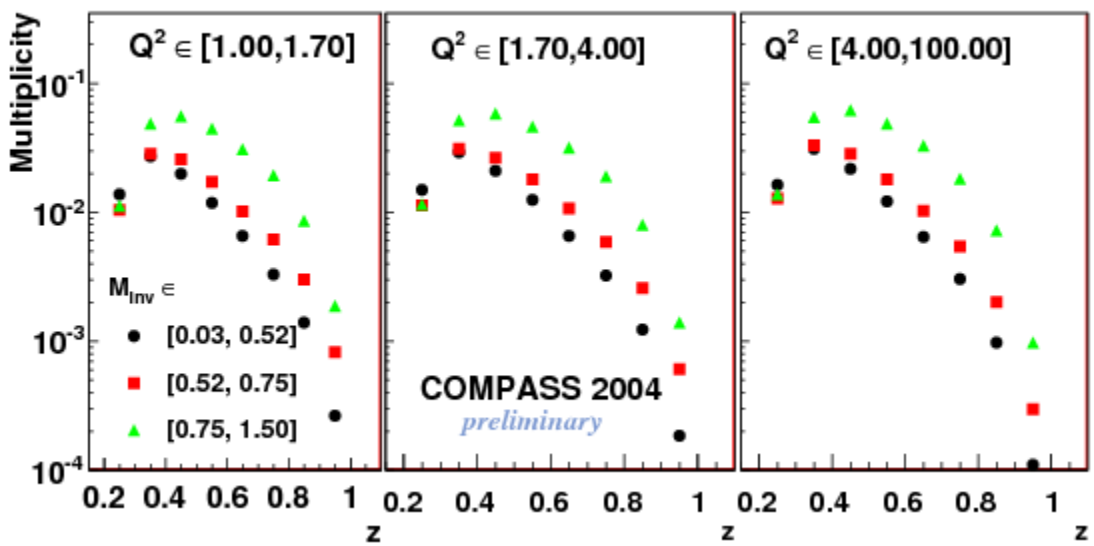
See Marco's talk

Pion Charge Ratios

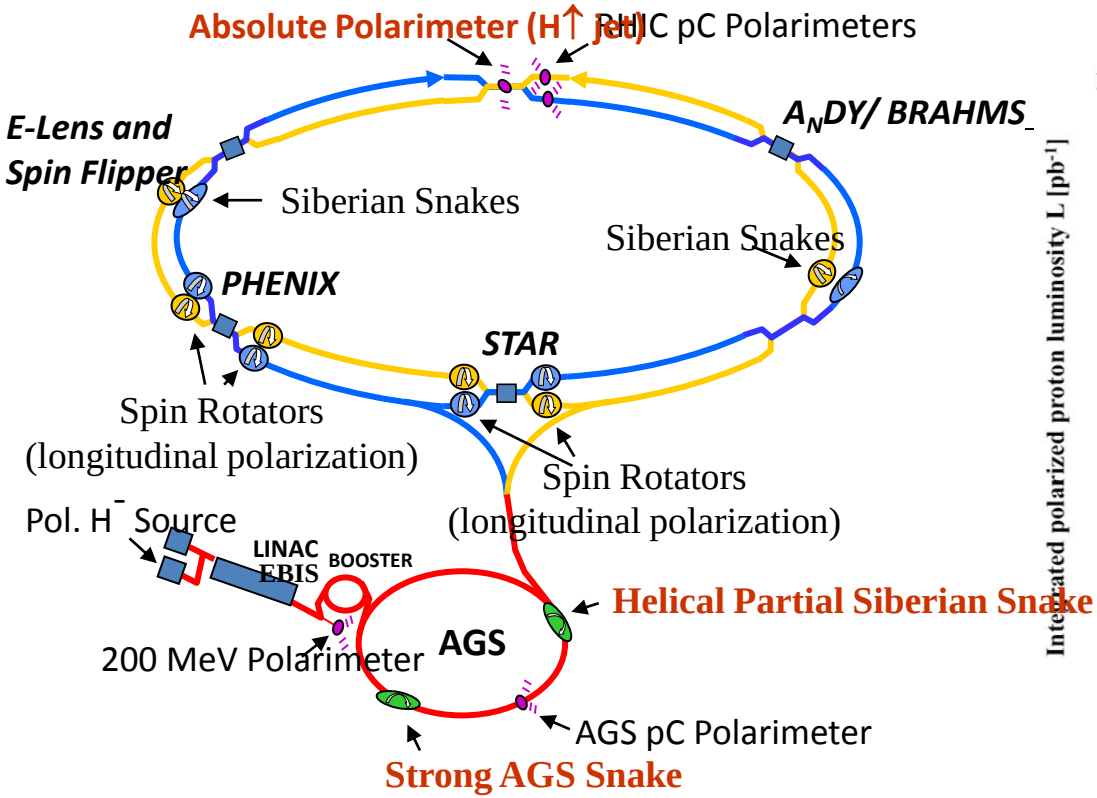


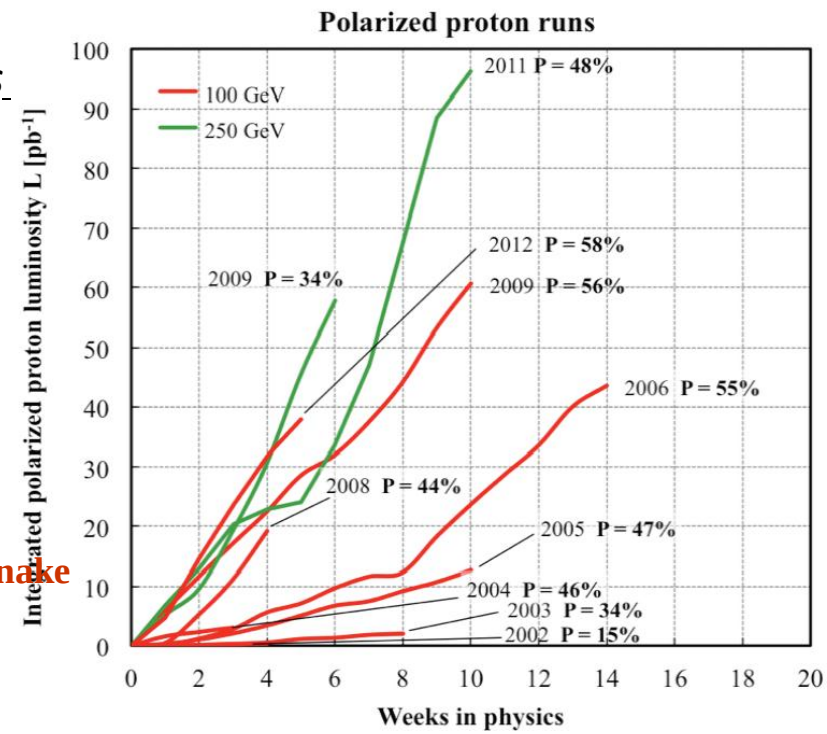
Di-Hadron Multiplicities





The RHIC Polarized Collider





Versatility:

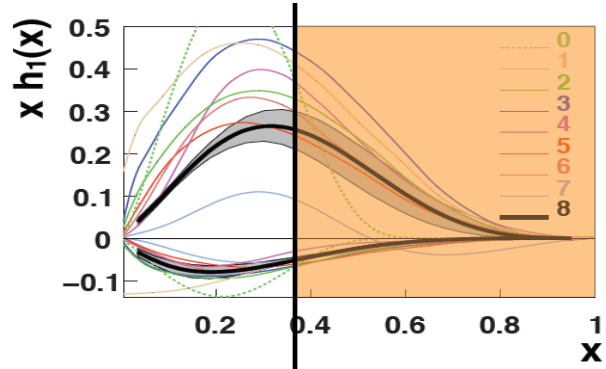
- Polarized p+p Sqrt(s) collisions at 62.4 GeV, 200 GeV and 500 GeV

Recent Spin Runs:

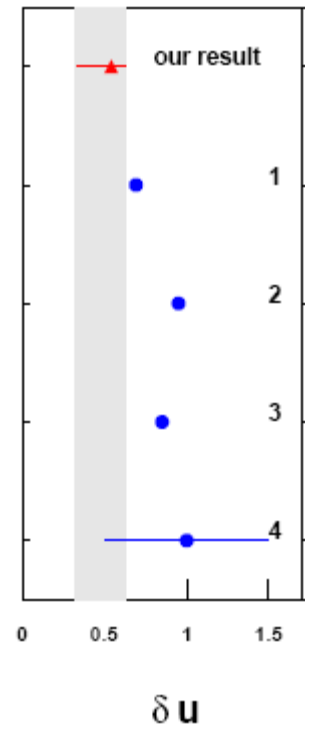
- 2011 500 GeV, longitudinal at Phenix, transverse at STAR ~30 pb^-1 sampled
- 2012 200 GeV, Phenix and STAR, transverse ~20 pb^-1 sampled (at STAR: ~x10 statistics)

At p+p collider: increased kinematic reach in x_{Bj},z

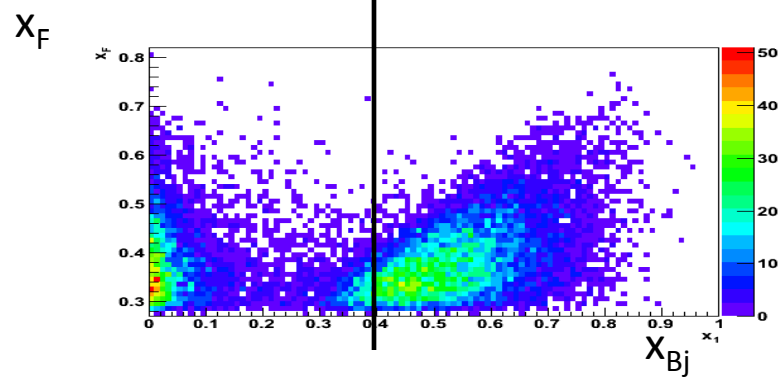
- Kinematic reach of SIDIS data

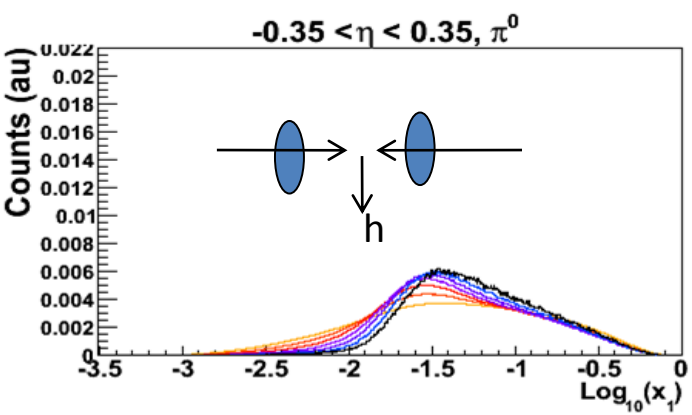


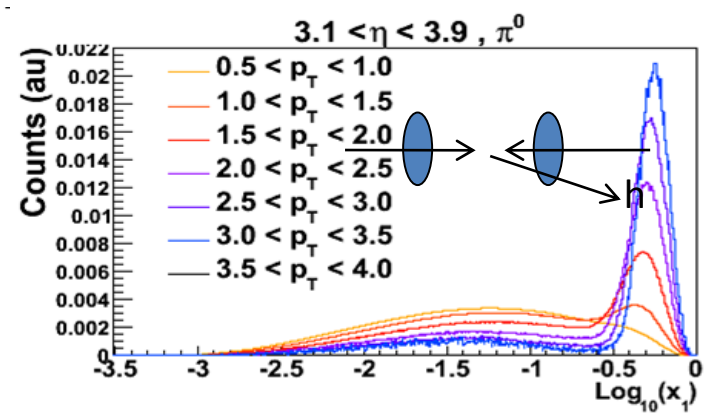
[1-7] models, [8] Anselmino et al., arXiv:0807.0173



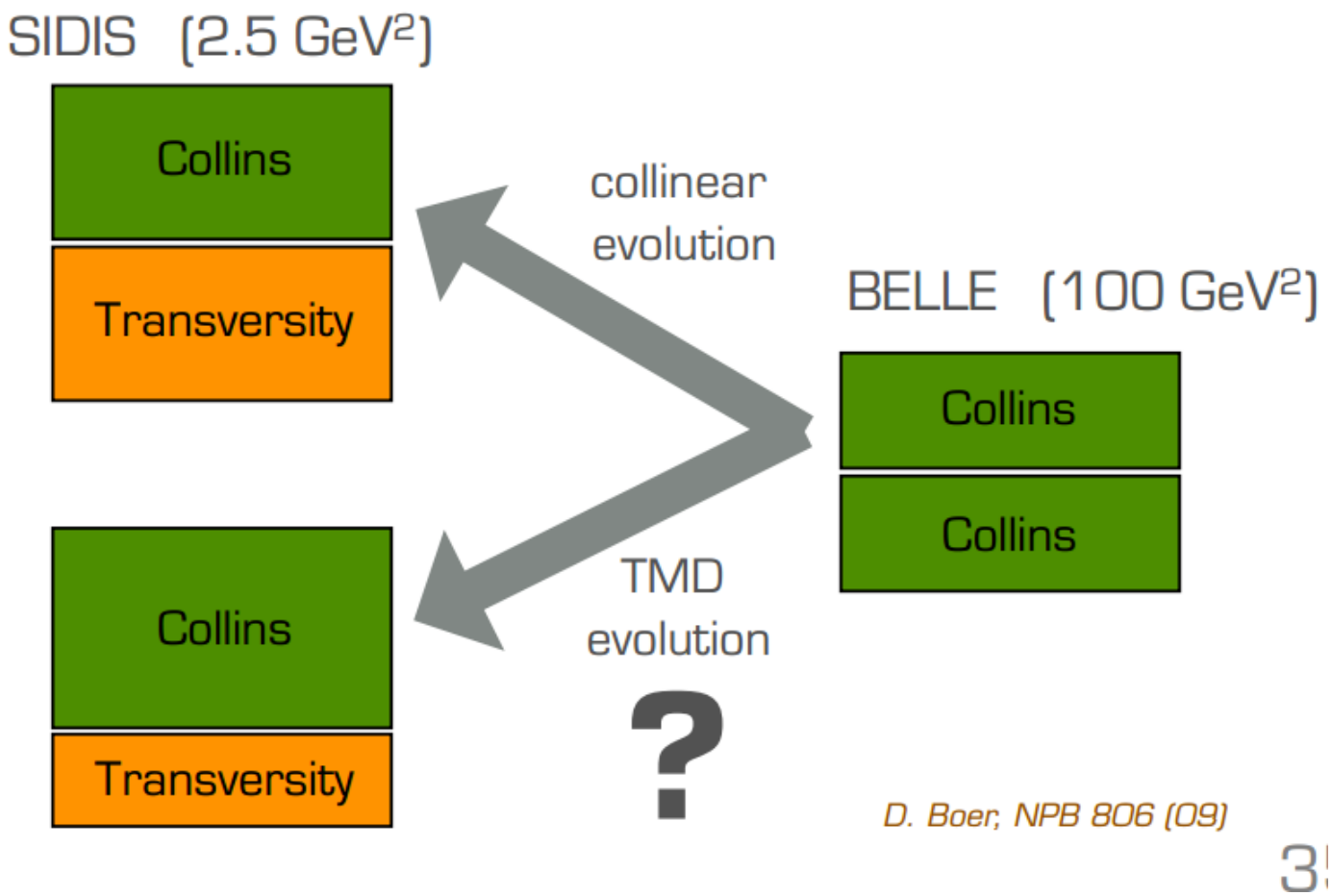
- Kinematic reach in p+p for single pions at 3<eta<4 (RHIC@200GeV)





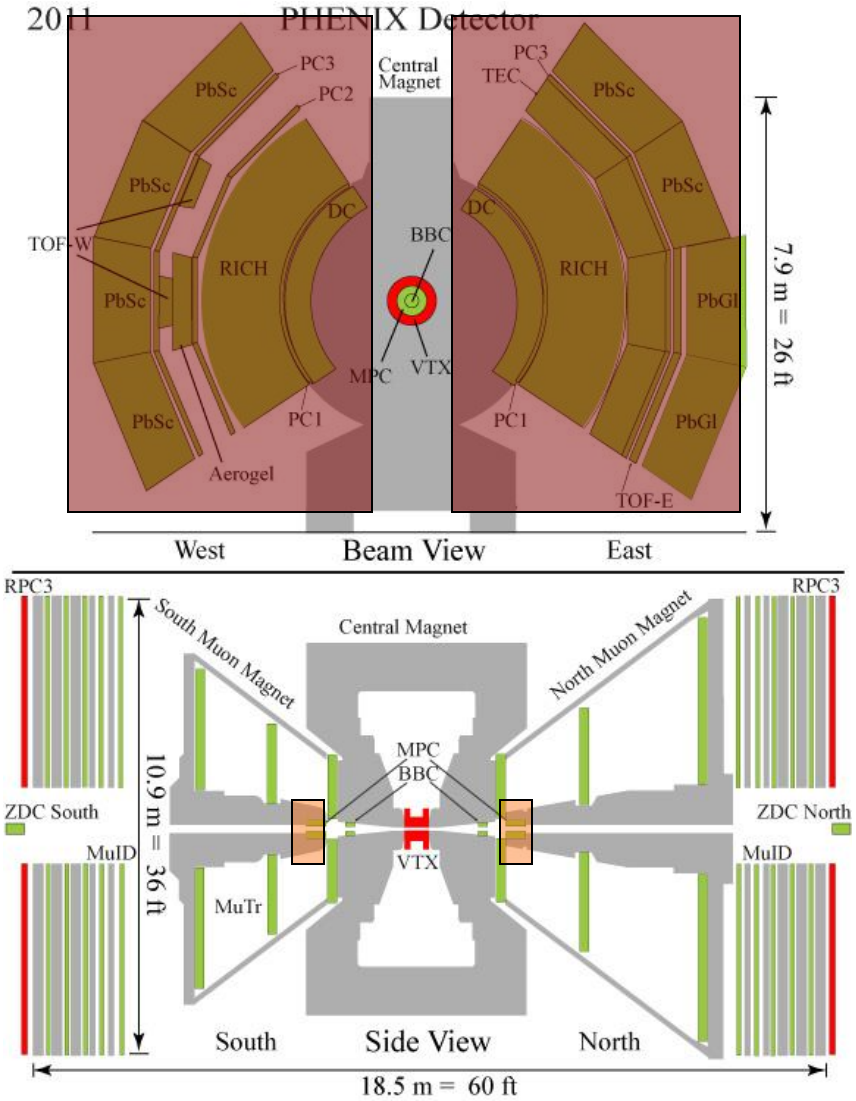


Compare Collins and IFF at different energies: Test evolution, Sudakov suppression effects



Pic by A. Bacchetta,

PHENIX Detector at RHIC

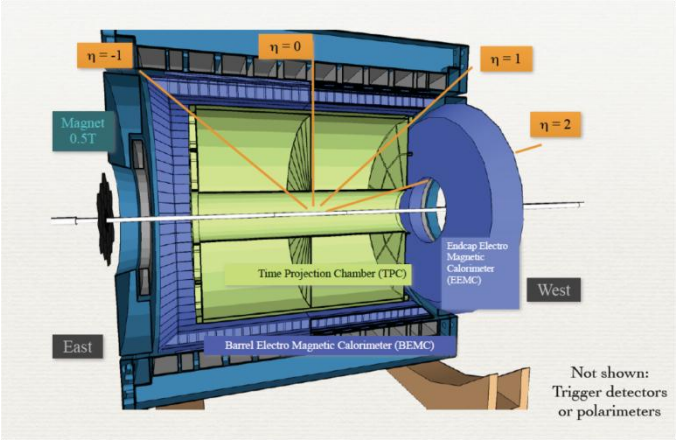


Central Arms $|\eta| < 0.35$

- Identified charged hadrons
- π^0, η
- Direct Photon
- J/Ψ
- Heavy Flavor

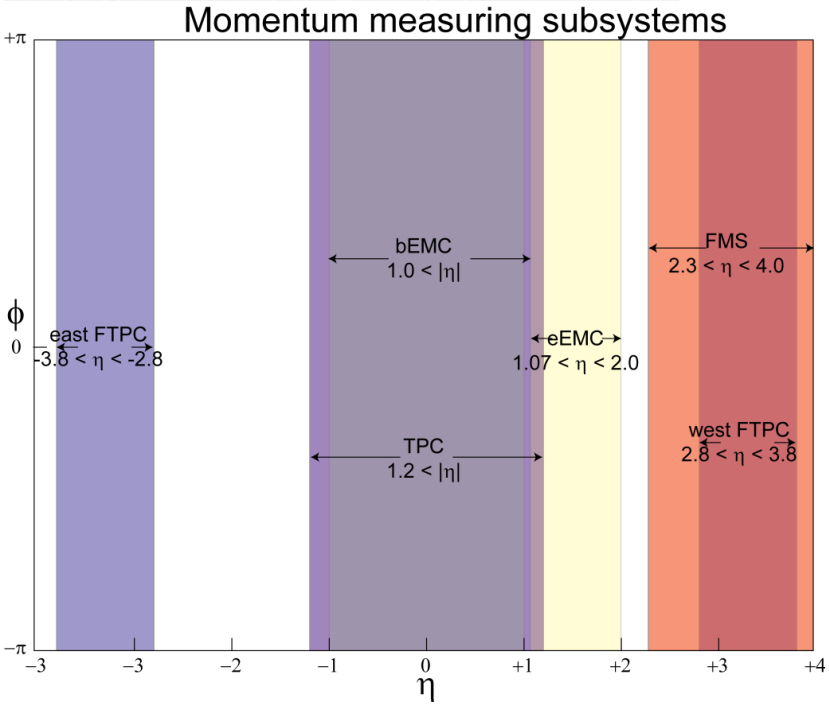
MPC $3.1 < |\eta| < 3.9$

- π^0, η



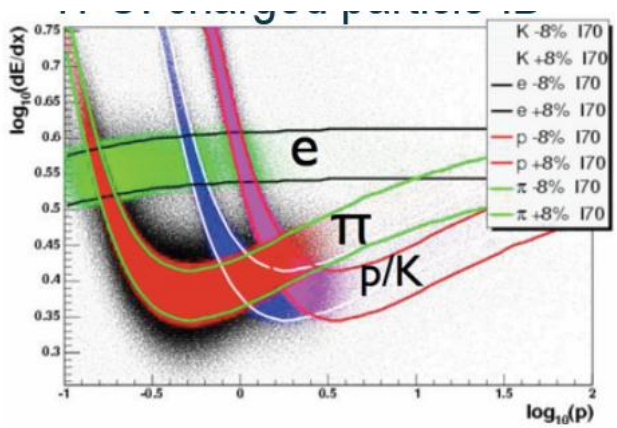
FMS

- Central Region (-1<eta<1)
  - Identified Pions, eta
  - Jets
- Endcap (1<eta<2)
  - Pi0, eta, (some) jets
- FMS (2<eta<4)
  - Pi0, eta



Full azimuth spanned with nearly contiguous electromagnetic calorimetry from -1<η<4

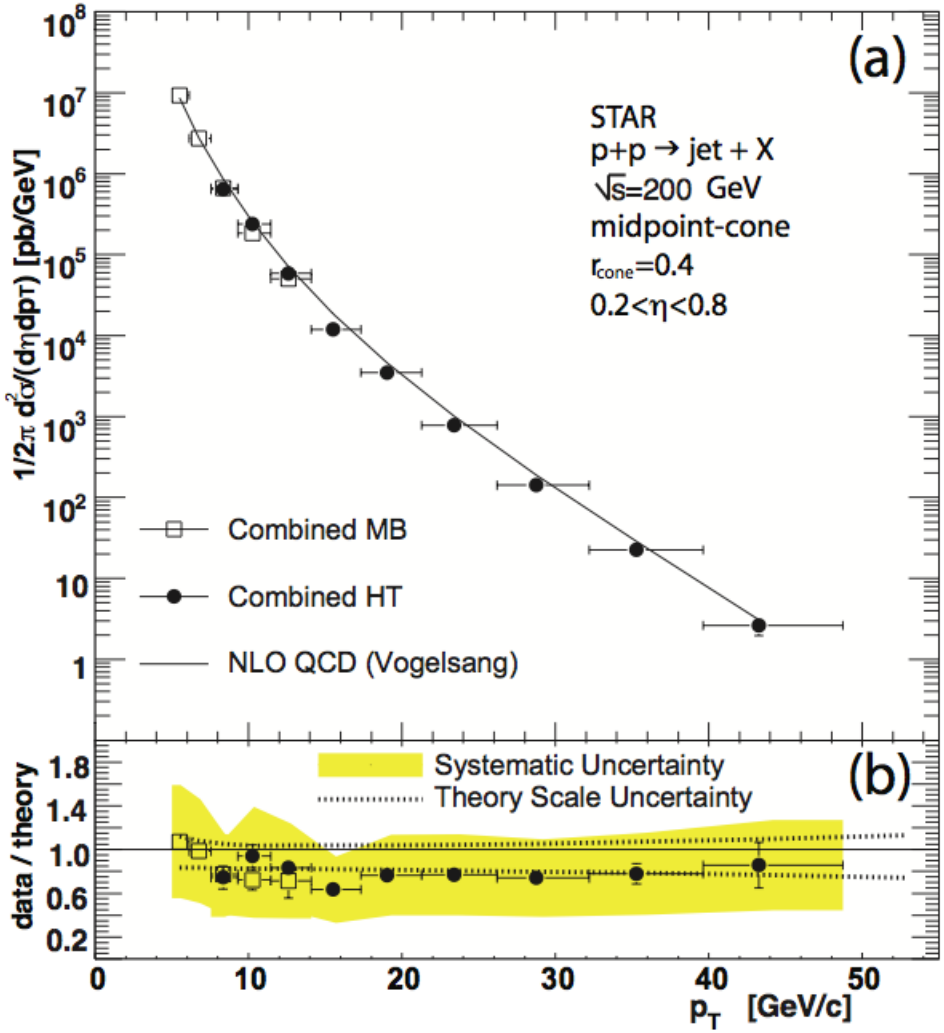
⇒ approaching full acceptance detector



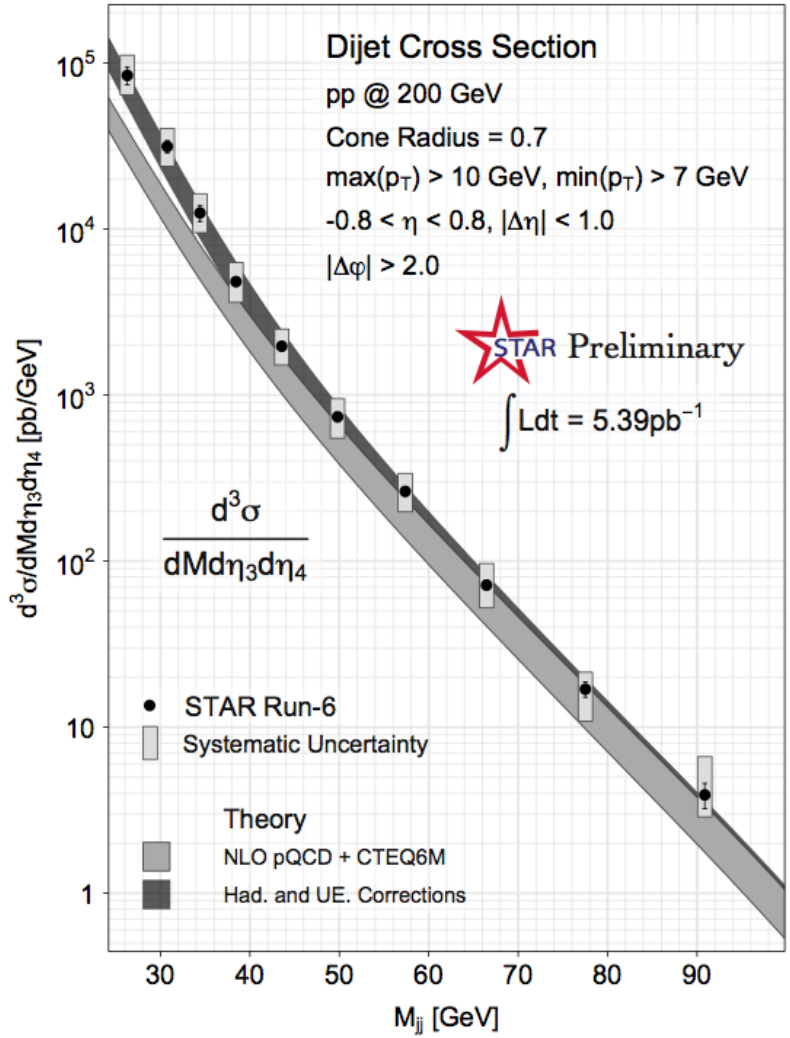
PID (Barrel) with dE/dx, in the future: ToF pi/K separation up to 1.9 GeV

Jets: Proven Capabilities in p+p

B.I. Abelev et al. (STAR Coll.), Phys.Rev.Lett. 97, 252001, 2006



SPIN-2010: Matt Walker/Tai Sakuma, *for the collaboration*



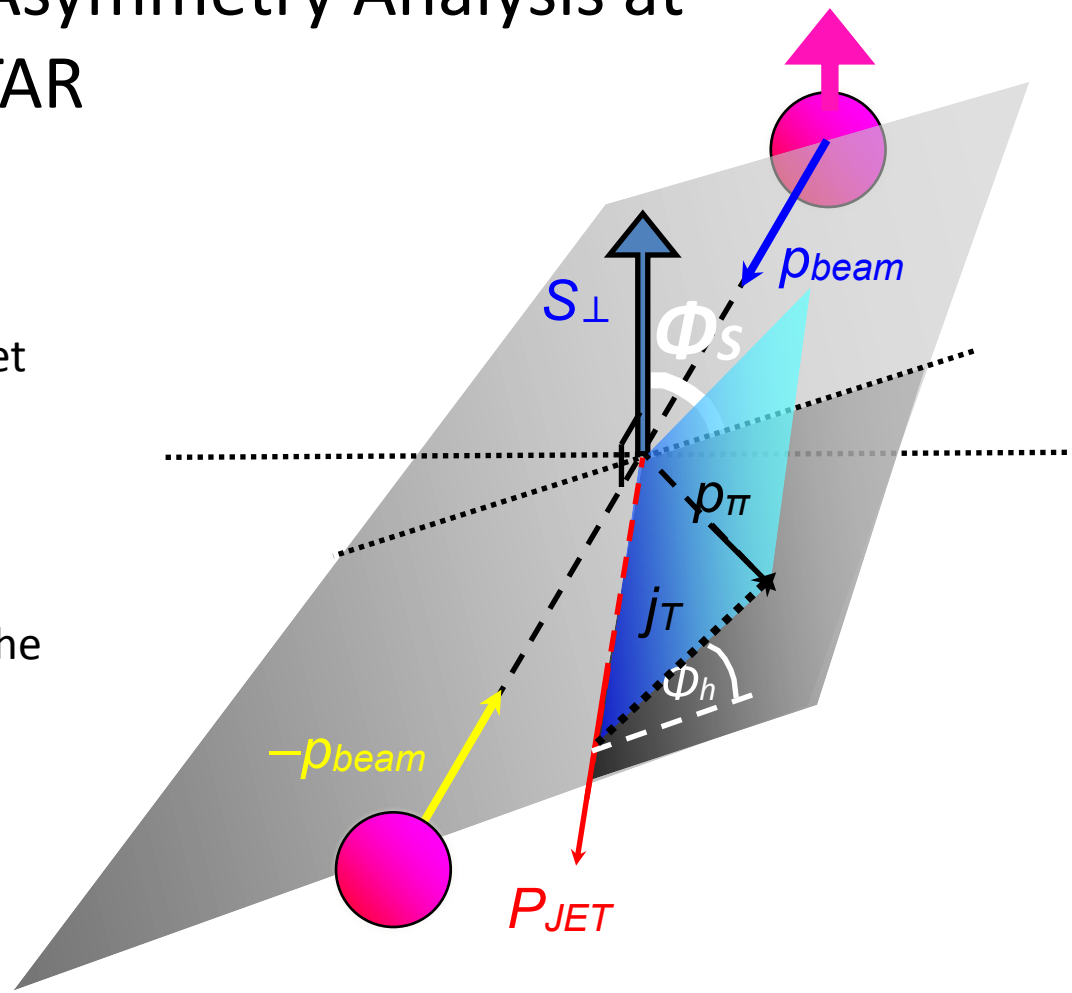
Jets well understood in STAR, experimentally and theoretically

Mid-Rapidity Collins Asymmetry Analysis at STAR

- STAR provides the full mid-rapidity jet reconstruction and charged pion identification

- Look for spin dependent azimuthal distributions of charged pions inside the jets! First proposed by F. Yuan in **Phys.Rev.Lett.100:032003.**

- **Measure average weighted yield:**



$$A_{\exp} = \frac{2\int N \sin(\phi_C)\, d\phi_c}{P_{Beam} N}$$

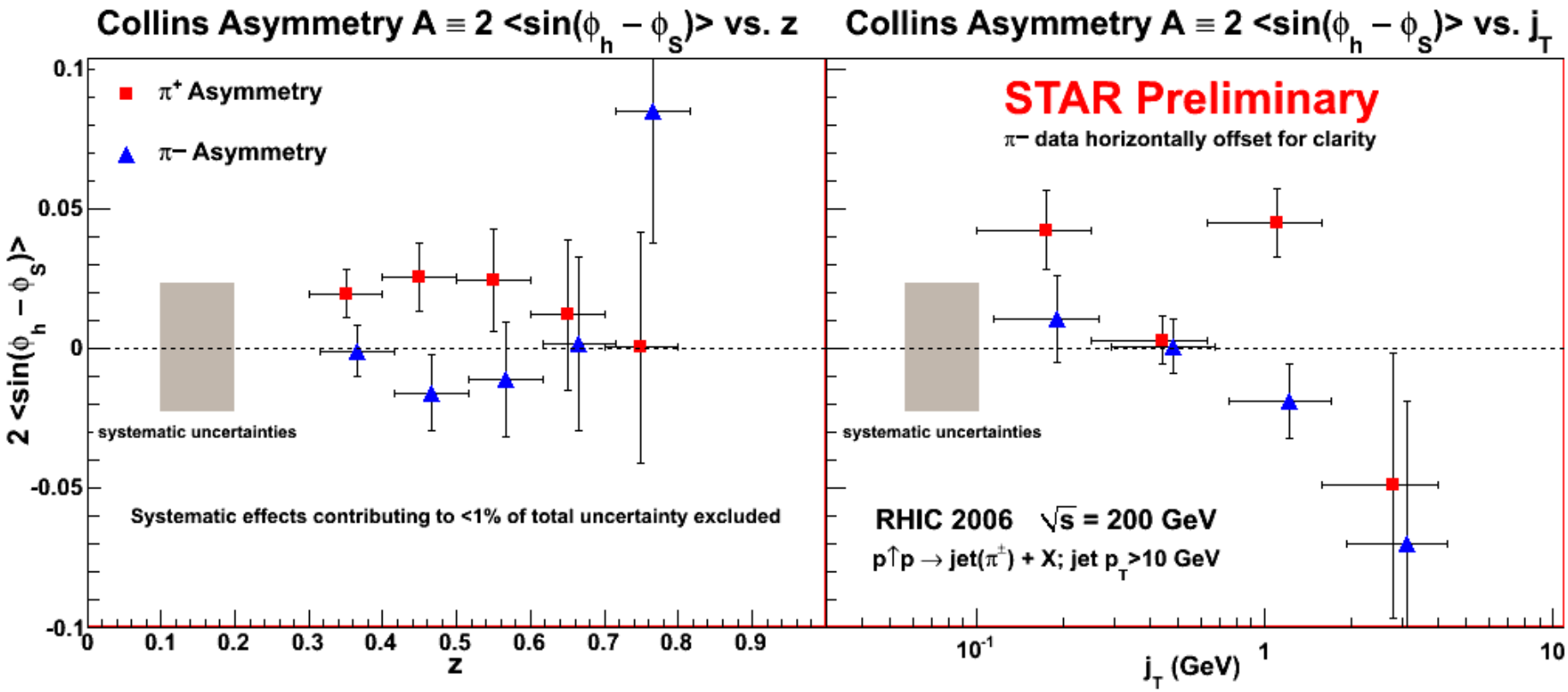
$$d\sigma \approx d\sigma^{UU}\left[1 + A_N \sin(\phi_h - \phi_s)\right]$$

Moving on to Correlation Measurements: Pions in Jets

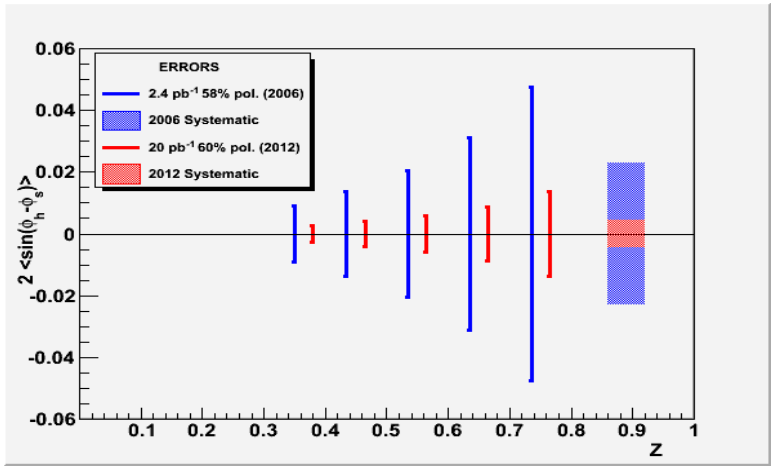
Terms in Numerator of TMD SSA for qq scattering	English Names	Modulate
$\Delta^N f_{a/A\uparrow} \bullet f_{b/B} \bullet D_{\pi/q}$	Sivers • PDF • FF	$\sin(\varphi_{S_A})$
$h_1^a \bullet \Delta^N f_{b\uparrow/B} \bullet D_{\pi/q}$	Transversity•Boer-Mulder•FF	$\sin(\varphi_{S_A})$
$h_{1T}^{\perp a} \bullet \Delta^N f_{b\uparrow/B} \bullet D_{\pi/q}$	Pretzelocity•Boer-Mulder•FF	$\sin(\varphi_{S_A})$
$h_1^a \bullet f_{b/B} \bullet \Delta D_{\pi/q\uparrow}$	Transversity•PDF •Collins	$\sin(\varphi_{S_A} - \varphi_\pi)$
$\Delta f_{a/A\uparrow}^N \bullet \Delta^N f_{b\uparrow/B} \bullet \Delta D_{\pi/q\uparrow}$	Sivers•Boer-Mulder•Collins	$\sin(\varphi_{S_A} - \varphi_\pi)$
$h_{1T}^{\perp a} \bullet f_{b/B} \bullet \Delta D_{\pi/q\uparrow}$	Pretzelocity•PDF•Collins	$\sin(\varphi_{S_A} + \varphi_\pi)$
$\Delta f_{a/A\uparrow}^N \bullet \Delta^N f_{b\uparrow/B} \bullet \Delta D_{\pi/q\uparrow}$	Sivers•Boer-Mulders•Collins	$\sin(\varphi_{S_A} + \varphi_\pi)$

Based on work by F.Yuan (*Phys.Rev.Lett.100:032003*) and D'Alesio et al. (*Phys.Rev. D83, 034021*)

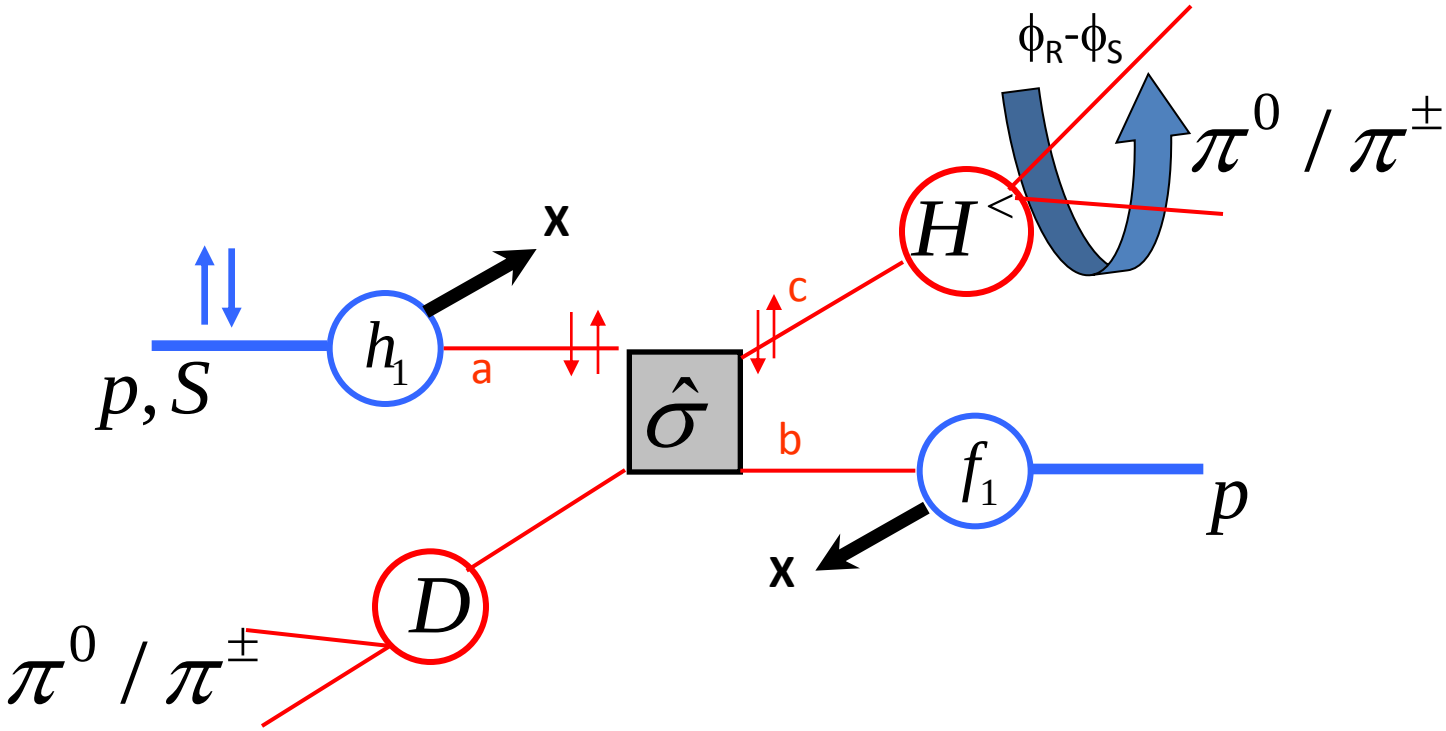
First Step: Mid-rapidity Collins analysis



Run 12 Projections



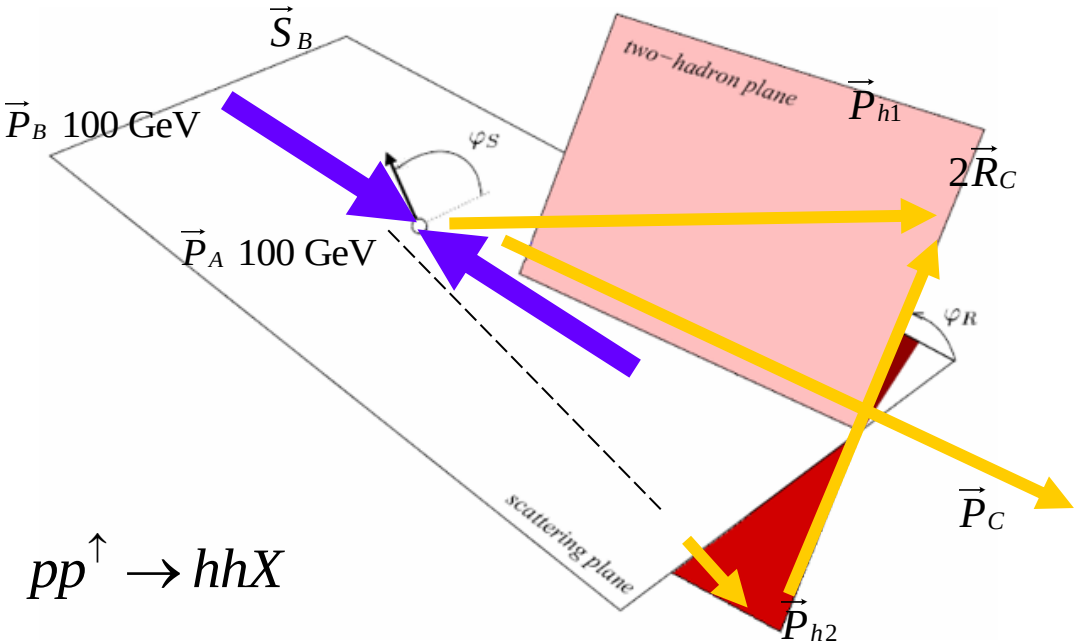
Interference Fragmentation Function in p-p



$$\frac{\sigma^\uparrow - \sigma^\downarrow}{\sigma^\uparrow + \sigma^\downarrow}(\phi_S - \phi_R) = A_{UT}\sin(\phi_S - \phi_R) \qquad A_{UT} \propto h_1 \otimes H_1^{\sphericalangle}$$

ϕ_S: Angle between polarisation vector and event plane

Di-Hadron Correlations



p+p c.m.s. = lab frame

$\vec{P}_A, \vec{P}_B$: momenta of protons

$\vec{P}_{h1}, \vec{P}_{h2}$: momenta of hadrons

$\vec{P}_C = \vec{P}_{h1} + \vec{P}_{h2}$

$\vec{R}_C = (\vec{P}_{h1} - \vec{P}_{h2})/2$

$\vec{S}_B$: proton spin orientation

hadron plane: $\vec{P}_{h1}, \vec{P}_{h2}$

scattering plane: $\vec{P}_C, \vec{P}_B$

ϕ_R : from scattering plane to hadron plane

ϕ_S : from polarization vector to scattering plane

$$\frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}(\phi_S - \phi_R) = A_{UT}\sin(\phi_S - \phi_R) \qquad A_{UT} \propto h_1 \otimes H_1^{\square}$$

: Angle between polarisation vector and event plane

Bacchetta and Radici, PRD70, 094032 (2004)

Transversity from di-Hadron SSA

Physics asymmetry $A_{UT} = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}} = \frac{\sigma_{UT}}{\sigma_{UU}}$

$$d\sigma_{UU} = 2\,|\mathbf{P}_{C\perp}| \sum_{a,b,c,d} \int \frac{dx_a dx_b}{4\pi^2 z_c} f_1^a(x_a)\, f_1^b(x_b)\, \frac{d\hat{\sigma}_{ab\to cd}}{d\hat{t}}\, D_{1,oo}(\bar{z}_c, M_C^2)$$

Unpolarized quark distribution
Known from DIS

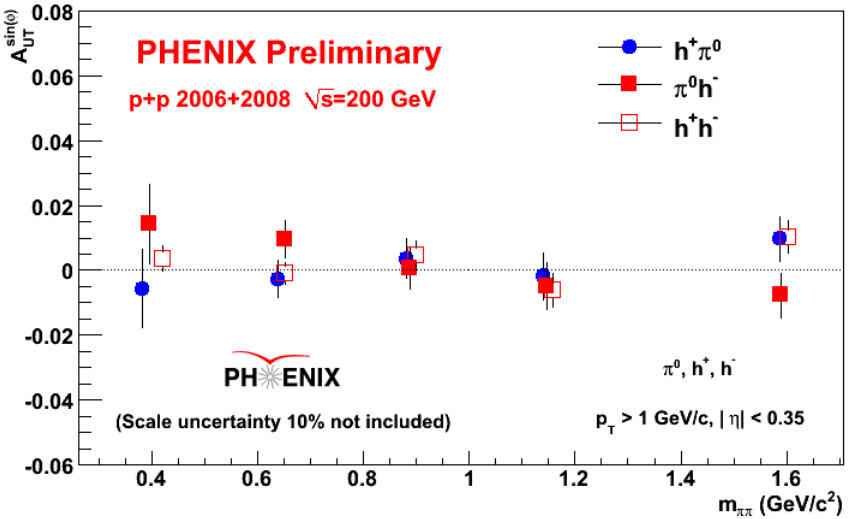
Transversity
to be extracted

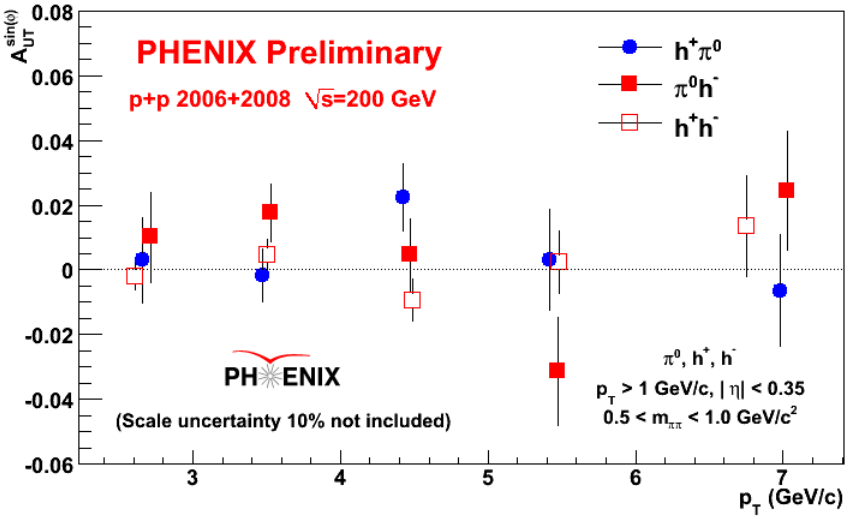
Hard scattering cross section
from pQCD

IFF + Di-hadron FF
measured in e+e-

$$d\sigma_{UT} = 2\,|\mathbf{P}_{C\perp}| \sum_{a,b,c,d} \frac{|\mathbf{R}_C|}{M_C} |\mathbf{S}_{BT}| \sin(\phi_{S_B} - \phi_{R_C}) \int \frac{dx_a dx_b}{16\pi z_c} f_1^a(x_a)\, h_1^b(x_b)\, \frac{d\Delta\hat{\sigma}_{ab^\uparrow\to c^\uparrow d}}{d\hat{t}}\, H_{1,ot}^{\sphericalangle c}(\bar{z}_c, M_C^2)$$

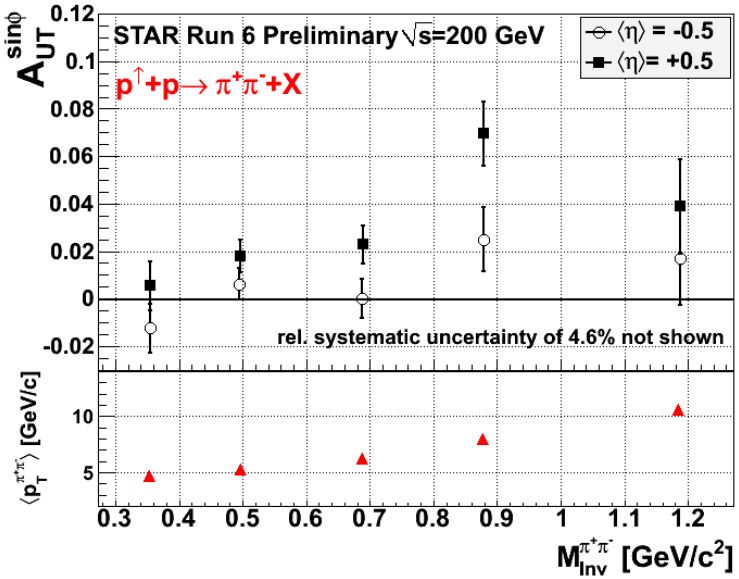
PHENIX IFF results shows small asymmetries.

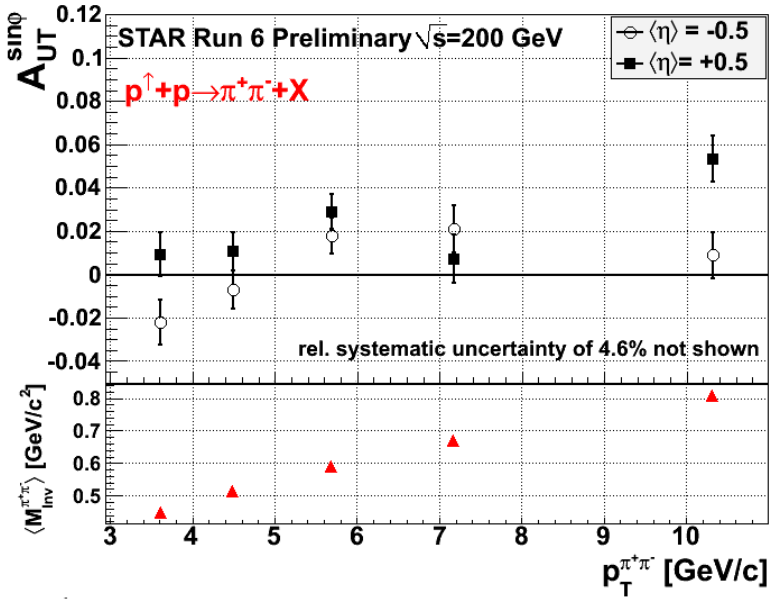


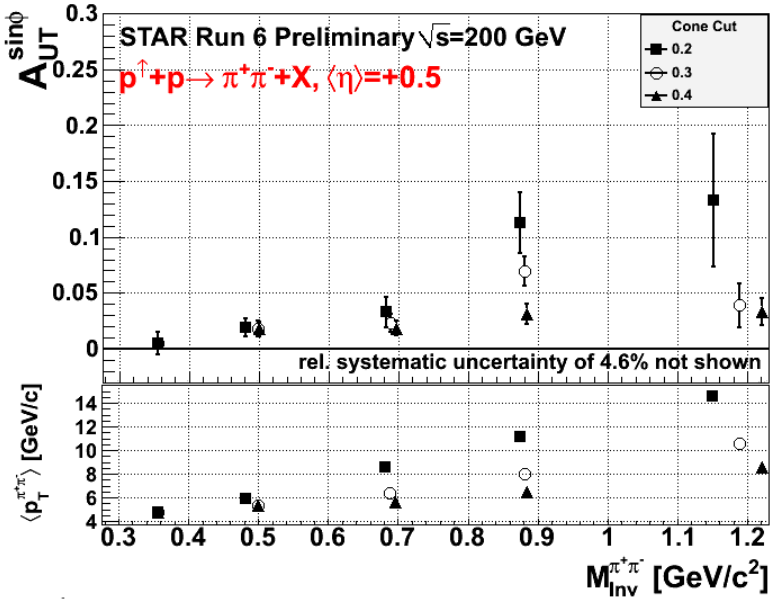


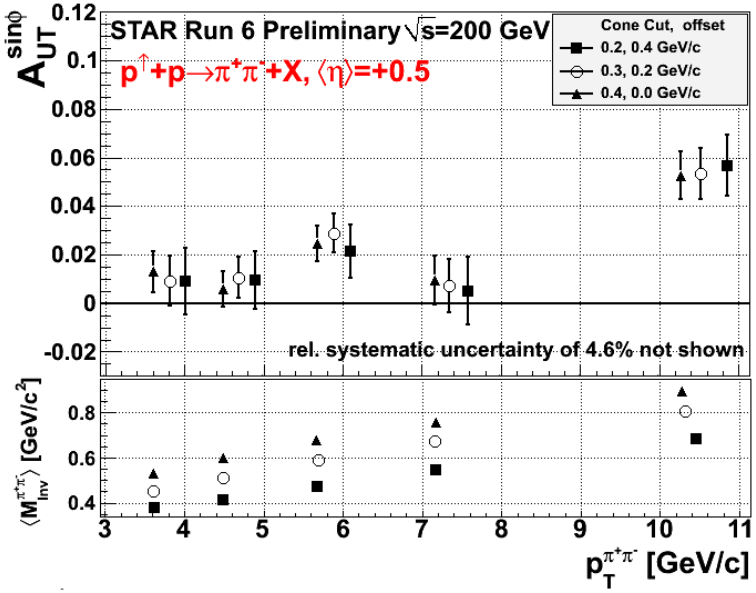
Phenix Sign convention opposite to STAR

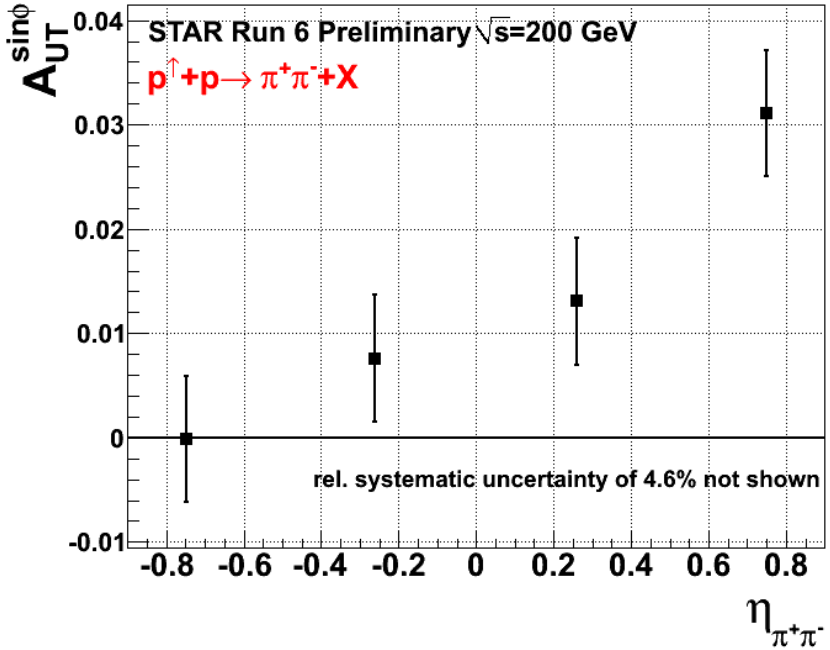
NEW: STAR shows significant Signal!

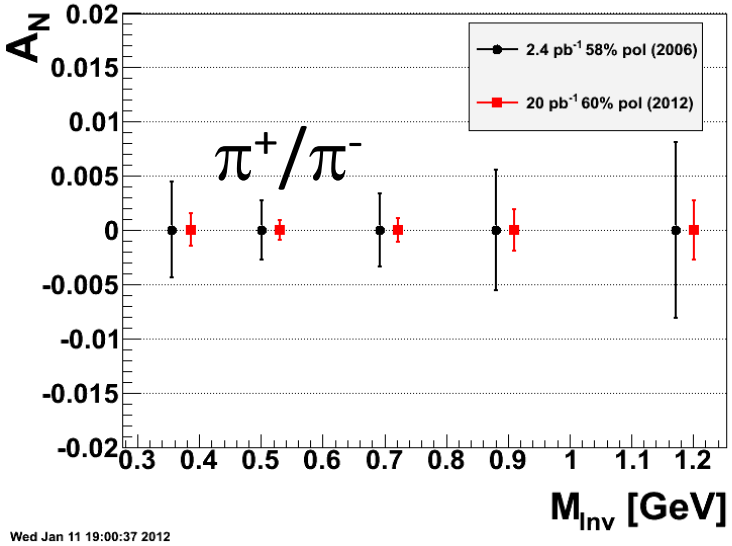


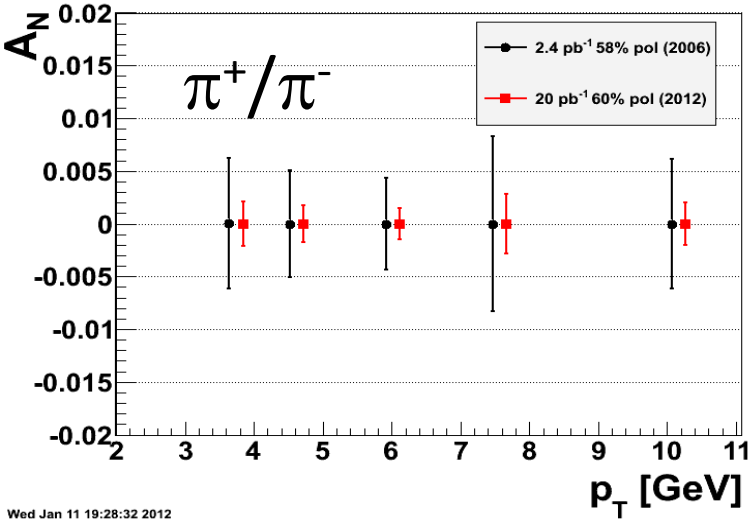






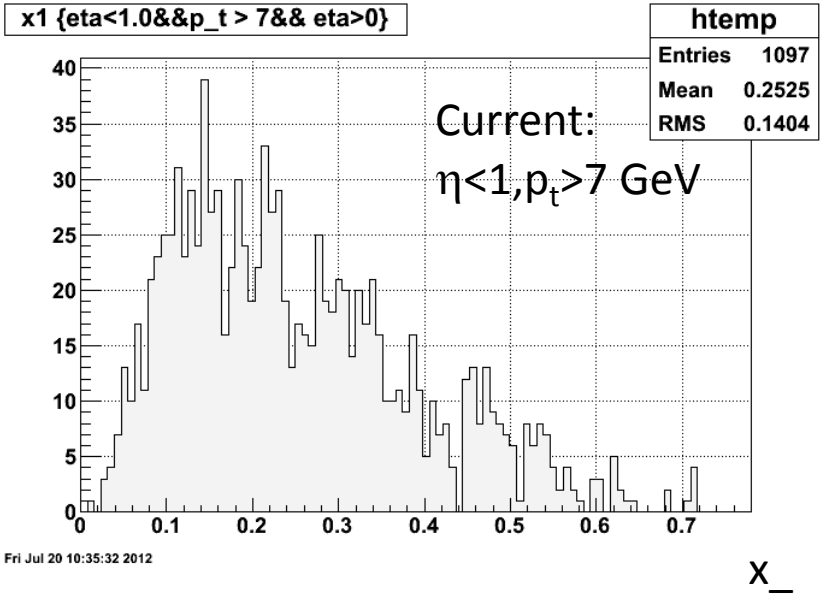


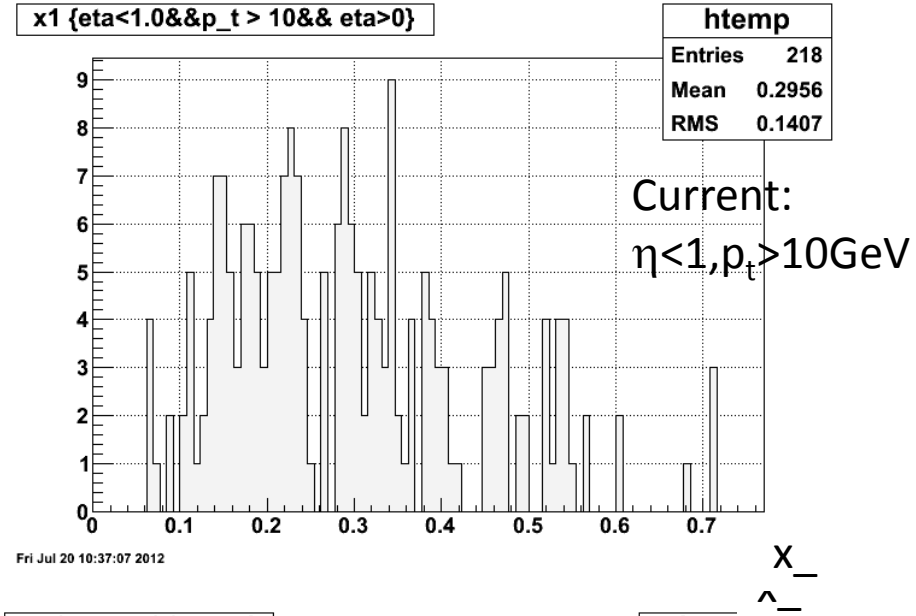


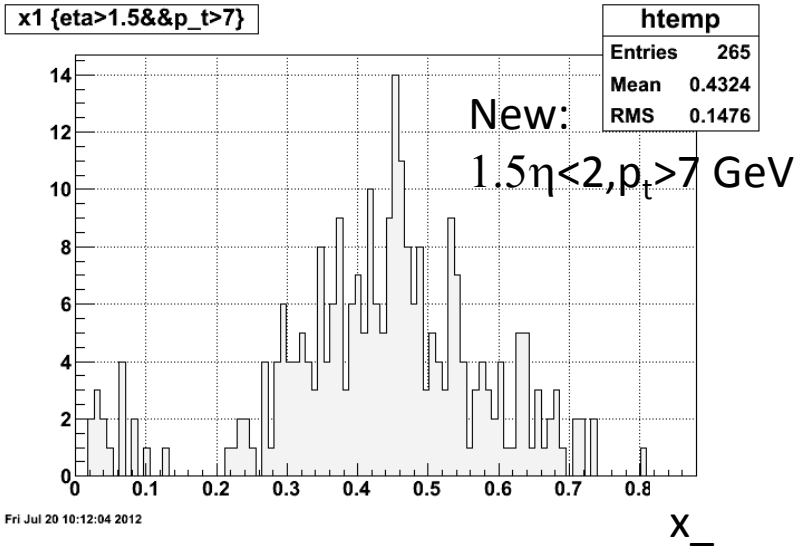


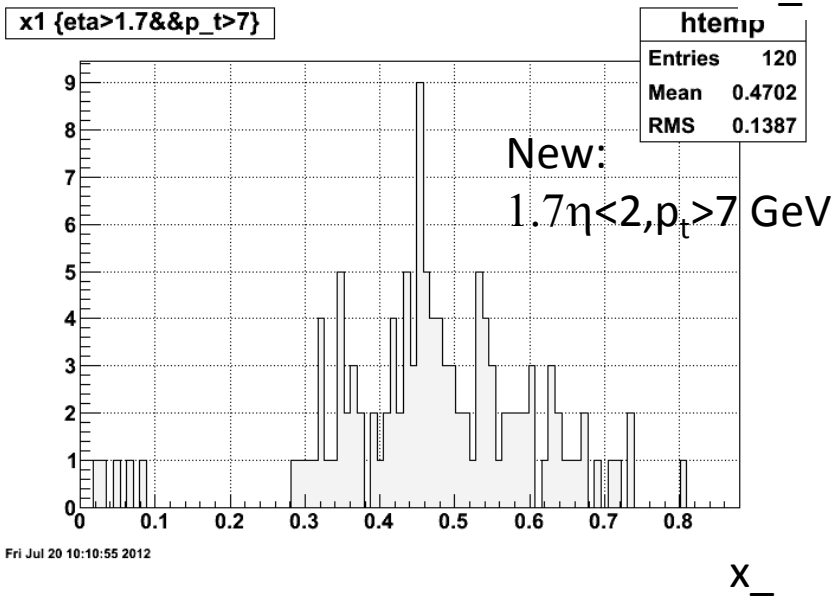
Additional precision data from last years run
+ increased kinematic reach
Explore π^0/π^{+-} channels

Enhanced Kinematic reach with TPC inner sector
Upgrade to enable tracking up to η=2









Summary

- Compass collected large set up data with transversely polarized proton and deuteron data
- STAR showed first significant transversity signals in p+p
- Jet capabilities make more correlation measurements possible
- 10x more data taken in 2012
- Explore channels including neutral pions
- Future upgrades to PHENIX and STAR aim to extend program to $2<\eta<4$

Backup