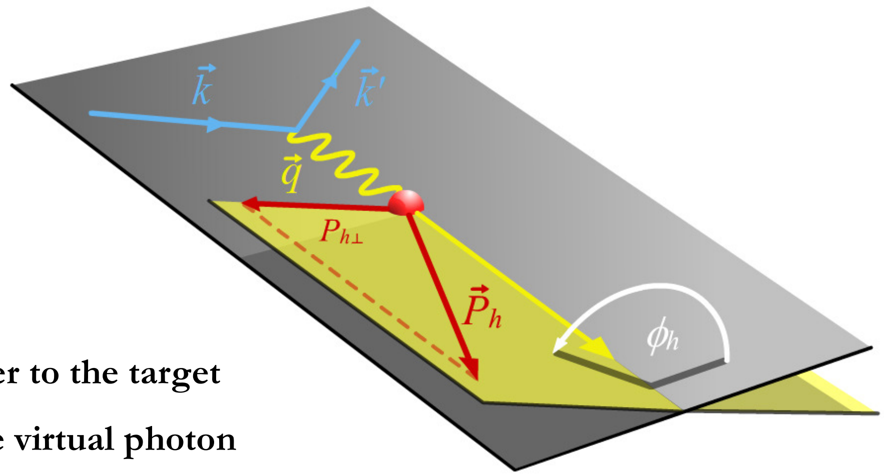
Pion unpolarized azimuthal modulations at HERMES

Firenze, DIS 2010

Francesca Giordano
Rebecca Lamb

For the hermes collaboration

Unpolarized Semi-Inclusive DIS



Q^2 Negative square four-momentum transfer to the target

y Fractional energy of the virtual photon

x Bjorken scaling variable

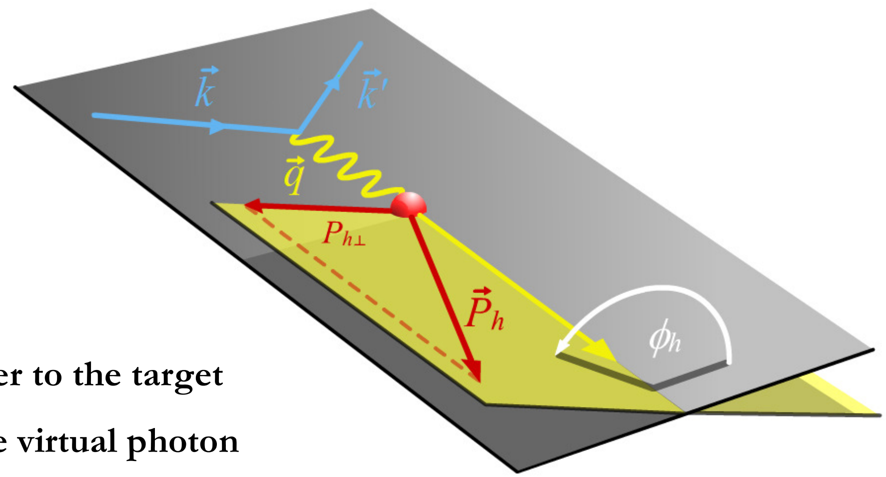
z Fractional energy transfer to the produced hadron

Collinear approximation

$$\frac{d^3\sigma}{dx\ dy\ dz} = \frac{\alpha^2}{xyQ^2}\left(1+\frac{\gamma^2}{2x}\right)\left\{A(y)\ F_{UU,T} + B(y)\ F_{UU,L}\right\}$$

$$F_{...} = F_{...}(x, y, z)$$

Unpolarized Semi-Inclusive DIS



- Q^2 Negative square four-momentum transfer to the target
- y Fractional energy of the virtual photon
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Target polarization

$$F_{XY,V}$$

Beam polarization

Virtual photon polarization

Collinear approximation

$$\frac{d^3\sigma}{dx\ dy\ dz} = \frac{\alpha^2}{xyQ^2}\left(1+\frac{\gamma^2}{2x}\right)\left\{A(y)\ F_{UU,T} + B(y)\ F_{UU,L}\right\}$$

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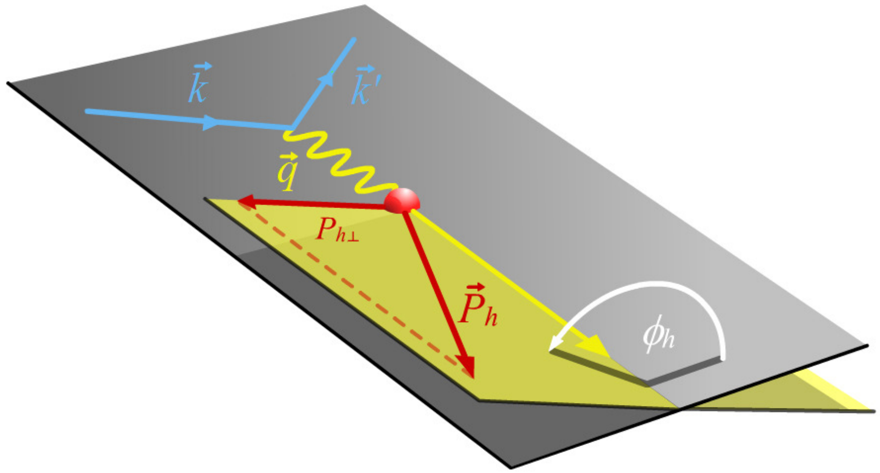

$$\frac{d^5\sigma}{dx\ dy\ dz\ d\phi_h dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\left(1+\frac{\gamma^2}{2x}\right)\Big\{A(y)\ F_{UU,T} + B(y)\ F_{UU,L}$$

$$+C(y)\ \cos\phi_h\, F_{UU}^{\cos\phi_h} + B(y)\ \cos 2\phi_h\ F_{UU}^{\cos 2\phi_h}\Big\}$$

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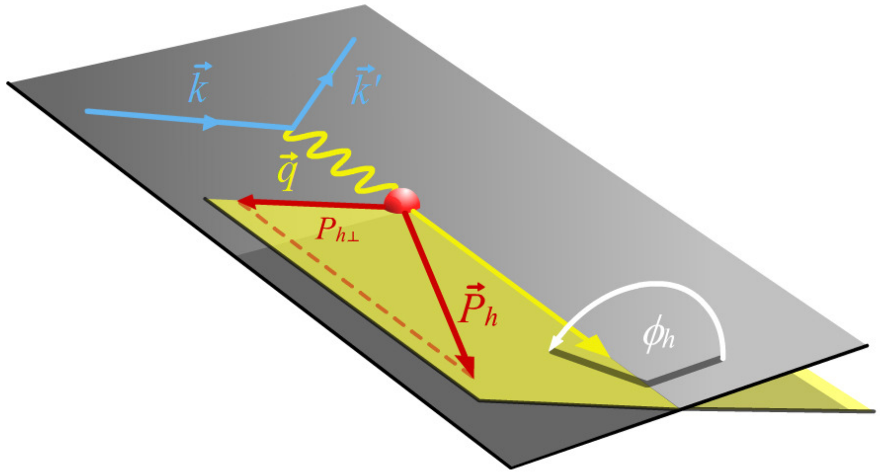
Unpolarized Semi-Inclusive DIS



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$$+C(y)\ \cos\phi_h\, F_{UU}^{\cos\phi_h} + B(y)\ \cos 2\phi_h\ F_{UU}^{\cos 2\phi_h}\Big\}$$

$$\langle \cos n\phi_h \rangle(x, y, z, P_{h\perp}) = \frac{\int \cos n\phi_h \sigma^{(5)} d\phi_h}{\int \sigma^{(5)} d\phi_h}$$

Leading twist expansion

FF

$$F_{UU,T} \propto C\left[f_1 D_1 \right]$$

DF

Leading twist expansion

Distribution Functions (DF)			
N / q	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	$g_{1T}^\perp$	$h_1, h_{1T}^\perp$

Fragmentation Functions (FF)	
q/h	U
U	D_1
T	$H_1^\perp$

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T	$f_{1T}^{\perp}$	$g_{1T}^{\perp}$	$h_1, h_{1T}^{\perp}$

Fragmentation Functions (FF)	
q/h	U
U	D_1
T	$H_1^{\perp}$

$h_1^{\perp}$ = Boer-Mulders function

CHIRAL-ODD

$$C\left[h_1^{\perp} H_1^{\perp}\right]$$

chiral-odd DF | **chiral-odd FF**

CHIRAL-EVEN!

Unpolarized Semi-Inclusive DIS

BOER-MULDERS EFFECT

leading twist

$$F_{UU}^{\cos 2\phi_h} \propto C\left[-\frac{2(\hat{P}_{h\perp}\cdot\vec{k}_T)(\hat{P}_{h\perp}\cdot\vec{p}_T)-\vec{k}_T\cdot\vec{p}_T}{MM_h}h_1^{\perp}H_1^{\perp}\right]$$

(Implicit sum over quark flavours)

Unpolarized Semi-Inclusive DIS

leading twist

$$F_{UU}^{\cos 2\phi_h} \propto C\left[-\frac{2(\widehat{P}_{h\perp}\cdot\vec{k}_T)(\widehat{P}_{h\perp}\cdot\vec{p}_T)-\vec{k}_T\cdot\vec{p}_T}{MM_h}\,h_1^{\perp}H_1^{\perp}\right]$$

BOER-MULDERS EFFECT

CAHN EFFECT

next to leading twist

$$F_{UU}^{\cos\phi_h} \propto \frac{2M}{Q}C\left[-\frac{\widehat{P}_{h\perp}\cdot\vec{p}_T}{M_h}\,x\,h_1^{\perp}H_1^{\perp}-\frac{\widehat{P}_{h\perp}\cdot\vec{k}_T}{M}\,x\,f_1D_1+\ldots\right]$$

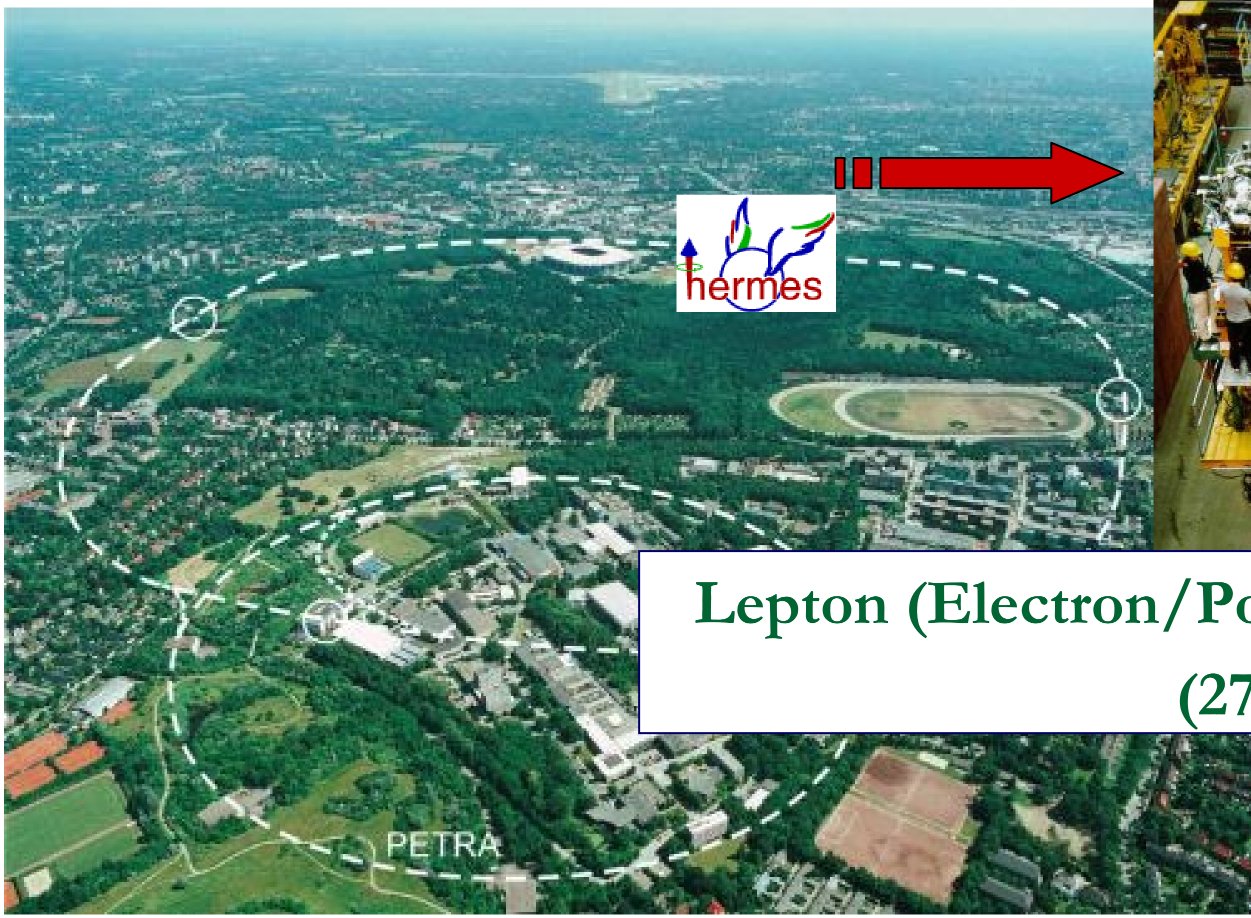
Interaction dependent terms neglected

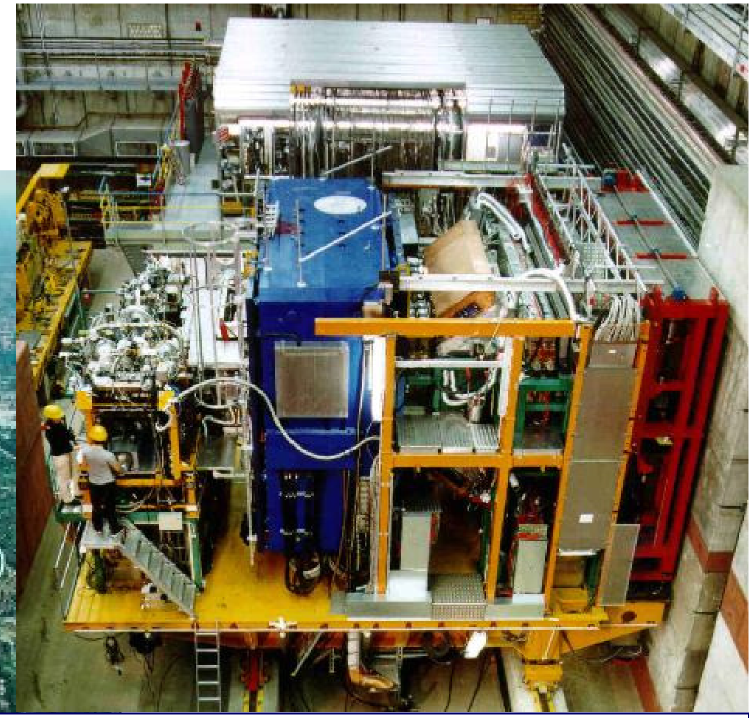
(Implicit sum over quark flavours)

HERa MEasurement of Spin

HERA storage ring @ DESY

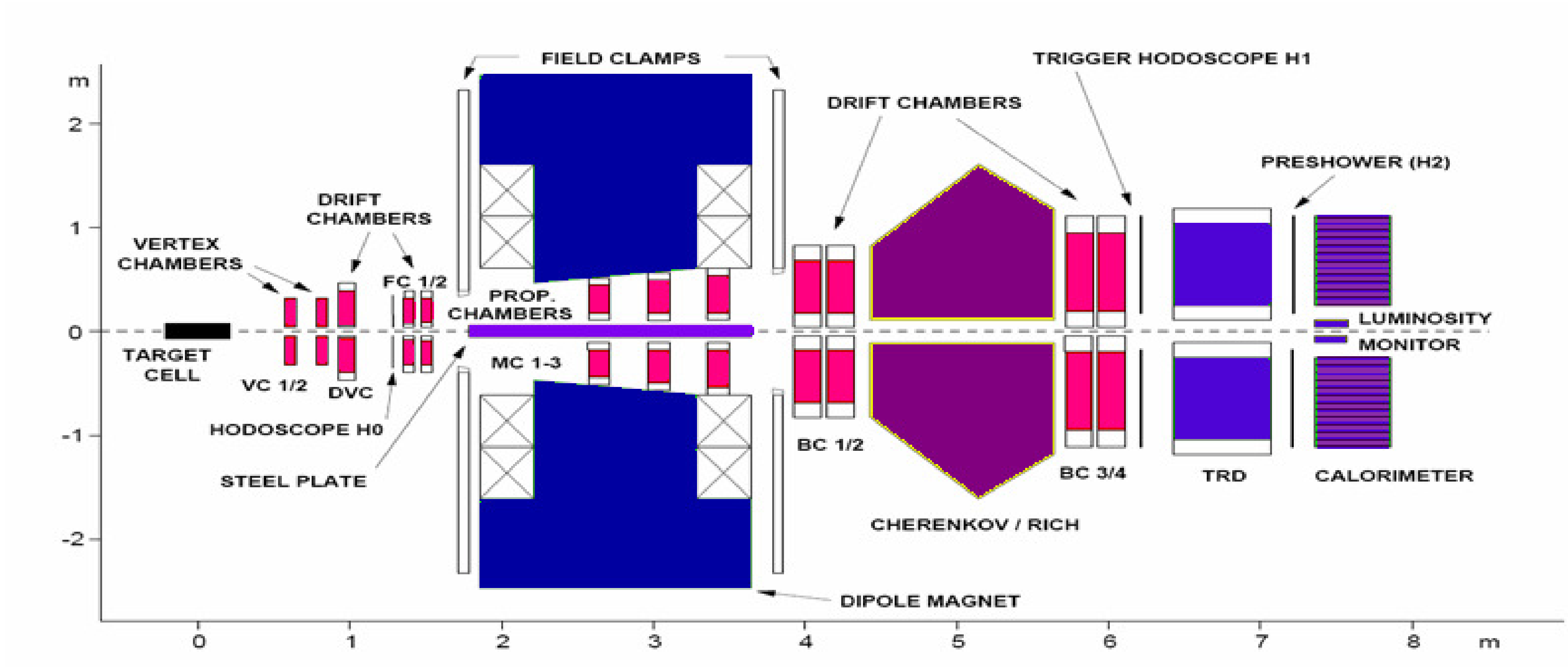
HERa MEasurement of Spin





Lepton (Electron/Positron) HERA beam (27.6 GeV)

HERMES spectrometer



Resolution: Δp/p ~ 1-2% Δθ <~0.6 mrad

Electron-hadron separation efficiency ~ 98-99%

Hadron identification with dual-radiator RICH

Experimental extraction

$$A = 2\langle \cos\phi_h \rangle$$

$$B = 2\langle \cos 2\phi_h \rangle$$

$$n^{EXP} = \int \sigma_0(w)\ \left[1 + A(w)\ \cos\phi_h + B(w)\ \cos 2\phi_h\right]\ L\, dw$$

$$w = (x, y, z, P_{h\perp})$$

Experimental extraction

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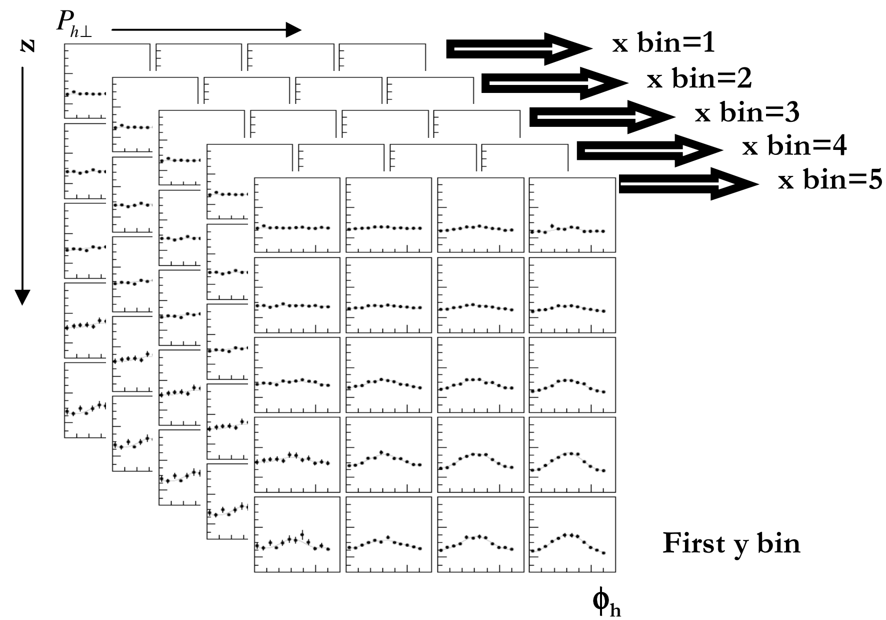
Multidimensional (W)



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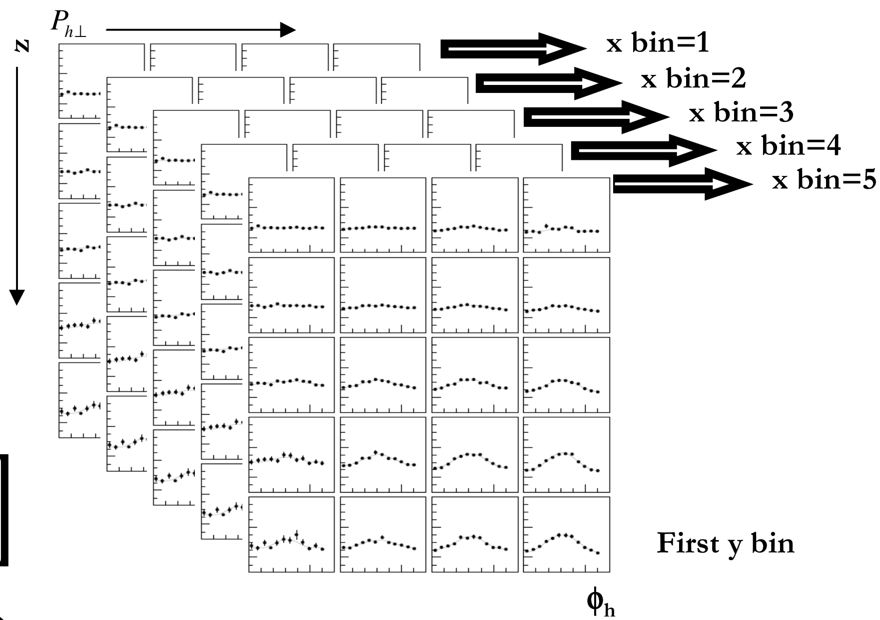

Multidimensional (W) unfolding procedure

$$n_{BORN} = S^{-1}\left[n_{EXP} - n_{Bg}\right]$$

Probability that an event generated with kinematics w is measured with kinematics w'

Includes the events smeared into the acceptance

Experimental extraction

$$A = 2\langle \cos \phi_h \rangle$$

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$$w = (x, y, z, P_{h\perp})$$

Multidimensional (W) unfolding procedure

BINNING **900 kinematical bins x 12 ϕ_η-bins**								
Variable	Bin limits							#
x	0.023	0.042	0.078	0.145	0.27	0.6		**5**
y	0.2	0.3	0.45	0.6	0.7	0.85		**5**
z	0.2	0.3	0.4	0.5	0.6	0.75	1	**6**
Pt	0.05	0.2	0.35	0.5	0.7	1	1.3	**6**

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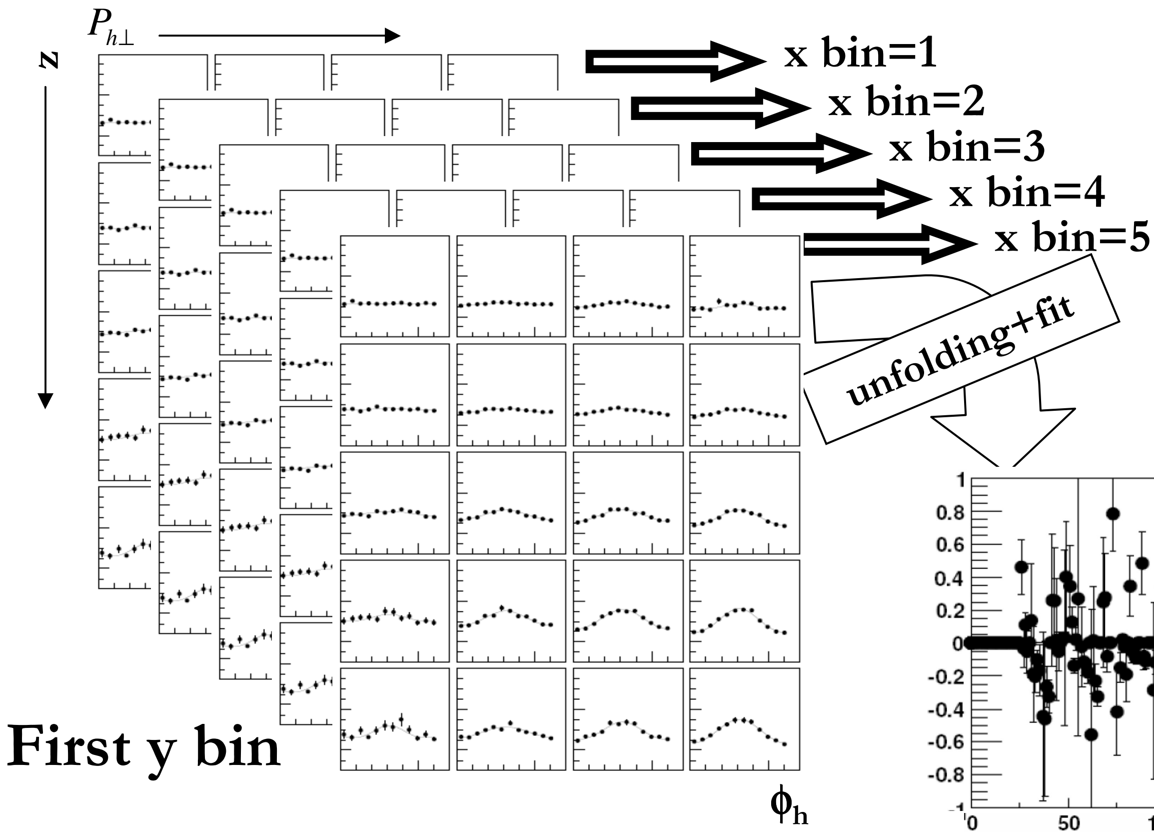
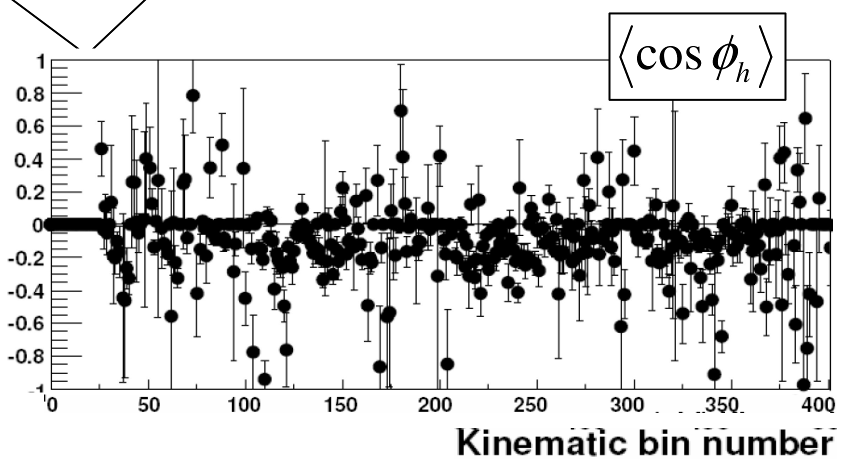
The multi-dimensional analysis





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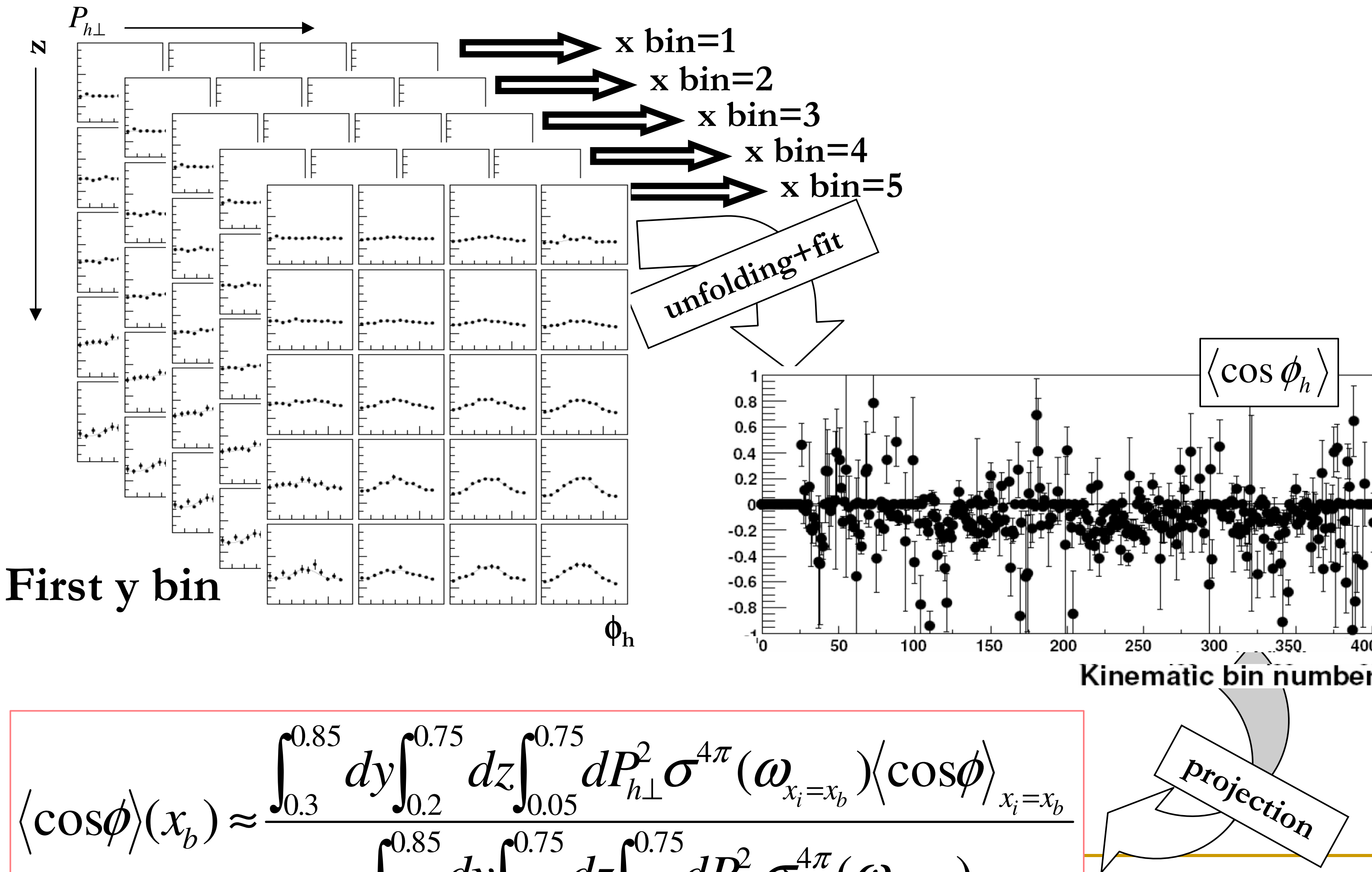

$$\langle\cos\phi\rangle(x_b) \approx \frac{\int_{0.3}^{0.85} dy \int_{0.2}^{0.75} dz \int_{0.05}^{0.75} dP_{h\perp}^2 \sigma^{4\pi}(\omega_{x_i=x_b}) \langle\cos\phi\rangle_{x_i=x_b}}{\int_{0.3}^{0.85} dy \int_{0.2}^{0.75} dz \int_{0.05}^{0.75} dP_{h\perp}^2 \sigma^{4\pi}(\omega_{x_i=x_b})}$$

Kinematic integration range

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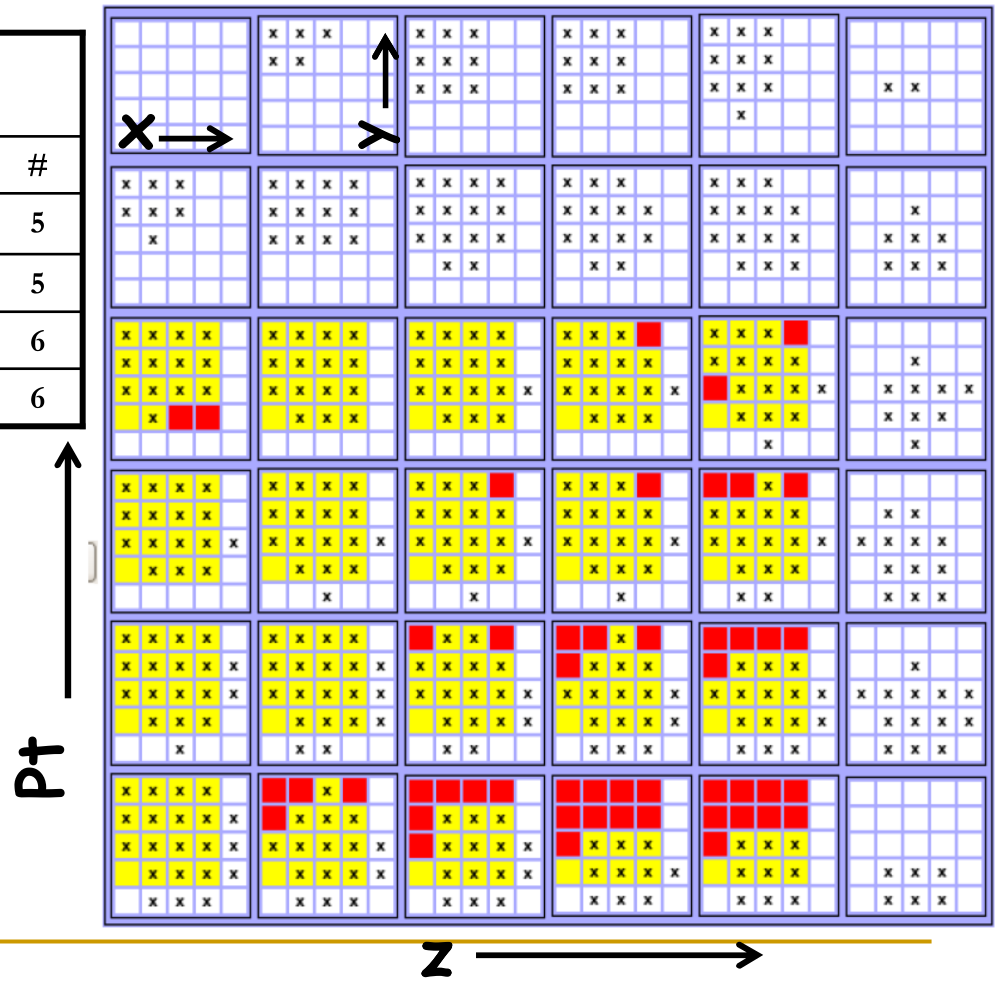

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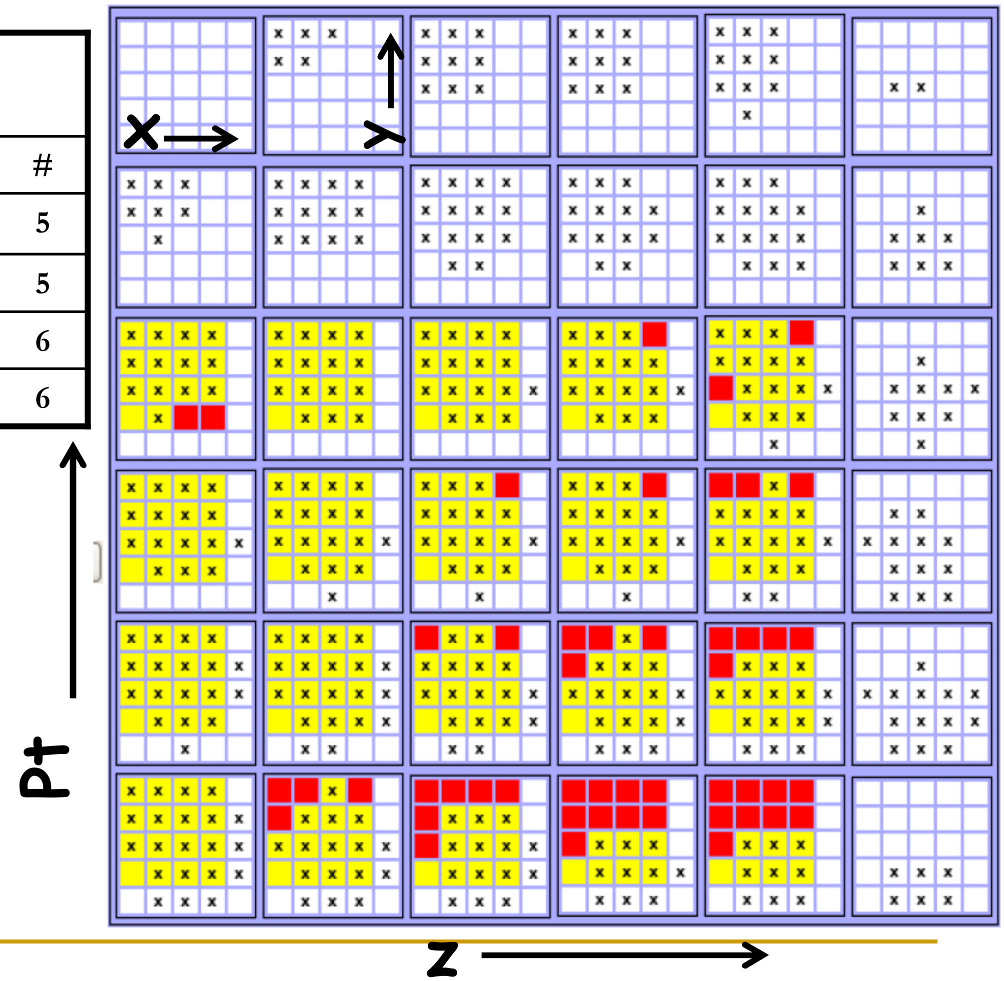
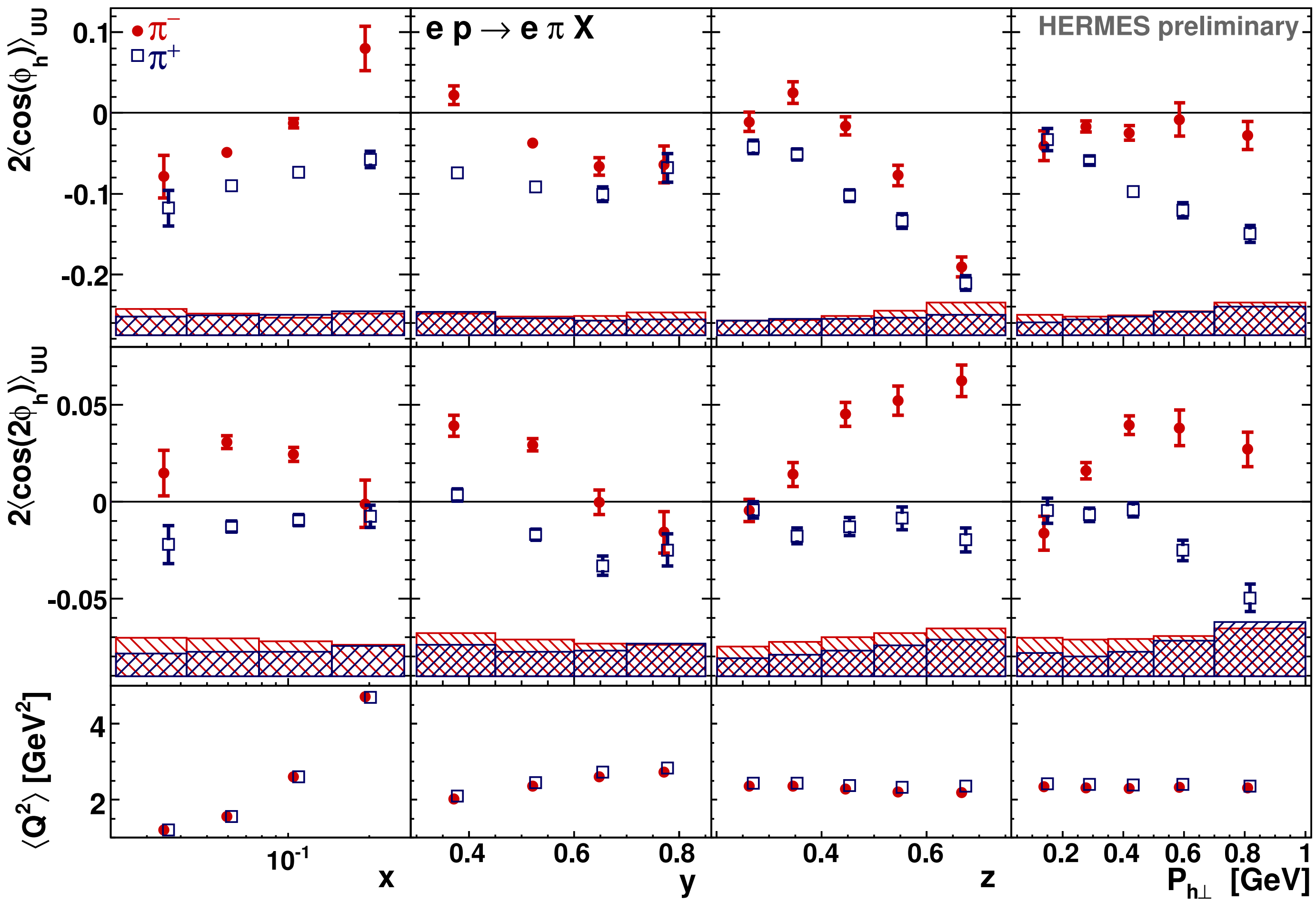


Hydrogen data



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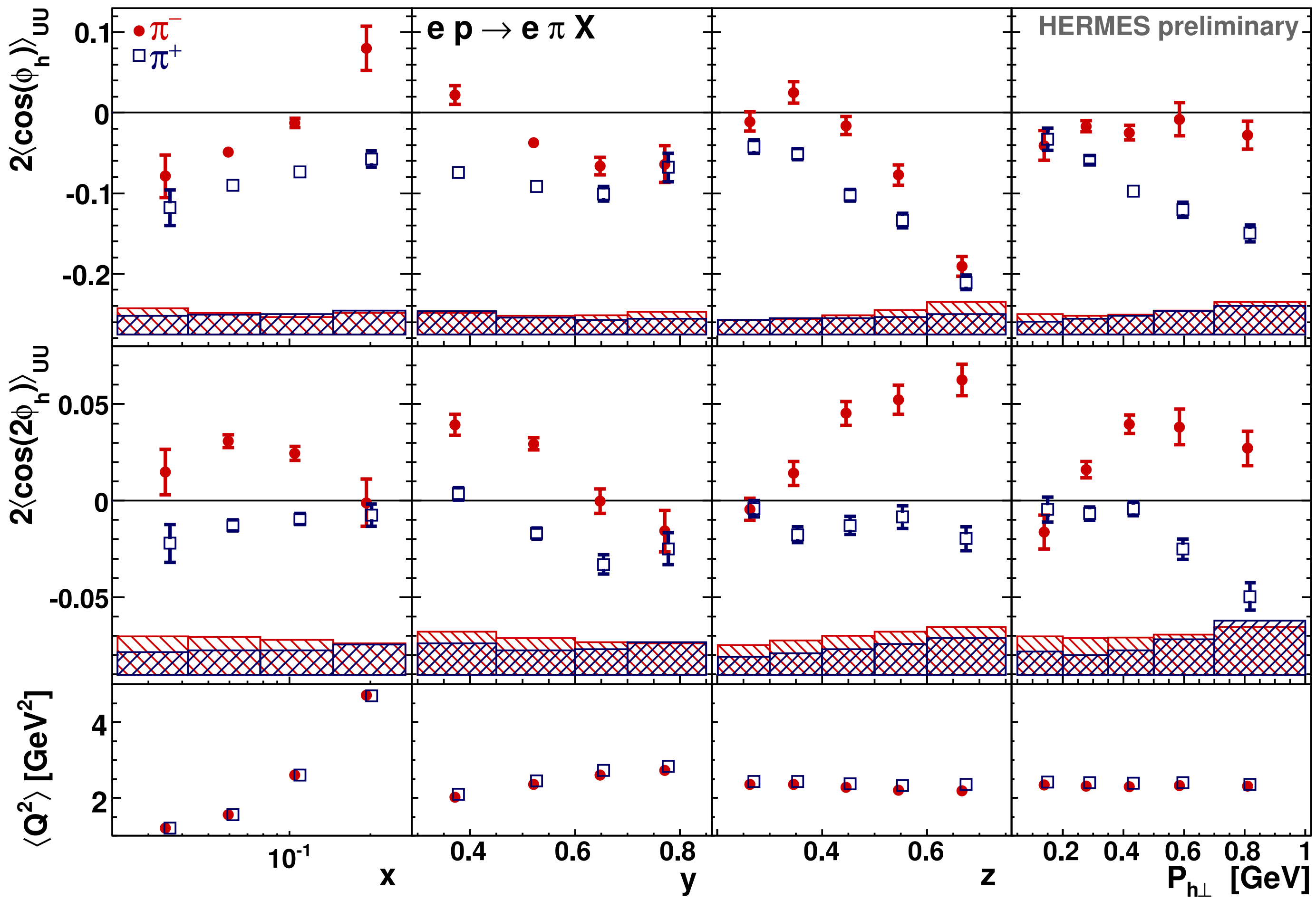
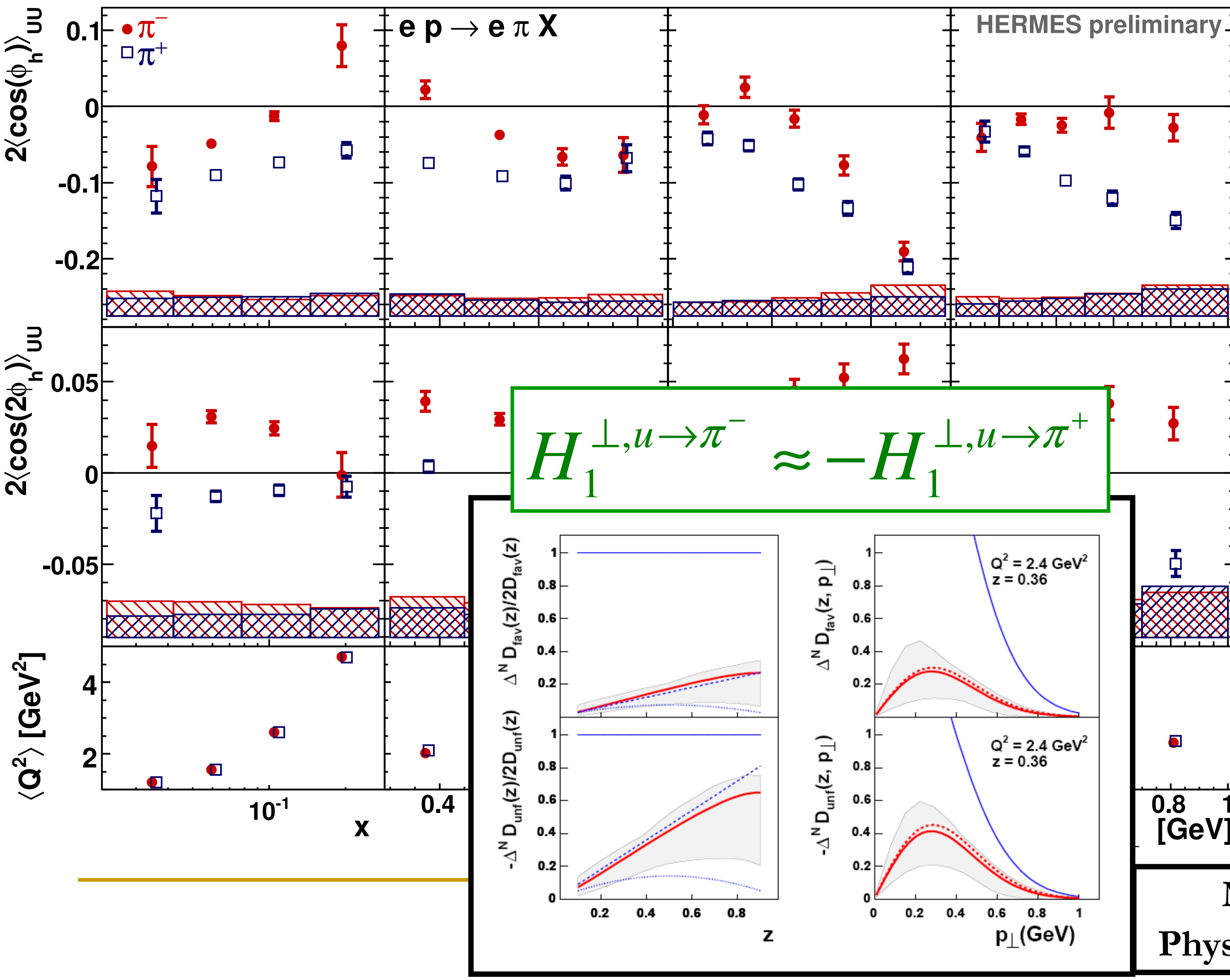


$$F_{UU}^{\cos\phi_h} \propto \frac{2M}{Q} C\left[-h_1^{\perp} H_1^{\perp} - f_1 D_1 + \ldots\right]$$

$$F_{UU}^{\cos 2\phi_h} \propto C\left[-h_1^{\perp} H_1^{\perp}\right]$$

Hydrogen data



$$H_1^{\perp,u\to\pi^-} \approx -H_1^{\perp,u\to\pi^+}$$

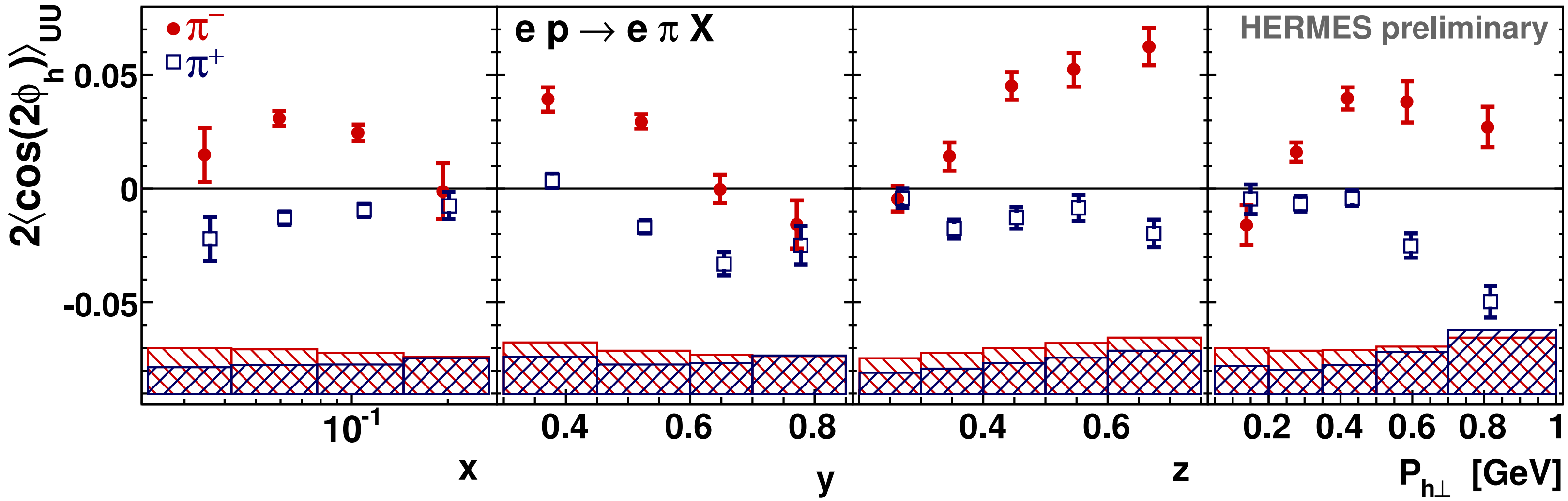
$$F_{UU}^{\cos\phi_h} \propto \frac{2M}{Q} C\left[-h_1^{\perp} H_1^{\perp} - f_1 D_1 + \dots\right]$$

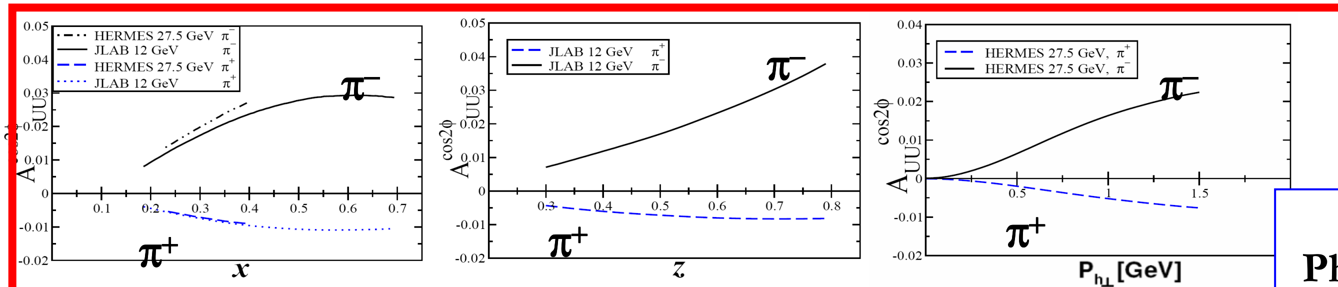
$$F_{UU}^{\cos 2\phi_h} \propto C\left[-h_1^{\perp} H_1^{\perp}\right]$$

M. Anselmino et al., Phys. Rev. D75:054032, 2007

cos2ϕ_h modulation

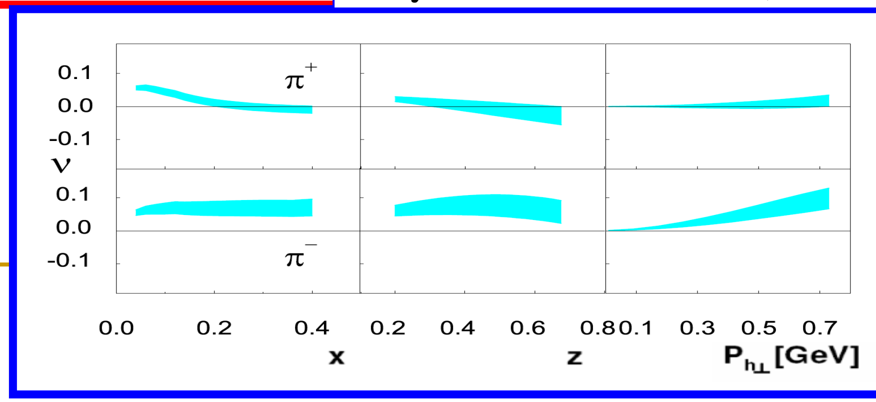
$$F_{UU}^{\cos 2\phi_h} \propto C\left[-h_1^{\perp} H_1^{\perp}\right]$$





L. P. Gamberg and G. R. Goldstein,
Phys. Rev. D77:094016, 2008

B. Zhang et al.,
Phys. Rev. D78:034035, 2008



$\cos 2\phi_h$ modulation

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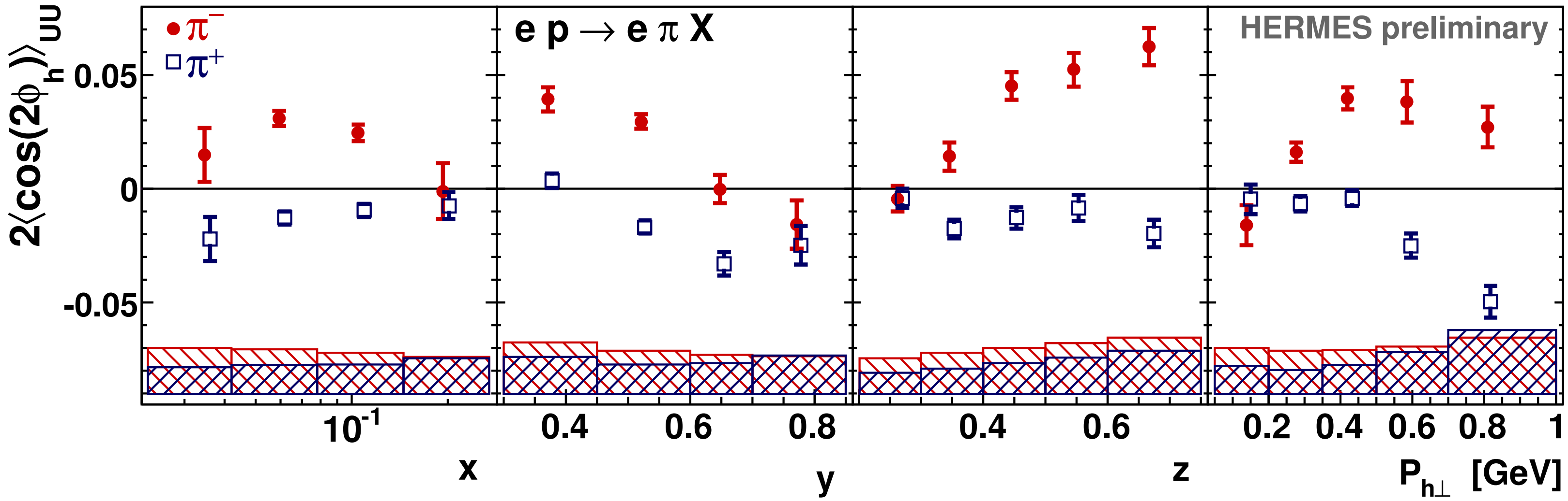
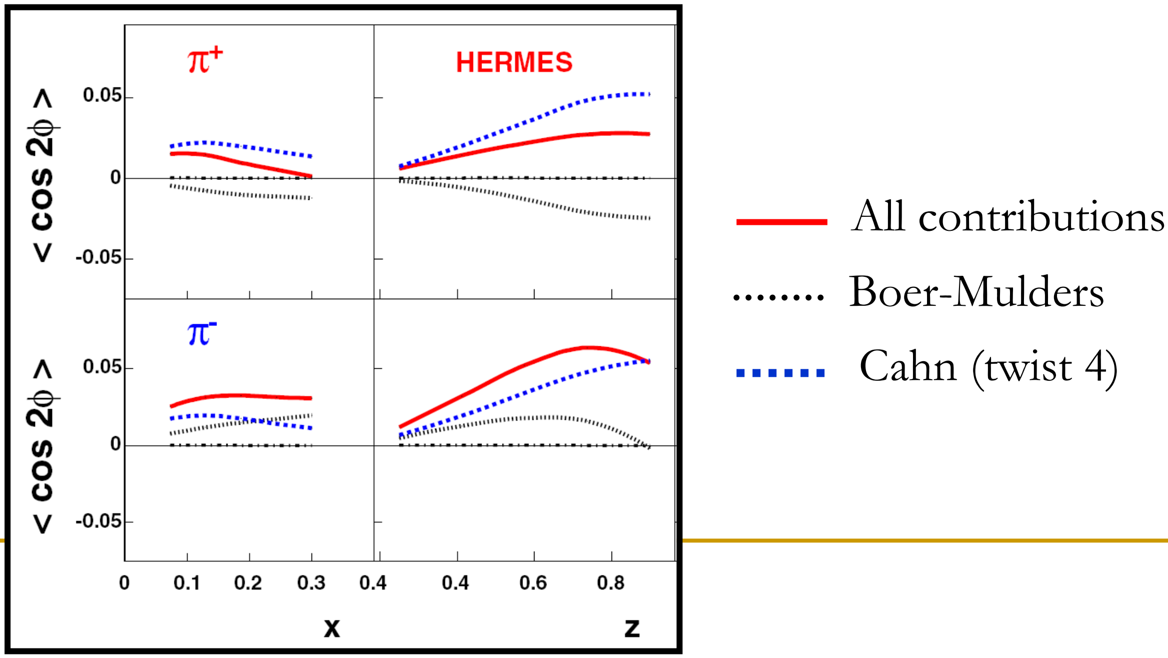


V. Barone et al.
Phys.Rev. D78:045022, 2008



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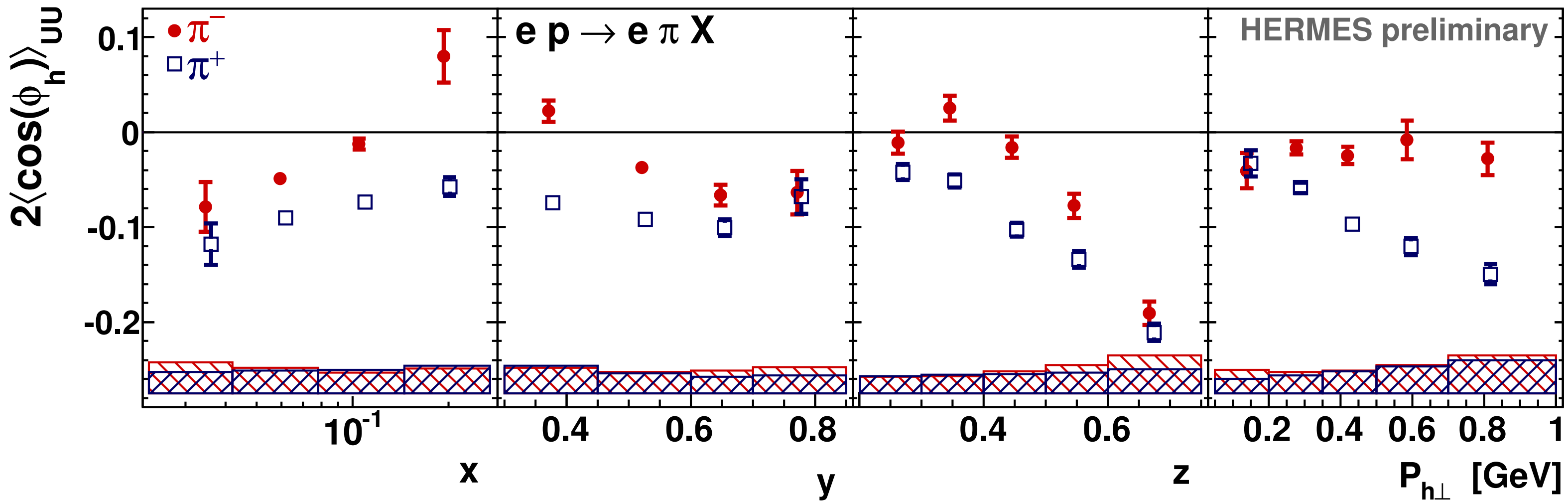
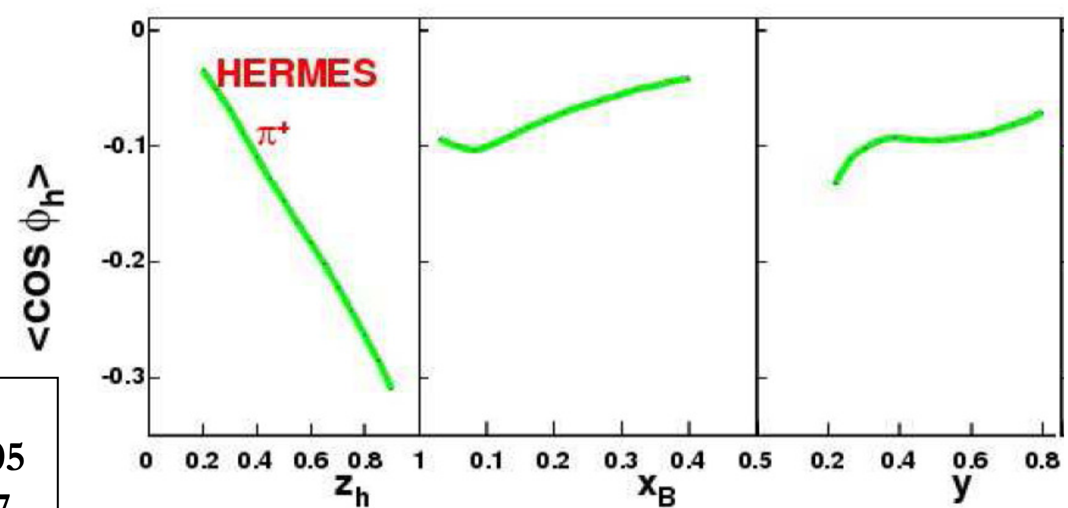
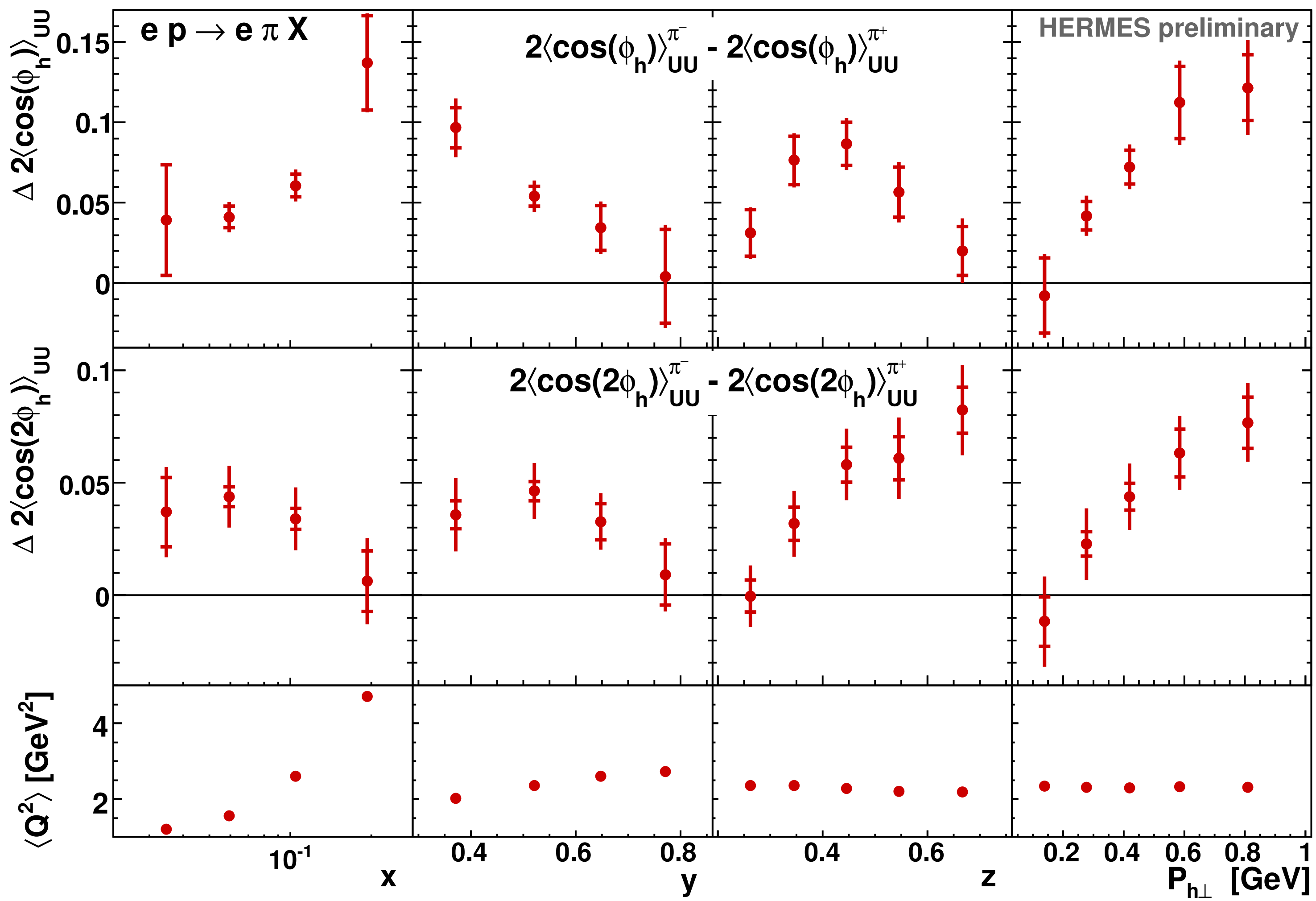


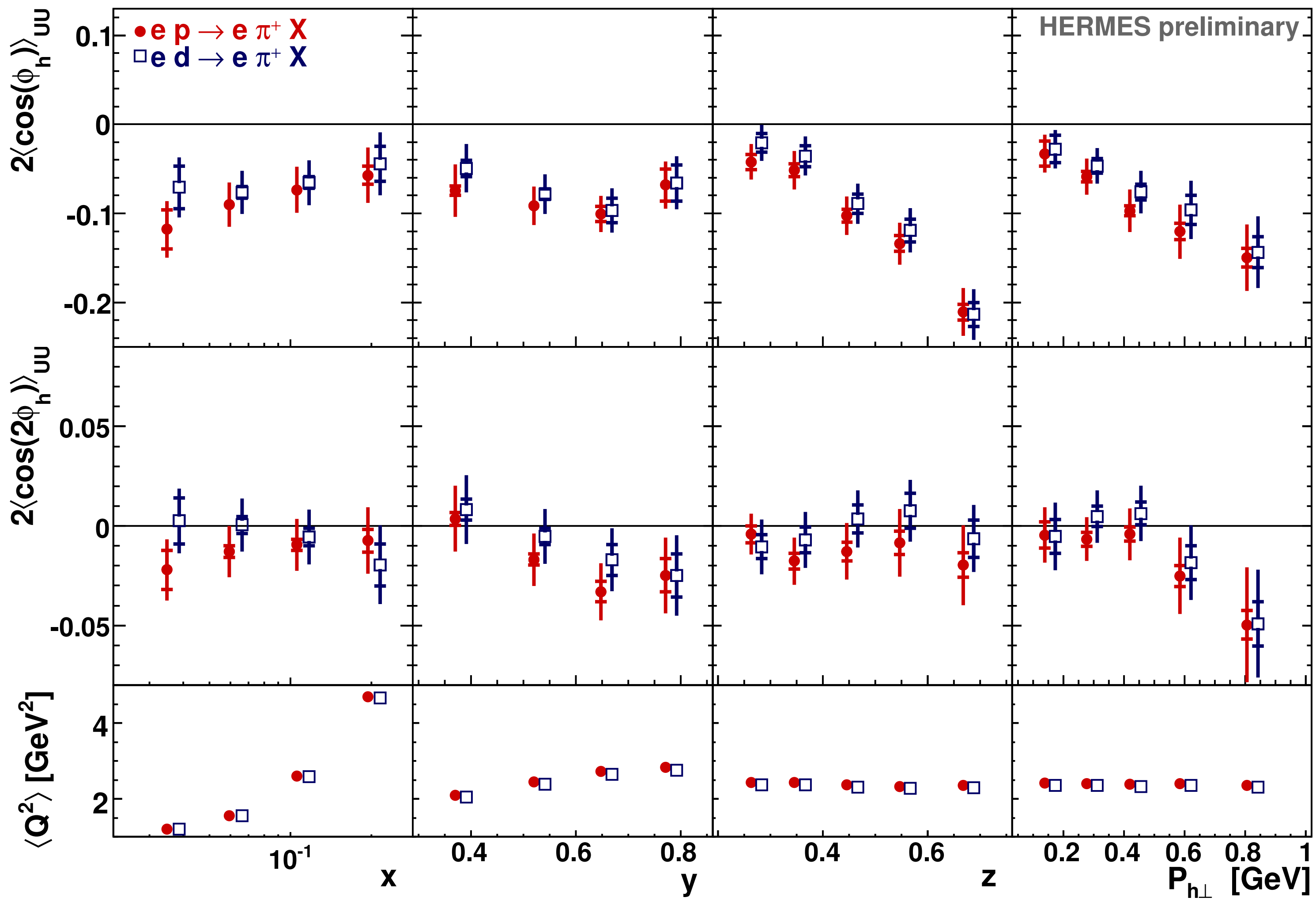


M. Anselmino et al.,
Phys. Rev. D71:074006, 2005
Eur. Phys. J. A31:373, 2007

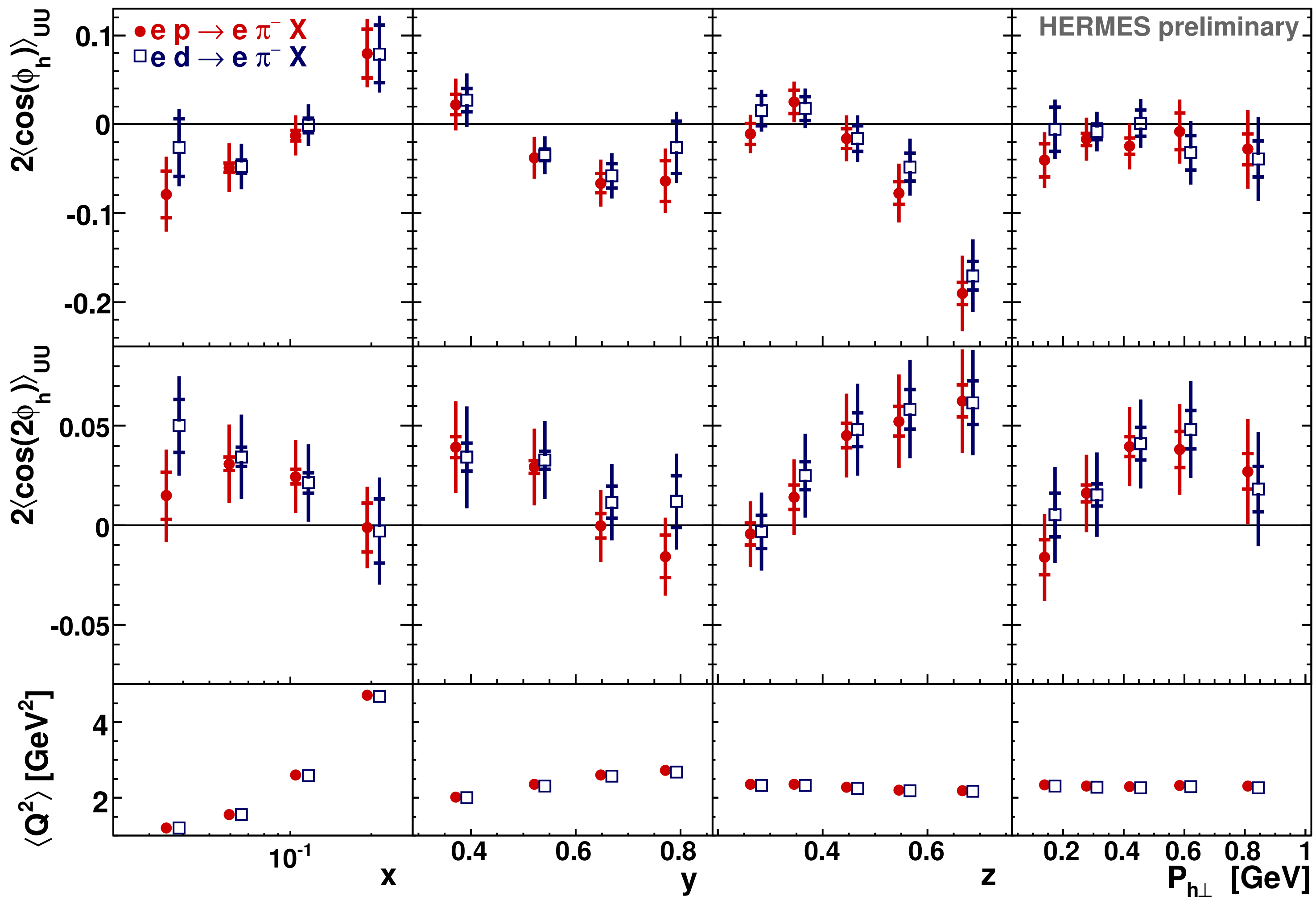
π^+-π^- moment difference



Hydrogen vs. Deuterium data π^+



Hydrogen vs. Deuterium data π^-



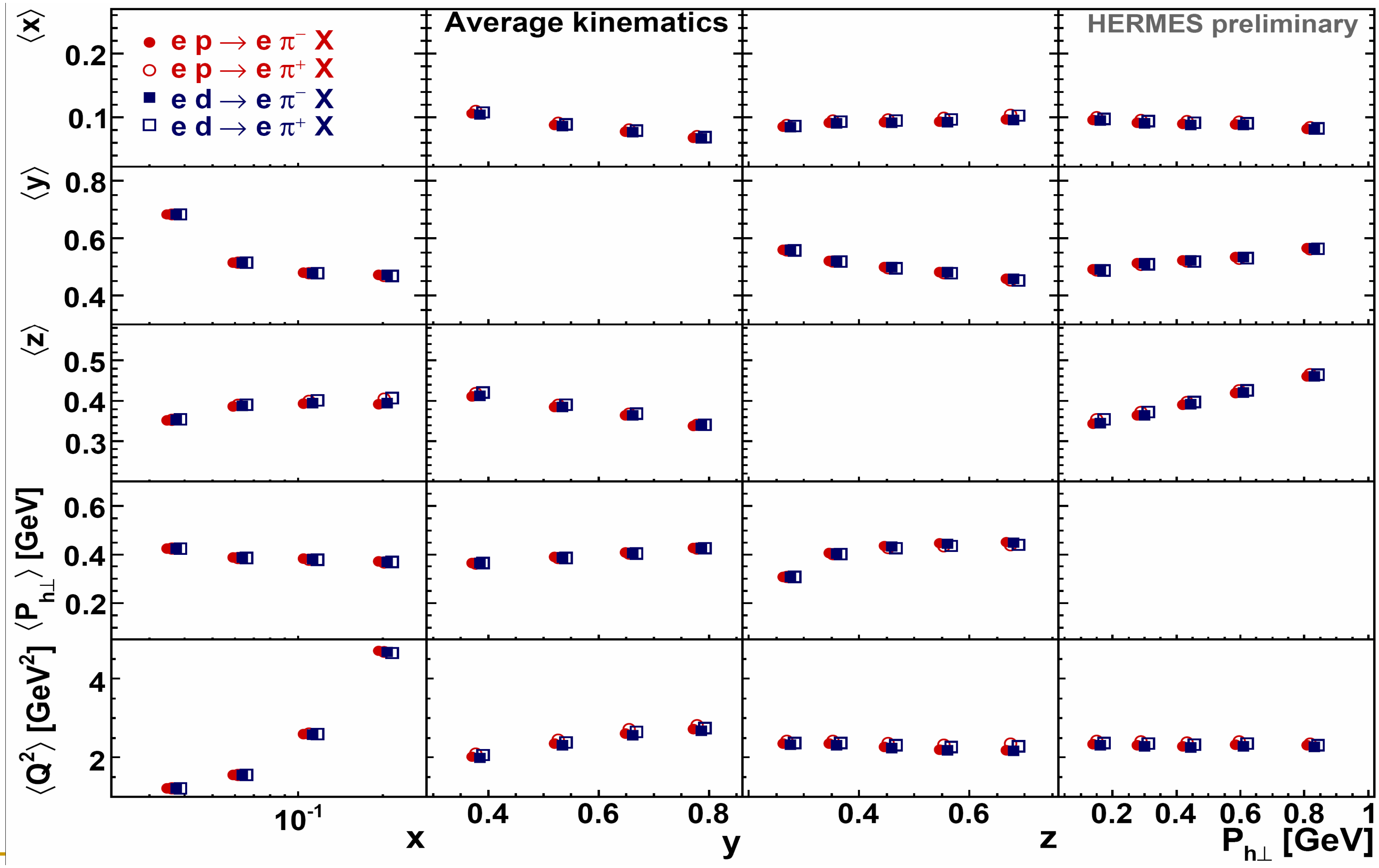
Summary

- The existence of an intrinsic **quark transverse motion** gives origin to an azimuthal asymmetry in the hadron production direction:
  - **Boer-Mulders effect**: a leading twist asymmetry originated from the correlation between the quark transverse motion and transverse spin (*spin-orbit effect*);
  - **Cahn effect**: an (higher twist) azimuthal modulation related to the existence of intrinsic quark motion.

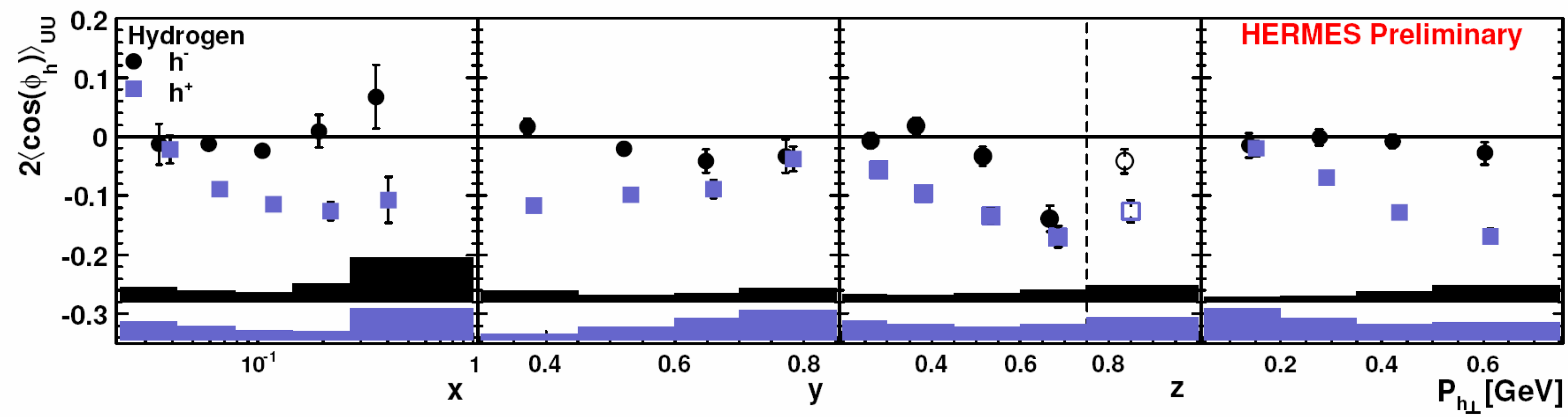
- **For the first time cosine modulations have been measured for <u>charged pions</u>:**
  - Negative **$\langle\cos\phi_h\rangle$ moments** are extracted for positive and negative pions;
  - The results for the **$\langle\cos2\phi_h\rangle$ moments** are positive for the negative pions and slightly negative for positive pions
  - Differences in the charged pion results can be interpreted as an

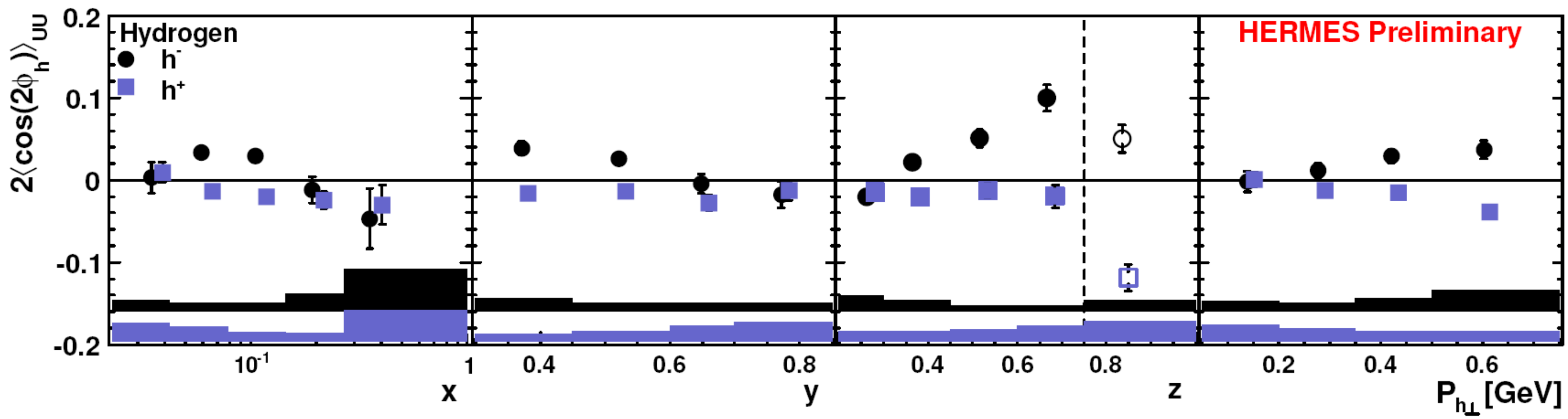
<u>evidence of a non-zero Boer-Mulders function</u>

Average kinematics



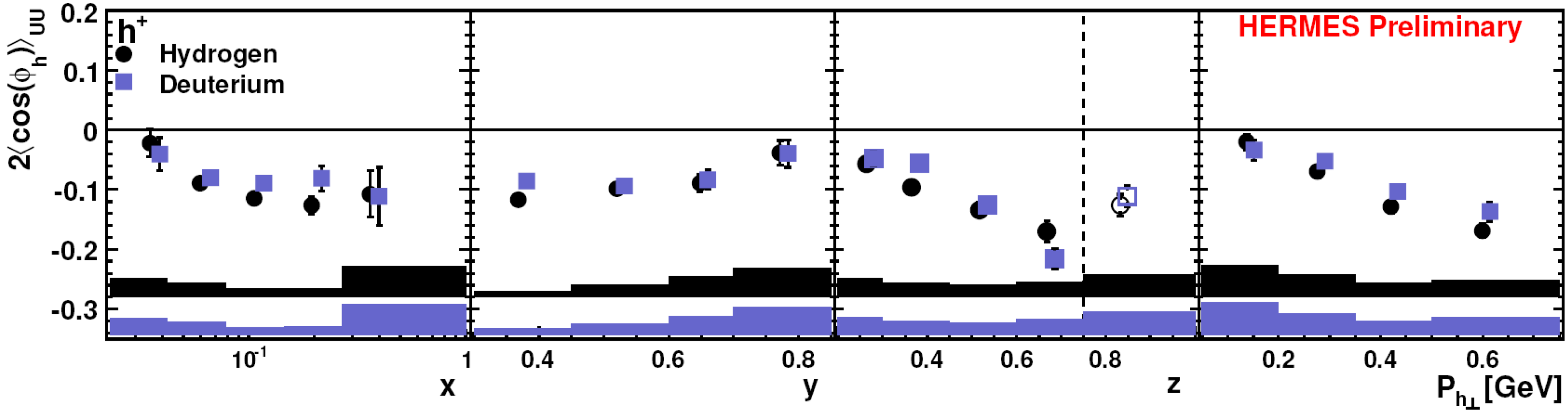
Hydrogen data: cosine moments for hadrons

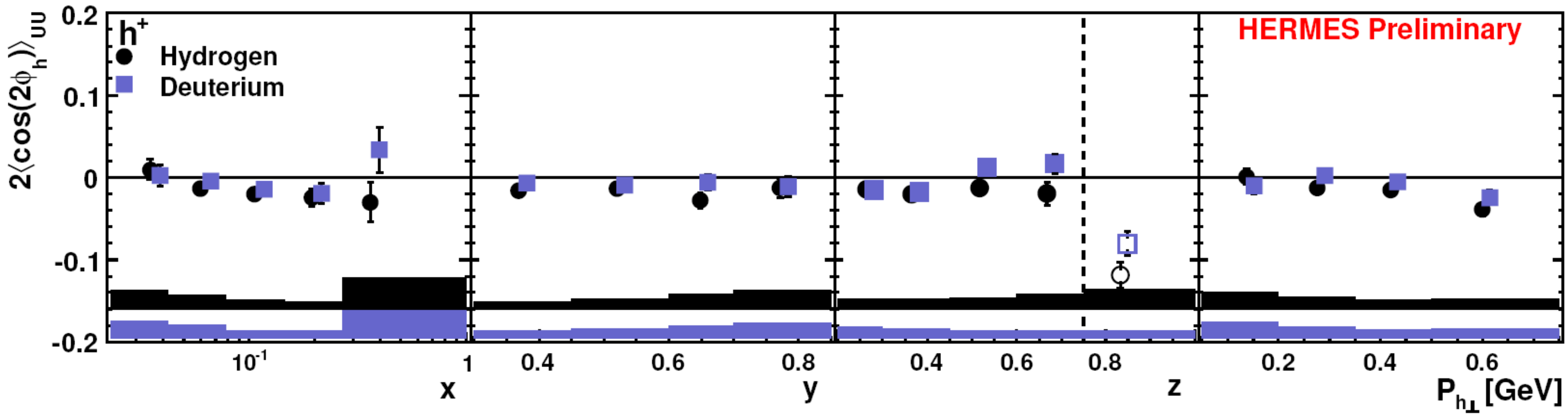




Hydrogen vs. Deuterium data

h^+





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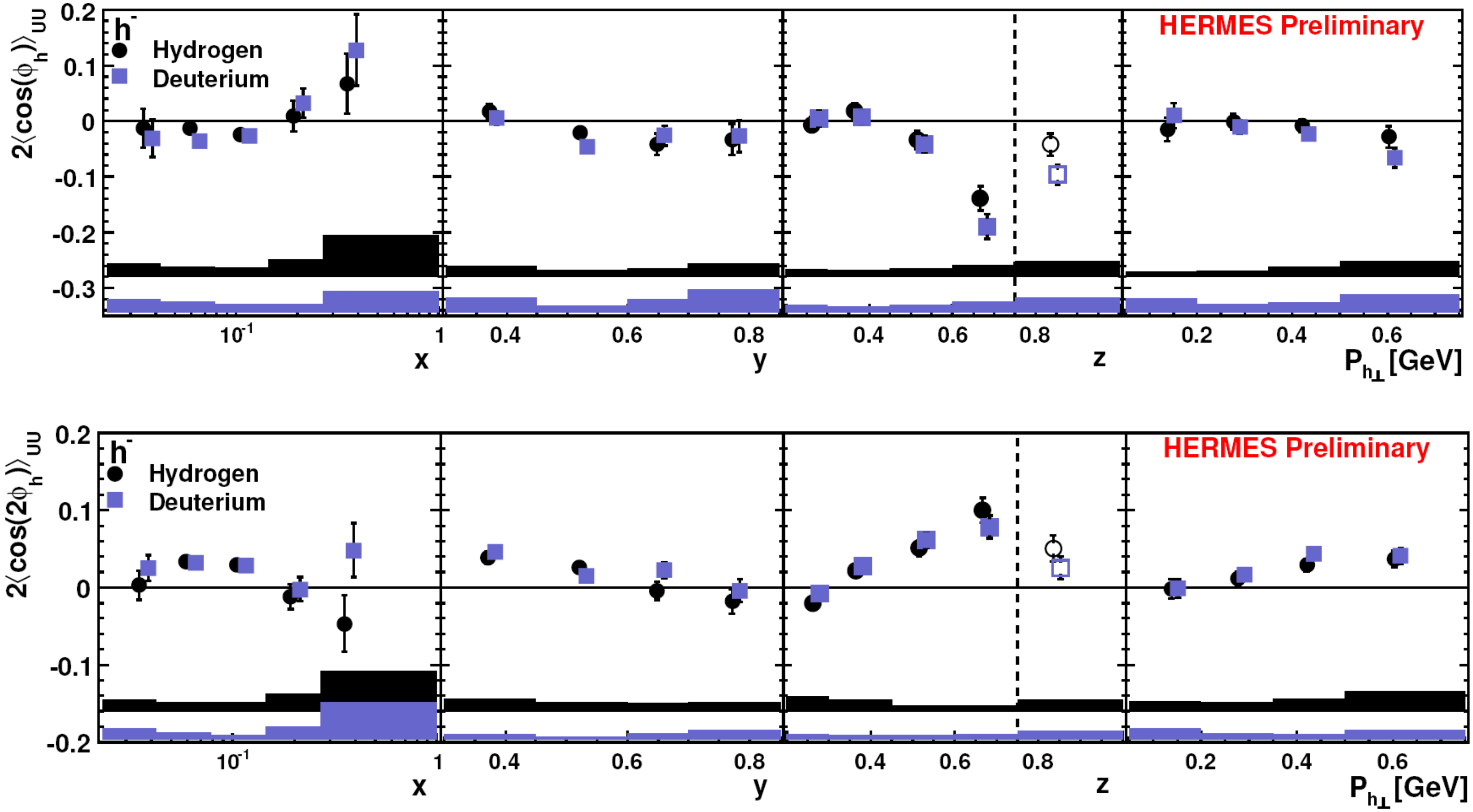
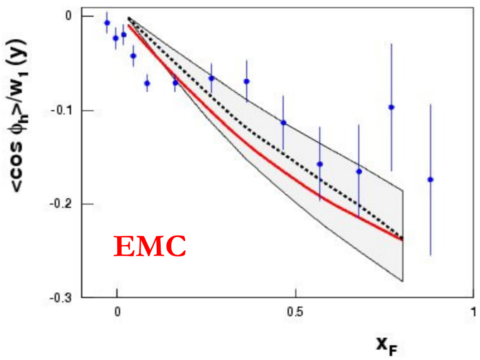
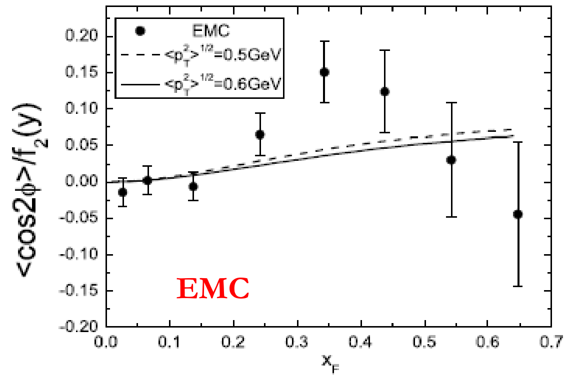


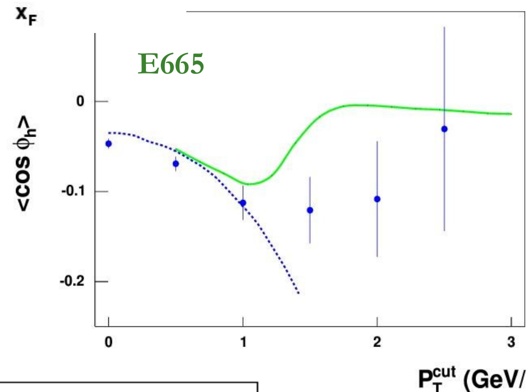
Experimental status

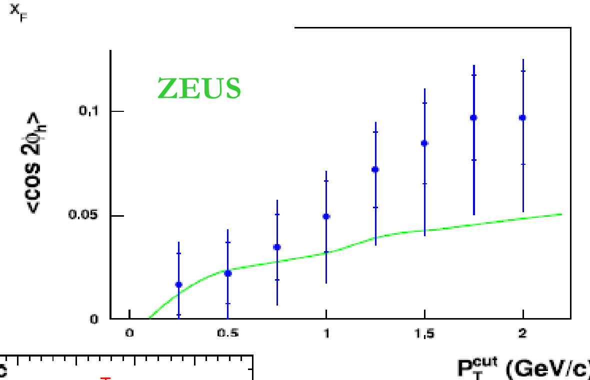
$\langle \cos \phi_h \rangle$

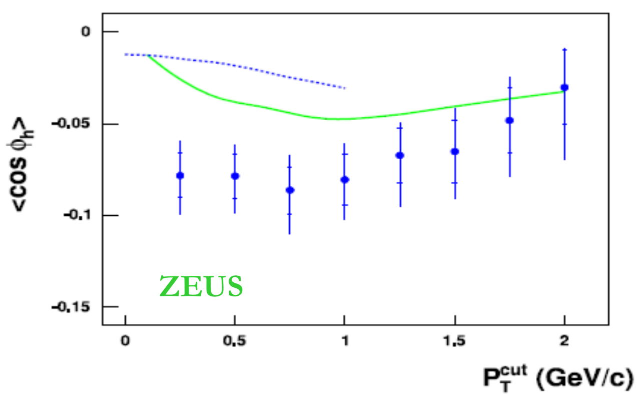
$\langle \cos 2\phi_h \rangle$

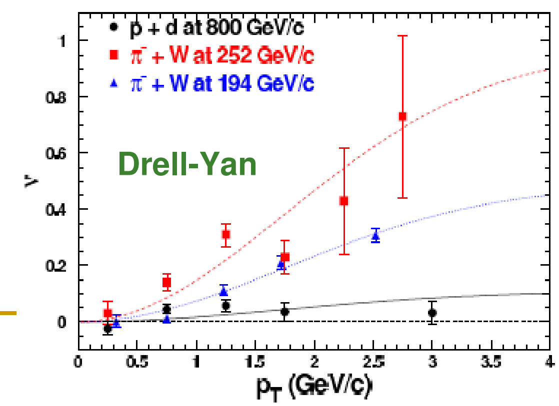




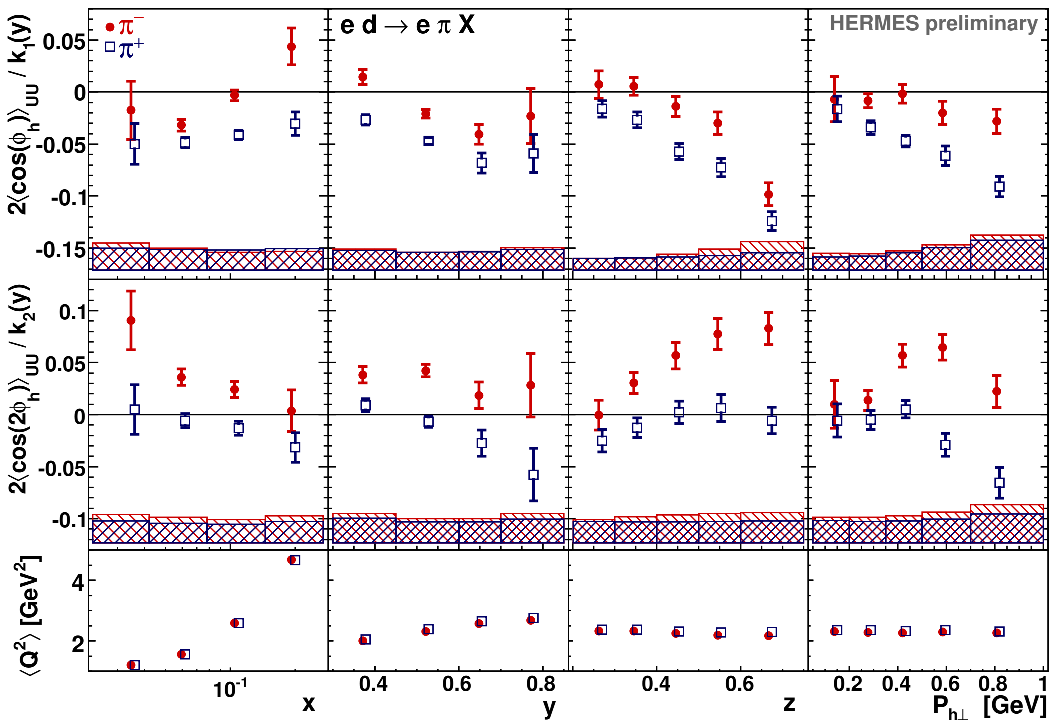




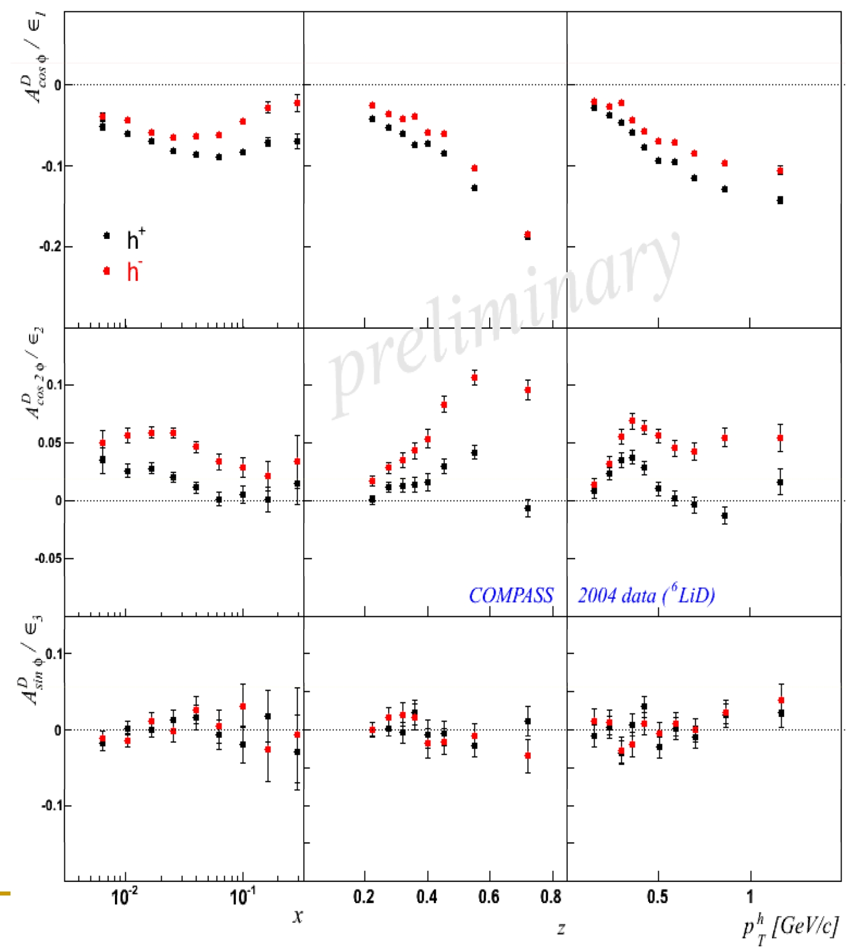




More recent results in SIDIS



$$2\langle\cos\phi_h\rangle\;/ = \frac{(2-y)\sqrt{1-y-\frac{1}{4}\gamma^2y^2}}{1-y+\frac{1}{2}y^2+\frac{1}{4}\gamma^2y^2}$$



$$2\langle\cos 2\phi_h\rangle\;/ = \frac{1-y-\frac{1}{4}\gamma^2y^2}{1-y+\frac{1}{2}y^2+\frac{1}{4}\gamma^2y^2}$$

$$\gamma = 2Mx/Q$$