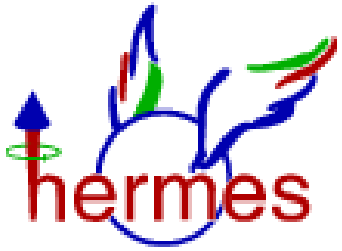
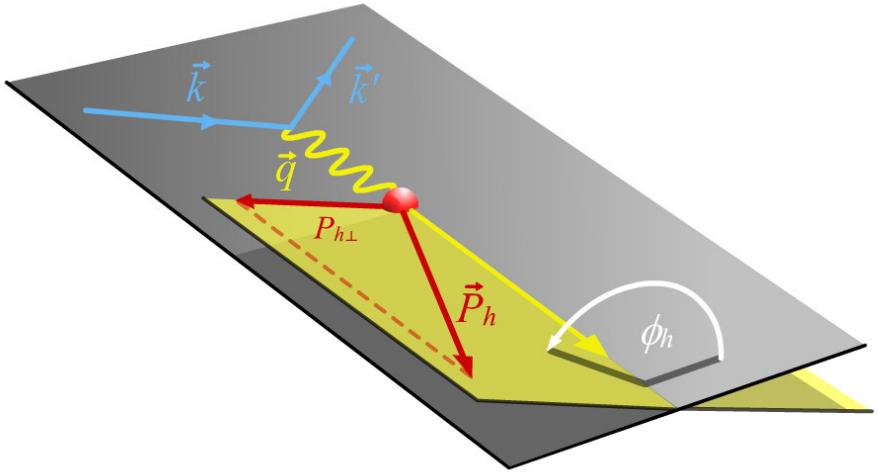


Azimuthal asymmetries of the unpolarized cross-section at HERMES

Francesca Giordano

Bochum, Germany, EuNPC 2009

Unpolarized Semi-Inclusive DIS (SIDIS)

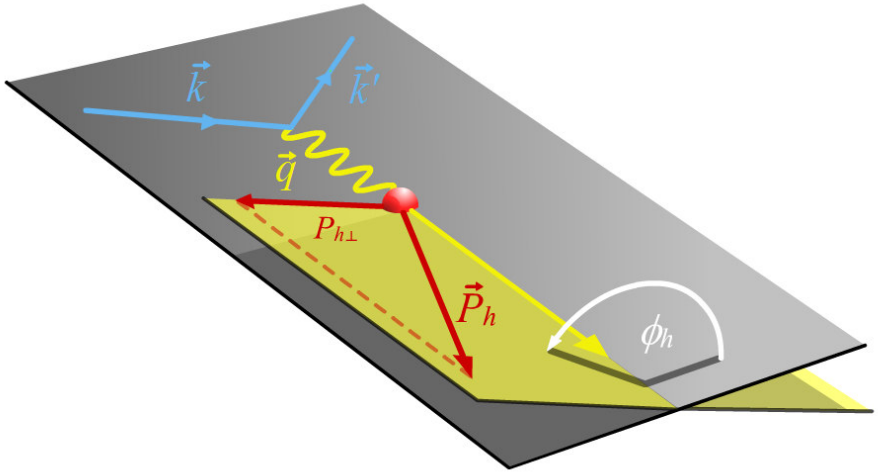


$$\frac{d^5\sigma}{dx\ dy\ dz\ d\phi\ dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\left(1+\frac{\gamma^2}{2x}\right)\Big\{A(y)\ F_{UU,T} + B(y)\ F_{UU,L}$$

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

$$F_{\ldots} = F_{\ldots}(x, Q^2, z, P_{h\perp})$$

Unpolarized Semi-Inclusive DIS (SIDIS)



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

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

Leading twist azimuthal modulation

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

(Implicit sum over quark flavours)

Leading & next to leading twist azimuthal modulation

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

$$F_{UU}^{\cos\phi} = \frac{2M}{Q} C\left[-\frac{\hat{h}\cdot\vec{p}_T}{M_h}\, x\, h_1^{\perp} H_1^{\perp} - \frac{\hat{h}\cdot\vec{k}_T}{M}\, x\, f_1 D_1 + \ldots \right]$$

...neglecting interaction dependent terms....

(Implicit sum over quark flavours)

Cahn and Boer-Mulders effects

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

CAHN EFFECT

$$F_{UU}^{\cos\phi} = \frac{2M}{Q} C\left[-\frac{\hat{h}\cdot\vec{p}_T}{M_h}\, x\, h_1^{\perp} H_1^{\perp} - \frac{\hat{h}\cdot\vec{k}_T}{M}\, x\, f_1 D_1 + \ldots \right]$$

Cahn and Boer-Mulders effects

BOER-MULDERS EFFECT

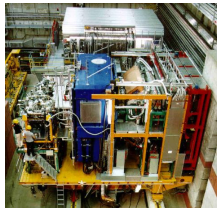
$$F_{UU}^{\cos 2\phi} = C\left[-\frac{2(\hat{h}\cdot\vec{k}_T)(\hat{h}\cdot\vec{p}_T)-\vec{k}_T\cdot\vec{p}_T}{MM_h}\,h_1^{\perp}H_1^{\perp}\right]$$

CAHN EFFECT

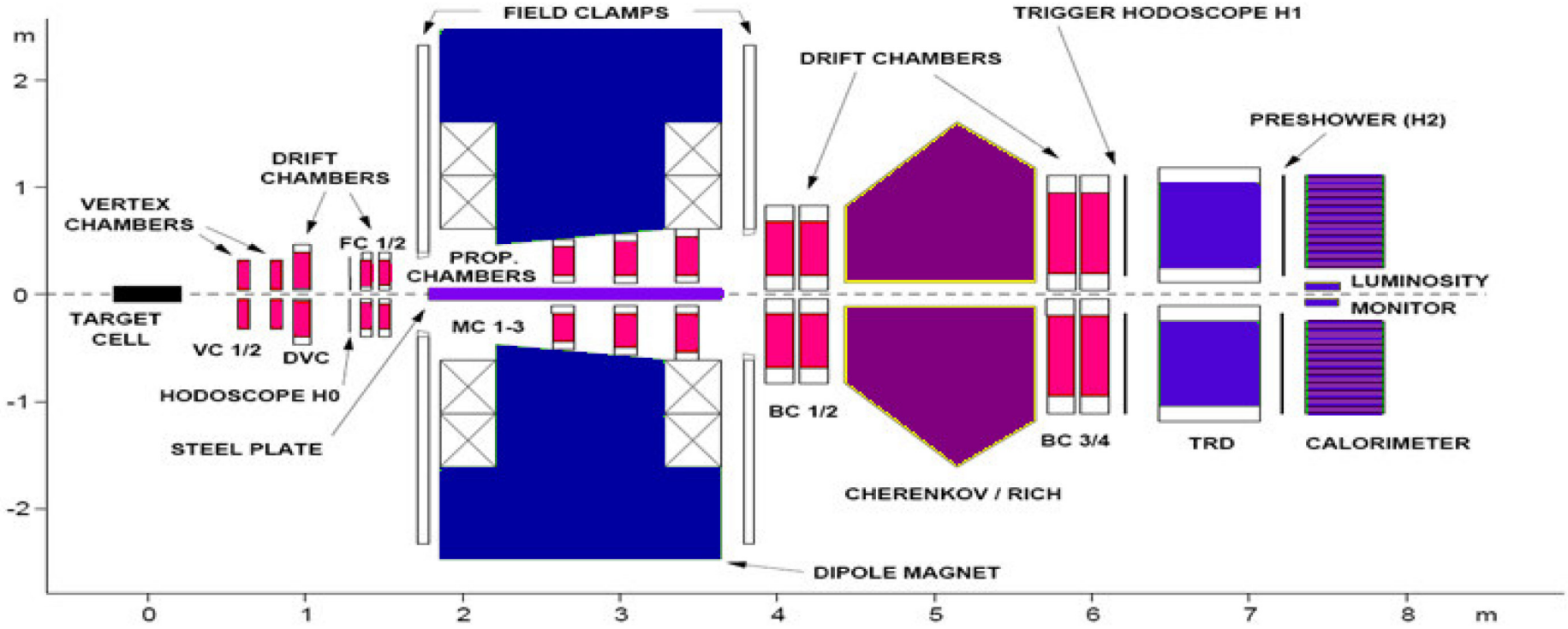
$$F_{UU}^{\cos\phi} = \frac{2M}{Q}C\left[-\frac{\hat{h}\cdot\vec{p}_T}{M_h}\,x\,h_1^{\perp}H_1^{\perp}-\frac{\hat{h}\cdot\vec{k}_T}{M}\,x\,f_1D_1+\ldots\right]$$

HERa **ME**asurement of **S**pin

HERA storage ring @ DESY

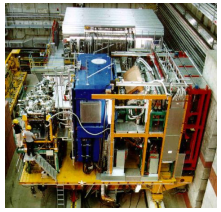


HERMES spectrometer

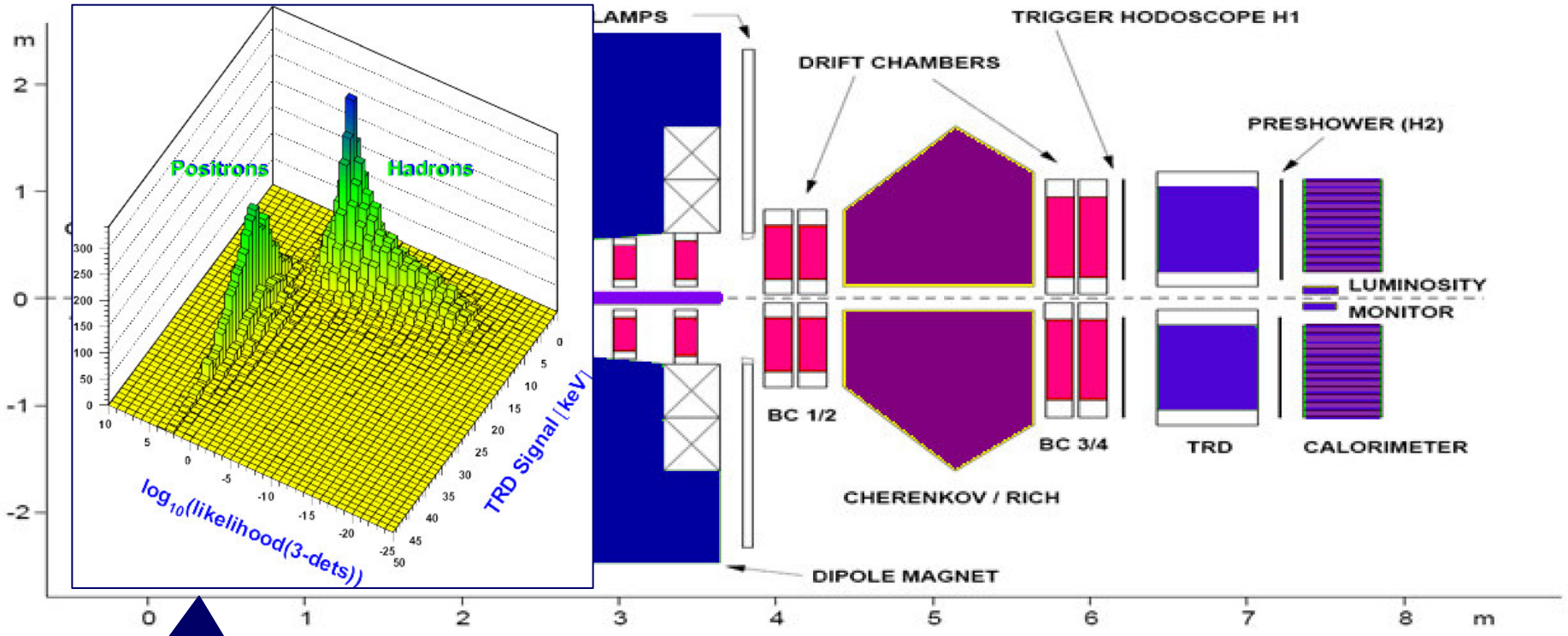


Resolution: $\Delta p/p \sim$ 1-2% $\Delta\theta <\sim$0.6 mrad

Electron-hadron separation efficiency ~ 98-99%



HERMES spectrometer



Resolution: $\Delta p/p \sim 1\text{-}2\%$ $\Delta\theta <\sim 0.6$ mrad

Electron-hadron separation efficiency ~ 98-99%

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

Experimental extraction

$$n^{EXP}=\int \sigma_0(\omega)L(1+A(\omega)\cos\phi+B(\omega)\cos 2\phi)\; d\omega$$

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

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

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

Experimental extraction

$$n^{EXP} = \int \sigma_0(\omega) L (1 + A(\omega)\cos\phi + B(\omega)\cos 2\phi\ ) \varepsilon_{acc}(\omega,\phi)\varepsilon_{RAD}(\omega,\phi)\ d\omega$$

Experimental extraction

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

$$n^{EXP} = \int \sigma_0(\omega) L (1 + A(\omega)\cos\phi + B(\omega)\cos 2\phi)\, \varepsilon_{acc}(\omega,\phi)\varepsilon_{RAD}(\omega,\phi)\, d\omega$$

unfolding procedure

Experimental extraction

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

$$n^{EXP} = \int \sigma_0(\omega) L (1 + A(\omega)\cos\phi + B(\omega)\cos 2\phi)\, \varepsilon_{acc}(\omega,\phi)\varepsilon_{RAD}(\omega,\phi)\, d\omega$$

Multidimensional (ω) unfolding procedure

The unfolding procedure

$$n_{EXP} = S_{MC} n_{BORN} + Bg_{MC}$$

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

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Accounts for acceptance, radiative and smearing effects

depends only on instrumental and radiative effects

The unfolding procedure

$$n_{EXP} = S_{MC}\, n_{BORN} + B g_{MC}$$

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

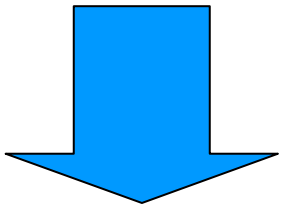
Accounts for acceptance, radiative and smearing effects

depends only on instrumental and radiative effects

Includes the events smeared within kinematic cuts

The unfolding procedure

$$n_{EXP} = S_{MC} n_{BORN} + Bg_{MC}$$



$$n_{BORN} = S_{MC}^{-1}\left[\ n_{EXP} - Bg_{MC}\ \right]$$

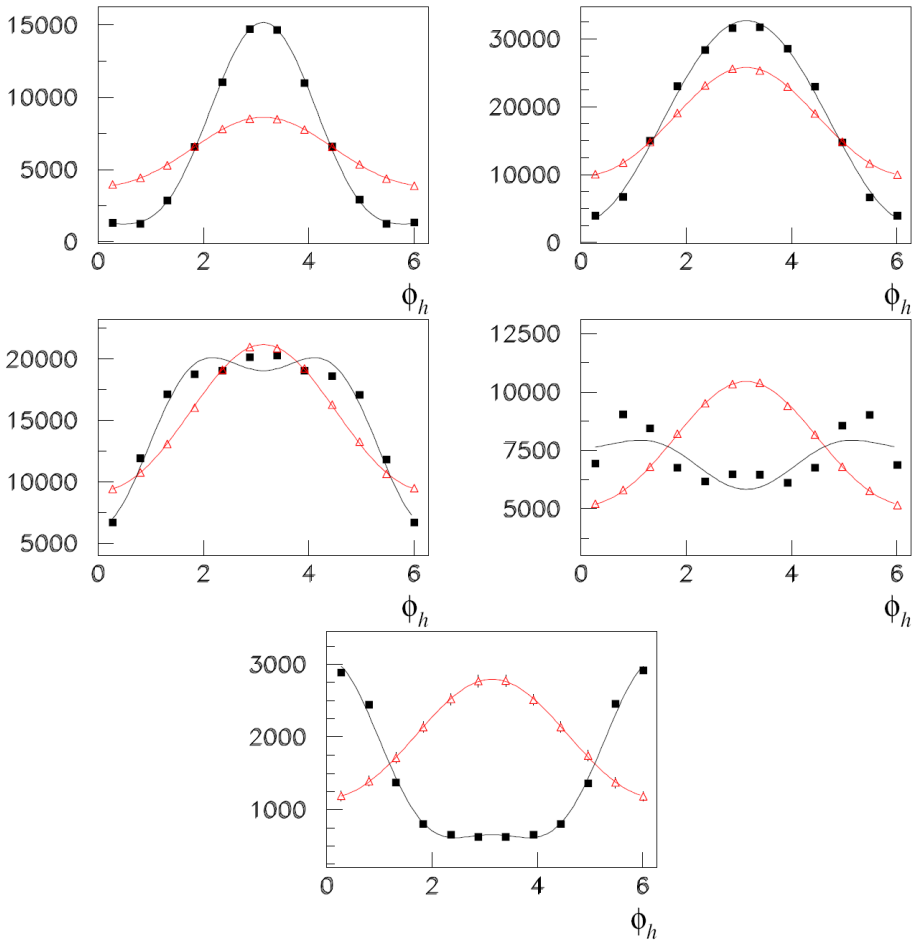
Why a multidimensional analysis?

$$n^{MC+CAHN} = \int \sigma_0(\omega) L (1 + A(\omega)\cos\phi + B(\omega)\cos 2\phi)\, \varepsilon_{acc}(\omega,\phi)\varepsilon_{RAD}(\omega,\phi)\, d\omega$$

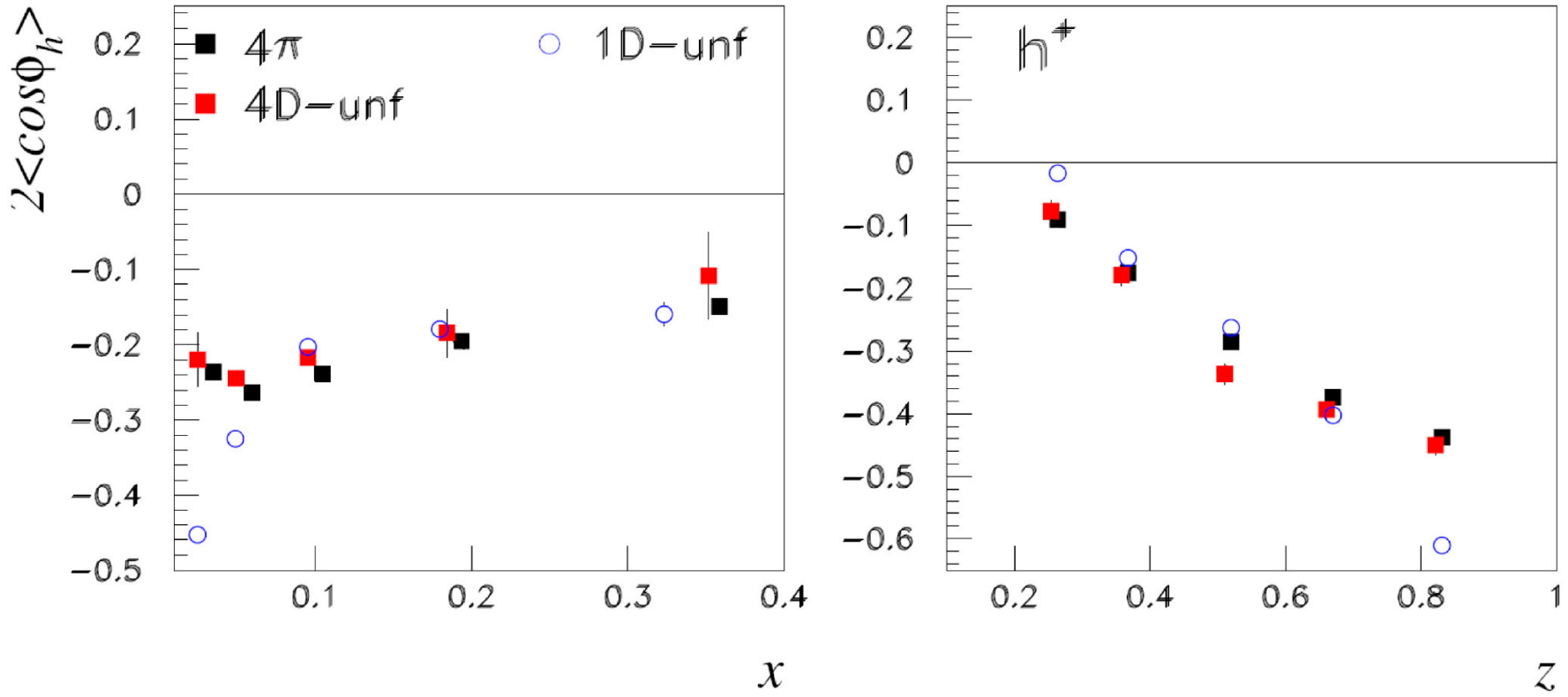
Monte Carlo + Cahn model

Generated in 4π

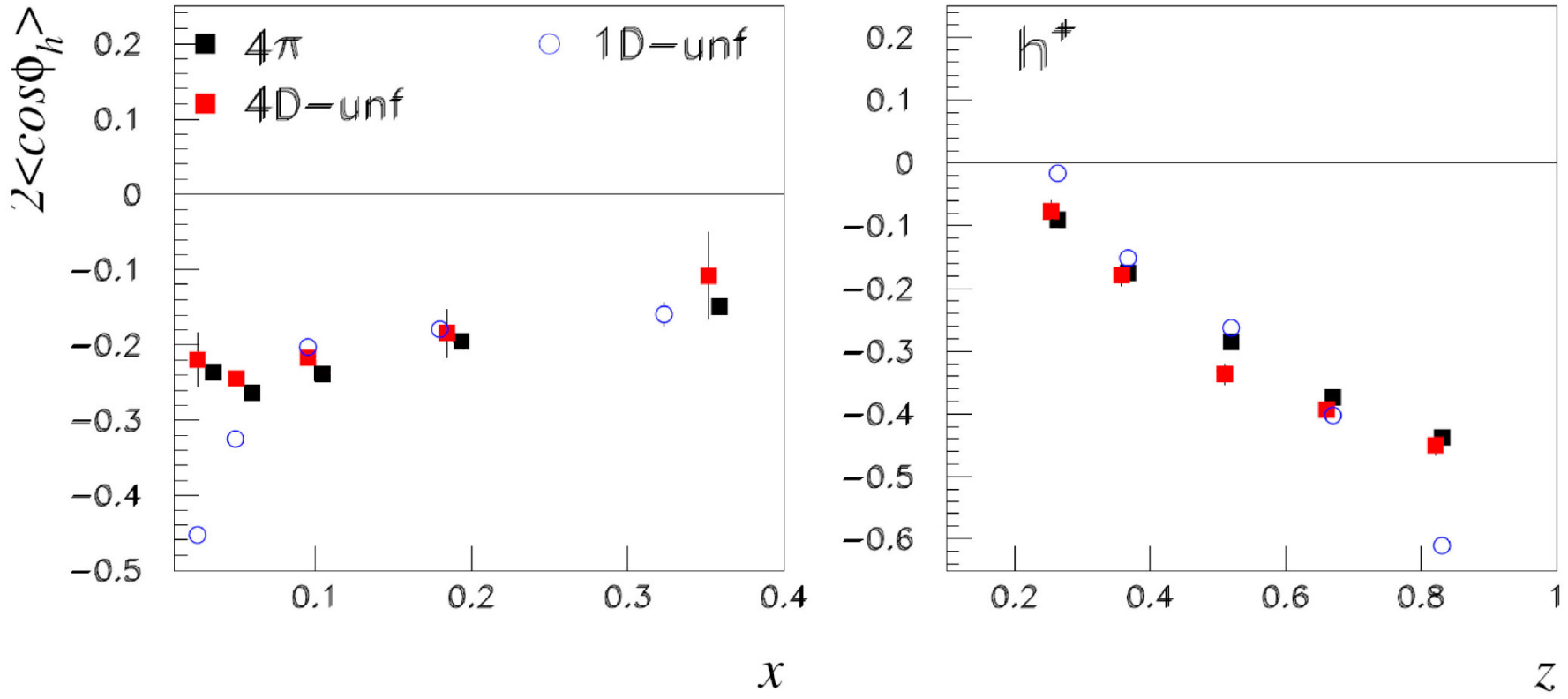
Measured inside acceptance



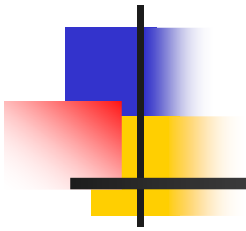
Monte Carlo Test



Monte Carlo Test

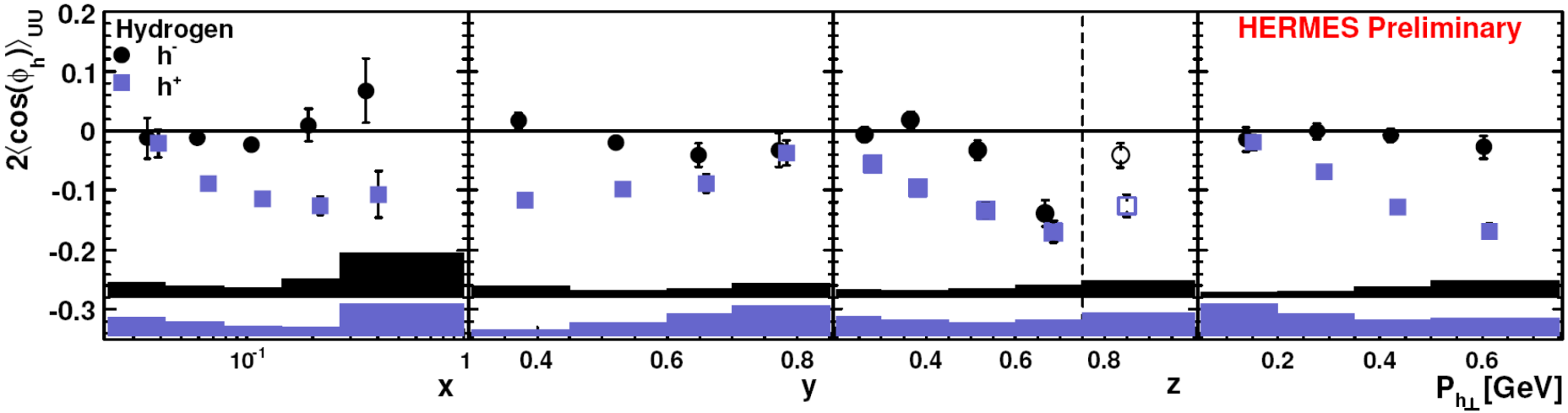


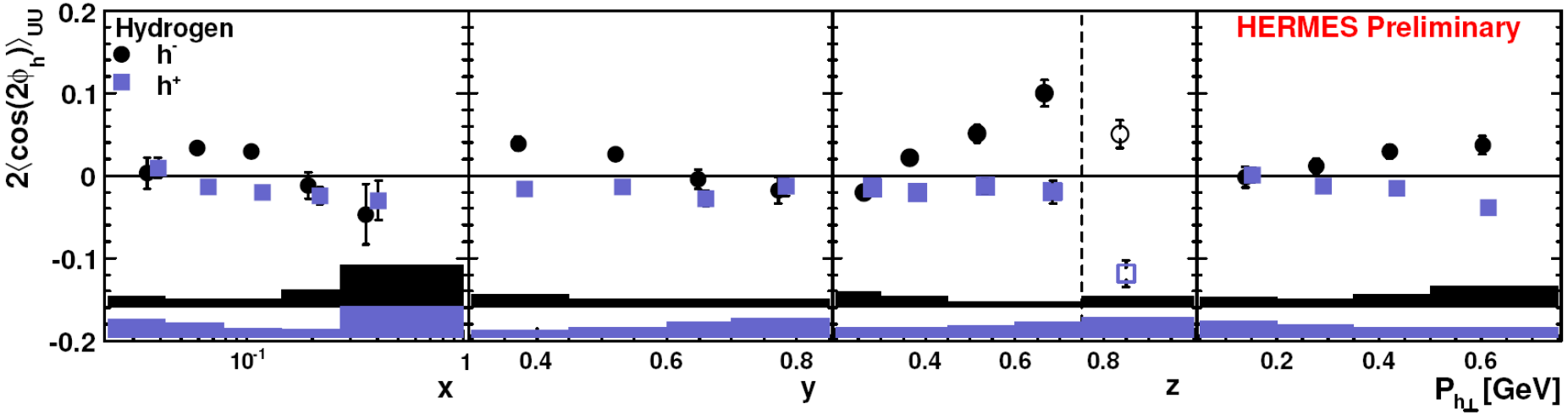
4D ⇒ **binned in** $(x, y, z, P_{h\perp})$



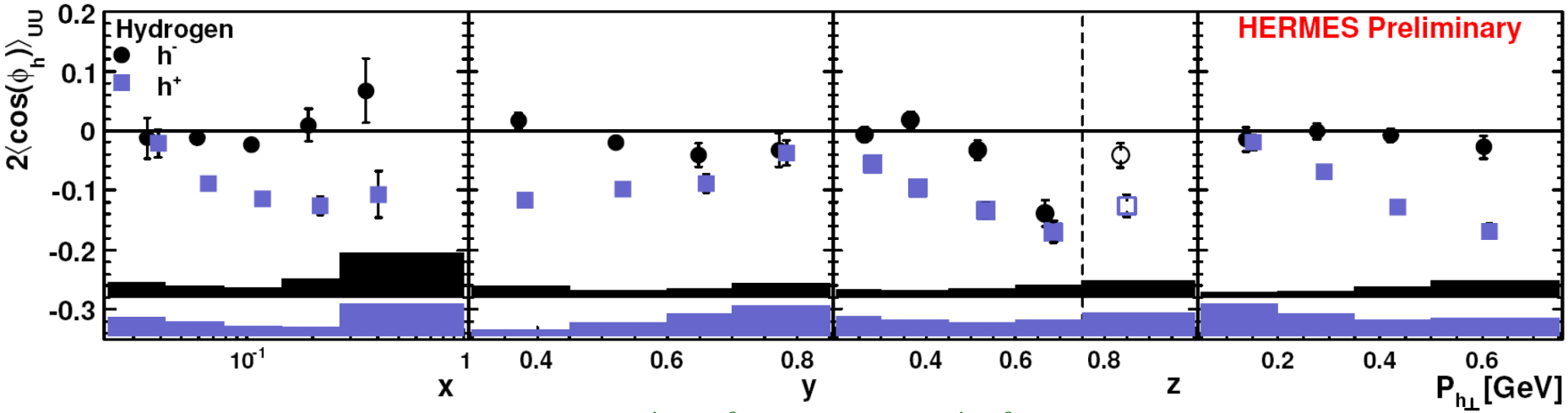
Results

Hydrogen target

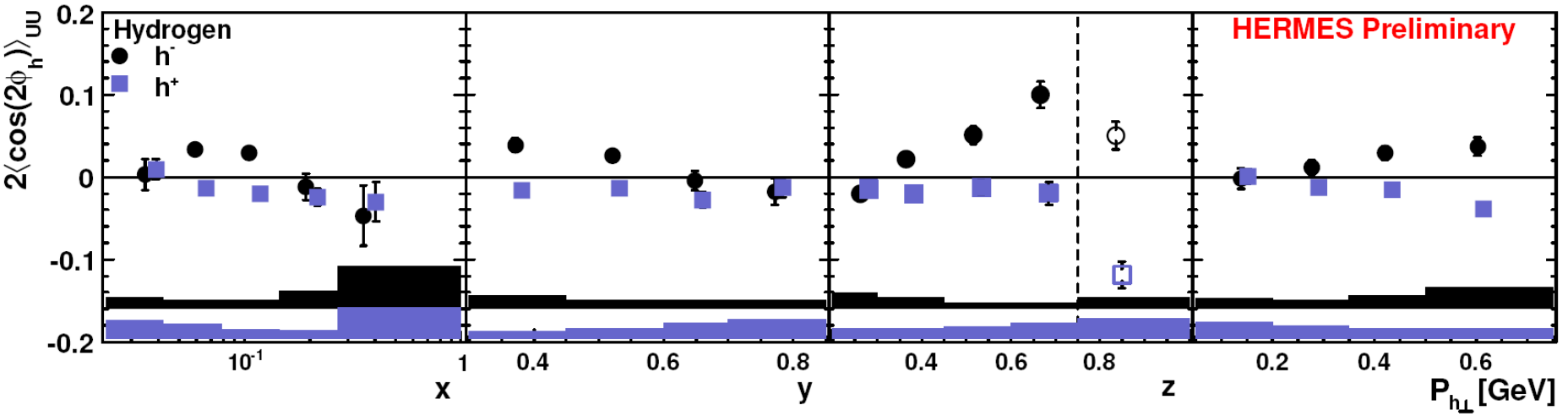




Hydrogen target



$$H_{1,u\to\pi^-}^{\perp,unf} \approx -H_{1,u\to\pi^+}^{\perp,fav}$$



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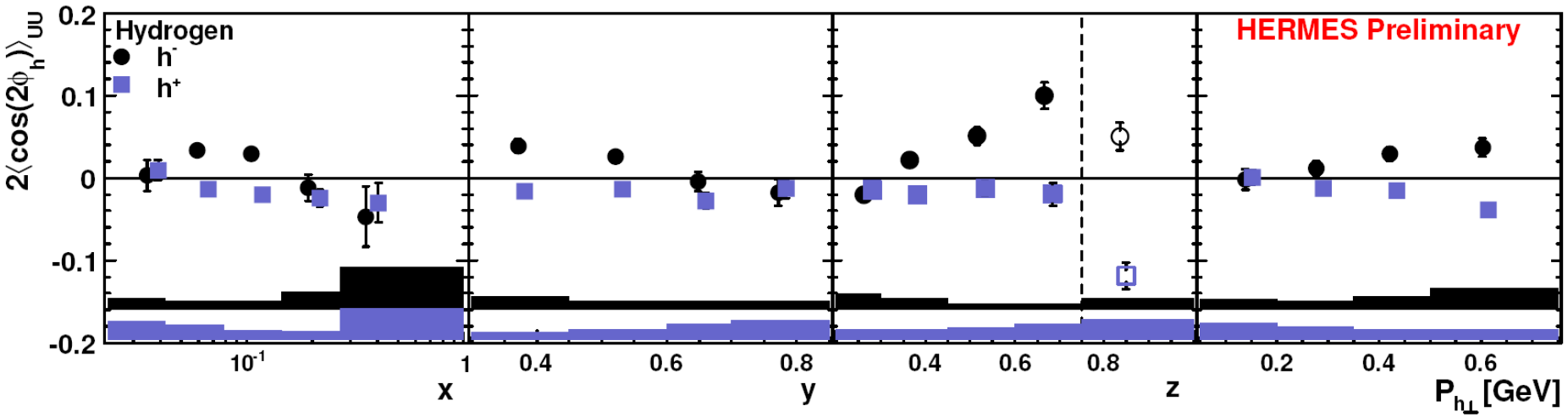
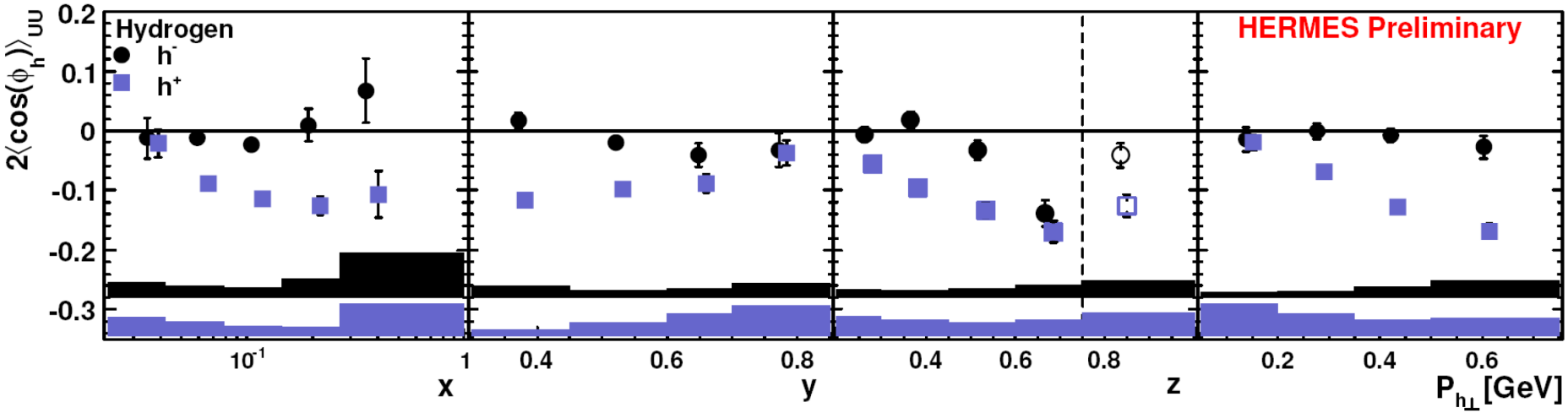


Hydrogen target



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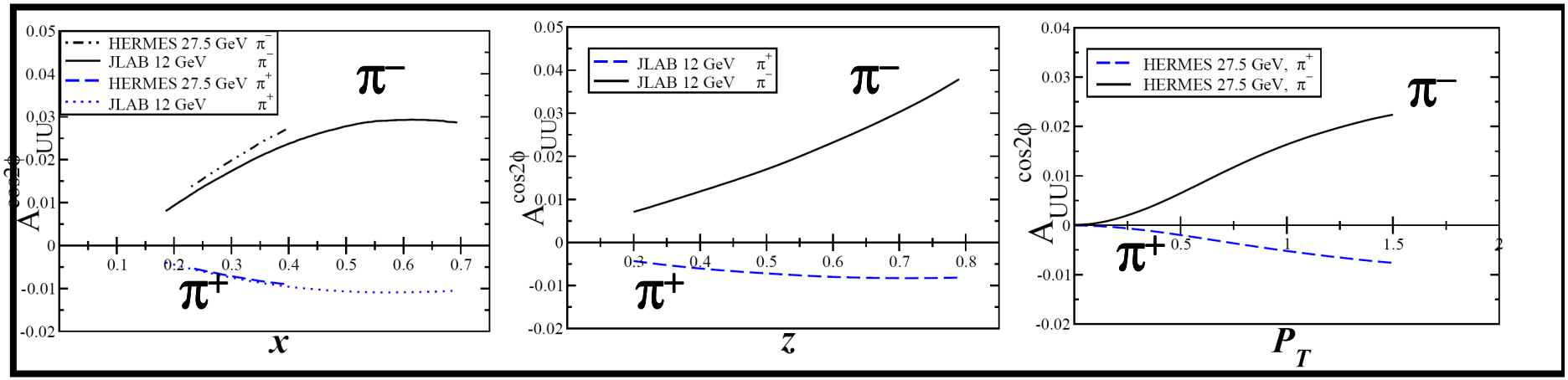
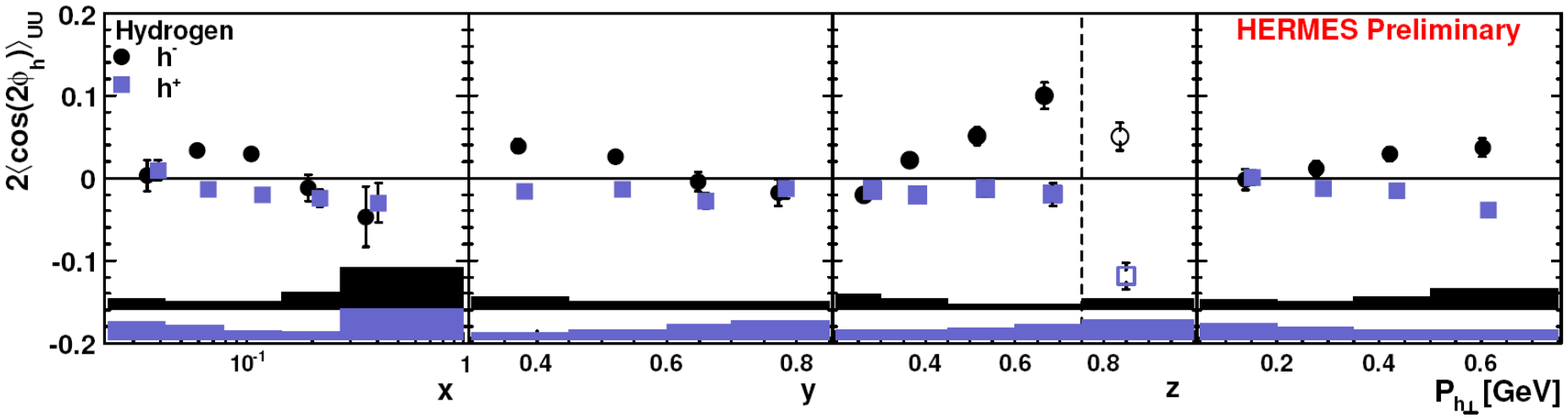
cos2ϕ interpretation



L. P. Gamberg et al., Phys. Rev. D67:071504, 2003
L. P. Gamberg and G. R. Goldstein, arXiv:0708.0324, 2007



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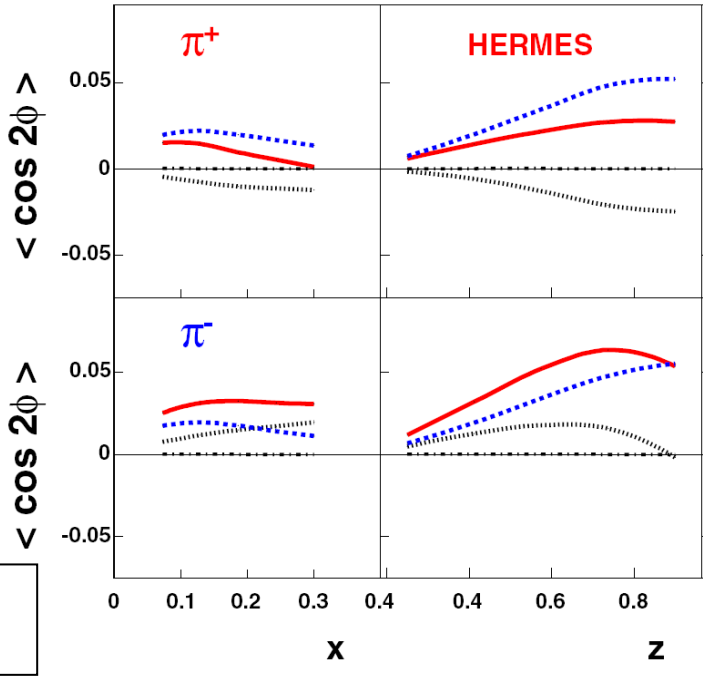
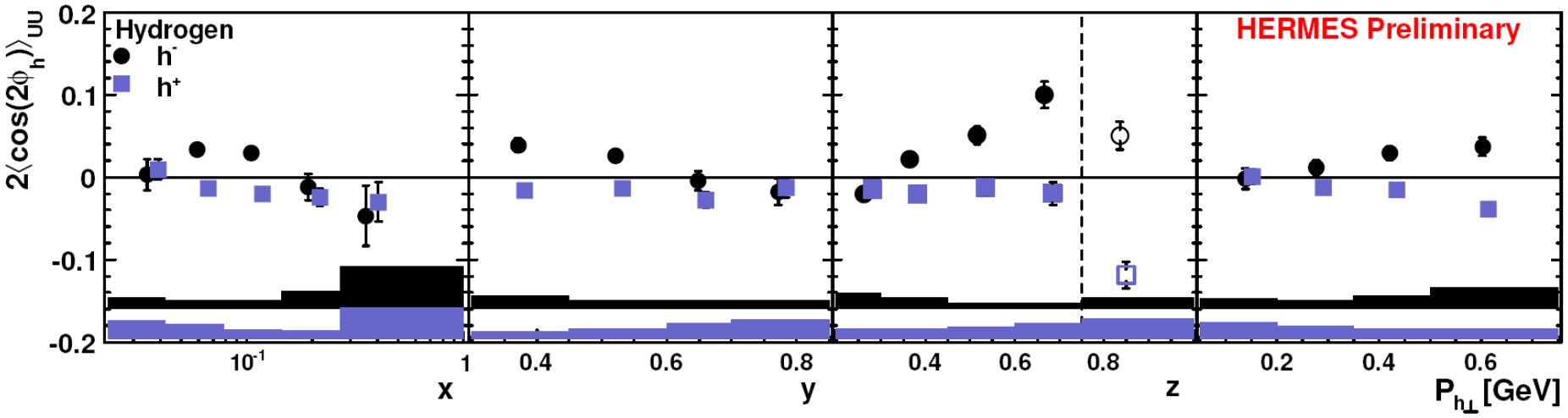


All contributions

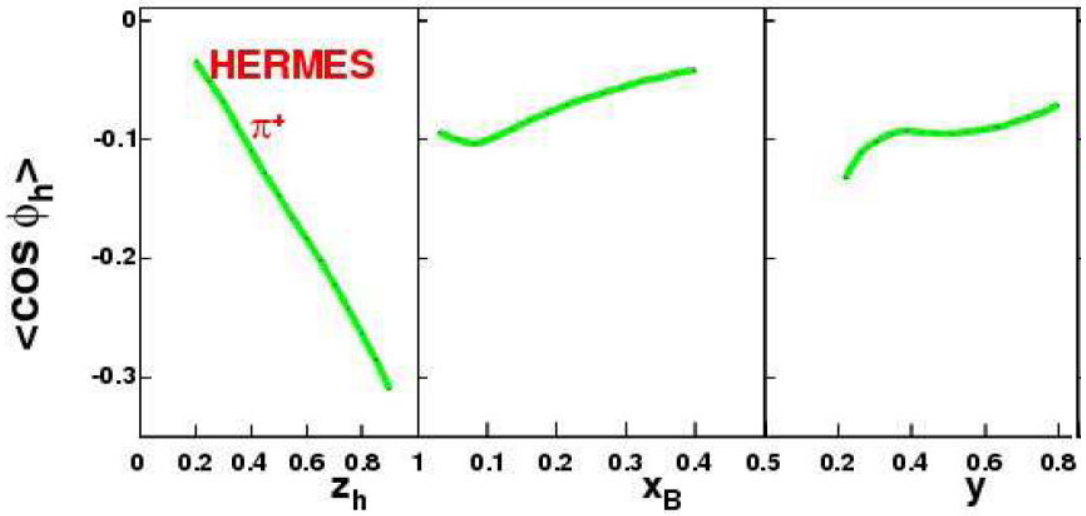
Boer-Mulders

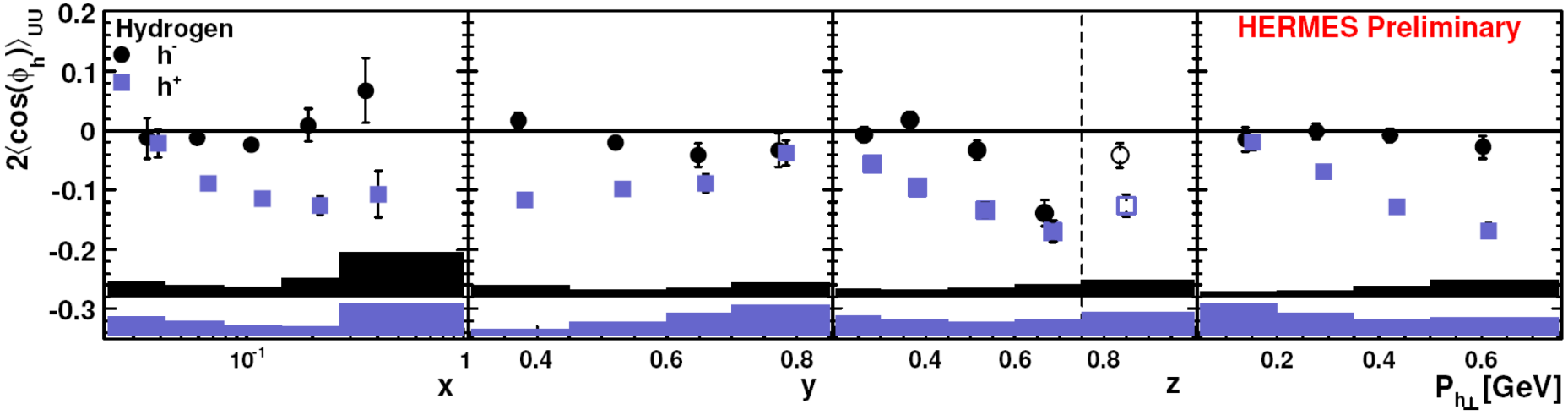
Cahn (twist 4)

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



cosϕ interpretation

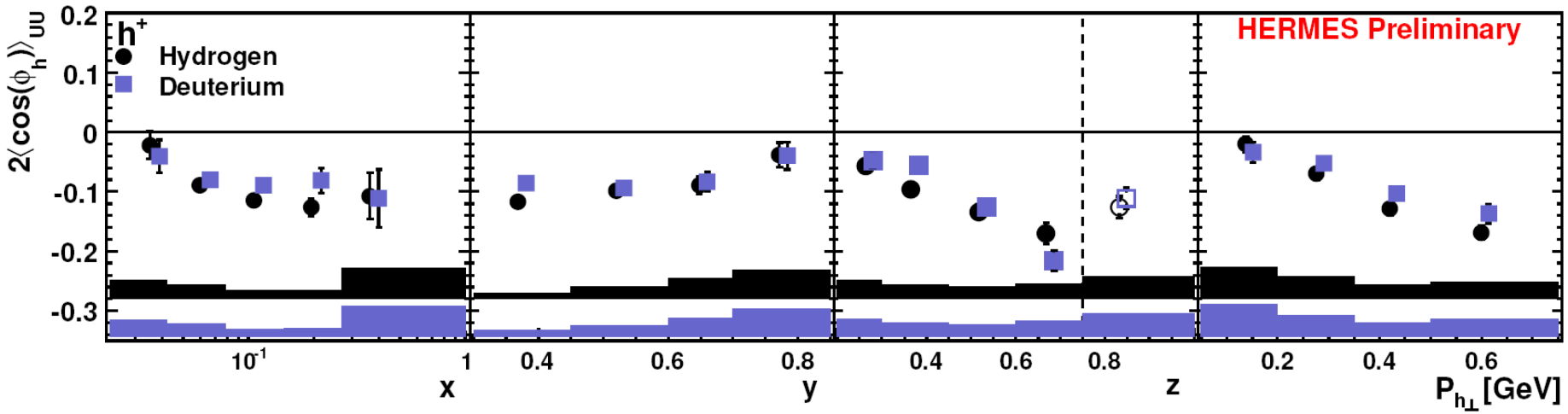


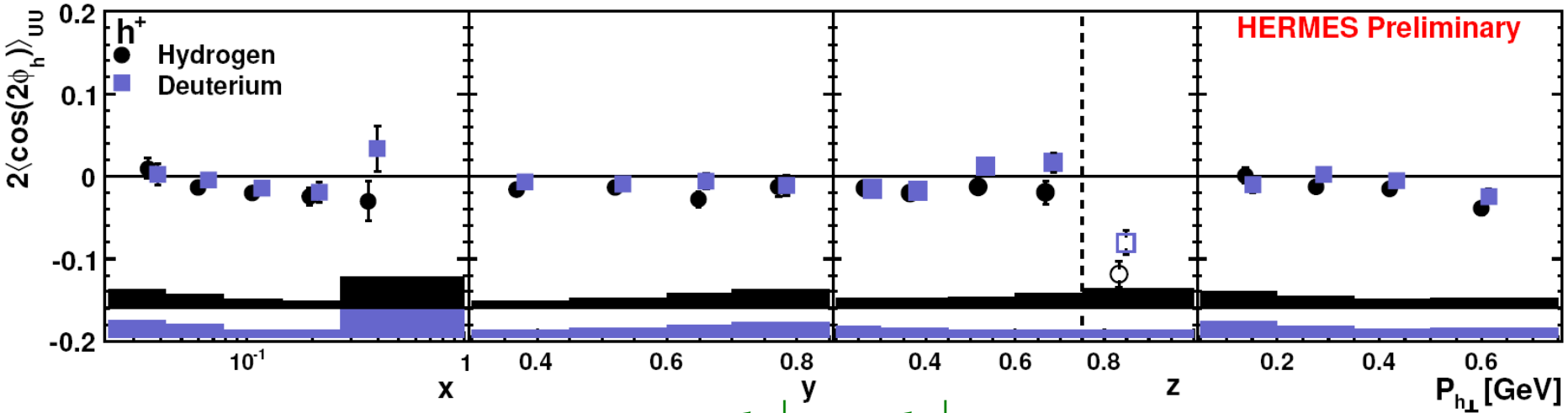


M. Anselmino et al., Phys. Rev. D71:074006, 2005
M.Anselmino et al., Eur. Phys. J. A31:373, 2007

Hydrogen VS. Deuterium

h^+

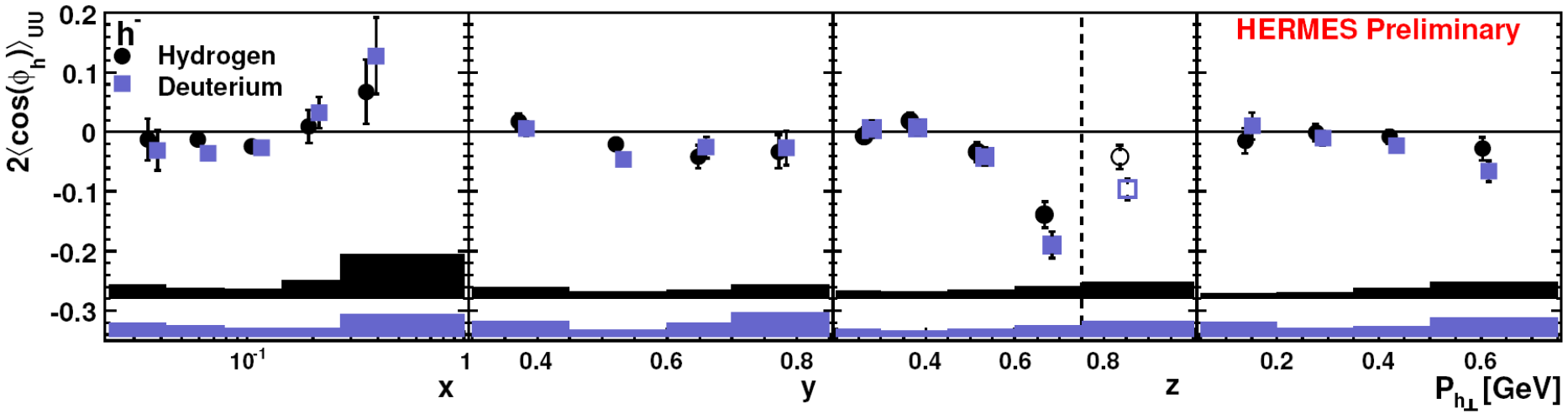


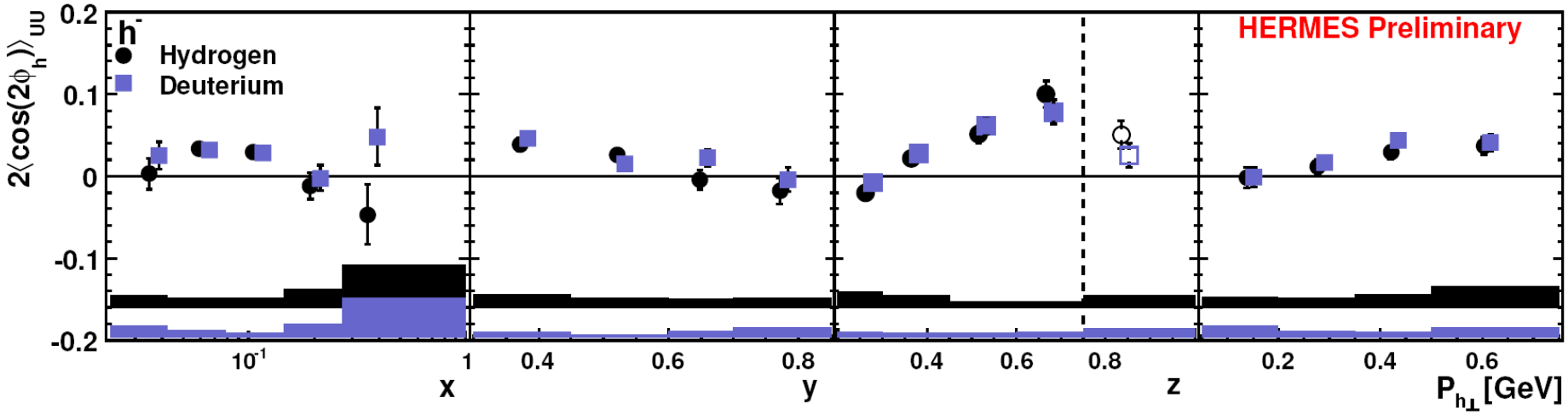


$$h_{1,u}^{\perp} \approx h_{1,d}^{\perp}$$

Hydrogen VS. Deuterium

h^-





$$h_{1,u}^{\perp} \approx h_{1,d}^{\perp}$$

Summary

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

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    - Evidence of a non-zero Boer-Mulders function

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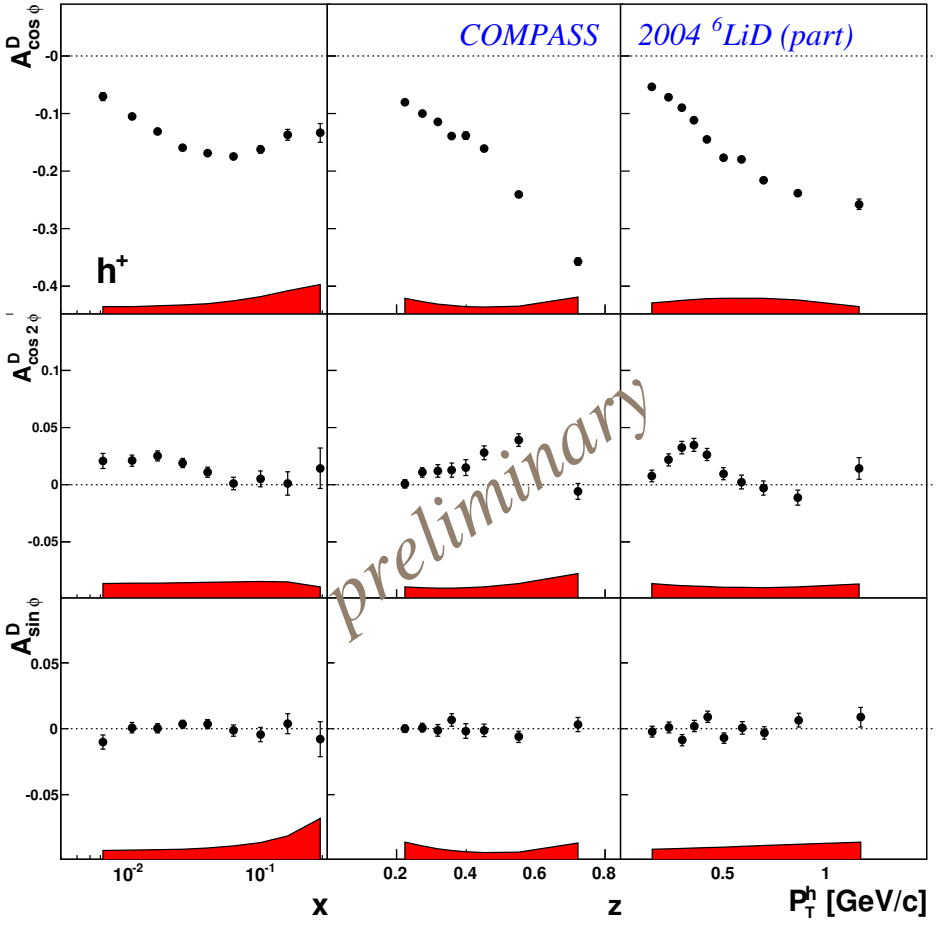
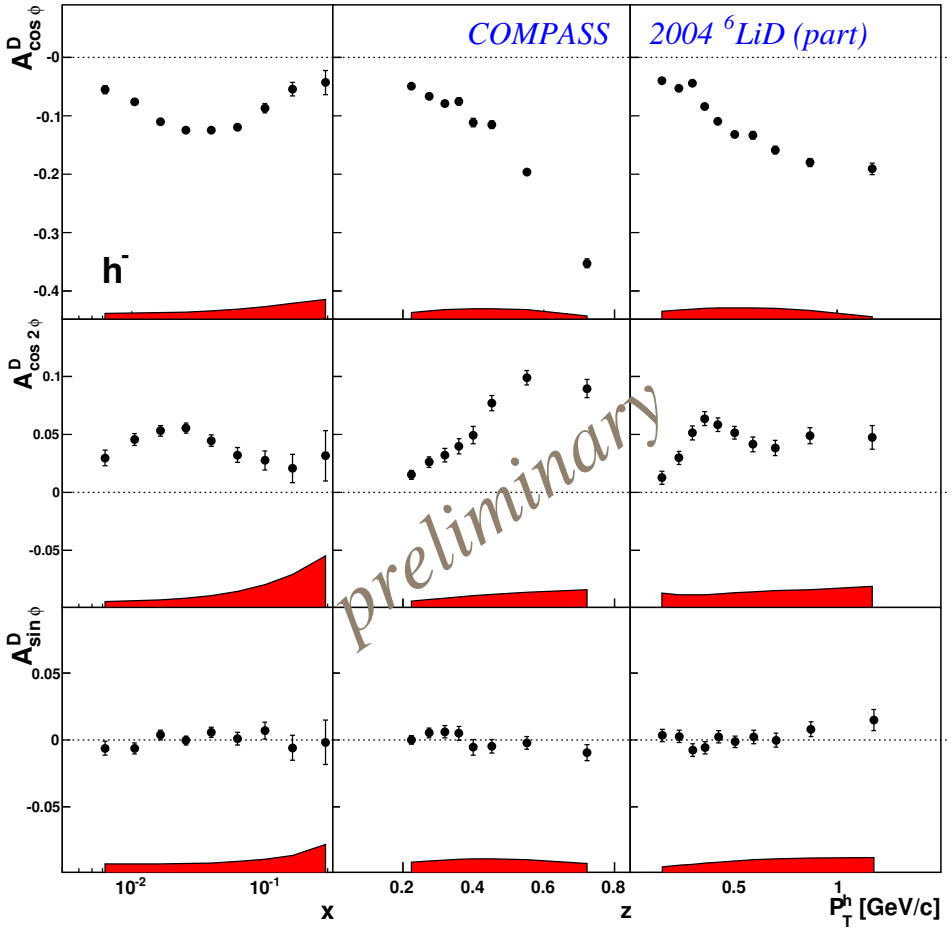
THANK YOU!

Compass results

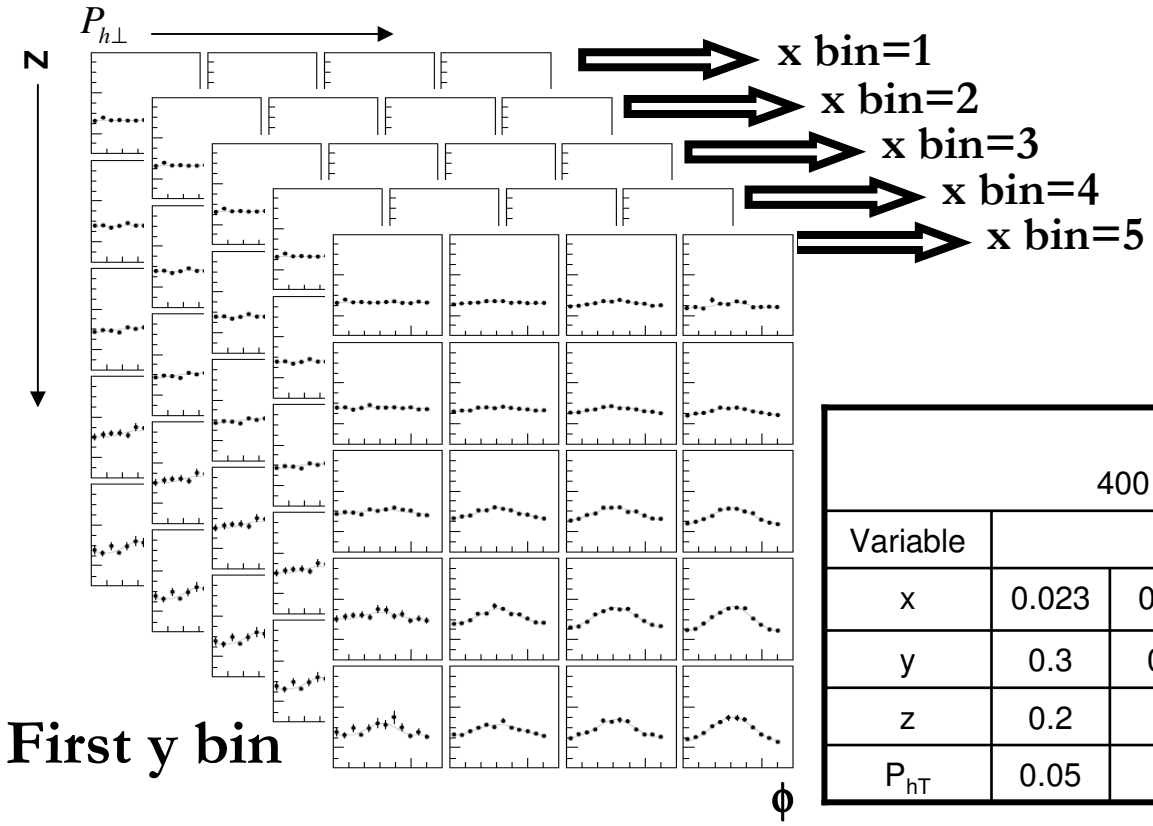




Statistics

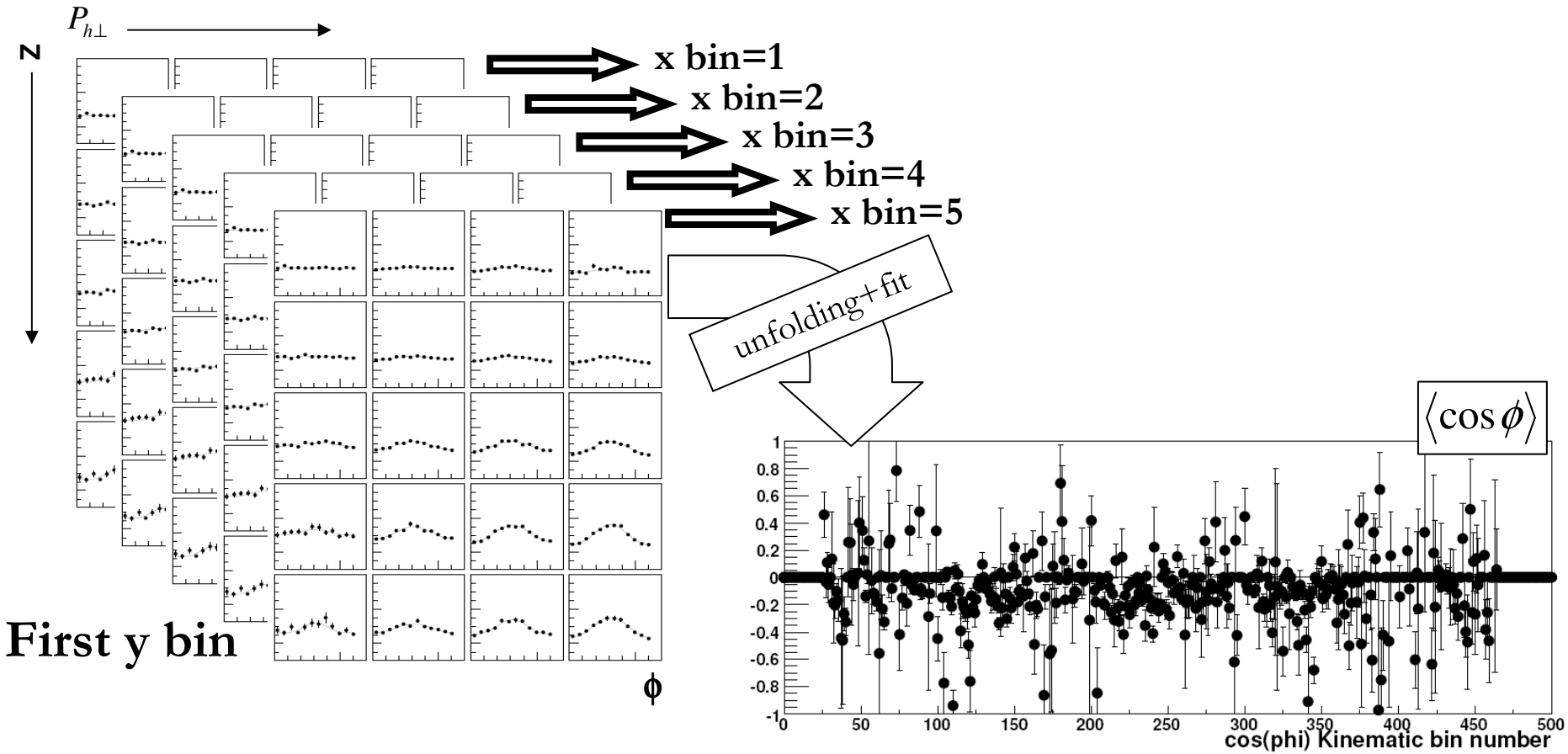
Target Type	Hadron charge	#SIDIS (Million)
Hydrogen	h^+	1.46
	h^-	0.82
Deuterium	h^+	1.53
	h^-	1.00

The multi-dimensional analysis

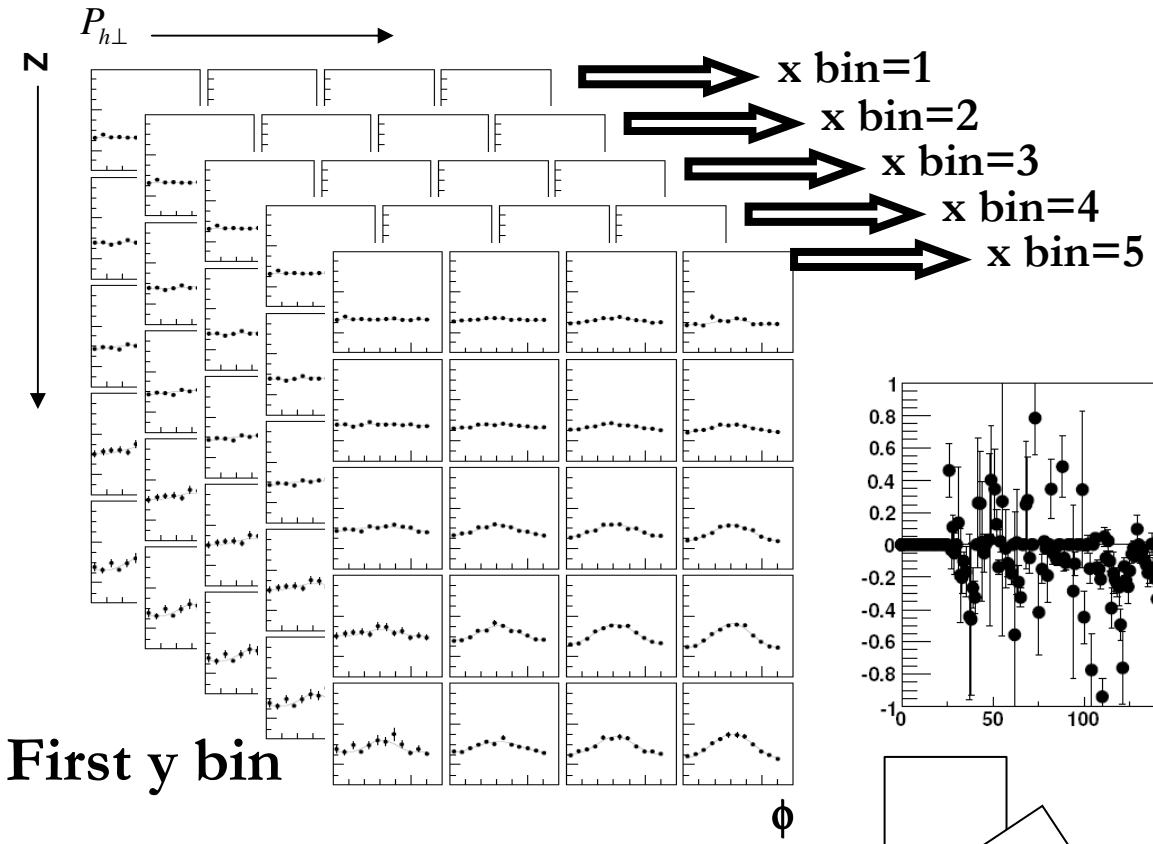


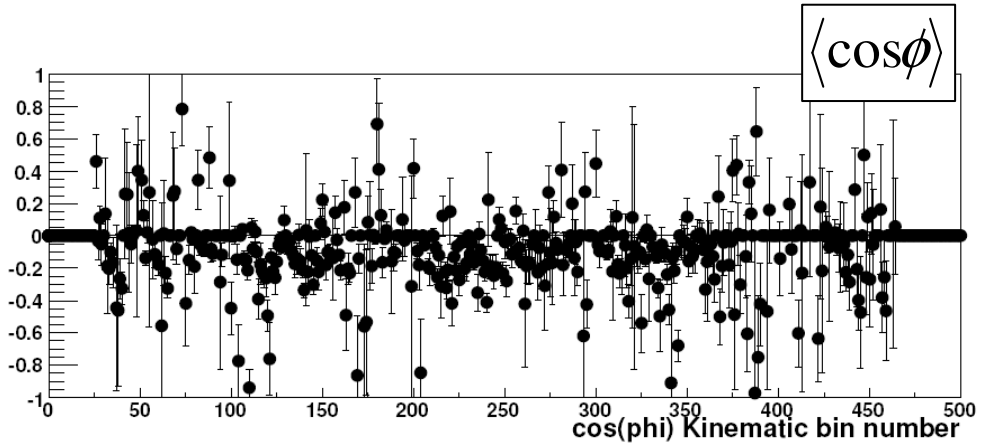
BINNING 400 kinematical bins x 12 ϕ-bins							
Variable	Bin limits						#
x	0.023	0.042	0.078	0.145	0.27	1	5
y	0.3	0.45	0.6	0.7	0.85		4
z	0.2	0.3	0.45	0.6	0.75	1	5
P_{hT}	0.05	0.2	0.35	0.5	0.75		4

The multi-dimensional analysis



The multi-dimensional analysis

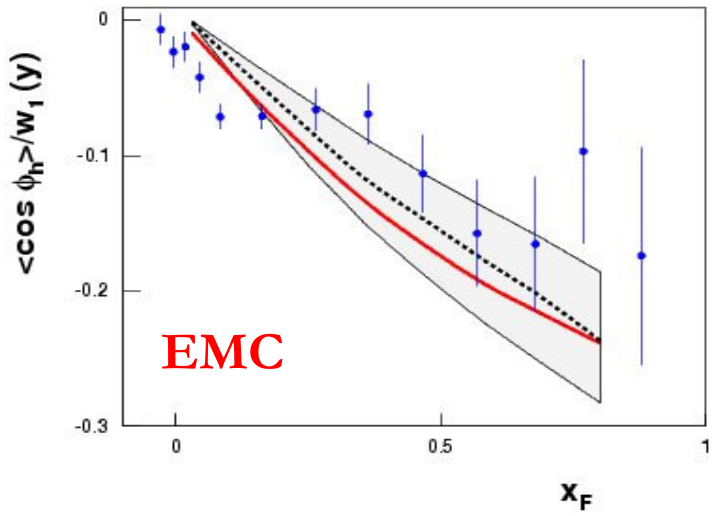


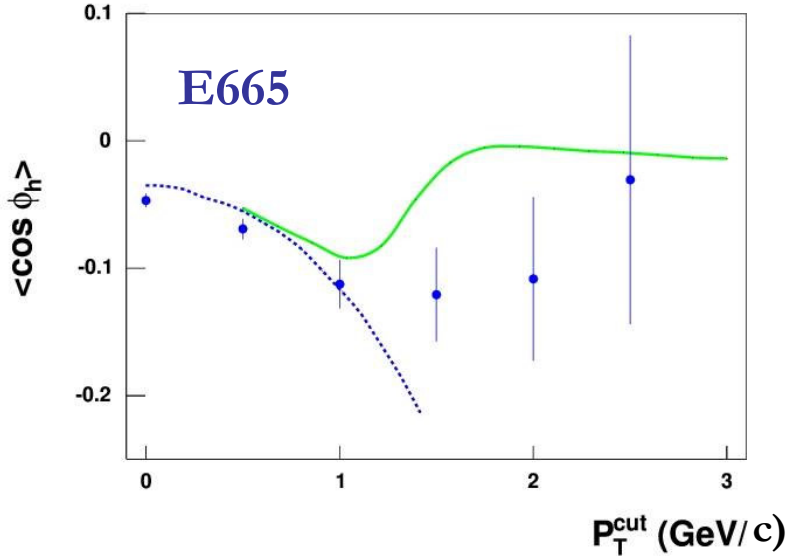


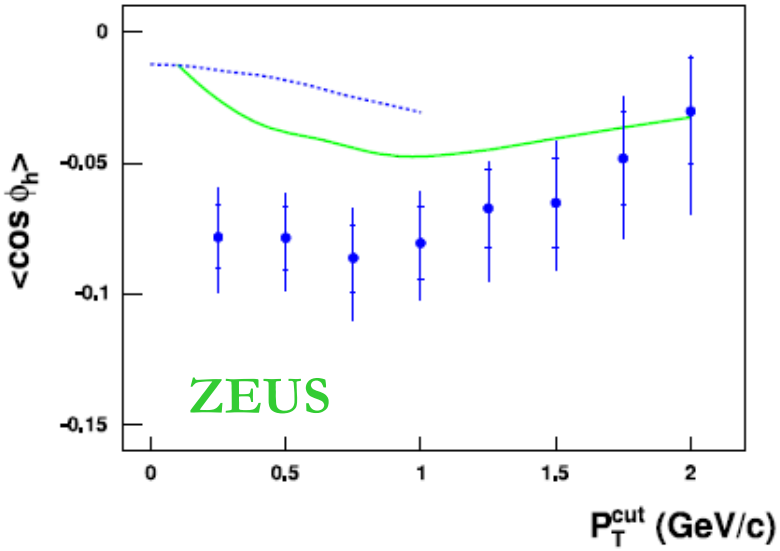
projection

$$\langle\cos\phi\rangle(x_b) = \frac{\sum \sigma^{4\pi}(\omega_{x_{i=}x_b})\langle\cos\phi\rangle_{x_{i=}x_b}}{\sum \sigma^{4\pi}(\omega_{x_{i=}x_b})}$$

Experimental status: $\langle \cos\phi \rangle$

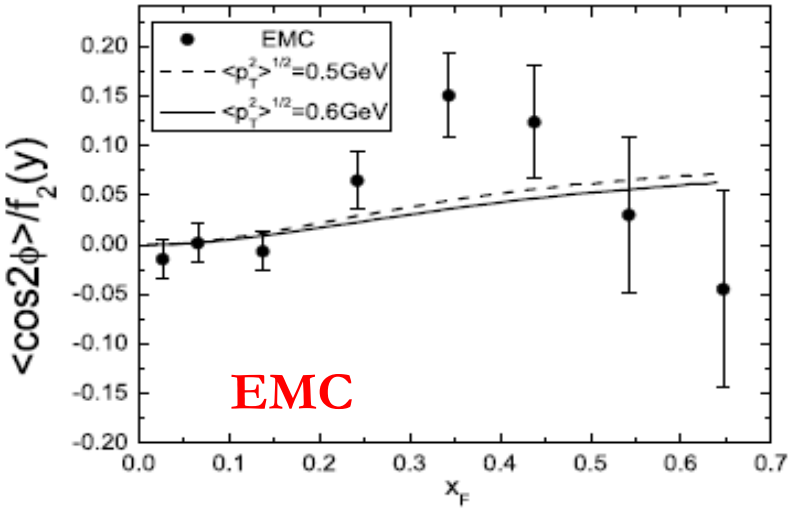


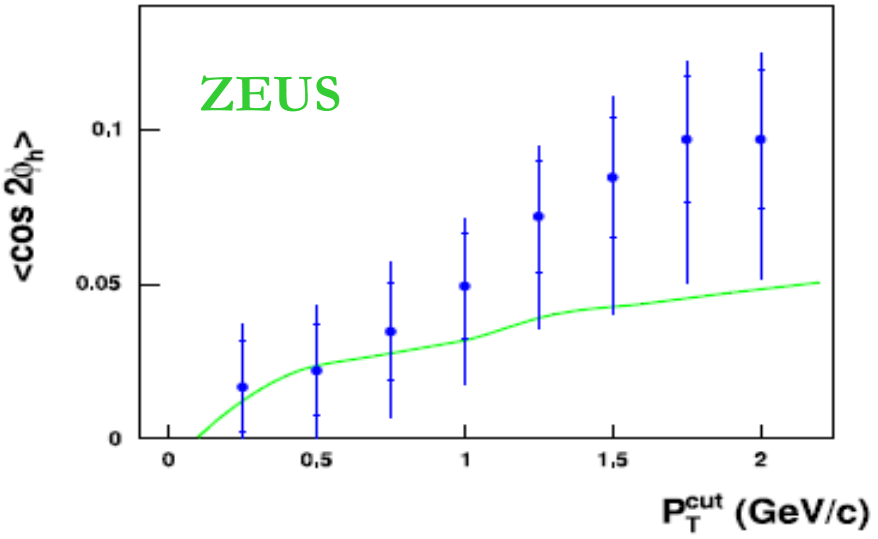




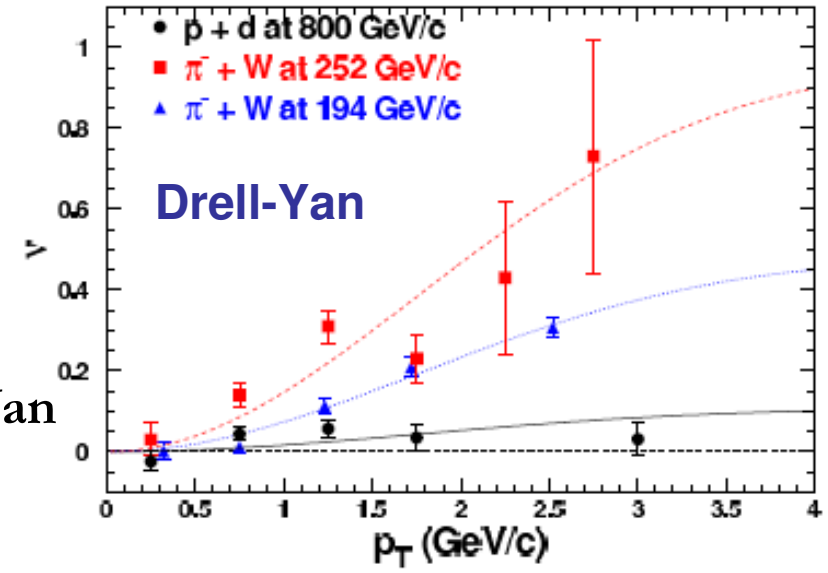
- **Negative results in all the existing measurements**
- **No distinction between hadron type or charge**

Experimental status: $\langle \cos 2\phi \rangle$

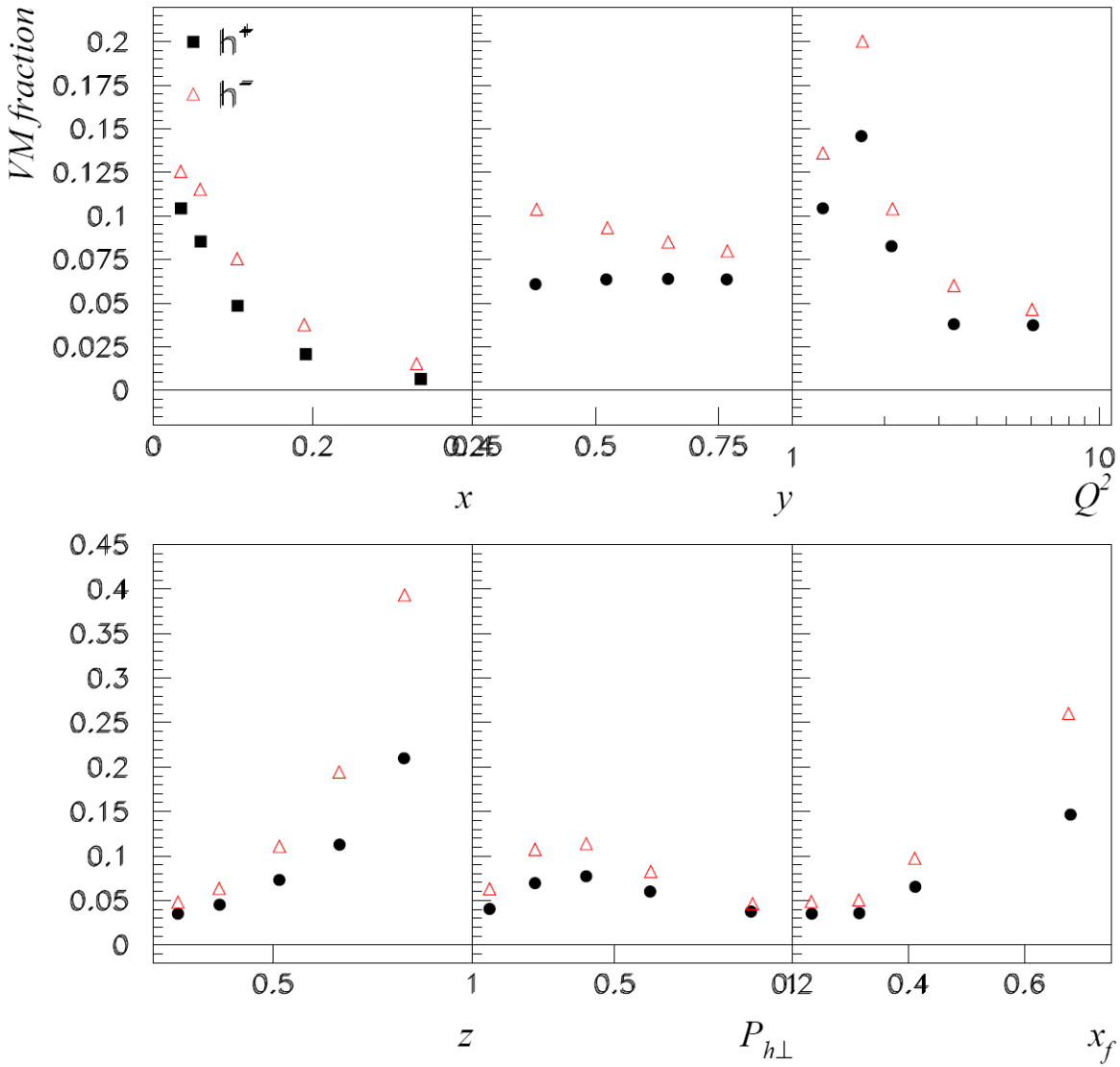




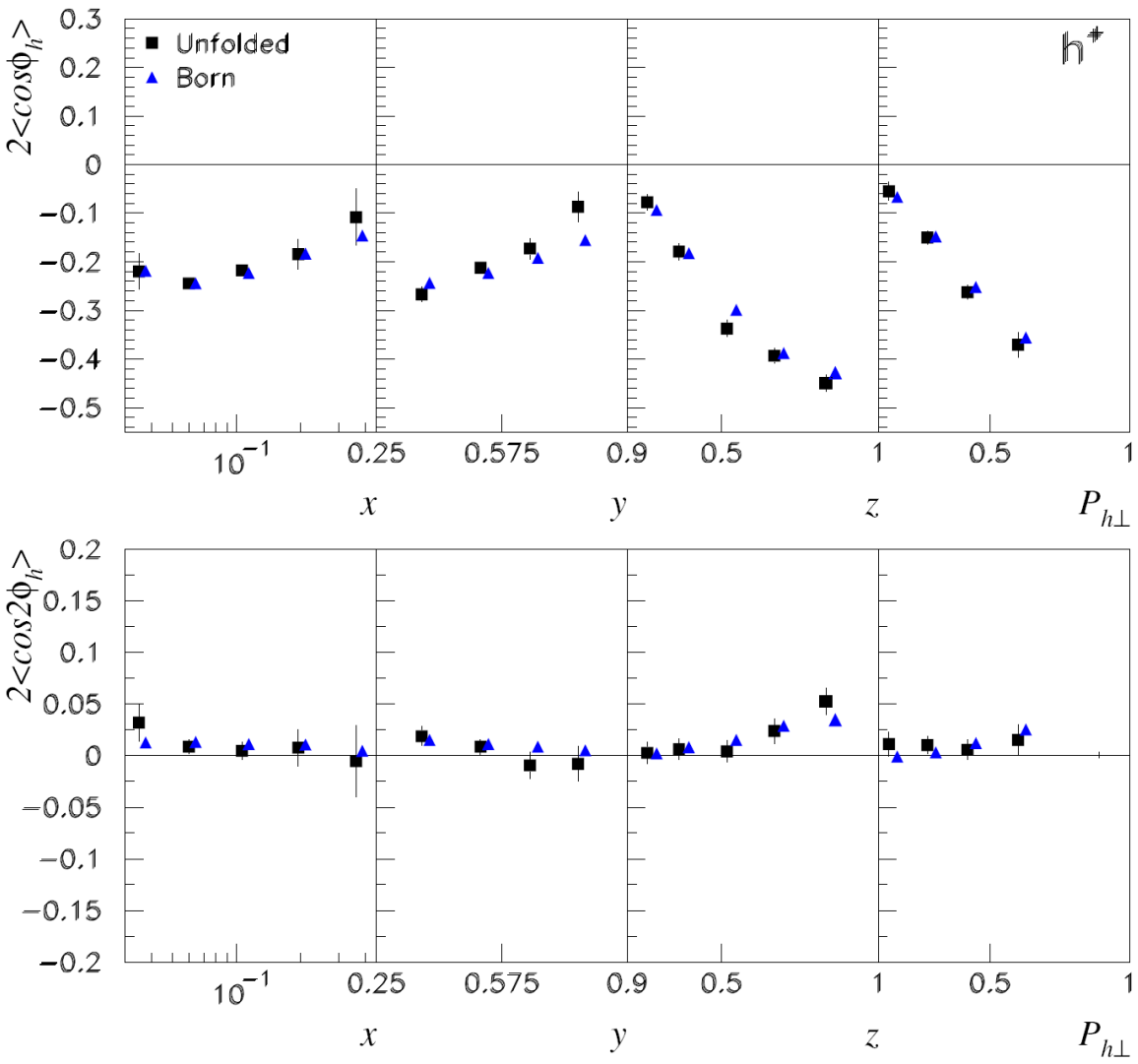
- Positive results in all the existing measurements
- No distinction between hadron type or charge (in SIDIS experiments)
- Indication of small Boer-Mulders function for the sea quark (from Drell-Yan experiments)



Vector meson dilution



Monte Carlo Test



Cahn Model

Unfolded