Recent Measurements of the $\cos(n\phi_h)$ Azimuthal Modulations of the Unpolarized Deep Inelastic Scattering Cross-section at hermes

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University of Illinois
on behalf of the HERMES collaboration

Theory & Experimental Introduction
Procedure
$\cos(\phi_h)$ Results & Model
$\cos(2\phi_h)$ Results & 3 Models

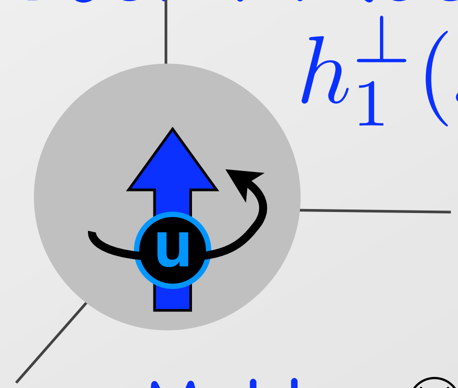
Spin, orbital motion, quarks, and protons

Cahn $f(x)D(z)$

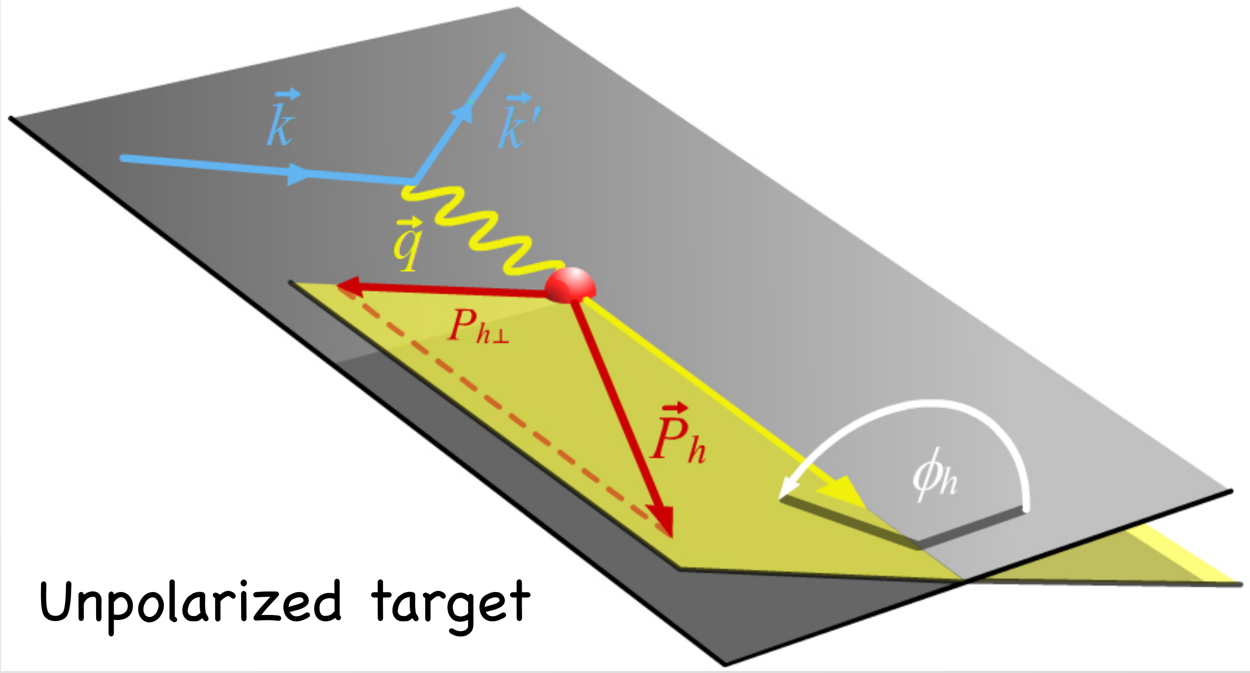
- Kinematic effect
- Known since EMC
- Sensitive to <k_T>

Cahn => $\cos(\phi_h)$

Boer-Mulders $h_1^{\perp}(x, k_T)$



Boer-Mulders⊗Collins => $\cos(2\phi_h)$



The LO, subleading twist (3) unpolarized SIDIS cross section

$$\frac{d\sigma}{dx\;dy\;dz\;dP_{h\perp}^2\;d\phi_h} =$$

$$2\pi\frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)\left[F_{UU,T}+\sqrt{2\epsilon(1+\epsilon)}\cos\phi_h F_{UU}^{\cos\phi_h}+\epsilon\cos(2\phi_h)F_{UU}^{\cos(2\phi_h)}\right]$$

$$F_{UU,T} \quad = \quad \mathcal{C}[f_1 D_1]$$

$$F_{UU}^{\cos\phi_h} \quad = \quad \frac{2M}{Q}\mathcal{C}\left[-\frac{\hat{\mathbf{P}}_{\mathbf{h}\perp}\cdot\mathbf{k}_T}{M_h}\frac{p_T^2}{M^2}h_1^\perp H_1^\perp - \frac{\hat{\mathbf{P}}_{\mathbf{h}\perp}\cdot\mathbf{p}_T}{M}f_1 D_1 + ...\right]$$

$$F_{UU}^{\cos(2\phi_h)} \quad = \quad \mathcal{C}\left[-\frac{2(\hat{\mathbf{P}}_{\mathbf{h}\perp}\cdot\mathbf{k}_T)(\hat{\mathbf{P}}_{\mathbf{h}\perp}\cdot\mathbf{p}_T)-\mathbf{k}_T\cdot\mathbf{p}_T}{M M_h}h_1^\perp H_1^\perp\right]$$

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leading twist

Boer-Mulders

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

Boer-Mulders Collins

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subleading twist

Cahn

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Cahn+Boer-Mulders

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subleading twist

leading twist

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interaction dependent terms

Cahn+Boer-Mulders

$$F_{UU}^{\cos\phi_h} = \frac{2M}{Q} \mathcal{C}\left[-\frac{\hat{\mathbf{P}}_{\mathbf{h}\perp} \cdot \mathbf{k}_T}{M_h} \frac{p_T^2}{M^2} h_1^\perp H_1^\perp - \frac{\hat{\mathbf{P}}_{\mathbf{h}\perp} \cdot \mathbf{p}_T}{M} f_1 D_1 + \ldots\right]$$

Cahn

Boer-Mulders

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Boer-Mulders Collins

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Cahn

Boer-Mulders

$$F_{UU}^{\cos(2\phi_h)} = \mathcal{C}\left[-\frac{2(\hat{\mathbf{P}}_{\mathbf{h}\perp} \cdot \mathbf{k}_T)(\hat{\mathbf{P}}_{\mathbf{h}\perp} \cdot \mathbf{p}_T) - \mathbf{k}_T \cdot \mathbf{p}_T}{M M_h} h_1^\perp H_1^\perp\right] + X \frac{1}{Q^2} f_1 D_1$$

twist-4 Cahn

Boer-Mulders Collins

The unpolarized SIDIS cross section

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

$$2\pi\frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)\left[F_{UU,T}+\sqrt{2\epsilon(1+\epsilon)}\cos\phi_h F_{UU}^{\cos\phi_h}+\epsilon\cos(2\phi_h)F_{UU}^{\cos(2\phi_h)}\right]$$

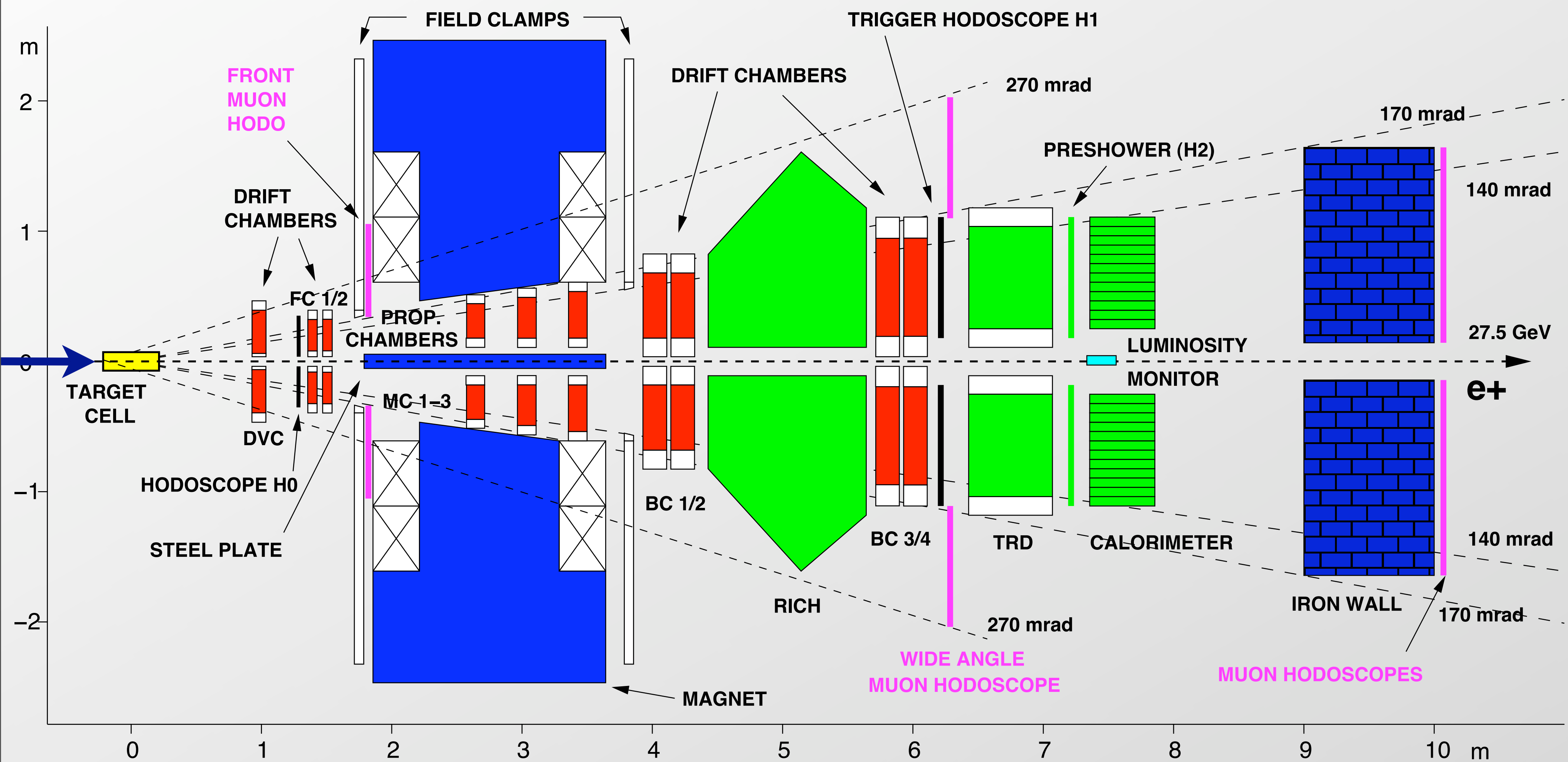
$$= A + B\cos(\phi_h) + C\cos(2\phi_h)$$

$$2\langle\cos(\phi_h)\rangle = 2\frac{\int\cos(\phi_h)d^5\sigma}{\int d^5\sigma} = \frac{B}{A}$$

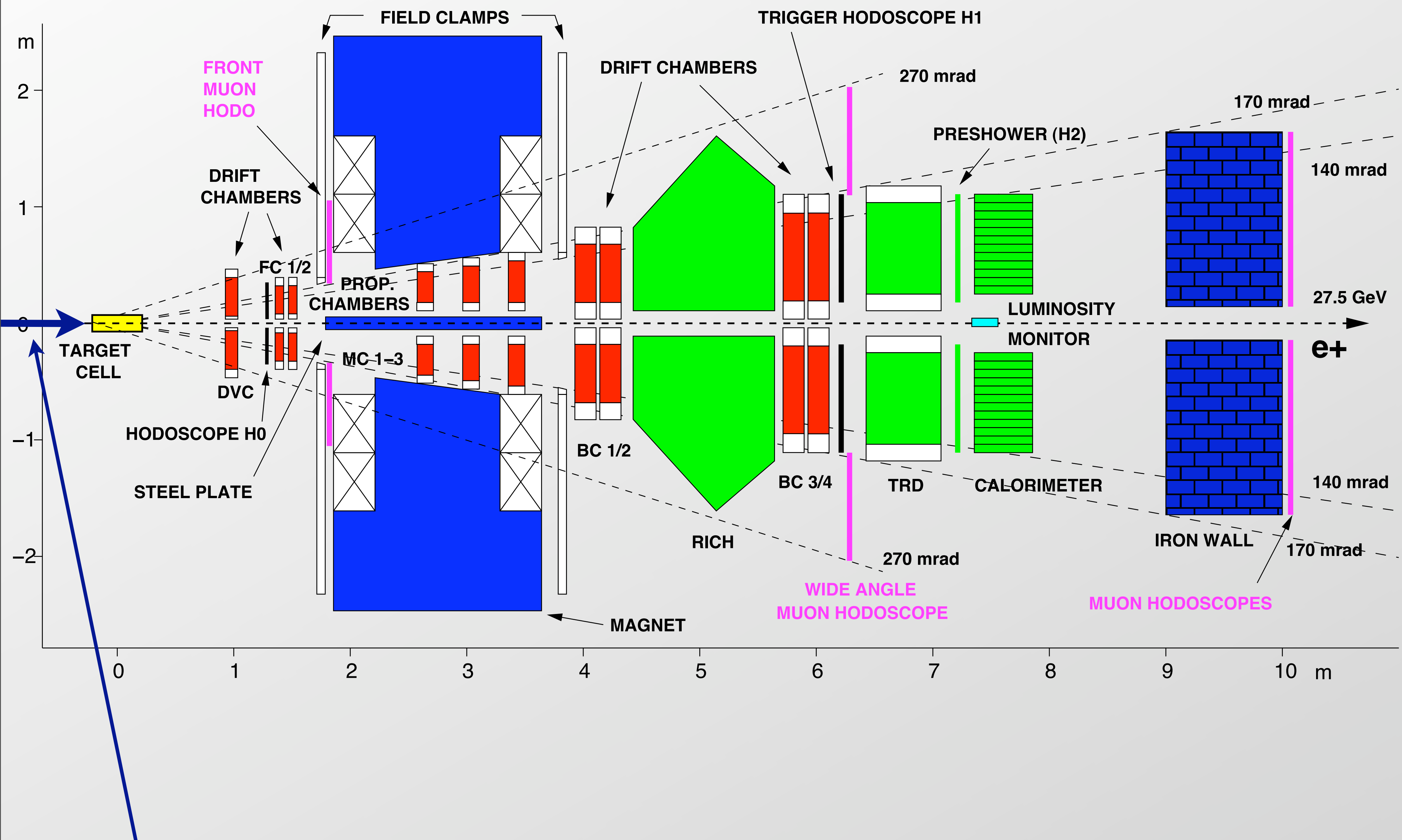
$$2\langle\cos(2\phi_h)\rangle = 2\frac{\int\cos(2\phi_h)d^5\sigma}{\int d^5\sigma} = \frac{C}{A}$$

The HERA Accelerator at DESY
Hamburg Germany

The HERMES Spectrometer

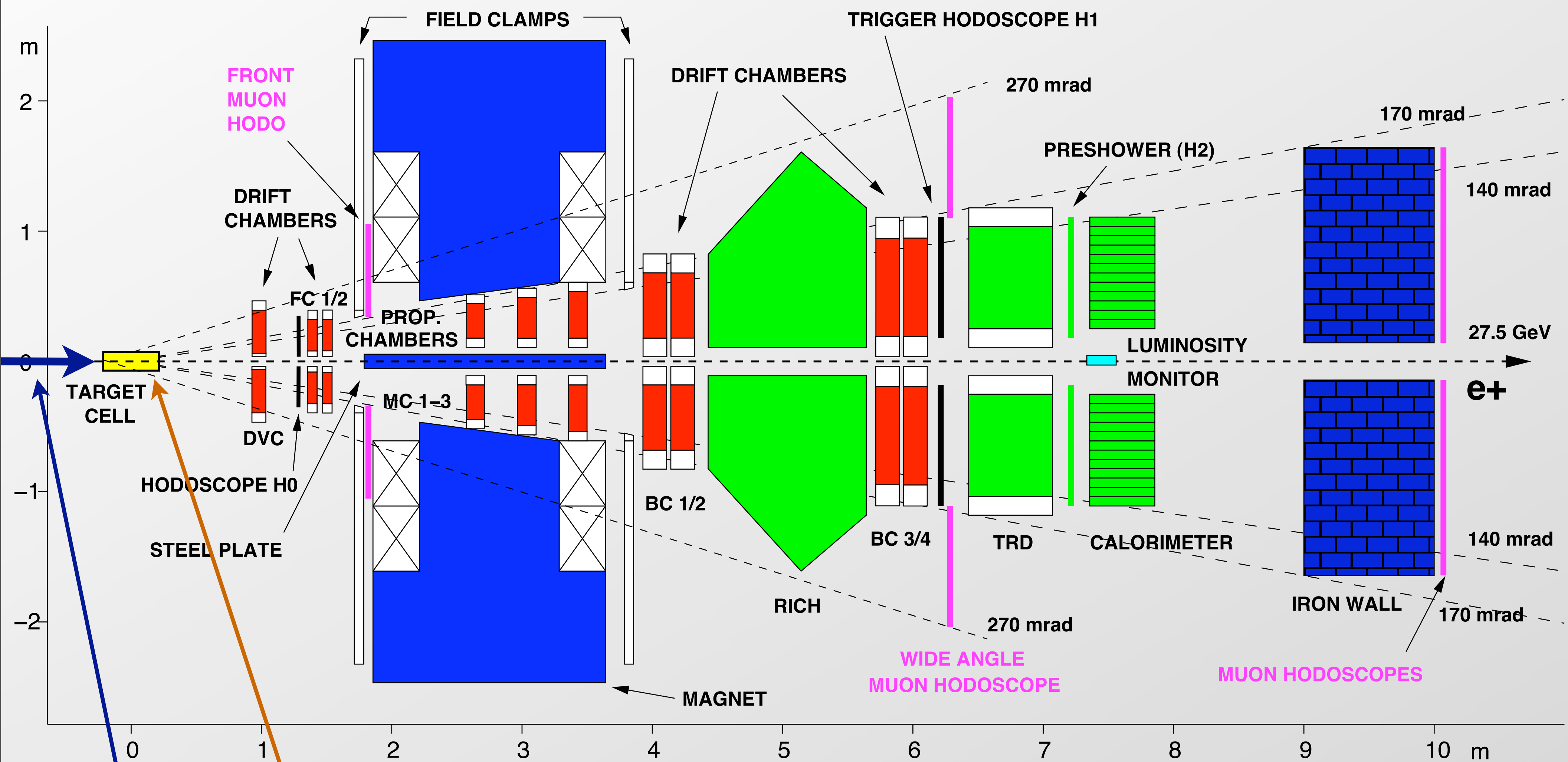


The HERMES Spectrometer



27.6 GeV $e^{\pm}$ beam

The HERMES Spectrometer



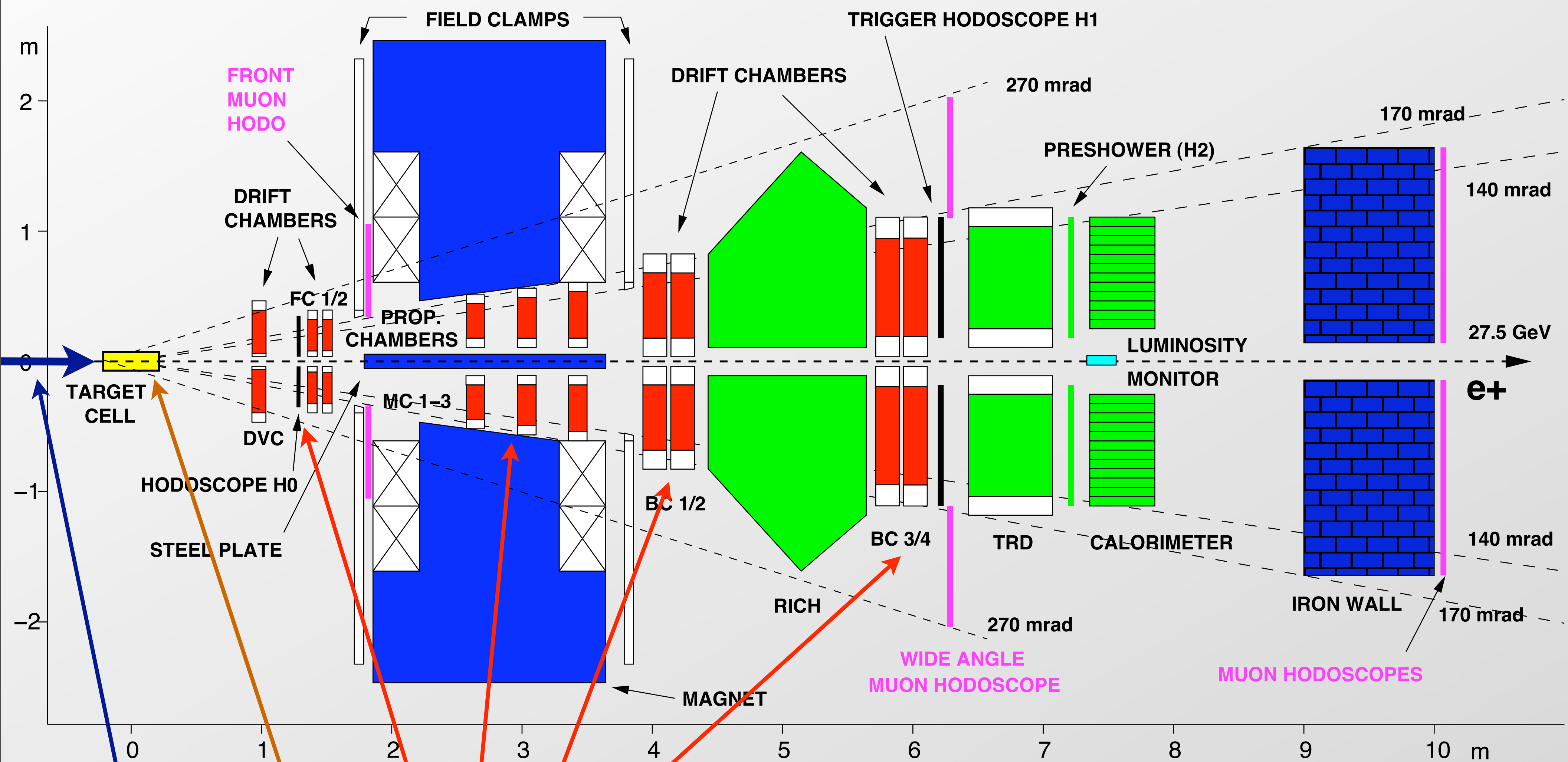
gas target

10M DIS unpol H 00,06e-

10M DIS unpol D 00,05

27.6 GeV $e^{\pm}$ beam

The HERMES Spectrometer



Tracking Chambers

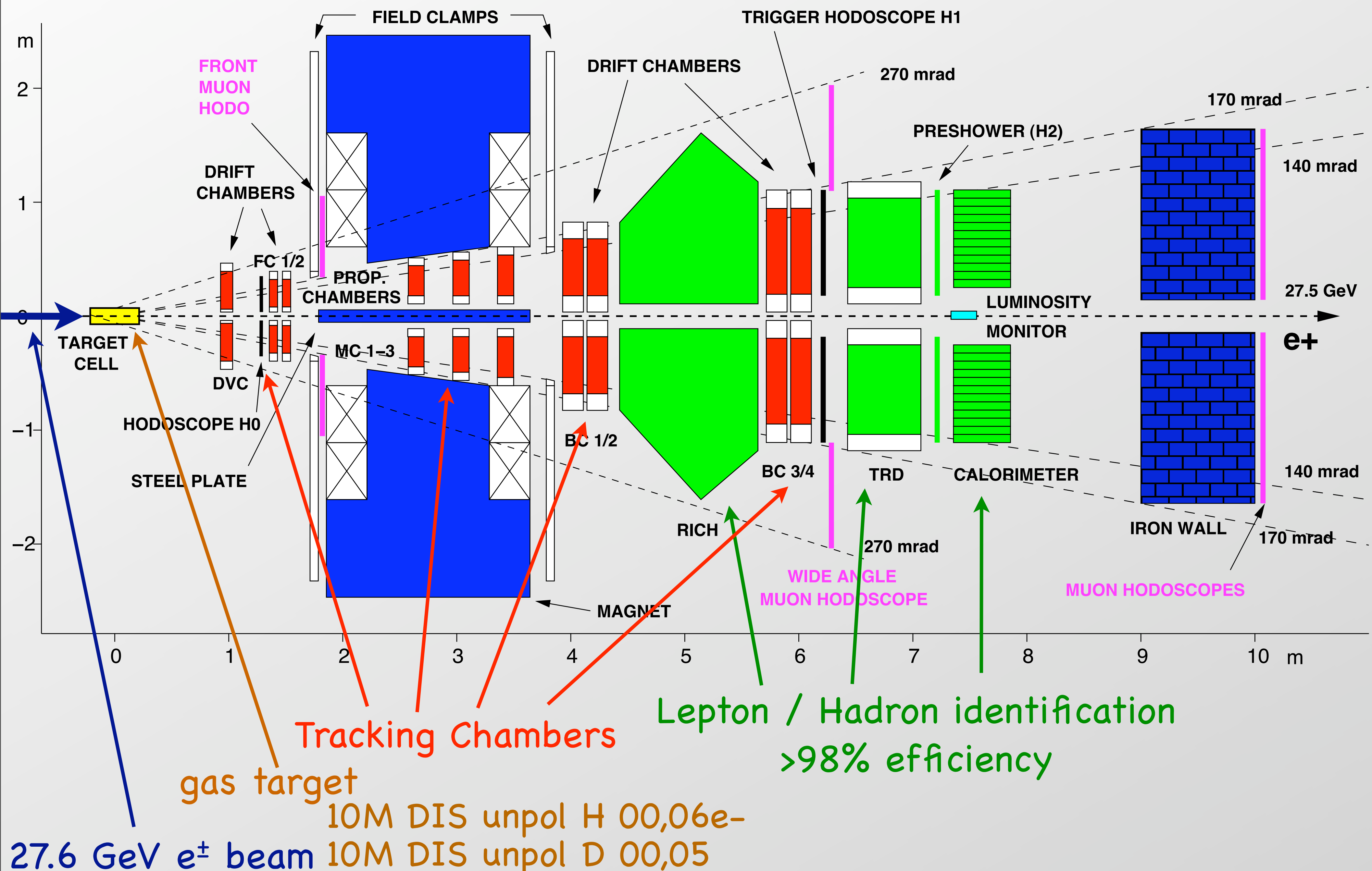
gas target

10M DIS unpol H 00,06e-

10M DIS unpol D 00,05

27.6 GeV $e^{\pm}$ beam

The HERMES Spectrometer



10M DIS unpol H 00,06e-

10M DIS unpol D 00,05

Procedure

Analysis Challenge!

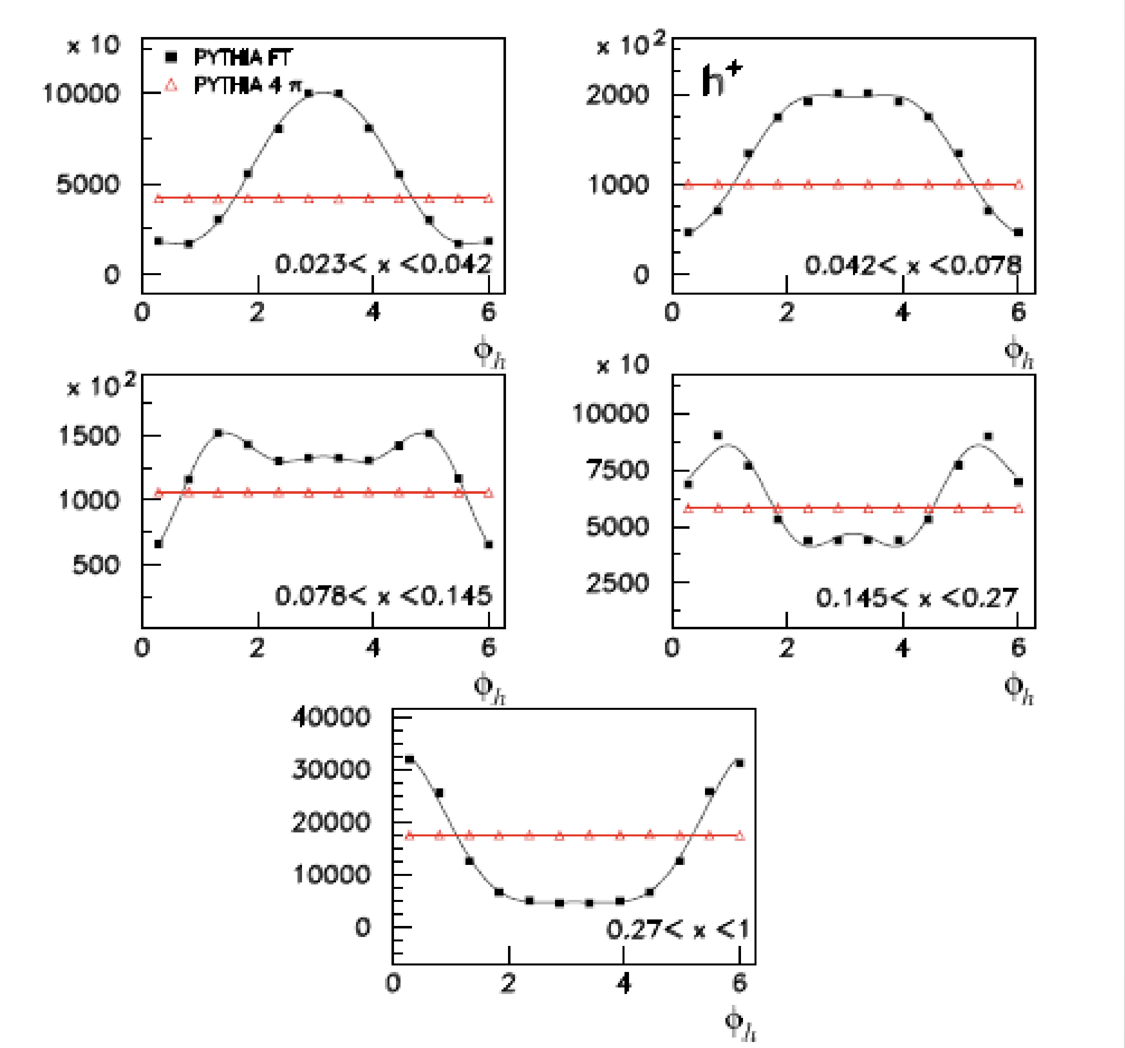
Monte Carlo:

- Generated in 4π (red)
- Measured inside acceptance (black)

Our acceptance and QED radiation generate $\cos(n\phi_h)$ moments

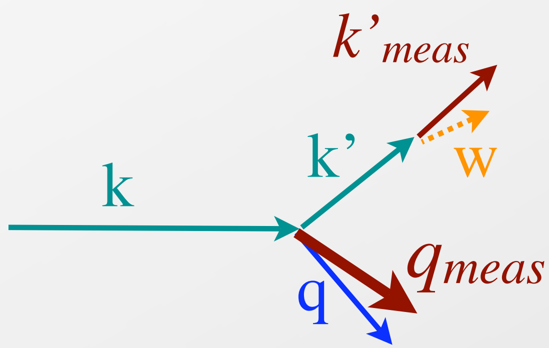
which depend on x, y, z, $P_{h\perp}$,

and so does PHYSICS!



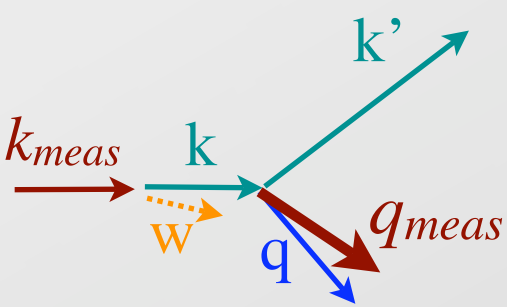
Azimuthal Moments due to QED Initial and Final State Radiation

ISR



$$q = k - k'$$
$$w = k' - k'_{meas}$$
$$q_{meas} = k - k'_{meas} = k - k' + w = q + w$$

FSR



$$q = k - k'$$
$$w = k_{meas} - k$$
$$q_{meas} = k_{meas} - k' = k + w - k' = q + w$$

Azimuthal Moments due to QED Initial and Final State Radiation

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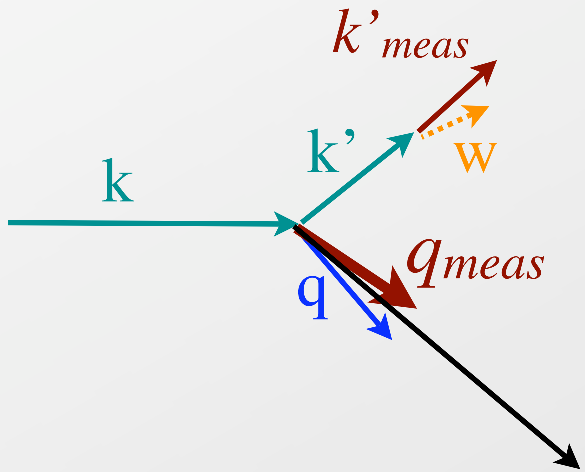
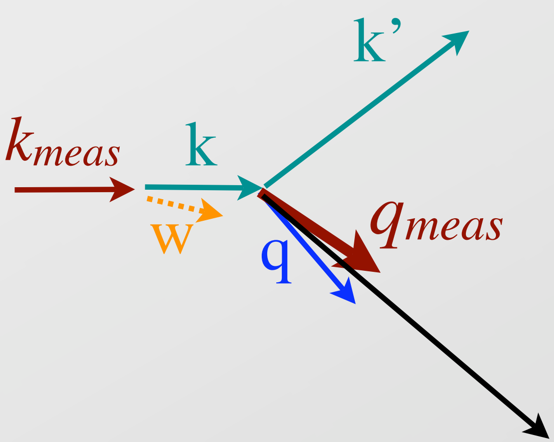


$$q \quad = k - k'$$
$$w \quad = k' - k'_{meas}$$
$$q_{meas} = k - k'_{meas} = k - k' + w = q + w$$

$\phi_{h(true)} = 0°$

$\phi_{h(meas)} = 180°$

FSR



$$q \quad = k - k'$$
$$w \quad = k_{meas} - k$$
$$q_{meas} = k_{meas} - k' = k + w - k' = q + w$$

$\phi_{h(true)} = 0°$

$\phi_{h(meas)} = 180°$

Unfolding for detector and QED radiative effects

Fully tracked Pythia MC

Probability that an event at true born kinematics j_{born} is measured at kinematics i_{meas}

$$S(i_{meas}, j_{born}) = \frac{\sigma^{MC}_{meas}(i_{meas}, j_{born})}{\sigma^{MC}_{born}(j_{born})}$$

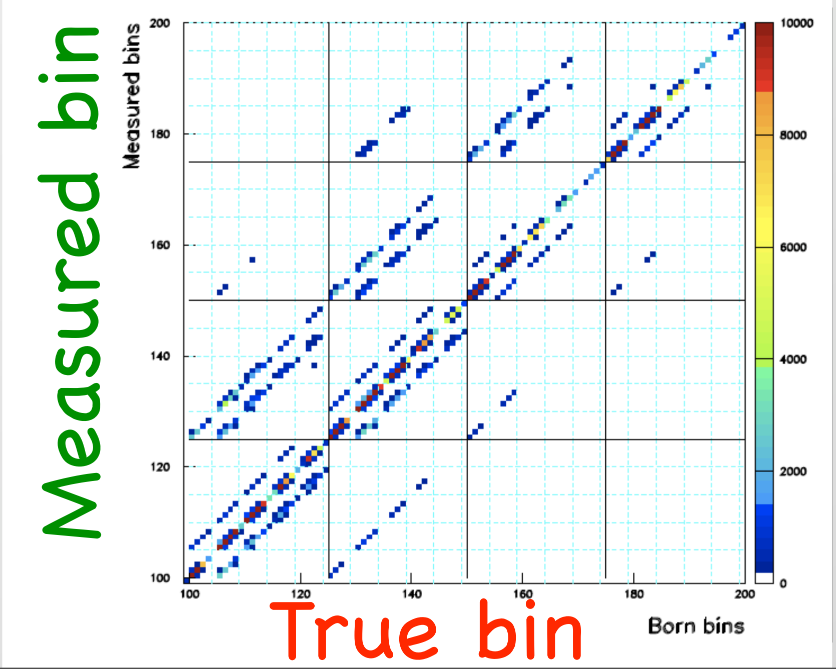
4π Pythia MC

$$\sigma_{meas}(i_{meas}) = \sum_{j=1}^{N} S(i_{meas}, j_{born})\, \sigma_{true}(j_{born}) + \sigma_{bkg}(i)$$

What we actually measure

What we'd like to know!

Events smeared in from outside DIS cuts (MC)



Five Dimensional Binning

- A **model independent** correction can be made with
  - bins in all 5 independent variables (max # for SIDIS!)
  - infinitely small bins sizes
  - no smearing in from outside DIS region (background)

- Given limited statistics, we have bin edges:

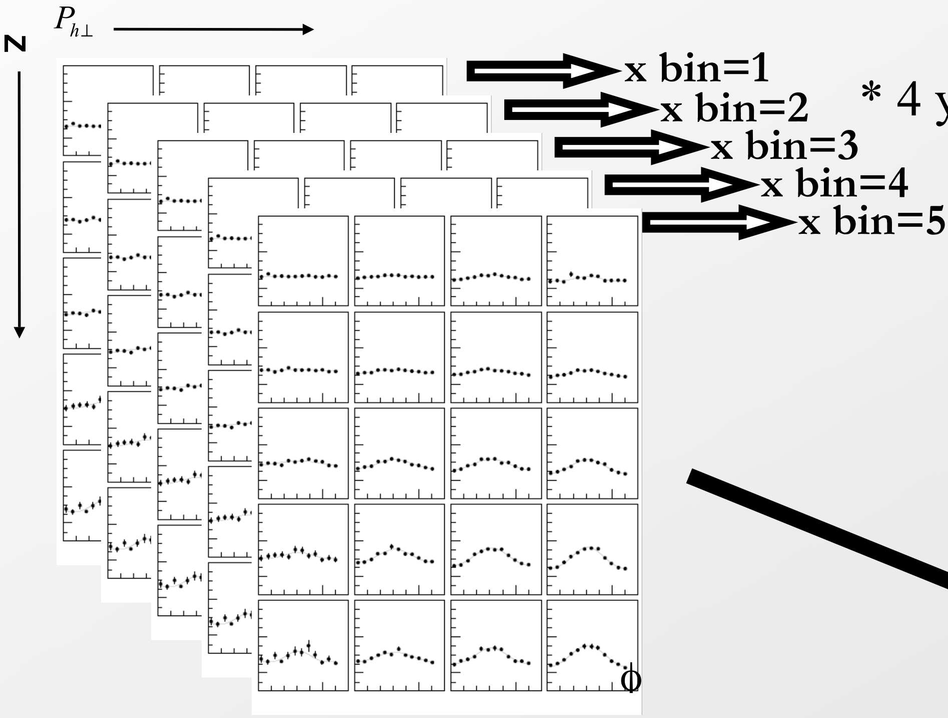
$x =$	0.023	0.042	0.078	0.145	0.27	1
$y =$	0.3	0.45	0.6	0.7	0.85	
$z =$	0.2	0.3	0.45	0.6	0.75	1
$P_{h\perp} =$	0.05	0.2	0.35	0.5	0.75	
$\phi =$	12 bins					

400 kinematic bins * 12 ϕ_h bins = 4800 bins

- Highest z bin not included in projections vs other variables

- With the additional DIS cuts
  - Q^2 > 1 GeV
  - W^2 > 10 GeV

Analysis Summary



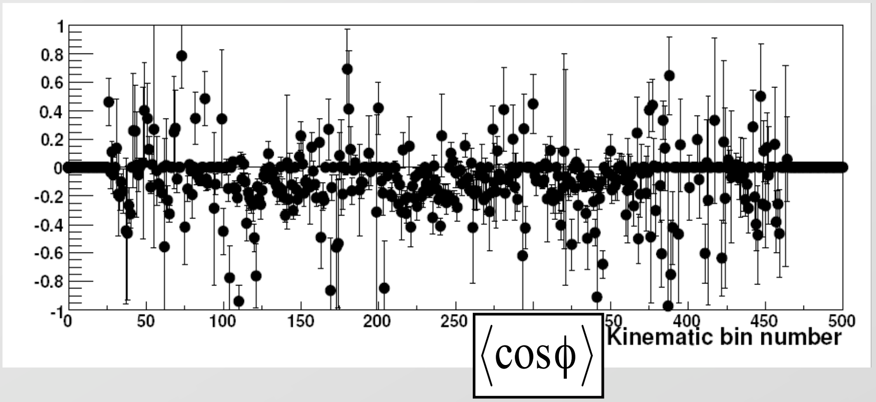
* 4 y bins

1. 4800 measurements are unfolded and fit in 400 bins

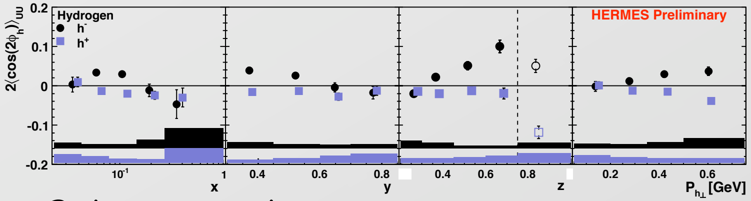
$$\frac{d\sigma}{dx\ dy\ dz\ dP_{h\perp}^2\ d\phi_h} = A + B\cos(\phi_h) + C\cos(2\phi_h)$$

2. 400 moments are calculated

$$2\langle\cos(\phi_h)\rangle = \frac{B}{A} \quad 2\langle\cos(2\phi_h)\rangle = \frac{C}{A}$$

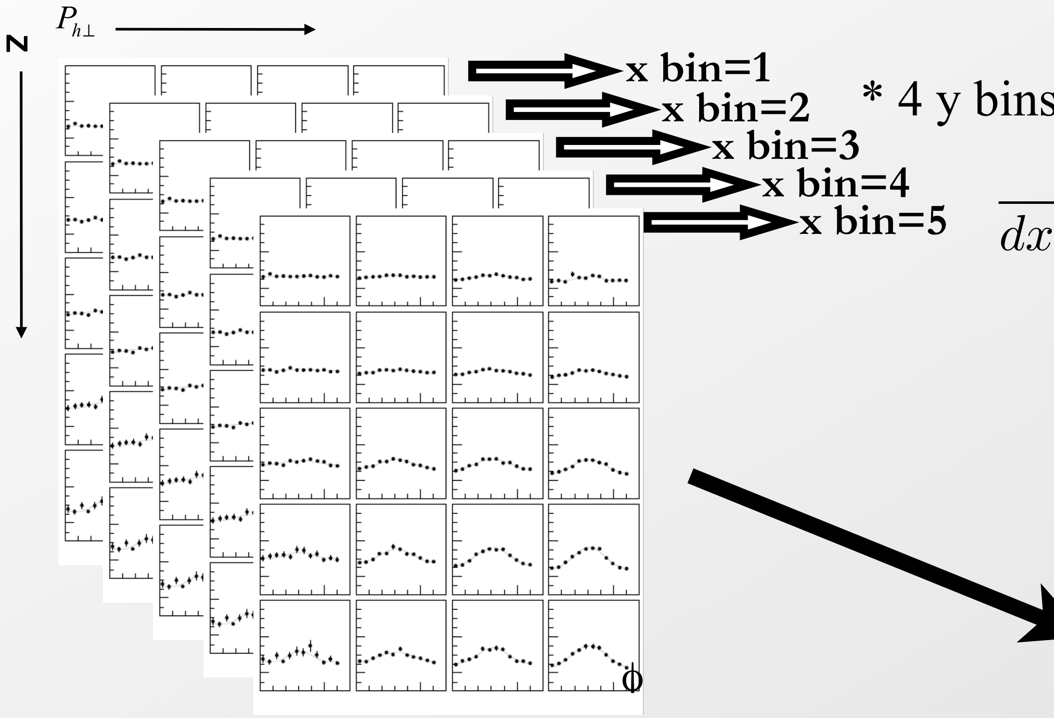


$$\langle\cos(\phi_h)\rangle(x) = \frac{\sum_{y,z,P_{h\perp}} \sigma^{4\pi}(x,y,z,P_{h\perp})\ \langle\cos\phi_h\rangle(x,y,z,P_{h\perp})}{\sum_{y,z,P_{h\perp}} \sigma^{4\pi}(x,y,z,P_{h\perp})}$$



3. 1-dimensional projections are calculated as the integral over the other 3 variables

Analysis Summary



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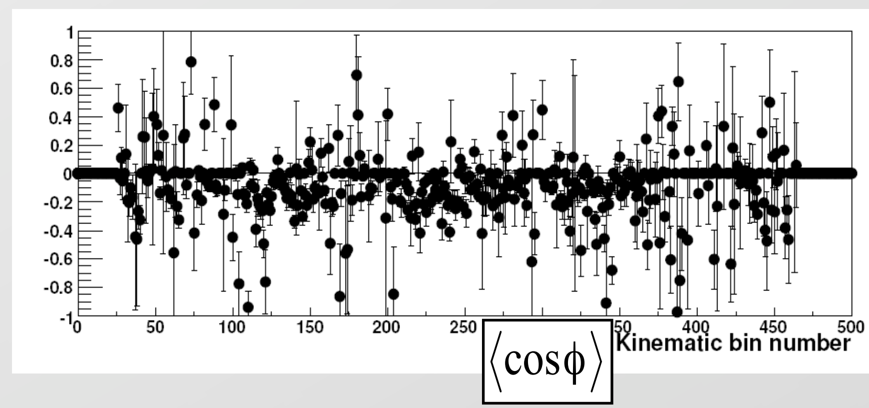
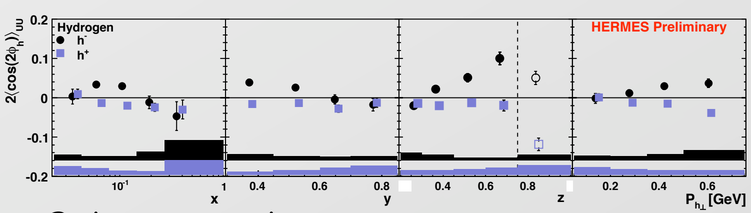


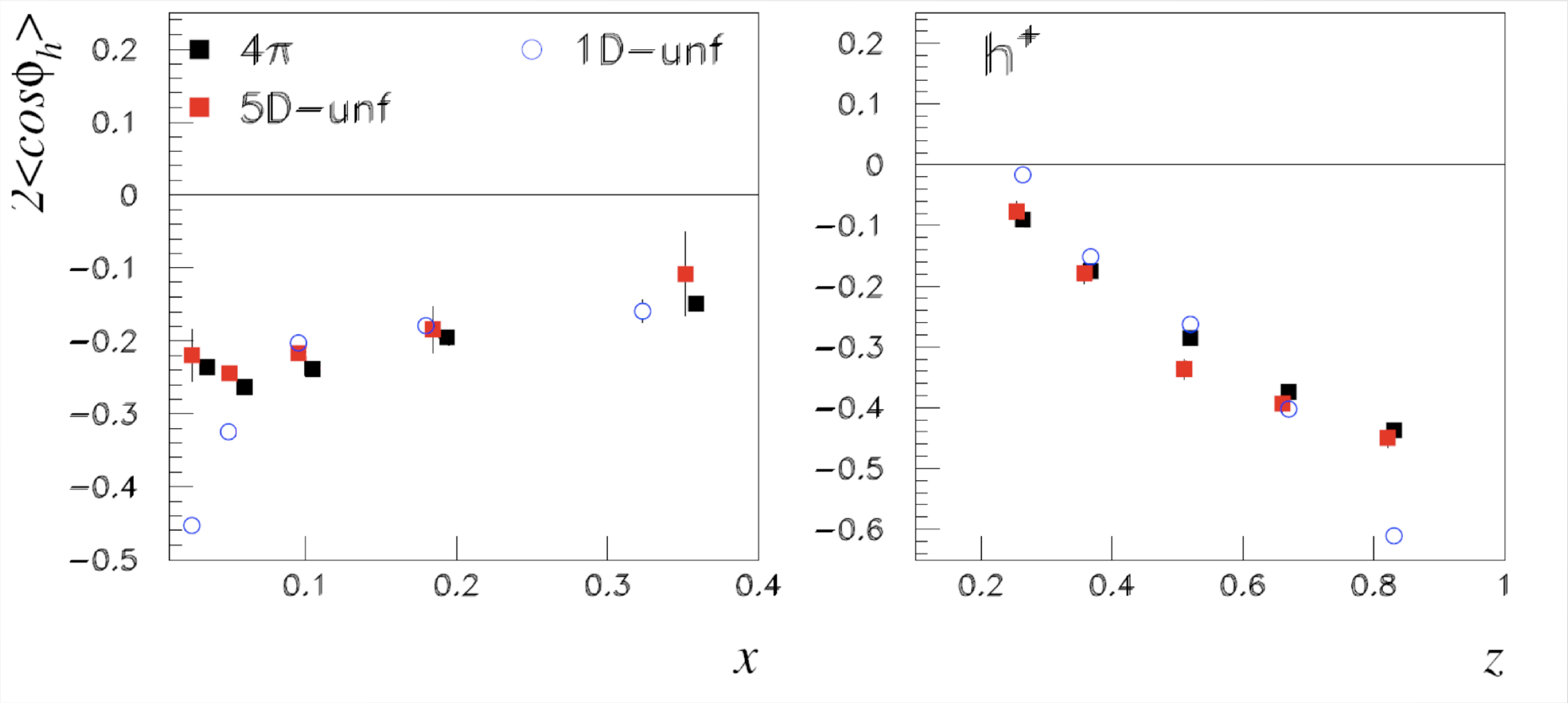
$$\langle\cos(\phi_h)\rangle(x) = \frac{\int_{0.3}^{0.85} dy \int_{0.2}^{0.75} dz \int_{0.05}^{0.75} dP_{h\perp}\ \sigma^{4\pi}(x,y,z,P_{h\perp})\ \langle\cos\phi_h\rangle(x,y,z,P_{h\perp})}{\int_{0.3}^{0.85} dy \int_{0.2}^{0.75} dz \int_{0.05}^{0.75} dP_{h\perp}\ \sigma^{4\pi}(x,y,z,P_{h\perp})}$$



3. 1-dimensional projections are calculated as the integral over the other 3 variables

Monte Carlo test

- One MC production as "data" $\langle\cos(\phi_h)\rangle$=Cahn Model
- A different MC production used to unfold $\langle\cos(\phi_h)\rangle=0$



■ Unfolded in 5D

■ Cahn Model in 4π

○ Unfolded in 1D -> Inacurate!!

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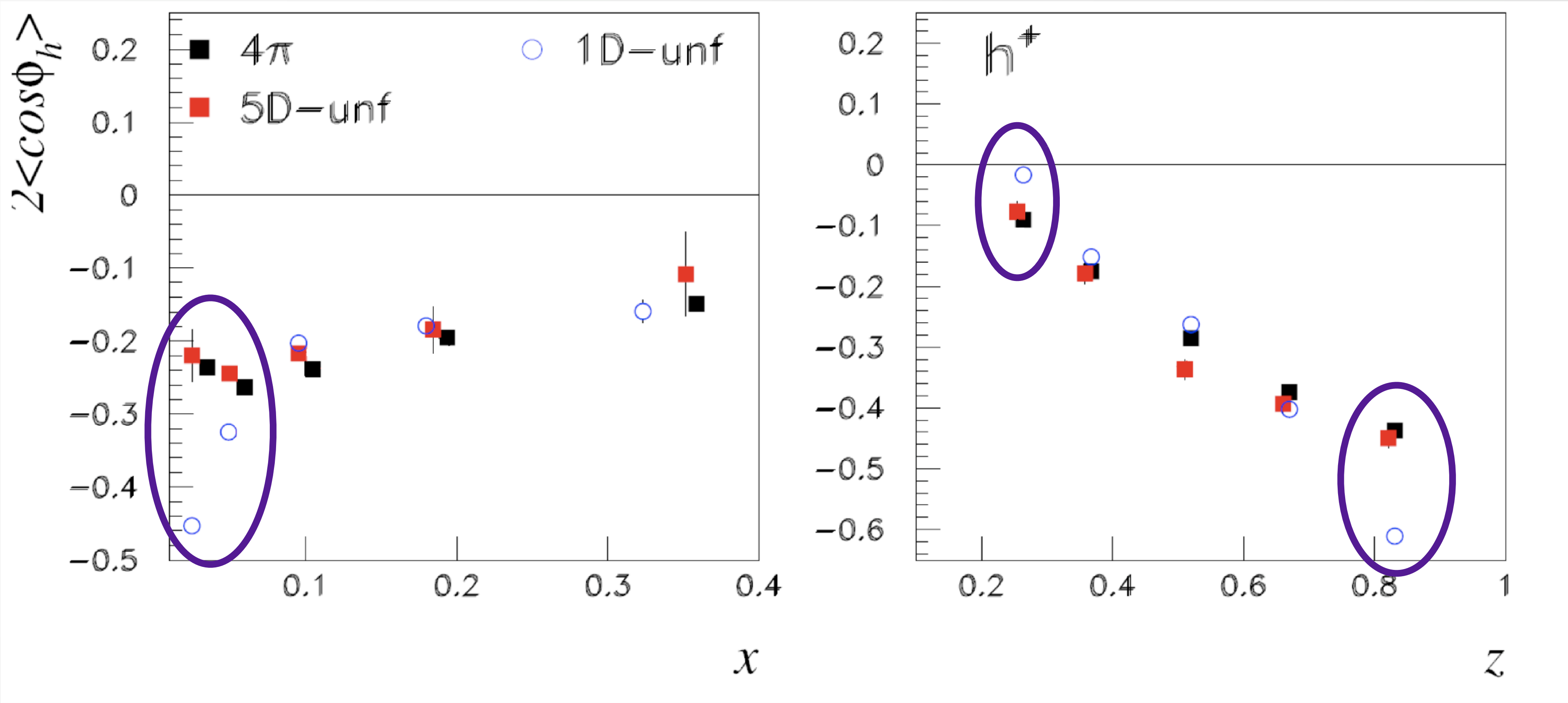

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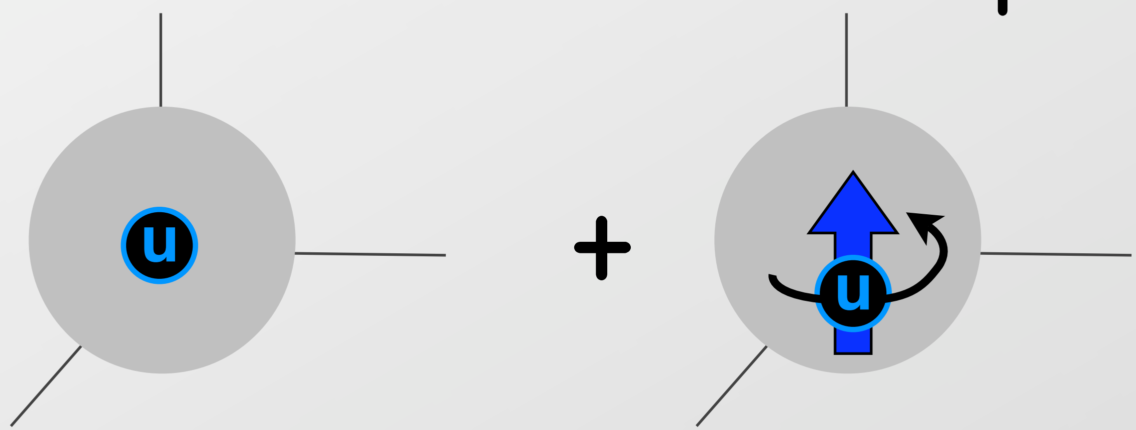
$\langle\cos(\phi_h)\rangle$ Results and Interpretation



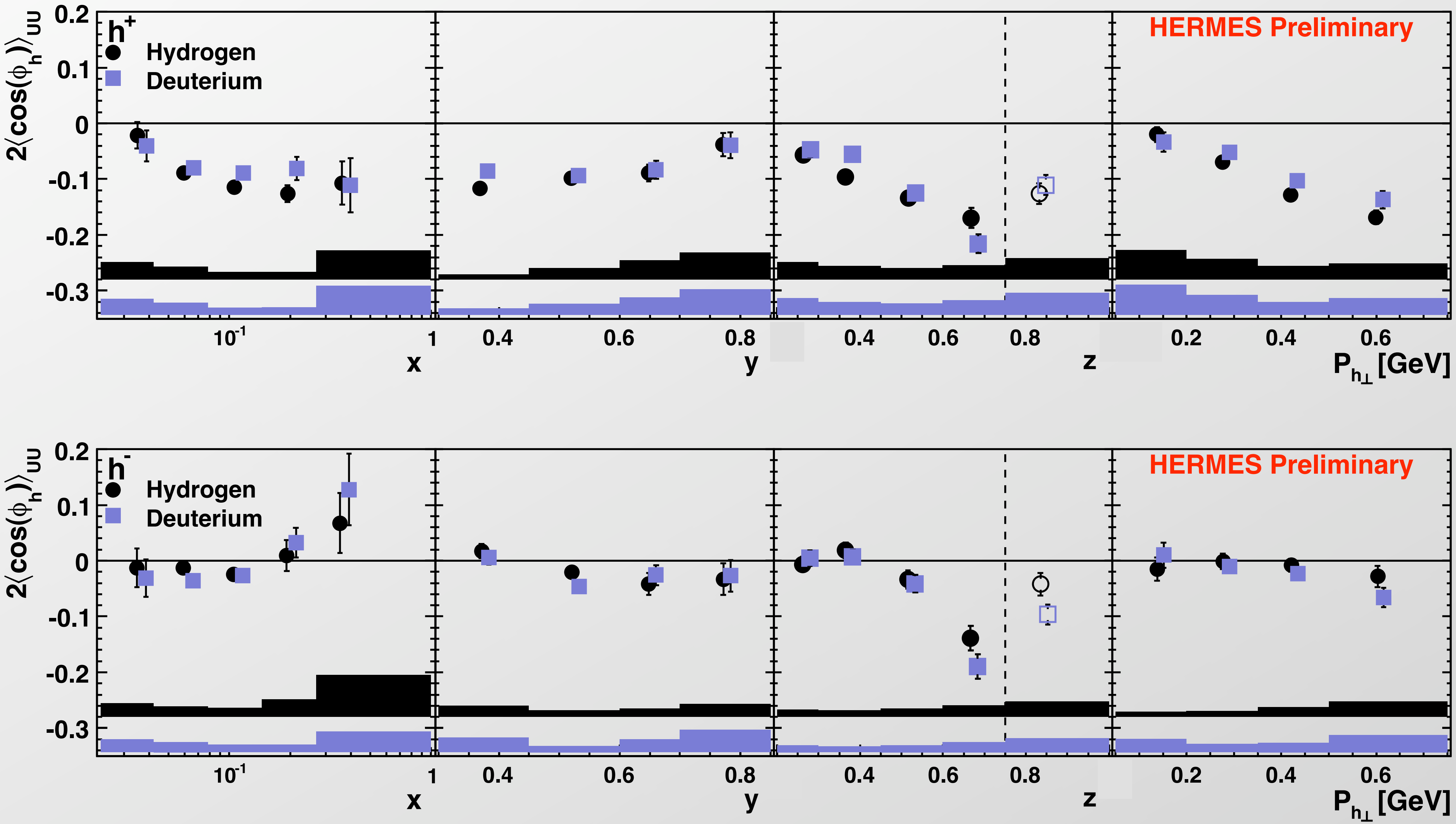
interaction dependent terms

Cahn+Boer-Mulders

$$F_{UU}^{\cos\phi_h} = \frac{2M}{Q}\,\mathcal{C}\left[-\frac{\hat{\mathbf{P}}_{\mathbf{h}\perp}\cdot\mathbf{k}_T}{M_h}\frac{p_T^2}{M^2}h_1^{\perp}H_1^{\perp} - \frac{\hat{\mathbf{P}}_{\mathbf{h}\perp}\cdot\mathbf{p}_T}{M}f_1 D_1 + \ldots\right]$$

Cahn

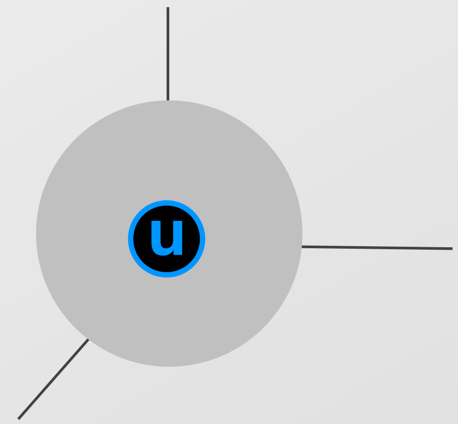
<cos(ϕh)> Results and Interpretation



$\langle\cos(\phi_h)\rangle$ Results and Interpretation

Data:

- H and D results very similar
- h+ and h- results differ



Questions:

- What can we learn about intrinsic $\langle k_T\rangle$ of quarks?

interaction dependent terms

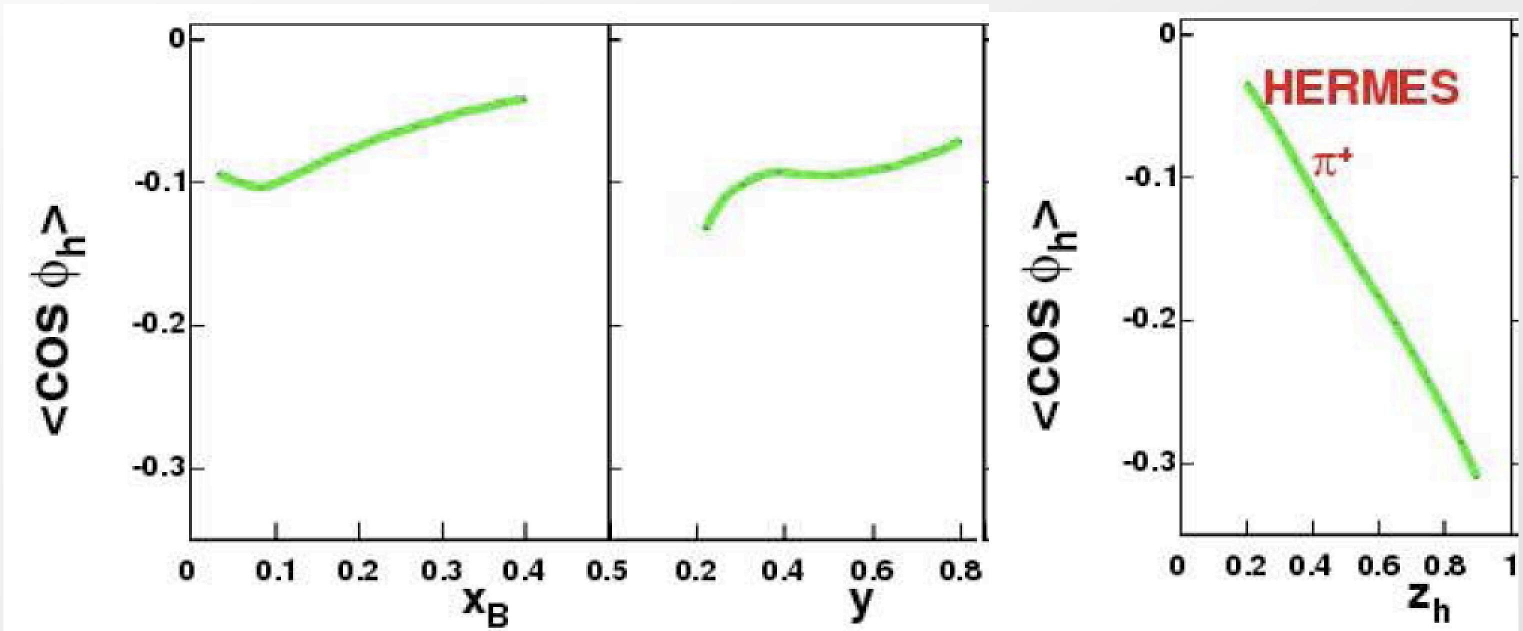
Cahn+Boer-Mulders

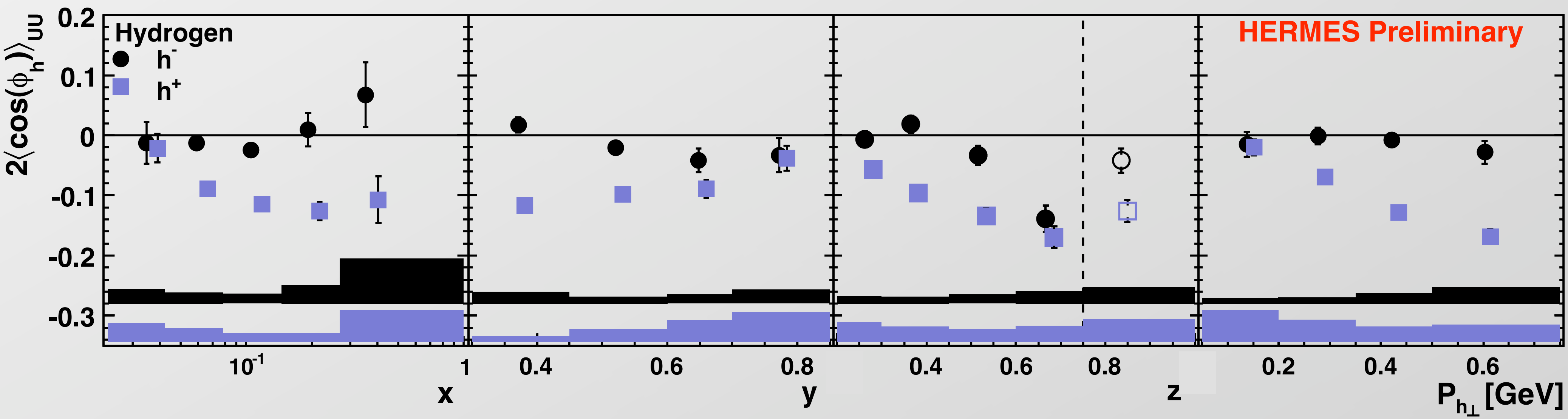
$$F_{UU}^{\cos\phi_h} = \frac{2M}{Q}\,\mathcal{C}\left[-\frac{\hat{\mathbf{P}}_{\mathbf{h}\perp}\cdot\mathbf{k}_T}{M_h}\frac{p_T^2}{M^2}h_1^\perp H_1^\perp - \frac{\hat{\mathbf{P}}_{\mathbf{h}\perp}\cdot\mathbf{p}_T}{M}f_1 D_1 + \ldots\right]$$

Cahn

<cos(ϕh)> Results and Interpretation

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





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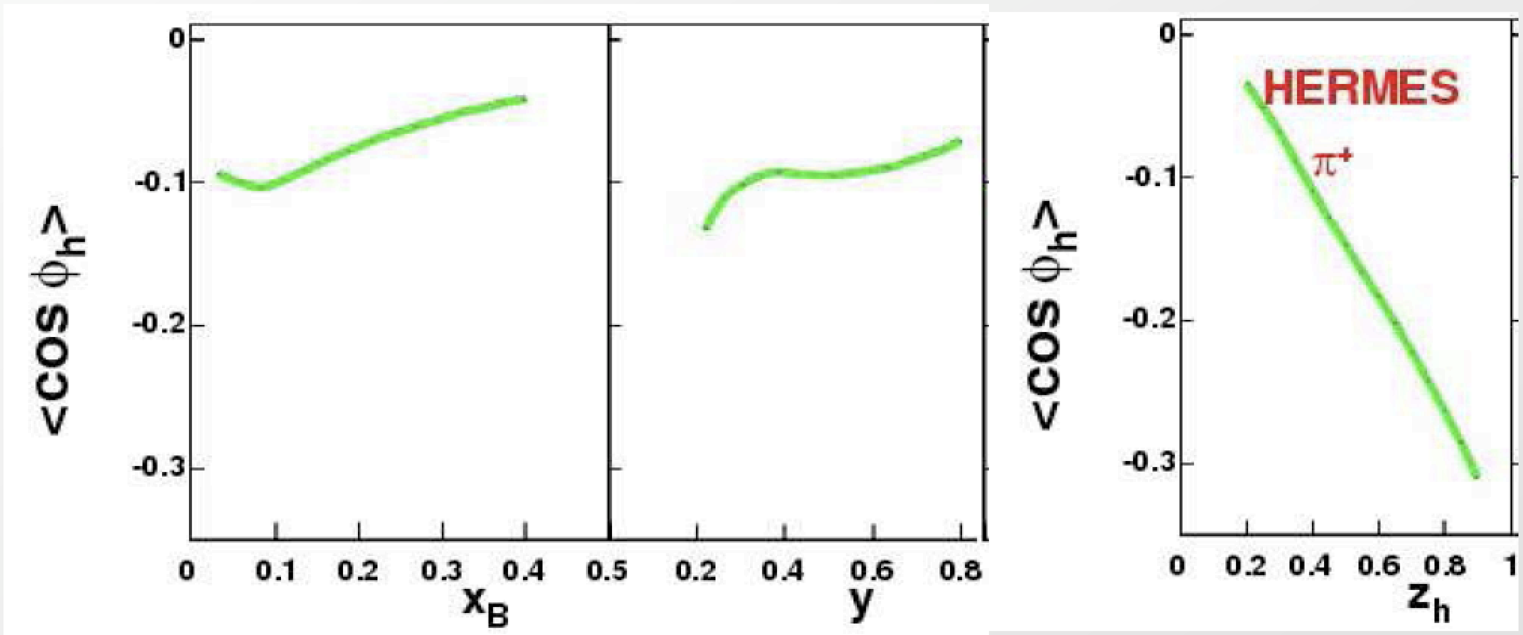
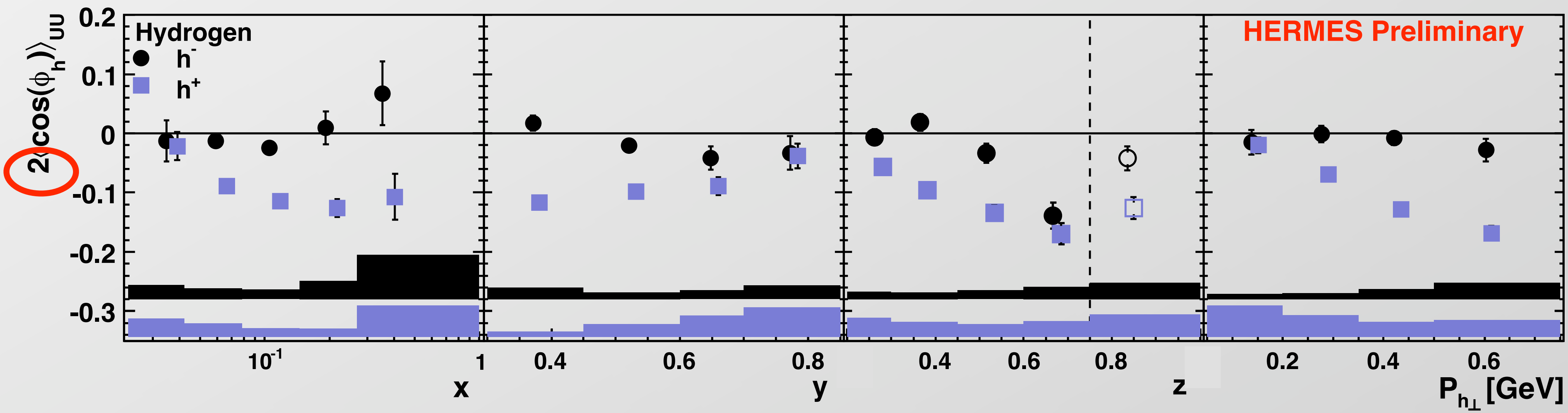
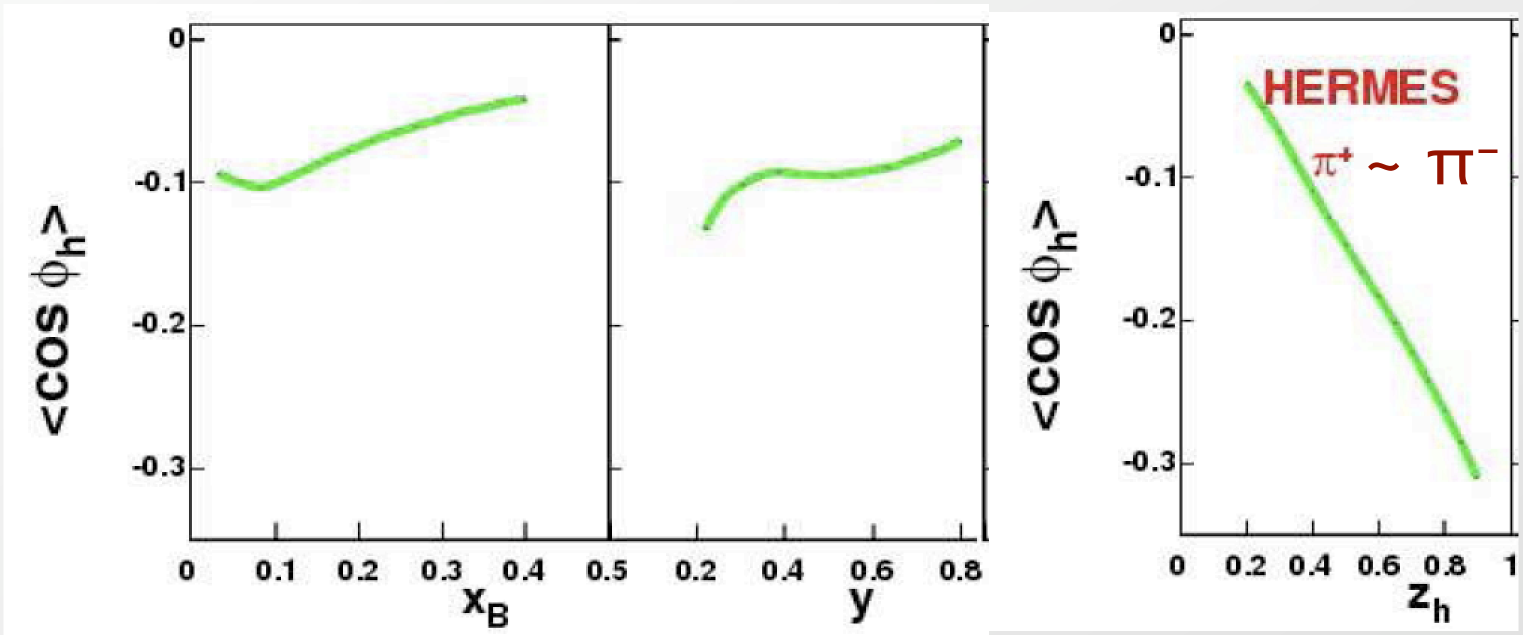
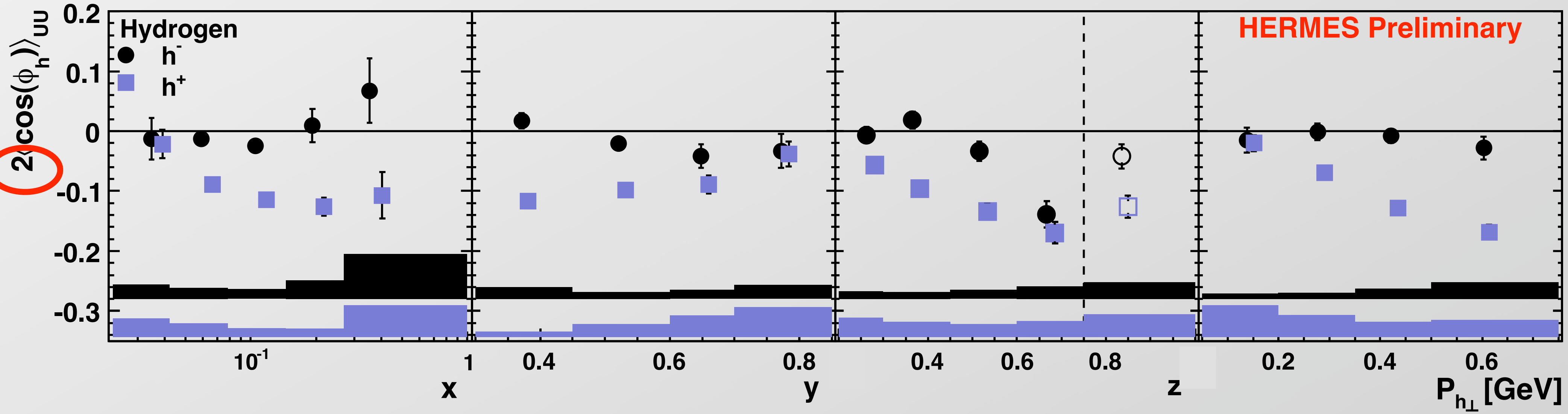




<cos(ϕh)> Results and Interpretation

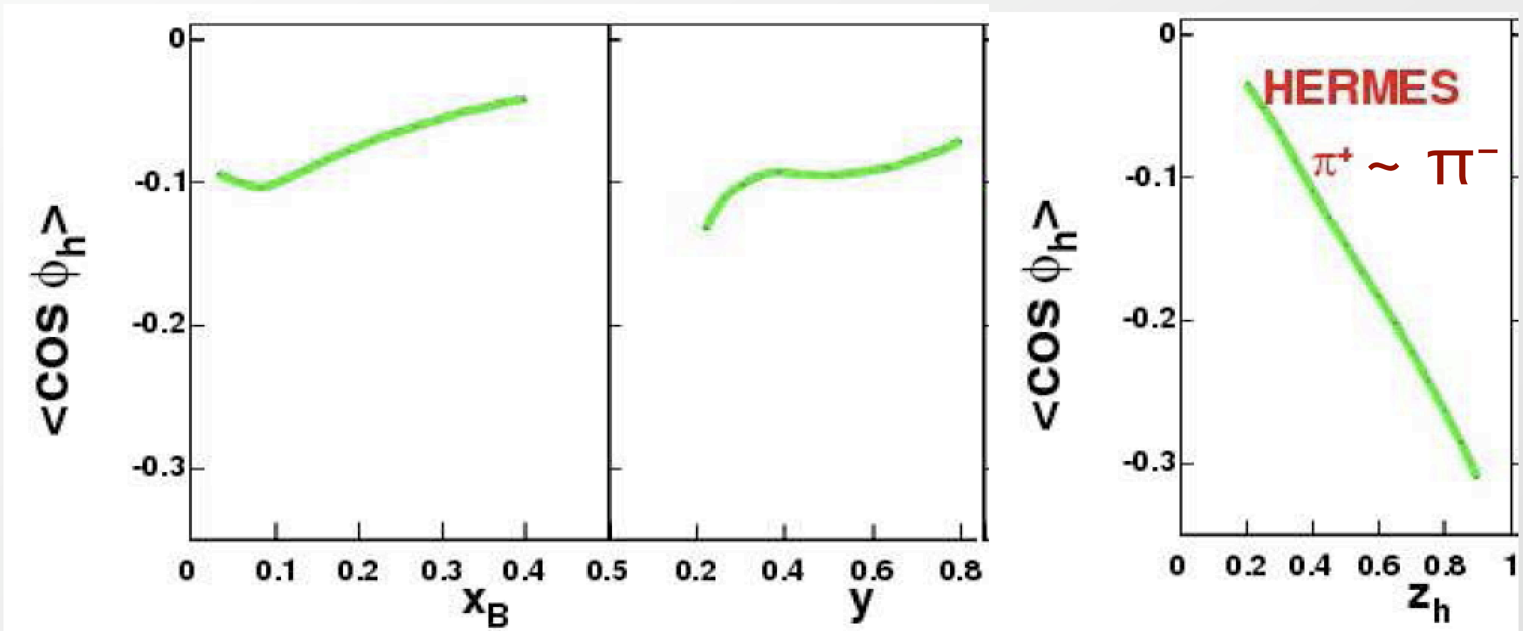
M. Anselmino et al., Phys Rev D71:074006, 2005
M. Anselmino et al., Eur. Phys J A31:373, 2007



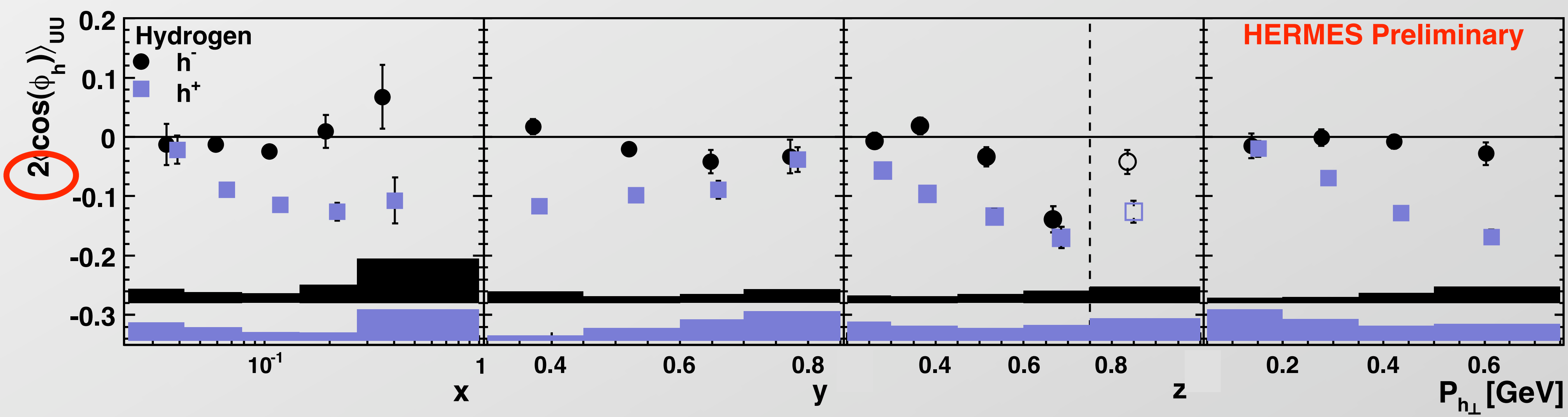


$\langle\cos(\phi_h)\rangle$ Results and Interpretation

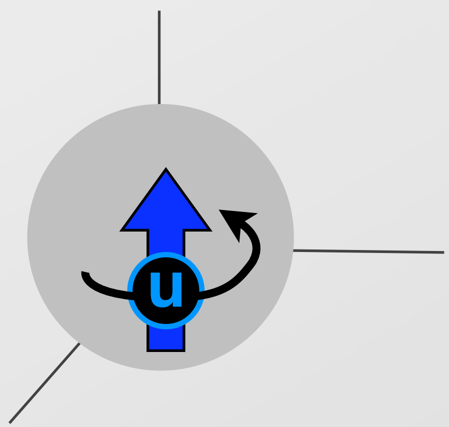
M. Anselmino et al., Phys Rev D71:074006, 2005
M. Anselmino et al., Eur. Phys J A31:373, 2007



Cahn-only doesn't describe data. Too large?



$\langle \cos(2\phi_h) \rangle$ Results and Interpretation



Boer-Mulders

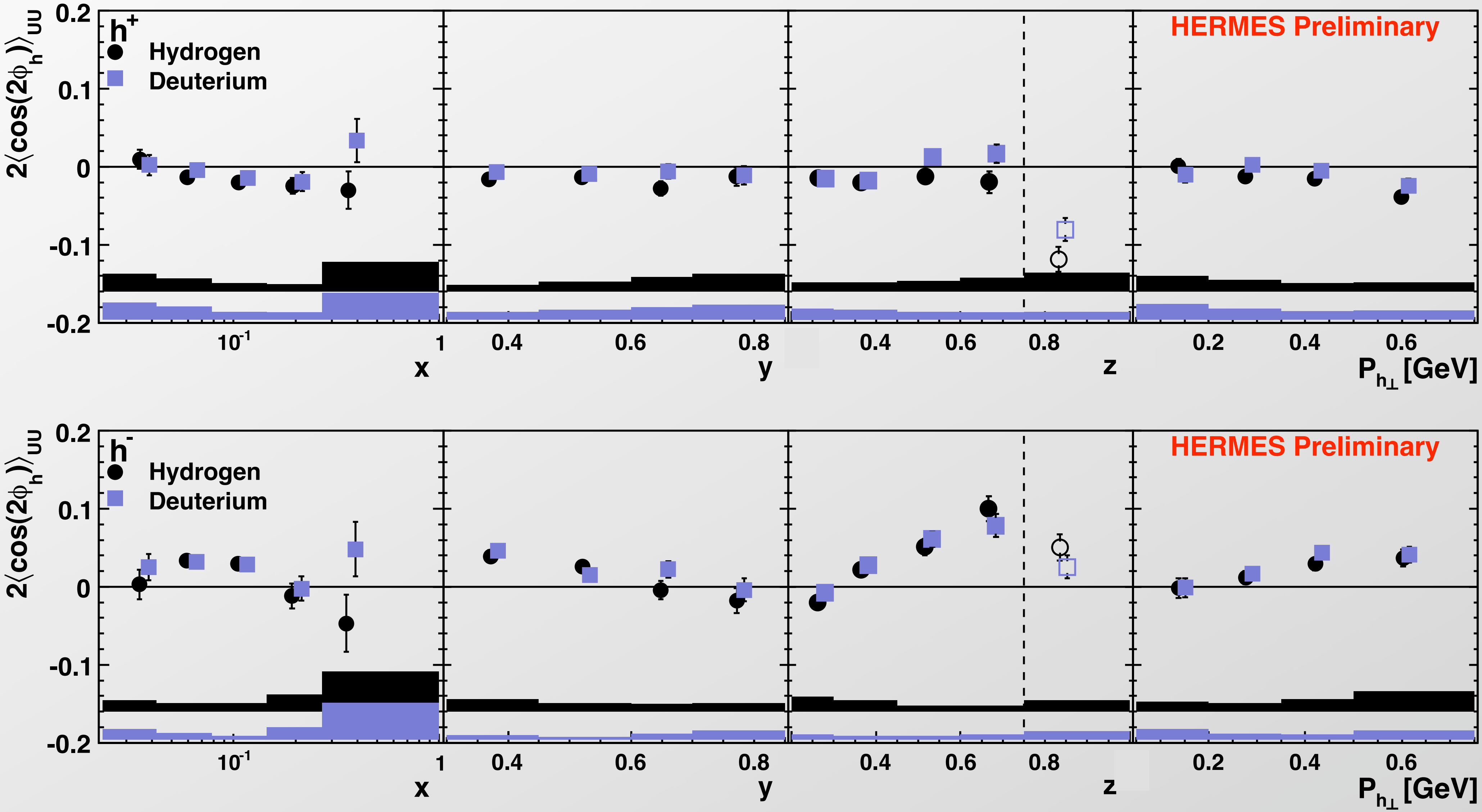
$$F_{UU}^{\cos(2\phi_h)} = \mathcal{C}\left[-\frac{2(\hat{\mathbf{P}}_{\mathbf{h}\perp}\cdot\mathbf{k}_T)(\hat{\mathbf{P}}_{\mathbf{h}\perp}\cdot\mathbf{p}_T)-\mathbf{k}_T\cdot\mathbf{p}_T}{MM_h}h_1^\perp H_1^\perp\right] + X\frac{1}{Q^2}f_1 D_1$$

twist-4 Cahn

Boer-Mulders Collins

<cos(2ϕh)> Results and Interpretation

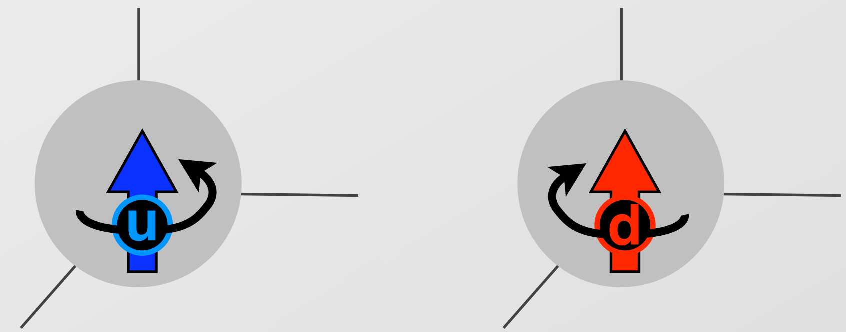
B. Zhang et al., Phys.Rev.D78:034035,2008



$\langle\cos(2\phi_h)\rangle$ Results and Interpretation

Data:

- H and D results very similar
- h+ ~ 0, slightly negative
- h- clearly positive



Questions:

- Is $\langle\cos(2\phi)\rangle$ a clean probe of $h_1^\perp$?
- What is the relative sign of $h_1^{\perp u}$ and $h_1^{\perp d}$?

Boer-Mulders

$$F_{UU}^{\cos(2\phi_h)} = \mathcal{C}\left[-\frac{2(\hat{\mathbf{P}}_{\mathbf{h}\perp}\cdot\mathbf{k}_T)(\hat{\mathbf{P}}_{\mathbf{h}\perp}\cdot\mathbf{p}_T)-\mathbf{k}_T\cdot\mathbf{p}_T}{MM_h}h_1^\perp H_1^\perp\right] + X\frac{1}{Q^2}f_1 D_1$$

twist-4 Cahn

Boer-Mulders   Collins

Model 1

L. P. Gamberg et al., Phys Rev D67:071504, 2003

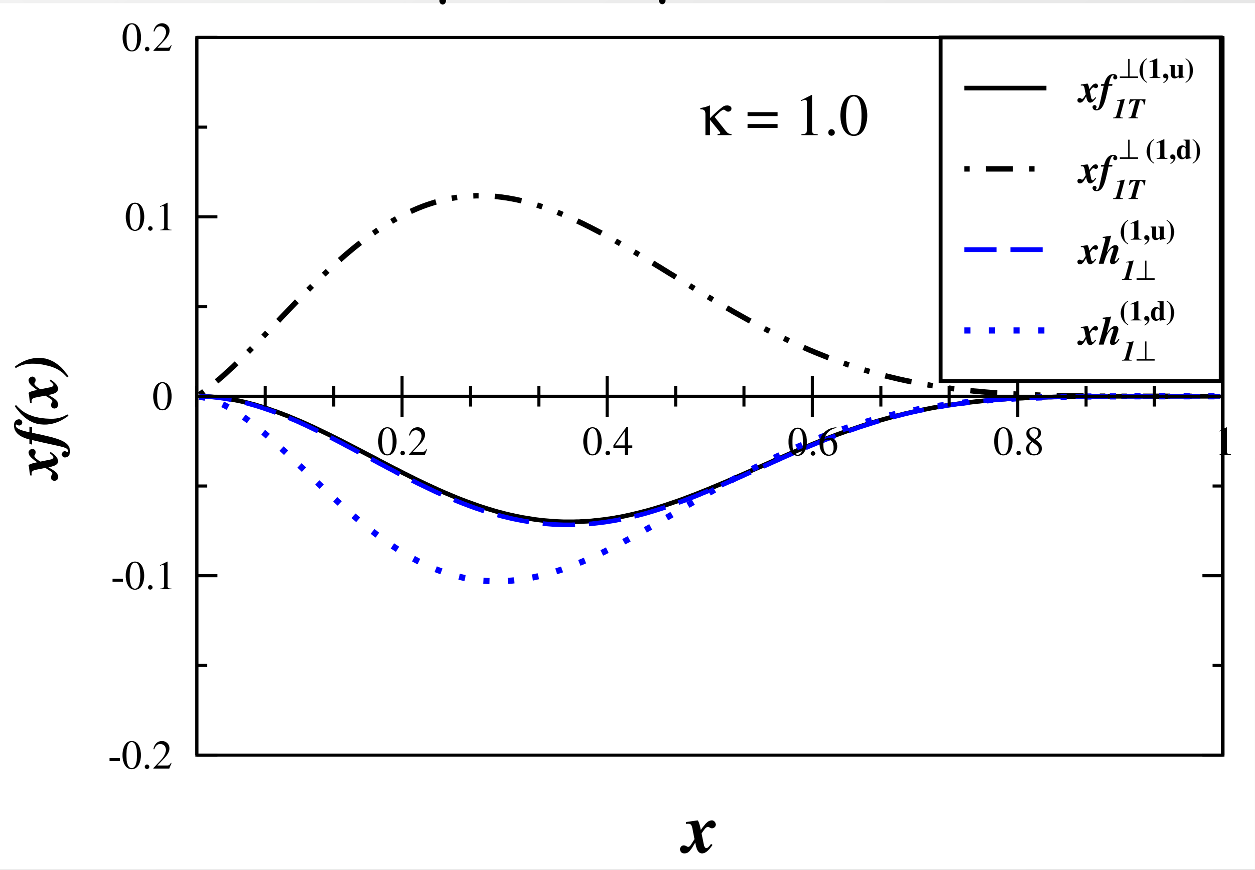
L. P. Gamberg and G. R. Goldstein, arXiv:0708.0324, 2007

<cos(2ϕ_h)>: Model 1

Gamberg et al.

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

Same sign u and d Boer-Mulders function from a diquark spectator model



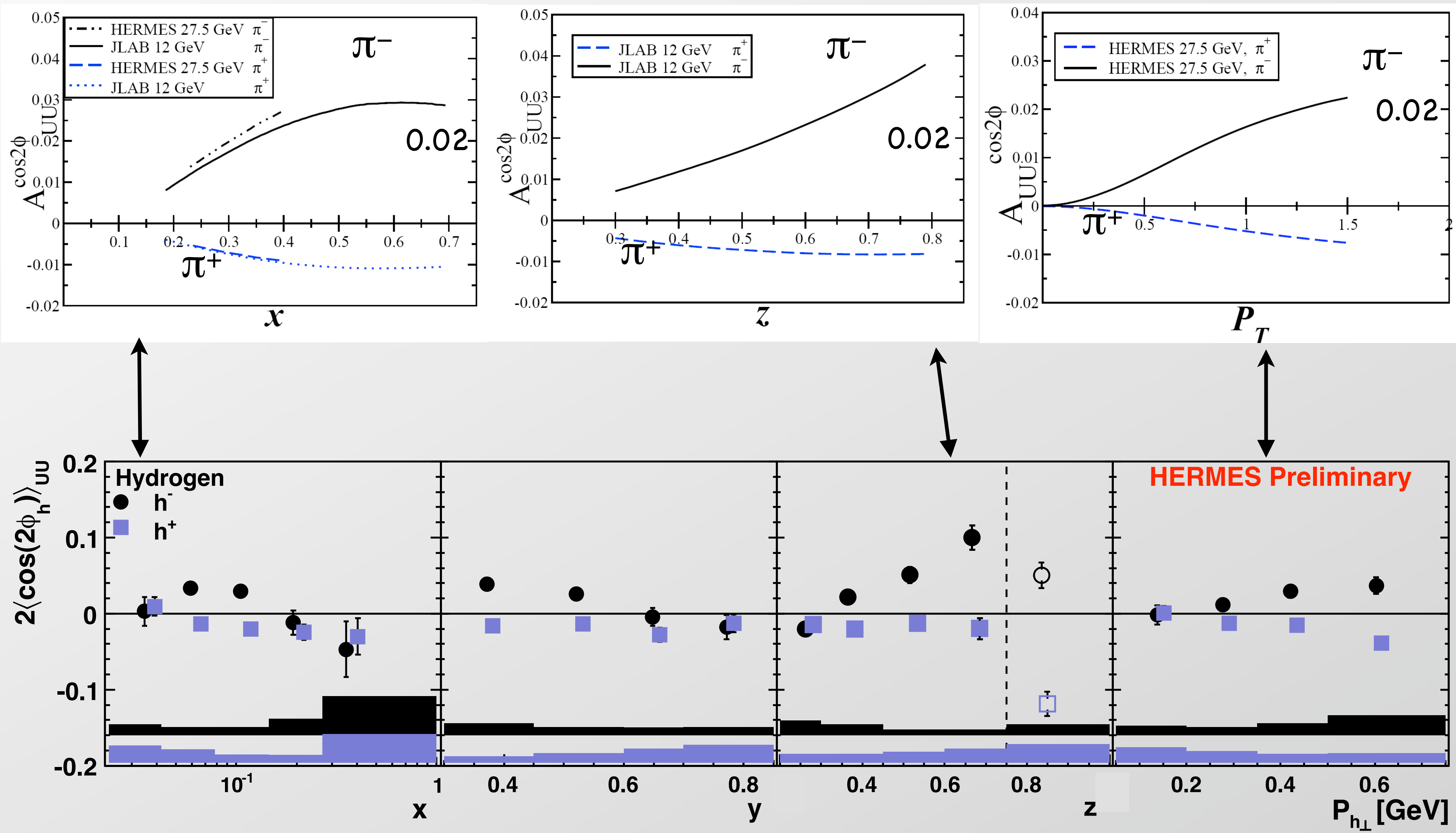
Collins calculated in the spectator framework
A. Bacchetta, et al., Phys. Lett. B 659, 234 (2008).

<cos(2ϕh)>: Model 1

Gamberg et al.

L. P. Gamberg et al., Phys Rev D67:071504, 2003

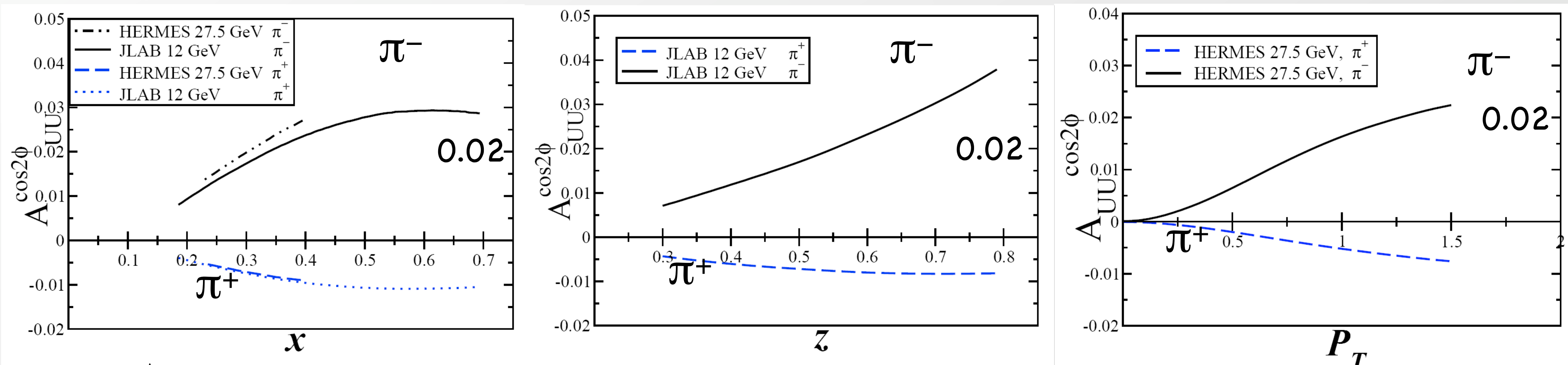
L. P. Gamberg and G. R. Goldstein, arXiv:0708.0324, 2007



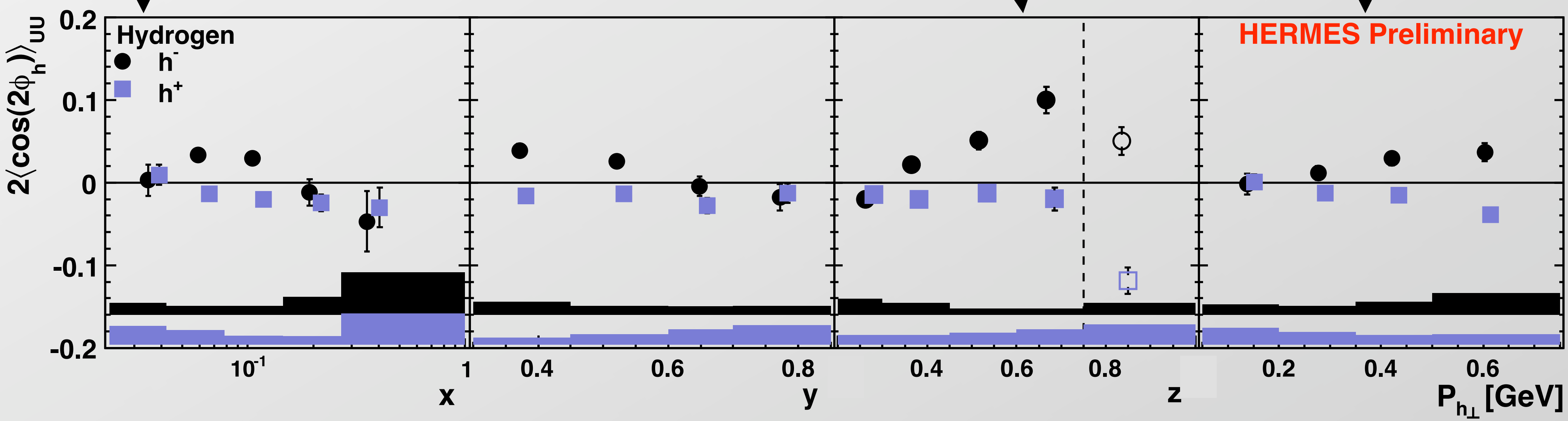
$\langle\cos(2\phi_h)\rangle$: Model 1

Gamberg et al.

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



Diquark spectator model does well… without Cahn term



<cos(2ϕh)>: Model 1

Gamberg et al.

L. P. Gamberg et al., Phys Rev D67:071504, 2003

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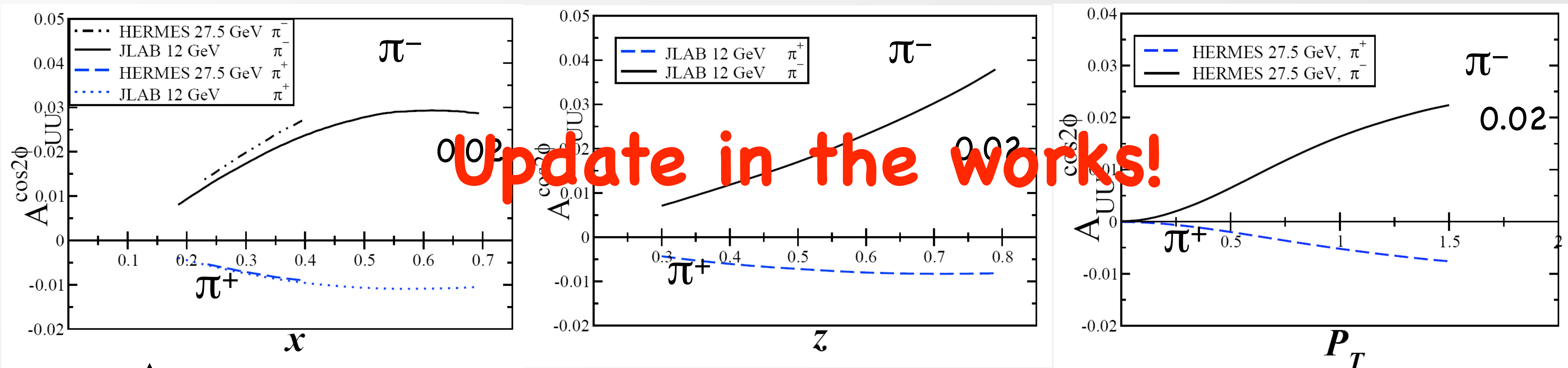

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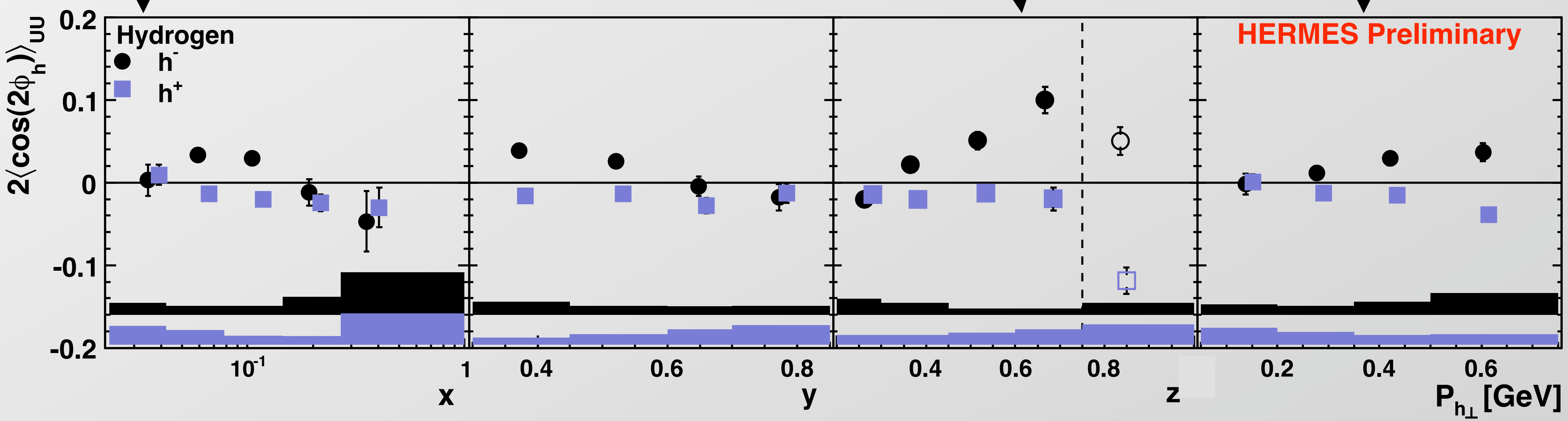


Model 2

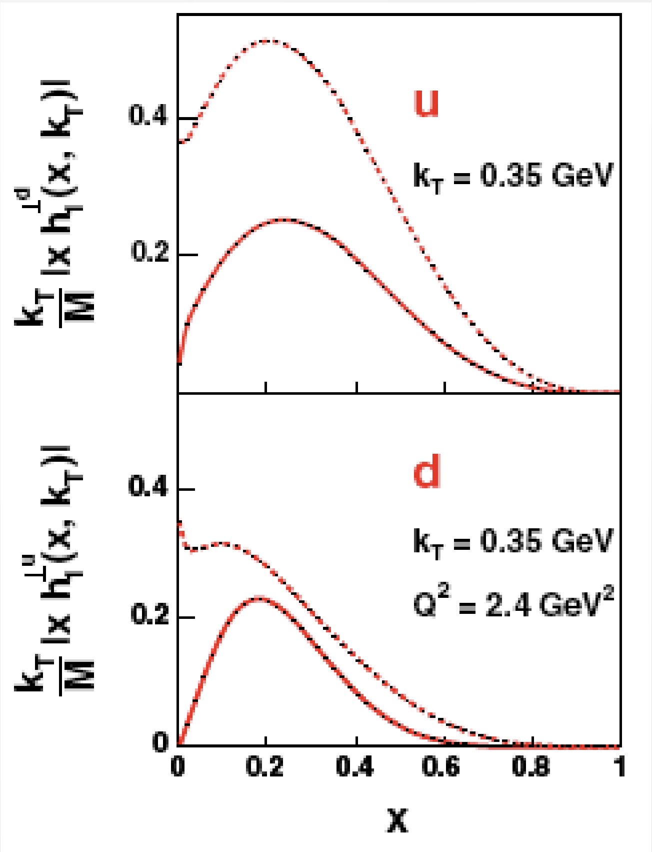
V. Barone et al. Phys.Rev.D78:045022,2008

$\langle\cos(2\phi_h)\rangle$: Model 2

Barone et al.

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

Same sign u and d Boer-Mulders function taken as a scaled Sivers function



anomalous tensor magnetic moment

$$h_1^{\perp q} \sim -\kappa_T^q$$

anomalous magnetic moment

$$f_{1T}^{\perp q} \sim -\kappa^q$$

$$h_1^{\perp q}(x, k_T^2) = \frac{\kappa_T^q}{\kappa^q} f_{1T}^{\perp q}(x, k_T^2)$$

$$h_1^{\perp u} = 1.80 f_{1T}^{\perp u},$$

$$h_1^{\perp d} = -0.94 f_{1T}^{\perp d}$$

Sivers fit to SSA data taken from M. Anselmino et al., Phys. Rev. D 72, 094007 (2005).

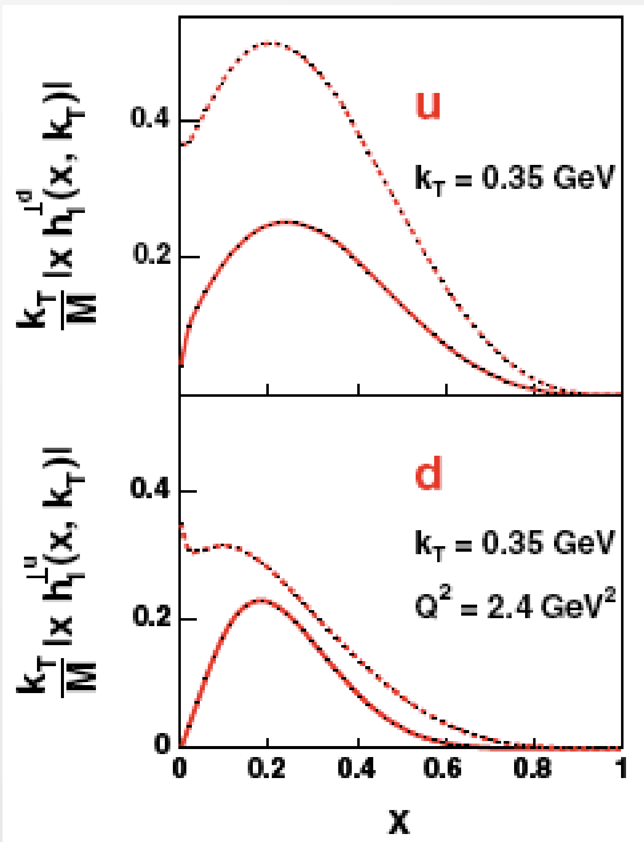
Collins parameterization to SIDIS and e+e- from M. Anselmino et al., Phys. Rev. D 75, 054032 (2007).

<cos(2ϕh)>: Model 2

Barone et al.

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

Same sign u and d Boer-Mulders function
taken as a scaled Sivers function



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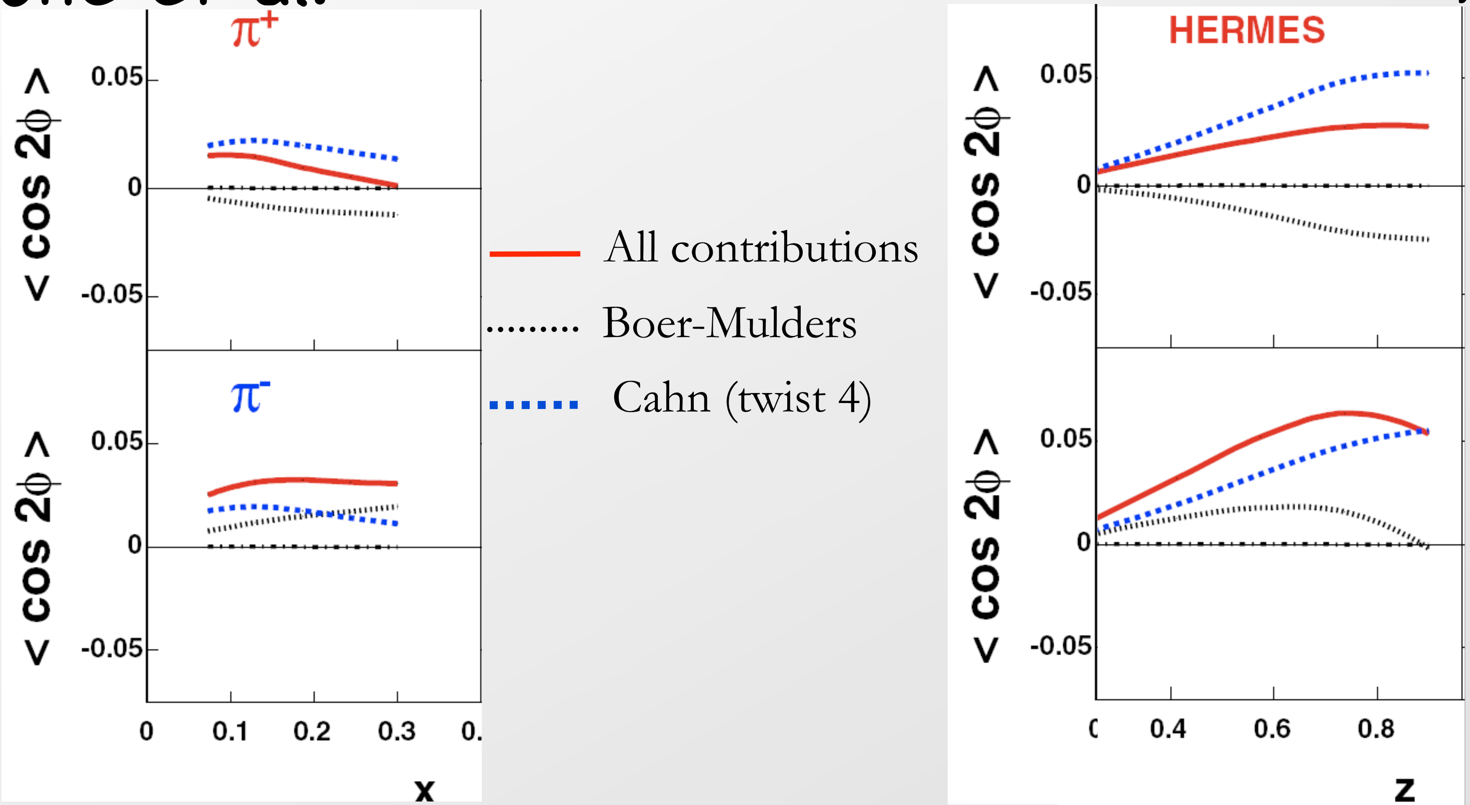
M. Anselmino et al., Phys. Rev. D 75, 054032 (2007).

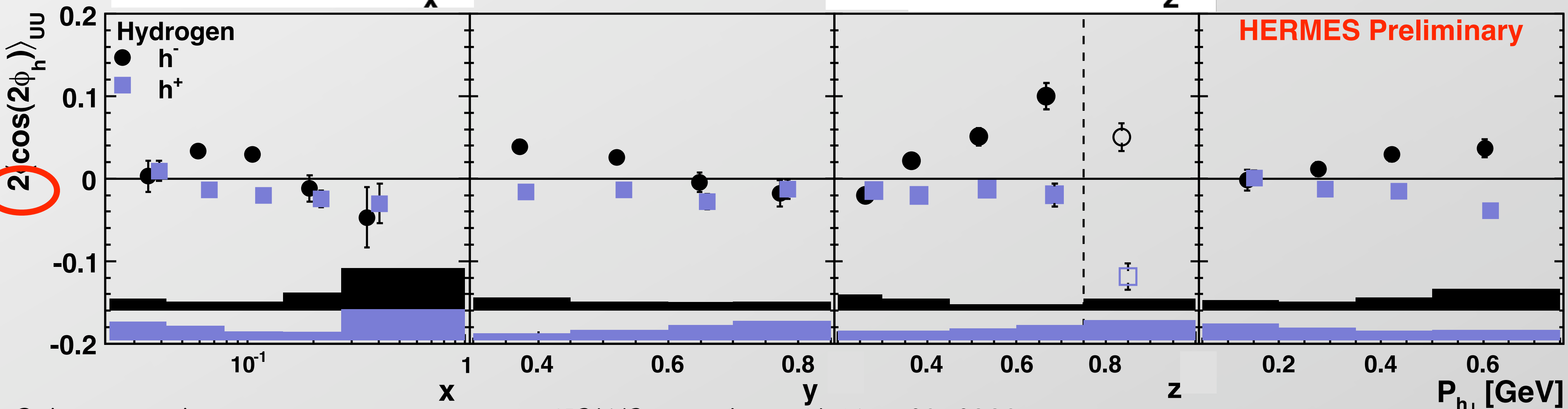
PLUS Cahn twist-4 contribution

<cos(2ϕh)>: Model 2

Barone et al.

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

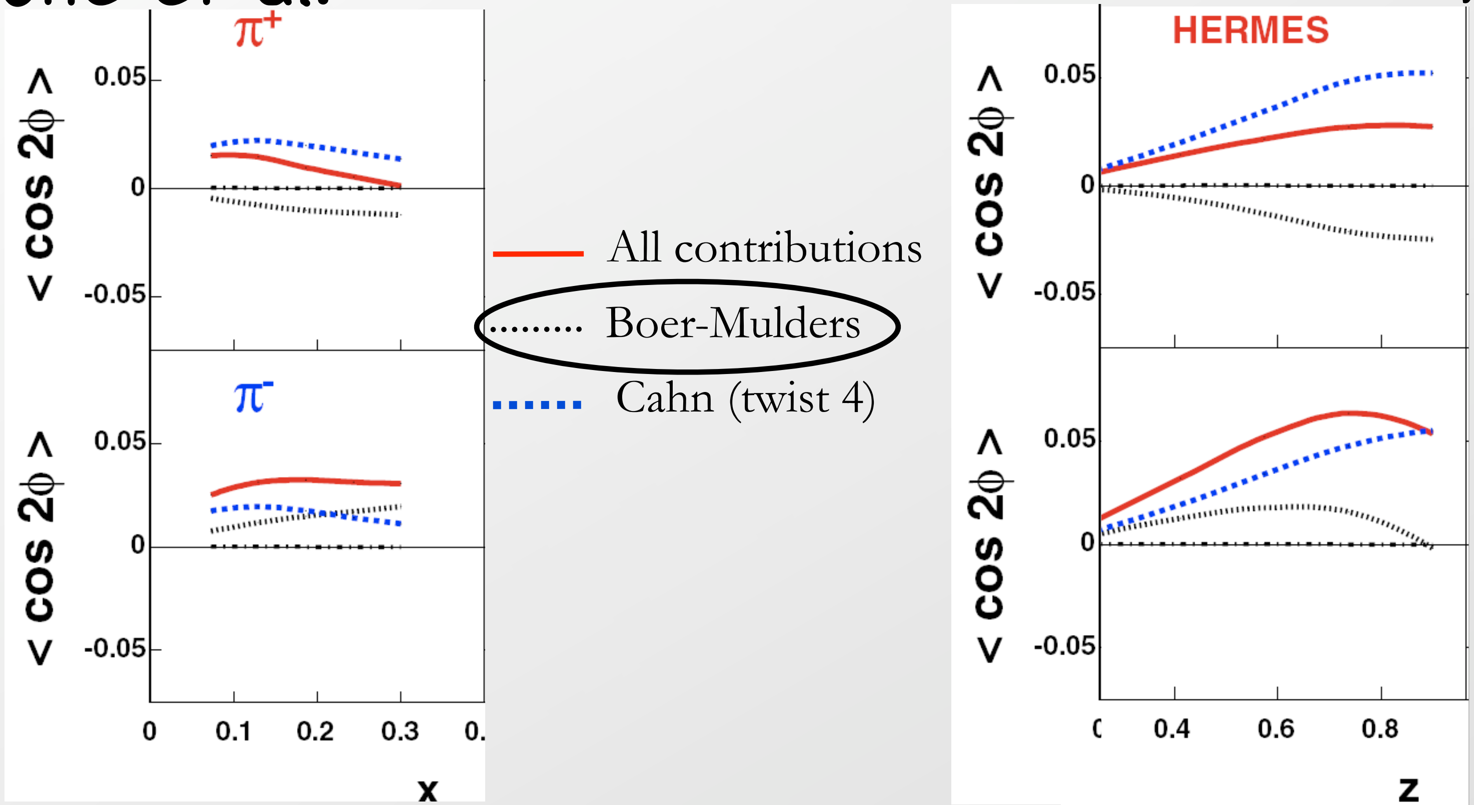




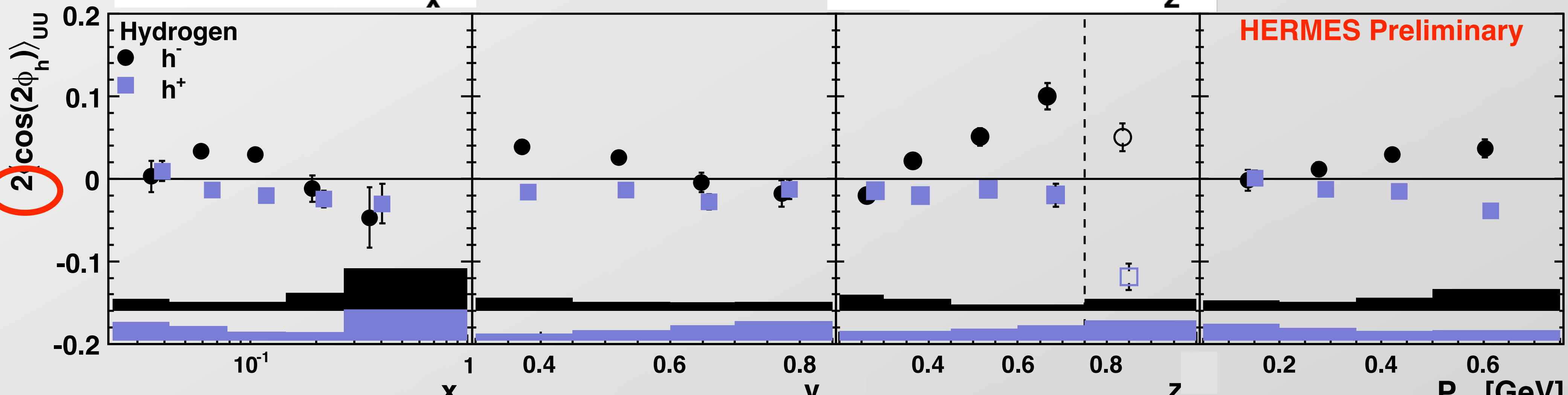
<cos(2ϕ_h)>: Model 2

Barone et al.

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



Cahn (twist 4) too large?



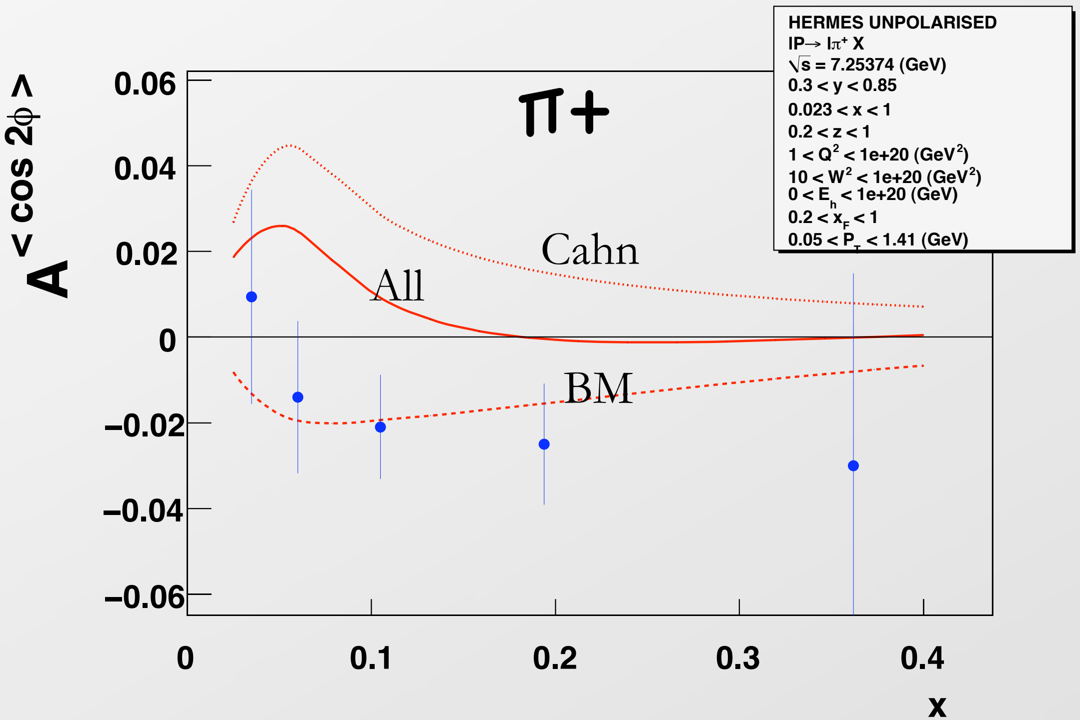
<cos(2ϕh)>: Model 2

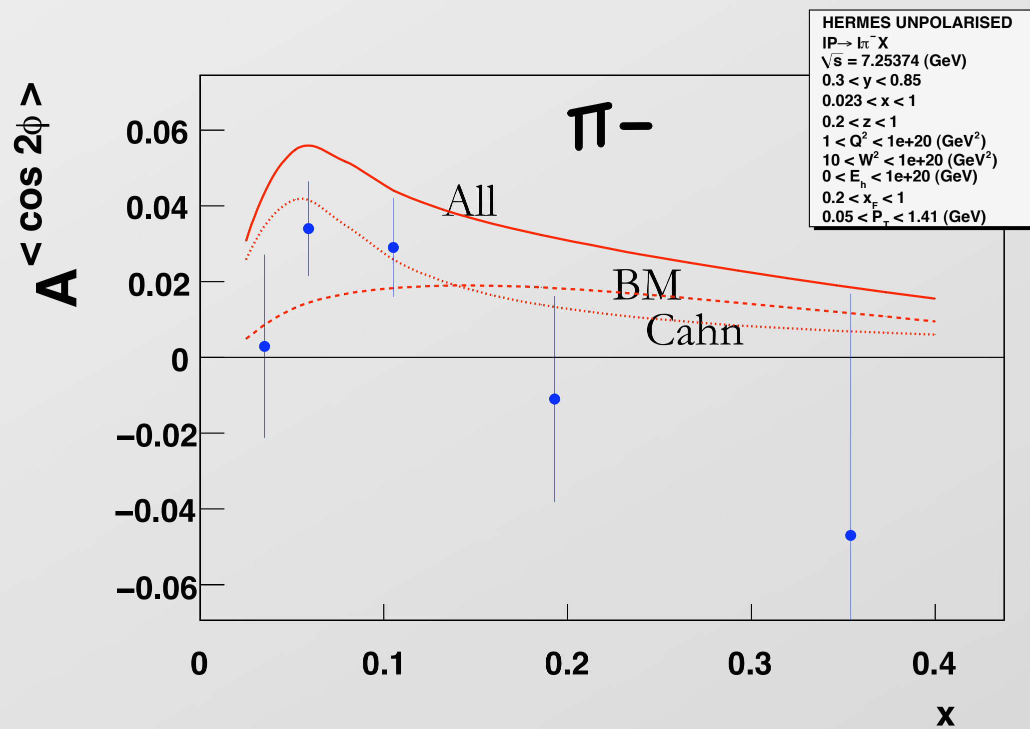
Barone et al.

V. Barone, S. Melis and A. Prokudin preliminary results

NEW work to update the twist-4 Cahn contribution

"standard" values $\langle k_\perp^2 \rangle = 0.25$ GeV^2 $\langle p_\perp^2 \rangle = 0.2$ GeV^2





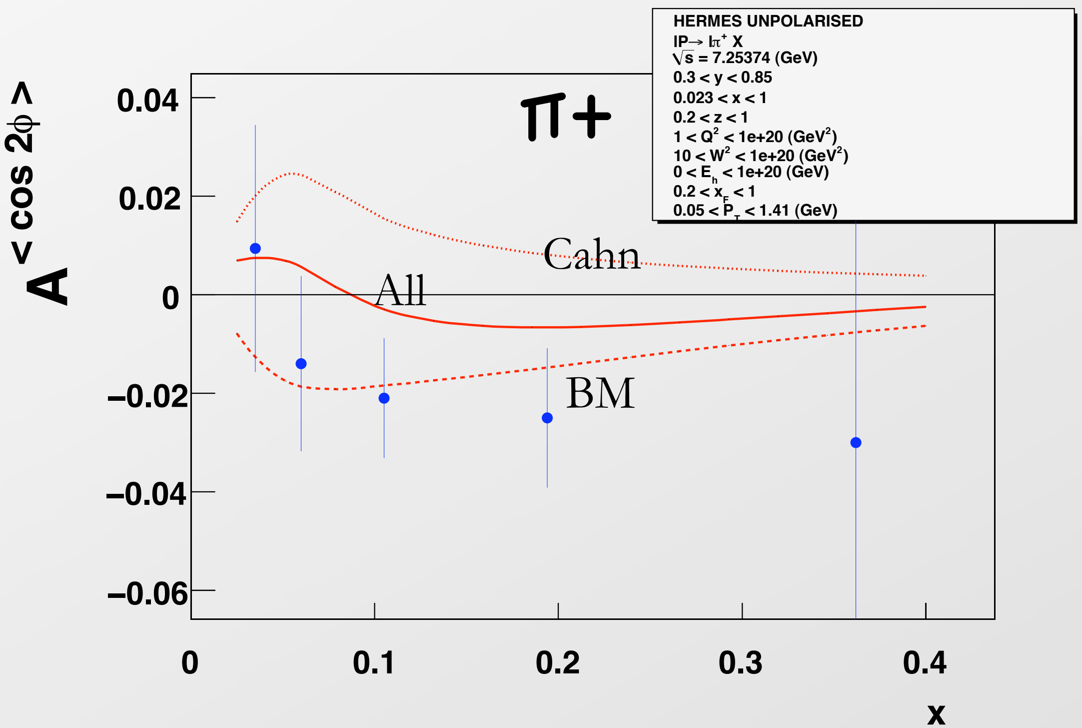
<cos(2ϕh)>: Model 2

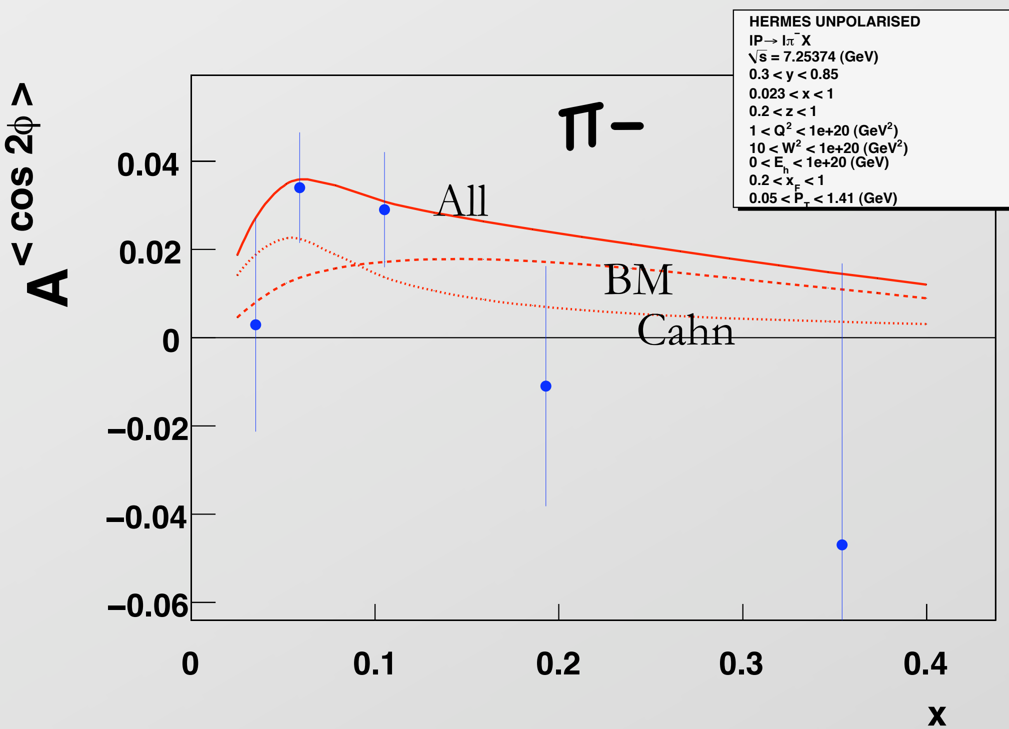
Barone et al.

V. Barone, S. Melis and A. Prokudin preliminary results

NEW work to update the twist-4 Cahn contribution

$$\langle k_\perp^2 \rangle = 0.18\ \mathrm{GeV}^2 \quad \langle p_\perp^2 \rangle = 0.42 \cdot (1-z)^{0.54} \cdot z^{0.37}\ \mathrm{GeV}^2$$





More work needs to be done to understand $\langle k_T^2 \rangle$ before BM can be cleanly extracted

Model 3

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

$\langle\cos(2\phi_h)\rangle$: Model 3

Zhang et al.

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

Boer-Mulders extracted from unpolarized p+D Drell-Yan data

$$h_1^{\perp,q}(x,\mathrm{k}_T^2) = h_1^{\perp,q}(x)\frac{\exp(-\mathrm{k}_T^2/p_{bm}^2)}{\pi p_{bm}^2},$$

$$\begin{aligned} h_1^{\perp,u}(x) &= \omega H_u\, x^c\,(1-x)\, f_1^u(x), \\ h_1^{\perp,d}(x) &= \omega H_d\, x^c\,(1-x)\, f_1^d(x), \\ h_1^{\perp,\bar{u}}(x) &= \frac{1}{\omega} H_{\bar{u}}\, x^c\,(1-x)\, f_1^{\bar{u}}(x), \\ h_1^{\perp,\bar{d}}(x) &= \frac{1}{\omega} H_{\bar{d}}\, x^c\,(1-x)\, f_1^{\bar{d}}(x), \end{aligned}$$

	Set I	Set II
H_u	3.99	4.44
H_d	3.83	-2.97
$H_{\bar{u}}$	0.91	4.68
$H_{\bar{d}}$	-0.96	4.98
p_{bm}^2	0.161	0.165
c	0.45	0.82
$\chi^2/d.o.f.$	0.79	0.79

Set II:

Boer-Mulders extracted assuming $h_1^{\perp,u}$ and $h_1^{\perp,d}$ of **opposite signs**

-> results in **large** $h_1^{\perp}$ for antiquarks

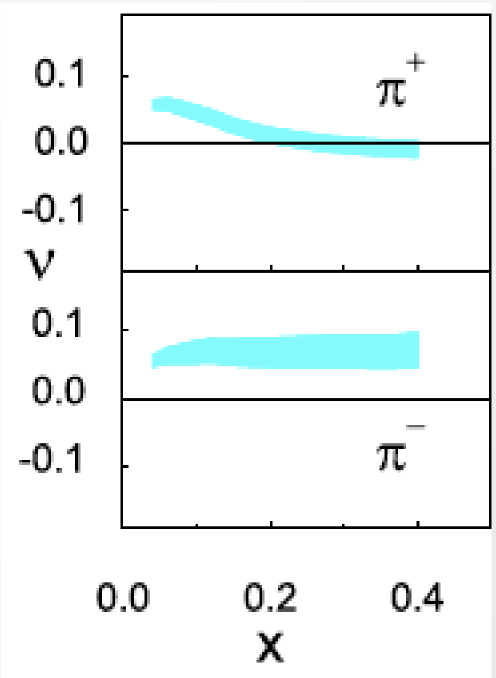
Collins parameterization to SIDIS and e+e- from
M. Anselmino et al., Phys. Rev. D 75, 054032 (2007).

f_1 MRST2001 LO
D_1 Kretzer

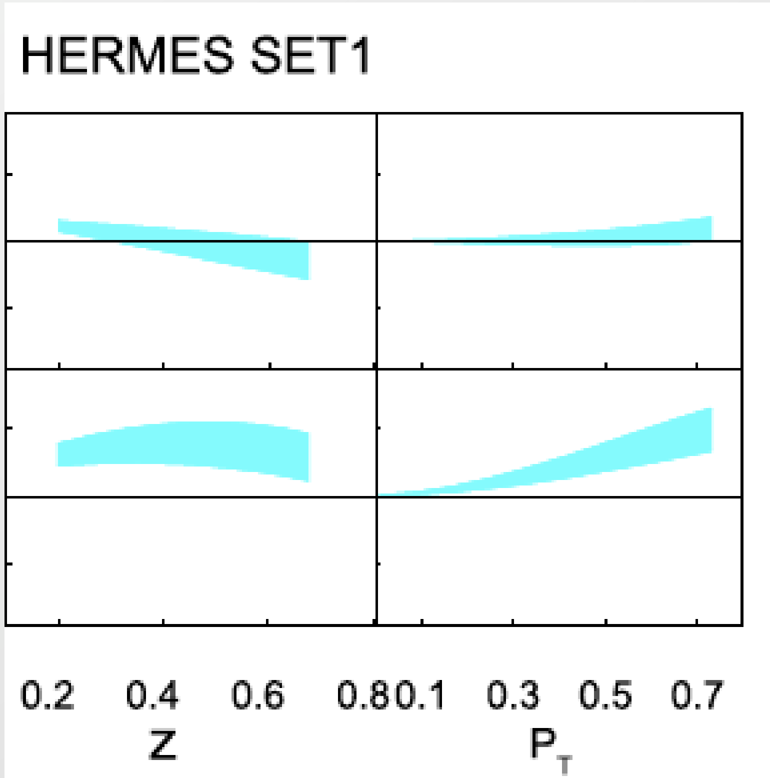
<cos(2ϕ_h)>: Model 3

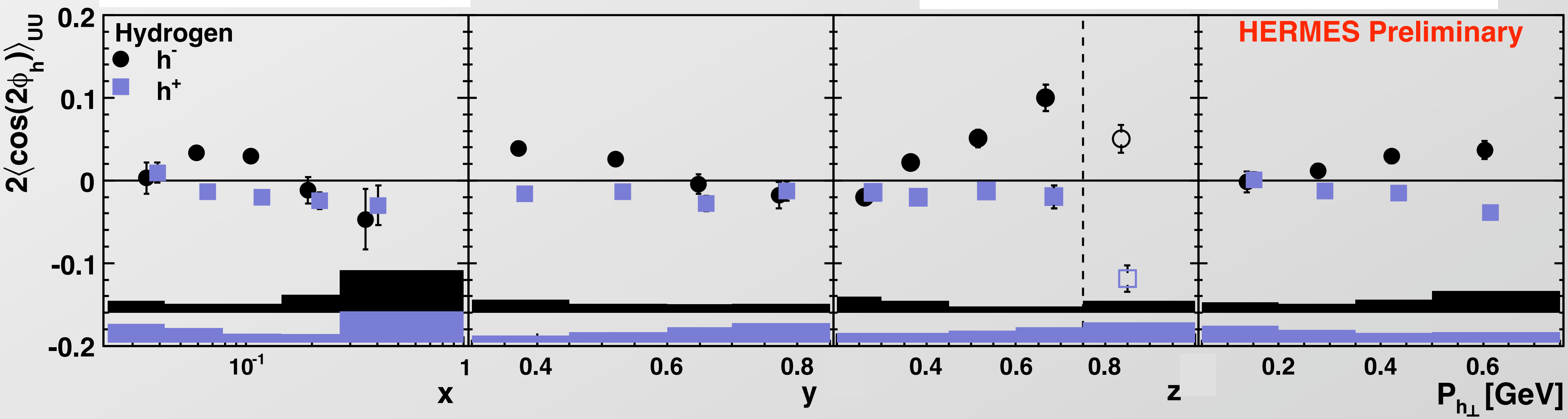
Zhang et al.

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



Same sign
u and d

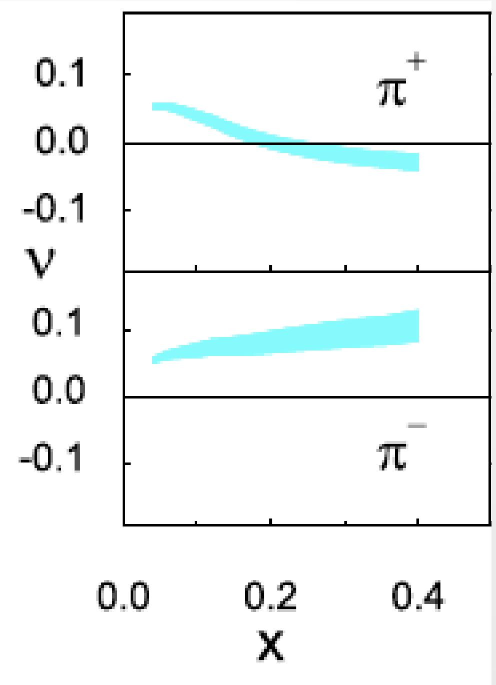




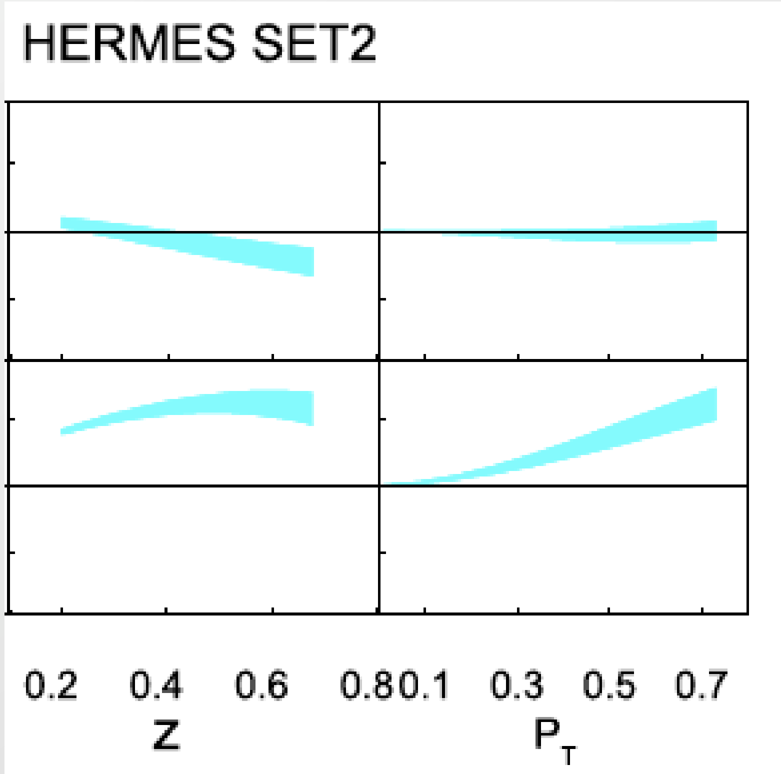
<cos(2ϕ_h)>: Model 3

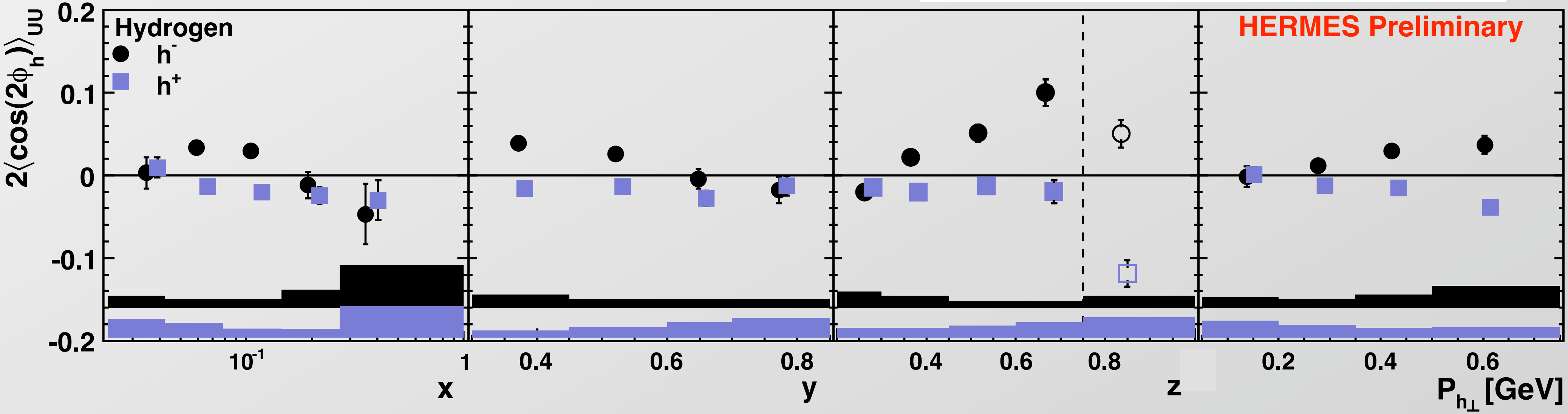
Zhang et al.

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



Opposite sign
u and d





<cos(2ϕ_h)>: Hydrogen vs Deuterium

in the (roughly implemented) Zhang model

Using:

$$\frac{\int H_{1,\text{disfav}}^{\perp}}{\int H_{1,\text{fav}}^{\perp}} = -1$$

$$\eta \equiv \frac{\int D_{1,\text{disfav}}}{\int D_{1,\text{fav}}} \simeq 0.35$$

Caveats of this rough version of the model

- PDFs
  - k_T dependence not included
  - Different unpolarized PDFs used
- FFs
  - Full Collins functions not included
  - Just a constant ratio of favored/disfavored used

$$\langle \cos(2\phi) \rangle_H^{\pi^+} \sim \frac{4\delta u_v - \delta d_v}{4u + \eta d + 4\eta \bar{u} + \bar{d}}$$

$$\langle \cos(2\phi) \rangle_H^{\pi^-} \sim \frac{-4\delta u_v + \delta d_v}{4\eta u + d + 4\bar{u} + \eta \bar{d}}$$

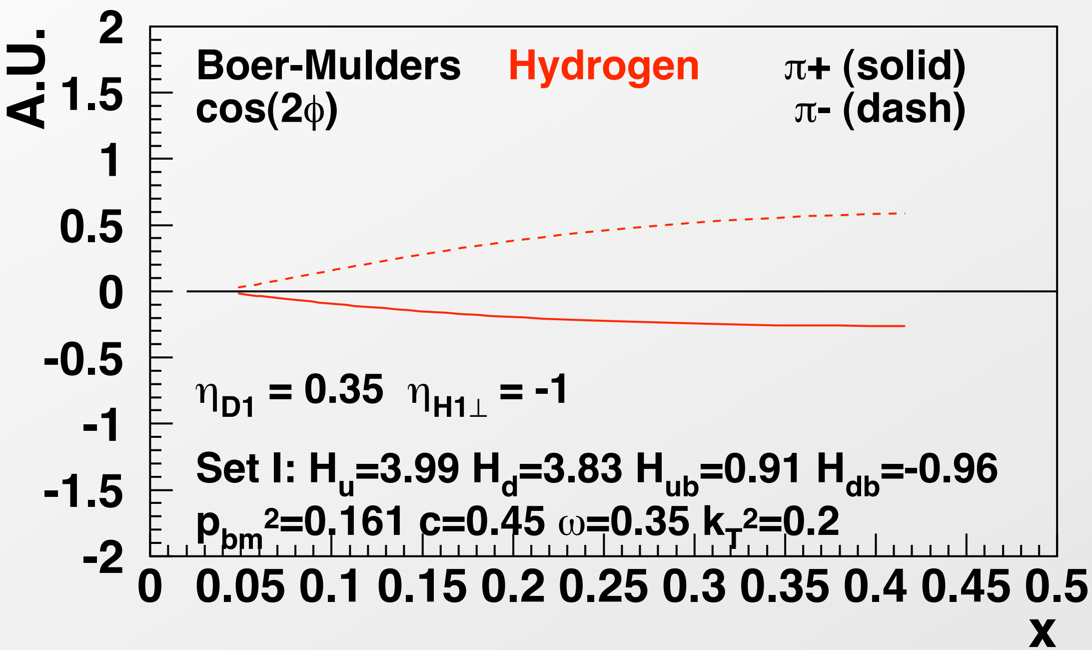
- Overall normalization missing
- Extra(??) -1 needed to get sign
  - ν <-> <cos(2ϕ)> ??
  - sign of Collins??

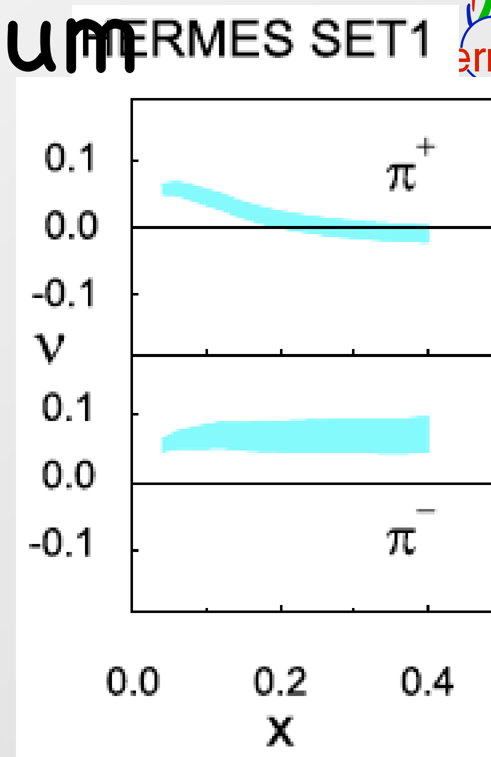
$$\langle \cos(2\phi) \rangle_D^{\pi^+} \sim \frac{3\delta u_v + 3\delta d_v}{(4+\eta)(u+d) + (4\eta+1)(\bar{u}+\bar{d})}$$

$$\langle \cos(2\phi) \rangle_D^{\pi^-} \sim \frac{-3\delta u_v - 3\delta d_v}{(4\eta+1)(u+d) + (4+\eta)(\bar{u}+\bar{d})}$$

<cos(2ϕh)>: Hydrogen vs Deuterium

in the (roughly implemented) Zhang model



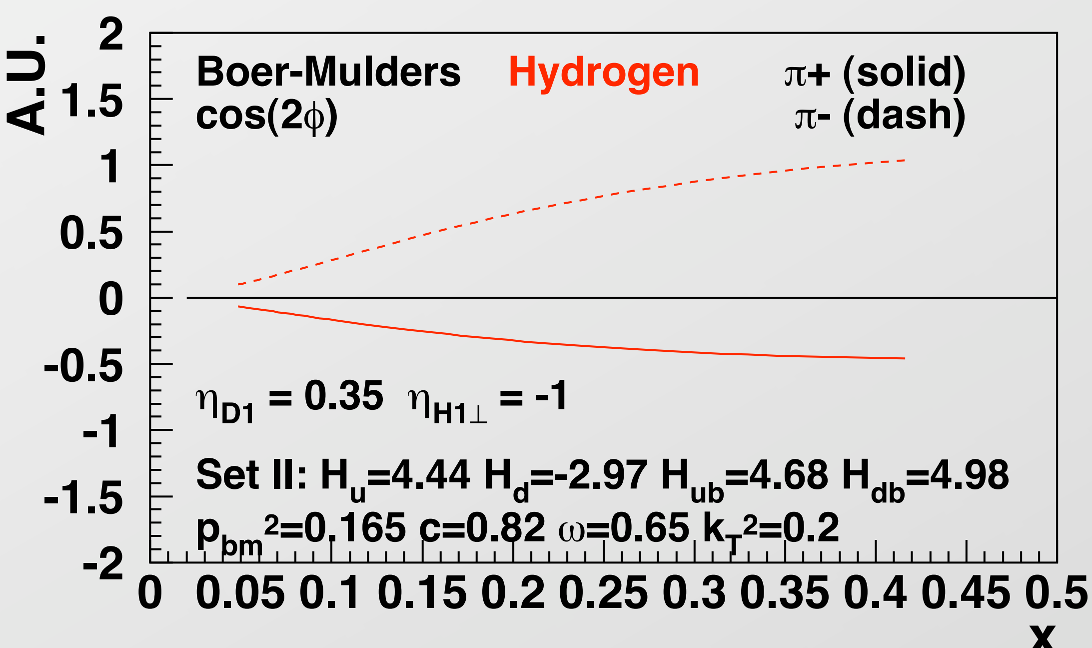


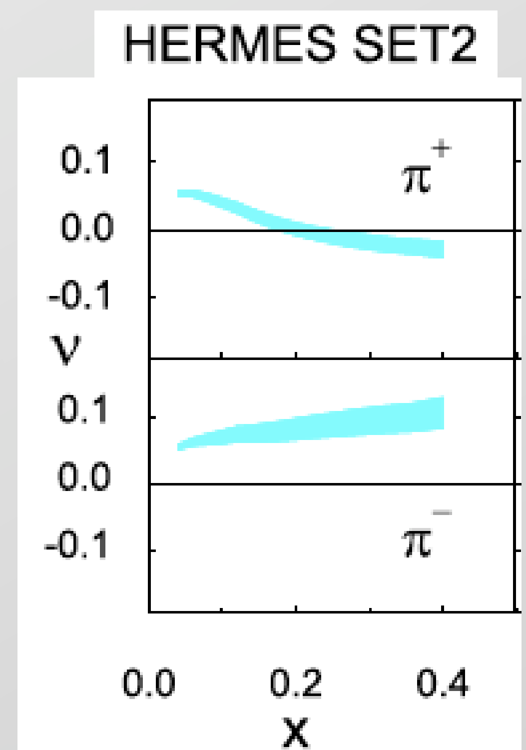
Set 1 & Set 2

similar shape

&

relative size

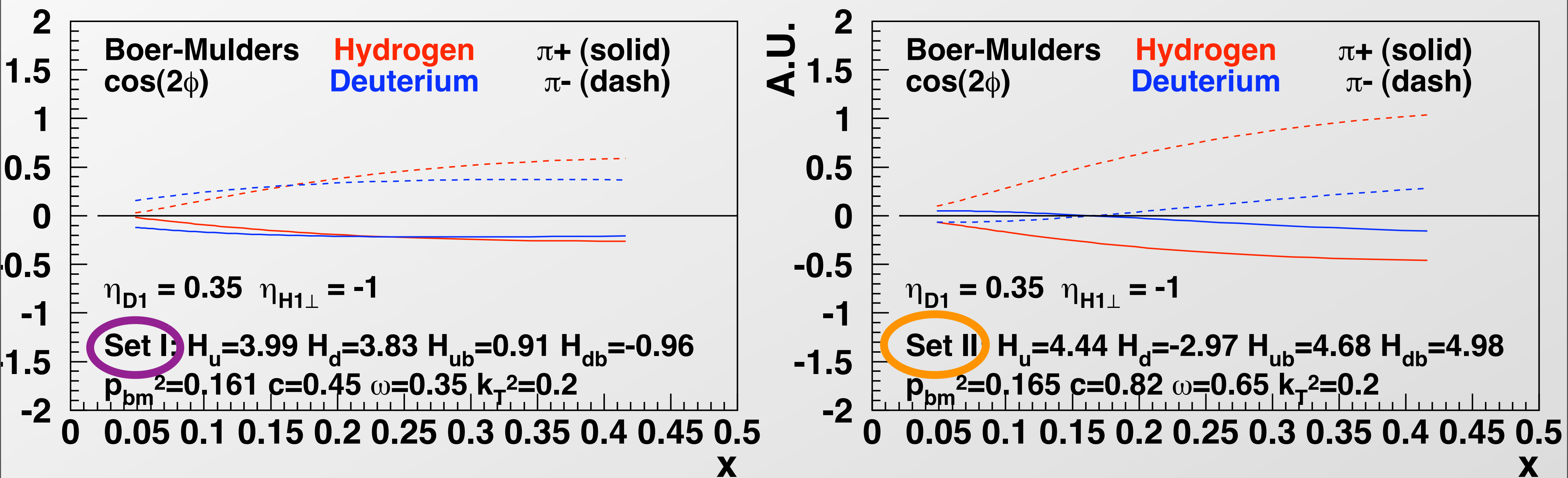




<cos(2ϕ_h)>: Hydrogen vs Deuterium

in the (roughly implemented) Zhang model

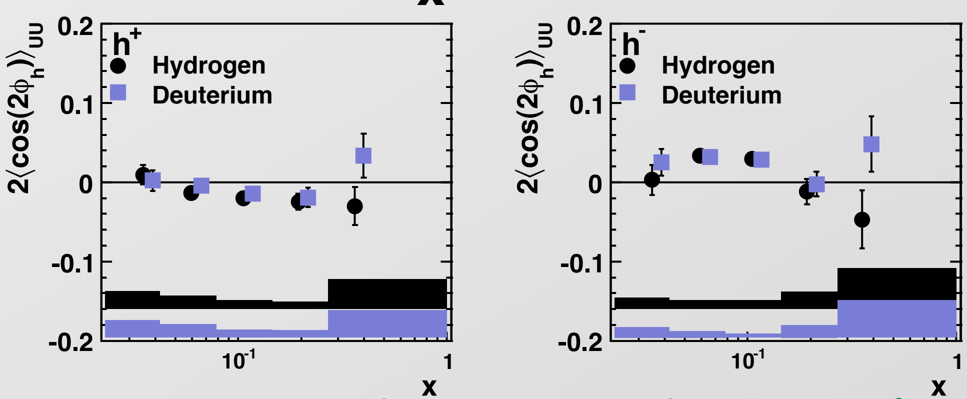
So given that we are doing something reasonable for H, let's calculate D...



Set 1

Like the data

H~D



Set 2

Not like the data

H~large D~0

We MUST use H AND D data to determine the u/d sign!!!

What's next?

- Our dual-radiator RICH has **improved** software for beautifully identified **pions**, kaons, and protons

- This analysis: ~1.5M SIDIS on both H and D
  Additional **~5M** SIDIS on both H and D available

- Novel 1D projections that
  - Reach to higher $P_{h\perp}$
  - Strive to disentangle our $x - Q^2$ dependence

Conclusions

NEW HERMES results!

- $\langle\cos(\phi_h)\rangle$ and $\langle\cos(2\phi_h)\rangle$ on Hydrogen and Deuterium

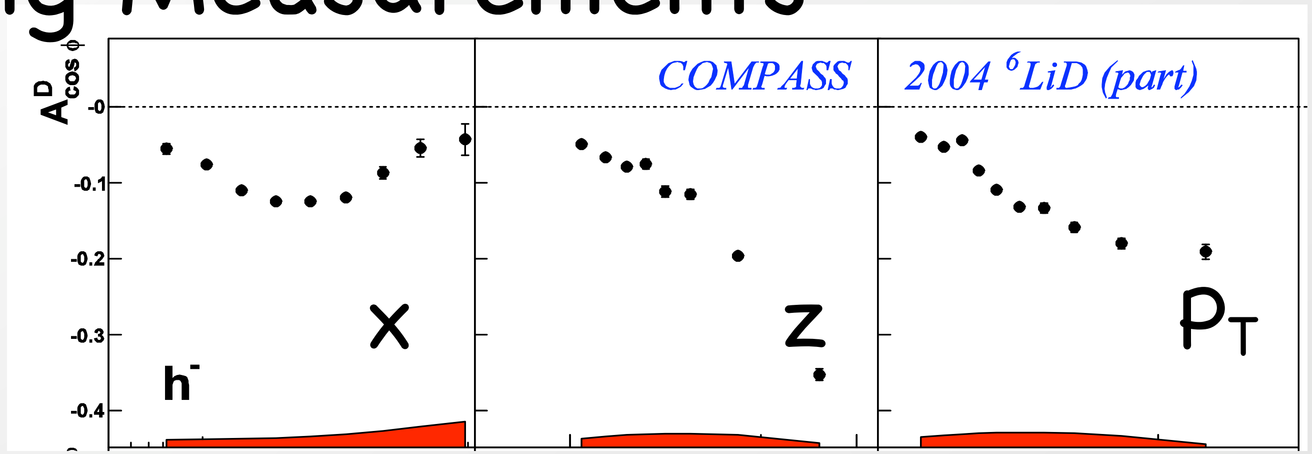
- $\langle\cos(\phi_h)\rangle$
  - $h+ \neq h-$
    - $\langle k_T\rangle^u \neq \langle k_T\rangle^d$??
    - $(h_1^\perp \otimes H_1^\perp)^{\pi+} \neq (h_1^\perp \otimes H_1^\perp)^{\pi-}$ significant??
- $\langle\cos(2\phi_h)\rangle$
  - Sensitive to Boer-Mulders DF
  - Twist-4 Cahn term must be taken into account!!
  - Models for D essential in determining u / d relative sign

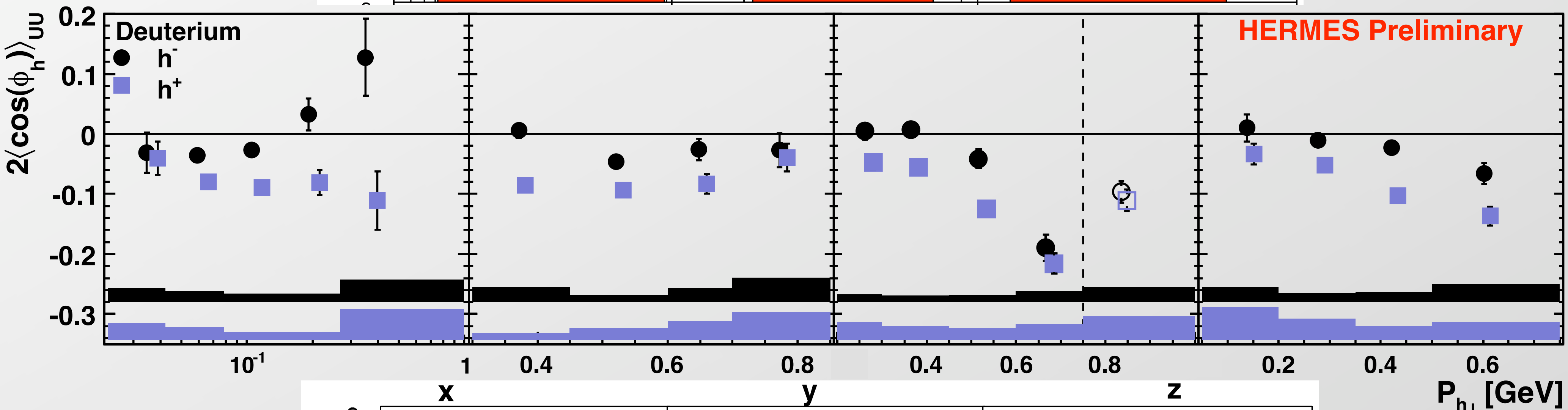
- Cahn and BM both contribute to both $\langle\cos(\phi_h)\rangle$ and $\langle\cos(2\phi_h)\rangle$
- Comprehensive models needed (BM+Cahn, H&D, $\langle\cos(\phi_h)\rangle$&$\langle\cos(2\phi_h)\rangle$

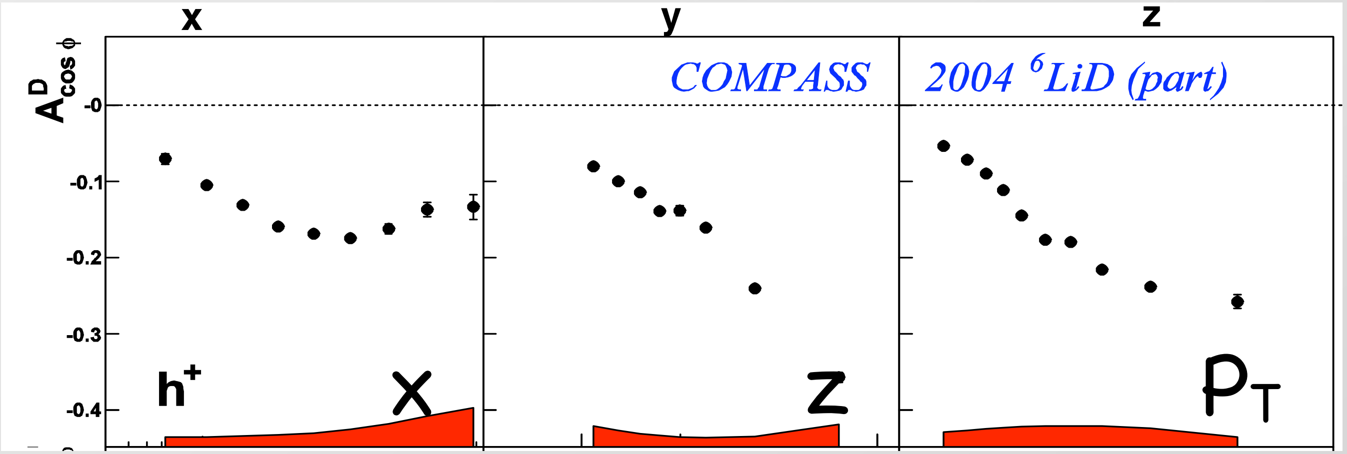
- Challenge: reconcile HERMES and COMPASS results
  - Different kinematic range?

Backup Slides

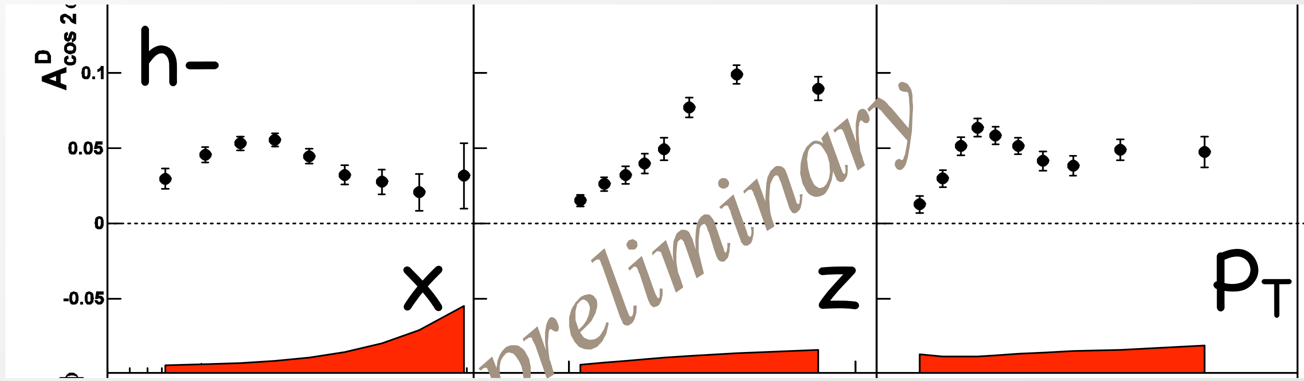
Existing Measurements

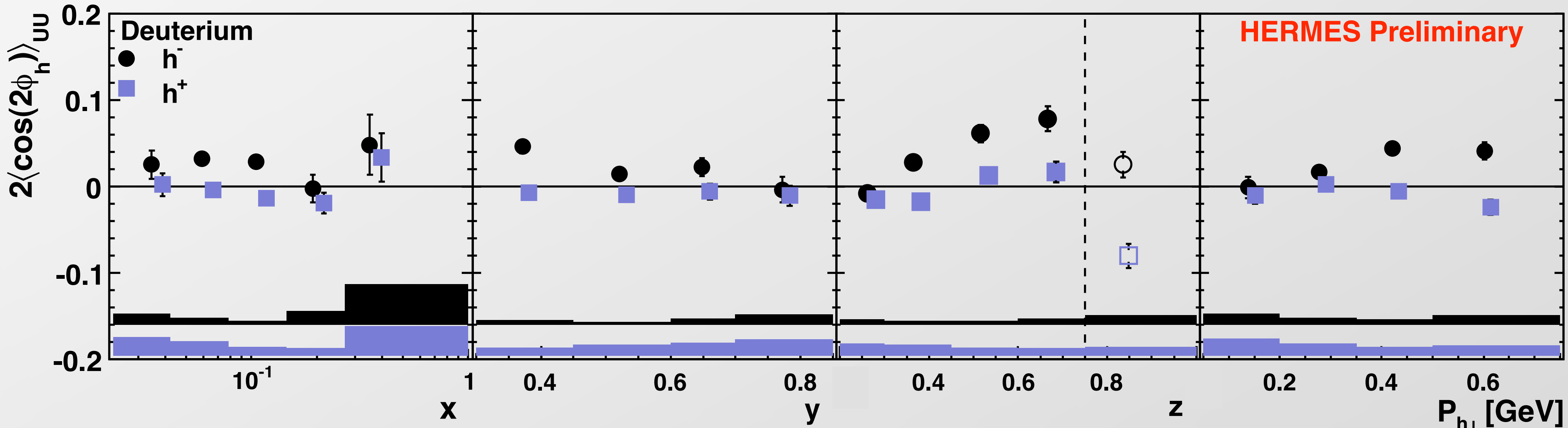


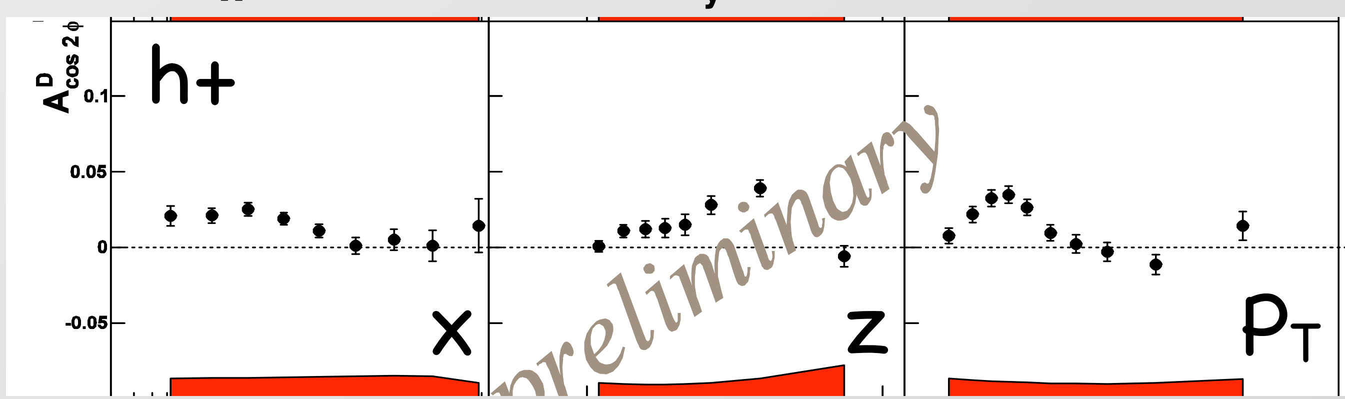




Existing Measurements

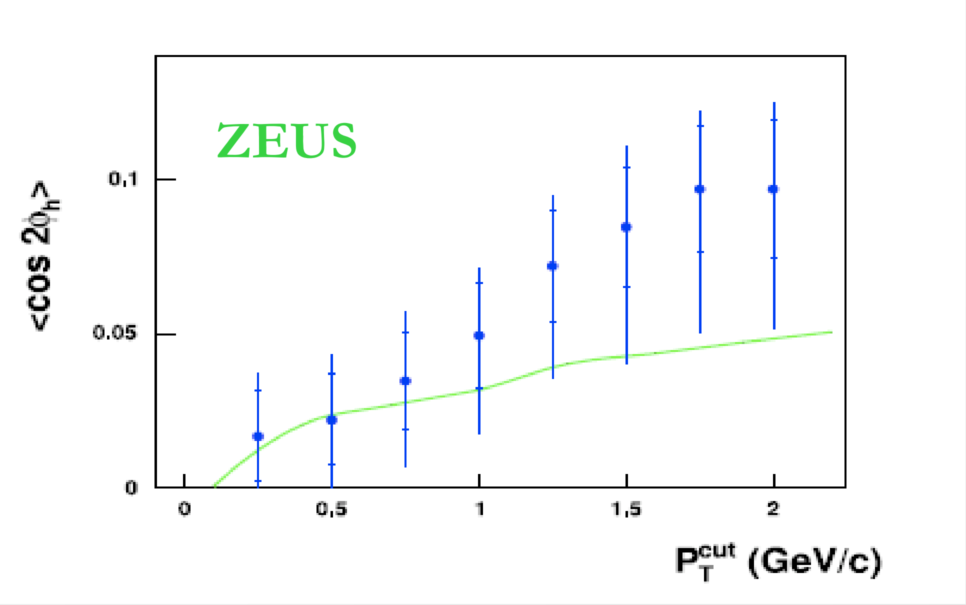


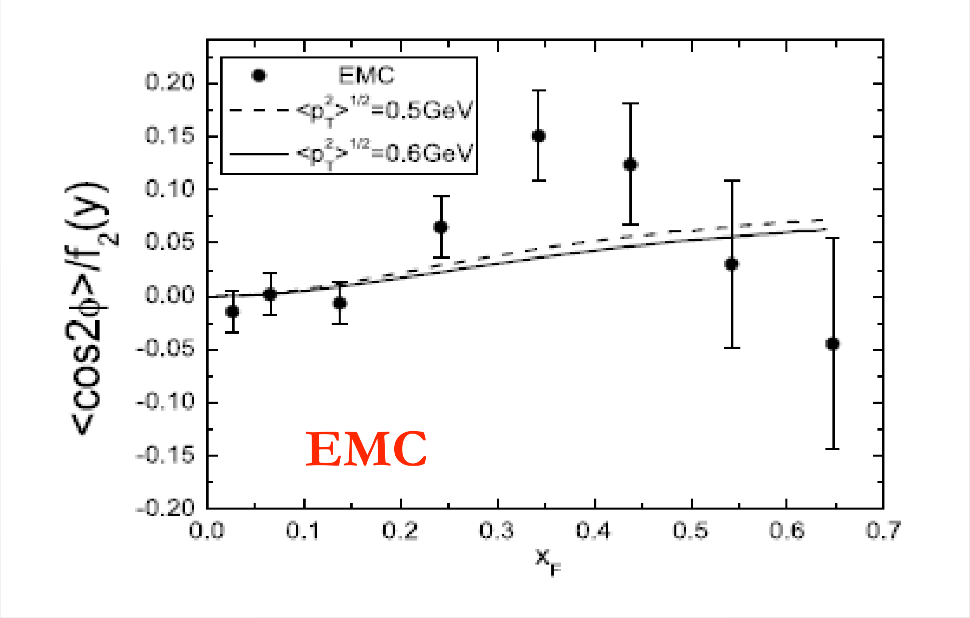




Existing Measurements

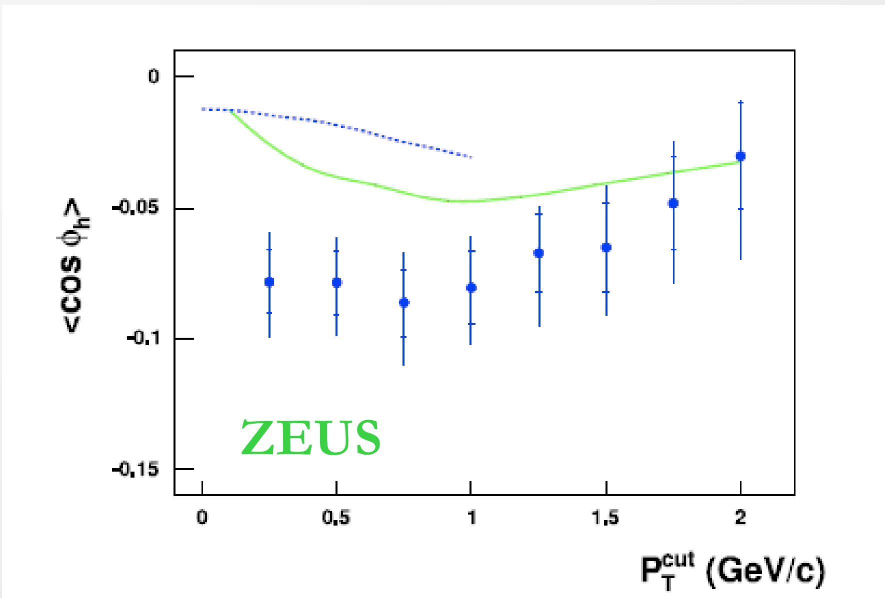
$\cos(2\phi_h)$

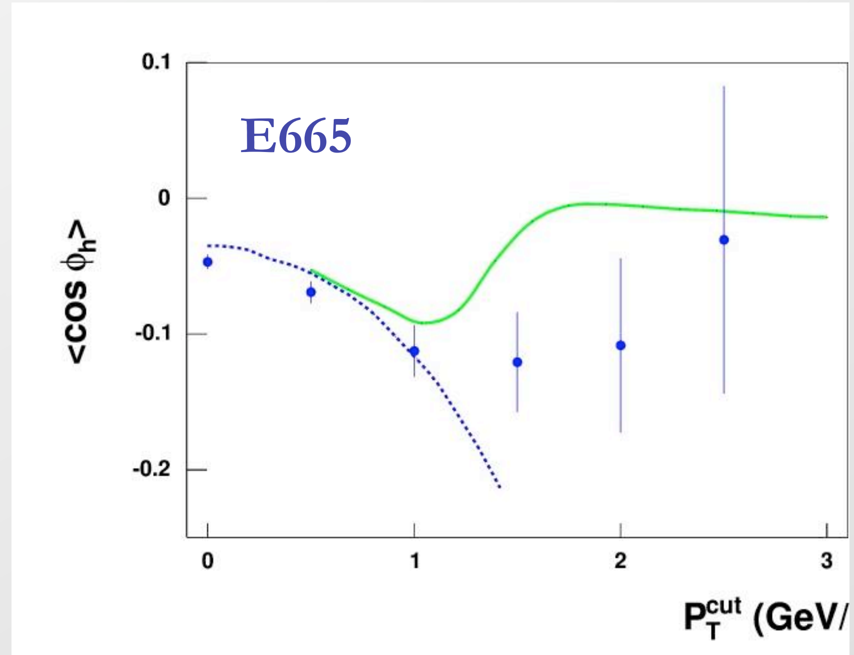


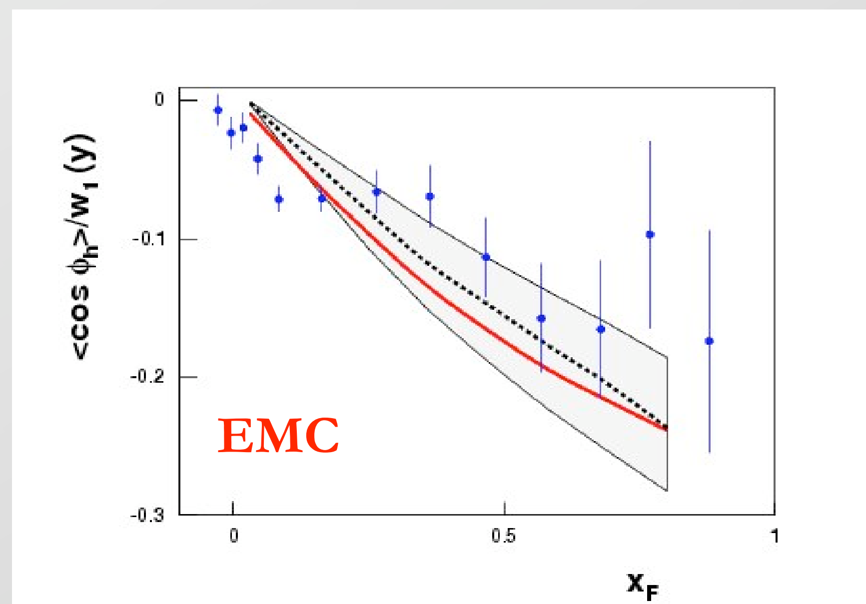


Existing Measurements

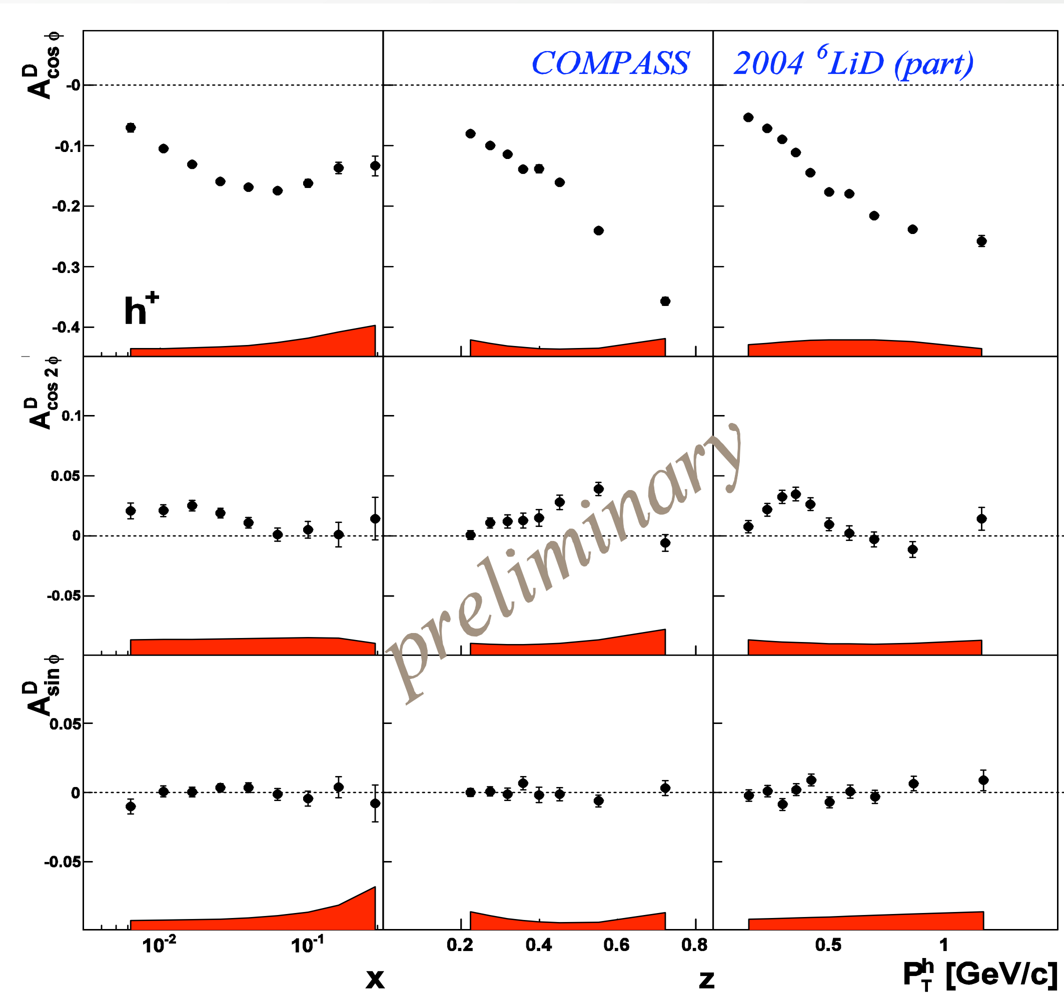
$\cos(\phi_h)$

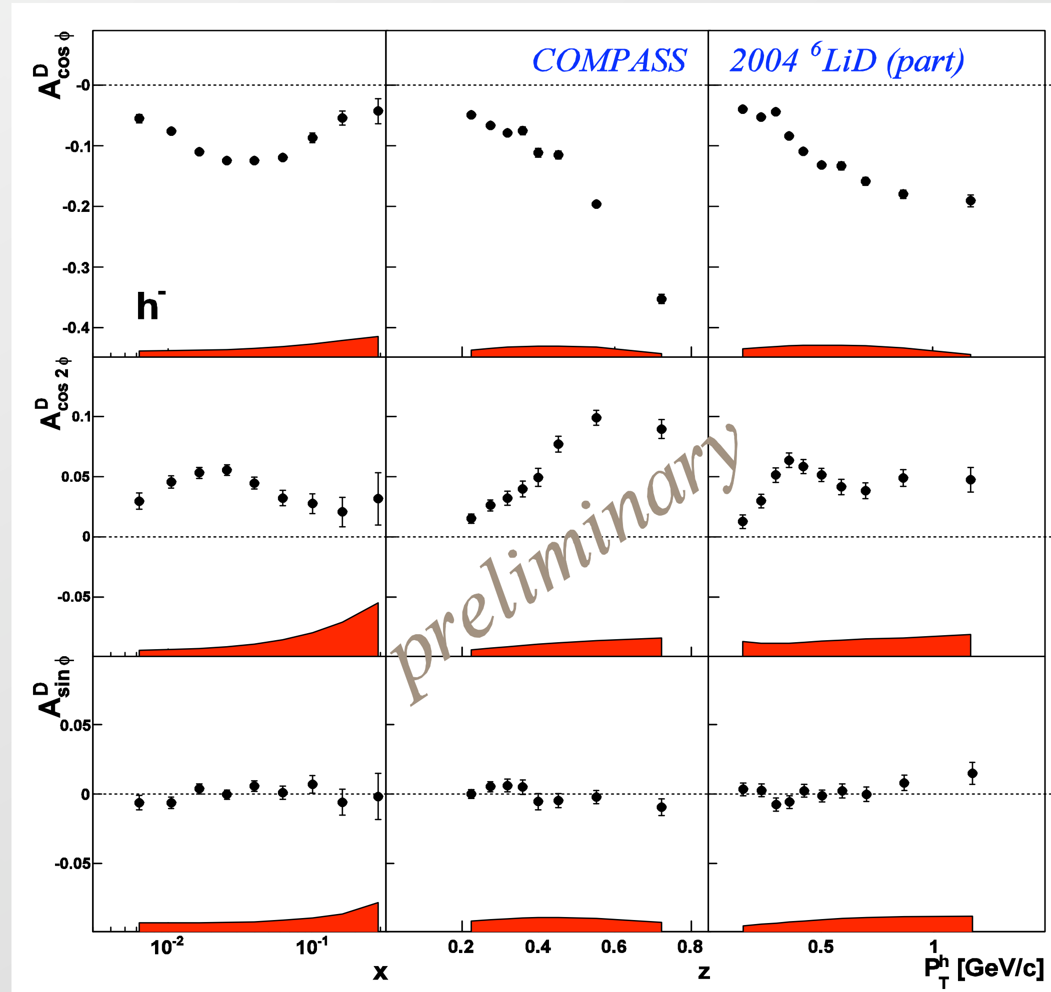




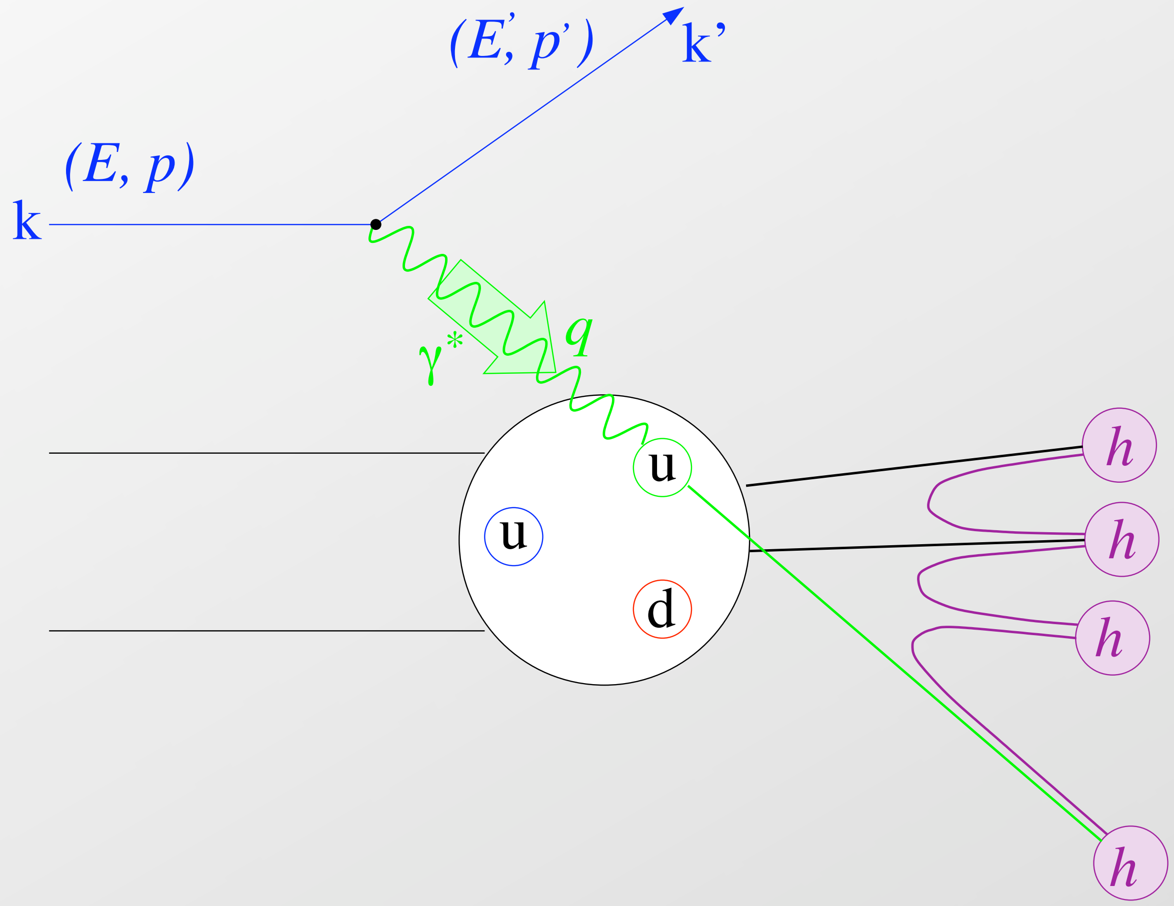


Existing Measurements





Semi-Inclusive Deep Inelastic Scattering



$$Q^2 = -q^2$$
$$x = \frac{Q^2}{2P\cdot q} \stackrel{lab}{=} \frac{Q^2}{2M\nu}$$
$$y = \frac{P\cdot q}{P\cdot k} \stackrel{lab}{=} \frac{\nu}{E}$$
$$z = \frac{P\cdot P_h}{P\cdot q} \stackrel{lab}{=} \frac{E_h}{\nu}$$
$$\gamma = \frac{2Mx}{Q}$$
$$W^2 = (P+q)^2 \stackrel{lab}{=} M^2 + 2M\nu - Q^2$$