Flavor dependent azimuthal modulations in unpolarized SIDIS cross section at HERMES

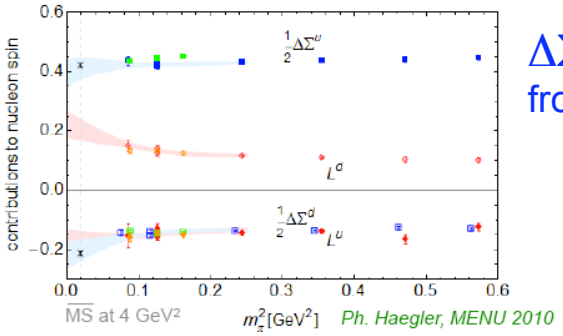
Contalbrigo Marco
INFN Ferrara

DIS 2011
April 13, 2011 Newport News

Open issues: test field for QCD

Proton spin budget: role of partonic orbital motion?

DSS, PRL101 (2008) 072001

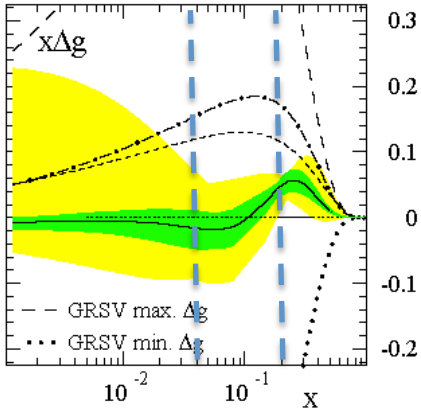


Ph. Haegler, MENU 2010

$\Delta\Sigma$=0.33±0.03
from DIS & Lattice

ΔG small at 0.02<x<0.3
from DIS and pp scattering

$$\frac{1}{2} = \frac{1}{2}\sum_f (q_f^+ - q_f^-) + L_q + \Delta G + L_g$$



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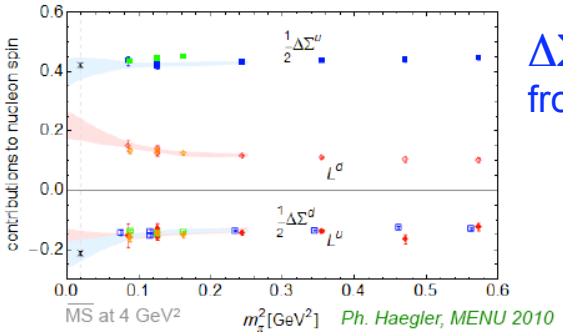

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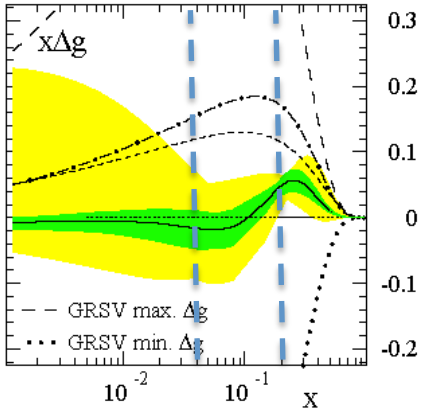
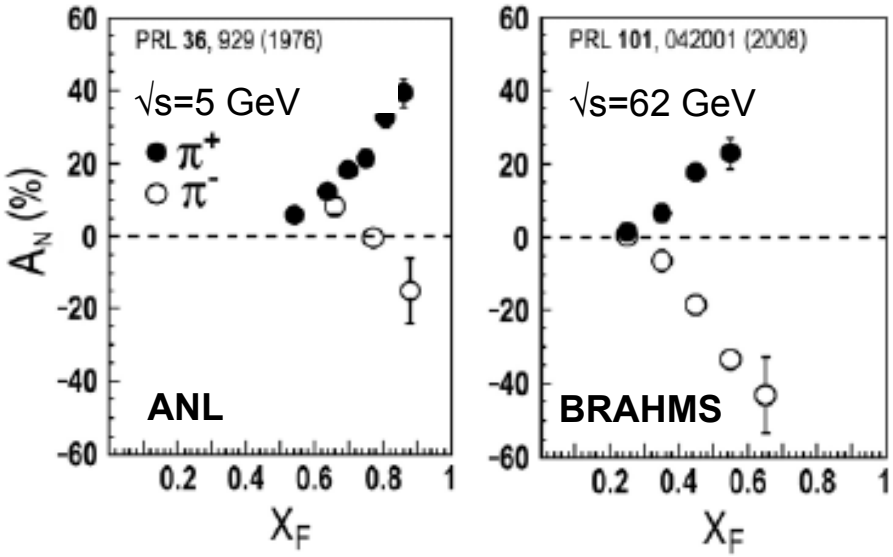
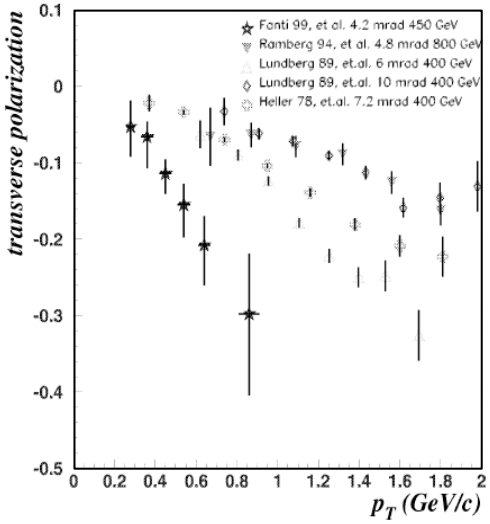


Single spin asymmetries: BIG (?!) although suppressed as m_q/Q^2 in pQCD

$p^\uparrow p \to \pi X$



$pp \to \Lambda^\uparrow X$



Leading Twist PDFs

quark polarisation

nucleon polarisation

N/q	U	L	T
U	f_1 *number density*		
L		g_1 *helicity*	
T			h_1 *transversity*

Leading Twist TMDs

quark polarisation

nucleon polarisation

N/q	U	L	T
U	f_1 number density		$h_1^\perp$ Boer-Mulders
L		g_1 helicity	$h_{1L}^\perp$
T	$f_{1T}^\perp$ Sivers	g_{1T}	h_1 transversity $h_{1T}^\perp$

Off-diagonal elements are important objects:

Interference between wave functions with different angular momenta: contains infos about parton orbital angular momenta

Testing QCD at the amplitude level

- Non trivial universality of T-odd TMDs

→ sign change between DY and SIDIS

Strict prediction of QCD !

Leading Twist TMDs

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N/q	U	L	T
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T	$f_{1T}^\perp$ - Sivers	g_{1T} -	h_1 - transversity; $h_{1T}^\perp$ -

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  - → sign change between DY and SIDIS

  Strict prediction of QCD !

$$\frac{d^5\sigma}{dx\,dy\,dz\,d\phi_h dP_{h\perp}} \propto \left\{ F_{UU,T} + \varepsilon F_{UU,L} + 2\sqrt{\varepsilon(1+\varepsilon)}\cos\phi_h F_{UU}^{\cos\phi_h} + \varepsilon\cos 2\phi_h F_{UU}^{\cos 2\phi_h} \right\}$$

$$\langle \cos n\phi \rangle (x,y,z,P_{h\perp}) = \frac{\int \cos n\phi\ \sigma^{(5)} d\phi}{\int \sigma^{(5)} d\phi} \propto \frac{F_{UU}^{\cos n\phi}}{F_{UU,T} + \varepsilon F_{UU,L}}$$

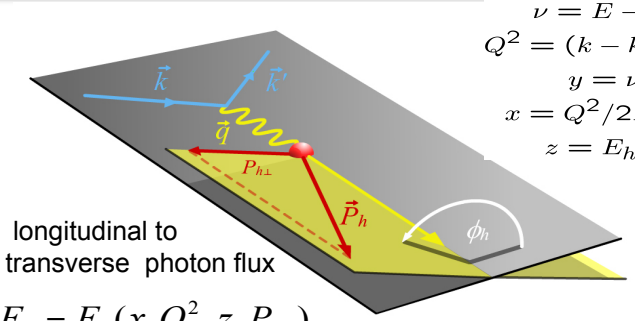
$\nu = E - E'$

$Q^2 = (k-k')^2$

$y = \nu/E$

$x = Q^2/2M\nu$

$z = E_h/\nu$

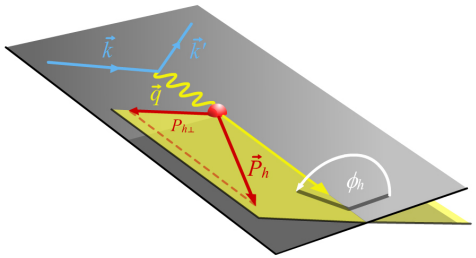


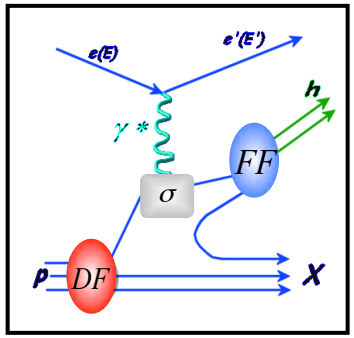
ε longitudinal to transverse photon flux

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

Cahn effect

Intrinsic k_T quark distribution





SIDIS:
ep → e'hX

$$\sigma_{UU}^{\cos(\phi)} \propto \left[f_1 \otimes D_1 + \ldots \right] / Q$$

Distribution Functions (DF)			
N/q	U	L	T
U	f_1 number density		$h_1^{\perp}$ - Boer-Mulders

Fragmentation Functions (FF)			
N/q	U	L	T
U	D_1 unpolarized		$H_1^{\perp}$ - Collins

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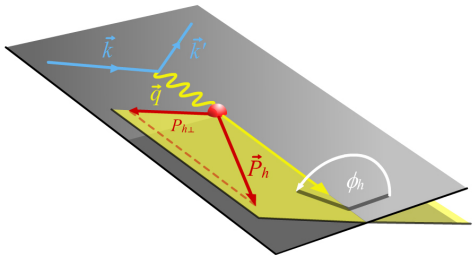

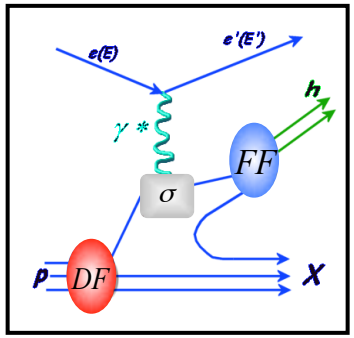

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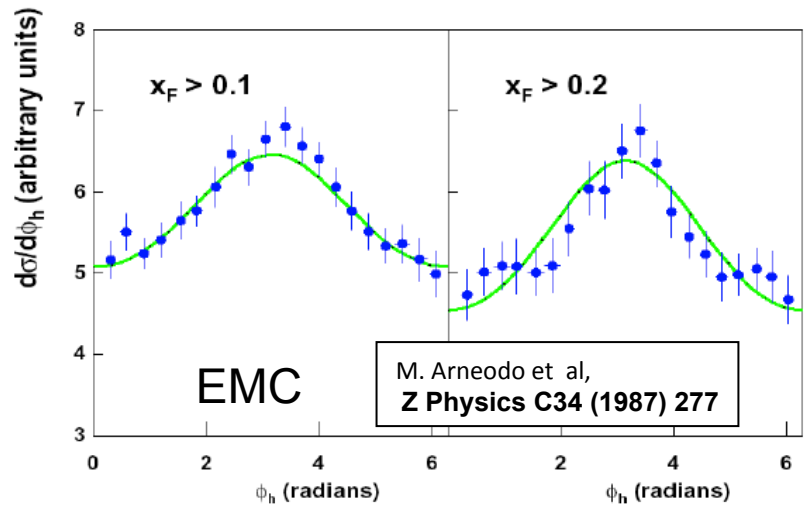
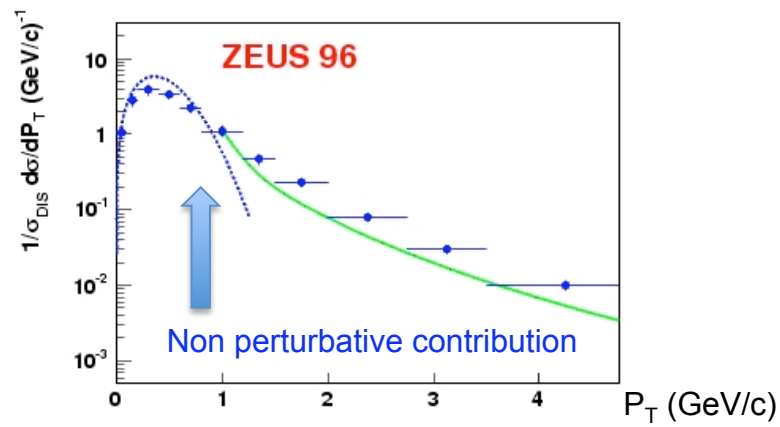


Predicted since 1978 by Cahn
Non-zero intrinsic k_T !!



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Boer-Mulders effect

Partonic spin-orbit effect

$$\sigma_{UU}^{\cos(\phi)} \propto \left[f_1 \otimes D_1 + h_1^{\perp} \otimes H_1^{\perp} + \ldots \right] / Q$$

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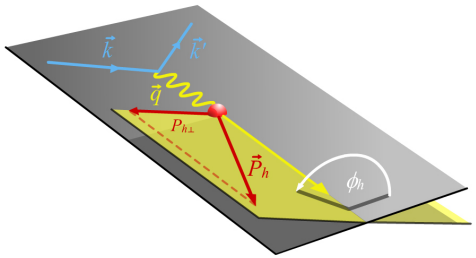

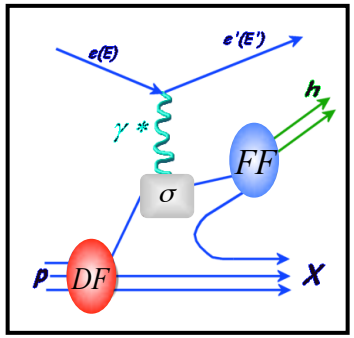

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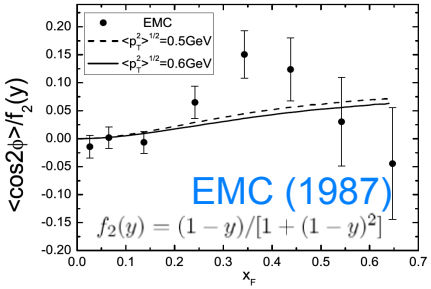
Sparse data before 2008



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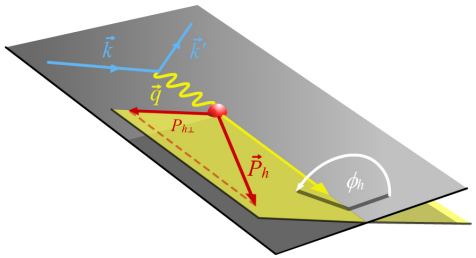

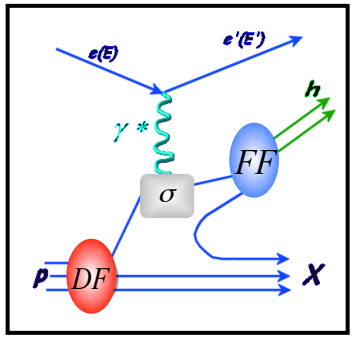

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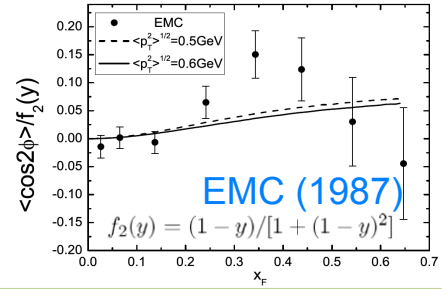

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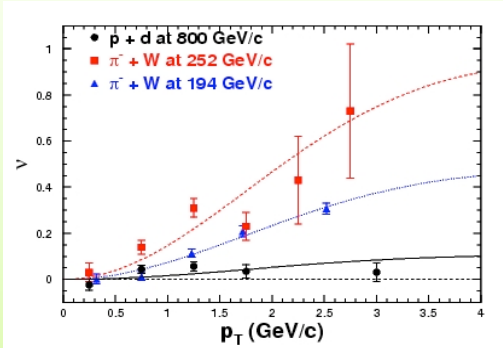
Drell-Yan

hp → μμX

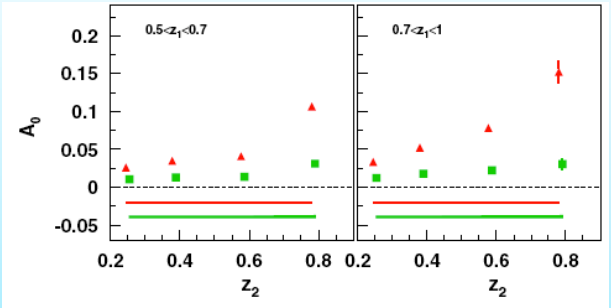
$$\sigma_{UU}^{\cos 2\phi} \propto h_1^{\perp} h_1^{\perp}$$



e+e- machines

ee → ππX

$$A_0^{\cos 2\phi_0} \propto H_1^{\perp} H_1^{\perp}$$

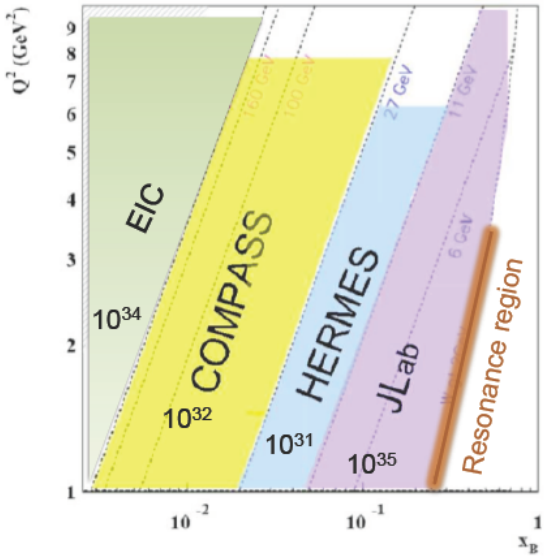


The HERMES Measurement

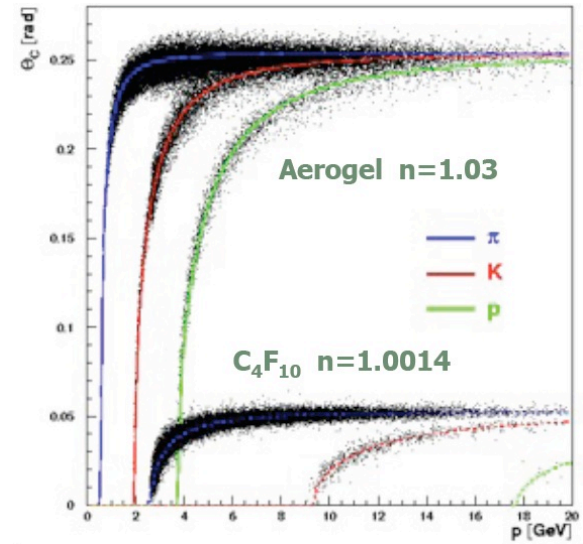
The experiment

27.6 GeV e+/e- HERA beam

Access to valence and sea



Electron and Hadron ID

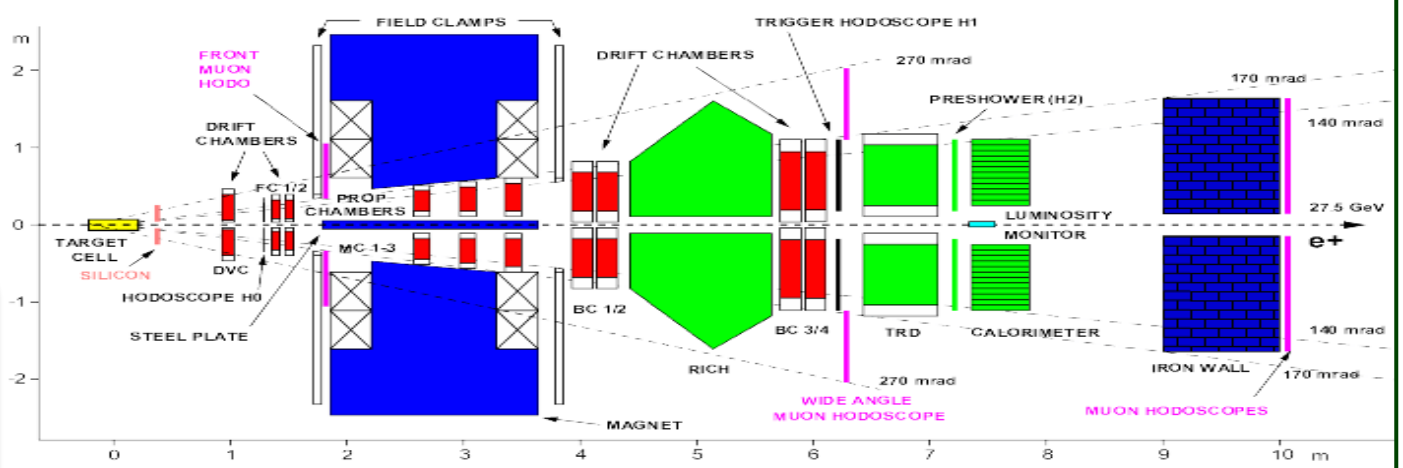


hermes

Data taking: 95-07

Internal gaseous target
(no nuclear effects)

96-00 (H/D) Lpol + Upol
02-05 (H) Tpol + Upol
06-07 (H/D) Upol+Recoil



Analysis

ϕ-integrated x-sec

Signal

Experimental effects

$$n(\phi) = \int L\sigma^0_w[1 + 2\langle\cos\phi_h\rangle_w + 2\langle\cos 2\phi_h\rangle_w]\epsilon^{acc}_{w,\phi_h}\epsilon^{rad}_{w,\phi_h}dw$$

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

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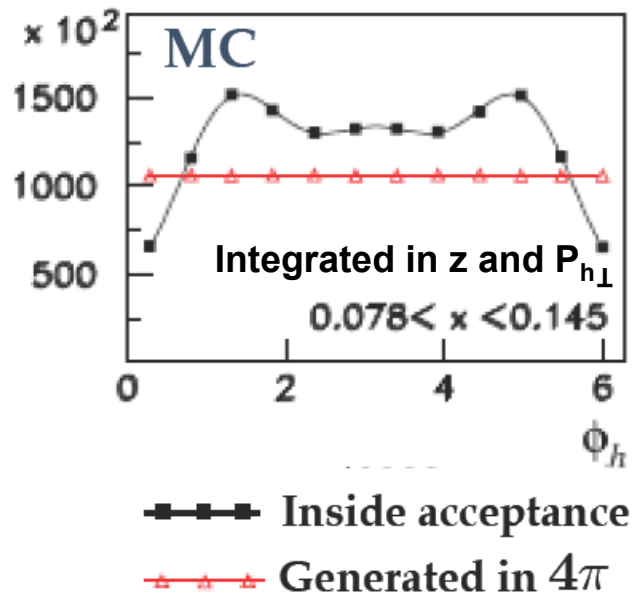
$w = (x, y, z, P_{h\perp})$

Experimental effects are studied by detailed Monte Carlo simulations

$$S_{MC}(\phi) = \frac{\int L\sigma^0_w\epsilon^{acc}_{w,\phi_h}\epsilon^{rad}_{w,\phi_h}\,dw}{\int L\sigma^0_w\,dw}$$

Wider the integration range larger the sensitivity on the x-sec model in MC



Analysis

Full-differential unfolding of detector and radiative effects

$$n_{born} = S^{-1}[n - B]$$

Bin-by-bin acceptance and smearing effects

Background events smeared into acceptance

Binning 900 kinematic bins x 12 ϕ_h-bins								
Variable	Bin limits							#
x	0.023	0.04	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
$P_{h\perp}$	0.05	0.2	0.35	0.5	0.7	1	1.3	6

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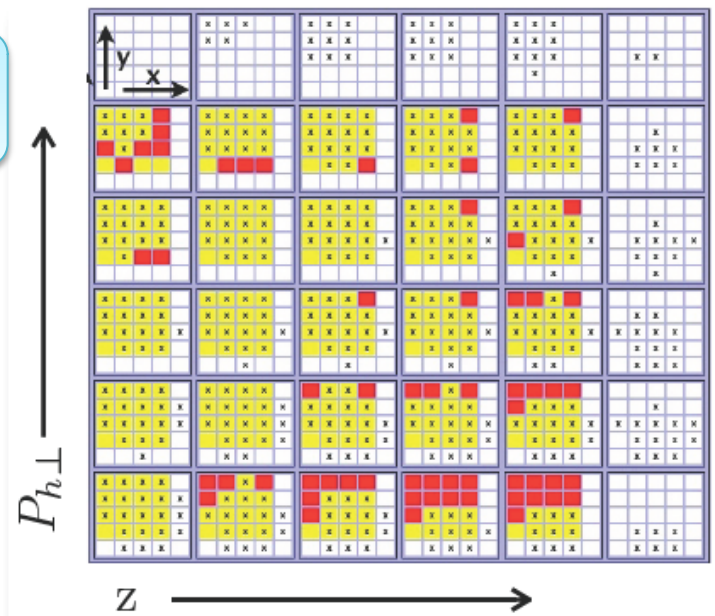
Full differential result !



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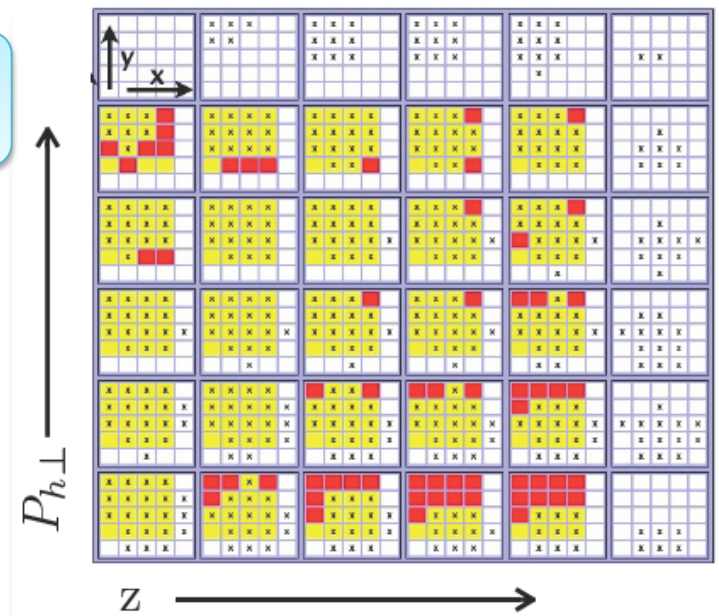

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Extraction method checks:

- Stable versus time and major target magnet and IP geometry variations
- Stable versus beam charge and misalignment
- Unphysical cos(3ϕ) and cos(4ϕ) terms consistent with zero
- Stable with different xsec models and binning schemes

The Results

Unpolarized cross-section

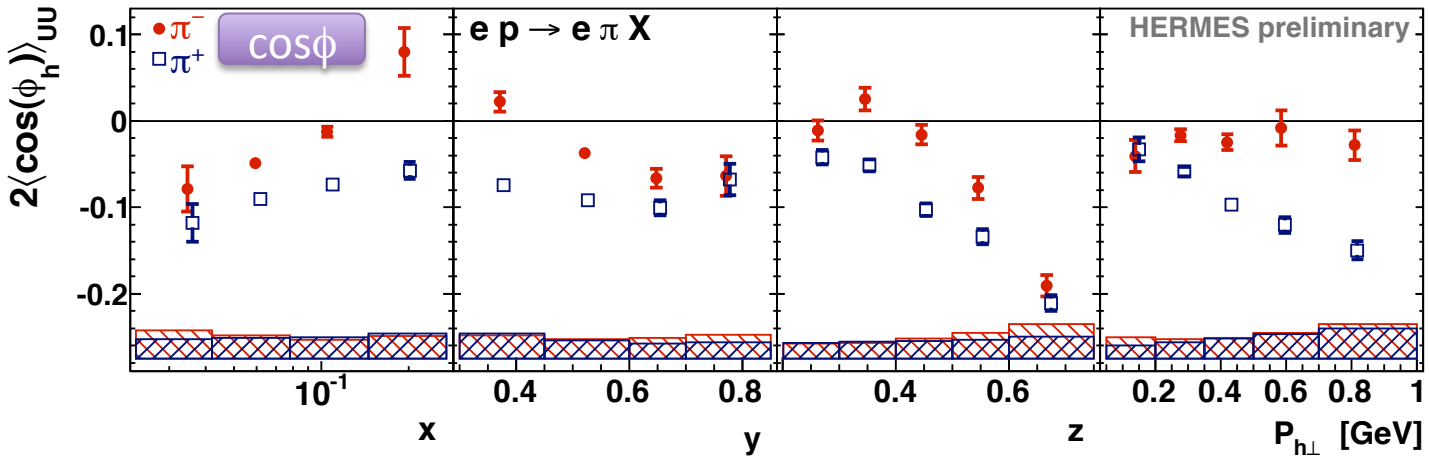
cosϕ large and negative !

$$\sigma_{UU}^{\cos(\phi)} \propto \left[f_1 \otimes D_1 + h_1^{\perp} \otimes H_1^{\perp} + \ldots \right] / Q$$

Increasing with z and P_h

Large difference in hadron charge !

Larger in magnitude for π+



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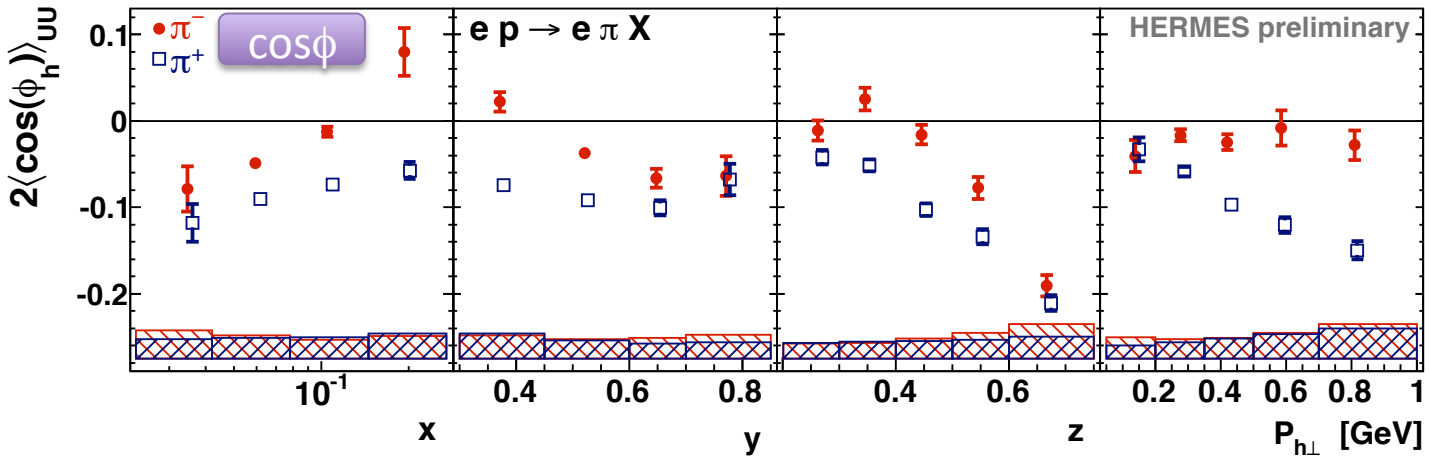


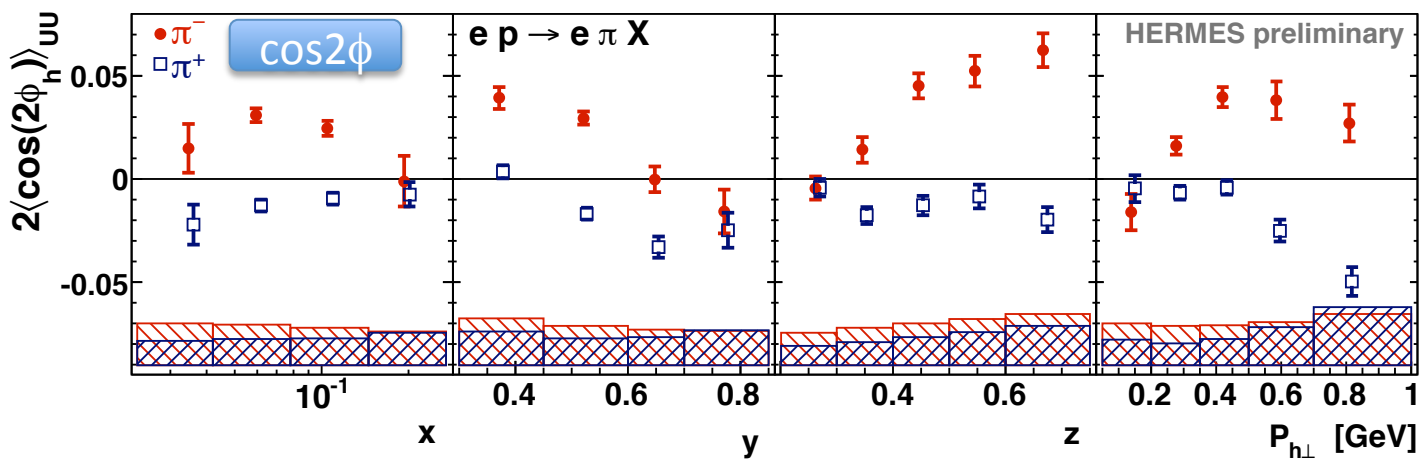
cos2ϕ non-zero !

$$\sigma_{UU}^{\cos(2\phi)} \propto h_1^{\perp} \otimes H_1^{\perp} + \left[f_1 \otimes D_1 + \ldots \right] / Q^2$$

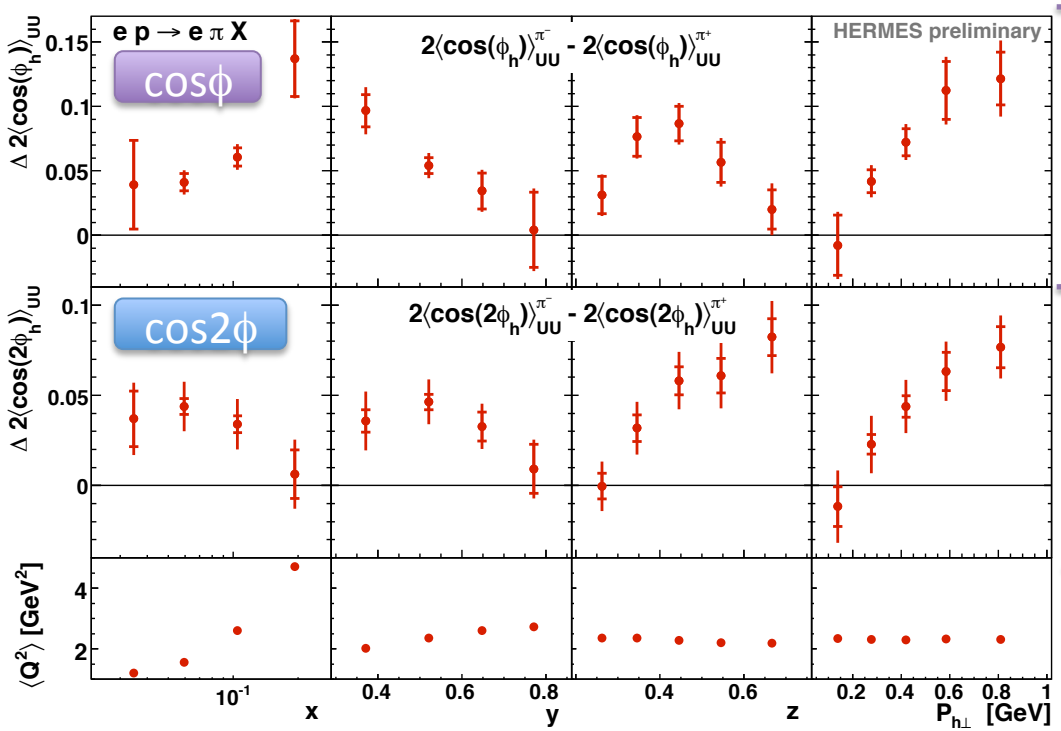
Difference in hadron charge !

Positive for π-

Negative for π+



Difference in pion charge



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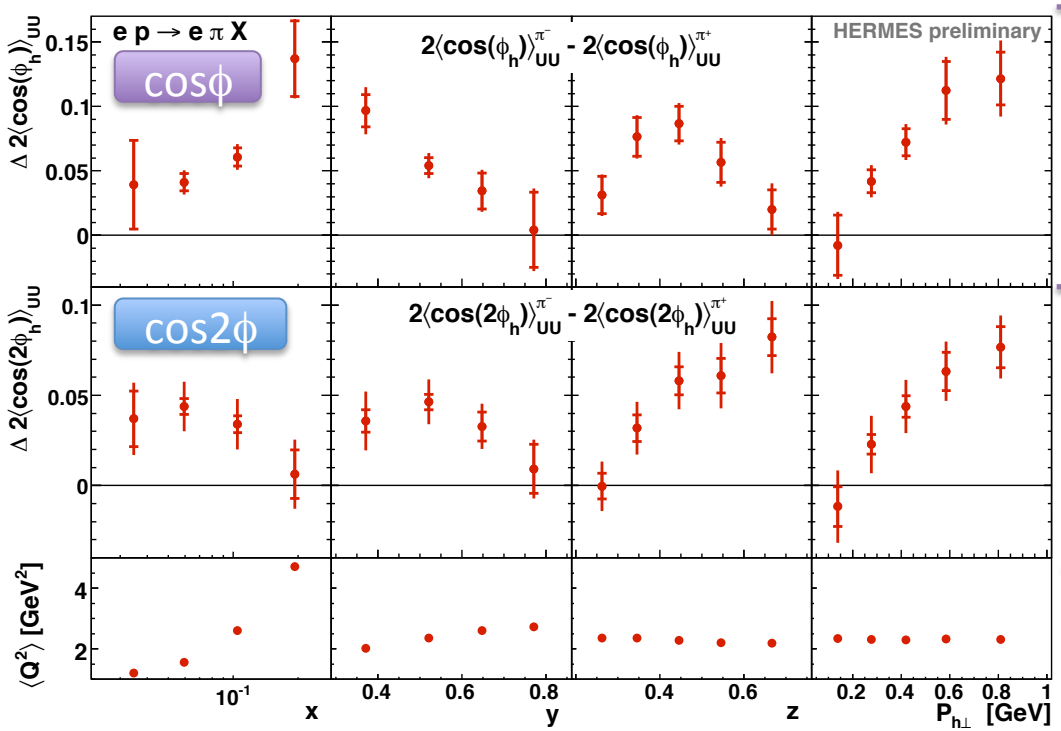

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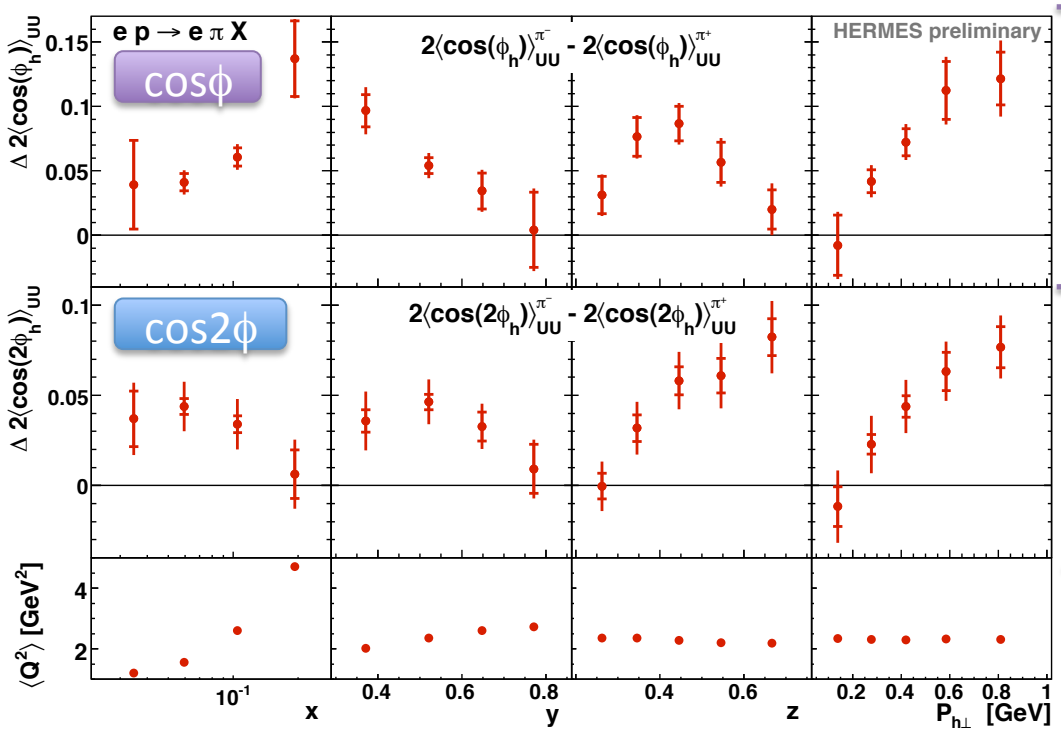
Mild flavor dependendence of k_T expected

Difference in pion charge



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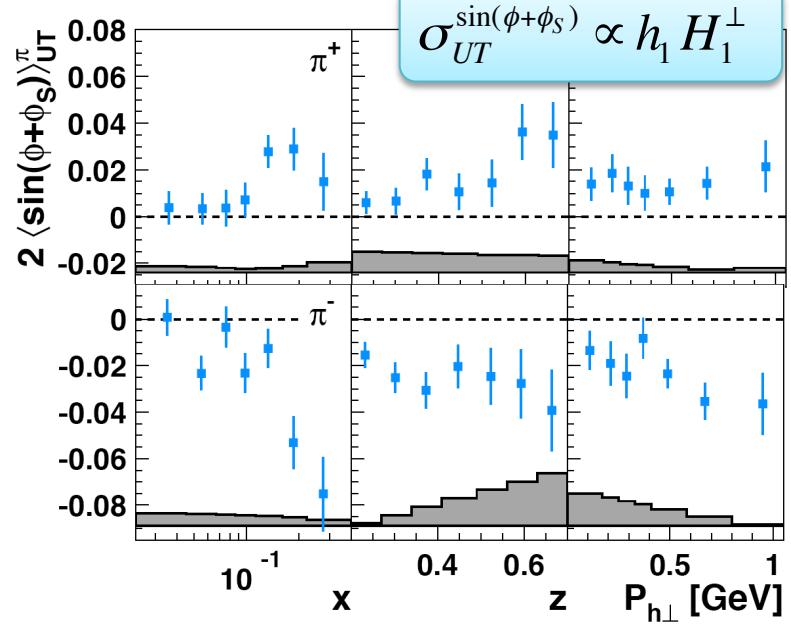
$$\sigma_{UT}^{\sin(\phi+\phi_S)} \propto h_1 H_1^{\perp}$$

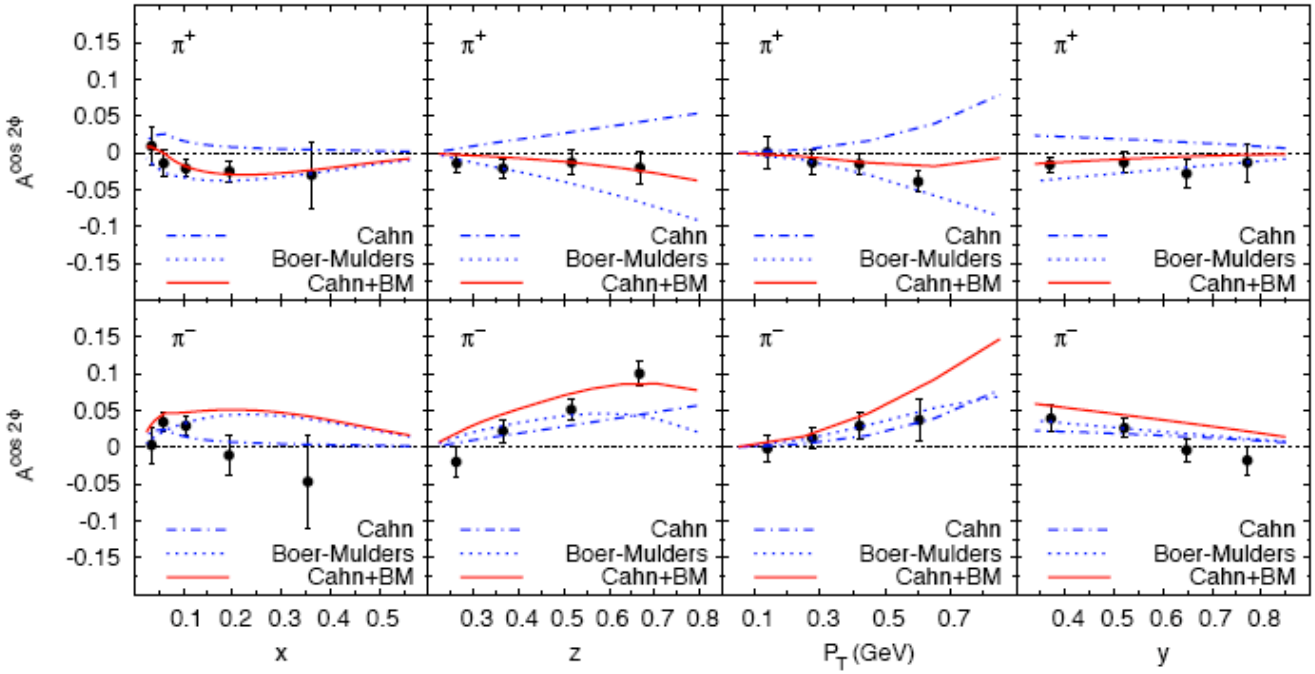


Mild flavor dependendence of k_T expected

From A_{UT}: Collins favored (u→π+) and unfavored (u → π-) fragmentation opposite in sign

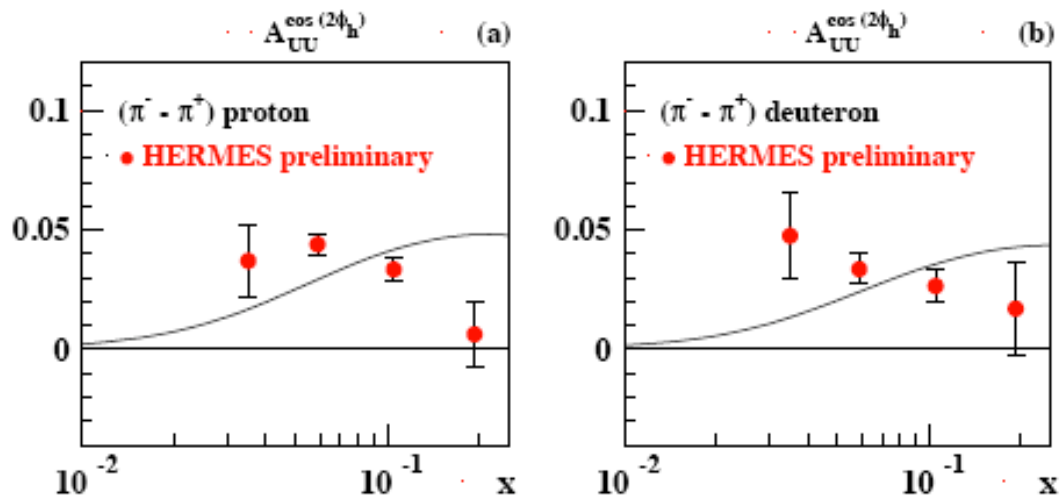
With u-dominance
Collins makes the difference !
Hint of non-zero Boer-Mulders

Phenomenological fits & models

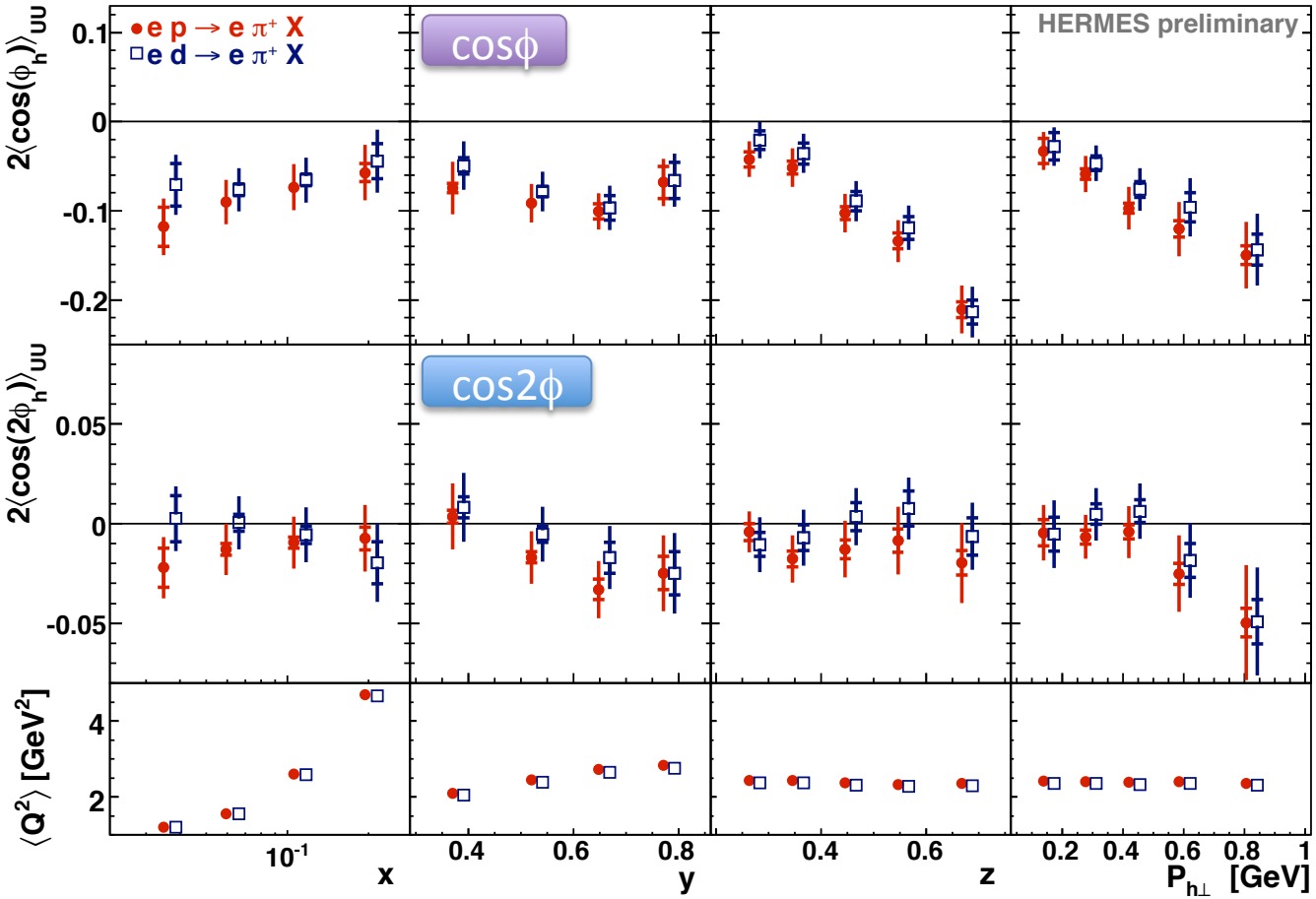


V. Barone, S. Melis, A. Prokudin, arXiV:**0912.5194**

LCCQM,
B. Pasquini, P. Schweitzer,
arXiV:**1103.5977**

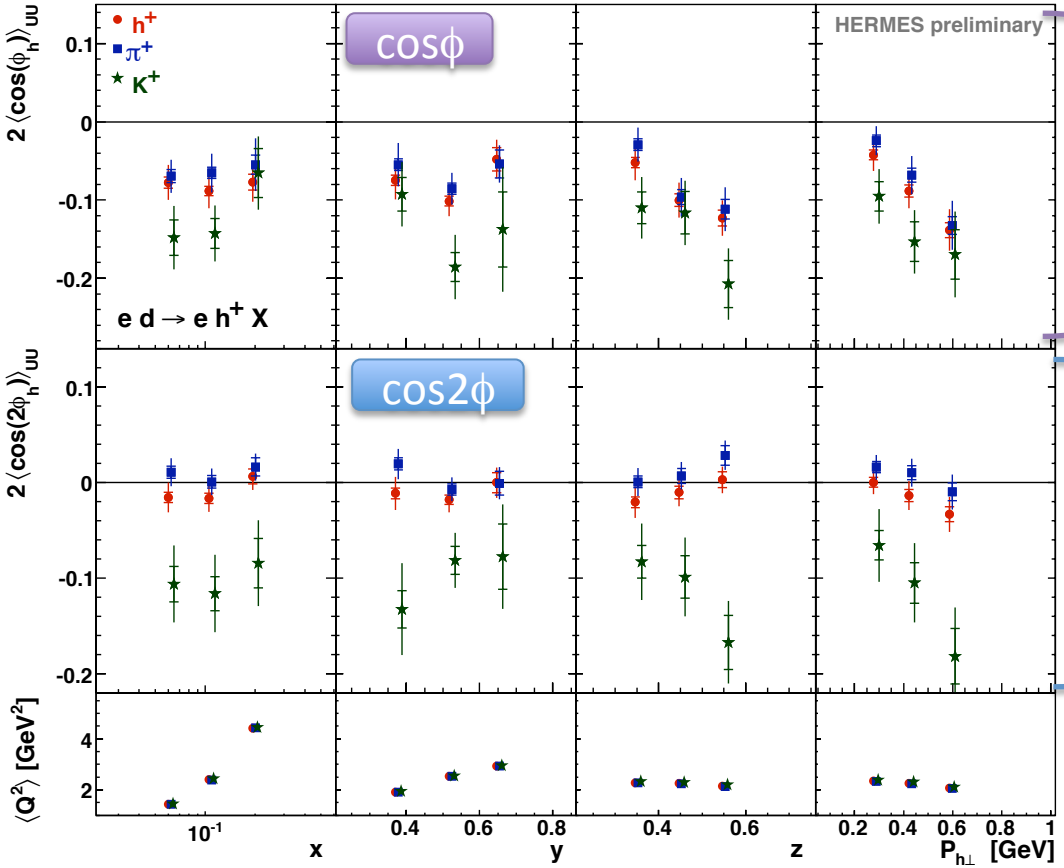


Proton vs Deuteron Target



Quark d vs u contribution ?
DATA support Boer-Mulders of same sign for u and d

The kaon signal



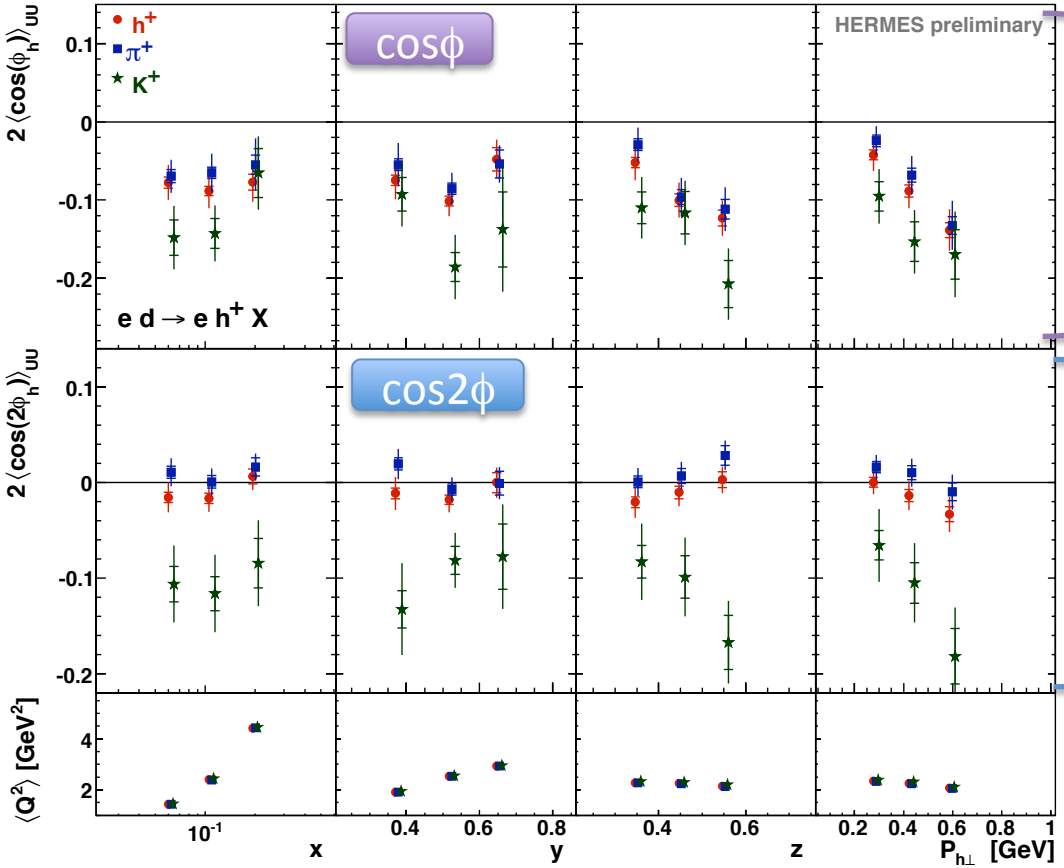
$$\sigma_{UU}^{\cos(\phi)} \propto \left[f_1 \otimes D_1 + h_1^{\perp} \otimes H_1^{\perp} + \ldots \right] / Q$$

NEW !!

$$\sigma_{UU}^{\cos(2\phi)} \propto h_1^{\perp} \otimes H_1^{\perp} + \left[f_1 \otimes D_1 + \ldots \right] / Q^2$$

Striking difference versus pions !

The kaon signal



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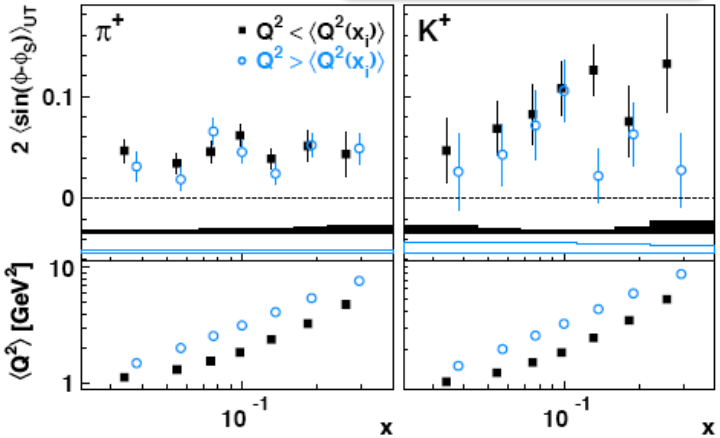
NEW !!

$$\sigma_{UU}^{\cos(2\phi)} \propto h_1^{\perp} \otimes H_1^{\perp} + \left[f_1 \otimes D_1 + \ldots \right] / Q^2$$

Phys. Rev. Lett. 103 (2009) 152002

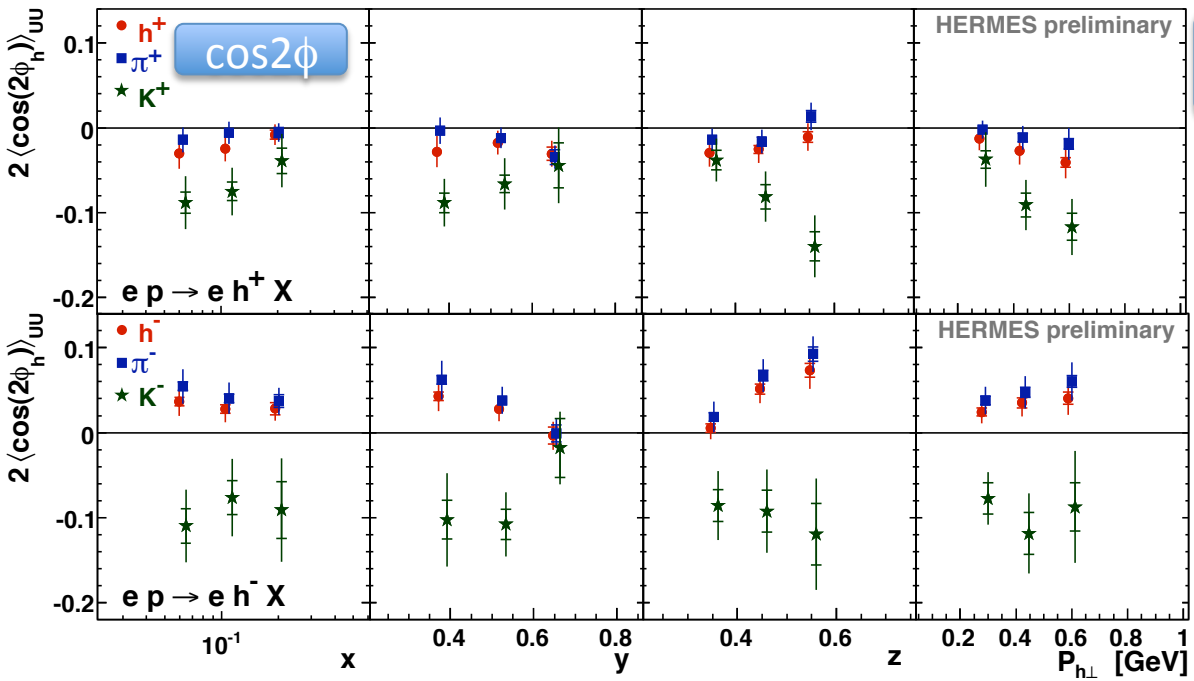
$$\sigma_{UT}^{\sin(\phi-\phi_S)} \propto f_{1T}^{\perp} D_1^{\perp}$$



Striking difference versus pions !

- Role of the sea
- Strange Collins
- Sub-leading twists

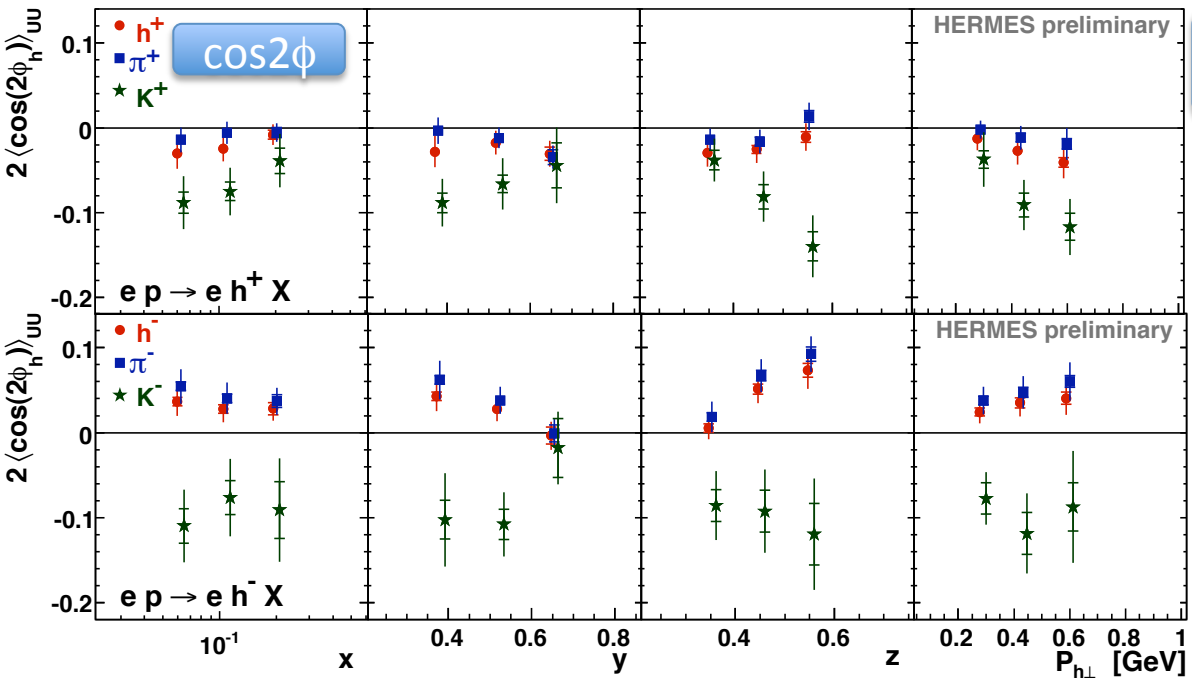
The kaon signal



$$\sigma_{UU}^{\cos(2\phi)} \propto h_1^{\perp} \otimes H_1^{\perp} + \left[f_1 \otimes D_1 + \ldots \right] / Q^2$$

NEW !!

The kaon signal

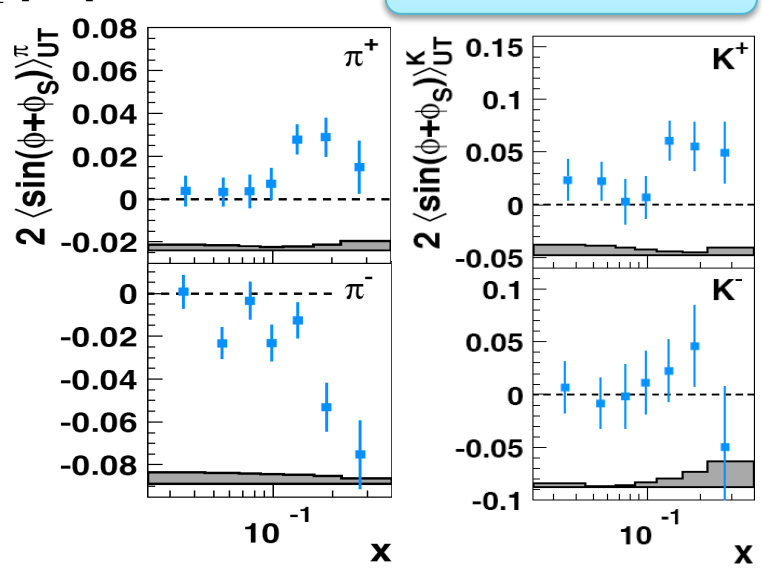


$$\sigma_{UU}^{\cos(2\phi)} \propto h_1^{\perp} \otimes H_1^{\perp} + \left[f_1 \otimes D_1 + \ldots \right] / Q^2$$

NEW !!

Phys. Lett. B 693 (2010) 11-16

$$\sigma_{UT}^{\sin(\phi+\phi_S)} \propto h_1 H_1^{\perp}$$



The kaon puzzle

Already found in A_{UT}: Collins+Transversity

Role of the sea in distribution and fragmentation functions

Conclusions

- HERMES has been a precursor experiment for TMD field
- Detailed knowledge of unpolarized cross-section is the base of any precise measurement
- First full-differential extraction of the azimuthal modulation in SIDIS unpolarized cross-section is here presented
- Flavor sensitivity from different targets and identified hadrons:

  - charged pion difference pin down the Boer-Mulders effect

  - D (vs H) target suggests same sign of u and d Boer-Mulders

  - kaon signals indicate peculiar role of sea flavors