CLAS Collaboration

Semi-Inclusive electroproduction of hadrons, unpolarized case:

part IV – n

part III – π^-

<u>part II – p</u>

part I – π^+: PRD80

M. Osipenko, October 19,

JLab12 meeting,

Rome 2009

Semi-inclusive Kinematics

Detect the scattered electron in coincidence with hadron h: $e + p \rightarrow e' + h + X$

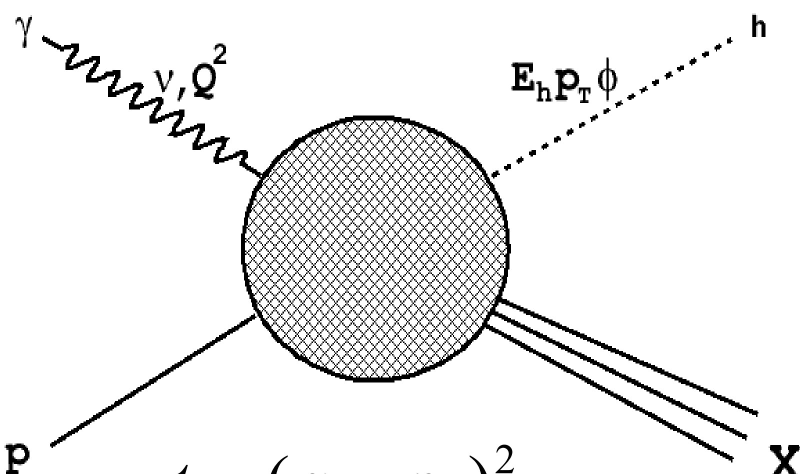
In OPE approximation: $\gamma_V(q) + p(P) \rightarrow h(p_h) + X$

Four-momenta in Lab: $q = (k - k') = (\nu, \vec{q}) \quad P = (M, 0) \quad p_h = (E_h, \vec{p}_h)$

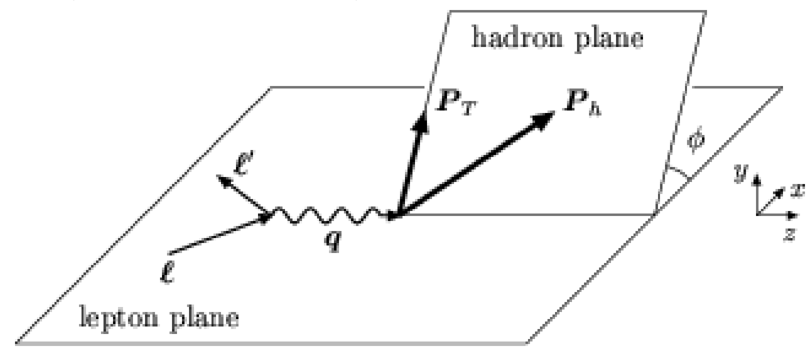
5 independent variables

Initial state: $Q^2 = -q^2 \qquad x = \dfrac{-q^2}{2qP} = \dfrac{Q^2}{2M\nu}$

Final state: $z = \dfrac{Pp_h}{Pq} = \dfrac{E_h}{\nu} \qquad p_T = \left|\vec{p}_T\right| = \left|\vec{p}_h - \vec{p}_h \vec{q}\right| \qquad \varphi = \varphi_{\gamma h} - \varphi_{\gamma e'}$



$$t = (q - p_h)^2$$



undetected hadronic final state of mass squared

$$M_X^2 = M^2 + 2M\nu(1 - z) + t$$

Observables

- Cross section is described by 4 functions of 4 variables: $H_i = H_i(x, Q^2, z, t)$

$$\frac{d^5\sigma}{dx\,dQ^2\,dz\,dp_T^2\,d\varphi} = N\frac{E_h}{|p_{\parallel}|}\zeta\left[\varepsilon H_1 + H_2 + (2-y)\sqrt{\frac{\kappa}{\zeta}}\cos\varphi H_3 + \kappa\cos 2\varphi H_4\right]$$

J.Levelt & P.Mulders, PRD49

where

$$N = \frac{2\pi\alpha^2}{xQ^4} \quad y = \frac{\nu}{E_{beam}} \quad \gamma = \frac{2Mx}{\sqrt{Q^2}} \quad \zeta = 1 - y - \frac{1}{4}\gamma^2 y^2 \quad \varepsilon = \frac{xy^2}{\zeta} \quad \kappa = \frac{1}{1+\gamma^2}$$

- Azimuthal asymmetries (moments): $\langle \cos n\phi \rangle = \frac{\int \sigma \cos n\varphi\, d\varphi}{\int \sigma\, d\varphi}$

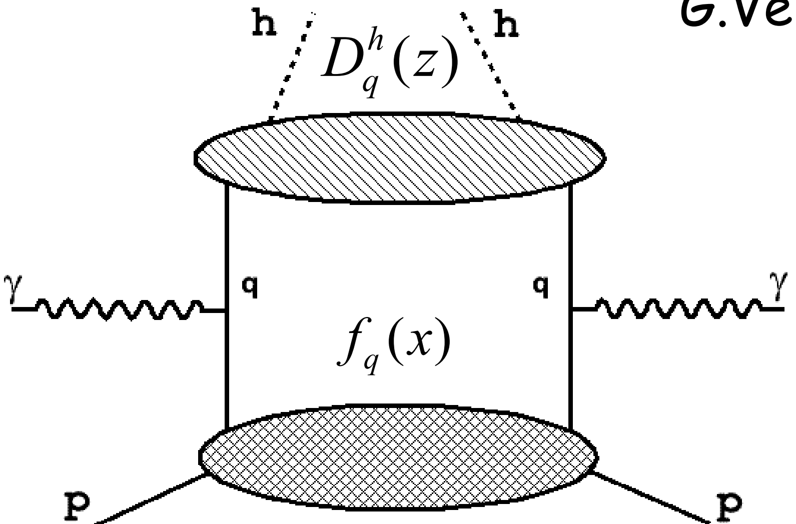
$$\langle \cos\phi \rangle = \frac{(2-y)}{2}\sqrt{\frac{\kappa}{\zeta}}\frac{H_3}{\varepsilon H_1 + H_2} \qquad \langle \cos 2\phi \rangle = \frac{\kappa}{2}\frac{H_4}{\varepsilon H_1 + H_2}$$

- p_T-integrated cross section:

$$H_2 = \pi E_h \int_0^{p_T^{2\,\max}} dp_T^2 \frac{H_2\left(p_T^2\right)}{\sqrt{E_h^2 - m_h^2 - p_T^2}}$$

SIDIS: constant in ϕ

Current fragmentation | L.Trentadue & G.Veneziano, PLB323 | **Target fragmentation**

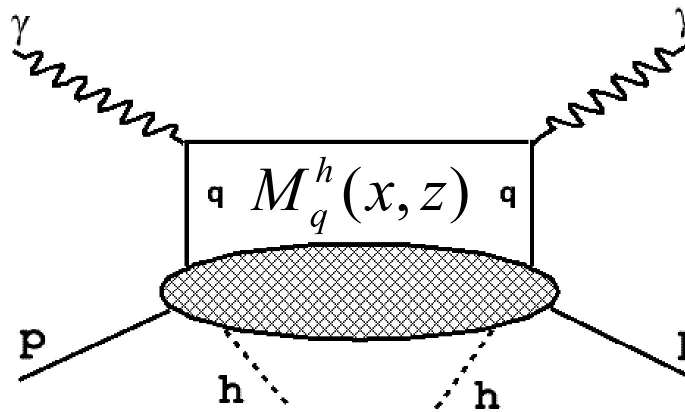


X.Ji et al., PRD71

$$H_2 = \sum_q e_q^2 f_q(x) D_q^h(z)$$

$$H_1 = 2xH_2$$

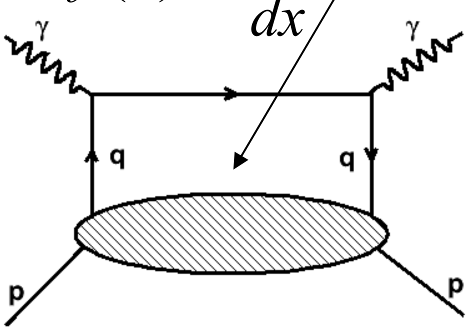
Factorization proved



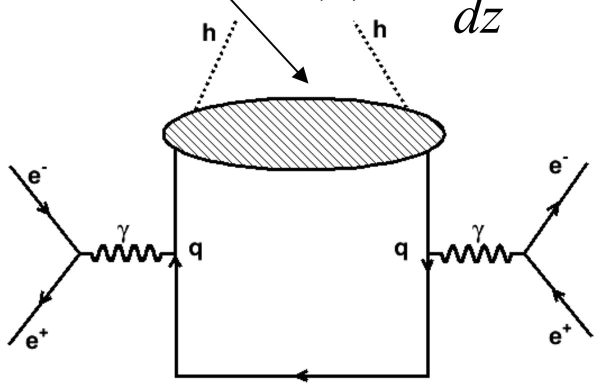
J.C.Collins, PRD57

$$H_2 = \sum_q e_q^2 M_q^h(x,z)$$

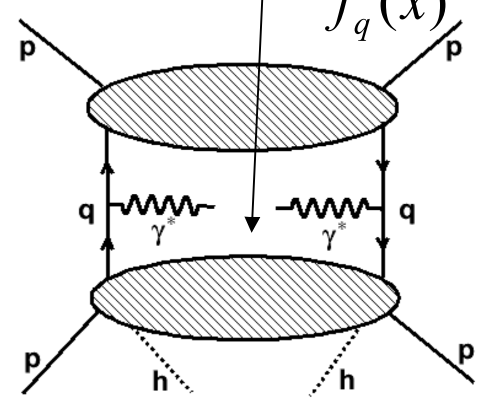
$$f(x) = \frac{d\sigma}{dx}$$



$$D^h(z) = \frac{d\sigma^h}{dz}$$

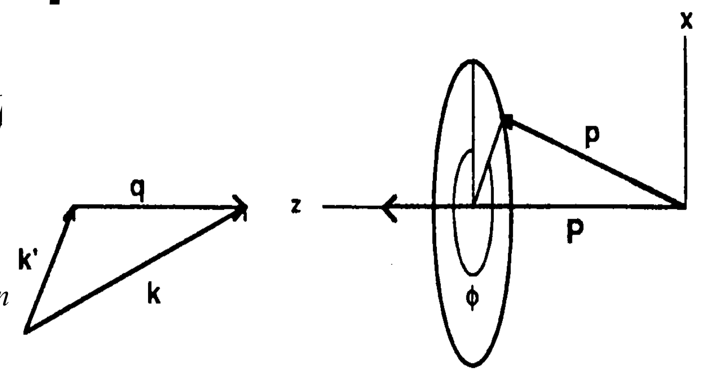


$f_q(x)$



SIDIS: ϕ-depen

R.N.Cahn, PRD40

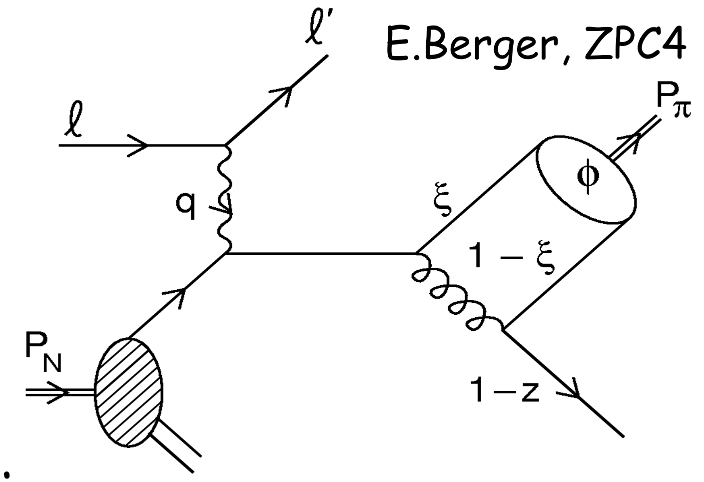


1.Cahn effect: $p = xP + k_\perp \quad k_\perp = (0, k_\perp \cos\phi,$

$$\langle p_T^2 \rangle = p_\perp^2 + k_\perp^2 z^2$$

$$\langle \cos n\varphi \rangle \sim \frac{H_{2+n}}{H_2 + \varepsilon H_1} = (-1)^n \, 4 \frac{1-y}{1+(1-y)^2} \left[\frac{k_\perp^2 z}{\langle p_T^2 \rangle} \sqrt{\frac{p_T^2}{Q^2}} \right]^n$$

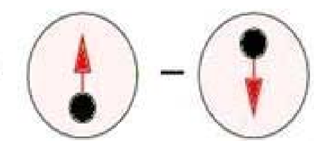
E.Berger, ZPC4



2.Berger effect (Collins fragmentation):

$$\langle \cos n\varphi \rangle \sim \int \frac{\psi^h(\xi)}{g_n(\xi, z, p_T^2)} d\xi \qquad \psi^h(\xi)$$ hadron wave function

3.Boer-Mulders function $h_1^\perp$ (TMD) contribution:

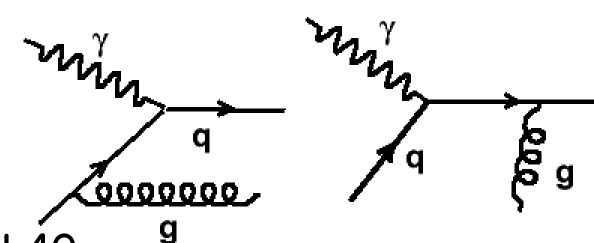


$$\langle \cos 2\varphi \rangle^{BM} \sim \frac{h_1^\perp(x, p_T^2) H_1^\perp(z, p_T^2)}{f(x) D(z)}$$

D.Boer&P.Mulders, PRD57

$H_1^\perp$ from e^+e^- collisions

4.Higher Order pQCD corrections:



$$\langle \cos\varphi \rangle = -\frac{\alpha_S(Q^2)}{2} \sqrt{1-z} \, \frac{(2-y)\sqrt{1-y}}{1+(1-y)^2}$$

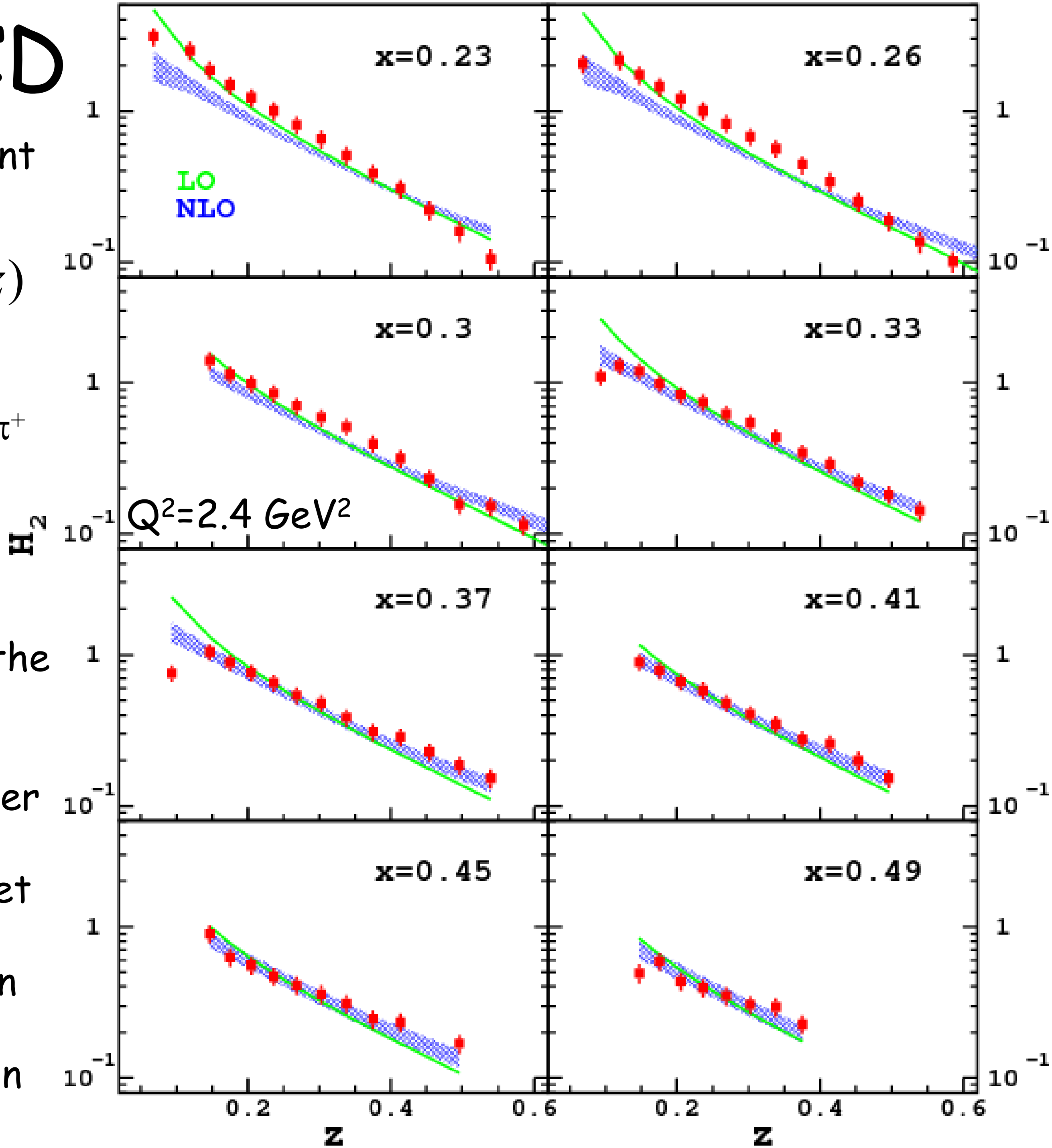
H.Georgi&H.Politzer, PRL40

Data & pQCD

Calculations contain current fragmentation only:

$$H_2 = \sum_q e_q^2 q(x) \otimes D(z)$$

CTEQ 5, Kretzer π^+



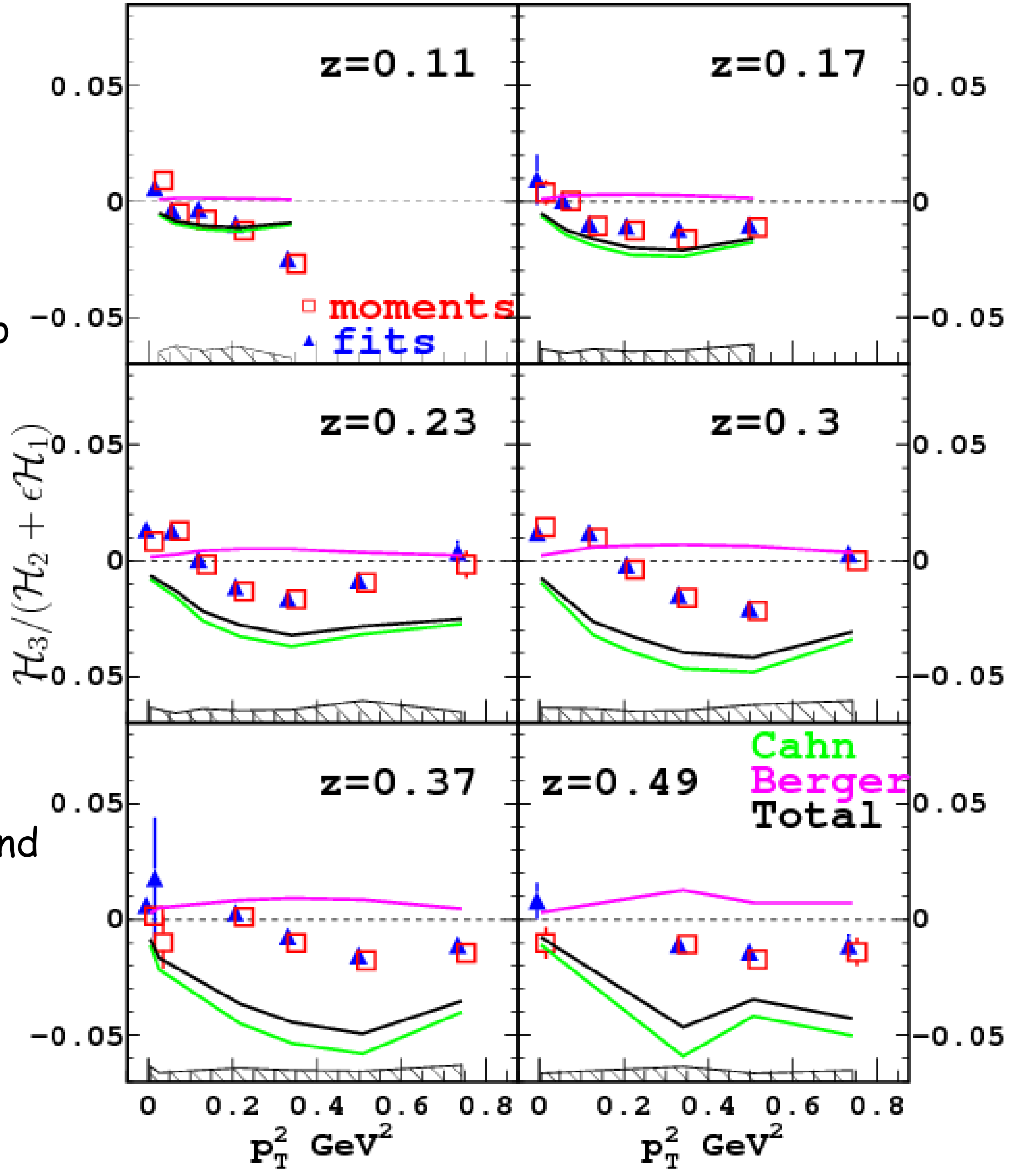
1. Except for low-x, the difference between data and pQCD is of the order of scale dependence,
2. NLO reproduces better data at low-z,
3. Leaves room for target fragmentation,
4. Calculations depend on the assumption about favored fragmentation (20% effect).

<cosφ> vs. p_T

Cahn effect calculations (using $k_\perp^2$=0.20 GeV^2 and $p_\perp^2$=0.25 GeV^2 from M.Anselmino et al., PRD71) do not reproduce measured <cosϕ> and the inclusion of Berger effect contribution does not improve the agreement significantly.

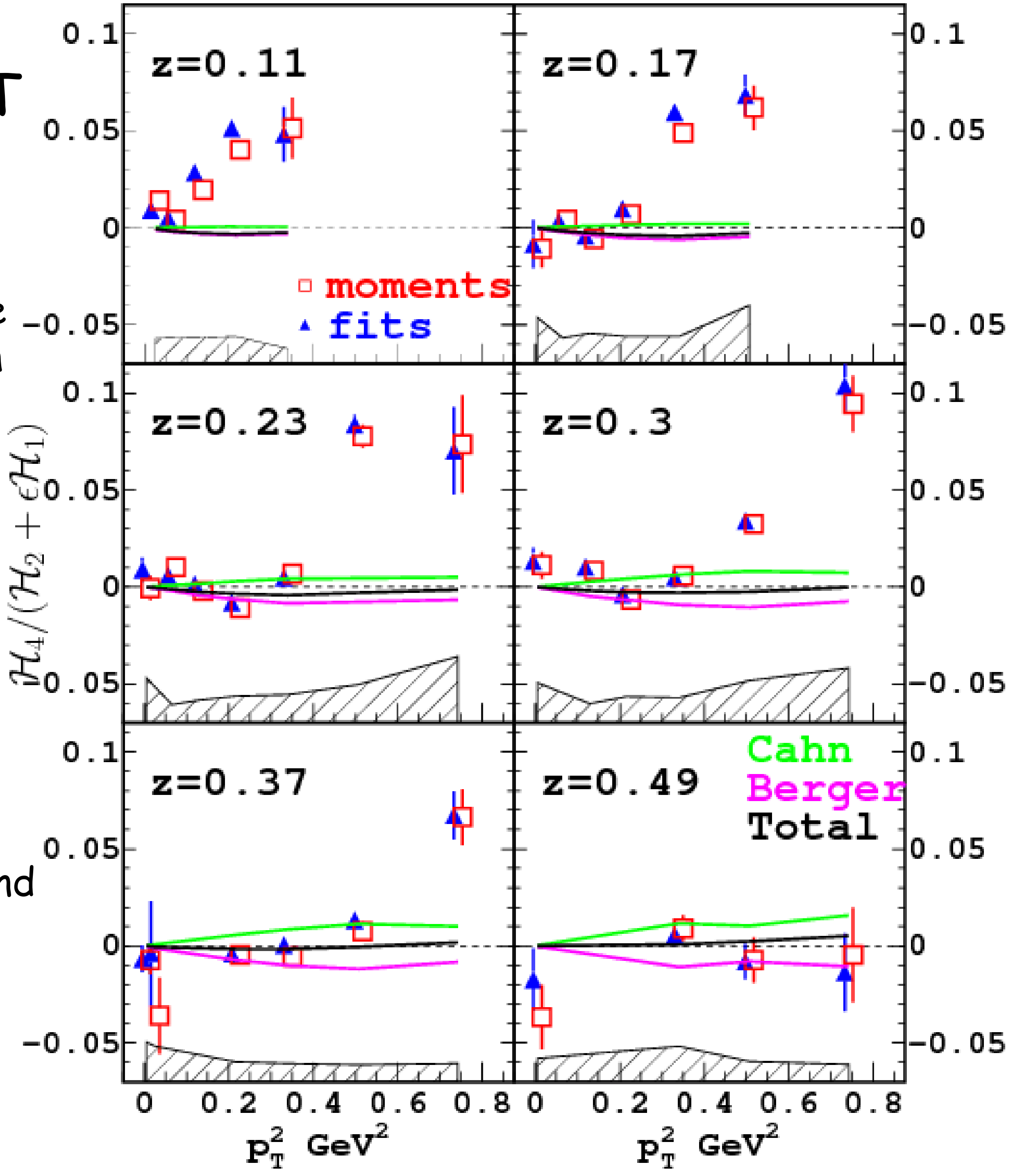
Data are integrated over x and Q^2 in DIS region.

<Q^2>=2.2 GeV^2



<cos2φ> vs. p_T

Cahn and Berger effect compensate each other to give zero <cos2ϕ> moment. Within systematic errors the data are also compatible with zero, except for low-z.



Data are integrated over x and Q^2 in DIS region.

$\langle Q^2\rangle$=2.2 GeV^2

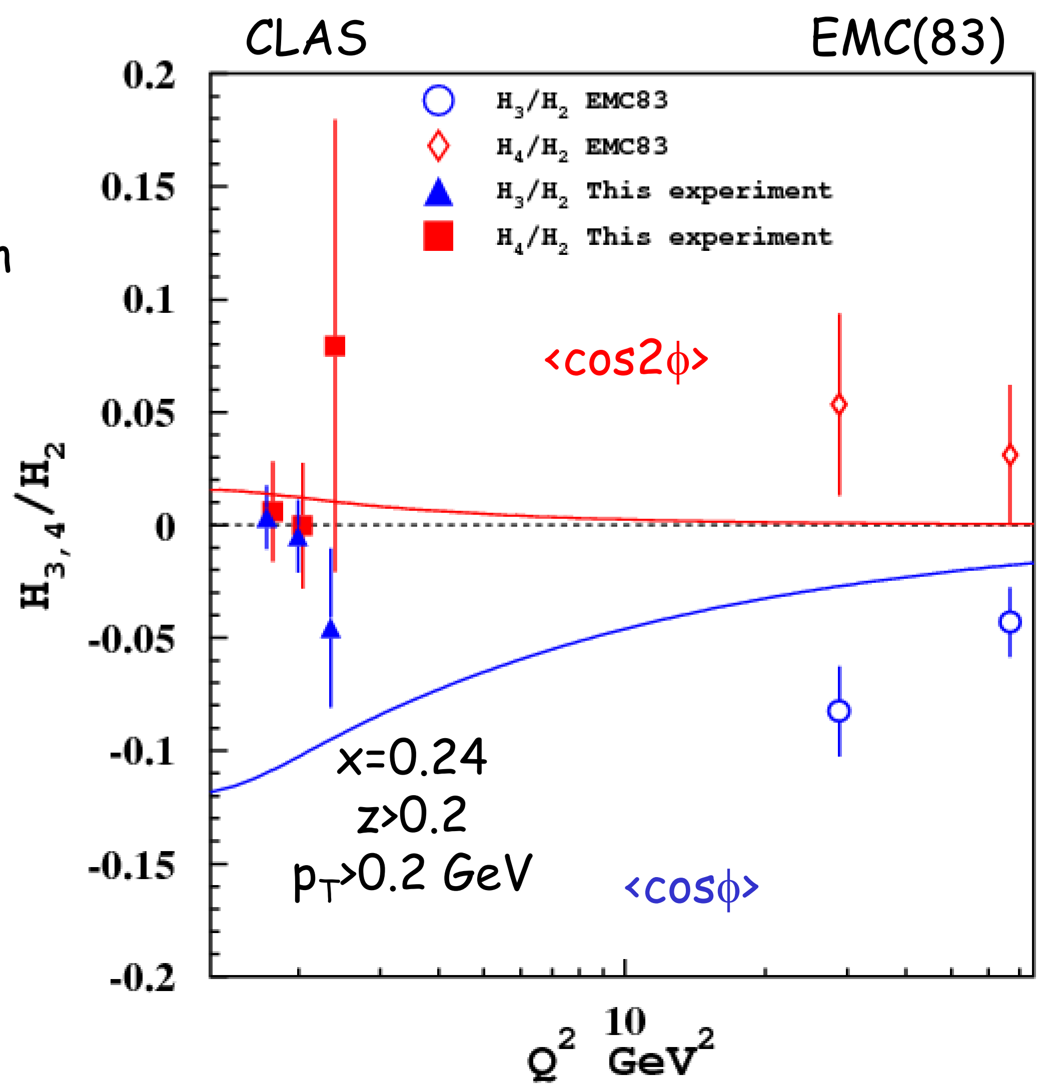
Q^2-dependence

We compared our data on φ-dependent terms with EMC measurement (J.Aubert et al., PLB130) performed at significantly higher Q^2:
curves show Cahn effect prediction corrected for threshold effect:

$$f_n(\nu, z) = \frac{\int_{p_T^{2\,\min}}^{p_T^{2\,\max}} p_T^n e^{-p_T^2/\langle p_T^2 \rangle} dp_T^2}{\int_{p_T^{2\,\min}}^{p_T^{2\,\max}} e^{-p_T^2/\langle p_T^2 \rangle} dp_T^2}$$

$$p_T^{2\,\max} \approx (z\nu)^2$$

and n=1,2



Summary

1. We measured 5-fold differential π^+ semi-inclusive electro-production cross sections in a wide kinematical range in all 5 independent variables,
2. Data are in reasonable agreement with current fragmentation pQCD calc.,
3. Measured $\langle\cos\phi\rangle$ moment is incompatible with Cahn and Berger effects and in disagreement with high Q^2 data, while $\langle\cos 2\phi\rangle$ is compatible with zero.
4. Paper published in PRD,

WG review (Deep): Moskov Amarian (chair), Hovanes Egiyan, Joe Santoro
Started – September 21, 2006
Approved – April 11, 2007 → 6 months
AdHoc review: Mac Mestayer (chair), Keith Griffioen, Kyungseon Joo
Started – April 11, 2007
Approved – July 28, 2008 → 1 year 4 months
Collaboration review:
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Journal review:
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Accepted – July 20, 2009 → 10 months
Total: 2 years 10 months