Azimuthal asymmetry using energy flow method

A.Ukleja on behalf of the ZEUS Collaboration

- Azimuthal angle distribution at $Q^2>100$ GeV^2
- Energy flow method
- Experimental results
- LO and NLO predictions
- Comparison DATA with predictions
- Summary

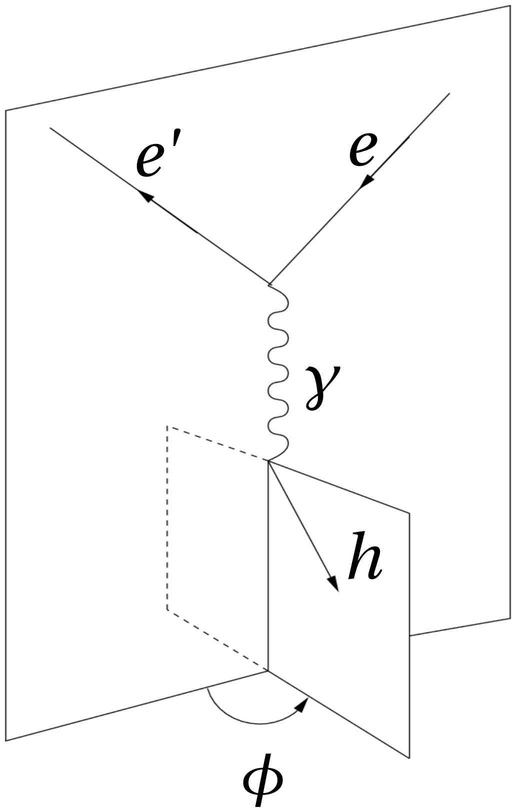
Azimuthal angle definition for the *ep*→*ehX* process

$$\frac{d\sigma^{ep\to ehX}}{d\phi} = A + B\cos(\phi) + C\cos(2\phi) + D\sin(\phi) + E\sin(2\phi)$$

Azimuthal asymmetry comes from:

- Two-body processes (BGF and QCDC)
- Boson polarization
- Longitudinally polarized electron beam
- Parity violating weak interactions
- Final hadron polarization
- Intrinsic parton momentum in the proton

$\gamma^* p$ *HCM frame*



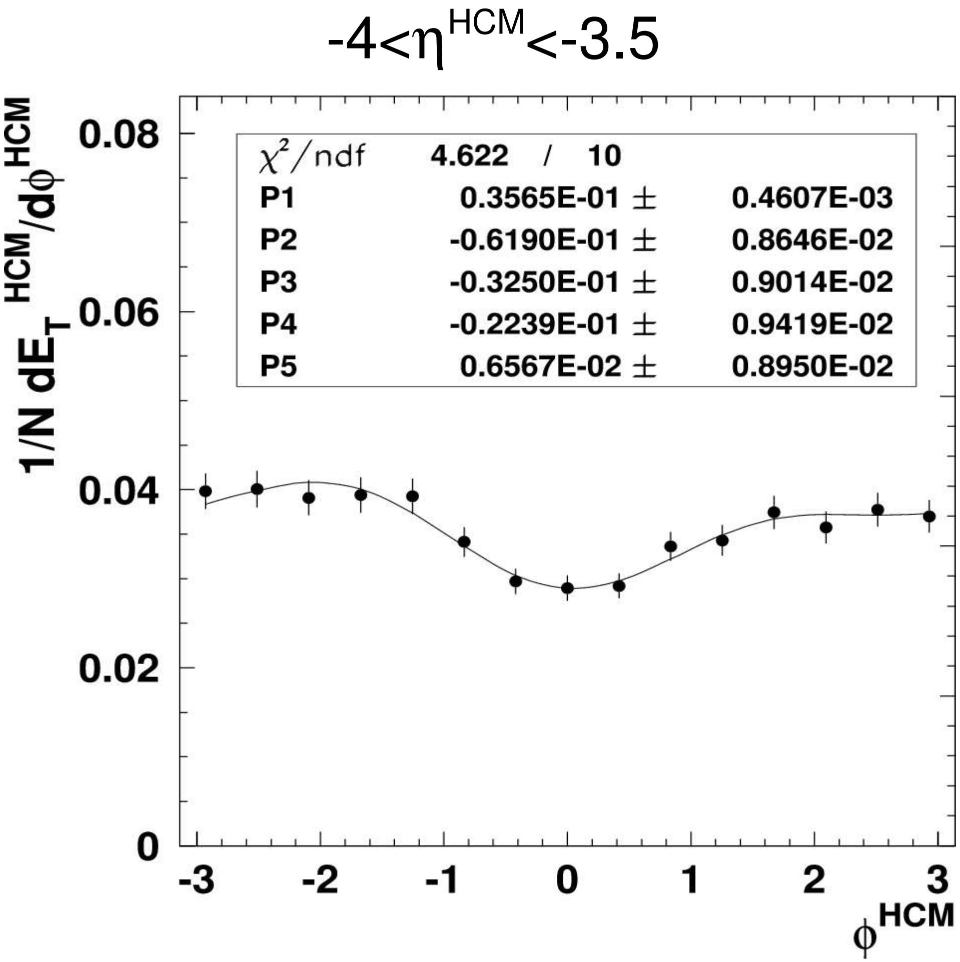
Future:

asymmetry can be measured for

- Longitudinally polarized lepton beam
- CC events

Experimental methods

$$\frac{d\sigma^{ep\to ehX}}{d\phi}=2\ P_1[\frac{1}{2}+P_2\cos(\phi)+P_3\cos(2\phi)+P_4\sin(\phi)+P_5\sin(2\phi)]$$



- Fitted function
- Moments of distributions of trigonometrical functions – means

$$\frac{d\sigma^{ep\rightarrow ehX}}{d\phi}=A+B\cos(\phi)+C\cos(2\phi)+D\sin(\phi)+E\sin(2\phi)$$

The 1st moment:

$$\langle\cos(n\phi)\rangle=\frac{\int d\sigma\cos(n\phi)}{\int d\sigma} \qquad n=1,2$$

Means:

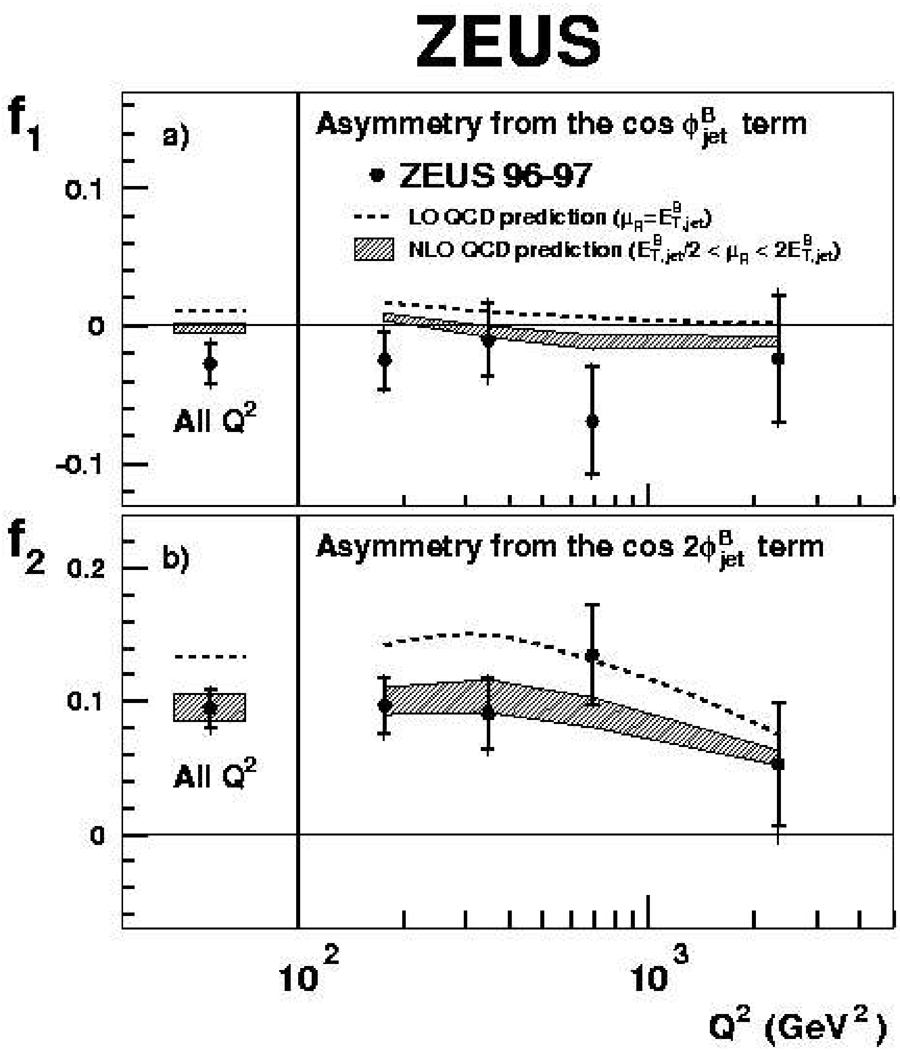
$$\langle\cos(\phi)\rangle=\frac{B}{2A} \qquad \langle\cos(2\phi)\rangle=\frac{C}{2A}$$

$$\langle\sin(\phi)\rangle=\frac{D}{2A} \qquad \langle\sin(2\phi)\rangle=\frac{E}{2A}$$

Previous ZEUS measurements

Distribution of the azimuthal angle – ZEUS paper 2002

Breit frame



Jet analysis

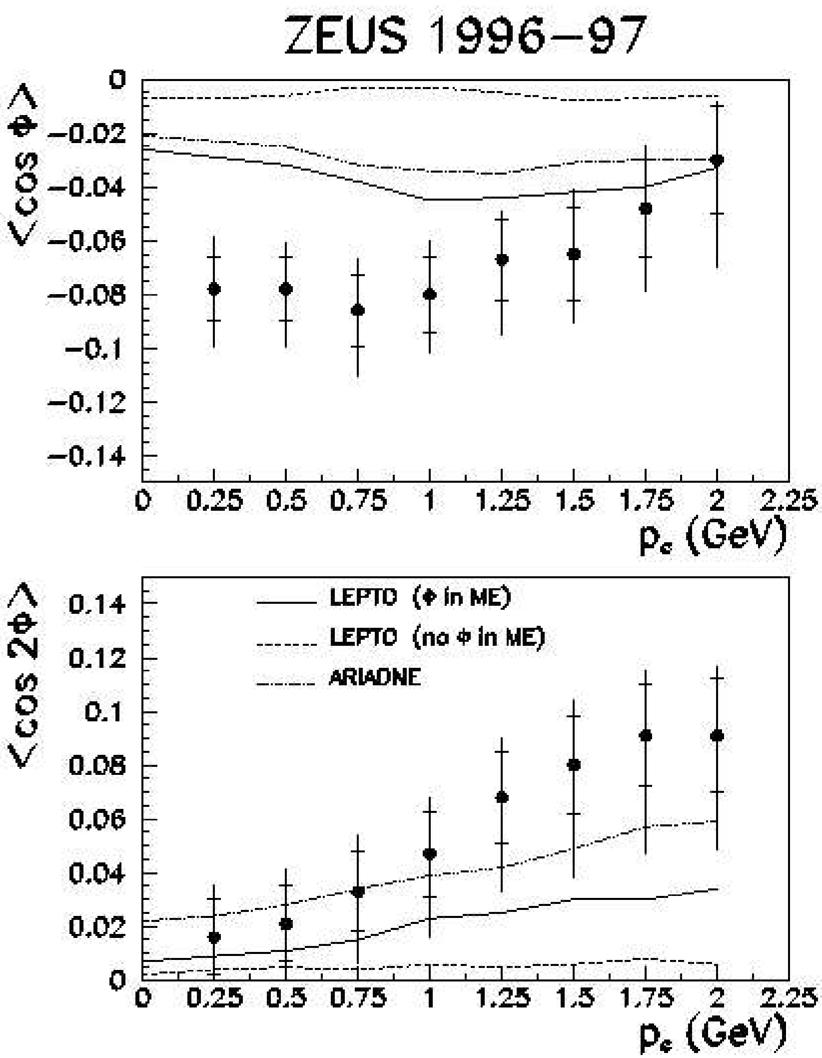
Fitted to experimental data

$$\frac{1}{\sigma}\frac{d\sigma}{d|\phi^B_{jet}|} = \frac{1}{\pi}[1 + f_1 \cos(\phi^B_{jet}) + f_2 \cos(2\phi^B_{jet})]$$

Small — Large

See Oscar Gonzalez thesis and
DESY 02-171, Phys.Lett. B551 (2003) 226-240

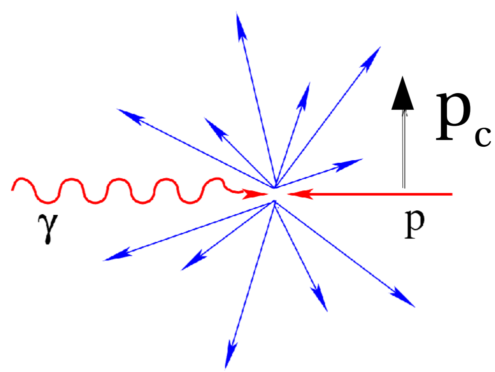
Distribution of the azimuthal angle – ZEUS paper 2000



HCM frame
z, p_T method

Multiplicity method
Charged hadrons

For hadrons with $p_T > p_c$



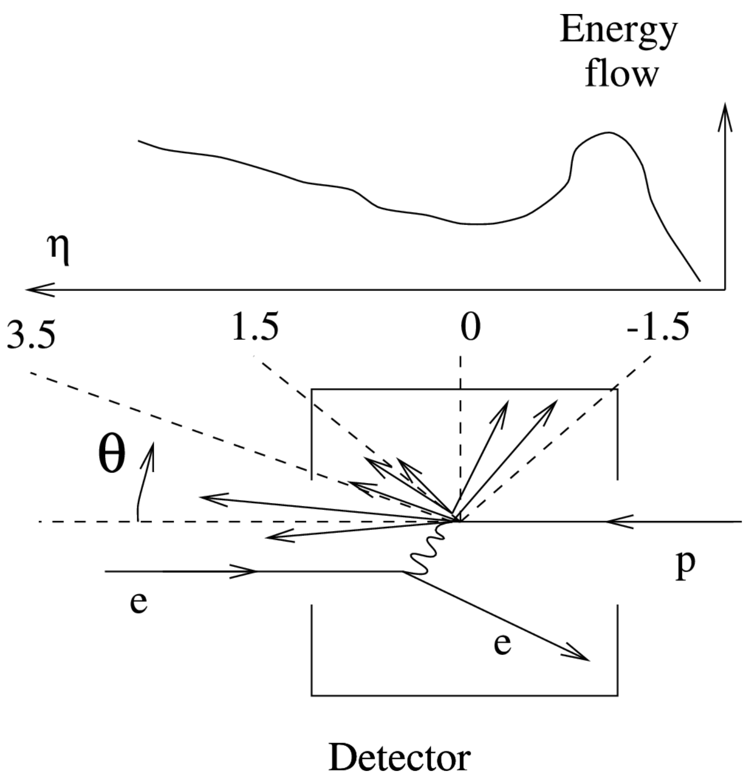
$$0.2 < z_h = \frac{P \cdot p_h}{P \cdot q} < 1$$

See Eduardo Rodriguez thesis and
DESY 00-040, Phys.Lett. B481 (2000) 199-212

New method of analysis
Energy Flow

Energy flow method in the laboratory frame

ZEUS UFO

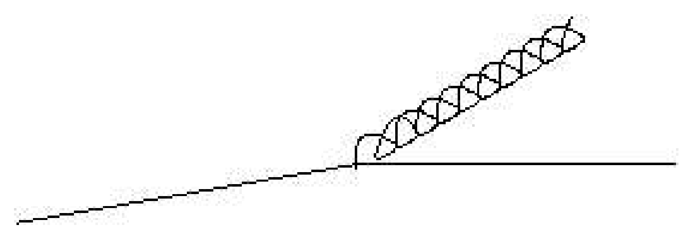


Energy flow objects EFO
EFO used as pseudohadrons

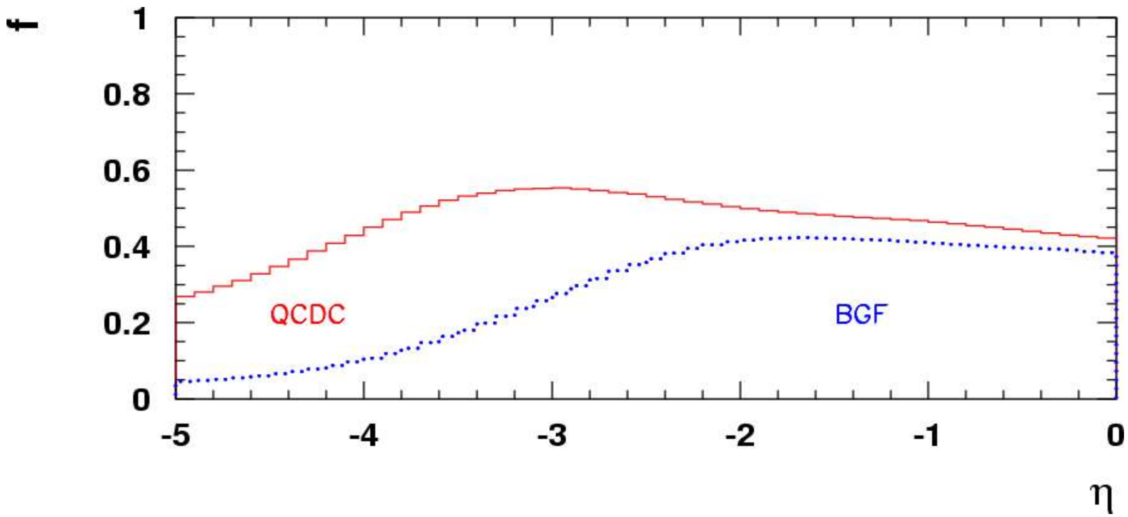
pQCD
infrared and collinear singularities out

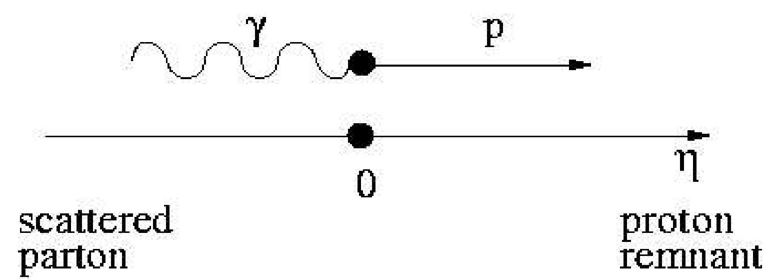
Peccei, Rückl (1978)

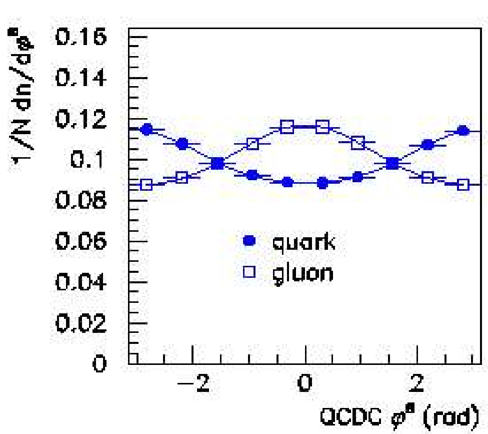
Each particle direction is weighted with its energy

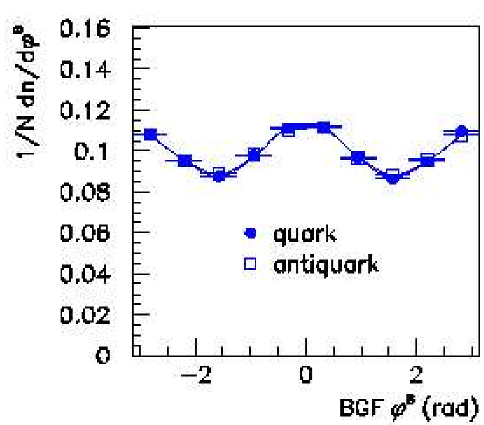


Look into pseudorapidity









If integrated over

the dominant contribution:
from QCDC $\gamma^* q \rightarrow qg$
to $\cos(\phi)$
from BGF $\gamma^* g \rightarrow q\bar{q}$
to $\cos(2\phi)$

Comments on the energy flow method and pseudorapidity

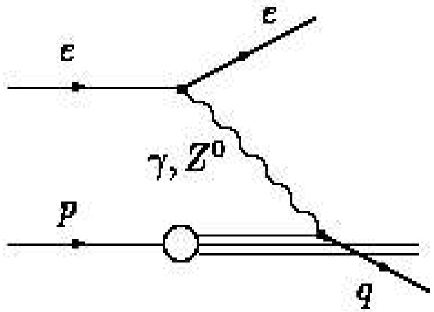
- charged and neutral hadrons included
- hard partons (E^*_T larger) provides a larger contribution
- hadrons nearby in the HCM frame → nearby in LAB
- sensitive to parton fragmentation → no dependence on jet algorithms
- multiplicity method with charged hadrons → sensitive to hadronization
- calorimeter energy scale is canceled

- no hadrons but clusters of energy
  the quantities like $z=Pp_h/Pq$ are not well measured

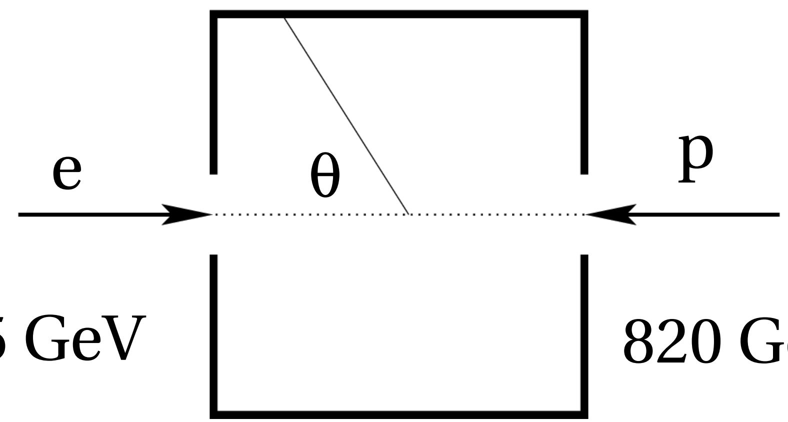
Global selection criteria

$$E_{e'}^{LAB} > 10\ GeV$$

$$100 < Q^2 < 8000\ GeV^2$$
$$0.2 < y < 0.8$$
$$0.01 < x < 0.1$$

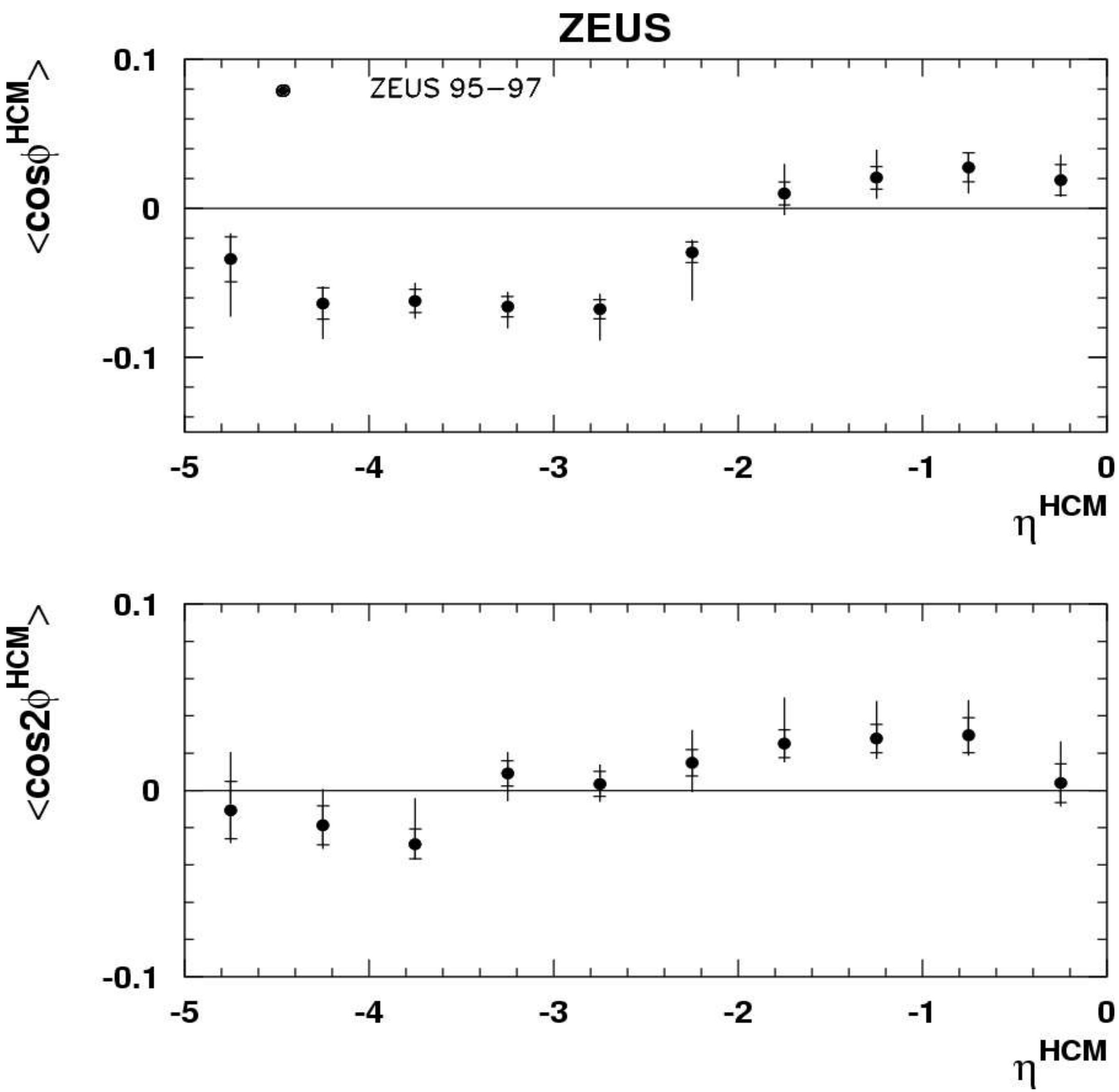


$$\theta_{particle}^{LAB} > 8^0\ (First\ ring)$$
$$p_T^{LAB} > 150\ MeV$$



$$Q^2 = -q^2 = -(k_{e'} - k_e)^2$$
$$x = Q^2 / 2 P \cdot q$$
$$y = P \cdot q / P \cdot k_e$$

Azimuthal asymmetry energy flow method



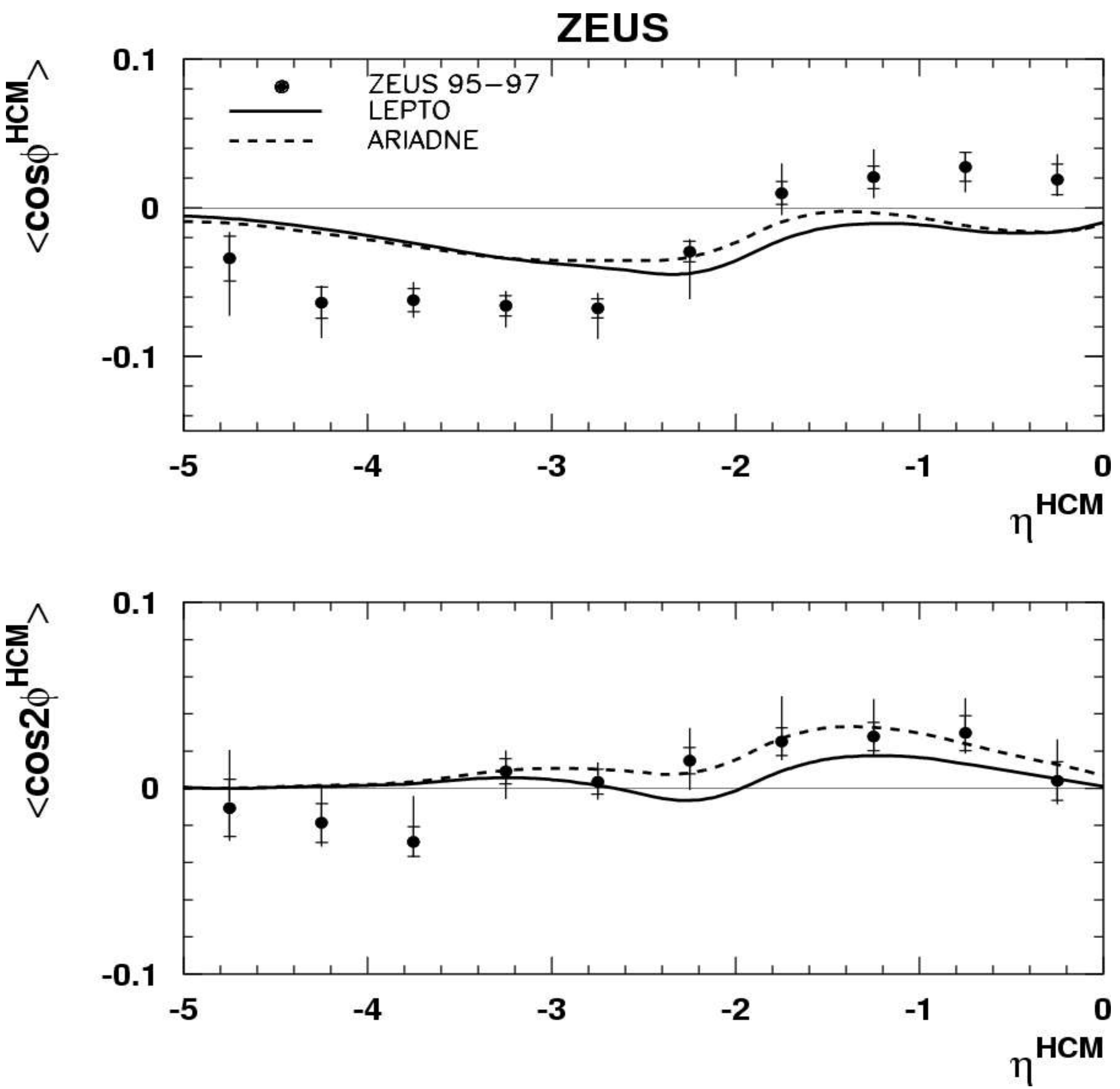
Monte Carlo Models

LEPTO 6.5.1 – matrix element and parton shower

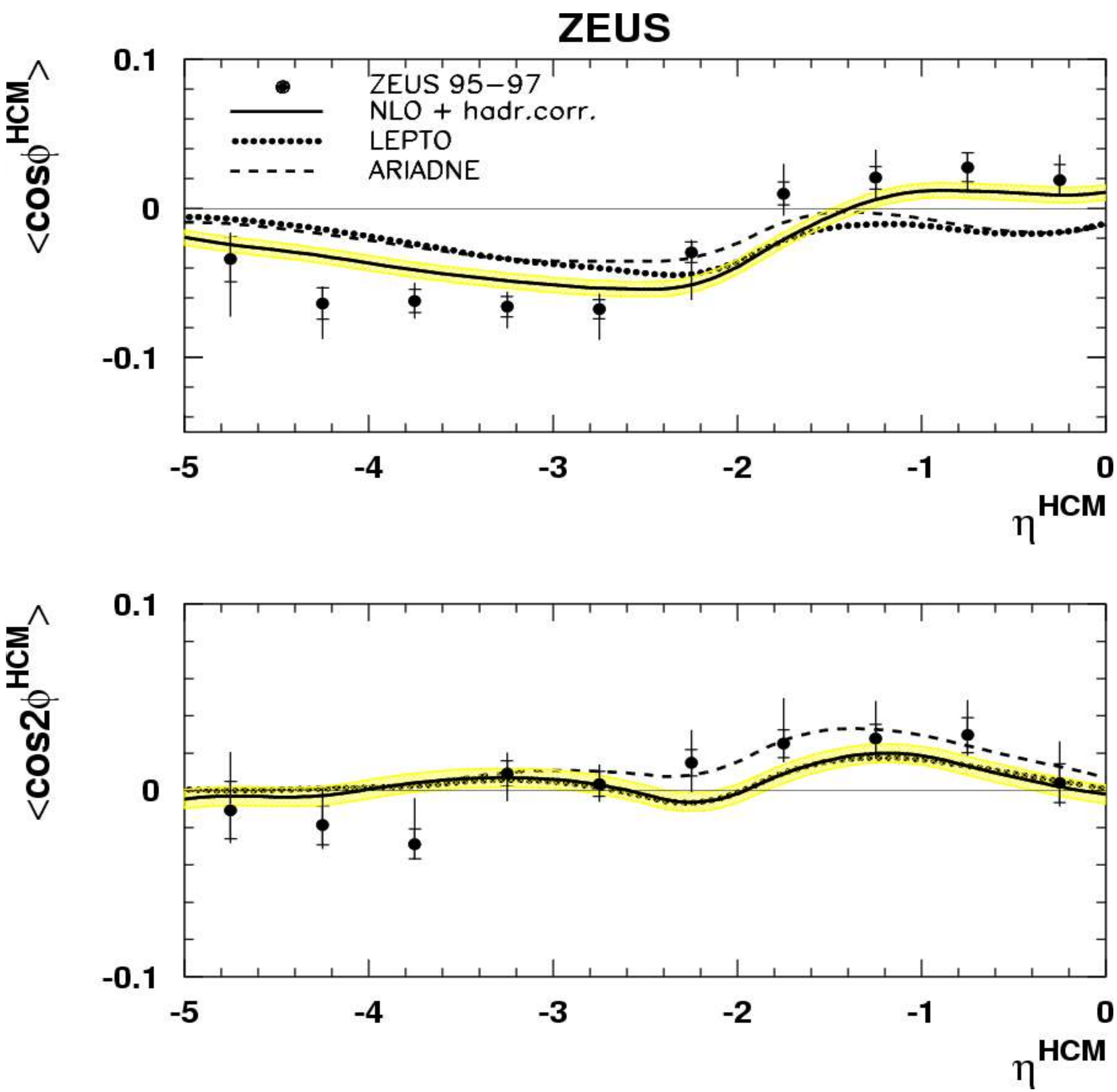
ARIADNE 4.12 – colour dipole model (LO)

DISENT – NLO dipole factorization formulae and subtraction technique

Azimuthal asymmetry energy flow method



Azimuthal asymmetry energy flow method

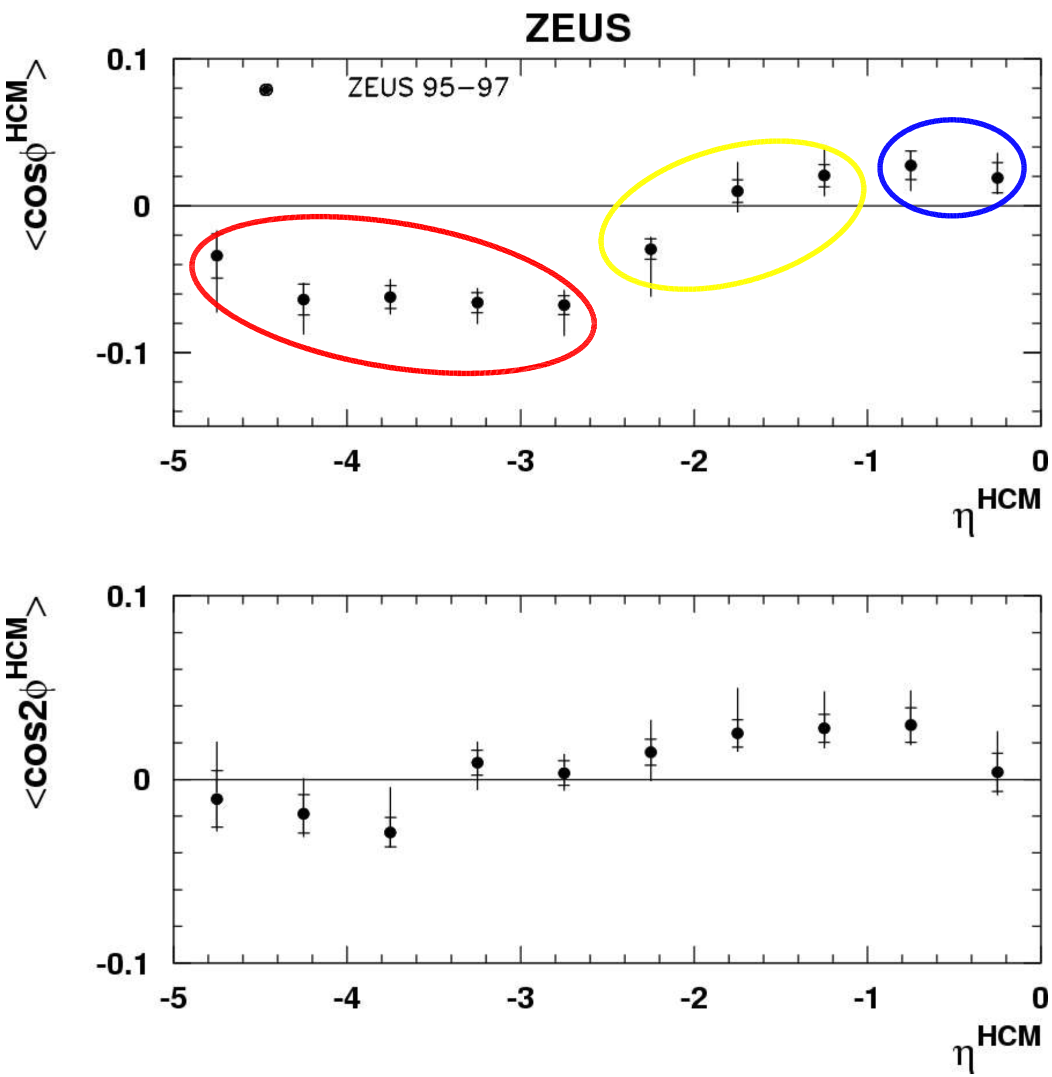


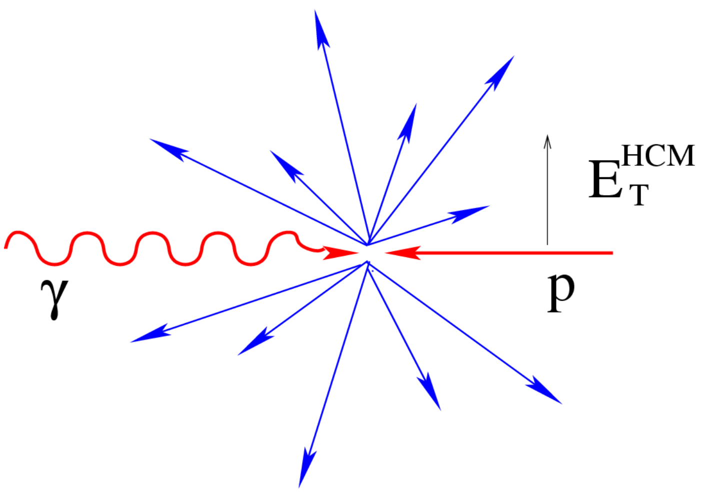
Uncertainties for NLO due to factorization and renormalization scales were calculated by changing

$\mu_{F,R} = Q$ *to* $0.5 \cdot Q$ *and* $2 \cdot Q$

Azimuthal Asymmetry as a function of E_T

Azimuthal Asymmetry as E_T^{HCM}



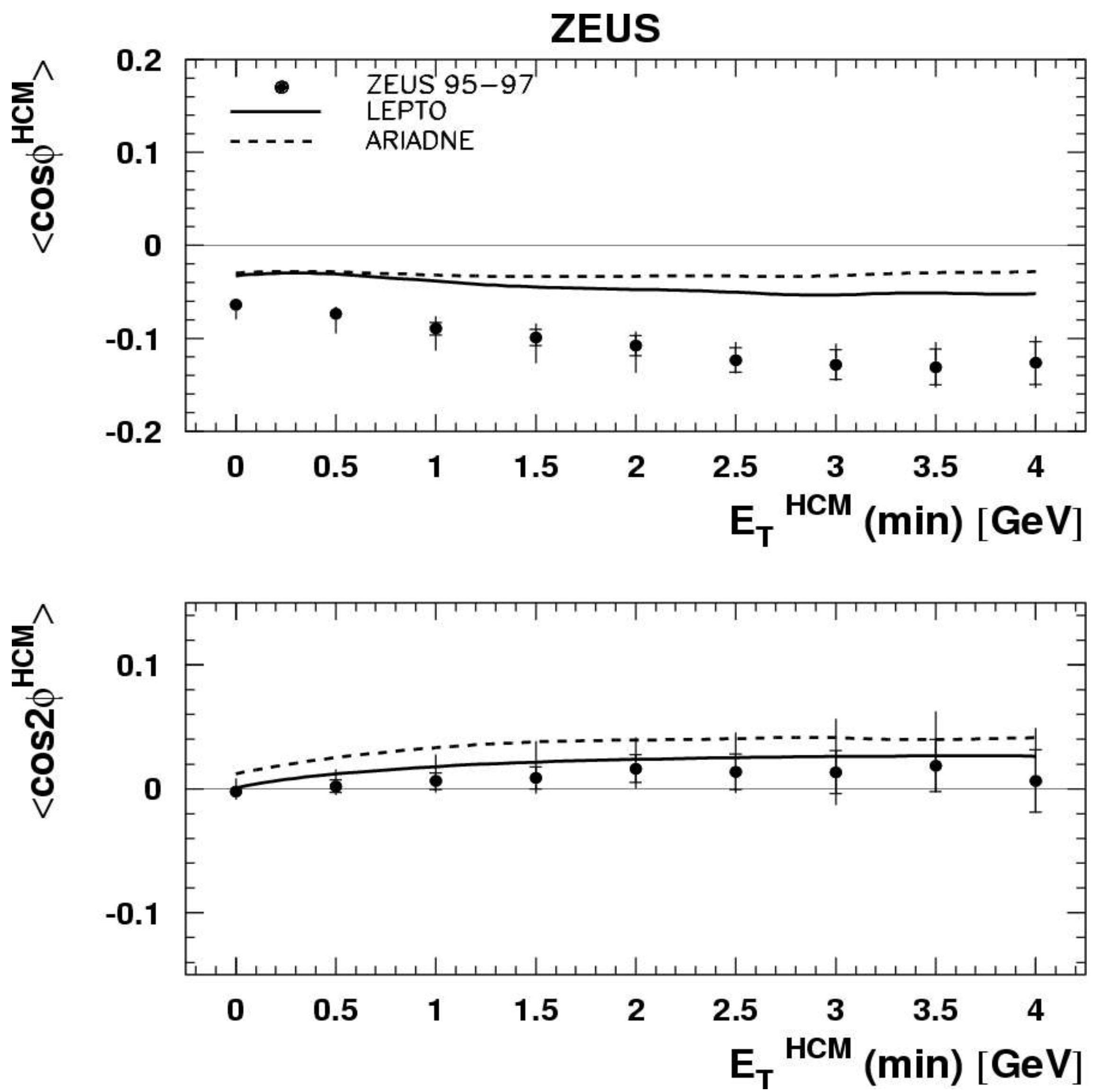


$-5. < \eta^{HCM} < -2.5$

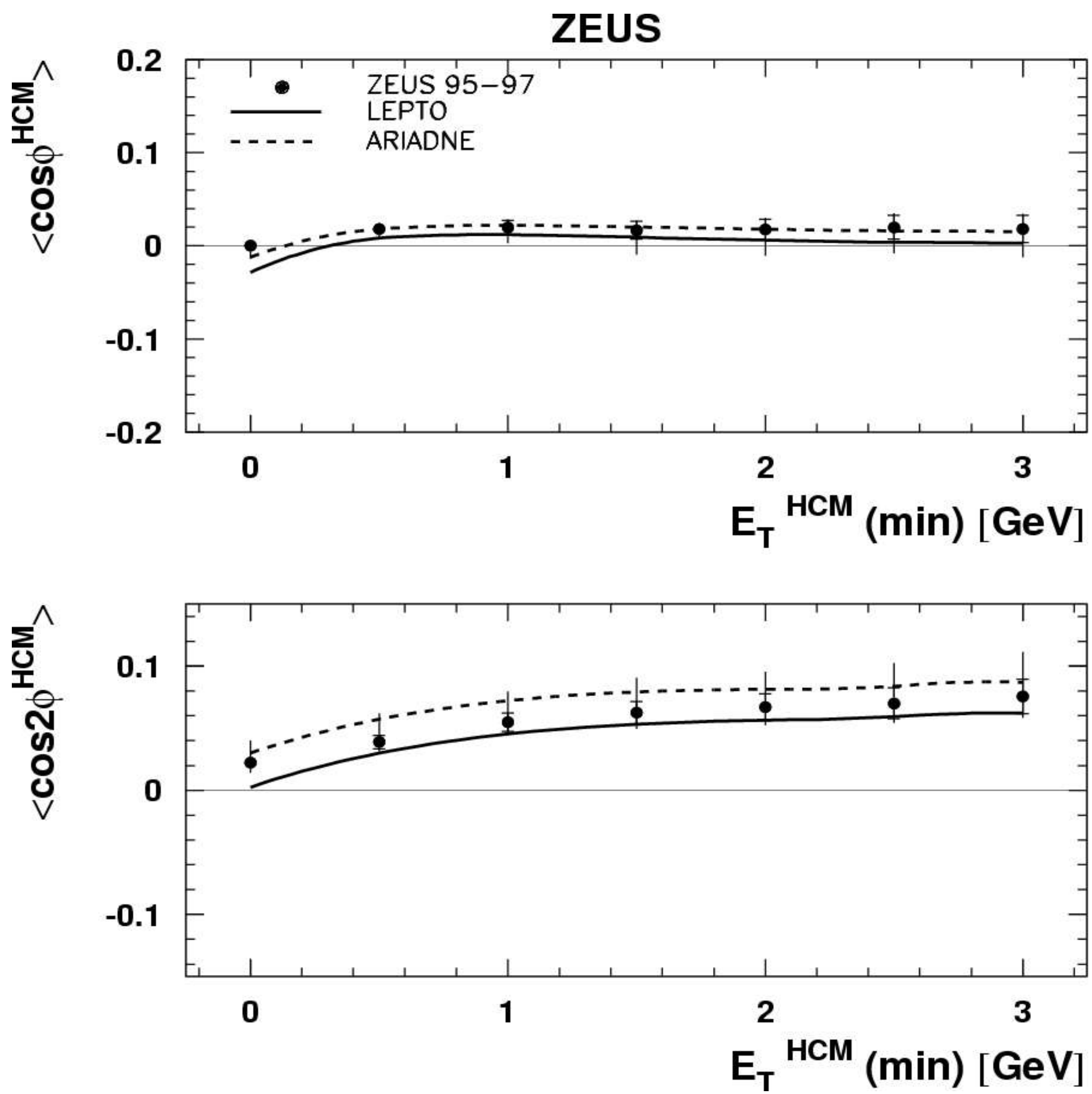
$-2.5 < \eta^{HCM} < -1.$

$-1. < \eta^{HCM} < 0.$

$-5. < \eta^{HCM} < -2.5$

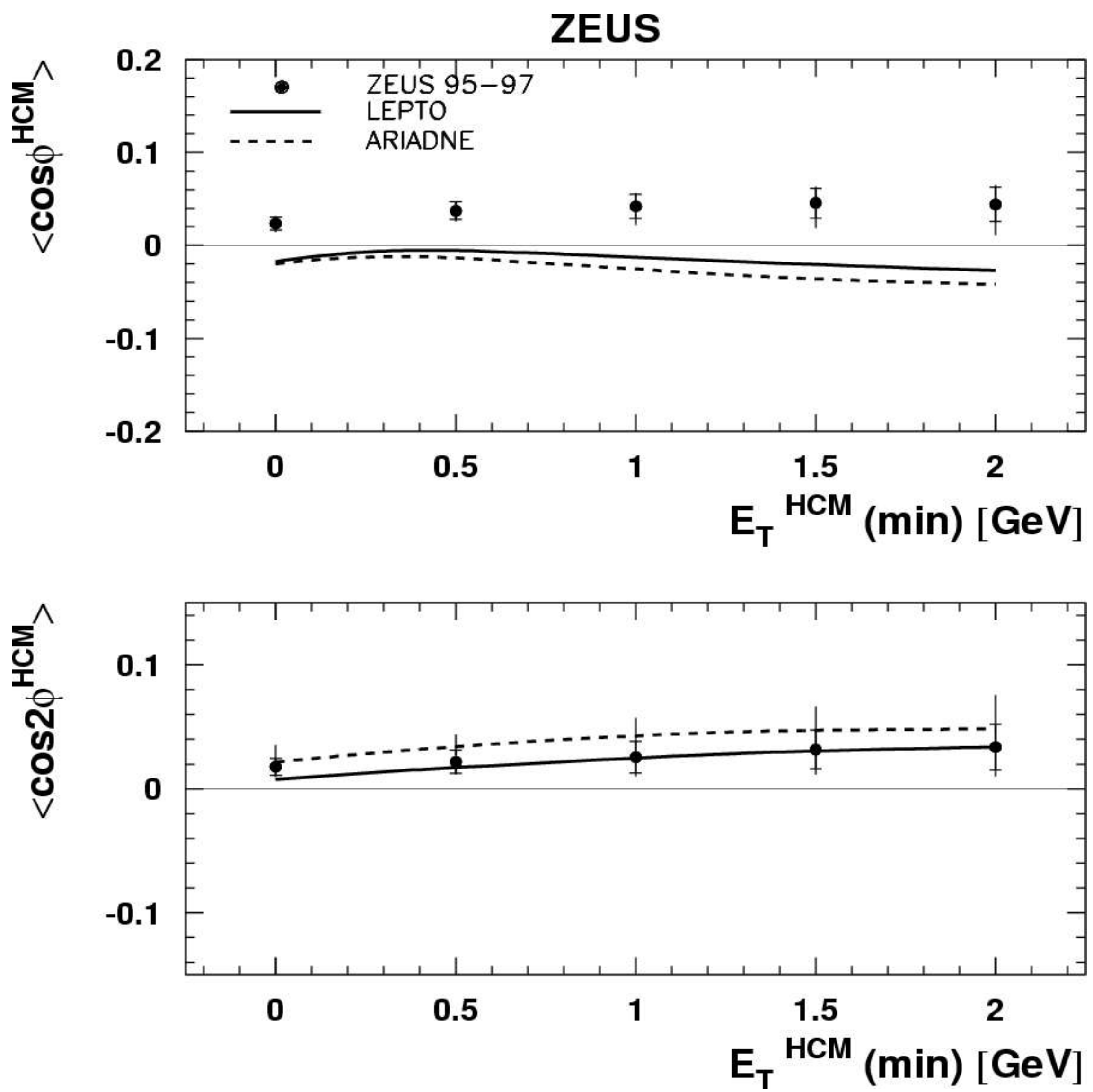

ZEUS
ZEUS 95–97
LEPTO
ARIADNE
<cosφ^HCM>
0.2
0.1
0
-0.1
-0.2
0
0.5
1
1.5
2
2.5
3
3.5
4
E_T HCM (min) [GeV]
<cos2φ^HCM>
0.1
0
-0.1
E_T HCM (min) [GeV]

$-2.5<\eta^{HCM}<-1.$



ZEUS
ZEUS 95–97
LEPTO
ARIADNE
$<\cos\phi^{HCM}>$
$<\cos2\phi^{HCM}>$
0.2
0.1
0
-0.1
-0.2
0
1
2
3
E_T^{HCM} (min) [GeV]

$-1. < \eta^{HCM} < 0.$


ZEUS
ZEUS 95−97
LEPTO
ARIADNE
0.2
0.1
0
-0.1
-0.2
0
0.5
1
1.5
2
E_T^{HCM} (min) [GeV]
$<\cos\phi^{HCM}>$
$<\cos2\phi^{HCM}>$

Summary and conclusions

A novel approach to azimuthal asymmetry is proposed which provides precise measurements and small statistical errors in the wider interval of phase space

<u>The method permits to:</u>

- include charged and neutral hadrons
- enhance contributions of hard partons by weighting with energy, i.e. energy flow
- investigate contributions of BGF w.r.t QCDC
- compare these results with the previous ZEUS measurements

Summary and conclusions

The main results are:

- the NLO effects give non negligible contribution
- they provide better agreement with experimental data
- some small discrepancies are visible which cannot be explained by experimental errors