Azimuthal Asymmetries in Neutral Current Deep Inelastic Scattering

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- Motivations
- Basics of Neutral Current DIS at HERA
- Phi Asymmetries with Hadrons and Jets
- Distinguishing Quark/Gluon Jets and QCDC/BGF Events at HERA: a Neural Network Approach
- Conclusions

IoP HEPP Conference 2001

Motivations

- Origin of Azimuthal asymmetries:
  Spin of scattering photon and partons.
  - **Non-perturbative: intrinsic transverse momentum of partons**
  - **Perturbative: QCD corrections**

- Fixed target experiments investigated a kinematical region where non-perturbative effects dominate and are sufficient to explain the data

- At HERA QCD effects should dominate
  ➨ clean and powerful test of pQCD

Kinematic Variables in DIS

➢ Negative of 4-momentum transfer squared

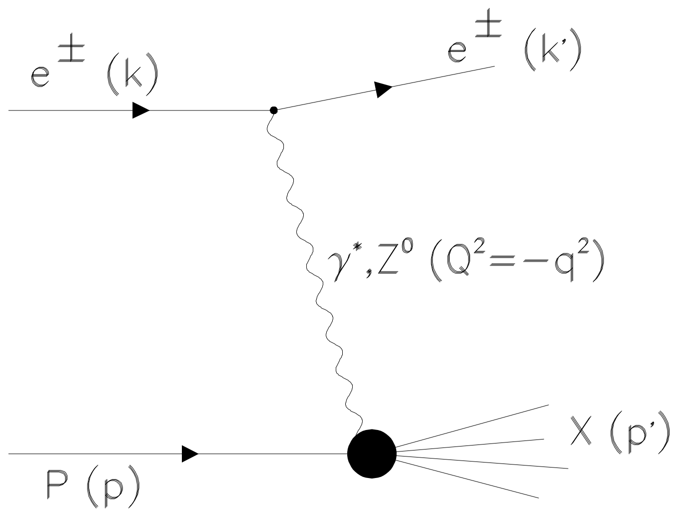
$$\boxed{Q^2 = -q^2 = -(k - k')^2 \cong 2E_e E'_e(1-\cos\theta)}$$

➢ Momentum fraction of struck parton in proton

$$\boxed{x = \frac{Q^2}{2P.q} \cong \frac{Q^2}{sy}}$$

➢ Fractional energy transfer to the proton

$$\boxed{y = \frac{P.q}{P.k} \cong 1 - \frac{E'_e}{2E_e}(1+\cos\theta)}$$



(θ is the scattered lepton polar angle in the Lab. frame)

NC DIS at HERA

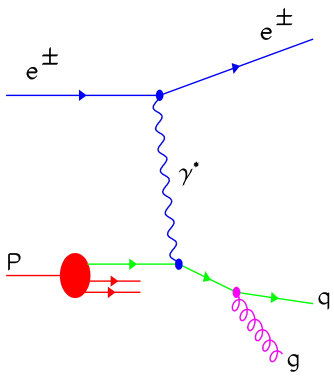
Described in QCD, up to order α_s , by 3 types of diagrams:

(a) **QCD-Compton (QCDC)**

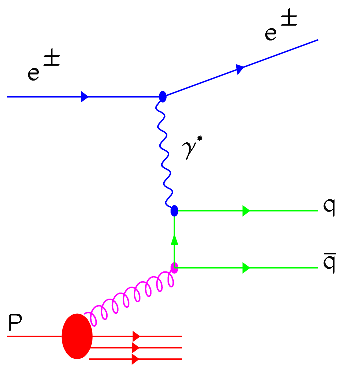
(b) **Boson-Gluon Fusion (BGF)**

(c) **"Quark Parton Model" event (QPM)**

$$\boxed{e^{\pm} + p \rightarrow e^{\pm\prime} + X}$$



(a)



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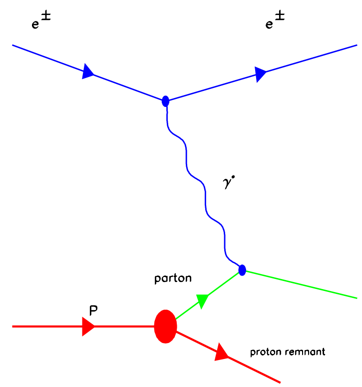
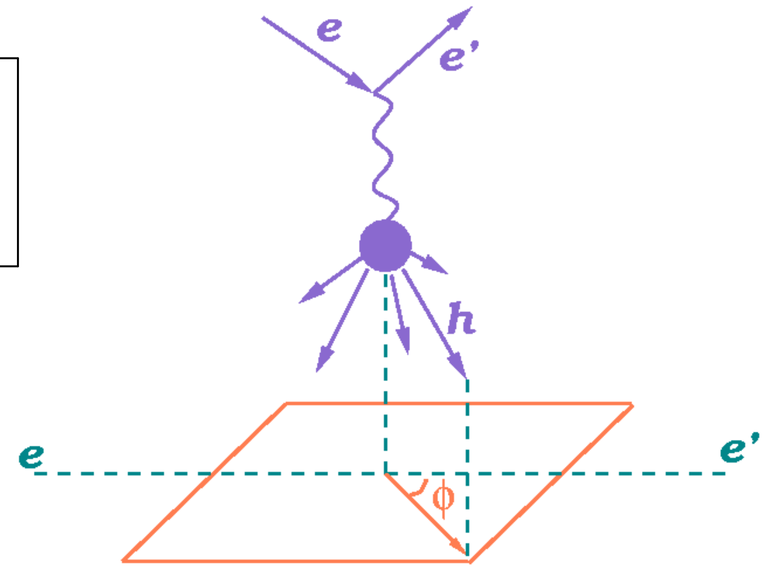


(c)

Theoretical Phi Distribution

- All 3 diagrams contribute to

$$\boxed{\frac{dn}{d\phi} \propto A + B\cos\phi + C\cos 2\phi + D\sin\phi}$$



Moments of distribution:

$$< \cos\phi >= B/2A$$

- main contribution from QCDC diag.
- transverse-longitudinal interference

$$< \cos 2\phi >= C/2A$$

- main contribution from BGF diag.
- interference of +1 and –1 helicity transverse amplitudes

$$< \sin\phi >= D/2A$$ (= 0 for non-polarised NC DIS)

General Description of the Analyses

- Using data taken with the ZEUS detector in 1996-97 ($38\ pb^{-1}$)

- Kinematic range:

$$0.01 < x < 0.1 \qquad\qquad 0.2 < y < 0.8$$

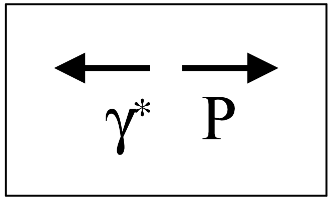
good detector acceptance

good hadronic activity

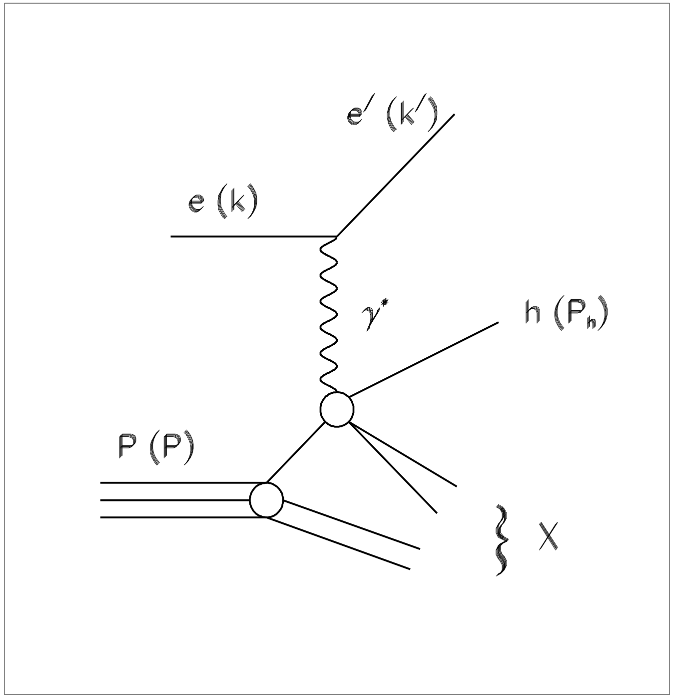
- Standard DIS cleaning cuts

Azimuthal Asymmetries with Hadrons

- Analysis in hadronic centre-of-mass frame



$\leftrightarrow$ **γ^*P collinear frame needed**



Selection of "leading" particles:

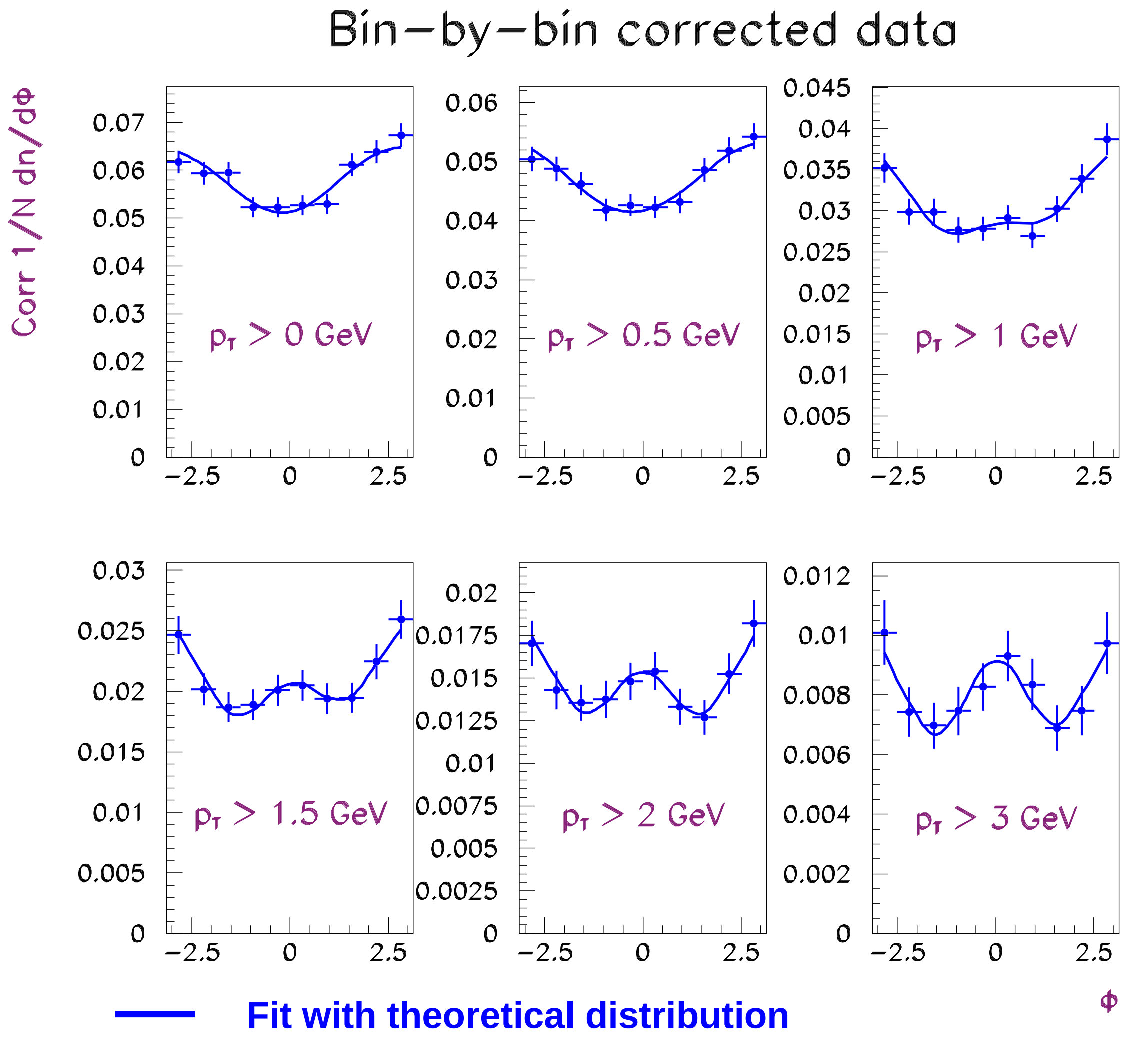
$$0 < z_h = \frac{P.p_h}{P.q} < 1$$

p_h is the momentum of hadron h

- cut $z_h > 0.2$

(main contribution from quark fragmentation)

Results for the Phi Distributions of Hadrons



$\cos\phi$ term present at all P_T values

$\cos 2\phi$ term arises as P_T cut ↗

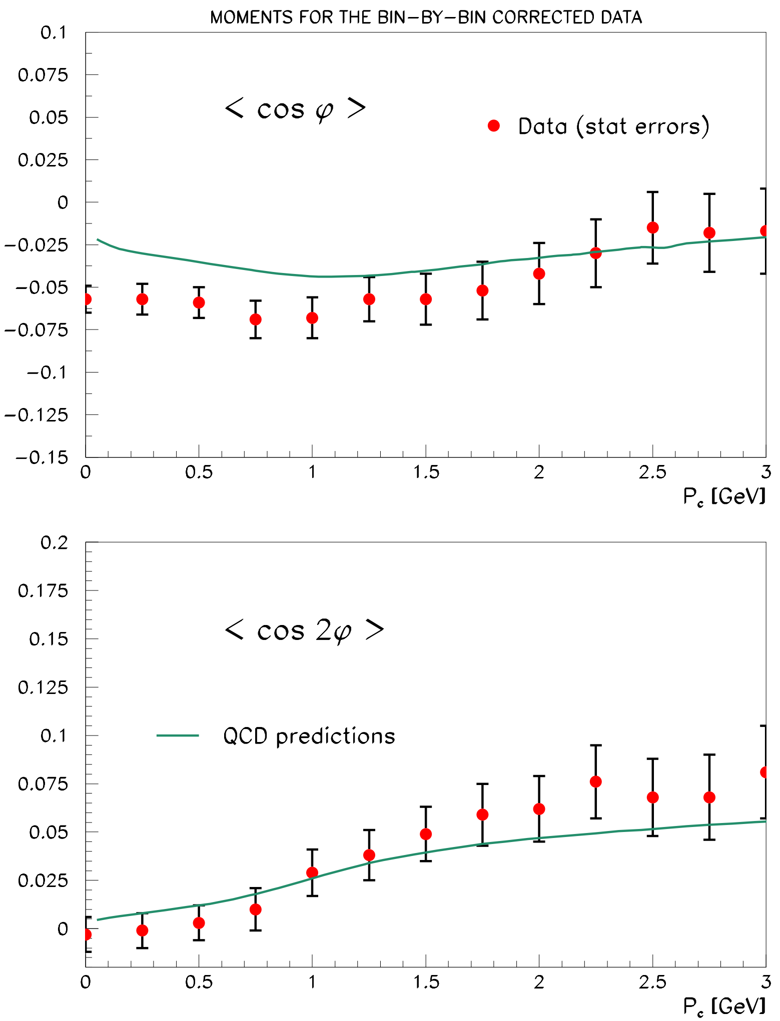
Moments of Phi Distributions for Hadrons

$< \cos\phi >$ negative

$< \cos 2\phi >$ positive

- Data qualitatively agrees with QCD LO predictions

- QCD LO calculations used mean intrinsic k_T and frag. p_T of 0.6 GeV

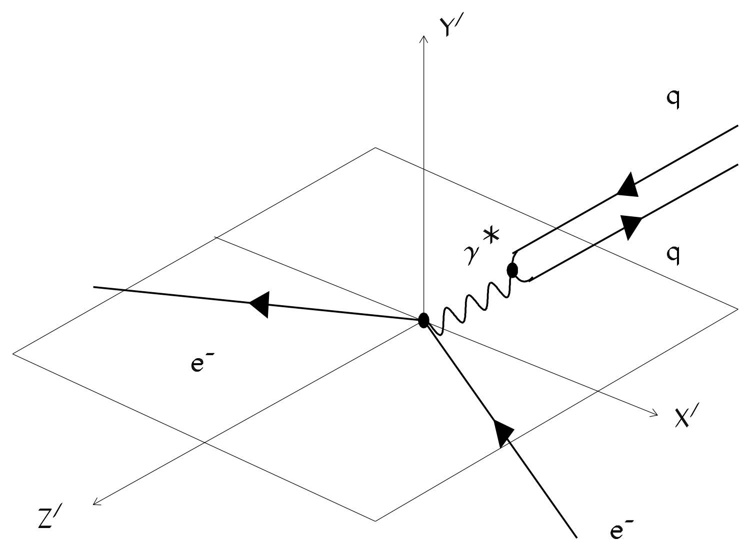


Azimuthal Asymmetries with Jets

- Study of jets ➨ inclusion of the whole hadronic final state

Study performed in the Breit frame

The Breit Frame



Jet cuts:

$E_{T,jet} > 8\ GeV$

$-2. < \eta_{jet} < 2.$

Cuts exclusively in the Breit Frame !

➨ No bias introduced in the ϕ distributions !

K_T Cluster Jet Algorithm

- For all particles, d_i and d_{ij} are calculated:

$$d_i = E_{T,i}^2 \qquad\qquad d_{ij} = \min(E_{T,i}^2, E_{T,j}^2) \cdot (\Delta\eta_{ij}^2 + \Delta\phi_{ij}^2)$$

- $\min(d_i, d_{ij}) = d_{ij}$ ➨ particles i,j merged according to a recombination scheme

- $\min(d_i, d_{ij}) = d_i$ ➨ particle i is a "protojet"

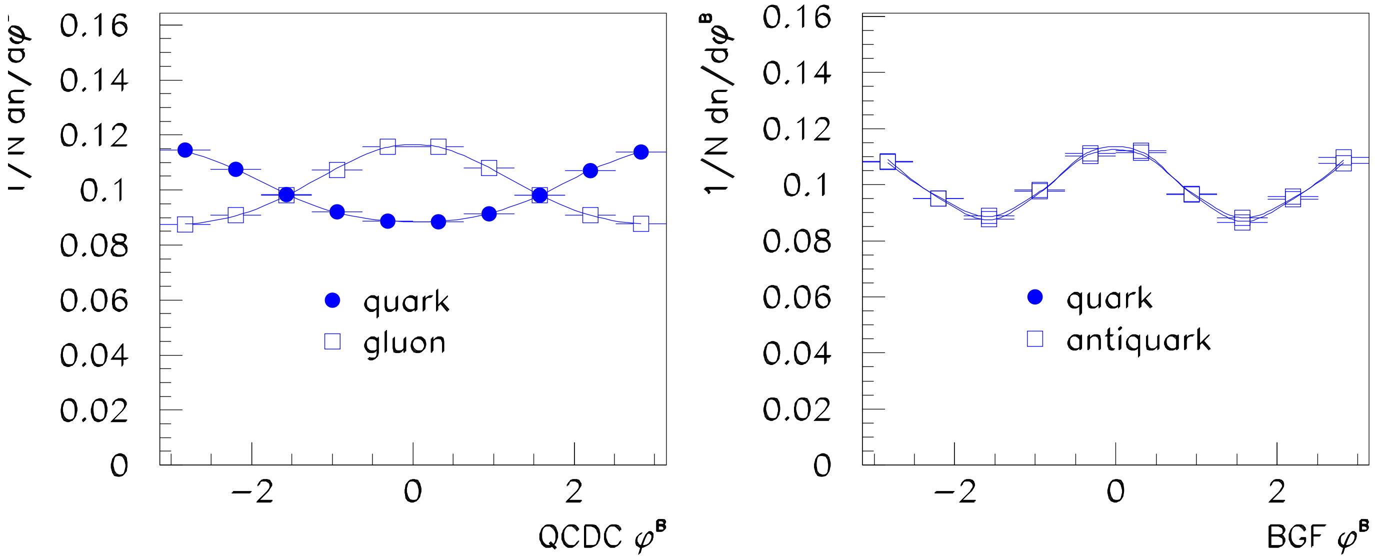
- Procedure repeated for all "non-protojets" until no more are left.

- Jets are the "protojets" with $E_T > E_T^{cut}$

The p_T recombination scheme was used.

Asymmetries for the “Hard” Partons

Studies with MC event generator Lepto



Predicted asymmetries are different for QCDC and BGF events and for quark and gluon initiated jets

➔ How to discriminate between them? A 1st attempt in DIS …

Separation of Quark and Gluon Jets

- QCD predicts gluon jets to
  - have a broader p_T spectrum
  - exhibit a softer hadron spectrum
  - have a higher multiplicity

  than quark jets
- Study of internal structure of jets provides a potential way of distinguishing q- from g- jets

➨ investigation of jet-structure sensitive variables

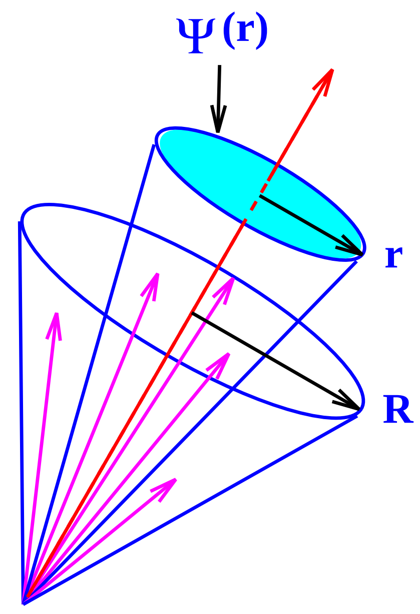
Jet Structure Sensitive Variables

- Subjet Multiplicities:

  Clustering procedure repeated for all particles in a jet until every pair (*i,j*) satisties $d_{ij} > y_{cut} \cdot (E_T^{jet})^2$
  The remaining “objects” are called subjets.

- Integrated Jet Shape:

$$\Psi(r) = \frac{1}{N_{jets}} \sum_{jets} \frac{E_T(r)}{E_T(r=1)}$$

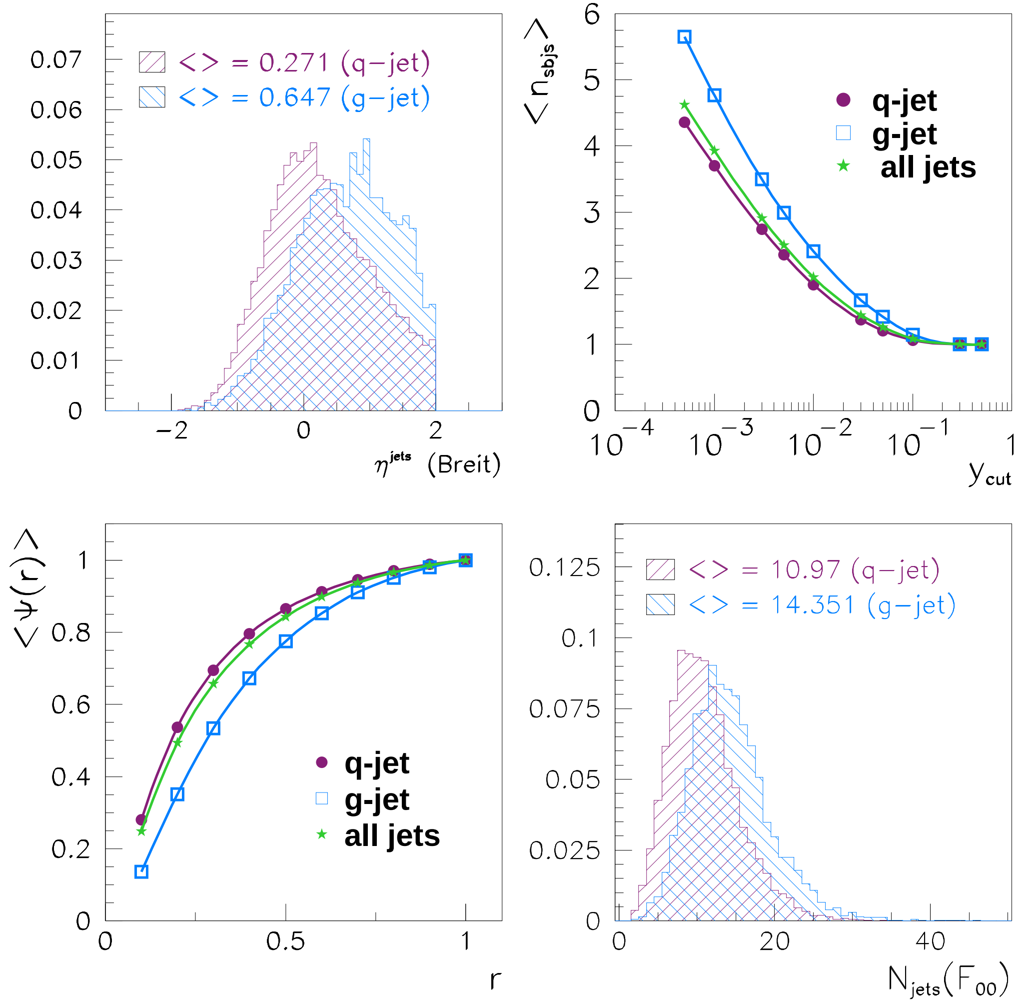


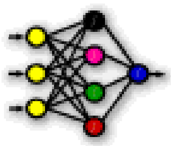
- Fodor Moments:

$$F_{mn} = \sum_i \left[\frac{p_{\perp,i}}{E_T^{jet}} \right]^m \eta_{\perp,i}^n$$

Discriminating Variables

4-vector studies with Lepto generator





Neural Network Approach to Jet & QCD Event Type Tagging

- MLPfit package used for the NN setup
- Several architectures of Multi-Layer Perceptrons studied
- Several discriminating variables studied:
  - **Jet's pseudorapidity**
  - **Subjet multiplicity at low y_{cut}**
  - **Integrated jet shape**
  - **Jet's multiplicity (F_{00}), F_{01}**
  - **...**

4-vector Study of the NN Tagging

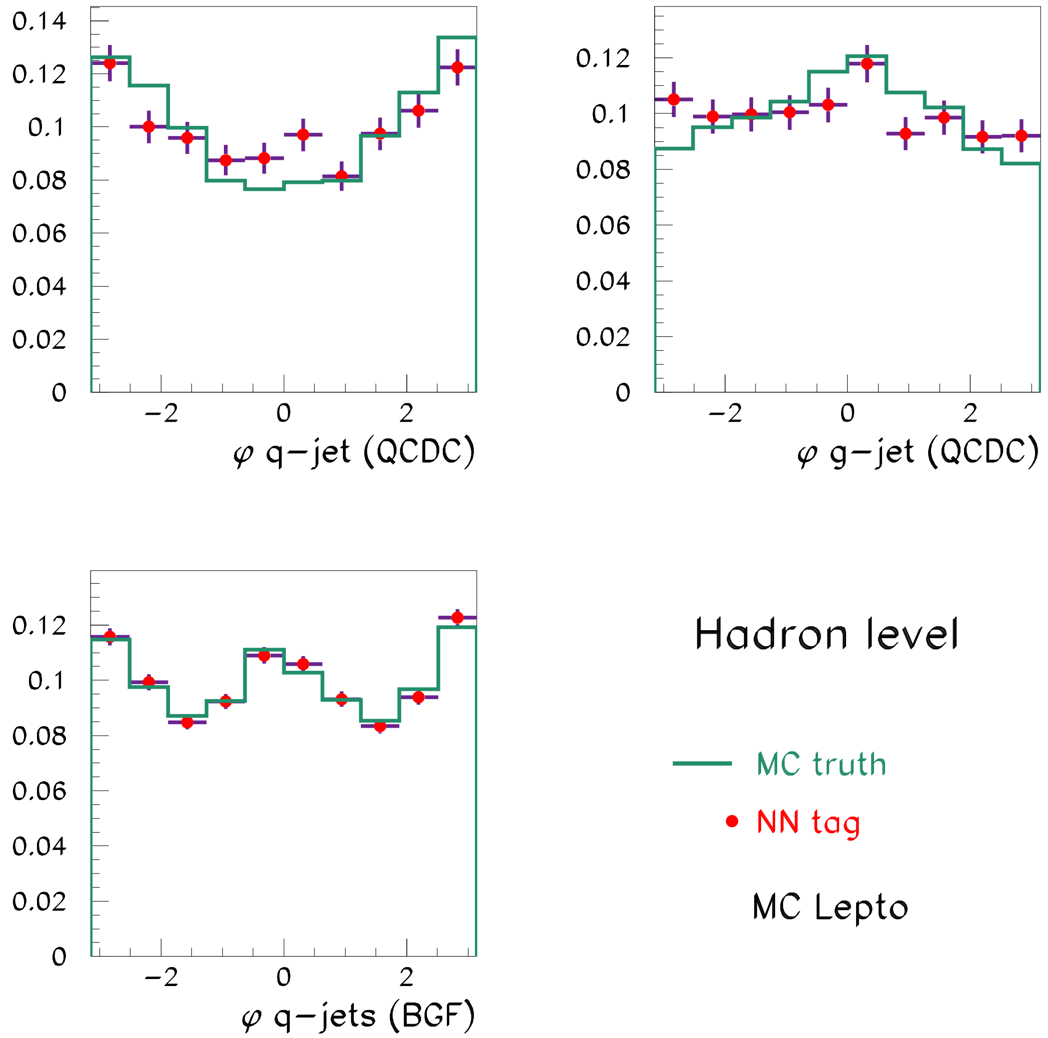
Purities for tagging:

$$\pi^{tag}_{QCDC} \approx 60\ \%$$

$$\pi^{tag}_{BGF} \approx 70\ \%$$

Efficiencies for tagging:

$$\varepsilon^{tag} \approx 30\ \%$$



Conclusions and Outlook

- Azimuthal asymmetries clearly observed in DIS both with hadrons and with jets

- A NN approach to jet and QCD event type tagging in DIS has shown promising results:
  1st time ever attempted at HERA

- Further studies needed at hadron/detector level

- HERA/ZEUS upgrade will give a boost to these *precision tests of QCD at HERA*:

  o polarisation → sin $\phi \neq 0$ in NC
  o more stats → CC studies where sin ϕ and sin 2ϕ are also present