Predictions for Azimuthal asymmetry

in $e^+p$ DIS at HERA
NC DIS at $Q^2 > 100$ GeV$^2$

Outline

• Monte Carlo DIS codes
• Experimental problems
• Predictions for asymmetries
  multiplicity method versus energy flow methods
  – Parton level (matrix element and parton showers)
  – Hadron level
  – next-to-leading order (NLO) versus leading order (LO)
• Summary
Azimuthal asymmetry

**Definition of the azimuthal angle**

\[
\phi = \phi_{e'} - \phi_h
\]

- \(\phi_{e'}\) the azimuthal angle of the final electron
- \(\phi_h\) the azimuthal angle of the final particle \(h\)
- \(h\) outgoing hadron (or charged and neutral cluster in calorimeter)

\[
\frac{d^5\sigma^{ep\rightarrow ehX}}{dx\,dQ^2\,dP_T^2\,dzd\phi} = A + B\cos\phi + C\cos 2\phi + D\sin\phi + E\sin 2\phi
\]

\(\gamma^*p\) frame
Breit or \(\gamma^*p\) cms

\(Z\)-axis
**Monte Carlo Investigation**

Generators used in leading order (LO) with hadronisation included:

**LO**

LEPTO 6.5.1 Matrix element and parton showers
ARIADNE 4.12 Colour dipole model

**NLO or LO**

DISENT NLO dipole factorization formulae, subtraction method

**Diagrams:**

- **QPM**
- **BGF**
- **QCD Compton**
Azimuthal asymmetry

The dominant contribution to:

- \( \cos \phi \) from QCD Compton \( (\gamma^* q \rightarrow qg) \)
- \( \cos 2\phi \) from BGF \( (\gamma^* q \rightarrow q\bar{q}) \)

hadronic centre of mass HCM
Azimuthal asymmetry

QCD Compton

LEPTO 6.5.1

Longitudinally polarised virtual photons $F_L$

$q_{\text{out}}$ $q_{\text{in}}$ $\gamma^*$ $g$
Methods for Inclusive Measurements of Asymmetries

- Multiplicity method
- Energy flow method \((E_T, E_{tot}, z)\)

Problems:
- Losses of
  - soft particles \((P_T^{LAB} < 150 \text{ MeV})\)
  - fragments of proton remnant
- Clustering of particles
Azimuthal asymmetry

**All hadrons detected**

**Energy flow**

\[
\langle \cos \phi_{\text{HCM}} \rangle
\]

\[
\langle \cos 2\phi_{\text{HCM}} \rangle
\]

**Multiplicity**

\[
\langle \cos \phi_{\text{HCM}} \rangle
\]

\[
\langle \cos 2\phi_{\text{HCM}} \rangle
\]

LEPTO — solid
ARIADENE — dashed
Azimuthal asymmetry

**Soft hadron lost** $P_{LAB}^T < 150$ MeV

**Energy flow**

**Multiplicity**

- **LEPTO** — solid
- **ARIADNE** — dashed
**Partons versus Hadrons**

**LEPTO predictions for**

\[ B = \langle \cos \phi \rangle \]
\[ C = \langle \cos 2\phi \rangle \]

Investigated processes:

- all processes together \hspace{1cm} solid line
- boson-gluon fusion (BGO) \hspace{1cm} dotted line
- QCD Compton \hspace{1cm} dashed line
Azimuthal asymmetry

\[ \mathcal{B} = \langle \cos \phi \rangle \]

**Parton level**
Matrix element only

**Parton level**
ME + parton shower

**Hadron level**
detection included
\[ C = \langle \cos 2\phi \rangle \]

Parton level
Matrix element only

Parton level
ME + parton shower

Hadron level
detection included
LO predictions on parton level

Energy flow

\[
\langle \cos \phi \rangle_{\text{HCM}}
\]

\[
\langle \cos 2\phi \rangle_{\text{HCM}}
\]

<table>
<thead>
<tr>
<th>Prediction</th>
<th>Line Style</th>
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<tbody>
<tr>
<td>LEPTO</td>
<td>solid</td>
</tr>
<tr>
<td>ARIADNE</td>
<td>dashed</td>
</tr>
<tr>
<td>DISENT LO</td>
<td>dotted</td>
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<tr>
<td>DISENT NLO</td>
<td>dashed-dotted</td>
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</tbody>
</table>
Azimuthal asymmetry

NLO vs LO predictions on parton level

Energy flow

\[ \langle \cos \phi \rangle_{\text{HCM}} \]

\[ \langle \cos 2\phi \rangle_{\text{HCM}} \]

\( \eta_{\text{HCM}} \)

NLO versus LO

LEPTO line
ARIADNE solid
DISENT LO dashed
DISENT NLO dashed-dotted
Experimental Data

ZEUS

$\langle \cos \phi \rangle$

$\langle \cos 2\phi \rangle$

DIS 2005

Teresa Tymieniecka
Summary

For the inclusive investigation of azimuthal asymmetries:

- Energy flow method is better than multiplicity method
- Energy flow method is less sensitive to undetected hadrons
Azimuthal asymmetry

Partons versus Hadrons $\mathcal{B} = \langle \cos \phi \rangle$

**Energy flow**

**Multiplicity**

LEPTO

hadron level — solid
parton level (MEPS) — dashed
parton level (ME) — dotted
Azimuthal asymmetry

**Partons versus Hadrons** \[ C = \langle \cos 2\phi \rangle \]

**Energy flow**

\[ \langle \cos 2\phi \rangle_{HCM} \]

**Multiplicity**

\[ \langle \cos 2\phi \rangle_{HCM} \]

**LEPTO**

hadron level — solid
parton level (MEPS) — dashed
parton level (ME) — dotted