Charged Particle Multiplicity in DIS

Progress Report
ZEUS Collaboration Week

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Outline

• Introduction and motivation
• Data selection & simulation
• Control plots
• Correction methods
• Measurement of \(<n_{\text{ch}}\> vs. M_{\text{eff}}\)
• Comparison of analyses
• Systematics
• Checks in the Breit frame
• Summary and plan
Multiplicity $e^+e^-$ and pp

\[ \sqrt{s_{e^+e^-}} = \sqrt{(p_{e^-} + p_{e^+})^2} \]

\[ \sqrt{s_{pp}} = \sqrt{(p_p + p_p)^2} \]

\[ \sqrt{(q_{tot}^{had})^2} = \sqrt{[(q_{1}^{inc} - q_{1}^{leading}) + (q_{2}^{inc} - q_{2}^{leading})]^2} \]

Agreement between $e^+e^-$ and pp plotted vs. pp invariant mass.
Multiplicity: ep vs. e^+e^- (1)

Breit Current region of ep similar to one hemisphere of e^+e^-

Use Q as scale, multiply hadrons by 2

Where does other end of the string connect?
Multiplicity: $ep$ vs. $e^+e^-$ (2)

$ep$ hadronization compared to $e^+e^-$.  

$ep$: Split into Current and Target Region – one string two segments.  

Use invariant masses of the string (Lab) and segments (Breit).

Breit Frame $=>$ Uniform string?
The use of $M_{\text{eff}}$ as energy scale

- Analogous to the pp study, is natural to measure dependence of $<n_{\text{ch}}>$ of on its total invariant mass. (Energy available for hadronization)

- For ep in lab frame, measure visible part of $<n_{\text{ch}}>$ vs. visible part of energy available for hadronization: $M_{\text{eff}}$

Visible part

$$M_{\text{eff}}^2 = \left( \sum_{i \neq e} E_i \right)^2 - \left( \sum_{i \neq e} p_x^i \right)^2 - \left( \sum_{i \neq e} p_y^i \right)^2 - \left( \sum_{i \neq e} p_z^i \right)^2$$

$M_{\text{eff}}$: HFS measured in the detector where the tracking efficiency is maximized
e^+e^-, pp, ep, 4 questions

- Differences between ep and e^+e^- and between Breit and Lab
- Is difference due to:
  1. Analysis method?
  2. use of frame (Lab, Breit)?
  3. quark / gluon distributions?
  4. Choice of scale?
- New analysis seeks to answer these questions

=> Analysis description
1996-97 Data sample

- **Event Selection**
  - Scattered positron found with $E > 12 \text{ GeV}$
  - A reconstructed vertex with $|Z_{vtx}| < 50 \text{ cm}$
  - Scattered positron position cut: radius > 25cm
  - $40 \text{ GeV} < E-p_z < 60 \text{ GeV}$
  - Diffractive contribution excluded by requiring $\eta_{\text{max}} > 3.2$

- **Track Selection**
  - Tracks associated with primary vertex
  - $|\eta| < 1.75$
  - $p_T > 150 \text{ MeV}$

- **Physics and Kinematic Requirement**
  - $Q^2_{\text{da}} > 25 \text{ GeV}^2$
  - $y_{el} < 0.95$
  - $y_{JB} > 0.04$
  - $70 \text{ GeV} < W < 225 \text{ GeV}$ ($W^2 = (q + p)^2$)

735,007 events after all cuts (38.58 pb$^{-1}$)
Event simulation

- Ariadne ’96-’97 4.08
  - Matrix elements at LO pQCD $O(\alpha_s)$
  - Parton showers: CDM
  - Hadronization: String Model
  - Proton PDF’s: CTEQ-4D

- Lepto 6.5.1
  - Including SCI
  - Also generated Lepto without SCI

Luminosity of MC : 36.5 pb$^{-1}$
Kinematic Variables

- 96-97 data compared to ARIADNE and LEPTO for kinematic variables
- Both ARIADNE and LEPTO show good agreement for kinematic variables
Lab analysis: $M_{\text{eff}}$ & Tracks

- LEPTO and ARIADNE comparisons to tracks and $M_{\text{eff}}$
- Tracks better described by ARIADNE
- $M_{\text{eff}}$ better described by LEPTO
- Will compare also with LEPTO without SCI
Correction to hadron level: bin by bin

Part one: correct to hadron level using only hadrons generated with $p_T > 0.15$ GeV

Part two: correct for hadrons with lower $p_T$, using ratio of $<\text{gen}>$ with $p_T$ cut to $<\text{gen}>$ no $p_T$ cut in each bin.
Correction to hadron level: bin by bin

Correction for detector effects

Correction of hadrons of $p_T > 0.15$ to all hadrons

Ariadne - Lepto very similar (see later)
Correction to hadron level: matrix

\[ M_{p,o} = \frac{\text{No. of events with } p \text{ tracks generated when } o \text{ tracks were observed}}{\text{No. events with } o \text{ tracks observed}} \]

The matrix relates the observed to the generated distributions of tracks in each bin of \( M_{\text{eff}} \) by:

\[ P_p = \sum_o M_{p,o} \cdot P_o \]

- Matrix corrects tracks to hadron level
- \( \rho \) corrects phase space to hadron level

\[ \rho = \frac{\text{Hadrons passing gen level cuts}}{\text{Hadrons passing det level cuts}} \]
Comparison of bin-by-bin and matrix methods

- Methods agree better than 2% in all $M_{\text{eff}}$ bins
- Use bin-by-bin for results
- Matrix sensitive to statistics
- Use matrix method considered as a systematic check
## Correlated & Uncorrelated Systematics

<table>
<thead>
<tr>
<th>Systematic</th>
<th>Change</th>
<th>% Difference in $M_{\text{eff}}$ bins</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Bin 1</td>
</tr>
<tr>
<td>matrix instead of bin-by-bin</td>
<td>1.3%</td>
<td>&lt; 0.5%</td>
</tr>
<tr>
<td>LEPTO instead of ARIADNE</td>
<td>&lt; 0.5%</td>
<td>&lt; 0.5%</td>
</tr>
<tr>
<td>$E_{e'}$</td>
<td>± 1 GeV</td>
<td>&lt; 0.5%</td>
</tr>
<tr>
<td>Radius Cut</td>
<td>± 1cm</td>
<td>&lt; 0.5%</td>
</tr>
<tr>
<td>$Q^2$</td>
<td>± 1.6 GeV$^2$</td>
<td>&lt; 0.5%</td>
</tr>
<tr>
<td>$y_{JB}$</td>
<td>± .0006</td>
<td>&lt; 0.5%</td>
</tr>
<tr>
<td>Track $p_T$</td>
<td>-.03/+.05 GeV</td>
<td>&lt; 0.5%</td>
</tr>
<tr>
<td>$Z_{\text{vtx}}$</td>
<td>± 5 cm</td>
<td>&lt; 0.5%</td>
</tr>
<tr>
<td>$W$</td>
<td>± 19 GeV</td>
<td>&lt; 0.5%</td>
</tr>
<tr>
<td>$E - p_z$</td>
<td>± 5 GeV</td>
<td>&lt; 0.5%</td>
</tr>
<tr>
<td>CAL energy scale</td>
<td>± 3 %</td>
<td>1.1%</td>
</tr>
</tbody>
</table>
Check with 2\textsuperscript{nd} analysis:
total, $Q^2$ and $x$ bins

- Agreement between 1\textsuperscript{st} and 2\textsuperscript{nd} analysis within 1\% for total and in bins of $x$ and $Q^2$

Full kinematic range:
agreement better than 1\% for both correction methods.
New measurement in the LAB

New 96-97 Lab Data

- Good agreement with 1995 prelim. points, with smaller statistical, systematic errors
- Confirm difference ep vs. e+e- and pp.
- ARIADNE describes data dependence, LEPTO higher than the data
Lab frame: $<n_{ch}>$ vs. $M_{eff}$ in x bins

- Check if ep vs. e+e- and pp difference is due to quark and gluon distributions: study x and $Q^2$ dependence
- x range split into similar bins as in previous multiplicity paper.
- weak x dependence in both data and MC observed not sufficient to explain difference
- $Q^2$ dependence? => next page
Data described by ARIADNE

LEPTO above data

No $Q^2$ dependence observed

Difference not due to quark / gluon distributions in the proton
Breit Frame: Current Region Analysis

- New analysis agrees with previously published ZEUS result in the Current Region of the Breit Frame for scale Q.

Using $M_{\text{eff}}$ agreement between:

- Lab frame
- Breit Frame Current Region
- Breit Frame Target Region

$\Rightarrow$ String is “uniform”
Summary

Measured mean charged multiplicity in the Lab and Breit frame. Compared to predictions, to other ZEUS data, and e+e-

Difference ep vs. e+e- and pp:
• not due to experimental measurement.
• not due to the choice of frame (Lab Breit).
• not due to quark/gluon distributions.
• is due to choice of scale (Q vs. $M_{\text{eff}}$)

Plans for the future
• Finish checks in the Breit frame.
• Run on Lepto without SCI
• Make results preliminary: soon!