Recent results on multiplicity from ZEUS

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• Use Breit frame to compare multiplicity for ep to $e^+e^-$

• Breit Frame definition:

\[ 2xP + q = 0 \]

• “Brick wall frame” incoming quark scatters off photon and returns along same axis.

• Current region of Breit Frame is analogous to $e^+e^-$. 
Measurement vs. Q in Breit Frame

- Current region Breit frame multiplicity vs. Q (hemisphere) shown along with $e^+e^-$ data (whole sphere divided by 2)
- Consistent with $e^+e^-$ data for high $Q^2$
- $ep$ has gluon radiation whereas $e^+e^-$ does not—source of disagreement at low $Q^2$ ??

- Idea of current analysis: Understand current and target multiplicity and compare to $e^+e^-$

Multiplicity: ep vs. e⁺e⁻ (1)

- **e⁺e⁻**: boson with virtuality $\sqrt{s}$ produces 2 quarks & hadronization is between 2 colored objects $q$ and $\bar{q}$
- **ep**: In the hard collision between the photon & quark only 1 final quark is produced, so the 2nd quark on the diagram is the incoming one
- **current region of Breit frame for ep similar to one hemisphere of e⁺e⁻**
Multiplicity: ep vs. e⁺e⁻ (2)

- ep: Split into Current and Target Region – one string two segments.
- In ep we have a color field between 2 colored objects the struck quark and the proton remnant
- When we use $Q^2$ as a scale we are assuming the configuration is as symmetric as it is in $e^+e^-$, but it isn’t
- This asymmetric configuration leads to migration of particles from the current region to the target region

Breit Frame diagram
Gluon radiation, Q, and $2E_{\text{Breit}}$

- In hard and soft processes, gluon radiation occurs.
- These gluons can migrate to the target region.
- Total energy in the current region of the Breit frame and multiplicity are decreased due to these migrations ($Q^2$ is not).
- Effect is more pronounced for low $Q^2$: more low energy gluons.
- Must use $2E_{\text{Breit}}$ instead of $Q$ for comparing with $e^+e^-$.

No migrations: $E_{\text{Breit}} = \frac{\sqrt{Q^2}}{2}$

With migrations: $\begin{cases} N < N_{\text{expected}} \\ E_{\text{Breit}} \left(\frac{\sqrt{Q^2}}{2}\right) \end{cases}$
• Measurement of multiplicity dependence on $2E_{\text{current}}$ compared to previous ZEUS measurement vs. $Q$, and to $e^+e^-$ and pp data ($<n_{\text{ch}}>$ is multiplied by 2 for comparison)

• $2E$ gives better description of multiplicity at lower energy

• Current region understood, would also like to compare the target region of ep to $e^+e^-$ but…
Visible multiplicity in Breit frame

...comparing the target region is not possible:

- **Breit Frame**: 90% of hadrons in current region visible in detector, only 30% of target region hadrons are visible

- Can’t easily measure target hadrons, but these are a huge portion of the produced hadrons which we would still like to study

- Need some other way to investigate these particles
Hadronic center of mass energy is $W$

$W = \sqrt{(q + P)^2}$

$E_{\text{cms}} = W$

$E_{\gamma^*} \rightarrow E_{\text{proton region}}$

$E_{\text{photon region}} \rightarrow E_{\text{photon region}}$

$E_{\text{proton region}} / 2 \rightarrow E_{\text{proton region}} / 2$

$N_{\text{proton region}} \rightarrow N_{\text{photon region}}$

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**Visible multiplicity in HCM frame**

- **HCM Frame:** Photon region dominated by contribution from target region of Breit frame (~80% of visible hadrons)

- Photon region HCM frame well contained in visible part of detector
Measurement of Multiplicity in photon region of HCM frame vs. W.

Both Lepto and Ariadne describe the data: last bin slightly above

Like to compare current region Breit frame and photon region HCM frame to $e^+e^-$

Must multiply $\langle n_{ch} \rangle$ by 2 because both measurements are for hemispheres and $e^+e^-$ is total sphere
Multiplicity in current region of Breit and HCM frames compared to $e^+e^-$ and pp

- Measurements in current region of Breit frame and photon region of HCM frame multiplied by 2.
- There is agreement with $e^+e^-$ at low and high energy and with the pp results which are plotted vs. $\sqrt{q^2_{\text{had}}}$ (the scale with the leading particles removed).
- The HCM prediction has been extended to lower energies where a measurement isn’t possible (region is outside detector acceptance) and it agrees with all the points at low energy.
- One can also measure $<n_{\text{ch}}>$ vs. the invariant mass of the corresponding hadronic system. Measure only what is visible in detector & minimize effect of acceptance correction.
Charged Hadrons & Effective Mass: experimental method

- Measure hadronic final state within $\Delta \eta$ for best acceptance in the central tracking detector (CTD)

- Measure # charged tracks, reconstruct number of charged hadrons

- Measure invariant mass of the system ($M_{\text{eff}}$) in corresponding $\Delta \eta$ region.

- Energy is measured in the Calorimeter (CAL)

Study: $<n_{\text{ch}}>$ vs. $M_{\text{eff}}$

\[
M_{\text{eff}}^2 = \left( \sum_{i \neq e} E_i \right)^2 - \left( \sum_{i \neq e} p_x^i \right)^2 - \left( \sum_{i \neq e} p_y^i \right)^2 - \left( \sum_{i \neq e} p_z^i \right)^2
\]
Lab frame: $\langle n_{ch} \rangle$ vs. $M_{eff}$ in $x$ bins

- Plot shown previously at ICHEP 2004
- Lab frame multiplicity vs. $M_{eff}$, shown in 4 $x$ bins, with Ariadne predictions.
- $x$ range split into similar bins as in previous multiplicity paper.
- Weak $x$ dependence in both data and Monte Carlo observed.
- $Q^2$ dependence? => next slide
Lab frame: x and $Q^2$ bins

- Data described by ARIADNE
- LEPTO slightly above data
- No $Q^2$ dependence observed
• For the 1\textsuperscript{st} time, the measurement of mean charged multiplicity had been extended to a higher energy scale than previously measured in ep collisions.

• Measurement in current region of the Breit frame shows similar dependence to $e^+e^-$ if $2E_{\text{current}}$ is used as the scale.

• The same dependence is observed for the photon region of the HCM frame vs. $W$. 