b-Quark Fragmentation Function in Z0 Decays

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SLAC

SLD Collaboration Meeting
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- Introduction
- Status of analysis of 1996-97 R15 data
- Latest updates of 1997-98 R17 data
- Plans for summer conferences and beyond
Motivation

- Improve understanding of hadronization process
  b-quark is the heaviest quark that hadronizes

- Test heavy quark fragmentation models
  Many phenomenological models exist, but not well tested

- Heavy-flavor hadron production
  B physics in $e^+e^- \rightarrow Z^0$: Significant source of systematics
  $b\bar{b}$ production rate in $pp$: ~ Twice that of theory prediction
  Top physics: $t \rightarrow bW \rightarrow 3$ jets
What was done before?

- Indirect $\langle x_B \rangle$ measurement (by PEP, PETRA, LEP)
  
  $\Rightarrow \langle x_B \rangle \approx 0.7$ with % statistics, but model-dependent.
  
  e.g. inclusive lepton momentum spectra

- Indirect shape measurements (by L3, OPAL)
  
  $\Rightarrow$ B energy NOT reconstructed.
  
  e.g. 2-D $(E_{D\ell}, M_{D\ell})$ fits

- Direct shape measurements (by ALEPH, DELPHI, SLD)
  
  $\Rightarrow$ B energy reconstructed.
  
  e.g. $B \rightarrow D\ell \nu X$ with (partially) reconstructed D
Problems with Earlier Results

1) limited statistics and poor coverage at low $X_B$
2) large model-dependence
3) Uncertainty in B/D decay ⇒ large systematic errors

Conclusion: Poor discrimination between models.
The Analysis of 1996-97 Data (using 150,000 $Z^0$ decays)

- Improved efficiency and energy resolution, using
  1. topological vertexing and b mass-tag
  2. the small SLC IP
  3. missing-mass technique to measure B-hadron energy

- Main conclusions (PRL 84:4300-4304, 2000)
  1. Exclusion of several fragmentation models
  2. The most precise average B hadron energy among direct measurements from LEP and SLD:

$$<x_B> = 0.714 \pm 0.005\text{(stat.)} \pm 0.007\text{(syst.)} \pm 0.002\text{(model)}$$
1997-98 R17 Analysis (350,000 Z0 Decays)

Hadron Flight Direction

To account for missing particles, the mass of the vertex is $P_T$-corrected:

$$M_{PT} = (M_{ch}^2 + P_T^2)^{1/2} + P_T$$

Efficiency vs $E_B$

2 < $M_{PT}$ < 2 * $M_{ch}$
Decay Length > 1 mm

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How to obtain $P_{0L}$ and $M_0$?

In the B rest frame,

$B$ energy = the ‘known’ B mass.

This equation leads to

1) $P_{0L}$ can be solved if $M_0$ is known.

2) $M_0$ has an upper bound.
The Missing Mass Technique to reconstruct the B energy

missing particles

B flight direction
charged tracks

The B energy

B energy = Charge-track Energy + Missing Energy

- Charge-track Energy = known
- Missing Energy = \( (M_0^2 + P_0L^2 + P_T^2)^{1/2} = ? \)
In the B rest frame,

\[ M_B = \sqrt{M_{ch}^2 + P_T^2 + P_L^2} + \sqrt{M_0^2 + P_T^2 + P_L^2} \]

\[ M_B \geq \sqrt{M_{ch}^2 + P_T^2} + \sqrt{M_0^2 + P_T^2} \]

\[ M_0^2 \leq M_{0\text{max}}^2 = M_B^2 + M_{ch}^2 - 2M_B\sqrt{M_{ch}^2 + P_T^2} \]

Note that \( M_0 = M_{0\text{max}} \) if \( P_L = 0 \) in rest frame.
In B rest frame, $P_L \ll P_T$ is more probable.

B Flight Direction

$P_L \gg P_T$
Less Probable

$P_T \gg P_L$
More Probable

Very small $P_L$ corresponds to $M_0 \approx M_{0\text{max}}$
In addition, large B decay multiplicity \( \Rightarrow \)

Missing mass is close to its upper bound \( M_{0\max} \)

If \( M_{0\max} \) is small, we obtain a very good estimate of \( M_0 \):

\[
M_0 \approx M_{0\max}
\]
Summary of the technique

- The missing mass $M_0$ is bounded by $M_{0\text{max}}$.
- On average, $M_0$ clusters near $M_{0\text{max}}$.
- If $M_{0\text{max}}$ is small, it is a good estimate of $M_0$.
- Using this estimate of $M_0$, solve for the missing energy.

Remarks

- $M_{0\text{max}}$ is boost-invariant and independent of the B energy.
- Only tracking and vertexing information are used.
- Beam energy is not used.
\( M_{0\text{max}}^2 \) for B-Tagged Sample

- \( M_{0\text{max}}^2 < 0 \) is due to detector resolution
- Non-b\( \bar{b} \) background concentrates at large \( M_{0\text{max}}^2 \)
- B energy resolution is good for small \( M_{0\text{max}}^2 \), but is poor for \( M_{0\text{max}}^2 < -1 \)

97-98 data

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Final B Sample Selection

- Final cut on missing mass: \(-1 < m_{0\text{max}}^2 < f(x_B^{\text{rec}})\)
- Good energy resolution

4164 vertices for 97-98 data (1920 for 96-97 data)

MC vs Data $M_{0\text{max}}^2$

MC Efficiency

Sample $b$ purity = 99.0%
Resolution

\[ \sigma = 9.6\% \]
\[ fr = 84\% \]

- Improved core resolution \(10.4\%\) from 1996-97
- Smaller tail fraction \(16.4\%\) \(17\%\) for 1996-97
Uncorrected B Energy Distribution

- Full kinematic coverage
- Small non-bb background
- MC (JETSET+Peterson model) is inconsistent with data
Compare with 96-97 MC vs Data

9798 R17
96697 R15

$E_{\text{true}}$ (GeV)

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Test of b Fragmentation Models

\[ E_b = 45.6 \text{ GeV} \]

- JETSET MC is used to simulate parton shower.
- Models can be put into MC to simulate hadronization.

Many models exist, but which ones produce the "right" shape that is consistent with SLD data?
Model Test Results

The same four models were found to be consistent with the SLD data:

1. JETSET + Lund
2. JETSET + Bowler
3. JETSET + Kartvelishvili (0.5% → 1%)
4. UCLA (10% → 6%)

The other five models are excluded in this context:

1. JETSET + BCFY
2. JETSET + Collins and Spiller
3. JETSET + Peterson
4. HERWIG (old version)
5. HERWIG (last version)

*DELPHI I and OPAL are tuning HERWIG 6.1 using SLD data.*
Test of $x_B$ Functional Forms $f(x_B, \lambda)$

- Improve estimate of the shape of $x_B$ distribution.
- Unfolding the raw $x_B$ distribution.
- Improve estimate of the $\langle x_B \rangle$ model-dependence.

$E_b = 45.6$ GeV

Other Hadrons

B Hadron

$x_B = E_B' / E_b$

Pert. QCD
Parton Shower
Nonpert. Fragmentation

$f(x_B, \lambda) = ?$
<table>
<thead>
<tr>
<th>Models</th>
<th>$\chi^2$</th>
<th>Prob %</th>
<th>$&lt;x_B&gt;$</th>
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<tbody>
<tr>
<td>Bowler</td>
<td>17/15</td>
<td>35</td>
<td>0.7087</td>
</tr>
<tr>
<td>Kartvelishvili</td>
<td>32/16</td>
<td>1</td>
<td>0.7077</td>
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<tr>
<td>Lund</td>
<td>17/15</td>
<td>31</td>
<td>0.7119</td>
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<tr>
<td>UCLA</td>
<td>27/17</td>
<td>6</td>
<td>0.7178</td>
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<tr>
<td>F1</td>
<td>20/15</td>
<td>18</td>
<td>0.7070</td>
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<tr>
<td>F2</td>
<td>31/15</td>
<td>1</td>
<td>0.7100</td>
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<tr>
<td>Peterson Form</td>
<td>31/16</td>
<td>1</td>
<td>0.7093</td>
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<tr>
<td>8th-order Polynomial</td>
<td>12/12</td>
<td>44</td>
<td>0.7042</td>
</tr>
</tbody>
</table>
Model Dependence

\[ x^2 \text{ Probability} \%

Bowler: 35
Kart: 1
Lund: 31
UCLA: 6
F1: 18
F2: 1
Peterson: 1
P8 (polyn.): 44

\[ <x_B> = 0.7098 \pm 0.0030 \pm 0.0048 \pm 0.0037

What would you have done?
$\langle x_B \rangle = 0.710 \pm 0.003\text{(stat.)} \pm 0.005\text{(syst.)} \pm 0.004\text{(model)}$ (Preliminary)
Conclusions

1) The analysis of 1997-98 data benefited from
   1. Larger data set (350,000 vs 150,000 Z decays)
   2. Improved data reconstruction (R17 vs R15)
   3. Potentially improved b-tagging (work in progress)

2) All conclusions of 1996-97 analysis still hold.

3) New preliminary $<x_B>$
   $<x_B> = 0.710 \pm 0.003 \text{ (stat.)} \pm 0.005 \text{ (syst.)} \pm 0.004 \text{ (model)}$

Plan for Summer Conferences

New preliminary result at ICHEP 2000 in Osaka. (unfolding will be done)

Gavin Nesom will present this new result at DPF 2000.