Hadronic Moments in Semileptonic B Decays from CDFII

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Analysis Strategy

Typical mass spectrum $M(X^0_c)$ (Monte Carlo):

$D^0$ and $D^{*0}$ well-known
⇒ measure only $f^{**}$
⇒ only shape needed

1) Measure $f^{**}(s_H)$
2) Correct for background, acceptances, bias
⇒ moments of $D^{**}$
3) Add $D$ and $D^*$ ⇒ $M_1, M_2$
4) Extract $\Lambda, \lambda_1$

\[s_H \equiv \frac{M_{X_c}^2}{2}\]

\[
\frac{1}{\Gamma_{sl}} \frac{d\Gamma_{sl}}{ds_H} = \frac{\Gamma_0}{\Gamma_{sl}} \delta(s_H - m_{D^0}^2) + \frac{\Gamma^*}{\Gamma_{sl}} \delta(s_H - m_{D^{*0}}^2) + \left(1 - \frac{\Gamma_0}{\Gamma_{sl}} - \frac{\Gamma^*}{\Gamma_{sl}}\right) f^{**}(s_H)
\]

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Channels

Possible $D' \rightarrow D^{(*)}\pi\pi$ contributions neglected:

- No $B \rightarrow D'$ experimental evidence so far
- DELPHI limit: \[ BR(\bar{b} \rightarrow D^+\pi^-\pi^-\ell^-\nu) < 0.18\% \ @ 90\% CL \]
  \[ BR(\bar{b} \rightarrow D^{*+}\pi^+\pi^-\ell^-\nu) < 0.17\% \ @ 90\% CL \]

We assume no $D'$ contribution in our sample

Must reconstruct all channels to get all the $D^{**}$ states.

⇒ However CDF has limited capability for neutrals

- $B^0 \rightarrow D^{**^-}\ell^+\nu$ always leads to neutral particles ⇒ ignore it
- $B^- \rightarrow D^{**0}\ell^-\nu$ better, use isospin for missing channels:
  - $D^{**0} \rightarrow D^+\pi^-$ OK
  - $D^{**0} \rightarrow D^{0}\pi^0$ Not reconstructed. Half the rate of $D^+\pi^-$
  - $D^{**0} \rightarrow D^{*+}\pi^-$
    - $D^{*+} \rightarrow D^{0}\pi^+$ OK
    - $D^{*+} \rightarrow D^{+}\pi^0$ Not reconstructed. Feed-down to $D^+\pi^-$
  - $D^{**0} \rightarrow D^{*0}\pi^0$ Not reconstructed. Half the rate of $D^{*+}\pi^-$
Event Topology

Exclusive reconstruction of D**:

D^{**0} \rightarrow D^+ \pi^{**-} \quad (Br=9.2\%)

"D^+"

D^{**0} \rightarrow D^{*+} \pi^{**-}

"D^{*+}"

D^{**0} \rightarrow D^0 \pi^{*+} \quad (Br=67.7\%)

K^- \rightarrow \pi^+ (Br=3.8\%)

K^- \rightarrow \pi^+ \pi^- \pi^+ (Br=7.5\%)

K^- \rightarrow \pi^+ \pi^0 (Br=13.0\%)
Backgrounds

Physics background:
$B \rightarrow D^{(*)+}D_{s}^{-}$, $D_{(s)} \rightarrow X\ell\nu$
$\rightarrow$ MC, subtracted

Combinatorial background under the $D^{(*)}$ peaks:
$\rightarrow$ sideband subtraction

Feed-down in signal:
$D^{**0} \rightarrow D^{*+}(\rightarrow D^{0}\pi^{0})\pi^{-}$
irreducible background to $D^{**0} \rightarrow D^{+}\pi^{-}$.
$\rightarrow$ subtracted using data:
$\rightarrow$ shape from $D^{0}\pi^{-}$ in $D^{**0} \rightarrow D^{*+}(\rightarrow D^{0}\pi^{+})\pi^{-}$
$\rightarrow$ rate:
$\frac{1}{2}$ (isospin) $\times$ eff. $\times$ BR

Prompt pions faking $\pi^{**}$:
• fragmentation
• underlying event
$\rightarrow$ separate $B$ and primary vertices
(kills also prompt charm)
$\rightarrow$ use impact parameters to discriminate
$\rightarrow$ model: wrong-sign $\pi^{**+}\ell^{-}$ combinations
Lepton + D Reconstruction

Data Sample:
- $e/\mu$ + displaced track
- $\sim 180 \text{ pb}^{-1}$

(→ Sept 2003)

Track Selection:
- $2 \text{ GeV track (SVT leg)}$
- $e/\mu$: $p_T > 4 \text{ GeV}$
- other: $p_T > 0.4 \text{ GeV}$

Lepton + D$(*)^+$:
- D vertex:
  - 3D
- $l^+D(+\pi^*)$ vertex (“B”):
  - 3D
  - $L_{xy}(B) > 500 \text{ \mu m}$
  - $m(B) < 5.3 \text{ GeV}$

Total: $\sim 28000 \text{ events}$
Raw $m^{**}$ Distributions

Measured in $\Delta m^{**}$, shifted by $M(D^{(*)+})$, side-band subtracted.

CDF Run II  $L=180pb^{-1}$

$B \rightarrow D^{*+} \pi^{-} \pi^{-} \pi^{-} X$
- right-sign $\bar{D}^{*+} \pi^{**}$
- wrong-sign $\bar{D}^{*+} \pi^{**}$

$B \rightarrow D^{+} \pi^{-} \pi^{-} X$
- right-sign $\bar{D}^{+} \pi^{**}$
- wrong-sign $\bar{D}^{+} \pi^{**}$

Feed-down
$D_1, D_1^*, D_2^*$

$D_2^*, D_0^*$
Efficiency Corrections

1) Correct the raw mass for any dependence of $\varepsilon_{\text{reco}}$ on $M(D^{**})$:
   - Possible dependence on the $D^{**}$ species (spin).
   - Monte-Carlo for all $D^{**}$ (Goity-Roberts for non-resonant), cross-checked with pure phase space decays.
   - Detector simulation shortcomings cause residual data/MC discrepancy: derive corrections from control samples ($D^*$ and $D$ daughters)

2) Cut on lepton energy in $B$ rest frame:
   - Theoretical predictions need well-defined $p_l^*$ cut.
   - We can’t measure $p_l^*$, but we can correct our measurement to a given cut: $p_l^* > 700$ MeV/c.
Corrected Mass and D** Moments

Procedure:

- Unbinned procedure using weighted events.
- Assign negative weights to background samples.
- Propagate efficiency corrections to weights.
- Take care of the D^+ / D** relative normalization.
- Compute mean and sigma of distribution.

Results (in paper):

No Fit !!!
Final Results

\[ m_1 \equiv \left\langle m_{D^{**}}^2 \right\rangle = (5.83 \pm 0.16_{\text{stat}} \pm 0.08_{\text{syst}}) \text{ GeV}^2 \]

\[ m_2 \equiv \left\langle \left( m_{D^{**}}^2 - \left\langle m_{D^{**}}^2 \right\rangle \right)^2 \right\rangle = (1.30 \pm 0.69_{\text{stat}} \pm 0.22_{\text{syst}}) \text{ GeV}^4 \]

\[ \rho(m_1,m_2)=0.61 \]

\[ M_1 \equiv \left( s_H \right) - m_D^2 = (0.467 \pm 0.038_{\text{stat}} \pm 0.019_{\text{exp}} \pm 0.065_{\text{BR}}) \text{ GeV}^2 \]

\[ M_2 \equiv \left\langle \left( s_H - \left\langle s_H \right\rangle \right)^2 \right\rangle = (1.05 \pm 0.26_{\text{stat}} \pm 0.08_{\text{exp}} \pm 0.10_{\text{BR}}) \text{ GeV}^4 \]

\[ \rho(M_1,M_2)=0.69 \]

Pole mass scheme

\[ \Lambda = (0.397 \pm 0.078_{\text{stat}} \pm 0.027_{\text{exp}} \pm 0.064_{\text{BR}} \pm 0.058_{\text{theo}}) \text{ GeV} \]

\[ \lambda_1 = (-0.184 \pm 0.057_{\text{stat}} \pm 0.017_{\text{exp}} \pm 0.022_{\text{BR}} \pm 0.077_{\text{theo}}) \text{ GeV}^2 \]

1S mass scheme

\[ m_{b^{1S}} = (4.654 \pm 0.078_{\text{stat}} \pm 0.027_{\text{exp}} \pm 0.064_{\text{BR}} \pm 0.089_{\text{theo}}) \text{ GeV} \]

\[ \lambda_{1S} = (-0.277 \pm 0.049_{\text{stat}} \pm 0.017_{\text{exp}} \pm 0.022_{\text{BR}} \pm 0.094_{\text{theo}}) \text{ GeV}^2 \]
## Systematic Errors (from the paper)

<table>
<thead>
<tr>
<th>Source</th>
<th>$\Delta m_1$ (GeV$^2$)</th>
<th>$\Delta m_2$ (GeV$^4$)</th>
<th>$\Delta M_1$ (GeV$^2$)</th>
<th>$\Delta M_2$ (GeV$^4$)</th>
<th>$\Delta \Lambda$ (GeV)</th>
<th>$\Delta \lambda_1$ (GeV$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stat.</td>
<td>0.16</td>
<td>0.69</td>
<td>0.038</td>
<td>0.26</td>
<td>0.078</td>
<td>0.057</td>
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<tr>
<td>Syst.</td>
<td>0.08</td>
<td>0.22</td>
<td>0.068</td>
<td>0.13</td>
<td>0.091</td>
<td>0.082</td>
</tr>
<tr>
<td>Mass resolution</td>
<td>0.02</td>
<td>0.13</td>
<td>0.005</td>
<td>0.04</td>
<td>0.012</td>
<td>0.009</td>
</tr>
<tr>
<td>Eff. Corr. (data)</td>
<td>0.03</td>
<td>0.13</td>
<td>0.006</td>
<td>0.05</td>
<td>0.014</td>
<td>0.011</td>
</tr>
<tr>
<td>Eff. Corr. (MC)</td>
<td>0.06</td>
<td>0.05</td>
<td>0.016</td>
<td>0.03</td>
<td>0.017</td>
<td>0.006</td>
</tr>
<tr>
<td>Bkgd. (scale)</td>
<td>0.01</td>
<td>0.03</td>
<td>0.002</td>
<td>0.01</td>
<td>0.003</td>
<td>0.002</td>
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<tr>
<td>Bkgd. (opt. Bias)</td>
<td>0.02</td>
<td>0.10</td>
<td>0.004</td>
<td>0.03</td>
<td>0.006</td>
<td>0.006</td>
</tr>
<tr>
<td>Physics bkgd.</td>
<td>0.01</td>
<td>0.02</td>
<td>0.002</td>
<td>0.01</td>
<td>0.004</td>
<td>0.002</td>
</tr>
<tr>
<td>$D^+ / D^{*+}$ BR</td>
<td>0.01</td>
<td>0.02</td>
<td>0.002</td>
<td>0.01</td>
<td>0.004</td>
<td>0.002</td>
</tr>
<tr>
<td>$D^+ / D^{*+}$ Eff.</td>
<td>0.02</td>
<td>0.03</td>
<td>0.004</td>
<td>0.01</td>
<td>0.005</td>
<td>0.002</td>
</tr>
<tr>
<td><strong>Semileptonic BRs</strong></td>
<td><strong>0.065</strong></td>
<td><strong>0.10</strong></td>
<td><strong>0.064</strong></td>
<td><strong>0.022</strong></td>
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<tr>
<td>$\rho_1$</td>
<td></td>
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<td></td>
<td>0.041</td>
<td>0.069</td>
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<tr>
<td>$T_i$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.032</td>
<td>0.031</td>
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<tr>
<td>$\alpha_s$</td>
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<td></td>
<td></td>
<td></td>
<td>0.018</td>
<td>0.007</td>
</tr>
<tr>
<td>$m_b, m_c$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.001</td>
<td>0.008</td>
</tr>
<tr>
<td><strong>Choice of $p_l^*$ cut</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.019</td>
<td>0.009</td>
</tr>
</tbody>
</table>
Comparison with Other Measurements

Pole mass scheme
Summary

• First measurement at hadron machines: different environment and experimental techniques.

• Competitive with other experiments. Little model dependency. No assumptions on shape or rate of D** components.

• Through integration with other experiments and other “moments” we can seriously probe HQET/QHD

• Let’s do it!
Motivation (I)

Most precise determination of $V_{cb}$ comes from $\Gamma_{sl}$ ("inclusive" determination):

$$\Gamma_{sl} (b \rightarrow c \ell \bar{\nu}) = \frac{BR (b \rightarrow c \ell \bar{\nu}_{\ell})}{\tau_b} = |V_{cb}|^2 \times F_{\text{theory}}$$

Y(4S), LEP/SLD, CDF measurements. Experimental $\Delta |V_{cb}| \sim 1\%$

Theory with pert. and non-pert. corrections. $\Delta |V_{cb}| \sim 2.5\%$

$F_{\text{theory}}$ evaluated using OPE in HQET: expansion in $\alpha_s$ and $1/m_B$ powers:

$O(1/m_B) \rightarrow 1$ parameter: $\Lambda$ (Bauer et al., PRD 67 (2003) 071301)

$O(1/m_B^2) \rightarrow 2$ more parameters: $\lambda_1, \lambda_2$

$O(1/m_B^3) \rightarrow 6$ more parameters: $\rho_1, \rho_2, T_{1-4}$

Constrained from pseudo-scalar/vector B and D mass differences

$$G_{sl} = \frac{G_F^2 |V_{cb}|^2}{192\pi^3} \left\{ m_b^5 c_1 \left\{ 1 - c_2 \frac{a_s}{\mathcal{p}} + \frac{c_3}{m_B} (1 - c_4 \frac{a_s}{\mathcal{p}}) + \frac{c_5}{m_B^2} \right\}^2 + c_6 \frac{a_s}{\mathcal{p}} + \frac{a_s}{\mathcal{p}} \right\}$$
Motivation (II)

Many inclusive observables can be written using the same expansion (same non-perturbative parameters). The spectral moments:

- **Photonic moments**: Photon energy in $b \rightarrow s \gamma$ (CLEO)
- **Leptonic moments**: $B \rightarrow X_c l \nu$, lepton $E$ in $B$ rest frame (CLEO, DELPHI, BABAR)
- **Hadronic moments**: $B \rightarrow X_c l \nu$, recoil mass $M(X_c)$ (CLEO, DELPHI, BABAR, CDFII)

\[
M_1 = \int_{s_{H}^{\text{min}}}^{s_{H}^{\text{max}}} ds_H \left( s_H - \bar{m}_D^2 \right) \frac{1}{\Gamma_{s l}} \frac{d\Gamma_{s l}}{ds_H} = \langle s_H \rangle - \bar{m}_D^2 , \quad s_H \equiv M_{X_c}^2
\]

\[
M_2 = \int_{s_{H}^{\text{min}}}^{s_{H}^{\text{max}}} ds_H \left( s_H - \langle s_H \rangle \right)^2 \frac{1}{\Gamma_{s l}} \frac{d\Gamma_{s l}}{ds_H} = \left\langle \left( s_H - \bar{m}_D^2 \right)^2 \right\rangle - M_1^2
\]

Constrain the unknown non-pert. parameters and reduce $|V_{cb}|$ uncertainty. With enough measurements: test of underlying assumptions (duality...).
What is $X_c$?

Semi-leptonic widths (PDG 04):

<table>
<thead>
<tr>
<th>Decay</th>
<th>$\text{Br} (%)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^+ \to X_c \ell \nu$</td>
<td>$10.99 \pm 0.31$</td>
</tr>
<tr>
<td>$B^+ \to D^* \ell \nu$</td>
<td>$6.04 \pm 0.23$</td>
</tr>
<tr>
<td>$B^+ \to D \ell \nu$</td>
<td>$2.23 \pm 0.15$</td>
</tr>
</tbody>
</table>

($\text{PDG b}/B^+/B^0$ combination, $b \to u$ subtracted)

$\Rightarrow \sim 25\%$ of semi-leptonic width is poorly known

Possible $D' \to D^{(*)}\pi\pi$ contributions neglected:
- No $B \to D'$ experimental evidence so far
- DELPHI limit:
  \[
  BR(b \to D^+\pi^+\pi^-\ell\nu) < 0.18\% \text{ at } 90\% \text{ CL} \\
  BR(b \to D^{*+}\pi^+\pi^-\ell\nu) < 0.17\% \text{ at } 90\% \text{ CL}
  \]

We assume no $D'$ contribution in our sample
Combination with $D^0$, $D^{*0}$

$$
\frac{1}{\Gamma_{sl}} \frac{d\Gamma_{sl}}{ds_H} = \frac{\Gamma_0}{\Gamma_{sl}} \cdot \delta(s_H - m^2_{D^0}) + \frac{\Gamma^*}{\Gamma_{sl}} \cdot \delta(s_H - m^2_{D^{*0}}) + \left(1 - \frac{\Gamma_0}{\Gamma_{sl}} - \frac{\Gamma^*}{\Gamma_{sl}}\right) \cdot f^{**}(s_H)
$$

Take $M(D^0)$, $M(D^{*0})$, $\Gamma_{sl}$, $\Gamma_0$, $\Gamma^*$ from PDG 2004:

- $\Gamma_{sl}$, $\Gamma_0$, $\Gamma^*$ are obtained combining BR's for $B^-$, $B^0$ and admixture, assuming the widths are identical (not the BR's themselves), and using

  $$f_-/f_0 = 1.044 \pm 0.05$$

  $$\tau(B^-)/\tau(B^0) = 1.086 \pm 0.017$$

- Average:

  $BR(B^+ \rightarrow X_c^0 l^+ \nu_l) = 0.1099 \pm 0.0031$

  $BR(B^+ \rightarrow D^0 l^+ \nu_l) = 0.0223 \pm 0.0015$

  $BR(B^+ \rightarrow D^{*0} l^+ \nu_l) = 0.0604 \pm 0.0023$
Monte-Carlo Validation (I)

MC vs. semileptonic sample:

\[ K\pi\pi, e \]
\[ K\pi\pi\pi, e \]
\[ K\pi, \mu \]

\[ K\pi\pi^0, e \]
\[ K\pi\pi\pi, \mu \]

Matching $\chi^2$ probability for those plots:

<table>
<thead>
<tr>
<th></th>
<th>67%</th>
<th>74%</th>
<th>23%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>43%</td>
<td>69%</td>
<td>87%</td>
</tr>
</tbody>
</table>
**Selection**

Based on topology:

- impact parameter significances w.r.t. primary, B and D vertices

\[ \pi^{**} \]

Cuts are optimized using MC and background (WS) data:

- \( p_T > 0.4 \text{ GeV} \)
- \( |d_0^{PV}/\sigma| > 3.0 \)
- \( |d_0^{BV}/\sigma| < 2.5 \)
- \( \Delta R < 1.0 \)
- \( |d_0^{BV}/\sigma| > 0.8 \)
- \( L_{xy}^{B \rightarrow D} > 500 \mu m \)
- Theory prediction depends on $P_l^*$ cuts. We cannot do much but:
  - see how our efficiency as a function of $P_l^*$ looks like
  - Use a threshold-like correction
  - Evaluate systematics for different threshold values
$V_{cb}$ measurements

$|V_{cb}|$ from exclusive B decays

- Large statistics on $B_d^0 \rightarrow D^{(*)}\ell^-\nu$ available and new measurements are coming
- Present precision (5%) is systematics limited:
  - Experiments: $D^{**}$ states, D's BR
  - Theory: form factor extrapolation, corrections to $F(1)=1$ can be reduced in the future

$|V_{cb}|_{\text{incl}} = (40.4 \pm 0.5_{\text{exp}} \pm 0.5_{\Lambda\lambda}\pm 0.8_{\text{theo}}) \times 10^{-3}$

(PDG 2002, $V_{cb}$ review)

$|V_{cb}|$ from inclusive B decays

- Experiment: large statistics on $\text{BR}(B \rightarrow X_c\ell^-\nu)$ and $t_B$ and small systematics

$|V_{cb}|_{\text{excl}} = (42.1 \pm 1.1_{\text{exp}} \pm 1.9_{\text{theo}}) \times 10^{-3}$

(PDG 2002, $V_{cb}$ review)
**D*+ Reconstruction and Yields**

**D*+ channels:** \( D_{m*} \equiv M(D^0\pi^*) - M(D^0) \)

---

**D(\*)+ l^- (+cc) yields:**

<table>
<thead>
<tr>
<th></th>
<th>( K^-\pi^+ )</th>
<th>( K^-\pi^+\pi^-\pi^+ )</th>
<th>( K^-\pi^+\pi^0 )</th>
<th>( D^+ ) channel</th>
<th>( K^-\pi^+\pi^+ )</th>
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<tbody>
<tr>
<td><strong>D(*)+ l^- yields</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrons</td>
<td>1723 ± 42</td>
<td>1200 ± 38</td>
<td>3037 ± 66</td>
<td>6850 ± 122</td>
<td></td>
</tr>
<tr>
<td>Muons</td>
<td>2168 ± 47</td>
<td>1695 ± 43</td>
<td>3611 ± 72</td>
<td>8204 ± 136</td>
<td></td>
</tr>
<tr>
<td>Combined</td>
<td>3890 ± 63</td>
<td>2994 ± 57</td>
<td>6638 ± 98</td>
<td>14416 ± 202</td>
<td></td>
</tr>
</tbody>
</table>

\(~ 28000 \) events
**MC validation: quantitative**

<table>
<thead>
<tr>
<th>Matching-χ² prob (%)</th>
<th>Kπ</th>
<th>Kπ(π⁰)</th>
<th>Kπππ</th>
<th>Kπππ</th>
</tr>
</thead>
<tbody>
<tr>
<td>e</td>
<td>μ</td>
<td>e</td>
<td>μ</td>
<td>e</td>
</tr>
<tr>
<td>p_T(l)</td>
<td>4</td>
<td>12</td>
<td>43</td>
<td>40</td>
</tr>
<tr>
<td>p_T(D)</td>
<td>3</td>
<td>7</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>p_T(l-D)</td>
<td>41</td>
<td>17</td>
<td>30</td>
<td>2</td>
</tr>
<tr>
<td>d_0(l)</td>
<td>10</td>
<td>92</td>
<td>75</td>
<td>27</td>
</tr>
<tr>
<td>m(l-D)</td>
<td>2</td>
<td>3</td>
<td>50</td>
<td>61</td>
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<tr>
<td>L_XY(l-D)</td>
<td>48</td>
<td>23</td>
<td>41</td>
<td>12</td>
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<tr>
<td>L_XY(D)</td>
<td>23</td>
<td>88</td>
<td>69</td>
<td>99</td>
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<tr>
<td>L_XY(B to D)</td>
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<td>29</td>
<td>6</td>
<td>13</td>
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<tr>
<td>p_T(π*) &gt;0.4 GeV</td>
<td>28</td>
<td>42</td>
<td>21</td>
<td>70</td>
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<tr>
<td>d_0(K)</td>
<td>68</td>
<td>72</td>
<td>83</td>
<td>54</td>
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<tr>
<td>ΔR(l-D)</td>
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<td>29</td>
<td>26</td>
<td>51</td>
</tr>
<tr>
<td>ΔR(l-K)</td>
<td>17</td>
<td>12</td>
<td>33</td>
<td>66</td>
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<tr>
<td>p_T(K)</td>
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<td>52</td>
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<tr>
<td>p_T(π)</td>
<td>90</td>
<td>20</td>
<td>14</td>
<td>59</td>
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<tr>
<td>p_T(2π)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Matching-χ² prob (%)**

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Impact Parameters in MC

Comparison data/MC for IP: (worst case)

Residual corrections:
• derived from data:
  • $\pi^*$
  • non-SVT D daughters ($p_T > 1.5 \text{ GeV}$)
• corrections from double ratios
  • in $p_T$
  • in $m^{**}$
Computing the $X_c$ Moments

- The $D^0$ and $D^{*0}$ pieces have to be added to the $D^{**0}$ moments, according to

$$
M_1 = \mu - m_{D}^2,
$$

$$
M_2 = \frac{\Gamma_0}{\Gamma_{sl}} \cdot (m_{D0}^2 - \mu)^2 f_0 + \frac{\Gamma_*}{\Gamma_{sl}} \cdot (m_{D^{*0}}^2 - \mu)^2 f_* + \left(1 - \frac{\Gamma_0}{\Gamma_{sl}} - \frac{\Gamma_*}{\Gamma_{sl}}\right) \cdot \left(m_2 + (m_1 - \mu)^2\right) f_{**}
$$

with $\mu$ defined as

$$
\mu = \frac{\frac{\Gamma_0}{\Gamma_{sl}} \cdot m_{D0}^2 f_0 + \frac{\Gamma_*}{\Gamma_{sl}} \cdot m_{D^{*0}}^2 f_* + \left(1 - \frac{\Gamma_0}{\Gamma_{sl}} - \frac{\Gamma_*}{\Gamma_{sl}}\right) \cdot m_1 f_{**}}{\frac{\Gamma_0}{\Gamma_{sl}} f_0 + \frac{\Gamma_*}{\Gamma_{sl}} f_* + \left(1 - \frac{\Gamma_0}{\Gamma_{sl}} - \frac{\Gamma_*}{\Gamma_{sl}}\right) f_{**}}.
$$

where the $f_i$ are the fractions of $D\pi$ events above the $p_{i*}$ cut. Only ratios of $f_i$'s enter the final result.
• Theory prediction depends on $P_1^*$ cuts. We cannot do much but:
  - see how our efficiency as a function of $P_1^*$ looks like
  - Use a threshold-like correction
  - Evaluate systematics for different threshold values
Lepton momentum cut-off

- We are not “literally” cutting on $P_l^*$ (it is not accessible, experimentally)
- Detector implicitly cuts on it
- Assume a baseline cut-off
- Vary in a reasonable range to evaluate systematics

- We use $f$ to derive $f^{**}$, given $f^0$, $f^*$
- $f=f(\Lambda,\lambda_1)$
- We use experimental prior knowledge on $\Lambda,\lambda_1$ to evaluate systematics
- Effect is negligible
Efficiency vs $m^{**}$

(a) $K\pi$

(b) $K\pi$ sat

(c) $K3\pi$

(d) $K2\pi$
**MC/Data corrections**

- Dominant source of systematics!
- $\pi^*$ reproduces $\pi^{**}$ topology but statistics too low:
  - Use all $D^*$ candidates
  - Cross check on non-triggering $D^0$ daughters (helps for $p_T$)
Background Subtraction

- Use mass side-bands to subtract combinatorial background.
- Use $D^{*+}[\rightarrow D^0\pi^+]\pi^-$ to subtract feed-down from $D^{*+}[\rightarrow D^+\pi^0]\pi^-\rightarrow D^+\pi^-$. 
- Use wrong-sign $\pi^{**+}$ $\pi^-$ combinations to subtract prompt background to $\pi^{**}$. 
  - Possible charge asymmetry of prompt background studied with fully reconstructed B's: 4% contribution at most.
BACK-UP: details on systematics
Systematics

• Input parameters
  • $D^{(*)+}$ Masses, in combining $D^{(*)}$ with $D^{**}$ $m \rightarrow M$ [PDG errors]
  • $BR (B \rightarrow D^+/D^{**} m \rightarrow M)$ [PDG errors]

• Experimental
  • Detector resolution [re-smear satellite sample by full resolution: ±60MeV]
  • Data/MC Efficiency discrepancies [measure $P_+$ and $m$ dependency on control sample, probe different fit models]
  • Decay models in MC [full kinematic description vs pure phase space]
  • $P_1^*$ cut correction [repeat measurement at various $P_1^*$ thresholds]

• Backgrounds
  • Scale [charge correlation WS/RS from fully reconstructed $B$: ±4%]
  • Optimization Bias [repeat optimization procedure on bootstrap copies of the sample]
  • Physics background [vary ±100%]
  • $B \rightarrow X_c \tau \nu$ [estimate $\tau/\mu$ yield and kinematic differences using MC]
  • Fake leptons [no evidence in WS $D^+ l^+$, charge-correlated negligible]
Data-based study

1. Extract a bootstrap sample $a$ of the data
2. Optimize $\Rightarrow$ get new set of cuts
3. Evaluate bias with respect to the parent distribution (initial data) with new cuts
   - We can repeat this 50 times and obtain 50 independent estimates of the bias(es)
   - CPU intensive
     - $[\sim 5 \text{ hours} / (\text{bootstrap} + \text{optimization} + \"\text{fit}\") ]$
   - Mean of those estimates is an unbiased estimator of the bias
     (as long as the data is a good representation of the ideal distribution)
   - $\sigma$ is a convolution of:
     1) Intrinsic fluctuation of bias
     2) Statistical fluctuation of $a$ after cuts

$\mu = \text{bias}$

$\sigma = (\text{bias fluctuation}) \otimes (\text{statistical uncertainty})$
Physics Background

- **Physics background studied with**
  \[ B \rightarrow D^{(*)+} D_s^- \]
- **Size wrt signal:**
  \[ \epsilon \times BR(D_s \rightarrow lX) \times \frac{BR(B \rightarrow D_s D^{(*)+})}{BR(B \rightarrow \text{signal})} \times 1.5 \]
  \(~7\%\)
- **Other modes**
  \(~7\%\)
- **~1**

- **100% uncertainty**
τ Background

• A problem if observed m** distributions are different!
• Two possible sources of difference:
  - Kinematics: different m** distribution to begin with because
    \[ m(\tau) / m(B) \gg m(e/\mu) / m(B) \]
  - Different reconstruction efficiency
• Study with generator-level MC + smearing + trigger & reco. parameterization
• Conclusion:
  - \[ [B \rightarrow lD**\tau] / [B \rightarrow lD**\mu] \approx 2\% \]
  - Difference in m** acceptance is \~10\% and mass-independent \rightarrow irrelevant
  - \[ m(\tau) / m(B) \] matters only for the nonresonant component which is in MC 13\% of the overall distribution I.e. 13\%x2\% \approx 0.003 \rightarrow small
  - \[(\Delta m_1, \Delta m_2) \approx (0.01 \text{ GeV}^2, 0.065 \text{ GeV}^4)\] is evaluated on the above montecarlo, the overall BKG systematics is (0.02,0.1))

- \[ B \rightarrow lD**\tau \] Not a Significant Source of Systematics
Fake Correlated Leptons

• For background which is sign correlated the nastiest source is $D^{**(-)}\pi^+X$ where we mismatch $\pi^+$ as a fake lepton:

<table>
<thead>
<tr>
<th></th>
<th>$C=D^0$</th>
<th>$C=D^{*0}$</th>
<th>$C=D_1^{*0}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_\nu$</td>
<td>2.2%</td>
<td>6.5%</td>
<td>0.56%</td>
</tr>
<tr>
<td>$C_\pi$</td>
<td>0.5%</td>
<td>0.5%</td>
<td>0.15%</td>
</tr>
<tr>
<td>$C_\rho$</td>
<td>1.3%</td>
<td>1%</td>
<td>&lt;0.14%</td>
</tr>
</tbody>
</table>

Decreasing efficiency AND BR

Assuming:

• An average efficiency equal to the one for signal
• Overall BR($B\rightarrow D^{**(-)}\pi^+X$) is at most 3xBR($B\rightarrow D^{**(-)}\ell^+X$)
• From Run I + Run II studies from Masa, $e+\mu$ fakes are about 1.6% in total for this trigger

We get a fake count of ~2.4% the signal

• Kinematic m** bias much smaller than for the $\tau$ background case
• Similar fake rate

⇒ As negligible (or more favorable) than $\tau$
One fit to combine them all, one fit to find them!

\ldots (\Lambda \lambda)

- Fit based on Bauer et al. (hep-ph/0210027)
- Fit ($\Lambda, \lambda_1$) in the pole scheme to moments vs $p_1^*$ cut
- Not including all the CLEO points
- Including BELLE's (thanks to the BELLE folks for privately providing the correlations)
Statistical Weight

Contour Plot

All

Contour Plot

All but BABAR

Contour Plot

All but BELLE

Contour Plot

All but CDF

Contour Plot

All but CLEO

Contour Plot

All but DELPHI
Statistical Weight

- Same fit as previous page, but excluding single experiments
- CDF contribution is significant