Heavy Flavor Physics at DØ

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DØ Collaboration
DØ Detector

Forward Mini-drift chambers

Central Scintillator

Forward Scintillator

Shielding

New Solenoid, Tracking System

Si, SciFi, Preshower
Tracker

Trigger: muon+track covers $|\eta|<2.2$

SMT+ CFT
$\eta_{\text{max}} = 1.65$

SMT region
$\eta_{\text{max}} = 2.5$

$\eta = - \ln (\tan(\theta/2))$

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Impact Parameter Resolution

\[ \sigma(DCA) \approx 53\,\mu m \quad @ \quad P_t = 1\,GeV \]

and

\[ \approx 15\,\mu m \quad @ \quad \text{higher } P_t \]

Can provide

- **K/π** separation for \( P_{\text{tot}} < 400 \,\text{MeV} \)
- **p/π** separation for \( P_{\text{tot}} < 700 \,\text{MeV} \)

NOT yet used for PID

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Data from semileptonic decays ($B \to \mu D X$)

Tracks are reconstructed
- over a wide $\eta$ range
- starting from $p_T = 180$ MeV

Efficient muon and tracking system give us a large sample of semileptonic B decays
A New Particle: X(3872)

- Last Summer BELLE announced a NEW particle around 3872 MeV/c² when looking at B → K⁺X (X → J/ψ π⁺π⁻)
- possible charmonium state or an exotic meson molecule (?)
- BELLE didn’t find evidence for γχc₁

- X(3872) → J/ψ π⁺π⁻ production in ppbar collisions has been confirmed by CDF

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What can we say about the X(3872)?

- Using 200 pb\(^{-1}\) of DATA collected April 2002 – September 2003, we look for \(X(3872) \rightarrow J/\psi \pi^+\pi^-\)
  - SMT hit > 1
  - num tracks < 100
  - \(p_T(J/\psi) > 4 \text{ GeV/c}\)
  - \(2.8 < M(\mu^+\mu^-) < 3.4 \text{ GeV/c}^2\)
  - \(p_T(\pi) > 0.4 \text{ GeV/c}\)
  - \(\pi's\) within same cone as \(J/\psi\)
  - \(M(\pi^+\pi^-) > 0.52 \text{ GeV/c}^2\)
  - \(M(\mu^+\mu^-) - M(\pi^+\pi^-) < 1.0 \text{ GeV/c}^2\)
  - \(\chi^2 (\mu^+\mu^-\pi^+\pi^- - \text{vertex}) < 16\)
  - \(|z_{\text{vertex}}| < 35 \text{ cm}\)

\[\Delta M = 0.7684 \pm 0.0035 \text{ (stat)} \pm 0.0039 \text{ (sys) GeV/c}^2\]

- 300 ± 61 \(X(3872)\) candidates

- 4.4\(\sigma\) effect

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Properties of X(3872)

- Look if production characteristics are similar to $\psi(2S)$.

- Data was binned for different variables: decay-length, isolation, $\eta$ (pseudo-rapidity) $p_T$, and helicity of $(\pi^+\pi^-)$.
Within the current statistical uncertainties, the production of $X(3872)$ has similar behavior as the $cc(\bar{c}\bar{c})$ state $\psi(2S)$.
What is $X(3872)$?

- If the charged analog $X^+ \rightarrow J/\psi \pi^+ \pi^0$ was observed, then $cc(\bar{c}b)$ hypothesis could be ruled out.

- While observing radiative decays $X \rightarrow \gamma c_c$ would favor $cc(\bar{c}b)$ hypothesis.

- Both of these would require $D\emptyset$ to identify low energy $\pi^0$ and $\gamma$ (work in progress).

- Our tests show: production characteristics of $X(3872)$ (in the used variables) seems similar to those from $\psi(2S)$ (within the statistical uncertainties), this would tend to favor a $cc(\bar{c}b)$ hypothesis, but we do not know (yet) how these characteristics look for an exotic meson-molecule (theoretical input needed).
B Semileptonic Samples

- Muon:
  - $\text{Pt} > 2 \text{ GeV/c}$
  - nSMT $> 1$
  - nCFT $> 1$
- Charged tracks:
  - $pT > 0.7\text{-}1 \text{ GeV/c}$
- Secondary Vertex
  - $L_{xy}/\sigma_L > 4$
  - $\cos(\theta(L,P_D)) > 0.95$

For Mixing and Lifetime studies

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$B_{d,s}$ Masses ($J/\psi + K^0, \phi, K^0_s$)

For CP and Lifetime studies

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B Lifetime Measurements

Predictions

- $\tau(B_d)/\tau(B_s) = 1 \pm 0.01$
- $\tau(\Xi^0_b) \approx \tau(\Lambda_b) < \tau(B_d) < \tau(\Xi^-_b) < \tau(\Omega_b)$
- $\Gamma(\Lambda_b) - \Gamma(\Xi^-_b) \approx 0.11 \pm 0.03$ ps$^{-1}$
- $0.9 < \tau(\Lambda_b)/\tau(B_d) < 1$

Comparisons

- $\tau(B^-)/\tau(B^0) = 1.081 \pm 0.015$
- $\tau(B_s)/\tau(B^0) = 1.03 - 1.07$
- $\tau(\Lambda_b)/\tau(B^0) = 0.99 - 1.01$
- $\tau(\Xi^-_b)/\tau(B^0) = 0.804 \pm 0.051$
- $\tau(b\text{ baryon})/\tau(B^0) = 0.789 \pm 0.034$
- $\tau(\Xi^-_b)/\tau(B^0) = 0.9 - 1.0$

Experimental Results

- $\tau(B) = 1.573 \pm 0.008$ ps
- $\tau(B^0) = 1.534 \pm 0.013$ ps
- $\tau(B^+) = 1.652 \pm 0.014$ ps
- $\tau(B^+)/\tau(B^0) = 1.081 \pm 0.015$
- $\tau(B_s) = 1.439 \pm 0.053$ ps
- $\tau(b\text{ baryon}) = 1.210 \pm 0.051$ ps
- $\tau(\Lambda_b) = 1.233 \pm 0.078$ ps

$B$ Lifetime Group (Summer 2003)

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Measuring Lifetime using $B \to \psi X$, $\psi \to \mu^+\mu^-$

Use $\psi \to \mu^+\mu^-$ for tagging, vertex constraint, $p_T$ determination:
- Clean signal
- Large statistics
- Good vertex resolution
- Good momenta resolution

$\psi$ Signal = 290.3k events
Mass = $3.0718 \pm 0.0002$ GeV/c$^2$
$\sigma = 0.0741 \pm 0.0002$ GeV/c$^2$

$\psi'$ Signal = 8.22K events
Mass = $3.668 \pm 0.002$ GeV/c$^2$
$\sigma = 0.071 \pm 0.002$ GeV/c$^2$

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B Lifetime from Inclusive $B \rightarrow J/\psi + X$

$F$: correction factor to use the $p_T(J/\psi)$ to estimate the momentum of the $B$ to find proper time. Obtained from Monte Carlo

$$\langle \tau \rangle = 1.564 \pm 0.014 \text{ ps (PDG)}$$

$$\langle \tau \rangle = 1.562 \pm 0.013 \pm 0.045 \text{ ps}$$

Correction factor leads to the major systematic error

$J/\psi$ from $B$’s $= 18\%$

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**B± Lifetime from B±→J/ψK±**

\[ \tau_{B±} = 1.65\pm0.083 \text{(stat)}\pm0.123 \text{(syst)} \text{ ps} \]

\[ \int \ell dt \approx 114 \text{ pb}^{-1} \]

**DØ Run II Preliminary**

Mean\[5.27 \pm 0.003 \text{ (GeV)}\]

\[\sigma = 47 \pm 3 \text{ (MeV)}\]

B± Signal 278 events

\[B^\pm \text{ mass } c\tau > 0.03 \text{ cm}\]

**B± Lifetime**

\[\tau_{B±} = 1.671\pm0.018 \text{ ps (PDG)}\]

Fully reconstructed→No Correction Factor!

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**B_{d,s} Lifetimes from B \rightarrow J/\psi + K^{0*}, \phi**

\[ \tau_{B_{d}} = 1.51^{+0.19}_{-0.17} \text{ (stat)} \pm 0.20 \text{ (syst) ps} \]

\[ \tau_{B_{s}} = 1.19^{+0.19}_{-0.16} \text{ (stat) } \pm 0.14 \text{ (syst) ps} \]

\[ \frac{\tau_{B_s}}{\tau_{B_d}} = 0.79 \pm 0.14 \]

Similar kinematics \rightarrow Some systematic errors can be cancelled in ratio!

PDG: \( \tau_{B_d} = 1.537 \pm 0.015 \text{ ps} \)

PDG: \( \tau_{B_s} = 1.461 \pm 0.057 \text{ ps} \)

PDG: \( \frac{\tau_{B_s}}{\tau_{B_d}} = 0.95 \pm 0.038 \)

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B Lifetime from Semileptonic Decays $B \rightarrow D^0\mu X$

We are able to measure Lifetime

$$c\tau = L_{xy}M_bK/Pt_{(D+\mu)}$$

$$K = Pt_{(D+\mu)}/Pt_B \quad \text{(from MC)}$$

$$\tau_B = 1.460 \pm 0.083 \text{ (stat) ps}$$

We will use this for mixing studies
Mixing: Flavour tagging

- Use **flavour-specific decays** to get flavour of B at decay. To get **flavour of B at production** use

  - **Soft-lepton tags** - High dilution power, low efficiency (SL decay of other B)
    
    \[ D = \frac{N_R - N_W}{N_R + N_W} \quad \varepsilon = \frac{N_R + N_W}{N_R + N_W + N_{\text{notag}}} \]

  - **Jet Charge tag** - Poorer dilution power, high efficiency (track-jet from other b quark)

  - **Same Side tagging** - Poorer dilution power, high efficiency (fragmentation, B**)

- We test this tools using B⁺ data sample
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Opposite Side Muon Tagging

- $P_T^\mu > 1.9$ GeV
- $Q_\mu$ – charge of muon with the highest $P_T$

Classification:
- $Q_\mu \neq Q_K$: correct tag
- $Q_\mu = Q_K$: wrong tag
- No muon: No tag

DØ RunII preliminary

- $D = (57.0 \pm 19.3)\%$
- $\varepsilon = (5.0 \pm 0.7)\%$
- $\varepsilon D^2 = (1.6 \pm 1.1)\%$

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Opposite Side Jet Charge Tagging

- $P_T > 0.5$ GeV
- $\Delta Z_{PV} < 2$ cm
- Classifications:
  - $|Q| > 0.2$ && $\text{sign}(Q) \neq Q_K$: correct tag
  - $|Q| > 0.2$ && $\text{sign}(Q) = Q_K$: wrong tag
  - $|Q| < 0.2$: no tag

\[ Q = \frac{\Sigma P_T q}{\Sigma P_T} \]

- $D = (26.7 \pm 6.8)\%$
- $\varepsilon = (46.7 \pm 2.7)\%$
- $\varepsilon D^2 = (3.3 \pm 1.7)\%$

DØ Run II preliminary

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Same Side Tagging

Excited $B^{**}$ decays into $B$ and pion/kaon that carries the initial state flavor information

Example: $B^{**}_d \rightarrow B^+\pi^-$

$D_0$ Run II Preliminary, Luminosity=114 pb$^{-1}$

$B^{\pm} \rightarrow J/\psi K^{\pm}$
$N = 1235 \pm 52$

$B^+ \pi^+$  
$B^+ \pi^-$

#events in peak = $65 \pm 17$

$M(B^+, \pi^-) - M(B^+) = 0.426 \pm 0.016$ GeV.

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Flavour Tagging results

<table>
<thead>
<tr>
<th>Method Based on B+ Signal</th>
<th>Efficiency $\mathcal{E}$</th>
<th>Dilution D</th>
<th>Tagging Power $\mathcal{E}D^2$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft Muon</td>
<td>5%</td>
<td>57%</td>
<td>$1.6 \pm 1.1$</td>
</tr>
<tr>
<td>Jet Charge</td>
<td>47%</td>
<td>27%</td>
<td>$3.3 \pm 1.7$</td>
</tr>
<tr>
<td>Same Side</td>
<td>79%</td>
<td>26%</td>
<td>$5.5 \pm 2.0$</td>
</tr>
</tbody>
</table>

Muon DATA, will also use electrons

Performance with $B^0/B_s$ is under study

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Search for $B_s \rightarrow \mu^+\mu^-$

$\int L dt \approx 100$ pb$^{-1}$

$\text{Br}(B_s \rightarrow \mu^+\mu^-) < 1.6 \times 10^{-6}$ at 90% CL
Summary

- DØ has observed the $X(3872)$ particle in 200 $pb^{-1}$ data
  - Statistical significance of 4.4$\sigma$
  - $\Delta M = 0.7684 \pm 0.0035 \text{ (stat)} \pm 0.0039 \text{ (sys)}$
  - Data separated into various regions, we found similar behaviour as $\psi(2S)$, within statistical uncertainties
- Many other results as B physics program under way
- We have reprocessed $\approx 200 \text{ pb}^{-1}$ of data to better improve our analyses
- A lot more interesting results very soon!
More Data

Reprocessed $\int L dt \approx 200$ pb$^{-1}$

$\int L dt \approx 114$ pb$^{-1}$

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