B-physics Results from DØ

Andrei Nomerotski (Fermilab) 6/10/2004

• This talk will cover things related to B Physics
  ♦ Detector performance
  ♦ Analyses
    ▲ in more detail about semileptonic modes
  ♦ Prospects for Bs oscillations

• Current datasets
  ~350 pb⁻¹ on tape
  ~250 pb⁻¹ analyzed
  ~100 pb⁻¹ Run I
Good performance of Accelerator Division in 2004

- Record peak luminosity two days ago: $76 \times 10^{30} \text{ 1/cm/sec}^2$
- Record integrated lumi last week: $13.5 \text{ pb}^{-1} \text{ /week}$
- DØ recorded $\sim 150 \text{ pb}^{-1}$ in 2004
Delivered Luminosity

FY04 (as of June 3rd, 2004):
Delivered 197 pb⁻¹
Design goal 306 pb⁻¹

Summer shut-down: August 23rd for 13 weeks
Peak Luminosity

![Graph showing peak luminosity over time with dates on the x-axis and luminosity in units of $\mu b^{-1}/sec$ on the y-axis. The graph includes data points, curves labeled 'Meas', 'Design', and 'Base'.]
Monthly efficiency

D0 & CDF Data Taking Efficiency

D0 (from April 19th 2002)
CDF (from February 9th 2002)

Efficiency

Feb-02 Apr-02 Jun-02 Aug-02 Oct-02 Dec-02 Feb-03 Apr-03 Jun-03 Aug-03 Oct-03 Dec-03 Feb-04 Apr-04

Through May 31 2004
B Physics at DZero

• Will present here
  ♦ Measurement of Lifetime Ratio for \(B^0\) and \(B^+\) Mesons
  ♦ Flavor Oscillations in \(B_d\) Mesons with Opposite Side Muon Tagging
  ♦ Observation of Semileptonic B decays to Narrow D** Mesons
  ♦ Samples of exclusive B decays
  ♦ Observation of X(3872) at DØ
  ♦ Sensitivity Analysis of Rare Bs\(\rightarrow\mu\mu\) Decays

• Key for DØ B-physics program:
  Successful combination of 3 main components
  ♦ Muon system
  ♦ Tracker
  ♦ Muon trigger
Tevatron vs. B factory

• Have higher b-quark production cross section
  ◆ Rates at typical lumi’s:
    ~10 Hz for B factory
    ~10 kHz for Tevatron
    < 1 kHz in detector eta/pt acceptance
  BUT: need to control background
    1) in trigger
    2) in analysis

• Tevatron produces all b-particle species
  ◆ Bs, Bc, b-baryons

• Tevatron does not have full energy constraint
  ◆ Pt though is conserved
• Muon system with coverage $|\eta|<2$ and good shielding

- **Trackers**
  - Silicon Tracker: $|\eta|<3$
  - Fiber Tracker: $|\eta|<2$

- **Magnetic field** 2T
Muon System

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Muon PT in semileptonic events

Turn-on shape determined by muon triggers

Corresponds to muon P threshold:
- ~4.5 GeV/c in central region
- ~5 GeV/c in forward region

Interaction lengths VS. θ

η=1

η=2

Muons P_T in semileptonic events

Calorimeter

Toroid = magnetic iron
Triggers for B physics

- Robust and quiet single- and di-muon triggers
  - Large coverage $|\eta|<2$
  - Momentum measurement at L1 (toroids)
  - Variety of triggers based on
    - L1 Muon & L1 CTT (Fiber Tracker)
    - L2 & L3 filters

- Typical total rates at medium luminosity ($40 \times 10^{30} \text{s}^{-1}\text{cm}^{-2}$)
  - Di-muons: 50 Hz / 15 Hz / 4 Hz @ L1/L2/L3
  - Single muons: 120 Hz / 100 Hz / 50 Hz @ L1/L2/L3
  - Rates before prescaling: typically single muon triggers are prescaled or/and used with raised $p_T$ threshold at L1
  - Muon purity @ L1: 90% - all charm/bottom decays
  - Current total trigger bandwidth
    - 1600 Hz / 800 Hz / 60 Hz @ L1/L2/L3

- B-physics semi-muonic yields are limited by L3 filters and L3 bandwidth
Muon Trigger Rates

- L1 Single and Di-Muon Trigger rates vs. luminosity

CTT helps to reduce the single muon trigger rate by ~3 for Pt>3 GeV/c

Single muon trigger is prescaled at high luminosities
Tracks are reconstructed starting from $p_T = 180$ MeV

Coverage of Muon system is matched by L3/offline tracking

Offline tracking code had a major breakthrough by summer 2003 – greatly improved performance compared to previous versions
• η acceptance determined by Fiber Tracker

• Statistics is decreased by 2.3 if cut |η|<1 applied to all particles

• Reconstruct B⁰ candidate (more later)
  • D⁰ : 2 tracks of opposite charge with $P_T > 0.7\,\text{GeV}$, |η|<2
  • D*
  • muon
Tracking Performance

Impact Parameter Resolution

- $\sigma(\text{DCA}) \approx 16 \, \mu\text{m} @ P_T = 10 \, \text{GeV}$
- $\sigma(\text{DCA}) \approx 54 \, \mu\text{m} @ P_T = 1 \, \text{GeV}$
- Resolution compares well with MC

NOT yet used for PID
Calibrations using $J/\psi$ sample

Large $J/\psi$ sample – currently 1.2 M events in 250 pb$^{-1}$

DfI Run II Preliminary

- $\sim 707k \ J/\psi$
- Mean = 3.0751 ± 0.0002 GeV
- $\sigma_{inner} = 58.1 \pm 0.5$ MeV

Mass resolution 60 MeV/c$^2$ in agreement with expectations

- $J/\psi$ mass is shifted by 22 MeV
- Observe dependence on $P_t$ and on material crossed by tracks
- Developed correction procedure based on field & material model
- Finalizing calibration of momentum scale using $J/\psi$, $K_s$, $D^0$

Mass resolution 60 MeV/c$^2$ in agreement with expectations

After magnetic field and material corrections

Before corrections

NOT yet used
• B\(^+\) and B\(^0\) lifetimes should be the same in naïve spectator model
• However there are differences at \(O(1/m_b^3)\) level explained by Weak Annihilation (for B\(^0\)) and Pauli Interference (for B\(^+\)) diagrams

• In general theory prefers to deal with ratios
• Recent progress in NLO Lattice QCD improved precision of theoretical prediction on the lifetime ratio

\[
\tau(B^+)/\tau(B^0) = 1.053 \pm 0.016 \pm 0.017 \ (m_B, V_{cb}, f_B)
\]

Motivates improvements in experimental accuracy
### Theory Predictions vs Experiment

**Lifetime ratio**

<table>
<thead>
<tr>
<th>Expression</th>
<th>PDG 2003</th>
<th>Theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau(B^+)/\tau(B^0)$</td>
<td>1.085±0.017</td>
<td>1.03 - 1.07</td>
</tr>
<tr>
<td>$\tau(B_s)/\tau(B^0)$</td>
<td>0.951±0.038</td>
<td>0.99 - 1.01</td>
</tr>
<tr>
<td>$\tau(\Lambda_b)/\tau(B^0)$</td>
<td>0.8±0.052</td>
<td>0.9 - 1.0</td>
</tr>
<tr>
<td>$\tau(b\text{-baryon})/\tau(B^0)$</td>
<td>0.786±0.034</td>
<td>0.9 - 1.0</td>
</tr>
</tbody>
</table>

Graphs depicting predicted and experimental values for each ratio.
DZero Semileptonic $B_d$ sample

- 109k $B \rightarrow \mu \nu D^0$ candidates
- 25k $B \rightarrow \mu \nu D^*$ candidates

$B \rightarrow \mu \nu D^0 X$

$\rightarrow K^+\pi$

Dominated by $B^+$ decays

Dominated by $B^0$ decays
Visible Proper Decay Length

- Determine distance between $\mu D^0$ vertex and primary vertex in transverse plane: $L_T$
- Determine transverse momentum of $\mu D^0$ system: $P_T(\mu D^0)$
- Calculate Visible Proper Decay Length:
  - $VPDL = \frac{L_T}{P_T(\mu D^0)} \cdot M_B$
Analysis: Novel Technique

Three important points:

1) **Measure directly ratio of lifetimes instead of measuring absolute lifetimes**
   - Group events into 8 bins of Visible Proper Decay Length (VPDL):
     
     \[
     \text{VPDL} = \frac{L_T}{p_T(\mu D^0)} \cdot M_B
     \]
     \[
     L_T = \text{transverse decay length}
     \]

2) **Measure** \( r = \frac{N(\mu D^*)}{N(\mu D^0)} \) **in each bin**
   - Number of events is extracted from the fit of mass peak
     \( \Rightarrow \) no need to know VPDL distribution for background

3) **If relative** \( D^*/D^0 \) **efficiency does not depend on VPDL it does not affect the lifetime ratio** =>
   - Reconstruct slow pion from \( D^* \) without biasing lifetime
D* Selections

- Only requirement on slow pion is to give correct $m(D^*) - m(D^0)$ value
- Slow pion is NOT used for calculation of VPDL
  NOT used in B-vertex
  NOT used in k-factors
D\(^0\) and D\(^*\) Samples

- **D\(^*\) sample:**
  - all identified D\(^*\) candidates

- **D\(^0\) sample:**
  - D\(^0\) candidates with removed D\(^*\) candidates
Ratio of $D^0$ and $D^*$ events

one example: VPDL bin $[0.10 - 0.15 \text{ cm}]$

$$r_i = \frac{N_i(\mu^+D^* \pi^-)}{N_i(\mu^+D^0)} = \frac{N_i^R - C \cdot N_i^W}{N_i^0 + (1 + C') \cdot N_i^W}$$

- Fit $D^0$ mass peak in both cases in exactly same way
  - Decreases fit systematics
- Number of $D^*$ events is corrected to account for combinatorial bkg
  - Estimated from wrong sign $D^*$ combinations
  - Small correction because $D^*$ S/B is good
- Number of $D^0$ events is corrected to account for genuine $D^0$'s lost due to $D^*$ window cut
  - Small correction as well

Fit function: Gaussian + 2nd order polynomial
Errors are statistical, derived from the fit of mass peaks

<table>
<thead>
<tr>
<th>$i$</th>
<th>VPDL range</th>
<th>$N^R_i$</th>
<th>$N^W_i$</th>
<th>$N^0_i + N^W_i$</th>
<th>$r_i$</th>
<th>$r^e_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.1 ÷ 0.0</td>
<td>1016 ± 39</td>
<td>43 ± 18</td>
<td>3175 ± 109</td>
<td>0.298 ± 0.018</td>
<td>0.325</td>
</tr>
<tr>
<td>2</td>
<td>0.0 ÷ 0.02</td>
<td>3482 ± 69</td>
<td>129 ± 22</td>
<td>9973 ± 162</td>
<td>0.328 ± 0.009</td>
<td>0.324</td>
</tr>
<tr>
<td>3</td>
<td>0.02 ÷ 0.04</td>
<td>3350 ± 67</td>
<td>111 ± 18</td>
<td>9850 ± 152</td>
<td>0.322 ± 0.009</td>
<td>0.318</td>
</tr>
<tr>
<td>4</td>
<td>0.04 ÷ 0.07</td>
<td>3593 ± 70</td>
<td>114 ± 18</td>
<td>10995 ± 155</td>
<td>0.310 ± 0.008</td>
<td>0.310</td>
</tr>
<tr>
<td>5</td>
<td>0.07 ÷ 0.10</td>
<td>2175 ± 55</td>
<td>75 ± 13</td>
<td>7144 ± 126</td>
<td>0.288 ± 0.010</td>
<td>0.301</td>
</tr>
<tr>
<td>6</td>
<td>0.10 ÷ 0.15</td>
<td>1932 ± 51</td>
<td>57 ± 13</td>
<td>6349 ± 120</td>
<td>0.290 ± 0.010</td>
<td>0.291</td>
</tr>
<tr>
<td>7</td>
<td>0.15 ÷ 0.25</td>
<td>1212 ± 42</td>
<td>36 ± 11</td>
<td>4189 ± 102</td>
<td>0.276 ± 0.013</td>
<td>0.274</td>
</tr>
<tr>
<td>8</td>
<td>0.25 ÷ 0.40</td>
<td>298 ± 21</td>
<td>5 ± 6</td>
<td>1022 ± 51</td>
<td>0.284 ± 0.027</td>
<td>0.252</td>
</tr>
</tbody>
</table>
Expected Ratio $r^e_i$

- To calculate expected ratio in each VPDL bin
  - Sort decay channels between $D^0$ and $D^*$ samples
  - For given decay channel determine probability for $B$ to have certain Visible Proper Decay Length taking into account:
    - Correct proper decay length by K-factor which takes into account not reconstructed particles
    - Resolution
    - Efficiency
  - Make a sum for each sample according to the branching rates
  - Integrate over the VPDL bin to get the number of events
  - Take the ratio
Fitting Procedure

\[ k \equiv \tau^+/\tau^0 - 1 \text{ is determined from } \chi^2(N, k) \text{ minimisation:} \]
\[
\chi^2(N, k) = \sum_i \frac{(r_i - N \cdot r_i^e(k))^2}{\sigma^2(r_i)}
\]

- Norm \(N\) and \(k\) are free parameters in minimisation;
- \(\tau^+ = 1.674 \pm 0.018\) ps is taken from PDG;
- \(\tau^0 = \tau^+/ (1 + k)\);
- \(Br_j\) are taken from PDG;
- \(D_j(K), Res_j(x)\) are taken from simulation;
- \(Eff_{D^0}(x)\) is taken from simulation;
- \(Eff_{D^*}(x) = C \cdot Eff_{D^0}(x)\) - verified in simulation;
Semileptonic Sample Composition

For $D^*$ sample:

- $B^0 \to D^+-\mu\nu$;
- $B^0 \to D^{*-}\mu\nu X$;
- $B^+ \to D^{*-}\mu\nu X$;
- $B^0_s \to D_{s}^{*-}\mu\nu X$;

For $D^0$ sample:

- $B^+ \to D^0\mu\nu$;
- $B^+ \to D^{*0}\mu\nu$;
- $B^+ \to D^{*-}\mu\nu X$;
- $B^+ \to D^{*0}\mu\nu X$;
- $B^0 \to D^{*-}\mu\nu X$;
- $B^0 \to D^{*0}\mu\nu X$;
- $B^0_s \to D_{s}^{*-}\mu\nu X$, $B^0_s \to D_{s}^{*0}\mu\nu X$;

Branching rates from PDG values for inclusive and exclusive measurements:

$$Br(B^+ \to \mu^+\nu D^0) = 2.15 \pm 0.22\%$$

$$Br(B^0 \to \mu^+\nu D^-) = 2.14 \pm 0.20\%$$

$$Br(B^+ \to \mu^+\nu \bar{D}^{*0}) = 6.5 \pm 0.5\%$$

$$Br(B^0 \to \mu^+\nu \bar{D}^{-}) = 5.53 \pm 0.23\%$$

$$Br(B^+ \to \mu^+\nu \bar{D}^{**0}) = 2.67 \pm 0.37\%$$

$$Br(B^+ \to \mu^+\nu \bar{D}^{**0} \to l^+\nu D^{-} X) = 1.07 \pm 0.25\%$$

Important: $D^*$ decays dominate both $D^0$ and $D^*$ samples.
Sample Composition

- Based on above and after corrections for reconstruction efficiency

- $D^*$ sample is composed of
  - $86\% B^0$
  - $12\% B^+$
  - $2\% B_s$

- $D^0$ sample is composed of
  - $82\% B^+$
  - $16\% B^0$
  - $2\% B_s$
K-factors

- K-factor accounts for missing decay products like neutrino in calculation of proper lifetime
- We always compute k-factors as: \( K = \frac{P_T(\mu D^0)}{P_T(B)} \) even for D*+ sample
  - Same K-factor for D*+ and D*0
  - Reduce systematic error
- K-factors are grouped into 4 categories
VPDL Resolution

- Determined from MC
  - Described by 3 Gaussians
- Ratio fitting procedure assumes resolution is the same for $D^0$ and $D^*$
  - We do not use slow pion for B-vertex
- Resolution and tails of resolution were varied in wide range to study systematics due to resolution effects
  - Not so important for $B_d$ studies

3 Gaussians
- $\sigma_1 = 22.2 \, \mu m \, - \, 28\%$
- $\sigma_2 = 47.3 \, \mu m \, - \, 57\%$
- $\sigma_3 = 131 \, \mu m \, - \, 15\%$
Slow pion efficiency

- **Key point:** Want to avoid lifetime bias
- **Eff** depends on \( P_T(D^0) \) because of tracking cutoff at \( P_T=0.18 \) GeV
  - May induce VPDL dependence
  - Cut at \( P_T(D^0) > 5 \) GeV/c
- After that \( Eff = 88\% \) and does not depend on VPDL in MC
- Error on possible slope was used to estimate systematics
- Investigating ways to double check it in data
τ(B+)/τ(B₀): Checks for slow pion efficiency

- Do not see dependence in MC on
  - Charged jet multiplicity
  - Axial impact parameter
$\tau(B^+)/\tau(B^0)$: Result

**Preliminary result:**

$\tau(B^+)/\tau(B^0) = 1.093 \pm 0.021 \text{ (stat)} \pm 0.022 \text{ (syst)}$

$N = 1.001 \pm 0.012$
### Systematic errors

<table>
<thead>
<tr>
<th>source</th>
<th>variation range</th>
<th>$\Delta(\tau^+/\tau^0)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Br(B^\rightarrow \mu^+\nu D^{*-})$</td>
<td>$5.53 \pm 0.23%$</td>
<td>0.0015</td>
</tr>
<tr>
<td>$Br(B^+ \rightarrow \mu^+\nu D^{*0})$</td>
<td>$6.50 \pm 0.5%$</td>
<td>0.0001</td>
</tr>
<tr>
<td>$Br(B^+ \rightarrow \mu^+\nu D^{*0})$</td>
<td>$2.67 \pm 0.37%$</td>
<td>0.0005</td>
</tr>
<tr>
<td>$Br(B^+ \rightarrow \mu^+\nu D^{*-}\pi^+X)$</td>
<td>$1.06 \pm 0.25%$</td>
<td>0.0074</td>
</tr>
<tr>
<td>$Br(B_s^0 \rightarrow \mu^+\nu D_s X)$</td>
<td>$7.9 \pm 2.4%$</td>
<td>0.0025</td>
</tr>
<tr>
<td>$R_{ss}$, see (11)</td>
<td>$0 \div 1$</td>
<td>0.0007</td>
</tr>
<tr>
<td>$Eff(x; B^+ \rightarrow \mu^+\nu D^{*0})$</td>
<td>set $Eff(x) = const$</td>
<td>0.0012</td>
</tr>
<tr>
<td>$Eff(\pi)$</td>
<td>$0.876 \pm 0.04$</td>
<td>0.0012</td>
</tr>
<tr>
<td>Time dependence of $Eff(x; \pi)$</td>
<td>slope $\pm 0.12 ,[1/cm]$</td>
<td>0.0132</td>
</tr>
<tr>
<td>$C_Y$</td>
<td>$C_Y = 1$</td>
<td>0.0086</td>
</tr>
<tr>
<td>VPDL resolution difference in resolution between $D^*$ and $D^0$</td>
<td>$MC$ resolution $\times (0.2 \div 4.0)$</td>
<td>0.0042</td>
</tr>
<tr>
<td>$K$-factors</td>
<td>$r_1^e \rightarrow r_1$</td>
<td>0.0060</td>
</tr>
<tr>
<td>Average value $\pm 2%$</td>
<td></td>
<td>0.0021</td>
</tr>
<tr>
<td>$K$-factors</td>
<td>$Z(K; D^{**}) = Z(K; D^0, D^*)$</td>
<td>0.0072</td>
</tr>
<tr>
<td>Fitting procedure</td>
<td>see section 10</td>
<td>0.0060</td>
</tr>
<tr>
<td>$C$ from eqn. (2)</td>
<td>$1.22 \pm 0.04$</td>
<td>0.0004</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>0.0215</td>
</tr>
</tbody>
</table>

- Work in progress to understand (and hopefully decrease) main contributors
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$\tau(B^+)/\tau(B^0)$: Consistency Checks

- Split data sample in two parts with respect to various parameters – all looks good

<table>
<thead>
<tr>
<th>Consistency test</th>
<th>$k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$</td>
<td>Z_{PV}</td>
</tr>
<tr>
<td>$</td>
<td>Z_{PV}</td>
</tr>
<tr>
<td>$\eta(\muon) &gt; 0$</td>
<td>0.107 ± 0.031</td>
</tr>
<tr>
<td>$\eta(\muon) &lt; 0$</td>
<td>0.079 ± 0.030</td>
</tr>
<tr>
<td>$p_T(D^0) &lt; 7.5$ GeV/c</td>
<td>0.105 ± 0.031</td>
</tr>
<tr>
<td>$p_T(D^0) &gt; 7.5$ GeV/c</td>
<td>0.083 ± 0.030</td>
</tr>
<tr>
<td>$\mu^+$ only</td>
<td>0.088 ± 0.030</td>
</tr>
<tr>
<td>$\mu^-$ only</td>
<td>0.111 ± 0.031</td>
</tr>
<tr>
<td>$p_T(\mu) &lt; 5.5$ GeV/c</td>
<td>0.104 ± 0.033</td>
</tr>
<tr>
<td>$p_T(\mu) &gt; 5.5$ GeV/c</td>
<td>0.083 ± 0.028</td>
</tr>
<tr>
<td>Different intervals</td>
<td>0.086 ± 0.021</td>
</tr>
<tr>
<td>Without last VPDL interval</td>
<td>0.107 ± 0.024</td>
</tr>
<tr>
<td>Additional VPDL interval 0.4-0.8 cm</td>
<td>0.092 ± 0.021</td>
</tr>
</tbody>
</table>

- Invert magnetic field (statistics splits 50/50)
  - Positive polarity:
    - $k=0.072±0.030$
  - Negative polarity:
    - $k=0.115±0.030$

- Rare possibility at detectors for B-physics – not very important here but important for CP studies

- Measured ratio in MC = 0.073 ± 0.030 (input 0.070)
Revisiting Slow Pion Efficiency

- Checked in data using $K_s \rightarrow \pi^+ \pi^-$ sample
  - Measured $K_s$ lifetime agrees with PGD - will allow to reduce this systematics

Note regeneration in beampipe and silicon layers
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\[ \frac{\tau(B^+)/\tau(B^0)}{\tau(B^+)/\tau(B^0)}: \text{Comparison with other experiments} \]

This is one of the most precise measurements to date

New DØ result
(average not updated, plot not official or approved by HFAG)
**B⁰/B̅⁰ mixing**

- **In SM B_d mixing is explained by box diagrams**
  - Constrains $V_{td}$ CKM matrix element
  - Mixing frequency $\Delta m_d$ has been measured with high precision at B factories ($0.502 \pm 0.007$ ps⁻¹)

- **We use our large sample of semileptonic B_d decays to measure $\Delta m_d$**
  - Benchmark the initial state flavor tagging for later use in $B_s$ and $\Delta m_s$ measurements
  - Can also constrain more exotic models of b production at hadron colliders
**Initial State Tagging**

- **B flavor tagging methods:**
  - Opposite Side Lepton Tag
    - High Dilution: $D=0.5$
    - Low Efficiency: $\varepsilon=0.05$
  - Jet Charge Tag
    - Moderate Dilution: $D=0.1-0.3$
    - Moderate Efficiency: $\varepsilon=0.5$
  - Same Side Tag
    - Low Dilution: $D=0.1-0.2$
    - High Efficiency: $\varepsilon=0.7-0.8$

- **Significance of mixing measurement:** $S \propto \varepsilon D^2$

- The methods can be combined
OS muon tagging

✓ For tag optimization used
  ➢ Semileptonic B⁺ sample
  ➢ B⁺ → J/ψ K⁺ sample

✓ Adopted the following tagging procedure
  ➢ Select certified muons
    ▪ Track with # SMT hits > 1, # CFT hits > 1
    ▪ Pt > 2.5 GeV
    ▪ Nseg = 2 or 3
    ▪ Not from the same jet as B candidate
    ▪ cos (ϕ angle between B and tag muon) < 0.5
    ▪ Not from J/ψ

  ➢ If more than one candidate-choose muon with max Pt
  ➢ Not oscillated: $Q_{μ_0} \cdot Q_{μ} < 0$; oscillated: $Q_{μ_0} \cdot Q_{μ} > 0$
Number of events in different bins of Visible Proper Decay Length

- **First bin VPDL = [0.0 - 0.025 cm] or [0 - 0.83 ps]**
  - D* signal
  - **non-osc**
  - 146 D*
  - **osc**
  - 58 D*

- **Last bin VPDL = [0.125 - 0.250 cm] or [4.17 - 8.33 ps]**
  - D* signal
  - **non-osc**
  - 64 D*
  - **osc**
  - 80 D*
Oscillations in $D^*$ and $D^0$ samples

- Expect to see oscillations
- Level is offset by $B^+$ contribution

- Expect to see no oscillations
- Some variation from oscillations due to $B^0$ contribution into sample composition

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\[ \Delta m_d = 0.506 \pm 0.055 \text{(stat)} \pm 0.049 \text{(syst)} \text{ ps}^{-1} \]

Tagging efficiency: 4.8 +/- 0.2 \%
Tagging purity: 73.0 +/- 2.1 \%

Systematic error dominated by signal shape fitting - will be improved
B_d mixing with Same Side Tagging

- **B^+:**
  - Correct tag: \( Q_t \cdot Q_\mu < 0 \)

- **B^0:**
  - Correct tag: \( Q_t \cdot Q_\mu > 0 \)

Tagging track:

- Lowest \( P_{t,rel} \) track wrt B-meson in \( \Delta R < 0.7 \) cone around B
  - Used by CDF in Run I
  - Other algorithms are being considered also
D** contribution

- Difficulties arise due to D** contribution
  - Charged pion from D** can be taken as a tag
- Evaluated from D** topological analysis
  - Use impact parameter of pion from D** → D*π
Oscillations with Same Side Tagging

DØ RunII Preliminary

✓ No oscillations in the D⁰ sample
✓ There are oscillations in the D⁺ sample

• Work in progress to measure $\Delta m$
BS mixing

- BS oscillation frequency is more than 30 times higher than for Bd
- Semileptonic channels: Ability to measure the ΔmS deteriorates due to smearing of proper time because of neutrino
  - Try to find ways to improve resolution and evaluate K-factor on event by event basis

- Hadronic channels: No smearing due to neutrino
BS mixing

- Semileptonic channels: only a few periods are visible due to smearing from neutrino
  - Try to find ways to improve resolution and evaluate K-factor on event by event basis
**B_s semileptonic decays**

\[ B_s \rightarrow \mu^+ \nu \ D_s \rightarrow \phi \, \pi^- \rightarrow K^+ K^- \]

- Excellent yield:
  - 9500 candidates in 250 pb\(^{-1}\)
- \( \phi \pi \) invariant mass plot:
  - some lifetime cuts applied

**Work in progress to measure**
- \( B_s/B_d \) lifetime ratio
- first results on \( B_s \) mixing
  - need to fully understand time resolution
  - if \( \Delta m_s \approx 15 \, \text{ps}^{-1} \) expect a measurement with 500 pb\(^{-1}\)
Oscillated $B_s$ candidate in Run 164082 Event 31337864

- OS muon tagging was used for semileptonic $B_s$ sample
- An example of tagged $B_s$ candidate is shown
  - Two same sign muons are detected
    - Tagging muon has $\eta=1.4$
    - See advantage of muon system with large coverage
  - $M_{KK}=1.019$ GeV, $M_{KK\pi}=1.94$ GeV
  - $P_T(\mu_{Bs})=3.4$ GeV; $P_T(\mu_{tag})=3.5$ GeV
Hadronic Bs at DZero

Idea: Trigger on opposite side muon - access to fully reconstructed $B_s$ / $B_d$ hadronic decays
- Poor statistics (but remember that OS muon tagging comes for free!)
- Excellent proper time resolution
- Observed preliminary $B_d$ signal but a lot of work is still needed
- Strong competition from CDF which can trigger directly on this mode (without muon requirement)

First hadronic $B_d \rightarrow D^* \pi$ signal with OS muon tag (250 pb$^{-1}$)
Bs mixing projections

- Proposal to increase L3 bandwidth from 50 to 100 Hz is being reviewed
  - Upgrade to 250 Hz under discussion
- Silicon upgrade (Layer0) is going ahead (see later)
Observation of $B \rightarrow \mu \nu D^{**} X$

- **$D^{**}$** are orbitally excited $D$ meson states, see diagram
- In heavy quark limit expect two sets of doublet states
  - Two broad
  - Two narrow
- **Narrow $D^{**}$**
  - $D_{1}^{0}(2420) \rightarrow D^{*+} \pi^{-}$
  - $D^{*0}_{2}(2460) \rightarrow D^{*+} \pi^{-}$
  ▲ One of decay channels

$D_{1}^{0}$, $D_{2}^{*0}$ have been observed and studied in several experiments, most recently by BaBar and Belle in $B^{-} \rightarrow D^{**0} \pi^{-}$

We study $D_{1}^{0}$, $D_{2}^{*0}$ produced in semileptonic $B$ decays.
D** Signal

- Take D* sample - add another pion
- Look at invariant mass of D*⁻ π⁺ system
- Observed merged D₁⁰(2420) and D₂*⁰(2460)

![Graph showing D** invariant mass distribution with B → μ ν (D₁⁰, D₂*⁰) X → μ ν D*⁻ π⁺ X. 250 pb⁻¹, 523 ± 40 candidates.](image)
Interference effects in D**

- Two D** resonances decay to same final state => must interfere
- Modelled with two interfering Breit-Wigner states with mass/width as measured by Belle (no resolution effects included)

- Work in progress: extract separate amplitude for each state and relative phase of interference
Measurement of Br

- Experimentally determine total # of events in two narrow peaks
- Measure Br of $B \rightarrow \mu \nu$ narrow $D^{**} X$
  - Normalize to known Br ($B \rightarrow D^{*+} \mu \nu X$)

$$\text{Br}(B \rightarrow \{D_1^0, D_2^{*0}\} \mu \nu X) \cdot \text{Br}([D_1^0, D_2^{*0}] \rightarrow D^{*+} \pi^-) = 0.280 \pm 0.021 \text{ (stat)} \pm 0.088 \text{ (syst)} \%$$

- Can be compared to LEP measurement of total $D^{**}$ Br
  $$Br(B \rightarrow D^{**}\pi^-\mu\nu X) = (0.48 \pm 0.10)\%$$
  - More than half of the rate goes through narrow states
Exclusive B Decays

- Accumulated large exclusive samples of $B^+$ and $B^0$

  Find in 250 pb$^{-1}$:
  - $B^+ \rightarrow J/\psi K^+$ 4300 events
  - $B^0 \rightarrow J/\psi K^*$ 1900 events
  - $B^0 \rightarrow J/\psi K_s$ 375 events

- $\Lambda_b \rightarrow J/\psi \Lambda$ 52 events

  - Good S/B
  - Lifetime cuts applied
Exclusive $B_s$ Sample

$D\bar{O}$ accumulated the world largest sample of exclusive $B_s \rightarrow J/\psi \phi (\rightarrow K^+K^-)$ decays

- Some lifetime cuts applied

$B_s^0 \rightarrow J/\psi + \phi$

$N = 403 \pm 28$

- We have good potential in all $B \rightarrow J/\psi$ exclusive modes, work in progress on
  - Lifetime measurement of different $B$ species
  - Studies of $CP$ effects in $B_s$ & $B_d$ mesons
Last summer, Belle announced a new particle at \( \cong 3872 \text{ MeV/c}^2 \), observed in \( B^+ \) decays:

\[
B^+ \rightarrow K^+ X(3872), \quad X(3872) \rightarrow J/\Psi \pi^+ \pi^-
\]

Belle’s discovery has been confirmed by CDF and DØ.

DØ preliminary:

- \( 300 \pm 61 \) events
- \( 4.4\sigma \) effect

\[
\Delta M = 0.768 \pm 0.004 \text{ (stat)} \pm 0.004 \text{ (syst)} \text{ GeV/c}^2
\]
$B_s \rightarrow \mu^+ \mu^-$ sensitivity study

$B_s \rightarrow \mu^+ \mu^-$ is a promising window on possible physics beyond the SM.

Expected SM branching ratio is small:

\[ \text{Br}(B_s \rightarrow \mu^+ \mu^-) = (3.4 \pm 0.5) \cdot 10^{-9} \]

$B_d \rightarrow \mu^+ \mu^-$ is suppressed by additional factor $|V_{td}/V_{ts}| \approx 4 \cdot 10^{-2}$

SUSY: at large $\tan \beta$ enhancement of up to 2-3 orders of magnitude

Dimuon invariant mass, GeV/c$^2$
$B_s \rightarrow \mu^+ \mu^-$ sensitivity study

- Optimisation based on mass sidebands using decay length, isolation and angle between muon and decay length direction
- Expected signal has been normalised to $B^\pm \rightarrow J/\Psi K^\pm$
- After final cuts
  - expect 7.3 background events in signal region
  - signal efficiency: 30%

Current expected limit:

$\text{Br}(B_s \rightarrow \mu^+ \mu^-) < 1.0 \cdot 10^{-6}$ @ 95% CL (stat + syst)

Have sensitivity for competitive measurement
Silicon Upgrade in 2005

- Install additional silicon layer (Layer0) close to beampipe during 2005 shutdown
- It must fit between radii of 16mm - beam pipe flange and 22.8mm - present silicon support structure openings - **6.8 mm gap**!
  - Six phi segments
  - Eight z segments 2x7, 2x12cm
  - Analog cables - low mass
  - 48 HDIs x 256 channels
  - 96 SVX4 chips
- Sensor pitch - 71 $\mu$m (inner), 81 $\mu$m (outer)
  - Phi acceptance 98.4%
  - Pitch adapter between sensor and analog cable
- Status : Production phase
Layer 0 Layout

Inside SMT: size of golf ball
Occupied presently by beampipe
Layer0 performance

- Recover deterioration due to radiation damage of inner layers and SMT readout failures
- Improve Impact Parameter resolution, especially at low momentum due to analog cables
Summary

- B-physics at DZero is online with world class results
  - Lifetime ratio
- Record semileptonic and exclusive B-samples
  - Great potential still to be explored
- Plan to upgrade silicon and write more to tape
  - Better IP resolution with Layer0
  - 100 Hz or higher rate to tape

Bs oscillations is highest priority topic – it appears close but it will be a long way
Status

- Good performance of Accelerator Division in 2004
- DØ recorded >100 pb⁻¹ in 2004
Daily Efficiency

19 April 2002 - 3 June 2004

Tevatron Shutdown
8 Sep - 21 Nov 2003

Daily Efficiency
△ 10 Day Average
Fitting Procedure

✓ Need expression for expected asymmetry
  ▪ Use exactly the same approach as in the lifetime ratio analysis
✓ First sort out how different B meson species behave wrt oscillation/tagging
  ▷ Bd tagged as oscillated
    \[ n_d^+ = \frac{K}{c \tau_{B_d}} \exp\left(-\frac{Kx}{c \tau_{B_d}}\right) \cdot 0.5 \cdot \left(1 + (2\eta - 1) \cos(\Delta m \cdot Kx / c)\right) \]
  ▷ Bd tagged as non-oscillated
    \[ n_d^- = \frac{K}{c \tau_{B_d}} \exp\left(-\frac{Kx}{c \tau_{B_d}}\right) \cdot 0.5 \cdot \left(1 - (2\eta - 1) \cos(\Delta m \cdot Kx / c)\right) \]
  ▪ Bd oscillates with frequency \( \Delta m \)
  ▪ \( x \) is VPDL
  ▪ \( \eta \) is tagging purity = fraction of correctly tagged events / total
## Systematics for the mixing

<table>
<thead>
<tr>
<th>Source</th>
<th>$\sigma_{\Delta m}^{\text{syst}}, \text{ps}^{-1}$</th>
<th>$\sigma_\eta^{\text{syst}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{Br}(B_d \to D^*-\mu^+\nu)$</td>
<td>0.003</td>
<td>0.0006</td>
</tr>
<tr>
<td>$\text{Br}(B \to D^*\pi\mu\nu X)$</td>
<td>0.009</td>
<td>0.0002</td>
</tr>
<tr>
<td>$\text{Br}(B_s \to D_s\mu^+\nu X)$</td>
<td>0.001</td>
<td>0.0040</td>
</tr>
<tr>
<td>B lifetime</td>
<td>0.004</td>
<td>0.0020</td>
</tr>
<tr>
<td>Resolution function</td>
<td>0.017</td>
<td>0.0040</td>
</tr>
<tr>
<td>Alignment</td>
<td>0.007</td>
<td>0.0040</td>
</tr>
<tr>
<td>K-factor</td>
<td>0.009</td>
<td>0.0004</td>
</tr>
<tr>
<td>Mass peak fitting procedure</td>
<td>0.041</td>
<td>0.0020</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0.049</strong></td>
<td><strong>0.0083</strong></td>
</tr>
</tbody>
</table>
• D** selections
  ◆ Additional pion
    ▲ $P_T > 0.3$ GeV/c
    ▲ Right charge correlation
    ▲ IP significance wrt PV / IP significance wrt D** vtx > 4

• B selections
  ◆ # CFT hits > 5 for all tracks
  ◆ Good B vertex ($\chi^2 < 25$)
    ▲ Made of all D** tracks and muon
  ◆ Lifetime cuts
    ▲ Lxy significance > 3
Systematic errors

- Considered the following systematic effects

<table>
<thead>
<tr>
<th>Source</th>
<th>$\mathcal{B}_\tau$ absolute error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^*$ branching rates</td>
<td>0.020%</td>
</tr>
<tr>
<td>MC statistics</td>
<td>0.023%</td>
</tr>
<tr>
<td>Normalization to $D^*/D^0$</td>
<td>0.023%</td>
</tr>
<tr>
<td>$P_t^{**}$ dependence</td>
<td>0.052%</td>
</tr>
<tr>
<td>Possible contribution from wide resonance</td>
<td>0.039%</td>
</tr>
<tr>
<td>Possible interference effects of $D^0_1$ and $D^0_2$</td>
<td>0.040%</td>
</tr>
<tr>
<td>Different modelling of $D^*$ fit</td>
<td>0.010%</td>
</tr>
<tr>
<td>Trigger bias</td>
<td>0.020%</td>
</tr>
<tr>
<td><strong>Total systematic error</strong></td>
<td><strong>0.088%</strong></td>
</tr>
</tbody>
</table>

- Can hope to decrease the main contributors in the future
Exclusive B decays

$\Lambda_b \rightarrow J/\psi + \Lambda$

$N = 52 \pm 13$

$B^d_0 \rightarrow J/\psi + K^*$

$N = 1857 \pm 72$