KATIE: 3.5

Tevatron results
B. Casey, FNAL

PONO: 6.1
• Overall comparison on Tevatron and 4S/5S environments

• Cover selected $B_s$ physics results from DØ and CDF
  – Try and point out where measurements can be improved with 5S data (or complement 4S data)

• Topics:
  – $B_s$ lifetime
  – $\Delta\Gamma/\phi_s$
  – Rare decays
# Tevatron versus Belle

<table>
<thead>
<tr>
<th></th>
<th>Belle</th>
<th>Tevatron</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Goal</strong></td>
<td>Dedicated B program</td>
<td>Main purpose is high $p_T$</td>
</tr>
<tr>
<td><strong>trigger</strong></td>
<td>Inclusive</td>
<td>$\mu$, or displaced vertex (semi-inclusive)</td>
</tr>
<tr>
<td><strong>Hadronic backgrounds</strong></td>
<td>~3:1</td>
<td>Enormous, very small fraction of produced B’s written to tape</td>
</tr>
<tr>
<td></td>
<td>~all B’s written to tape</td>
<td></td>
</tr>
<tr>
<td><strong>PID</strong></td>
<td>Excellent $K/\pi/\mu/e$</td>
<td>Excellent $\mu$, OK $K/\pi$, poor e, for e from B</td>
</tr>
<tr>
<td><strong>neutrals</strong></td>
<td>Excellent $\gamma, \pi^0, \eta$</td>
<td>~none from B</td>
</tr>
<tr>
<td><strong>Boost</strong></td>
<td>~0.5 parallel to silicon, known apriori</td>
<td>~1-2 perpendicular to silicon (sensitivity to $\Delta m_s$), unknown apriori</td>
</tr>
<tr>
<td><strong>B_s production</strong></td>
<td>Coherent, no tagging</td>
<td>Incoherent, tagging OK</td>
</tr>
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If you can do it, you can do it better at Belle

Still many interesting things you can only do now at the Tevatron
**Tevatron versus Belle**

B-factory numbers approximated for 250 fb⁻¹, Tevatron numbers estimated at 1 fb⁻¹

<table>
<thead>
<tr>
<th></th>
<th>Belle</th>
<th>CDF</th>
<th>DØ</th>
</tr>
</thead>
<tbody>
<tr>
<td>(B^+ \rightarrow J/\psi K^+)</td>
<td>~18k</td>
<td>~18k</td>
<td>~18k</td>
</tr>
<tr>
<td>(B_s \rightarrow J/\psi \phi)</td>
<td>?</td>
<td>~2k</td>
<td>~2k</td>
</tr>
<tr>
<td>(B_s \rightarrow D_s (\phi\pi)\pi)</td>
<td>?</td>
<td>~2k</td>
<td>~50</td>
</tr>
<tr>
<td>(B_d \rightarrow \pi^+\pi^-)</td>
<td>605</td>
<td>882</td>
<td>-</td>
</tr>
<tr>
<td>(B_d \rightarrow \rho^+\rho^-)</td>
<td>205</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>(B_s \rightarrow K^+K^-)</td>
<td>?</td>
<td>1473</td>
<td>-</td>
</tr>
<tr>
<td>(B_s \rightarrow \phi\gamma)</td>
<td>18</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

- Dimuons about same
- Tev on top for now
- Vertex versus muon trigger
- \(h^+h^-\) ~same but no \(\pi^0\)s
- Tev on top for now
- Some things only at 5S
### Lifetime Ratios

Sensitive probe of higher order terms in HQE

<table>
<thead>
<tr>
<th>Theory*</th>
<th>Data</th>
<th>What we learned</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^+/B_d$</td>
<td>$1.06 \pm 0.02$</td>
<td>$1.071 \pm 0.009$</td>
</tr>
<tr>
<td>$\Lambda_b/B_d$</td>
<td>$0.90 \pm 0.05$</td>
<td>$0.90 \pm 0.03$**</td>
</tr>
<tr>
<td>$B_s/B_d$</td>
<td>$1.00 \pm 0.01$</td>
<td>$0.94 \pm 0.02$***</td>
</tr>
</tbody>
</table>

1: Franco et al hep-ph/0203089  
2: PDG07 + new DØ  
3: HFAG07 (not recent CDF)  

Statistics or something else?
Flavor specific

1-D lifetime fit to $D_s \bar{\nu}$, $D_s \pi$...

$$\tau_{FS} = \frac{1}{\Gamma_s} \left( \frac{1 + y^2}{1 - y^2} \right)$$

$$y = \frac{\Delta \Gamma}{2 \Gamma}$$

Complicated by sizeable $\Delta \Gamma = \Gamma_H - \Gamma_L$

Direct

Simultaneous fit to lifetime and polarization in $J/\psi \phi$

$$\Gamma = \frac{1}{2} (\Gamma_L + \Gamma_H)$$

$$\Delta \Gamma = \Gamma_L - \Gamma_H$$

40% reduction in error including FS

But also drives discrepancy with $B_d$
Reconstruct signal as $D_s$ correlated with muon

Apply boost correction determined from MC

Fit for lifetime

~90% signal,
~10% peaking backgrounds:
$B \rightarrow D_s D$, direct $D_s D$

$$\tau_{FS}(B_s) = 1.398 \pm 0.044^{+0.028}_{-0.025} \text{ ps}$$
**Hadronic $B_s$ Lifetime**

CDFII Preliminary $L=360 \text{pb}^{-1}$

- **Data**
- **Global fit**
- **Signal**
- **Cabibbo**
- **Combinatorial**
- $B \rightarrow D^* \pi$
- $B \rightarrow D \chi$
- $B$ continuum

**Fully reconstruct $B_s$ signal and boost**

No background or boost issues, but need precise trigger model

$$\tau_{FS}(B_s) = 1.60 \pm 0.10 \pm 0.02 \text{ ps}$$

Correct for trigger efficiency

**Fit for lifetime**
Cross checks with $B_d$ lifetime in the same topologies:

$$DØ/world = 1.01 \pm 0.06$$

$$CDF/world = 0.99 \pm 0.02$$

World average $\sim 2.5 \sigma$ below $B_d$ lifetime
**B_s lifetime at the 5S**

- Less uncertainty associated with high statistics semileptonic modes
  - known boost
  - background samples from 4S

- Tevatron:
  - Hadronic results still stat limited
  - semileptonic can move to direct lifetime ratio measurement to reduce sys.
  - Both cases: Not far from sys. limited

- If there is a B_s lifetime problem, it needs to be confirmed in a b-factory environment

- we will always want a good B_s lifetime measurement independent of J/ψ φ
\[ |g^{\pm}(t)|^2 = \frac{e^{-\Gamma t}}{2} \left[ \cosh\left(\frac{\Delta \Gamma}{2} t\right) \pm \cos(\Delta m t) \right] \]

\[ \Delta m = m_H - m_L = 2|m_{12}| \]
\[ \Delta \Gamma = \Gamma_L - \Gamma_H = 2|\Gamma_{12}| \cos \phi \]
\[ \phi = \text{arg}\left(-\frac{m_{12}}{\Gamma_{12}}\right) \]

\[ \Gamma(M \Rightarrow \bar{M}) \neq \Gamma(\bar{M} \Rightarrow M) \]

\[ \begin{cases} \text{even} & \neq \text{light} \\ \text{odd} & \neq \text{heavy} \end{cases} \]
All measurements are untagged (or time-integrated)
- Sensitivity to CPV in untagged samples if $\Delta \Gamma \neq 0$

Everything is $\Delta \Gamma \times f(\phi_s)$
- Theory prediction for $\Delta \Gamma$ very important
  - Cant be trusted without $\tau(B_s) / \tau(B_d)$

$D_s^{(*)}D_s^{(*)}$ theory errors uncontrolled
- Best $\Delta \Gamma$ measurement but not used in constraint
**ΔΓ and D(*)_s D(*)_s**

Measured through correlated production of \(D_s \rightarrow φπ\) and \(D_s \rightarrow φμν\)

Or fully reconstructed channels

Measured through correlated production of \(D_s \rightarrow φπ\) and \(D_s \rightarrow φμν\)

Or fully reconstructed channels

**Partial reconstruction more complicated but gives direct access to \(ΔΓ_{CP}\)**

**BF** \((B_s \rightarrow D^{(*)}_s D^{(*)}_s) = 0.039^{+0.019}_{-0.017} +0.016_{-0.015} \)

\[
\frac{ΔΓ_{CP}}{Γ} = 0.079^{+0.038}_{-0.035} +0.031_{-0.030} \]

**B. CASEY, BNM 2008**
Recently proposed by to use lifetime measurement in $D_s K$ to determine sign of strong phases for $J/\psi \phi$ and remove 2-fold ambiguity

(Nandi, Nierste hep-arXiv:0801.0143)

$D_s K / D_s \pi = 0.107 \pm 0.019 \pm 0.008$

PID variable based on dE/dx and momentum asymmetry.

109±19 $D_s K$ events

~8 $\sigma$ significance
*ΔΓ* and Untagged $J/ψ$ φ

Polarization tells if you are looking at an even or odd Bs

Lifetime tells you if you are looking at a B long or a B short

Comparing the two (plus interference terms) allows CPV measurement

$B_s \rightarrow J/ψ$ φ

5.26 < $M(B_s)$ < 5.46 GeV

c/σ(ct) > 5

Fit prob: 67.3 %
Tagged versus untagged

Adding tagging where available increases sensitivity (but $\varepsilon D^2 \sim 5\%$)

More importantly, extra terms partially reduce 4 fold ambiguity to 2 fold ambiguity.
ΔΓ/φ_s AT THE 5S

• Tevatron: 10 publications on ΔΓ and φ_s so far, only 1 includes time dependent tagging
  – Combined DØ/CDF: tagged/untagged J/ψ φ, A_s, τ_{FS} will be interesting

• If φ_s is large:
  – Decreasing ambiguities more important than tagging
  – BF(D_s(∗)D_s(∗)), τ(D_sK)

• If φ_s is large:
  – Tevatron + Belle can discover new physics before LHC
    • At least we need a tie breaker for choosing conventions

• If φ_s is small:
  – Precision τ and ΔΓ measurements will help guide theory and extraction of φ_s at LHCb
**New Physics and Rare Decays**

**b → s:** Once everyone’s best guess for new physics

\[ \Delta B = \Delta s = 1 \]

\[ b \rightarrow s \gamma: \text{too small to measure} \]

\[ \Delta B = \Delta s = 2 \]

\[ \Delta m_s: \text{too small to measure} \]
New Physics and rare decays

**b → s:** Still everyone’s best guess for new physics.

But now need to look where we have a chance to see small effects

**CPV phases:**

\[ \Delta B = \Delta s = 1: \ b \rightarrow s \bar{s}s, \]
\[ \Delta B = \Delta s = 2: \ \phi_s \]

**Interference:**

\[ b \rightarrow s l^+ l^- \]

**Large SM suppression:**

\[ B_s \rightarrow \mu \mu \]
\[ (B^+ \rightarrow \tau \nu) \]
\[ (K \rightarrow \pi \nu \nu) \]

(Closely related to b → s)
Radiative decay: $B \rightarrow V_{\mu\mu}$

18.5 ± 6.7 $K^*$

7.5 ± 3.6 $\phi$

Should add not-trivial stats for world average $A_{FB}$ in next few years

1 fb$^{-1}$:
~26 $B \rightarrow V_{\mu\mu}$ events

5 fb$^{-1}$:
~250 events
(CDF + DØ)
Annihilation: $B_s \rightarrow \mu\mu$

~most important thing we are doing in the Tevatron B program right now

2 fb$^{-1}$ results:

- Low lum, old silicon
- high lum, new silicon

Pretend there is a CDF plot here
**B_{s} \rightarrow \mu \mu \text{ PAST AND FUTURE}**

- **Step 1 (0.5-1 fb^{-1}):**
  - Do we understand e(\mu\mu)/e(K\mu\mu)?
    - Not at all trivial since trigger is tight, p_T distributions are different, and B p_T not well known
  - Can we reduce combinatoric background?

- **Step 2 (1-2 fb^{-1}):**
  - Multivariate background suppression
  - B\rightarrow h^+ h^- (CDF)

- **Step 3 (2-4 fb^{-1}):**
  - Smarter pre-selection
  - B\rightarrow h^+ h^- ? (CDF and DØ)
  - Fake tracks at high lum (DØ)
  - Specific cuts to remove B background
$B_s \rightarrow \mu\mu$ **VERSUS** $B \rightarrow \tau\tau$

- No serious attempt (yet) at $B_s \rightarrow \tau\tau$ at Tevatron

- At B factories?
  - BaBar limit uses fully reconstructed B data set $\rightarrow$ not interesting ($4 \times 10^{-3}$)
  - Can it be done without reconstructing the other B?
    - Look at Belle note 296 for examples of finding back-to-back tau’s in hadronic events
    - 4S/5S lum ratio indicates $B_d$ decay just as possible as $B_s$ decay

- If there is a factor of 10 enhancement, Tevatron $\mu\mu + B$ factory $\tau\tau$ would be very interesting
Many very exciting questions will be difficult to answer at LHC (or at least require very large data sets)

- How does the higgs couple to fermions?
- How does TeV scale physics influence flavor?
- Is there lepton flavor violation at the TeV scale?
- Leptogenesis?
- Beyond TeV scale physics?
Future flavor at Fermilab

• Current accelerator complex:
  – Low mass higgs $\rightarrow$ bb at Tevatron
  – NOvA
  – $\mu \rightarrow e$ conversion

• Project X:
  – sensitivity to minimal flavor violation signatures in kaons
  – Next generation $\mu \rightarrow e$ conversion
  – Neutrino CPV
  – Long baseline to DUSEL (proton decay)
  – dedicated fixed target tau/charm

Possibility for a very exciting US accelerator-based program complementing or competing with flavor programs in Asia/Europe
Conclusions

• Many exciting $B_s$ results from Tevatron and more to come

• Results from the 5S can have a very significant impact, particularly on CPV measurements
  – When you think of $\phi_s$, think big

• Potential for exciting accelerator based program next decade in US that will complement super B factory and LHC results