Searches for New Physics in Charm and Beauty sector at the Tevatron

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Flavor Physics at the Tevatron

- Tevatron was shut down for good on Sep 30, 2011
- CDF and D0 each have about 10 fb$^{-1}$ of data on tape
- They were designed for high $P_T$ physics. And...
  - High-rate of all species of heavy flavors: actually higher than “B factories”
  - Excellent mass resolution
  - Precision vertex reconstruction capabilities
  - Powerful trigger on displaced vertices
  - Forward-Backward symmetric detectors and CP-symmetric initial state imply equal number of particles and antiparticles in the acceptance
- Good competitors to the B factories
Searches for New Physics in Charm and Beauty sector at the Tevatron

• This talk is focused on recent Tevatron results in the flavor sector that are believed to be particularly sensitive to departure from the Standard Model

• New results since last year:

  • CP violation in charmless B decays
  • $b \rightarrow s \mu^+\mu^-$ decays
  • Branching fraction of $B_s \rightarrow \mu^+\mu^-$
  • CP violation in $B_d$ and $B_s$ semi-leptonic decays

• All done with full data set (~10/fb)

http://www-cdf.fnal.gov/physics/new/bottom/bottom.html
http://www-d0.fnal.gov/Run2Physics/WWW/results/b.htm
CP Asymmetries in Charmless $b$-hadron Decays

\[ B^0 \rightarrow K^+ \pi^- \]
\[ B_s^0 \rightarrow K^- \pi^+ \]
\[ \Lambda_b^0 \rightarrow p\pi^-, pK^- \]

First observation of $B_s \rightarrow K^\pi^+$ and $B_s \rightarrow K^+K^-$, first evidence of $B_s \rightarrow \pi^\pi^-$

Flavor specific decays ($b$-flavor from final state charge)
Count events and correct for detector-induced charged asymmetries

\[
\frac{\mathcal{B}(b \rightarrow f) - \mathcal{B}(\bar{b} \rightarrow \bar{f})}{\mathcal{B}(b \rightarrow f) + \mathcal{B}(\bar{b} \rightarrow \bar{f})} = \frac{N_{b \rightarrow f} - c_f N_{\bar{b} \rightarrow \bar{f}}}{N_{b \rightarrow f} + c_f N_{\bar{b} \rightarrow \bar{f}}}
\]

Correction $c_f$ derived from $D^0 \rightarrow K^\pi^-$ (symmetric production)
Equal $b$ and $\bar{b}$ production
CP Asymmetries in Charmless $b$-hadron Decays

Analysis Strategy
1. Displaced vertex trigger
2. Reconstruct B-like two-pronged vertices
3. Build invariant mass, assuming $\pi\pi$ hypothesis
4. All individual modes overlap in a single broad peak
Particle ID with dE/dx and Kinematics

- Multi-dimensional unbinned likelihood fit to extract yields of each decay mode and its charge conjugate
- Use kinematic variables and particle ID
Correction of detector-induced charge asymmetries

- We are looking for small effects
- Need to correct for small detector asymmetries
- $\pi^+ \text{ vs } \pi^-$ and $K^+ \text{ vs } K^-$
- Millions of $D^0$ to $K^-\pi^+$ and c.c.
- Asymmetry corrections of order $\sim 1\%$
CP Asymmetries in Charmless $b$-hadron Decays

Fit results

<table>
<thead>
<tr>
<th>Mode</th>
<th>$N_{b \rightarrow f}$</th>
<th>$N_{\bar{b} \rightarrow \bar{f}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^0 \rightarrow K^+\pi^-$</td>
<td>6348 ± 117</td>
<td>5313 ± 109</td>
</tr>
<tr>
<td>$B^0_s \rightarrow K^-\pi^+$</td>
<td>354 ± 46</td>
<td>560 ± 51</td>
</tr>
<tr>
<td>$\Lambda_b^0 \rightarrow p\pi^-$</td>
<td>242 ± 24</td>
<td>206 ± 23</td>
</tr>
<tr>
<td>$\Lambda_b^0 \rightarrow pK^-$</td>
<td>271 ± 30</td>
<td>324 ± 31</td>
</tr>
</tbody>
</table>

$A_{CP}$

$A_{CP}(B^0 \rightarrow K^+\pi^-) = (-8.3 \pm 1.3 \pm 0.3)\%$

$A_{CP}(B^0_s \rightarrow K^-\pi^+) = (22 \pm 7 \pm 2)\%$

$A_{CP}(\Lambda_b^0 \rightarrow p\pi^-) = (7 \pm 7 \pm 3)\%$

$A_{CP}(\Lambda_b^0 \rightarrow pK^-) = (-9 \pm 8 \pm 4)\%$

| Competitive measurement for $B^0$. For $B^0_s$ confirm LHCb result with same resolution |
| new CDF = 0.22 ± 0.07 + - 0.02 |
| LHCb = 0.27 ± 0.08 + - 0.02 |

| Strong evidence ($4.5\sigma$) combining CDF and LHCb measurements: |
| $A_{CP}(B^0_s \rightarrow K^+\pi^-) = (24.2 \pm 5.4)\%$ |

precision measurement of $b$-baryon asymmetries still unique to CDF
$b \rightarrow s \mu^+\mu^-$ decays

- Flavor Changing Neutral Currents
- Yet another golden probe
- Look for new physics in the distributions of kinematic variables
  - Total/differential BR, isospin asymmetry, forward backward asymmetry...
$b \rightarrow s \mu^+\mu^-$ decays

$B^+ \rightarrow K^+\mu^+\mu^-$,
$B^0 \rightarrow K^{*0}(892)\mu^+\mu^-$,
$B^0 \rightarrow K_S^0\mu^+\mu^-$,
$B^+ \rightarrow K^{*+}(892)\mu^+\mu^-$,
$B_s^0 \rightarrow \phi\mu^+\mu^-$, and
$\Lambda_b^0 \rightarrow \Lambda\mu^+\mu^-$. 

Les Rencontres de Physique de la Vallée d'Aoste - La Thuile - Feb 27 2013 - Luciano Ristori
Differential BR in $b \rightarrow s \mu^+\mu^-$ decays

Consistent with SM
Isospin asymmetry in $b \rightarrow s \mu^+ \mu^-$ decays

$$A_I^{(*)} = \frac{B(B^0 \rightarrow K^{(*)0} \mu^+ \mu^-) - B(B^+ \rightarrow K^{(*)+} \mu^+ \mu^-)}{B(B^0 \rightarrow K^{(*)0} \mu^+ \mu^-) + B(B^+ \rightarrow K^{(*)+} \mu^+ \mu^-)}$$

Consistent with SM within errors

LHCb observes a 3 sigma effect in the highest $q^2$ bin

$A_I(B \rightarrow K \mu^+ \mu^-)$

$$q^2 \ (GeV^2/c^2) = 16.00-23.00$$

CDF $\ -0.29 \pm 0.28^{\text{stat}} \pm 0.06^{\text{syst}}$

LHCb $\ -0.52^{+0.18}_{-0.22}$

3 sigma discrepancy from SM

arXiv:1205.3422
Asymmetries in $b \rightarrow s \mu^+\mu^-$ decays

Forward-backward asymmetry

K* polarization

Also consistent with SM

Branching fraction of $B_s \rightarrow \mu^+ \mu^-$

- Flavor Changing Neutral Current restricted
- Helicity suppressed
- $\text{BR}(B^0_s \rightarrow \mu^+ \mu^-) \sim 3 \times 10^{-9}$

- Can be significantly enhanced by New Physics
Branching fraction of $B_s \rightarrow \mu^+ \mu^-$

- Normalization mode
  - $B^\pm \rightarrow J/\Psi K^\pm$ with $J/\Psi \rightarrow \mu^+ \mu^-$
- BDT Multivariate technique
  - Use data sidebands as background for training
- Blinded analysis
  - Dimuon mass range of 4.0 – 7.0 GeV
  - Blinded from 4.9 – 5.8 GeV
- Expected
  - SM Signal: $1.23 \pm 0.13$
  - Background: $4.3 \pm 1.6$
  - Limit: $\text{BR}(B_s \rightarrow \mu^+ \mu^-) = 23 \times 10^{-9}$
- Observed 3 events setting a 95% C.L. limit on the branching fraction of
  $$\text{BR}(B_s^0 \rightarrow \mu^+ \mu^-) < 15 \times 10^{-9}$$

$B_s \rightarrow \mu^+ \mu^-$ results
CP violation in $B_d$ and $B_s$ semileptonic decays

Neutral $B$ mesons oscillate into their antiparticles

Complex phase in CKM matrix can lead to asymmetry:

$\Gamma[B(s)_0 \rightarrow \bar{B}(s)_0] \neq \Gamma[\bar{B}(s)_0 \rightarrow B(s)_0]$

Define semileptonic mixing asymmetry:

$$a_{sl}^q = \frac{\Delta \Gamma_q}{\Delta M_q} \cdot \tan(\phi_q) = \frac{\Gamma(\bar{B}_q^0 \rightarrow B_q^0 \rightarrow \ell^+ X) - \Gamma(B_q^0 \rightarrow \bar{B}_q^0 \rightarrow \ell^- X)}{\Gamma(B_q^0 \rightarrow B_q^0 \rightarrow \ell^+ X) + \Gamma(B_q^0 \rightarrow B_q^0 \rightarrow \ell^- X)}$$

SM values for both $B^0$ and $B^0_s$ are negligible compared to experimental precision:

Any significant deviation from zero is hence a signal of new physics.

$$a_{sl}^d = (-0.041 \pm 0.006)\%$$

$$a_{sl}^s = (-0.0019 \pm 0.0003)\%$$

Courtesy of Mark Williams, HCP 2012
CP violation in $B_d$ and $B_s$ semileptonic decays

D0 experiment measures significant asymmetry in same-charge dimuons (2011)

Interpreted as arising from asymmetry in B mixing

~50% contributions from $B_d^0$ and $B_s^0$

Important to make separate, independent measurements of $a_{sl}^d$ and $a_{sl}^s$

Courtesy of Mark Williams, HCP 2012
CP violation in $B_d$ and $B_s$ semileptonic decays

Three decay channels:

- $B_s^0 \rightarrow \mu^+ \nu D_s^- X$
- $B^0 \rightarrow \mu^+ \nu D^- X$
- $B^0 \rightarrow \mu^+ \nu D^{*-} X$

Raw asymmetry extracted by counting $\mu D_{(s)}^{(*)\pm}$ signal yields

Detector-related asymmetries (e.g. positive kaons have higher detection efficiency).

Fraction of reconstructed $\mu D_{(s)}$ decays from oscillated $B_{(s)}^0$ mesons (assume other sources are charge symmetric).

Courtesy of Mark Williams, HCP 2012
CP violation in $B_d$ and $B_s$ semileptonic decays

Final result:

$$a_{sl}^d = [0.68 \pm 0.45 \text{ (stat.)} \pm 0.14 \text{ (syst.)}]\%$$

$$a_{sl}^s = [-1.12 \pm 0.74 \text{ (stat)} \pm 0.17 \text{ (syst.)}]\%$$

consistent with standard model


CP violation in $B_d$ and $B_s$ semileptonic decays

new results consistent with standard model, also consistent with previous results

overall combination still ~ 3 sigma away from SM

Conclusions

• The Tevatron legacy

The experiments at the Tevatron have shown that precision measurements in flavor physics at a hadron collider are possible and can be complementary and competitive to similar studies at dedicated facilities (B-factories)

• Data taking has ended but analysis continues

• More interesting results in flavor physics will be coming from dear old Tevatron
THE END