Branching Fractions and Direct CP Asymmetries of Charmless B Decay Modes at CDF

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$B^0 (B_s) \rightarrow \pi\pi, K\pi, KK$

- $B^0 \rightarrow K\pi$ is mode where the first direct CP asymmetry in b-sector was observed
- Can study poorly known annihilation diagrams in $B_s \rightarrow \pi\pi$ and $B^0 \rightarrow KK$
- Unique in comparison $B^0 \rightarrow K\pi$ and $B_s \rightarrow K\pi$
- $B_s \rightarrow K\pi$ can give useful information on the CKM angle $\gamma$
**Tevatron**

- $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV
- Peak luminosity $\approx 3 \cdot 10^{32} \text{ cm}^{-2} \text{s}^{-1}$

CDF II collected $\approx 2.5 \text{ fb}^{-1}$
  - This talk shows $1 \text{ fb}^{-1}$
  - First analyses with $\approx 2 \text{ fb}^{-1}$ coming to public
CDF Detector

- Good tracking resolution
  \[ \sigma(p_T)/p_T \approx 0.1\% \text{ (GeV/c)}^{-1} \]
  \[ \Rightarrow \text{ Good mass resolution} \]

- Silicon vertex Detector
  \[ \Rightarrow \text{ Excellent vertex resolution} \]
  \[ \Rightarrow \text{ Important for triggering} \]

- Good particle identification
  - \( dE/dx \) measurement in the drift chamber
  - Time of flight
B $\rightarrow$ hh$'$ Trigger

- Hard to trigger, only two "stable" hadrons in final state
- Exploit long lifetime of the $B$-hadrons
- Trigger selection:
  - Two tracks with opposite charge
  - Track’s $d_0 > 100 \mu m$
  - Track’s $p_T > 2.0 GeV/c$
  - B vertex $L_{xy} > 200 \mu m$
  - B’s $d_0 < 140 \mu m$
  - Opening angle 20° - 135°
  - $p_T(1) + p_T(2) > 5.5 GeV/c$

CDF Run II  Preliminary $L_{int}=1 fb^{-1}$

Confirm trigger cuts offline
Peak already visible
Selection

- Tighten trigger cuts
- Add two more variables
  - $\chi^2$ of the 3D vertex fit
  - Isolation $I = p_T(B)/[p_T(B) + \sum_i p_T(i)]$
- Minimize statistical uncertainty of quantity to be measured
- Derived two set of criteria
  - Looser for measurement of $A_{CP}(B^0 \rightarrow K^+\pi^-)$
    $\rightarrow$ Useful for all large-yield modes
  - Tighter for measurement of $B(B_s \rightarrow K^-\pi^+)$
    $\rightarrow$ Good for all rare modes
Disentangling modes

- Despite excellent mass resolution ($\approx 22\text{MeV}/c^2$) different decays overlaps

- Event-by-event particle ID not sufficient to separate modes

$\Rightarrow$ Combined kinematics and particle ID fit

CDF Run II Preliminary $L_{\text{int}}=1\text{ fb}^{-1}$

CDF Run II Monte Carlo

- $B^0 \rightarrow K\pi$
- $B^0_s \rightarrow K\pi$
- $B^0 \rightarrow \pi\pi$
- $B^0_s \rightarrow \pi\pi$
- $B^0 \rightarrow KK$
- $B^0_s \rightarrow KK$
- $\Lambda_0 \rightarrow pK$
- $\Lambda_0 \rightarrow p\pi$

Despite excellent mass resolution ($\approx 22\text{MeV}/c^2$) different decays overlaps. Event-by-event particle ID not sufficient to separate modes. Combined kinematics and particle ID fit.
Mass description

- Need very precise description
  - tails of final state radiation
  - non-Gaussian resolutions tails
- $D^0 \rightarrow K\pi$ from $D^*$ provides clean, high statistics control sample
- Very good description of control $D^0$ sample

CDF Run II Preliminary $L_{int}$=780 pb$^{-1}$

\[ \chi^2 / ndf = 161 / 83 \]
Momentum

- Pion mass used to calculate two track invariant mass $M_{\pi\pi}$
- Unique transformation from $M_{\pi\pi}$ to any $M_{hh'}$ if momentum of tracks known
- Use variables:
  - $M_{\pi\pi}$ - invariant $\pi\pi$-mass
  - $\alpha = (1 - p_1^{\min}/p_2^{\max})q_1^{\min}$ - signed momentum imbalance
  - $p_{\text{tot}} = p_1^{\min} + p_2^{\max}$ - scalar sum of momenta
Particle ID

- Use $dE/dx$ measurement in COT
- High statistics, high purity sample of $D^0$ from $D^*$ available for calibration
- In likelihood use
  \[
  \text{ID} = \frac{dE/dx(\text{meas}) - dE/dx(\pi)}{dE/dx(K) - dE/dx(\pi)}
  \]
- around $1.4\sigma$ separation between $K$ and $\pi$ for $p > 2\text{GeV}$
- Complements kinematics
Large-yield branching fractions

\[
\begin{align*}
\frac{\mathcal{B}(B^0 \to \pi^+ \pi^-)}{\mathcal{B}(B^0 \to K^+ \pi^-)} & = 0.259 \pm 0.017 \pm 0.016 \\
\frac{f_s \mathcal{B}(B_S \to K^+ K^-)}{f_d \mathcal{B}(B^0 \to K^+ \pi^-)} & = 0.324 \pm 0.019 \pm 0.041 \\
\mathcal{B}(B_S \to K^+ K^-) & = (5.10 \pm 0.33 \pm 0.36) \cdot 10^{-6} \\
\mathcal{B}(B^0 \to \pi^+ \pi^-) & = (24.4 \pm 1.4 \pm 4.6) \cdot 10^{-6}
\end{align*}
\]

Signal events:

\[B^0 \to \pi^+ \pi^- \quad 1121 \pm 63\]
\[B^0 \to K^+ \pi^- \quad 4045 \pm 84\]
\[B_S \to K^+ K^- \quad 1307 \pm 64\]

Large sample of \(B_S \to K^+ K^-\)

→ lifetime measurement

→ time-dependent tagged analysis
Direct CP asymmetry for $B^0 \rightarrow K^+\pi^-$

- Only significant difference in $K^+/K^-$ interaction with material
- Calibrate with $D^0 \rightarrow h^+h^-$ with assumption $A_{CP}(D^0 \rightarrow K\pi) = 0$
- Dominant systematic uncertainty
  - Particle ID model
  - WA B meson masses

$$A_{CP} = \frac{N(\overline{B}^0 \rightarrow K^-\pi^+) - N(B^0 \rightarrow K^+\pi^-)}{N(\overline{B}^0 \rightarrow K^-\pi^+) + N(B^0 \rightarrow K^+\pi^-)}$$

$$= -0.086 \pm 0.023 \pm 0.009$$
Rare modes results

Three new modes observed:

\( B_S \to K^- \pi^+ \quad 230 \pm 34 \pm 16 \quad 8\sigma \)

\( \Lambda_b \to p\pi^- \quad 110 \pm 18 \pm 16 \quad 6\sigma \)

\( \Lambda_b \to pK^- \quad 156 \pm 20 \pm 11 \quad 11\sigma \)

\[
\frac{f_s \mathcal{B}(B_S \to K^- \pi^+)}{f_d \mathcal{B}(B^0 \to K^+\pi^-)} = 0.066 \pm 0.010 \pm 0.010
\]

Using input from HFAG

\[
\Rightarrow \mathcal{B}(B_S \to K^- \pi^+) = (5.0 \pm 0.75 \pm 1.0) \cdot 10^{-6}
\]
$A_{CP}(B_s \rightarrow K^+\pi^-) \text{ vs. } A_{CP}(B^0 \rightarrow K^+\pi^-)$


$$\Gamma(B^0 \rightarrow K^-\pi^+) - \Gamma(B^0 \rightarrow K^+\pi^-) = \Gamma(B_s \rightarrow K^-\pi^+) - \Gamma(B_s \rightarrow K^+\pi^-)$$

→ Provides model independent test for new physics
Can be used to predict $A_{CP}(B_s \rightarrow K^-\pi^+)$ from other measurements

$$A_{CP}(B_s \rightarrow K^-\pi^+) = -A_{CP}(B^0 \rightarrow K^+\pi^-) \frac{\beta(B^0 \rightarrow K^+\pi^-)}{\beta(B_s \rightarrow K^-\pi^+)} \cdot \frac{\tau(B^0)}{\tau(B_s)}$$

Plugging in numbers

$$\Rightarrow A_{CP}(B_s \rightarrow K^-\pi^+) \approx +37\%$$
Direct CP asymmetry for $B_s \rightarrow K^+\pi^−$

$$A_{\text{CP}} = \frac{N(\overline{B}_s \rightarrow K^+\pi^-) - N(B_s \rightarrow K^-\pi^+)}{N(\overline{B}_s \rightarrow K^+\pi^-) + N(B_s \rightarrow K^-\pi^+)}$$

$= +0.39 \pm 0.15 \pm 0.08$

- First indication of CP violation in $B_s$ system
- Sign and size agree with SM expectation
- No evidence for 'exotic' sources of CP violation
- Will repeat with more data (already 2.5fb$^{-1}$ on tape)

CDF Run II Preliminary $L_{\text{int}}=1 \text{ fb}^{-1}$

Significance $2.5\sigma$
Conclusions

- Performed study of charmless two body $B^0/B_s$ decays
- $A_{CP}(B^0 \rightarrow K^+\pi^-)$ precision comparable to B-factories
  Goal uncertainty below 1% with $8fb^{-1}$
- First observation of $\Lambda_b \rightarrow pK$ and $\Lambda_b \rightarrow p\pi$
  Study direct CP violation soon
- First observation of $B_s \rightarrow K^-\pi^+$ decay
- First direct CP violation measurement in $B_s$ system
  $A_{CP}(B_s \rightarrow K^-\pi^+)$ in agreement with large SM prediction