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

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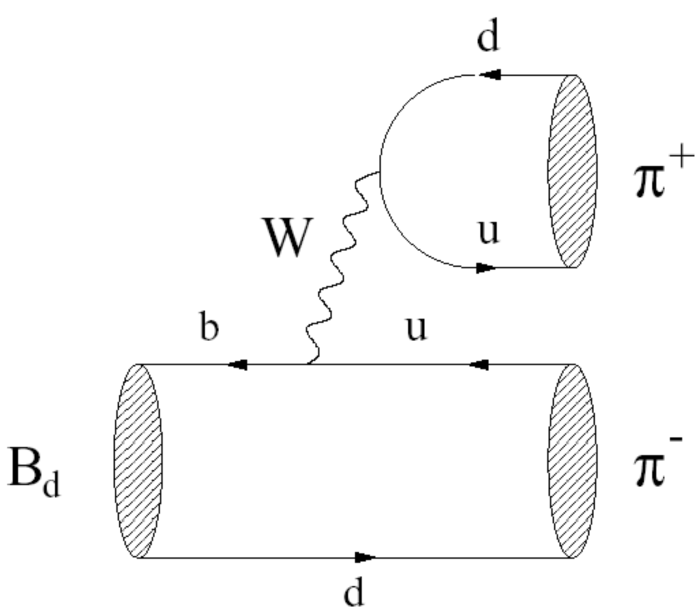
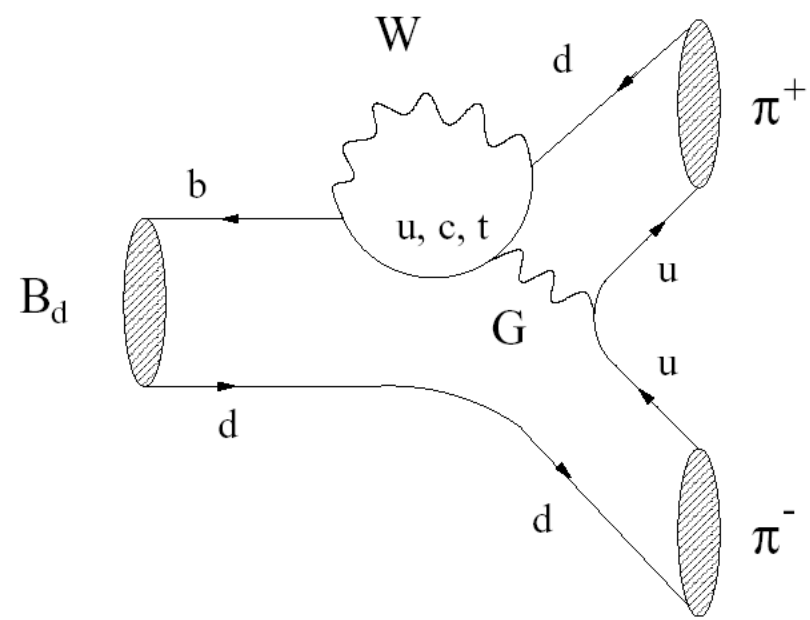
On behalf of the CDF Collaboration

$\mathbf{B^0(B_s) \to \pi\pi, K\pi, KK}$

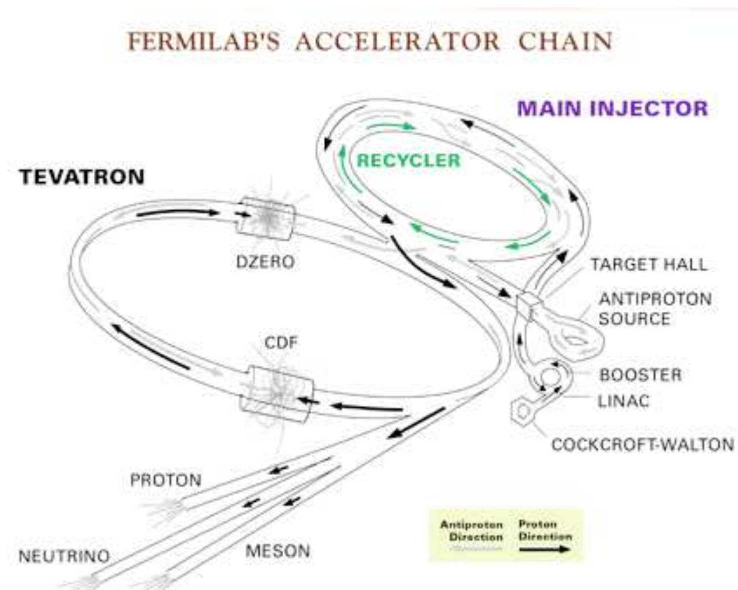
- $B^0 \to K\pi$ is mode where the first direct CP asymmetry in b-sector was observed
- Can study poorly known annihilation diagrams in $B_s \to \pi\pi$ and $B^0 \to KK$
- Unique in comparison $B^0 \to K\pi$ and $B_s \to K\pi$
- $B_s \to K\pi$ can give useful information on the CKM angle γ

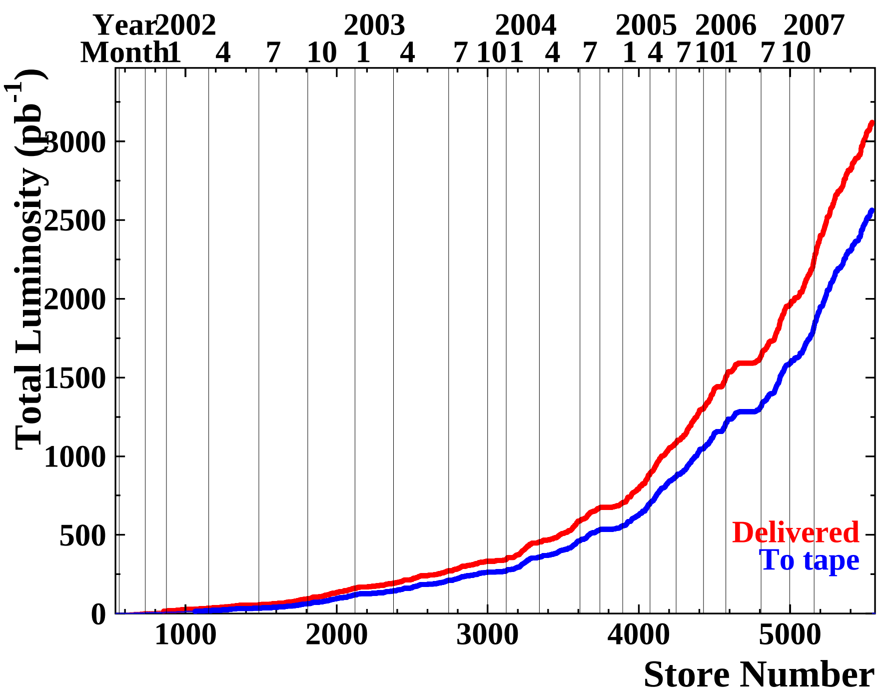


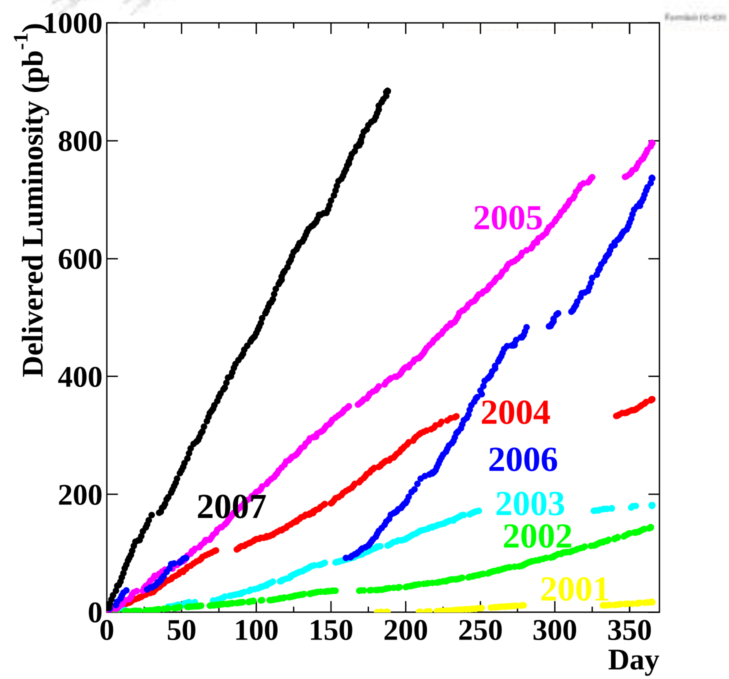


Tevatron

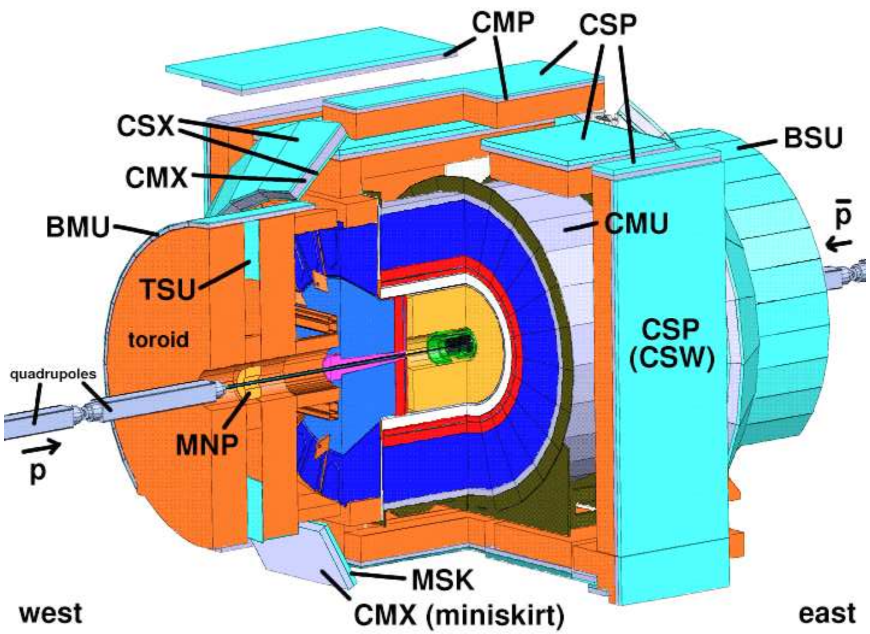
- $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV
- Peak luminosity $\approx 3 \cdot 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- CDF II collected $\approx 2.5\,\mathrm{fb}^{-1}$
  - $\rightarrow$ This talk shows $1\,\mathrm{fb}^{-1}$
  - $\rightarrow$ First analyses with $\approx 2\,\mathrm{fb}^{-1}$ coming to public

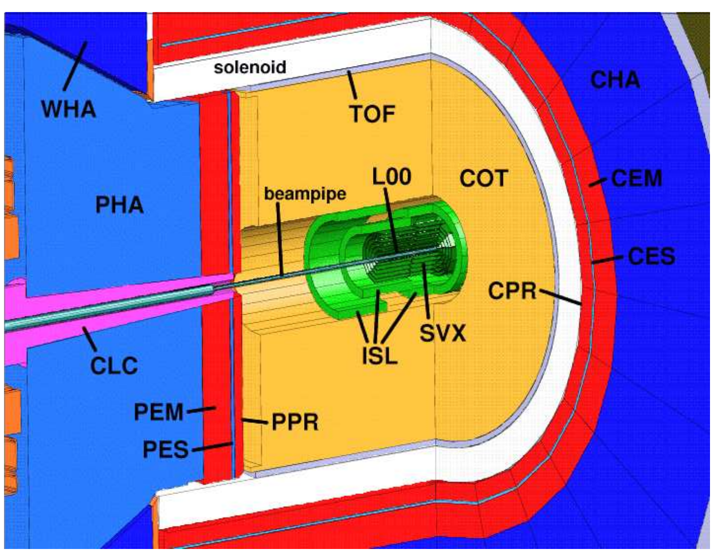






CDF Detector

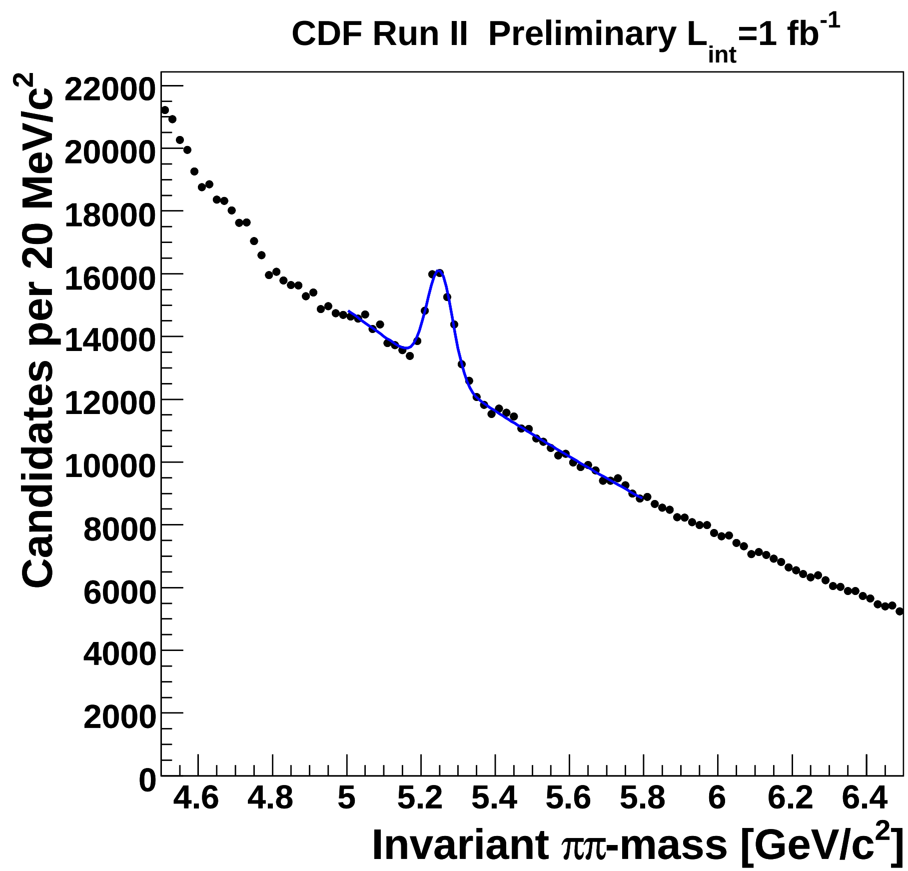




- Good tracking resolution $\sigma(p_T)/p_T \approx 0.1\% \,(\mathrm{GeV}/c)^{-1}$
  - $\Rightarrow$ Good mass resolution
- Silicon vertex Detector
  - $\Rightarrow$ Excellent vertex resolution
  - $\Rightarrow$ Important for triggering
- Good particle identification
  - dE/dx measurement in the drift chamber
  - Time of flight

$B \to hh'$ 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$/c$



Confirm trigger cuts offline
Peak already visible

Selection

- Tighten trigger cuts
- Add two more variables
  - χ^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 $A_{\mathrm{CP}}(B^0 \to K^+\pi^-)$

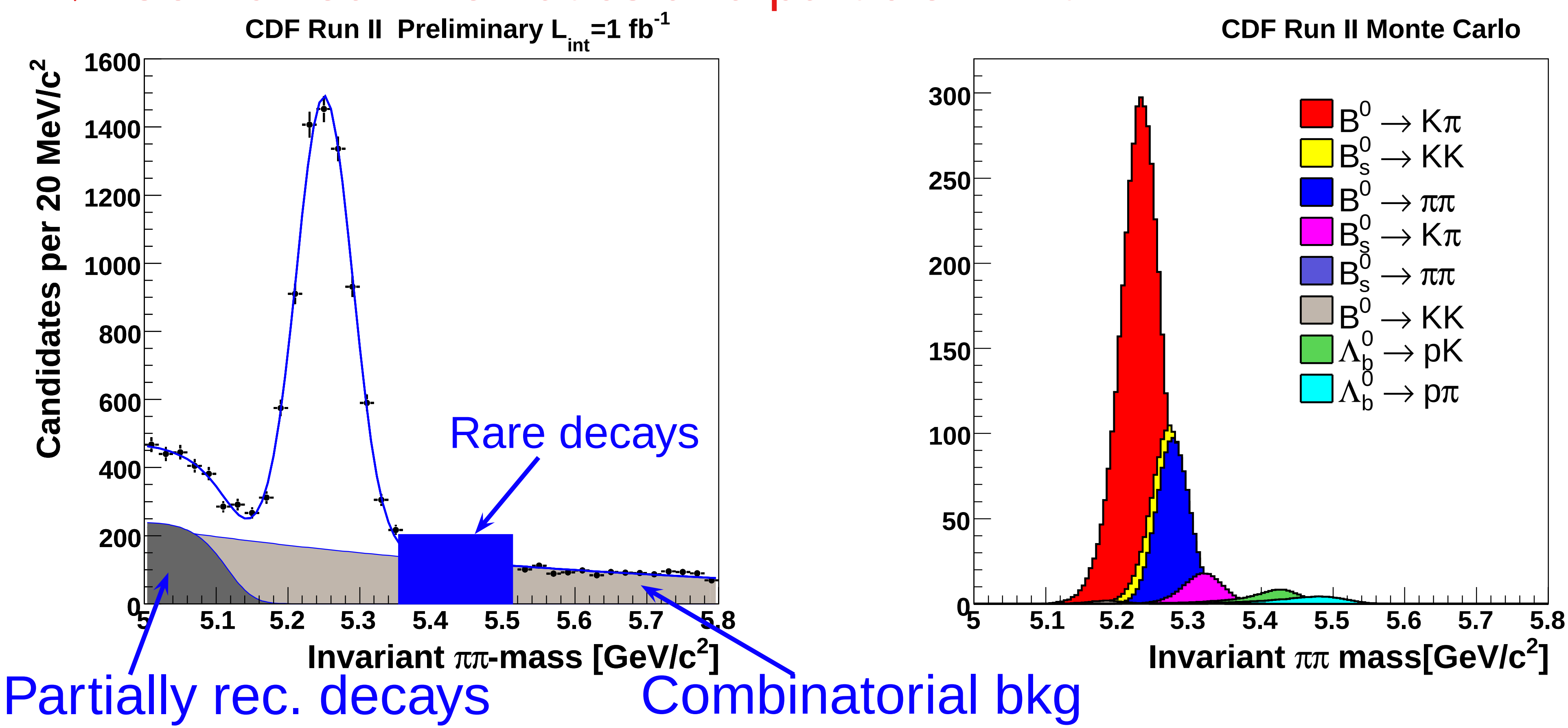
  $\longrightarrow$ Useful for all large-yield modes
  - Tighter for measurement of $\mathcal{B}(B_s \to K^-\pi^+)$

  $\longrightarrow$ Good for all rare modes

Disentangling modes

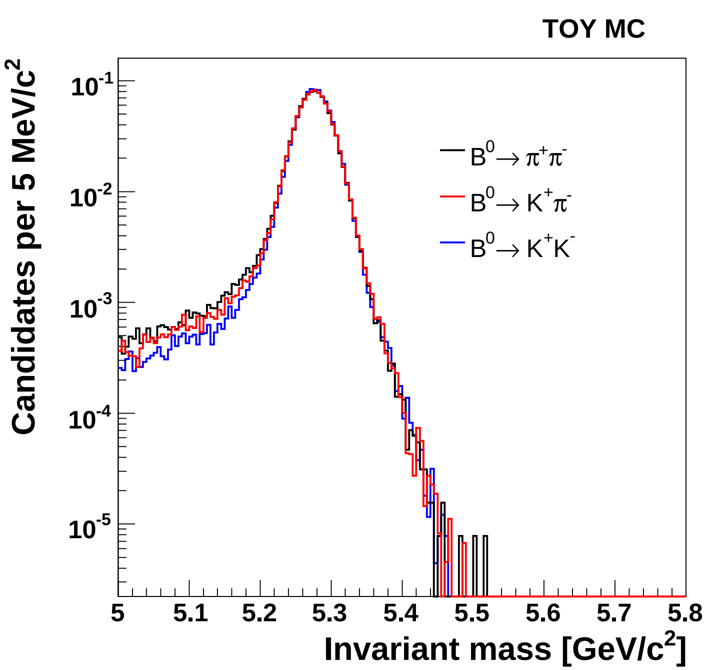
- Despite excellent mass resolution ($\approx 22\text{MeV}/c^2$) different decays overlaps
- Event-by-event particle ID not sufficient to separate modes

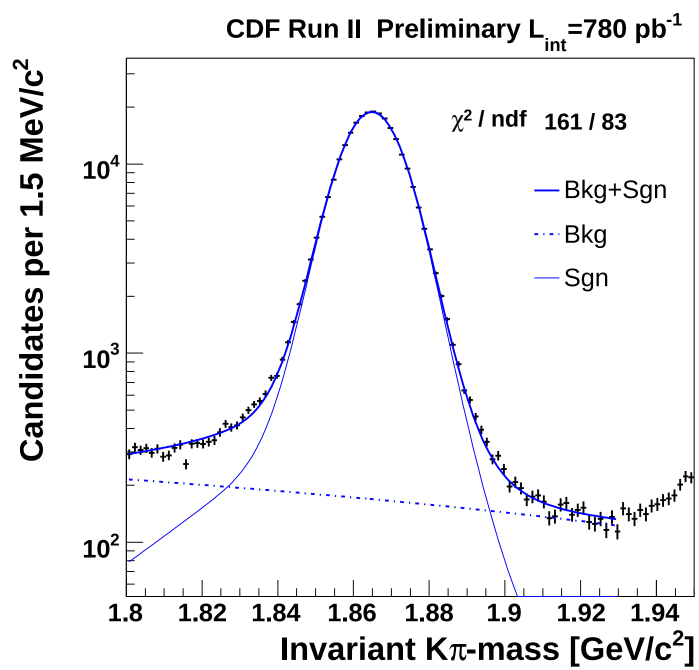
$\Rightarrow$ Combined kinematics and particle ID fit



Mass description

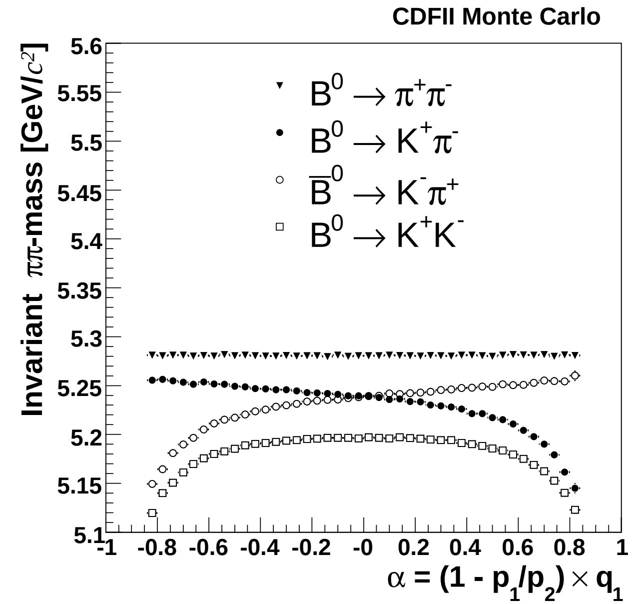
- Need very precise description
  - tails of final state radiation
  - non-Gaussian resolutions tails
- $D^0 \to K\pi$ from D^* provides clean, high statistics control sample
- Very good description of control D^0 sample

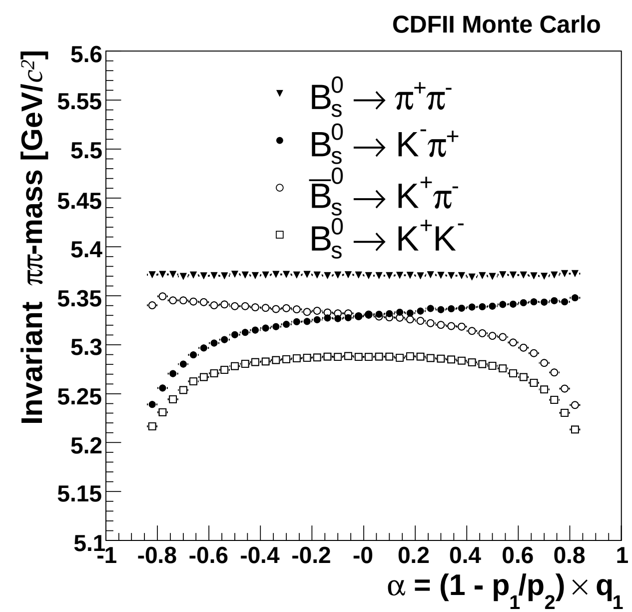




Momentum

- 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
  - $\alpha = (1 - p_1^{\mathrm{min}}/p_2^{\mathrm{max}})q_1^{\mathrm{min}}$ - signed momentum imbalance
  - $p_{\mathrm{tot}} = p_1^{\mathrm{min}} + p_2^{\mathrm{max}}$ - scalar sum of momenta



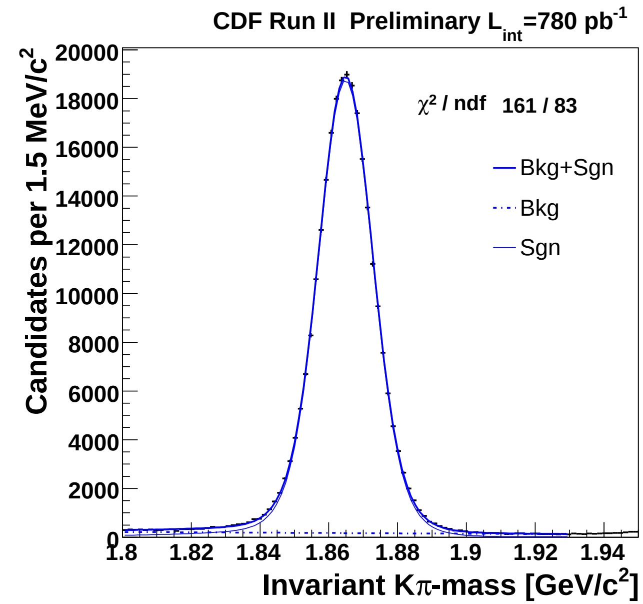


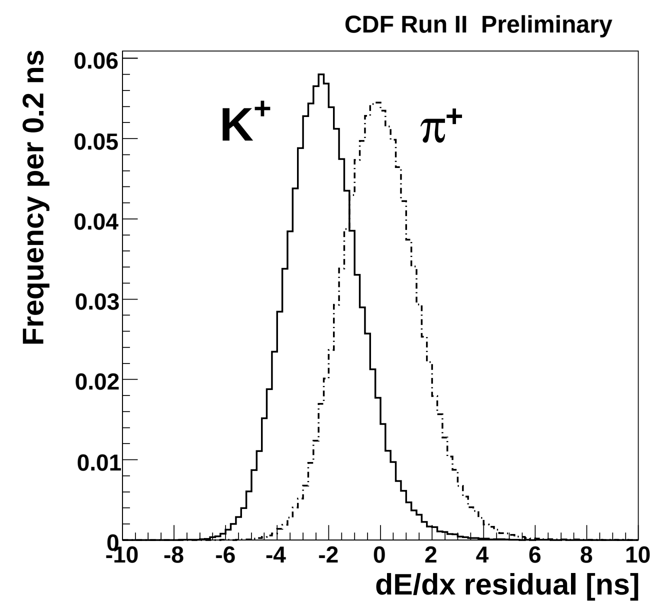
Particle ID

- 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 1.4σ separation between K and π for $p > 2$GeV
- Complements kinematics





Large-yield branching fractions

$\frac{\mathcal{B}(B^0\to\pi^+\pi^-)}{\mathcal{B}(B^0\to K^+\pi^-)}$	$0.259 \pm 0.017 \pm 0.016$
$\mathcal{B}(B^0 \to \pi^+\pi^-)$	$(5.10 \pm 0.33 \pm 0.36) \cdot 10^{-6}$
$\frac{f_s}{f_d}\frac{\mathcal{B}(B_s\to K^+K^-)}{\mathcal{B}(B^0\to K^+\pi^-)}$	$0.324 \pm 0.019 \pm 0.041$
$\mathcal{B}(B_s \to K^+K^-)$	$(24.4 \pm 1.4 \pm 4.6) \cdot 10^{-6}$

Signal events:

$B^0 \to \pi^+\pi^-$ 1121 ± 63

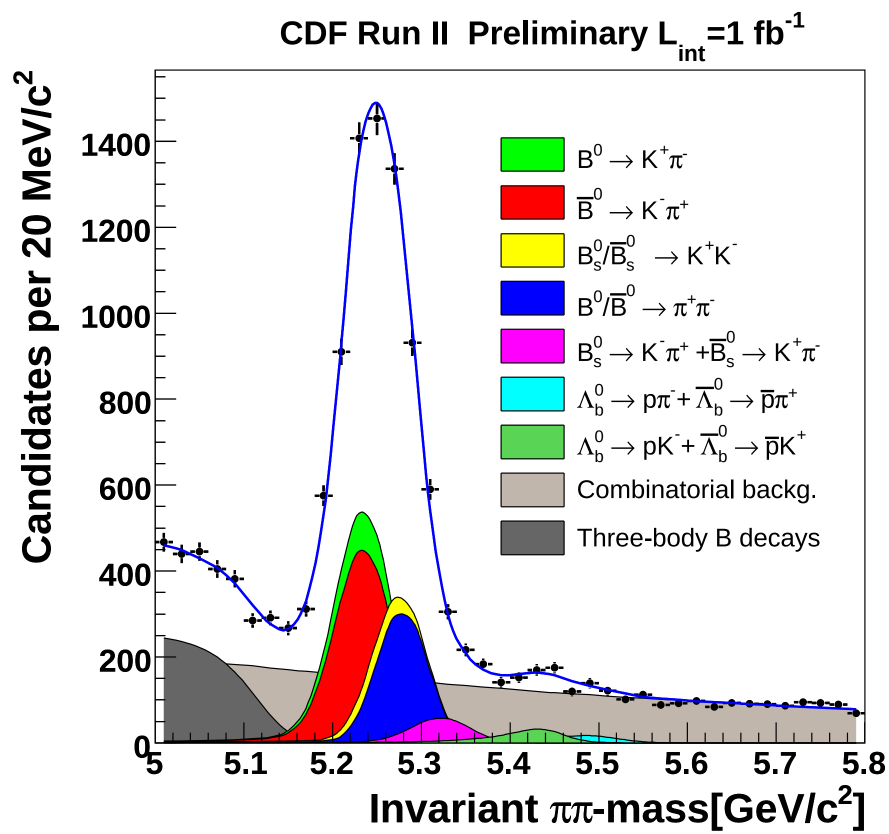
$B^0 \to K^+\pi^-$ 4045 ± 84

$B_s \to K^+K^-$ 1307 ± 64

Large sample of $B_s \to K^+K^-$

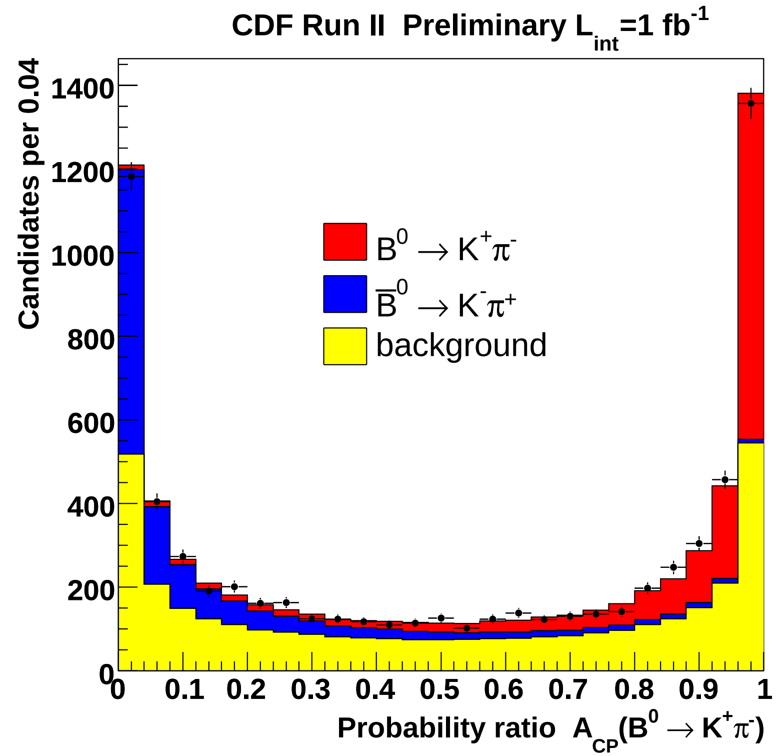
$\to$ lifetime measurement

$\to$ time-dependent tagged analysis

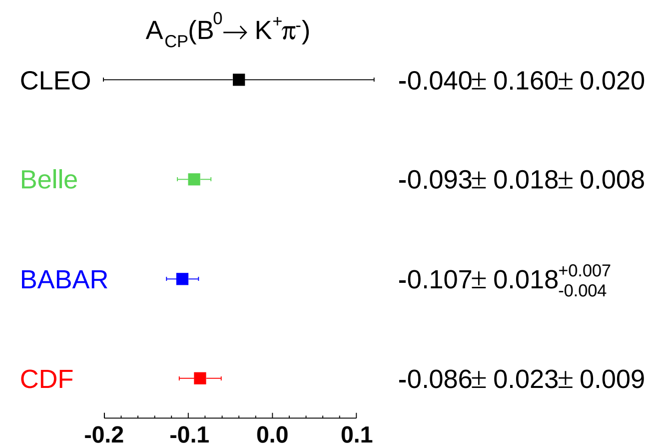


Direct CP asymmetry for $B^0 \to K^+\pi^-$

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



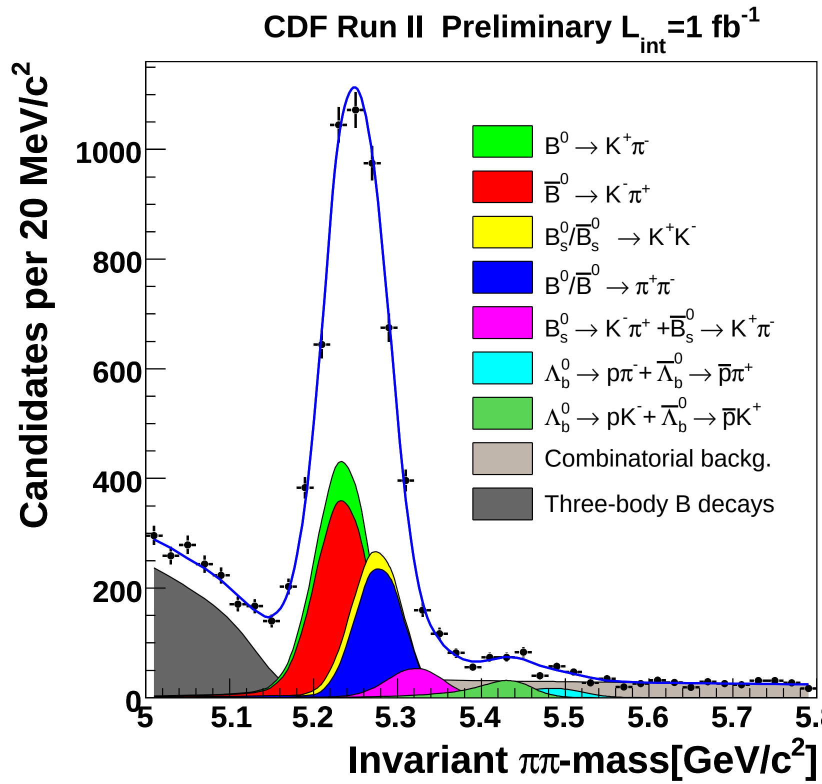
$$A_{CP} = \frac{N(\overline{B}^0 \to K^-\pi^+) - N(B^0 \to K^+\pi^-)}{N(\overline{B}^0 \to K^-\pi^+) + N(B^0 \to K^+\pi^-)} = -0.086 \pm 0.023 \pm 0.009$$

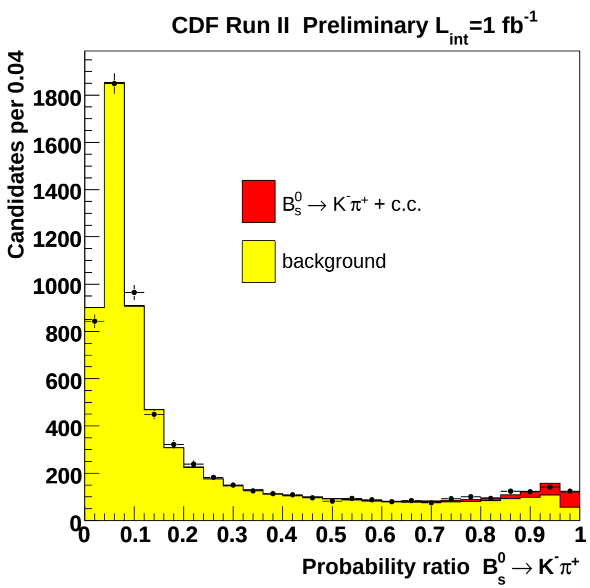


Rare modes results

Three new modes observed:

$B_s \to K^-\pi^+$	$230 \pm 34 \pm 16$	8σ
$\Lambda_b \to p\pi^-$	$110 \pm 18 \pm 16$	6σ
$\Lambda_b \to pK^-$	$156 \pm 20 \pm 11$	11σ





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

Using input from HFAG

$$\Rightarrow \mathcal{B}(B_s \to K^-\pi^+) = (5.0 \pm 0.75 \pm 1.0) \cdot 10^{-6}$$

$A_{CP}(B_s \to K^+\pi^-)$ vs. $A_{CP}(B^0 \to K^+\pi^-)$

SM (Lipkin, Phys. Lett. B621, 126; Gronau, Rosner, Phys. Rev. D71, 074019) predicts

$$\Gamma(\overline{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-) = \Gamma(B_s \to K^-\pi^+) - \Gamma(\overline{B}_s \to K^+\pi^-)$$

$\longrightarrow$ Provides model independent test for new physics

Can be used to predict $A_{CP}(B_s \to K^-\pi^+)$ from other measurements

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

Plugging in numbers

$$\Rightarrow A_{CP}(B_s \to K^-\pi^+) \approx +37\%$$

Direct CP asymmetry for $B_s \to K^+\pi^-$

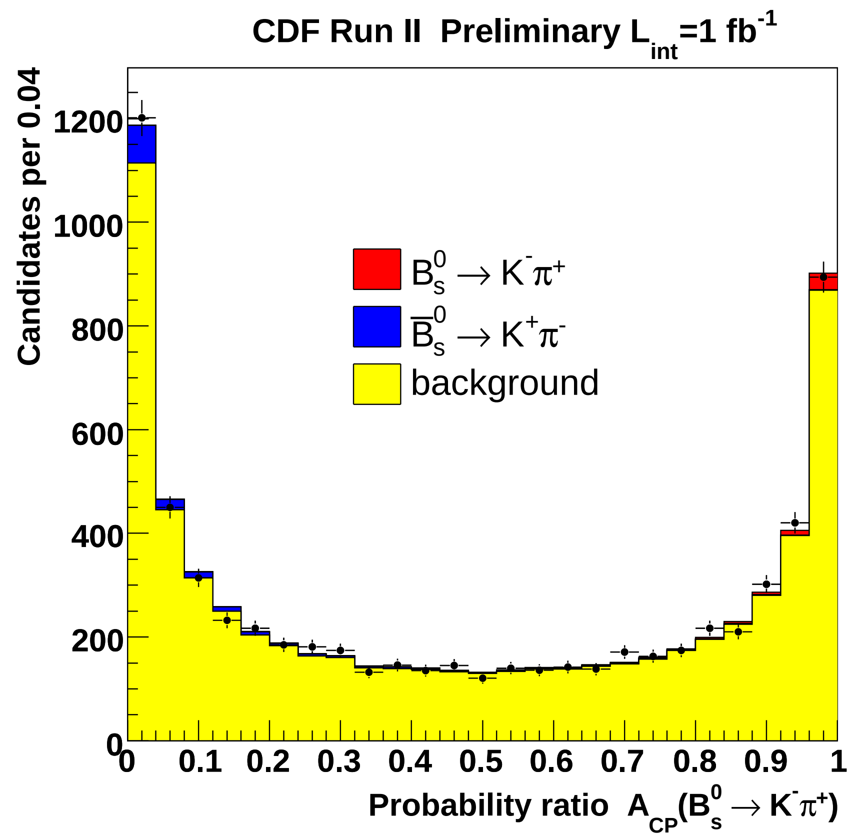
$$A_{CP} = \frac{N(\overline{B}_s \to K^+\pi^-) - N(B_s \to K^-\pi^+)}{N(\overline{B}_s \to K^+\pi^-) + N(B_s \to K^-\pi^+)}$$
$$= +0.39 \pm 0.15 \pm 0.08$$

2.5σ Significance

- First indication of CP violation in B_s system
- Sign and size agree with SM expectation

$\Rightarrow$ No evidence for 'exotic' sources of CP violation

- Will repeat with more data (already 2.5fb^{-1} on tape)



Conclusions

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