Measurements of *B* meson decay rates and CP –violating asymmetries

Flavour Physics and CP Violation 2011

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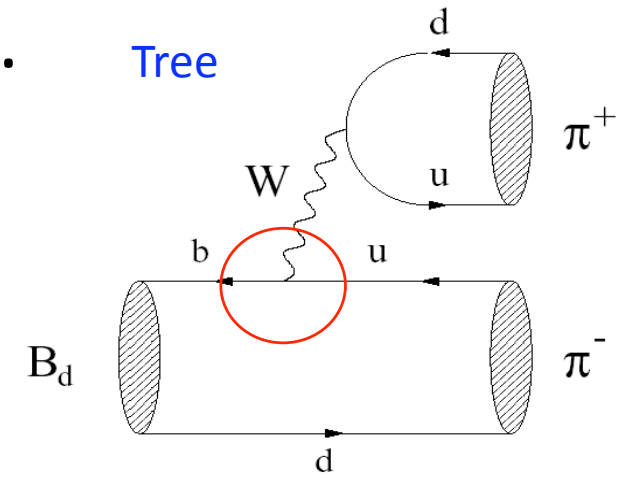
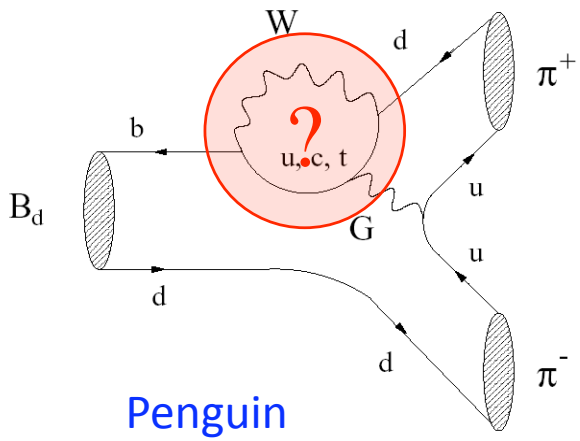
Outline

- Charmless two body B^0 and B^0_s decays
  - Recap of Br and CPV status (CDF 1 fb^{-1})
  - Recent Br and CPV results from LHCb (37 pb^{-1})
  - Results from CDF (6 fb^{-1}) - new for FPCP
  - $B^0_s \to K^+K^-$ lifetime
- First search for CPV in $B^0_s \to \phi\phi$ (new - CDF 3 fb^{-1})
- Observation of $B^0_s \to K^*\bar{K}^*$ (LHCb, 35 pb^{-1})
- Other LHCb and Belle results

B→hh' decays

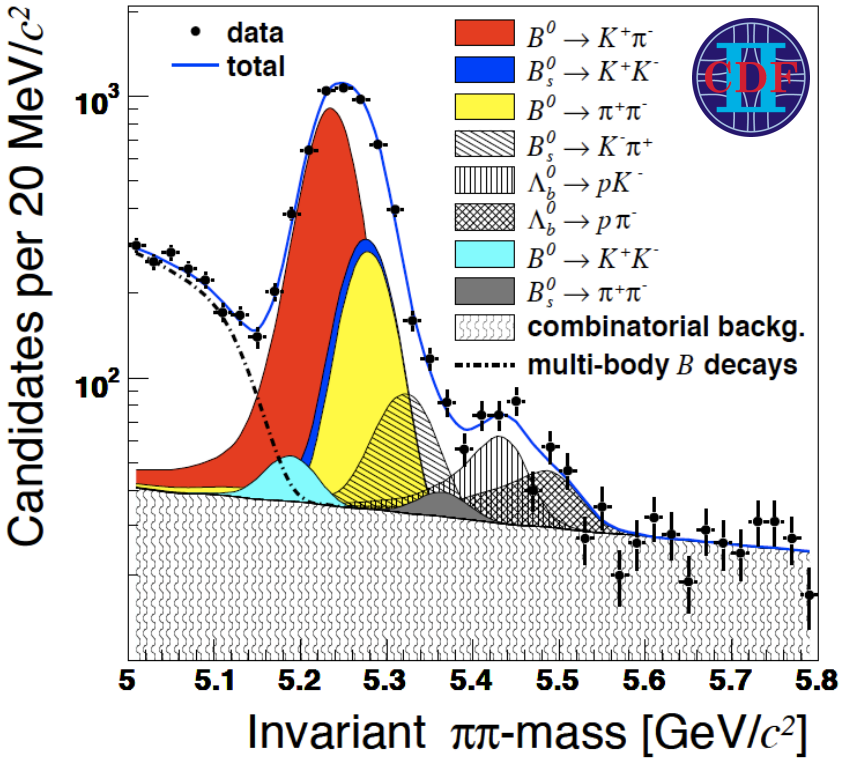
- B^0, B^0_s, and Λ^0_b decays into π, K or p.
- Amplitudes:
  - Tree
  - Penguin (strong and electroweak)
- Many open channels in similar final states: constrain hadronic unknown
- Contributions of new particles may enter in penguin diagrams (→NP)
- Sensitive to V_{ub} phase, CKM angle γ





B→hh' at CDF (1 fb^{-1})

Phys.Rev.Lett. 103, 031801(2009),
Phys.Rev.Lett. 106, 181802(2011)



Good mass resolution (~22 MeV/c^2), but individual modes overlap in a single peak (width ~35 MeV/c^2).

PID provides only statistical separation.

Each mode is a background for others. Eg, $\Lambda^0_b \to p\pi/pK$ are "backgrounds" of $B^0_s \to K^-\pi^+$ signal.

Signal composition from 5-dim ML fit, combining information from kinematics (mass and momenta) and particle ID (dE/dx).

Branching Ratios summary

$\mathcal{B}(10^{-6})$

Mode	CDF	Belle
$B_s^0 \to K^-\pi^+$	$5.0 \pm 0.7 \pm 0.8$ (A)	(< 26 @ 90% CL) (C)
$B_s^0 \to \pi^+\pi^-$	$0.49 \pm 0.28 \pm 0.36$ (< 1.2 @ 90% CL) (A)	(< 12 @ 90% CL) (C)
$B_s^0 \to K^+K^-$	$23.9 \pm 1.5 \pm 3.6$ (B)	$38\ ^{+10}_{-9} \pm 5 \pm 5(\mathrm{f}_s)$ (C)

World first

World best

$\mathcal{B}(10^{-6})$

Mode	CDF	BaBar	Belle
$B^0 \to K^+\pi^-$		$19.1 \pm 0.6 \pm 0.6$ (D)	$19.9 \pm 0.4 \pm 0.8$ (E)
$B^0 \to \pi^+\pi^-$	$5.02 \pm 0.33 \pm 0.35$ (B)	$5.5 \pm 0.4 \pm 0.3$ (D)	$5.1 \pm 0.2 \pm 0.2$ (E)
$B^0 \to K^+K^-$	$0.39 \pm 0.16 \pm 0.12$ (< 0.7 @ 90% CL) (A)	$0.04 \pm 0.15 \pm 0.08$ (D)	$0.09\ ^{+0.18}_{-0.13} \pm 0.01$ (F)

$\mathcal{B}(10^{-6})$

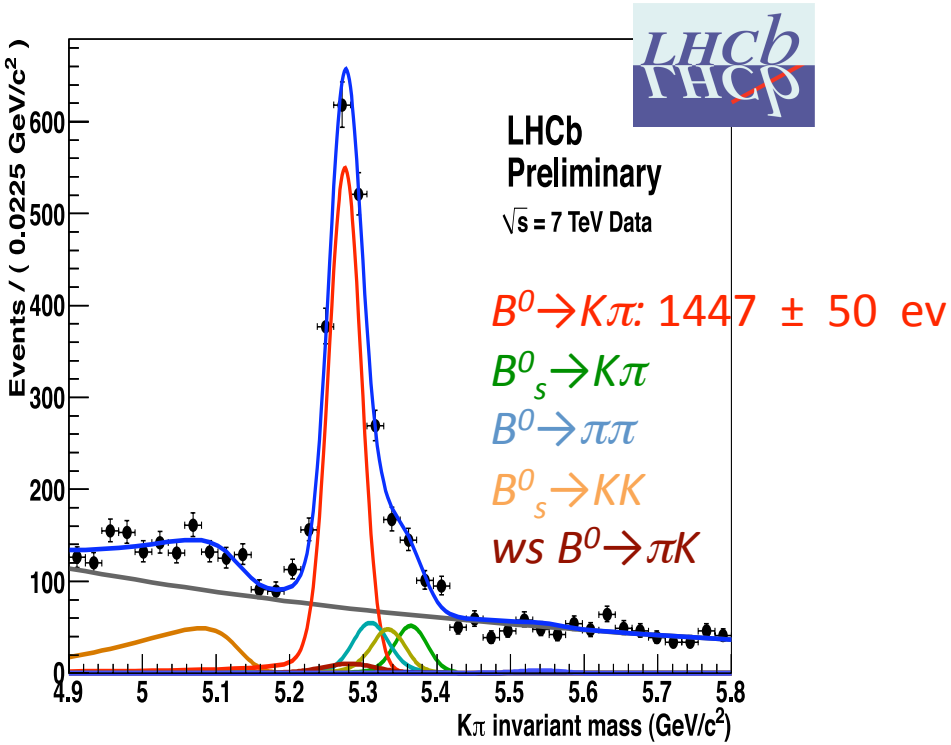
Mode	CDF
$\Lambda_b^0 \to pK^-$	$5.6 \pm 0.8 \pm 1.5$ (B)
$\Lambda_b^0 \to p\pi^-$	$3.5 \pm 0.6 \pm 0.9$ (B)

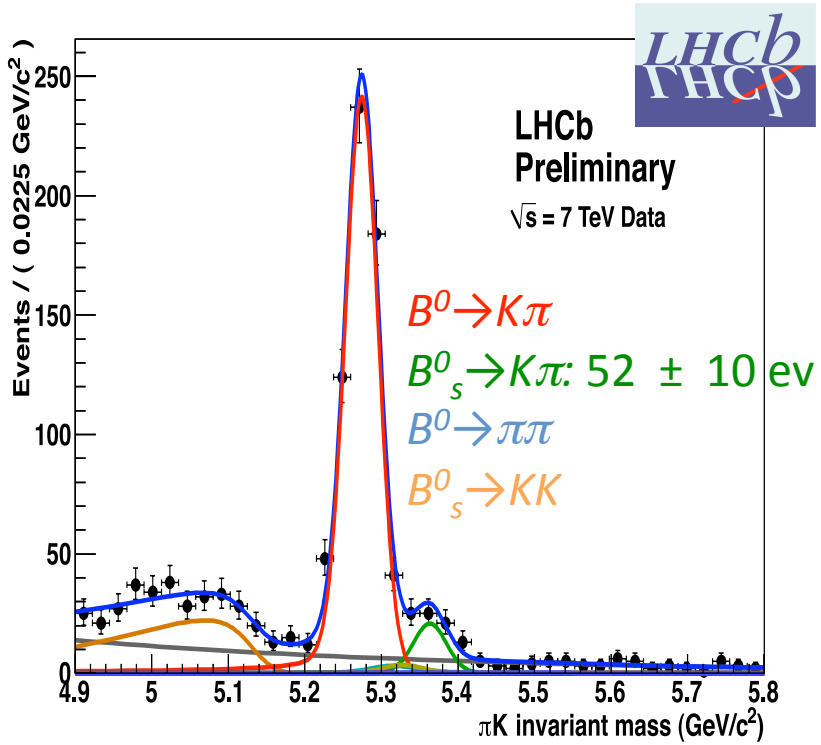
(A): PRL 103, 031801 (2009)
(B): PRL 106, 181802 (2011)
(C): PRD 82, 072007 (R) (2010)
(D): PRD 75, 012008 (2007)
(E): PRL 99, 121601 (2007)
(F): PRL 98, 181804 (2007)

LHCb recently joined …

- Environment: very high *B* production rate efficiently exploited by large trigger bandwidth. Advantage over CDF.
- Trigger: large E_T clusters in hadronic calorimeter and high p_T tracks with large impact parameter.
- Offline: independent selections for best sensitivity in A_{CP} ($B^0 \to K^+\pi^-$) and A_{CP} ($B^0_s \to K^-\pi^+$).
- Analysis:
  - Use powerful PID information to identify mutually exclusive samples for each mass hypothesis ($K^+\pi^-$, $K^-\pi^+$, $\pi^+\pi^-$, K^+K^-, pK…). Advantage over CDF.
  - Fit mass distributions and extract raw number of events.
  - Correct for instrumental and production asymmetries (pp is not CP-eigenstate). Latter may be limitation with respect to CDF

... and already very competitive (37 pb^{-1})





$A_{CP}(B^0 \to K^+\pi^-) = (-7.4 \pm 3.3 \pm 0.8)\%$ (preliminary)

$A_{CP}(B^0_s \to K^-\pi^+) = (15 \pm 19 \pm 2)\%$ (preliminary)

Statistical uncertainties already very promising.

CP violation in $B^0 \to K^+\pi^-$

BaBar	467M ($B\bar{B}$ pairs)	$-0.107 \pm 0.016^{+0.006}_{-0.004}$
Belle	535M ($B\bar{B}$ pairs)	$-0.094 \pm 0.018 \pm 0.008$
CDF	1 fb^{-1}	$-0.086 \pm 0.023 \pm 0.009$
LHCb	37 pb^{-1}	$-0.074 \pm 0.033 \pm 0.008$

- Known at 2% from B-factories. CDF has now the same sensitivity, LHCb will soon dominate the statistical precision.
- CP violation established at ~9σ but
  - incompatible with A_{CP} (B^+)(=0.051 ± 0.025) as expected by predictions that use $1/m_b$ expansion. Solid ~5σ discrepancy
  - Intense theoretical work to figure it out. Most probably due to unaccounted strong phases in $1/m_b$ expansions, although still no firm conclusion. Additional experimental input needed.
  - Interesting constraint from $B^0_s \to K^-\pi^+$. Compare rate asymmetries of $B^0 \to K^+\pi^-$ with $B^0_s \to K^-\pi^+$ to probe NP with little assumptions.

CP violation in $B^0_s \to K^-\pi^+$

CDF	1 fb^{-1}	(PRL 106, 181802 (2011)	$0.39 \pm 0.15 \pm 0.08$
LHCb	37 pb^{-1}	(Preliminary)	$0.15 \pm 0.19 \pm 0.02$

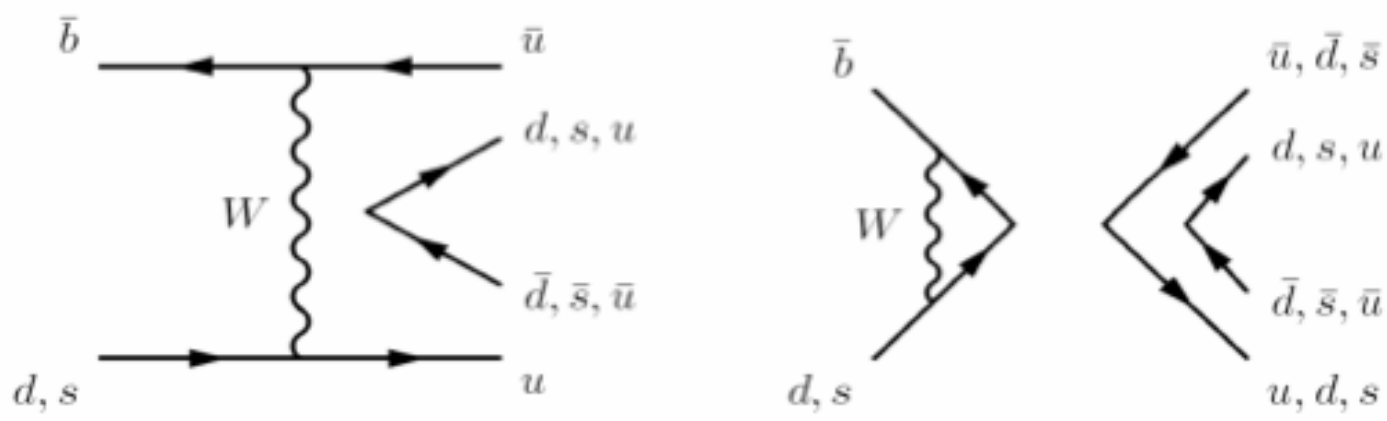
- CDF recently published first direct CPV in the B^0_s using just 1 fb^{-1}.
- Agrees with "sum rule" (*Gronau and Rosner, Phys.Rev. D71 (2005) 074019], [Lipkin, Phys. Lett. B621:126, .2005]*) SM prediction (+37%) within large uncertainties.

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

- More sensitive constraints expected with current sample.
- LHCb already sees a signal and has preliminary A_{CP} measurement
  - Will soon dominate the precision, and may use precision Br to extract information on γ angle *(Chiang, Gronau, Rosner PLB 664,169 (2008)])*

First evidence of annihilation B→hh decays – CDF, new for FPCP

- All final-state quarks different from initial state quarks ⇒only via annihilation-type diagrams.
- Not yet observed. Small BR, with large uncertainties.
  - Depends on hard-to-predict hadronic parameters ⇒large source of uncertainty in calculations.
- $B^0_s \to \pi^+\pi^-$ rate expected x3-x4 larger than $B^0 \to K^+K^-$.



CDF data - 6 fb^{-1}

New for FPCP

Improvements

- x3 in statistics
- Likelihood rewritten using easier to parameterize kinematic information

$B^0 \to K^+\pi^- \sim 10.200$ ev

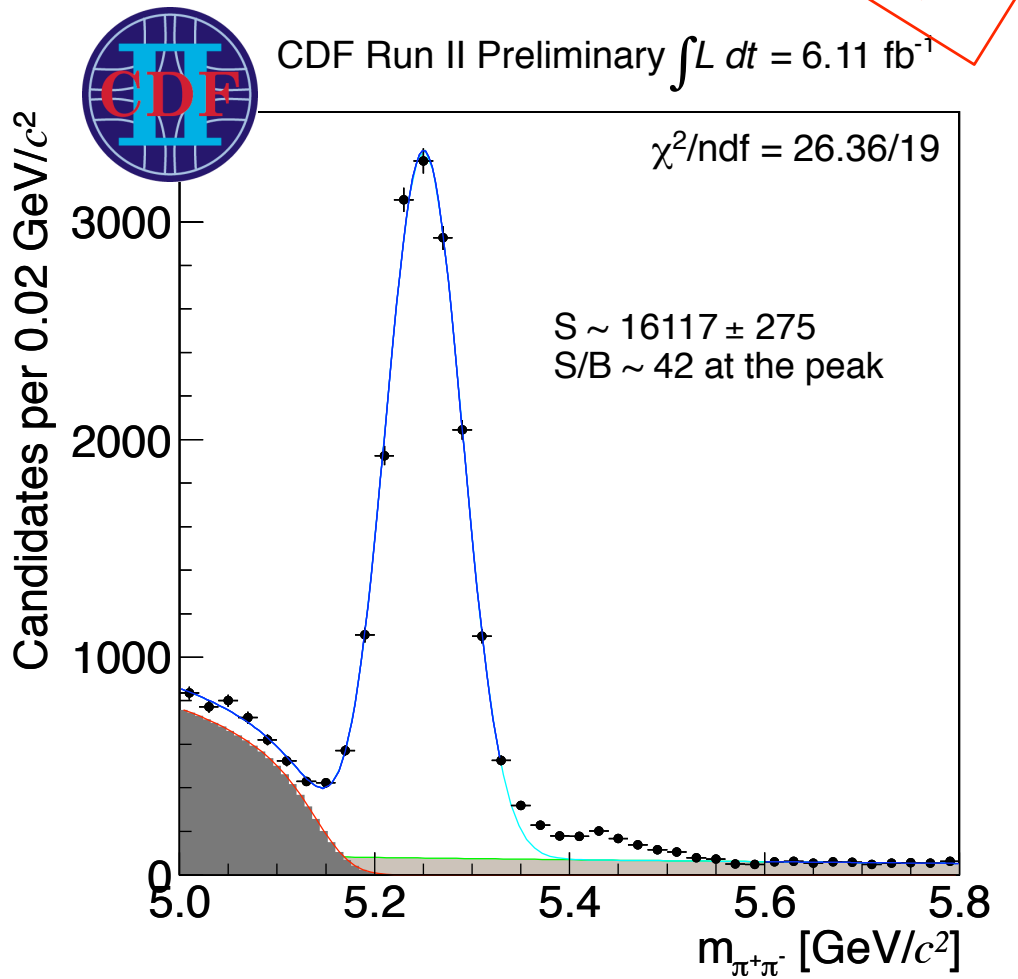
$B^0_s \to K^+K^- \sim 3.008$ ev

$B^0 \to \pi^+\pi^- \sim 2.600$ ev

$B^0_s \to K^-\pi^+ \sim 760$ ev

$B^0 \to K^+K^- \sim 120$ ev

$B^0_s \to \pi^+\pi^- \sim 94$ ev

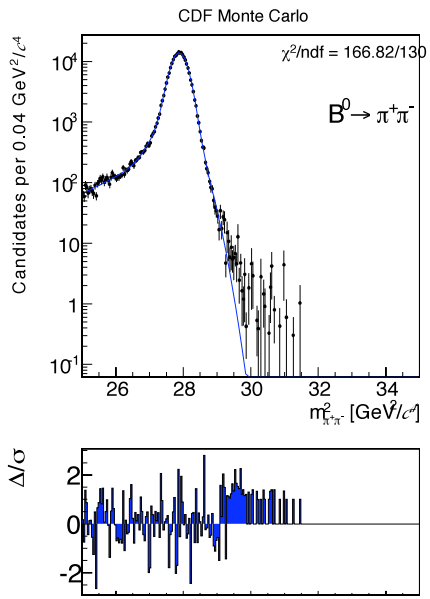


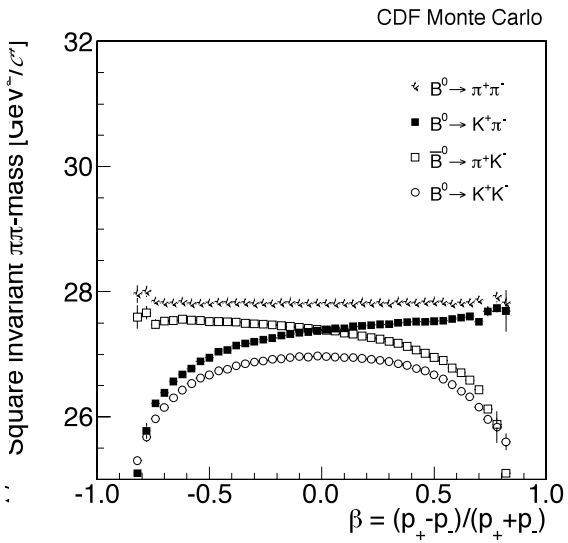
Separating signals: mass term

New for FPCP

$$\mathcal{L} \sim \wp_j^m(m^2_{\pi\pi}|\beta, p_{tot}) \cdot \wp_j^p(\beta, p_{\rm tot}) \cdot \wp_j^{\rm PID}(\kappa_1, \kappa_2|\beta, p_{\rm tot}).$$

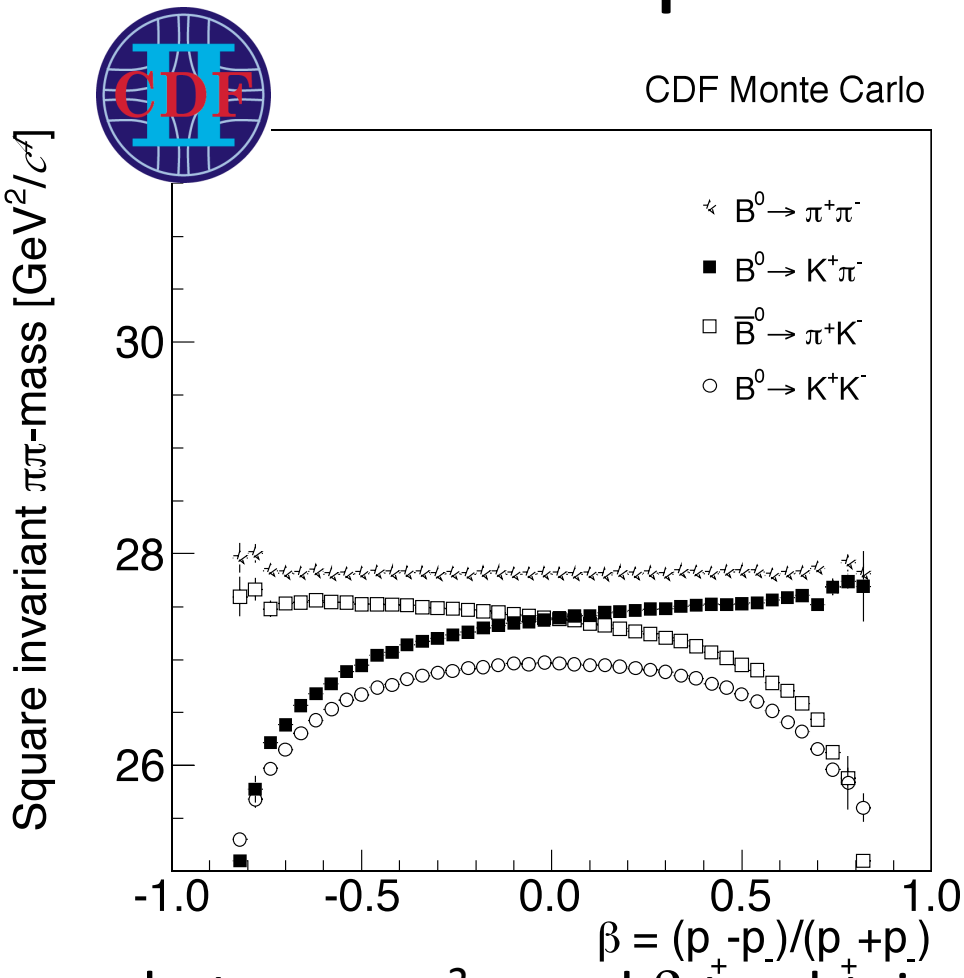
Probability of observing square ππ-mass given momentum asymmetry $\beta=(p_+ - p_-)/(p_+ + p_-)$ and sum $p_{tot} = p_+ + p_-$





The kinematic separation

New for FPCP



Exploit dependence between $m^2_{\pi\pi}$ and β to obtain discrimination power amongst modes. Useful to discriminate $K^+\pi^-/K^-\pi^+$ final states.

Separating signals: PID term

New for FPCP

$$\mathcal{L} \sim \wp_j^m(m^2_{\pi\pi}|\beta, p_{tot}) \cdot \wp_j^p(\beta, p_{\rm tot}) \cdot \wp_j^{\rm PID}(\kappa_1, \kappa_2|\beta, p_{\rm tot}).$$

PID information contained in Kaonness (κ) variable (0 for pions and 1 for kaons.)

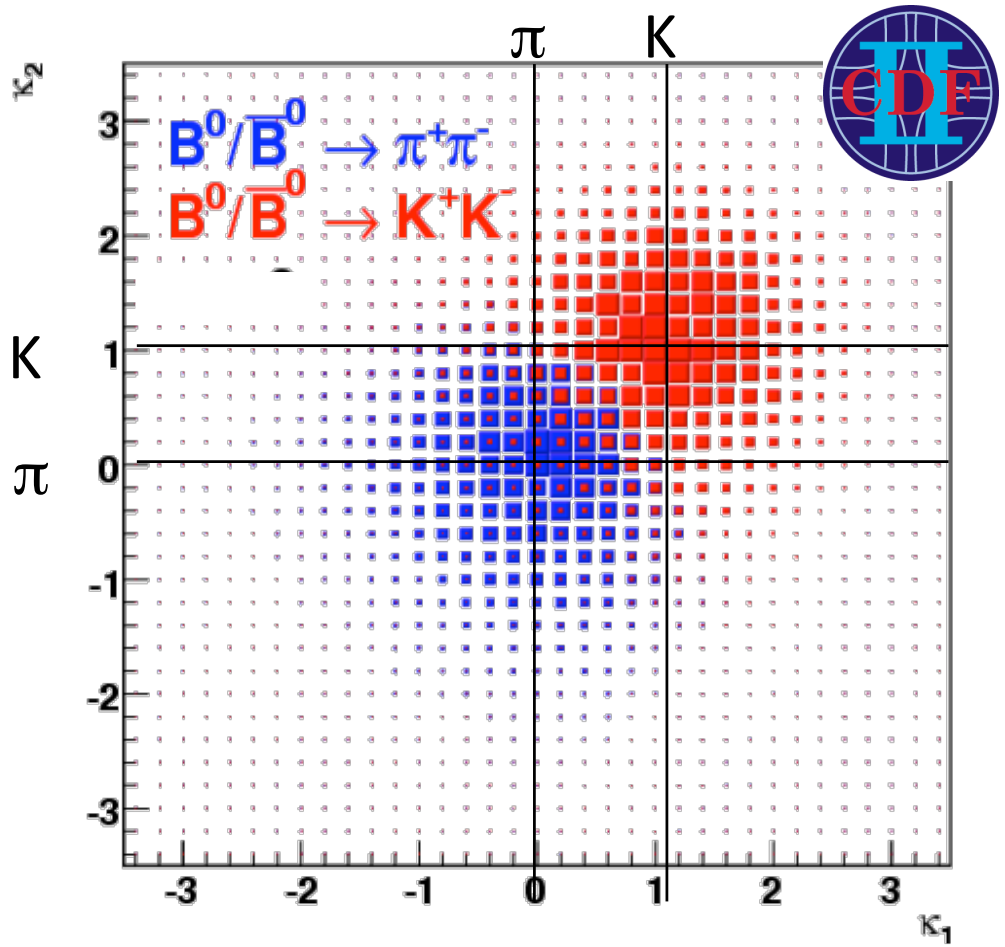
2-particle joint PID probability at given momenta.

dE/dx calibrated on pure *K* and π samples from 3.2M decays:
$D^{*+} \rightarrow D^0\pi^+ \rightarrow [K^-\pi^+]\pi^+$ (sign of D^{*+} pion tags D^0 flavor)

1.4σ K/π power separation for track p>2GeV/c. Becomes 2.0σ for the pairs $KK/\pi\pi$ and $K^+\pi^-/\pi^+K^-$.

The PID separation

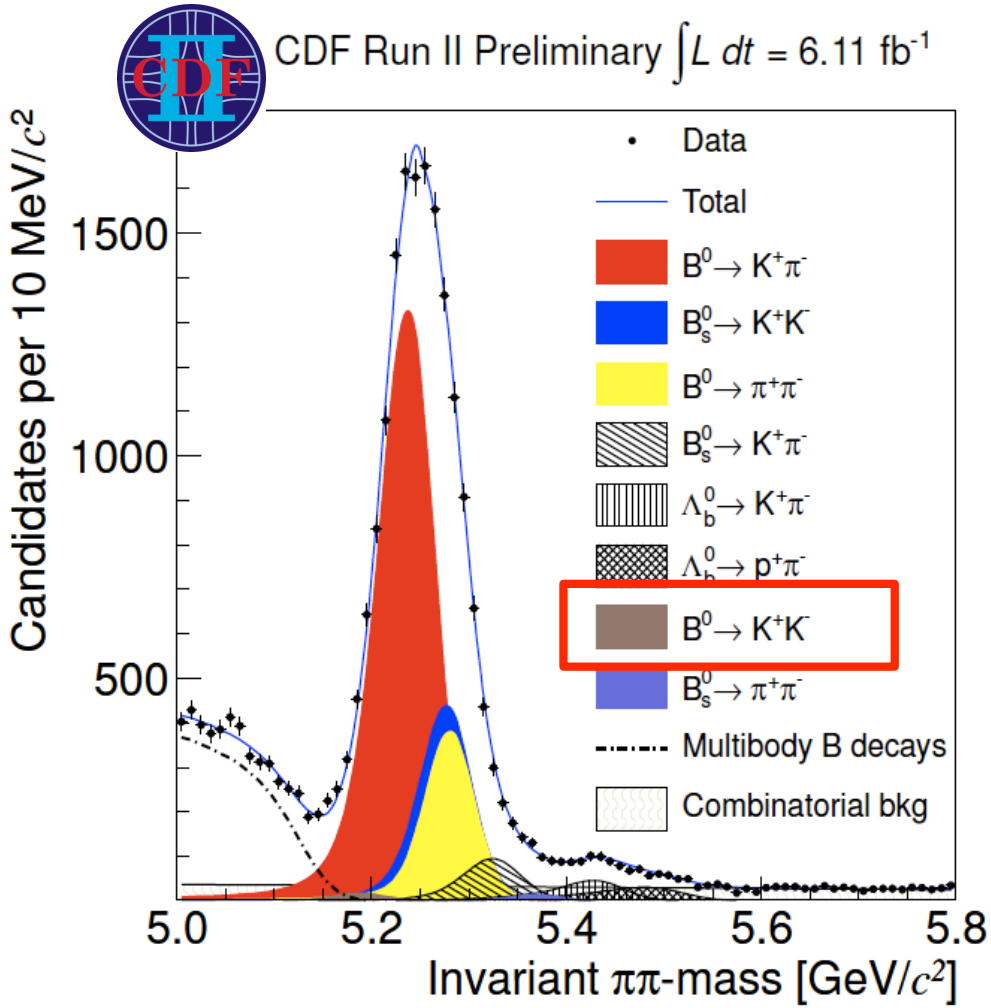
New for FPCP

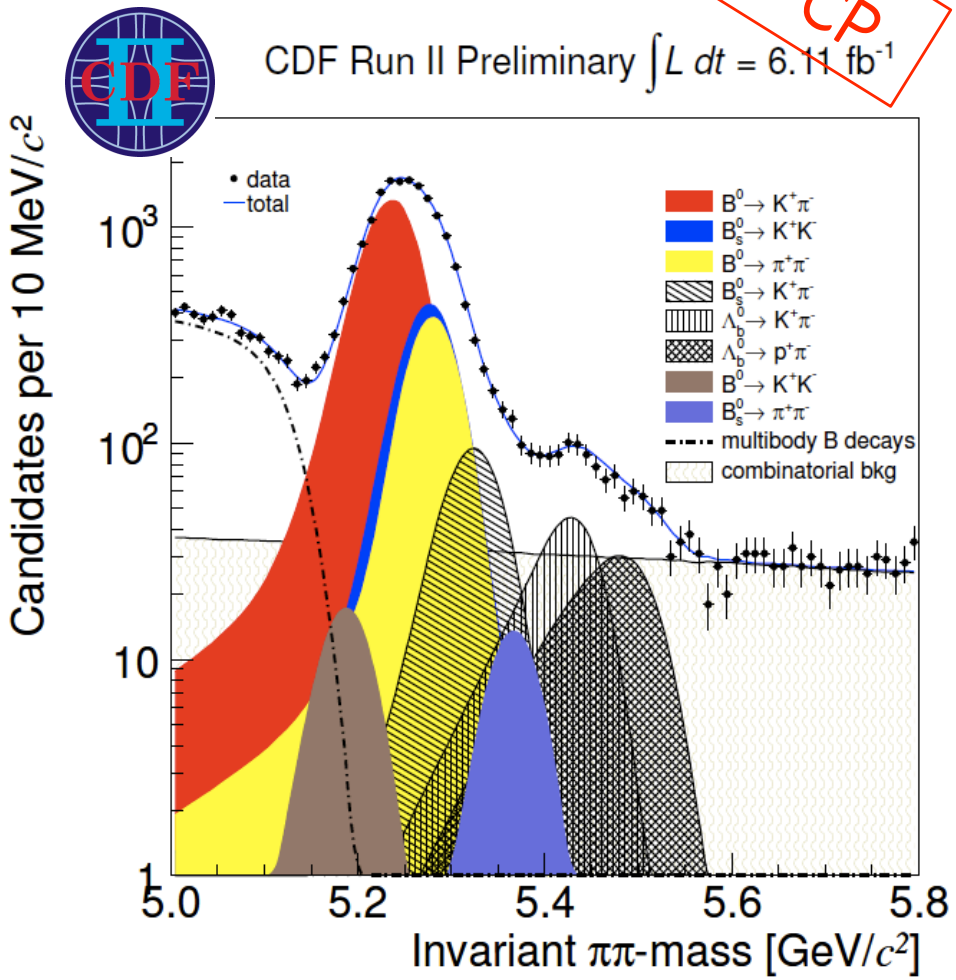


1.4σ K/π power separation for track p>2GeV/c. Becomes 2.0σ for the pairs $KK/\pi\pi$ and $K^+\pi^-/\pi^+K^-$.

New result: $B^0 \to K^+K^-$

New for FPCP



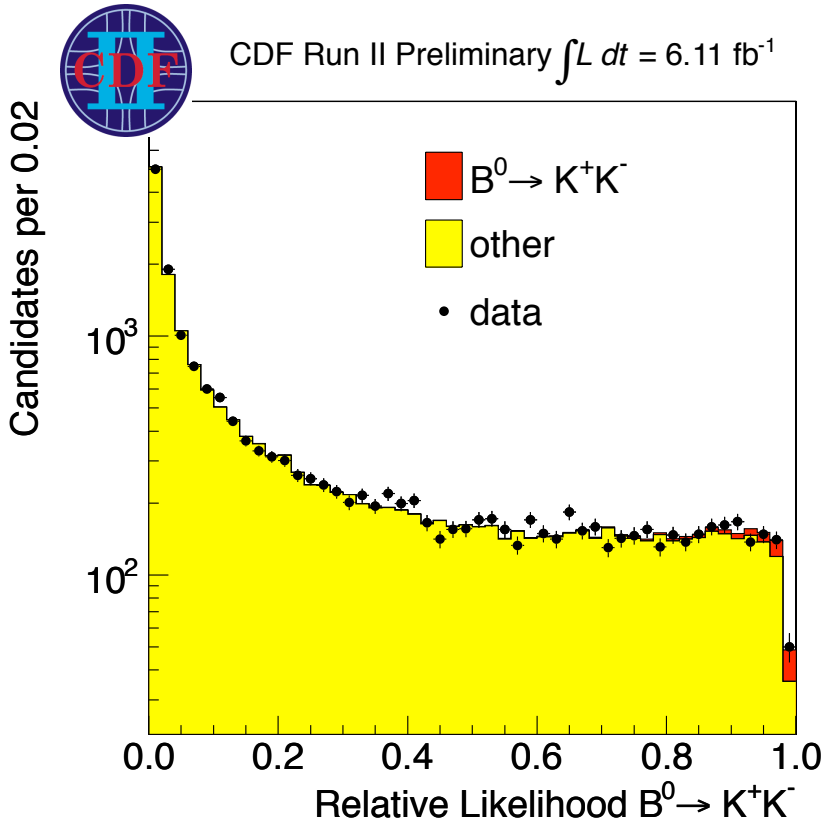


120 ± 49 ± 42 $B^0 \to K^+K$ decays observed. Signal seen at the 2σ level

Cdf public note 10498 http://www-cdf.fnal.gov/physics/new/bottom/110520.blessed-bspipi_6fb/bspipi_6fb.html

New result: $B^0 \rightarrow K^+K^-$

New for FPCP



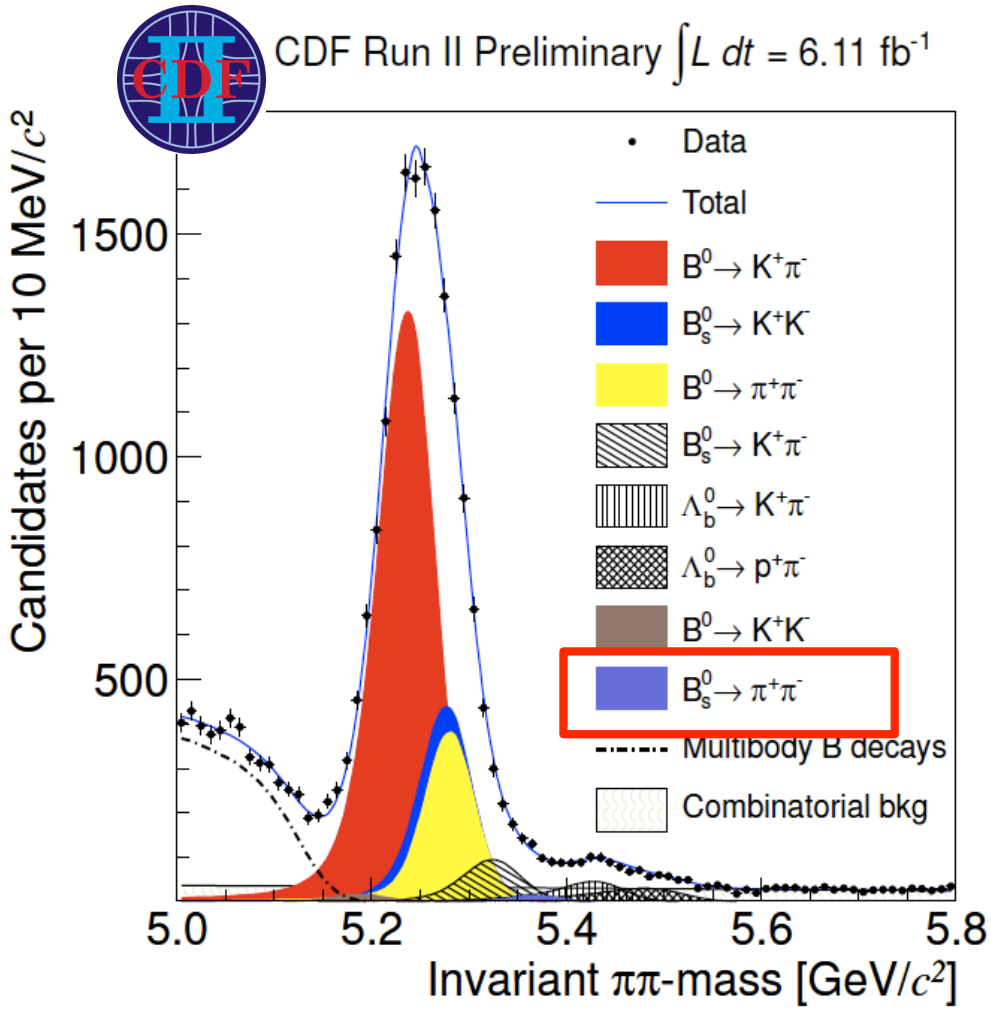
$$\frac{\mathcal{B}(B^0 \rightarrow K^+K^-)}{\mathcal{B}(B^0 \rightarrow K^+\pi^-)} = 0.012 \pm 0.005\ (stat.)\ \pm 0.005\ (syst.).$$

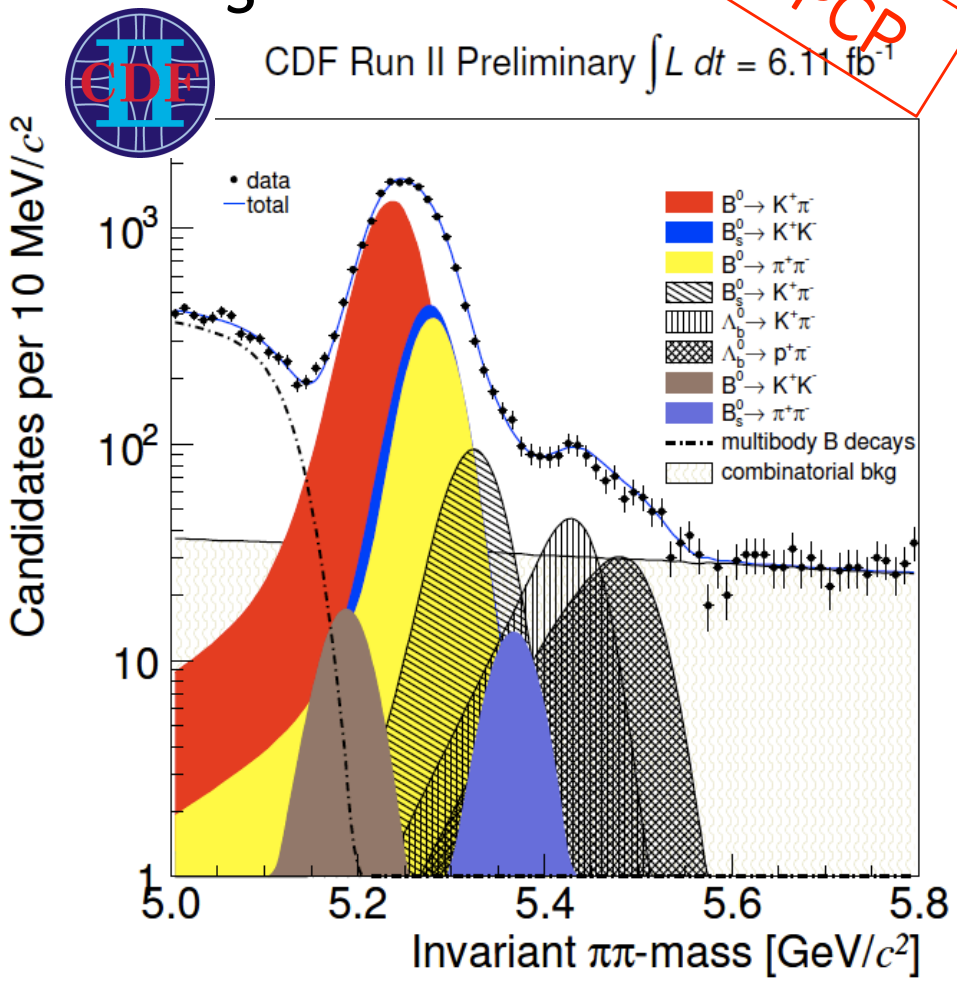
$$\mathcal{B}(B^0 \rightarrow K^+K^-) = (0.23 \pm 0.10\ (stat.) \pm 0.10\ (syst.)) \times 10^{-6}$$

World's best. Two sided limit $0.05 < Br*10^6 < 0.46$ @ 90% CL.

First evidence: $B^0_s \to \pi^+\pi^-$

New for FPCP





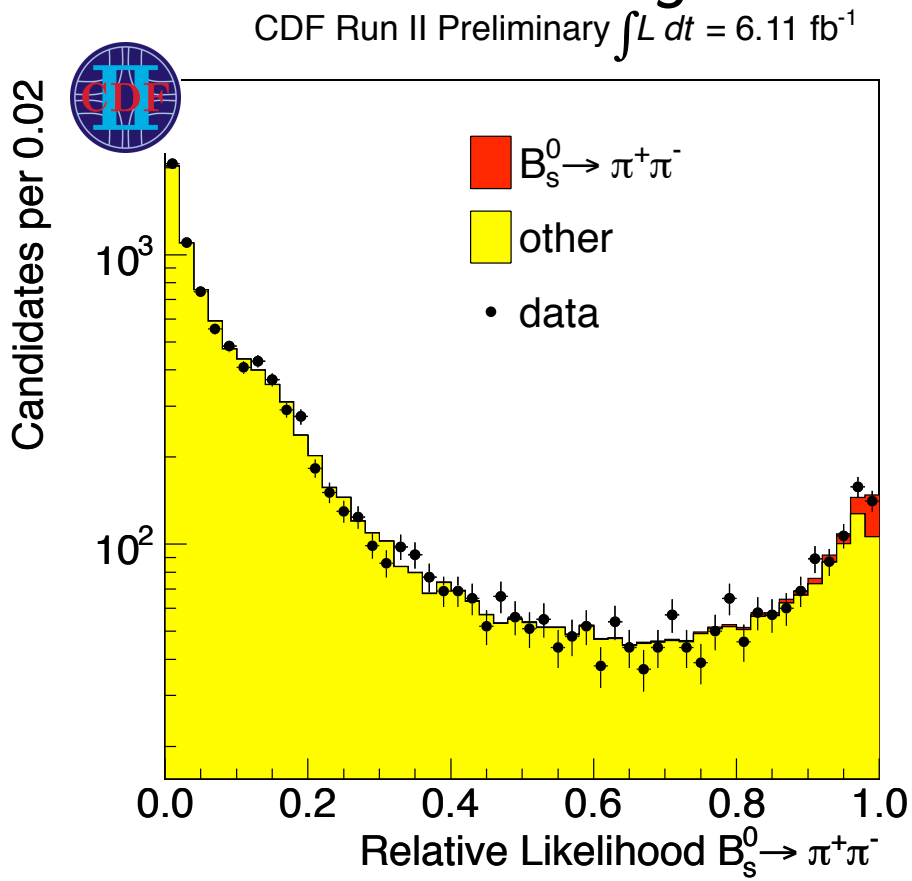
94 ± 28 ± 11 $B^0_s \to \pi^+\pi^-$ decays observed.

First evidence (3.7σ) of a pure-annihilation charmless B decay.

Cdf public note 10498 http://www-cdf.fnal.gov/physics/new/bottom/110520.blessed-bspipi_6fb/bspipi_6fb.html

First evidence: $B^0_s \to \pi^+\pi^-$

New for FPCP



$$\frac{f_s}{f_d} \times \frac{\mathcal{B}(B^0_s \to \pi^+\pi^-)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.008 \pm 0.002\ (stat.)\ \pm 0.001\ (syst.).$$

$$\mathcal{B}(B^0_s \to \pi^+\pi^-) = (0.57 \pm 0.15\ (stat.) \pm 0.10\ (syst.)) \times 10^{-6}.$$

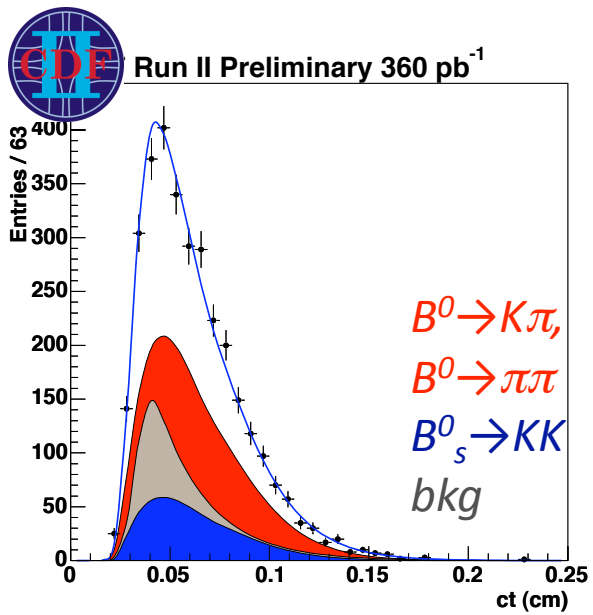
Agreement with pQCD: $0.57^{+0.18}_{-0.16}$ PRD 76, 074018(2008), and 0.42± 0.06 from Y Li et al., PRD 70, 034009 (2004)

$B^0_s \to K^+K^-$ lifetime

- $B^0_s \to K^+K^-$ a fairly copious B^0_s signal in a nearly pure CP eigenstate (light). Observed by CDF in 2006: PRL 97:211802 (2006).
- Lifetime provides information on decay-width difference, possibly sensitive to BSM physics.
- Fitting it with a single exponential yields

$$\tau(B_s^0 \to K^+K^-) = \frac{A/\Gamma_L^2 + B/\Gamma_H^2}{A/\Gamma_L + B/\Gamma_H} \approx 1.39 \text{ ps in SM}$$

- Experimental challenge correcting for trigger/selection biases on observed life.
- A preliminary CDF measurement (2006) with 360 pb^{-1} yields 1.53 ± 0.18 ± 0.02 ps.

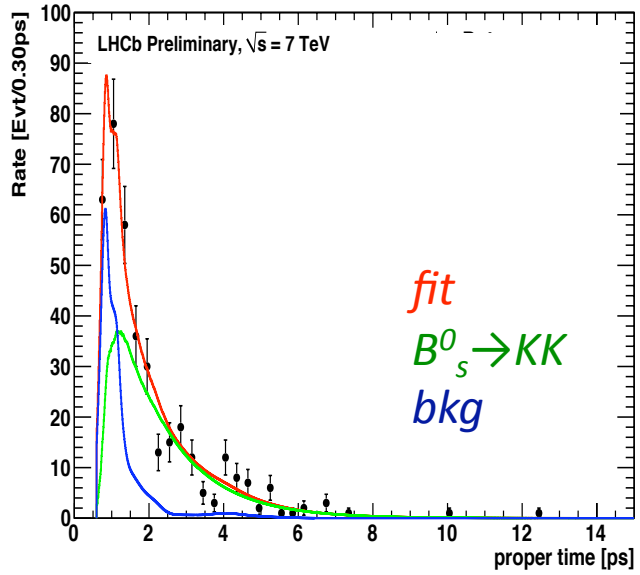


hep-ex/0605038

$B^0_s \rightarrow K^+K^-$ at LHCb

Two methods (with consistent results) to correct lifetime bias (see also M. Calvi's talk on Monday)

- **Absolute measurement:** two-steps unbinned ML where L ~ pdf(mass)*pdf(lifetime)
  - Pdf (mass) determines the S and bkg prob for each event.
  - Pdf (lifetime) takes into account:
    - result of the mass fit
    - per-event acceptance: given an event, there is a direct relation between proper decay time and kinematics. You take in account the acceptance using kinematics info.
- **Relative measurement:** $B^0_s \rightarrow K^+K^-$ and $B^0 \rightarrow K^+\pi^-$ differ only in the spectator quark
  - The two decays are kinematically similar
  - You cancel the acceptance by taking the ratio of the two correspondent proper decay time



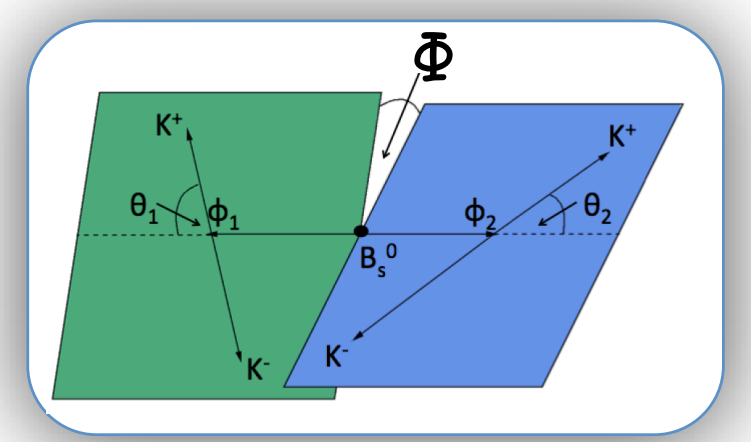
$\tau(B_s \rightarrow K^+K^-) = (1.440 \pm 0.096 \pm 0.010)$ ps

Preliminary

New

First search for CPV in $B^0_s \to \phi\phi$

- CP-violation expected tiny in SM for $B_s \to \phi\phi$. NP could enhance it.
- CDF uses 300 decays reconstructed in 2.9 fb^{-1} and look for asymmetry in angular quantities u and v. Proportional to Triple-Products and expected to vanish.
- Ingenious way to measure CPV with low stat samples, before any tagged analysis



$$u = \cos\Phi \sin\Phi \longrightarrow A_{||}A_{\perp}$$

$$v = \begin{cases} \sin\Phi & \text{if } \cos\vartheta_1 \cos\vartheta_2 > 0 \\ \sin(-\Phi) & \text{if } \cos\vartheta_1 \cos\vartheta_2 < 0 \end{cases} \longrightarrow A_0 A_{\perp}$$

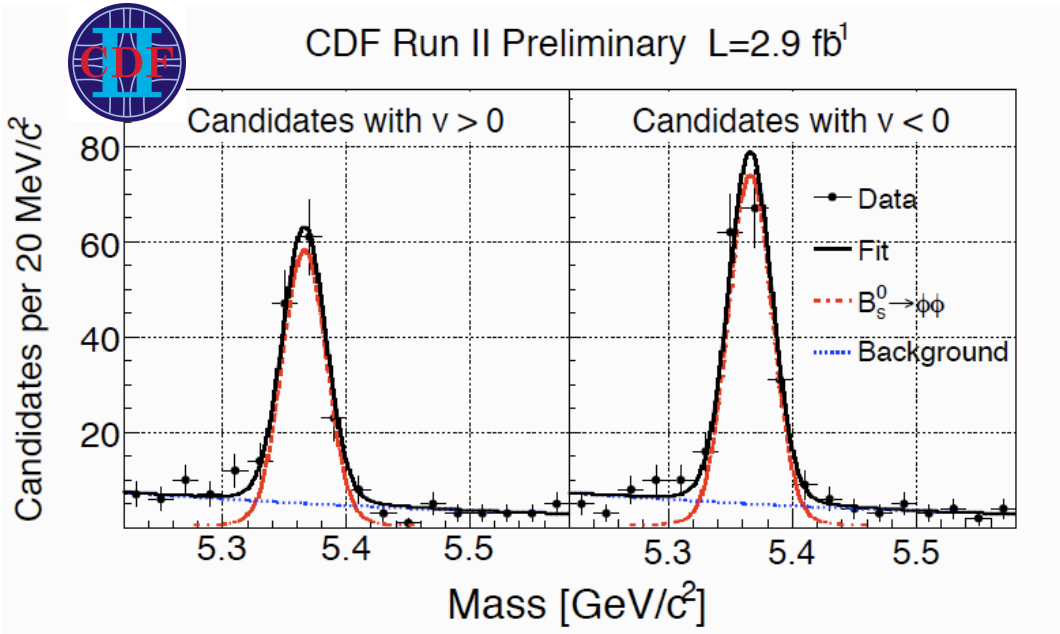
u is CP-odd
and it is a Triple Product (TP)

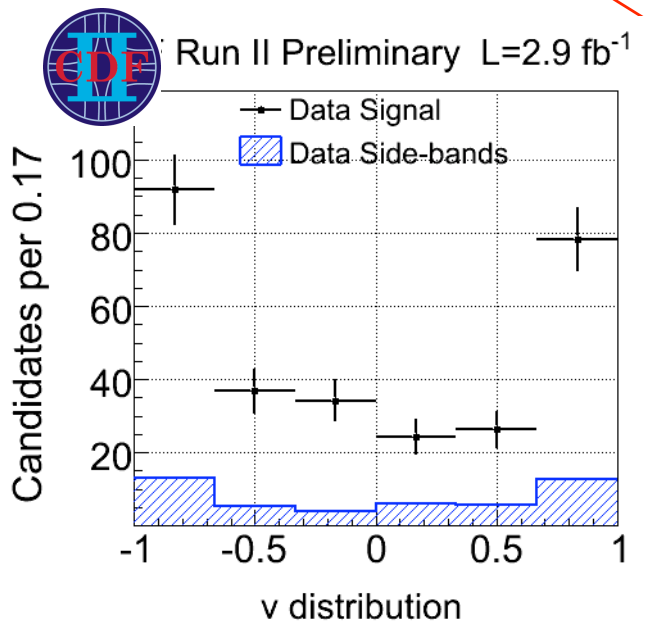
$$(\hat{n}_1 \times \hat{n}_2) \cdot \hat{n}_z (\hat{n}_1 \cdot \hat{n}_2)$$

For TP: D. London and A. Datta, hep-ph/0303159

$B^0_s \rightarrow \phi\phi$ results

New





A_u= (-0.8 ±6.4(stat.) ±1.8(syst.))%

A_v= (-12.0 ±6.4(stat.) ±1.6(syst.))%

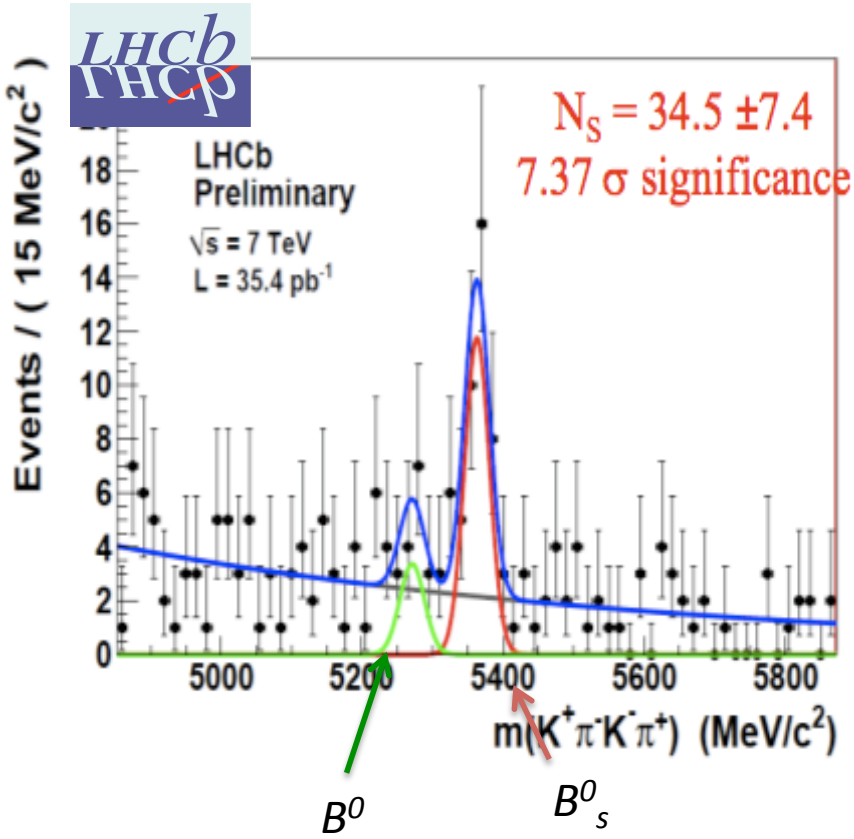
CDF Public Note 10424

No CPV found within 7% uncertainties.

First constraints to TP asymmetries.

First observation of $B^0_s \to K^* \overline{K}^*$

- Solely b→s loop penguin in SM. Mixing-induced and direct CP asymmetries sensitive to NP.
- Test hypothesis H_0(bkg-only) versus H_1(S+bkg) to evaluate significance of the decay
  - Mass and width of B^0_s from independent sample $B^0_s \to J/\psi\phi$
  - Mass and width of B^0 from independent sample $B^0 \to J/\psi \overline{K}^*$



$$\mathcal{B}\left(B^0_s \to K^{*0}\overline{K}^{*0}\right) = (1.95 \pm 0.47(stat.) \pm 0.51(syst.) \pm 0.29\,(f_d/f_s)) \times 10^{-5}$$

Other measurements

- LHCb: first observation $B^0_s \to D_{s2}^{*+} X \mu^- \bar{\nu}$ decays:

$$\frac{\mathcal{B}(\overline{B}^0_s \to D^{*+}_{s2} X \mu^- \overline{\nu})}{\mathcal{B}(\overline{B}^0_s \to X \mu^- \overline{\nu})} = (3.3 \pm 1.0 \pm 0.4)\%$$

- LHCb: improved measurements of the Cabibbo favoured $B^0_{(s)} \to D_{(s)} \pi\pi\pi$ and $\Lambda^0_b \to \Lambda^+_c \pi\pi\pi$ BR

$$\frac{\mathcal{B}(\bar{B}^0 \to D^+\pi^-\pi^+\pi^-)}{\mathcal{B}(\bar{B}^0 \to D^+\pi^-)} = 2.35 \pm 0.11(\text{stat}) \pm 0.24(\text{syst})$$

$$\frac{\mathcal{B}(B^- \to D^0\pi^-\pi^+\pi^-)}{\mathcal{B}(B^- \to D^0\pi^-)} = 1.26 \pm 0.07(\text{stat}) \pm 0.12(\text{syst})$$

$$\frac{\mathcal{B}(\bar{B}^0_s \to D^+_s\pi^-\pi^+\pi^-)}{\mathcal{B}(\bar{B}^0_s \to D^+_s\pi^-)} = 2.22 \pm 0.41(\text{stat}) \pm 0.25(\text{syst})$$

$$\frac{\mathcal{B}(\Lambda^0_b \to \Lambda^+_c\pi^-\pi^+\pi^-)}{\mathcal{B}(\Lambda^0_b \to \Lambda^+_c\pi^-)} = 1.32 \pm 0.15(\text{stat}) \pm 0.14(\text{syst})$$

Other measurements (cont'd)

- LHCb: first observation of $\overline{B}^0_s \to D^0 K^{*0}$ (34.5 ± 6.9 ev, 9σ sig) and measurement of the ratio $BR(\overline{B}^0_s \to D^0 K^{*0})/BR(\overline{B}^0 \to D^0 \rho^0) = 1.39 \pm 0.31 \pm 0.17 \pm 0.18 (f_d/f_s)$

- Belle: Observation of $B^0_s \to D^{-(*)}_s D^{+(*)}_s$

Mode	$\mathcal{B}$ (%)	S
$D_s^+ D_s^-$	$1.03^{+0.39+0.15}_{-0.32-0.13} \pm 0.21$	6.2
$D_s^{*\pm} D_s^{\mp}$	$2.75^{+0.83}_{-0.71} \pm 0.40 \pm 0.56$	6.6
$D_s^{*+} D_s^{*-}$	$3.08^{+1.22+0.57}_{-1.04-0.58} \pm 0.63$	3.1
Sum	$6.85^{+1.53}_{-1.30} \pm 1.11^{+1.40}_{-1.41}$	

Conclusions

With CDF at the peak of maturity and LHCb quickly ramping up, the physics of hadronic B decays is entering an exciting new era: the systematic and detailed exploration of the B^0_s sector. Many new interesting results are popping up – today just shown a subset:

- First evidence of annihilation $B^0_s \to \pi^+\pi^-$ decay (CDF - new)
- First two sided bound on Br($B^0 \to K^+K^-$) (CDF – new)
- First evidence of $B^0_s \to K^*\overline{K^*}$ decay (LHCb – new)
- First search for CPV in $B^0_s \to \phi\phi$ (CDF – new)
- World's best $B^0_s \to K^+K^-$ lifetime (LHCb – new)

CDF is finalizing analyses with full Run II samples, LHCb data are growing impressively fast.
Expect a lot of experimental progress in the next few months.

backup

Results on 1fb^{-1} - Summary

PRL 103, 031801 (2009)

Mode	Relative $\mathcal{B}$	Absolute $\mathcal{B}(10^{-6})$
✓ $B_s^0 \to K^-\pi^+$	$\frac{f_s}{f_d} \times \frac{\mathcal{B}(B_s^0 \to K^-\pi^+)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.071 \pm 0.010 \pm 0.007$	$5.0 \pm 0.7 \pm 0.8$
✓ $B_s^0 \to \pi^+\pi^-$	$\frac{f_s}{f_d} \times \frac{\mathcal{B}(B_s^0 \to \pi^+\pi^-)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.007 \pm 0.004 \pm 0.005$	$0.49 \pm 0.28 \pm 0.36$ (< 1.2 @ 90% CL)
$B^0 \to K^+K^-$	$\frac{\mathcal{B}(B^0 \to K^+K^-)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.020 \pm 0.008 \pm 0.006$	$0.39 \pm 0.16 \pm 0.12$ (< 0.7 @ 90% CL)
✓ $\Lambda_b^0 \to pK^-$	$\frac{\mathcal{B}(\Lambda_b^0 \to p\pi^-)}{\mathcal{B}(\Lambda_b^0 \to pK^-)} = 0.066 \pm 0.009 \pm 0.008$	$5.6 \pm 0.8 \pm 1.5$
✓ $\Lambda_b^0 \to p\pi^-$	$\frac{f_\Lambda}{f_d} \frac{\mathcal{B}(\Lambda_b^0 \to p\pi^-)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.042 \pm 0.007 \pm 0.006$	$3.5 \pm 0.6 \pm 0.9$

arXiv:1103.5762v1

Mode	Relative $\mathcal{B}$	Absolute $\mathcal{B}(10^{-6})$
$B^0 \to \pi^+\pi^-$	$\frac{\mathcal{B}(B^0 \to \pi^+\pi^-)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.259 \pm 0.017 \pm 0.016$	$5.02 \pm 0.33 \pm 0.35$
✓ $B_s^0 \to K^+K^-$	$\frac{f_s}{f_d} \times \frac{\mathcal{B}(B_s^0 \to K^+K^-)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.347 \pm 0.020 \pm 0.021$	$23.9 \pm 1.4 \pm 3.6$

arXiv:1103.5762v1

Mode	CP asymmetry	
$B^0 \to K^+\pi^-$	$\frac{\mathcal{B}(\overline{B}^0 \to K^-\pi^+) - \mathcal{B}(B^0 \to K^+\pi^-)}{\mathcal{B}(\overline{B}^0 \to K^-\pi^+) + \mathcal{B}(B^0 \to K^+\pi^-)}$	= -0.086 ± 0.023 ± 0.009
✓ $B_s^0 \to K^-\pi^+$	$\frac{\mathcal{B}(\overline{B}_s^0 \to K^+\pi^-) - \mathcal{B}(B_s^0 \to K^-\pi^+)}{\mathcal{B}(\overline{B}_s^0 \to K^+\pi^-) + \mathcal{B}(B_s^0 \to K^-\pi^+)}$	$= +0.39 \pm 0.15 \pm 0.08$
✓ $\Lambda_b^0 \to pK^-$	$\frac{\mathcal{B}(\Lambda_b^0 \to pK^-) - \mathcal{B}(\overline{\Lambda}_b^0 \to \bar{p}K^+)}{\mathcal{B}(\Lambda_b^0 \to pK^-) + \mathcal{B}(\overline{\Lambda}_b^0 \to \bar{p}K^+)}$	$= +0.37 \pm 0.17 \pm 0.03$
✓ $\Lambda_b^0 \to p\pi^-$	$\frac{\mathcal{B}(\Lambda_b^0 \to p\pi^-) - \mathcal{B}(\overline{\Lambda}_b^0 \to \bar{p}\pi^+)}{\mathcal{B}(\Lambda_b^0 \to p\pi^-) + \mathcal{B}(\overline{\Lambda}_b^0 \to \bar{p}\pi^+)}$	$= +0.03 \pm 0.17 \pm 0.05$

✓ World first
✓ World best

Branching Ratios summary

$\mathcal{B}(10^{-6})$

Mode	CDF	Belle
	PRL 103, 031801 (2009)	PRD 82.072007 (R) (2010)
$B_s^0 \to K^-\pi^+$	$5.0 \pm 0.7 \pm 0.8$	(< 26 @ 90% CL)
$B_s^0 \to \pi^+\pi^-$	$0.49 \pm 0.28 \pm 0.36$ (< 1.2 @ 90% CL)	(< 12 @ 90% CL)
	PRL 106, 181802 (2011)	PRD 82.072007 (R)
$B_s^0 \to K^+K^-$		$38 \pm^{10}_{-9} \pm 5 \pm 5(f_s)$

$\mathcal{B}(10^{-6})$

Mode	CDF	BaBar	Belle
		HFAG 2010	HFAG 2010
$B^0 \to K^+\pi^-$		$19.1 \pm 0.6 \pm 0.6$	$19.9 \pm 0.4 \pm 0.8$
	PRL 106, 181802 (2011)		
$B^0 \to \pi^+\pi^-$	$5.02 \pm 0.33 \pm 0.35$	$5.5 \pm 0.4 \pm 0.3$	$5.1 \pm 0.2 \pm 0.2$
	PRL 103, 031801 (2009)		
$B^0 \to K^+K^-$	$0.39 \pm 0.16 \pm 0.12$ (< 0.7 @ 90% CL)	$0.04 \pm 0.15 \pm 0.08$	$0.09\ ^{+0.18}_{-0.13} \pm 0.01$

$\mathcal{B}(10^{-6})$

Mode	CDF
	PRL 106, 181802 (2011)
$\Lambda_b^0 \to pK^-$	$5.6 \pm 0.8 \pm 1.5$
$\Lambda_b^0 \to p\pi^-$	$3.5 \pm 0.6 \pm 0.9$

World first

World best. (I will color the correspondent numbers)

Results on Bhh - Summary

PRL 103, 031801 (2009)

	Mode	$\mathcal{B}(10^{-6})$
✓	$B_s^0 \to K^-\pi^+$	$5.0 \pm 0.7 \pm 0.8$
✓	$B_s^0 \to \pi^+\pi^-$	$0.49 \pm 0.28 \pm 0.36$ (< 1.2 @ 90% CL)
	$B^0 \to K^+K^-$	$0.39 \pm 0.16 \pm 0.12$ (< 0.7 @ 90% CL)
✓	$\Lambda_b^0 \to pK^-$	$5.6 \pm 0.8 \pm 1.5$
✓	$\Lambda_b^0 \to p\pi^-$	$3.5 \pm 0.6 \pm 0.9$

PRL 106, 18102 (2011)

	Mode	$\mathcal{B}(10^{-6})$
	$B^0 \to \pi^+\pi^-$	$5.02 \pm 0.33 \pm 0.35$
✓	$B_s^0 \to K^+K^-$	$23.9 \pm 1.4 \pm 3.6$

PRL 106, 18102 (2011)

	Mode	CP asymmetry
	$B^0 \to K^+\pi^-$	$-0.086 \pm 0.023 \pm 0.009$
✓	$B_s^0 \to K^-\pi^+$	$+0.39 \pm 0.15 \pm 0.08$
✓	$\Lambda_b^0 \to pK^-$	$+0.37 \pm 0.17 \pm 0.03$
✓	$\Lambda_b^0 \to p\pi^-$	$+0.03 \pm 0.17 \pm 0.05$

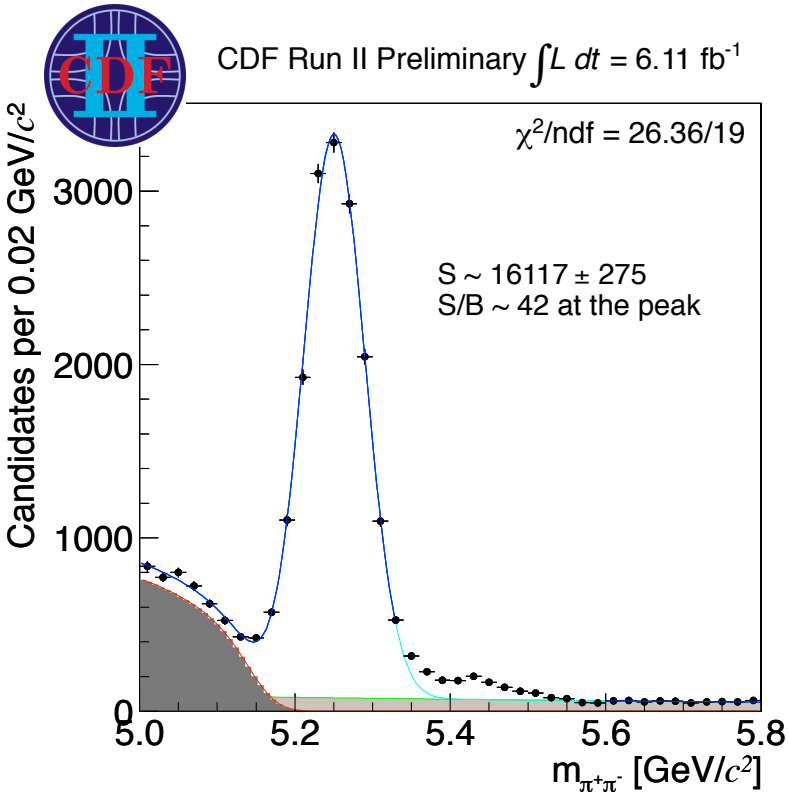
✓ World first
✓ World best

Specific motivations

- $B_s \to K^+K^-$
  - from the lifetime information on the relative width- difference $\Delta\Gamma s/\Gamma s$. Compare with B_s mixing results to search for new, CP- violating physics.
- $B^0 \to K^+\pi^-$
  - $A_{CP}(B^0)$ non compatible with $A_{CP}(B^+)$ as expected *[PRD71:074019, 2005]*
  - This prompted intense theoretical work to explain it in the SM. Still no firm conclusion because of large theory uncertainties. Hints of NP?
- $B_s \to K^-\pi^+$
  - Comparison rates and asymmetries of $B^0 \to K\pi$ with $B_s \to K\pi$ to probe NP with no need for specific assumption, just SM *[PLB621:126, .2005]*
  - BR sensitive to γ angle *[PLB 664,169 (2008)]*
- $B^0 \to K^+K^-$ and $B_s \to \pi^+\pi^-$
  - would allow a determination of strength of penguin-annihilation amplitudes *[NPB697,133(2004)]*.

CDF data - 6 fb^{-1}

New for FPCP



B→Kπ ~ 10200 ev
B→ππ ~ 2600 ev
B_s→Kπ ~ 760 ev
B→ KK ~ 120 ev
B_s→ππ ~ 90 ev

Improvements in the update:

- x3 in statistics
- Likelihood terms rewritten. Same kinematics info (mass, momenta and dE/dx) using different variables.
  - New variable β easier to parameterize

Momentum imbalance
$\beta = (p_+ - p)/(p_+ + p_-)$

dE/dx observables
(unchanged)

$$\mathcal{L} = \prod_{i=1}^{N} \mathcal{L}_i(\vec{\Theta}|m^2_{\pi\pi}, \beta, p_{tot}, k_1, k_2)$$

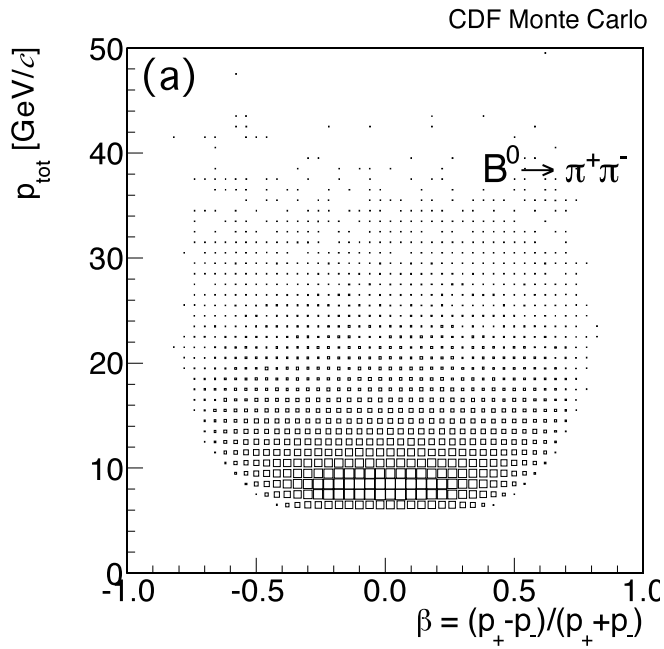
Scalar sum of 3D momenta
$p_{min} + p_{max}$

Square Invariant ππ-mass
(instead of ππ-mass)

Separating signals: momentum term

$$\mathcal{L} \sim \wp_j^m(m^2_{\pi\pi}|\beta, p_{tot}) \cdot \wp_j^p(\beta, p_{\rm tot}) \cdot \wp_j^{\rm PID}(\kappa_1, \kappa_2|\beta, p_{\rm tot}).$$

Two dimensional joint p.d.f. of beta and ptot

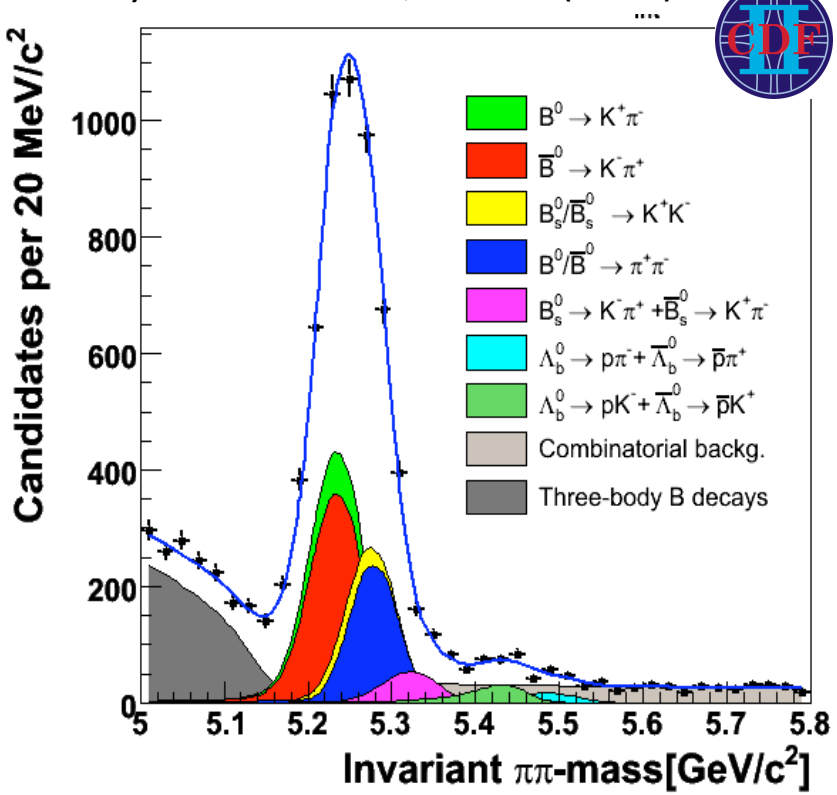


$\alpha = [1 - p_{min}/p_{max}]\, q_{min},$
Signed momentum-imbalance

$p_{tot} = p_{min} + p_{max}$
Scalar sum of 3D momenta

B→hh' at CDF (1 fb^{-1})

Phys.Rev.Lett. 103, 031801(2009),
Phys.Rev.Lett. 106, 181802(2011)



Good mass resolution (~22 MeV/c^2), but individual modes overlap in a single peak (width ~35 MeV/c^2).

PID provides only statistical separation.

Each mode is a background for others. Eg, $\Lambda^0_b \to p\pi/pK$ are "backgrounds" of $B^0_s \to K^-\pi^+$ signal.

Signal composition from 5-dim ML fit, combining information from kinematics (mass and momenta) and particle ID (dE/dx).