CPV in B → $h^+h'^-$ decays

13th International Conference on B-Physics at Hadron Machines
Beauty 2011
April 4th-8th 2011, Amsterdam, The Netherlands

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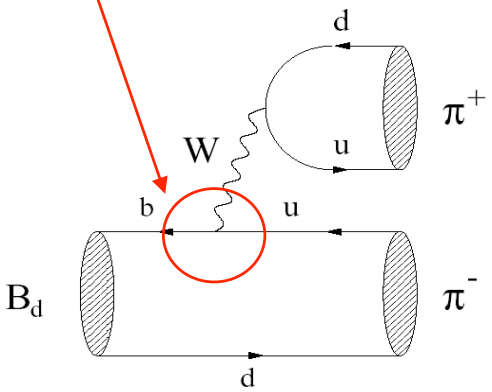
Outline

- BRs and CPV in charmless $B \to h^+ h'^-$ decays, i.e.:
  - $B^0 \to \pi^+\pi^-$, $B^0 \to K^+\pi^-$, $\bar{B}^0 \to K^-\pi^+$, $B^0 \to K^+K^-$
  - $B_s \to \pi^+\pi^-$, $B_s \to K^-\pi^+$, $\bar{B}_s \to K^+\pi^-$, $B_s \to K^+K^-$
  - $\Lambda^0_b \to p^+\pi^-$, $\Lambda^0_b \to p^+K^-$
- Motivations
- CDF results
- Prospects

B→hh decays measurements

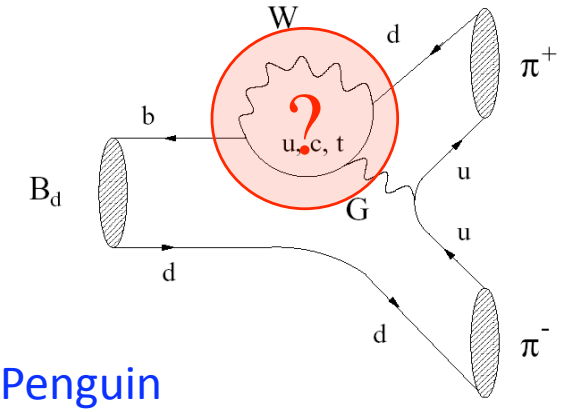
Important tests for Standard Model

Sensitive to
γ angle = arg(V_{ub})



Tree

Contributions of new particles may enter in penguin diagrams (→NP)



Penguin

Specific motivations

- $B^0 \rightarrow K^+\pi^-$
  - $A_{CP}(B^0)$ 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?
- $B_s \rightarrow K^-\pi^+$
  - Comparison rates and asymmetries of $B^0 \rightarrow K\pi$ with $B_s \rightarrow K\pi$ to probe NP with no need for specific assumption, just SM *[PLB621:126, .2005]*
  - BR sensitive to γ angle *[PLB 664,169 (2008)]*
- $B_s \rightarrow K^+K^-$
  - 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.
- $B^0 \rightarrow K^+K^-$ and $B_s \rightarrow \pi^+\pi^-$
  - would allow a determination of strength of penguin-annihilation amplitudes *[NPB697,133(2004)]*.

Data sample

Two opposite charge tracks (i.e. B candidate) from a long-lived decay

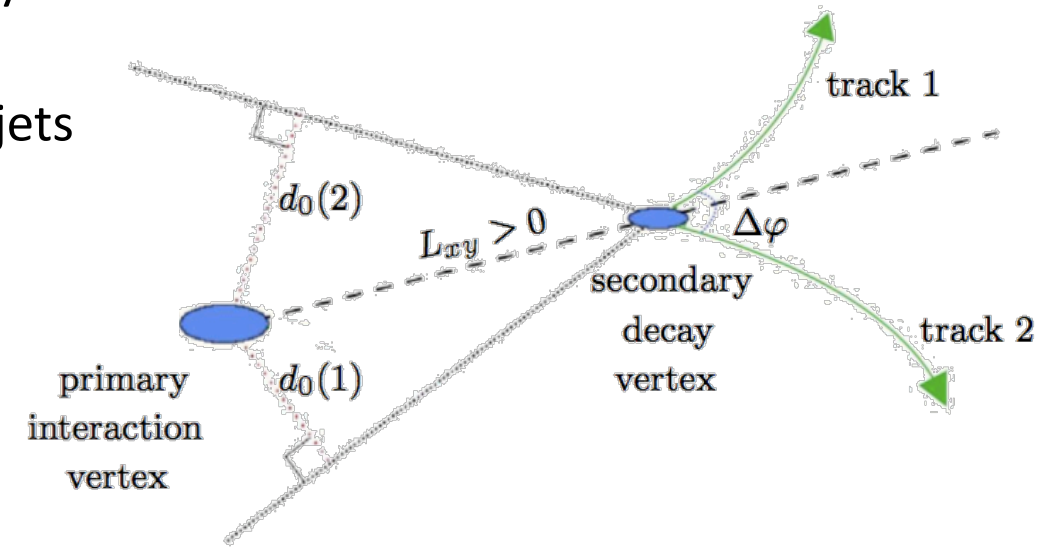
- high track's impact parameter (d_0)
- high transverse decay-length (L_{xy})

B-candidate pointing back to primary vertex

- impact parameter of B

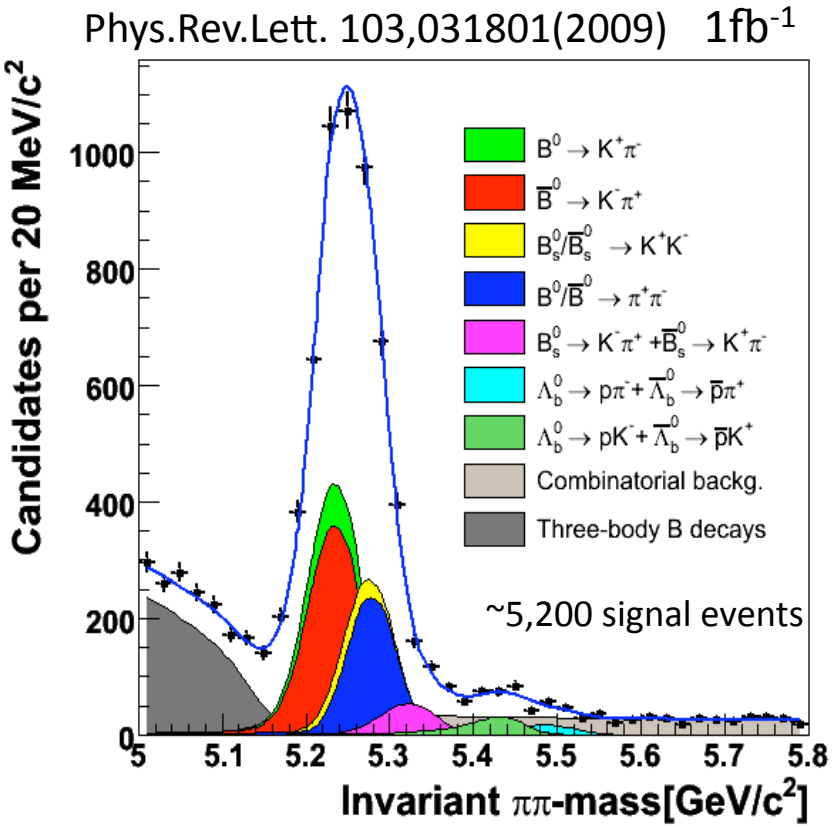
Reject light quark background from jets

- transverse opening angle $\Delta\phi$
- tracks transverse momentum
- Scalar sum of tracks transverse momenta



Offline selection optimized to maximize the probability to observe $B^0_s \rightarrow K^-\pi^+$ decay mode. Added observables with good separation power signal/noise: 3D vertex quality and Isolation of b-hadron candidate.

Data sample (con't)



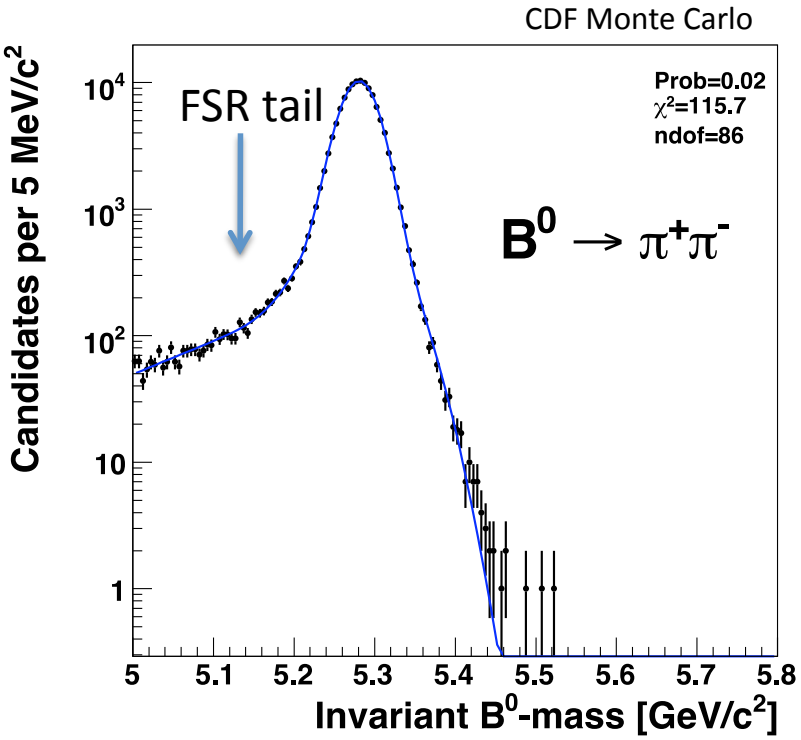
Despite good mass resolution (~22 MeV/c^2), individual modes overlap in a single peak (width ~35 MeV/c^2). PID provides only statistical separation.

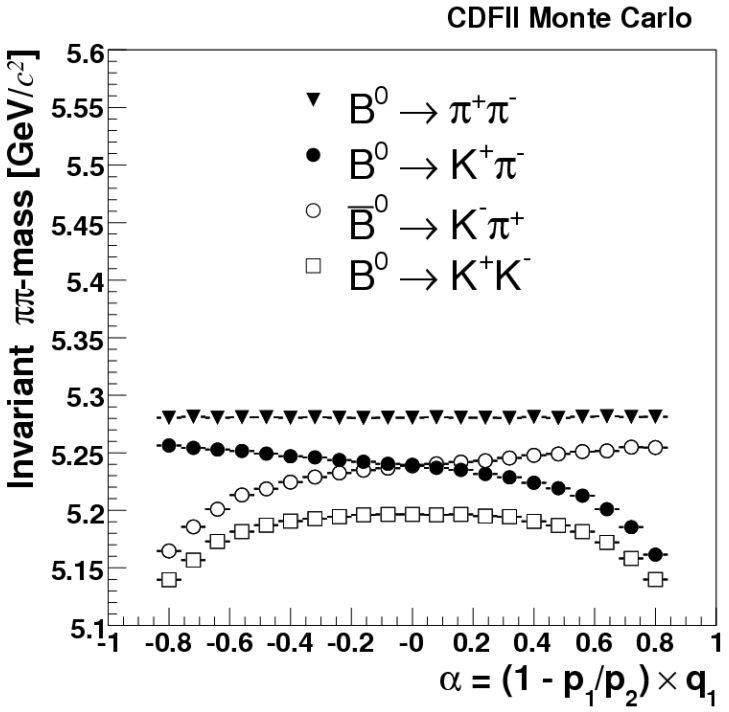
Each mode is a background for others. For example, $\Lambda^0_b \rightarrow p\pi/pK$ are "backgrounds" of $B^0_s \rightarrow K\pi$ "signal".

Need to determine signal composition with a 5-dim un-binned Maximum Likelihood fit, combining information from kinematics (mass and momenta) and particle ID (dE/dx), correlations among all variables accounted.

Separating signals: mass term

$$\mathcal{L} \sim \wp^{m}(m_{\pi\pi}|\alpha, p_{\rm tot}) \times \wp^{p}(\alpha, p_{\rm tot}) \times \wp^{PID}(\kappa_1, \kappa_2|\alpha, p_{\rm tot})$$





Exploit dependence between $m_{\pi\pi}$ and α to obtain discrimination power amongst modes. useful to discriminate $K^+\pi^-/K^-\pi^+$ final states.

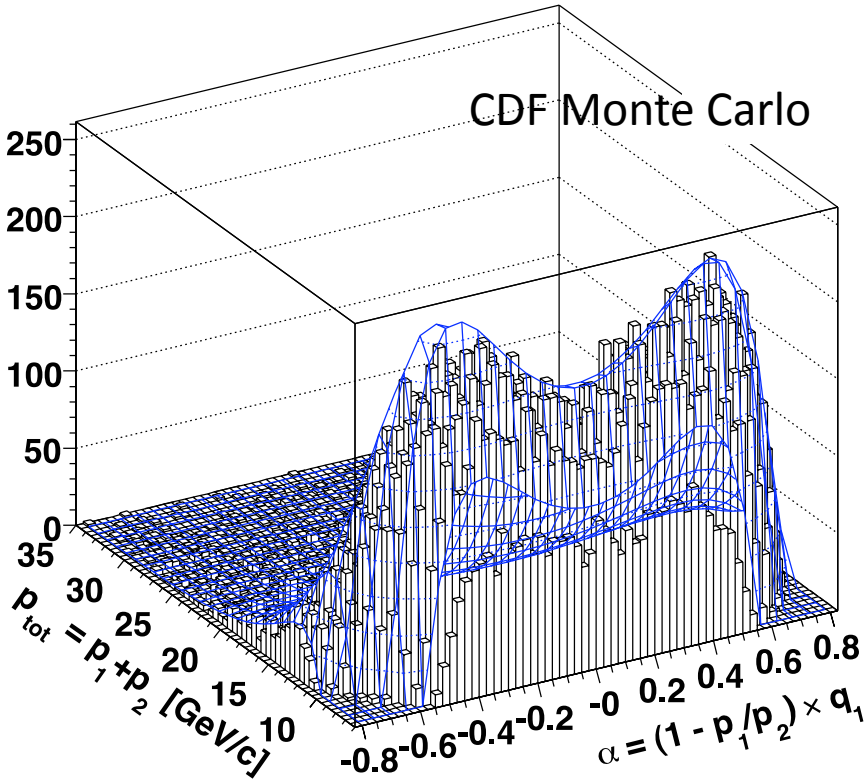
Separating signals: momentum term

$$\mathcal{L} \sim \wp^{m}(m_{\pi\pi}|\alpha, p_{\mathrm{tot}}) \times \wp^{p}(\alpha, p_{\mathrm{tot}}) \times \wp^{PID}(\kappa_1, \kappa_2|\alpha, p_{\mathrm{tot}})$$

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

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

Parameterization of the joint two-dimensional probability density.



Separating signals: PID term

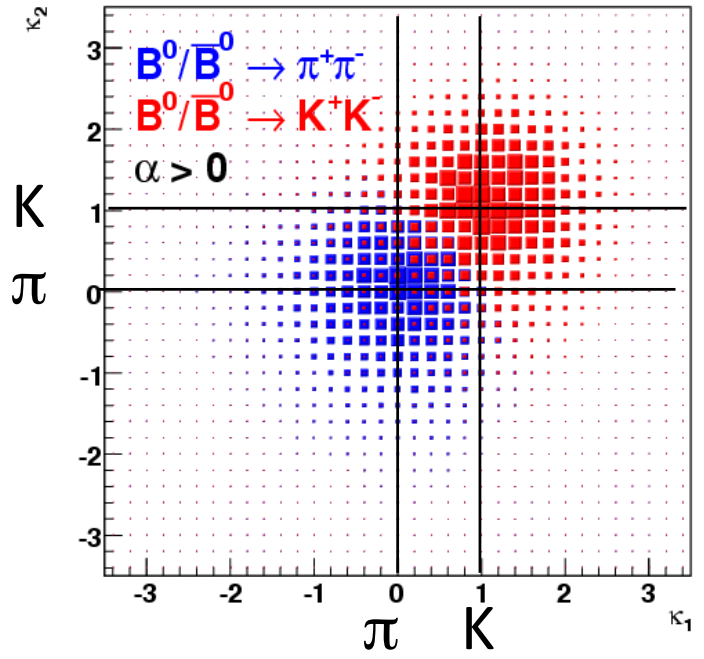
$$\mathcal{L} \sim \wp^m(m_{\pi\pi}|\alpha, p_{\rm tot}) \times \wp^p(\alpha, p_{\rm tot}) \times \wp^{PID}(\kappa_1, \kappa_2|\alpha, p_{\rm tot})$$

Kaonness (κ) summarizes Particle IDentification information; the average of this quantity, by construction, is 0 for pions and 1 for kaons.

dE/dx carefully calibrated on pure K and π samples from 1.5M decays:
$D^{*+} \rightarrow D^0\pi^+ \rightarrow [K^-\pi^+]\pi^+$
(sign of D^{*+} pion tags D^0 flavor)

1.5σ K/π power separation for track p>2GeV/c which becomes 2.1σ for KK/ππ and $K^+\pi^-/\pi^+K^-$.

2.1σ sep KK/ππ



$B^0 \to hh'$ results

Mode		CP asymmetry		
$B^0 \to K^+\pi^-$	$\frac{\mathcal{B}(\bar{B}^0 \to K^-\pi^+) - \mathcal{B}(B^0 \to K^+\pi^-)}{\mathcal{B}(\bar{B}^0 \to K^-\pi^+) + \mathcal{B}(B^0 \to K^+\pi^-)}$	$-0.086 \pm 0.023 \pm 0.009$	← 3.5σ	arXiv:1103.5762v1

Mode		Relative $\mathcal{B}$	Absolute $\mathcal{B}(10^{-6})$	
$B^0 \to \pi^+\pi^-$	$\frac{\mathcal{B}(B^0 \to \pi^+\pi^-)}{\mathcal{B}(B^0 \to K^+\pi^-)}$	$0.259 \pm 0.017 \pm 0.016$	$5.02 \pm 0.33 \pm 0.35$	arXiv:1103.5762v1
$B^0 \to K^+K^-$	$\frac{\mathcal{B}(B^0 \to K^+K^-)}{\mathcal{B}(B^0 \to K^+\pi^-)}$	$0.020 \pm 0.008 \pm 0.006$	$0.39 \pm 0.16 \pm 0.12$	PRL 103, 031801 (2009)

In particular, for $A_{CP}(B^0 \to K\pi)$

- Our measurement agrees with Bfactories measurement

HFAG 2010	
BaBar	Belle
467 M	535 M
($B\bar{B}$ pairs)	($B\bar{B}$ pairs)
$-0.107 \pm 0.016^{+0.006}_{-0.004}$	$-0.094 \pm 0.018 \pm 0.008$

- $A_{CP}(B^0 \to K^+\pi^-) \neq A_{CP}(B^+ \to K^+\pi^0)$ puzzle:
  - expected to be compatible in SM *[Gronau and Rosner, Phys. Rev. D71:074019, 2005]*
  - But discrepancy up to 4.9 σ with $A_{CP}(B^+ \to K^+\pi^0) = 0.051 \pm 0.025$ (pdg2010 Avg.)

$B_s \to hh'$ results

✓ World first
✓ World best

Mode		Relative $\mathcal{B}$	Absolute $\mathcal{B}(10^{-6})$	
✓ $B_s^0 \to \pi^+\pi^-$	$\frac{f_s}{f_d} \times \frac{\mathcal{B}(B_s^0 \to \pi^+\pi^-)}{\mathcal{B}(B^0 \to K^+\pi^-)}$	$0.007 \pm 0.004 \pm 0.005$	$0.49 \pm 0.28 \pm 0.36$ (< 1.2 @ 90% CL)	PRL 103, 031801 (2009)
✓ $B_s^0 \to K^+K^-$	$\frac{f_s}{f_d} \times \frac{\mathcal{B}(B_s^0 \to K^+K^-)}{\mathcal{B}(B^0 \to K^+\pi^-)}$	$0.347 \pm 0.020 \pm 0.021$	$23.9 \pm 1.5 \pm 3.6$	arXiv:1103.5762v1
✓ $B_s^0 \to K^-\pi^+$	$\frac{f_s}{f_d} \times \frac{\mathcal{B}(B_s^0 \to K^-\pi^+)}{\mathcal{B}(B^0 \to K^+\pi^-)}$	$0.071 \pm 0.010 \pm 0.007$	$5.0 \pm 0.7 \pm 0.8$	PRL 103, 031801 (2009)

Mode		CP asymmetry		
✓ $B_s^0 \to K^-\pi^+$	$\frac{\mathcal{B}(\overline{B}_s^0 \to K^+\pi^-) - \mathcal{B}(B_s^0 \to K^-\pi^+)}{\mathcal{B}(\overline{B}_s^0 \to K^+\pi^-) + \mathcal{B}(B_s^0 \to K^-\pi^+)}$	$0.39 \pm 0.15 \pm 0.08$	← 2.3σ	arXiv:1103.5762v1

In particular, for $A_{CP}(B_s \to K\pi)$

- First measurement of DCPV in the B_s
- Sign and magnitude agree with SM predictions within errors ⇒no evidence for "exotic" sources of CP violation (yet)
- opportunity of checking for the SM origin of direct CP violation, by means of a "sum rule" (*[Gronau and Rosner, Phys.Rev. D71 (2005) 074019], [Lipkin, Phys. Lett. B621:126, .2005]*):

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

From our measured BR, we can predict $A_{CP} \approx$ **+37%**

$\Lambda^0_b \to ph$ results

✓ World first
✓ World best

	Mode	CP asymmetry		
✓	$\Lambda_b^0 \to pK^-$	$\frac{\mathcal{B}(\Lambda_b^0\to pK^-)-\mathcal{B}(\overline{\Lambda}_b^0\to \bar{p}K^+)}{\mathcal{B}(\Lambda_b^0\to pK^-)+\mathcal{B}(\overline{\Lambda}_b^0\to \bar{p}K^+)}$	$= +0.37 \pm 0.17 \pm 0.03$	PRL 103, 031801 (2009)
✓	$\Lambda_b^0 \to p\pi^-$	$\frac{\mathcal{B}(\Lambda_b^0\to p\pi^-)-\mathcal{B}(\overline{\Lambda}_b^0\to \bar{p}\pi^+)}{\mathcal{B}(\Lambda_b^0\to p\pi^-)+\mathcal{B}(\overline{\Lambda}_b^0\to \bar{p}\pi^+)}$	$= +0.03 \pm 0.17 \pm 0.05$	PRL 103, 031801 (2009)
	Mode	Relative $\mathcal{B}$	Absolute $\mathcal{B}(10^{-6})$	
✓	$\Lambda_b^0 \to pK^-$	$\frac{\mathcal{B}(\Lambda_b^0\to p\pi^-)}{\mathcal{B}(\Lambda_b^0\to pK^-)} = 0.066 \pm 0.009 \pm 0.008$	$5.6 \pm 0.8 \pm 1.5$	arXiv:1103.5762v1
✓	$\Lambda_b^0 \to p\pi^-$	$\frac{f_\Lambda}{f_d}\frac{\mathcal{B}(\Lambda_b^0\to p\pi^-)}{\mathcal{B}(B^0\to K^+\pi^-)} = 0.042 \pm 0.007 \pm 0.006$	$3.5 \pm 0.6 \pm 0.9$	arXiv:1103.5762v1

- First observation of $\Lambda^0_b \to pK$ and $\Lambda^0_b \to p\pi$ decay modes and CPV.
- BR consistent with the previous upper-limit from CDF ($<2.3\times10^{-5}$ @90%C.L.).
  - In agreement with SM predictions $BR(\Lambda^0_b \to pK^-) \approx [1.4\text{-}1.9]\times10^{-6}$ and $BR(\Lambda^0_b \to p\pi^-) \approx [0.9\text{-}1.2]\times10^{-6}$ *[Mohanta et al., PRD63,074001(2001)]* .
- SUSY effects are disfavored.

Results on 1fb^{-1} - Summary

PRL 103, 031801 (2009)

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✓	$B_s^0 \to K^-\pi^+$	$\frac{f_s}{f_d} \times \frac{\mathcal{B}(B_s^0\to K^-\pi^+)}{\mathcal{B}(B^0\to K^+\pi^-)} = 0.071 \pm 0.010 \pm 0.007$	$5.0 \pm 0.7 \pm 0.8$
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arXiv:1103.5762v1

	Mode	CP asymmetry	
	$B^0 \to K^+\pi^-$	$\frac{\mathcal{B}(\overline{B}^0\to K^-\pi^+)-\mathcal{B}(B^0\to K^+\pi^-)}{\mathcal{B}(\overline{B}^0\to K^-\pi^+)+\mathcal{B}(B^0\to K^+\pi^-)}$	$= -0.086 \pm 0.023 \pm 0.009$
✓	$B_s^0 \to K^-\pi^+$	$\frac{\mathcal{B}(\overline{B}_s^0\to K^+\pi^-)-\mathcal{B}(B_s^0\to K^-\pi^+)}{\mathcal{B}(\overline{B}_s^0\to K^+\pi^-)+\mathcal{B}(B_s^0\to K^-\pi^+)}$	$= +0.39 \pm 0.15 \pm 0.08$
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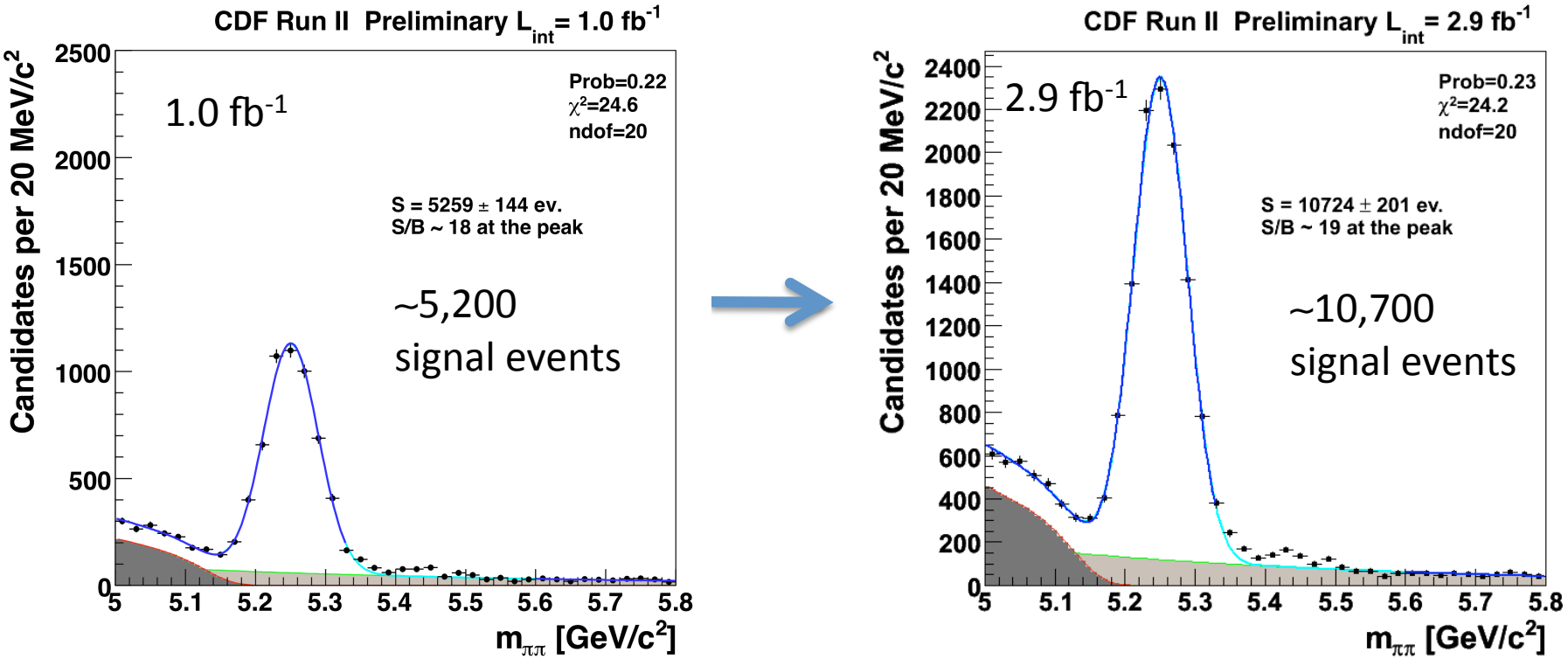
✓ World first
✓ World best

Prospects



- ≈ 10 fb^{-1} expected by end 2011.
- Analysis with full data sample in progress.

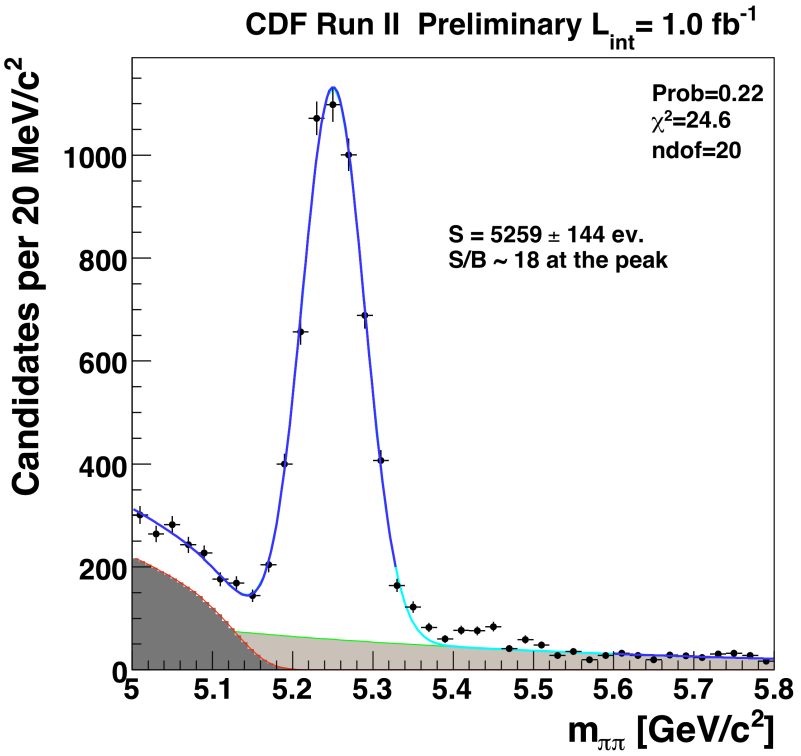
Conclusions

- CDF has pioneered the study of charmless B→hh decays in hadronic environment:
  - First observation of $B_s \to K^+K^-$, $B_s \to K^-\pi^+$, $\Lambda_b \to ph$ decays
  - First measurement of direct CP asymmetry in Strange Bottom Mesons and Bottom Baryons decays.
  - Improved upper limits on $B_s \to \pi^+\pi^-$, $B^0 \to K^+K^-$ decays.
  - $A_{CP}(B^0 \to K\pi)$ competitive with other experiments
- More is coming soon with full RunII data sample.

backup

Optimized Selection

Maximizing the probability to observe $B^0_s \rightarrow K^-\pi^+$ decay mode



- More tight requirements on impact parameters
- Added observables with good separation power signal/background:

- 3D Vertex chi-square χ^2 and Isolation

  - $|d_0(1,2)| > 120$ µm
  - $L_{xy} > 350$ µm
  - $\chi^2 < 5$
  - Isolation > 0.525
  - |eta| < 1.0
  - $|d_0(B)| < 60$ µm
  - $5 < M_{\pi\pi} < 5.8$ GeV/c^2

ML fit

The Likelihood function combines information from kinematics (mass and momenta) and particle ID (dE/dx).

$$\mathcal{L}(\vec{\theta}|\vec{x}) = \prod_{i=1}^{N} \mathcal{L}_i(\vec{\theta}|\vec{x})$$

$$\mathcal{L}_i = (1-b)\sum_j f_j \mathcal{L}_j^{sig} + b\mathcal{L}^{bkg}$$

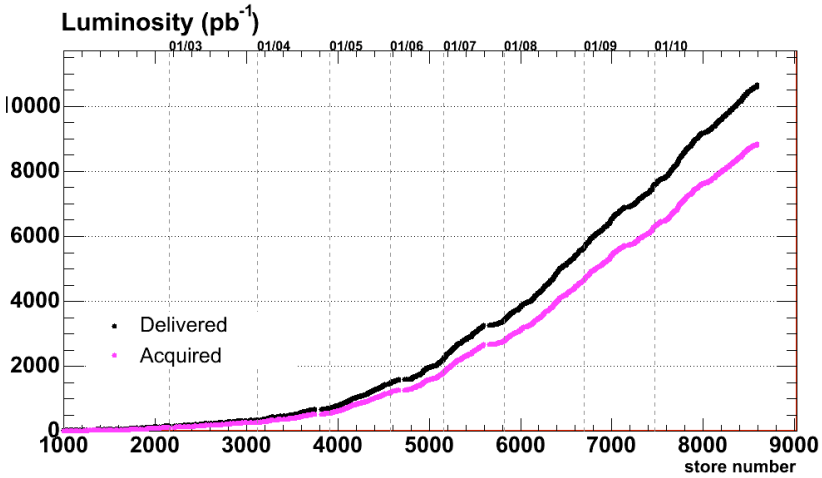
fraction of j[th] mode, to be determined by the fit

$$\mathcal{L} \sim \wp^m(m_{\pi\pi}) \times \wp^p(\alpha, p_{\rm tot}) \times \wp^{PID}(\kappa_1, \kappa_2 | \alpha, p_{\rm tot})$$

TeVatron and CDF II features

TeVatron

- p-$\bar{p}$ collisions at 1.96 TeV;
- Typical initial inst. luminosity ~ 3.4 x 10^{32} $cm^{-2}s^{-1}$
- CDF has already 9 fb^{-1} on tape (50pb^{-1}/week)
- Expect ~10 fb^{-1} on tape by end 2011



CDF II

Drift chamber (COT) in magnetic field

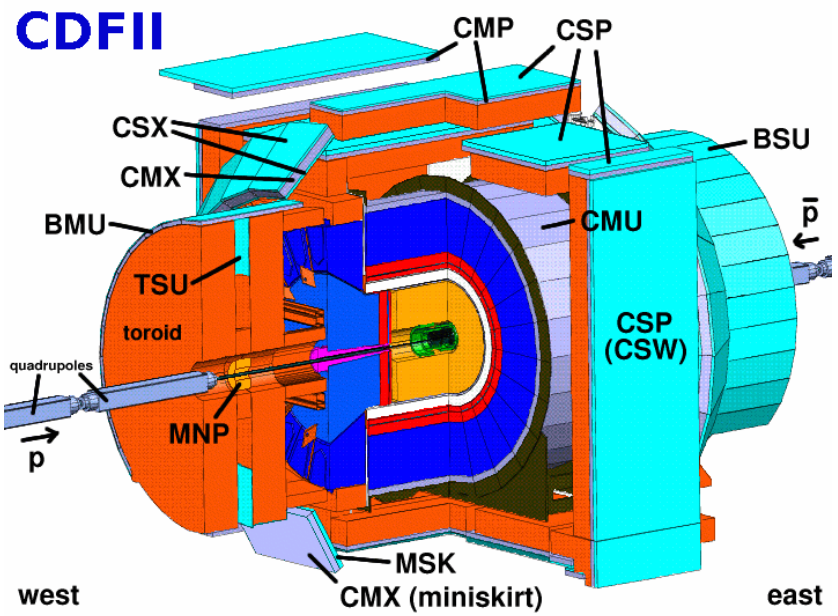
- $\sigma(p_T)/p_T^2 \sim 0.15\%\ p_T(GeV/c)^{-1}$ (good tracking resolution);

Silicon Vertex detector

- Good vertex resolution;
- Important for triggering

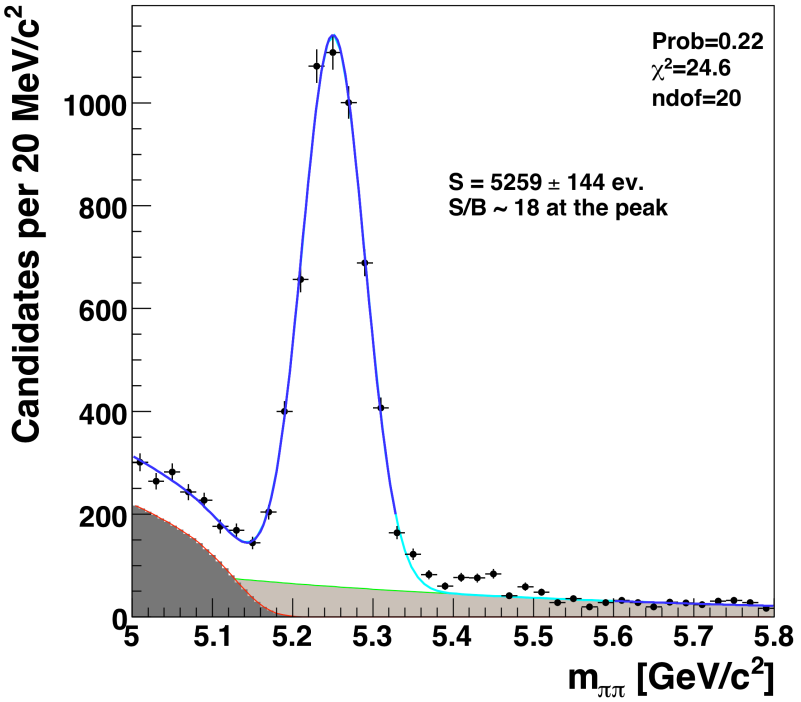
(using a displaced track trigger, SVT);

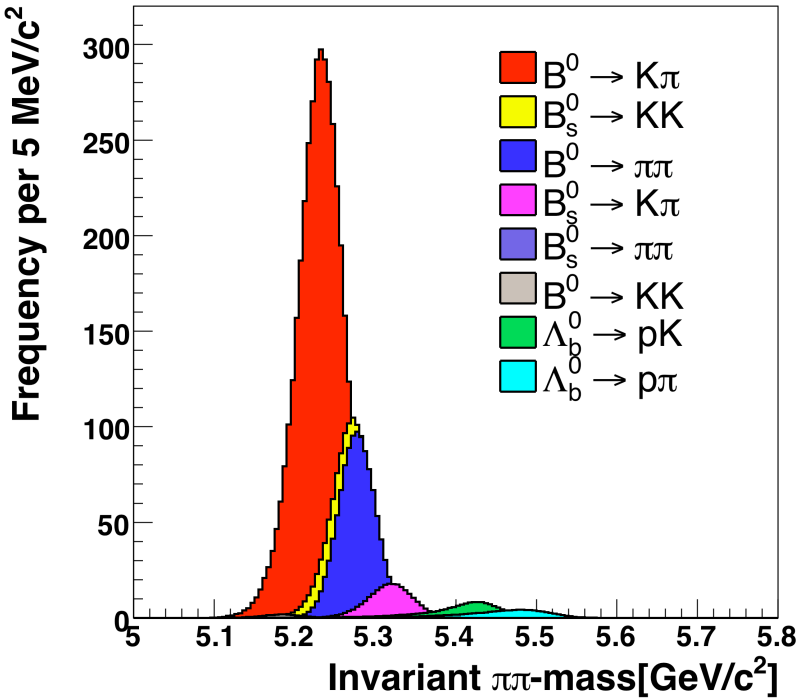
dE/dx from COT (Good particle identification)



Data sample: composition (1)

Phys.Rev.Lett. 103,031801(2009) L_{int} = 1.0 fb^{-1}





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