BR e violazione di CP in decadimenti *charmless* a CDF

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Talk layout

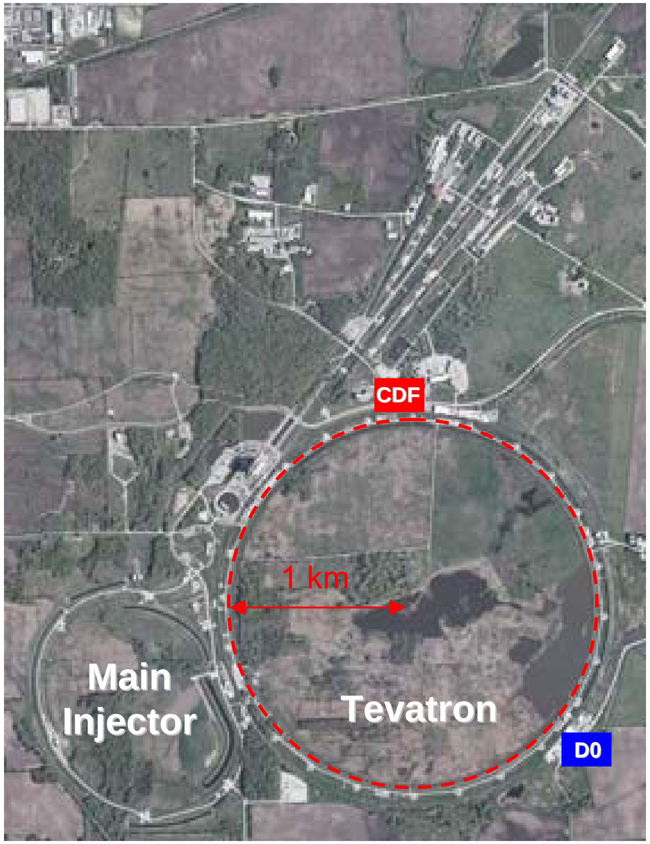
- Experimental setup:
  - the Tevatron collider;
  - the CDF detector.

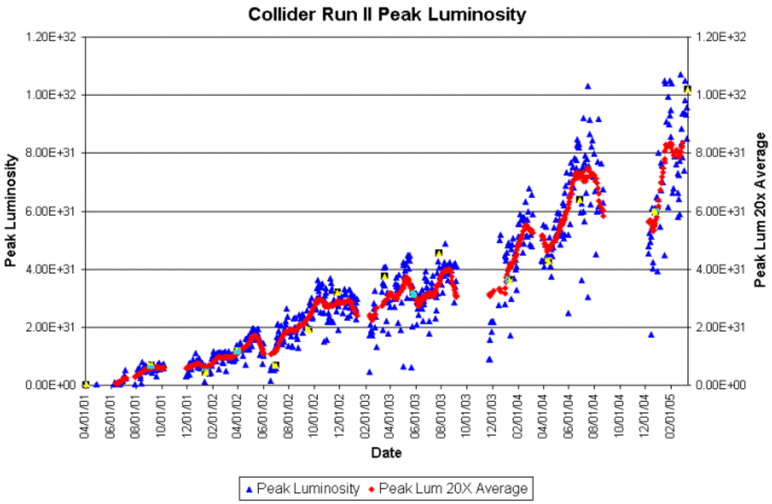
- The hadronic trigger.

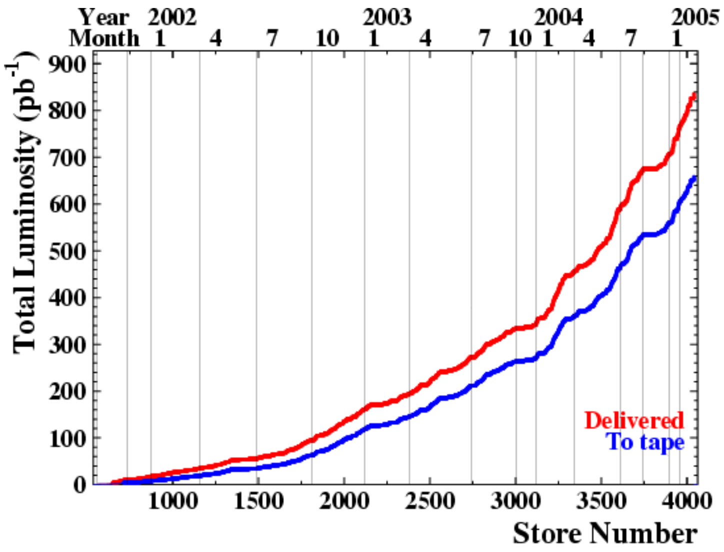
- Overview of CDF results on charmless decays:
  - $B_{d,s} \rightarrow h^{-}h'^{+}$ (h,h′ = π,K), BR and A_{CP};
  - $B^{\pm} \rightarrow \phi K^{\pm}$, BR and A_{CP};
  - $B_s \rightarrow \phi\phi$ evidence and BR;
  - search for $\Lambda_b \rightarrow p\pi^{-}/pK^{-}$.

- Conclusion and perspective.

The Tevatron collider

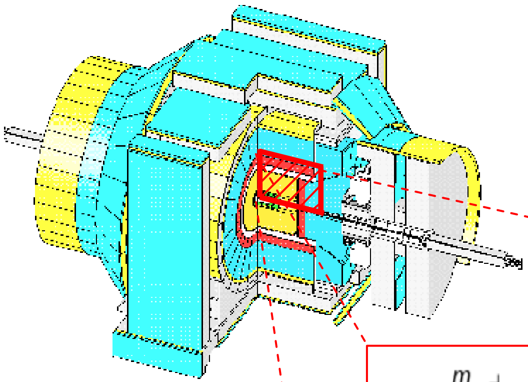






- 36×36 bunch p-$\bar{p}$ beams collide every 396 ns at 1.96 TeV

The CDF tracking system

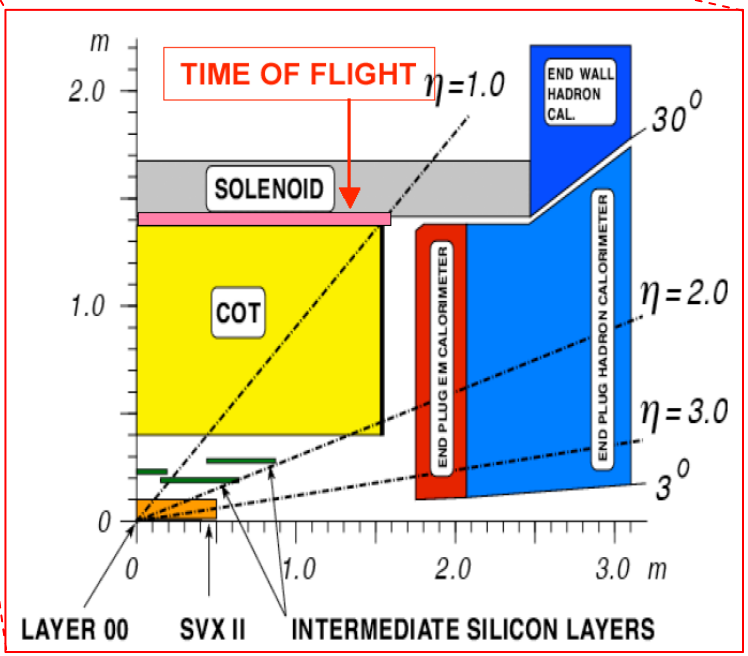


ToF 279×4×4 cm^3 Bicron BC-408 scintillator bars

- 100 ps resolution;
- 2σ K/π separation for tracks with p_T<1.6 GeV/c.

COT 1.4 m radius Ar-Ethane multiwire drift chamber

- 96 layers, 200ns drift time;
- precise p_T above 0.4 GeV/c,
- precise 3D tracking for |η|<1:
  $\sigma(p_T)/p_T^2 \approx 0.0017\ [\text{GeV/c}]^{-1}$
  $\sigma(\text{hit}) \approx 150\ \mu m$
- dE/dx provides 1.4σ K/π separation for p_T>2 GeV/c.



Muon 4 layers of single wire drift cells

- cover the rigion |η|<1;

Solenoid

- 1.4 T field

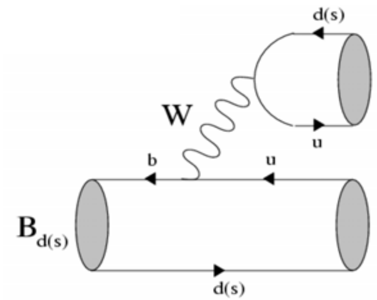
SVX II - ISL 6 (7) double-sided micro-strip Si layers between 3 cm < R < 30 cm

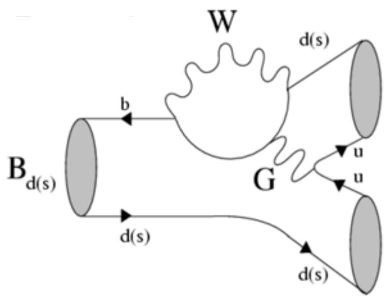
- standalone 3D tracking up to |η|=2;
- very good I.P. resolution: ~30 μm (~20 μm with L00).

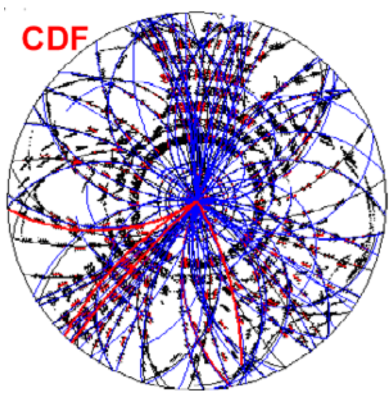
LAYER00 1 radiation-hard silicon layer at R = 1.5 cm.

Introduction

- Charmless two-body B decays are important tools for understanding the CKM mixing and looking for new physics.
- Hadronic machines offer large yields ($\sigma_{bb} \approx$ 50-100 μb) and additional access to B_s and b baryons.
- Total inelastic cross-section is $\sim 10^3 \times \sigma_{bb}$ while BR of interesting processes are of the order $O(10^{-5}\text{-}10^{-6})$.







- Messy environment, large combinatorics, need for a high selective trigger.

CDF hadronic trigger

Three level trigger

L1

two opposite-charge XFT (eXtreme Fast Tracker) tracks:

- $p_T^{(1)}, p_T^{(2)} > 2$ GeV/c;
- $p_T^{(1)} + p_T^{(2)} > 5.5$ GeV/c.

L2

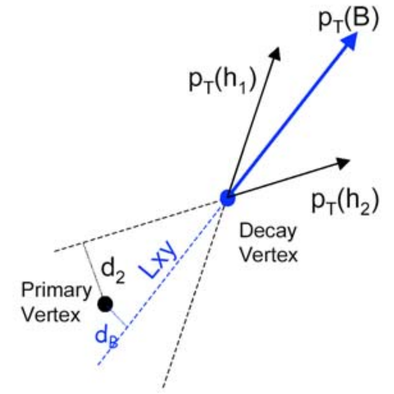
two opposite-charge SVT (Silicon Vertex Tracker) tracks:

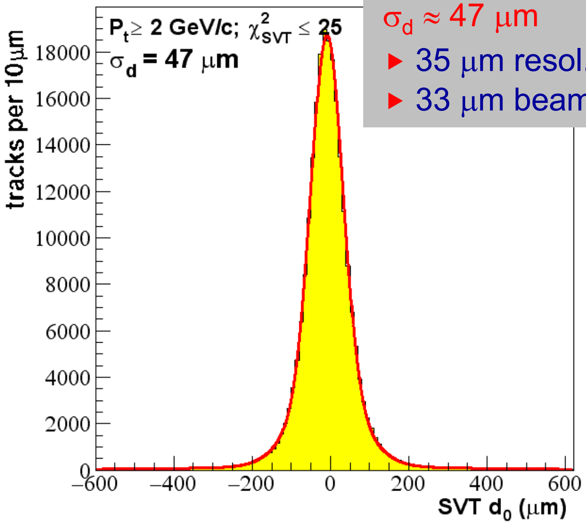
- $p_T^{(1)}, p_T^{(2)} > 2$ GeV/c;
- $p_T^{(1)} + p_T^{(2)} > 5.5$ GeV/c;
- $|d_0^{(1)}|, |d_0^{(2)}| > 120\ \mu$m;
- $L_{xy} > 200\ \mu$m.

L3

offline event reconstruction:

- L1 and L2 requirements reconfirmed.





$\sigma_d \approx 47\ \mu$m

- 35 μm resol.
- 33 μm beam

Selects events with displaced secondary vertices.

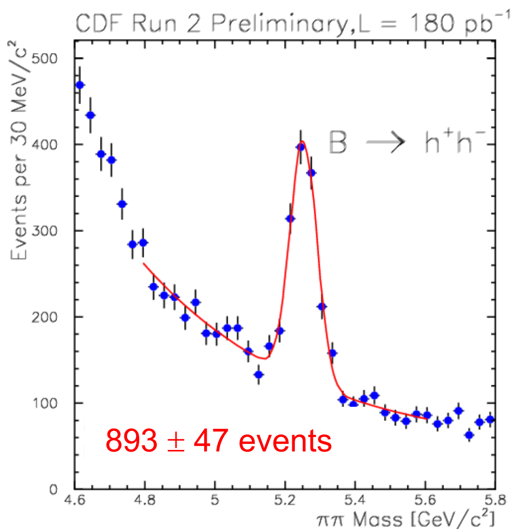
$B_{d,s} \to h^- h'^+$: signal selection

- ✓ $b \to u, d, s$ quark level transition;
- ✓ BR and A_{CP} are sensitive to CKM parameters (γ);
- ✓ $\Delta\Gamma_s$ (KK mode).

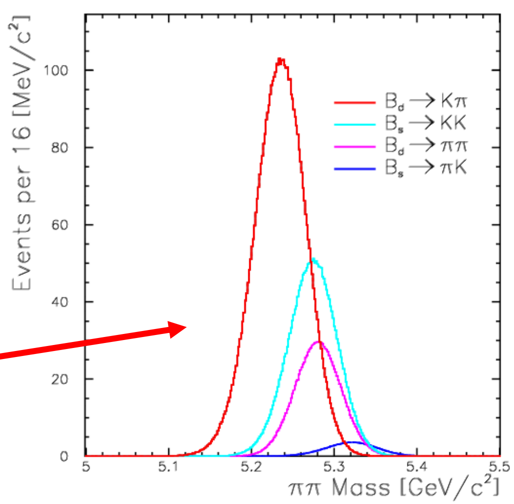
180 pb^{-1}

- Selection cuts simultaneously optimized for max. $S/(S+B)^{1/2}$ [S from MC, B from data sidebands]:
  - $p_T^{(1)}, p_T^{(2)} > 2$ GeV/c;
  - $p_T^{(1)} + p_T^{(2)} > 5.5$ GeV/c;
  - $|d_0^{(1)}|, |d_0^{(2)}| > 150\ \mu m$ and $d_0^{(1)} \times d_0^{(2)} < 0$;
  - $L_{xy} > 300\ \mu m$;
  - $|d_B| < 80\ \mu m$;
  - $\text{Isol} = \dfrac{p_T(B)}{p_T(B) + \sum_i p_T^{(i)}} > 0.5$

85% efficiency on signal reduces bkg by factor 4



- Candidates reconstructed with $\pi\pi$ hypothesis $\Rightarrow$ the four major expected modes overlap to form a single unresolved bump:
  - $B_d \to \pi\pi$
  - $B_d \to K\pi$
  - $B_s \to KK$
  - $B_s \to K\pi$



$B_{d,s} \to h^- h'^+$: modes separation

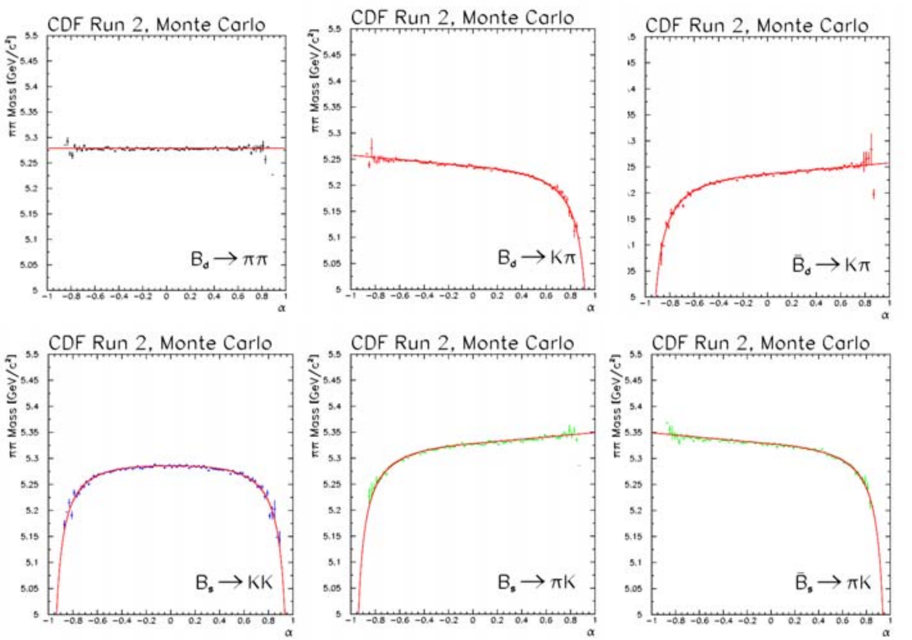
kinematics

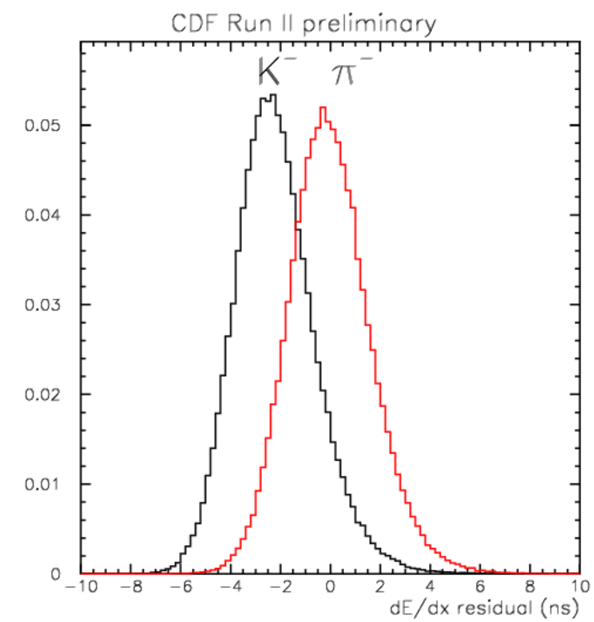
- Exploit correlations between mass and signed momentum imbalance:

$$M_{\pi\pi} \text{ vs } \alpha = q_{min}\,(1-p_{min}/p_{max})$$

Particle ID

- Based on dE/dx measured in COT.
- dE/dx calibrated on $D^{*+} \to D^0\pi^+$.
- 1.4σ K/π separation for $p_T > 2$ GeV/c.

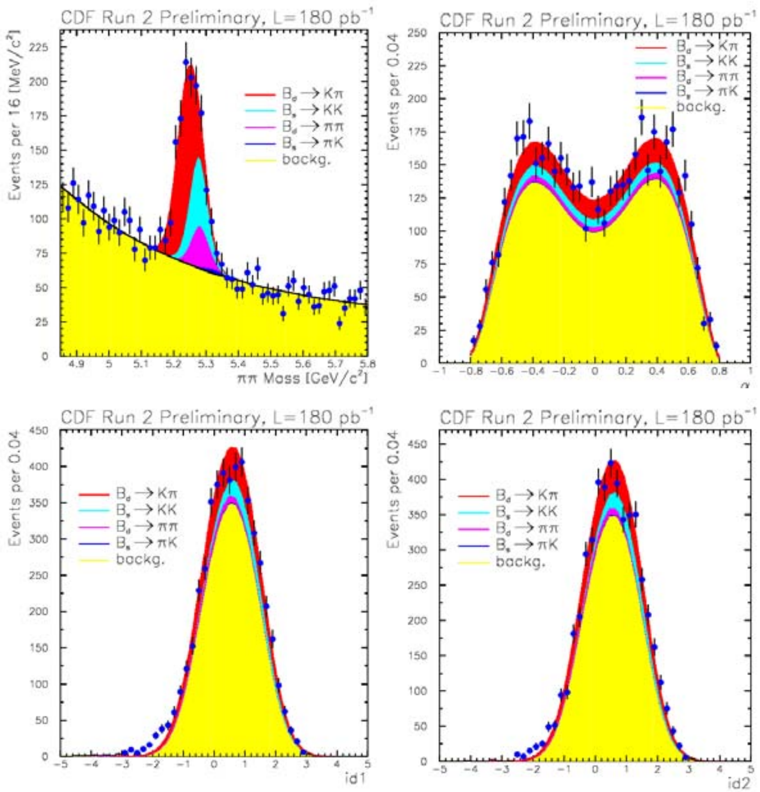




$B_{d,s} \rightarrow h^{-}h'^{+}$: fit

- The fraction of each compenent is extracted from an unbinned Maximim-Likelihood fit on: $M_{\pi\pi}$, α, tracks PID.

Parameter	Value	# of events
$f(B_d \rightarrow \pi\pi)$	0.15 ± 0.03	134
$f(B_d \rightarrow K\pi)$	0.57 ± 0.03	509
$A_{CP}(B_d \rightarrow K\pi)$	–0.05 ± 0.08	–
$f(B_s \rightarrow K\pi)$	0.02 ± 0.03	0
$f(B_s \rightarrow KK)$	0.26 ± 0.03	232



- Raw results need 5-10% corrections for efficiency differences between channels:
  - ✓ ε_{trig}
  - ✓ ε_{reco}
  - ✓ ε_{ana}
  - ✓ ε_{XFT}
  - ✓ ε_{isol} (only for B_s/B_d ratios)

- Main systematic sources:
  - 16% from dE/dx calibration ($D^{*+} \rightarrow D^0\pi^+$ sample);
  - 10% from isolation cut efficiency (B_u ,B_d, B_s control samples).

$B_{d,s} \to h^- h'^+$: final results (I)

B_d sector

	CDF (180 pb^{-1})	BaBar (200 fb^{-1})	Belle (140 fb^{-1})
$N(B_d \to K^+\pi^-)$	509	1600	1030
$\frac{BR(B_d \to \pi^+\pi^-)}{BR(B_d \to K^+\pi^-)}$	**$0.24 \pm 0.06 \pm 0.04$**	$0.26 \pm 0.036 \pm 0.015^{(*)}$	$0.24 \pm 0.035 \pm 0.018^{(*)}$
$A_{CP}(B_d \to K^+\pi^-)$	**$-0.04 \pm 0.08 \pm 0.01$**	$-0.133 \pm 0.03 \pm 0.009$	$-0.088 \pm 0.03 \pm 0.013$

(*) calculated from HFAG2004

- Ratio of B_d BR consistent with other experiments
  $\Rightarrow$ provides valuable cross-check for the other BR measurements.
- A_{CP} compatible with BaBar/Belle.
- Systematic uncertainties at the same level.

$B_{d,s} \to h^- h'^+$: final results (II)

B_s sector

	CDF (180 pb^{-1})	Expectations
BR($B_s \to KK$)	(0.50±0.08±0.09) BR($B_d \to K\pi$) (f_d / f_s) **= [34.3 ± 5.5 ± 5.2] × 10^{-6} (*)**	[23-36] × 10^{-6} Beneke Neubert, Nucl. Phys. B675 (2003)
BR($B_s \to K\pi$)	< 0.11 × BR($B_d \to K\pi$) (f_d / f_s) **⇒ < 7.55 × 10^{-6} @ 90% C.L. (*)**	[7-10] × 10^{-6} Beneke Neubert, Nucl. Phys. B675 (2003)

(*) based on BR($B_d \to K\pi$) and f_d / f_s from PDG2004

$B_{d,s}$ rare modes

	CDF (180 pb^{-1})	PDG2004	Expectations
BR($B_d \to KK$)	< 0.17 × BR($B_d \to K\pi$) **⇒ < 3.1 × 10^{-6} @ 90% C.L.**	<0.6 × 10^{-6}	[0.01-0.2] × 10^{-6} Beneke Neubert, Nucl. Phys. B675 (2003)
BR($B_s \to \pi\pi$)	0.10 × BR($B_s \to KK$) **⇒ < 3.4 × 10^{-6} @ 90% C.L.**	<1700 × 10^{-6}	[0.03-0.16] × 10^{-6} Beneke Neubert, Nucl. Phys. B675 (2003)

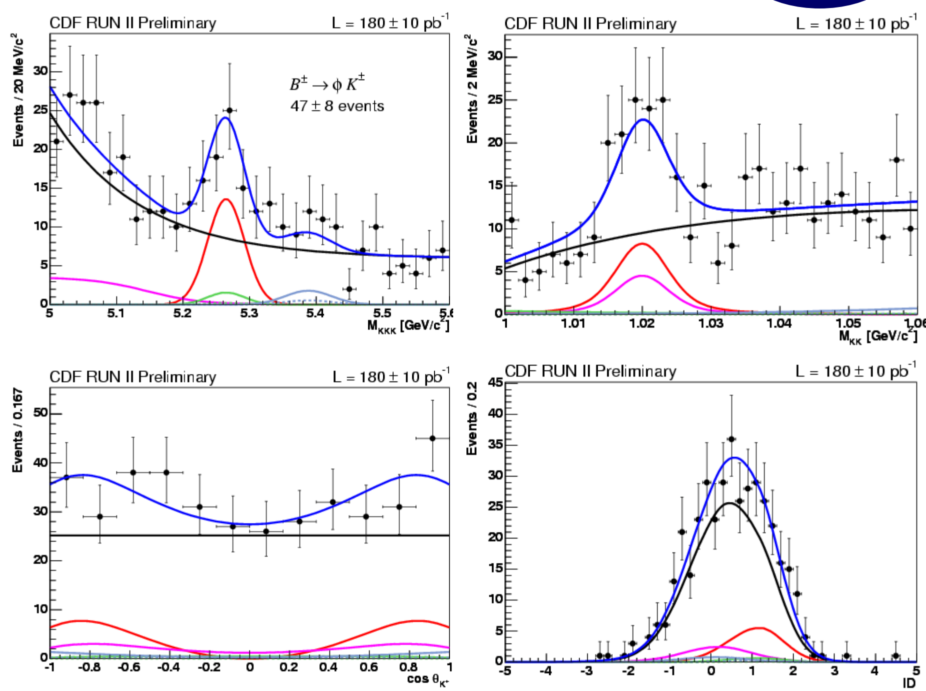
$B^{\pm} \to \phi K^{\pm}$: sample selection

- ✓ $b \to s\bar{s}s$ quark level transition: in SM dominated by gluon penguin;
- ✓ no A_{CP} expected
  $\Rightarrow$ sensitive to new physical states.

- ϕ is reconstructed in K^+K^- final state.
- Selection cuts optimized for max $S/(S+B)^{1/2}$ [S from MC, B from data sidebands]:
  - $p_T^{(soft)} > 1.3$ GeV/c;
  - $|d_0^{(soft)}| > 120$ μm;
  - $\chi_{xy}^2 < 8$;
  - $L_{xy} > 350$ μm;
  - $p_T^{(B)} > 4$ GeV/c;
  - $|d_0^{(B)}| < 100$ μm;
  - Isol > 0.5.

180 pb^{-1}

- Yield and A_{CP} asymmetry are extracted simultaneously from an extended unbinned Maximum-Likelihood fit on:
  - ✓ M_{KKK},
  - ✓ M_{ϕ},
  - ✓ ϕ helicity,
  - ✓ dE/dx.



- BR relative to $B^{\pm} \to J/\psi K^{\pm}$ w/ $J/\psi \to \mu\mu$:
  - ✓ B production cross section cancels;
  - ✓ systematic on efficiencies reduced.

Channel	Yield	Asymmetry
$B^{\pm} \to \phi K^{\pm}$	47.0 ± 8.4	–0.07 ± 0.17
$B^{\pm} \to J/\psi K^{\pm}$	439 ± 22	0.046 ± 0.050

$B^{\pm} \rightarrow \phi K^{\pm}$: BR and A_{CP}

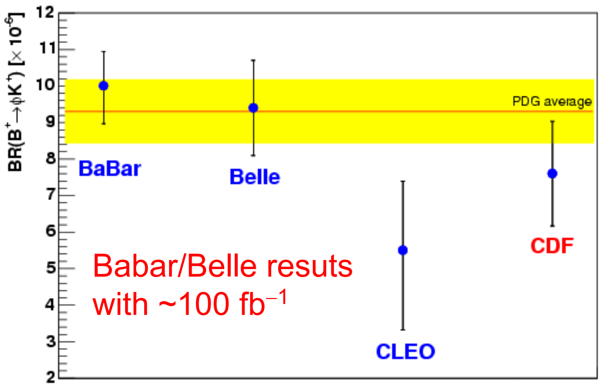
DATA — MC — PDG

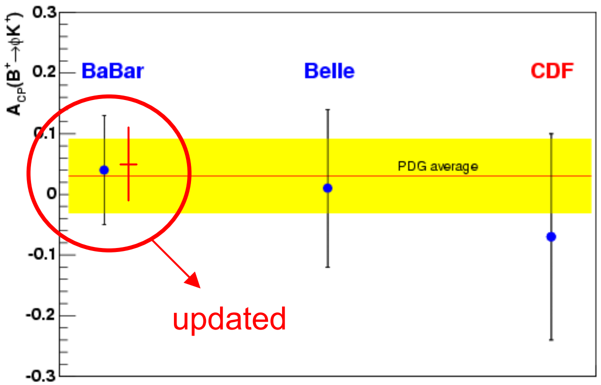
$$BR(B^{\pm} \rightarrow \phi K^{\pm}) = \frac{N_{\phi K}}{N_{\psi K}} \cdot \frac{\varepsilon_{\psi K}}{\varepsilon_{\phi K}} \cdot \frac{BR(B^{\pm} \rightarrow J/\psi K)\, BR(J/\psi \rightarrow \mu\mu)}{BR(\phi \rightarrow KK)}$$

$$= [\, 7.6 \pm 1.3(stat.) \pm 0.7(syst.)\,] \times 10^{-6}$$

$$A_{CP} = \frac{\Gamma(B^- \rightarrow \phi K^-) - \Gamma(B^+ \rightarrow \phi K^+)}{\Gamma(B^- \rightarrow \phi K^-) + \Gamma(B^+ \rightarrow \phi K^+)} = -0.08 \pm 0.17(stat.)^{+0.03}_{-0.02}(syst.)$$

- Main systematic error sources:
  - ✓ 3% from fit modeling;
  - ✓ 5.6% from efficiencies (only BR).





Search for $B_s \to \phi\phi$

- ✓ $b \to s\bar{s}s$ quark level transition: in SM dominated by gluon penguin;
- ✓ mixture of CP-even and CP-odd eigenstates, angular analysis allows to project out CP components:
  - ⇒ access $\Delta\Gamma_s$;
  - ⇒ test polarization predictions.

- Never seen before.
- A blind analysis was performed in anticipation of a small signal rate.
- Cuts optimized using the score function [G.Punzi hep-physics/0308063]:

MC efficiency for the i-th set of cuts

$$\frac{1}{S_{min}} \propto \frac{\varepsilon_i}{a/2 + \sqrt{B_i}} \quad \text{with } a = 3$$

expected bkg from ϕ sidebands for the i-th set of cuts

- ✓ for a=3 maximize the sensitivity region for a 3σ discovery with 99% C.L.;
- ✓ optimization independent from MC normalization;
- ✓ divergence safe for $B_i << 1$.

$B_s \to \phi\phi$ evidence

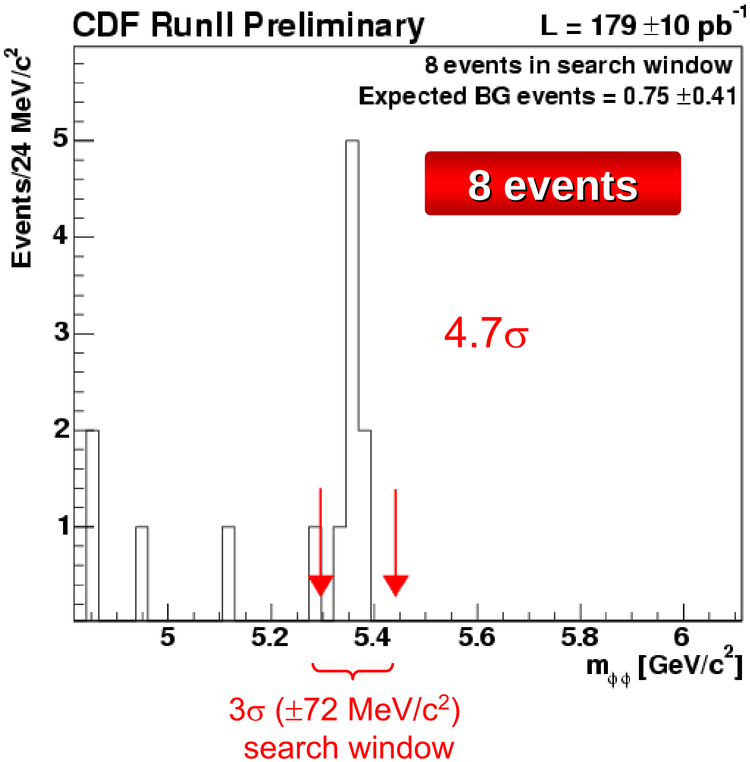
- ϕ's are reconstructed in K^+K^- final state.

180 pb^{-1}

- Selection cuts:
  - $| M_{KK}^{(1,2)} - M_\phi | < 15$ GeV/c^2;

  Optimized cuts:
  - $\chi_{xy}^2 < 10$;
  - $L_{xy} > 350\ \mu$m;
  - $|d_0^{(B)}| < 80\ \mu$m;
  - $p_T^{(\phi 1)} > 2.5$ GeV/c
  - $|d_0^{(\phi 1)}| < 40\ \mu$m;
  - $|d_0^{(\phi 2)}| < 110\ \mu$m.

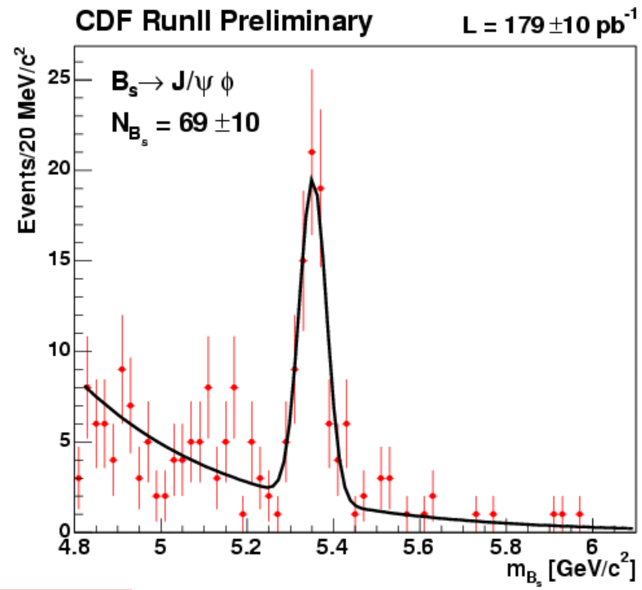
- Backgrounds in B_s mass window:
  - total: 0.75 ± 0.41;
  - combinatorial bkg: 0.35 ± 0.37 estimated from both ϕ's sidebands;
  - $B_d \to \phi K^{*0}$: 0.37 ± 0.18 estimated from MC.



- Poisson probability of a bkg fluctuation to the observed or higher number of signal events: 1.3×10^{-6}.

$B_s \to \phi\phi$ branching ratio

- BR normalized to $B_s \to J/\psi\phi$ w/ $J/\psi \to \mu\mu$ and $\phi \to KK$:
  - ✓ $S/(S+B)^{1/2}$ maximized;
  - ✓ 69 ± 10 events;
  - ✓ 3.7 ± 1.7 bkg events from $B_d \to J/\psi K^{*0}$.



DATA | MC | PDG

$$BR(B_s \to \phi\phi) = \frac{N_{\phi\phi}}{N_{\psi\phi}} \cdot \frac{\varepsilon_{\psi\phi}}{\varepsilon_{\phi\phi}} \cdot \frac{BR(B_s \to J/\psi\phi)\, BR(J/\psi \to \mu\mu)}{BR(\phi \to KK)}$$

$$= [\, 14^{+6}_{-5}\,(stat.) \pm 6(syst.)\,] \times 10^{-6}$$

- Main systematic error sources:
  - ✓ 36% from $B_s \to J/\psi\phi$ BR;
  - ✓ 8% from $B_s \to J/\psi\phi$ yield and background;
  - ✓ 4% from $B_s \to \phi\phi$ polarization and $\Delta\Gamma_s$.

- QCDF expectation:

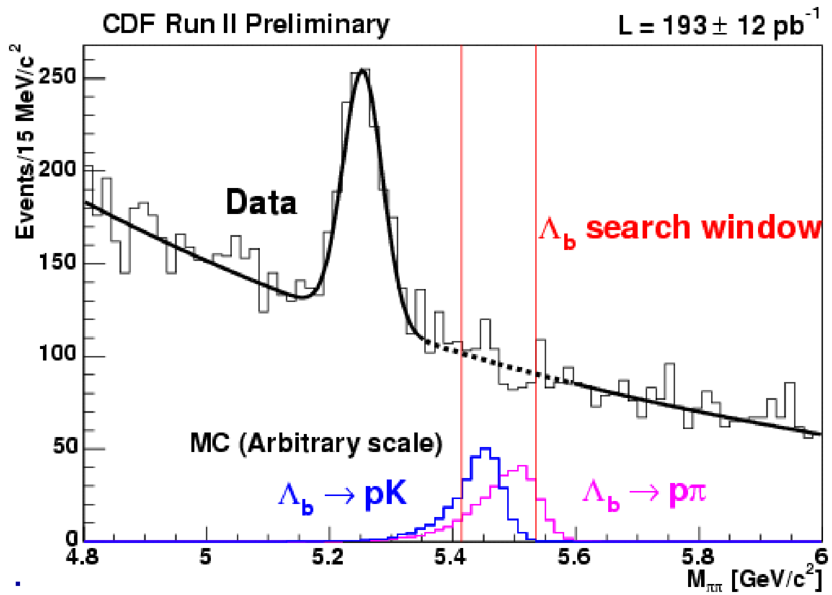
  $BR(B_s \to \phi\phi) = 13.1 \times 10^{-6}$

  [Li,Lu,Yang hep-ph/0309136]

Search for $\Lambda_b \to p\pi^-/pK^-$

- ✓ Large A_{CP} expected;
- ✓ not affected by mixing
  - ⇒ no need for tagging

193 pb^{-1}



- Theoretical predictions:
  - ✓ BR($\Lambda_b \to p\pi^-$) $\approx 0.9\text{-}1.2 \times 10^{-6}$;
  - ✓ BR($\Lambda_b \to pK^-$) $\approx 1.4\text{-}1.9 \times 10^{-6}$.

[Mohanta, Phys. Rev. D63:74001, 2001]

- Current experimental limits:
  - ✓ BR($\Lambda_b \to p\pi^-$) $< 50 \times 10^{-6}$ @ 90% C.L.;
  - ✓ BR($\Lambda_b \to pK^-$) $< 50 \times 10^{-6}$ @ 90% C.L.

- Blind optimization to reduce background in Λ_b mass region.
- Normalized to $B_d \to K\pi$.
- Using $f_\Lambda / f_d = 0.25 \pm 0.04$:

BR($\Lambda_b \to p\pi^-$) + BR($\Lambda_b \to pK^-$) < 22 × 10-6 @ 90% C.L.

Conclusion and perspective

- CDF is now a player in the field of charmless 2-body B decays, increasingly important with Tevatron higher luminosity.

- First generation results will be improved soon:
  - ✓ $\times$3 more luminosity;
  - ✓ better tracking and PID;
  - ✓ dedicated trigger on non-prompt $\phi \to K^+K^-$.

- New results expected:
  - ✓ $B_s \to KK$ lifetime $\Rightarrow \Delta\Gamma_s$;
  - ✓ $B_s \to K\pi$ BR and A_{CP};
  - ✓ $\Lambda_b \to ph$ BR and A_{CP};
  - ✓ $B_s \to \phi\phi$ polarization amplitudes and lifetime;
  - ✓ new B_s decays visible.

Backup slides

$B_{d,s} \to h^- h'^+$: systematics

source	$\frac{f_s}{f_d} \cdot \frac{BR(B_s \to KK)}{BR(B_d \to K\pi)}$	$A_{CP}(B_d \to K\pi)$	$\frac{BR(B_d \to \pi\pi)}{BR(B_d \to K\pi)}$	$\frac{f_d}{f_s} \cdot \frac{BR(B_d \to \pi\pi)}{BR(B_s \to KK)}$
mass resolution	$^{+0.001}_{-0.004}$	$^{+0.001}_{-0.001}$	$^{+0.001}_{-0.002}$	$^{+0.001}_{-0.001}$
dE/dx correlation: RMS(s)	$^{+0.043}_{-0.031}$	$^{+0.002}_{-0.002}$	$^{+0.034}_{-0.025}$	$^{+0.029}_{-0.017}$
dE/dx correlation: pdf(s)	$^{+0.002}_{-0.002}$	$^{+0.002}_{-0.002}$	$^{+0.000}_{-0.000}$	$^{+0.002}_{-0.002}$
dE/dx tail	$^{+0.056}_{-0.056}$	$^{+0.003}_{-0.003}$	$^{+0.020}_{-0.020}$	$^{+0.017}_{-0.017}$
dE/dx shift	$^{+0.001}_{-0.002}$	$^{+0.001}_{-0.001}$	$^{+0.001}_{-0.003}$	$^{+0.017}_{-0.005}$
input masses	$^{+0.027}_{-0.028}$	$^{+0.003}_{-0.003}$	$^{+0.009}_{-0.010}$	$^{+0.009}_{-0.010}$
background model	$^{+0.005}_{-0.005}$	$^{+0.002}_{-0.002}$	$^{+0.003}_{-0.003}$	$^{+0.000}_{-0.000}$
lifetime	$^{+0.004}_{-0.004}$	-	-	$^{+0.004}_{-0.004}$
isolation efficiency	$^{+0.051}_{-0.051}$	-	-	$^{+0.050}_{-0.050}$
MC statistics	$^{+0.004}_{-0.004}$	$^{+0.001}_{-0.001}(*)$	$^{+0.003}_{-0.003}$	$^{+0.006}_{-0.006}$
charge asymmetry	-	$^{+0.002}_{-0.002}$	-	-
XFT-bias correction	$^{+0.010}_{-0.007}$	-	$^{+0.004}_{-0.004}$	$^{+0.015}_{-0.010}$
$p_T(B)$ spectrum	$^{+0.007}_{-0.007}$	-	-	$^{+0.007}_{-0.007}$
$\Delta\Gamma_s/\Gamma_s$ Standard Model	$^{+0.007}_{-0.006}$	-	-	$^{+0.006}_{-0.006}$
TOTAL	± 0.09	± 0.01	± 0.04	± 0.07

$B^{\pm} \to \phi K^{\pm}$: systematics

BR

SYSTEMATIC	ERROR [%]
$B^{\pm} \to \phi K^{\pm}$ yield	3.0
$B^{\pm} \to J/\psi K^{\pm}$ yield	3.3
$\varepsilon_{\mu\mu K}/\varepsilon_{KKK}$	1.5
$\langle \varepsilon_{\mu} \rangle$	2.6
$\varepsilon_{R_{iso}}$	1.4
Particle dependent XFT efficiency	3.3
acceptance φ dependence due to COT ageing	0.3
χ^2_{xy} cut efficiency	3.0
$BR(J/\psi \to \mu\mu)$	1.2
$BR(\phi \to KK)$	1.7
TOTAL	7.4

A_{CP}

SYSTEMATIC	ERROR
fit	$^{+0.034}_{-0.020}$
detector charge asymmetry	0.005
TOTAL	$^{+0.034}_{-0.021}$

$B_s \to \phi\phi$: systematics

Systematic	Error
XFT efficiency by particle species	2.5%
XFT efficiency due to COT ageing	0.3%
XFT efficiency correction parameterization	2.1%
Polarization of $B_s \to \phi\phi$ decay	3.8%
Polarization of $B_s \to J/\psi\phi$ decay	1.4%
$\Delta\Gamma_s$ theory uncertainty	0.6%
$B_s \to J/\psi\phi$ yield determination	6.1%
Backgrounds	5.4%
track–muon stub matching efficiency	5.8%
J/ψ,ϕ BR	2.1%
sub-total	11%
BR($B_s \to J/\psi\phi$)	36%
Total	38%

$\Lambda_b \rightarrow p\pi^-/pK^-$: systematics

$B_d \rightarrow h^\pm h^\mp$	
Model function	5.7%
Background	
Model function	3.3%
Efficiency ratio	
$\Lambda_b \rightarrow p\pi / \Lambda_b \rightarrow pK$ ratio	2.3%
Window position	1.2%
Window width	9%
Lifetime	3.6%
XFT proton efficiency	6%
$p_T(\Lambda_b)$	17%
Overall systematic	21%
$\mathrm{BR}(B_d \rightarrow K\pi)$	8.6%
$f(\Lambda_b)/f(B)$	16%