Rare and charmless decays at CDFII
IFAE 2006, Pavia

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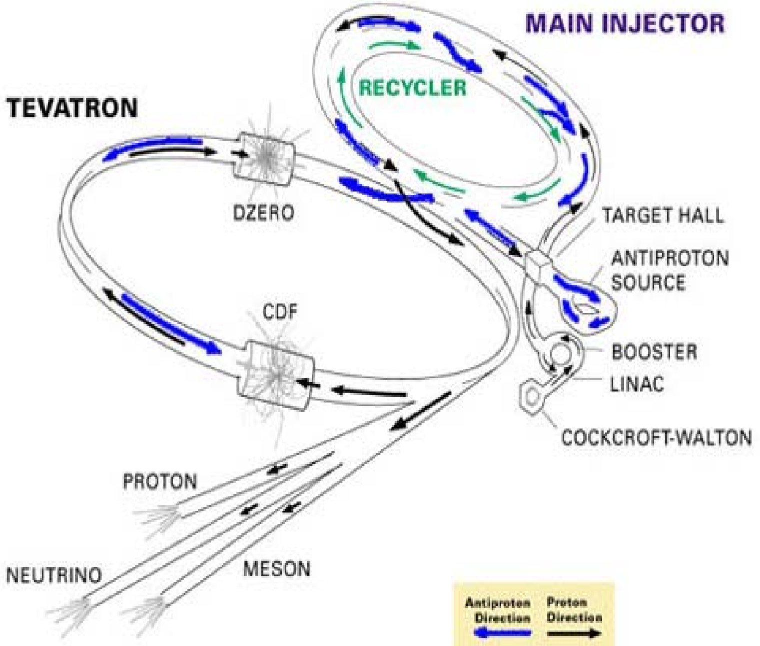
Outline

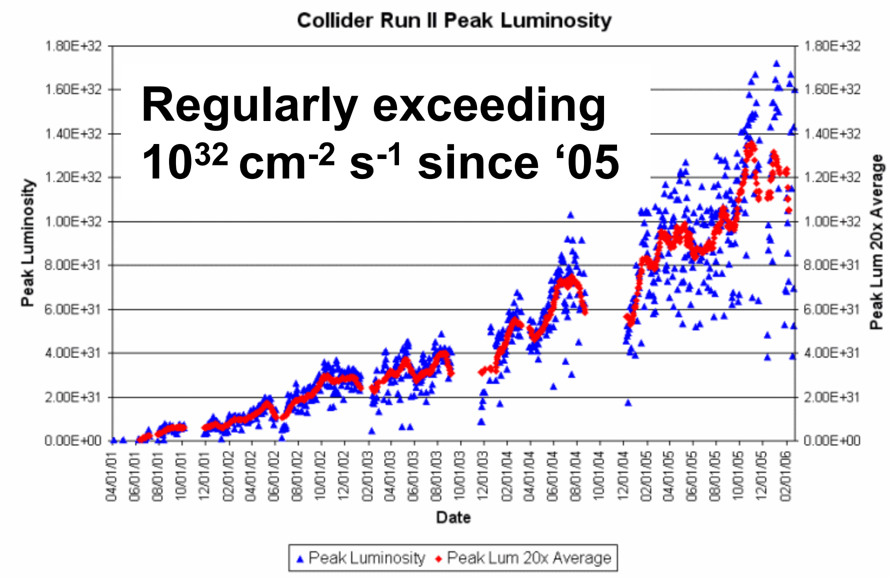
This focus on rare and charmless B decays.
Analysis of such modes provides CDF with a physics program competitive with (B^0 modes), and complementary (B^0_s modes) to B-factories. Well suited to illustrate the methods used in flavor physics analyses at CDF.

- CDF at the Tevatron: HF physics at hadron colliders;
- triggering on displaced tracks;
- search for FCNC $B^0_{(s)} \longrightarrow \mu^+\mu^-$ decays;
- BRs and DCPV in $B^0_{(s)} \longrightarrow \pi\pi/K\pi/KK$ (PP) decays;
- $\Delta\Gamma_s/\Gamma_s$ in $B^0_s \longrightarrow K^+K^-$ decays;
- BR in $B^0_s \longrightarrow \phi\phi$ (VV);
- Recent measurement of B_c mass and lifetime.

The Tevatron $p\bar{p}$ collider

36 (*proton*) × 36 (*antiproton*) bunches
X-ing time 396 ns at $\sqrt{s}$ = 1.96 TeV
record peak is L=1.82 × 10^{32} cm^{-2} s^{-1}
~ 18 pb^{-1} / week recorded on tape
# of interactions per bunch-crossing:
< N >poisson = 2 (at 10^{32} $cm^{-2}s^{-1}$)

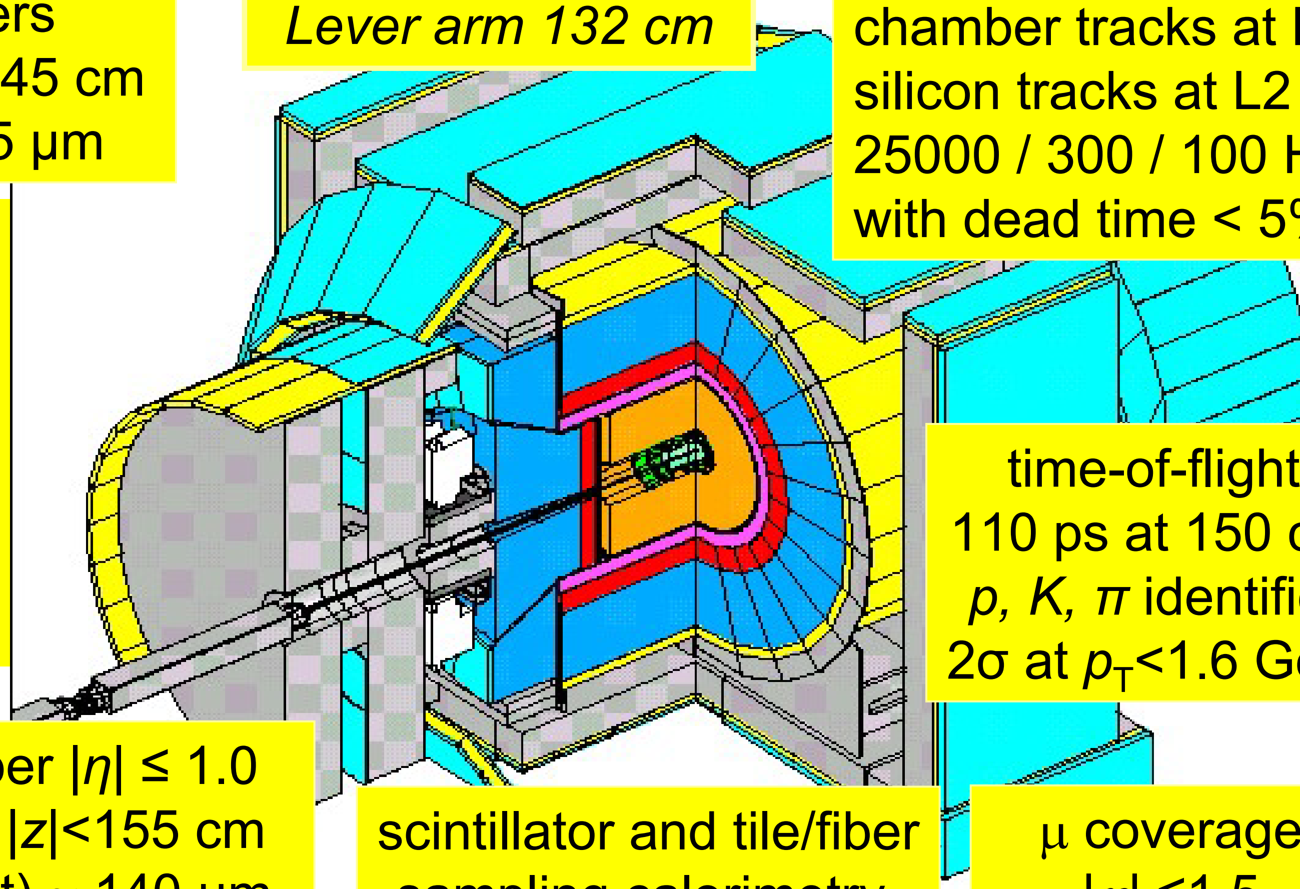




L_{int}~ 1400 pb^{-1} on tape
(~ 1000 pb^{-1} for analysis)

Stable data taking efficiency: > 85%.
Results here use ~180-800 pb^{-1}

The CDF II detector



7 to 8 silicon layers
$1.6 < r < 28$ cm, $|z|<45$ cm
$|\eta| \leq 2.0$ σ(hit) ~ 15 μm

1.4 T magnetic field
Lever arm 132 cm

132 ns front end
chamber tracks at L1
silicon tracks at L2
25000 / 300 / 100 Hz
with dead time < 5%

Some resolutions:
p_T~0.15% p_T (c/GeV)
J/Ψ mass ~14 MeV
EM E ~ 16%/√E
Had E ~ 80%/√E
d_0 ~ 40 μm
(includes beam spot)

time-of-flight
110 ps at 150 cm
p, K, π identific.
2σ at p_T<1.6 GeV

96 layer drift chamber $|\eta| \leq 1.0$
$44 < r < 132$ cm, $|z|<155$ cm
30k channels, σ(hit) ~ 140 μm
dE/dx for *p, K, π* identification

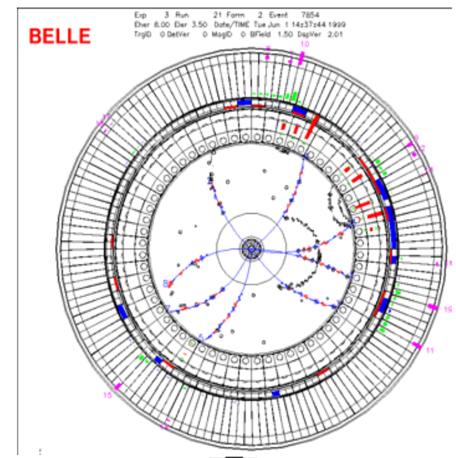
scintillator and tile/fiber
sampling calorimetry
$|\eta| < 3.64$

μ coverage
$|\eta| \leq 1.5$
84% in ϕ

Heavy Flavor physics at the Tevatron

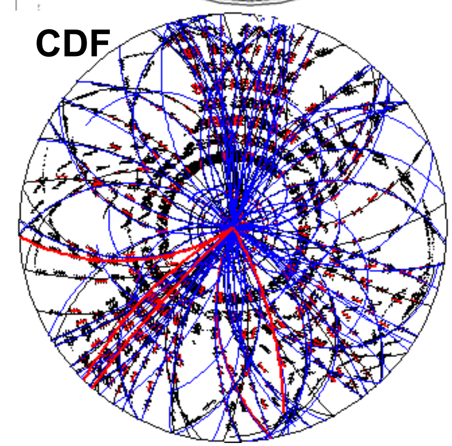
The Good

$b\bar{b}$ production x-section O(10^5) larger than e^+e^- at $\Upsilon(4S)$ /Z^0. Incoherent strong production of all *b*-hadrons: B^+, B^0, B^0_s, B_c, Λ_b, Ξ_b …



The Bad

Total inelastic x-section ×10^3 larger than $\sigma(b\bar{b})$. BRs' for interesting processes O(10^{-6}).



…and The Ugly

Messy environments with large combinatorics.

Need highly selective trigger

B hadron signature

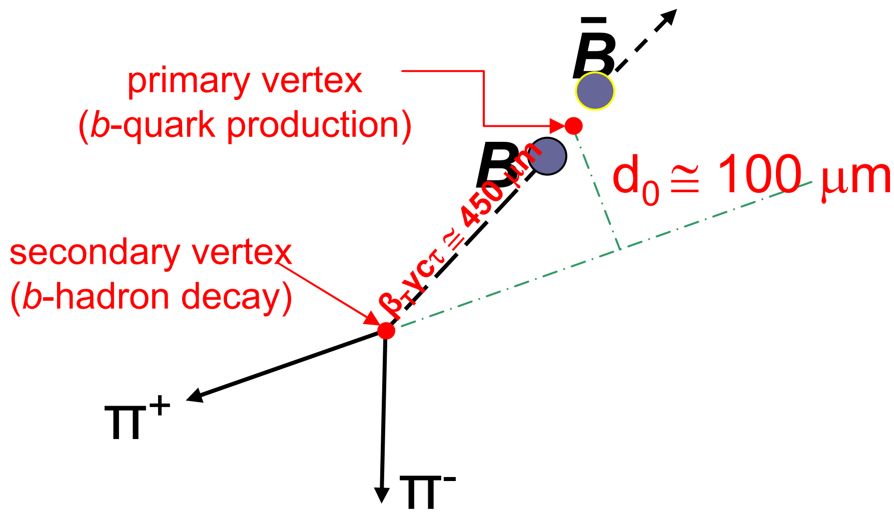
"Long" (~1.5 ps) lifetime of *b*-hadrons: a powerful signature against light-quark background.

Traditional *B*-trigger at hadronic collider: look for one ($B \rightarrow l \nu X$) or two leptons ($B \rightarrow J/\psi X$) exploiting easy signature and ~20% of total width.

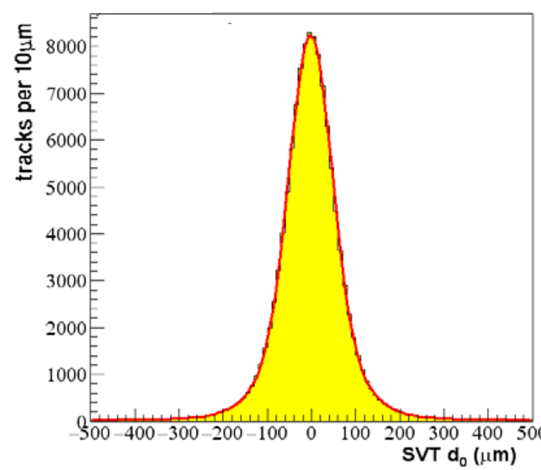
For the first time, trigger HF without leptons: rare hadronic *B* decays. Cut online (L2 trigger) on impact parameter d_0(track).

Very high-purity samples of hadronic *B* (and *D)* decays. Price to pay: trigger-bias distorts proper-time distributions. Complexity in lifetime-based analyses.

PLANE TRANSVERSE TO THE BEAM



$\sigma(d_0)$ = 48μm =35 [SVT] ⊕ 33 [beam-spot size]



Charmless $B^0/B^0_s \to PP$ ($\pi\pi/K\pi/KK$)

- Interpretation of B results often plagued by uncertainties from non-perturbative QCD uncertainties.
- Joint study of B^0 and B^0_s decays into 2-body charm-less ($\pi\pi/K\pi/KK$) plays a key role, related by subgroup of SU(3) symmetry.
- Until the beginning of the planned Y(5S) at Belle only CDF has simultaneous access to both $B^0/B^0_s \to h^+h'^-$ decays thus exploiting an original physics program complementary to the B-Factories

Some specific motivations

- These modes include $B^0 \rightarrow K^+\pi^-$, where the direct CP asymmetry was observed for the first time in B sector (B-Factories).
- Large (~10%) effect established, but still many things to understand, i.e. asymmetry in B^0 not compatible with B^+ as expected. [Gronau and Rosner, Phys. Rev. D71:074019, 2005]
- Additional experimental input is helpful: copious yields at TeVatron make CDF a major player in the direct-CPV game.

- Compare rates and asymmetries of $B^0 \rightarrow K^+\pi^-$ and $B^0_s \rightarrow K^-\pi^+$ unique to CDF – to probe NP with no need for assumption, just SM. [Lipkin, Phys. Lett. B621:126, .2005]

- Currently accessible BR can constrain theory too: compare CDF measurements with allowed regions in spaces of $B^0 \longrightarrow \pi^+\pi^-$ and $B^0_s \longrightarrow K^+K^-$ observables: a <u>probe for both γ and NP</u> [Fleischer and Matias PRD66: 054009,2002 - London and Matias PRD70:031502, 2004]

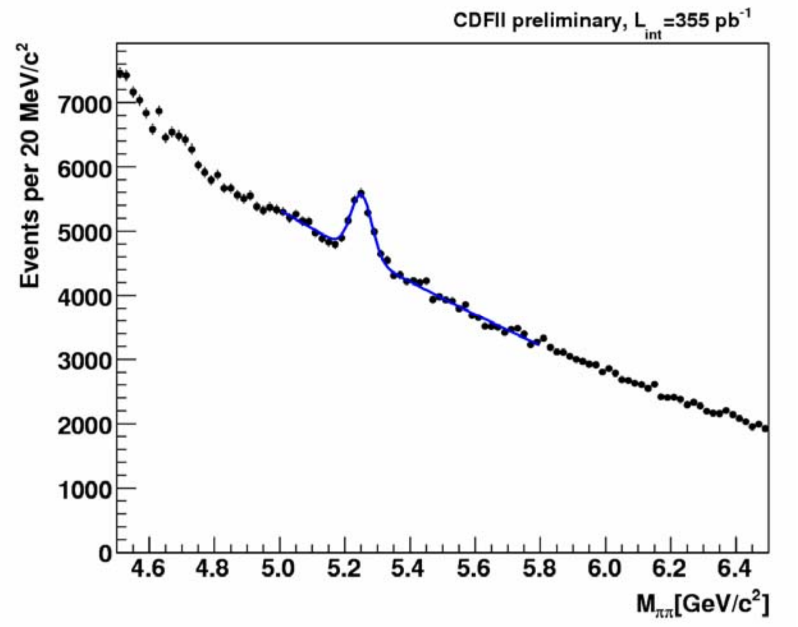
- From lifetime of $B^0_s \rightarrow K^+K^-$ (unique to CDF), information on the relative width-difference $\Delta\Gamma_s/\Gamma_s$. Compare with B^0_s mixing results to search for new, CP-violating physics. Can be strong affected by new, CP-violating physics.

Trigger confirmation

TRIGGER REQUIREMENTS

- Two oppositely-charged tracks (i.e. *B* candidate) from a long-lived decay:
  - track's impact parameter >100 μm;
  - *B* transverse decay length > 200 μm;
- *B* candidate pointing back to primary vertex:
  - impact parameter of the *B* < 140 μm;
- Reject light-quark background from jets:
  - transverse opening angle [20^o, 135^o];
  - p_{T1} and p_{T2} > 2 GeV;
  - $p_{T1}+p_{T2}$ > 5.5 GeV.

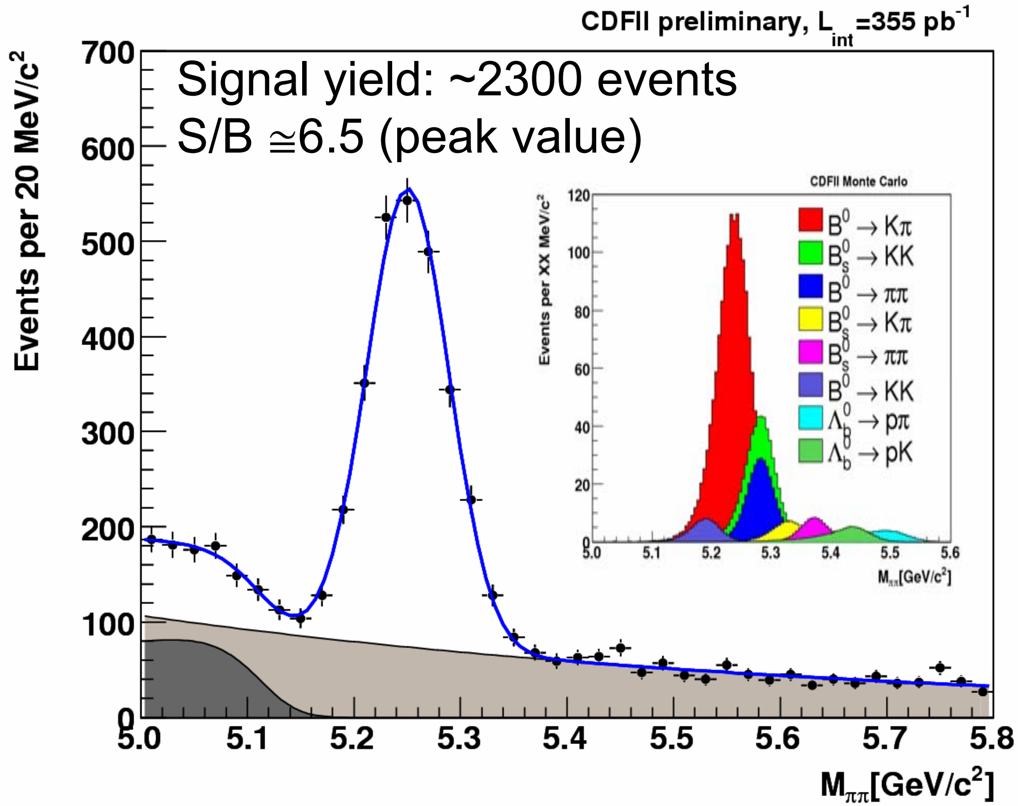
Signal (BR ~ 10^{-5}) visible with just offline trigger cuts confirmation:



a bump of ~3850 events with S/B ≈ 0.2 (at peak) in *ππ*-invariant mass

$B^0/B^0_s \rightarrow$PP DATA SAMPLE

Optimize cuts (IP, transverse decay length, 3D-vertex quality, isolation of B candidate and IP of both tracks) by minimizing the expected statistical resolution on A_{CP}. Its expression in terms of S and B is determined from actual resolutions observed in analysis of toy-MC samples.



Despite excellent mass resolution, modes overlap an unresolved peak, and PID resolution is insufficient for event-by-event separation. Hence, fit signal composition with a Likelihood that combines information form kinematics ($M_{\pi\pi}$, α=(1-p_1/p_2)·q_1 where $p_1<p_2$, $p_{tot}=p_1+p_2$) and particle ID (dE/dx).

Fit of composition

Un-binned ML fit that uses <u>kinematic and PID information</u> from 5 observables

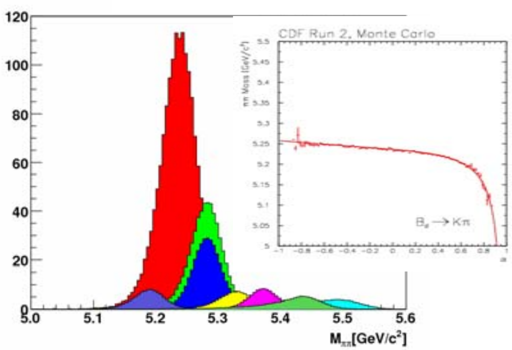
$$\mathscr{L}(\vec{\theta}) = \prod_{i=1}^{N} \mathscr{L}_i(\vec{\theta})$$

$$\mathscr{L}_i(\vec{\theta}) = (1-b)\sum f_j \mathscr{L}_j^{\text{sign}} + b\mathscr{L}^{\text{bckg}}$$

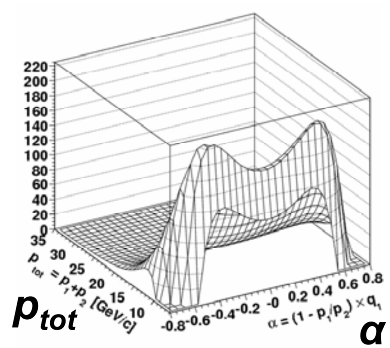
fraction of j[th] mode, to be determined by the fit

$$\mathscr{L} \sim \wp^m(m_{\pi\pi}|\alpha) \times \wp^p(\alpha, p_{\text{tot}}) \times \wp^{\text{PID}}(dE/dx_1, dE/dx_2|\alpha, p_{\text{tot}})$$

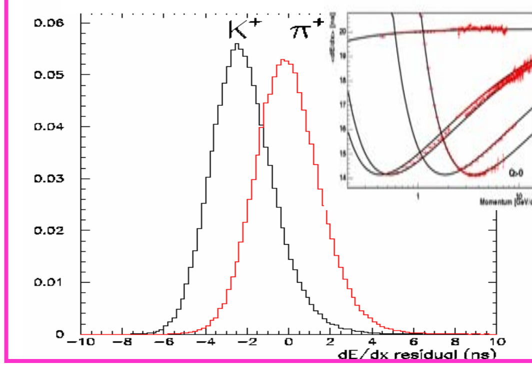
mass term



momentum term



PID term

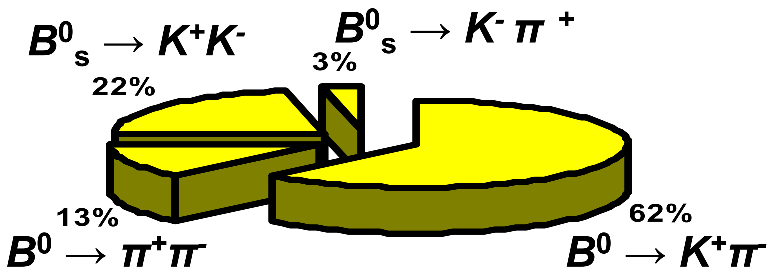


Signal shapes: from MC and analytic formula
Background shapes: from data sidebands

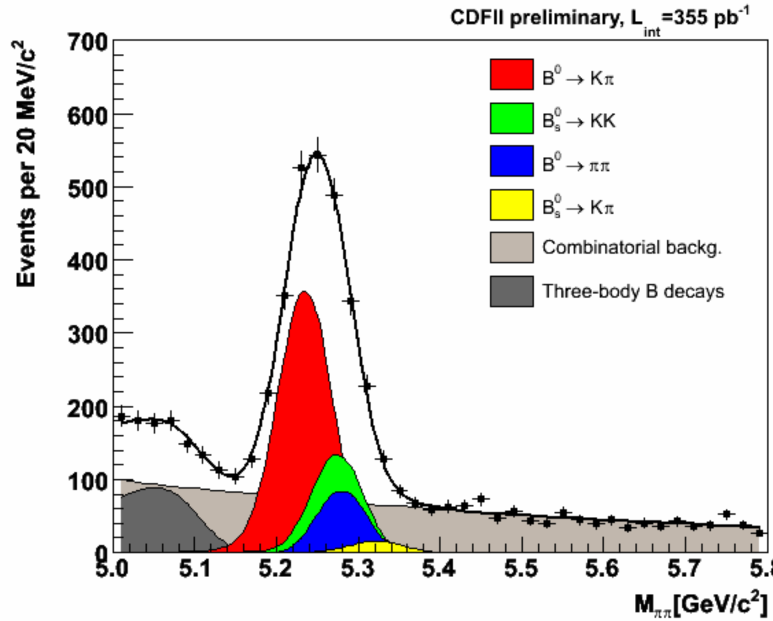
sign and bckg shapes from $D^0 \longrightarrow K^-\pi^+$

Direct CP asymmetry $B^0 \to K^+\pi^-$ (360 pb^{-1})

Uncorrected fractions



$B^0 \to K^+\pi^-$	–	787 ± 42
$\overline{B}^0 \to K^-\pi^+$	–	689 ± 41



NEW

$$A_{CP}^{CDF}(B^0 \to K^+\pi^-) = -0.058 \pm 0.039\ (stat.) \pm 0.007\ (syst.)$$

$$A_{CP}^{Babar}(B^0 \to K^+\pi^-) = -0.133 \pm 0.030\ (stat.) \pm 0.009\ (syst.)$$

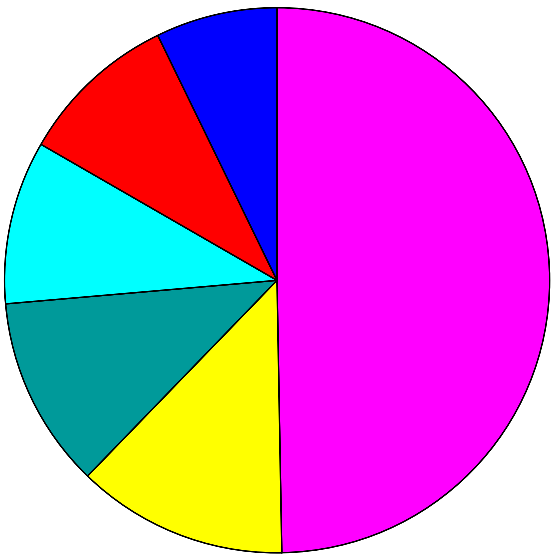
$$A_{CP}^{Belle}(B^0 \to K^+\pi^-) = -0.113 \pm 0.022\ (stat.) \pm 0.008\ (syst.)$$

Result is ~1.5σ different from 0, and compatible with *B*-factories results. With data already available on disk (1fb^{-1}), we expect ~2.5% statistical uncertainty: CDF will be soon (summer) very competitive.

In same data, is likely first observation of $B^0_s \longrightarrow K^-\pi^+$ self-tagged decay: will measure its BR and CP asymmetry that is expected large. [Lipkin, Phys.Lett.B621:126, 2005].

Systematics $A_{CP}(B^0 \to K^+\pi^-)$ (360 pb^{-1})

Total systematic uncertainty is 0.7% , much smaller than the 3.9% statistical uncertainty.



- dE/dx model (partially reduces with statistics);
- nominal *B*-meson masses input to the fit (reduces with statistics);
- mass-resolution model;
- global scale of masses;
- charge-asymmetries in background;
- combinatorial background model.

BRs: $B^0/B^0_s \to$ PP (180 pb^{-1})

$$\frac{f_s \cdot BR(B^0_s \to K^+K^-)}{f_d \cdot BR(B^0 \to K^+\pi^-)} = 0.46 \pm 0.08\ (stat.) \pm 0.07\ (syst.)$$

<u>$B^0_s \to K^+K^-$ decay established</u>. BR ratio may favor large SU(3) breaking as predicted from sum rules [Khodjamirian et al. PRD68:114007, 2003].

$$\frac{f_s \cdot BR(B^0_s \to K^-\pi^+)}{f_d \cdot BR(B^0 \to K^+\pi^-)} < 0.08\ @\ 90\%\ C.L.$$

No evidence for $B^0_s \to K^-\pi^+$, set a limit a <u>factor ~40 better than PDG04.</u>

$$\frac{BR(B^0_s \to \pi^+\pi^-)}{BR(B^0_s \to K^+K^-)} < 0.05\ @\ 90\%\ C.L$$

$$\frac{BR(B^0 \to K^+K^-)}{BR(B^0 \to K^+\pi^-)} < 0.10\ @\ 90\%\ C.L.$$

Upper limit on annihilation mode $B^0_s \to \pi^-\pi^+$ and $B^0 \to K^+K^-$ Great improvement on $B^0_s \to \pi^-\pi^+$: a factor >100 below PDG04 (time-evolutions of $B^0_s \to \pi^-\pi^+$ and $B^0_s \to K^-K^+$ assumed the same).

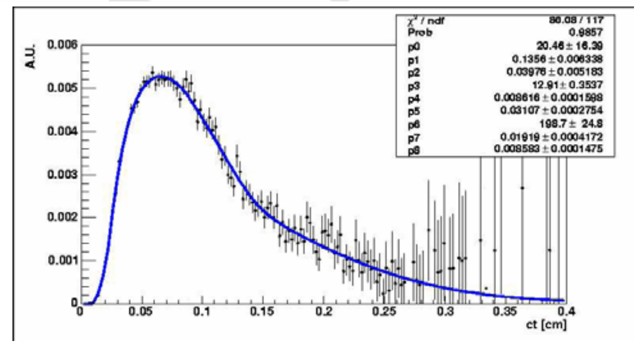
$B^0_s \to K^+K^-$ lifetime (360 pb^{-1})

Add lifetime information to the fit of composition:

$$\mathscr{L} \sim \wp^m(m_{\pi\pi}|\alpha)\,\wp^p(\alpha, p_{\text{tot}})\,\wp^{\text{PID}}(dE/dx_1, dE/dx_2|\alpha, p_{\text{tot}})\,\wp^{\text{life}}(ct).$$

$$\wp^{\text{life}}(ct) = \exp(\text{ct}) \times \text{Gauss}(\text{ct}) \times \varepsilon(\text{ct})$$

decay — detector smearing — trigger bias



Trigger bias for signal is extracted from detailed simulation.

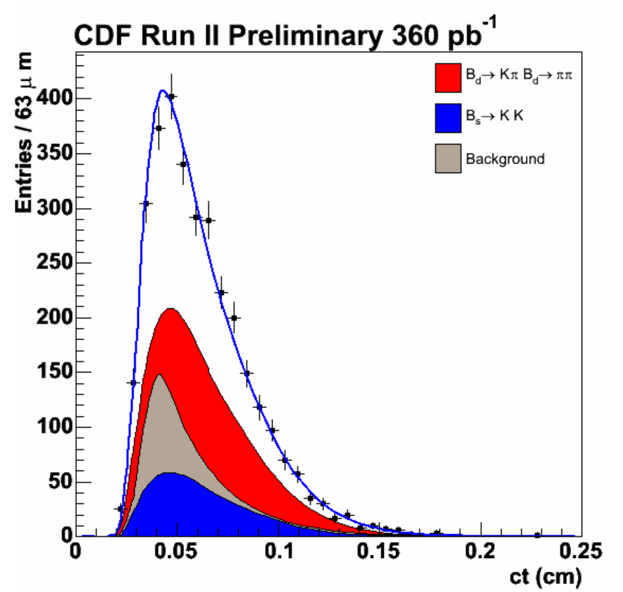
Procedure validated in unbiased $B \to J/\psi X$ decays from dimuon trigger.

Check that lifetime fits of samples with/without applying track-trigger cuts yield consistent results.

Lifetime p.d.f for background is extracted from higher mass data sideband.

$B^0_s \rightarrow K^+K^-$ lifetime results (360 pb^{-1})

	$c\tau(B^0)$ [μm]	$c\tau(B^0_s \rightarrow K^+K^-)$ [μm]
both free	452 ± 24	463 ± 56
$c\tau(B^0)$ constrained to PDG	–	458 ± 53



$B^0_s \rightarrow K^+K^-$ predicted ~95% CP-even: has the lifetime of "light B^0_s" :

NEW

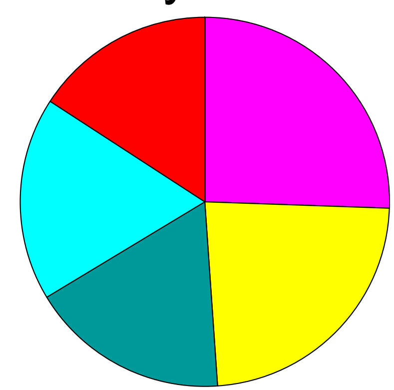
$$\tau_L = 1.53 \pm 0.18\ (stat.) \pm 0.02\ (syst.)\text{ps}$$

Combine with HFAG average $(\tau_L^2 + \tau_H^2)/(\tau_L + \tau_H)$:

NEW

$$\frac{\Delta\Gamma_s^{CP}}{\Gamma_s^{CP}} = -0.08 \pm 0.23\ (stat.) \pm 0.03\ (syst.)$$

Dominant systematics :

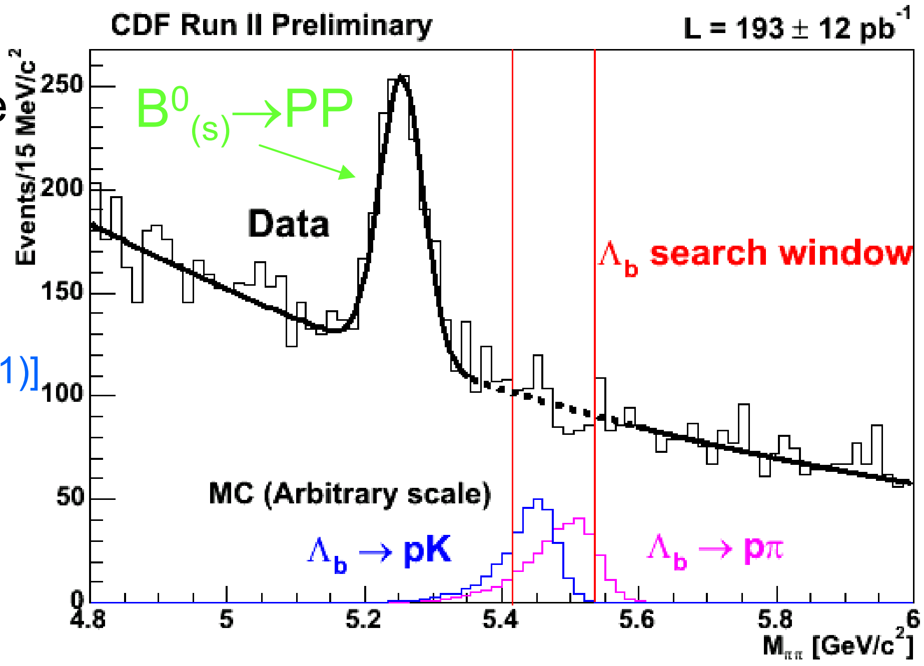


- detector alignment;
- dE/dx model;
- input $p_T(B)$ in simulation;
- trigger-bias.
- lifetime model of background;

$\Delta\Gamma_s/\Gamma_s$ compatible with direct measurement from $B^0_s \rightarrow J/\psi\phi$ [PRL 94:101803(2005)]

Behind the corner: $\Lambda^0_b \to p\pi/pK$ (190 pb^{-1})

- In the same data of charmless $B^0_{(s)} \to PP$ decays to look for evidence of charmless $\Lambda_b \to pK/p\pi$ decays.
- Theoretical expectations for BRs:
  $BR(\Lambda_b \to p\pi)) = [0.9 – 1.2] \cdot 10^{-6}$
  $BR(\Lambda_b \to pK)) = [1.4 – 1.9] \cdot 10^{-6}$
  [R. Mohanta at al. Phys. Rev.: D63 074001(2001)]
- Large direct CP asymmetries expected.
- Analysis on 190 pb^{-1} without PID.
- Normalize to $BR(B^0 \to K\pi)$.



[Phys. Rev. D72, 051104 (2005)]

Our current limit on 190 pb^{-1} is already the world best
$BR(\Lambda_b \to pK) + BR(\Lambda_b \to p\pi) < 2.3 \cdot 10^{-5}$ @ 90% C.L

World best

Assuming theoretical values for BRs, expect in 1 fb^{-1} $\sigma(BRs)_{TOY} \cong [0.3\text{-}0.2] \cdot 10^{-6}$, data already under analysis using the complete framework for $B^0_{(s)} \to PP$.
Likely observation and measurement of BRs and “direct CPV”.

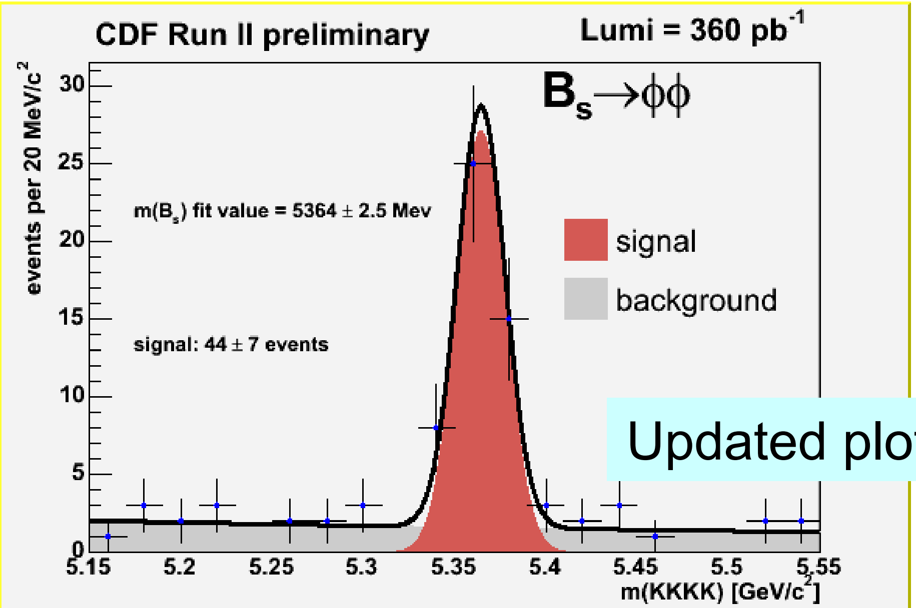
Charmless $B^0/B^0_s \to VV$

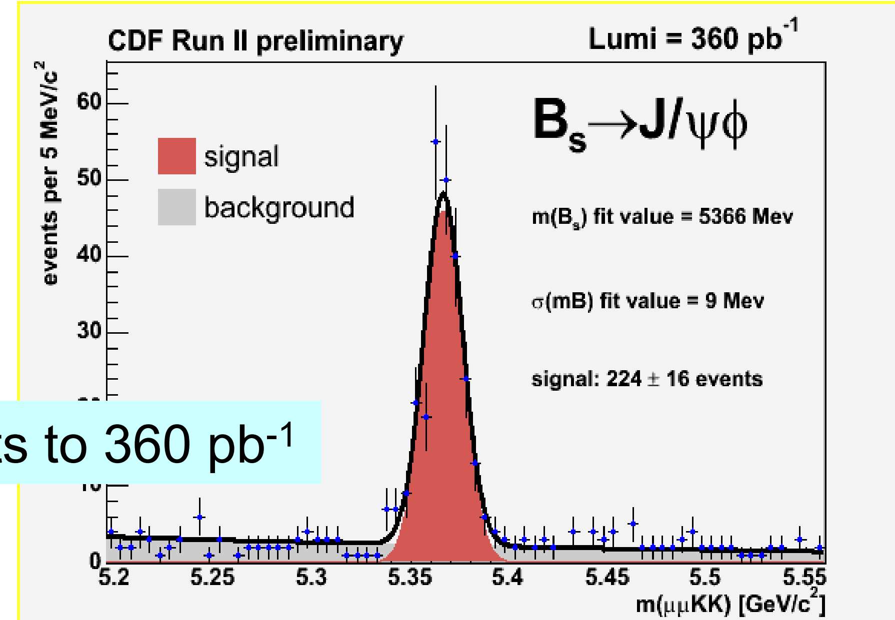
Motivations

- CDF can access to $B^0_s \to VV$ decays into self-coniugate final states, like $B^0_s \to \phi\phi$.
- Angular correlations (polarization) between the final state particles allow the statistical separation of the CP-even and CP-odd components of the decay amplitude.
- With sufficient statistics, this decomposition allows of the B^0_s decay width difference $\Delta\Gamma_s$, CKM studies and the tests of decay polarization.
- The BR measurement gives insight into the size of penguin amplitude.
- $B^0_s \to \phi\phi$ proceeds through a pure $b \to s\bar{s}s$ transition $\Longrightarrow$ probe for NP [hep-ph/0510245].
- Hints of NP in $B^0 \to \phi K^0_s$, $B^0 \to \eta' K^0_s$ from B-factories suggest to investigate in other pure $b \to s\bar{s}s$ transitions like $B^0_s \to \phi\phi$ and $B^+ \to \phi K^+$.

$B_s \to \phi\phi$ (VV)

Normalize to another $B_s \to VV$: $B_s \to J/\psi\phi$ Using the same hadronic trigger





Updated plots to 360 pb^{-1}

On the first 180 pb^{-1} data CDF established the the $B_s \to \phi\phi$ decay and measure its BR:

[PRL 95:031801(2005)]

180 pb^{-1}

$$BR(B_s^0 \to \phi\phi) = (14\,^{+6}_{-5}(stat.) \pm 6(syst.)) \times 10^{-6}$$

Soon update with the completely angular analysis using the full data sample (1fb^{-1})!!!!

Search for FCNC current $B^0/B^0_s \to \mu^+\mu^-$

Motivation: $B^0/B^0_s \to \mu^+\mu^-$

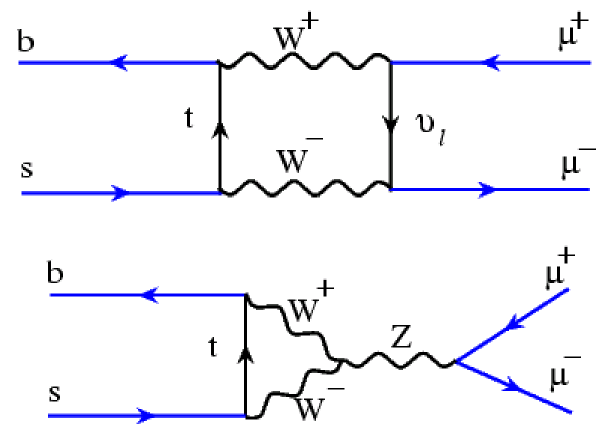
Standard Model

In the SM FCNC decays are highly supressed. Expectations:

$BR(B^0_s \to \mu\mu) \propto |V_{ts}|^2 \cong (3.42 \pm 0.54) \cdot 10^{-9}$

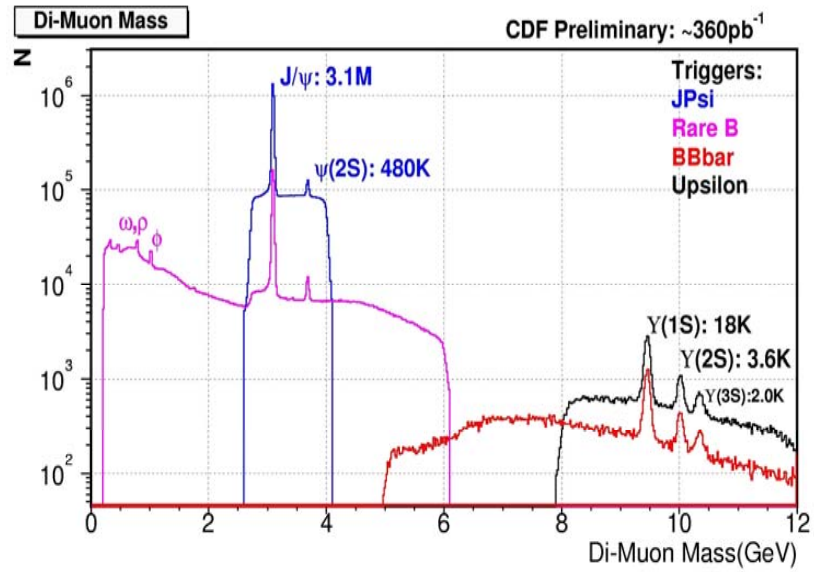
$BR(B^0 \to \mu\mu) \propto |V_{td}/V_{ts}|^2 \cong (1.00 \pm 0.14) \cdot 10^{-10}$

[Buchalla and Buras Nucl. Phys. B400,225(1993); Buras, Phys. Lett. B 566,115(2003)]



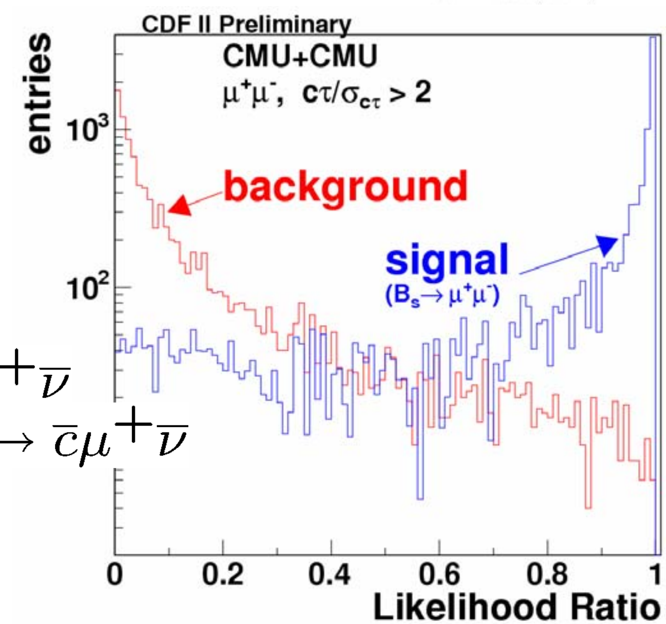
The BRs predicted form SM are about two orders of magnitude smaller than the current experimental sensitivity. However NP (SUSY) can significantly enhance (up to x100) these BRs $\Longrightarrow$ simultaneous observation of $B^0/B^0_s \to \mu^+\mu^-$ is important in determining structure of NP otherwise significant constraints to many SUSY models.

Analysis strategy: $B^0/B^0_s \to \mu^+\mu^-$



Search the sample from rare di-muon trigger (tracking + μ-system):
CMU(drift chambers)
$|\eta|<0.6$ muons with $p_T>1.4$ GeV
CMX(drift tubes)
$0.6<|\eta|<1$ muons with $p_T>2$ GeV

Offline reconstruction:
Confirmation trigger requirements
Discriminate using multivariate LR (decay length, 3D-pointing of the B to PV, isolation)



Significant backgrounds from:
- (a) Sequential semileptonic: $b \to c\mu^-\nu, c \to s\mu^+\overline{\nu}$
- (b) Double semileptonic decays: $b \to c\mu^-\nu, \overline{b} \to \overline{c}\mu^+\overline{\nu}$
- (c) Drell-Yan $p\overline{p} \to \mu^+\mu^-$
- (d) Fake leptons

Upper limit (780 pb^{-1}): $B^0/B^0_s \to \mu^+\mu^-$

CDF (not D0) has good mass resolution (~24 MeV) allows separation of $B^0_s \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$:

Measure of BR (or set limit) with respect to normalization decay $B^+ \to J/\psi K^+$.

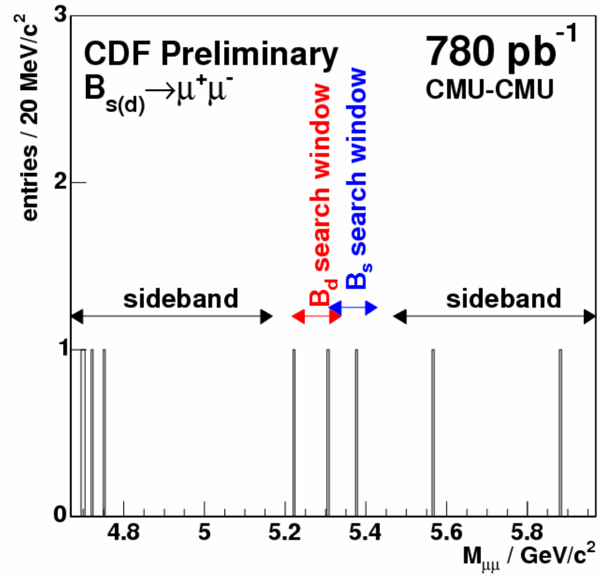
Number of events observed in either mass window compatible with background, set upper limit for both decays (world best):

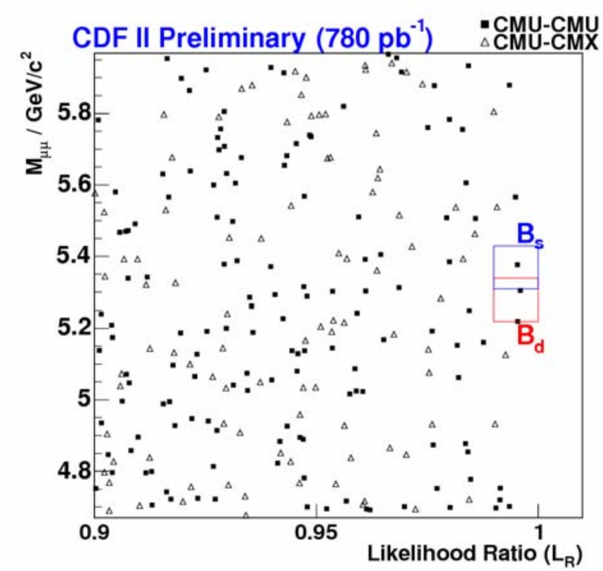
NEW 780 pb^{-1}

$BR(B^0_s \to \mu^+\mu^-) < 8 \times 10^{-8}$ @ 90% CL

$BR(B^0 \to \mu^+\mu^-) < 2.3 \times 10^{-8}$ @ 90% CL

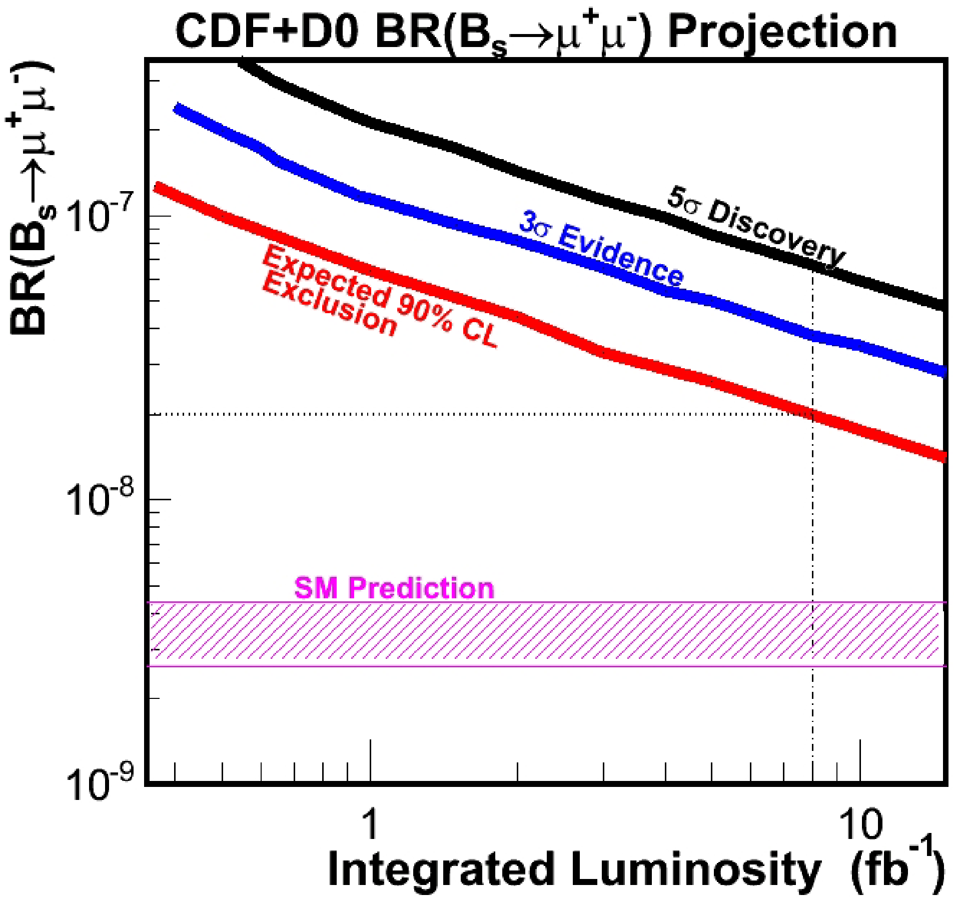
Previous results:
PRL 95, 221805(2005)
PRL 93, 032001(2004)





Future prospects for $B^0_s \to \mu^+ \mu^-$

- Assuming unchanged analysis techniques and reconstruction and trigger efficiencies are unaffected with increasing luminosity
- for 8fb^{-1}/experiment an exclusion at 90%C.L. down to 2×10^{-8} is possible
- both experiments (CDF + D0) pursue further improvements in their analysis.



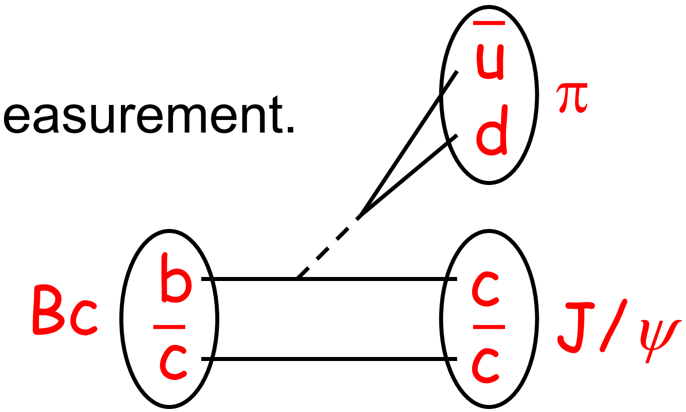
B_c properties

Motivations

- Bound state of two heavy quarks ($b\bar{c}$).
- Good lab for potential models, lattice QCD (only meson with different heavy flavors).
- Experimental challenge
  - $B^0:B^+:B^0_s:\Lambda^0_b \cong 40:40:10:10$, $B^-_c \cong 0.5\%$
  - Short lifetime $\Longrightarrow$ difficult selection
- First observation by CDF (1998) in semi-leptonic decays
  - properties not well measured.
- Today in Run II
  - higher statistics
  - more precise lifetime
  - access to exclusive modes $\Longrightarrow$ mass measurement.

B^-_c observation and mass (800 pb^{-1})

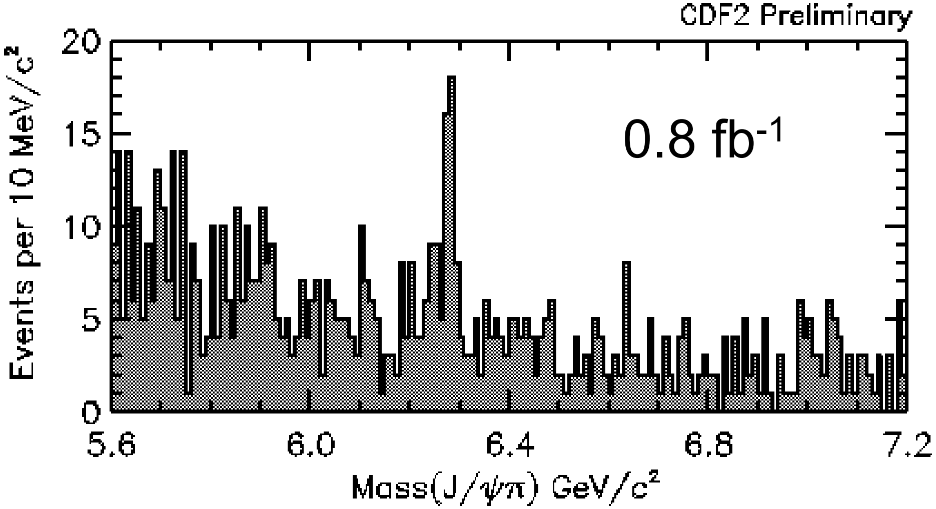
B_c is not produced at B factories
Full reconstruction allows for precise mass measurement.



Signal yield ≅ 38.9 events
Background yield ≅ 26.1
between 6.24 and 6.3 GeV/c^2
Significance > 6σ over search area

Lattice calculations [PRL 94:1720001]
show moderately good agreement with the CDF measurement:

$$m_{B_c} = 6304 \pm 4 \pm 11^{+18}_{-0}\ \mathrm{MeV}$$



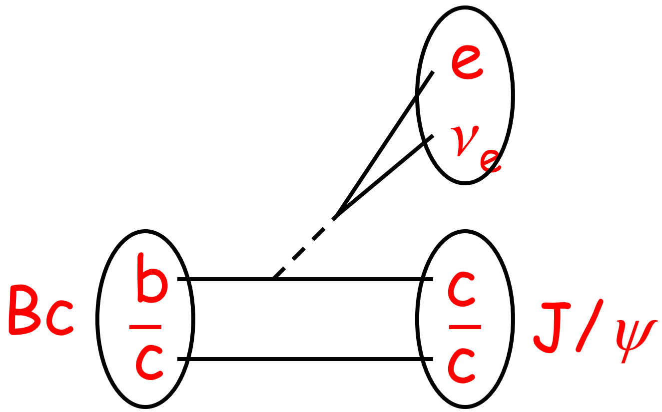
NEW

Mass(B^-_c) = 6275.2 ± 4.3 ± 2.3 MeV/c^2

World best

B^-_C lifetime (360 pb^{-1})

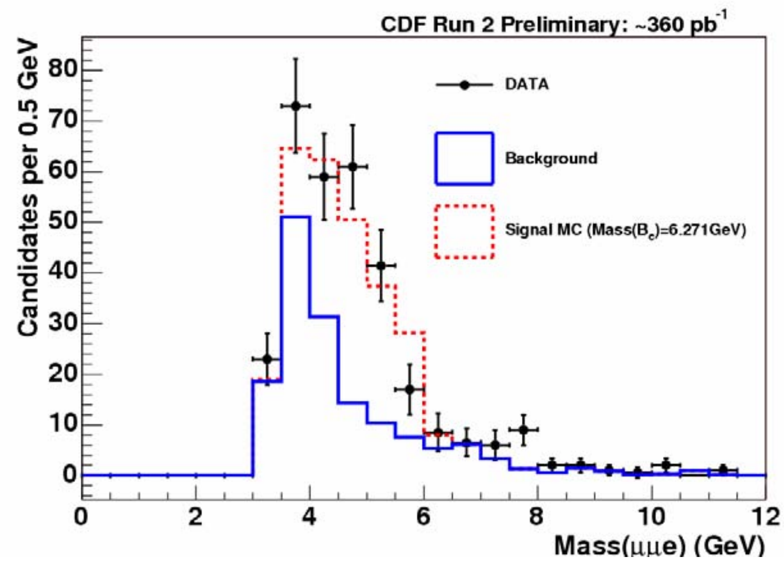
B_c lifetime extracted from semi-leptonic decay modes $\Longrightarrow$
more statistics than hadronic mode
but also more background too

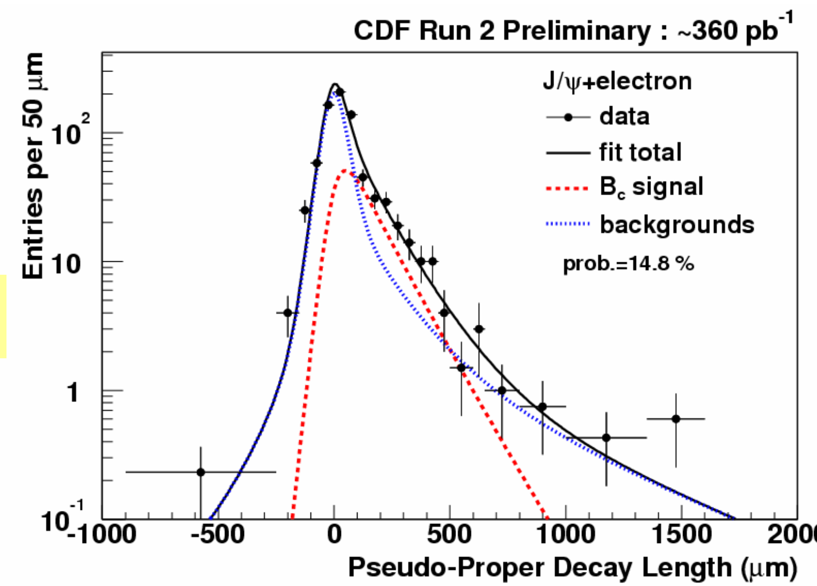


$$\tau_{B_c^+} = 0.474^{+0.073}_{-0.066}(\text{stat.}) \pm 0.033(\text{syst.})\ \text{ps.}$$

World best

Theoretical prediction [V. Kiselev hep/ph 0308214]:
$\tau(B_c) \cong 0.55 \pm 0.15$ ps.





Conclusions

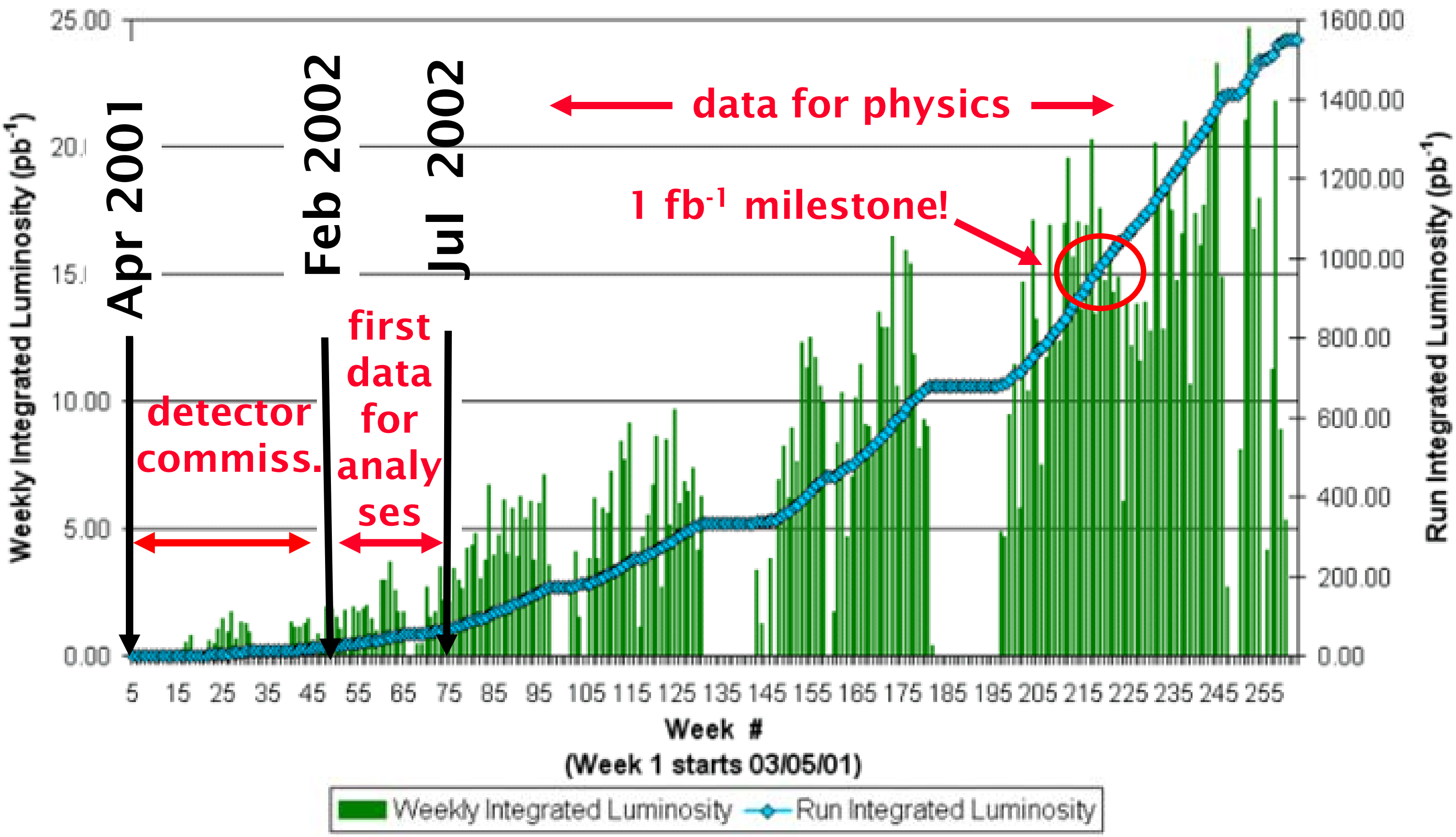
As data keep flowing, CDF impact on FP becomes more and more crucial: Charm-less two-body *B* decays, a case-study to show how CDF is competitive with (B^0) and complementary to (B^0_s) B-factories.

- direct CPV in $B^0 \longrightarrow K^+\pi^-$, small systematics, and as yet available statistics places CDF among the best by this summer;
- unique opportunity to combine $A_{CP}(B^0 \longrightarrow K^+\pi^-)$ with $A_{CP}(B^0_s \longrightarrow K^-\pi^+)$;
- precise and unique measurement of $BR(B^0_s \longrightarrow K^+K^-)$: SU(3) breaking issue and γ angle useful information;
- $B^0_s \longrightarrow K^+K^-$: the statistics(1fb-1) may be sufficient to look at measurement time-dependent $A_{CP}(t)$ (from mixing analysis: $\epsilon D^2 \cong 5\%$ and Δm_s);
- world best upper-limit on annihilation mode $B^0_s \longrightarrow \pi^+\pi^-$;
- world best upper-limit on mode $\Lambda_b \longrightarrow pK/p\pi$ and big probability to observe this decay in the next step of the analysis.
- unique extraction of $\Delta\Gamma_s/\Gamma_s$ in $B^0_s \longrightarrow K^+K^-$ (already one of world best results);
- first establishment of $B^0_s \longrightarrow \phi\phi$ (VV) and measurement its BR with the possibility to perform very soon a full angular analysis;
- Unique simultaneous sensitivity to $B^0 / B^0_s \rightarrow \mu^+\mu^-$ (already world best results);
- study of B_c properties in a fully reconstructed and semi-leptonic mode.

backup

Luminosity

~ 1400 pb^{-1} on tape (~ 1000 with silicon)

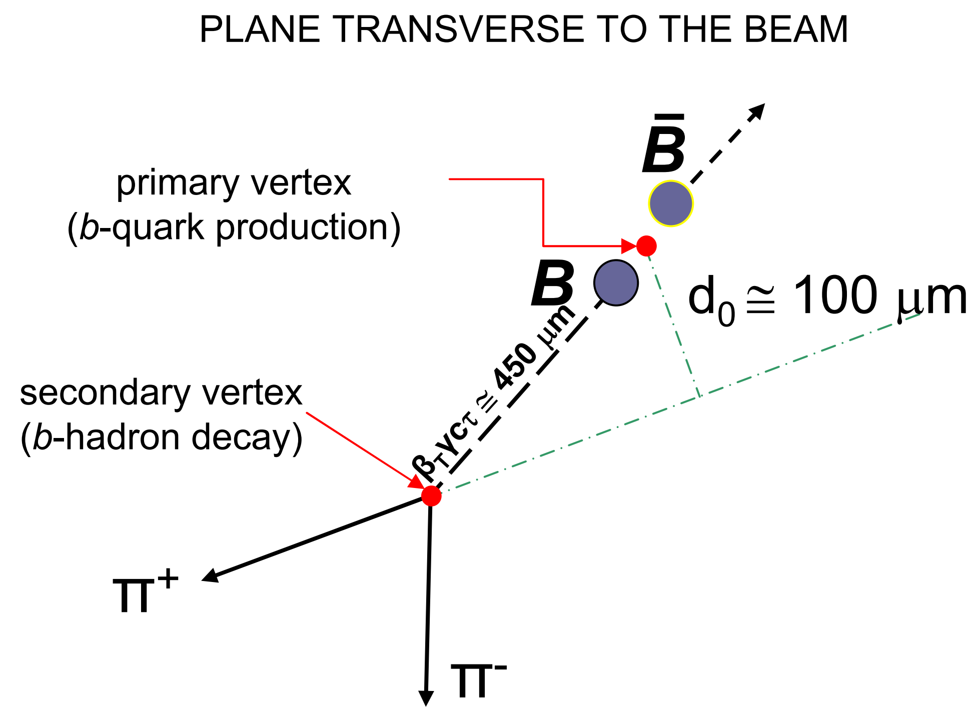


Stable data taking efficiency: > 85%. Results here use ~180-800 pb^{-1}

Heavy flavor signature

"Long" (~1.5 ps) lifetime of *b*-hadrons: a powerful signature against light-quark background. Before decaying, sufficiently boosted *b*-hadrons fly a distance resolvable with vertex detectors.

In Run I, CDF exploited this in offline analyses.
In Run II, we exploit it at trigger level. An experimental challenge that requires:



(1) <u>high resolution</u> vertex detector (silicon)

(2) <u>read out</u> silicon r-φ side (212,000 channels);

(3) do <u>pattern recognition</u> and <u>track fitting</u> in silicon.

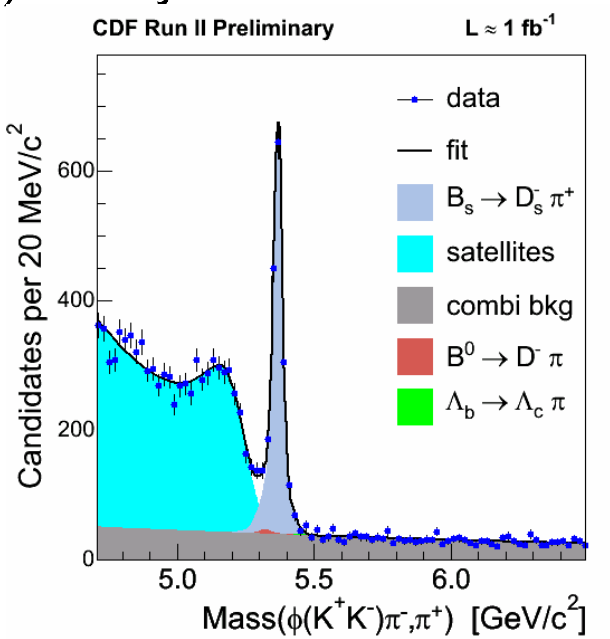
} <u>within 25 μs,</u>

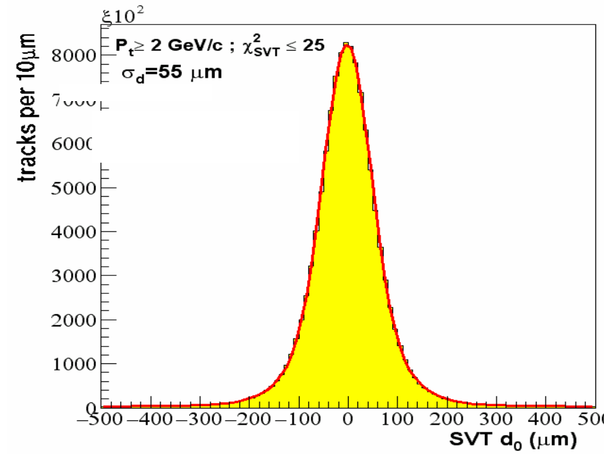
Displaced track trigger: pros and cons

impact parameter resolution

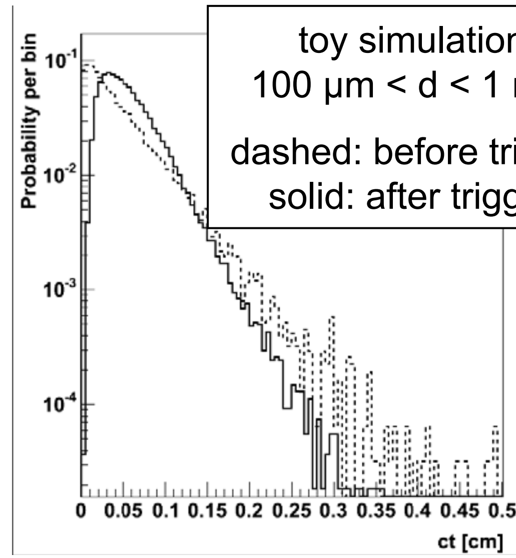
48 μm = 35 [SVT] ⊕ 33 [beam-spot size]

Very high-purity samples of hadronic *B* (and *D*) decays.





"golden" modes for B^0_s mixing



toy simulation
100 μm < d < 1 mm

dashed: before trigger
solid: after trigger

price to pay: trigger-bias distorts proper-time distributions. Introduce complexity in lifetime-based analyses, ...more later...

Triggering heavy flavors

Traditional *B*-trigger at hadronic collider: look for one ($B \to l\nu X$) or two leptons ($B \to J/\psi X$) exploiting easy signature and ~20% of total width.

For the first time, trigger HF without leptons: rare hadronic *B* decays.

conventional	***partially new approach***	***new approach***
di-muon	electron or μ and displaced track	two displaced tracks
$B \longrightarrow$ charmonium $B \longrightarrow \mu\mu$	$B \to l\nu X$	$B \to hh$
two muons with:	electron (or μ) with:	two tracks with:
$p_T > 1.5$ GeV $\|\eta\| < 1$	$p_T > 4$ (or 1.5) GeV $\|\eta\| < 1$	$p_T > 2.0$ GeV
	and one track with:	$\Sigma p_T > 5.5$ GeV
	$p_T > 2.0$ GeV $d_0 > 120\ \mu$m	$d_0 > 100\ \mu$m

Motivation: $B^0/B^0_s \rightarrow \mu^+\mu^-$

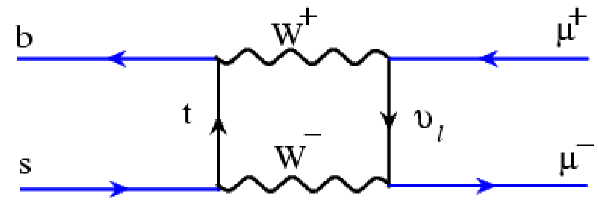
Standard Model

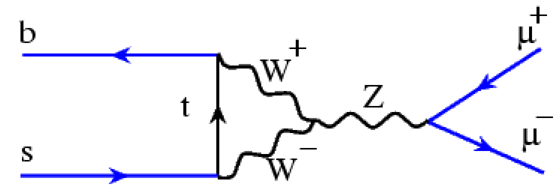
In the SM FCNC decays are highly supressed. Expectations:

$BR(B^0_s \rightarrow \mu\mu) \propto |V_{ts}|^2 \cong (3.42 \pm 0.54)\cdot 10^{-9}$

$BR(B^0 \rightarrow \mu\mu) \propto |V_{td}/V_{ts}|^2 \cong (1.00 \pm 0.14)\cdot 10^{-10}$

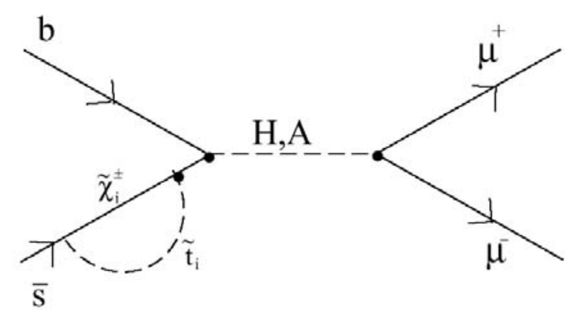
[Buchalla and Buras Nucl. Phys. B400,225(1993); Buras, Phys. Lett. B 566,115(2003)]





SUSY (MSSM)

However NP can significantly enhance these BRs: $BR(B^0_s \rightarrow \mu\mu) \propto (\tan\beta)^6$ where β is the ratio of vacuum expectation values of the neutral CP-even Higgs fields. Large $\tan\beta$ enhance the decay rate (up to x100) to a level observable by the TeVatron.

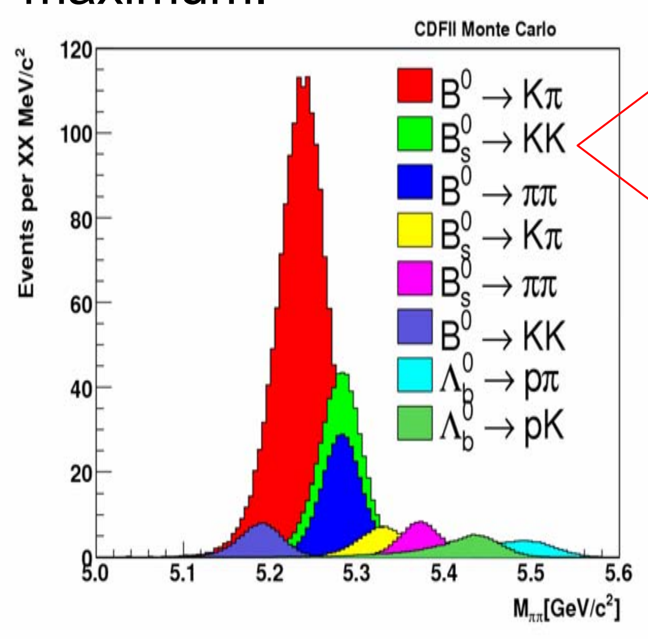


Cuts optimization

Optimize cuts by minimizing the expected statistical resolution on A_{CP}. Its expression in terms of S and B is determined form actual resolutions observed in analysis of toy-MC samples.

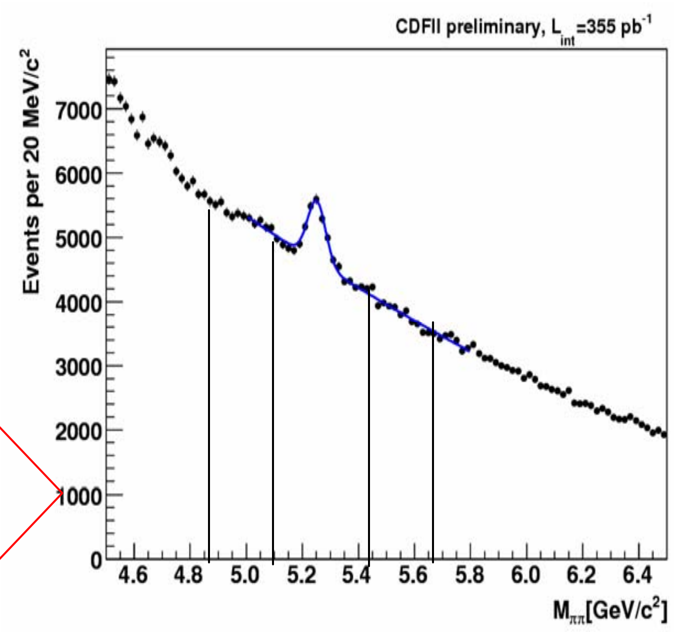
Gain ~10% improvement in the resolution versus standard $S/\sqrt{(S+B)}$.

<u>Unbiased</u> cut optimization where: for any combination cuts, evaluate the above score function; optimal cuts are found when the functions reach the maximum.



signal yield S is derived from MC simulation

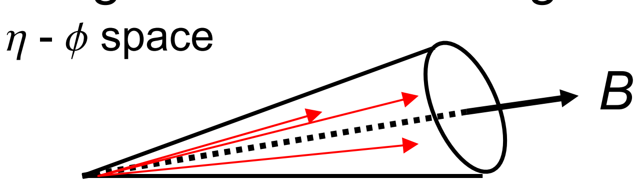
background B is estimated from mass sidebands on data

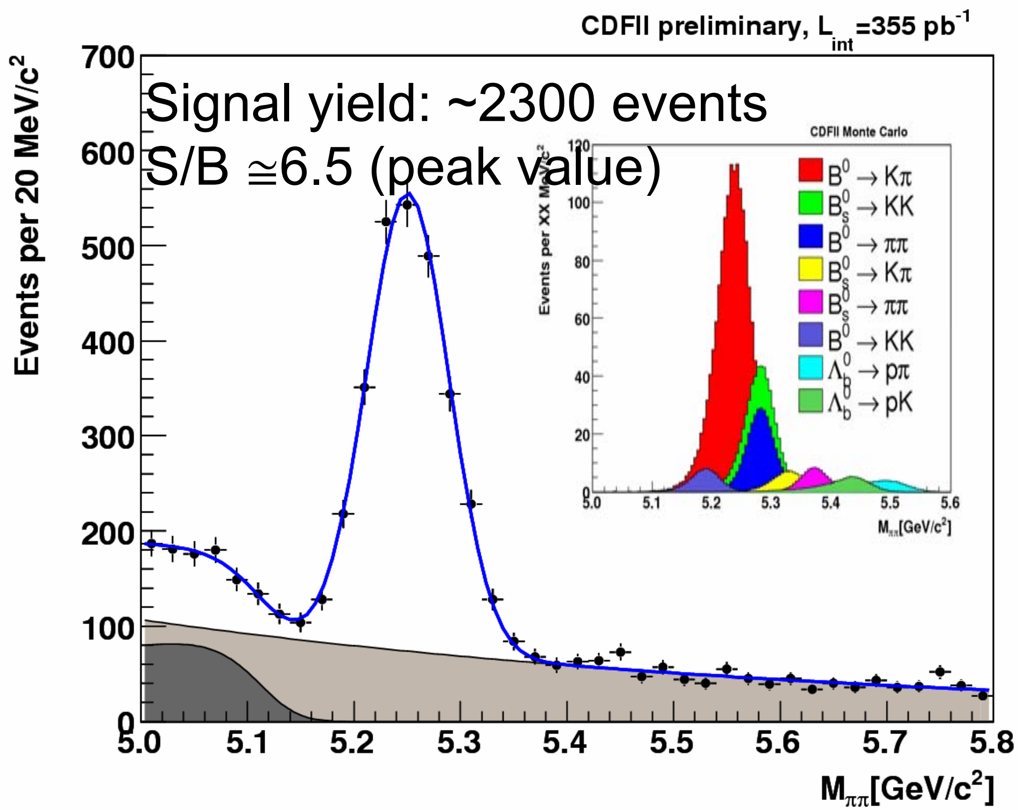


$B^0/B^0_s \to PP$ DATA SAMPLE

Optimize cuts by minimizing the expected statistical resolution on A_{CP}. Its expression in terms of S and B is determined form actual resolutions observed in analysis of toy-MC samples.

Crucial isolation: fraction of p_T carried by the B after fragmentation. Rejects 18% of sig. and ~4x of background

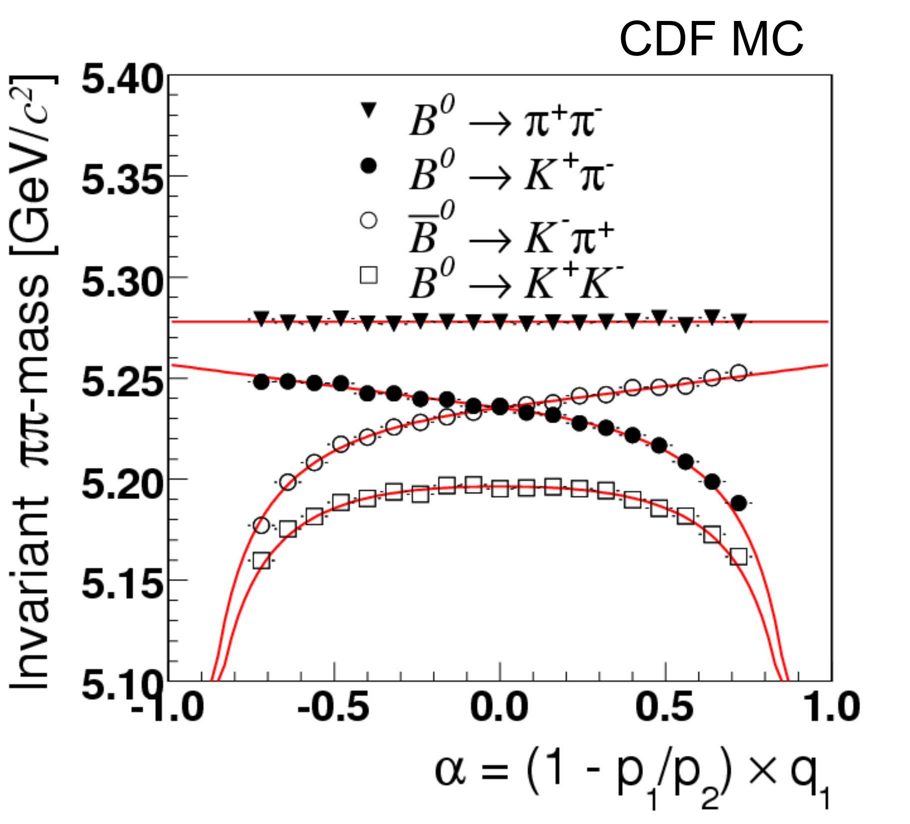


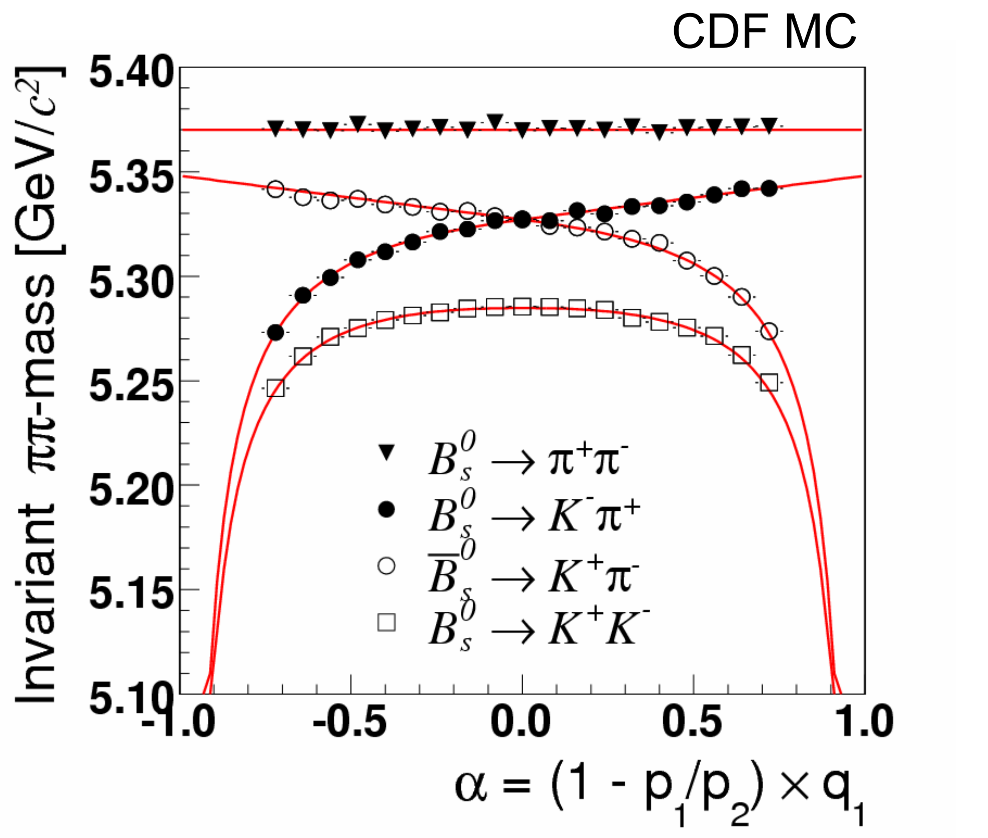


Despite excellent mass resolution, modes overlap an unresolved peak, and PID resolution is insufficient for event-by-event separation. Hence, fit signal composition with a Likelihood that combines information form kinematics (masses and momenta) and particle ID (dE/dx).

Peak composition handle 1: Kinematic

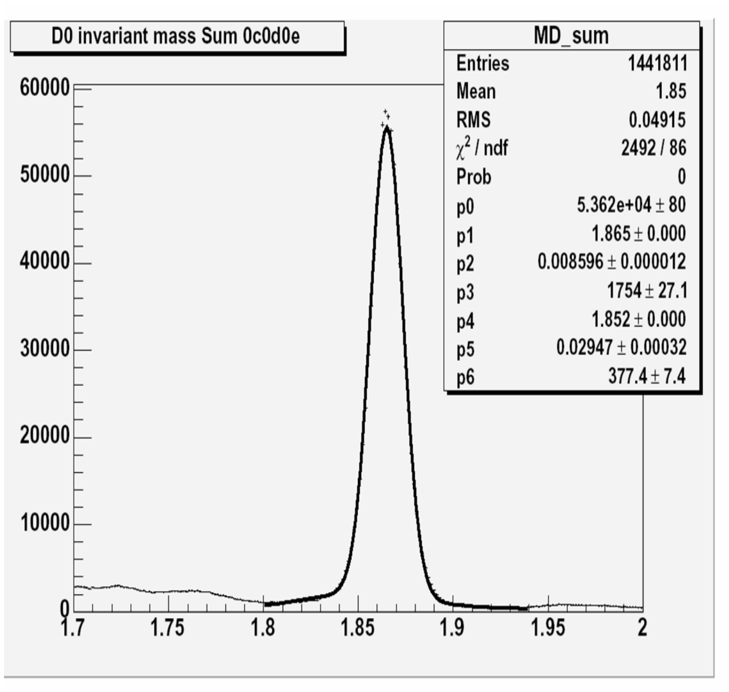
Invariant $\pi\pi$-mass vs signed momentum imbalance: $(1-p_{min}/p_{max})q_{min}$

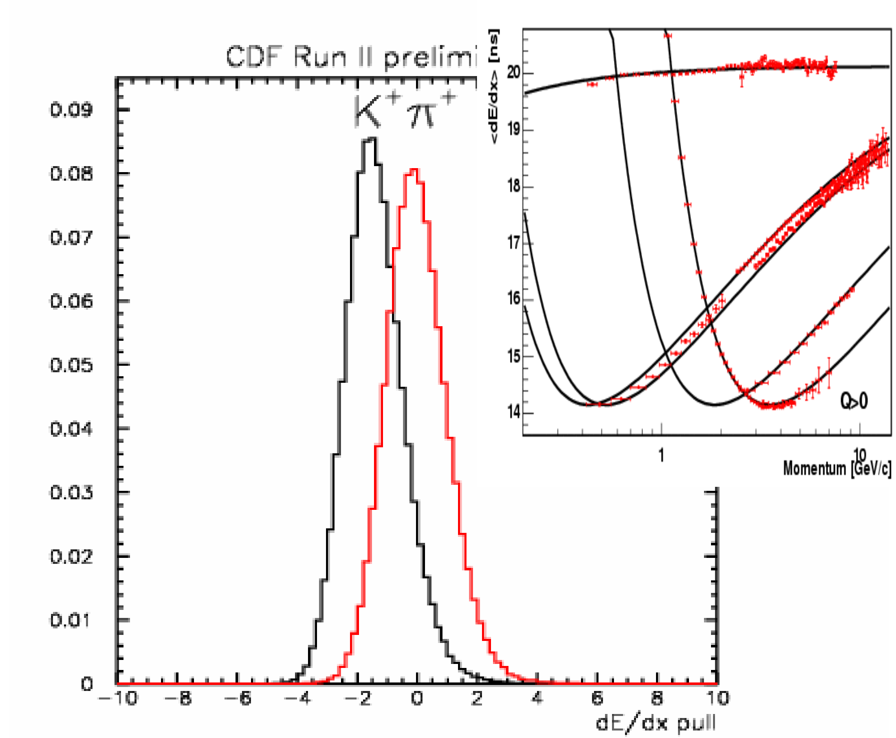




Discriminates among modes (and among self-tagging modes $K^+\pi^-$ / $K^-\pi^+$)

Peak composition handle 2: dE/dx





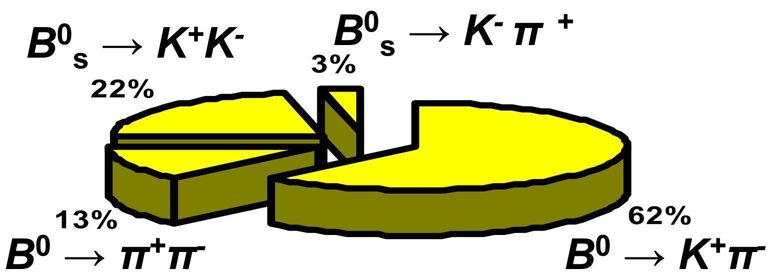
~95% pure K and π samples from ~700K decays:

$D^{*+} \rightarrow D^0\pi^+ \rightarrow [K^-\pi^+]\ \pi^+$

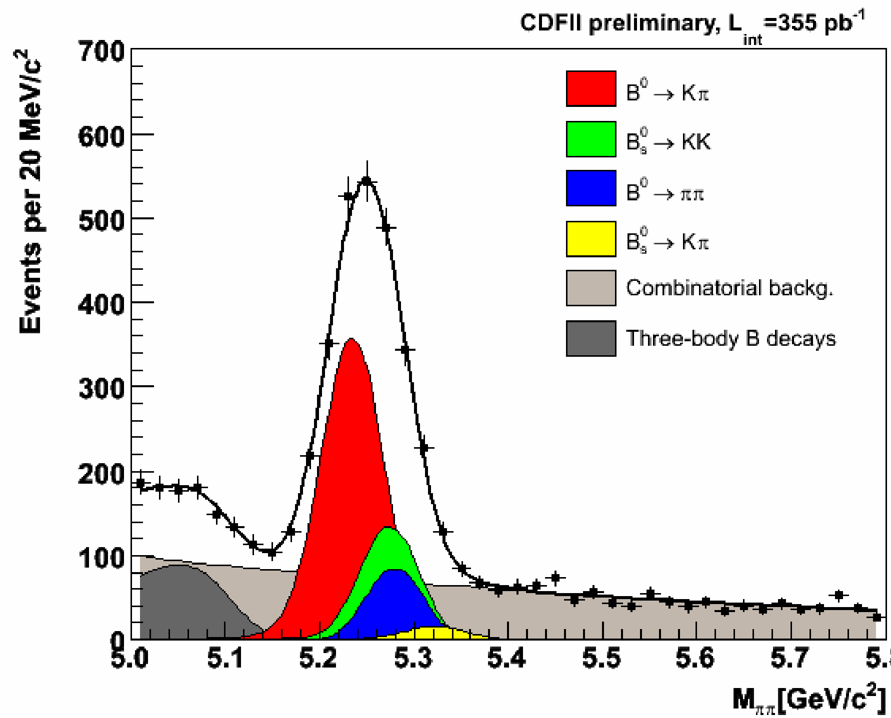
Strong D*+ decay tags the D0 flavor. dE/dx accurately calibrated over tracking volume and time.

1.4σ K/π separation at p>2GeV (60% of "perfect" separation) ~11% residual correlation form gain/baseline fluctuations included int the fit of composition

Uncorrected fit results



mode	fraction [%]	yield
$B^0 \to \pi^+\pi^- + \overline{B}^0 \to \pi^+\pi^-$	13.2 ± 1.4	313 ± 34
$B_s^0 \to K^-\pi^+ + \overline{B}_s^0 \to K^+\pi^-$	2.7 ± 1.3	64 ± 30
$B_s^0 \to K^+K^- + \overline{B}_s^0 \to K^+K^-$	22.0 ± 1.6	523 ± 41
$B^0 \to K^+\pi^- + \overline{B}^0 \to K^-\pi^+$	62.1 ± 1.7	1475 ± 60
$B^0 \to K^+\pi^-$	–	787 ± 42
$\overline{B}^0 \to K^-\pi^+$	–	689 ± 41



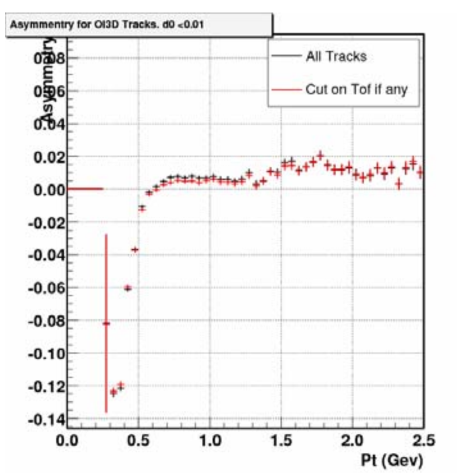
$$A_{CP}\Big|_{\mathrm{RAW}} = \frac{N_{\mathrm{raw}}(\overline{B}^0 \to K^-\pi^+) - N_{\mathrm{raw}}(B^0 \to K^+\pi^-)}{N_{\mathrm{raw}}(\overline{B}^0 \to K^-\pi^+) + N_{\mathrm{raw}}(B^0 \to K^+\pi^-)} = -0.066 \pm 0.039$$

Small (~1%) correction of fit result for trigger, acceptance, and selection efficiency to convert it into a measurement

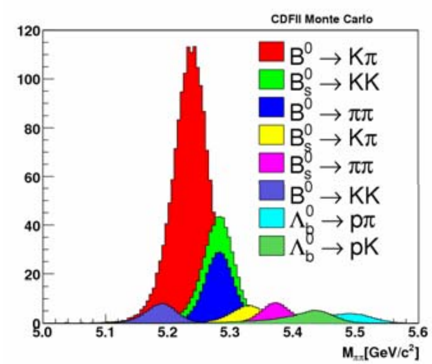
Extraction of asymmetry

$$A_{CP} = \frac{N(\overline{B}^0 \to K^-\pi^+)\Big|_{raw} \cdot \frac{\epsilon_{kin}(B^0 \to K^+\pi^-)}{\epsilon_{kin}(\overline{B}^0 \to K^-\pi^+)} - N(B^0 \to K^+\pi^-)\Big|_{raw}}{N(\overline{B}^0 \to K^-\pi^+)\Big|_{raw} \cdot \frac{\epsilon_{kin}(B^0 \to K^+\pi^-)}{\epsilon_{kin}(\overline{B}^0 \to K^-\pi^+)} + N(B^0 \to K^+\pi^-)\Big|_{raw}}$$

A < 2% charge asymmetry affects the CDF II detector and tracking code.



Only the different K^+/K^- interaction rate with material matters.
Effect under control down to 0.5% in CDF $A_{CP}(D^0 \longrightarrow h^+h^-)$ measurement
(Phys.Rev.Lett.94:122001, 2005).
Used unbiased kaons to extract the ~ 1% correction



Asymmetry Result (360 pb^{-1})

$$A_{\text{CP}}^{\text{CDF}}(B^0 \to K^+\pi^-) = -0.058 \pm 0.039\ (stat.) \pm 0.007\ (syst.)$$

Result is ~1.5σ different from 0, and compatible with *B*-factories results:

$$A_{\text{CP}}^{\text{Belle}}(B^0 \to K^+\pi^-) = -0.113 \pm 0.022\ (stat.) \pm 0.008\ (syst.)$$

$$A_{\text{CP}}^{\text{Babar}}(B^0 \to K^+\pi^-) = -0.133 \pm 0.030\ (stat.) \pm 0.009\ (syst.)$$

Systematic uncertainties from CDF and *B*-factories are comparable.

With data already available on disk, we expect ~2.5% statistical uncertainty: CDF will be soon (summer) very competitive.

In same data, is likely first observation of $B^0_s \longrightarrow K^-\pi^+$ decay: will measure its BR and CP asymmetry that is expected large. Model-independent NP-probe proposed by Lipkin (Lipkin, Phys.Lett.B621:126, 2005).

BR($B^0_s \to K^+K^-$) (180 pb^{-1})

$$\frac{f_s \cdot BR(B^0_s \to K^+K^-)}{f_d \cdot BR(B^0 \to K^+\pi^-)} = 0.46 \pm 0.08\ (stat.) \pm 0.07\ (syst.)$$

The $B^0_s \to K^+K^-$ decay has been established.

BR($B^0_s \to K^+K^-$) consistent with QCD-factorization predictions [M. Beneke *et al.*, Nucl.Phys.B675:333-415,2003]

This BR ratio is crucial to check assumptions on U-spin symmetry. Exact U-spin symmetry would predict this BR ratio to be 1. Our result may favor large SU(3) breaking as predicted from QCD sum-rules [Khodjamirian *et al.* PRD68:114007, 2003].

For the summer update of this measurement with data already available on tape (1fb^{-1}). Expected resolution from TOY $\sigma \cong 0.02$.

The statistics(1fb^{-1}) may be sufficient to look at measurement time-dependent $A_{CP}(t)$ (from mixing analysis: $\epsilon D^2 \cong 5\%$ and Δm_s).

$BR(B_s \to K^- \pi^+)$: upper limit (180 pb^{-1})

$$\frac{f_s \cdot BR(B_s^0 \to K^-\pi^+)}{f_d \cdot BR(B^0 \to K^+\pi^-)} < 0.08 \text{ @ } 90\% \; C.L.$$

HFAG 2005

$$BR(B_s^0 \to K^-\pi^+) < 5.4 \cdot 10^{-6} \text{ @ } 90\% \; C.L.$$

On 180 pb^{-1} no evidence for $B^0_s \to K^- \pi^+$, set a limit a <u>factor ~40 better than PDG04.</u> Our current upper-limit constrains already

Expected $BR(B^0_s \to K^- \pi^+)$:
Beneke&Neubert [NP B675, 333(2003)]: $\cong$ [7-10] $\cdot 10^{-6}$
PQCD [Yu, Li, Yu, Phys.Rev. D71: 074026) (2005)]: $\cong$ [6-10]$\cdot 10^{-6}$
SCET [Williamson, Zupan. Jan 2006. hep-ph/0601214]: $\cong 4.9 \cdot 10^{-6}$

More recent

Assuming BR $\cong 4.9 \cdot 10^{-6}$ [hep-ph/0601214] $\Longrightarrow$ expect in 1fb^{-1} $\sigma(BR)_{TOY} \cong 0.8 \cdot 10^{-6}$ corresponding to observe this decay with significance $\cong 6\sigma$. This is a self-tagging mode $\Longrightarrow$ DCPV measurement to compare with $A_{CP}(B^0 \to K^+ \pi^-)$.

Upper limits on annihilation mode (180 pb^{-1})

Both $B^0_s \to \pi^+\pi^-$ and $B^0 \to K^+K^-$ are annihilation-dominated decays and no observed yet them – they are hard to predict exactly.

It will be very interesting to be able to measure one because these unknown amplitudes contribute to many relevant process as $B^0_s \to K^+K^-$ decay.

$$\frac{BR(B^0_s \to \pi^+\pi^-)}{BR(B^0_s \to K^+K^-)} < 0.05 \text{ @ } 90\% \ C.L.$$

Great improvement on annihilation mode $B^0_s \to \pi^-\pi^+$. <u>A factor >100 below PDG04</u> (time-evolutions of $B^0_s \to \pi^-\pi^+$ and $B^0_s \to K^-K^+$ assumed the same).

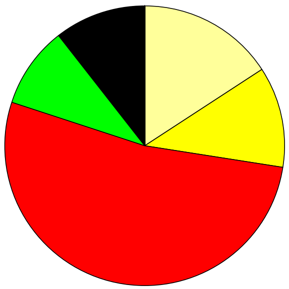
$$\frac{BR(B^0 \to K^+K^-)}{BR(B^0 \to K^+\pi^-)} < 0.10 \text{ @ } 90\% \ C.L.$$

Limit on pure annihilation/exchange mode $B^0 \to K^+K^-$. A factor ~3 above B-factories, expect much better performance on current sample(1fb^{-1}).

Incertezze sistematiche dominanti

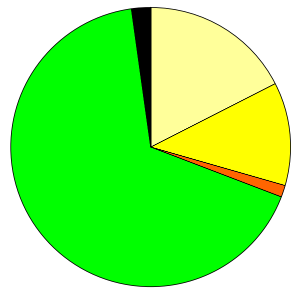
$$\frac{f_s \cdot BR(B_s^0 \to K^+K^-)}{f_d \cdot BR(B^0 \to K^+\pi^-)}$$

(stat. ~ 17%)
syst. ~ 15%



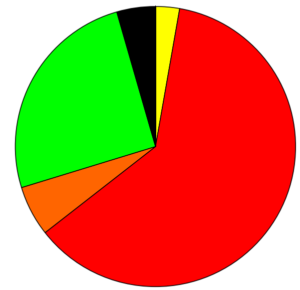
$$\frac{BR(B^0 \to \pi^+\pi^-)}{BR(B^0 \to K^+\pi^-)}$$

(stat. ~ 24%)
syst. ~ 14%



$$\frac{f_d \cdot BR(B^0 \to \pi^+\pi^-)}{f_s \cdot BR(B_s^0 \to K^+K^-)}$$

(stat. ~ 29%)
syst. ~ 13%



- dE/dx correlazione track-to-track (si riduce con la statistica);
- Masse dei mesoni B in input al fit (si riduce con la statistica);
- Efficienza relativa Isolamento tra B^0_s e B^0 (si riduce con la statistica);
- Code radiative FSR;
- Trigger bias sull'efficienza;
- Dipend. della carica del dE/dx;
- Background shape;
- Asimmetria di carica nel background;
- Altro.

$B_s \to \phi\phi$(VV) sample selection

TRIGGER: very similar requirement to B→PP, based just on impact parameter

Blind analysis (expected a small yield)

Optimized cuts: lifetime,Vertex quality, impact parameter of B_s, transverse momentum of ϕ, impact parameter of ϕ daughter tracks

Signal search and BR measurement → maximize:

$$\frac{1}{S_{\min}} \propto \frac{\varepsilon(t)}{a/2+\sqrt{B(t)}} \quad ; \; a=3.$$

t=set of cuts

Where ϵ(t) is the signal efficiency from MC and B(t) is the expected background from sidebands extrapolation for the set t of selection cuts. For a=3 maximize the sensitivity region for a 3 sigma discovery with 99% C.L. [G.Punzi,hep-ph/0308063]

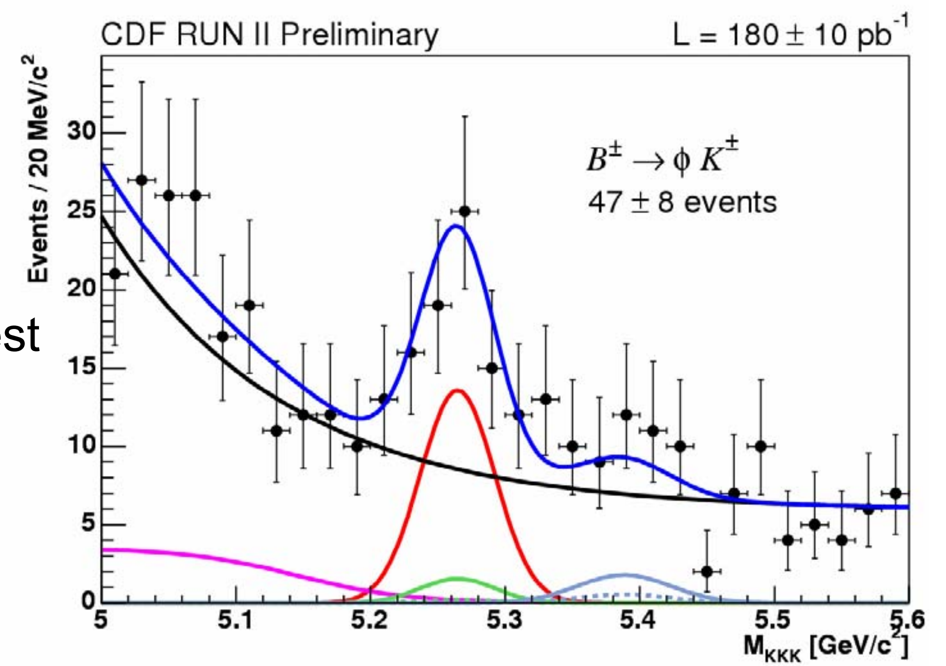
Nice feature:optimization independent of MC normalization

For the control sample $B_s \to J/\psi\phi$ maximize usual significance:

$$Sig = \frac{S(t)}{\sqrt{S(t)+B(t)}}$$

$B^\pm \to \phi K^\pm$(VP) (180 pb^{-1})

- Extended unbinned ML fit to:
  - M_{KKK}
  - $M\phi$
  - Cosine of ϕ meson Helicity angle
  - dE/dx deviation from the expected value (pion hypothesis) for the lowest momentum trigger track.
- Background sources:
  - $B^\pm \to f^0 K^\pm$
  - $B^\pm \to K^{*0}\pi$,
  - $B_{u,d} \to \phi X$
  - combinatorial background



[PRL 95:031801(2005)]

Normalize yield to $B^\pm \to J/\psi K^\pm$ to measure

$$BR(B^\pm \to \varphi K^\pm) = (7.6 \pm 1.3(stat.) \pm 0.7(syst.)) \cdot 10^{-6}$$

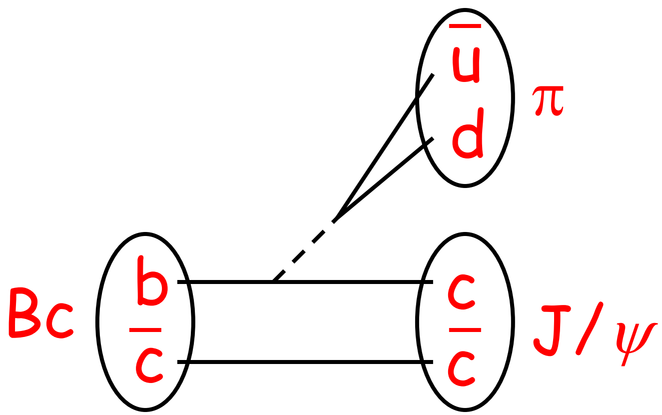
$$A_{CP}(B^\pm \to \varphi K^\pm) = \frac{\Gamma(B^- \to \varphi K^-) - \Gamma(B^+ \to \varphi K^+)}{\Gamma(B^- \to \varphi K^-) + \Gamma(B^+ \to \varphi K^+)} = -0.07 \pm 0.17(stat.)^{+0.03}_{-0.02}(syst.)$$

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

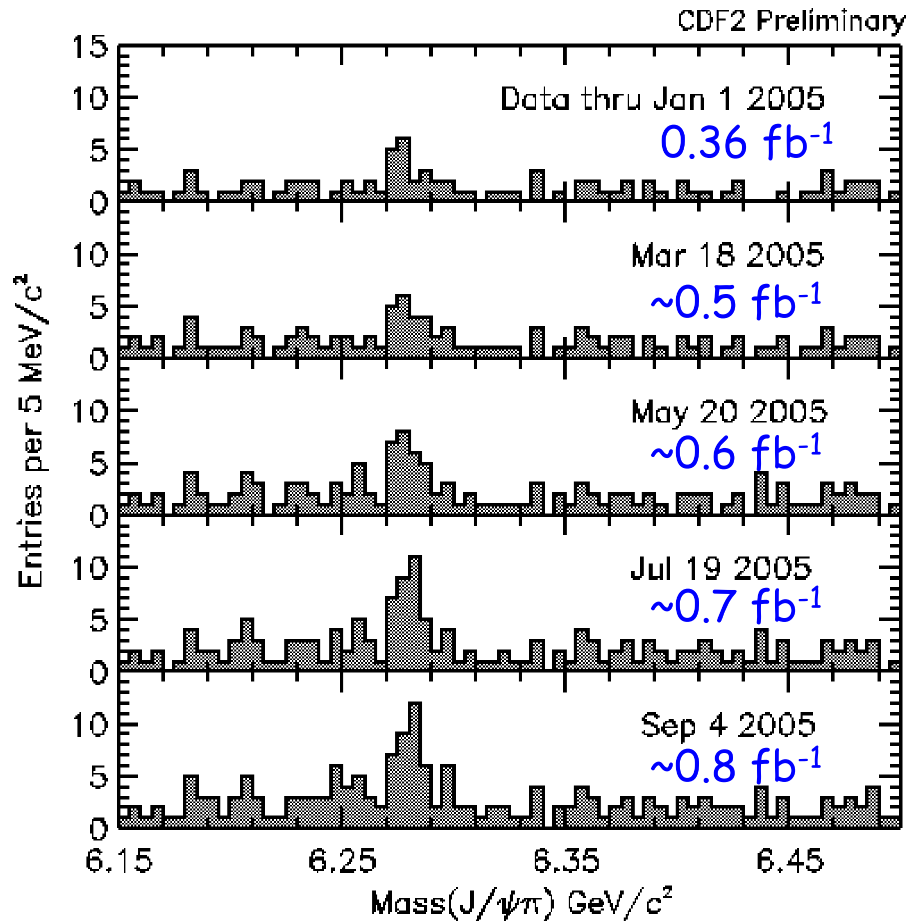
source	shift wrt central fit
mass scale	0.0022
mass resolution	0.0024
asymmetric momentum-p.d.f	0.0003
dE/dx	0.0050
input masses	0.0025
combinatorial background model	0.0019
p **spectra of background**	0.0005
MC statistics	0.0010
charge asymmetry	0.0022
$m_{\pi\pi} - p_{tot}$ **non-factorizability**	0.0018
TOTAL (sum in quadrature)	**0.0074**

B_C observation and mass (800 pb^{-1})

B_c is not produced at B factories
Full reconstruction allows for precise mass measurement.



Signal yield ≅ 38.9 events
Background yield ≅ 26.1
between 6.24 and 6.3 GeV/c^2
Significance > 6σ over search area



NEW

Mass(B_c) = 6275.2 ± 4.3 ± 2.3 MeV/c^2