Physics of Heavy Flavour at

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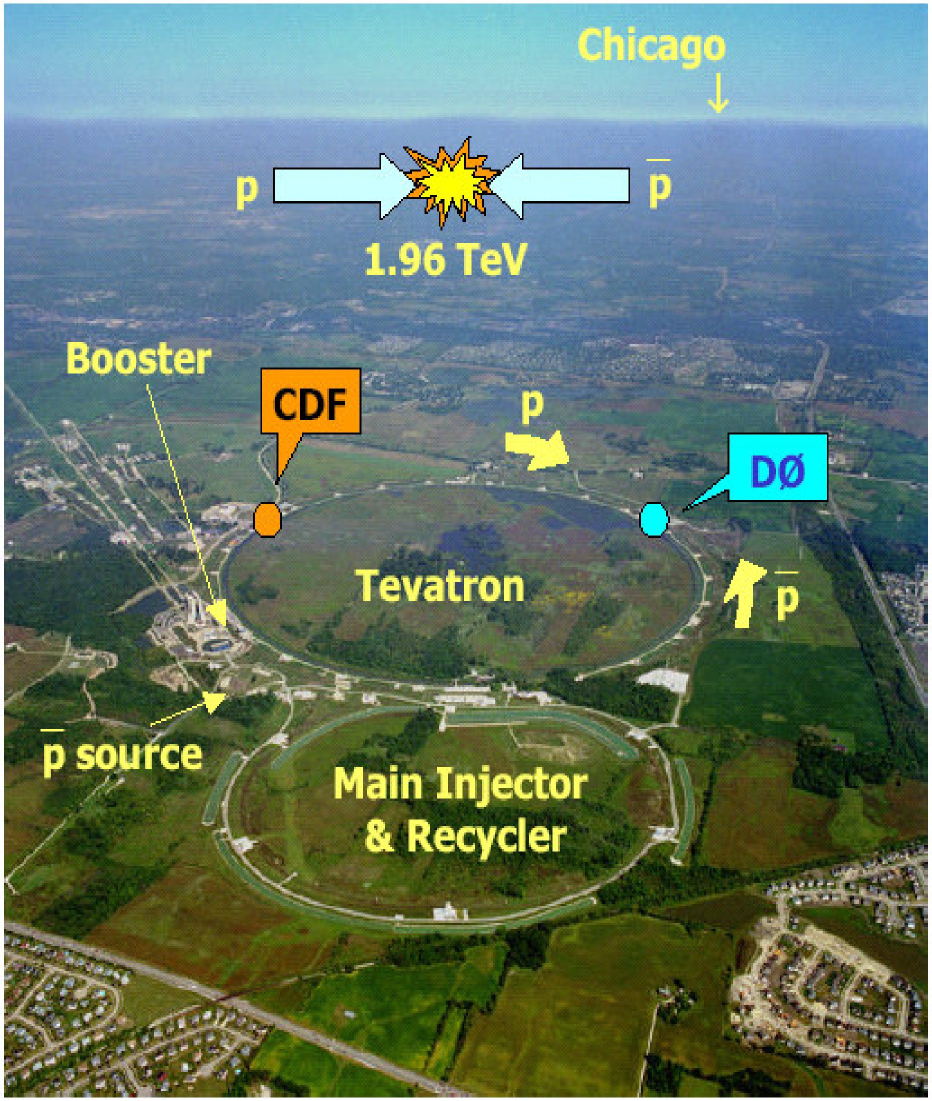
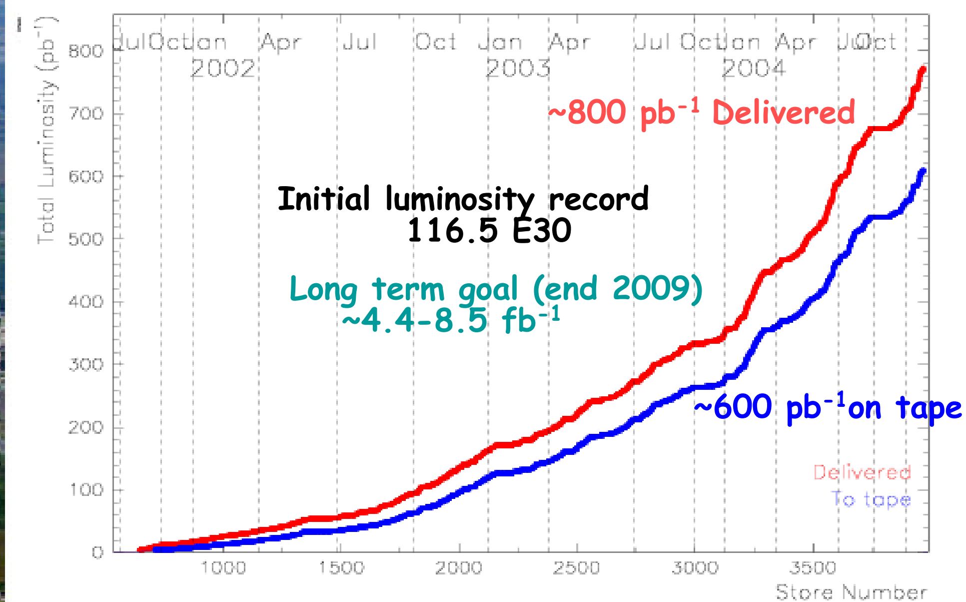
for the CDF Collaboration

Outline

- Tevatron @ Fermilab
- Detector & trigger description
- Selected topics
    - BR & A_{CP} in 2-body charmless decays
    - $B_s \rightarrow \phi\phi$ & $B^{\pm} \rightarrow \phi K^{\pm}$
    - $\Delta\Gamma_s$
    - Λ_b measurements
    - Precise measurement of mass of B_c
- Conclusions

Tevatron


Chicago
p
p
1.96 TeV
Booster
CDF
p
DØ
Tevatron
p
p source
Main Injector
& Recycler


Total Luminosity (pb⁻¹)
Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct
2002
2003
2004
~800 pb⁻¹ Delivered
Initial luminosity record
116.5 E30
Long term goal (end 2009)
~4.4-8.5 fb⁻¹
~600 pb⁻¹ on tape
Delivered
To tape
Store Number

CDF detector @Tevatron

solenoid 1.4 T

TRACKING system:

- **SILICON TRACKER**

  up to $|\eta|\sim 2$

  SVX Fast r-ϕ readout

  for trigger

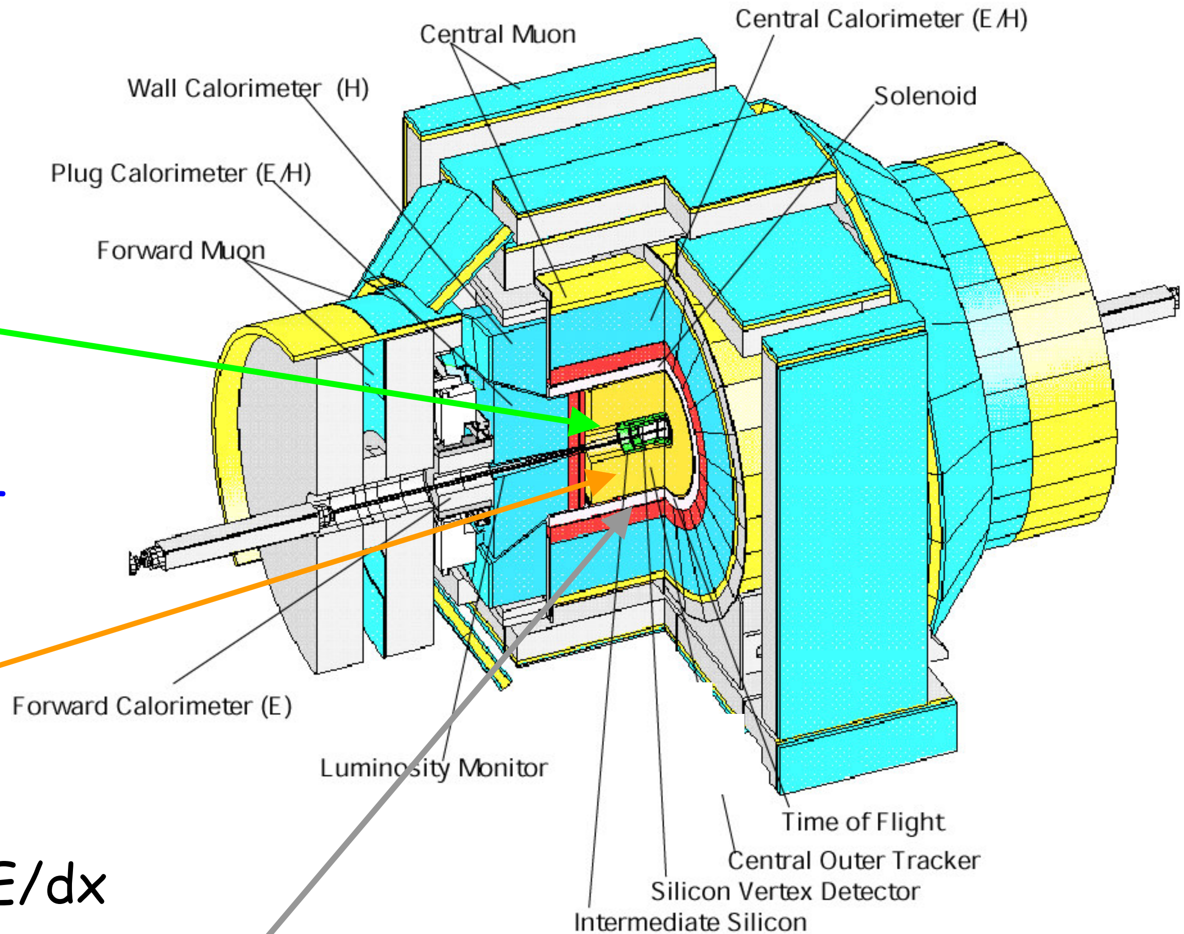
- **DRIFT CHAMBER**

  96 layers in $|\eta|<1$

  → particle ID with dE/dx

  r-ϕ readout for trigger

TIME OF FLIGHT→particle ID



Triggers and data samples

Canonical

Di-Muon (J/ψ)

Pt(μ) > 1.5 GeV/c

J/ψ modes down to low Pt(J/ψ) (~ 0 GeV)

- $\Delta\Gamma_s$ in fully rec. decays
- $B_c \rightarrow J/\psi\pi$
- Masses, lifetimes of B_d, B_s, Λ_b
- Quarkonia
- X(3872)
- Rare decays ($B_{S(d)} \rightarrow \mu\mu$ & $D^0 \rightarrow \mu\mu$)

New for run II

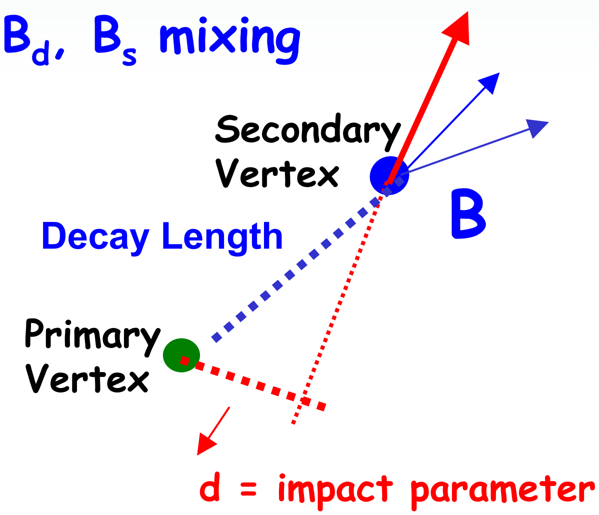
Displaced trk + lepton (e, μ)

IP(trk) > 120μm

Pt(lepton) > 4 GeV/c

Semileptonic modes

- Hadronic Moments
- High statistics lifetimes
- B_d, B_s mixing



2-Track Trig.

Pt(trk) > 2 GeV/c

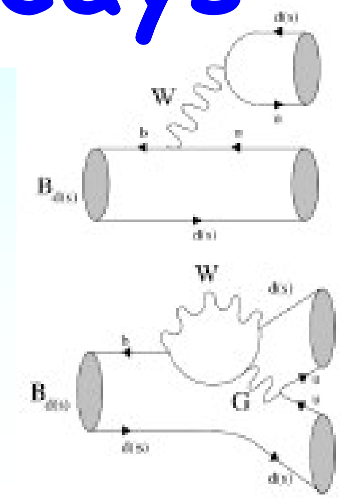
IP(trk) > 100 μm

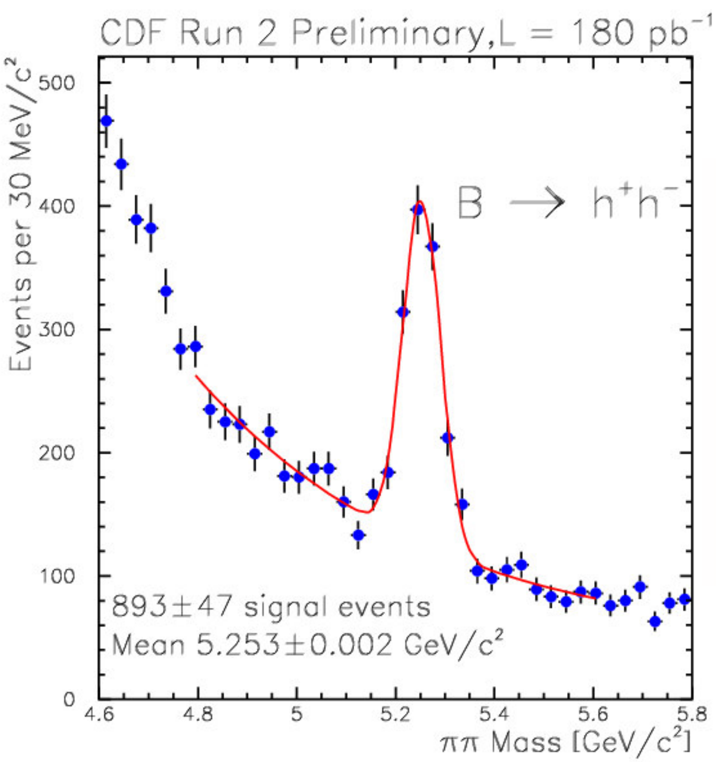
Fully reconstructed hadronic modes

- $B_{d,s}$ 2-body charmless decays
- $B_s \rightarrow \phi\phi$ & $B^\pm \rightarrow \phi K^\pm$
- $\Lambda_b \rightarrow \Lambda_c\pi$, $\Lambda_b \rightarrow ph$
- A_{CP} in 2-body D decays
- B_d, B_s mixing & lifetimes

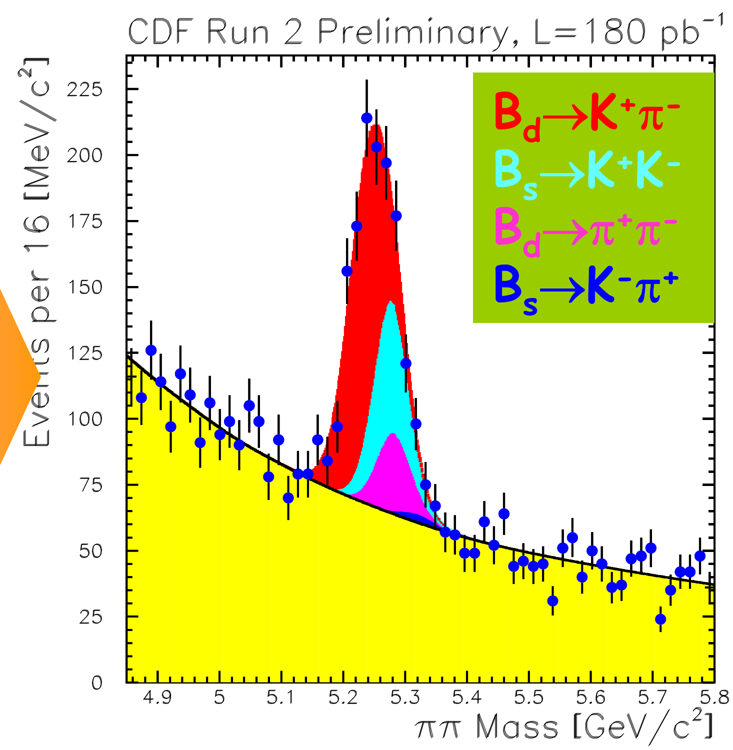
2 body charmless B decays

- First evidence of CP violation in the $B_d \to K^+\pi^-$ @B factories
- Several modes @CDF: $B_d \to \pi^+\pi^-$, $B_s \to K^+K^-$, $B_s \to K^-\pi^+$, …
- BR & A_{CP} can be predicted w/ hadronic unknowns
- Several decays to eliminate unknowns
- Under surveillance (only @CDF): $B_s \to K^+K^-$
  - Measure $\Delta\Gamma_s$ and γ (via $B_s \to K^+K^- / B_d \to \pi^+\pi^-$)





unbinned Max-Likelihood fit on mass+ kin.+dE/dx



Analysis results

Decay	# B
$B_d \to K^+\pi^-$	509
$B_d \to \pi^+\pi^-$	134
$B_s \to K^+K^-$	232
$B_s \to K^-\pi^+$	---

Only @ CDF

$$\frac{f_s\, BR(B_s \to K^\pm K^\mp)}{f_d\, BR(B_d \to K^\pm \pi^\mp)} = 0.50 \pm 0.08(stat) \pm 0.07(syst)$$

$$\frac{f_s\, BR(B_s \to K^\pm \pi^\mp)}{f_d\, BR(B_d \to K^\pm \pi^\mp)} < 0.11 @ 90\% C.L.$$

$$\frac{BR(B_s \to \pi^\pm \pi^\mp)}{BR(B_s \to K^\pm K^\mp)} < 0.10 @ 90\% C.L.$$

$$A_{CP} = \frac{N(B_d \to K^-\pi^+) - N(B_d \to K^+\pi^-)}{N(B_d \to K^-\pi^+) + N(B_d \to K^+\pi^-)} = -0.04 \pm 0.08(stat) \pm 0.01(syst)$$

Babar: A_{CP} = -0.133±0.030(stat.)±0.009(syst.)
Belle: A_{CP} = -0.101±0.025(stat.)±0.005(syst.)

$$\frac{BR(B_d \to \pi^\pm \pi^\mp)}{BR(B_d \to K^\pm \pi^\mp)} = 0.24 \pm 0.06(stat) \pm 0.05(syst)$$

Babar: $BR(B_d \to \pi^+\pi^-)$ = 4.7 ± 0.6 ± 0.2
Belle: $BR(B_d \to \pi^+\pi^-)$ = 4.4 ± 0.6 ± 0.3

Search for $\Lambda_b \to pK$ and $p\pi$ decays

Prediction[1]:

$Br(\Lambda_b \to pK) = (1.4\text{-}1.9) \times 10^{-6}$

$Br(\Lambda_b \to p\pi) = (0.8\text{-}1.2) \times 10^{-6}$

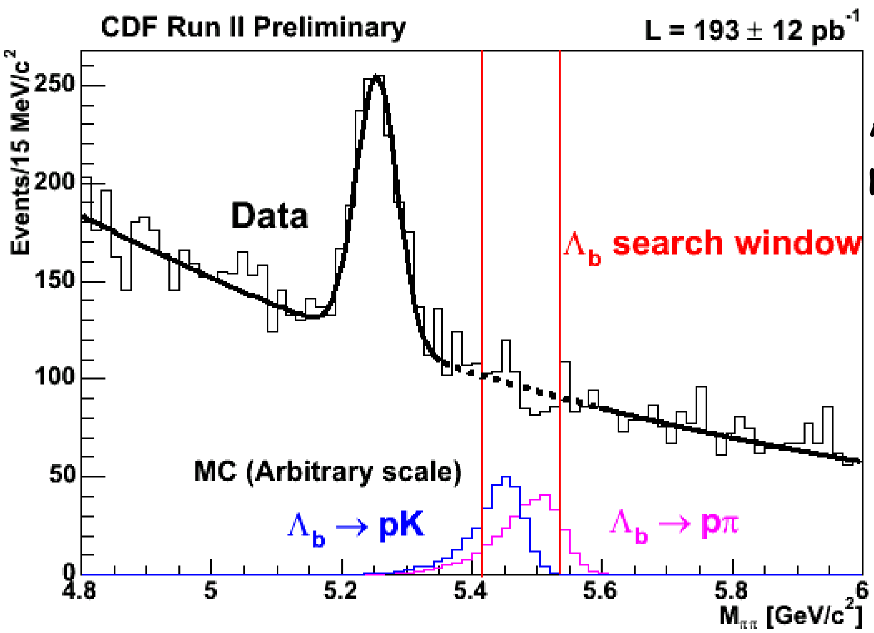
compare to $Br(B^0 \to K\pi) = 18 \times 10^{-6}$

Previous best limit from ALEPH

$BR(\Lambda_b \to pK) < 50 \times 10^{-6}$ @ 90%

$BR(\Lambda_b \to p\pi) < 50 \times 10^{-6}$ @ 90%

Large CP asymmetries O(10%) expected in b-baryons



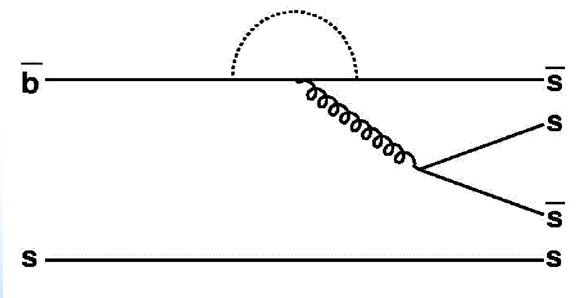
Assign to both tracks the π mass to maximize separation from the Bhh

$N(\Lambda_b \to ph) < 75$ @90%C.L.

$Br(\Lambda_b \to pK + p\pi) < 22 \times 10^{-6}$ @90%C.L.

[1] Mohanta, Phys. Rev. D63:074001,2001

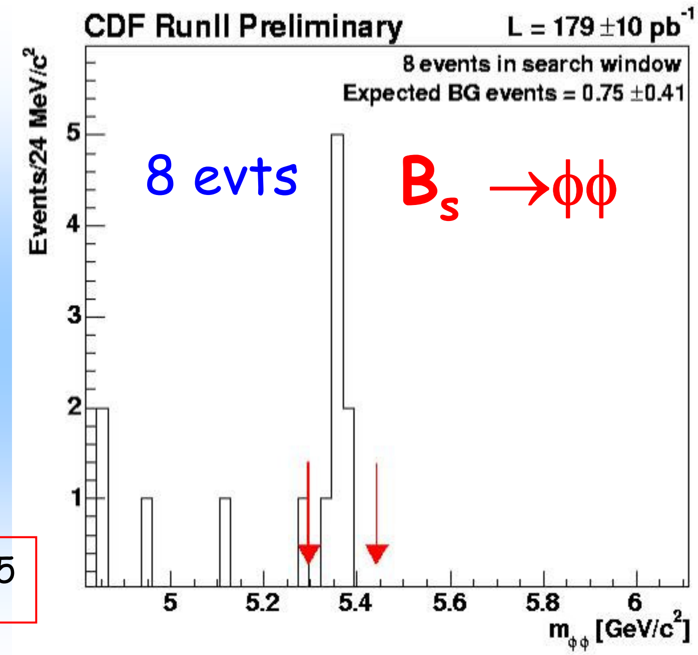
$B_s \to \phi\phi$ & $B^\pm \to \phi K^\pm$



- $b \to sss$ decays in B_s mesons
- Extract information on α and γ
- Direct ~~CP~~ small ⇒ test SM
- @CDF fully reconstructed hadronic decays

First evidence of $B_s \to \phi\phi$

$$BR(B_s \to \phi\phi) = (1.4\,^{+0.6}_{-0.5}\,_{stat.} \pm 0.2_{syst.} \pm 0.5_{BR}) \times 10^{-5}$$



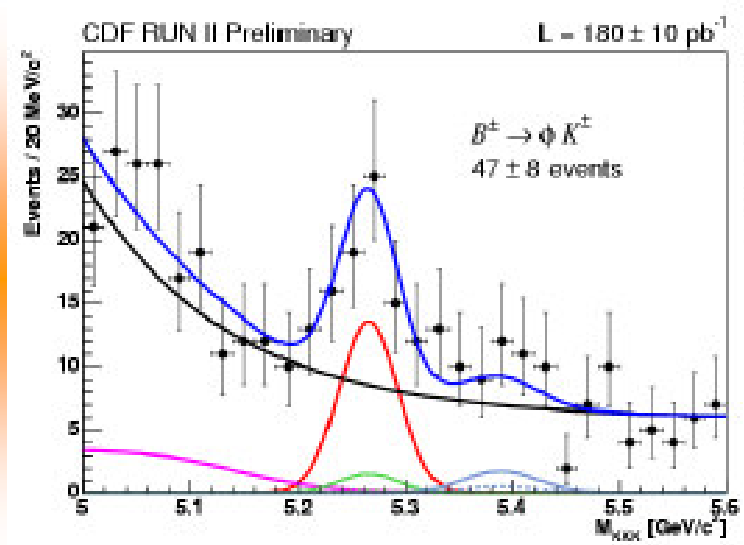
$B^\pm \to \phi K^\pm$

Unbinned likelihood fit to disentangle signal and background

$$BR(B^\pm \to \phi K^\pm) = (7.6 \pm 1.3_{stat.} \pm 0.6_{syst.}) \times 10^{-6}$$

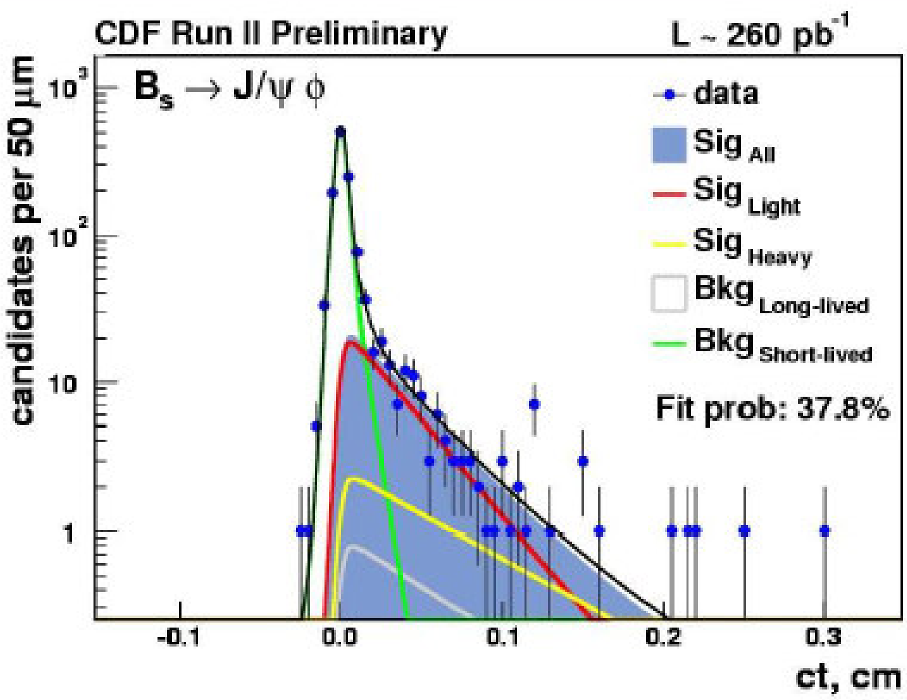
$$A_{CP}(B^\pm \to \phi K^\pm) = -0.07 \pm 0.17_{stat.}\,^{+0.03}_{-0.02}\,_{syst.}$$

Babar: A_{CP} = 0.054±0.056 (stat)±0.012 (syst)
Belle: A_{CP} = 0.01±0.12(stat.)±0.05(syst.)



$\Delta\Gamma_s$

- $B_s \to J/\psi\phi$: Pseudoscalar → Vector Vector
  - Three different linear amplitudes ↔ relative orbital angular momentum
  - $B_{s,L} \approx$ CP even ≈ Long lifetime (L=0,2)
  - $B_{s,H} \approx$ CP odd ≈ Short lifetime (L=1)
- Simultaneous fit of lifetime and amplitudes
- Use $B^0 \to J/\psi K^{*0}$ for X-check
- CDF finds large value for the lifetime difference



$$\frac{\Delta\Gamma_s}{\Gamma_s} = 65\,^{+25}_{-33} \pm 1\,\%$$

$$\text{SM}\ :\ \frac{\Delta\Gamma_s}{\Gamma_s} \sim 14 \pm 5\,\%^{[1]}$$

Accepted by P.R.L

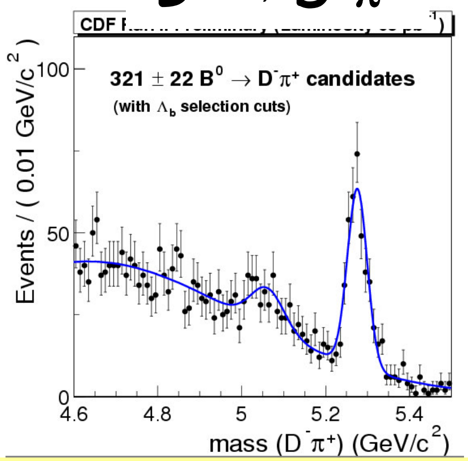
[1] hep-ph/0311130

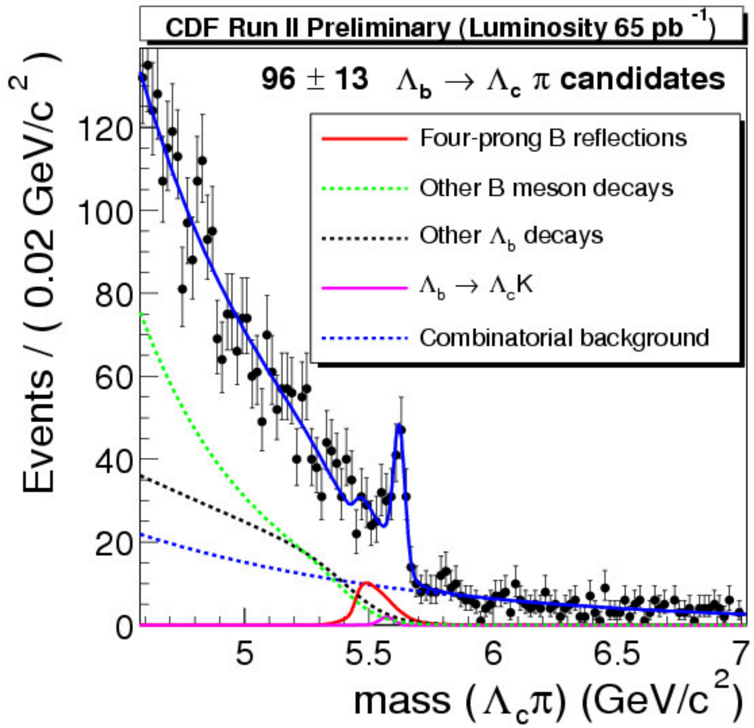
Fully hadronic Λ_b decay

$\Lambda_b \rightarrow \Lambda_c \pi$

- Test for theoretical models of b-baryon weak decays
- Understanding of QCD
- First BR measurement

$B^0 \rightarrow D^- \pi^+$





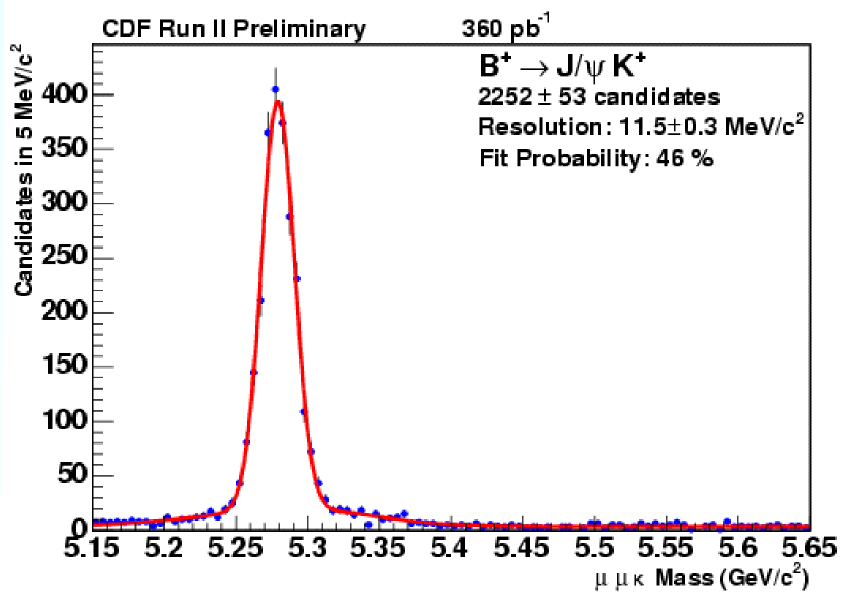
$$\frac{\sigma_{\Lambda b}(p_t > 6GeV/c) \times Br(\Lambda_b \rightarrow \Lambda_c \pi)}{\sigma_{B0}(p_t > 6GeV/c) \times Br(B^0 \rightarrow D\pi)} = \frac{\varepsilon_{B0} \times N_{\Lambda b} \times Br(D \rightarrow K\pi\pi)}{\varepsilon_{\Lambda b} \times N_{B0} \times Br(\Lambda_c \rightarrow pK\pi)}$$

$$= 0.82 \pm 0.08_{stat.} \pm 0.11_{syst.} \pm 0.22_{BR}$$

$M(B_c)$ in $B_c \to J/\psi\pi$

- B_c:
  - $B_c \to J/\psi l\nu$ observed @CDF [1] and D0[2]
  - Large experimental uncertainty on M
  - Validation of theoretical models (Lattice QCD and potential models)
- Fully reconstructed decay→Better mass resolution
- Blind search analysis
  - Search region defined from previous mass meas.:

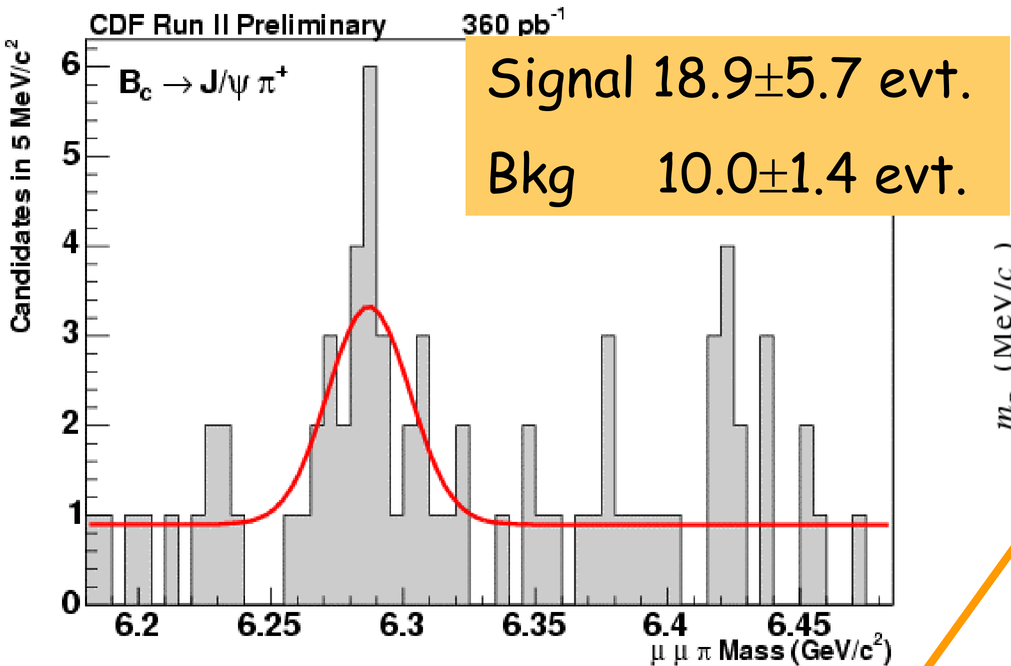
    $6.4 \pm 2\sigma$ = [5.6 to 7.2] GeV/c^2
  - Use $B^+ \to J/\psi K^+$ to estimate effect on signal (same topology)



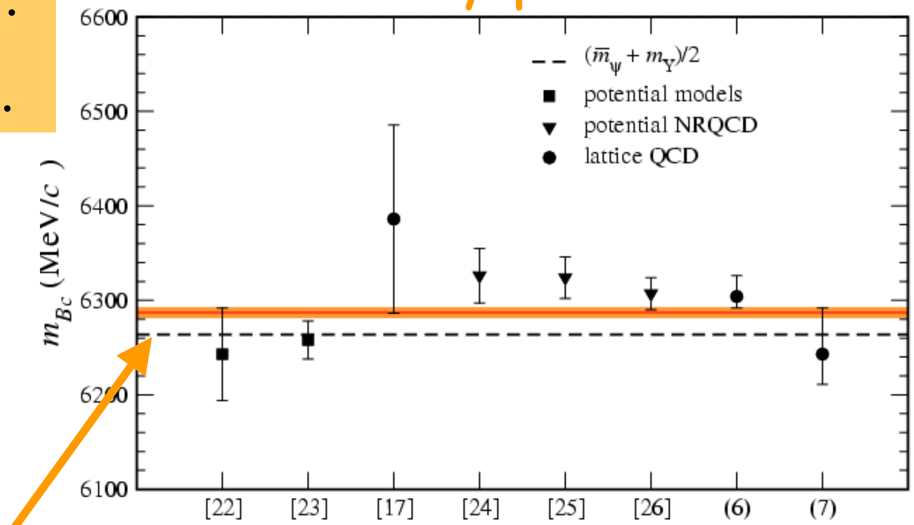
[1] CDF Collaboration in PRL 81 n.12 (1998)

[2] ICHEP 2004

$B_c \to J/\psi\pi$ - Results



Theory predictions [1]



$M(B_c) = (6287.0 \pm 4.8_{stat.} \pm 1.1_{syst.})\,MeV/c^2$

- Precision on $M(B_c)$ improved by a factor 100
- Main syst. from Bkg shape given by low statistics
- Good agreement with theory

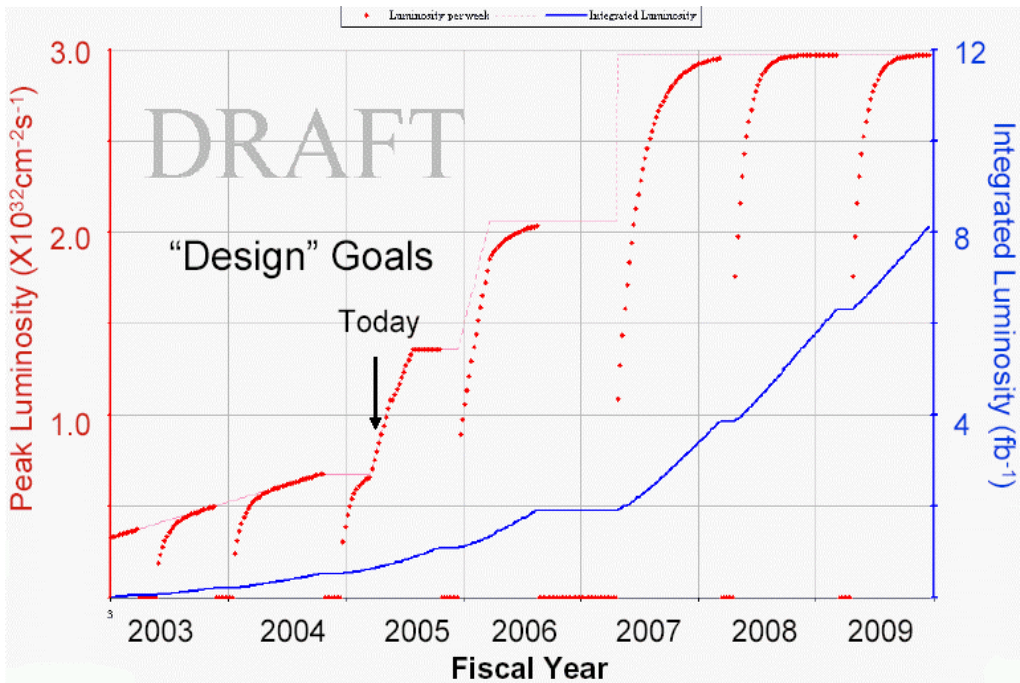
[1] hep-lat/0411027

Conclusions…

- CDF has many interesting results
  - Two body charmless B-decays
    - Unique measurement of B_s BRs
    - Promising sensitivity to A_{CP}
  - First observation of $B_s \to \phi\phi$
  - $B^{\pm} \to \phi K^{\pm}$ promising measurement of A_{CP} and BR
  - Large $\Delta\Gamma_s$ in $B_s \to J/\psi\phi$
  - Λ_b
    - Fully reconstructed hadronic decays
    - Search for rare decays
  - Best measurement of B_c mass in agreement with theory
- But this is just a part of the beginning…

…and perspectives

A lot of new data coming…



Many analysis are still statistically limited and will see considerable improvements in sensitivity

BACKUP

B_c cut optimization

Analysis cut optimization based on:

- total number of events in search region assume signal negligible
- Monte Carlo events MC for signal

Monte Carlo used for: optimizing cuts, estimating sensitivity, relative to B^+

$$\text{Maximize}\ \Sigma = \frac{S}{1.5 + \sqrt{B}}$$

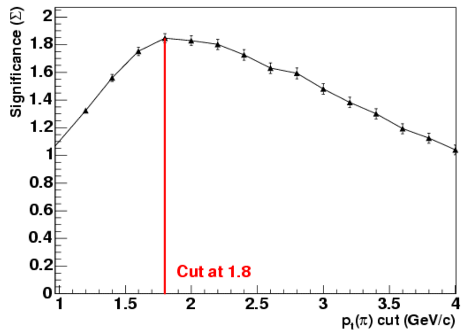
S = number of signal events from MC

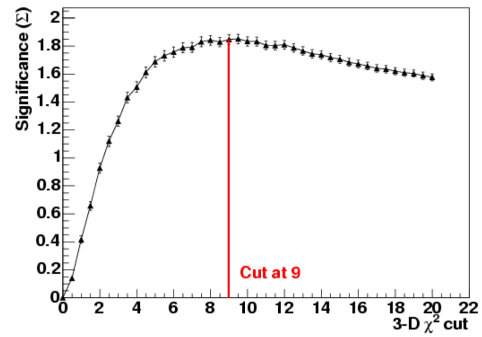
B = average number of background events (data) from whole region in a window $\pm 2\text{-}s_M$ wide (60.4 MeV/c^2).

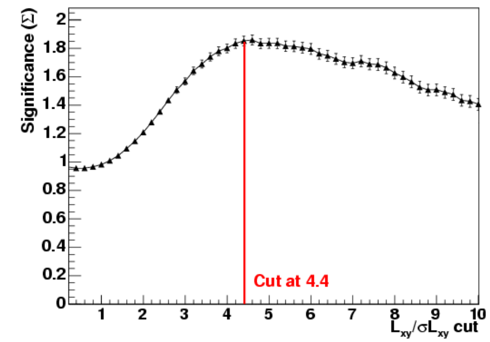
Balanced score-function for limit and "discovery"

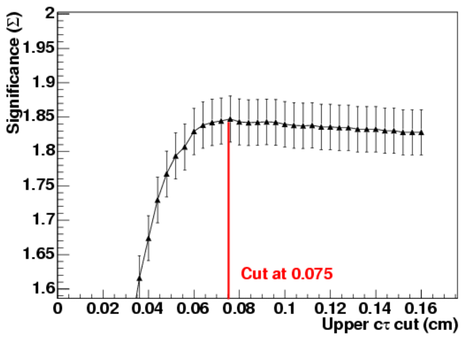
(hep-physics/0308063)

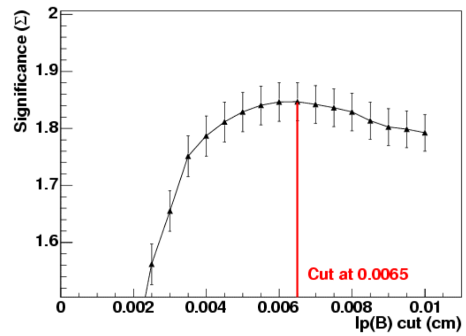
B_c - cut optimization

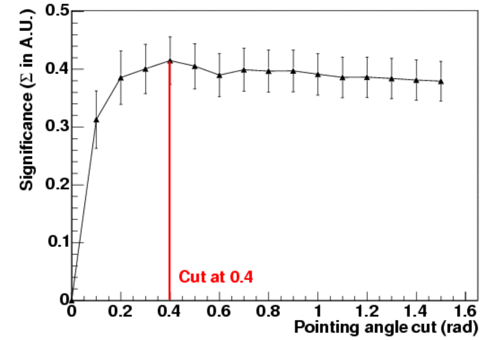


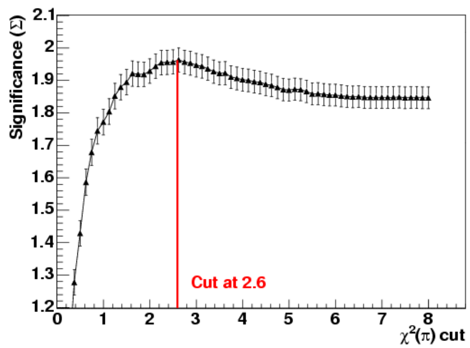






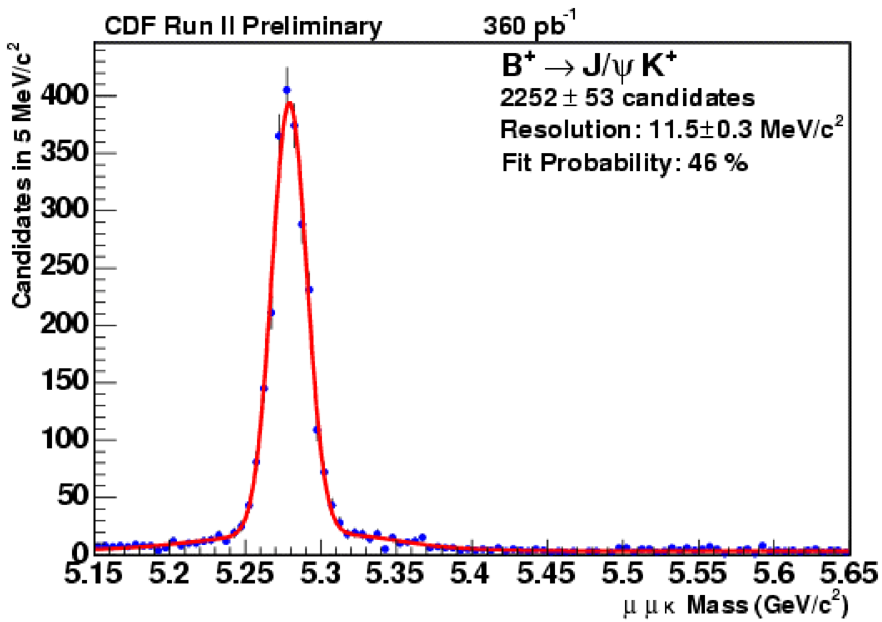






$$\Sigma = \frac{S}{1.5 + \sqrt{B}} \quad \text{vs. cut value}$$

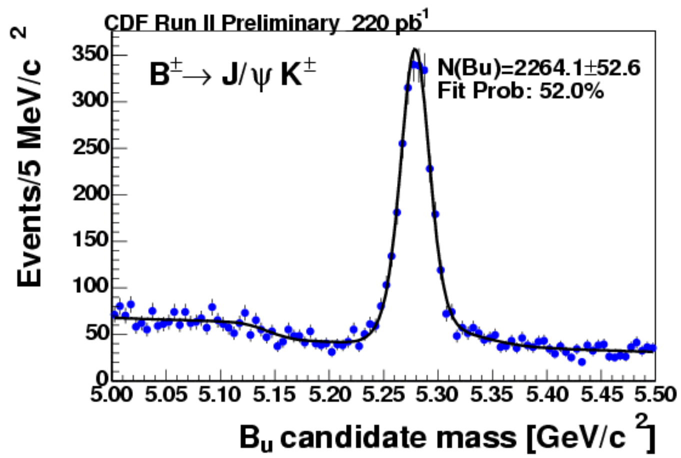
B_c – reference channel



$B^+ \to J/\psi\ K^+$

Used for

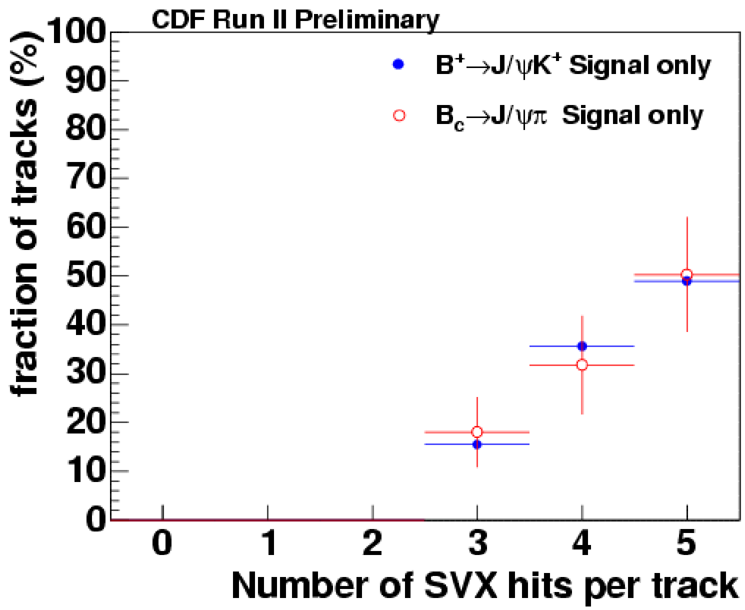
- checking data/MC
- estimating expected significance

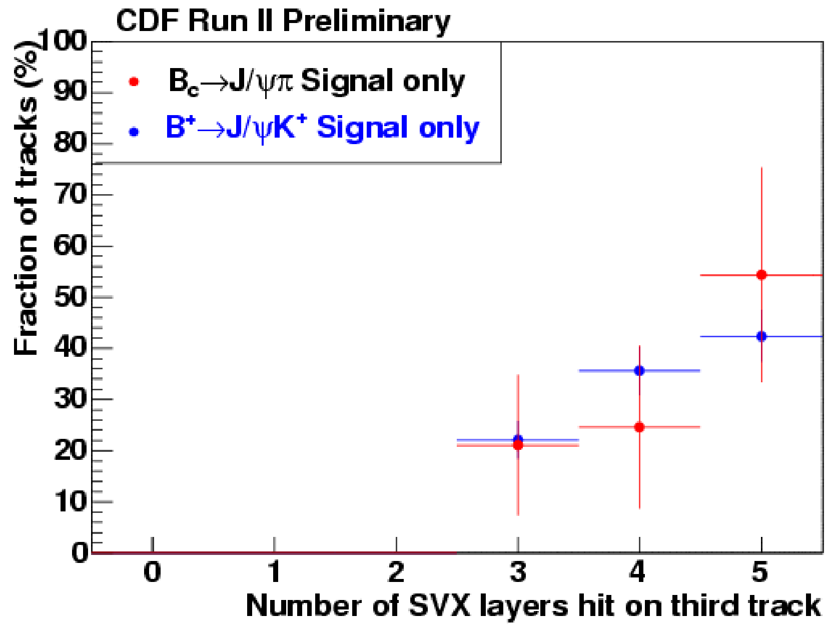


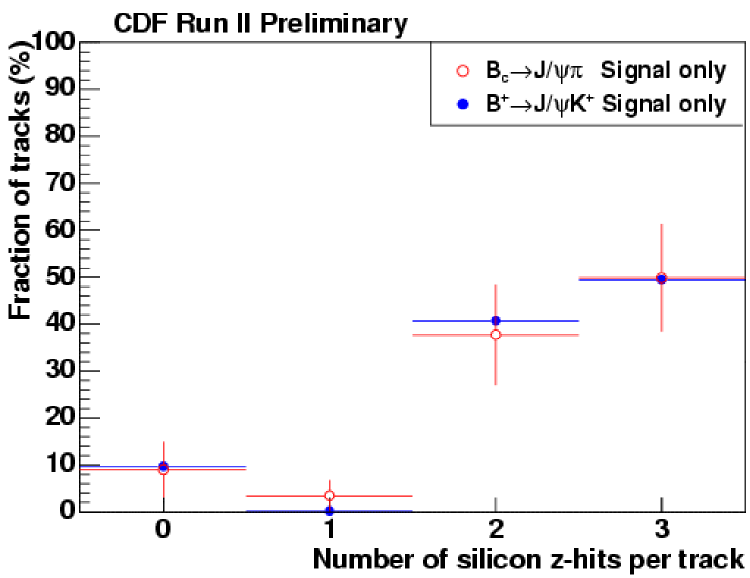
$$S = \frac{\varepsilon_c}{\varepsilon_u} N_u R$$

- R = ratio of production fractions
- Expected estimated signal from 4 to 30 events

B_c – track quality (Silicon)



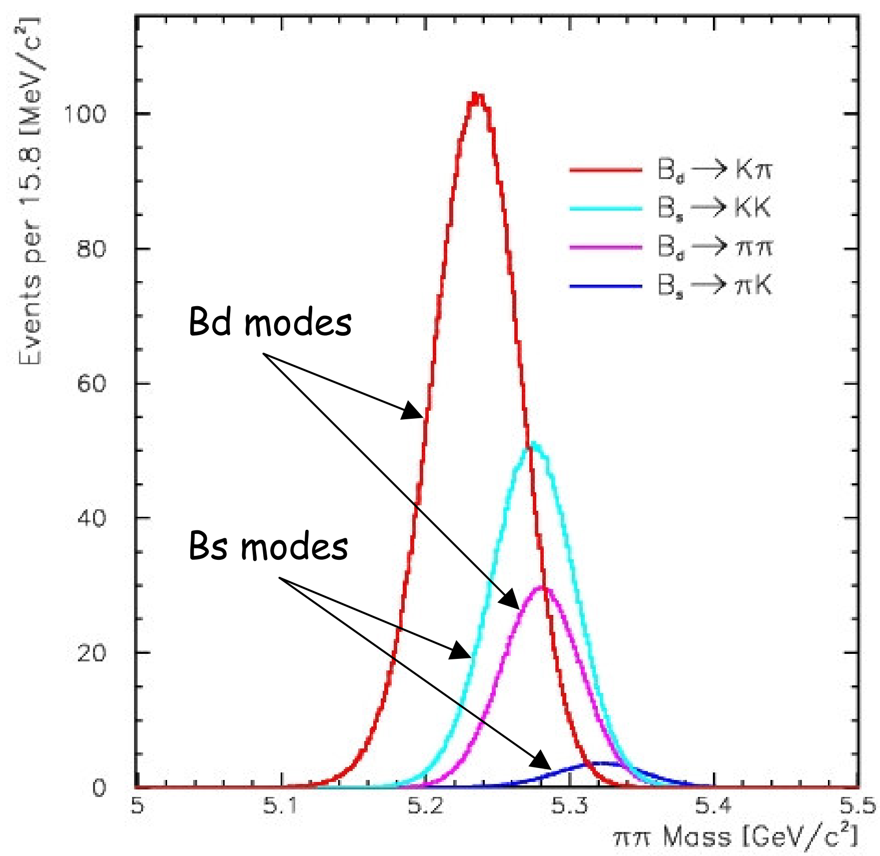




Compare hits/track in silicon of B_c and B^+

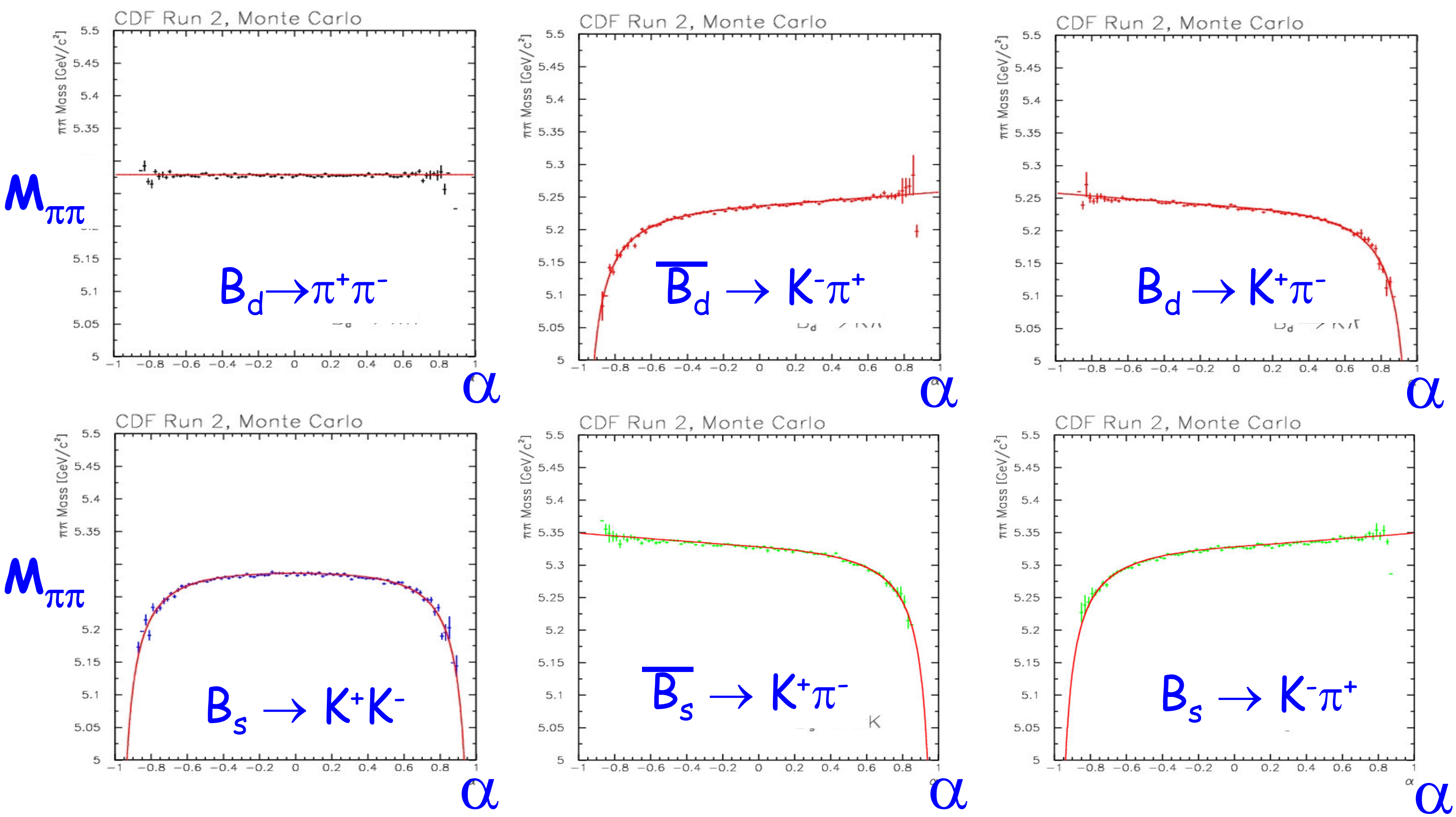
Separation of individual modes

- The 4 major expected modes overlap to form a single unresolved bump
- Approach: use Mass+kinematics+track PID in an unbinned Max-Likelihood fit $\Rightarrow$ extract the fraction of each component.

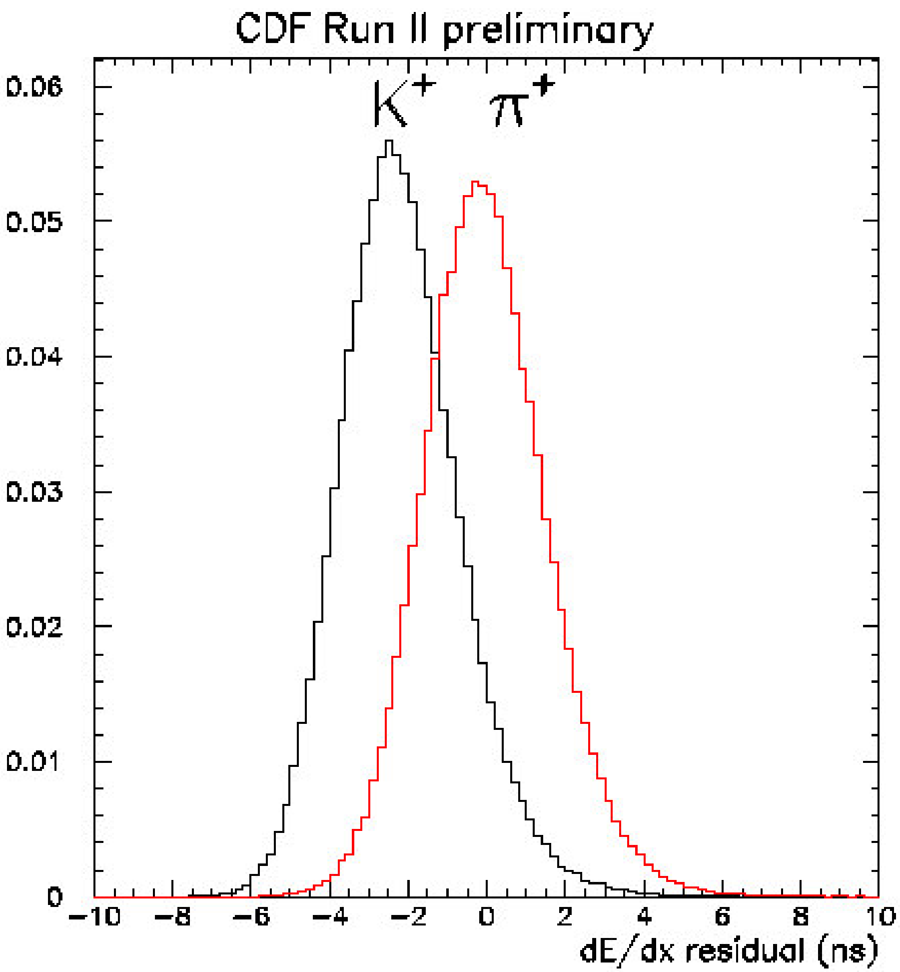


Separation from Kinematics

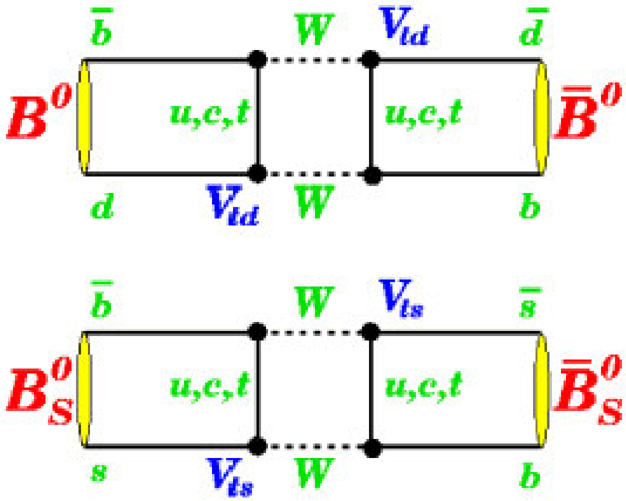
Mass ($\pi\pi$ hypothesis) vs signed momentum imbalance α=**[1–p1/p2] × q1.**
discriminates amongst signals and between flavors for self-tagging decays.
All 4 possible mass assignments (strongly correlated) depend on them
$\Rightarrow$ *(α, $M\pi\pi$)* carry all relevant information.



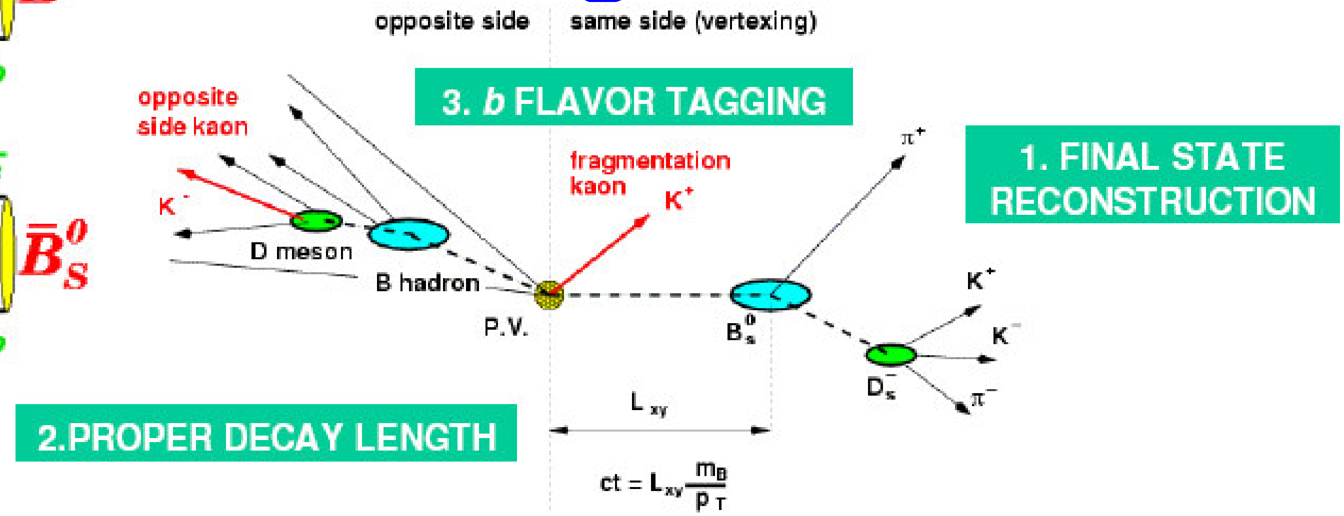
Separation from PID (dE/dx)



- K/π separation: **1.4σ** @P_T>2 GeV/c
- Use time-dependent calibrations on CDF's huge $D^{*+} \to D^0\pi^+$ sample.
- This PID performance implies statistical separation of K-pi with resolution 60% of a "perfect" PID.
- Control of systematics:
  Residual gain/baseline fluctuations cause correlated fluctuations of tracks in same event. They have been measured and explicitly included in the fit.



B Mixing



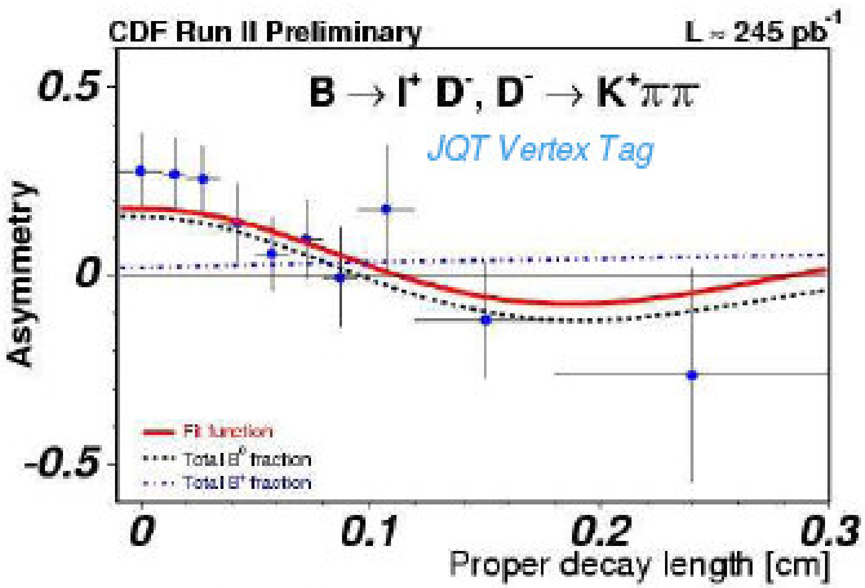
- Measure the b flavour as function of time→Need to know the initial flavour
- Same Side Tag (SST): track from fragmentation of the b
- Opposite Side Tag (OST): informations from partially reconstructed B
  - Soft Muon (SMT) / Soft Electron (SET) / Jet Charge (JQT)
- Tagger effectiveness εD^2
  - ε: efficiency
  - D = (2P-1) where P=correct answer probability

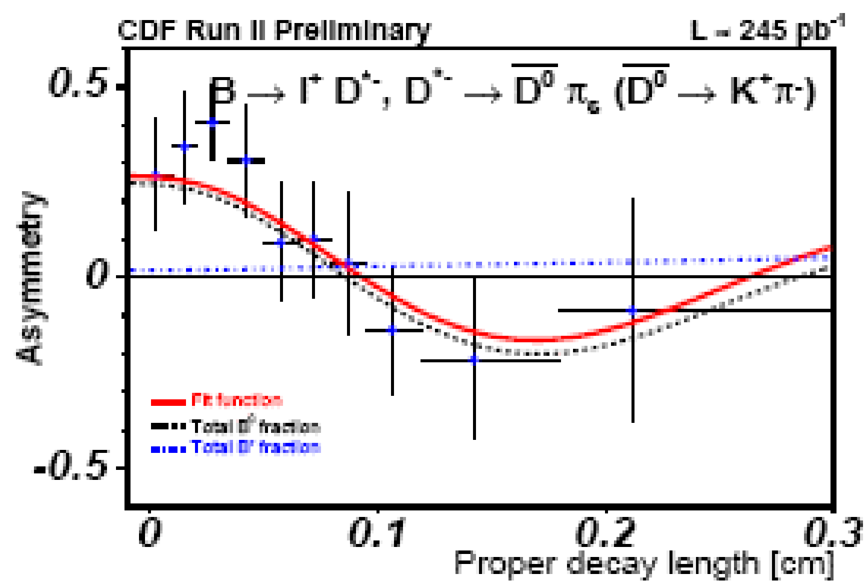
B^0 Mixing

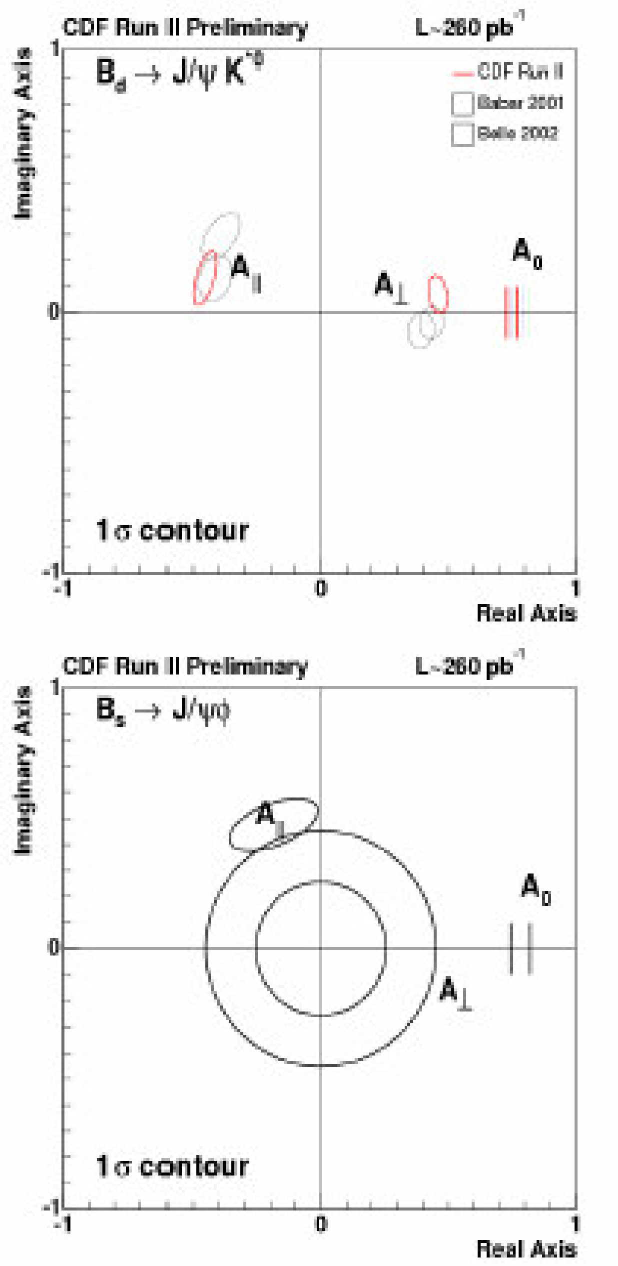
B^0 mixing measurements $\Rightarrow$ test the machinery for B_s

	Semileptonic decays:	Fully reco. Decays
Δm_d	$0.536 \pm 0.037 \pm 0.009(s.c.) \pm 0.015 ps^{-1}$	$0.526 \pm 0.056 \pm 0.005 ps^{-1}$
SST	$1.1 \pm 0.3 \pm 0.2(s.c.) \pm 0.1\%$	$1.0 \pm 0.35 \pm 0.06\%$
OST+SST	$1.820 \pm 0.114\%$	

$\Delta m_d = 0.502 \pm 0.007 ps^{-1}$







$\Delta\Gamma_s$

- Evaluate the percentage of long living state after applying cut on decay length
- Fit the time-integrated fraction

Cut(μm)	Fitted (%)
> 0	21.6 ± 4.4
> 150	23.0 ± 3.6
> 300	23.0 ± 4.0
> 450	23.6 ± 4.9

Cut(μm)	Fitted (%)	Predicted (%)
> 0	20.1 ± 9.0	–20.1–
> 150	24.2 ± 10.3	24.1
> 300	29.6 ± 12.7	28.6
> 450	38.7 ± 11.6	33.6