Measuring Δm_s

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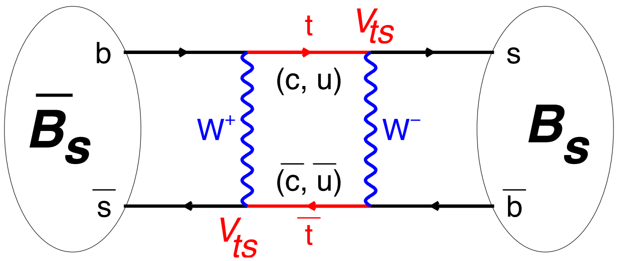
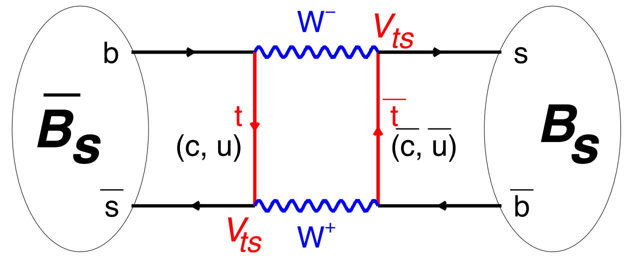
Lattice QCD Meets Experiment
April 26, 2010

B_s Oscillations





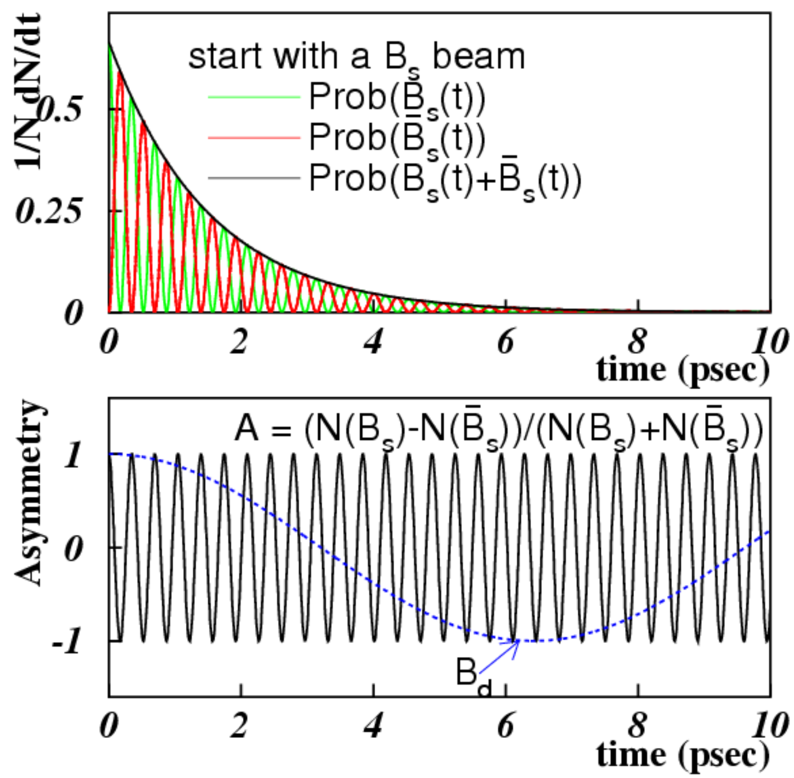
$$P(t)_{B_s^0 \to \bar{B}_s^0} = \frac{1}{2\tau} e^{-\frac{t}{\tau}} \left(1 - \cos\left(\Delta m_s t\right)\right)$$

$$\Delta m_s = m_H - m_L$$

In conjunction with existing results and lattice QCD quantity ξ:

$$\frac{\Delta m_d}{\Delta m_s} = \frac{m_{B_d}}{m_{B_s}} \frac{1}{\xi^2} \left| \frac{V_{td}}{V_{ts}} \right|^2$$

$$\xi^2 \equiv \frac{f_{B_s}^2 B_{B_s}}{f_{B_d}^2 B_{B_d}}$$



Measuring Δm_s

In order to determine the mixing frequency, there are three ingredients to be obtained:

- Flavor at time of decay
  - ➡Final state products
- Flavor at time of production
  - ➡Flavor tagging
- Proper decay time
  - ➡Time dependent analysis

Flavor Tagging

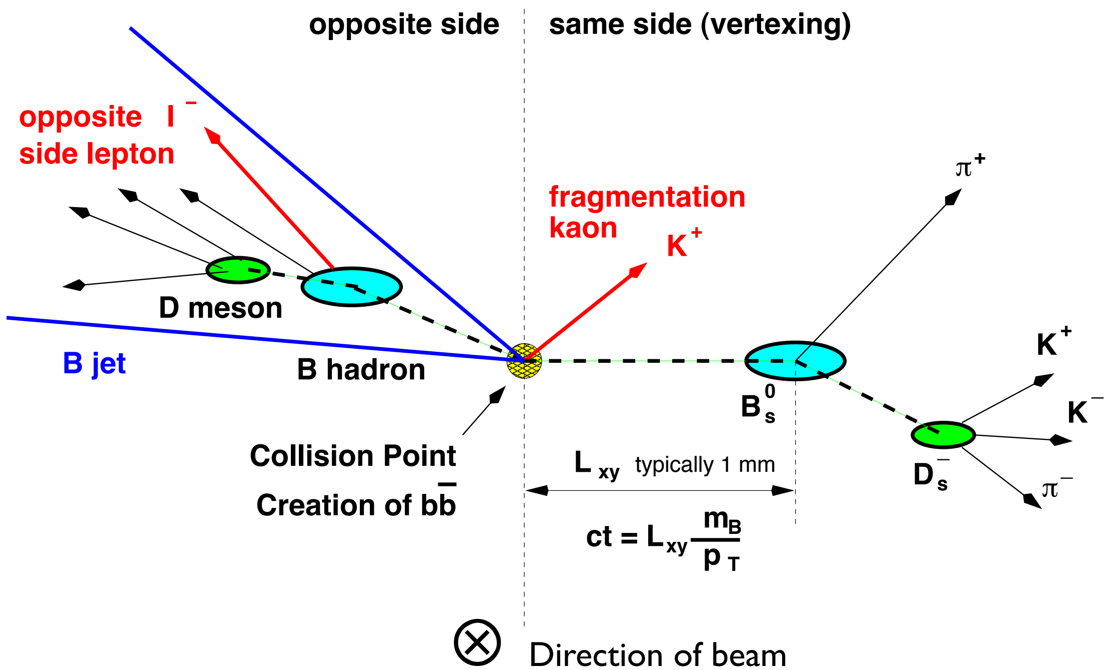
Bs or $\overline{\text{B}}$s at time of production?

Opposite Side (OST)

- Electron tagging
- Muon tagging
- JetQ tagging

Same Side (SST)

- Correlation between fragmentation particles and flavor of B meson



- CDF uses a combined same side and opposite side tag

Flavor Tagging

- Parameters of tagging
  - Dilution: D=1-2p (p is mis-tag rate)
  - Tagging Efficiency ε = tagged events/total
  - Tagging Power = εD^2
- An Example
  - D = 40% (Correct tag 70% of the time)
  - ε = 5%
  - $\varepsilon D^2 \approx 1\%$
    - ➡ 1K typical signal events has "power" of 10 perfectly tagged events

Opposite Side Tagging

lepton+track sample at CDF

tagger [%]	efficiency	dilution	εD^2
Muon	4.6 ± 0.0	34.7 ± 0.5	0.58 ± 0.02
Electron	3.2 ± 0.0	30.3 ± 0.7	0.29 ± 0.01
JQT	95.5 ± 0.1	9.7 ± 0.2	0.90 ± 0.03
Kaon	18.1 ± 0.1	11.1 ± 0.9	0.23 ± 0.02
OST old	95.6 ± 0.1	11.9 ± 0.1	1.34 ± 0.03
OST NN	95.8 ± 0.1	12.7 ± 0.2	1.54 ± 0.04

Challenges include detector acceptance and misidentification (fake leptons, imperfect JQT)

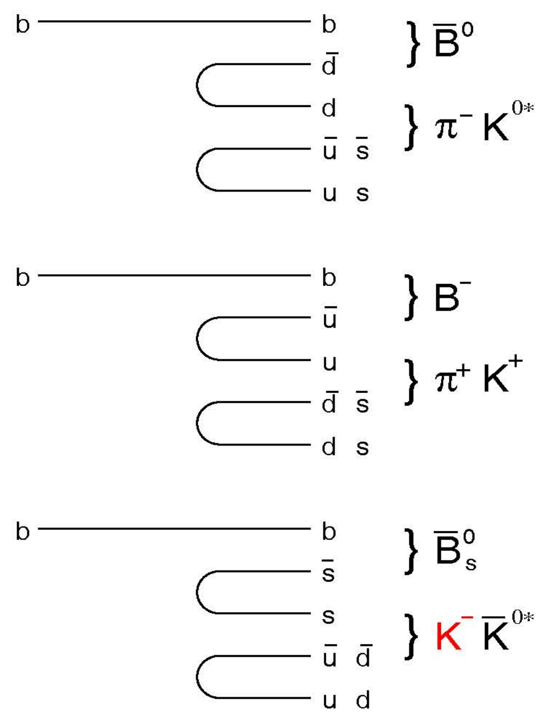
Same Side Tagging

Fragmentation

- B^0/B^+ likely accompanied by π^+/π^-
- Bs likely accompanied by a K^+
- need MC to measure D

Strategy

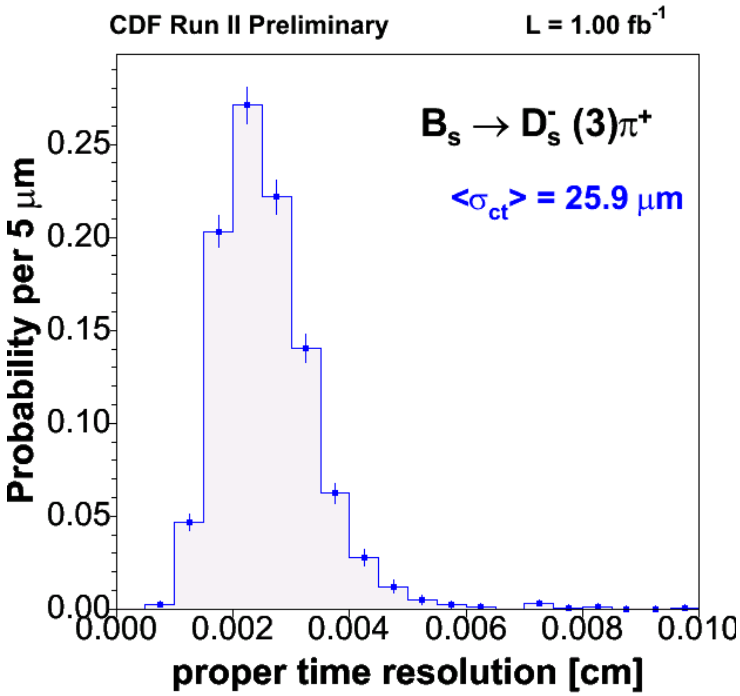
- tune MC using B^+ and B^0
- use PID to de-weight pions
  - very important



CDF: $\epsilon D^2 \approx 3.7\%(4.8\%) hadronic(semileptonic)$

Lifetime Measurement

- Mean proper time resolution of 25.9 μm (~90 fs) in hadronic decays (worse in semileptonic)
- In the fit, events are weighted based on this resolution



osc. period at Δm_s = 18 ps^{-1}

$$\sigma_{ct} = \left(\frac{L_{xy}}{p_T}\right)\sigma_{m_B} \oplus \left(\frac{m_B}{p_T(B)}\right)\sigma_{L_{xy}} \oplus ct\left(\frac{\sigma_{p_T}}{p_T}\right)$$

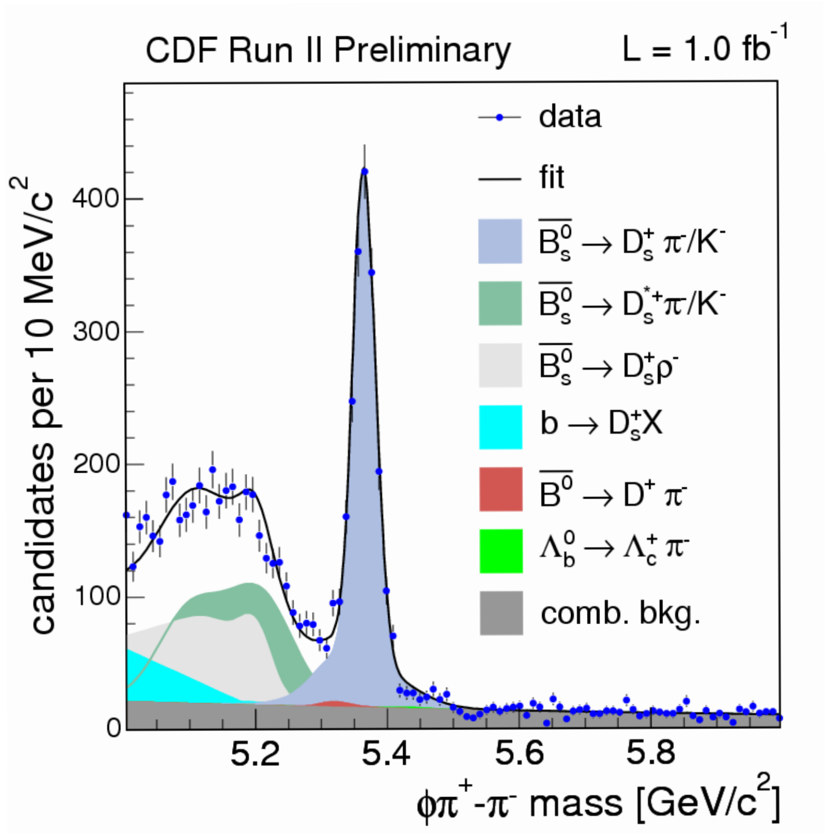
negligible

Becomes dominant in semileptonic events

CDF Results

Hadronic Yields

	Yield	S/B
$B_s \to D_s\pi$ ($\phi\pi$)	2000	11.3
Partially recon	3100	3.4
$B_s \to D_s\pi$ ($K^* K$)	1400	2.0
$B_s \to D_s \pi$ (3π)	700	2.1
$B_s \to D_s 3\pi$ ($\phi\pi$)	700	2.7
$B_s \to D_s 3\pi$ (K^*K)	600	1.1
$B_s \to D_s 3\pi$ (3π)	200	2.6
Total	8700	

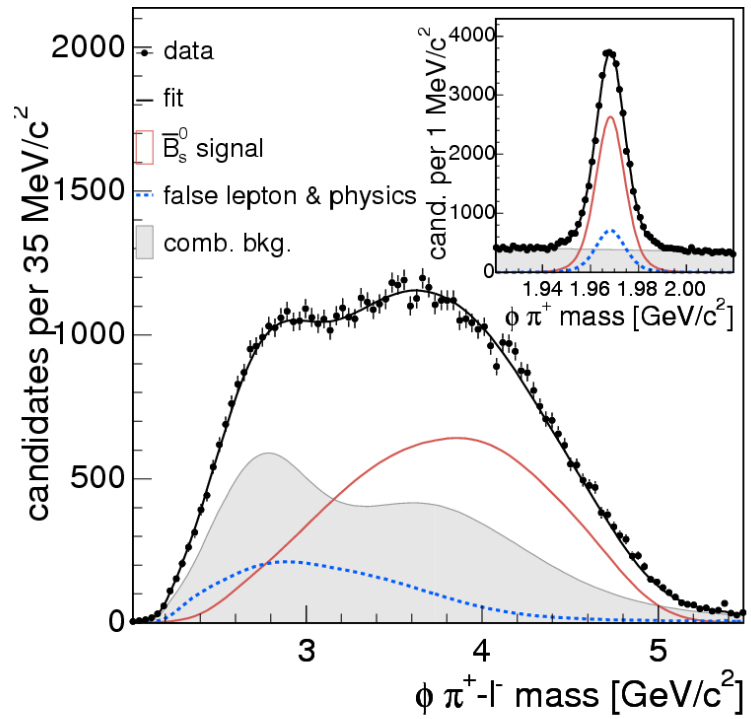


These fully reconstructed decays provide the most statistical weight to the measurement

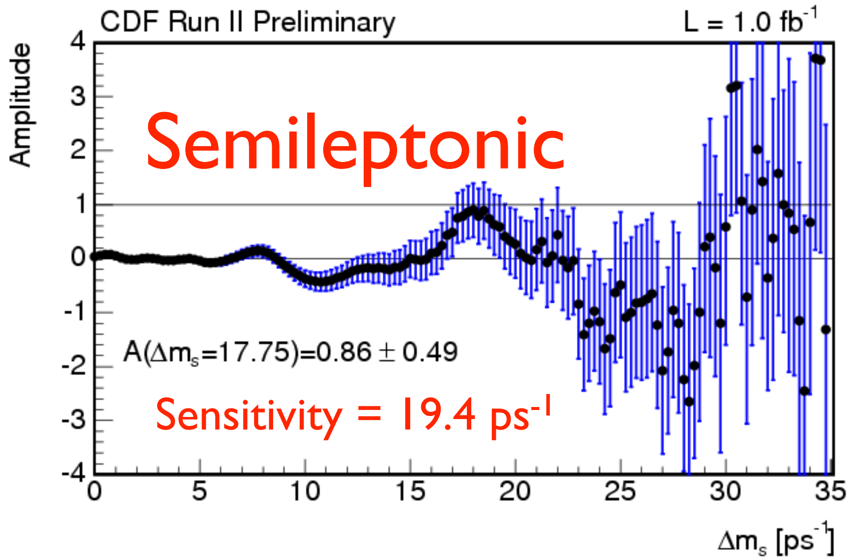
CDF Results

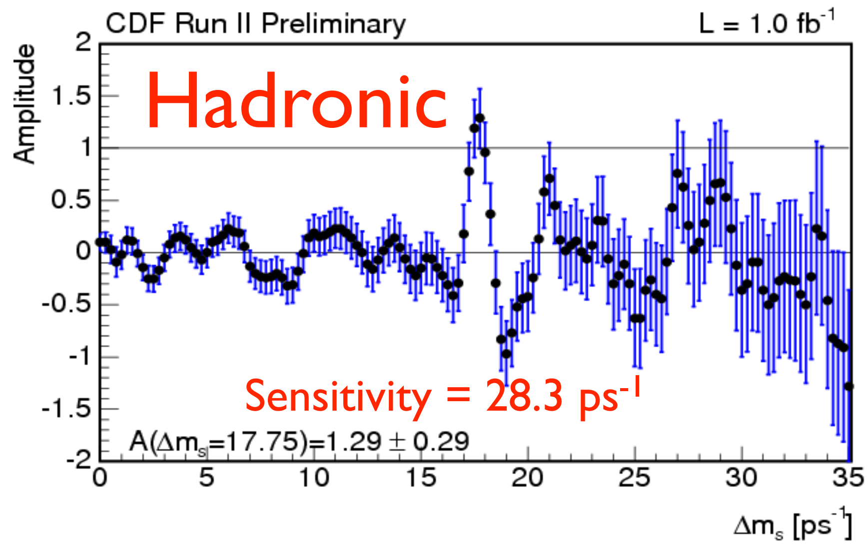
Semileptonic Yield

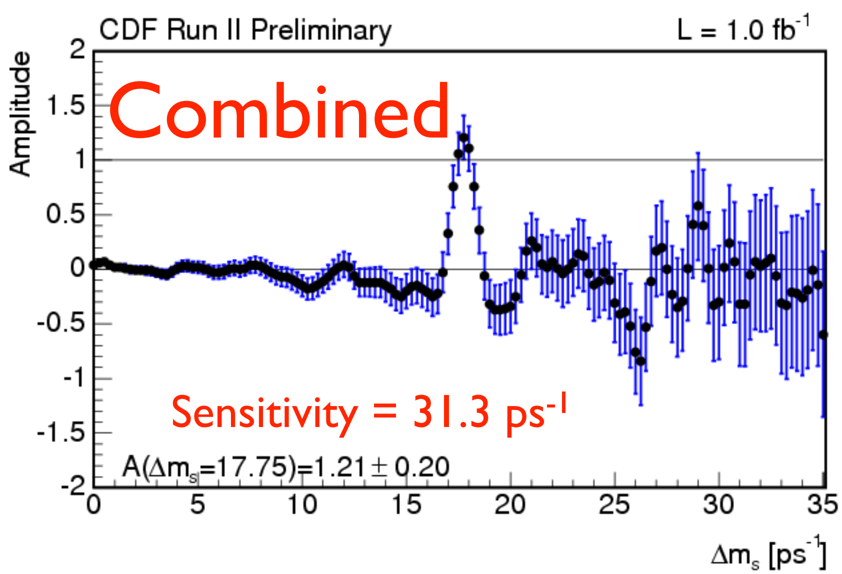
- Semileptonic yields are much greater ~67K events in all channels
- But we miss the neutrino, which hurts our momentum resolution
- Which hurts our proper decay time resolution
- More events, but much less powerful



CDF Results





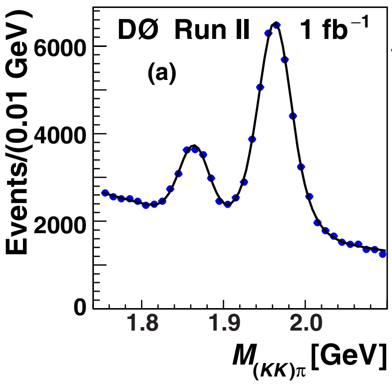


- Perform likelihood fit of A each fixed Δm_s value
- If D is correct, A = 1

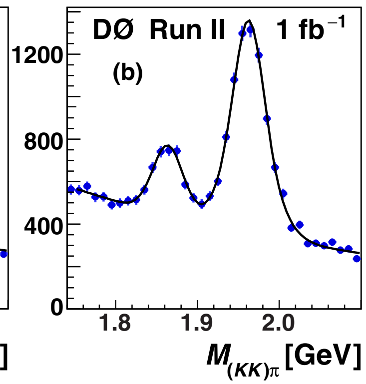
$$P(t) = (1 + AD\cos(\Delta m_s t))\, e^{\frac{-ct}{c\tau}}$$

$$\Delta m_s = 17.77 \pm 0.10(stat) \pm 0.07(syst) ps^{-1}$$

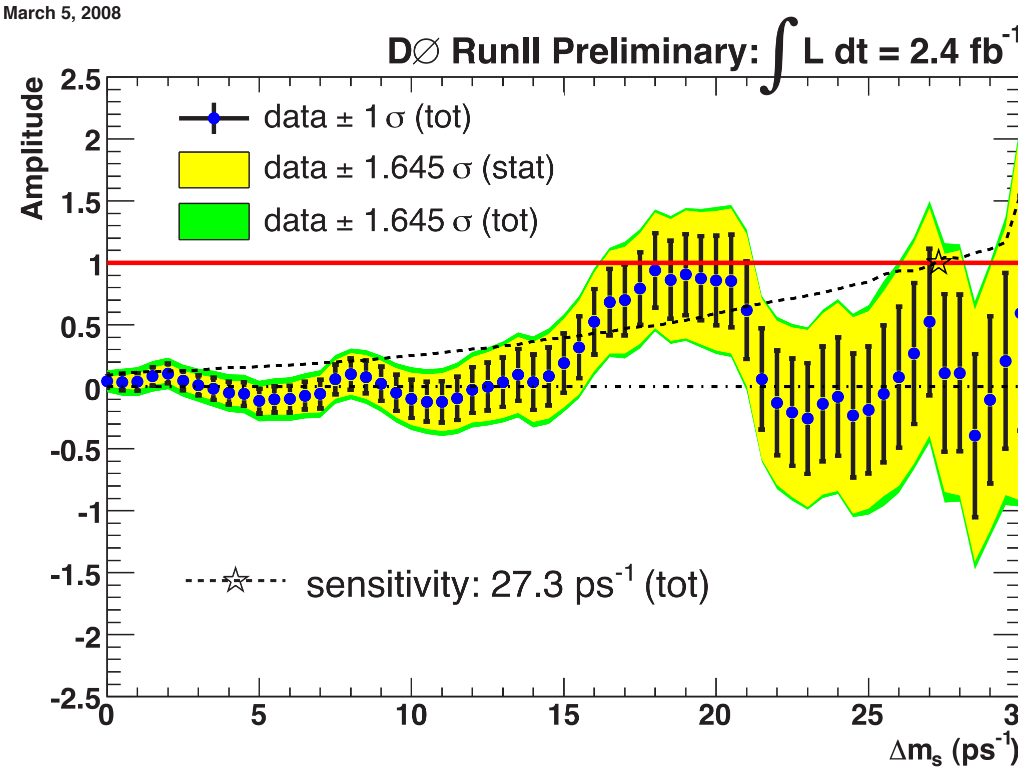
DØ Results



Untagged



Tagged



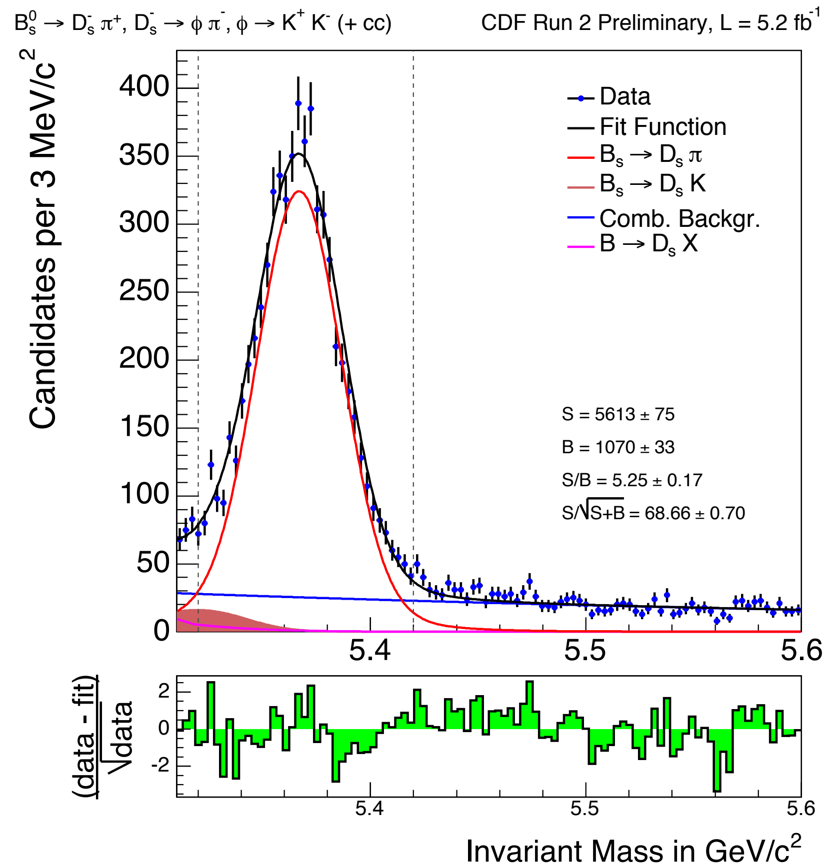
Decay Mode	95% C.L. Sensitivity (ps^{-1}) RunIIa	RunIIb	RunIIa+b
$e\phi\pi$	8.9	6.0	10.0
$\mu K^* K$	11.3	12.0	15.2
$\mu\phi\pi$	19.7	19.3	23.9
$\mu K_S K$	2.0		
Semi-Leptonic	20.5	21.5	25.4
$\pi\phi\pi$			14.0
Full Combination			27.3

$$\epsilon D^2 = 2.48 \pm 0.21(stat)^{+0.08}_{-0.06}(syst)\%$$

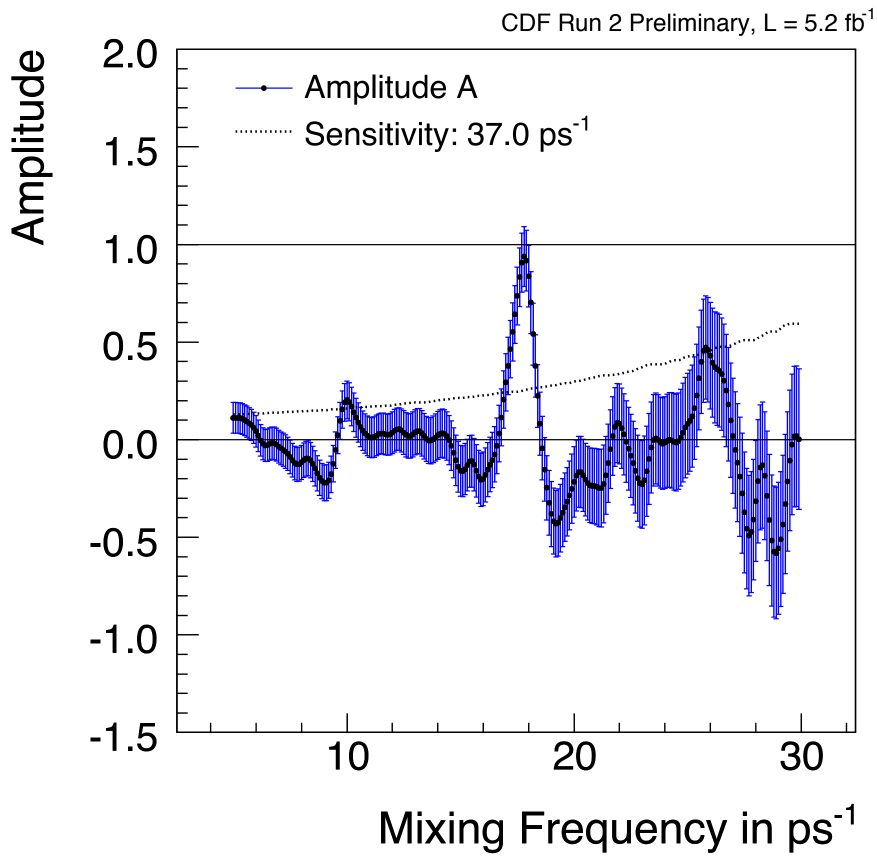
$$\Delta m_{\rm s} = 18.53 \pm 0.93({\rm stat}) \pm 0.30({\rm syst})\ {\rm ps}^{-1}.$$

CDF Projections

- With the 5σ measurement of Δm_s, CDF uses Bs oscillations to calibrate the SSKT.
- Yield should scale by about 0.8 times per fb^{-1} (trigger prescales at higher instantaneous luminosities means fewer events)



CDF Projections



Stat only

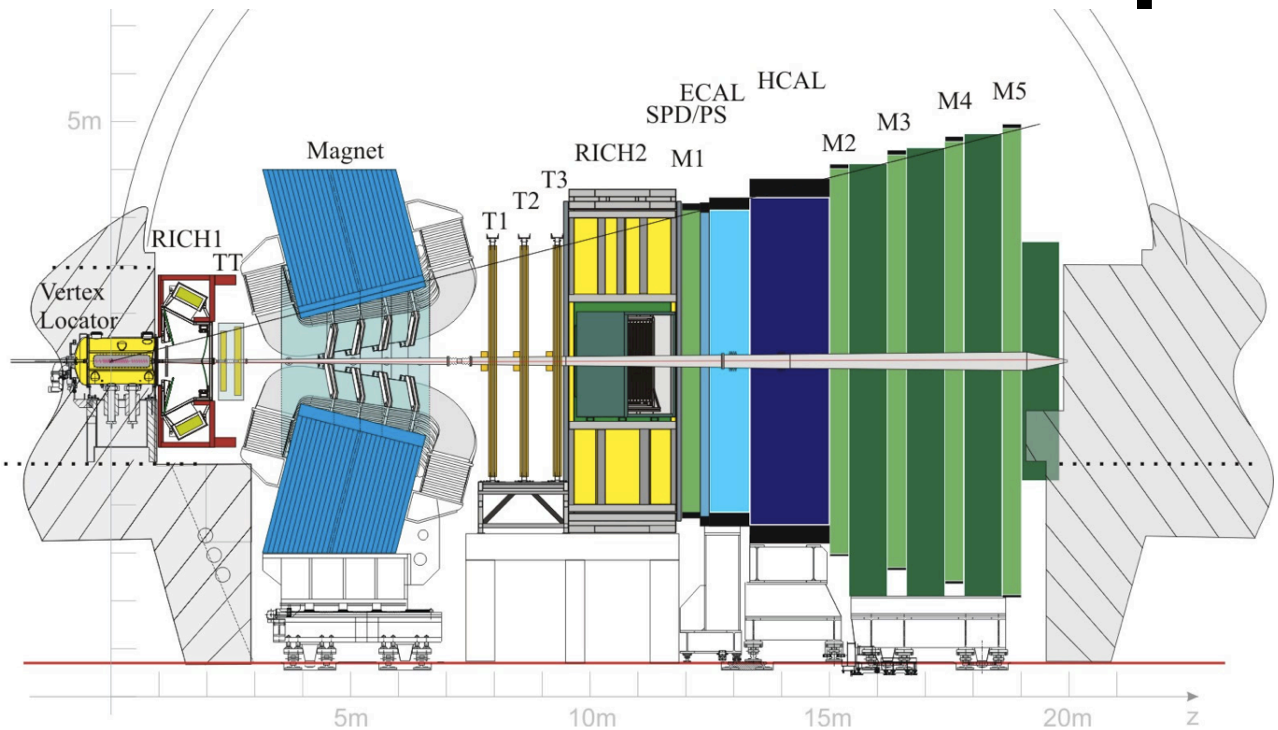
$$\Delta m_s = (17.79 \pm 0.07)\ \text{ps}^{-1}$$

- Measurement performed without OST, partially reconstructed decays, semileptonic events
- Full measurement won't be much better (most powerful events used here)
- But with added statistics, will be in systematic dominated regime

Decay Channel	S	B	S/B	$S/\sqrt{S+B}$
$B_s^0 \to D_s^- \pi^+,\ D_s^- \to \phi\pi^-$	5613 ± 75	1070 ± 33	5.25 ± 0.17	68.66 ± 0.70
$B_s^0 \to D_s^- \pi^+,\ D_s^- \to K^* K^-$	2761 ± 53	1619 ± 40	1.71 ± 0.05	41.72 ± 0.74
$B_s^0 \to D_s^- \pi^+,\ D_s^- \to (3\pi)^-$	2652 ± 52	3533 ± 59	0.75 ± 0.02	33.72 ± 0.68
$B_s^0 \to D_s^- (3\pi)^+,\ D_s^- \to \phi\pi^-$	1852 ± 43	695 ± 26	2.66 ± 0.12	36.69 ± 0.73
Sum	**12877 ± 113**			

$$\sigma_{syst} \approx 0.07 ps^{-1}$$

LHCb Prospects



Lots of forward B mesons that are lost in a central detectors like CDF and D∅

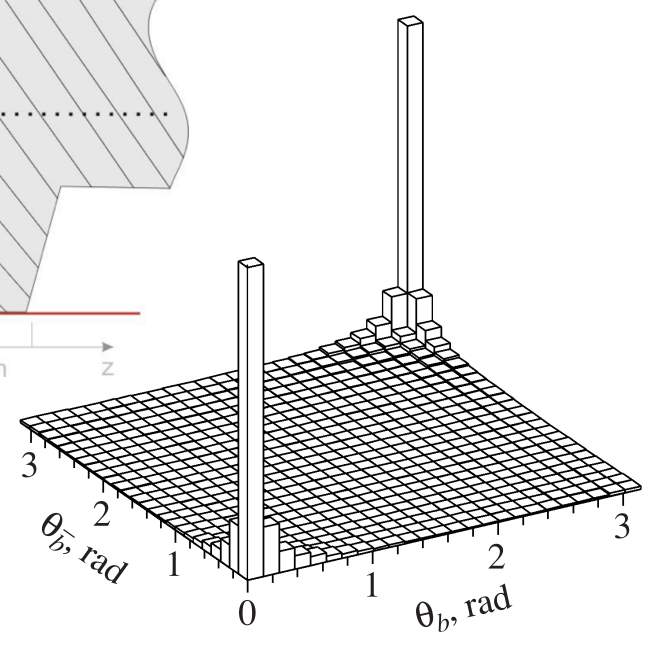
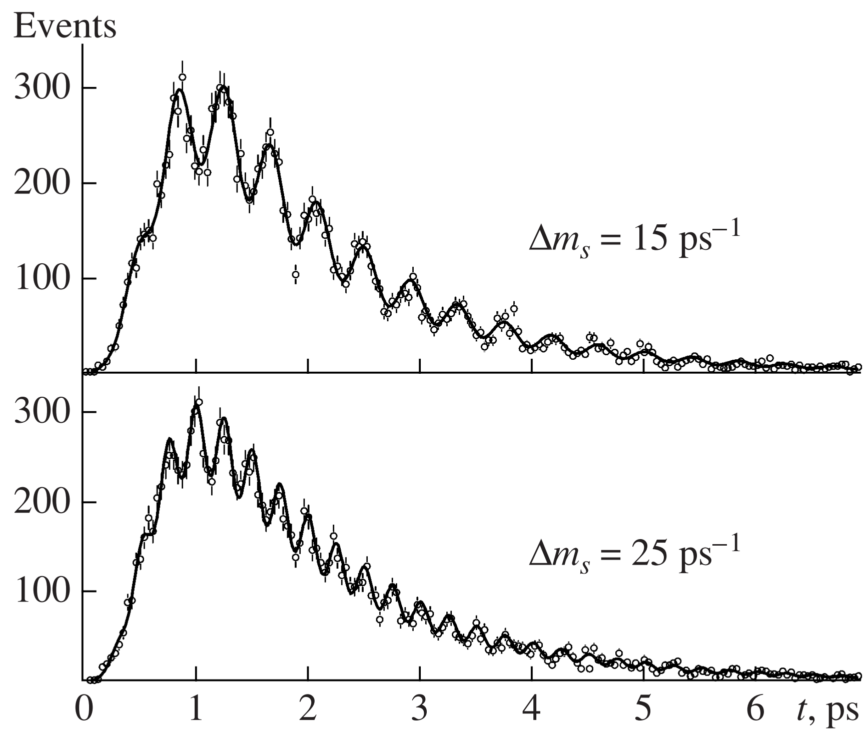


Fig. 4. The distribution (arbitrary scale) of polar angles of hadrons containing b and $\bar{b}$ quarks at the LHC.

(N. Harnew, Physics of Atomic Nuclei, 2008, Vol. 71, No. 4, pp568-604)

LHCb Prospects

- High yield and excellent PID gives LHCb some advantages
  - εD^2 = 8.7%
  - σ_{ct}=40fs
  - Triggered Yield = 264K
  - B/S = 0.6
    - These are “optimistic” projections



$$B_s^0 \rightarrow D_s^- \pi^+$$

(N. Harnew, Physics of Atomic Nuclei, 2008, Vol. 71, No. 4, pp568-604)

- $\sigma_{\Delta ms}$ ~ 0.003 ps^{-1} (stat) from 1fb^{-1} at $\sqrt{s}$ = 7 TeV

Current State

$$\frac{\Delta m_d}{\Delta m_s} = \frac{m_{B_d}}{m_{B_s}} \frac{1}{\xi^2} \left| \frac{V_{td}}{V_{ts}} \right|^2$$

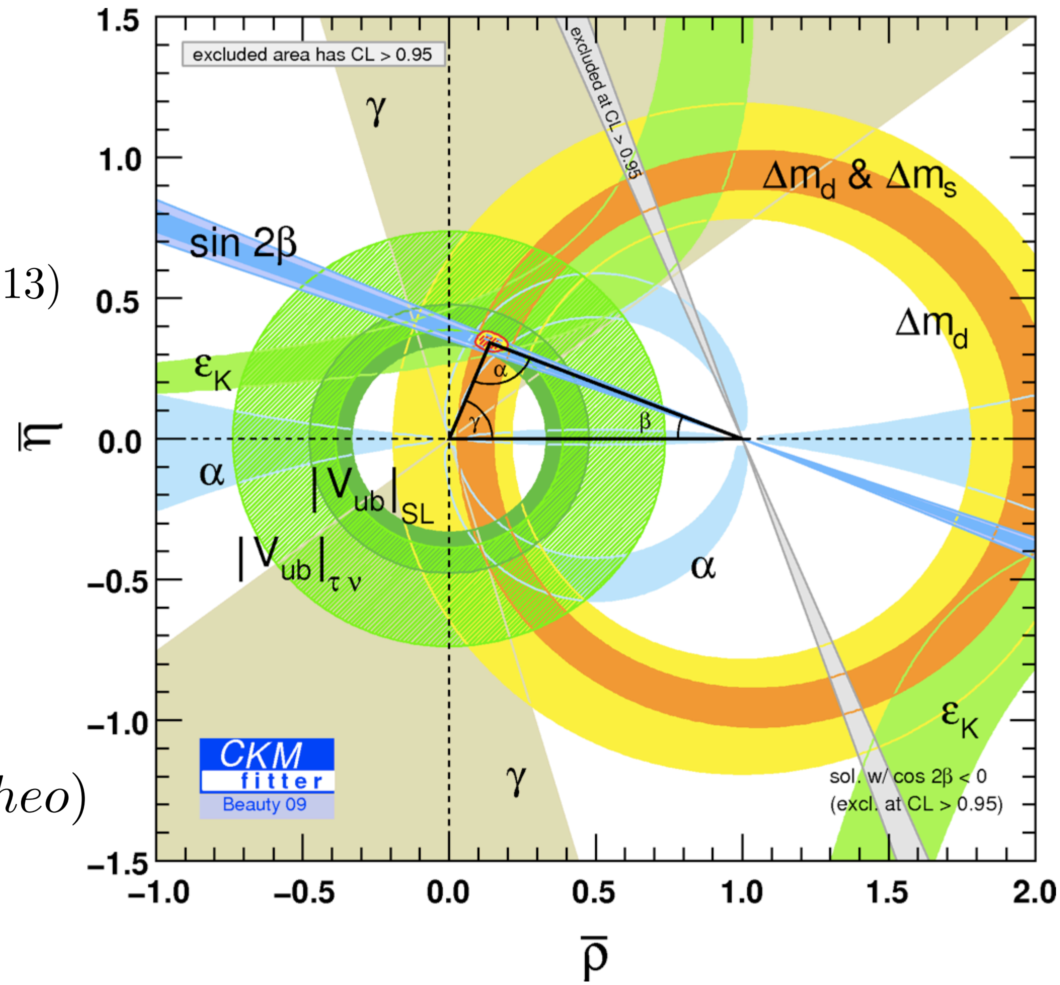
$$\xi = 1.21^{+0.047}_{-0.035} (M.Okamoto, hep-lat/0510113)$$

(For example)

$$\frac{m_{B_d}}{m_{B_s}} = 0.983 \pm 0.001 (PDG, 2009)$$

$$\Delta m_d = 0.507 \pm 0.005 (PDG, 2009)$$

$$\left| \frac{V_{td}}{V_{ts}} \right| = 0.2060 \pm 0.0007 (exp)^{+0.0081}_{-0.0060} (theo)$$



Recent Example of a CKM fit

Summary

- CDF and D∅ have directly measured Δms
- CDF should be able to produce a result that is limited by systematics to a precision of $0.07ps^{-1}$
- LHCb is predicting a measurement with precision on the order of $0.003ps^{-1}$ on a relatively short time scale
- Any advances from theory will further constrain |Vtd|/|Vts|