B Mixing and Flavor Tagging at CDF

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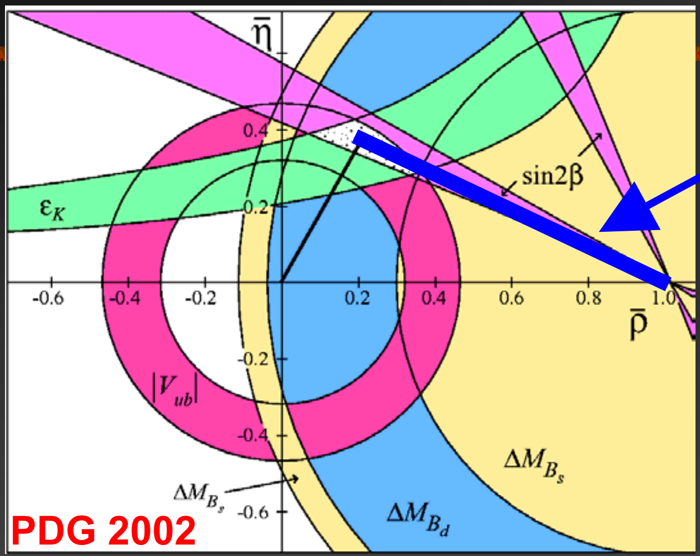
for the CDF Collaboration

OUTLINE

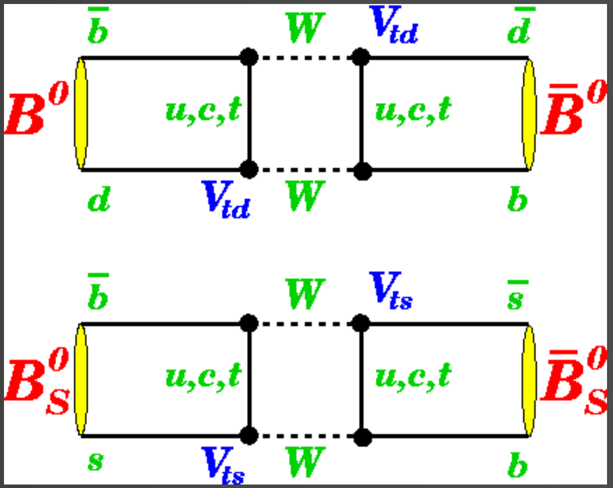
- Motivation and Methods
- Recent B_d Mixing Results from CDF
- Projections for B_s Mixing at CDF

The Name of the Game: B_s Oscillations

Why are we interested in B_s Oscillations?



$$\frac{|V_{td}|}{|V_{ts}|}$$



$$\Delta m_d = \frac{G_F^2}{6\pi^2}\, m_B (f_B^2 B_B) \eta_B\, m_t^2\, F\!\left(\frac{m_t^2}{m_W^2}\right) |V_{tb}^* V_{td}|^2$$ CKM elements

Experiment

Lattice QCD

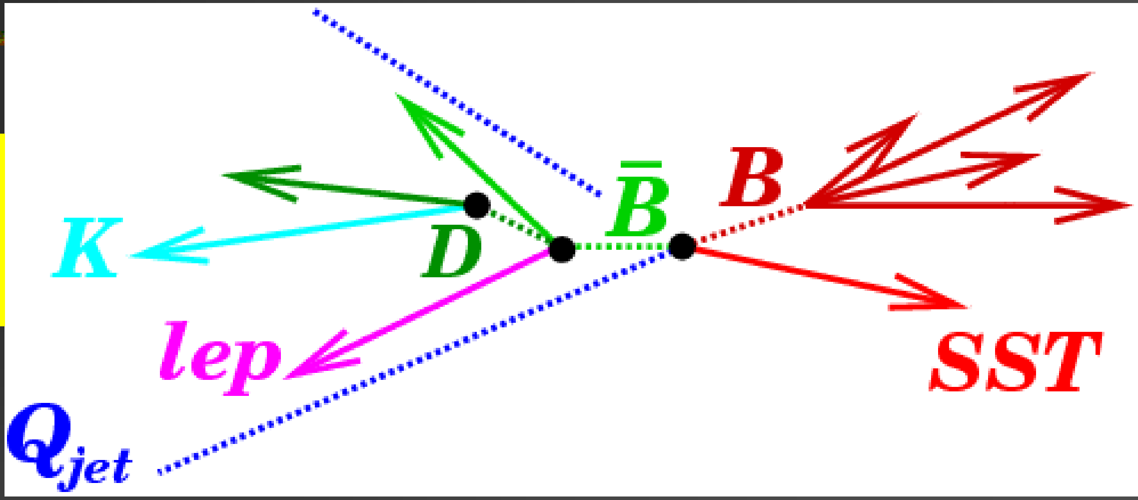
<u>Want to measure:</u>

ξ^2 from Lattice

$$\frac{\Delta m_S}{\Delta m_d} = \frac{m_{B_S^0}}{m_{B^0}} \frac{f_{B_S^0}^2 B_{B_S^0}}{f_{B^0}^2 B_{B^0}} \frac{|V_{ts}|^2}{|V_{td}|^2}$$

Tagging B Decays

For B $\bar{B}$ pair, either use B – primary correlation (SST) or opposite side decay properties (OST)



Handles on B Flavor at Production:

- Opposite Side Lepton ($\bar{B} \Rightarrow Q_{lep} < 0$)
- Opposite Side Jet Charge ($\bar{B} \Rightarrow Q_{jet} < 0$)
- Opposite Side Kaon ($\bar{B} \Rightarrow Q_K < 0$)

- Same Side pion (Kaon) ($B \Rightarrow Q_{\pi,K} > 0$)

How Does CDF Tag the B Flavor?

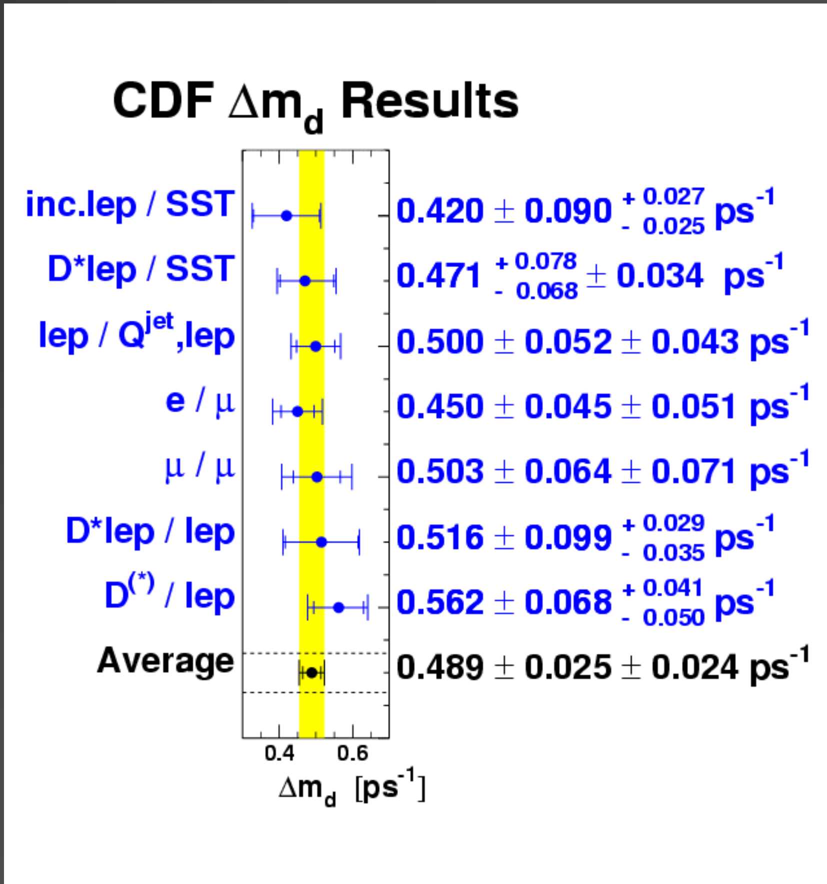
Follow methods pioneered in Run I:

- Soft Lepton Tag (e, μ)
- Jet Charge Tag
- Same-side Tag

Extend Methods for Run II

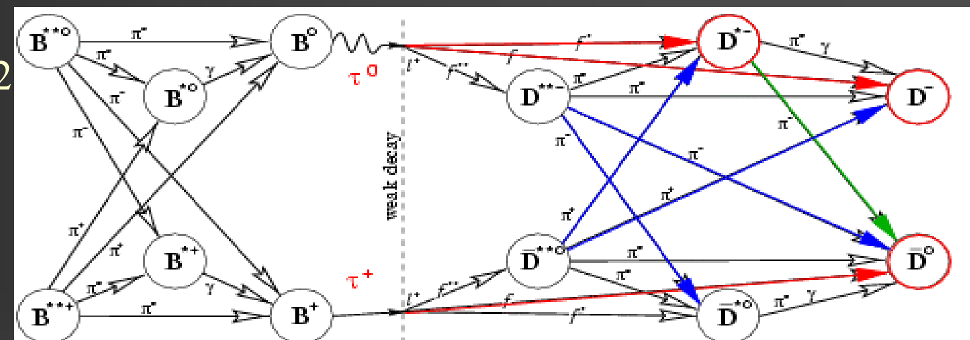
- New Lepton Taggers
- Extend Jet Charge Tags
- Use TOF, dE/dx for Kaon Tags

Use Exclusive Decays too!



A First Step: Tagging in $B_d \rightarrow DXl\nu$

- Combine Tags
  - Measure tag significance εD^2 for each tag
  - Establish hierarchy for multiple tags
- Measure Δm_D using multiple tags



- Sample Composition is a challenge

CDF Semileptonic Data

$B \rightarrow D^{*+}Xl^-\nu$ 9737(113) evts

$B \rightarrow D^{+}Xl^-\nu$ 35951(411) evts

$B \rightarrow D^{o}Xl^-\nu$ 69378(378) evts

- Use only $D^o \rightarrow K^- \pi^+$ and $D^+ \rightarrow K^- \pi^+ \pi^+$ decays, but their origin is complicated.

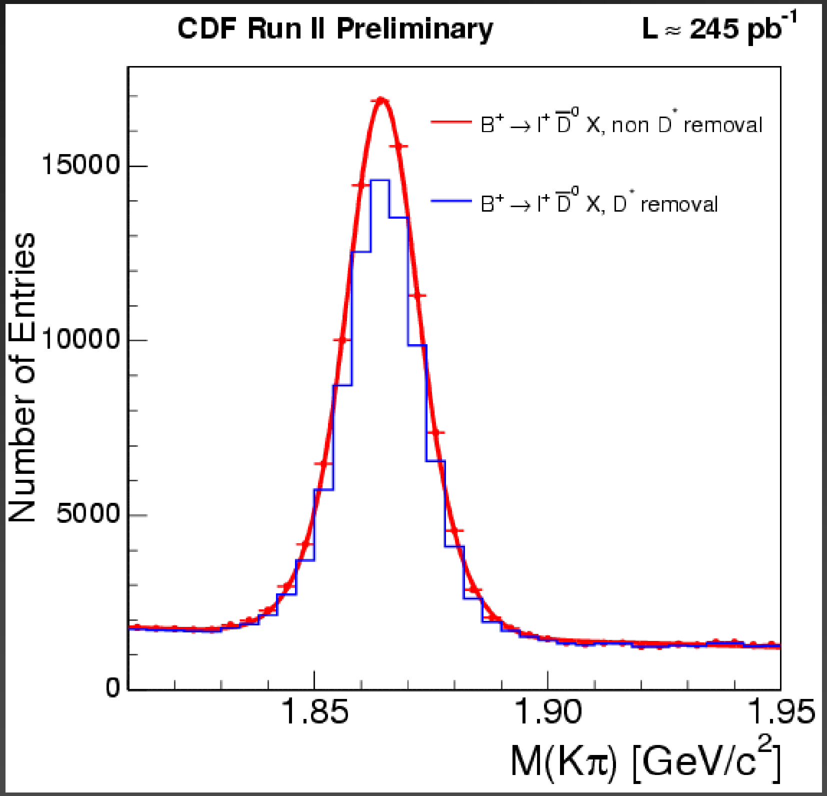
How to Combine Tags

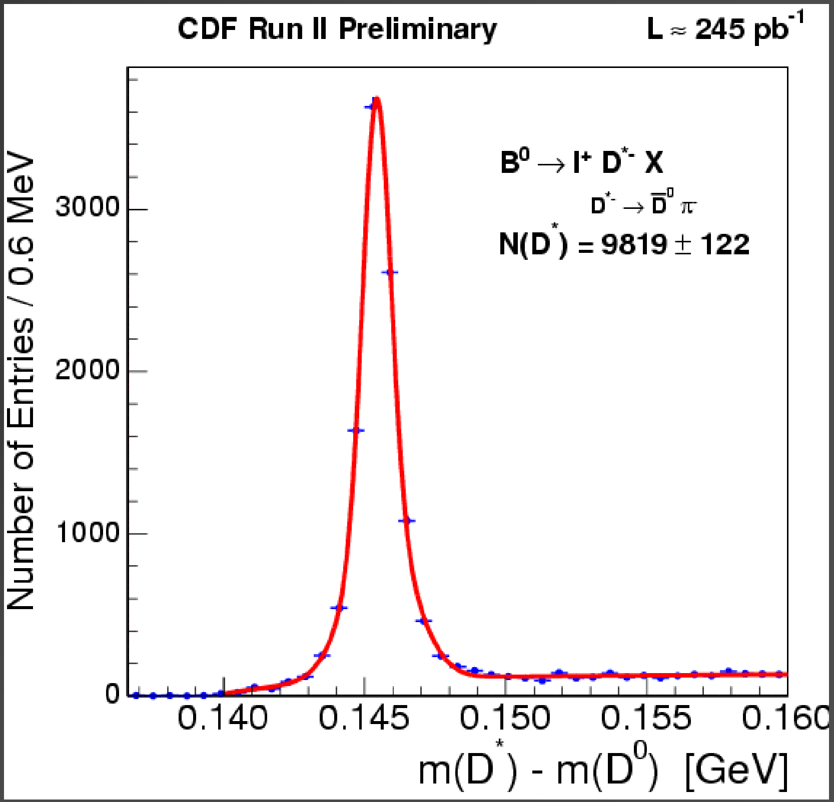
- establish tagging hierarchy (most decays aren't tagged)
  - SST: Yes or No ?
  - OST: No or Which?
    - SMT
    - JQT(B VTX)
    - JQT(high PT)
- Compare and Combine Tags
  - Agree: $$D_{\mathrm{agree}} = \frac{D_{\mathrm{SST}} + D_{\mathrm{OST}}}{1 + D_{\mathrm{SST}} * D_{\mathrm{OST}}}$$
  - Disagree: $$D_{\mathrm{dis}} = \frac{|\, D_{\mathrm{SST}} - D_{\mathrm{OST}} \,|}{1 - D_{\mathrm{SST}} * D_{\mathrm{OST}}}$$

- Make binned χ^2 fit to 13 parameters:
  - Dilutions for SST(B^o), SST(B+), SMT, JQT(BVTX), JQT(PT) and Δm_d
  - 3 Sample composition parameters (PDG constrained)
  - 2 efficiency parameters
  - 2 lifetimes (PDG constrained)

Bin in 10 proper time bins for each tag option (10) and each decay option (3)

CDF: Good Mass Resolution





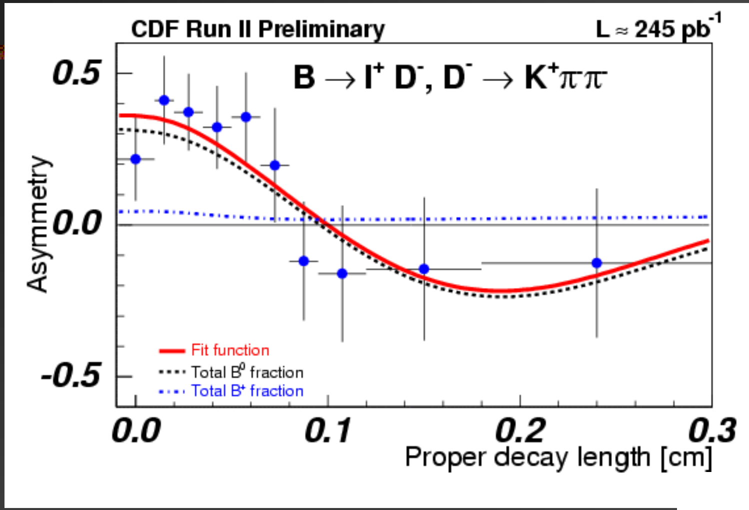
remove D° from reconstructed D^{*+}

Soft pion: $p_T > 0.4$ GeV/c

B_d Mixing in SL Decays with 3 tags

RESULTS

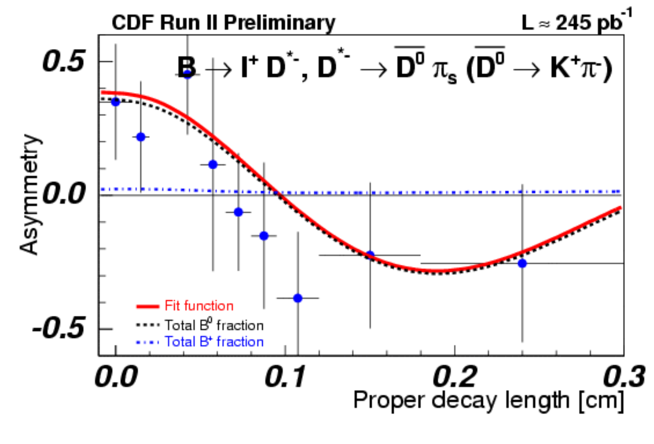
- εD^2 (SST) (%)
  - B^+ 4.69(0.38)
  - B^o 1.04(0.24)
- εD^2 (SMT) (%)
  - B^o 0.32(0.05)
- εD^2 (JQT) (%)
  - B^o 0.49(0.07)



Typical oscillation plots: SMT+SST

(2 of 30 plots from fit)

B factories have εD^2 ~30% Life is tougher at hadron machines!



$$\Delta m_d = 0.532 \pm 0.037 \pm 0.009(\text{sc}) \pm 0.006(\text{syst})$$

New Step: Fully-reconstructed Decays

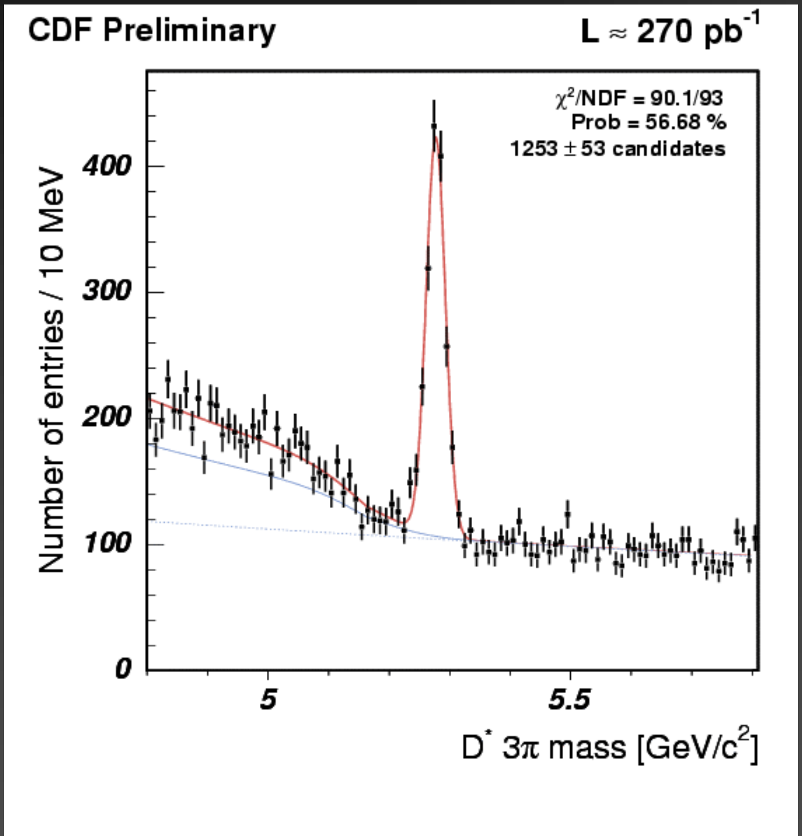
- Semileptonic Decays are not optimal for precision B_s mixing measurement.
  - time-dependent proper time error (K factor issue)
- Hadronic decays have good resolution but lower rate.
- CDF has a first collider measurement of Δm_D using five modes:

  $B^o \rightarrow J/\psi\ K^{*o}$; $D^-\pi^+$; $D^{*-}\pi^+$; $D^{*-}\ \pi^+\ \pi^+\ \pi^-$; $D^-\ \pi^+\ \pi^+\ \pi^-$

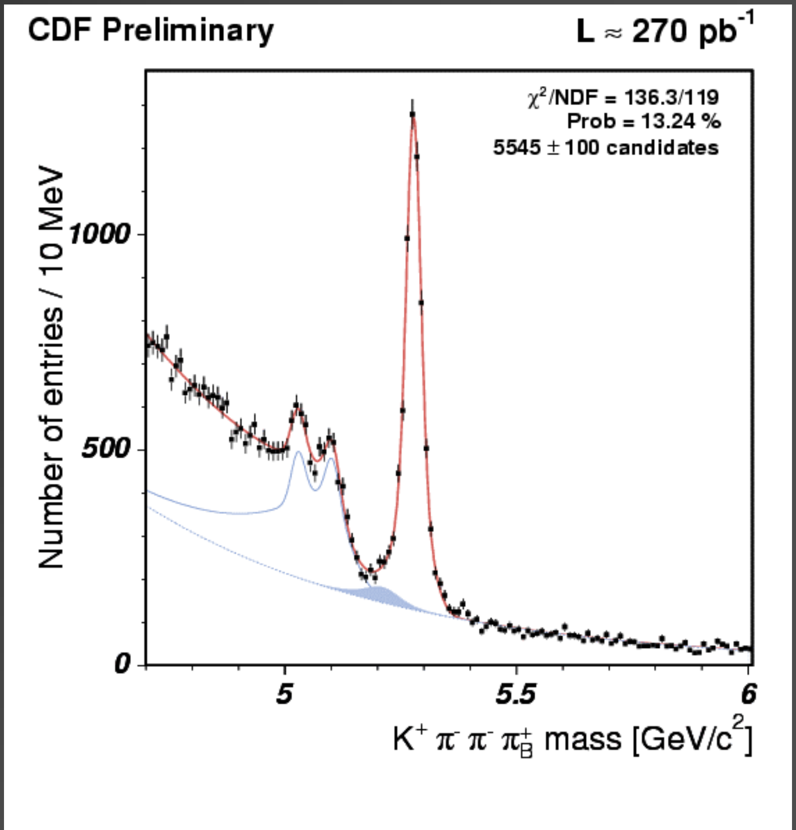
  Reconstruct D^o in both $K^-\pi^+$ and $K^-\ \pi^+\ \pi^+\ \pi^-$ modes

  Use Same Side Tagging

CDF: Fully-reconstructed Mass Plots

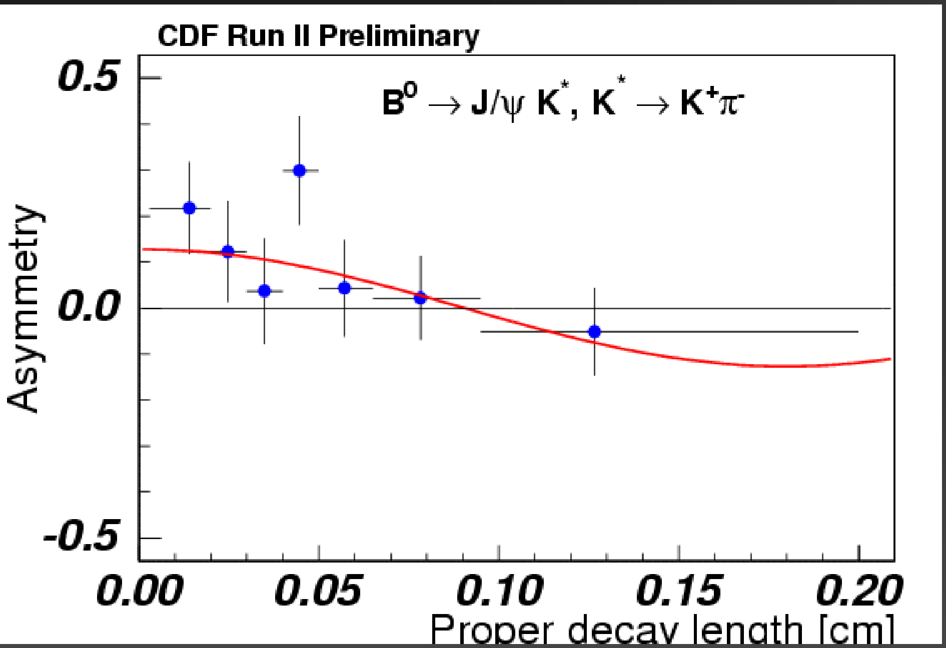


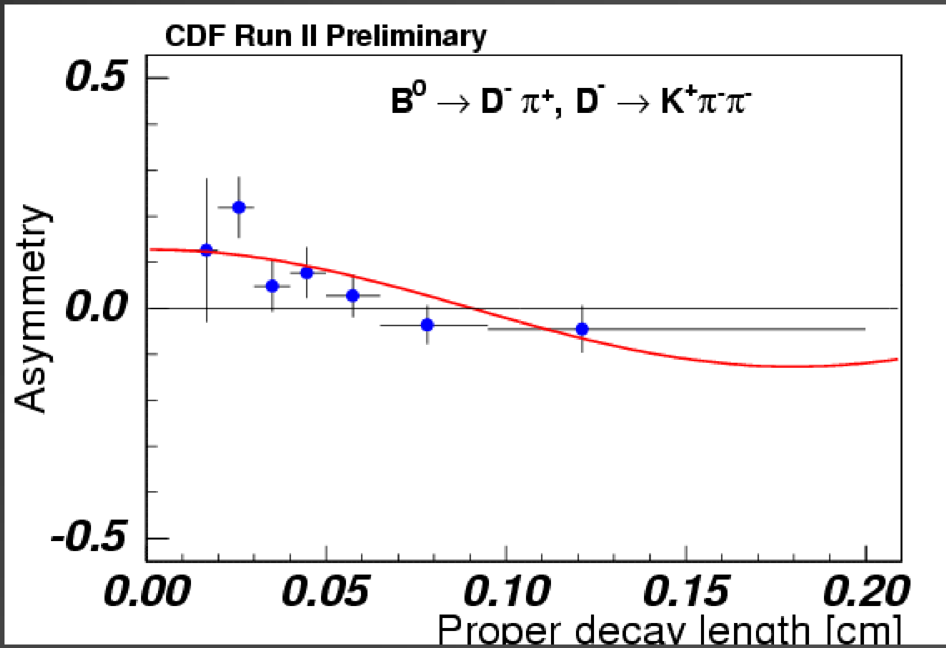
$B^o \rightarrow D^{*-} \pi^+ \pi^+ \pi^-$ --6(8) tracks



$B^o \rightarrow D^- \pi^+$ -- 4 trks

Hadron Mixing Analysis – SST





Fit All 5 Modes Simultaneously

1405 $J/\psi\ K^{*o}$ evts

5545 $D^-\ \pi^+$ evts

Comparison of B_d Mixing Results

For 11K Fully-Reconstructed Hadronic B Decays with SST:

- $\Delta m_D = 0.526 \pm 0.056$ (stat.) ± 0.006 (syst.) ps^{-1}
- εD^2 (SST) = 1.00 ± 0.35 (stat.) ± 0.06 (syst.) %

Compare to 115K Semileptonic Decays with SST only:

- $\Delta m_D = 0.443 \pm 0.052$ (stat.) ± 0.03 (s.c.) ± 0.012 (syst.) ps^{-1}
- εD^2 (SST) = 1.1 ± 0.3 (stat.) ± 0.2 (s.c.) ± 0.1 (syst.) %

Hadronic Decays have more analyzing power per event

Interim Summary

Following the general Run I analysis scheme, CDF has:

- Demonstrated the effectiveness of combining flavor tags for semileptonic decays and measured εD^2 for the tags.
- Used the Same Side Tag method to measure Δm_d in fully-reconstructed B_d decays.

Work now underway using B_d decays to:

- Improve tagging efficiency with new tags in hand: SMT $\uparrow$ ~2x; add SET ~ SMT/2; JQT $\uparrow$ ~1.4x
- Include new tags, especially those with TOF and dE/dx

Looking ahead: Issues in B_s Mixing

Proper time resolution is critical for B_s analysis

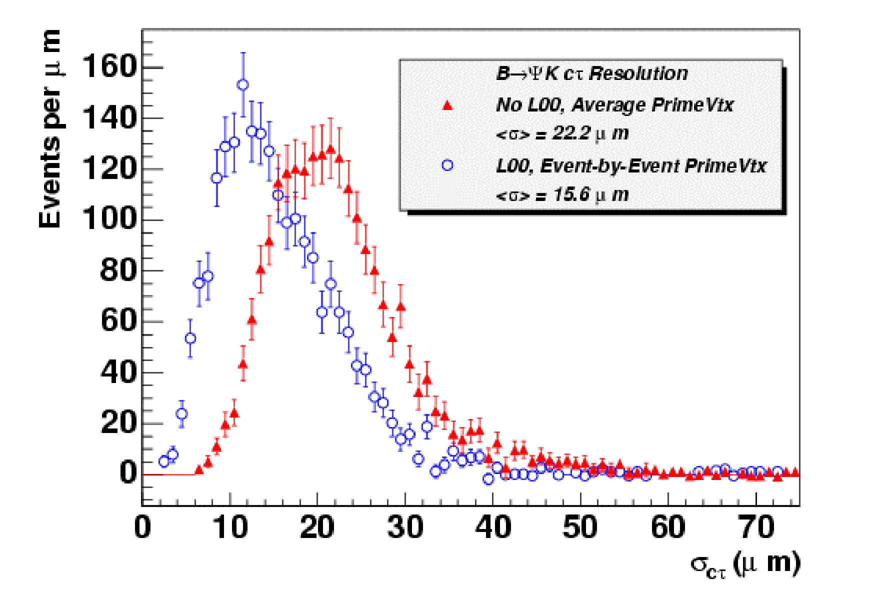
Transverse Flight Path Resolution improves with inner Si layer

Now: Without L00:

$\overline{\sigma}$(transverse proper time) = 67 fs

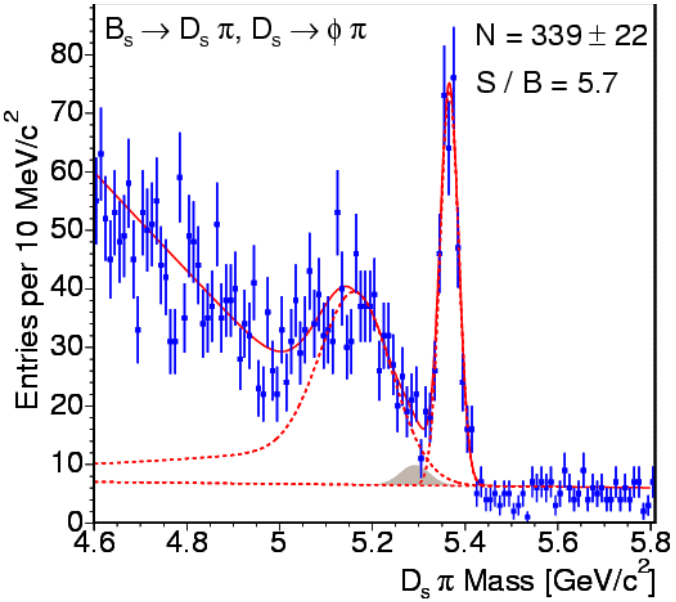
Coming: L00 now useful for 60% of tracks (will go up)

$\overline{\sigma}$ (transverse proper time) → 47 fs

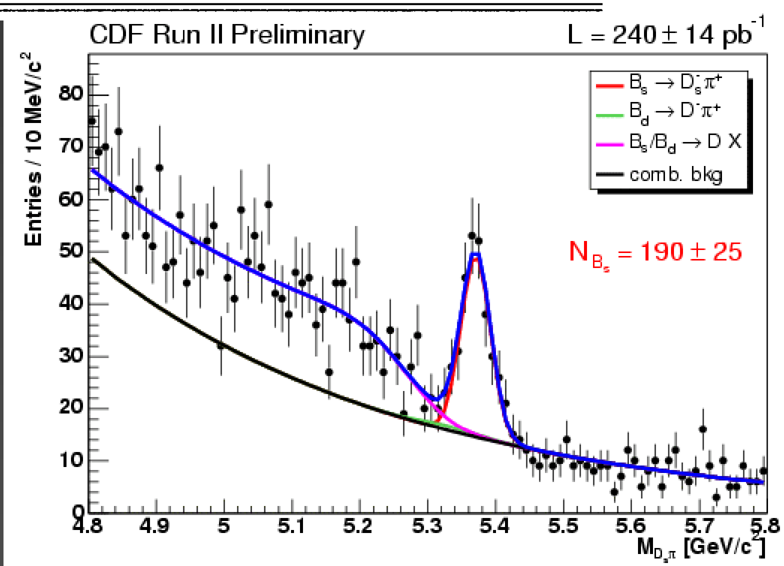


What are B_s Mixing Prospects?

Channel	Observed events	Luminosity (pb^{-1})	Yield ($/250\ pb^{-1}$)	S/B
$D_s\pi(D_s \to \phi\pi)$	339 ± 22	264	320	5.7
$D_s 3\pi(D_s \to \phi\pi)$	95 ± 17	264	90	1.0
$D_s\pi(D_s \to K^*K)$	190 ± 25	240	200	1.3
$D_s\pi(D_s \to 3\pi)$	57 ± 11	124	115	1.75
$\ell\nu D_s X(D_s \to \phi\pi)$	2342 ± 66	245	2400	3.5



Present CDF B_s Data Set: ~700 hadronic decays



B_s Projections from the Present Data

Define two analysis levels:

Baseline:

- σ(transverse proper time) = 67 fs
- tagging significance $\varepsilon D^2 = 1.6\%$

(already achieved in OST for B_d)

Stretched:

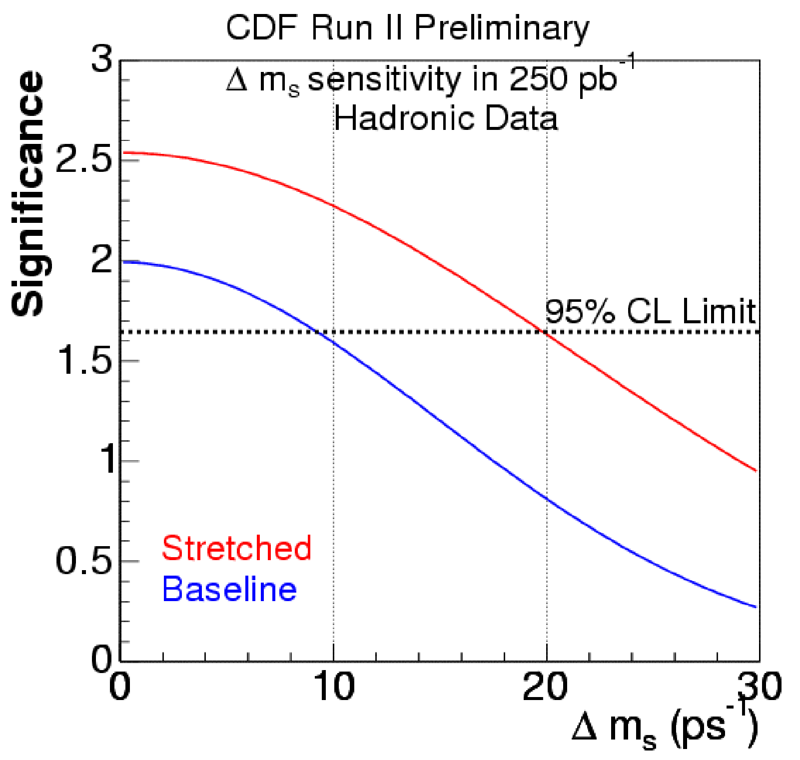
- σ(transverse proper time) = 47 fs
- tagging significance $\varepsilon D^2 = 2.6\%$

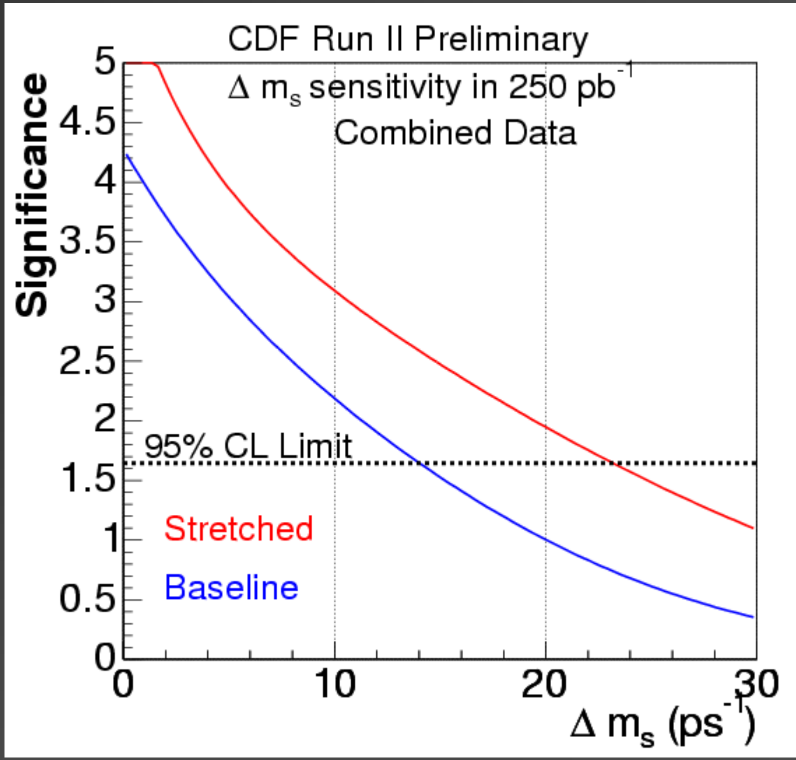
(additional 1% already achieved in SST for B_d)

Estimate Δm_s Reach for Hadronic and Total B_s Data

Remember that B_s tagging significance may well differ from B_d

95% CL Δm_s Reach from Present Data

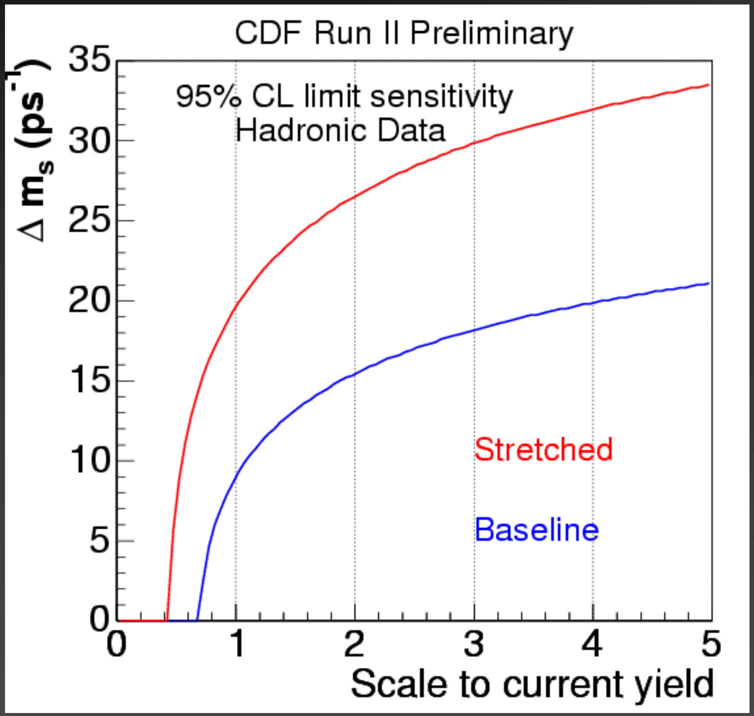


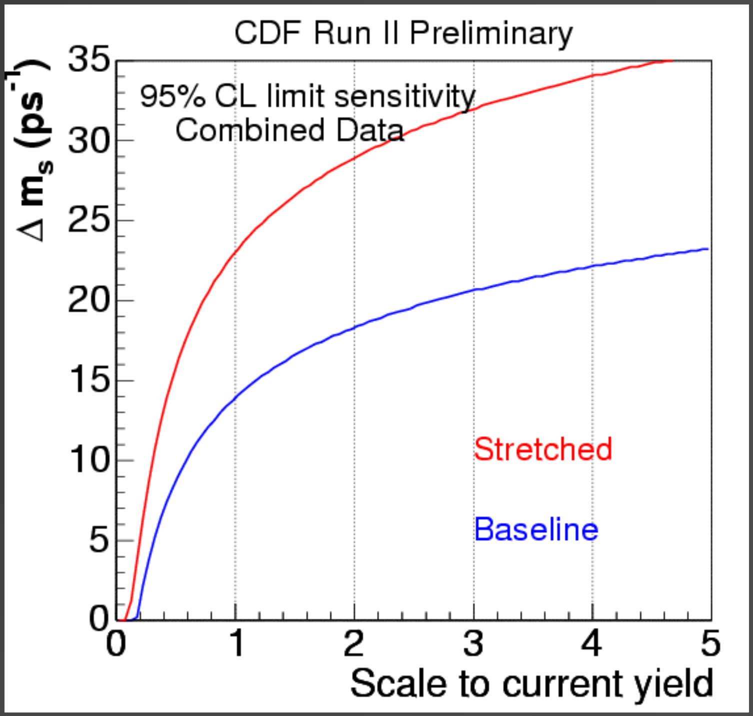


Hadrons only: $9 < \Delta m_s < 20$

Hadron + SL: $14 < \Delta m_s < 24$

We WILL Run Longer – What then?





With combined data and somewhat better than baseline tagging and resolution, CDF can reach SM expectation at 95% CL with 4x more events (not luminosity, due to triggers)

Summary

- CDF Run II J/ψ and Two-Track Triggers plus SVT give a good set of fully-reconstructed B mesons of all flavors.
- Nature is a worthy and wily adversary – the Run II B_s data set is far short of the projections made before the run, but …
- Tagging methods in B_d mixing already extend Run I techniques
- Further improvements in triggering, tracking, vertex resolution and tagging are under active development.
- We think that a B_s mixing measurement will be made at CDF if the Standard Model projection is correct.