Search for B_s Oscillations at CDF

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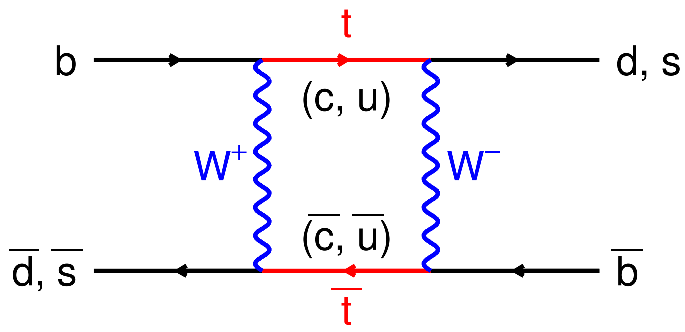
for the CDF II collaboration

Motivation

- Neutral B mesons flavor-oscillate
- Measure fundamental SM parameters

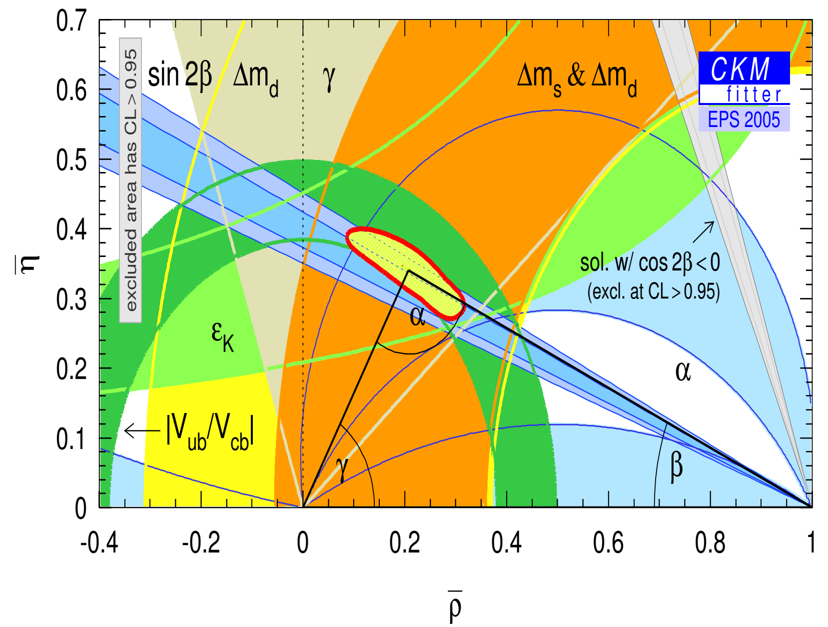


$$\Delta m_s = \frac{G_F^2 m_W^2 \eta S(m_t^2/m_W^2)}{6\pi^2} m_{B_s} f_{B_s}^2 B_{B_s} |V_{ts}^* V_{tb}|^2$$

- Hadronic uncertainties cancel in ratio

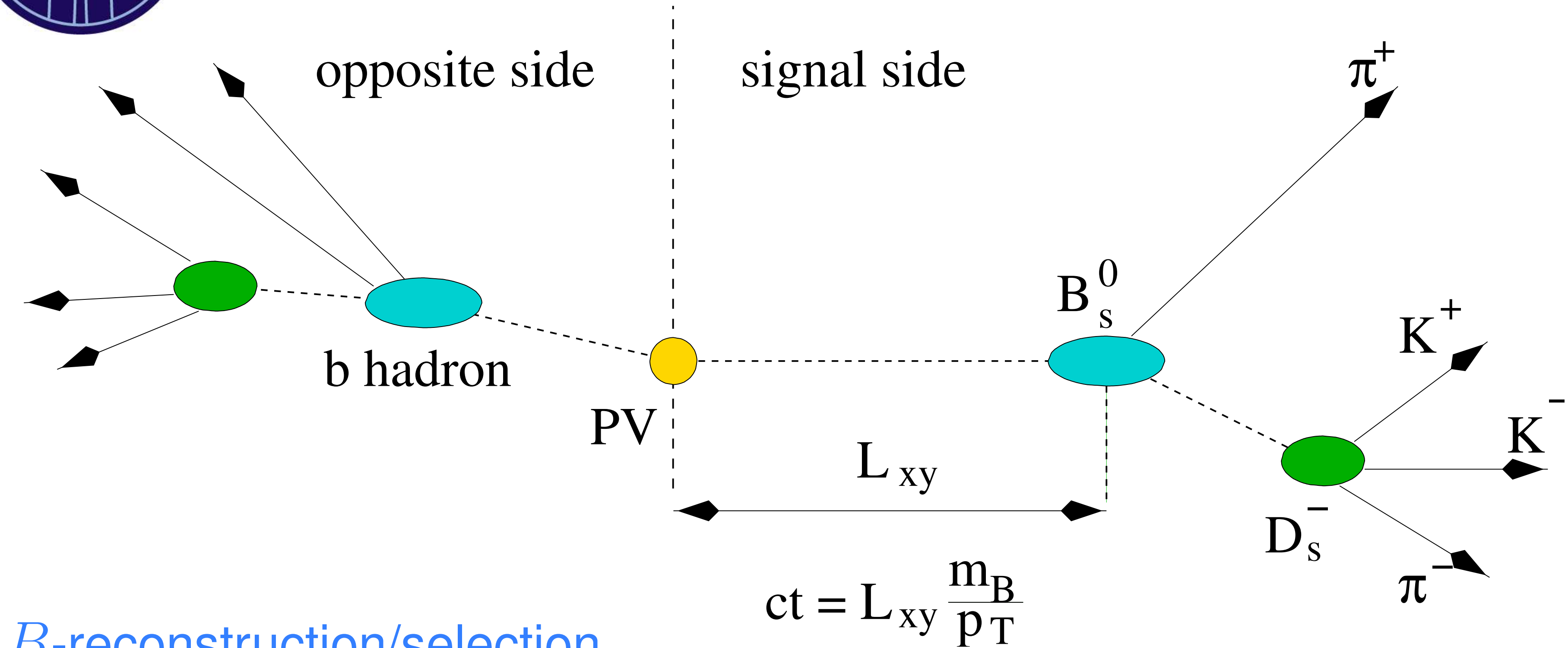
$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s}}{m_{B_d}} \xi^2 \frac{|V_{ts}|}{|V_{td}|}$$

Improved lattice computation:
$\xi = 1.21 \pm 0.022^{+0.035}_{-0.014}$



- Prerequiste for timed dependent CPV
- New Physics may have sizeable effect

Outline Mixing Analysis



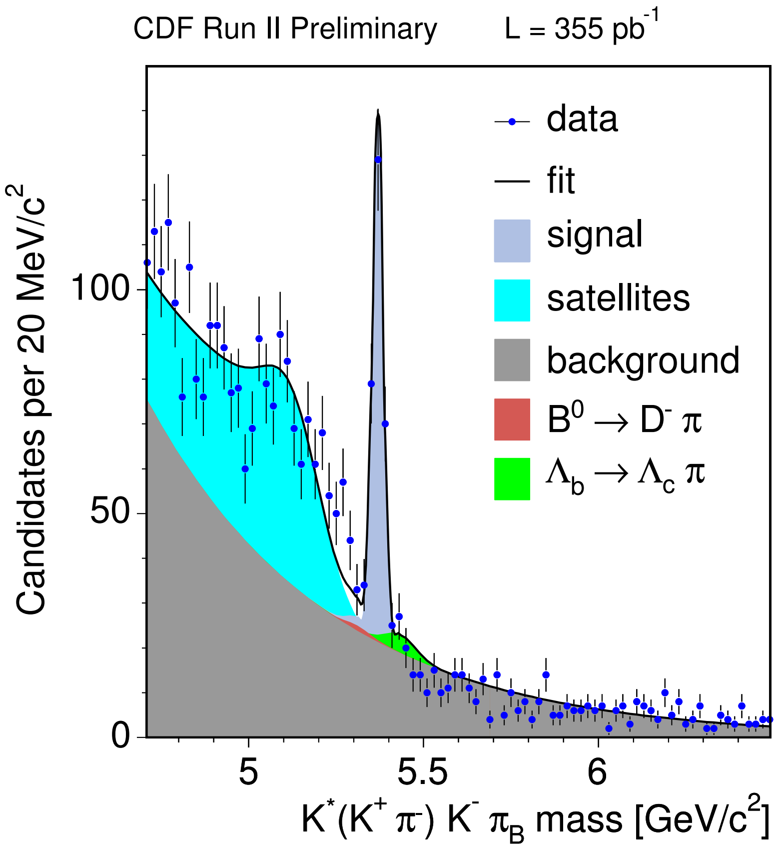
1) B-reconstruction/selection
2) Proper time measurement ct, understanding of σ_{ct} crucial!
3) Flavor tagging, main issue at hadron colliders
   (calibrate opposite side taggers on B_d sample)
4) Measure time-dependent asymmetry:

$$\mathcal{A}(t) \equiv \frac{N(t)_{mixed} - N(t)_{unmixed}}{N(t)_{mixed} + N(t)_{unmixed}} = \mathcal{D} \cos(\Delta m_s t), \qquad \mathcal{D} = 1 - 2P_{mistag}$$

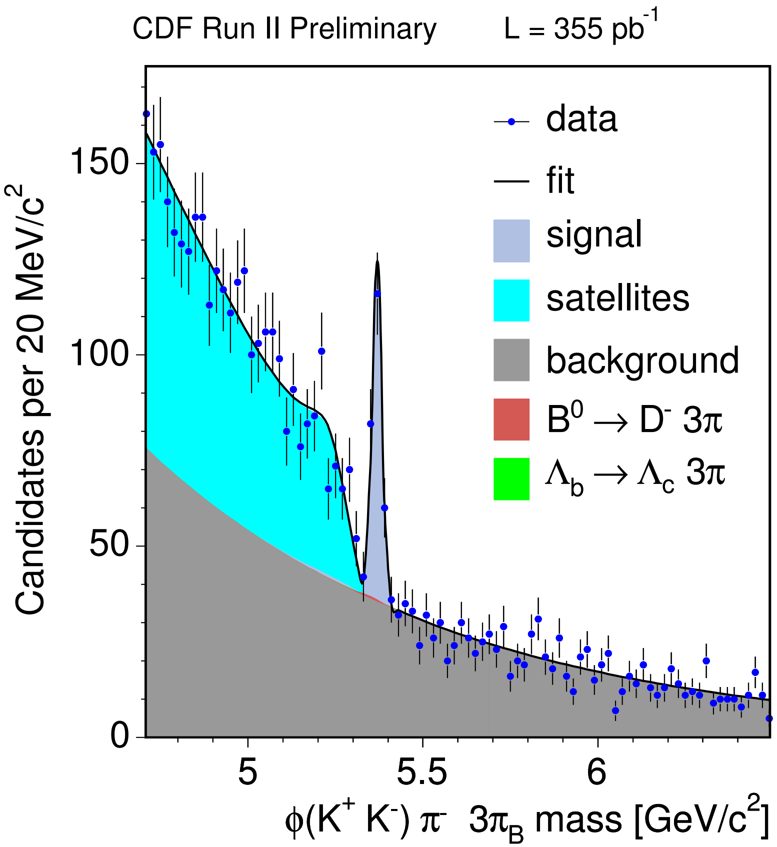
Hadronic B_s Candidates

$B_s \longrightarrow D_s\pi$, where $D_s \longrightarrow \Phi\pi, K^*K, 3\pi$

$B_s \longrightarrow D_s 3\pi$, where $D_s \longrightarrow \Phi\pi, K^*K$



$B_s \longrightarrow D_s\pi, D_s \longrightarrow K^*K$

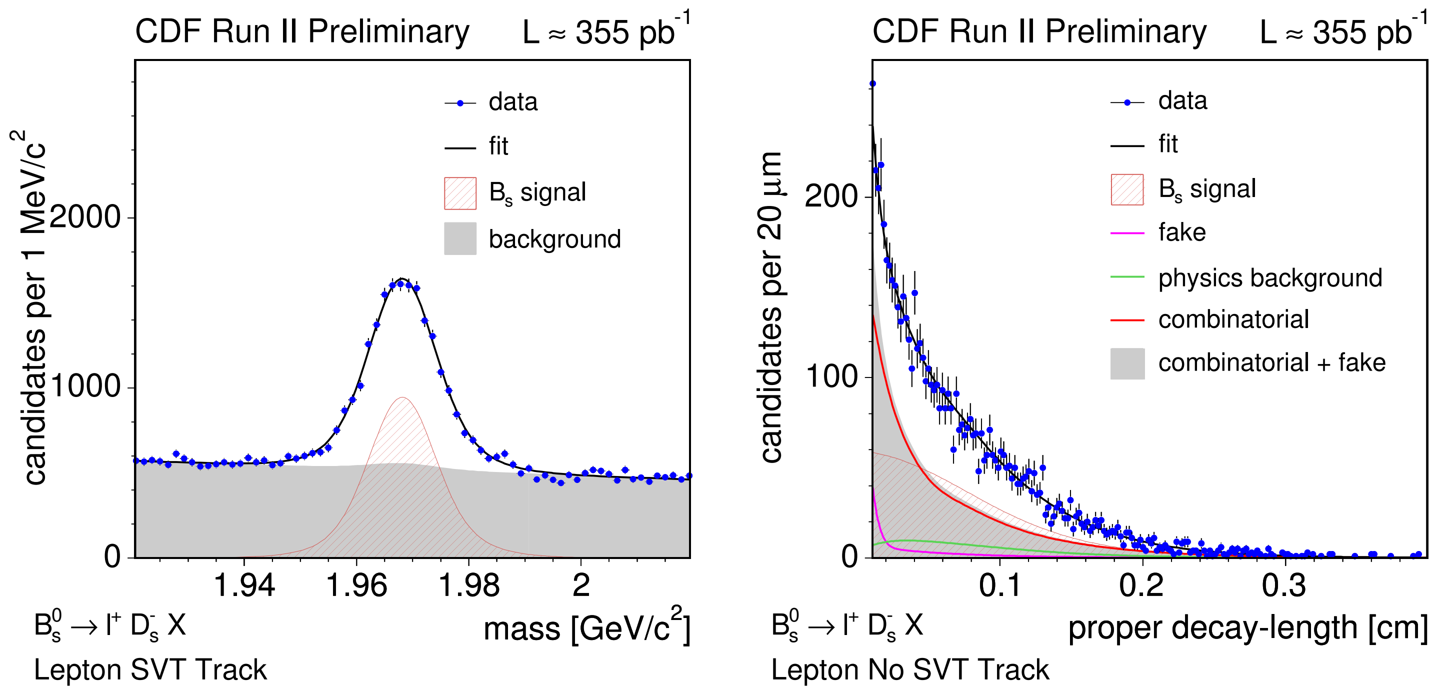


$B_s \longrightarrow D_s 3\pi, D_s \longrightarrow \phi\pi$

About 1.100 fully reconstructed B_s candidates available

Semileptonic B_s Candidates

$B_s \to \ell D_s X$, where $D_s \to \phi\pi, K^*K, 3\pi$



about 16.800 reconstructed $B_s \to \ell D_s X$ candidates

Higher statistics but worse ct resolution compared to hadronics

$$ct = \frac{L_{xy}}{\gamma\beta};\ \gamma\beta = \frac{p_T(B)}{M(B)} = \frac{p_T(\ell D)}{M(B)} * 1/K\ (K \text{ from MC});$$

$$\sigma_{ct} = \left(\frac{\sigma_{L_{xy}}}{\gamma\beta}\right) \oplus \left(\frac{\sigma_{\gamma\beta}}{\gamma\beta}\right) * ct$$

Low ct candidates have better resolution but worse S/B

Lifetime Measurement

Bias in ct due to trigger cuts
(in hadronic & semileptonic decays):

- two displaced trigger tracks
- turnon $d_0 \geq 120\ \mu$m
- trunoff: $d_0 \leq 1$ mm
- selection increase bias

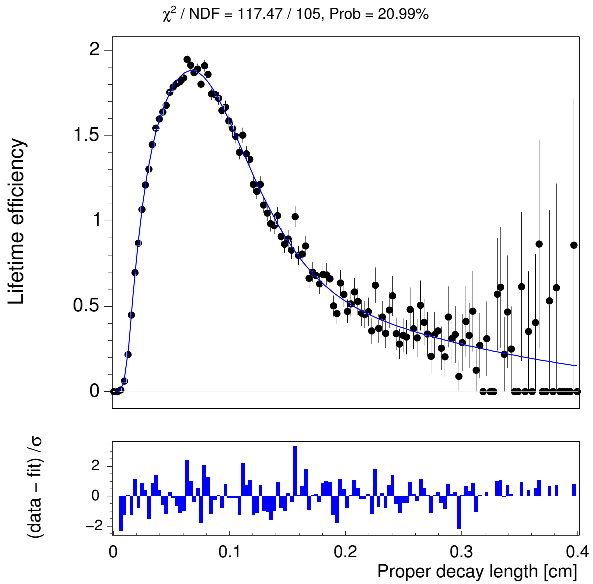
Adjust probability density:

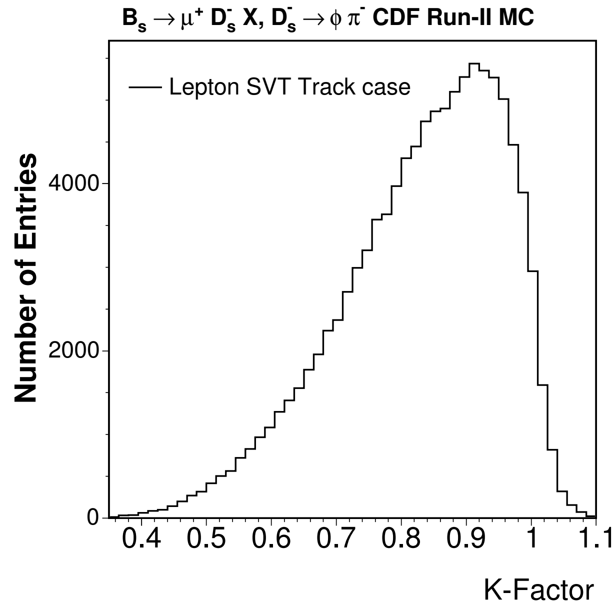
$\rho(t) = N(e^{t/\tau} \times G(\sigma_{ct}))\epsilon(t)$

The bias cancels for mixing!

For semileptonic decays,
correct for missing momentum

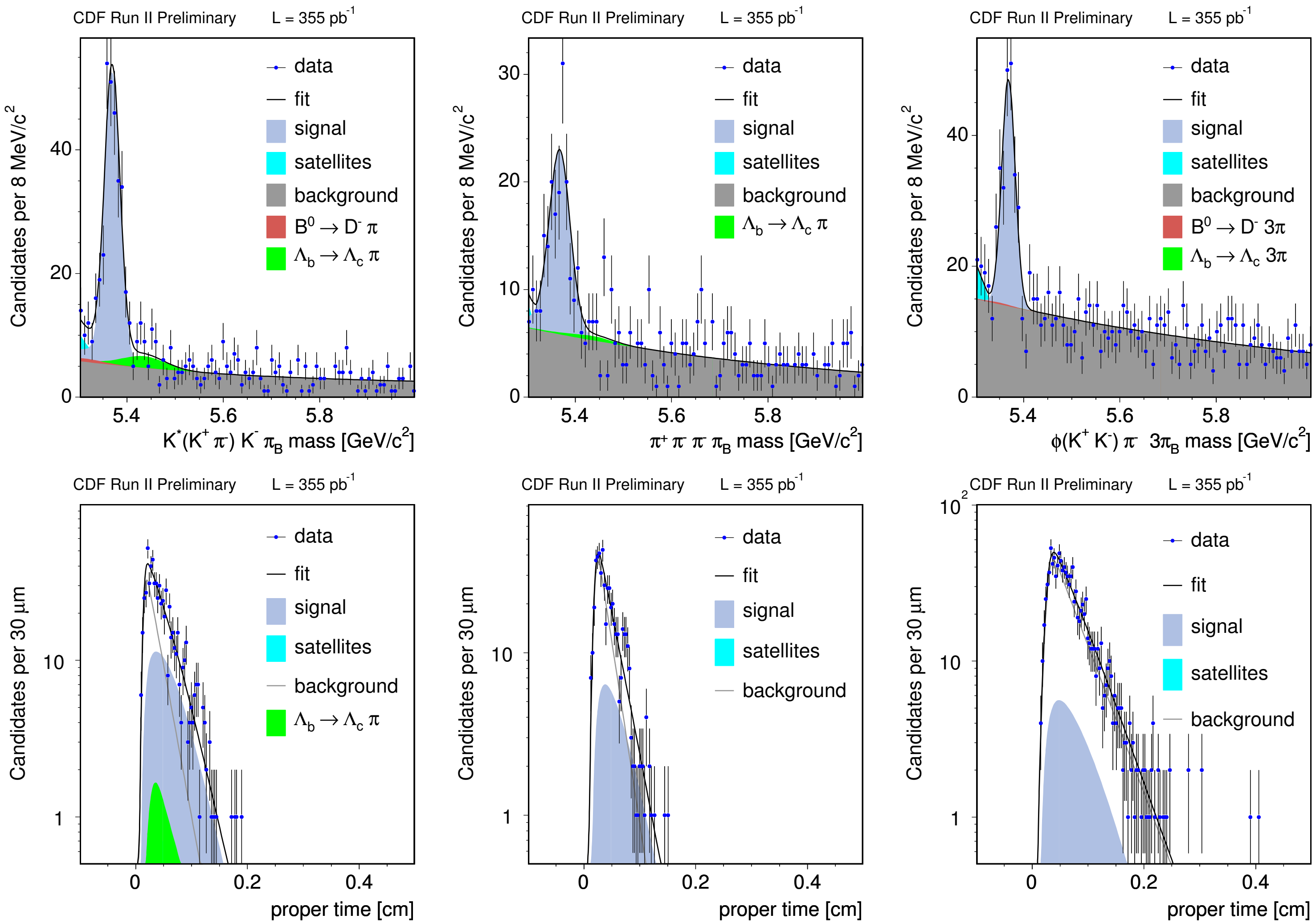
trigger efficiency (ϵ)





B_s Lifetime

Lifetime fit within narrow mass range (reject background)



Measurement not yet complete, only statistical uncertainties

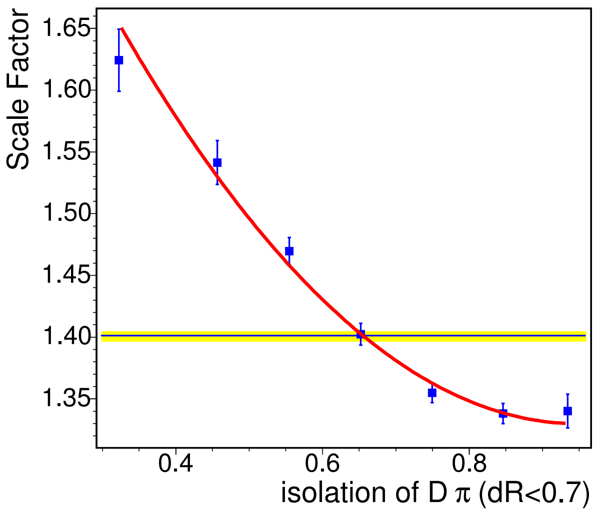
Combined B_s lifetime in hadronic modes consistent with PDG value

ct Resolution

mixing sensitivity: $S = \sqrt{\frac{N_S \epsilon D^2}{2}} \exp(-\frac{(\Delta m_s \sigma_{ct})^2}{2}) \sqrt{\frac{N_S}{N_S+N_B}}$

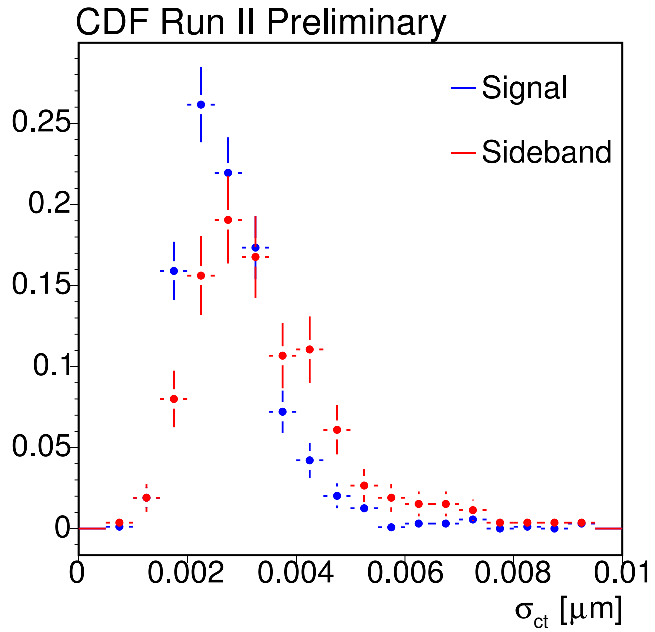
The proper decay length resolution is the limiting factor at high Δm_s

σ_{ct} determined from high statistics calibration data sample!



Study dependences on several variables:

isolation, vertex fit χ^2, ...



$B_s \rightarrow D_s(\Phi\pi)\pi$

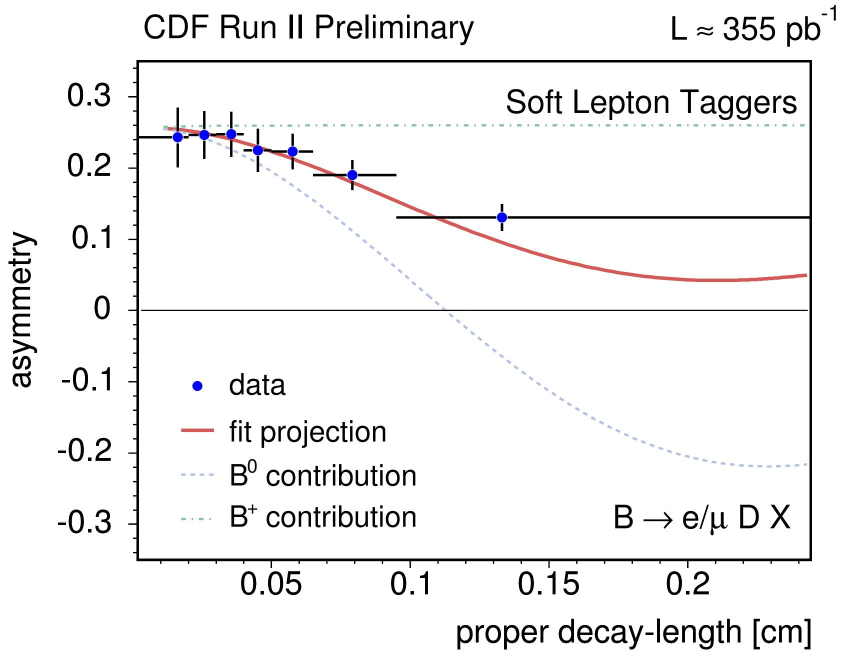
Mode	$<\sigma(ct)>$ [μm]
$B_s \rightarrow D_s(3)\pi$	30
$B_s \rightarrow \ell D_s X$	50*

* not include <k-factor> = 0.85

B_d Mixing

Proof of principle and calibration of tagger performance

- For setting limit, knowledge of tagger performance is crucial $\rightarrow$ measure tagging dilution in kinematically similar B^0/B^+ samples
- Δm_d and Δm_s fits are very complex, test fitter framework
- Study common backgrounds on high statistic B^0 modes



Semileptonic modes:

$\Delta m_d = 0.511 \pm 0.020$(stat)$\pm 0.014$(sys) ps^{-1};

total $\epsilon D^2(OST)$: 1.55 ± 0.08(stat)± 0.03(sys) %

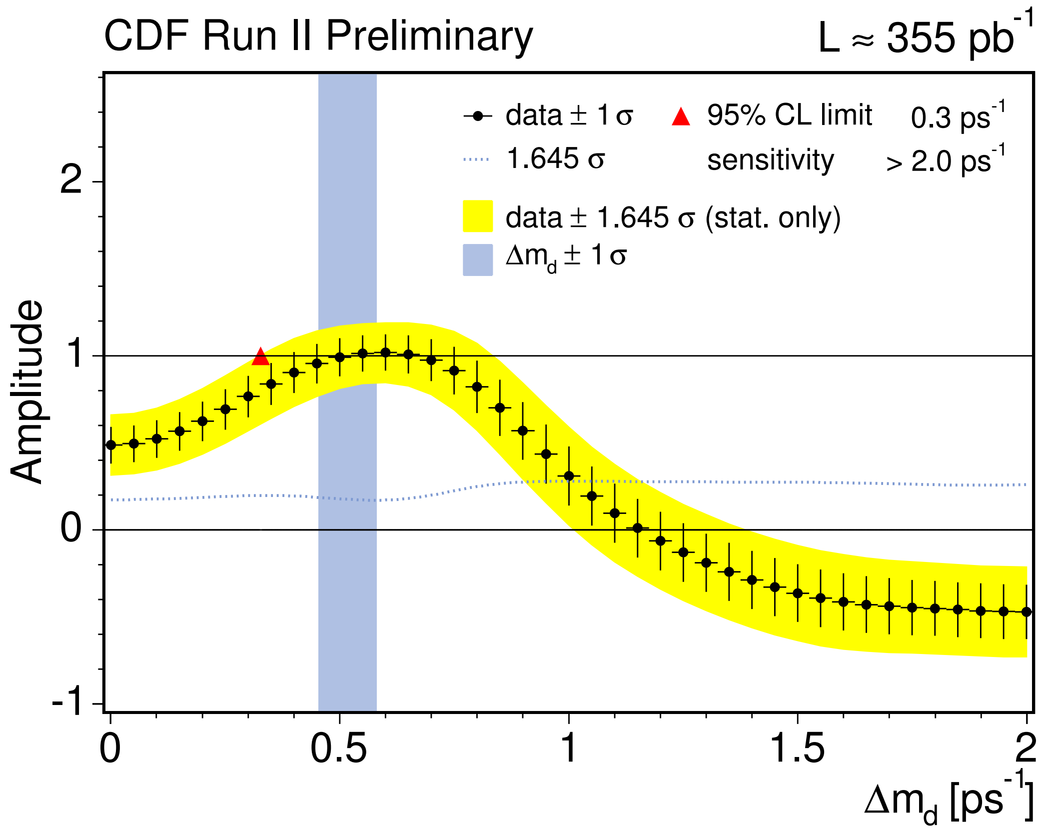
Hadronic modes:

$\Delta m_d = 0.536 \pm 0.028$(stat)$\pm 0.006$(sys) ps^{-1};

total $\epsilon D^2(OST)$: 1.55 ± 0.16(stat)± 0.05(sys) %

Amplitude Scan Method

B^0 example scan, winter 2005 analysis



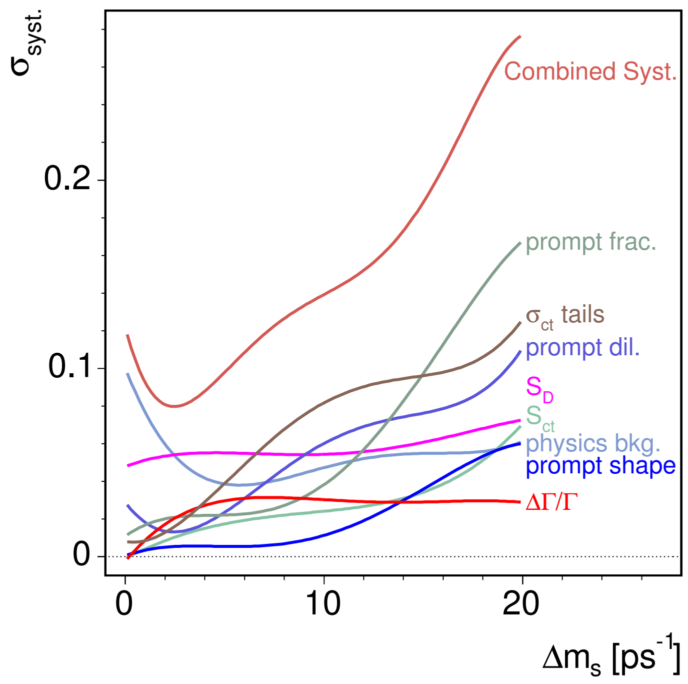
- introduce amplitude A to the unbinned likelihood fit $\mathcal{L} \sim \frac{1 \pm A \cdot D \cdot \cos(\Delta m_s t)}{2}$
- fit for A for each Δm_s hypothesis
- record A and σ_A at each value

- Signal $\Leftrightarrow$ unit amplitude, else A consistent with 0
- exclude Δm_s @ 95% CL for A+1.645$\sigma_A < 1$

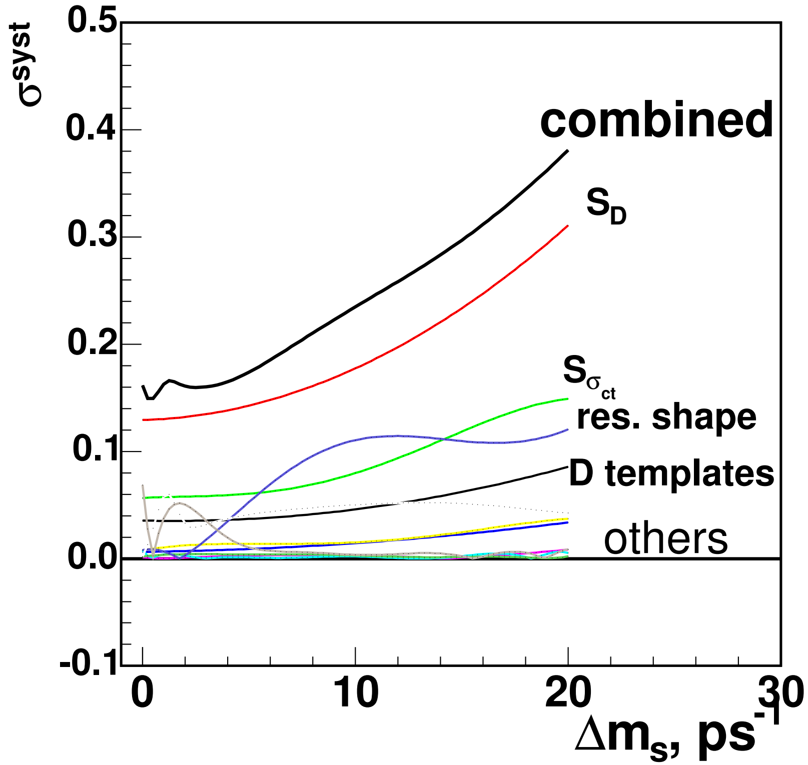
Systematic Uncertainties

A and σ_A are correlated, systematics need to be evaluated with hundreds of toy MC experiments for each Δm_s value.

Semileptonic Modes



Hadronic Modes



Measurements is dominated by statistics

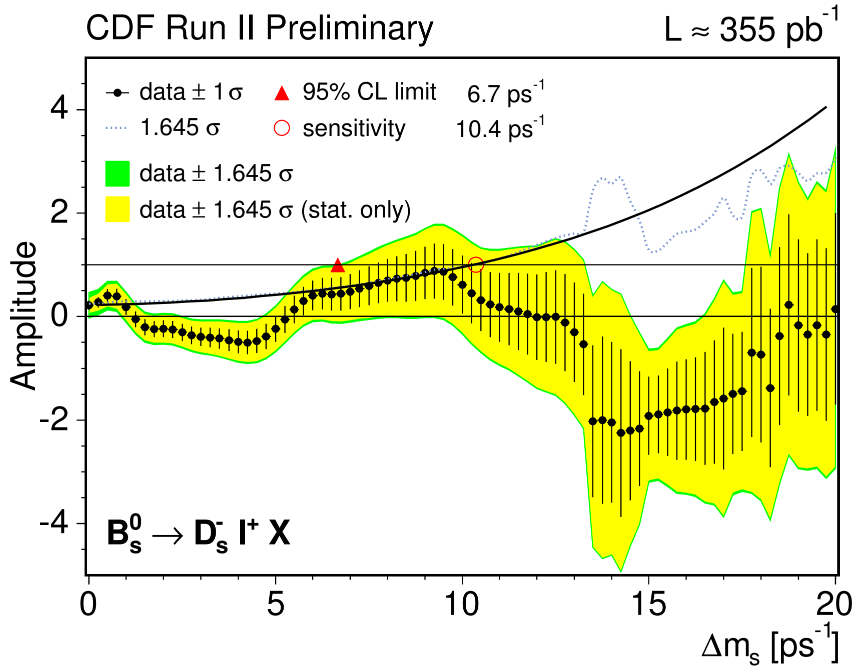
With increase in statistics leading systematics will go down

Results on Δm_s

Semileptonic modes

Sensitivity: 10.4 ps^{-1}

95% CL Limit: 6.7 ps^{-1}

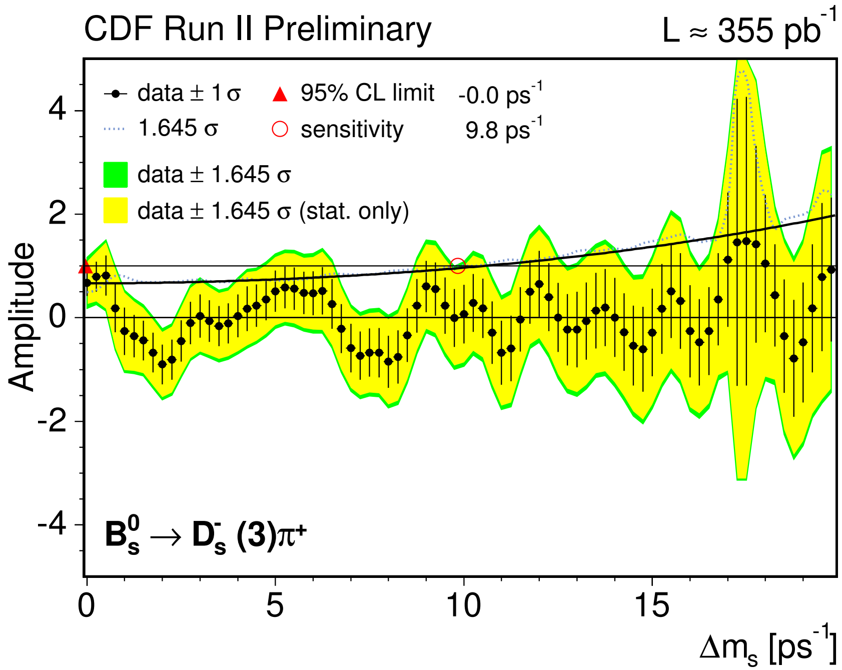


Sensitivity is fading out rapidly

Hadronic modes

Sensitivity: 9.8 ps^{-1}

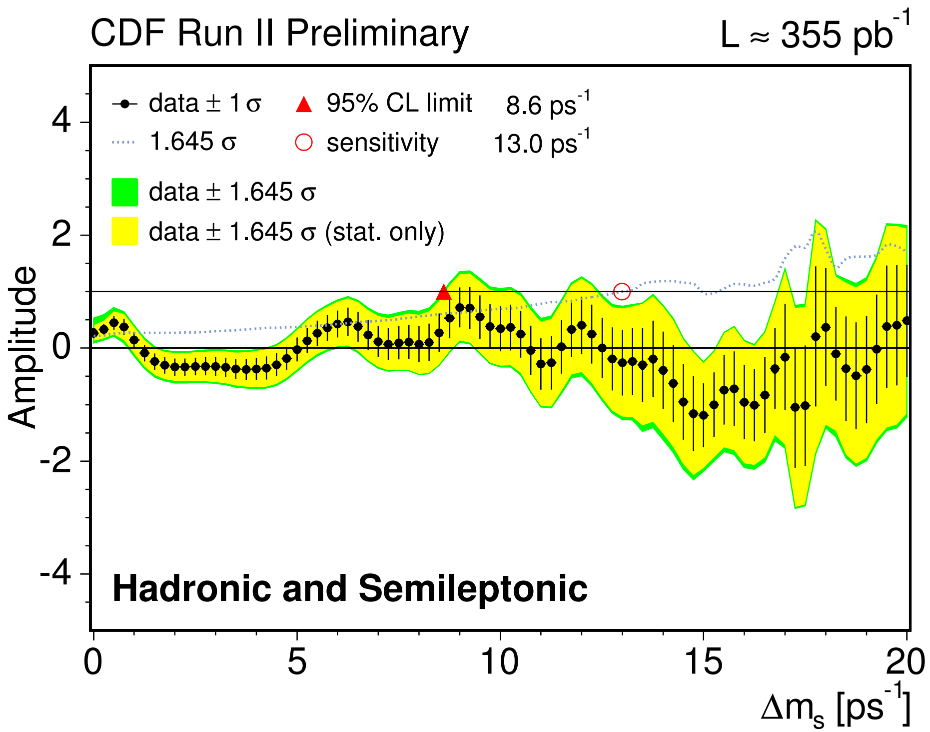
95% CL Limit: 0.0 ps^{-1}

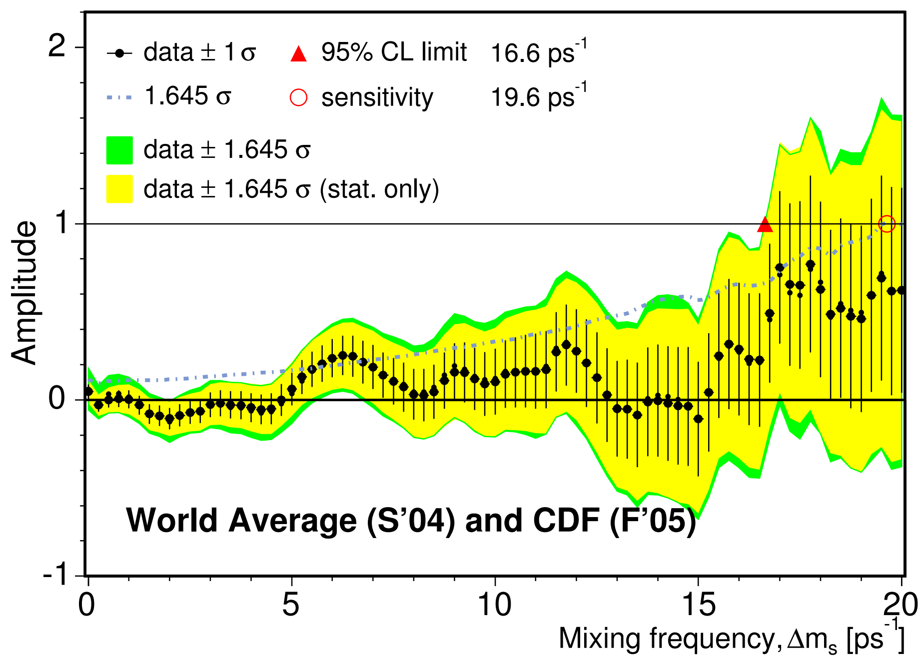


Uncertainties are smooth

Combined CDF Result

Comb. CDF result	Comb. CDF + World average
	(hand-made ...)
Sensitivity: 13.0 ps^{-1}	Sensitivity: 19.6 ps^{-1}
95% CL Limit: 8.6 ps^{-1}	95% CL Limit: 16.6 ps^{-1}





Sensitivity before: 18.2 ps^{-1}

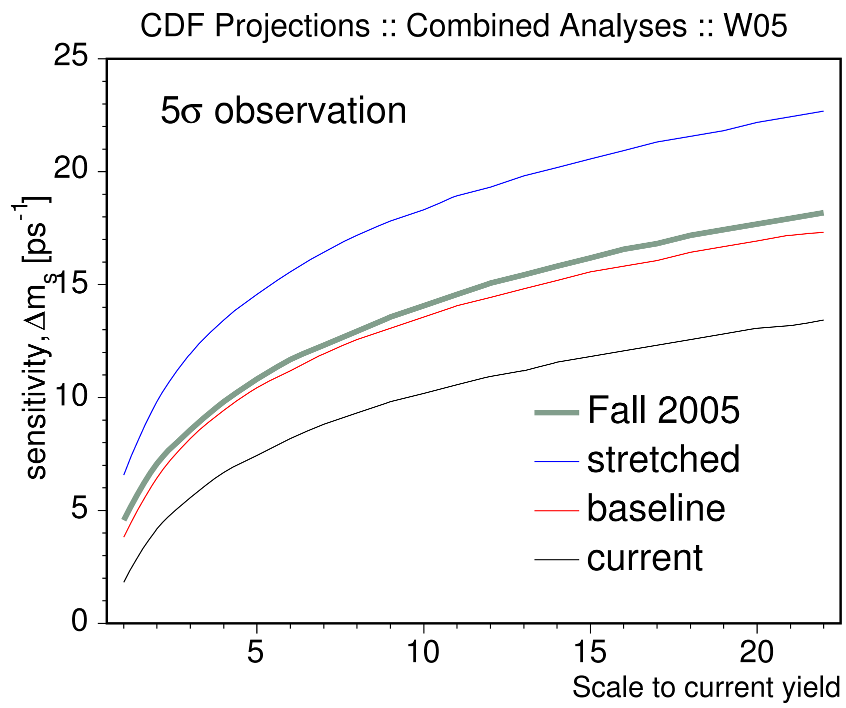
This measurement has significant impact on the world average!

Coming Improvements

- Additional data
  ($\times$2 luminosity already on tape)
- Same Side Kaon Tagging
- Additional trigger path
- Add satellites in hadronic modes
- Reoptimize event selection (NN)
- $m(\ell D)$ dependent k-factor binning
- Combined opposite side taggers
- Better understanding of ct resolution

Long term projections

Δm_s measurement



Projections based on winter results

Many of them are doable on few months time scale!

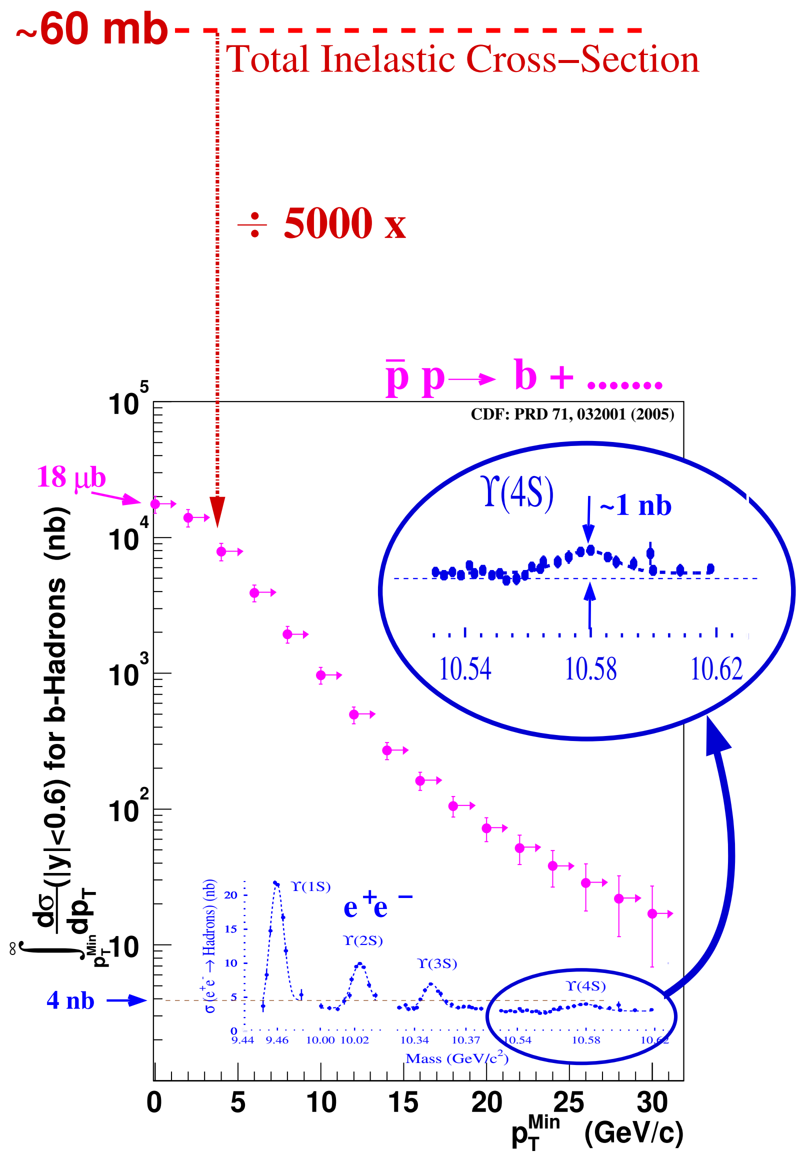
Summary

- Δm_s mixing analysis has been performed in hadronic & semileptonic modes
- Combined results yield a sensitivity of 13.0 ps^{-1} and 95% CL lower limit of 8.6 ps^{-1}
- We have a significant impact on the world average!
- Large room for further improvement, many people are working very hard to get that measurement done
- The analysis is at an exciting stage!

- Backup -

B-Physics at Hadron Colliders

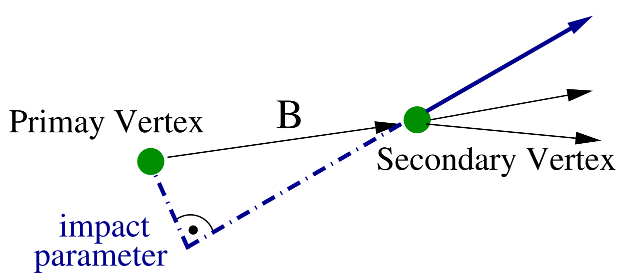
- Large production rates
  $\sigma(p\bar{p} \to bX, |y| < 0.6) \approx 18\mu b$
  10^3 higher than at $\Upsilon(4S)$
- Heavy and excited B states currently uniquely at Tevatron:
  $B_s, B_c, \Lambda_b, \Xi_b, B^{**}, B_s^{**}, ...$
- But QCD background is 10^3 higher than signal
  Triggers are critical.
- Event signature polluted by many fragmentation tracks;
  High precision vertex tracker + dedicated reconstruction algorithms needed

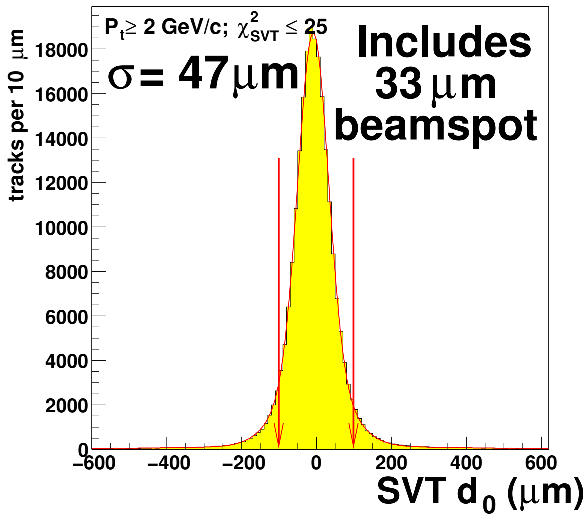


B-Triggers

Trigger signatures: lepton (e, μ) and displaced tracks

- B decays to $J/\Psi \rightarrow \mu^+\mu^-$ $\Rightarrow$ Di-Muon Trigger
  - + muon provides easy trigger
  - - small branching fraction
- Semi-leptonic B decays $\Rightarrow$ Lepton Trigger, + Displaced Track
  - + large branching rations ($\approx$ 20%)
  - - missing neutrino
- Fully hadronic B decays $\Rightarrow$ Two Track Trigger
  - + $\approx$ 80% of branching fraction
  - - requires displaced track trigger

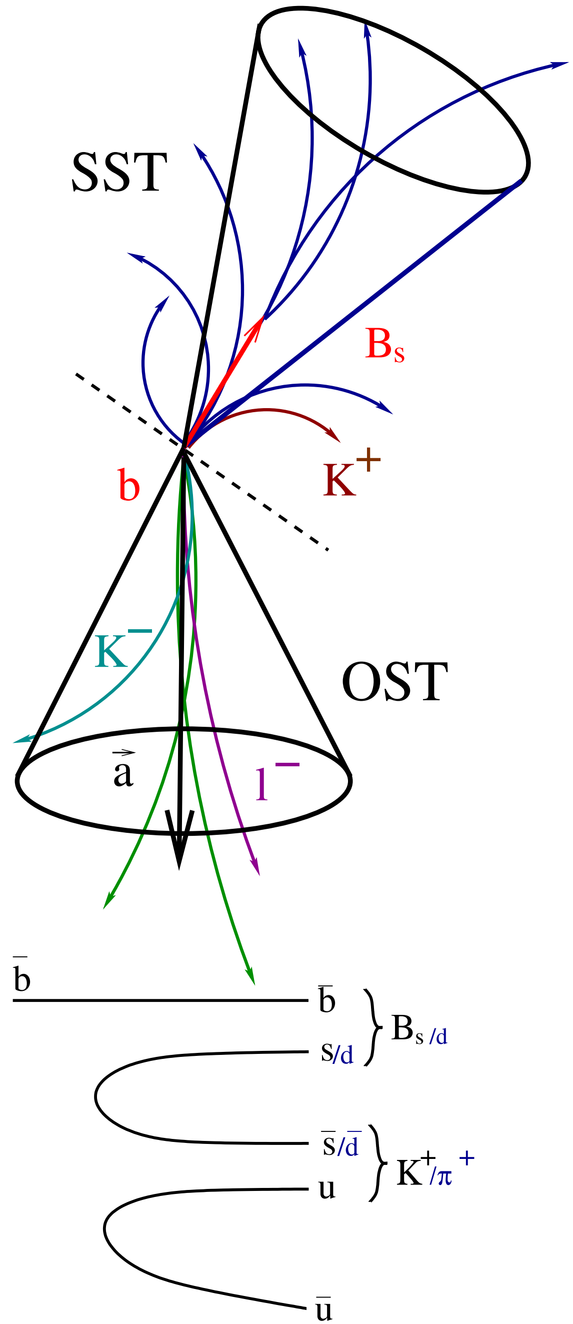




B Flavor Tagging

Opposite Side Tagging:

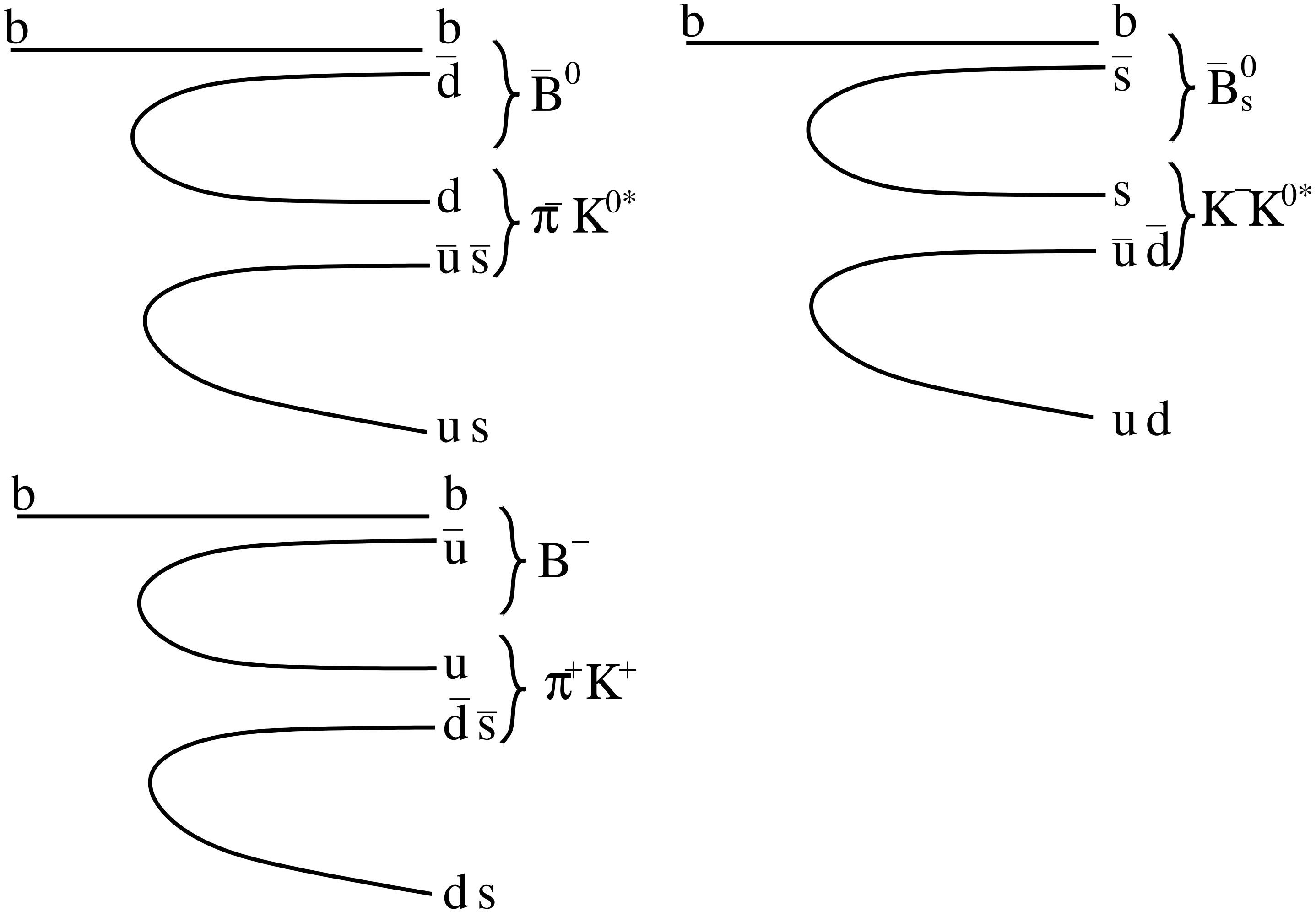
- Jet-Charge-Tagging:
  sign of the weighted average charge of opposite B-Jet
  high efficiency & low dilution
- Soft-Lepton-Tagging:
  identify soft lepton (e, μ) from semileptonic decay of opposite B: $b \rightarrow l^- X$ (BR $\approx 20\%$),
  low efficiency but high dilution
- Kaon-Tagging:
  due to b→c→s it is more likely that a $\bar{B}$ meson contains a K^- than a K^+ in the final state
  (not implemented at CDF)



Same Side Tagging:

- $B_{s/d}$ is likely to be accompanied close by a K^+/π^+
  (ongoing effort but not used in current analysis)

Same Side Tagging



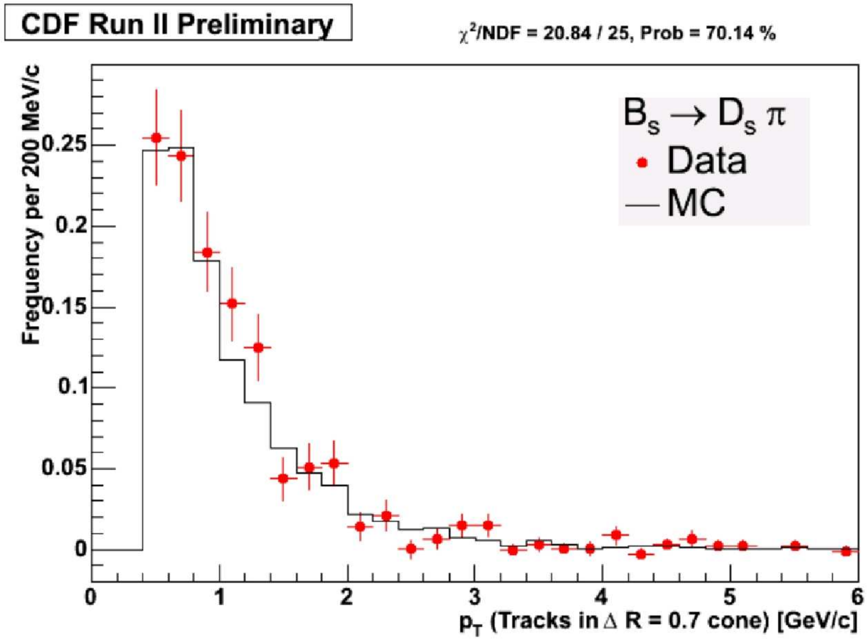
some of the possible species of particles produced in the fragmentation of a b quark to a B meson.

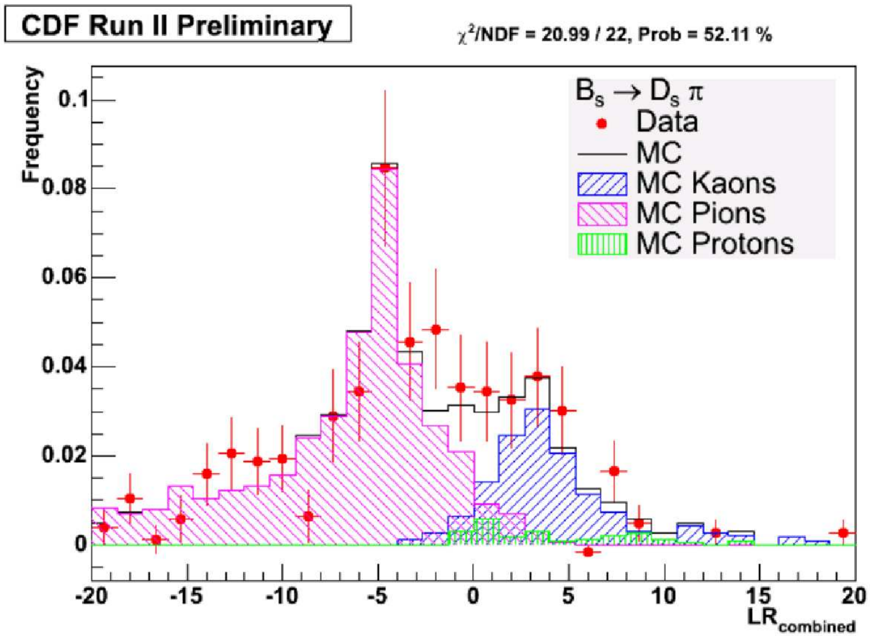
SSKT: Work in Progress

- There is no straight forward way to measure the tagger dilution on data unless we observe mixing
- But we have to know the dilution to set a limit

Have to rely on SSKT Monte Carlo predictions

Tuning is in progress!





Improvements Compared to Winter

Improved Tagging

Improved JQT + larger statistics for B^0 calibration sample

mode	ϵD^2 winter 05	ϵD^2 fall 05
hadronic	1.21%	1.55%
semil.	1.45%	1.55%

Additional decay modes

- $B_s \to D_s 3\pi, D_s \to \Phi\pi$
- $B_s \to D_s 3\pi, D_s \to K^* K$

900 $\longrightarrow$ 1.100 had. candidates

Improved ct resolution

- Event-by-event primary vertex instead of average beamline;
- Add L00
- Better understanding of σ_{ct}

+15% (in hadronic modes), +3% (in semileptonic modes)

Semileptonics in TTT instead of ℓSVT

- lower lepton momentum
- about 2 $\times$ higher yields but higher background

Winter Results

Semileptonic modes

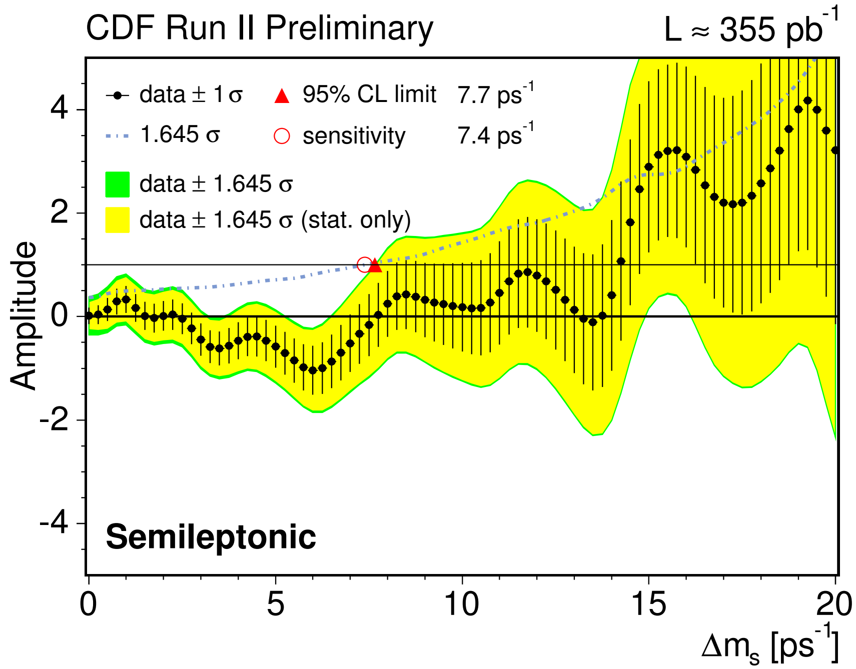
Sensitivity: 7.4 ps^{-1}

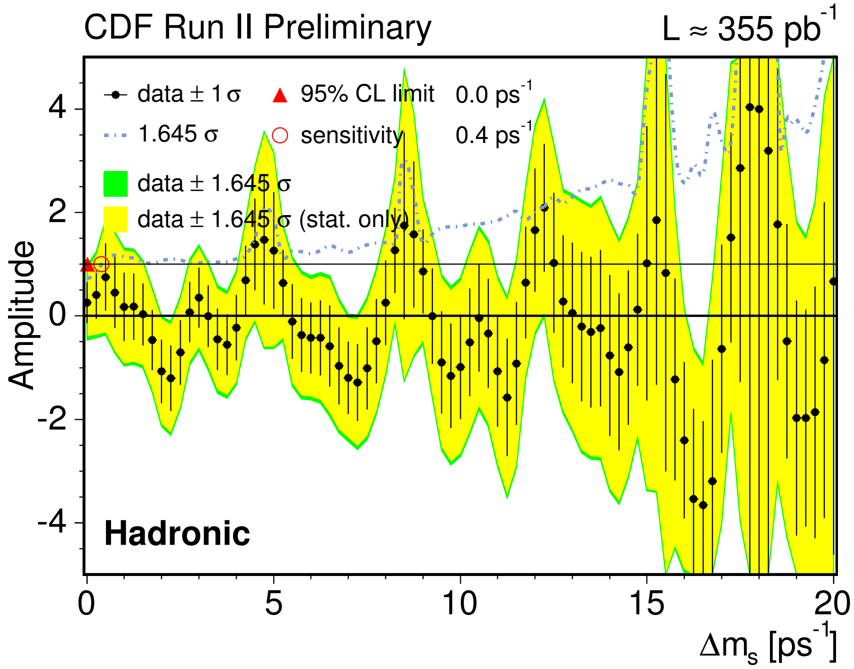
95% CL Limit: 7.7 ps^{-1}

Hadronic modes

Sensitivity: 0.4 ps^{-1}

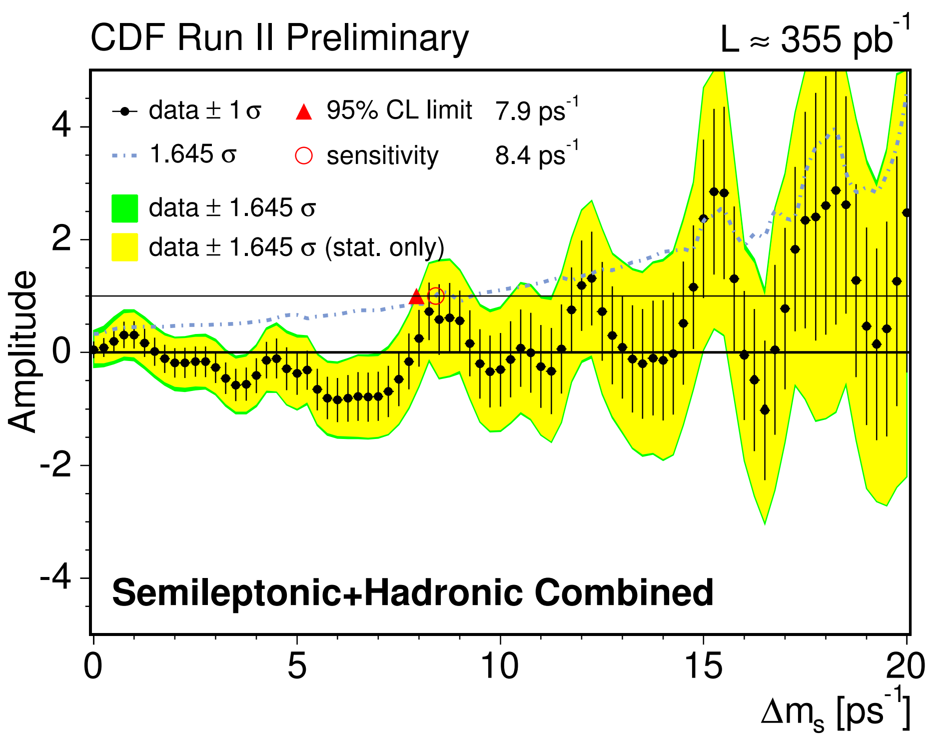
95% CL Limit: 0.0 ps^{-1}

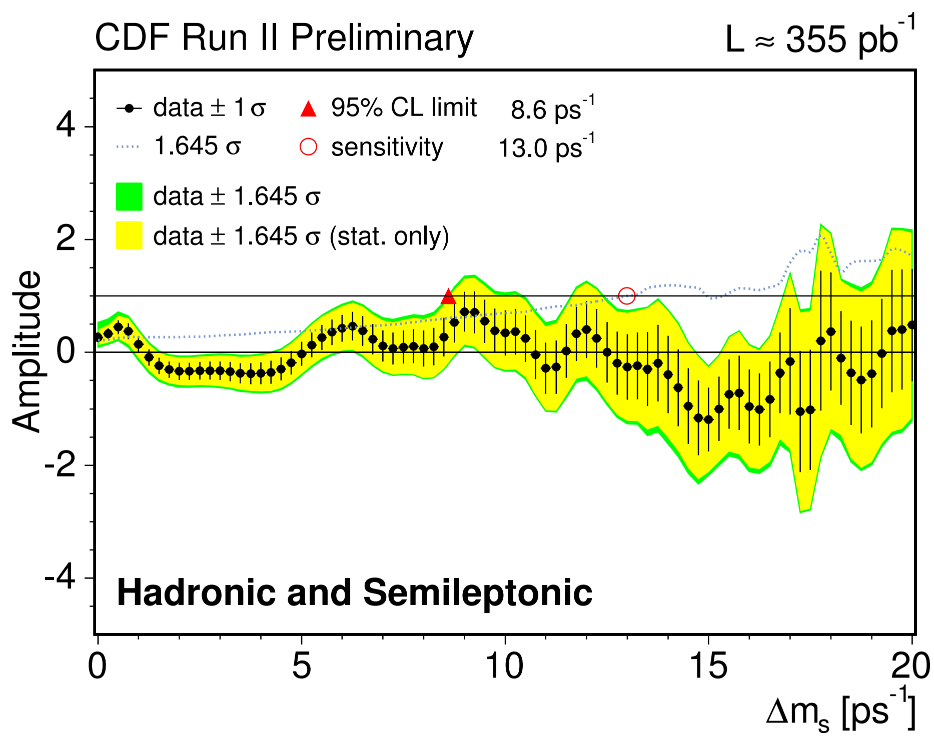




Combined CDF Results

Comb. CDF result, winter 2005	Comb. CDF result, fall 2005
Sensitivity: 8.4 ps^{-1}	Sensitivity: 13.0 ps^{-1}
95% CL Limit: 7.9 ps^{-1}	95% CL Limit: 8.6 ps^{-1}





It's the same data!