B masses, lifetimes and mixing at the Tevatron

XXXXth Rencontres de Moriond
La Thuile, March 12-19 2005

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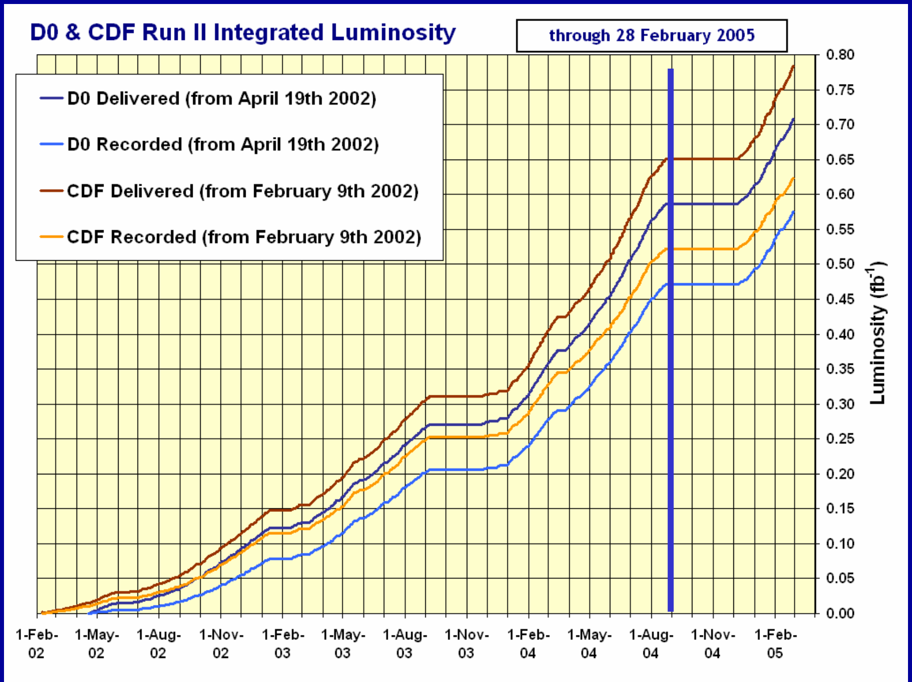
OUTLINE

- ~~Tevatron and Detectors~~
- Data sets
- ~~Masses~~
- Lifetimes
- Mixing

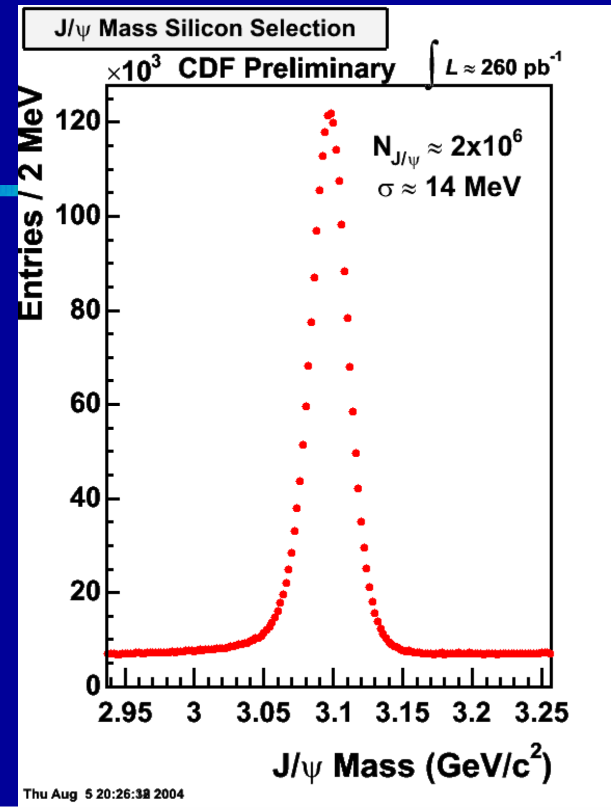
Data sets

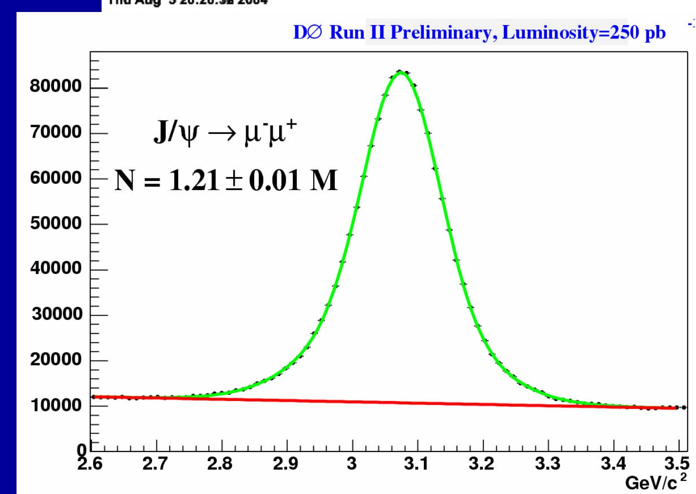
- CDF/D0 use data collected in the period 2002-2004
  - ~ 600 pb^{-1} recorded
  - D0:
    - ~ 220-450 pb^{-1} used for B physics
  - CDF:
    - ~ 240-360 pb^{-1} used for B physics
    - Lost ~ 100 pb^{-1} due to Central Tracking Chamber ageing problem
      - Now completely resolved



Data samples

- J/ψ samples:
  - Millions! ~ 20% are from B's
  - Reconstruct exclusive $B/\Lambda_B \rightarrow J/\psi\ K/\Lambda^0$ modes
- Semi-leptonic B → D lν X samples:
  - ~ 100 K events with fully reconstructed D
    - D0 has larger muon acceptance
    - CDF lowers lepton trigger pt by requiring additional displaced track
- Fully hadronic decays (CDF only)
  - ~ 10 K events fully reconstructed B's
  - Requires trigger on secondary vertex (SVT)

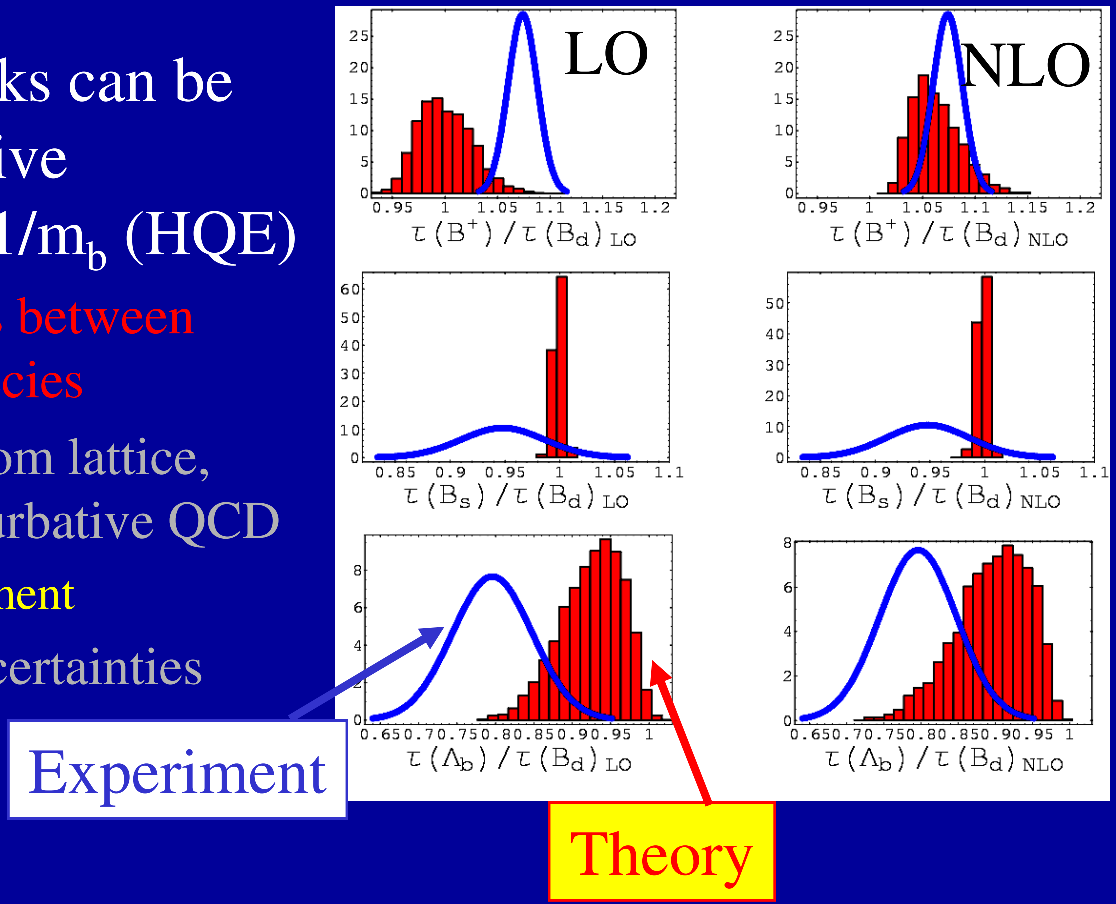




B hadron lifetimes

- B hadron decays dominated by b-quark decay
  - Effect of spectator quarks can be included with perturbative expansions in terms of $1/m_b$ (HQE)
    - Expect small differences between lifetimes of different species
    - Non-perturbative ME from lattice, Wilson coeff. from perturbative QCD
      - NLO improves agreement
    - Ratios reduce theory uncertainties

C. Tarantino, hep-ph/0310241
October 2003



Lifetimes

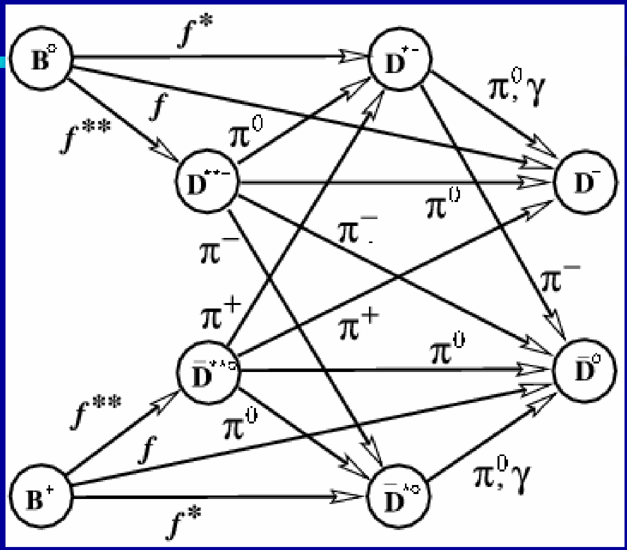
- HFAG 2004 averages as of summer 04 (hep-ex/0412073 Jan. 2005)
  - B0, B+ dominated by BaBar/Belle (latest not yet included in HFAG average)
    - Best result from Belle: → calibration result for Tevatron measurements ←
      - B0: 1.534±0.008±0.010, B+: 1.635±0.011±0.011, $\tau(B+)/\tau(B0)$=1.066±0.008±0.008
  - Bs, Λ_B: dominated by CDF/D0, LEP
  - $\tau(B^+)/\tau(B^0)$: No Tevatron Run II results included
  - Bs: Includes Run II D0 $J/\psi\phi$ (220 pb^{-1}), CDF $J/\psi\phi$ (240 pb^{-1})
    - See talk by S. Burdin for new $\Delta\Gamma_s/\Gamma_s$ measurements
  - Λ_B: Includes Run II D0 $J/\psi\Lambda$ (250 pb^{-1}), CDF $J/\psi\Lambda$ (65 pb^{-1})

b hadron species	average lifetime	$\tau/\tau(B^0)$ measurement	$\tau/\tau(B^0)$ Theory 2004 (*) (NLO)
B0	1.534 ± 0.013 ps		
B+	1.653 ± 0.014 ps	1.081 ± 0.015	1.06±0.02
Bs	1.469 ± 0.059 ps	0.958 ± 0.039	1.00±0.01
Λ_B	1.232 ± 0.072 ps	(0.803 ± 0.047)	0.86±0.05

(*) Gabbiani et al., hep-ph/0407004 **Oct.2004**

Lifetimes with B→lνDX modes

- Highest statistics samples
  - Difficult systematics:
    - Sample composition for Bu, Bd
      - Cross talk from D**, D*
    - Backgrounds:
      - Combinatorial
      - Physical: $B \to D^{(*)}D^{(*)}$
      - Prompt: c-cbar, b-bbar, D+fake

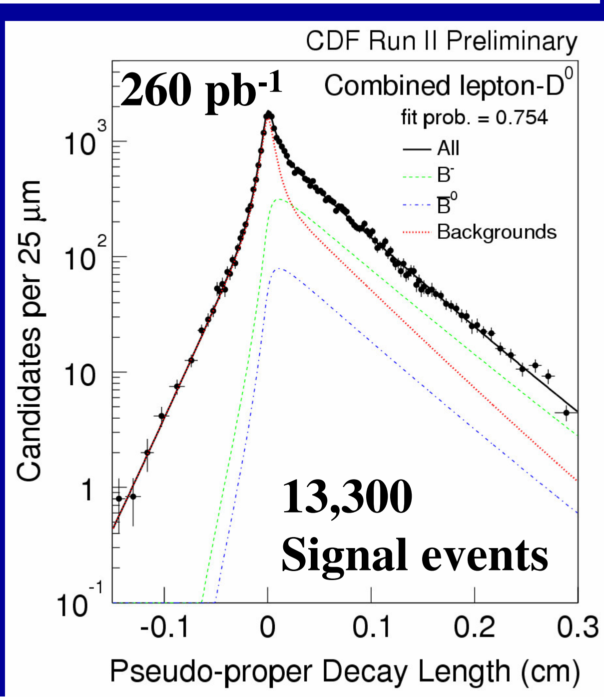


- Recent result from CDF with low statistics lepton pt > 8 GeV sample

$\tau(B^+)$ = **1.653±0.029±0.032 ps**, $\tau(B^0)$ = **1.473±0.036±0.054 ps**

$\tau(B+)/\tau(B0)$ = **1.123±0.040±0.040**

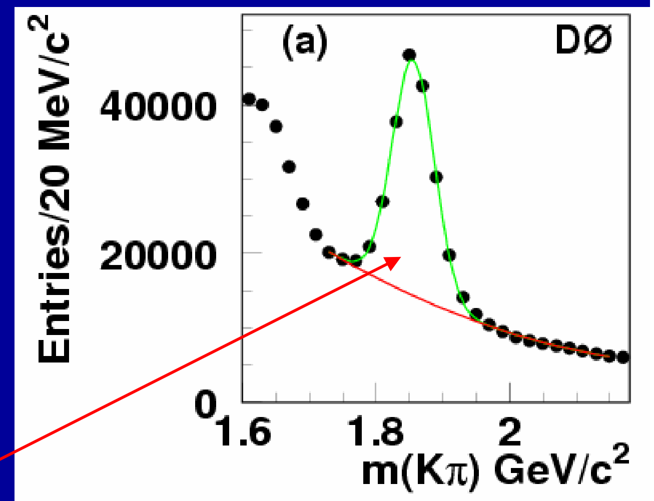
- Very high statistics secondary vertex triggered sample still under study

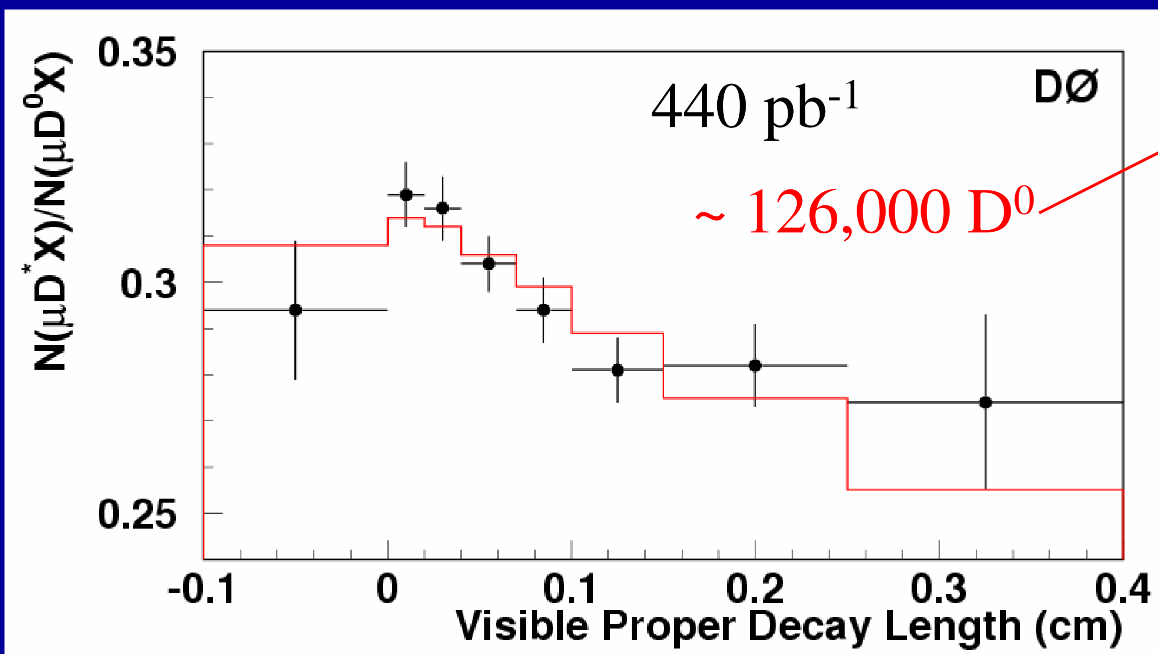


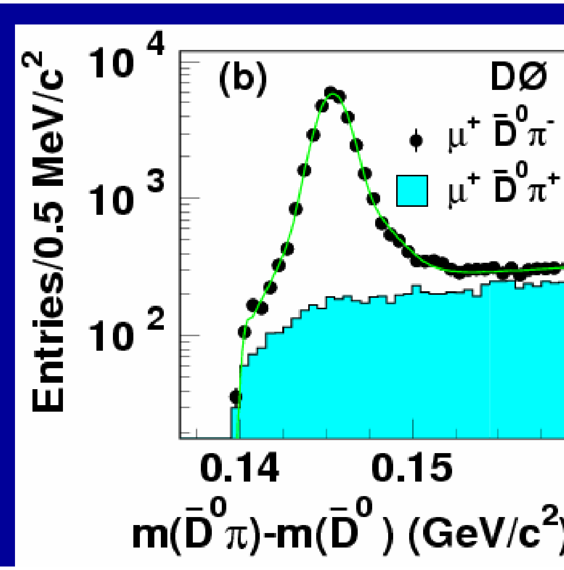
Lifetime ratio with B→lνDX modes

- D0: new method to determine $\tau(B^+)/\tau(B^0)$:
  - Fit the ratio of the lifetime distributions
    - Many systematics are reduced in the ratio
    - Best measurement of this ratio at Tevatron

$$\tau(B^+)/\tau(B^0) = \mathbf{1.08 \pm 0.016 \pm 0.014}$$



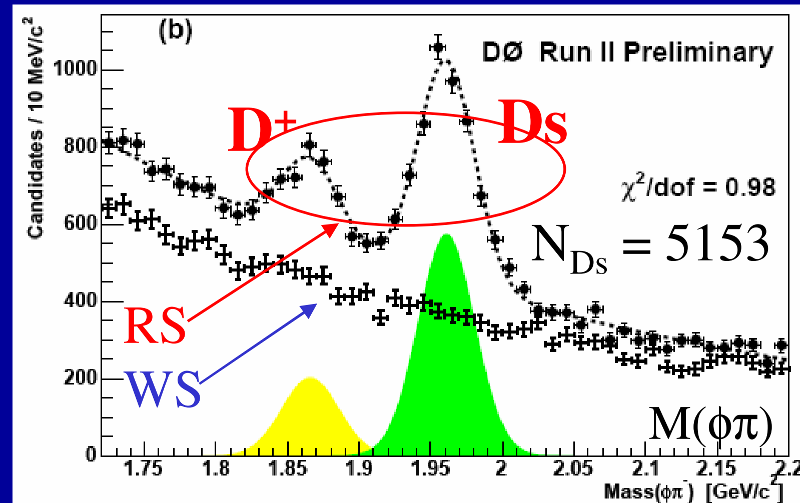


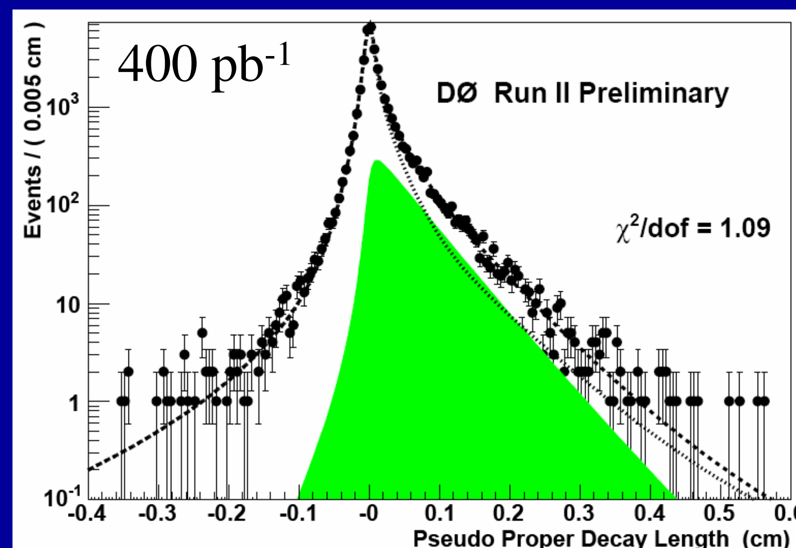


Lifetimes with Bs→lνDsX modes

- First high statistics Bs lifetime measurement from D0
  - Use $Ds^+ \rightarrow \phi\pi^+$ decay
  - Difficult background systematics:
    - Combinatorial
    - Physical: $B \rightarrow D^{(*)}D^{(*)}$
    - Prompt: c-cbar, b-bbar, D+fake
  - Currently best measurement

    $\tau(Bs)$ = **1.420±0.043±0.057 ps**



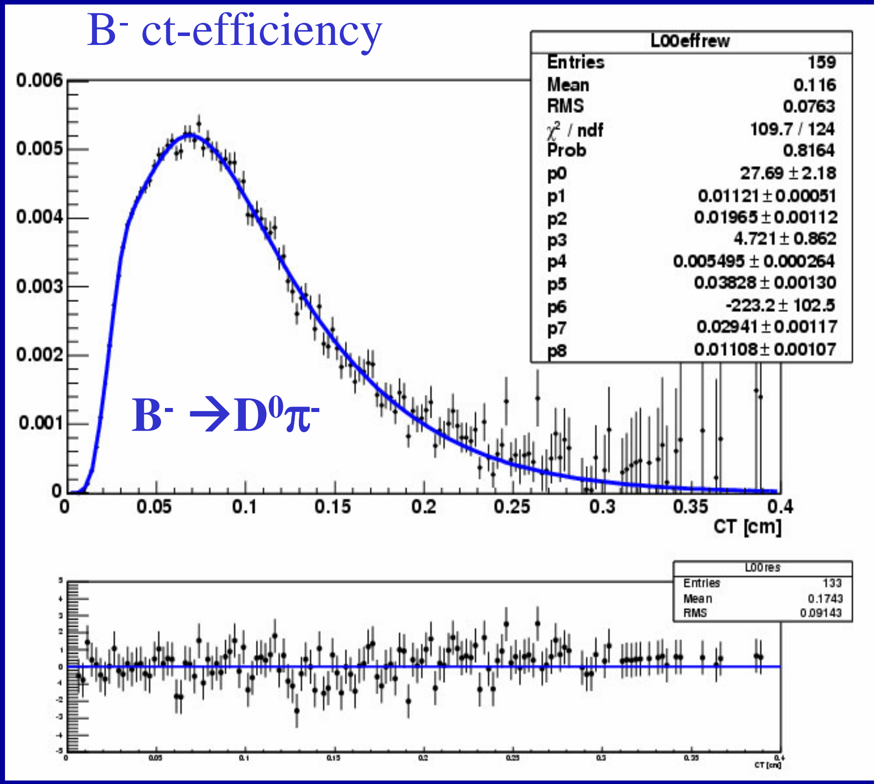


Systematics Summary (μm)

Source	$\Delta c\tau$ (μm)
Detector alignment [8]	±5.0
Background estimate	±15.0
Selection criteria	+3.6
Decay length resolution	±1.6
K–factor determination	$^{+3.5}_{-4.1}$
Non-combinatorial background	$^{+3.6}_{-4.4}$
Total	**±17.0**

Lifetime with hadronic decays

- CDF:
  - First measurement with Secondary Vertex Trigger biased samples
  - Trigger/analysis ct-efficiency curves from "realistic" MC
- Check by emulating trigger cuts on $B^+ \rightarrow J/\psi K^+$
- Use several final states
  - $B^\pm$: $D^0\pi^\pm$ [8380 ev.] ($D^0 \rightarrow K\pi$)
  - B^0: $D^\pm\pi^\mp$ [5280 ev.] ($D^\pm \rightarrow K\pi\pi$)
    $D^\pm 3\pi$ [4173 ev.] ($D^\pm \rightarrow K\pi\pi$)
  - Bs: Ds $\pi^\pm$ [465 ev.] ($Ds \rightarrow \phi\pi$)
    Ds 3π [133 ev.] ($Ds \rightarrow \phi\pi$)
    - **Important for Δm_s measurement**



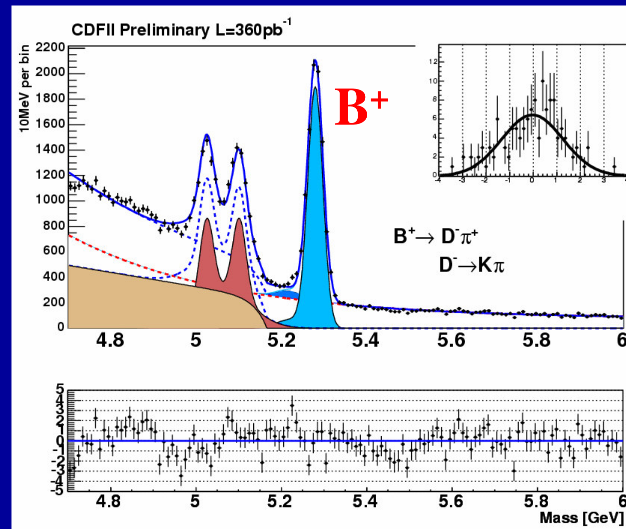
Lifetimes with hadronic decays

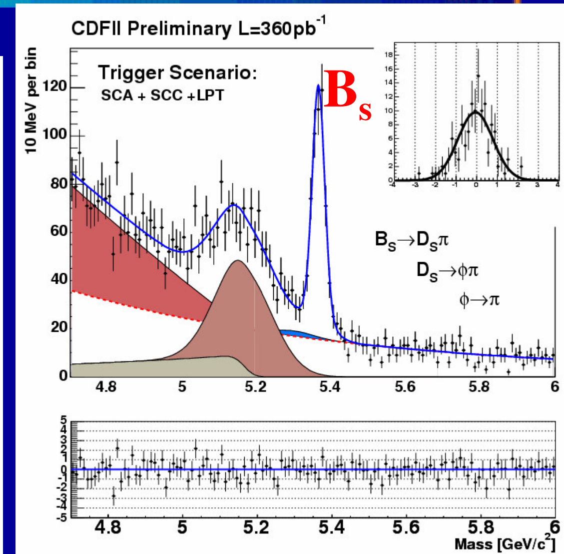
- More statistical power than J/ψ modes
  - Slightly larger systematics
    - Efficiency curve
    - backgrounds

$\tau(B^+) = \mathbf{1.661 \pm 0.027 \pm 0.013}$ **ps**

$\tau(B^0) = \mathbf{1.511 \pm 0.023 \pm 0.013}$ **ps**

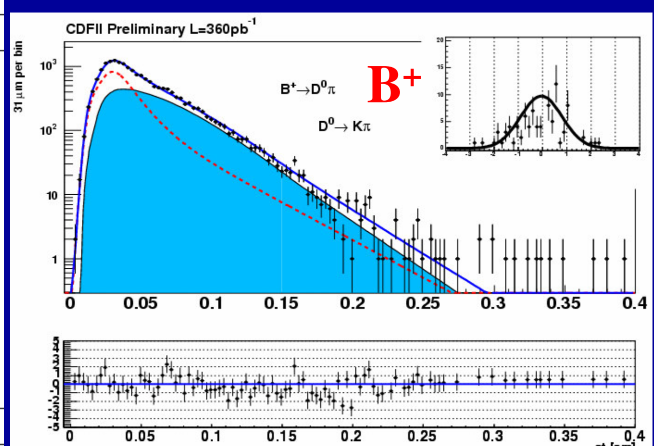
$\tau(B_s) = \mathbf{1.598 \pm 0.097 \pm 0.017}$ **ps**

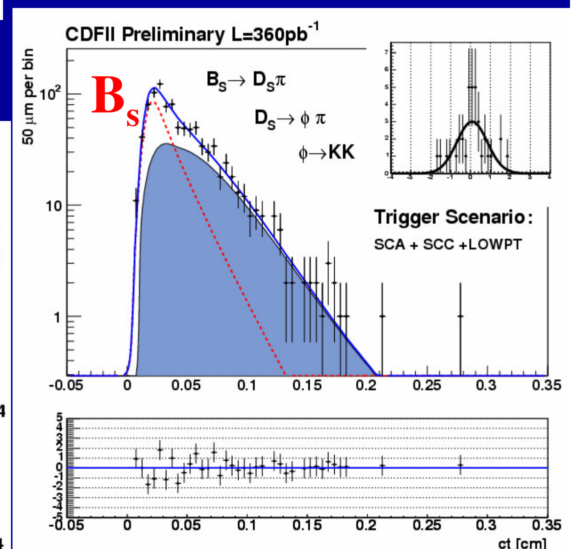




Systematics (μm)

Effect	Variation(μm)	Variation(μm)
	B^0	B_s
MC input $c\tau$	negligible	negligible
p_T reweight	1.9	1.9
Scale Factor	negligible	negligible
Bkg ct description	1.1	1.1
Bkg fraction	2.0	2.0
I.P. correlation	1.0	1.0
Eff. parameterization	1.5	1.5
L_{xy} significance	negligible	2
$\Delta\Gamma_s$	-	1.0
Alignm. + others	2.4	2.4
Total	4.2	4.7





Lifetimes: new results summary

- Many new results not included in HFAG 2004 averages
  - To come:
    - CDF high statistics semi-leptonic results
    - Ratios in several modes
    - Updates on Λ_B

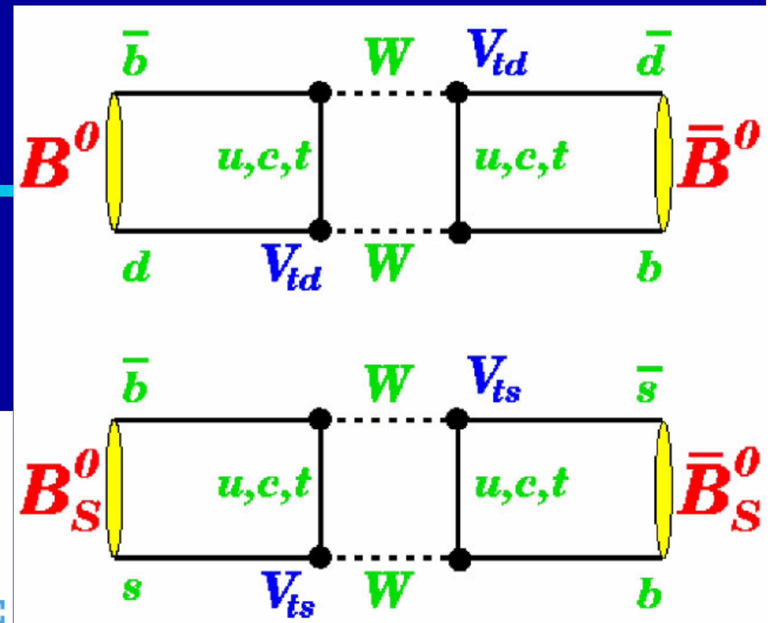
Lum.	CDF ψ modes	D0 ψ modes	CDF hadronic	CDF semi-leptonic (Hi pt)	D0 semi-leptonic (ψ)	HFAG
pb^{-1}	240	220 (250)	360	260	400	2004
B0	1.539±0.051±0.008	1.473±0.051±0.023	1.511±0.023±0.013	1.473±0.036±0.054		1.534 ± 0.013
B+	1.662±0.033±0.008		1.661±0.027±0.013	1.653±0.029±0.032		1.653 ± 0.014
B+/B0	1.08±0.042			1.123±0.040±0.040	1.08±0.016±0.014	1.081 ± 0.015
Bs	1.369±0.100±0.009	1.444±0.094±0.020	1.598±0.097±0.017		1.420±0.043±0.057	1.469 ± 0.059
Bs/B0	0.890±0.072	0.980±0.073±0.003				0.958 ± 0.039
Λ_B		(1.22±0.20±0.04)				1.232 ± 0.072

Included in HFAG averages

Red = Very recent! Just approved

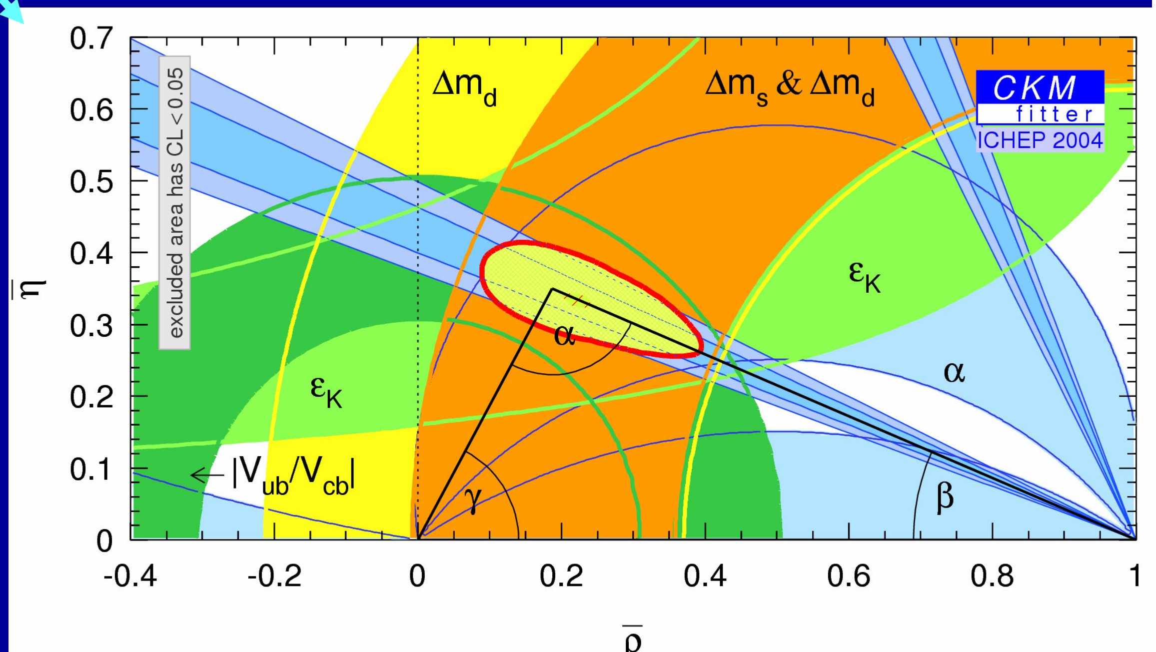
B mixing

- Neutral B's mix:
  - SM interpretation with box diagrams
    - Frequency $\Delta m_{d,s} \propto |V_{td,s}|^2$
    - Constraints to CKM weak due to theory uncertainties
      - Theory accuracy ~5% in ratio $\Delta m_d/\Delta m_s$
  - Bd mixing measured and established clearly
    - LEP, CDF-1, CDF-2, D0-2, **BaBar, Belle**
  - Bs mixing not observed
    - Limits set by LEP, SLD, CDF-1



$$\frac{|V_{td}|}{|V_{ts}|} = 1.01\xi\sqrt{\frac{\Delta m_d}{\Delta m_s}}$$

from LATTICE



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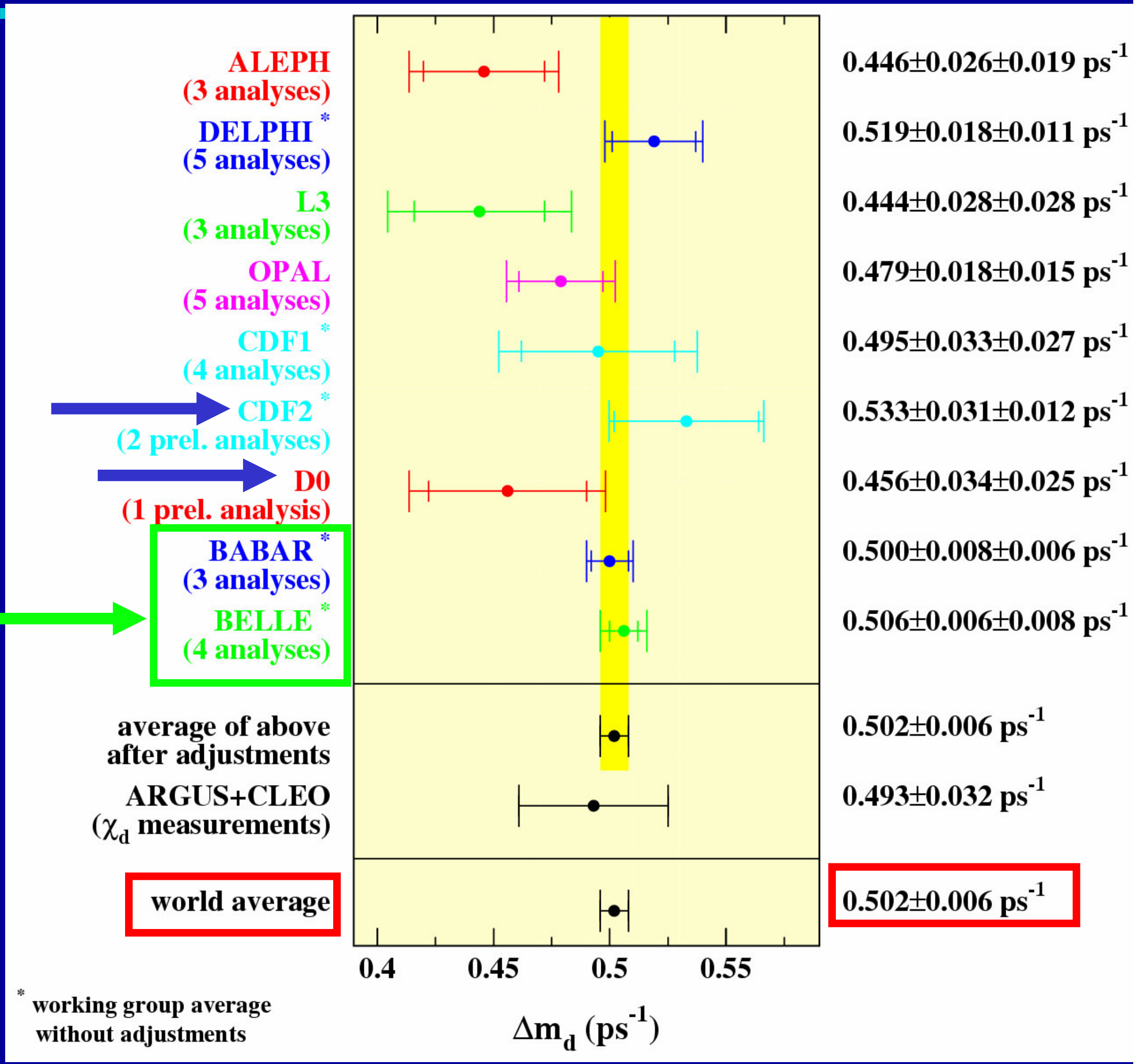
B mixing

- Basic ingredients for the measurement:
  - High statistics samples of neutral B's in flavor specific decays
    - CDF: $J/\psi K$, $D\pi$, $l\nu DX$
    - D0: $J/\psi K$, $l\nu DX$
  - Proper decay length reconstruction
    - Fully reconstructed modes provide better accuracy
  - Tagging of flavor at production (flavor tagging)
    - Key problem at the Tevatron!
    - Equivalent statistical power: $N\,\varepsilon D^2$
      - **ε = tagger efficiency**
      - **D = tagger dilution = $2*\eta-1$ (η = probability of correct tag)**
- Measure: $A(t) = (N_{nm}-N_m)/\,N = D\cos(\Delta m\, t)$
  - N_{nm} (N_m): number of B's with same (different) flavor at production and decay
  - Mixing measurement calibrates dilution
    - Impossible for Bs until oscillation observed

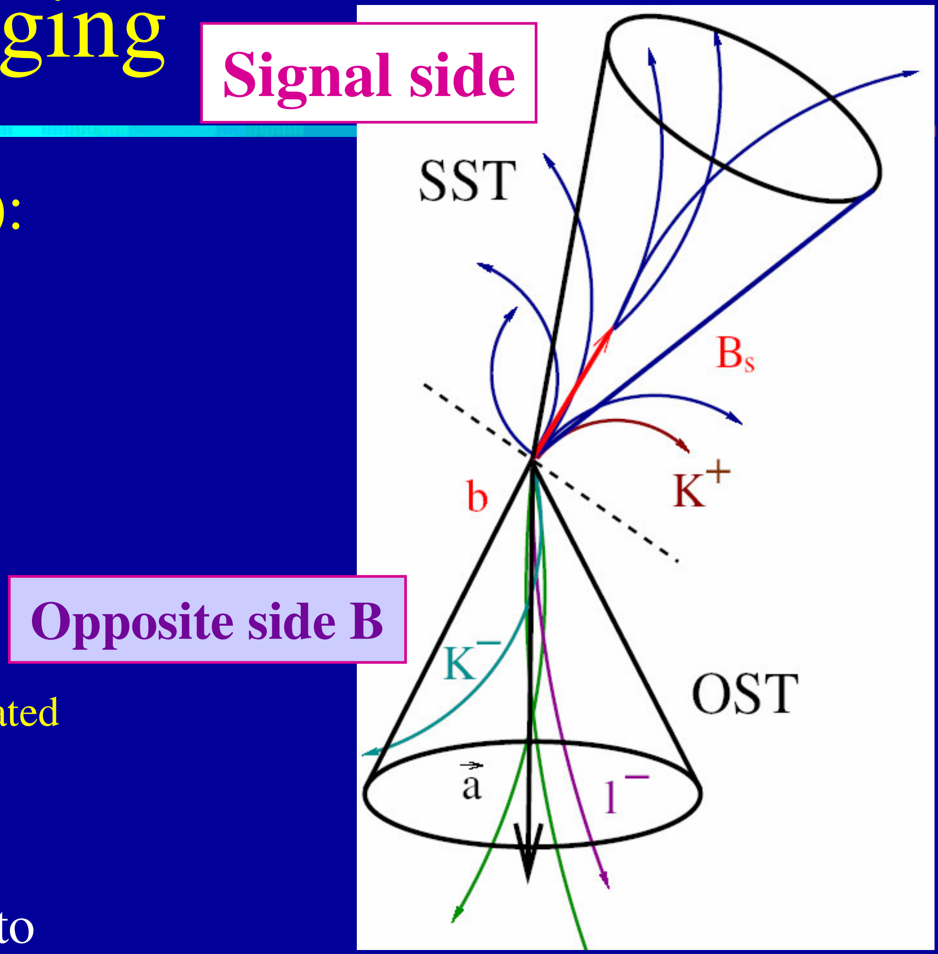
B_d Mixing

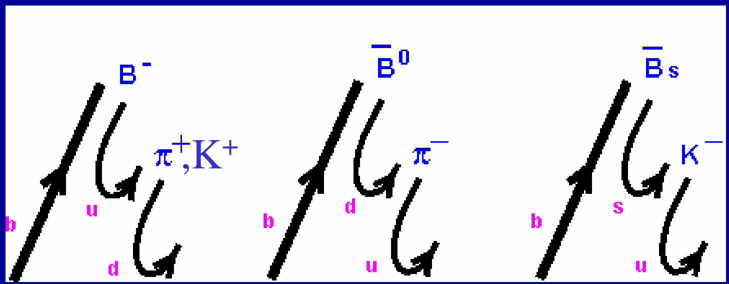
- HFAG Summary Based on result presented in summer 2004
- World Average dominated by BaBar/Belle



Flavor tagging

- Opposite side techniques (OST):
  - CDF: total $\varepsilon D^2 \sim 1.1 - 1.4$ %
    - Soft Muon Tag
    - Soft Electron Tag
    - Jet Charge Tag
  - D0: $\varepsilon D^2 \sim 1.1\%$
    - Enhanced muon tag $\varepsilon D^2 \sim 1.1\%$
      - Add-in correlations with associated jet in likelihood
- Same side techniques (SST):
  - Sign of nearby track is correlated to b type (SST)
    - Tagging power depends on B type
    - PID helps for Bs
    - $\varepsilon D^2 \sim 1\%$ for CDF&D0 in Bd





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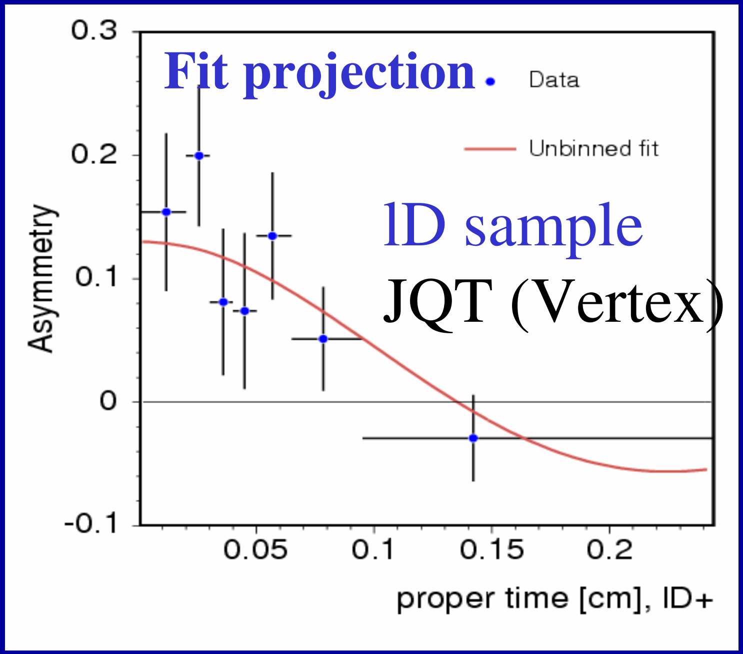
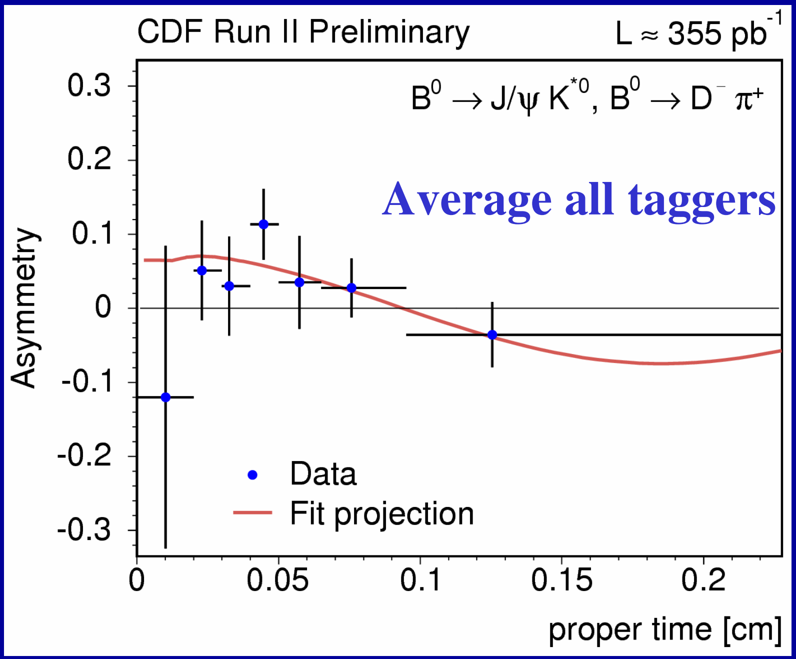
B_d mixing

- 2 recent results from CDF using 355 pb^{-1} and OST
  - Semi-leptonic sample: 124k lD^0 (24k lD^{*+}), 53k lD+
    - $\Delta m_d = 0.497 \pm 0.028(\text{stat.}) \pm 0.015(\text{syst.})\ ps^{-1}$
  - Hadronic sample: 5.3k ψK^+, 2.2k ψK^+, 6.2k $D^0\pi^-$, 5.6k $D^-\pi^+$
    - $\Delta m_d = 0.503 \pm 0.063(\text{stat.}) \pm 0.015(\text{syst.})\ ps^{-1}$





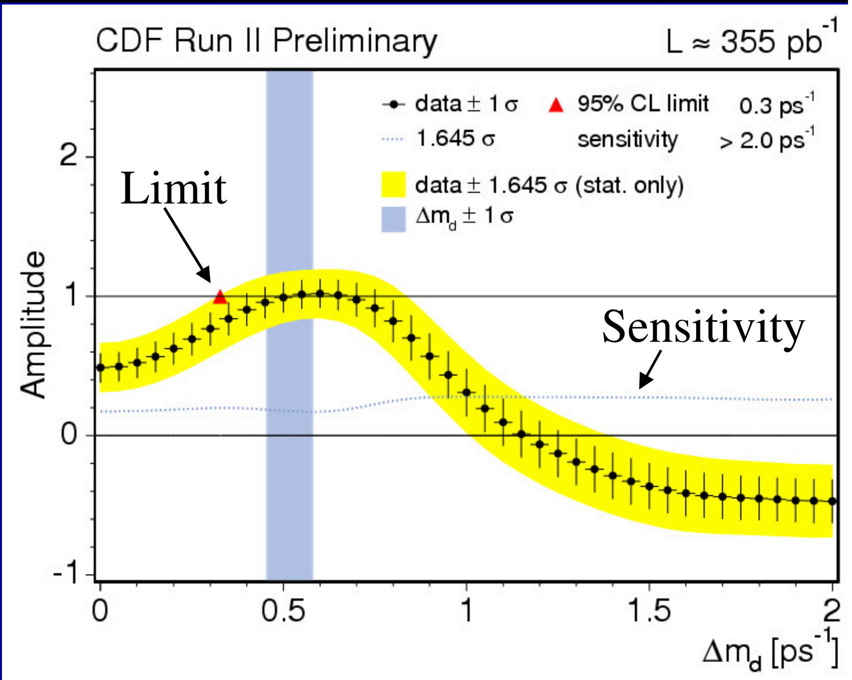
B_d Mixing

- These results obtained using many features important for Bs mixing
  - Unbinned fit
  - Parametrized dilutions
  - Calibrate dilutions

Tagger	CDF had %	CDF semi %	D0 semi %
OST μ	0.46	0.50	1.07
OST e	0.18	0.28	
OST jet	0.49	0.61	
Total OST	1.13±0.18	1.38±0.10	1.07

- Test amplitude scan on fully reconstructed B_d
  - Fit D*A*cos(Δm t) at fixed Δm
  - Expect A=1 for $\Delta m \sim \Delta m_d$
  - Limit (95% CL):
    - Δm such that $A+1.645\sigma_A = 1$
  - Sensitivity: Δm such that $1.645\sigma_A = 1$

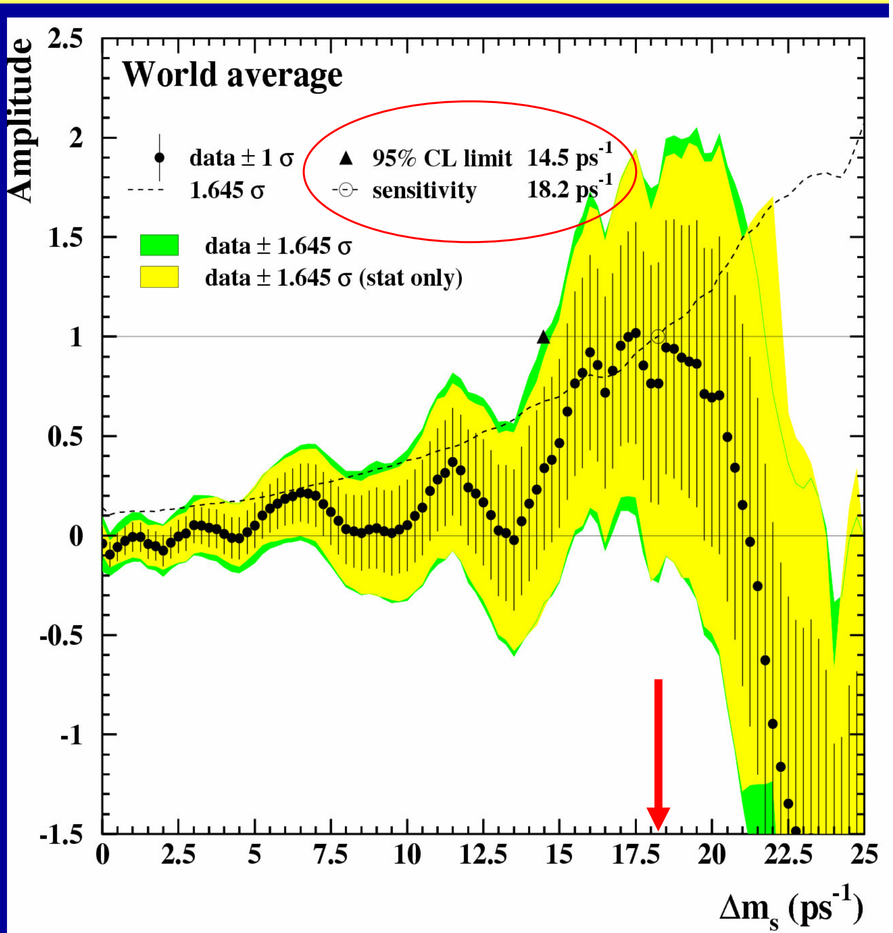
H. G. Moser, A. Roussarie, NIM **A384** (1997)



Bs mixing

SM Fit (2004): $\Delta m_s = 18.3 \pm 1.6\ ps^{-1}$

- Tevatron experiments do not have **yet** sensitivity for observation of SM prediction
- **New results:**
  - CDF:
    - Limit with combined fully reconstructed and semi-leptonic modes (this talk)
  - D0:
    - Limit with semi-leptonic modes (S. Burdin talk)

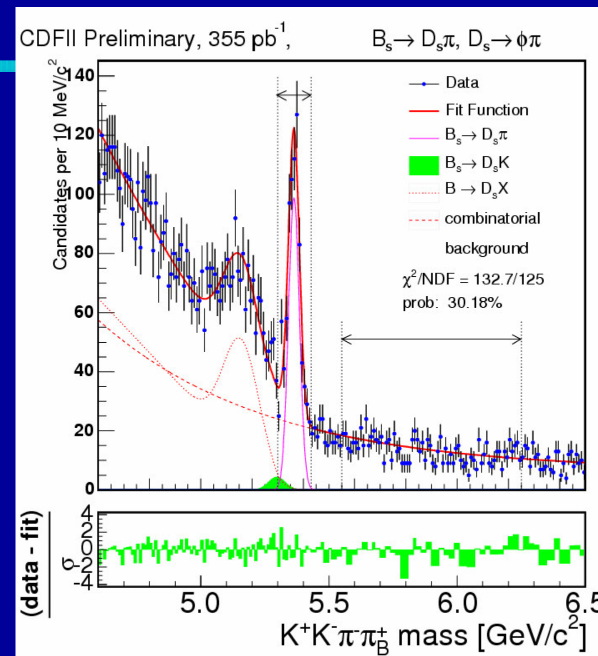


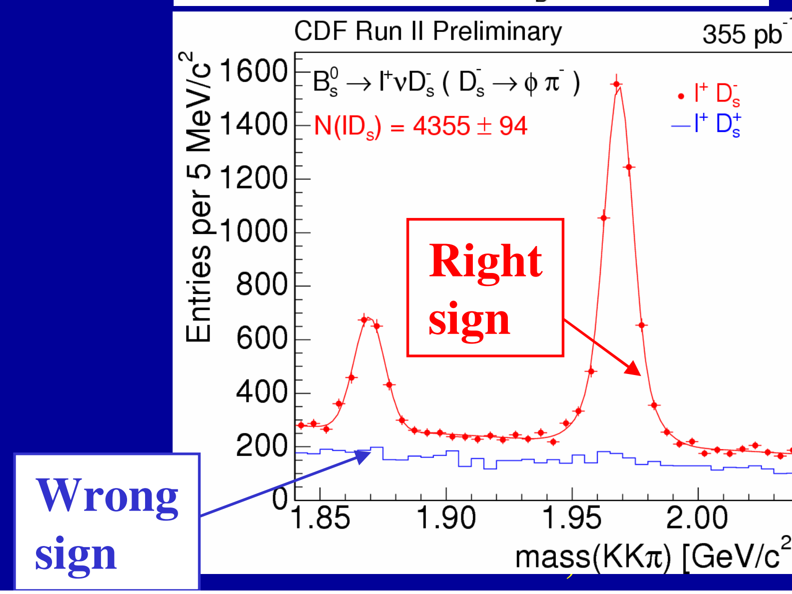
→hadronic peaks
→semi peaks

CDF: Bs mixing (signals)

- Hadronic analysis: Bs→Dsπ
  - ~ 900 events
  - Cross-check with hadronic lifetime analysis (independent group)
- Semi-leptonic analysis: Bs→Dslν
  - ~ 7.5k events
  - Cross-check with parallel independent analysis

Channel	Yield	S/B
Bs→Dsπ (Ds→φπ)	526±33	1.80
Bs→Dsπ (Ds→K*K)	254±21	1.69
Bs→Dsπ (Ds→3π)	116±18	1.01
Bs→Dslν (Ds→φπ)	4355±94	3.12
Bs→Dslν (Ds→K*K)	1750±83	0.42
Bs→Dslν (Ds→3π)	1573±88	0.32



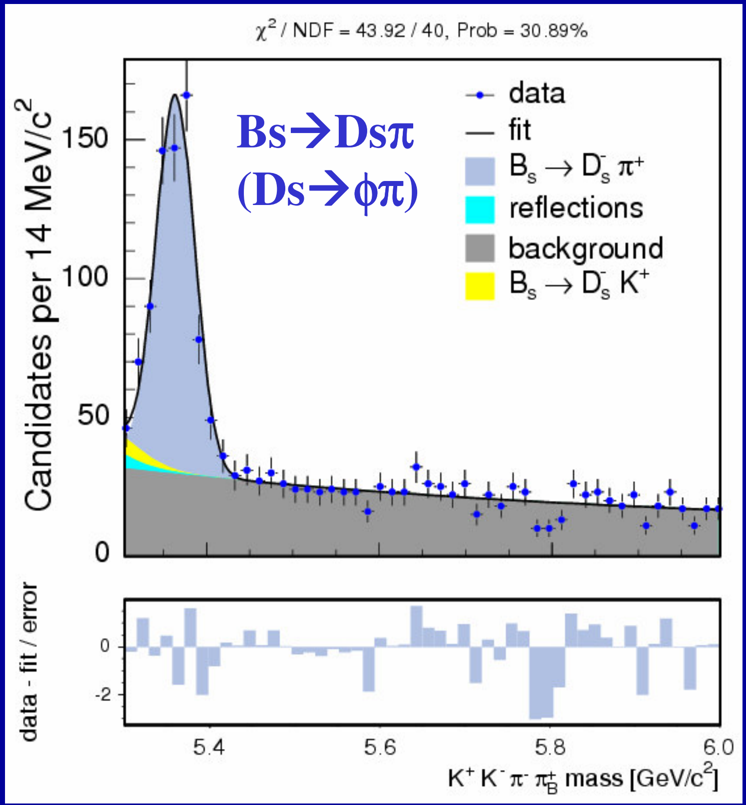


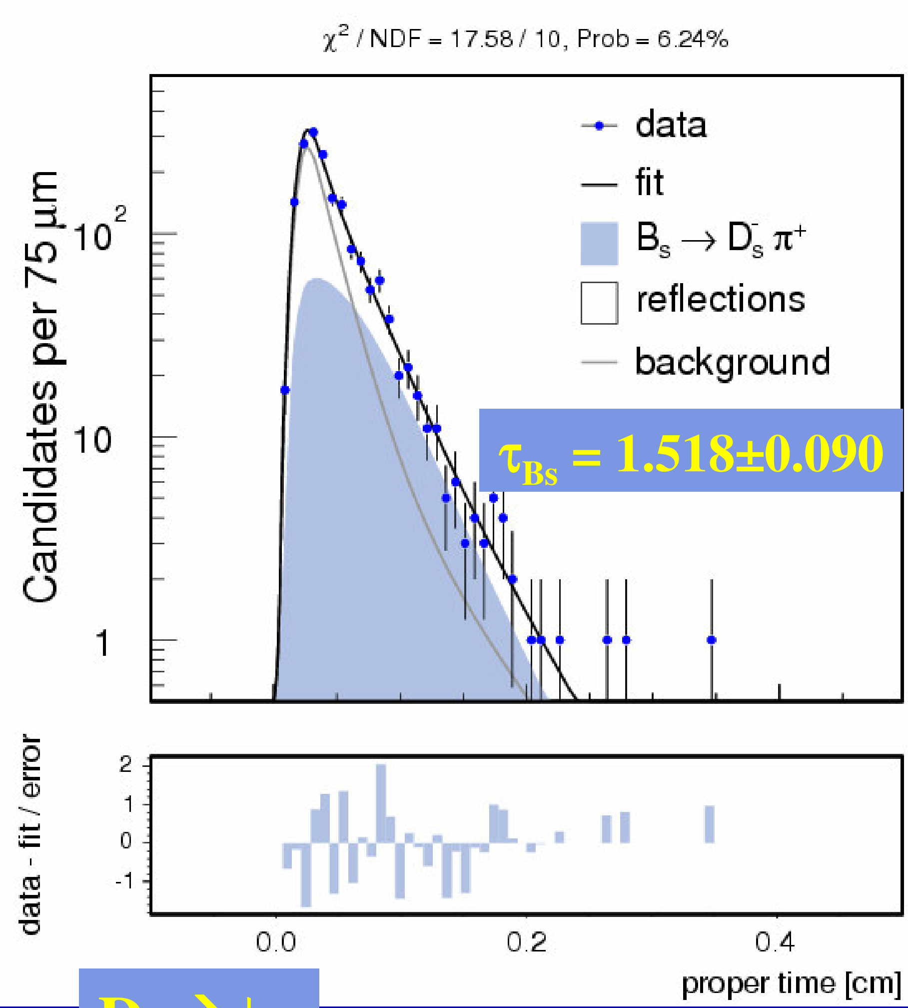
CDF: Bs mixing (cross-checks)

→Details (K-f)
→ (ct-eff)
→ (σ_{ct}-SF)
→τ (had, lD)

Mass and lifetime projections

- Mass and lifetime consistent with World Avg. values/D0





Ds→φπ

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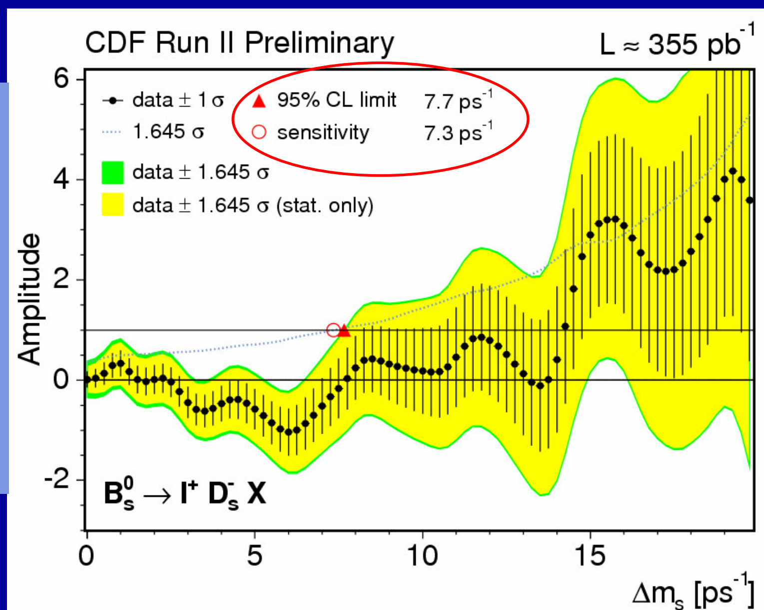
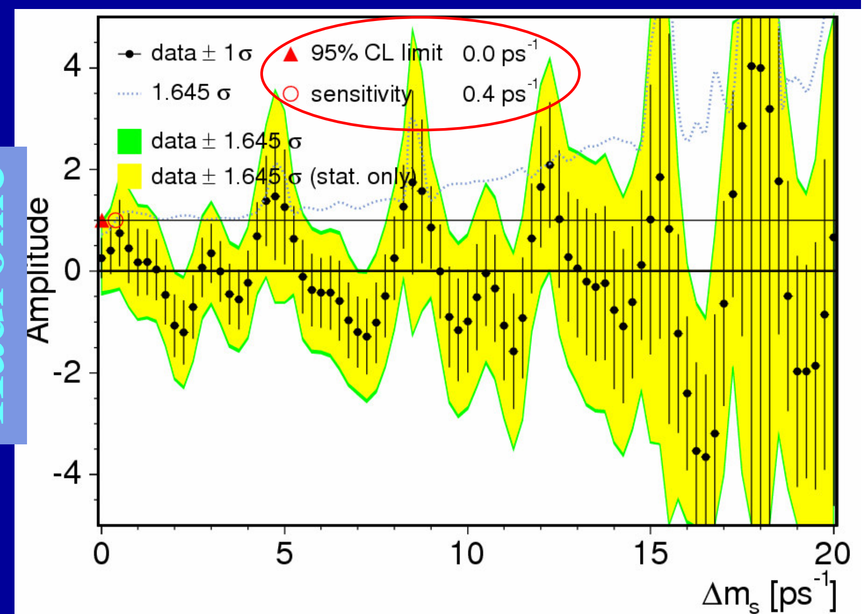
CDF: Bs Mixing (scans-1)

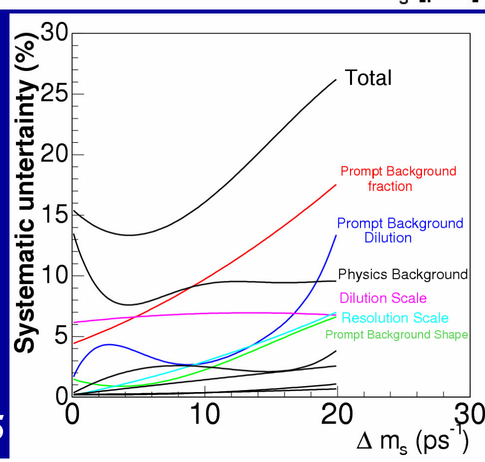
❖ Amplitude scans all statistics dominated

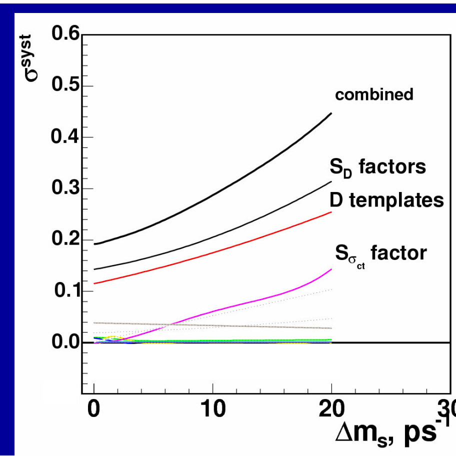
Semi-leptonic



Hadronic



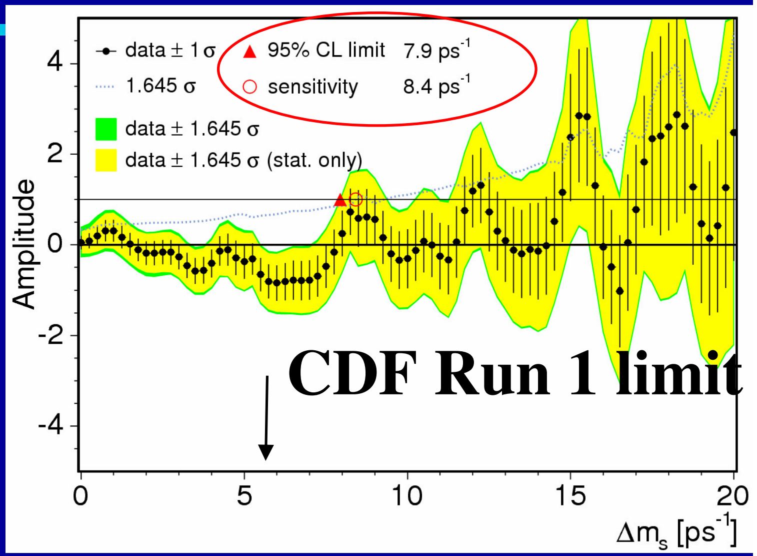




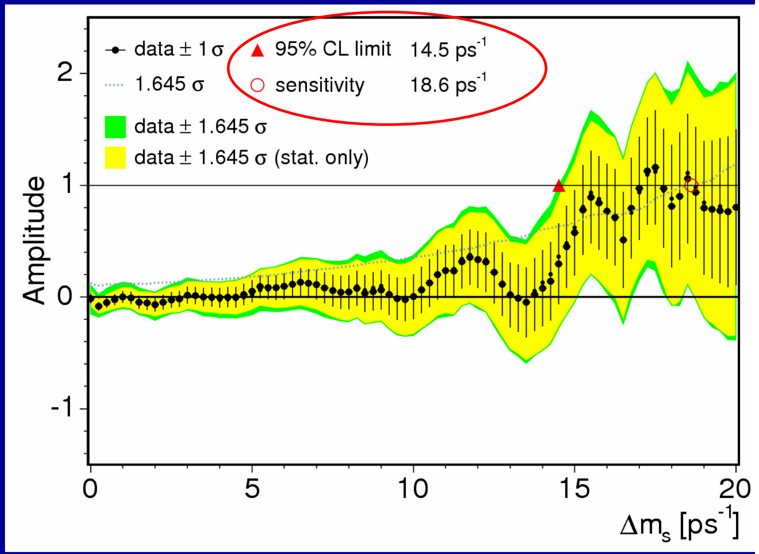
→Old projections

CDF: Bs mixing (scans-2)

- Combined scan results:
  - 7.9 ps^{-1} 95% CL limit
  - Sensitivity: 8.4 ps^{-1}



- Effect on World Average:
  - Limit: 14.5 → 14.5 ps^{-1}
  - Sensitivity: 18.2 → 18.6 ps^{-1}



Conclusions

- Many new results from the Tevatron
- Major new results in Bs sector
  - More Bs results from D0 (talk by S. Burdin)
  - Lifetime updated and more to come
  - First CDF/D0 Bs mixing limits
    - Lower than expectations
    - Additional improvements could reduce the statistical error on the amplitude by up to a factor two with same data set
    - It is a very difficult analysis, but now we are in business