B_s, B_c and b-baryons

XXV Physics in Collision

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Prague, July 6-9 2005

OUTLINE

- **Tevatron** and the CDF and D0 **detectors**

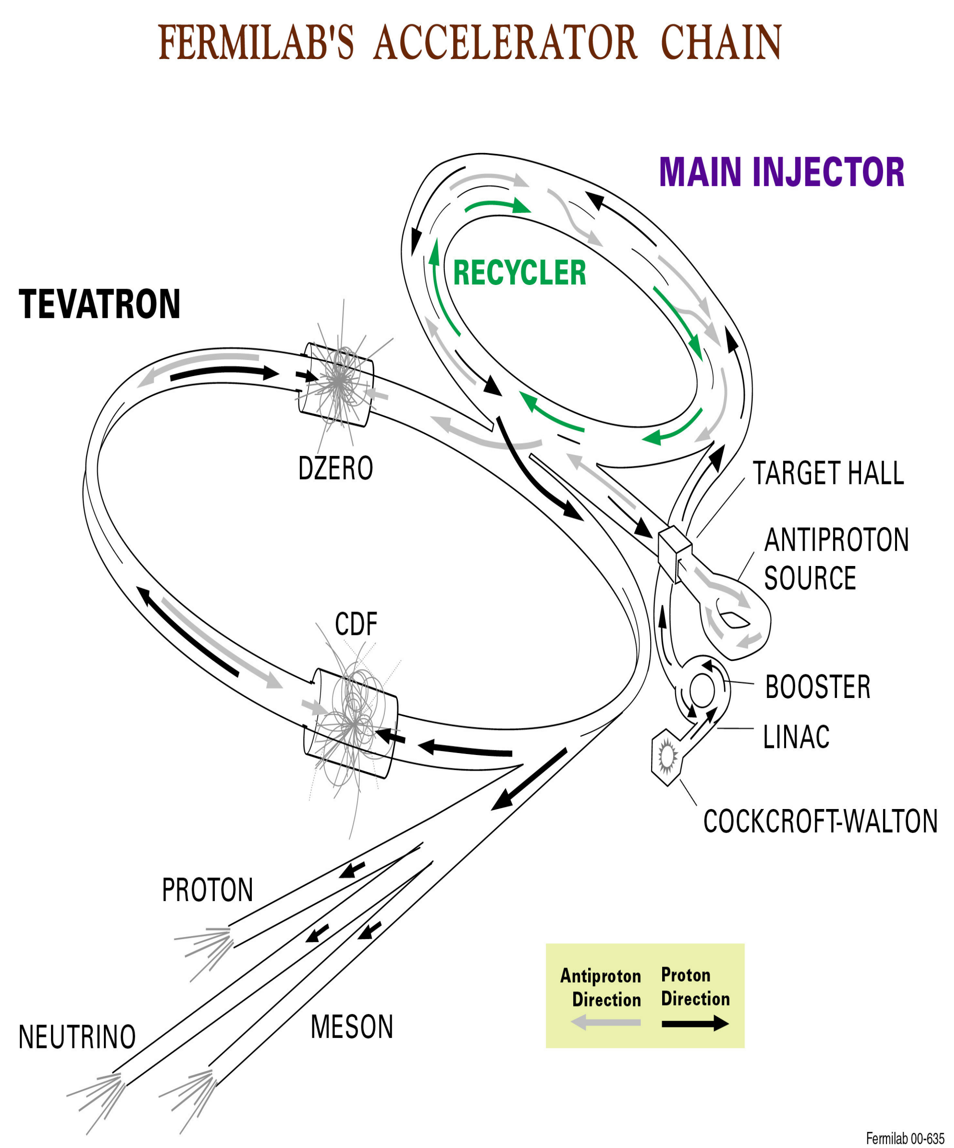
- B_s
  - Mass
  - Lifetime
  - Bs mixing ($\Delta\Gamma_s$, Δm_s)
  - Branching fractions - Rare decays

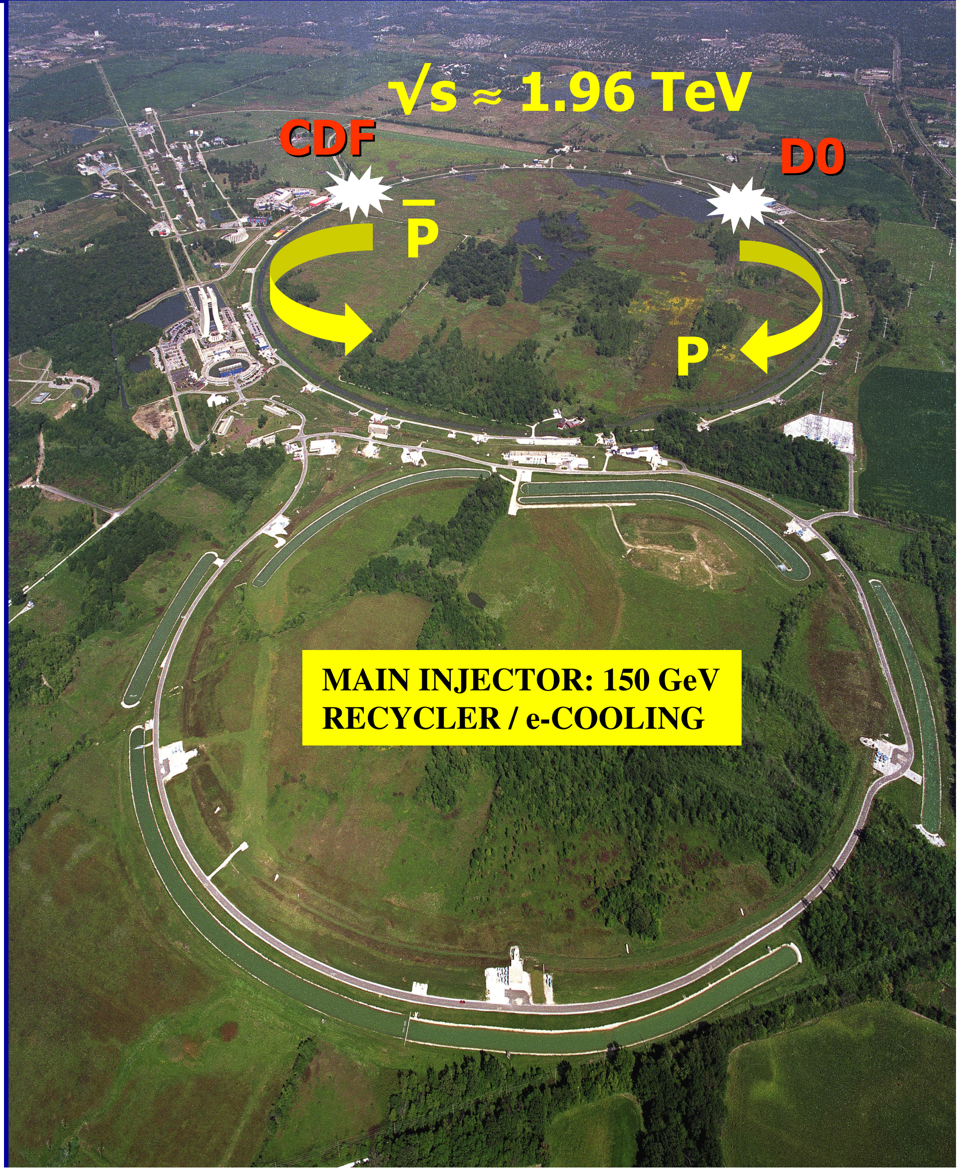
- B_c
  - Mass
  - Lifetime
  - Branching fractions

- b-baryons
  - Spectroscopy
  - Lifetime
  - Branching fractions

- Conclusion

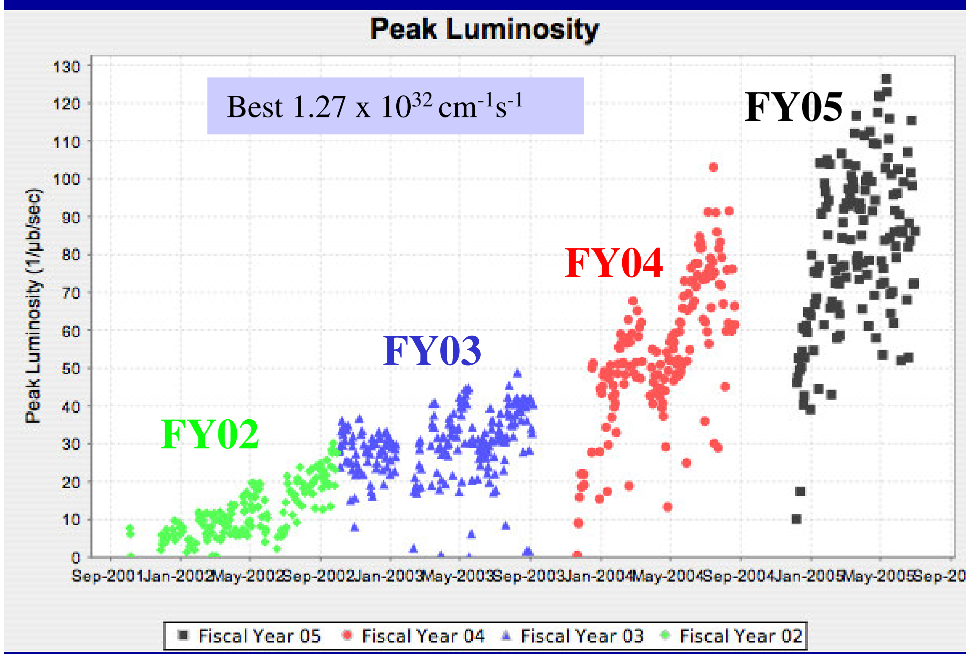
The Fermilab Accelerator Complex

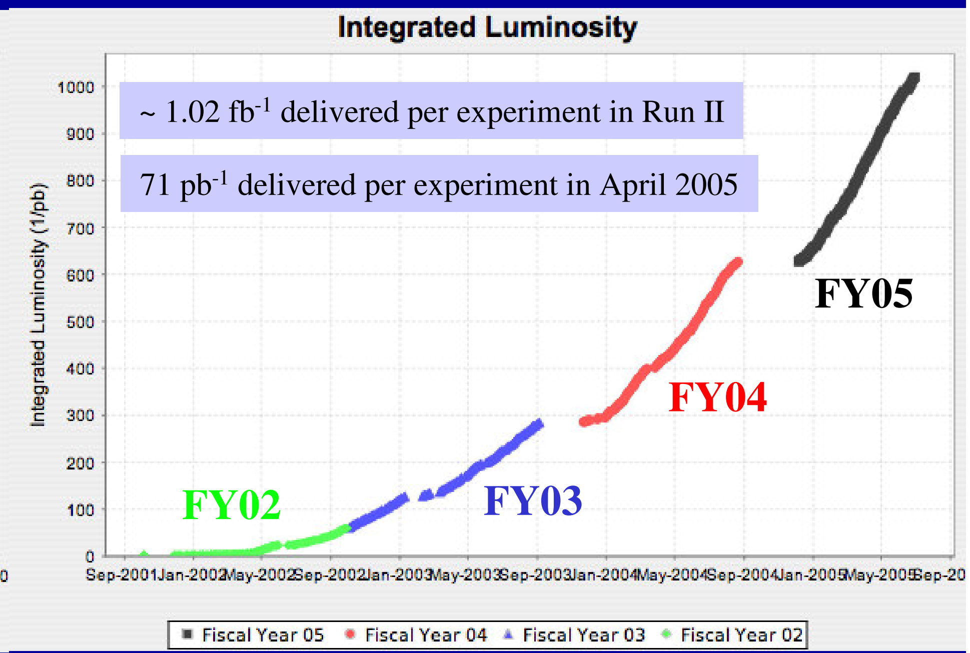




Tevatron Performance

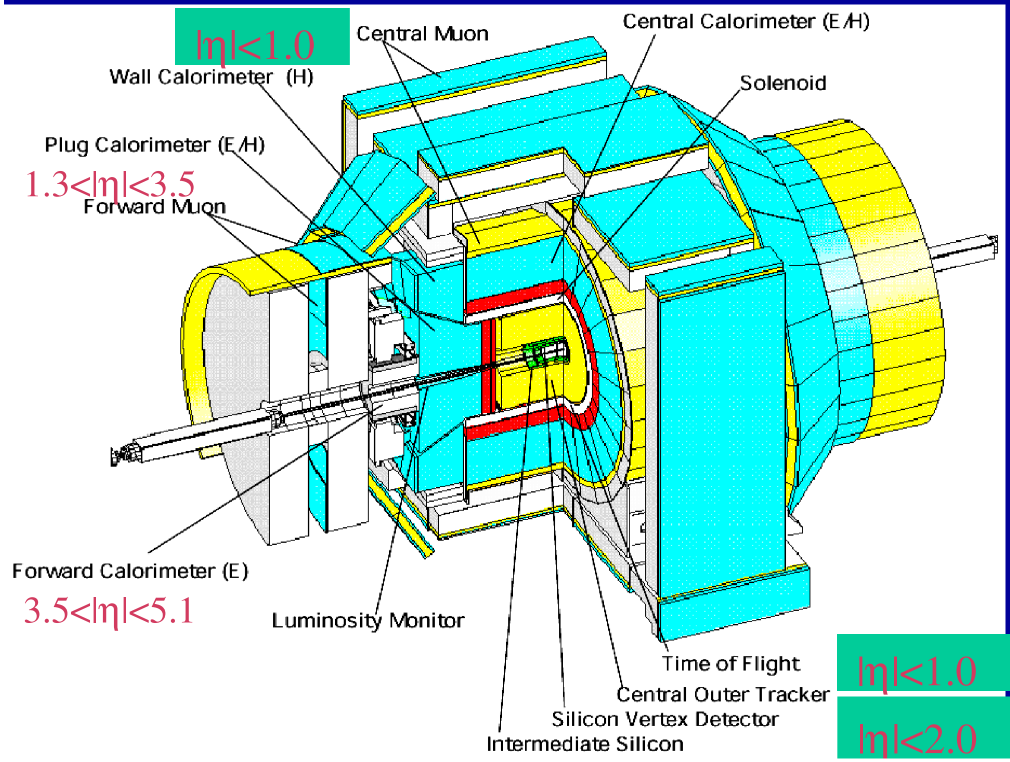
- **Tevatron (Run I 1992-96, ∫L dt = 110 pb-1):**
  - **p → ← pbar at √s = 1.8 TeV, 3.5 μs between collisions**
- **Tevatron (Run II 2002-Present, ∫L dt = ~1.02 fb-1):**
  - **p → ← pbar at √s = 1.96 TeV, 396 ns between collisions**

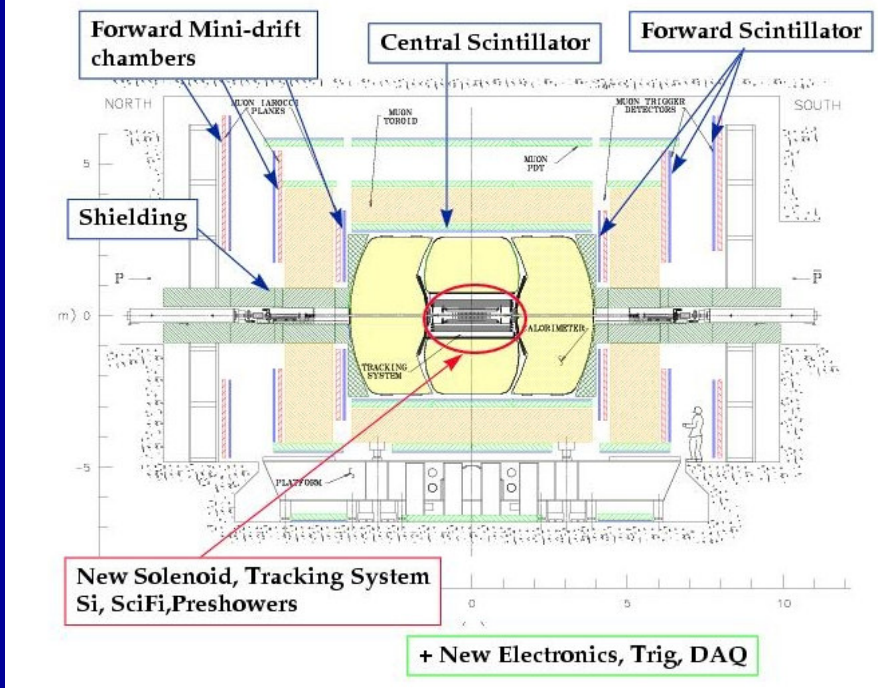




The CDF and D0 Detectors

- CDF:
  - Excellent mass resolution
  - Particle ID: dE/dx, TOF
  - Tracking triggers (Hadronic B's):
    - L1: Tracks
    - L2: Secondary vertex





- D0:
  - Excellent muon and tracking coverage
    - Tracking up to |η|<3
    - Muons up to |η|<2

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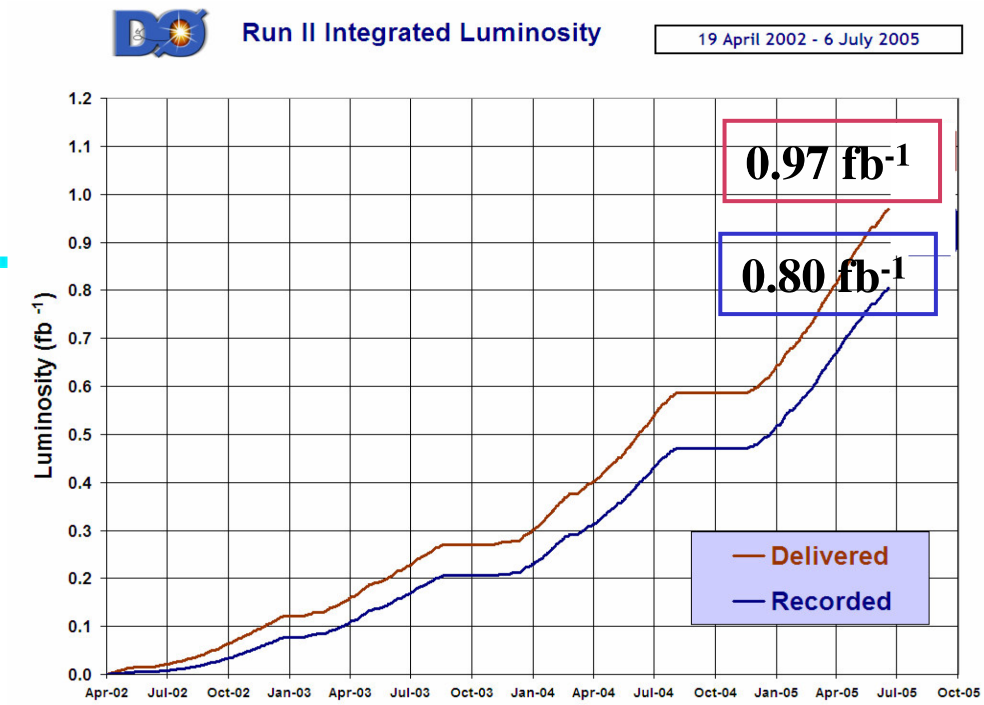
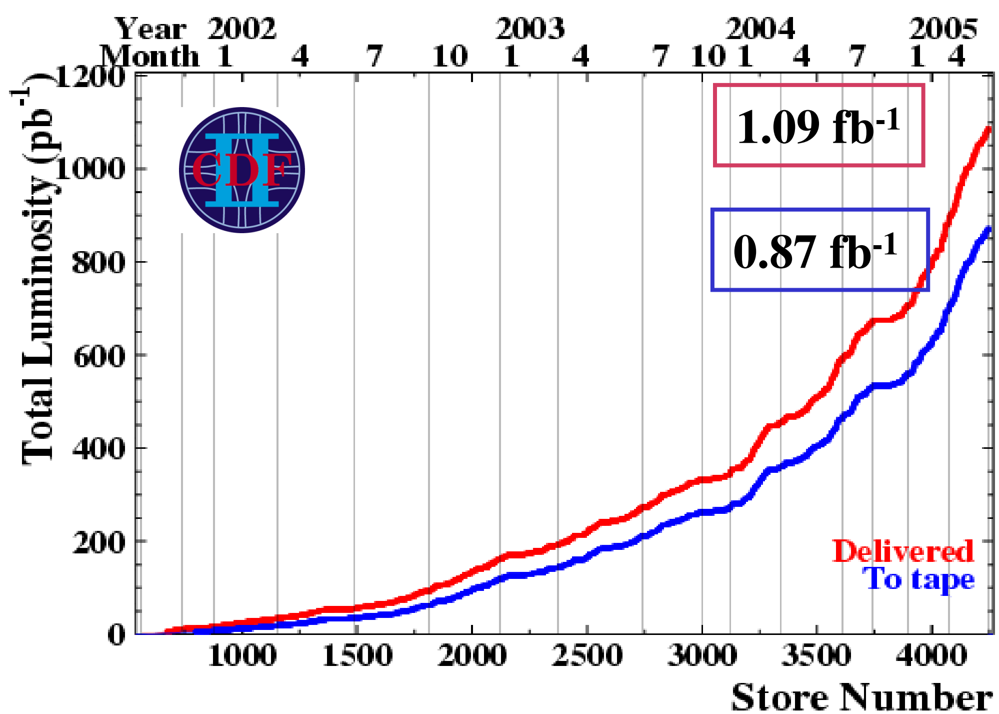
Data sets

- CDF/D0 use data collected in the period 2002-2004
  -
    - up to ~ 490 pb^{-1} used for B physics
  -
    - up to ~ 360 pb^{-1} used for B physics
    - Lost ~ 100 pb^{-1} due to Central Tracking Chamber ageing problem
      - Now completely resolved





B-Physics cross sections and triggers

b Production cross section:

$$\sigma\left(p\bar{p} \rightarrow \bar{b}X\right) = \left(29.4 \pm 0.6_{(stat)} \pm 6.2_{(sys)}\right)\mu b$$

|y| < 1 CDF, PRD 71, 032001, (2005)

Inelastic cross section: ≈ 60 mb→ factor 1/1000 trigger.

Compare with *b*-factories: σ is 10^3 higher.

L is 1 fb^{-1} (TeVatron) vs. a few hundred fb^{-1} (*Y*(4S))

	σ (μb)	$\mathcal{L}$ $cm^{-2}\ s^{-1}$	Integrated L	*b*-events
Tevatron	29	1.27×10^{32}	1 $fb^{-1} \times 2$	29×10^9
KEKB	0.001	1.58×10^{34}	470 fb^{-1}	0.47×10^9
PEP-II	0.001	0.92×10^{34}	273 fb^{-1}	0.27×10^9

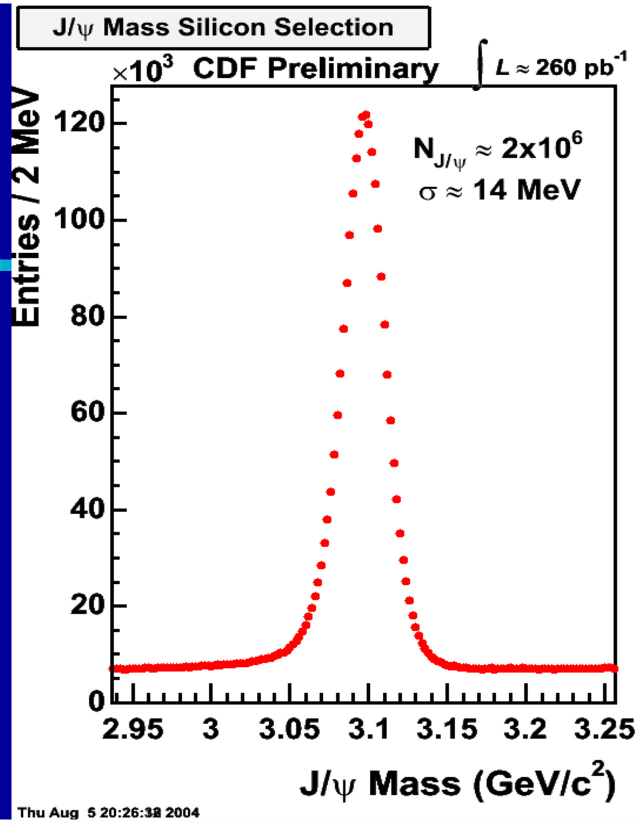
Trigger crucial point:

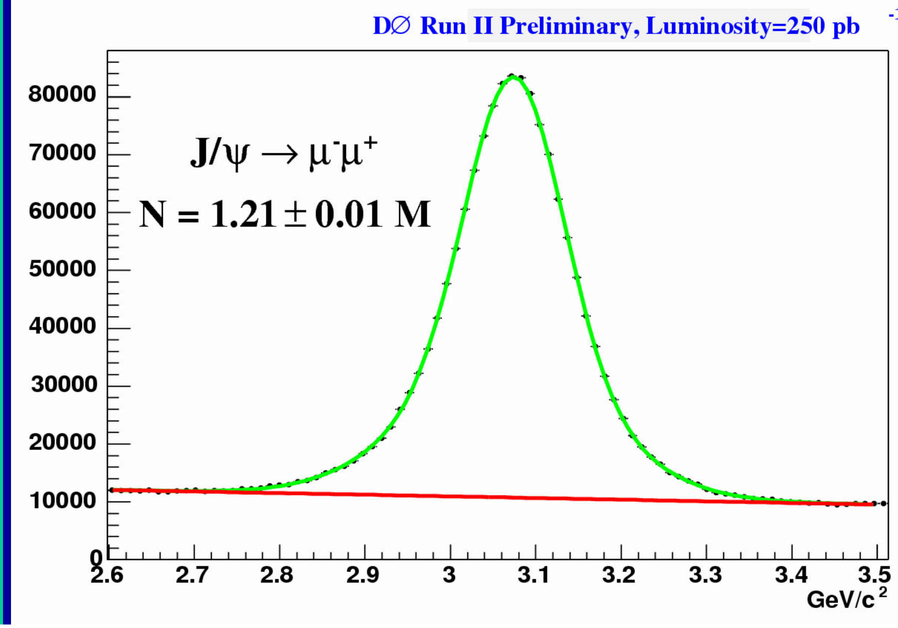
- 2 μ (e) from J/ψ **CDF**, **D0**
- soft lepton, (soft lepton+non prompt track) **CDF**, **D0**
- 2 non-prompt tracks **CDF**, **D0 under commissioning**

B-Physics 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 $B \rightarrow D\ l\nu\ X$ 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)

IP resolution: ~ 50 mm
33mm beam size + 35mm SVT



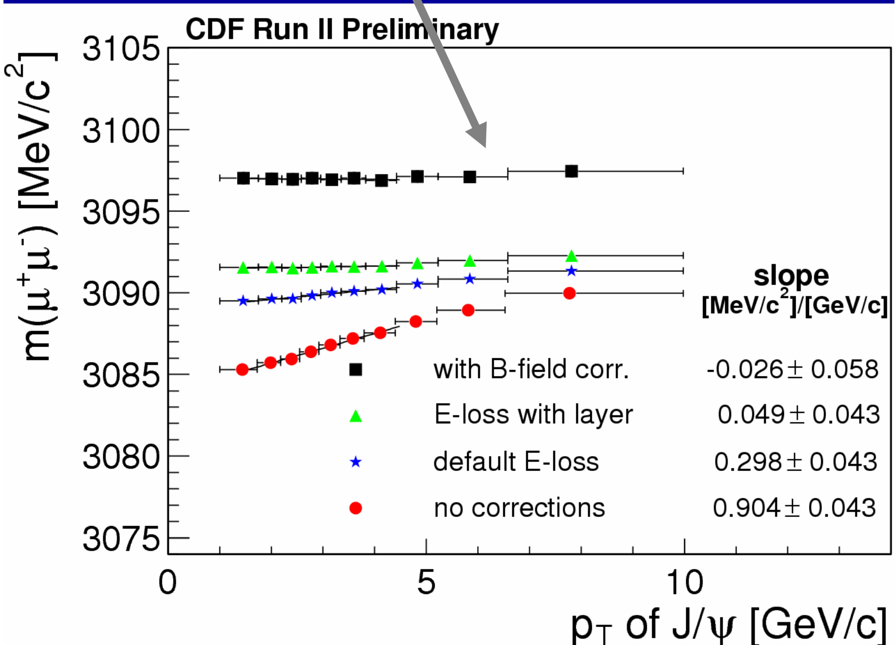


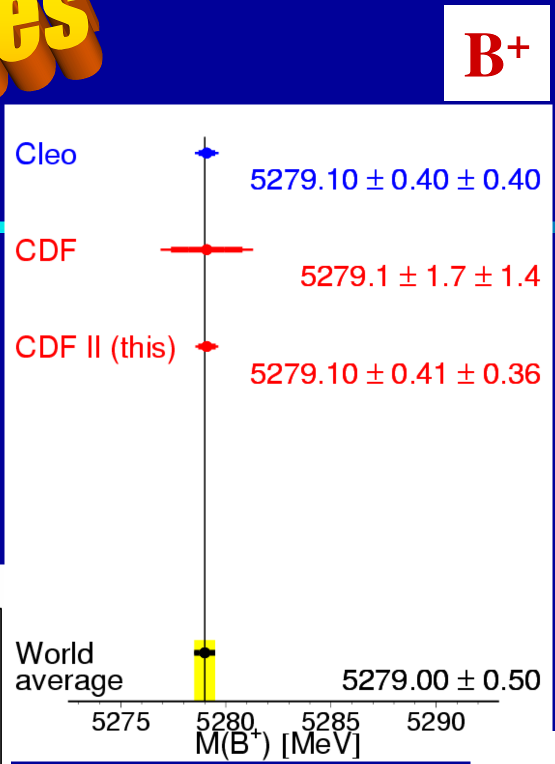
B_s meson

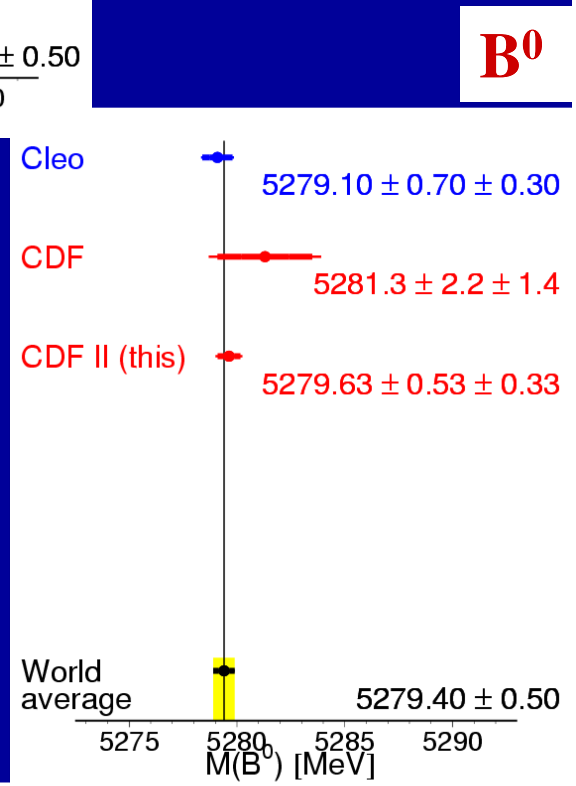
B_s meson

B hadron masses

- B mass determination
  - Use clean J/ψK modes
  - Accurate tuning of momentum scale with large J/ψ sample



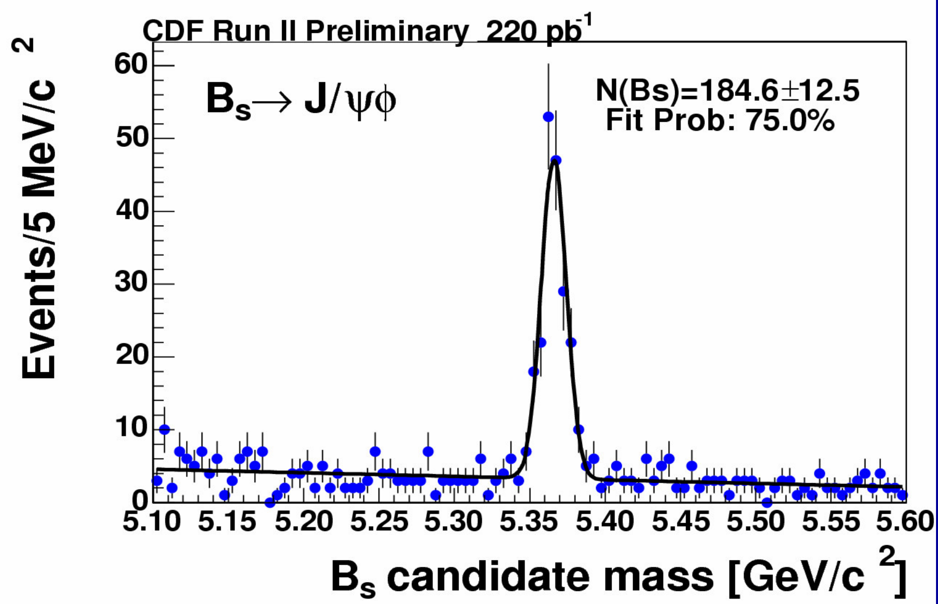




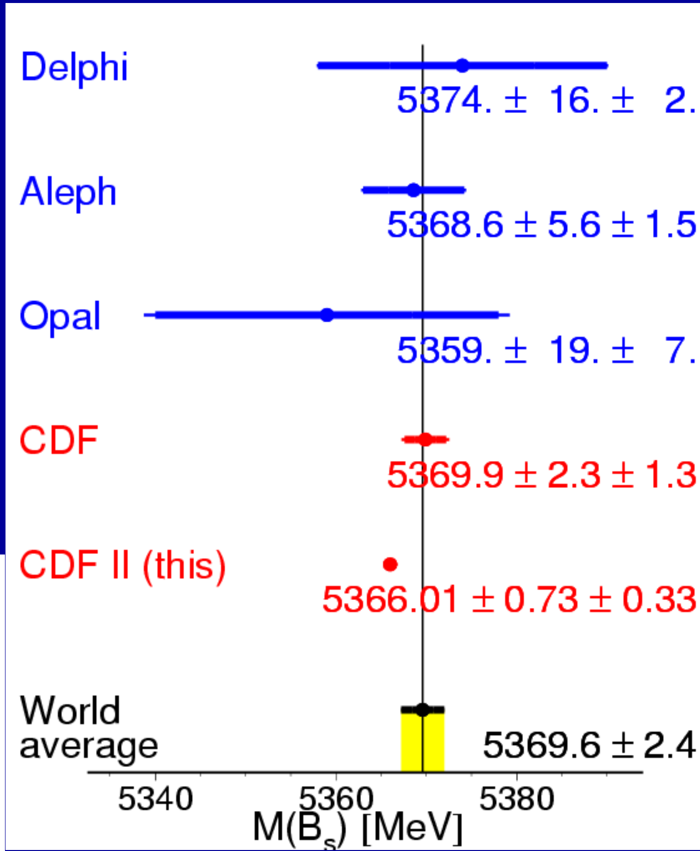
Systematics below 1 MeV for high statistics channels

Best single measurements of *b*-hadron masses

B_s mass



B_s mass



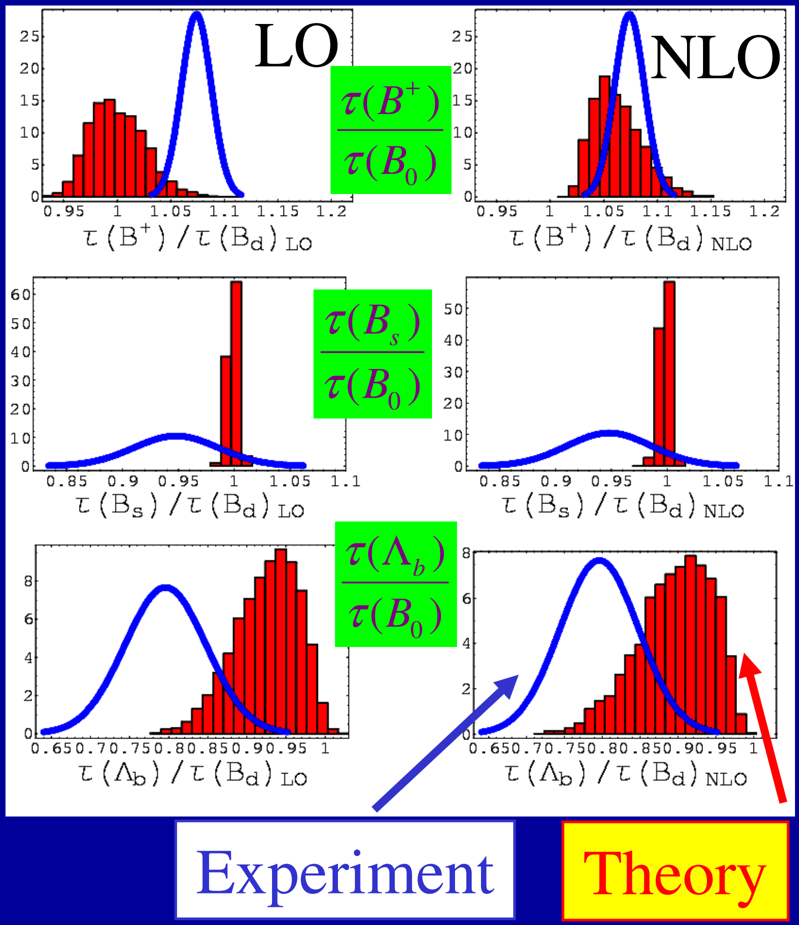
Source	$B^0 \to J/\psi K^{*0}$	$B^\pm \to J/\psi K^\pm$	$B^0_s \to J/\psi\phi$
Tracking & Corrections			
momentum scale	0.20	0.22	0.20
Tracking	0.18	from B^0	from B^0
False Curvature	0.02	from B^+	from B^+
Fitting	0.10	from B^0	from B^0
Resolution bias	0.13	0.13	0.13
Fit Systematics			
K^{*0}'s with K-π Swapped	0.06	—	—
$J/\psi\pi$ contamination	—	0.13	—
Total Systematic Uncertainty	0.33	0.36	0.33

MeV

B hadron lifetimes

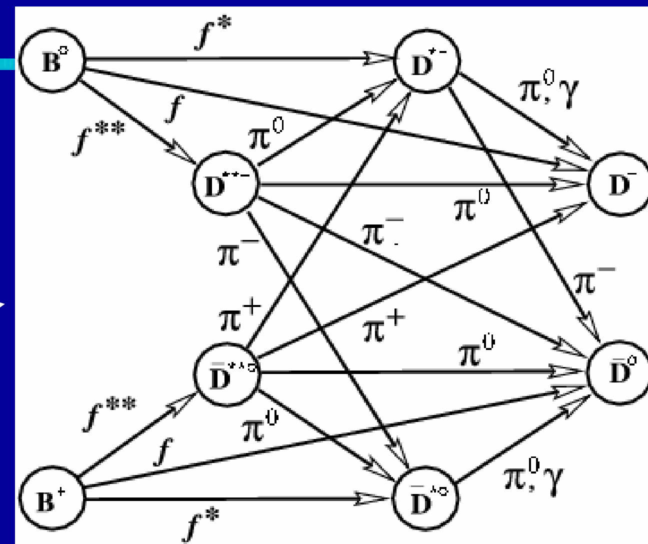
- B hadron lifetimes provide understanding of detector, trigger, analysis biases
- B hadron decays dominated by b-quark decay
  - Effect of spectator quarks can be included with perturbative expansions in terms of $1/m_b$ (HQET)
    - Expect small differences between lifetimes of different species
    - 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 with B→lνDX modes

- Highest statistics samples
  - Difficult systematics:
    - Sample composition for B^+, B^0
      - Cross talk from D**, D*
    - Backgrounds:
      - Combinatorial
      - Physical: $B \to D^{(*)}D^{(*)}$
      - Prompt: c-cbar, b-bbar, D+fake

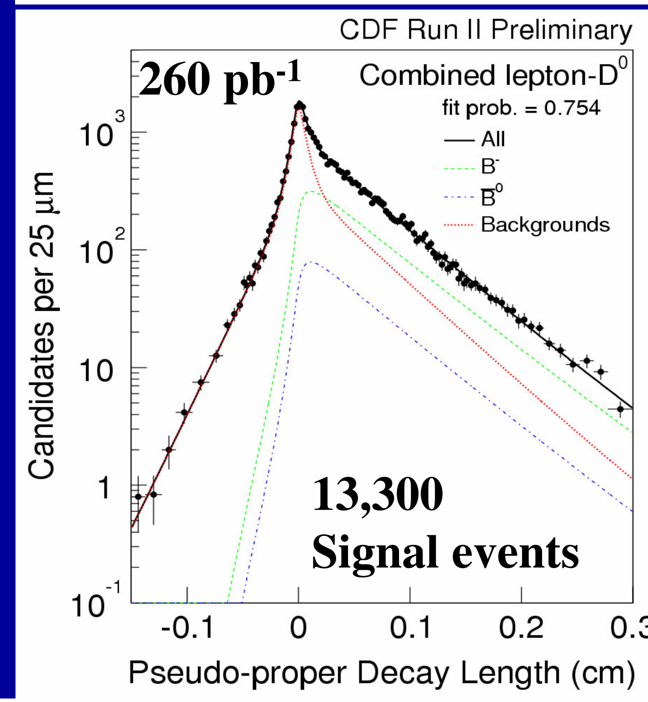


- Recent result from CDF with low statistics lepton pt > 8 GeV sample

$\tau(B^+)$ = **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



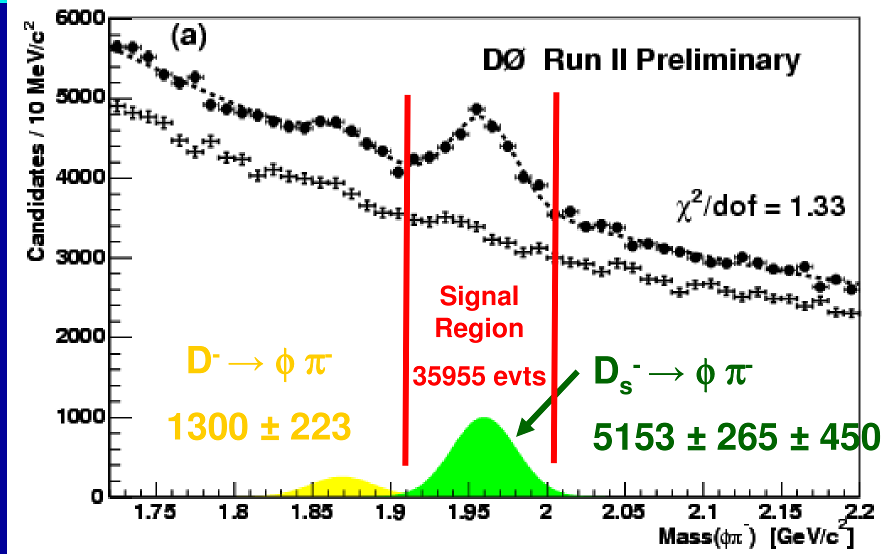
Lifetimes with $B_s \longrightarrow l\nu D_s X$ modes

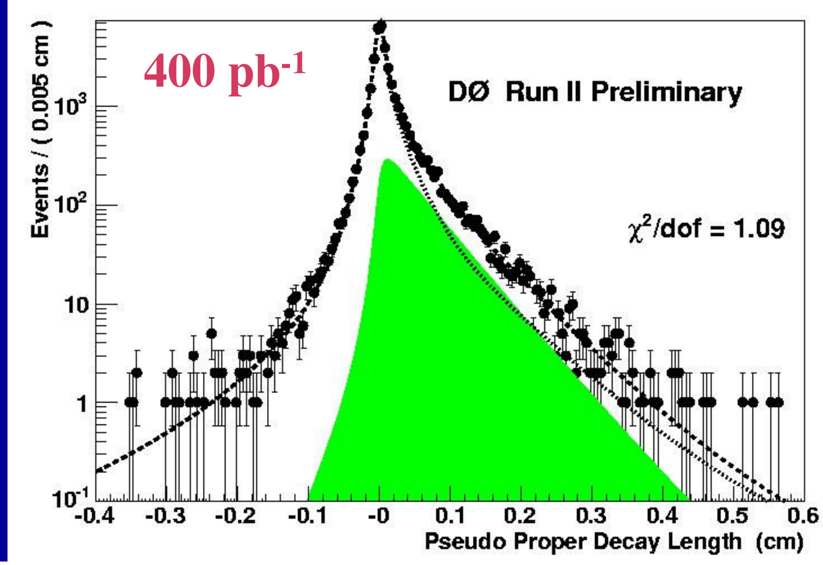
- First high statistics B_s lifetime measurement from D0
  - Use $D_s^- \rightarrow \phi\pi^-$ decay
  - Difficult background systematics:
    - Combinatorial
    - Physical: $B \rightarrow D^{(*)}D^{(*)}$
    - Prompt: c-cbar, b-bbar, D+fake
  - Currently best measurement

$\tau(Bs) = \mathbf{1.420 \pm 0.043 \pm 0.057}$ **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



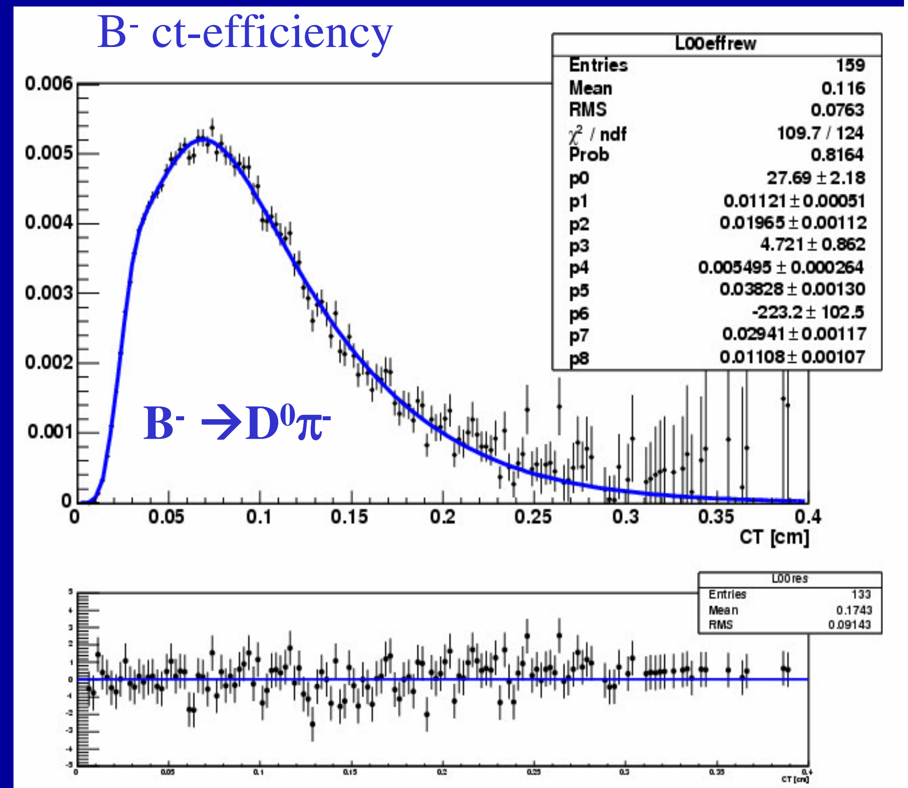


Lifetime with hadronic decays

- 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: $D^\pm\pi^\mp$ [7957 ev.] ($D^\pm \rightarrow K\pi\pi$)

    $D^\pm 3\pi$ [4173 ev.] ($D^\pm \rightarrow K\pi\pi$)
  - Bs: Ds $\pi^\pm$ [472 ev.] ($Ds \rightarrow \phi\pi$)

    Ds 3π [133 ev.] ($Ds \rightarrow \phi\pi$)
    - **Important for Δm_s measurement**



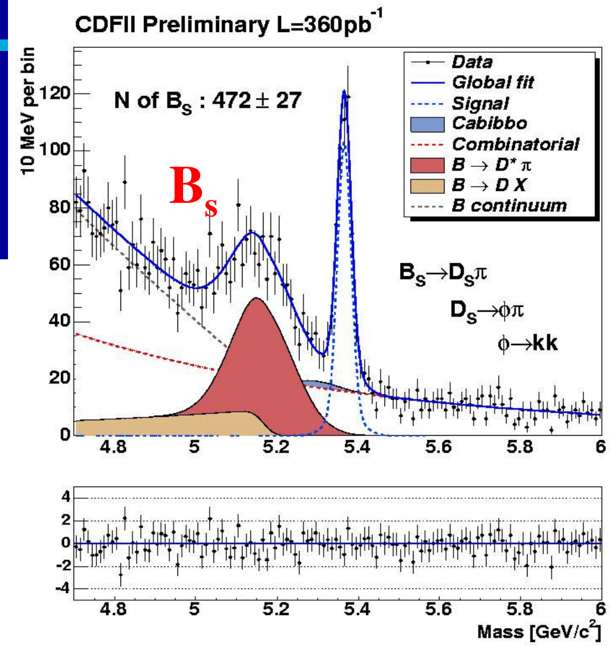
Lifetimes with hadronic decays

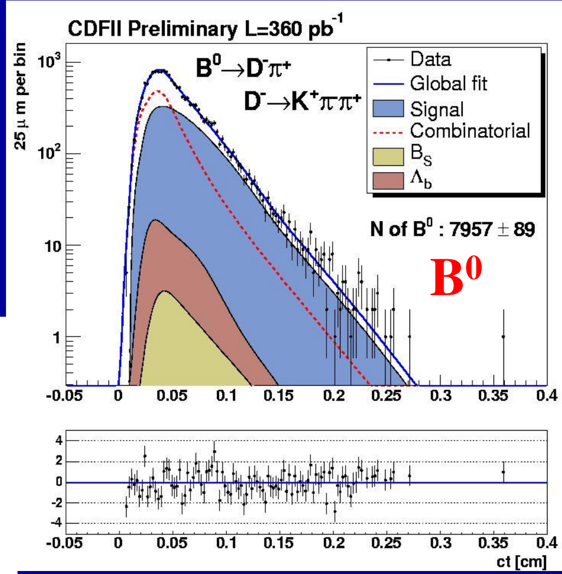
- More statistical power than J/ψ modes
  - Slightly larger systematics
    - Efficiency curve
    - backgrounds

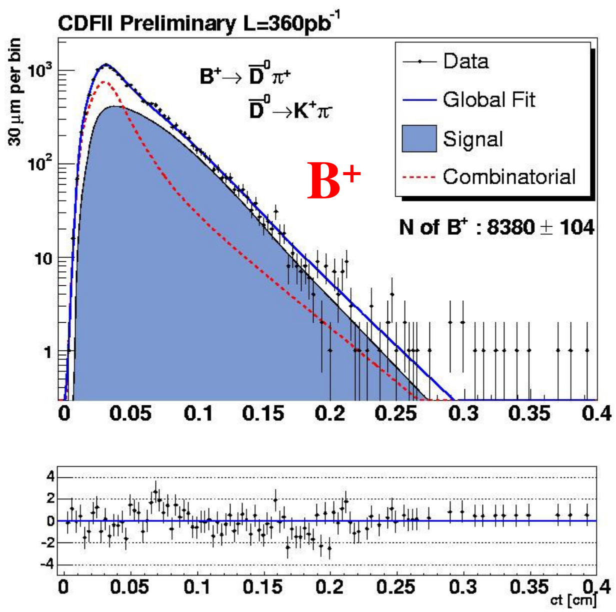
$\tau(B^+) = 1.66 \pm 0.03 \pm 0.01$ ps

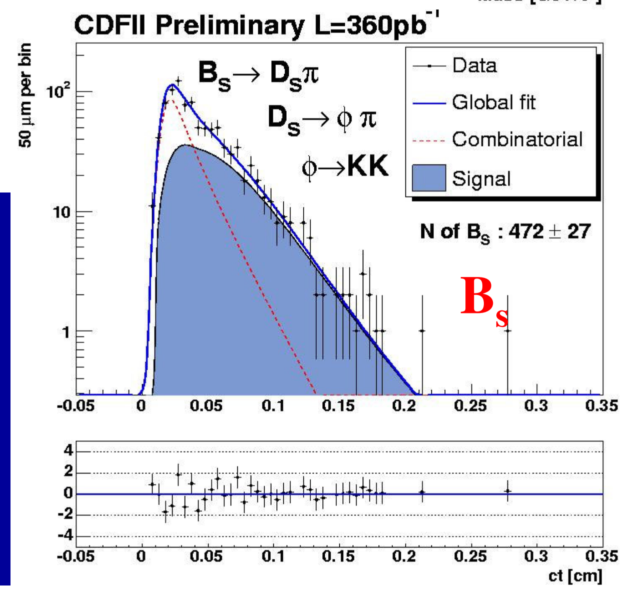
$\tau(B^0) = 1.51 \pm 0.02 \pm 0.01$ ps

$\tau(B_s) = 1.60 \pm 0.10 \pm 0.02$ ps









Lifetimes

- Several new results included in HFAG 2005 averages
  - B^0, B^+ dominated by BaBar/Belle
  - B_s: dominated by CDF/D0, LEP

hep-ex/0505100, May 2005

Lum. pb^{-1}	CDF ψ modes 240	CDF hadronic 360	CDF semi-leptonic (Hi pt) 260	D0 semi-leptonic (ψ) 400	HFAG 2005
B0	1.539±0.051±0.008	1.511±0.023±0.013	1.473±0.036±0.054		1.528 ± 0.009
B+	1.662±0.033±0.008	1.661±0.027±0.013	1.653±0.029±0.032		1.643 ± 0.010
B+/B0	1.08±0.042		1.123±0.040±0.040	1.08±0.016±0.014	1.076 ± 0.008
Bs	1.369±0.100±0.009	1.598±0.097±0.017		1.420±0.043±0.057	1.479 ± 0.044
Bs/B0	0.890±0.072				0.968 ± 0.029

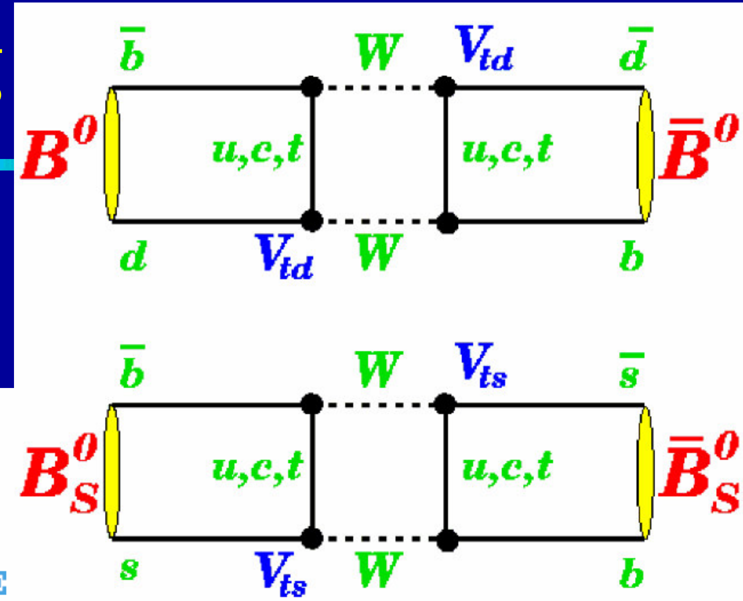
Red = Very recent!

Theory (*) (NLO): 1.00±0.01 (Bs/B0); 1.06±0.02 (B+/B0)

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

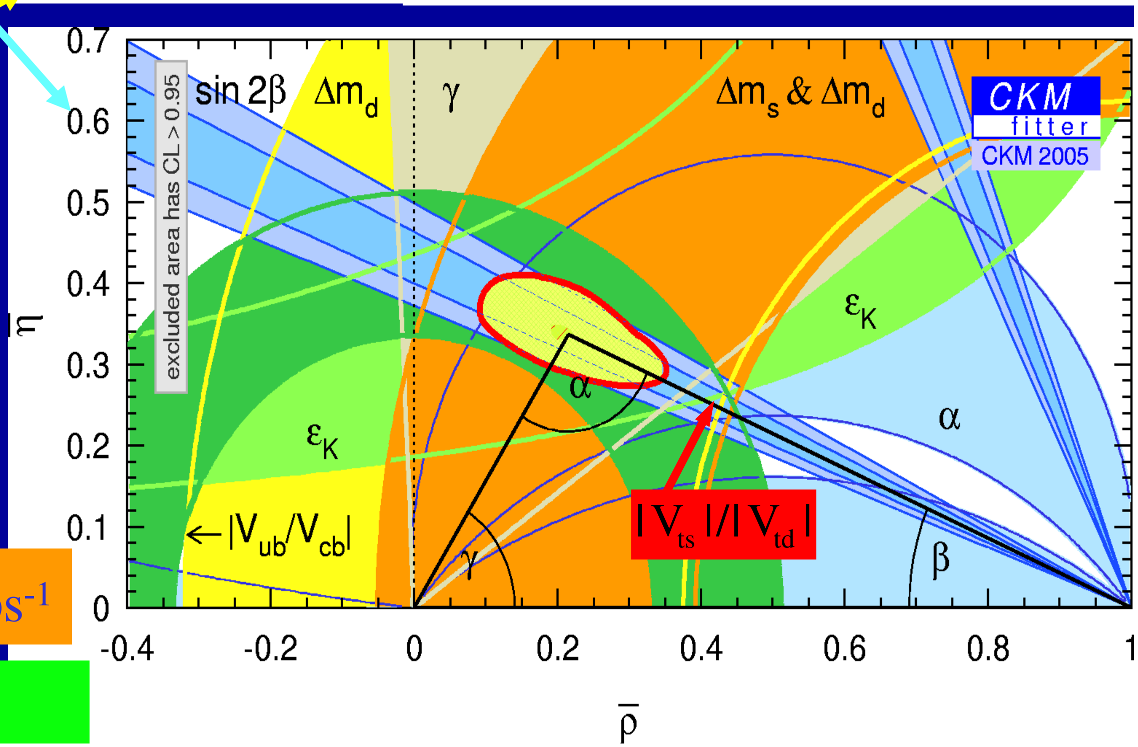
B mixing

- 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-I, CDF-II, D0-II, **BaBar, Belle**
  - Bs mixing not observed
    - Limits set by LEP, SLD, CDF-I



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

from LATTICE



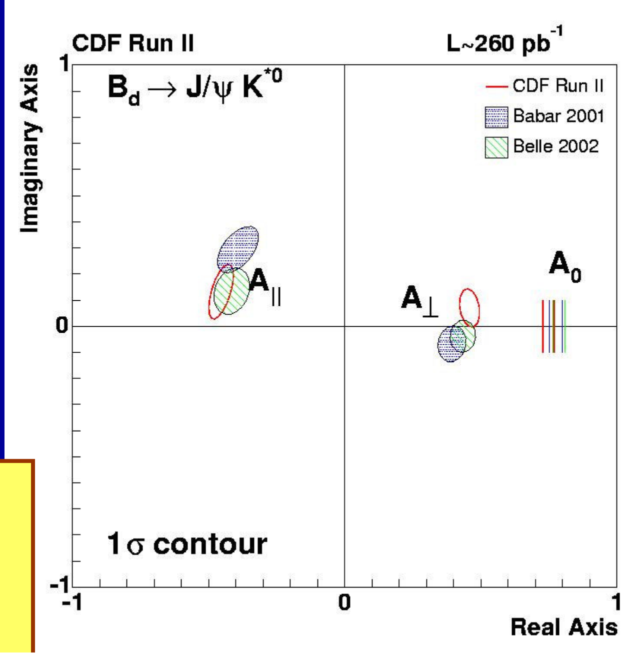
SM Fit (2004): $\Delta m_s = 18.3 \pm 1.6$ ps^{-1}

New physics may affect $\Delta m_s/\Delta m_d$

ΔΓs

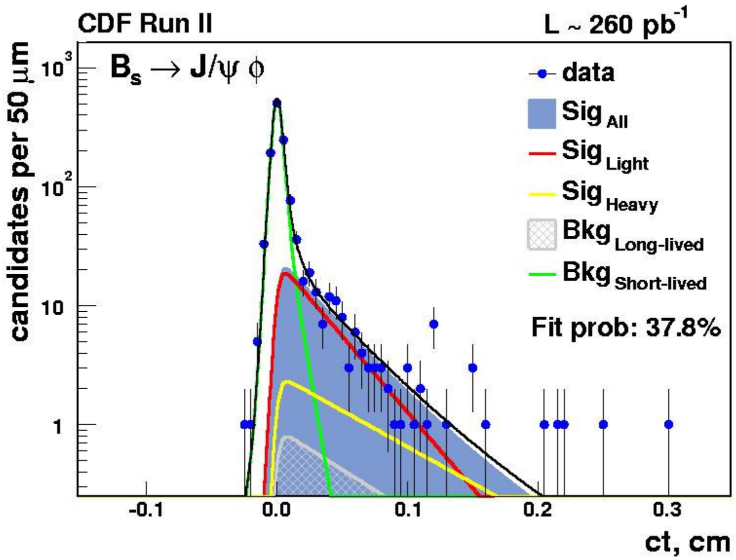
- In the Bs system CP violation is small:
  - $B_{s,light}$ = CP even (S, D waves)
  - $B_{s,heavy}$ = CP odd (P wave)
- Generally final states are mixture of CP even and odd states, but for Pseudoscalar ⟶ VV, we can disentagle them.
- Time-dependent angular analysis for $B^0 \to J/\psi K^{*0}$ and $B_s \to J/\psi\phi$ together with lifetime meas. can separate heavy and light mass eigenstates.
- Determine $\Delta\Gamma_s \to \Delta m_s$

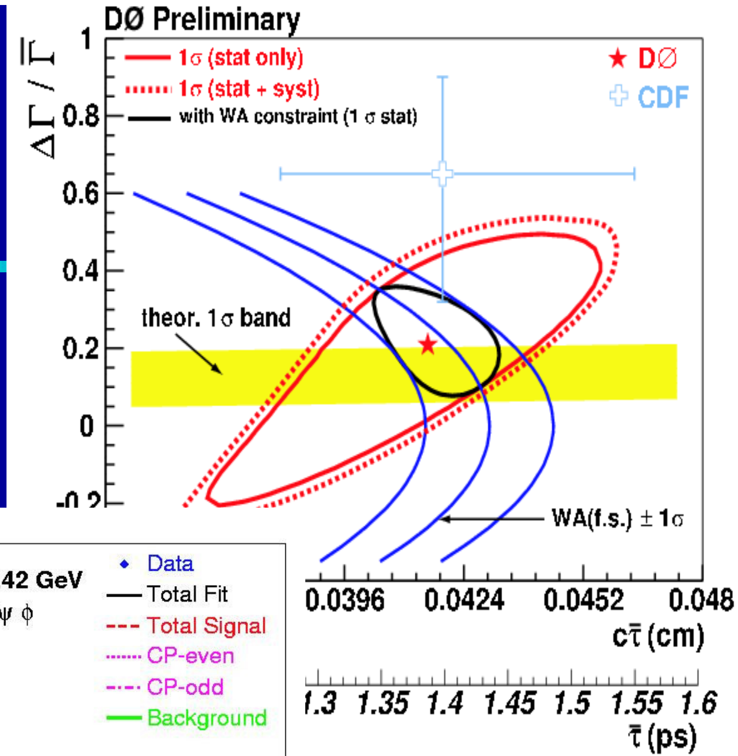
$$\frac{\Delta m_s}{\Delta\Gamma_s} \approx \frac{2}{3\pi}\cdot\frac{m_t^2}{m_b^2}\cdot\left(1-\frac{8}{3}\frac{m_c^2}{m_b^2}\right)^{-1} h\left(\frac{m_t^2}{M_W^2}\right)$$



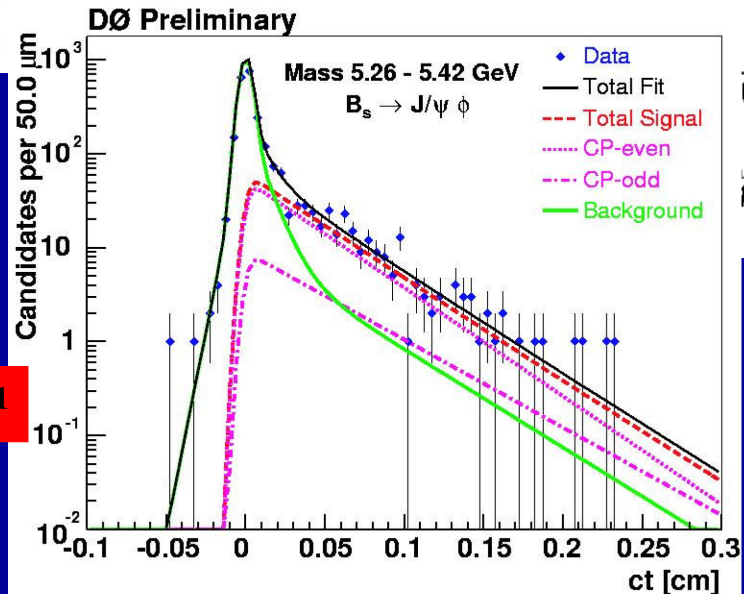
The B^0 decay amplitudes (3 linear polarizations) are of comparable precision and compatible with the measurements of BaBar and Belle

ΔΓs





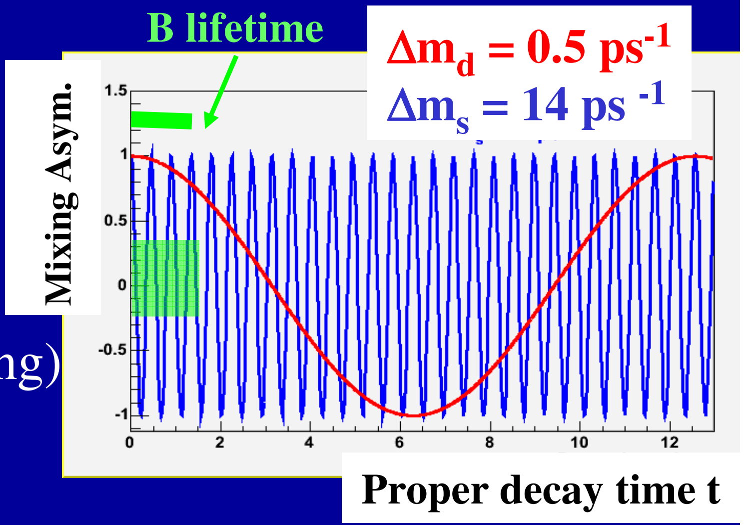
450 pb^{-1}



Experiment	$\Delta\Gamma_s/\Gamma_s$	<τ> ps	τ_L ps	τ_H ps
CDF	$0.65^{+0.25}_{-0.33}$	$1.40^{+0.15}_{-0.13}$	$1.05^{+0.16}_{-0.13}$	$2.07^{+0.58}_{-0.46}$
D0	$0.21^{+0.33}_{-0.45}$	$1.39^{+0.15}_{-0.16}$	$1.23^{+0.16}_{-0.13}$	$1.52^{+0.39}_{-0.43}$

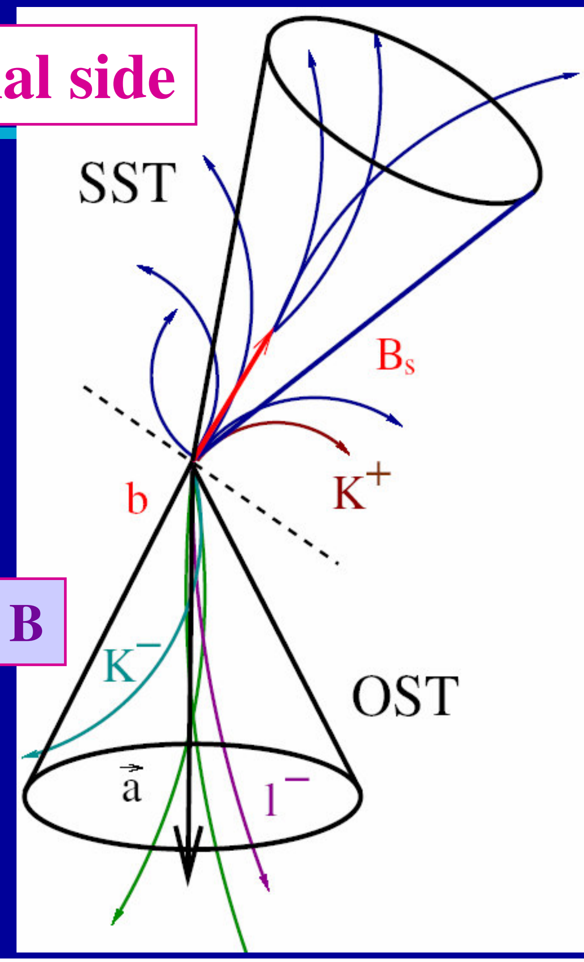
B mixing

- 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*η-1 (η = probability of correct tag)**

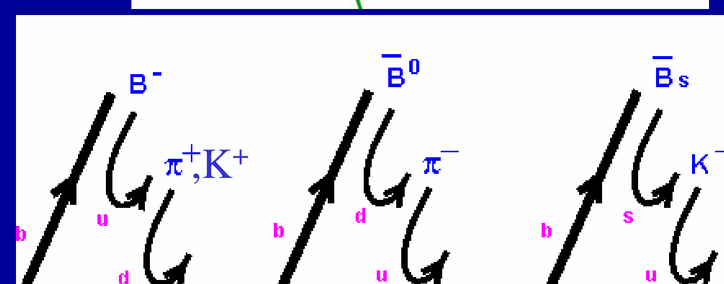


- Measure: $A(t) = (N_{nm}-N_m)/N = D\cos(\Delta m\, t)$
  - N_{nm} (N_m): number of B's with same (different) flavor at production and decay
  - Mixing measurement calibrates dilution
    - Impossible for B_s until oscillation observed

Flavor tagging



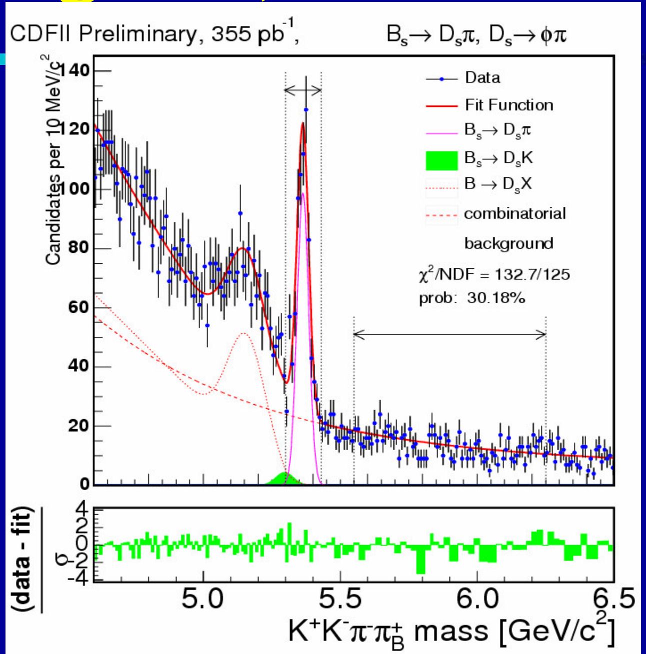
- Opposite side techniques (OST):
  - CDF: total εD^2 ~ 1.1 – 1.4 %
    - Soft Muon Tag
    - Soft Electron Tag
    - Jet Charge Tag
  - D0: εD^2 ~ 1.1%
    - Enhanced muon tag εD^2 ~ 1.1%
      - Add-in correlations with associated jet in likelihood
- Same side techniques (SST):
  - Sign of nearby track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

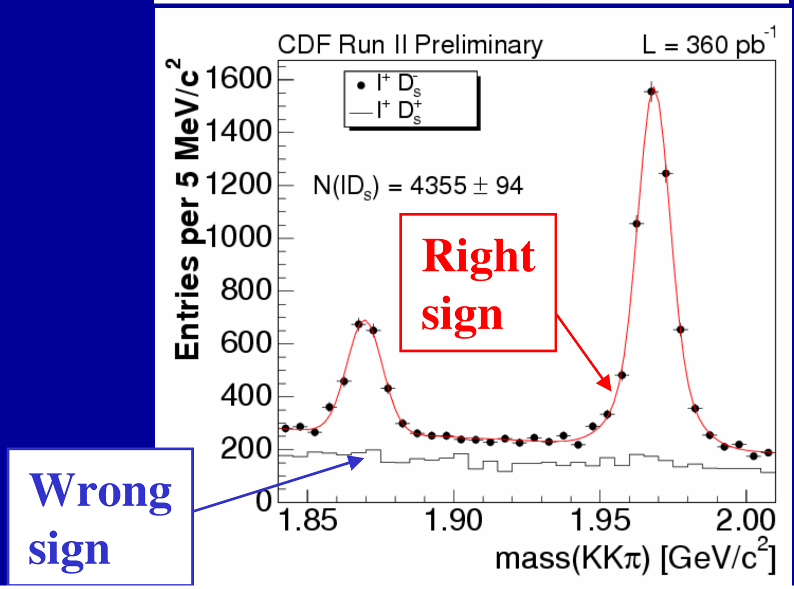


CDF: Bs mixing (signals)

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

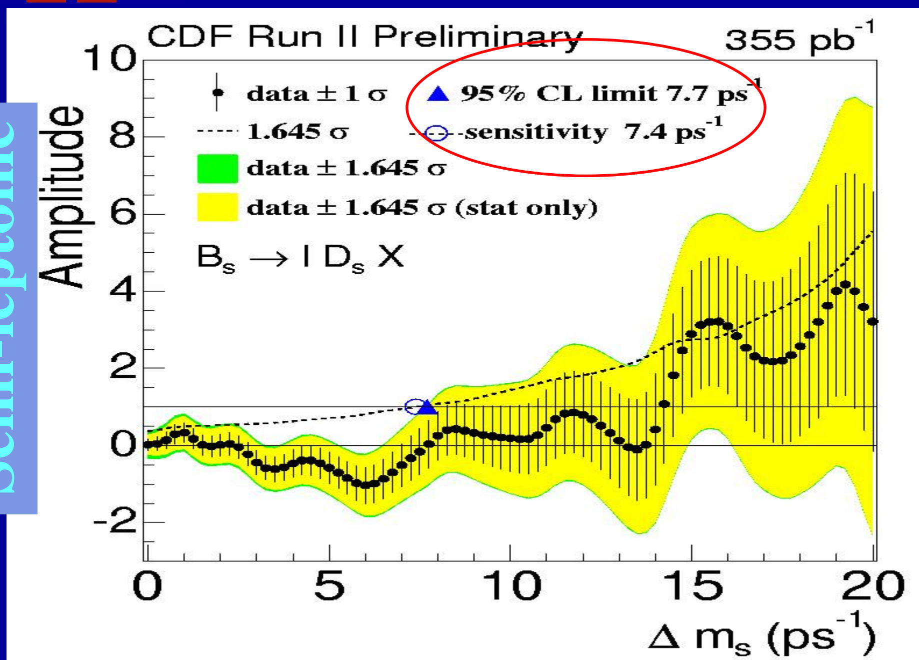
Channel	Yield	S/B
Bs→Dsπ (Ds→ϕπ)	526±33	1.80
Bs→Dsπ (Ds→K*K)	254±21	1.69
Bs→Dsπ (Ds→3π)	116±18	1.01
Bs→Dslν (Ds→ϕπ)	4355±94	3.12
Bs→Dslν (Ds→K*K)	1750±83	0.42
Bs→Dslν (Ds→3π)	1573±88	0.32



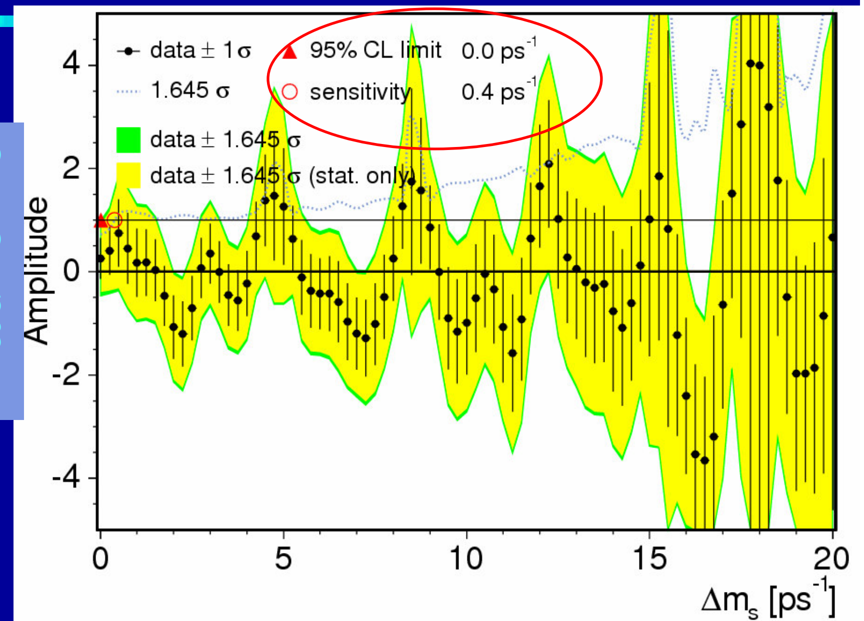


CDF: Bs Mixing

Semi-leptonic

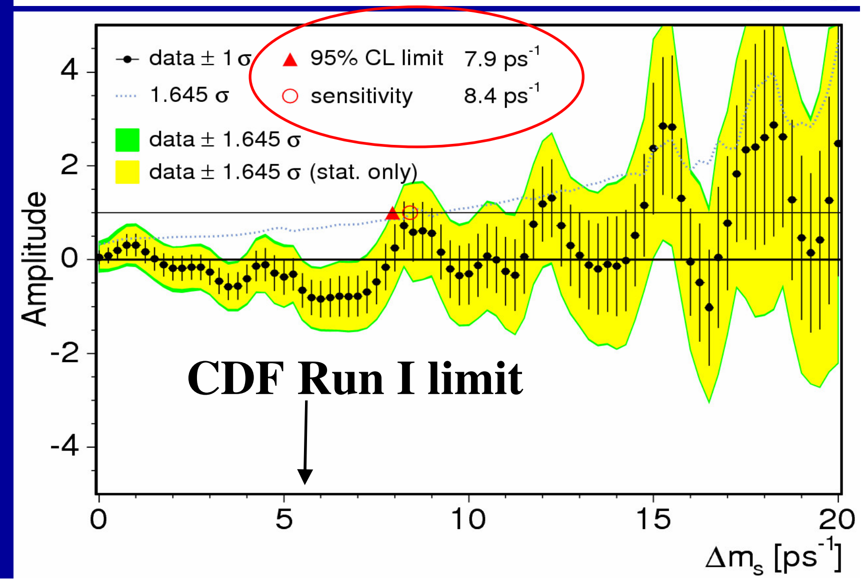


Hadronic

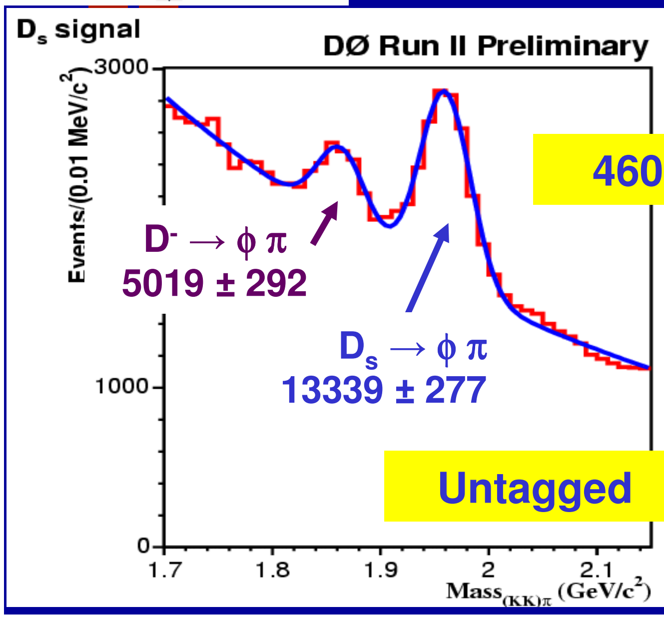


- Amplitude scans: all statistics dominated

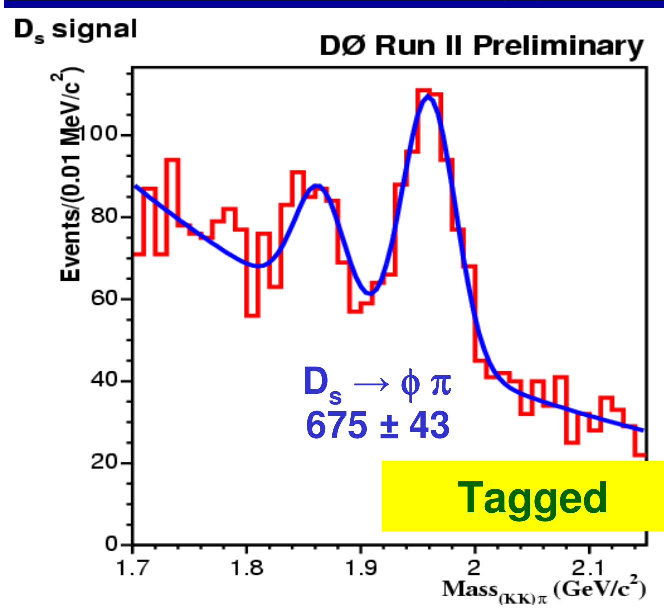
- Combined scan results:
  - 7.9 ps^{-1} 95% CL limit
  - Sensitivity: 8.4 ps^{-1}



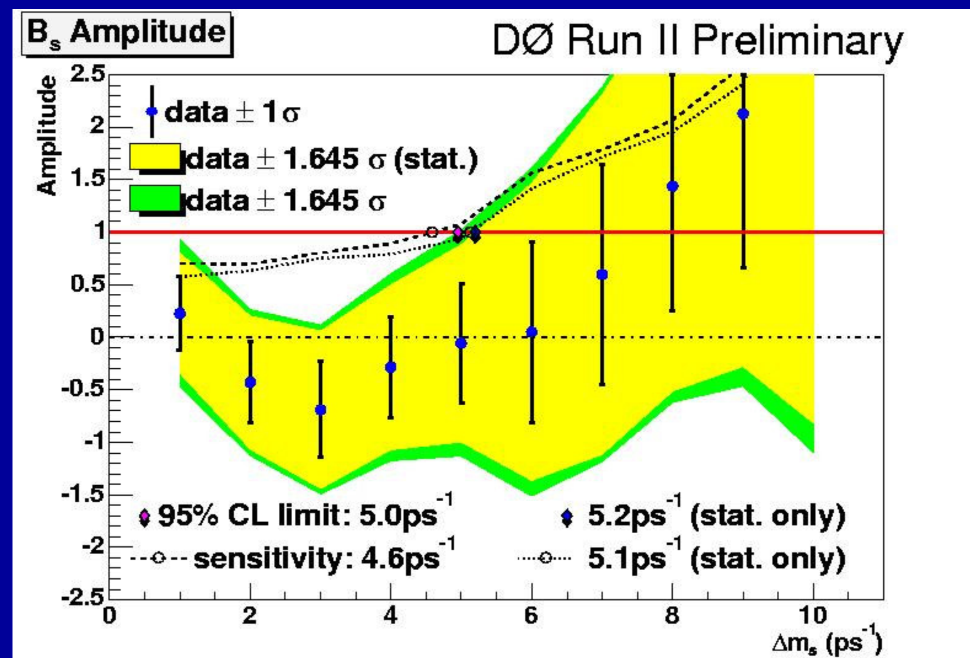
D0: Bs mixing



460 pb^{-1}

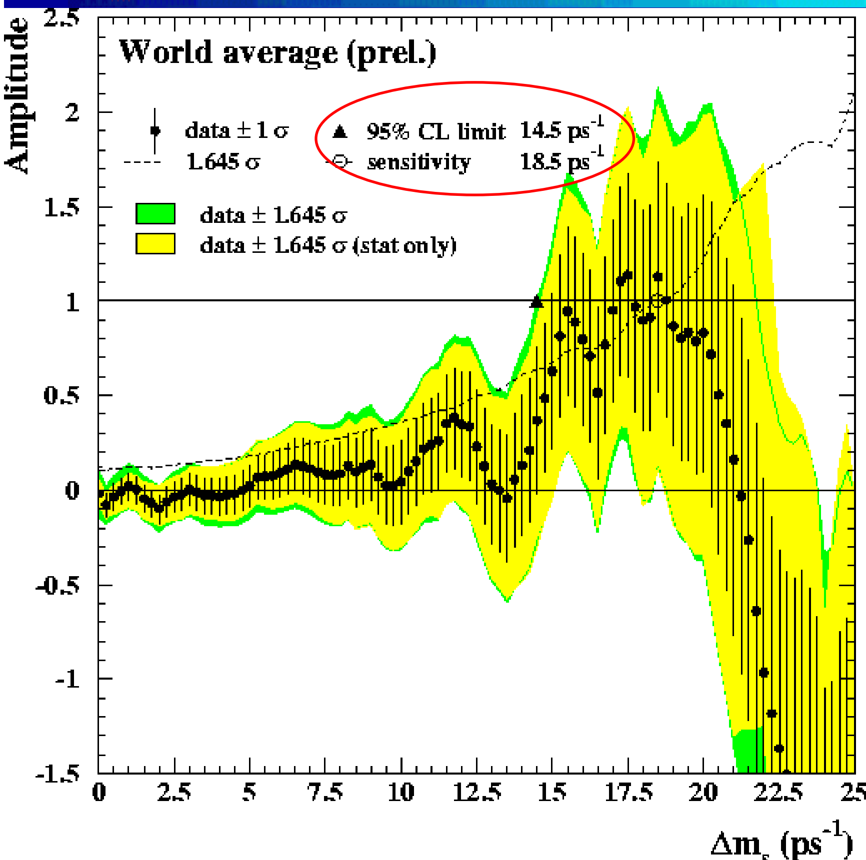


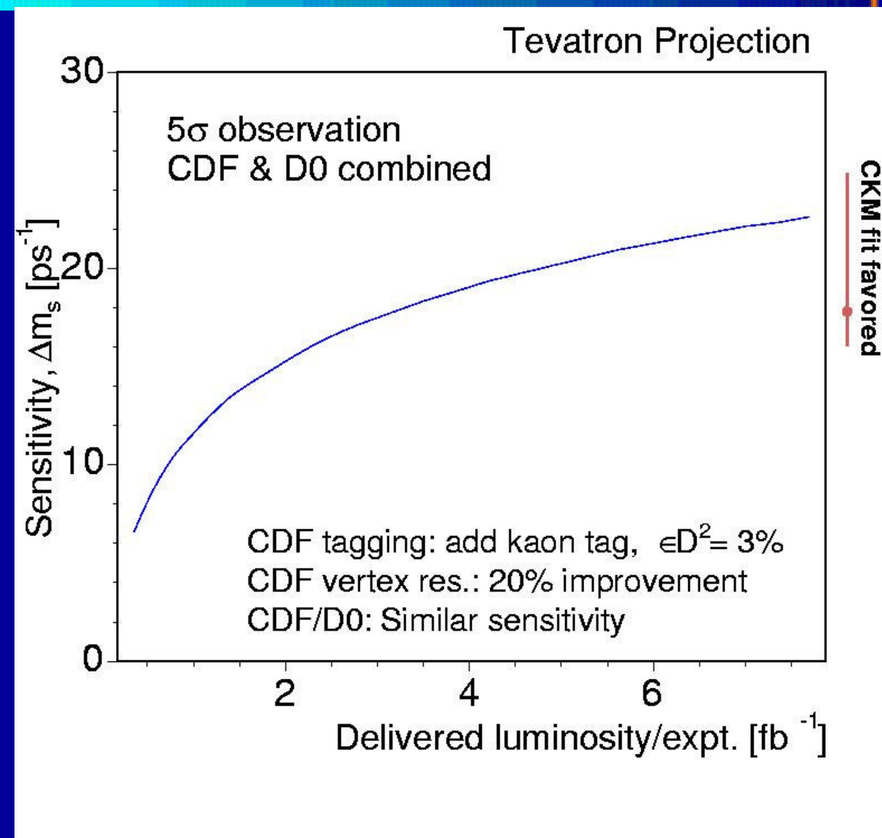
- Semi-leptonic analysis: $B_s \to D_s \mu\nu$



- Amplitude scan results:
  - 5.0 ps^{-1} 95% CL limit
  - Sensitivity: 4.6 ps^{-1}

Mixing Status and Prospects

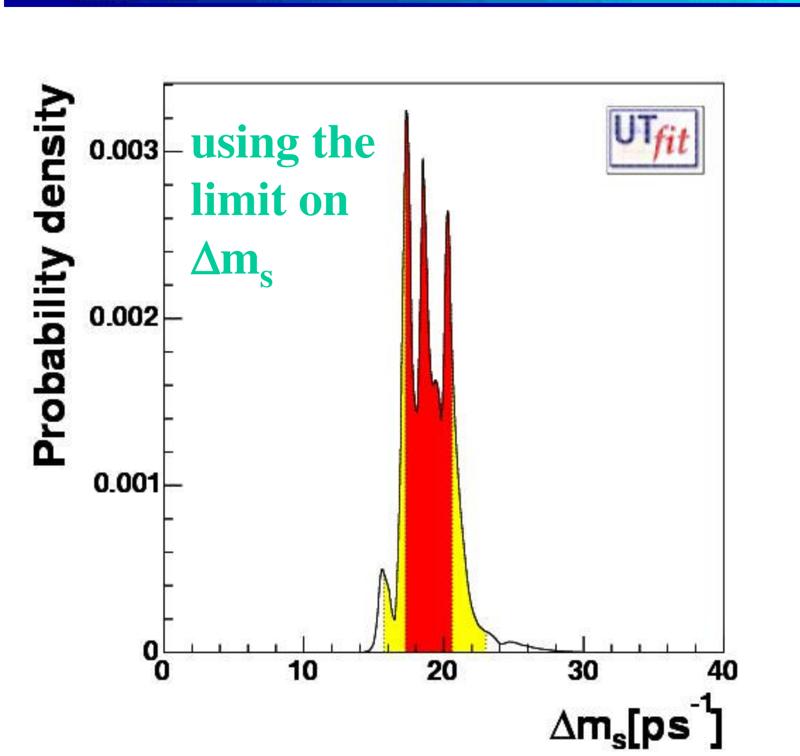




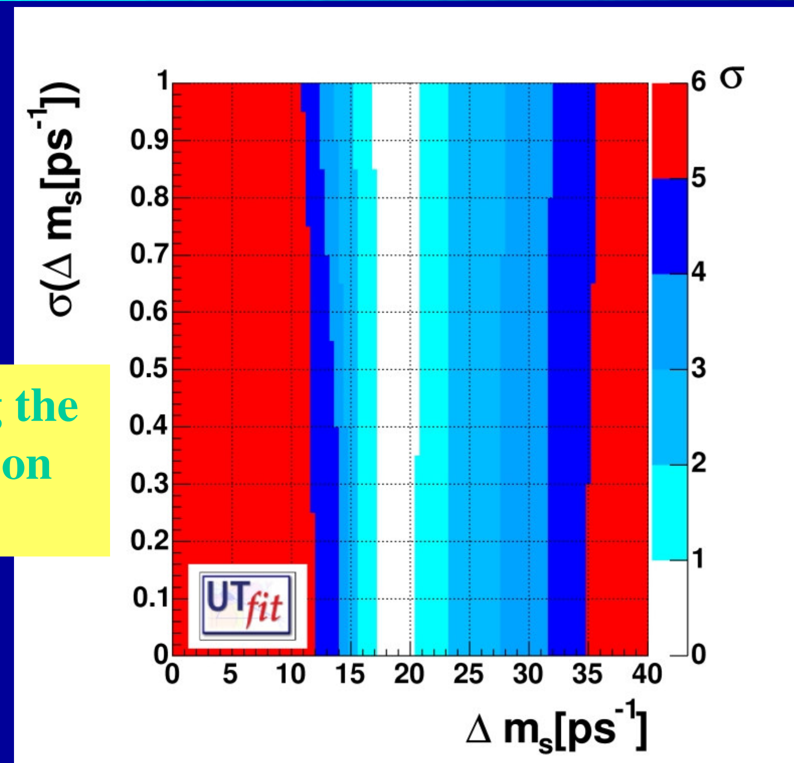
- Effect on World Average:
  - Limit: 14.5 → 14.5 ps^{-1}
  - Sensitivity: 18.2 → 18.5 ps^{-1}

- 5σ observation:
  - L = 2 fb^{-1}: Δm_s < 15 ps^{-1}
  - L = 8 fb^{-1}: Δm_s < 22 ps^{-1}

Mixing Status and Prospects



using the limit on Δm_s

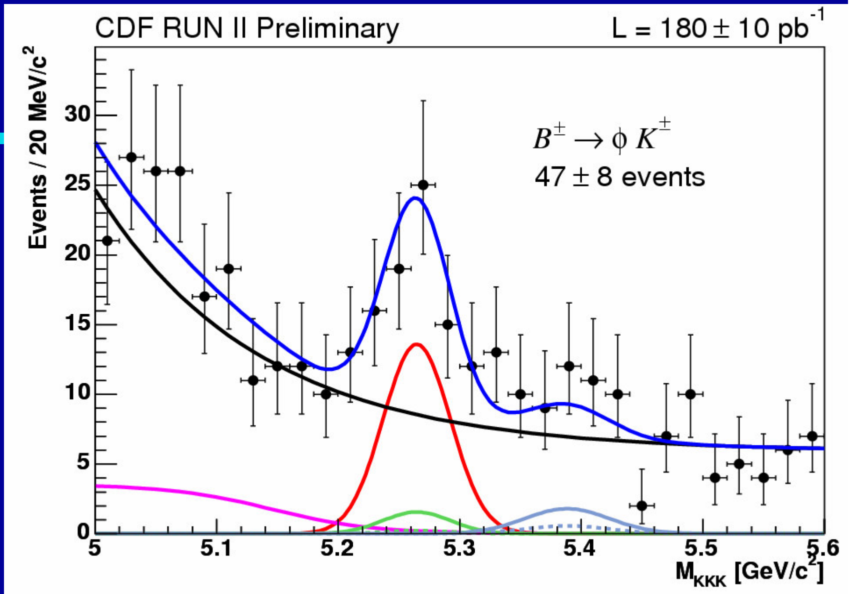


CKM fit: $\Delta m_s = 18.9 \pm 1.7\ ps^{-1}$ [15.7, 23.0] @ 95% C.L.

- New physics:
  - 3σ if: $\Delta m_s > 28\ ps^{-1}$ (**31** ps^{-1})
  - 5σ if: $\Delta m_s > 35\ ps^{-1}$ (**38** ps^{-1})

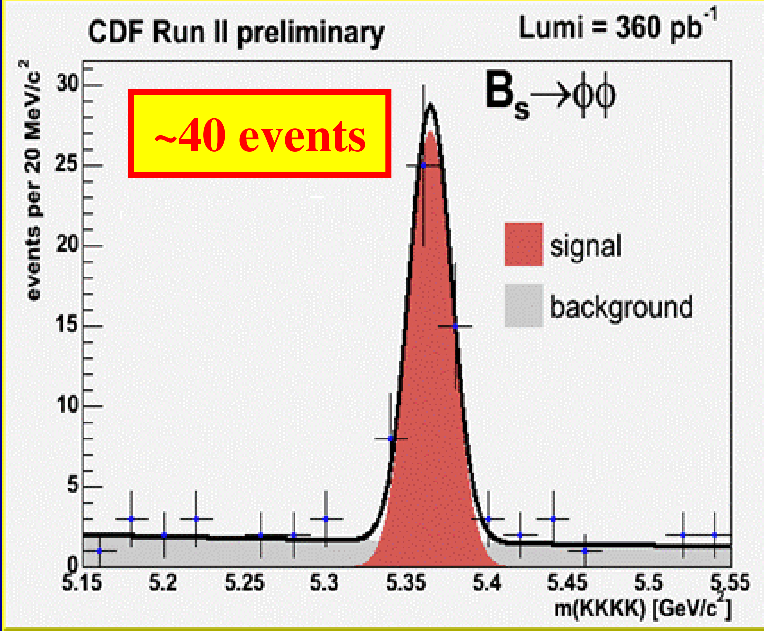
B → φh

- CDF: B⁺→ φK⁺
  - $A_{CP} = -0.07 \pm 0.17\ ^{+0.03}_{-0.02}$
    (BaBar: 0.054 ± 0.056 ± 0.012)
  - $BR(B^+ \to \phi K^+) = (7.6 \pm 1.3\ ^{+0.65}_{-0.63}) \times 10^{-6}$
    HFAG05: $(9.0 \pm 0.6) \times 10^{-6}$



- CDF: Bs→ φφ
  - $BR(B_s \to \phi\phi) = (1.4^{+0.6}_{-0.5} \pm 0.6) \times 10^{-5}$
    QCD fact. 3.68×10^{-5}
    NF fact. 1.79×10^{-5}

First observation!

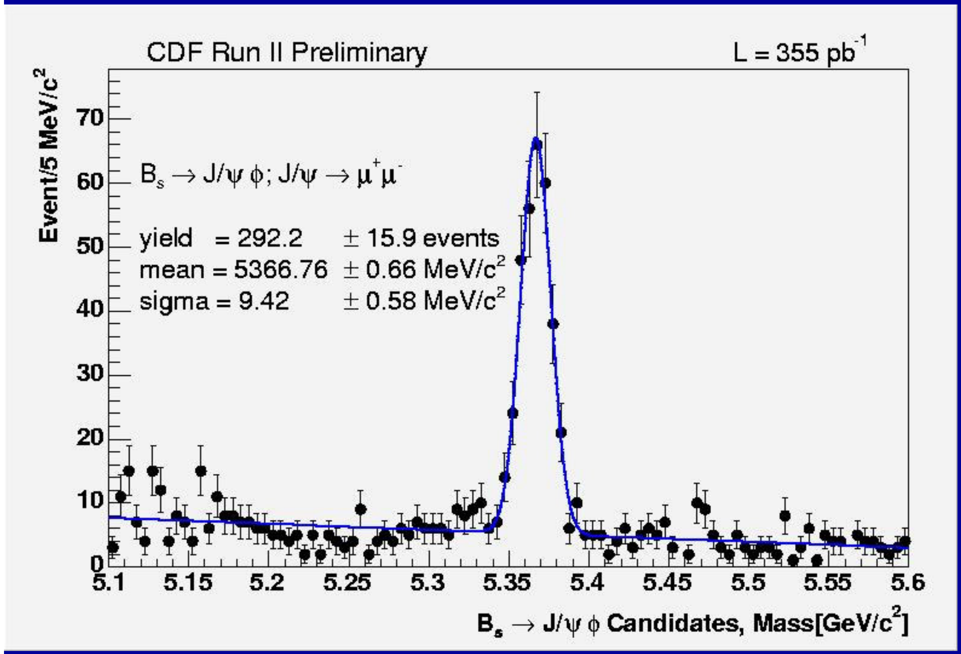


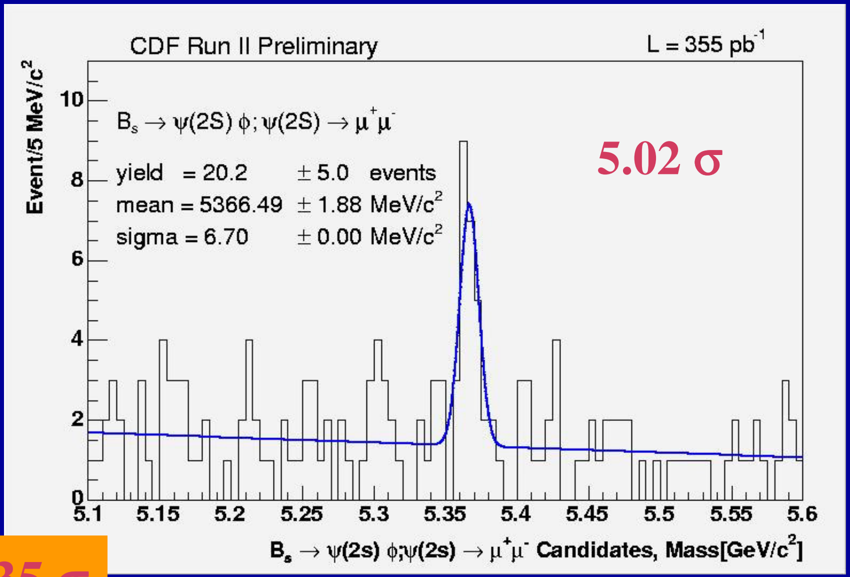
$B_s \to \psi(2S)\phi$

Run II, 355 pb^{-1}

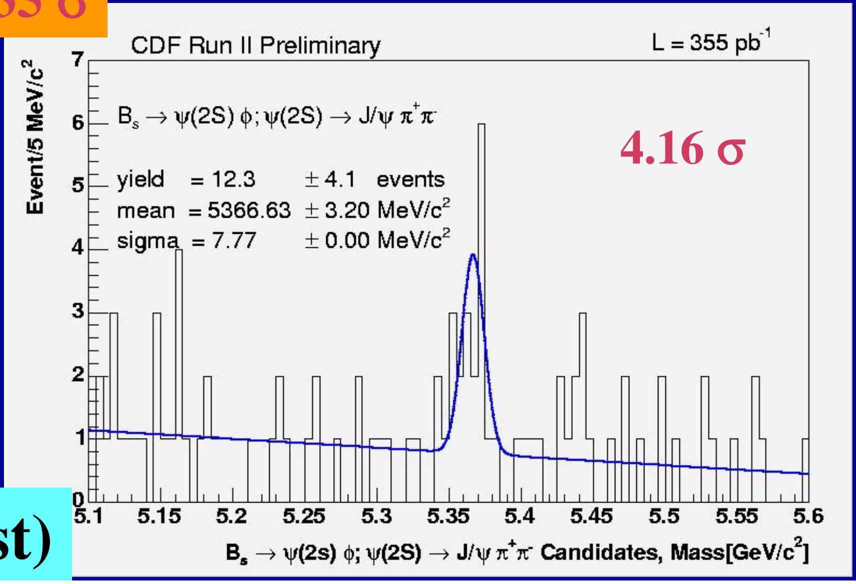
$B_s \to J/\psi\varphi$; $J/\psi \to \mu\mu$

used as a control sample and for normalization





6.35 σ



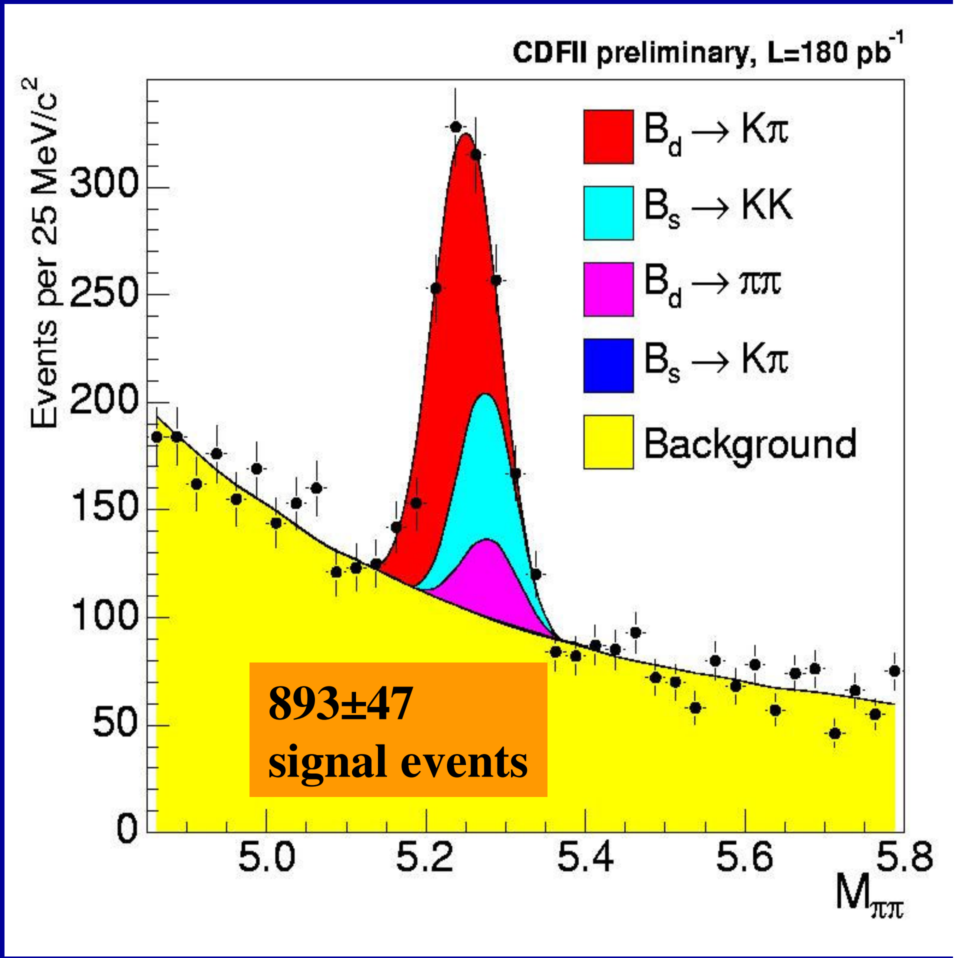
$$\frac{BR(B_s \to \psi(2S)\varphi)}{BR(B_s \to J/\psi\varphi)} =$$

0.52 ± 0.13(stat) ± 0.06(BR) ± 0.04(syst)

$B \longrightarrow h^+h^-$

- Exploit the two-track trigger sample.
- Combine mass, kinematics and PID in an unbinned maximum likelihood fit to extract the fraction of each of the expected components.
- P_T(track) > 2 GeV/c; K/π separation of 1.4σ.

  1.4σ ⟶ 1.6σ by including TOF information.



$B_s \longrightarrow h^+h^-$

B⁰ sector

$$\frac{BR(B^0 \to \pi^+\pi^-)}{BR(B^0 \to K^+\pi^-)} = 0.21 \pm 0.05(stat.) \pm 0.03(syst.)$$

HFAG Win05 : 0.247 ± 0.024

$$A_{CP}(B_d \to K\pi) = -0.022 \pm 0.078(stat.) \pm 0.012(syst.)$$

HFAG Win05 : -0.109 ± 0.019

B_s sector

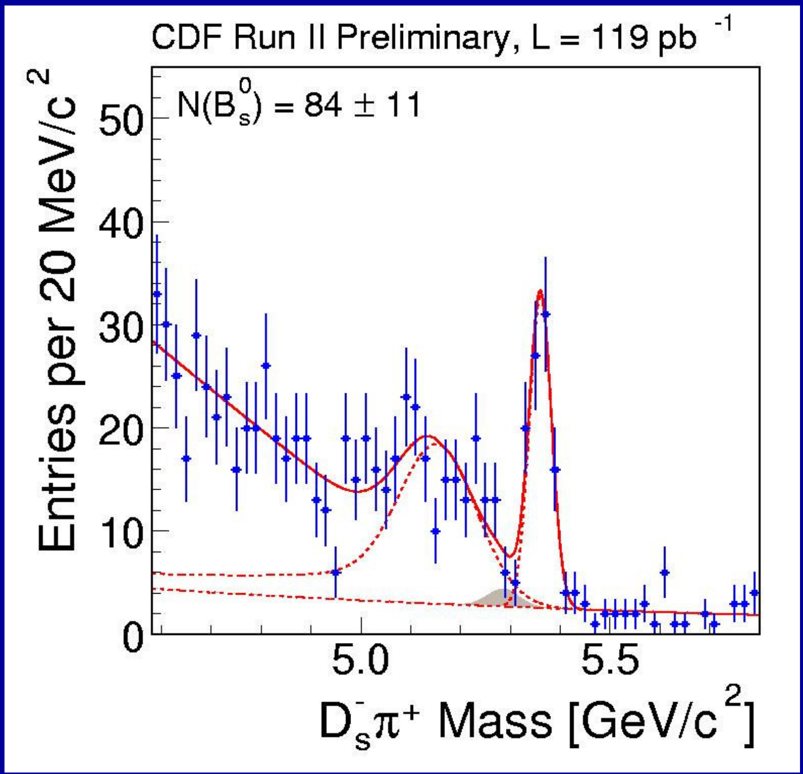
$$\frac{f_s \cdot BR(B_s^0 \to K^+K^-)}{f_d \cdot BR(B^0 \to K^+\pi^-)} = 0.46 \pm 0.08(stat.) \pm 0.07(syst.)$$

$$\frac{f_s \cdot BR(B_s^0 \to K^-\pi^+)}{f_d \cdot BR(B^0 \to K^+\pi^-)} < 0.08 \ @\ 90\% \ C.L.$$

To follow:

- Measure CP asymmetry in the B_s system
- Observe $BR(B_s \longrightarrow K\pi)$

$B_s \rightarrow D_s\pi$ and $B_s \rightarrow D_{s1}(2536)\mu\nu X$



$$D_s^- \rightarrow \varphi\pi^- ; \varphi \rightarrow KK$$

$$\frac{f_s \cdot BR(B_s \rightarrow D_s^- \pi^+)}{f_d \cdot BR(B^0 \rightarrow D^- \pi^+)} = 0.35 \pm 0.05\,(\text{stat.}) \pm 0.04\,(\text{syst.}) \pm 0.09\,(BR)$$

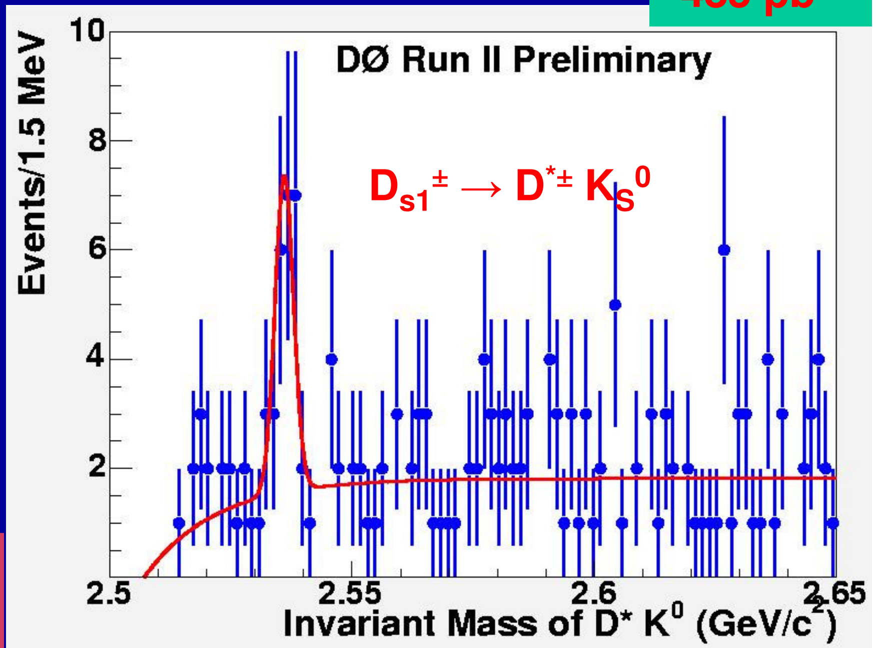
Evidence for:

$$B_s \rightarrow D_{s1}^{\pm}(2536)\mu^{\mp}\nu X$$

$$D_{s1}^{\pm}(2536) \rightarrow D^{*\pm}K_s^0 \quad D^{*\pm} \rightarrow D^0\pi^{\pm}$$

$$D^0 \rightarrow K^-\pi^+ \quad K_s^0 \rightarrow \pi^+\pi^-$$

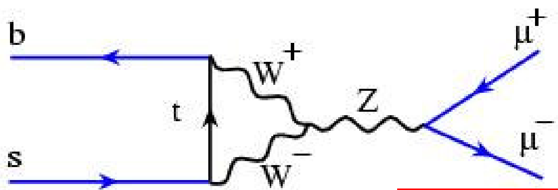
485 pb^{-1}



Signal: 18.5 ± 5.5 (3.4σ)

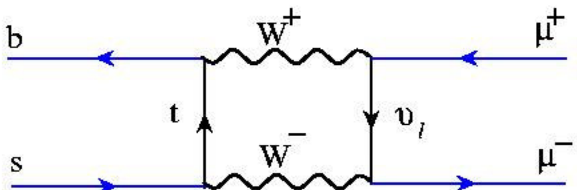
$B_{s(d)} \rightarrow \mu\mu$

Sensitive probe of New Physics

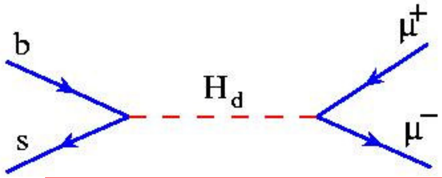


SM penguin

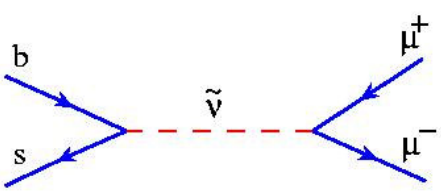
BR prediction: (3.5±0.9) x 10^{-9}



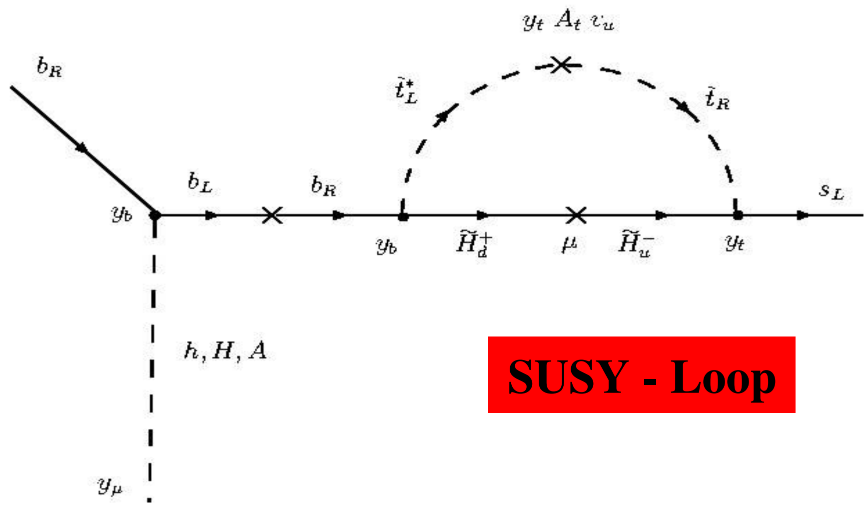
SM box



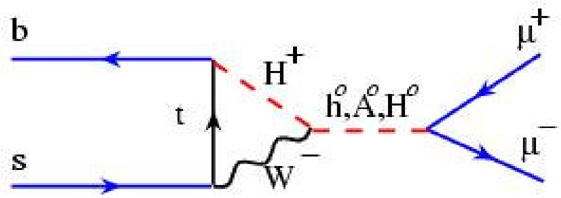
Higgs mediated - tree



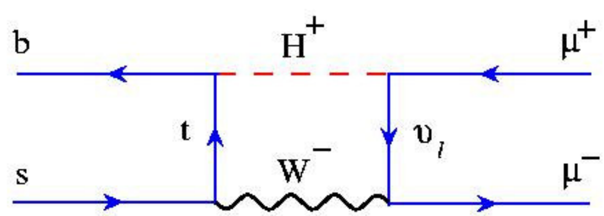
R parity violating



SUSY - Loop



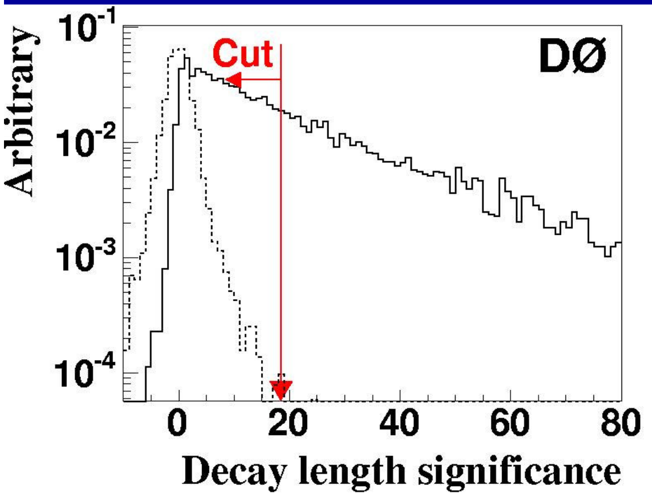
2HDM - penguin

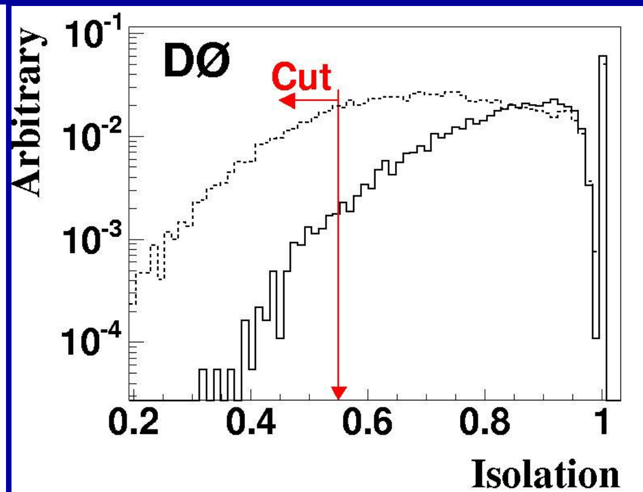


2HDM - box

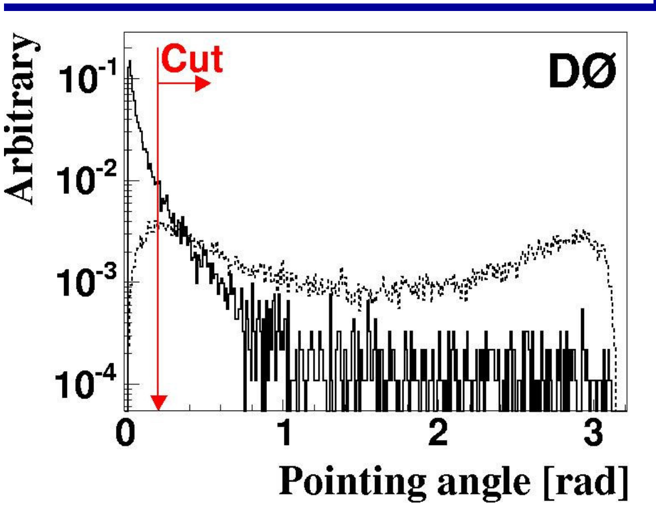
$B_s \rightarrow \mu\mu$

Run II, 240 pb^{-1}





- Optimization
  - Used simulated signal and data sidebands
  - Random grid search, optimizing for 95%



- Used 3 primary discriminating variables
  - $L_{xy}/\sigma(L_{xy}) > 18.5$; $\sigma(L_{xy}) < 0.15$ mm
  - $\Delta\alpha$: $|\phi_B - \phi_{vtx}| < 0.2$ rad
  - Isolation: $p_{TB}/(\Sigma trk + p_{TB}) > 0.56$

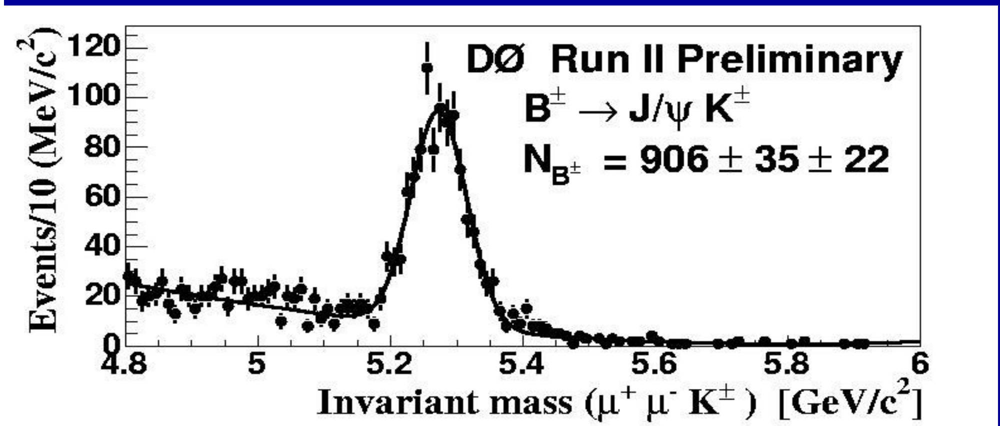
$4.53 < M_{\mu\mu} < 6.15$ GeV/c^2

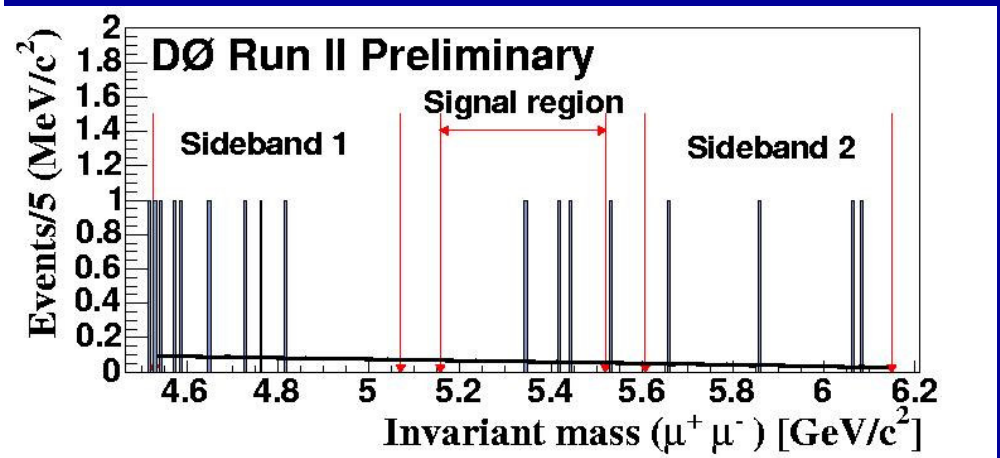
σ = 90 MeV/c^2

$B_s \to \mu\mu$

Run II, 240 pb^{-1}

$B^{\pm} \to J/\psi\, K^{\pm}$: used as a control sample and for normalization





N_{bkg} expected: 4.3±1.2
4 candidates found

$BR(B_s \to \mu\mu) < 3.0 \cdot 10^{-7}$ **90% CL**

$BR(B_s \to \mu\mu) < 3.7 \cdot 10^{-7}$ **95% CL**

$B_{s(d)} \rightarrow \mu\mu$

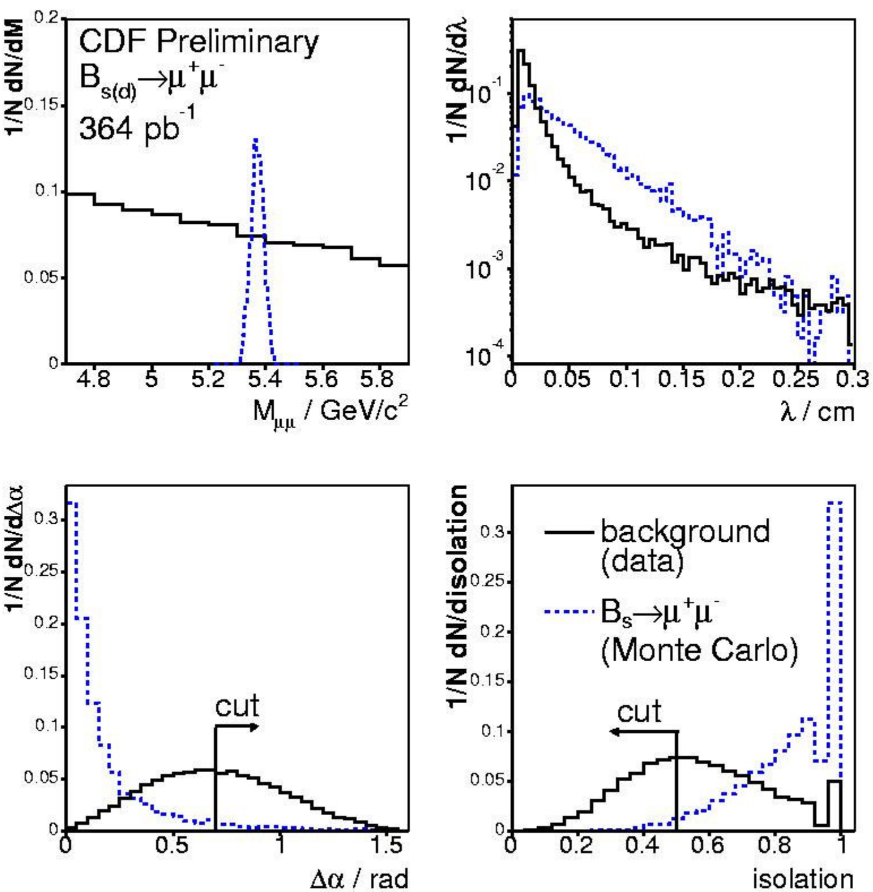
Run II, 364 pb^{-1}

CDF $B_s(d) \rightarrow \mu^+\mu^-$: Used blind analysis technique

$B^{\pm} \rightarrow J/\psi K^{\pm}$: used as a control sample and for normalization

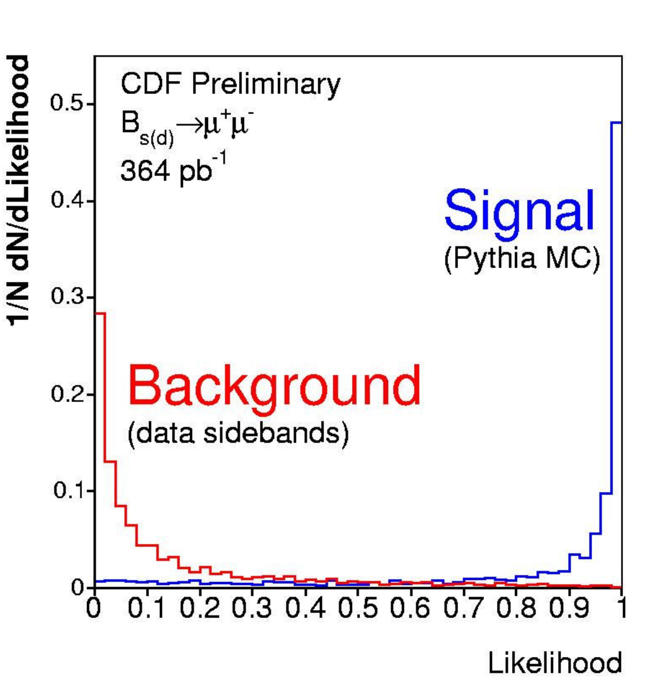
- Used 3 primary discriminating variables
  - λ: $cL_{3D} \cdot M_{\mu\mu}/p(B)$ $\lambda/\sigma(\lambda) > 2$
  - $\Delta\alpha$: $|\alpha_B - \alpha_{vtx}| < 0.7$ rad
  - Isolation: $p_{TB}/(\Sigma trk + p_{TB}) > 0.5$

  Mass $M_{\mu\mu}$: choose $\pm 2.5\sigma$ window: $\sigma = 24$ MeV/c^2
- Optimization
  - Used simulated signal and data sidebands
  - Background estimates were checked in same sign lepton and -ct samples

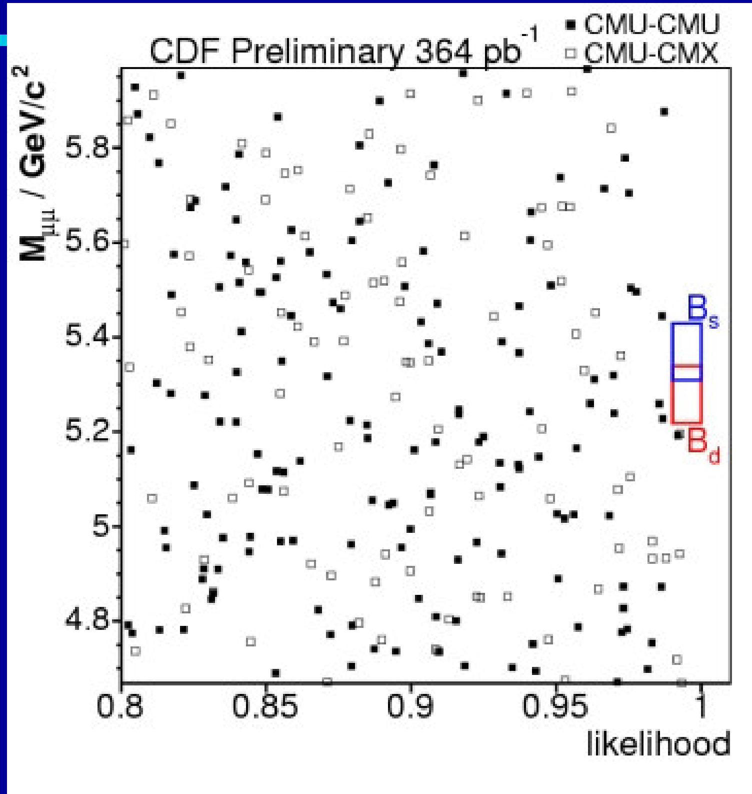


$B_{s(d)} \to \mu\mu$

Multi-variate Relative Likelihood Discriminant



$p_T(B) > 4$ GeV/c
LH > 0.99



N_{bkg} expected: 0.81±0.12
ses: (1.0±0.2) x 10^{-7}

N_{bkg} expected: 0.66±0.13
ses: (1.6±0.3) x 10^{-7}

comb. ses: 0.607 x 10^{-7}

$BR(B_s \to \mu\mu) < 1.5\times10^{-7}$	90% CL
$BR(B_s \to \mu\mu) < 2.0\times10^{-7}$	95% CL
$BR(B_d \to \mu\mu) < 3.8\times10^{-8}$	90% CL
$BR(B_d \to \mu\mu) < 4.9\times10^{-8}$	95% CL

apadi

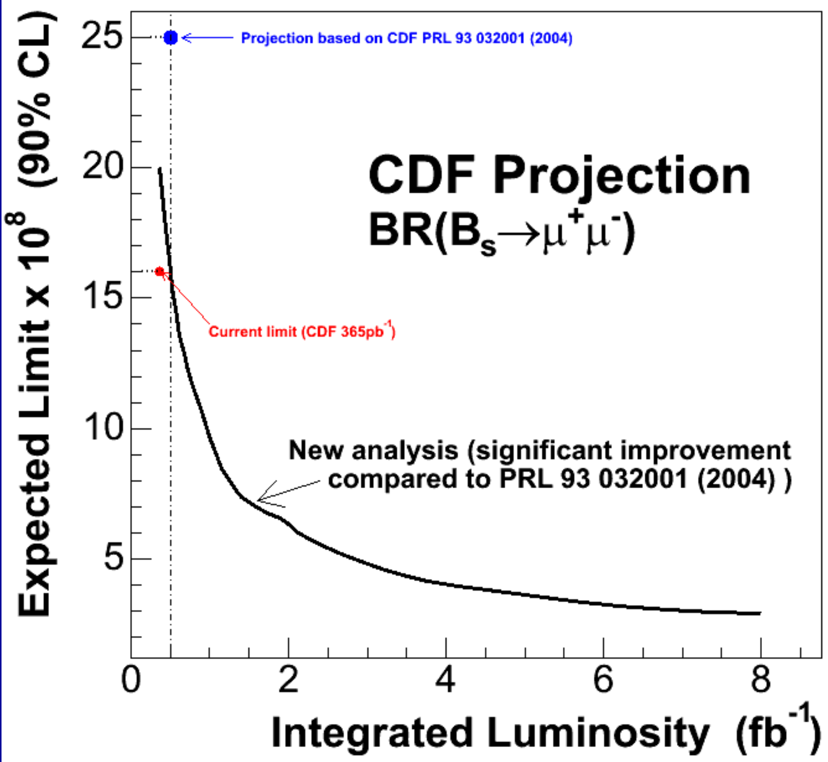
$B_{s(d)} \rightarrow \mu\mu$

❖ **Combination of the CDF and D0 limits:**

- **use a Bayesian integration technique**
- **takes into account correlated and uncorrelated systematic uncertainties**

$$BR(B_s \rightarrow \mu\mu) < 1.6 \times 10^{-7}$$ **95% CL**

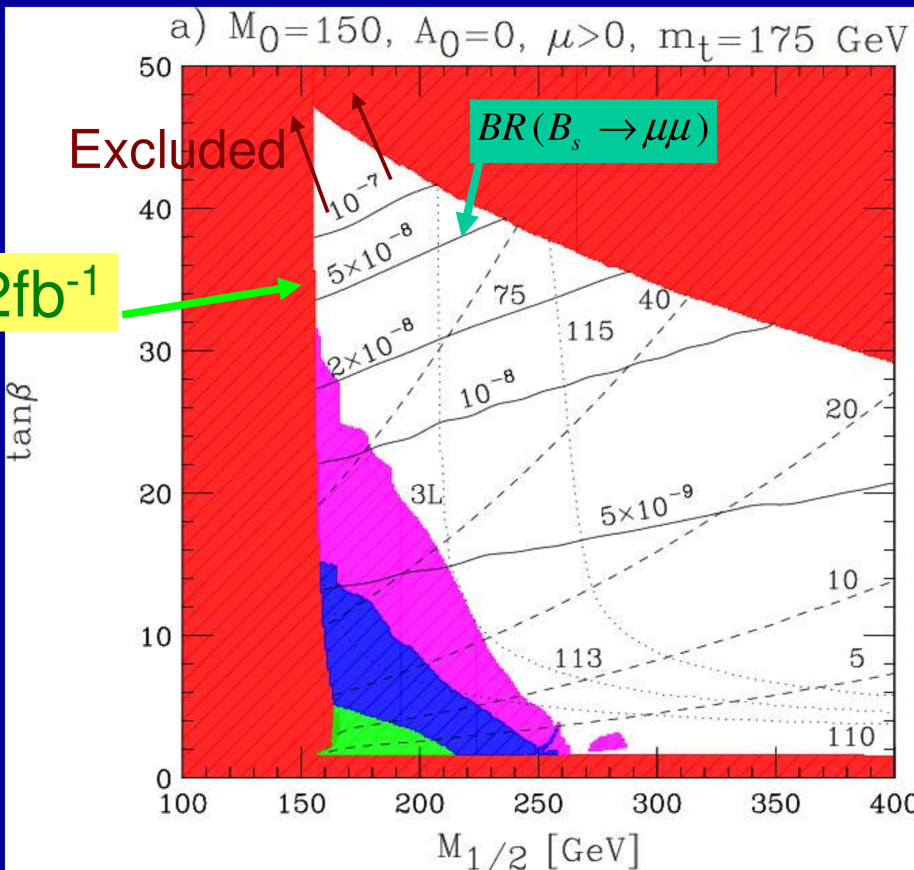
$$BR(B_d \rightarrow \mu\mu) < 3.8 \times 10^{-8}$$ **95% CL**



Prague, July 2005

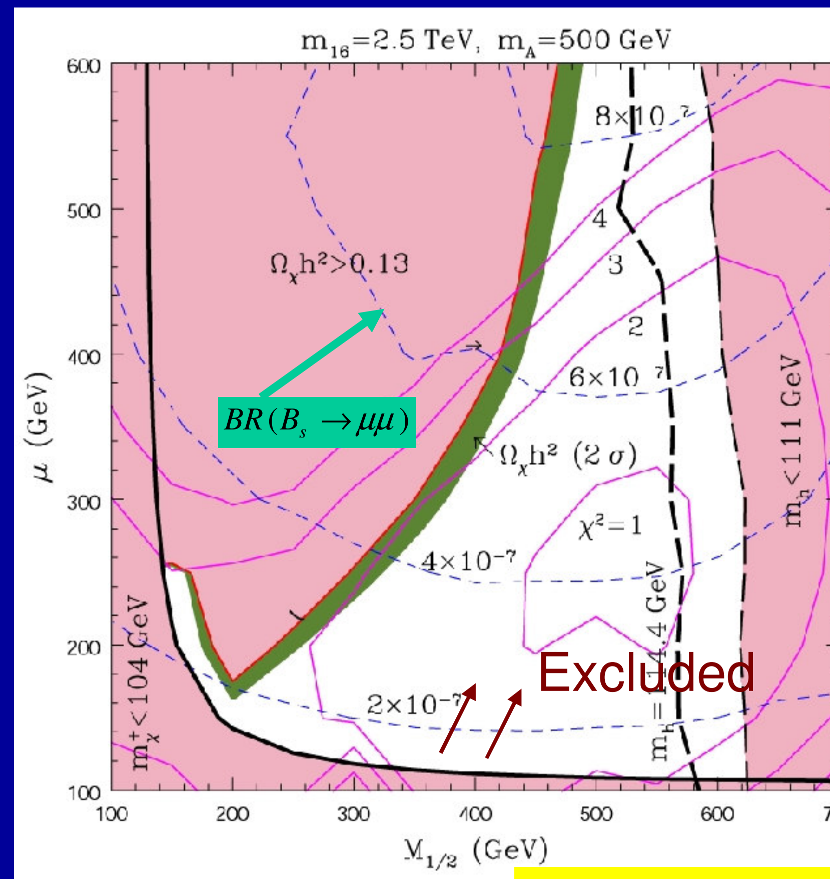
$B_{s(d)} \rightarrow \mu\mu$: Physics Reach

- mSUGRA



A. Dedes et al.
hep-ph/0207026

- SUSY SO(10) Unification
  - Allows for massive neutrino
  - Relic density of cold dark matter



R. Dermisek et al.
hep-ph/0304101

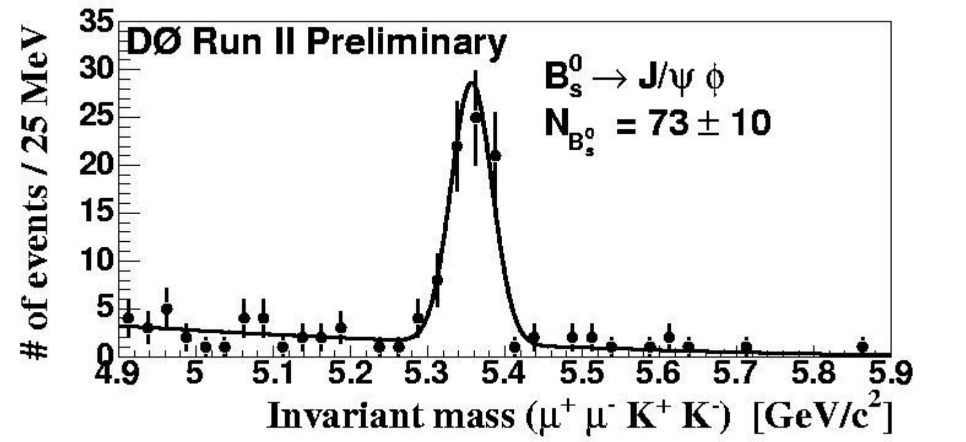
$B_s \to \mu\mu\phi$

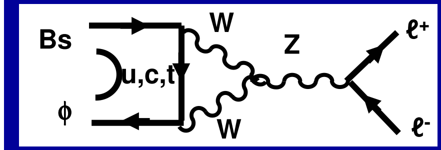
Run II, 300 pb^{-1}

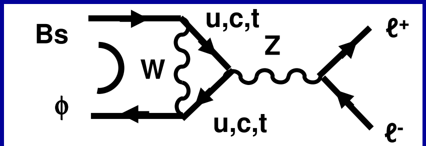
$B_s \to J/\psi\varphi\,;\; J/\psi \to \mu\mu$

used as a control sample and fornormalization

Blind analysis

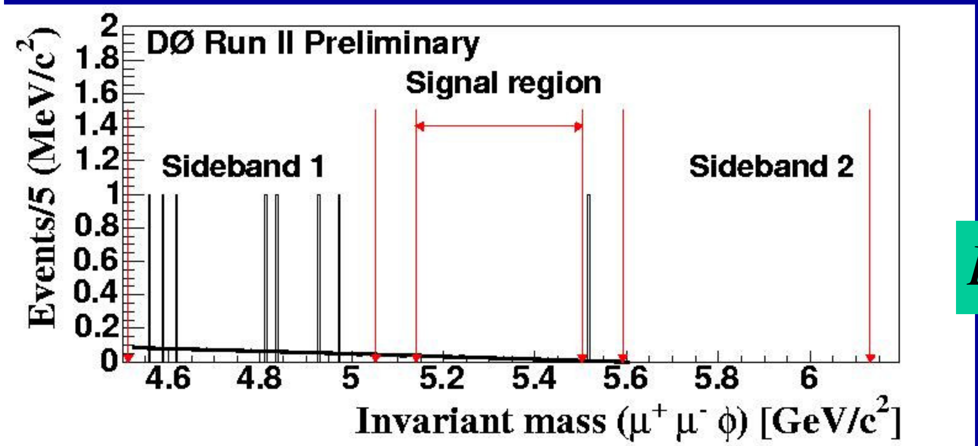






- SM BR ~ 1.6×10^{-6}
- Smaller enhancement at large tanβ
- CDF-I: BR < 6.7×10^{-5}

N_{bkg} expected: 1.6±0.4
0 events found



$$BR(B_s \to \mu^+\mu^-\varphi) < 4.1\times10^{-6}\ @\ 90\%\ C.L.$$

B_c meson

B_c meson

$B_c^{\pm}$

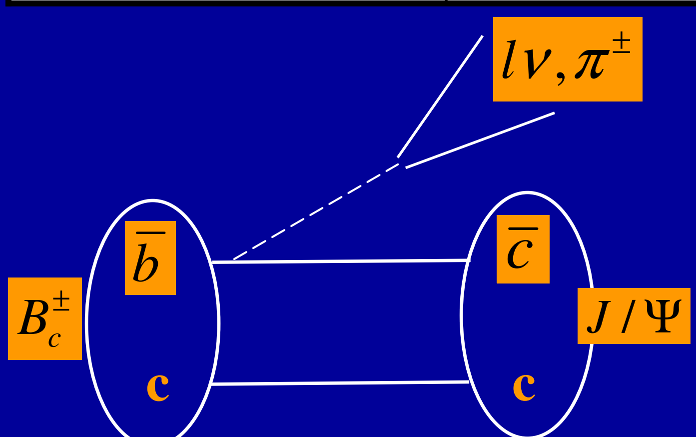
Heaviest ground state of two different quarks

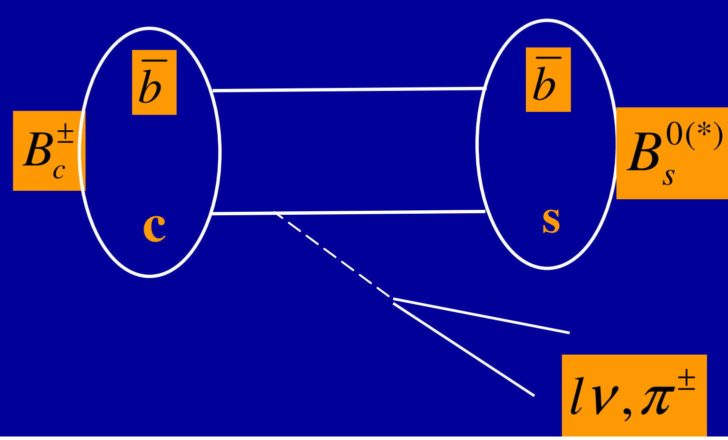
species	~ prod. fraction
$B^{\pm}$	40%
B_0	40%
B_s	10%
b-baryons	10%
B_c	~0.05%

Latest cross section calculation: 7.4 nb
Phys. Lett. B605, 311 (2005)

Rich spectroscopy

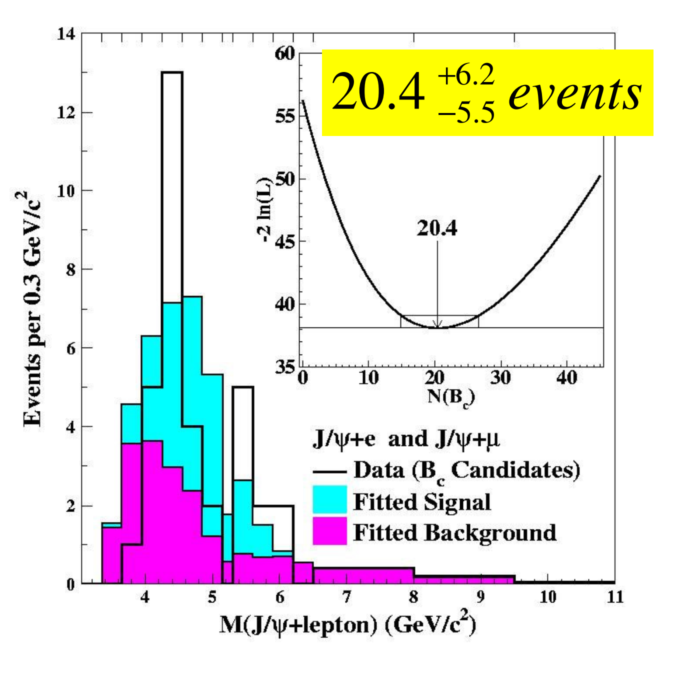
It decays weakly





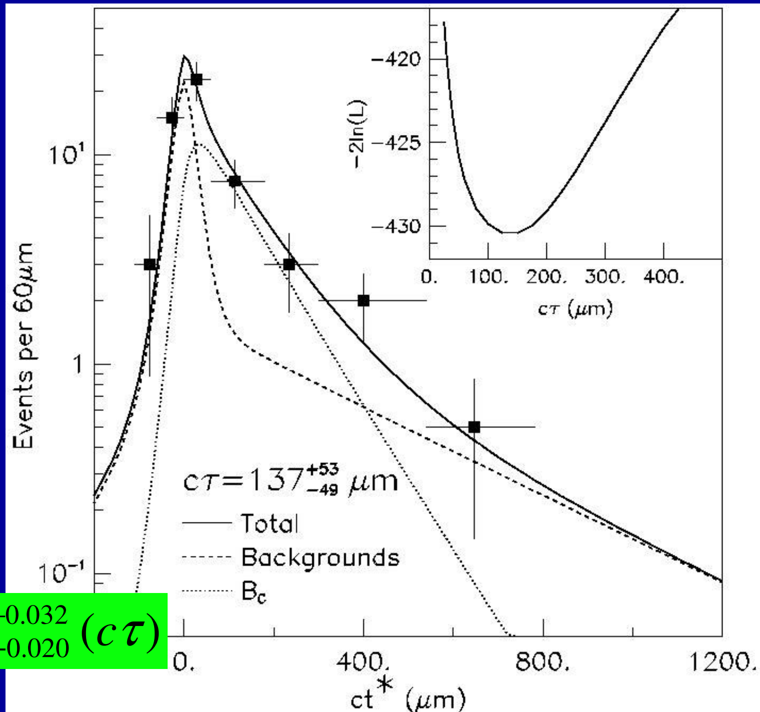
$B_c^\pm \rightarrow J/\Psi l^\pm \nu$

Run I, 110 pb^{-1}



PRL 81, 2432 (1998), PRD 58, 112004 (1998)

- Original B_c observation (CDF I, 1998) was in the trilepton mode:
  - $B_c^\pm \longrightarrow J/\psi l^\pm \nu,\ J/\psi \longrightarrow \mu\mu$ **(l = e, μ)**



$M(B_c) = 6.40 \pm 0.39\ (stat) \pm 0.13 (syst)\ GeV/c^2$

$$\frac{\sigma(B_c)\times B(B_c \to J/\psi \ell \nu)}{\sigma(B_u)\times B(B_u \to J/\psi K)} = 0.132\ ^{+0.041}_{-0.037}\ (stat) \pm 0.031 (syst)\ ^{+0.032}_{-0.020}\ (c\tau)$$

$P_T(B) > 6\ GeV/c; |\eta| < 0.6$

$c\tau(B_c) = 0.46\ ^{+0.18}_{-0.16} \pm 0.03\ ps$

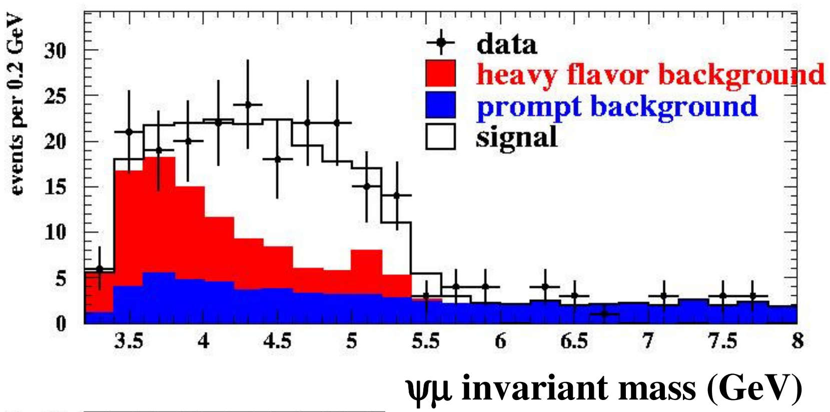
$B_c^{\pm} \rightarrow J/\Psi \mu^{\pm} \nu$

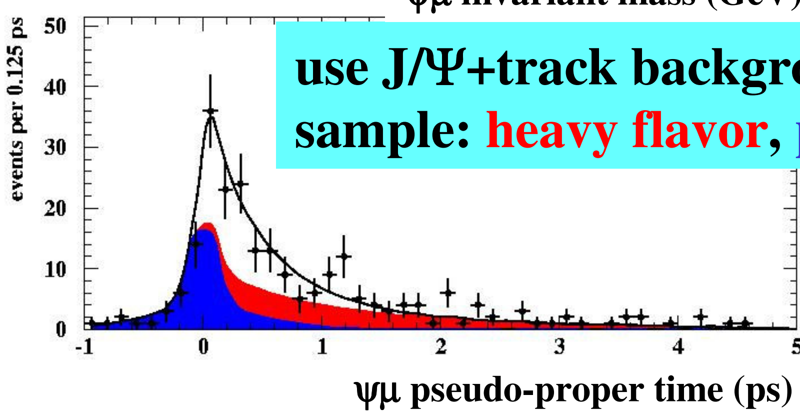
Run II, 210 pb^{-1}

- B_c observation by D0 II, 2004, in the trimuon mode:
  - $B_c^{\pm} \longrightarrow J/\psi\mu^{\pm}\nu$, $J/\psi \longrightarrow \mu\mu$

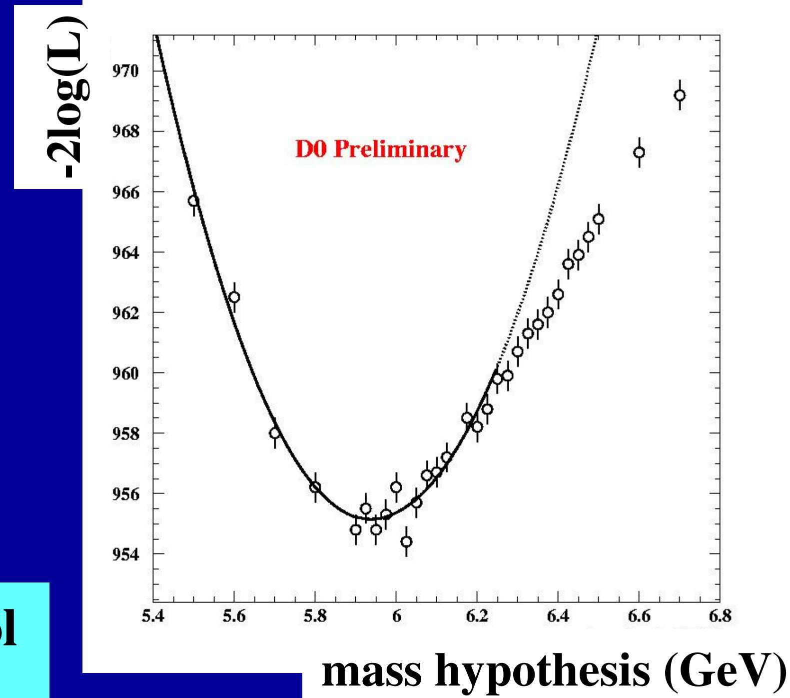
231 candidates

combined lifetime and mass fit
95 ± 12 ± 11 signal events





use J/Ψ+track background control sample: heavy flavor, prompt



$M(B_c) = 5.95 \pm 0.14\ (stat) \pm 0.34 (syst)\ GeV/c^2$

$$c\tau(B_c) = 0.448\,^{+0.123}_{-0.096}\,(stat) \pm 0.121\,(syst)\,ps$$

$B_c^{\pm} \rightarrow J/\Psi\pi^{\pm}$

Run II, 360 pb^{-1}

hep-ex/0505076

- New analysis
  - Blind search

Hypothesis test set up before opening the box.

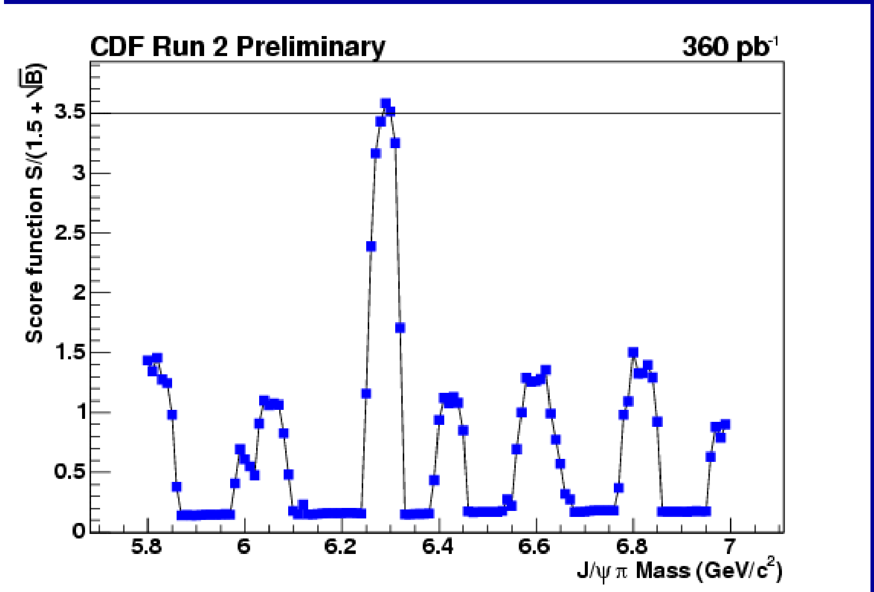
Score function

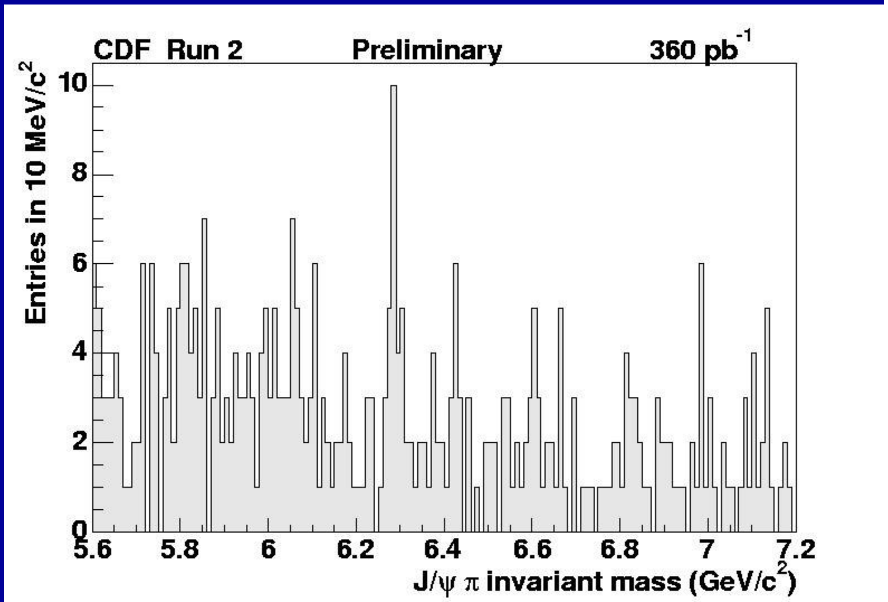
$$\Sigma = \frac{S}{1.5+\sqrt{B}}$$

Threshold value

$$\Sigma_{thr} = 3.5$$

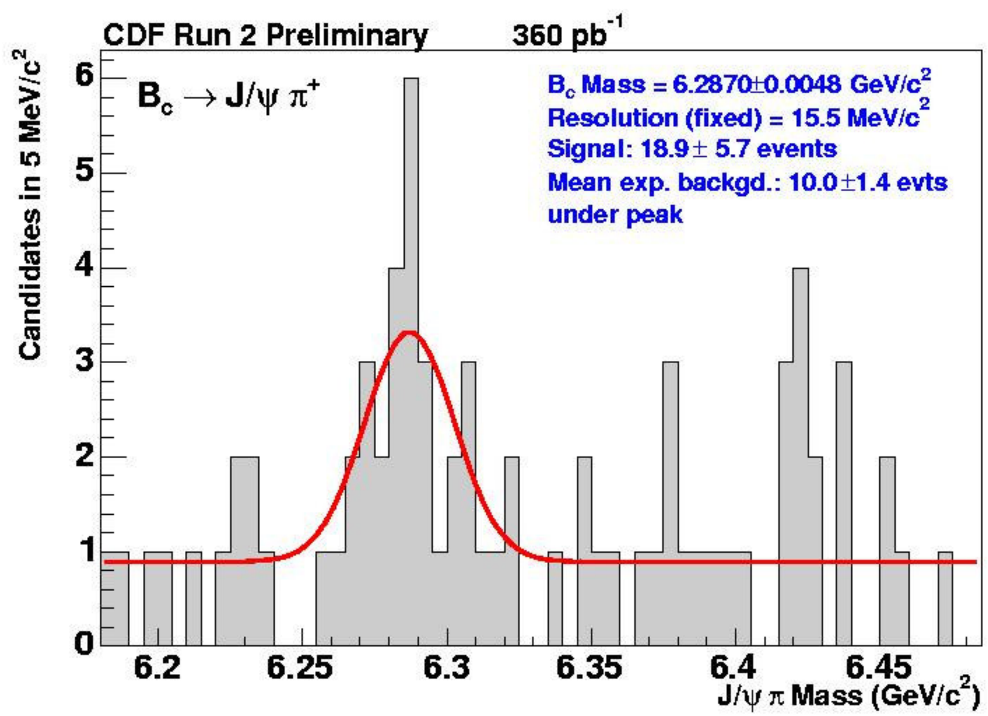
The probability for the signal being a random fluctuation is less than 0.27%.





After box was open: scan search region with binned likelihood fit:
mass fixed (scanned), resolution constrained, S, B fit parameters

$B_c^{\pm} \longrightarrow J/\Psi\pi^{\pm}$

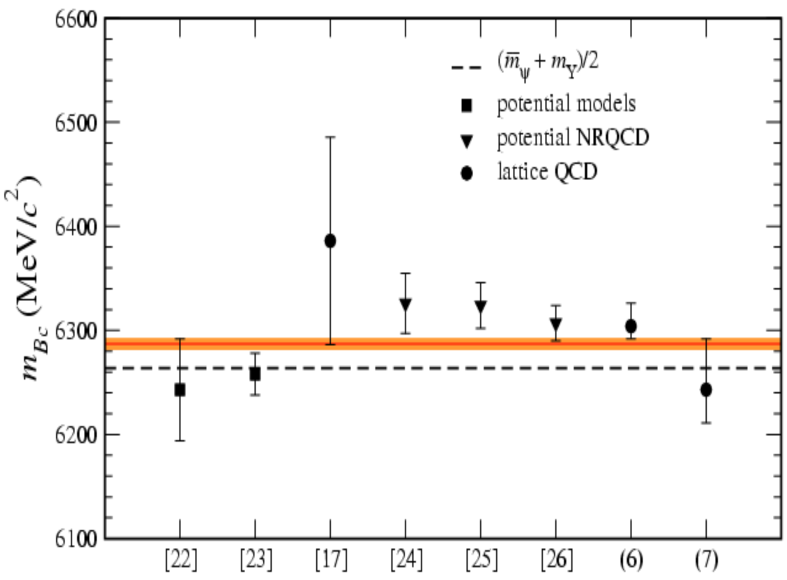


- New CDF analysis
  - Blind search, control sample 2378±57

    $B_u^{\pm} \longrightarrow J/\psi K^{\pm}$

$M(B_c) = 6287.0 \pm 4.8\ (stat) \pm 1.1 (syst)\ MeV/c^2$

This result



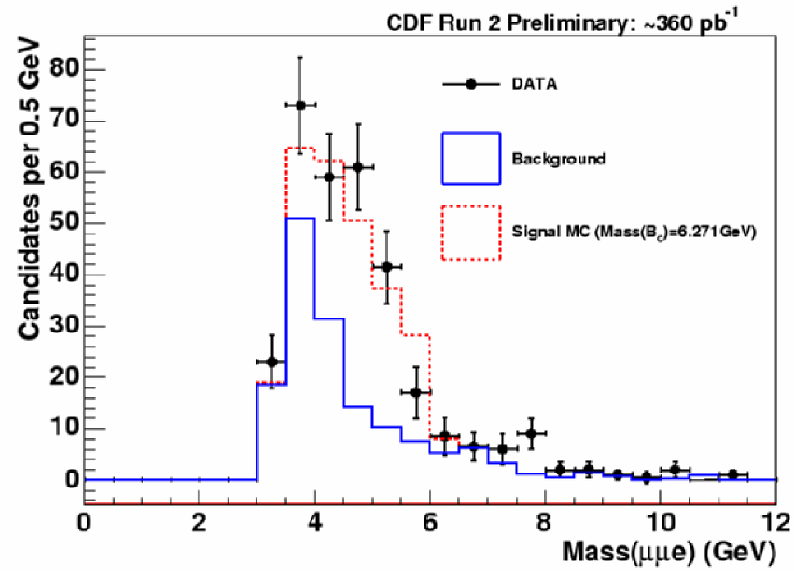
Theory in very good agreement
Potential models, NRQCD, LQCD

$B_c^{\pm} \rightarrow J/\Psi e^{\pm}\nu$

Run II, 360 pb^{-1}

Background :
63.6±4.9(stat.)±13.6(syst.)
Observe :
178.5±14.7(stat.)
Excess :
114.9±15.5(stat.) ±13.6(syst.)

Significance : 5.9σ



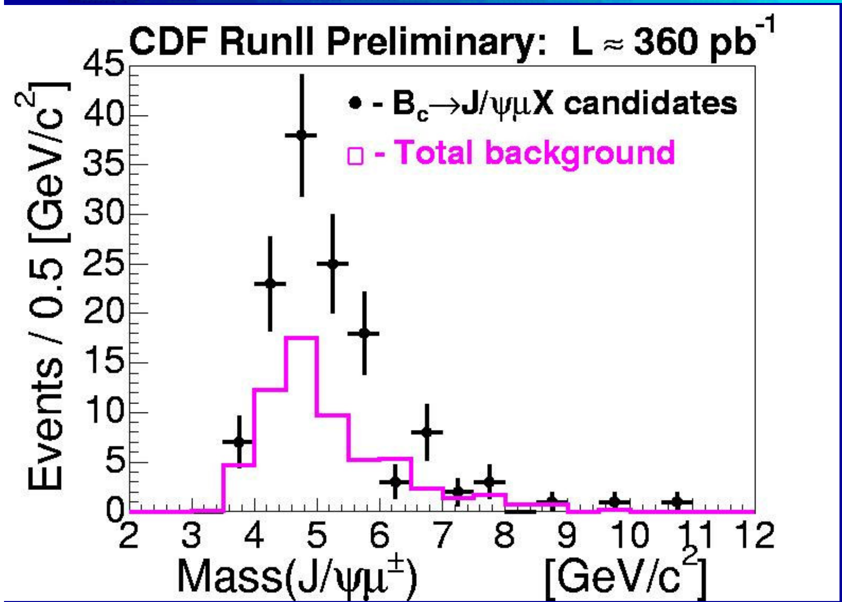
$$\frac{\sigma(B_c^+)\times BR(B_c^+ \rightarrow J/\psi e^+\nu)}{\sigma(B^+)\times BR(B^+ \rightarrow J/\psi K^+)}$$

- Cross section ratio is defined within the kinematical limits
  - $p_T(B) > 4.0\text{GeV}$, $|y(B)| < 1.0$

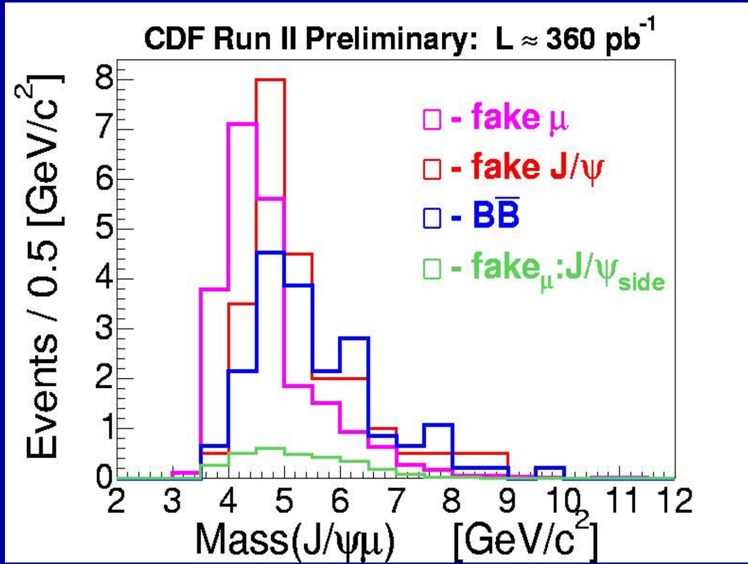
σ_{ratio}=0.282±0.038(stat.)±0.074(syst.)

$B_c^{\pm} \rightarrow J/\Psi\mu^{\pm}\nu$

Run II, 360 pb^{-1}



Background : 44.9±7.3
Observe : 104±10.2
Excess : 59.1 ±12.5
Significance : 5.2σ



$$\frac{\sigma(B_c^+)\times BR(B_c^+ \rightarrow J/\psi\mu^+\nu)}{\sigma(B^+)\times BR(B^+ \rightarrow J/\psi K^+)}$$

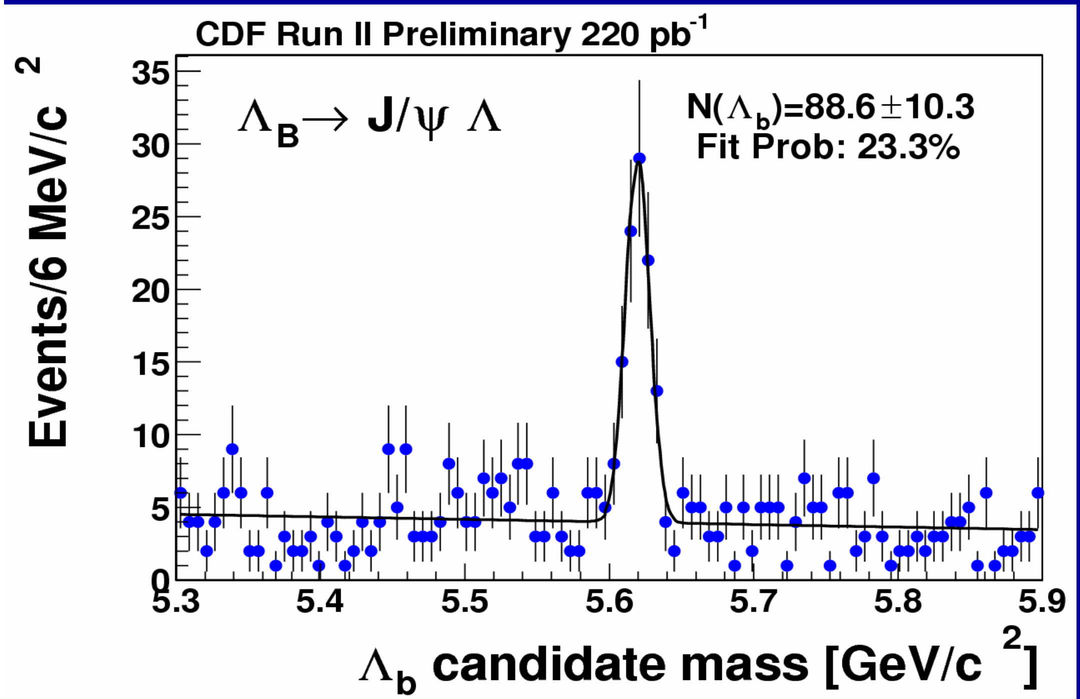
- Cross section ratio is defined within the range
  - $p_T(B) > 4.0$GeV , $|y(B)| < 1.0$

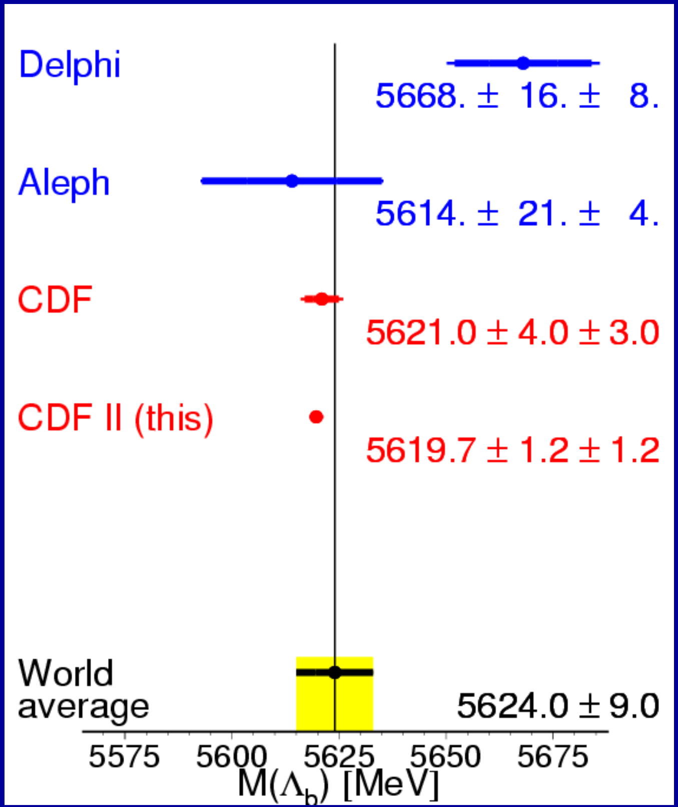
$$\sigma_{ratio} = 0.249 \pm 0.045(stat.)^{+0.107}_{-0.076}(syst.)$$

b-Baryons

b - Baryons

Λ_b mass





Source	$B^0 \to J/\psi K^0_s$	$\Lambda_b \to J/\psi\Lambda$
Tracking & Corrections		
momentum scale	0.2	0.2
Tracking	1.0	from $B^0 \to J/\psi K^0_s$
Fitting	0.7	from $B^0 \to J/\psi K^0_s$
Total Systematic Uncertainty	1.2	1.2

MeV

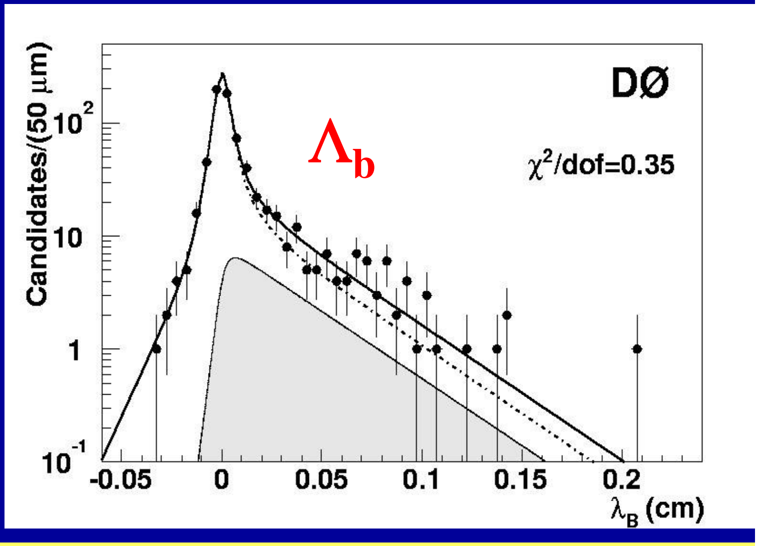
Lifetimes

- D0 (Run II, 250 pb^{-1}) : $\tau(\Lambda_b) = 1.22^{+0.22}_{-0.18} \pm 0.04\ ps$
- CDF (Run II, 65 pb^{-1}): $\tau(\Lambda_b) = 1.25 \pm 0.26 \pm 0.10$ ps
- HFAG 2005: $\tau(\Lambda_b) = 1.232 \pm 0.072$ ps
- $\tau(\Lambda_b)/\tau(B^0) = 0.806 \pm 0.047$ exp

  $= 0.86 \pm 0.05$ theory

Improved measurements coming

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



$\Lambda_b \to J/\psi \Lambda^0 ; J/\psi \to \mu\mu ; \Lambda^0 \to p\pi^-$

- HFAG 2005: $\tau(\Xi_b) = 1.39^{+0.34}_{-0.28}$ ps

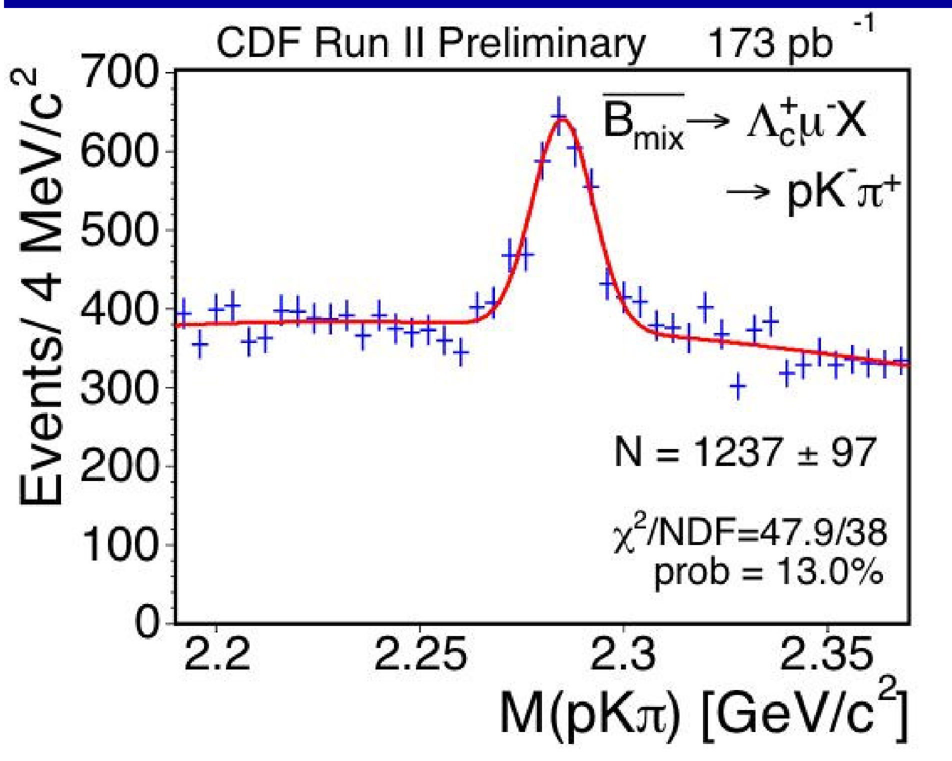
Mixture of Ξ_b^0, Ξ_b^-

Delphi 95, Aleph 96

Branching Ratios

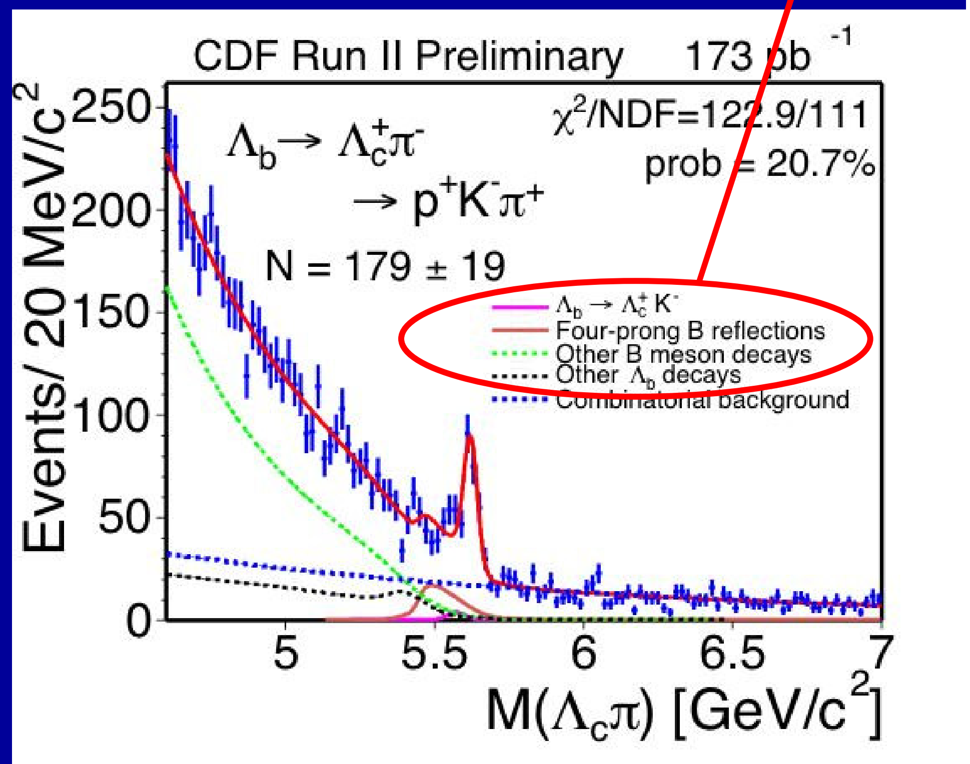
Signal Sample: $\Lambda_b \to \Lambda_c X$; $\Lambda_c \to p^+ K^- \pi^+$

Inclusive Semileptonic Signal



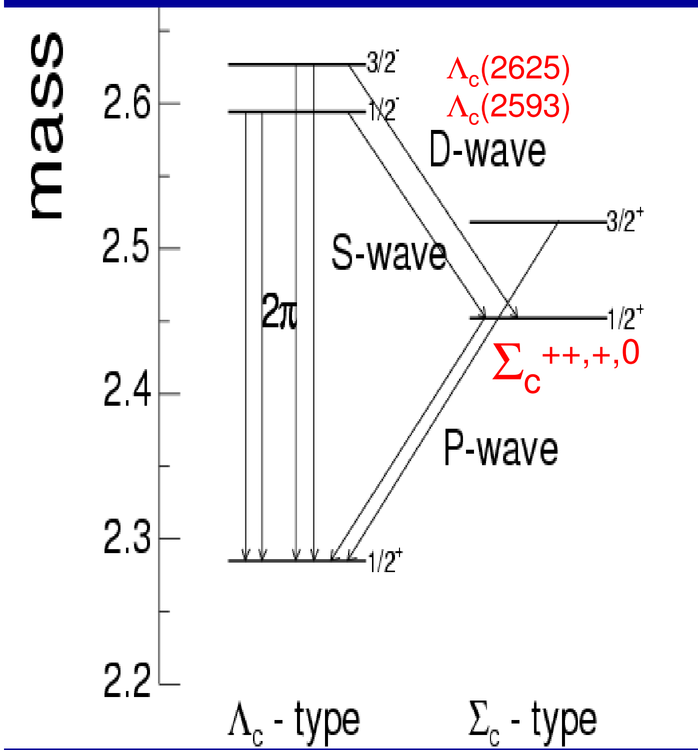
Hadronic Signal

from MC

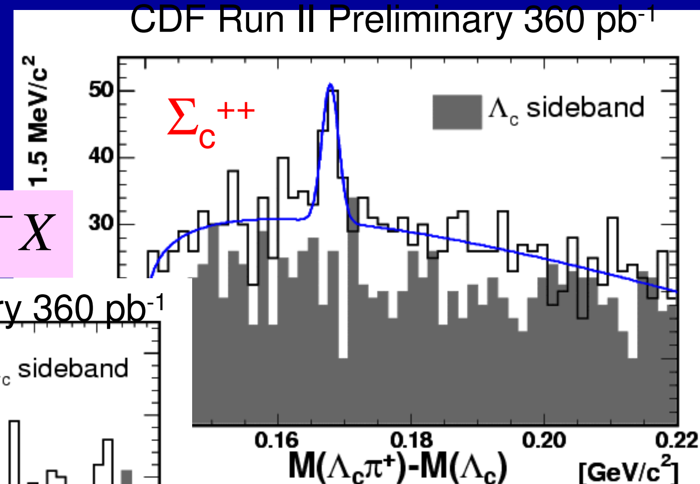


$$\frac{\mathcal{B}(\Lambda_b \to \Lambda_c^+ \mu^- \overline{\nu}_\mu)}{\mathcal{B}(\Lambda_b \to \Lambda_c^+ \pi^-)} = 20.0 \pm 3.0\ (stat) \pm 1.2\ (syst)\ ^{+0.7}_{-2.1}\ (BR) \pm 0.5\ (UBR)$$

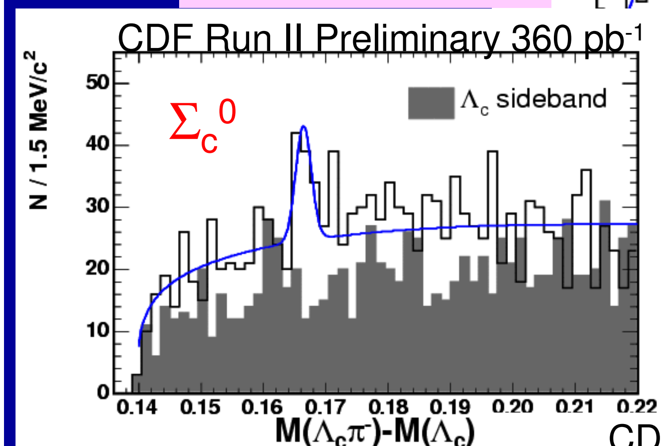
Source of semileptonic backgrounds



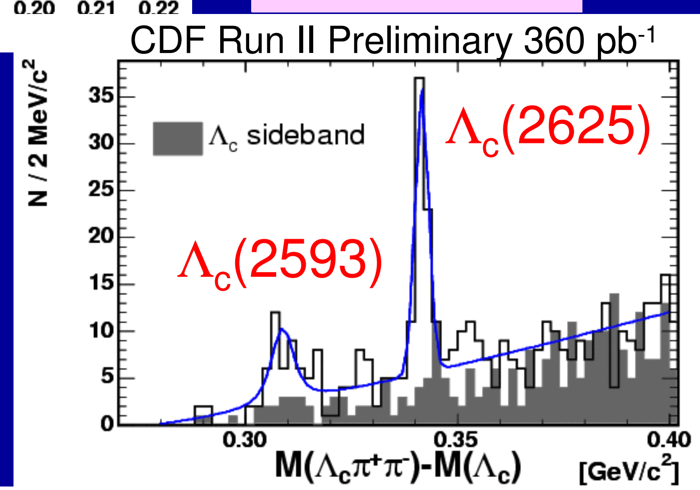
$$\Lambda_b \to \Sigma_c^{++}\pi^-\mu^- X$$



$$\Lambda_b \to \Sigma_c^{0}\pi^+\mu^- X$$



$$\Lambda_b \to \Lambda_c^{*+}\mu^- X$$

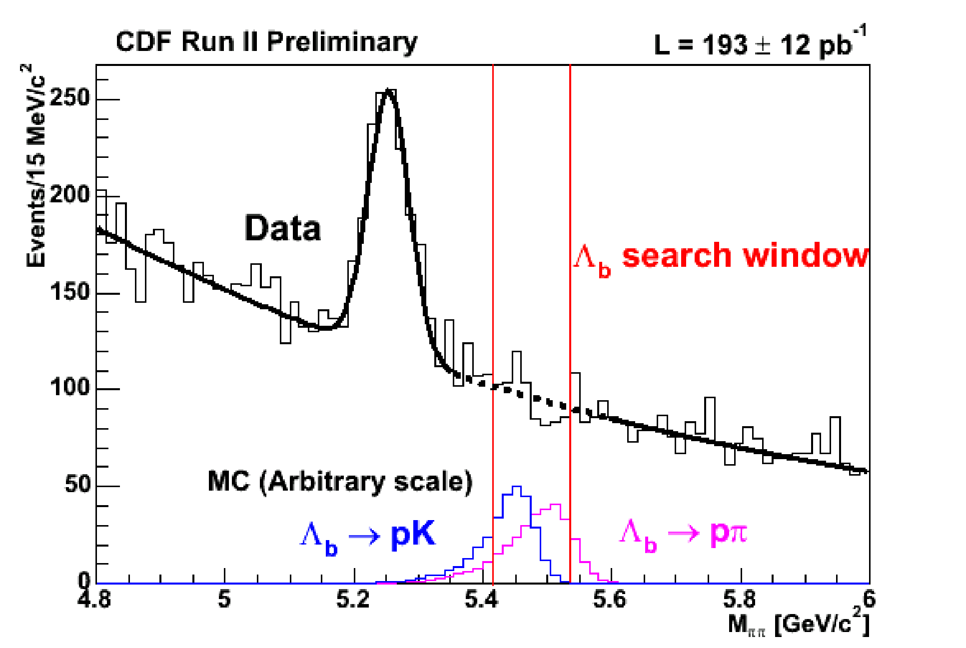


First observation of several Λ_b semileptonic decays that can 'mimic' the signal

Branching Ratios

Signal Sample: $\Lambda_b \rightarrow p^+\pi^-$ and $\Lambda_b \rightarrow p^+K^-$

- Predictions for BR are in the range 1 x 10^{-6} – 2 x 10^{-6}
- Large direct CP violation expected (Z. Phys. C56 (1992) 129)
- Exploit the two-track trigger sample
- Use $B^0 \rightarrow K\pi$ for normalization
- Backgrounds are combinatorial and from the tail of $B \rightarrow hh$
- BR($\Lambda_b \rightarrow ph$) < 2.3 x 10^{-5} @ 90% C.L. $h = K, \pi$



$f_\Lambda/f_d = 0.25 \pm 0.04$

Updated knowledge for Λ_b

Mass m = 5619.9 ± 1.7 MeV/c²

Mean life $\tau = (1.232 \pm 0.072) \times 10^{-12}$ s

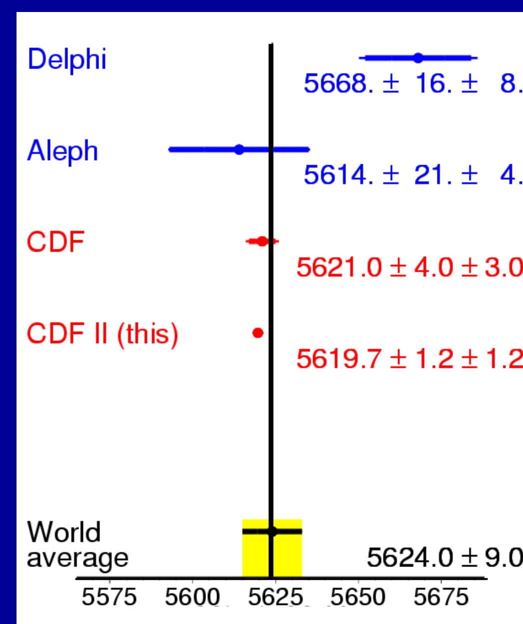
$c\tau = 368.9$ μm

Λ_b^0 DECAY MODES	Fraction (Γ_i/Γ)
$J/\psi(1S)\Lambda$	$(4.7 \pm 2.8) \times 10^{-4}$
$\Lambda_c^+ \pi^-$	$(4.1 \pm 2.0) \times 10^{-3}$
$\Lambda_c^+ a_1(1260)^-$	seen
$\Lambda_c \ell \upsilon$	(5.5 ± 1.8) %
pK + pπ	$< 2.2 \times 10^{-5}$
$\Lambda_c^+ \pi^- \pi^- \pi^+$	seen
$\Lambda\gamma$	$< 1.3 \times 10^{-3}$
$\Lambda_c(2593)^+ \ell \upsilon$	seen
$\Lambda_c(2625)^+ \ell \upsilon$	seen
$\Sigma_c^{++} \pi^- \ell \upsilon$	seen
$\Sigma_c^0 \pi^+ \ell \upsilon$	seen

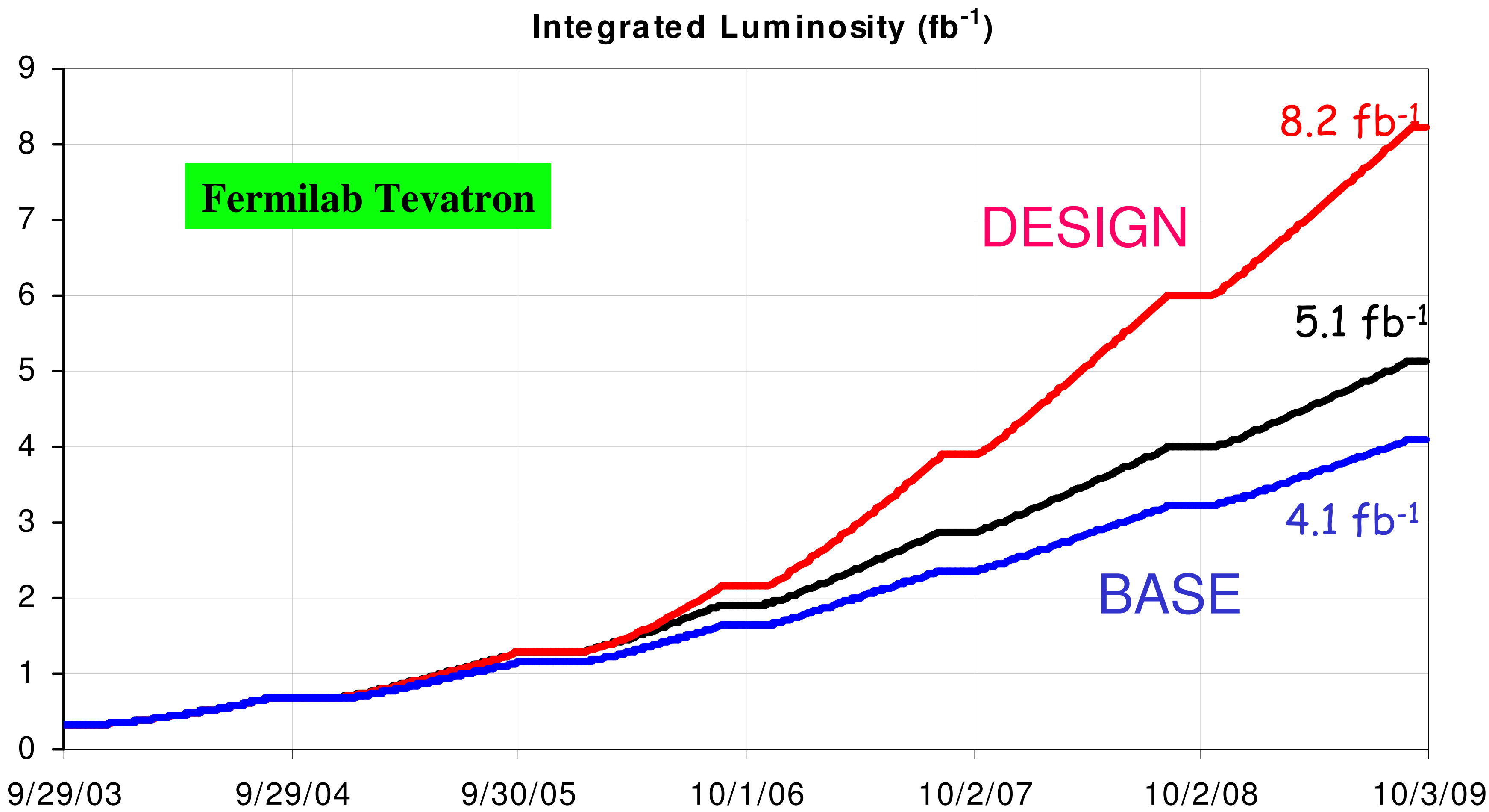
Colors:

- PDG2004
- CDF & D0 contribution beyond PDG2004

Λ_b mass



Expected Integrated Luminosity



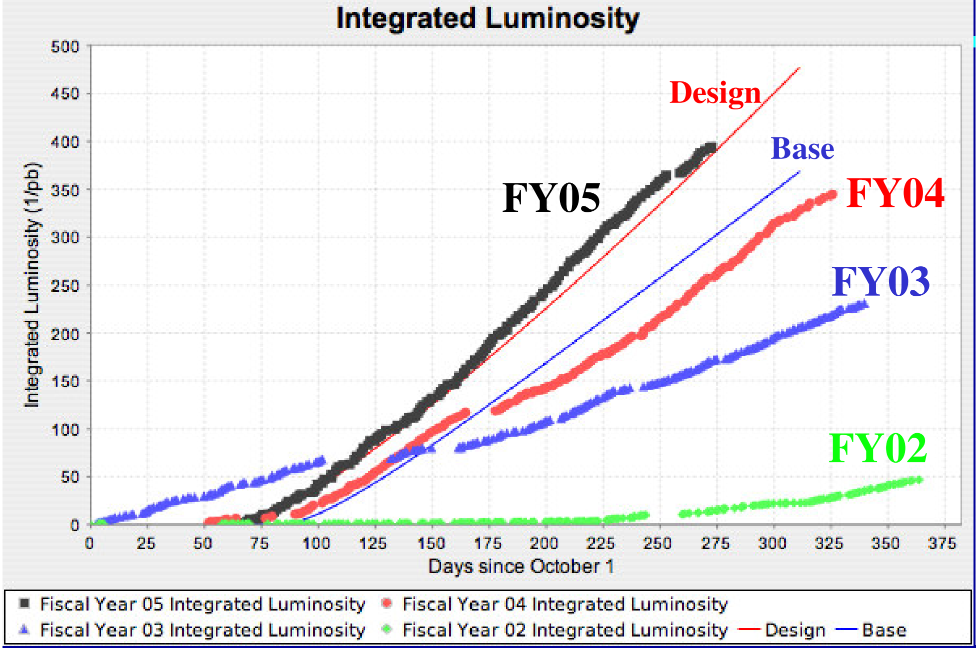
Conclusions

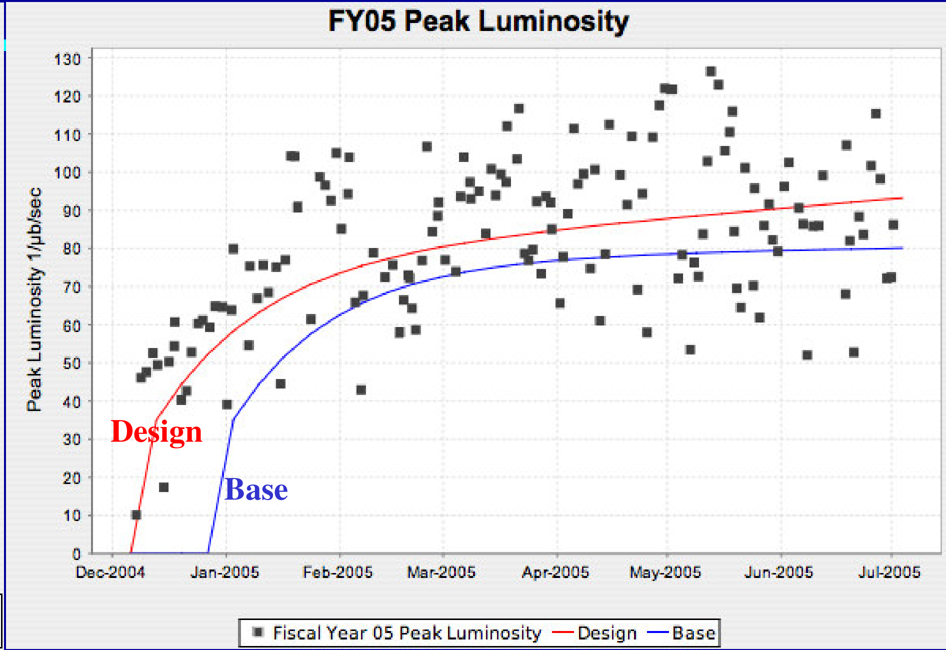
- The Tevatron is running very well
- Many new results
- The Tevatron is expected to provide 4.1 – 8.2 fb^{-1} by October 2009
- A lot of answers and surprises awaiting!!

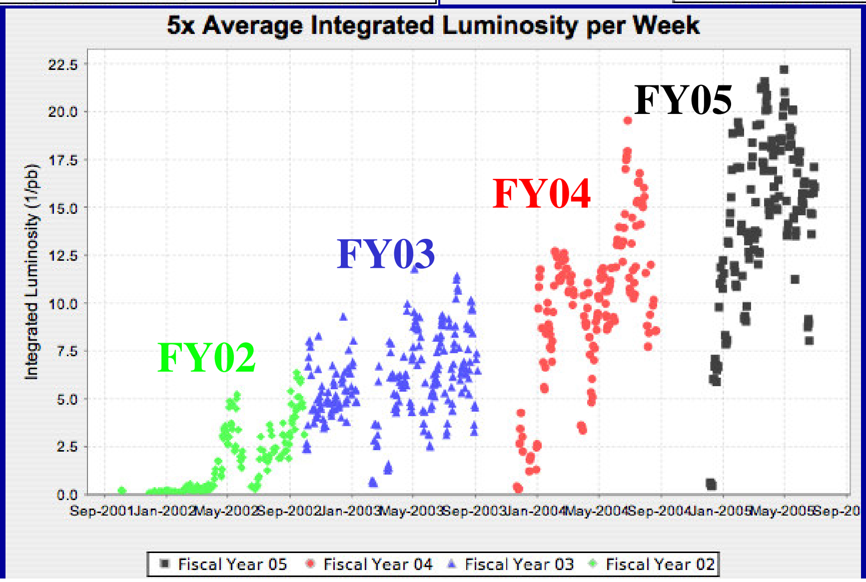
Backup

Backup Slides

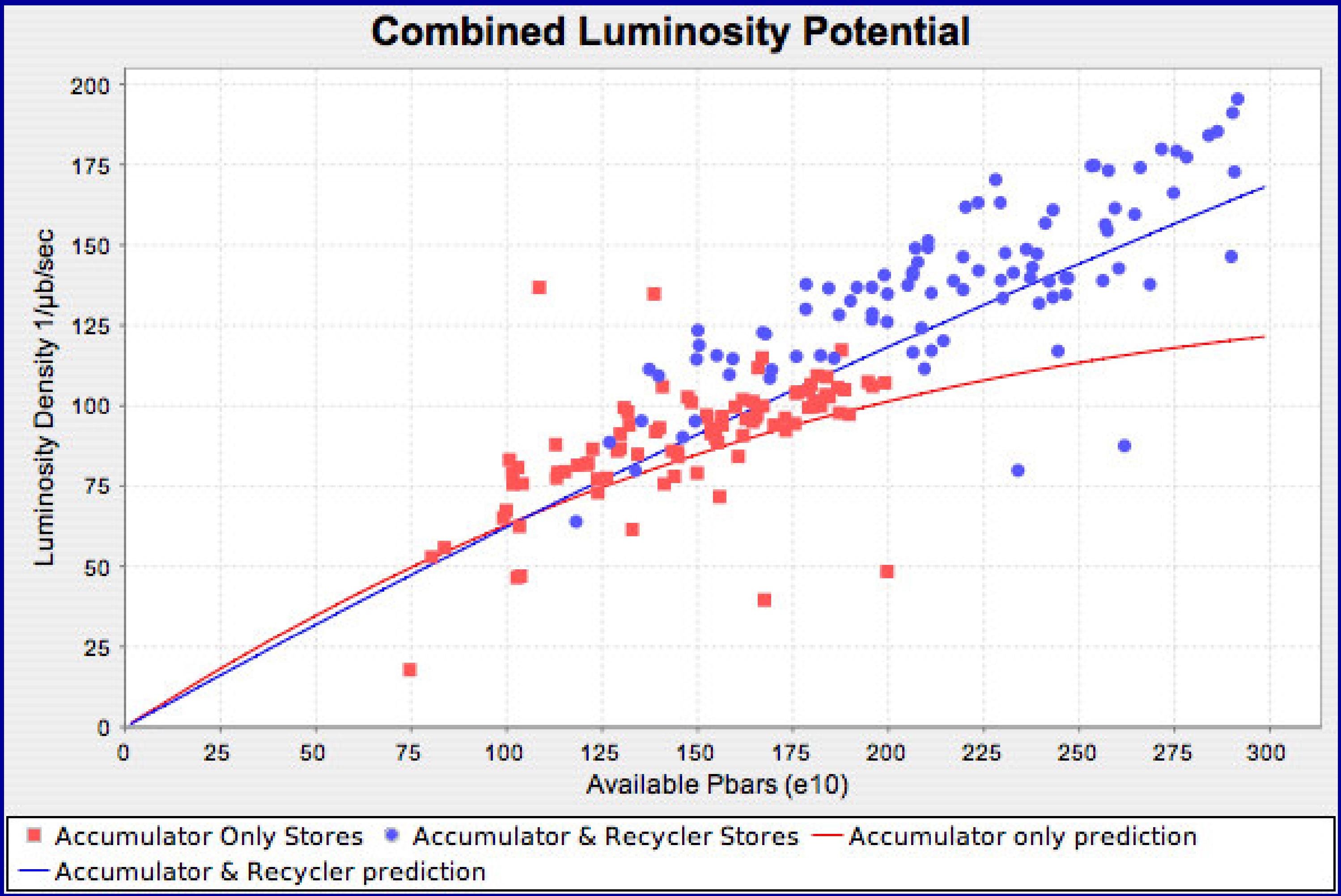
Tevatron Performance



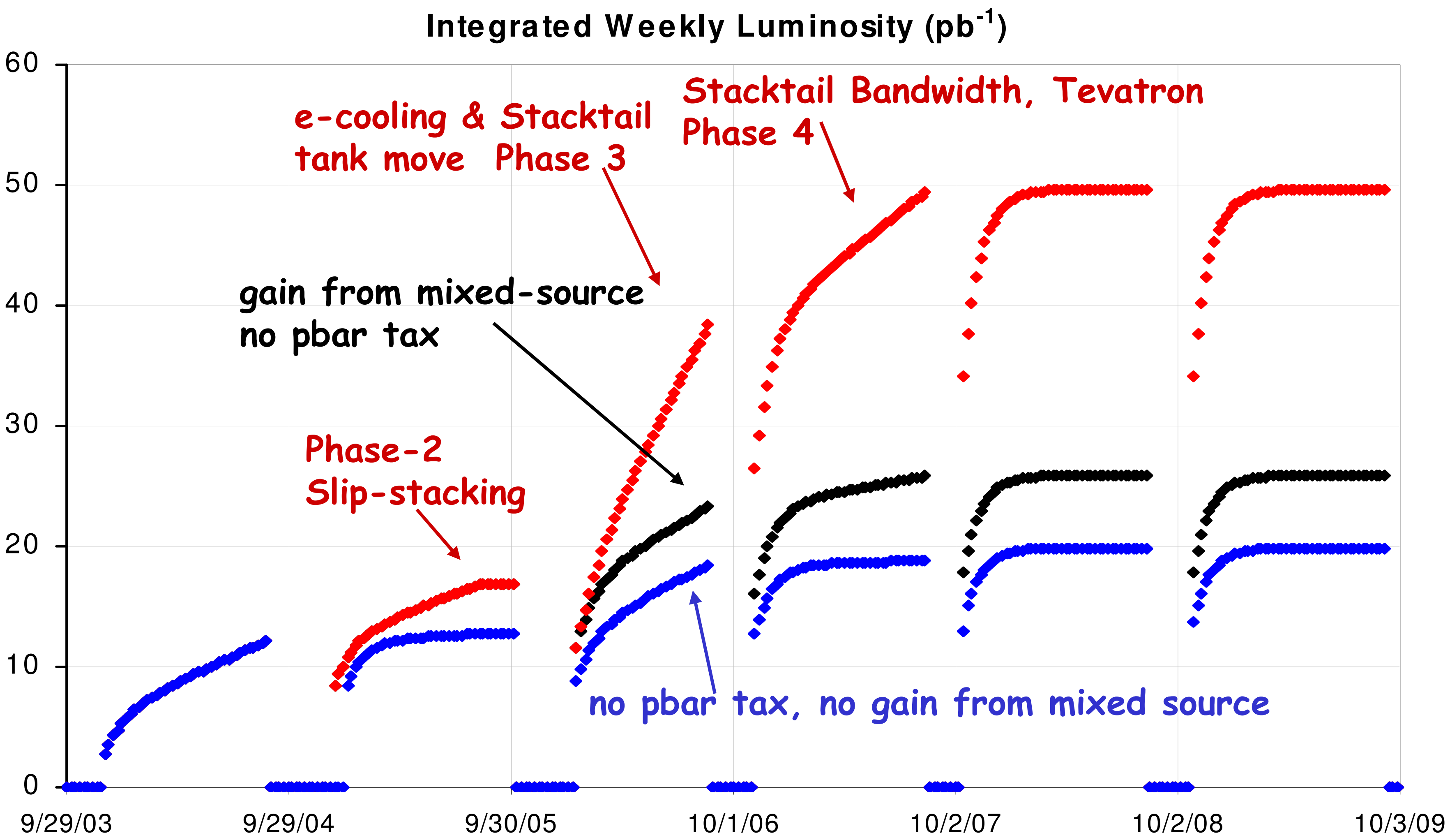




Tevatron Performance



Expected Weekly Luminosity



Parameters: Design Curve

Phase	2	2	3	4_5	6	
Parameter	FY05 Last 10	Slip Stacking	Recycler Ecool + Stacktail tank move FY05 Goal	Stacktail +Helix	Reliability	Units
Initial Luminosity	98	96	219	284	284	$\times 10^{30}$ cm^{-2} sec^{-1}
Integrated Luminosity per week	19	17	38	50	50	pb^{-1}
Average Store Hours per Week	128	100	100	100	100	Hours
Store Length	21.6	20	20	15	15	Hours
Number of Protons per bunch	240	260	260	270	270	$\times 10^{9}$
Number of Pbars per bunch	37	42	99	131	131	$\times 10^{9}$
Zero Stack Stacking Rate	14	24	30	46	46	$\times 10^{10}$/hour
Average Stacking Rate	8	10	22	39	39	$\times 10^{10}$/hour
Stack Size transferred	200	201	447	589	589	$\times 10^{10}$
Pbar Production	16	17	21	32	32	$\times 10^{-6}$
Protons on Target	6.1	8	8	8	8	$\times 10^{12}$
Pbar cycle time	2	2	2	2	2	Secs.
Pbar up time fraction	0.74	0.75	1	1	1	
A->R Transfer interval			2.5	0.5	0.5	Hours
A->R Transfer efficiency			90	98	98	%
A->R Transfer Time			0.2	0.05	0.05	Hours

merge

e-cool

Luminosity Projections

Our plan is to deliver the Design Projection

Also, develop an understanding of fallback scenarios

In v3, mixed-source operation and the phased stacktail upgrade allow more natural introduction of key upgrades (e-cooling and Stacktail upgrades) and provide a more robust fall-back position

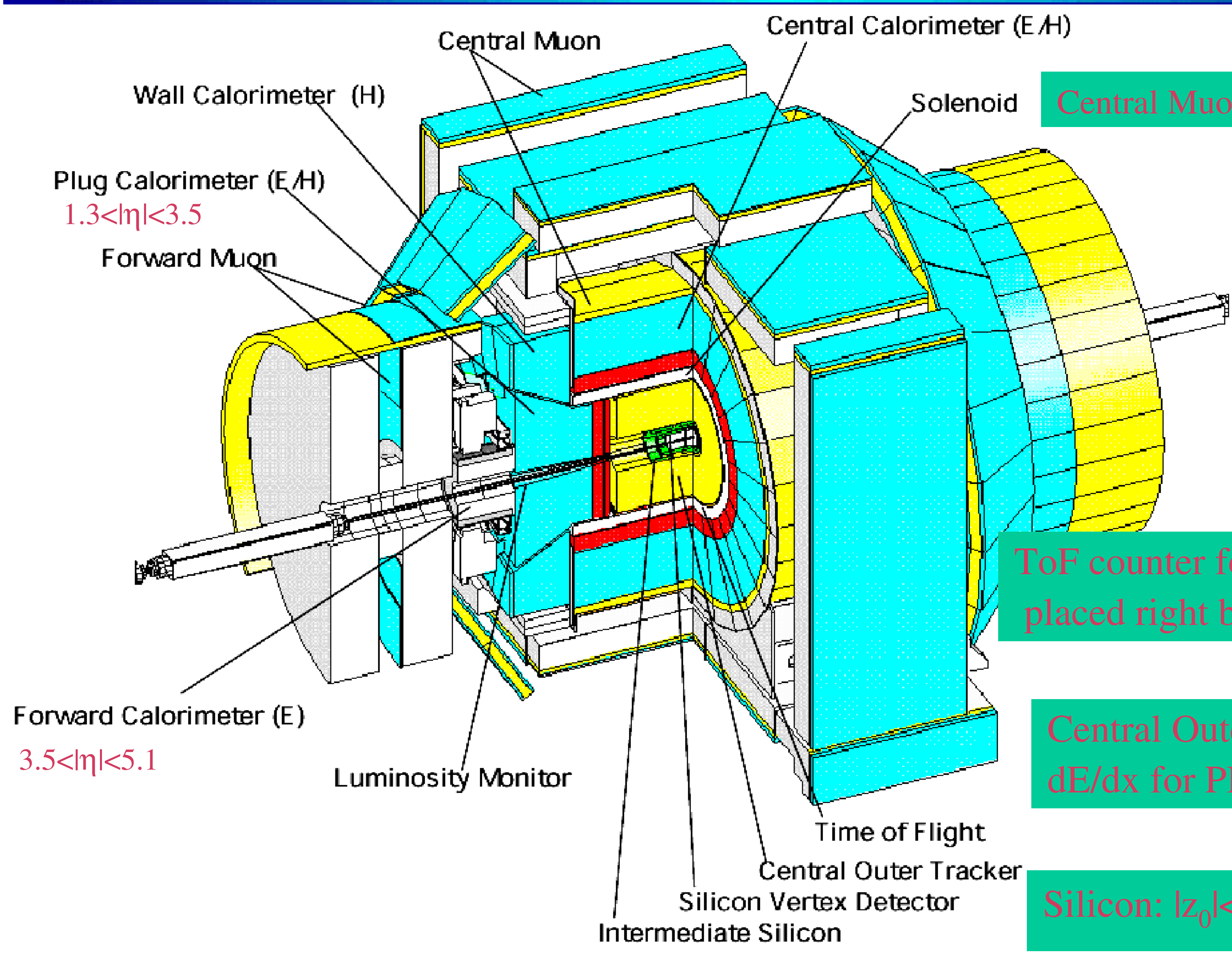
Three Curves

- Design Projection: electron cooling and Stacktail upgrade
- Black Projection: no electron cooling, mixed-source operation beyond 05 (20% gain), Deb→Acc acceptance issues solved
- Blue Projection: no electron cooling, Deb-Acc acceptance only minor improvements and no gain from mixed-source

All assume slip stacking and 100 HEP hrs per week average long-term

Vaia Papadimitriou

The CDF Detector



Central Muon Detectors: $|\eta|<1.0$

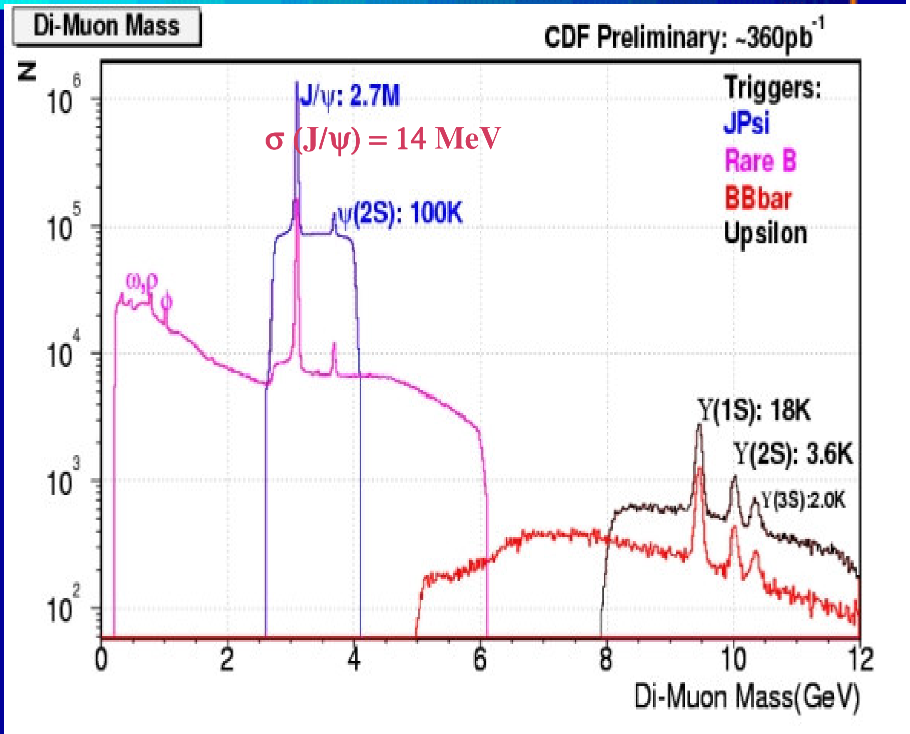
ToF counter for K/π separation placed right before the solenoid

Central Outer Tracker: $|\eta|<1.0$
dE/dx for PID

Silicon: $|z_0|<45$ cm, $|\eta|<2.0$

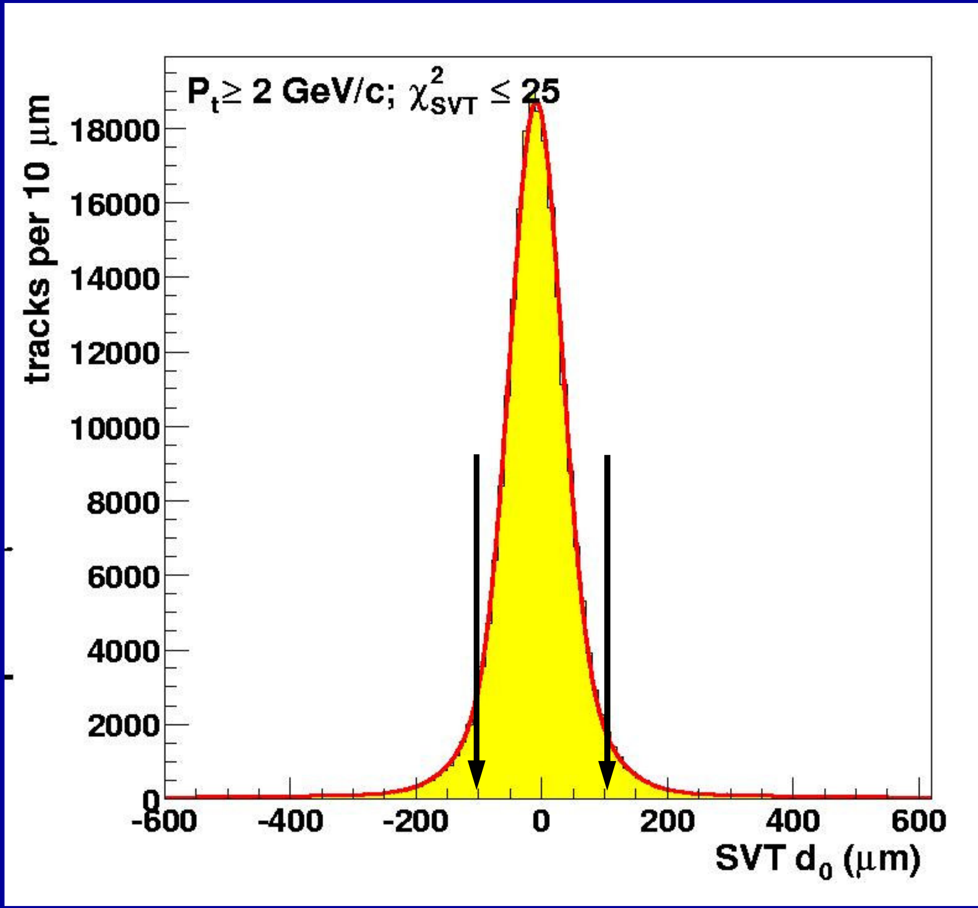
B-Physics Data samples

- J/ψ samples:
  - Millions! ~ 20% are from B's
  - Reconstruct exclusive $B/\Lambda_B \rightarrow J/\psi\ K/\Lambda^0$ modes
- Semi-leptonic $B \rightarrow D\ l\nu\ X$ 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)



Triggering on displaced tracks

- Level 2: Silicon Vertex Trigger
  - Use silicon detector information
    - Good IP resolution
    - Trigger on displaced track
  - Beamline reconstruction
    - update every ~ 30 seconds
  - IP resolution: ~ 50 µm
    - 33µm beam size + 35µm SVT



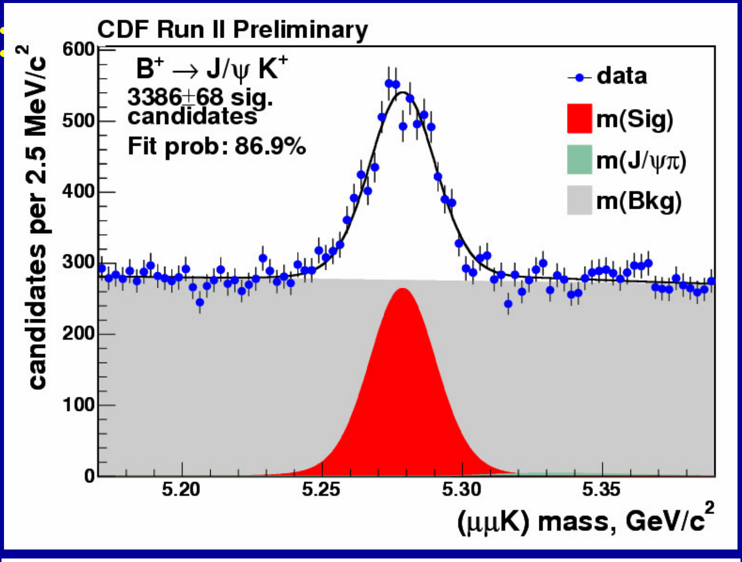
35µm ⊕ 33µm
resol ⊕ beam
⇒ σ = 48µm

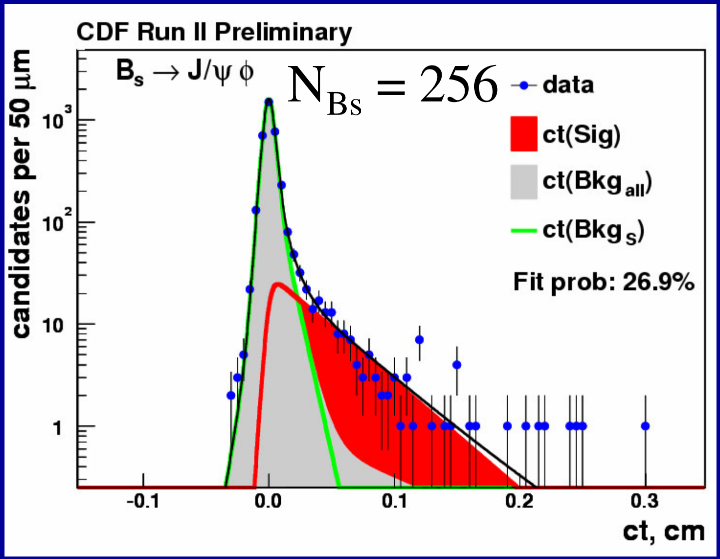
Lifetimes with J/ψ K modes

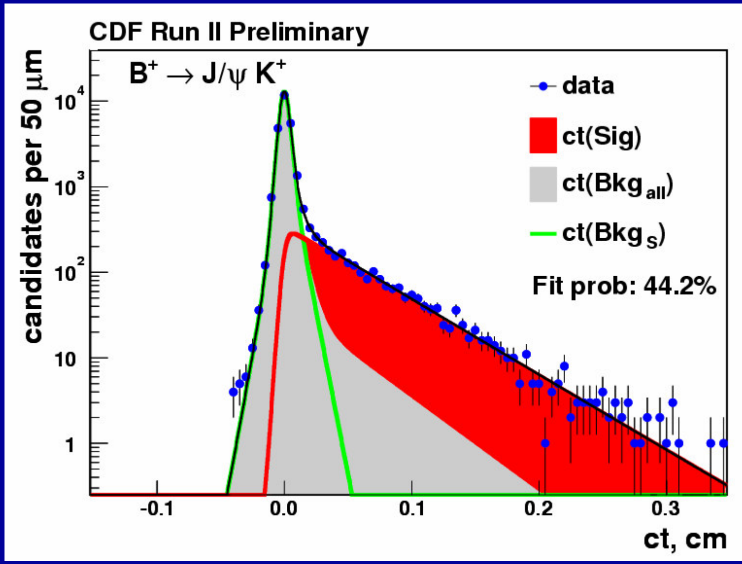
- Cleanest channels, but statistics limited:
  - Best Tevatron results from CDF (240 pb^{-1})
    - $B^+ \rightarrow \psi K^+$, $B^0 \rightarrow \psi K^*$, K^0_S, $Bs \rightarrow \psi\phi$
  - Main background from prompt ψ + tracks
  - No kinematic uncertainty
  - Systematics at level of B factories

$\tau(B^+)$ = **1.662±0.033±0.008**, $\tau(B^0)$ = **1.539±0.051±0.008**

$\tau(Bs)$ = **1.369±0.100±0.009**







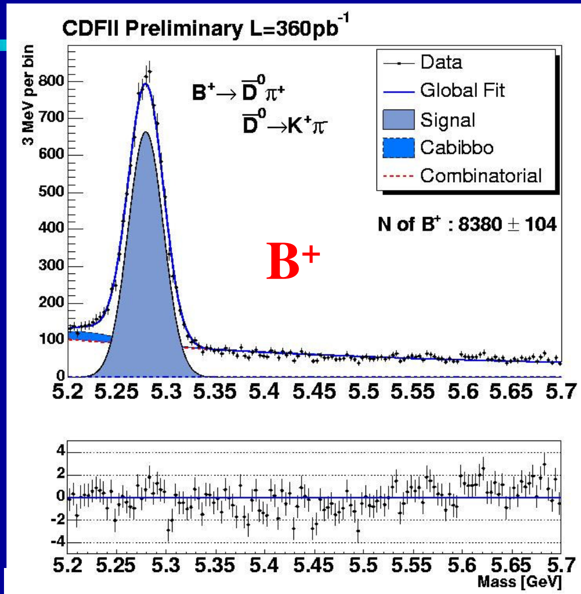
Lifetimes with hadronic decays

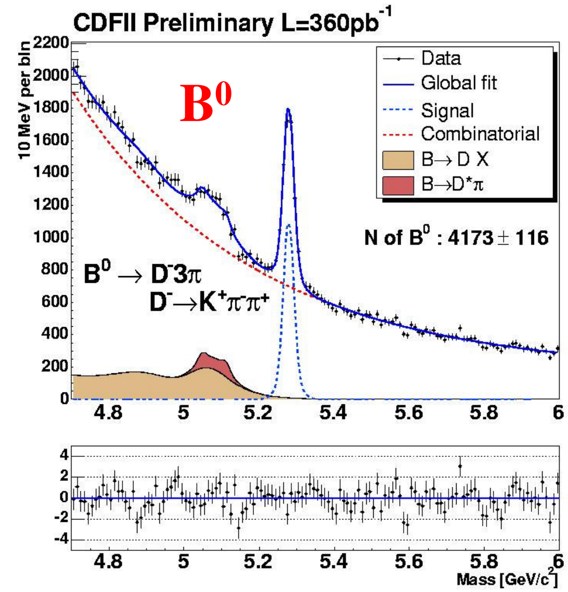
- More statistical power than J/ψ modes
  - Slightly larger systematics
    - Efficiency curve
    - backgrounds

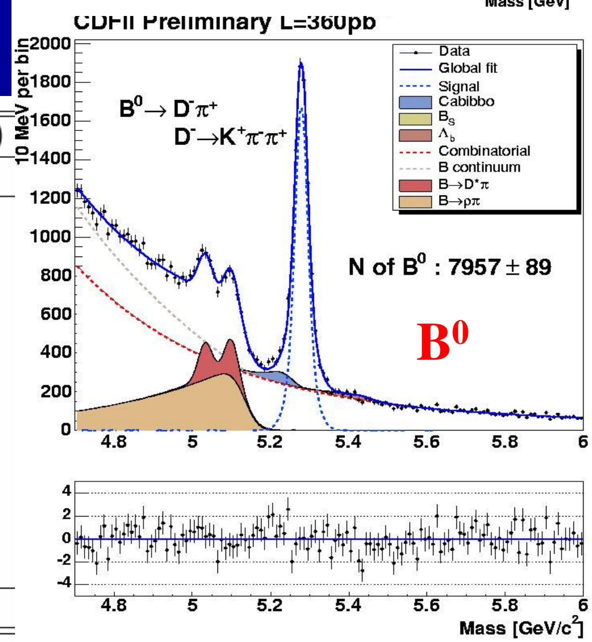
$\tau(B^+) = 1.66 \pm 0.03 \pm 0.01$ ps
$\tau(B^0) = 1.51 \pm 0.02 \pm 0.01$ ps
$\tau(B_s) = 1.60 \pm 0.10 \pm 0.02$ ps

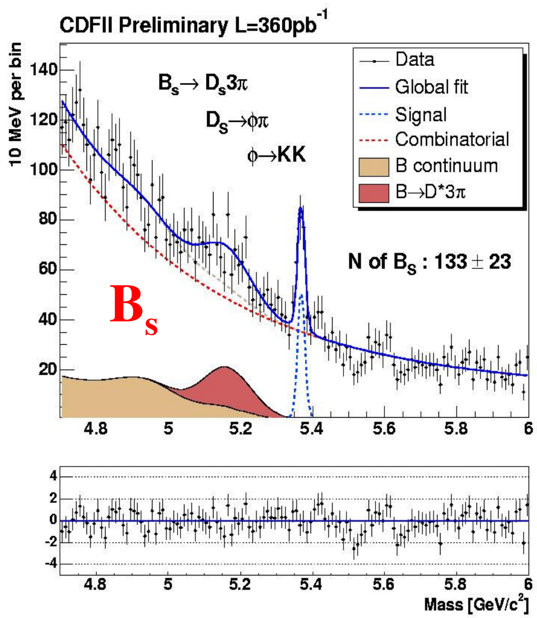
Systematics (μm)

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



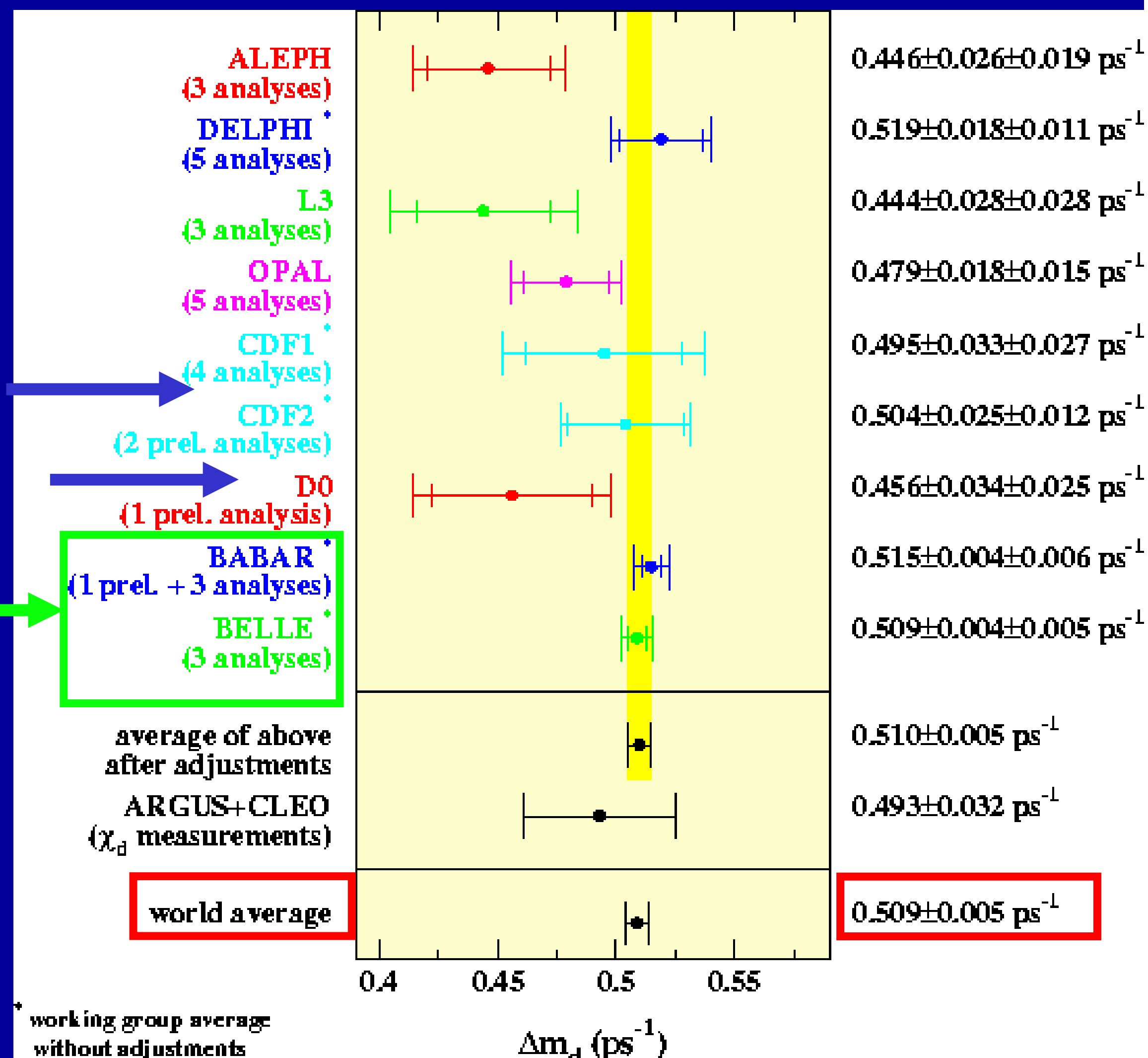






B_d Mixing

- HFAG Summary based on results presented in Winter 2005
- World Average dominated by BaBar/Belle

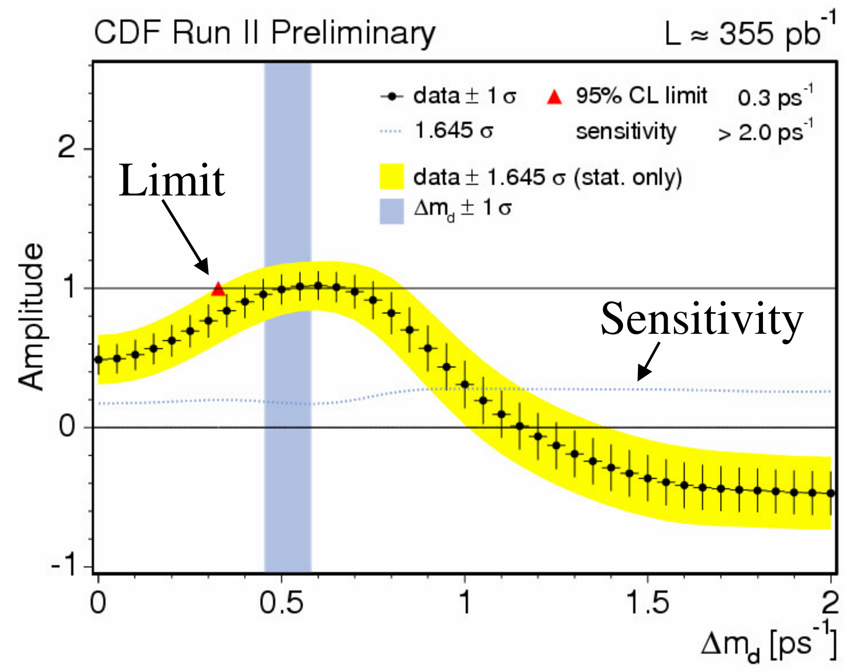


B_d Mixing

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

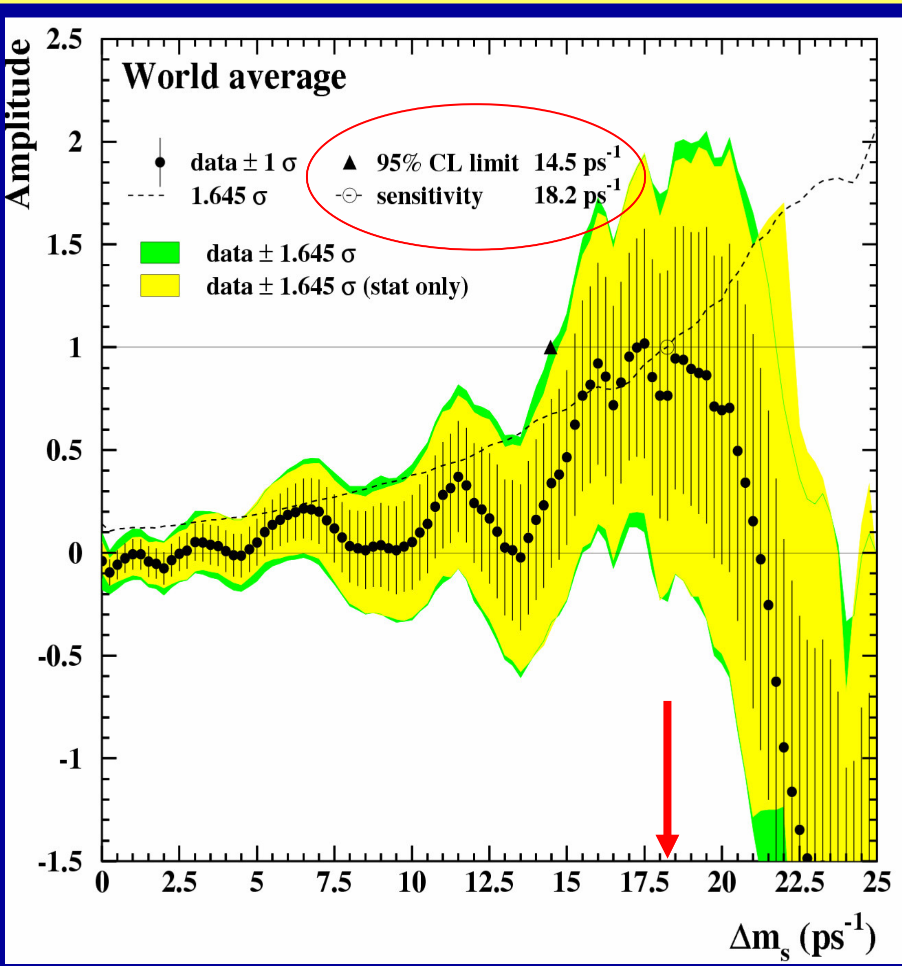
Tagger	CDF had %	CDF semi %	D0 semi %
OST μ	0.46	0.50	1.07
OST e	0.18	0.28	
OST jet	0.49	0.61	
Total OST	1.13±0.18	1.38±0.10	1.07



Bs mixing

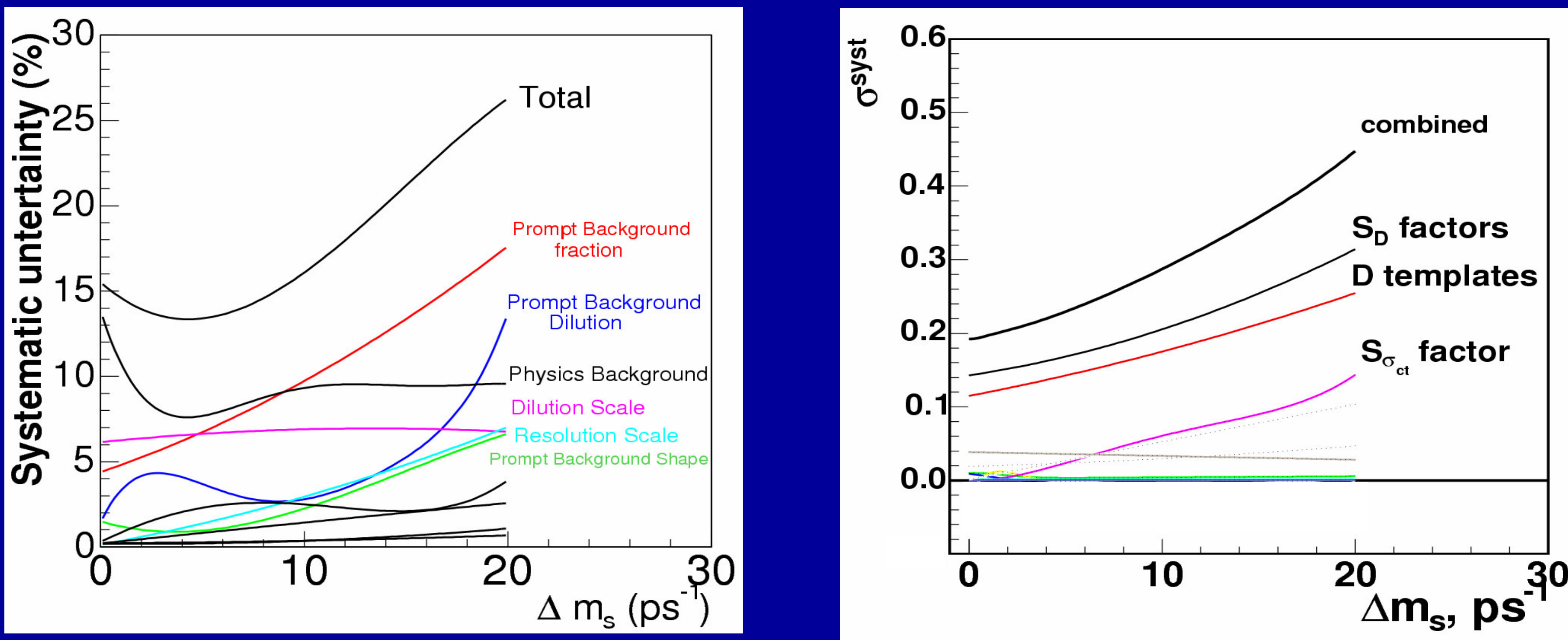
SM Fit (2004): $\Delta m_s = 18.3 \pm 1.6\ ps^{-1}$

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



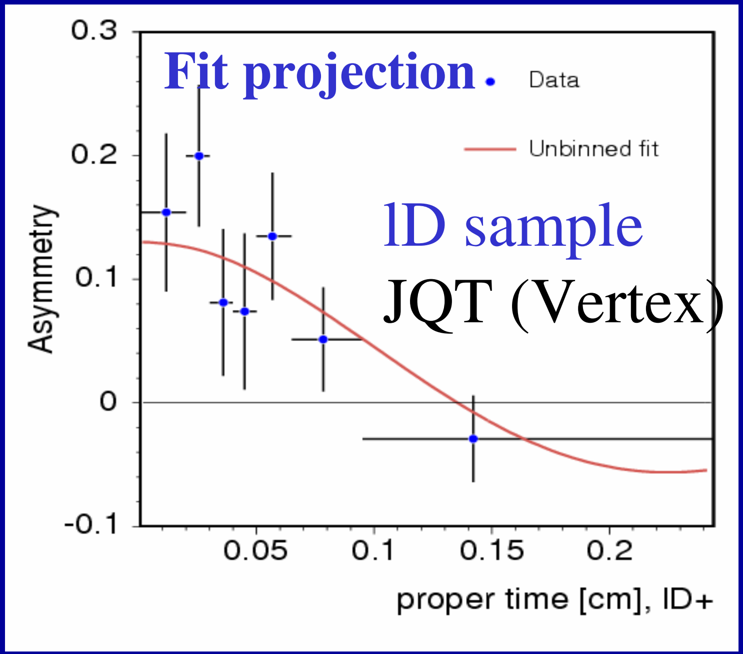
Systematics in B_s Mixing

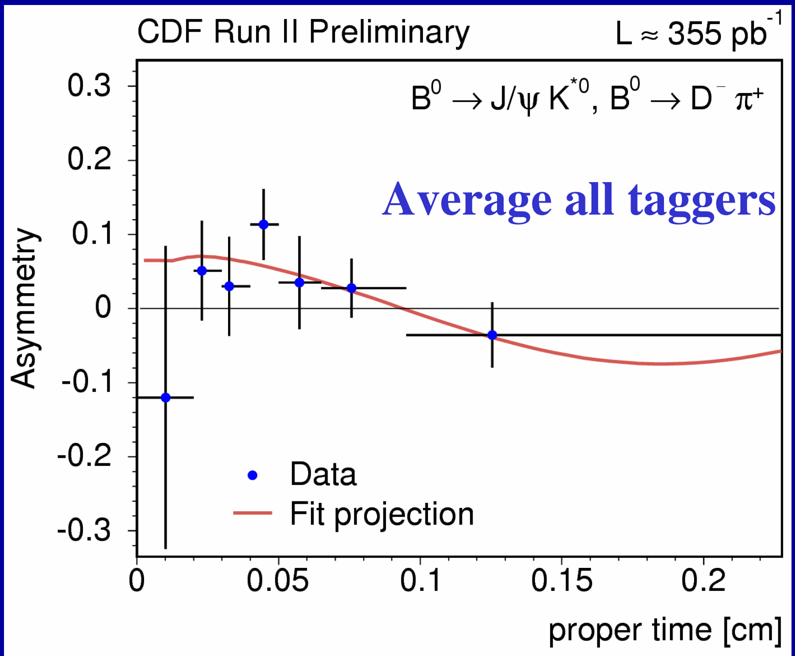
Semi-leptonic **Hadronic**



B_d mixing

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



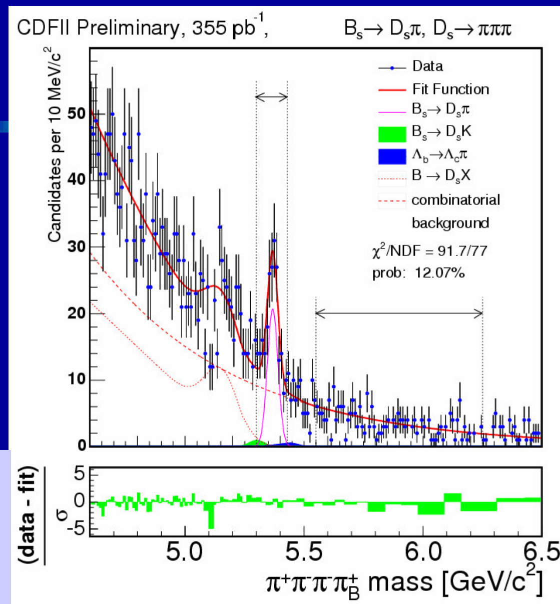


CDF: Bs signals

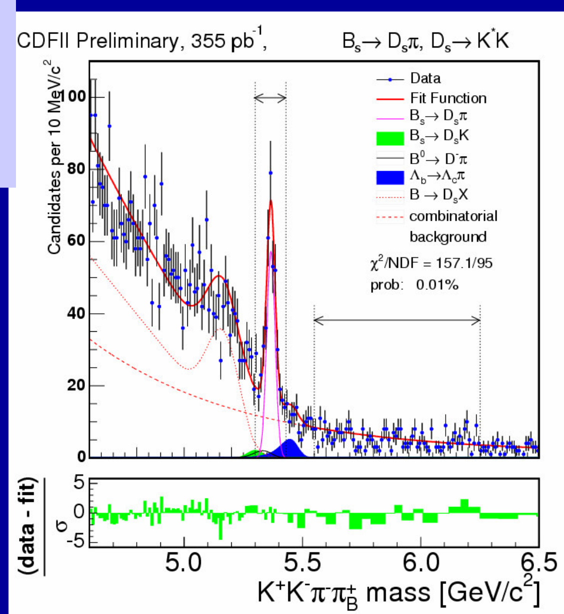
Hadronic samples

Wide range

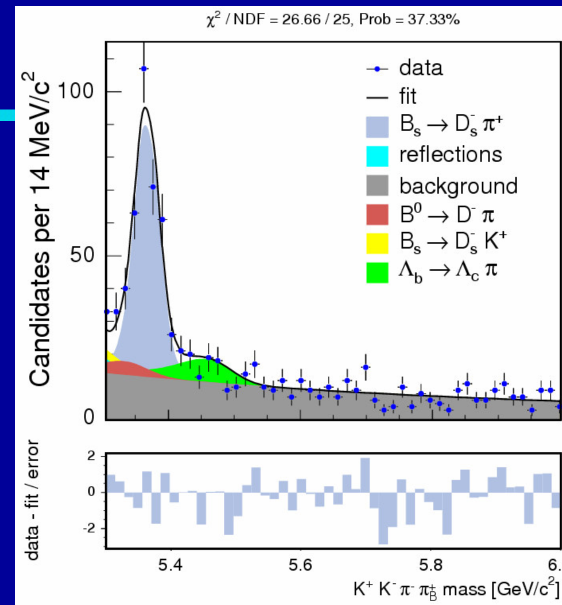
3π →

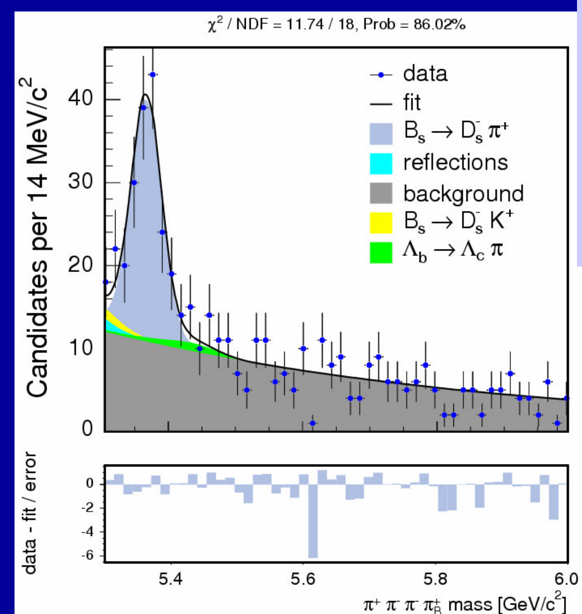


K*K →



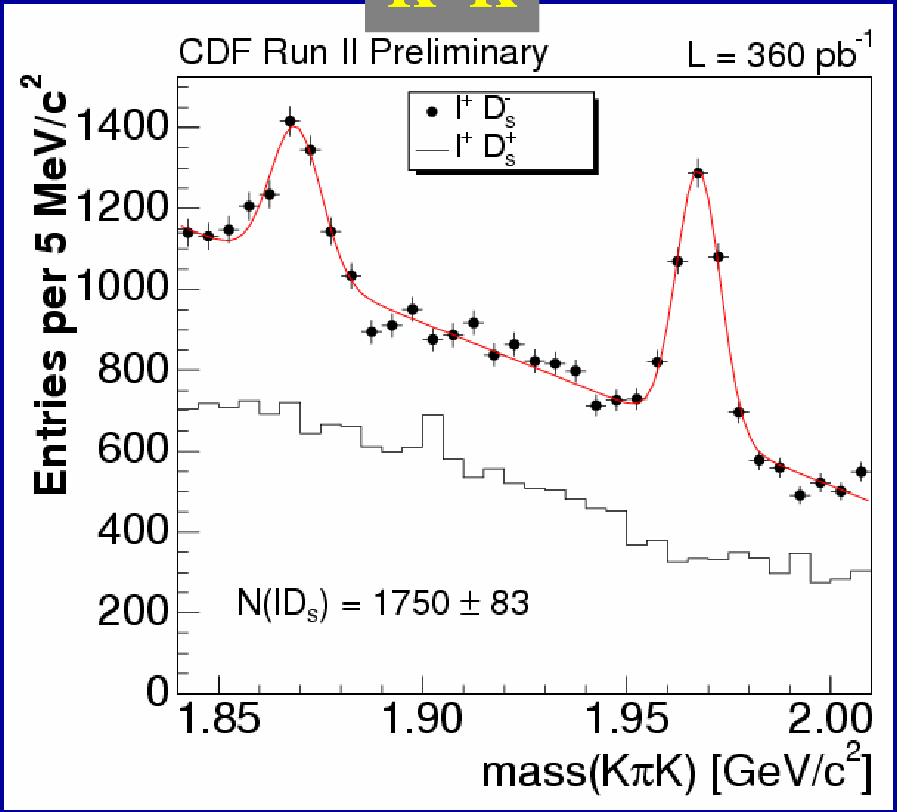
Fit projection



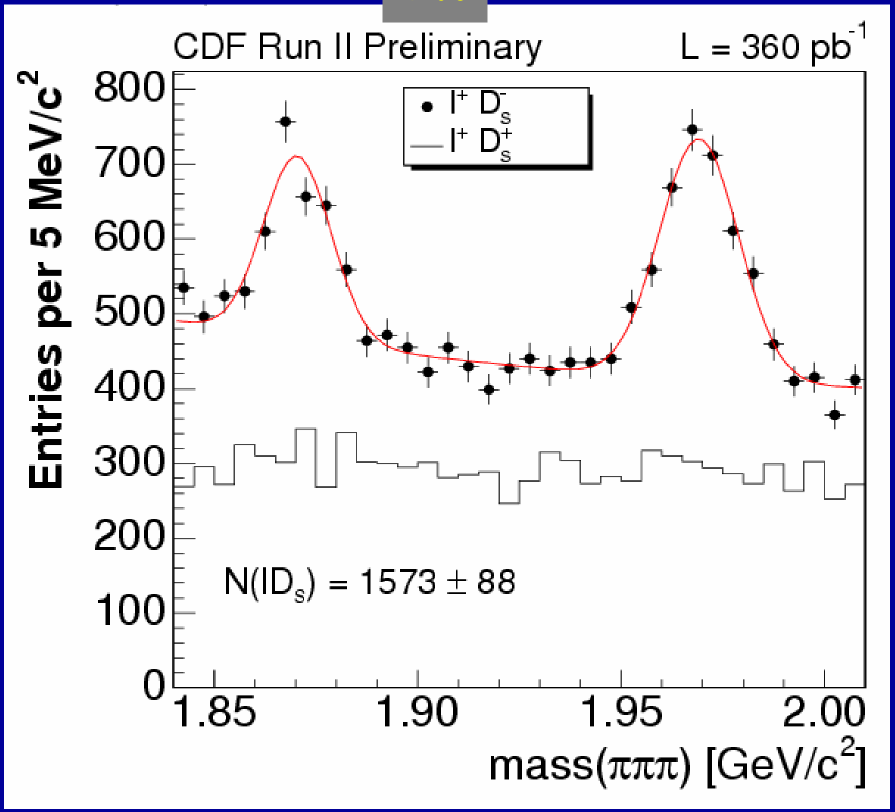


CDF: Bs signals semi-leptonic samples

K*K

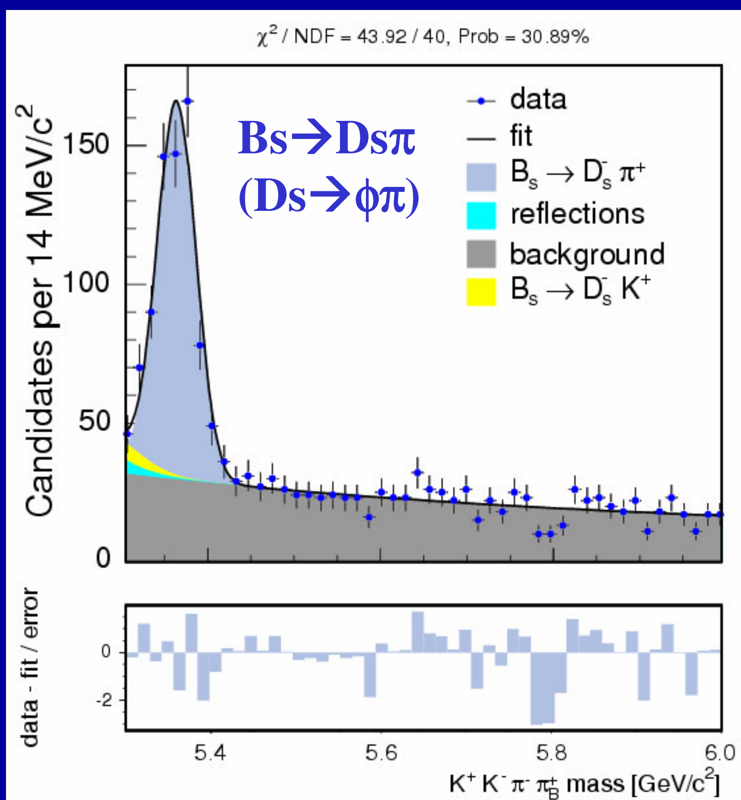


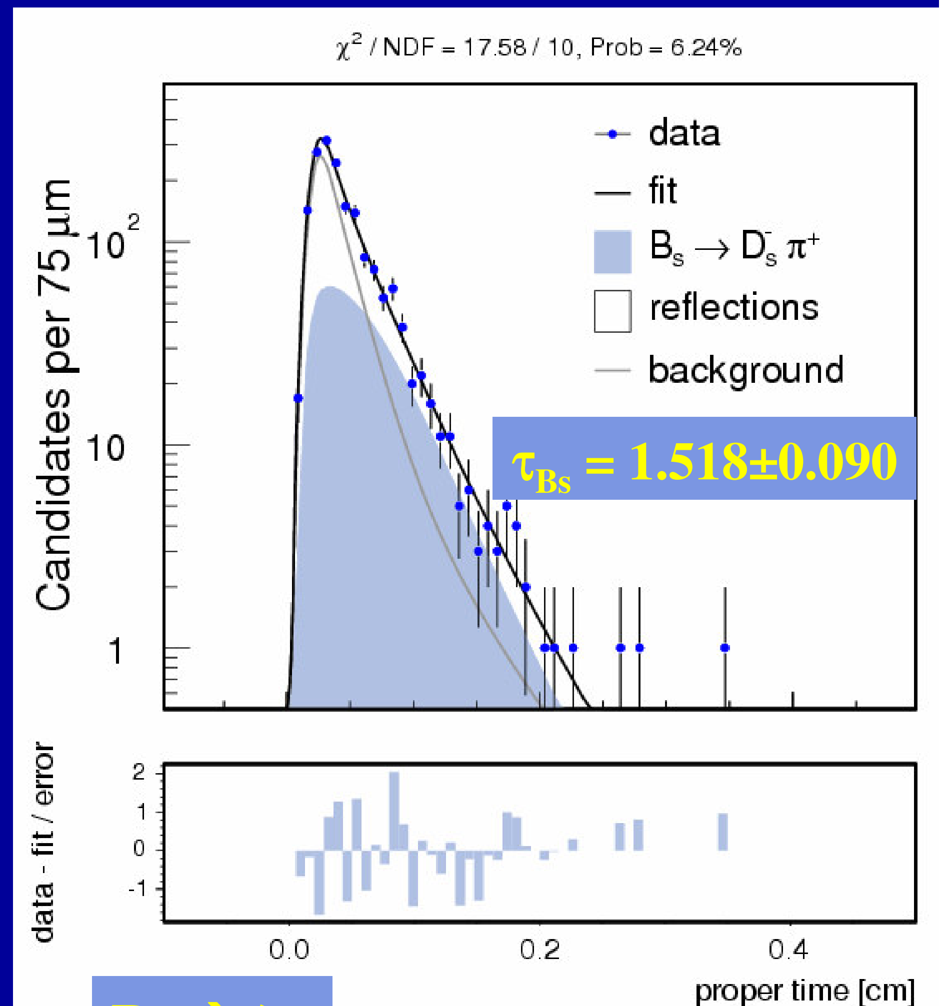
3π



CDF: Bs mixing (cross-checks)

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



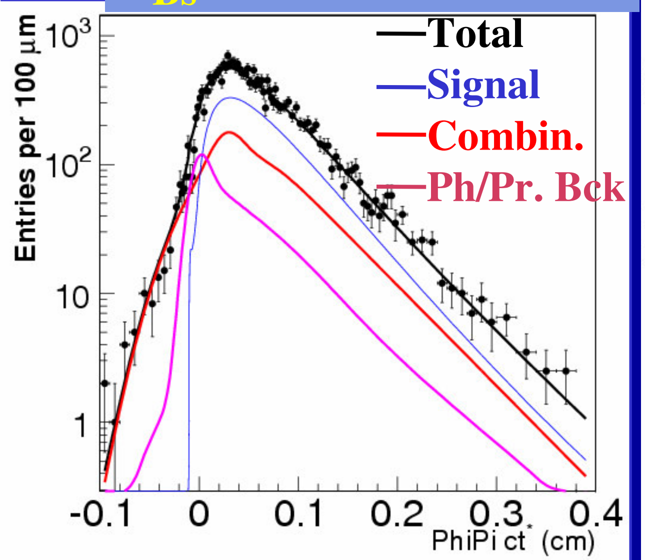


Ds→φπ

CDF: Bs lifetime checks semi-leptonic sample

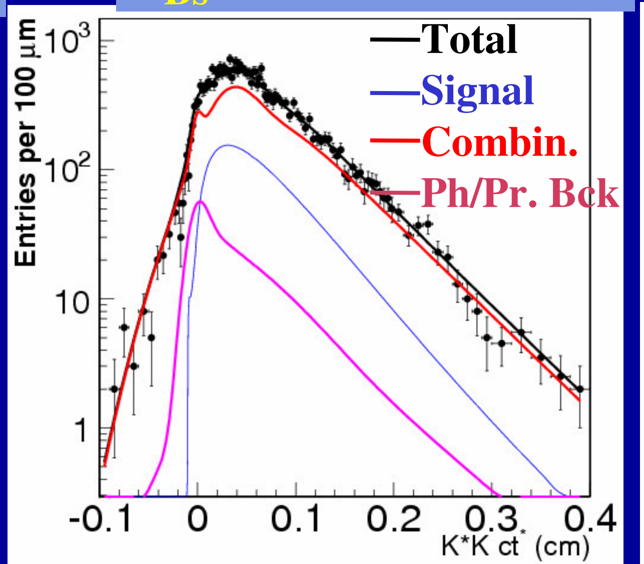
- Raw lifetimes from mixing fit – not good for averaging
  - Average: τ_B = **1.477±0.032 ps** no systematics evaluated
    - **D0:** τ(Bs) = **1.420±0.043±0.057 ps**, **WA:** τ(Bs) = **1.469 ± 0.059 ps**

τ_{Bs} = 1.521±0.040



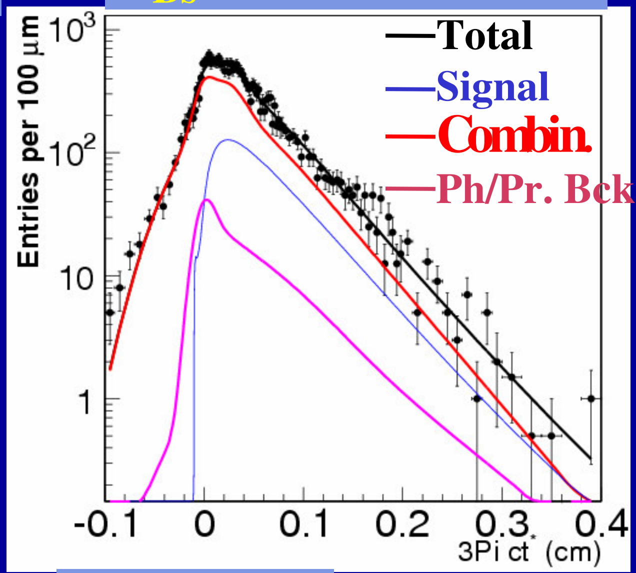
Ds→φπ

τ_{Bs} = 1.381±0.067



Ds→K*K

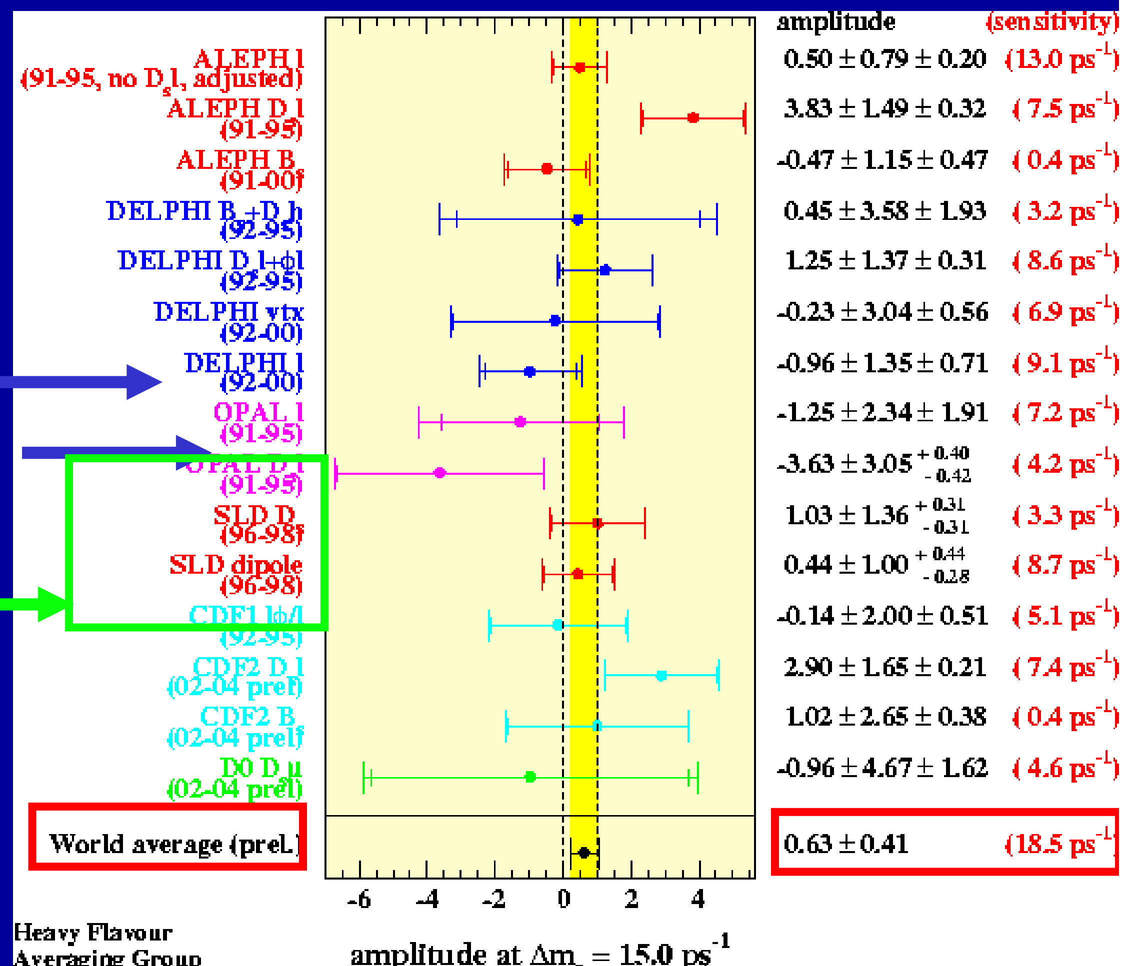
τ_{Bs} = 1.410±0.086



Ds→πππ

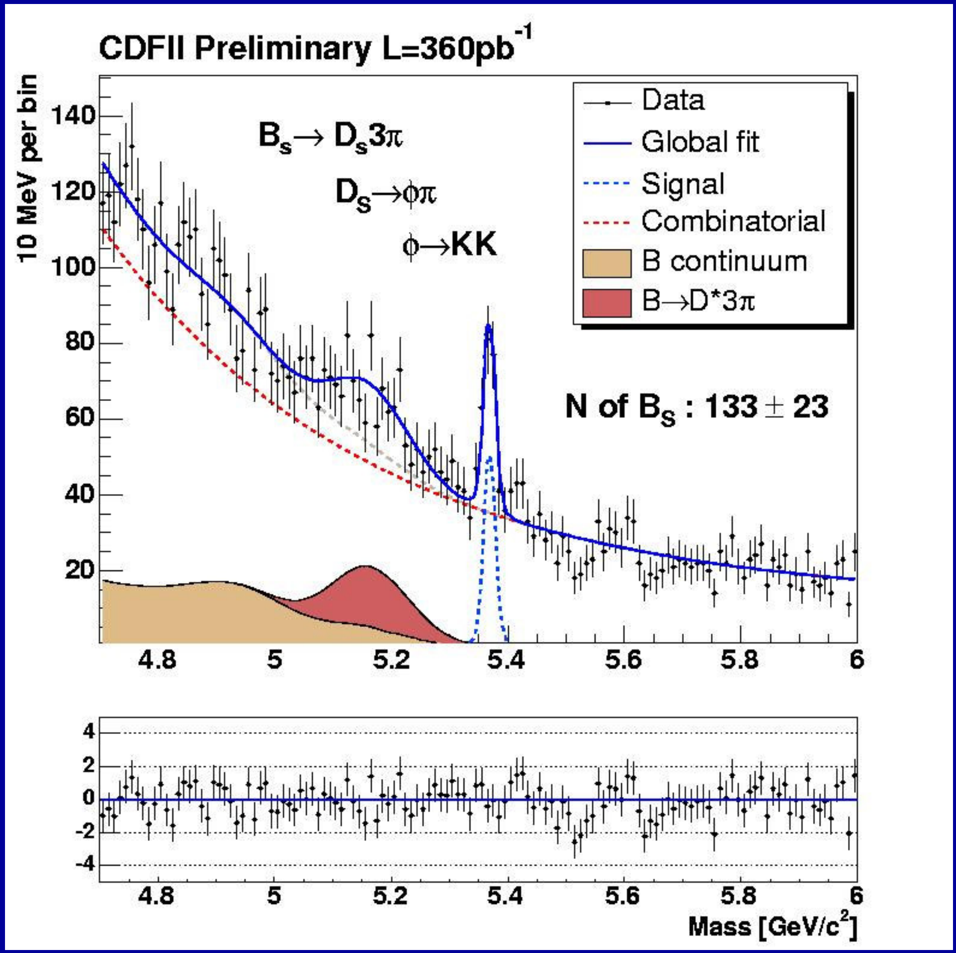
B_s Mixing

- HFAG Summary Based on result presented in Winter 2005

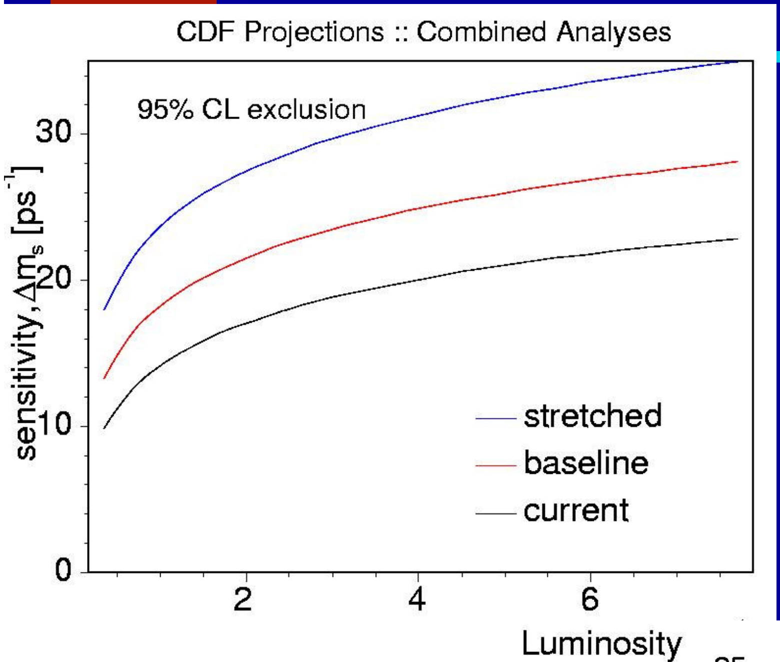


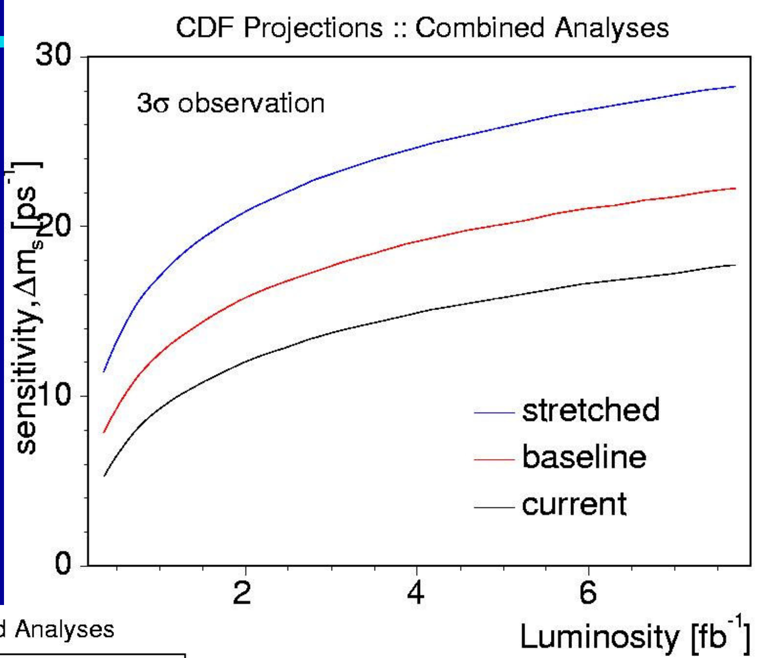
Future Mixing Improvements

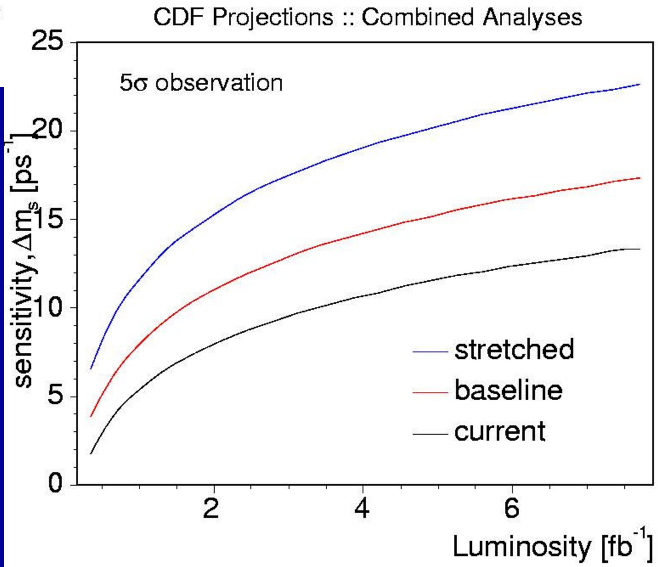
- Include Same Side (Kaon) Tagging
  - Expect twice tagging power than OST combined
- Improve accuracy of primary vertex
- Add more channels:
  - Bs→Ds3π
  - Bs→Ds*π, Bs→Dsρ+
    - Partial reconstruction can treat as semi-leptonic case



Mixing Prospects

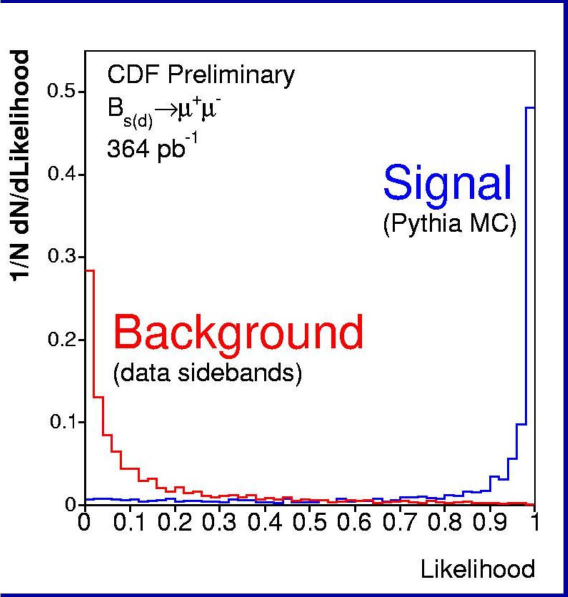






$B_{s(d)} \rightarrow \mu\mu$

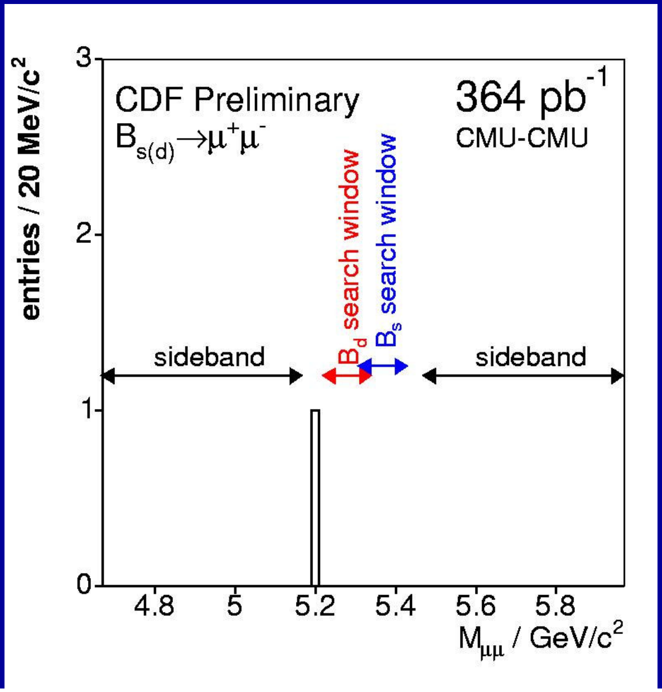
Multi-variate Relative Likelihood Discriminant

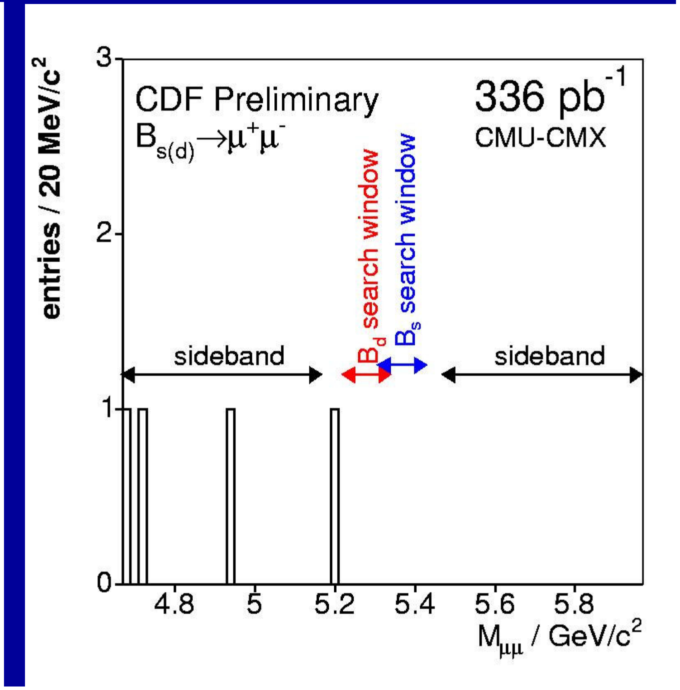


$p_T(B)$ > 4 GeV/c
LH > 0.99

N_{bkg} expected: 0.81±0.12
ses: (1.0±0.2) x 10^{-7}

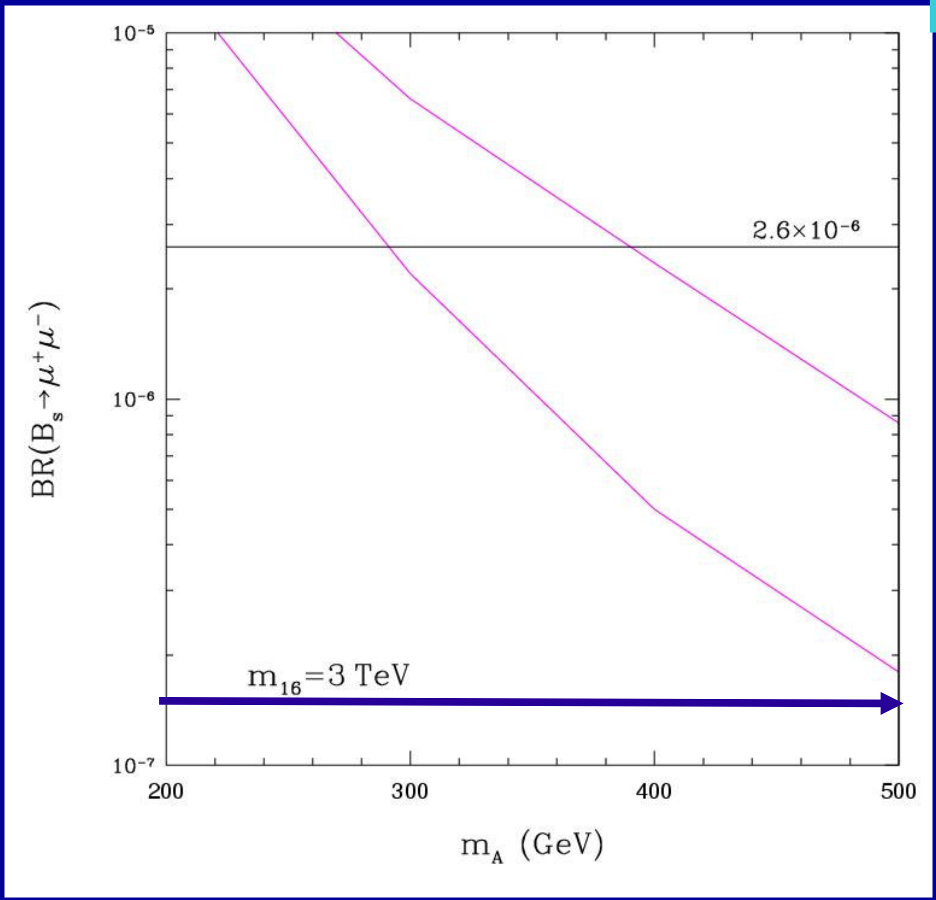
N_{bkg} expected: 0.66±0.13
ses: (1.6±0.3) x 10^{-7}





$B_{s(d)} \to \mu\mu$: Physics Reach

- SUSY SO(10) Unification
  - Allows for massive neutrino
  - Relic density of cold dark matter



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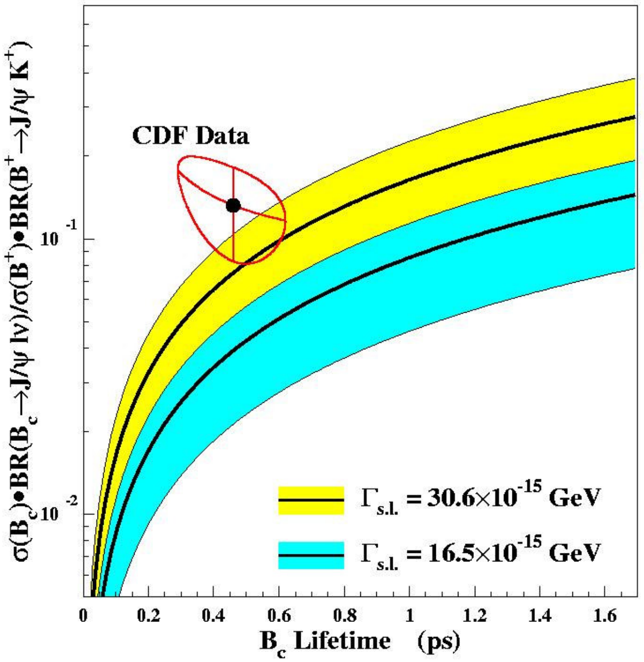
hep-ph/0304101

$B_c^{\pm} \rightarrow J/\Psi l^{\pm} \nu$

Run I, 110 pb^{-1}



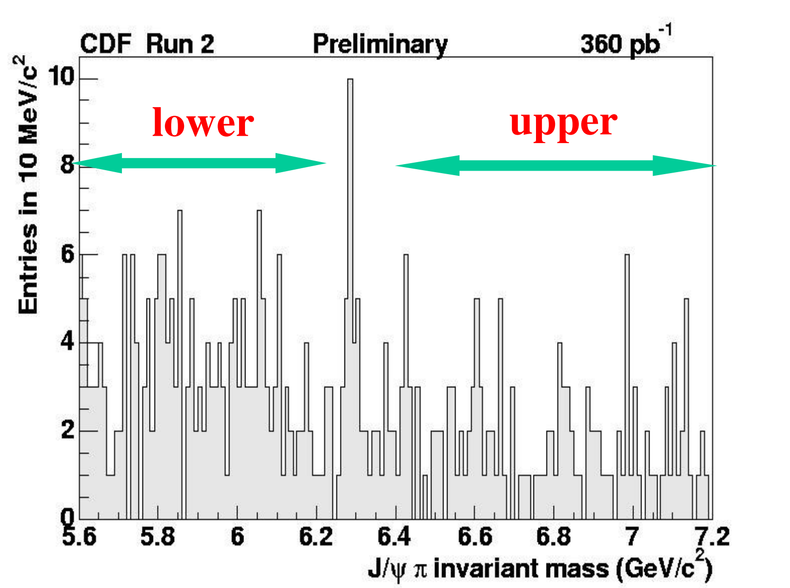
Production measurement

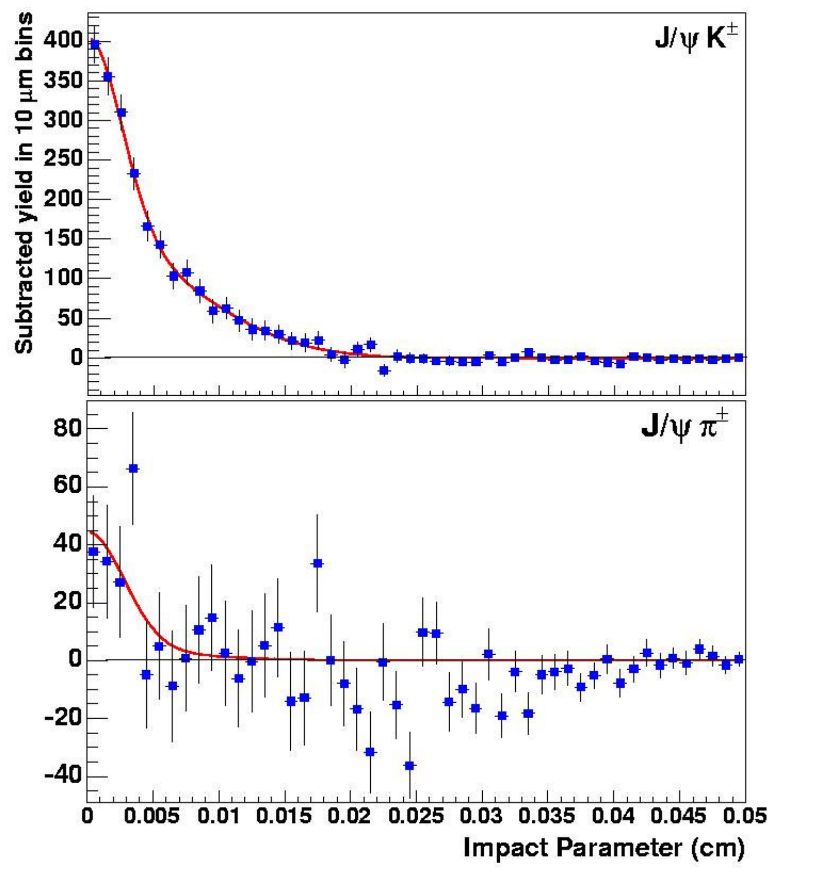
$$P_T(B) > 6\,\mathrm{GeV/c}; |\eta| < 0.6$$

$$\frac{\sigma(B_c) \times B(B_c \rightarrow J/\psi \ell \nu)}{\sigma(B_u) \times B(B_u \rightarrow J/\psi K)} = 0.132\,^{+0.041}_{-0.037}\,(stat) \pm 0.031(syst)\,^{+0.032}_{-0.020}\,(c\tau)$$

PRL 81, 2432 (1998), PRD 58, 112004 (1998)

$B_c^{\pm} \rightarrow J/\Psi\pi^{\pm}$





- Cross check: Look for partially reconstructed B_c decays below the peak.
  - Relax cuts. Compare upper and lower sidebands. Use $B^{\pm}$ as reference. Expect to see partially reconstructed B_c decays in lower sideband.
  - Use J/ψ vertex as reference; look at events where the 3rd track is common to the J/ψ vertex.

See an excess in B_c data that is similar to $B^{\pm}$ data.

172 ± 49 (stat) ± 15 (syst) events

Masses

- Run II results ~ or better of current world averages
  - CDF has very good results due to excellent tracking resolution
  - Close to being systematics dominated

B hadron species	Mass (MeV/c^2) CDF Run II (04-05)	Mass (MeV/c^2) PDG 2004 average	PDG Reference
B^+	**5279.1 ± 0.41 ± 0.36**	5279.1 ± 0.5	CLEO2 (00), CDF(96)
B^0	**5279.6 ± 0.53 ± 0.33**	5279.3 ± 0.7	CLEO2 (00), CDF(96)
B_s	**5366.0 ± 0.73 ± 0.33**	5369.6 ± 2.4	CDF(96), LEP
Λ_B	**5619.7 ± 1.2 ± 1.2**	5624 ± 9	CDF(97), LEP
B_c	**6287.0 ± 4.8 ± 1.1**	6400 ± 390 ± 130 6320 ± 60	CDF(98) - Semileptonic OPAL(98) - $J/\psi\pi$