CDF hot topics

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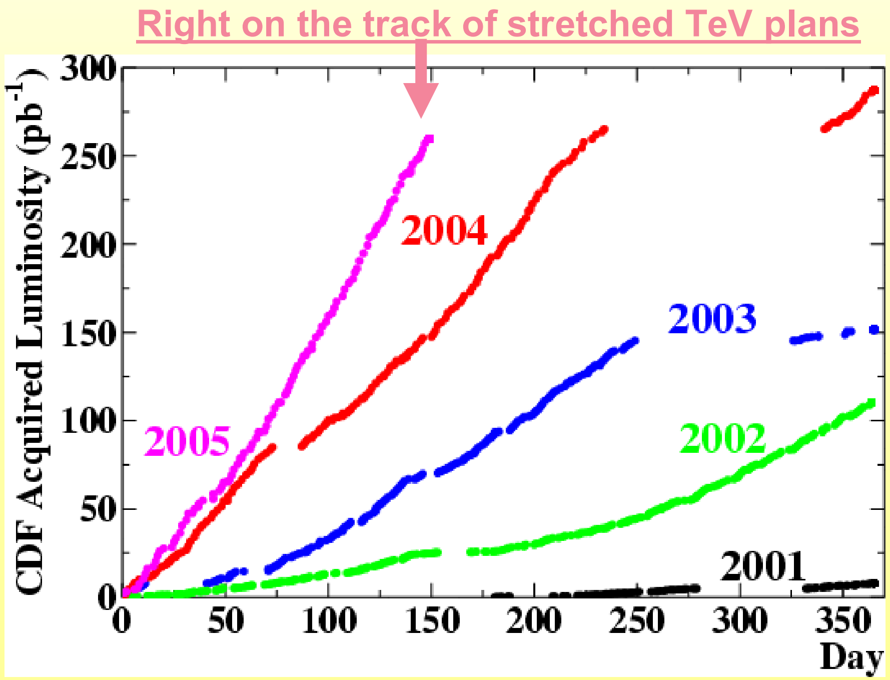
FNAL & INFN Roma 1

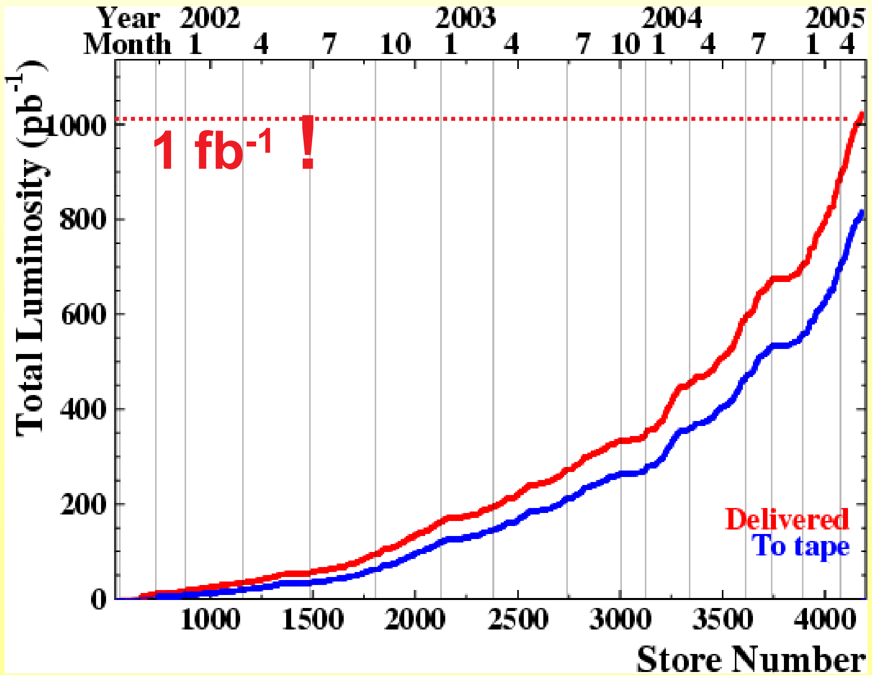
Outline

- Tevatron performances
- CDF detector and B physics triggers
- Recent and new results:
  - **B_s mixing**
  - **b-hadrons Lifetimes & $\Delta\Gamma_s/\Gamma_s$**
  - **Λ_b modes**
  - **Charmless $B_{d,s}$ decays**
  - **Rare decays**
- Summary and perspectives

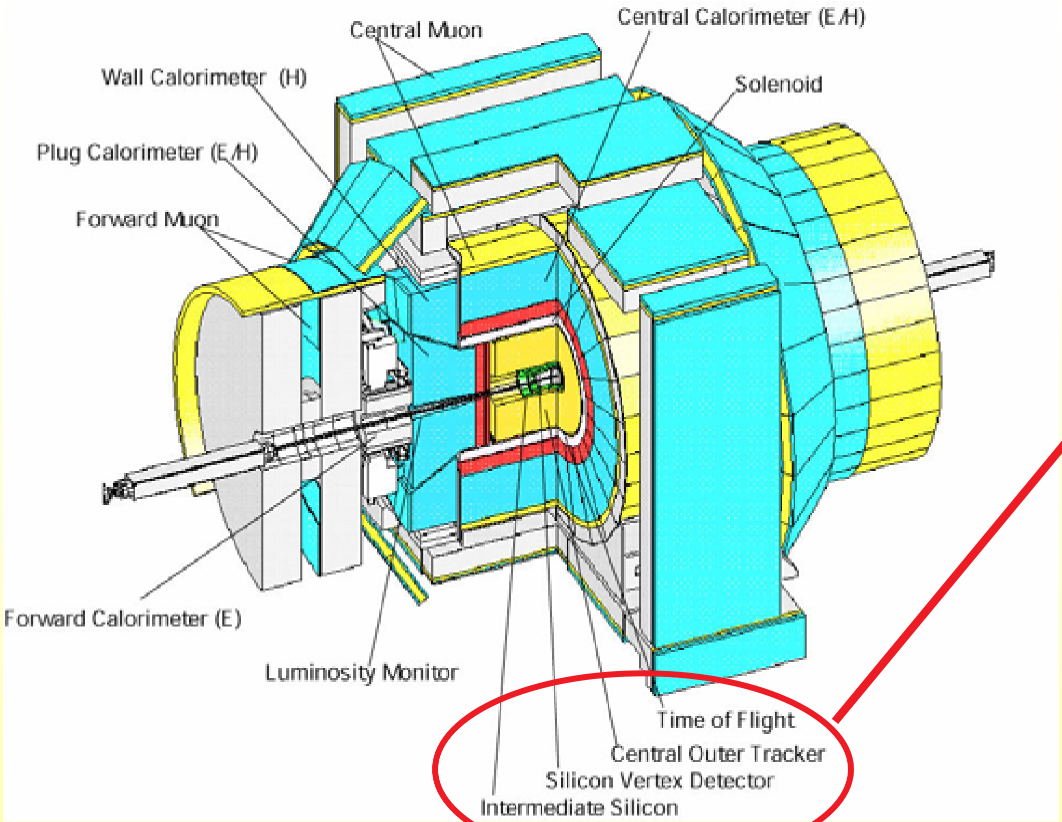
Tevatron performances

- CDF II has collected so far ~ 0.8 fb^{-1} out of >1 fb^{-1} delivered by Tevatron.
- Record peak luminosity is ~ $1.3 \cdot 10^{32}\ cm^{-2}s^{-1}$
- Around 600 pb^{-1} are available for B physics (good tracking detector conditions)
- Current analyses use 180 - 350 pb^{-1} of integrated luminosity

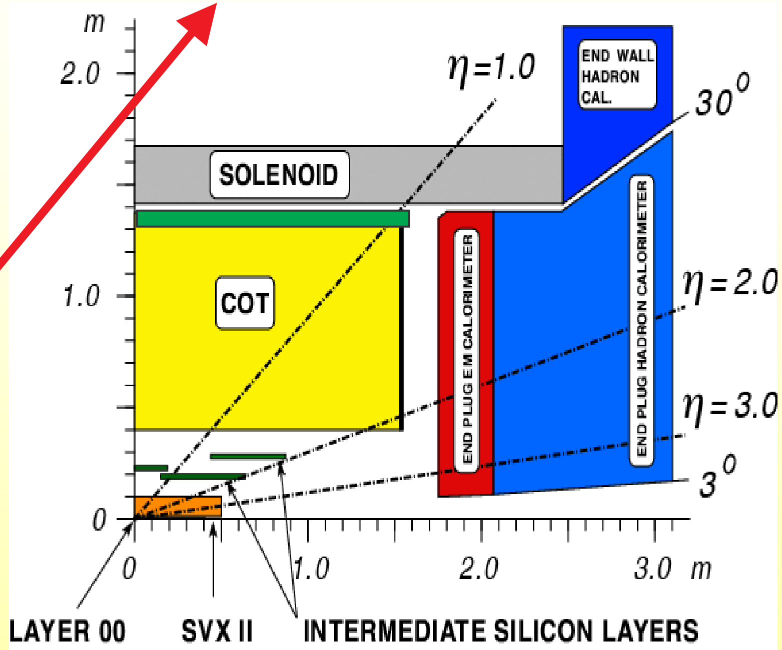




The CDF II detector



CDF Tracking System



Lepton ID

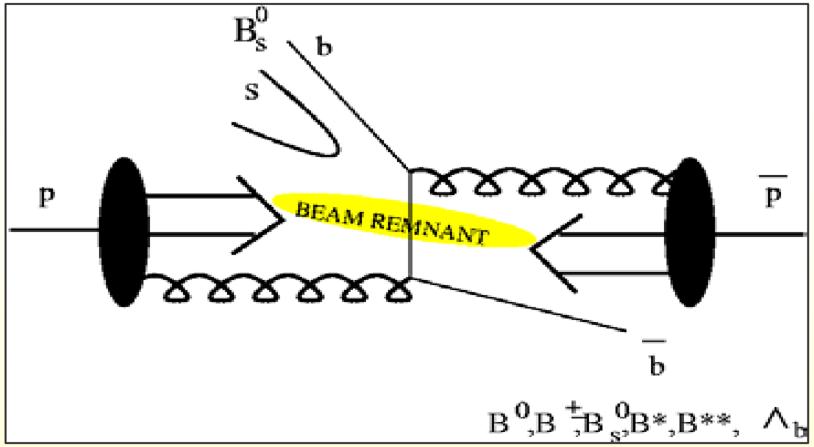
<u>Muons:</u> CMU, CMP, CMX ($|\eta|<1.1$)

<u>Electrons:</u> CEM (EM calorimeter)
CPR (pre-shower detector)

Particle ID

- dE/dX in **COT**
- **T**ime **O**f **F**light detector

B Physics at $p\bar{p}$ collider



- All *B* species produced:

  $B_u, B_d, B_s, B_c, \Lambda_b, \Xi_b \ldots$

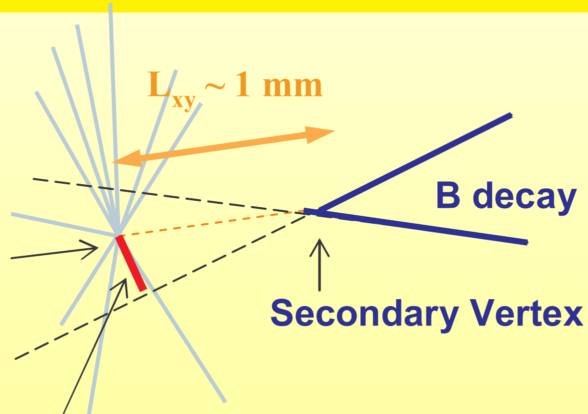
- With production fractions:

$f_u : f_d : f_s : f_\Lambda \approx 4 : 4 : 1 : 1$

- Acceptance for other B is 20-40%

BUT: **σ(bb) << σ(pp) (~65 mb)** ⇒ **B have to be selected with specific Triggers**

Example:



the **Secondary Vertex Trigger SVT**

- Online (L2) selection of **displaced tracks** based on Silicon detector hits.

→ *see talk by Mauro Dell'Orso*

- b production is so large (~300 Hz @ 10^{32} cm^{-2} Hz) that we could not even cope with writing it all to tape! → trigger quasi-exclusively on specific decay modes

B physics triggers at CDF II

Conventional at colliders (Run I)

With SVT trigger

Di-Muon
(J/ψ)

$Pt(\mu) > 1.5$ GeV

J/ψ modes down to low $Pt(J/\psi)$~0 (Run II)

+

1-Displaced track
+ *lepton* (e, μ)

120 μm < I.P.(trk) < 1mm

P_T(*lepton*) > 4 GeV

Semileptonic modes

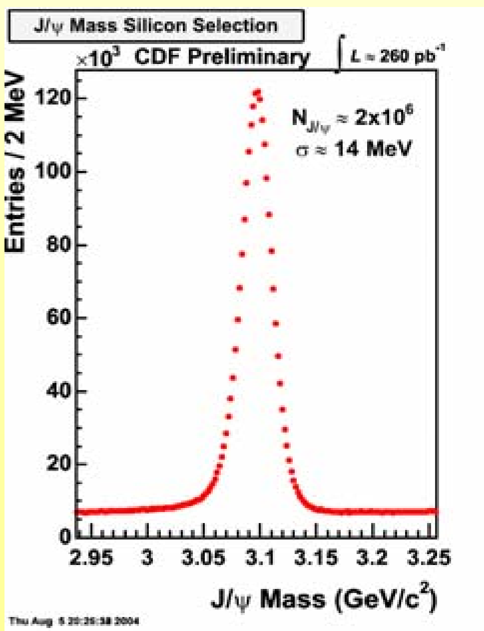
2-Displaced tracks

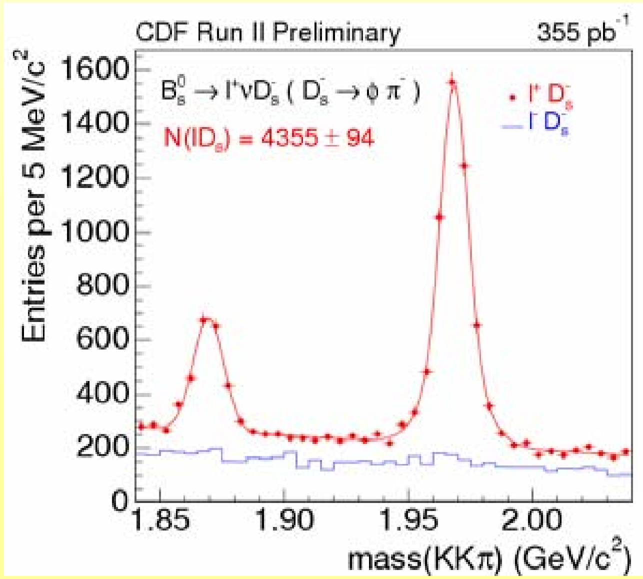
P_T(trk) > 2 GeV

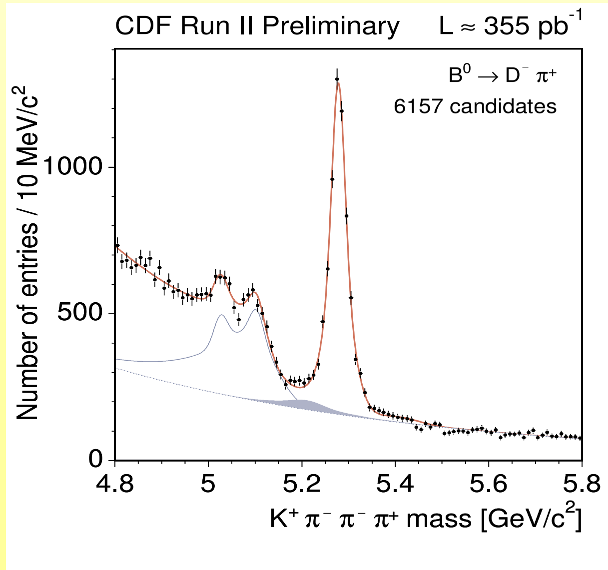
120 μm < I.P.(trk) < 1mm

Σp_T > 5.5 GeV

fully hadronic modes

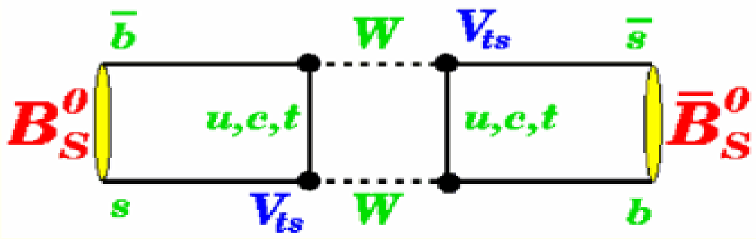






Mixing

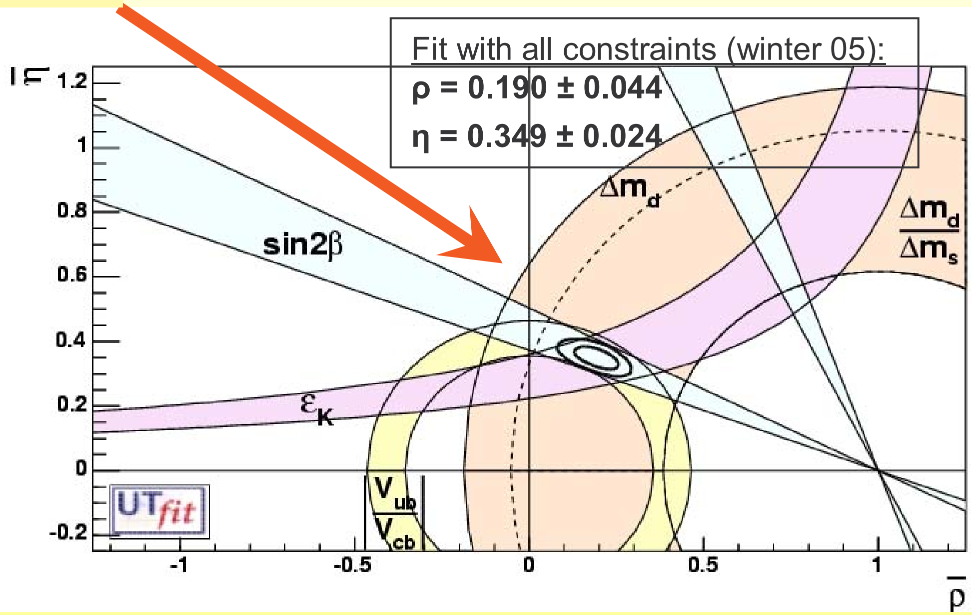
B_s Mixing



but: $|V_{ts}| >> |V_{td}|$ → $\Delta m_s >> \Delta m_d$

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{Bs}}{m_{Bd}} \frac{f_{Bs}^2 B_{Bs}}{f_{Bd}^2 B_{Bd}} \frac{|V_{ts}|^2}{|V_{td}|^2} = \frac{m_{Bs}}{m_{Bd}} \xi^2 \frac{|V_{ts}|^2}{|V_{td}|^2}$$

Measuring $\Delta m_s/\Delta m_d$ determines $|V_{ts}|/|V_{td}|$
Lattice calculation error O(5%)

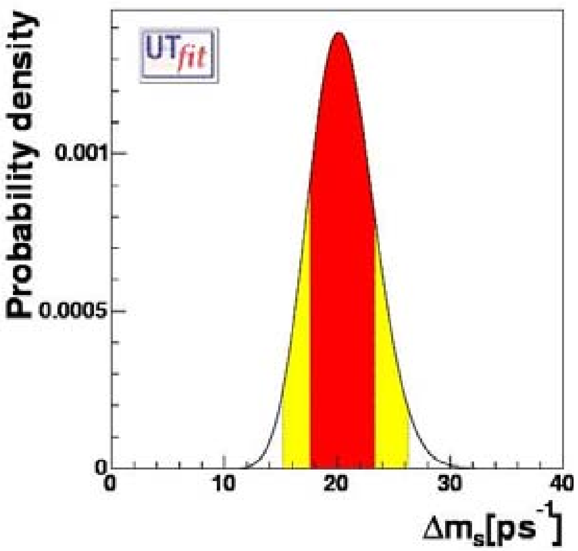


WA experimental limit:
$\Delta m_s > 14.5\ ps^{-1}$ (95%CL)
(LEP+SLD+CDF 1)

SM CKM-fit prediction for Δm_s

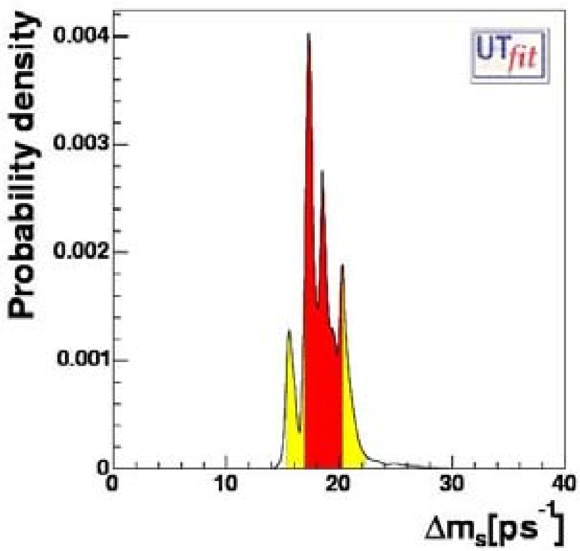
SM

(Δm_s not used)



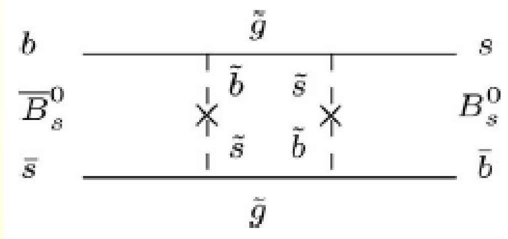
Δm_s = 20.5 ± 3.2 ps^{-1}
[14.4, 27.1] @ 95% CL

(with all constraints)

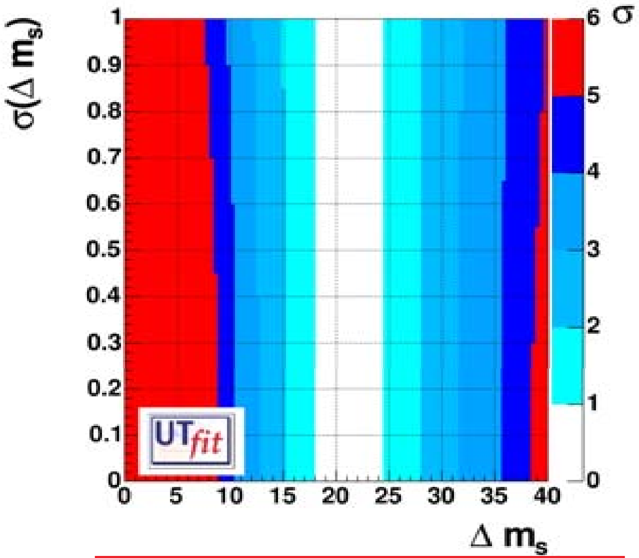


Δm_s = 18.9 ± 1.6 ps^{-1}
[15.7, 23.0] @ 95% CL

New Physics models can allow high Δm_s

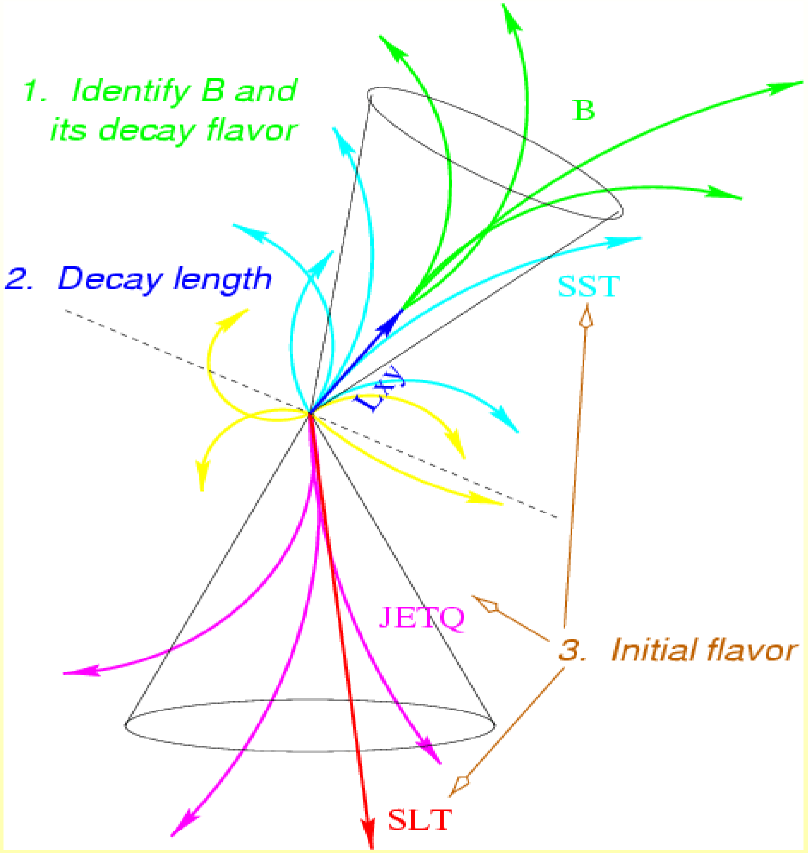


compatibility plot



If Δm_s > 30 ps^{-1}
New Physics @ 3σ

Analysis Strategy

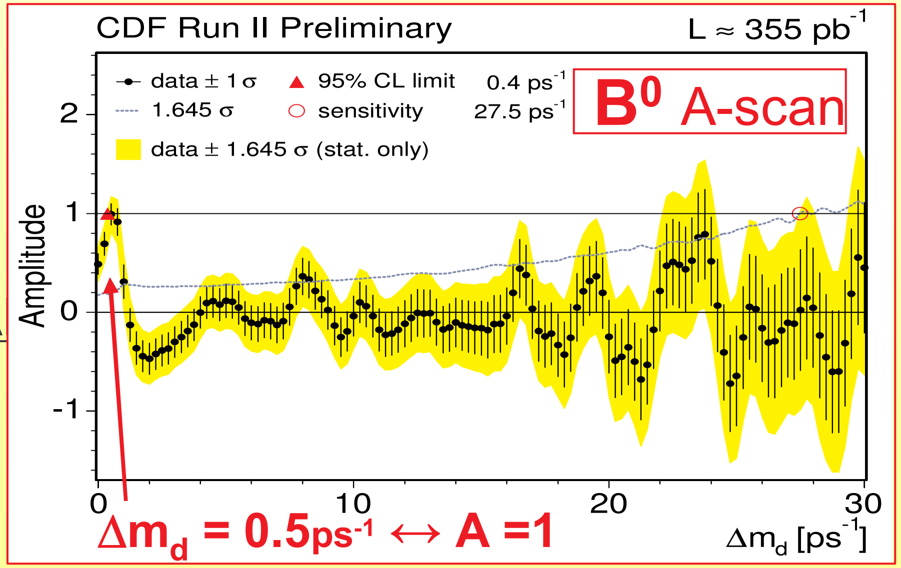


- B_s signal reconstruction
  - Flavour specific states
- B_s decay time
  - proper time reconstruction
  - **Lifetime** measurement
- Initial flavour of the B_s
  - **Flavour tagging** techniques
  - calibrate on B_d mixing

→ B^0 Mixing

perform a "Blind AMPLITUDE SCA

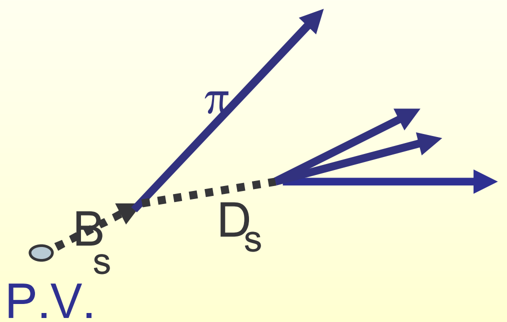
$$L^t_{sig} = \frac{1}{\tau} e^{-t/\tau} \left(1 \pm \mathbf{A}\, D \cdot S \cdot \cos(\Delta m t)\right)$$



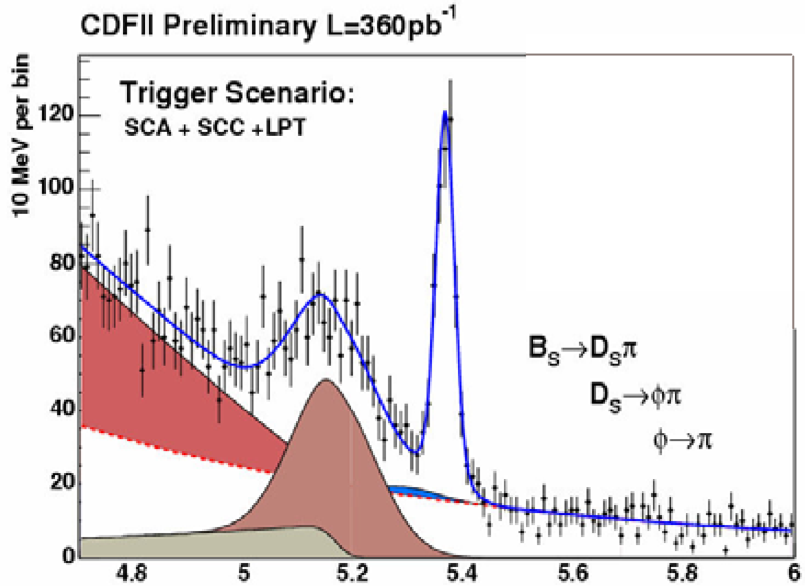
Two different B_s signatures:

Fully reconstructed HADRONIC modes:

- Good proper time resolution
- High B_s mass resolution
- Selected by Two Track Trigger (SVT)

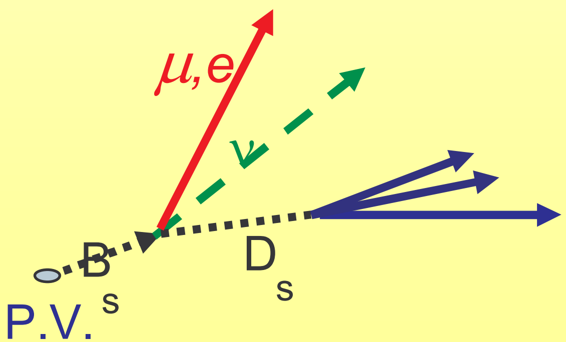


$$B_s^0 \to D_s^- \pi^+$$

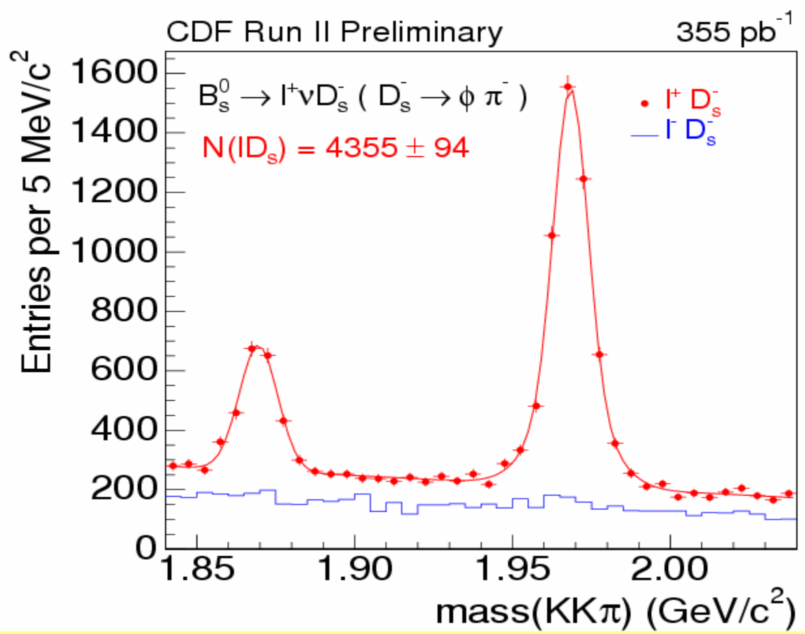


SEMILEPTONIC modes:

- Missing momentum carried by the ν
- Diluted proper time resolution
- Selected by dedicated trigger (l+SVT):



$$B_s^0 \to D_s^- l^+ \nu_l X$$



Flavour tagging

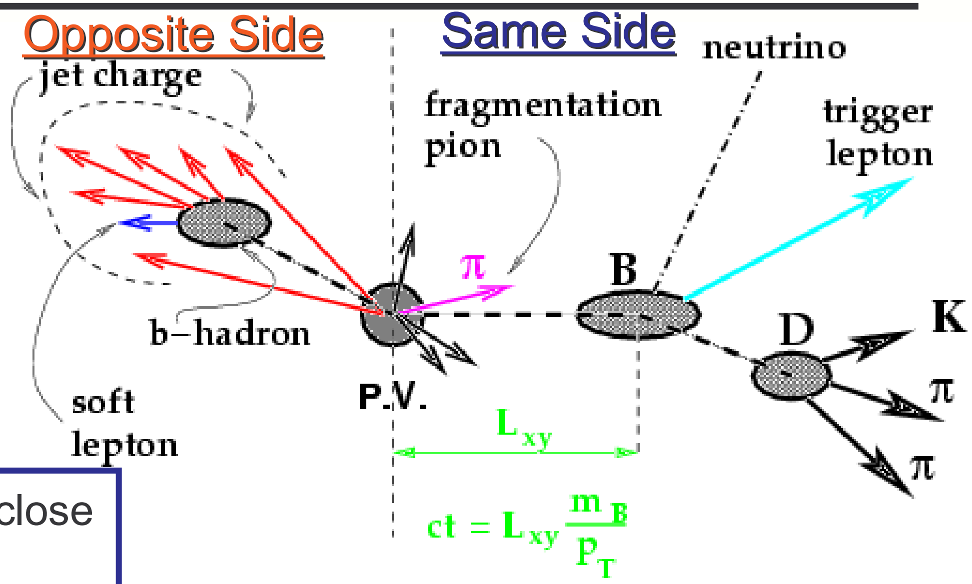
Used for today results

Jet Charge: the sum of **charges** of the **b-Jet** tracks correlated to the b-flavour

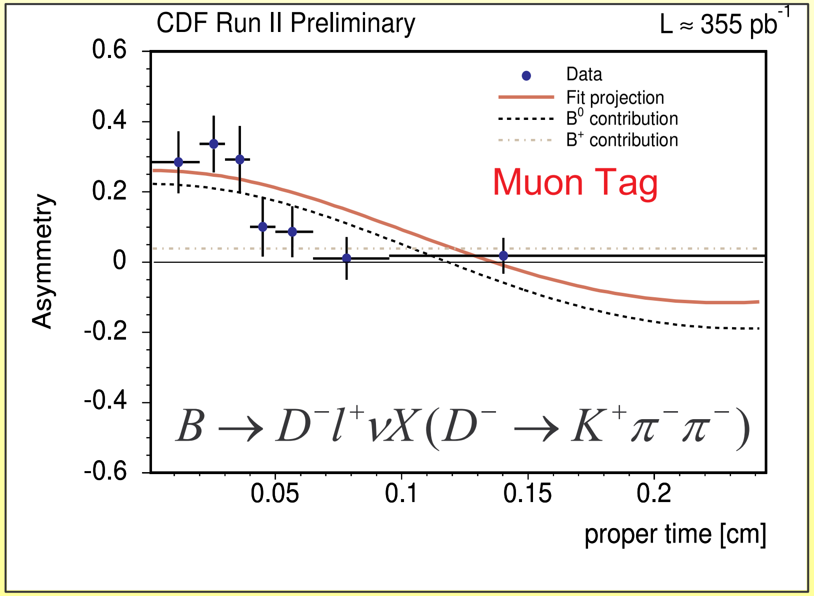
Soft Lepton (e,μ) due to **b→ℓνX**
ℓ charge correlated to b-flavour

NOT yet used

Same Side Kaon: for $\mathbf{B^0_s}$ is likely to have close in DR a **K+. High εD²** is expected

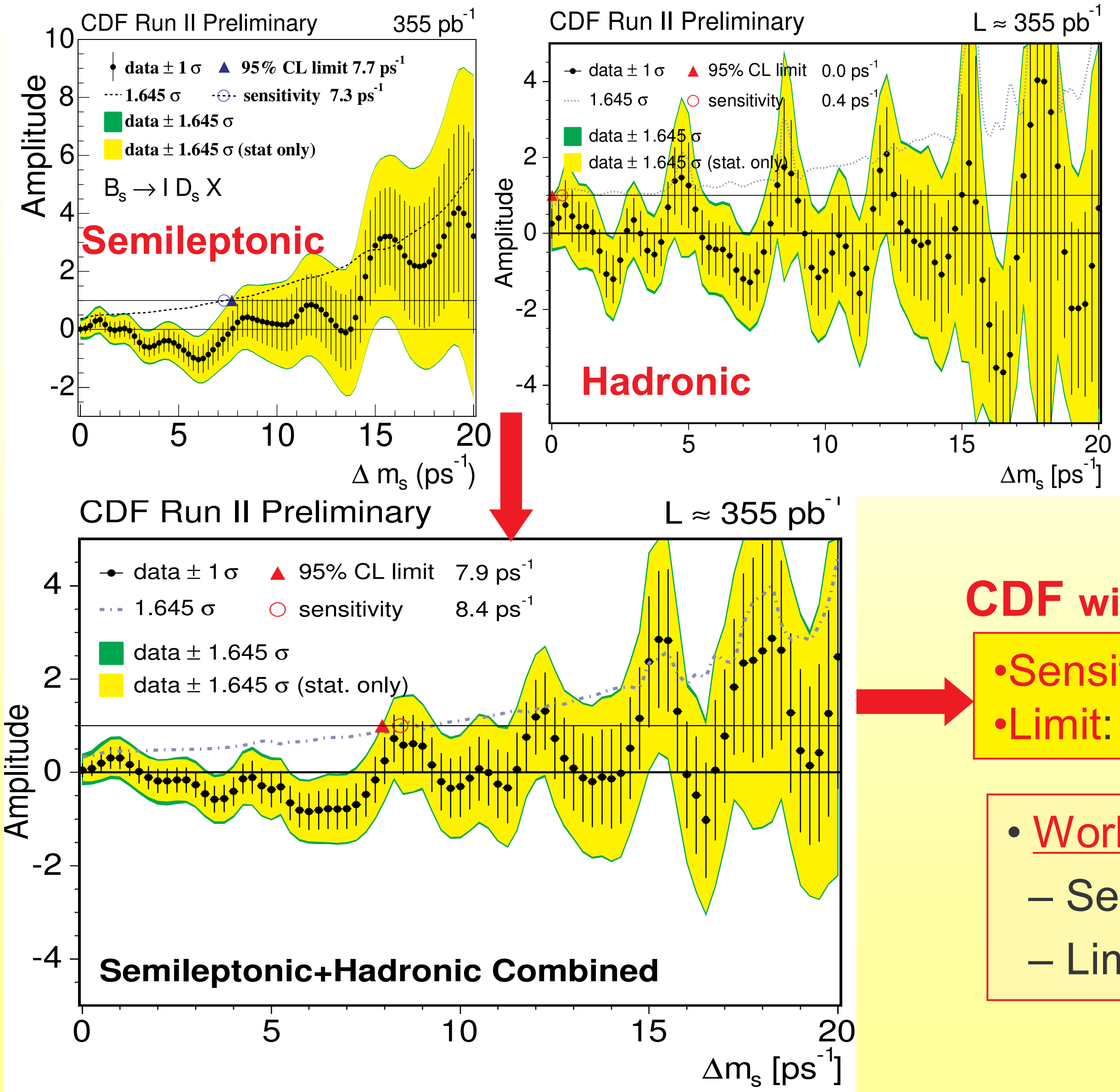


Calibrate the OS taggers on **B⁰ mixing** →



	HADRONIC	SEMILEPTONIC
Δm_d	(0.503±0.063±0.015) ps^{-1}	(0.498±0.028±0.015) ps^{-1}
Tot. εD²	(1.12±0.23)%	(1.43±0.09)%

B_s Amplitude Scan results



Semileptonic

- **Sensitivity: 8.4 ps^{-1}**
- **Limit: Δm_s > 7.9 ps^{-1}** @ 95% CL

Hadronic

- **Sensitivity: 0.4 ps^{-1}**
- **Limit: Δm_s > 0 ps^{-1}** @ 95% CL

CDF winter ’05 Combined

- Sensitivity: **8.4 ps^{-1}**
- Limit: Δm_s > **7.9 ps^{-1}** @ 95% CL

- World Average + **CDF Run II**
  - Sensitivity: 18.2 → **18.6 ps^{-1}**
  - Limit: **14.5 ps^{-1}**

→ see talk by Marco Rescigno

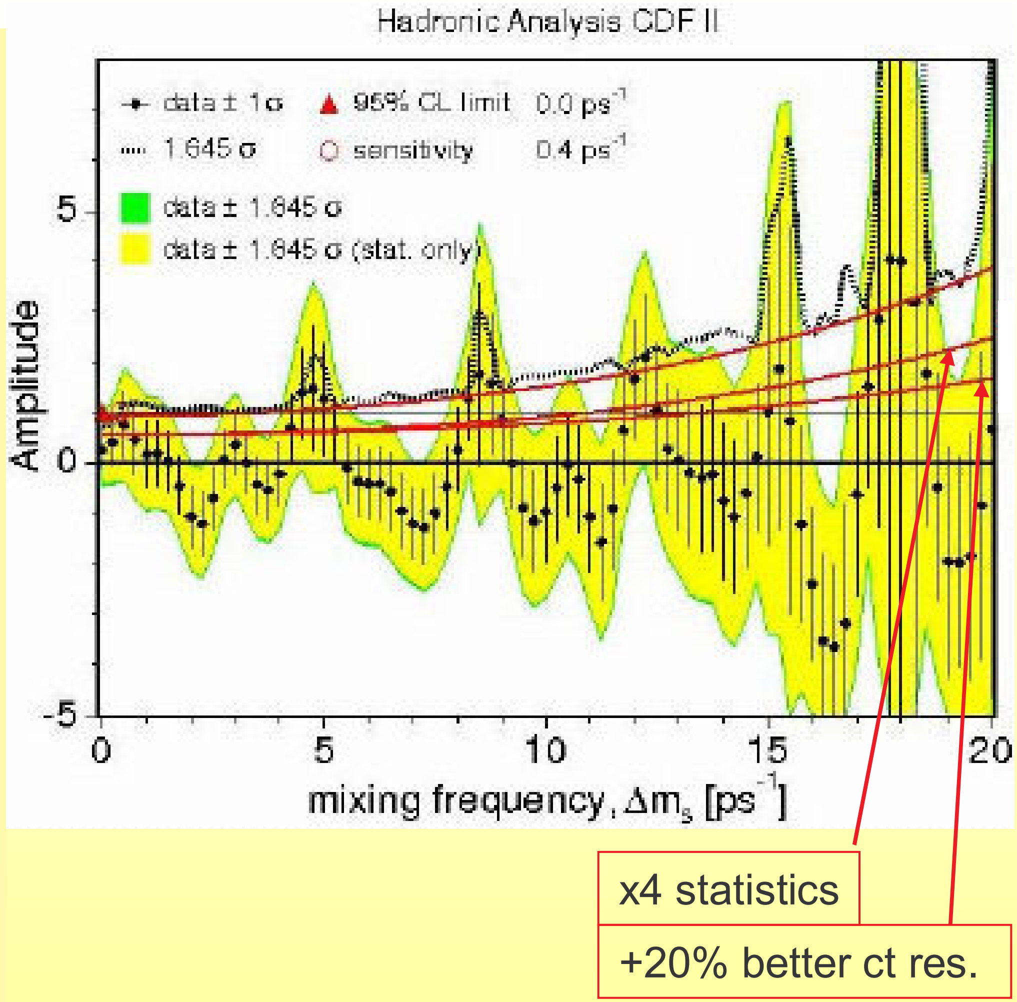
Near future for Δm_s

With the SAME data:

- Add new tagging algorithms
Same Side Kaon Tag
- Add more channels
- Add signals from other triggers
- Improve decay time resolution with PV event by event

With NEW data:

- Increased Luminosity ($0.8 fb^{-1}$ on tape!)
- Use new trigger strategies
  - 2 SVT Tracks + tagging muon at trigger level (already in place since summer 2004)

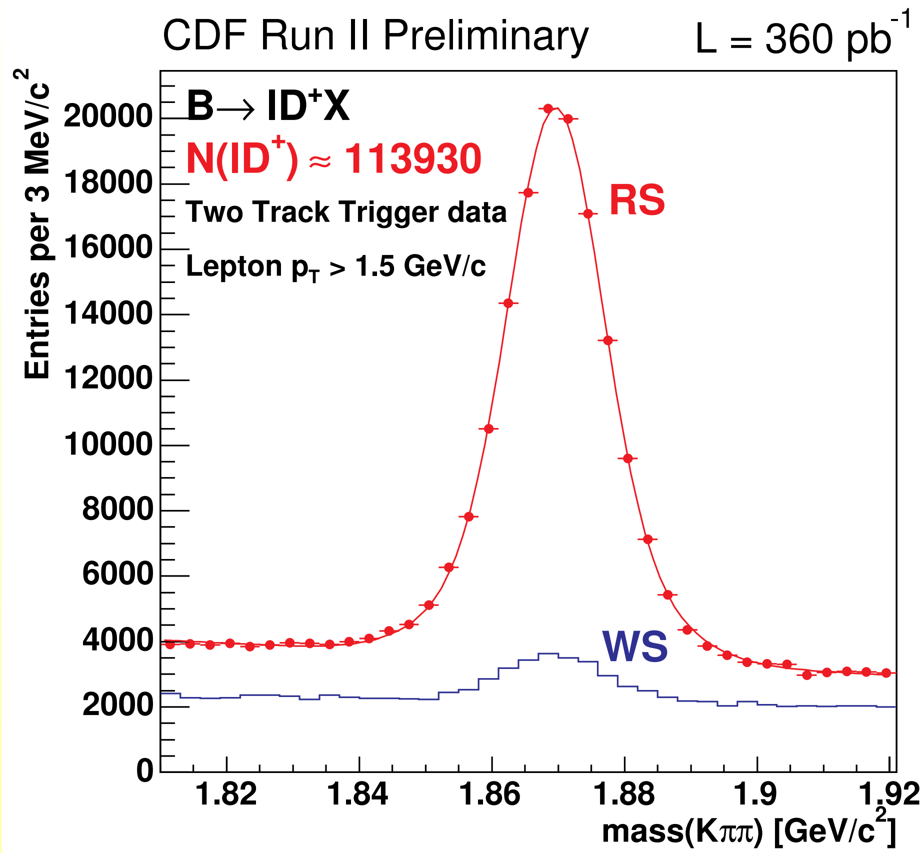


- Hadronic analysis will begin to lead the sensitivity
- Start to “eat” interesting Δm_s range (expect comb. sens. ~ $15 ps^{-1}$)

***NEW*: additional semileptonic B decays**

From the same data (360 pb^{-1}) used in mixing analysis:

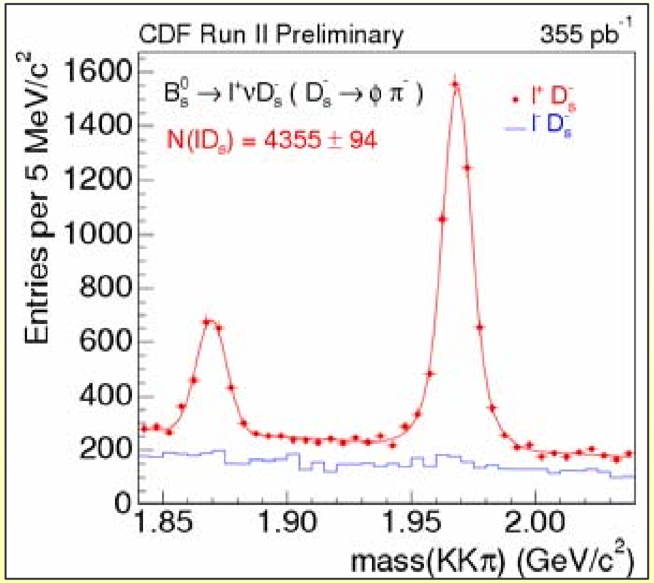
- Use SVT trigger (2 displaced and 2 GeV tracks)
- Select e and μ offline
- Allow lower LEPTON P_T ($4 \rightarrow 2$GeV)
- Increase the overall acceptance of more than **x 3**



At low Lepton P_T, expect more backgrounds from $B \rightarrow DDX$ decays

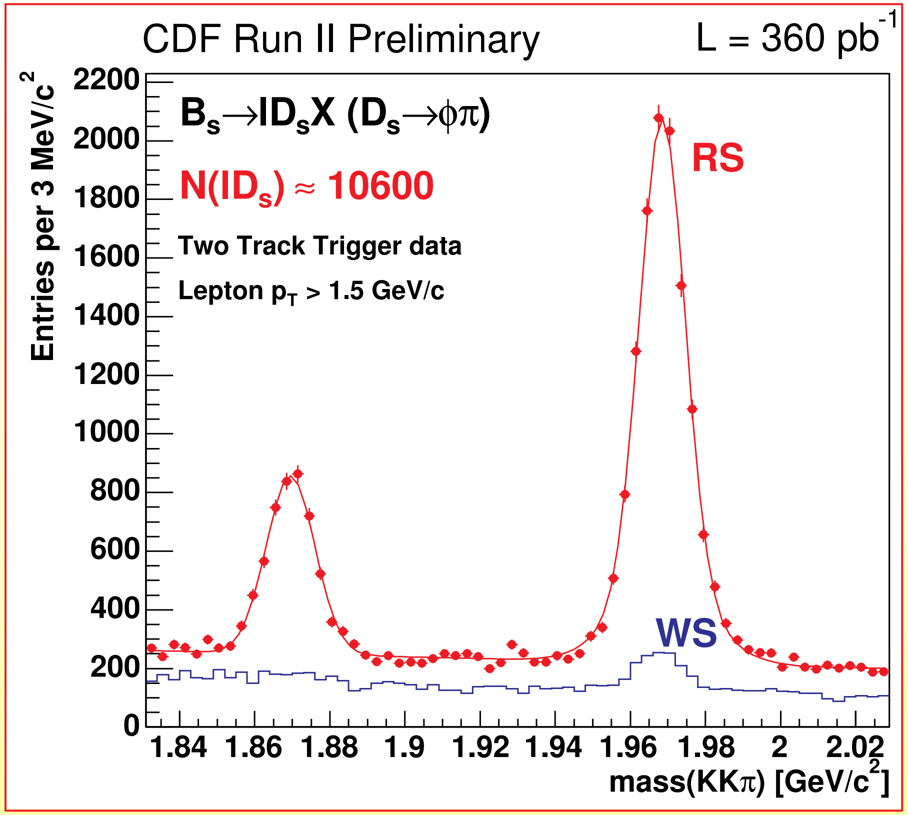
→ more semileptonic B_s for Δm_s analysis

4GeV-lepton + 1 displaced track trigger



+

2 displaced track trigger



Additional new sample overlap with the one already used ~ 20%

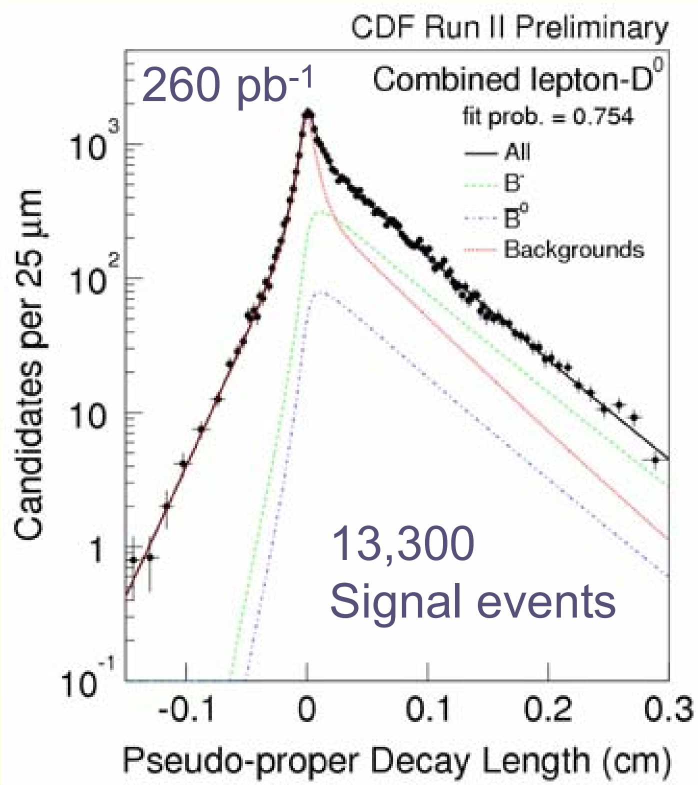
→Effective ~ X 3 more semileptonic B_s yield to be used for MIXING

→Expect significant sensitivity increase in semileptonic Δm_s search

b-hadron lifetimes and $\Delta\Gamma_s/\Gamma_s$

Lifetimes in semileptonic B decays

http://www-cdf.fnal.gov/physics/new/bottom/050224.blessed-bsemi-life/



- Largest statistics B sample
- More complicated background

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

- Full statistics sample still under study.

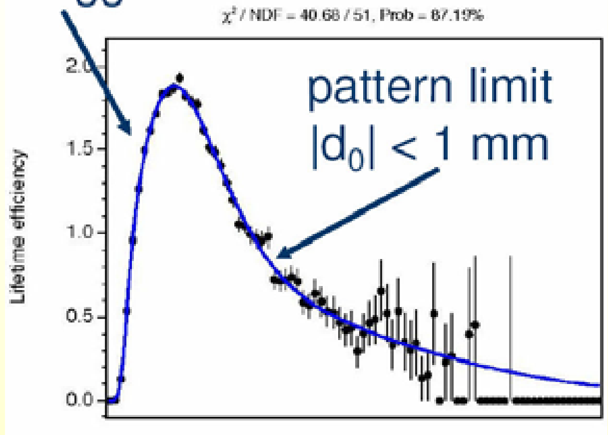
Statistical uncertainty expected:

B^+	$\pm$ 0.017 ps
B^0_d	$\pm$ 0.025 ps
B^0_s	$\pm$ 0.03 ps
Λ_b	$\pm$ 0.037 ps

@ ~400 pb^{-1}

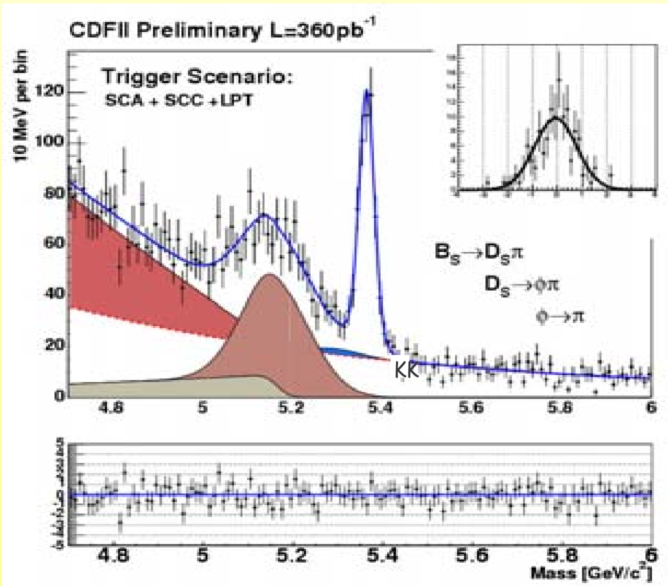
Lifetimes in fully reconstructed modes

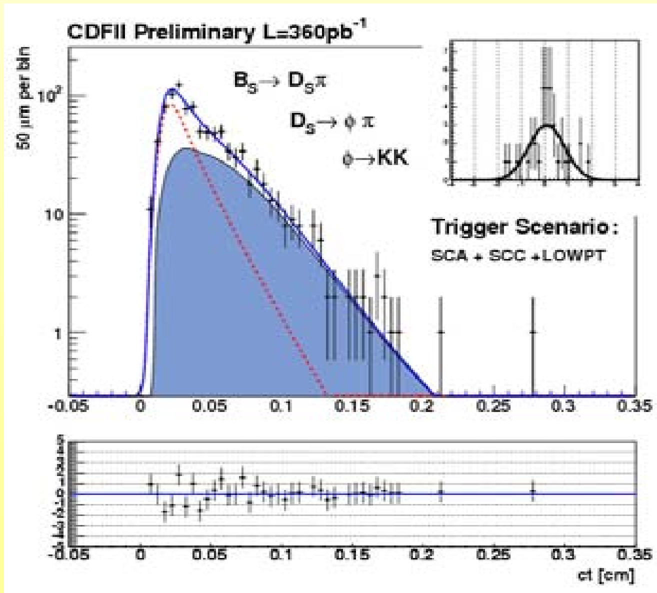
- Test for our ability to understand SVT trigger biases
- Very clean samples
- Prerequisite for mixing fits



CDF '05 preliminary result

$\tau(B^+)$ = **1.661±0.027±0.013 ps**
$\tau(B^0)$ = **1.511±0.023±0.013 ps**
$\tau(B_s)$ = **1.598±0.097±0.017 ps**





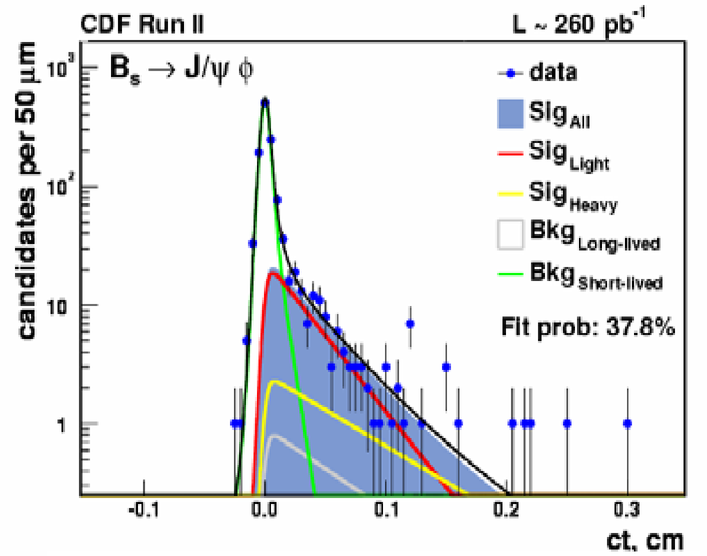
$B_s \rightarrow J/\psi\ \phi$ and $\Delta\Gamma_s / \Gamma_s$

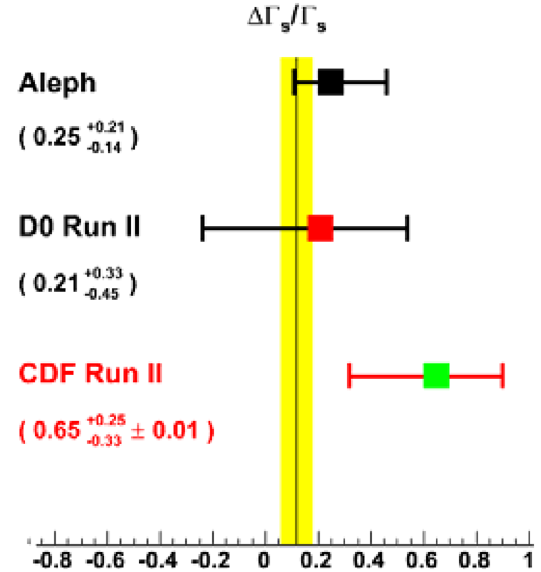
- $B_S \rightarrow J/\psi\ \phi \rightarrow \mu^+\mu^- K^+K^-$
- $B \rightarrow VV$ decays: Heavy and Light state decay with distinct angular distributions and different lifetimes.

- Result (260 pb^{-1})
  - 1/4 heavy - 3/4 light state
  - Lifetime - $\tau_{heavy} \sim 2 \times \tau_{light}$

$$\frac{\Delta\Gamma_s}{\Gamma_s} = 0.65^{+0.25}_{-0.33} \pm 0.01$$

- Lifetime difference measures "same" CKM element as Δm (oscillation frequency)
- Exciting!! Need more data
  - ~ 5 % sensitivity by 2009
  - $\Delta m_s = 10\ ps^{-1} \rightarrow \Delta\Gamma_S / \Gamma_S = 7\%$
- Test still possible CP violation effect in B_s mixing

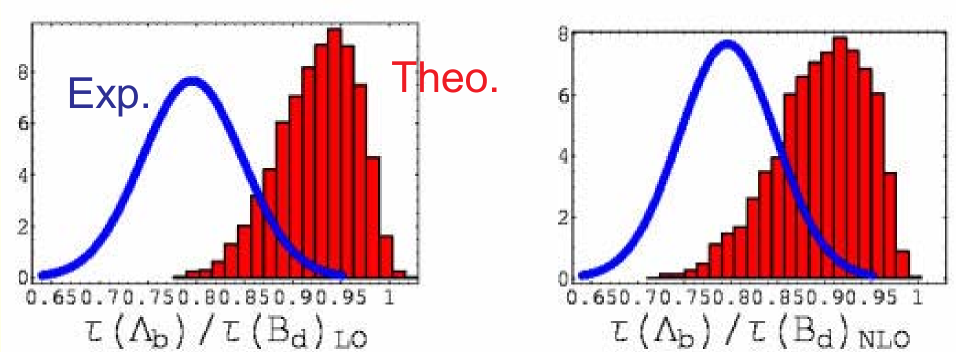




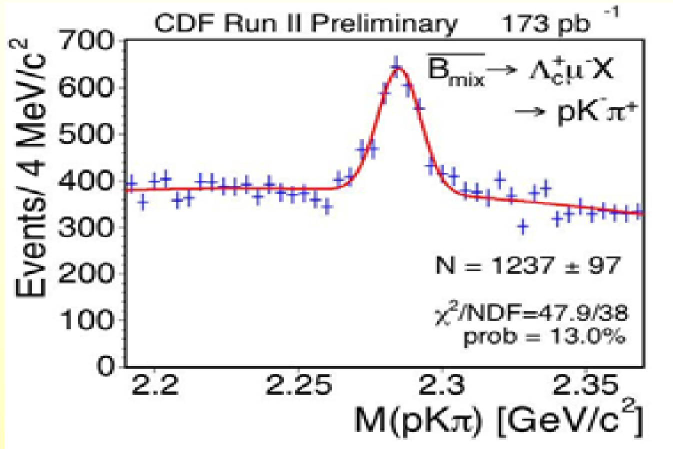
b-Barions

Λ_b modes

- Lifetimes are an important experimental reference:
  - –Overlap with B factories → understanding of detector/trigger/analysis biases
  - –Further test on species not produced at B factories: $\Lambda_b \to \Lambda_c \mu X$



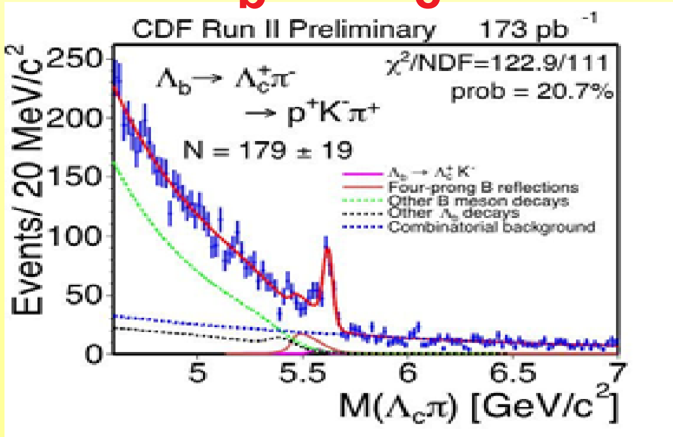
C. Tarantino, hep-ph/0310241 Oct 2003



Λ_b Branching ratios:

$$\frac{BR(\Lambda_b \to \Lambda_c^+\pi^-)}{BR(\bar{B}^0 \to D^+\pi^-)} = 3.3 \pm 0.3\ (\mathrm{stat}) \pm 0.4\ (\mathrm{syst}) \pm 1.1\ (\mathrm{BR{+}FR})$$

$\Lambda_b \to \Lambda_c \pi$



NEW:

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

http://www-cdf.fnal.gov/physics/new/bottom/050407.blessed-lbbr/

Λ_b Updated knowledge

Mass m = 5619.9 ± 1.7 MeV/c^2

Mean life $\tau = (1.229 \pm 0.080) \times 10^{-12}$ s

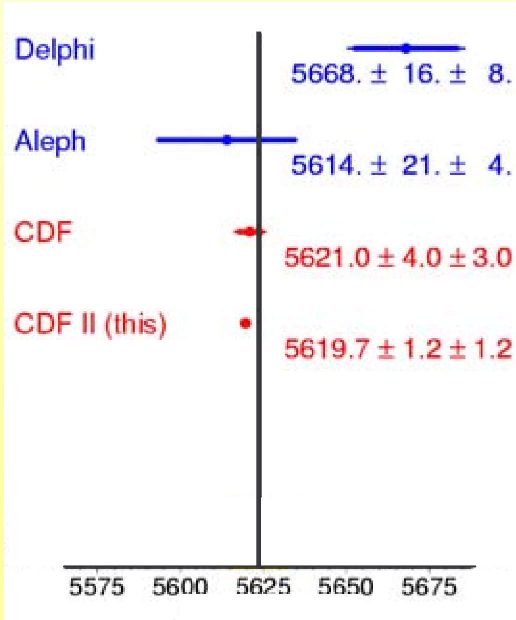
$c\tau = 368\ \mu m$

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 contribution beyond current PDG2004

Λ_b mass



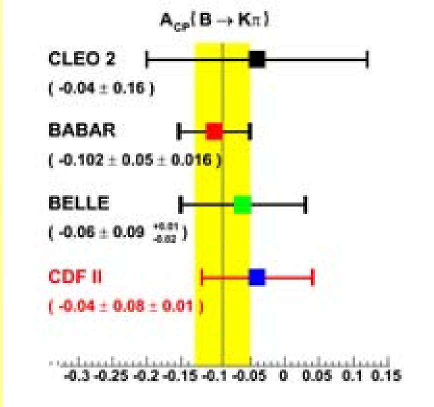
CP violation and charmless B decays

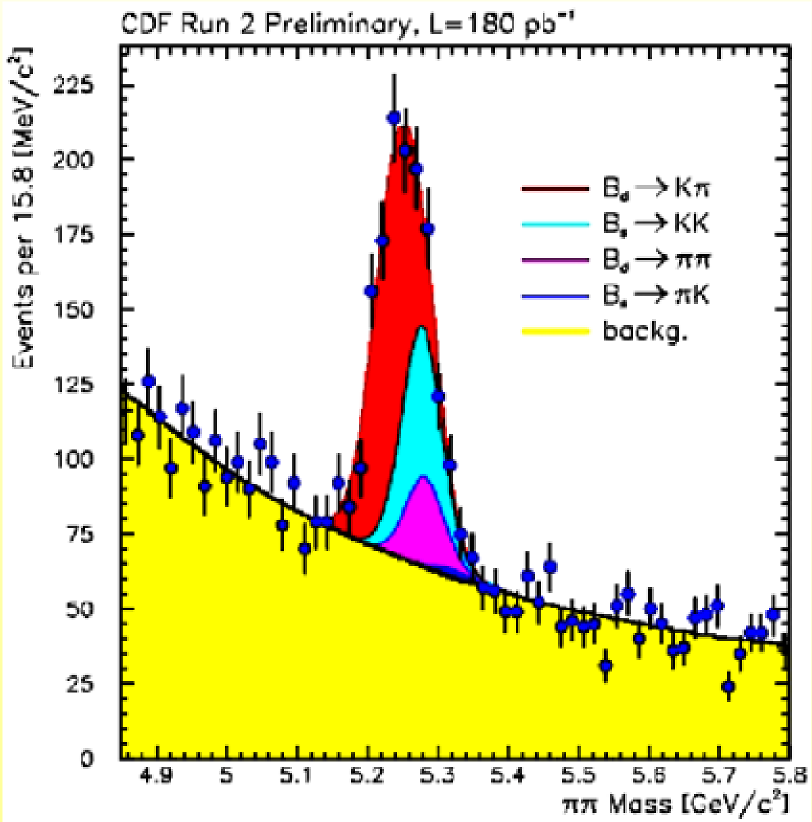
Charmless $B \to hh'$

- Difficult competition with B factories for t-dependent tagged measurements
- Interesting B physics measurement of B_s BR and $A_{CP}(B^0 \to K\pi)$
  - Signals overlap within mass resolution
  - Kinematic and dE/dX to disentangle components in a combined fit:

$$\frac{f_s \cdot BR(B_s \to K^\pm K^\mp)}{f_d \cdot BR(B_d \to K^\pm \pi^\mp)} = 0.50 \pm 0.08\,(stat.) \pm 0.07\,(syst.)$$

$$A_{CP} = \frac{N(\overline{B}_d^0 \to K^-\pi^+) - N(B_d^0 \to K^+\pi^-)}{N(\overline{B}_d^0 \to K^-\pi^+) + N(B_d^0 \to K^+\pi^-)} = -0.04 \pm 0.08\,(stat.) \pm 0.01\,(syst.)$$





Future: measure B_s lifetime in the CP even mode KK
$\to$ extract $\Delta\Gamma_s/\Gamma_s$

→ *see talk by Simone Donati*

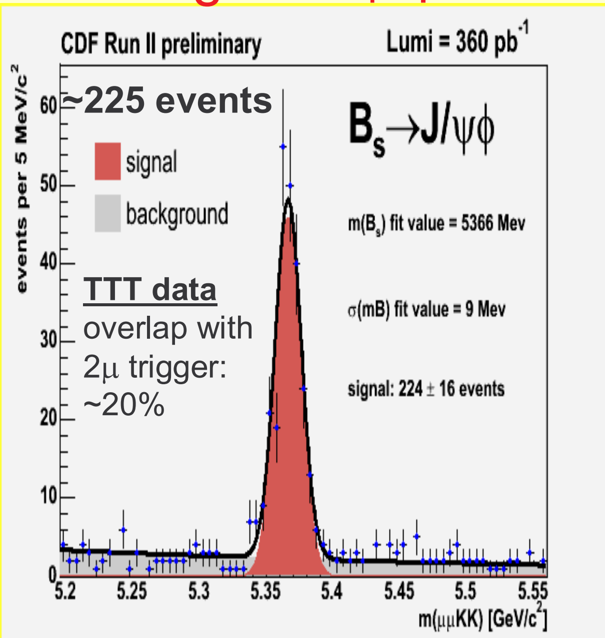
Charmless $B \to VV$ decays

→ see talk by Simone Donati

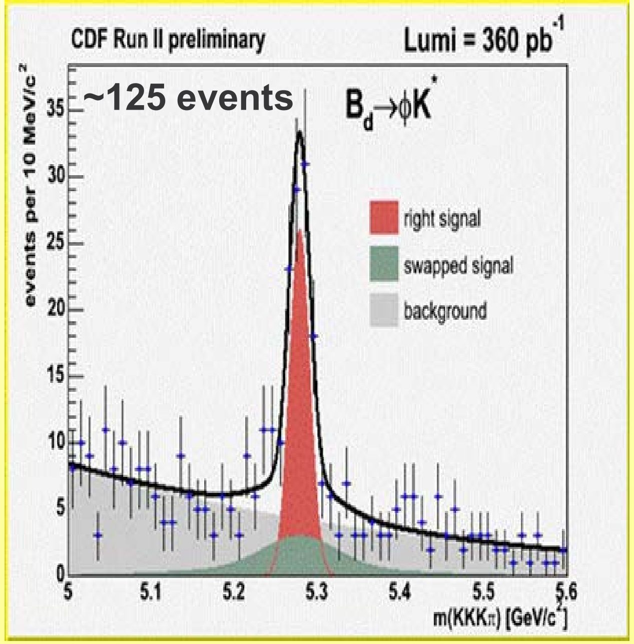
- Measured BR($B_s \to \phi\phi$) with 8 events (180 pb^{-1})
- Update with 360 pb^{-1}
- Will go soon for **Polarization Amplitude analysis**
- Expected significance similar to B-factories

Future: measure $\Delta\Gamma_s/\Gamma_s$ in $B_s \to \phi\phi$ penguin mode

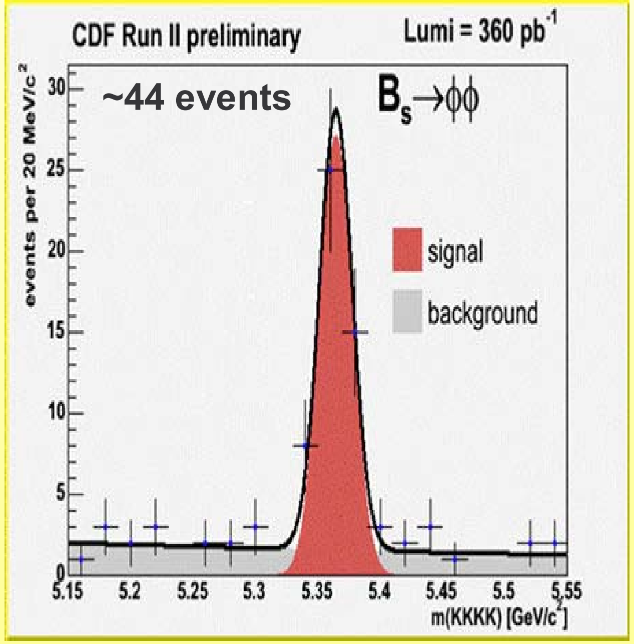
$B_s \to J/\psi\phi$



$B_d \to \phi K^*$

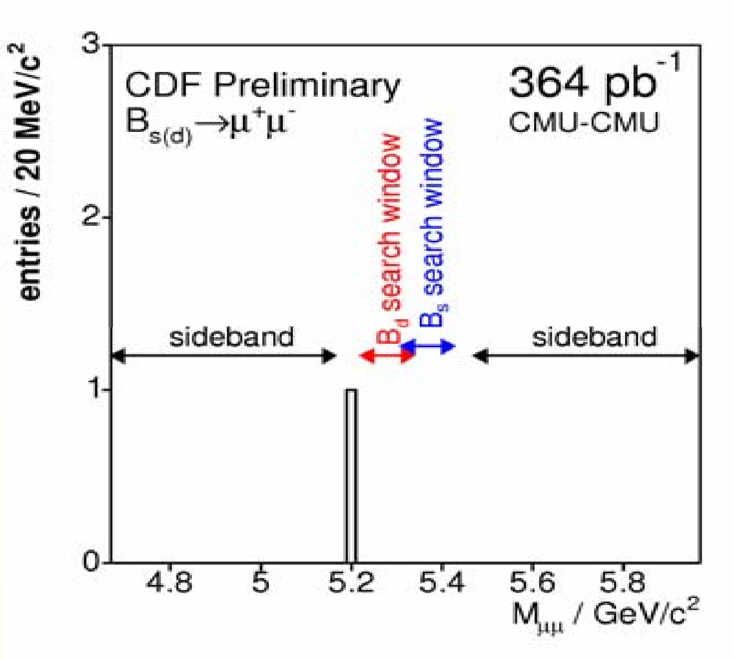


$B_s \to \phi\phi$



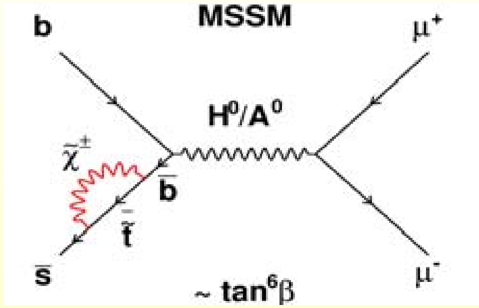
Search for $B_{s,d} \rightarrow \mu\mu$

→ *see talk by Sinead Farrington*



SM: BR(Bs→μμ) < $3.8 \cdot 10^{-9}$
Sensitive to new physics

Ex.:

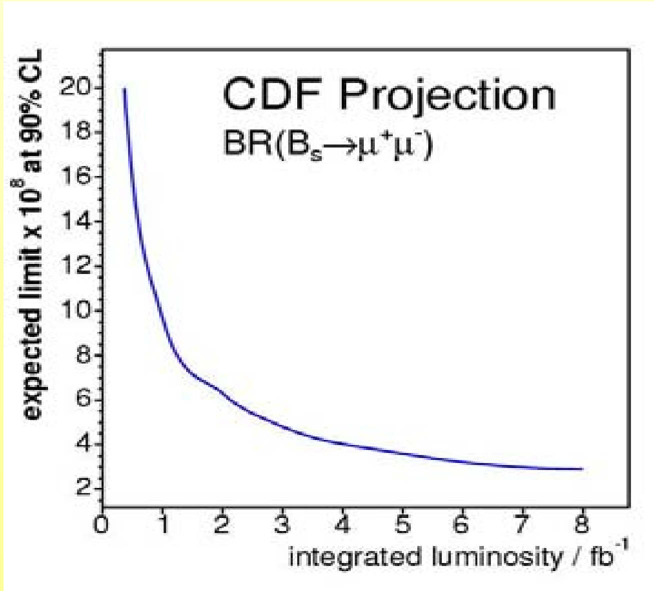


<u>NEW Results (360 pb^{-1}):</u>

BR($B_s \rightarrow \mu\mu$) < 1.6×10^{-7} @ 90% CL
< 2.1×10^{-7} @ 95% CL

BR($B_d \rightarrow \mu\mu$) < 3.9×10^{-8} @ 90% CL
< 5.1×10^{-8} @ 95% CL

These are currently world best limits



… and also at BEAUTY 05:

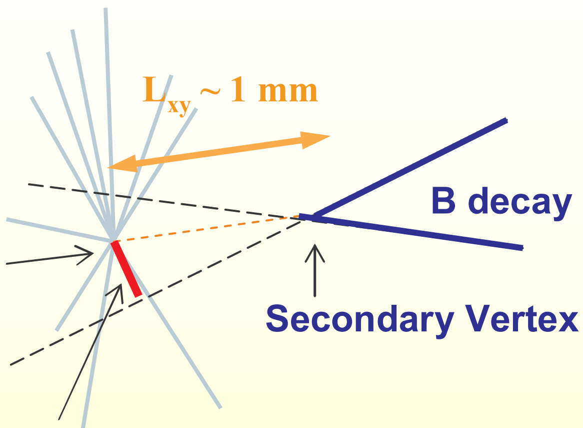
- Other VERY INTERESTING results from TEVATRON Heavy Flavour physics on:
  - ***B_c meson at CDF and D0*** → *see talk by William Wester*
  - ***X(3872) at CDF and D0*** → *see talk by Ulrich Kerzel*

Conclusions

- CDF performed the first B_s mixing analysis in run II
- We foresee a substantial update with new samples, new data collected and improved tagging power for winter 2006
- Working to have world class measurements on b-hadron lifetimes and lifetime difference $\Delta\Gamma_s/\Gamma_s$
- Perform complementary studies in the field of charmless B decays: $B_{d,s} \rightarrow hh$, $B_{d,s} \rightarrow VV$, help digging the penguin sector
- *Huge CDF legacy of knowledge in Beauty to next generation B physics experiments.*

Backup slides

SVT: the hadronic B trigger

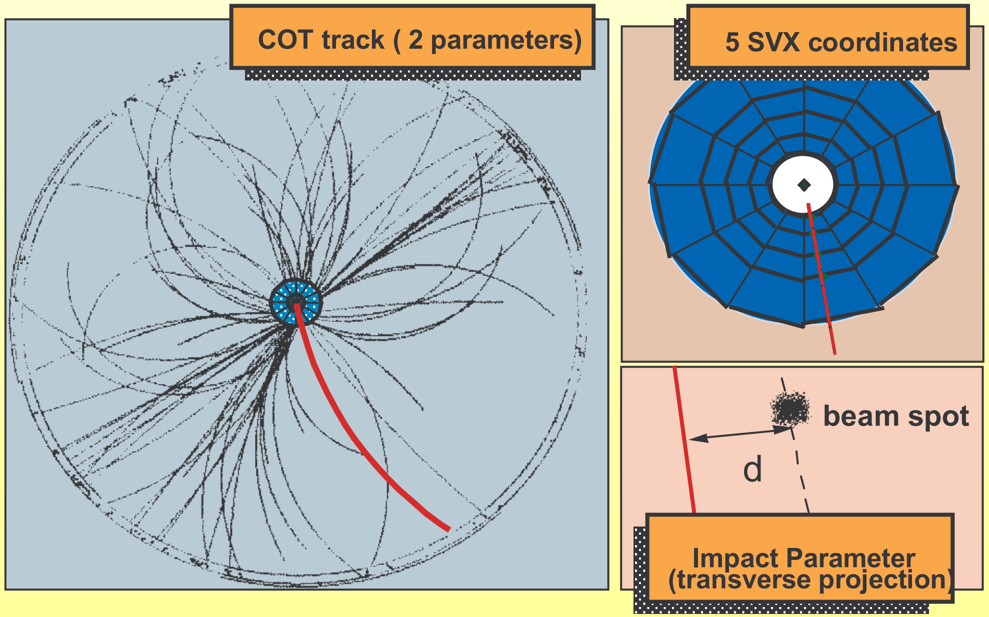


→Online Impact parameter
Available at Level 2 trigger (20μs latency)

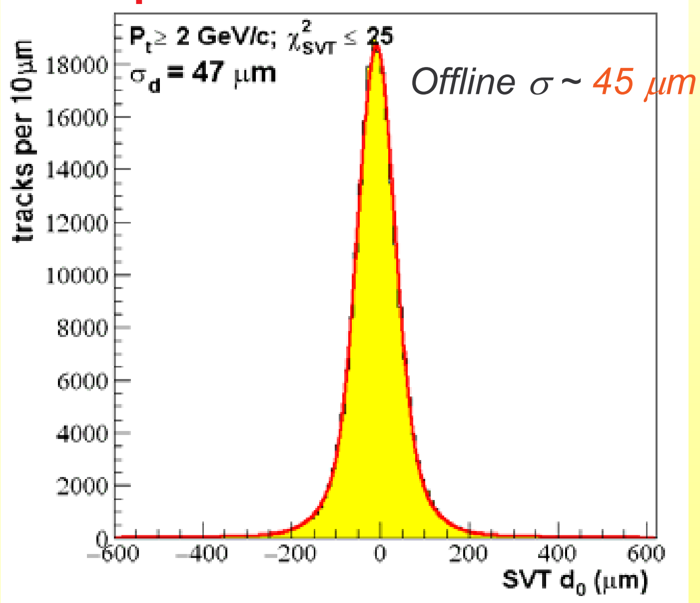
→convolution of transverse size of the beam spot with the impact parameter resolution of the SVT:

$\sigma \approx 47\ \mu m \approx 35\ \mu m \oplus 30\ \mu m$

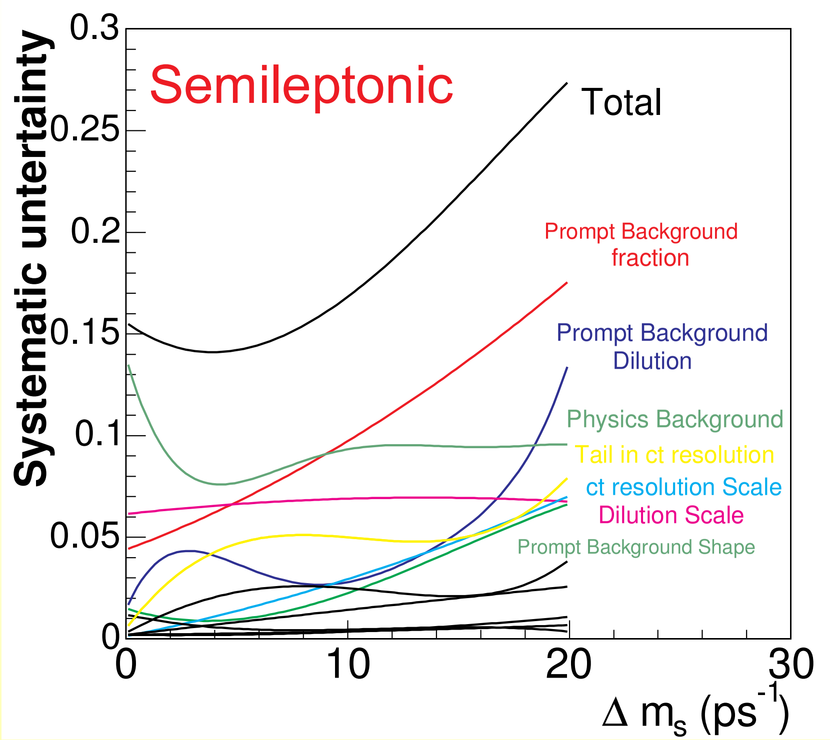
SVT resolution — Beam spot size

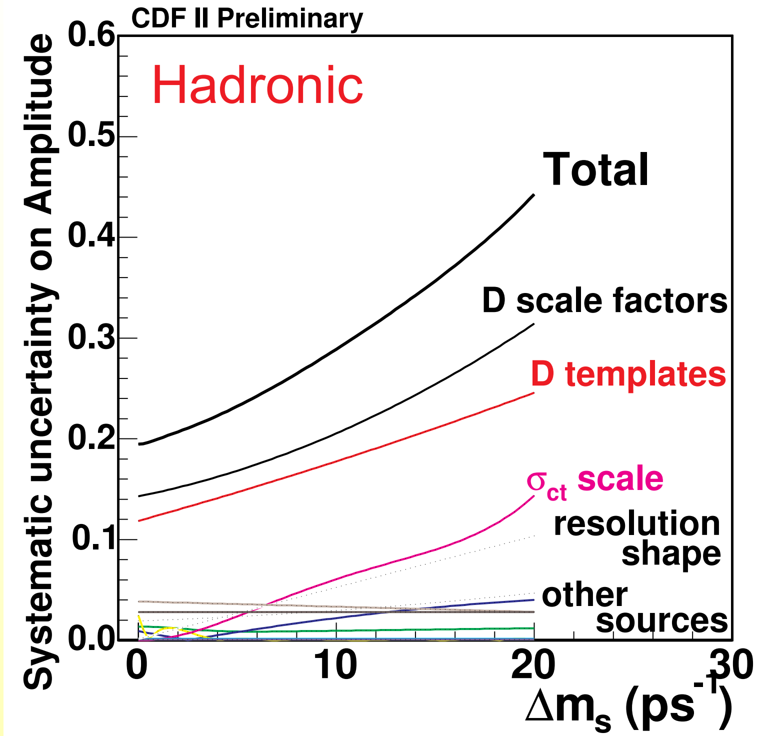


Impact Parameter distribution



Δm_s : systematic Uncertainties





- **Physics** background at low Δm_s
- **Prompt** background at high Δm_s

- **Dilution scale factors** and templates systematic limited from control sample statistics

Systematic errors **are negligible** with respect to statistical in both cases

Heavy Flavour Production

bb

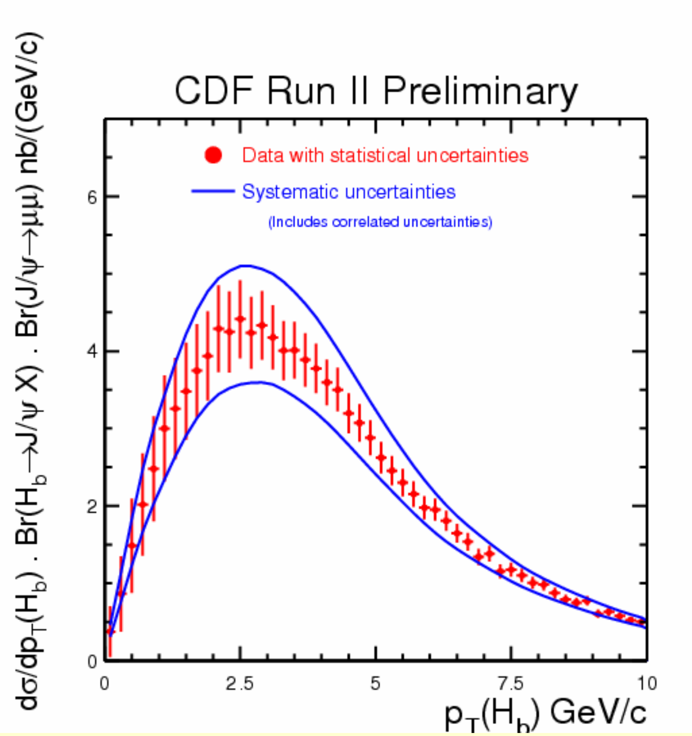
$$\sigma(p\bar{p} \rightarrow J/\psi X, |\, y(J/\psi)\,| < 0.6) \cdot Br(J/\psi \rightarrow \mu\mu)$$
$$240 \pm 1(stat) \pm 21(syst)\ \mathrm{nb}$$

$$\sigma(p\bar{p} \rightarrow H_b X, |y| < 0.6).Br(H_b \rightarrow J/\psi X).Br(J/\psi \rightarrow \mu\mu)$$
$$24.5 \pm 0.5(stat) \pm 4.7(syst)$$

$$\sigma(p\bar{p} \rightarrow \bar{b}X, |y| < 1.0) = 29.4 \pm 0.6(stat) \pm 6.2(syst)\mu\mathrm{b}$$

from $H_b \rightarrow \psi X$ in 37 pb^{-1} of data!

PRD 71, 032001 (2005)

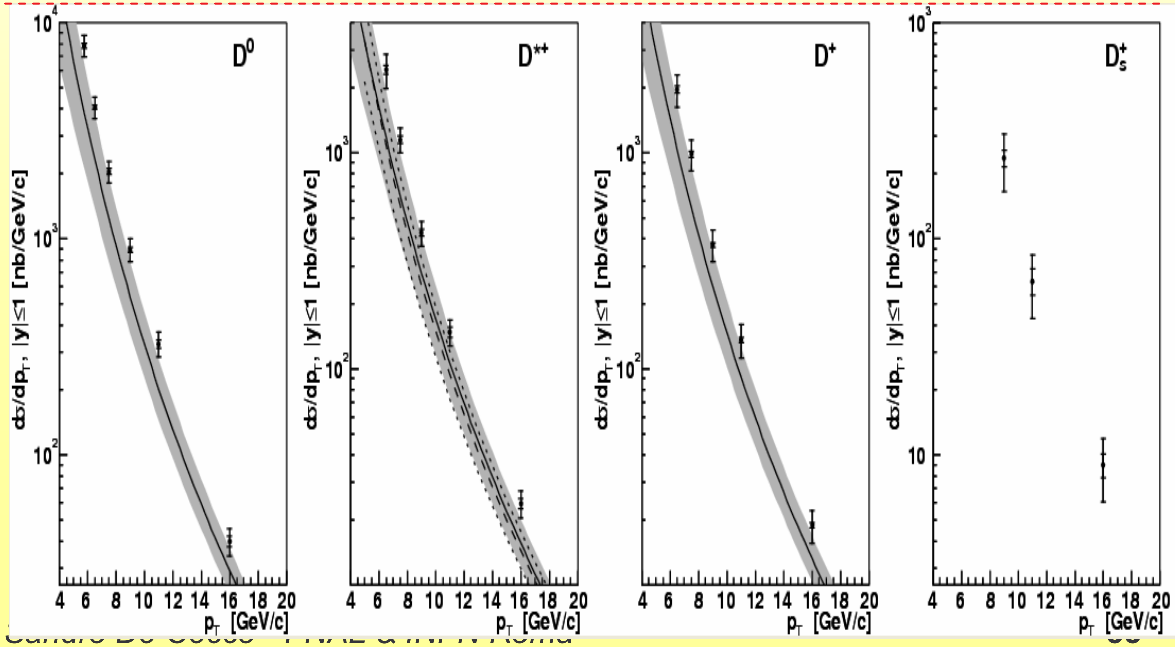


cc

with first 6.5 pb^{-1} !

	P_t > GeV/c	σ(y<1) μb
D^0	5.5	**13.3±0.2±0.5**
D^{*+}	6.0	**5.2±0.1±0.8**
D^+	6.0	**4.3±0.1±0.7**
D_s	8.0	**0.75±0.05±0.22**

PRL 91, 241804 (2003)

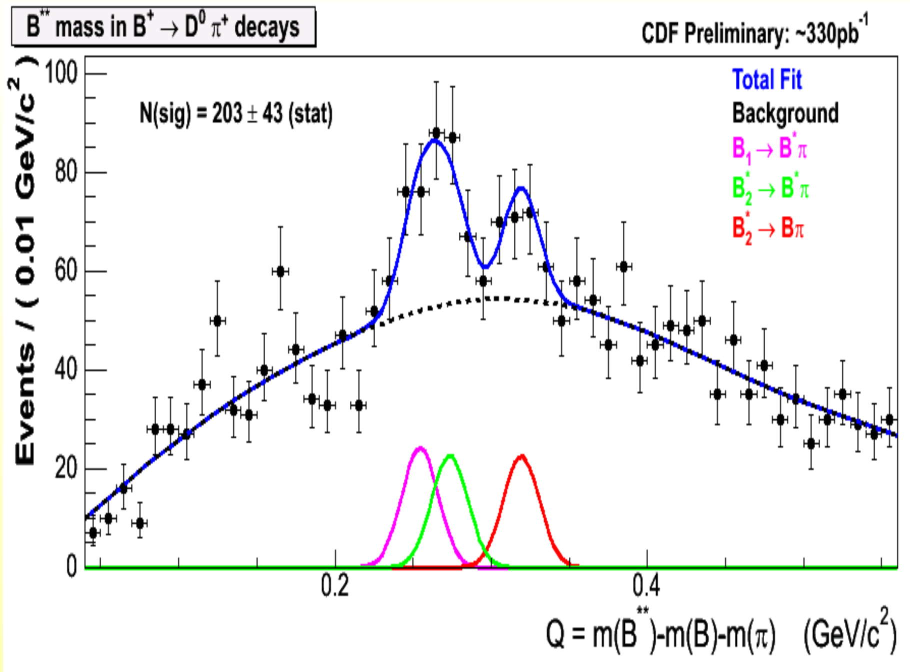


Excited Heavy Flavor states

- $B^{**}(L=1) \rightarrow B\pi$ →

  – $B \rightarrow J/\psi K$ and $D\pi$ modes

  – Important to understand impact for <u>Same Side Kaon tagging</u> → mixing



Common σ

$$m(B_2 \rightarrow B\pi) - m(B_2 \rightarrow B^*\pi) = 45\,MeV/c^2$$

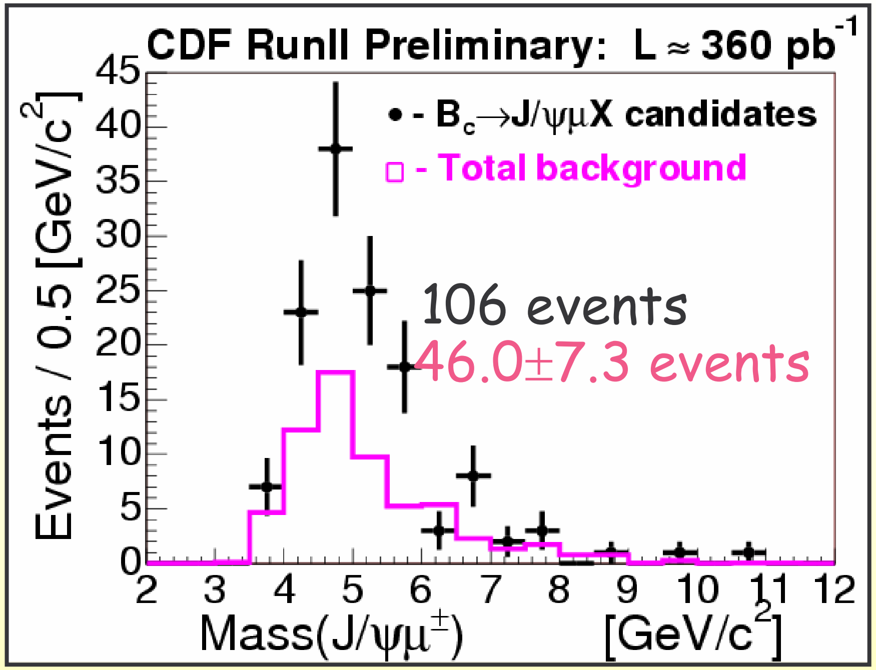
$$f(B_2 \rightarrow B\pi) = f(B_2 \rightarrow B^*\pi)$$

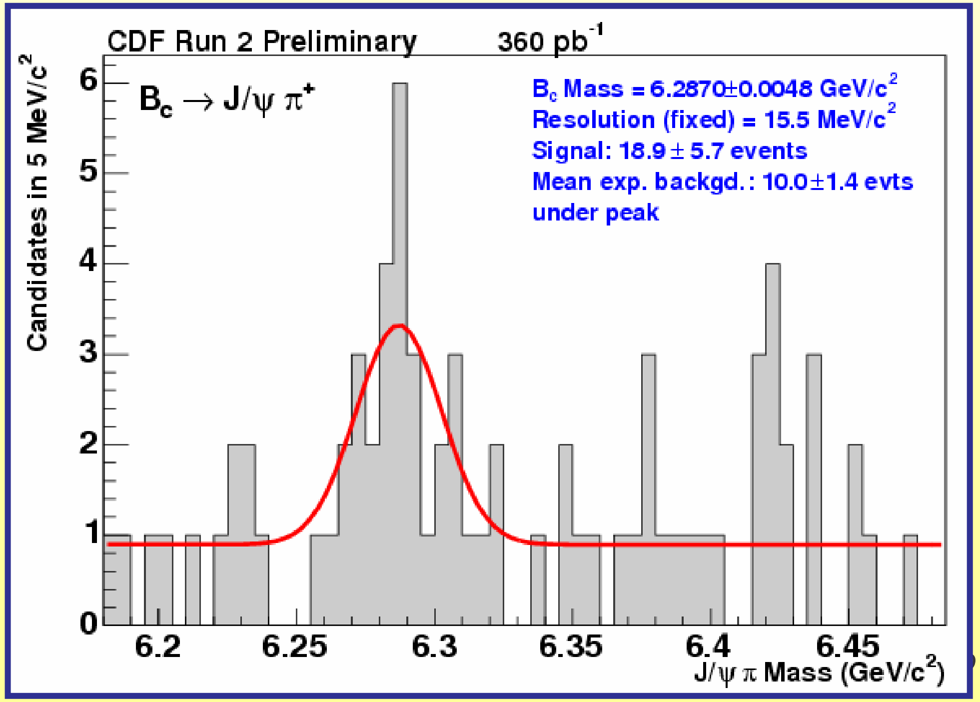
Welcome back to B_c

http://www-cdf.fnal.gov/physics/new/bottom/050330.blessed-bc-jpsimu/

- Mode that gave the first evidence of the B_c (CDF Run I)
- Large yield, no clean resonance though!

$$\frac{\sigma_{B_c}(P_t > 6GeV)\cdot BR(B_c \to J/\psi\mu\nu)}{\sigma_{B^\pm}(P_t > 6GeV)\cdot BR(B^\pm \to J/\psi K^\pm)} = 0.245 \pm 0.045^{+0.080}_{-0.032}$$





- First signal of fully reconstructed B_c
- Direct mass measurement!

$$m = 6.287 \pm 0.0048 \pm 0.0011 \, GeV/c^2$$

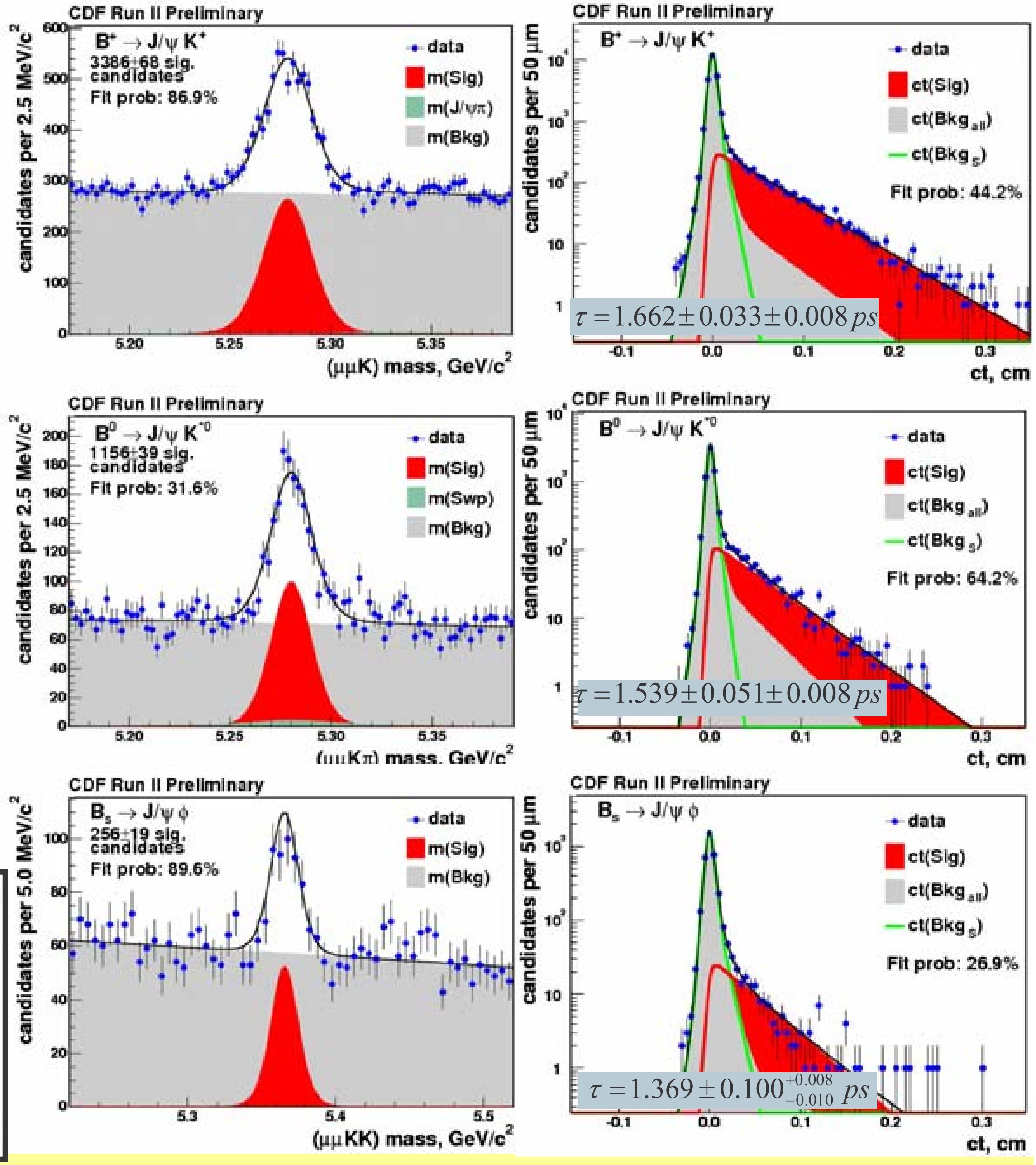
Hep-ex/0505076

Lifetimes: J/ψ modes

http://www-cdf.fnal.gov/physics/new/bottom/040428.blessed-lft2/

This was the starting point:

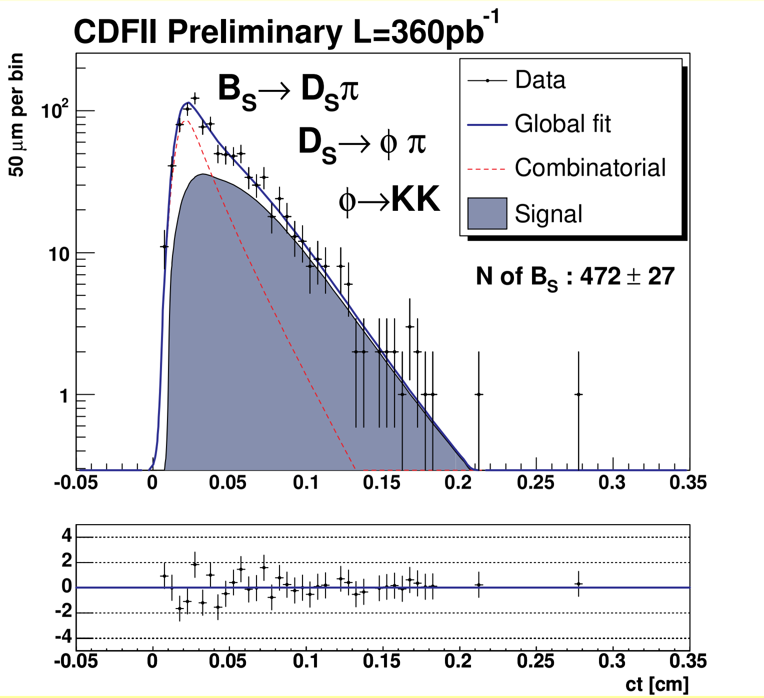
- Clean unbiased sample
  - Precision measurement
  - Reference for biased (e.g. displaced track) triggers
  - Test for the understanding of:
    - Detector
    - Analysis technique
    - Sample composition

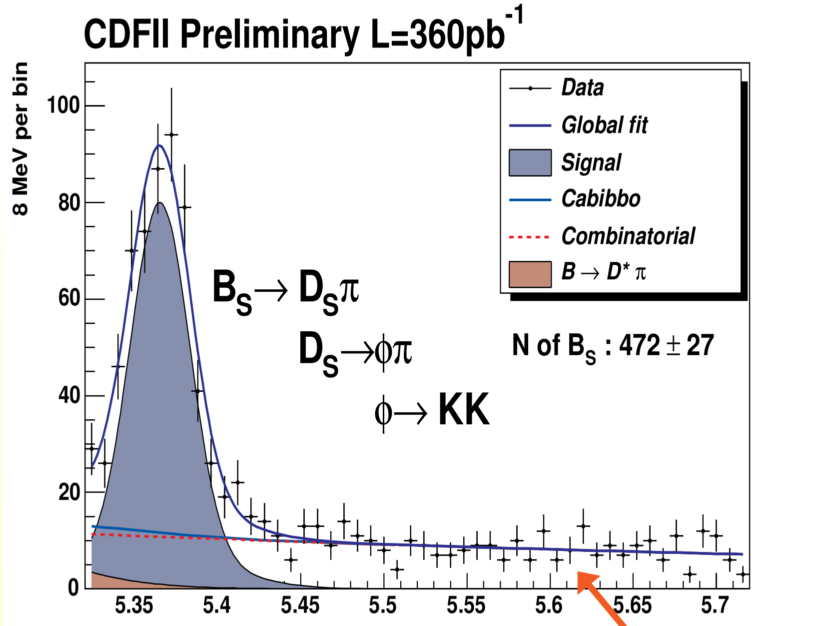


Systematic effect	Uncertainty on $c\tau_{B^+}\mu m$	Uncertainty on $c\tau_{B^0}\mu m$	Uncertainty on $c\tau_{B_s}\mu m$
SVX Alignment	±1.0	← same	← same
Fit Model	±1.7	← same	← same
Selection	negligible	← same	← same
Procedure Bias	±1.3	← same	← same
Cross-feed	—	$+0.2\mu m$	$-1.7\mu m$
Total	±2.4	±2.4	$^{+2.4}_{-2.9}$

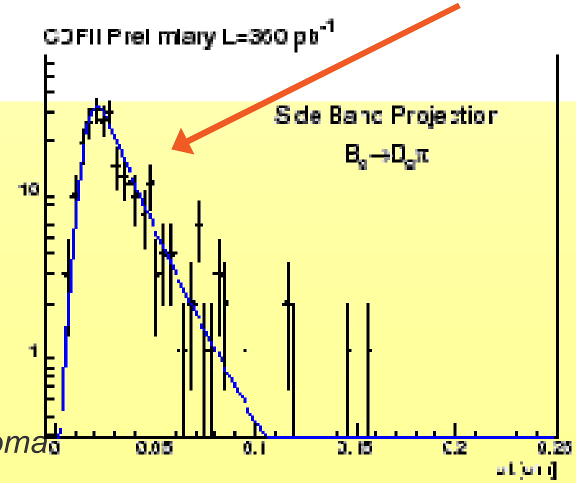
Lifetime in the hadronic B_s modes

- Decay time $t = L / \beta\gamma_c = L \frac{m}{p}$
- actually measure transverse quantities:
  - L_{xy}, $P_T(B)$
- Un-binned likelihood fit
- Used: $B_s^0 \to D_s^- \pi^+$ and $B_s^0 \to D_s^- \pi^+ \pi^- \pi^+$





Combinatorial background **ct** template from high mass sideband



Hadronic B-lifetimes results

CDF $\pm$ (stat) $\pm$ (syst)

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

$\tau(B^+)/\tau(B^0) = 1.10 \pm 0.02 \pm 0.01$
$\tau(B_s)/\tau(B^0) = 1.06 \pm 0.07 \pm 0.01$

Systematic summary

Effect	Variation(μm) B^0	Variation(μm) 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

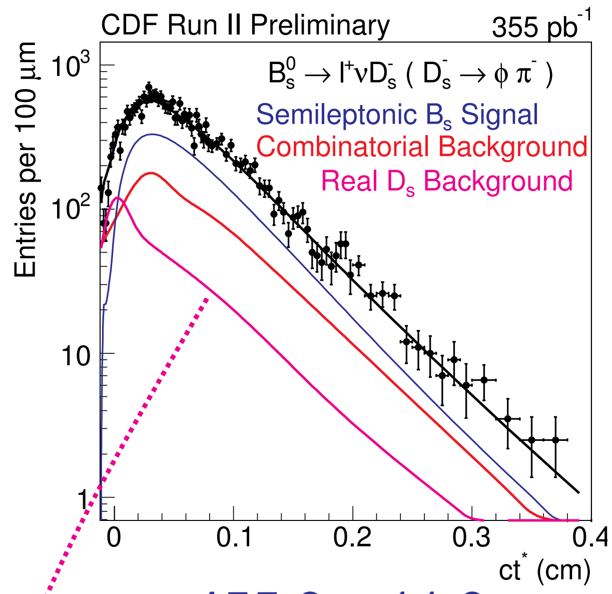
World Average lifetimes (exp.):

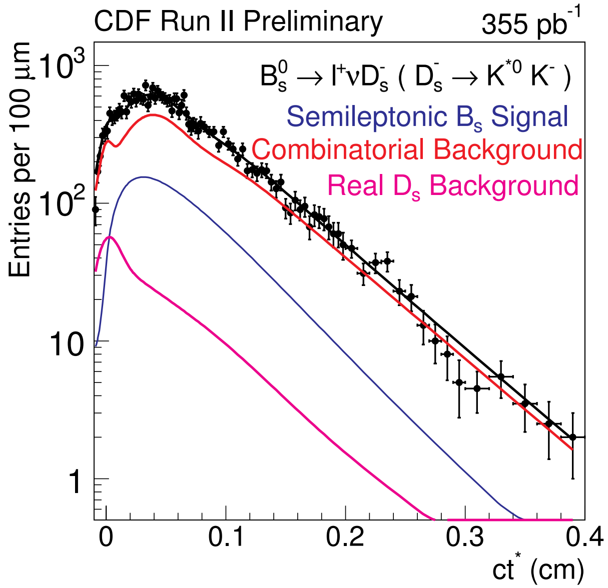
$\tau(B^+) = 1.653 \pm 0.014$ ps
$\tau(B^0) = 1.534 \pm 0.013$ ps
$\tau(B_s) = 1.469 \pm 0.059$ ps

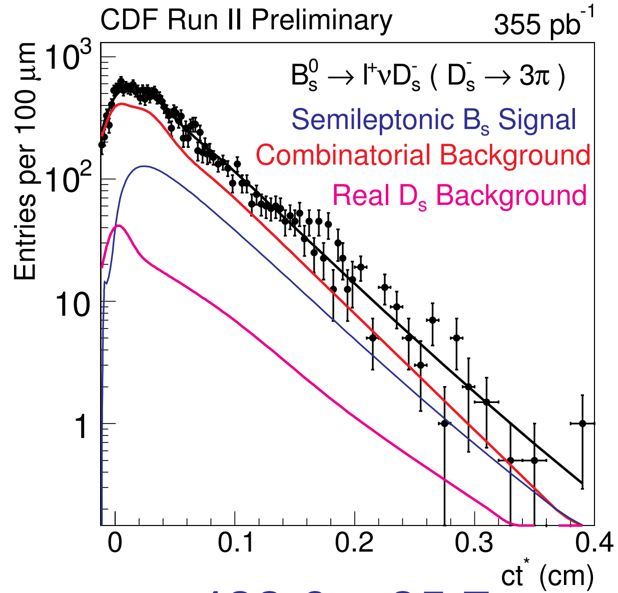
Theory prediction *(see Cecilia Tarantino CKM05):*

$\tau(B^+)/\tau(B^0) = 1.06 \pm 0.02$
$\tau(B_s)/\tau(B^0) = 1.00 \pm 0.01$

Lifetime in the semileptonic B_s modes







$c\tau = 455.9 \pm 11.9\ \mu m$ $c\tau = 413.8 \pm 20.1\ \mu m$ $c\tau = 422.6 \pm 25.7\ \mu m$

Combined **ℓ-D_s** lifetime result: **$445.0 \pm 9.5\ \mu m$** *(W.A.: $438 \pm 17\ \mu m$)*

statistical err .only, ***→NOT for Averages←*** *(DØ '05: $426 \pm 13 \pm 17\ \mu m$)*

Real D_s backgrounds: prompt and physics

HQET: baryon lifetimes and B moments

B lifetimes ↔ Vcb

Dominant uncertainty comes from HQET extraction!

CDF can probe HQET and constrain it!

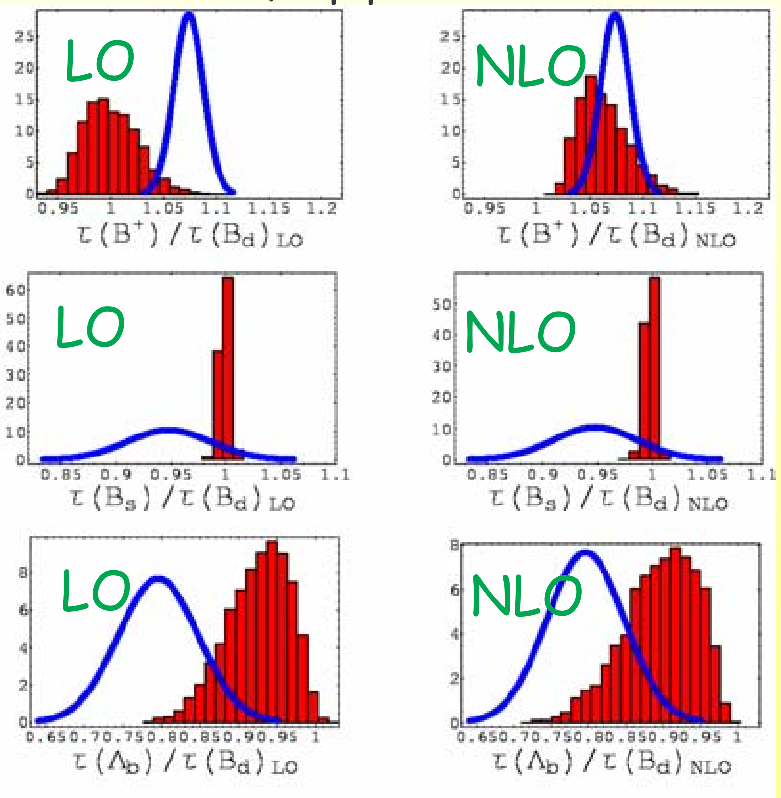
http://www-cdf.fnal.gov/physics/new/bottom/030710.blessed-lambdab-lifetime/

C. Tarantino, hep-ph/0310241 Oct 2003

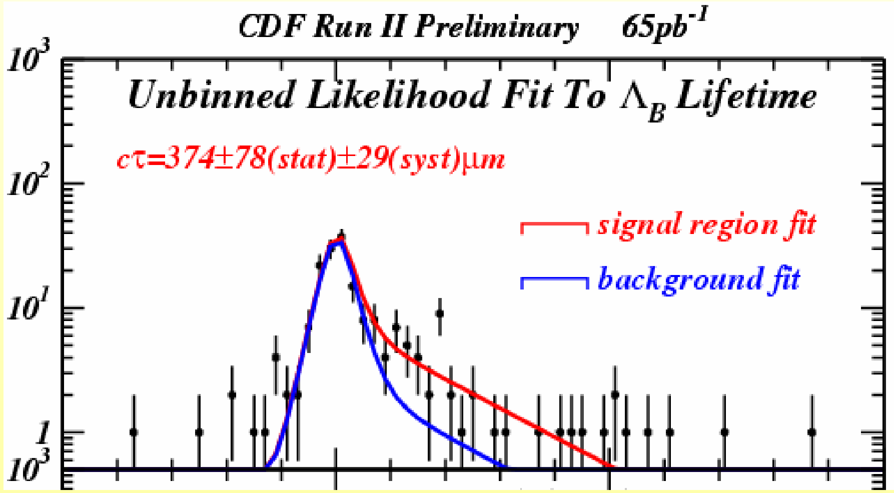
$\frac{\tau(B^+)}{\tau(B^0)}$

$\frac{\tau(B_s)}{\tau(B^0)}$

$\frac{\tau(\Lambda_b)}{\tau(B^0)}$



Λ_b lifetime



$$\frac{\tau(\Lambda_b)}{\tau(B^0)} = (81.3 \pm 18)\%$$