Highlights From Flavor Physics at

CDF II

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Contents

Caveat Emptor

- The B group at CDF is very active!
- At the moment we have:
  - 48 "public" B physics results
    - 18 since ICHEP '04
    - 8 published (lots of publications in the pipeline!)
- Too vast to be covered in 30 minutes!
- I made my choices, we can chat offline about your favorite analysis!

Other little caveat:

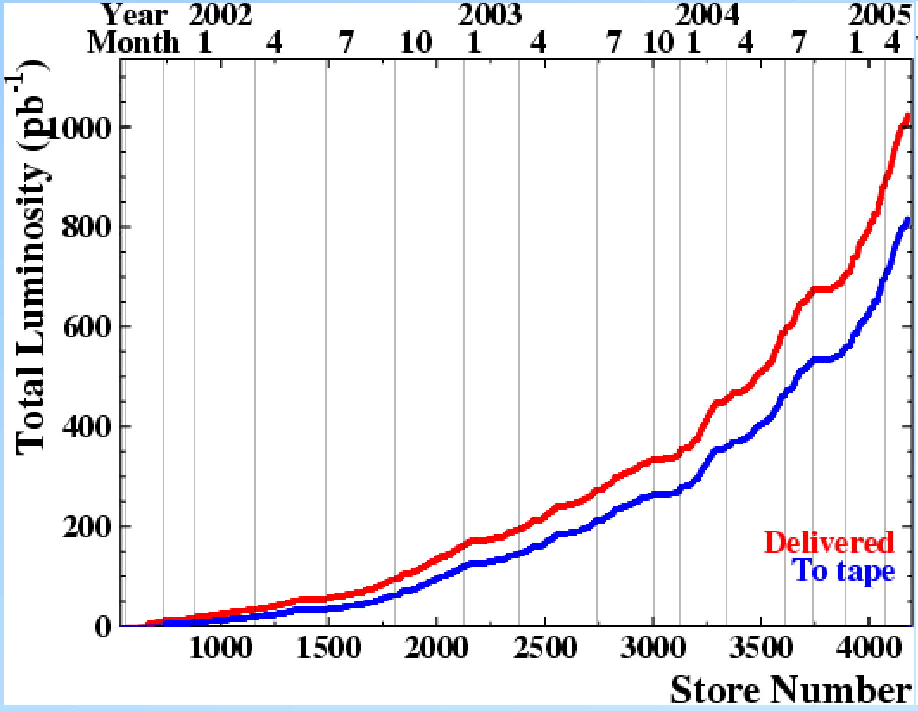
- HEP is a 'large' community but CDF has been around for years... I will not cover explicitly detector performances and features!
- Minimal description of reference information

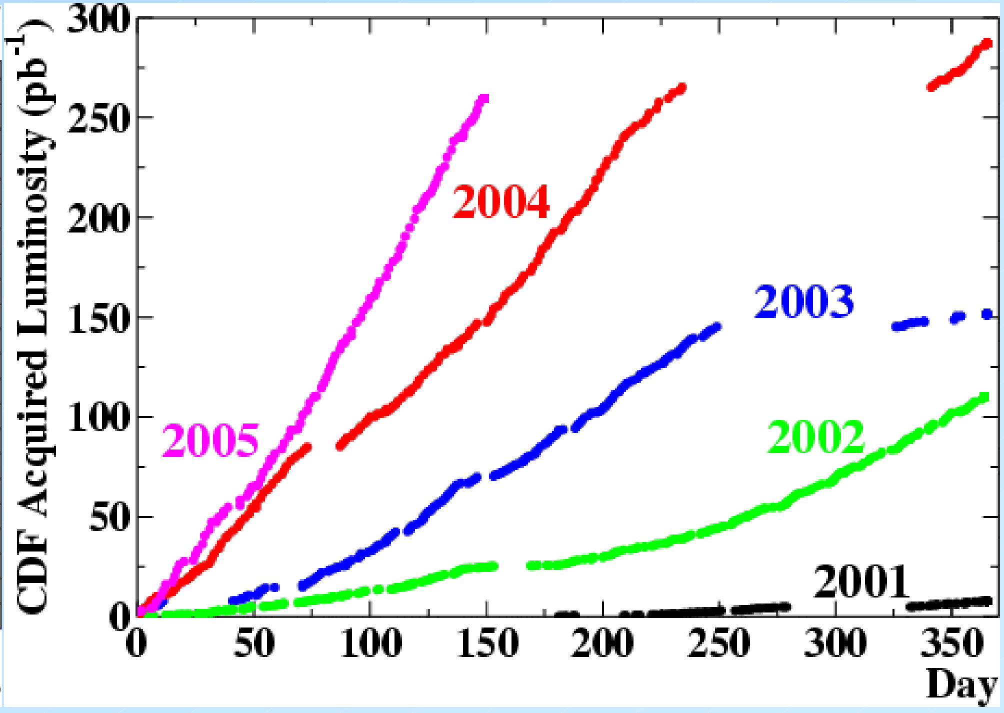
The basics!

- CDF II has collected so far ~0.8 fb^{-1} out of the delivered Tevatron luminosity

- Out of these there are 600 pb^{-1} available for B physics (tracking detectors restrictions)

- Most analyses shown today use between 250 pb^{-1} and 350 pb^{-1} of luminosity!





The Tevatron is competitive in HF

- B factories program extensive and very successful BUT limited to B_u,B_d
- Tevatron experiments can produce all b species: B_u,B_d,B_s,B_c, B**, Λ_b, Ξ_b

$$s_{B^\circ} = 3.51 \pm 0.42 \pm 0.53\, mb\, @\ |y| < 1\quad p_t > 6$$

Compare to:

•Υ(4S) ≈ 1 nb (only B^0, B^+)

•Z^0 ≈7 nb

Unfortunately

•pp ≈100 mb

•b production in pp collisions is so large (~300 Hz @ 10^{32} cm^{-2} Hz) that we could not even cope with writing it to tape!

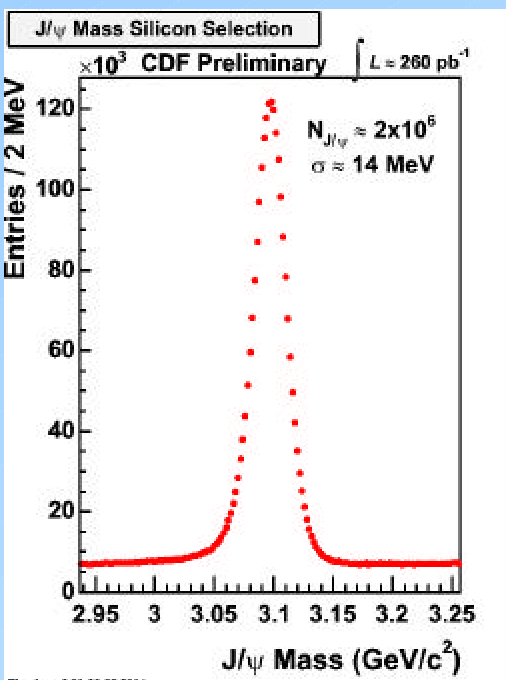
Samples

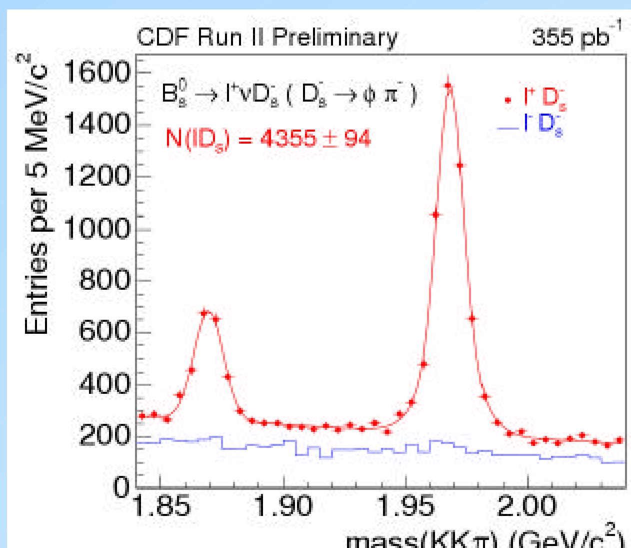
•Good lifetime (~100fs) and mass resolutions (~15 MeV)

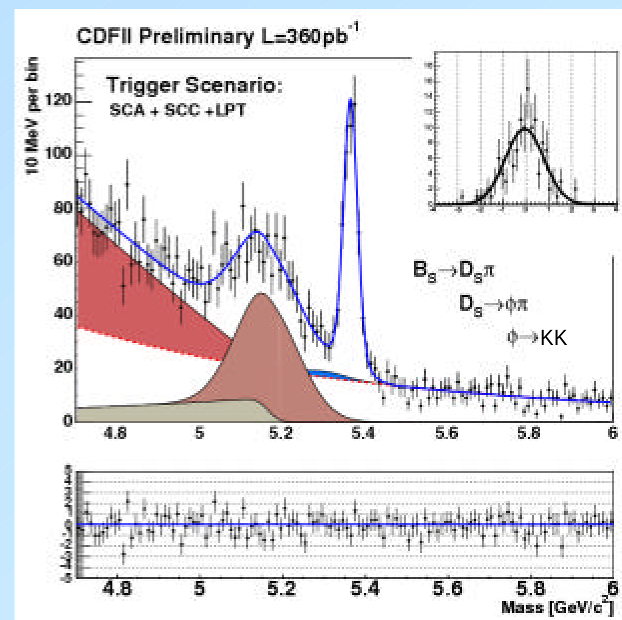
•Mostly HF-dominated background → well modeled

•LARGE:

- •J/ψ (dimuon trigger): ~ 1,000,000 J/ψ
- •lDX (4 GeV lepton+displaced track) ~ 100,000 lD
- •Fully hadronic (two displaced tracks) ~ 10,000 B
- ~ 1,000,000 D







Organizaton of this talk

- Time frame:
  - New results since last users meeting (few exceptions...)
- Focus on results which are complementary to/competitive with B factories
- Emphasize the development of tools and techniques at each step

Complementarity to B factories

$B_c^{\pm}$ MASS

VALUE (GeV)	DOCUMENT ID	TECN	COMMENT
6.4 ±0.39±0.13	[1] ABE	98M CDF	$p\overline{p}$ 1.8 TeV
• • • We do not use the following data for averages, fits, limits, etc. • • •			
6.32±0.06	[2] ACKERSTAFF	98O OPAL	$e^+e^- \to Z$

[1] ABE 98M observed $20.4^{+6.2}_{-5.5}$ events in the $B_c^+ \to J/\psi(1s)\ell\nu_\ell$ with a significance of > 4.8 standard deviations. The mass value is estimated from $m(J/\psi(1S)\ell)$.

[2] ACKERSTAFF 98O observed 2 candidate events in the $B_c \to J/\psi(1S)\pi^+$ channel with an estimated background of 0.63 ± 0.20 events.

$B_c^{\pm}$ MEAN LIFE

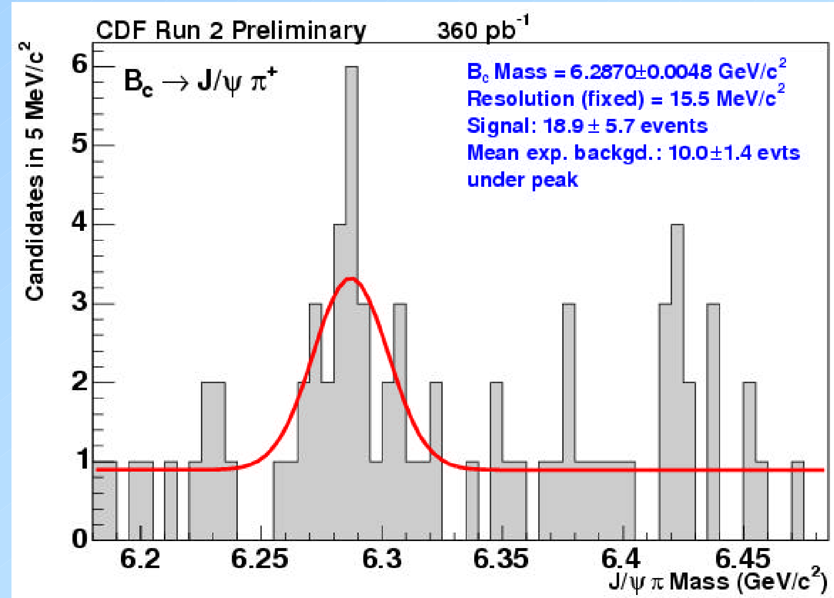
VALUE (10^{-12} s)	DOCUMENT ID	TECN	COMMENT
$\mathbf{0.46^{+0.18}_{-0.16}\pm0.03}$	[3] ABE	98M CDF	$p\overline{p}$ 1.8 TeV

[3] The lifetime is measured from the $J/\psi(1S)\ell$ decay vertices.

B_c^+ DECAY MODES × B($\overline{b} \to B_c$)

B_c^- modes are charge conjugates of the modes below.

	Mode	Fraction (Γ_i/Γ)	Confidence level
	The following quantities are not pure branching ratios; rather the fraction $\Gamma_i/\Gamma \times$ B($\overline{b} \to B_c$).		
Γ_1	$J/\psi(1S)\ell^+\nu_\ell$ anything	$(5.2^{+2.4}_{-2.1}) \times 10^{-5}$	
Γ_2	$J/\psi(1S)\pi^+$	$< 8.2 \times 10^{-5}$	90%
Γ_3	$J/\psi(1S)\pi^+\pi^+\pi^-$	$< 5.7 \times 10^{-4}$	90%
Γ_4	$J/\psi(1S)a_1(1260)$	$< 1.2 \times 10^{-3}$	90%
Γ_5	$D^*(2010)^+\overline{D}^0$	$< 6.2 \times 10^{-3}$	90%



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

Hep-ex/0505076

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

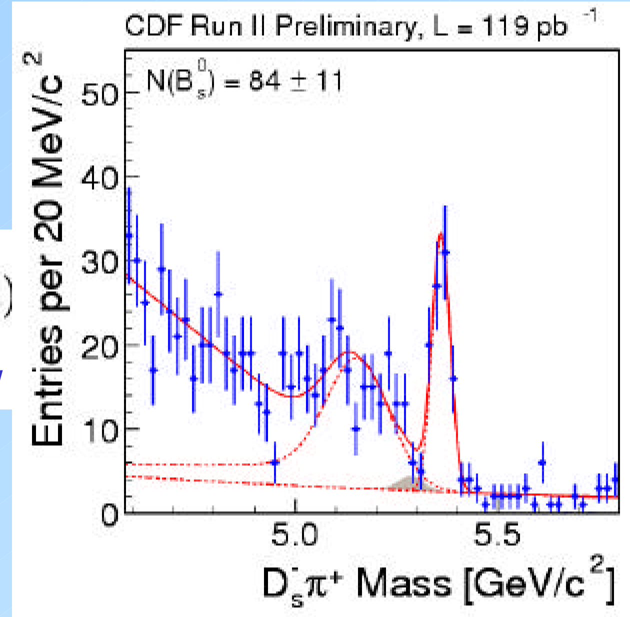
Branching ratios

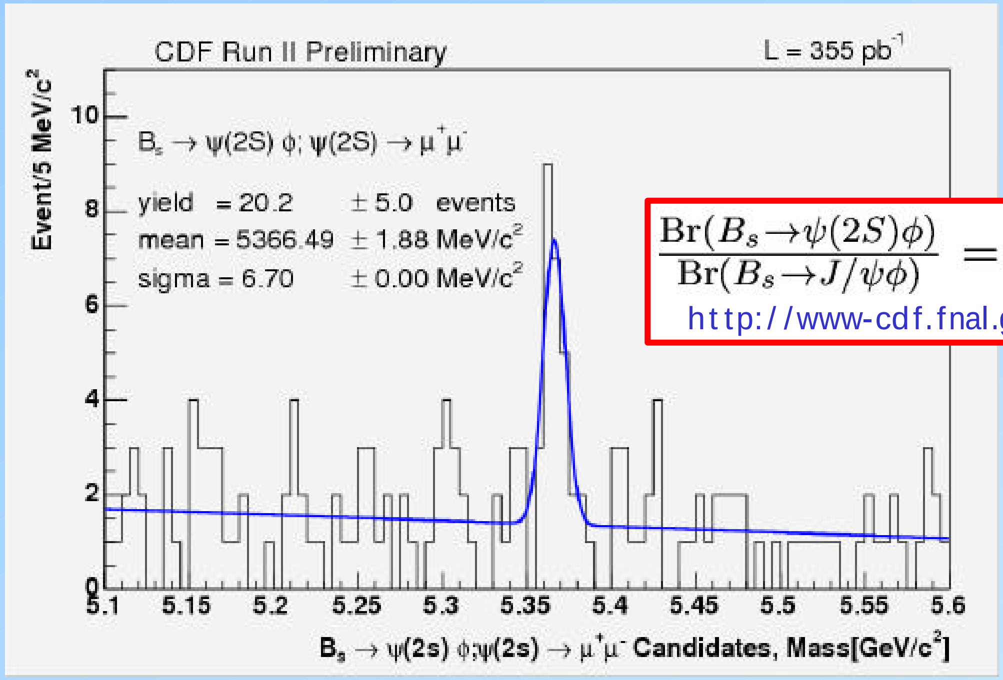
We have measured several branching ratios...

(and many more to come!)

$$\frac{f_s}{f_d}\cdot\frac{Br(B_s\to D_s^-\pi^+)}{Br(B^0\to D^-\pi^+)} = 0.35\pm0.05(stat)\pm0.04(syst)\pm0.09(BR)$$

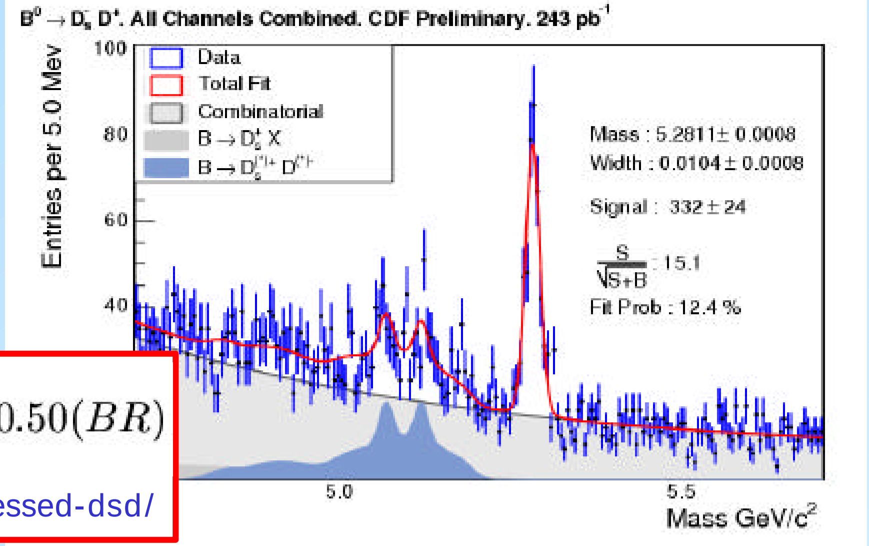
http://www-cdf.fnal.gov/physics/new/bottom/031002.blessed-bs-br/





$$\frac{Br(B_s\to\psi(2S)\phi)}{Br(B_s\to J/\psi\phi)} = 0.52\pm0.13[\text{stat}]\pm0.06[BR]\pm0.04[\text{sys}]$$

http://www-cdf.fnal.gov/physics/new/bottom/050310.blessed-dsd/



$$\frac{Br(B^0\to D_s^+D^-)}{Br(B^0\to D^-3\pi)} = 2.00\pm0.16(NC)\pm0.12(syst)\pm0.50(BR)$$

http://www-cdf.fnal.gov/physics/new/bottom/050310.blessed-dsd/

Branching Rations, continued: Baryons

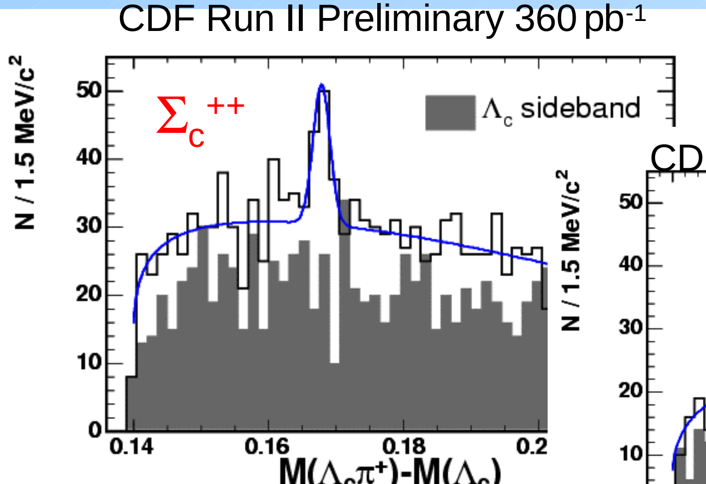
The field to explore is so extensive that we have been 'stumbling' upon unobserved signals all over the place, in the 'easiest' cases:

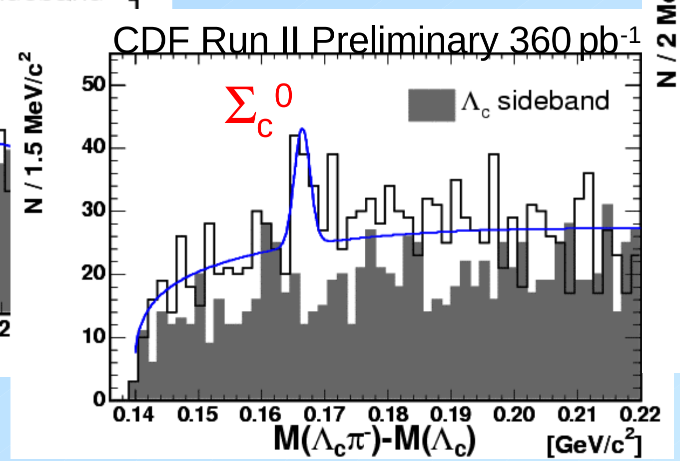
$$\frac{\mathcal{B}(\Lambda_b \to \Lambda_c^+ \mu^- \overline{\nu}_\mu)}{\mathcal{B}(\Lambda_b \to \Lambda_c^+ \pi^-)} = 20.0 \pm 3.0\ (stat) \pm 1.2\ (syst)\ {}^{+0.7}_{-2.1}\ (BR) \pm 0.5\ (UBR)$$

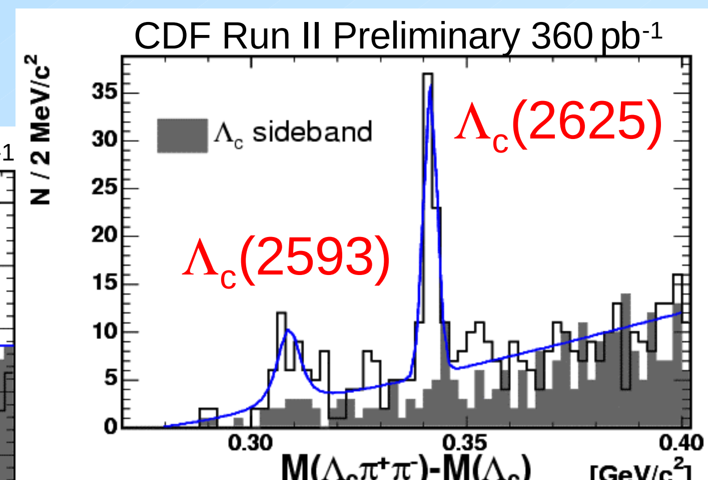
http://www-cdf.fnal.gov/physics/new/bottom/050407.blessed-lbbr/

First observation of several Λ_b semileptonic decays that can 'mimic' the signal $\Lambda_b \rightarrow \Lambda_c^+ m\bar{n}$

– Estimate the BR based on the observation







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

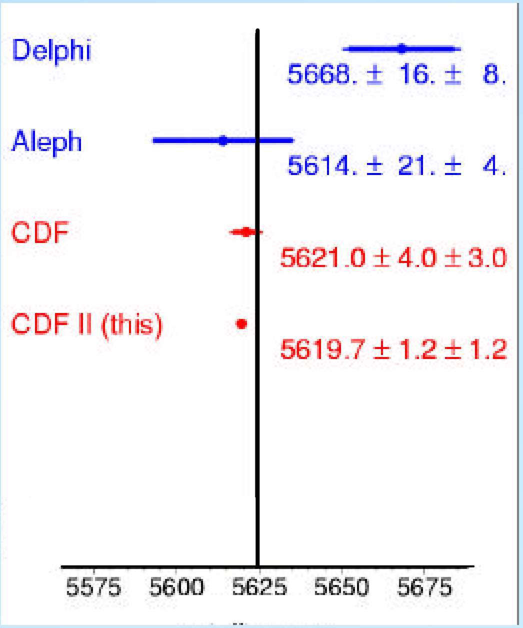
$c\tau = 368\ \mu m$

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
$\Lambda_c\, l\, \upsilon$	(5.5 ± 1.8) %
pK + pπ	$< 2.2 \times 10^{-5}$
$\Lambda_c^+ \pi^- \pi^- \pi^+$	seen
$\Lambda\gamma$	$< 1.3 \times 10^{-3}$
$\Lambda_c(2593)^+\, l\, \upsilon$	seen
$\Lambda_c(2625)^+\, l\, \upsilon$	seen
$\Sigma_c^{++} \pi^-\, l\, \upsilon$	seen
$\Sigma_c^0 \pi^+\, l\, \upsilon$	seen

Colors:

- PDG2004
- CDF contribution beyond current PDG2004

L_b mass



BR & Rare decays

•Exploit the large B production rate

•Measure relative BR (e.g. $\mu\mu$ to $J/\psi K$) to factor out absolute ε and luminosity measurements

•SM: BR($B_s \to \mu\mu$) <3.8E-9

•Sensitive to new physics!

Result: World's best limits

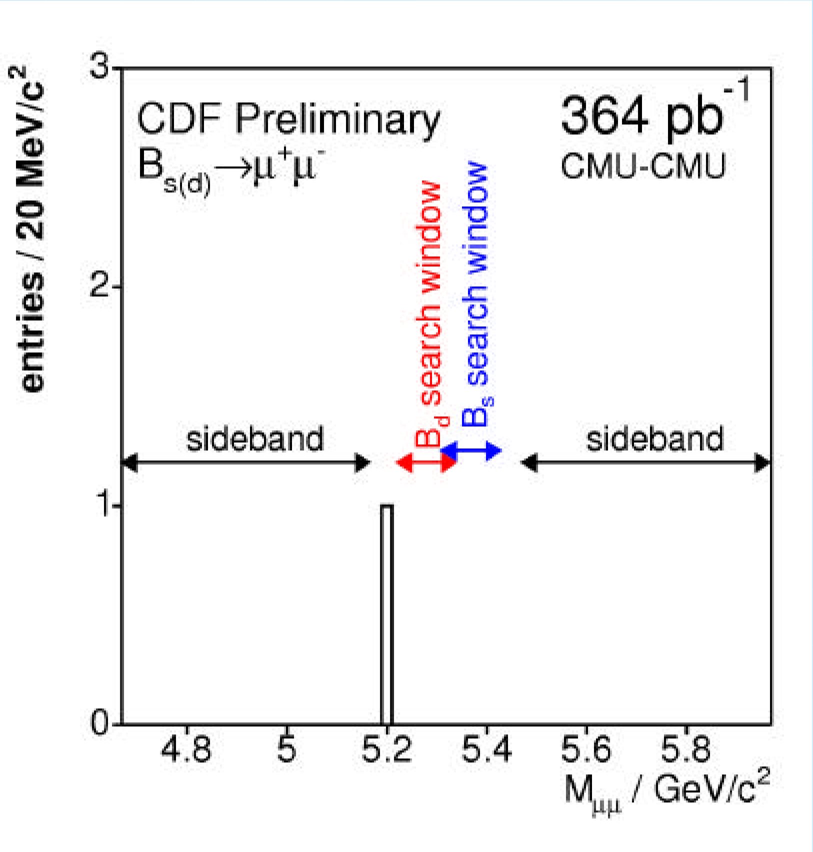
BR($B_s \to \mu\mu$) < $2.0\text{x}10^{-7}$ @95% CL

BR($B_d \to \mu\mu$) < $4.9\text{x}10^{-8}$ @95% CL

Publ: PRL 93, 032001 2004   Update: Hep-ex/0502044

$$BR(D^0 \to mm) \leq 2.4 \times 10^{-6}\ at\ 90\%\ CL$$

PRD 68, 091101 2003

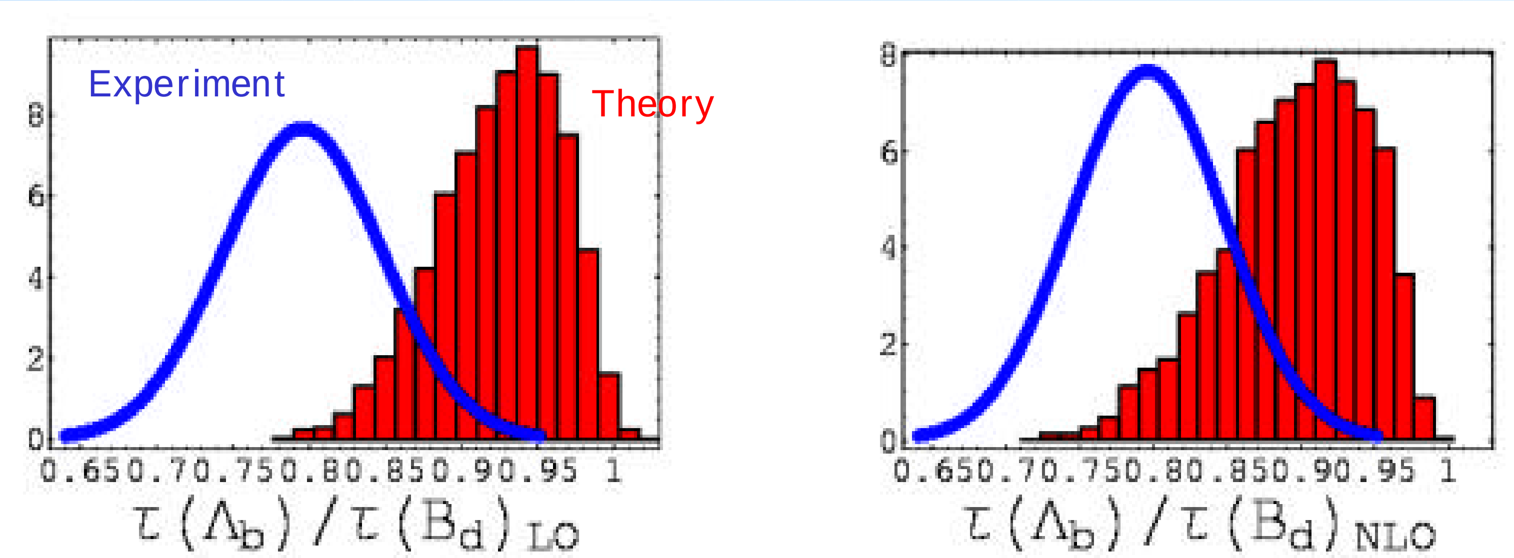


Lifetimes

- 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

- Systematic shift in HQE predictions?

- We can test this: samples are at hand!



C. Tarantino, hep-ph/0310241 Oct 2003

Lifetimes: fully reconstructed hadronic modes

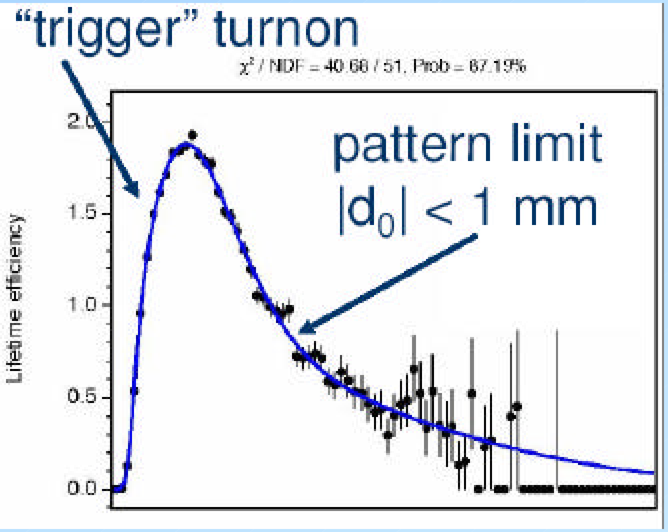
- Testbed for our ability to understand trigger biases

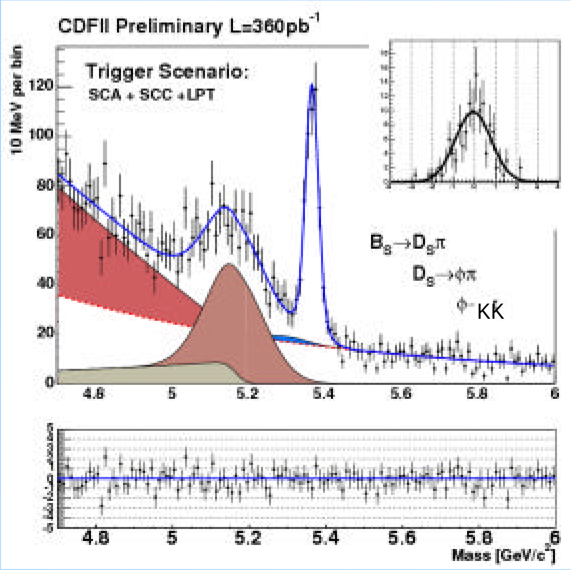
- Large, clean samples

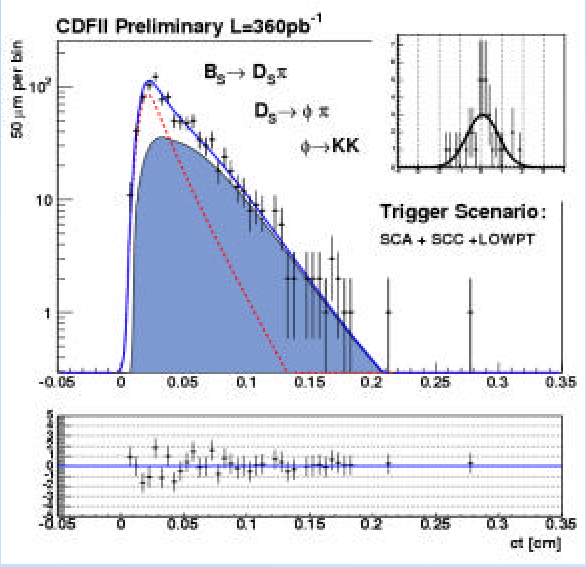
- Prerequisite for mixing fits!

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







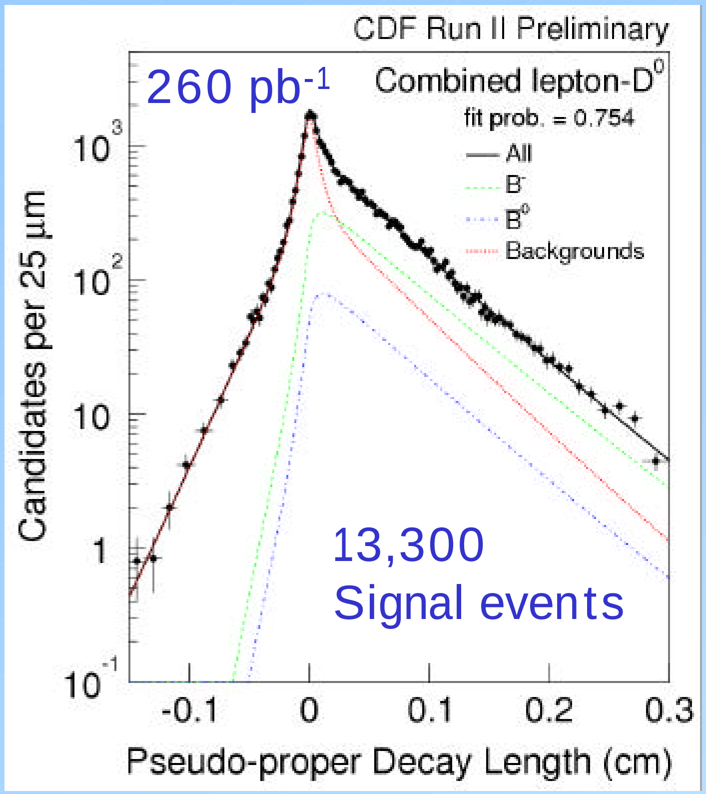
Systematics (μm)

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

http://www-cdf.fnal.gov/physics/new/bottom/050303.blessed-bhadlife/

Lifetimes: semileptonic

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



- Largest statistics B sample
- More complicated background
- Full statistics sample still under study. Statistical uncertainty expected:

B^+	± **0.025 ps**
B^0_d	± **0.035 ps**
B^0_s	± **0.04 ps**
L_b	± **0.05 ps**

@ ~400 pb^{-1}

- Our understanding of sample composition tested with 'inclusive lepton' 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**

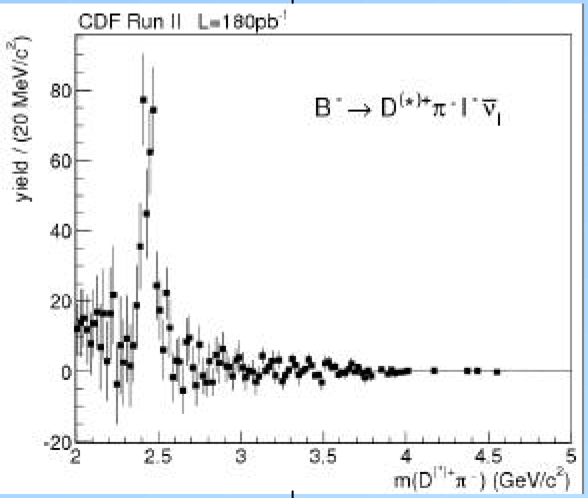
- Working on systematics!

Constraining HQET tools for V_{cb}

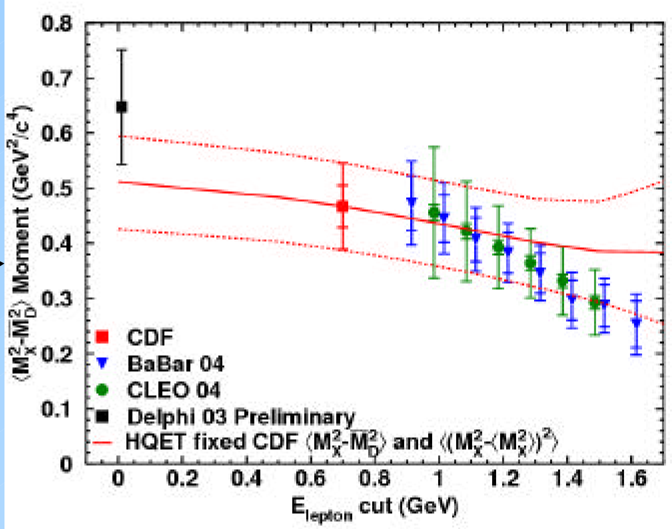
CDF can probe HQET and constrain it!

Moments: kinematic parameters in $B \to l\nu X_c$ decays

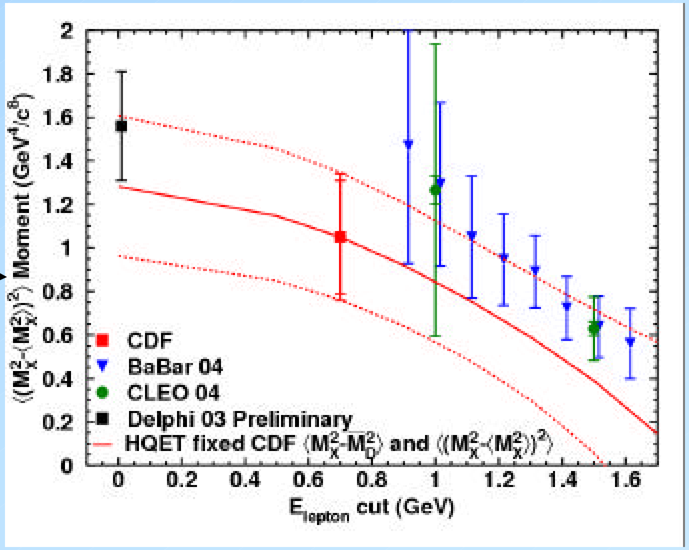
Non-leptonic mass in $B \to l\nu X_c$



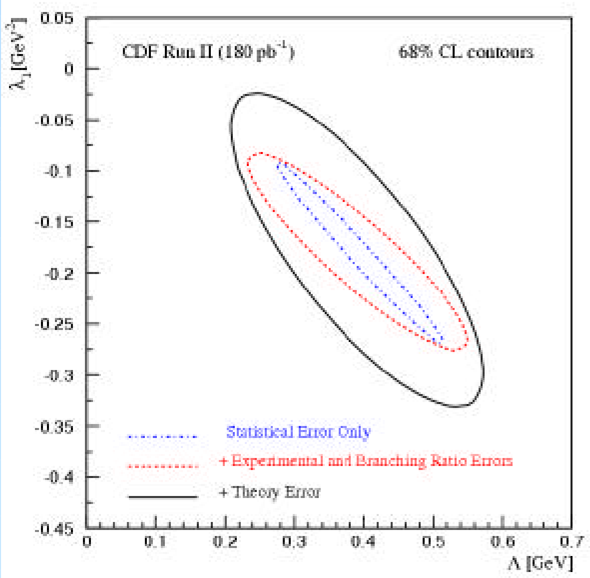
→ Mean →



→ RMS →



HQET Parameters



PRDRC 71, 051102 2005

CP Violation & Mixing

CP: B→hh modes

•Difficult competition with B factories for t-dependent tagged measurements

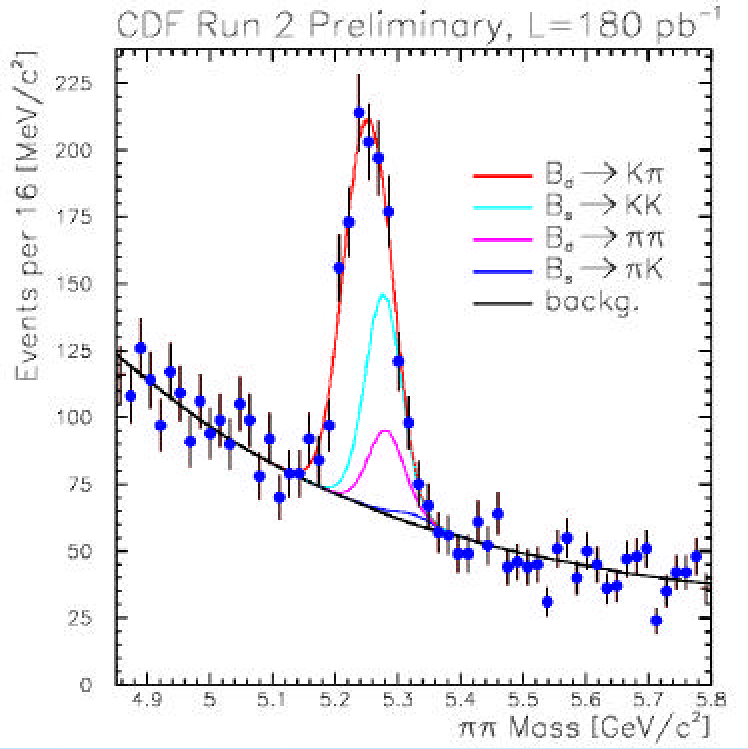
•Interesting B physics measurement of BR and γ

•Signals overlap within mass resolution

•Exploit kinematic handles and dE/dX to disentangle components in a combined fit:

- $M_{\pi\pi}$
- the two track's momentum imbalance
- dE/dX

With perfect particle ID, separation would be 'only' ~60% better



CP: hh modes

- Good agreement with B factories
- First measurement ever of $B_s \to KK$

$$\frac{BR(B_d \to \pi^{\pm}\pi^{\mp})}{BR(B_d \to K^{\pm}\pi^{\mp})} = 0.24 \pm 0.06\ (stat.) \pm 0.05\ (syst.)$$

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

$$\frac{f_d \cdot BR(B_d \to \pi^{\pm}\pi^{\mp})}{f_s \cdot BR(B_s \to K^{\pm}K^{\mp})} = 0.48 \pm 0.12\ (stat.) \pm 0.07\ (syst.)$$

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

$$\frac{BR(B_s \to \pi^{\pm}\pi^{\mp})}{BR(B_s \to K^{\pm}K^{\mp})} < 0.10 \ @\ 90\%\ C.L.$$

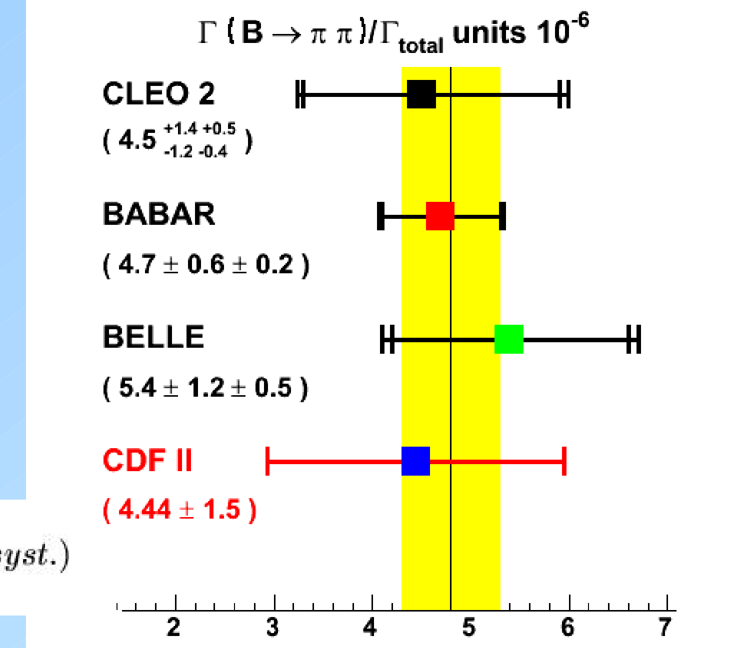
$$\frac{BR(B_d \to K^{\pm}K^{\mp})}{BR(B_d \to K^{\pm}\pi^{\mp})} < 0.17 \ @\ 90\%\ C.L.$$

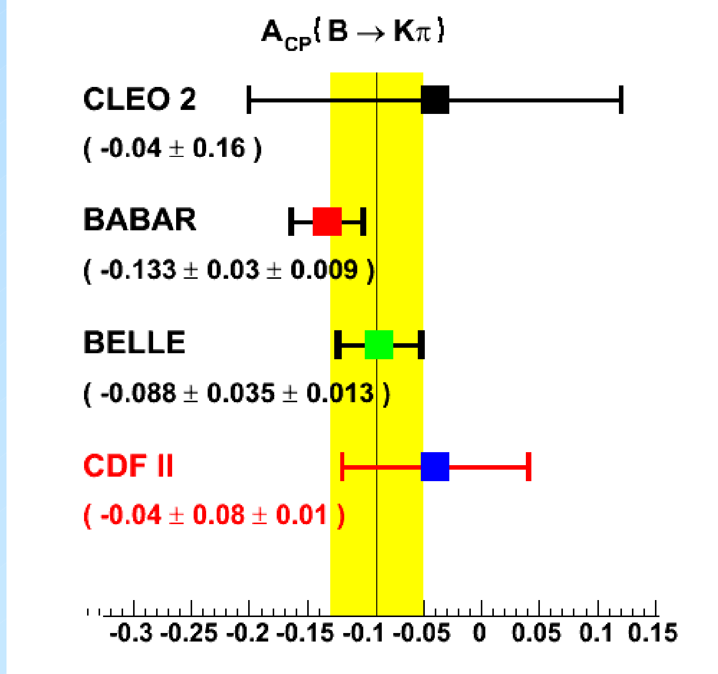
$$\frac{f_s \cdot BR(B_s \to K^{\pm}\pi^{\mp})}{f_d \cdot BR(B_d \to K^{\pm}\pi^{\mp})} < 0.11 \ @\ 90\%\ C.L.$$

http://www-cdf.fnal.gov/physics/new/bottom/040722.blessed-bhh/

$$BR(\Lambda_b \to hh) < 22 \cdot 10^{-6} \quad (90\% C.L.)$$

http://www-cdf.fnal.gov/physics/new/bottom/040624.blessed_Lb_hh_limit/

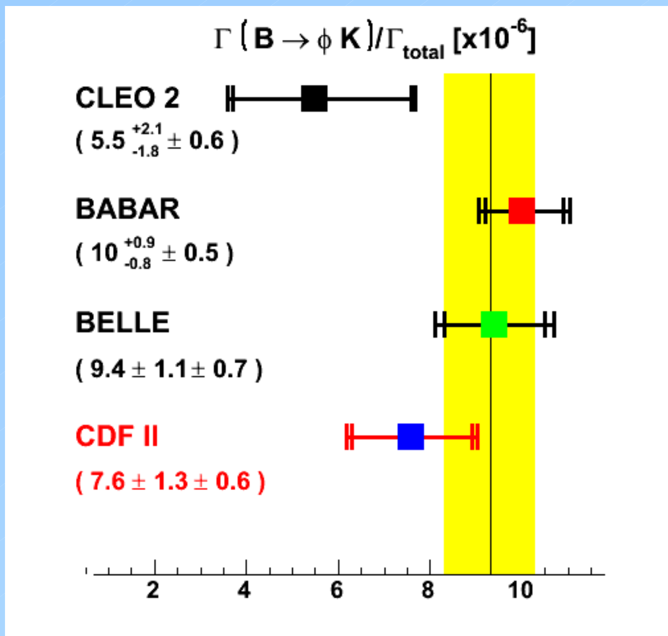


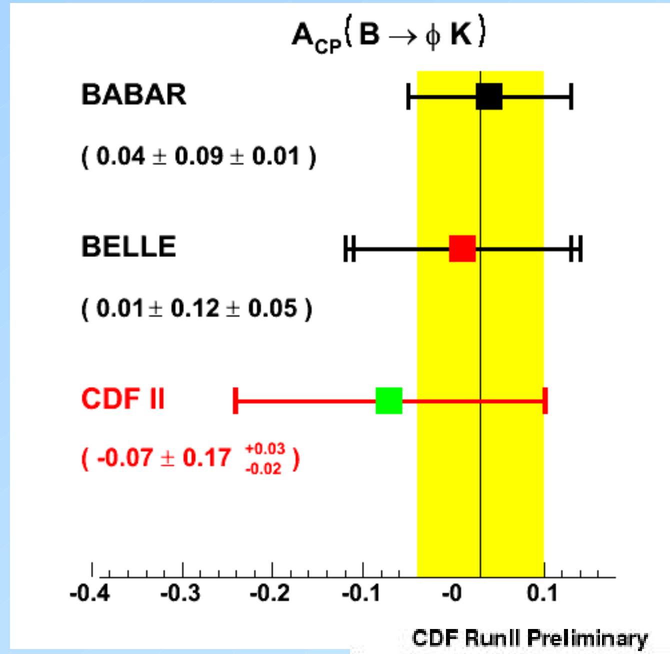


CP: $s\bar{s}s$

Hep-ex/0502044

- $b \to sss$ transitions are 'misbehaving' at B factories
- ...CDF II can look at them too. We started from ϕK:

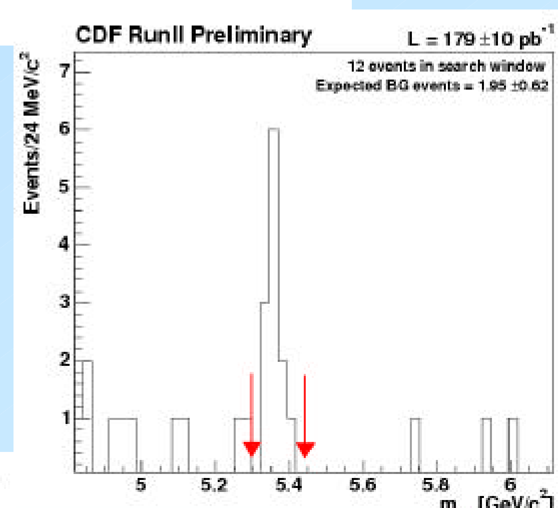




$$\frac{BR(B^\pm \to \phi K^\pm)}{BR(B^\pm \to J/\psi K^\pm)} = 0.0076 \pm 0.0013\,(stat.) \pm 0.0006\,(syst.)$$

$$A_{CP}(B^\pm \to \phi K^\pm) = -0.07 \pm 0.17\,(stat.)\,^{+0.03}_{-0.02}\,(syst.)$$

- ...With the advantage of being able to look at Bs too:



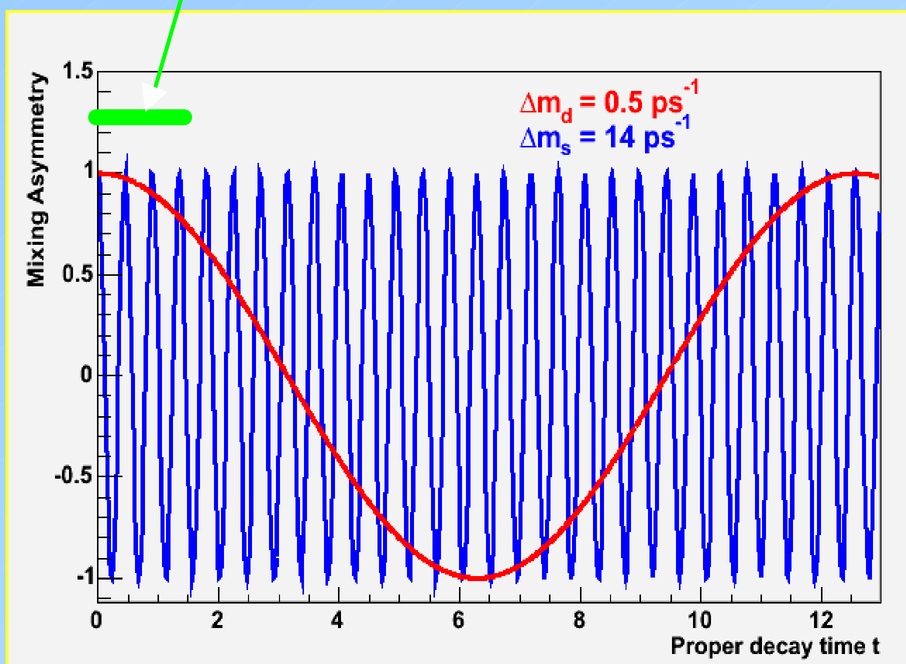
$$BR(B_s \to \phi\phi) = (1.4 \pm 0.6(stat.) \pm 0.2(syst.) \pm 0.5(BR's)) \cdot 10^{-5}$$

B_s Mixing 101

- $\Delta m_s \gg \Delta m_d$
- Different oscillation regime → Amplitude Scan

Perform a 'fourier transform' rather than fit for frequency

B lifetime



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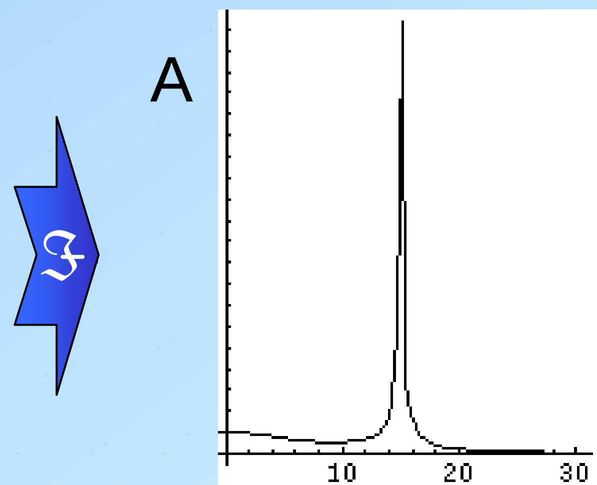


Δm_s [ps^{-1}]

$$Significance = \frac{A}{s(A)} = \sqrt{\frac{SeD^2}{2}}\, e^{-\frac{(\Delta m_s s_t)^2}{2}} \sqrt{\frac{S}{S+B}}$$

B_s Mixing Ingredients

Proper time resolution

Flavor tagging

Signal-to-noise

Event yield

$$Significance = \sqrt{\frac{S\epsilon D^2}{2}}\, e^{-\frac{(\Delta m_s \sigma_t)^2}{2}} \sqrt{\frac{S}{S+B}}$$

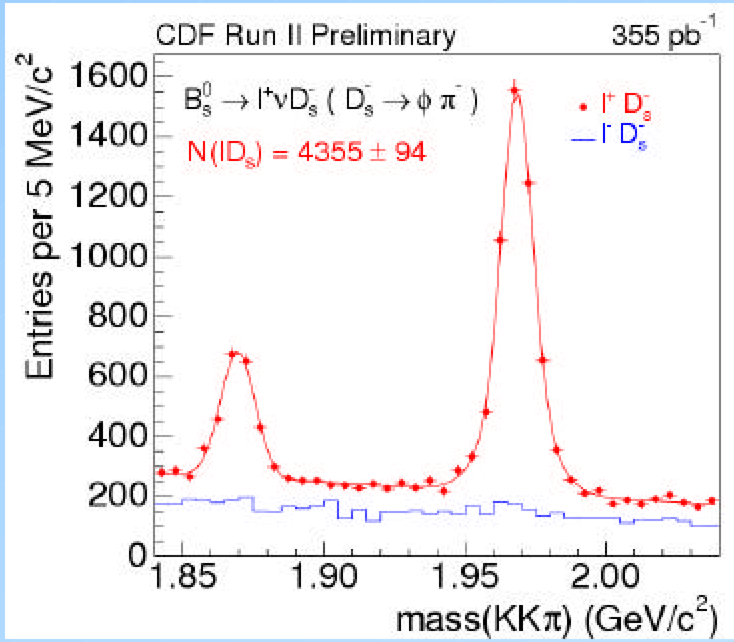
B_s Mixing: tagging performance

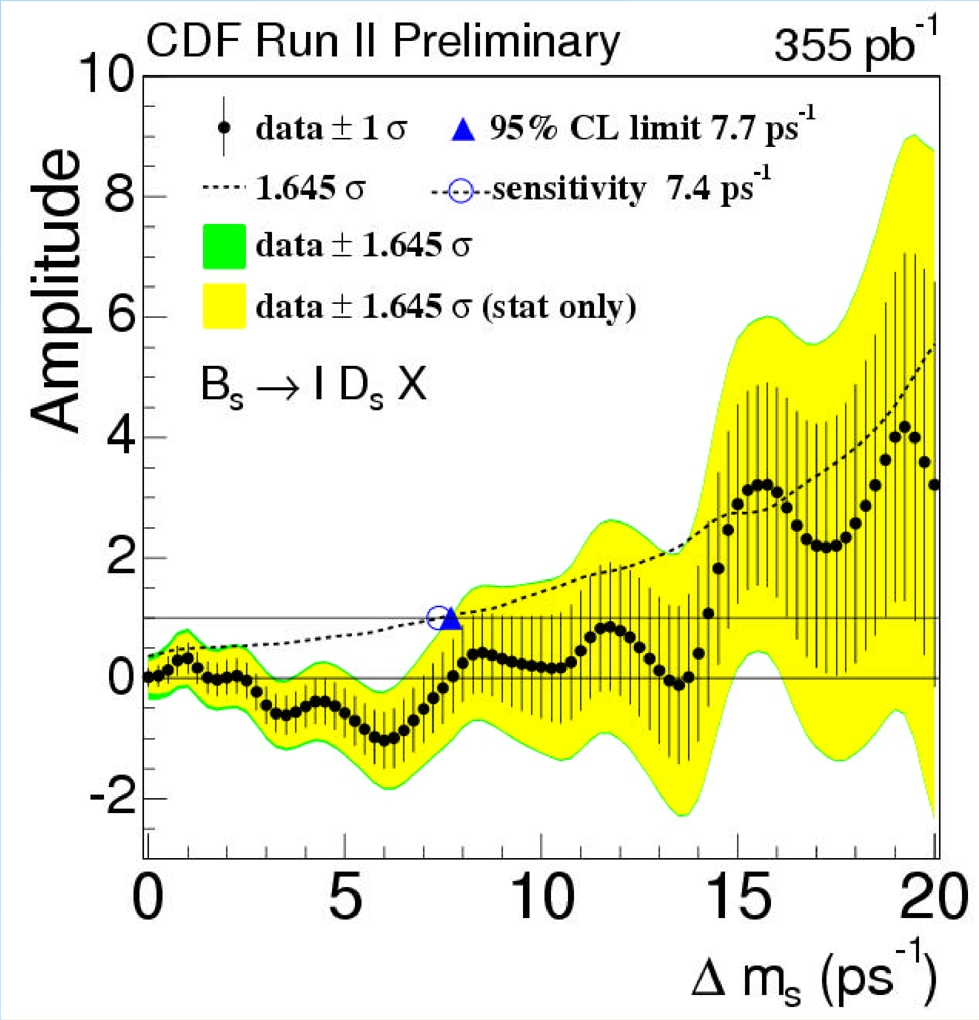
	εD^2 Hadronic (%)	εD^2 Semileptonic (%)
Muon	$0.46 \pm 0.11 \pm 0.03$	$0.577 \pm 0.047 \pm 0.034$
Electron	$0.18 \pm 0.06 \pm 0.02$	$0.293 \pm 0.033 \pm 0.017$
JQ/Vertex	$0.14 \pm 0.07 \pm 0.01$	$0.263 \pm 0.035 \pm 0.021$
JQ/Prob.	$0.11 \pm 0.06 \pm 0.01$	$0.150 \pm 0.026 \pm 0.015$
JQ/High p_T	$0.24 \pm 0.09 \pm 0.01$	$0.157 \pm 0.027 \pm 0.015$
Total	1.12 ± 0.18	1.429 ± 0.093

- convention: first uncertainty is statistical, second is systematic
- use exclusive combination of tags
- results for hadronic and semileptonic comparable within errors
- use calibration derived from appropriate sample (ie hadronic for $D_s\pi$)

B_s Mixing: semileptonic

- $B_s \to D_s l\nu$
  - $D_s \to \phi\pi$ (4355±94 3.1)
  - $D_s \to K^*K$ (1750±83 0.42)
  - $D_s \to \pi\pi\pi$ (1573±88 0.32)





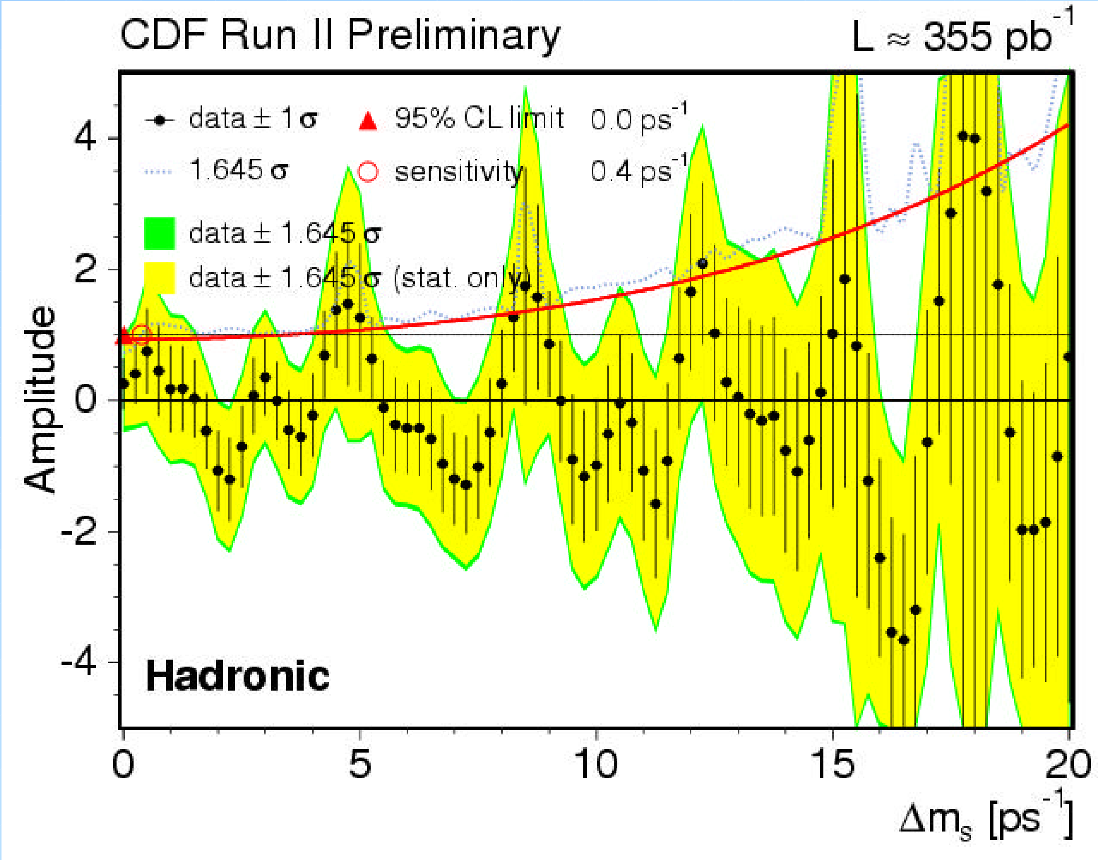
Reach at large Δm_s limited by incomplete reconstruction (σ_{ct})!

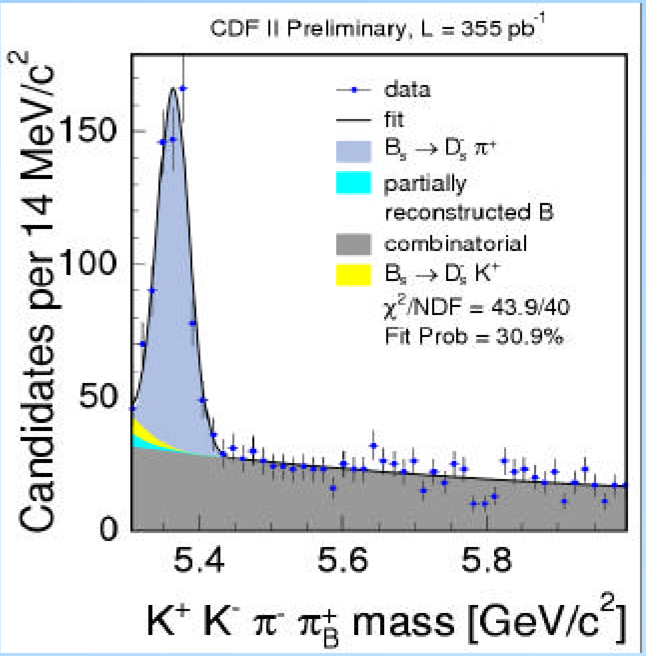
$\Delta m_s > 7.7\ ps^{-1}$ @ 95% CL

Sensitivity: $7.4\ ps^{-1}$

B_s Mixing: hadronic

- $B_s \to D_s\pi$
  - $D_s \to \phi\pi$ (526±33 1.8)
  - $D_s \to K^*K$ (254±21 1.7)
  - $D_s \to \pi\pi\pi$ (116±18 1.0)



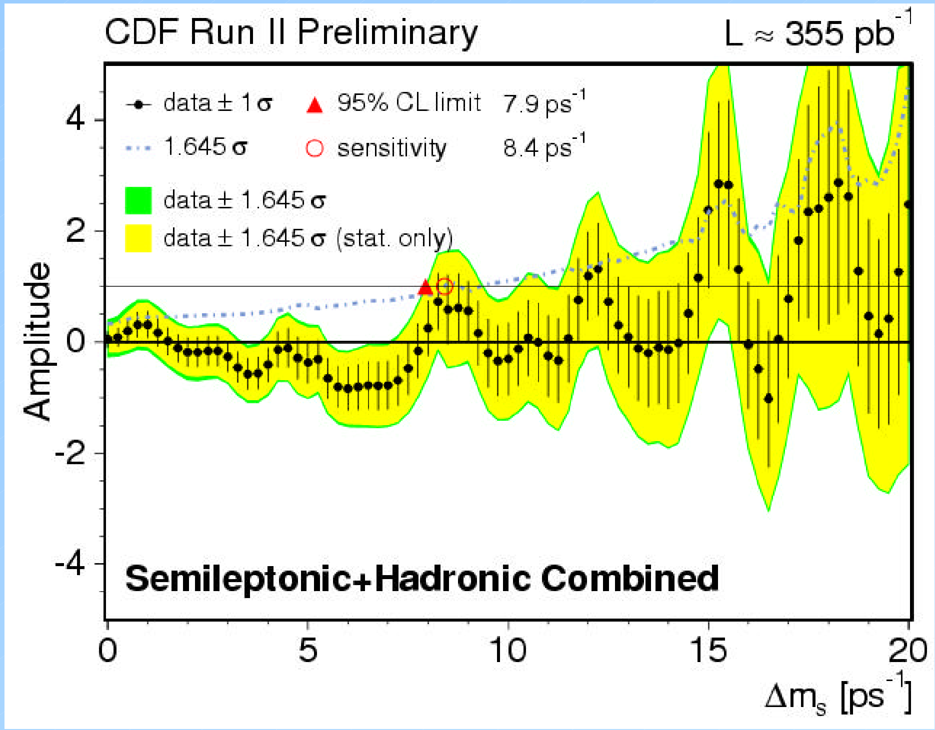


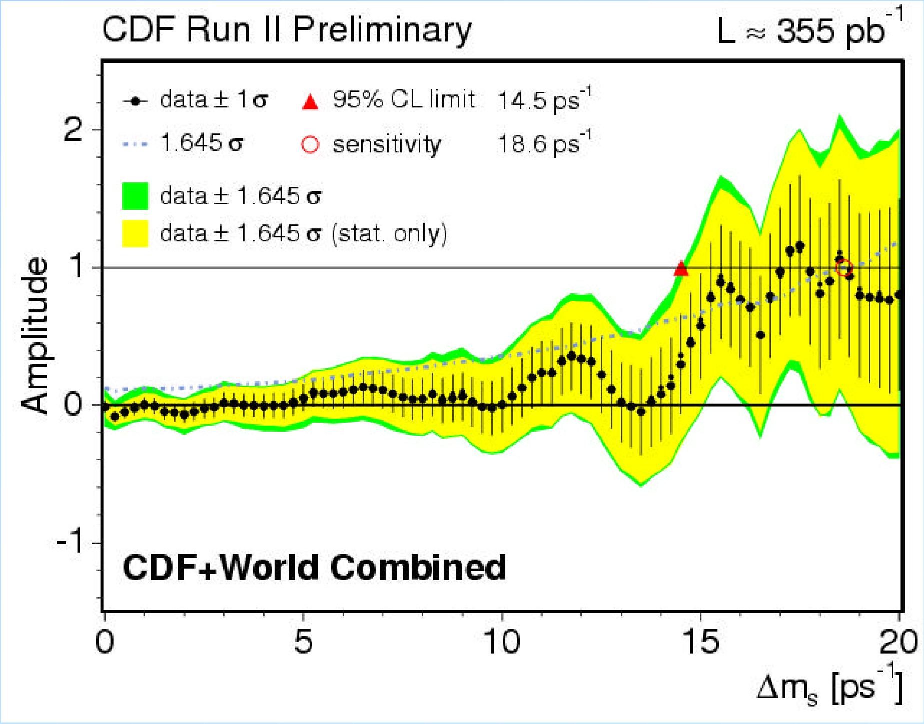
$\Delta m_s > 0.0\ ps^{-1}$ @ 95% CL

Sensitivity: $0.4\ ps^{-1}$

Low statistics, but promising!

Combined Bs mixing limit





$\Delta m_s > 7.9\ ps^{-1}$ @ 95% CL

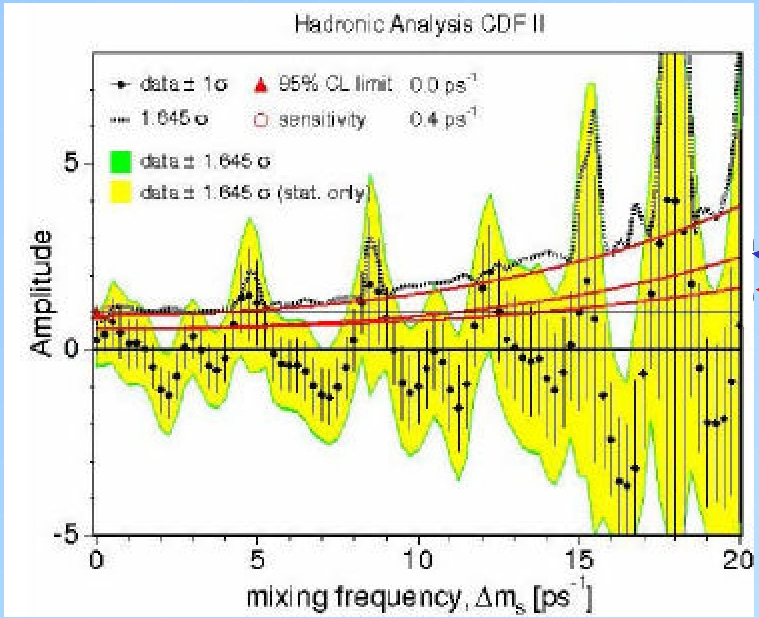
Sensitivity: 8.4 ps^{-1}

$\Delta m_s > 14.5\ ps^{-1}$ @ 95% CL

Sensitivity: 18.6 ps^{-1}

B_s Mixing Perspectives

Analysis is pretty much defined! We know where we can improve:



- Statistics
  - Data (brute force)
  - εD^2 :
    - Additional taggers (SSK, OSK…)
    - Improve existing algorithms
- Proper time resolution

- What happens for extremely large values of Δm_s?
- We have a backup plan…

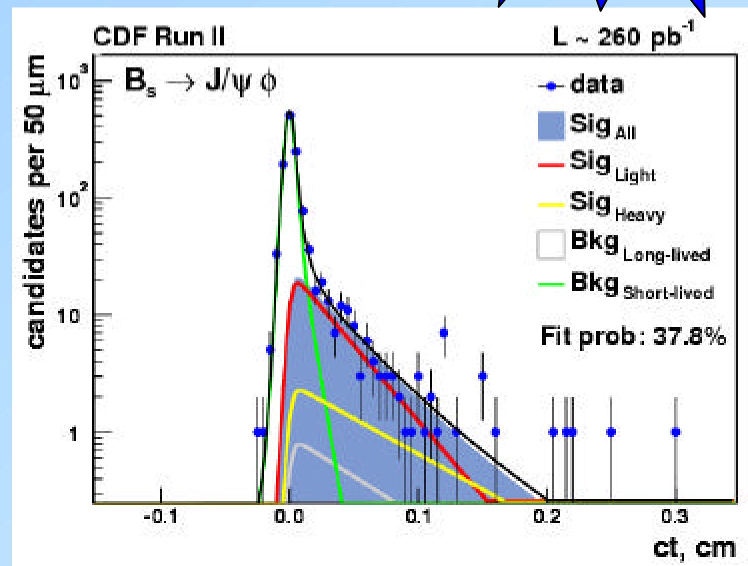
Probing at large Δm_s: $\Delta\Gamma/\Gamma$

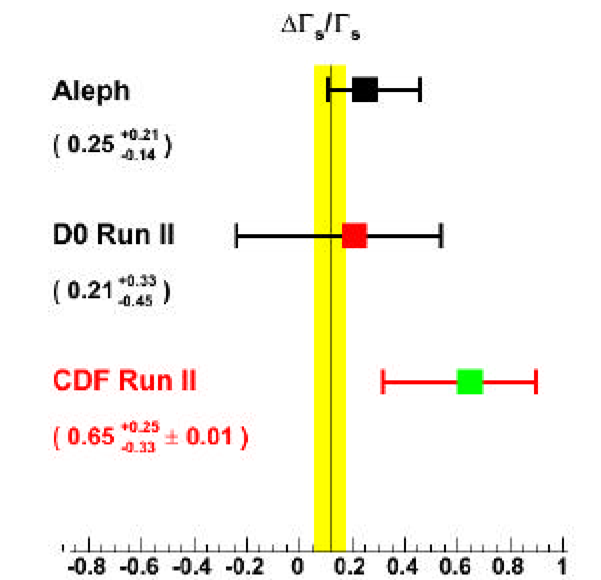
URA thesis award!

- $B_s \to J/\psi\phi$
  - $B \to VV$, mixture of CP even/odd separate by angular analysis
  - Combine two-lifetime fit + angular$\to$ $\Delta\Gamma_s = \Gamma_H - \Gamma_L$
  - SM $\Delta\Gamma_s/\Gamma_s = 0.12 \pm 0.06$ (Dunietz, Fleischer & Nierste)
- Indirect Measurement of Δm_s
  - $$\left.\frac{\Delta\Gamma_s}{\Delta m_s}\right|_{SM} = \frac{2}{3p}\frac{m_t^2}{m_b^2}\frac{h\left(\frac{m_t^2}{M_W^2}\right)}{\left(1-\frac{8}{3}\frac{m_c^2}{m_b^2}\right)} = \left(3.7^{+0.8}_{-1.5}\right)\times 10^{-3}$$

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

few ps^{-1} in Δm_s !





PRL 94, 101803 2005

Conclusions

- 48 public results so far: lots of successful h.f. physics!
  - Well established samples and techniques
  - Competitive with and complementary to B factories
- Infrastructure, tools and first measurements of B_s mixing are ready!
- Accumulating statistics is now crucial!
- …still much more to come!

Backup Slides

Results Omitted

- Taggers calibration
  - Semileptonic (050224)
  - Hadronic (050224)
- B mixing with SST (040812)
- Mixing with combined taggers (040812)
- NN based JQT on semileptonics (050303)
- Improved JQT in semileptonics (040812)
- Likelihood based SET (040812)
- Likelihood based SμT (040722)
- Relative BR and CP asym. For $D^0 \rightarrow KK, K\pi, \pi\pi$ (031211)
- Λ_b lifetime (030710)
- X(3872) (040624, 040920, 050324)
- $\Delta M(D_s - D^+)$ (030320)
- D_1 and D_2 masses (040805)
- B hadrons masses (040428)
- Pentaquark searches (040819, 040428,040219,040428)
- J/ψ inclusive cross section (030904)
- Direct charm cross section (030403)
- (Wrong sign) $D^0 \rightarrow K\pi$ PR (040930)
- QCD:
  - Inclusive B jet production (Apr '05)
  - Bbbar dijet production (Apr '05)

The Collider Detector at Fermilab

Tracking:

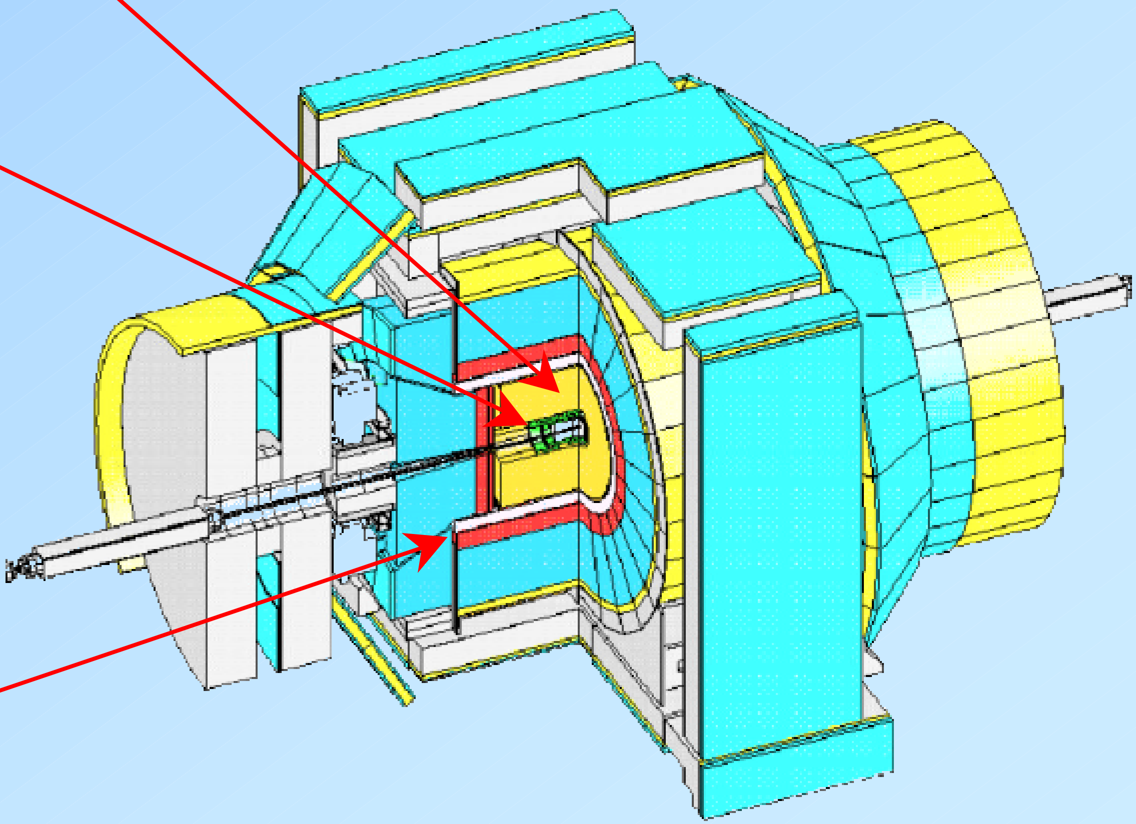
- COT (central wire chamber)
- ISL (Intermediate Silicon Layers)
- SVX II (silicon vertex detector)
- Layer 00 (Innermost layer of the Si detector, glued to the beam pipe)

Lepton ID:

Muons: CMU, CMX, CMP

Electrons: CEM (EM calorimeter)

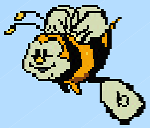
CPR (pre-shower detector)



PID:

- dE/dX in COT
- TOF (Time of flight detector)

Exciting results in the B sector



- $B_{d,s}\to hh$
- $B_{u,d,s}\to lD^{*/+/0}X$
- $B_{u,d}\to lD^{**}X$
- $B_s\to D_s\pi$
- $B_s\to \phi K$
- $B_s\to \phi\phi$
- $B_s\to \psi(2s)\phi$
- $B_c\to J/\psi\pi$
- $B_c\to J/\psi X$

•Despite the great success of B factories, there is room for interesting B physics at an hadron machine!

- •Lifetimes
- •Branching ratios
- •Rare decays
- •CP violation
- •Probing of HQET
- •Mixing!

We also have Baryons!

- $\Lambda_b \to l\Lambda_c X$
- $\Lambda_b \to J/\psi\Lambda$
- $\Lambda_b \to \Lambda_c\pi$
- $\Lambda_b \to ph$

- Nice probe of HQET
- Inaccessible to b factories
    - Lifetimes
    - BR
    - CP violation?

Λ_b^0 DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$J/\psi(1S)\Lambda$		$(4.7\pm2.8)\times10^{-4}$		1744
$\Lambda_c^+\pi^-$		seen		2345
$\Lambda_c^+ a_1(1260)^-$		seen		2156
$\Lambda_c^+\ell^-\overline{\nu}_\ell$ anything	[t]	(9.2 ± 2.1) %		–
$p\pi^-$		$< 5.0 \times 10^{-5}$	90%	2732
pK^-		$< 5.0 \times 10^{-5}$	90%	2711
$\Lambda\gamma$		$< 1.3 \times 10^{-3}$	90%	2701

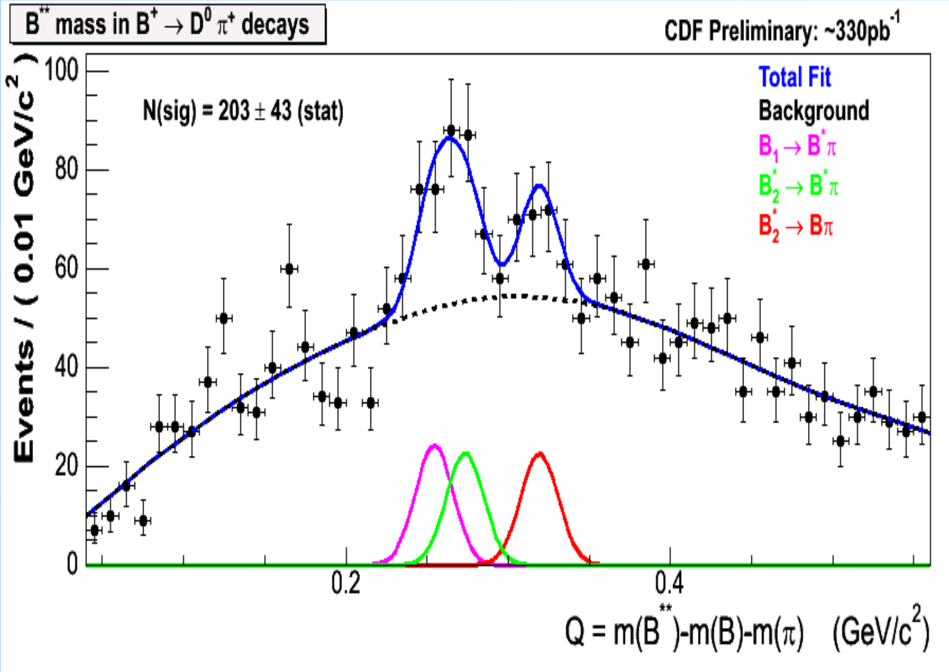
- $D^0 \to K\pi/\pi\pi/KK$
- $D^0 \to \mu\mu$
- $D^+ \to K\pi\pi$
- $D^* \to D^0\pi$
- $J/\psi \to \mu\mu$
- $D^{**} \to D\pi$

- Large statistics: charm factory!
- Mostly prompt production
- Many interesting questions:
  - Production (σ, correlations, mechanisms)
  - Branching ratios
  - CP violation
  - Masses and widths (excited states)

More ‘exotic’ stuff

Several nice results:

- Baryons
- X(3872)
  - Mass
  - Lifetime
- Pentaquarks



... I don’t have to cover them, but you can look at:

http://www-cdf.fnal.gov/physics/new/bottom/bottom.html

Production

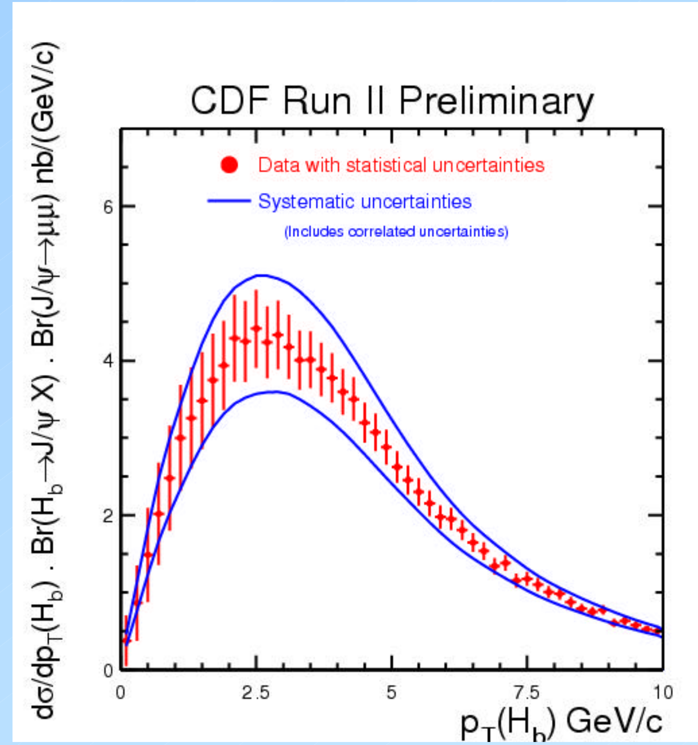
$$\sigma(p\bar{p} \to J/\psi X, |\, y(J/\psi)\, | < 0.6) \cdot Br(J/\psi \to \mu\mu)$$
$$240 \pm 1(stat) \pm 21(syst)\ \text{nb}$$

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

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

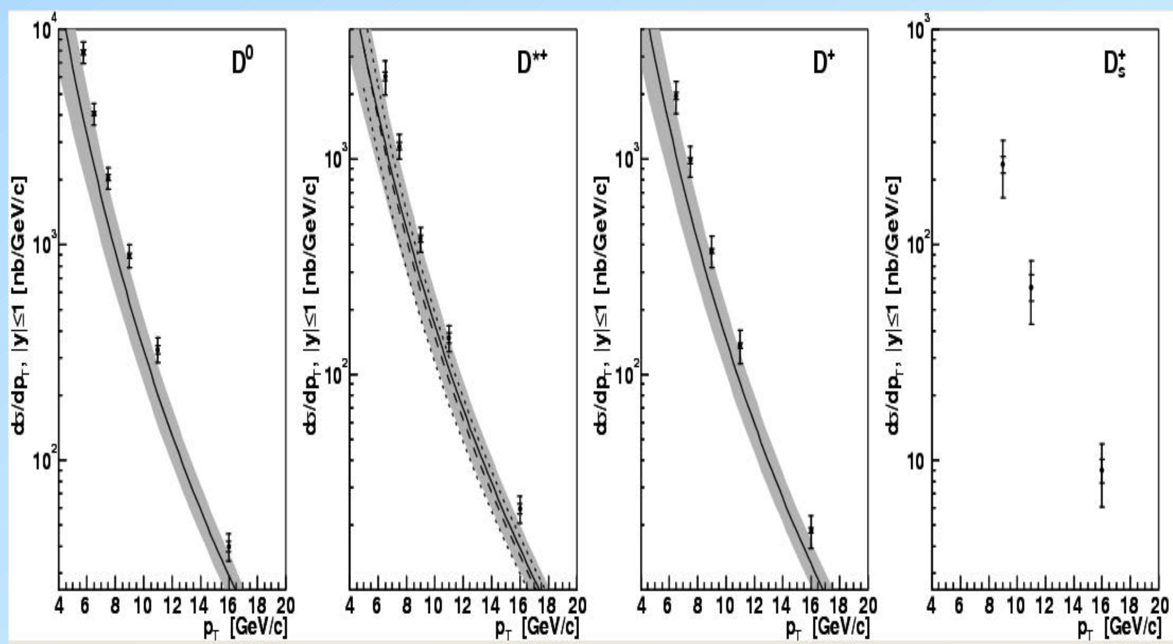
$H_b \to \psi X$ in 37 pb^{-1} of data!

PRD 71, 032001 (2005)



	P_t thr. GeV/c	s **(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)

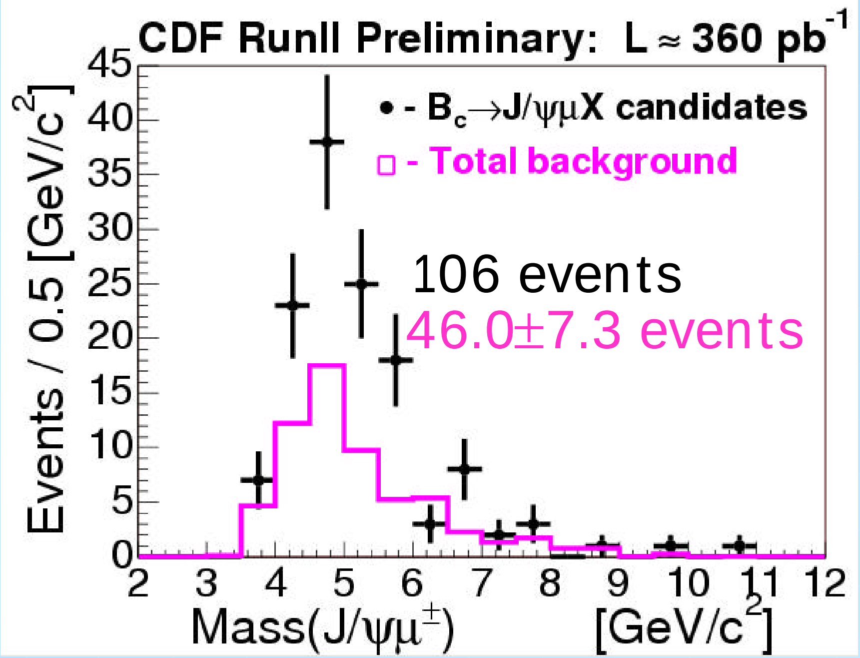


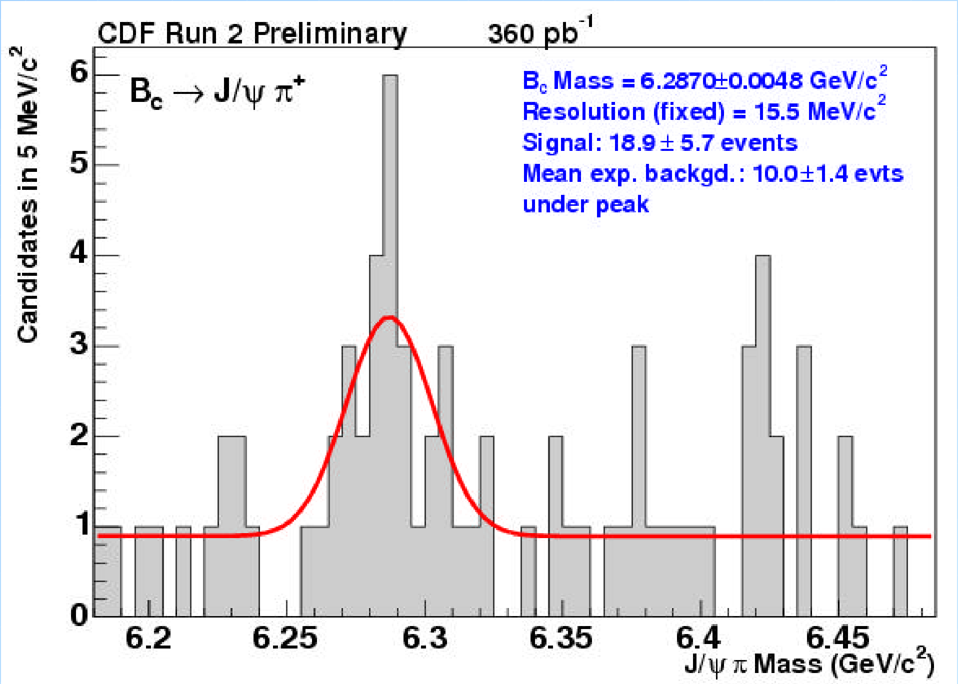
Complementarity: B_c

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!

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





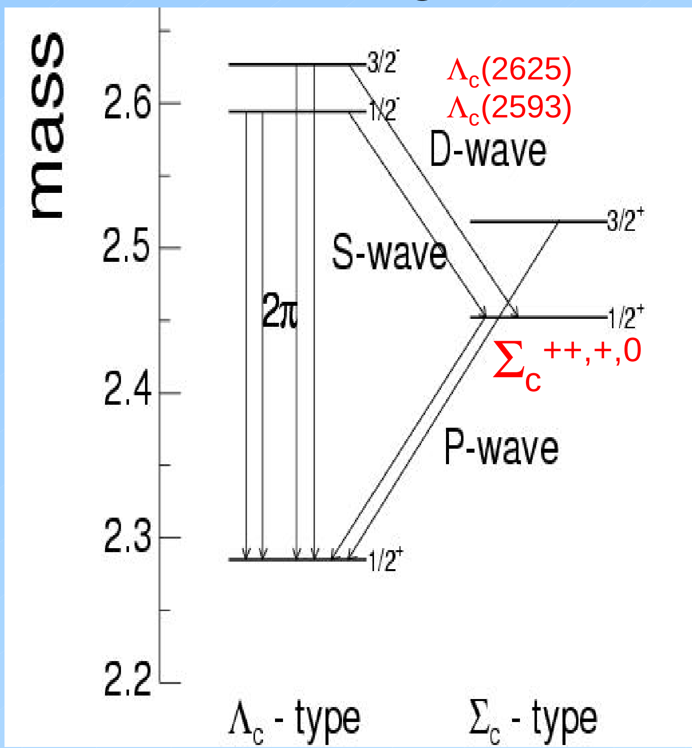
- First signal of fully reconstructed B_c
- Direct mass measurement!

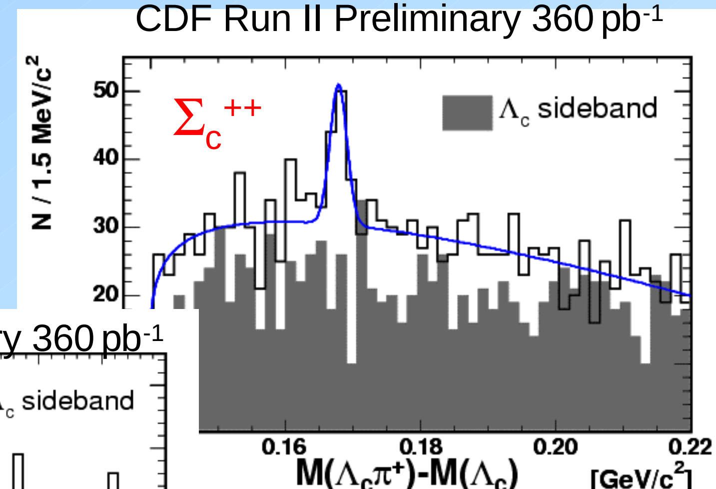
$$m = 6.287 \pm 0.0048 \pm 0.0011 \, {GeV}/{c^2}$$

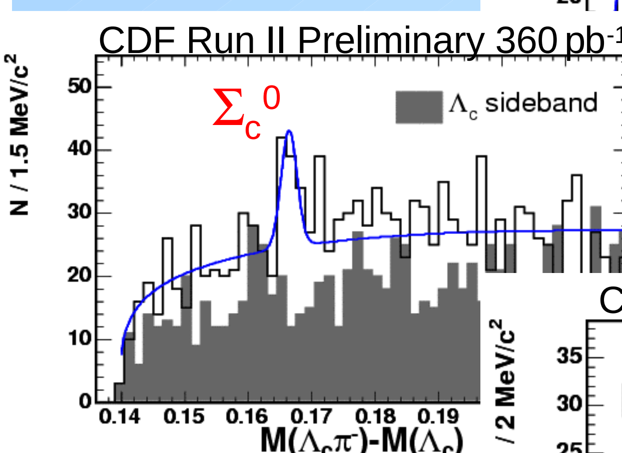
Hep-ex/0505076

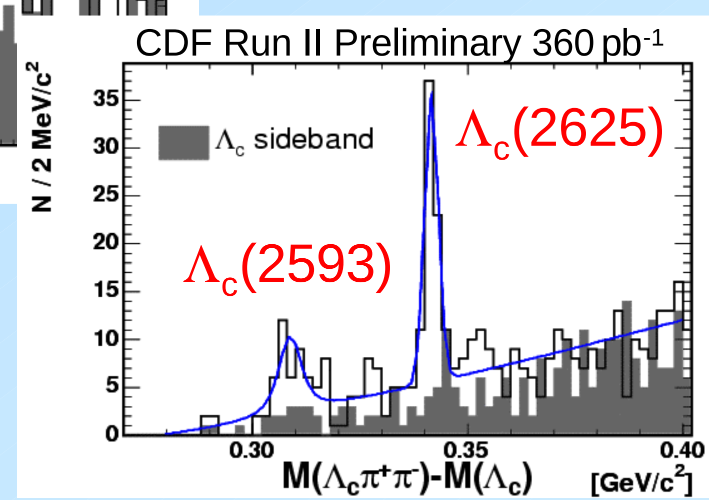
…incidentals!

The field to explore is so extensive that we have been 'stumbling' upon unobserved signals all over the place!









- First observation of several Λ_b semileptonic decays that can fake the signal $\Lambda_b \rightarrow \Lambda_c^+ m\bar{n}$
  - Estimate the BR based on the observation

Lifetimes

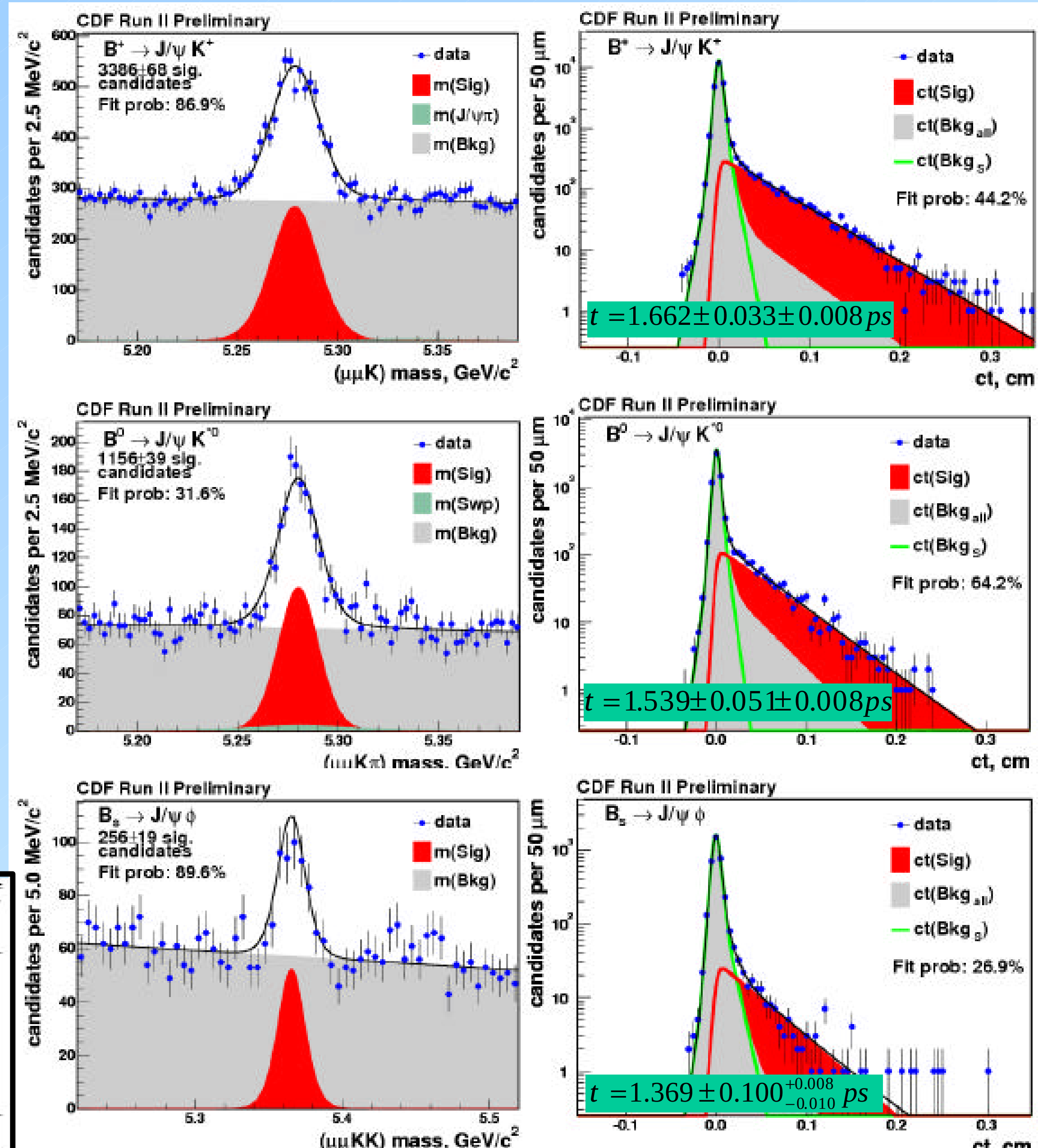
- Critical testbed of HQE
  - HQE vastly used for phenomenology predictions
  - b-hadrons lifetime ratios accurately predicted
- Important experimental reference
  - Overlap with B factories $\rightarrow$ understanding of detector/trigger/analysis biases
  - Further test on species not produced at B factories

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
    - Crucial test of our 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	$^{+2.4}_{-2.9}$

HQET: baryon lifetimes and B moments

B lifetimes ↔ Vcb

Dominant uncertainty comes from HQET extraction!

CDF can probe HQET and constrain it!

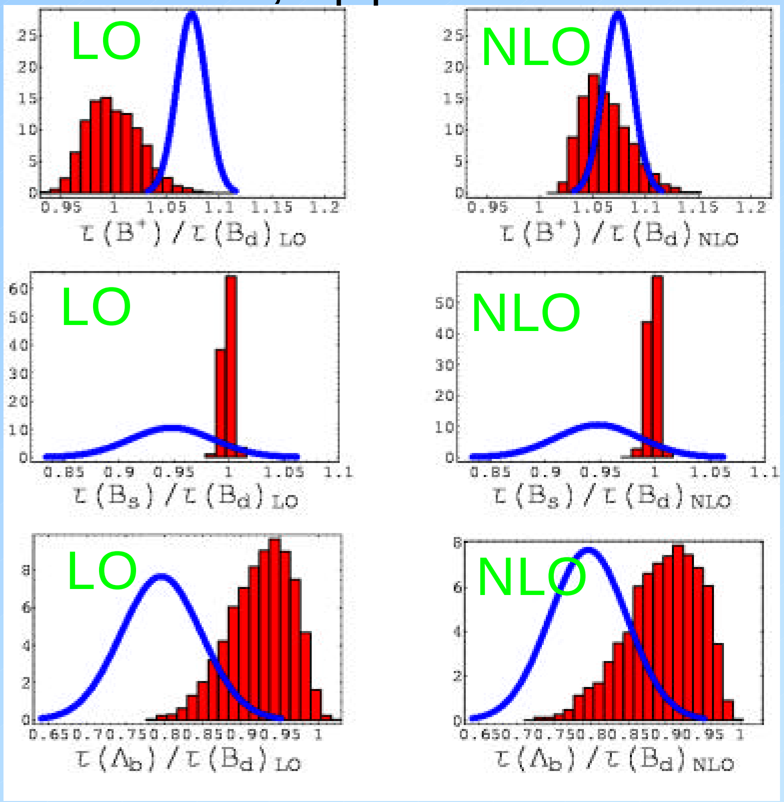
Probing: Λ_b lifetime

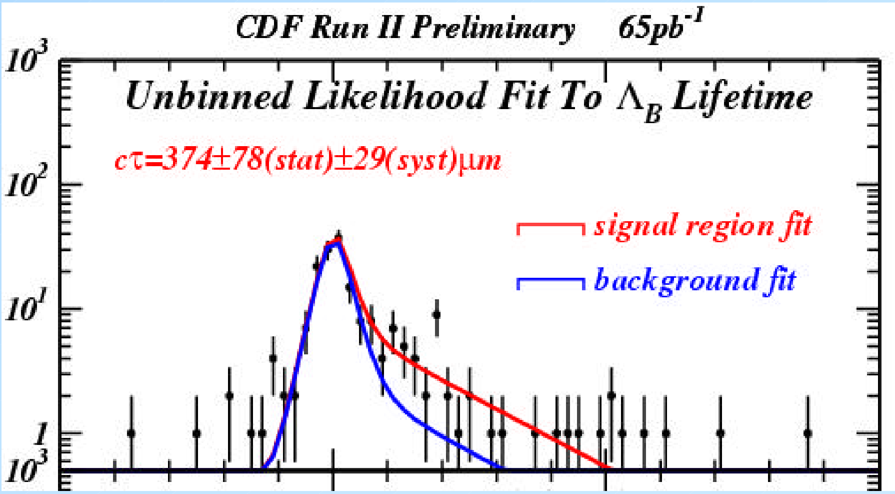
C. Tarantino, hep-ph/0310241 Oct 2003

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

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

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

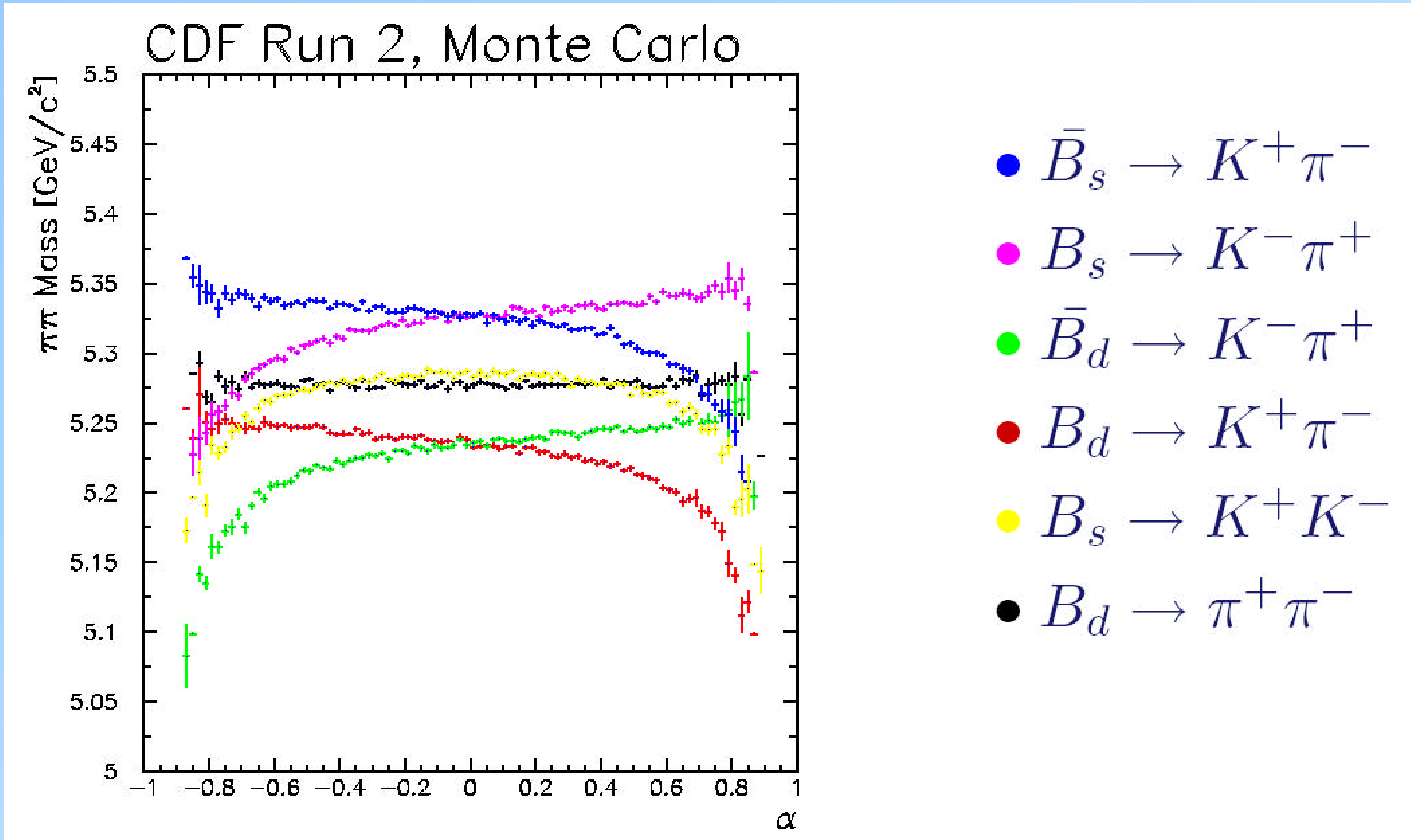




$$\frac{t(\Lambda_b)}{t(B^0)} = (81.3 \pm 18)\%$$

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

B→hh kinematics



Extracting γ from B→hh

Fleischer Hep-ph/9903456

- Measure $A_{CP}(B_s \to KK)$, $A_{CP}(B_d \to \pi\pi)$: 4 parameters:

$$A_{CP}^{B\to KK}(t) = A_{CPdir}^{B\to KK}\cos(\Delta m_s\, t) + A_{CPmix}^{B\to KK}\sin(\Delta m_s\, t)$$

$$A_{CP}^{B\to pp}(t) = A_{CPdir}^{B\to pp}\cos(\Delta m_d\, t) + A_{CPmix}^{B\to pp}\sin(\Delta m_d\, t)$$

- With each asimmetry:

$$A_{CP\,dir} = \pm\frac{2d\sin q\sin g}{1-2d\cos q\cos g + d^2}$$

$$A_{CP\,mix} = \pm\frac{\sin 2(f+g) - 2d\cos q\sin(2f+g) + d^2\sin 2f}{1-2d\cos q\cos g + d^2}$$

Where d and θ are different for Bs and Bd, but related under U-spin by:

$$\Theta_{B_s} = \Theta_{B_d}$$

$$d_{B_s} = d_{B_d}\,\frac{1-l^2}{l^2}$$

Extracting γ from B→hh

Fleischer Hep-ph/9903456

$$A_{CP\,dir} = \pm \frac{2d \sin q \sin g}{1 - 2d \cos q \cos g + d^2}$$

$$A_{CP\,mix} = \pm \frac{\sin 2(f+g) - 2d \cos q \sin(2f+g) + d^2 \sin 2f}{1 - 2d \cos q \cos g + d^2}$$

$$\begin{cases} \Theta_{B_s} = \Theta_{B_d} \\ d_{B_s} = d_{B_d} \dfrac{1 - l^2}{l^2} \end{cases}$$

Assuming also $\phi_d = \beta$, $\phi_s = 0$ we can constrain to the $B \to \psi K_s$ value and constrain simultaneously $(\beta, \gamma, d, \theta)$

•SU(3) breaking of the order of 10-15% will lead to systematic effects on this determination of the order of 3º

This method requires measuring $A_{CP}(t)$ for $B_s \to KK$...

Rather unlikely at CDF

Extracting γ from B→hh

London & Matias Hep-ph/0404009

$$A_{CP}^{B\to pp}(t) = A_{CPdir}^{B\to pp}\cos(\Delta m_d\, t) + A_{CPmix}^{B\to pp}\sin(\Delta m_d\, t)$$

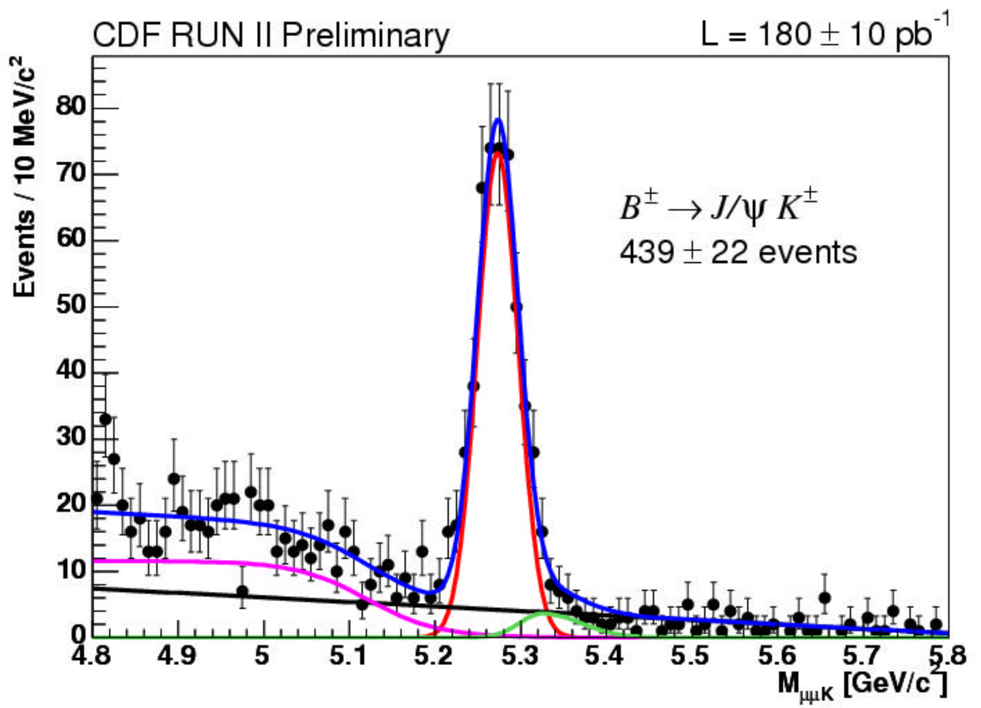
$$A_{CP\,dir} = \pm\frac{2d\sin q\sin g}{1-2d\cos q\cos g + d^2}$$

$$A_{CP\,mix} = \pm\frac{\sin 2(f+g) - 2d\cos q\sin(2f+g) + d^2\sin 2f}{1-2d\cos q\cos g + d^2}$$

$$R_d^s = \frac{\Gamma(B_s \to KK)}{\Gamma(B_d \to pp)} = e^{-1}\left|\frac{C'}{C}\right|^2 \frac{e^2 + 2ed_s\cos q_s\cos g + d_s^{\,2}}{1-2d\cos q\cos g + d^2}\, f_{PS}$$

- Assuming also SU(3) ($d_d = d_s$, $\theta_d = \theta_s$) we have 3 unknowns (d_d, θ_d, γ) and 3 measurements (including the value of sin2β) ⇒ we can determine γ
- SU(3) breaking effects are parameterized as well

CP: ϕK



BR systematics

SYSTEMATIC	ERROR [%]
$B^{\pm} \to \phi K^{\pm}$ yield	3.0
$B^{\pm} \to J/\psi K^{\pm}$ yield	3.3
$\varepsilon_{\mu\mu K}/\varepsilon_{KKK}$	1.5
$\langle \varepsilon_{\mu} \rangle$	2.6
$\varepsilon_{R_{iso}}$	1.4
Particle dependent XFT efficiency	3.3
acceptance φ dependance due to COT ageing	0.3
χ^2_{xy} cut efficiency	3.0
$BR(J/\psi \to \mu\mu)$	1.2
$BR(\phi \to KK)$	1.7
TOTAL	7.4

A_{CP} systematics

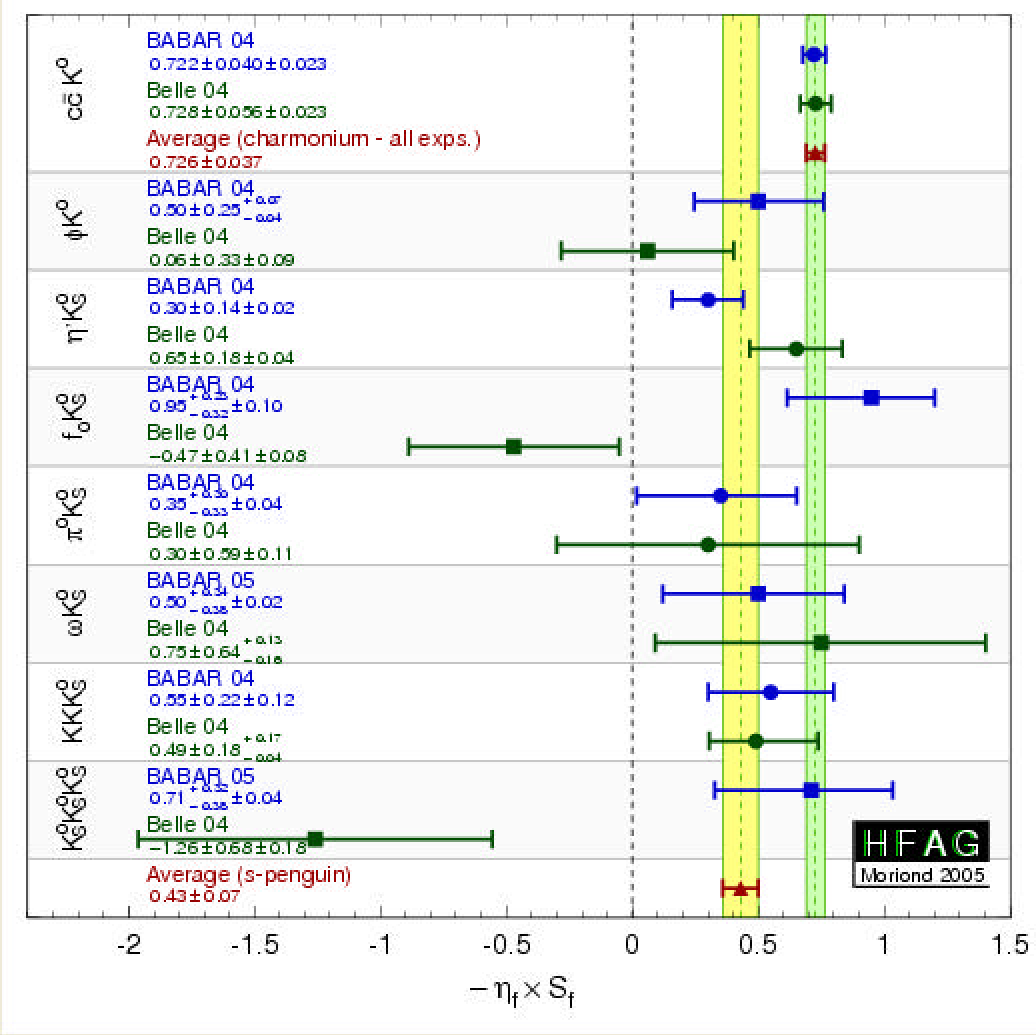
SYSTEMATIC	ERROR
fit	$^{+0.034}_{-0.020}$
detector charge asymmetry	0.005
TOTAL	$^{+0.034}_{-0.021}$

$$\frac{BR(B^{\pm} \to \phi K^{\pm})}{BR(B^{\pm} \to J/\psi K^{\pm})} = 0.0076 \pm 0.0013\,(stat.) \pm 0.0006\,(syst.)$$

$$A_{CP}(B^{\pm} \to \phi K^{\pm}) = -0.07 \pm 0.17\,(stat.)\ ^{+0.03}_{-0.02}\,(syst.)$$

Hep-ex/0502044

$b \to sss$



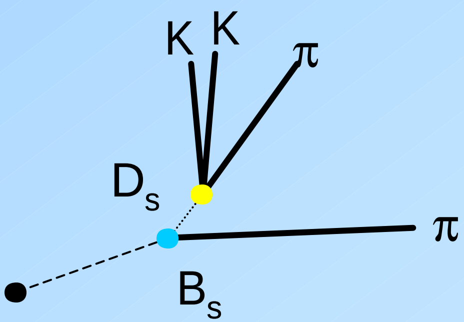
BABAR 04
0.722±0.040±0.023
Belle 04
0.728±0.056±0.023
Average (charmonium - all exps.)
0.726±0.037
BABAR 04
Belle 04
0.06±0.33±0.09
BABAR 04
0.30±0.14±0.02
Belle 04
0.65±0.18±0.04
BABAR 04
Belle 04
−0.47±0.41±0.08
BABAR 04
Belle 04
0.30±0.59±0.11
BABAR 05
Belle 04
BABAR 04
0.55±0.22±0.12
Belle 04
BABAR 05
Belle 04
Average (s-penguin)
0.43±0.07
HFAG
Moriond 2005
-2
-1.5
-1
-0.5
0
0.5
1
1.5

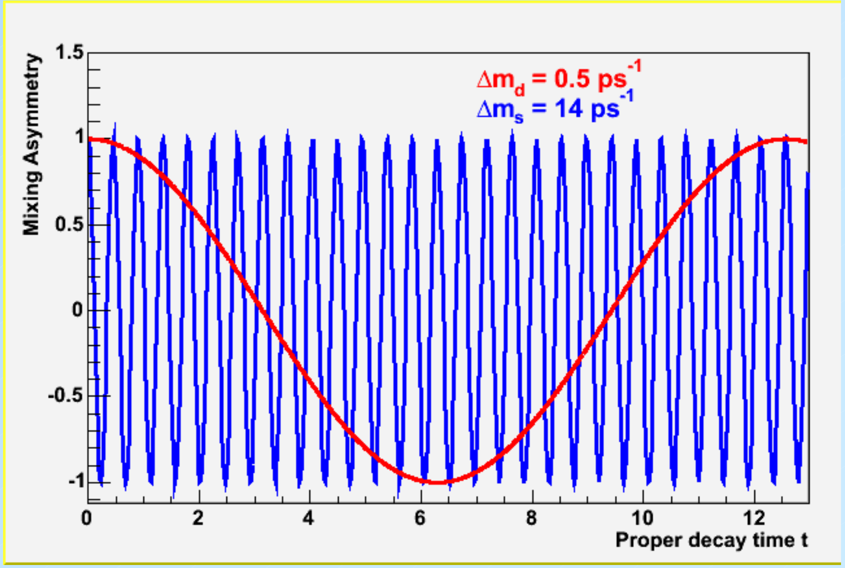
B_s Mixing 101

It's an Asymmetry measurement!!

- Reconstruct signal
  - Hadronic:
    - good momentum resolution
    - low statistics
  - Semileptonic:
    - worse momentum resolution
    - higher statistics
- Determine "time" of Decay
  - measure decay length
  - apply boost
- Sort the mixed from unmixed via b charge at production and decay
  - $S´e$ = $N_{mix}+N_{unmix}$
  - D = "Dilution" = $1-2P_{mistag}$
  - $S \to S\varepsilon D^2$
- Fix Δm and fit A
- Scan vs Δm

$$A_{mix}(t) = \frac{N_{mix}(t) - N_{unmix}(t)}{N_{mix}(t) + N_{unmix}(t)} \propto \cos \Delta m t$$

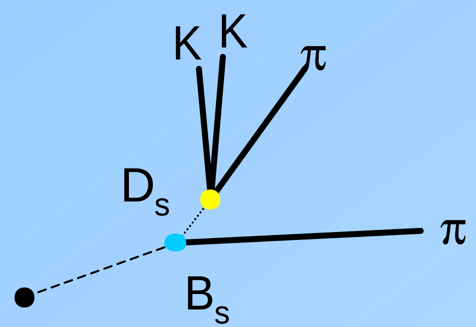




$$\mathrm{Sig}(\Delta m) = \sqrt{\frac{S}{S+B}}\, e^{-(\Delta m\, s_t)^2/2} \sqrt{\frac{S e D^2}{2}}$$

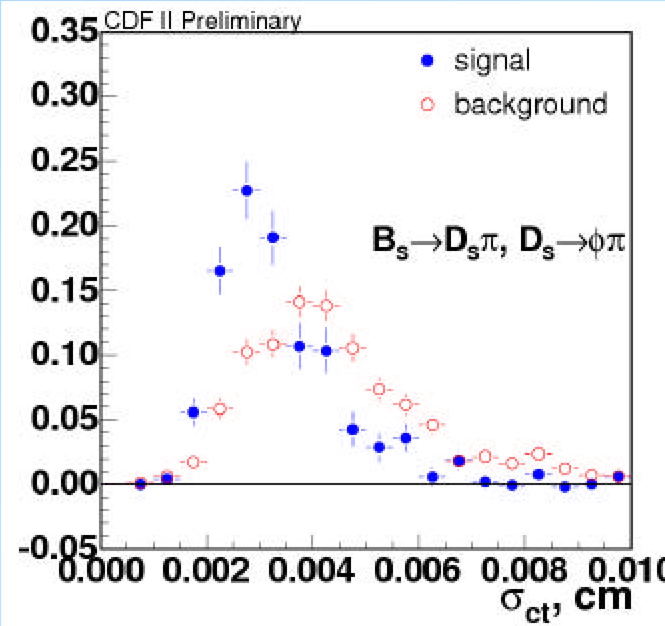
B_s Mixing: proper time

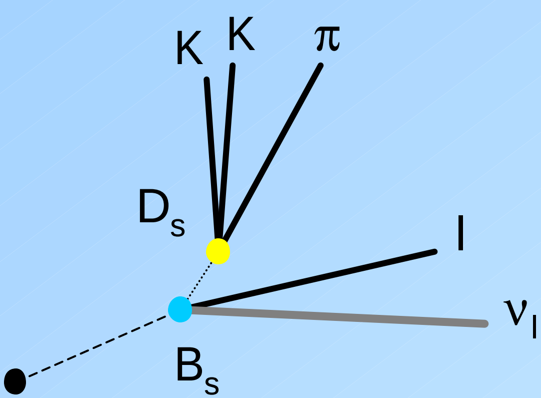
- Samples (N, S/B)
- Proper decay length resolution



$$ct = \frac{L_{xy}}{bg} = \frac{L_{xy} m_B}{p_t}$$

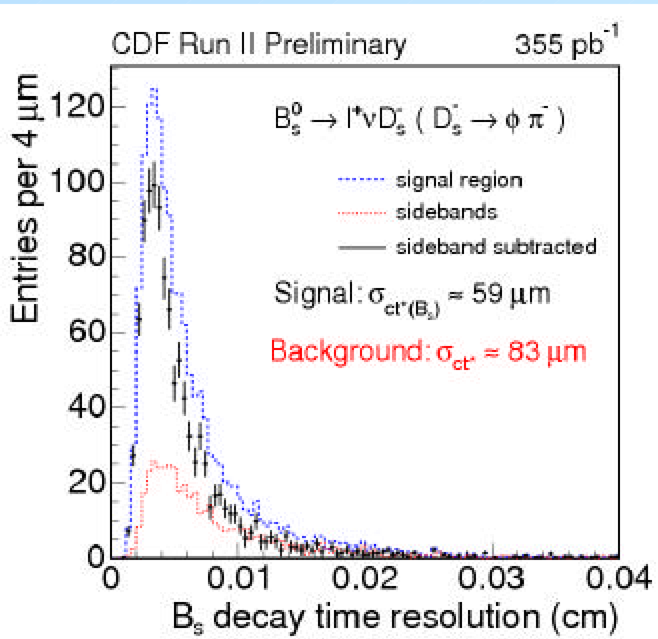
$$s_{ct} = \frac{m_B}{p_t} s_{L_{xy}} \oplus ct\left(\frac{s_{p_t}}{p_t}\right)$$



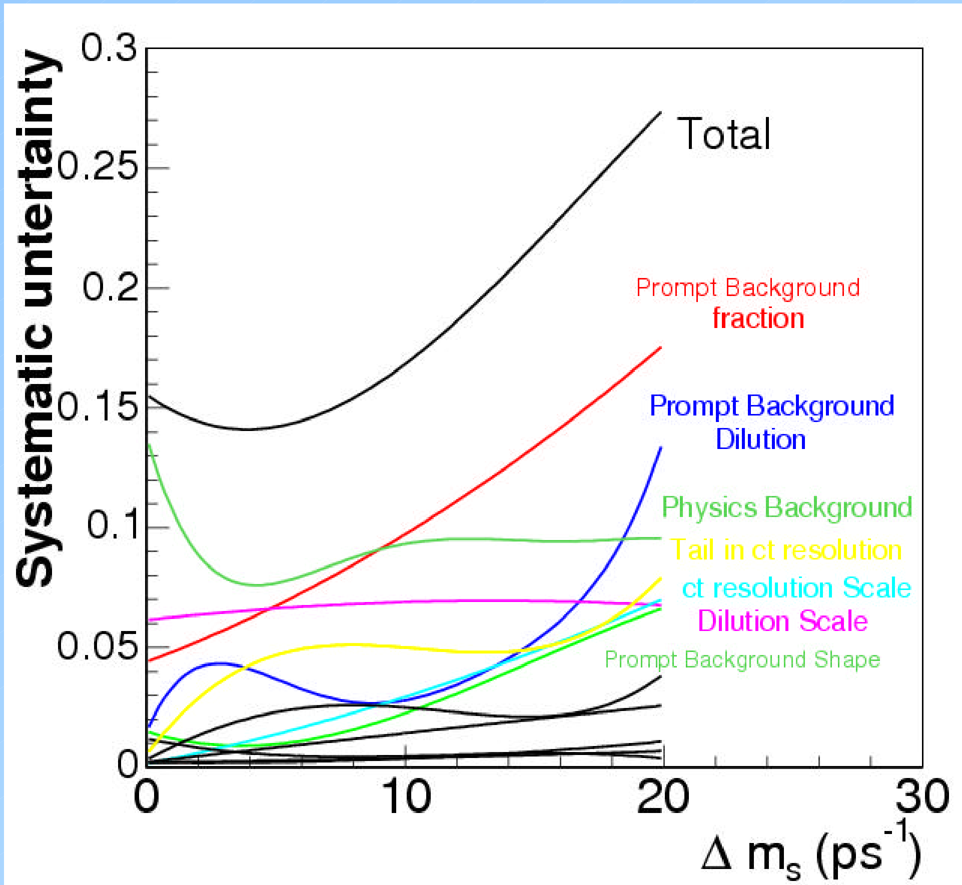


$$ct = \frac{m_B L_{xy}}{P_t(lD_s)} \cdot \left\langle \frac{P_t(lD_s)}{P_t(B_s)} \right\rangle_{mc}$$

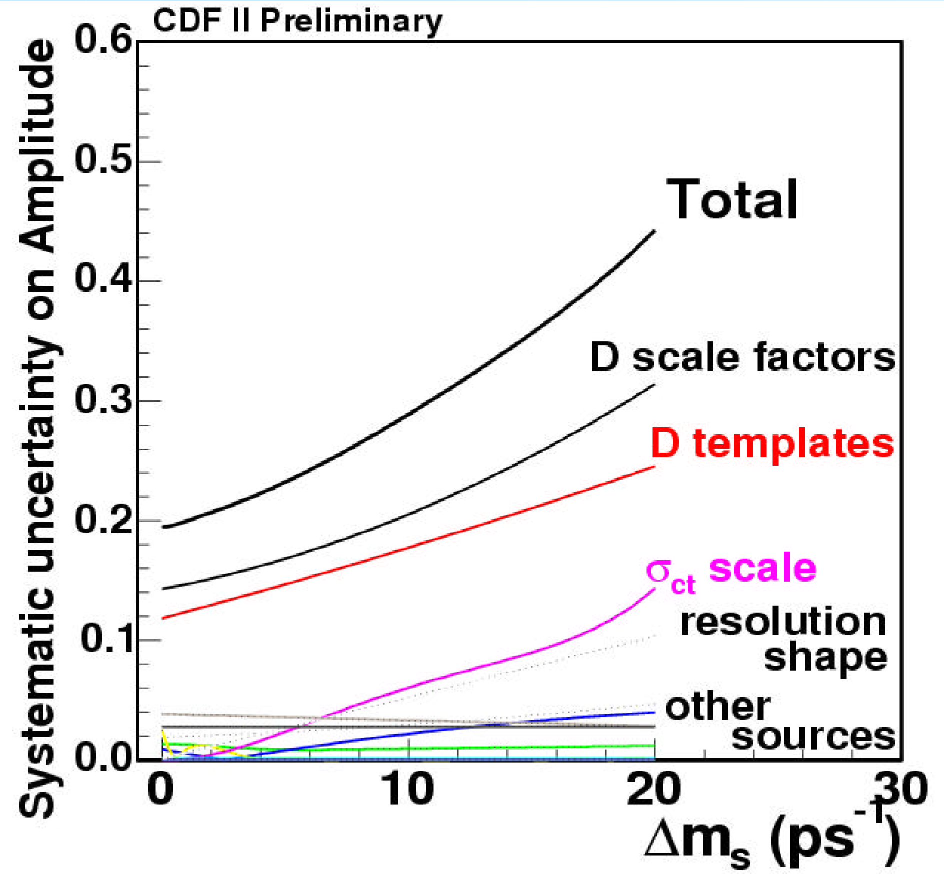
$$s_{ct} = \frac{m_B}{p_t} s_{L_{xy}} \oplus \left[ct\left(\frac{s_{p_t}}{p_t}\right) \otimes s_K \right]$$



B_s Mixing: systematics

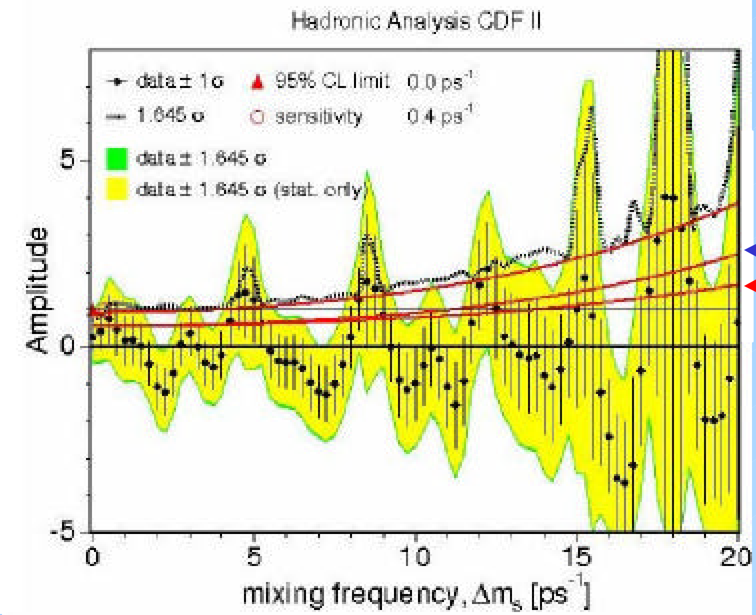


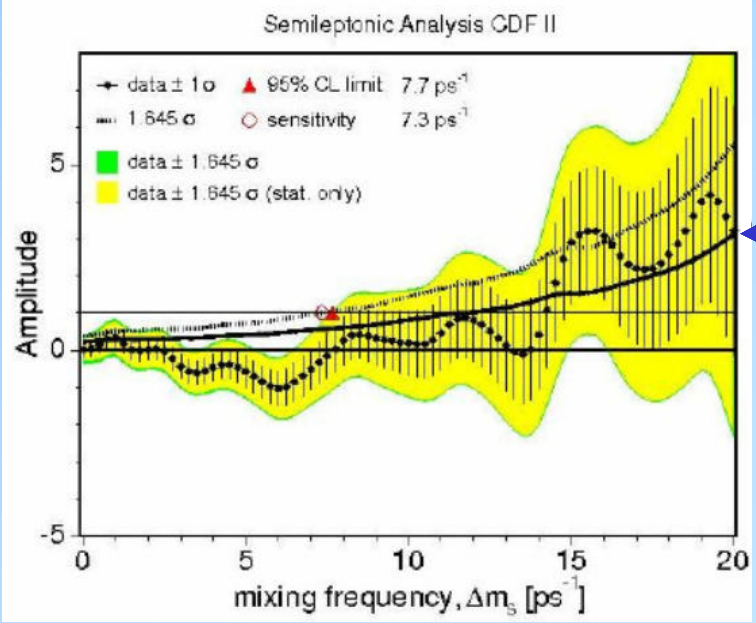
Semileptonic sample



Hadronic sample

B_s Mixing: perspectives



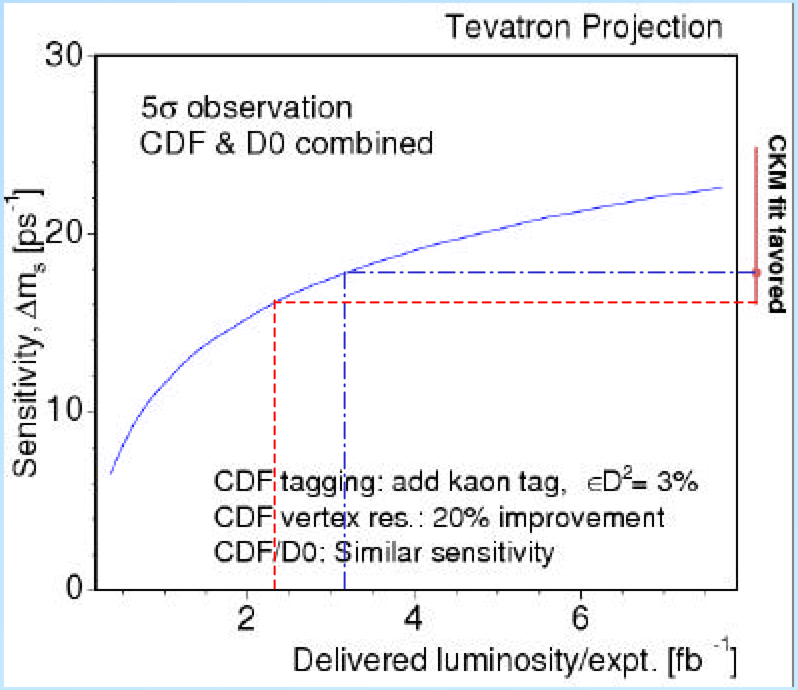


4x effective statistics

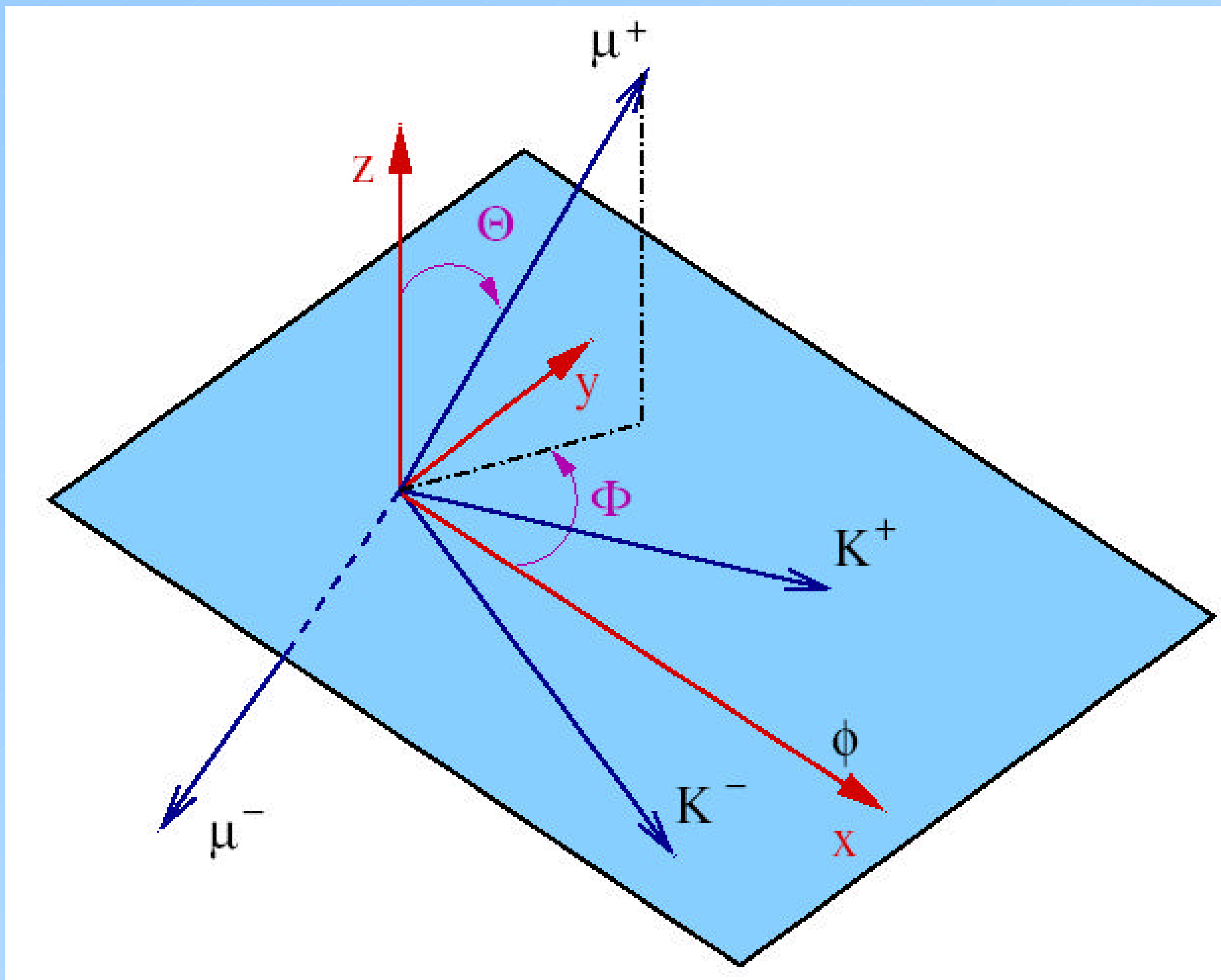
20% improvement in $c\tau$ resolution

Improvements:

- Yield
- Tagger performance
- Proper time resolution



Transversity angles



- J/ψ rest frame
- (x,y) from KK
- X axis along ϕ momentum
- (Θ,φ) polar and azimuthal angles of μ^+
- Ψ helicity angle of ϕ

CP violation in charm

$$A(D^\circ \to K^+K^-) = 2.0 \pm 1.2(stat) \pm 0.6(syst)\ \%$$
$$A(D^\circ \to \pi^+\pi^-) = 1.0 \pm 1.3(stat) \pm 0.6(syst)\ \%$$

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

PDG 2004 averages:

$A(D^0 \to KK)$: 0.5±1.6 %

$A(D^0 \to \pi\pi)$: 2.1±2.6 %

Best single exp. (CLEO02):

$A(D^0 \to KK)$: 0.0±2.2±0.8 %

$A(D^0 \to \pi\pi)$: 21.9±3.2±0.8 %

For the future:

- Increase statistics
- Mixing:

$$\frac{\Gamma\left(D^0 \to K^+ p^-\right)}{\Gamma\left(D^0 \to K^- p^+\right)}$$

- Large statistics gives access to detailed features!
- We will soon improve the knowledge of $BR(D^+ \to \pi^+\pi^-\pi^-)$
- Theory predicts that direct CP asymmetry could be $O(10^{-3})$ [hep-ex/9612005]
- E792: -0.017±0.042 [hep-ex/9612005]