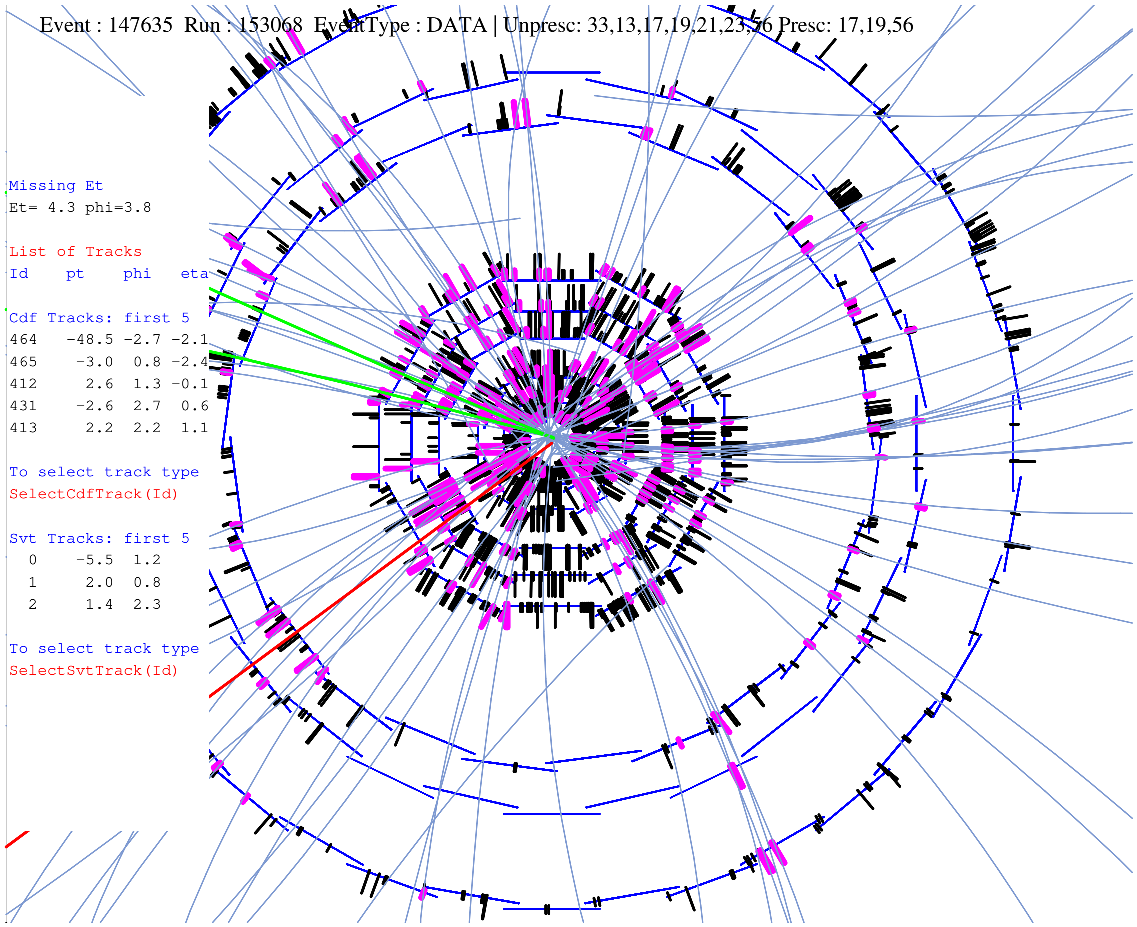
Ricerca delle oscillazioni del sistema $B_s^0 \div \overline{B_s^0}$ a



Sandro De Cecco

INFN Roma

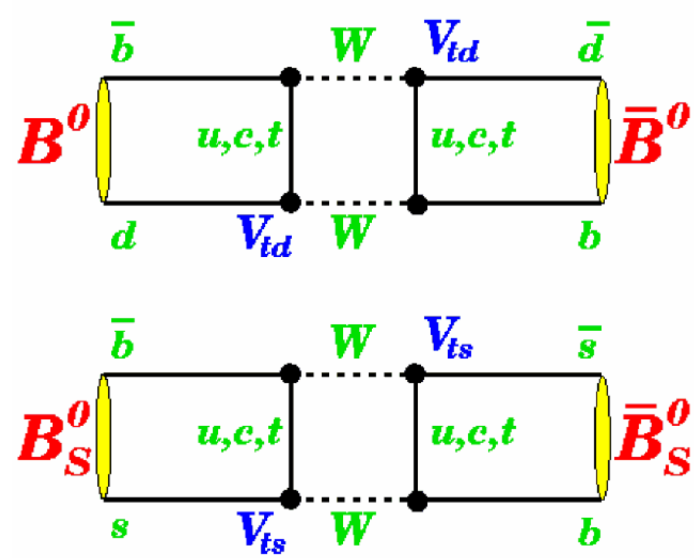
Universita' di Roma "La Sapienza" Roma, 4 aprile 2005

Outline

- Highlights on Bs mixing (see R. Oldeman talk 25-02-05)
- CDF detector and triggers (see R. Oldeman talk 25-02-05)
- B_s mixing analysis:
  - **B_s** signals
  - Lifetime measurement
  - Flavour tagging calibration
  - **B_d** mixing
  - Amplitude scan for $\Delta\mathbf{m_s}$
- Preliminary CDF result
- Future prospects

B^0 meson flavour oscillations

Flavour oscillations occur through
2nd order weak interactions



$$\Delta m_q = \frac{G_F^2 m_W^2 \eta S(m_t^2/m_W^2)}{6\pi^2} m_{Bq} f_{Bq}^2 B_{Bq} \left|V_{tq}^* V_{tb}\right|^2$$

Δm_d (exp.)= 0.510$\pm$0.005 ps^{-1} *(HFAG 2005)*

Lattice QCD:

$f^2_{Bd}B_{Bd}$ = (223$\pm$33$\pm$12) MeV
$f^2_{Bs}B_{Bs}$ = (276$\pm$38) MeV
+ $|V_{td}|$ determined at ~15%

But in the ratio uncertainties cancels:

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

ξ = 1.24$\pm$0.04$\pm$0.06

Measuring $\Delta m_s/\Delta m_d$ determines $|V_{ts}|/|V_{td}|$ at 5% precision

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

CKM Unitarity Triangle

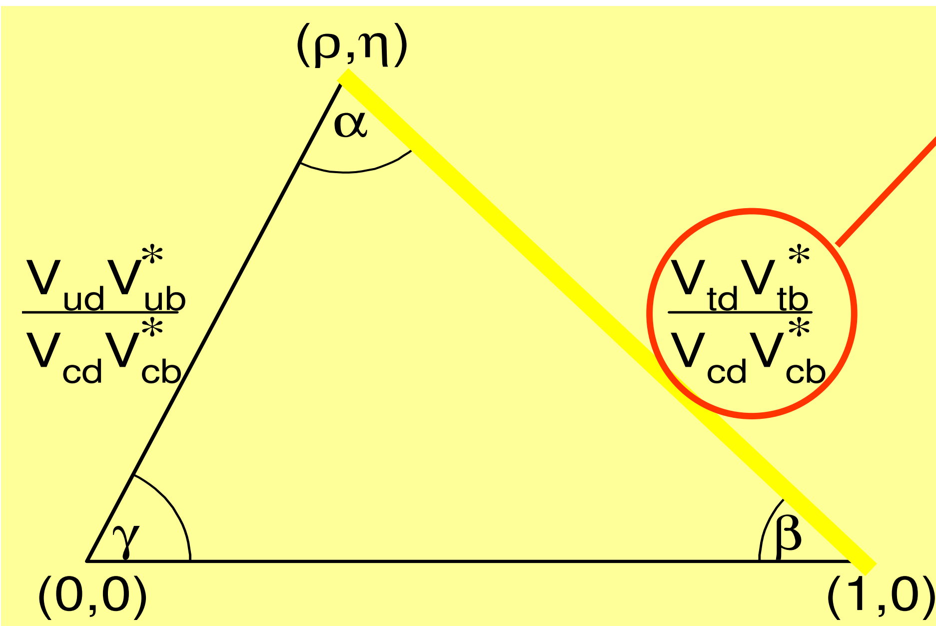
In **SM**, the CKM unitary matrix describes the weak decays of quarks, CPV allowed through phase η

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

Unitarity relations:

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

are represented as U.T. (area α CPV):



$$\left|\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right| = \frac{|V_{td}|}{|V_{ts}|} \times \frac{1}{|V_{cd}|}$$

(since $|V_{\mathbf{cb}}|=|V_{\mathbf{ts}}|=A\lambda^2$)

Measurement of Bs mixing frequency Δm_s determines one side of UT

→ confirm SM or NP hint

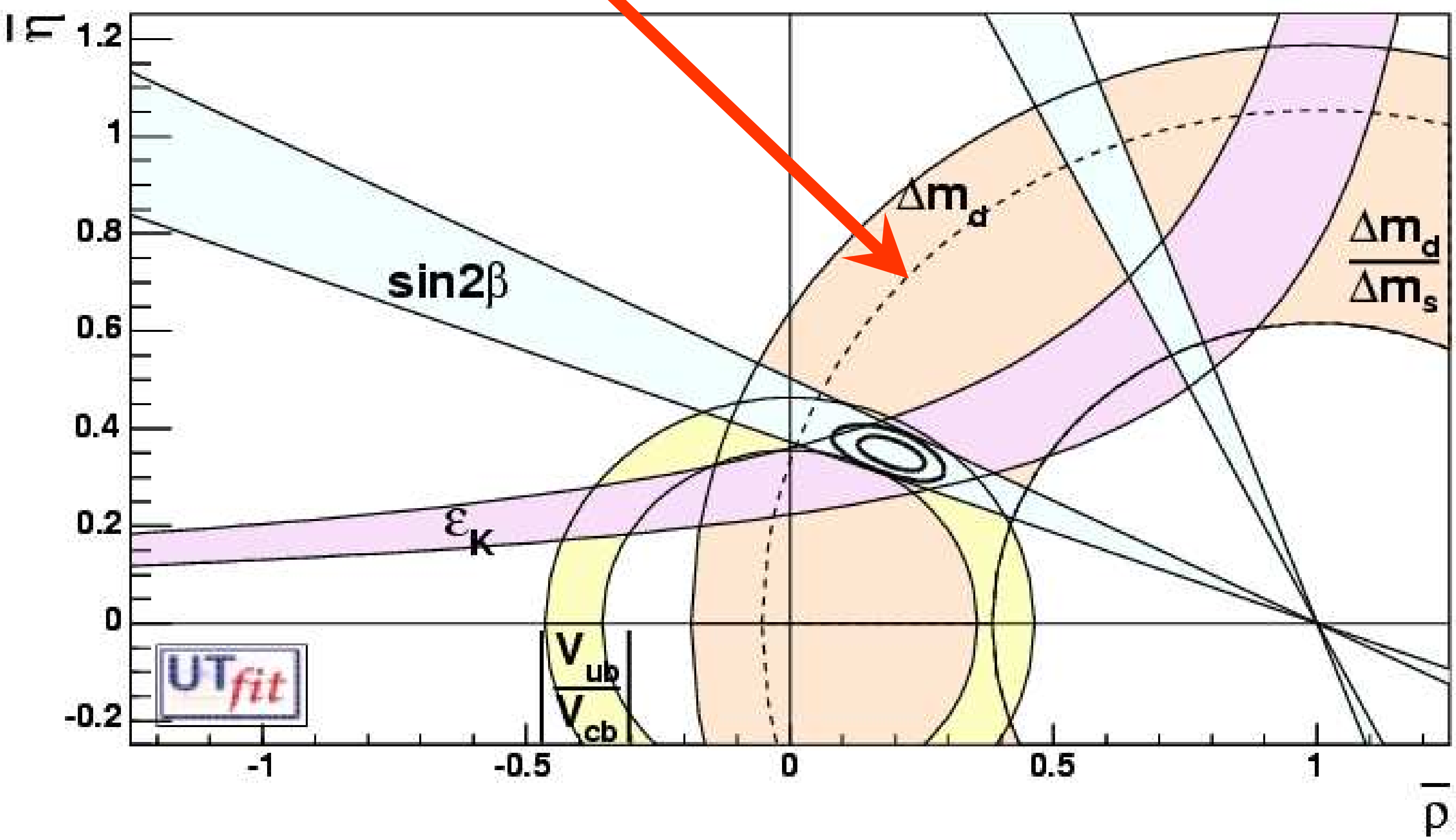
Δm_s constraint to U.T.

Experimental lower limit on Δm_s

<u>Fit with all constraints (winter 05):</u>

ρ = 0.190 ± 0.044

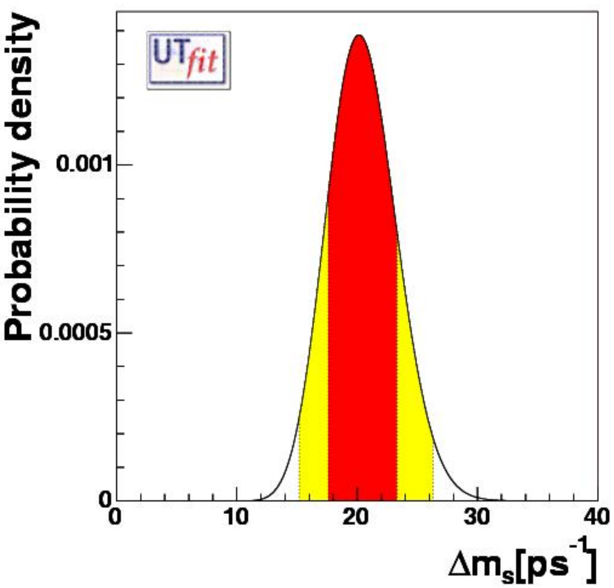
η = 0.349 ± 0.024



SM CKM-fit prediction for Δm_s

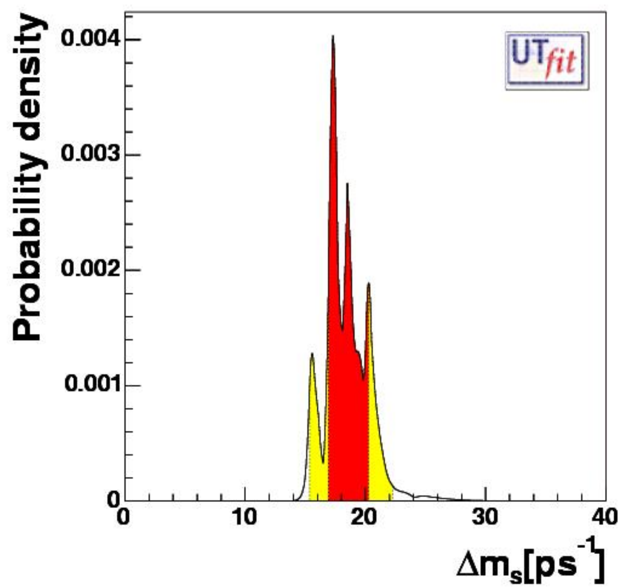
SM

(Δm_s not used)



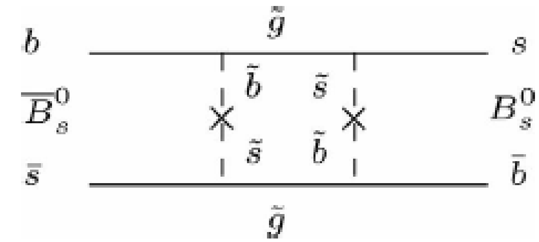
Δm_s = 20.5 ± 3.2 ps^{-1}
[14.4, 27.1] @ 95% CL

(with all constraints)

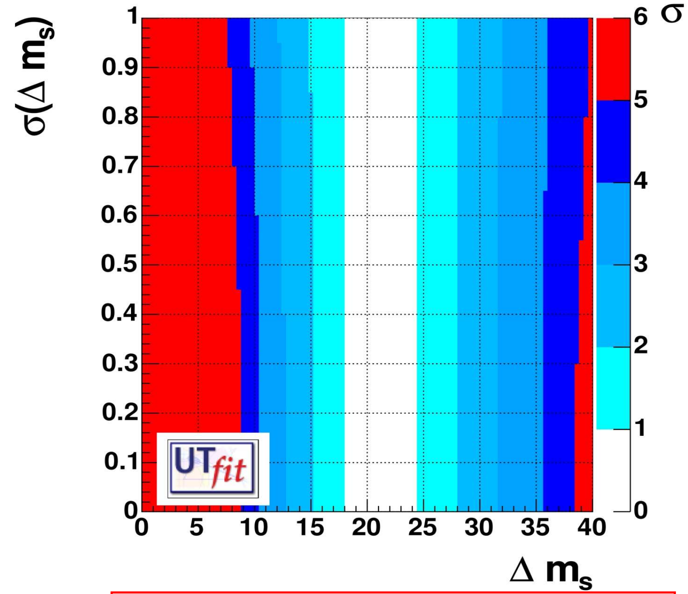


Δm_s = 18.9 ± 1.6 ps^{-1}
[15.7, 23.0] @ 95% CL

New Physics models
can allow Δms being higher



compatibility plot

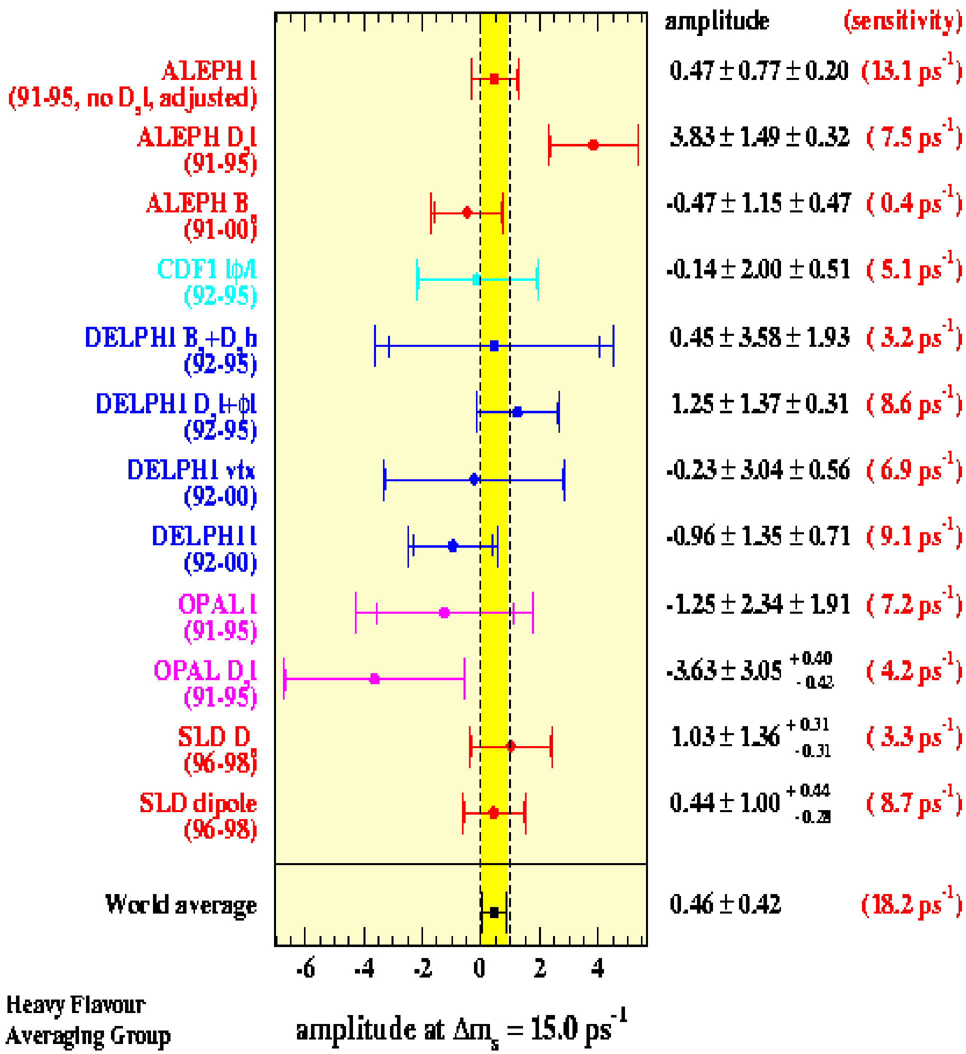


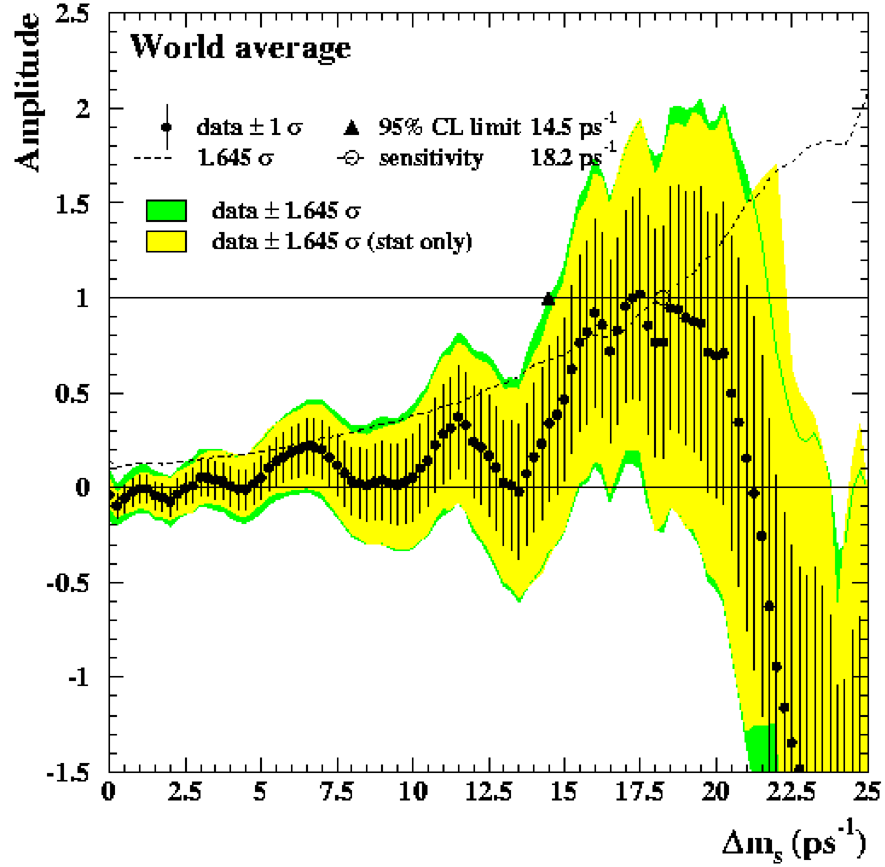
If Δm_s > 30 ps^{-1}
New Physics @ 3σ

Experimental status on Δm_s

Present limit (HFAG 2004)
from: **LEP / SLD / CDF run I**

Amplitude scan method discussed later





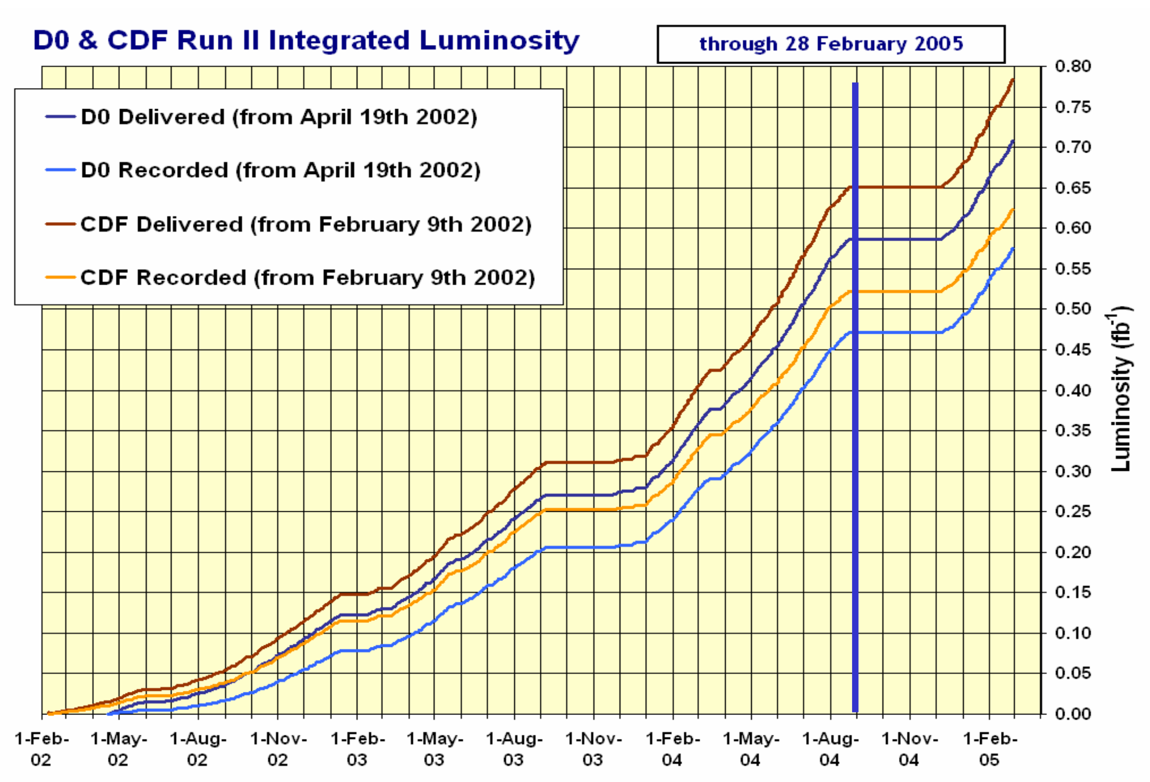
- 95% CL limit is : $\Delta m_s > 14.5\ ps^{-1}$
- Sensitivity: $18.2\ ps^{-1}$

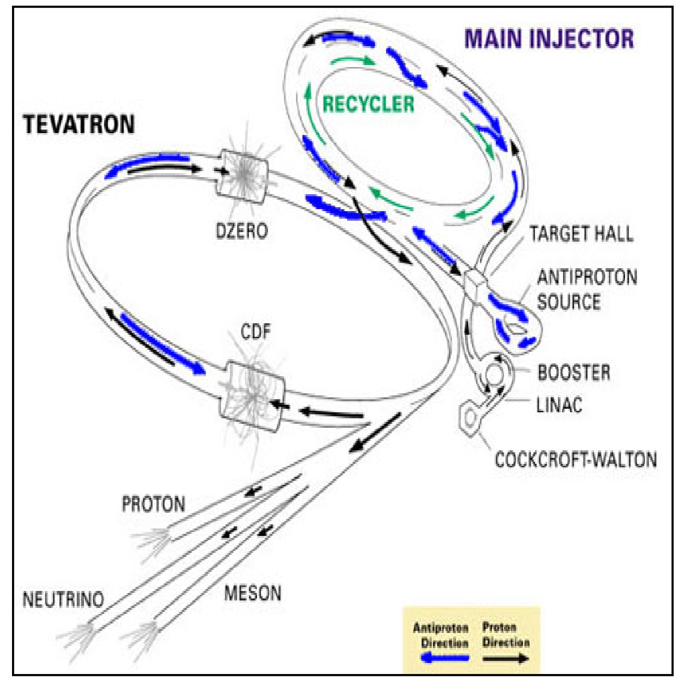
The Collider Detector at Fermilab

The Tevatron $p\bar{p}$ collider

Superconducting proton-synchrotron: $36p\times36\bar{p}$ bunches, crossing each 396 ns at $\sqrt{s}$ = 1.96 TeV

Luminosity……………………………..: record peak $L = 1.2 \times 10^{32}\ cm^{-2}\ s^{-1}$

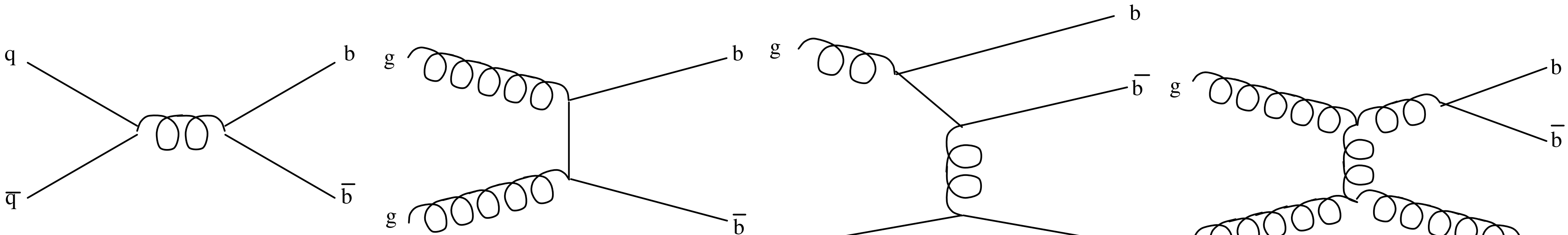




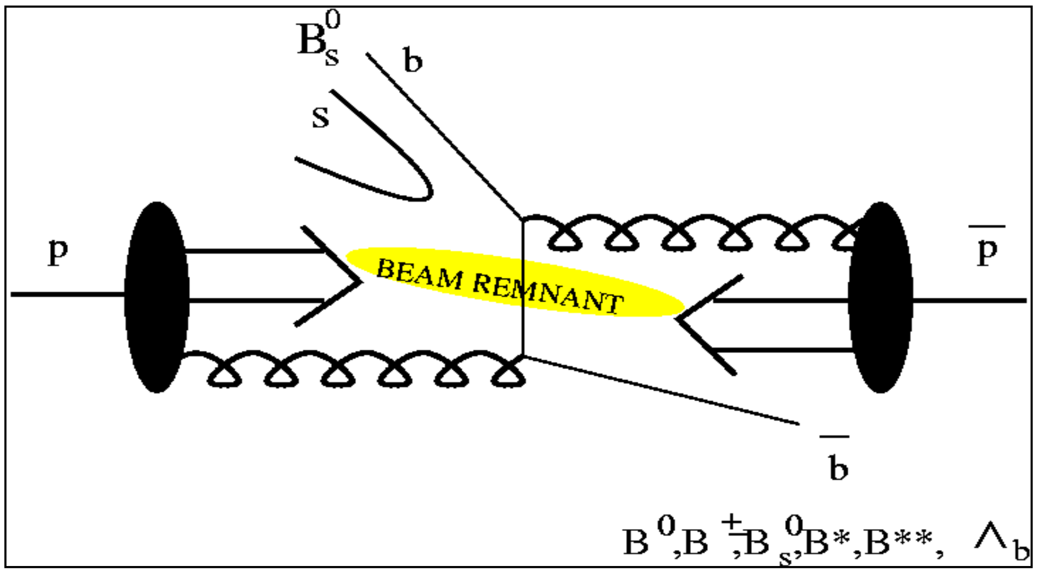
@CDF : 240-360 pb-1 used for B physics
lost ~ 100 pb-1 due to COT crisis

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

BB production mechanics in hadron collider:



Flavor Creation (annihilation) | Flavor Creation (gluon fusion) | Flavor Excitation | Gluon Splitting



- Huge cross-section: 50-100 μb
- All *B* species produced:

$B_u, B_d, \mathbf{B_s}, \mathbf{B_c}, \Lambda_b, \Xi_b \ldots$

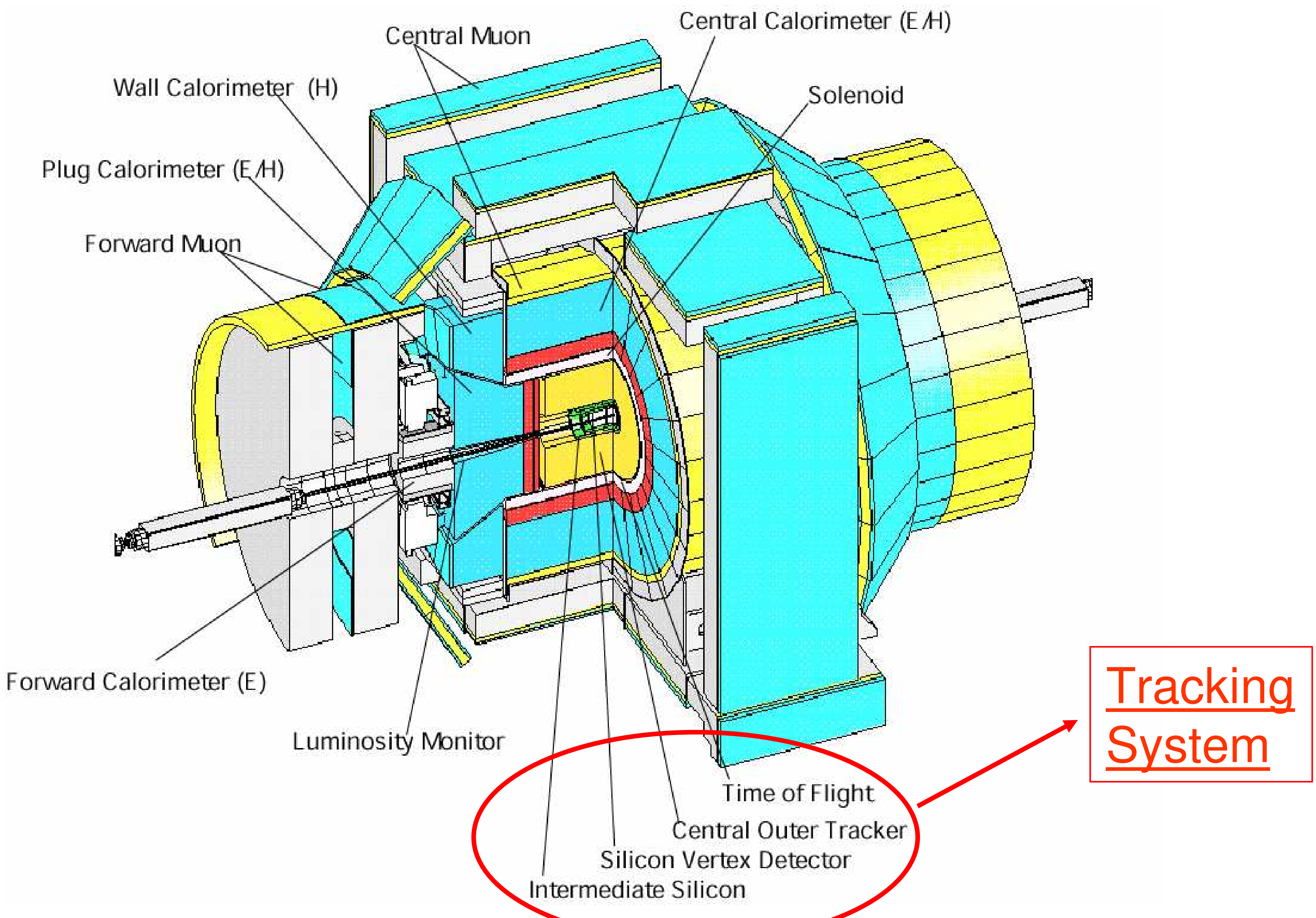
with production fractions:

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

BUT: $\sigma(bb) << \sigma(pp)$ (~65 mb) $\Rightarrow$ B events have to be selected with specific triggers

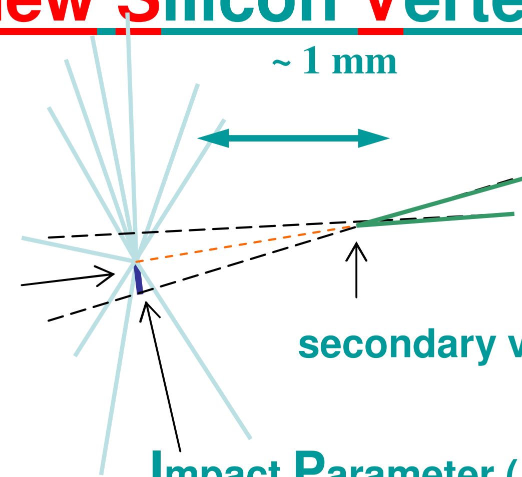
Trigger requirements: **large bandwidth, background suppression, small dead-time**

The CDF II detector



B physics triggers at CDF II

With the New Silicon Vertex Trigger



Conventional at colliders (Run I)

Di-Muon (J/ψ)

Pt(μ) > 1.5 GeV

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

- CP violation
- Masses, lifetimes
- Quarkonia, rare decays

+

Displaced track + *lepton* (*e*, *μ*)

120 μm < I.P.(trk) < 1mm

P_T(*lepton*) > 4 GeV

Semileptonic modes

- High statistics lifetimes
- Sample for tagging studies

2-Displaced tracks

PT(trk) > 2 GeV

120 μm < I.P.(trk) < 1mm

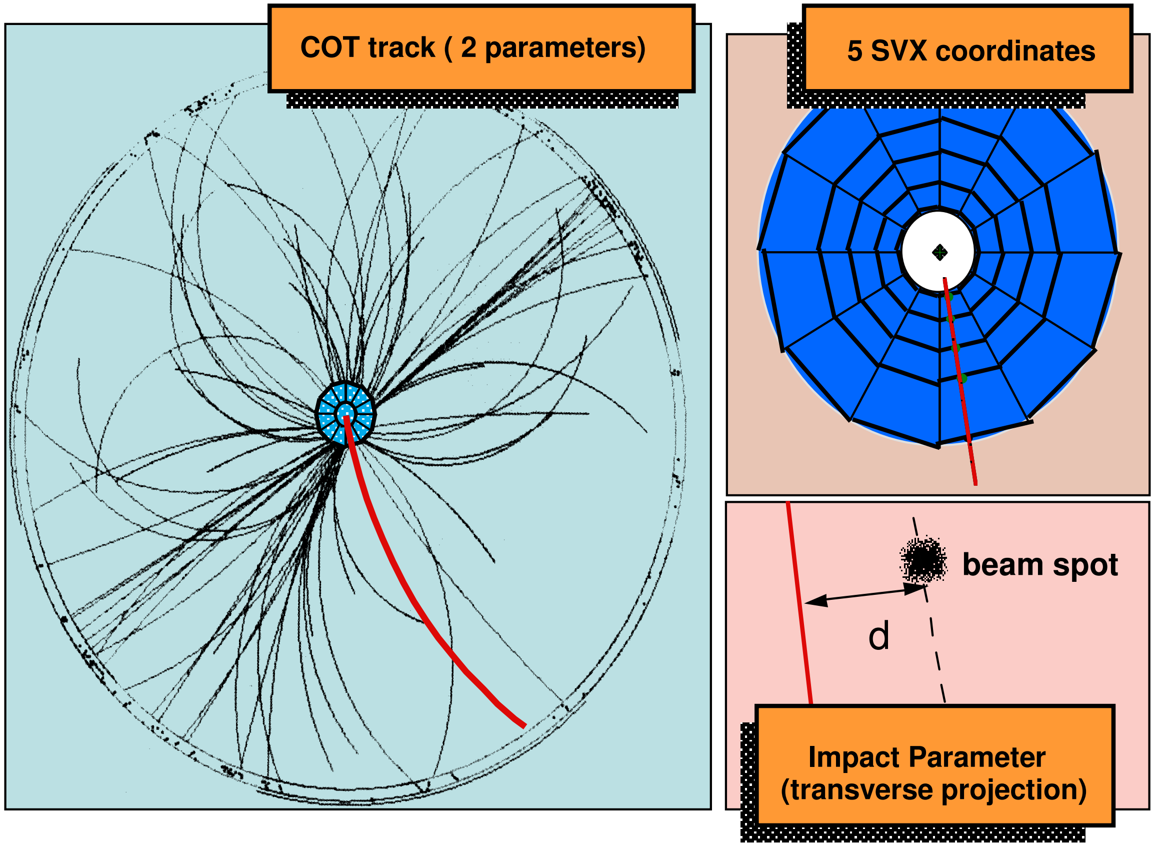
Σp_T > 5.5 GeV

fully hadronic modes

- B_s mixing
- Charmless decays

SiliconVertexTracker: the hadronic B trigger

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

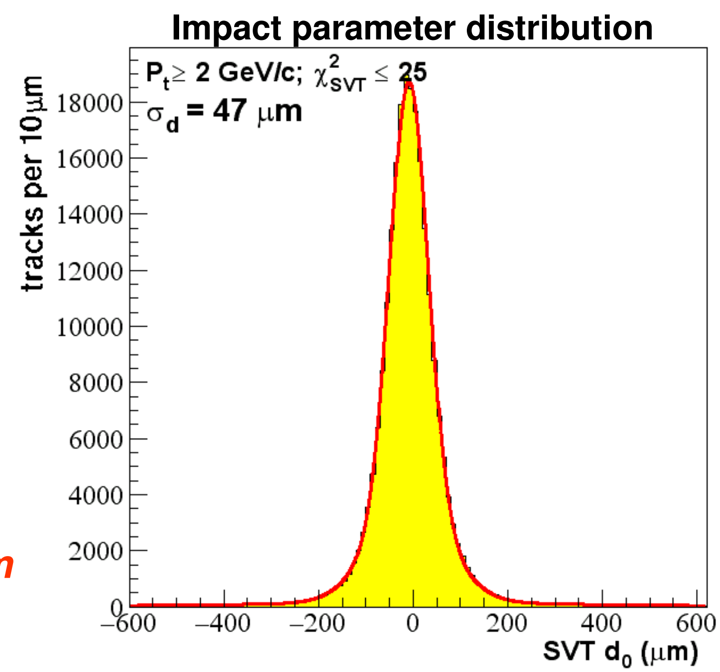


→**convolution of transverse size of the beam spot with the impact parameter resolution of the SVT:**

$\sigma \approx 47$ um $\approx$ 35 um $\oplus$ 30 um

SVT resolution

Beam spot size



Compare to offline ~ *46 μm*

CDF Roma

Searching for B_s mixing @ CDF

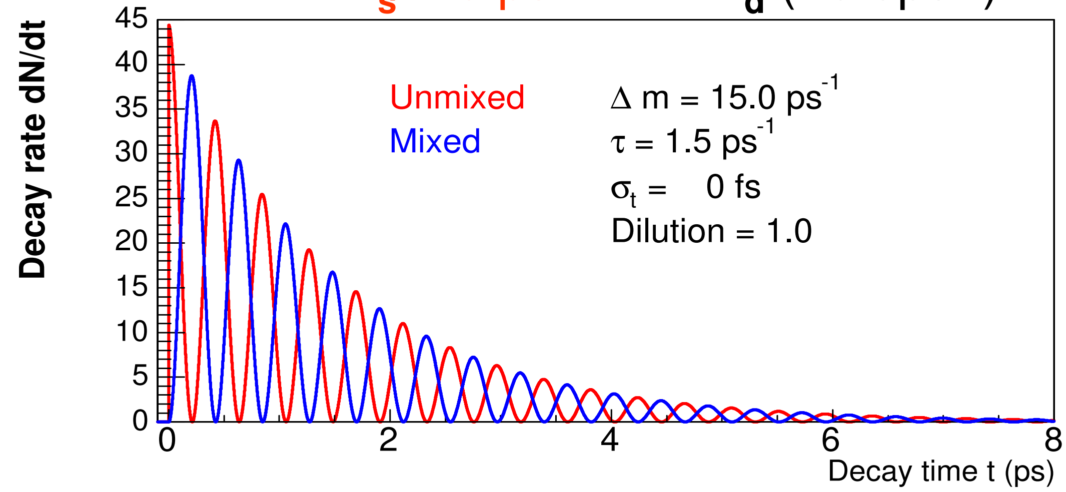
B_s time evolution

Mix and un-mix time dependent probabilities:

$$P(B \to B) = \frac{e^{-t/\tau}}{2\tau}(1 + \cos \Delta m t) = P_{unmix}$$

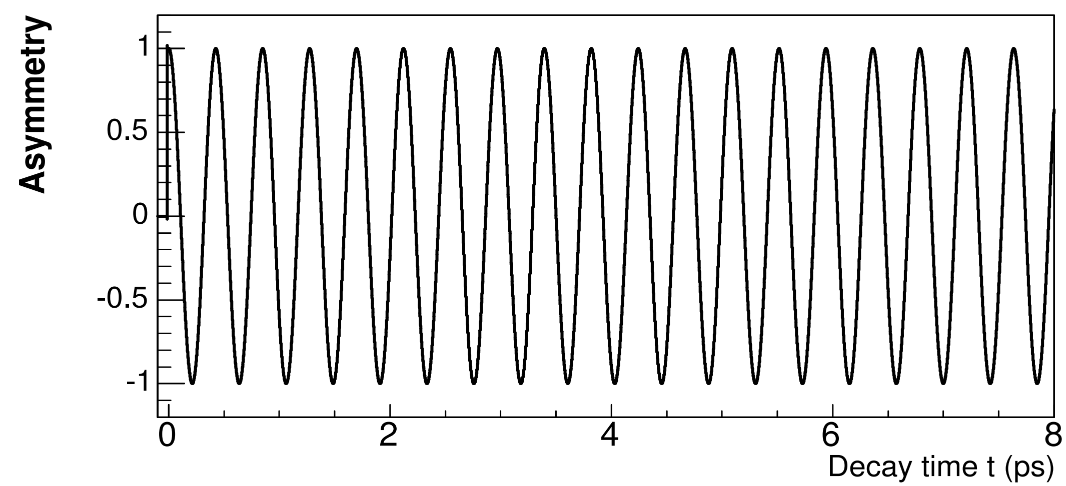
$$P(B \to \overline{B}) = \frac{e^{-t/\tau}}{2\tau}(1 - \cos \Delta m t) = P_{mix}$$

Ex. Δm_s=15 ps^{-1} >> Δm_d (=0.5ps^{-1})



Time dependent Asymmetry:

$$A = \frac{P_{unmix} - P_{mix}}{P_{unmix} + P_{mix}} = \cos \Delta m t$$



Bs fully mixes in < 0.15 ps → Several oscillations per lifetime

…. experimental challenge

Significance of B^0_s mixing measurement

- Since initial state flavour sign is "far from ideally" known

$$A = \frac{P_{unmix} - P_{mix}}{P_{unmix} + P_{mix}} = D \cos \Delta m t$$

where: $D = \frac{N^{right} - N^{wrong}}{N^{right} + N^{wrong}}$

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

Signal / Noise

<u>Effective tagging power:</u>

ε= efficiency of taggers

$$\epsilon = \frac{N^{right}}{N^{right} + N^{wrong} + N^{no-tag}}$$

D = 1 – 2***w*** ***w*** = mistag prob.

→ ε**D**^{2} figure of merit

$$c\tau = \frac{L_{xy}}{\beta_T \gamma} = \frac{L_{xy} m(B)}{p_T(B)}$$

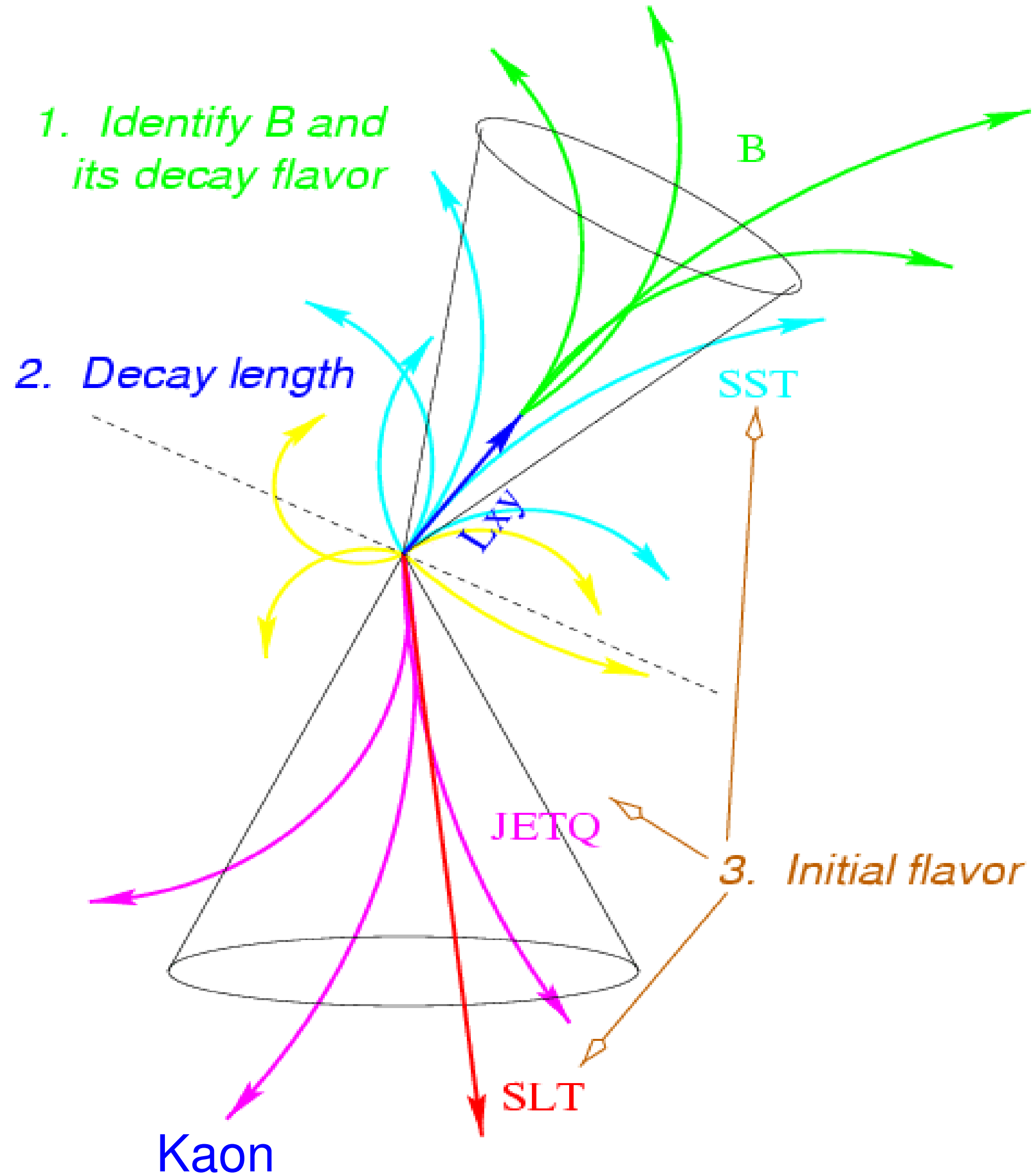
<u>**vertexing and momentum resolution**</u>

$$\sigma_{c\tau} = \left(\frac{\sigma_{L_{xy}} \cdot m(B)}{p_T(B)} \right) \oplus \left(\frac{\sigma_{p_T}}{p_T(B)} \right) \cdot c\tau$$

Analysis Strategy

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

→ B_s Mixing
  - performed a "Blind Analysis"

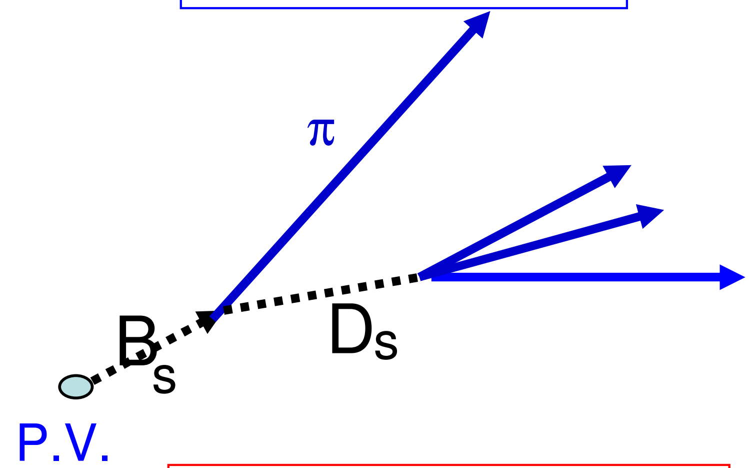


Two different B_s signatures:

Fully reconstructed HADRONIC modes:

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

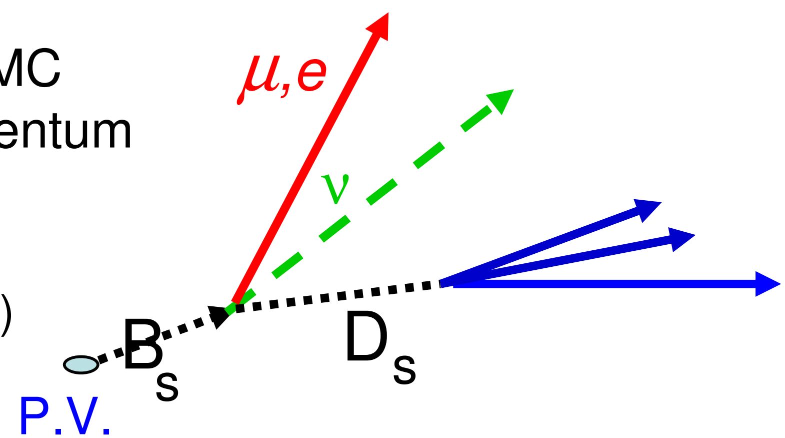
- Complete momentum reconstruction
- Good proper time resolution
- High Bs mass resolution → high S/B
- Selected by Two Track Trigger (SVT)
  - Two displaced tracks (w SVT Impact parameter)
- LOW statistics



Partially reconstructed SEMILEPTONIC modes:

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

- Missing momentum carried by the ν
- Visible proper time corrected by K factor from MC
- Proper time resolution diluted by missing momentum
- Cannot reconstruct Bs mass → different S/B
- Selected by dedicated trigger (l+SVT):
  - One displaced tracks (w SVT Impact parameter)
  - One Lepton μ,e w p_T >4 GeV/c
- HIGH statistics

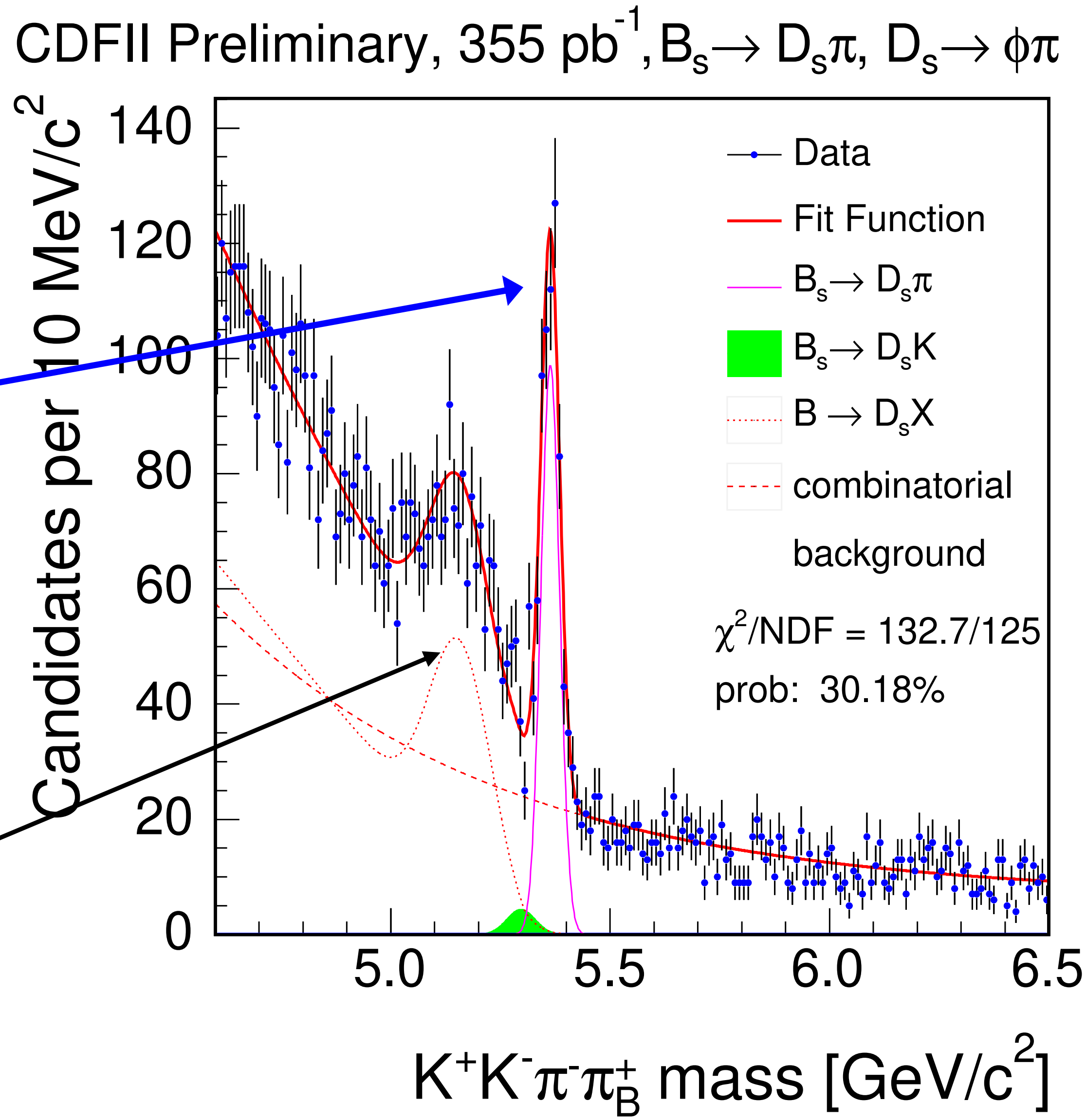


Hadronic B_s signals

CDF Roma

$$B_s^0 \to D_s^- \pi^+ (D_S^- \to \phi\pi^-)$$

$[\phi \to K^+ K^-]$



$N_{B_s} = 526 \pm 33$

S/B ~ 2

$\sigma_M \approx 15$ MeV

"Satellites":

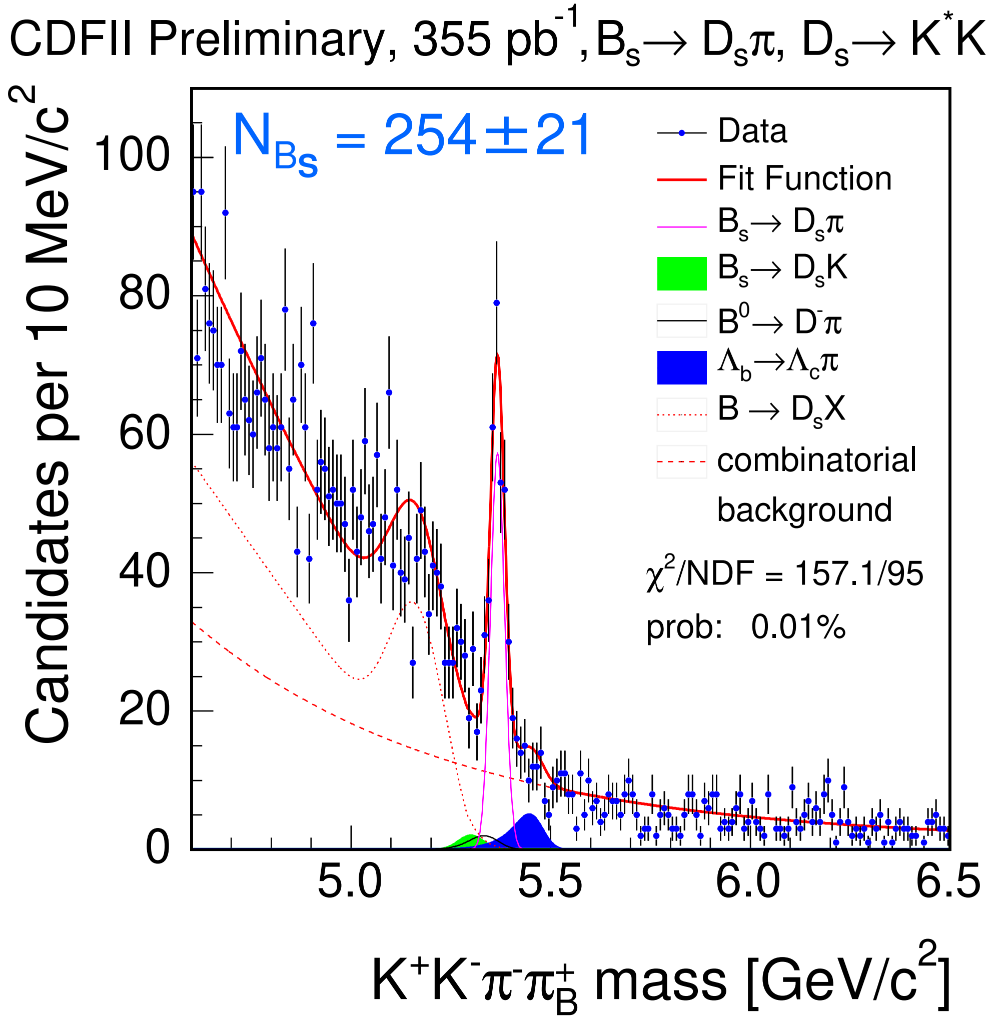
$$B_s^0 \to D_s^{*-} \pi^+ (D_s^{*-} \to D_s^- \gamma)$$

$$B_s^0 \to D_s^- \rho^+ (\rho^+ \to \pi^+ \pi^0)$$

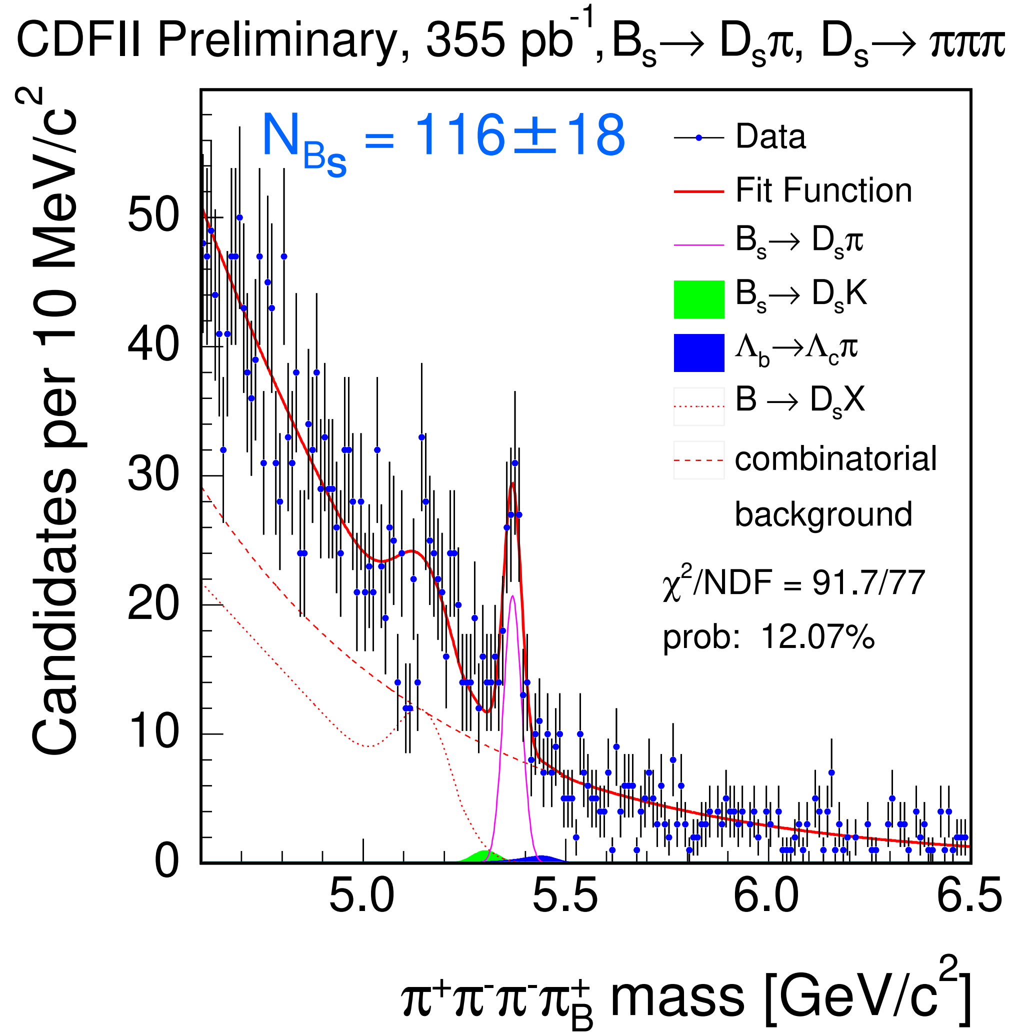
(Not used in this analysis)

Hadronic B_s signals (2)

$B_s^0 \to D_s^- \pi^+ (D_S^- \to K^{*0} K^-)$

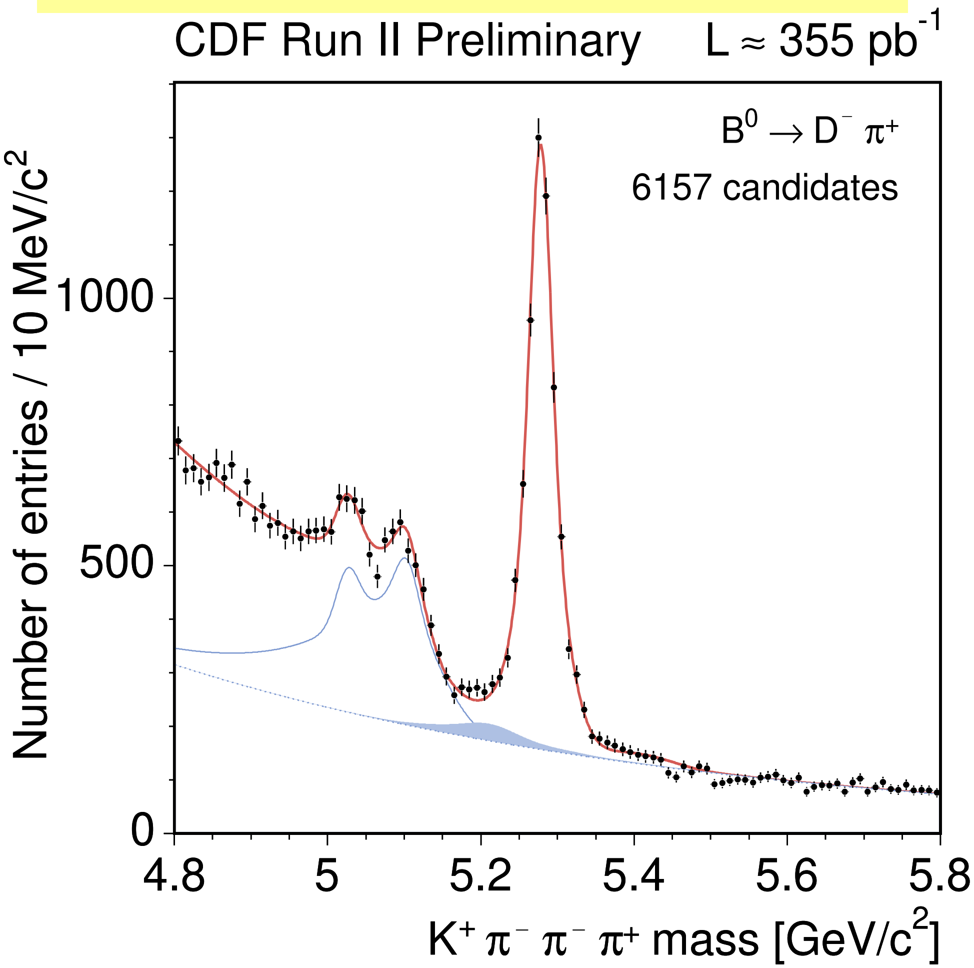


$B_s^0 \to D_s^- \pi^+ (D_S^- \to \pi^+ \pi^- \pi^-)$

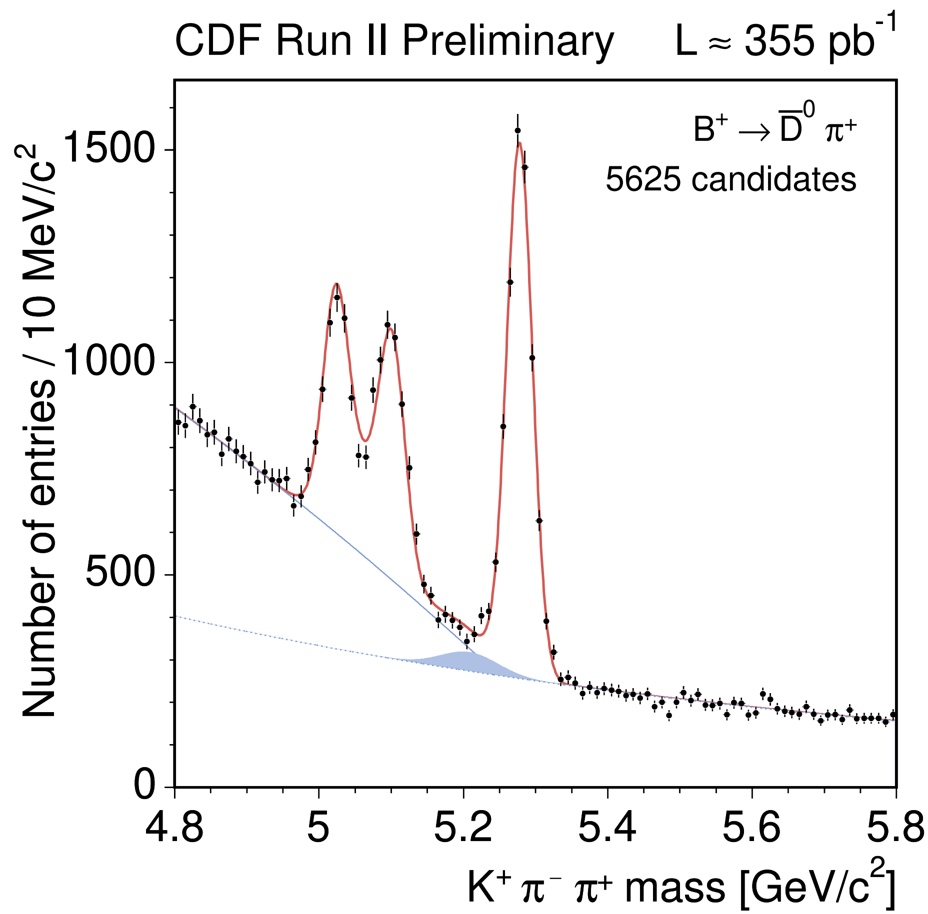


Calibration B^0 and B^+ hadronic signals

$$B^0 \to D^-\pi^+(D^- \to K^+\pi^-\pi^-)$$



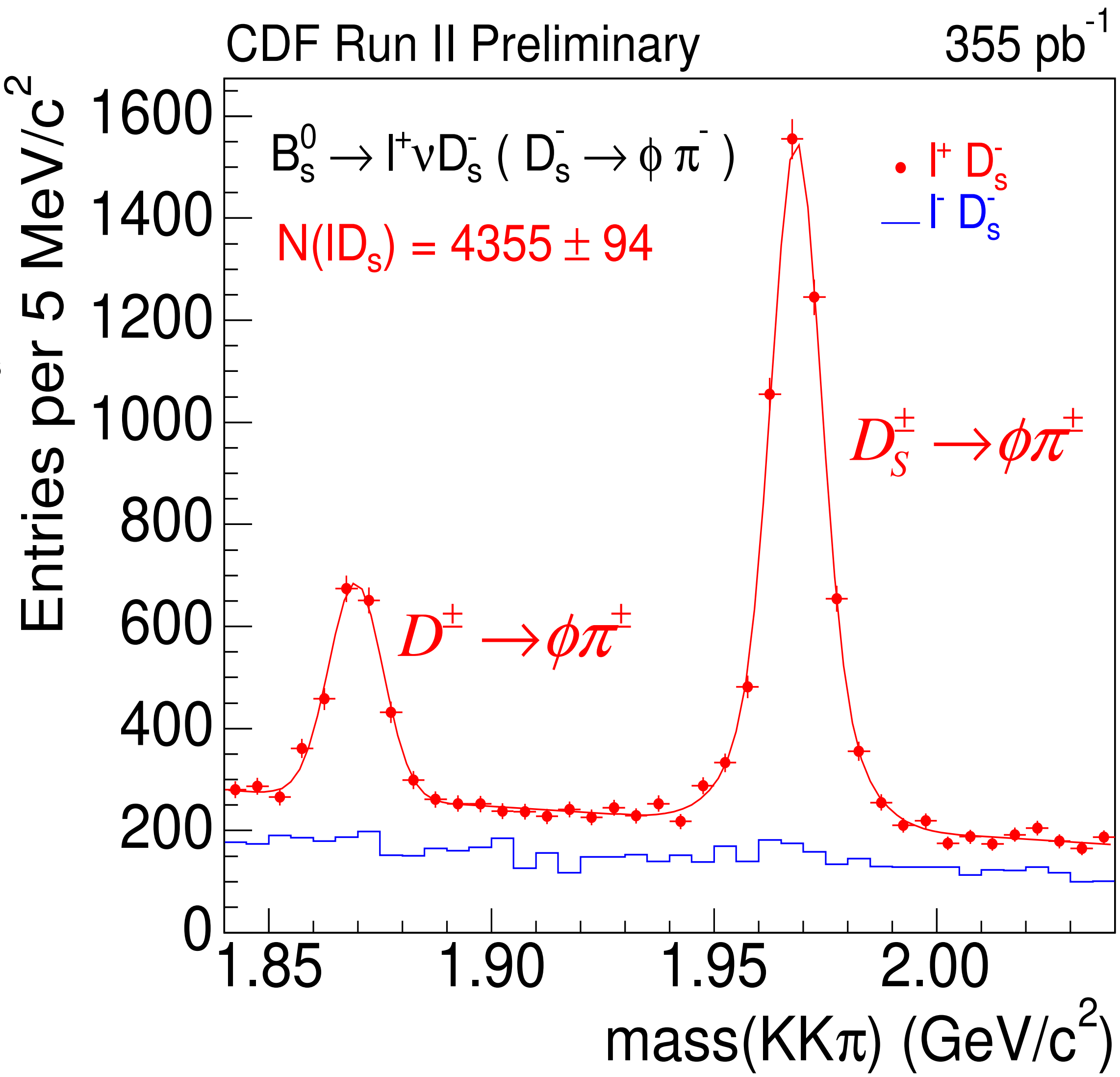
$$B^+ \to D^0\pi^+(D^0 \to K^+\pi^-)$$



Semileptonic B_s Signals

$$B_s^0 \to D_s^- l^+ \nu X \, (D_S^- \to \phi\pi^-)$$

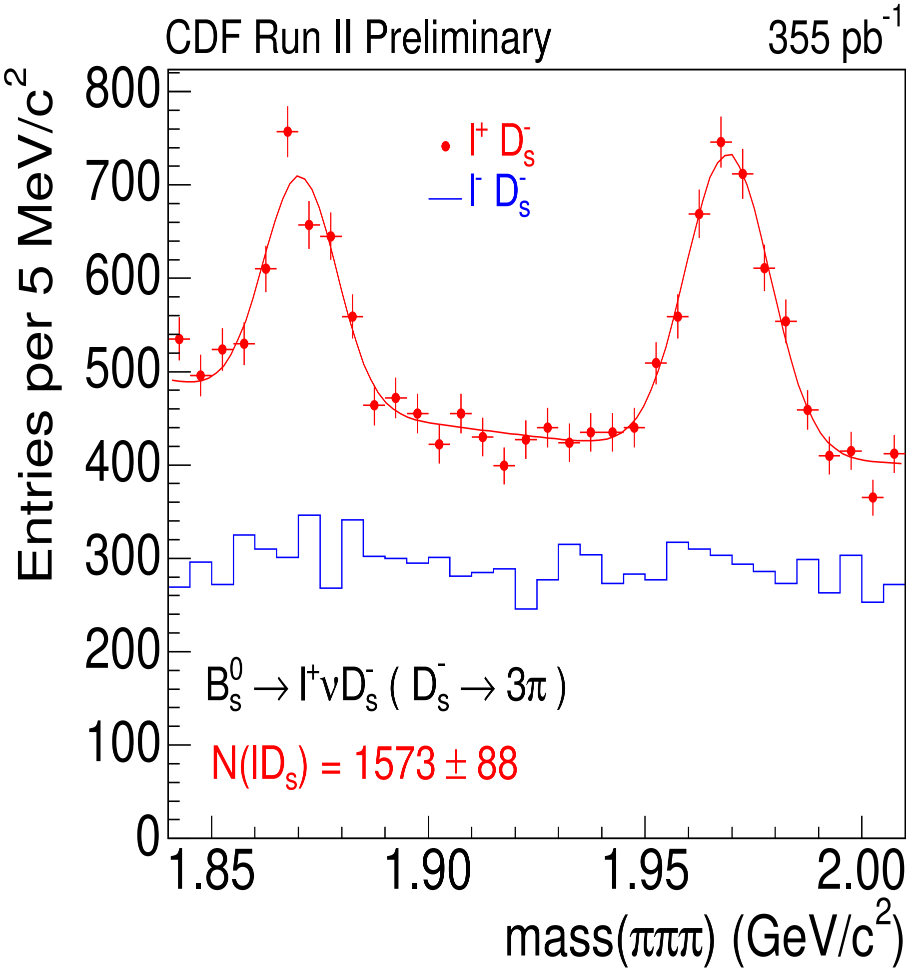
- Missing P_T ➡ No B_s mass peak
- Use D_s mass signals
- Charge correlation between ℓ and D_s
  - $\ell^+ D_s^-$: "Right-sign" = signal
  - $\ell^+ D_s^+$: "Wrong-sign" = background
- Right-sign peak is not pure signal
  - ~20% background:
    - » **D_s + fake lepton** from primary
    - » **B^0,B^+ → D_s D X** with D → $\ell\nu$X
    - » **c-$\bar{c}$** backgrounds

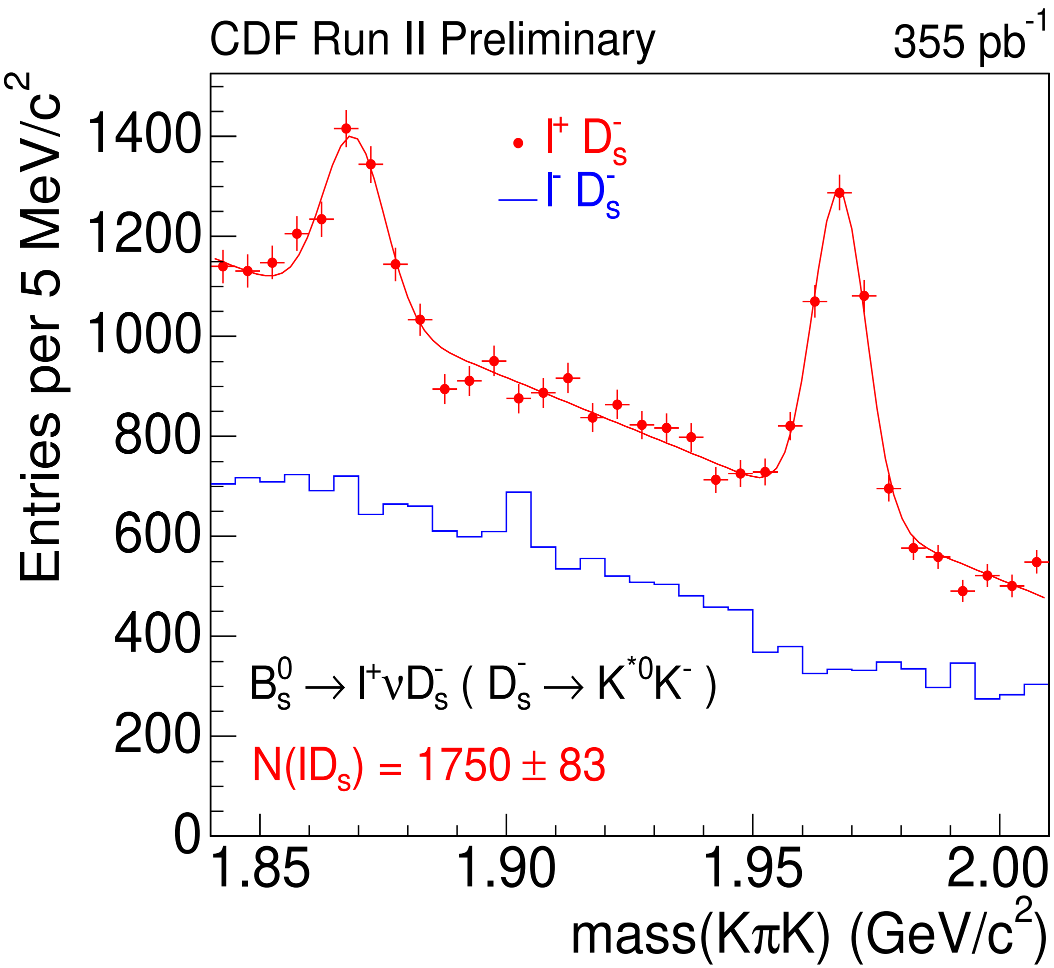


Semileptonic B_s Signals (2)

$$B_s^0 \rightarrow D_s^- l^+ \nu (D_S^- \rightarrow K^{*0} K^-)$$

$$B_s^0 \rightarrow D_s^- l^+ \nu (D_S^- \rightarrow \pi^+ \pi^- \pi^-)$$



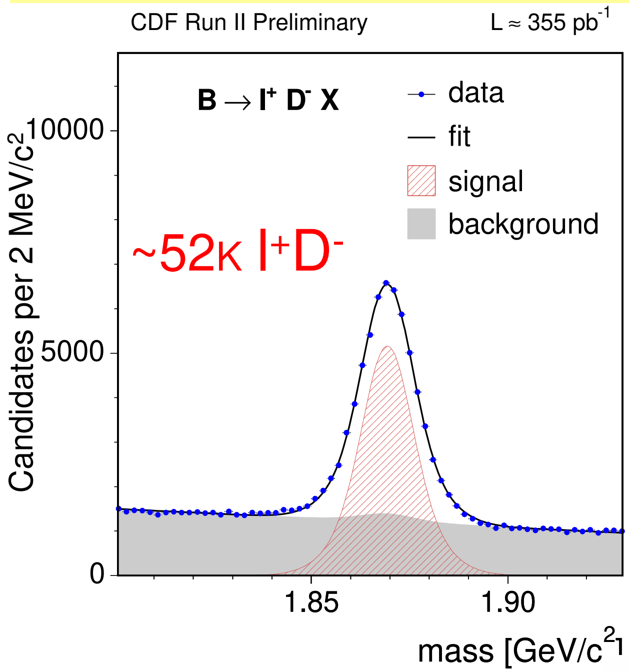


1573±88 events

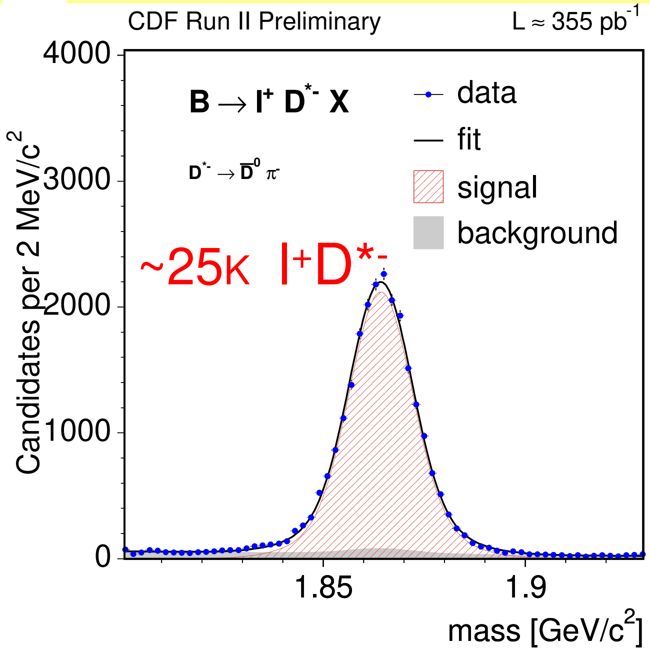
1750±83 events

Semileptonic B^0 and B^+ Signals

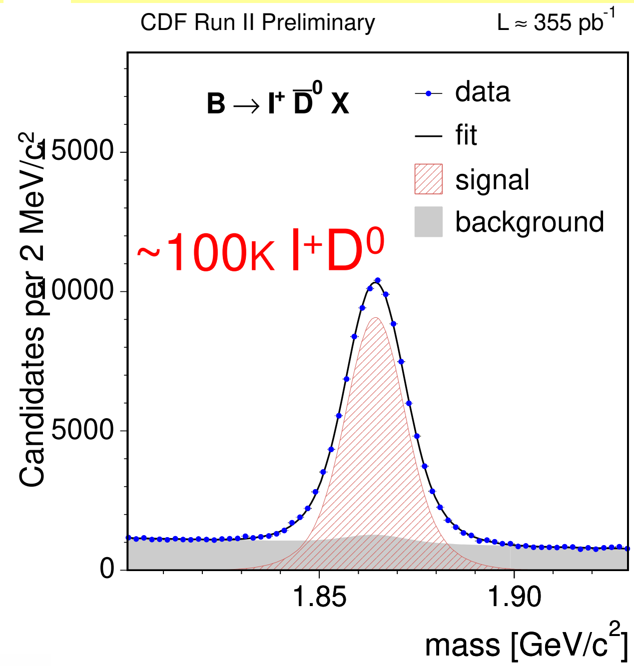
$B \to D^- l^+ \nu X \,(D^- \to K^+ \pi^- \pi^-)$



$B \to D^{*-} l^+ \nu X \,(D^{*-} \to D^0 \pi^-)$

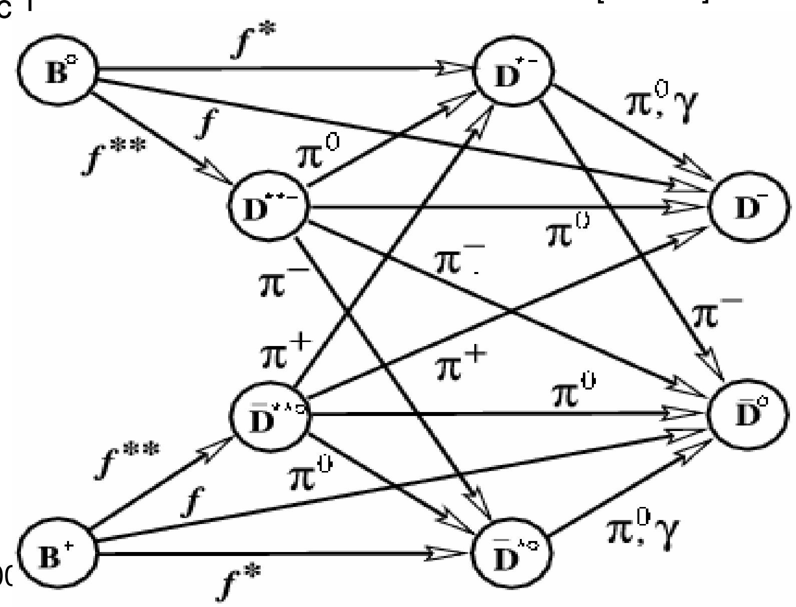


$B \to D^0 l^+ \nu X \,(D^0 \to K^+ \pi^-)$



$B^0 \leftrightarrow B^+$ crosstalks:

- $B^0 \to l^+ \nu D^-$
- $B^+ \to l^+ \nu D^{**0}$
  with $(D^{**0} \to D\ \pi)$



<u>Sample composition</u>

- ℓ + D⁺ : B^0/B^+ ~ 85/15
- ℓ + D*⁺ : B^0/B^+ ~ 85/15
- ℓ + D⁰ : B^0/B^+ ~ 20/80

Signal yields summary

	(S/B)
$B_s \to D_s\pi$; $D_s \to \phi\pi$	526 ± 33 (1.8)
$B_s \to D_s\pi$; $D_s \to K^*K$	254 ± 21 (1.7)
$B_s \to D_s\pi$; $D_s \to \pi\pi\pi$	116 ± 18 (1.0)
$B^+ \to D^0\pi^+$; $D^0 \to K\pi$	~6200
$B^0 \to D^{*+}\pi^-$; $D^{*+} \to D^0\pi^+$	~2800
$B^0 \to D^+\pi^-$; $D^+ \to K\pi\pi$	~5600

Hadronic B_s modes
~900 events

O(10^4) calibration modes

	(S/B)
$B_s \to \ell D_s$; $D_s \to \phi\pi$	4355 ± 94 (3.1)
$B_s \to \ell D_s$; $D_s \to K^*K$	1750 ± 83 (0.4)
$B_s \to \ell D_s$; $D_s \to \pi\pi\pi$	1573 ± 88 (0.3)
$B^+ \to \ell D^0$; $D^0 \to K\pi$	~100K
$B^0 \to \ell D^{*+}$; $D^{*+} \to D^0\pi^+$	~25K
$B^0 \to \ell D^+$; $D^+ \to K\pi\pi$	~52K

Semileptonic B_s modes
~7700 events

O(10^5) calibration modes

Lifetime bias from SVT trigger

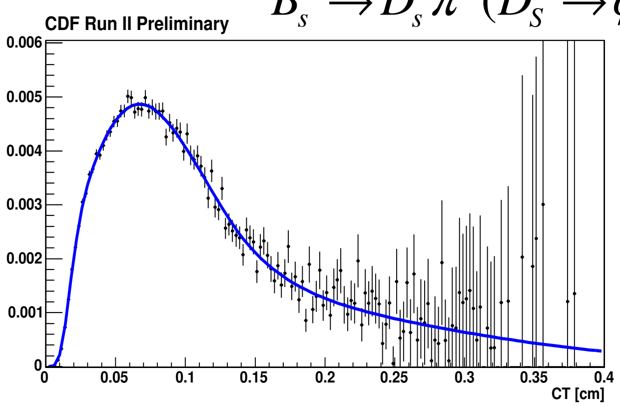
CDF Roma

SVT cuts on track **I**mpact **P**arameter: 120 μm < **I.P.**(trk) < 1mm

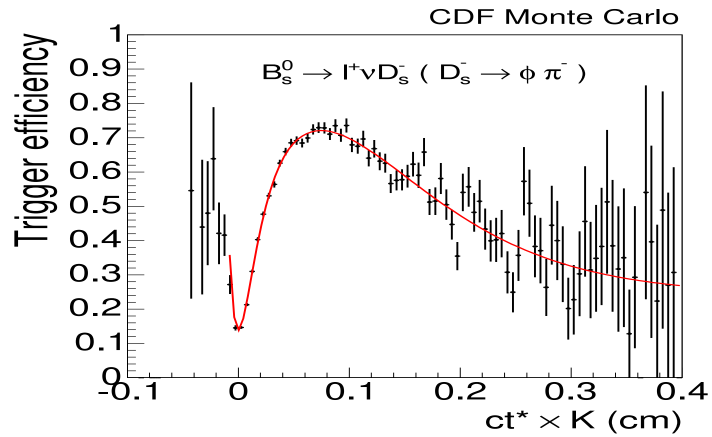
Proper time distribution is sculpted

Hadronic: **2 SVT** tracks

$B_s^0 \to D_s^- \pi^+ (D_S^- \to \phi\pi)$



Semileptonic: **1 SVT** track



Efficiency as a function of decay time is obtained using **M**onte**C**arlo:

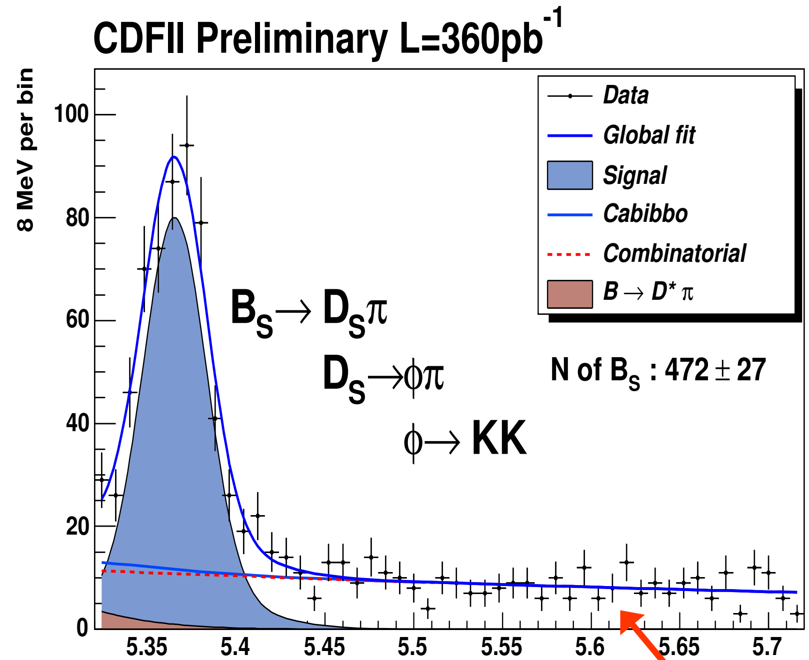
- B production (B p_T spectrum from data), decay model (EvtGen)
- full simulation of Detector & Trigger reproducing run by run conditions (alignments, beam line, …)

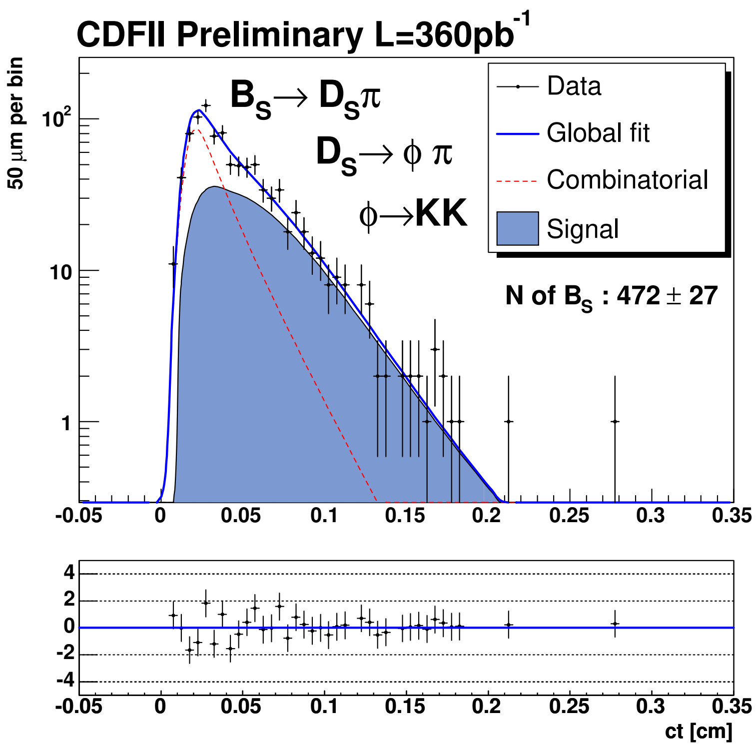
•Check: emulate SVT sculpting on $B^+ \to J/\Psi\ K^+$ unbiased sample

Lifetime in the hadronic B_s modes

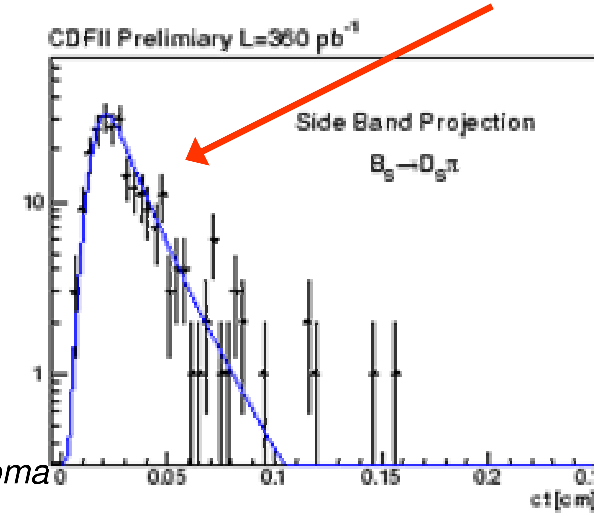
CDF Roma

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



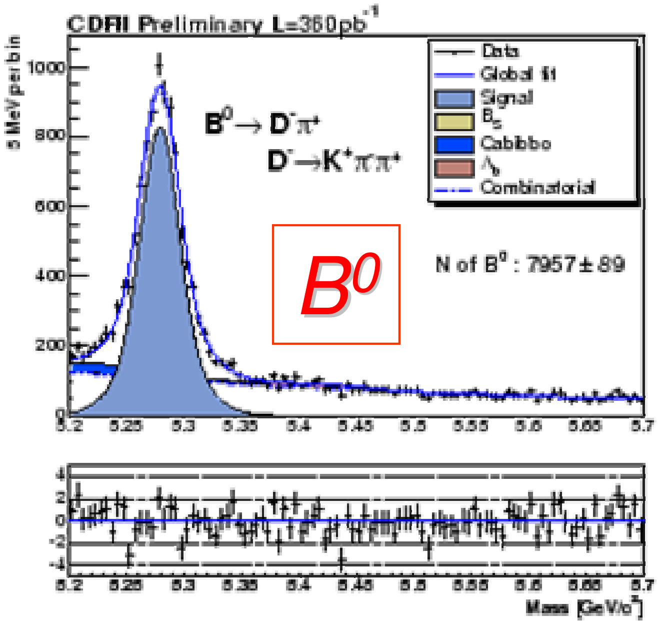


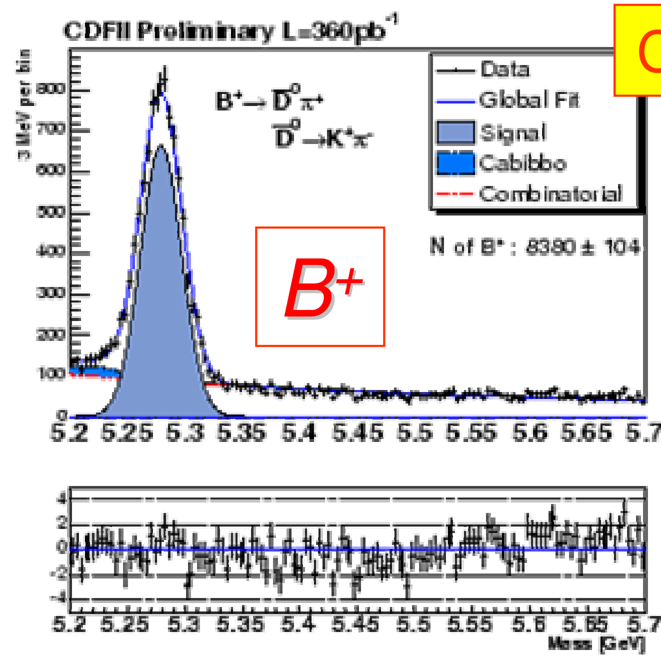
Combinatorial background **ct** template from high mass sideband

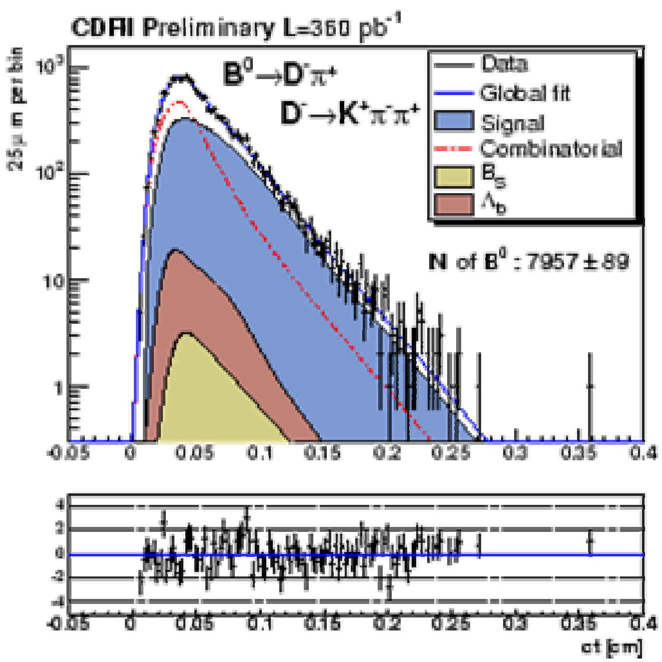


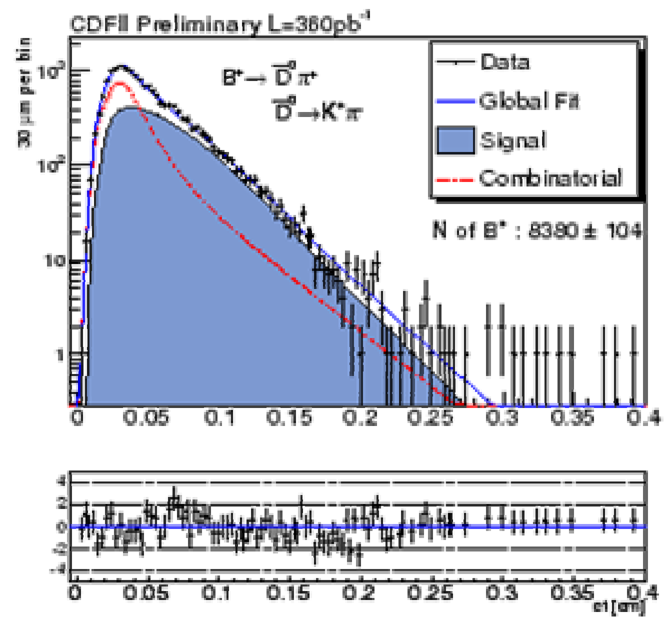
Lifetime in the B^0 and B^+ hadronic modes

CDF Roma









Hadronic B-lifetimes results

CDF Roma

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)	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

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

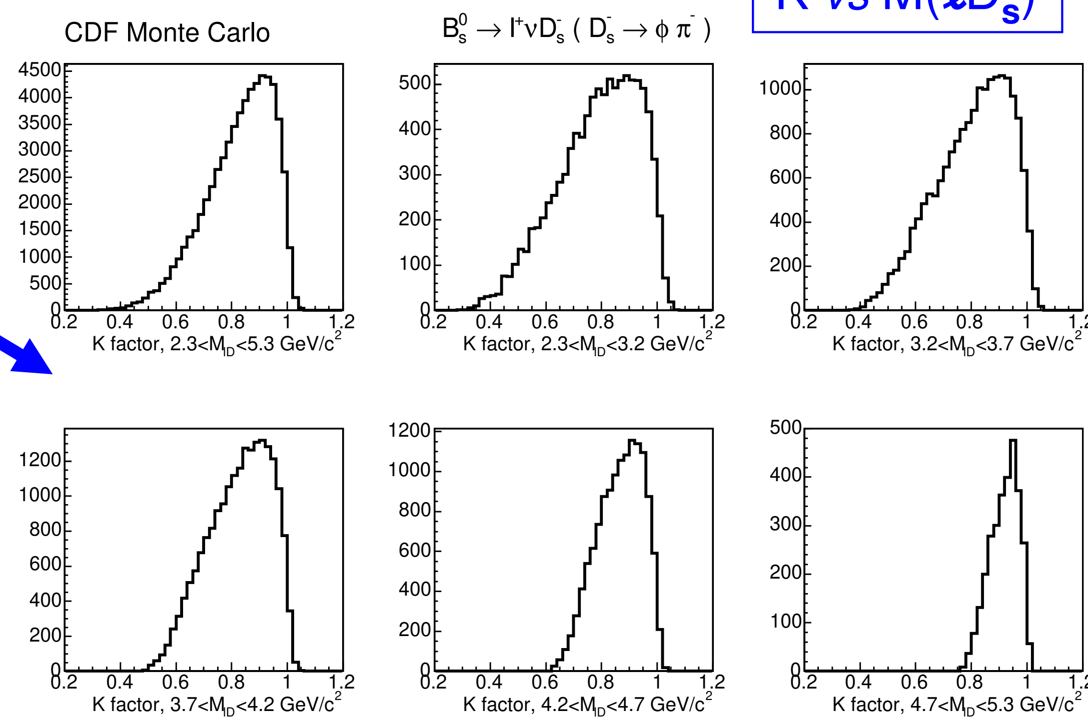
Measure the B decay distance L intersection of ℓ and $\mathbf{D_s}$

K *vs* M(ℓD_s)

– Observable momentum p* = p($\ell \mathbf{D_s}$)

– Correct statistically for missing momentum factor (from MC)

$$K = \frac{p(lDs)}{p(B)}$$



decay time

$$t = L \times \frac{m(B)}{p(B)}$$

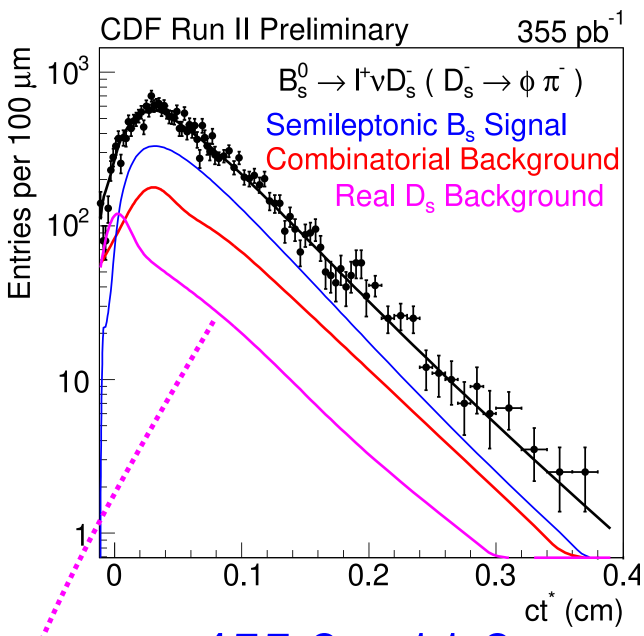
pseudo decay time

$$t^* = L \times \frac{m(B)}{p(\ell D_s)} \otimes K$$

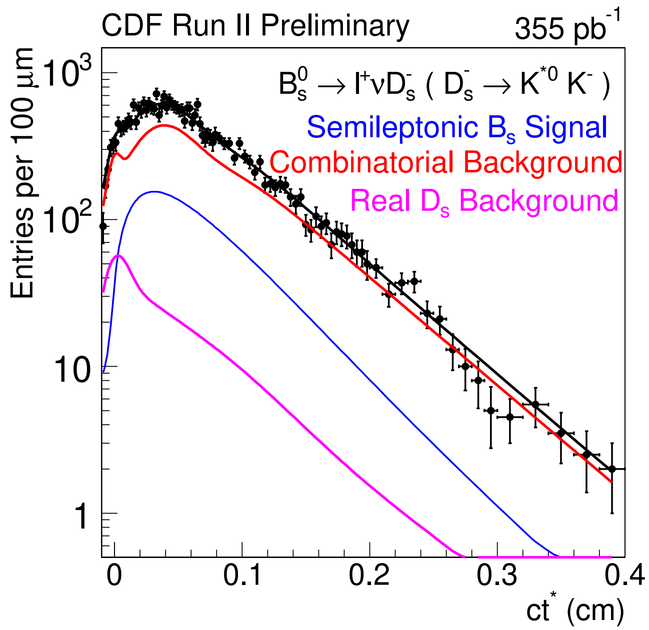
Perform an unbinned Likelihood fit:

- D_s meson mass, pseudo decay time, pseudo-decay time resolution
- Integration over K-factor p.d.f.
- Combinatorial background from D_s sidebands

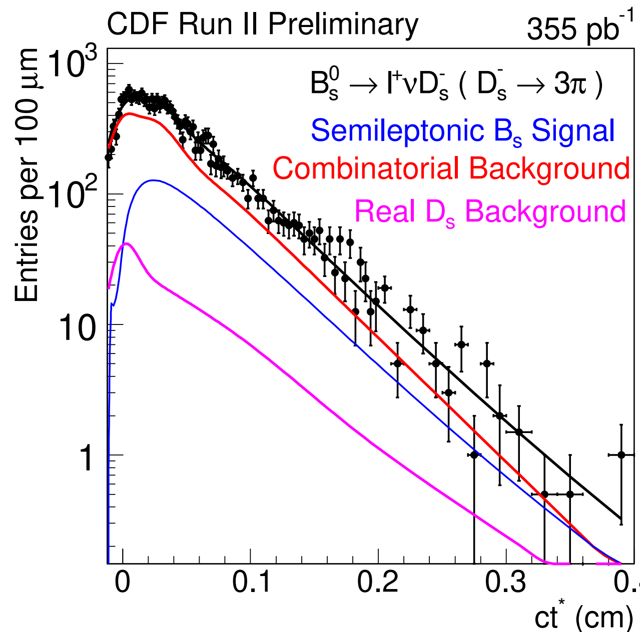
Lifetime in the semileptonic B_s modes



$c\tau = 455.9 \pm 11.9\ \mu m$



$c\tau = 413.8 \pm 20.1\ \mu m$



$c\tau = 422.6 \pm 25.7\ \mu m$

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

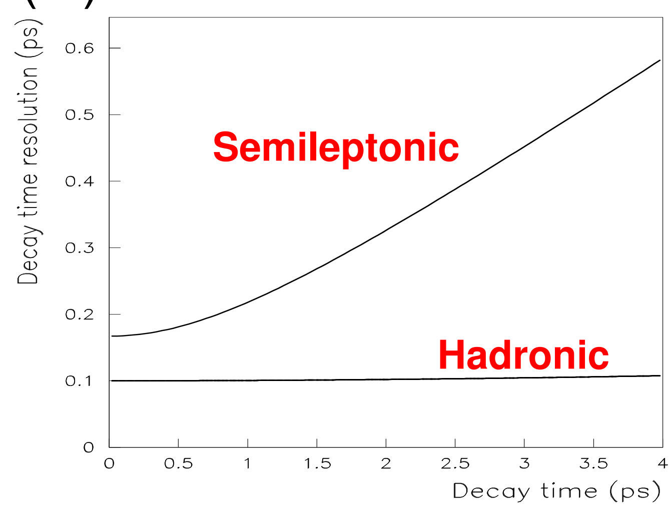
B_s decay time Resolution

$$\sigma_{ct} = \sqrt{\left(\sigma_{ct}^{0}\right)^2 + \left(ct \times \frac{\sigma_p}{p}\right)^2}$$

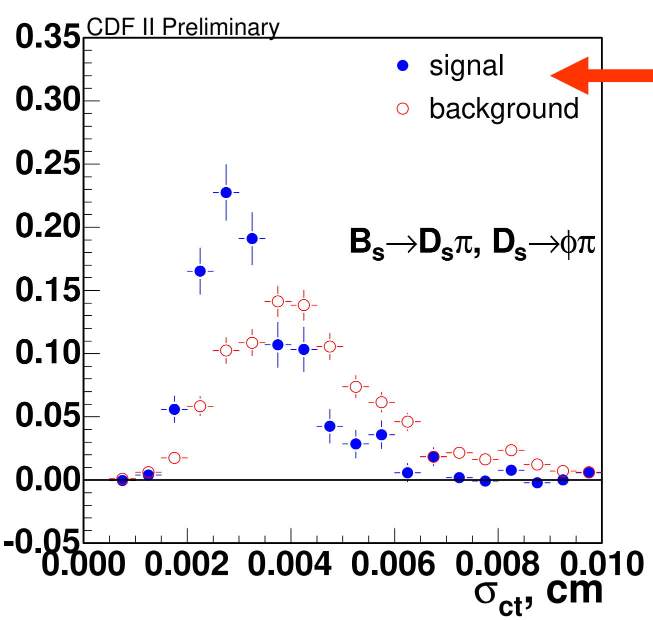
Vertex resolution (constant)

Momentum resolution (proportional to ct)

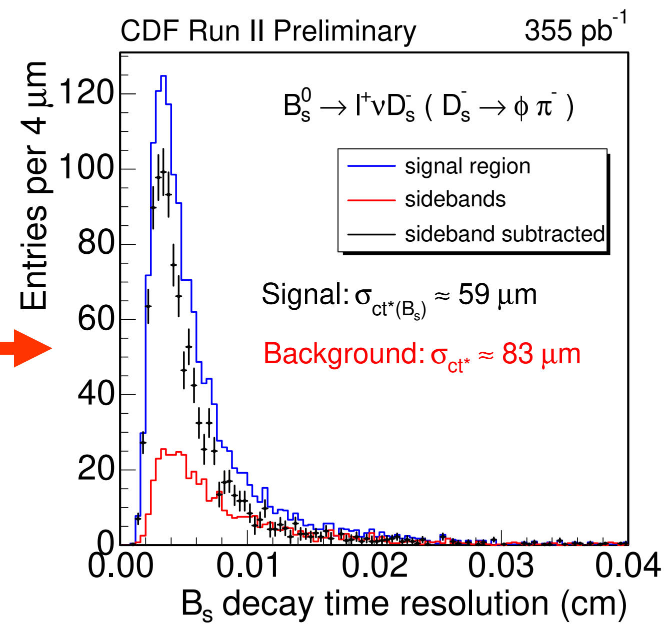
σ(ct)



ct



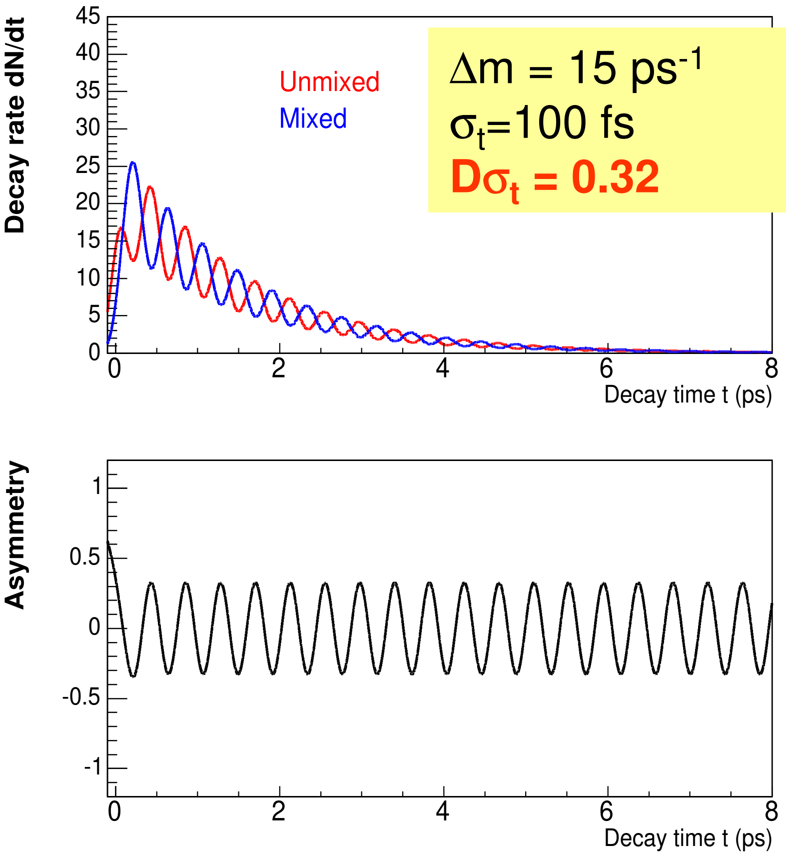
- Hadronic:
  - $\langle\sigma_{ct}^{0}\rangle$: ~ 30 μm (100 fs)
  - σp/p < 1%
- Semileptonic
  - $\langle\sigma_{ct}^{0}\rangle$: ~ 50 μm (167 fs)
  - σp/p ~ 15% (K factor)



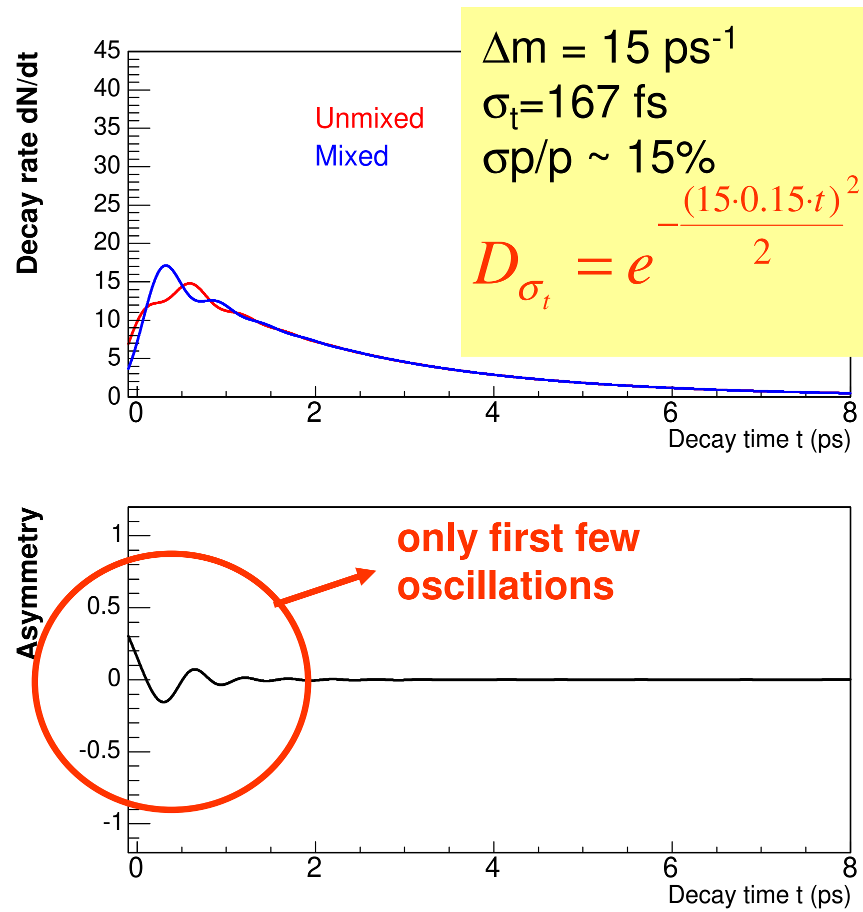
Time resolution effect on mixing

The amplitude of mixing asymmetry is diluted by a factor: $D_{\sigma_t} = e^{-\frac{(\Delta m \cdot \sigma_t)^2}{2}}$

Hadronic $D_{\sigma t}$ = const.



Semileptonic $D_{\sigma t}$ = f(t)



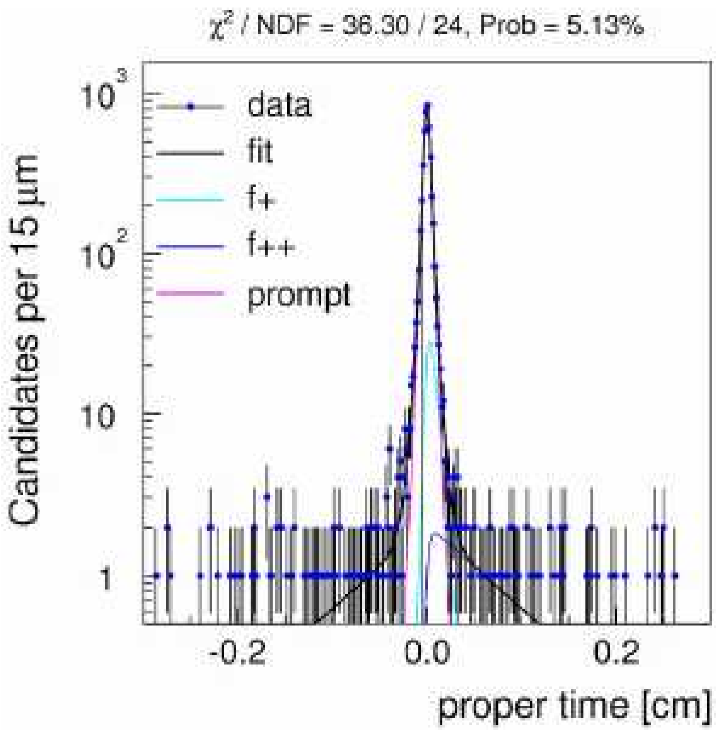
Determination of decay time resolution

Decay vertex error matrix overall correction for mis knowledge of hit resolution

→ Apply a scale factor **S** to σ**(ct)** from vertex fit:

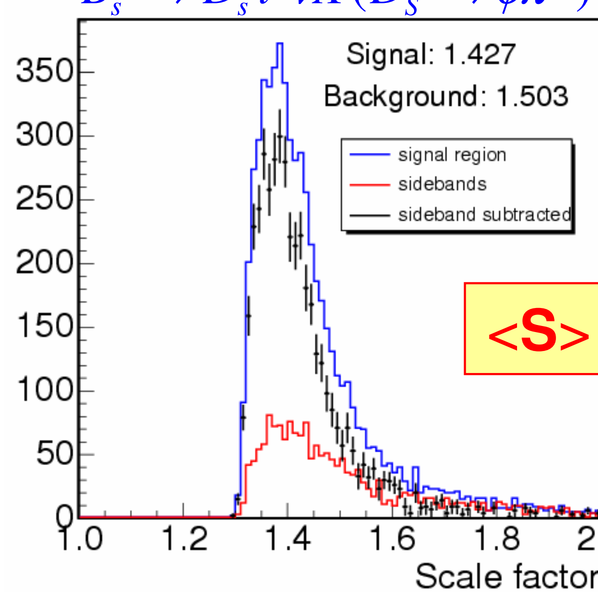
- Use large data control sample, real Ds + track from Primary Vertex
- Parameterize **S** in terms of several variables (P_T, Isolation,…)
- Correct σ**(ct)’** = **S**·σ**(ct)** event by event.

Prompt track + D_s vertex



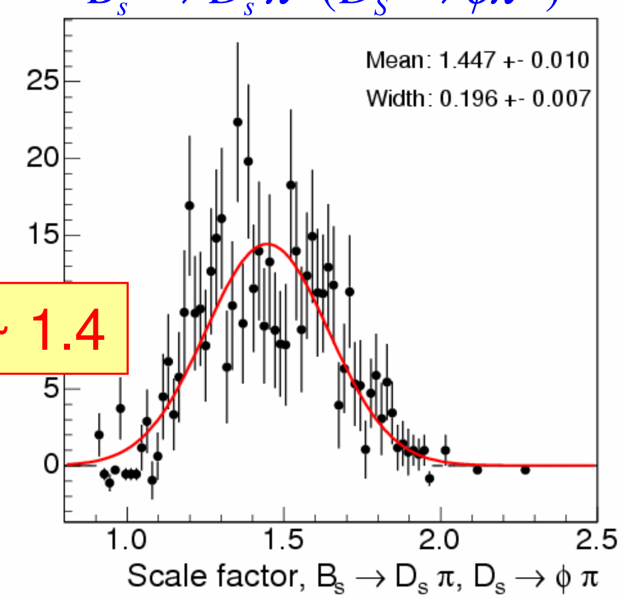
“Semileptonic” B_s signal

$B_s^0 \to D_s^- l^+ \nu X \,(D_S^- \to \phi\pi^-)$



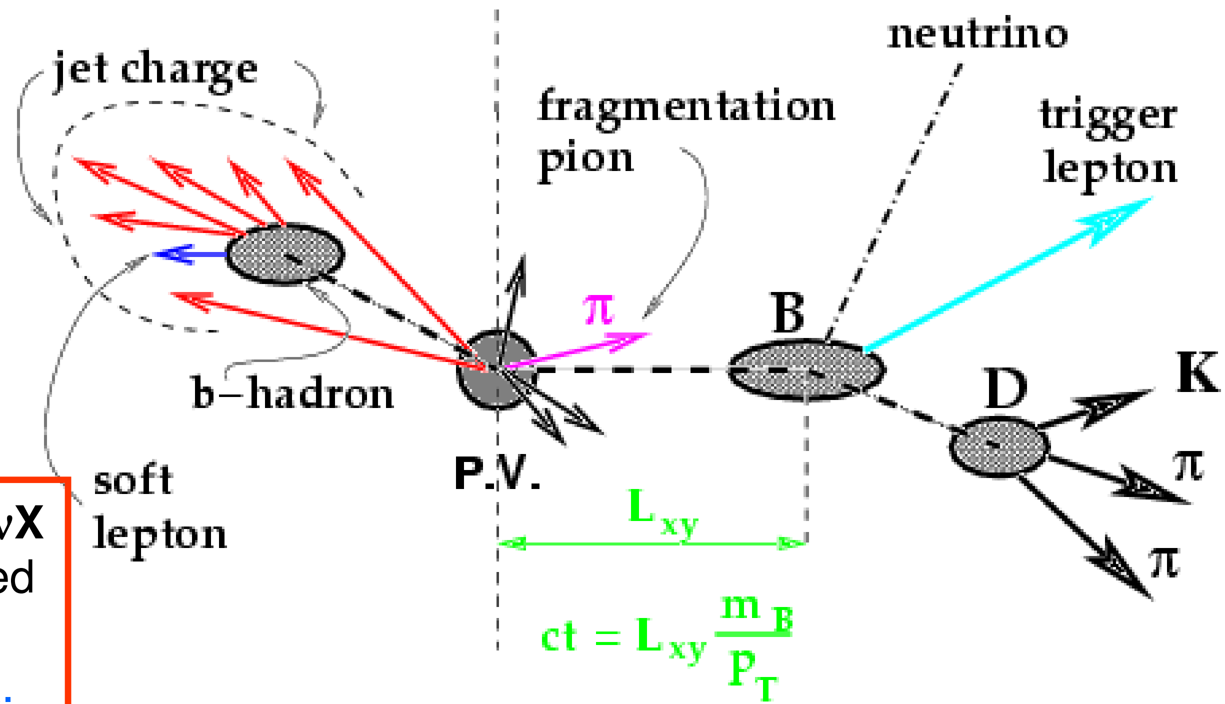
“Hadronic” B_s signal

$B_s^0 \to D_s^- \pi^+ \,(D_S^- \to \phi\pi^-)$



<S> ~ 1.4

Flavour tagging



Opposite Side

Jet Charge: the sum of **charges** of the **b-Jet tracks** is correlated to the b-flavour
→ Away Jet reconstruction

Used for today results

Soft Lepton (e,μ) due to **b→lνX**
The charge of the **l** is correlated to b-flavour
→ Search lepton from sec. vtx.

NOT yet used

Opposite Side K: due to **b→c→s** it is more likely that a $\mathbf{B^0}$ meson will contain in final state a $\mathbf{K^+}$ than a $\mathbf{K^-}$.
(→PID)
→search for **K** from secondary opposite vtx

Same Side

SS Pion: $\mathbf{B^0_d}$ is likely to be accompanied close in DR by a π^+ from fragmentation
SS Kaon: for $\mathbf{B^0_s}$ is likely to be accompanied close in DR by a **K+**
(→PID)
→search for π/**K** from Primary vertex

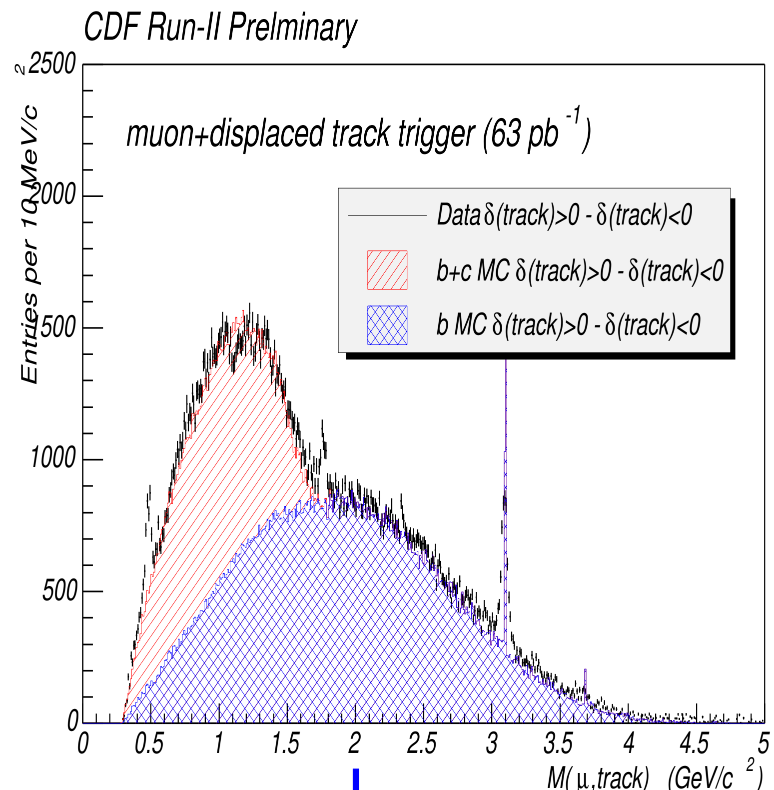
Calibrating the taggers

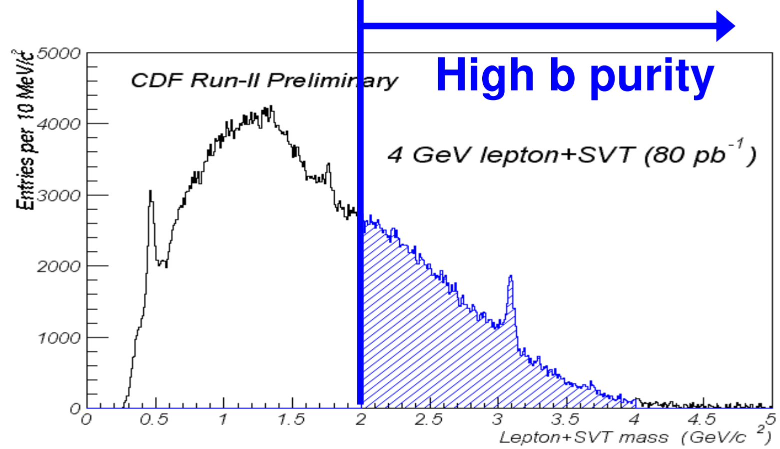
- **Statistical uncertainty for tagging efficiency:**
  - A typical tagging: ε=0.1,D=0.4,εD^2=1.6%
  - **1000** events: εD^2 =1.6$\pm$0.7% **(44%)**
  - **100K** events: εD^2=1.60$\pm$0.07% **(4.4%)**
- **Dividing events into classes based on tagging power improves εD^2**

$$\langle D^2(x)\rangle > \langle D(x)\rangle^2$$

→ **Binned Dilution**: needs statistics

- **Solution:** Lepton + Displaced track trigger
  - **~1.4 M sample rich in semileptonic B**
  - **High B purity**
  - **Lepton Charge = Decay flavor of B**

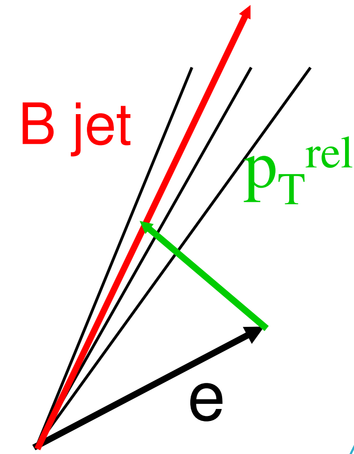




Soft lepton tagging

• The soft electron and muon tagger are built in a Likelihood based aproach

•Dilution is binned as a function of the lepton transverse momentum wrt the B jet direction in the opposite hemisphere



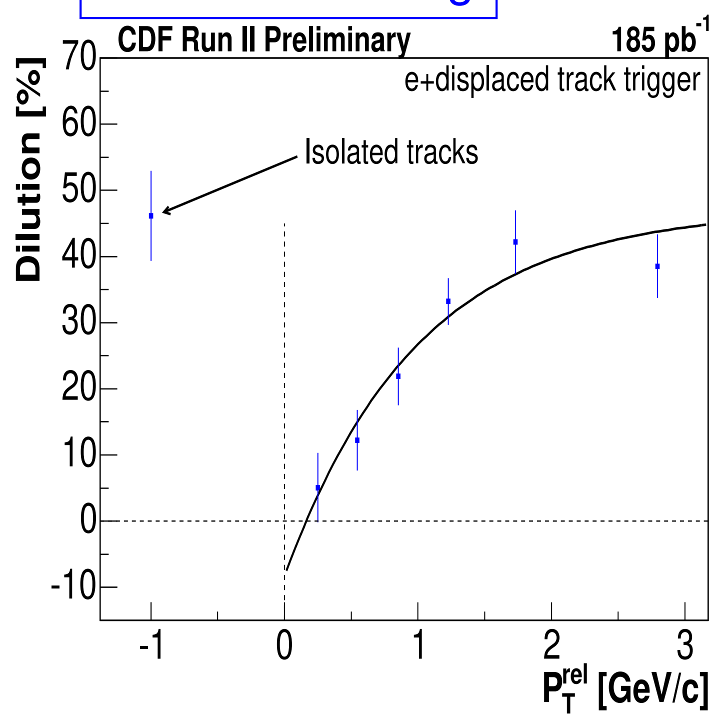
$b \rightarrow c + l^-$:

•High p_T^{rel}

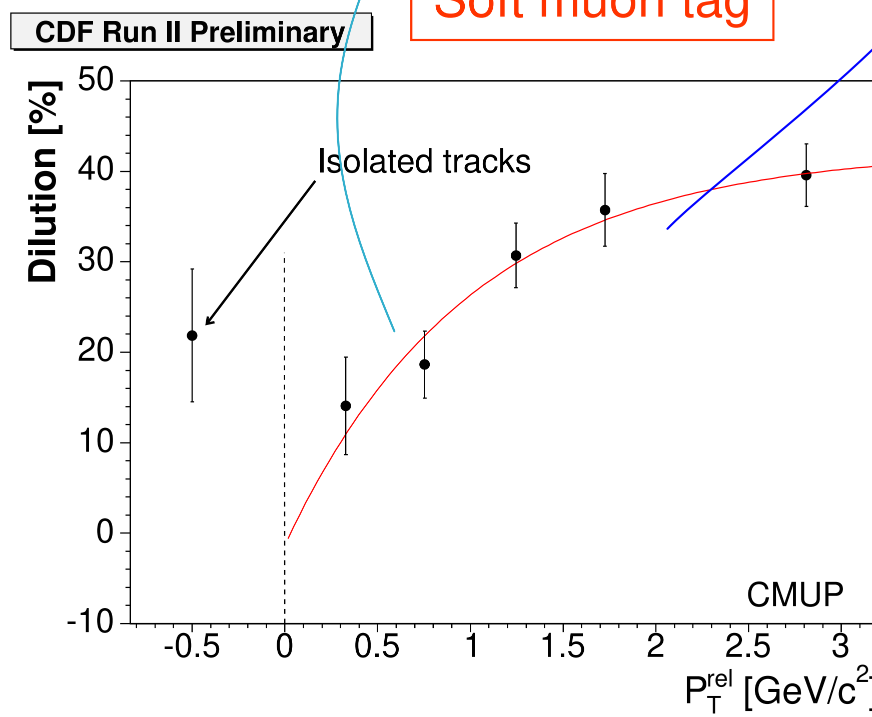
$b \rightarrow c \rightarrow s + l^+$:

•Low p_T^{rel} (sequentials)

Soft electron tag



Soft muon tag

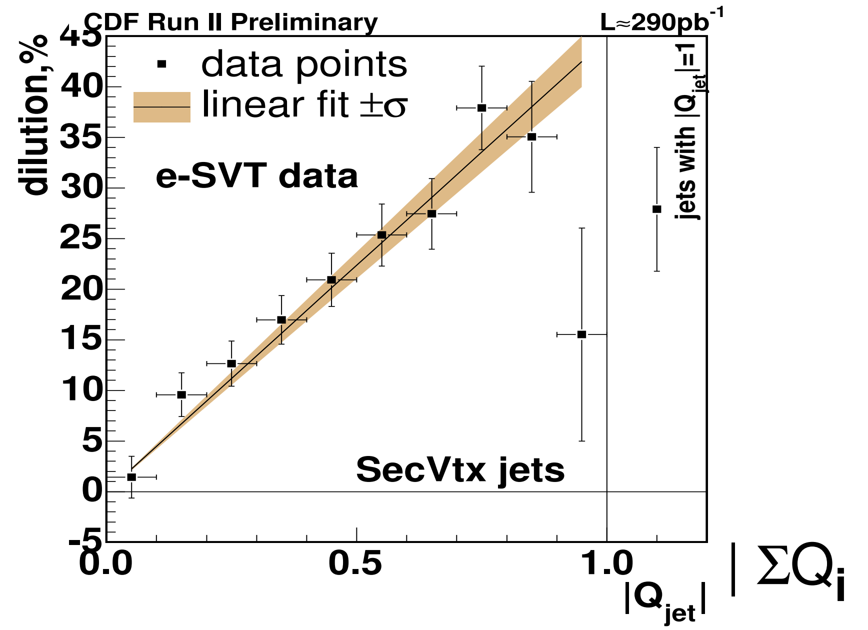


Jet Charge - Flavor Tagging Summary

Jet charge Q algorithms:

- Jet with 2ndary vertex found
- Jet containing displaced track
- Highest momentum Jet

D ε



•Measure the 5 taggers effective Dilutions in the ℓ + track calibration sample:

→Predict εD^2 event by event

→Test in Δm_d measurement →

Tag type	εD^2 (%)
Muon	$(0.70\pm0.04)\%$
Electron	$(0.37\pm0.03)\%$
2ndary vtx	$(0.36\pm0.02)\%$
Displaced track	$(0.36\pm0.03)\%$
Highest p jet	$(0.15\pm0.01)\%$
Total (exclusive)	~1.6%

B^0 mixing in the hadronic channels

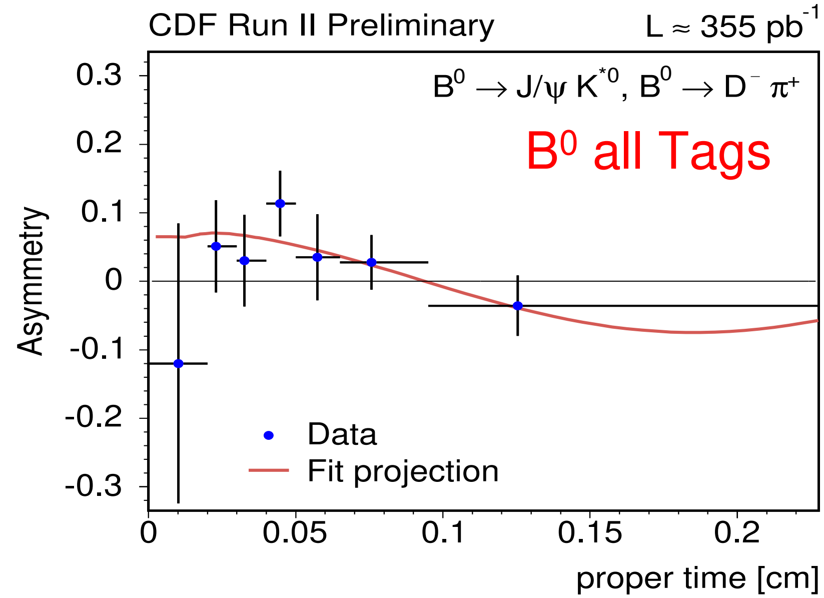
- Validation of the flavor tag calibration using B^0 and B^+ sample
  - $B^0 \to D\pi$, $B^+ \to D^0\pi$
  - $B^0 \to J/\psi K^{*0}$, $B^+ \to J/\psi K$
- Event by event predicted dilution **D** from the flavor tag calibration

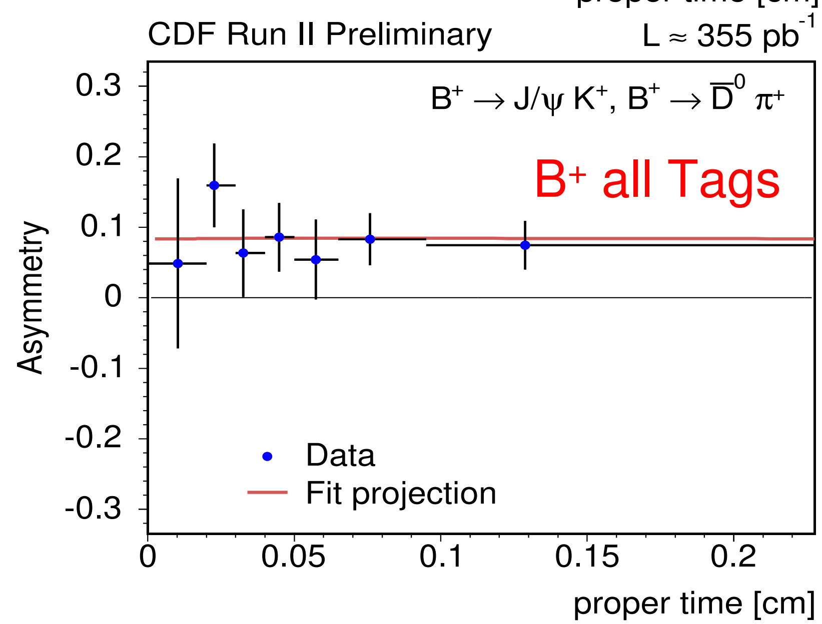
$$B^0 : e^{-t/\tau}\left(1 \pm S \cdot D \cdot \cos(\Delta m_d t)\right)$$

$$B^+ : e^{-t/\tau}\left(1 \pm S \cdot D\right)$$

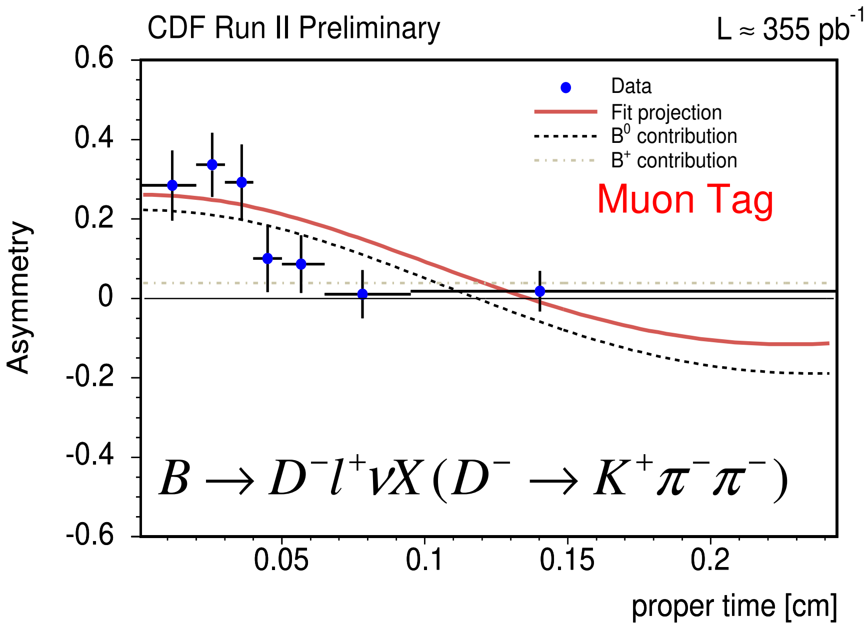
- Fit the "Dilution scale factor" **S**
  - S=1 if the tag calibration is correct.
  - 5 scale factors for 5 tag types

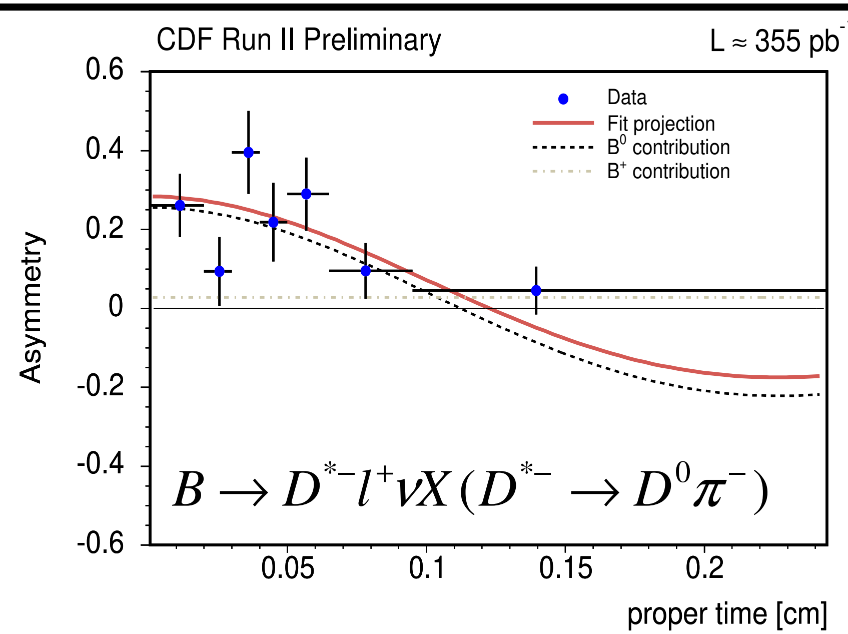
*→ Scale factors are then used for **B_s mixing** analysis in the hadronic*

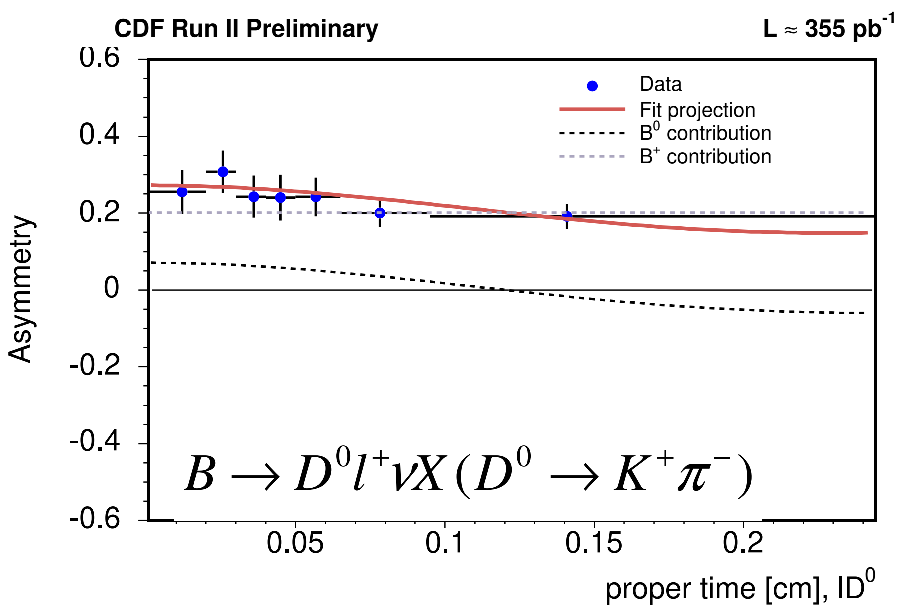




B^0 mixing in the semileptonic channels







– Measure Δm_d

– Extract 5 dilution scale factors

*→ The dilution scale factors are used for semileptonic **B_s mixing** analysis*

B^0 mixing results

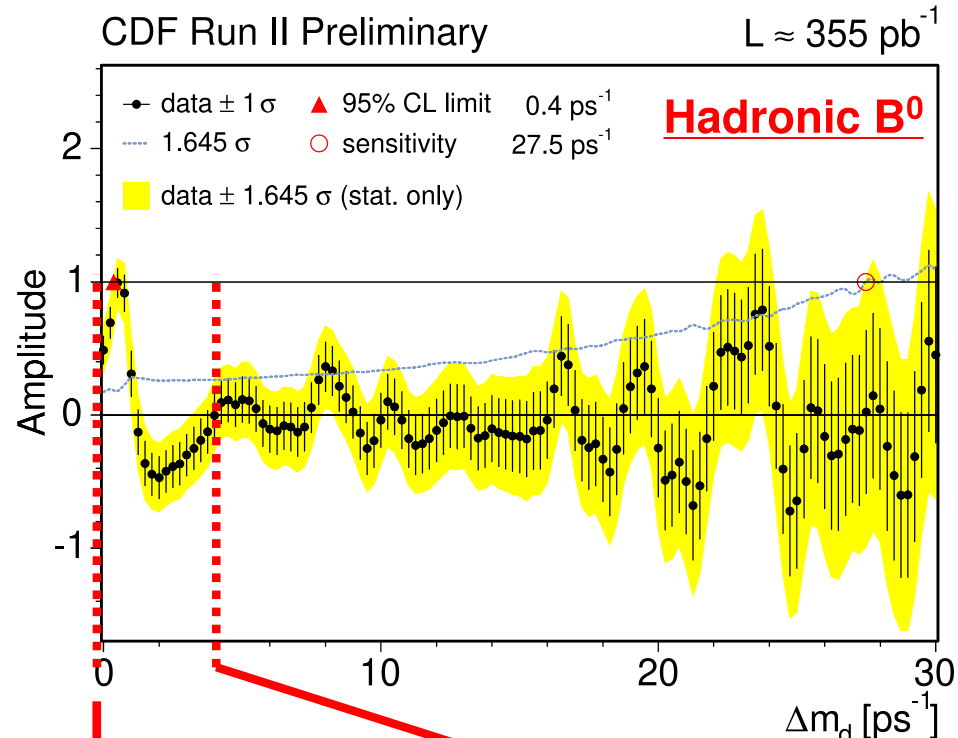
	HADRONIC	SEMILEPTONIC
Δm_d	$(0.503\pm0.063\pm0.015)$ ps^{-1}	$(0.498\pm0.028\pm0.015)$ ps^{-1}
Total εD^2	$(1.12\pm0.23)\%$	$(1.43\pm0.09)\%$
Dilution scale S		
Muon	$0.83\pm0.10\pm0.03$	$0.93\pm0.04\pm0.03$
Electron	$0.79\pm0.14\pm0.04$	$0.98\pm0.06\pm0.03$
Vertex	$0.78\pm0.19\pm0.05$	$0.97\pm0.06\pm0.04$
Track	$0.76\pm0.21\pm0.03$	$0.90\pm0.08\pm0.05$
Jets	$1.35\pm0.26\pm0.02$	$1.08\pm0.09\pm0.09$

- Δm_d consistent with WA: 0.510 ± 0.005 ps^{-1}
- **Total εD^2**: 1.1—1.4%
- All dilution scale factors consistent with 1
  - Hadronic: 15~25% uncertainty
  - Semileptonic: 5~15% uncertainty

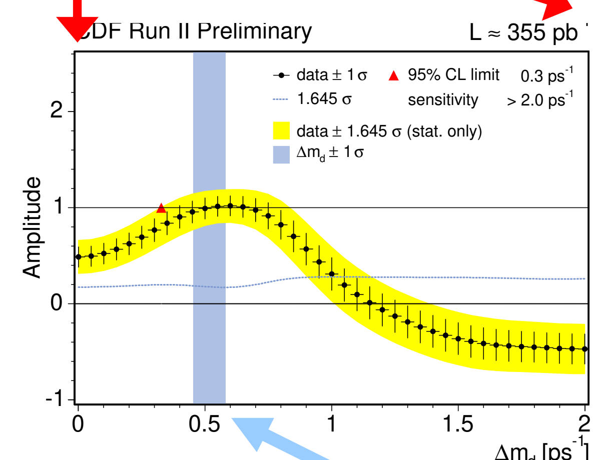
Amplitude scan method, ex.: *the B^0 case*

- Standard cosine fit not very sensitive for high Δm (i.e. the B_s case)
- Method: Introduce "Amplitude" ***A*** in Likelihood:

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



- perform "Amplitude Scan" ***(~AM band radio)***
  - Fit the amplitude ***A*** fixing **Δm**
    - → Amplitude: ***A***, uncertainty: σ_A
  - Repeat the fit with a set of Δm values



Ex.: hadronic B^0
A = 1 at Δm = 0.5
A = 0 at Δm >> 0.5

→ Amplitude ***A*** is consistent with:

- **1** if there is mixing
- **0** if there is no mixing

Δm_d meas. ± 1σ

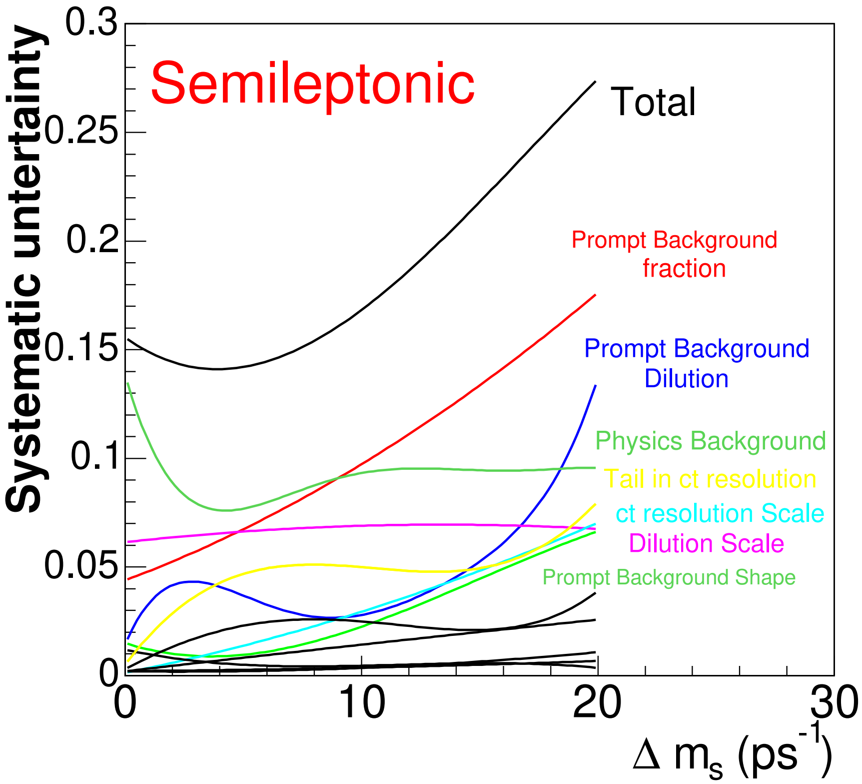
Δm_s amplitude scan road map

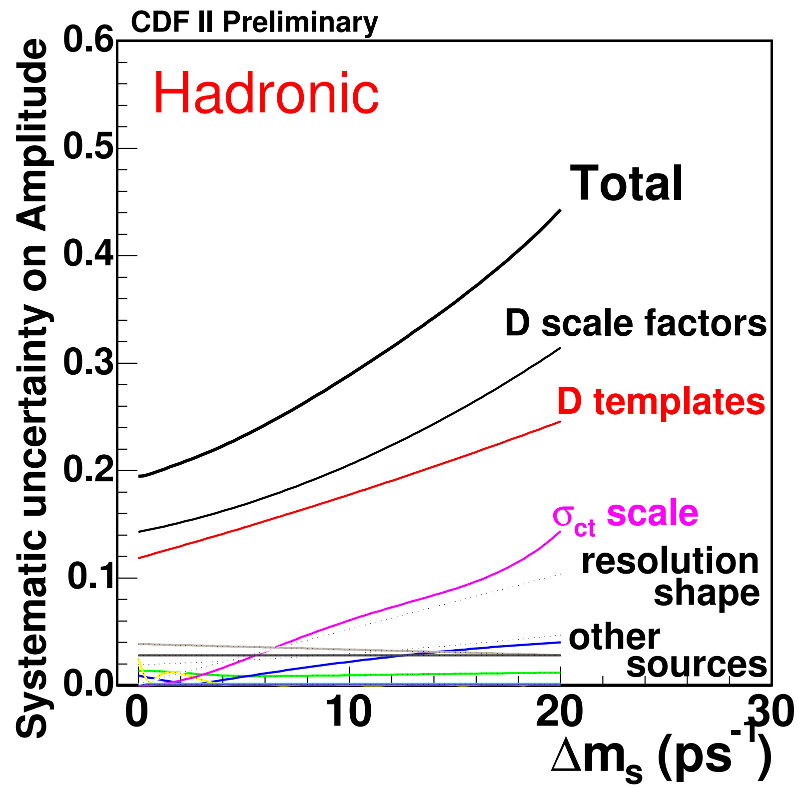
- **"Blind Analysis":**
  - Scrambling flavor tag decision ←→ multiply the tag decision x $(-1)^{\text{Run Number}}$
- Perform the blind amplitude scan to the Bs candidates:
- Amplitude **A is randomized** in the blind scan but: $\boldsymbol{\sigma_A}$ **is not biased**
- **Evaluate sensitivity** → exclude Δm_s range where **(1-A)>1.645·** σ_A (**95% C.L.**)
- **Systematic uncertainty**
  - Following the prescription by ***Moser, et.al. (NIM A 384 491)***
- We use **toy Monte-Carlo** sample generated at each value of Δm_s in the amplitude scan
  - Toy MC includes all variables and distributions used in Likelihood
  - Take shifts in amplitude (Δ**A**) and statistical uncertainty ($\Delta\sigma_A$).
- Derive systematic using formula

$$\sigma_A^{syst} = \Delta A + (1 - A)\frac{\Delta\sigma_A}{\sigma_A}$$

- **Open the box after:**
  - Sensitivity estimation
  - Systematic evaluation

Systematic Uncertainties



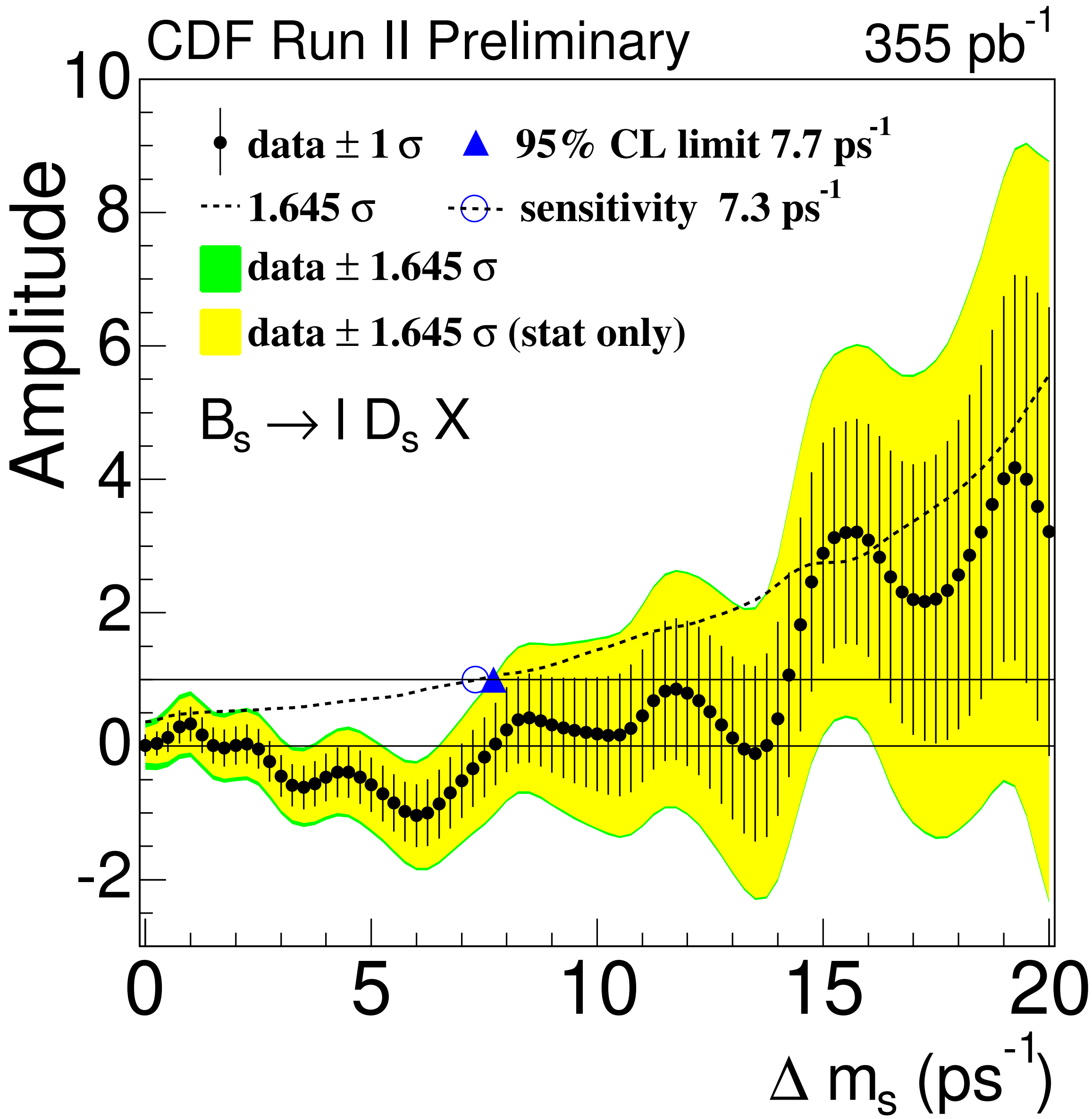


- **Physics** background at low Δm_s
- **Prompt** background at high Δm_s

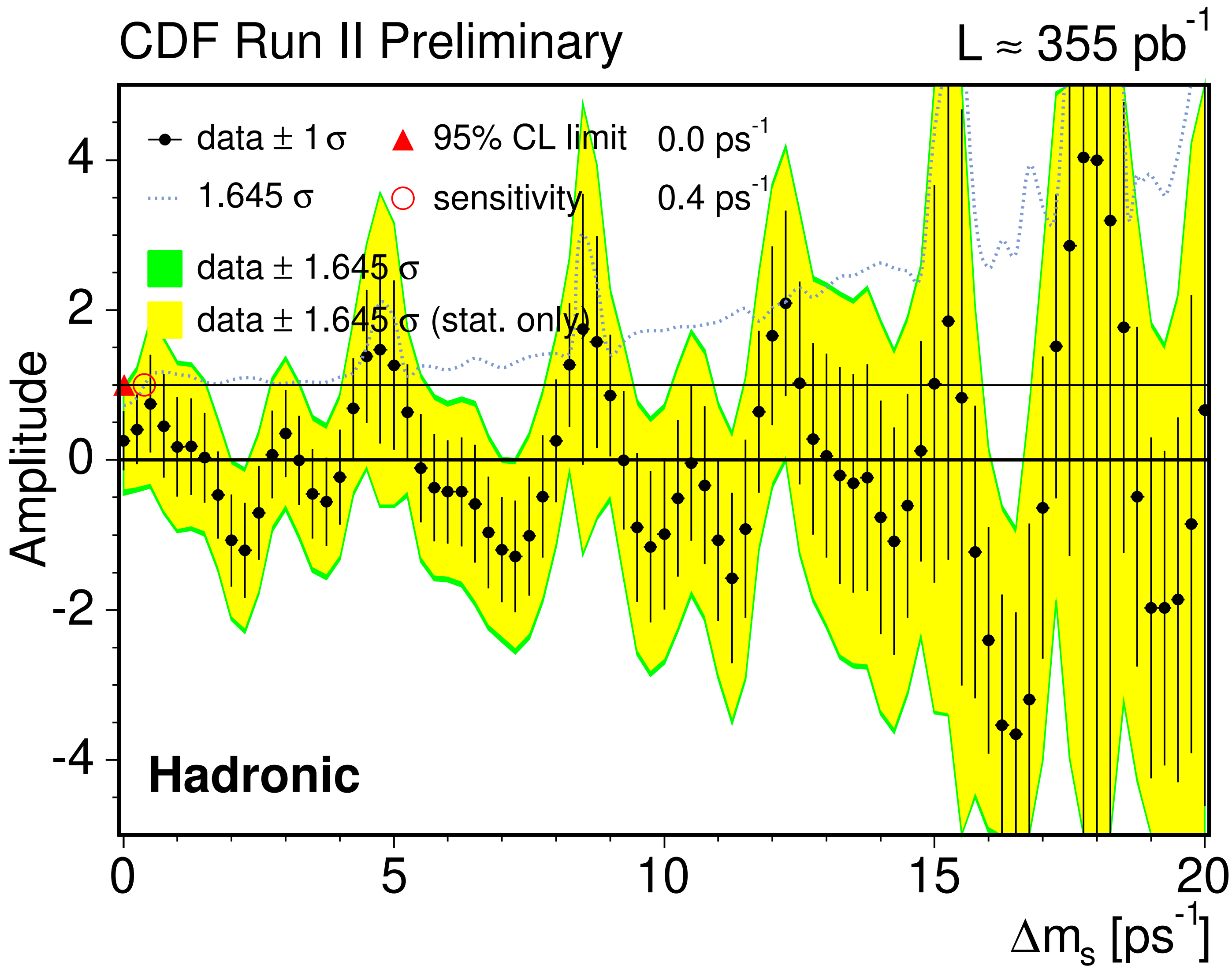
- **Dilution scale factors** and templates systematic limited from control sample statistics

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

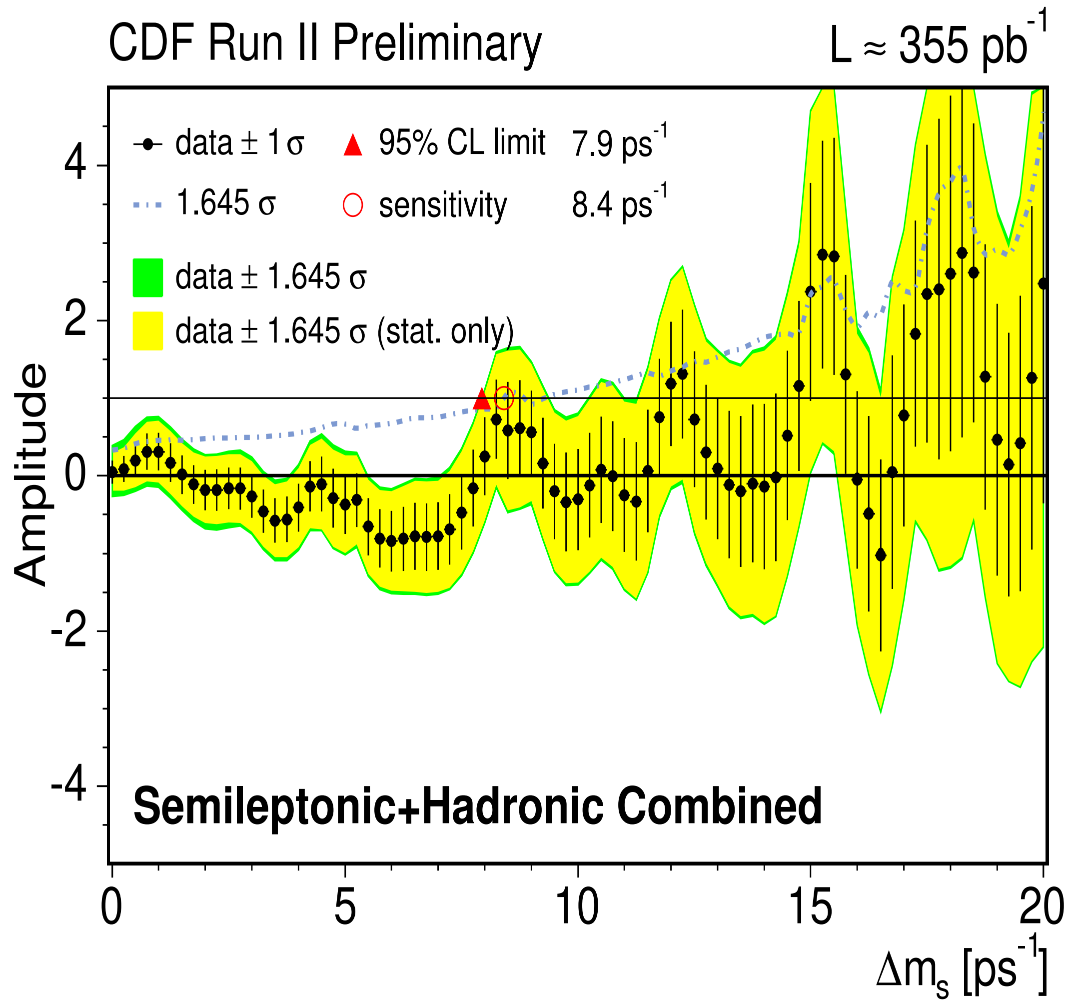
Amplitude Scan result (semileptonic)



Amplitude Scan result (hadronic)



CDF Combined Result



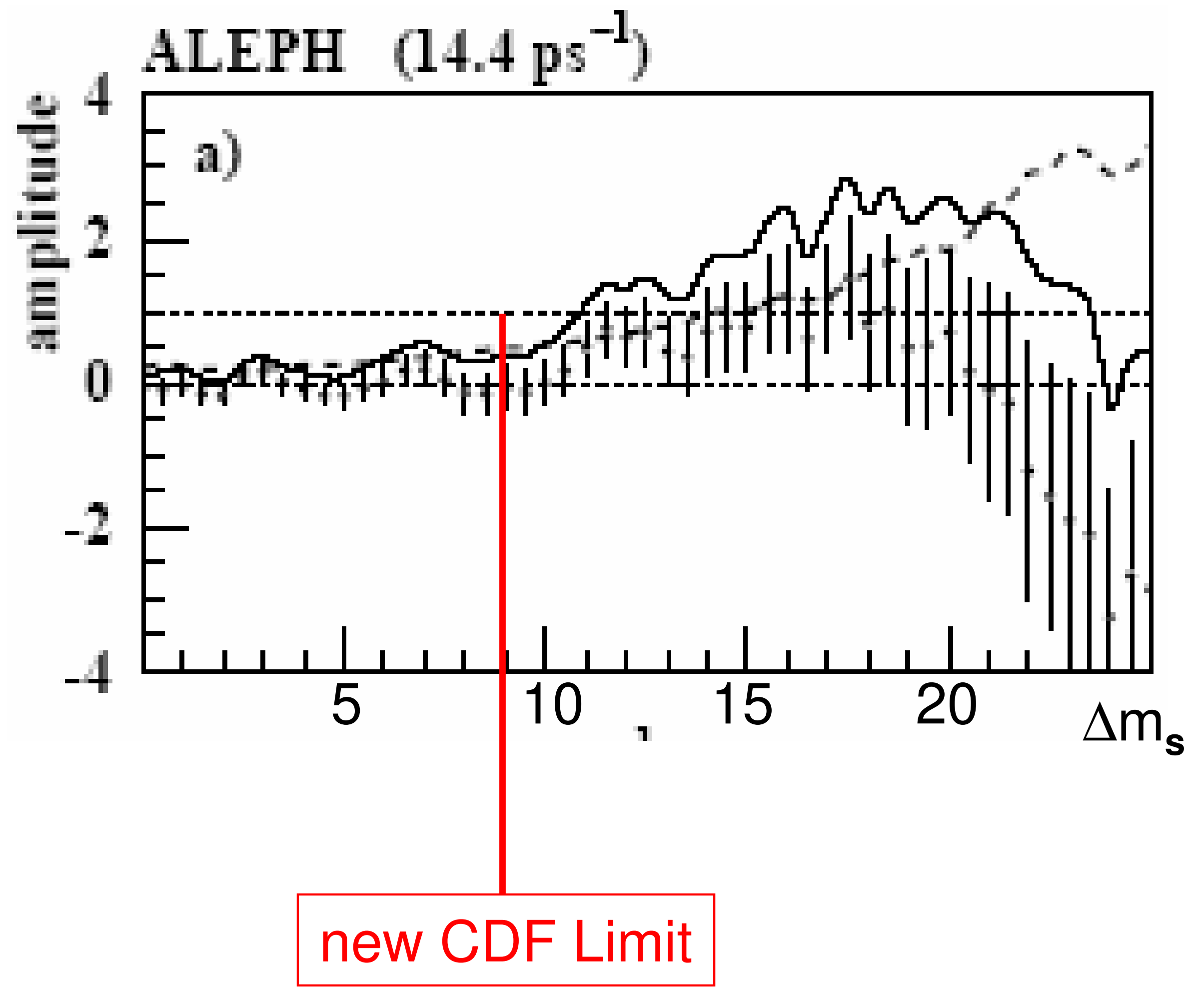
•Sensitivity: **8.4 ps^{-1}**

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

Comparison with best single experiment

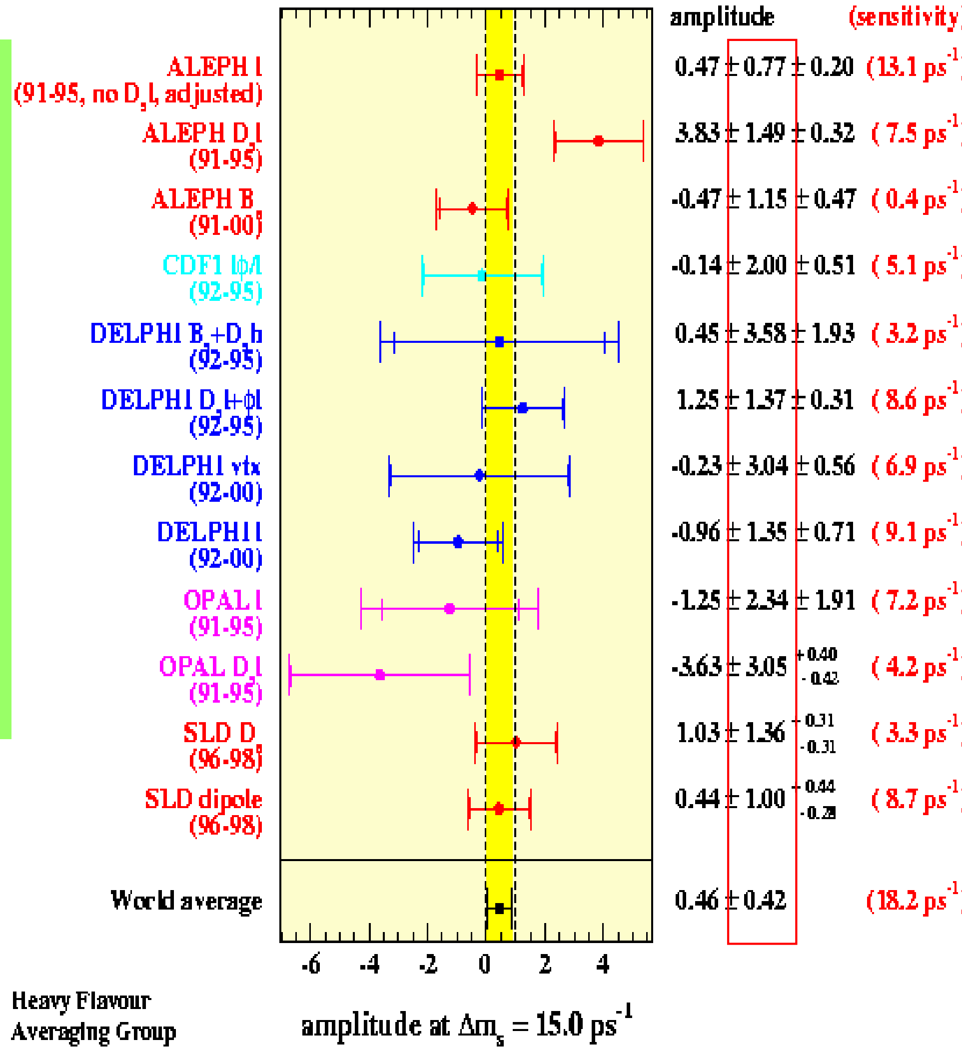
Best single experiment
Result from ALEPH:

Sensitivity 14.4 ps^{-1}
Limit >10.8 ps^{-1}



Amplitude fit value and uncertainty at Δm_s = 15.0 ps^{-1}: <u>(this CDF result)</u>

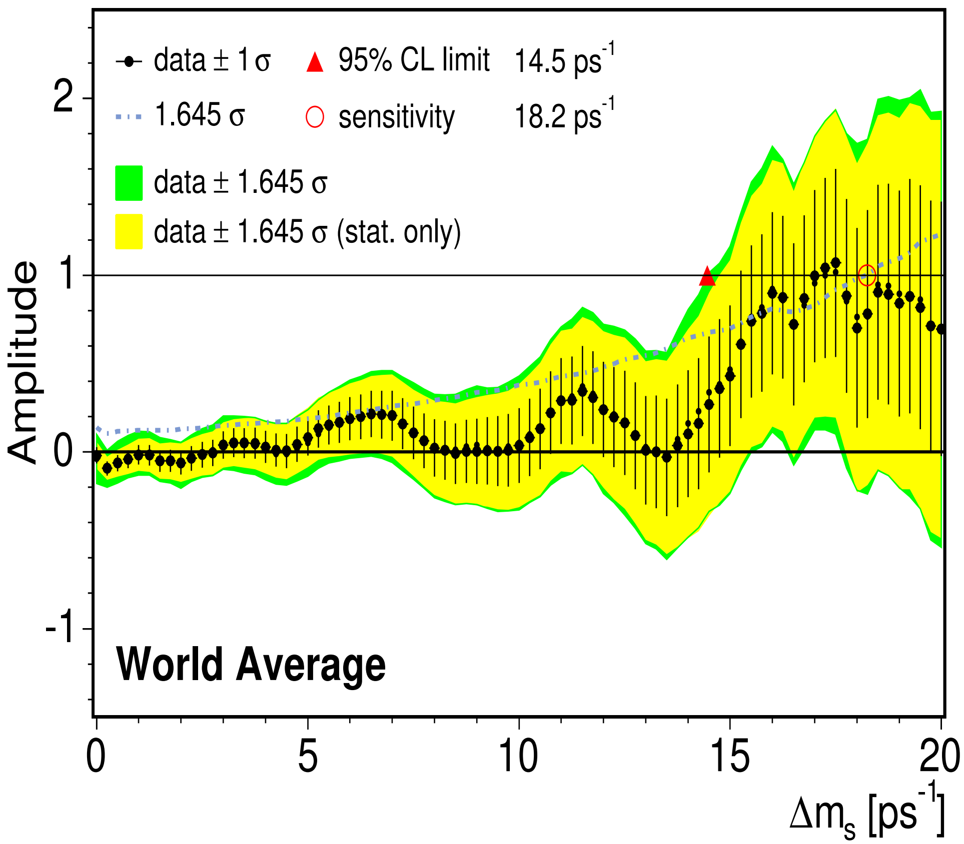
- 2.90±1.65±0.21 (Semileptonic)
- 1.02±**2.66**±0.35 (Hadronic, 15.00)
- 0.12±**1.47**±0.35 (Hadronic, 14.75)
- *Statistical fluctuations too dominate the hadronic CDF result by now*

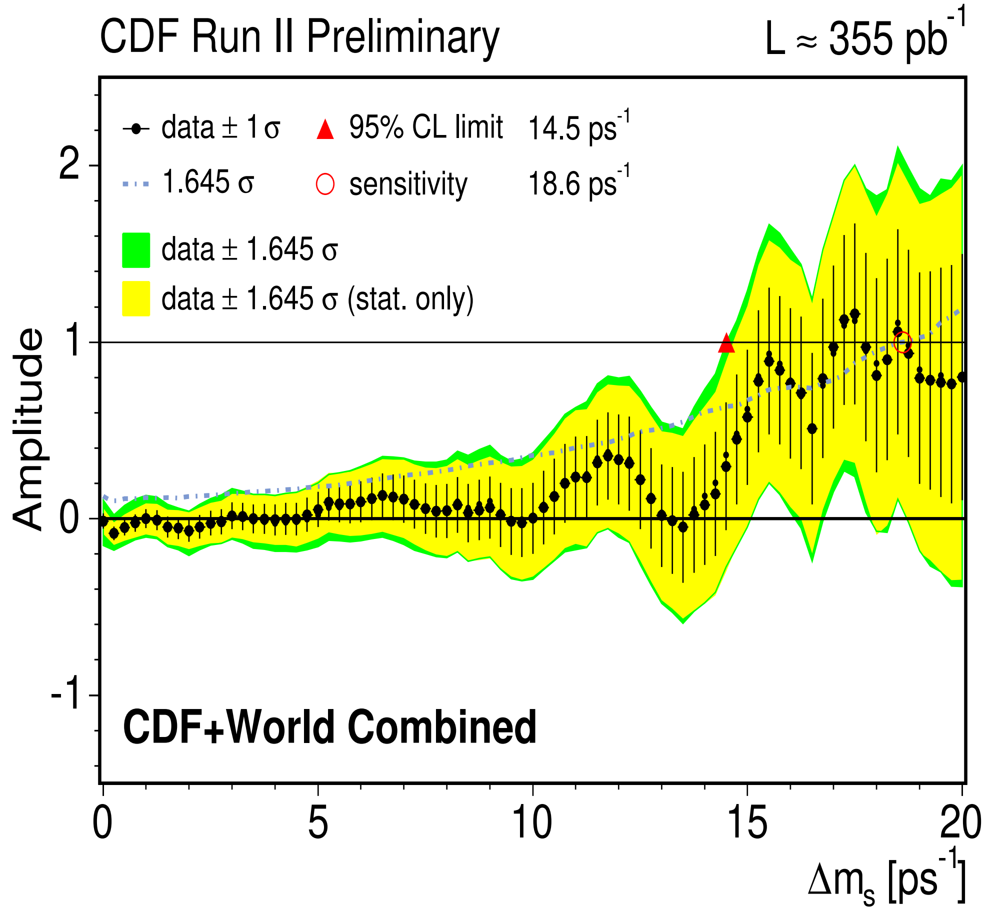


CDF+World Combined Result

- World Average (LEP, SLD, CDF run I)
  - Sensitivity: **18.2 ps^{-1}**
  - Limit: **14.5 ps^{-1}**

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





Future perspectives

With the same data:

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

With new data:

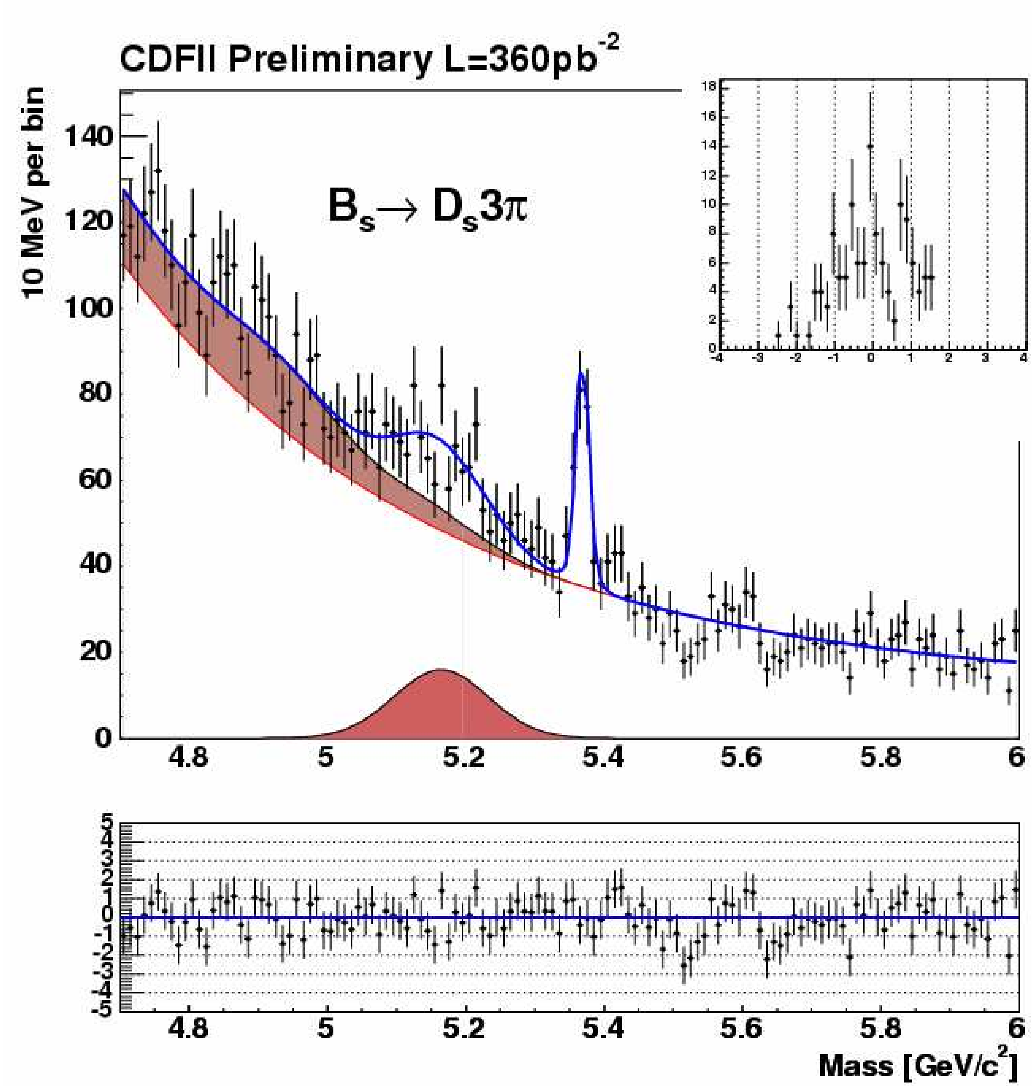
- Increased Luminosity
- Use new trigger strategies
  - 2 SVT Tracks + tagging muon at trigger level (already in place since summer 2004)

Other channels, example

CDF Roma

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

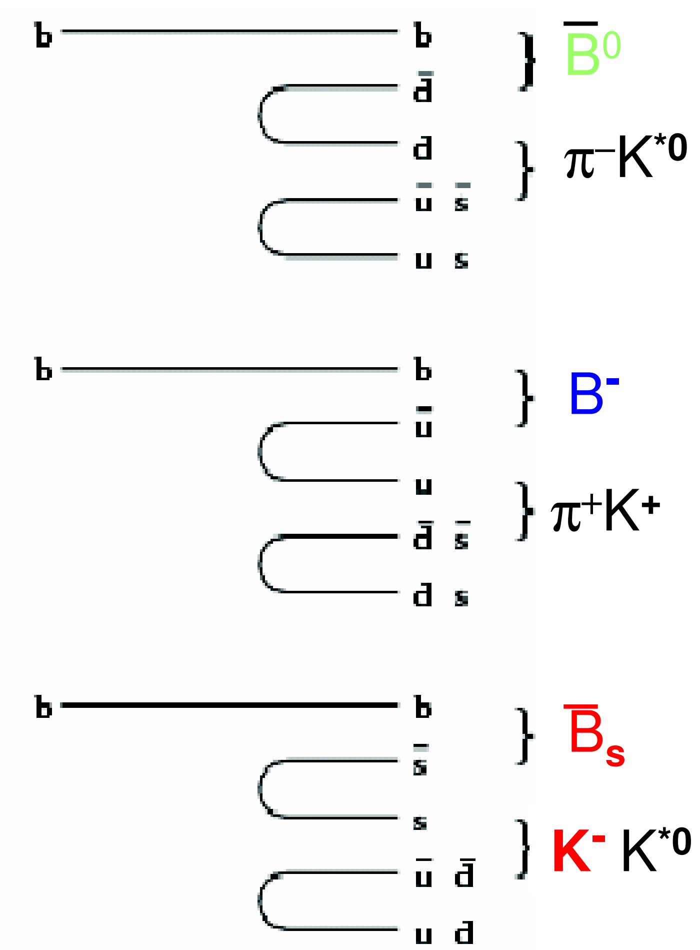
- 133±23 Bs candidates
- Already used for lifetime
- But not for mixing



Same Side Kaon Tagging

CDF Roma

Exploits the charge correlation between the b quark and the leading product of b hadronization.



Already used in Δm_d measurement, gives an $\varepsilon D^2 = 1.1 \pm 0.4$ %

B^+ case is complicated by the contribution of excited B_d and B_s states

SS Kaon tag possible with PID

"Simple case": so excited states expected

Issues:

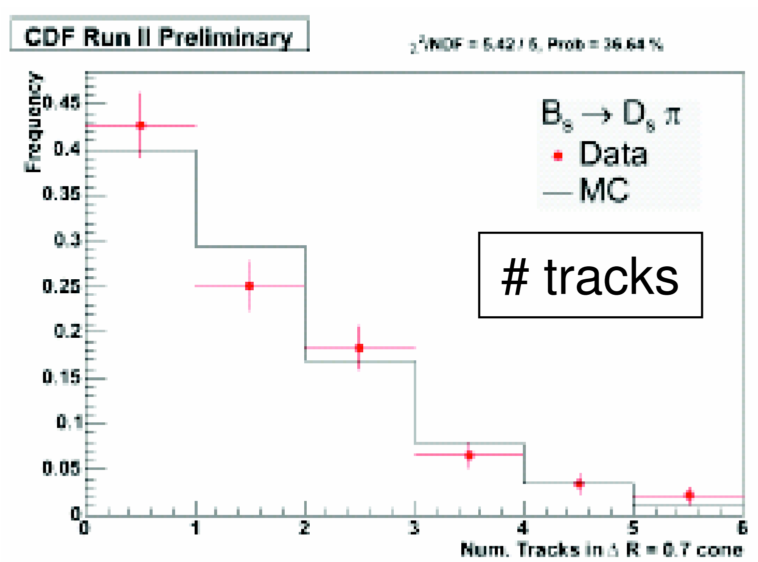
- Need to know εD^2 to set a limit on Δm_d
- Underlying event backgound

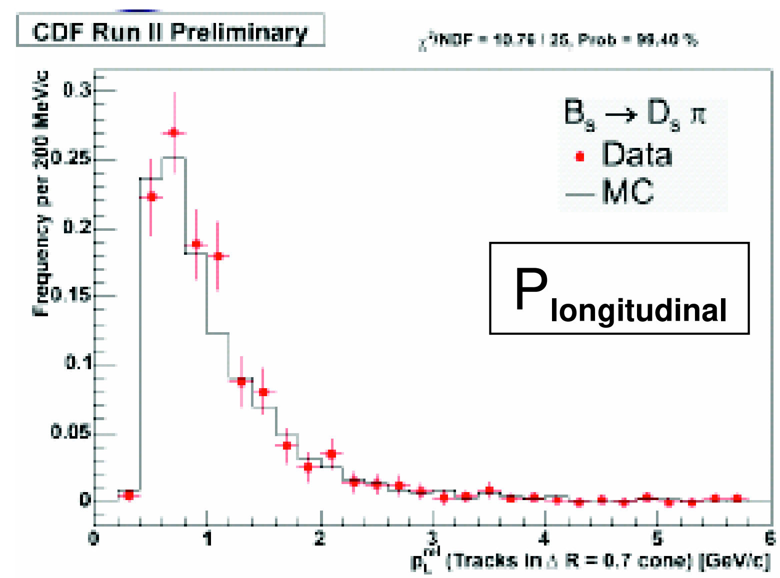
SSKT; is MC describing the data?

One possible way to solve the issue of having a prediction for the SSKT dilution is to extract it from MC.

→Compare DATA with Pythia $b\bar{b}$ production and hadronization with all the processes on, underlying event “tune A” from HF x sec. CDF data.

Look at the charged tracks in a cone of ΔR=0.7 around the B_s (no PID)





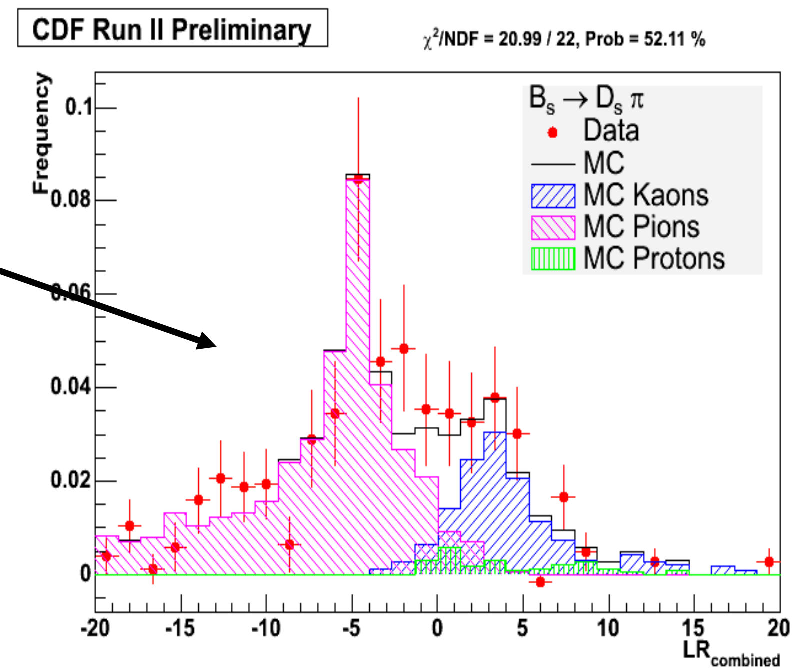
First order good agreement

CDF Roma

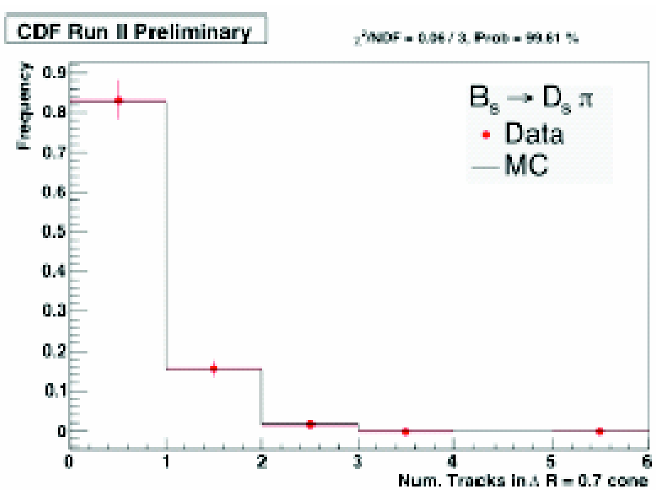
SSKT; MC-data comparison with PID

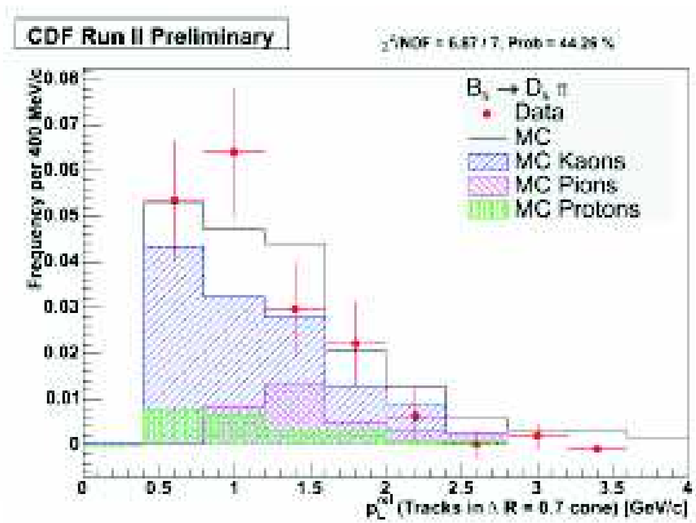
CDF Roma

Apply PID, **T.O.F.** and **dE/dx** combined
In a Likelihood approach **L(K)/L(π)**



- LR cut → candidate **tag Kaon**





Still good agreement

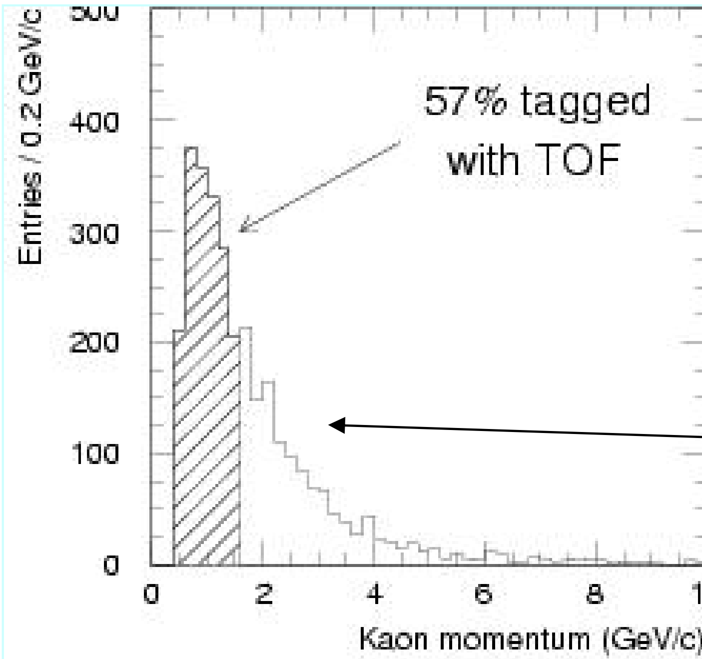
Issues:

- *Particle fractions in MC*
- *PID resolution tuning*
- *backgrounds*

expect $\varepsilon D^2 \sim 3\%$

Opposite Side Kaon Tagging

CDF Roma



Opposite side Kaon momentum spectra from B^0, B^+, B^s admixture MC

We can implement **OSKT** with the use of **TOF** and **dE/dx** PID .

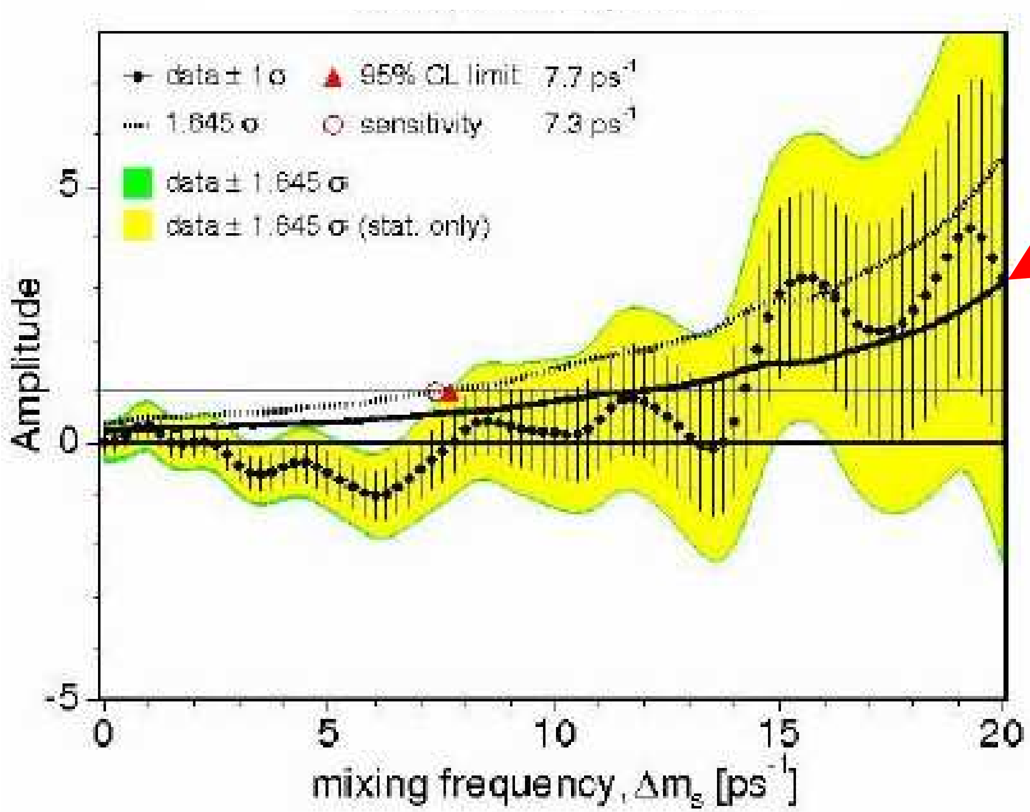
Issues:

- $N(B^0/B^+ \rightarrow K^+) / N(B^0/B^+ \rightarrow K^-) \approx 5$, not infinite, intrinsic Dilution.
- Only 20 40% chance for both B in the detector acceptance
- Tagging purity depends on TOF resolution.
- Tagging algorithm figure of merit εD^2 depends on TOF matching efficiency

Short term realistic scenario

Increase the actual effective statistics **x4** (i.e. increase **N**ε**D**² x**4**)

Semileptonic analysis

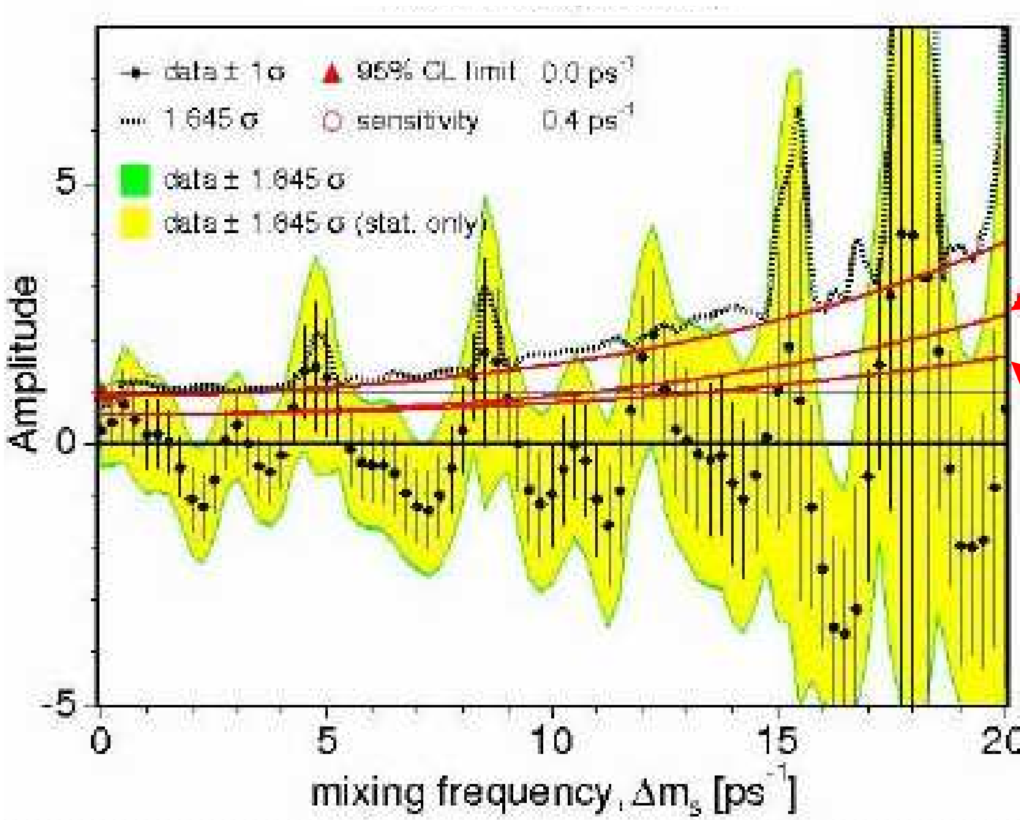


$\sigma_A \rightarrow \sigma_A/2$

Short term realistic scenario

Increase the actual effective statistics **x4** (i.e. increase **N**ε**D²** x**4**)

Hadronic analysis



x4 statistics

+ 20% better ct res.

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

BACKUP slides

Systematics Summary Table (Hadronic)

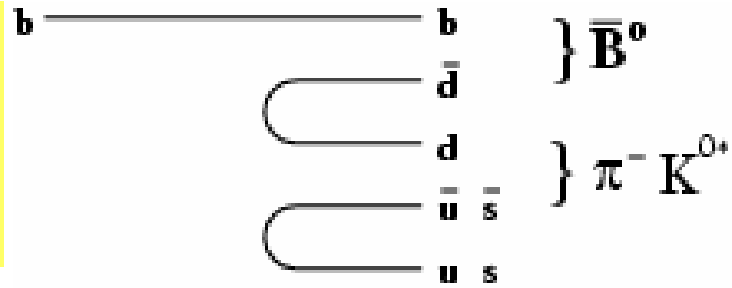
source	selected Δm_s scan points				
	0.0	5.0	10.0	15.0	20.0
$B_s \to D_s K$ level	0.019	0.024	0.030	0.037	0.047
dilution scale factors	0.143	0.168	0.205	0.254	0.314
dilution templates	0.119	0.147	0.178	0.211	0.246
fraction of Λ_b	0.014	0.009	0.009	0.011	0.012
Punzi term for σ_{ct}	0.009	0.008	0.022	0.033	0.030
dilution of $B \to DX$	0.025	0.001	0.000	0.000	0.001
σ_{ct} scale factor	0.000	0.024	0.061	0.090	0.144
usage of L00 in bias curve	0.001	0.001	0.001	0.001	0.001
Bs lifetime uncertainty	0.001	0.001	0.001	0.001	0.001
reweighted p_t spectrum	0.001	0.001	0.001	0.001	0.001
non-Gaussian tails in ct resol.	0.001	0.027	0.052	0.078	0.104
neglect B^0 in fit	0.039	0.036	0.033	0.031	0.028
effect of $\Delta\Gamma/\Gamma = 0.2$	0.028	0.028	0.028	0.028	0.028
Total systematic	0.195	0.232	0.289	0.357	0.443
Statistical	0.393	1.129	1.010	2.652	5.281

Systematics Summary Table (Semileptonic)

Source	selectex Δm_s scan points				
	0.0	5.0	10.0	5.0	20.0
Prompt background fraction	0.044	0.065	0.102	0.145	0.143
Prompt background dilution	0.014	0.040	0.027	0.062	0.157
Prompt background shape	0.015	0.010	0.019	0.054	0.057
Physics background fraction	0.134	0.078	0.093	0.096	0.103
Sample composition	0.002	0.015	0.022	0.021	0.039
Dilution scale factors	0.061	0.071	0.068	0.070	0.069
σ_{ct^*} scale factor	0.002	0.012	0.033	0.047	0.065
SVT bias curve	0.002	0.001	0.005	0.005	0.012
Primary vertex	0.007	0.003	0.003	0.005	0.007
B_s lifetime	0.001	0.011	0.014	0.020	0.026
non-Gaussian tails in ct resol.	0.005	0.047	0.049	0.052	0.078
effect of $\Delta\Gamma/\Gamma$=0.2	0.012	0.005	0.005	0.005	0.009
Total Systematics	0.156	0.142	0.167	0.220	0.273
Statistical	0.159	0.406	0.856	1.654	3.364

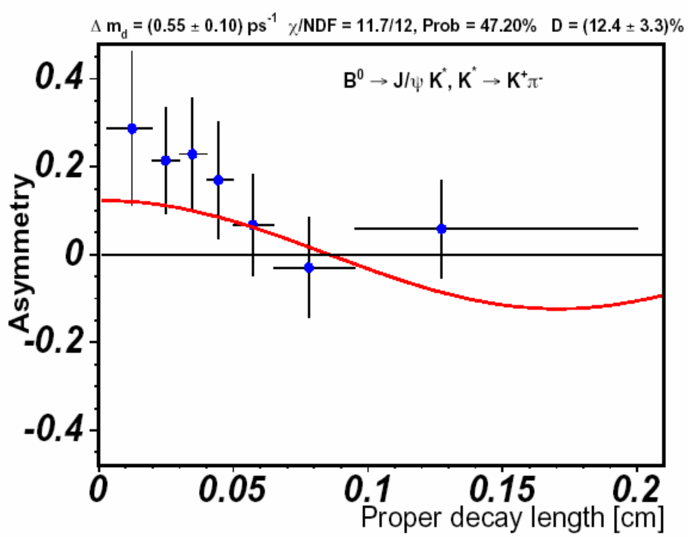
B_d mixing with Same Side π tagging

Based on correlation between <u>charge</u> of <u>fragmentation π</u> and <u>flavor</u> of b in B meson

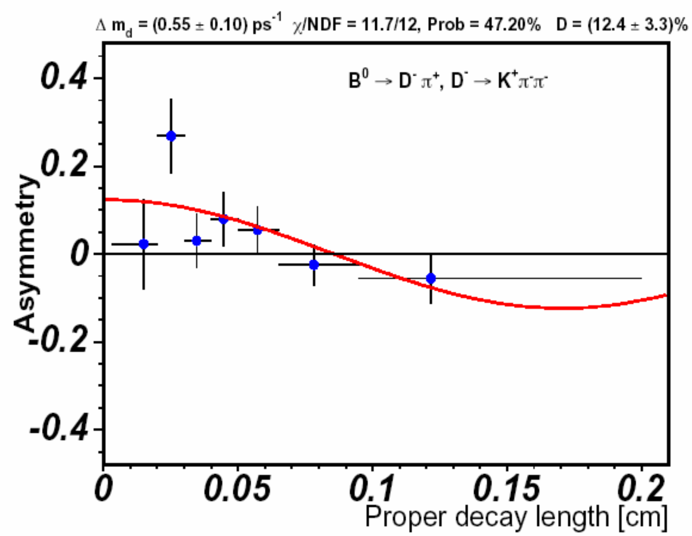


Run II PRELIMINARY 2004

$B^0 \to J/\psi K^{*0}$



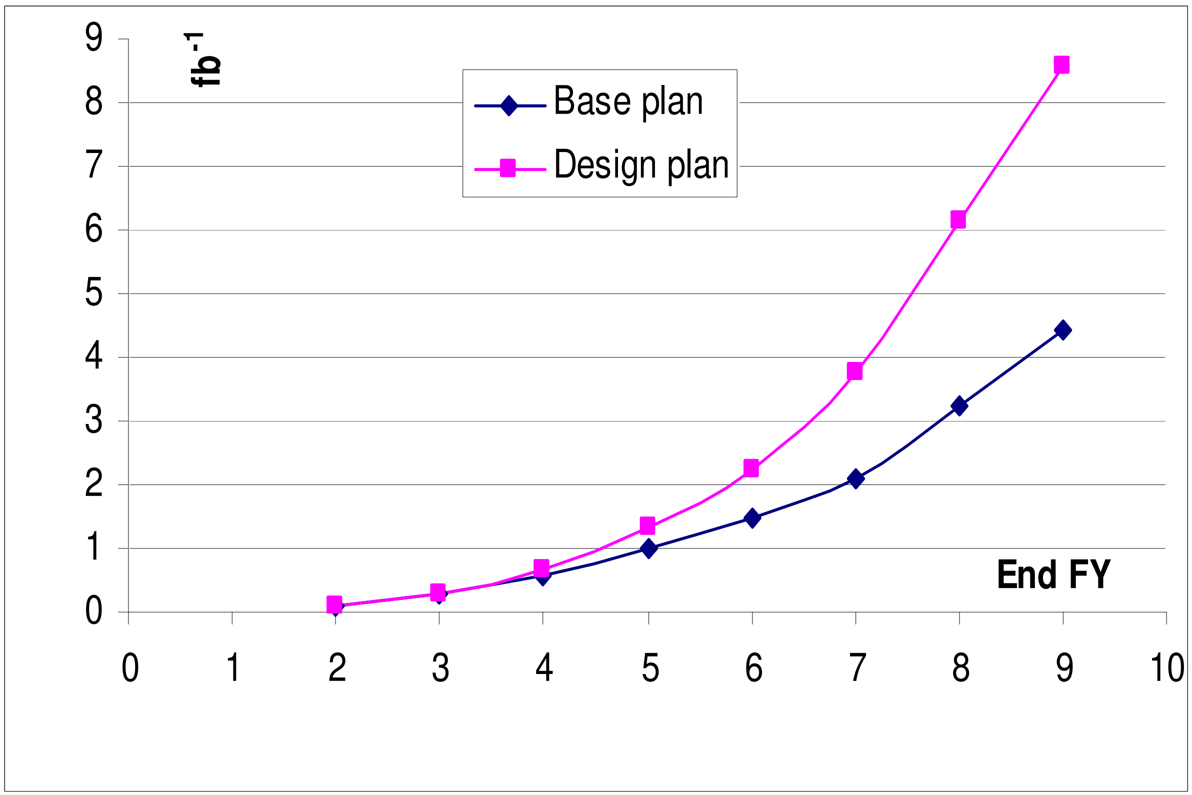
$B^0 \to D^-\pi^+$



Δm_d (ps^{-1})	D_0 (%)	ϵD_0^2 (%)
0.55 ± 0.10	12.4 ± 3.3	1.0 ± 0.5

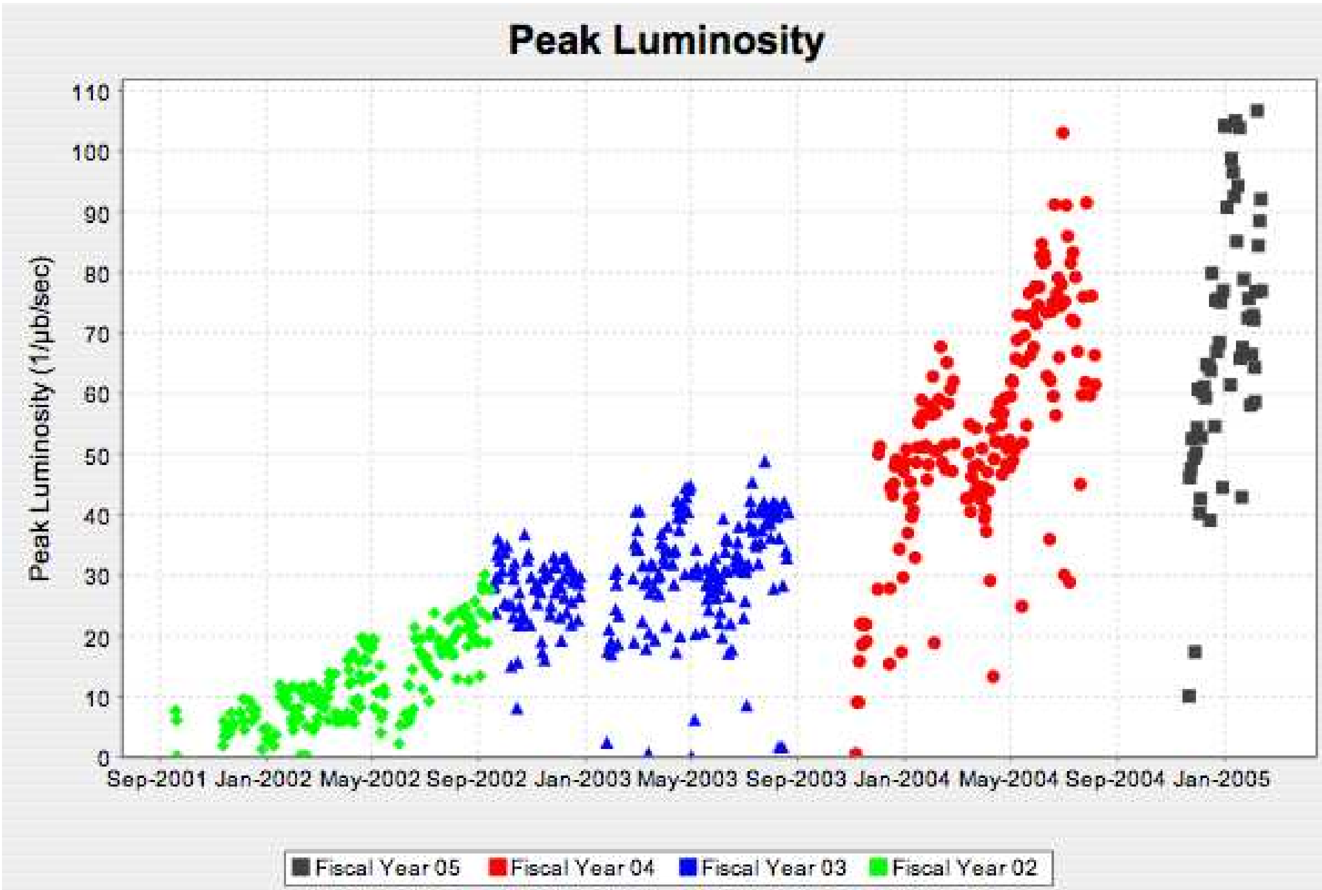
Tevatron plans

- RECYCLER had a first successful test
- Plans beyond FY 05 depends on Recycler ring and electron cooling performances

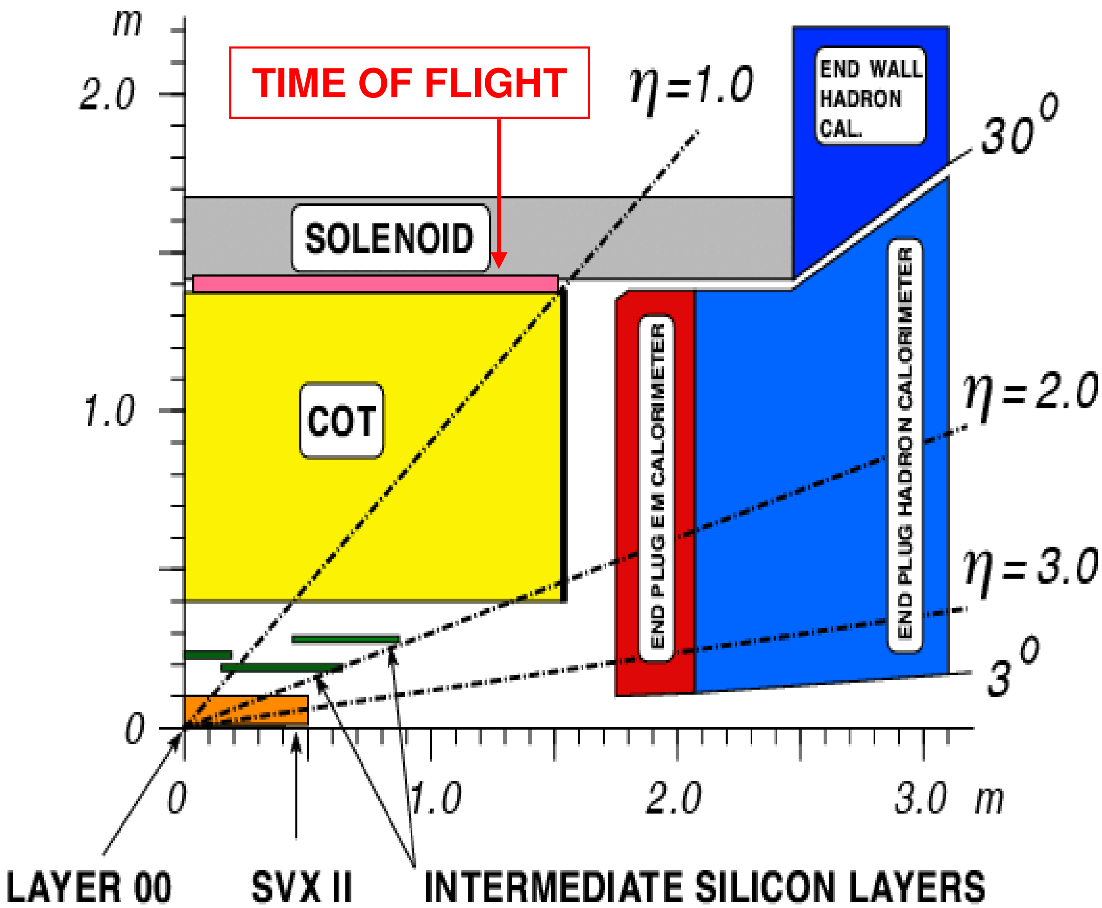


Year	Base plan luminosity/yr (fb^{-1})	Design plan Luminosity/yr (fb^{-1})
FY02	0.08	0.08
FY03	0.20	0.22
FY04	0.31	0.38
FY05	0.39	0.67
FY06	0.50	0.89
FY07	0.63	1.53
FY08	1.14	2.37
FY09	1.16	2.42
Total	4.41	8.56

Tevatron performances



CDF II tracking system



TOF: 100ps resolution, 2 sigma K/π separation for tracks below 1.6 GeV/c

COT: large radius (1.4 m) **Drift chamber**

- 96 layers, ~100ns drift time
- Precise P_T above 400 MeV/c
- Precise 3D tracking in $|\eta|<1$

$\sigma(1/P_T)$ ~ 0.1%GeV $^{-1}$; σ(hit)~150μm

- dE/dx info provides ~1.4σ K/π separation above 2 GeV

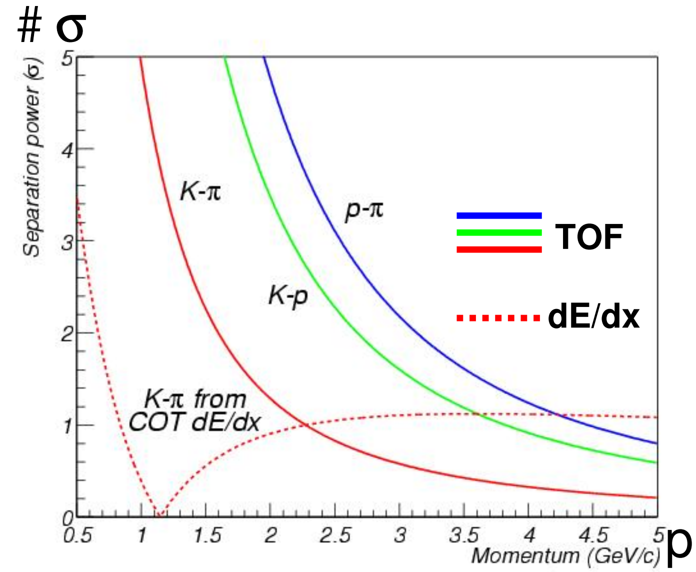
SVX II + ISL: 6 (7) layers of double-side silicon (3cm < R < 30cm)
- Standalone 3D tracking up to $|\eta|$= 2
- Very good I.P. resolution: ~30μm

LAYER 00: 1 layer of radiation-hard silicon at very small radius (1.5 cm)

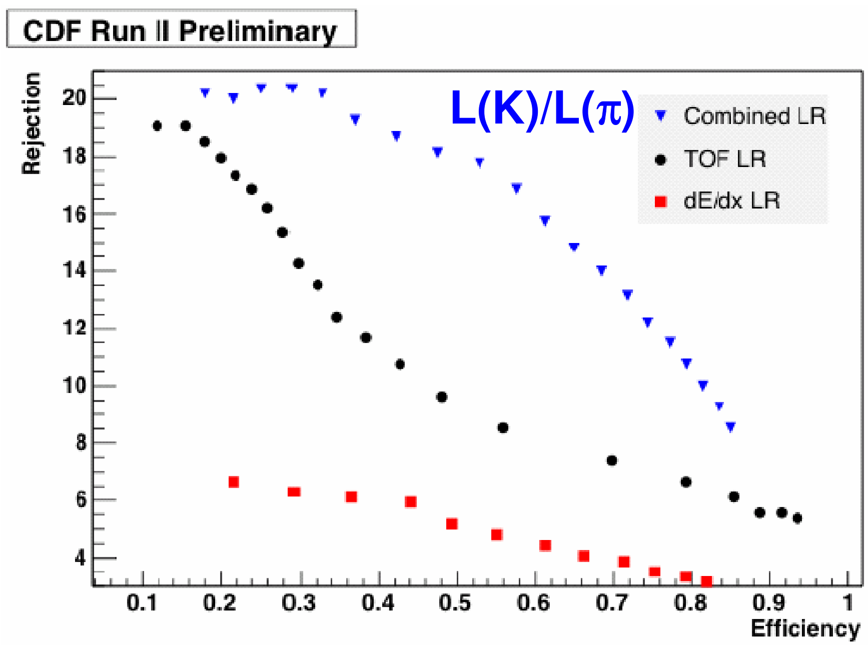
CDF Particle IDentification

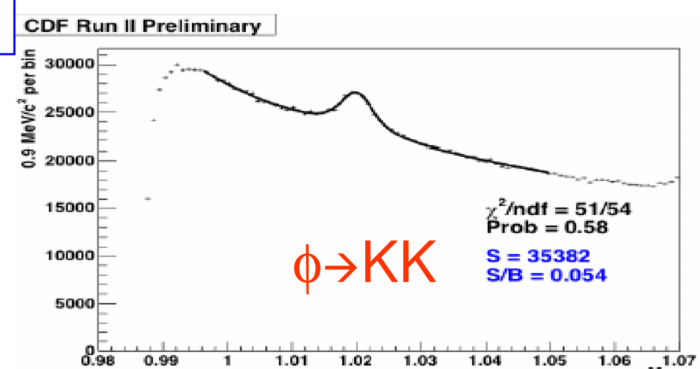
CDF Roma

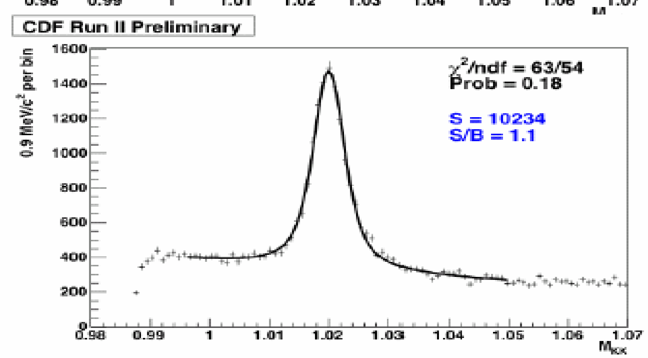
- Specific Ionization of charged particles (**dE/dx**) measurement in the COT gas chamber.
- Time of flight measurement with the new scintillator bars detector (**TOF**) at R=1.4m with a σ_{TOF} = 100 ps



dE/dx & T.O.F. combined performances





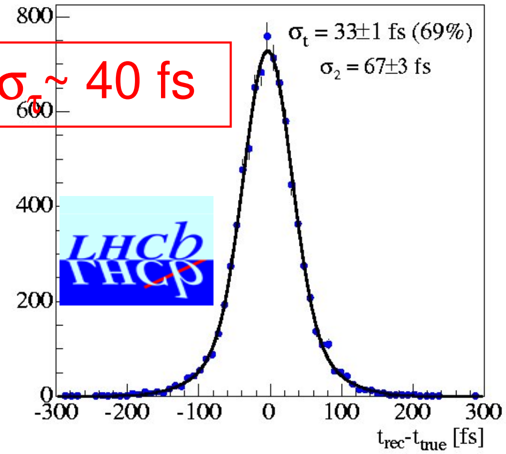


B^0_s-$\overline{B^0}_s$ mixing @ LHC

$B_s^0 \to D_s^- \pi^+$ ($D_s^- \to \phi\pi^-$, $\phi \to K^+K^-$)

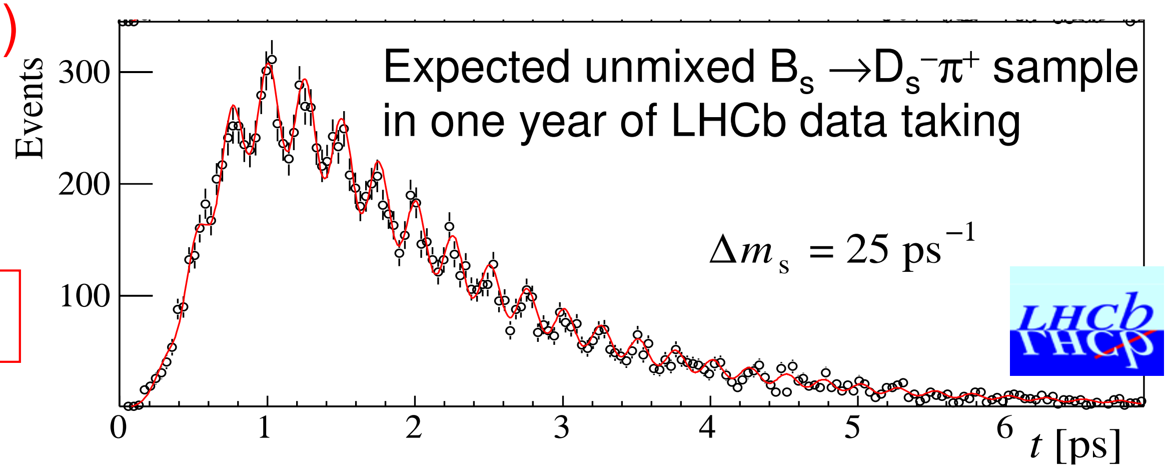
LHCb: 80k events/yr   B/S=0.32

σ_τ ~ 40 fs



proper time resolution (fs)

εD^2 ~ 6%



5σ observation of B^0_s–$\overline{B^0}_s$ oscillation up to Δm_s=68 ps^{-1} 1 yr

Once observed, precision to measure Δm_s is ~0.01 ps^{-1}

ATLAS/CMS   Events triggered by m from opposite b decay. Performance strongly dependent on the allocated bandwidth.

ATLAS: (LVL1 p_T^m > 6 GeV/c) in 10 fb^{-1} expect. sensitivity up to Dm_s=36 ps^{-1}

CMS: (restricting to 5 Hz at HLT) in 20 fb^{-1} expect. sensitivity up to Dm_s=20 ps^{-1}