B Physics @ CDF:
Mixing and Lifetimes

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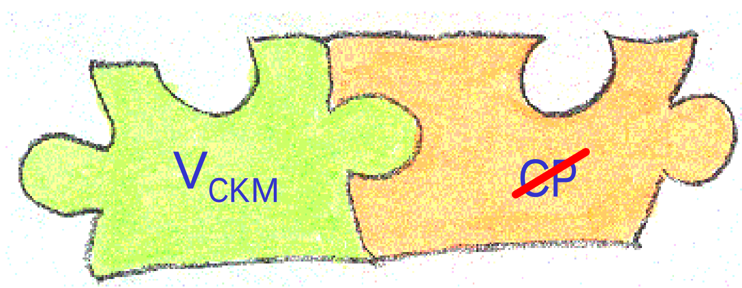

Plan

- Introduction:
  - B physics @ CDF
  - Tools
- Lifetimes
  - Exclusive
  - Inclusive
- Bs Mixing perspectives
  - Ingredients:
    - Time resolution
    - Flavour Tagging
    - Signal & Background
  - $\Delta\Gamma/\Gamma$
  - Where do we stand?

DISCLAIMER: this talk contains strictly CDF restricted materia. If you are not from CDF, close your ears, shut your eyes and vanish from the room.

Prologue

- Will focus mostly on perspectives!
- CDF2 Started...
- TeVatron performance is not thrilling
  - Not disastrous either
  - Do we care?
- Detector works flawlessy... ehm...
- You've heard the details too many times!
- SVT ad nauseam...
- Why don't we have yet a B_s mixing measurement?

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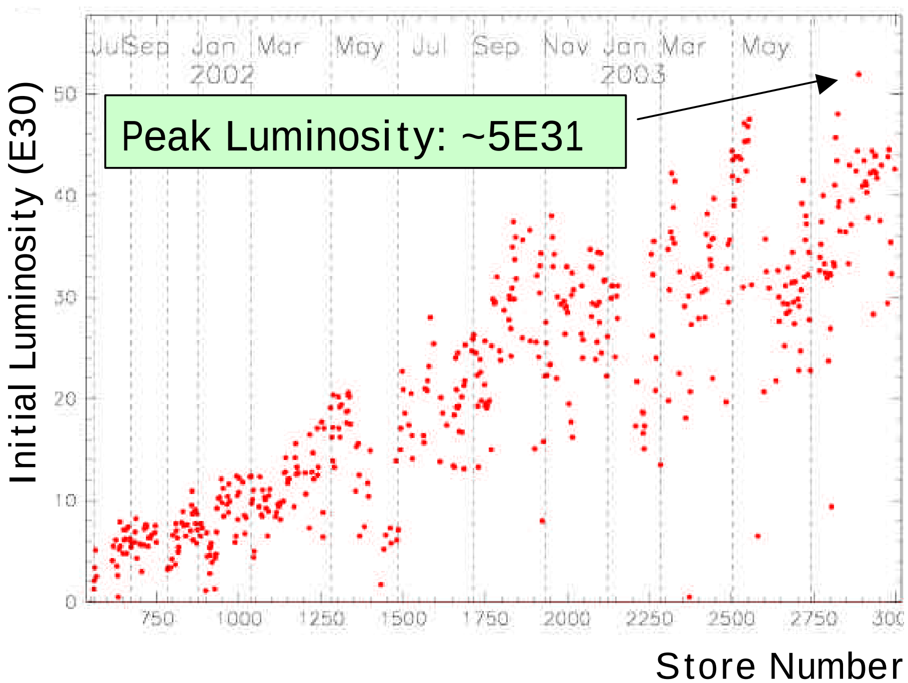
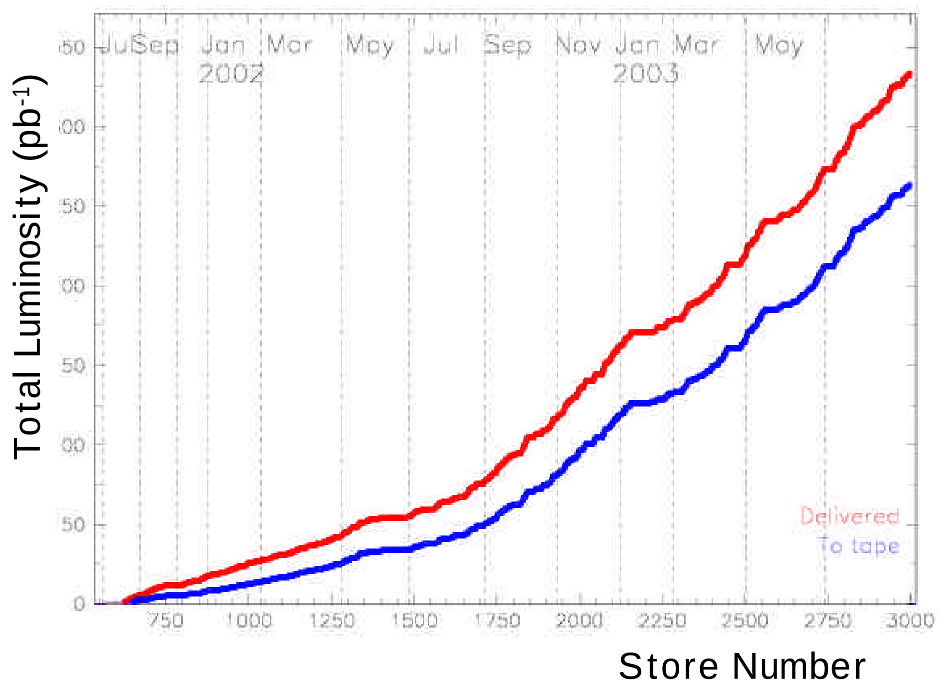
TeVatron Performance





This is still 2x below nominal !!!

We are currently using about $170pb^{-1}$ for analyses !!!

B physics?

Production Rates:

- B^+: 3.6±0.6 μb
- D^+: 4.3±0.7 μb
- D^0: 9.3±1.1 μb

} ... and BTW this is a Run II result!

x1000 more B physics than at Υ(4s)

All sort of b-flavored stuff: B_u, B_d, B_c, B_s, Λ_b...

Problems are x10000 worse:

σ(all)~100 mb

The trigger is THE essential tool !!!

B physics topics @ CDF

- Production
  - Cross section
  - Polarization
- Lifetimes
  - B_d, B^+, B_s, Λ_b
    - Inclusive, Exclusive
- Mixing
  - B_d
  - B_s

- CP violation
  - Asymmetries
    - Tag based
    - Self tagging
  - BR based methods
- Rare decays
  - B_d
  - B_s

B Production

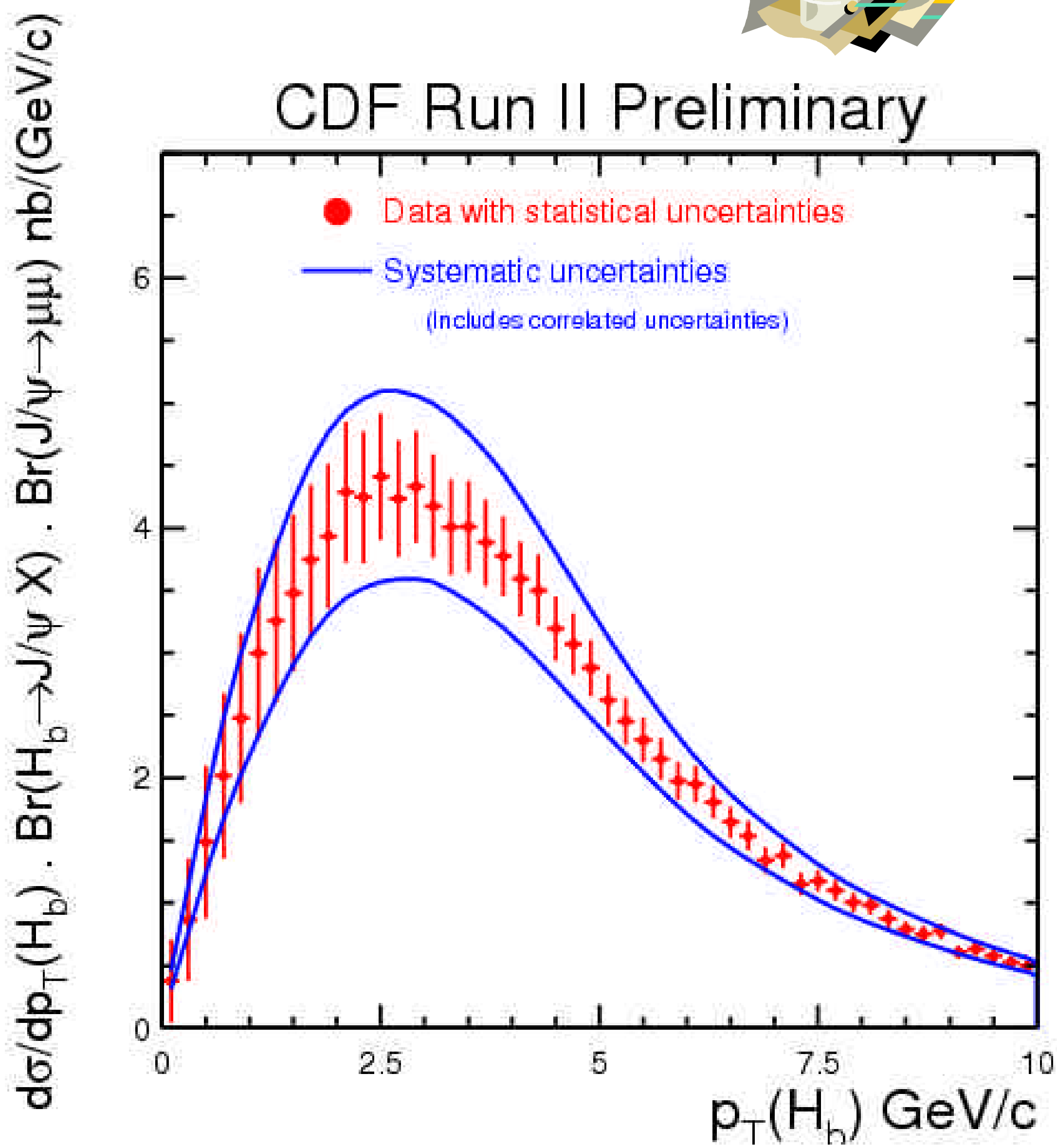
We can get to P_t lower than in Run I!

Example:

$$b \rightarrow J / y X$$

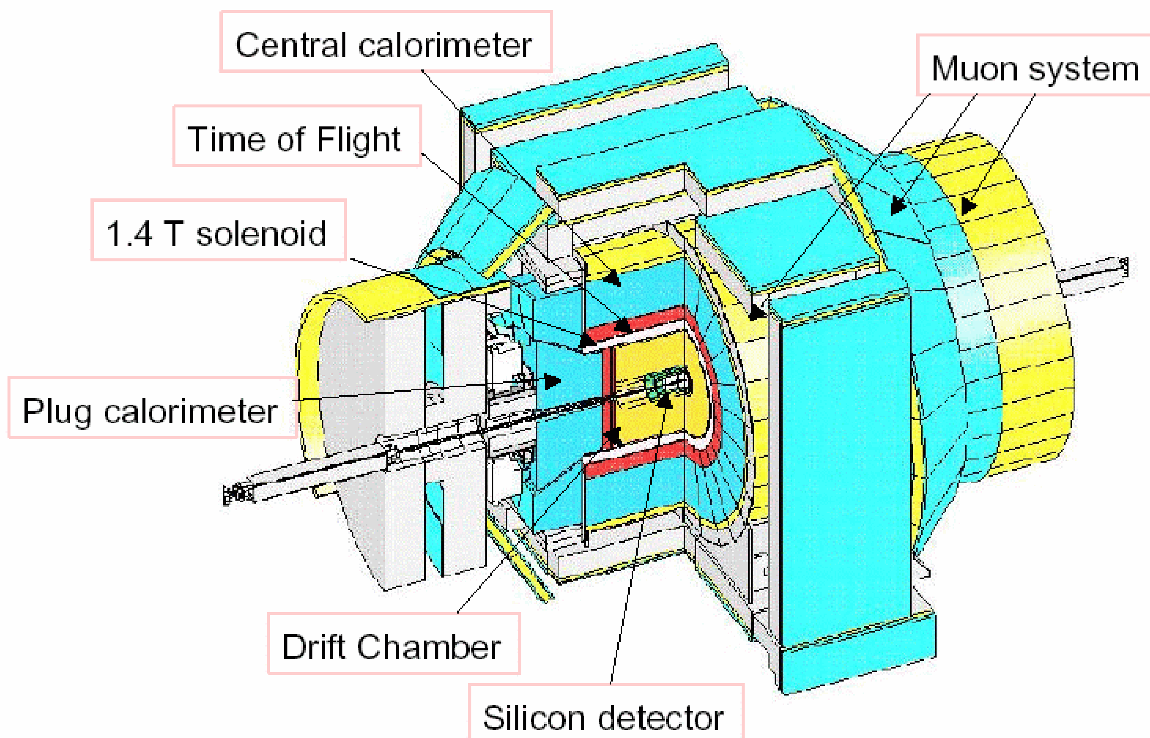
How is this possible?

- Detector
- ...

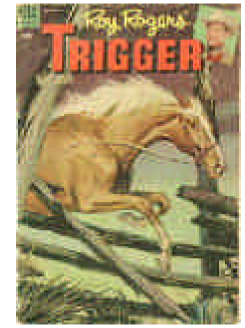


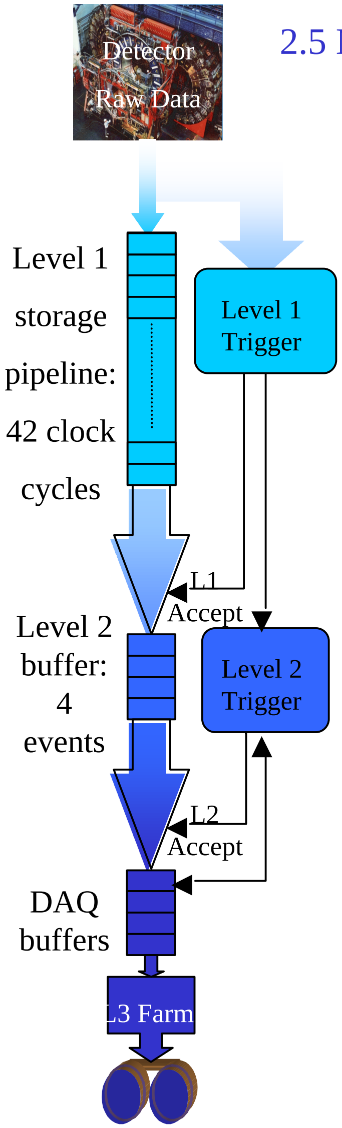
Tools...

- Tracking
  - Central Outer Tracker
  - Silicon VerteX detector
- Particle ID
  - Electromagnetic (CEM/CES/CPR)
  - Muon Detectors (CMU/CMP)
  - Time Of Flight



...and the trigger, of course!





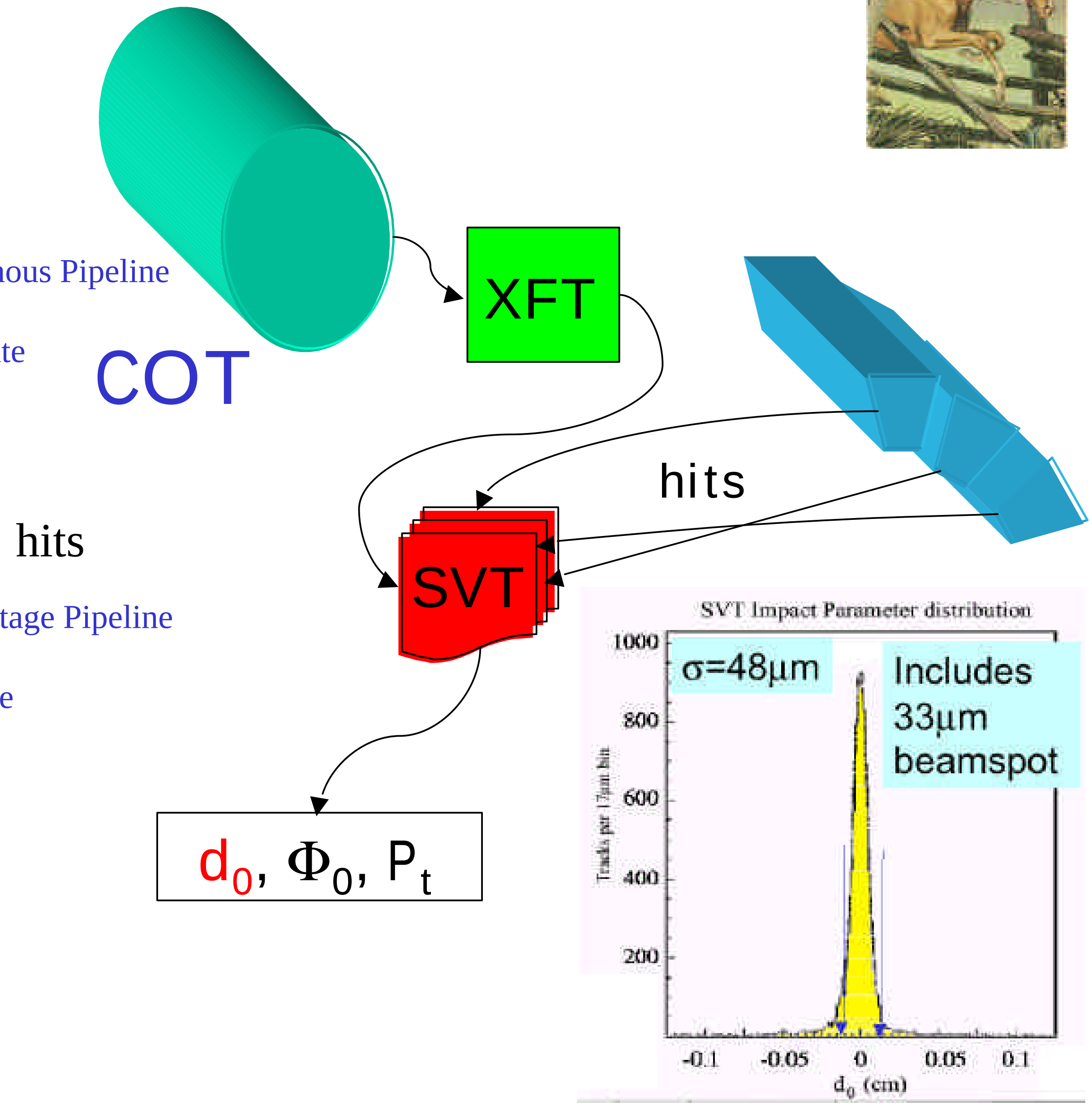
Mass Storage (~50 Hz)

2.5 MHz Crossing rate

396 ns clock

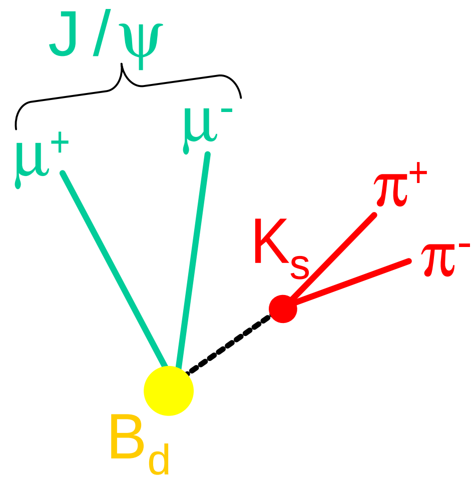
Level 1
- 7.6 MHz Synchronous Pipeline
- 5544 ns Latency
- ~16 KHz accept rate

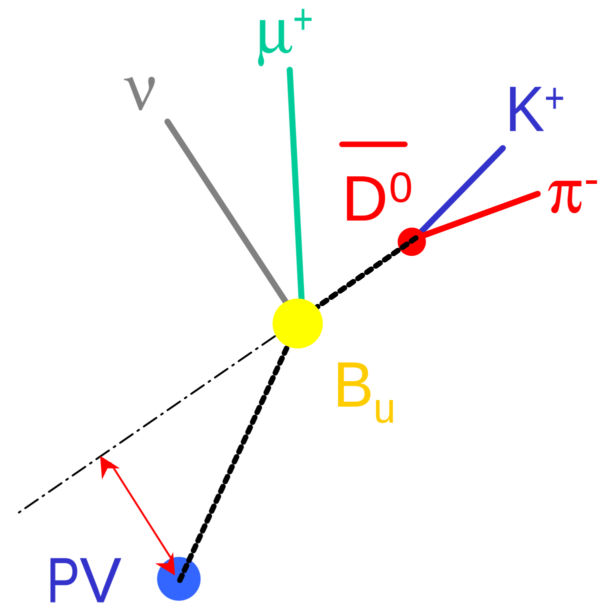
Level 2
- Asynchronous 2 Stage Pipeline
- 40 µs Latency
- ~250 Hz accept rate

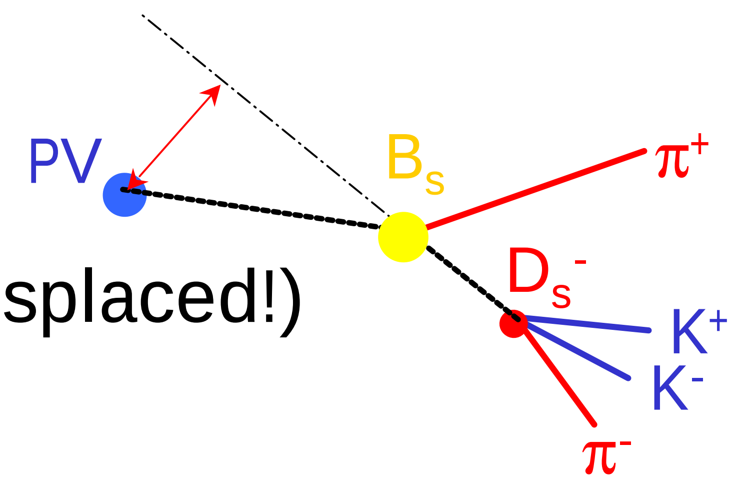


What's on the menu?

- Leptons
  - μμ
  - ee?
- ½ Leptons
  - e, μ + "displaced" track
  - 8 GeV?
    - Thanks, but no Thanks…
    - Er… maybe… if you insist
- Hadrons
  - Track and… track! (both displaced!)
  - Are all the decays equal?







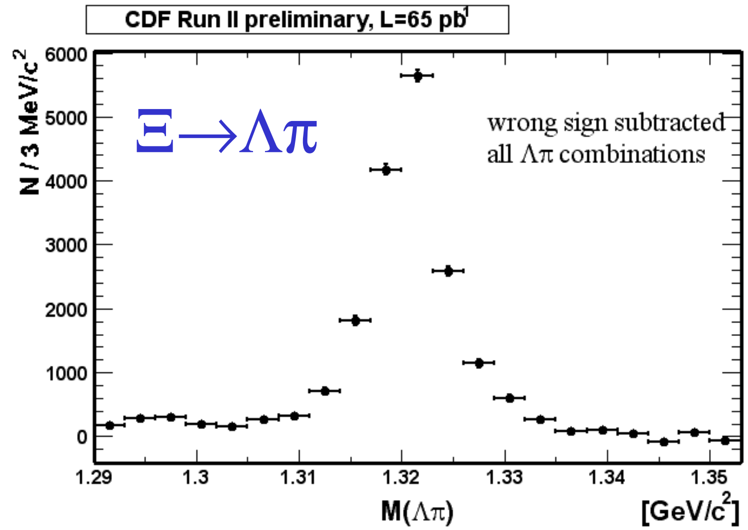
The Baryons...

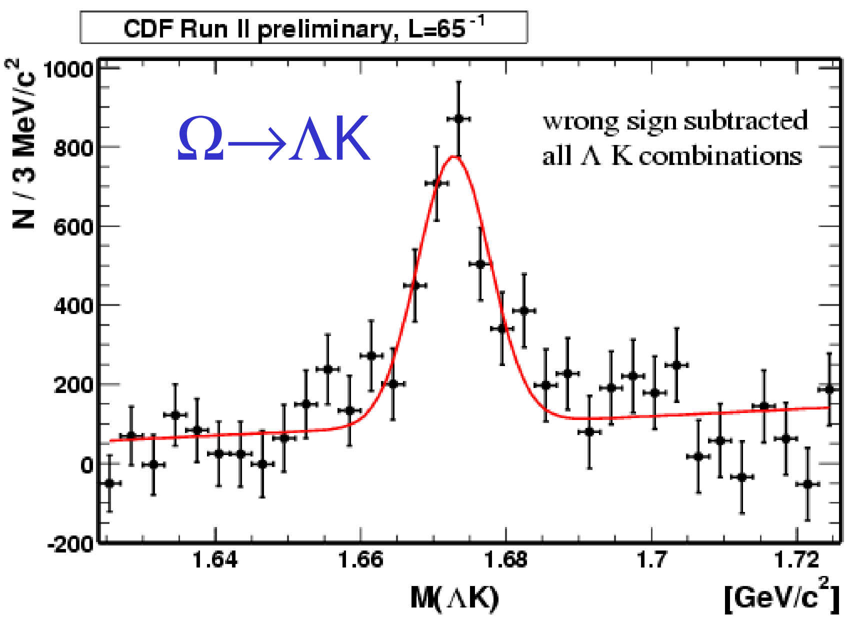
First glance:

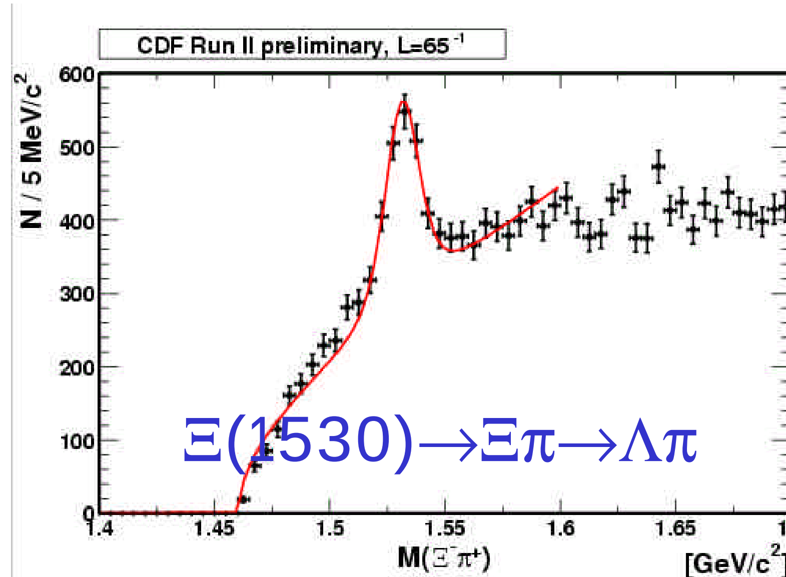
≈15350 $\Xi \to \Lambda\pi$

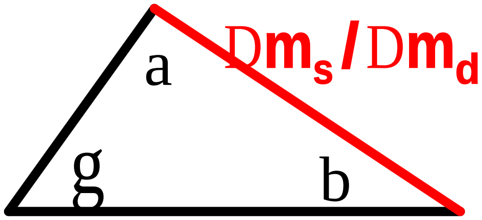
≈3353 $\Omega \to \Lambda K$

≈1325 $\Xi(1530) \to \Xi\pi \to \Lambda\pi$





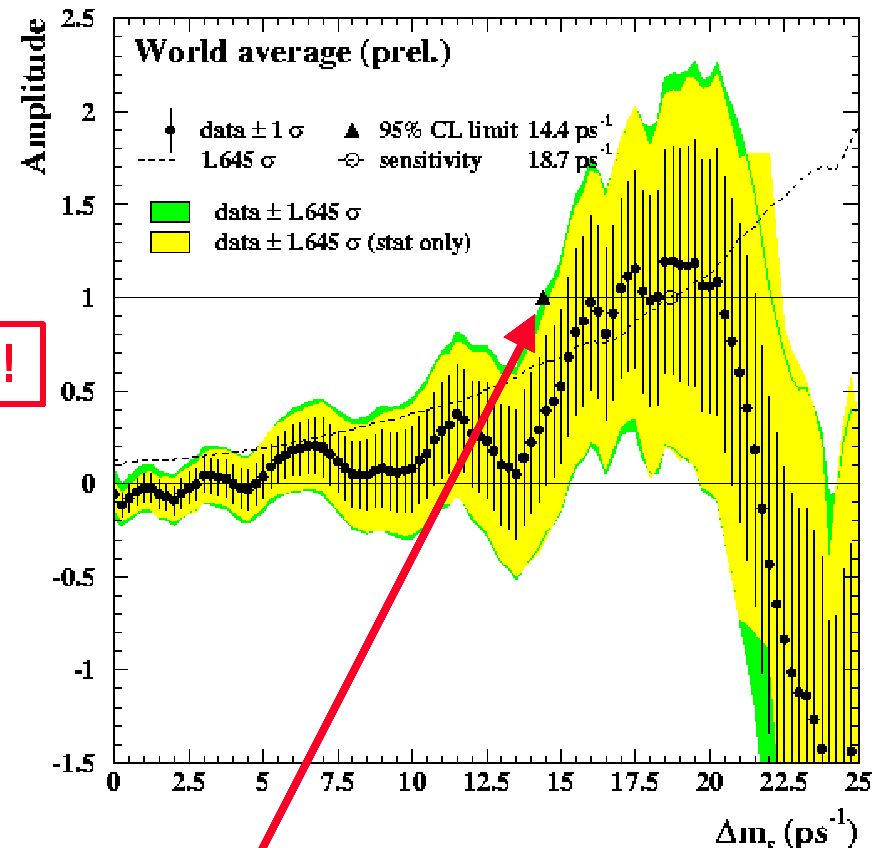




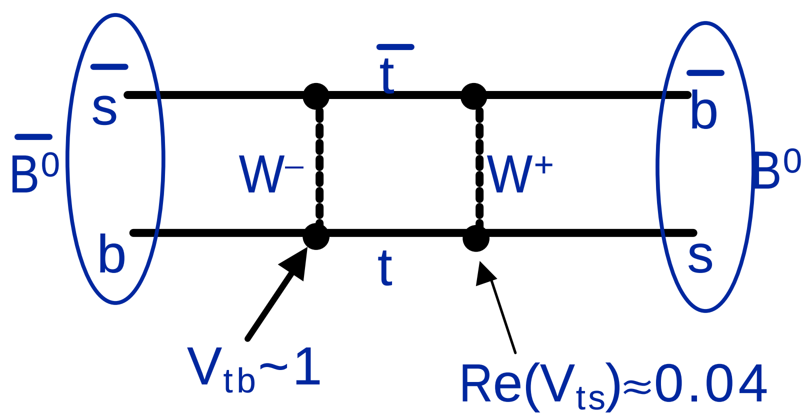
Towards B_s Mixing

- **Measurement of *Dm*$_s$ helps improve our knowledge of CKM triangle.**
- Combined world limit on B_s mixing
  - $\Delta m_s > 14.4 ps^{-1}$ @95%CL
  - **B_s fully mixes in <0.15 lifetime!!!**
- B_s oscillation much faster than B_d because of coupling to top quark:

$Re(V_{ts}) \approx 0.040 > Re(V_{td}) \approx 0.007$



Combined limit comes from 13 measurements from LEP, SLD & CDF Run I



Mixing 101

Proper time resolution

Flavor tagging

Signal-to-noise

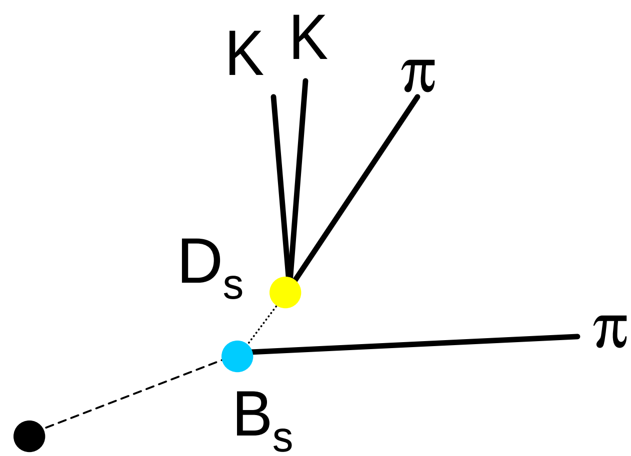
Event yield

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

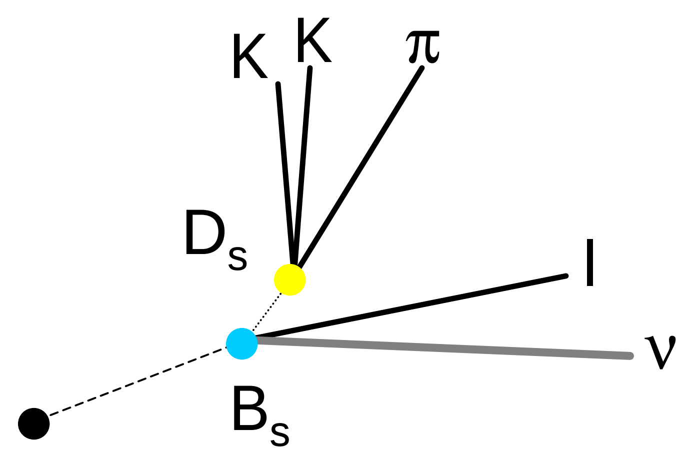
- Significance (in number of standard deviations) is “average significance”

Strategies

$B_s \to \pi D_s$



$B_s \to l \nu_l D_s$



$$ct = \frac{L_{xy}}{(bg)} = \frac{L_{xy} m_B}{p_T}$$

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

~0.5%

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

~15%

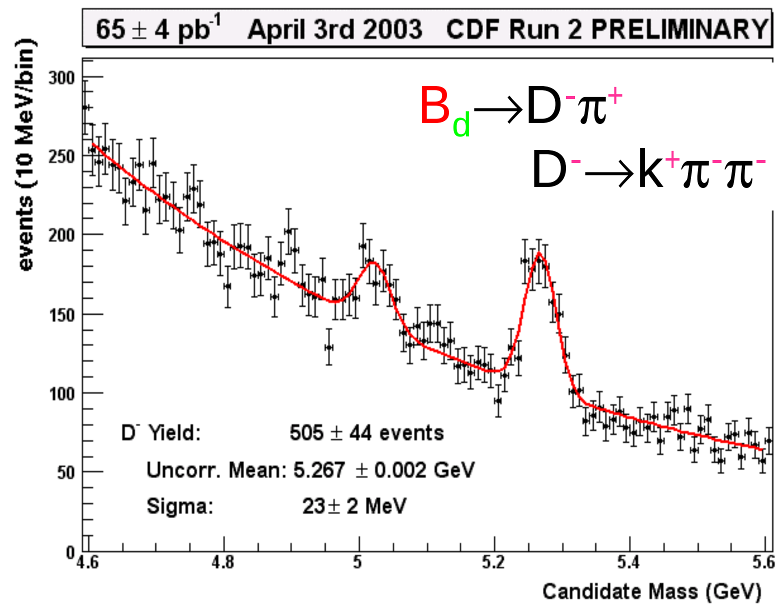
$$s_{ct} = \frac{m_B}{P_t} s_{L_{xy}} \otimes ct\left(\frac{s_{P_t}}{P_t}\right) \otimes s_K$$

Event Collection

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

f_s, f_d and the Branching Fractions...

- Understand relative efficiency:
  - –Trigger biases
  - –Detector effects (e.g. coverage)
- fs/fd shows a well known discrepancy between CDF and LEP



$$\frac{N(B_s)}{N(B_d)} = \frac{f_s}{f_d}\,\frac{\varepsilon_s}{\varepsilon_d}\,\frac{Br(B_s \to D_s^- \pi^+)\,Br(D_s^- \to \varphi\pi^-)\,Br(\varphi \to k^+k^-)}{Br(B_d \to D^-\pi^+)\,Br(D^- \to k^+\pi^-\pi^-)}$$

$\varepsilon_s/\varepsilon_d$ → Monte Carlo

$Br(D_s^- \to \varphi\pi^-)\,Br(\varphi \to k^+k^-)$, $Br(D^- \to k^+\pi^-\pi^-)$ → PDG

f_s / f_d, cont'd…

Need a robust and accurate model of the trigger and detector effects, something CDF never had in Run I:

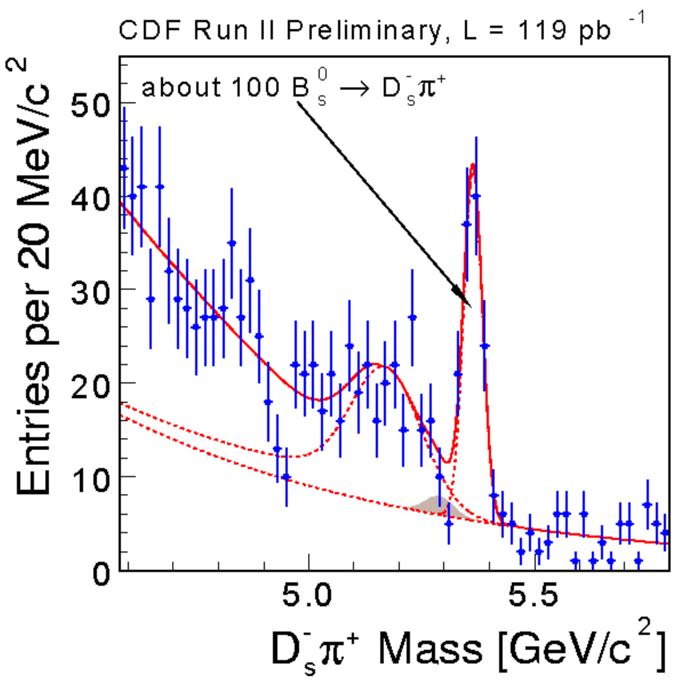
•Run by run emulation of the configuration

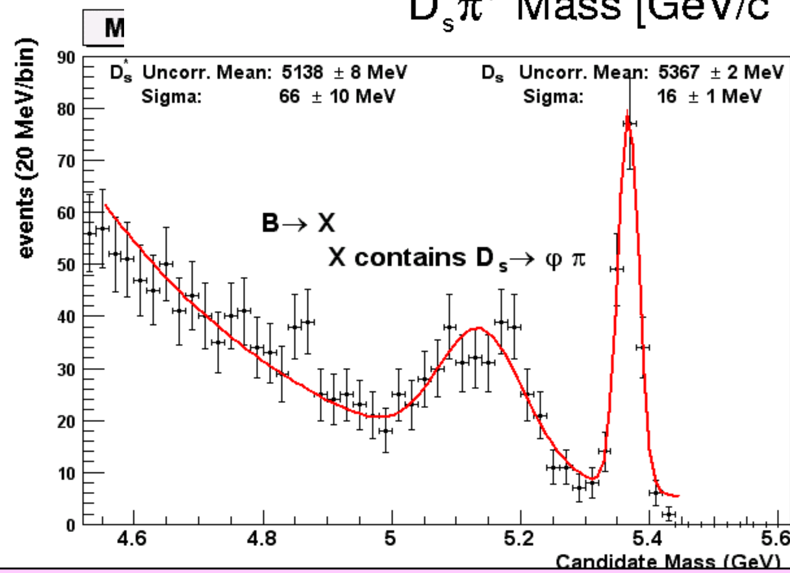
•As realistic as possible (geometry, material etc.)

New measurement !

Previous limit set by OPAL:

BR ($B_s \rightarrow D_s\, p^{\pm}$) < 13%



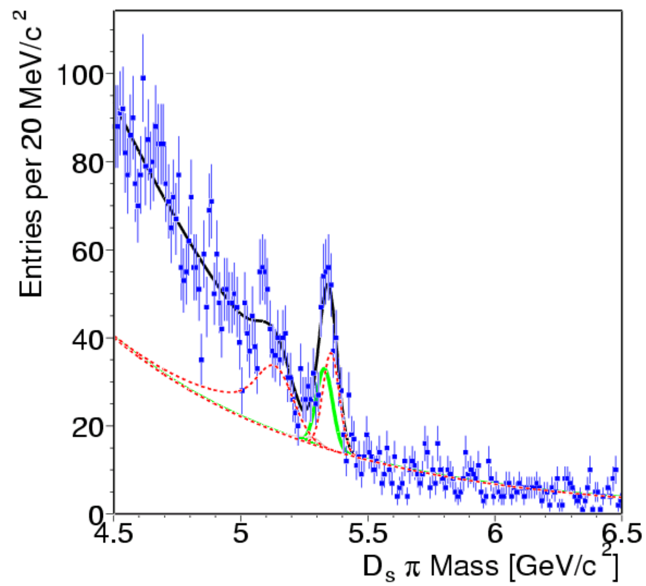


$$\frac{f_s}{f_d}\;\frac{Br(B_s \rightarrow D_s^- \pi^+)}{Br(B_d \rightarrow D^- \pi^+)} = 0.48 \pm 0.12(\text{stat.}) \pm 0.18(\text{Br.}) \pm 0.08(\text{sys}) \pm 0.06(f_s/f_d)$$

Other modes?

$D_s \to K^*K$ is only the tip of the iceberg:

We can (must!) investigate other B_s decay modes!!!



1. $B_s \to \pi^+ D_s^- [\to \pi^- \phi [\to K^+ K^-]]$
($\bar{b} \to \bar{c} u \bar{d}$ decay)

$$\mathcal{B}(B_s \to D_s^- \pi^+) = 4 \cdot 10^{-3}, \quad \mathcal{B}(D_s^- \to \phi\pi^-) = 3.6 \cdot 10^{-2}$$
$$\mathcal{B}(\phi \to K^+K^-) = 0.5$$
$$\Rightarrow \quad \mathcal{B}(B_s \to D_s^- \pi^+)\,\mathcal{B}(D_s^- \to \phi\pi^-)\,\mathcal{B}(\phi \to K^+K^-) = 7 \cdot 10^{-5}$$

2a. $B_s \to J/\psi K^- \pi^+$
($\bar{b} \to \bar{c} c \bar{d}$ decay)

$$\mathcal{B}(B_s \to J/\psi K^- \pi^+) = 6 \cdot 10^{-5}$$

More than half is from $B_s \to J/\psi \overline{K}^{*0} [\to K^- \pi^+]$.
Further $\mathcal{B}(J/\psi \to \ell^+ \ell^-) = 12\%$.

2b. $B_s \to J/\psi K^{*-} \pi^+$

$$\mathcal{B}(B_s \to J/\psi K^{*-}\pi^+) = 4 \cdot 10^{-5}, \quad \mathcal{B}(K^{*-} \to \pi^- K_S [\to \pi^+\pi^-]) = 0.33$$
$$\Rightarrow \quad \mathcal{B}(B_s \to J/\psi K^{*-}\pi^+)\,\mathcal{B}(K^{*-} \to \pi^- K_S) = 1.3 \cdot 10^{-6}$$

3a. $B_s \to \psi(2S) K^- \pi^+$
($\bar{b} \to \bar{c} c \bar{d}$ decay)

$$\mathcal{B}(B_s \to \psi(2S) K^- \pi^+) = 4 \cdot 10^{-5}, \quad \mathcal{B}(\psi(2S) \to J/\psi \pi^+\pi^-) = 0.3$$
$$\Rightarrow \quad \mathcal{B}(B_s \to \psi(2S) K^-\pi^+)\,\mathcal{B}(\psi(2S) \to J/\psi\pi^+\pi^-) = 10^{-5}$$

3b. $B_s \to \psi(2S) K^{*-} \pi^+$

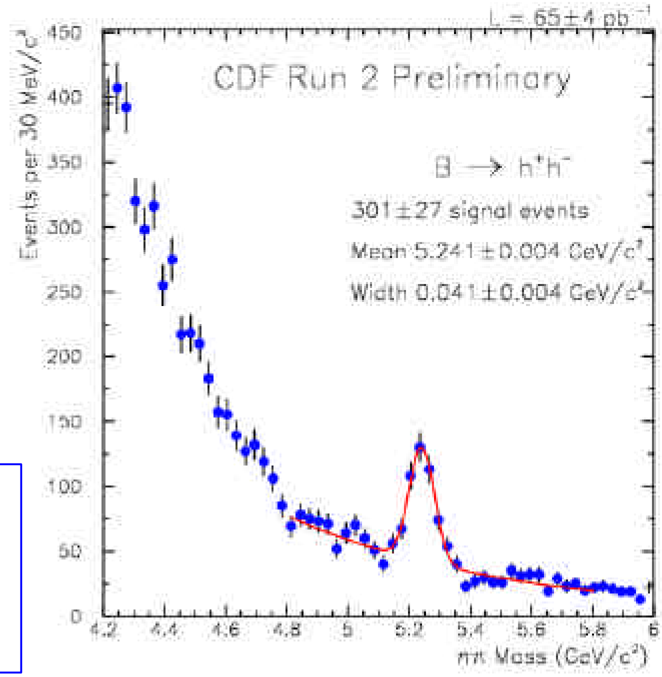
$$\mathcal{B}(B_s \to \psi(2S) K^{*-}\pi^+) = 3 \cdot 10^{-5}$$
$$\Rightarrow \quad \mathcal{B}(B_s \to \psi(2S) K^{*-}\pi^+)\,\mathcal{B}(\psi(2S) \to J/\psi\pi^+\pi^-)\,\mathcal{B}(K^{*-} \to \pi^- K_S) = 3 \cdot 10^{-6}$$

4a. $B_s \to K^- \pi^+$
($\bar{b} \to \bar{u}u\bar{d}$ decay)

$$\mathcal{B}(B_s \to K^-\pi^+) = 10^{-5}$$

4b. $B_s \to K^{*-} \pi^+$

$$\mathcal{B}(B_s \to K^{*-}\pi^+) = 10^{-5}$$
$$\Rightarrow \quad \mathcal{B}(B_s \to K^{*-}\pi^+)\,\mathcal{B}(K^{*-} \to \pi^- K_S) = 3 \cdot 10^{-6}$$



5. $B_s \to D_s^- \pi^+ \pi^+ \pi^-$
($\bar{b} \to \bar{c}u\bar{d}$ decay)

$$\mathcal{B}(B_s \to D_s^-\pi^+\pi^+\pi^-) = 8 \cdot 10^{-3}$$
$$\Rightarrow \quad \mathcal{B}(B_s \to D_s^-\pi^+\pi^+\pi^-)\,\mathcal{B}(D_s^- \to \phi\pi^-)\,\mathcal{B}(\phi \to K^+K^-) = 1.4 \cdot 10^{-4}$$

6a. $B_s \to K_S \overline{D}^0 [\to K^+\pi^-]$
This is a $\bar{b} \to \bar{c}u\bar{d}$ decay with small pollution from a $\bar{b} \to \bar{u}c\bar{d}$ decay of a $\overline{B}_s$. Also $\overline{B}_s \to K_S D^0$ can contribute via $c \to s\bar{d}u$. This slightly modifies the oscillation amplitude and phase, but does not affect the measurement of Δm_s.

$$\mathcal{B}(B_s \to K_S\overline{D}^0) = 3 \cdot 10^{-4}, \qquad \mathcal{B}(\overline{D}^0 \to K^+\pi^-) = 3.8 \cdot 10^{-2}$$
$$\mathcal{B}(K_S \to \pi^+\pi^-) = 0.69$$
$$\Rightarrow \quad \mathcal{B}(B_s \to K_S\overline{D}^0)\,\mathcal{B}(\overline{D}^0 \to K^+\pi^-)\,\mathcal{B}(K_S \to \pi^+\pi^-) = 8 \cdot 10^{-6}$$

6b. $B_s \to K_S \overline{D}^0 [\to K^+\pi^+\pi^-\pi^-]$

$$\mathcal{B}(\overline{D}^0 \to K^+\pi^+\pi^-\pi^-) = 7.5 \cdot 10^{-2}$$
$$\Rightarrow \quad \mathcal{B}(B_s \to K_S\overline{D}^0)\,\mathcal{B}(\overline{D}^0 \to K^+\pi^+\pi^-\pi^-)\,\mathcal{B}(K_S \to \pi^+\pi^-) = 1.5 \cdot 10^{-5}$$

6c. $B_s \to K_S \overline{D}^0 [\to K^{*+}\pi^-]$

$$\mathcal{B}(\overline{D}^0 \to K^{*+}\pi^-) = 6 \cdot 10^{-2}$$
$$\Rightarrow \quad \mathcal{B}(B_s \to K_S\overline{D}^0)\,\mathcal{B}(\overline{D}^0 \to K^{*+}\pi^-)\,\mathcal{B}(K^{*+} \to K_S\pi^+)\,\mathcal{B}(K_S \to \pi^+\pi^-) = 4 \cdot 10^{-6}$$

Lessons learned

- An accurate model of the detector and trigger performances is essential
- We know how to do that with most of the bells and whistles!
- Knowledge is sufficient for many results, the only limit is the lack of manpower!

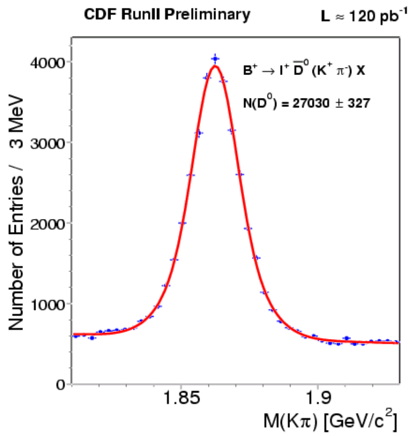
In the same style...

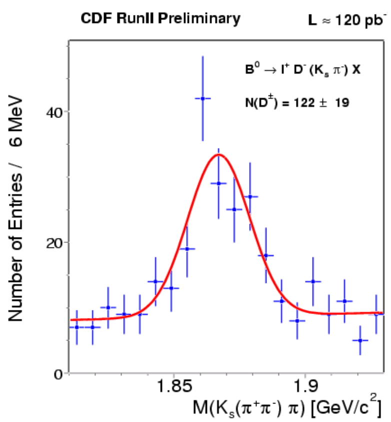
	Mode		Fraction (Γ_i/Γ)	Confidence level
Γ_1	D_s^- anything		(94 ± 30) %	
Γ_2	$D_s^- \ell^+ \nu_\ell$ anything	[a]	(7.9 ± 2.4) %	
Γ_3	$D_s^- \pi^+$		< 13 %	
Γ_4	$D_s^{(*)+} D_s^{(*)-}$		$(23 {}^{+21}_{-13})$ %	
Γ_5	$J/\psi(1S)\phi$		$(9.3 \pm 3.3) \times 10^{-4}$	
Γ_6	$J/\psi(1S)\pi^0$		$< 1.2 \times 10^{-3}$	90%
Γ_7	$J/\psi(1S)\eta$		$< 3.8 \times 10^{-3}$	90%
Γ_8	$\psi(2S)\phi$		seen	
Γ_9	$\pi^+\pi^-$		$< 1.7 \times 10^{-4}$	90%
Γ_{10}	$\pi^0\pi^0$		$< 2.1 \times 10^{-4}$	90%
Γ_{11}	$\eta\pi^0$		$< 1.0 \times 10^{-3}$	90%
Γ_{12}	$\eta\eta$		$< 1.5 \times 10^{-3}$	90%
Γ_{13}	$\rho^0\rho^0$		$< 3.20 \times 10^{-4}$	90%
Γ_{14}	$\phi\rho^0$		$< 6.17 \times 10^{-4}$	90%
Γ_{15}	$\phi\phi$		$< 1.183 \times 10^{-3}$	90%
Γ_{16}	π^+K^-		$< 2.1 \times 10^{-4}$	90%
Γ_{17}	K^+K^-		$< 5.9 \times 10^{-5}$	90%
Γ_{18}	$K^*(892)^0\rho^0$		< 7.67	
Γ_{19}	$\overline{K}^*(892)^0 K^*(892)^0$		< 1.681	
Γ_{20}	$\phi K^*(892)^0$		< 1.013	
Γ_{21}	$p\overline{p}$		< 5.9	
Γ_{22}	$\gamma\gamma$		< 1.48	
Γ_{23}	$\phi\gamma$		< 7	

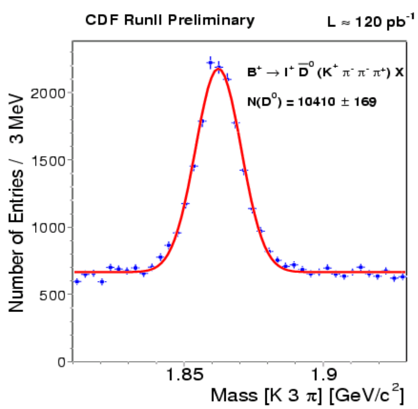
We are able, in principle, to fill in most of these blanks, at least the ones with charged final states!

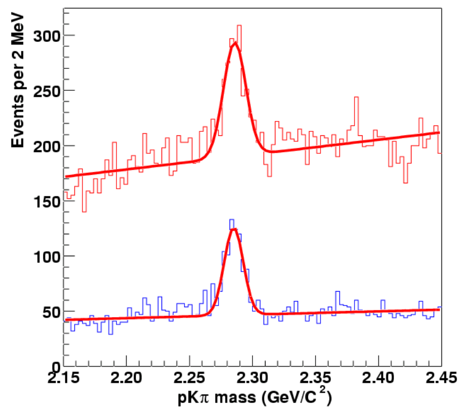
	Mode		Fraction (Γ_i/Γ)	Confidence level
Γ_1	$J/\psi(1S)\Lambda$		$(4.7 \pm 2.8) \times 10^{-4}$	
Γ_2	$pD^0\pi^-$			
Γ_3	$\Lambda_c^+\pi^-$		seen	
Γ_4	$\Lambda_c^+ a_1(1260)^-$		seen	
Γ_5	$\Lambda_c^+\pi^+\pi^-\pi^-$			
Γ_6	$\Lambda K^0 2\pi^+ 2\pi^-$			
Γ_7	$\Lambda_c^+ \ell^- \overline{\nu}_\ell$ anything	[a]	(7.7 ± 1.8) %	
Γ_8	$p\pi^-$		$< 5.0 \times 10^{-5}$	90%
Γ_9	pK^-		$< 5.0 \times 10^{-5}$	90%

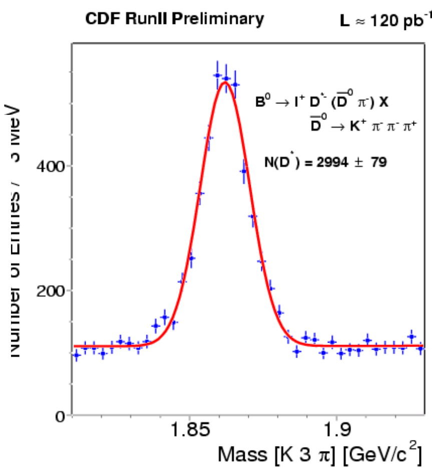
Semileptonic bees...

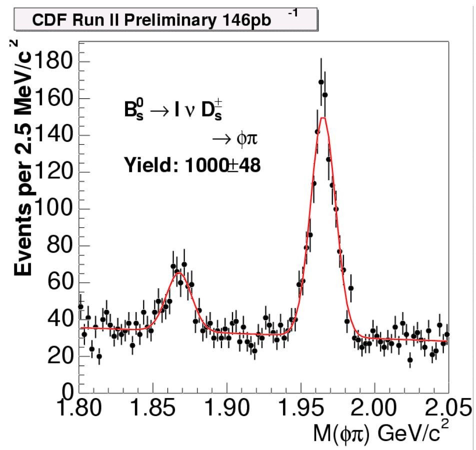


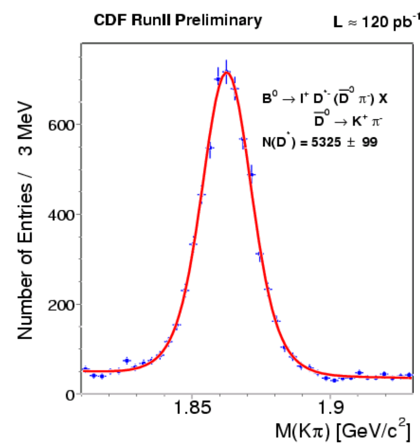


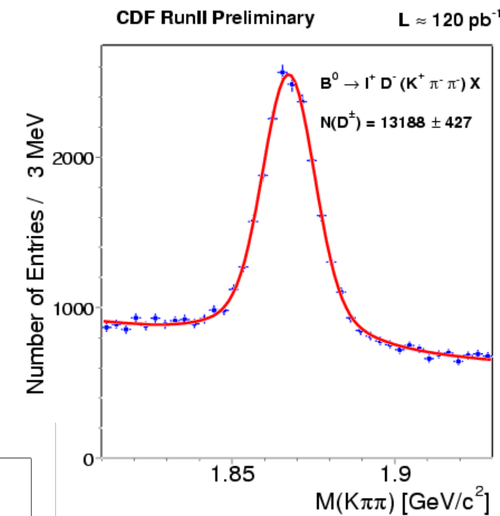


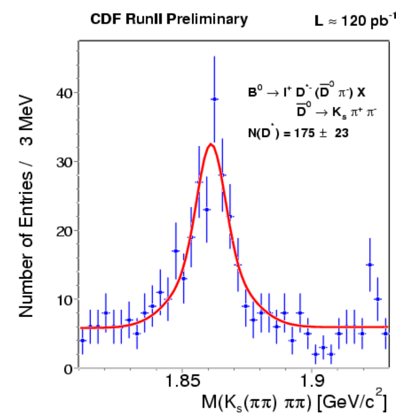


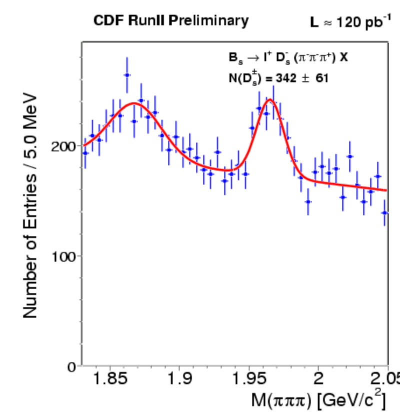






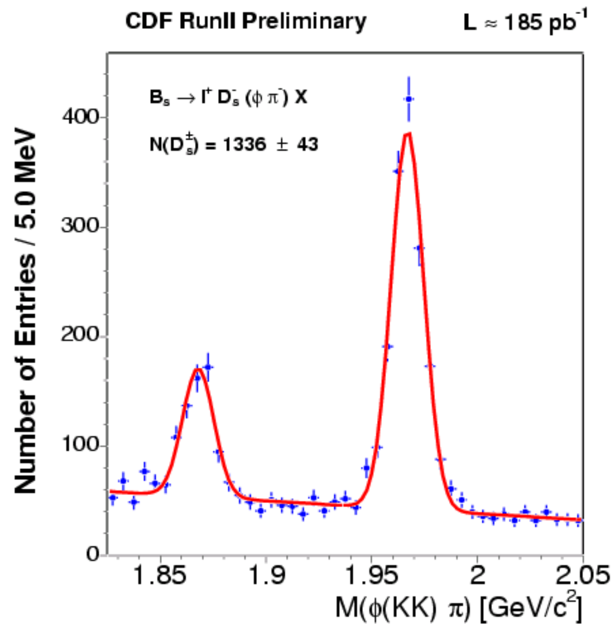


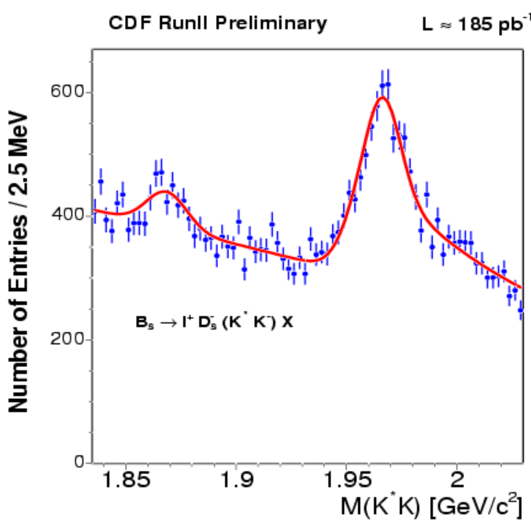


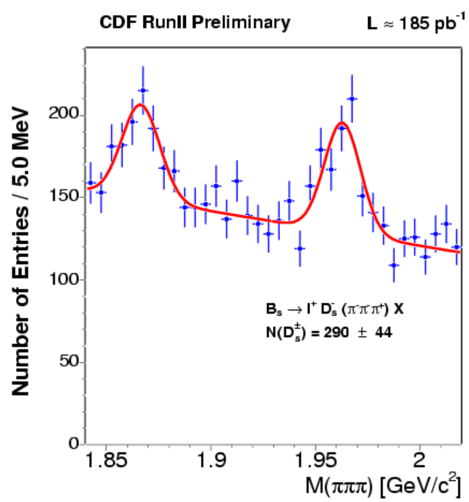


Other B_s modes...

Channel	Yield	$\frac{S}{\sqrt{S+B}}$	$\frac{S}{B}$
$B^+ \to l^+\overline{D}^0 X(\overline{D}^0 \to K^+\pi^-)$	41801 ± 327	184.6	4.4
$B^+ \to l^+\overline{D}^0 X(\overline{D}^0 \to K^+\pi^-\pi^-\pi^+)$	17828 ± 235	98.6	1.2
$B^+ \to l^+\overline{D}^0 X(\overline{D}^0 \to K_s\pi^-\pi^+)$	596 ± 45	15.7	0.7
$B^0 \to l^+\overline{D-}^* X(\overline{D}^0 \to K^+\pi^-)$	8426 ± 138	82.5	4.2
$B^0 \to l^+\overline{D-}^* X(\overline{D}^0 \to K^+\pi^-\pi^-\pi^+)$	4536 ± 102	55.0	0.6
$B^0 \to l^+\overline{D-}^* X(\overline{D}^0 \to K_s\pi^-\pi^+)$	129 ± 17	8.5	1.3
$B^0 \to l^+D^- X(D^- \to K^+\pi^-\pi^-)$	18682 ± 293	97.0	1.0
$B^0 \to l^+D^- X(D^- \to K_s\pi^-)$	93 ± 19	5.1	0.4
$B_s \to l^+D_s^- X(D_s^- \to \phi\pi^-)$	1336 ± 43	32.1	3.4
$B_s \to l^+D_s^- X(D_s^- \to K_sK^-)$	118 ± 29	4.6	0.2
$B_s \to l^+D_s^- X(D_s^- \to K^*K^-)$	1064 ± 136	11.4	0.1
$B_s \to l^+D_s^- X(D_s^- \to \pi^+\pi^-\pi^-)$	290 ± 44	7.2	0.2





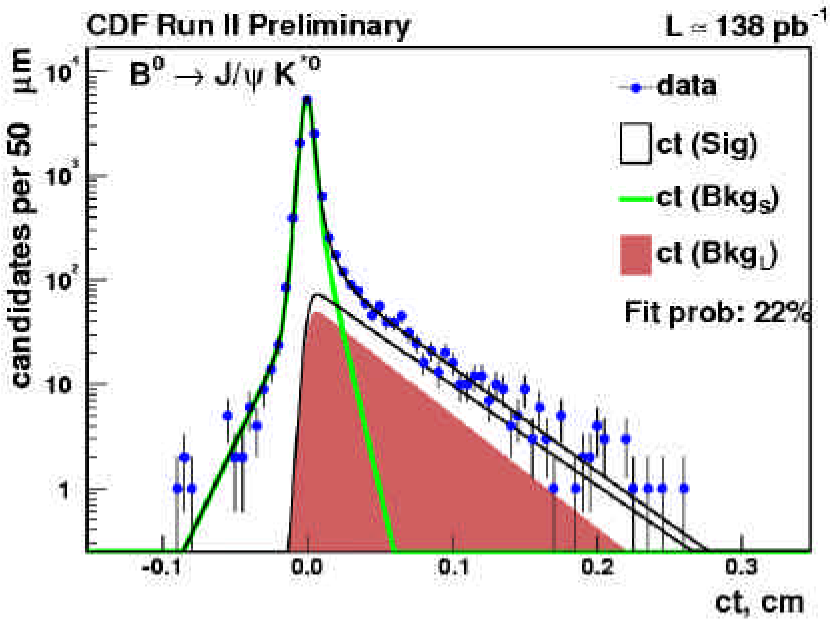


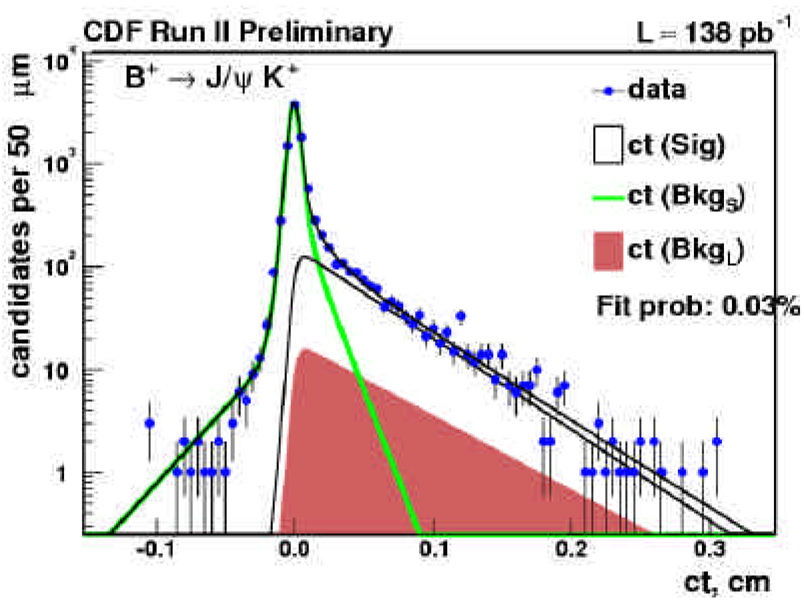
$\phi\pi$ is at this point the only useful channel. We can work to clean up and better understand the others though!

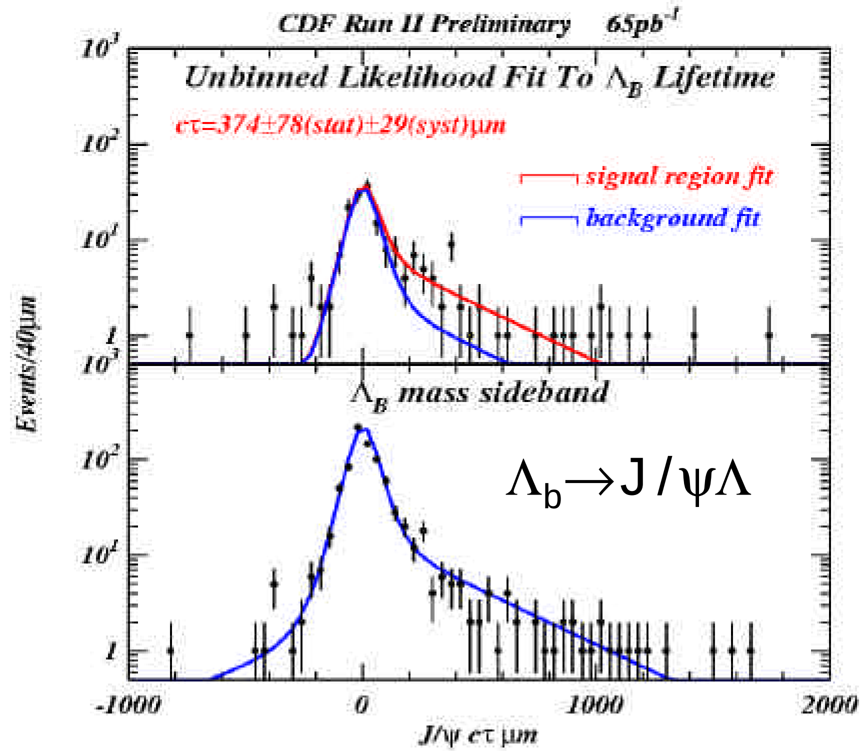
Lifetime Resolution

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

Lifetimes in the dilepton trigger







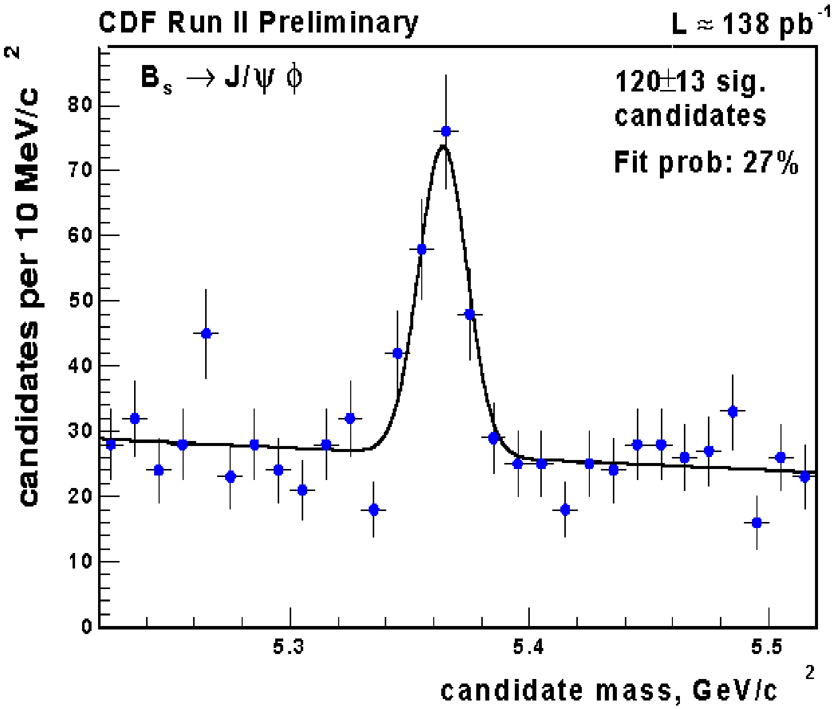
$c\tau(B^+)=490\pm15\pm11\ \mu m$

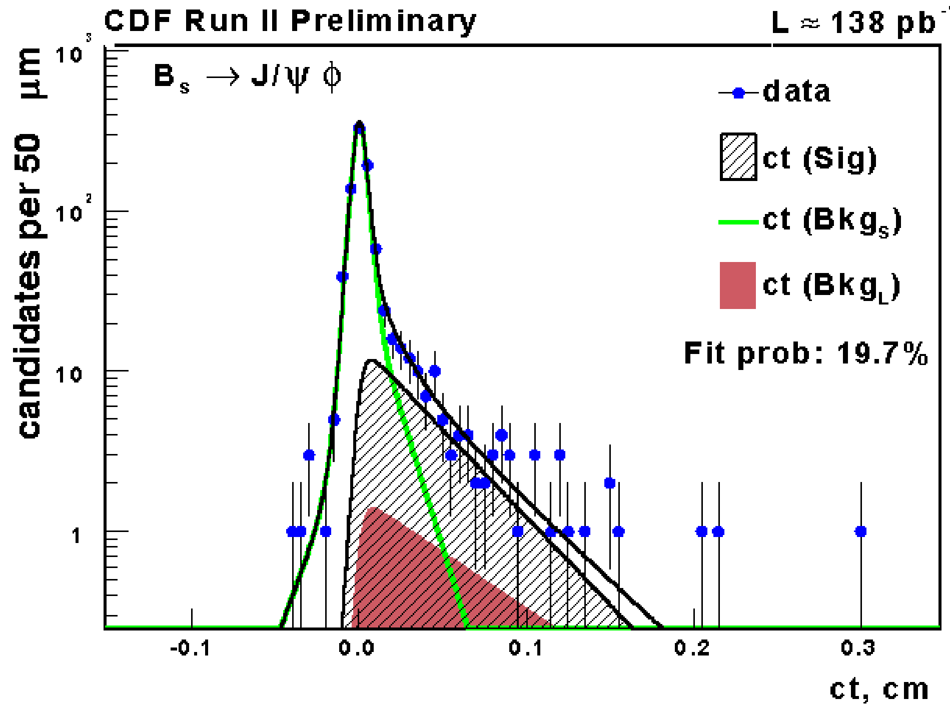
$c\tau(B^0)=453\pm19\pm6\ \mu m$

$c\tau(\Lambda_b)=374\pm78\pm29\ \mu m$

Old technology, new data!

Exclusive reco'd σ

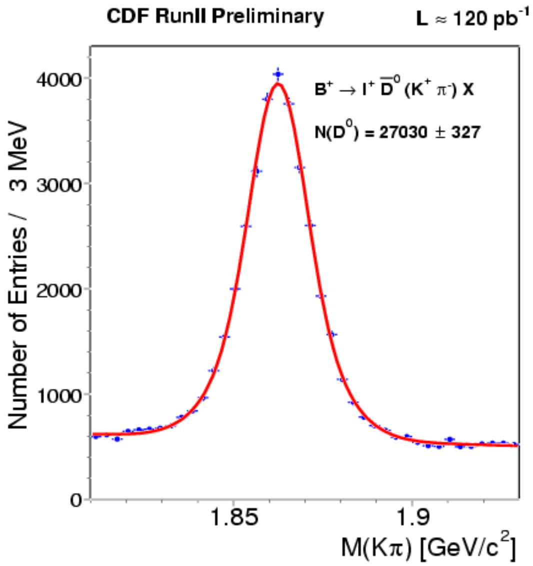


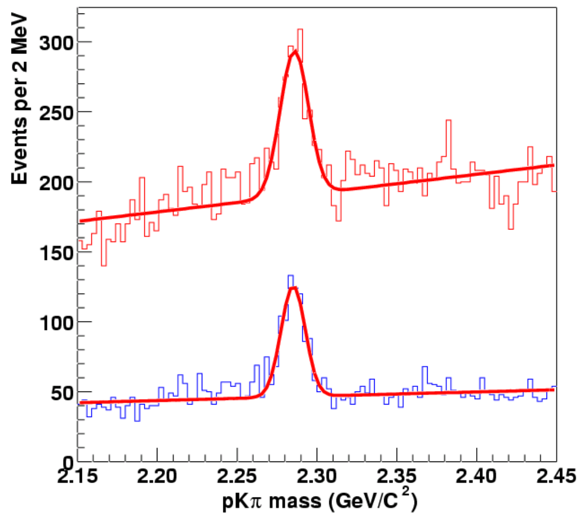


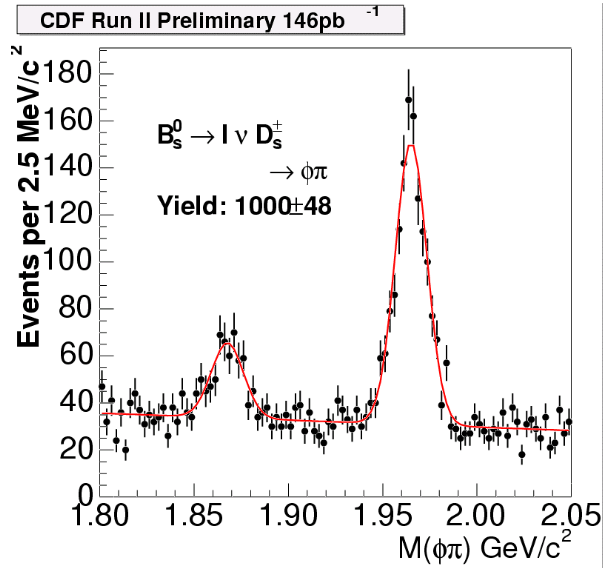
$t(B_s)$=1.33±0.14(stat.) ±0.02(syst.) ps

@ ~120 events

Semileptonics

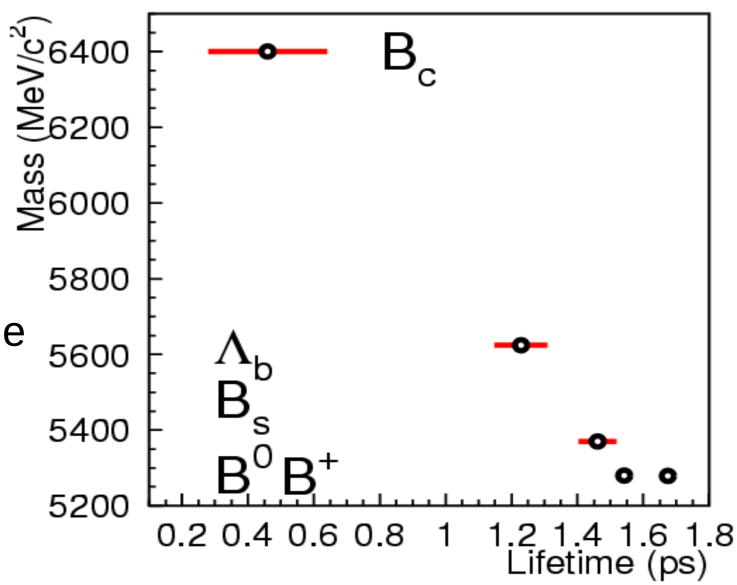






•CDF/D0 are the only experiments on earth that can cross check HQE through:

$$\frac{\Gamma(B_s)}{\Gamma(B_d)}, \quad \frac{\Gamma(\Lambda_b)}{\Gamma(B_d)}$$



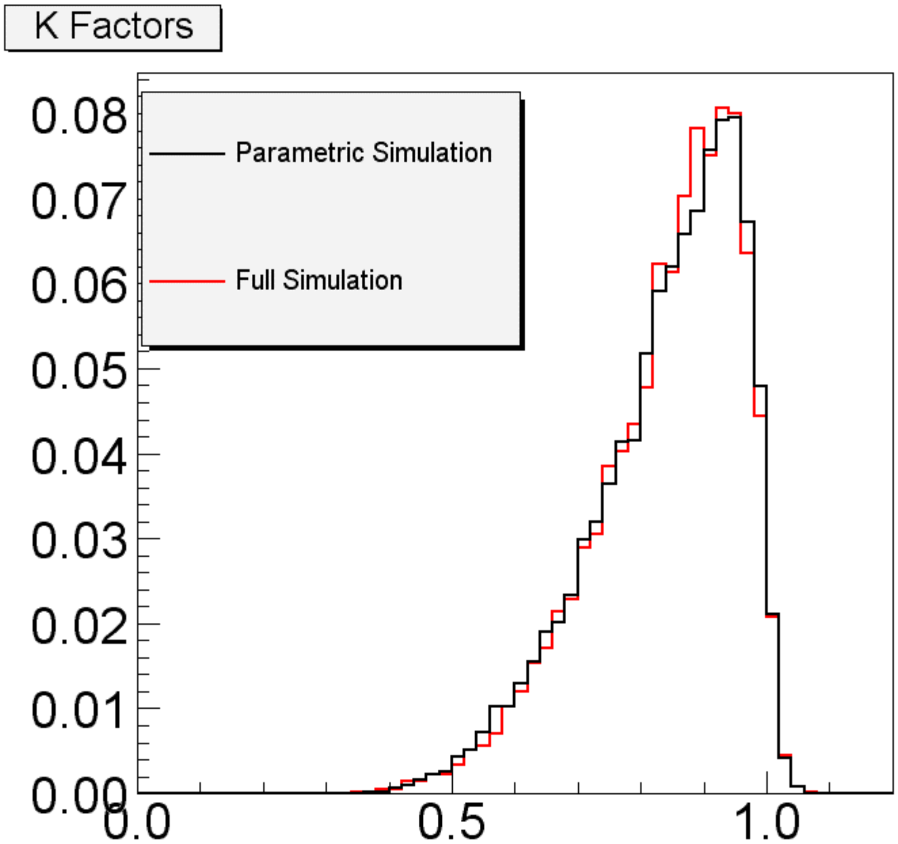
•We have a full fledged lifetime anaylsis for each mode

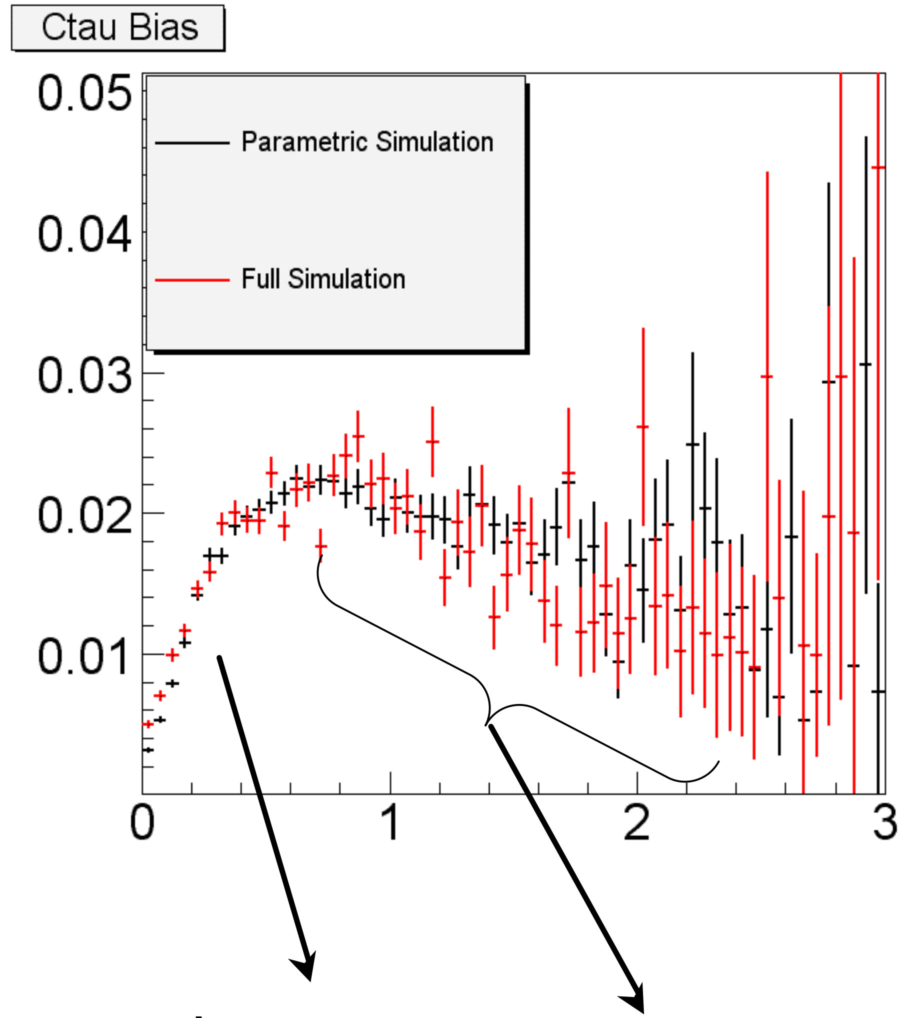
•In most cases also more than one, as a cross check

•Using lD^*, lD^+ as control samples against PDG

•Inconsistency!

K factor and Bias (B_s)





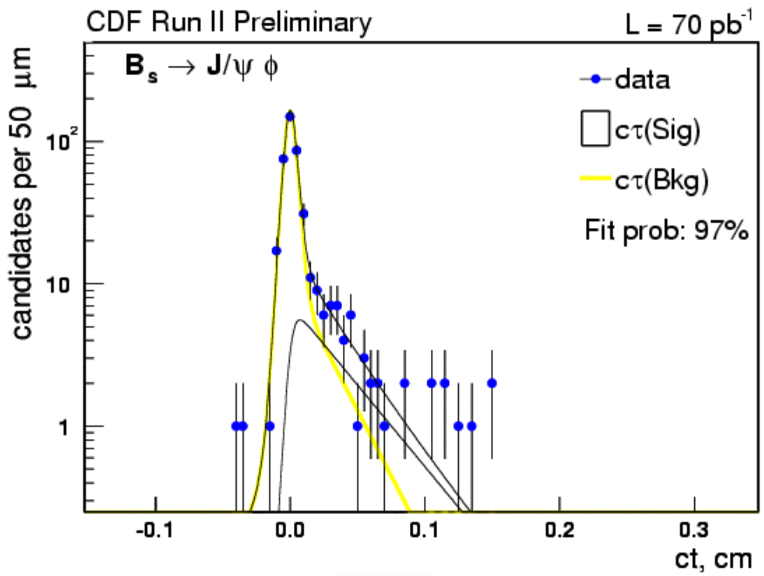
d_0>120μm

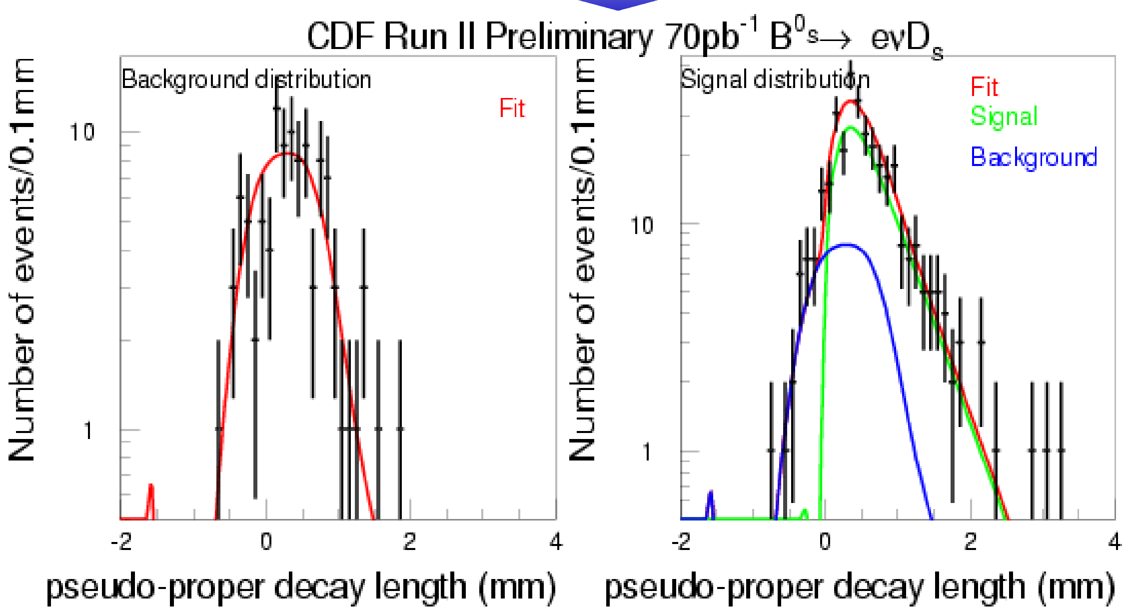
d_0<1 mm !!!

βγ correction

$$ct = \frac{L_{xy} m(B_s^0)}{p_t(B_s^0)} = \frac{L_{xy} m(B_s^0)}{p_t(lD_s^{\pm})} K; K = \frac{p_t(lD_s^{\pm})}{p_t(B_s^0)}$$

Resolution function?!?





•Usually relies on the "prompt" component

•The trigger kills it!

•Need an alternate model:

Lepton+SVT track with no impact parameter and all the analysis cut but lifetimes

•Ethic issue: physics is not the same, should we believe it?

Lifetimes

Ilya, Satoru, Sinead, Kai, Andy, Alex, Barry, Fumi, Manfred, Masa

- We are collecting one of the largest single-experiment sample of semileptonic decays

BUT

- Lifetime bias:
    - ~ -50 μm / -10% / 7σ discrepancy with PDG
    - >1 year of investigation and still no smoking gun!
- Several analyses are already pretty much laid down and await the solution of this puzzle!
- This is the first gym where we can probe our reliability in understanding SVT triggers from the lifetime point of view!!!

Where do we stand?

- Appointed a committee of wise, prudent and sage experts
- Went critically through the information we have
- Clarified and cleaned up several points
- No smoking gun yet! ☹
- Pretty much running out of new ideas
- Still some hints and old ideas to probe:
    - RunI-like (a.k.a. 8 GeV) sample suffers from the same problem!
    - Usual suspects (fitting procedures, bias modeling and K factor) seem ultra safe! (see in particular Masa's study on J/ψ)
    - Pollution from gluon splitting
- Need new impulse on this, maybe also fresh ideas
- No, not maybe

Impact on B_s mixing

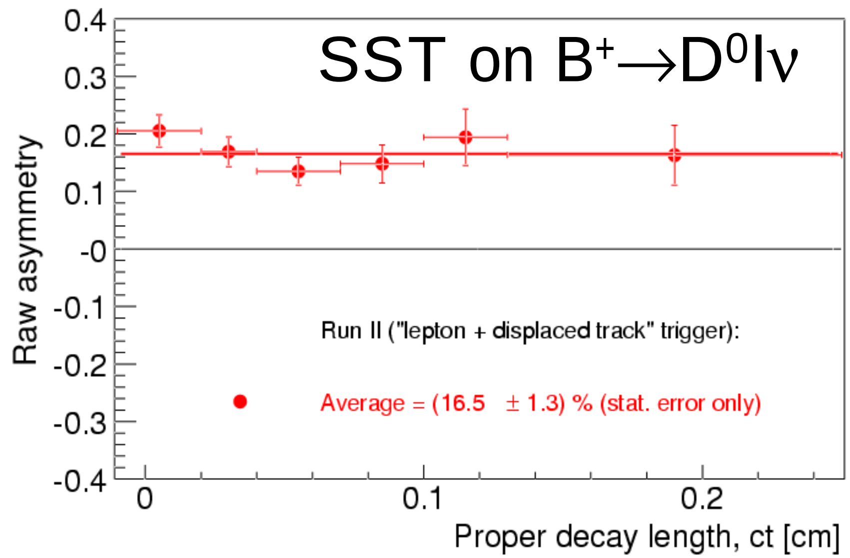
- To 1st order it's 0:
  - $(N^+-N^-)/(N^++N^-)$ must be measured as a function of t!
  - 2nd order?
- Yield is the main issue
- Tagging performance is the next one:

We are carefully working

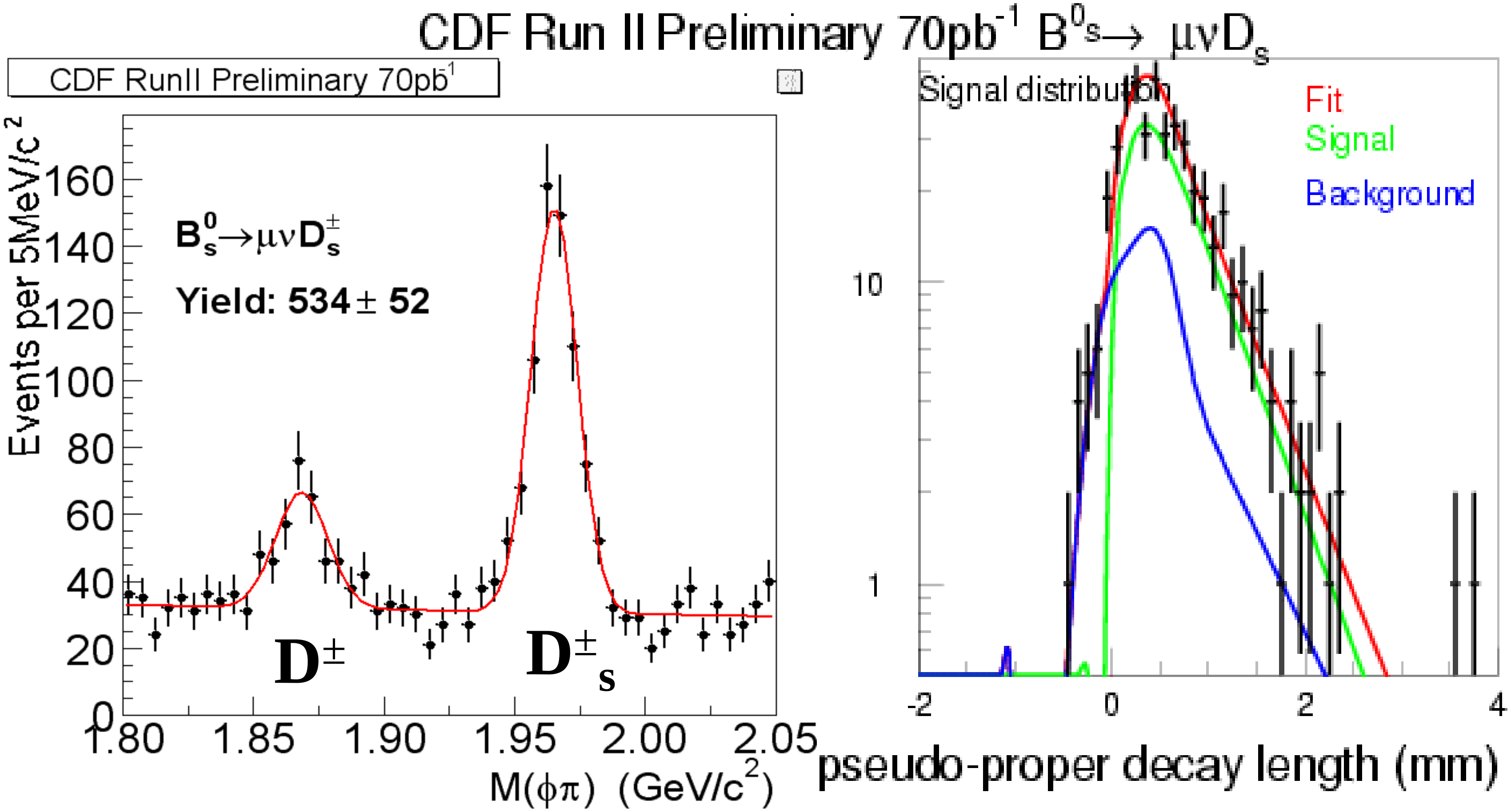
On the most robust taggers

To verify the performances

We expected to have...

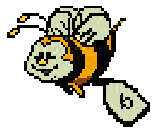


Semileptonic σ



$\sigma_{ct} \approx \pm 0.07$ ps @ ~1000 events   Sys?!??

DISCLAIMER: this talk contains strictly CDF restricted materia. If you are not from CDF, close your ears, shut your eyes and vanish from the room.



Tagging

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

DISCLAIMER: this talk contains strictly CDF restricted materia. If you are not from CDF, close your ears, shut your eyes and vanish from the room.

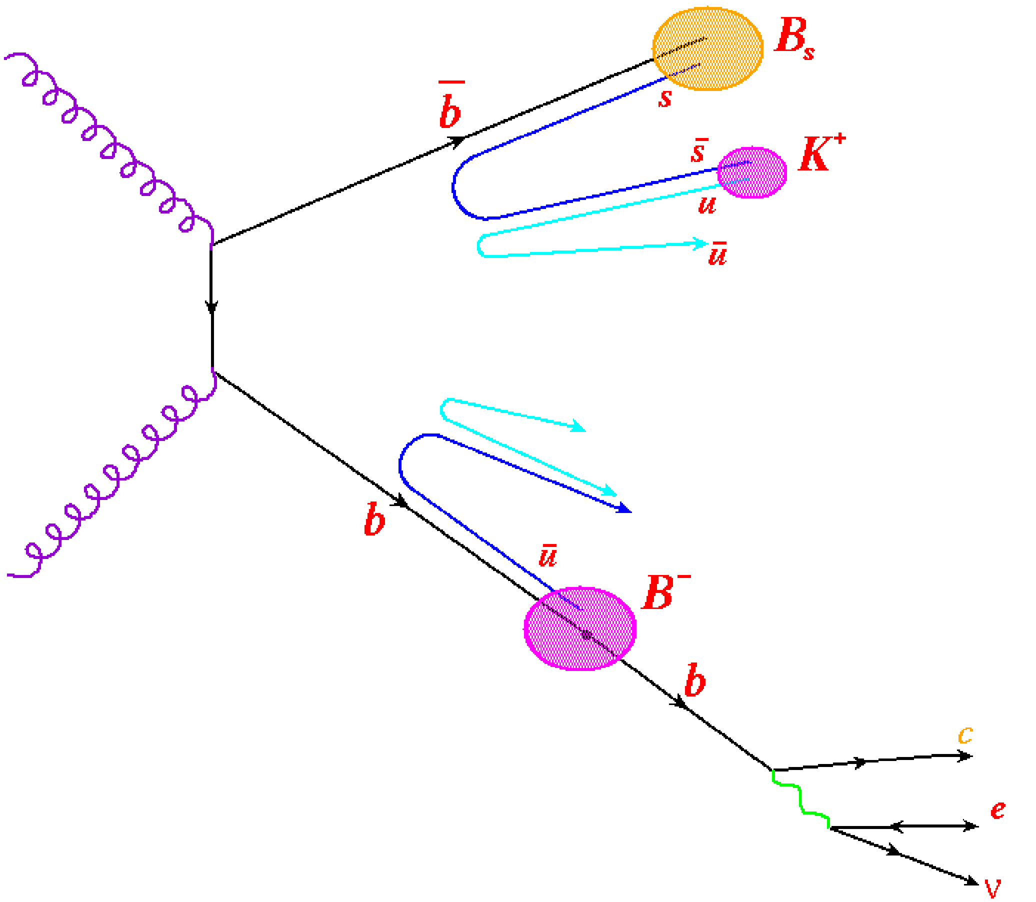
Mixing in the laboratory

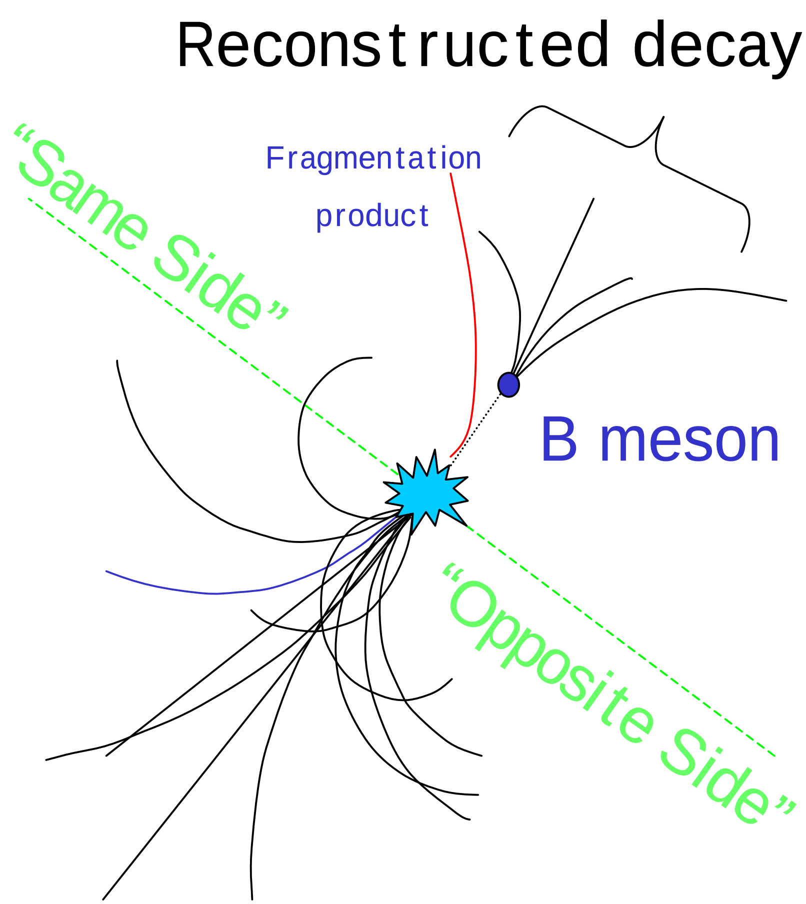
- To resolve the oscillations, we need to measure
  - B_s vs $\overline{B}_s$ at t=0 (at production)
  - B_s vs $\overline{B}_s$ at decay
  - proper decay time
- for large numbers of events

$$A_{meas.}(t) = \frac{N_{same}(t) - N_{different}(t)}{N_{same}(t) + N_{different}(t)}$$

Measuring B_s vs $\overline{B}_s$ at t=0

- This is an art called "flavor tagging"

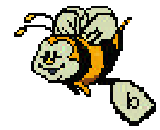




Several methods, none is perfect !!!

Building a Tagger

- Pick your favorite algorithm

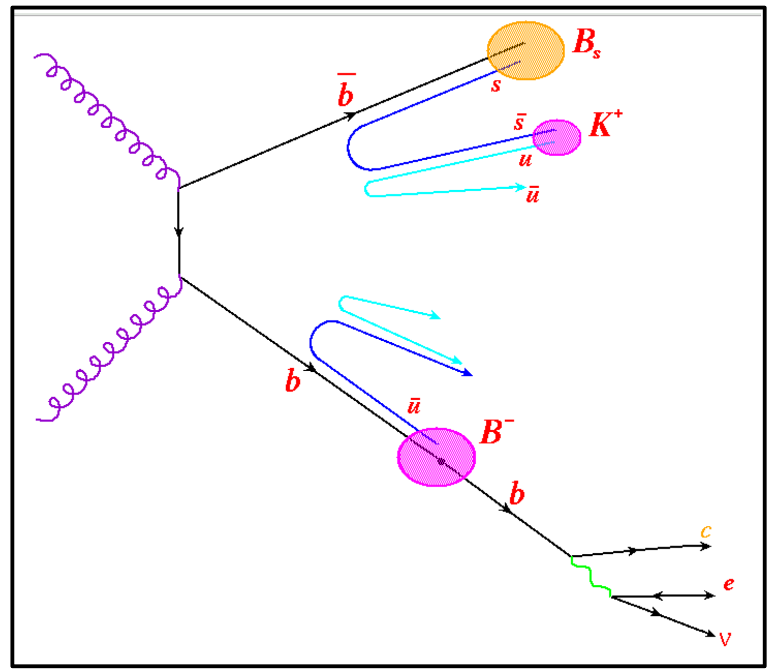


- Pick a sample where flavor does not change (e.g. $B^+ \rightarrow l^+ \nu_l X$ decays)

- Apply your algorithm

- Measure efficiency

$$e = \frac{N_{taggable}}{N_{tot}}$$



- Count RS and WS tags

$$P_{mistag} = \frac{N_{WS}}{N_{RS} + N_{WS}}$$

Performances

Due to mistagging effects:

$$A_{meas.} = DA_{true}$$

$$D = \frac{N_R - N_W}{N_R + N_W} = 1 - 2P_{mistag}$$

$B_s \to D_s^- \pi^+$: ϵD^2	
Same-Side Kaon	**4.2%**
μ **tag**	**1.0%**
e **tag**	**0.7%**
Jet Charge	**3.0%**
Opp.-Side Kaon	**2.4%**
Total (correl. small)	**11.3%**

(some year ~2000 projections)

And the algorithm can't be applied to the whole sample:

$$dA_{meas.} \propto \frac{1}{\sqrt{eD^2 N}}$$

In the projections we will stay on the safe side, assuming eD^2 = 4%

(this is ~ what we have at hand right now)

eD^2 is mostly a tool for back of the envelope calculations: in reality you use all the events, weighted by their individual D

Tagging

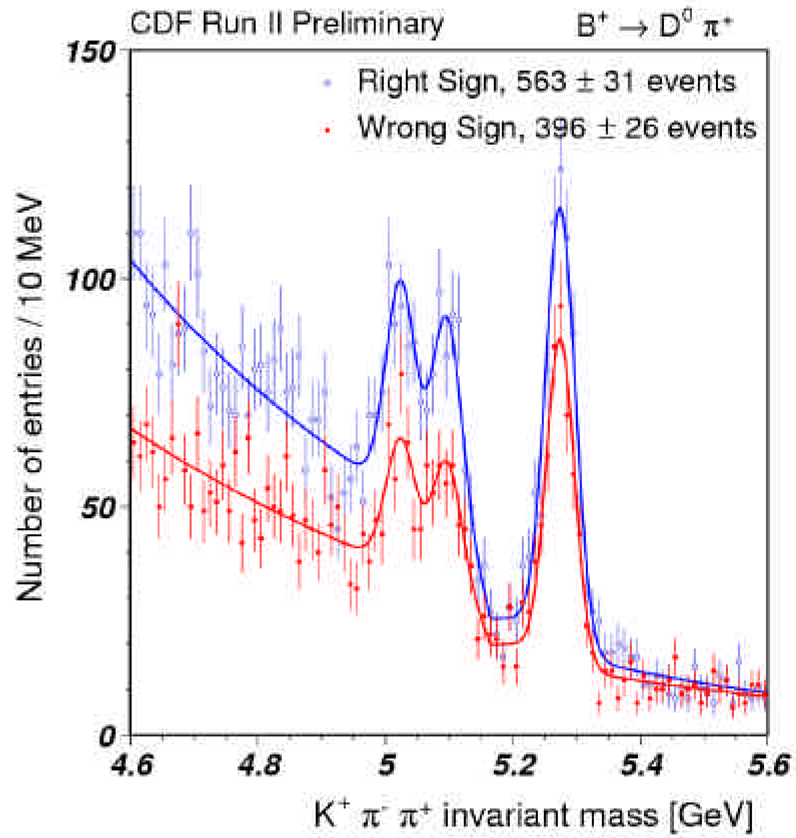
Barry Wicklund, Matthew Jones, Denys Usynin, Vivek Tiwari, Gavril Giurgiu, Guillelmo Gomez-Ceballos, Sasha Rakitin, Ilya Kravchenko, Ivan Vila, Alberto Ruiz, Jonatan Piedra, Marcin Wolter, Nuno Leonardo, Tania Moulik

- To some degree, each of these can be developed and checked on the semileptonic sample:
  - Soft muon
  - Soft electron
  - Jet Charge
  - OSK
  - Same Side
- We have blessed results for:
  - Soft muon
  - SST (≈2.6±1 %)
- SeT is almost there (≈0.44±0.1 %)
- JQT made great progress
- First tagger tests ran on $J/\Psi K$ and $D^0\pi$
- What I'm saying is very simplistic, I strongly suggest that you look at the notes/talk slides
- Flavor tagging is not an easy task, and we still have a big portion of uncharted territory (e.g. TOF based tagging, detector effects, montecarlo tuning)

muon	raw D,%	ϵ, %
IMU	43 ± 9	0.18 ± 0.02
CMX	22 ± 5	0.59 ± 0.03
CMU only	13 ± 4	1.20 ± 0.05
CMP only	20 ± 7	0.36 ± 0.03
CMUP	27 ± 5	0.62 ± 0.03
Any	20.2 ± 2.5	2.92 ± 0.07

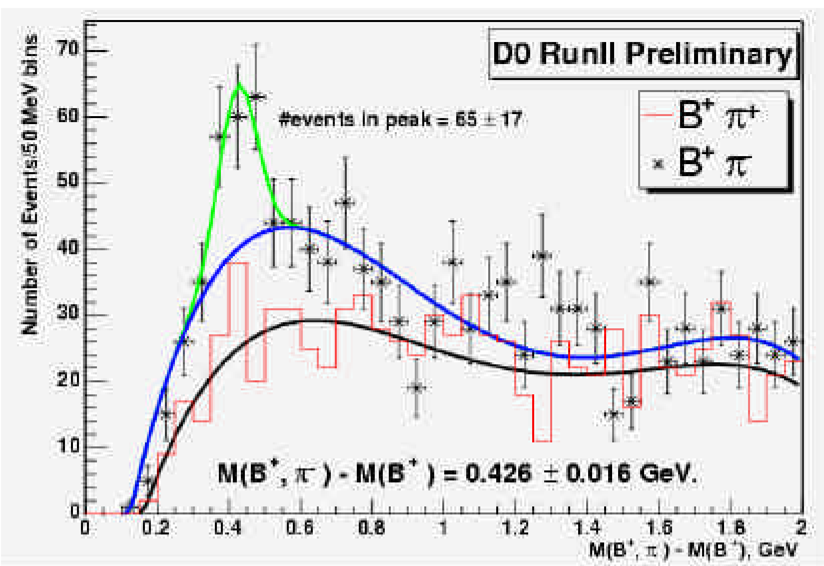
Current Performances

- Strategy: use data for calibration (*e.g.* $B^{\pm} \to J/y K^{\pm}$, $B \to$ lepton)
  - "know" the answer, can measure right sign and wrong sign tags.



<u>DØ Results:</u>

- Jet charge eD^2=(3.3±1.1)%
- Muon tagging eD^2=(1.6±0.6)%

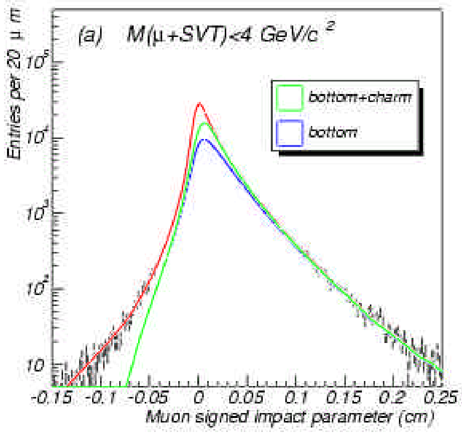


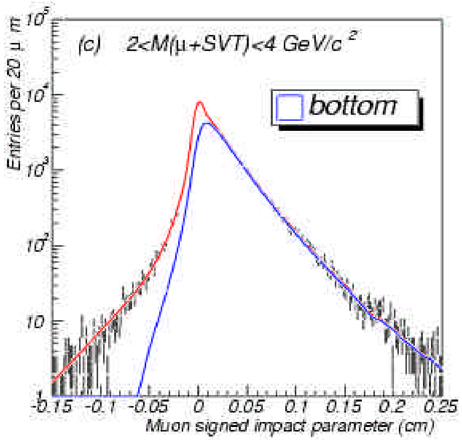
<u>CDF Results:</u>

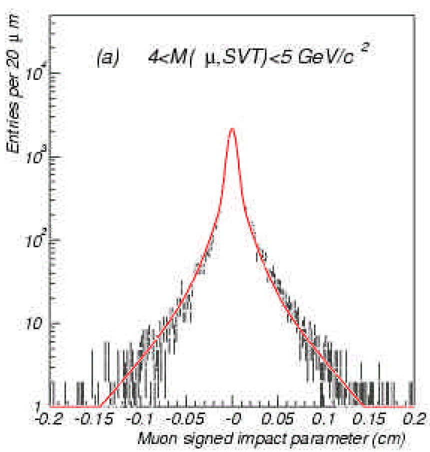
- Same-side (B^+) eD^2≈(2.1±0.7)%
  ($B^+/B^0/B_s$ correlations different)
- Muon tagging eD^2≈(0.7±0.1)%

Sample Composition

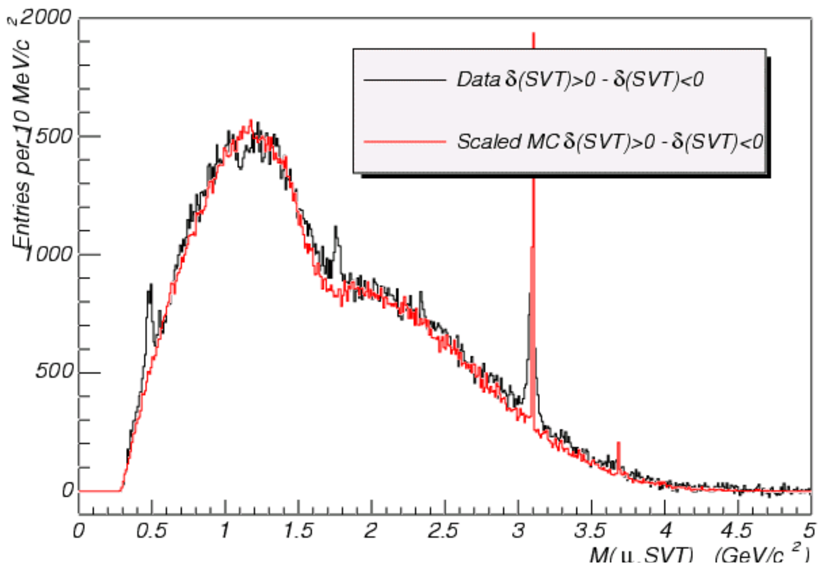
M. Jones, J. Kroll, A. Wicklund, D. Usynin







- Starting point for tagging studies: know your sample (how much b? → effective dilution)
- Use signed lepton d_0
- Take cc and bb model from MC templates
- Residual background model from [4,5] GeV region + prompt component
- Simultaneous fit:



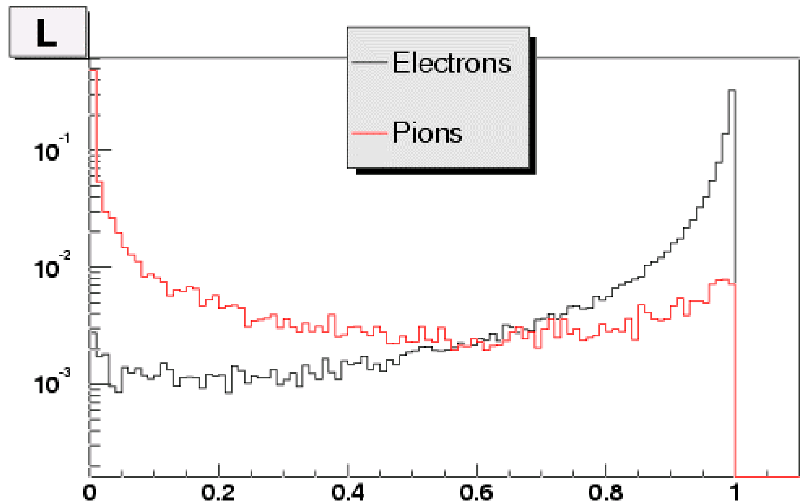
component	$\mu + SVT$ $0 - 4\ \mathrm{GeV}/c^2$
$b \to \ell$	3290 ± 21 pb
$c \to \ell$	1234 ± 23
prompt	1018 ± 50
symmetric	382 ± 26

$$D_{\rm sub} = \begin{cases} 0.641 \pm 0.002\ (\mathrm{stat})^{+0.014}_{-0.023}\ (\mathrm{syst}) & \mu + SVT \\ 0.641 \pm 0.002\ (\mathrm{stat})^{+0.022}_{-0.037}\ (\mathrm{syst}) & e + SVT \end{cases}$$

SeT

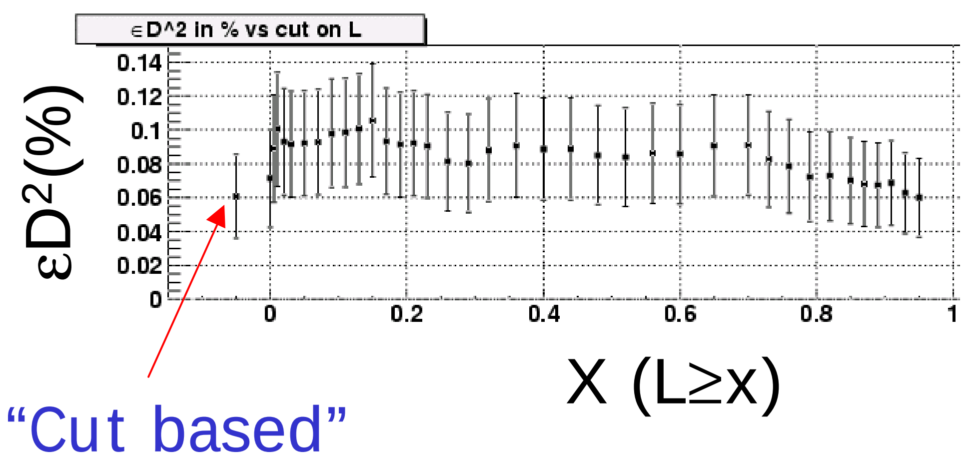
V. Tiwari, G. Giurgiu, M. Paulini, J. Russ, B. Wicklund, T. Moulik

- Two approaches so far:
  - Cut on electron ID
  - Build a likelihood and weight
- Improve efficiency
- Exploit the full rejection power of eid



- Efficiency for Electrons and Fakes

Likelihhod based, vs L lower cut



$L \geq$	$\epsilon_\pi(\%)$	$\epsilon_e(\%)$	ϵ_e/ϵ_π
0.01	48	100	2.1
0.05	38	99	2.6
0.10	33	99	3.0
0.15	28	98	3.5
0.20	26	97	3.7
0.50	16	94	5.9
0.70	11	89	8.1
0.90	5	75	15.0

Table 1: Efficiencies of the cuts on L for pure electrons and pions.

L-based SeT performance (cont'd)

V. Tiwari, G. Giurgiu, M. Paulini, J. Russ, B. Wicklund, T. Moulik

- Binning in ${p_T}^{rel}$
  - Choose the cut on likelihood, $L \geq 0.15$ and bin in ${p_T}^{rel}$.

${p_T}^{rel}$	OS/SS	$\epsilon(\%)$	$D(\%)$	$\epsilon D^2(\%)$
0.0	91/59	0.251 ± 0.025	21.33 ± 10.03	0.011 ± 0.011
0.0-0.4	55/22	0.129 ± 0.021	42.86 ± 17.26	0.024 ± 0.019
0.4-0.7	70/66	0.227 ± 0.025	02.94 ± 10.86	0.000 ± 0.001
0.7-1.0	78/60	0.230 ± 0.024	13.04 ± 10.70	0.004 ± 0.006
1.0-1.5	122/56	0.297 ± 0.024	37.08 ± 09.07	0.041 ± 0.020
1.5-2.0	77/28	0.175 ± 0.020	46.67 ± 10.64	0.038 ± 0.018
> 2.0	61/28	0.149 ± 0.020	37.08 ± 12.85	0.020 ± 0.014
Sum	554/319	1.458 ± 0.062		0.138 ± 0.038
Avg	554/319	1.458 ± 0.062	26.92 ± 04.21	0.106 ± 0.033
Cuts	318/183	0.837 ± 0.046	26.95 ± 05.46	0.061 ± 0.025

Table 2: ϵ, D and ϵD^2 in % after binning in ${p_T}^{rel}$ with the cut L ≥ 0.15 for the 8 variables case. Also shown are the average numbers from the likelihood and the cut-based approaches without binning in ${p_T}^{rel}$.

- The total raw ϵD^2 after binning in ${p_T}^{rel} = 0.180 \pm 0.043$.
- Correcting for trigger side dilution and sequential decays using $D_{sub} = 0.6412 \pm 0.0015$, we get $\epsilon D^2 = 0.438 \pm 0.105$ % for a total efficiency, $\epsilon = 1.927 \pm 0.072$ %.
- Run I number from CDF note 3809, corrected $\epsilon D^2 = 0.34 \pm 0.08$ % (with dE/dx).

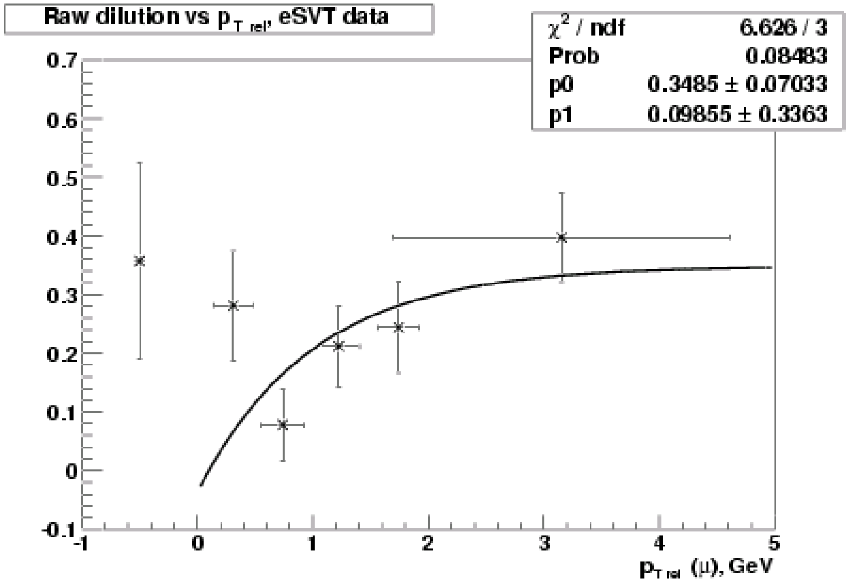
Please note:

There are several other very nice works in progress!

SμT

M. Jones, J. Kroll, A. Wicklund, D. Usynin V. Tiwari, G. Giurgiu, M. Paulini, J. Russ, B. Wicklund

- Compared to electrons:
  - Higher purity
  - Less handles to discriminate fakes
  - "Natural" fakes from decays in flight



muon	raw D,%	ϵ, %
IMU	30 ± 11	0.20 ± 0.02
CMX	26 ± 7	0.57 ± 0.04
CMU only	12 ± 6	0.89 ± 0.05
CMP only	15 ± 9	0.32 ± 0.03
CMUP	37 ± 6	0.54 ± 0.04
Any	22 ± 3	2.52 ± 0.08

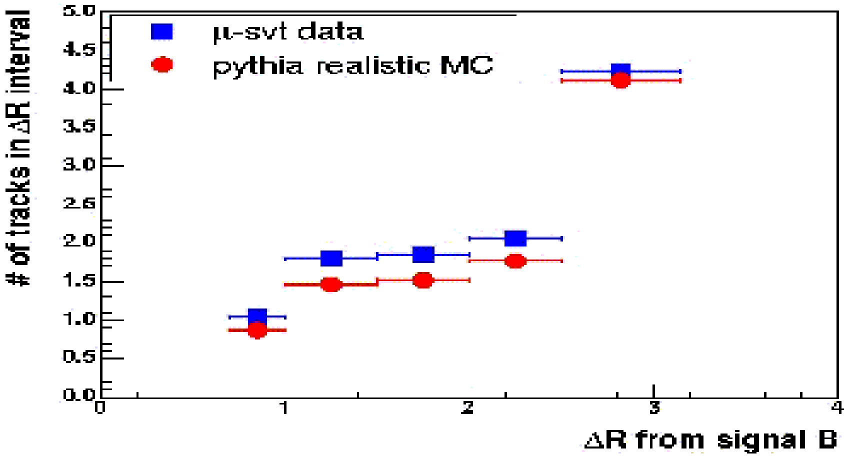
muon	raw D,%	ϵ, %
IMU	39 ± 9	0.23 ± 0.02
CMX	21 ± 6	0.60 ± 0.04
CMU only	9 ± 5	0.90 ± 0.05
CMP only	16 ± 8	0.33 ± 0.03
CMUP	25 ± 5	0.59 ± 0.03
Any	19 ± 3	2.62 ± 0.08

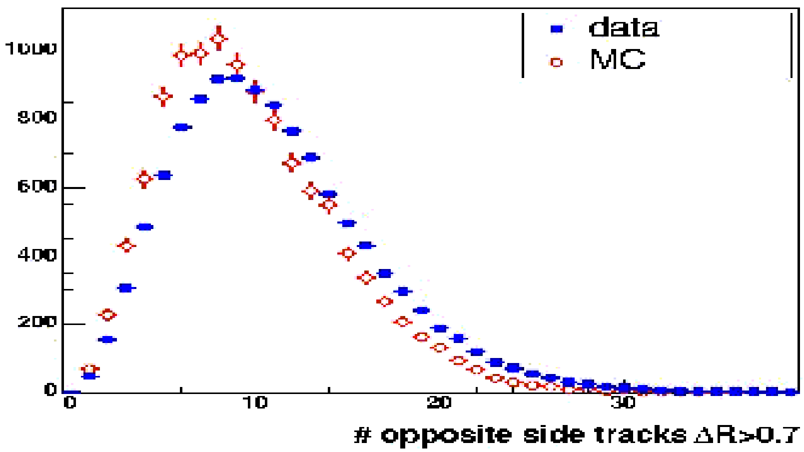
A likelihood-based approach is being developed

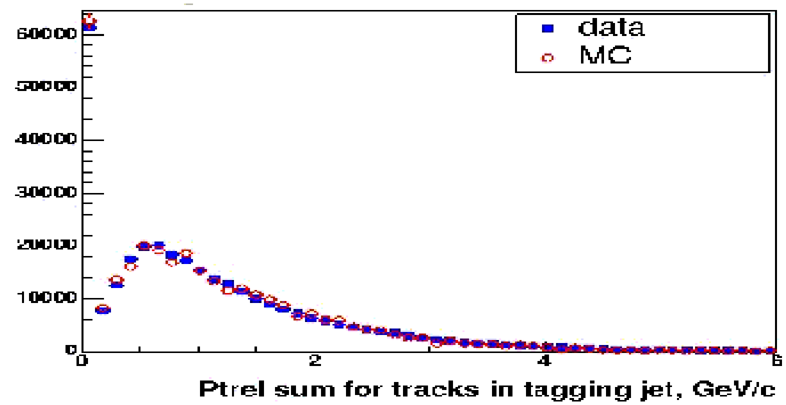
JQT

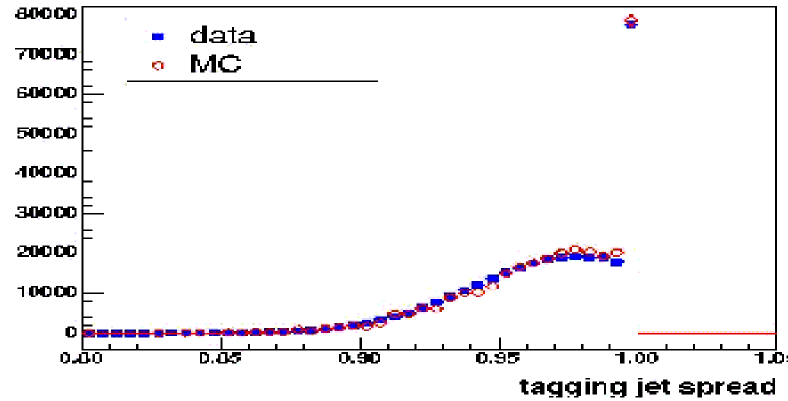
Ilya Kravchenko

- Exercising in a full-fledged data/MC comparison [ID^0]
- Still significant discrepancies in the montecarlo: needs tuning!









First Glance Performance:

$\varepsilon \approx 65\%$

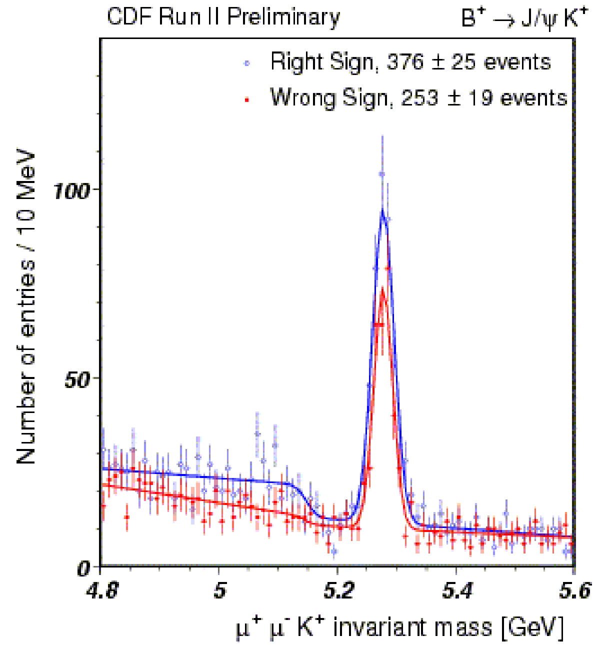
$D_{raw} \approx 4\%$

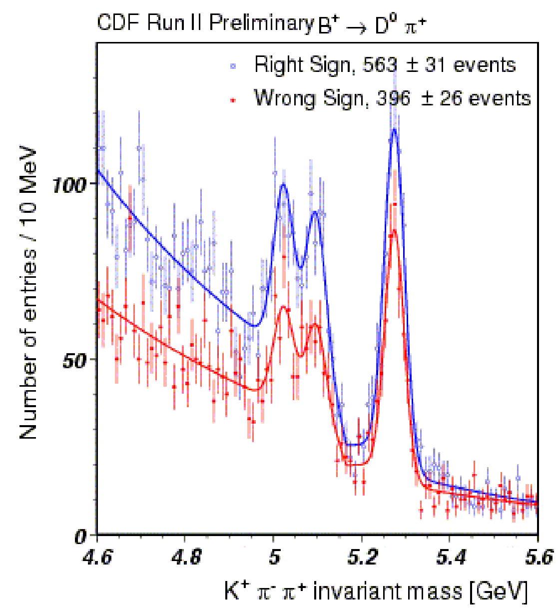
$\varepsilon D^2_{raw} \approx 0.11\%$

SST

Gerry Bauer, Guillelmo Gomez-Ceballos, Ilya Kravcenko,
Nuno Leonardo, Cristoph Paus, Jonatan Piedra,
Sasha Rakitin, Alberto Ruiz, Ivan Vila

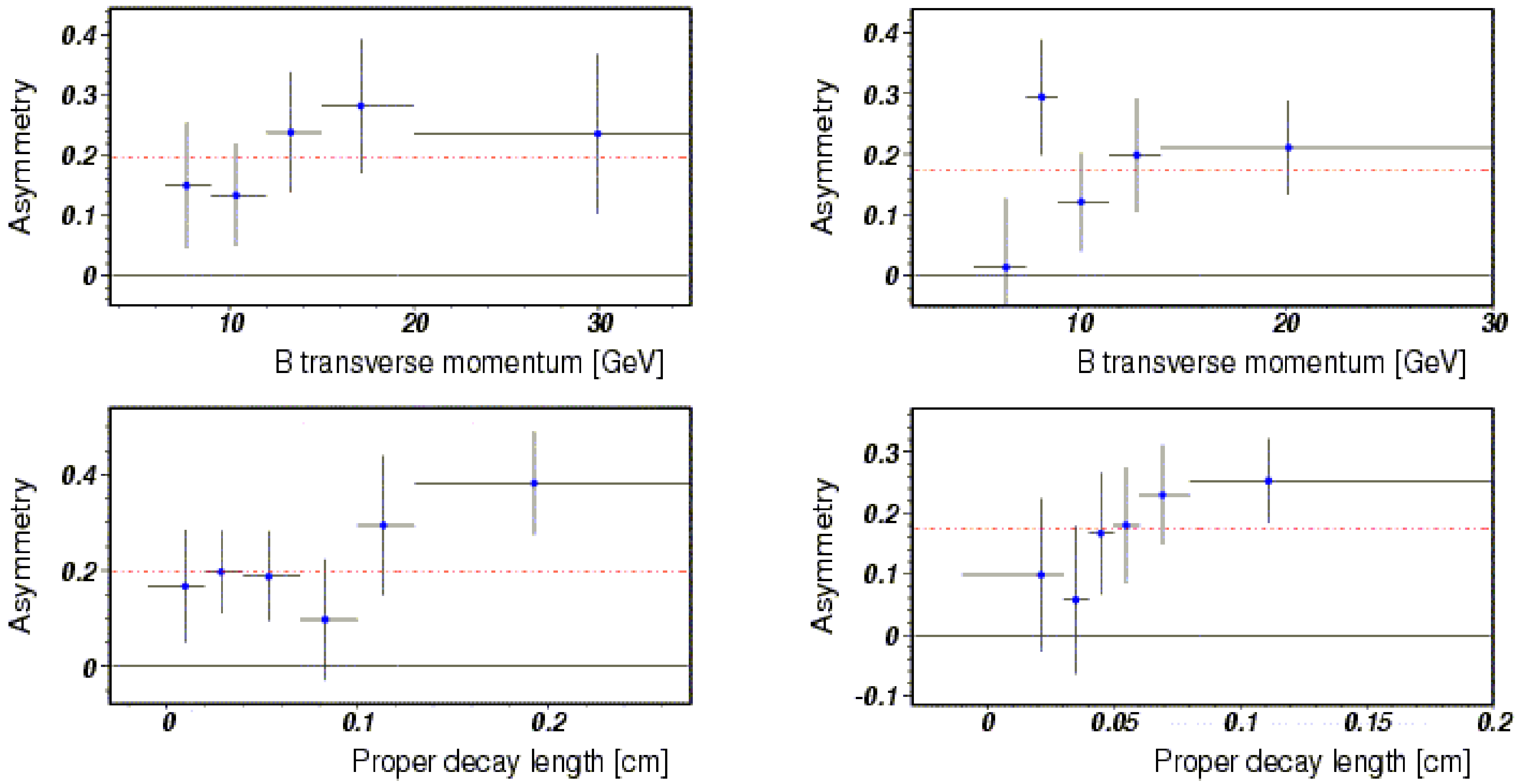
- Run I-like algorithm has been implemented:
  - $\Delta R<0.7$, $Pt>0.4$
  - $|d_0/\sigma|<3.0$
  - Minimum P_t^{rel}
- Results are checked on two samples:
  - $B^+ \to \psi K^+$
  - $B^+ \to D^0 \pi^+$
- Encouraging results, working on a large statistics study (e.g. ID^0)





SST (cont'd)

$B^+ \to J/\psi K^+$ $B^+ \to D^0\pi^+$

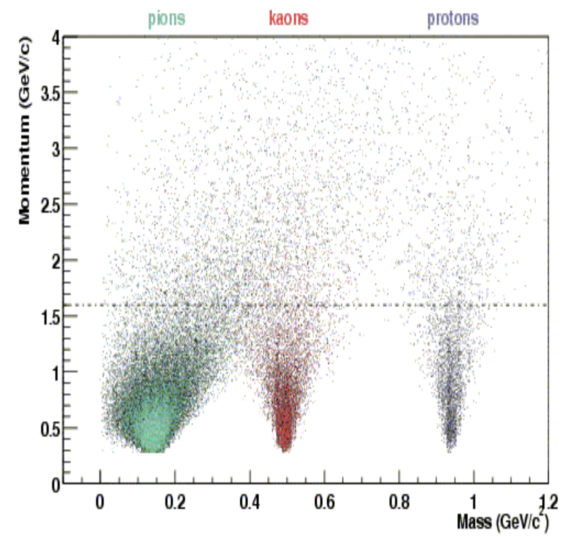


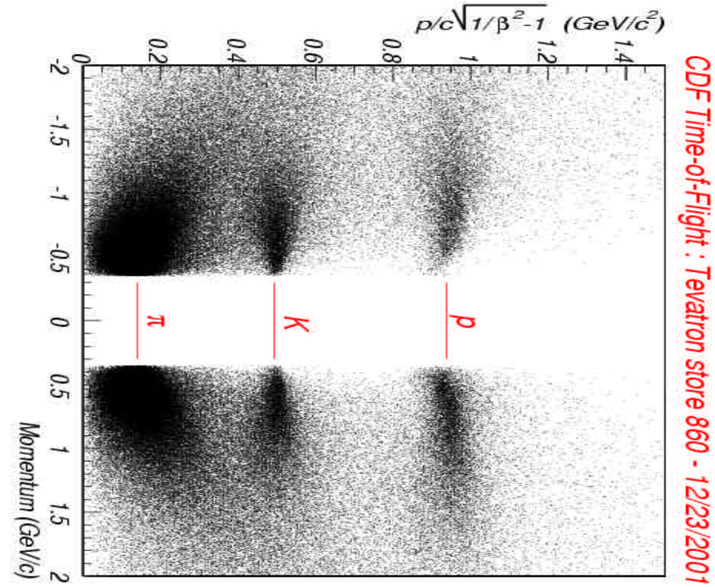
	N_{RS}	N_{WS}	N_{NT}	ϵ	D	ϵD^2
$J/\psi K^+$	376 ± 25	253 ± 19	379 ± 23	62.4 ± 1.8	19.7 ± 4.9	2.4 ± 1.2
$D^0\pi^+$	563 ± 31	396 ± 26	588 ± 27	62.0 ± 1.5	17.4 ± 4.1	1.9 ± 0.9

OSK: TOF

J. Piedra, A. Ruiz, I. Vila, M. Wolter and Ch. Paus

	ε	D	εD²
100% eff., 110ps	12.2±0.3	30.6±2.9	1.14±0.25
GEANT 110ps	10±0.3	28.4±3.2	0.81±0.21
GEANT, ε=0.8 t_0 truth	11.2±0.3	26.8±3.8	0.8±0.2
GEANT	11.2±0.3	23.9±3.0	0.64±0.18
GEANT 65% eff.	9.4±0.3	27.0±3.3	0.68±0.19





First naïve attempts on data:

$$\epsilon = 4.34 \pm 0.41$$

$$D = 17.43 \pm 9.43$$

$$\epsilon D^2 = 0.13 \pm 0.16$$

Projections

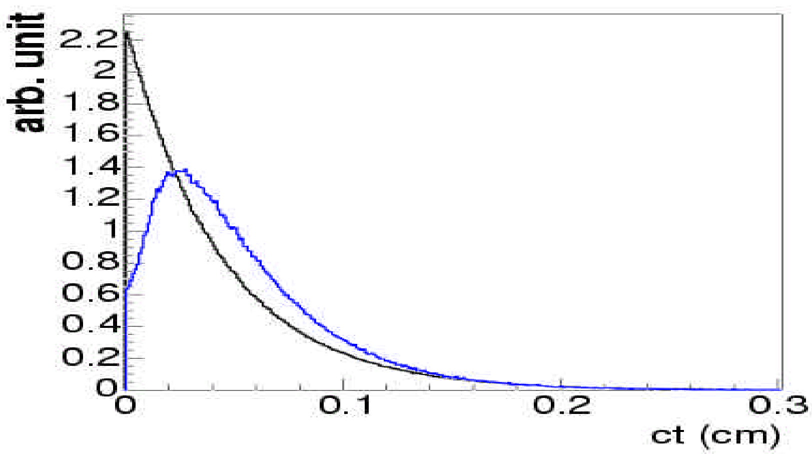
B_s mixing?

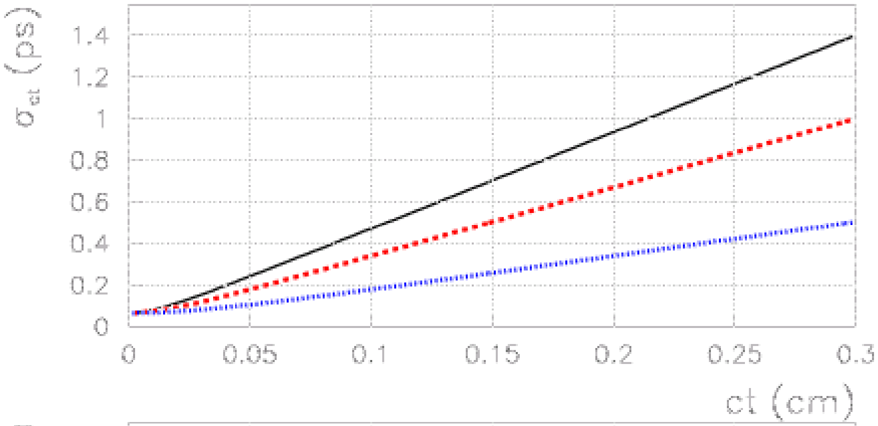
Semileptonic is the most likely place to start to set a limit

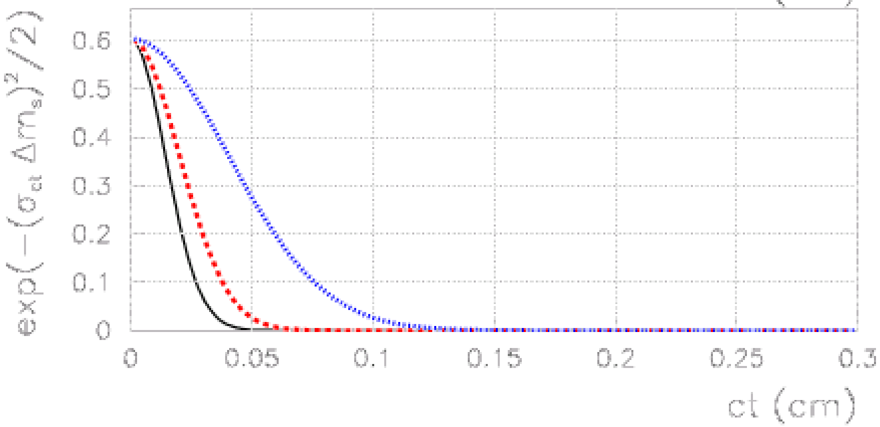
Assuming σ_t=(67fs)+t (σ_k/K) εD^2=4%

Δm_s	Signal	σ_K/K	Significance
15 ps^{-1}	7000	14%	1.6
20 ps^{-1}	7000	14%	0.7
15 ps^{-1}	7000	10%	2.3
15 ps^{-1}	7000 (no bias)	14%	2.3

- Adding $D_s \to K^*K, 3\pi$ may help (+50%×2), but need to improve S/B (currently $S/B < 0.5$)
- K factor resolution can be improved
- Sensitivity for the Δm_s is determined by the event with $ct < 500\mu$m
  - We want to collect the semileptonic decay events with NO ct bias







We are proposing a l+SVT trigger with l and SVT on opposite sides need help to better quantify the gain!

CDF B_s Sensitivity Estimate

hadronic mode only

- Current performance:
  - S=1600 events/fb^{-1} (*i.e.* $\sigma_{effective}$ for produce+trigger+recon)
  - S/B = 2/1
  - ϵD^2 = 4%
  - σ_t = 67fs

2σ sensitivity for Δm_s=15ps^{-1} with ~0.5fb^{-1} of data

- surpass the current world average

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  - eD^2 = 4%
  - s_t = 67fs

  2σ sensitivity for Δm_s=15ps^{-1} with ~0.5fb^{-1} of data

    - surpass the current world average
- With "modest" improvements
  - S=2000 fb (improve trigger, reconstruct more modes)
  - S/B = 2/1 (unchanged)
  - eD^2 = 5% (kaon tagging)
  - s_t = 50fs (event-by-event vertex + L00)

  5σ sensitivity for Δm_s=18ps^{-1} with ~1.7fb^{-1} of data

  5σ sensitivity for Δm_s=24ps^{-1} with ~3.2fb^{-1} of data

    ✓ Δm_s=24ps^{-1} "covers" the expected region based upon indirect fits.
- *This is a difficult measurement.*
- *There are ways to further improve this sensitivity…*

Work In Progress

Estimates based current performance plus modest improvements. Further gain is possible on all of these pieces:

- s_t
  - Event-by-event vertex
  - Additional Si layer at ~1cm from the beam pipe (Layer 00)
- Flavor tagging
  - Kaon tagging (same-side and opposite-side)
- Yields
  - Other B_s modes (hadronic and semileptonic)
  - Other D_s modes
  - Triggering
    - Improved use of available bandwidth
    - Improve available bandwidth
    - Improve SVT efficiency

Matters most for going to Dm_s > 20 ps^{-1}

Trigger improvements matter most for yields

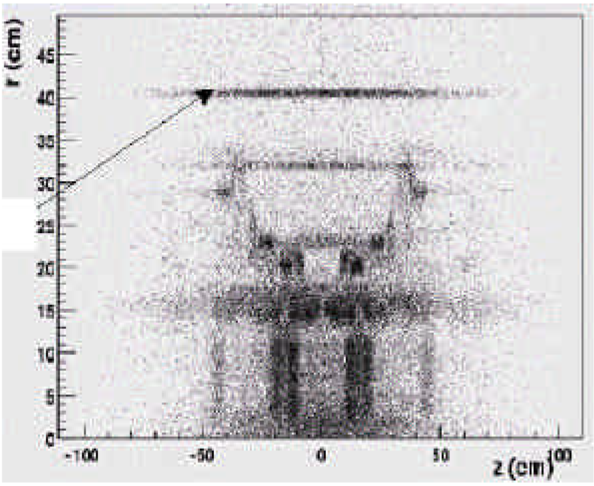
It's doable! It will take time, luminosity and more hard work!

Conclusions

- Yes, we have been optimistic
- We are already competitive in lifetimes where B factories can't get
- Still puzzled by the semileptonic lifetimes (sample composition?)
- Bs mixing is still feasible!
- Needs a collective effort
- Join the fun, it is worth!

BACKUP SLIDES

Si Tracking...



Material: 15% X_0

SVX II

- Beam incidents (“Kicker prefires”)

Operate Si only in safe conditions

- Wire bonds resonate

Avoid fixed frequency data taking

ISL

- Cooling lines obstructed (epoxy!)

11/12 lines cleared so far with the help of a boroscope

L00

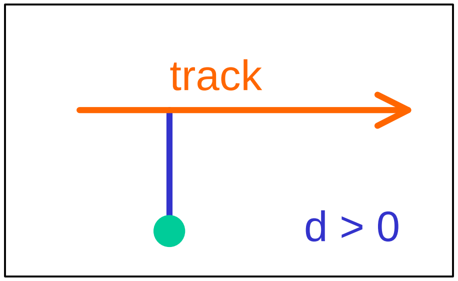
- Cross talk on readout cables

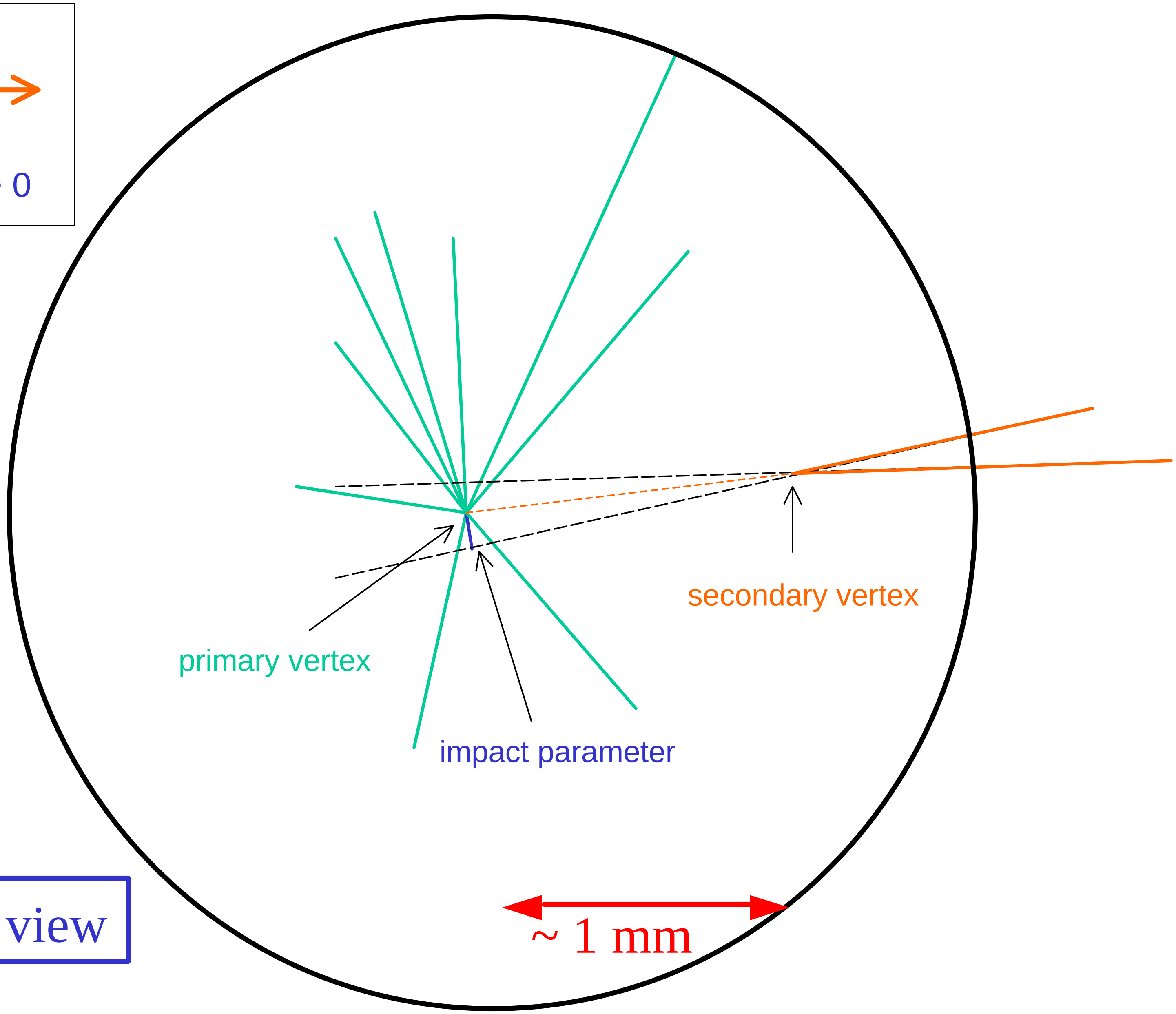
Software subtraction on event by event basis

- Radiation-related power supply troubles

Replaced radiation sensitive devices in PS

A salient property of b,c decays: lifetime





Transverse view