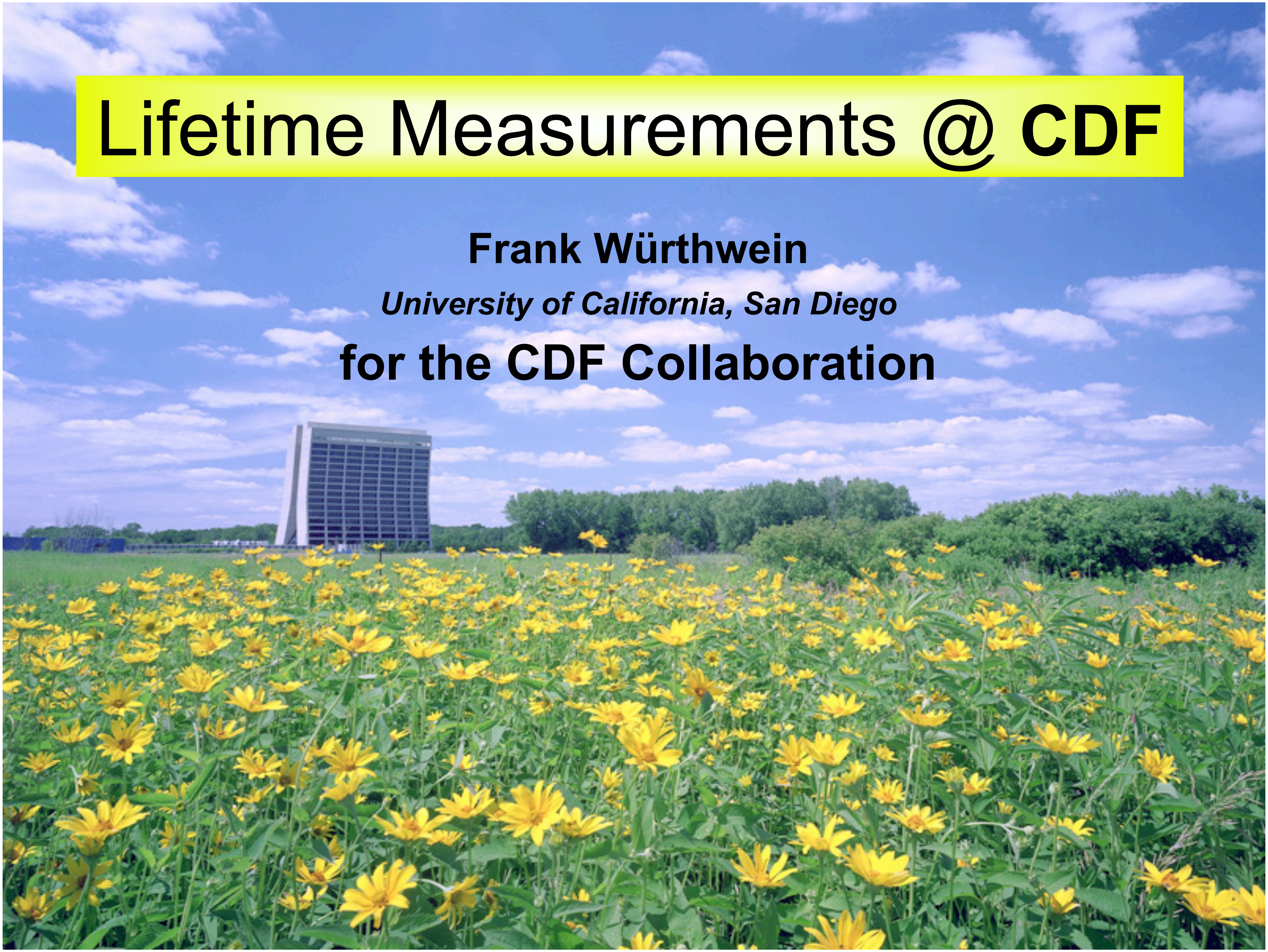
Lifetime Measurements @ **CDF**

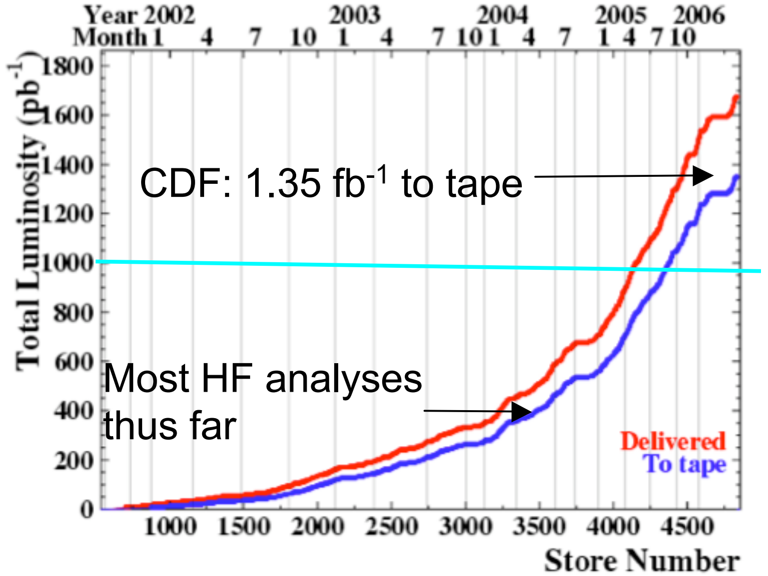
Frank Würthwein

University of California, San Diego

for the CDF Collaboration



Heavy Flavor Physics at CDF



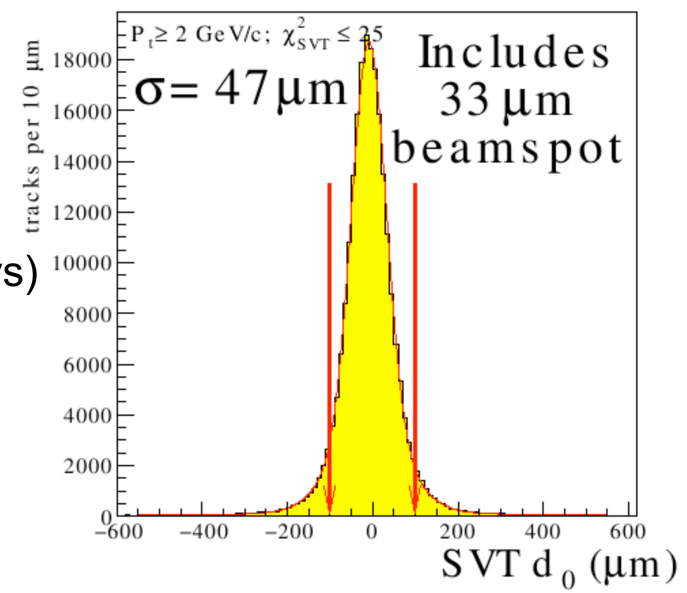
b production at the Tevatron (p anti-p coll.):

- Produce all *b*-species (B^0,B^+,B_s,B_c,B^{**},Λ_b,Ξ_b...)
  - Results based on 0.26 - 1fb^{-1}
- Triggering crucial:
  - Single & di-lepton
  - Impact parameter

Rich program in heavy flavor:

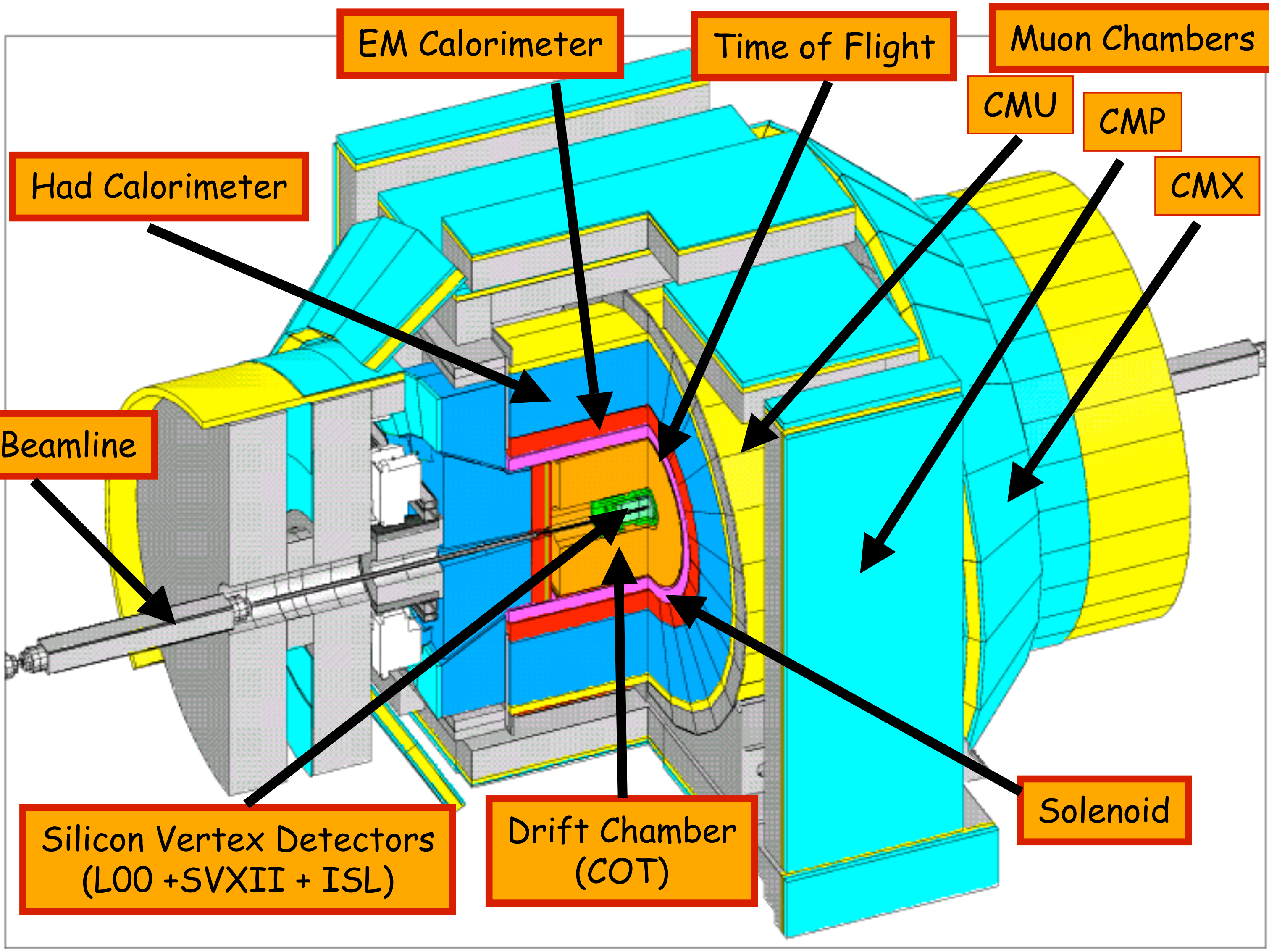
- B, D, and Quarkonium production
- Mixing
- CP violation
- Rare decays
- Spectroscopy
- *b-Hadron Lifetimes*

Triggering on tracks with large impact parameter (rich in heavy flavor decays)



Thanks to Mark Neubauer for significant part of the talk.

The CDF II Detector



Major Upgrades for Run II:

Time-of-Flight
- particle ID

Silicon systems
- larger η coverage for tracking/ b-tagging
- 3D vs. 2D

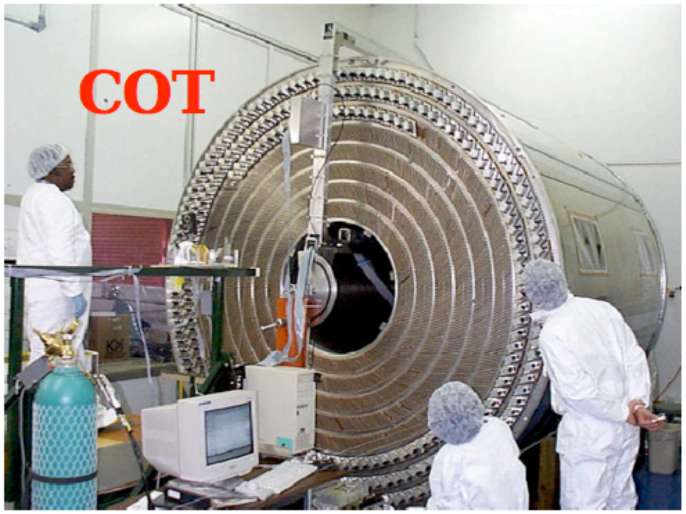
Improved COT
- better stereo
- faster drift

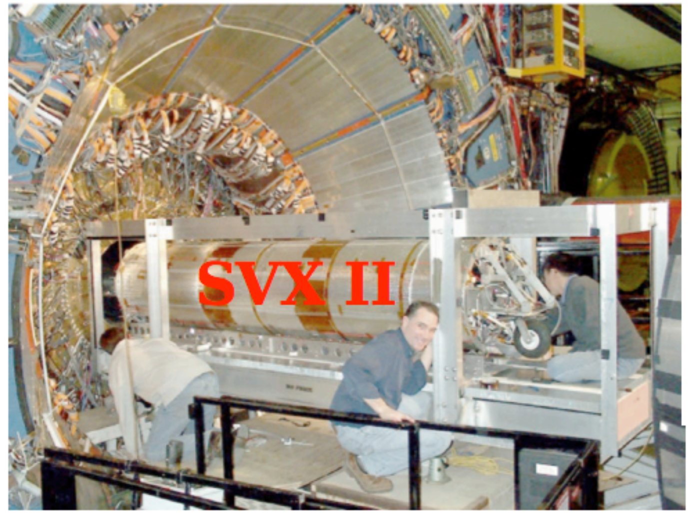
Muons
- improved coverage

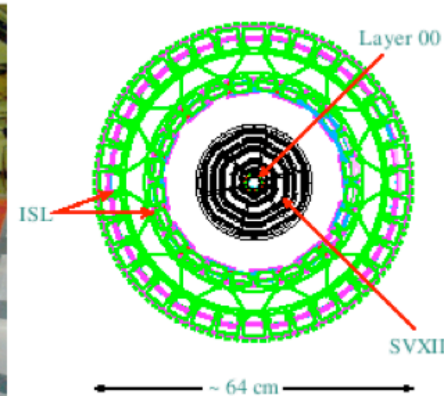
Endplug Calorimeter
- larger η coverage for electron ID

SVT Trigger
- triggering on displaced vertices at Level-2

Integrated Tracking System







Silicon system:

SVX II
- 5 layers double-sided silicon → r-ϕ, r-z tracking
- 2.5 < r < 10.6 cm
- 96 cm long → ×2 RunI acceptance

ISL
- 2 additional Si layers
- r < 28 cm; cover |η|<2

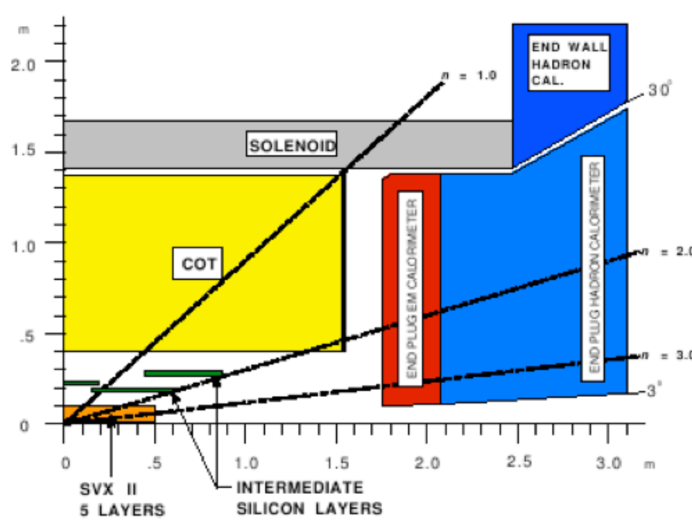
L00
- inner Si layer at beam pipe (R = 1.5 cm)

(L00 not used in our analysis)

Tracking in a nutshell:

1) Segments formed from hits each COT superlayer (SL)
2) Segments linked together to form 2D track
3) Stereo segments linked into 2D track and helix fit is performed
4) COT track extrapolated into SVXII, outer layers first
5) SVXII hits consistent with COT track are added succession, with track refit after each iteration

CDF Tracking Volume



Triggers & Samples

All weakly decaying b-hadrons are being studied in both fully reconstructed as well as semi-leptonic decays.

	Yields	Lumi	Results available	Future?
• No lifetime bias:				
– 8GeV lepton	1k-10k	260-360pb^{-1}	3/05-8/05	unlikely
– J/ψ di-muon	0.5k-10k	1fb-1	6/06 *New result!*	yes
• Lifetime biased:				
– Lepton & svt	50k-400k	1fb-1	none	yes
– Hadronic	0.4k-8k	360pb^{-1}	2/06 *Recent result!* 3/05	yes

CDF Lifetime results I will not talk about in detail:

- 2005:
  - 8GeV lepton B^+,B^0,B_s:

$$\tau_{B_s} = 1.381 \pm 0.055^{+0.052}_{-0.046}\, ps$$

$$\tau_{B^+} = 1.653 \pm 0.029^{+0.033}_{-0.031}\, ps$$

$$\tau_{B^0} = 1.473 \pm 0.036 \pm 0.054\, ps$$

  - Hadronic trig. B^+,B^0,B_s:

$$\tau_{B_s} = 1.60 \pm 0.10 \pm 0.02\, ps$$

$$\tau_{B^+} = 1.66 \pm 0.03 \pm 0.01\, ps$$

$$\tau_{B^0} = 1.51 \pm 0.02 \pm 0.01\, ps$$

  - J/ψ trig. $B_c \rightarrow J/\psi X l \nu$:

$$\tau_{B_c} = 0.463^{+0.073}_{-0.065} \pm 0.036\, ps$$

- 2004:
  - J/ψ trig. B^+,B_s:

$$\tau_{B_s} = 1.369 \pm 0.100^{+0.008}_{-0.010}\, ps$$

$$\tau_{B^+} = 1.662 \pm 0.033 \pm 0.008\, ps$$

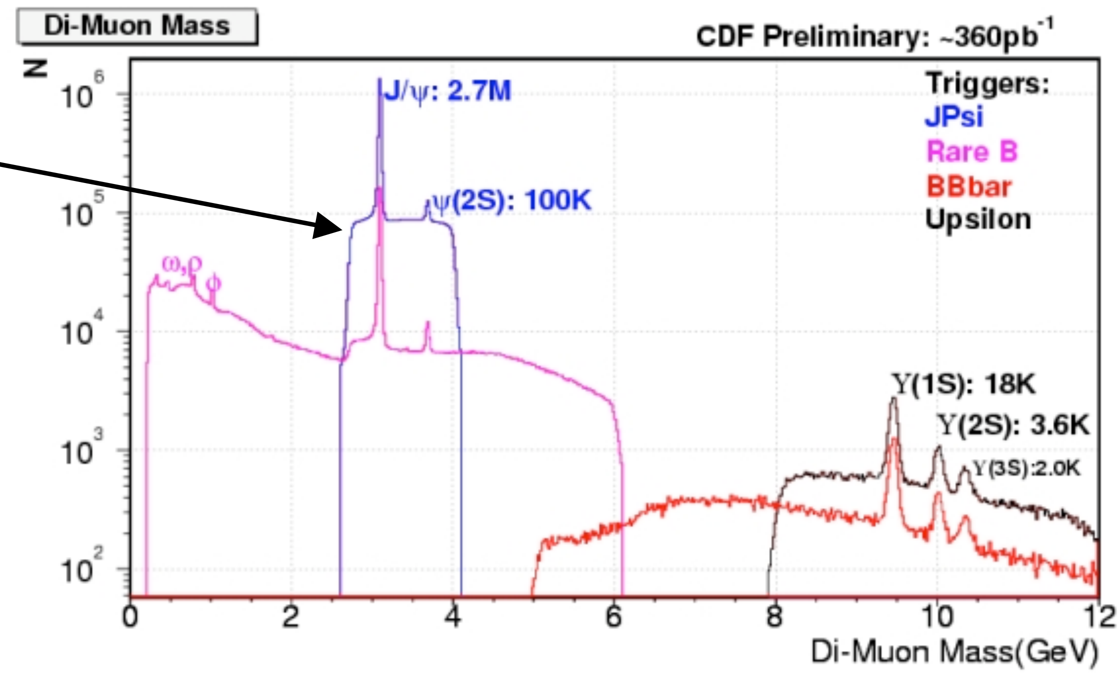
New Results from di-muon trigger

$\Lambda_b \rightarrow J/\psi \Lambda$

$B^0 \rightarrow J/\psi K_s$

Di-muon Triggers @ CDF

$J/\psi \rightarrow \mu^+\mu^-$ trigger

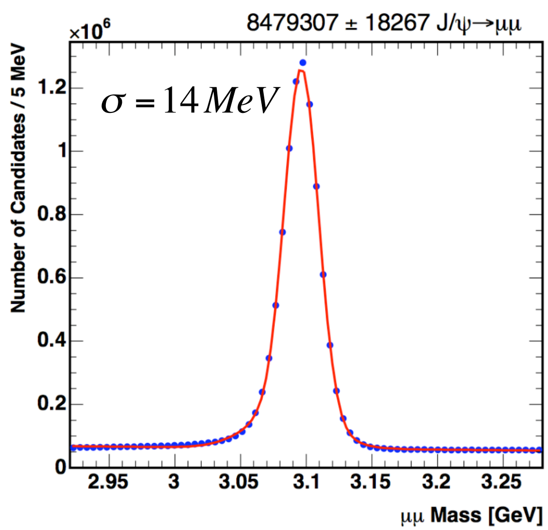


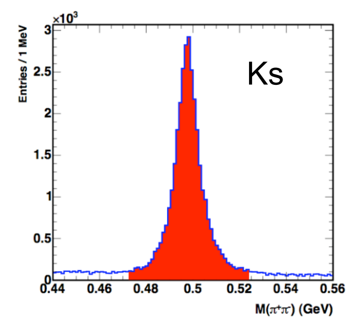
Level 1: 2 muons
$p_T(m) > 1.5$ GeV/c
Level 3: Opposite charge
$m(\mu^+\mu^-)$ region for ψ, ψ'

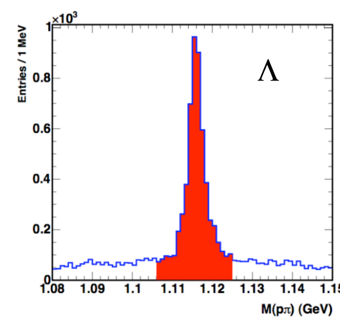
Our dataset:

8.5Million clean $J/\psi \rightarrow \mu^+\mu^-$
Clean Ks and Λ.

Backgrounds in
$\Lambda_b \rightarrow J/\psi\Lambda$, $B^0 \rightarrow J/\psi K_s$
are combinations of true
J/ψ, Λ, K_s

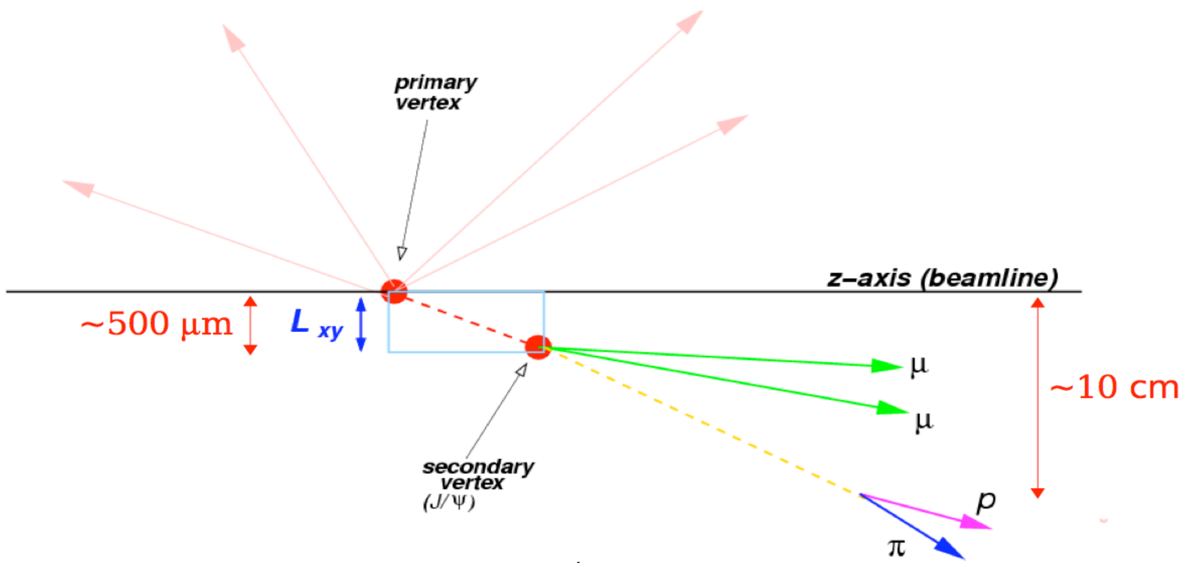






Analysis Strategy

- Use $B^0 \rightarrow J/\psi K_s$ as reference to develop analysis and check for systematics.
- Check lifetime in all other $B_{u.d} \rightarrow J/\psi X$ decays, using J/ψ vertex only.
- Unblind $\Lambda_b \rightarrow J/\psi \Lambda$ after all checks are done.



$$\text{Proper Decay Length (PDL)} = \frac{L^b_{xy}}{(\beta\gamma)^b_T} = L^b_{xy}\, c\, \frac{M_b}{p^b_t}$$

$$\text{where } L^b_{xy} = \left(\vec{x}(J/\psi)\ \ \vec{x}(PV)\right)\cdot \hat{p}_T^{\,b}$$

b-hadron lifetimes we measure

$B^0 \to J/\psi\, K_s$, with $J/\psi \to \mu\mu$, $K_s \to \pi\pi$ ← **Full systematics**

$B^0 \to \psi(2S)\, K_s$, with $\psi(2S) \to \mu\mu$, $K_s \to \pi\pi$

$B^0 \to \psi(2S)\, K_s$, with $\psi(2S) \to J/\psi\pi\pi$, $J/\psi \to \mu\mu$, $K_s \to \pi\pi$

$B^0 \to J/\psi\, K^{*0}$, with $J/\psi \to \mu\mu$, $K^{*0} \to K\pi$

$B^0 \to \psi(2S)\, K^{*0}$, with $\psi(2S) \to \mu\mu$, $K^{*0} \to K\pi$

$B^0 \to \psi(2S)\, K^{*0}$, with $\psi(2S) \to J/\psi\pi\pi$, $J/\psi \to \mu\mu$, $K^{*0} \to K\pi$

$B^+ \to J/\psi\, K^+$, with $J/\psi \to \mu\mu$

$B^+ \to \psi(2S)\, K^+$, with $\psi(2S) \to \mu\mu$

$B^+ \to \psi(2S)\, K^+$, with $\psi(2S) \to J/\psi\pi\pi$, $J/\psi \to \mu\mu$

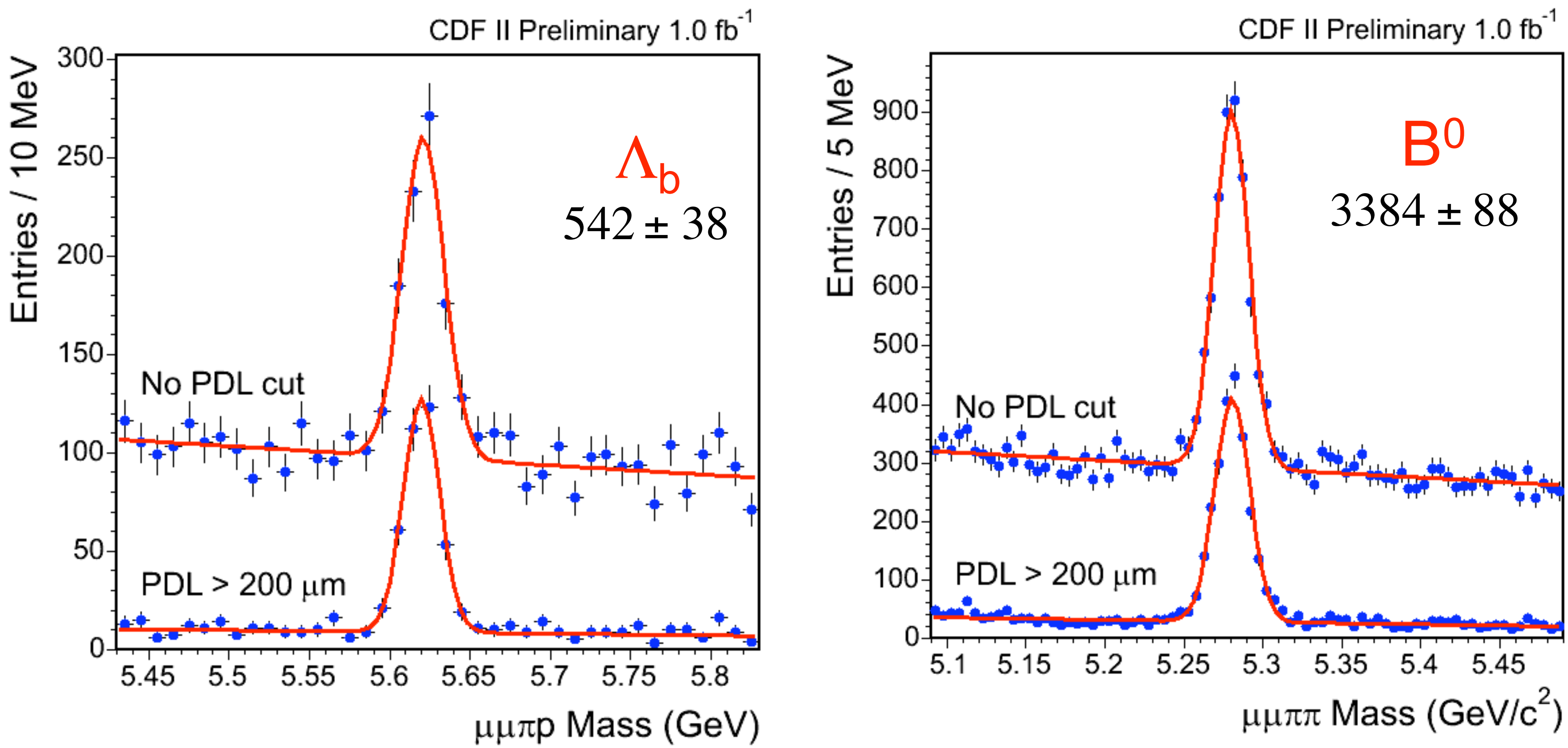
$B^+ \to J/\psi\, K^{*+}$, with $J/\psi \to \mu\mu$, $K^{*+} \to K_s\pi$

(second through last B modes above) ← **Statistical errors only (for cross-√)**

$\Lambda_b \to J/\psi\, \Lambda^0$, with $J/\psi \to \mu\mu$, $\Lambda^0 \to p\pi$ ← **Full systematics**

Our primary goal (→ Λ_b)

$\Lambda_b \to J/\psi\Lambda$ and $B^0 \to J/\psi K_s$



Fit Model: Signal

Signal PDL modeled as an exponential decay convoluted with a Gaussian resolution function :

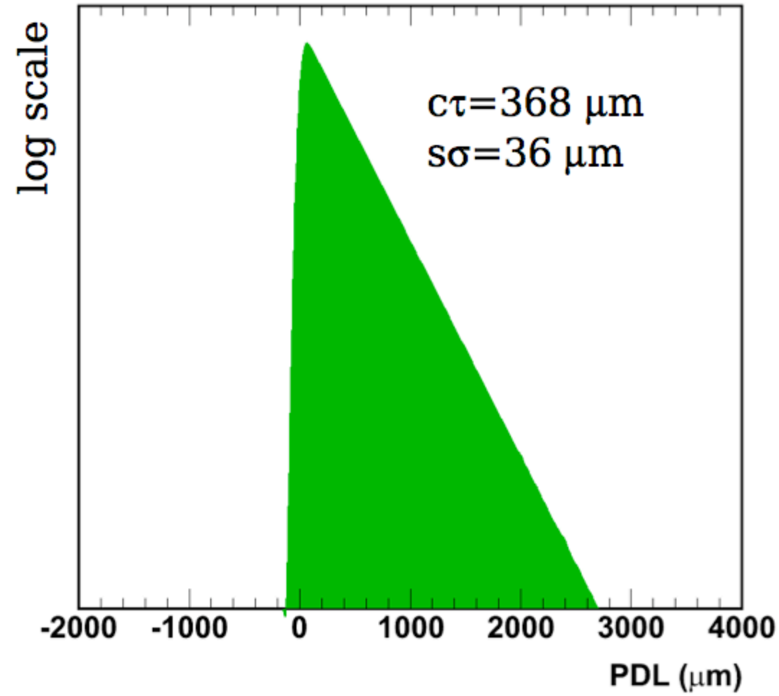
$$P^{\lambda}_{sig}(\lambda_i, \sigma^{\lambda}_i | \vec{\alpha}_{sig}) = E(\lambda_i | c\tau) * G(\lambda_i, \sigma^{\lambda}_i | s)$$

where:

τ = signal lifetime (the goal)
s = overall scale factor on PDL errors

$$E(\lambda_i | c\tau) = \begin{pmatrix} \frac{1}{c\tau} e^{-\lambda_i / c\tau} & , \lambda_i \geq 0 \\ 0 & , \lambda_i < 0 \end{pmatrix}$$

$$G(\lambda_i, \sigma^{\lambda}_i | s) = \frac{1}{\sqrt{2\pi} s \sigma^{\lambda}_i} e^{\frac{-\lambda_i^2}{2(s\sigma^{\lambda}_i)^2}}$$



Fit Model: Background

Background PDL modeled as sum of four components:

$$P^{\lambda}_{bkg}(\lambda_i|\sigma^{\lambda}_i, s, f_-, \lambda_-, f_+, \lambda_+, f_{++}, \lambda_{++}) = G(\lambda_i, \sigma^{\lambda}_i|s) * \{ (1-f_- -f_+ -f_{++})\ \delta(0) + f_-\ E(-\lambda_i|\lambda_-) + f_+\ E(\lambda_i|\lambda_+) + f_{++} E(\lambda_i|\lambda_{++}) \}$$

zero lifetime (prompt)

"negative lifetime" (resolution tails)

long-lived background ($b \rightarrow J/\psi\ X$ combined with unrelated tracks)

where:

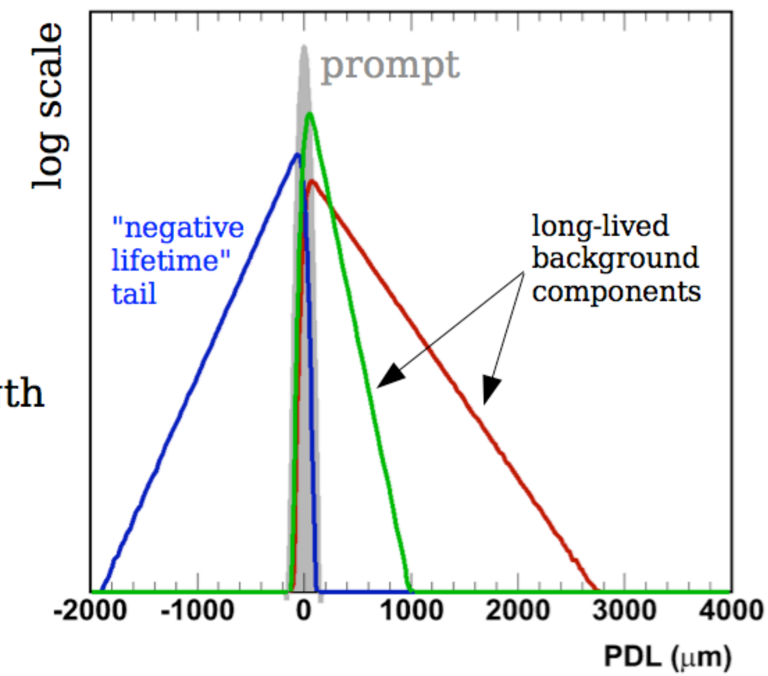
f_- = negative exponential fraction

λ_- = negative exponential decay length

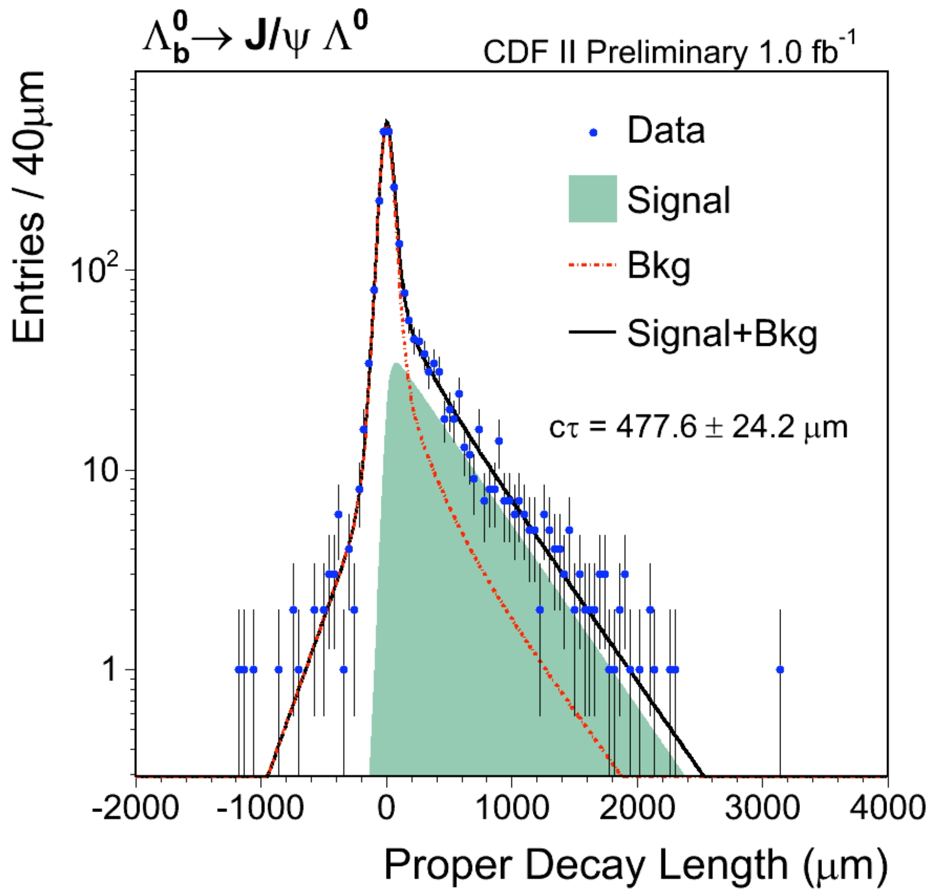
$f_{+(++)}$ = $1^{st}(2^{nd})$ positive exponential fraction

$\lambda_{+(++)}$ = $1^{st}(2^{nd})$ positive exponential decay length

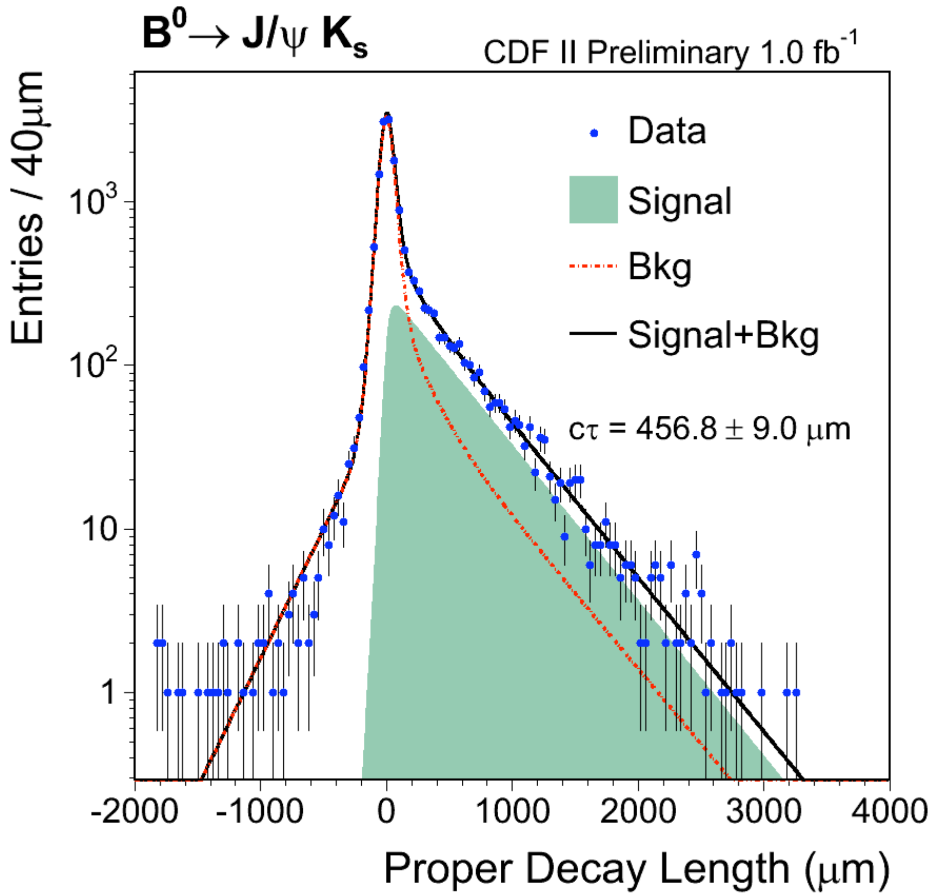
Fits with different shape assumptions used to constrain systematic



Measured Lifetimes

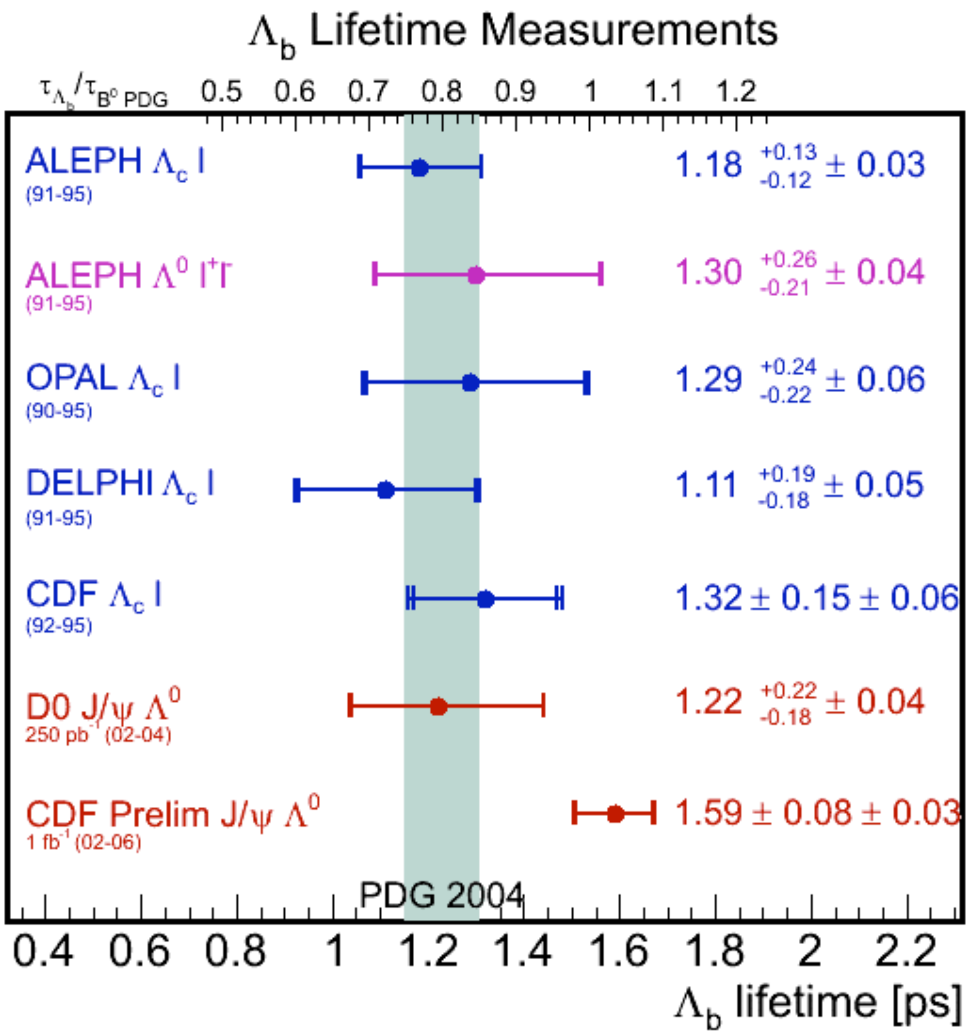


$$\tau(\Lambda_b^0) = 1.593^{+0.083}_{-0.078}(stat.) \pm 0.033(syst.)$$



$$\tau(B^0) = 1.524 \pm 0.030(stat.) \pm 0.016(syst.)$$

Λ_b Lifetime Summary



Single most precise, competitive with world avg, 3.1σ higher than world avg.

$$\frac{\tau_{\Lambda_b}}{\tau_{B^0}} = 1.037 \pm 0.058$$

(stat+syst)

Consistent with theory!

Lifetime Systematics

Source	$c\tau$ (B^0) [μm]	$c\tau$ (Λ_b) [μm]
Fitter Bias	0.4	0.5
Fit Model:		
PDL Resolution	3.1	5.5
Mass Signal	0.7	2.3
Mass Background	0.1	0.1
PDL Background	0.5	0.7
PDL Error Modeling	0.1	0.2
Mass Error Modeling	0.6	0.2
Mass-PDL Background Correlation	1.9	4.1
PDL-σ(PDL) Background Correlation	0.3	1.3
Primary Vertex Determination	0.2	0.3
Alignment:		
SVX Internal	2.0	2.0
SVX/COT Global	2.2	3.2
V^0 Pointing	0.6	5.4
Total	**4.9**	**9.9**

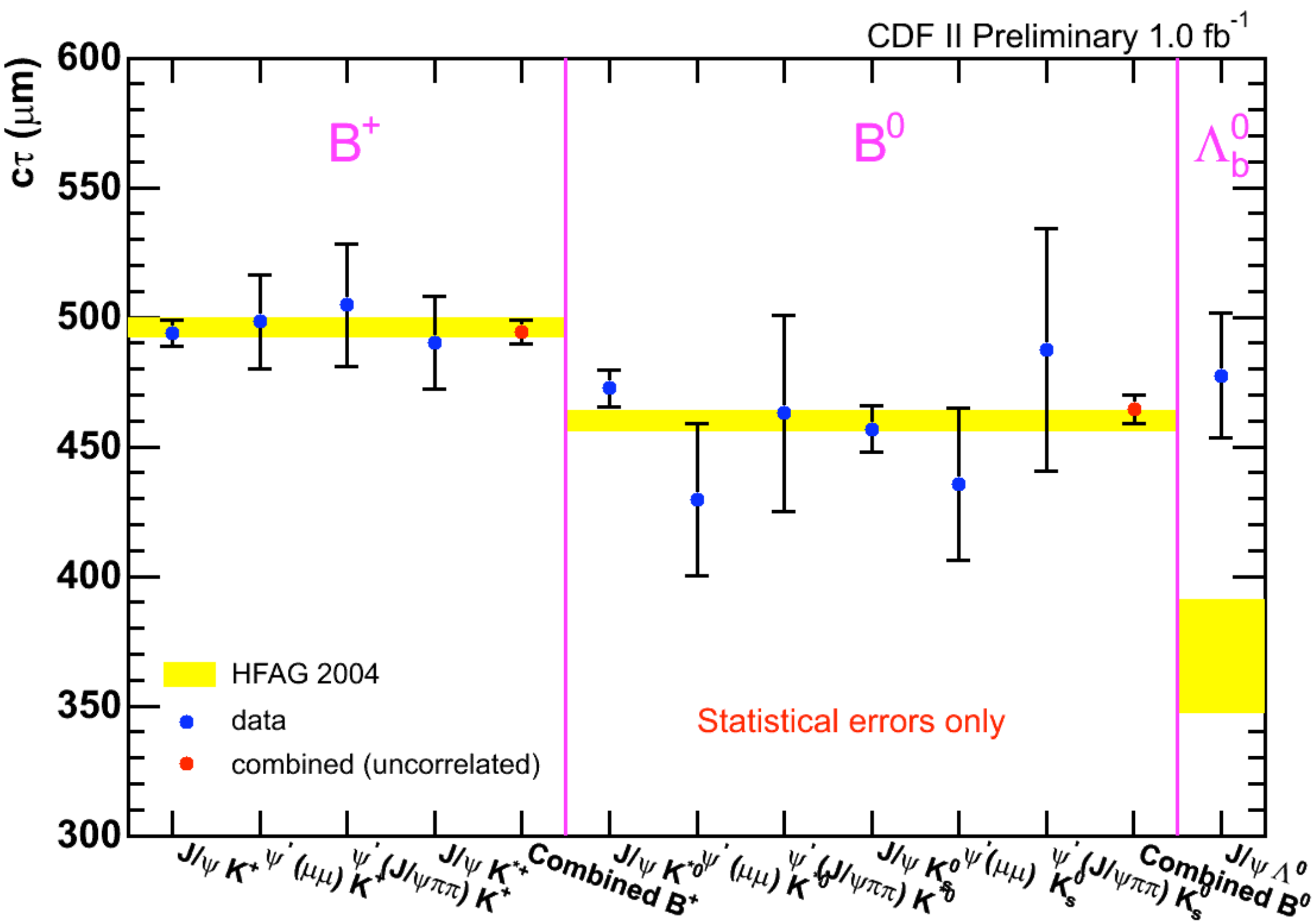
Adding in second Gauss to res. function (PDL Resolution)

Fitting different mass sidebands (Mass-PDL Background Correlation)

Derived from study of pointing pulls vs ctau (V^0 Pointing)

Systematics are factor 10 smaller than difference between PDG '04 and CDF '06 !!!

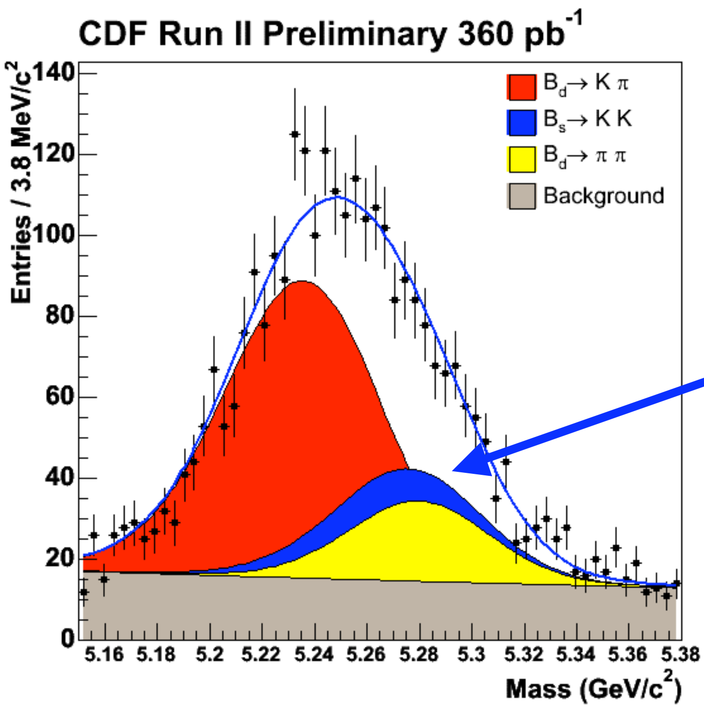
All di-muon trigger lifetimes



B0: 494.3+-4.5μm
B+: 464.5+-5.3μm
Δ= 0.9+-3.4μm

Note:
These avg aren't measurements!
They lack systematic errors and are only done as a crosscheck!

Lifetimes with hadronic trigger: e.g. $B_s \rightarrow K^+K^-$

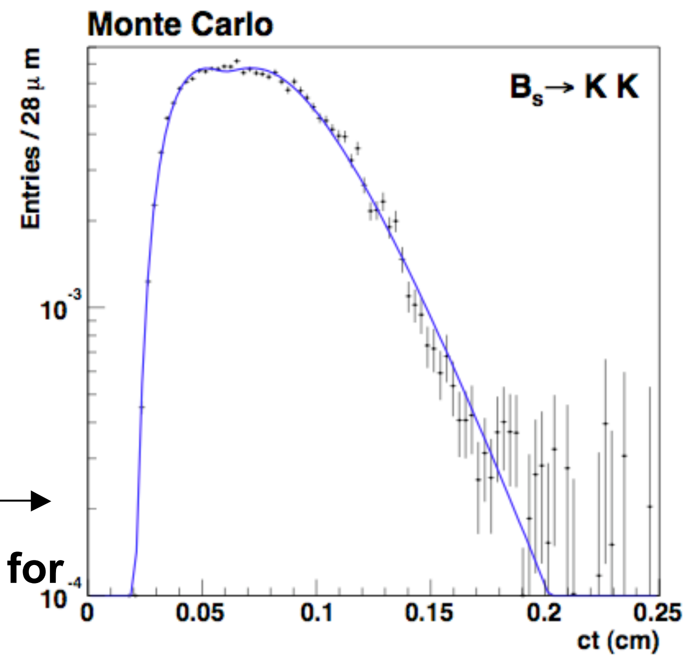


← h^+h^- mass

$B_s \rightarrow K^+K^-$

Eff(ctau) →

Trigger sculpting for low & high ct !!!



$$\tau_{B_s} = 1.53 \pm 0.18 \pm 0.02\,ps$$

$$\frac{\Delta\Gamma_{CP}}{\Gamma_{CP}}(B_s \rightarrow K^+K^-) = -0.08 \pm 0.23 \pm 0.03$$

Some details on $B_s \rightarrow K^+K^-$

- Two fits:
  - Float B_d and $B_s \rightarrow K^+K^-$ lifetimes
  - Fix B_d to PDG value
  - In both cases $B_s \rightarrow K^+\pi^-$ lifetime is fixed to PDG.
  - Simultaneous fit to yields & lifetimes.
- Signal fractions:
  - $B_s \rightarrow K^+K^-$ = 22.3 +- 1.7 %
  - $B_d \rightarrow K^+ \pi^-$ = 62.7 +- 1.7 %
  - $B_d \rightarrow \pi^+ \pi^-$ = 15.3 +- 1.5 %
  - $B_s \rightarrow K^+ \pi^-$ = -0.3 +- 1.0 %

Future Attractions

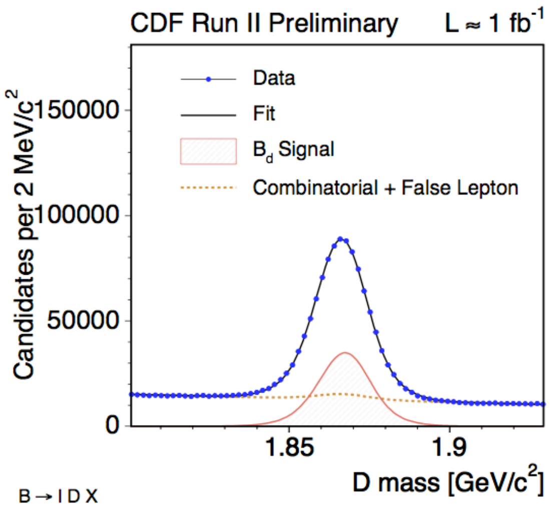
Precision Measurements (incl. Λ_b) using

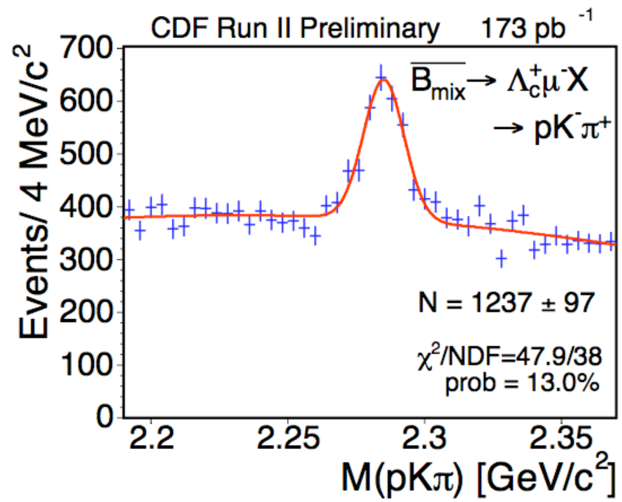
Lepton & svt

lepton (pt>4GeV) & track (pt>2GeV), one of which with d_0>120micron.

Hadronic trigger

2 tracks with pt>2GeV, positive Lxy, and d_0>120micron.

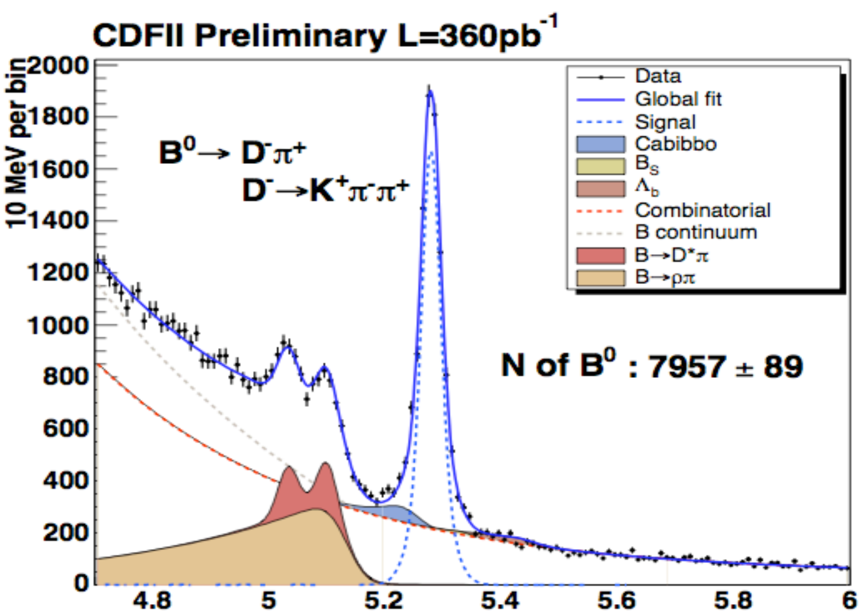


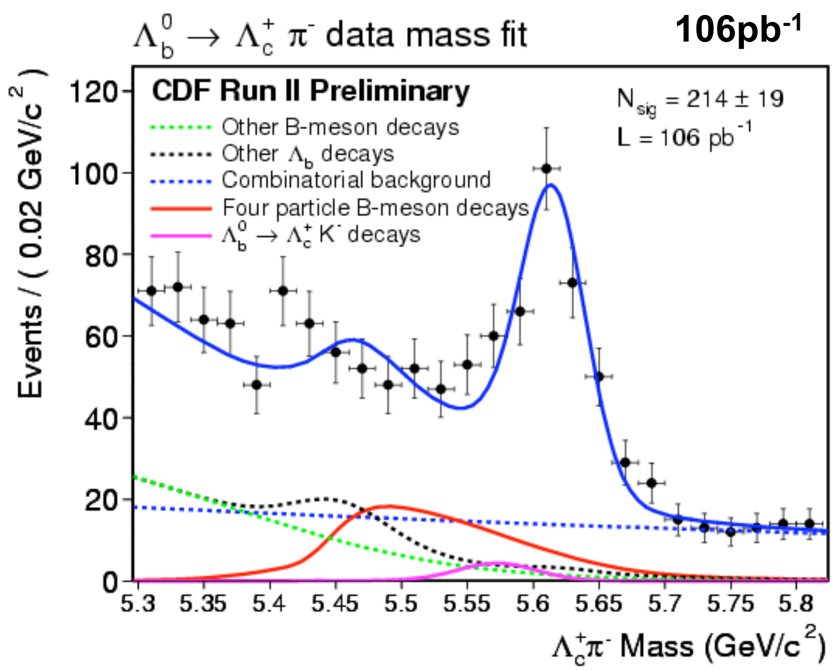


Lepton $D^{(*)0}, D^+, D_s, \Lambda_c \approx$5,000-400,000 evts per fb^{-1}

Fully reconstructed b-hadrons ≈1,000-20,000 evts per fb^{-1}

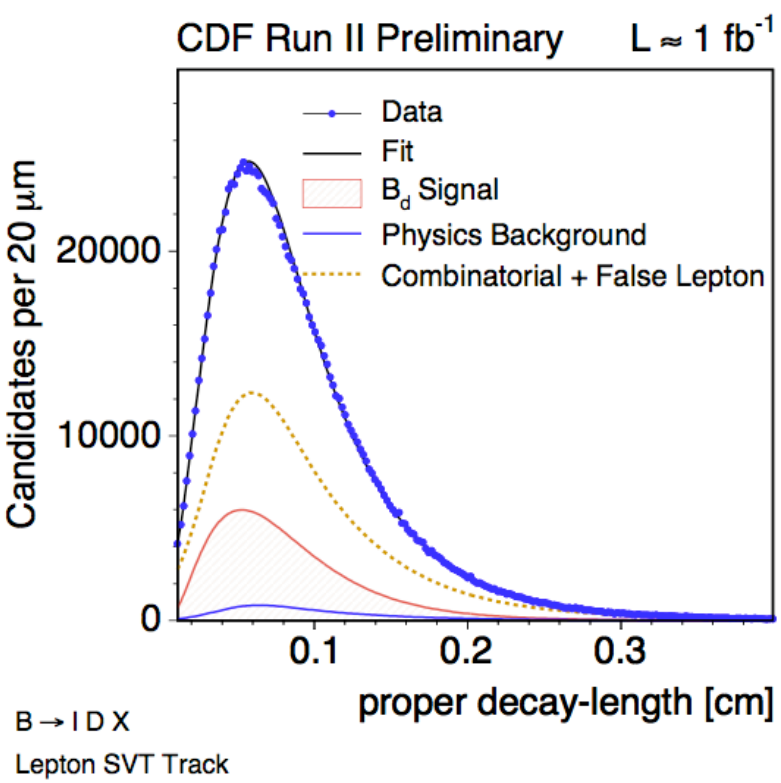
Both types of triggers have a lifetime bias!



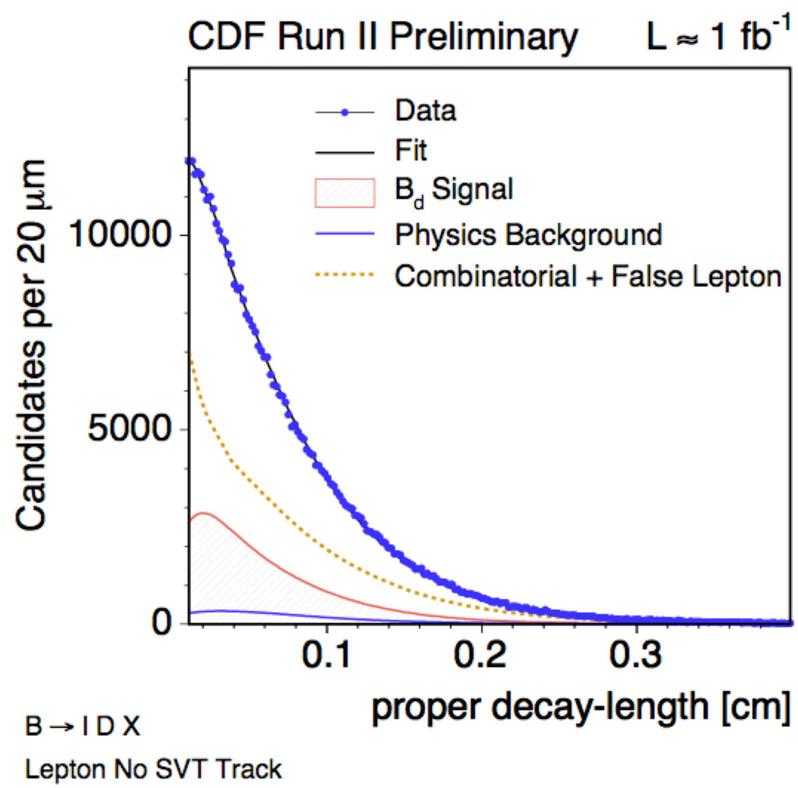


Lifetime sculpting in lepton & svt trigger

Triggered on lepton



Triggered on charm



Summary & Conclusion

- CDF continues to have a very active program of measuring lifetimes of weakly decaying b-hadrons.
- The latest on Λ_b

$$\tau(\Lambda_b^0) = 1.593^{+0.083}_{-0.078}(stat.) \pm 0.033(syst.)$$

$$\frac{\tau_{\Lambda_b}}{\tau_{B^0}} = 1.037 \pm 0.058$$

(stat+syst)

- Two more Λ_b measurements coming:
  - $\Lambda_b \rightarrow \Lambda_c \pi$ using the hadronic trigger.
  - $\Lambda_b \rightarrow \Lambda_c X l \nu$ using the lepton & svt trigger.
- The latest $B_s \rightarrow K^+K^-$ measurements:

$$\tau_{B_s} = 1.53 \pm 0.18 \pm 0.02\, ps$$

$$\frac{\Delta\Gamma_{CP}}{\Gamma_{CP}}(B_s \rightarrow K^+K^-) = -0.08 \pm 0.23 \pm 0.03$$