World's Best $\Lambda_b^0 \to \Lambda_c^+ \pi^-$ Lifetime Measurement

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Talk Outline

- Current Λ_b^0 lifetime status.
- Analysis Description.
- Anticipated Λ_b^0 Lifetime Result.

Theoretical Predictions

Qualitative B lifetime hierarchy: $\tau(B^+) \geq \tau(B^0) \sim \tau(B_s^0) > \tau(\Lambda_b^0) >> \tau(B_c)$

Heavy Quark Expansion (HQE) predicts values for weakly decaying hadrons

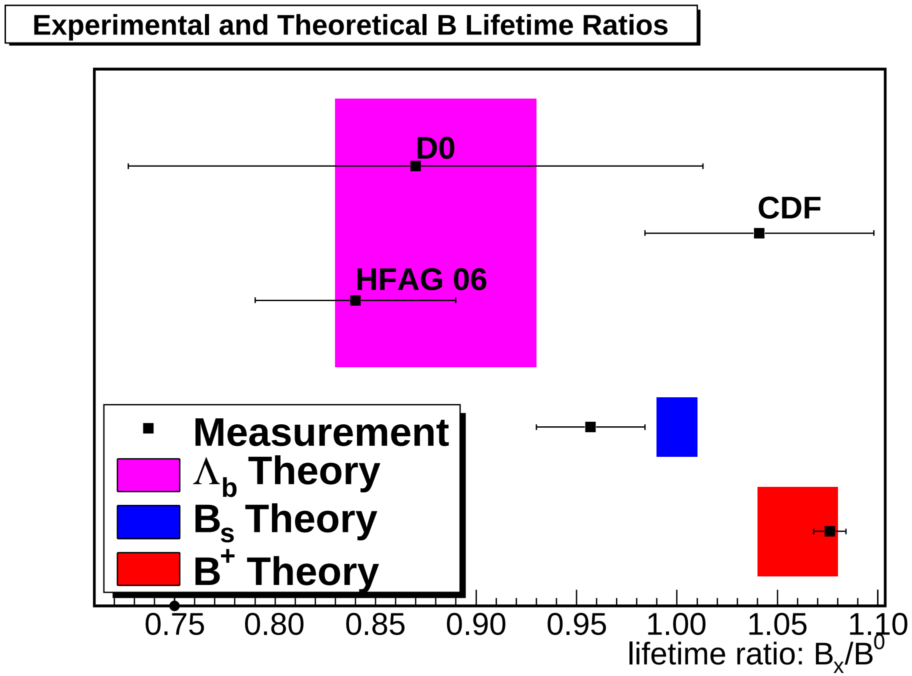
$$\Gamma = \frac{G_F^2 m_b^5}{192\pi^3}|V_{cb}|^2 \cdot \left[A_0 + A_2\left(\frac{\Lambda_{QCD}}{m_b}\right)^2 + A_3\left(\frac{\Lambda_{QCD}}{m_b}\right)^3 + \cdots\right]$$

Theoretical lifetime predictions:

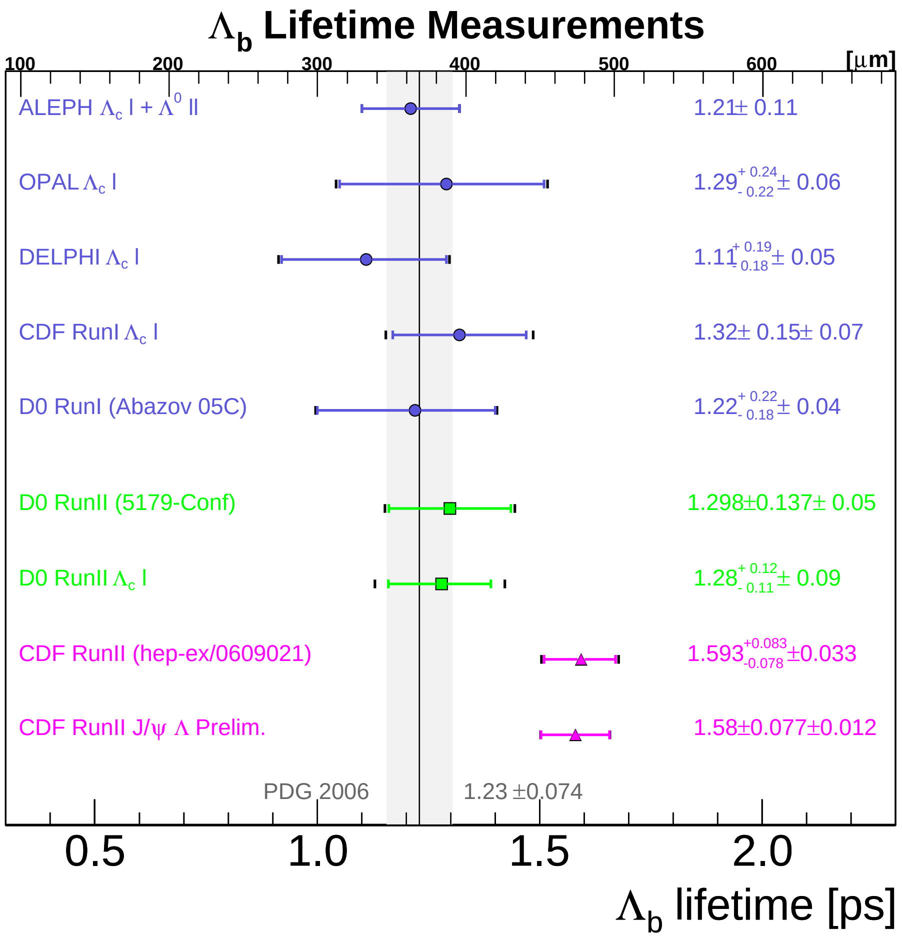
- $\tau(B^+)/\tau(B^0) = 1.06 \pm 0.02$
- $\tau(B_s^0)/\tau(B^0) = 1.00 \pm 0.01$
- $\tau(\Lambda_b^0)/\tau(B^0) = 0.88 \pm 0.05$

C. Tarantino *et al* hep-ph/0310241

C. Tarantino *et al* hep-ph/0702235v2



Recent CDF Λ_b^0 Lifetime Results



- Recent CDF measurements of $ct(\Lambda_b^0)$ in $\Lambda_b^0 \rightarrow J/\psi\Lambda$ decays disagree with previous measurements by several sigma.
  - `cdfnote 8248`
  - `cdfnote 8524`
- Our measurement of $ct(\Lambda_b^0)$ in fully-reconstructed, $\Lambda_b^0 \rightarrow \Lambda_c^+\pi^-$ decays will be an important piece of the puzzle.

Analysis Description

Goal: Measure $\tau(\Lambda_b^0)$ using fully-reconstructed $\Lambda_b^0 \to \Lambda_c^+\pi^-$ decays from TTT.

Method: Generally the same approach as described in `cdfnote 7386`

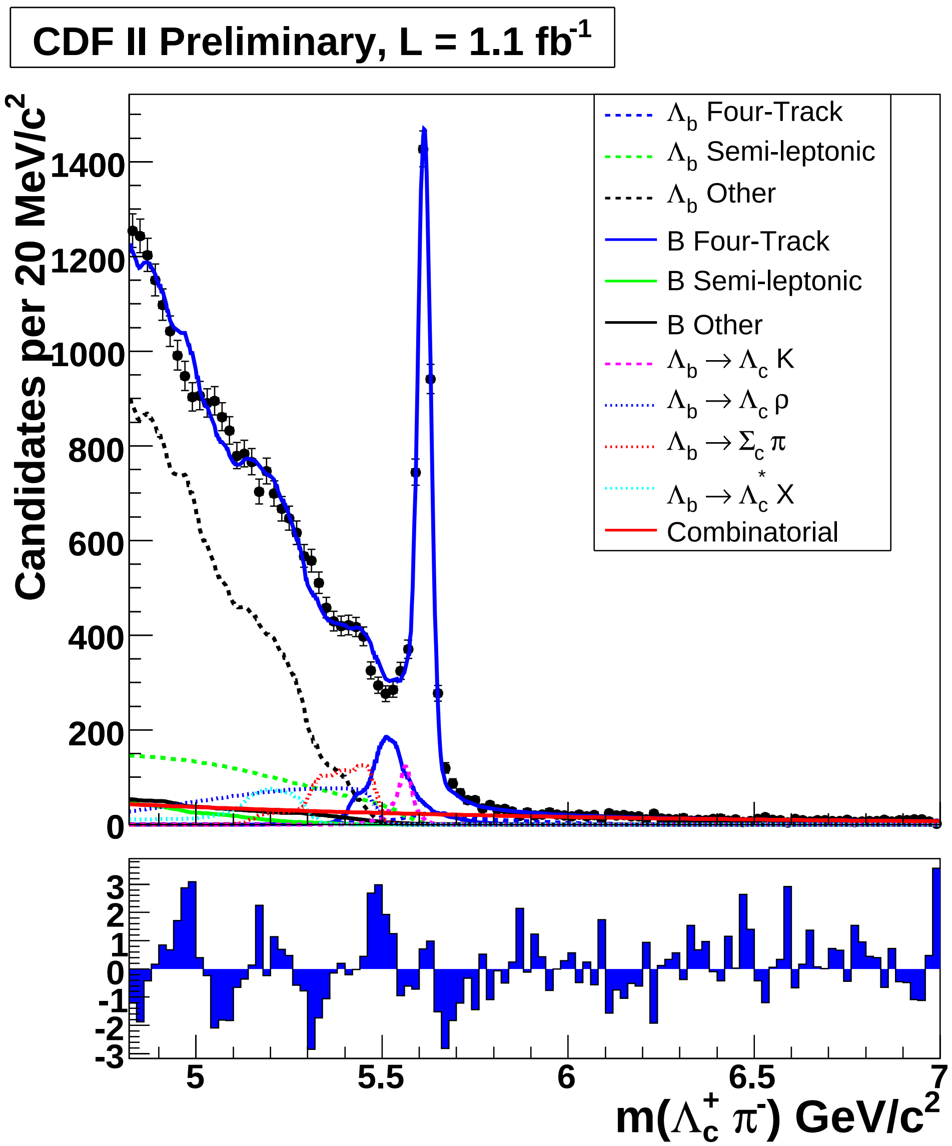
Analysis Features:

- High statistics sample: ~ 3000 reconstructed Λ_b^0 decays.
- 2-step, sequential fit; Mass fit followed by Λ_b^0 Lifetime fit.
- Binned Mass fit.
- Un-binned, maximum-likelihood, 2-D (ct,σ_{ct}) Lifetime fit.
- Blind lifetime measurement.
- Correct for the two-track trigger bias.
- Fit framework developed under RooFit.
- Analysis details documented in `cdfnote 8578`.

$\Lambda_b^0 \to \Lambda_c \pi$ Mass Fit

- The details of the mass fit are described in `cdfnote 8395`.
- The same mass fit that was used for the Σ_b discovery (`cdfnote 8396`).
- Binned, constrained mass fit.
- $\Lambda_b^0 \to \Lambda_c^+ \pi^-$ Signal + 11 background components.
- Most background templates are smoothed histograms from Monte Carlo.
- Gaussian + Smeared double-sided exponential for Λ_b^0 signal mass.
- 5 signal shape parameters + 12 normalizations are floating in the fit.

$\Lambda_b^0 \to \Lambda_c \pi$ Mass Fit



$m(\Lambda_c^+\pi^-)$ Windows:

Signal region $\in [5.565, 5.670]\mathrm{GeV}$

Upper sideband $\in [5.800, 7.000]\mathrm{GeV}$

Normalization	Value
$N_{\Lambda_b^0 \to \Lambda_c^+\pi^-}$	2904.9 ± 57.9 (82%)
$N_{B\,Four-Track}$	250.5 ± 15.4 (7%)
$N_{\Lambda_b^0 \to \Lambda_c^+ K^-}$	138.6 ± 15.9 (4%)
$N_{Combinatorial}$	116.2 ± 5.0 (3%)
$N_{\Lambda_b^0\,Four-Track}$	113.7 ± 15.9 (3%)
$N_{\Lambda_b^0 \to \ell\bar{\nu}_\ell X}$	27.0 ± 7.8 ($<1\%$)
$N_{\Lambda_b^0\,`Other'}$	7.2 ± 6.8 ($<1\%$)
$N_{B`Other'}$	3.5 ± 0.3
$N_{\Lambda_b^0 \to \Sigma_c^+\pi^-}$	0.763917 ± 0.112236
$N_{B \to \ell\bar{\nu}_\ell X}$	0.643348 ± 0.27741
$N_{\Lambda_b^0 \to \Lambda_c^{+*} X}$	0.097919 ± 0.0217996
$N_{\Lambda_b^0 \to \Lambda_c^+\rho^-}$	0.0265047 ± 0.00408758

The Lifetime Fit

The general form of the lifetime likelihood;

$$\mathcal{L}(ct, \sigma_{ct}) = \sum_i P^i_{ct,\sigma_{ct}}(ct, \sigma_{ct}; S_{ct}).$$

$P^i_{ct,\sigma_{ct}}(ct, \sigma_{ct}; S_{ct})$ 2-D, joint probability that can be factorized;

$$P^i_{ct,\sigma_{ct}}(ct, \sigma_{ct}; S_{ct}) = P^i_{ct}(ct|\sigma_{ct}; S_{ct}) \cdot P^i_{\sigma_{ct}}(\sigma_{ct}) \cdot \epsilon_{TTT}(ct)$$

$P^i_{ct}(ct\|\sigma_{ct}; S_{ct})$	Conditional PDF that predicts ct **given** a distribution of σ_{ct}.
S_{ct}	Global σ_{ct} scale factor
$P^i_{\sigma_{ct}}(\sigma_{ct})$	Distribution of σ_{ct} needed to complete the conditional P^i_{ct}.
$\epsilon_{TTT}(ct)$	Trigger efficiency. Used to correct bias from trigger and analysis cut selection.

$\Lambda_b^0 \to \Lambda_c \pi$ Lifetime Fit Summary

$$\mathcal{L}(ct, \sigma_{ct}) = \sum_7 f^i \cdot P^i_{ct}(ct|\sigma_{ct}; S_{ct}) \cdot P^i_{\sigma_{ct}}(\sigma_{ct}) \cdot \epsilon^i_{TTT}(ct)$$

Component	f^i	$P_{ct}(ct)$	$P^x_{\sigma_{ct}}(\sigma_{ct})$	ϵ^i_{TTT}
$\Lambda_b^0 \to \Lambda_c^+ \pi^-$	0.82	signal	S	Λ_b^0
$B \to$ four tracks	0.07	adjusted signal	S	B^0
$\Lambda_b^0 \to \Lambda_c K^-$	0.04	signal	S	Λ_b^0
Combinatorial	0.03	upp-sb data	B	-
$\Lambda_b^0 \to$ four tracks	0.03	signal	S	Λ_b^0
$\Lambda_b^0 \to l\bar{\nu}_l X$	< 0.01	IncRealMC	S	-
Λ_b^0 Other	< 0.01	IncRealMC	S	-

Signal $P_{ct}(ct)$ $= \frac{1}{c\tau} \cdot e^{\frac{ct'}{c\tau}} \otimes R(ct, \sigma_{ct} : ct')$

Adjusted Signal $P_{ct}(ct)$ $= \frac{1}{c\tau_B} \cdot \frac{m(B)}{m(\Lambda_b^0)} \cdot e^{\frac{ct'}{c\tau_B} \cdot \frac{m(B)}{m(\Lambda_b^0)}} \otimes R(ct, \sigma_{ct} : ct')$

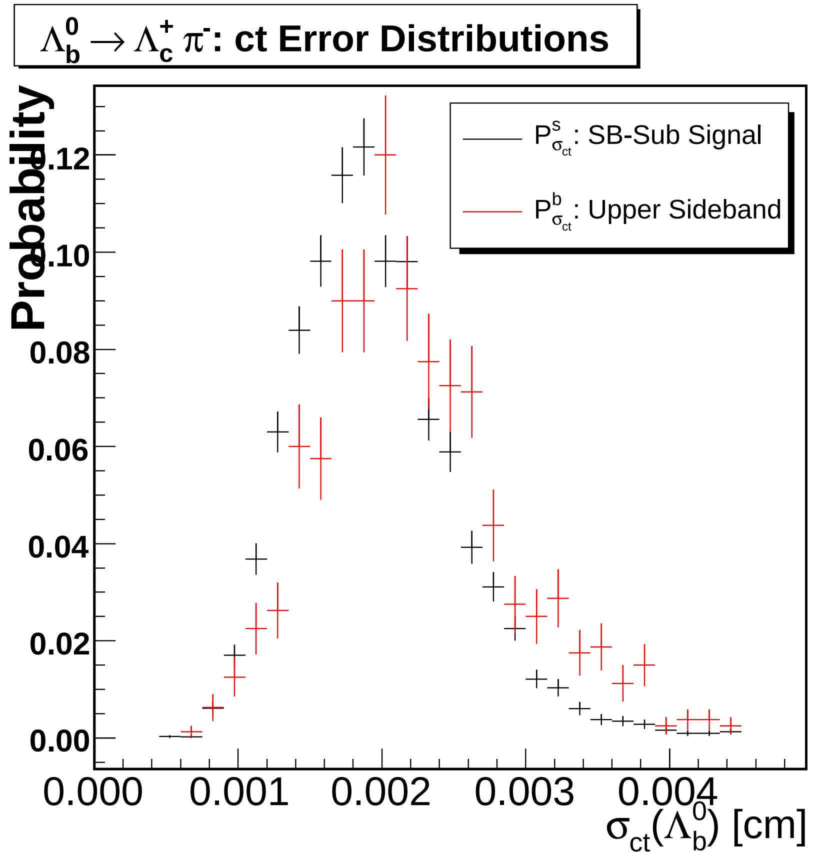
IncRealMC Realistic Monte Carlo: soup of generic B decays.

$P^i_{\sigma_{ct}}(\sigma_{ct})$ Templates

In general, only two $P^i_{\sigma_{ct}}$ templates are used.

$P^s_{\sigma_{ct}}$ Sideband-subtracted distribution of errors in the signal region
$P^b_{\sigma_{ct}}$ Distribution of errors from the upper-sideband.

- Templates are histograms.
- Obtained directly from the data being fit.



Trigger Efficiency, $\epsilon_{TTT}(ct)$

Trigger selection and analysis cuts are modeled in signal-only Monte Carlo.

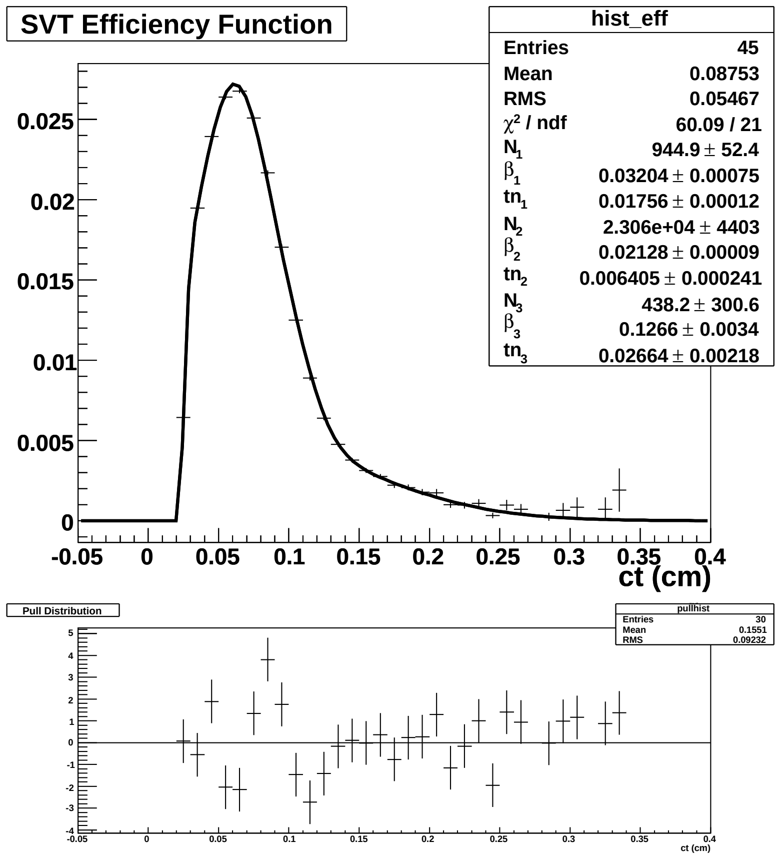
The efficiency is a histogram computed by;

$$h_{TTT}(ct) = \frac{Histo^{TTT}(ct)}{\sum_i exp(ct^i, ct^{MC}) \otimes Gauss(\sigma^i_{ct})}.$$

and fit, w/ an arbitrary, $\epsilon(ct)$, to obtain the efficiency.

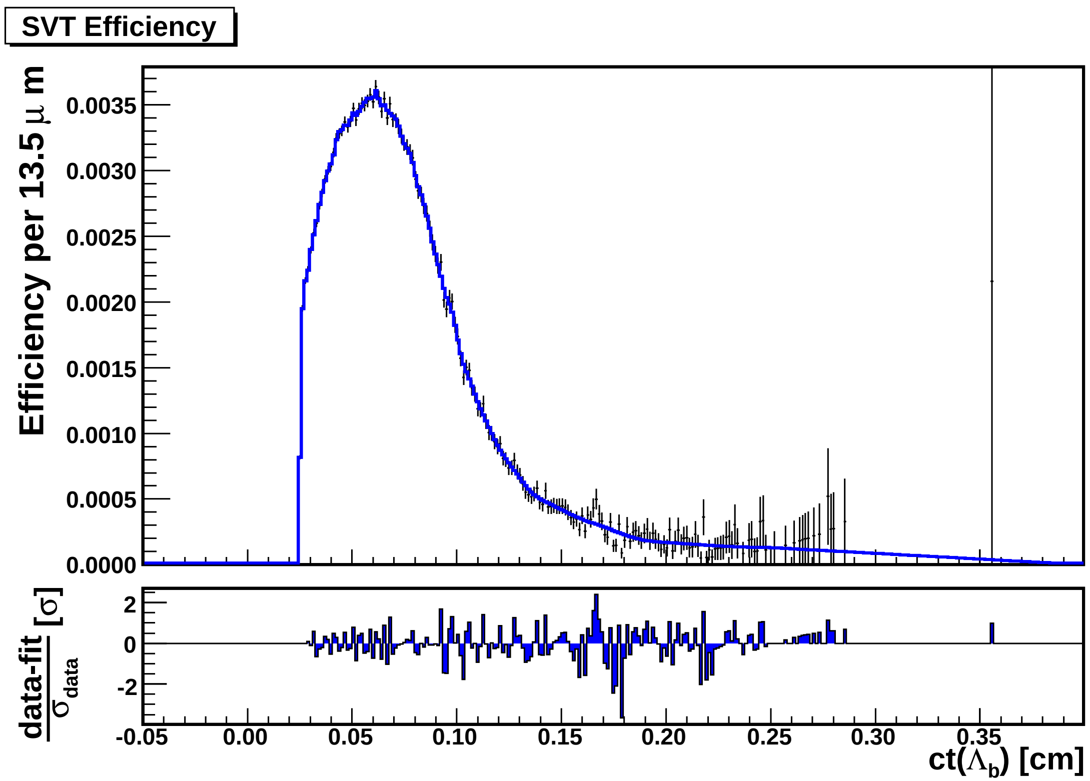
The function used to fit the efficiency in `cdfnote` 7385 is;

$$\epsilon_{TTT}(ct) = \sum_{i=1}^{i=3} N_i \cdot (x - \beta_i)^2 \cdot e^{-x/\tau_i} \cdot (x > \beta_i).$$



Trigger Efficiency II

- Parametric Fits are insufficient for our efficiency shape.
- Small changes in the fit, result in large fluctuations in measured lifetime.
- Instead of fitting, we use a smoothed histogram to model the efficiency.
- Lifetime fit results with this method are much more stable.



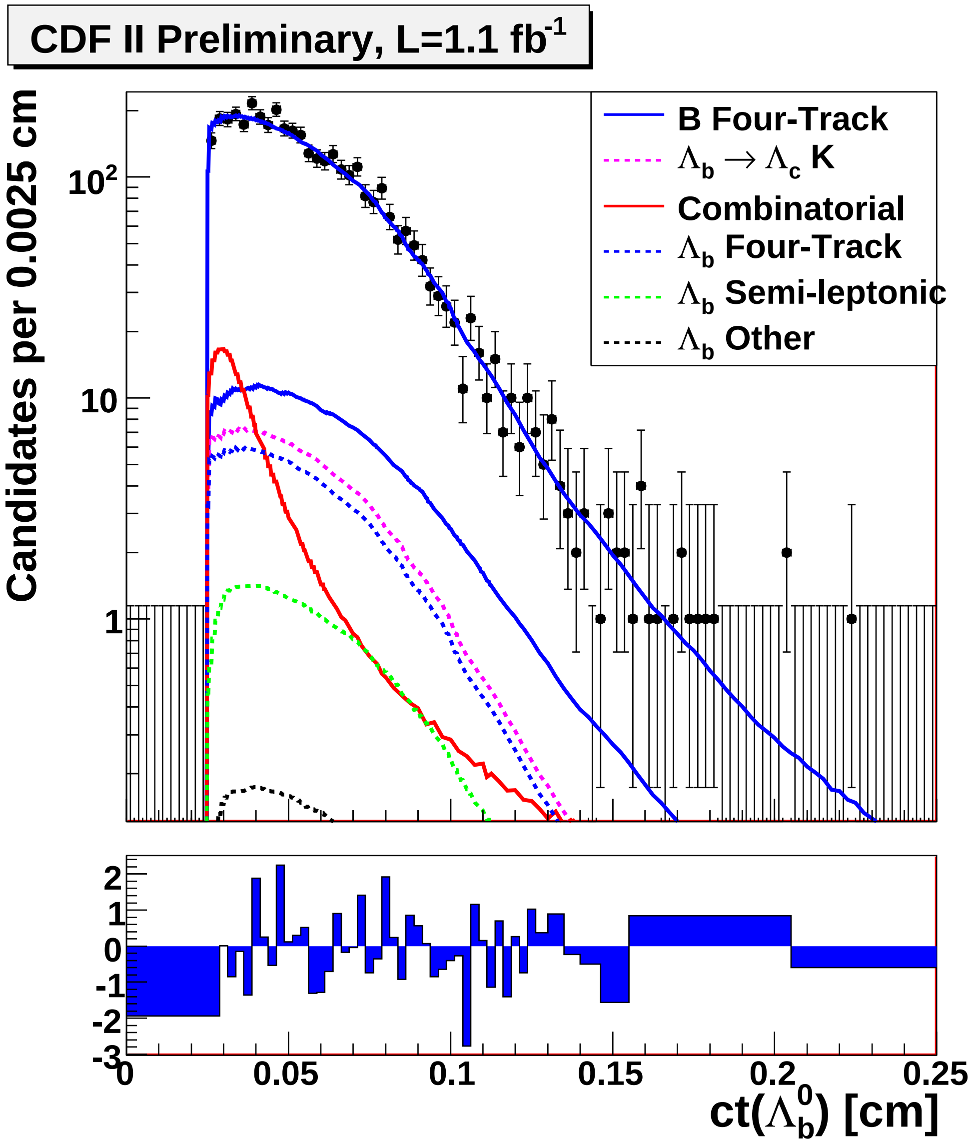
$$\epsilon_{TTT}(ct) = \frac{Histo^{TTT}_{smooth}(ct)}{\sum_i exp(ct^i, ct^{MC}) \otimes Gauss(\sigma^i_{ct})}$$

$\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$ Signal Monte Carlo

Signal Monte Carlo sample generated using the HQGen package.

- Consists of $\sim 1M$, $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$ decays.
- $c\tau(\Lambda_b^0) = 368.0\mu\text{m}$
- Custom $p_T(\Lambda_b^0)$ spectrum (`cdfnote 8156`).
- Generated using B group MC `5.3.4`
- Includes Four Λ_c Dalitz modes.
- Re-weight by throwing away events.
- Re-weight Dalitz fractions, Polarization, Trigger tracks, and $p_T(\Lambda_b^0)$ to more closely match data.
- $\sim 230k$ events remain after re-weighting.

Blind Data Fit Projection



- Lifetime result is **blinded** with an unknown, additive offset.
- $ct(\Lambda_b^0)$ value is meaningless.
- Statistical error is real.

$$c\tau(\Lambda_b^0) = XXX.X \pm 13.7\mu\text{m}$$

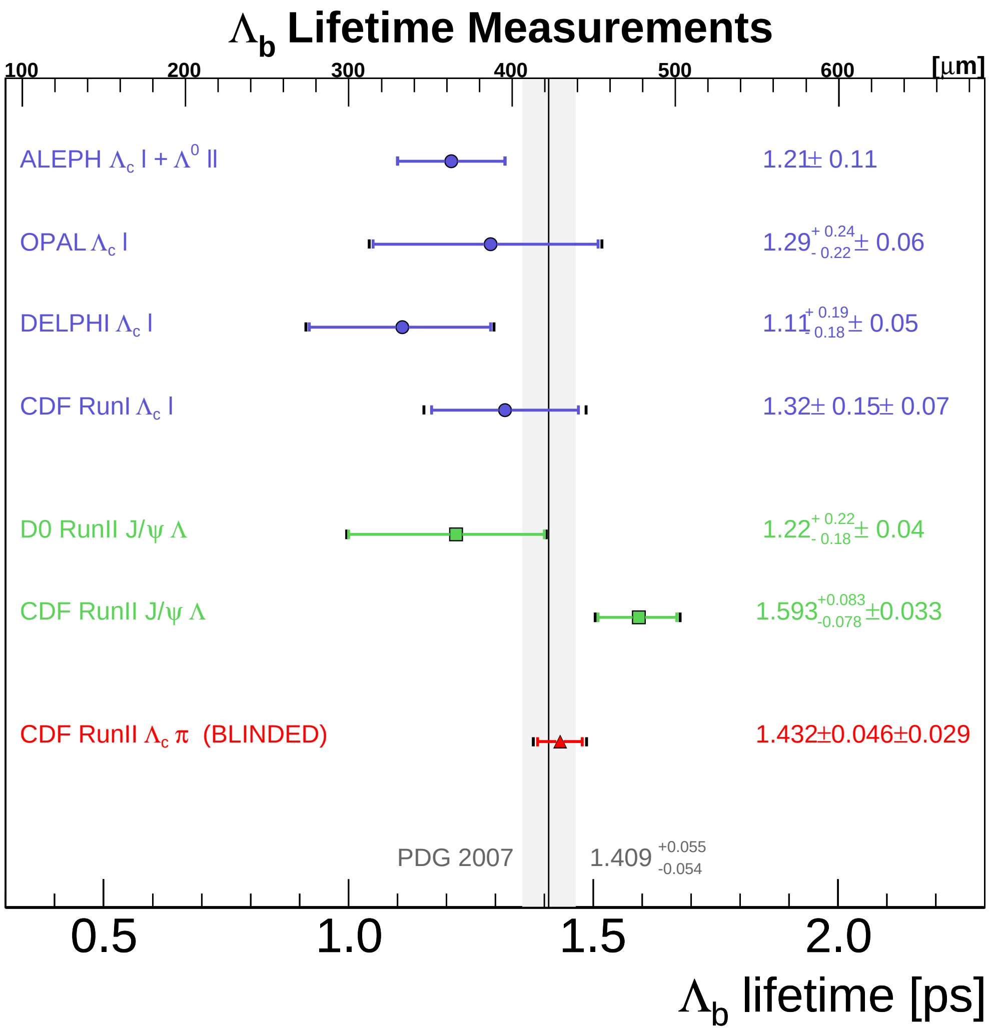
Systematic Errors

Description	Value $[\mu m]$
Alignment	2.0
SVT-SVX d0 correlation	1.0
Background Normalizations	1.0
Mass Template Shapes	negligible
SVT Model	6.3
Data-MC Agreement: Λ_c Dalitz structure	3.7
Combinatorial ct Template	2.9
Data-MC Agreement: TrigCode re-weighting	2.0
Data-MC Agreement: Λ_b^0 polarization	1.4
Data-MC Agreement: Primary Vertex Position	1.2
B^0 Efficiency	1.0
B^0 Lifetime	1.0
Data-MC Agreement: $pt(\Lambda_b^0)$ spectrum	negligible
Data-MC Agreement: Primary Vertex Error	negligible
σ_{ct} Scale Factor	negligible
Fitter Bias	negligible
σ_{ct} Binning	negligible
Λ_c Lifetime	negligible
Total Systematic Uncertainty	8.8

- Systematics divided into non-SVT-biased and SVT-biased groups.
- SVT-biased systematics require us to fluctuate the signal MC sample.
- Generated a *rigged* efficiency from fluctuated MC.
- Generate 500 Toy MC datasets based on *rigged* PDF.
- Fit with baseline fit.
- Systematic is mean of 500, *rigged* - Toy results.

Conclusion

$$c\tau(\Lambda_b^0) = XXX.X \pm 13.7(stat.) \pm 8.8(syst.)\mu\mathrm{m}$$



- Lifetime result is still Blind.
- Statistical error is factor ~ 2 better than previous best (CDF) measurement.
- Will bless blind this afternoon.
- Then open the box...

Backup

Systematic: SVT Model I

- Goal is to estimate the difference between SVT triggered events in data and MC.
- svtsim code in the realistic MC production is almost identical to its version run on the L2 farm during data taking. Both are known to agree to 10^{-6} level.
- Sources of difference can be broken down to 2 major categories:
  - Physics effects may cause data and MC to have different efficiencies because of SVT cuts.
  - The charge deposition model used in MC to reconstruct silicon hits doesn't accurately represent the real detector. So the SVT track acceptance may be different between data and MC.
- Both issues are addressed when real data events are used to simulate MC. One can then calculate a correction factor as a function of $L_{xy}(\Lambda_b^0)$ to apply to our analysis for systematic estimation.

Systematic: SVT Model II

- Mostly follow the prescription of `cdfnote 6018` to estimate SVT track efficiency in data and MC.

- $J/\psi \rightarrow \mu\mu$ are reconstructed from the `xpmm0d` sample.

- HEPG banks are made from the J/ψ and μ momenta in data. These are passed through 5.3.4 mcProduction exactly the same way we produce realistic MC.

- SVT track efficiency is defined by taking ratio of muon tracks that pass SVT matching and Scenario-A cuts with the tracks in the whole sample.

- A correction factor is estimated as the ratio of eff. in data with eff. in MC.

Systematic: SVT Model III