Measurements of B Hadron Lifetimes at CDF

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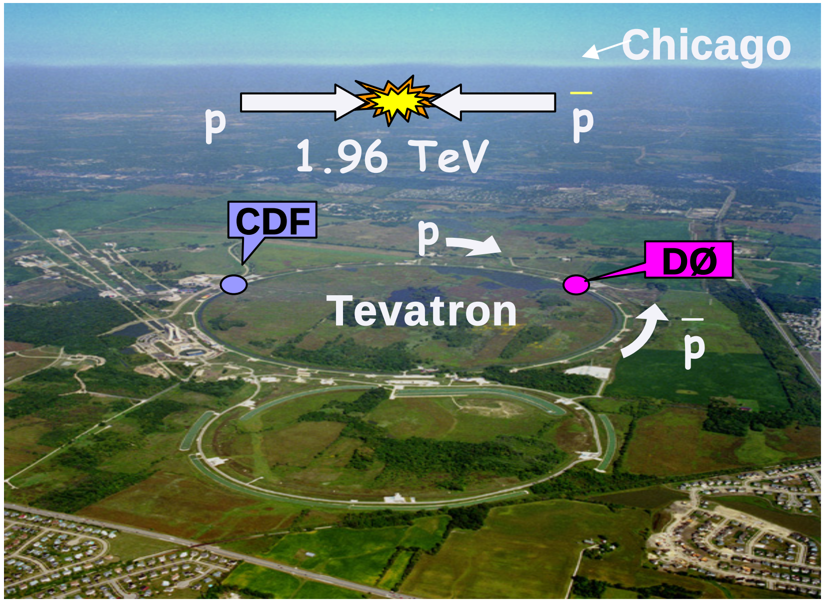
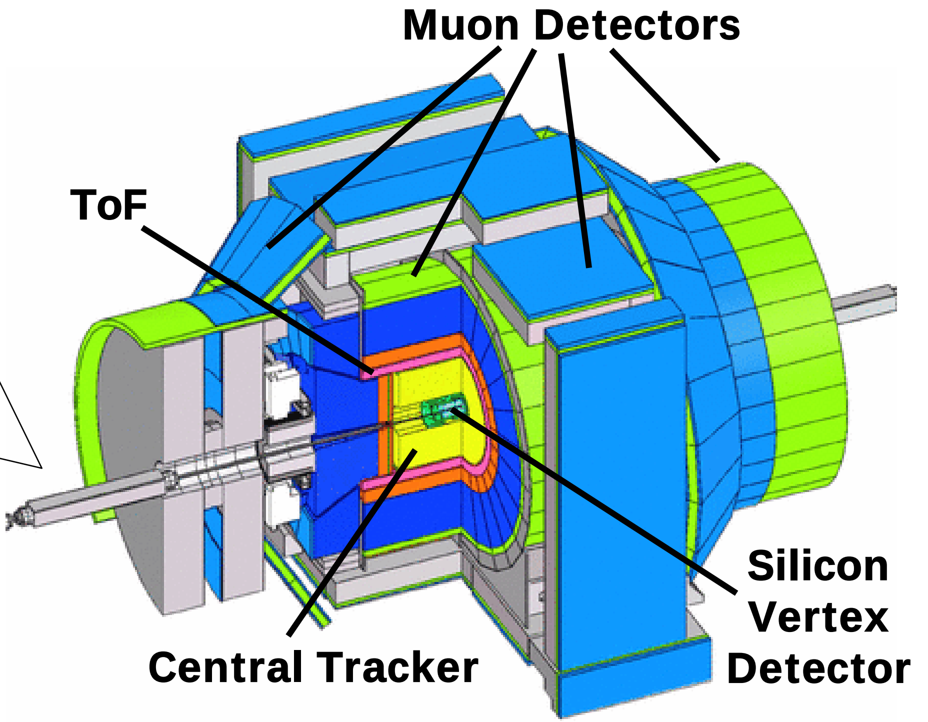
- Introduction
- **Measurements of…**
  - B_c lifetime **(semi-leptonic)**
  - Flavor-specific B_s lifetime **(fully hadronic)**
  - Λ_b lifetime **(fully hadronic)**
  - B^+ lifetime **(fully hadronic)**
    - proof of principle measurement using a data driven technique
- Summary

Tevatron and CDF Detector



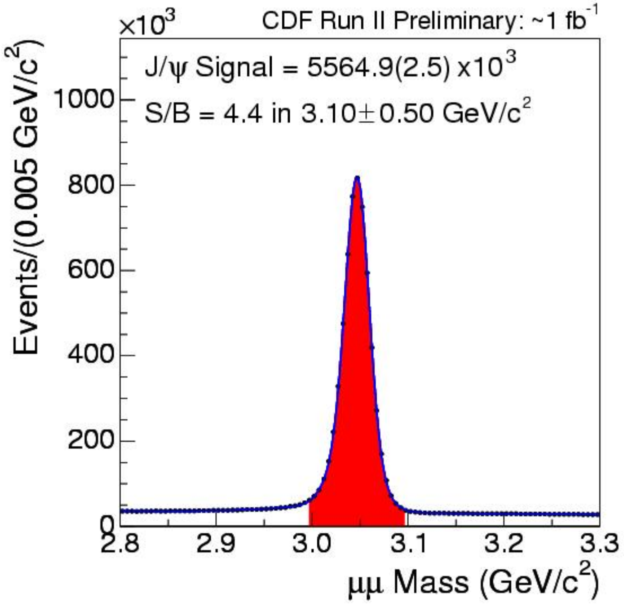
- Tevatron performing well!
- > 3 fb^{-1} on tape
- In this talk 1-2 fb^{-1} results!

- SVXII + L00
  - hit resolution: 9-11 μm
- Central Tracker
  - $\sigma p_T/p_T^2$ < 0.1%, dE/dx
- Time-of-Flight
  - Particle ID
- Muon detectors
  - Lepton triggers, Lepton ID



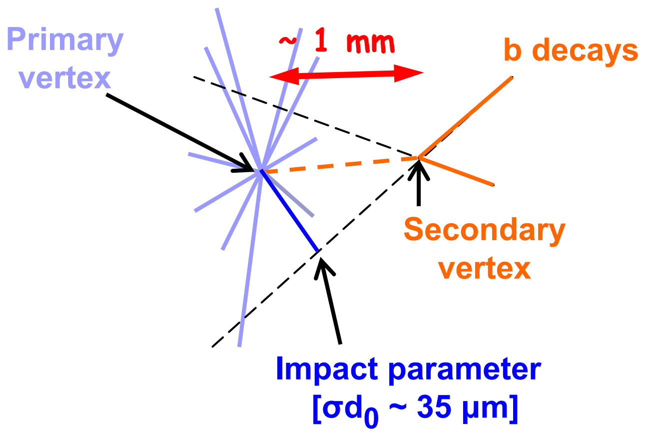
Triggers for B Lifetime Measurements

- **Di-Muon Trigger**
  - Two muons with $p_T > 1.5$ GeV in central pseudo-rapidity region.
  - J/Ψ modes, masses, lifetimes, x-section …
  - Today B_c lifetime in J/Ψ ℓ X, ℓ=e,μ



Decay length distribution biased!!

- **Displaced vertex trigger**
  - p_T(Trk) >2 GeV/c, 120 μm < d_0(Trk) < 1mm
  - X-section, branching ratios, B_s mixing…
  - Today B_s, Λ_b and B^+ lifetimes



Interests in B Hadron Lifetimes

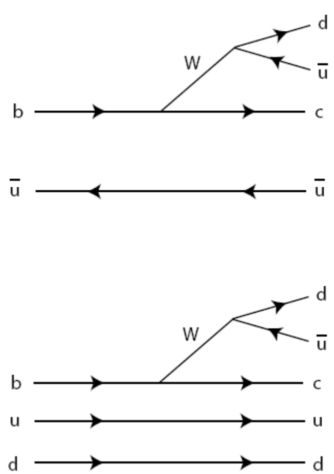
Heavy Quark Expansion

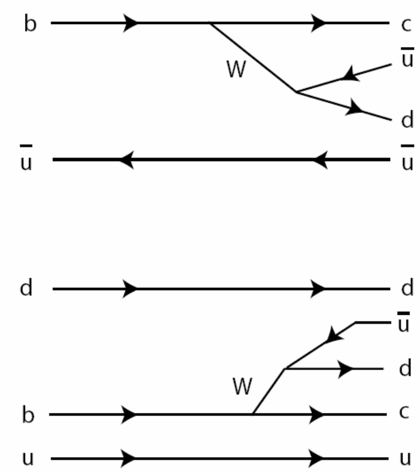
$$\Gamma = \frac{G_F^2 m_b^5}{192\pi^3}|V_{cb}|^2 \cdot \left[A_0 + A_2\left(\frac{\Lambda_{QCD}}{m_b}\right)^2 + A_3\left(\frac{\Lambda_{QCD}}{m_b}\right)^3\right]$$

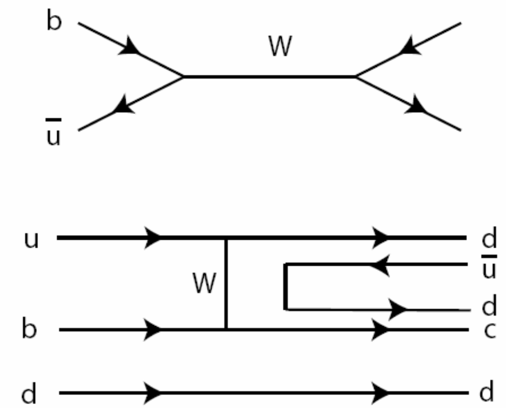
I. Bigi et. al,
Ann. Rev. Nucl. Part. Sci. 47 (1997) 591.

B^+

Λ_b







Spectator model:
b hadron lifetimes are equal.

Pauli Interference:
prolongs lifetimes,
+5% for B^+, +3% for Λ_b

Weak Annihilation and Exchange:
reduce lifetimes -7% Λ_b

$$\tau(B^+) \geq \tau(B^0) \approx \tau(B_s^0) > \tau(\Lambda_b) \gg \tau(B_c)$$

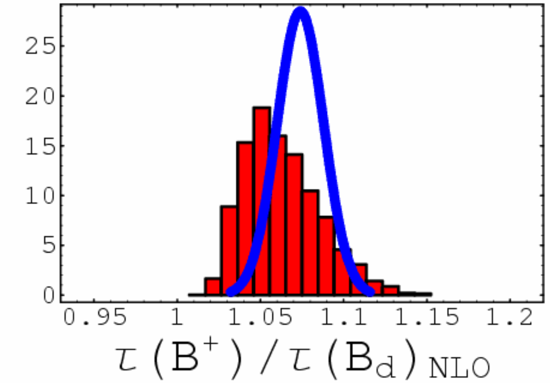
Interests in B Hadron Lifetimes *Continued...*

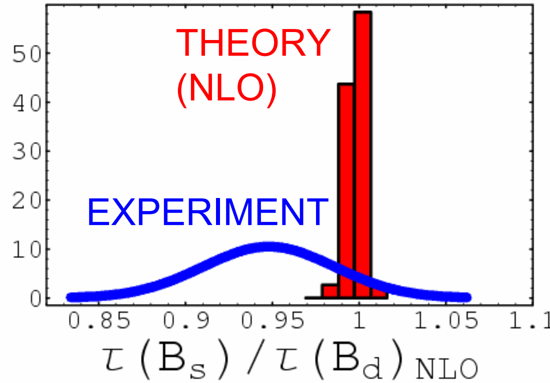
- The B^+,B^0 lifetimes are precisely measured at B-factories.
- Experimental error on $\tau(B_s^0)/\tau(B^0)$ far higher than theory error!
- World average of $\tau(\Lambda_b)/\tau(B^0)$ too low compared to $O(1/m_b^3)$ HQE prediction. CDF 2006 measurement was precise but too high!
- Lifetime ratio world averages:

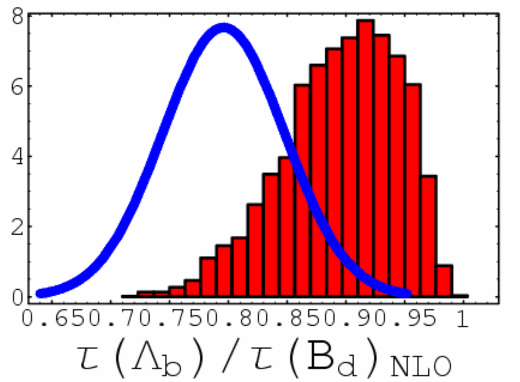
	Theory $O(1/m_b^4)$
$\tau(B^+)/\tau(B^0)$ = 1.071 +- 0.009	1.06 ± 0.02
$\tau(B_s^0)/\tau(B^0)$ = 0.939 +- 0.021	1.00 ± 0.01
$\tau(\Lambda_b)/\tau(B^0)$ = 0.904 +- 0.032	0.88 ± 0.05

PDG 2007

C. Tarantino, hep-ph/0310241

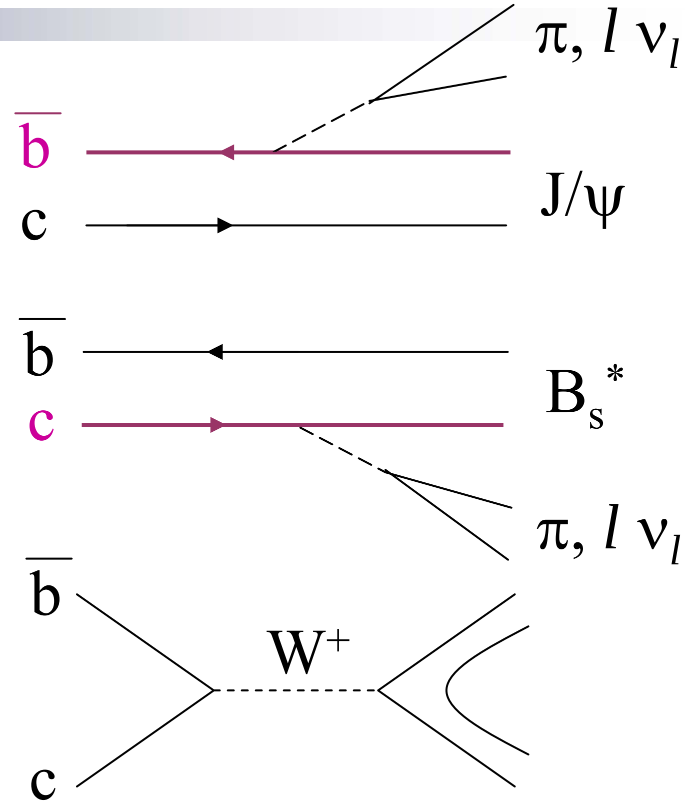






B_c : A Special Case…

- Doubly heavy $\bar{b}c$ bound state
- Decays via weak decays of b- or c-quark or via weak annihilation



$$\Gamma_{B_C} = \Gamma_b(\approx 25\%) + \Gamma_c(\approx 65\%) + \Gamma_W$$

- Shorter lifetime than light B mesons

Theory prediction:

$\tau(B_c)$ = 0.47 – 0.59 ps

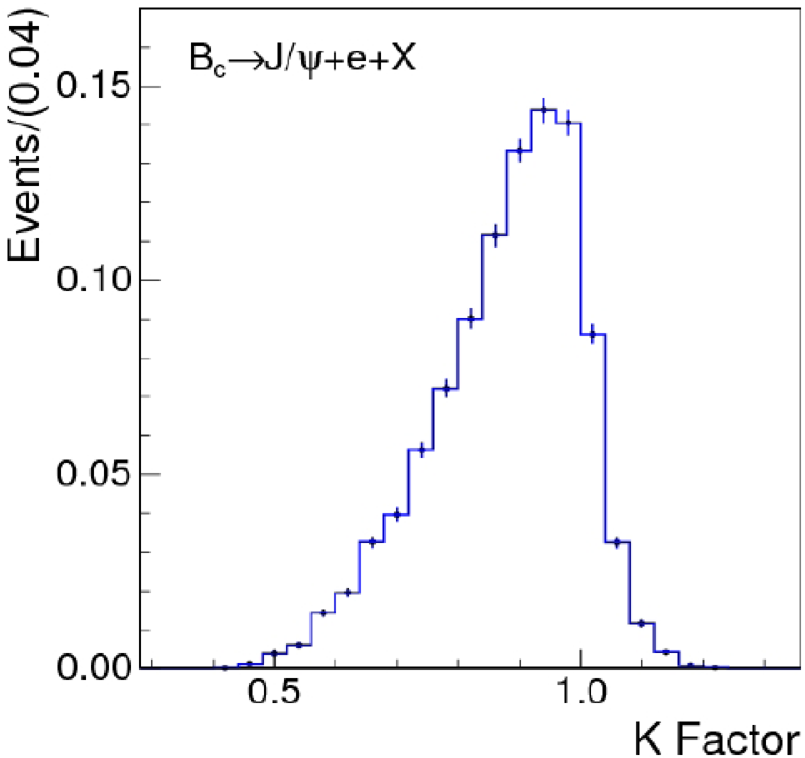
arXiv:hep-ph/0308214v1
Phy Rev. D 64, 14003 (2001)
Phy Lett. B 452, 129 (1999)
hep-ph/0002127

Lifetime in $B_c \rightarrow J/\psi\ e,\mu\ \nu$

- **Missing momentum**, correct pseudo-lifetime:
  - $ct = \mathbf{K} \times ct^*$
  - $$ct^* = \frac{M(B_c)\, L_{xy}(J/\psi + l)}{p_T(J/\psi + l)}$$
  - $\mathbf{K} = p_T(J/\psi\ \ell) / p_T(B_c)$

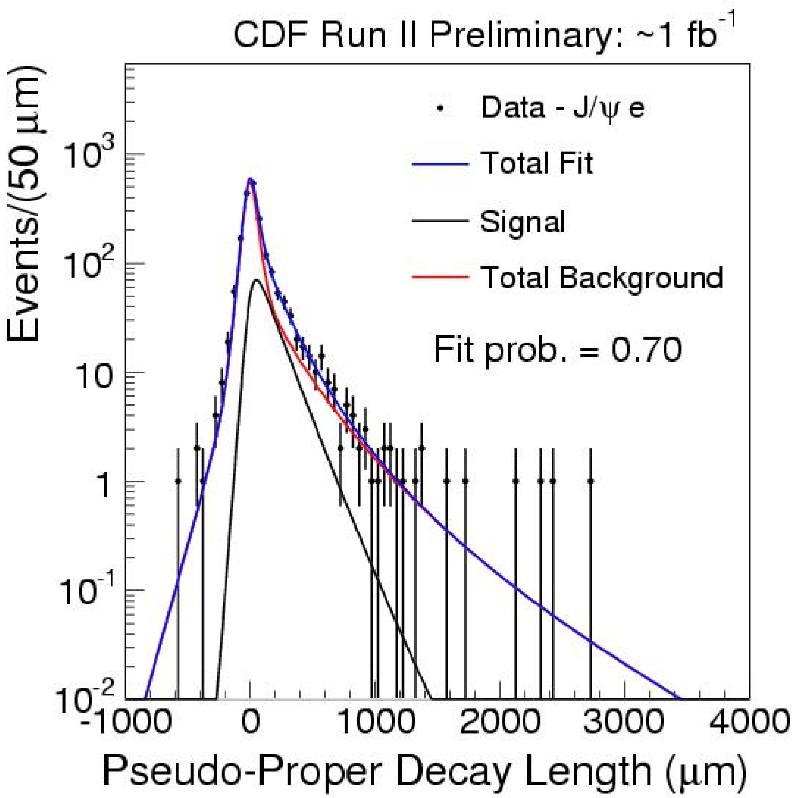
- Main challenge is **multiple backgrounds**:
  - real J/Ψ + fake lepton
  - fake J/Ψ + real lepton
  - real J/Ψ + real lepton → from bb events
  - prompt J/Ψ + lepton
  - residual conversion (J/Ψ+e only)

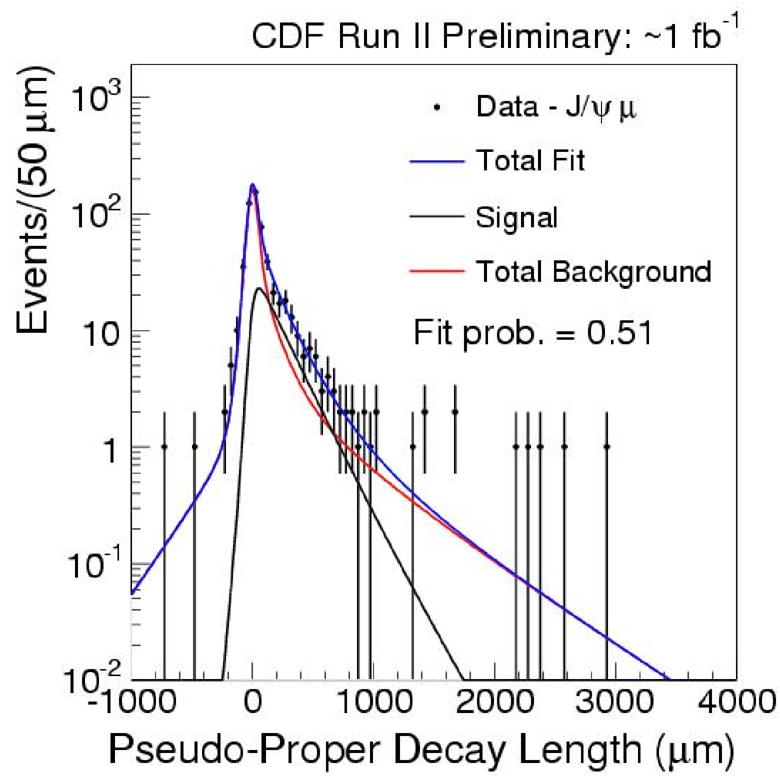
CDF Run II Monte Carlo



5564.9k signal J/Ψ events from **1 fb^{-1}** data

Lifetime in $B_c \rightarrow J/\psi\ e,\mu\ \nu$

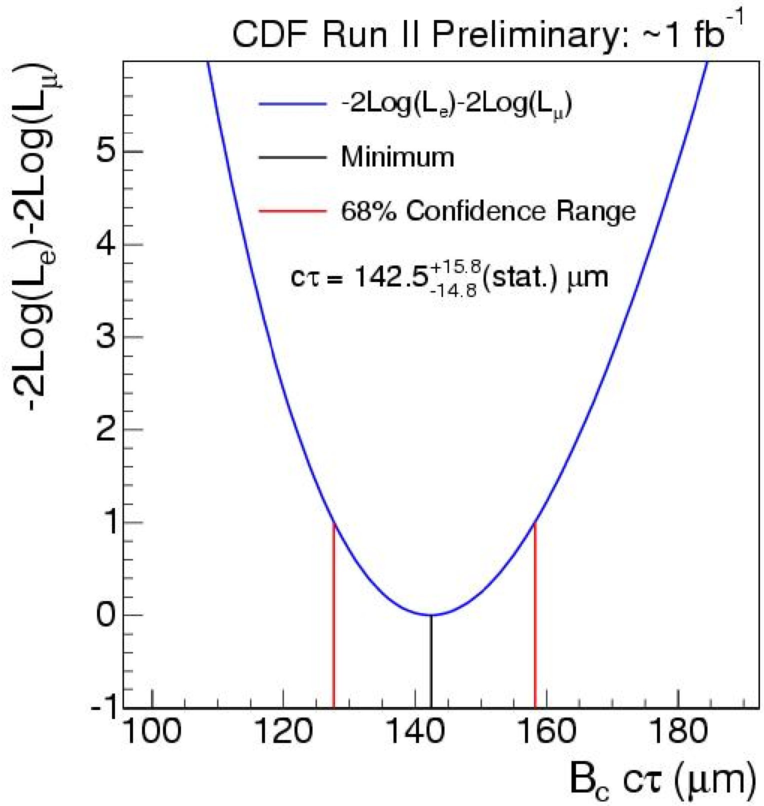


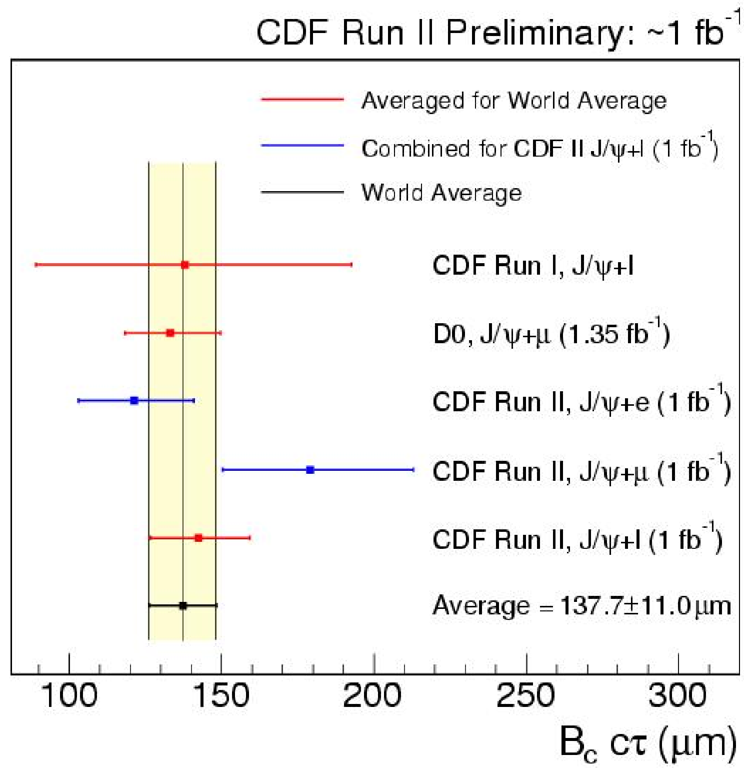


$$c\tau(B_c) = 121.7^{+18.0}_{-16.3}\ \text{(stat)}\ \mu\text{m}$$

$$c\tau(B_c) = 179.1^{+32.6}_{-27.2}\ \text{(stat)}\ \mu\text{m}$$

Lifetime in $B_c \rightarrow J/\psi$ e,μ ν





$$\tau(B_c) = 0.475^{+0.052}_{-0.049}\,(\text{stat}) \pm 0.018\,(\text{syst})\,\text{ps}$$

World best measurement!

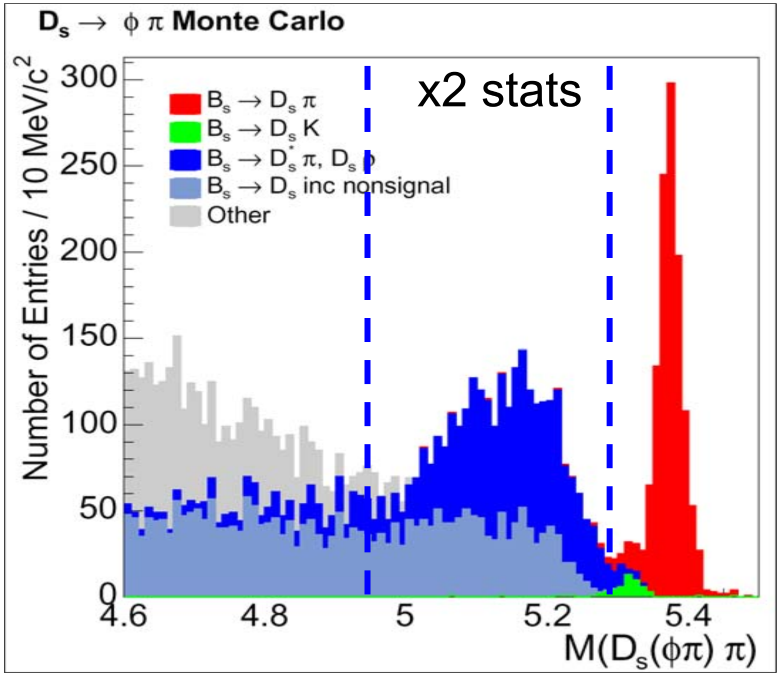
Tevatron weighted average:

$\tau = 0.459 \pm 0.037$ ps

Theory: τ = 0.47 – 0.59 ps

B_s Lifetime in $B_s \rightarrow D_s^+(\phi\pi)\,\pi^- X$

- Data sample:
  - **1.3 fb-1**, collected with displaced vertex trigger
  - ~ 1100 fully reconstructed events
  - ~ 2000 partially reconstructed events



- Lifetime bias is modeled with a trigger efficiency curve from MC

- Partially reconstructed channels: $B_s \rightarrow D_s^* \pi$, $D_s\, \rho^-(\pi^0\, \pi^-)$ triple the statistics!

Bs lifetime difference: presented by **Farrington**

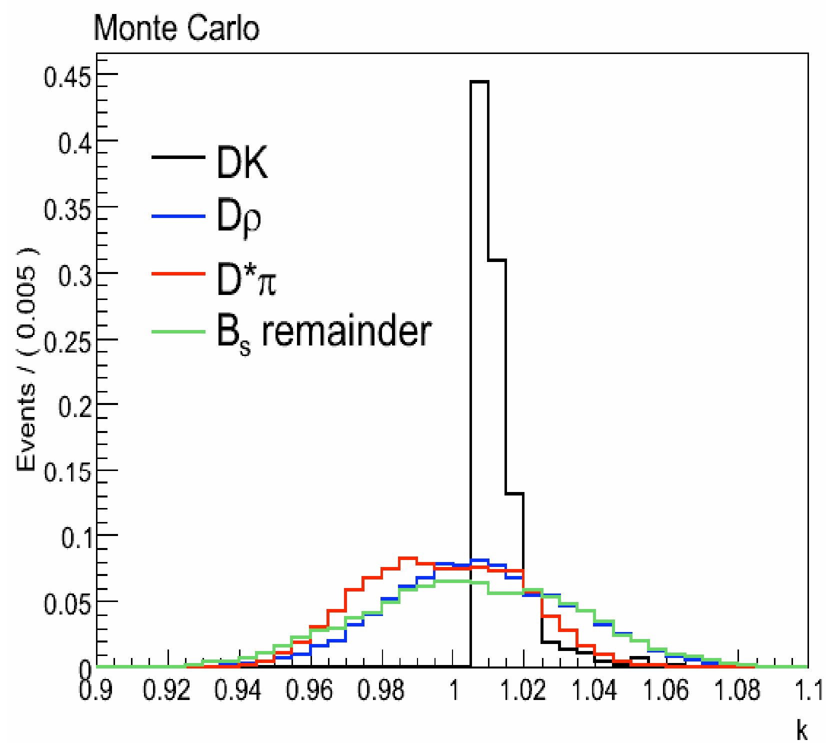
B_s Lifetime in $B_s \to D_s^+(\phi\pi)\,\pi^- X$

- For partially reconstructed modes a k-factor accounts for missing momentum and mass

$$ct = \frac{L_{xy} \cdot m_B^{rec}}{p_T} \cdot K$$

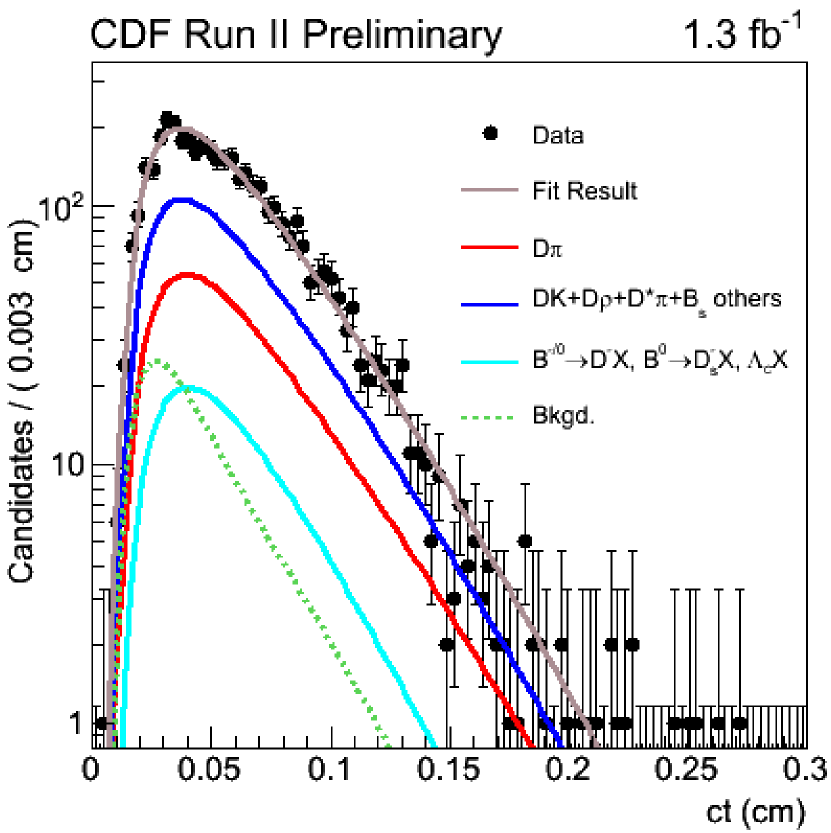
- Extensive test on B^0, B^+ control samples

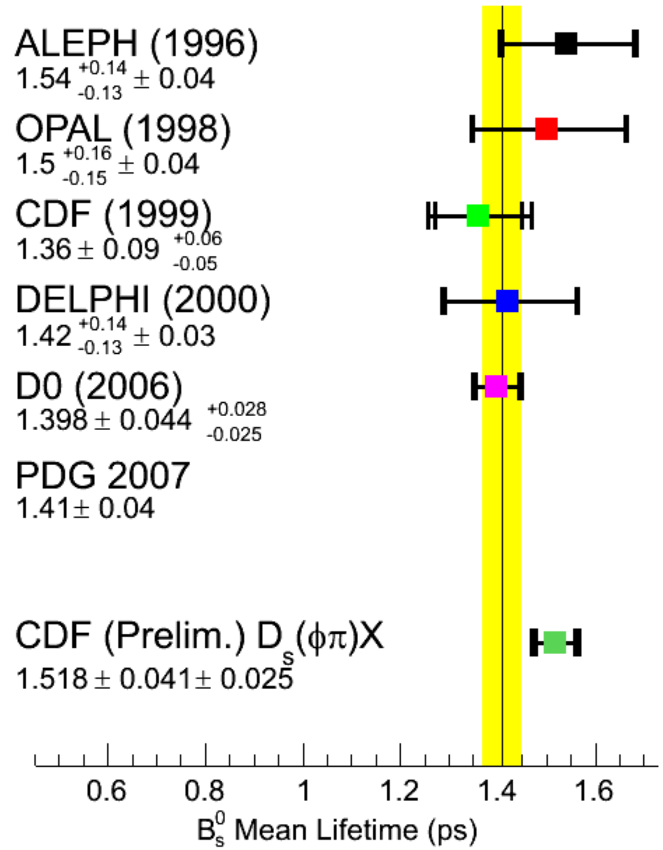
- **Two-step fit**
  - mass fit: relative fraction of various modes and background
  - lifetime fit: shapes from MC/data, fractions from mass fit.
    - **Extract lifetime only**



Lifetime for control samples:
$B^0 \to D^-(K^+\pi^-\pi^-)\,\pi^+$
$B^0 \to D^{*-}(D^0(K^+\pi^-)\pi^-)\,\pi^+$
$B^+ \to D^0(K^+\pi^-)\,\pi^+$
agree well with PDG

B_s Lifetime in $B_s \to D_s^+(\phi\pi)\,\pi^- X$



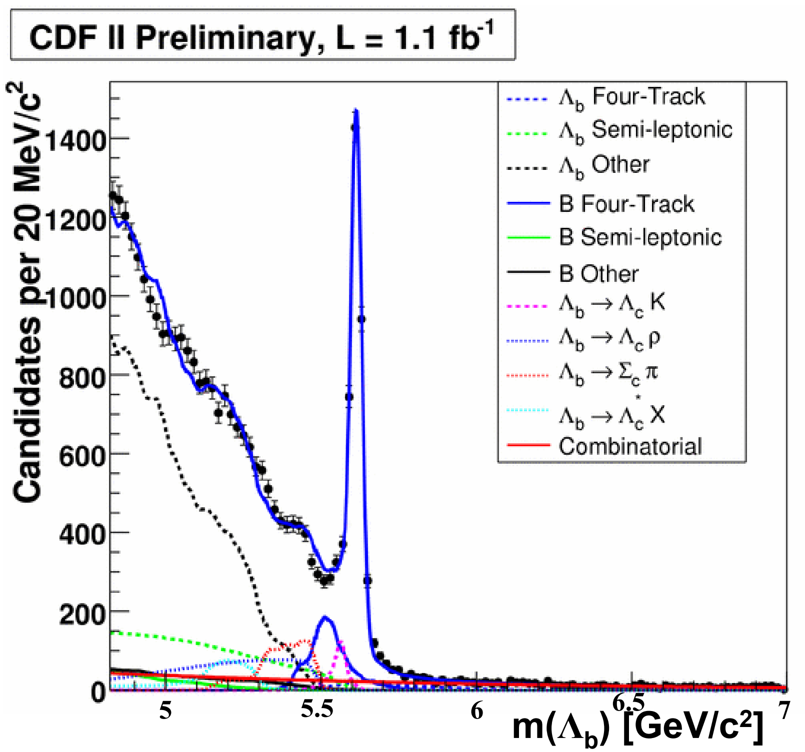


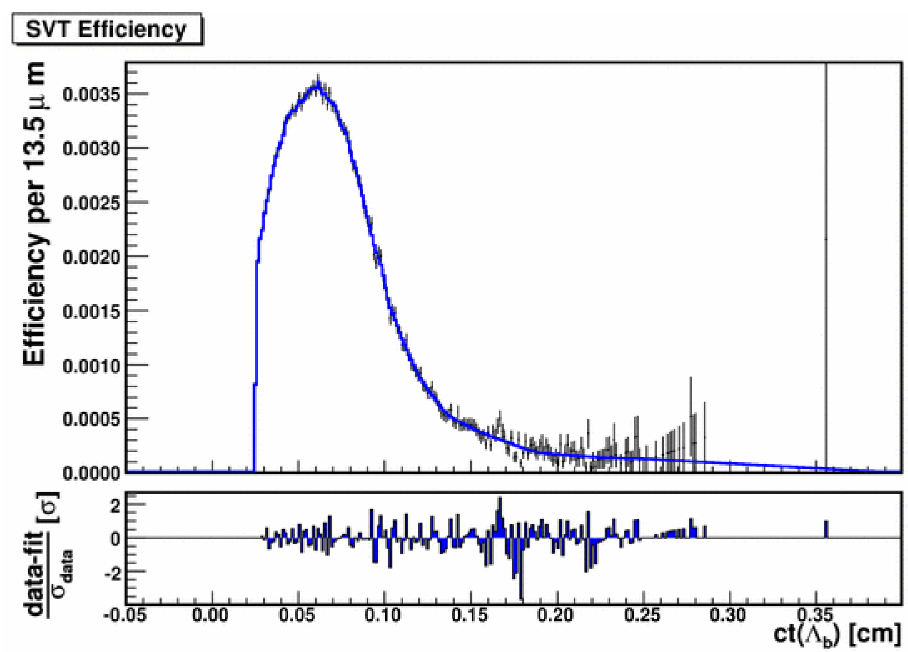
Flavor-specific $\tau(B_s) = 1.518 \pm 0.041\,(\text{stat}) \pm 0.025\,(\text{syst})\,\text{ps}$

World best measurement!

Λ_b Lifetime in $\Lambda_b \rightarrow \Lambda_c \pi$

- 1 fb^{-1} data, 2900 events
- Signal region:
  $5.565 < m(\Lambda_b) < 5.670$ GeV/c2
- Lifetime analysis developed w/ data fit blinded.
- Trigger efficiency curve from MC simulation
- Two step fit: mass, lifetime
- Fit checked with MC samples with input lifetimes between 325 - 500 μm.





Λ_b Lifetime in $\Lambda_b \rightarrow \Lambda_c \pi$

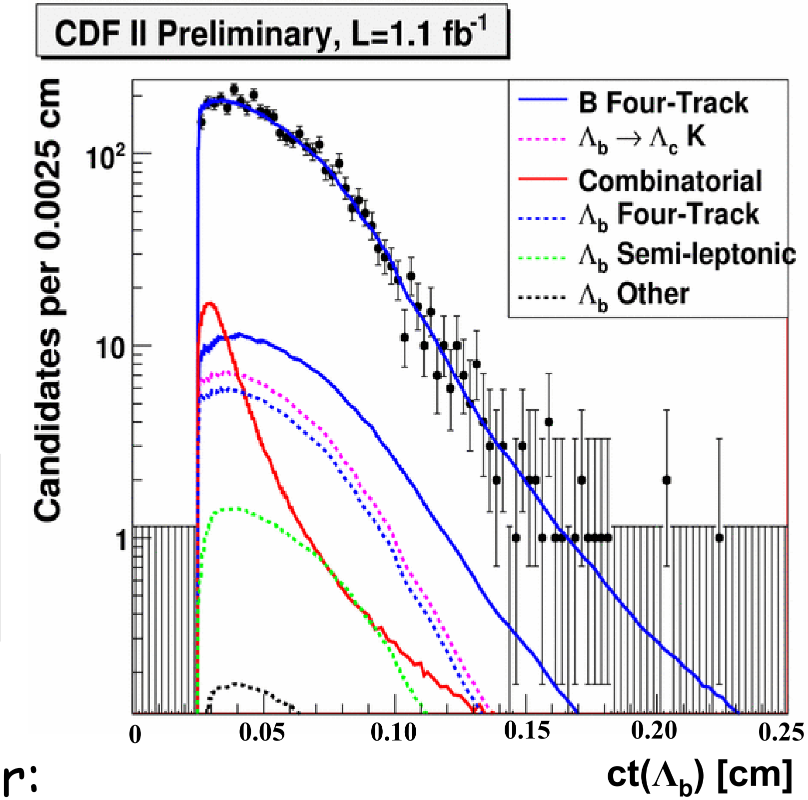
- We measure:

$$\tau(\Lambda_b) = 1.410 \pm 0.046\,(\text{stat}) \pm 0.029\,(\text{syst})\,\text{ps}$$

World best measurement!

- Using world average B^0 lifetime:

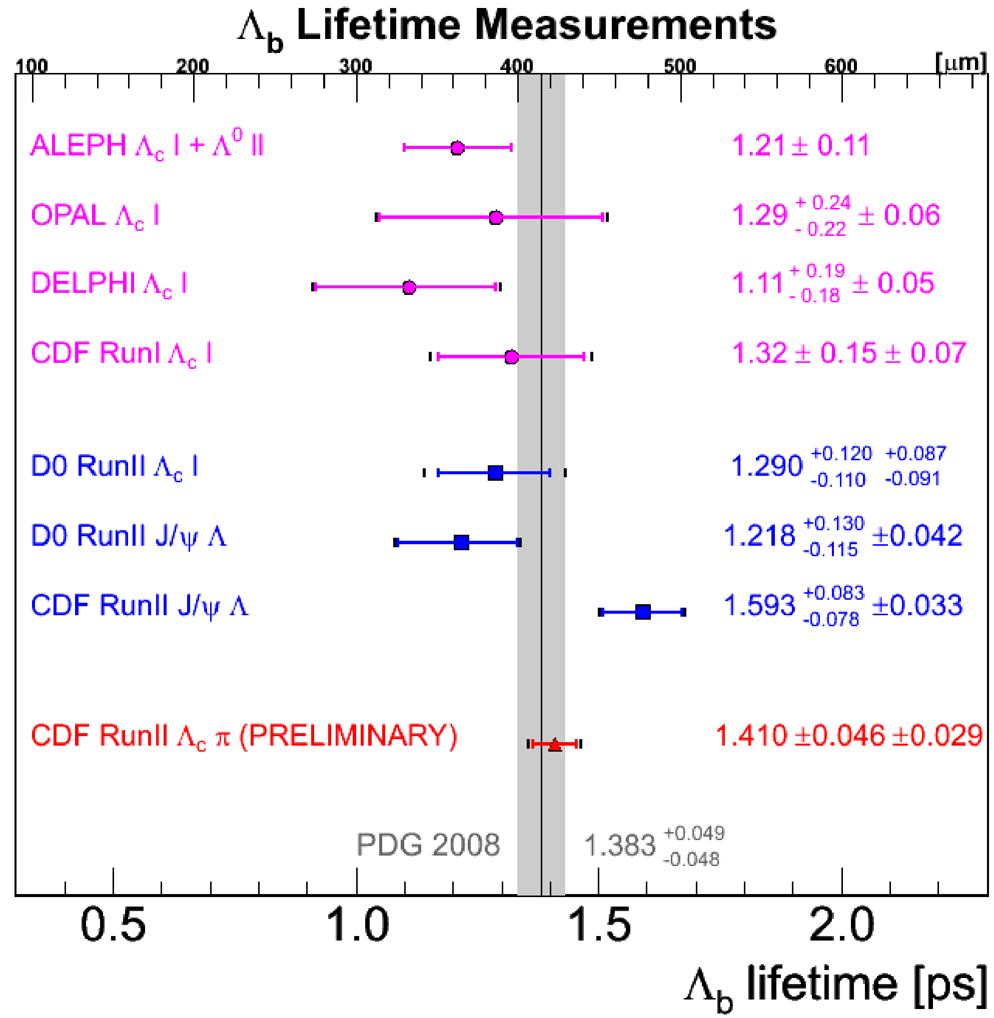
$$\frac{\tau(\Lambda_b)}{\tau(B^0)} = 0.922 \pm 0.039\,(\text{stat} + \text{syst})$$



- Leading sources of systematic error:
  - Displaced vertex trigger modeling: 71.6%
  - Λ_c Dalitz structure: 42.0%
  - Combinatoric ct template: 32.9%

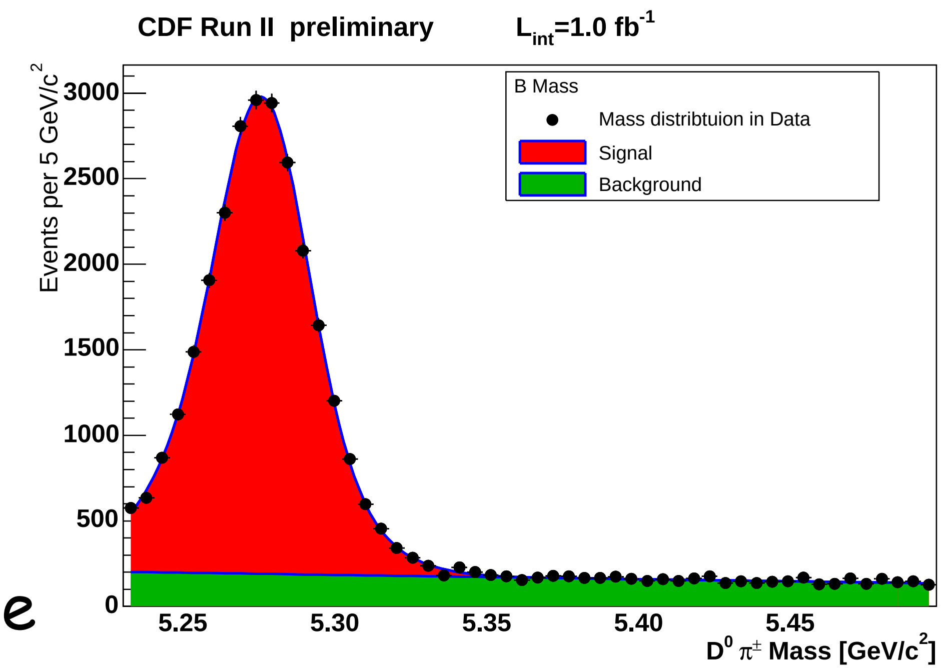
Λ_b Lifetime in $\Lambda_b \rightarrow \Lambda_c \pi$

- Good agreement with world average and theory (lifetime ratio).



B^+ Lifetime in $D^0 \pi^+$ Decays

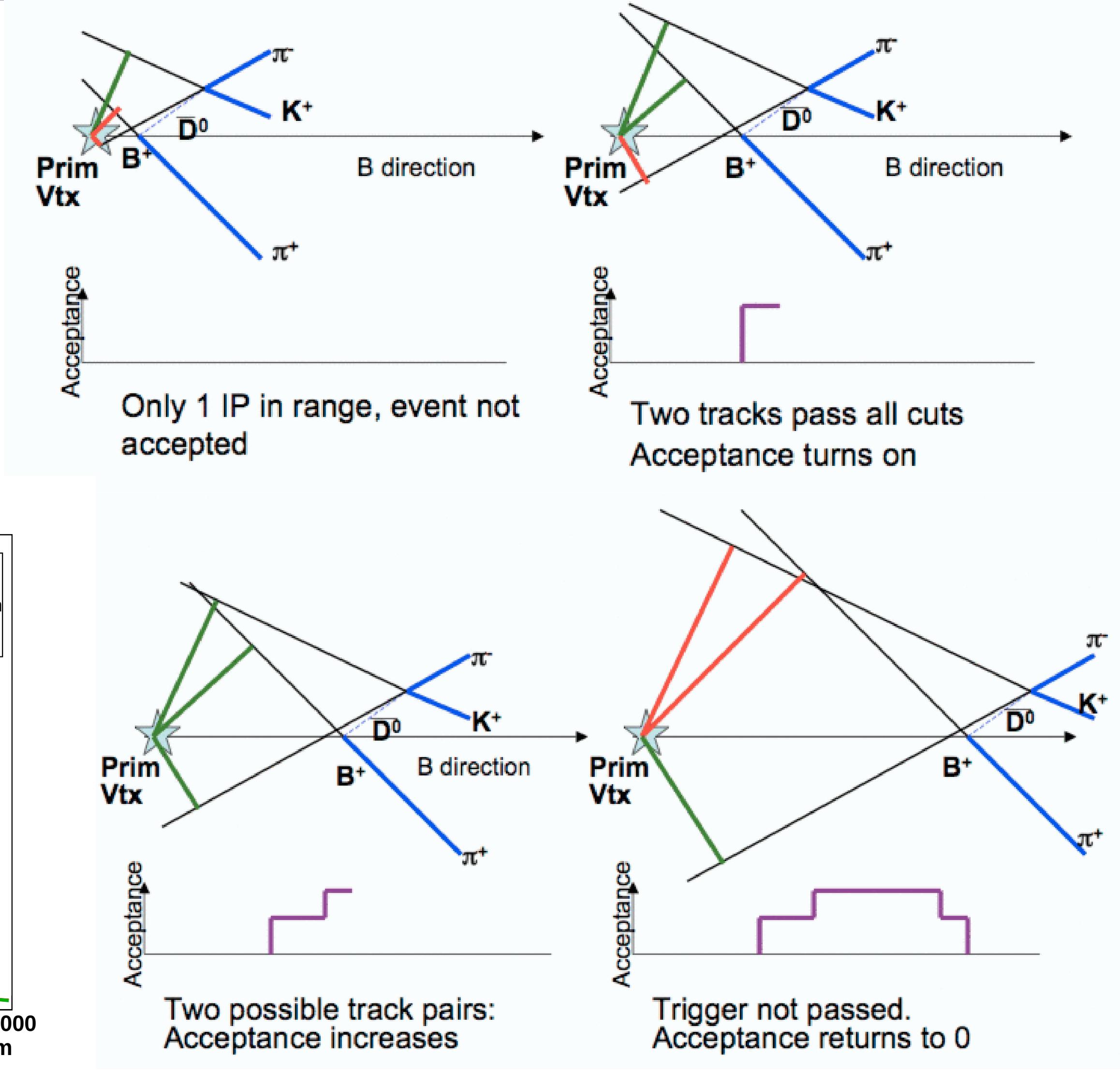
- Proof of principle measurement employing a data driven method to correct for trigger bias.
- Uses decay kinematics to correct bias on an event-by-event basis.
- Method applicable to future experiments which use impact parameter based triggers.
- Systematic error due to MC modeling is completely avoided.

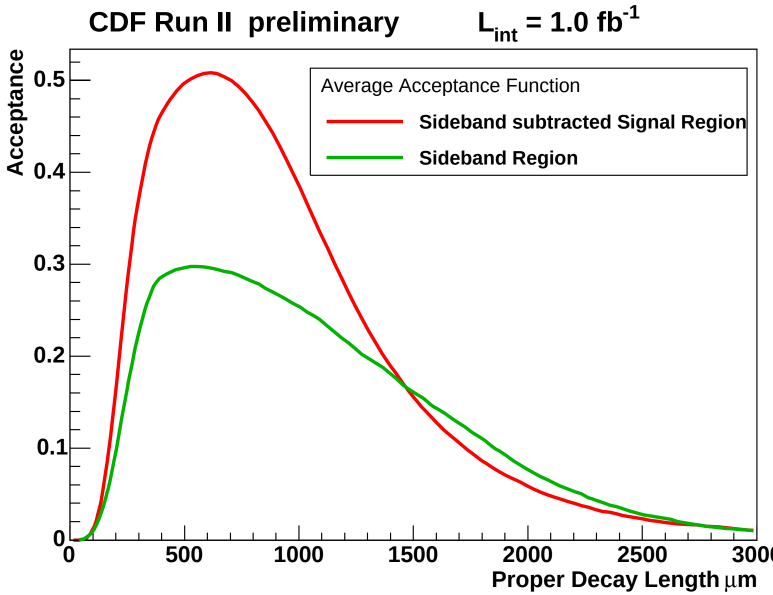


24200 ± 200 signal events from **1 fb^{-1}** data

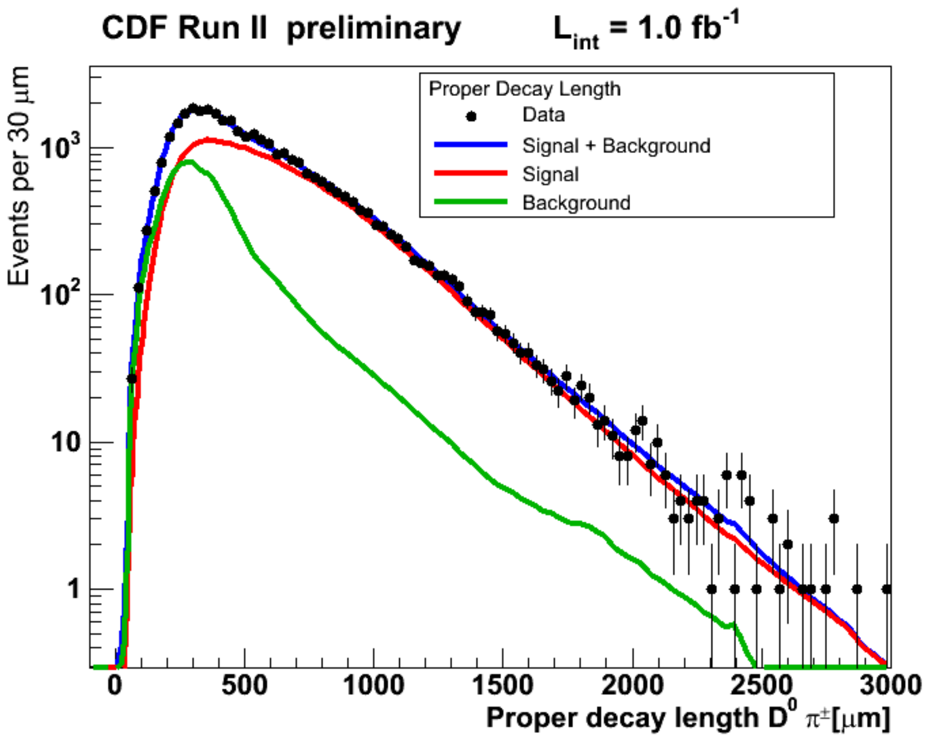
Data Driven Trigger Bias Correction

- Events are slid along the B direction and trigger acceptance is evaluated as a function of proper decay length





B^+ Lifetime in $D^0 \pi^+$ Decays



- Dominant sources of systematic error:
  - IP (68.9%), p_T (40%) dependence of track finding efficiency
  - Mass-lifetime correlation (55.6%) in background

- We measure: $\tau(B^+) = 1.662 \pm 0.023\,(\text{stat}) \pm 0.013\,(\text{syst})\text{ ps}$

- Current world average: 1.638 ± 0.011 ps

Summary

- With over 3 fb^{-1} accumulated data and much more to come, heavy flavor physics at CDF has entered a precision era.
- World's best B_s, B_c and Λ_b lifetime measurements from CDF are in agreement with the world averages and HQE predictions.
- Stay tuned for more!!

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

Backup-1 Data Driven Lifetime Method

- Unbiased decay PDF: $\frac{e^{-\frac{t}{\tau}}}{\tau}$
- … with high and low IP cuts: $\frac{e^{-\frac{t}{\tau}}}{\tau(e^{-\frac{t_{min}}{\tau}} - e^{-\frac{t_{max}}{\tau}})}$
- A triggered event w/ IP cuts, single track eff. and multiple track combination considered:

$$\frac{e^{\frac{-t_j}{\tau}}([\Theta(t^1_{min}) - \Theta(t^1_{max})]p(n_1, k_1, \epsilon_s) + ..[\Theta(t^N_{min}) - \Theta(t^N_{max})]p(n_N, k_N, \epsilon_s))}{\tau((e^{\frac{-t^1_{min}}{\tau}} - e^{\frac{-t^1_{max}}{\tau}}))p(n_1, k_1, \epsilon_s) + ..p(n_N, k_N, \epsilon_s)(e^{\frac{-t^N_{min}}{\tau}} - e^{\frac{-t^N_{max}}{\tau}}))}$$

- where, k_i out of n_i tracks have a matching trigger track in the i^{th} of N different ways to satisfy the trigger.