Bottom Hadron Lifetimes at CDF: Run I Experiences and Run II Expectations

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Mixing and Lifetimes Subgroup
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- ▷ Introduction
- ▷ Lifetimes in Run I
- ▷ Run II

Lifetime Expectations

Lifetimes are a useful meeting point between theory and experiment
e.g., I.I. Bigi, UND-HEP-95-BIG02

$$\frac{\tau(B^-)}{\tau(B_d^0)} \simeq 1 + 0.05\frac{f_B^2}{(200\ \mathrm{MeV})^2} \qquad \frac{\tau(\Xi_b^-)}{\tau(\Lambda_b)} \sim 1.1$$

$$\frac{\tau(B_s^0)}{\tau(B_d^0)} \simeq 1 \pm \mathcal{O}(1\%) \qquad \frac{|\tau(\Xi_b^0) - \tau(\Lambda_b)|}{\tau(\Lambda_b)} < 0.1$$

$$\frac{\tau(\Lambda_b)}{\tau(B_d^0)} \simeq 0.9 - 0.95 \qquad \frac{\Delta\Gamma(B_s)}{\Gamma(B_s)} \simeq 0.18\frac{f_B^2}{(200\ \mathrm{MeV})^2}$$

$$\tau(B_s \to \ell\nu D^{(*)}) - \tau(B_s \to \psi\phi) \simeq 0.09\frac{f_B^2}{(200\ \mathrm{MeV})^2}$$

- not all of these lifetime comparisons have been made
- none of these have been measured with sufficient precision to test or distinguish theories

Lifetime measurements will continue as a very important part of the physics program

Run I Exclusive Lifetimes

▷ Use decay modes where all decay products are detected:

$\surd$ $B_{u,d} \to \psi(1S, 2S)K$,
$\psi(2S) \to J/\psi\pi^+\pi^-$,
$J/\psi \to \mu^+\mu^-$

$\surd$ $B_s \to J/\psi\phi$,
$\phi \to K^+K^-$

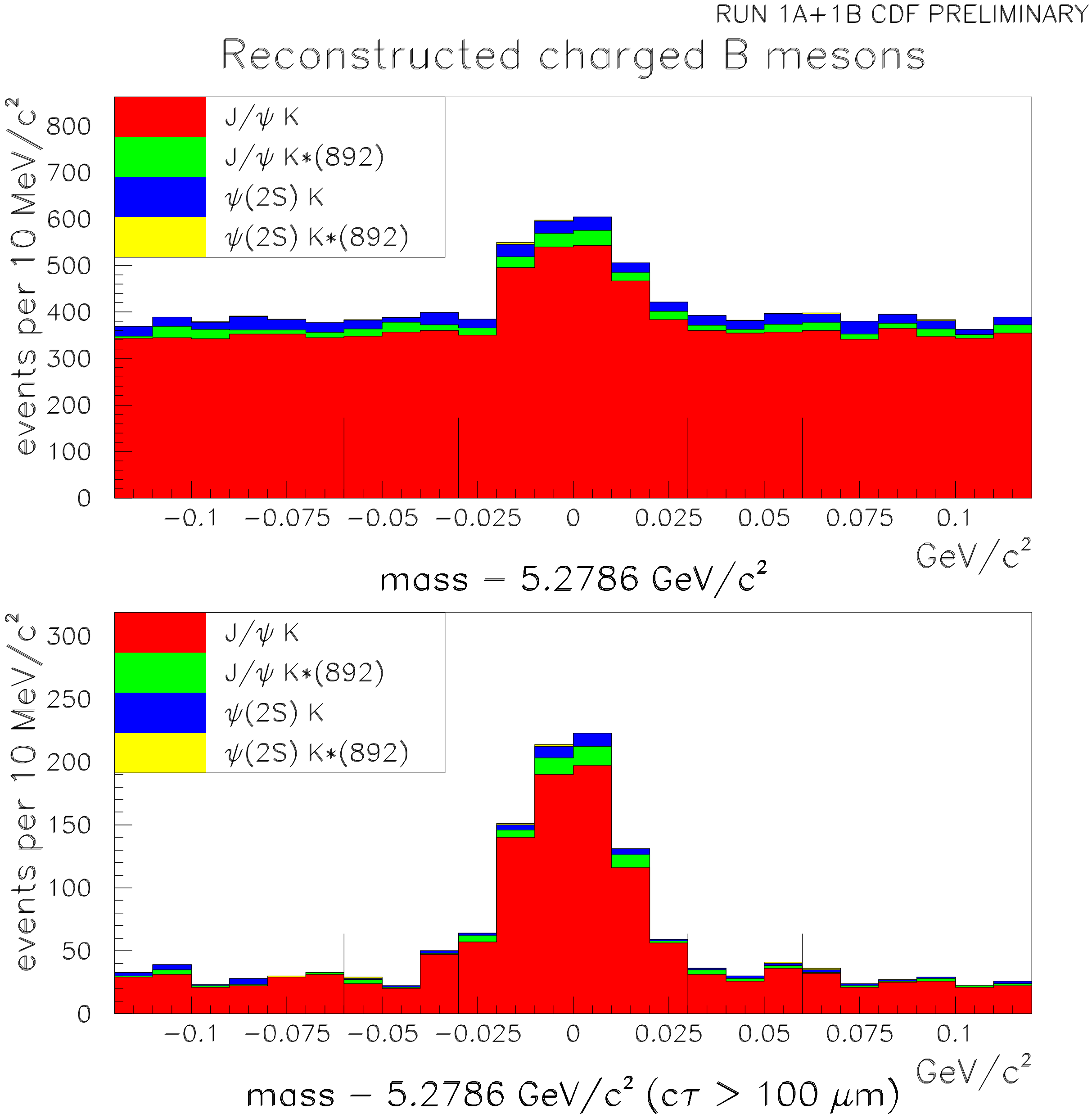
▷ $c\tau$ is determined from measured quantities:

$$c\tau = \frac{L_{xy} m_B}{p_T^B}$$

▷ Small branching fractions

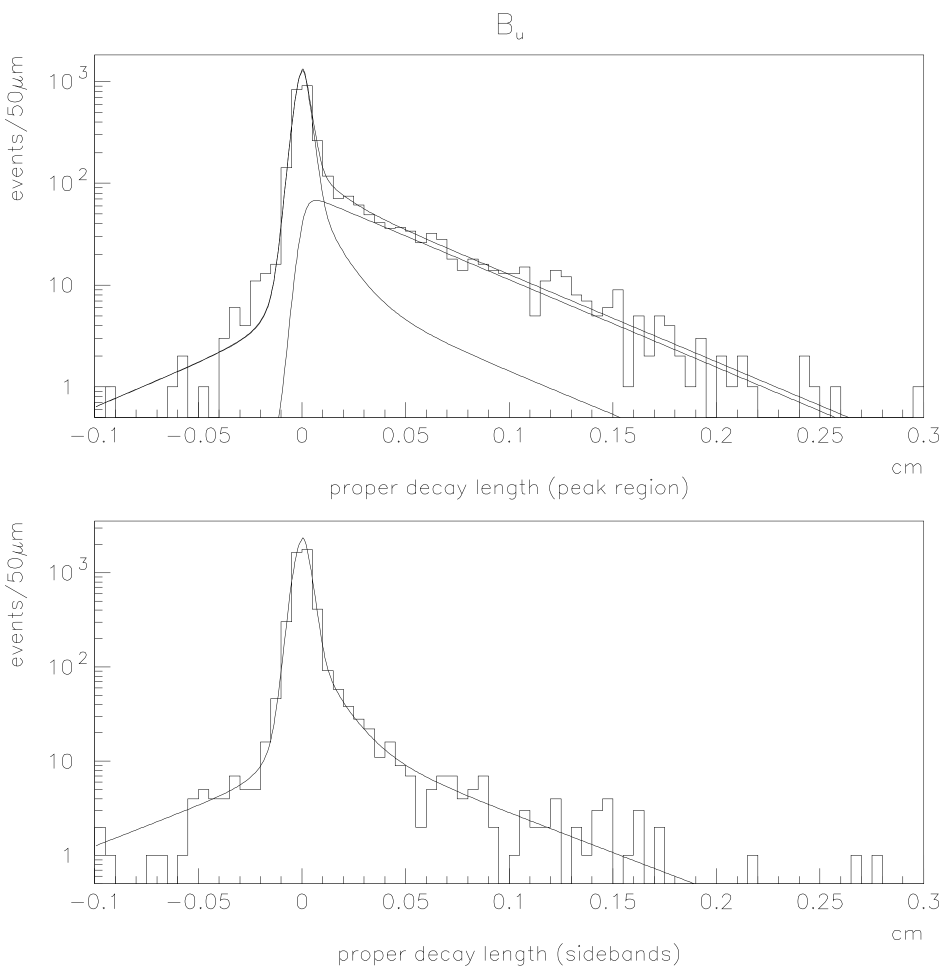
▷ Requires good momentum and impact parameter resolution

Run I Exclusive Lifetimes (II)



▷ Background model provided by mass sidebands

Run I Exclusive Lifetimes (III)



▷ Fit background and signal mass regions simultaneously

Run I Exclusive Lifetimes (IV)

Species	Signal	Lifetime (ps)
B^0	436 ± 27	$1.58 \pm 0.09 \pm 0.02$
B^-	824 ± 36	$1.68 \pm 0.07 \pm 0.02$
B_s	58 ± 12	$1.34^{+0.23}_{-0.19} \pm 0.05$

$$\frac{\tau(B^-)}{\tau(B^0)} = 1.06 \pm 0.07 \pm 0.01$$

√ Systematic uncertainties:

- Non-gaussian tails
- Fitting procedure
- SVX length scale/alignment

√ Limited by sample size

⇒ Try modes with larger branching fractions

Run I Inclusive Lifetimes

▷ Semileptonic branching fractions $\sim 10\%$, *e.g.*,

$\surd$ $B^- \rightarrow \ell^- \overline{\nu} D^0 X$

$\surd$ $\overline{B}^0 \rightarrow \ell^- \overline{\nu} D^{(*)+} X$

$\surd$ $\overline{B}_s \rightarrow \ell^- \overline{\nu} D_s^+ X$

$\surd$ $\Lambda_b \rightarrow \ell^- \overline{\nu} \Lambda_c^+ X$

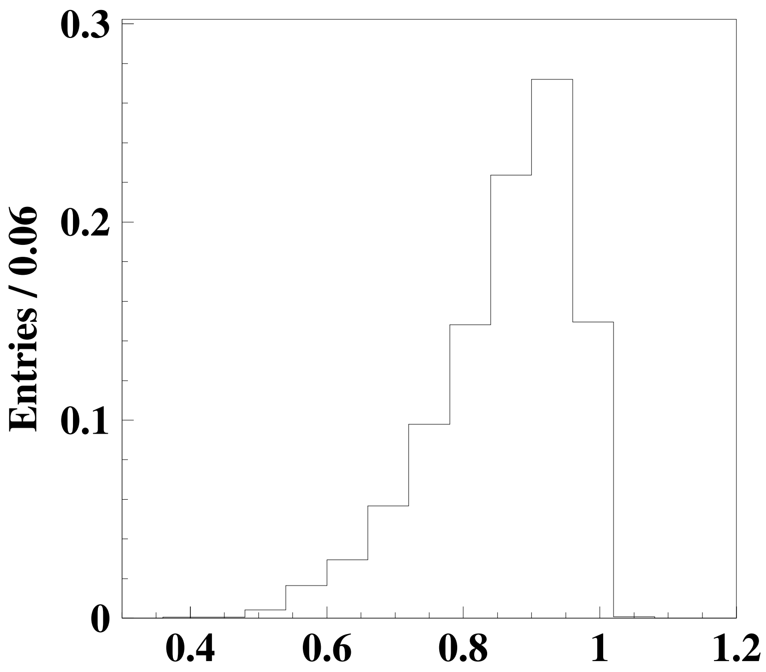
▷ Must correct for ν and other missed particles with Monte Carlo models:

$$c\tau = \frac{L_{xy} m_B}{p_T^{\ell D}} \left(\frac{p_T^{\ell D}}{p_T^B} \right)$$

Run I Inclusive Lifetimes (II)

$$c\tau = \frac{L_{xy} m_B}{p_T^{\ell D}} \left(\frac{p_T^{\ell D}}{p_T^B} \right)$$

$B_s \to \ell \nu D_s X$ simulation



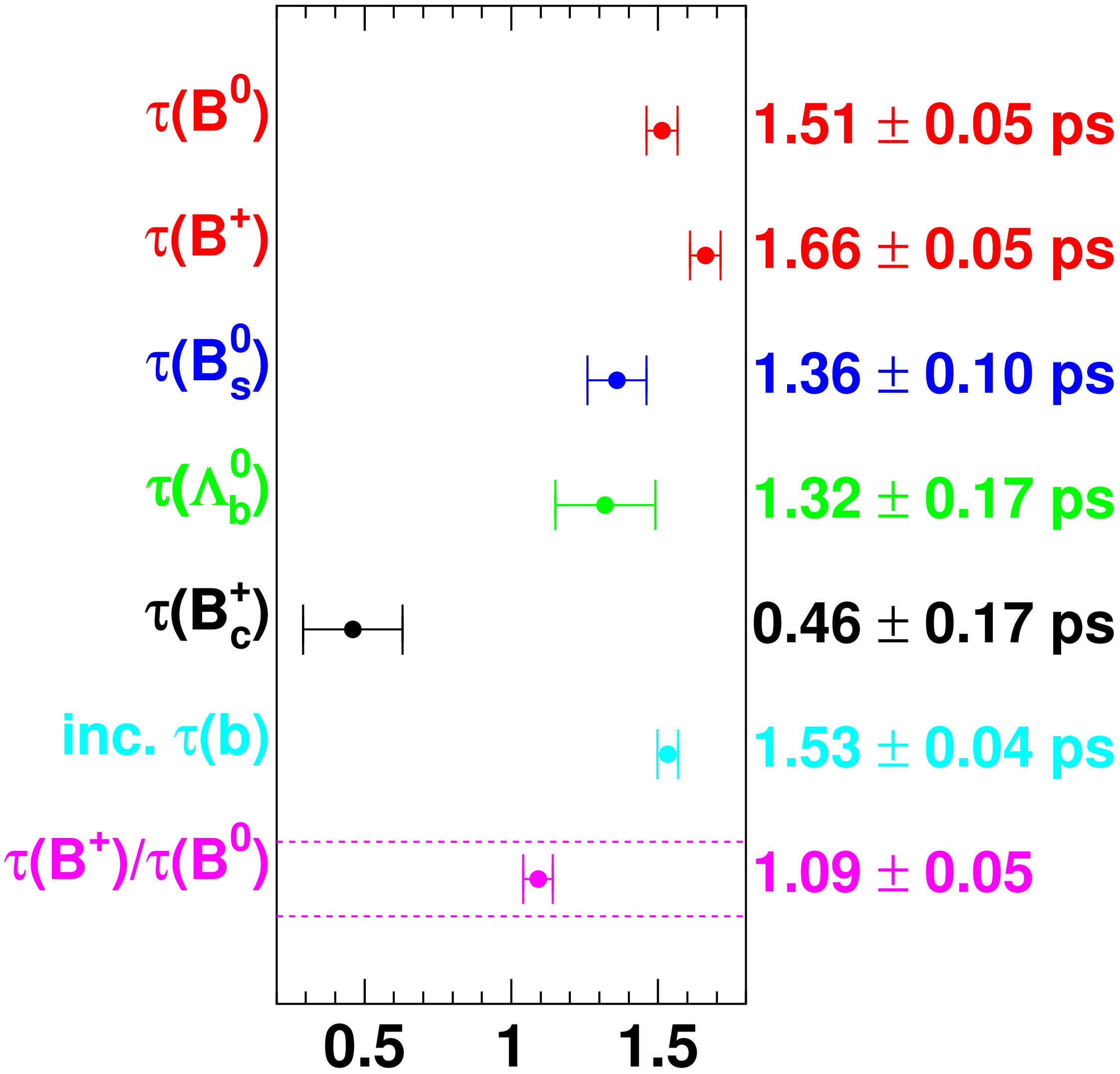
▷ Now also sensitive to

⇒ intermediate states ($e.g.$, D^{**}, $\Lambda_c(1520)$)
- what is missing?

⇒ decay model
- how much is missing?

⇒ initial B energy
- how much was there to begin with?

CDF B Lifetimes

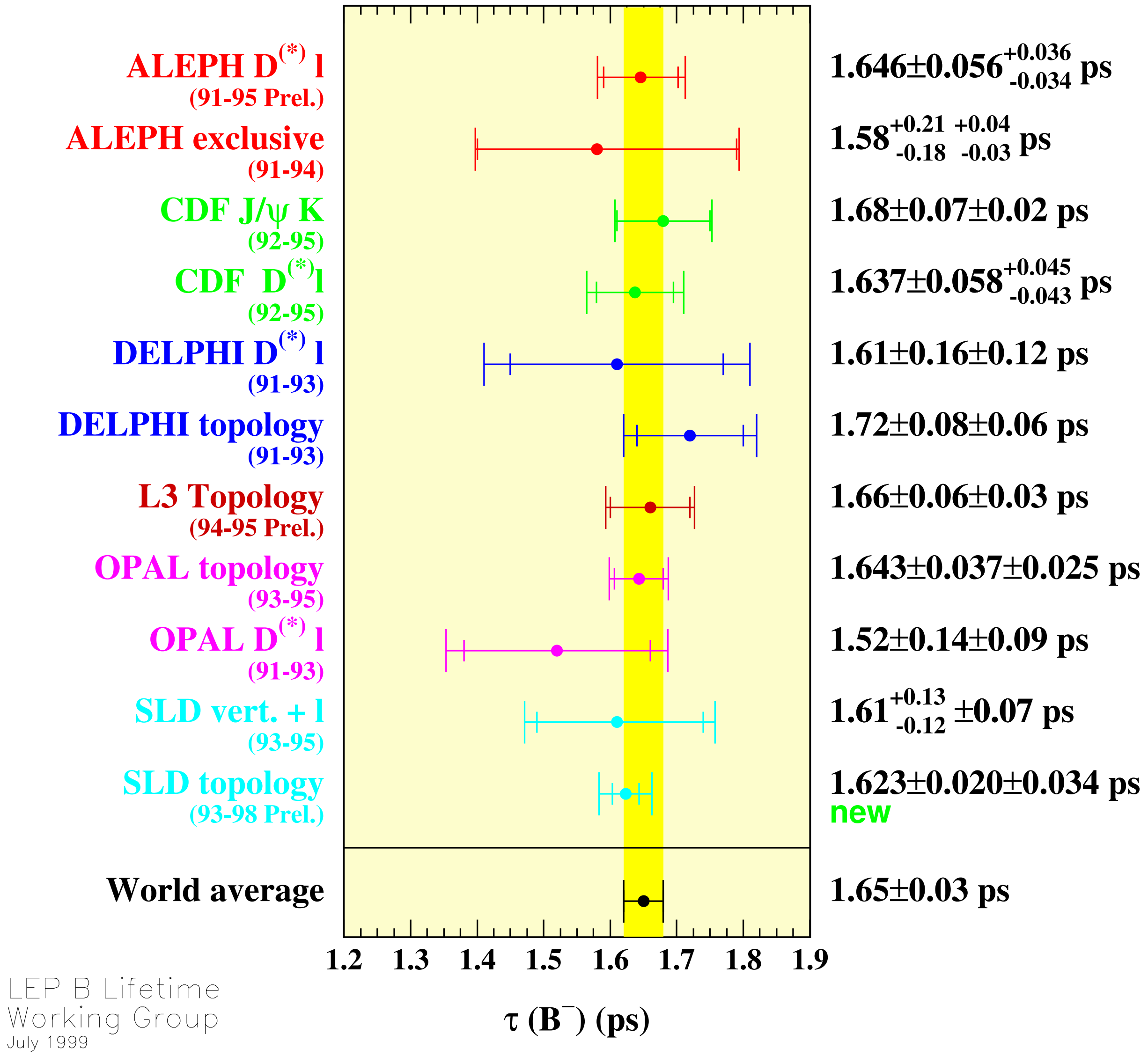


$$\frac{\Delta\Gamma(B_s)}{\Gamma(B_s)} < 0.83 (95\% C.L.)$$

CDF Run I itself not sufficient to test theory...
not the only game in town!

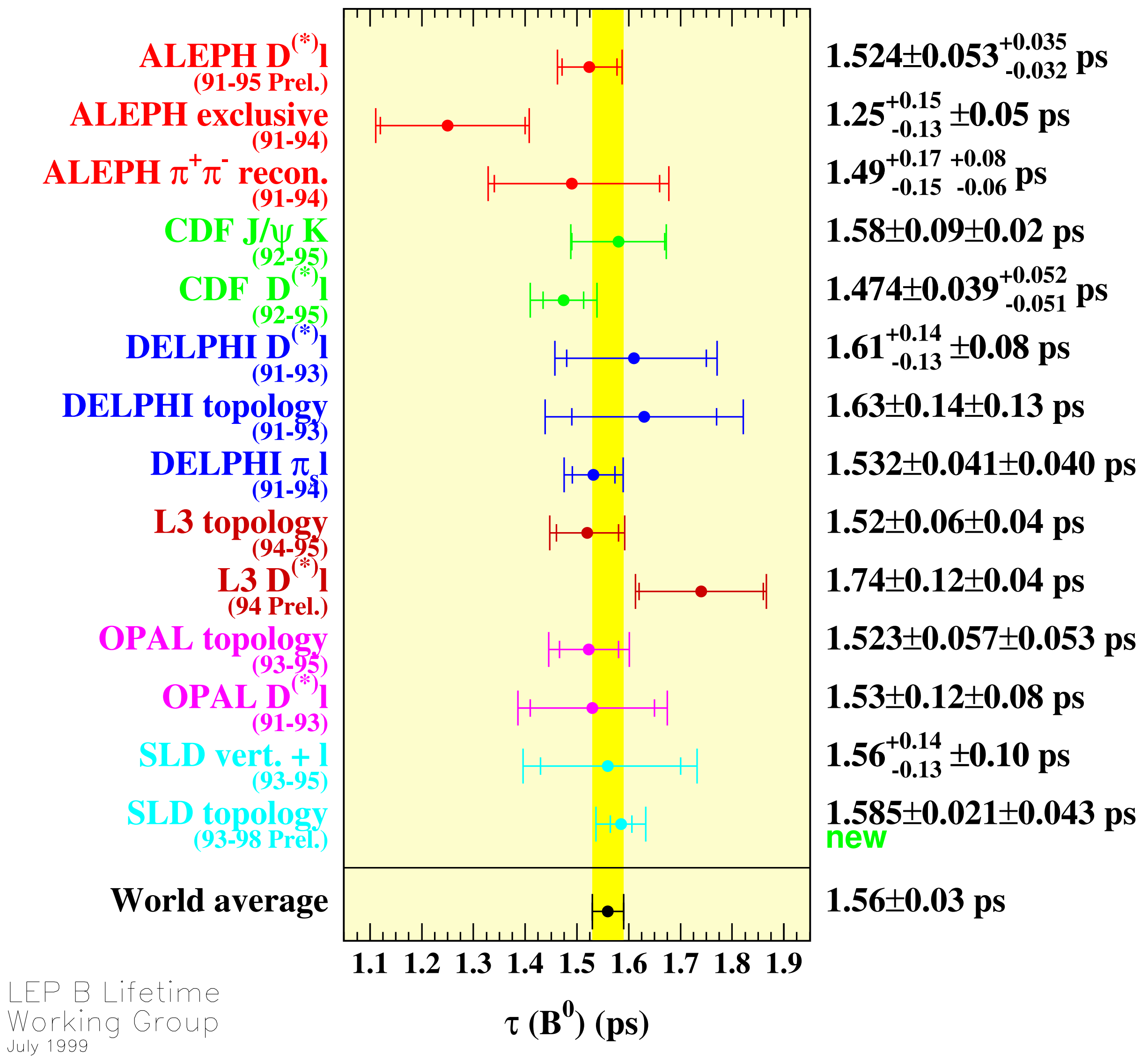
World Lifetime Measurements

B^- Lifetime



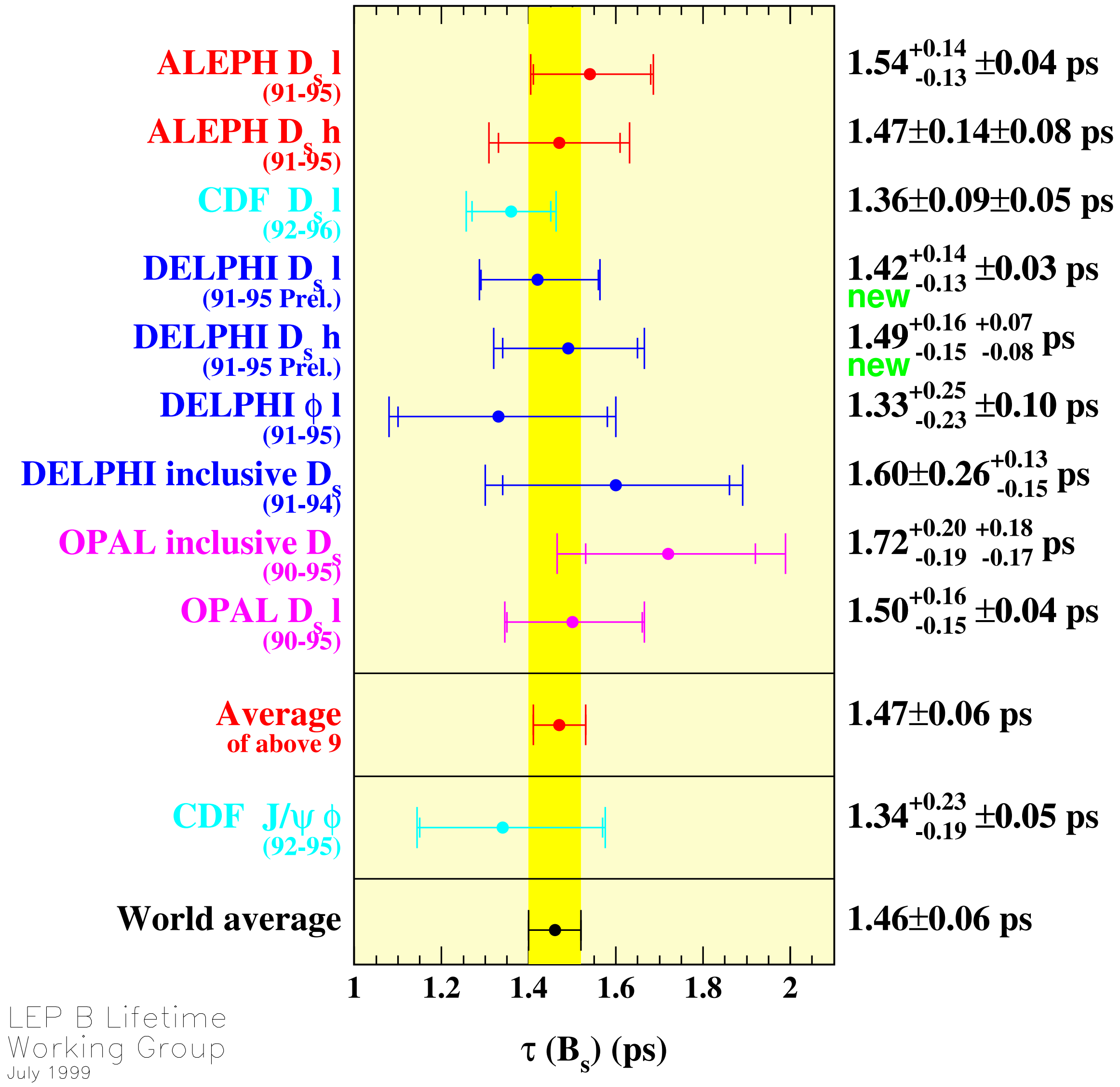
World Lifetime Measurements

B^0 Lifetime



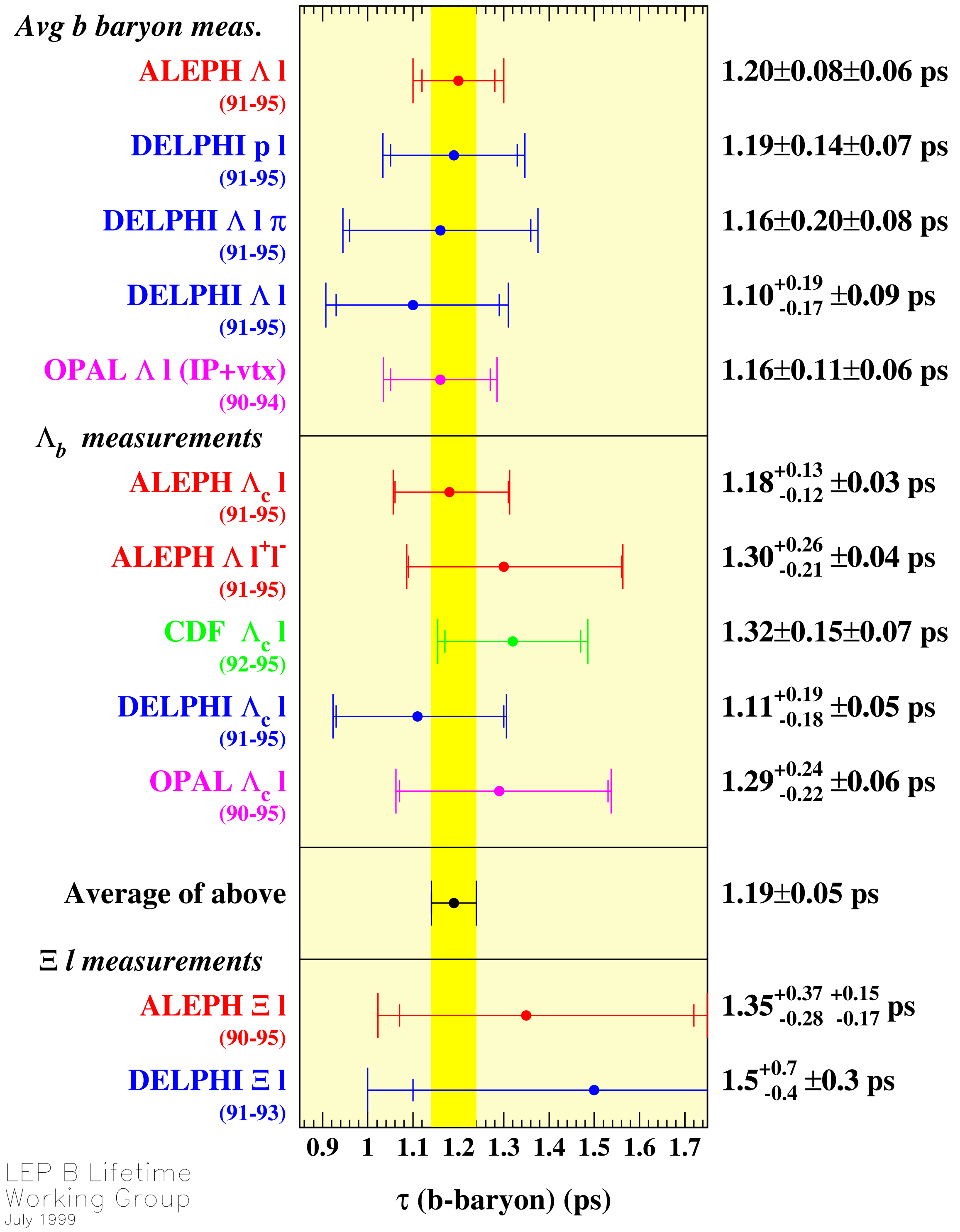
World Lifetime Measurements

B_s^0 Lifetime



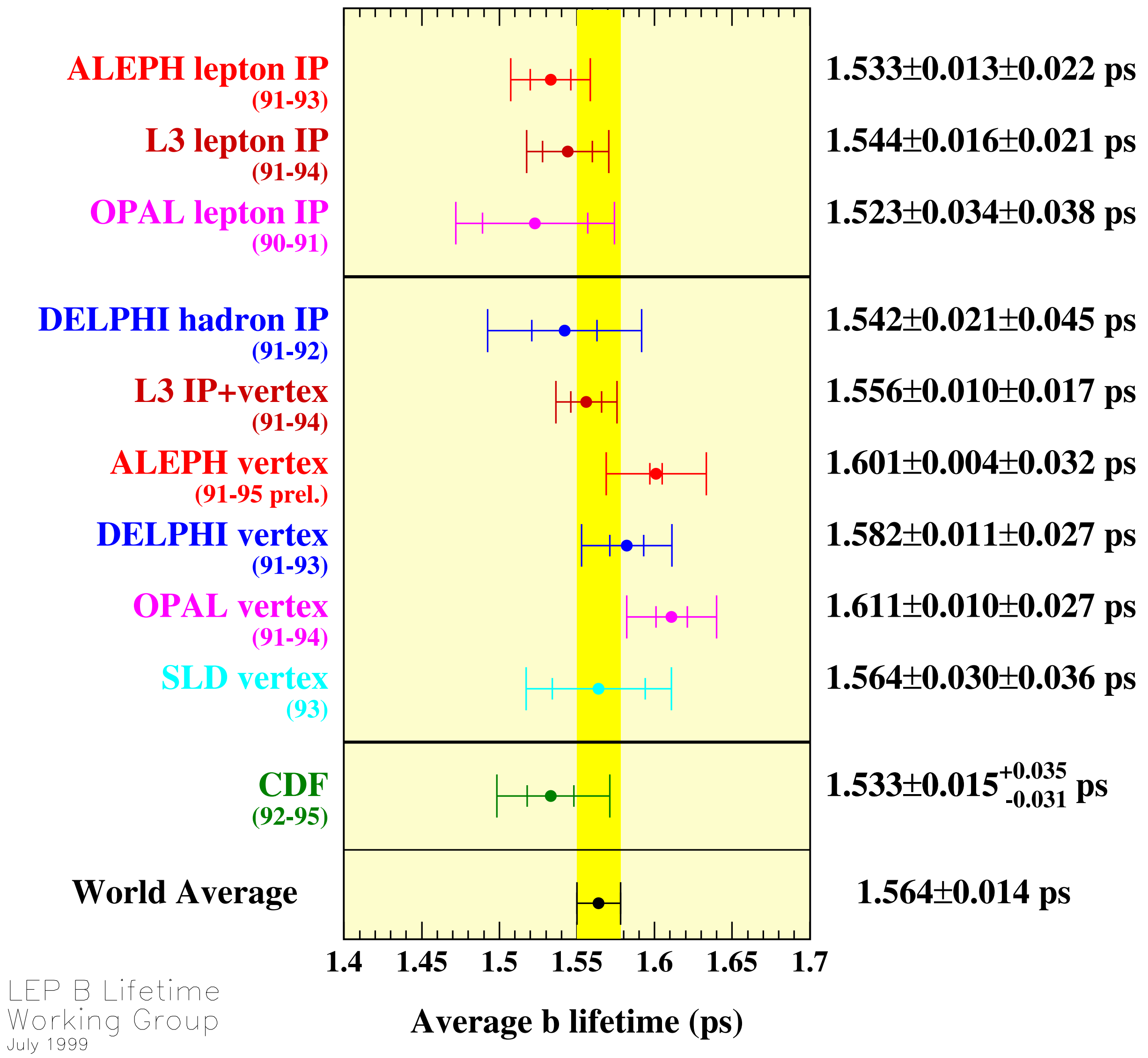
World Lifetime Measurements

b Baryon Lifetimes



World Lifetime Measurements

Average b Hadron Lifetime



World Lifetime Measurements

Different approaches to inclusive lifetimes

Event selection

- ▷ other decay modes of lighter hadrons
- ▷ b-tagged samples
  - ∘ track/calorimeter based secondary vertices
  - ∘ topological vertex search

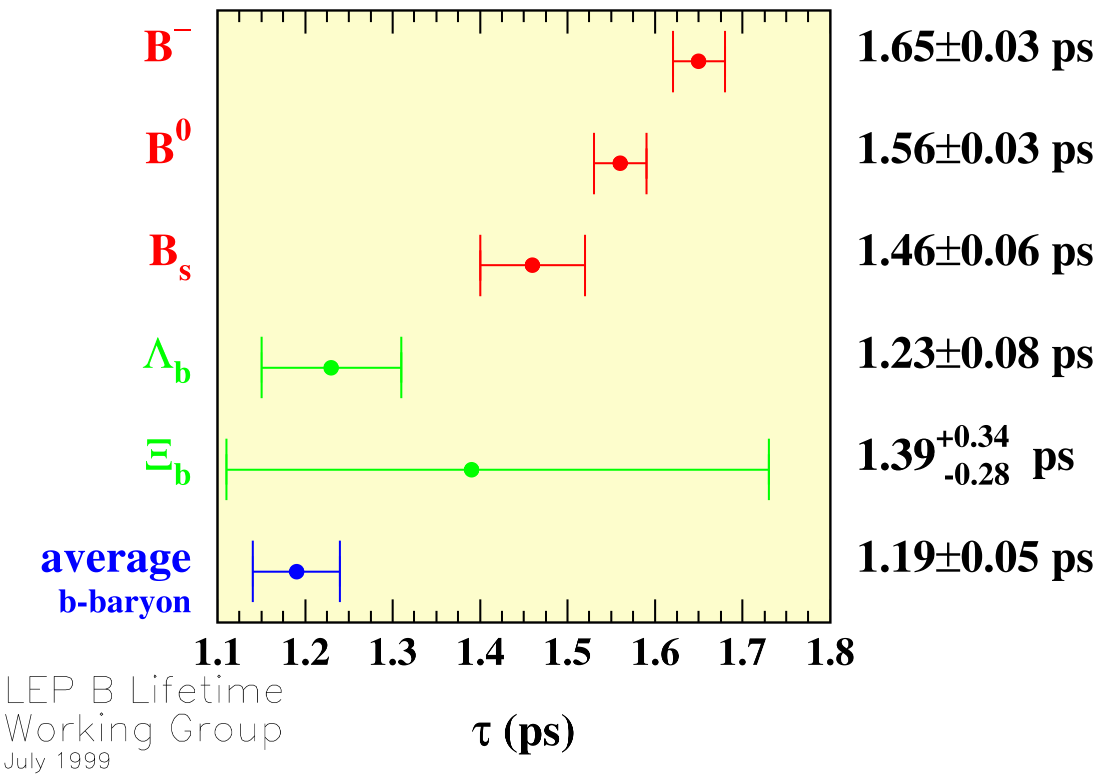
Inclusive b reconstruction

- ▷ Vertex "aggregation"
  - ∘ add tracks to a secondary vertex
  - ∘ distinguish charged and neutral B's with charge of "aggregate"
- ▷ Inclusive track-based vertex opposite to b tag

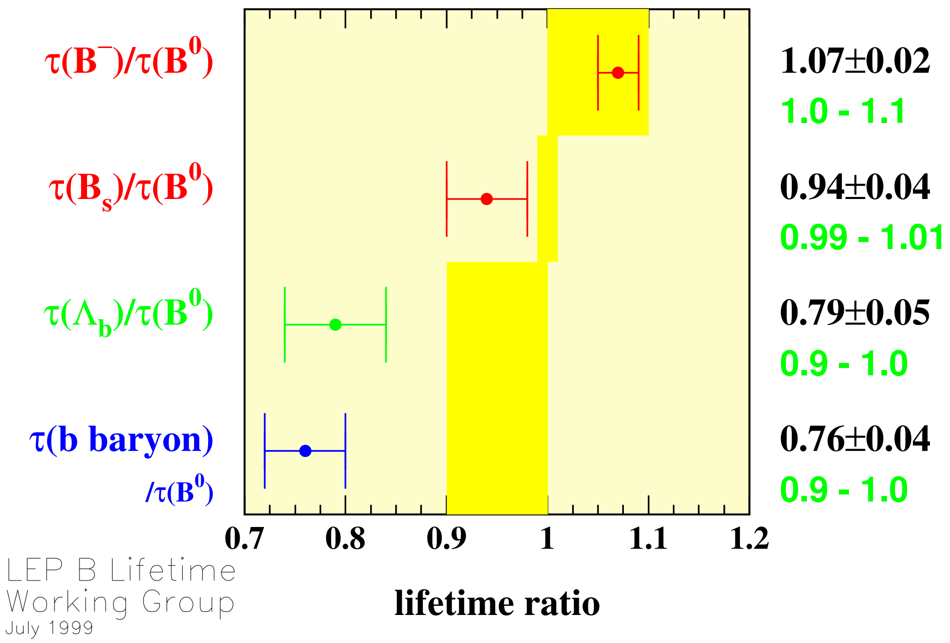
The Tevatron is a more challenging environment
for these more inclusive methods,
but we may yet find usable variants

World Lifetime Measurements

Averages over LEP, CDF, SLD



World Lifetime Measurements



A lot of work has gone into increasing the precision of the lifetime measurements, but we still have a way to go yet:

- LEP and SLD have ended their b runs
- $\Upsilon(4S)$ colliders can contribute significantly to $B_{u,d}$ lifetime measurements
- Tevatron and HERA-B: B_s, B_c, Λ_b, Ξ_b...
  - ▷ More, higher-quality data
  - ▷ Improved systematics
  - ▷ More approaches

More Data: Run II Prospects

2 fb^{-1}	$\Rightarrow$	$20\times$
extended μ coverage	$\Rightarrow$	$2\times$
SVX II	$\Rightarrow$	$1.5\times$

$\Rightarrow$ Large exclusive samples

(the quick and dirty extrapolation)

species	Run 1 sample size	Run 2 sample size	projected $c\tau$ error (ps)
B^-	820	50000	0.01
B^0	440	30000	0.01
B_s	60	4000	0.03
Λ_b	40	2000	0.04

Other improvements:

- e^+e^- triggers: $1.5\times$
- Si layer at $r = 1.4$ cm: 30 to 60% improvement in impact parameter resolutions
- B_s hadronic trigger: ~ 10000 more B_s's, but require trigger simulation

Run II Prospects (II)

- $\triangleright$ B^-/B^0 ratio error $\sim 1\%$
  $\Rightarrow$ distinguish between some theories
- $\triangleright$ B_s/B^0 ratio error $\sim 2\%$
  $\Rightarrow$ could find large SM deviations
- $\triangleright$ Λ_b/B^0 ratio error $\sim 4\%$
  Caveat: $B_{u,d}$ backgrounds
  $\Rightarrow$ could cause some headaches
- $\triangleright$ Ξ_b/Λ_b: still need to find Ξ_b

Inclusive analysis still useful for B_s, Λ_b, Ξ_b

- More data, and input from theorists and other experiments should help reduce systematic uncertainties (*e.g.*, decay kinematics)
- May use more inclusive methods; requires additional information from the tags (*e.g.*, K or baryon content of jets)
- Ξ_b: need to find Ξ_c first

Run II Prospects (III)

- B^- and B^0 lifetimes will be very precise, but systematic uncertainties will need more work
- Inclusive analyses useful for B_s, B_c, Λ_b, Ξ_b
- Comparison of $B_s \to \psi\phi$ and $B_s \to \ell\nu D_s X$ requires both anyway

$$\boxed{\text{Run II upgrades and datasets promise to enhance lifetime measurements of sufficient precision to promote fruitful comparison with theory}}$$