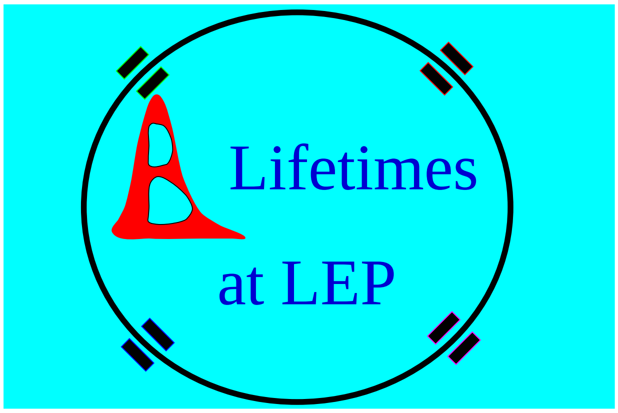


presented by

Richard Hawkings

(CERN, OPAL collaboration)

- Introduction
- Average B-hadron lifetime—theory and results
- Individual measurements—theory and results for B^0, B^-, B_s, Λ_b, Ξ_b
- Comparison with theoretical predictions
- The future of B-hadron lifetime measurements at LEP
- Conclusions

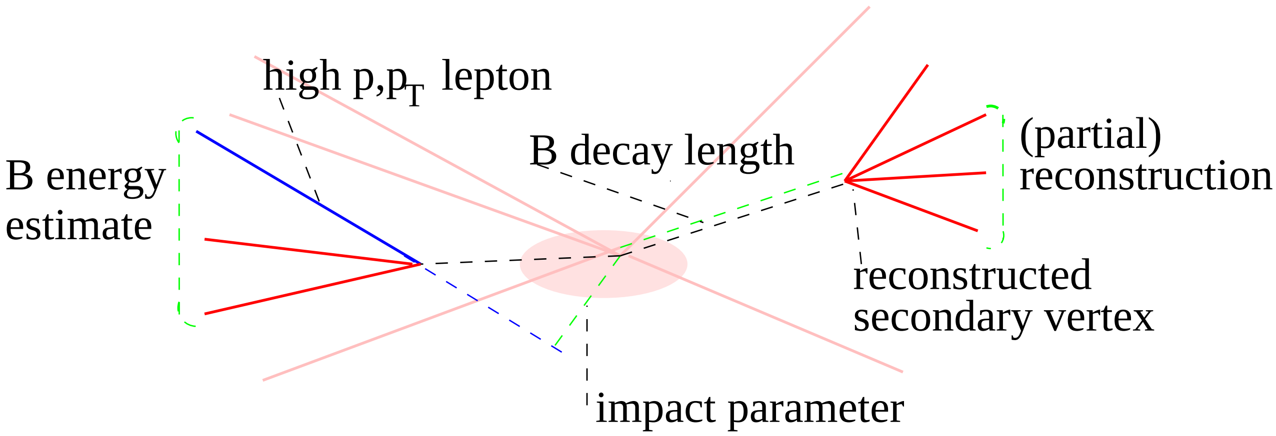
Thanks to other LEP collaborations for preliminary results,
and the LEP B-lifetimes working group for averaging guidelines.

Introduction

- During 1991-1995, each LEP experiment has collected $\sim 4 \times 10^6$ $Z^0 \rightarrow q\bar{q}$ events.

  1.7×10^6 b decays per experiment: B^-, B^0, B_s, Λ_b,B^*, ...

- Clean e^+e^- environment and high boost $< p_B >= 35$ GeV allows clean separation of B decay products from background.



Experiments require:

- High precision tracking

  Silicon vertex detectors (IP resolution: σ_{d0}, σ_{z0} =100–300 μm)

  Large volume tracking chambers (p_T and mass resolution)

- Particle identification (lepton identification; p, K, π separation)

  dE/dx measurements

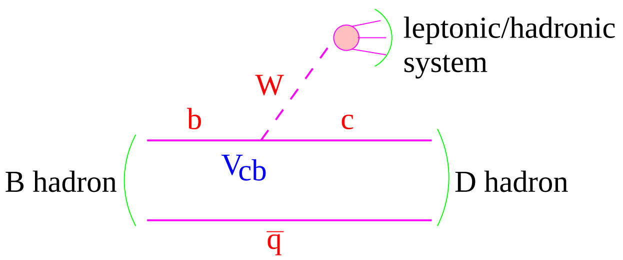
  Cherenkov detection (DELPHI RICH)

Average B lifetime

Spectator model: b quark decays independently $b \to cW^-$

$\Rightarrow$ All b hadrons should have same lifetime (NOT true experimentally)

Final state interactions, interference, change individual hadron lifetimes.



$$\Gamma(b \to l\nu X) \propto G_F^2 m_b^5 \mid V_{cb} \mid^2$$

but V_{cb} better measured in e.g.:

$$\overline{B}_d^0 \to D^{*+} l^- \overline{\nu}$$

Experimental measurements

Differences in selection efficiency for individual B-hadron bias the measured lifetime. Normally quote for the fractions produced in Z decays.

- Lepton impact parameters: ALEPH,L3,OPAL,DELPHI (also hadrons)

  High p_T leptons come mainly from B-hadron decays

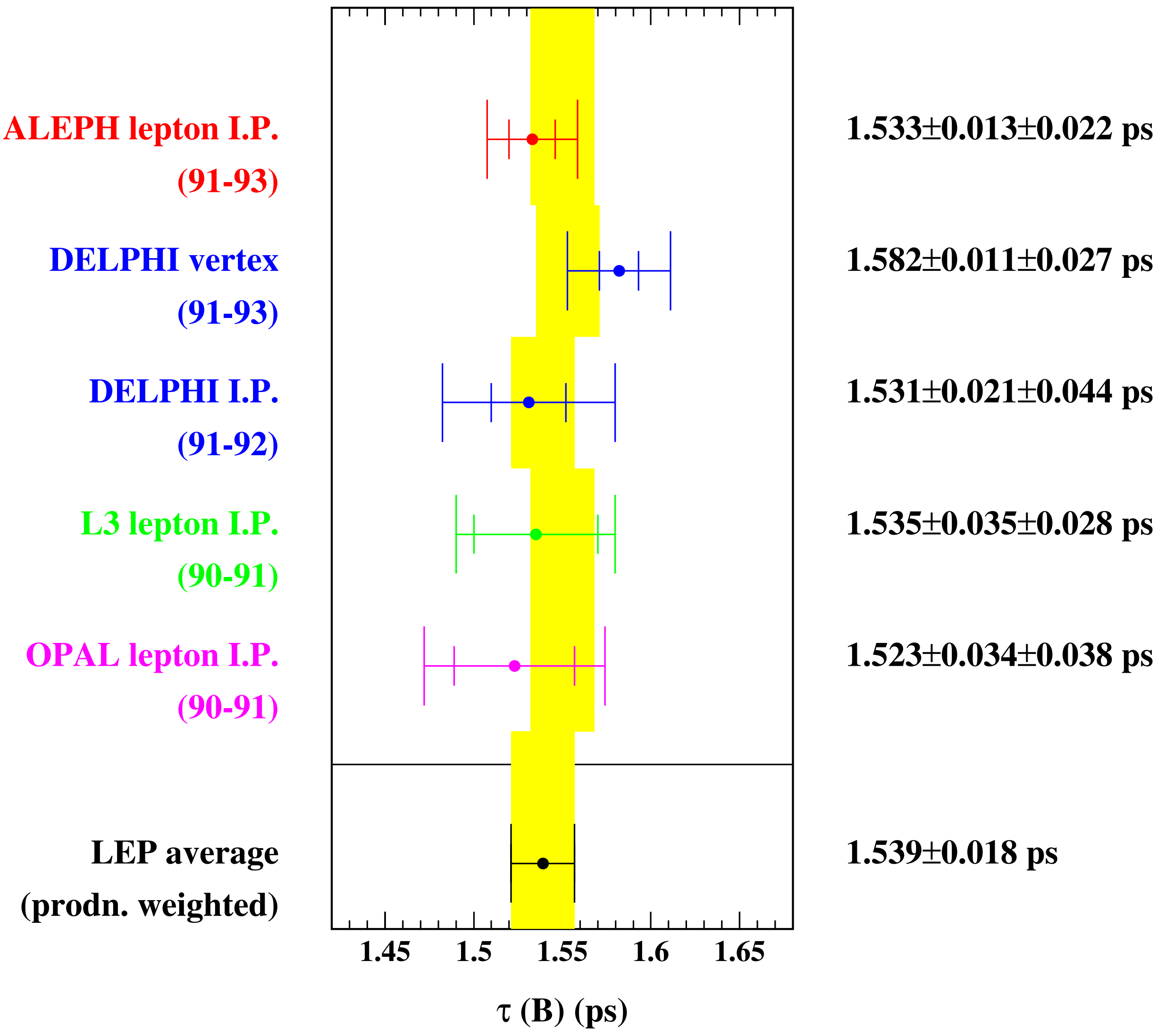
  Fit impact parameter distribution to determine B lifetime

  Assuming semileptonic width is same for all B-hadrons, bias on $< \tau(B) >$ is +0.011 ps.

- Inclusive displaced vertex reconstruction: DELPHI

  Decay length cut gives bias against B-baryons of +0.014 ps

Average B lifetime - LEP results



- Results are systematics limited: decay models, b fragmentation, ...
- More interesting to measure individual B hadron lifetimes (B^0, B^-, B_s, Λ_b, ...)

Individual B lifetimes - Theory

Spectator Model: All B-hadron lifetimes are equal …

Heavy Quark Expansion: but some are more equal than others.

Analysis using Operator Product Expansion shows that for B-hadrons, $1/m_b$ terms are absent, $1/m_b^2$ terms produce differences between meson and baryon lifetimes, and only $1/m_b^3$ and higher terms produce meson-meson differences. But what is the coefficient for $1/m_b^3$…?

Opinion is divided: I.I. Bigi (hep-ph 9507364)

$$\begin{aligned}\tau_{B^-}/\tau_{B^0} &= 1+0.05\left(\frac{f_B}{200\,\mathrm{MeV}}\right)^2 , \text{ i.e. } 1+\mathcal{O}(10\%)\\ \tau_{B_s}/\tau_{B^0} &= 1\pm\mathcal{O}(0.01)\\ \tau_{\Lambda_b}/\tau_{B^0} &= \sim 0.9\end{aligned}$$

$\Rightarrow \tau_{\Lambda_b} < \tau_{B^0} = \tau_{B_s} < \tau_{B^-}$

…however: M. Neubert, C.T. Sachrajda (CERN-TH/96-19)

$$\begin{aligned}\tau_{B^-}/\tau_{B^0} &= 1\pm\mathcal{O}(1/m_b^3) , \text{ but could be 0.8–1.2 !}\\ \tau_{B_s}/\tau_{B^0} &= 1\pm\mathcal{O}(0.01)\\ \tau_{\Lambda_b}/\tau_{B^0} &= 0.98\pm\mathcal{O}(1/m_b^3)\end{aligned}$$

$\Rightarrow \tau_{\Lambda_b} < \tau_{B^0} = \tau_{B_s}$ but no useful prediction for τ_{B^-}.

- Perhaps experiments can help…
- Differences between lifetimes are expected to be small, so precise measurements are required.

Individual B lifetimes - Techniques

- Measurement of an individual B-hadron lifetime requires:

  Isolation of a single B-hadron species, with low background.

  Measurement of the B decay length and energy: $t = \frac{m_b L}{c\sqrt{E^2 - m_b^2}}$

  Normally, a log likelihood fit is performed to extract the lifetime.

- **Complete reconstruction:** B^0, B^-

  Very good boost and decay length resolution.

  Very low backgrounds, but …

  Very low statistics (e.g. ALEPH 121 B^0 from 3M Z^0)

- **Decay product reconstruction:** B^0, $B-$, B_s, baryons

  Lepton + reconstructed charm hadron (D^0, D^{*+},Λ_c) or Λ.

  Purity limited by other B-hadrons decaying into 'wrong' D state.

  Efficiency limited by BR($b \to lX$) and e.g. BR($D^0 \to K^- \pi^+$).

  Good decay length resolution, neutrino degrades boost estimate.

- **More inclusive techniques**

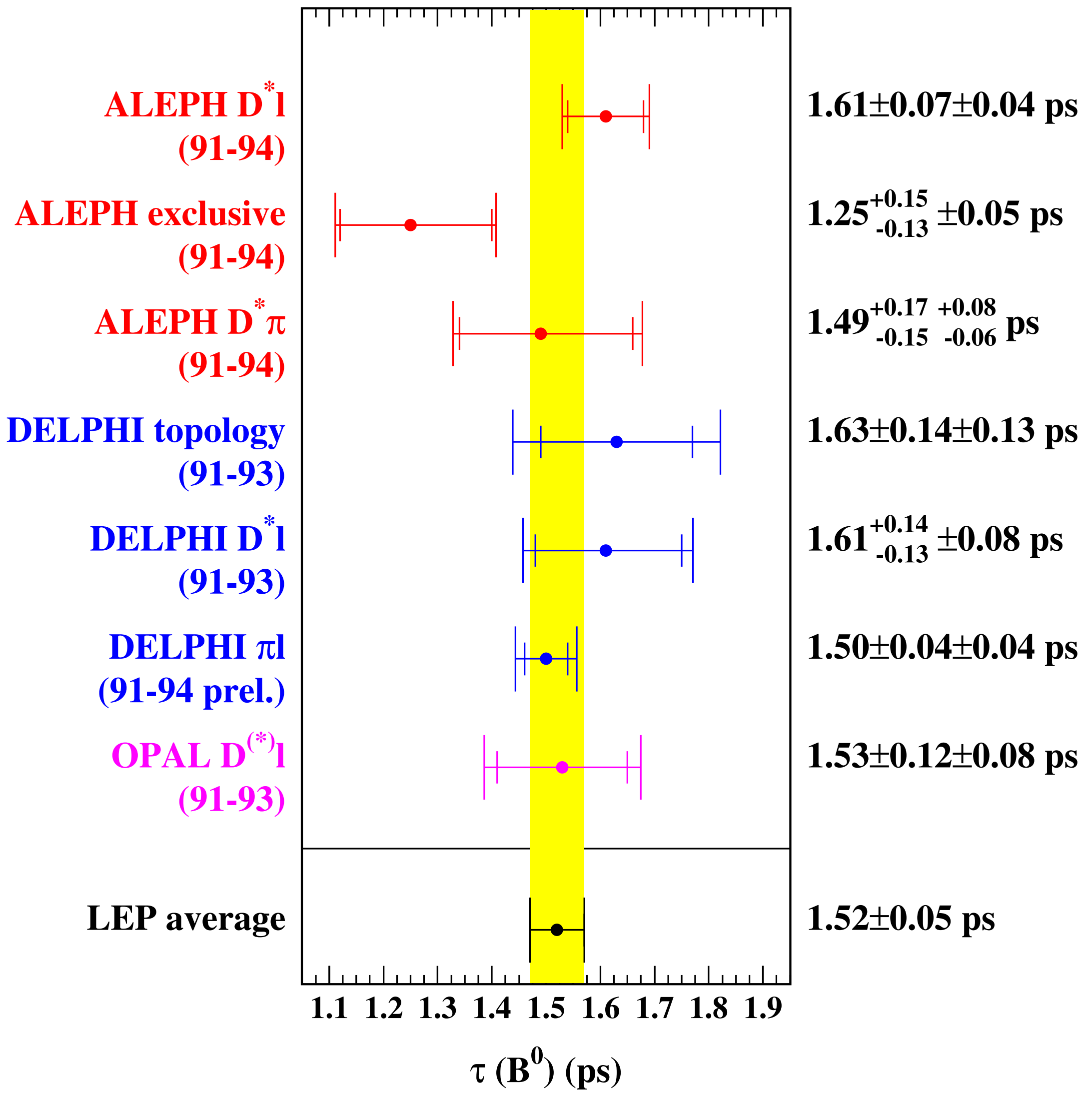
  Decay product + hadron: ALEPH, DELPHI B_s

  Vertex topology: DELPHI B^0, B^-

  Lepton + partial reconstruction: DELPHI B^0,Λ_b

  Gain in statistics but larger background, poorer t resolution.

B^0 lifetime - LEP results



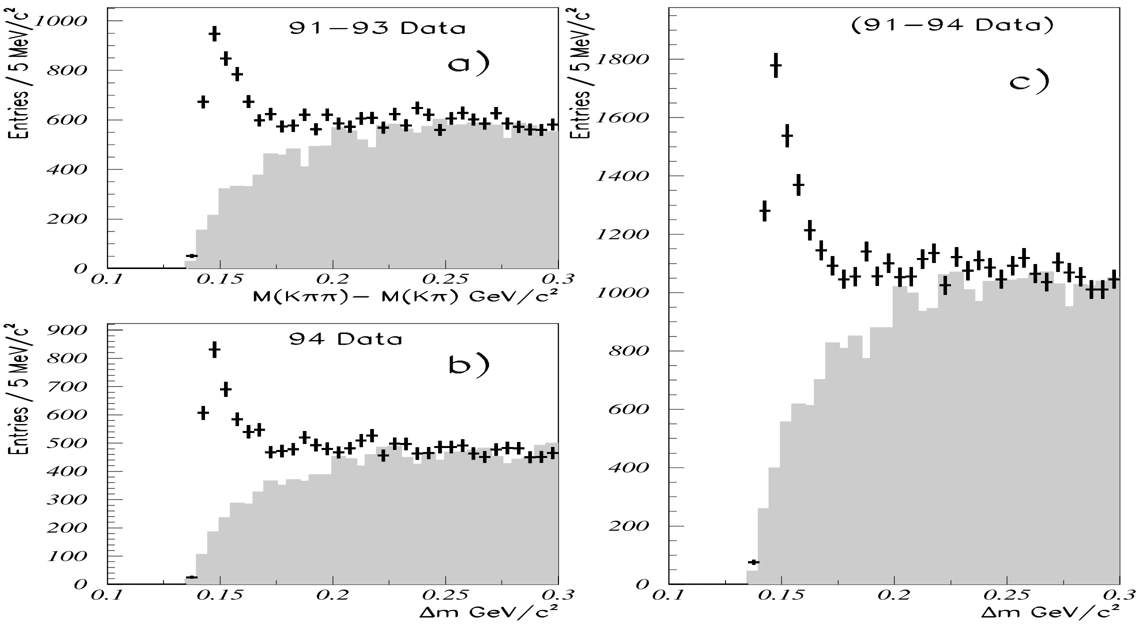
Most accurate measurements are:

- ALEPH D^* lepton (high statistics 91-94)
- DELPHI preliminary π lepton (inclusive D reconstruction) $\Leftarrow$

DELPHI B^0 lifetime from $\pi_s^+ l^-$ corrl.

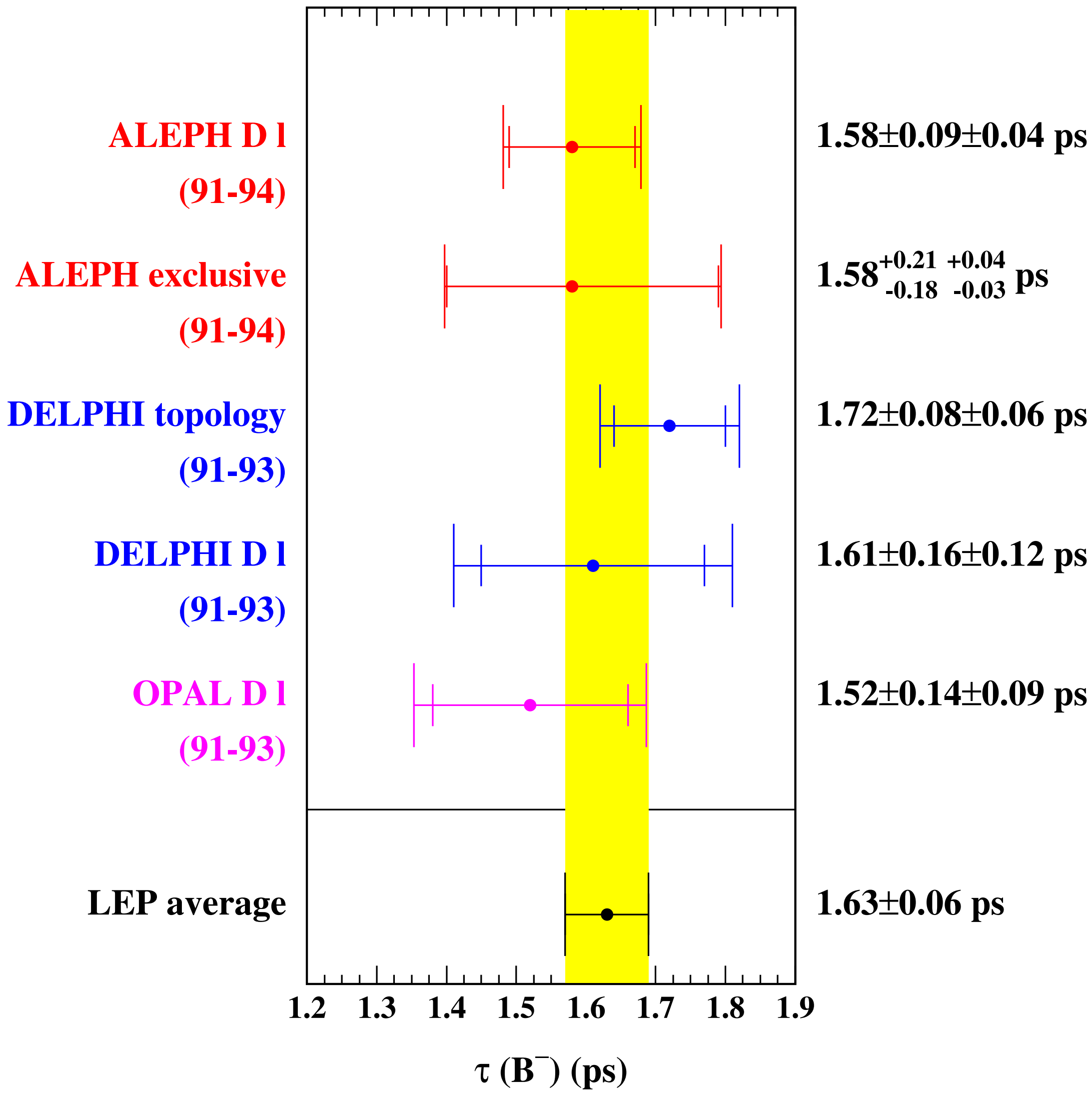
$$\overline{B^0} \rightarrow D^{*+} X l^- \overline{\nu_l}$$
$$\hookrightarrow D^0 \pi^+$$

- Reconstruct D hadron inclusively by clustering particles in jet up to 2.2 GeV (excluding lepton)
- Search for the 'slow pion' π^+ which alters the cluster mass by Δm when included - peak is seen at $\Delta m = m(D^{*+}) - m(D^0)$.
- Combinatiorial background controlled from wrong sign sample $(\pi^+ l^+)$ in data for shape, and ratio right sign:wrong sign in MC.
- 4130 events reconstructed, with background of 30%



DELPHI measure $\tau_{B^0} = 1.502^{+0.040}_{-0.039} \pm 0.042$ ps (preliminary)

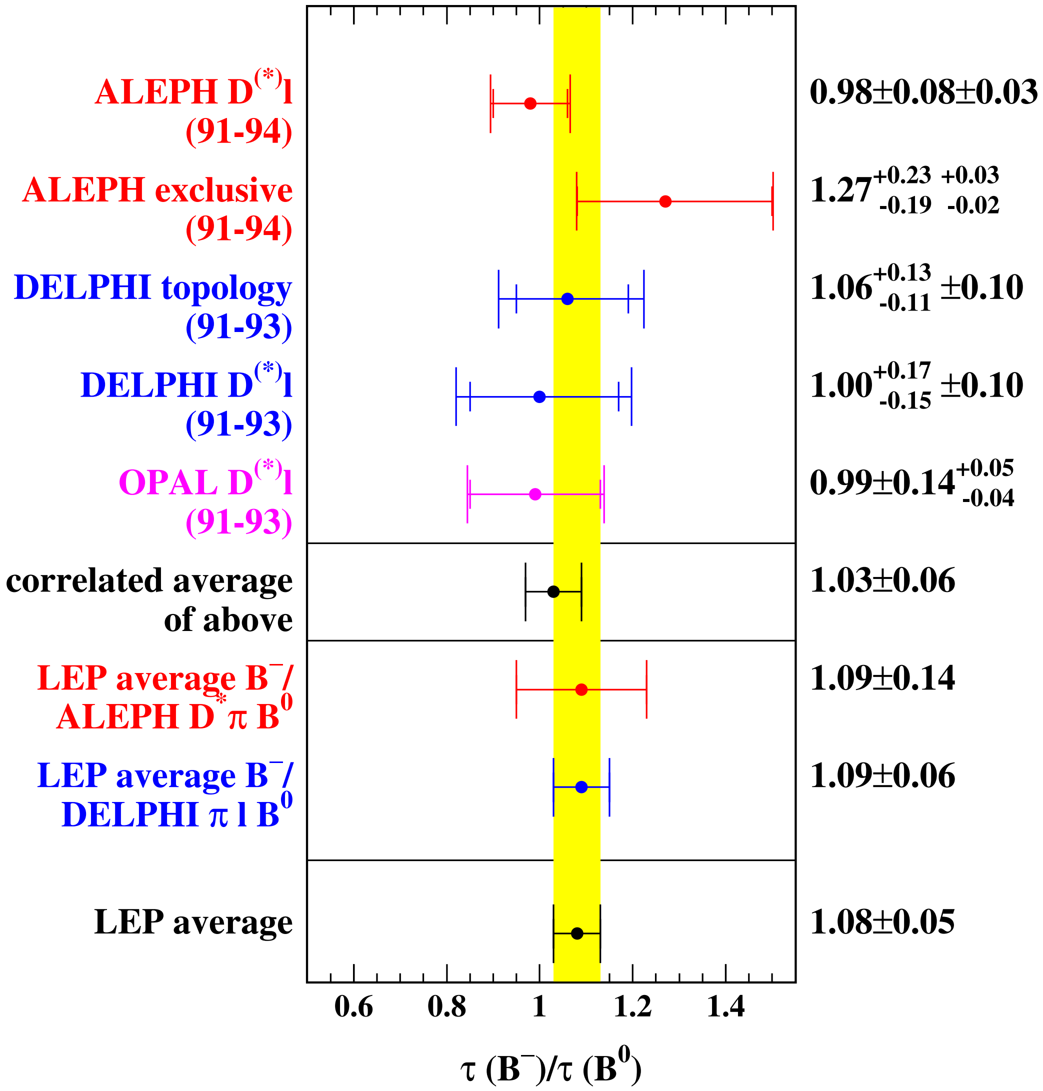
B^- lifetime - LEP results



Most accurate measurements are:

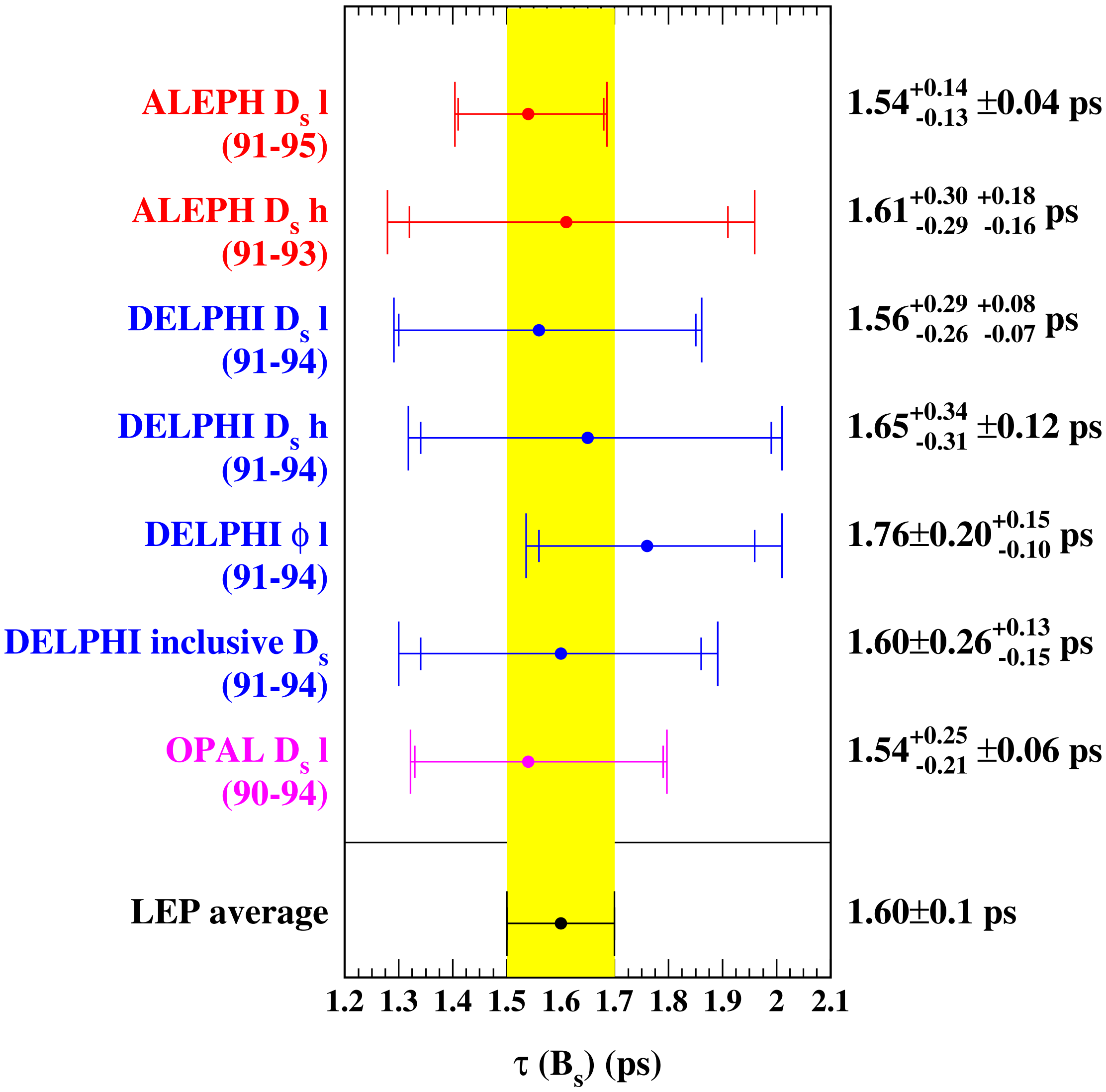
- ALEPH D lepton (high statistics 91-94)
- DELPHI vertex topology search for unambiguous charge ± 1 vertices

B^+/B^0 lifetime ratio - LEP results



- Many analyses measure τ_{B^-}/τ_{B^0} explicitly - (cross correlations).
- Most precise B^0 measurement does not have corresponding B^-.
- Include all data by calculating $\tau_{B^-\mathrm{LEP}}/\tau_{B^0\mathrm{LEP}}$ and estimating individual B^-/B^0 correlations from quoted τ_{B^-,B^0} and ratios.

B_s lifetime - LEP results

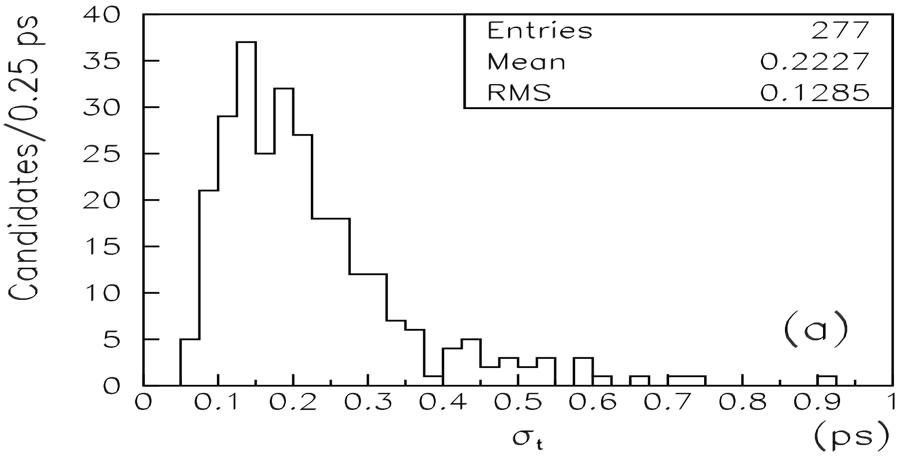


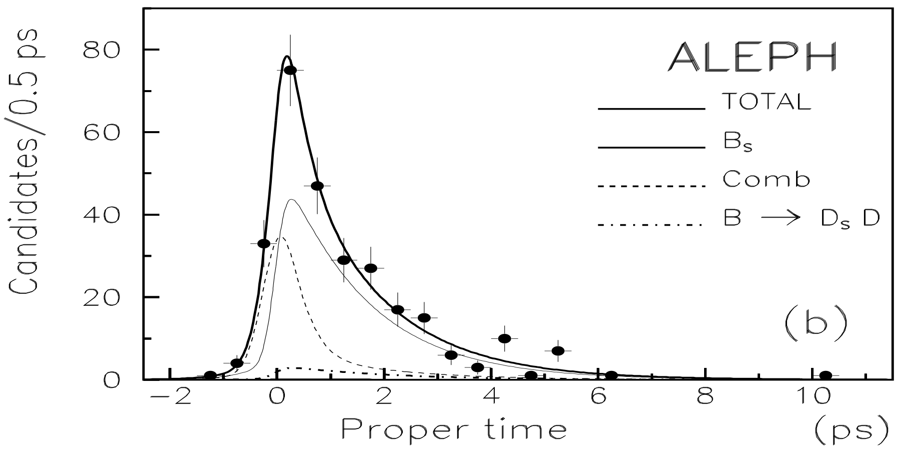
- Result is less precise than B^0, B^- (lower rate, higher backgrounds)
- ALEPH D_s lepton dominates result - full data sample with seven D_s^- decay modes - result published in B_s oscillation paper.

ALEPH B_s lifetime from $D_s^- l^+$ comb.

$$B_s \rightarrow D_s^- l^+ \nu_l X$$

D_s^- channel	Events	Purity
$\phi\pi^-$	61	78%
$K^{*0}K^-$	102	63%
$K_s^0 K^-, \phi 3\pi, K^{*0}K^-$	70	56%
$\phi e^- \nu, \phi\mu^-\nu$	44	68%





ALEPH measure $\tau_{B_s} = 1.54^{+0.14}_{-0.13} \pm 0.04$ ps (91-95)

B-baryon lifetime measurements

- A mixture of B-baryon states is produced at LEP: ($\Lambda_b^0, \Sigma_b, \Xi_b, \Omega_b$)
  Only ground state baryons $\Lambda_b^0, \Xi_b^0, \Xi_b^-, \Omega_b^-$ should decay weakly.

- B-baryons (Λ_b) are tagged with lepton + baryon ($\Lambda \to p\pi^-$ or p)
  Lifetimes can be measured from:

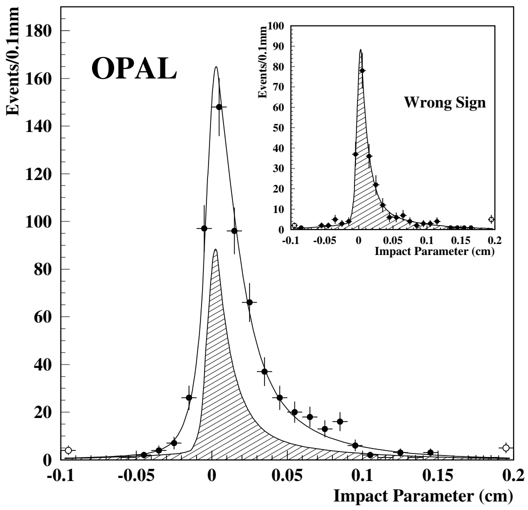
  lepton impact parameter (ALEPH, DELPHI, OPAL)

  lepton-Λ (pseudo track) vertex (OPAL)

  lepton-Λ-hadron vertex (DELPHI)

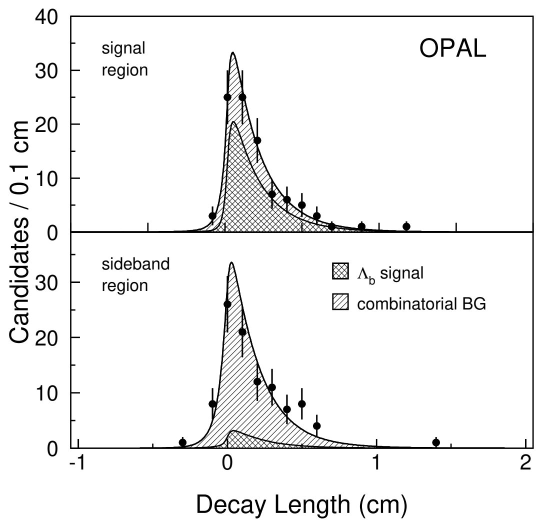
- Exclusive reconstruction of Λ_c^+ provides tag of specific Λ_b^0 (bdu).
  $\Lambda_c^+ \to pK^-\pi^+, pK^0, \Lambda\pi^+\pi^+\pi^-$ (lower statistics).

- Backgrounds controlled using 'wrong sign' samples (Λl^+, $\Lambda_c^+ l^+$)



OPAL lepton IP:

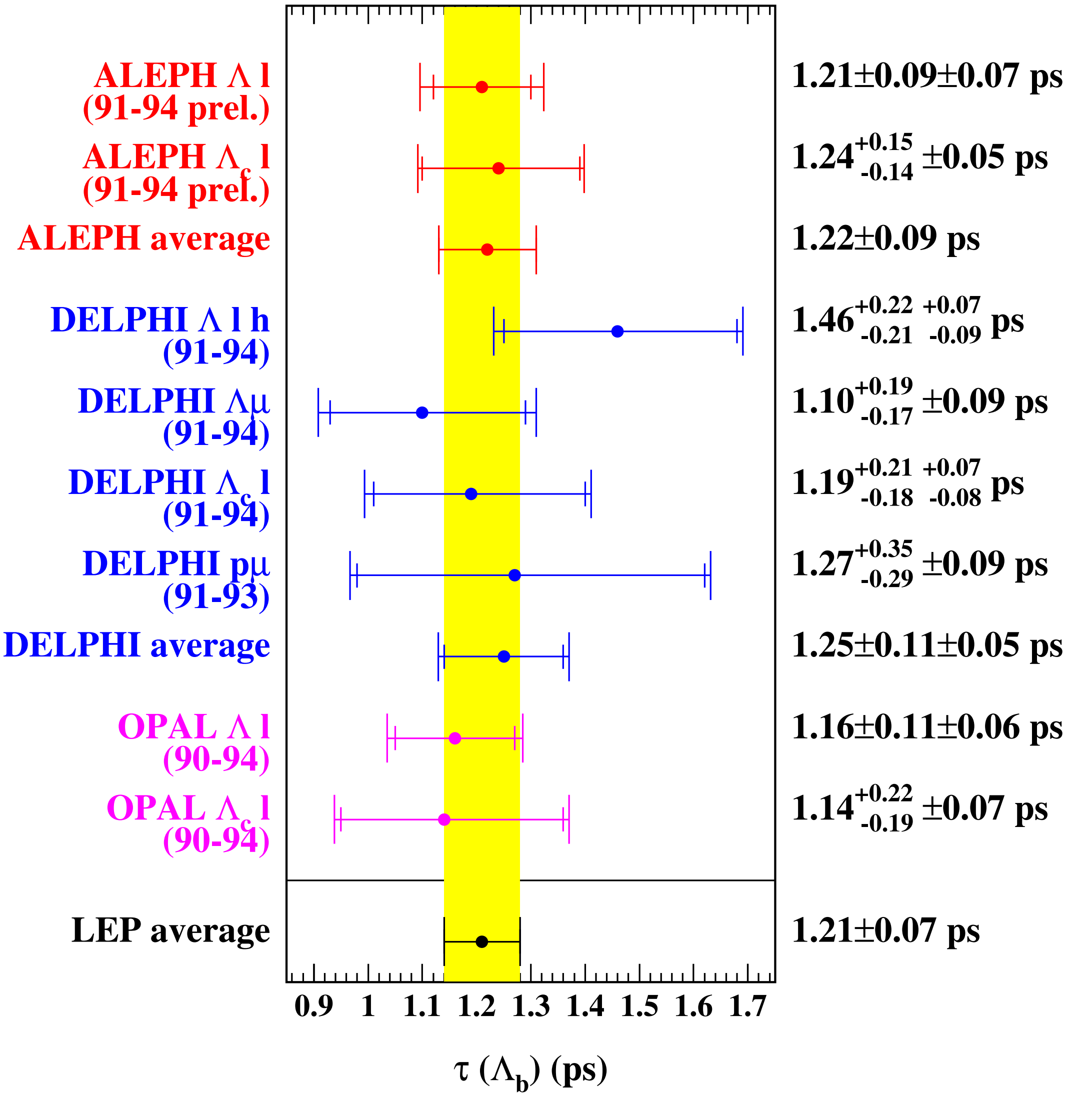
$\tau_{\Lambda_b} = 1.21^{+0.15}_{-0.13} \pm 0.10$ ps



OPAL $\Lambda_c^+ l^-$:

$\tau_{\Lambda_b^0} = 1.14^{+0.22}_{-0.19} \pm 0.07$ ps

B-baryon lifetimes - LEP results



- No evidence for difference between Λ_b (inclusive) and Λ_b^0.
- Precision is almost as good as B^0 and B^- lifetimes
- τ_{Λ_b} is 3.6σ smaller than τ_{B^0}.

Strange B-baryon (Ξ_b) lifetime

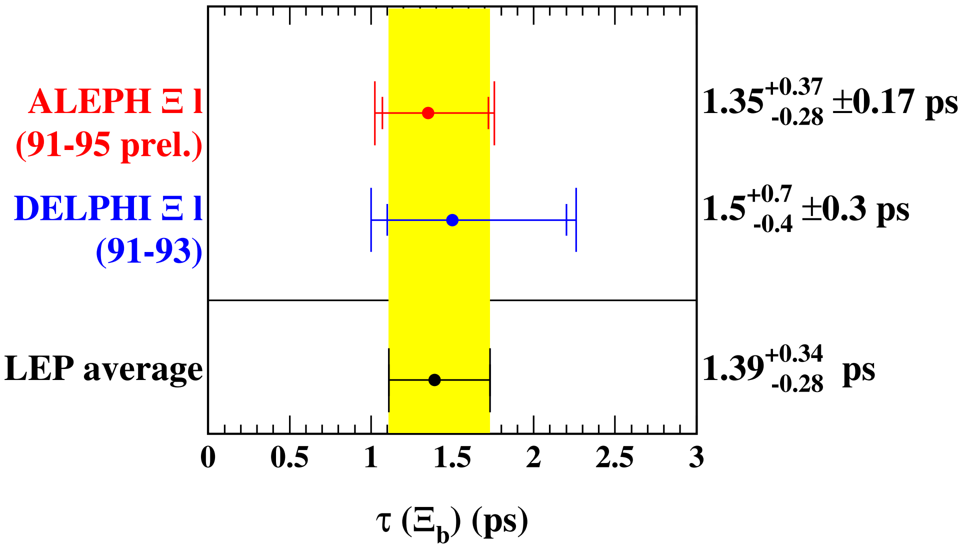
Ξ_b (bsu or bsd) was first reported by DELPHI, now also seen by ALEPH. However, discovery was anticipated by Francis Bacon (1561-1626):

> "There is no excellent beauty that hath not some strangeness in the proportion." *Essays - 43. On Beauty*

Idea similar to Λ_b reconstruction:

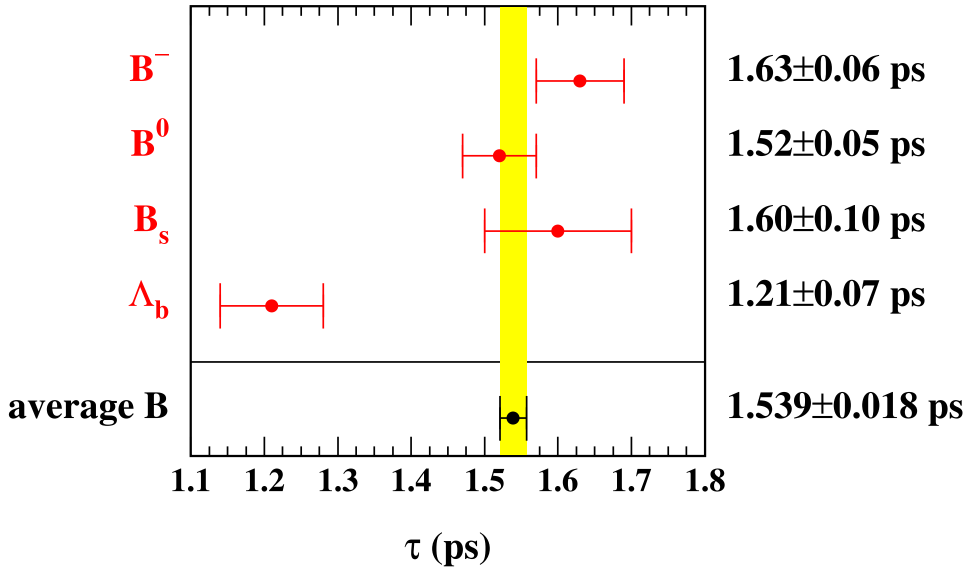
$$\begin{array}{llll} \Xi_b \rightarrow & \Xi^- l^- \overline{\nu_l} X & & \text{N.B. same sign!} \\ & \hookrightarrow & \Lambda\pi^- & \\ & & \hookrightarrow p\pi^- & \end{array}$$

DELPHI have 10 candidates (91-93), and ALEPH have 44 (91-95 prel.)



τ_{Ξ_b} is consistent with both Λ_b and B meson lifetimes …

Where are we now ?



- $\tau_{B^-}/\tau_{B^0} = 1.08 \pm 0.05$, theory $1 + \mathcal{O}(10\%)$ ..?
  Ratio is > 1 at 1.6σ, can start to place constraints on the coefficients in the heavy quark expansion.

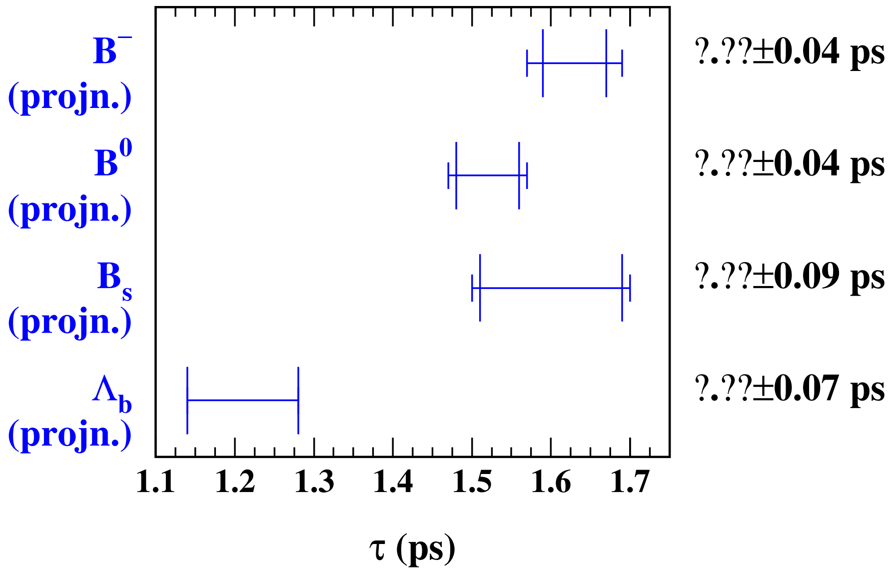
- $\tau_{B_s}/\tau_{B^0} = 1.05 \pm 0.07$, theory $1 + \mathcal{O}(1\%)$
  Measurements are not precise enough to test the prediction.

- $\tau_{\Lambda_b}/\tau_{B^0} = 0.80 \pm 0.05$, theory 0.9–0.99
  Ratio is interesting but not conclusive, and has gone up in the last year.

Most recent change is reduction in the B^0 lifetime measurement…
Ratios are now closer to theoretical prediction!

Where can we get to?

- Size of the LEP $Z \to q\bar{q}$ sample is now known…but not results!
- Predict final errors on lifetimes based on existing analysis techniques scaled to full data sample, and extended to other LEP experiments (scaling statistical errors only)



- B^0: apply DELPHI π_s lepton technique to other experimnets, use full data sample.
- B^-: apply vertex charge measurement to all experiments, use full data sample.
- B_s, Λ_b: little improvement possible - most analyses up to 94 or 95 data.

Only incremental improvements—new techniques will be needed…

Conclusions

- B-hadron lifetimes and ratios provide insights into the interplay between weak and strong interactions.
- An area of intensive theoretical study.
- LEP provides the best measurements of B-hadron lifetimes…
  (…but CDF is catching up fast).
- LEP measurements are now rather mature—starting to be limited by common systematics, so new techniques will be needed to make big improvements.
- Watch the Λ_b lifetime!

☺