A Review of B Hadron Lifetime Measurements

from LEP, the Tevatron, and SLC

presented by

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(CERN/PPE, OPAL Collaboration)

- Motivation
- Measurement Techniques
- Lifetime measurements and world averages for the

  average b hadron lifetime, B^0, B^-, B_s, and b baryons
- Status and Prospects

Acknowledgements:

Thanks to the LEP B Lifetime Working Group for compiling the averages.
(See http://wwwcn.cern.ch/∼claires/lepblife.html.)

Motivation for Measuring B Lifetimes

- Interesting Non-Spectator Effects
  - Quark Interference
  - Weak Annihilation
  - W Exchange
- Expected hierarchy:

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

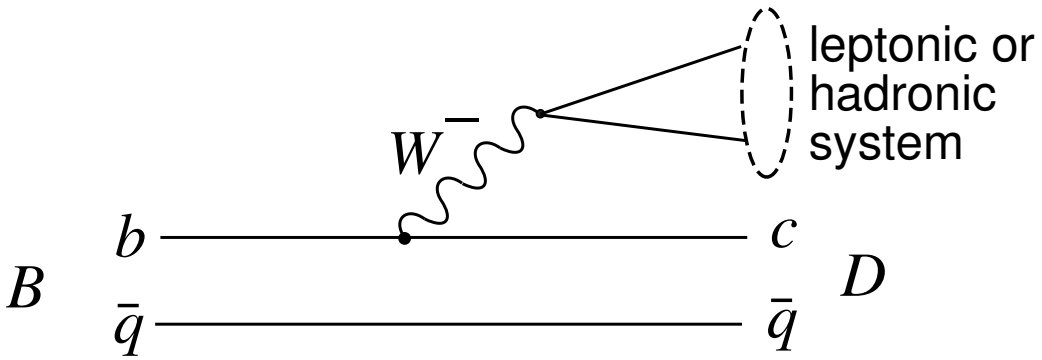
c.f. the charm sector: $\tau_{D^+} \sim 2\tau_{D_s} \sim 2.5\tau_{D^0} \sim 5\tau_{\Lambda_c}$

Non-spectator effects scale inversely with m_q^2
And may have larger terms scaling inversely with m_q^3.
$\Rightarrow$ *these effects should be smaller for b hadrons.*

- Sensitive to V_{cb} (and V_{ub}).
- Sensitive to QCD corrections.
- Lifetimes and ratios are inputs to B_d and B_s oscillation analyses.
- B_s CP Eigenstates are expected to have different lifetimes (up to 30% different)
  – I.I. Bigi (hep-ph 9507364); I. Dunietz, Phys. Rev. **D52** (1995) 3048.

Introduction

Spectator Model: b quark decays independently $b \to cW^{*-}$ ...



$\Rightarrow$ all b hadrons should have equal lifetimes

Non–spectator effects cause lifetime differences:

c.f. the charm sector: $\tau_{D^+} \sim 2\tau_{D_s} \sim 2.5\tau_{D^0} \sim 5\tau_{\Lambda_c}$

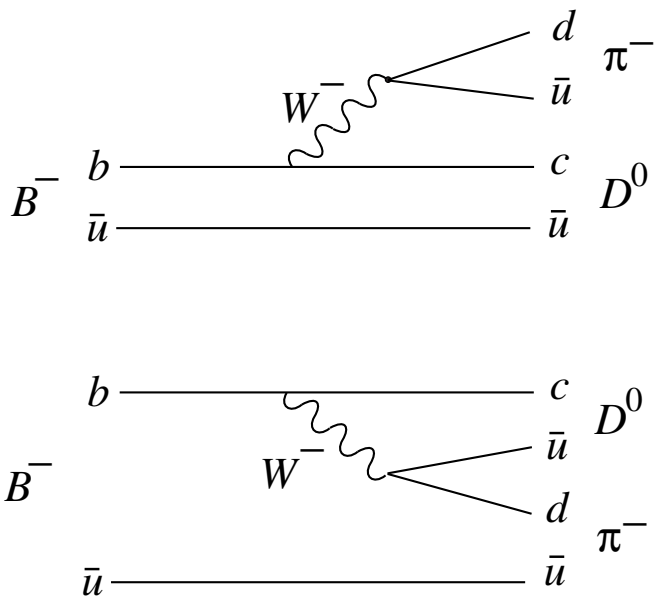
1. Quark Interference
2. Weak Annihilation
3. W Exchange

Non-spectator effects scale inversely with quark mass

$\Rightarrow$ *these effects should be smaller for b hadrons.*

Non-spectator effects

1. Quark Interference



Identical states

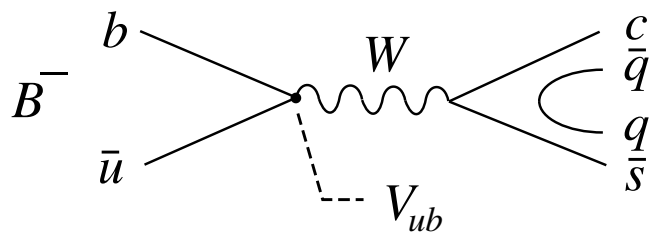
⇒ taken altogether, the identical states produce *destructive interference*

⇒ longer B^- lifetime

For B^0, the similar decay is $B^0 \to D^+\pi^-$ and $B^0 \to \overline{D}^0\pi^0 \Rightarrow$ distinguishable states, no interference.

$\Rightarrow$ B^- lifetime longer than B^0

2. Weak Annihilation

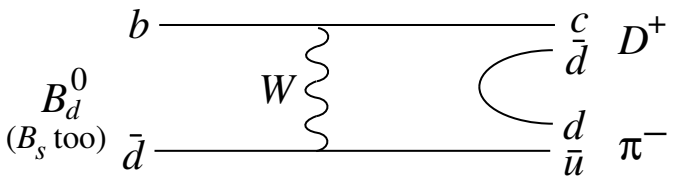


$|V_{ub}|^2$ is small

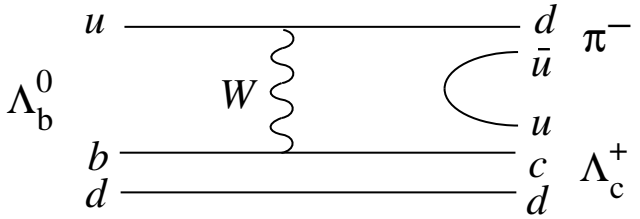
$\Rightarrow$ only important for B_c^-

Non-spectator effects (cont.)

3. W Exchange



Helicity suppressed



Not helicity suppressed

$\Rightarrow$ lower Λ_b lifetime

Expected hierarchy:

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

But what about the size of these lifetime differences?

Individual B lifetimes - Theory

Heavy Quark Expansion gives size of differences . . .

- Baryon–meson differences given by $\mathcal{O}(1/m_b^2)$ terms
- Meson–meson differences smaller $\mathcal{O}(1/m_b^3)$ — but what size is the coefficient of these terms?

Standard predictions: I.I. Bigi (hep-ph 9507364)

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

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

. . . however: M. Neubert, C.T. Sachrajda (CERN-TH/96-19) question some assumptions used above, and find:

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

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

Perhaps experiments can help. . .

Differences between lifetimes are expected to be small
$\Rightarrow$ precise measurements are required.

Required Precisions

Goal: test the validity of heavy-quark expansion and understand QCD and weak corrections.

- The b Baryon lifetime is already significantly discrepant from the meson lifetimes.
  Would like to know $\tau_{\Lambda_b}/\tau_{B_d}$ to 5%
- M. Neubert: Measurements of τ_{B^-}/τ_{B^0} and τ_{B_s}/τ_{B_d} to 5% accuracy would be "nice."
- 1% Measurements of τ_{B^-}/τ_{B^0} and τ_{B_s}/τ_{B_d} would be "extremely interesting."

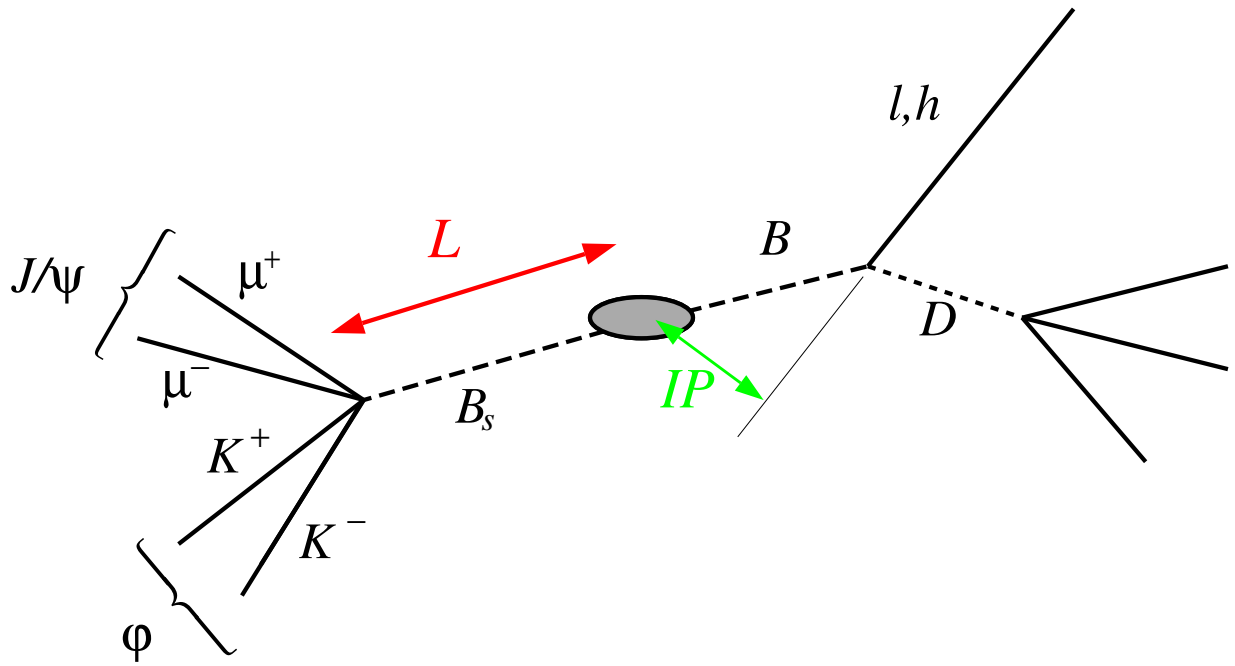
Measurement Strategy

To measure B lifetimes, one needs to reconstruct:

B decay length & momentum: $t = \frac{m_B}{c\, p_B} L$

or

Impact Parameter of a track from B decay, e.g. a lepton



Lifetime Measurement Techniques

- ## Decay Length (vertex):

  Select a sample enriched in an exlusive decay of a particular B species

  Use sidebands and wrong-sign combinations to estimate background and background lifetime shape. Find a displaced vertex, measure distance (in 2D or 3D) to the B production vertex.

  – LEP beam spot: $\sim 120\ \mu$m $\times\ 10\ \mu$m $\times$ $\sim$1 cm. Typical resolution: 60 μm $\times\ 10\ \mu$m $\times\ 60\mu$m.

  – Tevatron beam spot: $\sim 35\ \mu$m $\times\ 35\ \mu$m $\times\ 30$ cm.

  – SLC beam spot: 1 μm $\times\ 2\ \mu$m $\times\ 700\ \mu$m. Known to 6 μm in x, y.

  Use boost estimate to get length to time $\Rightarrow$ some model dependence

  Fit to exponential convoluted with a resolution function, with estimated backgrounds.

- ## Impact Parameter (IP):

  Select samples of a B species and estimate background

  Measure IP of a track (e.g a high p, p_t lepton). Less boost dependence. Fit data with a convolution of a "physics function" — estimated from Monte Carlo models — and a resolution function.

- ## Systematic Errors

  – Signal composition

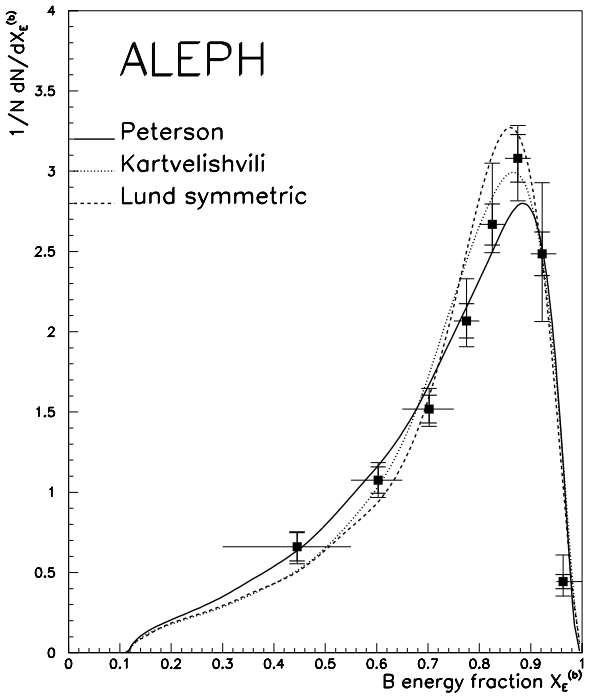
  – Background parameterization

  – Boost estimation

  – Detector alignment, Tracking Resolution, Primary vertex determination

B Hadron Production at the Z^0

At LEP/SLC, B hadrons have a large boost:
$p_{B_{\rm av}} \sim 30$ GeV, $\rightarrow \ell_{\rm av} \sim 3$mm

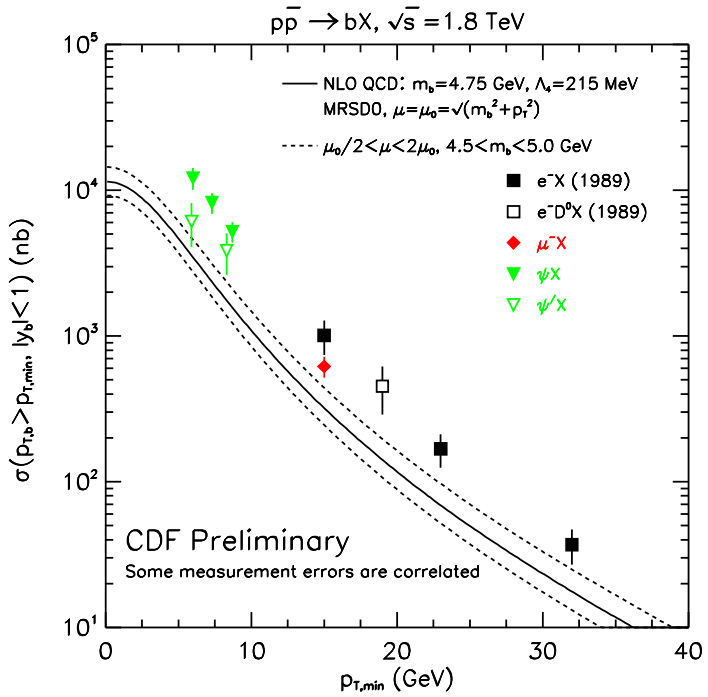


b hadron type	nominal	PDG 1996 Average
$B^0 + B^-$	0.80	0.756 ± 0.044
B_s	0.12	$0.112^{+0.018}_{-0.019}$
b baryons	0.08	0.132 ± 0.041

- e^+e^-: Clean environment with beam energy constraint
  ($Z^0 \rightarrow b\bar{b}$ & BR = 22%)
  LEP: 1.7×10^6 B hadrons/expt; SLD 64,000 B hadrons

B Hadron Production in $p\bar{p}$

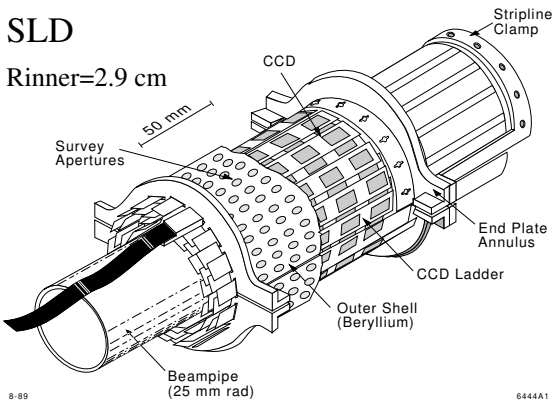
At the Tevatron, many more B's are produced, but the spectrum is softer. Species fractions and momentum spectrum of accepted events depend on trigger.

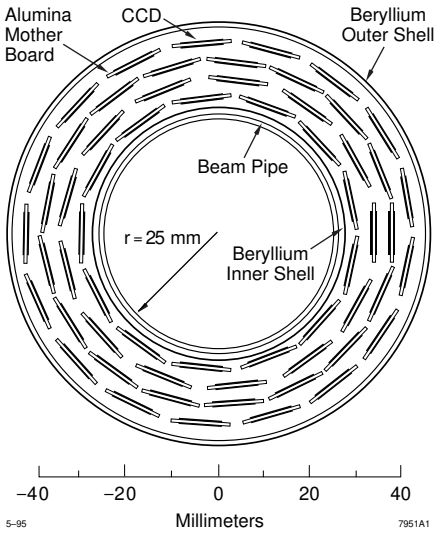


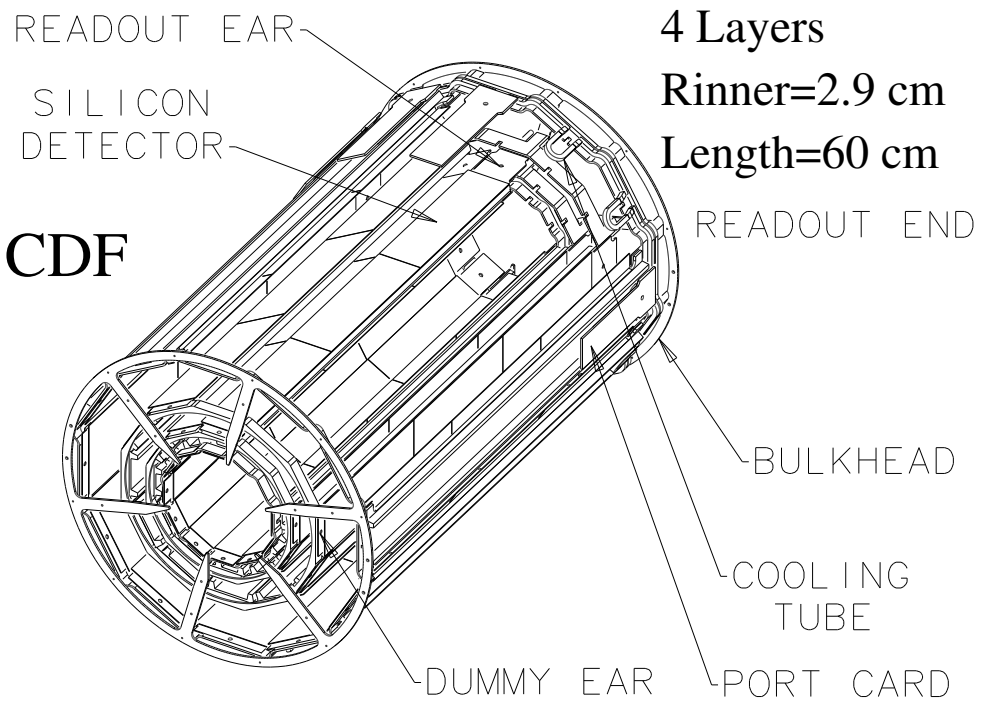
- $p\bar{p}$: Many b hadrons ($\sigma \approx 37\ \mu$b), but high BG — best to use fully reconstructed modes
- During Runs 1a and 1b, CDF accumulated $\sim 10^9$ b decays.
- Species fractions less well known.

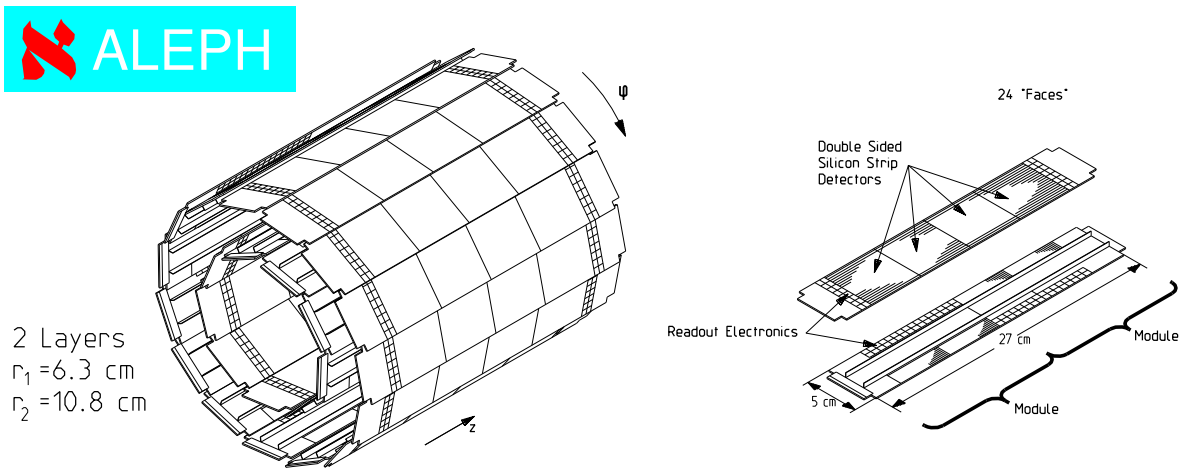
Detector Requirements

- Good vertex reconstruction Si vertex dets. ($\delta\ell \sim 300\mu$m)





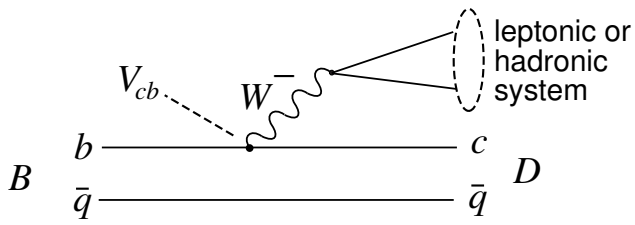




- Silicon Detectors
  - SLD – r_{inner}=29.5 mm, r_{outer}=41.5 mm. 11 μm resoution in xy for $Z^0 \to \mu^+\mu^-$ tracks, 70 μm for 1 GeV tracks. Already upgraded – more coverage and 2$\times$ better resolution.
  - CDF – r_{inner}=29 mm, r_{outer}=78 mm, similar resolutions. Long beam spot – $\sim$60% acceptance.
  - LEP: $r_{inner} \sim 60$ mm, similar high-momentum resolutions, longer lever arm for multiple scattering errors.
- Other Requirements
  - Also need Good invariant mass resolution – tens of MeV resolution on D^*, J/ψ masses $\Rightarrow$ large tracking chambers
  - Particle identification dE/dx & RICH

Average B lifetime

Why measure average B lifetime?



$$\Gamma = \frac{1}{\tau_B} \propto G_F^2 m_b^5 \mid V_{cb} \mid^2$$

but V_{cb} better measured using

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

Inclusive techniques – low statistical error.

Most useful for checking consistency of individual-hadron lifetime results.

What *is* the "average B lifetime"?

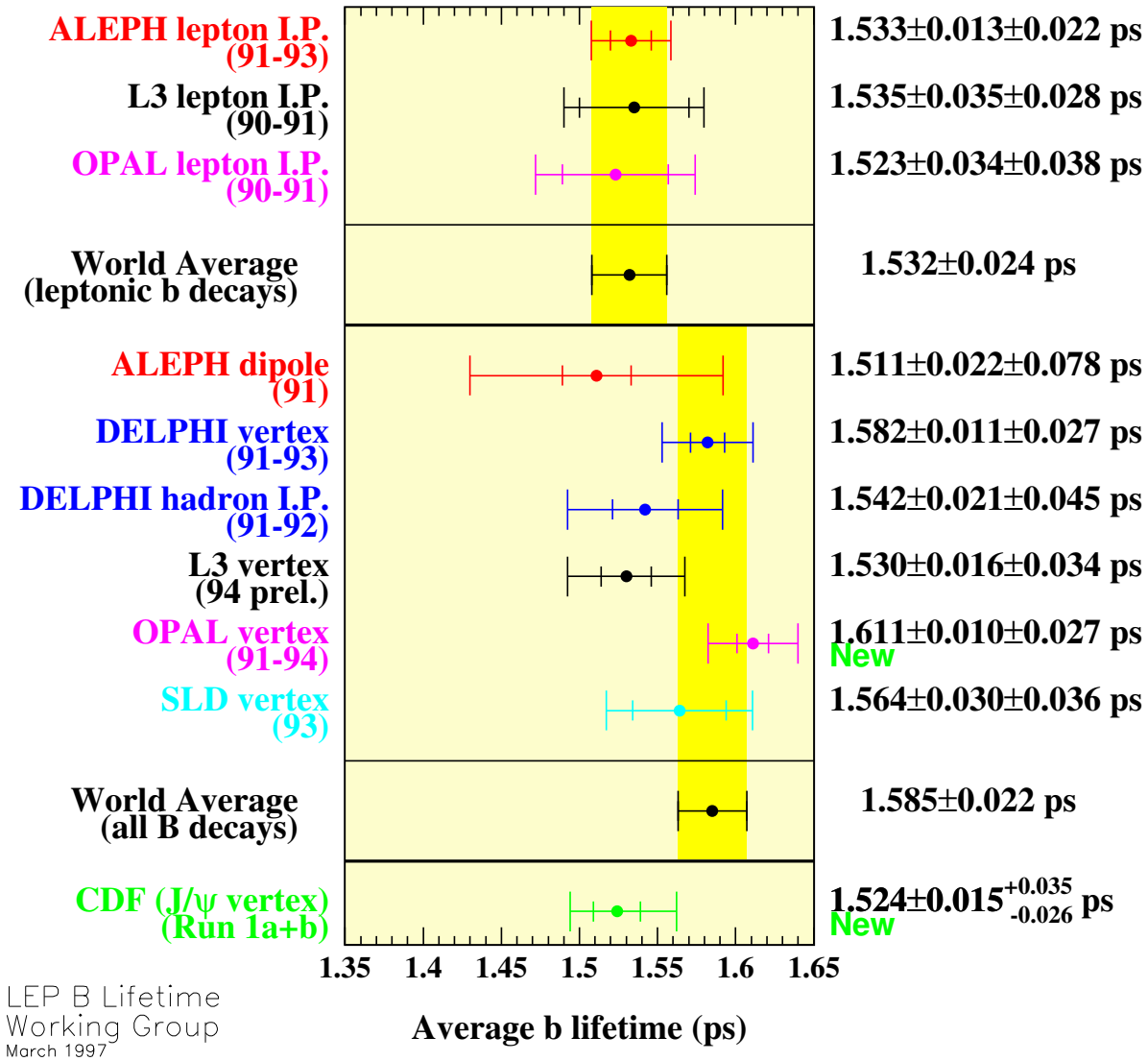
τ_B depends on mixture of b hadrons in the sample — production fractions and selection efficiencies differ...

$\Rightarrow$It is not trivial to compare results of different analyses!

Experimental techniques

- Impact parameters: using leptons (ALEPH,L3,OPAL) & hadrons (DELPHI)
- Inclusive displaced vertex reconstruction: DELPHI, L3, OPAL, SLD (ALEPH uses dipole method – need not know e^+e^- interaction point)
- $J/\psi \to \ell^+\ell^-$ vertex: CDF
- NB: Hadron impact parameters and IP-vertex techniques need "away-side" B-tags. Typically 20% efficient and 95% pure. Use an uncorrelated PV estimate to avoid biasing.

Average B Lifetime Measurements



- Averages performed separately because of biases from different b hadron composition among techniques.
- Results are systematics limited: decay models, b fragmentation, ...

More interesting to measure individual B hadron lifetimes:

$B^0, B^-, B_s, \Lambda_b, \ldots$

Individual B lifetimes - Techniques

- Full reconstruction e.g. $B_s \to J/\psi\phi$
  - Good vertex and boost resolution – no missing momentum.
  - Very little dependence on MC simulations – can obtain backgrounds from mass sidebands.
  - Poor statistics (e.g. ALEPH 121 B^0 and 94 B^- from 3M Z^0 using many modes.)

  Good at CDF — very large B sample

- Partially reconstructed vertices e.g. $B \to Dl(X\nu)$
  - More statistics – limited by BR($b \to lX$)
  - Good vertex determination
  - Missing $\nu(X)$ degrades boost resolution (typically ∼10%), introduces MC dependence. e^+e^- beam constraint helps with ν.

  Good at LEP and CDF

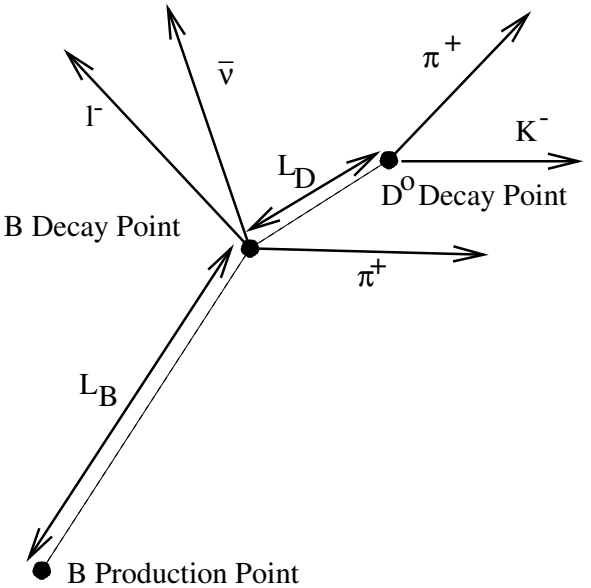
- Inclusive vertex reconstruction e.g. topological analyses, $\Lambda_b \to \Lambda\ell X$
  - Large statistics
  - Worse vertex resolution, but see DELPHI topological vertex
  - Can be heavily MC dependent – need to determine sample composition and boost biases.
  - Assumptions necessary to extract individual hadron lifetimes

  Good at SLD (very good vertexing) and LEP

B^-/B^0 Lifetimes

$B \to D^{(*)} l\nu(X)$ — ALEPH, DELPHI, OPAL & CDF

The basic idea...



$D^{(*)+}\ell^-$ correlations $\Rightarrow B^0$

$B^0 \to D^{*+}\ell^-\nu$
$\hookrightarrow D^0\pi^+$
$\hookrightarrow K^-\pi^+$
$K^-\pi^+\pi^-\pi^+$
$K^-\pi^+\pi^0$

$B^0 \to D^+\ell^-\nu$
$\hookrightarrow K^-\pi^+\pi^+$

$D^0\ell^-$ correlations $\Rightarrow B^-$

$B^- \to D^0\ell^-\nu$
$\hookrightarrow K^-\pi^+$

Harder cut on D^0 momentum

$\Rightarrow$ be sure D^0 not from $D^{*+} \to D^0\pi^-$

But: each final state is a mixture of B^- and B^0 because of D^{**} decays, e.g.

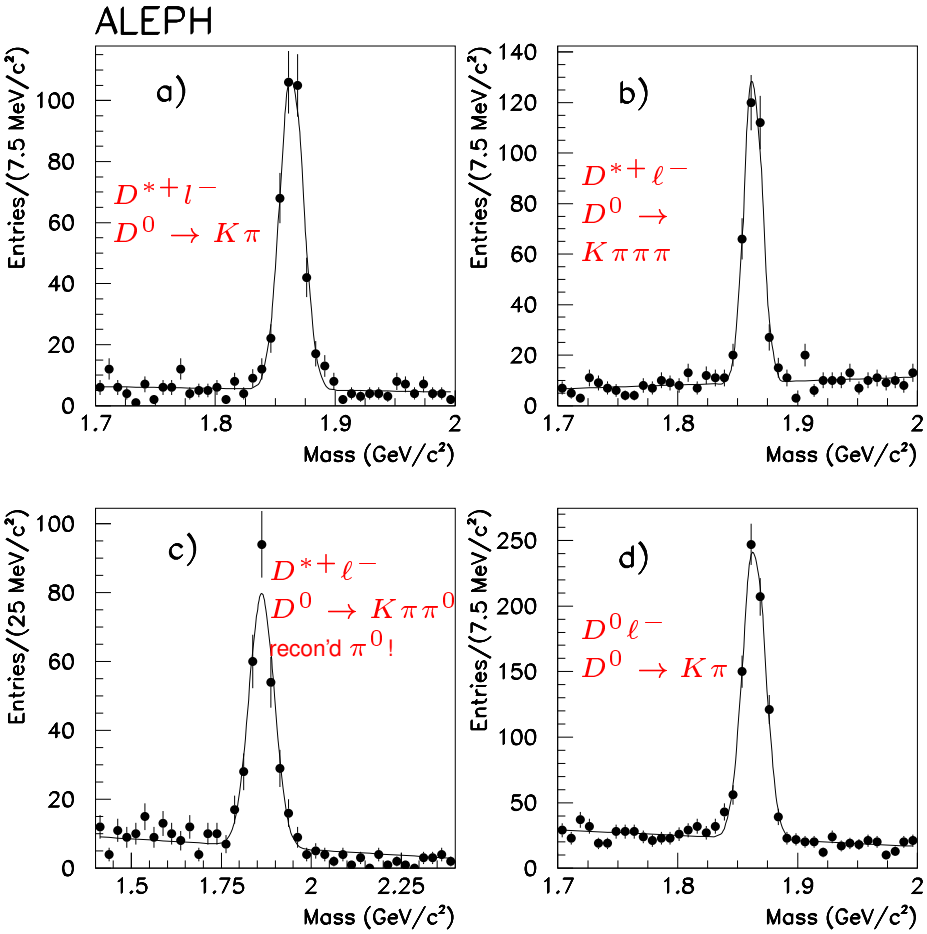
$B^- \to D^{**0}\ell^-\nu$
$\hookrightarrow D^{*+}\pi^-$

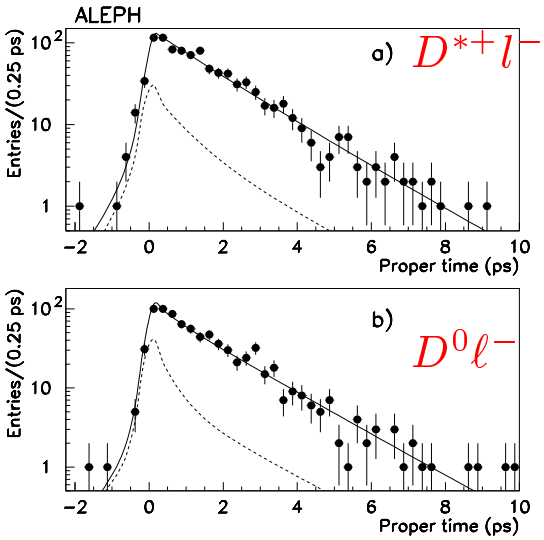
$\Rightarrow$ Now $D^{*+}\ell^-$ combination is from a B^-!

Use CLEO $B \to D^{**}\ell\nu = 36 \pm 12\%$ to compute sample composition.

$B \to D^{(*)} l\nu(X)$ Analysis

Invariant mass of D^0 candidates





Proper time distributions

$\tau(B^0) = 1.61 \pm 0.07^{+0.043}_{-0.041}$ ps

$\tau(B^-) = 1.58 \pm 0.09^{+0.044}_{-0.042}$ ps

Cross-check: D^0 Lifetime

$\tau(D^0) = 0.404 \pm 0.012$ (stat) ps

World Average:

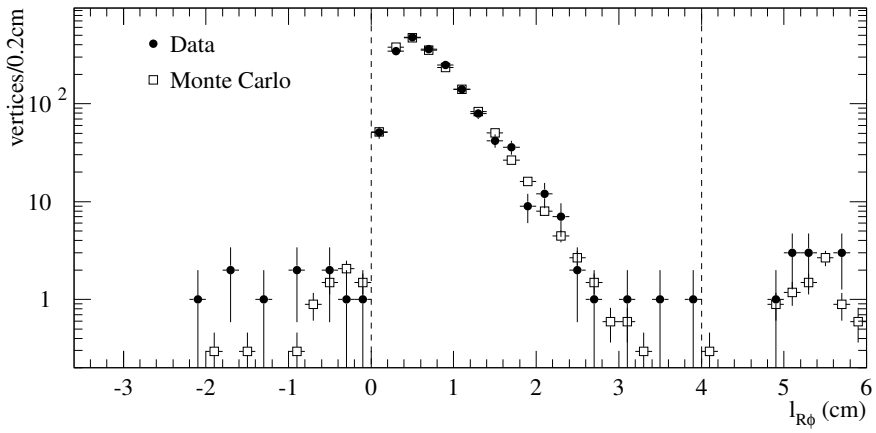
$\tau(D^0) = 0.414 \pm 0.004$ ps

Topological vertexing — DELPHI

Inclusively reconstruct secondary vertices well-separated from primary in 2D

Secondary vertex Mass $>$ 2.2 GeV $\Rightarrow$ $<$ 1% non-B hadron background.

- Separate vertices into charged and neutral ones
- Fit for correct charge assignment using
  - Fraction of doubly- and triply-charged vertices
  - Number of tracks cut based on momentum or impact parameter to PV.
  - Correct for biases from B decay multiplicity.
  - Charge assigned correctly in 77% of $B^{\pm}$, 57% of B^0



- Determine minimum possible decay length to form the vertex – move secondary vertex towards PV until it cannot be cleanly separated.

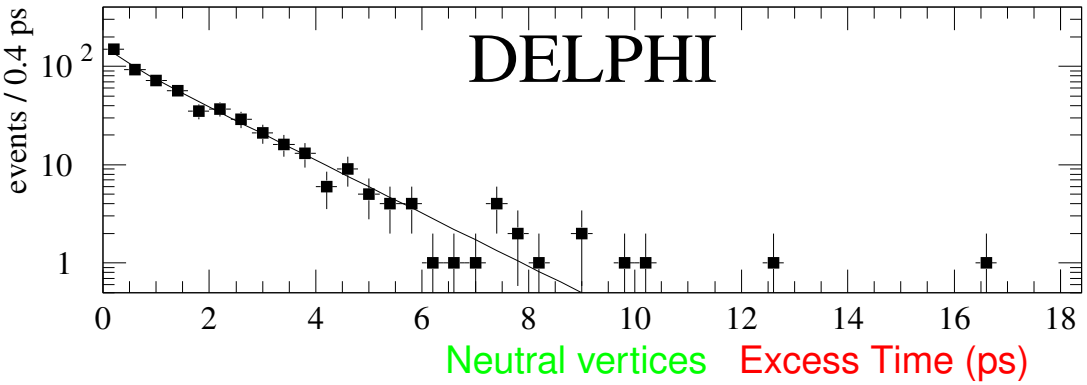
  Find $\ell_{excess} = \ell - \ell_{min}$

  Excess decay length is independent of distortions from acceptance and charm decay.

  Estimate boost from visible p and m of vertex – Error = 22%

Topological vertexing — DELPHI, SLD

- Use vertex change $\Rightarrow$ fit t_{excess} separately for charged and neutral B lifetimes.



- Assume B_s and Λ_b content and lifetimes to get $\tau(B^-)$ and $\tau(B^0)$

$$\tau(B^-) = 1.72 \pm 0.08 \pm 0.06 \quad \tau(B^0) = 1.63 \pm 0.14 \pm 0.13$$

- Systematic uncertainty largely from possible fit biases and B_s contribution

- Inclusive vertex reconstruction also done by SLD
  - Better Vertexing and a novel algorithm $\Rightarrow$ Increased efficiency: 9698 inclusively reconstructed B decays at 98% purity (c.f. DELPHI's 1817 with 10$\times$ the data sample.
  - Systematic errors from fragmentation function and B decay multiplicity. Smaller fitting systematics.

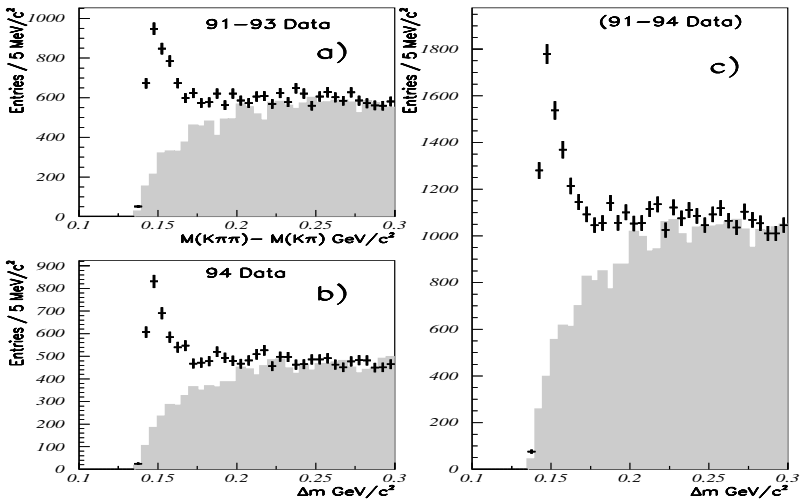
B^0 lifetime from $\pi_s^+\ell^-$ corrl. — DELPHI

$$\overline{B^0} \rightarrow D^{*+} X \ell^- \overline{\nu_l}$$

$$\hookrightarrow D^0 \pi_s^+ \qquad \pi_s^+ = \text{“slow pion”}$$

- In events with high p, p_t lepton inclusively reconstruct D candidate by clustering tracks with high pseudo-rapidity w.r.t the jet until the cluster mass would exceed 2.2 GeV.
- Look for right sign π ($\pi^+\ell^-$) and form invariant mass with and without π.

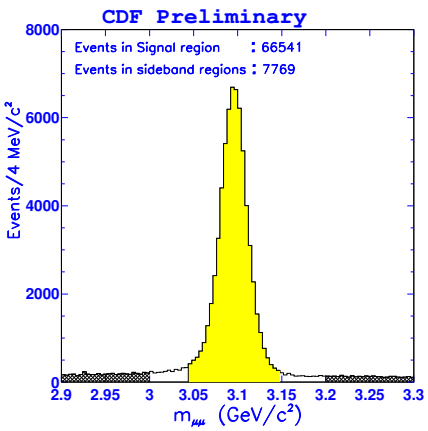
  Peak due to D^*. Wrong-sign combinations provide combinatorial background estimate.
- Find 3523 ± 150 signal cands in $0.14 < \Delta m < 0.016$ ($\sim 30\%$ background)

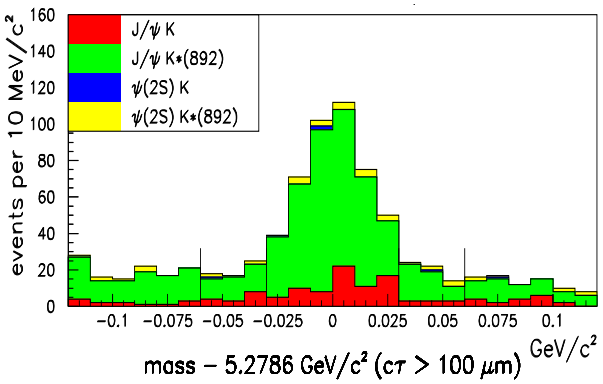


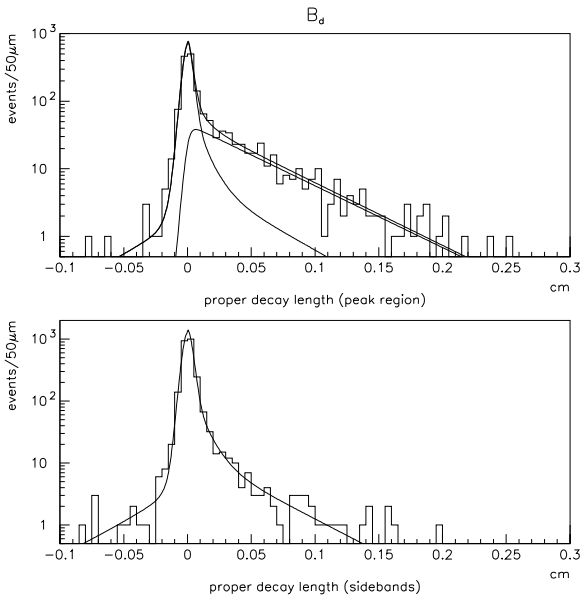
- DELPHI measures $\tau_{B^0} = 1.537 \pm 0.041 \pm 0.039$ ps
- Systematic uncertainty from combinatorial BG fraction and lifetime, resolution, fit bias.

CDF Exclusive $B \to \psi K$

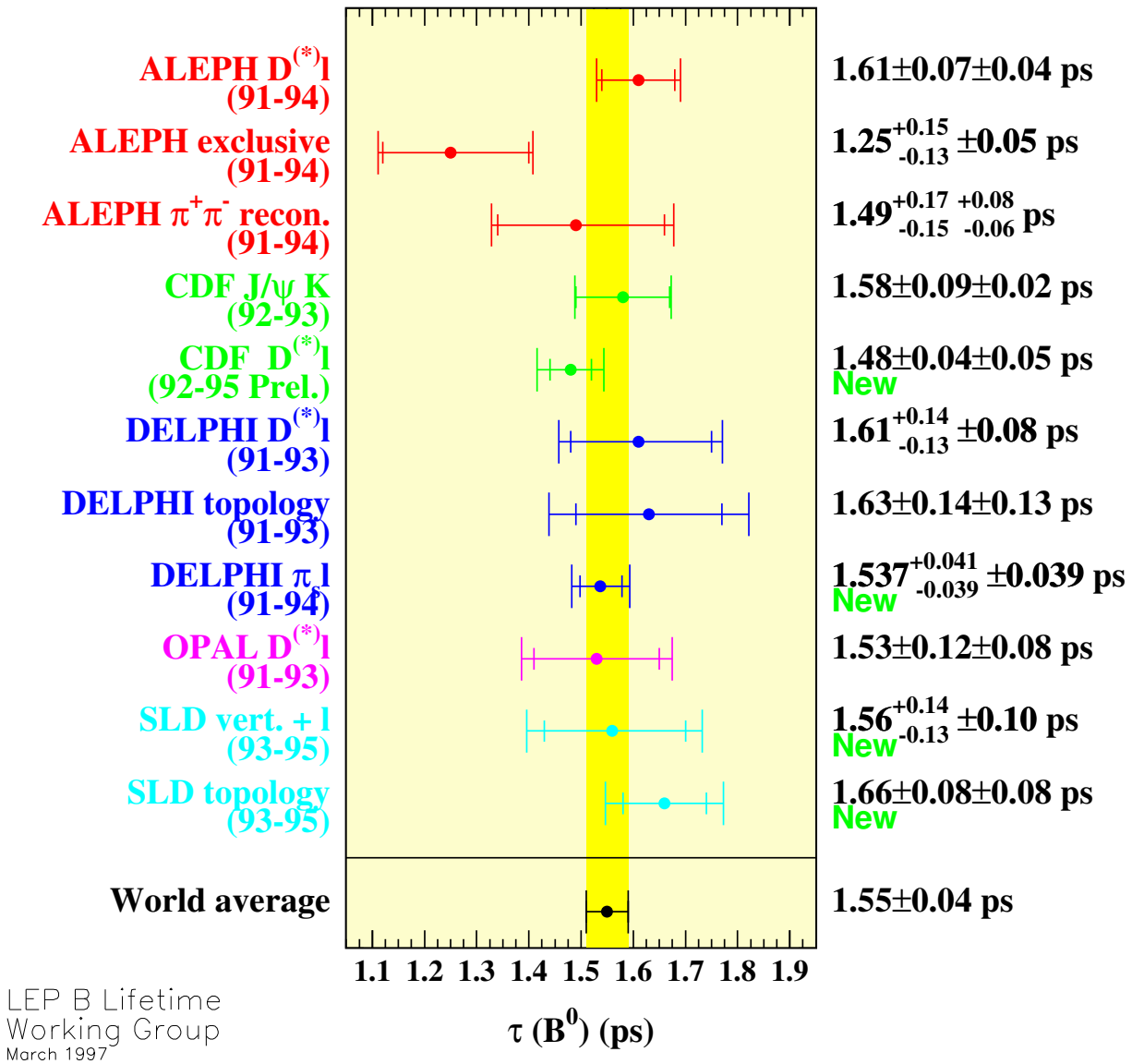
- Combine $J/\psi \to \mu^+\mu^-$ and $\psi(2S) \to \pi^+\pi^-$ candidates with a track ($\equiv K^\pm$) or a K^0_s or with $K^*(892)^0$ or $K^*(892)^\pm$.
- Fit lifetime distribution in signal B mass region and use sidebands to estimate background level and lifetime.
- Background from prompt J/ψ+combinatorics, double-semileptonic B decay, and muon misid and punchthrough.





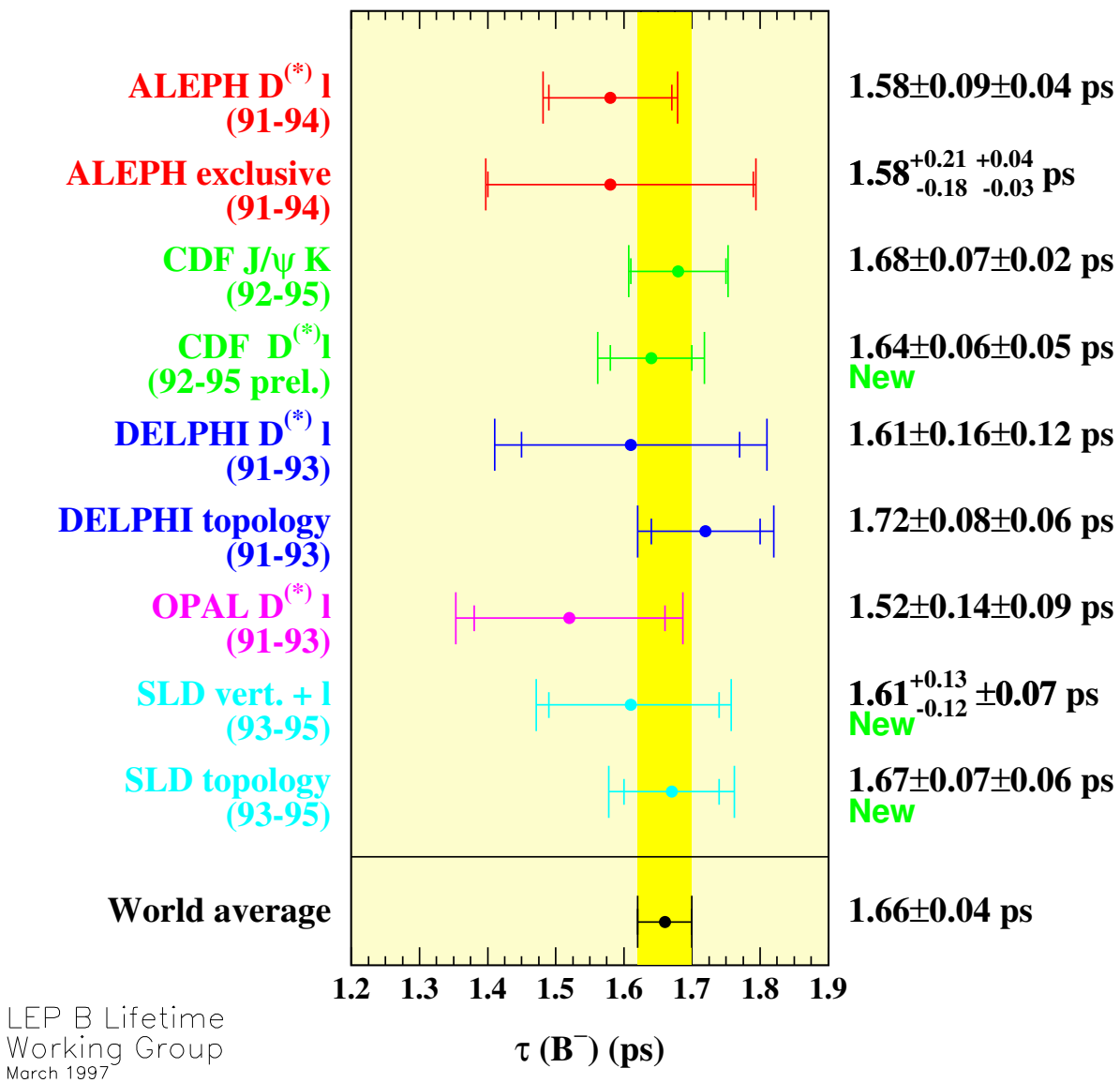


World Average – B^0 lifetime



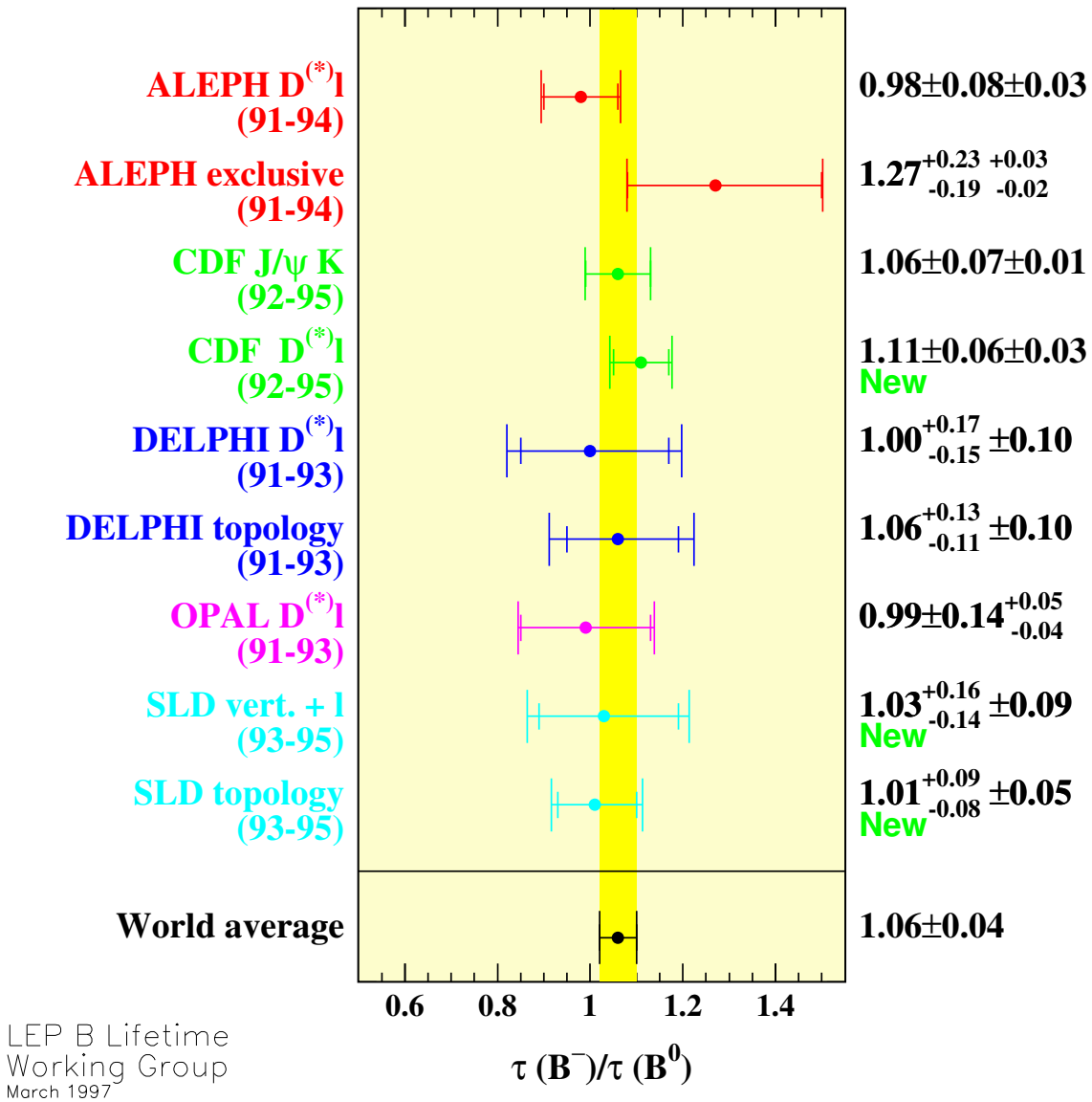
- SLD impressive – only 150,000 Z^0
- Error on world average is $\sim$ 2.5%
- Most measurements statistics dominated. Watch CDF/D0 in Run 2.

World Average – B^- lifetime



- Error on world average is $\sim$ 2.5%

World Average – B^-/B^0 lifetime ratio



- N.B. World average does not include DELPHI's π_s-ℓ analysis (τ_{B^0} only)
  Average uses each expt's measurement of the lifetime ratio (proper treatment of correlated errors, etc.)

  Ratio of averages: $\langle \tau_{B^-} \rangle \; / \; \langle \tau_{B^0} \rangle = 1.07$ (uncertainty $\approx \pm 0.04$)

B_s lifetime

$B_s \to D_s \ell \nu(X)$ — ALEPH,OPAL,DELPHI & CDF

D_s reconstructed in 7 channels ALEPH DELPHI

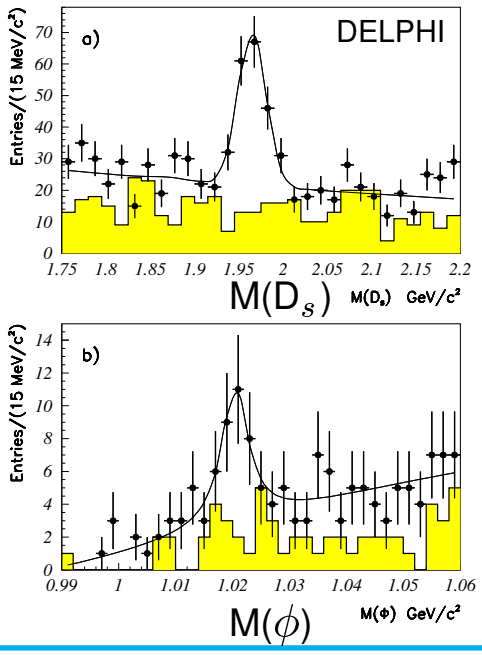
D_s^- channel (ALEPH)	Events	Purity
$\phi\pi^-$	61	78%
$K^{*0}K^-$	102	63%
$K_s^0 K^-, \phi 3\pi, K^{*0}K^{*-}$	70	56%
$\phi e^- \nu, \phi \mu^- \nu$	44	68%

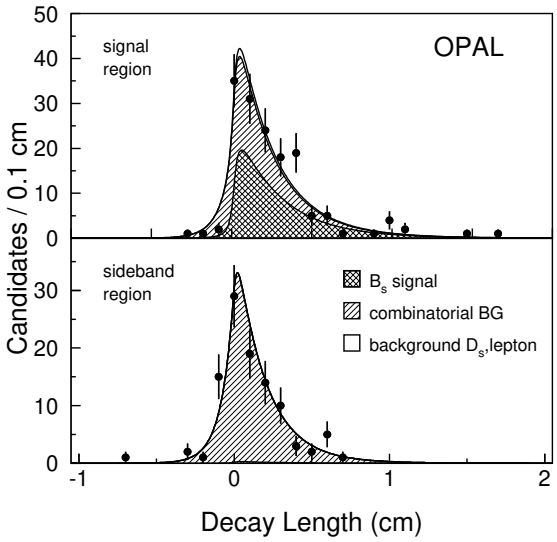
N.B. DELPHI does $f^0\pi^+$ instead of $\phi 3\pi$; OPAL uses only $\phi\pi^-$ and $K^{*0}K^-$.

- ALEPH has 181 signal using 7 channels — CDF has 254 in just $\phi\pi$!
- Background: combinatoric – estimated with D_s mass sidebands.

Physics backgrounds: $B \to D_s^+ \overline{D}(X)$ with $\overline{D} \to \ell^- \overline{\nu}(X)$ and $B \to D_s^- K \ell^+ \nu(X)$.

Also π misid as K – need good particle ID to reduce.

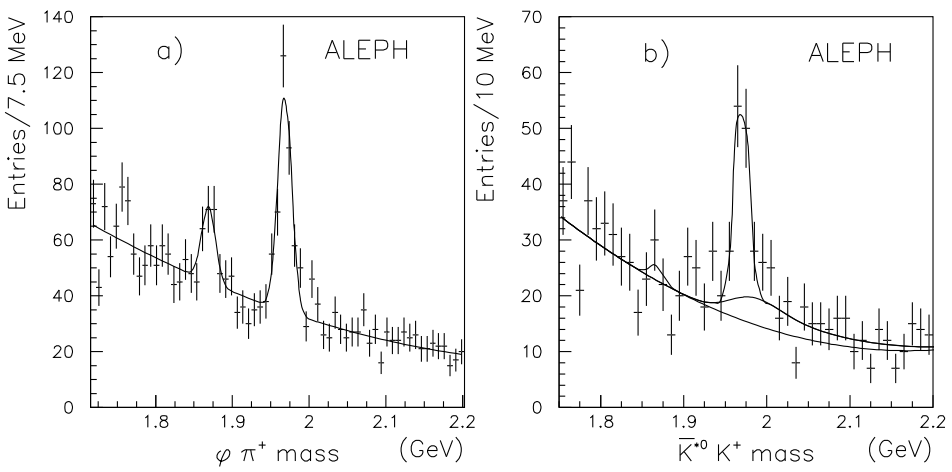


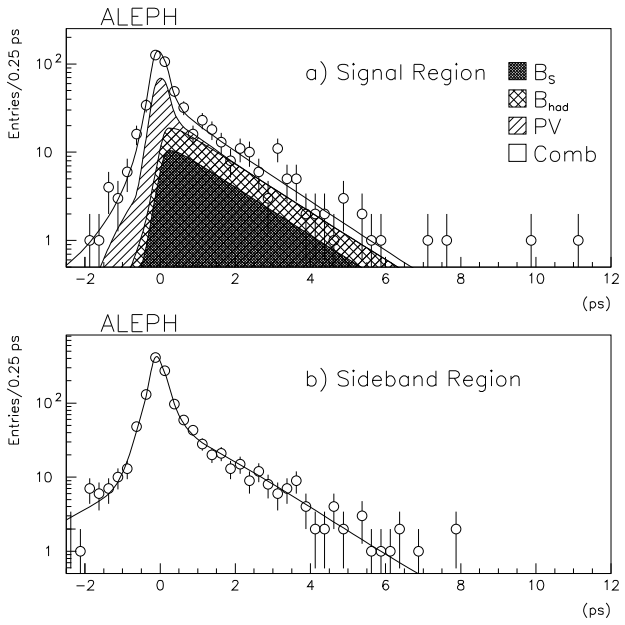


B_s Lifetime via Inclusive Techniques

- Inclusive D_s — DELPHI – 516 candidates in the $\phi\pi^+$ and $\overline{K}^{*0}K^+$ modes. B_s purity: 57%. BG from $Z \to c\bar{c}$ and non-strange B decays.
- D_s–hadron — ALEPH & DELPHI
- ϕ–lepton — DELPHI – 433 candidates, 50% pure in B_s.

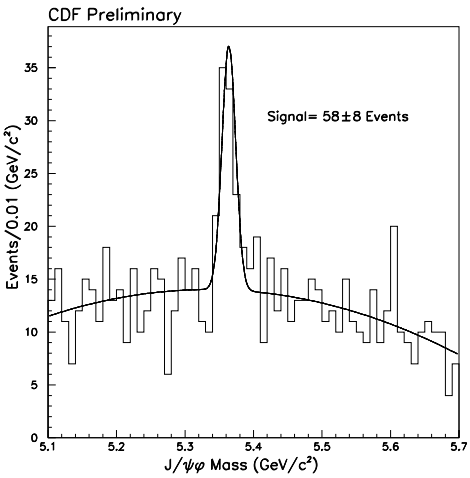
Example: ALEPH D_s–hadron analysis...





B_s Lifetime via Exclusive Techniques

- $B_s \to J/\psi\,\phi$ — CDF $J/\psi \to \mu^+\mu^-, \phi \to K^+K^-$. Promising, but lacking statistics. Runs 1a+1b: 58$\pm$12 candidates.
- $B_s \to J/\psi\,\phi$ is CP even; expected to have a shorter lifetime than the CP odd state – up to 30% difference in lifetimes is possible.
  I. Dunietz, Phys. Rev. **D52** (1995) 3048.

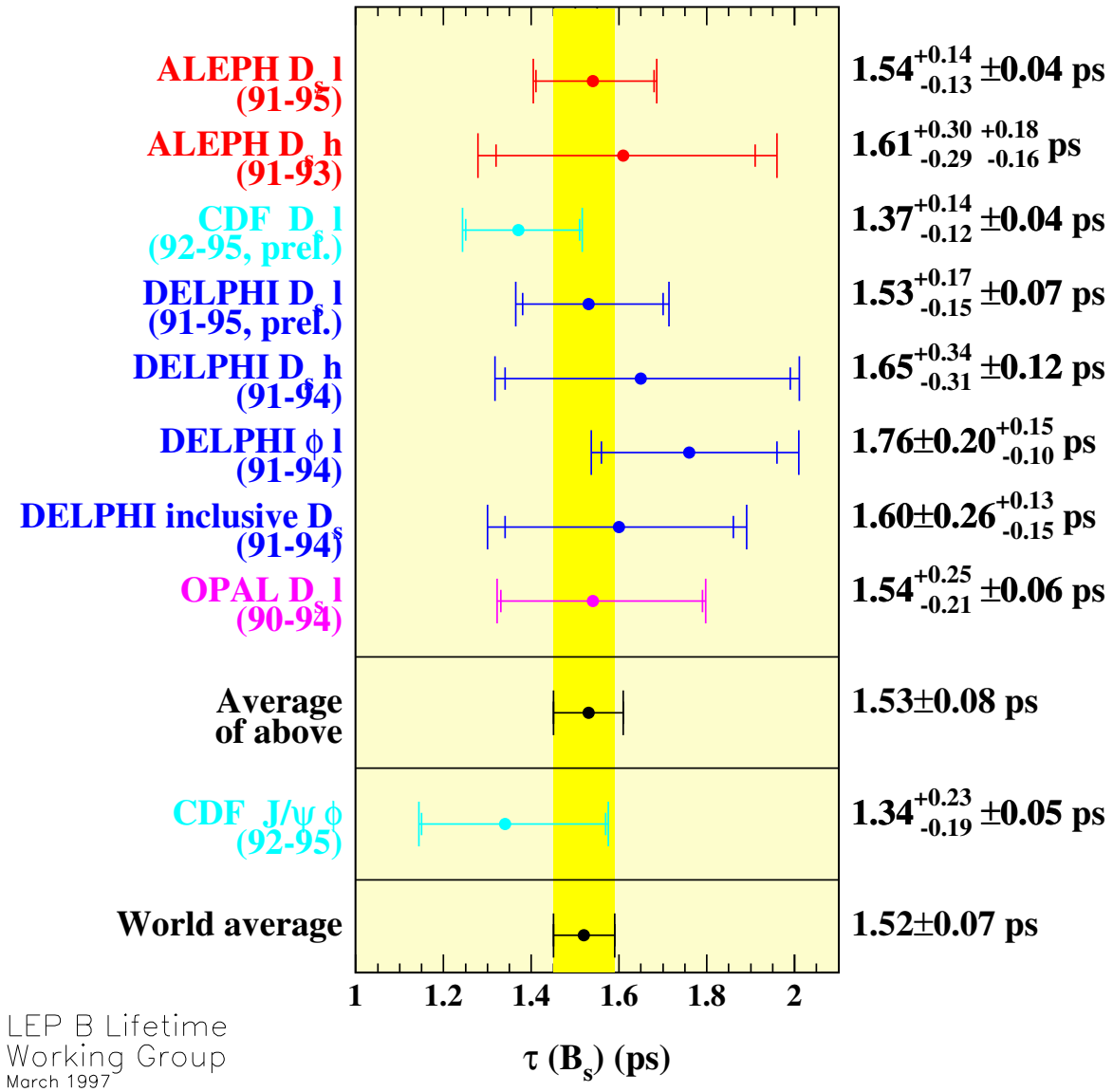


- Note: CDF $D_s^-\ell^+$ analysis ($\sim 50\%$ CP even, $\sim 50\%$ CP odd, fits proper decay length to two exponentials:

$$p(t) = Ae^{\left(c\tau + \frac{\Delta c\tau}{2}\right)} + Be^{\left(c\tau - \frac{\Delta c\tau}{2}\right)}$$

- CDF finds $\Delta c\tau = 205^{+127}_{-205}\ \mu$m, or less than 70% of $c\tau$. Not yet sensitive.
- $\Delta\Gamma \propto \Delta M$, depending on QCD corrections only, hence an upper limit on $\Delta\Gamma$ is an upper limit on x_s.

World Average – B_s lifetime



- Average shown with and without $J/\psi\phi$ channel. This has different CP eigenstate composition.

B-baryon lifetime measurements

A mixture of B-baryon states is produced at LEP: Λ_b^0, Σ_b, Ξ_b, Ω_b

Only ground state baryons Λ_b^0, Ξ_b^0, Ξ_b^-, Ω_b^- should decay weakly.

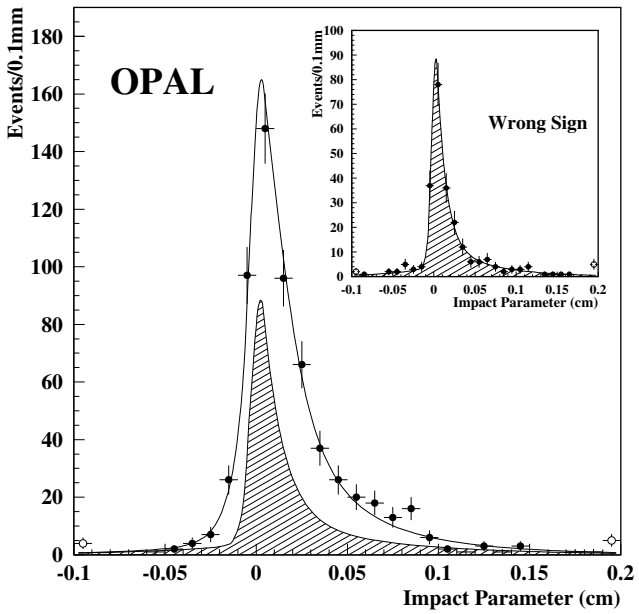
Average b baryon lifetime — ALEPH, DELPHI & OPAL

- One can measure the average b baryon lifetime by observing properly correlated b baryon decay products: e.g. $\Lambda\ell^-$

$$\Lambda_b^0/\Xi_b^0/\Xi_b^-/\Omega_b^- \rightarrow \Lambda\, \ell^-\, \overline{\nu_l} X$$
$$\hookrightarrow p\pi^-$$

- Techniques: the average b baryon lifetime can be measured using:

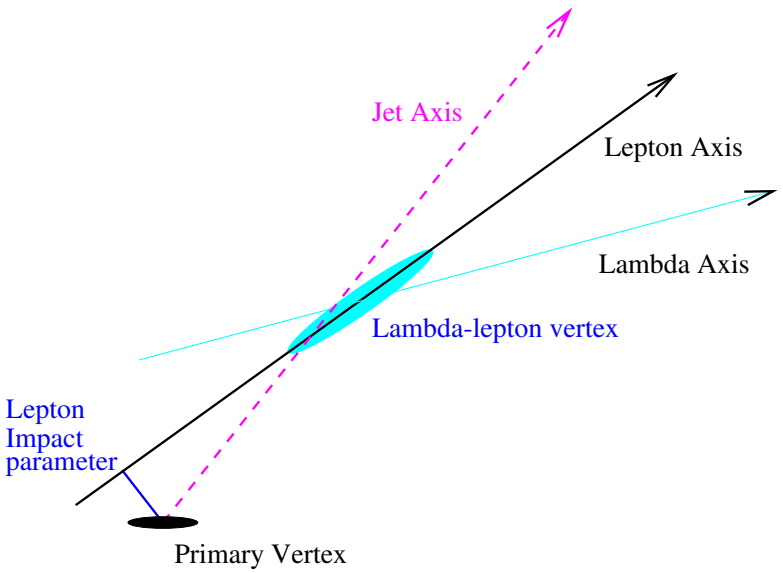
  Λ-lepton using lepton impact parameter (ALEPH, DELPHI, OPAL)
  Λ-lepton vertex (OPAL)
  Λ-lepton-π vertex (DELPHI)
  proton-muon vertex (DELPHI)



OPAL lepton IP:

$$\tau_{\text{b baryon}} = 1.21^{+0.15}_{-0.13} \pm 0.10\,\text{ps}$$

Average B Baryon Lifetime: $\Lambda\ell$ Vertices - OPAL



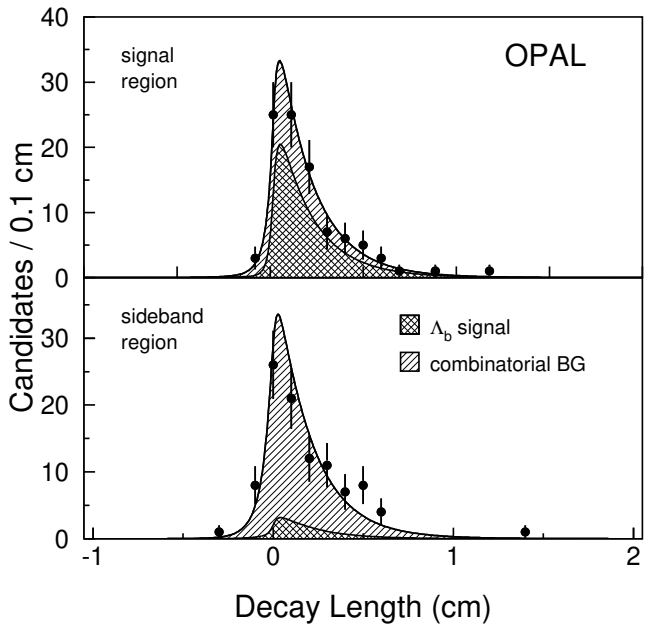
- 490 lambda-lepton candidates (wrong-sign background subtracted)
- Lambda lifetime long – poor extrapolation. $\Rightarrow$ B baryon flight constrained along the jet axis.
- $\Lambda - \ell$ vertex resolution: 500 μm.
- Boost estimated from $p(\Lambda\ell)$ with probability distrib. of true boost estimated from Monte Carlo.
- A 7% upwards correction applied because of errors in jet axis determination.
- Lifetime fit with background function taken from wrong-sign distribution.
- Result correlated with $\Lambda\ell$ impact parameter analysis.
- Less sensitive to B baryon polarization than lepton impact parameter – error: 0.03 ps (0.065 ps) for lepton impact parameter.

$$\tau_{\mathrm{b\ baryon}} = 1.15 \pm 0.12 \pm 0.06\ \mathrm{ps}$$

Λ_b^0 Lifetime

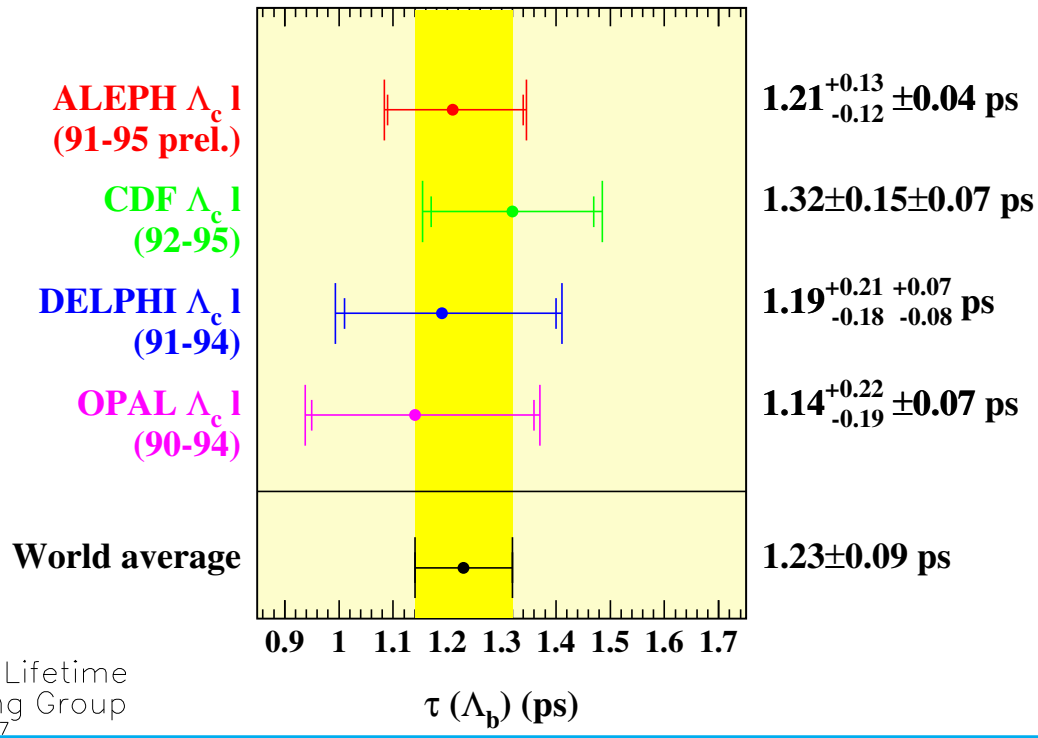
Exclusive reconstruction of Λ_c^+ provides tag of specific Λ_b^0 (bdu).

$\Lambda_c^+ \to pK^-\pi^+, pK^0, \Lambda\pi^+\pi^+\pi^-$ (lower statistics than $\Lambda\ell$).



OPAL $\Lambda_c^+\ell^-$:

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



LEP B Lifetime Working Group
March 1997

Strange B-baryon (Ξ_b) lifetime

Ξ_b (bsu or bsd) was first reported by DELPHI, now also seen by ALEPH.

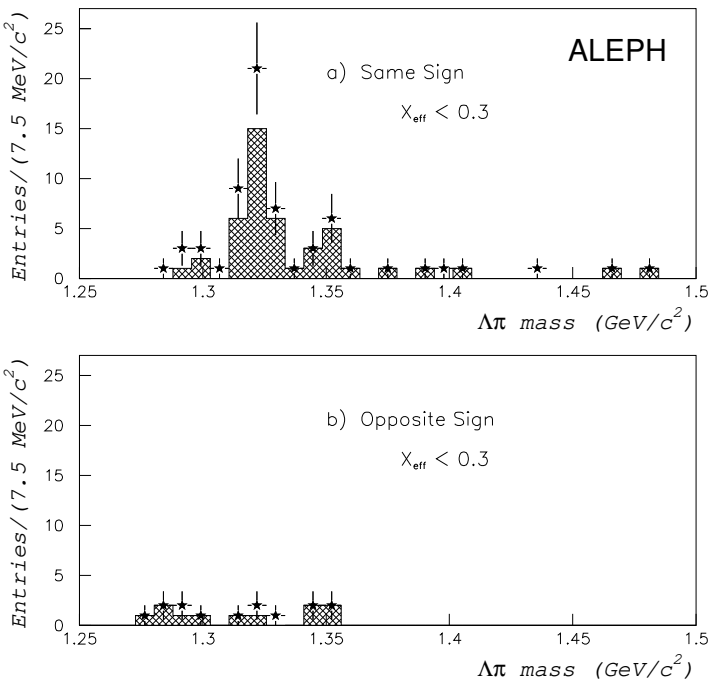
However, discovery was anticipated by Francis Bacon (1561-1626):

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

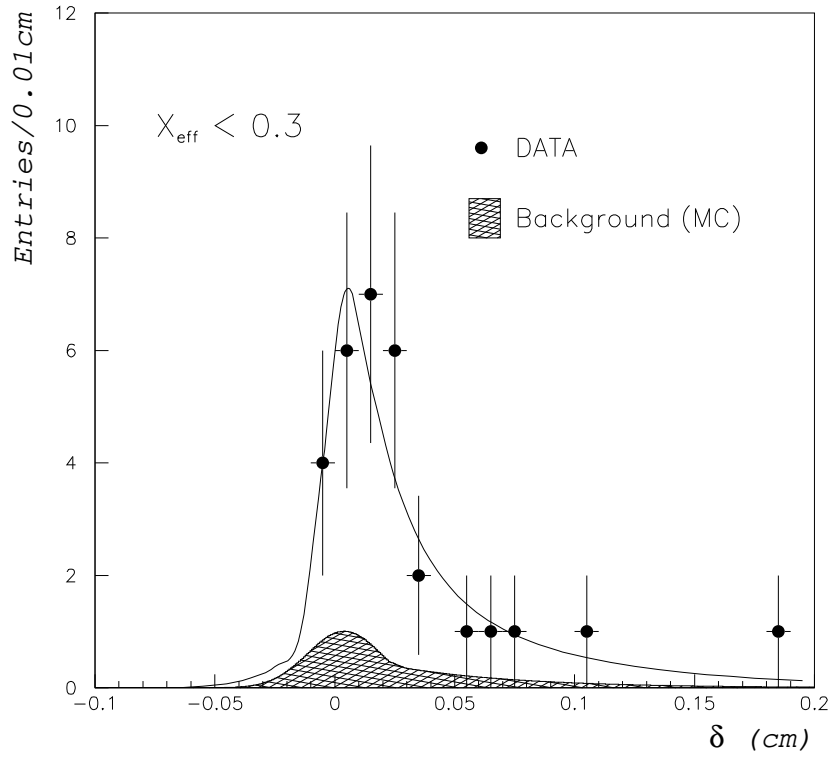
Idea similar to Λ_b reconstruction: correlated $\Xi^-\ell^-$ pairs...

$$\Xi_b \to \Xi^-\ell^-\overline{\nu_l}X \qquad \text{N.B. same sign!}$$
$$\hookrightarrow \Lambda\pi^-$$
$$\hookrightarrow p\pi^-$$

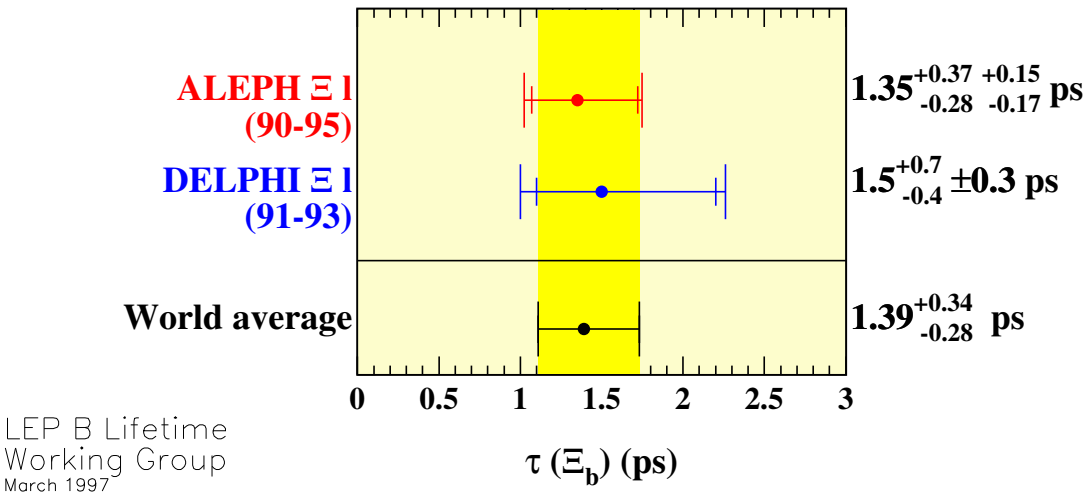
DELPHI have 10 candidates (91-93), and ALEPH have 44 (91-95 prel.)



ALEPH uses the lepton impact parameter to extract the lifetime...

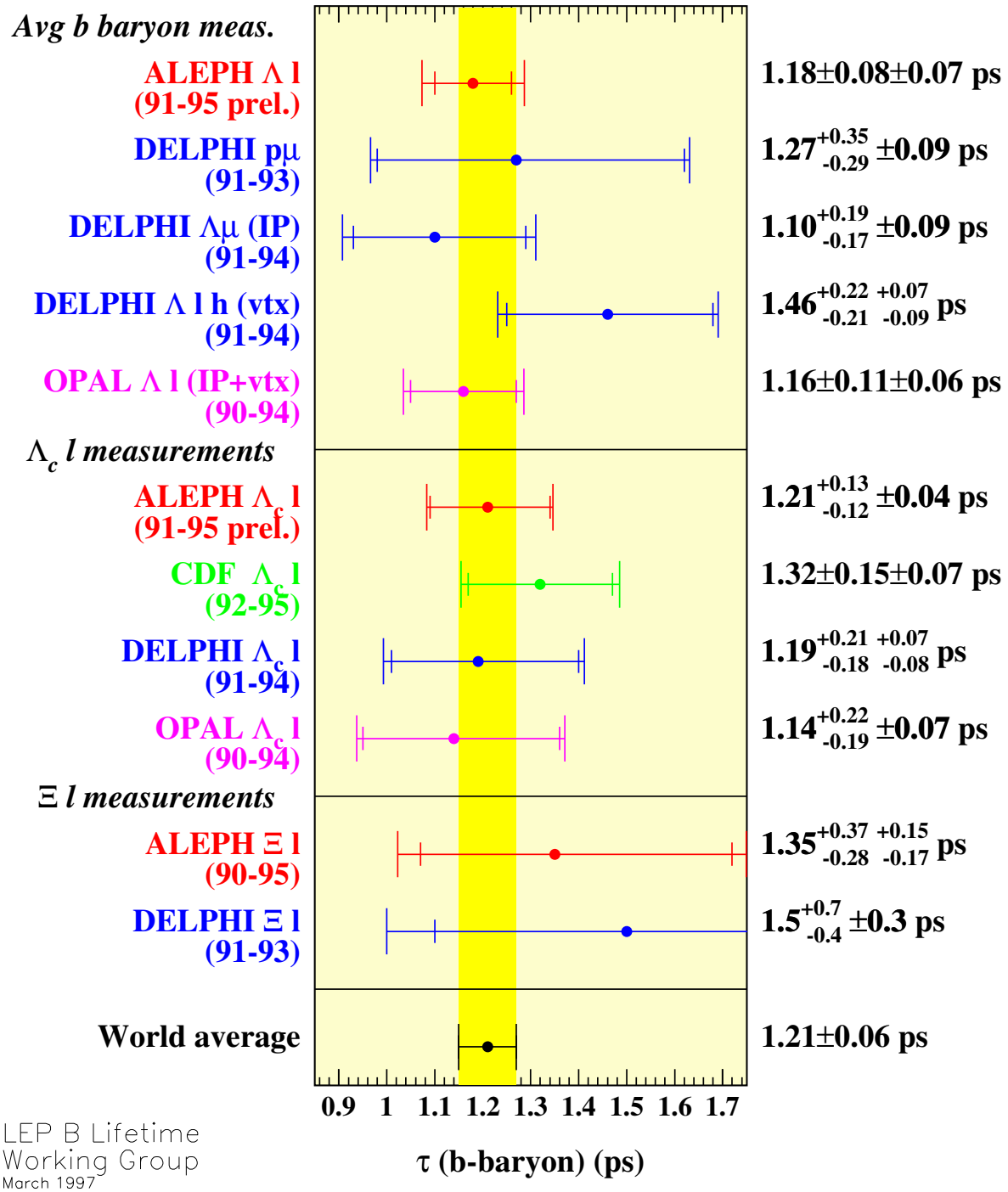


World Average (Ξ_b) lifetime



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

World Average - B-baryon lifetimes



- No evidence for difference between average b-baryon and Λ_b^0.

(almost the) B Baryon Semileptonic BR

New measurement from OPAL: CERN-PPE/96-166.

Measurement of $R_{\Lambda\ell} \equiv \mathrm{Br}(\Lambda_b \to \Lambda\ell X)/\mathrm{Br}(\Lambda_b \to \Lambda X)$, where Λ_b is the average mix of B baryons at the Z^0.

Semileptonic decays are pointlike; non-spectator processes do not contribute. Expect $\Gamma\left(\Lambda_b \to \ell\nu X\right) = \Gamma\left(B^{0,\pm} \to \ell\nu X\right)$

Expect $\mathrm{Br}(\Lambda_b \to \ell\nu X) = \frac{\tau_{\Lambda_b}}{\tau_{B^{0,\pm}}}\mathrm{Br}(B^{0,\pm} \to \ell\nu X)$

Taking $\mathrm{Br}(B^{0,\pm} \to \ell\nu X) = 10.43\%$ (CLEO), and the average B-baryon/B-meson lifetimes, expect $\mathrm{Br}(\Lambda_b \to \ell\nu X) = (7.5 \pm 0.6)\%$.

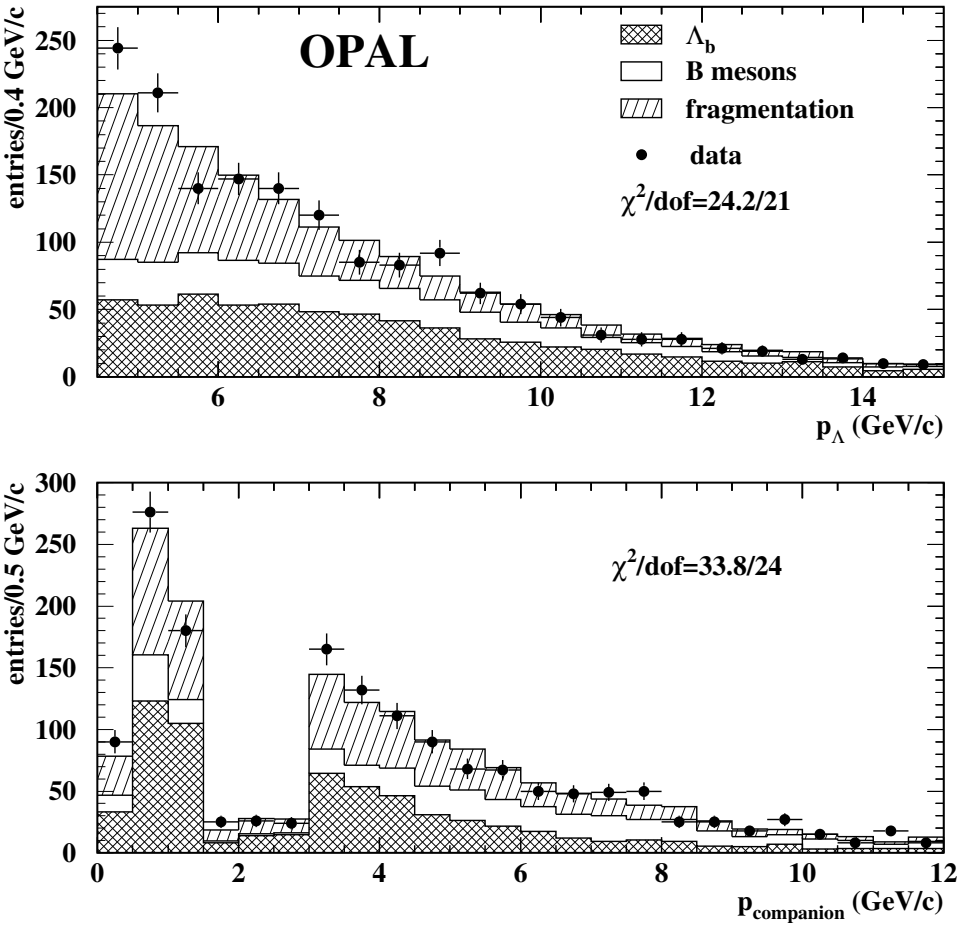
Technique:

- Use lifetime-tagged $Z^0 \to b\overline{b}$ events.
- Count $\Lambda - \ell$ pairs and use wrong-sign combinations and sidebands to estimate B.G.
- Need the denominator, Br($\Lambda_b \to \Lambda X$).
- Tricky part: separating $\Lambda_b \to \Lambda X$ from $B^{\pm,0} \to \Lambda X$ and Λ's from fragmentation.
- Rely on local baryon number conservation and look for a "companion baryon." Momentum spectrum of both baryons separates signal from background.

(almost the) B Baryon Semileptonic BR

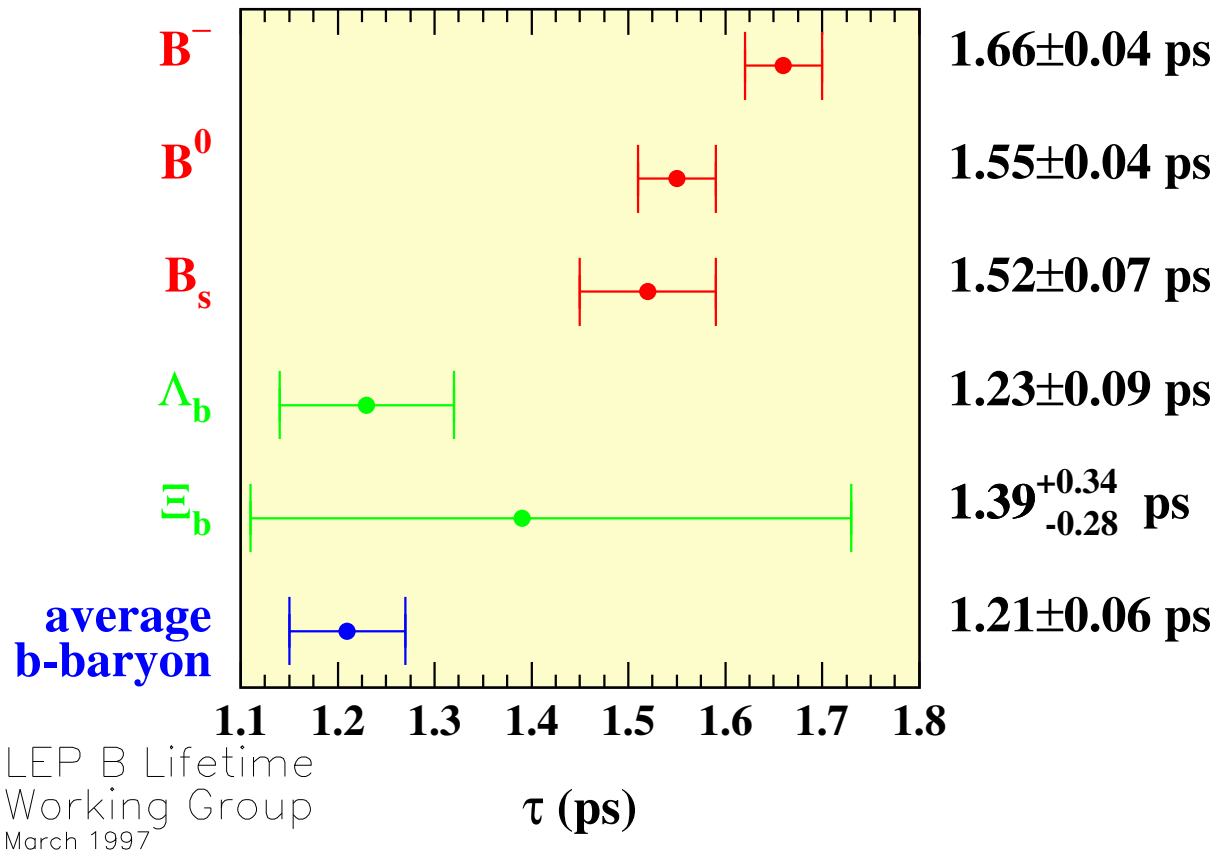
	Λ	companion
$\Lambda_b \to \Lambda$ X	hard	soft
B$\to \Lambda$ X	hard	hard
fragmentation & others	soft	soft

- Use d$E/$dx to select baryons. Cut between 1.4–3.0 GeV where d$E/$dx is ambiguous between p and π.



$$R_{\Lambda\ell} = (7.0 \pm 1.2 \pm 0.7)\%$$

World Averages Summary



- $\tau_{B^-}/\tau_{B^0} = 1.06 \pm 0.04 \iff$ theory: $1 + \mathcal{O}(10\%)$ ...?

  Ratio is > 1 at 1σ, can start to place constraints on the coefficients in the heavy quark expansion.

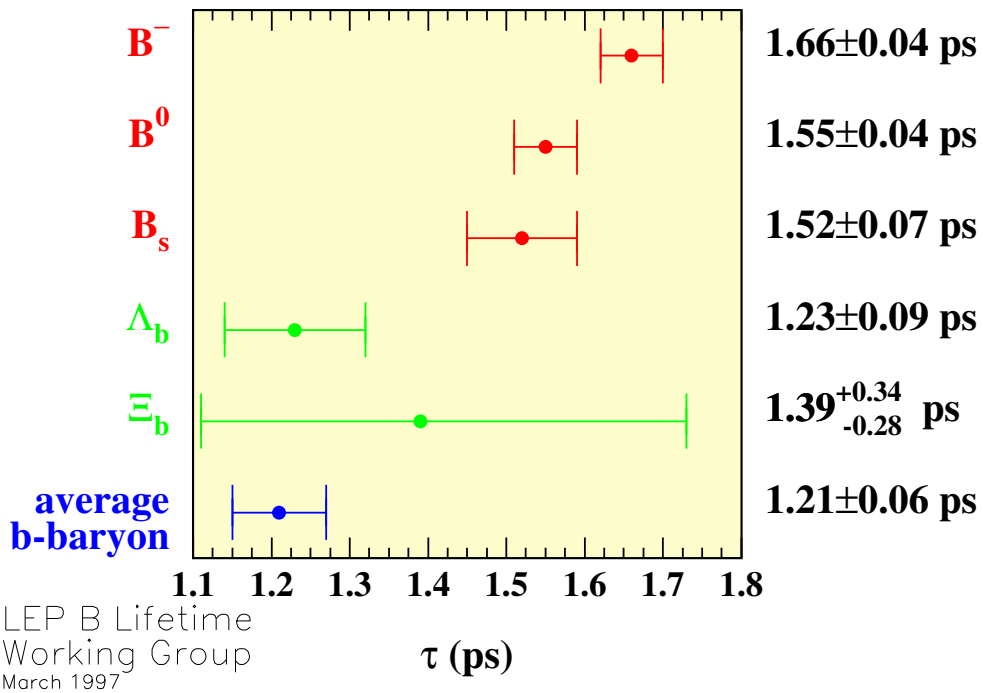
- $\tau_{B_s}/\tau_{B^0} = 0.98 \pm 0.05 \iff$ theory: $1 + \mathcal{O}(1\%)$

  Measurements are not precise enough to test the prediction.

- $\tau_{\Lambda_b}/\tau_{B^0} = 0.79 \pm 0.06 \iff$ theory: 0.9 to 0.99

  $\tau_{\text{b-baryon}}/\tau_{B^0} = 0.78 \pm 0.04$

  Ratio is interesting but not conclusive

Conclusions

- Large number of measurements of each B hadron lifetime
- Errors on averages
  - $\sim 2.5\%$ for B^0 and B^-,
  - $\sim 5\%$ for B_s and average b baryon, and
  - $\sim 7\%$ for Λ_b^0
- Most (not all) of LEP, CDF and SLD data already analyzed.
  - SLD will be getting more data.
  - CDF will get $\sim 10\times$ the data after the Tevatron upgrade.
  - D0 will start measuring B lifetimes.
  - Asymmetric factories will do B^- and B_d^0.
- Wider use of new methods and more difficult decay channels should give further improvement.