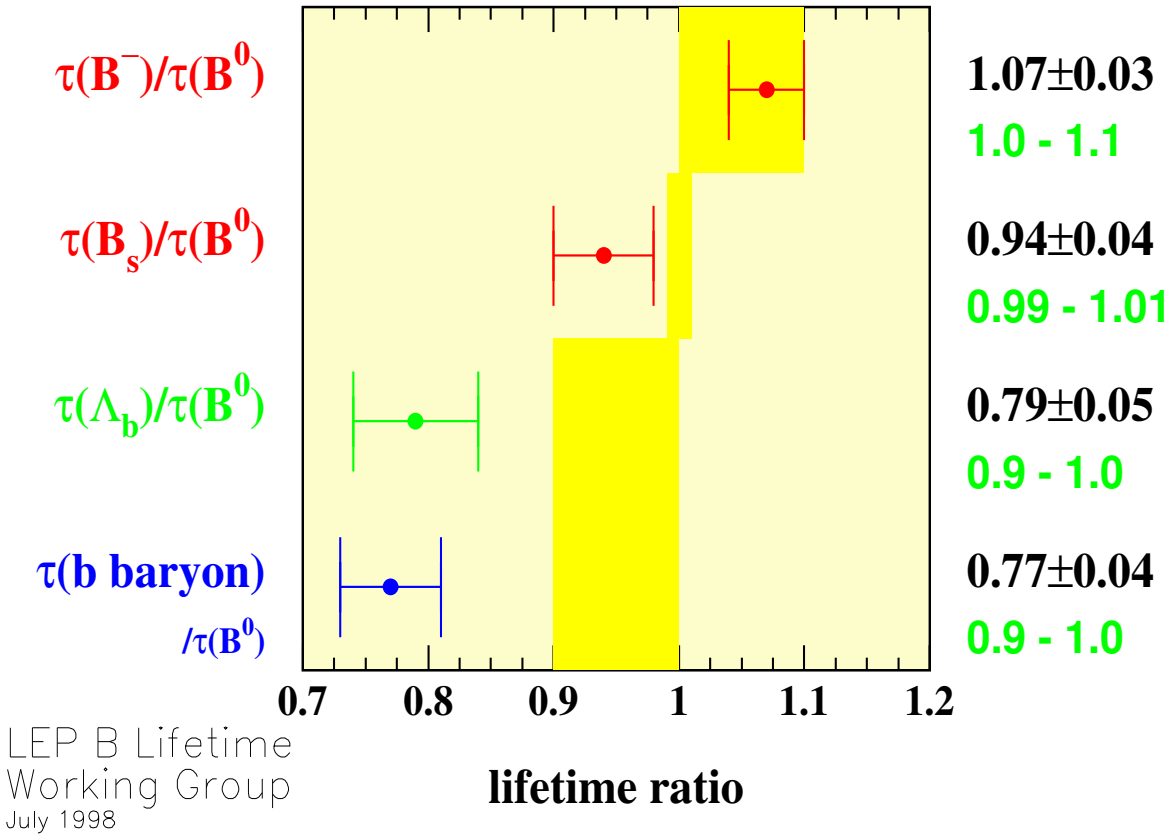
Summary:



→ Small lifetime differences confirmed

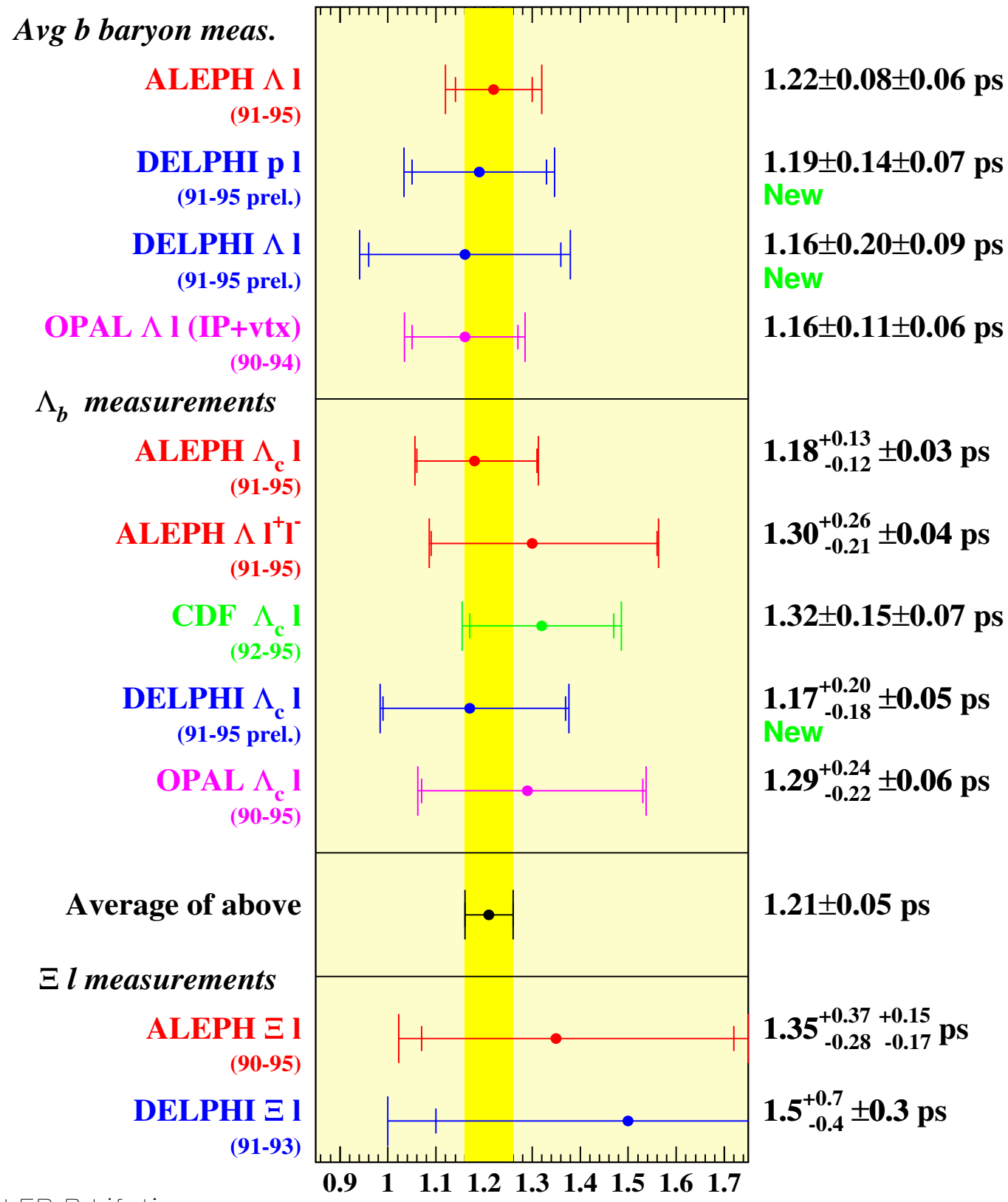
→ Beginning to see $\tau(B^+) / \tau(B^0) > 1$ (2.6 σ)

→ τ(b-baryon) remains low

Future:

→ Further improvements from SLD
150K $Z^0 \to q\bar{q}$ unanalyzed + Run extension requested

→ B Factories and Tevatron Run-II will provide
next step in precision

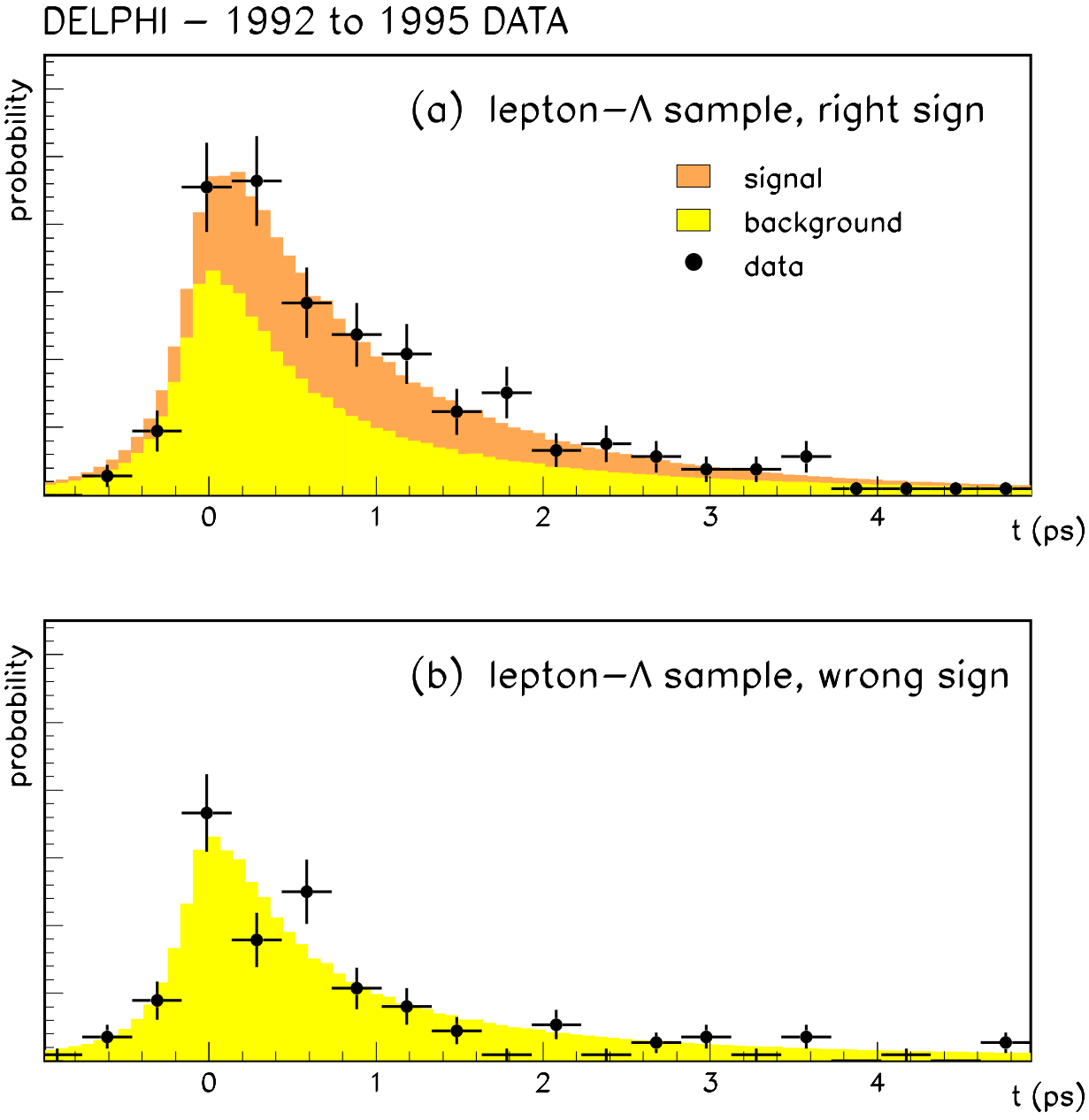


LEP B Lifetime Working Group
July 1998

→ Inclusive (vtx+kinem.) reconstruction of semileptonic decays

→ Select vtx with lepton-Λ pair

→ $\Lambda \rightarrow p\,\pi$ with opposite-sign lepton-proton



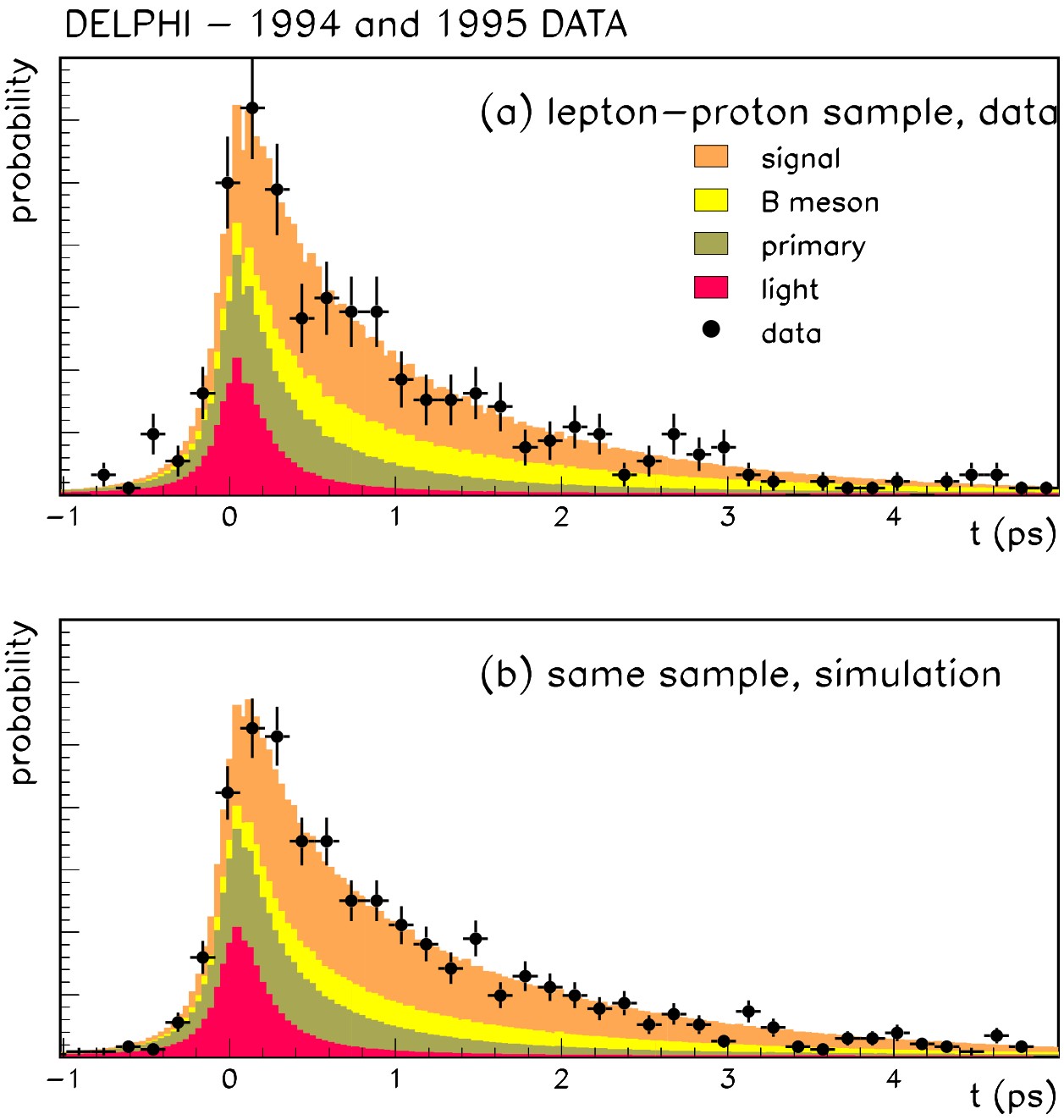
Fraction signal = (35 ± 8)% estimated from data

τ(b-baryon) = 1.16 ± 0.20 ± 0.09 ps

→ Inclusive (vtx+kinem.) reconstruction of semileptonic decays

→ Select vtx with opposite-sign lepton-proton pair

→ Proton is leading hadron in vtx identified by RICH (K/p sep.)

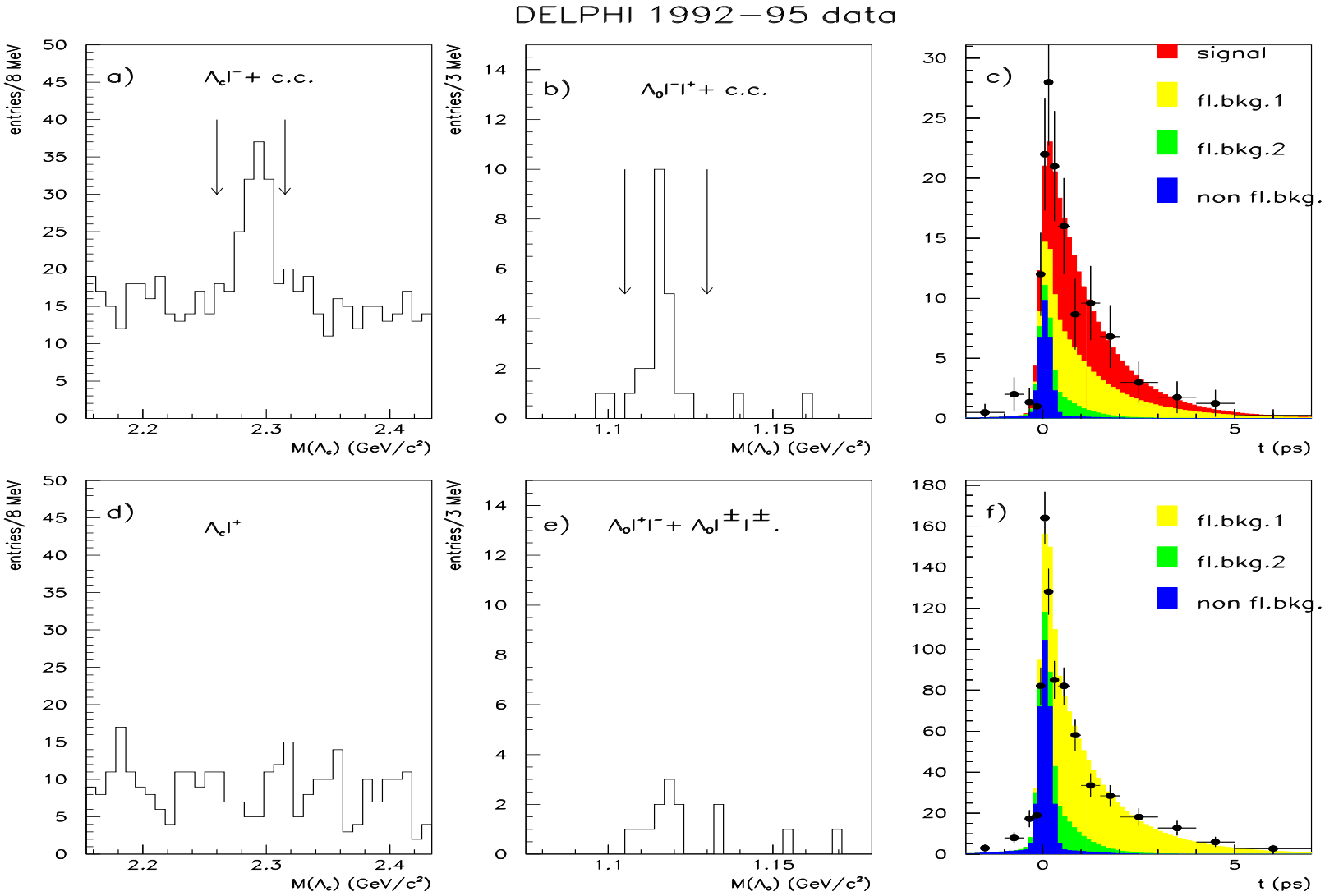


Fraction signal = (47 ± 5)% estimated from data

τ(b-baryon) = 1.19 ± 0.14 ± 0.07 ps

- DELPHI Λ_b (92-95) 3.6 M $Z^0 \rightarrow q\bar{q}$ (prel.)

  same Λ^+_c modes as OPAL



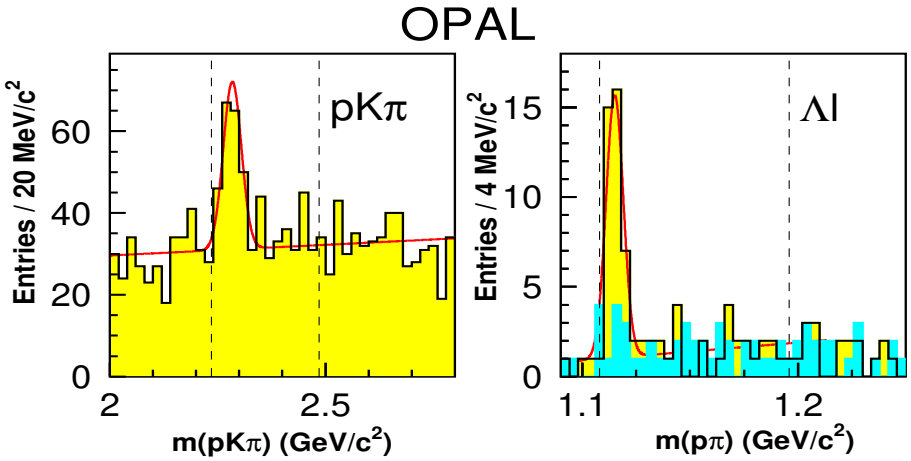
$$\tau(\Lambda_b) = 1.17 \pm \begin{matrix} 0.20 \\ 0.18 \end{matrix} \pm \begin{matrix} 0.04 \\ 0.05 \end{matrix} \text{ ps}$$

b-baryon lifetime:

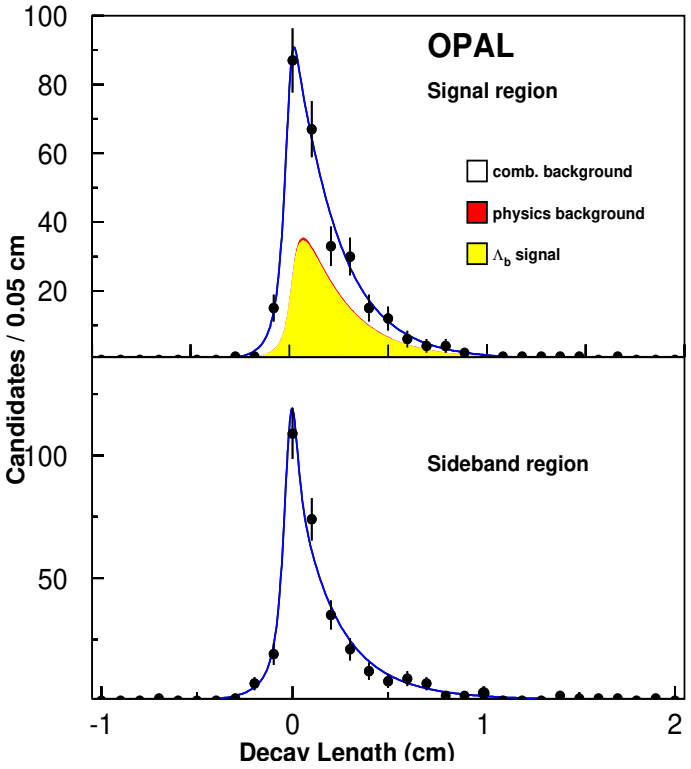
b-baryon decays not well known + smaller production rate vs. B
⇒ need to understand sample composition

- OPAL Λ_b (90-95) 4.4 M $Z^0 \to q\bar{q}$ (publ.)

Partially reconstruct $\Lambda_b \to \Lambda^+_c \, l^- \, \bar{\nu} \, X$

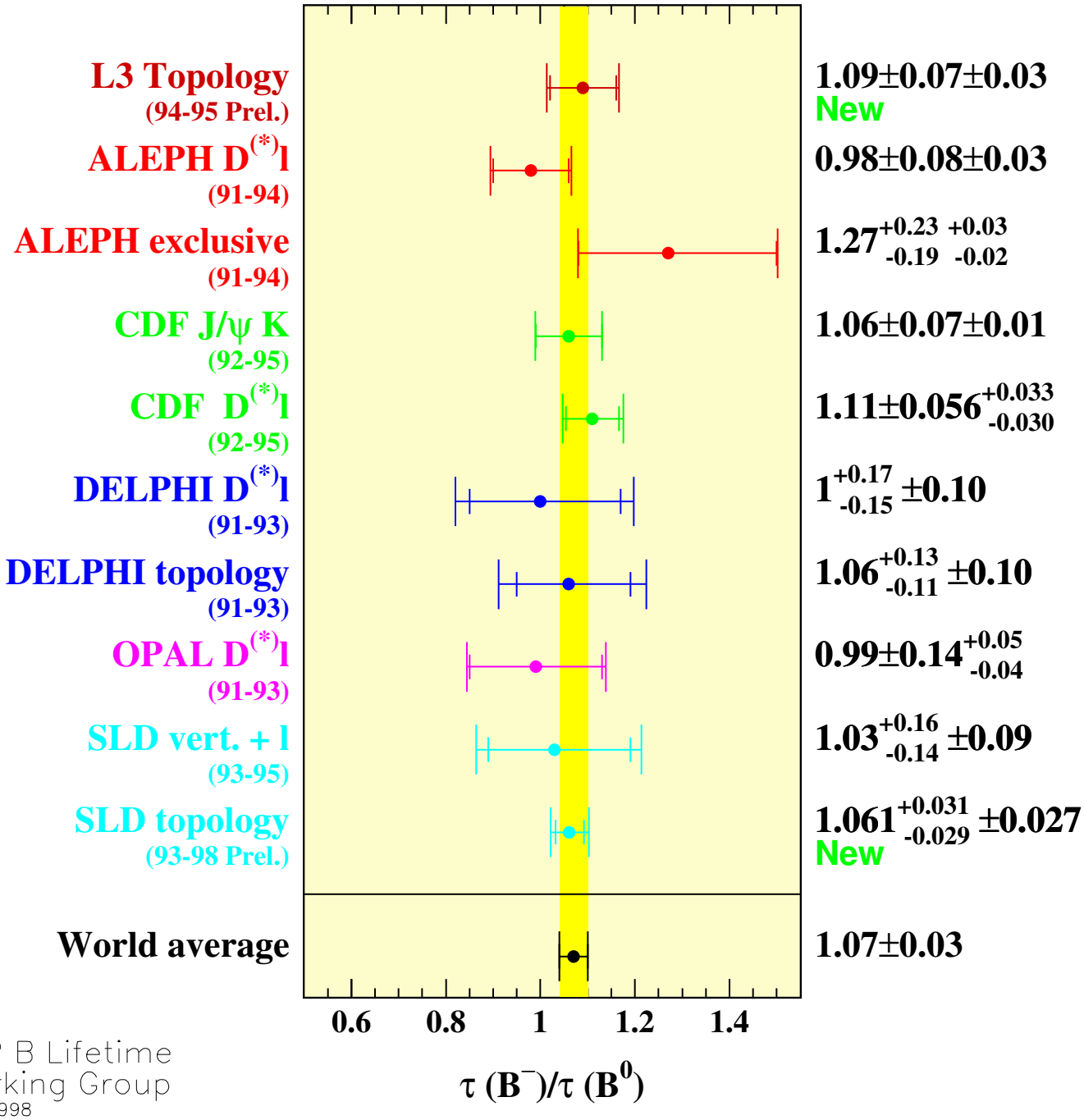


with $\Lambda^+_c \to p \, K^- \, \pi^+$ or $\Lambda^+_c \to \Lambda \, l^+ \, \nu \, X$

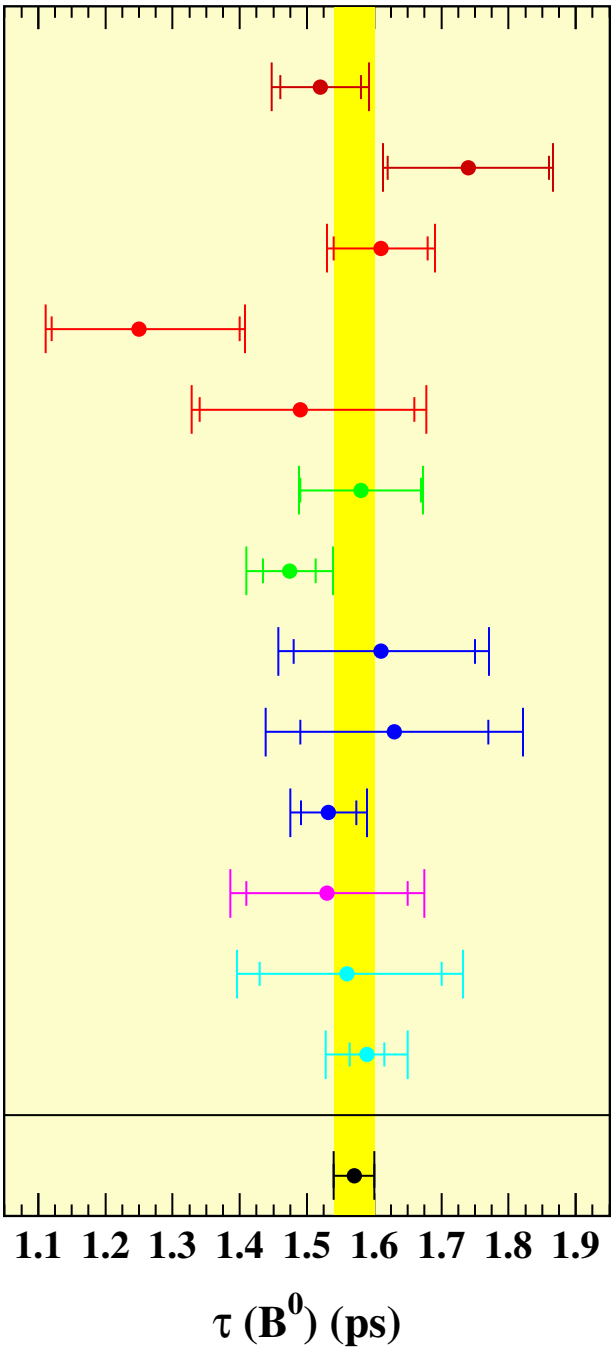


$129 \pm 25 \; \Lambda^+_c \, l^-$ signal

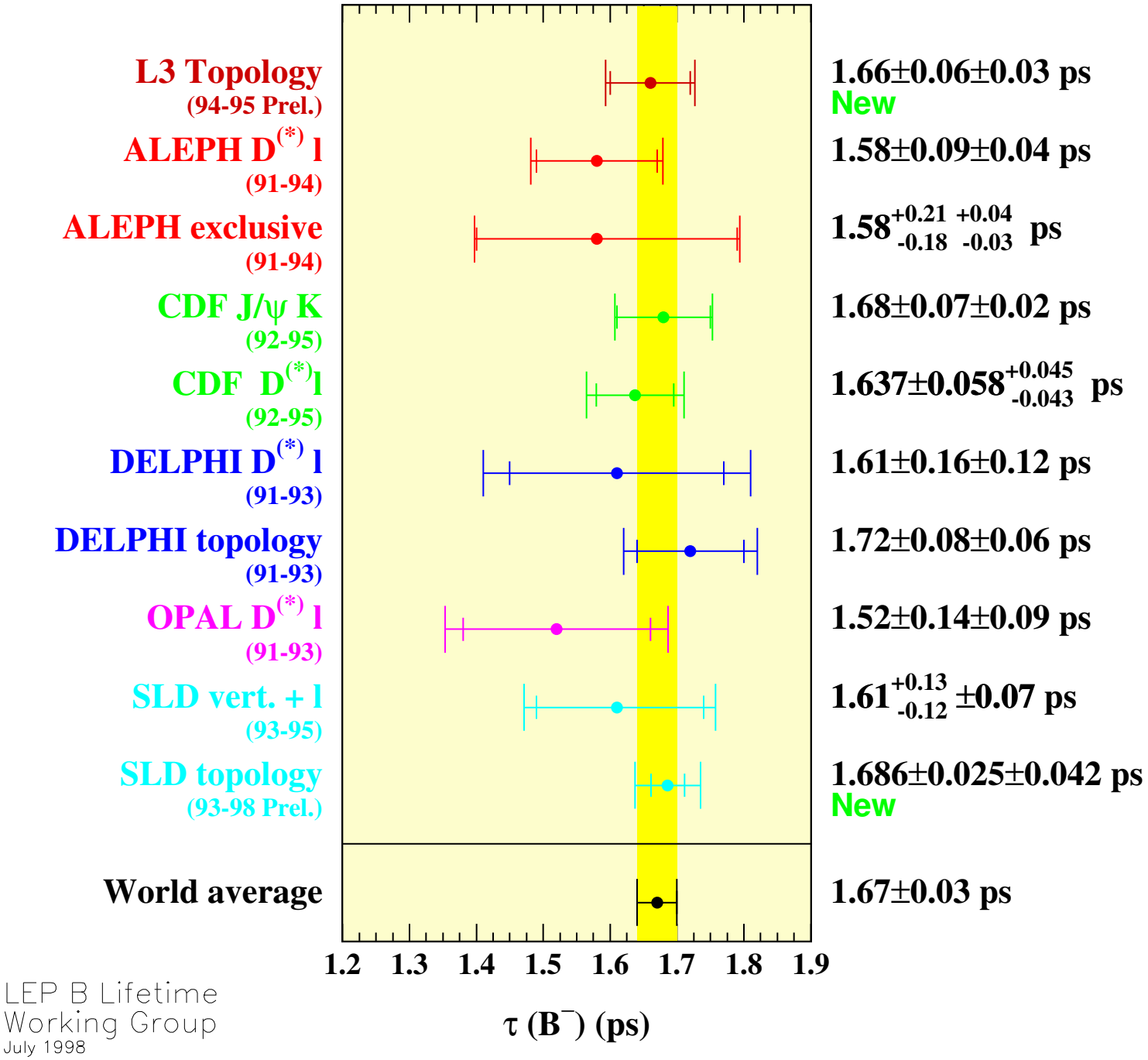
$\tau(\Lambda_b) = 1.29 \pm {}^{0.24}_{0.22} \pm 0.06$ ps



LEP B Lifetime
Working Group
July 1998



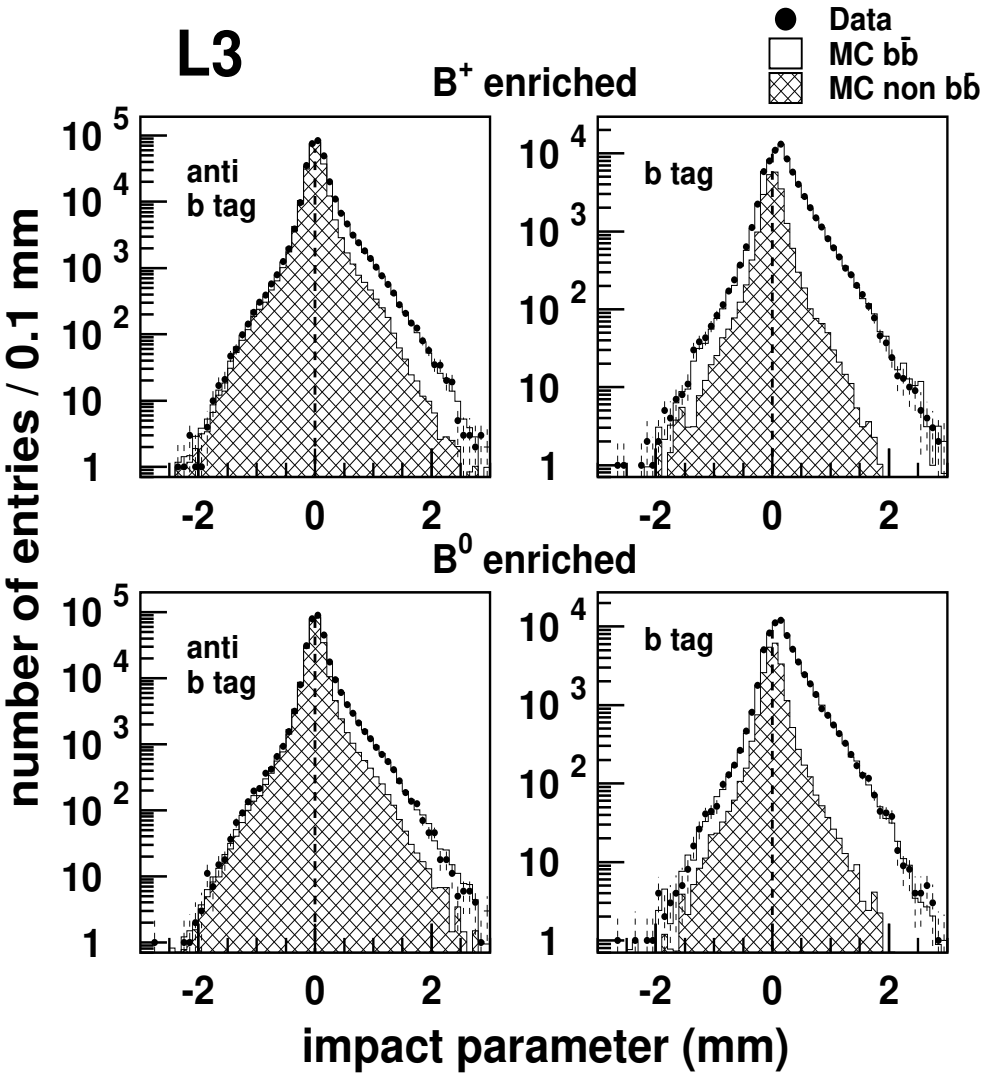
LEP B Lifetime Working Group
July 1998


L3 Topology
(94-95 Prel.)
1.66±0.06±0.03 ps
New
ALEPH D(*) l
(91-94)
1.58±0.09±0.04 ps
ALEPH exclusive
(91-94)
1.58 +0.21 -0.18 +0.04 -0.03 ps
CDF J/ψ K
(92-95)
1.68±0.07±0.02 ps
CDF D(*)l
(92-95)
1.637±0.058 +0.045 -0.043 ps
DELPHI D(*) l
(91-93)
1.61±0.16±0.12 ps
DELPHI topology
(91-93)
1.72±0.08±0.06 ps
OPAL D(*) l
(91-93)
1.52±0.14±0.09 ps
SLD vert. + l
(93-95)
1.61 +0.13 -0.12 ±0.07 ps
SLD topology
(93-98 Prel.)
1.686±0.025±0.042 ps
New
World average
1.67±0.03 ps
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
τ (B⁻) (ps)
LEP B Lifetime
Working Group
July 1998

→ Lifetimes determined using weighted average of track impact parameters ⇒ reduced b fragmentation dependence

→ b-tag: L > 2 mm in opposite hemisphere
+ anti-tag to control background contribution

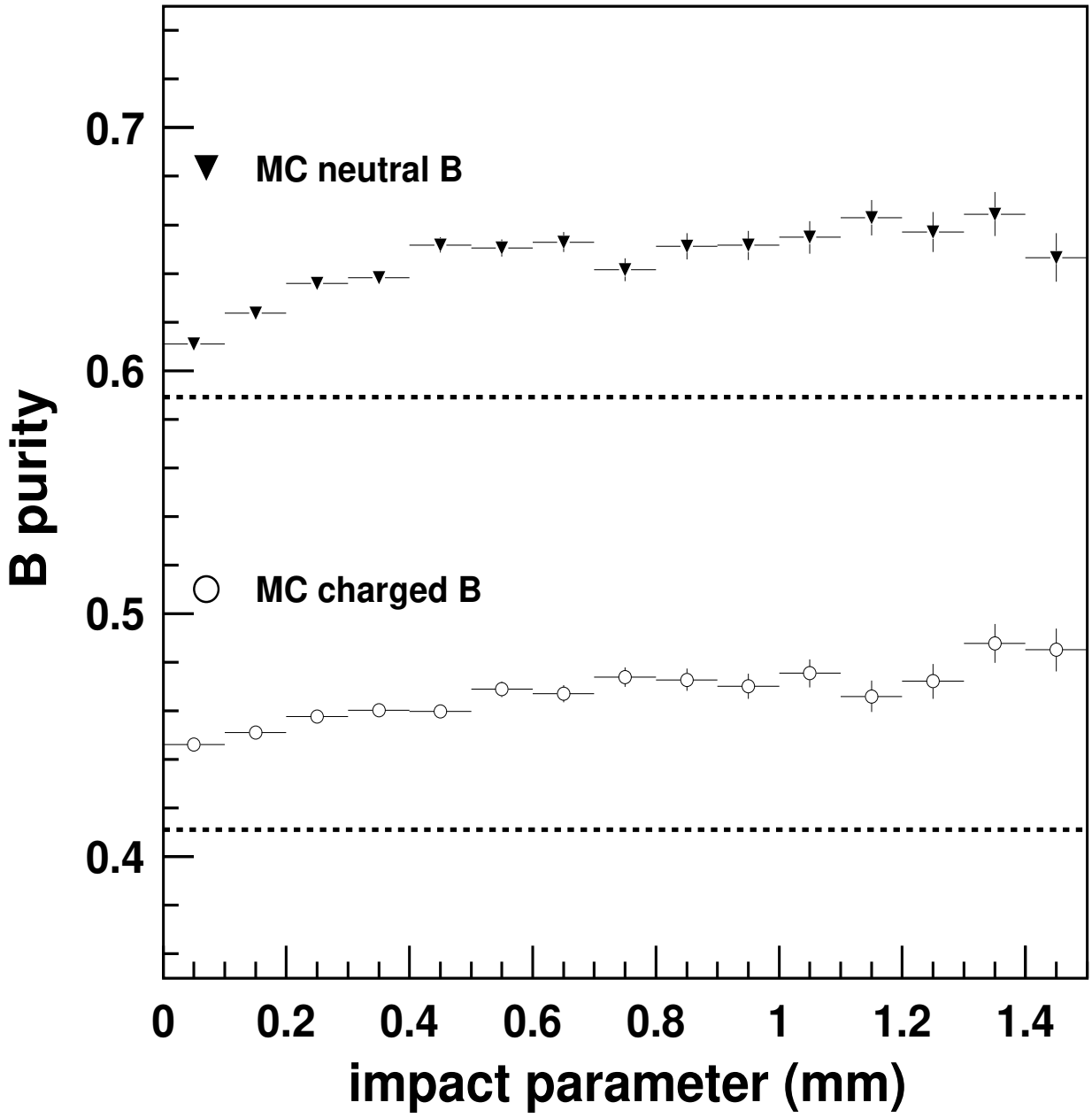
→ Fit for $<\tau(B^+) + \tau(B^0)>$, $\tau(B^+)/\tau(B^0)$, $\Delta\Gamma_s/\Gamma_s$
use B_s and Λ_b production rates and lifetimes as input



$\tau(B^+) = 1.662 \pm 0.056$ (stat) ± 0.025 (syst) ps

$\tau(B^0) = 1.524 \pm 0.055$ (stat) ± 0.037 (syst) ps

$\tau(B^+) / \tau(B^0) = 1.09 \pm 0.07$ (stat) ± 0.03 (syst)

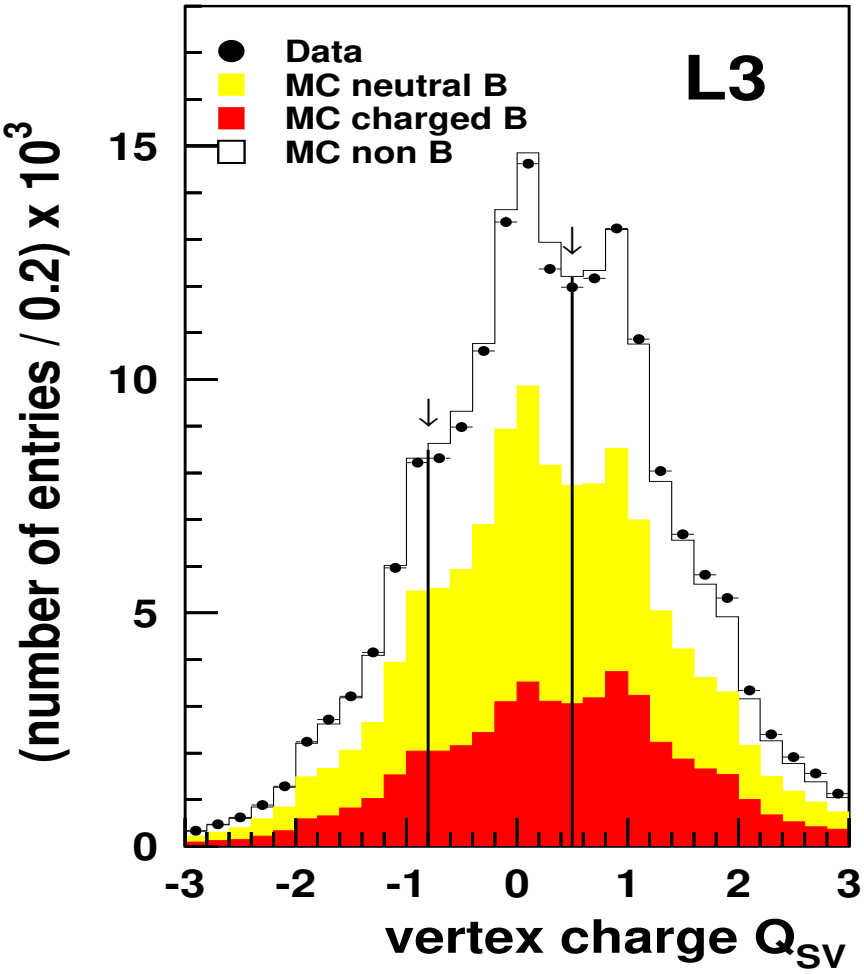

0.7
0.6
0.5
0.4
B purity
MC neutral B
MC charged B
0
0.2
0.4
0.6
0.8
1
1.2
1.4
impact parameter (mm)

- L3 *Topological Vtx* (94-95) 2M $Z^0 \to q\bar{q}$ (prel.)

→ 3-vtx χ^2 procedure as for τ_b measurement
⇒ 890,506 secondary vertices

→ Define Vertex Charge Q_{SV} as product of
weighted Σ of track charges *and* SIGN(Jet Q)

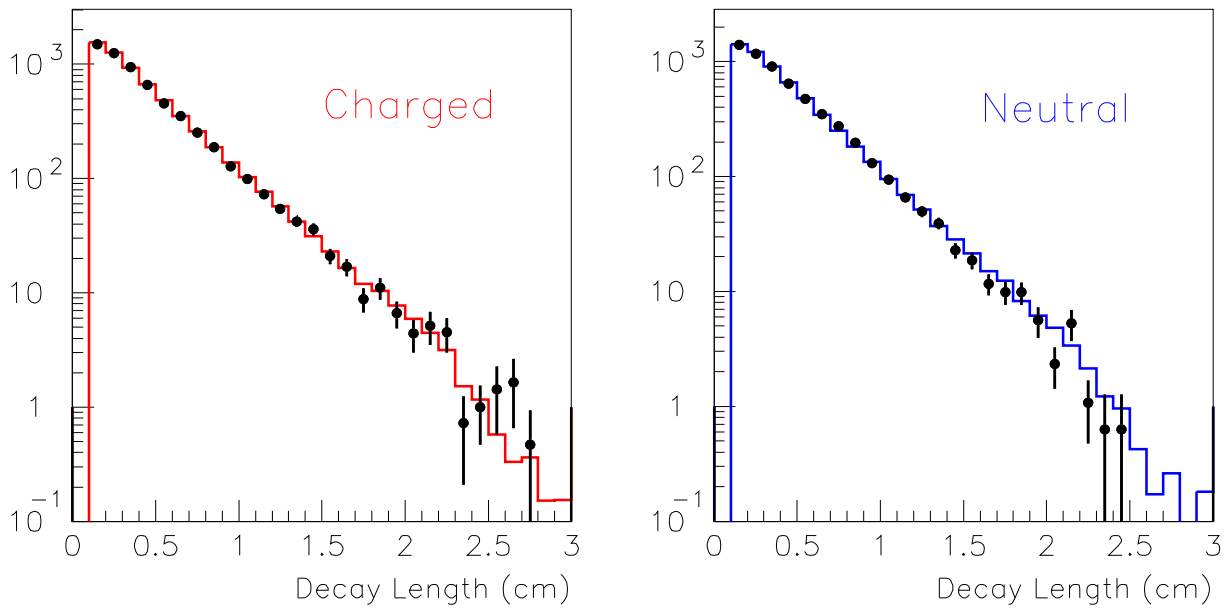
weight = probability to belong to sec. vtx



Charged sample : $Q_{SV} > 0.5$
Neutral sample : $-0.8 < Q_{SV} < 0.5$

• Fit charged and neutral decay length distributions *simultaneously* using binned max likelihood

SLD 97-98 Data



Combining 1997-98 data with 1993-96 preliminary analysis:

$$\tau(B^+) = 1.678 \pm 0.025 \text{ (stat)} \pm 0.042 \text{ (syst) ps}$$

$$\tau(B^0) = 1.589 \pm 0.026 \text{ (stat)} \pm 0.055 \text{ (syst) ps}$$

$$\tau(B^+) / \tau(B^0) = 1.061 \; {}^{+\,0.031}_{-\,0.029} \text{ (stat)} \pm 0.027 \text{ (syst)}$$

Main systematic uncertainties in $\tau(B^+) / \tau(B^0)$:

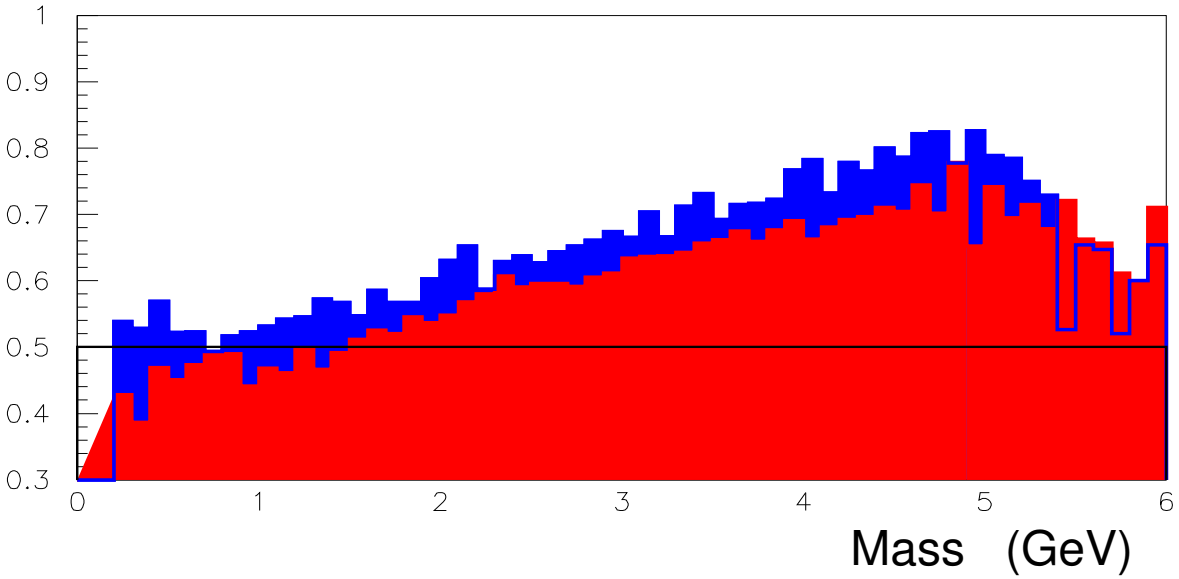
Detector	0.010
$\tau(B_s)$	0.009
f(b-baryons)	0.013
BR(B → DX, DDX)	0.013
Fit systematics	0.009
MC statistics	0.007

⇒ b fragmentation $\langle x_E \rangle = 0.700 \pm 0.011 \Rightarrow \Delta\tau = \pm 0.035$ ps

⇒ Topol. vtx and kinematics to measure $\langle x_E \rangle$ to ±0.003 (stat.)
→ See talk by D. Muller in QCD Parallel session

Charge reconstruction purity enhancement

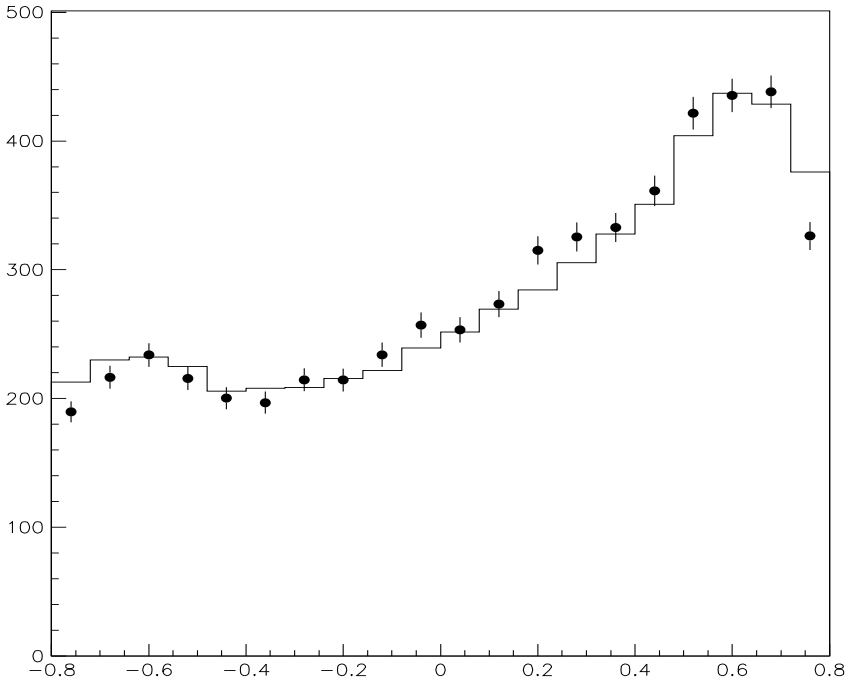
1996 VXD3 MC



Charged sample: Purity = B^+ / (B^+ + B^0)

Neutral sample: Purity = B^0 / (B^+ + B^0)

B^+ / B^0 separation is ~ 4 : 1 at high mass –> weight(Mass)



Charge reconstruction modelling check: polarized A_{FB}

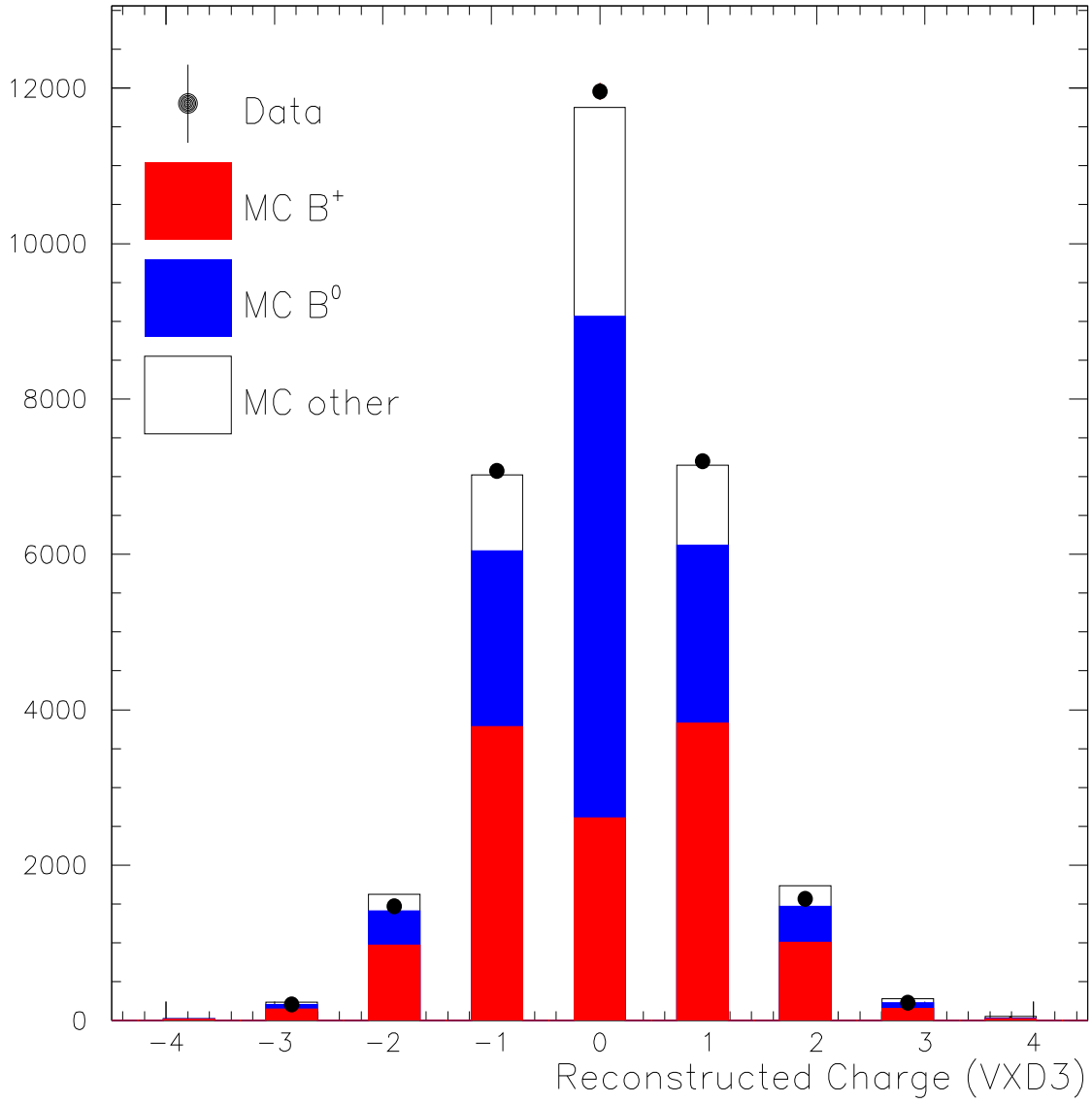
⇒ Additional weight with vtx charge sign - b/$\bar{b}$ tag correlation

• Cuts: 2.0 < M < 5.2 GeV & L > 1 mm & radius < 2.4 (2.2) cm

⇒ *49,664 reconstructed vertices*

→ $B^+ : B^0$ separation directly from measured total charge

30028 charged (|Q| = 1, 2, 3) and 19636 neutral (Q = 0)

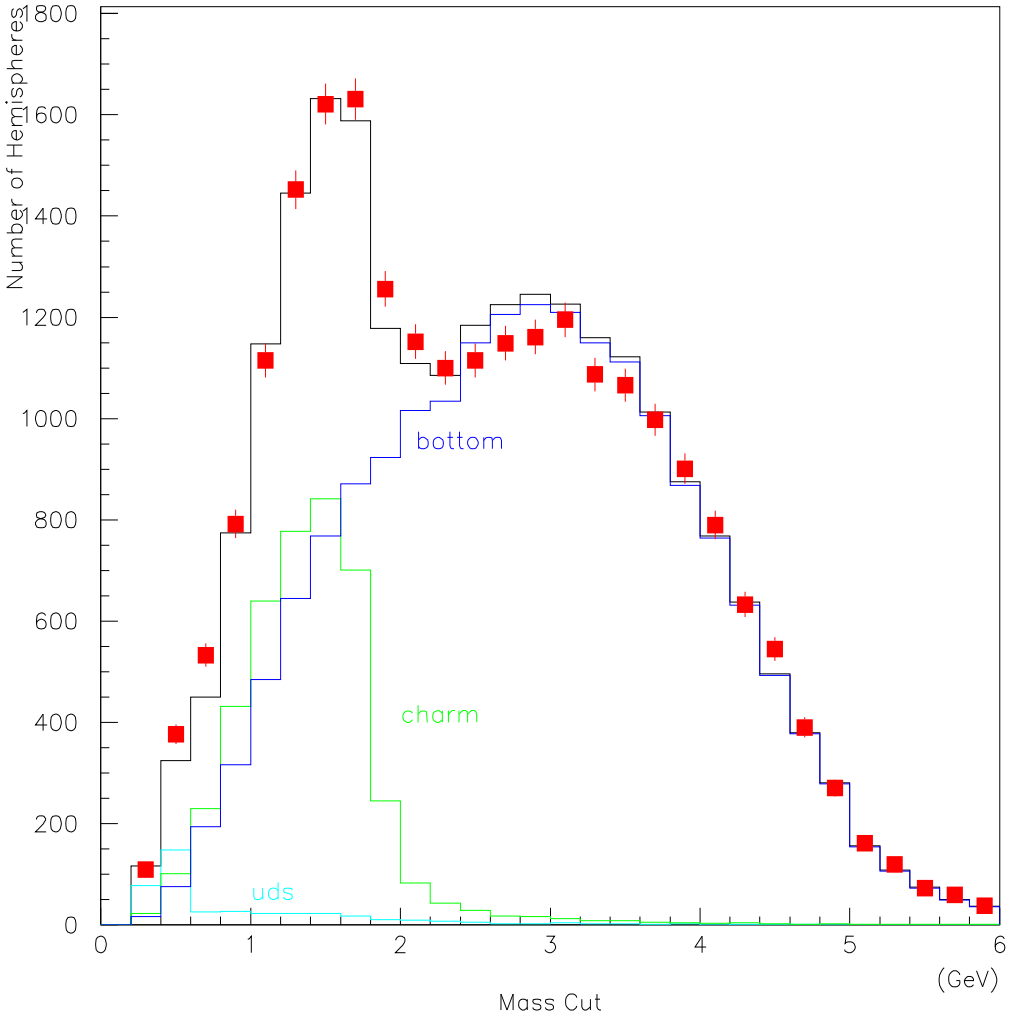


VXD3: Neutral → $B^0 : B^+ = 2.2 : 1$

Charged → $B^+ : B^0 = 1.7 : 1$

- SLD *Topological Vtx* (93- Mar.98) 400K $Z^0 \to q\bar{q}$ (prel.)

High resolution vertex detector
⇒ clean inclusive topological vertexing

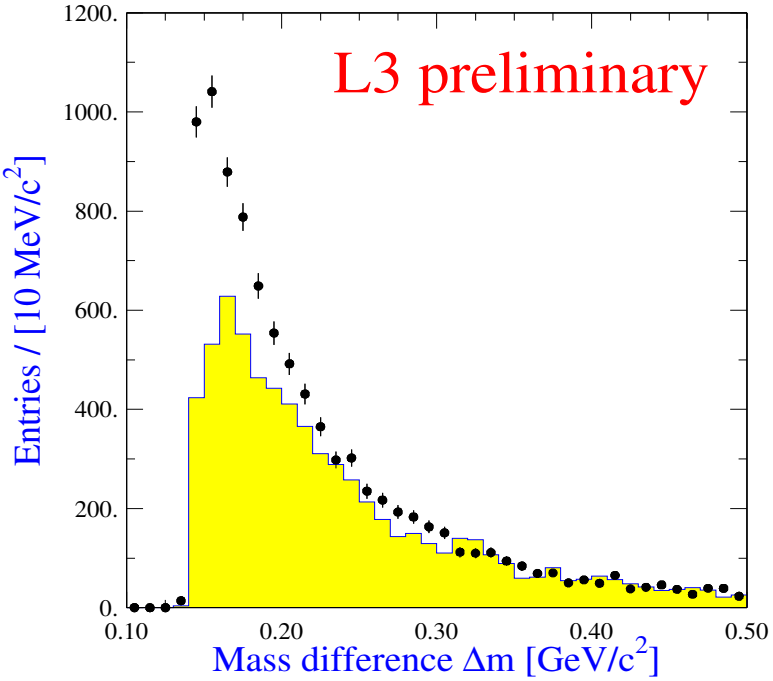


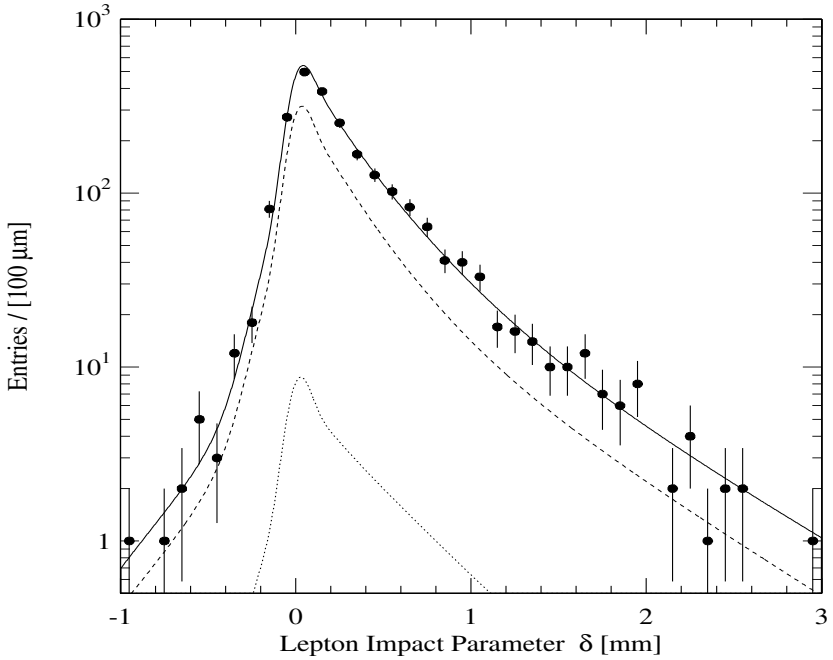
Vertex mass corrected for minimum missing pT

VXD3 b-tag with efficiency = 50% (Mass > 2 GeV)
purity = 98%

- L3 *inclusive D*l* (94) 1.5 M $Z^0 \rightarrow q\bar{q}$ (prel.)

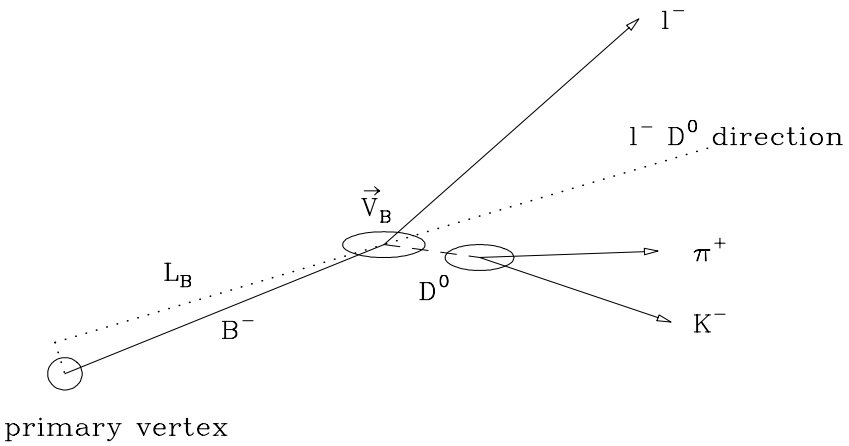
Inclusive D* method

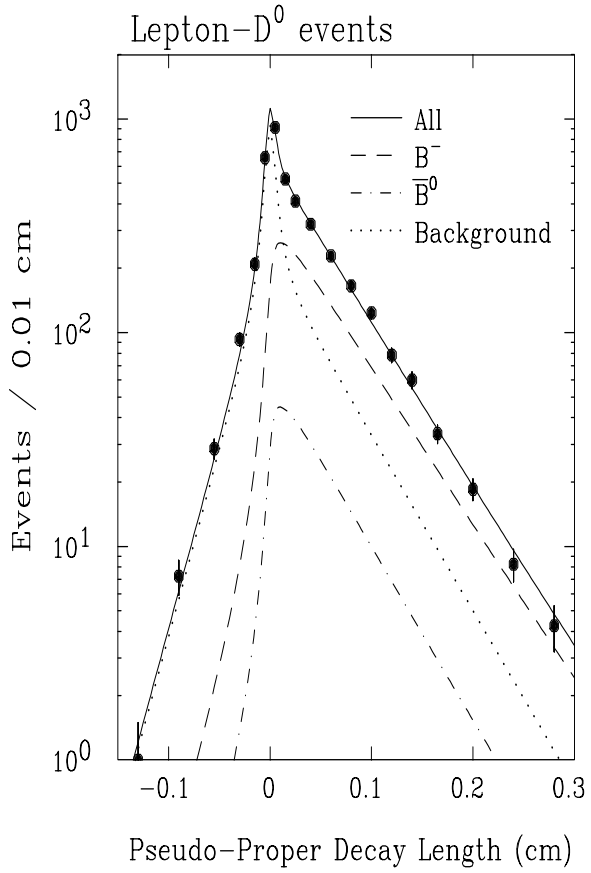


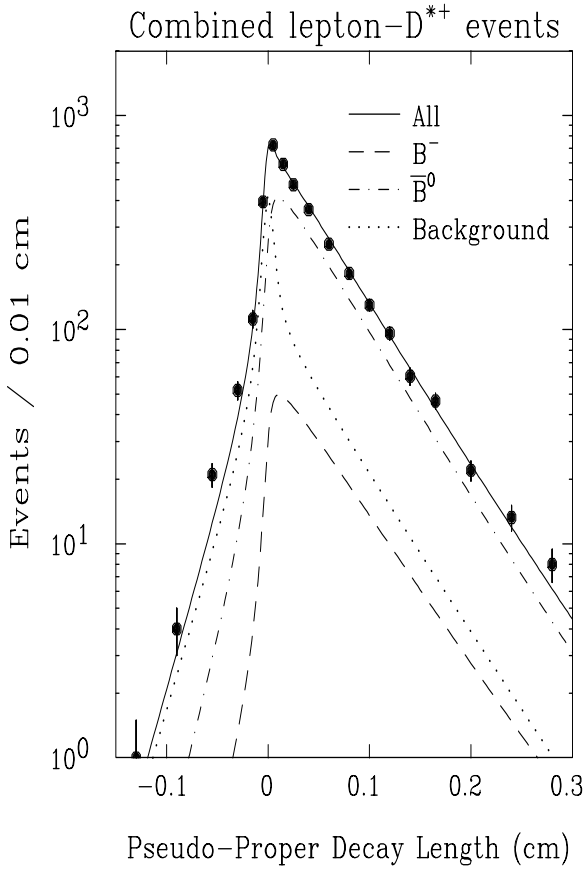


$\tau(B^0) = 1.74 \pm 0.12 \pm 0.04$ ps

B decay vtx = lepton - D trajectory intersection







CDF

$\tau(B^+) = 1.637 \pm 0.058\ (\text{stat})\ ^{+0.045}_{-0.043}\ (\text{syst})$ ps

$\tau(B^0) = 1.474 \pm 0.039\ (\text{stat})\ ^{+0.052}_{-0.051}\ (\text{syst})$ ps

$\tau(B^+) / \tau(B^0) = 1.110 \pm 0.056\ (\text{stat})\ ^{+0.033}_{-0.030}\ (\text{syst})$

- CDF D(*)l (92-95) 110 pb^{-1} (to be publ.)

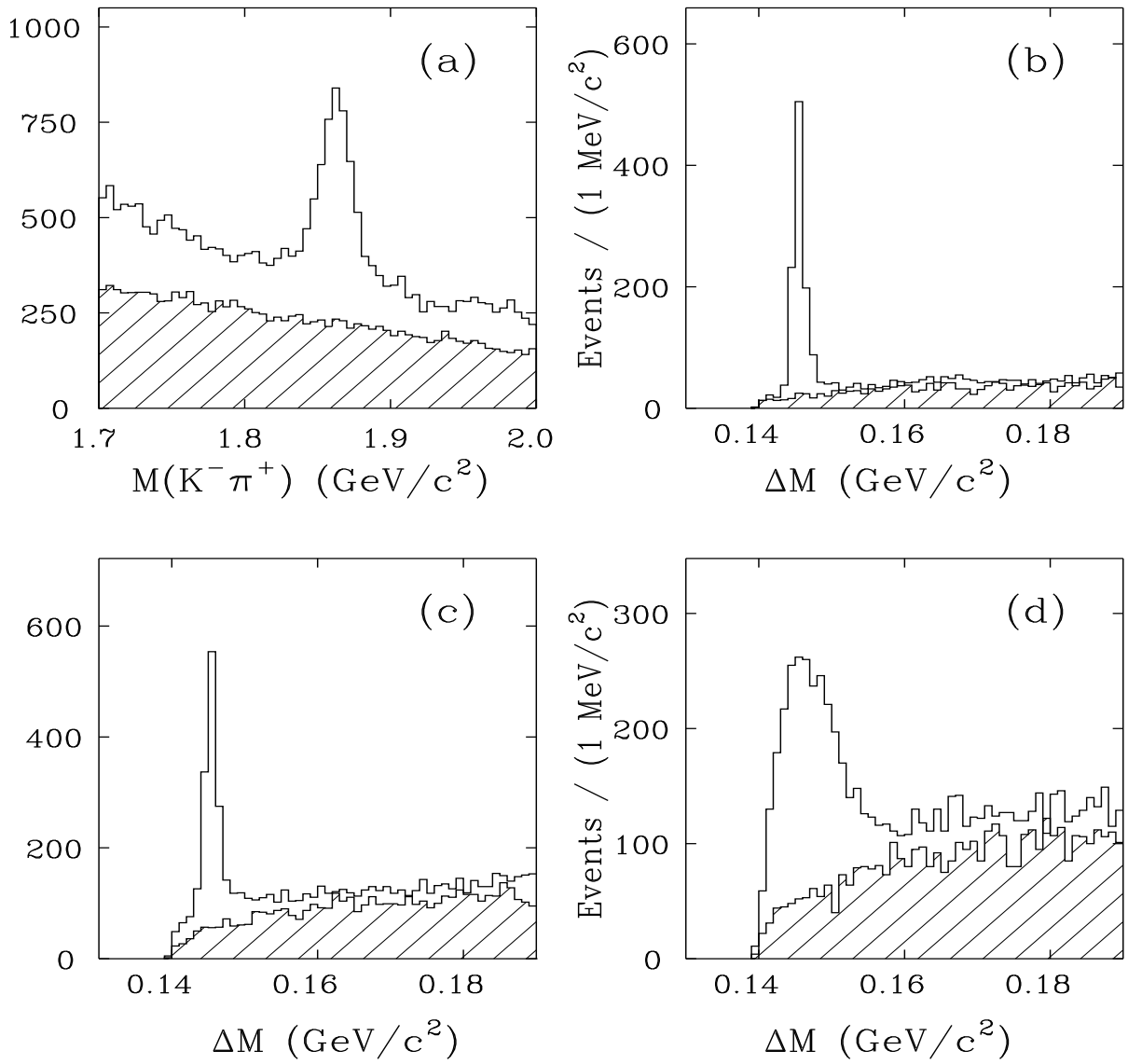
Partially reconstructed $B \to D\, l\, \nu\, X$

→ 'B^{+}' sample: $\overline{D}^{0}\, l^{+}$ with $\overline{D}^{0} \to K^{+}\, \pi^{-}$

→ 'B^{0}' sample: $D^{*-}\, l^{+}$ with $D^{*-} \to \overline{D}^{0}\, \pi^{-}$

and $\overline{D}^{0} \to K^{+}\, \pi^{-}\, (\pi^{0})$ or $K^{+}\, \pi^{-}\, \pi^{+}\, \pi^{-}$

*Contamination from D** is 10-15%*



B^+ and B^0_d Lifetimes

1. Exclusive B Decay Reconstruction

- FULL reconstruction of B decay
- NO B decay model uncertainty for boost or charge

  => small systematic uncertainties
- Ideal method for lifetime measurement

  but small B.R. 10^{-4} - 10^{-3} *e.g.* $B \to J/\psi\ K$

2. $D^{(*)}$ - lepton Charge Correlation

- Identify lepton from semileptonic B decay
- FULL reconstruction of D meson

  $B^+ \to \overline{D}^0\ l^+\ \nu\ X$

  $B^0 \to D^{(*)-}\ l^+\ \nu\ X$ *and* $D^{*-} \to \overline{D}^0\ \pi^-$

  with fully reconstructed D :

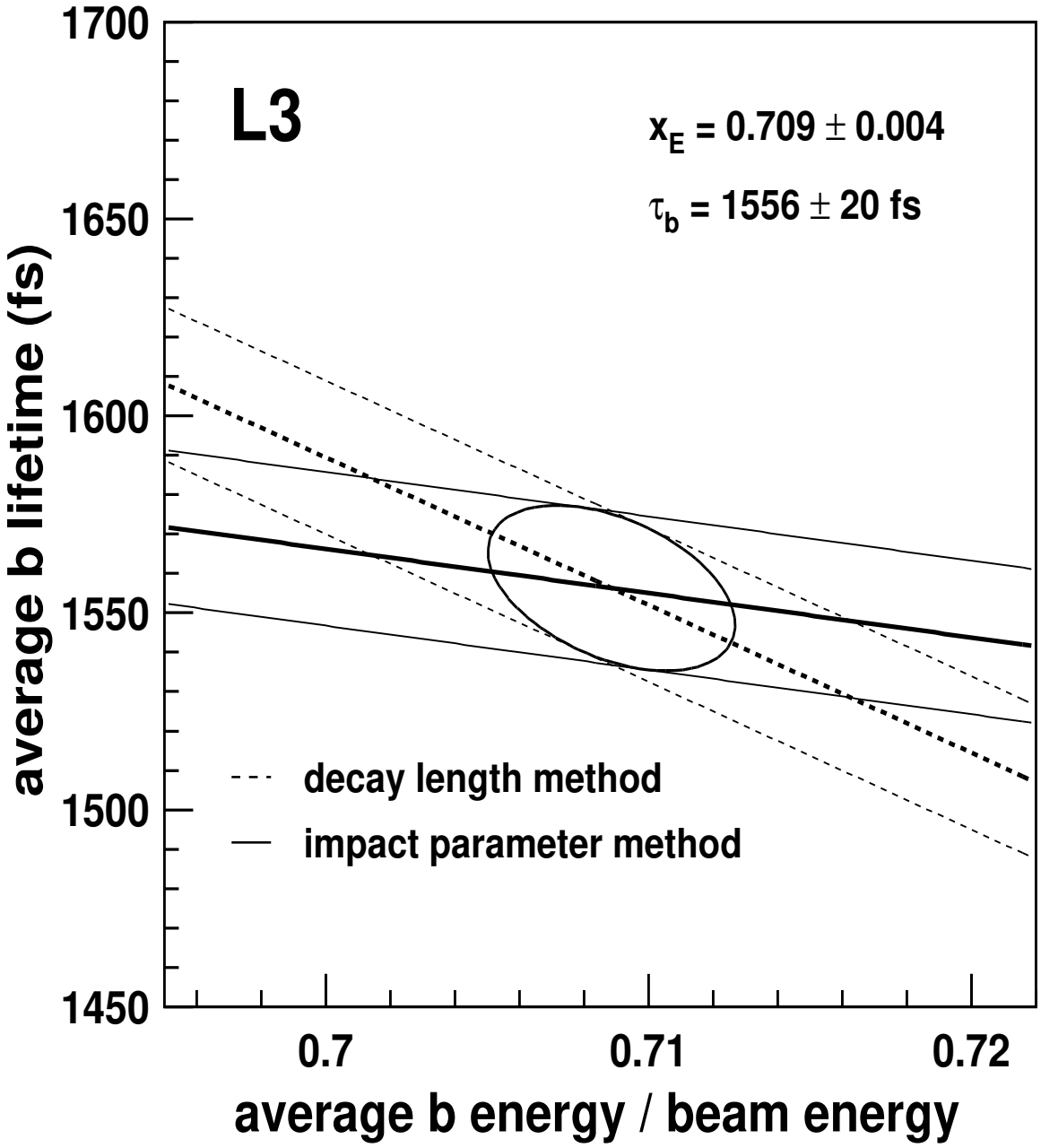
  $\overline{D}^0 \to K^+\ \pi^-$ *or* $K^+\ \pi^-\ \pi^+\ \pi^-$

  $D^- \to K^+\ \pi^-\ \pi^-$
- Complications from $B \to D^{**}\ l\ \nu$ *not well known*

3. Topological Charge Reconstruction

- Find ALL tracks from B decay attached to sec. vertex
- High selection efficiency => large statistics

  but need good control of charge reconstruction purity

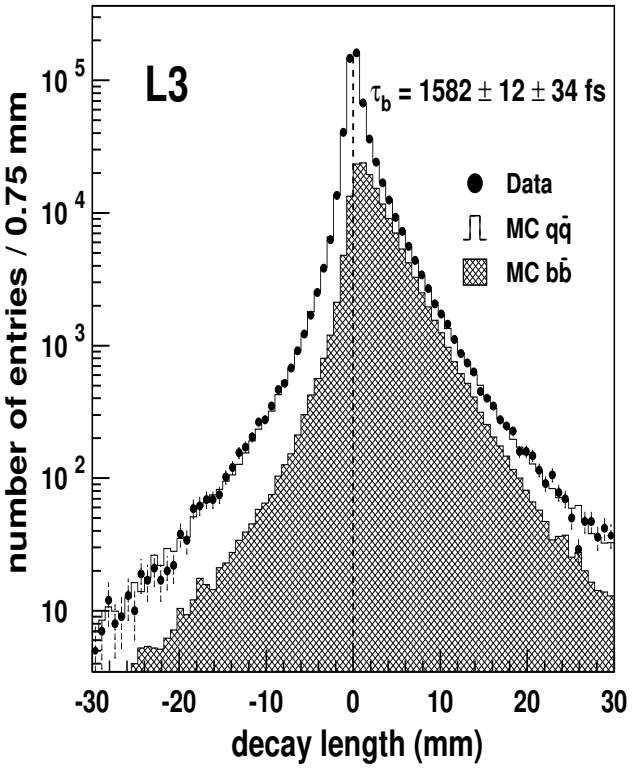


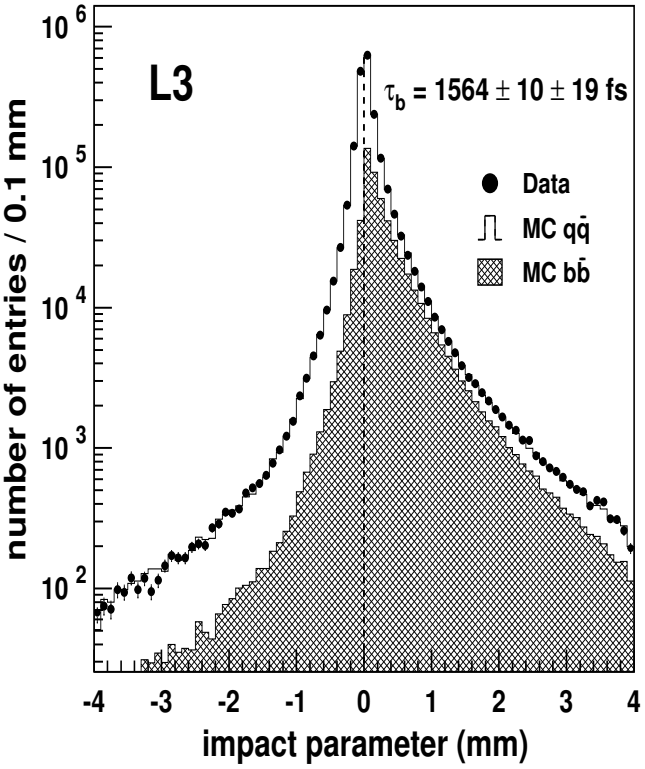
⇒ Most precise single measurement of τ_b

⇒ Precise determination of the scaled b-hadron energy x_E

τ_b measured from:
- secondary vtx decay length
- secondary vtx track impact parameters

large fragmentation track background





$\Rightarrow$ fit for τ_b, $\langle n_b \rangle$, $\langle n_{K^0} + n_\Lambda \rangle$ + resolution parameters

Average b-hadron lifetime:

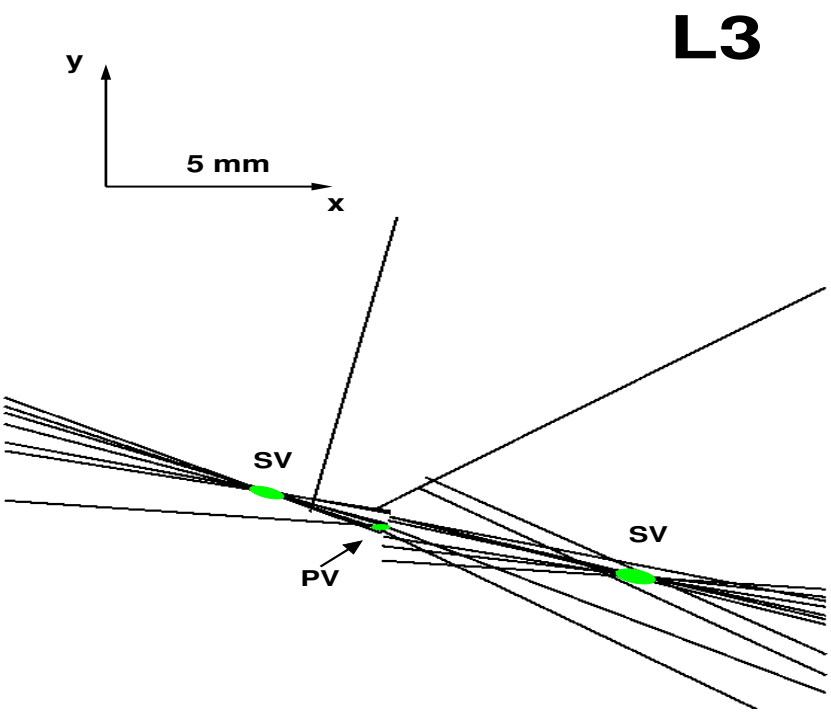
Measure $\tau_b = f_u \tau_{B+} + f_d \tau_{B0d} + f_s \tau_{B0s} + f_{\Lambda b} \tau_{\Lambda b}$

Bigi, Shifman, Uraltsev, hep-ph/9703290

$$|Vcb| = 0.0419 \left[\sqrt{\frac{BR(B \to X_c l \nu)}{0.105}} \sqrt{\frac{1.55\,ps}{\tau_b}} \right]$$

- L3 *Topological Vertexing* (94) 1.5 M $Z^0 \to q\bar{q}$ (publ.)

→ Reconstruct 3 vertices/event with minimal χ^2 for track association
→ Use track 3-D impact param. and rapidity (pri. vs. sec. track)

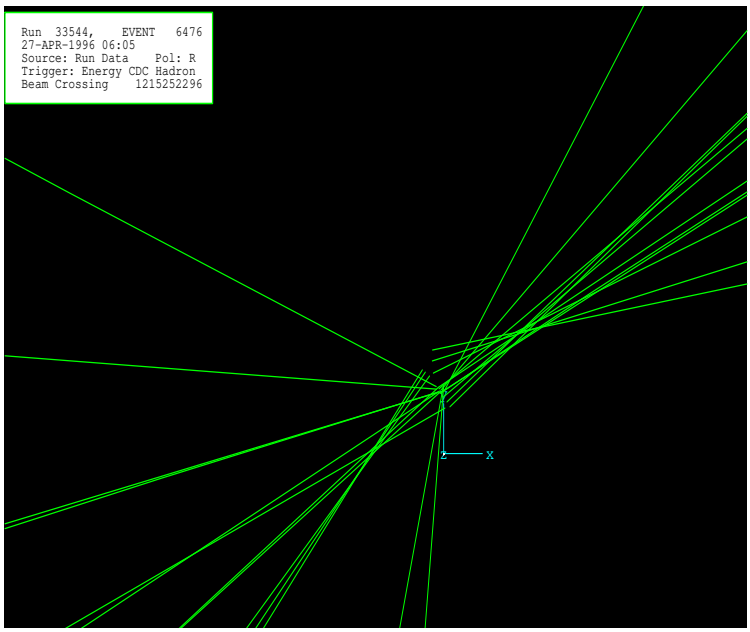


⇒ 27% b purity

	LEP	SLD	CDF
Data	1990-95	1993-98	1992-95
$Z \rightarrow q\bar{q}$	4 M / exp	0.55 M (0.4 M)*	
b hadrons	1.7 M / exp	240 K	600 M
Trigger			J/ψ, e, μ
Vertex Detector	Si strips	CCD pixels	Si strips
	rϕ, rz	3-D	rϕ
# layers	2 or 3	3	4
min radius	6 - 6.5 cm	2.5 cm	3 cm
σ_X	130 μm	2 μm	25 μm
Beam spot σ_Y	5 μm	1 μm	25 μm
σ_Z	7 mm	0.7 mm	300 mm
Avg. Dec.Length	3 mm	3 mm	1-2 mm

* Reported in this talk

(table from O. Schneider)



SLD VXD3 (1996-?)

Impact parameter resolution rϕ plane

$11\ \mu m \oplus 40\ \mu m/p\ \sin^{3/2}\theta$

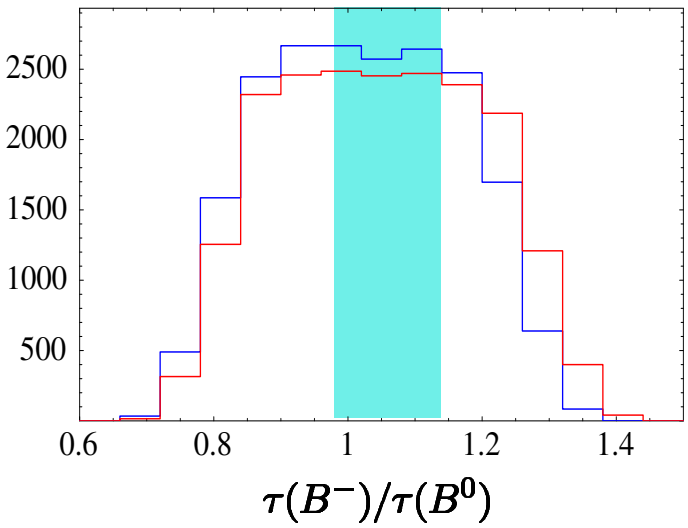
rz plane

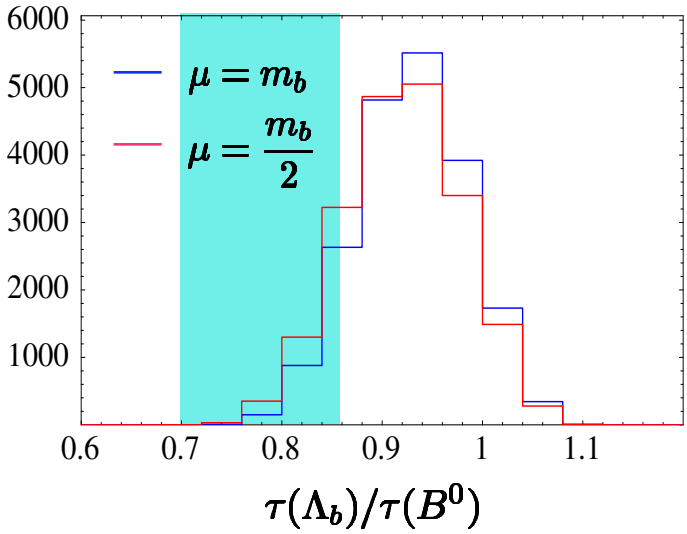
$23\ \mu m \oplus 40\ \mu m/p\ \sin^{3/2}\theta$

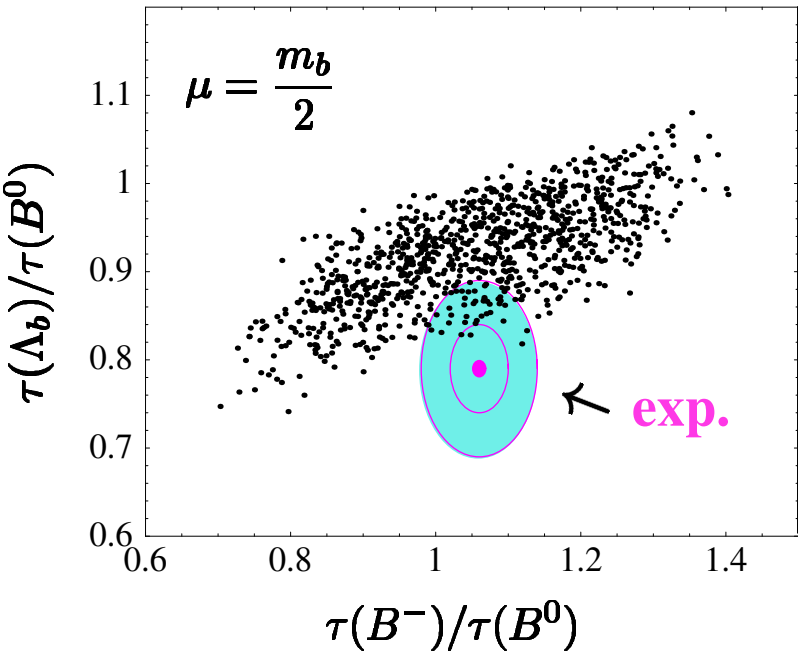
M. Neubert (EPS 97-Jerusalem):

→ Large uncertainty in parametrization of hadronic matrix elements (bag parameters)

- $\tau(B^+) / \tau(B^0) = 1.06 \pm 0.04$ easily accommodated by theory
- $\tau(\Lambda_b) / \tau(B^0) = 0.78 \pm 0.04$ just accommodated by theory







⇒ Need calculations for bag parameters possibly from Lattice Gauge Theory or QCD sum rules

But quarks are confined inside hadrons

⇒ *strong interactions play important role*

QCD-based Heavy Quark Effective Theory and
Heavy Quark Expansion predict spectator contributions
of order 5% for B decays (Charm: $\tau(D^+) / \tau(D^0) = 2.5$)

- $1/m_b$ expansion prediction (Bigi et al. in '*B Decays*' ,2nd Ed.) :

$$\tau(B^+) / \tau(B^0) = 1 + 0.05\ (f_B/200\ \text{MeV})^2 \approx 1.05$$

$$\tau(\Lambda_b) / \tau(B^0) \approx 0.9$$

⇒ Lifetime differences < 10%

- <u>but</u> Neubert et al. predict: $0.8 < \tau(B^+) / \tau(B^0) < 1.2$

⇒ *Lifetime measurements provide important test of our understanding of inclusive B decay dynamics*

⇒ *Also important as input for other measurements (e.g. $|V_{cb}|$ from $B \to D^* l\nu$)*

Introduction

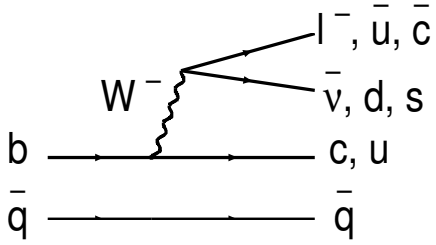
$$\Gamma(b \to X) = \frac{G_F^2 m_b^5}{192\pi^3} |V_{cb}|^2 \Phi(m_f)$$

Lifetime yields $|V_{cb}|$ but large uncertainty in m_b

However, $\tau_b + B_{SL}$ yield precise $|V_{cb}|$

Spectator model:

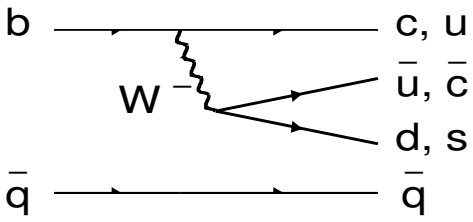
$$\tau(B^+) = \tau(B^0) = \tau(B_s) = \tau(\Lambda_b)$$



but other diagrams can contribute also:

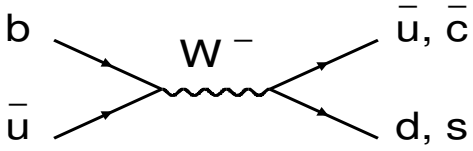
Internal W

destructive interference
for B^+ only



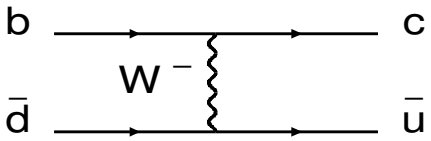
Annihilation

helicity suppressed
and small value of |Vub|



W exchange

helicity suppressed
for B mesons only



B^+, B^0 and b-BARYON LIFETIMES

Stéphane Willocq

(SLAC)

XXIXth ICHEP

23 - 29 July 1998

- *Introduction to b lifetimes*
- *Average b lifetime*
- *B^+ and B^0 lifetimes*
- *b-baryon lifetimes*
- *Summary*

Thanks: LEP B Lifetime Working Group