The Legacy of LEP B Program

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- The PreLEP B world
- Expectation from the LEP B program
- Major modification
- LEP B program - results
- Comments, future, summary

The PreLEP B world

- Active players:

ARGUS

CLEO1 (1.5)

- Spectroscopy:

Fairly well established Υ states (1-5).

Only B_u and B_d were seen.

- Branching fractions - Only 9 B_u exclusive modes were measured with a total under 7% ($< 3\%$). Only $b \rightarrow c$ decays were measured*.

- Rare decays - of-course (if you call 10^{-3} rare)

- CKM elements:

$$V_{cb} = 0.044 \pm 0.009$$

$V_{ub} = 0.004 \pm 0.002$ mostly sl decays with one controversial non leptonic evidence.

- B mixing: time integrated - leading to

$$\Delta m = 4.0 \pm 0.8 \times 10^{-10} \text{ MeV}$$

- B lifetime: $1.18 \pm 0.11 \text{ ps}$ (from non- Υ machines)

The expected LEP B program

- Lifetime

2.6.2. EXPERIMENTAL ASPECTS*

The inclusive mean B lifetime, averaging the results from the PEP and PETRA experiments, is measured to be $\tau_B = 13.1^{+1.4}_{-1.3} 10^{-13}$ s [14] What are the prospects at LEP for improving this measurement? Can we go beyond and measure individual B_d^0, B_u^+, B_s^0 and Λ_b^0 lifetimes? As seen in the theory section, the theoretical expectation for the B^0, B^+ lifetime difference is at most 30%. Can we reach the interesting level of 10% precision on individual lifetimes?

- B mixing

Time integrated methods:

1. **b-b** expected precision on $\overline{\chi}$ of 15% for $10^6 Z^0$
2. **B-b** with $10^7 Z^0$ LEP expected 25% statistical accuracy on χ_s
3. **B-B** not clear if possible even with $10^7 Z^0$

Time dependent: expecting to confirm B_d time evolution of mixing - no prediction for error size.

- CKM

A conservative estimate for $|V_{ub}/V_{cb}|$ was expecting an upper limit below 0.21.

Remembering LEP

- First collision - Aug. 1989
- Last collision - Nov. 2000
- 175 pb^{-1} or 4.4M hadronic events/exp around 91GeV
- 725 pb^{-1} between 130 and 210 GeV
- 4 Detectors:

Parameter	ALEPH	DELPHI	L3	OPAL
Tracking	TPC	TPC	small drift ch.	Drift ch. (4 bar)
Calorimetry	lead/wire ch.	HPC	BGO	lead-glass
Particle ID	dE/dx	RICH	e/μ	dE/dx
Magnet	1.5 T	1.2 T	0.5 T	0.4 T
Vertexing	Si 89,91	Si 89,91,94	Si 93	Si 91 93

Improved Vertexing - The B Program Booster

With an average momentum of 25 GeV a B meson travels an average of 2.5 mm.

It was quickly realized that a precise vertex determination will dramatically improve the B program.

All 4 detectors armed themselves with SVDs.

Performance:

ALEPH - IP resolution of $25 \mu m$ in both $r - \phi$ and z .

DELPHI - IP resolution of $\sqrt{(69/p_t)^2 + 24^2}$ (9.5).

L3 - single track resolution of 7 and $14 \mu m$.

OPAL - IP resolution of 18-24 μm .

LEP B Physics - Results

• Lifetime.

1. B_d^0

B Lifetime
Working Group
CKM WKS February 2002

2. B_u^-

3. Direct measurements of the Ratio $\tau_{B_u^-} / \tau_{B_d^0}$

B Lifetime
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CKM WKS February 2002

4. B_s^0

B Lifetime
Working Group
July 2000

5. Λ_b

Avg b baryon meas.

Λ_b measurements

Average of above 10

1.208 ± 0.051 ps

Ξ l measurements

B Lifetime
Working Group
July 2000

τ (b-baryon) (ps)

6. Comparison with theory

7. Lifetime summary

- $\tau_{B_d^0} = 1.543 \pm 0.015 ps$
- $\tau_{B_u^-} = 1.658 \pm 0.014 ps$
- $\tau_{B_s^0} = 1.464 \pm 0.057 ps$
- $\tau_{\Lambda_b} = 1.208 \pm 0.051 ps$

- V_{ub}

1. Find $Br(b \rightarrow X_u l \nu)$

Example - DELPHI

- Hadronic mass of X_u is expected to be smaller than that of D.

- Lepton IP w.r.t the secondary vertex should be negative for $b \rightarrow c$.

2. Use the connection

$$|V_{ub}| =$$

$$0.00445 \left[\frac{BR(b \rightarrow X_u l \nu)}{0.002} \frac{1.55}{\tau_b} \right]^{1/2} [1 \pm 2\%_{pert} \pm 3.5\%_{m_b}]$$

3. Obtain:

$$|V_{ub}| = (4.09^{+0.59}_{-0.69}) \times 10^{-3}$$

- V_{cb}

Method 1 - using $B^0 \rightarrow D^{*+} l^- \nu$

Measure the decay rate as a function of ω

$$\omega = \frac{m_{D^*}^2 + m_B^2 - q^2}{2m_{D^*}m_B}$$

and use the connection:

$$\frac{d\Gamma(B^0 \rightarrow D^{*+} l^- \nu)}{d\omega} = \mathcal{K}(\omega) \mathcal{F}^2(\omega) |V_{cb}|^2$$

Example - OPAL

Using $D^0 \rightarrow K^- \pi^+$, $D^0 \rightarrow K^- \pi^+ \pi^0$ and an inclusive search for $l\pi^+$

Extracting ω distribution:

and finally:

$$|V_{cb}| = (40.7 \pm 1.1 \pm 2.2 \pm 1.6) \times 10^{-3}$$

All exclusive results:

Method 2 - using inclusive $b \rightarrow cl\nu$

- LEP measured $Br(b \rightarrow Xl\nu) = 10.654 \pm 0.23\%$
- Subtract $Br(b \rightarrow ul\nu)$
- Obtain $Br(b \rightarrow cl\nu)$
- $|V_{cb}| = 0.0411 \sqrt{\frac{1.55}{0.105} \Gamma(b \rightarrow cl\nu) (1 - 0.024(\frac{\mu_\pi^2 - 0.5}{0.2}))}$

CKM summary

- $|V_{ub}| = 4.09^{+0.59}_{-0.69} \times 10^{-3}$
- $|V_{cb}| = 41.8 \pm 1.0 \times 10^{-3}$
- $\frac{|V_{ub}|}{|V_{cb}|} = 0.103 \pm 0.022$

B Oscillation

How to Measure B Oscillation

- Find a B^0 (background)
- Measure the decay time (resolution)
- Find decay flavor (B^0 or $\bar{B}^0$)
- Find production flavor (mistag)

- Fit

$$R(t) = \frac{N_{\pm\pm}}{N_{\pm\pm} + N_{+-}} = f + (1 - 2f) \cdot \sin^2 \left(\frac{\Delta m \cdot t}{2} \right)$$

B_d^0 mixing

Amplitude method

- Substitute in likelihood function:

$$1 \pm \cos \Delta m_s t \rightarrow 1 \pm A \cos \Delta m_s t$$

- Fit **amplitude** A for **fixed** Δm_s .
- Expect $A = 1$ for true value of Δm_s and $A = 0$
(far) below true Δm_s .

- Values of Δm_s excluded (95% C.L.) if

$$A + 1.645\sigma_A < 1.$$

- Sensitivity is defined for $A + 1.645\sigma_A = 1$.

Search Methods for B oscillation

- Inclusive.
- Semi-Inclusive:
 - Single Lepton.
 - Dileptons.
- Semi-exclusive:
 - Lepton-kaon.
 - ϕ lepton.
 - Lepton+"D".
- Exclusive:
 - D_s -hadron.
 - D_s -lepton.

Eff. *Purity* *Resolution*

Fully inclusive search - DELPHI

- **Event selection:** soft leptons and inclusively reconstructed vertices (120K/500K)
 - **Decay time reconstruction:**
 1. E/p constraint to rescale B momentum and estimate ν momentum - global fit using direction and mass constraint
 2. Inclusive B reconstruction based on B track probability (NN)
 - **Decay flavor:**
 1. Lepton charge (special care for b/c origin due to softness)
 2. For inc. vtx. use the dipole charge of charm/bottom tracks in the B rest-frame.
 - **Production flavor:** Jet-charge, leptons, kaon and protons.
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- **Result:** $\Delta m_s > 1.1 \text{ ps}^{-1}$
(sensitivity 6.1 ps^{-1})

Inclusive lepton analysis - ALEPH

- Event selection: High p , p_T leptons.
- Decay time reconstruction:

charm vtx combined with the lepton for decay length and momentum is estimated with the addition of the hemisphere missing energy (ν)

Decay time resolution $\approx 1/4 - 1/3 \text{ ps}$

- Decay flavor: Directly from the lepton charge.
- Decay flavor: Opp. hem. lepton, frag. kaon, jet-charge.

• Result: $\Delta m_s > 11.1 \text{ ps}^{-1}$

(sensitivity 11.9 ps^{-1})

SLD analyses

- Much smaller Z sample (400K).
- Much better vtxing. $\rightarrow$ at best $\sigma_t = 0.05ps$
- Polarized electrons.
- Three final states: lepton + “D”, D_s + tracks, **dipole analysis.**

- Unique tag from FB asymmetry - 100% efficient, 72% correct tag.

- Result: $\Delta m_s > 7.6 \text{ ps}^{-1}$
(sensitivity 13.0 ps^{-1})

Exclusive analysis from OPAL

- Four decay channels of the D_s :

$$B_s \rightarrow D_s l^+ \nu$$

$$\begin{array}{ll} \hookrightarrow K^{*0} K^-, & K^{*0} \rightarrow K^+ \pi^- \\ \hookrightarrow \phi \pi^-, & \phi \rightarrow K^+ K^- \\ \hookrightarrow K^0 K^-, & K^0 \rightarrow \pi^+ \pi^- \\ \hookrightarrow \phi l^- \bar{\nu} X, & \phi \rightarrow K^+ K^- \end{array}$$

OPAL

- Total of 116 $B_s \rightarrow D_s l$ events.

- Result: $\Delta m_s > 1 \text{ ps}^{-1}$
(sensitivity 4.1 ps^{-1})

B_s Oscillation Summary

● World Combined Result

Limit at 14.6 ps^{-1} Sensitivity at 18.3 ps^{-1}

● Is there a hint at 17 ps^{-1} ?

- 2.6σ effect.
- No (real) improvement is expected before the onset of LHC
- ATLAS/CMS sensitivity $\approx 38 \text{ ps}^{-1}$

Summary and Outlook

- The LEP B program exceeded all expectations.
- $\sigma_{\tau_{B_u, B_d}} \approx 1\%$, $\sigma_{\tau_{B_s, \Lambda_b}} \approx 4\%$
- $\sigma_{V_{ub}} = 16\%$
- $\sigma_{V_{cb}} = 2.4\%$
- $\Delta m_d = 0.484 \pm 0.016 \text{ ps}^{-1}$ (3.3%)
- $\Delta m_s > 14.6 \text{ ps}^{-1}$
- Comparing results from LEP and SLD, statistics .vs. resolution, SLD performs as well as the “big guys”.
Concluding that the key for measuring Δm_s is in the resolution...