Measurement of Heavy Quark Forward-Backward Asymmetries Using a Lepton Tag in Hadronic Z Decays in Multihadronic Z Events

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Representing the 4 LEP collaborations

ALEPH, **DELPHI**, **L3**, and **OPAL**

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Tests of the Standard Model

Outline

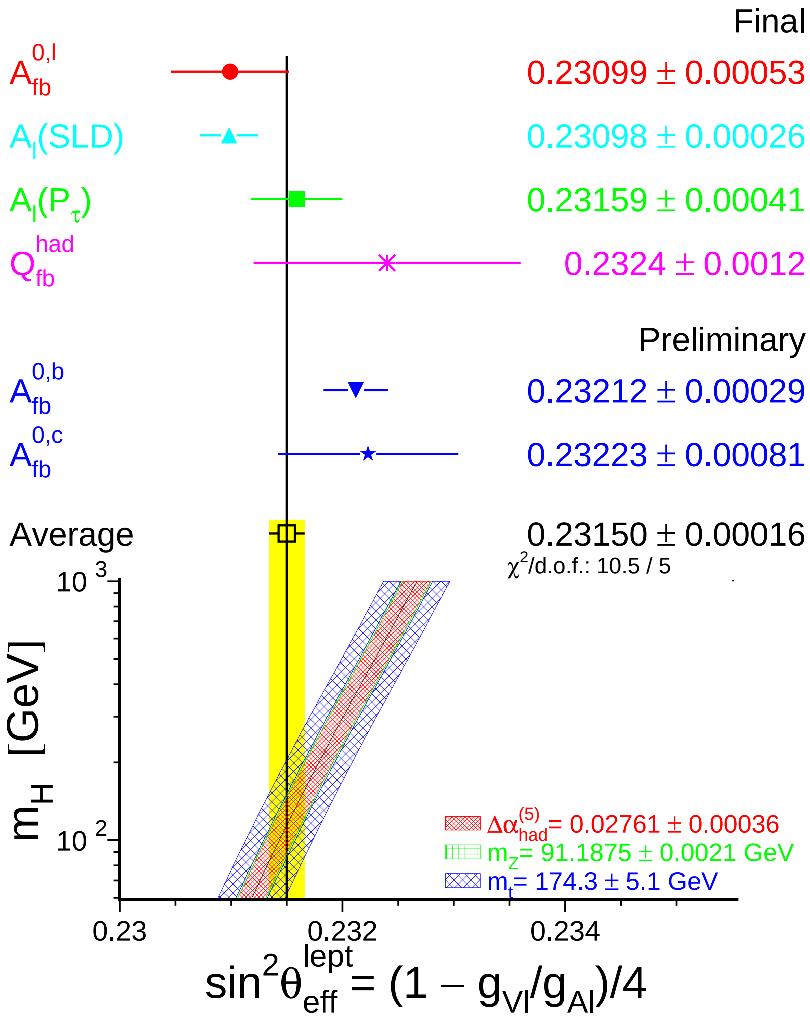
- Introduction
- Asymmetry measurement
- Quark flavour separation
- LEP results and conclusion

Latest LEP Results

DELPHI:	July 2003
OPAL:	July 2003
ALEPH:	December 2001
L3:	October 1999

Introduction

Measurements of $\sin^2\theta_{\rm eff}$



- $\sin^2\theta_{\rm eff}$ from lepton measurements smaller than from $A_{\rm FB}^{\rm b}$
- About 3.0σ discrepancy between $\sin^2\theta_{\rm eff}^{A_{\rm L}}$ (SLD) and $\sin^2\theta_{\rm eff}^{A_{\rm FB}^{0,b}}$ (LEP)

$$\sigma_{\rm SLD}\left(\sin^2\theta_{\rm eff}^{A_{\rm L}}\right) \approx \sigma_{\rm LEP}\left(\sin^2\theta_{\rm eff}^{A_{\rm FB}^{0,b}}\right)$$

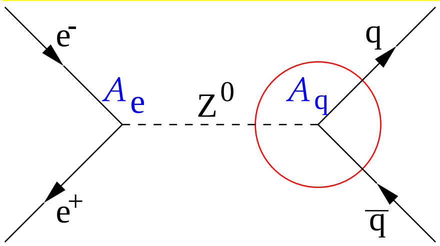
- New $A_{\rm FB}^{\rm b}$ and $A_{\rm FB}^{\rm c}$ measurements:
  DELPHI and **OPAL** (July 2003)
  - Z^0 data sample:
    DELPHI 1991-1995, **OPAL** 1990–2000
  - Reprocessing of data set (final tracking algorithms and detector calibrations)
  - Improved lepton ID
  - Improved quark flavour separation
  - Fit method improved
  - Better knowledge of the properties of heavy flavour production and decay
  - Smaller errors of external measurements

$\Rightarrow$ Reduction of systematic uncertainties

The Asymmetry

- Primary processes:

$$\begin{array}{ccccc} e^+e^- & \rightarrow & Z^0 & \rightarrow & b\,\bar{b} \\ e^+e^- & \rightarrow & Z^0 & \rightarrow & c\,\bar{c} \end{array}$$



- Definition: Only valid for 4π acceptance

$$A_{FB}^{q} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

- Efficiency not constant over $|\cos\theta|$
  $\Rightarrow$ Use differential cross-section:

$$\frac{d\sigma}{d\cos\theta} \propto 1 + \cos^2\theta + \frac{8}{3} A_{FB}^{q} \cos\theta \quad \longrightarrow$$

$\Rightarrow$ Or use bins, i of $\cos\theta$

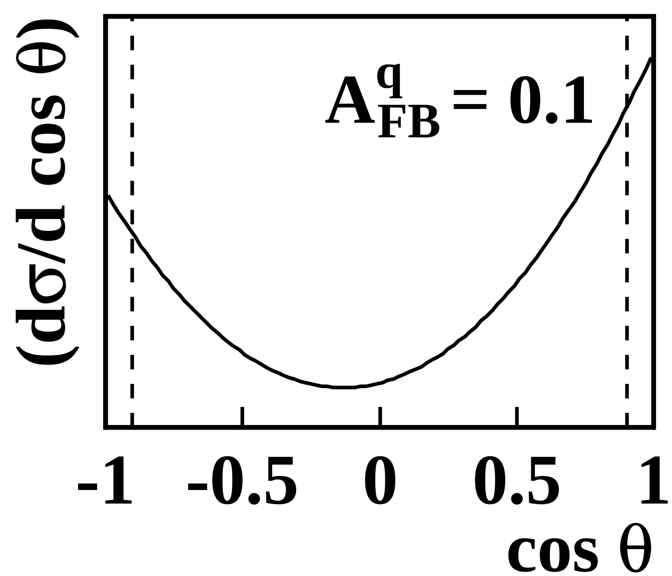
$$\frac{\sigma_{F_i} - \sigma_{B_i}}{\sigma_{F_i} + \sigma_{B_i}} = A_{FB}^{q} \cdot \frac{8}{3} \frac{|\cos\theta_i|}{1+\cos^2\theta_i}$$

- Relation of A_{FB}^{q} to Z^0 to fermion couplings:

$$A_{FB}^{q} = \frac{3}{4}\mathcal{A}_e\mathcal{A}_q = \frac{3}{4}\frac{c_{Le}^2 - c_{Re}^2}{c_{Le}^2 + c_{Re}^2}\frac{c_{Lq}^2 - c_{Rq}^2}{c_{Lq}^2 + c_{Rq}^2}$$

$$c_{Lf} = g_{Vf} + g_{Af} \quad \text{left handed coupling}$$
$$c_{Rf} = g_{Vf} - g_{Af} \quad \text{right handed coupling}$$

- Weak interaction $\Rightarrow c_L \neq c_R$
- Measured asymmetry $\longrightarrow$ pole asymmetry
  (Z^0/γ interference, pure γ exchange)



Measurement

- Z^0 data at three $\sqrt{s}$ values
- $Z^0 \longrightarrow$ hadron event selection
- Reconstruct event thrust axis

  $\Rightarrow$ Direction of $q\bar{q}$, can't yet distinguish q or $\bar{q}$
- Tag heavy flavours from b, c hadron semileptonic decays, *i.e.* identify leptons

  $\Rightarrow$ Heavy flavour enriched sample
- Reconstruct properties for quark flavour separation (find jets, reconstruct secondary vertices ...)
- Do quark flavour separation to find

  $b \longrightarrow \ell^-$ and $c \longrightarrow \ell^+$
- Lepton charge $\Rightarrow$ q or $\bar{q}$
- A_{FB}^{b} measurement

  diluted by cascade decays $b \longrightarrow c \longrightarrow \ell^+$
- B mixing $\Rightarrow$ $A_{FB}^{b,obs} = (1 - 2\bar{\chi}) A_{FB}^{b}$
- Apply a fit to 2 event classes
  - 1 lepton events

    (at least 1 identified lepton)

    $\Rightarrow$ A_{FB}^{b} and A_{FB}^{c} measurement
  - 2 lepton events

    (2 leptons, both with high b probab.)

    $\Rightarrow$ mixing parameter $\bar{\chi}$

Lepton Identification

- Electron candidates: $p > 2$ GeV
  - Neural Network:
  - Shower shape (ECAL) $\frac{E}{p}$ (ECAL/tracking), $\frac{\mathrm{d}E}{\mathrm{d}x}$ (Tracking system)
  - Veto to γ-conversions
- Muon candidates: $p > 2$ GeV (O), $p > 2.5$ GeV (D)
  - Spatial match: track in tracking detectors $+$ track segment found in μ chambers
  - Soft $\frac{\mathrm{d}E}{\mathrm{d}x}$-cut $\Rightarrow$ Kaon reduction

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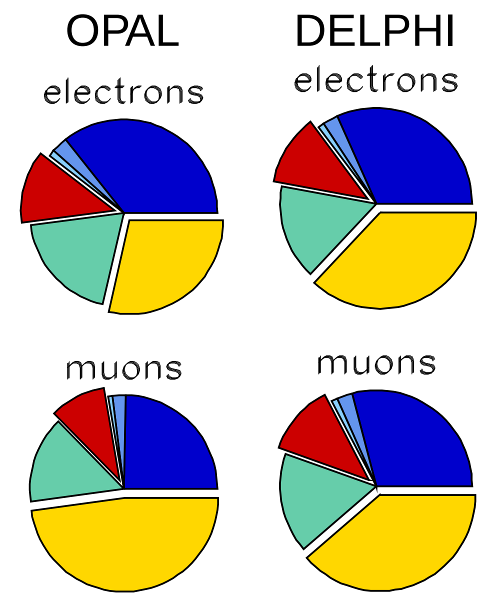
- The background is predominantly at low p, p_T
- Divide lepton candidates in 4 groups:

(1) $\mathrm{b} \to \ell^-$
$\mathrm{b} \to \overline{\mathrm{c}} \to \ell^-$
$\mathrm{b} \to \tau^- \to \ell^-$
(2) $\mathrm{b} \to \mathrm{c} \to \ell^+$
(3) $\mathrm{c} \to \ell^+$
(4) background



- Observed asymmetry:

$$A_{\mathrm{FB}}^{\mathrm{obs}} = f_1(1-2\bar{\chi})A_{\mathrm{FB}}^{\mathrm{b}} - f_2(1-2\bar{\eta}\bar{\chi})A_{\mathrm{FB}}^{\mathrm{b}} - f_3 A_{\mathrm{FB}}^{\mathrm{c}} + f_4 A_{\mathrm{FB}}^{\mathrm{back}}$$

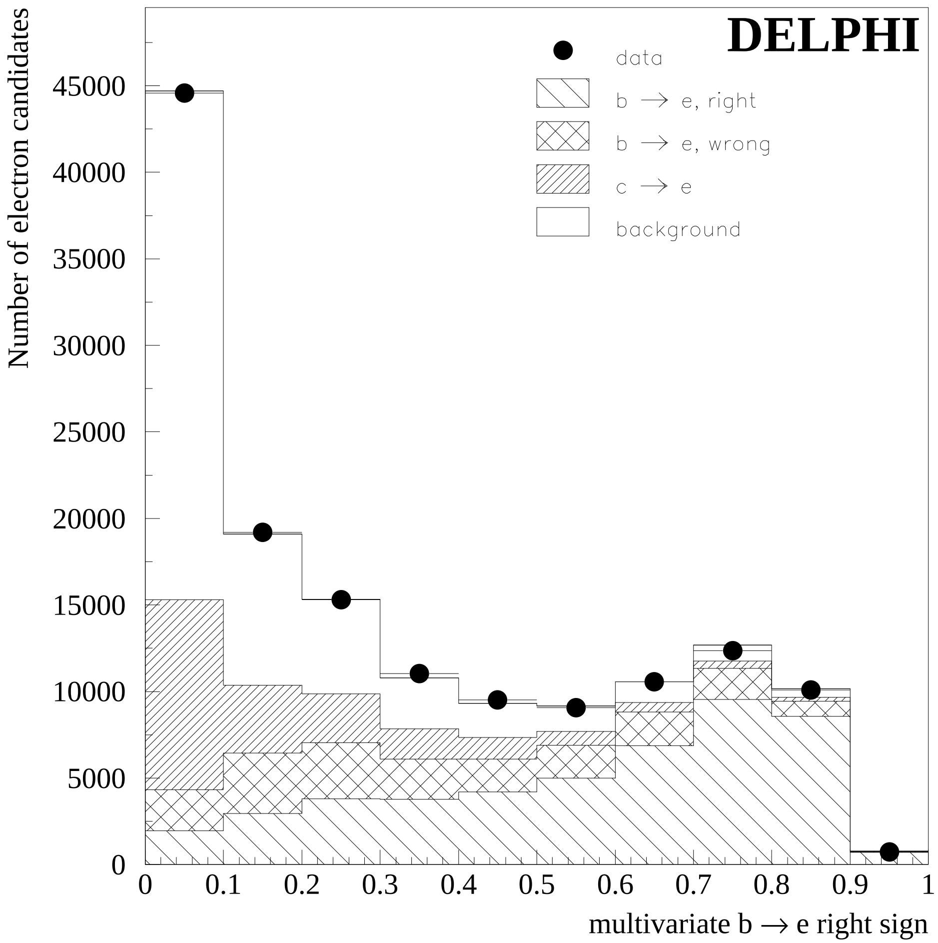
- Measurement of $A_{\mathrm{FB}}^{\mathrm{b}}$ and $A_{\mathrm{FB}}^{\mathrm{c}}$ $\Rightarrow$ flavour separation

Quark Flavour Separation (DELPHI)

DELPHI: Likelihood Selection

- Construct likelihood ratios $\mathcal{P}_k$ separately for the 4 groups
- Information used:
  - Lepton p and p_{T}
  - Jet charge
  - b-tagging variable
    - ∗ Jet lifetime probability
    - ∗ Effective mass assigned to secondary vertex
    - ∗ Rapidity of tracks associated to secondary vertex
    - ∗ Jet energy fraction carried by charged particles from secondary vertex
- Fit uses 2 dim. distribution:

$(\mathcal{P}_{\mathrm{b}\,\rightarrow\,\ell^-} - \mathcal{P}_{\mathrm{b}\,\rightarrow\,\mathrm{c}\,\rightarrow\,\ell^+})$ vs. $\mathcal{P}_{\mathrm{c}\,\rightarrow\,\ell^+}$

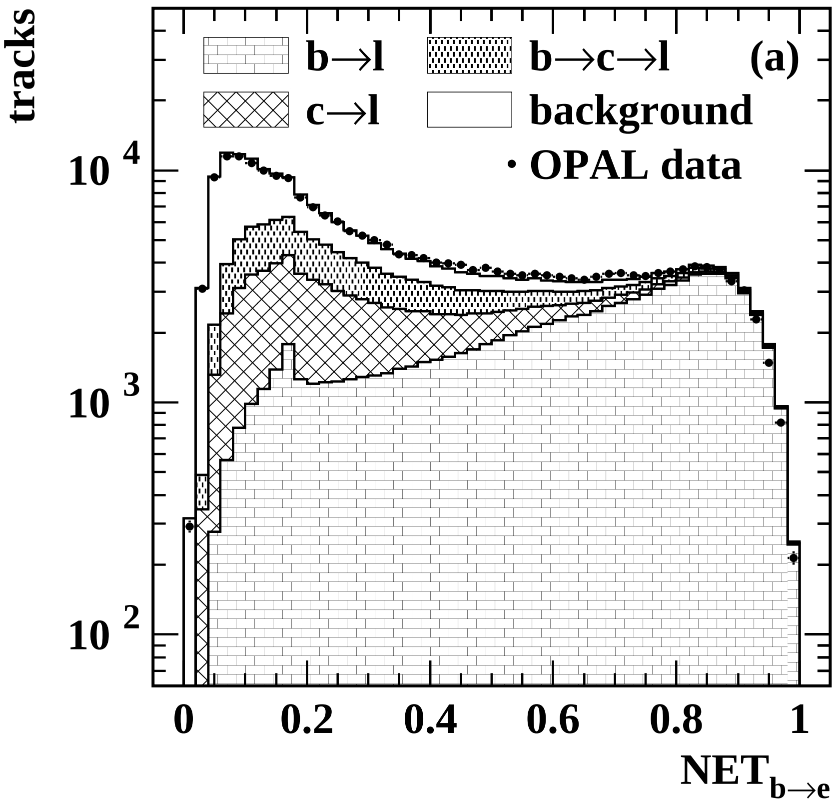


Quark Flavour Separation (OPAL)

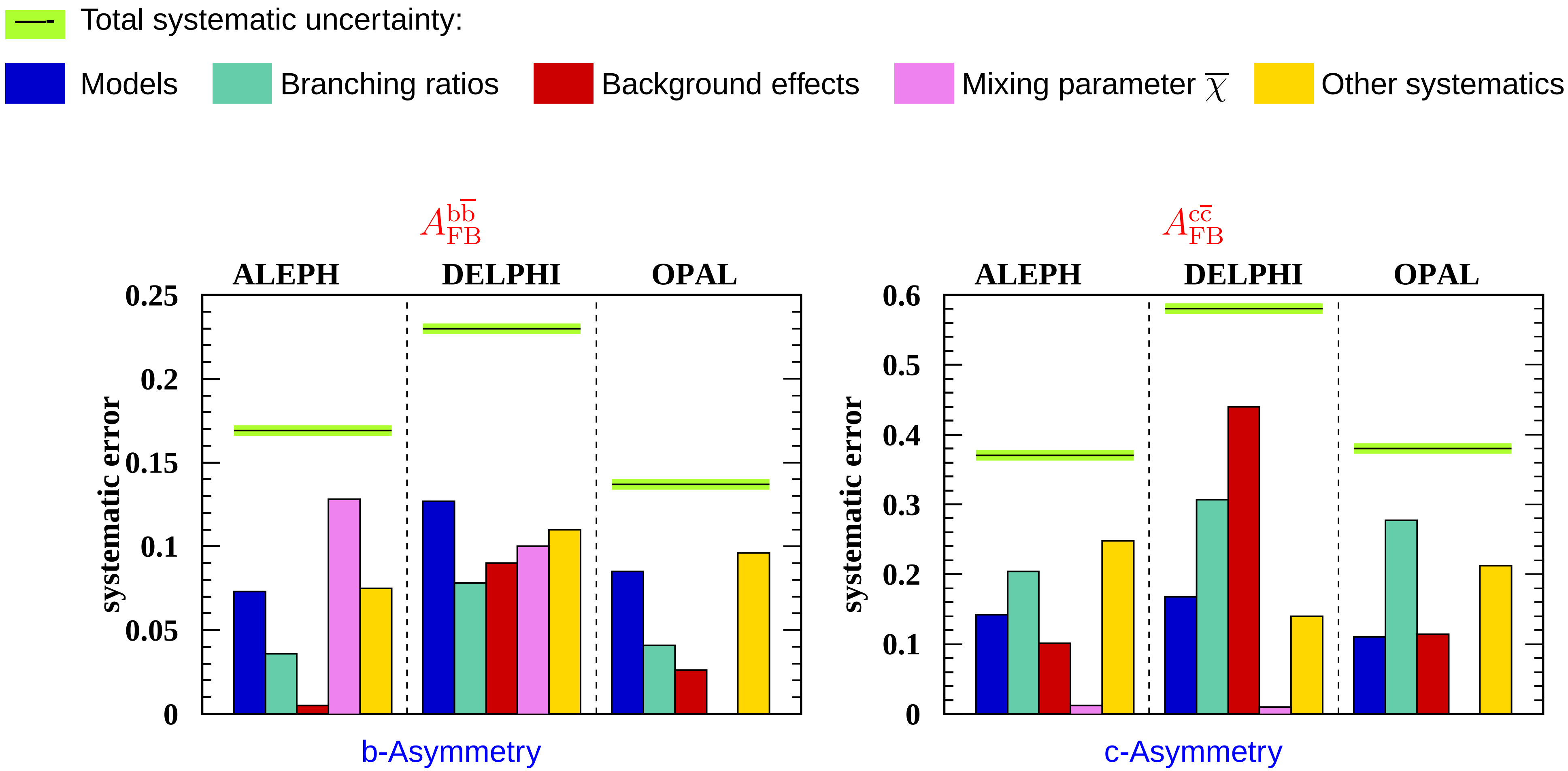
OPAL: 2 Neural Networks

1. $\mathrm{b} \longrightarrow \ell^-$ identification with $\mathrm{NET_b}$
2. $\mathrm{c} \longrightarrow \ell^+$ identification with $\mathrm{NET_c}$

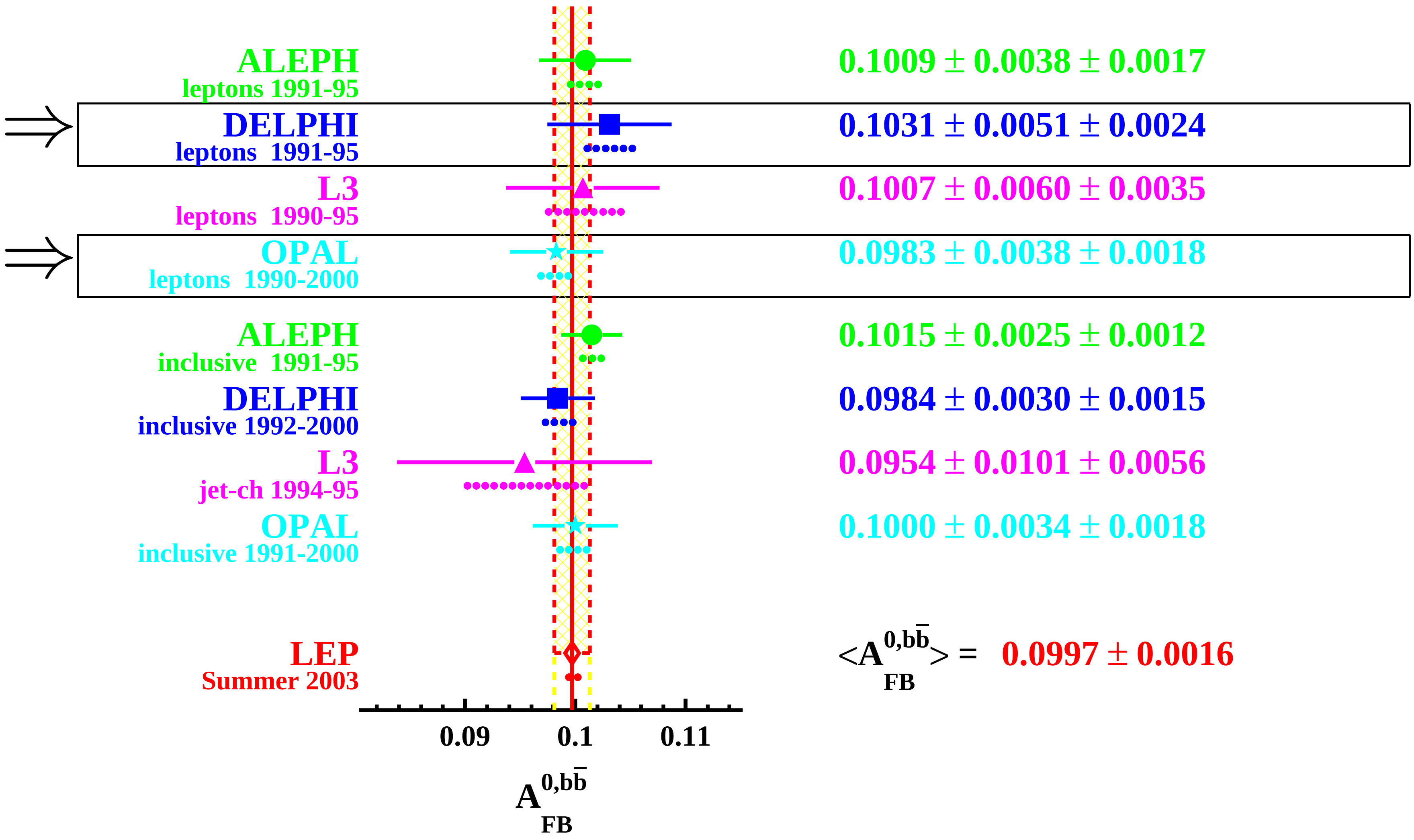
- Variables common to $\mathrm{NET_b}$ and $\mathrm{NET_c}$
  - Lepton p and p_T
  - Lepton jet energy
  - Scalar sum of p_T
- Additional variables for $\mathrm{NET_c}$
  - Vertex decay length significance for lepton jet and jet without lepton
  - Impact parameter sig.
- Fit uses 2 dim. distributions of $\mathrm{NET_b}$ vs. $\mathrm{NET_b}$



Systematics Overview



LEP Results for $A_{FB}^{0,b}$



LEP Results for $A_{FB}^{0,c}$