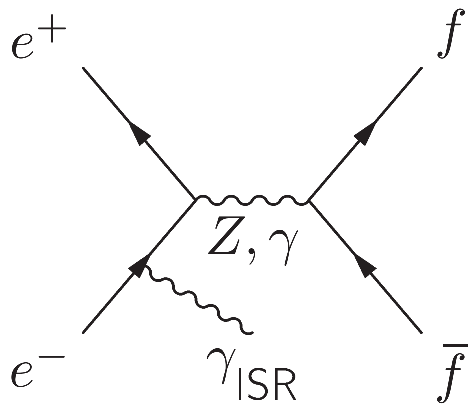
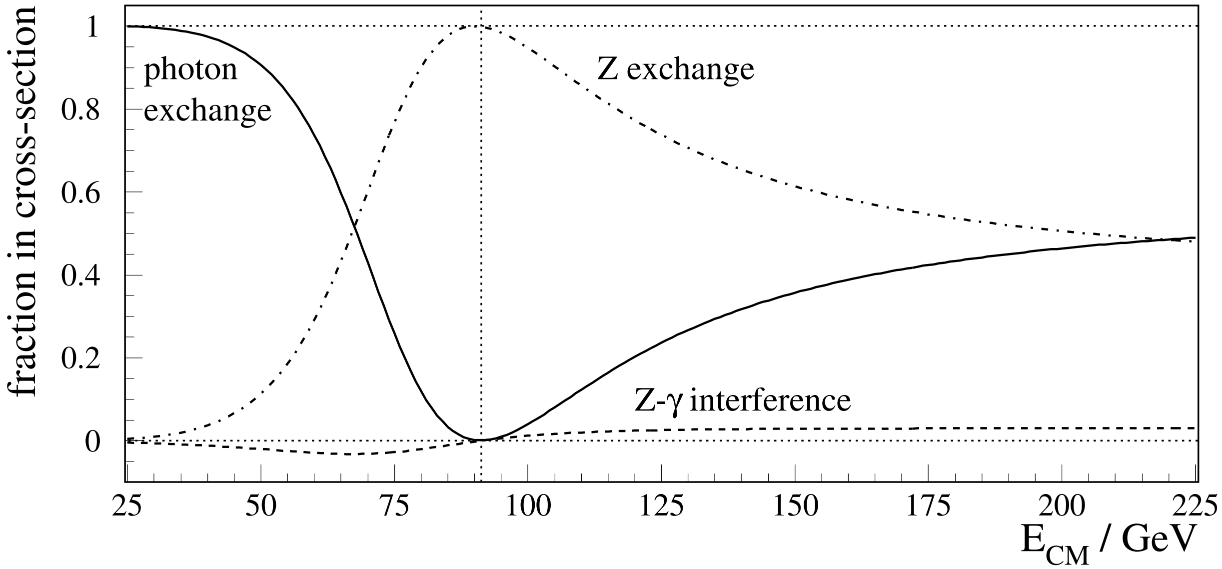
Heavy Flavours Forward-Backward Asymmetries at LEP

W. Liebig

Topical Seminar on the Legacy of LEP and SLC, Oct 8th-11th 2001

Forward-Backward Asymmetries in $e^+e^- \to f\bar{f}$





$$\left(\frac{d\sigma}{d\cos\theta}\right)_f \sim$$

$$(1+\cos^2\theta)\cdot\left[Q_f^2 - 2v_e v_f Q_f \mathrm{Re}\chi_0(s) + (v_e^2+a_e^2)(v_f^2+a_f^2)\left|\chi_0(s)\right|^2\right]$$

$$+\,2\cos\theta\cdot\left[\quad - 2a_e a_f Q_f \mathrm{Re}\chi_0(s) + \qquad 4v_e a_e v_f a_f\left|\chi_0(s)\right|^2\right]$$

Forward-Backward Asymmetry $A_{\mathrm{FB}} = \frac{\sigma_{\mathrm{F}}-\sigma_{\mathrm{B}}}{\sigma_{\mathrm{tot}}}$

What Is So Interesting About $A_{\mathrm{FB}}^{b\bar{b}}$ and $A_{\mathrm{FB}}^{c\bar{c}}$ Measurements?

A_{FB} at LEP 1

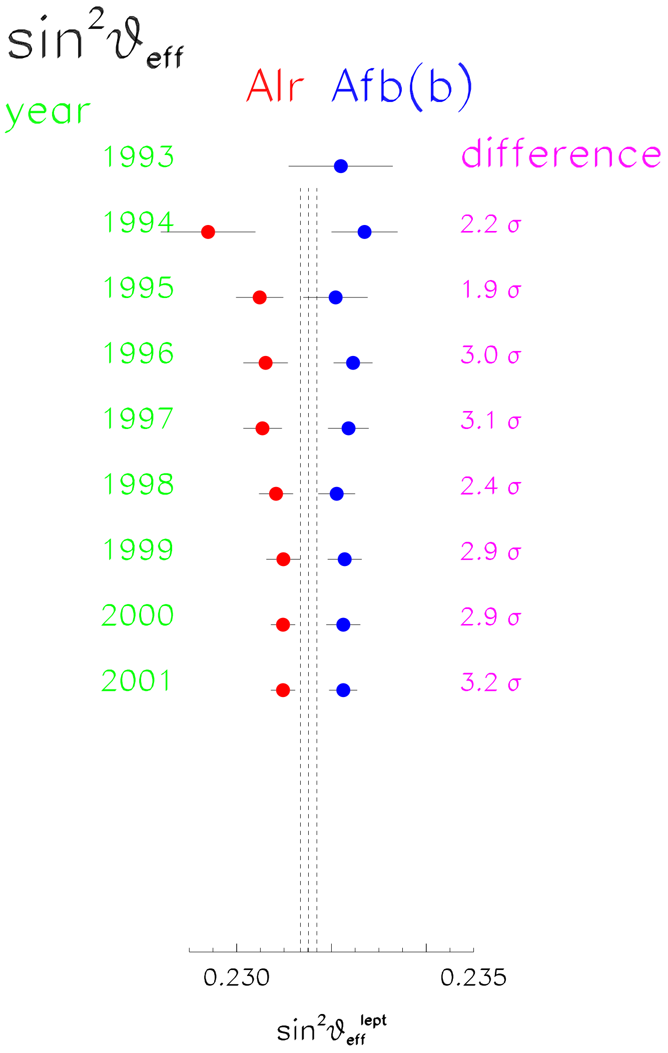
- Z exchange absolutely dominant
- P-violating $V-A$ structure gives rise to F-B asymmetry

$$A_{\mathrm{FB}}^{f,0} = \frac{3}{4}\mathcal{A}_e\mathcal{A}_f$$

- $\mathcal{A}_b \lesssim 1$, thus $\mathcal{A}_e$ determines product. $\mathcal{A}_e$ has good sensitivity to $\sin^2\theta_{eff}^{lept}$

$\Longrightarrow$ just as A_{LR}, $A_{\mathrm{FB}}^{q,0}$ measures $\sin^2\theta_{eff}^{lept}$

- A 3.26 σ discrepancy with SLD remains!
- $\sin^2\theta_{eff}^{lept}$ is the most sensitive quantity to m_h



Introduction

Outline of this talk

(1) Introduction

(2) Analysis Techniques and Challenges (LEP 1)

(3) Discussion

(4) LEP 2 Results

Ingredients to an A_{FB} measurement

- the quark polar angle — e.g. thrust axis
- a flavour tag — b-tag, also c-tag
- a quark charge reconstruction — notably:

$\longrightarrow$ exclusive D decays
$\longrightarrow$ prompt leptons
$\longrightarrow$ jet + vertex charge NNs

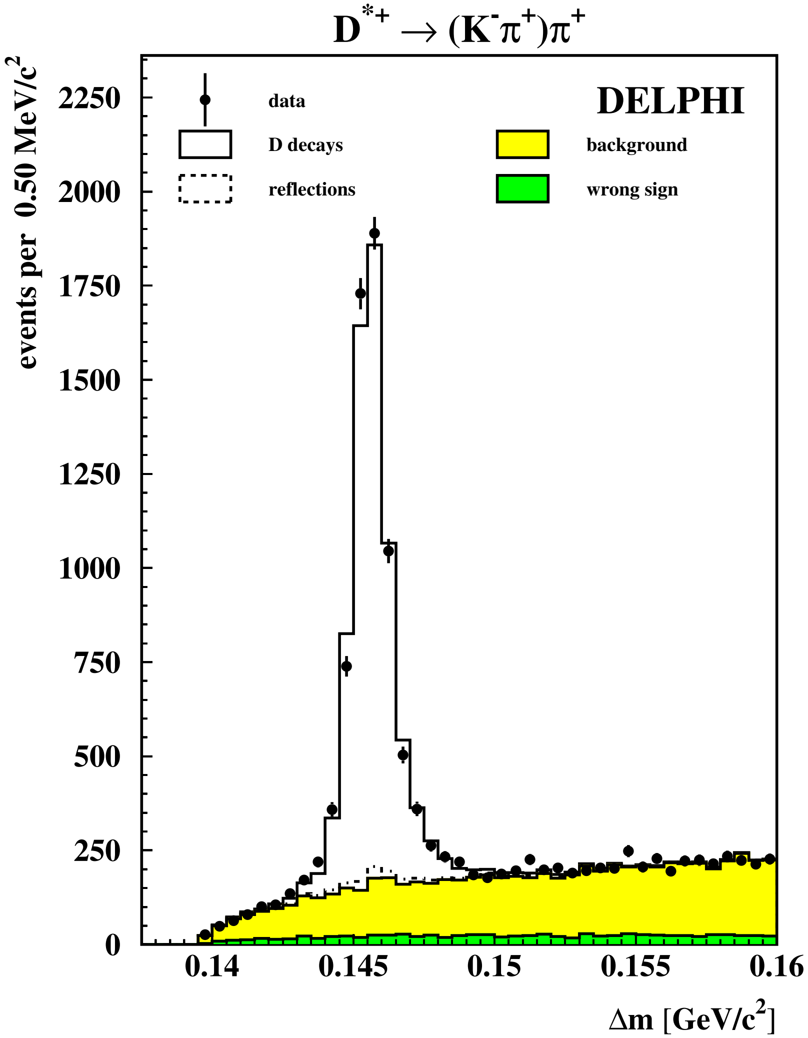
$A_{\text{FB}}^{c\bar{c}}$ with Exclusively Reconstructed D^*

- 6..9 different D decay channels reconstructed

- quark charge obtained from D reconstruction

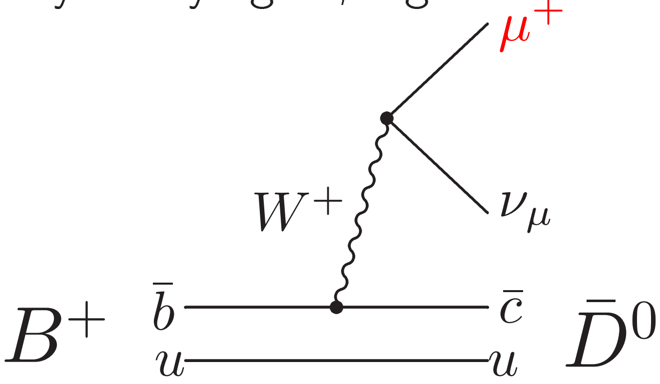
- fit to observed A_{FB} taking into account combinatorial background
  DELPHI: fit in bins of $b-c$ separation variables b-tag, x_E.

- DELPHI, OPAL: simultaneous fit to $A_{\text{FB}}^{b\bar{b}}$ and $A_{\text{FB}}^{c\bar{c}}$ with correlations of -0.22 ... -0.28

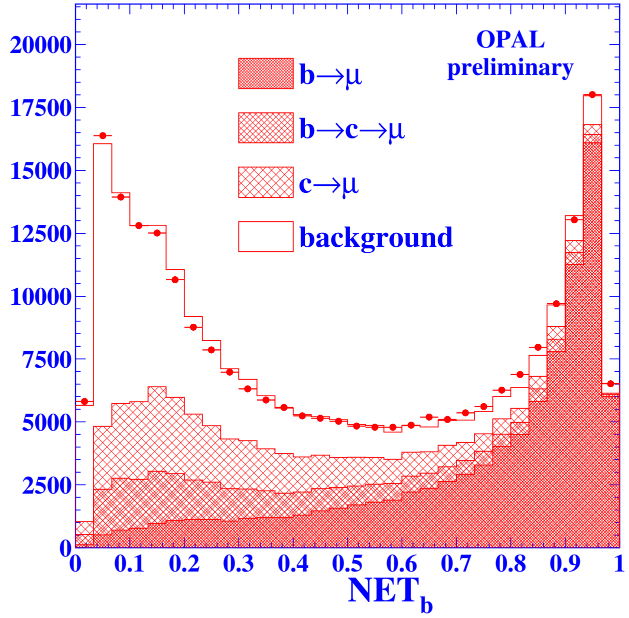


$A_{\text{FB}}^{b\bar{b}}$, $A_{\text{FB}}^{c\bar{c}}$ with Leptons

- weakly decaying B, e.g.



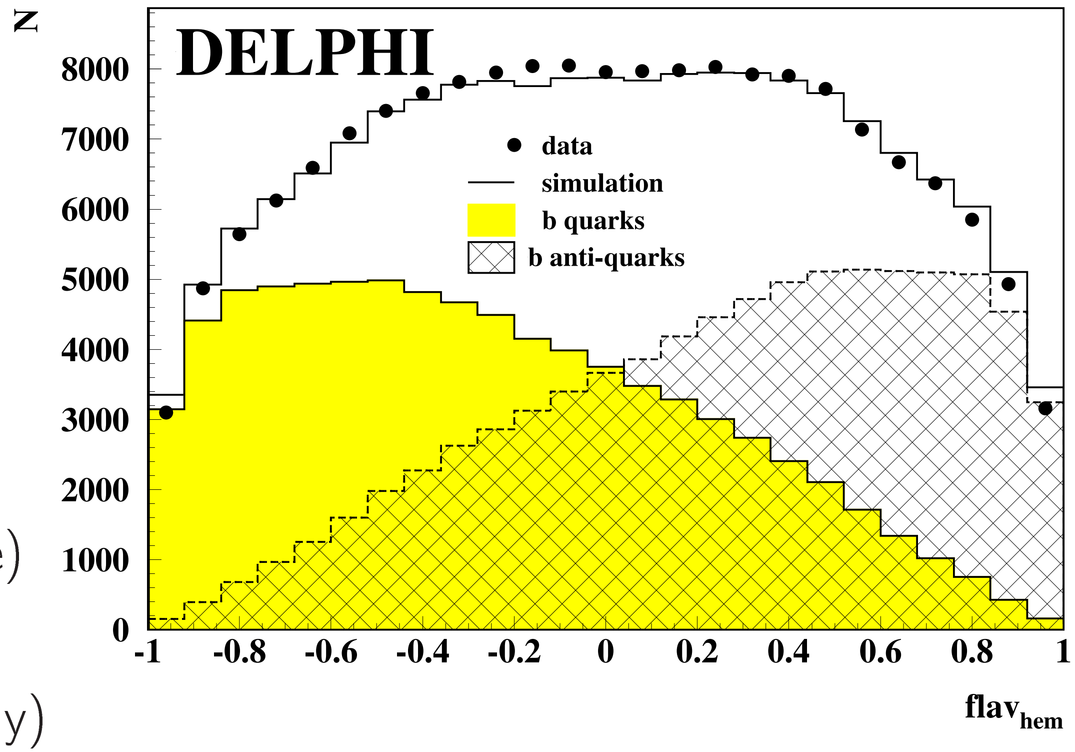
- high p, p_T lepton ID
- separate $b \to l$, $c \to l$, $b \to c \to l$, BG:
  - using just (p^l, p_T^l) (L3)
  - NNs (Likelihood ratios) combining flavour tag inputs and lepton p, p_T.
- fit to $A_{\text{FB}}^{b\bar{b}}$ and $A_{\text{FB}}^{c\bar{c}}$ in $\cos\theta_i$ and 2..3 b/c identifier („multivariate analyses")



- mixing + $b \to c \to l$: wrong-sign decays !
- tools optimised to reduce modelling dependence (p_T^l spectra, wrong-sign).
- e.g. reduce fraction of w.-sign decays: DELPHI: $Q_{\text{lept.}} \times Q_{\text{jet}}^{\text{opp}}$, ALEPH: $\text{NN}_{b \to c \to l}$

New Tools for Charge Tagging

- Neural Nets reconstruct the quark charge in each hemisphere
- combine all available info:
  - ▶ jet charge at various weighting powers κ
  - ▶ secondary vertex charge
  - ▶ B_x charge tags ($\rightarrow$ PV charge)
  - ▶ identified particles (p,K,π)
  - ▶ NO leptons (in DELPHI indirectly)
- quality information (SV fit, E_B, ...) also included



$\Longrightarrow$ charge tagging performance improved in both analyses by $\approx 10\,\%$.

(with respect to pure jet-charge)

New Inclusive Jet Charge + NN Analyses

ALEPH analysis

- jet charge method:

$$\langle Q_{\mathsf{F}} - Q_{\mathsf{B}} \rangle = \sum_f \mathcal{P}_f(\theta)\delta_f(\theta)A^f_{\mathsf{FB}}(\theta)$$

- very inclusive hemisphere tags to build $Q_{\mathsf{F}} - Q_{\mathsf{B}}$.
- working at $\sim 88\,\%$ b-purity $\mathcal{P}_b$
  extract flavour eff. via double tag
- calibrate δ_f by measuring

$$\bar{\delta}^2 = \sigma^2(Q_{\mathsf{FB}}) - \sigma^2(Q_{\mathsf{tot}}) \approx \sum_f \mathcal{P}_f \delta_f^2$$

DELPHI analysis

- counting method

$$\frac{N_{\mathsf{F}} - N_{\mathsf{B}}}{N_{\mathsf{F}} + N_{\mathsf{B}}} = \sum_f (2w_f - 1)\mathcal{P}_f A^f_{\mathsf{FB}}(\theta)$$

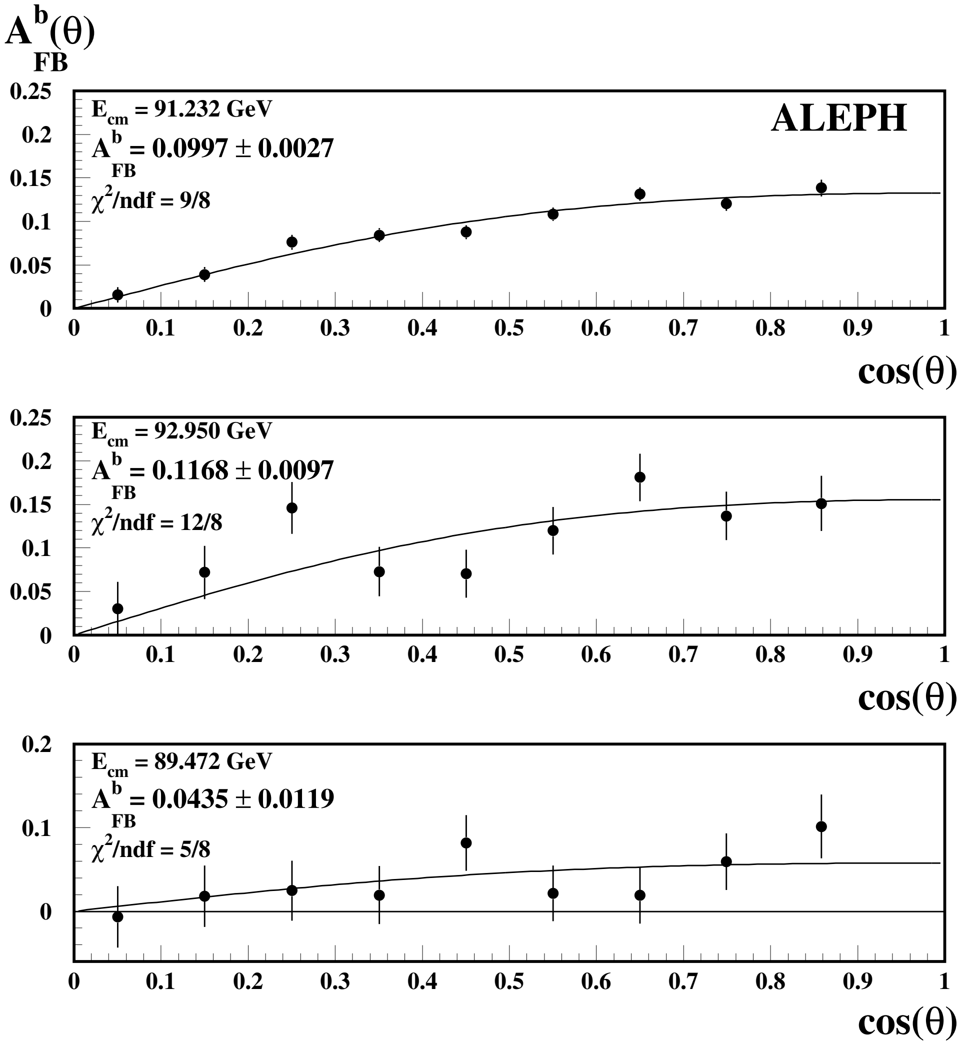
- cut-based selection of hemispheres
- working at $\sim 96\,\%$ b-purity $\mathcal{P}_b$
  extract b-eff. from data
- calibrate w_b from like-sign and unlike-sign events:

$$\begin{aligned} N^{\text{unlike}} &\approx w_b^2 + (1 - w_b)^2 \\ N^{\text{like}} &\approx 2 \cdot w_b \cdot (1 - w_b) \end{aligned}$$

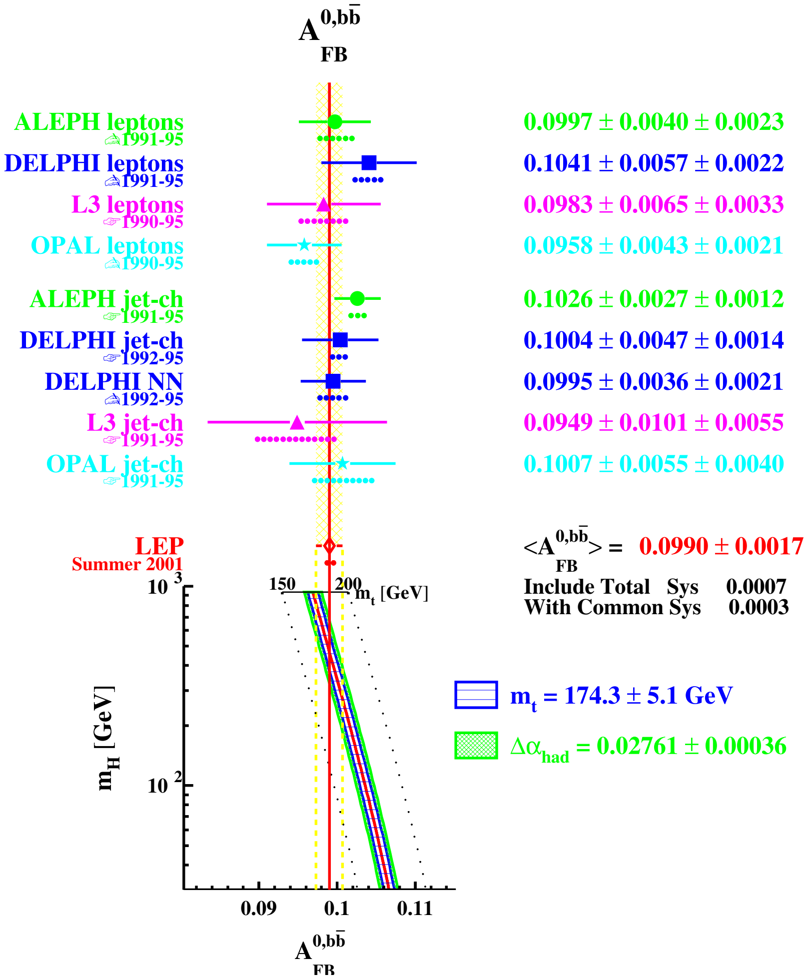
Charge NN Analyses: Corrections, Checks and Results

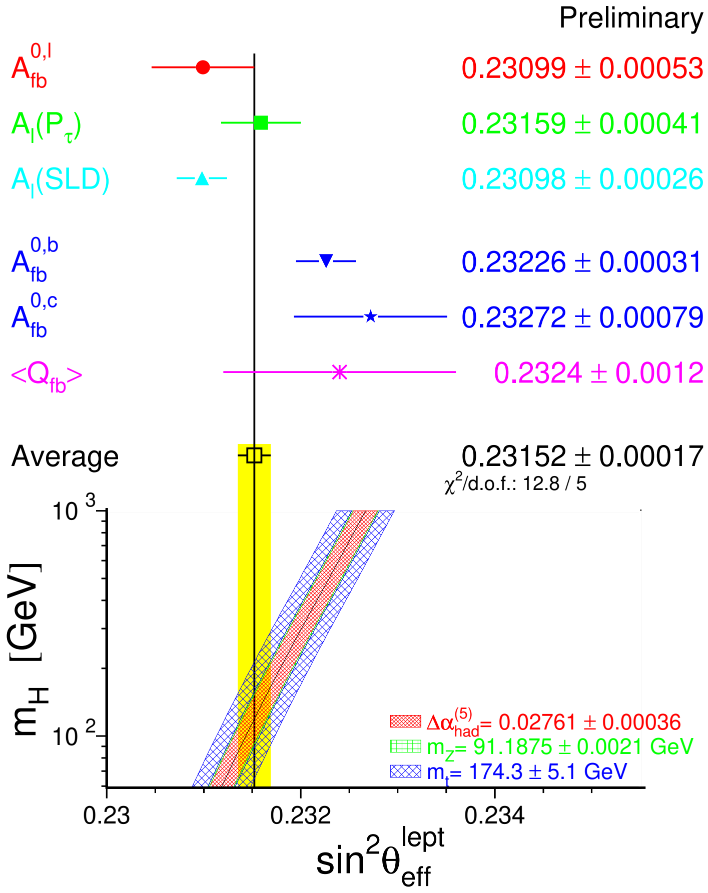
- QCD corrections $3\% \times 0.20$
- hemisphere correlations arise mainly from charge conservation
- they have to be taken from MC ! $[w_b,\ \delta_f] \cdot (1 + k_f)$, with $k_f \sim 10\,\%$.
- ALEPH checks: vary $\mathcal{P}_b$, reproduce δ_b by means of high-p_T leptons.
- DELPHI checks: vary $\mathcal{P}_b$, measure $\mathcal{P}_c$ in double tag fits, estimate w_c with opp. hemisphere D^*
- fit results, e.g. ALEPH $\longrightarrow$

$$A^f_{\mathrm{FB}}(\theta) = \frac{8}{3} \frac{\cos\theta}{(1+\cos^2\theta)}$$



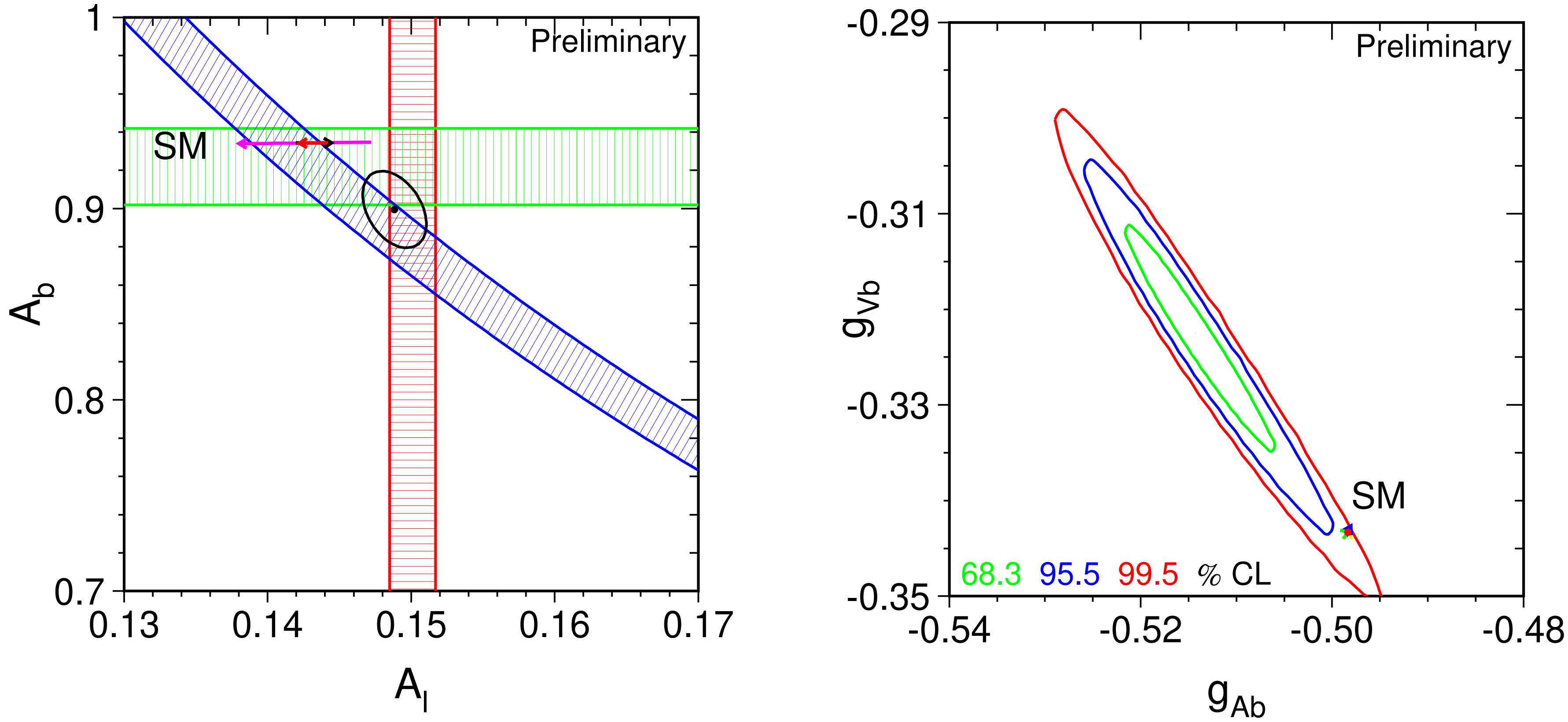
LEP 1 Combined $A_{\mathrm{FB}}^{b\bar{b}}$ Results





- measurements are consistent !
- $A_{\mathrm{FB}}^{b\bar{b}}$ prefers high Higgs mass !

LEP 1 $A_{FB}^{b\bar{b}}$ Results and the Standard Model



A_{LR} & lepton A_{FB} • pol. $A_{FB}^{b\bar{b}}$ • LEP $A_{FB}^{b\bar{b}}$

Are the $A_{\rm FB}^{b\bar{b}}$ results reliable?

6 years after LEP 1, many analyses preliminary or just published – why?

- final detector calibrations available
- powerful tools developed lately, with feedback from analyses
- careful work on model independence and self-calibration
- room for improvement in sight

LEP's $A_{\rm FB}^{f,0}$ will outlast next decade(s) !

- Combined b pole asymmetry is statistics dominated, small correlated error:

stat. error $\Delta A_{\rm FB}^{b,0}$	0.00156
uncorr. syst.	0.00061
corr. syst.	0.00039
total syst.	0.00071

- corr. syst. error arises from mainly QCD correction and light quark fragmentation.

$\Longrightarrow$ no large changes in results expected.

LEP and SLD results inconsistent ?

$$\mathcal{A}_b(\text{LEP only}) = 0.891 \pm 0.022$$
$$\mathcal{A}_b(\text{SLD}) = 0.921 \pm 0.020$$

- $\mathcal{A}_b$ from LEP and SLD agree within 1σ !

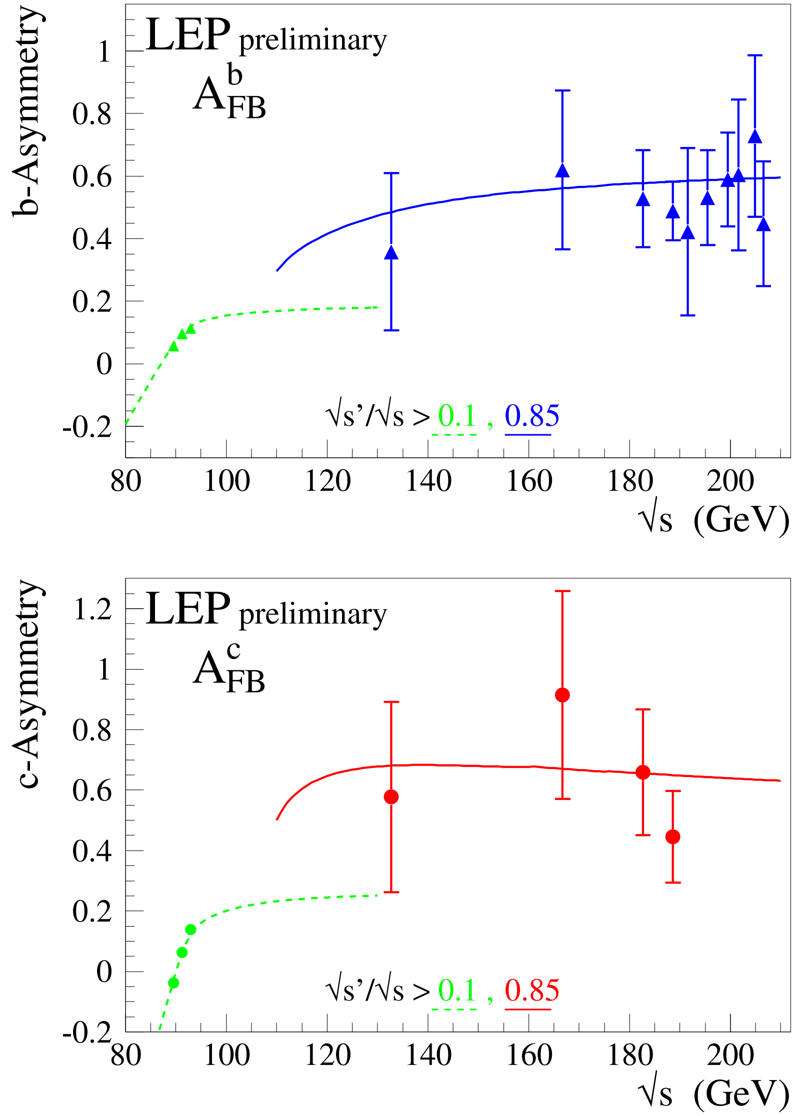
LEP 2 A_{FB} Measurements

At LEP 2, $Z - \gamma$ interference causes large asymmetry; focus of interest moves.

Issues at LEP 2:

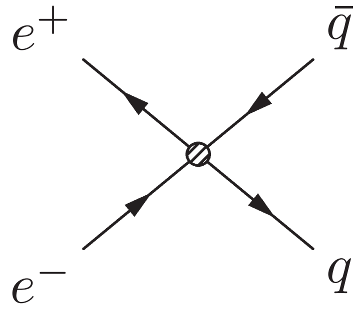
- decreasing signal cross-section and non-negligible backgrounds (Z-returns, 4f)
- double tagging impossible, use MC for b / c purities and charge probabilities
- inclusive charm tagging requires developing new tools
- Precision averaged over $\sqrt{s}$:

$$\Delta A_{\text{FB}}^{b\bar{b}} = 0.06$$



LEP 2 Heavy Flavour Contact Interaction Fits

- new process interfering with Standard Model



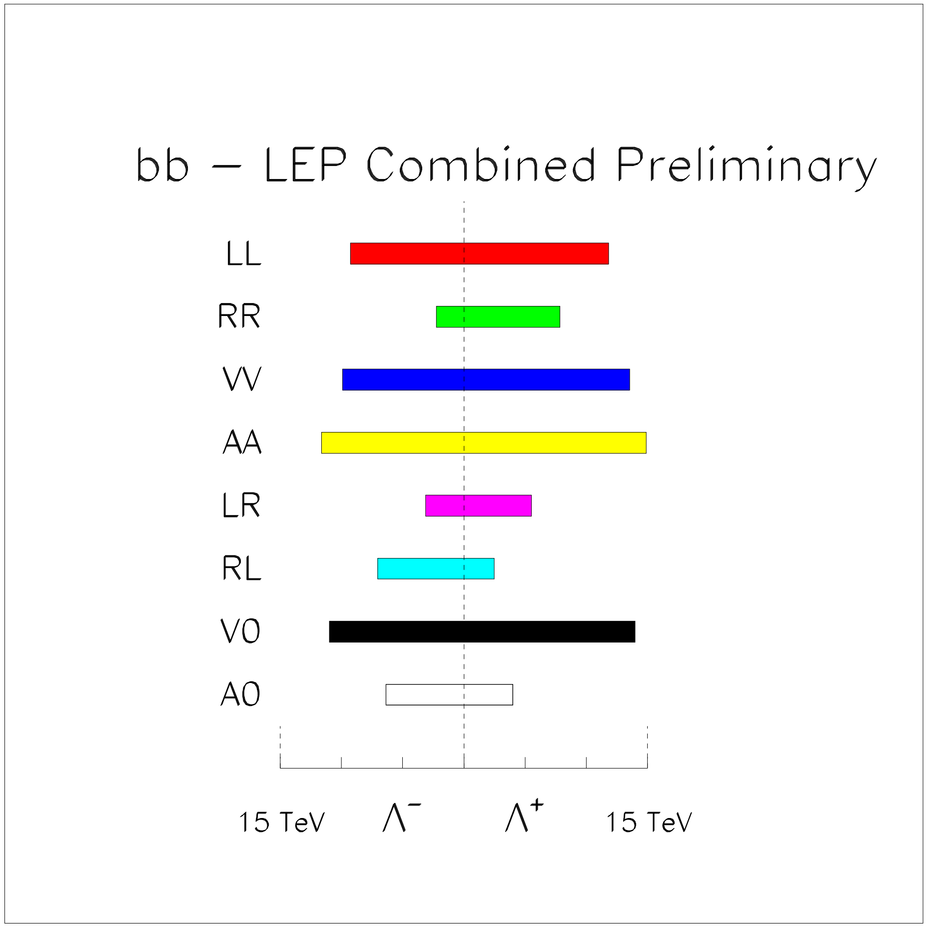
- Lagrangian for pointlike interaction

$$\mathcal{L}_{\text{eff}} = \frac{4\pi}{\Lambda_\pm^2} \sum_{i,j=L,R} \eta_{ij} (\bar{e}_i \gamma^\mu e_i)(\bar{f}_j \gamma^\mu f_j)$$

- energy scale $\Lambda^2 = 4\pi M^2/\lambda^2$

  μ-decay: $\Lambda = \left(\sqrt{2} G_{\text{F}}\right)^{-1/2} \sim \mathcal{O}(TeV)$

- assume CI affects only one flavour
- fit $\sigma_{b\bar{b}}$, $A_{\text{FB}}^{b\bar{b}}$ and $\sigma_{c\bar{c}}$, $A_{\text{FB}}^{c\bar{c}}$.



(95 % CL)

Summary

- forward-backward asymmetries are interesting to study both at LEP 1 and LEP 2.
- many different A_{FB} measurements at LEP, all very consistent with each other.
- expect still some improvements in methods and statistical error
- if disagreement in $\sin^2\theta^{lept}_{eff}$ is not a systematic error, is it a statistical fluctuation or new physics? LEP and SLC will probably leave this question open...

in my opinion there is no reason to distrust A_{FB}
— and now it is up to you to trust !