

Asymmetries and Tau Polarization at LEP

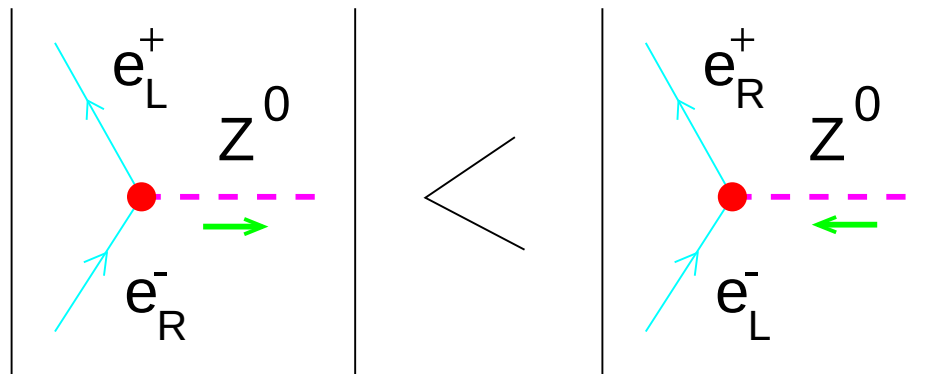
Günter Dückeck
LMU Munich

WIN 99, Cape Town, January 1999

- I. Introduction
- II. Lepton forward–backward asymmetries
- III. Quark forward–backward asymmetries
- IV. Tau polarization
- V. Summary

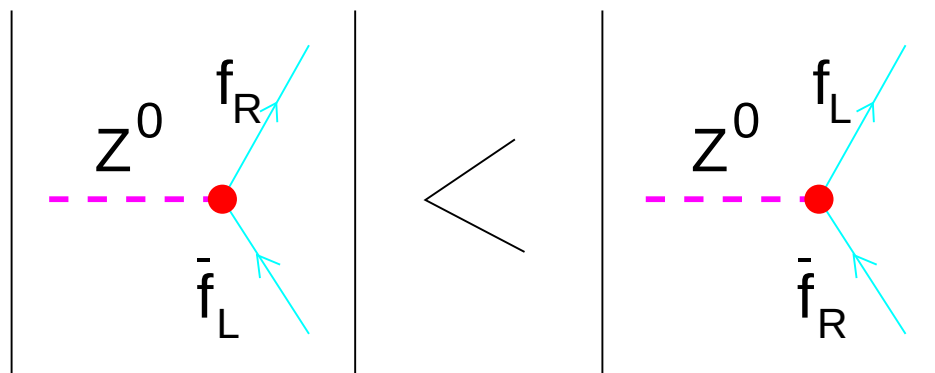
Introduction

Asymmetry at LEP caused by small parity violation in leptonic Z^0 couplings:



→ Z^0 polarized: $\mathcal{A}_e = \frac{2 \hat{g}_v^e \hat{g}_a^e}{(\hat{g}_v^e)^2 + (\hat{g}_a^e)^2}$.

Similar in decay:



→ final state polarized $\mathcal{A}_f = \frac{2 \hat{g}_v^f \hat{g}_a^f}{(\hat{g}_v^f)^2 + (\hat{g}_a^f)^2}$.

Observables

- Residual polarization of final state
(measurable in τ decays)

$$\langle P_\tau \rangle = \frac{\sigma_r - \sigma_l}{\sigma_r + \sigma_l} \approx -\mathcal{A}_\tau$$

- Polarization asymmetry

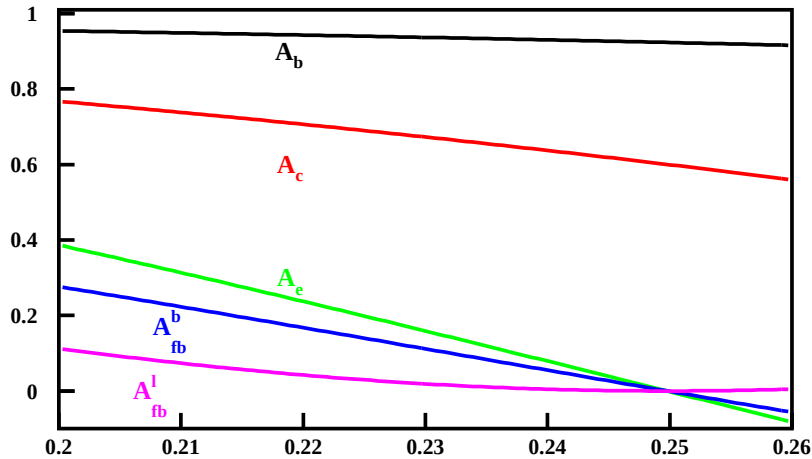
$$A_{\text{FB}}^{\text{pol}} = \frac{(\sigma_r^F - \sigma_l^F) - (\sigma_r^B - \sigma_l^B)}{\sigma_{\text{tot}}} \approx -\frac{3}{4}\mathcal{A}_e$$

- Forward-backward charge asymmetry

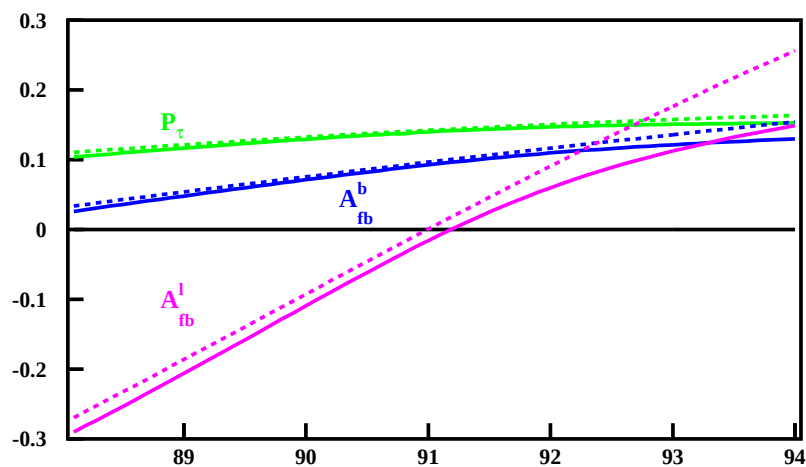
$$A_{\text{FB}}^f = \frac{\sigma_f^F - \sigma_f^B}{\sigma_f^F + \sigma_f^B} = \frac{3}{4}\mathcal{A}_e \cdot \mathcal{A}_f$$

Observables related to $\sin^2 \theta_{\text{eff}}^l$:

$$\mathcal{A}_f = \frac{2(1 - 4|Q_f| \sin^2 \theta_{\text{eff}}^l)}{1 + (1 - 4|Q_f| \sin^2 \theta_{\text{eff}}^l)^2}$$



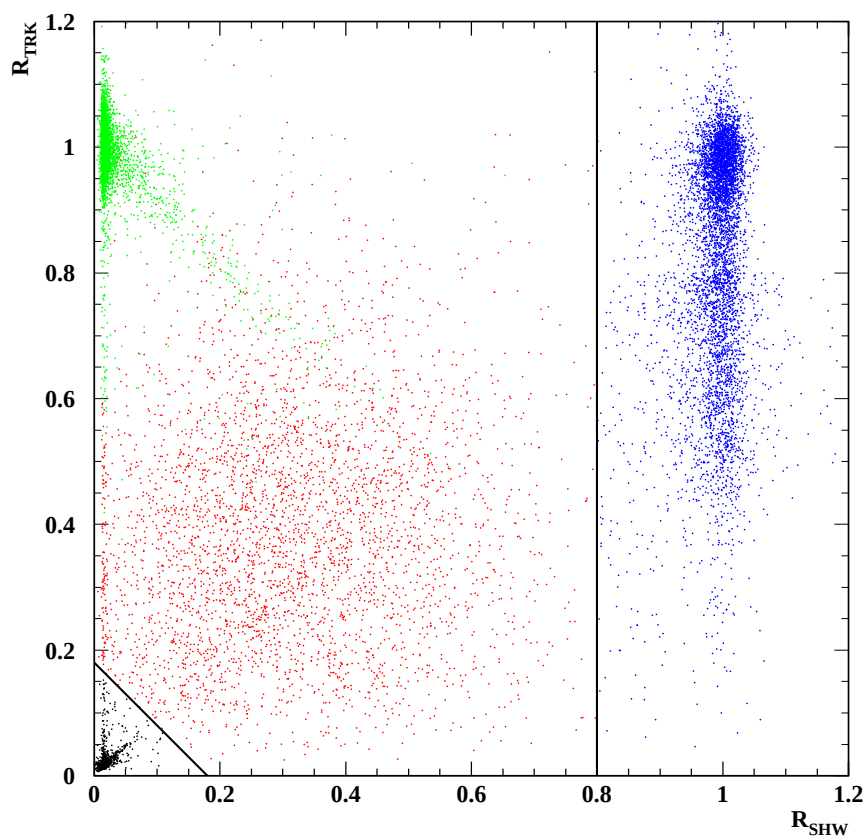
ISR, γ , γZ and $\sqrt{s}$ modify pure Z^0 effects:



Lepton charge asymmetries

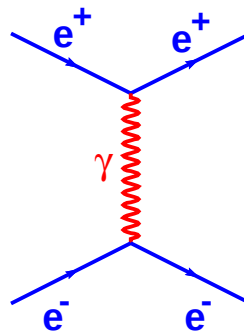
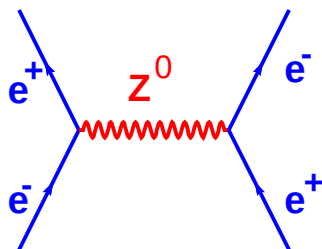
Conceptually ‘cleanest’ measurement at LEP (in particular $\mu^+\mu^-$)

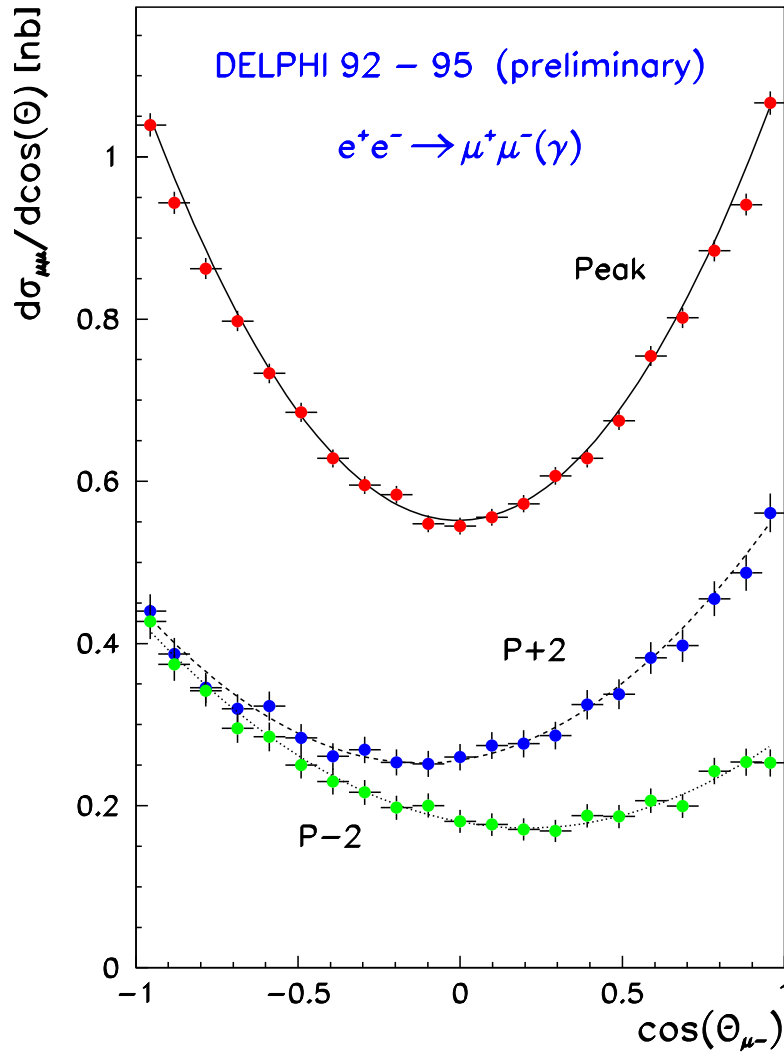
- clear separation of lepton species



- unambiguous charge identification

- A_{FB}^ℓ is ratio of numbers
→ luminosity uncertainty and most selection systematics cancel
- t -channel diagrams complicate e^+e^- channel





A_{FB} determined in maximum likelihood fit to differential distribution

$$\frac{1}{\sigma} = \frac{d\sigma}{d\cos\theta} = \frac{3}{8} (1 + \cos^2\theta) + A_{\text{FB}} \cos\theta$$

Systematics

Systematics of A_{FB} measurement

- charge & efficiency symmetry of detector & selection
- fiducial cut on angular range (e^+e^- t -channel)
- background (e^+e^- for $\tau^+\tau^-$)
- physics (asymmetric acceptance for e^+e^- , τ polarization)

in general small, well below statistics.

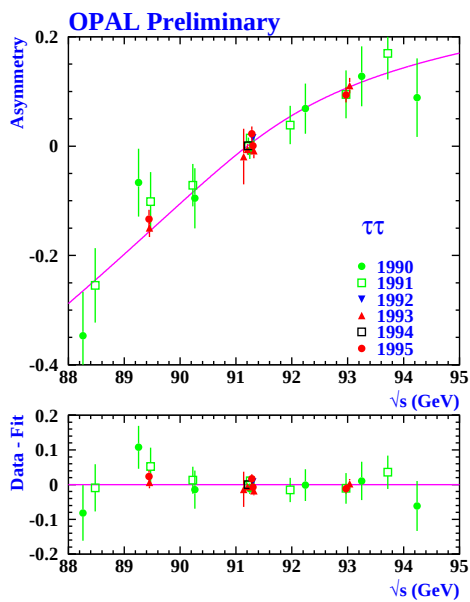
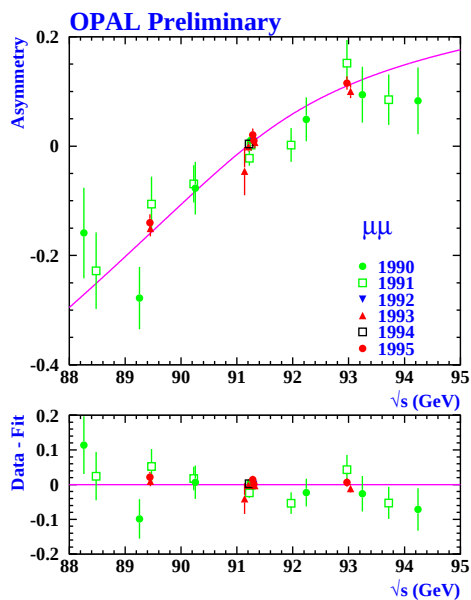
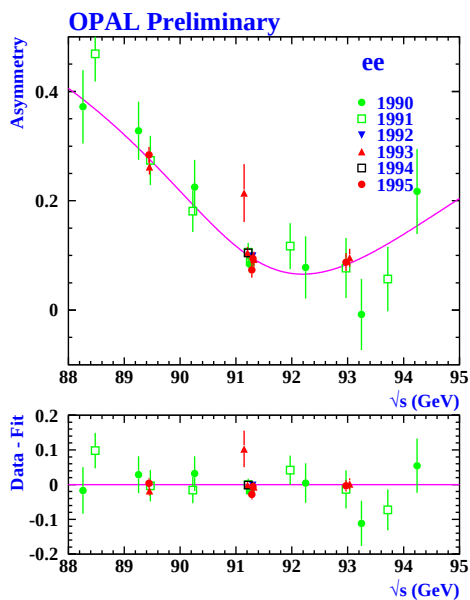
$A_{\text{FB}}^{0,\ell}$ determined in global lineshape fit to σ and asymmetries, accounts for all effects of ISR, γ , γZ and $\sqrt{s}$.

t -channel correction done with ALIBABA/TOPAZ.

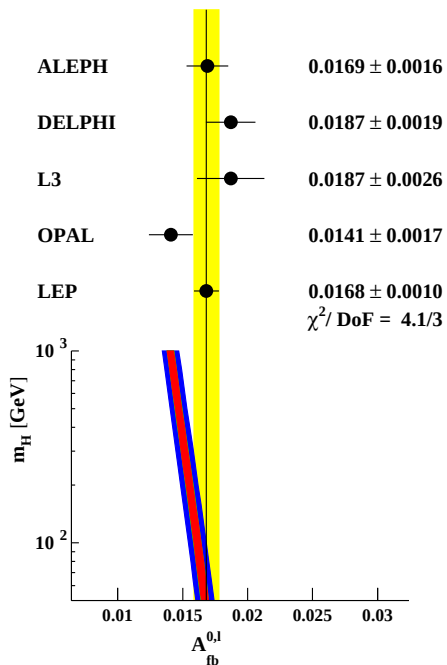
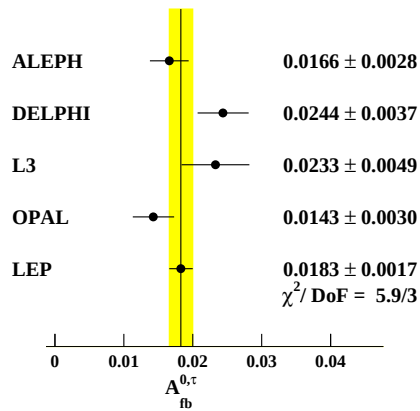
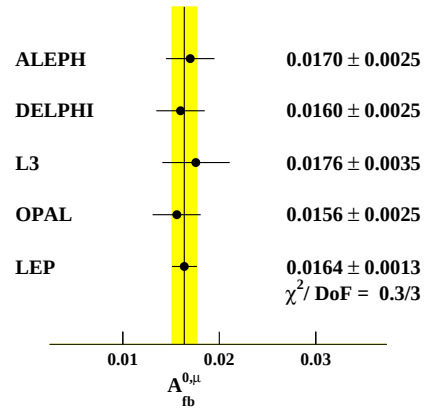
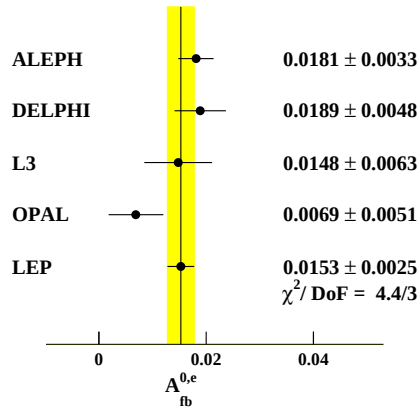
Introduces additional systematics of ≈ 0.0013 and correlations with $\sigma_{e^+e^-}$.

→ Common to all experiments

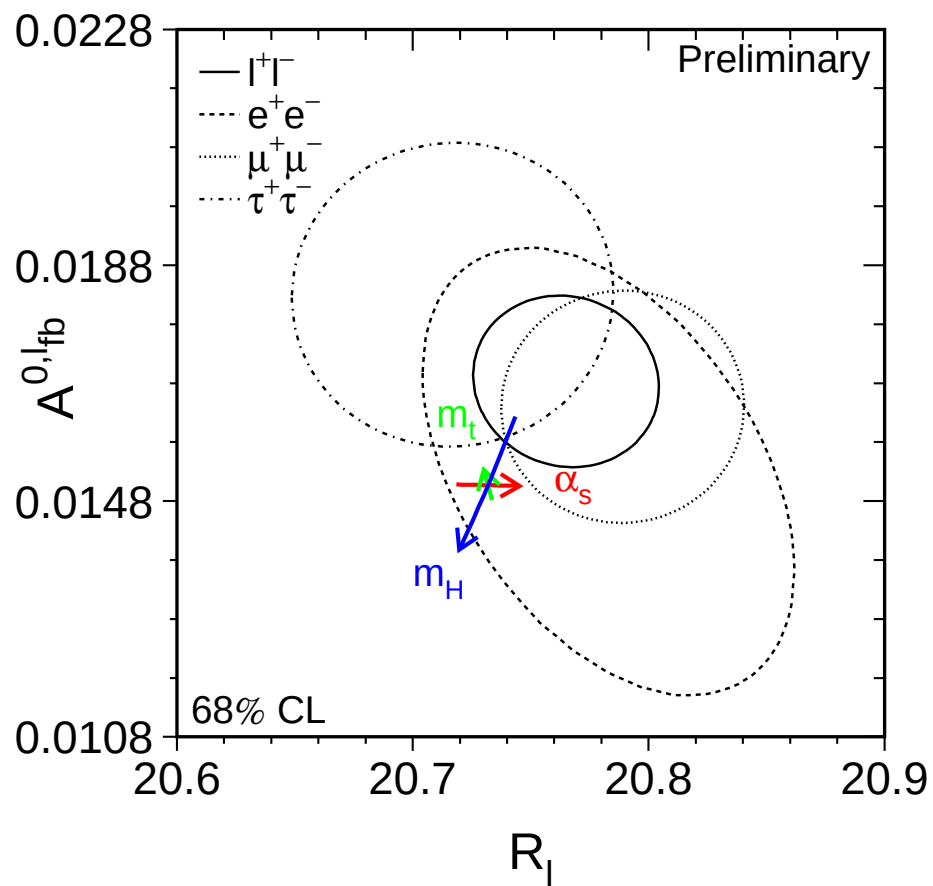
Results



Results



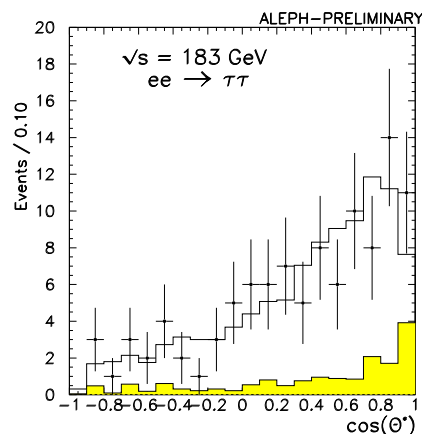
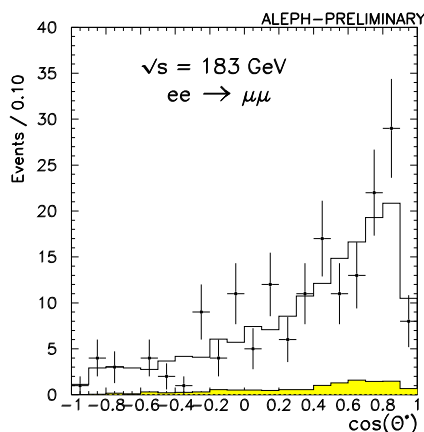
Lepton cross sections and asymmetries



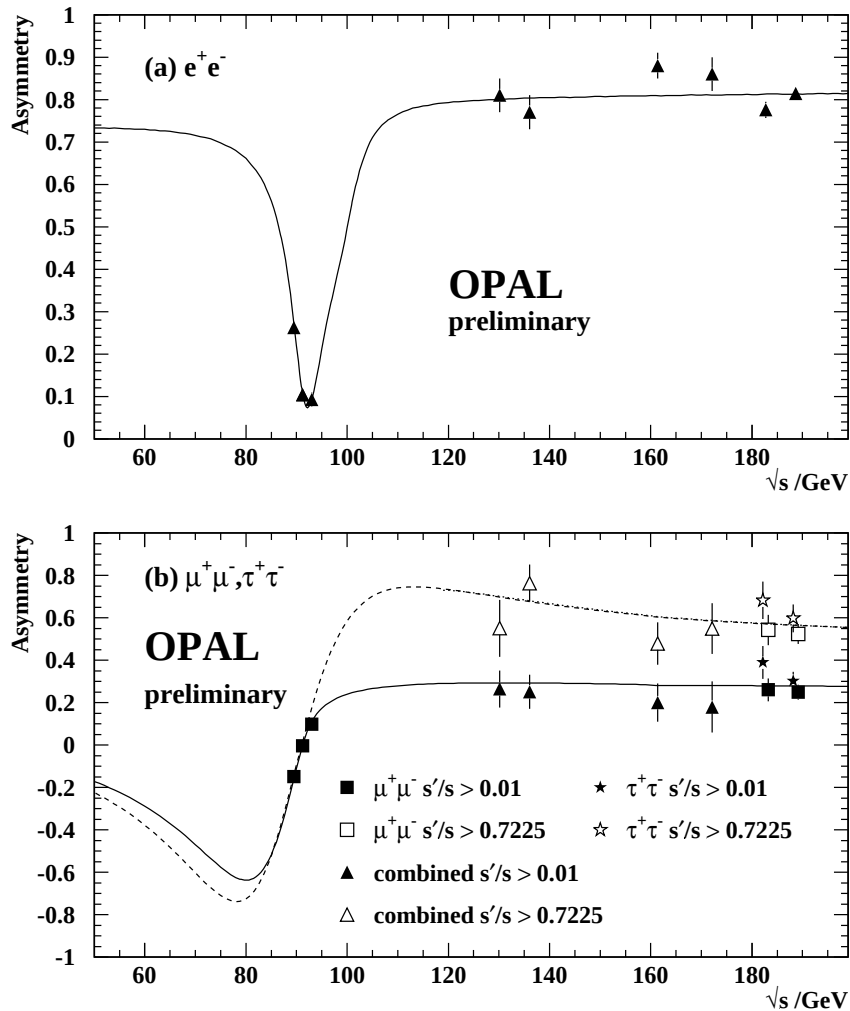
Asymmetry at LEP2

Measurements continue at LEP2

- γ exchange dominates, $\sigma_{\ell\ell}$ reduced by factor ≈ 500 , correspondingly less statistics.
- large fraction of 'radiative return' events
- analysis separated for inclusive ($\sqrt{s'/s} > 0.10$) and non-radiative ($\sqrt{s'/s} > 0.85$)



Asymmetry at LEP2



Results consistent with Standard Model expectations

Quark asymmetries

Hadronization obscures both flavour and charge of the primary quark.

Precise measurements possible for b and c

Two principal methods:

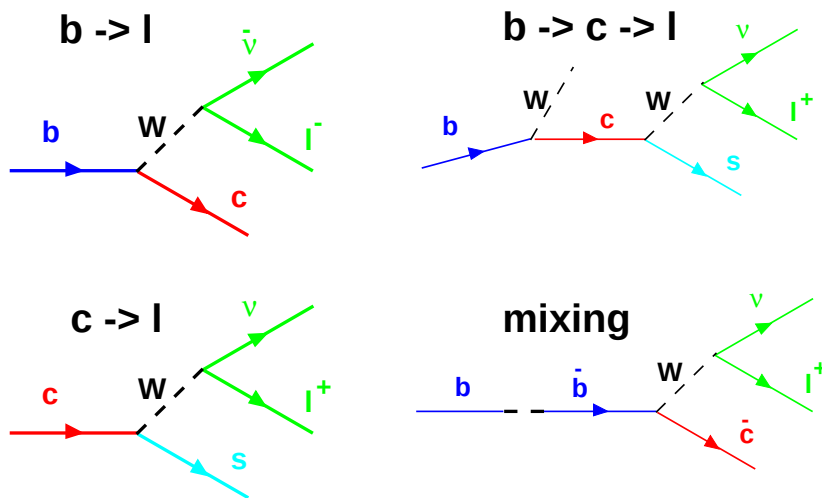
- particle tag (leptons, D-mesons) gives both quark flavour and charge.
- lifetime tag selects flavour, jet or hemisphere charge determines (statistically) primary quark charge.

$$Q_{jet} \equiv \frac{\sum_i Q_i |p_i^{\parallel}|^{\kappa}}{\sum_i |p_i^{\parallel}|^{\kappa}}$$

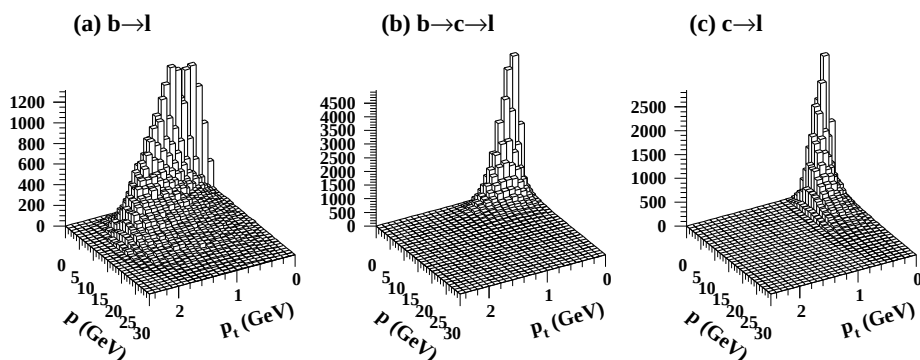
Lepton tags

Classical method to determine charge & and flavour of heavy quarks.

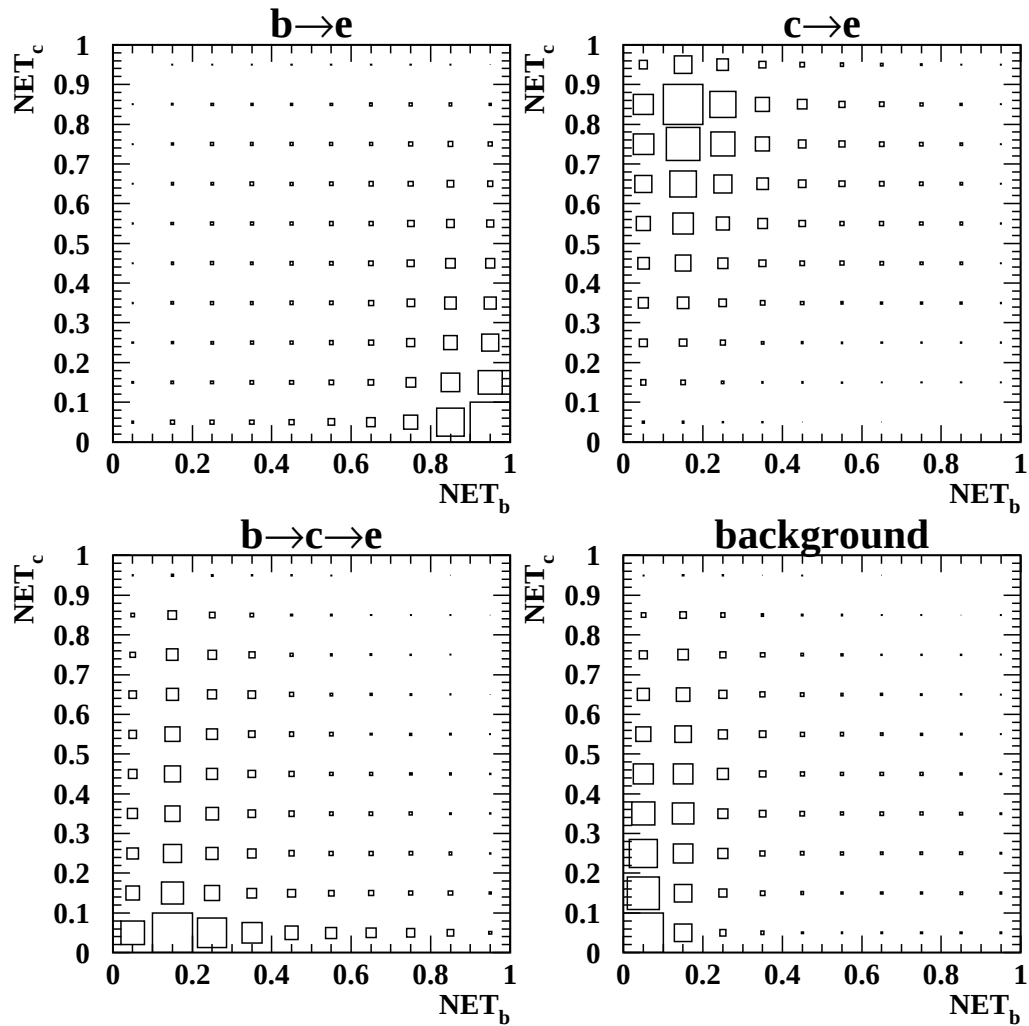
- Several sources must be distinguished



- Separation based on (p, p_T) of lepton w.r.t. jet axis



- Further improvement using additional info (lifetime, jet-shape) and neural net



- Uncertainties from
 - lepton spectra
 - leptonic branching ratios
 - mixing

Best to determine A_{FB}^b and A_{FB}^c (+ mixing) in common fit.

	ALEPH	DELPHI	L3	OPAL
A_{FB}^b	X	X	X	X
A_{FB}^c		X		X
$\bar{\chi}$	X			X

D^(*) reconstruction

D^(*) mesons originate from two sources:

1. primary c quark + fragmentation quark
2. Decay product of primary B meson

→ both heavy flavour tag and charge id

D mesons reconstructed in various channels:

$$D^0 \rightarrow K^- \pi^+, D^+ \rightarrow K^- \pi^+ \pi^+$$

$$D^{*+} \rightarrow D^0 \pi^+$$

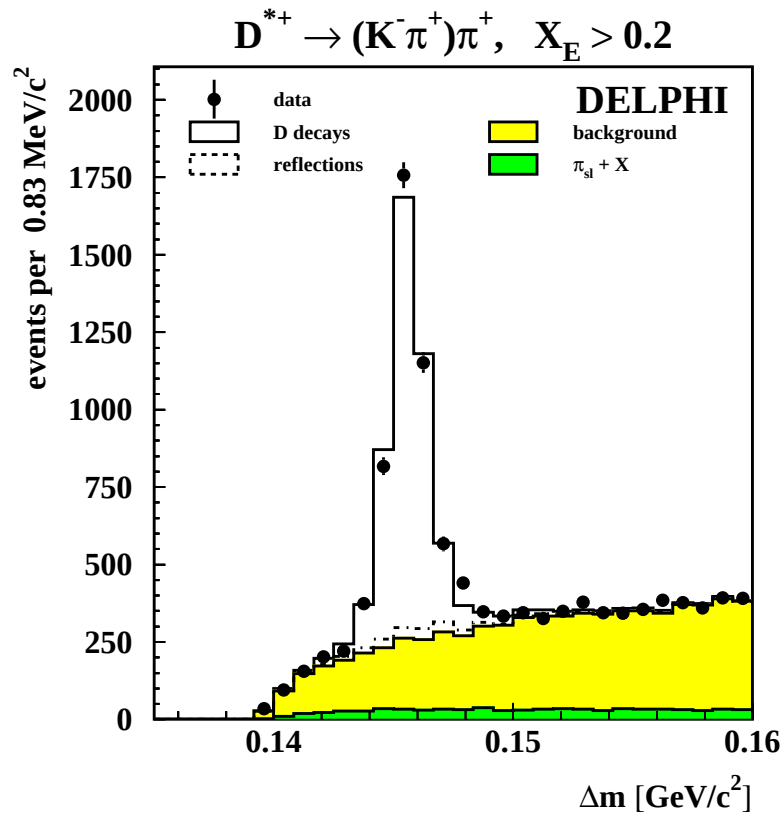
$$| \rightarrow K^- \pi^+$$

$$| \rightarrow K^- \pi^+ \pi^0$$

$$| \rightarrow K^- \pi^+ \pi^- \pi^+$$

$$| \rightarrow \dots$$

Slow pion characteristic signature for D^* :



D reconstruction used for A_{FB}^c by A D O.

Background from $B \rightarrow D$ decays controlled with D-momentum, lifetime, jet-shapes.

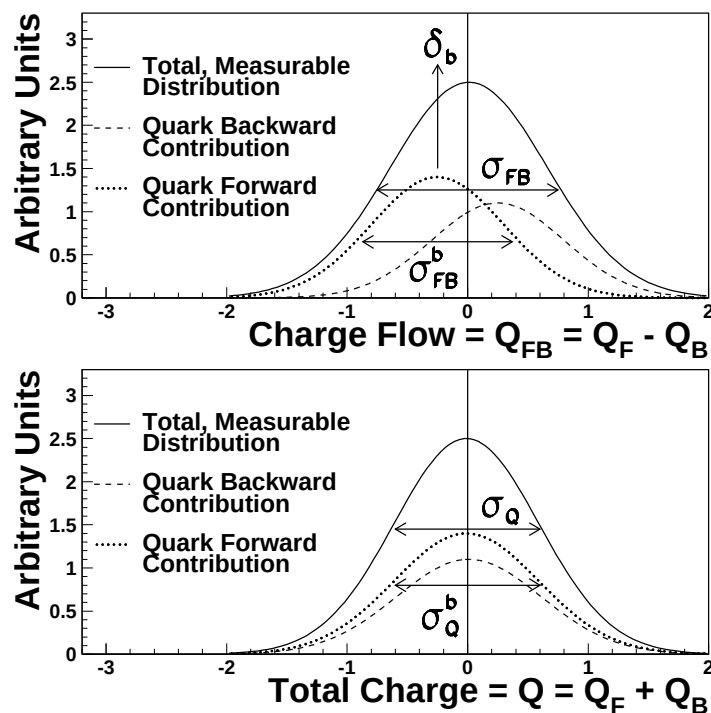
Jet charge

- Efficient & pure lifetime tags to select $b\bar{b}$ events.
- charge asymmetry

$$\langle Q_F - Q_B \rangle = \frac{N_F - N_B}{N_F + N_B} \langle Q_b - Q_{\bar{b}} \rangle = A_{\text{FB}} \cdot \delta$$

- For a single flavour δ measured with data:

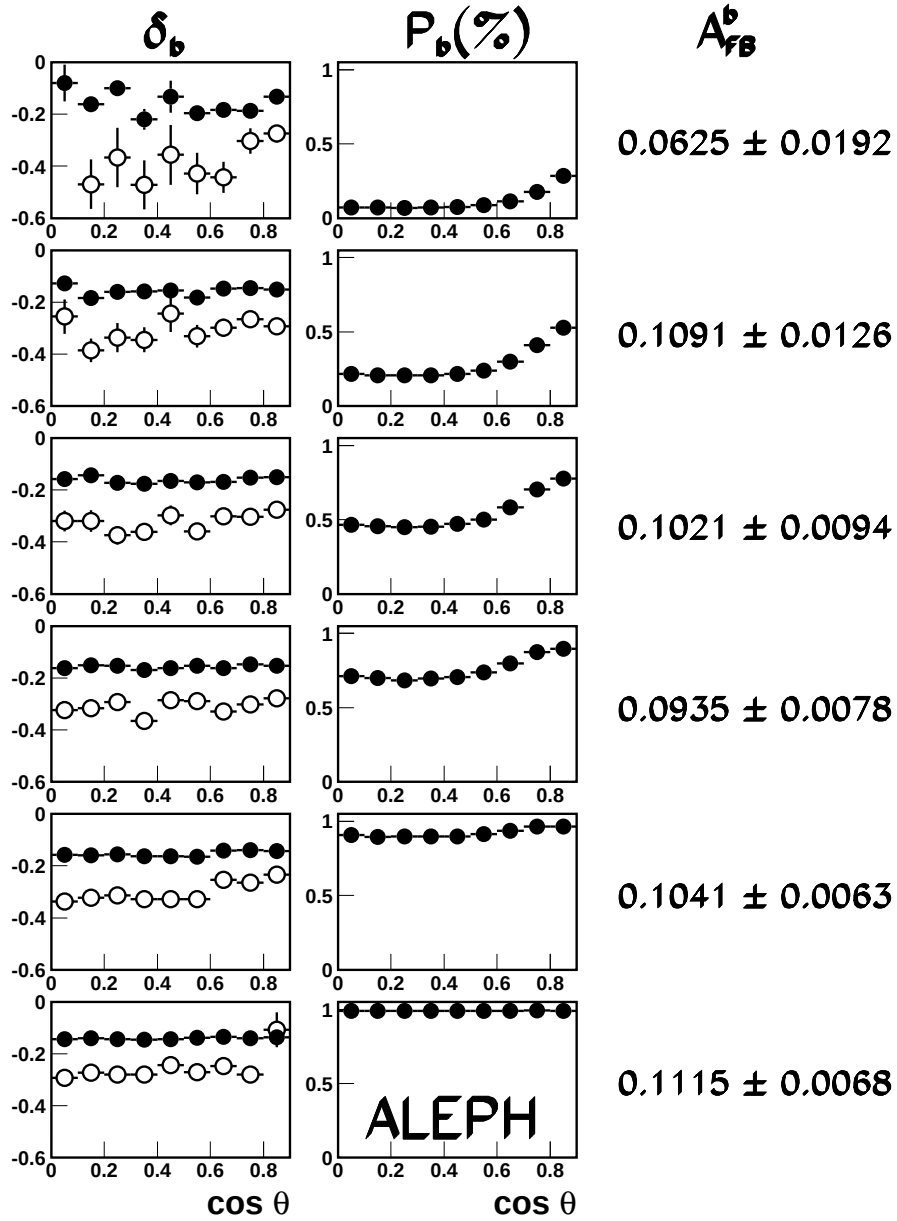
$$\delta \approx -4 \langle Q_F Q_B \rangle$$



- Correction to δ due to charge bias, background and correlations.
- Analogy to R_b double tag: Observable and main correction determined with data.
- Effects of QCD & $B^0\overline{B}^0$ mixing $\approx$ absorbed in δ
- Sophisticated techniques to extract maximal information:

Fit as function of

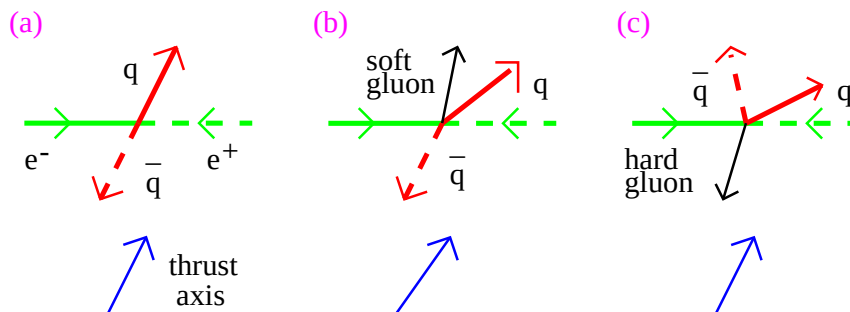
- b-purity
- $\cos \theta$
- κ ($Q_{jet} = \sum_i Q_i |p_i^{\parallel}|^{\kappa} / \sum_i |p_i^{\parallel}|^{\kappa}$)



A_{FB}^q corrections

Measured $A_{\text{FB}}^q \rightarrow \text{pure } Z^0 A_{\text{FB}}^{0,q}$

- ‘oblique’ corrections due to ISR, γ , γZ and $\sqrt{s}$.
- Large QCD corrections ($\approx$ error), depending on details of analysis



$$A_{\text{FB}}^q = (1 - B_{\text{exp}} \delta_{\text{QCD}}) A_{\text{FB}}^{0,q}$$

- δ_{QCD} analytically calculable ($\approx 5\%$)
- B_{exp} additional experimental bias, specific for experiment and method:

leptons	0.5
D recon.	0.2
jet-charge	< 0.1

Combination of heavy flavour results

Averaging heavy flavour results from different analyses & experiments complicated due to

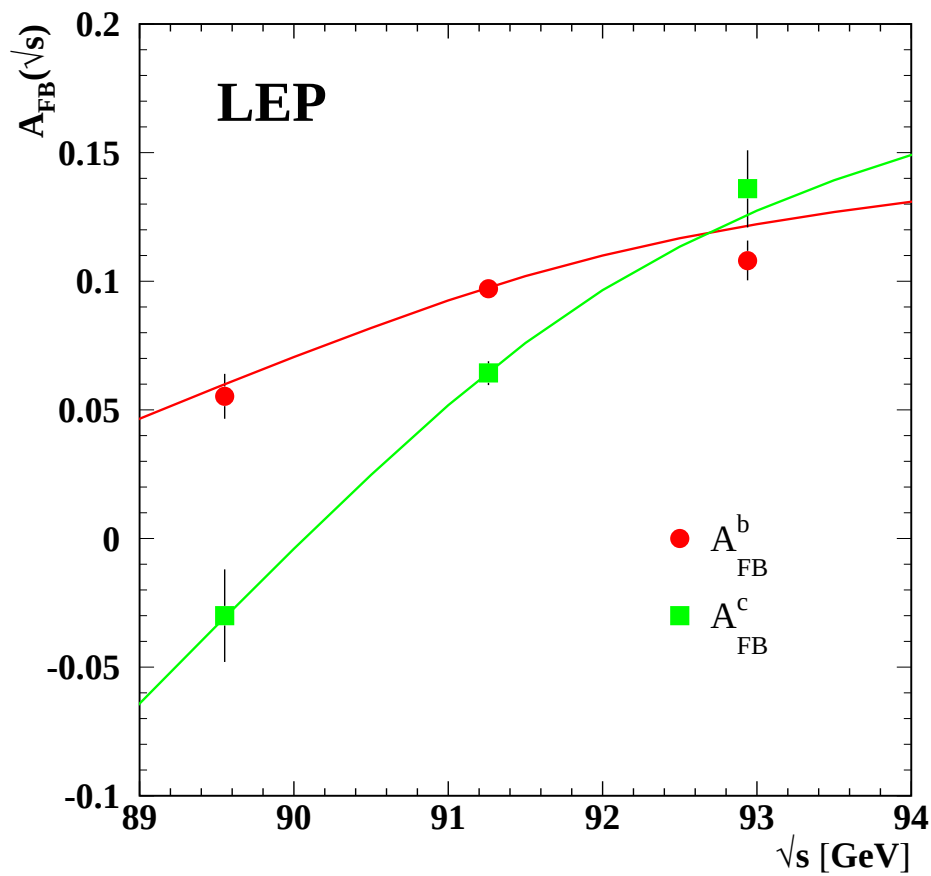
- Correlations between e-weak observables (R_b , R_c)
- Correlations between physics input (mixing, production and decay rates)

LEP & SLD agreed on common definition of input parameters & errors.

Averaging done by fit to 88 input quantities from LEP & SLD

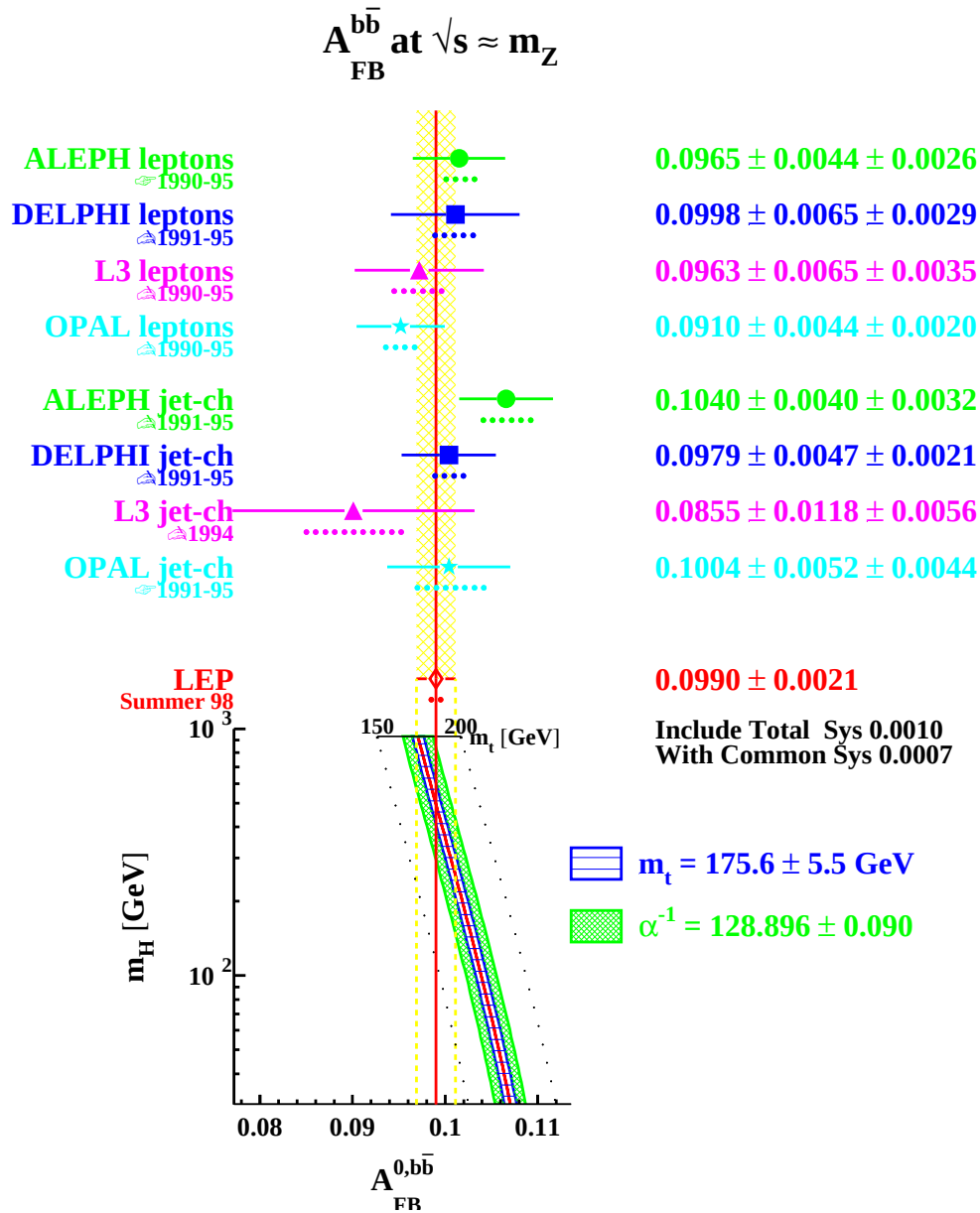
→ 17 fit parameters.

$A_{\text{FB}}^{b,c}$ energy dependence

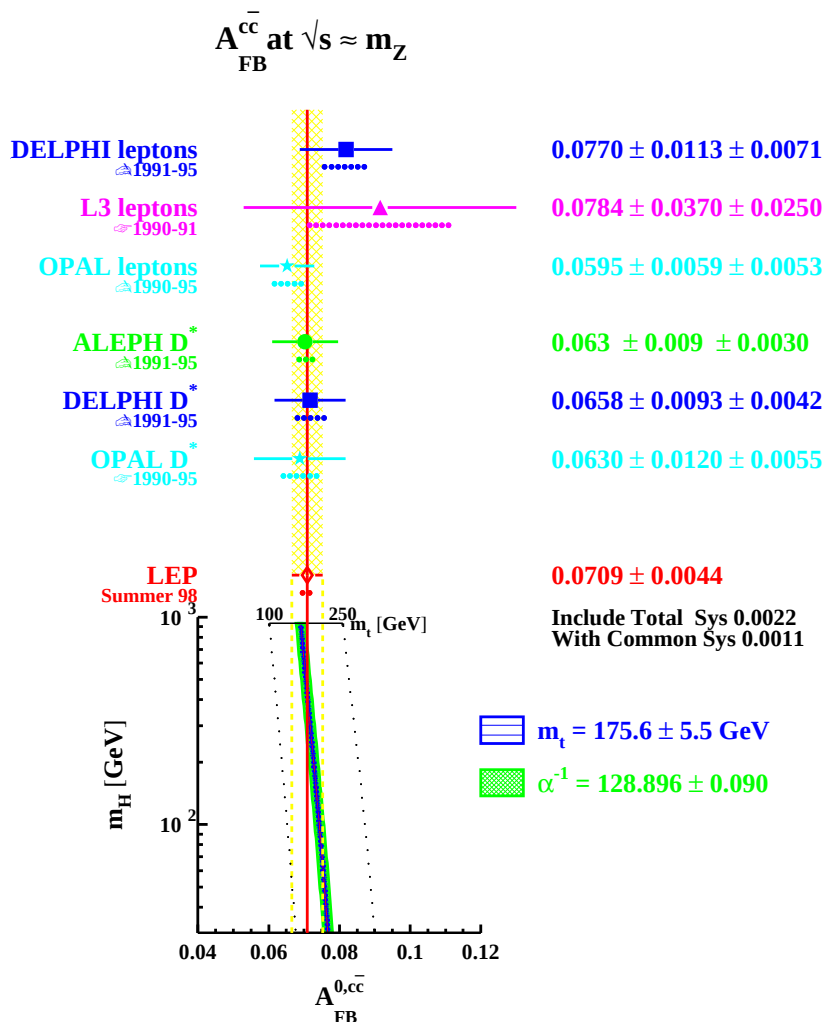


Off-peak measurements consistent with SM expectation.

$A_{FB}^{0,b}$ results



$A_{FB}^{0,c}$ results

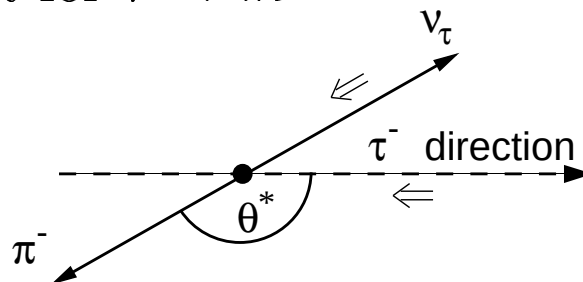


Tau polarization

τ only fermion where polarization **precisely** measurable.

- $(V - A)$ structure of τ charged current decay causes maximal parity violation.
- Decay directions in τ rest frame depend on polarization.

Most evident for $\tau \rightarrow \pi \nu$



$$\frac{dN}{d \cos \theta^*} \propto (1 + P_\tau \cos \theta^*)$$

$\cos \theta^*$ in τ rest frame related to E/E_{beam} in lab frame

$$\cos \theta^* \approx 2 \frac{E_\pi}{E_{beam}} - 1$$

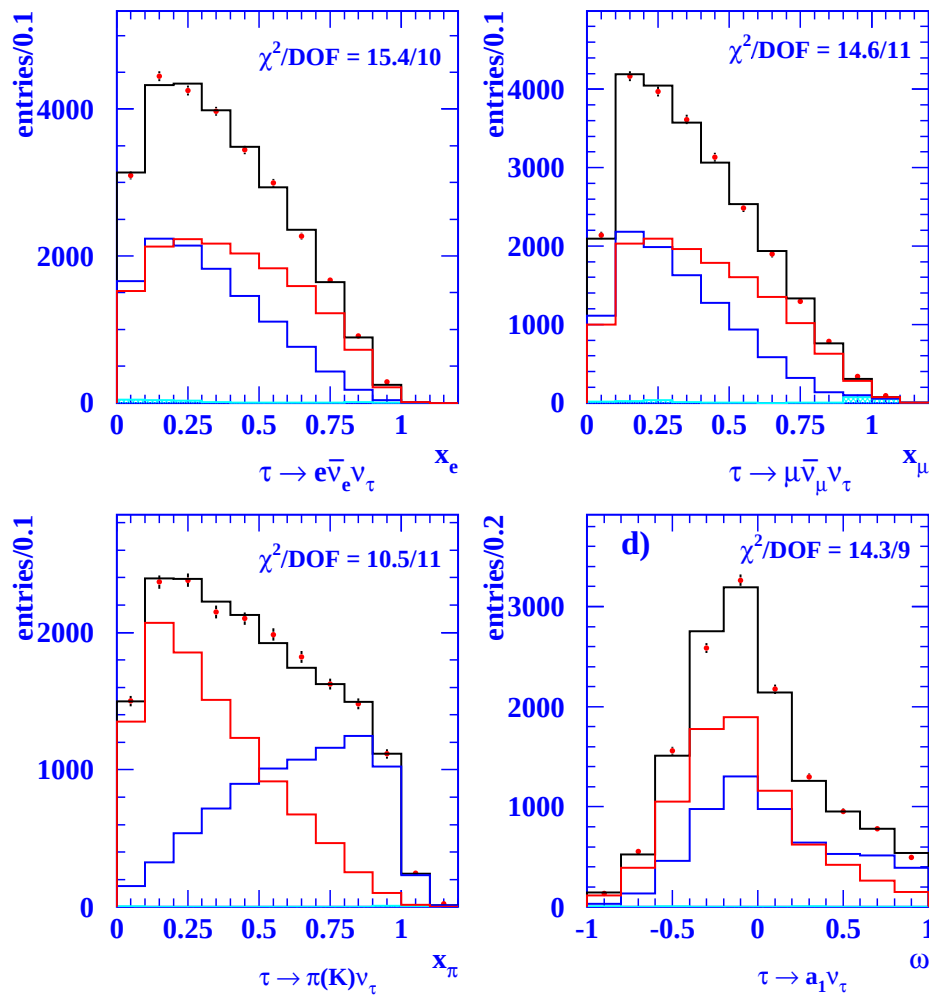
Other channels less direct:

- $\tau^- \rightarrow e^- \bar{\nu}_e \nu_\tau$ & $\tau^- \rightarrow \mu^- \bar{\nu}_\mu \nu_\tau$ are 3-body decays into **3** spin 1/2 particles, only **1** observed
→ signal strongly diluted
- Decays modes to spin-1 mesons (ρ , a_1) more complicated, two spin configurations of the meson. But subsequent decays ($\rho \rightarrow 2\pi$, $a_1 \rightarrow 3\pi$) give info on meson spin state.
→ part of τ polarization regained

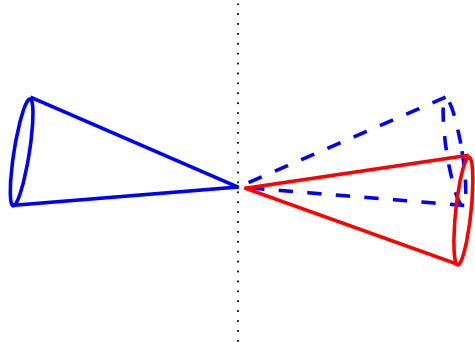
	$\tau \rightarrow e \nu \nu$	$\tau \rightarrow \pi \nu$	$\tau \rightarrow \rho \nu$	$\tau \rightarrow a_1 \nu$
	$\tau \rightarrow \mu \nu \nu$	$\tau \rightarrow K \nu$		
Br	0.35	0.12	0.25	0.09
Sens.	0.22	0.58	0.49	0.45
Weight	0.12	0.30	0.44	0.13

Polarization determined by fitting MC spectra
for $\langle P_\tau \rangle = 1$ and $\langle P_\tau \rangle = -1$ to data.

OPAL

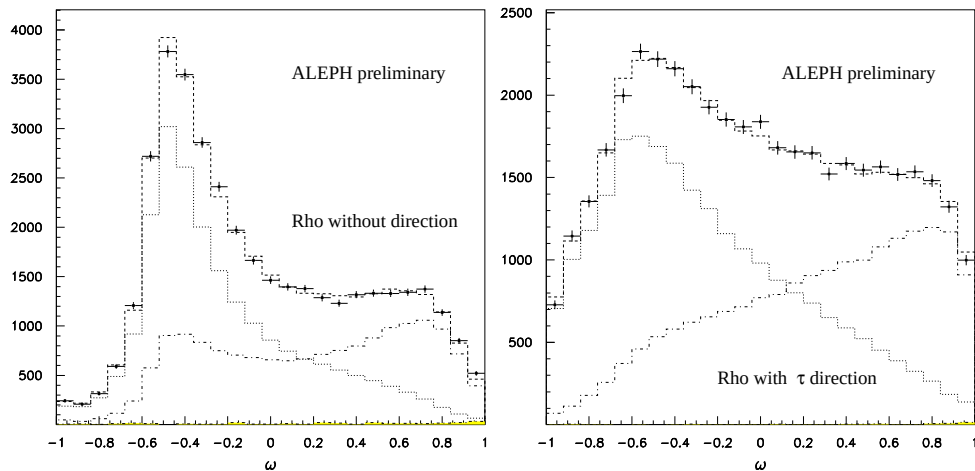


Recent progress by new ALEPH analysis:
 $\tau^+\tau^-$ direction determined for whole event:



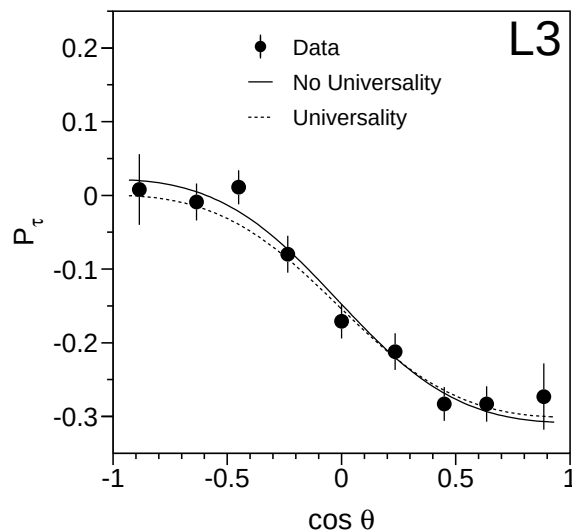
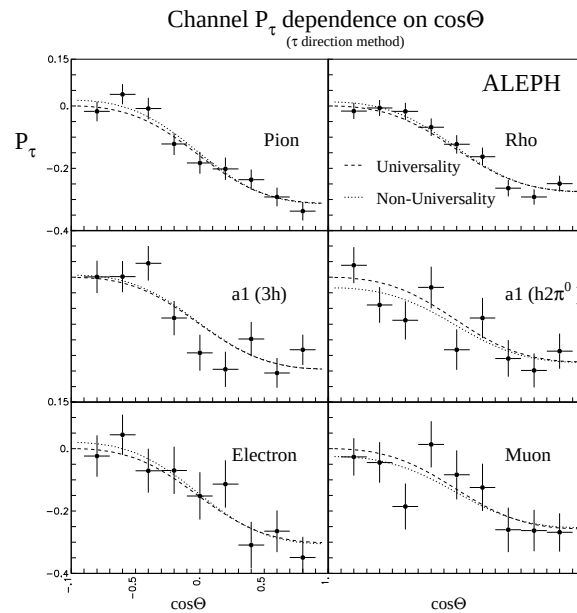
τ direction given by in-
 tersection of cones (2
 fold ambig.)

Improves sensitivity of a_1 and ρ channels
 ($0.48 \rightarrow 0.58$)

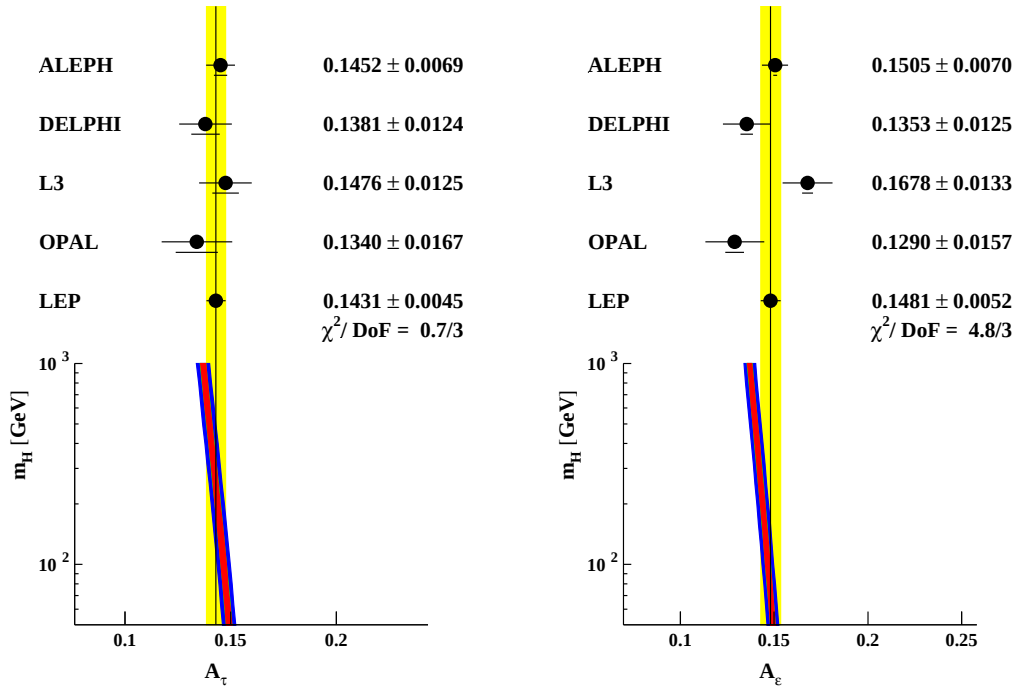


Angular distribution

$\langle P_\tau \rangle$ and $A_{\text{FB}}^{\text{pol}}$ determined by fitting observed
 $d\langle P_\tau \rangle / d\cos\theta$



Combined Results

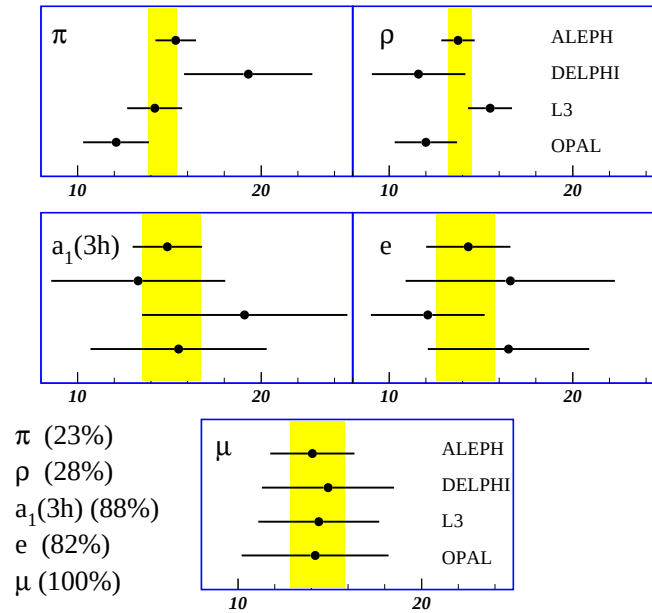


Systematics mostly uncorrelated among experiments: Detector simulation, PID and calibration.

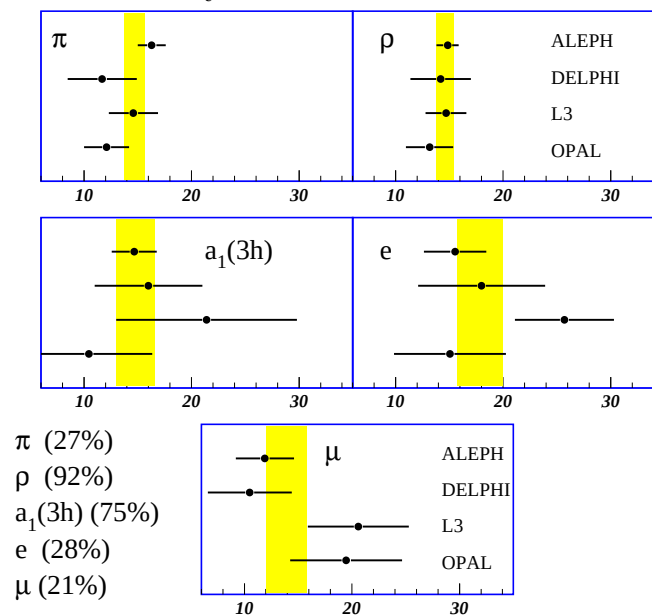
Correlated sources (a_1 decay, τ Br's, corrections) at the 1-2% level.

Results by Channel

A_τ measurements by channel at LEP



A_e measurements by channel at LEP



Detector characteristics

Significant differences in precision already reflected in $\tau^- \rightarrow \nu_\tau \rho^-$ efficiency & purity.

	ALEPH	DELPHI	L3	OPAL
eff.	51 %	41 %	58 %	41 %
bkgr.	8.9 %	15 %	10.5 %	27 %

τ polarization poses specific challenges on ECAL performance. Most crucial π^0 id and separation of $\pi^0, \pi^\pm$ showers.

	ALEPH	DELPHI	L3	OPAL
Magnet	1.5 T	1.23 T	0.5 T	0.435 T
ECAL				
granularity	$3 \times 3 \text{ cm}^2$	$2 \times 2 \text{ cm}^2$	$2 \times 2 \text{ cm}^2$	$10 \times 10 \text{ cm}^2$
energy σ_E/E	$0.18/\sqrt{E}$	$0.32/\sqrt{E}$	$0.02/\sqrt{E}$	$0.06/\sqrt{E}$

Interpretation

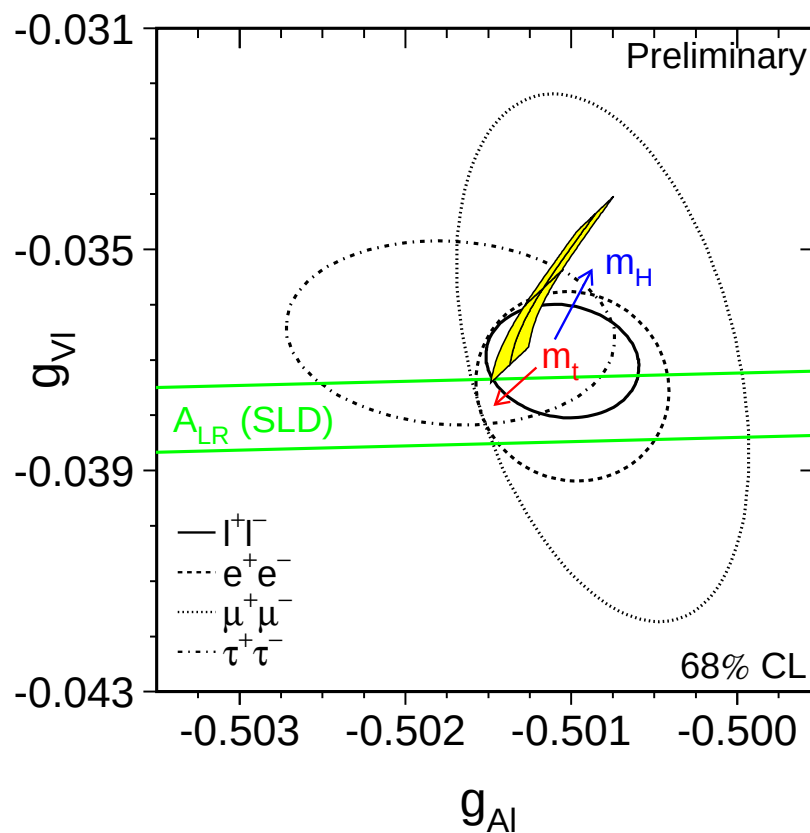
Lepton universality:

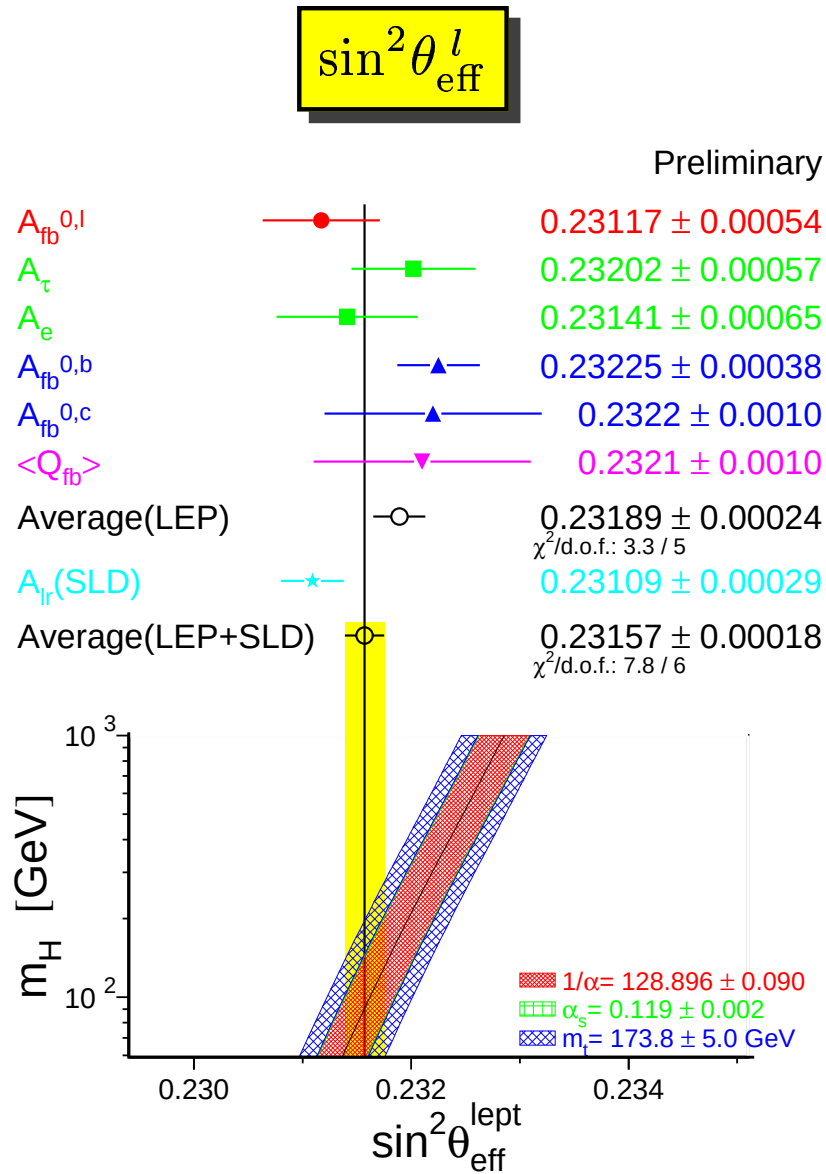
Couplings $\hat{g}_v^l$ & $\hat{g}_a^l$ given by:

$$\Gamma_l \propto (\hat{g}_v^l)^2 + (\hat{g}_a^l)^2$$

$$A_{\text{FB}}^{0,l} \propto (\hat{g}_v^l / \hat{g}_a^l)^2$$

$$\langle P_\tau \rangle \text{ and } A_{\text{FB}}^{\text{pol}} \propto (\hat{g}_v^l / \hat{g}_a^l)$$





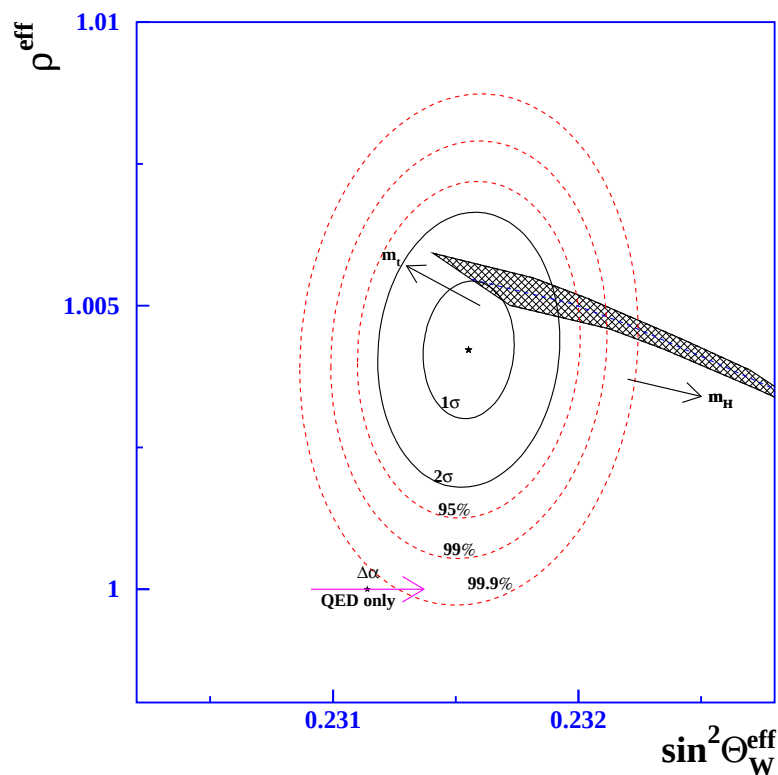
χ^2 quite ok now, was **12/6** at EPS 1997

($P(\chi^2) : 5\% \rightarrow 25\%$)

A_{LR} and $A_{\text{FB}}^{0,b}$ disagree by about **2.5 σ** .

$$\rho_{\text{eff}}^l \text{ vs } \sin^2 \theta_{\text{eff}}^l$$

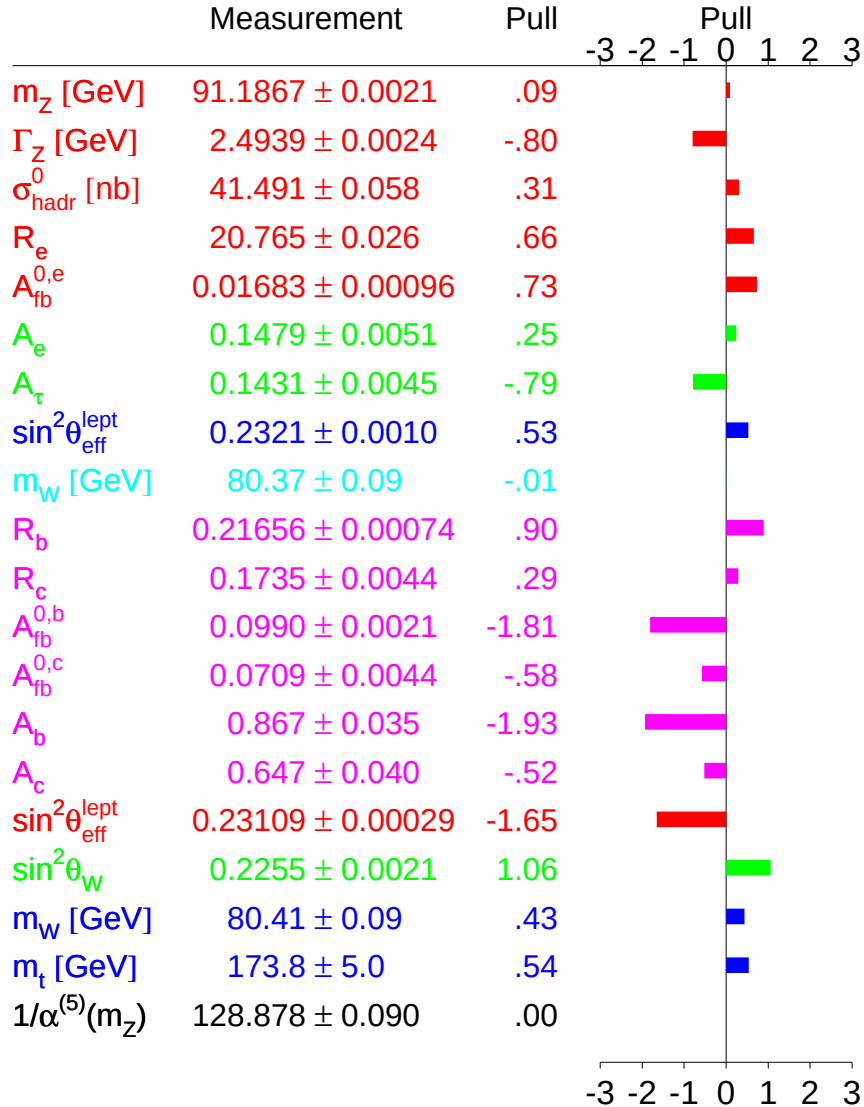
$$\Gamma_l \propto \rho = \frac{1}{1 - \Delta\rho}$$



Presence of genuine electroweak corrections with
>99 % C.L. (mainly due to ρ)

Pulls for SM fit

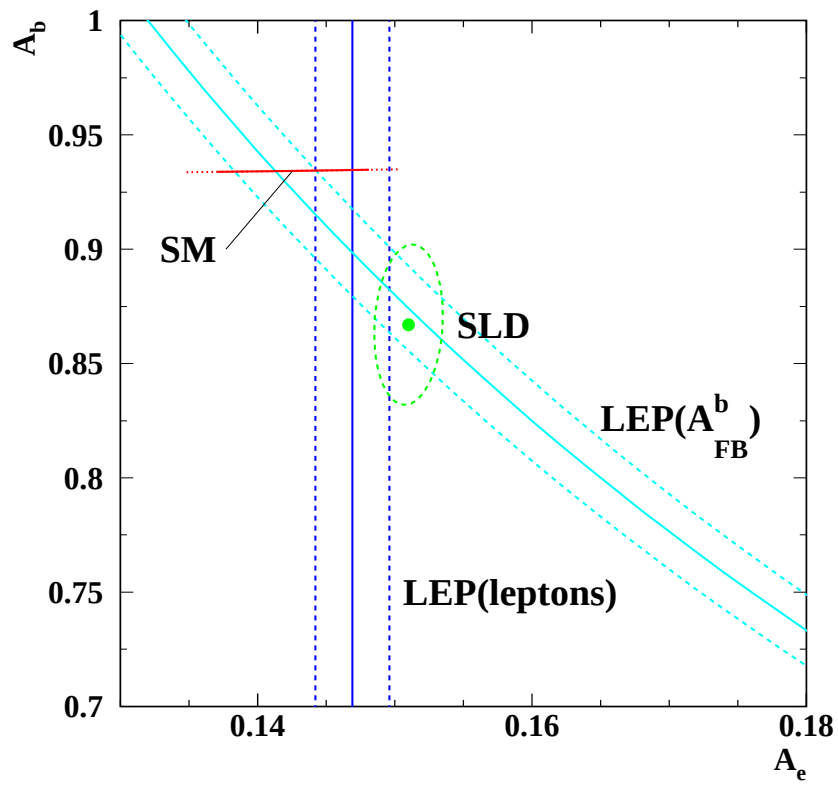
Vancouver 1998



Overall $\chi^2/\text{d.o.f.}$ ok with 15/15, no measurement more than 2σ away.

but $A_{\text{FB}}^{0,b}$, A_{LR} & and $\mathcal{A}_b$ alone give $\chi^2 = 9.7$.

LEP and SLD asymmetries



Summary

- Lepton charge asymmetries essentially finalized. **No change** expected.
- Heavy quark asymmetries full statistics analyzed. **Small improvements** in some areas with refined analyses possible.
- Precision of LEP tau polarization substantially improved last year. Most analyses use full statistics. Some **further gain in accuracy** likely.
- Discrepancy in $\sin^2\theta_{\text{eff}}^l$ measurements significantly reduced (**$P(\chi^2) = 25\%$**).

Standard Model still in perfect shape !