LEP1 HEAVY FLAVOUR ELECTROWEAK PHYSICS

AND

2-FERMION PHYSICS AT LEP2

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OVERVIEW

¶ LEP1 HEAVY FLAVOUR EW MEASUREMENTS
- Introduction and Status
- Experimental Techniques and Uncertainties
- Results and Standard Model Interpretation

¶ 2-FERMION PROCESSES @ LEP2

¶ SUMMARY

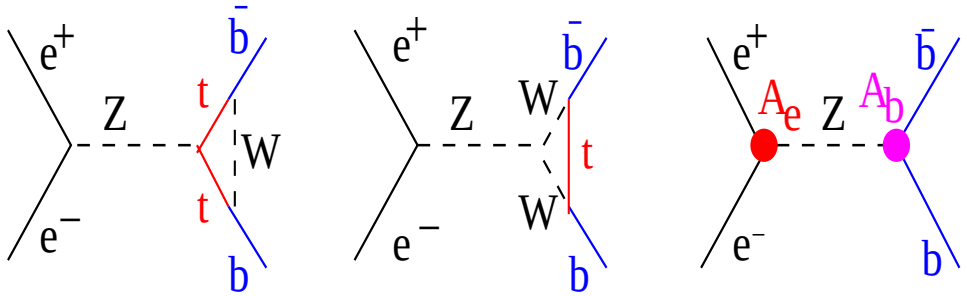
INTRODUCTION

LEP1 heavy flavour measurements ➔EW/new physics quantities

Z^0 partial decay widths:

$R_{b,c}=\Gamma_{bb,cc}/\Gamma_{had}$

$\Gamma_Q \sim g_{AQ}^2 + g_{VQ}^2$



➔ vertex corrections with W,top?

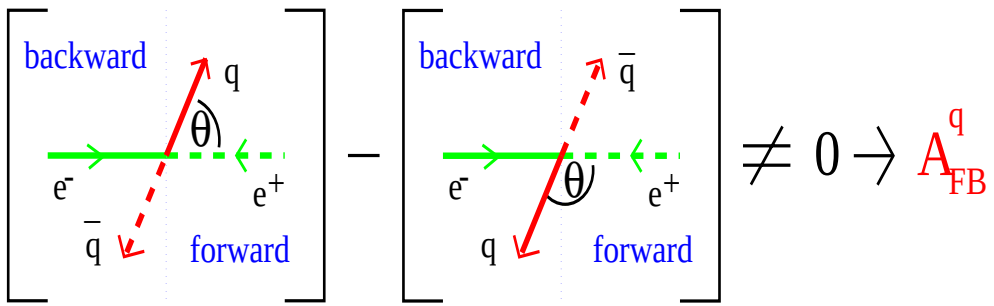
➔ new physics coupling to mass?

Asymmetry at LEP:

$A_{FB}^{0,q} = \frac{3}{4} A_e A_q$

$A_f = 2 g_V g_A / (g_A^2+g_V^2)$

g_V/g_A ➔ $\sin^2\theta_{eff}$



➔ LEP: $A_{FB}^{b,c}$ mainly sensitive to A_e:

➔ SLD: e^- beam ~73% polarised ➔Ab

At LEP: Use Γ_b and A_{FB}^b

→ A_b and A_e separately!

HEAVY FLAVOUR E'WEAK: STATUS

LEP1 heavy flavour measurements ~complete.

$R_{b,c}$

- Measurements completed.
  - multitag analyses using vertices, vertex mass, leptons etc.

hadronic $A_{FB}^{b,c}$

- Summer 2002: New measurement from OPAL.
  - Using jet/vertex/kaon charge
  - New tools from B oscillations / CP violation / R_b analyses.
  - Greatly reduced stat. and syst. errors.
- To come: New result from DELPHI

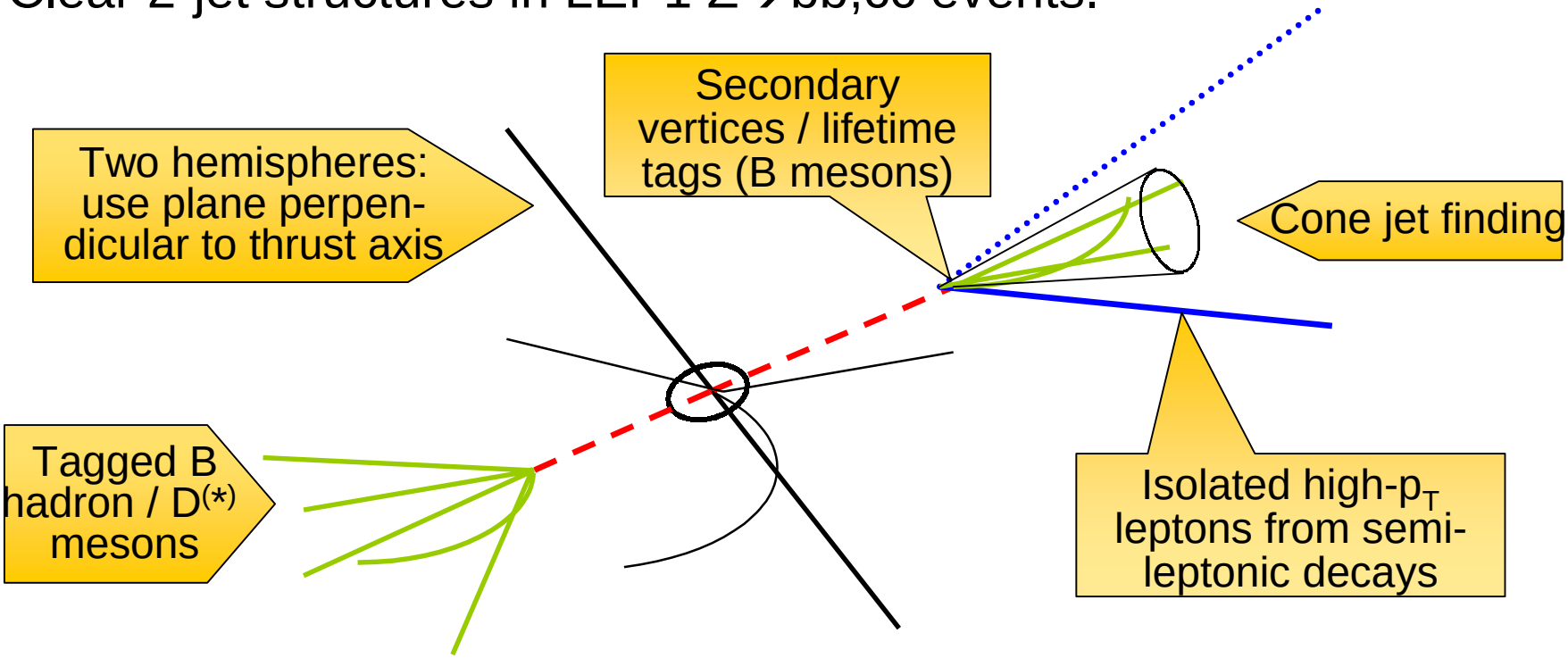
leptonic $A_{FB}^{b,c}$

- Summer 2002: New preliminary DELPHI $A_{FB}^{b,c}$
  - Update of older preliminary analysis with new systematics
- To come: New result from OPAL

Final LEP1 + SLD HF EW results very close!

THE ENVIRONMENT

Clear 2-jet structures in LEP1 Z→bb,cc events.



Flavour/ charge tags

Independent hemisphere with various tag methods:

¶ flavour: lifetime/vertex, leptons, D* …

¶ charge (for asymmetries): vertex, jet, kaon, lepton, D* …

Systematic issues

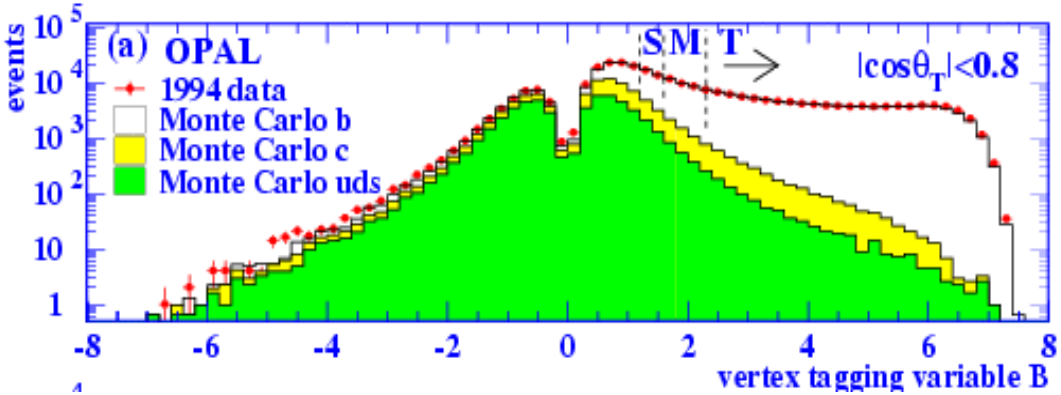
Wrong flavour backgrounds, hemisphere correlations, heavy quark fragmentation, semileptonic decay models.

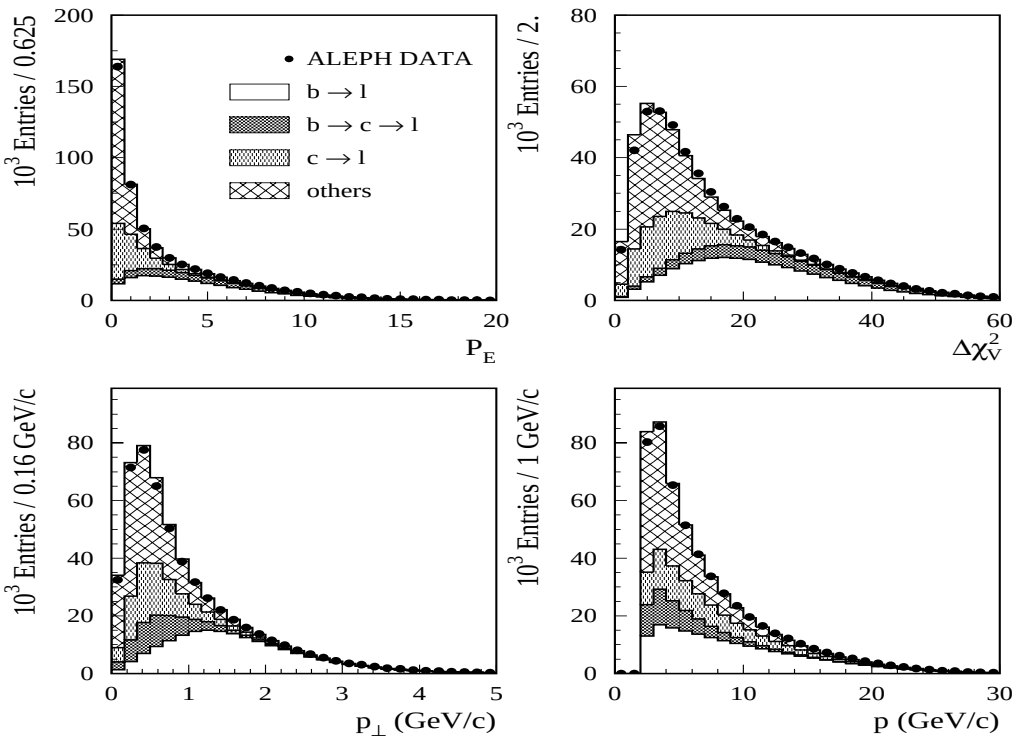
HEAVY FLAVOUR TAGGING

Separate b and c events from uds background.

Vertex b tagging:

- ¶ Combine vertex parameters with likelihood or NN.
- ¶ Several tagging classes?
- ¶ High purities, ε=25-50%





Lepton b,c tagging:

- ¶ high p_T of leptons from semi-leptonic b,c,decays.
- ¶ Limited by small branching ratios for b,c,→l.
- ¶ High weight for A_{FB} (lepton tags quark charge).
- ¶ c tagging with $D^{(*)}$ mesons (small statistics).

$A_{FB}^{b,c}$: TAGGING THE QUARK FLAVOUR

Hadrons: b,c ↔ anti-b,c? Leptons: b→l ↔ c→ ↔ b→c→l ↔ BG

Jet charge

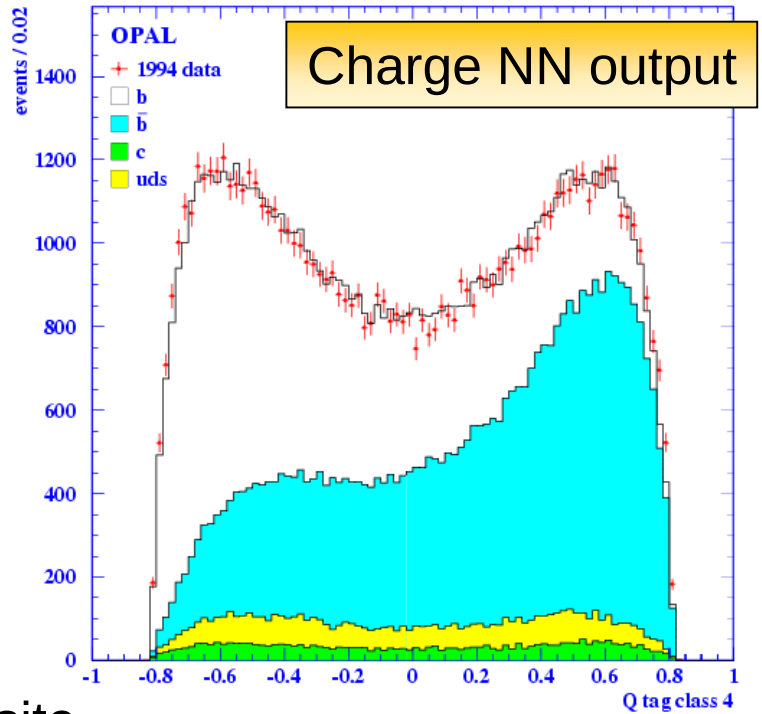
$Q_{jet}^{\kappa} = \Sigma_l(p_i^l)^{\kappa} q_i / \Sigma_l(p_i^l)^{\kappa}$
(track momentum p)

Vertex charge

$Q_{vtx} = \Sigma_l \omega_i q_i$ (track charge q_i)

Kaon charge

From cascades b→c→s.
Use dE/dx, RICH etc.



Lepton analyses

Use lepton p, p_T, E_{miss}, opposite hemisphere charge, track charges (~same var.s as for HF tag).

Correlation

leptonic ↔ hadronic analyses. Statistical approach: Repeat analyses in many MC samples.

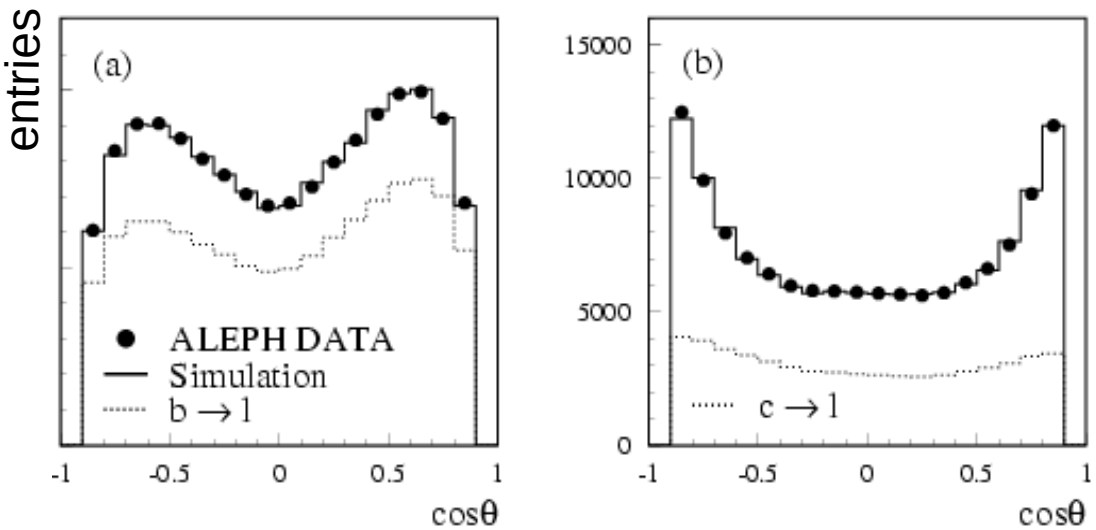
EXTRACTING $R_{b,c}$ AND $A_{FB}^{b,c}$

Challenge: Determination of sample purities, efficiencies etc.

$$N_t / 2N_{had} = R_b \cdot \varepsilon_b + R_c \cdot \varepsilon_c + (1-R_b-R_c) \cdot \varepsilon_{uds}$$
$$N_{tt} / N_{had} = D_b \cdot R_b \cdot \varepsilon_b \cdot \varepsilon_b + D_c^{kl} \cdot R_c \cdot \varepsilon_c \cdot \varepsilon_c + (1-R_b-R_c) \cdot \varepsilon_{uds} \cdot \varepsilon_{uds}$$

$$\langle Q_F - Q_B \rangle = \Sigma_i \, s_i \cdot \delta_i \cdot P_i \cdot C_i \cdot A_{FB}^{\,i}$$

- Complex multi-dimensional fits
- As much info as possible from data
- Performed in various tagging classes → exploit all information



Lepton analyses

- Wrong-sign leptons: B^0 mixing or b→c→l decays
- Improve precision by extracting $A_{FB}^{\,b}$ and $A_{FB}^{\,c}$.

HEMISPHERE CORRELATIONS

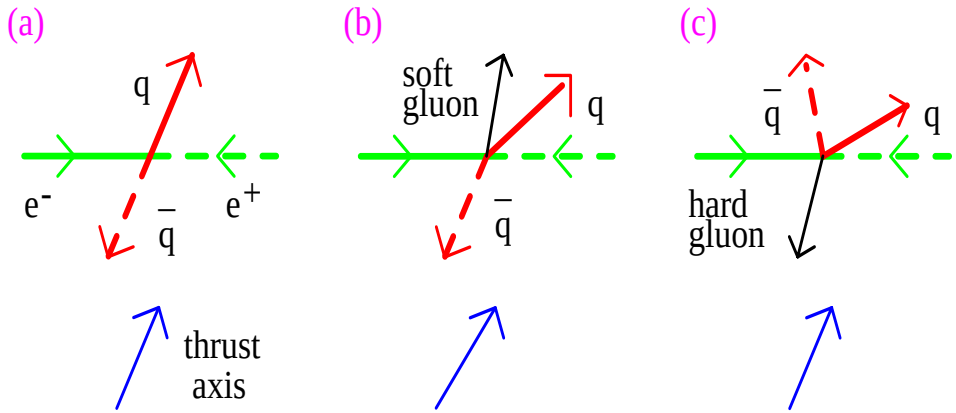
For flavour and charge tags → large uncertainty.

Problem

¶ Measurements of flavour and charge tags correlated between both hemispheres

-Tag efficiency is function of θ
→ geometrical correlations

- gluon radiation + soft particles
→ kinematical correlations



Effect

¶ For R_b dominant error; in A_{FB}^b measurements large charge tag correlation due to gluon radiation.

¶ Geometrical correlation can be taken from data; for A_{FB}^b kinematical correlation small → take from MC.

OPAL A_{FB}^b at peak energy: 0.00089 (of 0.00179).

HEAVY FLAVOUR EW FITS

Combine all knowledge, taking correlations into account.

Task

Derive best HF EW parameters from all measurements (LEP1 and SLD), taking full correlation into account:

Inter-dependence ($R_b = R_b(<R_c>)$), common syst. (QCD corrections), specific syst. and external inputs

Fit

Simultaneous fit to 'all' EW observables and of

- Charm hadron production fractions (D, D_s, baryons)
- leptonic BRs b→l, b→c→l, c→l, mixing χ.

Perform separate fits to LEP $A_{FB}^{b,c}$ and SLD $A^{b,c}$.

- For LEP at different energy points → change of A_{FB}.

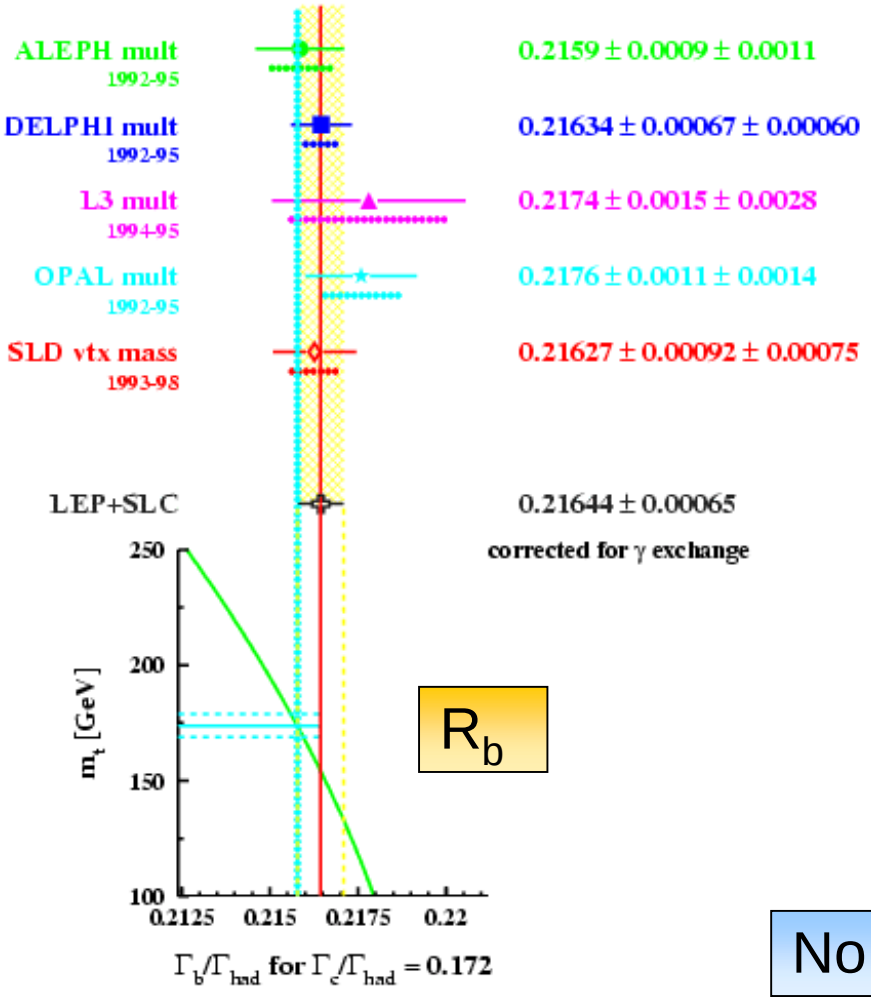
Result

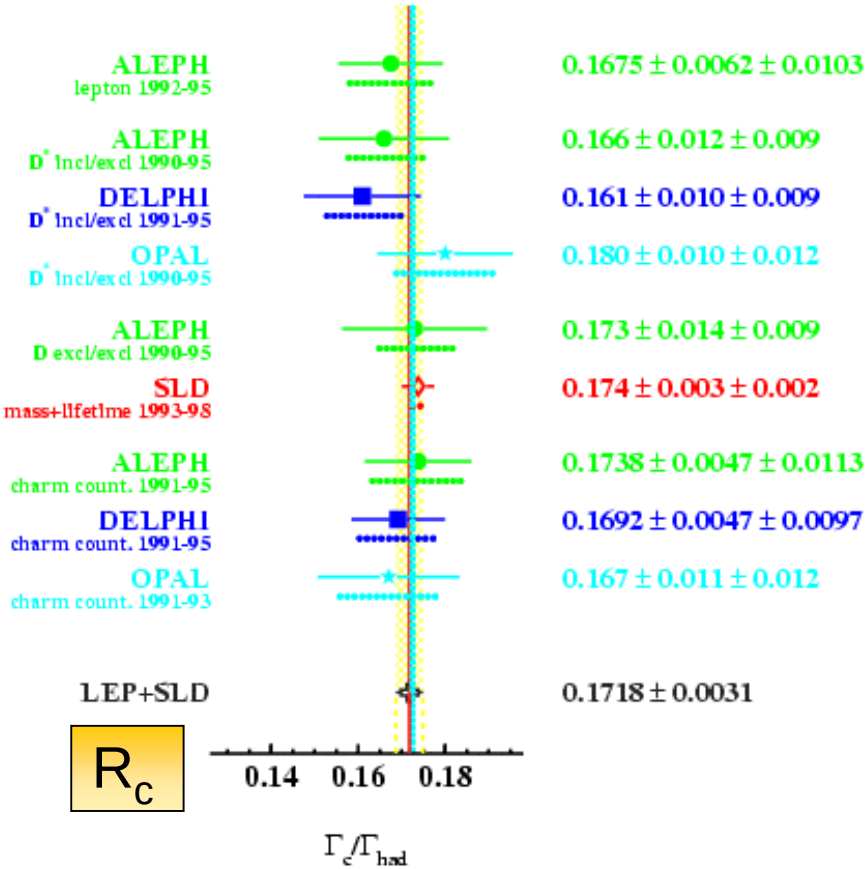
Final χ^2 rather small: 48/(105-14).

mainly from large correlated systematics.

RESULTS: R_b and R_c

R_b measurement in good agreement with Tevatron top mass.

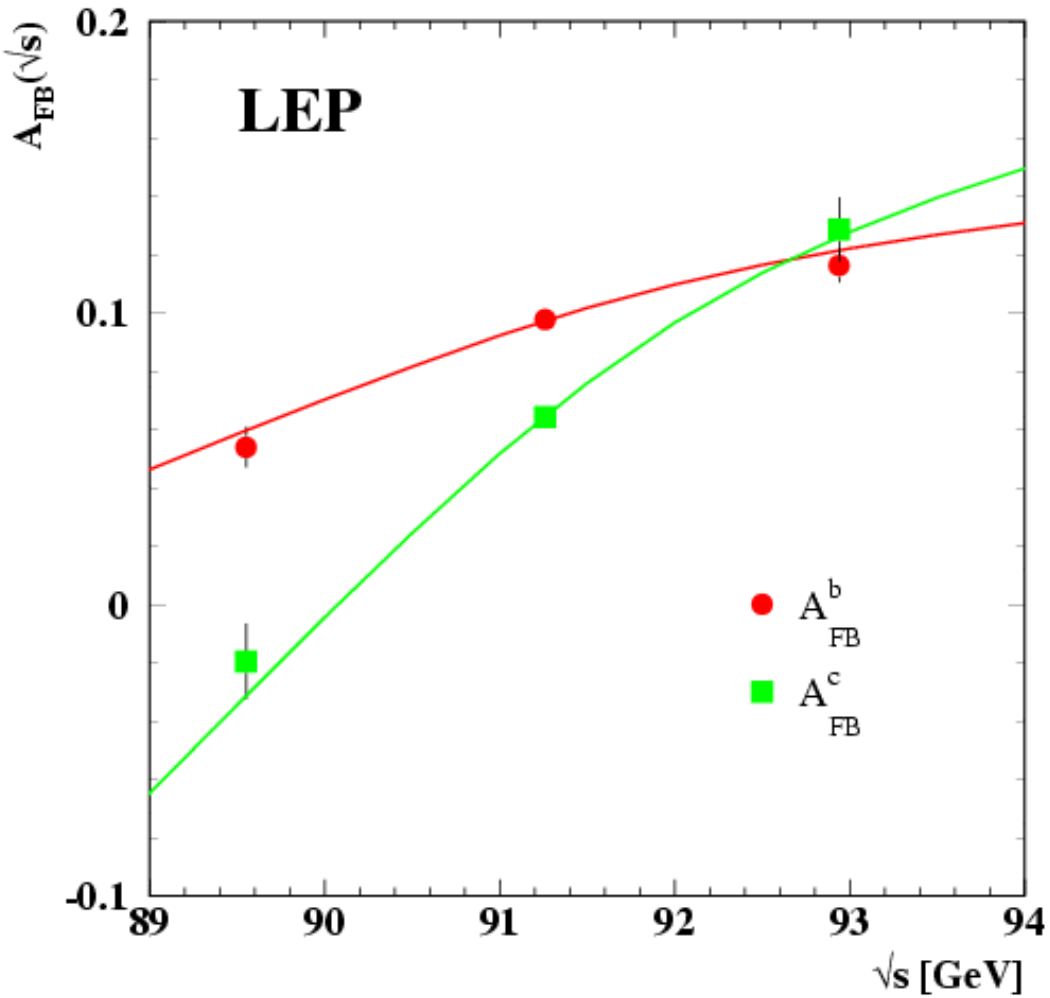




No news since quite some time.

RESULTS: ASYMMETRIES vs. ENERGY

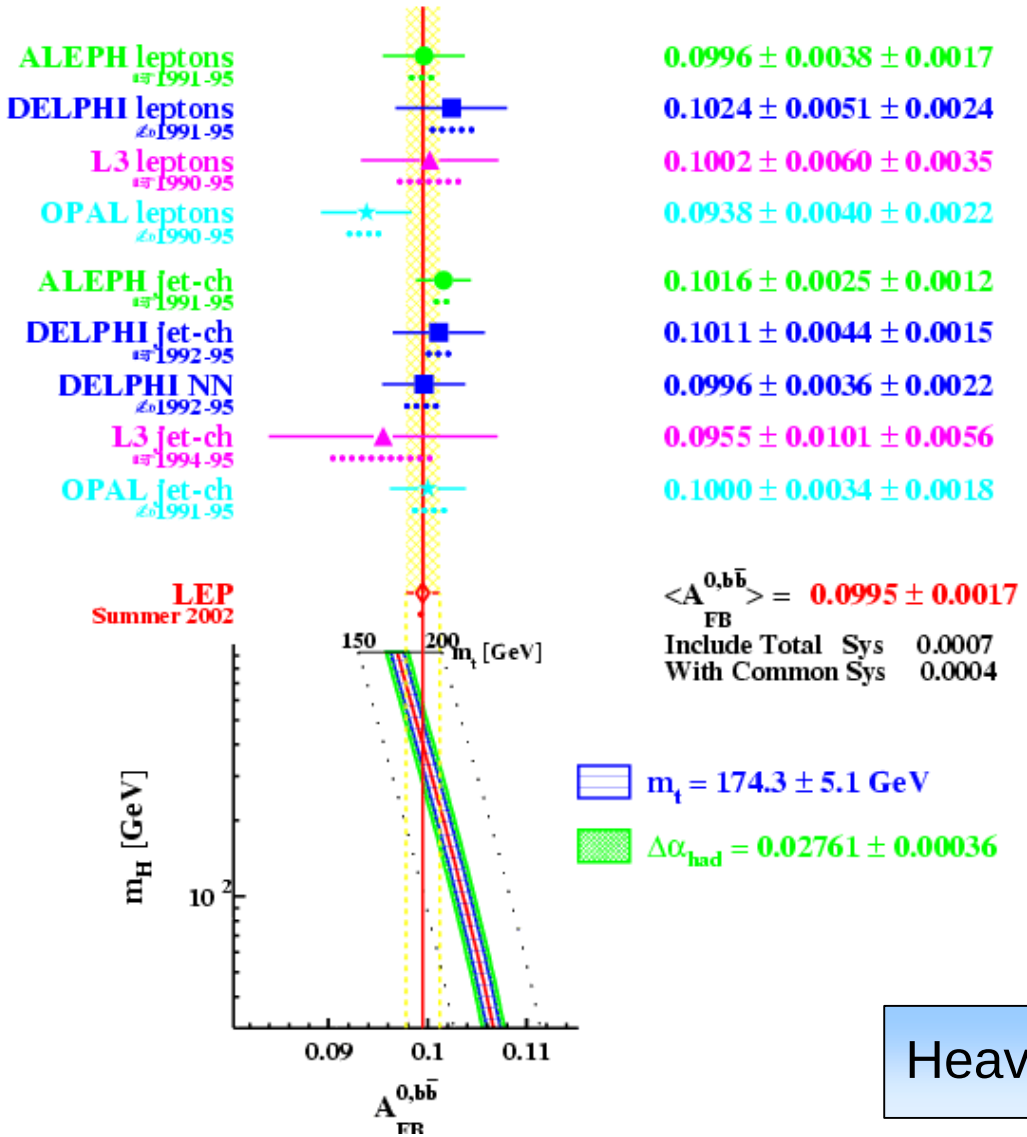
Influences Z/γ contributions and interference between them.



Correct all A_{FB} values to 3 common energies, average at each energy in one single fit.

Data in agreement with SM expectation (ZFITTER)

RESULTS: b ASYMMETRIES AT Z



Many measurements with good agreement

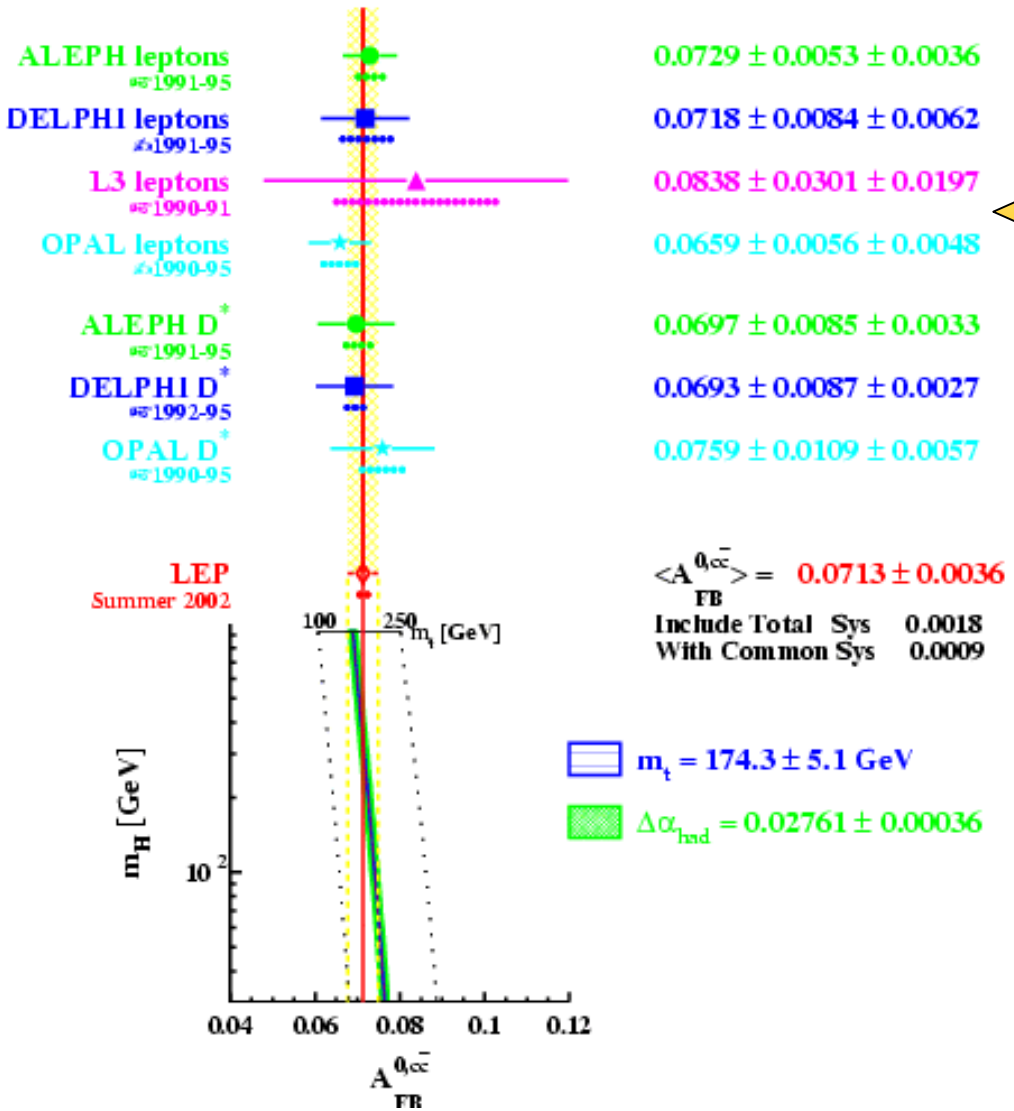
- leptonic analyses (b→l)
- inclusive (jets, vertices, leptons,…)
- inclusive more precise.

Stable combined value:

$A_{FB}^{0,b} = 0.0995 \pm 0.0015 \pm 0.0007 \pm 0.0004$

Heavy Higgs (400 GeV) prefered.

RESULTS: c ASYMMETRIES AT Z

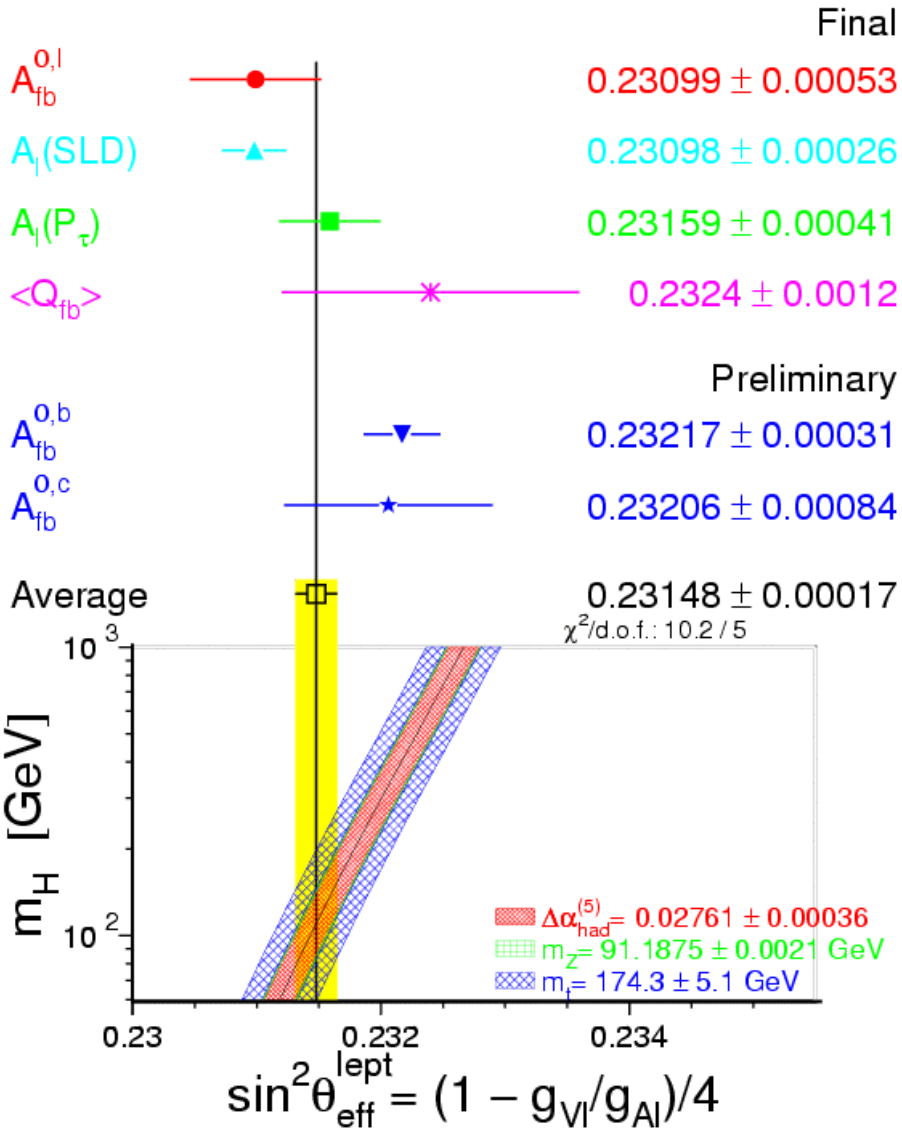


Also several analyses.

- leptonic analyses (c→l)
- D*.

$A_{FB}^{0,c} = 0.0713 \pm 0.0031 \pm 0.0018 \pm 0.0009$

STANDARD MODEL INTERPRETATION



Interpretation in terms of $\sin^2\theta_{eff}$.

- leptons: 0.23113±0.00021
- hadrons: 0.23217±0.00029

2.9σ discrepancy!!!

- mainly due to A_{LR} vs. A_{FB}^b

Overall combination:

- $\sin^2\theta_{eff}$ = 0.23148±0.00017
- χ^2 = 10.2/5 (7%)
- prefers m_H ~ 100 GeV

Statistical fluctuation? Very large common syst. effect? New physics in b couplings?

OVERVIEW

¶ HEAVY FLAVOUR E'WEAK MEASUREMENTS

¶ 2-FERMION PROCESSES @ LEP2
- Issues in LEP2 ee→ff
- Measurements
- Interpretation in Terms of New Physics

¶ SUMMARY

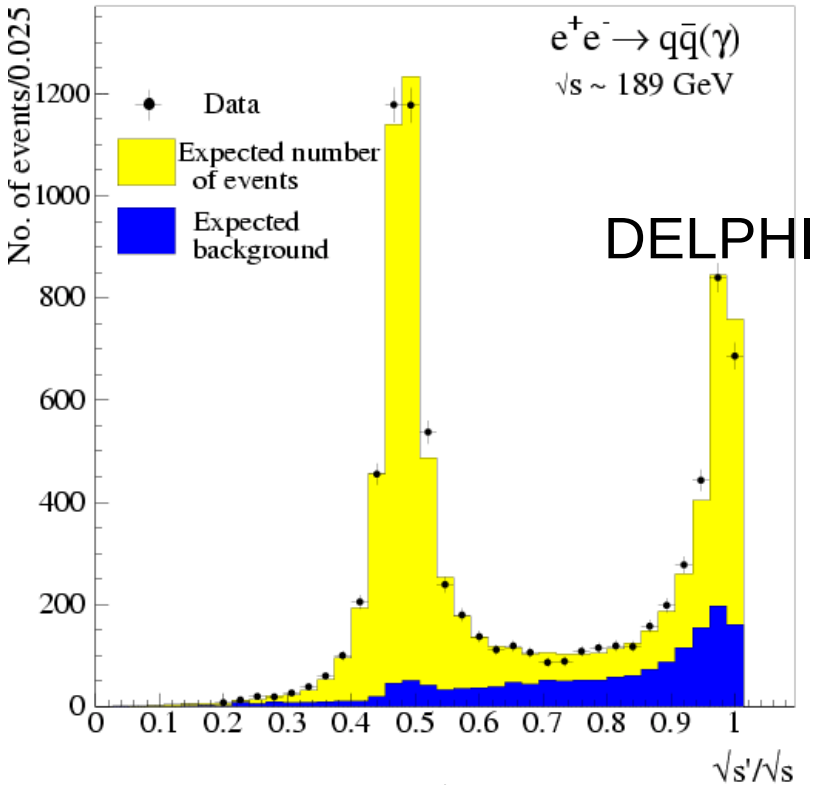
ISSUES IN ee→ff @ LEP2

Different to LEP1: Now assume Z,γ and look for new physics.

Interest:

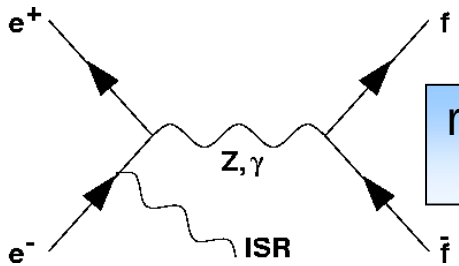
Z exchange off resonance

➔ interference with new physics?



Problem ISR

Remove by cut on √s' (0.85-0.9 × √s)



radiative Z return

Measure

¶ Cross-sections for ee→ff

¶ FB asymmetries, $R_{b,c}$

New models

¶ Contact interactions

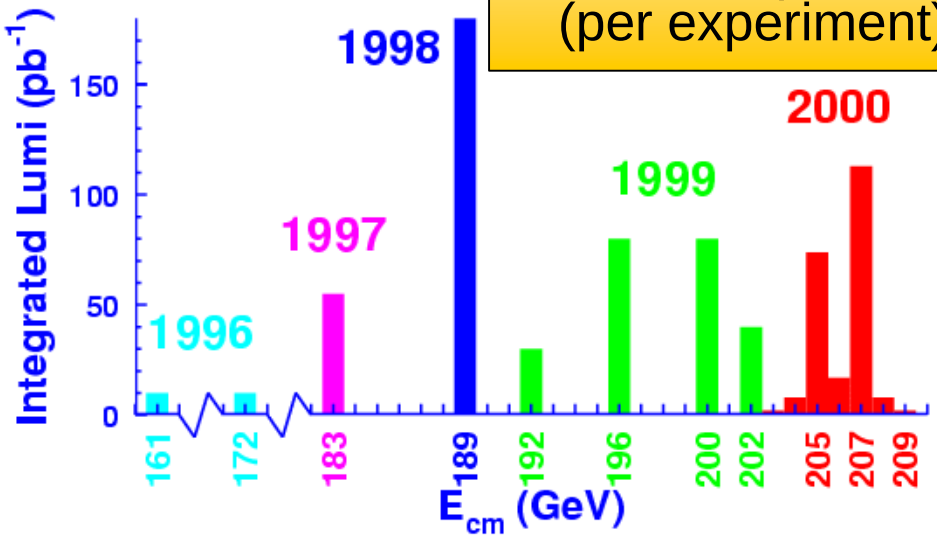
¶ low scale gravity

¶ Leptoquarks

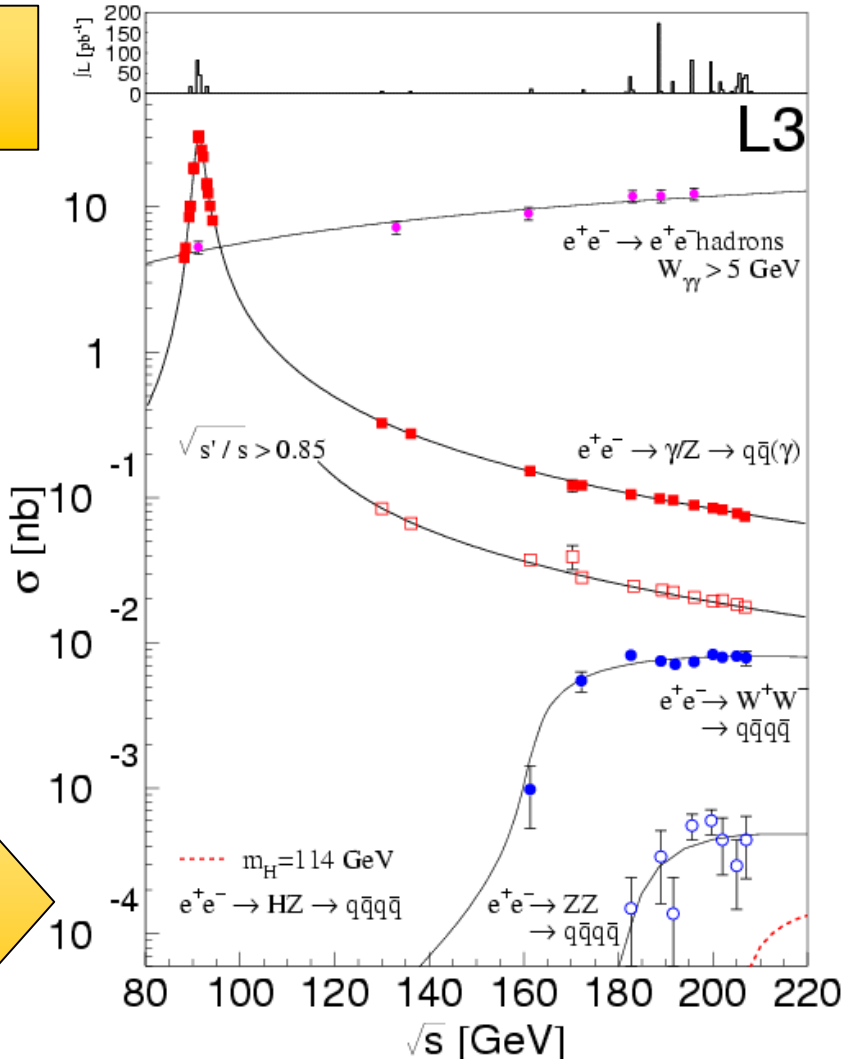
¶ Z' bosons

LEP2 RUNNING

Overview on Luminosities and Centre-of-Mass Energies.



~700 pb^{-1}
(per experiment)



Cross-sections dominated by Σqq(ISR) with ~100 pb (s' cut)

CROSS-SECTIONS FOR qq, μμ, ττ

2f Signal — Corrections to have common definition

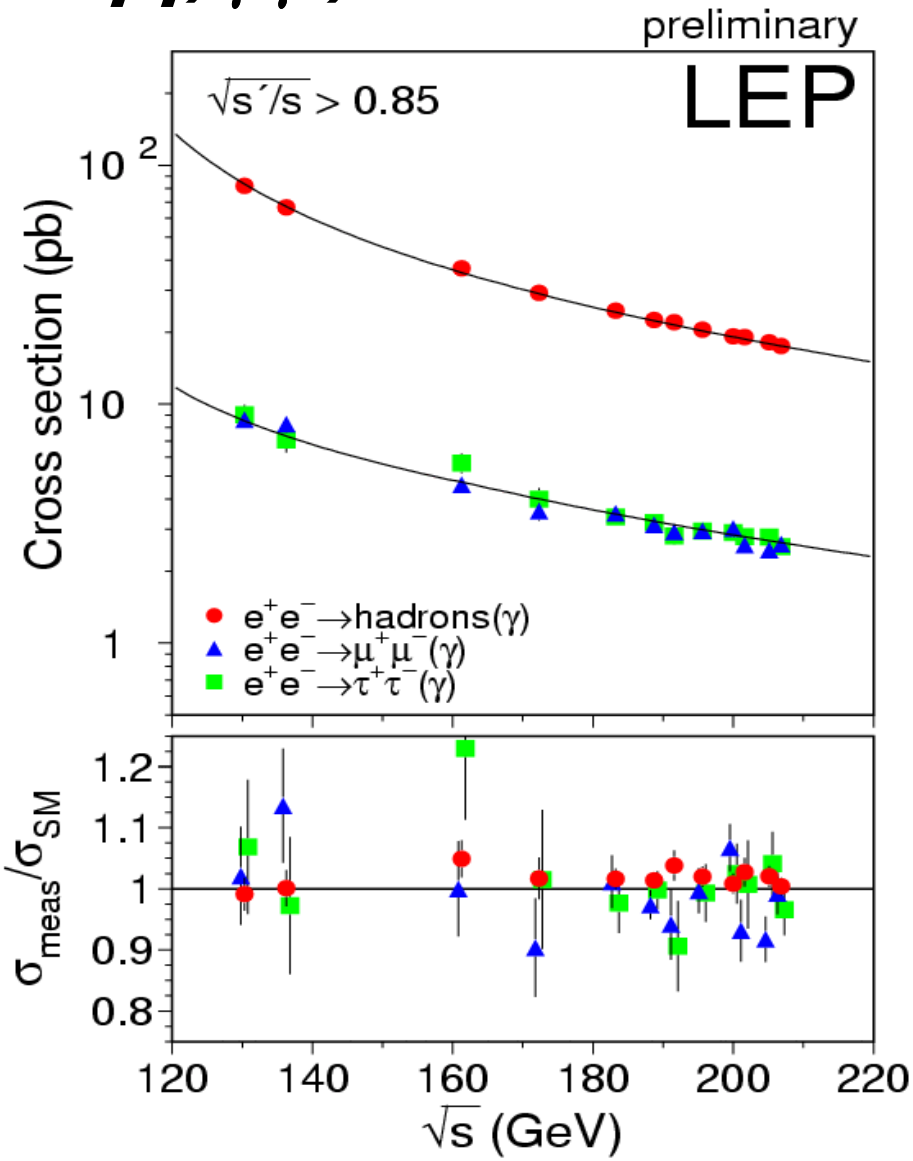
- $\sqrt{s'} = Q$ (or M_{ff}?) > 0.85/0.9 $\sqrt{s}$?
- Extrapolation to 4π detector
- ISR-FSR interference, IS non-singlet contributions?

Procedure — All data averaged at same time.

- Best linear estimator technique (~χ^2 minimisation).
- New prel. results from ALEPH

Result — σ(hadrons) high

- 1.7 standard deviations, taking all correlations into account.
- Total χ^2 = 160/180.

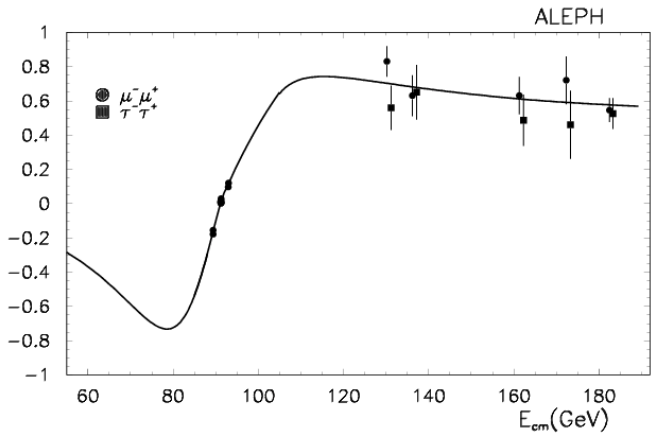


ASYMMETRIES

Separately for ee→μμ and ττ.

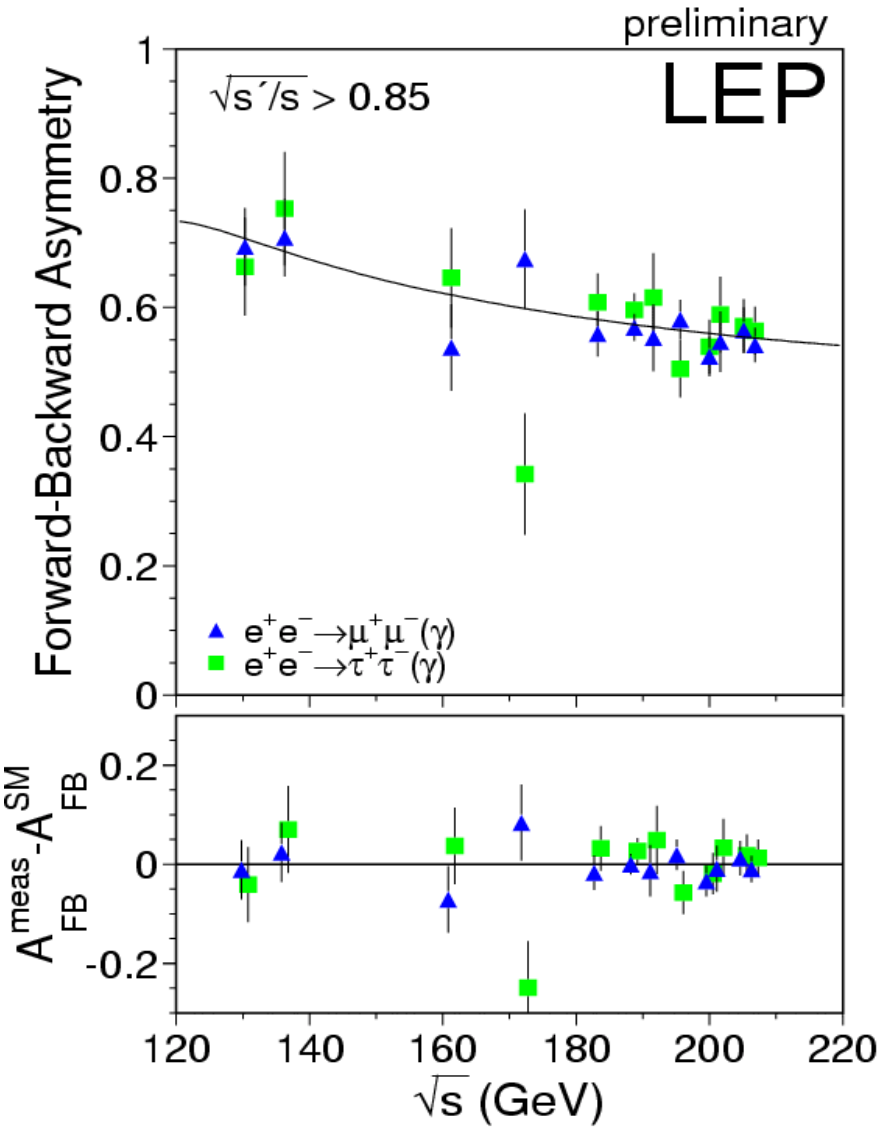
$A_{FB}(E_{CM})$

Transition γ/Z interference →EW model



Result

Good description by ZFITTER prediction

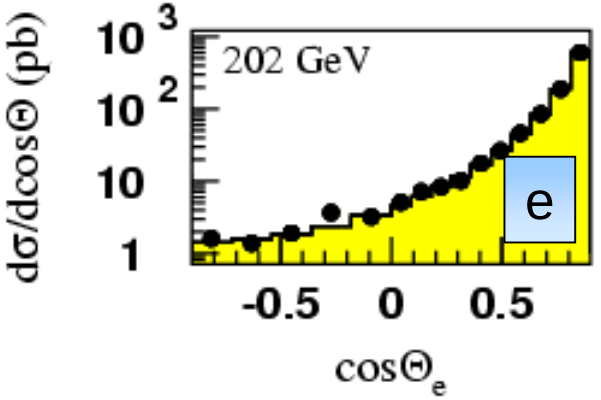


DIFFERENTIAL CROSS-SECTIONS

Special case for ee→ee.

General

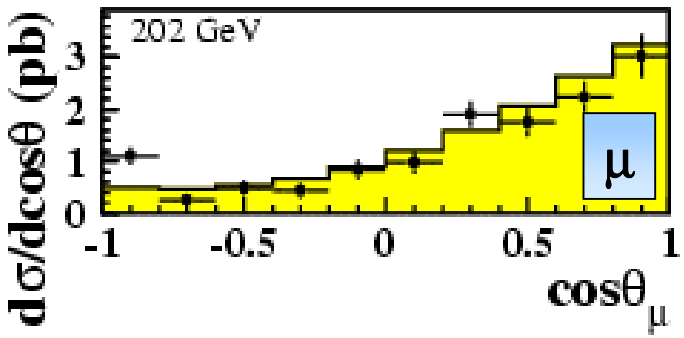
- First and last bin correlated (forward charge determination)
- Bin-to-bin correlations?



ee→ee

Additional process: electron scattering

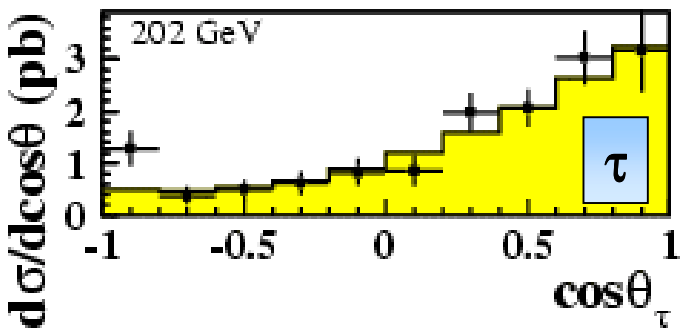
- Diverges for cosθ=1
  → maximal asymmetry (log scale!)



Results

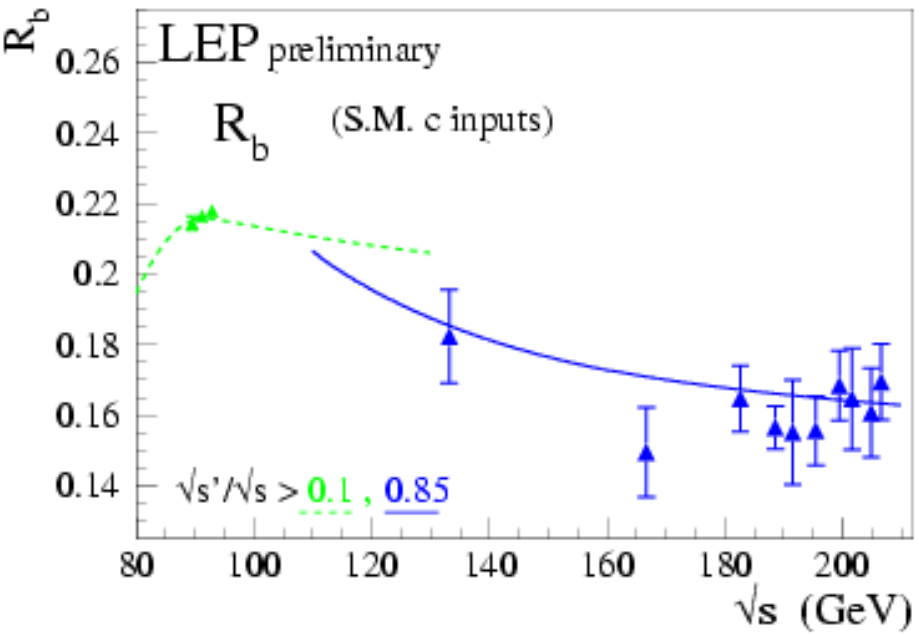
Good description by ZFITTER prediction

- total χ^2 = 200/160
- 202 GeV: lowest bin high (μ and τ), but low statistics



HEAVY FLAVOURS AT LEP2 I

Heavy flavour fractions $R_q = \sigma(e^+e^- \to qq)/\sigma(e^+e^- \to qq)$ q=b,c.



Signal

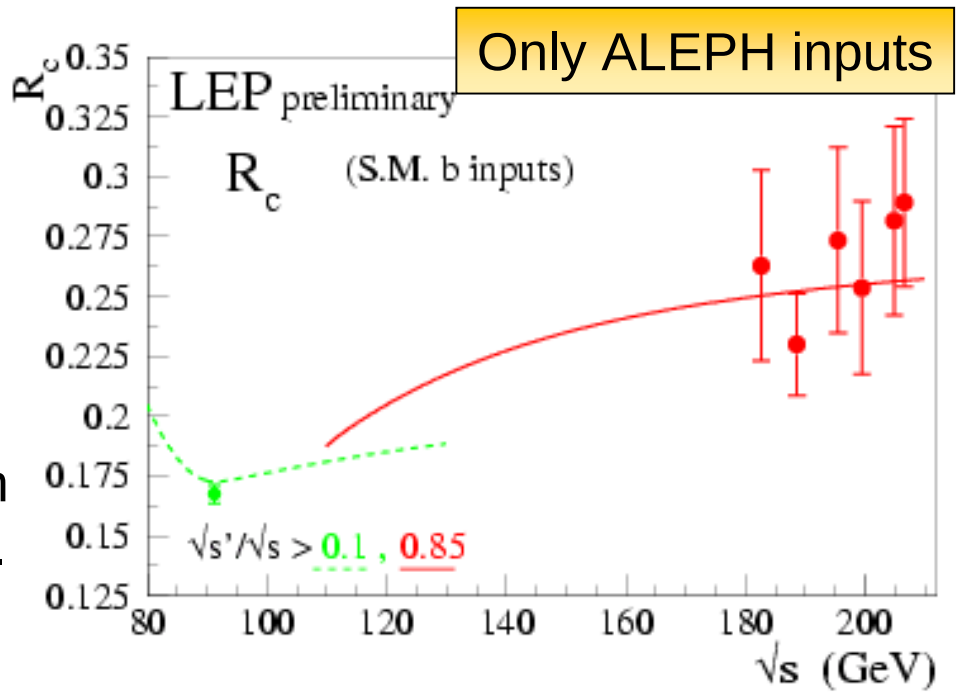
- √s' > 0.85 √s
- extrapolation to 4π
- no ISR/FSR inter-ference subtraction

Also shown — data from LEP1

Result — Good agreement with ZFITTER predictions.

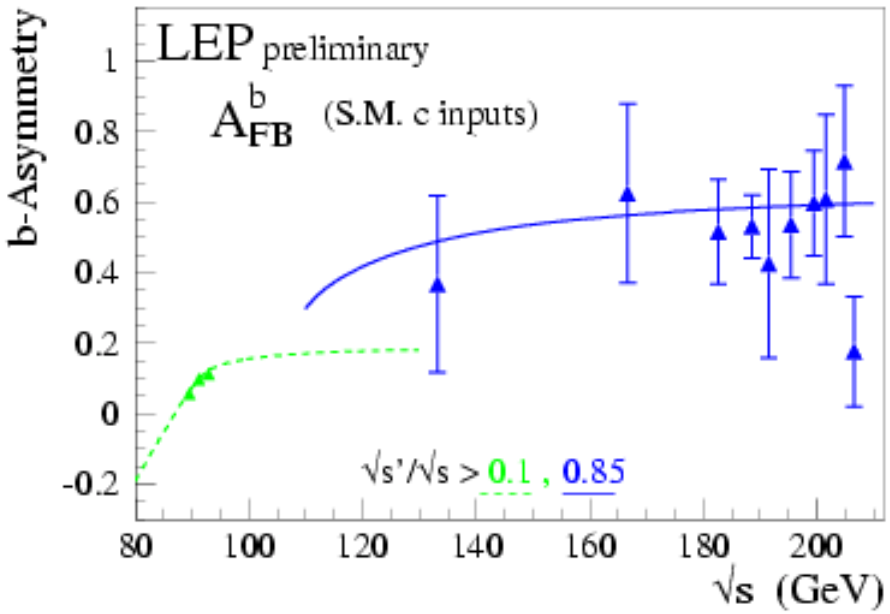
Largest discrepancy: -2.08σ for R_b

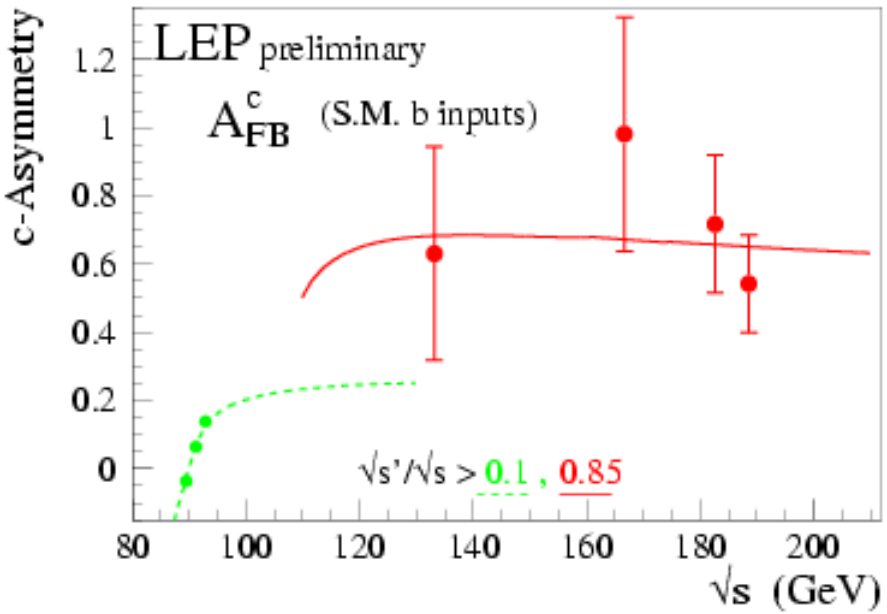
Only ALEPH inputs



HEAVY FLAVOURS AT LEP2 II

Forward-backward asymmetries $A_{FB}^{b(c)}$.

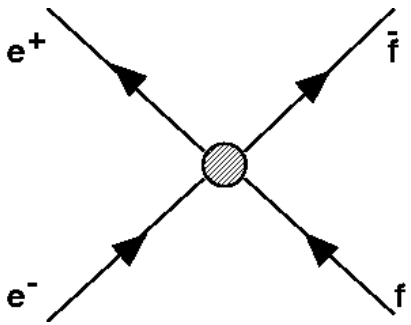




CONTACT INTERACTIONS I

Idea LEP2 sensitive to new Lagrangian contributions

$$L_{eff} = \frac{g^2}{(1+\delta)\Lambda^2} \sum_{i,j=L,R} \eta_{ij} (\bar{e}_i \gamma_\mu e_i)(\bar{f}_j \gamma^\mu f_j)$$

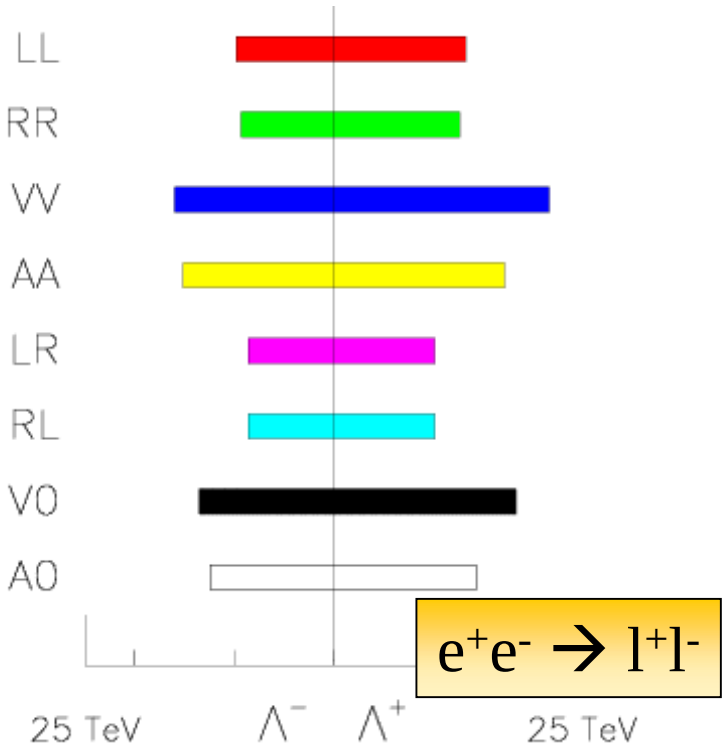


Models Different helicity couplings between IS and FS with constructive/destructive SM interference → variety of models.

Results

- Fit for $\varepsilon = 1/\Lambda^2$ (0 for no CI)
- Convert ε in limit on Λ.

$\Lambda > 2.1 – 21.7$ GeV



Z' BOSONS AT LEP2

Z' might be sign of more complete theory above/behind SM.

GUT

E6 → SO(10) x $U(1)_\chi$

SO(10) → SU(5) x $U(1)_\psi$

SU(5) → $SU(3)_C$ x $SU(2)_L$ x $U(1)_Y$

→ χ,ψ and (mix) η models

Sequential SM

Existence of Z' (same couplings).

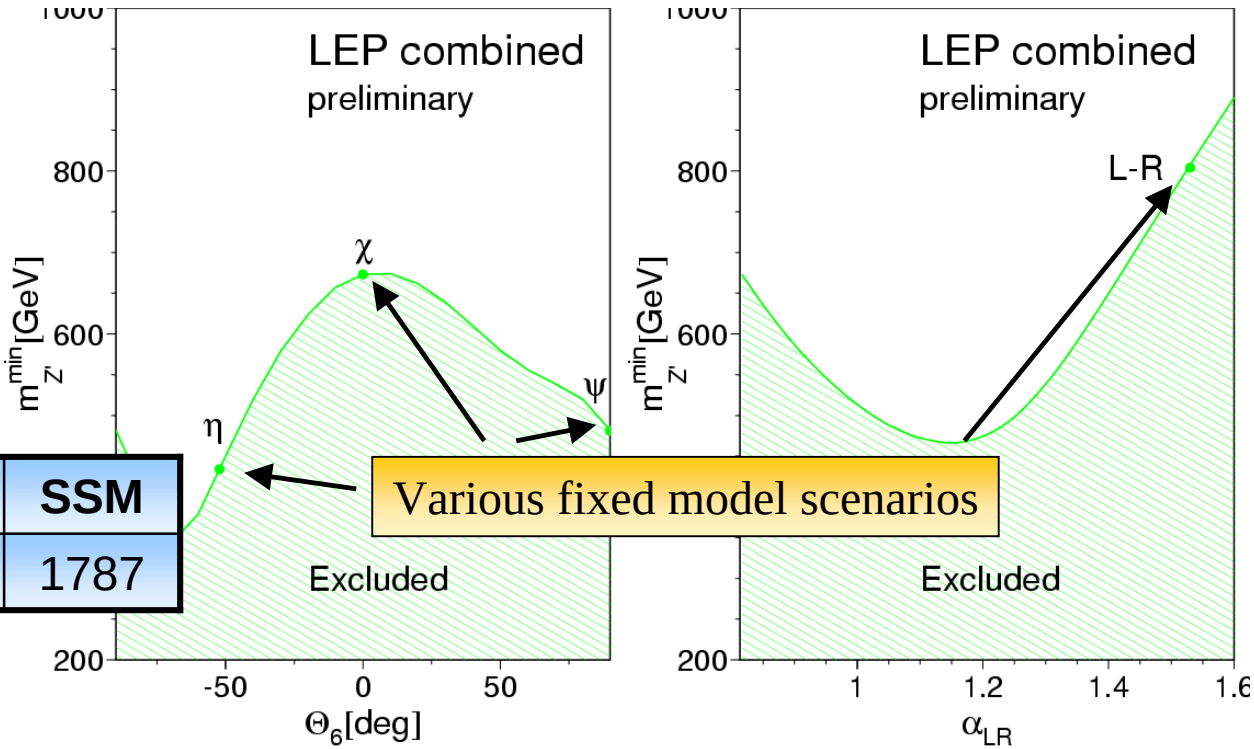
L/R model

Additional $SU(2)_R$ with Z' and W'+/-.

Fit for $M_{Z'}$

- No evidence for Z'.
- Limits: Introduce contact terms $\Lambda \sim M_{Z'}$ (values in GeV).

χ	ψ	η	L/R	SSM
673	481	434	804	1787



LOW SCALE GRAVITY

Large extra dimensions possible solution to hierarchy problem → connect m_{EW} (1 TeV) and M_{Pl}.(10^{15} TeV).

Introduce new scale $M_{Pl}^2 = M^{2+n}_{Pl(4+n)} R^n$

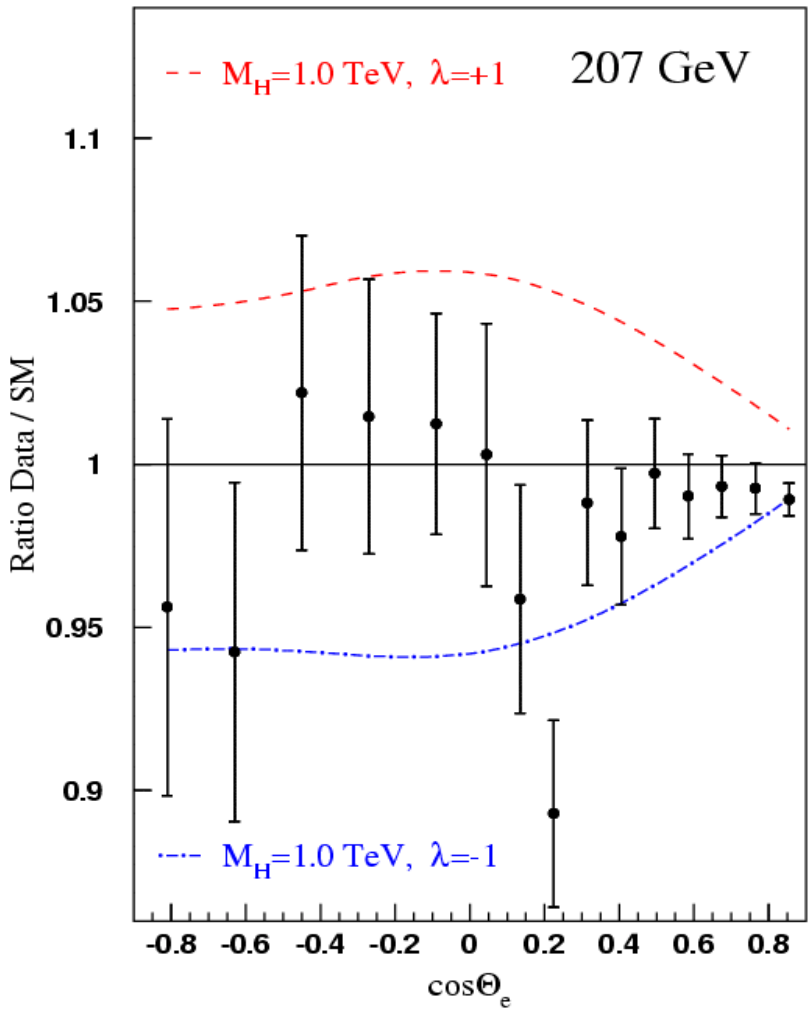
- $M_{Pl(4+n)}$: new 'Planck' scale (~EW)
- R: radius of new dimension (mm)

Effect Interference Graviton-SM

- New terms in cross-section:
  ~ A(SM) + B λ/M_H^4 + C$(\lambda/M_H^4)^2$
  with $M_H \sim M_D$.
- With $\varepsilon = \lambda/M_H^4$ and $\lambda = \pm 1$ can fit for ε and derive limit on M_H.

Result ε in agreement with SM (0).

$M_H > 1.20\ (1.09)$ TeV for $\lambda = +1\ (-1)$



SUMMARY

Heavy Flavours @ LEP1

- Heavy flavour EW physics results from LEP1/ SLD slowly coming to an end.
- OPAL leptons and DELPHI jet charge A_{FB} to come. Some analyses still preliminary.

EW Physics @ LEP1

- EW results on asymmetries / $\sin^2\theta_{eff}$ interesting:
  - 2.9σ discrepancy between leptonic and hadronic measurements. Statistical?
  - New physics? Modification of b vertex? New gauge bosons?

2f proc.s @ LEP2

- Aim: Find interferences with γ/Z from new physics and place limits.
- All cross-sections and asymmetries well described (largest deviation: R_b with 2.08σ.
- No evidence for new physics. Limits > 1 TeV.

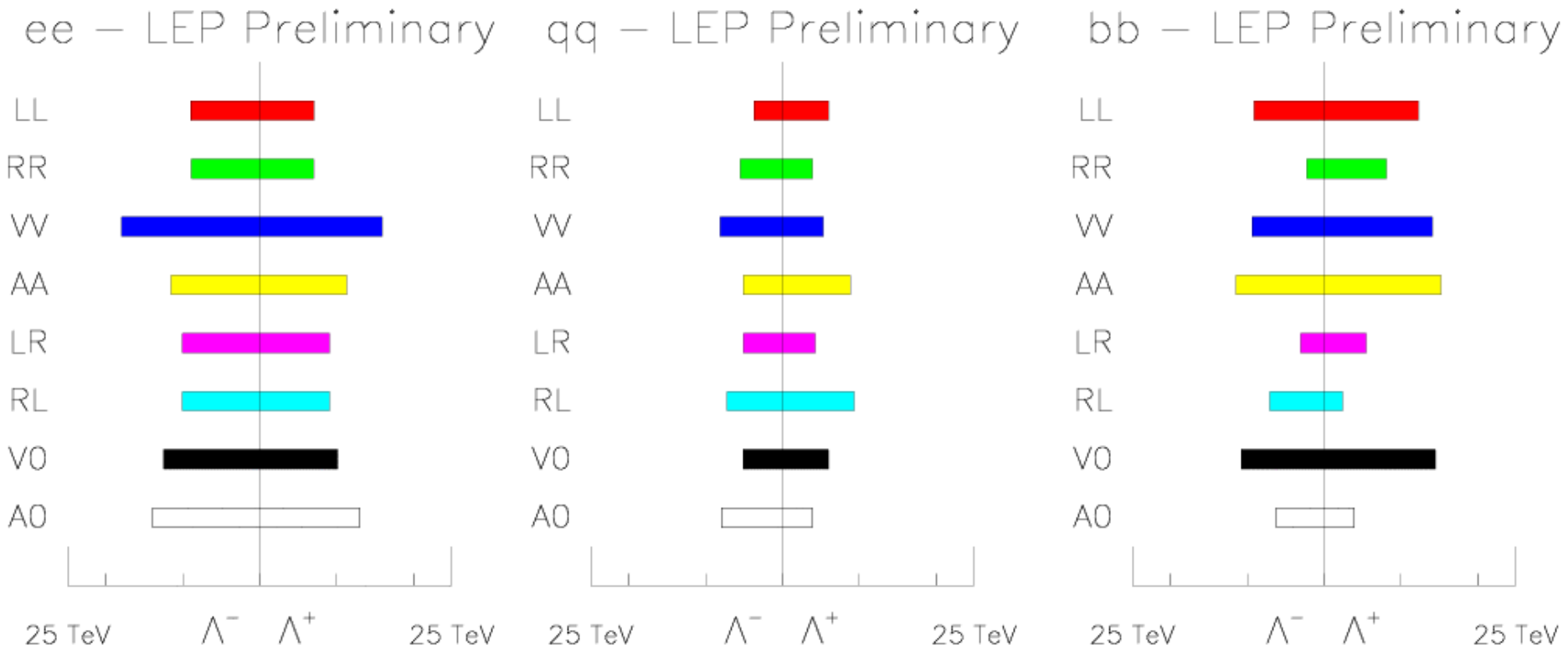
BACK-UP MATERIAL

CONTACT INTERACTIONS II

Results $\Lambda > 2.1 - 21.7$ TeV.

Electron radius ee channel → upper limit on r_e (VV models, pos. interference, electron coupling strength):

$r_e < 1.4 \times 10^{-19}$ m



LEPTOQUARKS

Mediate quark-lepton transitions → modification of hadronic σ,A_{FB}.

Lepto-quarks

- Classified by (iso)spin: S_l, V_l.
- Carry fermion number F=L+3B and preserve L and B.

Analysis

- Use σ(had), $R_{b,c}$, A_{FB}b,c to set upper limits on LQ couplings to 1st, 2nd, 3rd generation quarks.
- Derive 95% CL lower limit on M_{LQ}.

3rd generation results:

- for various LQs.
- line: e coupling g~$\sqrt{4\pi\alpha_{EM}}$