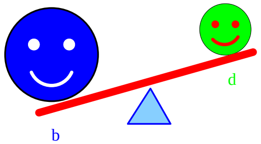
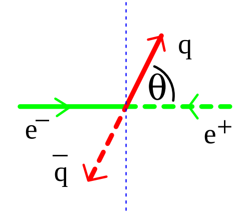


Heavy flavour electroweak physics at LEP1/SLD

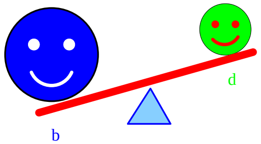


Richard Hawkings (CERN/OPAL)

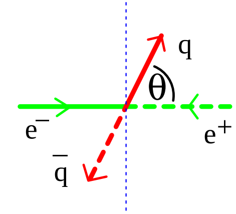
ICHEP02 (Amsterdam), session 4

- Heavy flavour electroweak measurements at the Z^0:
  - Motivation and background
  - What's new – details of the latest measurements
    - b and c quark asymmetries, (partial widths)
  - Heavy flavour electroweak fit results
  - Interpretation and conclusions

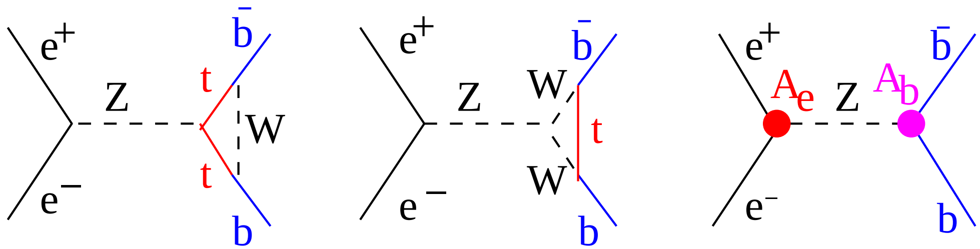
  - Thanks to LEP heavy flavour electroweak group.
    - See http://lepewwg.web.cern.ch/LEPEWWG for numbers, plots…

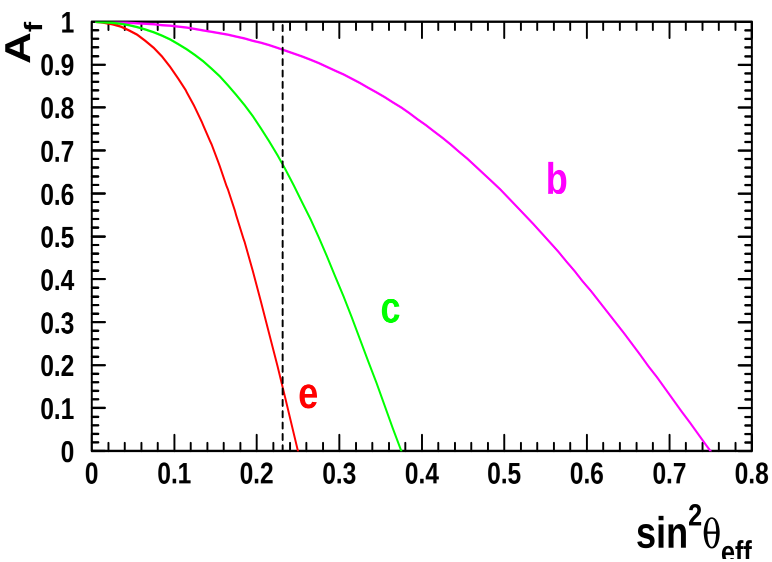


Theoretical Motivation

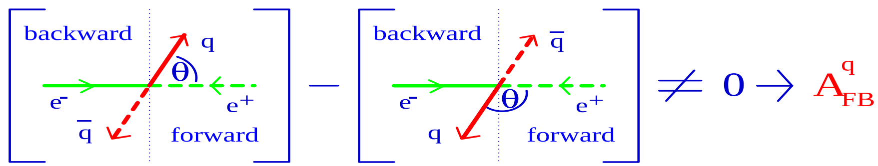


- Measurement Z^0 partial decay width:
  - $R_b \cong \Gamma(b\bar{b})/\Gamma(had)$
  - Vertex corrections involving top
    - New physics coupling to mass ?

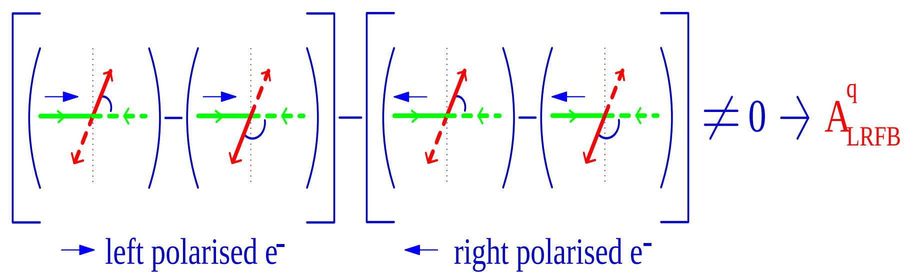


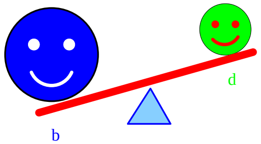


- Measurement of asymmetries:
  - At LEP $A_{FB}^{0,q} = \frac{3}{4} A_e A_q$

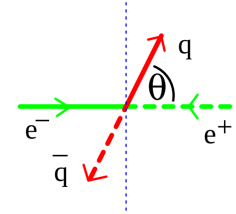


    - $A_f = 2g_V g_A/(g_V^2 + g_A^2)$
    - Effective couplings $g_V/g_A \Rightarrow \sin^2\theta_{eff}$
  - LEP: A_{FB}^b mainly sensitive to A_e
    - Due to isospin structure for e,b.
  - SLD: e^- beam polarisation (~73%) allows direct measurement of A_b

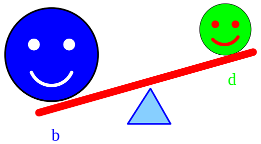




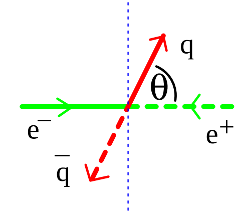
Heavy flavour electroweak - what's new ?



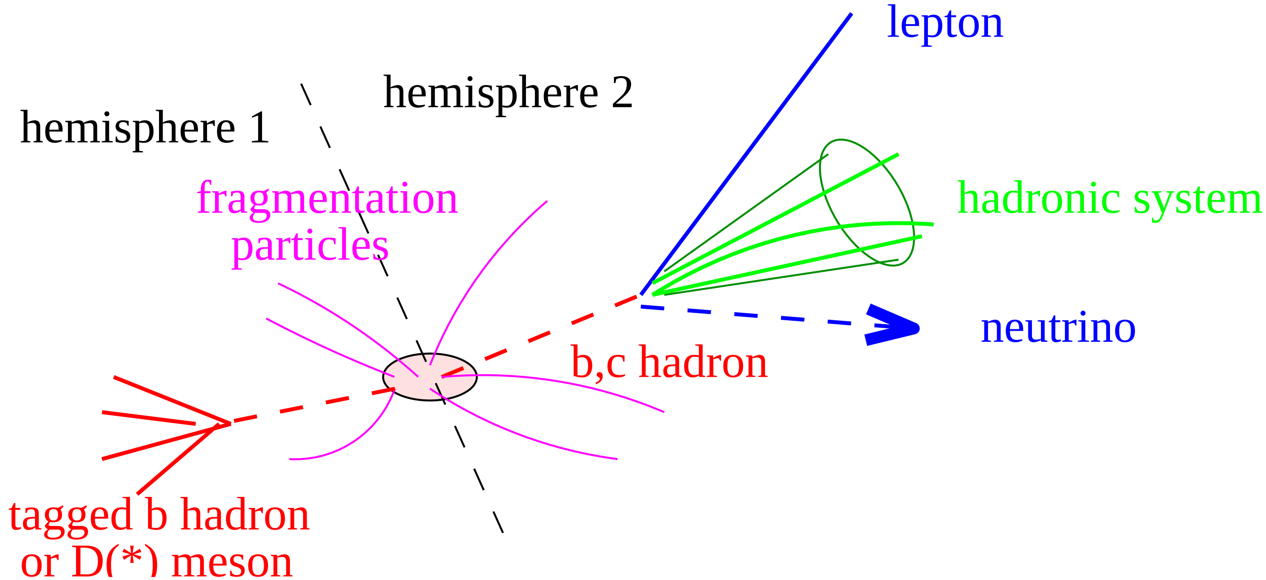
- New since Winter 02:
  - R_b/R_c - nothing… everything is finished.
  - New OPAL A_{FB}^b result using jet/vertex/kaon charge:
    - Improved b-tagging (from R_b measurement)
    - New charge tagging (from B oscillations/CP-violation analyses)
    - Extend $|\cos\theta|$ acceptance from 0.8 to 0.95.
    - Add 0.5M Z^0 from LEP2 calibration data…
    - Uncertainty now 57% of old OPAL jet/vertex charge analysis.
    - Final: CERN-EP-2002-053, submitted to Phys. Lett. B.
  - Updated DELPHI A_{FB}^b and A_{FB}^c analysis with leptons
    - Update of existing preliminary result
    - Basically same analysis, updated systematics
    - Almost finalised for publication



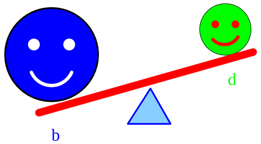
Experimental environment at LEP and SLD



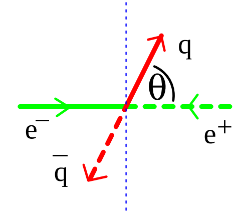
- Basic structure of $Z \to b\bar{b}$ and $Z \to c\bar{c}$ events:



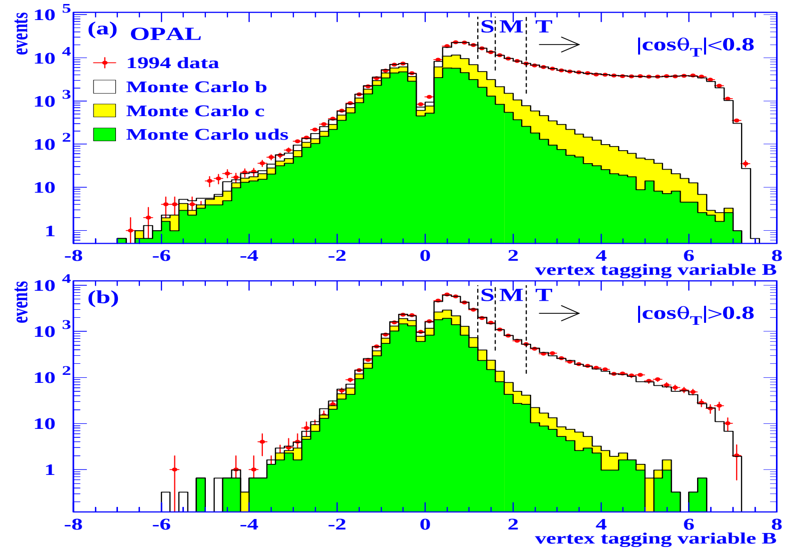
- Separated two-jet structure ⇒ independent hemispheres
  Various tagging methods: lifetime, leptons, D^* mesons
  - Main systematic issues: control of background from other flavours and understanding hemisphere correlations from e.g. 3 –jet events

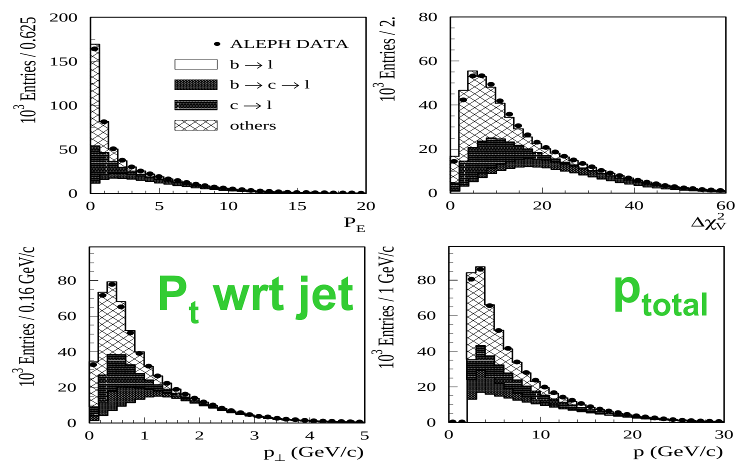


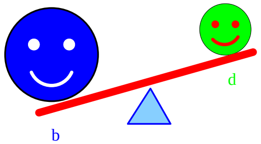
Techniques – b and c flavour tagging



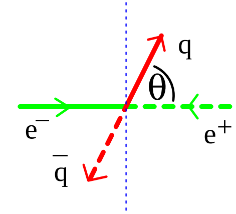
- b-tagging based on vertex detectors:
  - Impact parameters, secondary vertex reconstruction, vertex mass
    - Combine likelihood or neural network
    - Purities 95-99%, efficiency 25-50%
- b/c tagging based on leptons (e or μ)
  - Less efficient than vertex tagging
    - Limited by BR(b→l) and (c→l) ~20%
    - Also tags quark charge (for asym.)
- c-tagging based on $D^{(*)}$ mesons
  - Small samples, enhanced with inclusive slow pion techniques



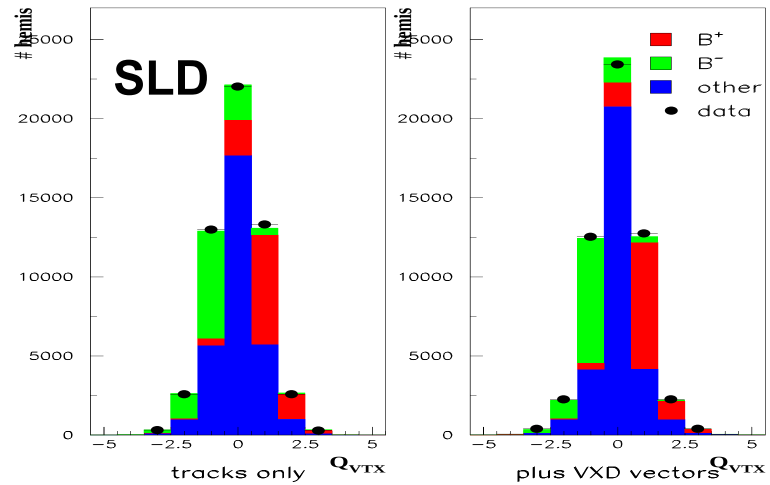


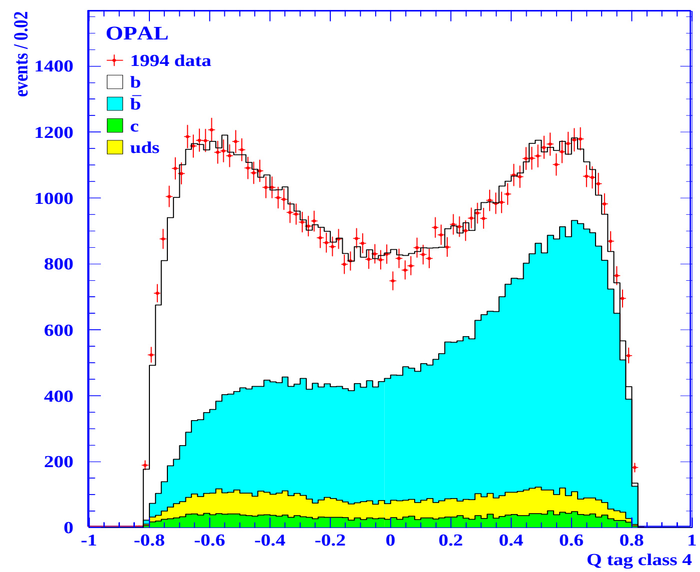


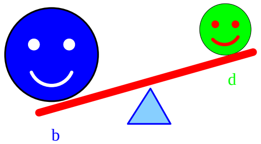
Asymmetry analyses – separating b and b-bar



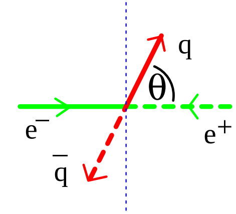
- Vertex b-tags ⇒no quark charge
  - Jet charge variables:
    - Momentum-weighted track charge
    - Multiple weights (p^k, κ=0 to 1)
  - Secondary vertex charge
    - Good for $B^{\pm}$, no info for B^0
    - Only useful for long-lived b's
  - Kaon charges ($b \rightarrow c \rightarrow s \rightarrow K^-$)
    - Kaon ID with CRID, RICH, dE/dx
  - Again, combine to multivariate tag variable, mistag 25-30%.
  - Self calibration – compare tags in two hemispheres of event.



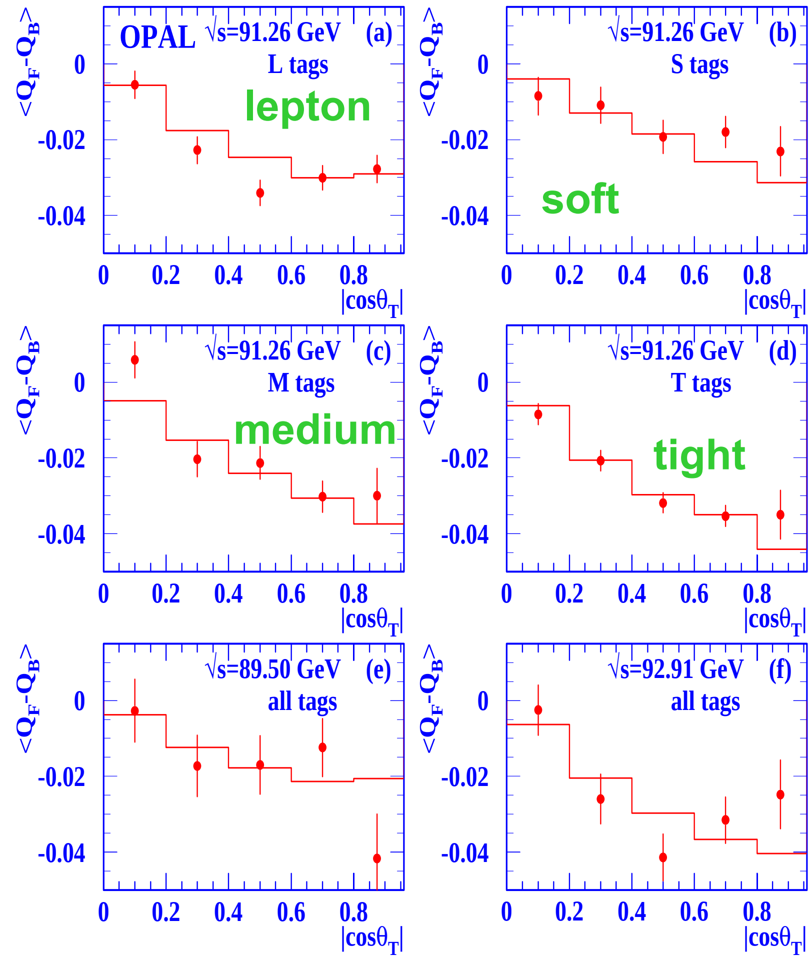


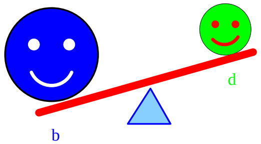


Multitag analyses

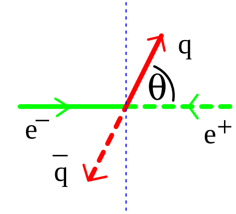


- Control of systematics…
  - b-efficiencies from data:
    - Compare sngl/dbl tag rates
    - Extend to multiple tag types, also measure c-efficiencies
  - For asymmetries, measure b and sometimes c mis-tags from data
  - Complex multi-dimensional fits
    - Allow all information to be used - pure/less pure well/badly tagged samples.
    - Some residual charm (mainly for R_b) and uds background systematics
  - Multitag assumes hemispheres are independent - not quite true



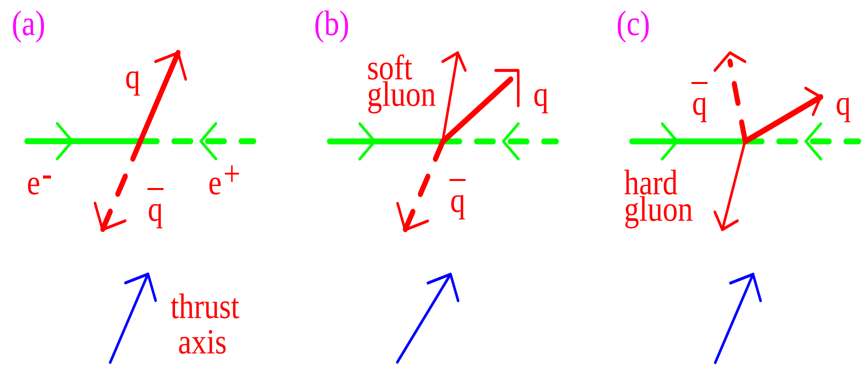


Hemisphere correlations

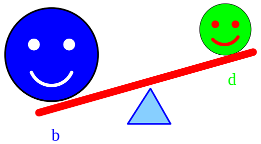


- Hemisphere correlations from:
  - Detector performance vs cosθ
  - Gluon radiation, fragmentation
- Very important for R_b, many studies – dominant corl. systematic
- Also important for asymmetries:
  - Tag performance worse in 3-jet events with low b momenta.
  - Charge conservation between hemispheres

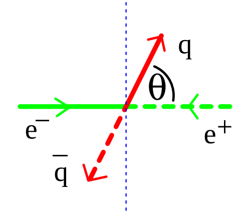
- Gluon radiation also modifies measured asymmetries directly:



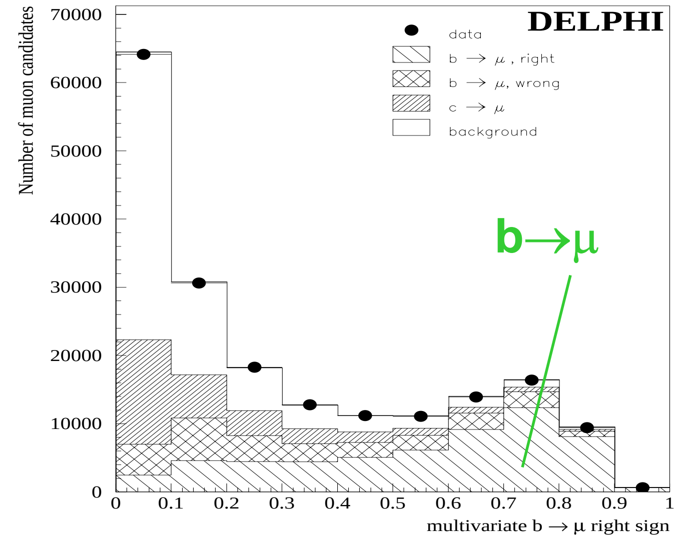
- Effects up to parton level are calculable in QCD (α_s^2) ~4%.
  - Monte Carlo $\Rightarrow$detector level
- Corrections affect analyses in different ways…
  - Some self-calibration of events of type (c) – reduces effect of gluon radiation.

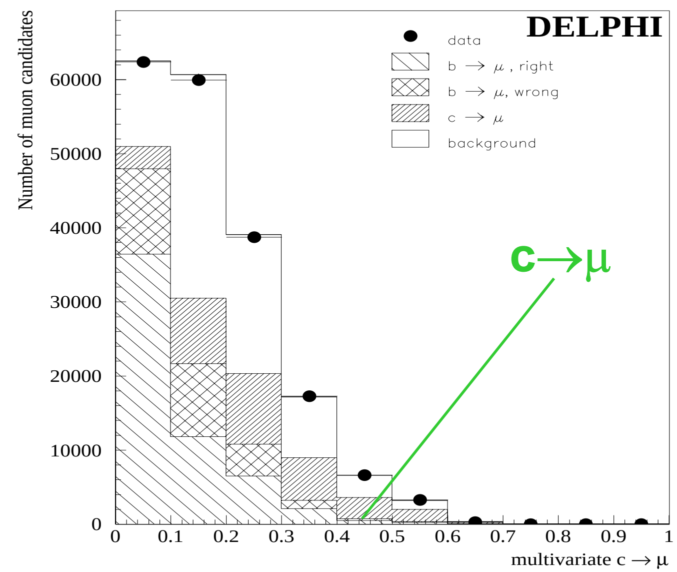


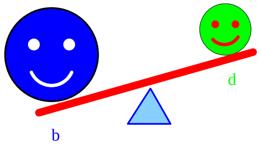
Lepton analyses – flavour separation



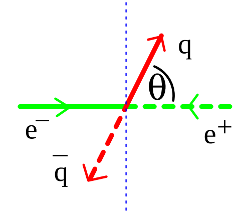
- Separate $b \to l^-$, $b \to c \to l^+$, $c \to l^+$, bgd
  - Lepton momenta (p, p_t) plus
    - Kinematic info (jet shape)
    - Vertex b-tags (both hemispheres)
    - Opposite hemisphere jet charge
  - More variables bring separation
    - But more complexity, correlations with jet-charge analyses…
  - Typically combined in neural network or likelihood
    - Several outputs for event classes
    - Fit multidimensional distribution
    - DELPHI: R_b-type fit to get purities



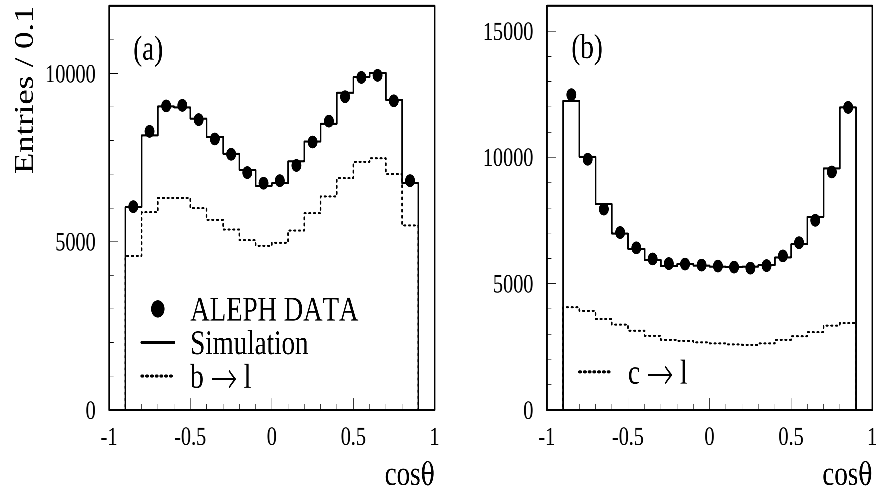


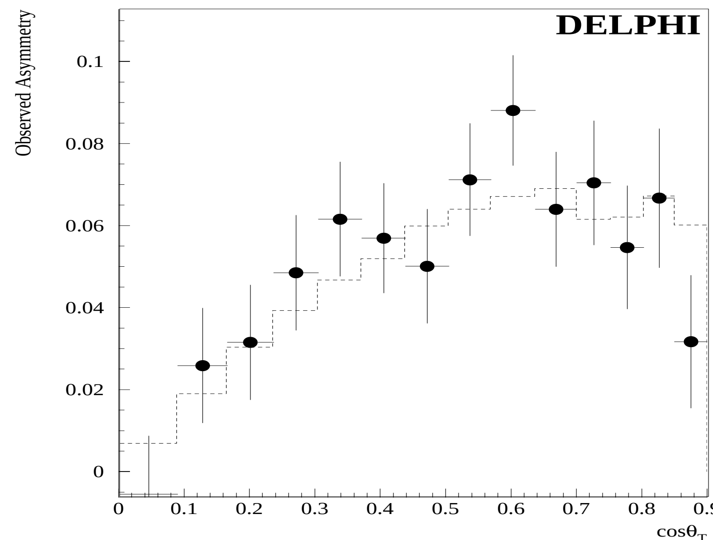


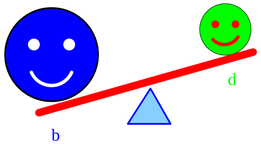
Lepton analyses – asymmetry extraction



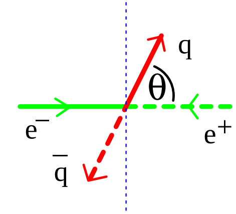
- Fit to extract A_{FB}^b and A_{FB}^c:
  - Lepton-charge-signed cosθ distⁿ or differential asym. vs cosθ
- Two sources of wrong sign leptons:
  - $b \to c \to l^+$ decays and B^0 mixing
    - 'Traditional' analyses fit average b-mixing parameter χ at same time from events with two leptons.
    - Corrections are needed for sample biases (e.g. use of b-vertices)
    - DELPHI uses opposite hemisphere jet charge to control B-mixing contribution.
  - … not just using lepton info !





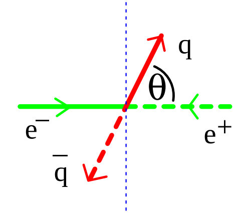


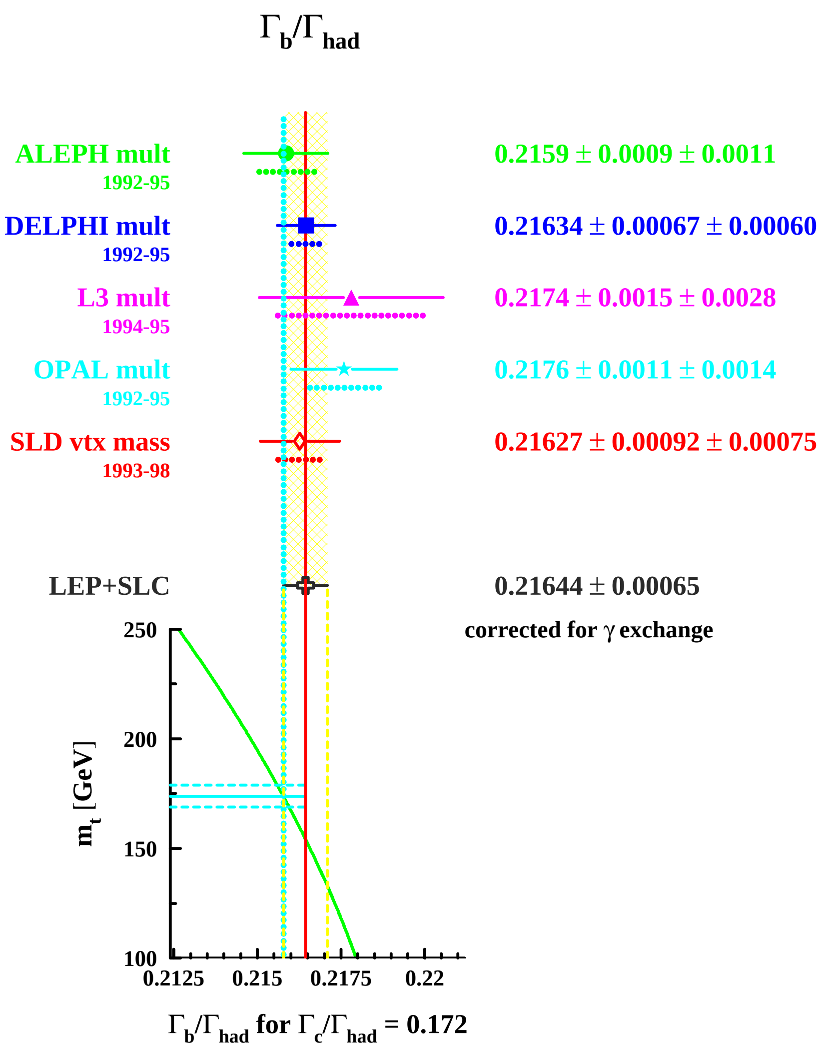
Heavy flavour electroweak fits

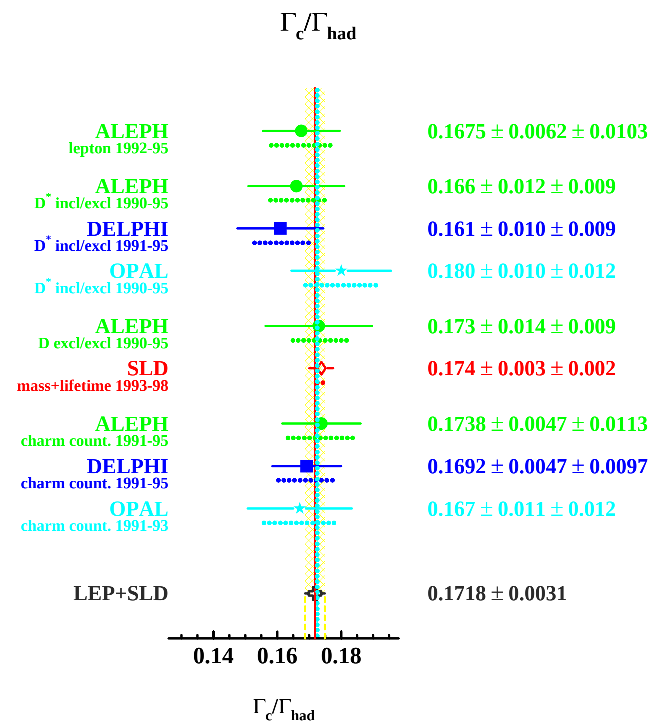


- Measurements of R_b, R_c and asymmetries are correlated.
  - Dependence on each other, common systematic uncertainties and external inputs (LEP and elsewhere)
  - Simultaneous fit to electroweak observables plus
    - Charm hadron production fractions (D^0, D^+, D_s, baryons)
    - Leptonic branching ratios $b\to l$, $b\to c\to l$, $c\to l$ and mixing χ
  - LEP asymmetries $A_{FB}^{b,c}$ and SLD $A^{b,c}$ fitted separately
    - Also fit LEP off-peak energy points separately, then combine.
  - Final fit χ^2 is 48/(105-14) – rather low…
    - Mainly from systematics – in many cases conservative (stat limited)

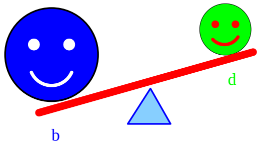
Results for R_b and R_c



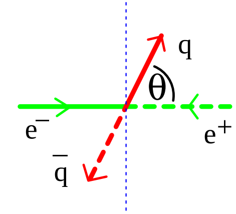


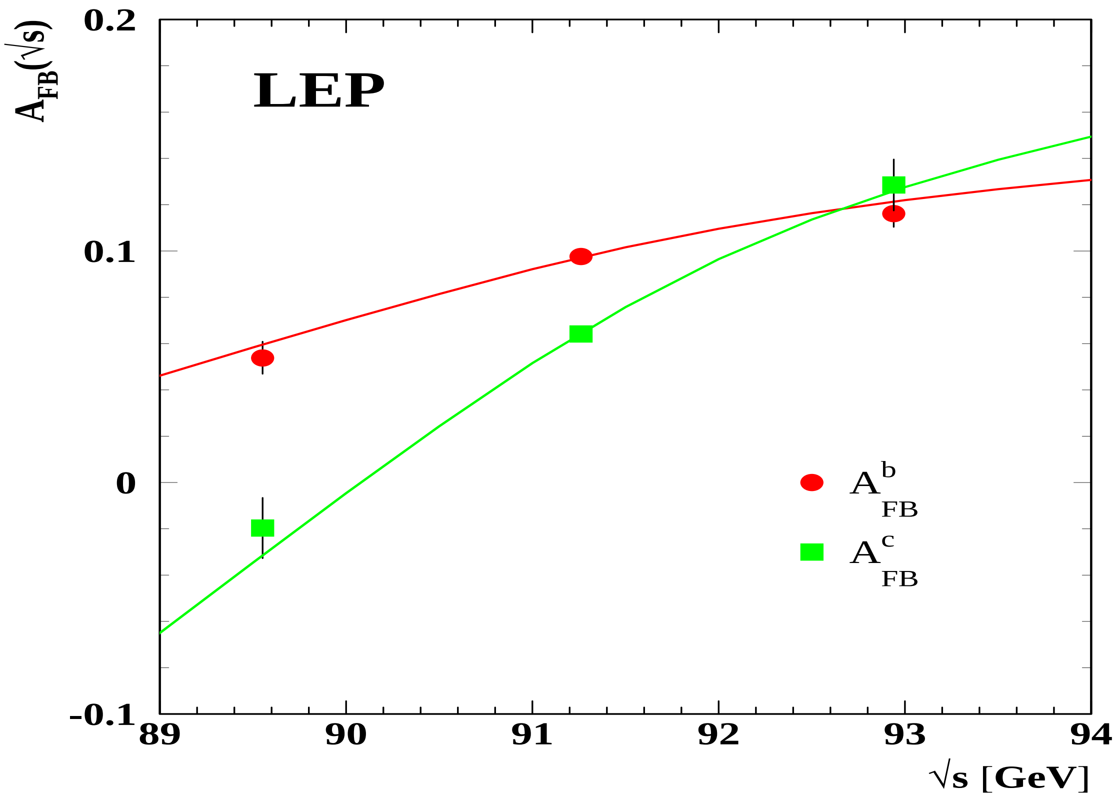


- No new measurements…
  - R_b in good agreement with direct top mass measurement

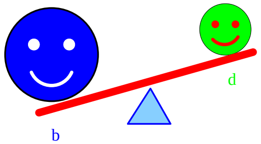


Asymmetries vs energy

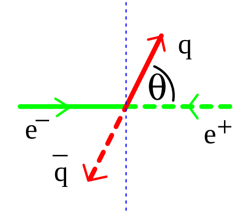


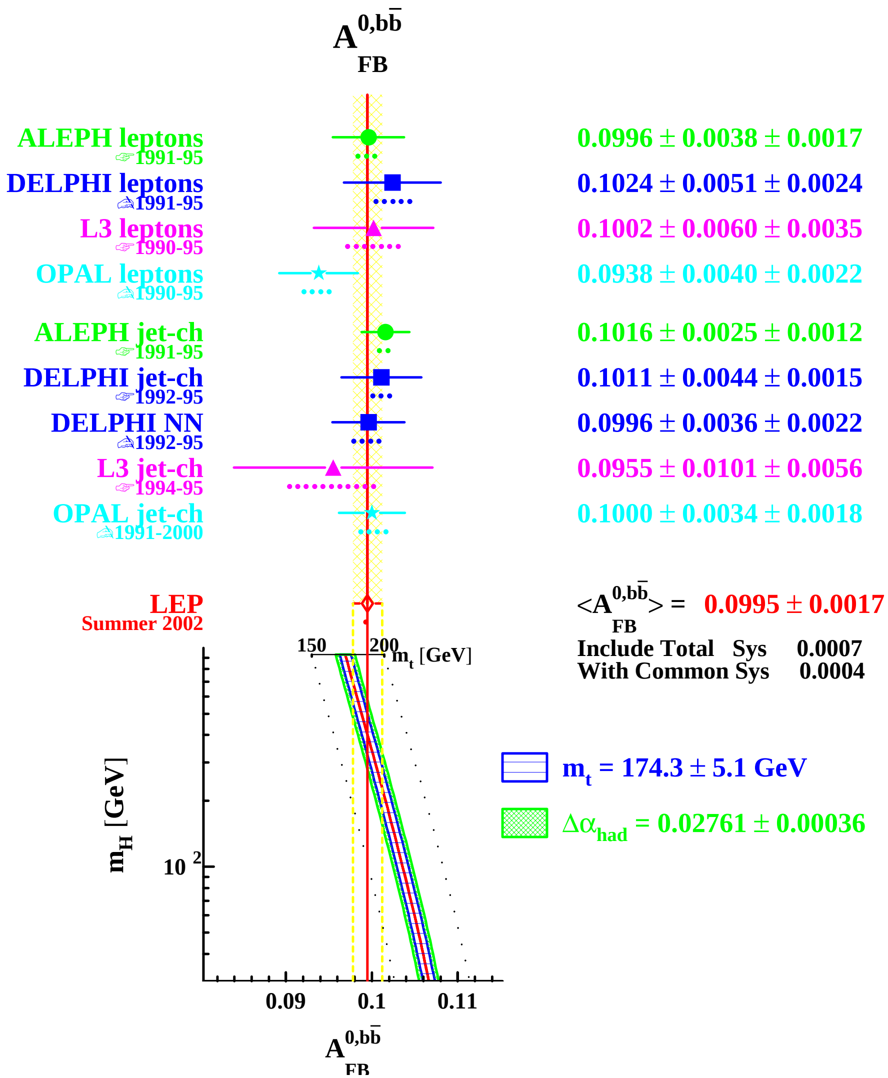


- Changing Z/γ contributions and interference between them
  - Data in good agreement with Standard Model expectation
  - Now combine all energy points, and correct to 'pole asymmetry'.



b asymmetry at Z-pole

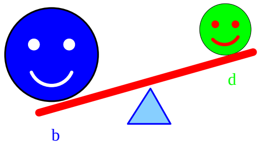




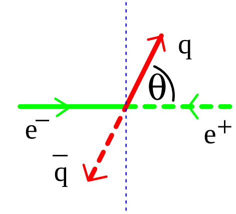
- Contributions from
  - Leptonic analyses (also A_{fb}^{c})
  - Inclusive (jet charge++)
- Good agreement between them
- Most precise results from ALEPH, OPAL, DELPHI inclusive

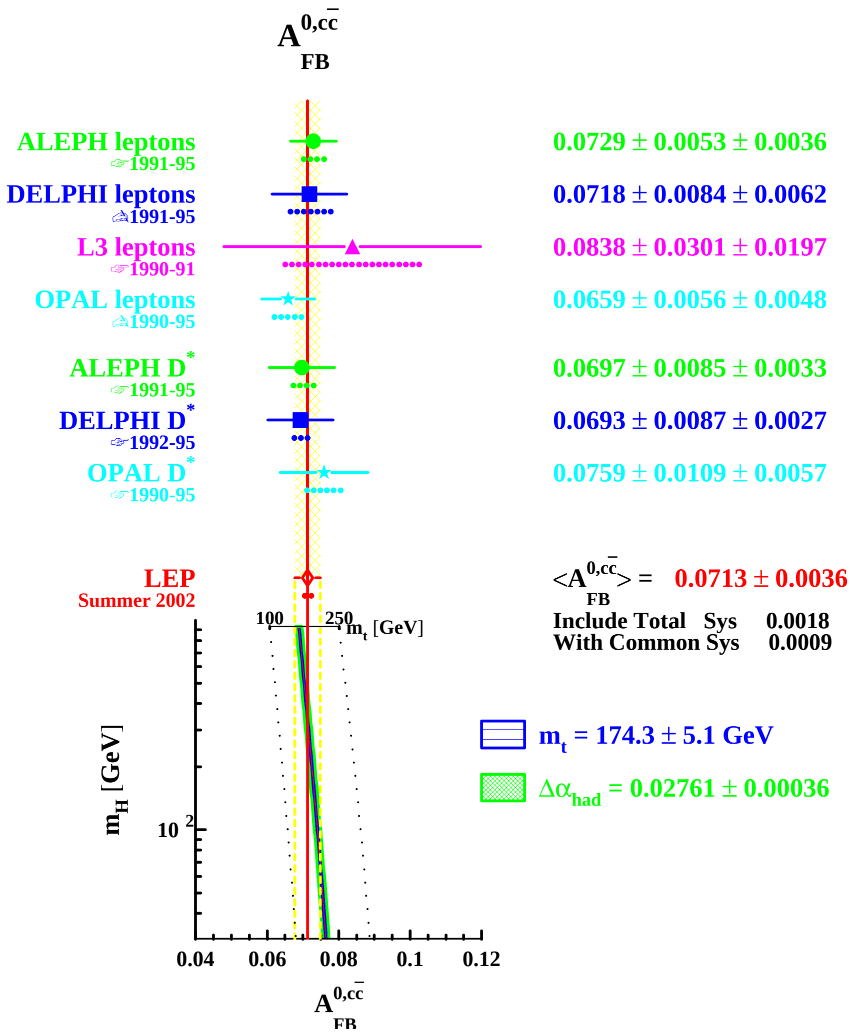
- A_{FB}^{b}=0.0995±0.0015±0.0007

- Statistics dominated, common systematic is only 0.0004 (mainly from QCD effects).
  - Change of +1/6σ since Winter 02
- A_{FB}^{b} prefers m_H ~ 400 GeV



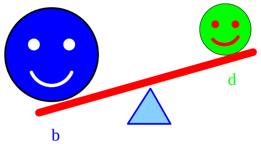
c asymmetry at Z-pole



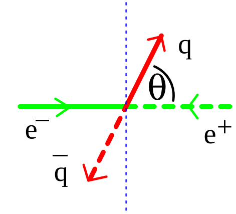


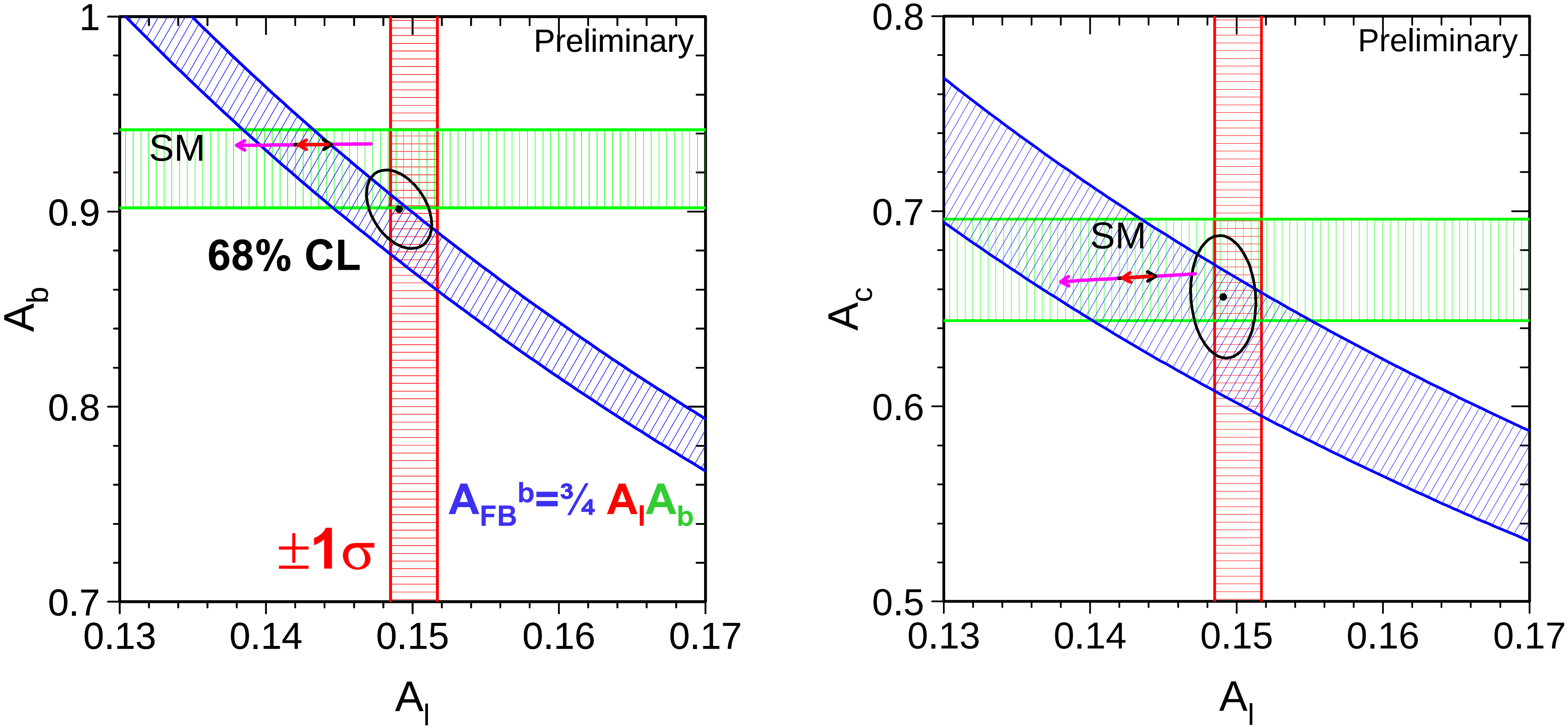
- Contributions from
  - Leptonic analyses (also A_{fb}^{b})
  - D^* mesons
- Good agreement between them
  - Provides confidence that b/c separation in leptonic events is understood

- A_{FB}^{c}=0.0713±0.0031±0.0018
  - Again statistics dominated, common systematic is only 0.0009.
    - Change of +1/6σ since Winter 02

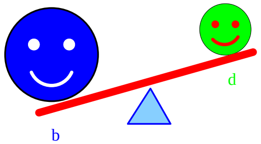


Coupling parameters

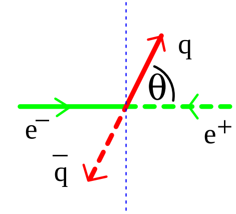


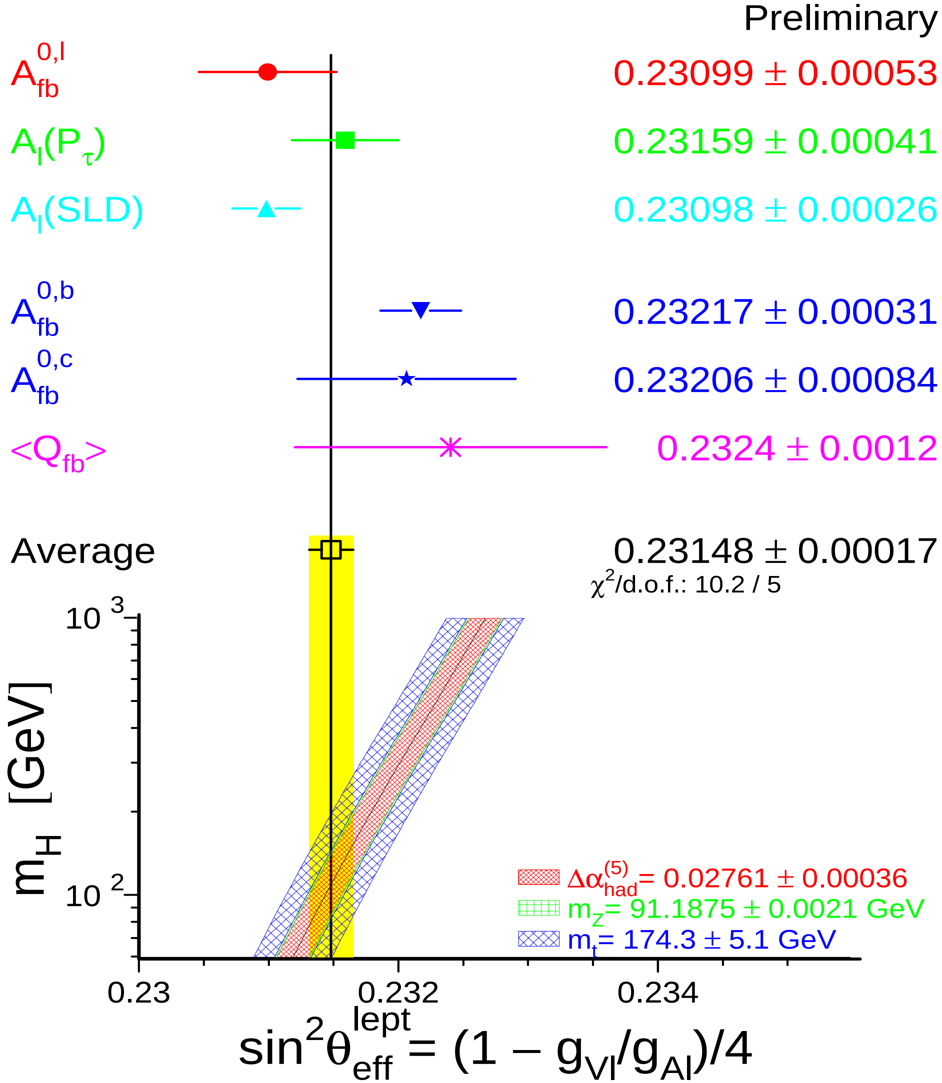


- $A_{b,c}$ from SLD consistent with SM, as are $A_{FB}^{b,c}$ 'bands'
  - A_l (from A_{LR}, lepton asymmetries and tau polarisation is 'high')
  - Using this to convert LEP A_{FB}^b to A^b results in a 'low' A_b, still compatible with SLD direct measurement

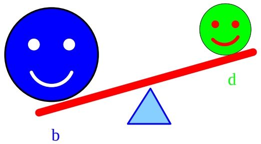


Standard Model interpretation

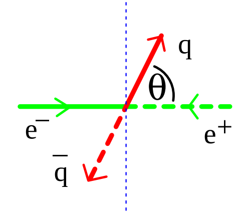




- Interpretation as $\sin^2\theta_{eff}$:
  - First three from leptons, last three from hadrons:
  - 0.23113±0.00021 (leptons)
  - 0.23217±0.00029 (hadrons)
- 2.9σ discrepancy, driven by A_{LR} vs A_{FB}^b – also 2.9σ
  - Same effect as seen on coupling plots…
- Overall average:
  - $\sin^2\theta_{eff}$=0.23148±0.00017, χ^2=10.2/5 (7%)
  - Prefers m_H around 100 GeV.



Summary and outlook



- LEP/SLD electroweak measurements continue to improve…
  - Reaching the end of the road
    - Squeezing the maximum out of the data – a few new analyses.
    - Nearly all results finalised (DELPHI leptons/NN, OPAL leptons, SLD still to be done, but no big improvements expected).
    - Much effort in improving and checking asymmetry analyses over last couple of years – no sign of problems.
  - Electroweak results are 'intriguing / 'unsatisfactory':
    - Statistical fluctuation ($O(3\sigma)$ effect) ?
    - Systematic problems ? – would have to be BIG on level of estimated systematics.
    - New physics ?
  - Need new accelerators to decide …