W mass at LEP and ElectroWeak fits

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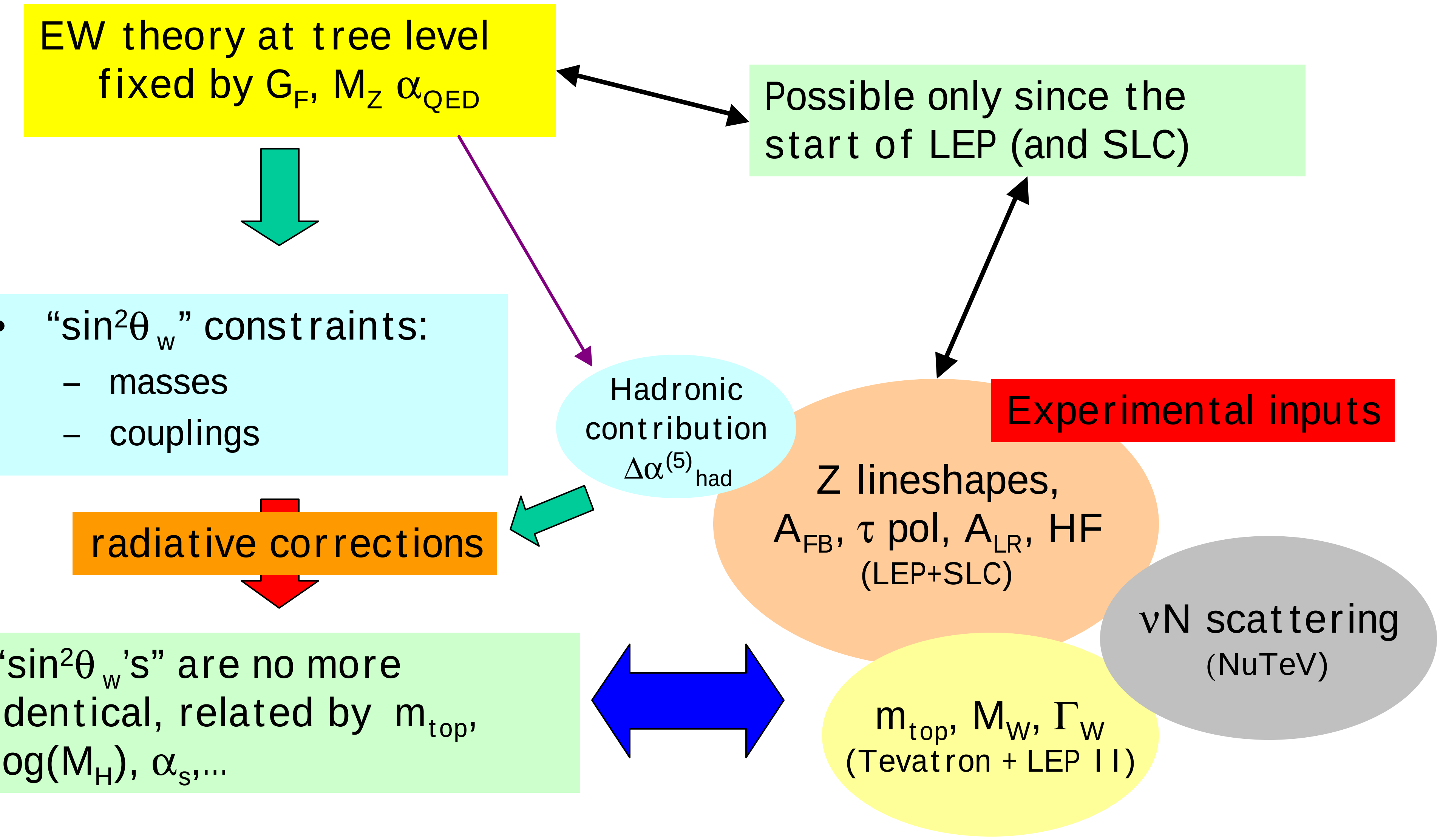
On behalf of the LEP Collaborations: ALEPH. DELPHI, L3 and OPAL

Electroweak result combination: a VERY simplified description



Electroweak result combination (cont'd)

Enough measurements to determine m_{top}, M_w, M_H (α_s) indirectly

m_{top} and M_w direct and indirect measurements: comparable accuracy

- m_{top}: 5 GeV direct, 10 GeV indirect
- m_w: 34 MeV direct, 32 MeV indirect

This talk

$$M_W^2\left(1-\frac{M_W^2}{M_Z^2}\right)=\frac{\pi\alpha}{G_F\sqrt{2}}\left(1-\Delta r\right)$$

M_H, m_{top}

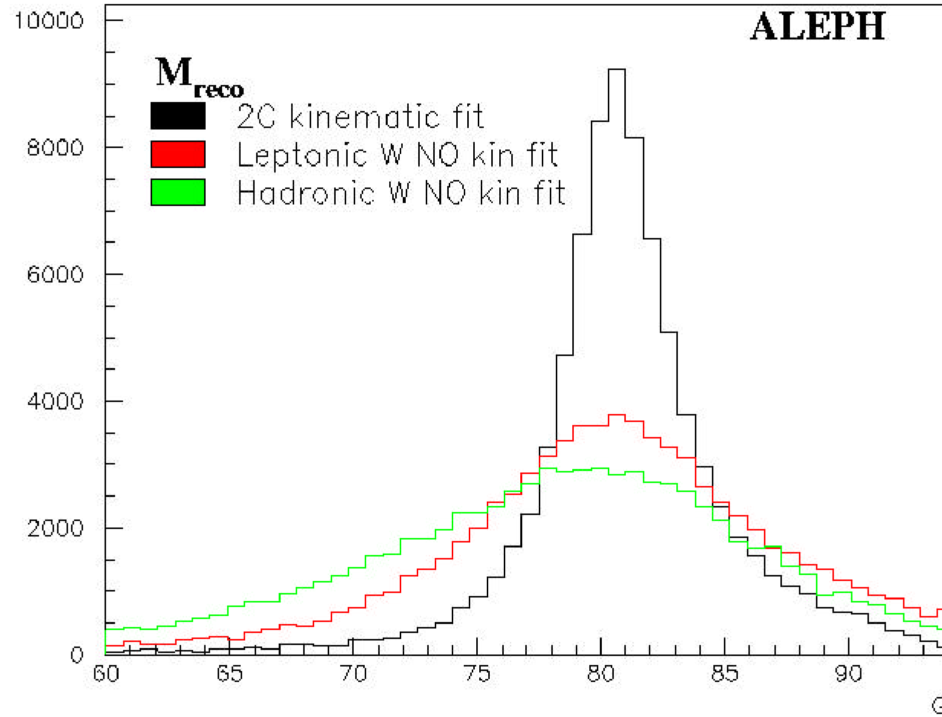
- Therefore:
  1. Direct and indirect results comparison: EW rad corr test
  2. Direct measurements improve the (indirect) M_H determination

- Why W mass is one of the few inputs still "alive"
  - Combination of Tevatron and LEP
  - LEP results are still preliminary
  - Tevatron run2 + LHC

W mass measurement at LEP

WW boson pairs at LEP since 1996

- 161 – 209 GeV centre of mass energy
- ~700 pb^{-1} by each experiments
- ~4500 qqqq , ~4000 lνqq events for each experiments.



W mass from direct reconstruction: qqqq and lνqq event

- jet and lepton 4-momenta reconstruction (tracks + calorimeters)
- Impose E,p conservation (+equal masses)
  - improved resolution: from 6-8 GeV to 2-4 GeV
  - reconstruction of ν 4-momentum

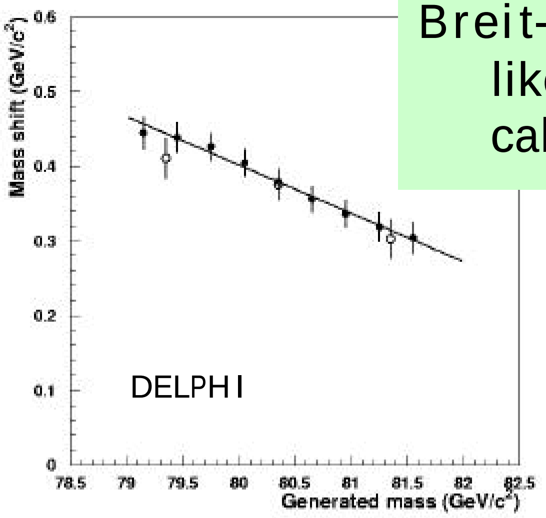
  ⇒ LEP energy has to be known accurately
- "solve" the 3-fold ambiguity of qqqq jet pairing

- Other W mass measurements
  - WW threshold cross section
  - W mass from fully leptonic WW events

W mass extraction

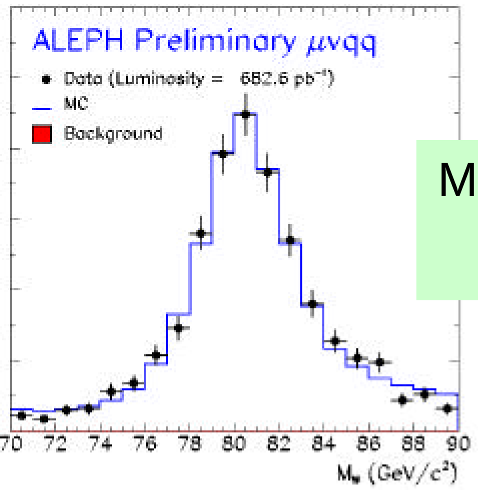
- Event observables:
  - reconstructed mass(es)
  - kinematic fit error
  - complete event likelihood function
- Masses have biases:
  - ISR, resolutions, particle losses, thresholds: ~300 MeV

⇒ MC is needed to correct for



Breit-Wigner or likelihood fit + calibration curves

⇒ MC simulation affects W mass
- WW event kinematic (+ISR)
- jet fragmentation
- detector



MC event reweigthing

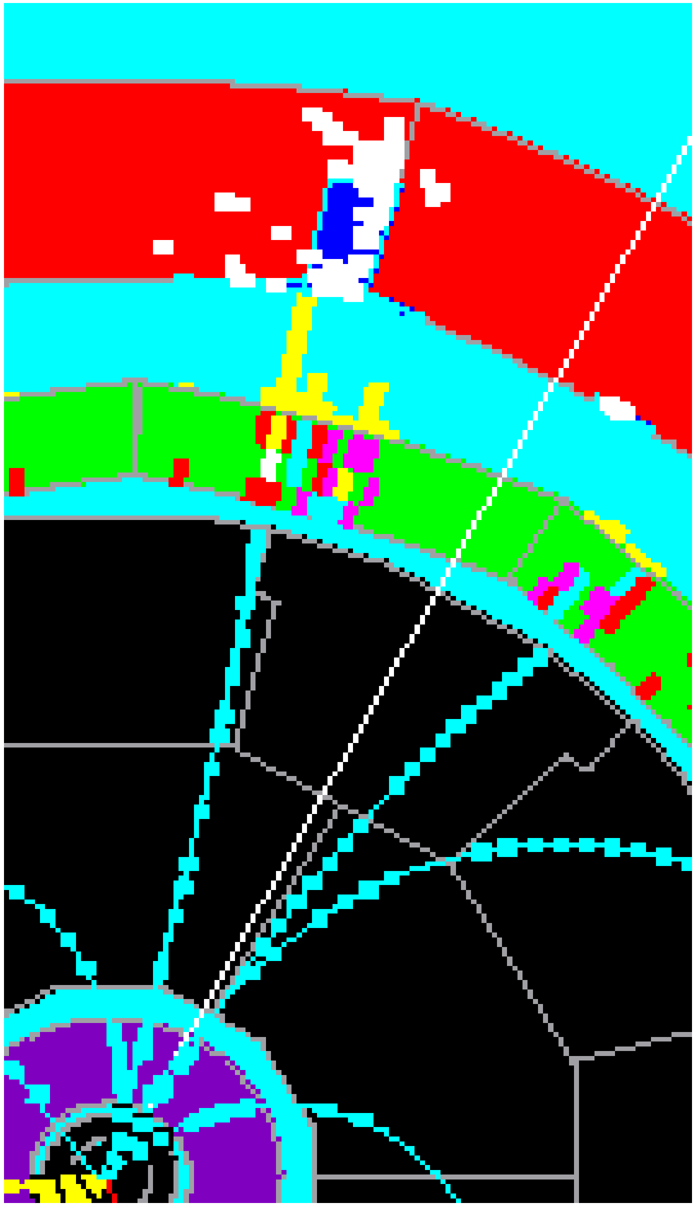
- W width measurement
  - release the SM relation between M_W and Γ_W: 2 parameter fit

New ALEPH PRELIMINARY results

- ALEPH is working on the final W mass results (189 GeV last published result)
  - final version of analysis for all data set
  - homogenous MC production

- Improving data /MC agreement ($\sim 10^{-4}$)
  - non-negligible shift observed
  - ⇒ **New preliminary results released**

- ALEPH "energy flow" reconstruction:
  - charged tracks ~60%
  - photons inside e.m. calorimeter (ECAL) clusters (~26%)
  - remaining energy in calorimeters: "neutral hadrons" or "residuals" (~14%, ~4% in ECAL only)
  - thanks to ECAL fine granularity
    - 1° x 1° projective towers segmented in 3 stacks longitudinally



Improved understanding of simulation

Known discrepancy

- the simulation "residuals" multiplicity, especially in ECAL only, has never been fully satisfactory

New findings

- small fraction of energy but causes instabilities in the W mass
- **Jet masses** are mainly affected

Investigation tool

- Modified e.m. showers simulation
  - ALEPH standard simulation: parametrization of the shower: good shower core description
  - **Full EGS simulation**: better simulation of shower fluctuations and shower satellites

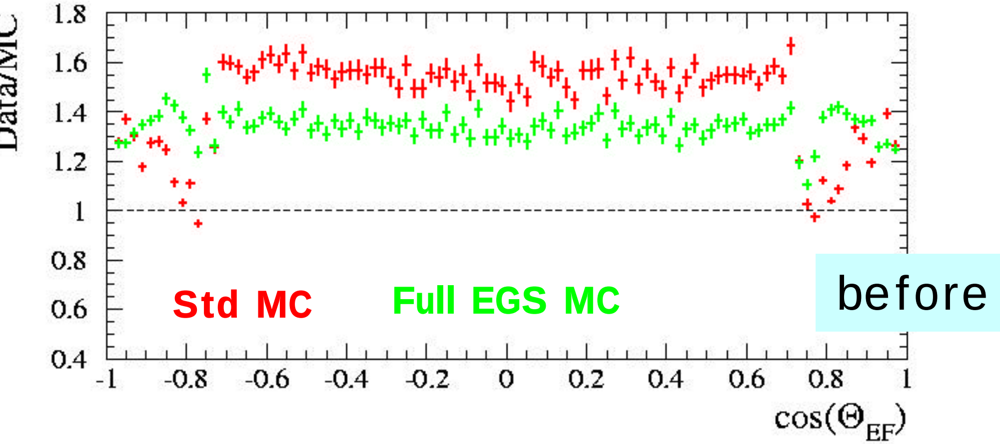
- Results of the comparison:
  - likely multiplicity discrepancy because of e.m. shower satellites
    - Full EGS simulation not perfect ye

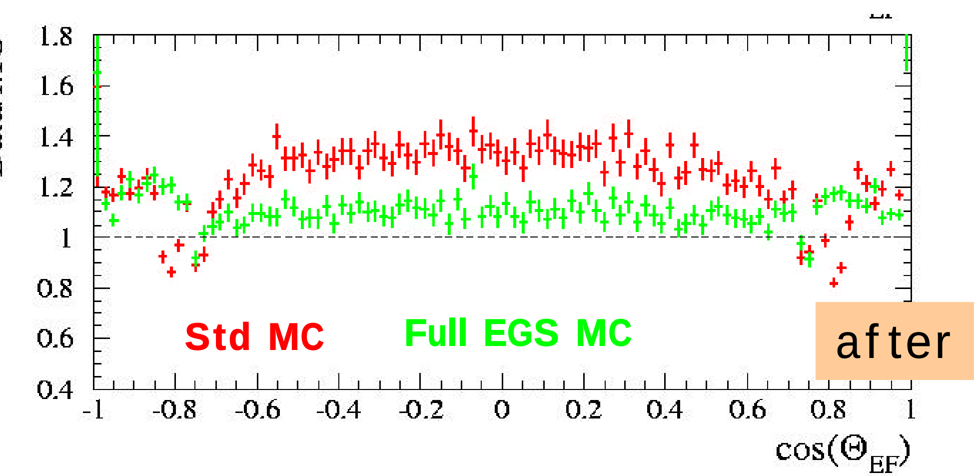
⇒ Possible solutions

- Improve simulation
  - too late (?)
- **Reconstruction less sensitive to this effect**

- Event "cleaning"
  - Remove ECAL clusters fully contained i one longitudinal segment only (single stack)
    - ~2% of the total energy
  - "cleaned cone" opening angle around th leptons (e and μ) increased from 2 degrees to 8 degrees

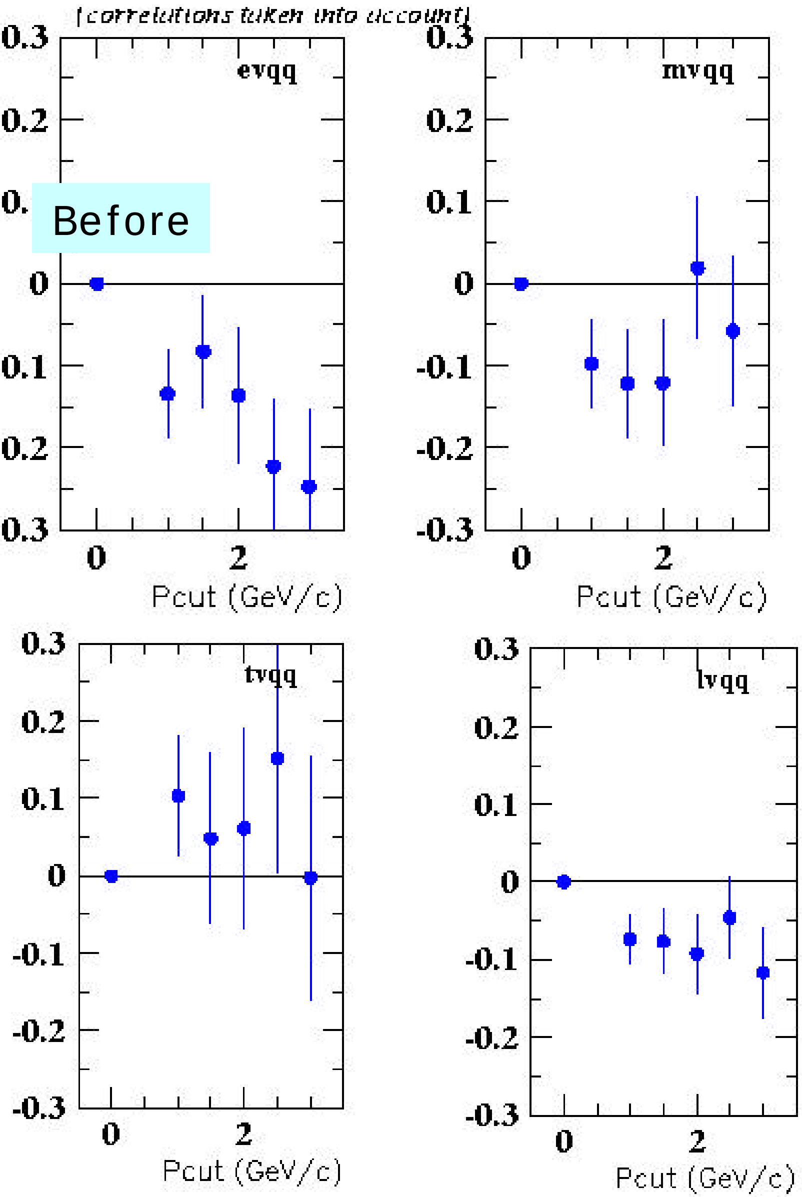
ECAL residuals multiplicity in Z events



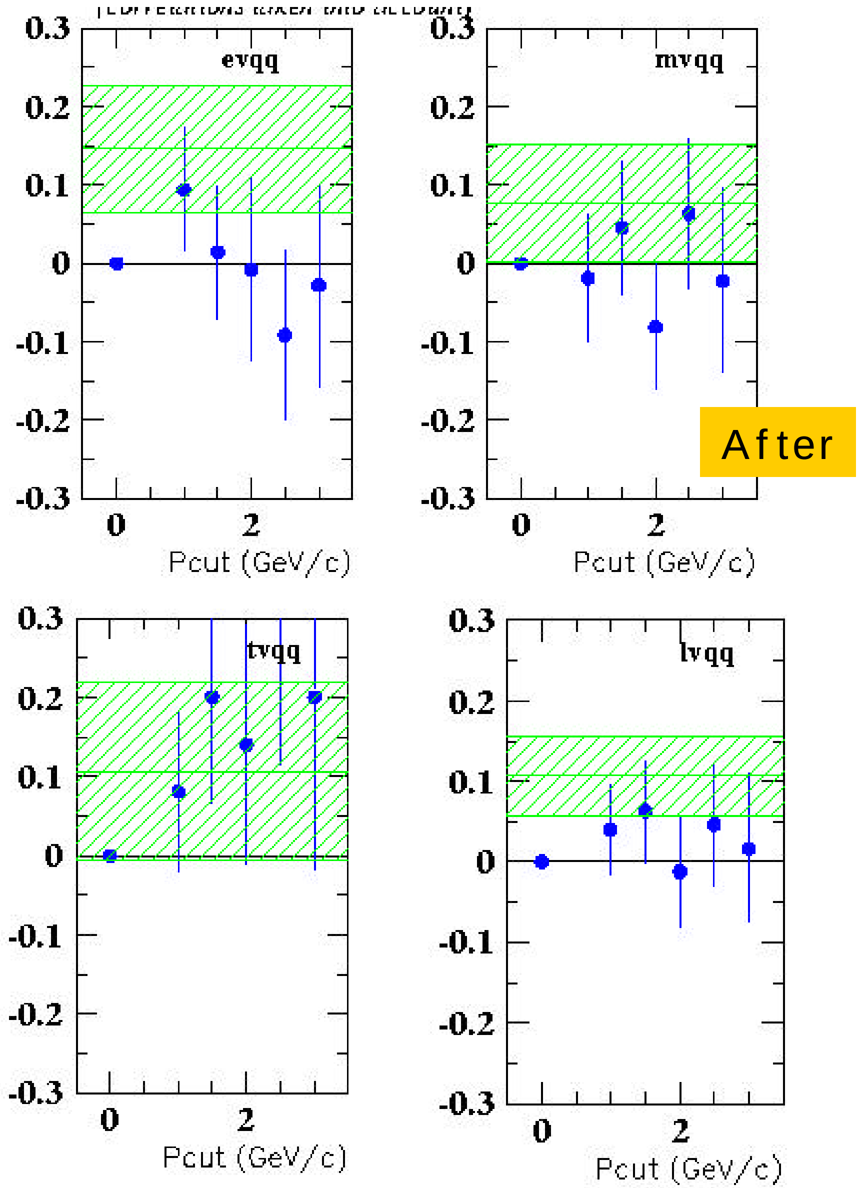


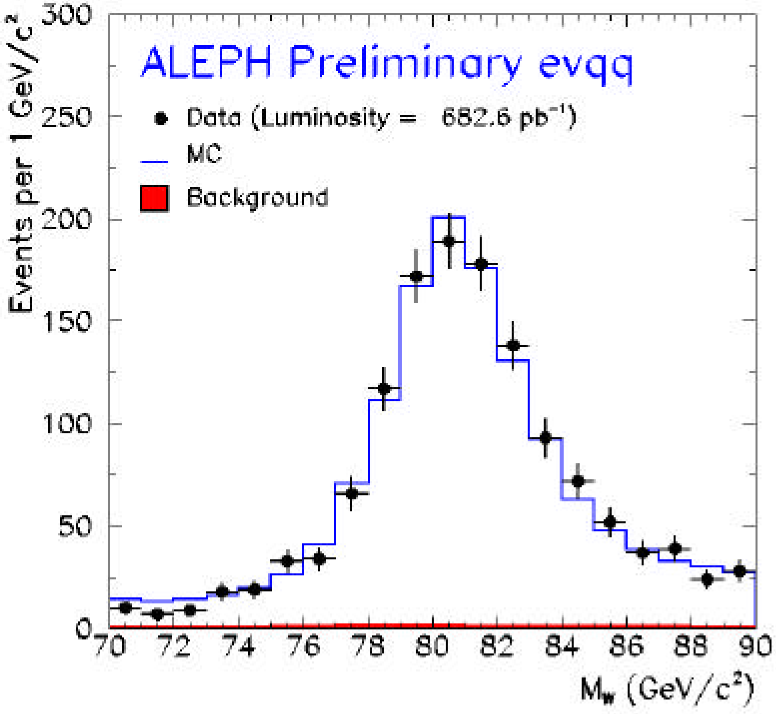
ECAL residuals
(~4% total energy)
Data/MC mutiplicity as a
function of the polar angle
in Z hadronic events

W mass stability vs particle momentum threshold



Mass shift vs momentum threshold





- New ALEPH PRELIMINARY W mass results (183-208 GeV)
  - M_W(all)= 80.385±0.042(stat) ±0.041 (syst) GeV
  - M_W(lνqq)= 80.375±0.062 GeV
  - M_W(qqqq)= 80.431±0.117 GeV
    - LEP prescription used for FSI systematics
  - Detector simulation uncertainties
    - from 20 to 30 MeV (lνqq)
    - from 15 to 25 MeV (qqqq)
    - based on full EGS and std MC comparison

New W mass results with the event cleaning

- W mass shifted by:
- ~-50 MeV 4q,
- ~ -85 MeV lνqq,
- ~-150 MeV eνqq

LEP W mass combination: the procedure

Inputs from experiments

- W mass from direct reconstruction
  - from qqqq and lνqq channels
  - for each year
- systematic uncertainties tables

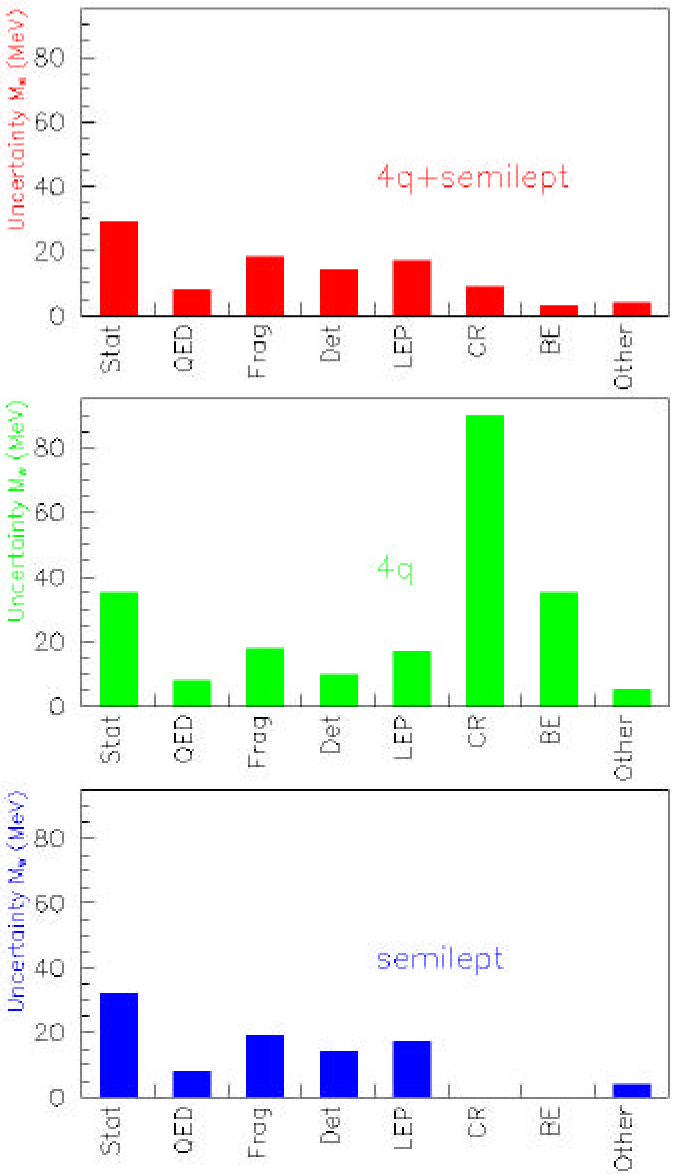
Systematic correlations

- correlated systematics affect the final accuracy
- FSI systematics affect the 4q result weight.

Optimal combination

- WW threshold measurements included

⇒ Contributions to the combined systematic and statistical uncertainties:

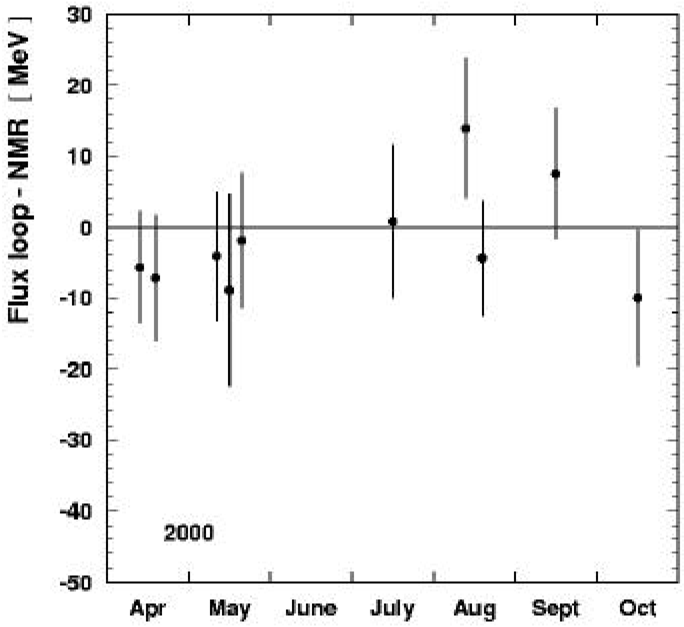


W mass systematic uncertainties: :LEP beam energy

- LEP energy in kinematic fit:

  $\Delta M_W / M_W \approx \Delta E_{LEP} / E_{LEP}$

  - fully correlated between channels and experiments



Energy calibration

- Resonant depolarization up to 60 GeV
- Extrapolation to physics energies with magnetic field measurements (NMR)
- linearity checked with flux-loop measurements
  - uncertainty dominated by the spread between the two methods

$\Rightarrow \Delta E_{beam}$=20-25 MeV $\Rightarrow \Delta M_W$=17 MeV

- Cross-checks and possible improvements
  - LEP spectrometer
    - beam energy from beam deflection
  - Synchrotron tune
    - beam energy from beam energy losses
- Final LEP energies and uncertainties will be ready soon

Fragmentation and Hadronization

MC models to generate hadrons
- particle spectra, angular distributions and contents (baryons) are affected
- Interplay with real detector
  - resolutions, thresholds

$\Rightarrow$ biases, non-linearities,...

How well they simulate the data
- JETSET used by all LEP experiments
  - internal MC parameters tuned with Z peak data by each experiments

- Systematic uncertainty on W mass
  - Changing the MC parameters
    - MC tuning statistical errors
  - Compare MC models
    - JETSET vs ARIADNE vs HERWIG
    - improve model tunings to reduce the W mass differences

$\Rightarrow \Delta M_W$=10-30 MeV $\Rightarrow$ 18 MeV
- correlated between channels and experiments

Work in progress
- real data vs MC comparison:
  - particle (baryons) rate reweighting
  - boosted Z events
  - event shape reweighting

- Detector simulation
  - detector response $\Rightarrow$ biases and resolutions
  - $\Rightarrow$proper simulation
    - both for jet and leptons
    - see ALEPH new results
  - Z peak data to correct MC
  - Systematic uncertainties from:
    - correction statistical accuracies
    - MC with changes in the detector simulations
    - data vs MC comparison at Z peak

$\Rightarrow \Delta M_W$= 5-35 MeV $\Rightarrow$ 14 MeV (lνqq)

$\Rightarrow \Delta M_W$= 5-25 MeV $\Rightarrow$ 10 MeV (qqqq)

- uncorrelated between experiments

- QED corrections
  - ISR: boosted WW + kinematic fi $\Rightarrow$ biases
    - uncertainties by comparing different computations
  - O(α) corrections: affect W mass distribution
    - uncertainty obtained by reweighting MC events with and without corrections (YFSWW)
      - cancellations occur

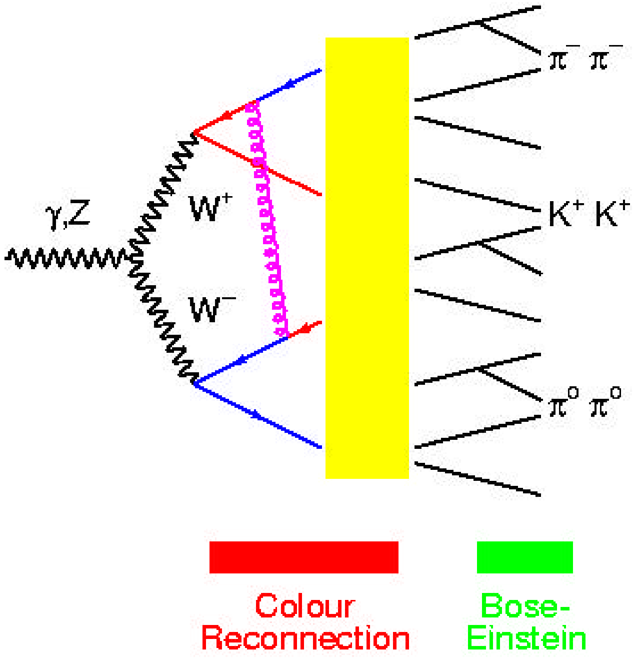
    $\Rightarrow \Delta M_W$< 10 MeV
  - correlated between experiments and channels

- Work in progress:
  - Comparison RacoonWW and YFSWW

Final State Interactions in qqqq channel

Hadronically decaying W pairs short living (~0.1 fm) ⇒ their decay products can interact among each other

- Colour Reconnection (CR)
  - color singlets across W's
- Bose-Einstein correlation (BE)
  - coherently produced identical pions are closer in phase space (also from different W's?)



- We cannot ask ourselves which W a particle comes from
  - reconstructed W mass distribution is affected
  - not included in usual MC models

⇒ possible bias on the W mass measurement

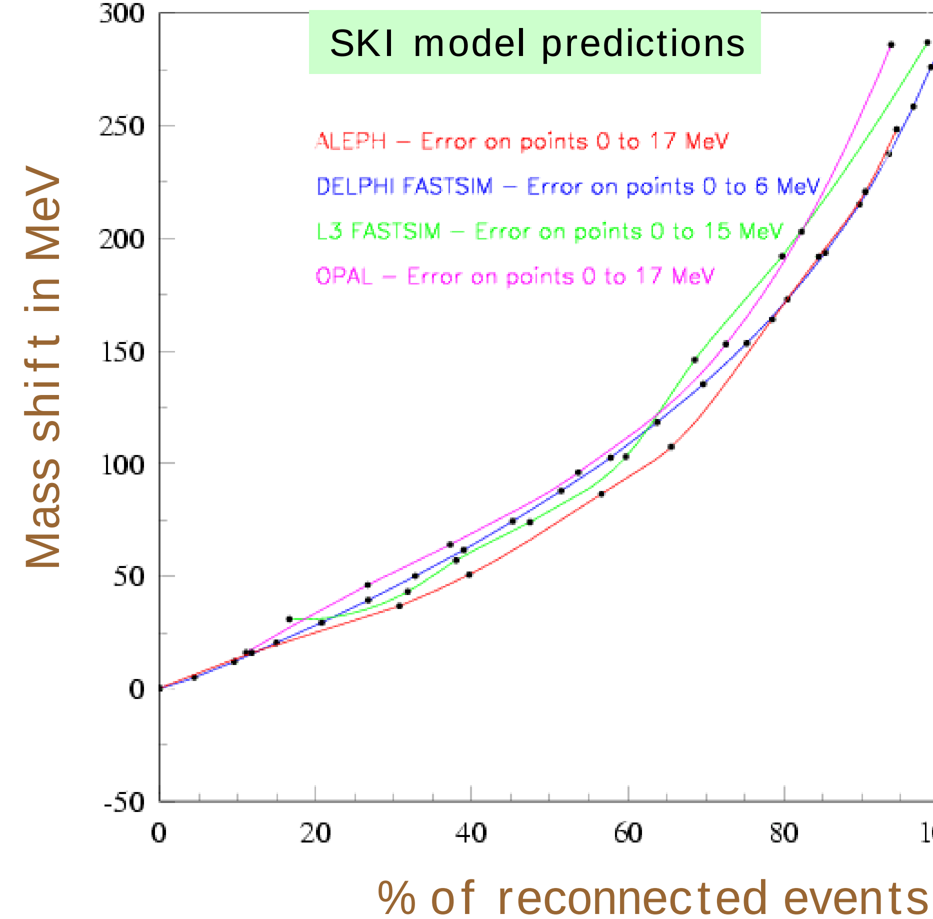
- Relevant at the end of the hadronic shower (CR) or after the hadronization (BE)
  - full MC calculation is impossible

⇒ predictions rely on phenomenological MC models

M_W biases and CR models

- MC models which "survive" comparison with Z peak data
  - Herwig (clusters), Ariadne (dipoles), Rathsman (strings)
    - "tunable" with Z data
  - SKI (JETSET) (strings)
    - not "tunable" at Z

Model	**ΔM (MeV)**
Herwig (CR)	30-40
Ariadne 2 (CR)	70-80
Rathsman	40-60



- New since Summer 2002:
  - **Particle Flow** analysis results to restrict model range for W mass uncertainty

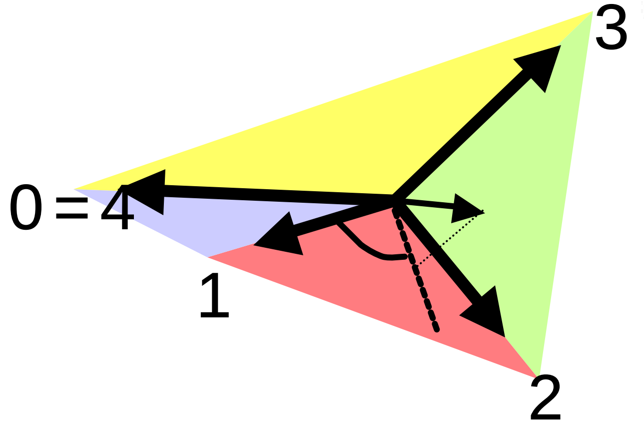
In SKI model $\mathbf{P_{reco}}$ is controlled by the parameter $\mathbf{K_i}$

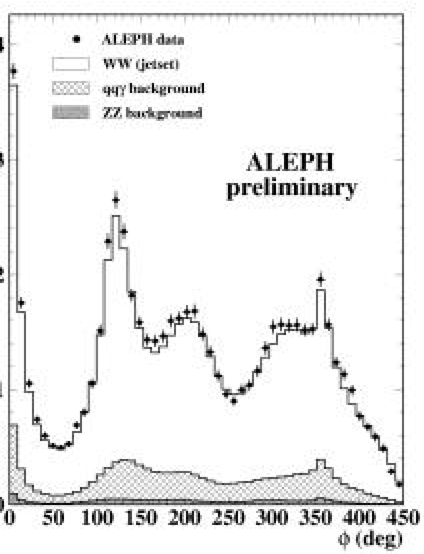
CR: Particle flow between W's

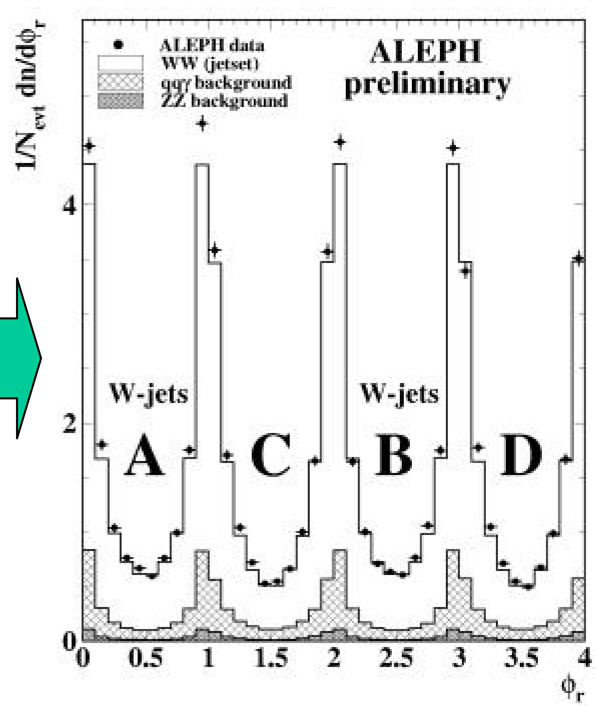
In WW → 4q events particles projected to the closest inter-jet plane and angles w.r.t. jet measured

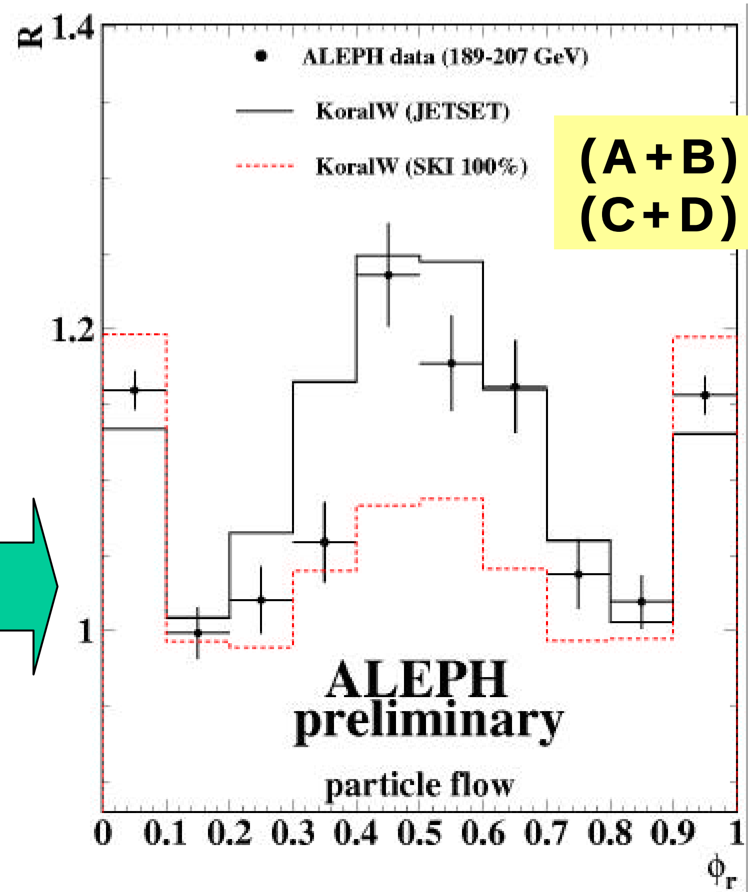
Inter-jet angles normalized to 1

Distribution folded and binned ratio done.





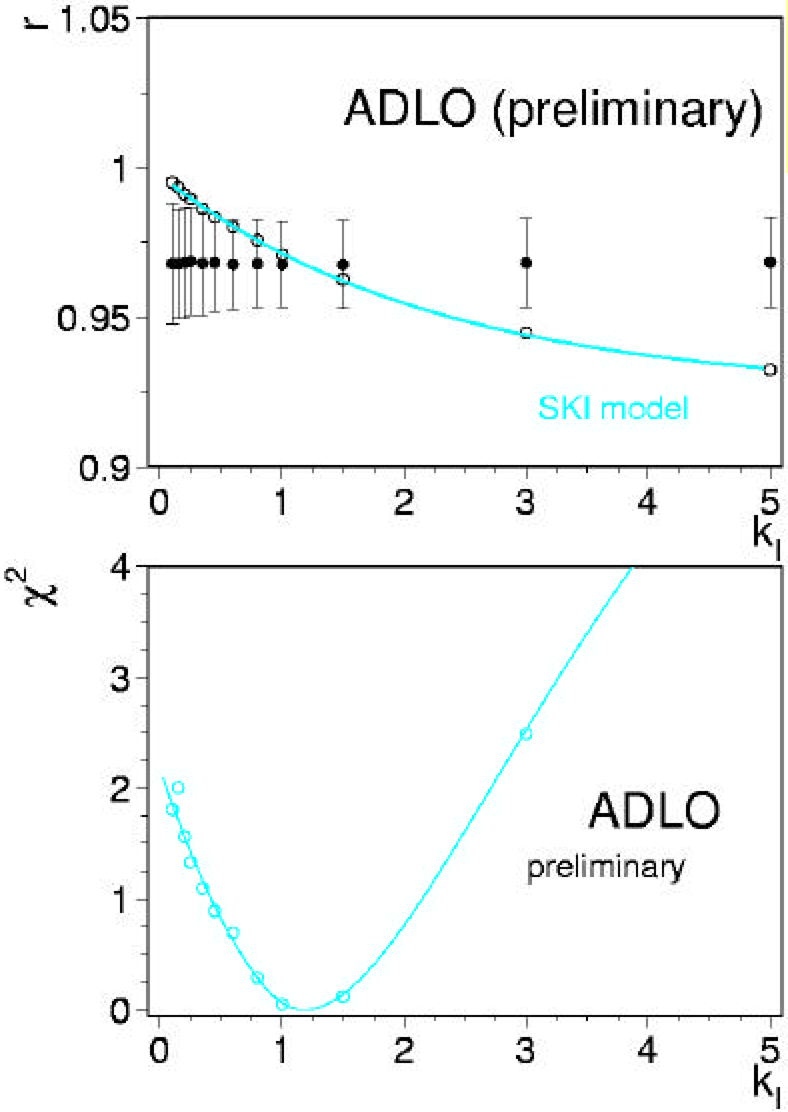




(A+B) / (C+D)

The ratio computed from 0.2 to 0.8 compared with MC predictions with and without CR

Particle Flow results and W mass CR systematic



Particle Flow ratio
vs
SKI k_i parameter

- SKI model 1σ upper limit: k_i=2.13
  - no sensitivity to Ariadne 2 and Herwig
- The shift predicted by SKI (k_i=2.13) is the largest

$\Rightarrow$systematic for the W mass

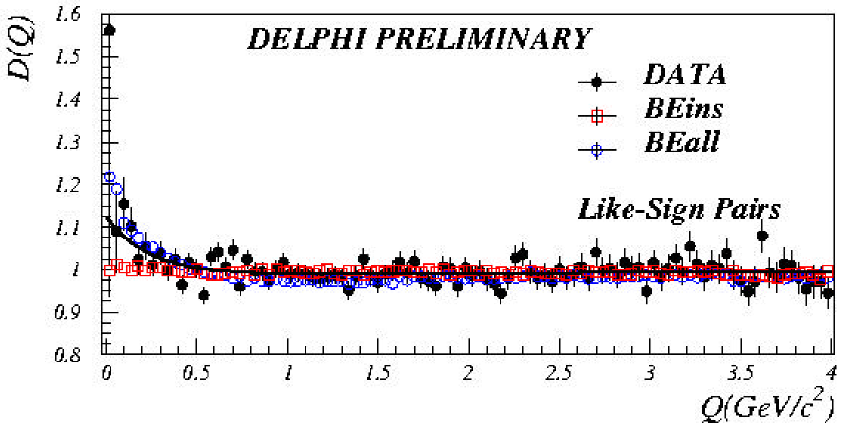
- from **74 MeV** at 172 GeV to **105 MeV** at 207 GeV
- correlated between experiments
- was 40 MeV before Summer 2002 based on theorists suggestions

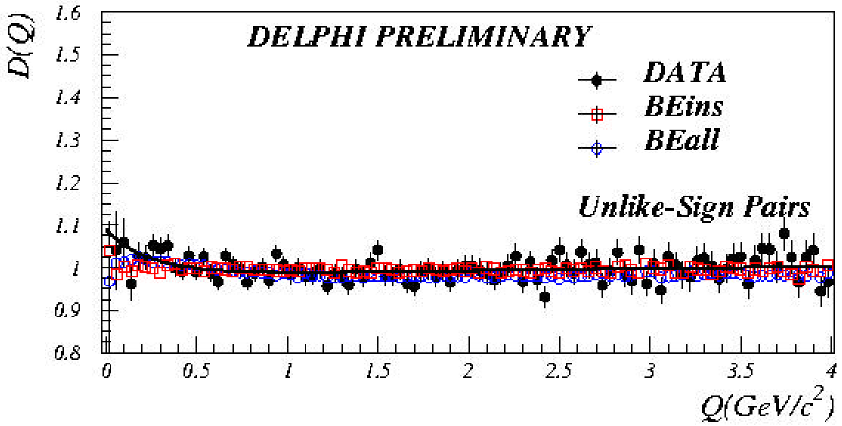
$\Rightarrow$ strong reduction of the 4q W mass weight in the combination

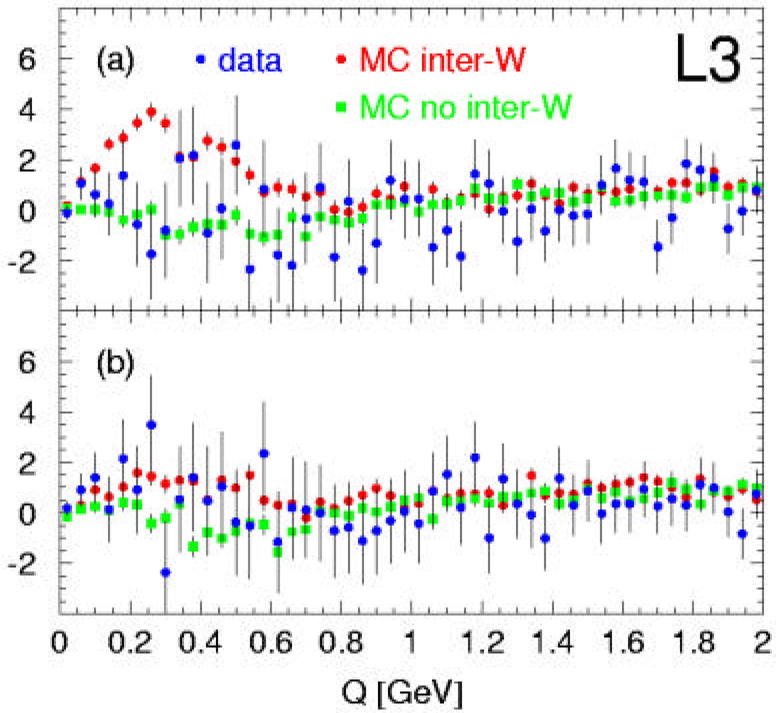
BE correlation: dedicated analyses and W mass

BE correlations between different W's has been being investigated at LEP

- 2-particles correlations in 4q events vs two "mixed" lνqq events
- L3 and ALEPH: no hint for BE corr
- DELPHI evidence for BE corr
  - (un)consistency under investigation







- W mass uncertainty: full shift from the LUBOEI (JETSET) model:

$$\Rightarrow \Delta M_W = 35 \text{ MeV}$$

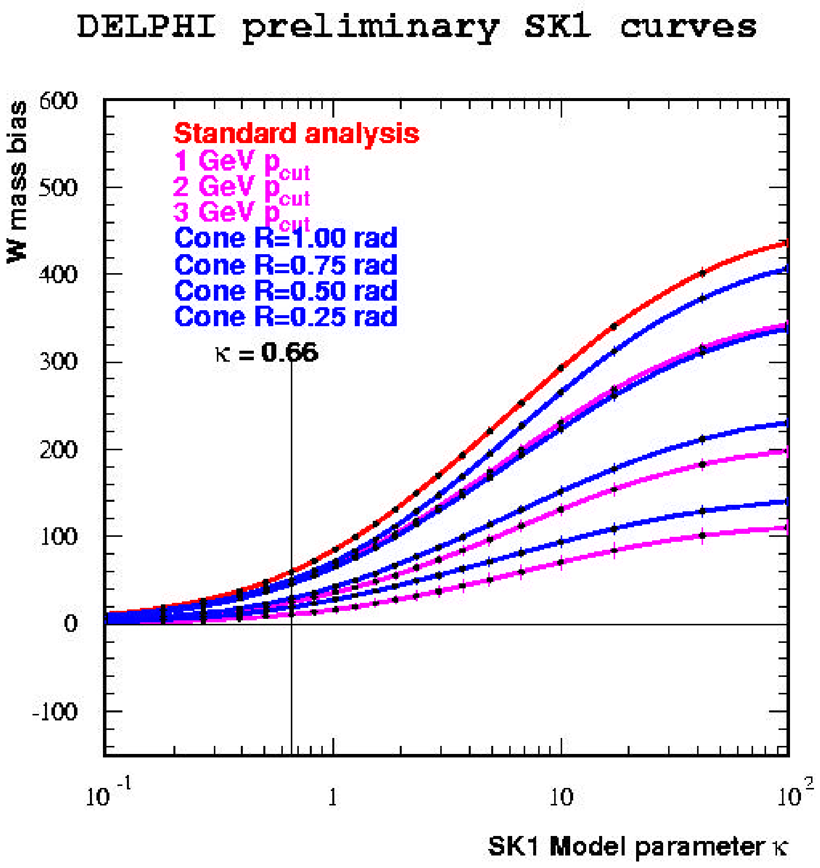
  - correlated between experiments

Work in progress: reduce W mass sensitivity on CR

CR is expected to affect mainly:

- low momentum particles
- particles away from the jet core

- Measure W mass removing:
  - or low momentum particles (pcut)
  - or far away particles (cone)
- Two-fold result:
  - new W mass estimator less sensitive to CR biases
  - the difference std W mass and (pcut/cone) W mass used to “measure” CR and constraint the MC models
    - it can be combined with Particle Flow



LEP W mass combined results

Combined LEP results (including threshold measurements)

M_W=80.412±0.029(stat)±0.031(syst) GeV

Γ_W=2.150 ±0.068(stat)±0.060(syst) GeV

M_W(lνqq)=80.411±0.032(stat)±0.030(syst) GeV

M_W(qqqq)=80.420±0.035(stat)±0.101(syst) GeV

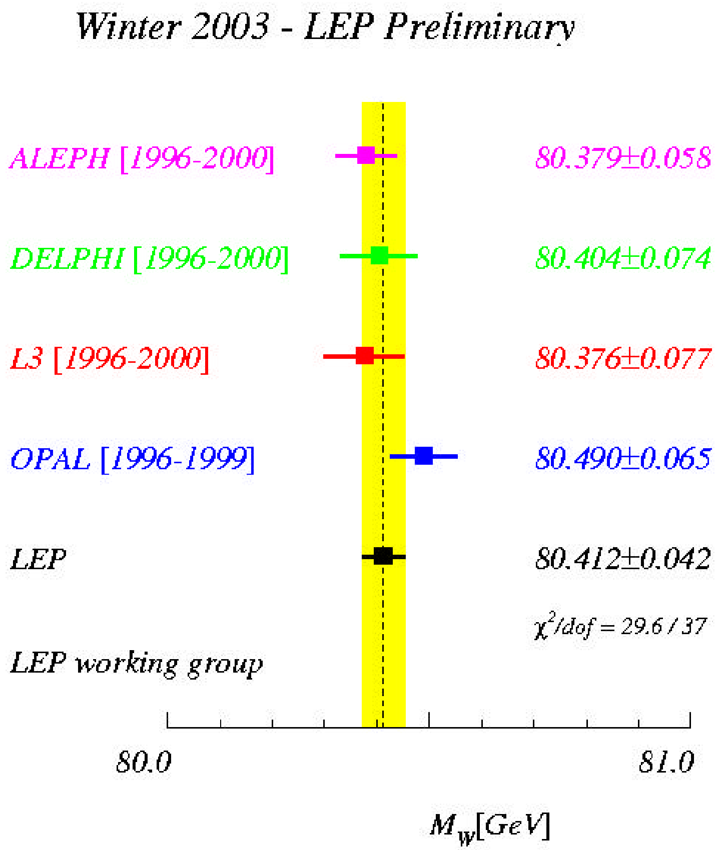
(18% correlation)

– qqqq - lνqq mass difference (no FSI syst)

ΔM_W(qqqq-lνqq)= +22±43 MeV

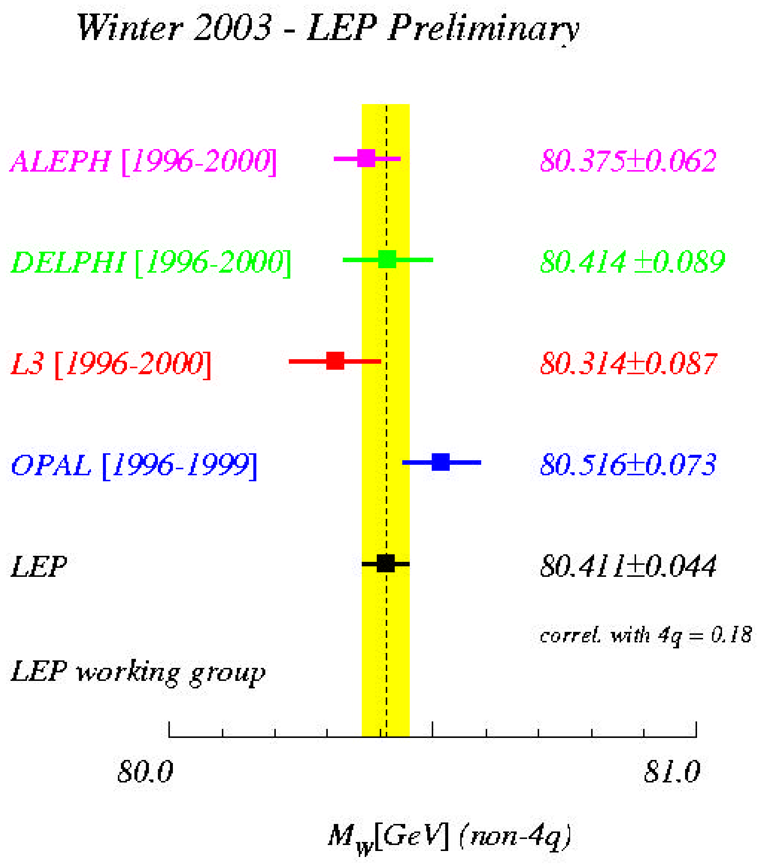
Weight of qqqq channel: 9% (was 27% before summer 2002)

– if no FSI: 21 MeV statistical error

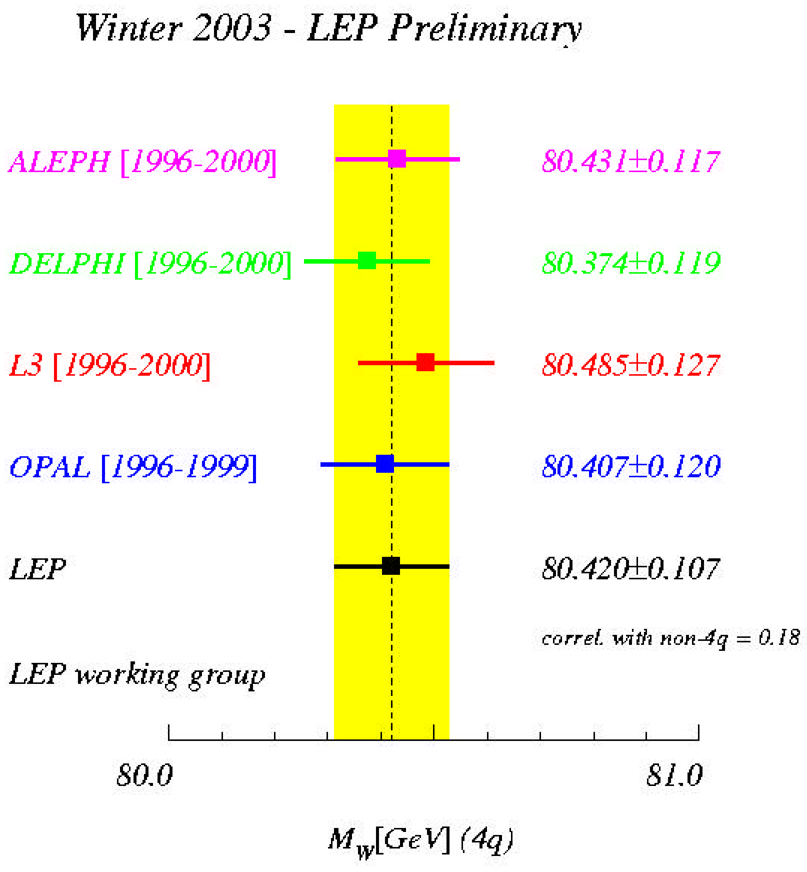


- W mass result shifted by –35 MeV with respect to Summer 2002 non-4q

4q



Winter 2003 - LEP Preliminary
ALEPH [1996-2000] 80.375±0.062
DELPHI [1996-2000] 80.414 ±0.089
L3 [1996-2000] 80.314±0.087
OPAL [1996-1999] 80.516±0.073
LEP 80.411±0.044
correl. with 4q = 0.18
LEP working group
80.0
81.0
M_W[GeV] (non-4q)



Winter 2003 - LEP Preliminary
ALEPH [1996-2000] 80.431±0.117
DELPHI [1996-2000] 80.374±0.119
L3 [1996-2000] 80.485±0.127
OPAL [1996-1999] 80.407±0.120
LEP 80.420±0.107
correl. with non-4q = 0.18
LEP working group
80.0
81.0
M_W[GeV] (4q)

Why W mass measurement at LEP is still PRELIMINARY

Because the LEP Collaborations say that "it is still preliminary" ...

- They are working for the final publications and already published can be changed
- OPAL results with year 2000 data have not been made public yet

Because there are a lot of discussions and exchanges of ideas among the LEP Collaborations

- LEP W workshops

Because of the present treatment of the final state interaction syst in 4q channel

- data-driven evaluation which can improve in the future and increase the weight of the W mass from the fully hadronic channel

Because "external" inputs can change

- LEP energy calibration
- Final state interaction MC models

Therefore LEP W mass results can/will change in the future: both central value and uncertainty.

ElectroWeak fit results

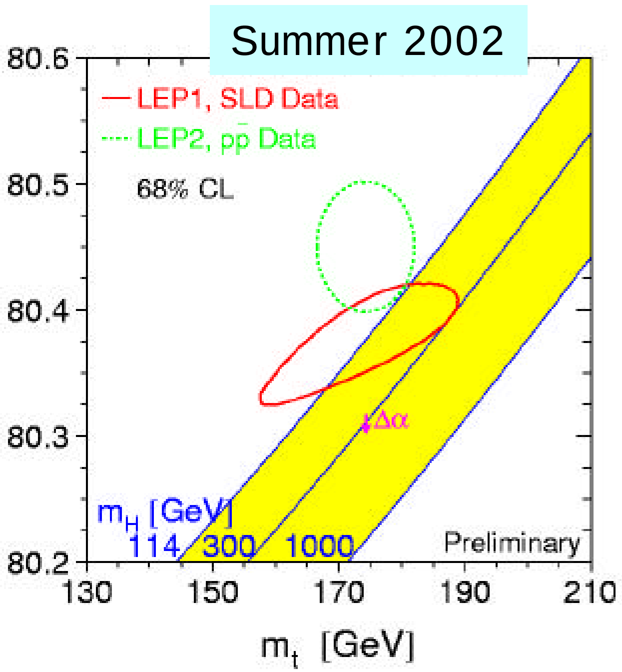
LEP W mass measurement combined with the Tevatron result :

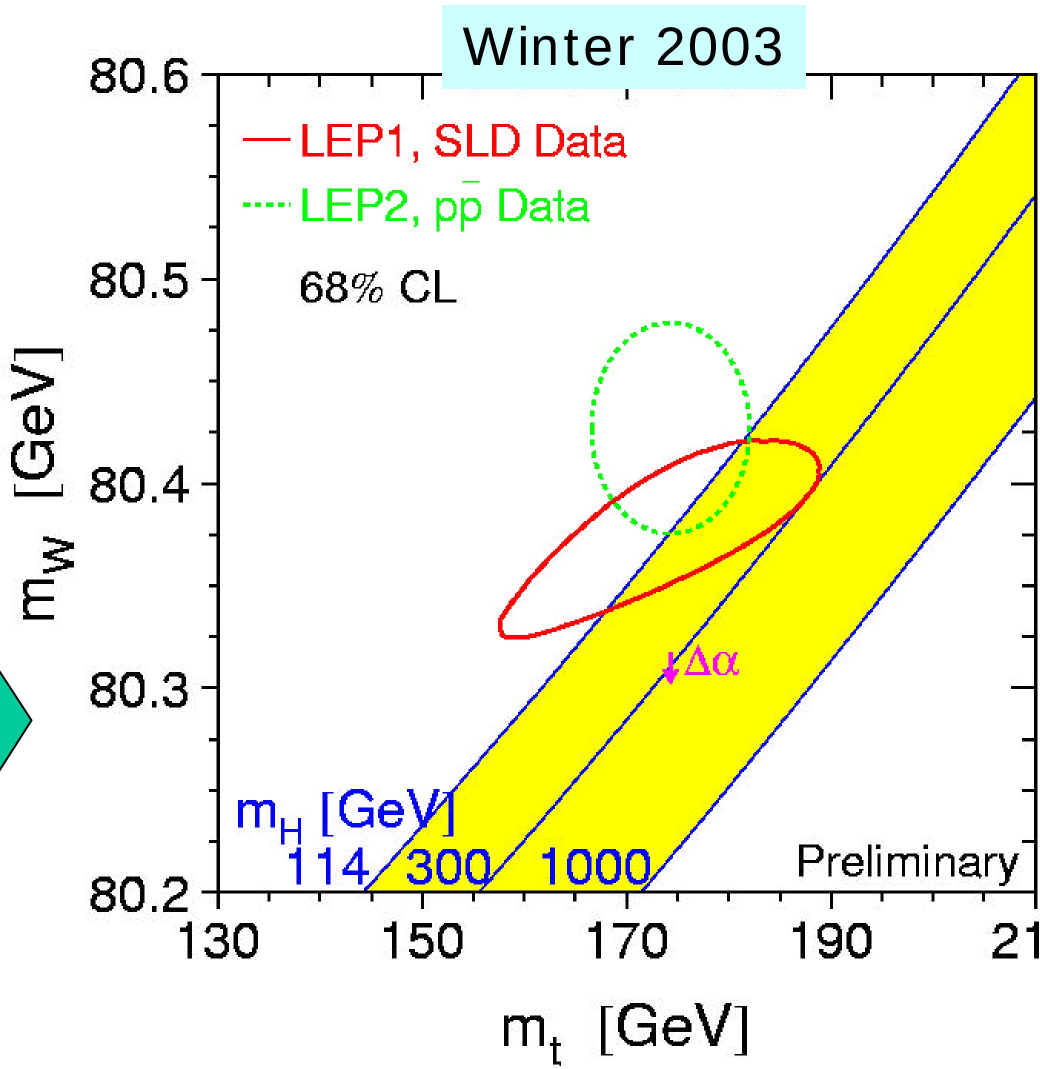
- M_W= 80.454±0.059 GeV (pp)

M_W= 80.426±0.034 GeV (LEP+pp)

Γ_W=2.139 ±0.069 GeV (LEP+pp)

– Other new input
  - revised theory corrections for APV



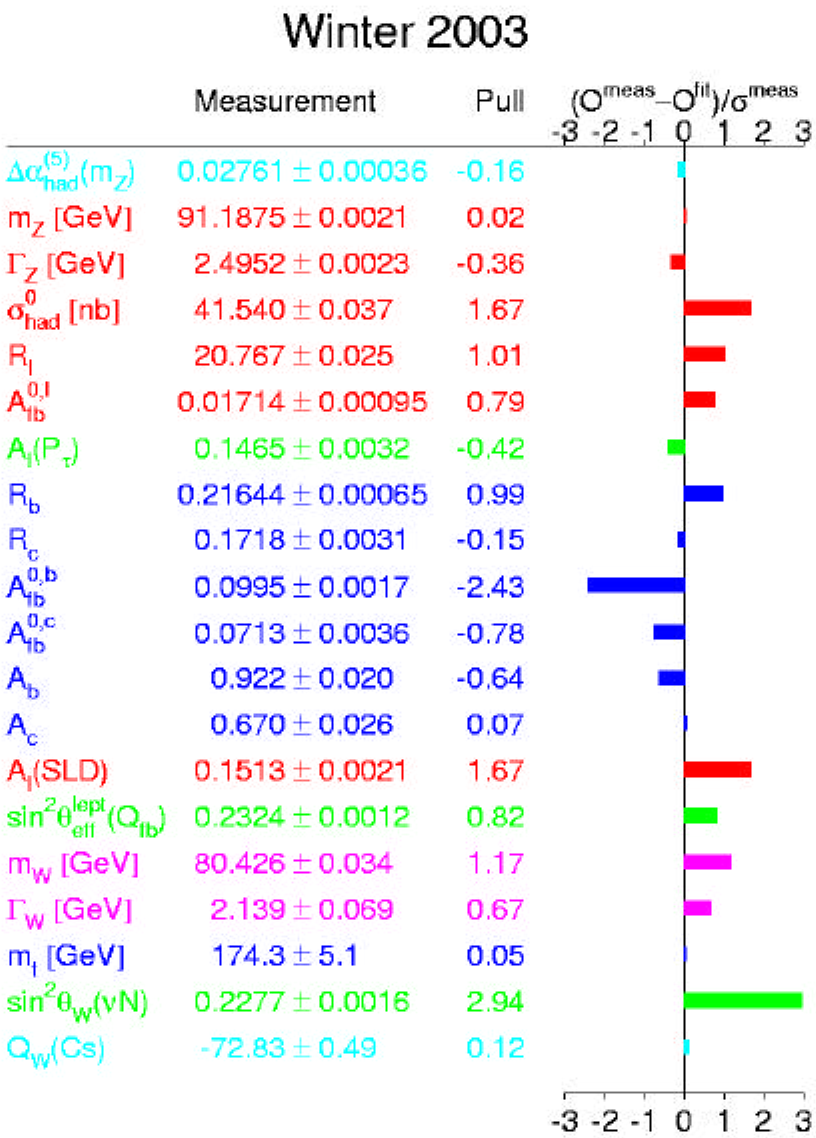


Global fit

Combination of:

- Z-pole results (LEP + SLC)
- Direct M_W and m_{top} measurements
- NuTeV νN scattering
- APV

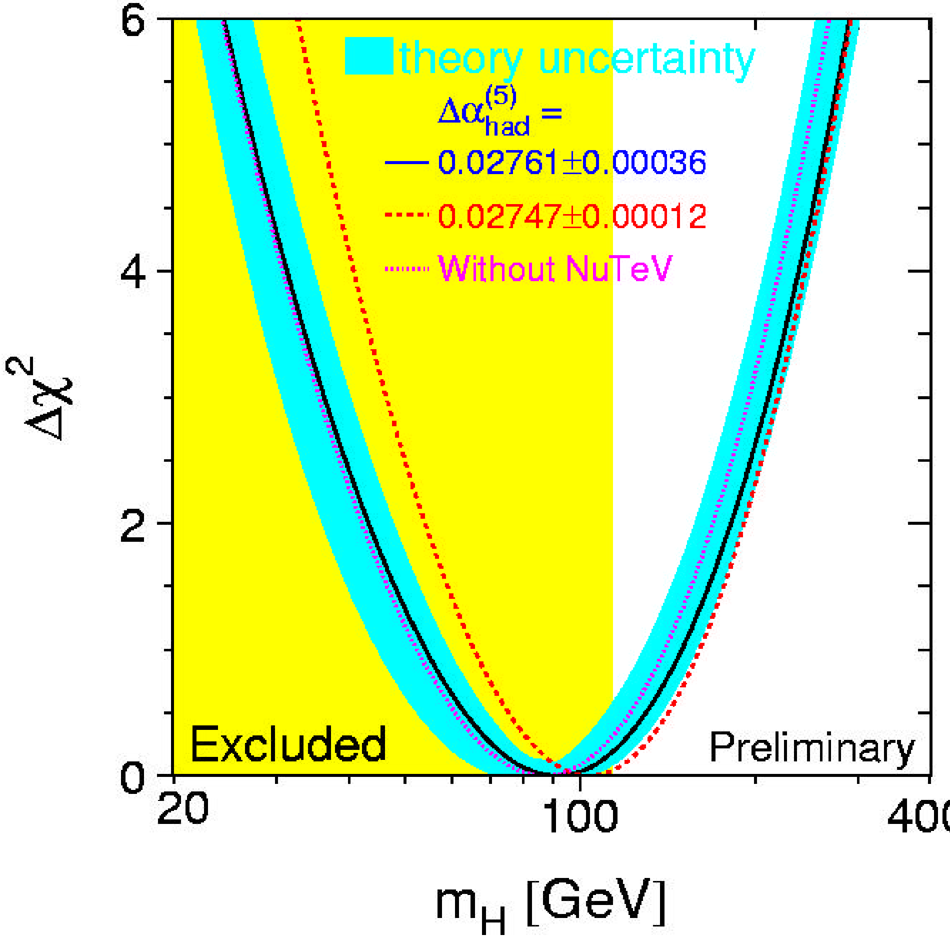
- χ^2/ndof = 25.5/15 (4.4%)
  - largest contribution comes from NuTEV
  - χ^2/ndof = 16.7/14 (27.3%) without NuTeV



Indirect Higgs mass constraint

The combined fit allows an indirect determination of $\log(M_{Higgs})$

- $M_{Higgs} = 91^{+58}_{-37}$ GeV
- $M_{Higgs} < 211$ GeV at 95% CL
  - fit result is stable with or without NuTeV
  - Theory uncertainty included



Conclusions

An updated measurement of the W mass at LEP has been presented

- new/updated ALEPH preliminary results

The LEP W mass result is still PRELIMINARY

- LEP collaborations are still working on this measurement
- part of the statistics has not been used yet
- the statistical power of the 4q channel is very depressed by the FSI uncertainty
  - Activities to reduce the CR effects and to constraint the model predictions

The ElectroWeak global fit is in good shape

- the fit is robust