New (almost final) W mass and width results from LEP

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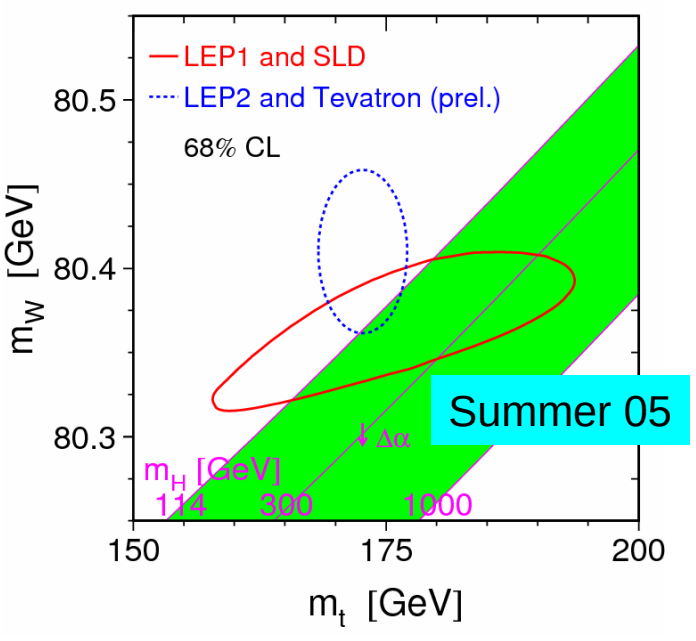
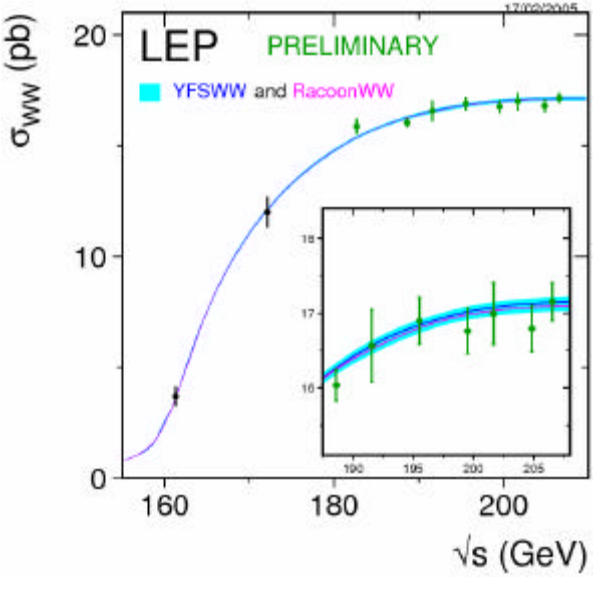
On behalf of ALEPH, DELPHI, L3, OPAL collaborations and the LEP EW WG

W mass measurement and LEP2

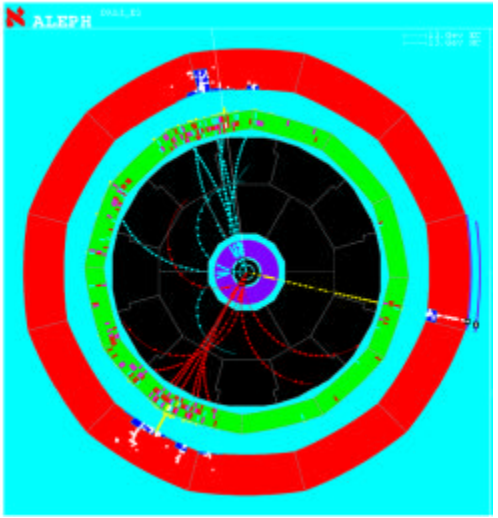
- W mass measurement is important because:
  - direct vs indirect measurements: EW radiative correction test
    - Δm_W (indirect)~ 32 MeV
  - improve indirect Higgs boson mass determination
    - optimum: $\Delta m_W \sim 0.007\ \Delta m_{top}$

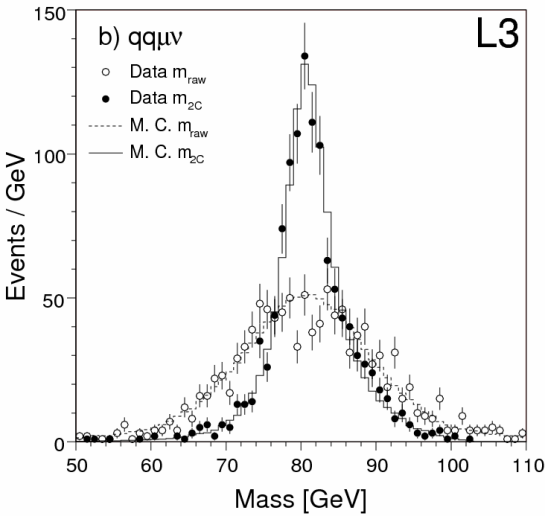


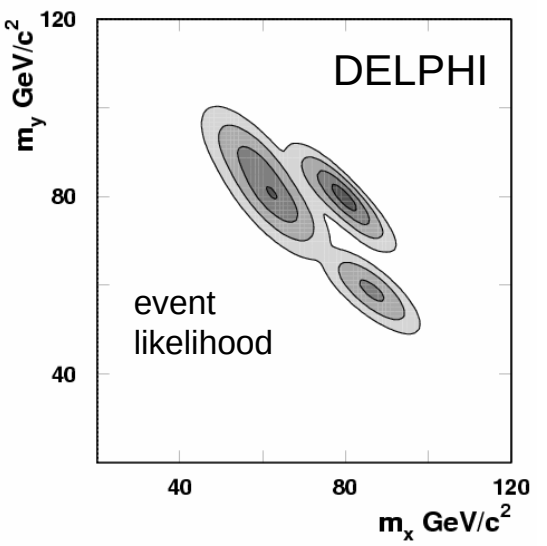
- W boson at LEP2 e^+e^- collider
  - $E_{CM} > 2M_W$: WW pair production
  - ~ 700 pb^{-1}/exp ⇒ ~10000 WW evts
  - Final states
    - ~45% qqqq
    - ~44% lνqq
    - ~11% lνlν
  - High purities and efficiencies



W mass measurement







- Jet and leptons reconstruction:
  - From charged tracks and calorimeters
- E, p conservation:
  - improved resolution (6-8 → 2-4 GeV)
  - neutrino reconstrcution

  ⇒ LEP energy affects W mass
- Jet pairing in 4q events
  - Matrix element, χ^2, ...

  ⇒ ~80-90% of correct pairings

- W mass extraction
  - W mass dependent reweighted MC to fit estimator distributions
    - W mass, kinematic fit errors,...
  - BW or event likelihood fit + MC calibration
  - W width from 2 params fit
- MC is needed to correct biases:
  - ISR, resolutions, thresholds,...

  ⇒ Systematics due to data vs MC discrepancies

Winter 2006: what is new

- New and FINAL results from:
  - OPAL (already available in Summer 2005)
  - L3
  - ALEPH
    - DELPHI will be ready next Summer.
  - Improved analyses and systematics estimates applied to the full LEP2 datasets
- New and FINAL LEP energy calibration with REDUCED uncertainty have been used
- New reconstruction for the WW→qqqq events to reduce the Final State Interactions uncertainties

  - Reminder: LEP W mass uncertainty was:
    - 42 MeV last year (all preliminary)
    - 39 MeV last Summer (only OPAL final)

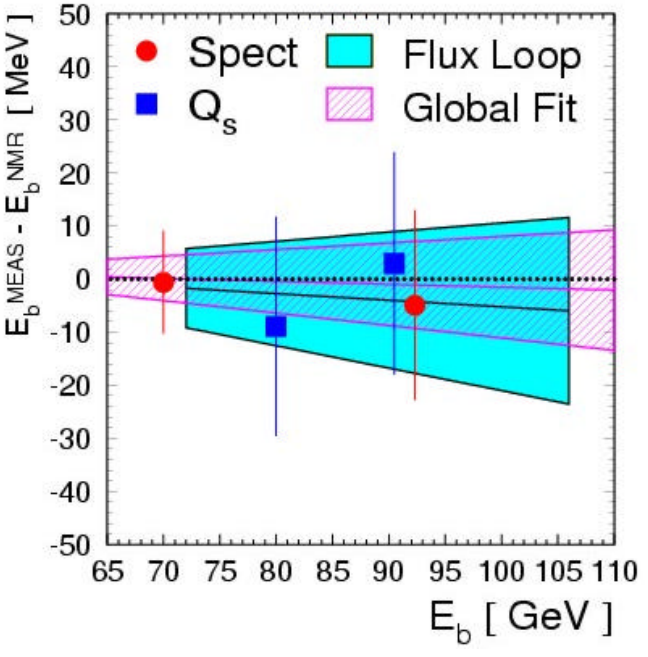
NEW LEP energy calibration

- Because of kinematic fit ($E_{tot}=E_{LEP}$)

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

  – energy and experiments correlated

- Beam energy calibration:
  – Resonant depol. up to 60 GeV
  – Extrapolation up to 100 GeV with NMR probes (B field measurement)
- NMR extrapolation checks
  – Flux loop measurement
  – Spectrometer
    - Beam energy from beam deflection
  – Synchrotron oscillations
    - Beam energy from synchrotron radiation energy losses



- Calibration uncertainty
  – **NEW**:

  ΔE_{beam}=10-20 MeV $\Rightarrow \Delta M_W$=9 MeV
  – OLD

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

Detector simulation systematic uncertainty

- Detector response ⇒ biases and resolutions
  - accurate simulation is needed
    - jets and leptons
  - Z events to correct/validate MC
  - W mass syst. estimated from:
    - correction statistical errors
    - data vs MC comparison:
      - peak Z events (calibr runs)
      - **radiative Z events**
      - three jet events
      - high energy two jet events

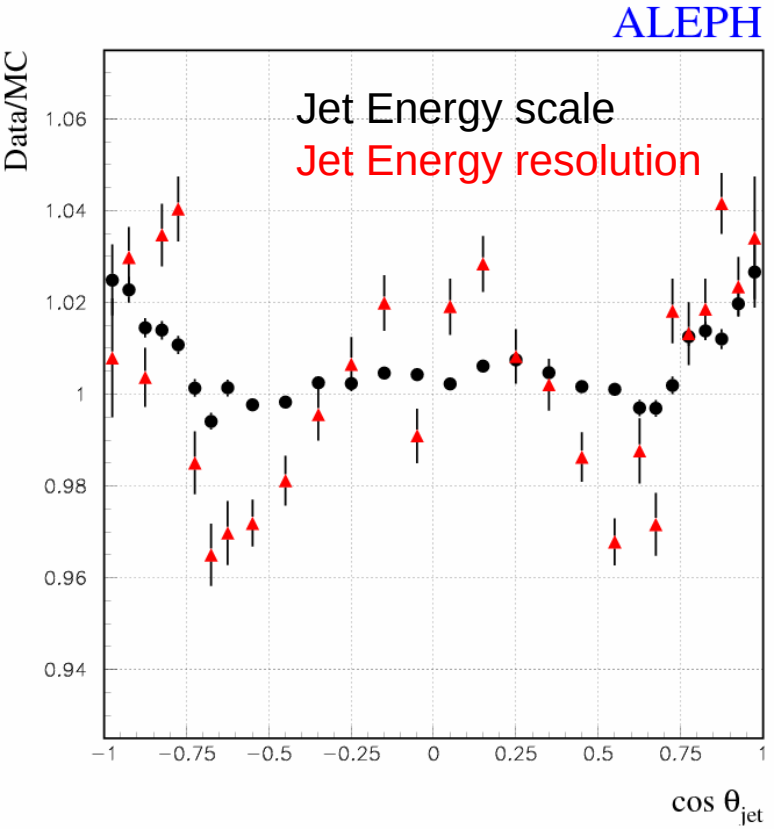
- Studies observables:
  - Jets and Leptons:
    - Energy/momentum scale/resolution
    - **Energy/momentum linearity**
    - **Jet boost/mass**
    - direction bias/resolution

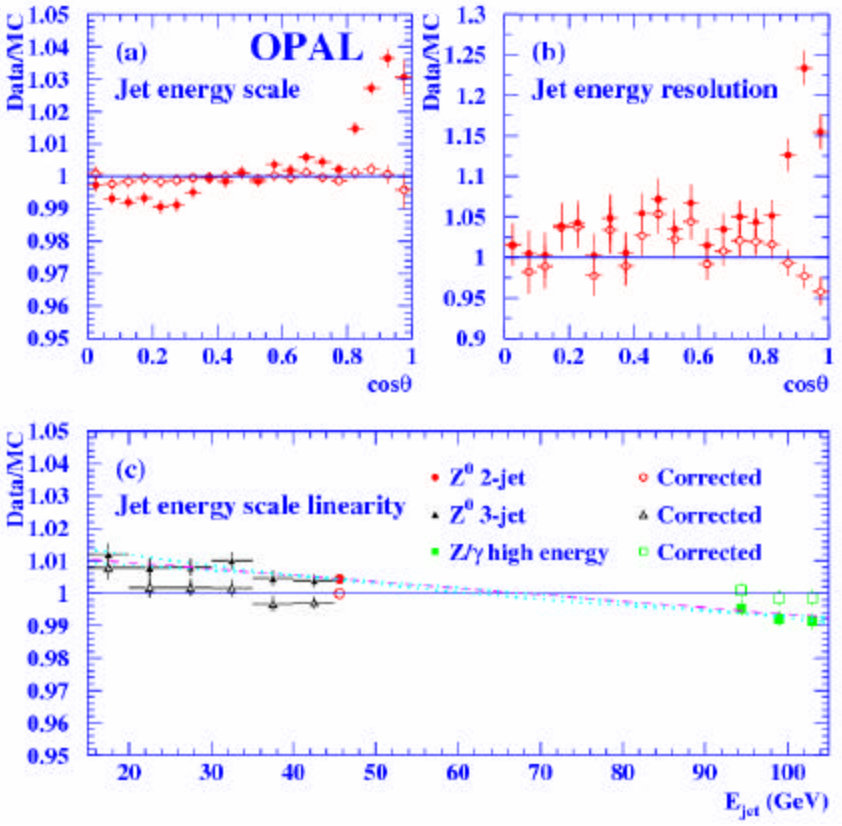
- Typical uncertainties

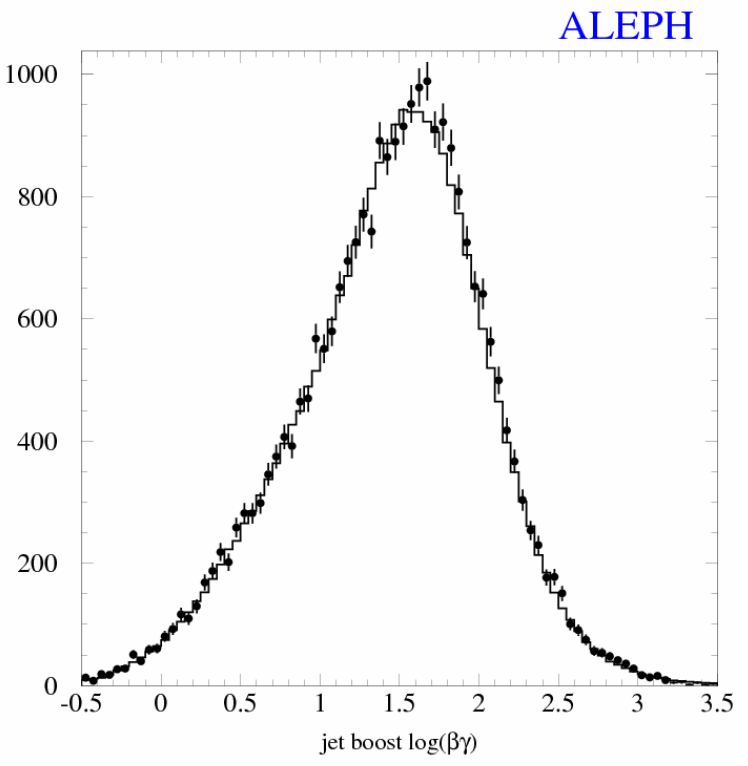
⇒ ΔM_W= 10-20 MeV ⇒ 11 MeV (lνqq)

⇒ ΔM_W= 5-20 MeV ⇒ 8 MeV (qqqq)

- uncorrelated among experiments







- Examples:
  - OPAL jet energy simulation
  - ALEPH jet boost/mass data vs MC agreement in radiative Z events

Hadronization and radiative corrections

- Hadronization:
- MC models to generate hadrons
  - particle spectra, and contents (baryons) are affected
  - Interplay with Detector resolution and thresholds

  ⇒ biases, non-linearities,…
- How well data are simulated
  - JETSET used by all LEP experiments
    - internal MC parameters **extensively** tuned with Z peak data by each experiments
- Systematic uncertainty on W mass by comparing MC models
  - JETSET vs ARIADNE vs HERWIG
  - **NEW: rescale to the same baryon/kaon content before comparing models**
    - particles are reconstructed massless or as pions
- ΔM_W=10-15 MeV ⇒ 14 MeV (lνqq)
  - correlated among the experiments

- QED radiative corrections
- Real photon emission
  - ISR, WSR, FSR
  - kinematic fit is affected

  ⇒ biases
- Virtual corrections
  - W mass spectrum affected
- O(α) (or better) corrections are included in the generators (**YFSWW**, RacoonWW)
  - with exponentiation (YFSWW)
- W mass uncertainties estimated by:
  - degrading the correction accuracy (ISR)
  - Comparing different correction schemes

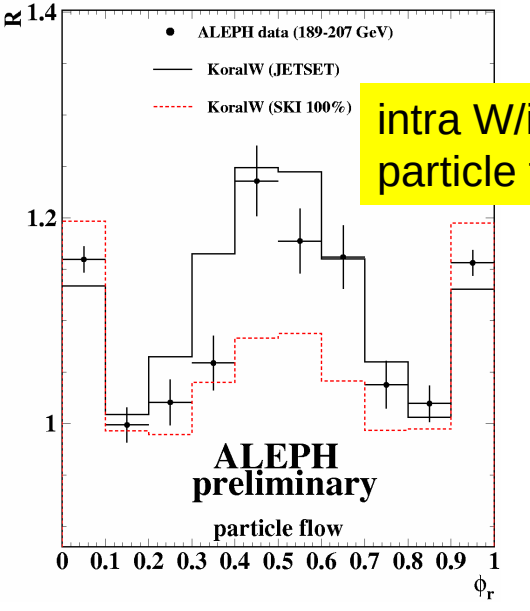
⇒ ΔM_W< 10 MeV
- correlated among experiments

Final State Interactions in qqqq events: the bottleneck

- Hadronically decaying W pairs short living (~0.1 fm) ⇒their decay products can interact among each other
  - Colour Reconnection (CR)
  - Bose-Einstein correlation (BE)
- 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 from MC models:

- SKI (JETSET) δM_W = 0 – 200 MeV
  - parameter dependent (k_i, p_{reco}, ...)
- Ariadne: δM_W = 50-60 MeV
- Herwig: δM_W = 40 MeV



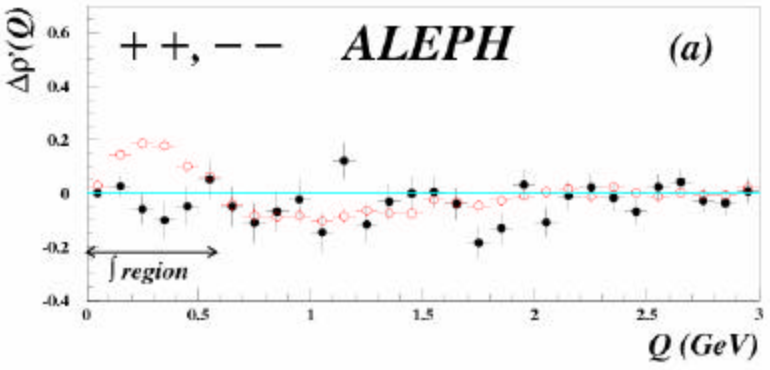
intra W/inter W particle flow

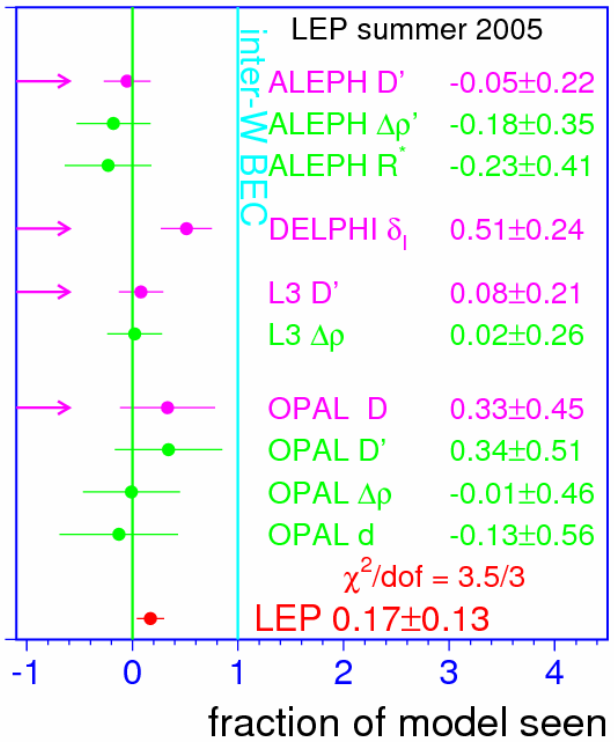
- CR limit from data: Particle Flow in WW→qqqq events (SKI model)
  - ⇒ ΔM_W=75-105 MeV (k_i=2.13)
- BE : full LUBOEI effect:
  - ⇒ ΔM_W=35 MeV

⇒ 4q channel "killed" : 9% weight (before Summer 05)

BE correlation: what the data tell us

- BE correlations between different W's has been being investigated at LEP
  - 2-particles correlations in 4q events vs two "mixed" lνqq events
- Final results published by all experiments



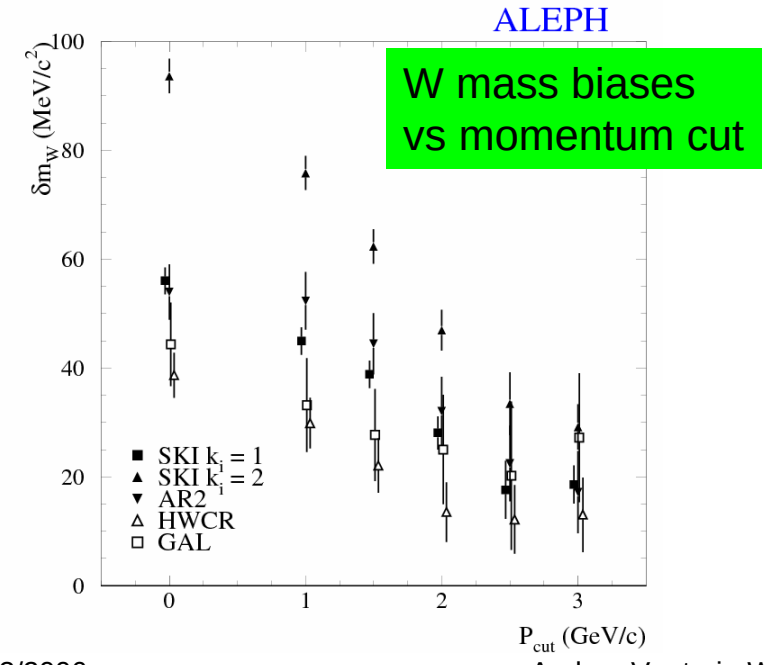


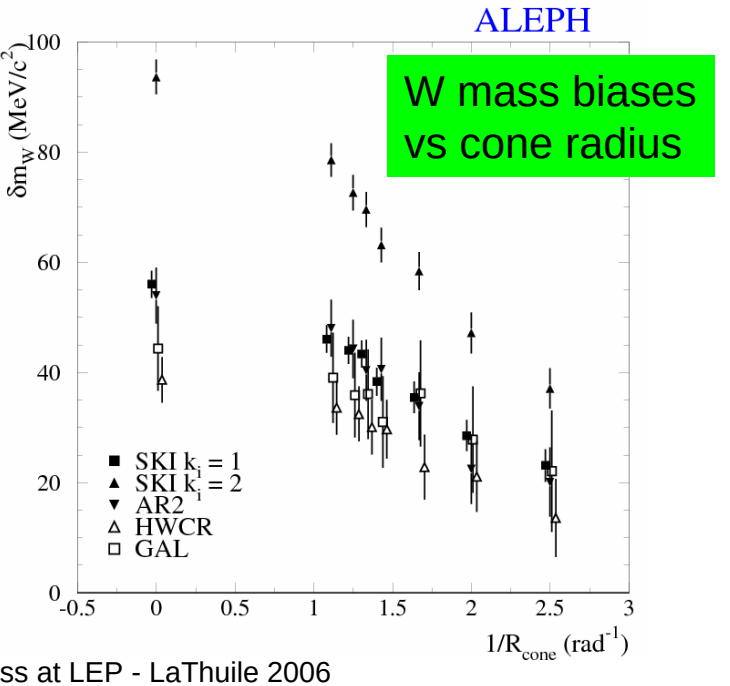
- Data do not show an effect as large as the one predicted by LUBOEI model
- W mass bias estimate can be reduced
- NOT DONE YET!

FSI and W(qqq) mass bias: the wayout

- CR is expected to affect mainly:
  - low momentum particles
  - particles away from the jet core
- Measure W mass by removing:
  - or low momentum particles (Pcut)
  - or far away particles (cone)

- Balance between
  - smaller FSI bias/ systematic uncertainty
  - worse statistical error
  - worse fragmentation error: ΔM_W=20 MeV (qqqq)
- Pcut applied by
  - ALEPH (3 GeV)
  - L3 (2 GeV)
  - OPAL (2.5 GeV)





The Results: W mass

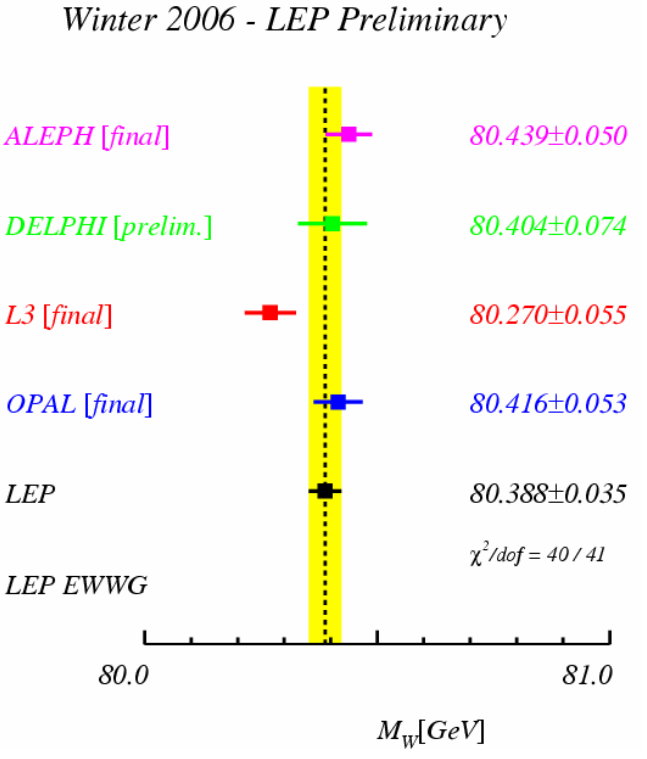
- NEW 4q event reconstruction:
  - stat error worse by ~15-35%
  - hadr error worse by ~30-100%
  - FSI error reduced by ~ 2-3 times

- Combined 4q W mass result:
  - **new uncertainty: 61 MeV**
    - **43 MeV stat + 43 MeV syst**
    - **(34 MeV FSI)**
  - it was: 79 MeV (48 + 62 MeV)

- Global result:

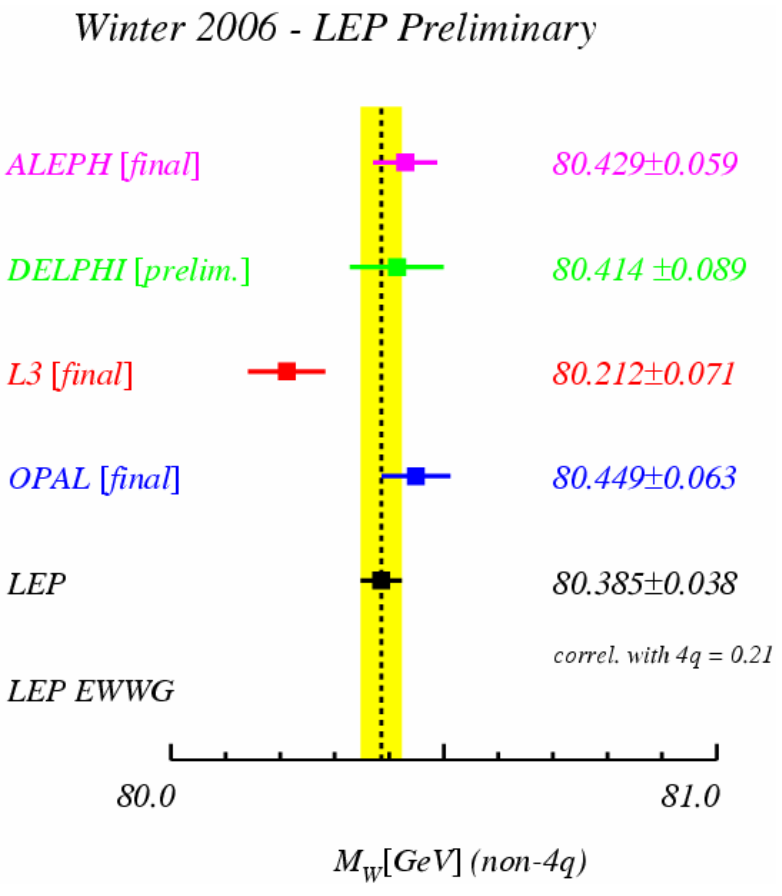
M_W=80.388±0.035 GeV

- 26 MeV stat + 24 MeV syst (7 MeV FSI)
- 4q weight: 23%

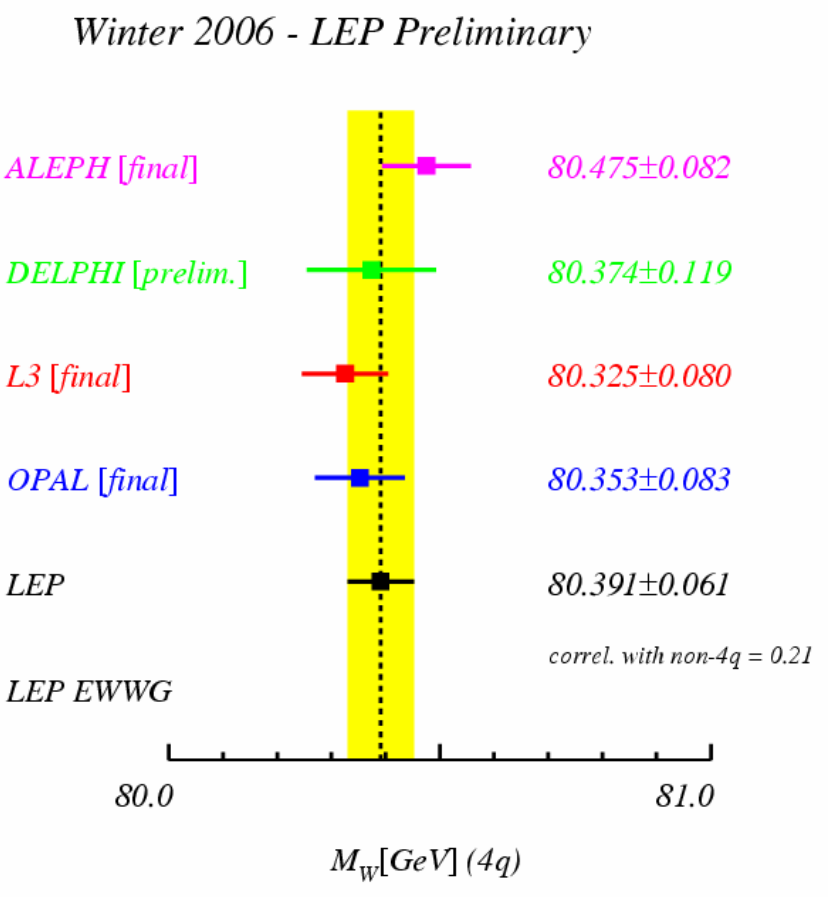


- It was (already with final OPAL results):
  - 39 MeV total error = 27 + 28 MeV (8 Mev FSI)
  - 4q weight: 16%

lνqq and 4q results



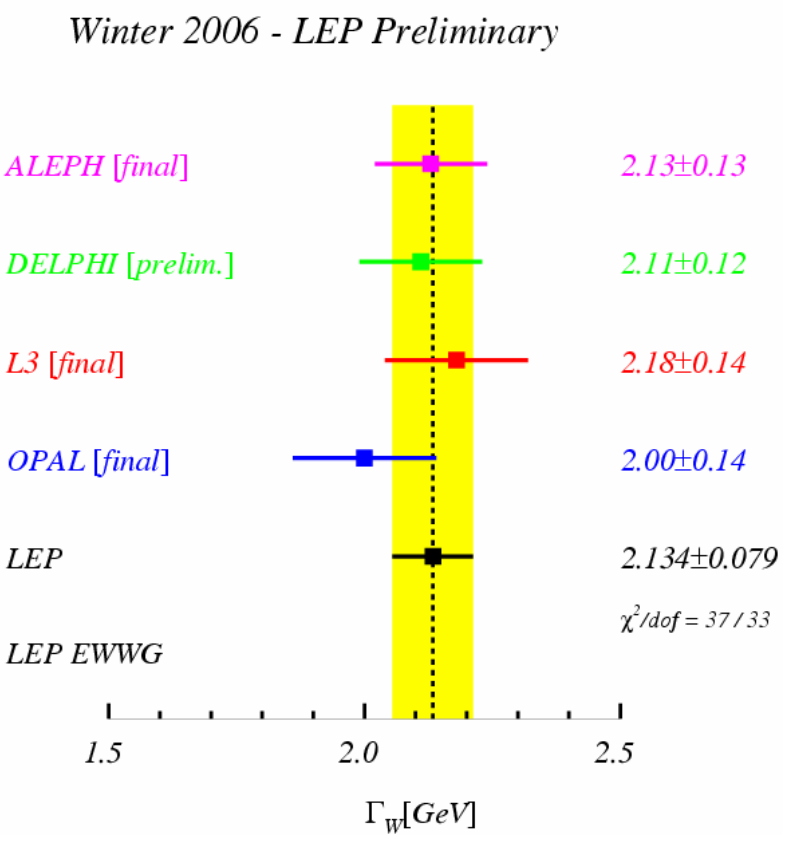
lνqq



qqqq

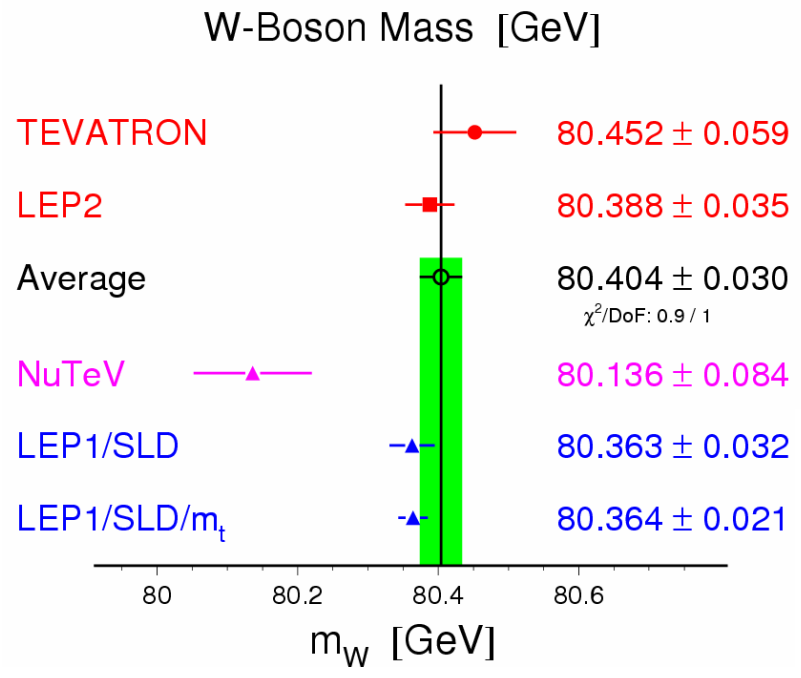
W width results

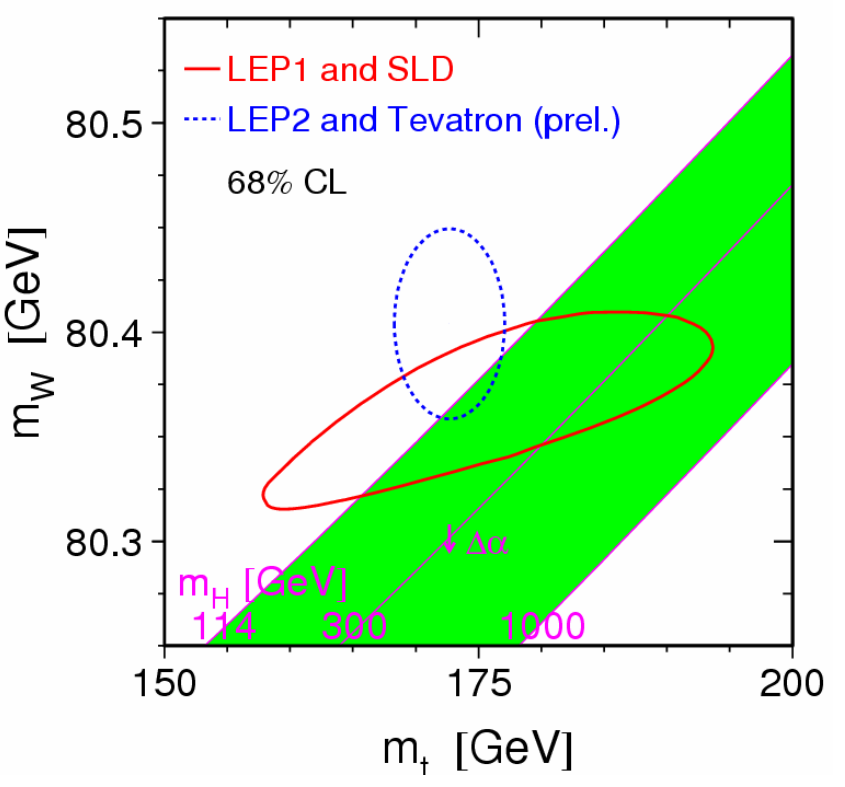
- LEP W width extracted from 2 param fit
  - ALEPH and OPAL did not use Pcut for W width in the qqqq final state
- New LEP result:
- $\Gamma_W = 2.134 \pm 0.079$ GeV
  - 59 MeV stat + 52 MeV syst
- New Tevatron result:
- $\Gamma_W = 2.078 \pm 0.087$ GeV



W mass and EW global fit (Winter 2006 update)

- LEP + Tevatron:
- $M_W = 80.404 \pm 0.030$ GeV
- $\Gamma_W = 2.115 \pm 0.058$ GeV

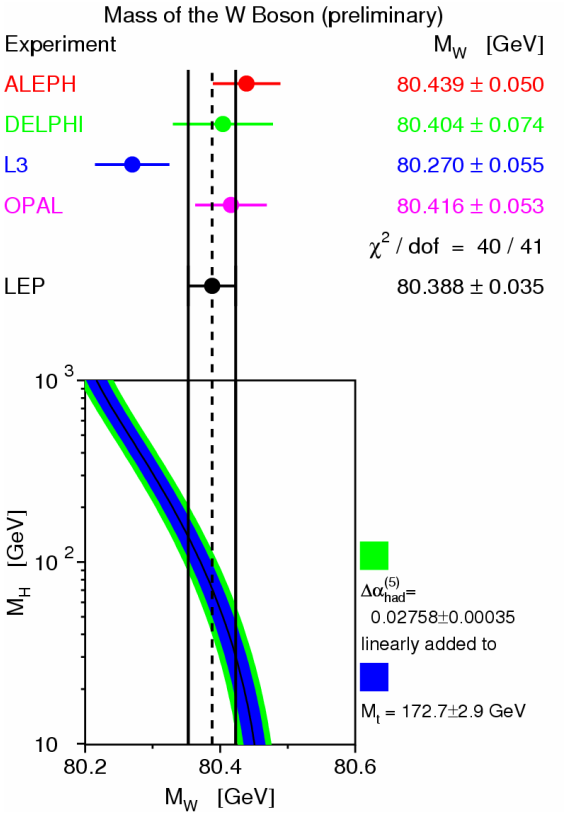


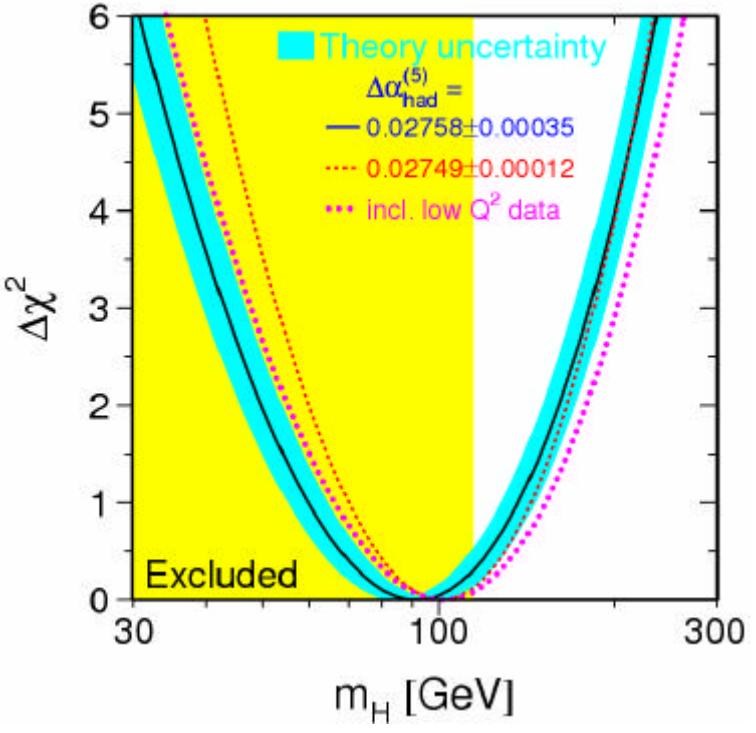


- **Agreement between direct and indirect W mass determinations is nicely confirmed by these final LEP results.**

W mass and Higgs mass

- W mass measurement helps to constrain SM Higgs mass indirect determination





- Results (high Q^2 measurements)
  - $M_{Higgs} = 92\ ^{+45}_{-32}$ GeV
    - ~10 GeV effect due to $\Delta\alpha$ or NuTeV
  - $M_{Higgs} < 186$ GeV at 95% CL

Conclusions

- ALEPH, L3 and OPAL have presented their FINAL W mass results
- NEW detailed systematics studies confirmed and in some cases reduced the preliminary estimates
  - but it has not been painless...
- A NEW event reconstruction procedure has strongly reduced the impact of the uncertainty of the Final State Interaction in the WW→qqqq final state
- NEW LEP energy determination has reduced by a factor ~2 its uncertainty

⇒ **LEP W mass total uncertainty reduced from 39 (42) to 35 MeV since last Summer (last year) .**

- Future (Summer 06):
  - wait for DELPHI final results
  - constraint a little bit better the FSI models using the data

How to constraint CR models with W mass data

- If CR exist than W mass bias depends on how strongly soft/far away particles are rejected

⇒ Differences in W mass measured with different cuts are sensitive to CR effects

- TO BE COMBINED !