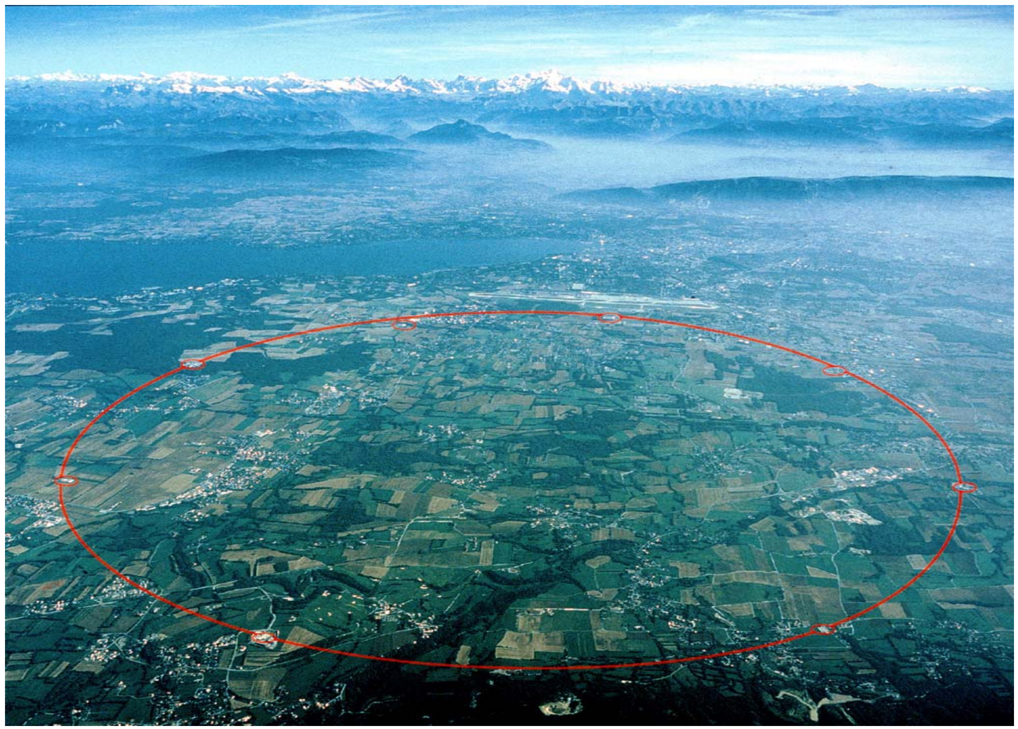
W Mass & Width Measurement at LEP II



BEACH 04, IIT Chicago, 08/03/04

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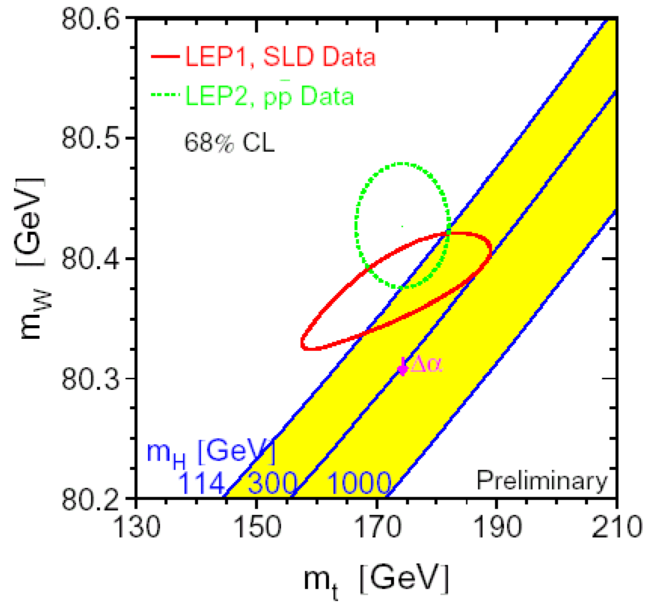
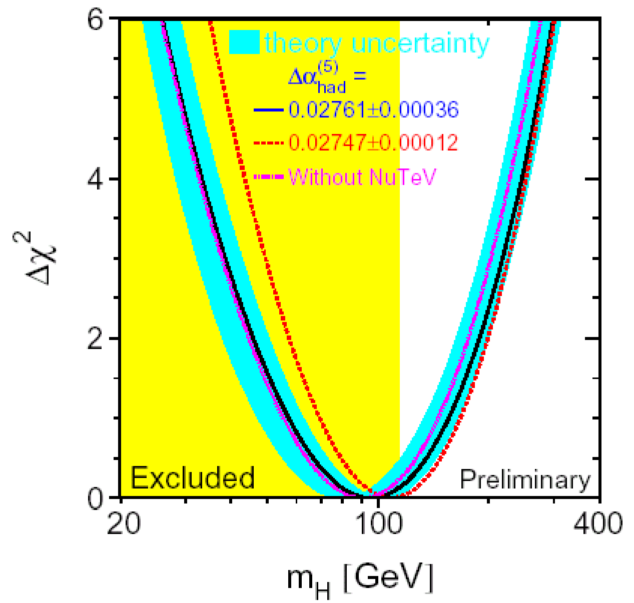
Introduction

- Indirect measurement of W mass
  - LEP1 and SLD measure W mass with an uncertainty of 32 MeV
  - Taking account of Top mass from Tevatron reduces this error to 23 MeV



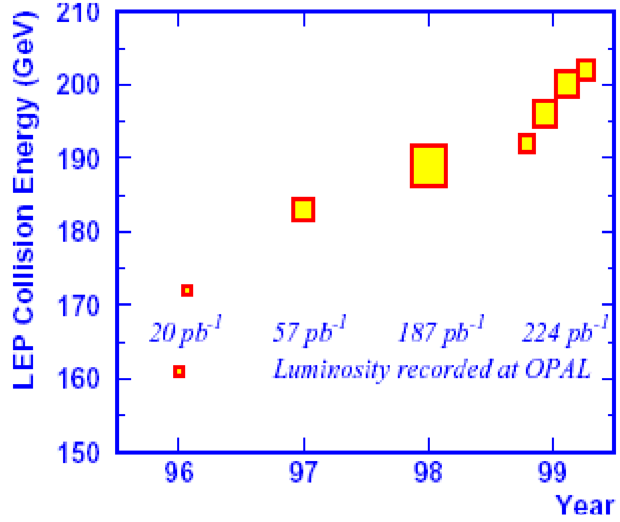
- A direct measurement of W mass with similar precision is of great interest
  - To test the consistency of Standard Model
  - To better constraint the Higgs mass



- Measurement of the width of W boson can also be carried out at LEP providing further consistency of the SM

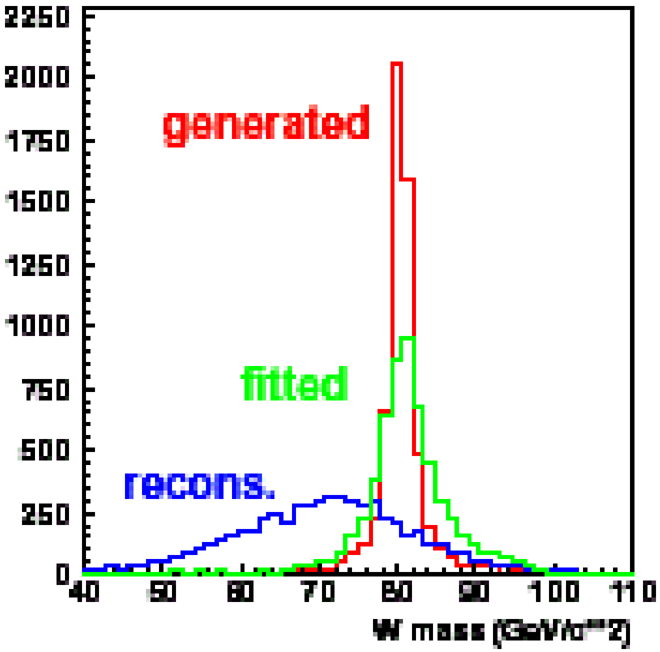
WW Production and Decay at LEP

- W's are produced in pairs at LEP
  - 700 pb^{-1}/experiment; 40,000 WW events
  - $WW \rightarrow qql\nu$ BR ~ 44%
  - $WW \rightarrow qqqq$ BR ~ 46%



- Kinematics fitting
  - LEP beam energy precisely measure; Constraint event kinematics with
    - -- Total Energy = $\sqrt{s}$
    - -- Total Momentum = 0
    - $\Rightarrow$ Improves mass resolution
  - Additionally, apply equal mass constraint

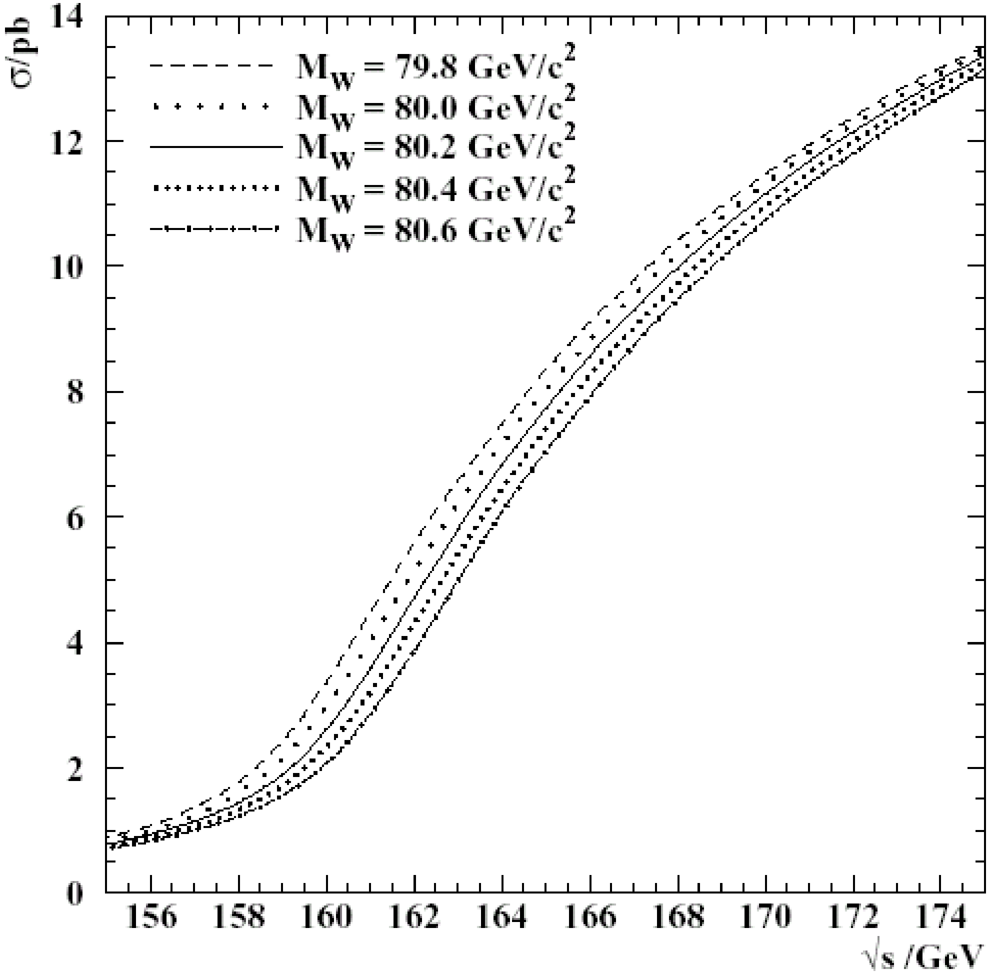
$m_{w+} - m_{w-} = 0$



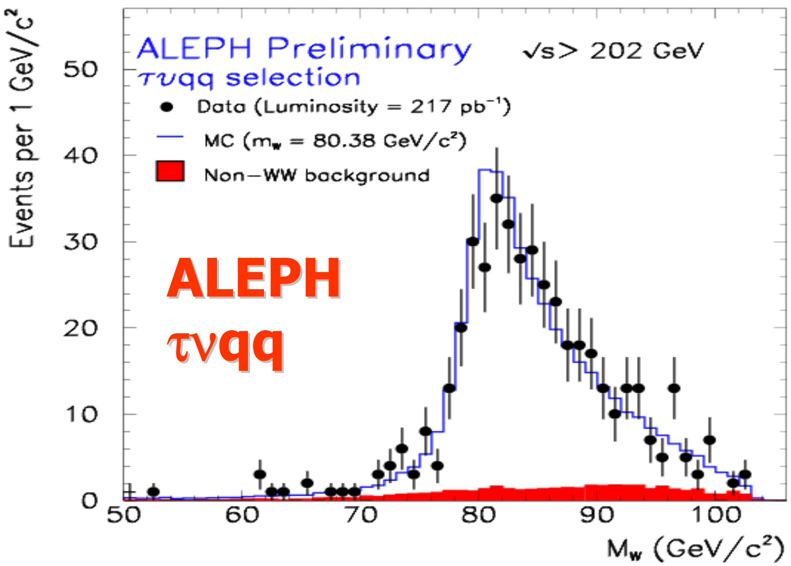
Mw Measurement at Kinematic Threshold

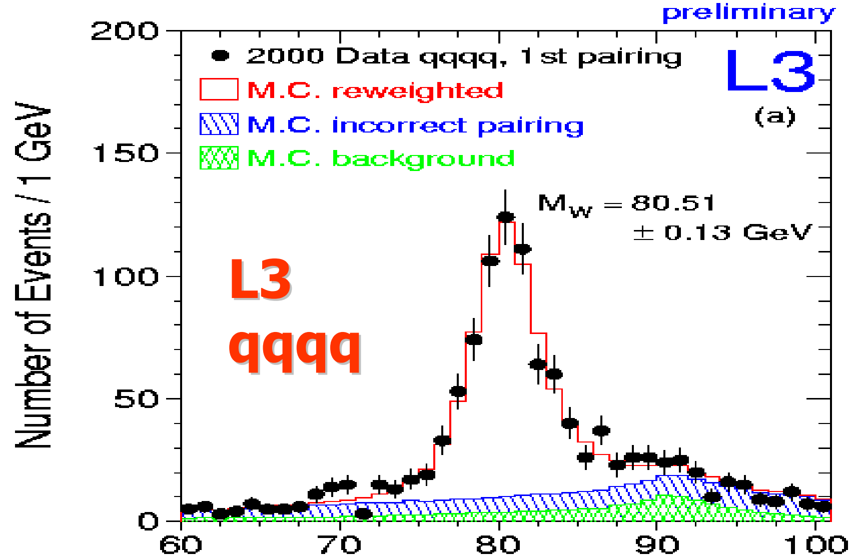
- The WW cross section at $\sqrt{s} = 2M_W$ sensitive to W mass
- LEP experiments collected 10 pb^{-1} data at $\sqrt{s}$ = 161 GeV.
- Combined Result :

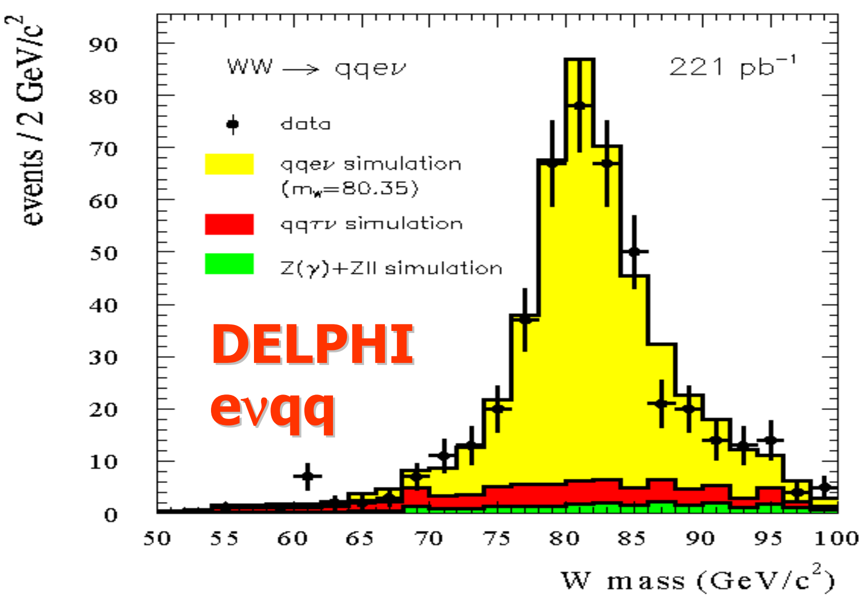
  Mw = 80.40 ± 0.21 GeV



W Mass Distribution







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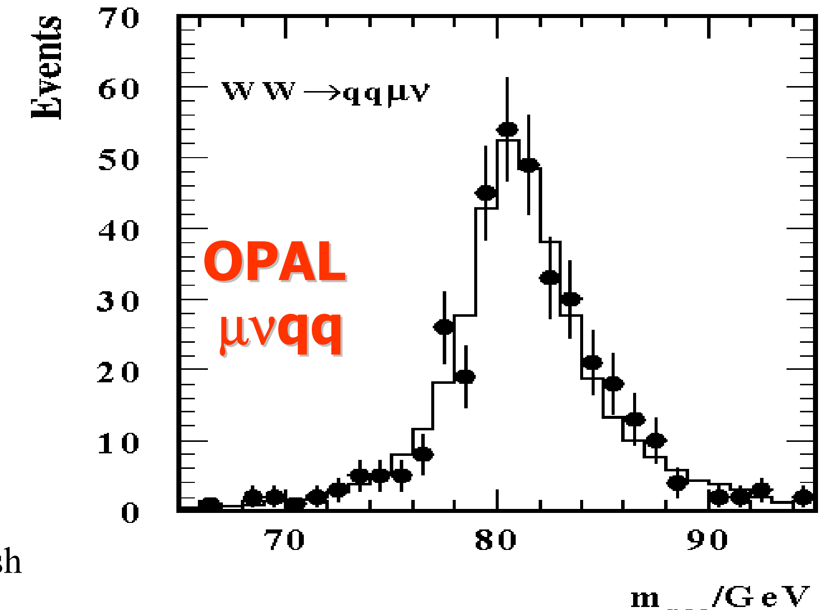


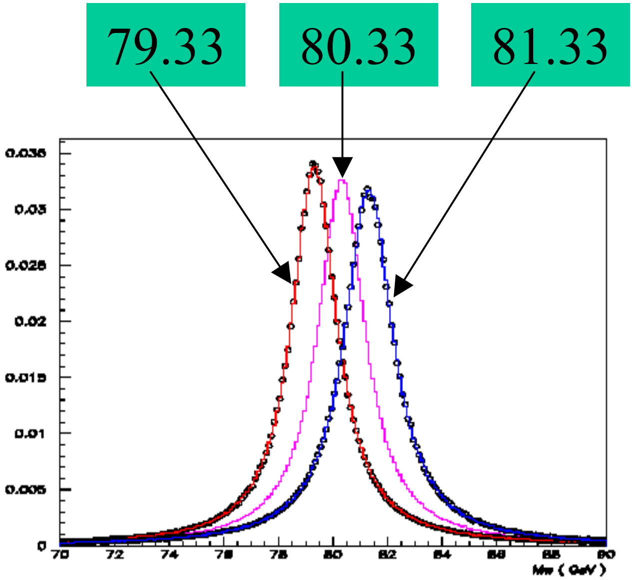
W Mass & Width Extraction

• Maximum likelihood fit to extract mass and width from direct reconstruction

- One parameter fit to extract mass
- Two parameter fit to extract mass and width simultaneously

Breit-Wigner Technique (O): Simple fit to data with a BW distribution. Take care of resolution and ISR effects with MC studies

Convolution Technique(D,O): Convolve physics and detector Resolution; use event-by-event information. Correct bias with fully simulated Monte Carlo events.



Re-Weighting Technique(A,L,O)

Re-Weight fully simulated MC to different Mw, Gw. Data and MC treated identically; no bias correction needed.

Measurement & Uncertainties

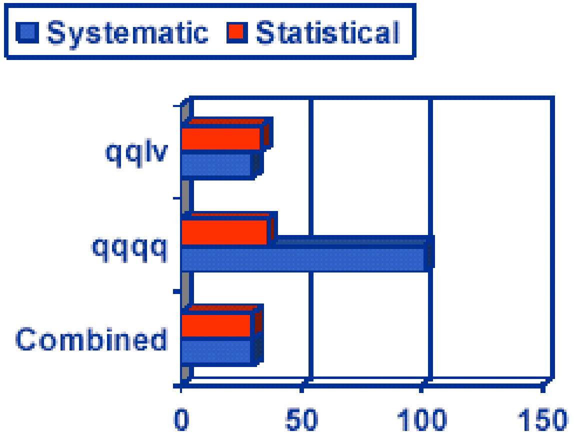
- The combined preliminary LEP W mass

  $M_W = 80.412 \pm 0.029\ (\text{stat}) \pm 0.031(\text{syst})\ \text{GeV}$

  (Does not include OPAL 2000 data)

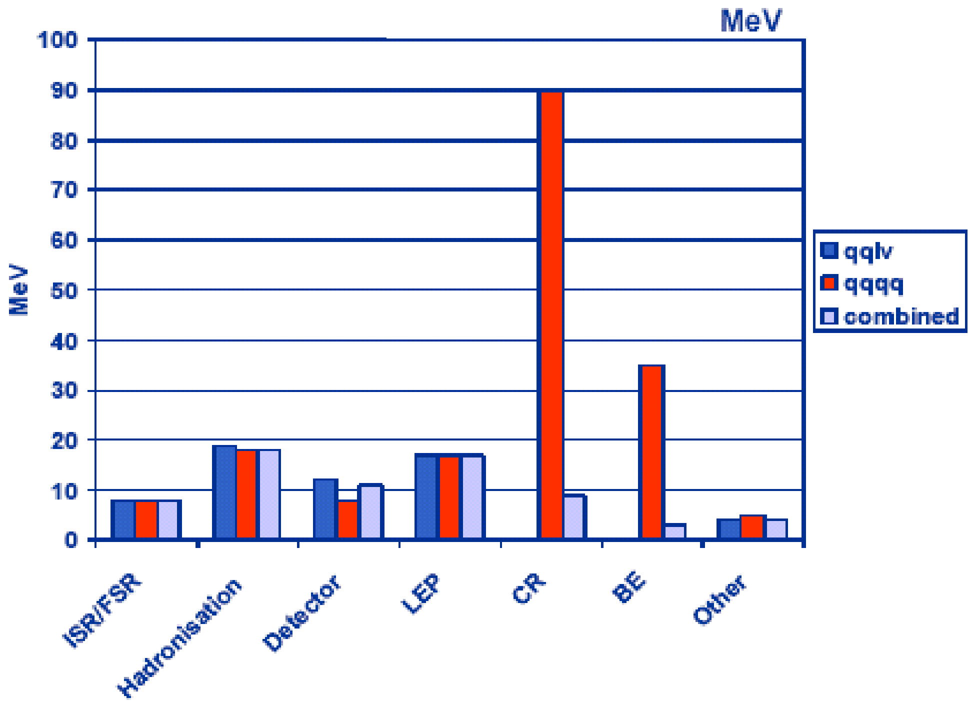
- Systematic error can be broken in two main pieces

  1. LEP Beam energy
  2. MC Modeling



Weight of qqqq channel only 9%

With equal weight for qqqq statistical uncertainty : 22 MeV



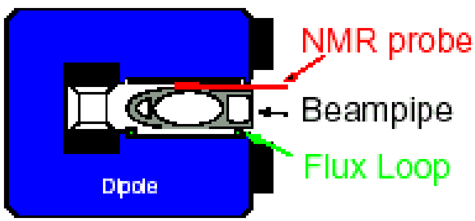
LEP II Beam Energy

$$\frac{\Delta M_W}{M_W} = \frac{\Delta E_{beam}}{E_{beam}}$$

- LEP center of mass energy sets the energy scale for W mass measurement

- E_{beam} is obtained from total bending field

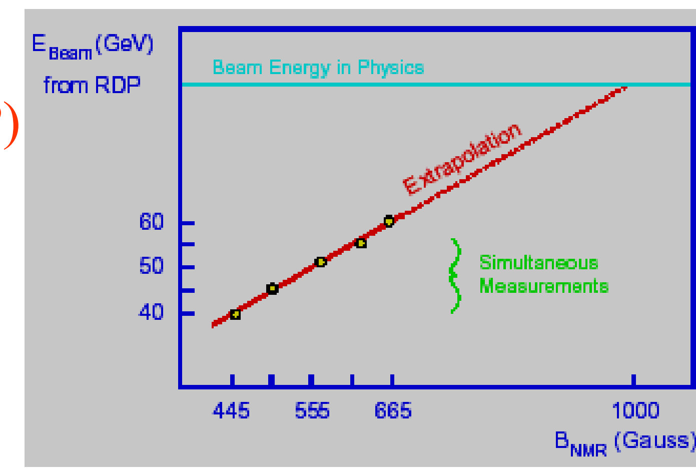
$$E_{Beam} \propto \oint B_\perp dl$$



16 Probes $\frac{\delta B}{B} \sim 10^{-6}$
Continuous Readout

- Field is mapped with 16 NMR probes.

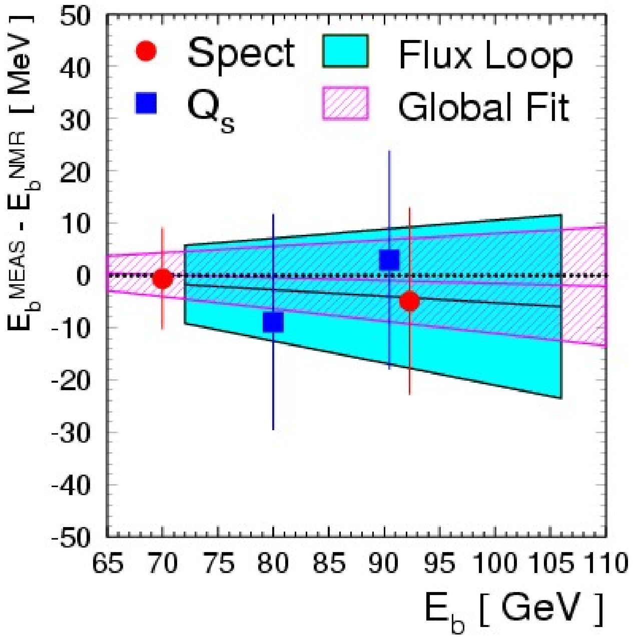
- Calibrated using Resonant De-Polarization (RDP)
  - Works between 41 – 60 GeV.
  - Extrapolated to LEP II energies.



- Main systematic error due to extrapolation

LEP II Beam Energy

- Extrapolation checked with
  - Flux loops
  - Spectrometer (New results)
  - Energy loss methods (New results)

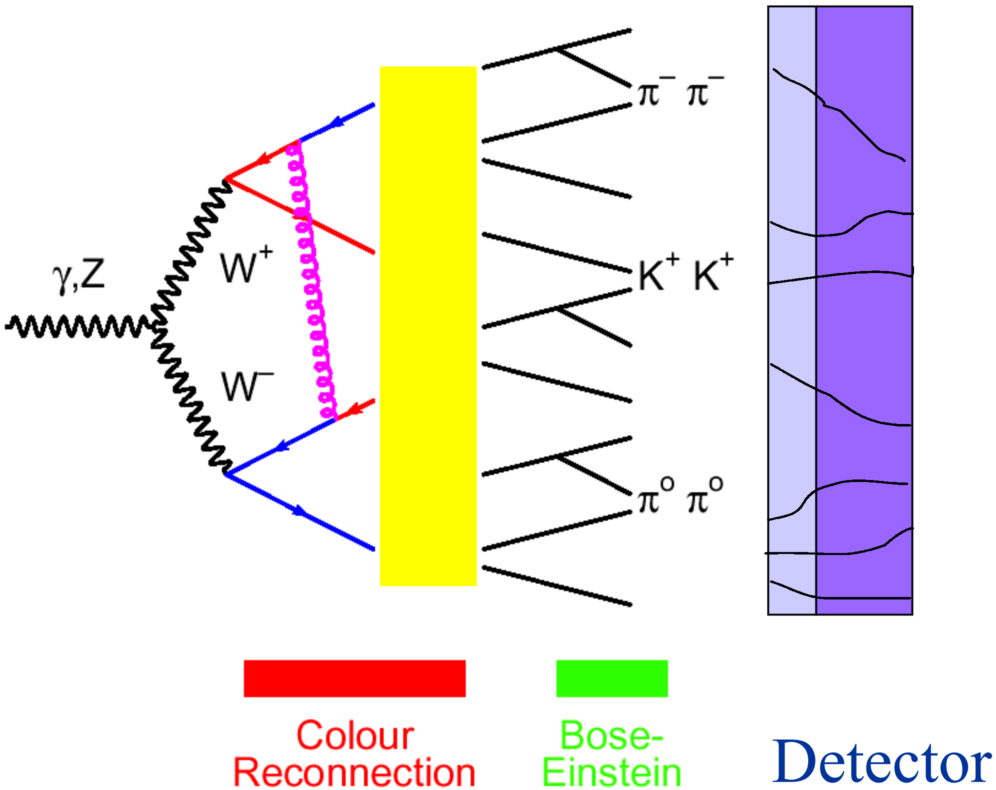


- With the new results from extrapolation and cross-checks
  - Reduction of beam energy error
  - new : $\Delta E_{beam} = 10\text{-}20$ MeV $\Rightarrow \Delta M_W = 10$ Mev
  - old : $\Delta E_{beam} = 20\text{-}25$ MeV $\Rightarrow \Delta M_W = 17$ Mev

Systematics from Monte Carlo Modeling

Main Sources

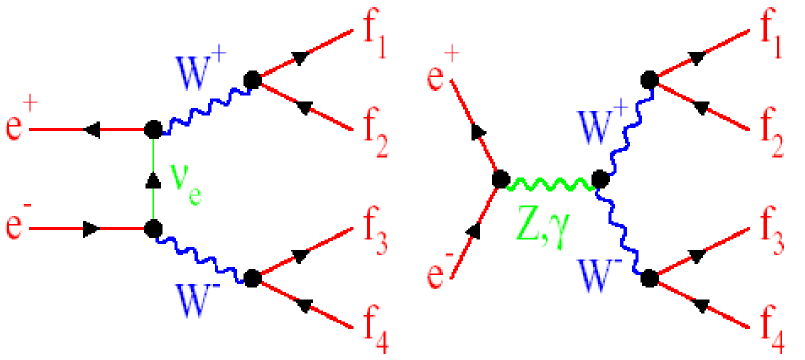
- QED/EW radiative effects
- Detector Modeling
- Hadronisation Modeling
- Final State Interaction
- Background Modeling



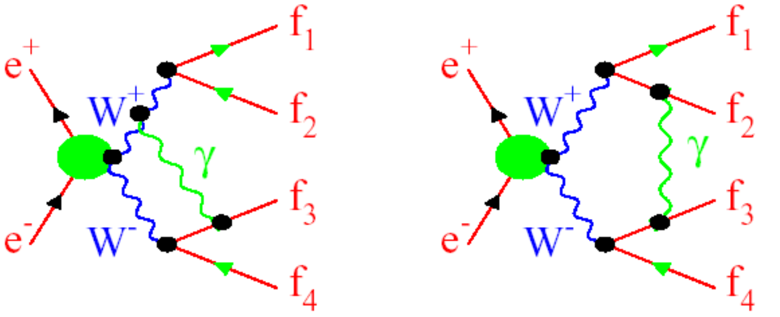
MC modeled to represent data;
Disagreements ⇒ Systematic error

QED/EletroWeak Radiative Corrections

- KoralW's O(α^3) implementation adequate, but misses
  - WSR
  - interference between ISR,WSR & FSR



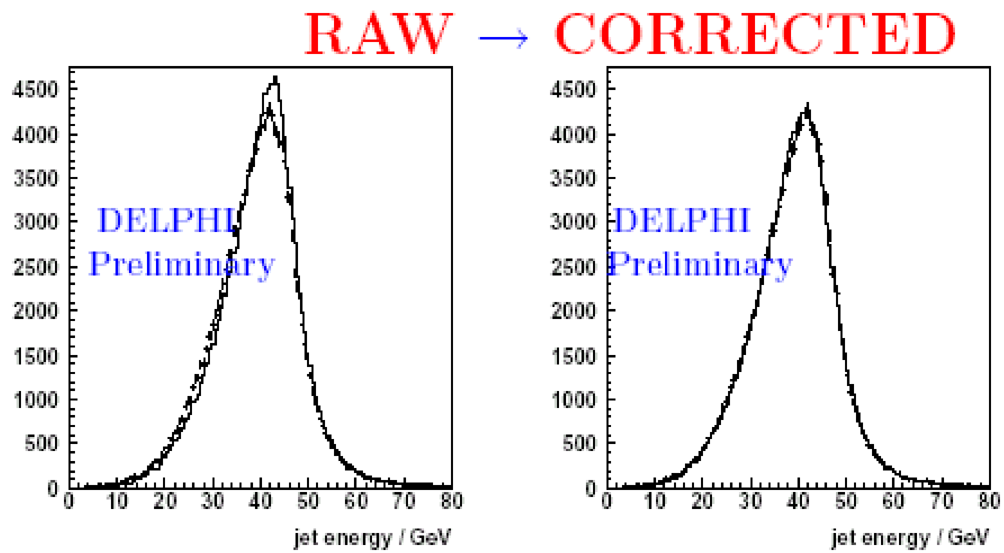
- KandY includes
  - O(α) corrections
  - Screened Coulomb Correction



Error ~ 10 MeV

Detector Simulation

- Z0 calibration data recorded annually provides control sample of leptons and jets (energy ~ 45 GeV)
- Data/Mc comparison is used to estimate corrections for
  - Jet/Lepton energy scale/resolution
  - Jet/Lepton energy linearity
  - Jet/Lepton angular resolution/biases
  - Jet mass



- Error is assigned from the error on correction

Error qqlv (qqqq) ~ 20 (15) MeV

Hadronisation Modeling

- MC models (JETSET,HERWIG,ARIADNE) generate hadrons

  - Difference in particle spectra, angular distributions and contents (baryons)

  $\Rightarrow$ Interplays with detector response

  - JETSET used by all LEP experiment with parameters tuned with Z peak data

- Systematic uncertainty on W mass
  - Comparison between MC models produces shift ~ 30-40 MeV
  - Difference of baryon rate between models; but their mass is neglected in reconstruction $\Rightarrow$ a bias, which is not genuine hadronisation effect
  - Solution: Re-weight fully simulated models for difference in rates

Expected error qqlv (qqqq) ~ 40 Mev → 15 (25) MeV

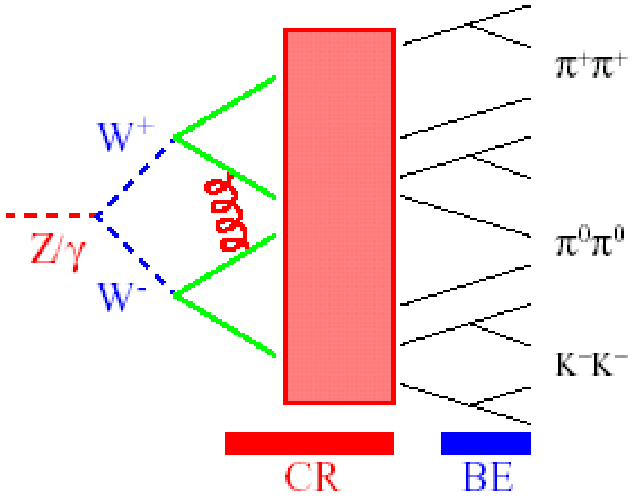
Final State Interactions

Hadronically decaying W pairs short living (~0.1 fm)

- their decay products can interact among each other

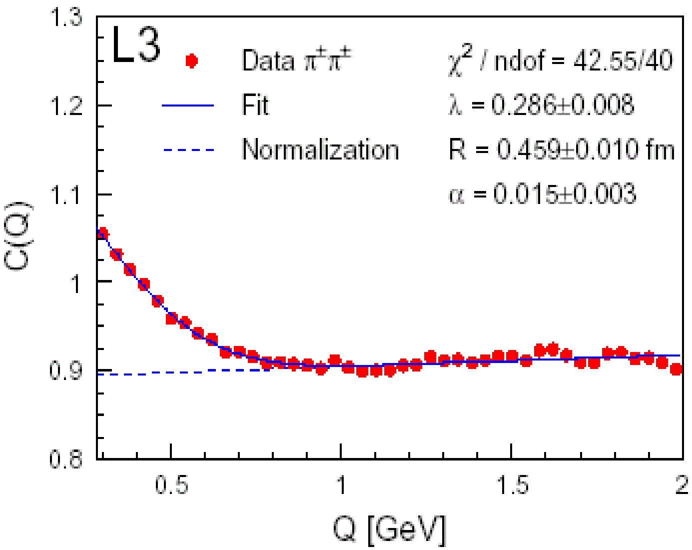
Color Reconnection (CR)

- color flow between W's could bias their masses
- only phenomenological models exist. Effect small(?) and hard to measure.



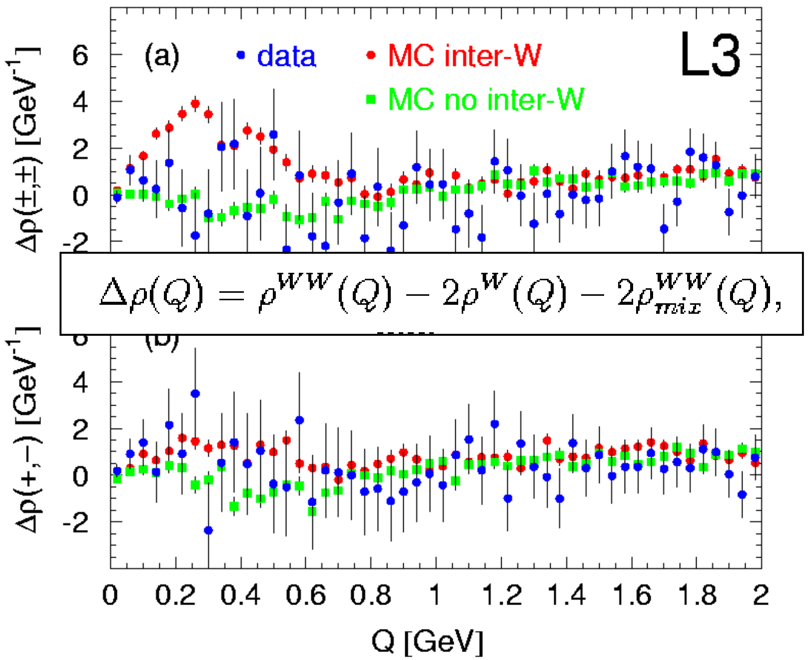
Bose-Einstein correlation (BEC)

- coherently produced identical pions are closer in phase space.
- BE correlation between neutral and charged pion established.
- Does the effect exist between W's?

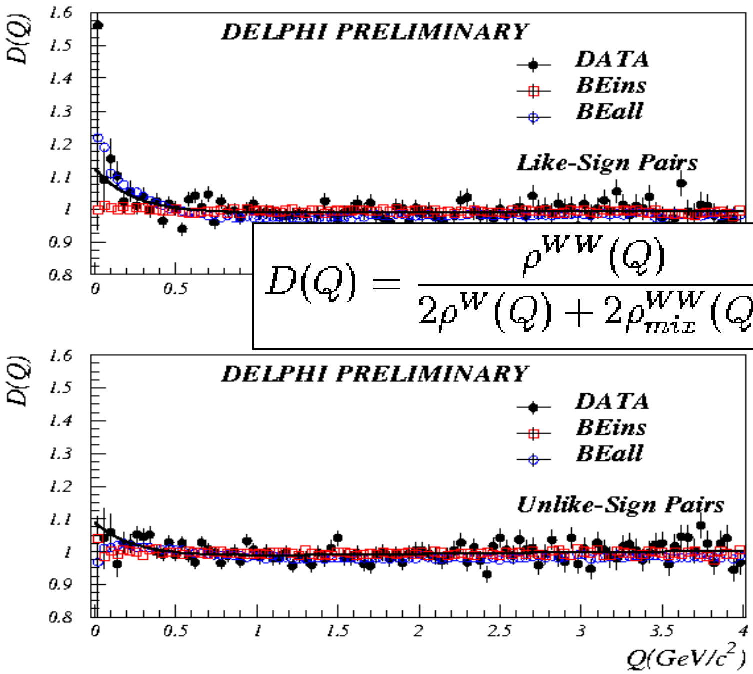


Bose-Einstein Correlation in WW events

- Studies on BEC between different W's at LEP
  - 2-particles correlations in qqqq events vs. two "mixed" qqlv events
  - ALEPH, L3 and OPAL: no hint for BE corr.
  - DELPHI: evidence for BEC
    - -- under investigation



$$\Delta\rho(Q) = \rho^{WW}(Q) - 2\rho^{W}(Q) - 2\rho^{WW}_{mix}(Q),$$



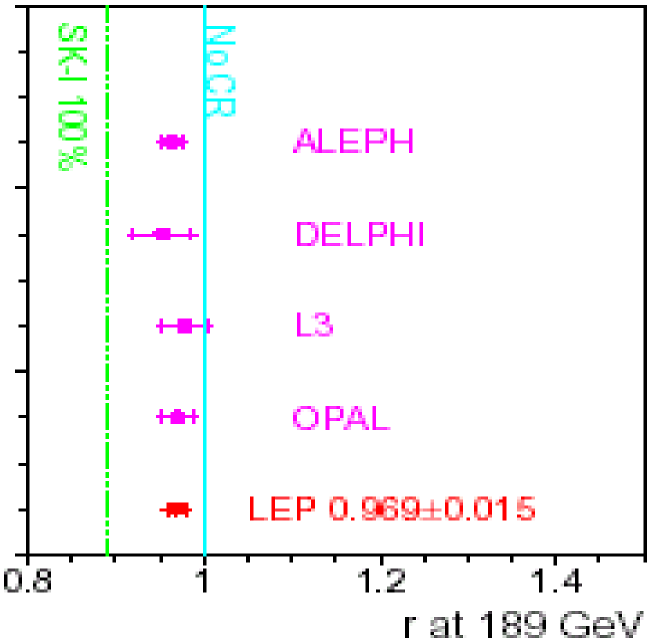
$$D(Q) = \frac{\rho^{WW}(Q)}{2\rho^{W}(Q) + 2\rho^{WW}_{mix}(Q)},$$

- W mass uncertainty due to BEC
  - Error ~ 40 MeV (same inter & intra corr.)
  - Track momentum cut analysis helps reduce this to ~ 25 MeV
  - Data limits on strength parameter will also reduce it further

Color Reconnection

- Several Model exist.
  - String based (SKI, SKII in JETSET)
  - Color dipoles (ARIADNE)
  - Cluster based (HERWIG)

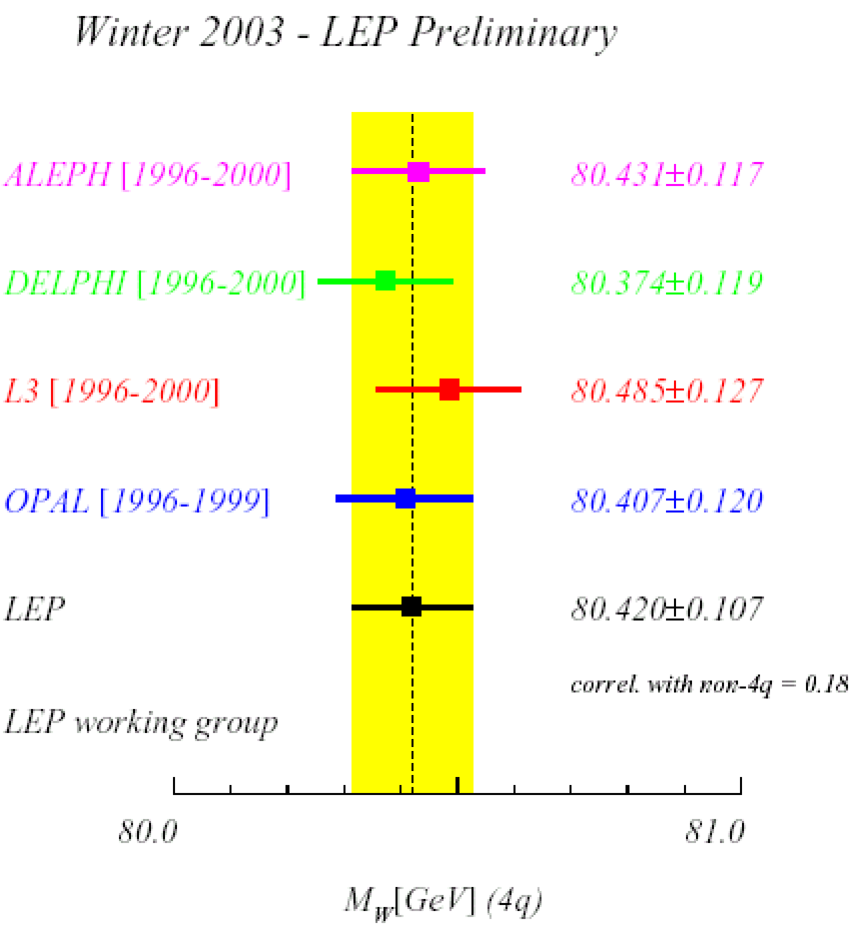
SK-I 100%	300 MeV
ARIADNE AR2	70-80 MeV
Rathsmann	40-60 MeV
Herwig	30-40 MeV

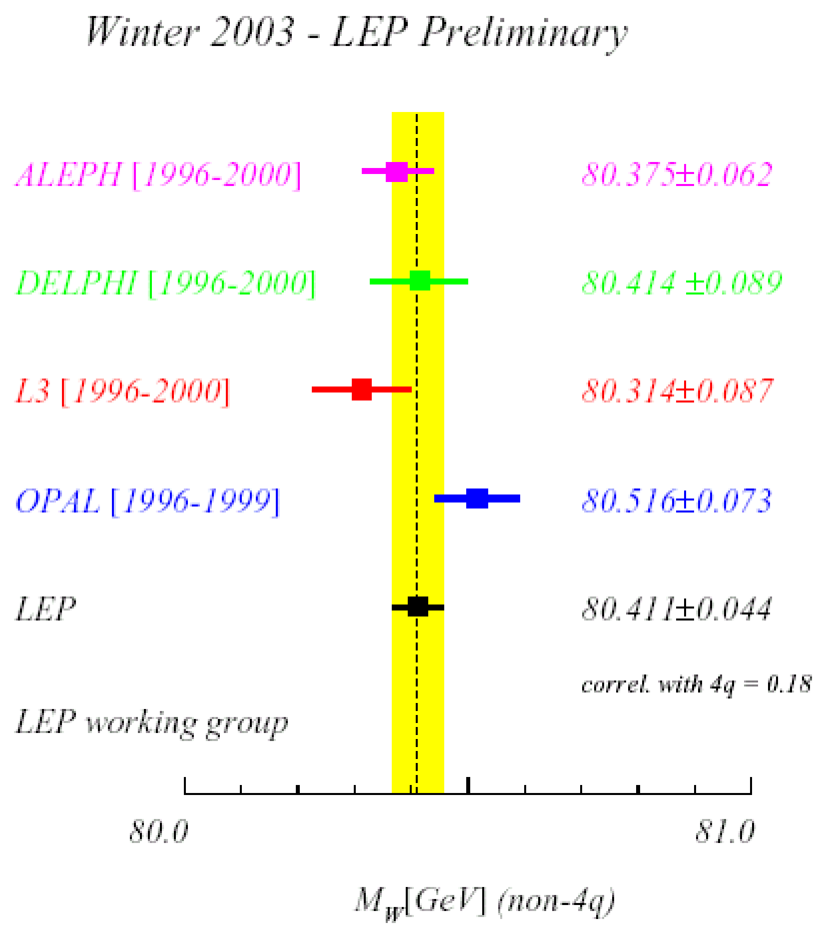


- Particle flow between inter jet region
  - limit on CR probability (SK1 model)
  - use limit to set CR uncertainty (data driven).
- CR expected to effect soft particles and particles away from cone jet
  - harder cut on track momentum to redefine jet direction reduces the sensitivity to CR

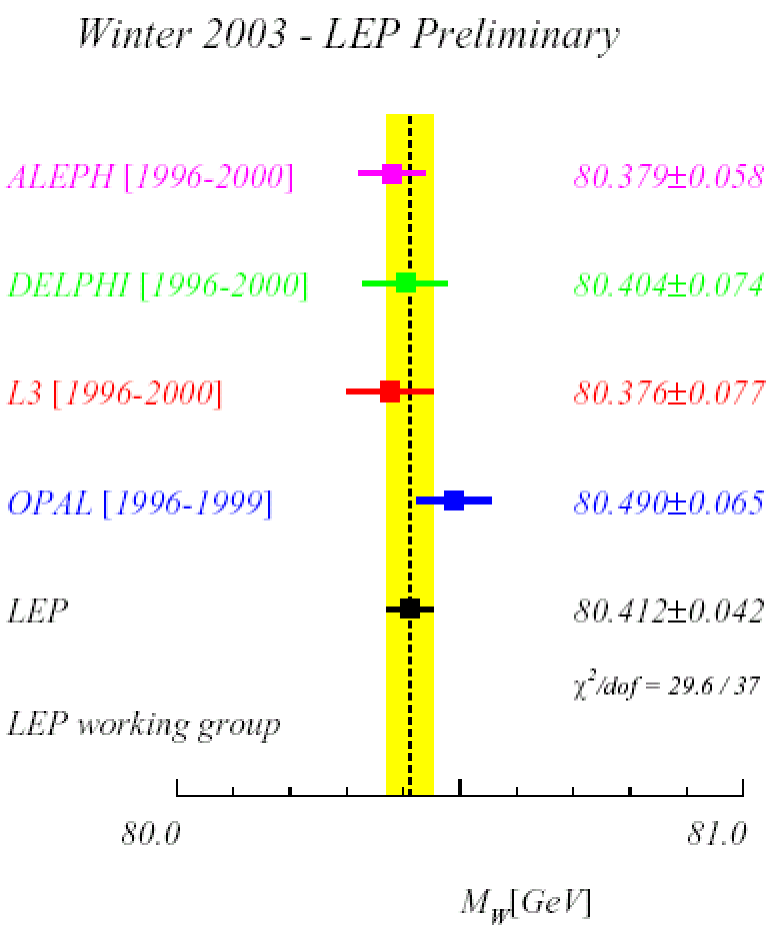
CR uncertainity ~ 120 MeV, with p-cut ~ 50 MeV

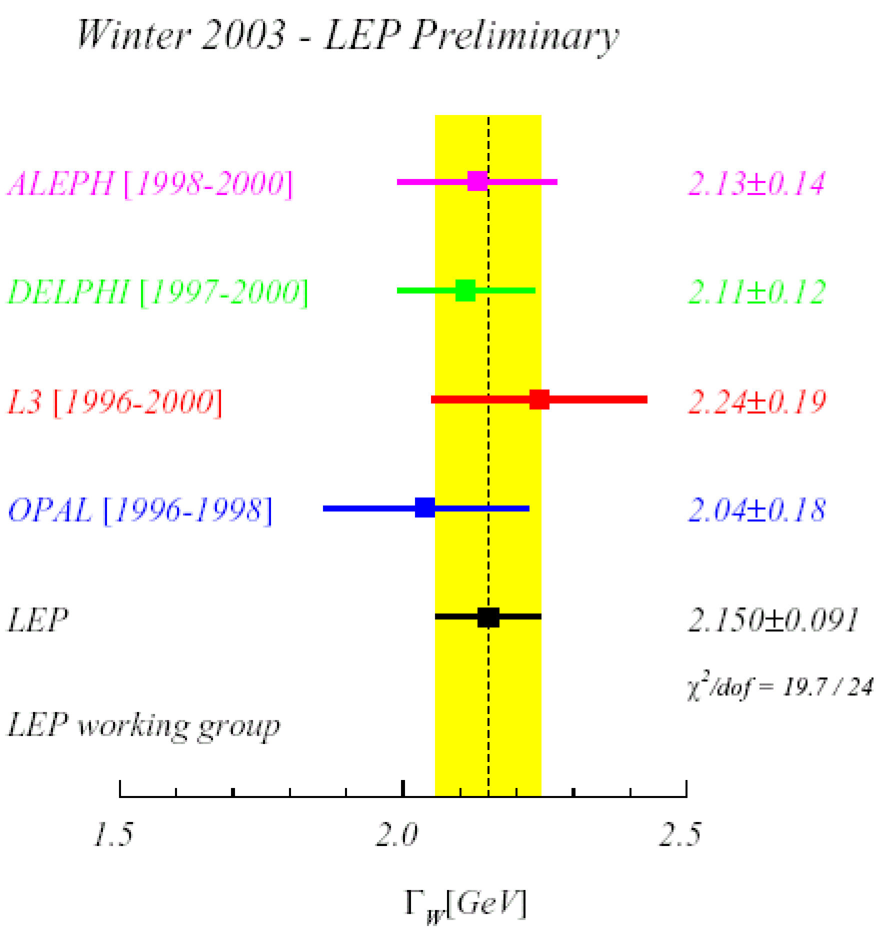
Results: qqqq and qqlv channels





Results: LEP W mass and Width





Summary

- Final W mass from LEP should be available by the end of this year.

- The expected changes from present result
  - Full statistics: OPAL analysis from full dataset
  - Improved LEP beam energy measurement
  - Improved understanding on Final State Interactions
    -- Reduction in CR and BEC uncertainty
  - Most systematic errors revised
    -- Hadronisation, Higher Order Corrections

- Possible improvement in W mass error
  - 43 MeV to 37 MeV (. . . Expected)