Determination of the W mass and the WW and ZZ cross-section at LEP

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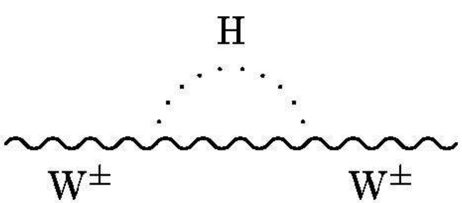
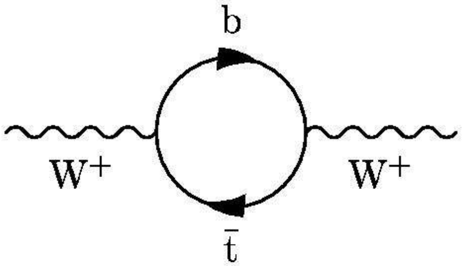
- Introduction
- WW and ZZ cross-section
- Methods of mass extraction
- Systematic uncertainties
- Conclusions

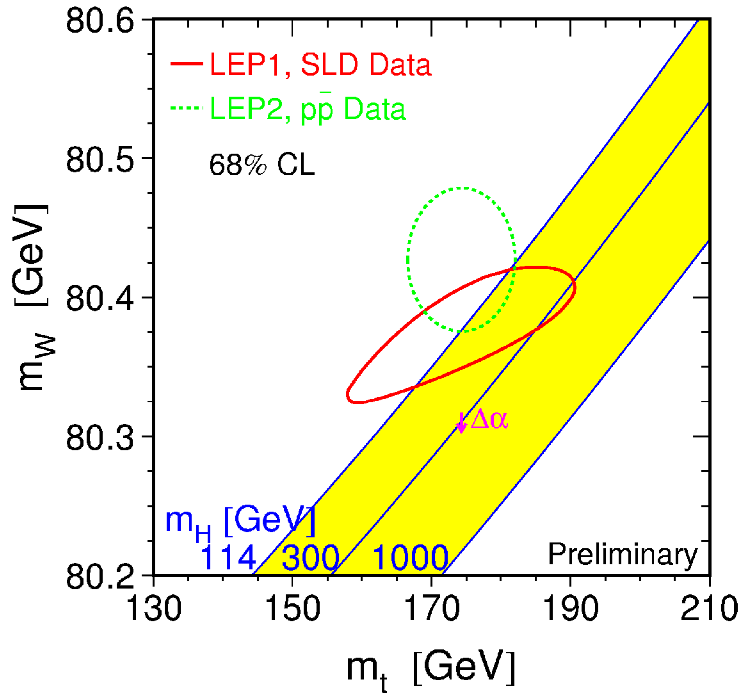
Motivation

In lowest order the W-mass is determined by three parameters (e.g.: M_Z, G_μ, α)

Additional dependence on M_{Top} and M_{Higgs} from higher order contributions





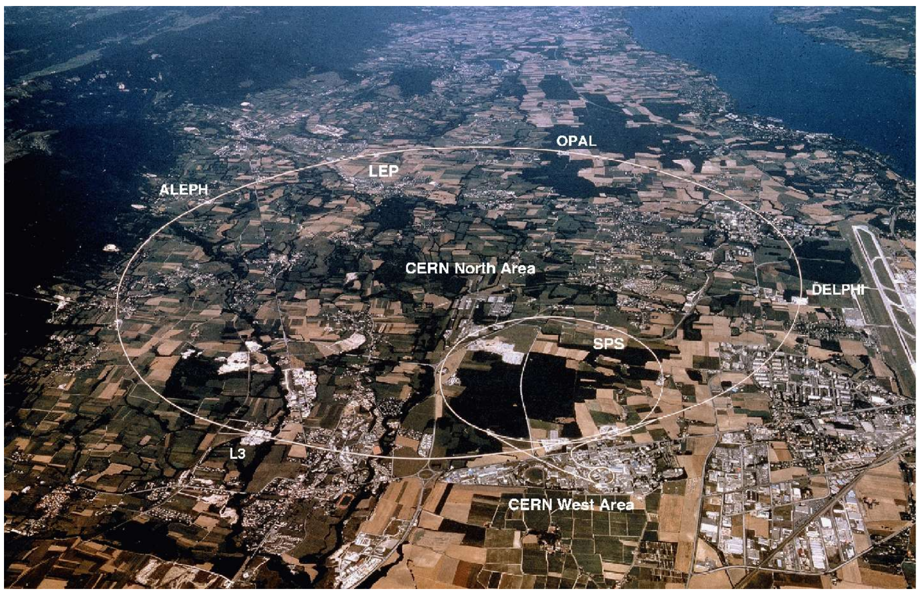


Measurement of M_w and M_{Top} tests the Standardmodel at the level of loop corrections.

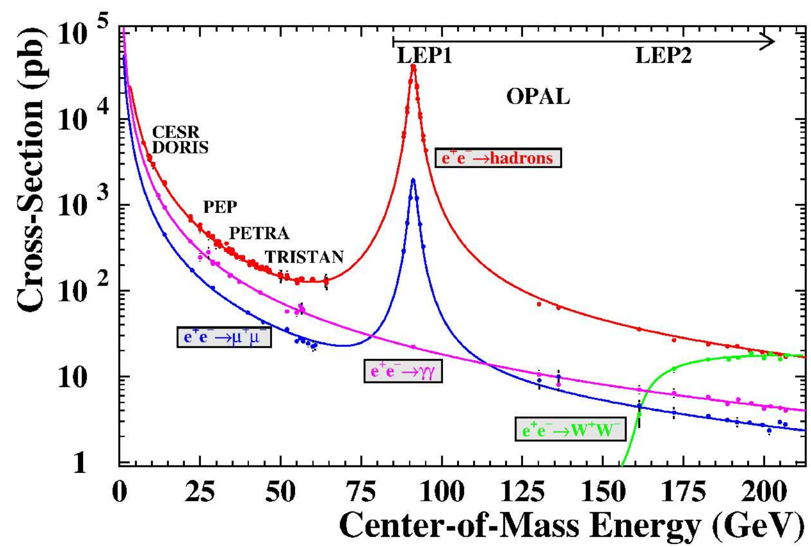
Determination of W-Masse at LEP

e^+e^- - Collider: 27 km circumference

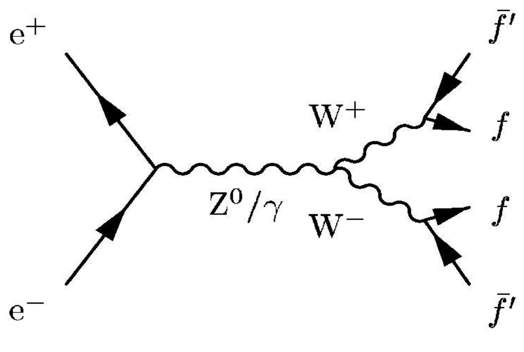
LEP I: 1989-1995
E_{CM}= 91 ±3 GeV, 4 x 4 ·10^6 Z^0

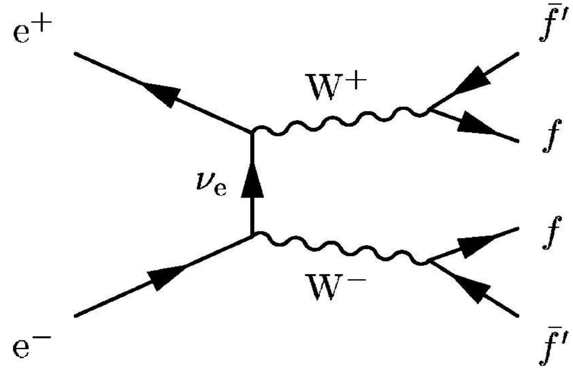


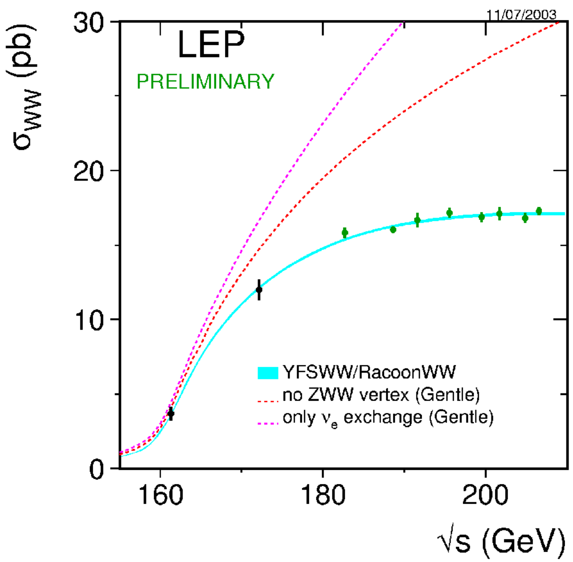
LEP II: 1996-2000
E_{CM}= 161-208 GeV,
4 x 10 ·10^3 W-Pairs

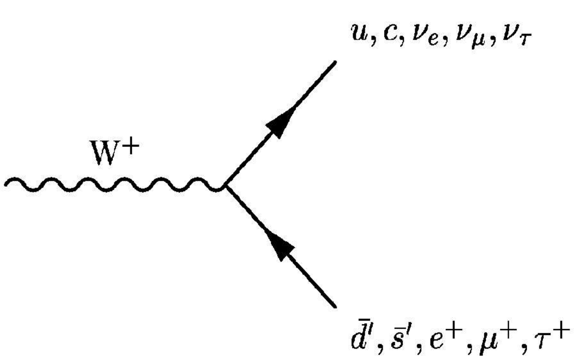


W-Pair production and decay



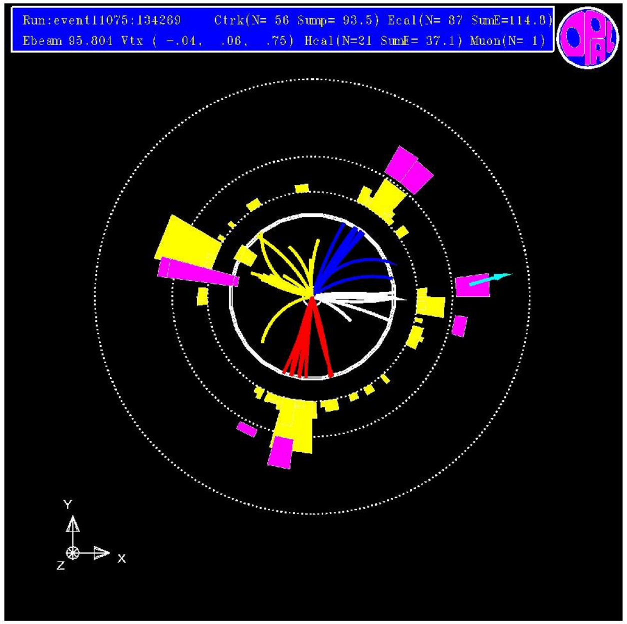


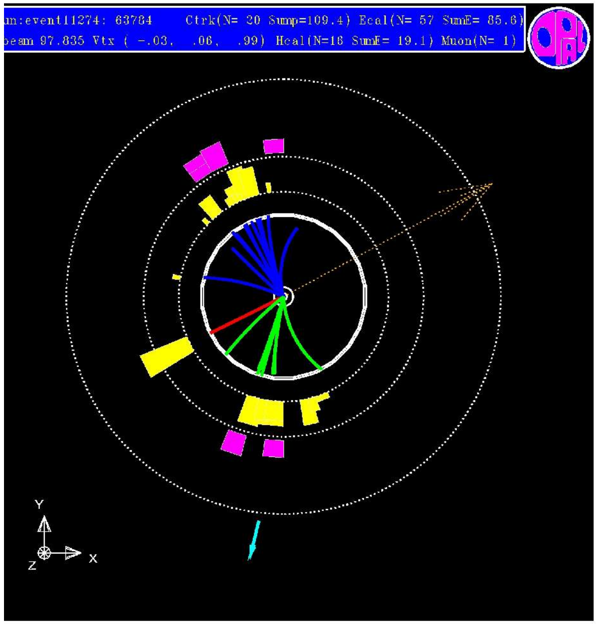


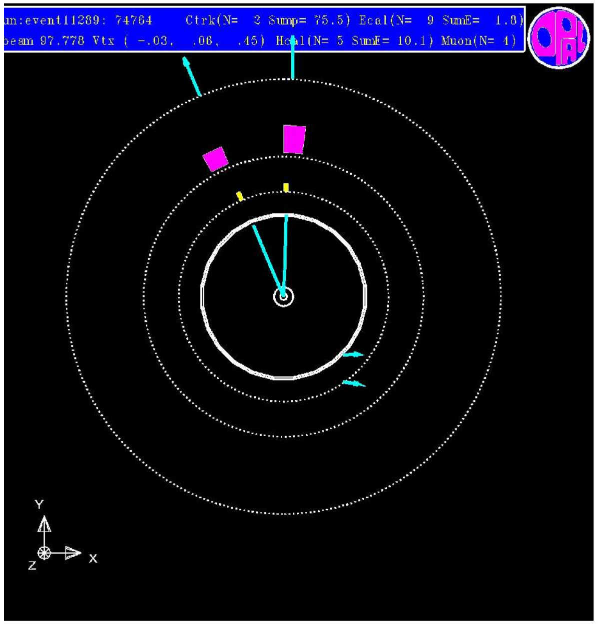


68% of W-bosons decay hadronicly

Event topologies





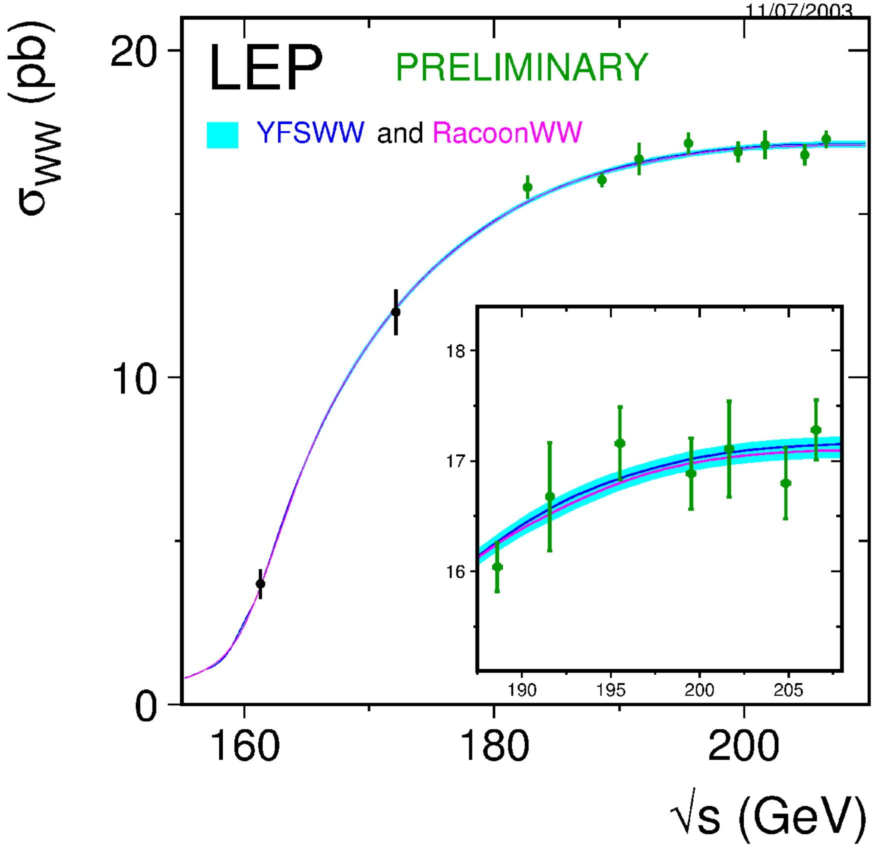


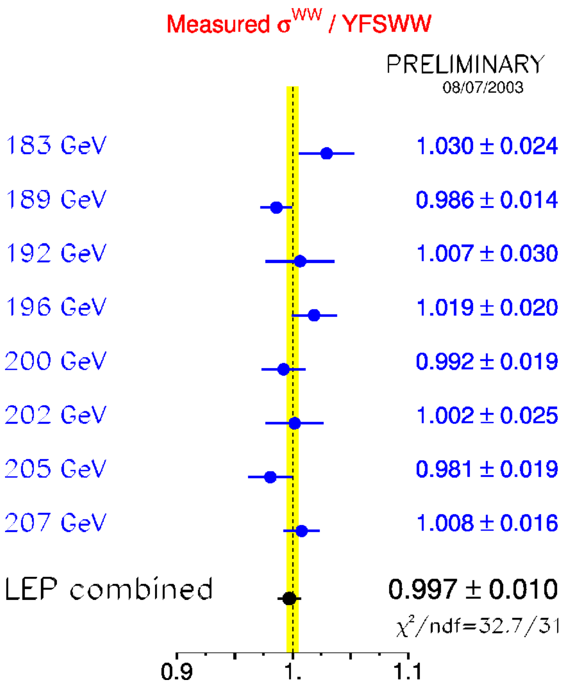
fully hadronic 46%
no missing energy
jets have to be associated to W
FSI between Ws

semi leptonic 44%
neutrino reconstructed from missing energy
no ambiguity in assigning particles to jets

fully leptonic 10%
full reconstruction is not possible
mass extraction from observables sensitive to W-mass

W pair cross-section



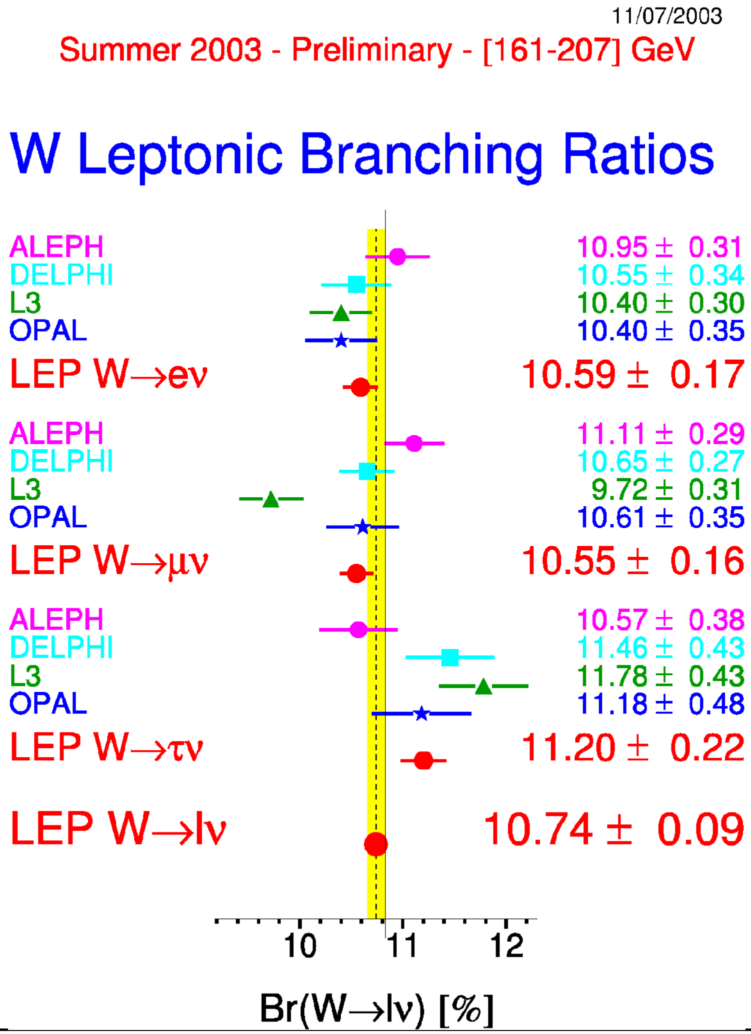


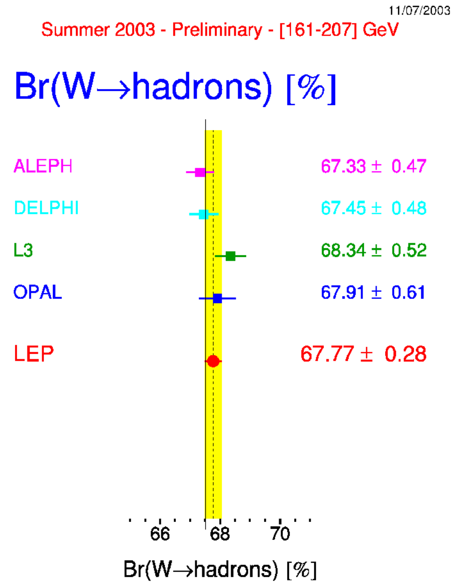
Theoretical precision ~0.5%

Thanks to 2000 calculations RACOONWW, YFSWW with improved O(α) corrections

LEP measurement precision ~1%

W branching ratios and $|V_{cs}|$





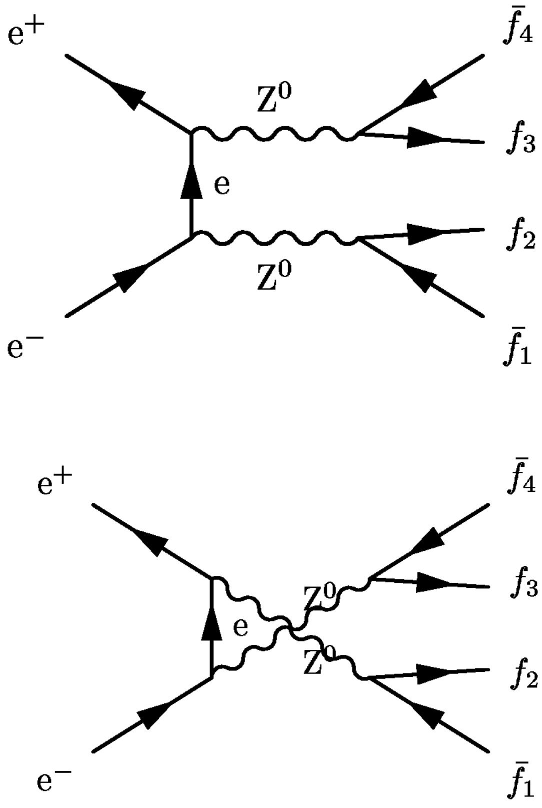
$$\frac{1}{\mathcal{B}(\mathrm{W} \to \ell \overline{\nu}_\ell)} = 3\left\{1 + \left[1 + \frac{\alpha_s(\mathrm{M}_\mathrm{W}^2)}{\pi}\right] \sum_{\substack{i=(u,c),\\ j=(d,s,b)}} |\mathrm{V}_{ij}|^2\right\},$$

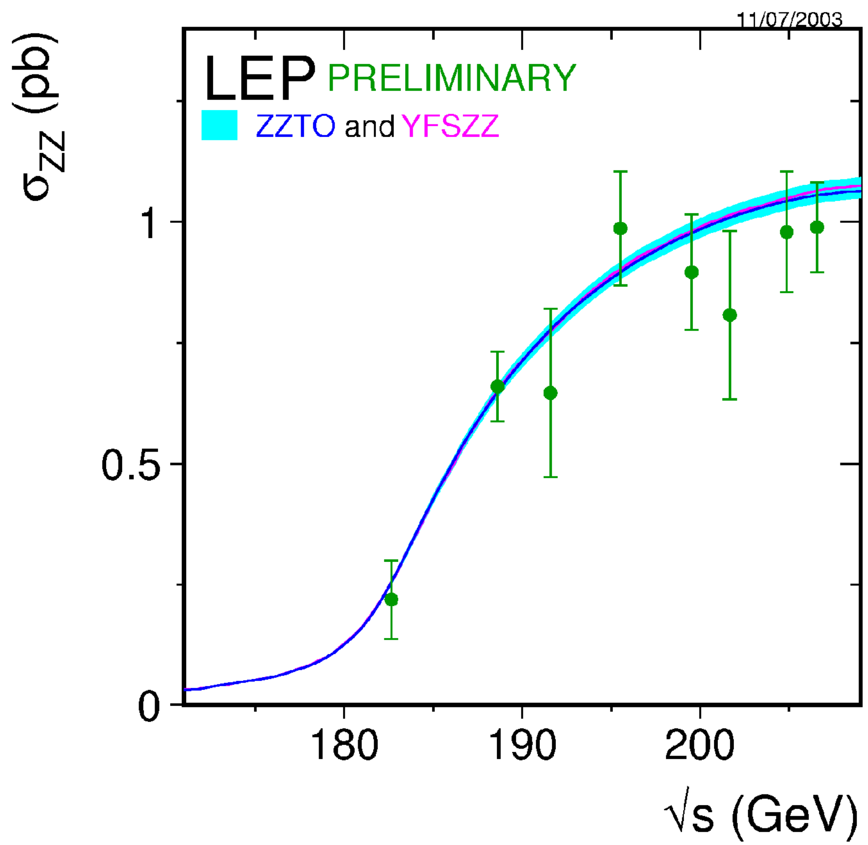
Input from PDG:

$$|\mathrm{V}_{ud}|^2 + |\mathrm{V}_{us}|^2 + |\mathrm{V}_{ub}|^2 + |\mathrm{V}_{cd}|^2 + |\mathrm{V}_{cb}|^2 = 1.0476 \pm 0.0074$$

$$|\mathrm{V}_{cs}| = 0.989 \pm 0.014.$$

Z pair cross-section



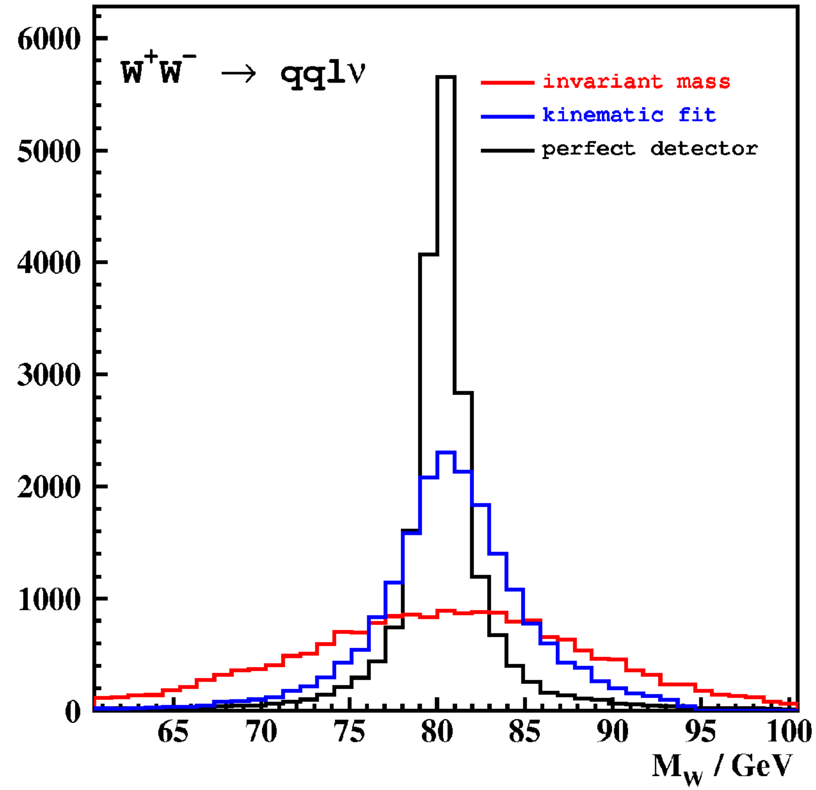


Event Reconstruction

Invariant mass of jet pair has low resolution of about 10%. (limited by jet energy resolution)

Kinematic fit: Determine jet and lepton energy and direction which:

- best agree with measurement
- fulfils momentum and energy conservation.
- (And equal mass of the two W bosons)



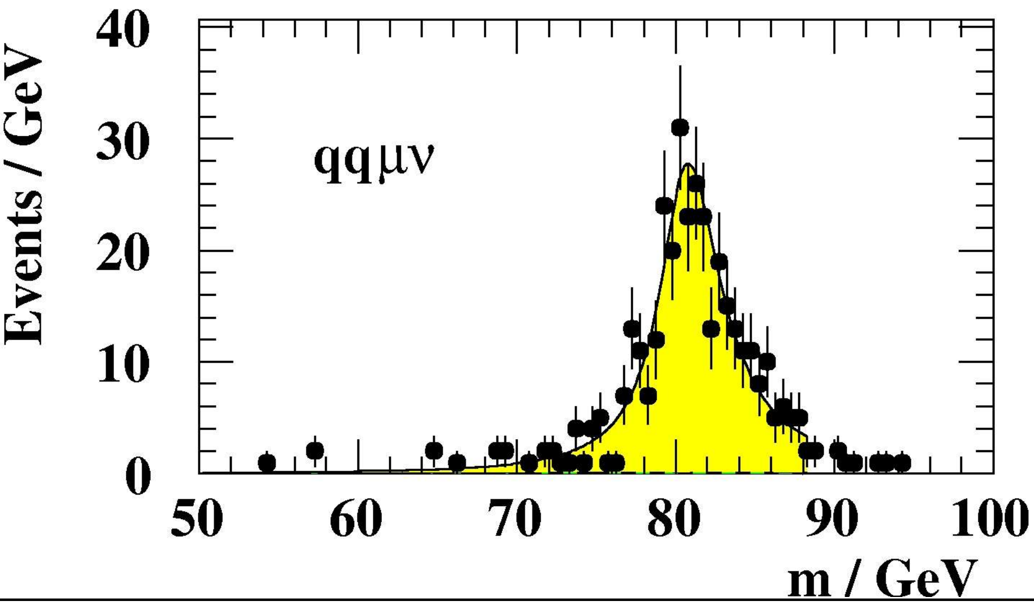
Bias in ISR events due to energy cons. constraint (since centre of mass energy is used)

Mass Determination

The 4 LEP Experiments use different techniques to extract the W mass from the event information.

Monte Carlo simulations are used to test/correct a possible bias (e.g. early DELPHI analysis treated 0.5 GeV shift from ISR in bias corr.)

Analytic Fit:

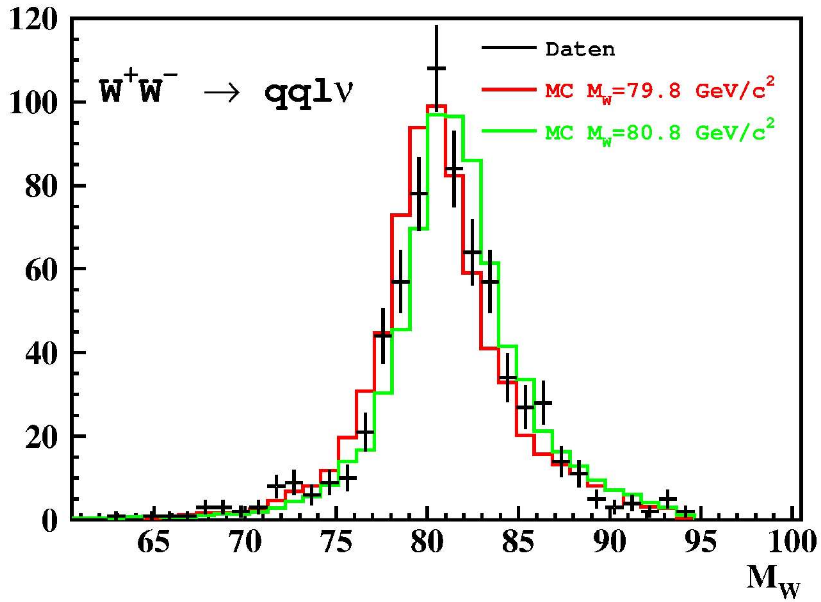


Used by OPAL as cross check

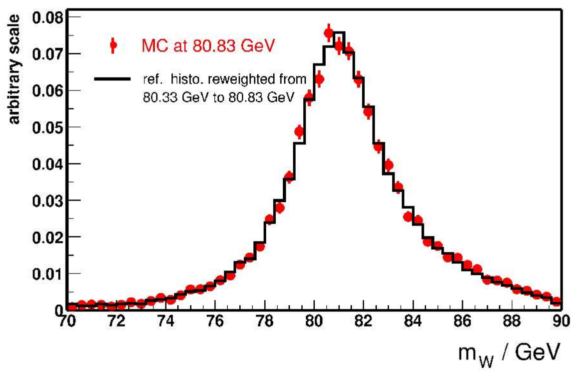
- Use analytic function to include: Resolution, ISR, background.
- Use Monte Carlo to extract W mass from fit parameter

Data- Monte Carlo Comparison

- Comparison of Data and MC mass spectra.
- All correlations and effects described by MC are taken into account.



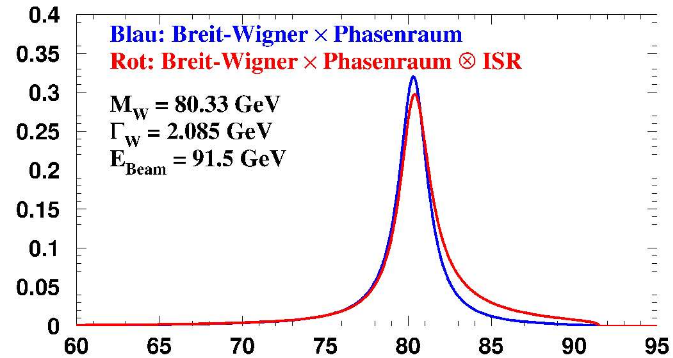
Technique: reweight MC events as function of the generated W-mass to get MC sample at arbitrary mass.



Event probability

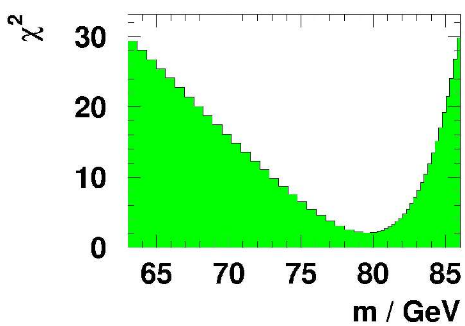
Calculate event probability as function of M_W by a convolution of:

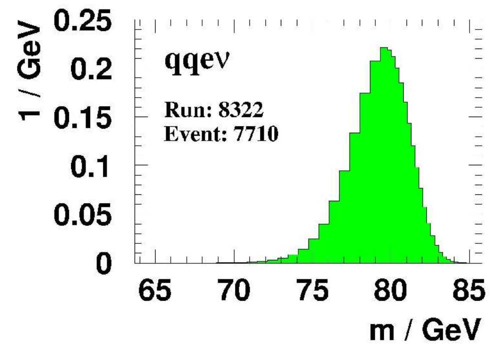
physics function (prob. to produce W mass in an event)

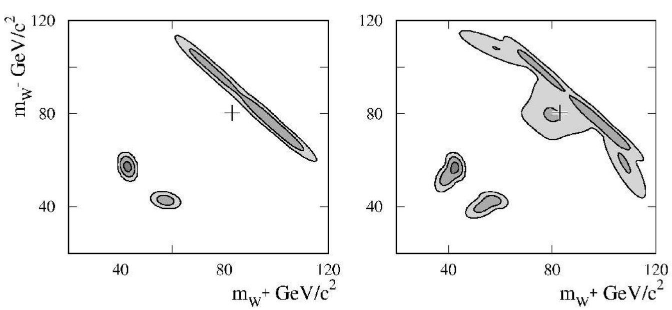


with a

resolution function (probability to observe measured result as function of the produced W mass)







DELPHI included all 3 jet comb. in resolution function and an extra fit with a ISR photon along the beam direction

Systematics (largest)

Source	Currently/MeV
• LEP Energy determination	17
• Detector Simulation	
- Jet & Leptons energy/direction	14
(calibration with Z^0 events)	
• QCD simulation	
- Jet Fragmentation	18
- Jet-Jet interactions(4q)	
▪ Bose Einstein Correlation	35
▪ Color Reconnection	90

Systematic-Error: Beam Energy

Beam energy systematic enters because of energy conservation constrain in the kinematic fit: $dM_W/M_W = dE_{beam}/E_{beam}$

For beam energies < 60 GeV measurement with resonant depolarisation

Calibration for measurement of magnetic bending field with NMR probes and flux loop.

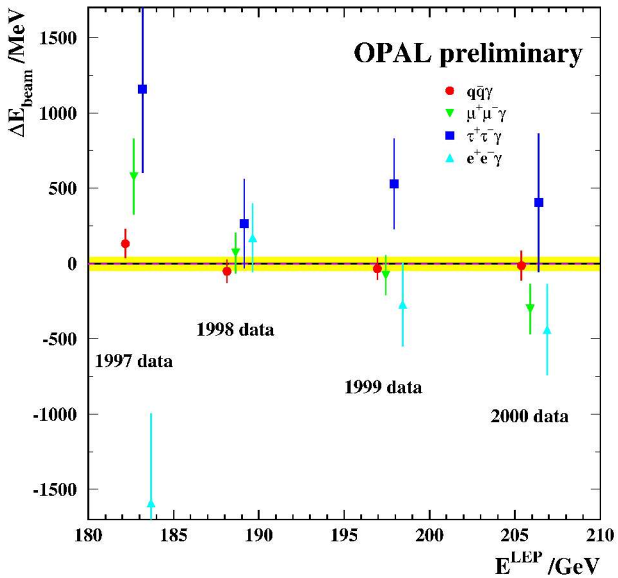
Current error on W mass 17 MeV (correlated between experiments)

(Will be reduced for final publication)

Reconstruct Z^0 mass $e^+e^- \rightarrow Z^0\gamma$ events

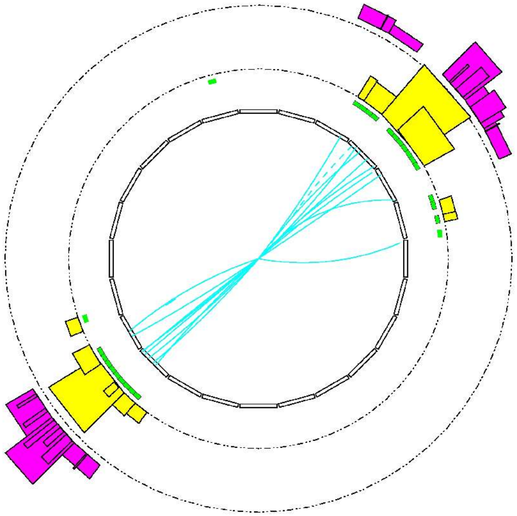
Interpret result as beam energy measurement or as cross check of the W mass measurement

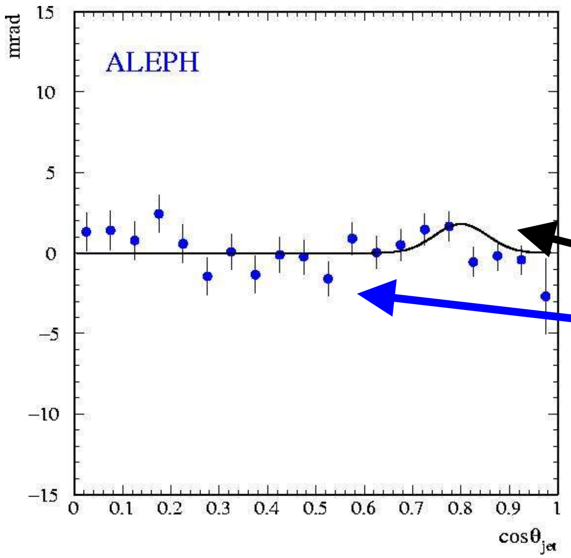
(both measurements have similar sources of systematic errors)



Systematic-Error: Detector Resolution

- Good detector resolution important
- Excellent understanding of resolution necessary
- Use Z^0 calibration data taken each year to measure jet and lepton energy and direction
- Use 3-Jet and bremsstrahlungs events for different energies
- Compare different detector components



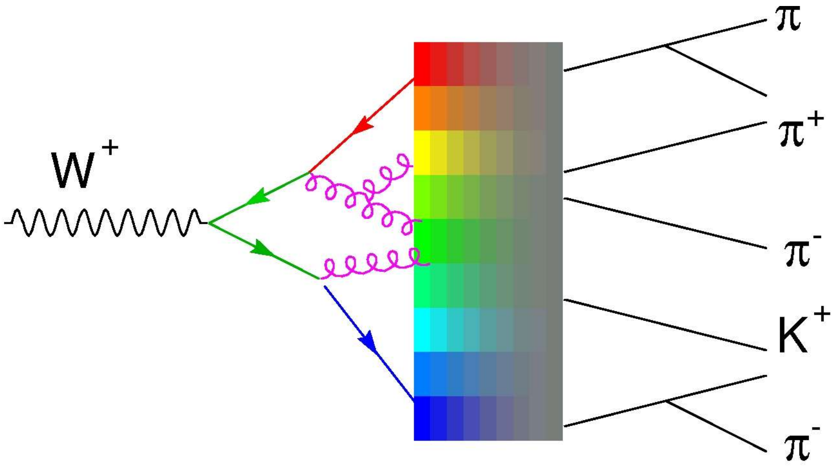


Comparison of jet direction measured with tracks and calorimeter

line: fit to 1994 high stat. data
points: 1998 Z^0 calibration data

Systematic Uncertainty : Hadronisation

- The transition of colored quarks and gluons to hadrons can only be described by models
- For a perfect detector, because of energy and momentum conservation hadronisation would have no effect on M_W.



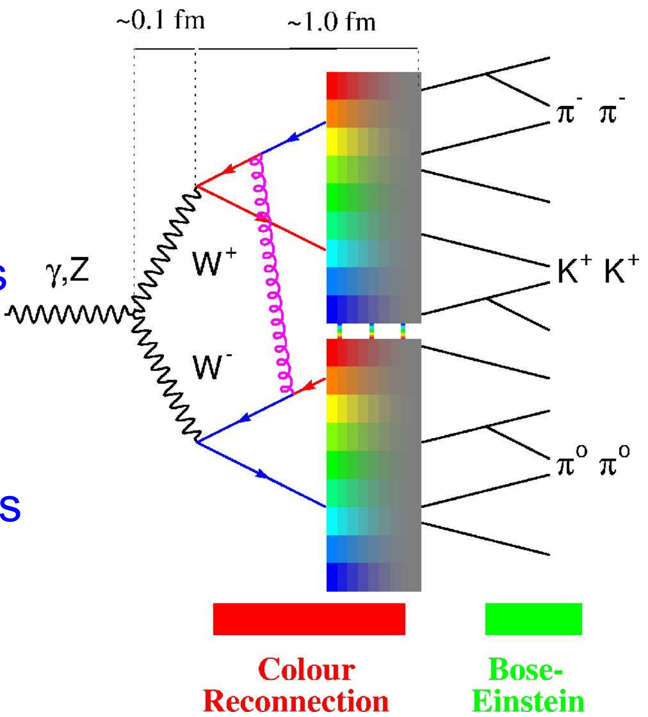
Systematic unceraint[y] because of:

- assignment of particles to jets.
- not measuring low momentum particles.
- low resolution for neutral hadrons $(n, K_L^0, ...)$
- all tracks are assigned pion mass.

Estimate systematic uncertainty by comparing different model and tunes which describe the Z^0 well.

Systematic Uncertainty : Final State Interaction

When both W decay hadronicly momentum transfer or interference between the final states is possible



Color reconnection: Interaction between colored objects from different W
Small effect in pertubative phase. Possible large effect during Hadronisation.
Bose-Einstein Correlation: Enhanced production of pairs of identical Bosons (from different W) close in phase space

If both W do not decay independently the reconstructed mass can be influenced

e.g. Jets from different W pulled closer ⇒ larger angle between Jets from same W ⇒ larger reconstructed mass

Color Reconnection Models

SK-Models (based on string fragmentation) Strings connect a quark and an anti-quark which form a color singlet. Reconnect strings which cross (SK II) or are close (SK I, free parameter defines close).
⇒ Quarks from different Ws can be connected.

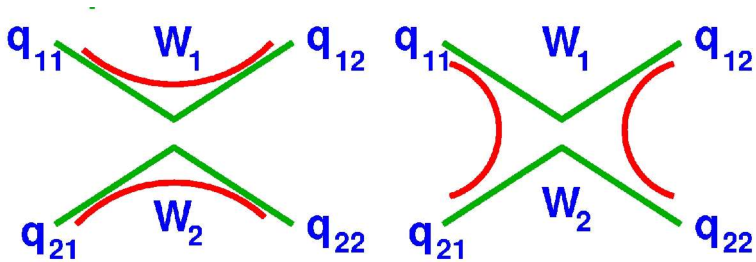
Ariadne (gluon radiation from color dipoles) Which particle form the dipole is based on string length: $\lambda = \sum_{1}^{n-1} \ln(p_i + p_{i+1})^2/m_0^2.$
only for gluon energies smaller 2 GeV particles from different W are allowed to form dipols.
Model also affect Z^0 events. (Excluded by measurements of gluon jets)

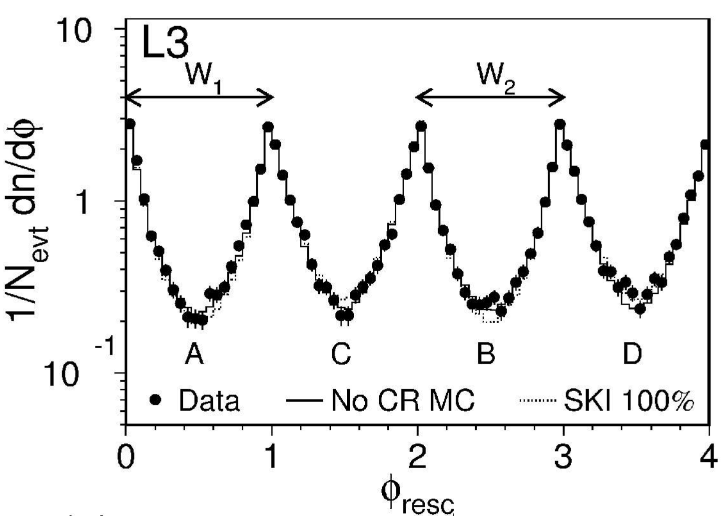
Rathsman model (Cluster fragmentation based on HERWIG) Use gluons closed together (minimize 'string length') to from cluster.
Allow gluons from different Ws to form cluster.

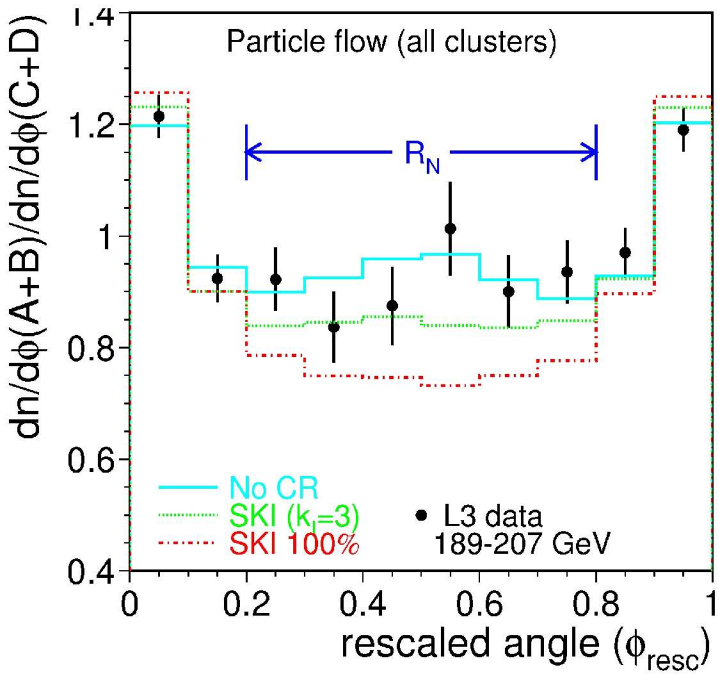
The models affect mostly soft particles between the jets.

Measurement of Color Reconnection

Color reconnection affects: Particle flow between jets, multiplicity, mass and width of W.







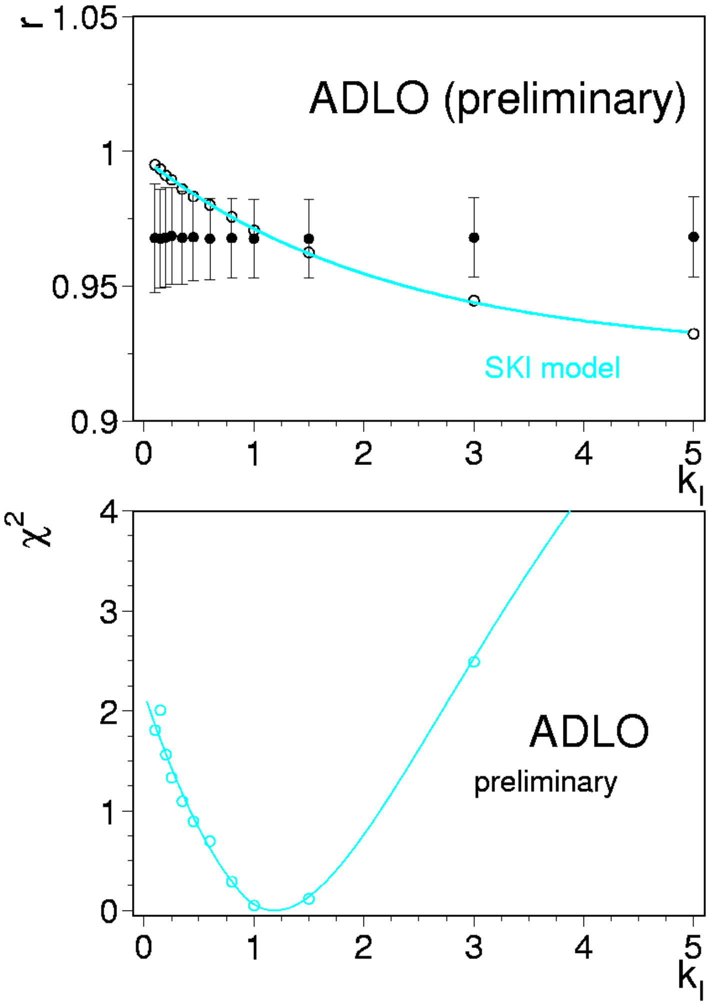
SK I 100% extreme model with CR in every event even if strings not close

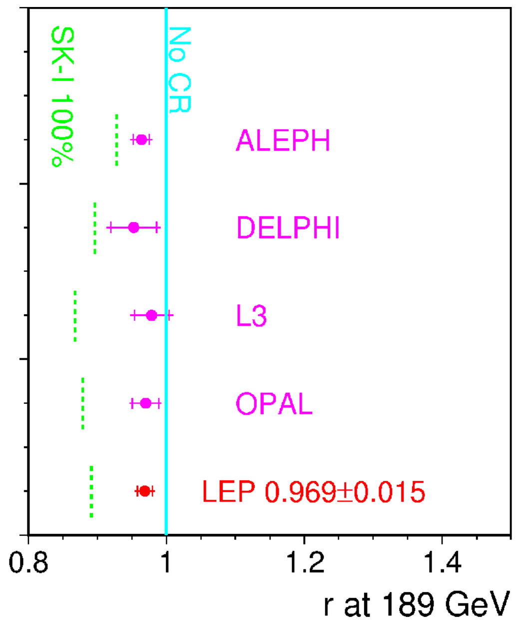
Measurement of Color Reconnection

Particle flow difficult to combine directly

- Not corrected for detector effects.
- Each experiment has different definitions a cuts.

⇒ Take ratio to non CR model in order to combine the experiments.



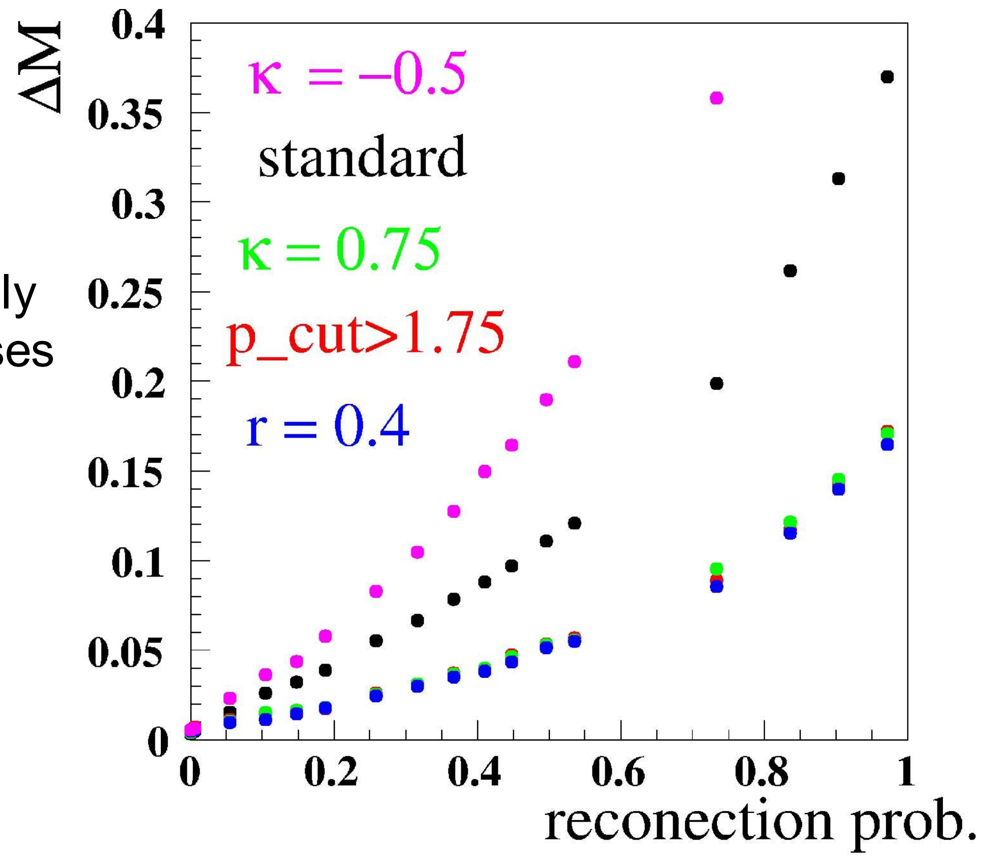


Reducing the Effect of CR on W Mass Measurement

Color reconnection effects mostly soft particles between jets (shifts jet direction)

⇒ calculated jet direction from:

- particle in a cone r,
- with momenta >p_cut
- weight particles with $|p|^k$.



CR systematic can be dramatically while statistical error only increases by 15%.

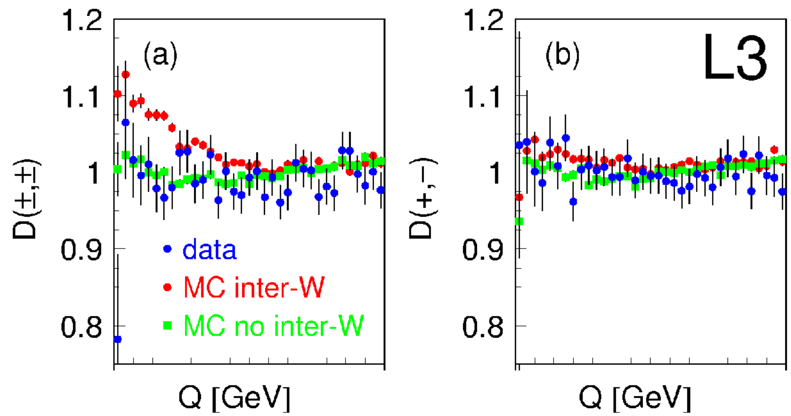
Measurement of BE-Corr. between different W

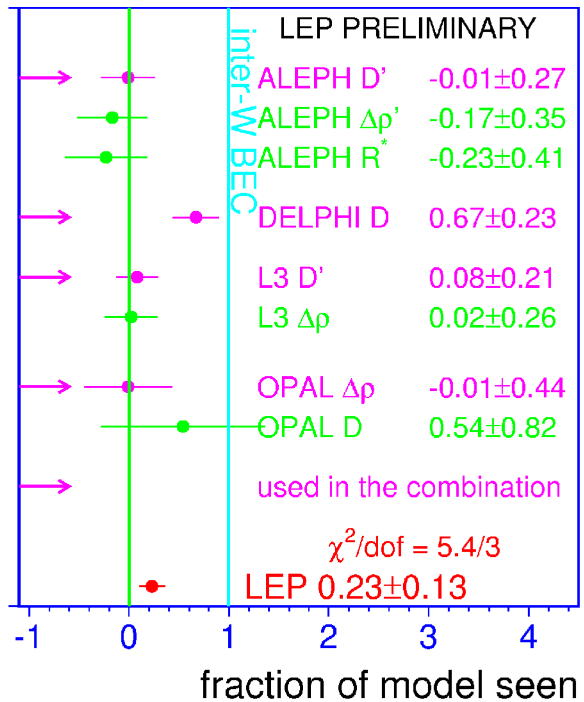
Separate BE correlation between particles from the same W (intra BE) from BE correlation between particles from different W (inter BE)

Use semileptonic W decays for intra BE and mixed events (or MC) for kinematic (non BE) correlations

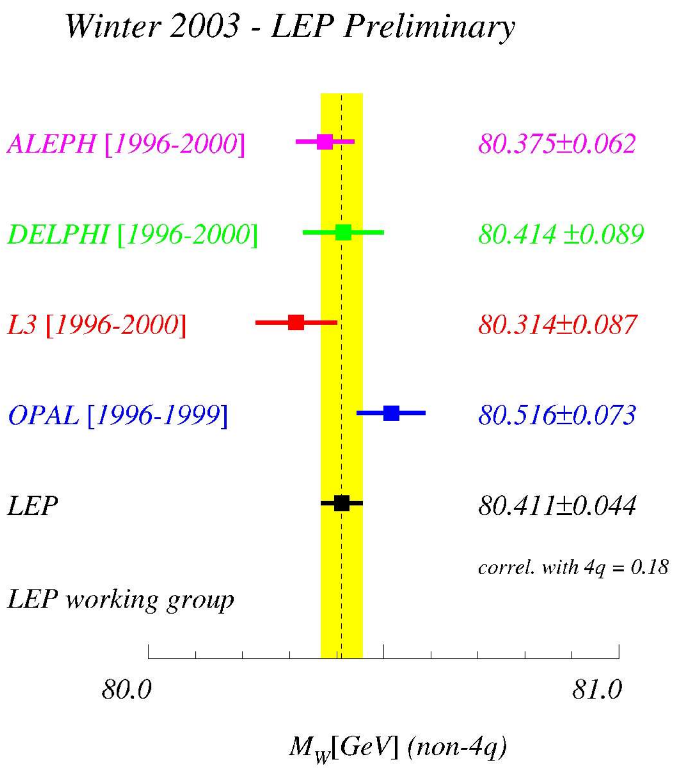
$$\Delta\rho(Q) = \rho^{WW}(1,2) - 2\rho^{W}(1,2) - \rho^{WW}_{mix}$$

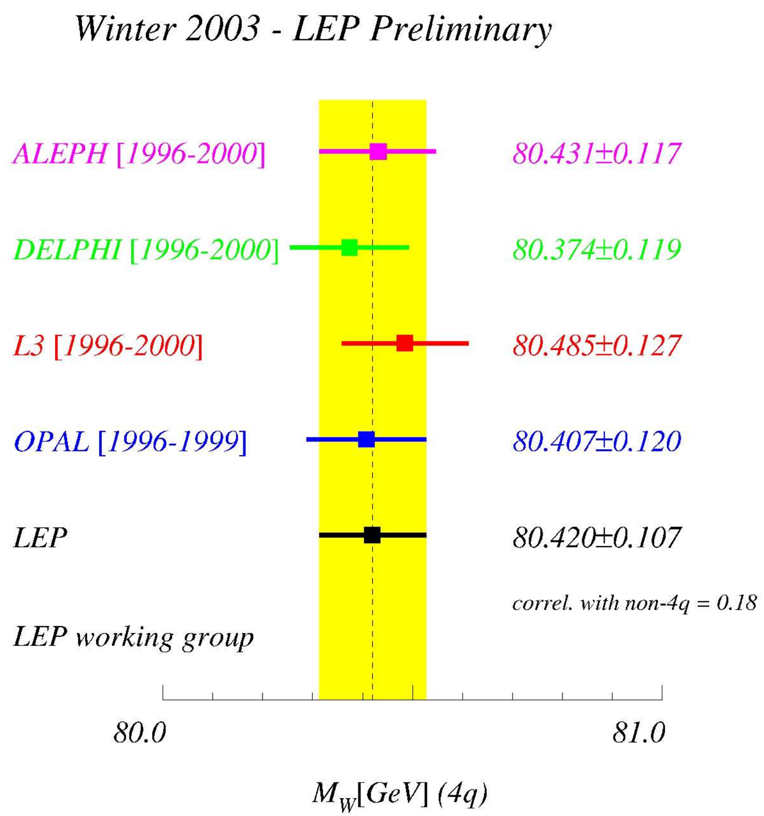
$$D(Q) = \frac{\rho_2^{WW}(Q)}{2\rho_2^{W}(Q) + 2\rho^{mix}(Q)}$$





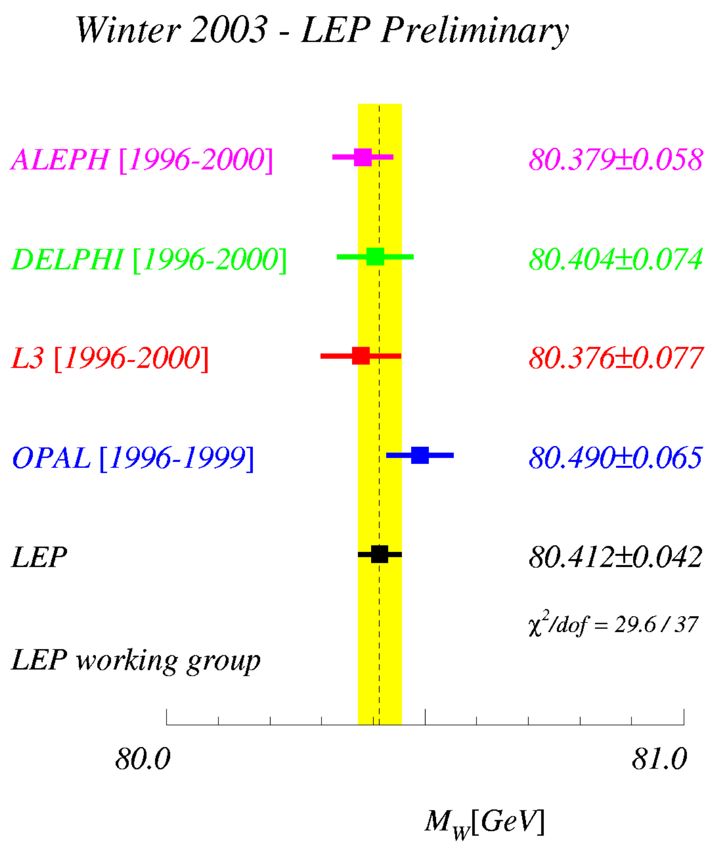
Results



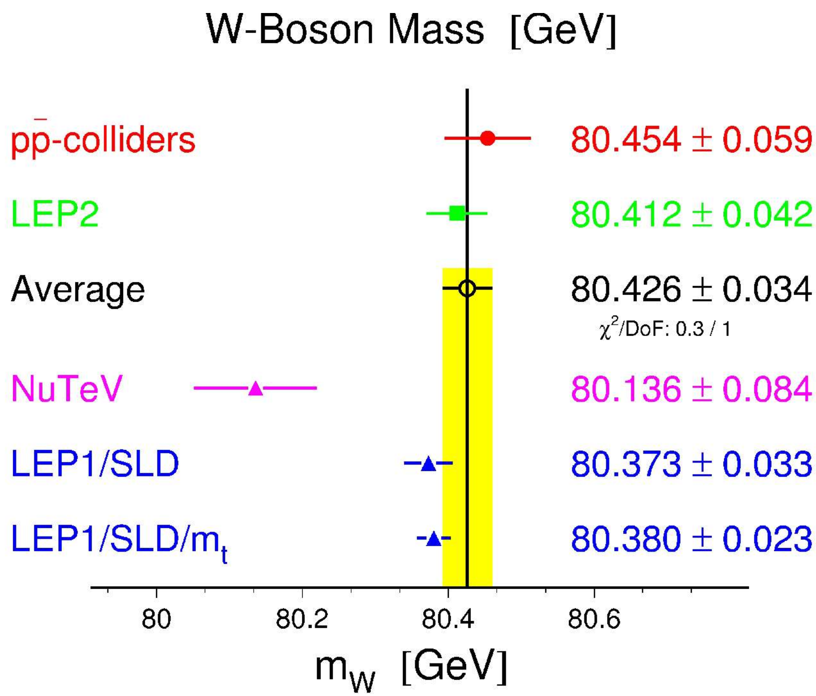


$$\Delta m_{\mathrm{W}}(\mathrm{q\bar{q}q\bar{q}} - \mathrm{q\bar{q}}\ell\overline{\nu}_{\ell}) = +22 \pm 43\ \mathrm{MeV}.$$

Results

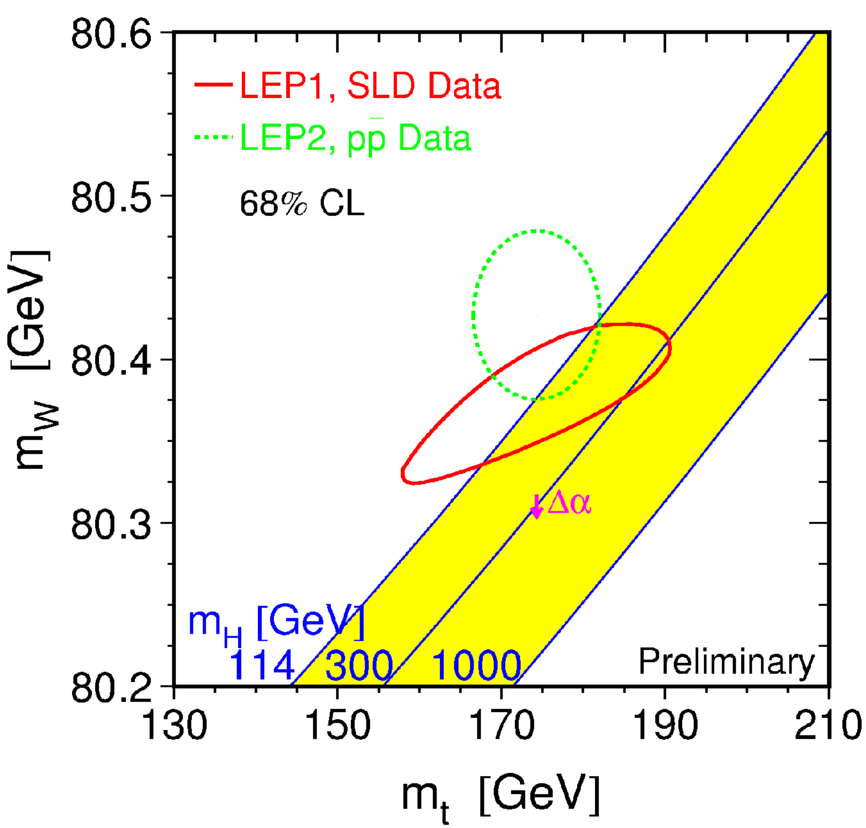


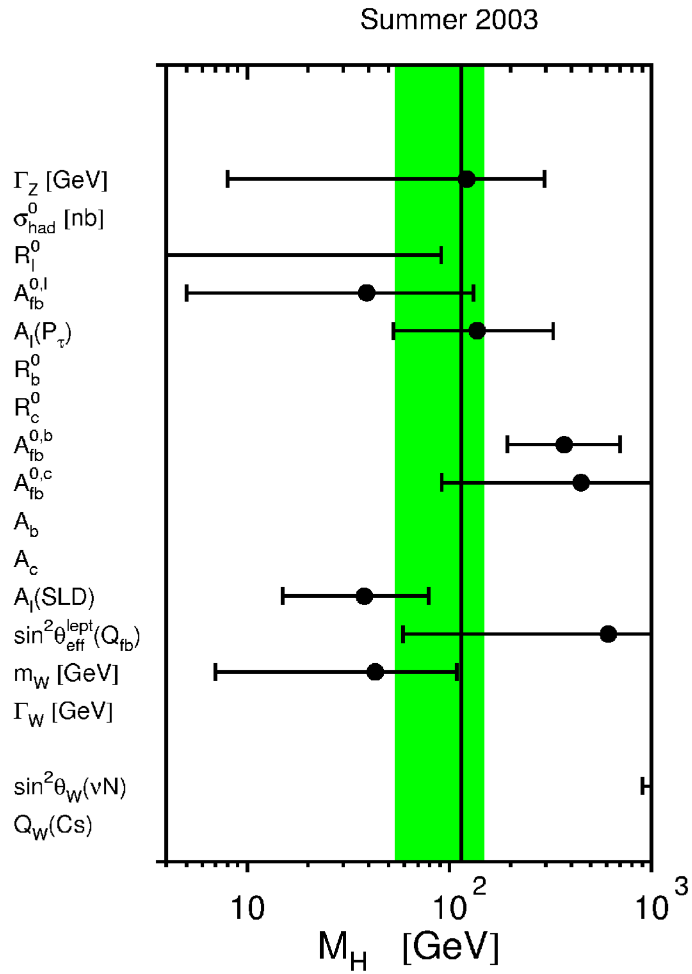
Winter 2003 - LEP Preliminary
ALEPH [1996-2000]
80.379±0.058
DELPHI [1996-2000]
80.404±0.074
L3 [1996-2000]
80.376±0.077
OPAL [1996-1999]
80.490±0.065
LEP
80.412±0.042
χ²/dof = 29.6 / 37
LEP working group
80.0
81.0
M_W[GeV]



W-Boson Mass [GeV]
p̄p-colliders
80.454 ± 0.059
LEP2
80.412 ± 0.042
Average
80.426 ± 0.034
χ²/DoF: 0.3 / 1
NuTeV
80.136 ± 0.084
LEP1/SLD
80.373 ± 0.033
LEP1/SLD/m_t
80.380 ± 0.023
80
80.2
80.4
80.6
m_W [GeV]

Implication for the Standardmodel





Conclusion and Outlook

- WW and ZZ cross section agree with predictions
- Current W mass measured to:

  $M_W = 80.412 \pm 0.042$ GeV/c^2

- Final publication in the Summer
  - Improved beam energy uncertainty
  - Improved treatment of color reconnection and Bose Einstein Correlation

  $\Rightarrow$ Expected Error ~35 GeV/c^2