W Boson Mass and Properties at LEP

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on behalf of the LEP Collaborations
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Outline:

- W Mass Measurements at LEP
  - Direct Measurement
  - Systematic Effects
- W Cross-Section
- W Spin Density Matrix
- Summary

W Boson Measurements at LEP

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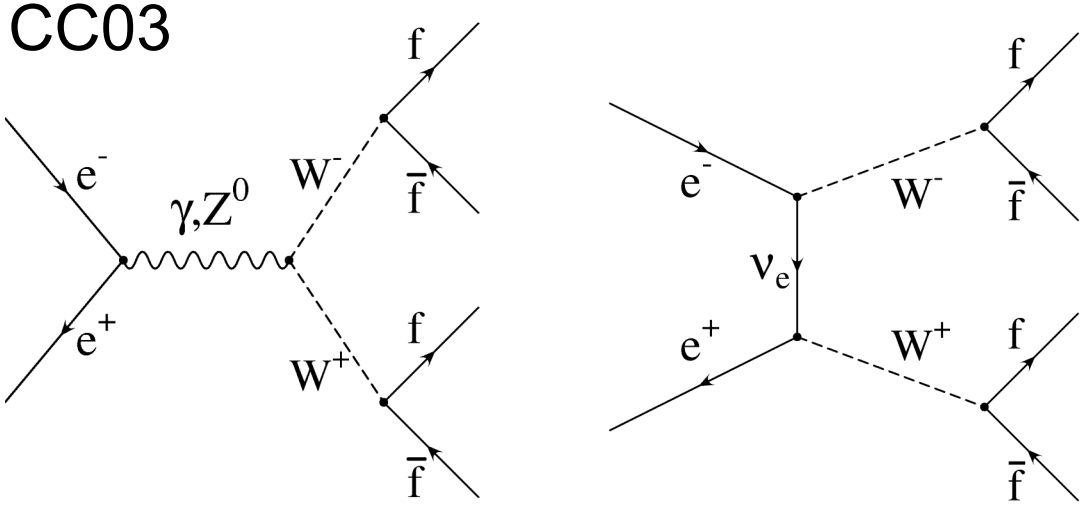
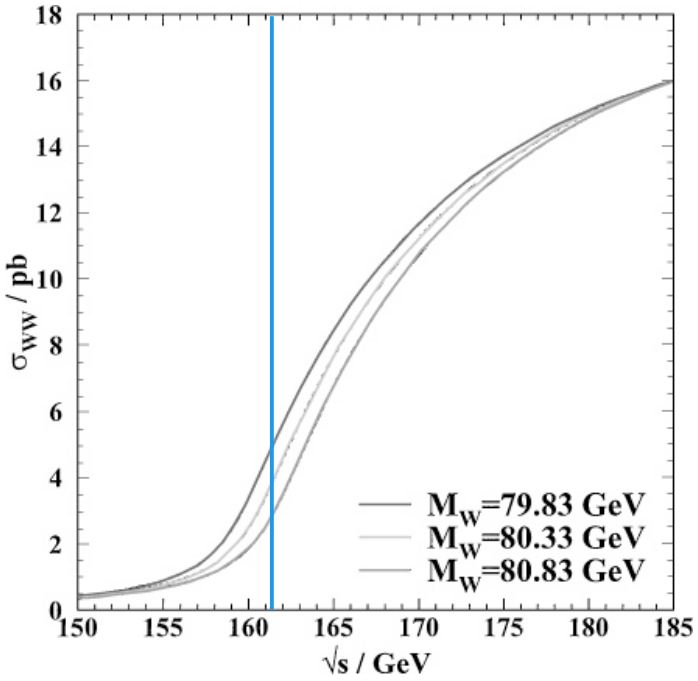


- W-pair final states:
  - fully hadronic (~45%)
  - semileptonic (~44%)
  - fully leptonic (~11%)

- Measurements using data collected at $\sqrt{s}$ = 161-209 GeV, about 700 pb^{-1} per experiment, in total ~40000 W-pairs:
  - W mass and width
  - W cross-section and branching ratios
  - Triple Gauge Couplings WWγ and WWZ
  - Spin Density Matrix and Polarisation

W Mass

- Direct measurement of W mass “competes” with indirect measurement (20 MeV from Standard Model fit).
- Direct measurement constitutes important test of the Standard Model and to constrain Higgs mass better.
- At production threshold, measure W mass from the WW cross-section.
- At higher c.m. energies, reconstruct the W invariant mass from observed jets and leptons.

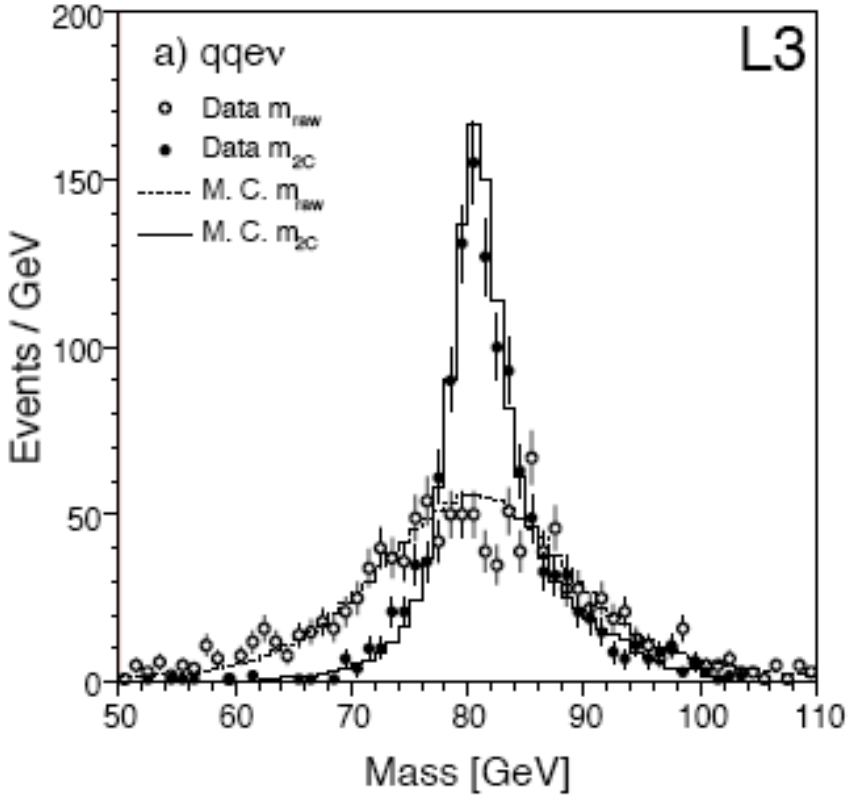


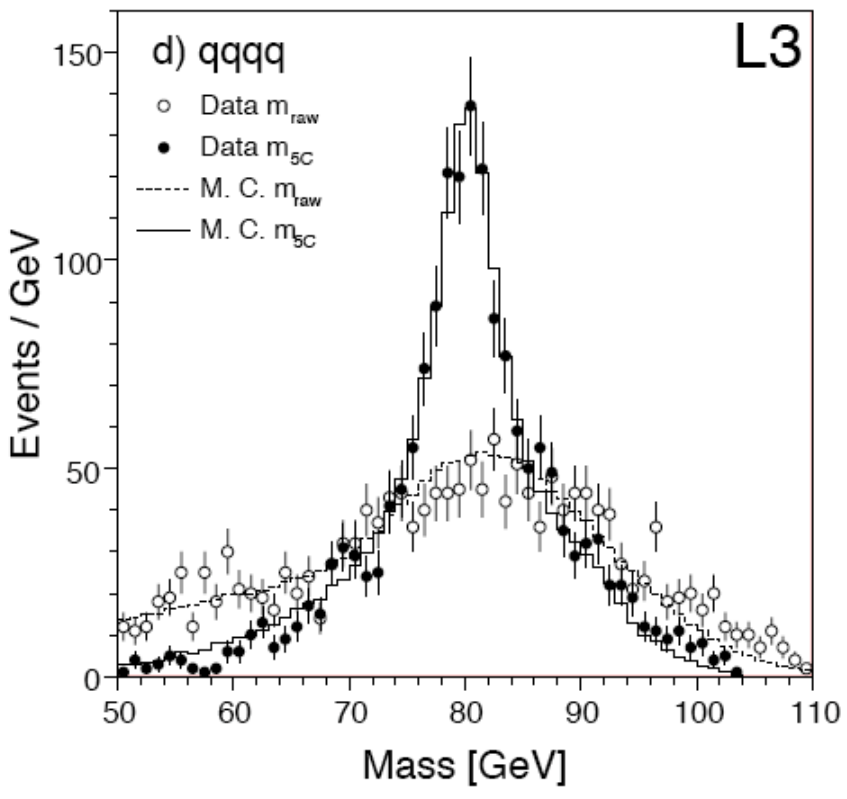
NEW:

- Color Reconnection:
  - all four experiments have published final results
  - new LEP-Combination is being performed
- Delphi: W mass paper being published (final results already included in LEP combination)
- W mass LEP combination: waiting for the CR-combination

W Mass Measurement at LEP (1)

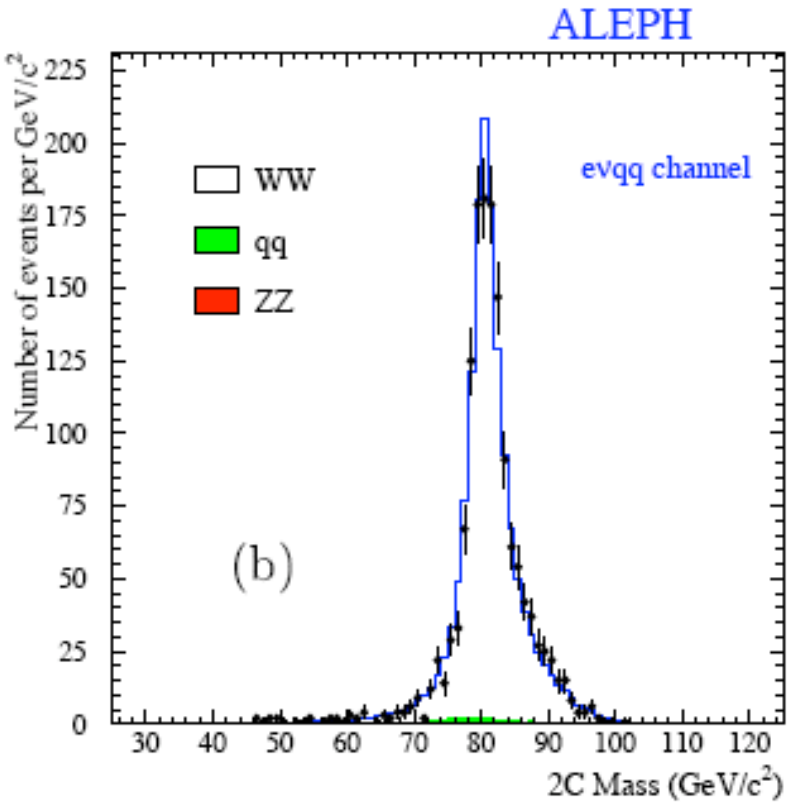
- Standard selection of qqlν and qqqq.
- Kinematic fit to improve resolution:
  use four-momentum conservation (for jets, velocity fixed to measured value)
  ⇒ qqlν: 1C, qqqq: 4C
- Further constraint: equal W masses
  ⇒ **qqlν: 2C, qqqq: 5C**

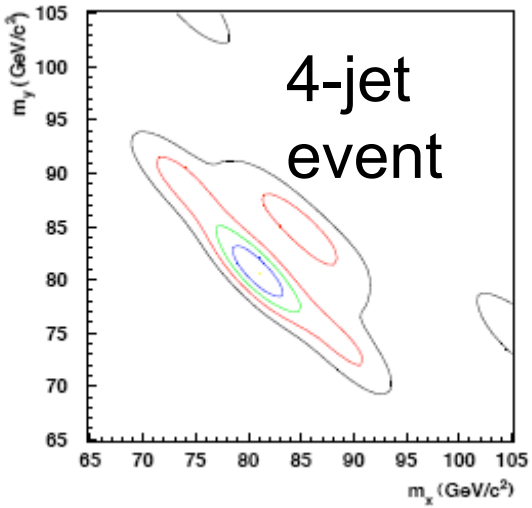


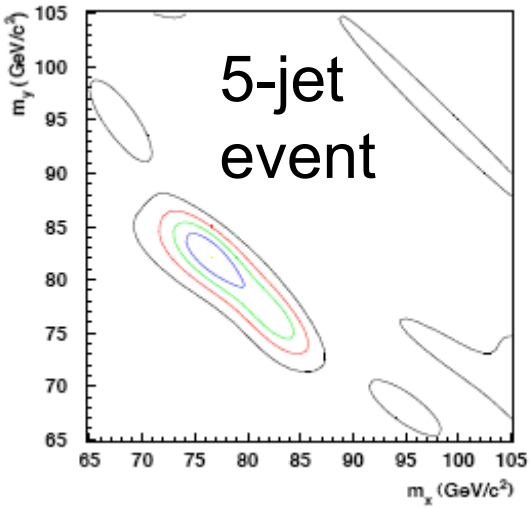


W Mass Measurement at LEP (2)

- W boson mass and width extracted from:
  - maximum likelihood fit comparing data to MC samples with different underlying masses,
  - W mass variation implemented by MC reweighting or convolution techniques.
  - DELPHI: use ideograms (reconstructed mass information from the event kinematics), then form likelihood





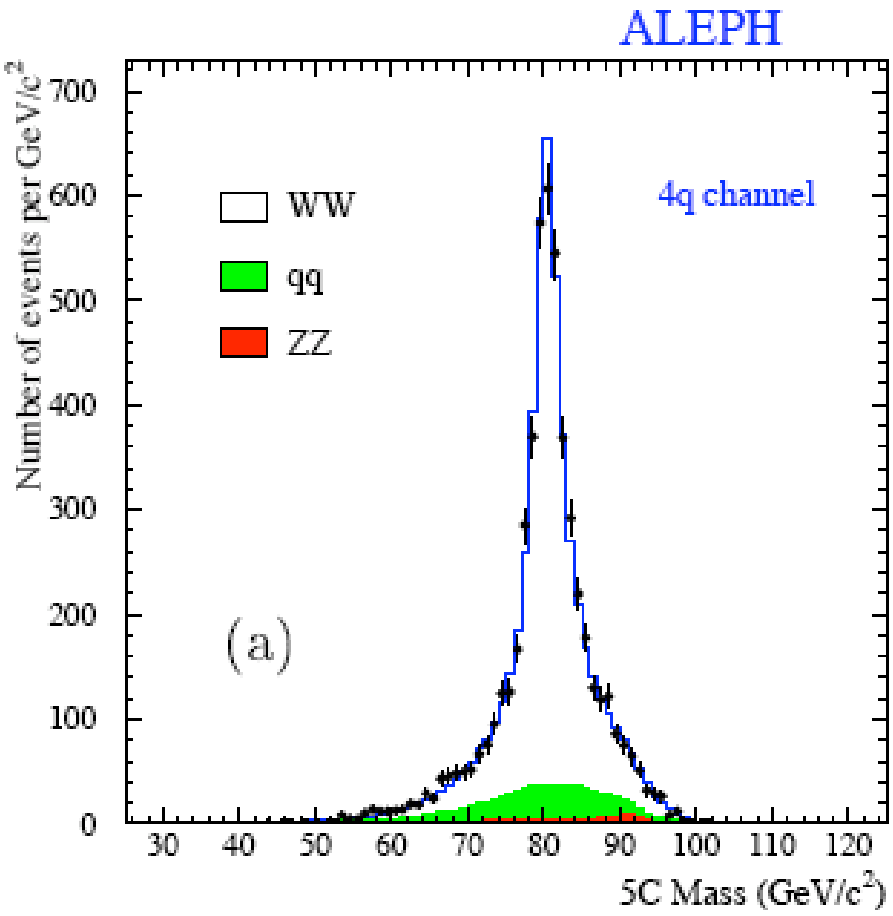


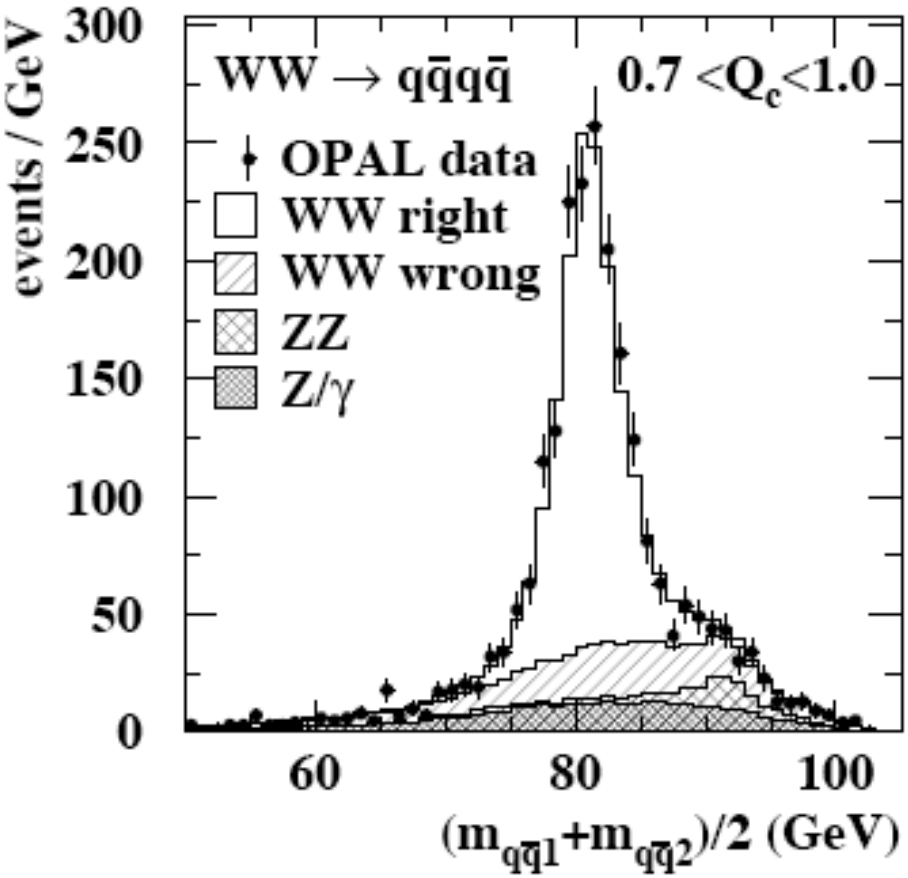
Generally: systematics dominated by uncertainties from hadronisation.

W Mass Measurement at LEP (3)

WW→qqqq

- reduce influence of Final State Interaction by using only particles which have momentum above a certain threshold, determined by each experiment separately.

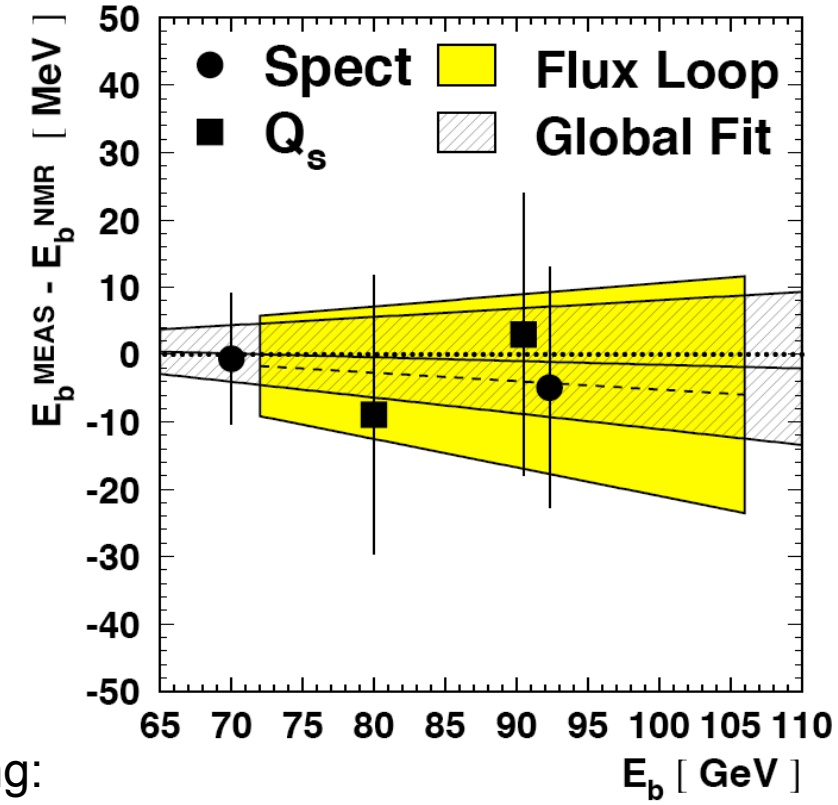




- Systematics dominated by uncertainties from Final State Interaction systematic: Color Reconnection and Bose-Einstein-Correlations

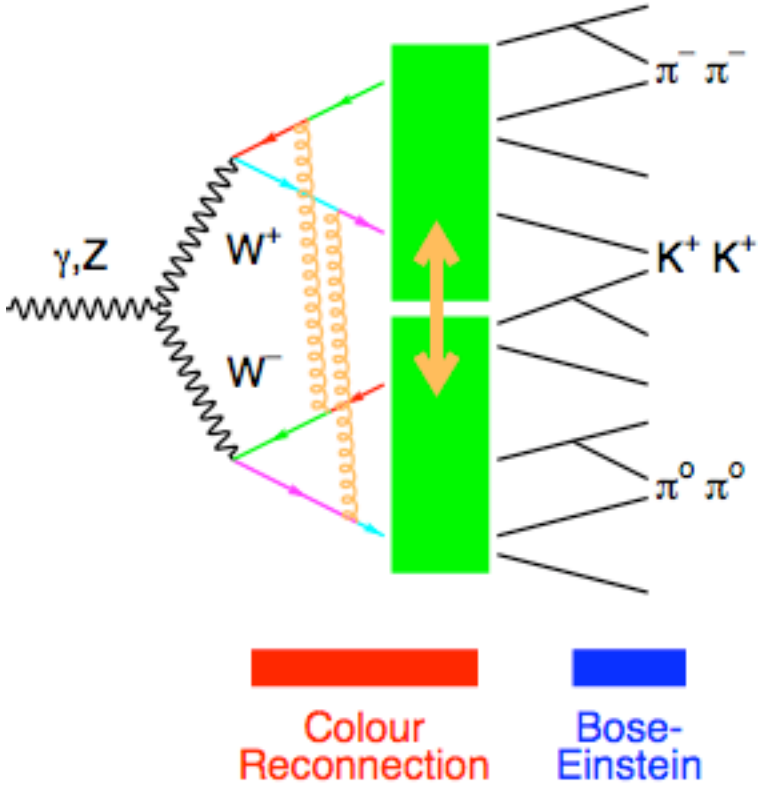
Systematic Uncertainties (1)

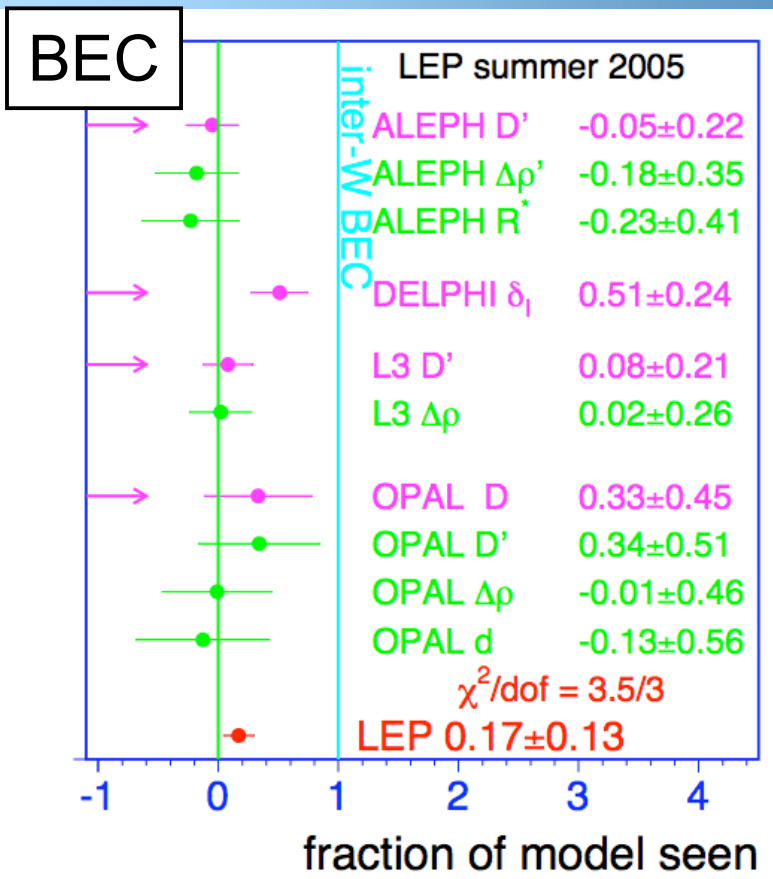
- LEP beam energy (9 MeV):
  - used as constraint in kinematic fits
  - from calibration at low energies (resonant spin depolarisation), extrapolated to LEP2 beam energies, using model established by B-field measurements with NMR probes [EPJ C39 253]
  - systematic uncertainties: comparison of the default NMR measurements with alternative methods



- Uncertainties connected to Monte Carlo modeling:
  - EW radiation (7 MeV): include full O(α) corrections
  - detector modeling (10 MeV): uncorrelated between experiments

Systematic Uncertainties (2)





– hadronisation modeling (14 MeV): compare MC (PYTHIA, HERWIG, ARIADNE)

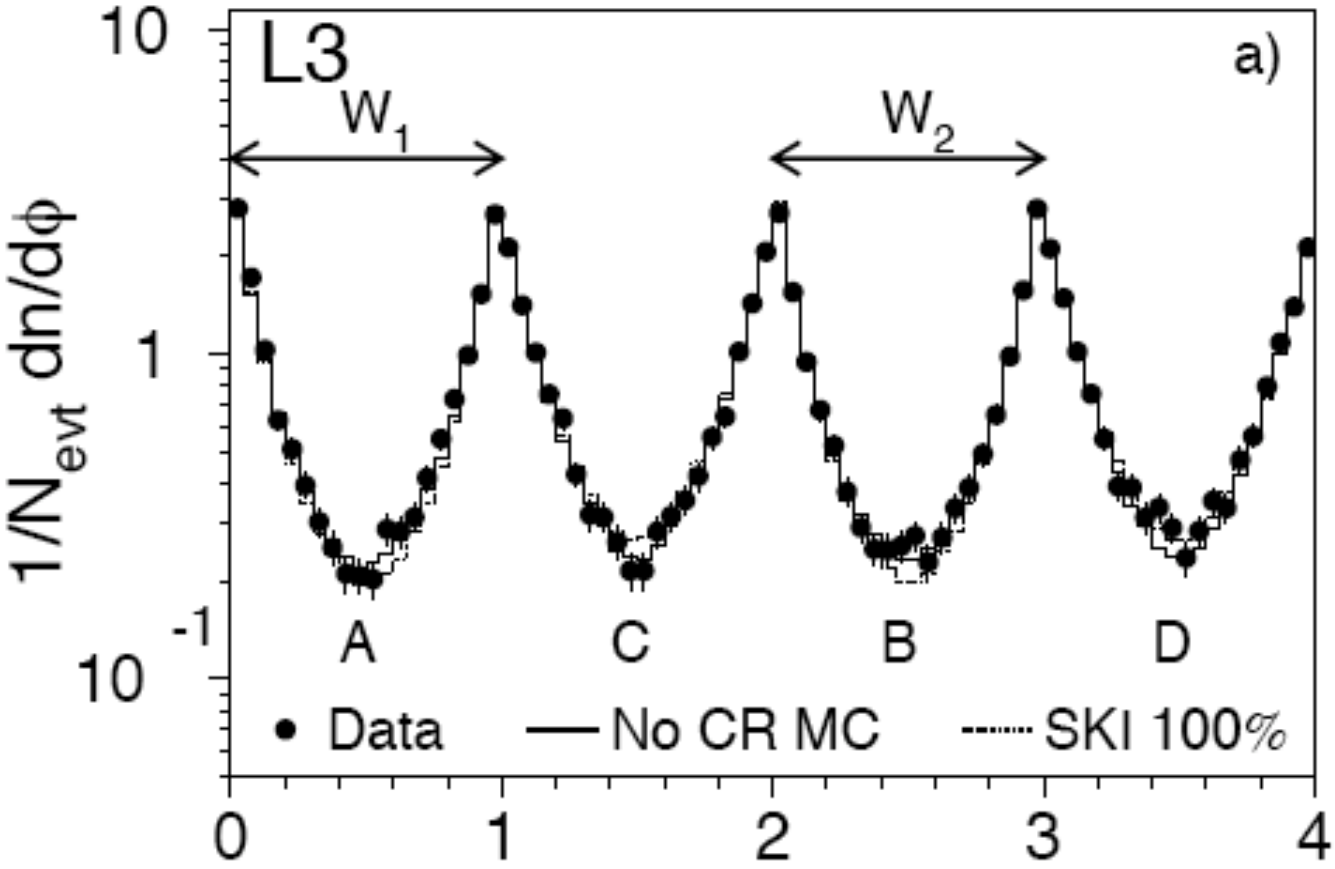
– final state interactions (FSI):

- Bose-Einstein-Correlations (BEC) (2 MeV, qqqq: 7 MeV)
- Color Reconnection (CR) (8 MeV, qqqq: 35 MeV)

Color Reconnection (1)

- Energy-momentum is not any more conserved in each of the W bosons due to rearrangement of momentum of hadrons by CR.
- Several phenomenological models exist.

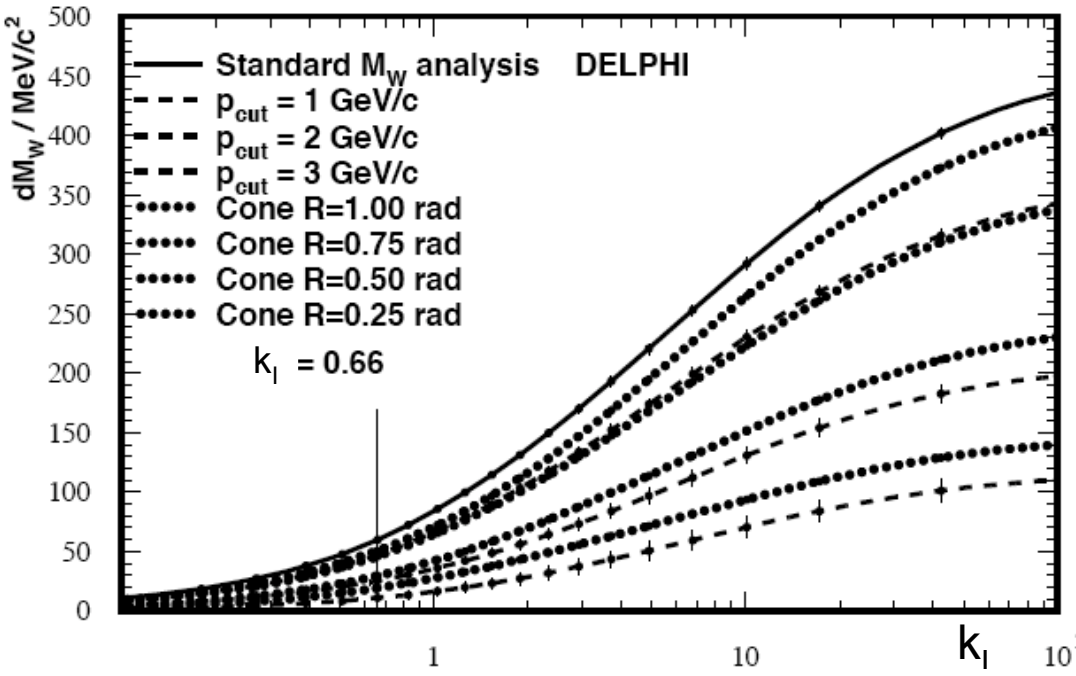
- Commonly used as a benchmark: SK-I model with parameter k_I (probability of an event to be reconnected).
- Measurements using **particle flow** (DLO) - compare the particle flow intra-W and inter-W

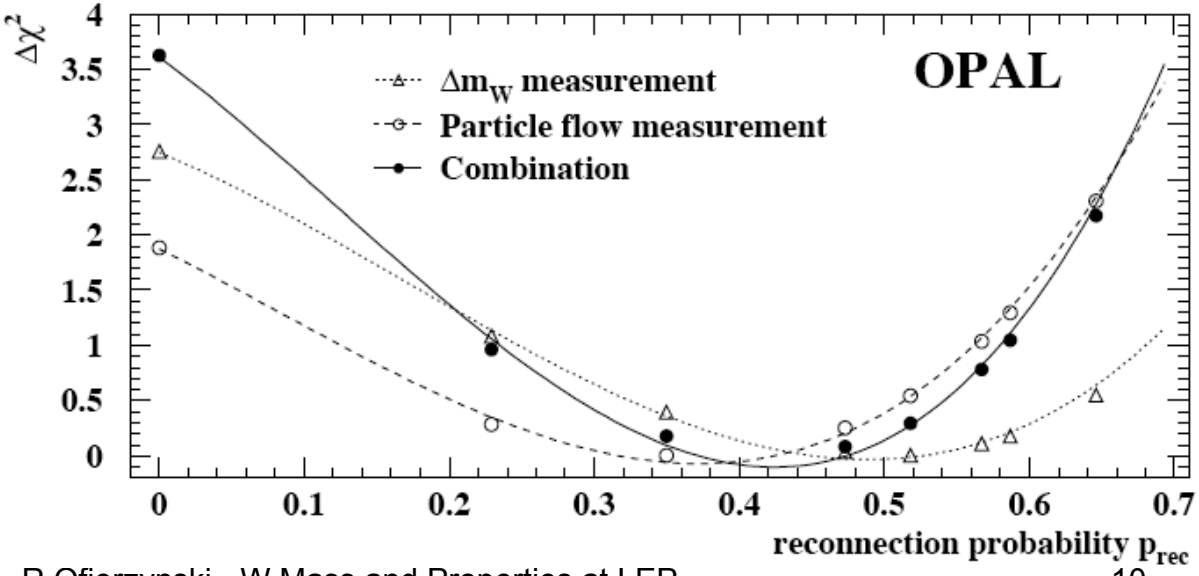


Color Reconnection (2)

- **m_W based** (ADO):compare standard analysis with
  - PCUT analysis: select only particles above an energy threshold
  - CONE analysis: calculate jet 3-momentum from vector sum of particles inside a cone
  - determine W mass bias in data and compare with MC with different CR-scenarios

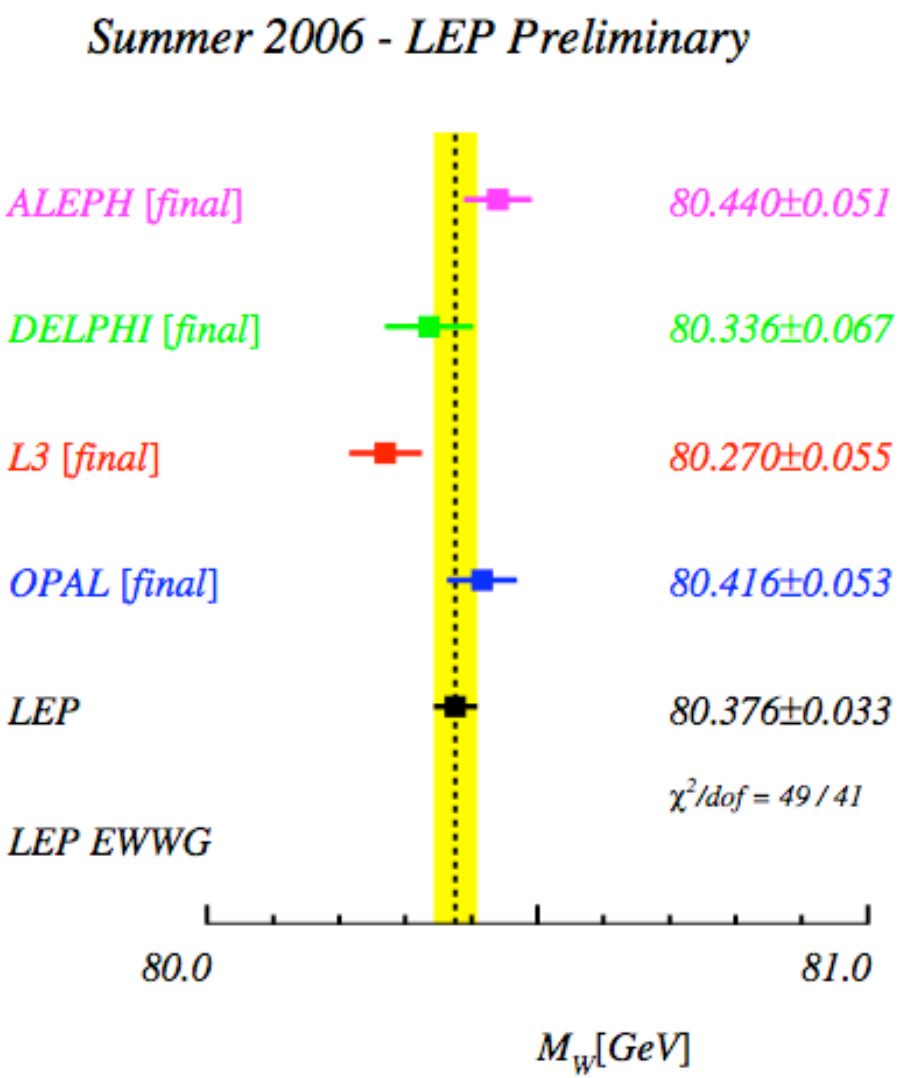
LEP-combination: for systematics $k_I < 2.13$ (preliminary)



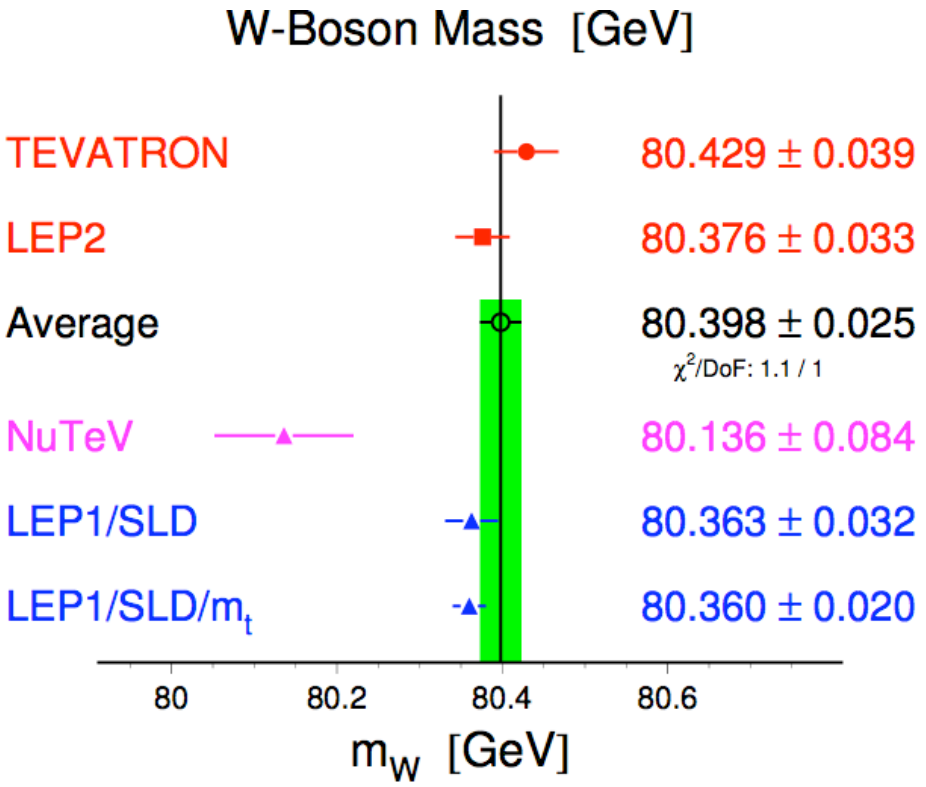


Results: W Mass at LEP

- Includes final W mass results from ADLO, only preliminary Color Reconnection results.



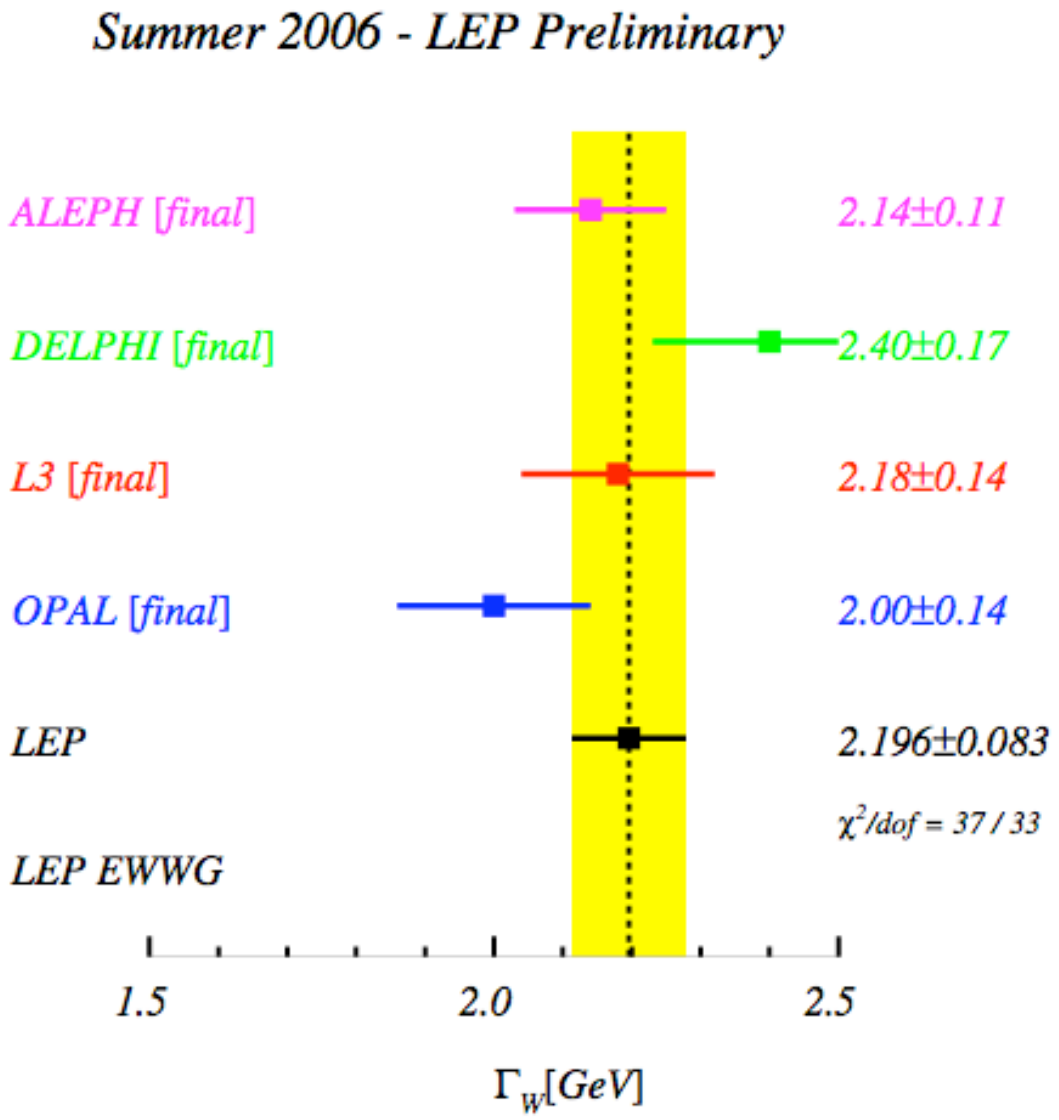
- LEP preliminary combination: m_W = 80.376 ± 0.033 GeV
- Difference between final states: $\Delta m_W(4q\text{-}qql\nu)$ = -12 ± 45 MeV



Results: W Width at LEP

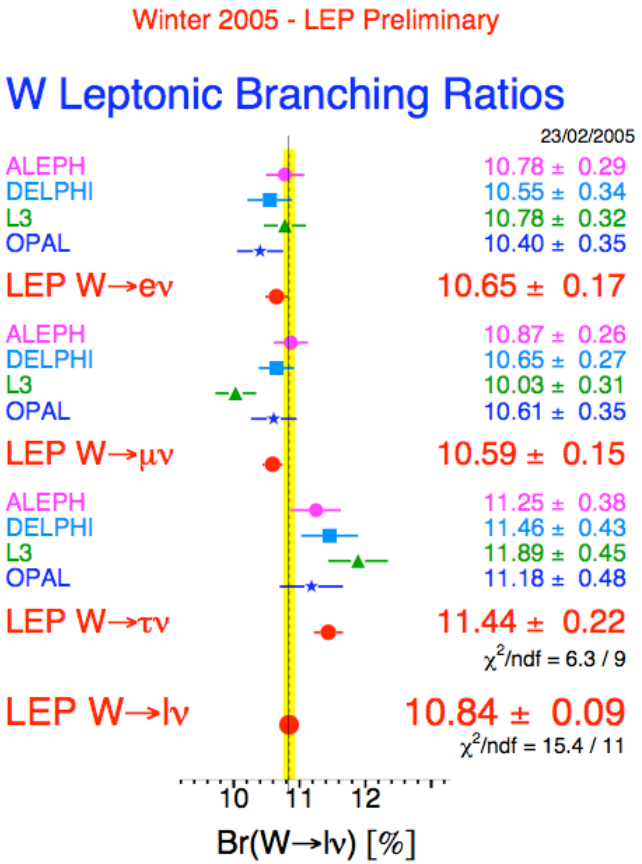
- Includes final W mass results from ADLO, only preliminary Color Reconnection results.

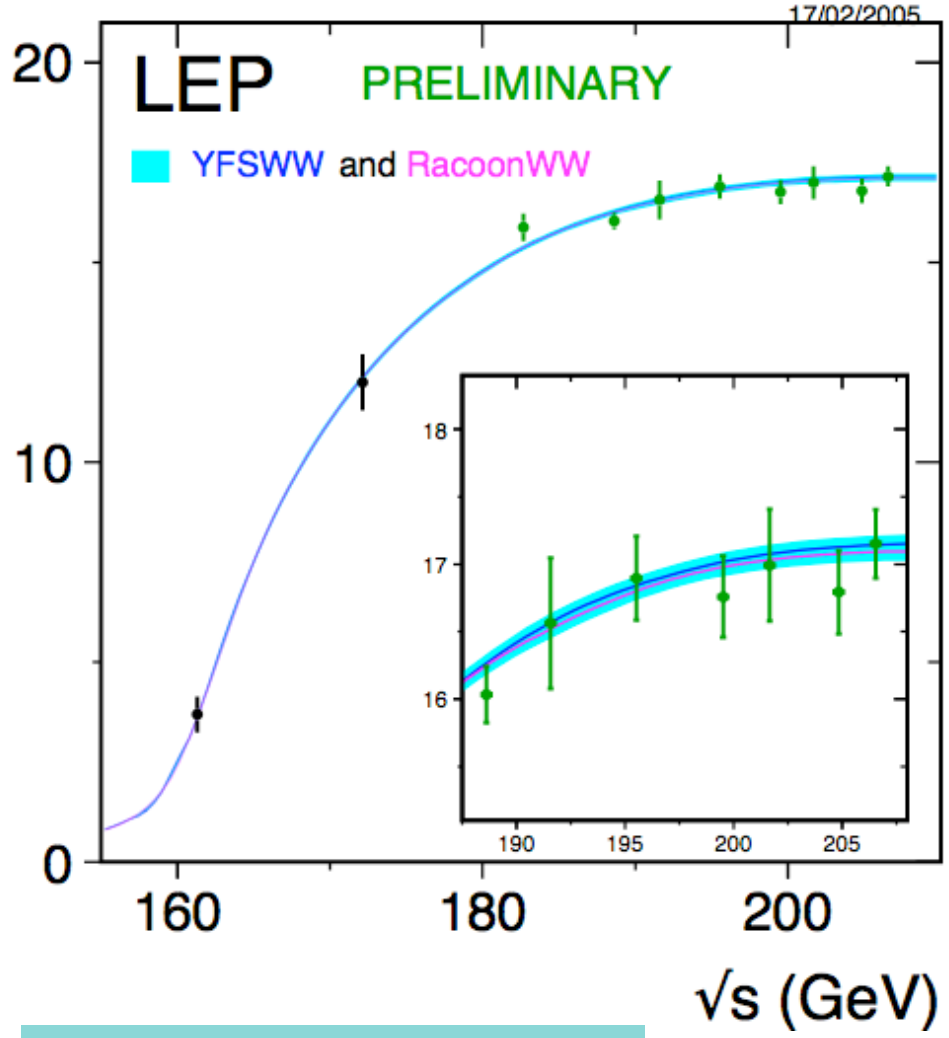
- LEP preliminary combination: Γ_W = 2.196 ± 0.083 GeV



W Cross-Section and BR at LEP

- LEP-combination includes ADL final results, OPAL preliminary results.
- Very good agreement with theoretical calculations.





data/SM = 0.994 ± 0.009

W Cross-Section and BR (OPAL)

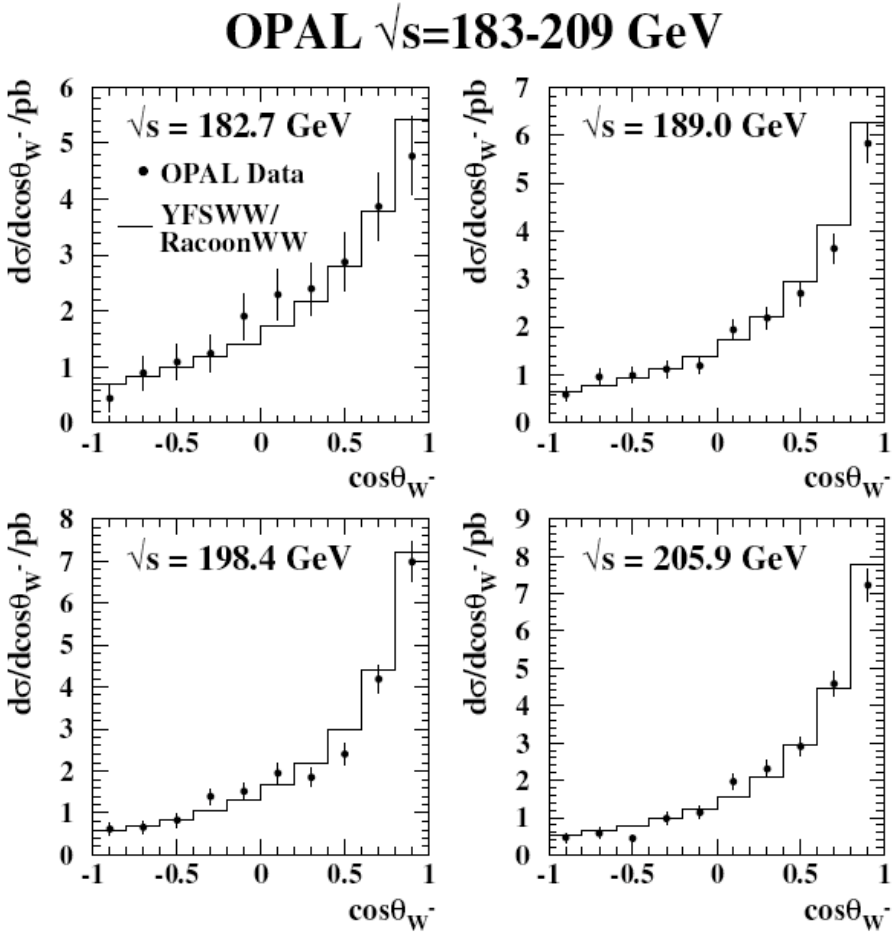
- OPAL final results (paper in preparation) consistent with SM expectation
- data/SM = 1.002 ± 0.014

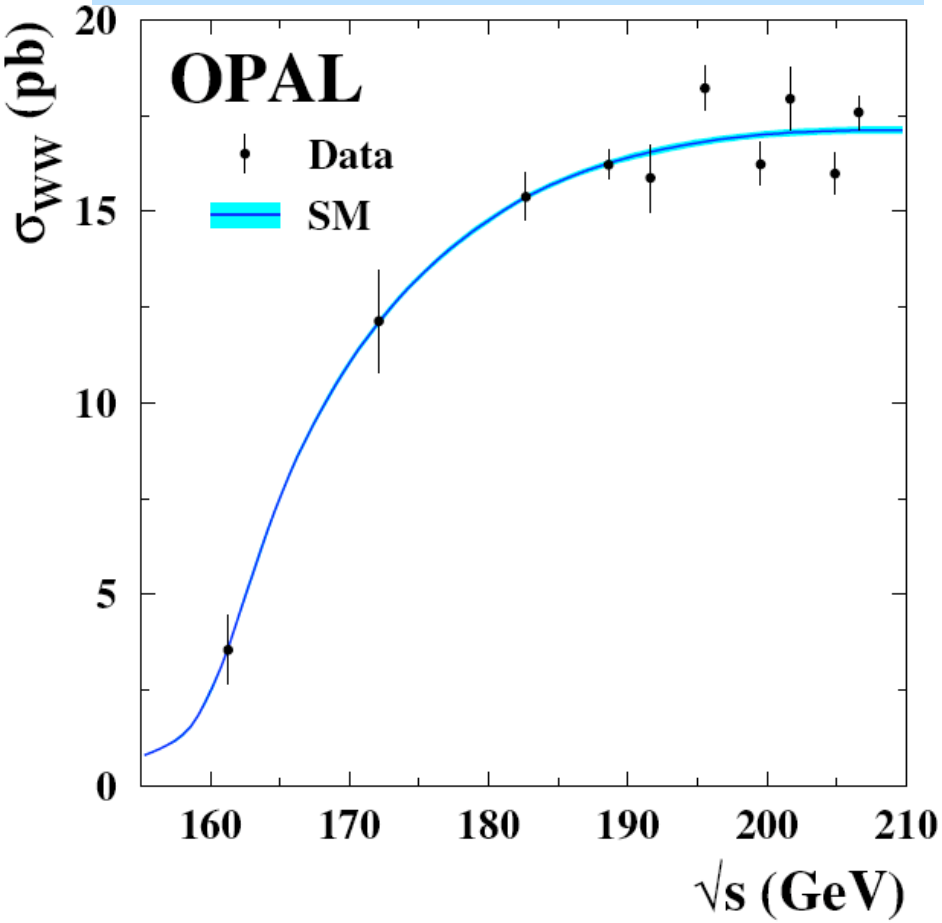
BR(W→eν) = 10.71 ± 0.25(st) ± 0.11(sys)

BR(W→μν) = 10.78 ± 0.24(st) ± 0.10(sys)

BR(W→τν) = 11.14 ± 0.31(st) ± 0.17(sys)

BR(W→qq) = 67.41 ± 0.37(st) ± 0.23(sys)



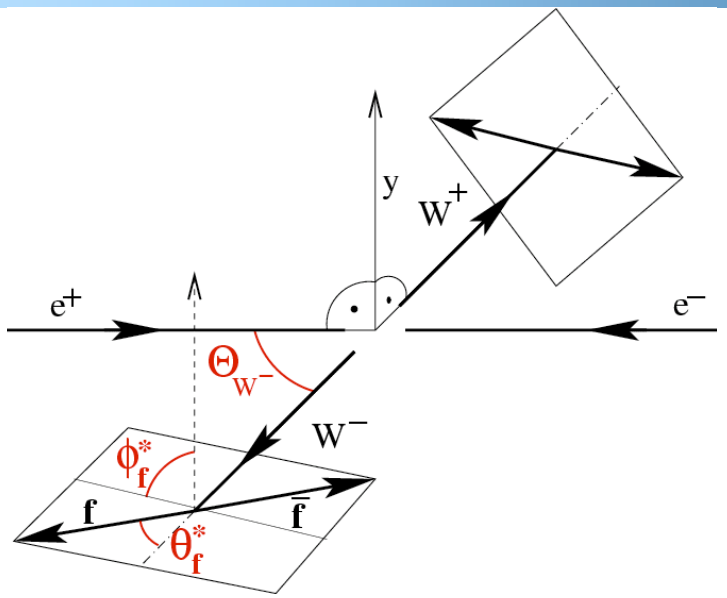


W Boson Spin Density Matrix

- test SM TGC WWγ and WWZ by measuring helicity fractions
- test of CPT and CP invariance at tree level
- **$e^+(\lambda')\ e^-(\lambda) \rightarrow W^+(\tau_2)\ W^-(\tau_1) \rightarrow 4f$**
  ($\lambda = -\lambda' = \pm 1/2$, $\tau_1, \tau_2 = \pm 1, 0$)
- Two-particle SDM:

$$\rho_{\tau_1\tau_1'\tau_2\tau_2'}(s, \cos\Theta_W) = \frac{\Sigma_\lambda F^\lambda_{\tau_1\tau_2} (F^\lambda_{\tau_1'\tau_2'})^*}{\Sigma_{\lambda,\tau_1,\tau_2} |F^\lambda_{\tau_1\tau_2}|^2}$$

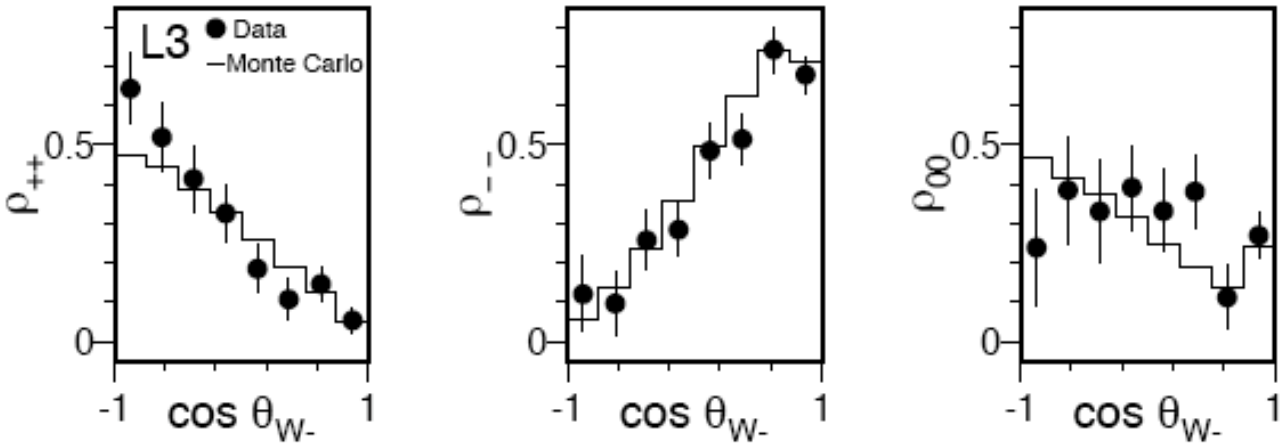
- $F^\lambda_{\tau_1\tau_2}$: helicity amplitude
- Single-particle SDM: sum over all possible helicities of the other W
  - diagonal elements (real) → probability to produce W^- with helicity +1,0,-1
  - off-diagonal elements (complex) → linear superposition of helicity states



- Experimentally: divide cos θ_W in 8 bins
- In each bin, apply projection operators:
  - diagonal SDM elements: f(cos θ^*_f)
  - non-diagonal SDM elements: f(cos θ^*_f, Φ^*_f)
- correct for detector acceptance, resolution effects, background contamination → compare to SM prediction

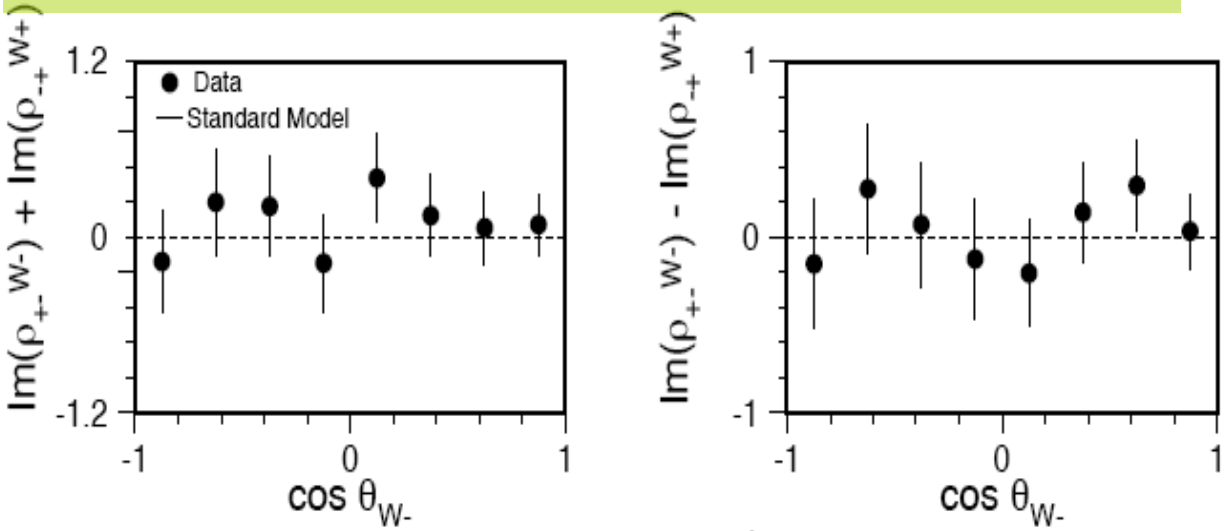
W Spin Density Matrix (L3)

- L3 final results (paper in preparation)
- $\sqrt{s}$=189-209 GeV combined, using WW → (e/μ)νqq.
- SDM for W → l ν, in agreement with SM



f_+ = (20.4±2.5)%, f_- = (51.8±2.8)%, f_0 = (27.8±4.0)%
MC: 17.4±0.2, 58.6±0.2, 24.0±0.3

- Test of CP(T) invariance
- CPT-invariance:
  $\mathbf{Im}(\rho^{W^-}_{\tau,\tau'}) + \mathbf{Im}(\rho^{W^+}_{-\tau,-\tau'}) = 0$
- CP-invariance:
  $\mathbf{Im}(\rho^{W^-}_{\tau,\tau'}) - \mathbf{Im}(\rho^{W^+}_{-\tau,-\tau'}) = 0$
- measured sums compatible with 0, no CP- or CPT-violation at tree level



all results consistent with previous publications

(OPAL SDM: PL B585 (2004) 223, L3 direct fit: PL B557 (2003) 147)

Summary and Outlook

- LEP2 close to finish.

- All LEP-experiments have final results on W mass and on systematic uncertainties.
- Final results on Color Reconnection are being combined.
- W mass combination follows.

- W cross-section: all final results from the LEP experiments available.
- LEP-combination follows.

- W Spin Density Matrix final results from L3.