Evaluation of a new method for W mass measurement at LEP

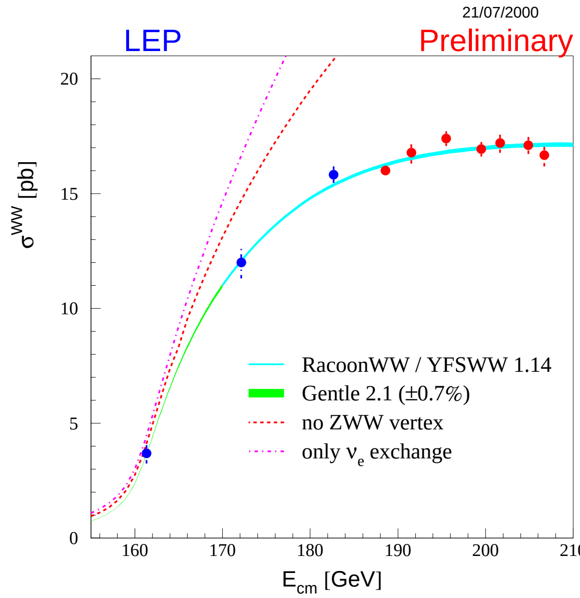
Outline

- Motivation
- $\mathbf{e^+e^- \rightarrow WW \rightarrow ffff}$ process
- W mass measurement:
  - The method
  - Implementation
  - Results
- Summary and conclusions

Artur Barczyk

ETH Zürich, PSI Villigen

- $W^{\pm}$: carrier of weak charged force



- WW cross section
  - well predicted by SM calculations
  - sensitive to
    - W mass (in part. at threshold)
    - Triple Gauge Boson couplings
    - New physics

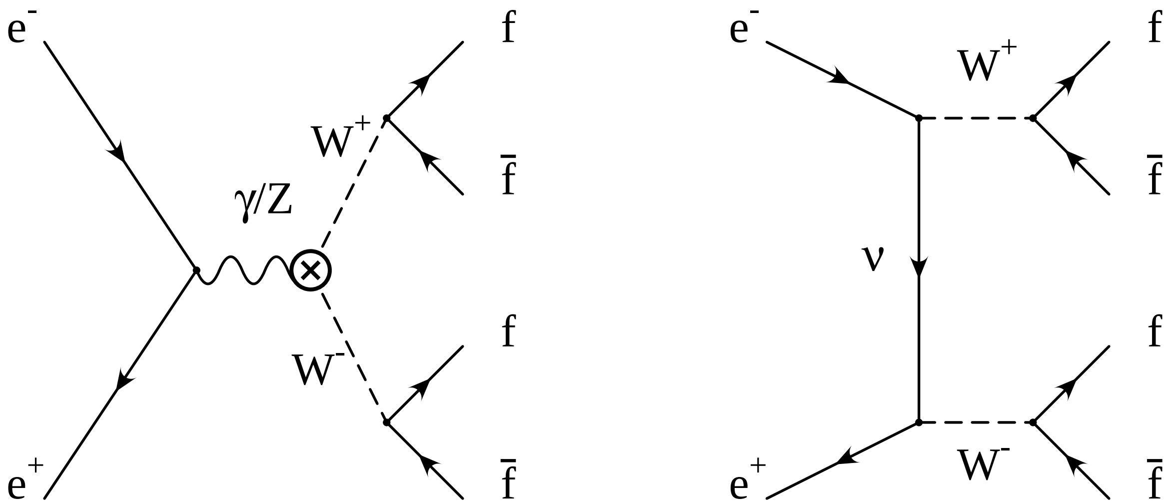
- W mass measurement
  - Higgs mechanism:

$$\sin^2\theta_W = 1 - \frac{M_W^2}{M_Z^2}$$

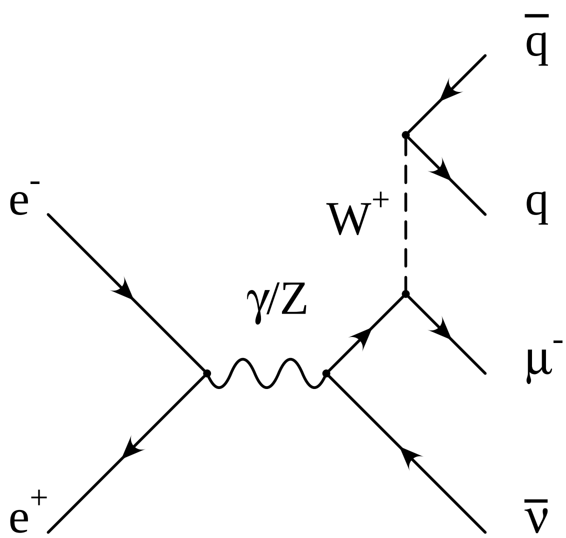
  - LEP1: M_Z measured to high accuracy (±7 MeV)
  - CCFR (νN), LEP1: $\sin^2\theta_W$ (±1%), from comparison of charged current to neutral current couplings
  - LEP2: direct measurement of M_W (goal: ±35 MeV)

- Triple Gauge Boson couplings
  - LEP1 and SLC: measurement of boson-fermion couplings $\Rightarrow$ confirmation of SM
  - $SU(2) \times U(1)$ gauge theory $\Rightarrow$ non-Abelian self-couplings of W, Z and γ
  - LEP2: direct measurement of trilinear self-couplings through W pair production

Tree level diagrams



Other ffff final state processes, e.g.



The W pairs (top diagrams) is what we want!

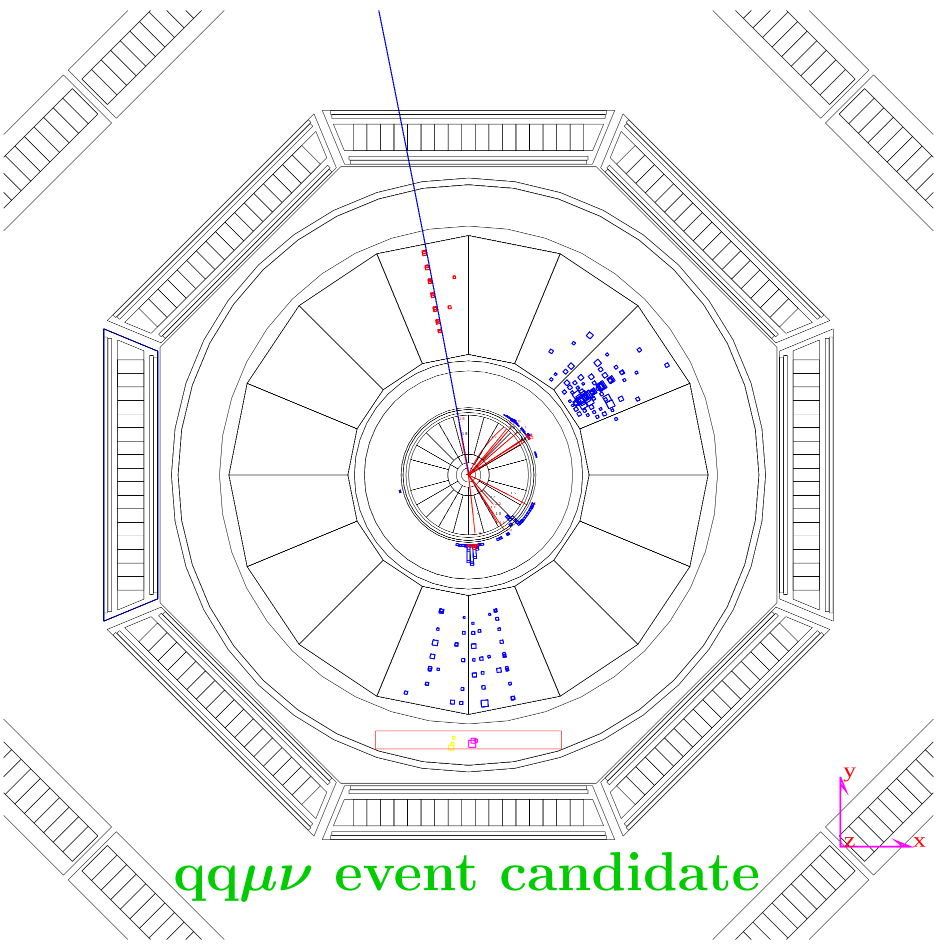
$e^+e^- \longrightarrow$ WW event selection

possible non-WW background:	$\sigma(\sqrt{s} = 189$ GeV)
• $e^+e^- \rightarrow Z/\gamma$	98.4 pb
• $e^+e^- \rightarrow ZZ$	0.97 pb
• two-photon interactions	15580 pb
• cosmic muon events with high energy deposits in the calorimeters	
SM W-pair cross section:	16.6 pb

Background rejection based on:

- cuts, asking kin. comp. with WW signature (qqlν, lνlν channels)
- Neural Network (qqqq channel)

Typical efficiency $\approx 70 - 90\%$
Typical purity $\approx 80 - 90\%$



(F.A.Berends et al., Phys. Lett. 417B (1998) 385 & CERN-TH/98-221)

Direct fit method:

- use well measured quantities $\{\Omega\}$ (energies, angles)

- for every event i calculate

$$\mathcal{P}(\{\Omega_i\}, M_{\rm W}) = \frac{1}{\sigma}\frac{d\sigma(\{\Omega_i\}, M_{\rm W})}{d\{\Omega_i\}}$$

- maximum likelihood fit:

$$\log \mathcal{L} = \sum_{i=1}^{N} \log\left(\frac{d\sigma}{d\{\Omega_i\}}\right) - N \log\sigma$$

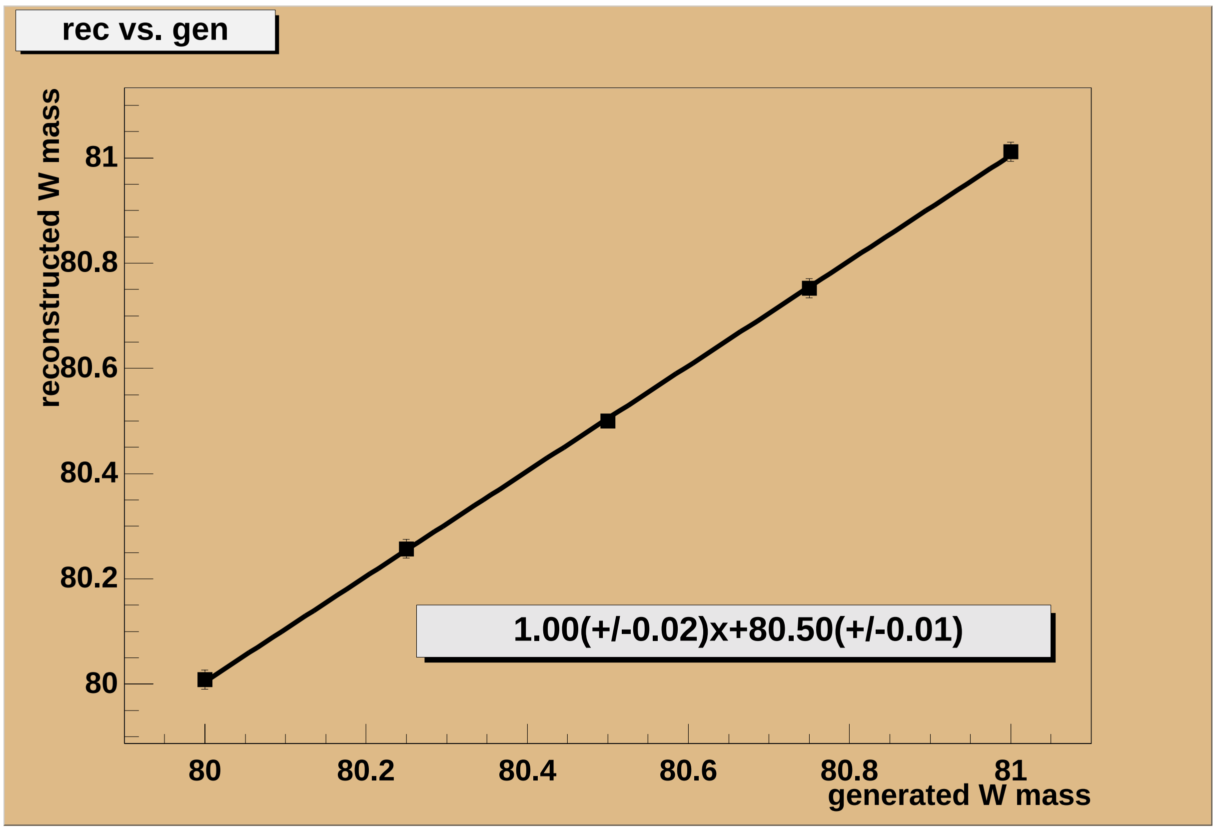
- analytical expression for $\frac{d\sigma}{d\{\Omega\}}(|\mathcal{M}|^2)$

- numerical calculation of $|\mathcal{M}|^2(\{\Omega\}, M_{\rm W})$ using core code of EXCALIBUR

Pros and Contras:

- + ISR properly taken into account (no kinematic fit)
- + integration over badly/not measured variables
- − CPU consuming

- MC generated events
- CC03 calculation
- $\sim$ 6000 events / M_{W} sample
- e.g. $\mathrm{qq}\tau\nu$:



(origin shifted to $M_{\mathrm{W}}^{gen} = 80.5$ GeV)

Detector effects

are included by convolution:

$$\frac{d\sigma(\{\Omega_j\})}{d\{\Omega\}} = \int d\{\Omega'_j\} \times \mathcal{R}(\{\Omega'_j\},\{\Omega_j\}) \times \frac{d\tilde{\sigma}(\{\Omega'_j\})}{d\{\Omega\}}$$

Resolution functions $\mathcal{R}$:

- assume uncorrelated measurement of $\{\Omega\}$
- use Gaussian/double Gaussian

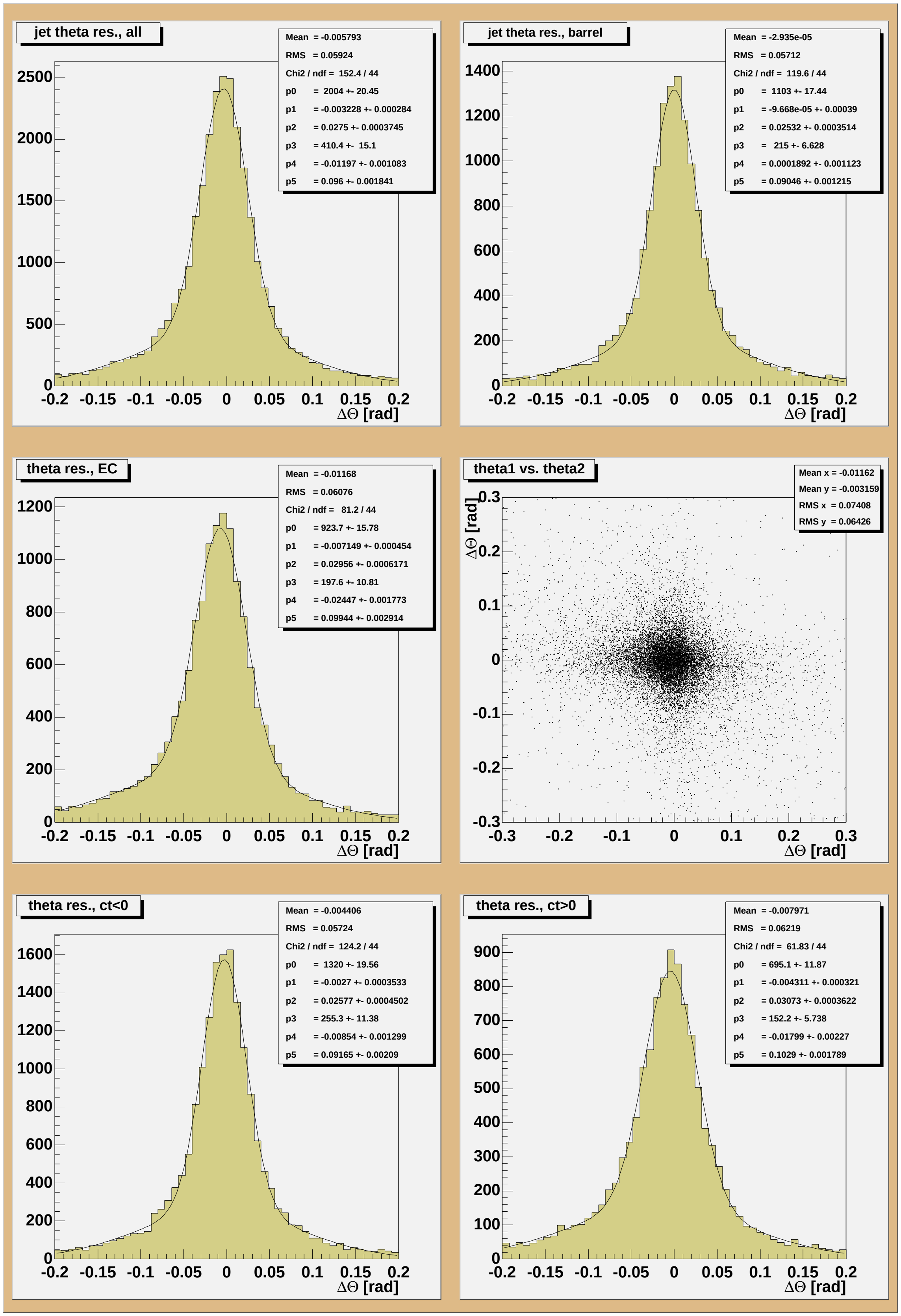
Parameter sets:

- qqqq: $\{\Omega\} = \{\theta_1^{jet}, \phi_1^{jet}, \theta_2^{jet}, \phi_2^{jet}, \theta_3^{jet}, \phi_3^{jet}, \theta_4^{jet}, \phi_4^{jet}\}$
- qlν: $\{\Omega\} = \{E_l, \theta_l, \phi_l, \theta_1^{jet}, \phi_1^{jet}, \theta_2^{jet}, \phi_2^{jet}, E_{hadr}^{tot}\}$
- lνlν: $\{\Omega\} = \{E_1^l, \theta_1^l, \phi_1^l, E_2^l, \theta_2^l, \phi_2^l\}$.

Integration:

- 8 parameters + 2 ISR photons $\rightarrow$ 10 dimensional integration
- MC integration method
- importance sampling for faster processing

Detector response functions

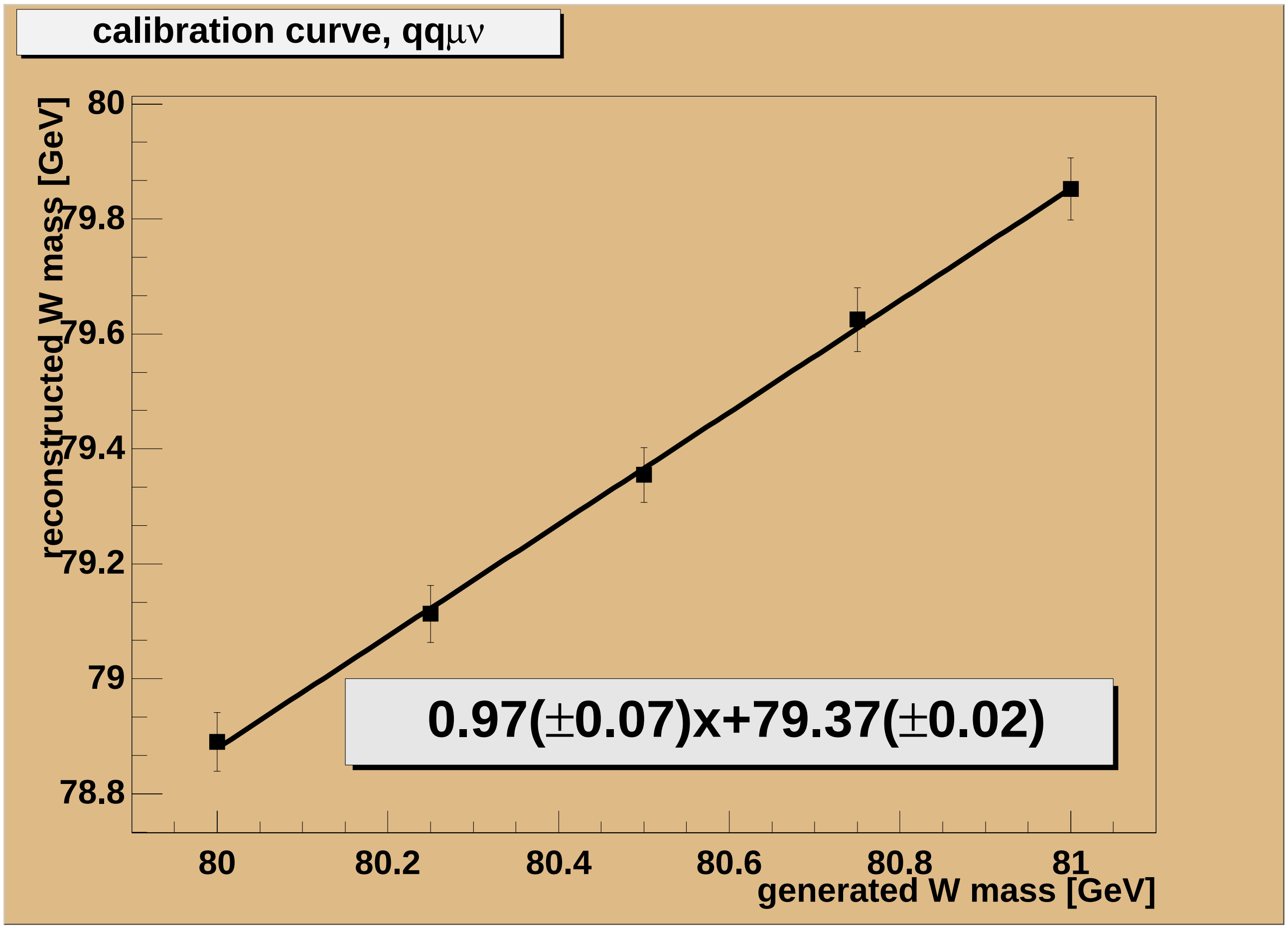


Correlation matrix of the errors on the measured quantities in the qq$\mu\nu$ channel:

	E_μ	θ_μ	ϕ_μ	θ_{jet}	ϕ_{jet}	E_{had}
E_μ	1.0	0.01	0.00	-0.01	-0.03	-0.01
θ_μ	0.01	1.0	-0.01	0.06	-0.03	0.00
ϕ_μ	0.00	-0.01	1.0	0.01	0.00	0.00
θ_{jet}	-0.01	0.06	0.01	1.0	0.00	-0.01
ϕ_{jet}	-0.03	-0.03	0.00	0.00	1.0	0.00
E_{had}	-0.01	0.00	0.00	-0.01	0.00	1.0

Correlation coefficients well below 10%, justifies the approximation.

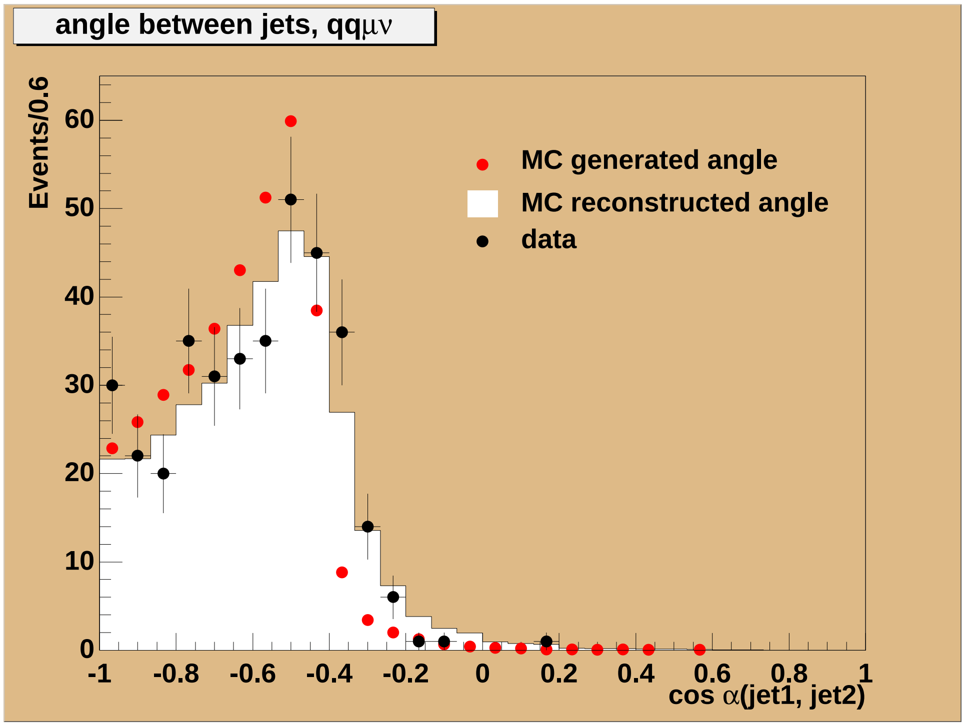
reconstructed vs. generated W mass after full detector simulation:



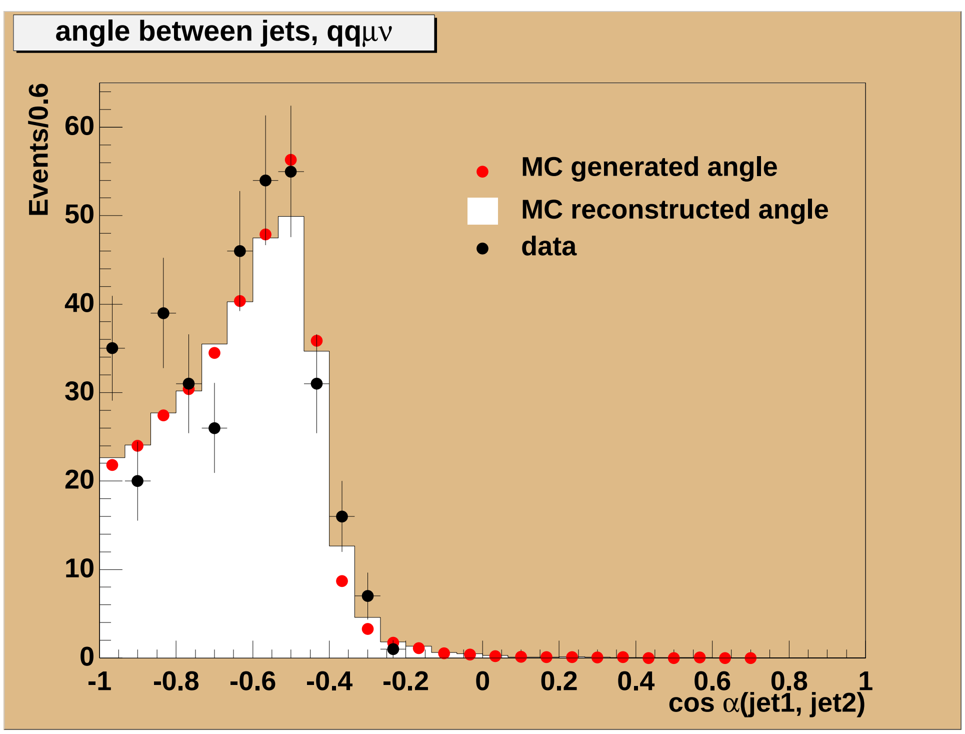
(origin shifted to $M_W^{gen} = 80.5$ GeV)

- Slope consistent with 1.0
- Bias towards lower values

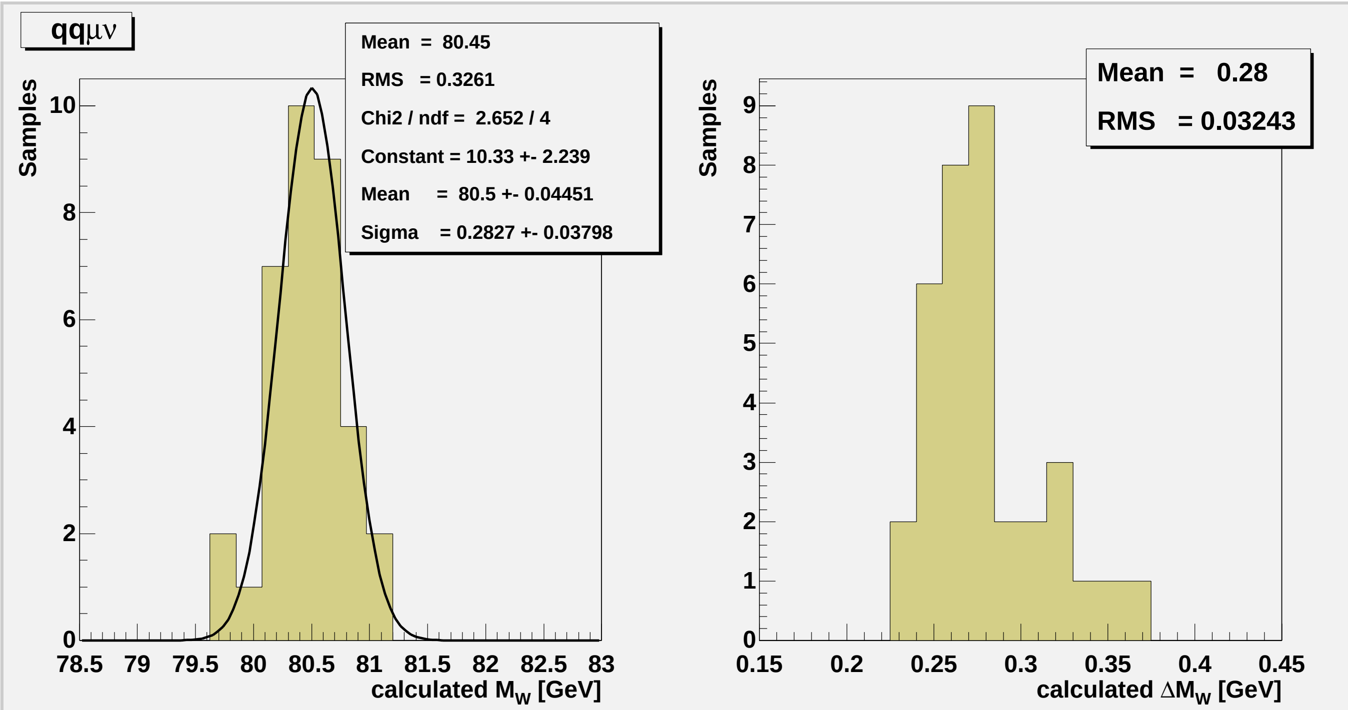
Angle between jets



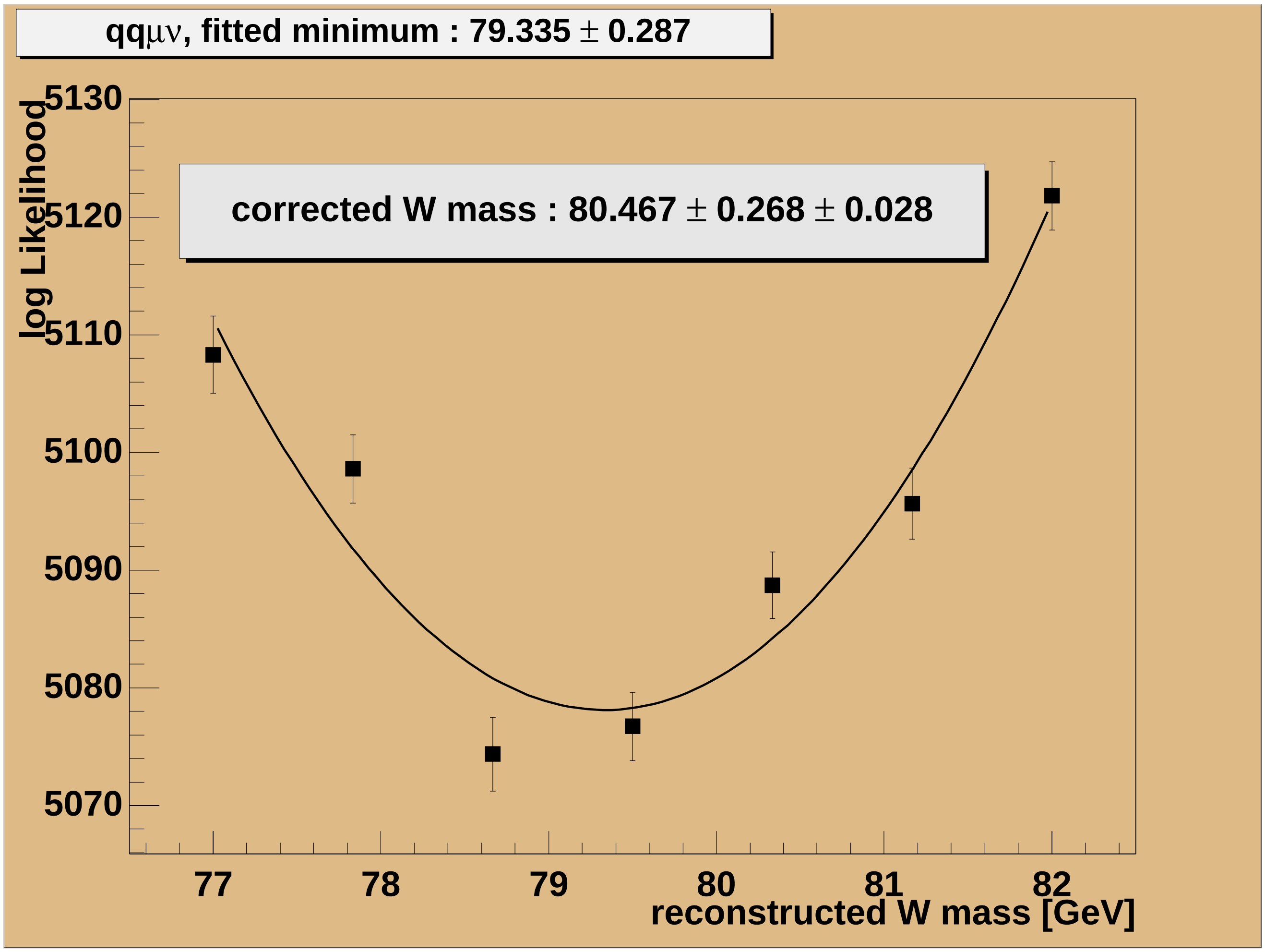
- Shift in mean of the distibution ⇒ shift in measured M_{W}
- Comes from neglecting hadron masses in jet reconstruction
- Reconstructed angle distribution agrees with data
- Use calibration curve to account for this effect
- Direct correction possible, but need flavour tagging:



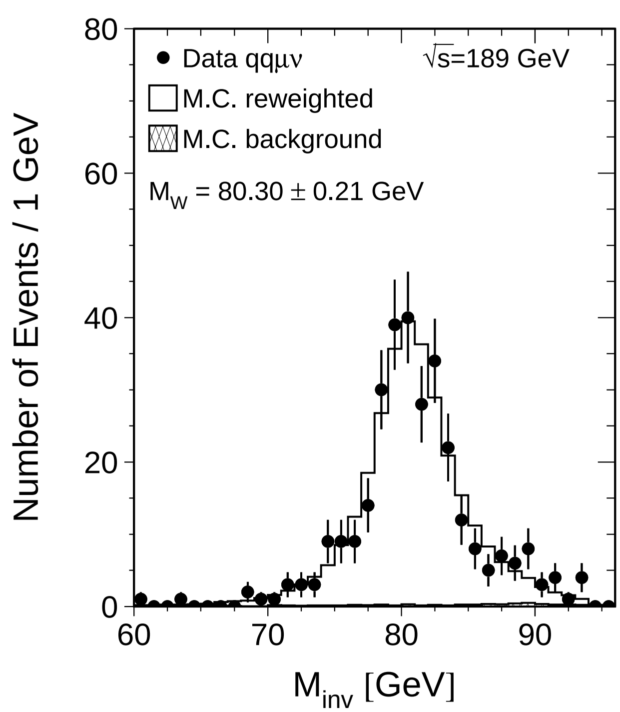
using independent test samples of 320 $qql^{\pm}\nu$ events



⇒ Mean calculated error consistent with width of mass distribution!



MC reweighting:



using $\int \mathcal{L} = 177$ pb^{-1} at $\sqrt{s} = 189$ GeV:

$M_W = 80.47 \pm 0.27$ GeV

consistent with traditional (MC reweighting) method

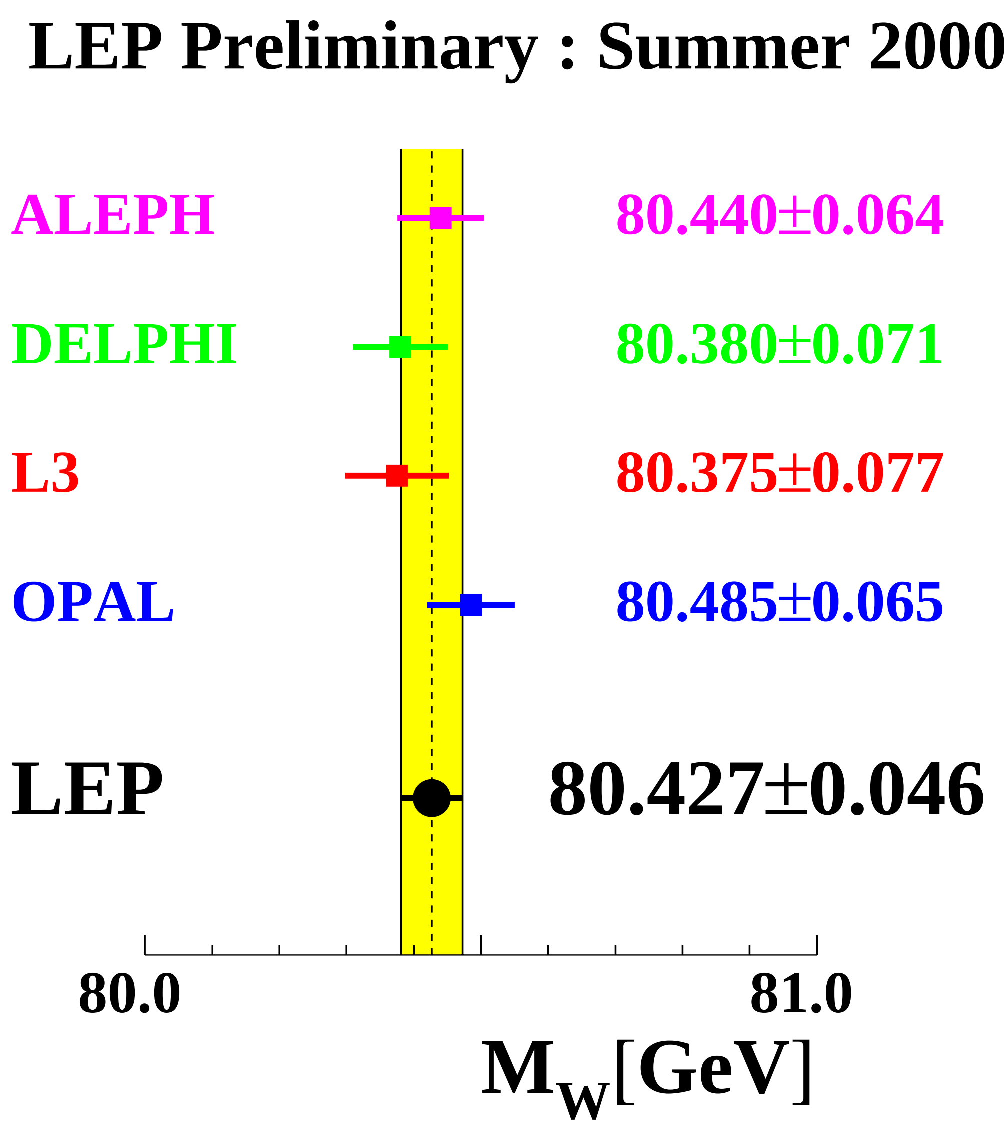
All semi-leptonic and fully hadronic final states evaluated:

channel	M_W[GeV]
WW → qqeν	$79.78 \pm 0.24 \pm 0.05$
WW → qq$\mu\nu$	$80.47 \pm 0.30 \pm 0.05$
WW → qq$\tau\nu$	$80.61 \pm 0.45 \pm 0.05$
WW → qqlν	80.13 ± 0.17
WW → qqqq	$80.49 \pm 0.13 \pm 0.09$
WW → ffff	**$80.33 \pm 0.10 \pm 0.07$**

L3, MC rew., 189 GeV: $M_W = 80.35 \pm 0.09 \pm 0.08$ GeV

Main systematic error sources:

Source	ΔM_W^{syst}(qqlν) [MeV]	ΔM_W^{syst}(qqqq) [MeV]
Fitting Method	40	35
Resolution Parameters	20	20
LEP Energy	20	20
Fragmentation	15	54
Bose-Einstein	-	38
Colour Reconnection	-	37
Total	51	88

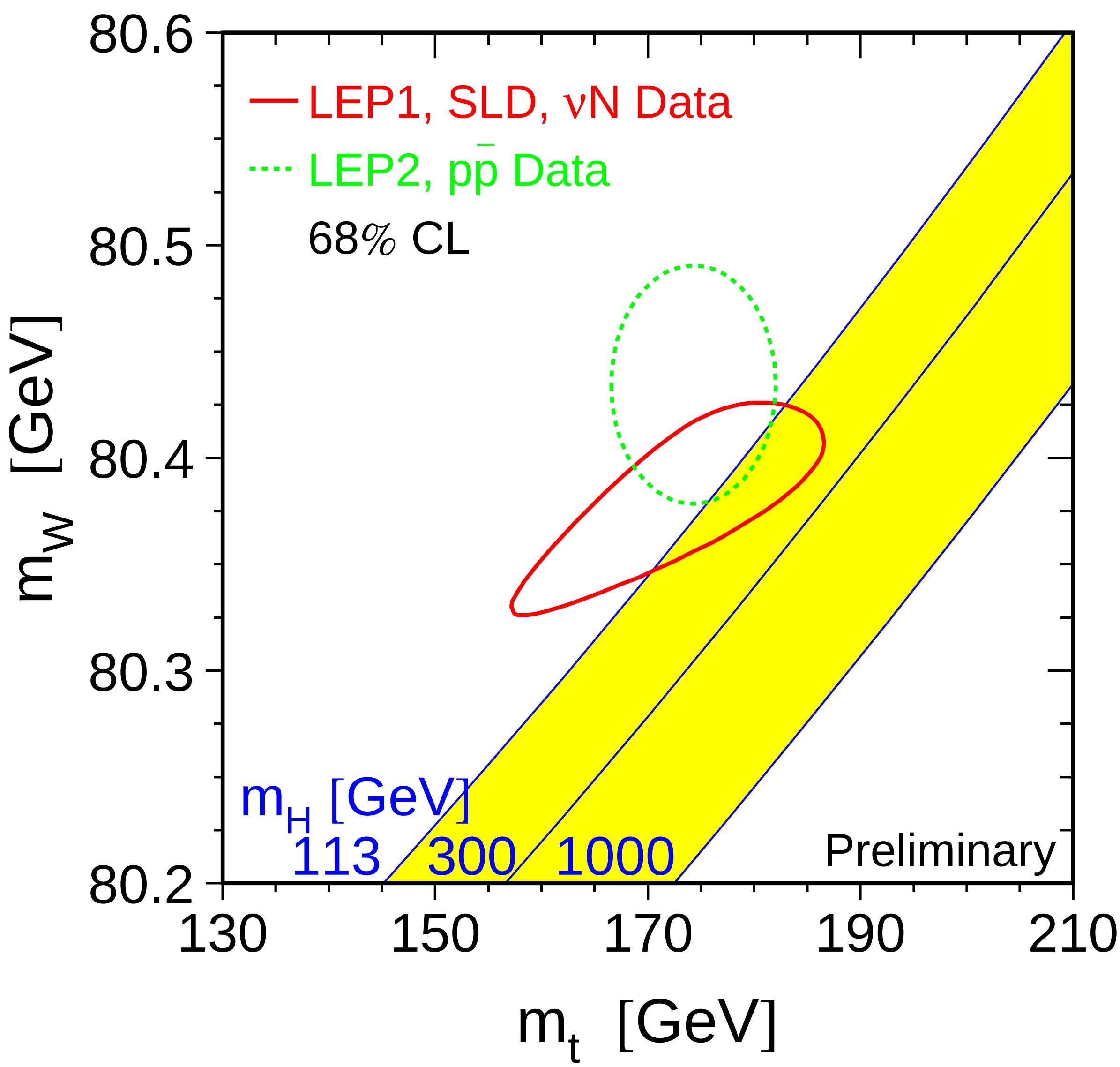

LEP Preliminary : Summer 2000
ALEPH
80.440±0.064
DELPHI
80.380±0.071
L3
80.375±0.077
OPAL
80.485±0.065
LEP
80.427±0.046
80.0
81.0
M_W[GeV]

Summary

- LEP2 data analyzed at $\sqrt{s} = 189$ GeV
- Selected events used for M_{W} measurement:
  - New method evaluated in semi-leptonic and fully hadronic channels
  - $M_{\mathrm{W}} = 80.33 \pm 0.10(stat.) \pm 0.07(syst.)$

Conclusions

- High precision achieved in M_{W} measurement
- This new method is competitive with traditional methods
- Systematic uncertainties well under control


LEP1, SLD, νN Data
LEP2, pp̄ Data
68% CL
m_H [GeV]
113
300
1000
Preliminary
80.6
80.5
80.4
80.3
80.2
m_W [GeV]
130
150
170
190
210
m_t [GeV]