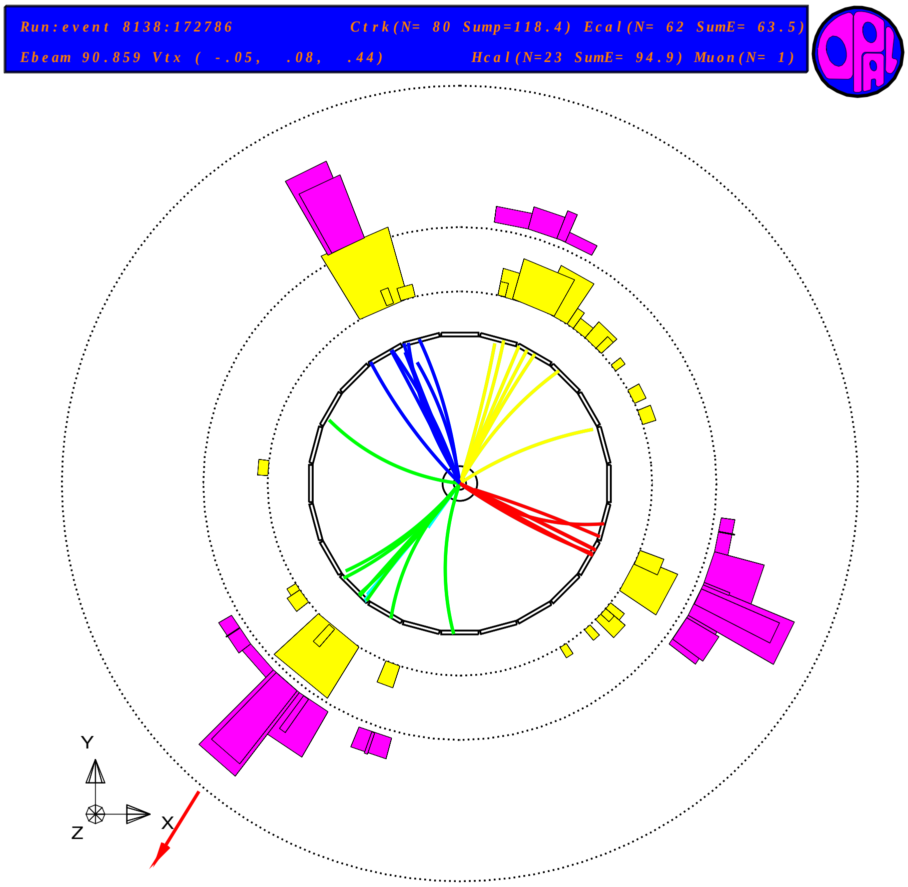
M_W from LEP

Part II

M_W from $W^+W^- \rightarrow q\bar{q}q\bar{q}$

Mark Thomson

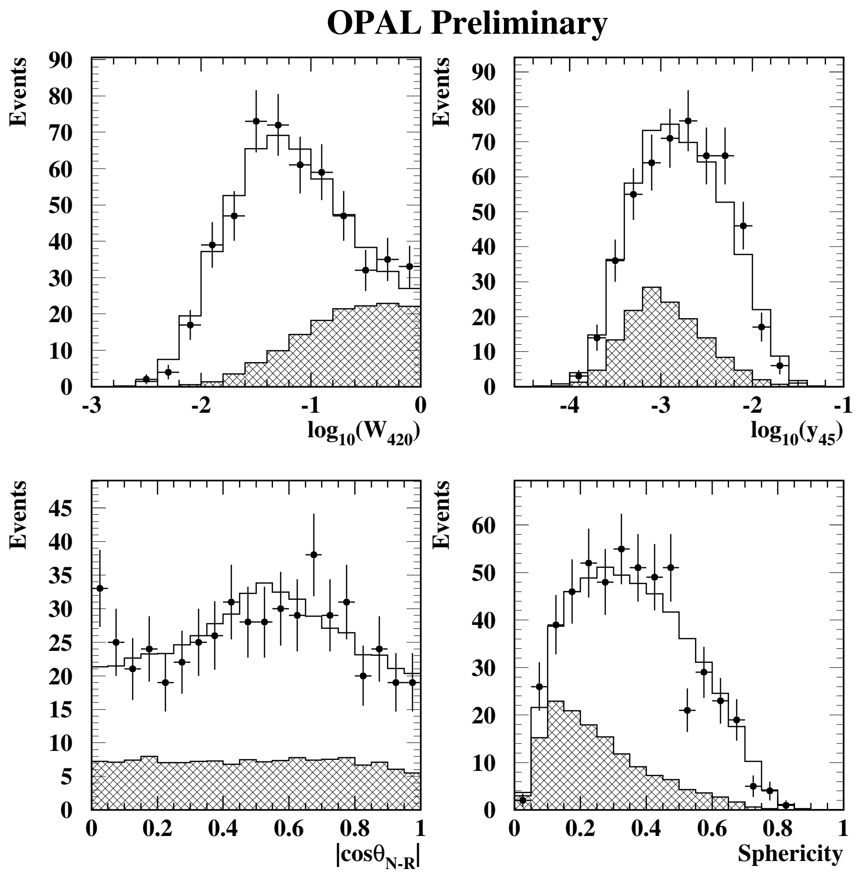
CERN

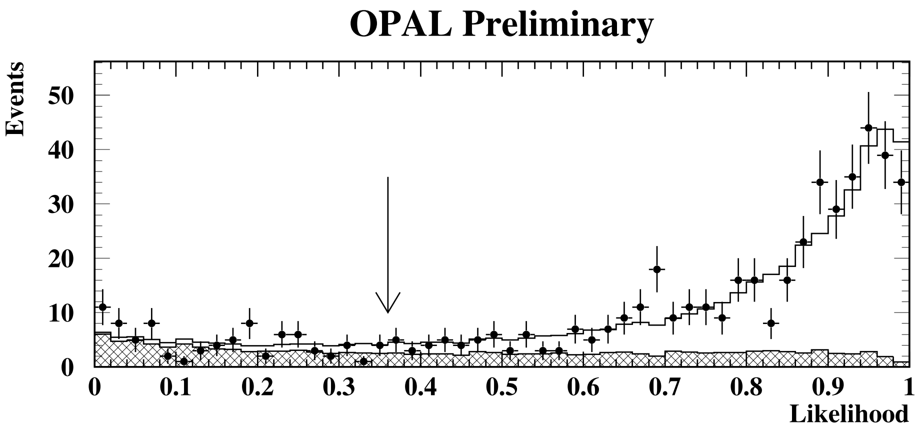


- LEP analysis of $\sim 65\ \mathrm{pb}^{-1}$ at $\sqrt{s} = 172 - 183\ \mathrm{GeV}$

$W^+W^- \rightarrow q\bar{q}q\bar{q}$ Event Selection

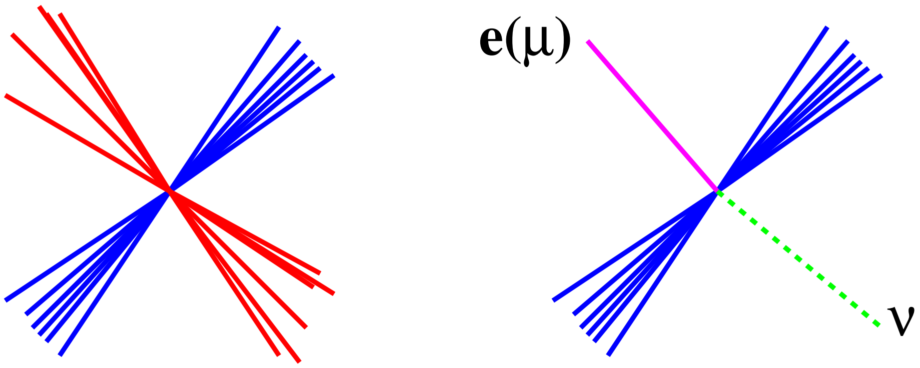
- Multivariate analysis to separate $W^+W^- \rightarrow q\bar{q}q\bar{q}$ and $Z^0/\gamma \rightarrow q\bar{q} \rightarrow$ 4 jets





	Efficiency	Purity
ALEPH	89%	82%
DELPHI	85%	65%
L3	88%	80%
OPAL	85%	79%

$W^+W^- \to q\bar{q}q\bar{q}$ vs. $W^+W^- \to q\bar{q}\ell\bar{\nu}_\ell$



- Comparable Branching Fractions $\sim 46\%$
- Comparable Selection Efficiencies $\sim 85\%$

Advantages :

- Observe all 'fermions' -**no missing energy !**

Disadvantages :

- Ambiguous assignment of tracks to jets
- Ambiguous assignment of jets to W^+W^-
- Higher background (mainly QCD $Z^0/\gamma \to q\bar{q} \to$ **4 jets**)
- Additional systematics

  Colour Reconnection **?**

  Bose-Einstein Correlations **?**

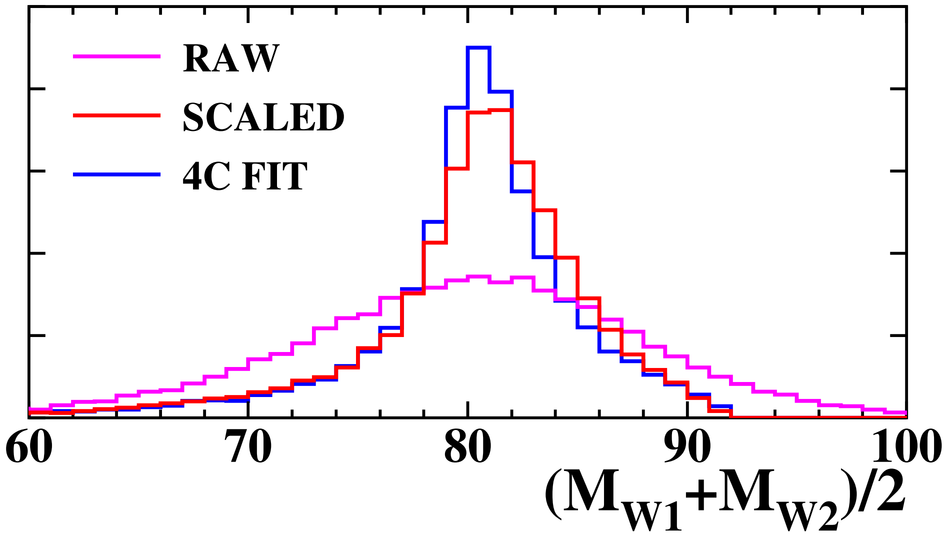
Overall : $\mathbf{W^+W^- \to q\bar{q}q\bar{q}}$ and $\mathbf{W^+W^- \to q\bar{q}\ell\bar{\nu}_\ell}$

give **very similar mass resolution**

Invariant Mass Reconstruction

Possible Methods:

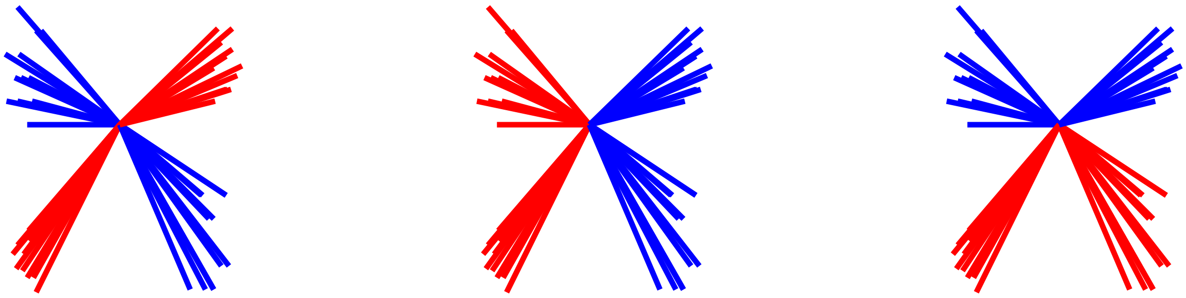
- A) Raw : $M_{q\bar{q}} = \sqrt{2\mathrm{E}_1\mathrm{E}_2}(1 - \cos\theta_{12})$
- B) Scaled : $M'_{q\bar{q}} = M_{q\bar{q}} \frac{\mathrm{E}_{\mathrm{beam}}}{(\mathrm{E}_1+\mathrm{E}_2)}$
- C) **Kinematic fit (4C)** using $(E, \underline{p})$ conservation
- D) **Kinematic fit (5C)** = **4C** + equal mass constraint.



- **As a result of Kinematic fit relatively insensitive to Jet Energies**
- Experimentally **Jet angles** determined better than **jet energies**

Jet-Pairing

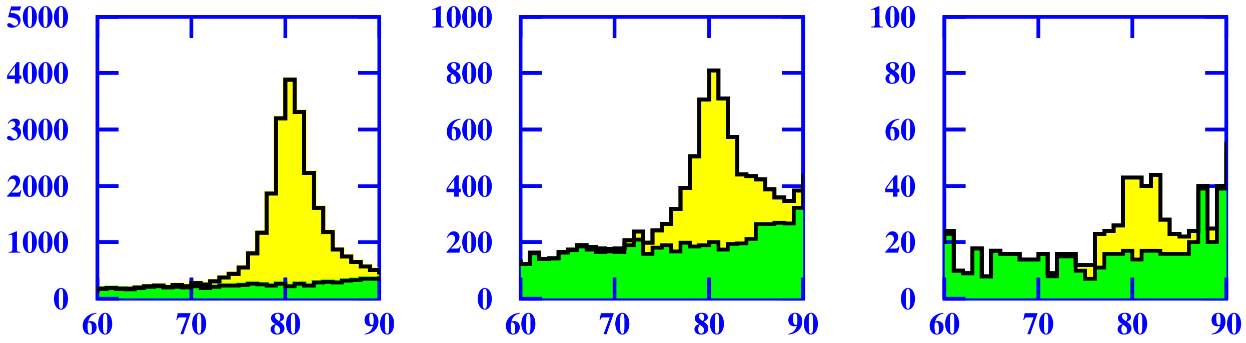
- Events forced to 4 jets (Durham algorithm)
- **3 possible pairings of jets to WW**



- **Incorrect pairing $\Rightarrow$ Combinatoric background**
- **Only Correct pairing contains M_{W} information**

OPAL and L3 use 5C fit probability:

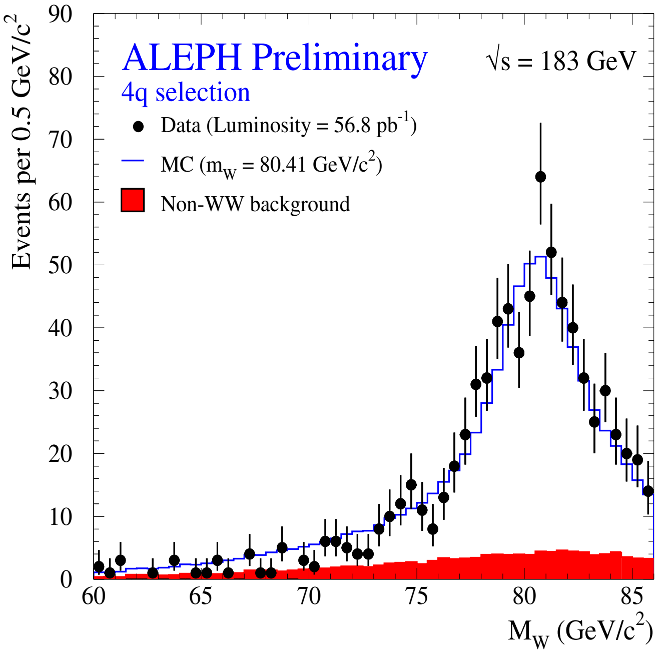
- 5C fit probability = 'consistency of combination with equal mass hypothesis'
- Order by 5C fit probability, $P_1 > P_2 > P_3$

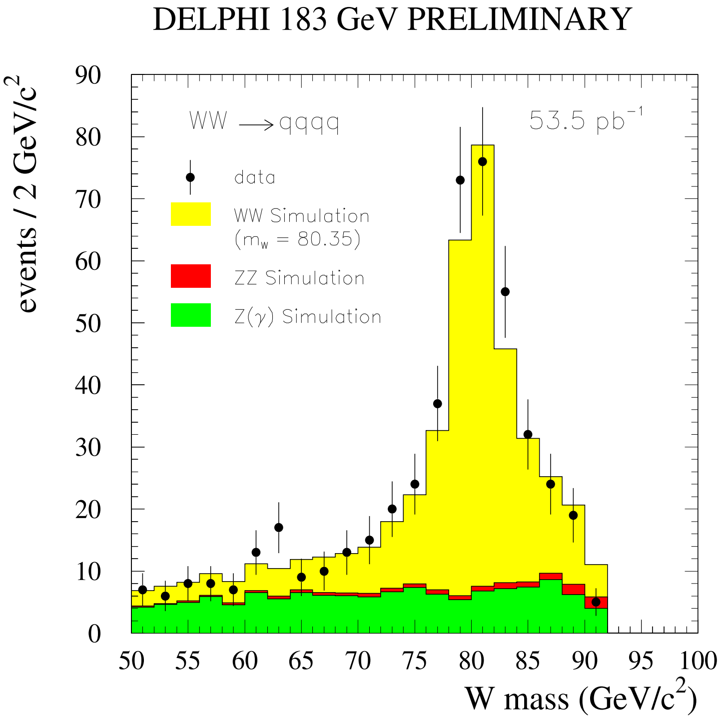


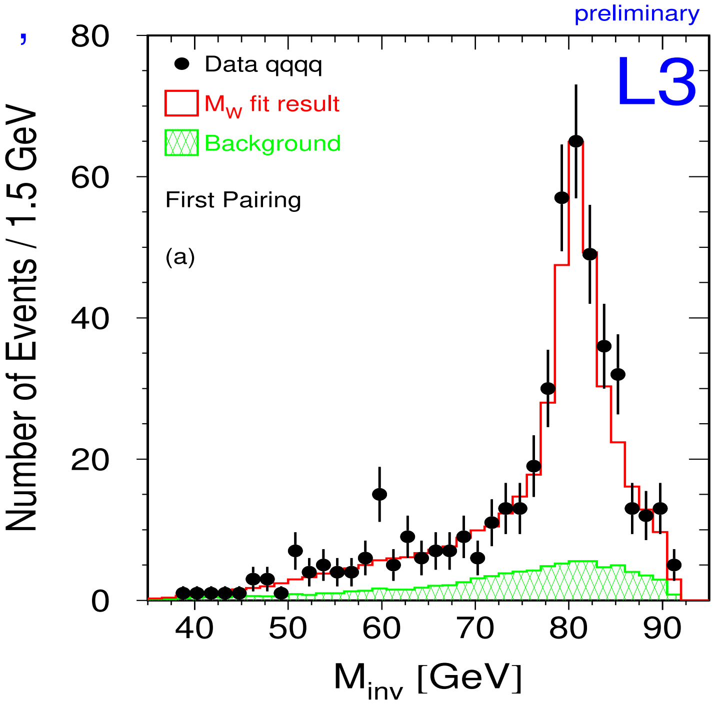
- Use highest prob. fit (correct $\sim 80\%$)
- Also use 2nd best (correct $\sim 15\%$)

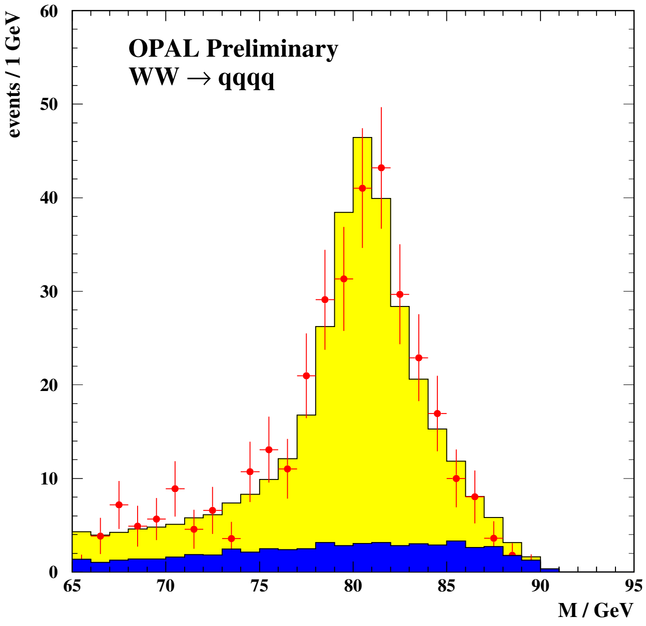
$W^+W^- \rightarrow q\bar{q}q\bar{q}$ Mass distributions

- $W^+W^- \rightarrow q\bar{q}q\bar{q}$ events, $\sqrt{s} = 183$ GeV
- ~300-400 $W^+W^- \rightarrow q\bar{q}q\bar{q}$ candidates/expt.









- **L3 and OPAL : MC reweighting to fit 5C Mass distribution, i.e. 1 mass per jet-pairing**

Mass Fit : ALEPH

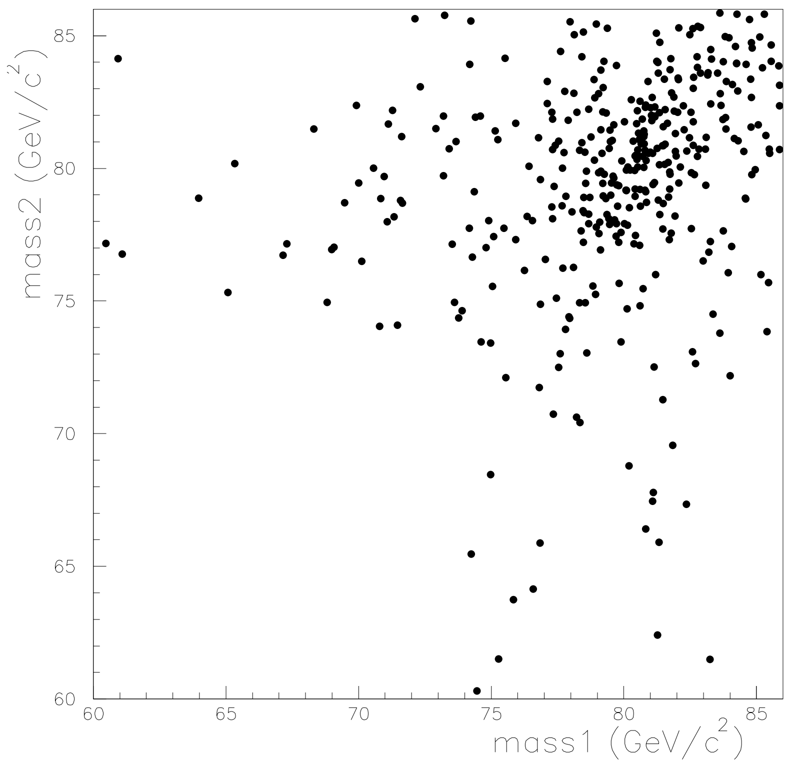
ALEPH also use MC reweighting technique.

- One jet-pairing per event
- But ALEPH fit in 2 dimensions !

Use energy rescaling

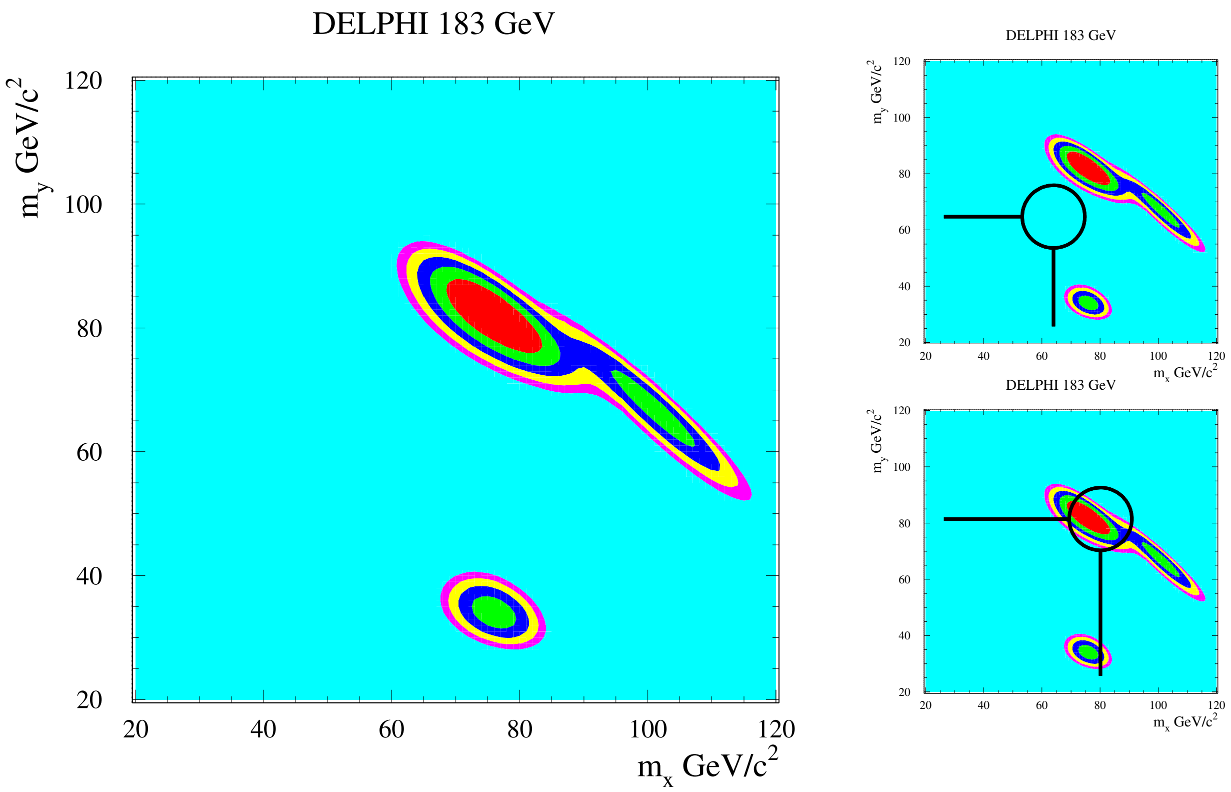
- 4C kinematic fit $\Rightarrow$ 2 mass per event
- **Rescale** fitted masses
- $M_{ij}^{\rm scaled} = M_{ij}^{4C} \frac{\rm E_{beam}}{(\rm E_1 + E_2)}$
- **Use mass difference** $\Rightarrow$ **One jet pairing per event**

Rescaled mass distribution for **ALEPH** 183 GeV data.

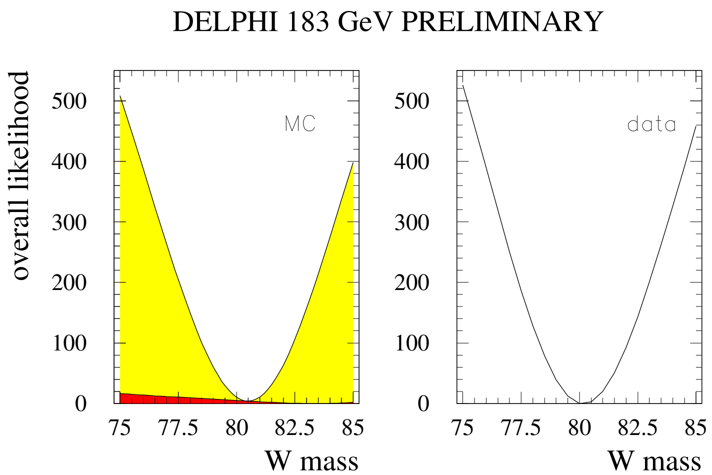


Convolution Method : DELPHI

- Use 4C fit ⇒ 2 masses for each jet pairing
- ⇒ event PDF (3 jet pairings used !)
- calculate overlap integral of event PDF with a 2D Breit-Wigner, $\mathcal{BW}(M_{\mathrm{W}})$ ⇒ event likelihood, $\mathcal{L}(M_{\mathrm{W}})$



- Sum likelihood for all events.
- $\mathcal{L}(M_{\mathrm{W}}) = \sum_i \mathrm{PDF}_i \otimes \mathcal{BW}(M_{\mathrm{W}})$



Systematic Uncertainties

All those of $\mathrm{W^+W^-} \rightarrow \mathrm{q\overline{q}}\ell\overline{\nu}_\ell$ plus a few of its own....

Typical Systematic Errors

Source	ΔM_{W} (MeV)
Detector calibration	**30**
QCD background	**10**
MC statistics	**10**
Hadronization	**30**
Initial state radiation	**15**
Beam energy	**25**
Final State Interactions	**90**
Total	**110**

Largest sys. $\Rightarrow$ Final State Interactions

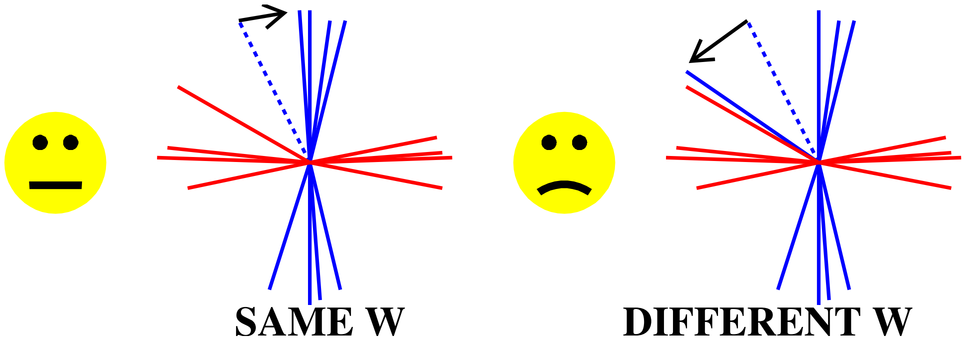
- W decay $<$ **0.1 fm**
- Hadronization scale $\sim$ **1.0 fm**
- $\Rightarrow$ **Non-independent fragmentation ?**
- If not independent $\Rightarrow$ mass shifts can occur
- Standard MCs $\Rightarrow$ **independent fragmentation** for the two W bosons in $\mathrm{W^+W^-} \rightarrow \mathrm{q\overline{q}q\overline{q}}$

FSI systematic not relevant to $\mathrm{W^+W^-} \rightarrow \mathrm{q\overline{q}}\ell\overline{\nu}_\ell$

Final State Interactions

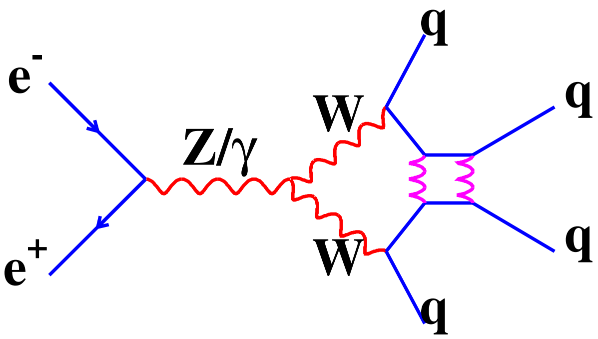
Bose-Einstein Correlations (R.Moller's talk)

- BEC - Quantum mechanical effect
- Like sign pions tend to be produced close in phase space
- **BEC between pions from different Ws ?**



Colour Reconnection (N.Watson's talk)

Perturbative phase (QCD)



- Suppressed by 2 gluon exchange + colour
- Negligible mass shifts < 10 MeV

Hadronization phase (non-pertubative)

- Rely on models (string, cluster...)
- **Mass bias ? : Predictions from 0-300 MeV**

Systematic Error from FSI

Compare mass from $W^+W^- \rightarrow q\overline{q}\ell\overline{\nu}_\ell$ and $W^+W^- \rightarrow q\overline{q}q\overline{q}$ (4 expts.)

$$M_W^{q\overline{q}q\overline{q}} = 80.39 \pm 0.10\,\mathrm{GeV} \quad (\mathrm{stat.only})$$
$$M_W^{q\overline{q}\ell\overline{\nu}_\ell} = 80.31 \pm 0.10\,\mathrm{GeV} \quad (\mathrm{stat.only})$$

- No evidence of Mass bias in $W^+W^- \rightarrow q\overline{q}q\overline{q}$.
- But can't use this $\Rightarrow$ systematic error.

Sys. Errors estimated by comparing Models

Some typical values:

Model	Effect	Mass shift
Herwig	CR	$\sim$ 10-30 MeV
Pythia	CR	$\sim$ 20-50 MeV
Ariadne	CR	$\sim$ 50-150 MeV
VNI***	CR	$\sim$??? MeV
Pythia	BE	$\sim$ 20-50 MeV
KoralW	BE	$\sim$ 20-50 MeV

Currently assign 90 MeV systematic due to FSI

*** The current implementation of the VNI model (Ellis/Geiger) does not reproduce the particle momentum distributions seen in the data $\Rightarrow$ not used for systematic

M_{W} from $\mathbf{W^+W^-} \to \mathbf{q\bar{q}q\bar{q}}$: Results

Results from 172 + 183 GeV $\mathbf{W^+W^-} \to \mathbf{q\bar{q}q\bar{q}}$

- all 183 GeV results : **PRELIMINARY**
- Only ALEPH use final LEP energies for 189 GeV data

		stat.	sys.	FSI	$\mathrm{E_{beam}}$
ALEPH	80.53	$\pm\ 0.017$	± 0.05	$\pm\ 0.05$	$\pm\ 0.02$
DELPHI	80.01	$\pm\ 0.019$	± 0.04	$\pm\ 0.10$	$\pm\ 0.03$
L3	80.59	$\pm\ 0.019$	± 0.08	$\pm\ 0.10$	$\pm\ 0.03$
OPAL	80.40	$\pm\ 0.020$	± 0.08	$\pm\ 0.10$	$\pm\ 0.03$
COMBINED	80.39	$\pm\ 0.093$	± 0.05	$\pm\ 0.09$	$\pm\ 0.03$

Correlated systematic errors :

- Assume **100 %** correlated systematic of **90 MeV** from FSI
- and **40 MeV** common systematic from **hadronization and ISR**

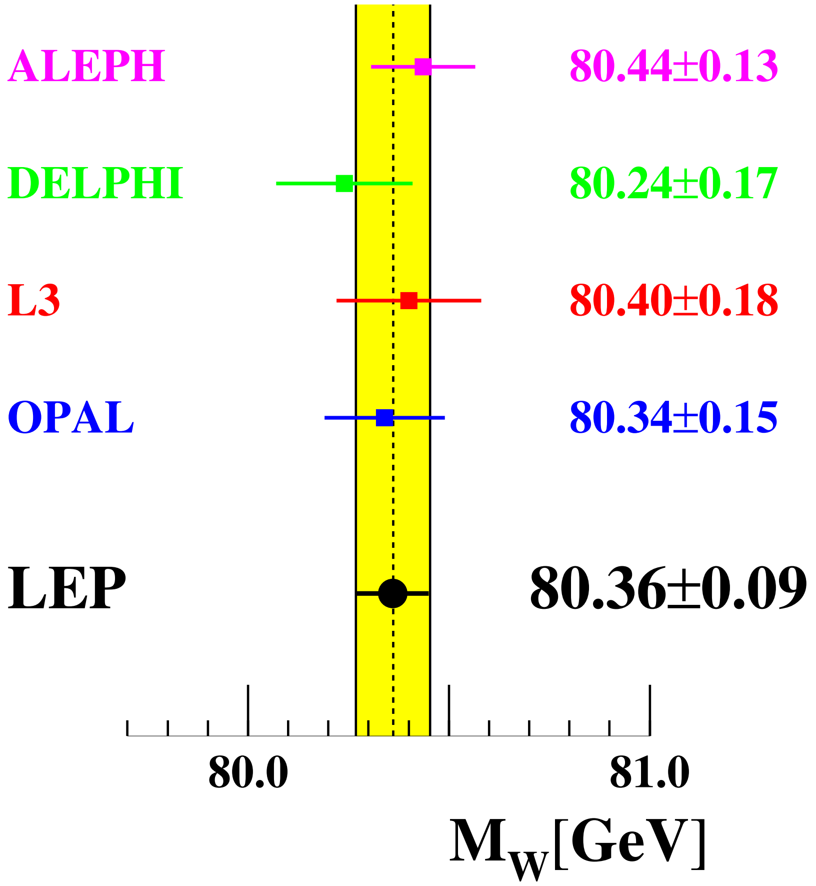
Combine with mass from $\mathbf{W^+W^-} \to \mathbf{q\bar{q}\ell\bar{\nu}_\ell}$ (H.Prsysiezniak's talk)

Combining $W^+W^- \to q\bar{q}q\bar{q}$ and $W^+W^- \to q\bar{q}\ell\overline{\nu}_\ell$

LEP result from Direct Reconstruction:

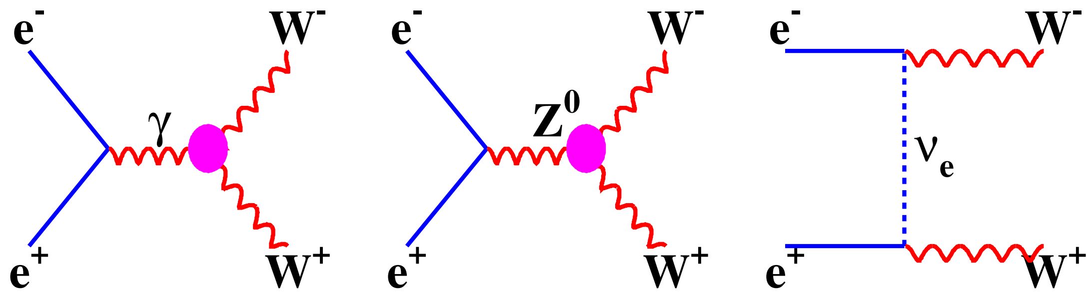
- Combine $W^+W^- \to q\bar{q}q\bar{q}$ and $W^+W^- \to q\bar{q}\ell\overline{\nu}_\ell$
- **Statistical errors similar**
- **Correlated** : ISR, Beam Energy

(183 GeV results all preliminary)

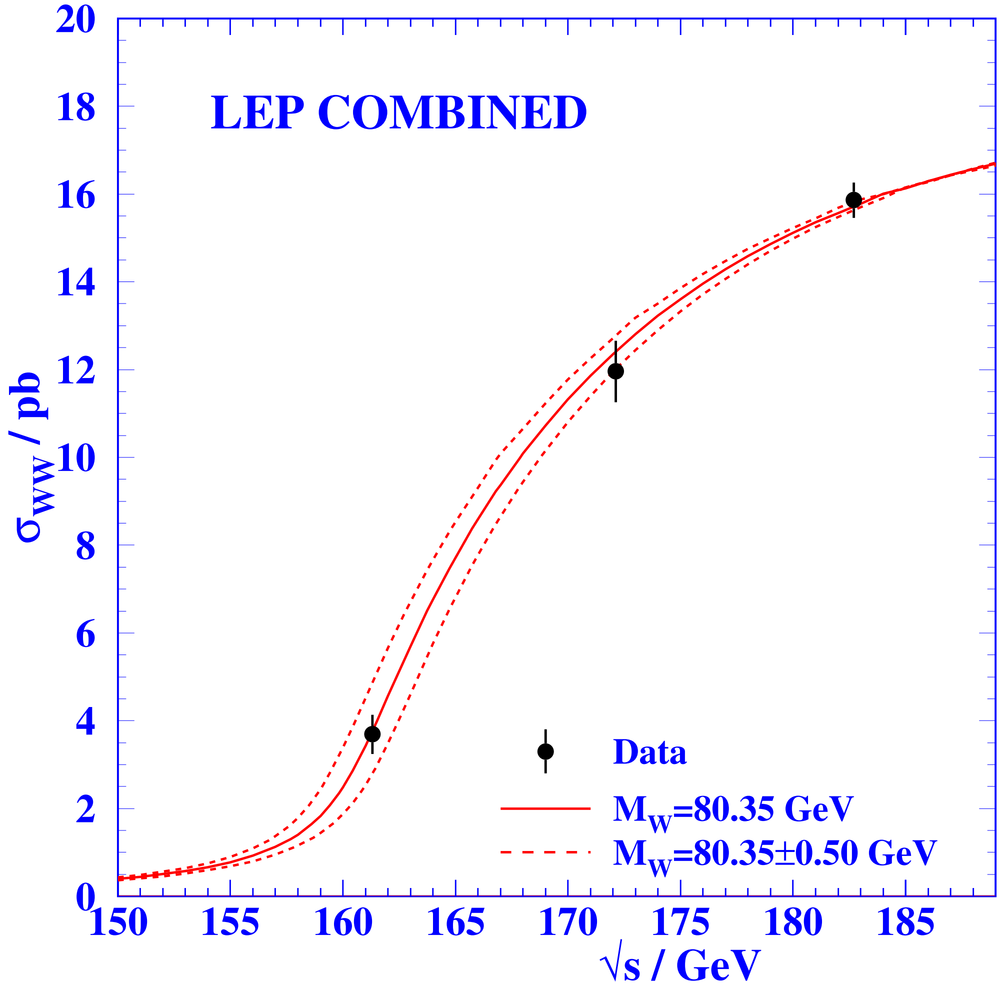


+ LEP M_W from threshold cross section !

Cross Section



- Measure CC03 WW production cross section
- At threshold: sensitive to M_W



M_W from cross section (10 pb^{-1} at 161 GeV)

$$M_W{}^{\text{threshold}} = 80.40 \pm 0.22\ \text{GeV}$$

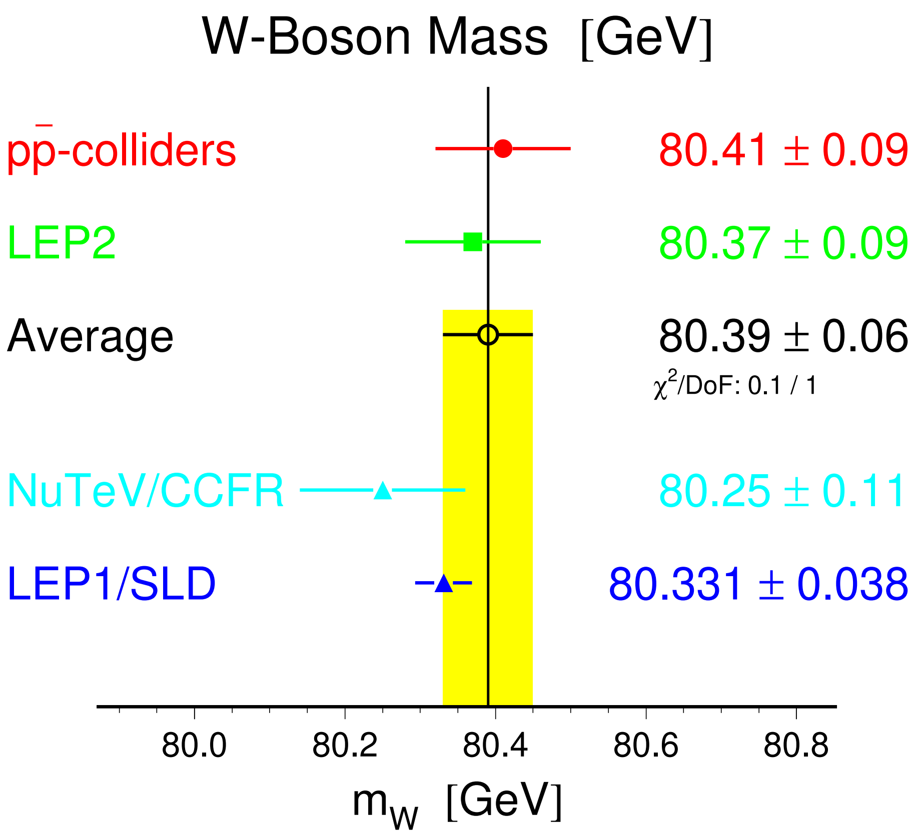
Combined Result

Combined M_W from

- **cross section @ 161 GeV**
  80.40 ± 0.22 GeV
- **direct reconstruction @ 172-183 GeV**
  80.36 ± 0.09 GeV

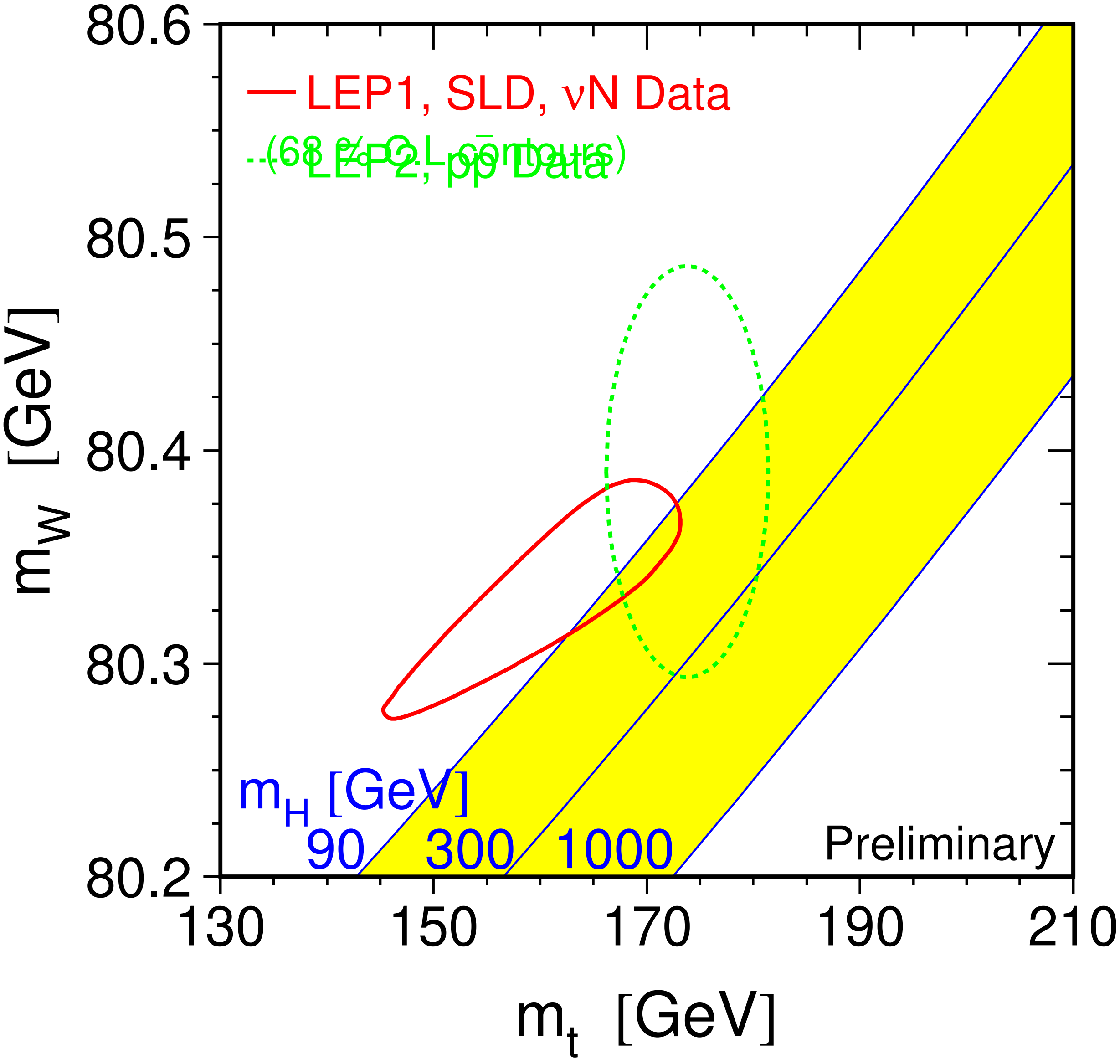
M_W(LEP) = 80.37 $\pm$0.07(experimental)
$\pm$0.04(FSI)$\pm$0.02 (E_{beam}) GeV

- LEP and TeVatron : $\Delta(M_W) \sim$ 90 MeV



Direct vs. Indirect

- **DIRECT : measurements of $M_{\mathbf{W}}$ and $M_{\mathbf{top}}$ from TeVatron and LEP**
- **INDIRECT : Electroweak data *excluding* direct measurements of $M_{\mathbf{W}}$ and $M_{\mathbf{top}}$**



Direct measurements of $(M_{\mathbf{W}}, M_{\mathbf{top}})$ + $(\mathrm{M_Z}, \mathrm{G}_\mu, \alpha)$:

- $\mathbf{m_{Higgs}} = \mathbf{80^{+160}_{-70}\,GeV}$

Conclusions

LEP 2 results $\Rightarrow$ M_{W} to 90 MeV

LEP 2 target luminosity, $\sim 500\mathrm{pb}^{-1} \Rightarrow$

- **Stat. Err. on M_{W} ~35 MeV from $\mathrm{W^+W^-} \rightarrow \mathrm{q\overline{q}}\ell\overline{\nu}_\ell$**
- **Stat. Err. on M_{W} ~35 MeV from $\mathrm{W^+W^-} \rightarrow \mathrm{q\overline{q}q\overline{q}}$**

Need to understand Colour Recon. and BEC !

This year : LEP 189 GeV run, 200 pb^{-1}/expt.

- This time next year :

$$M_{\mathrm{W}} = 80.xxx \pm 0.040(stat.)$$

- A lot of work needed to understand systematics