W mass measurement at LEP

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(On behalf of ALEPH,DELPHI,L3 and OPAL Collaborations)

XXXIIst Rencontres de Moriond,
QCD and Hadronic interactions
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Contents

Introduction

LEP2 started in 1996 at sqrt(s)=161 GeV

W pair-production threshold ~ 160 GeV

---->First WW events are observed in e+e- collisions

Int. L ~ 10 pb^{-1}/ exp.

In autmun, sqrt(s)=172 GeV

Int. L ~ 10 pb^{-1}/ exp.

In 1997, sqrt(s)=183 GeV

Int. L ~ 55 pb^{-1}/ exp.

In 1998, sqrt(s)=189 GeV

Int. L ~ 175 pb^{-1}/ exp.

In 1998, sqrt(s)=192, 196, 200 GeV ?

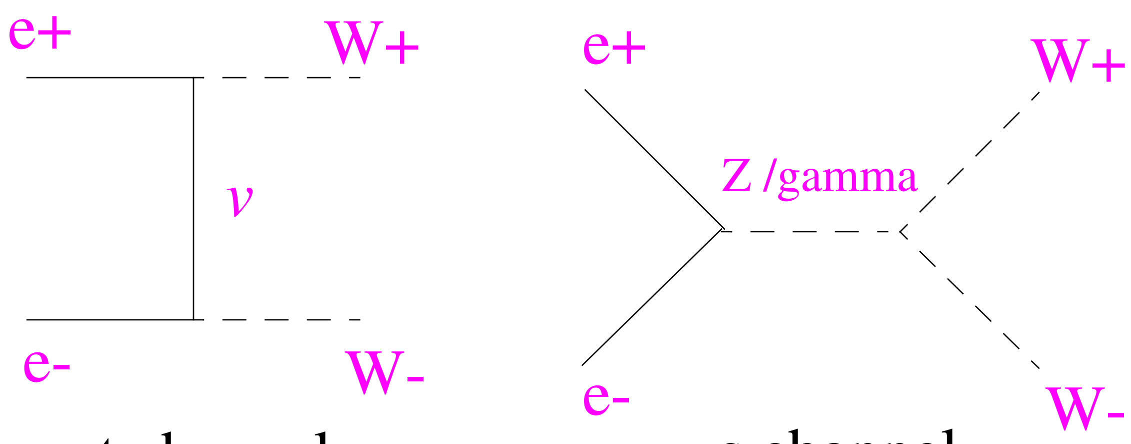
(Not official statement.)

Int. L ~ 25 pb-1/exp. at 192 GeV ?

Int. L ~40 pb-1/exp. at 196 GeV ?

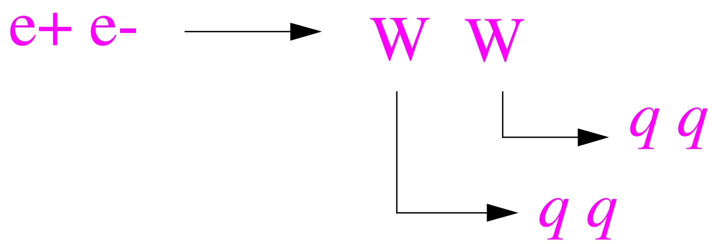
Int. L. ~100 pb-1/exp. at 200 GeV ?

CC03 diagram

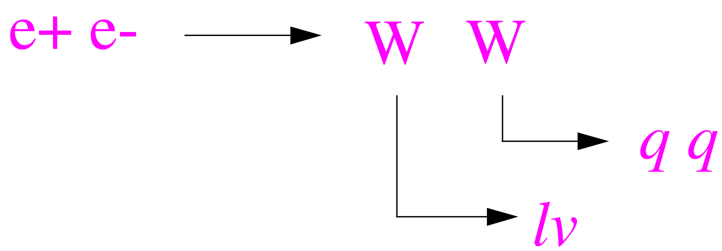


t channel s channel

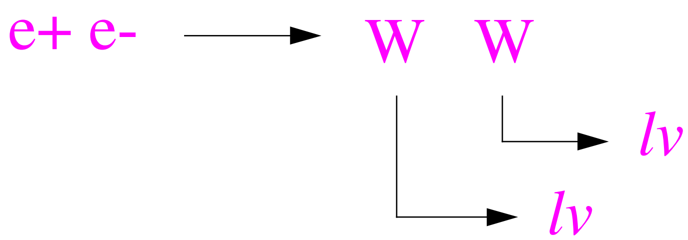
1. *qqqq* channel (46 %)



2. *qqlv* channel (44 %)

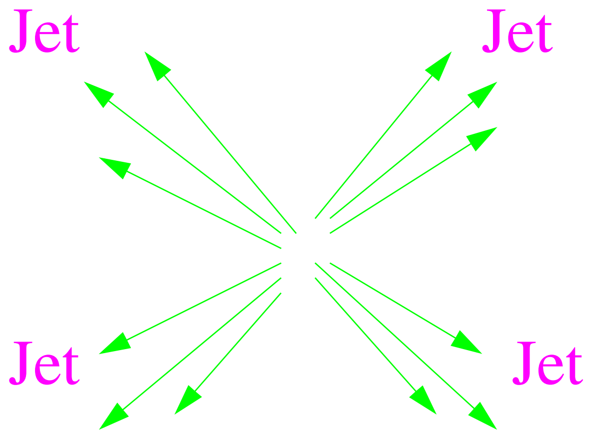


3. *lvlv* channel (10%)



Event Topology

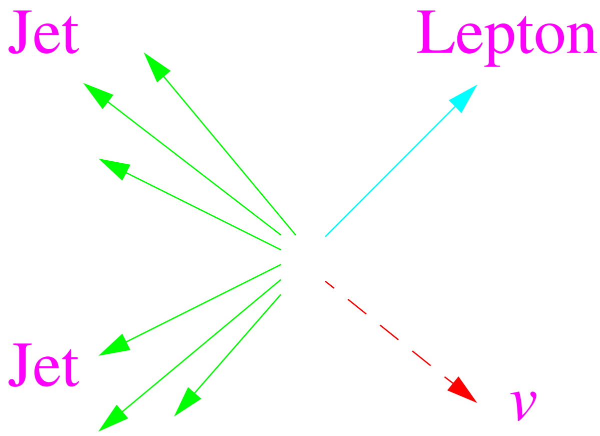
1 qqqq channel



4 jets
(well balanced)

Total E = sqrt(s)

2 qqlv channel

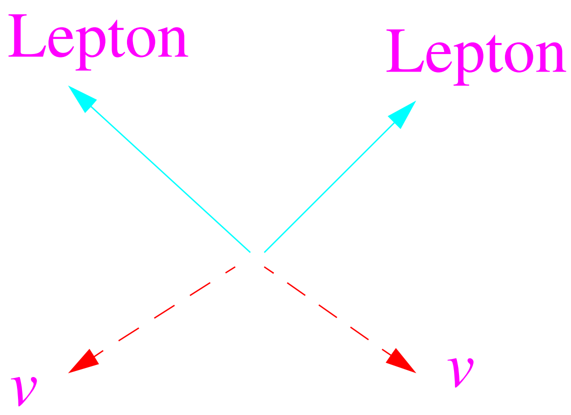


2 jets

1 energetic lepton
(well isolated)

Missing (E ,P)

3 lvlv channel



2 energetic leptons
(Acoplanar)

Missing (E ,P)

Selection

1. qqqq channel

Main Background Z/gamma ---> *qq*

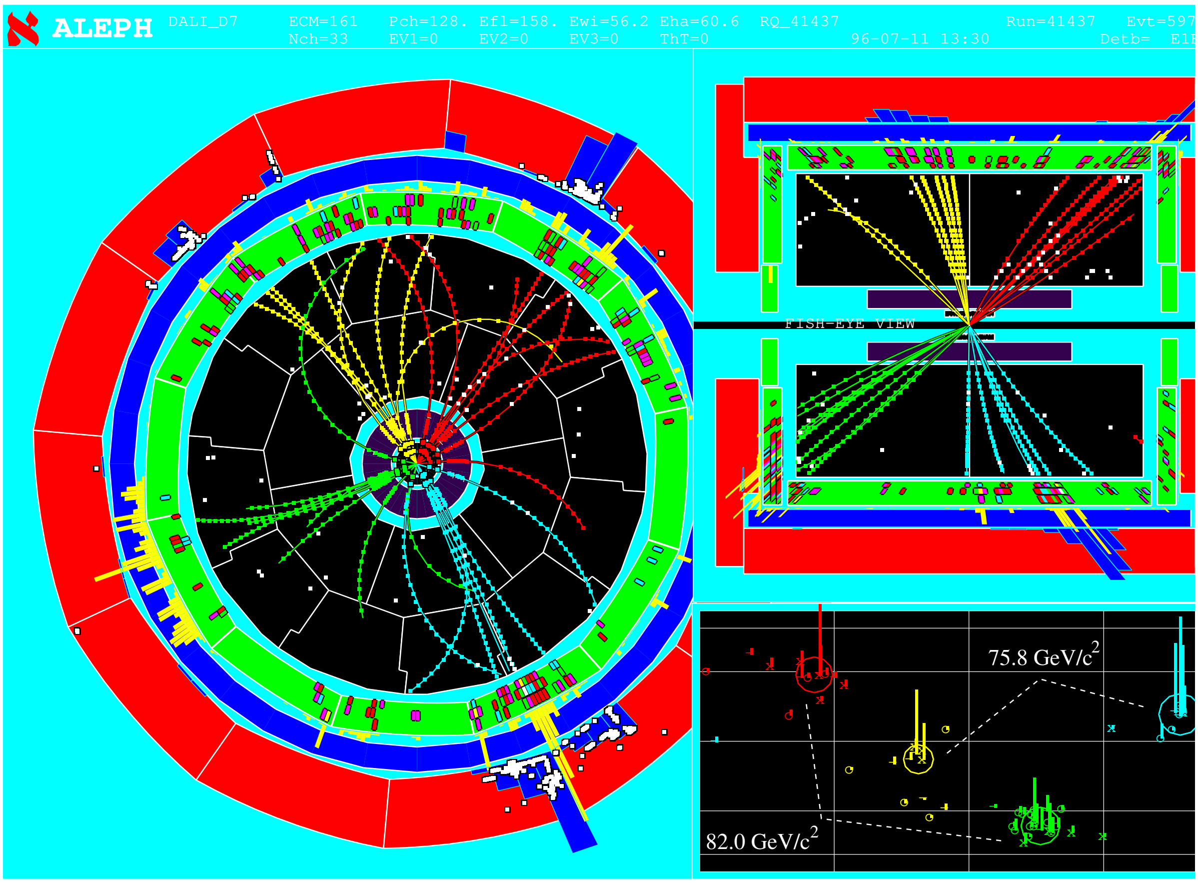
Two order of magnitude larger than for the signal(161GeV)
Order of magnitude larger than for the signal(High E)

sqrt(s') cut, E_gamma cut .... ===> Preselection

Other Background ===> LH, NN selection.

qqlv, (Z/gamma)(Z/gamma), QCD(qqgg...)

ZZ BG at ECM>182 GeV



2. qqlv channel

Main Background Z/gamma ---> *qq*

(Misidentification of ISR photon as a lepton)

Other Background : four-fermion process

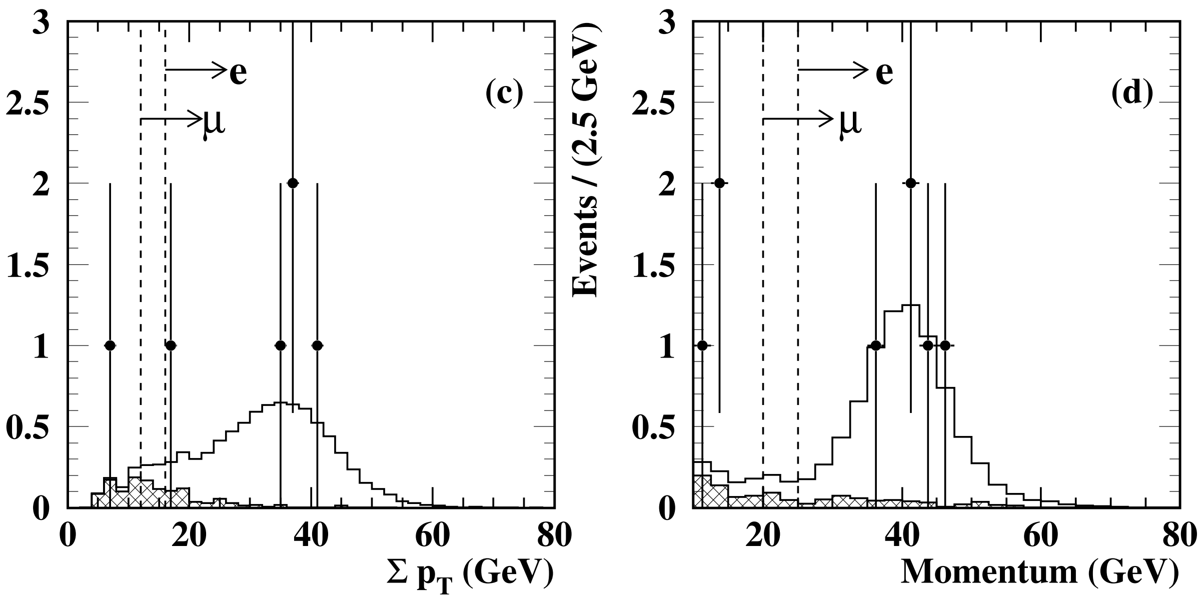
Z0 e+e-, W ev, ZZ ---> 2 jets and 1 id-lepton

OPAL at 161 GeV

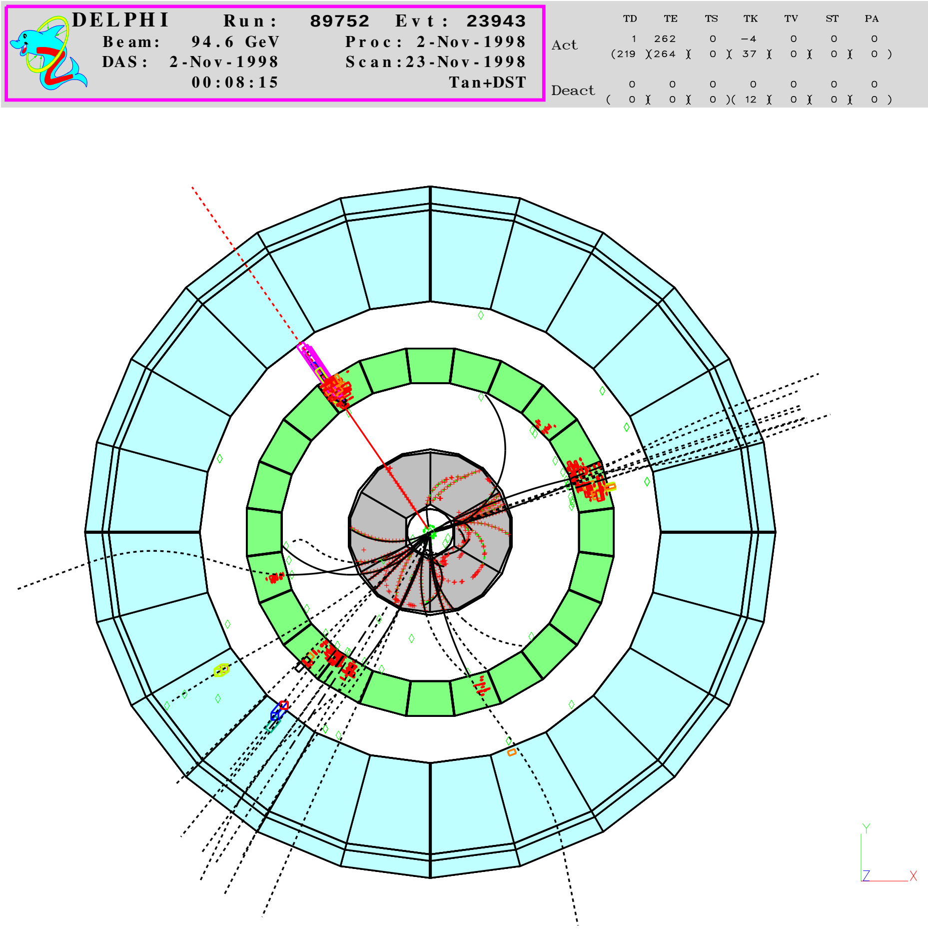
Lepton ID : E > 25 GeV (e), p > 20 GeV (muon)

Well isolated (200 mrad cone)

Large missing p, off beam direction

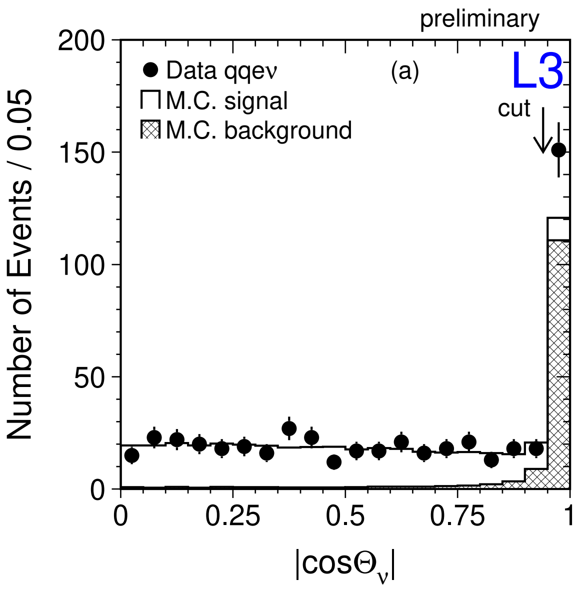


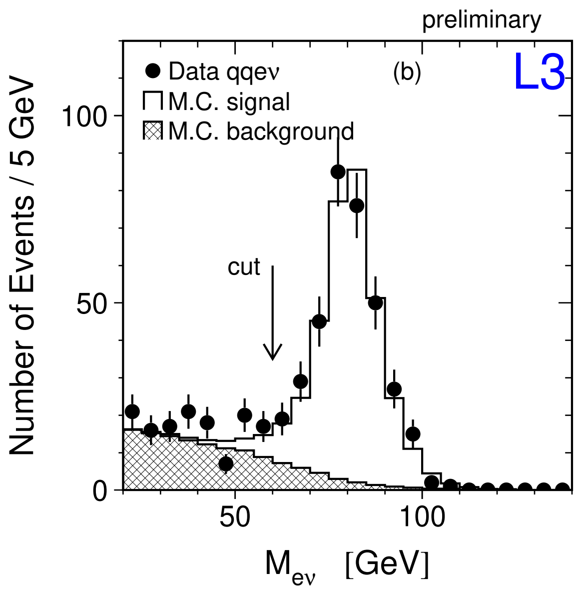
DELPHI WW --> qqev event at 189 GeV



L3 selection at 189 GeV

qqev channel:





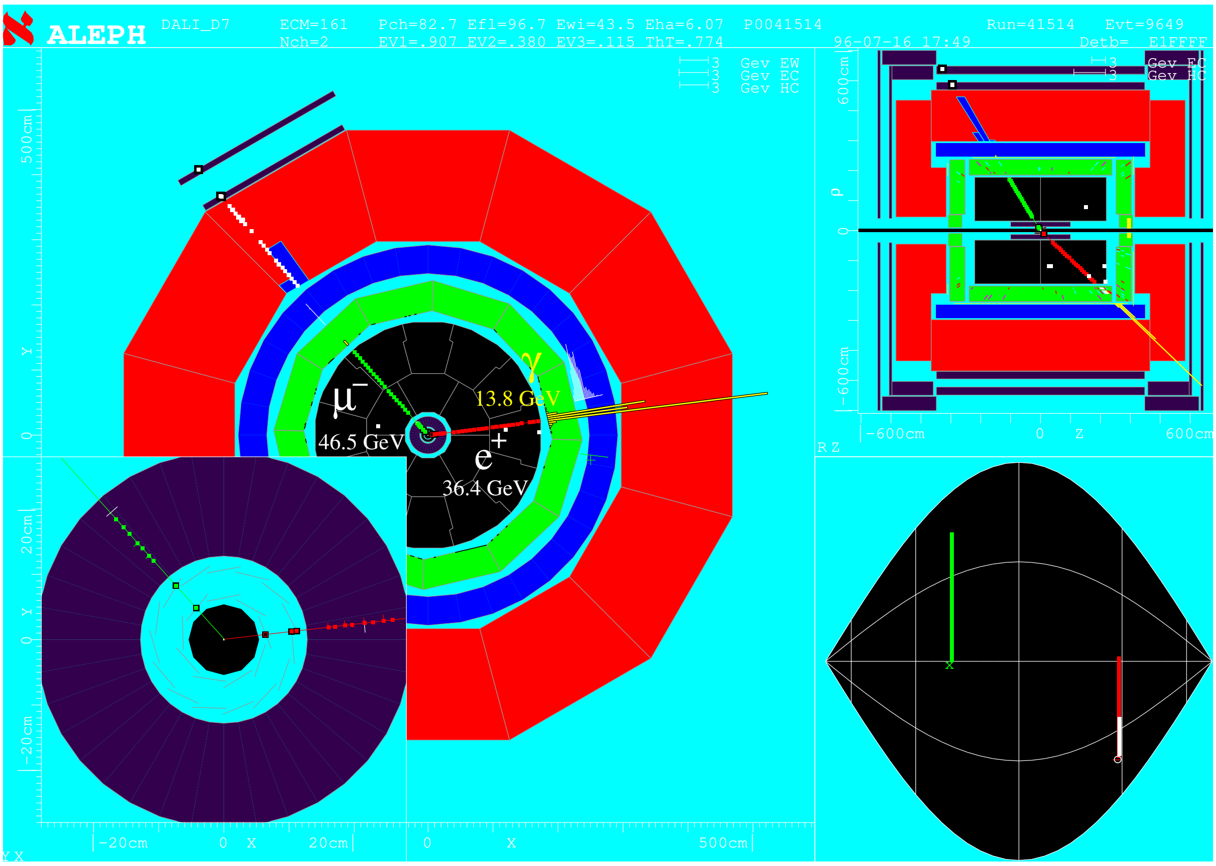
Polar angle of ν

(e,ν) invariant mass

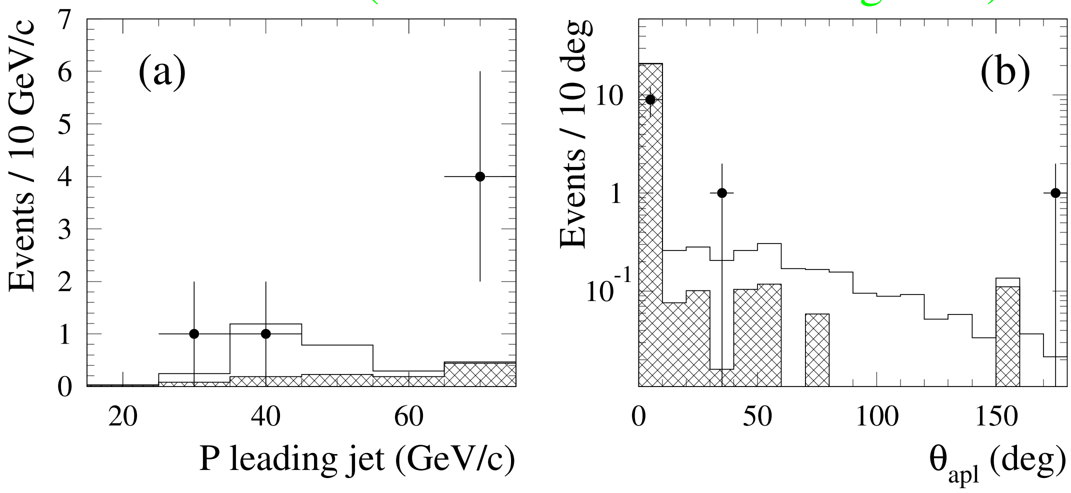
3. *lvlv* channel

Main Background is e+e- ---> *Z* gamma, Bhabha scattering, and two-photon events

APLEPH



DELPHI at 161 GeV (--> Scale cut-values at higher E)



All particles were clustered into 2 jets

Table 1: Efficiency and Number of Events
161 GeV (OPAL)

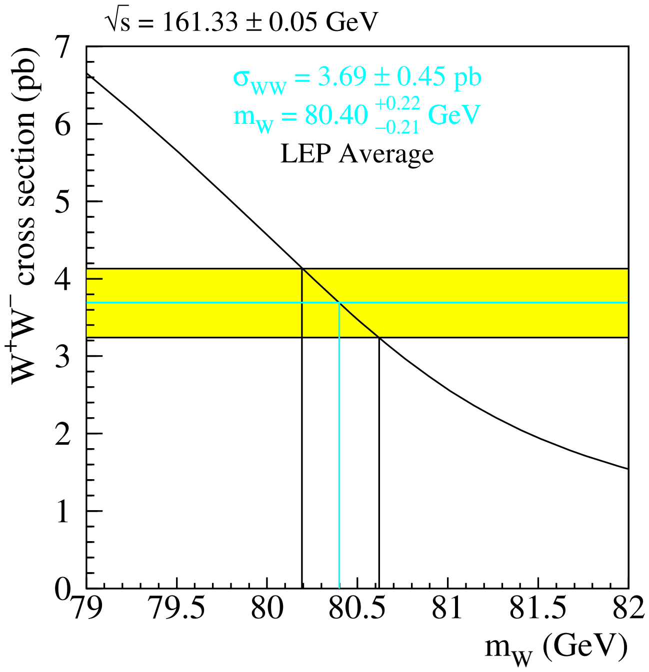
	Eff. (%)	Expected signal	Expected BG	Obs
qqqq	56.7	9.6 +- 1.0	3.44 +- 0.39	14
qqev	71.4	3.89 +- 0.44	0.18 +- 0.27	3
qqmv	76.9	4.19 +- 0.46	0.27 +- 0.15	2
qqtv	42.5	2.32 +- 0.28	0.96 +- 0.34	7
lvlv	65.4	2.58 +- 0.28	0.19 + 0.12 - 0.04	2

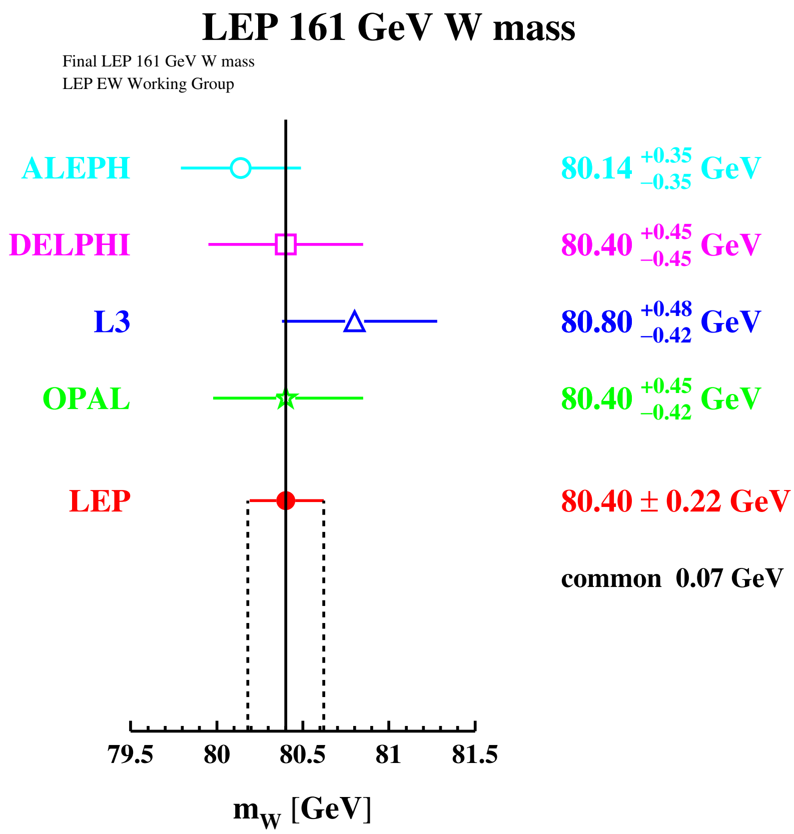
Table 2: Number of events at 161 GeV

	qqlv	lvlv	qqqq	Total
ALEPH	16	6	16	38
DELPHI	12	2	15	29
L3	11	2	9	22
OPAL	12	2	14	28
Total	51	12	54	117

Extraction of W Mass

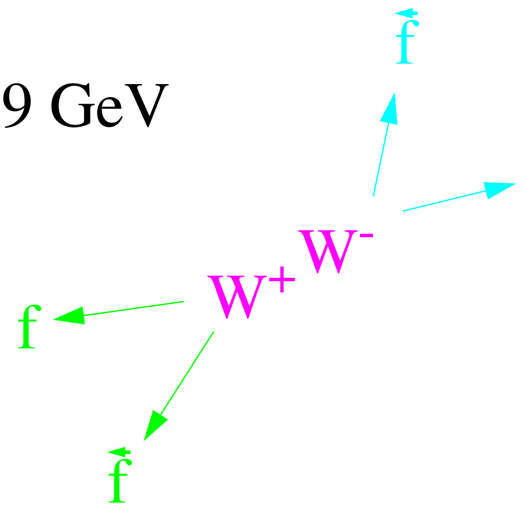
m_W from σ_{WW} at 161 GeV





Mw mesurement by direct reconstruction

172 - 189 GeV



Invariant mass of the $f\bar{f}$ / $f\bar{f}$ is reconstructed

ff=qq ---> (E,P) of each jet

ff=lv ----> (E,P) of a lepton

Error on (E,P) are estimated.

Input

Kinematic fit with constrains

- (E, P) conservation (4C fit)
- \+ Equal mass on WW (5C fit)
- or E-beam rescaling on 2-jet system

improves mass resolution

Output

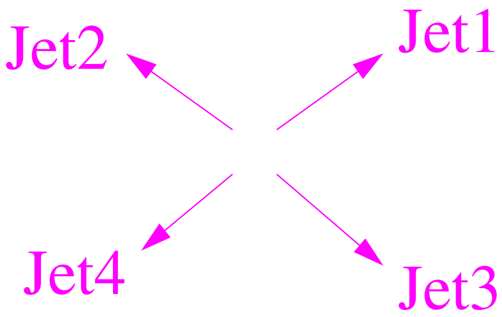
Reconstructed M_{inv}, event by event

==> 5C fit yields one M_{inv} / event

4C fit yields two M_{inv}'s / event

Combinatorial Background in qqqq channel

Jet-pairing combination --> multiple solutions



3 combinations for 4 jets

But only one correct combination has Mw info.

ALEPH

Use two Minv's for a combination choosen by min(Minv1-Minv2)+not min[sum(di-jet angle)].

DELPHI

Uses two Minv's for each of all combinations, and gluon radiation probability for 5 jets.

L3

Use one Minv for eahc of two combinations choosen by kinematic fit probability ordering.

OPAL

Use one Minv for a combination choosen by LH jet-pairing method.

Additional selection
in direct reconstruction Mw measurement

$$\Delta M_W \sim \frac{1}{\sqrt{\text{Efficiency}}} \times \frac{1}{\sqrt{\text{Purity}}}$$

Mass window cut, Kine-fit prob. cut
Jet-pairing selection
to reject combinatorial BG in 4q ch.....etc.

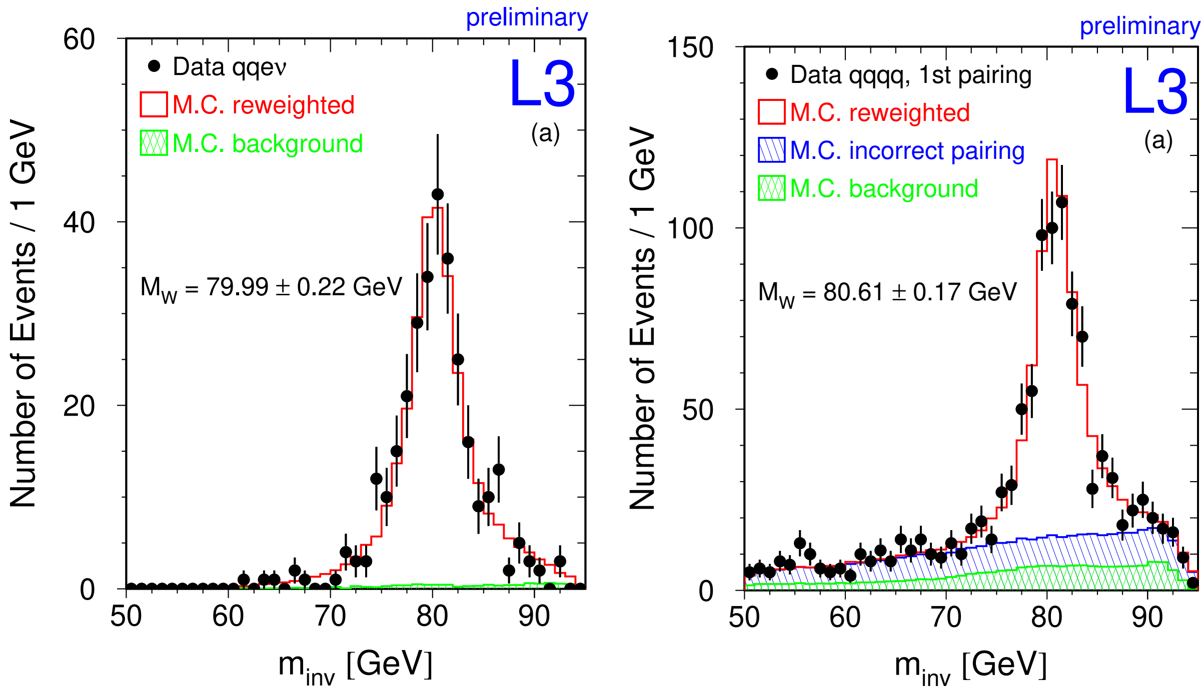
Selection Efficiency and Purity at 189 GeV

Table 3: ALEPH

	Effi (%)	Purity	Exp. # evt	Obs. # evt
qqqq	71.4	84.7	1173	1068
qqev	81.3	92.7	371	358
qqmv	84.1	96.6	365	363
qqtv	41.5	95.4	176	159

Nww = Sigma(WW) x Lumi
At 172 GeV Nww ~ 0.5 K evts (4exp.)
At 183 GeV Nww ~ 3.5 K evts (4exp.)
At 189 GeV Nww ~ 11 K evts (4exp.)
===> In total
15 K x R(4q+qqln) x Eff WW events
are used in the analysis (R(4q+qqln)=0.9)

Two Fitting Methods



1)Reweighting Method (ALEPH, L3, OPAL)

Generating MC samples with various Mw's

↓

Reweight these samples to

Minv histograms of arbitrary Mw (and Gw)

↓

Fit the Minv histogram of DATA

to reweighted histogram

↓

Find best matching Mw (and Gw)

(Assumeing all info. are in MC ==> no bias.)

2)Comvolution Method(BWxPS modeling)

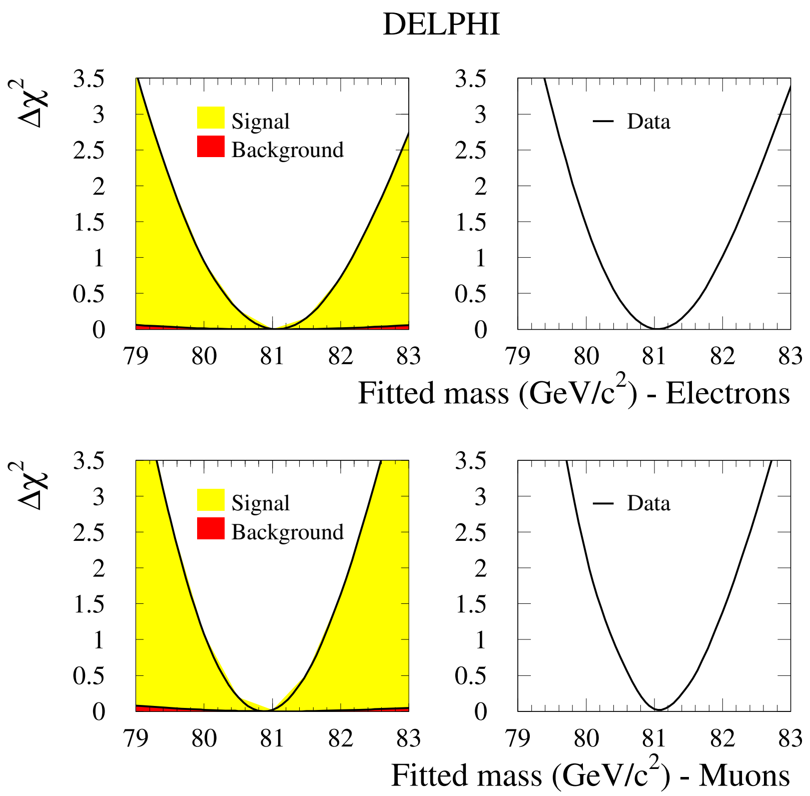
DELPHI

Event by Event Likelihood L_e(Mw) ,

$$L_e(\mathrm{Mw}) =$$

$$\int\left(\sum_i p_i(\mathrm{Minv})\cdot(P\cdot S(\mathrm{Minv}|\mathrm{Mw})+(1-P)B(\mathrm{Minv}))\right)d\mathrm{Minv}$$

includes detector resolution, BWxPS, purity,BG,all jet-pairings in 4q ch.....



Expected LH curve (MC) LH curve (DATA event)

$$\Delta\chi^2(\mathrm{Mw}) =$$

$$\sum_e(-2\cdot\ln(Le(\mathrm{Mw})))-\sum_e(-2\cdot\ln(Le(\mathrm{Mw\ max})))$$

LEP Mw results at 189 GeV

qqlv channel:

	Mw +/- (stat.) +/- (syst.) GeV	expected stat.
ALEPH	80.406 +/- 0.114 +/- 0.033	0.111
DELPHI	80.163 +/- 0.174 +/- 0.067	
L3	80.12 +/- 0.14 +/- 0.08	0.13
OPAL	80.366 +/- 0.111 +/- 0.055	0.108

qqqq channel:

	Mw +/- (stat.) +/- (syst.) GeV	expected stat.
ALEPH	80.561 +/- 0.116 +/- 0.077	0.101
DELPHI	80.467 +/- 0.110 +/- 0.067	
L3	80.62 +/- 0.13 +/- 0.12	0.12
OPAL	80.315 +/- 0.112 +/- 0.093	0.102

DELPHI and OPAL Mw results at 189 GeV
were approved on last Tuesday (23Mar99)

LEP Average of Mw (direct reconstruction)

	Mw +/- (stat.) +/- (syst.) +/- (FSI) +/- (LEP)	DATA
Official	80.368 +/- 0.044 +/- 0.039 +/- 0.023 +/- 0.018	A+L 172-189 GeV D+O 172-183 GeV
Private	80.347 +/- 0.036 +/- 0.033 +/- 0.020 +/- 0.017	A+D+L+O 172-189 GeV

Systematics

OPAL Systematic Errors at 183 GeV

Systematic errors (MeV)	qqqq	qqlv	Combined
Beam Energy	22	22	22
ISR	10	10	10
Hadronization	21	21	16
Four-fermion	30	28	21
Detector Effects	38	31	26
Fit Procedure	15	15	15
Background	25	10	10
MC statistics	15	15	11
Sub-total	67	58	53
Bose-Einstein	32	0	11
Colour Reconnection	49	0	16
Total	89	58	53

Beam Energy

==> Delta Mw (delta Ebeam = +/- 25 MeV)

ISR/Hadronization/Four-fermion errors

==> Limited by statistics of MC's.

Detector Effects

==> Smearing (E,P) and its resolution.
Compare DATA v. MC to determine Smearing.

Fit Procedure

==> ECM reweighting uncertainty.

Background

==> Background shapes and normalization.

MC statistics

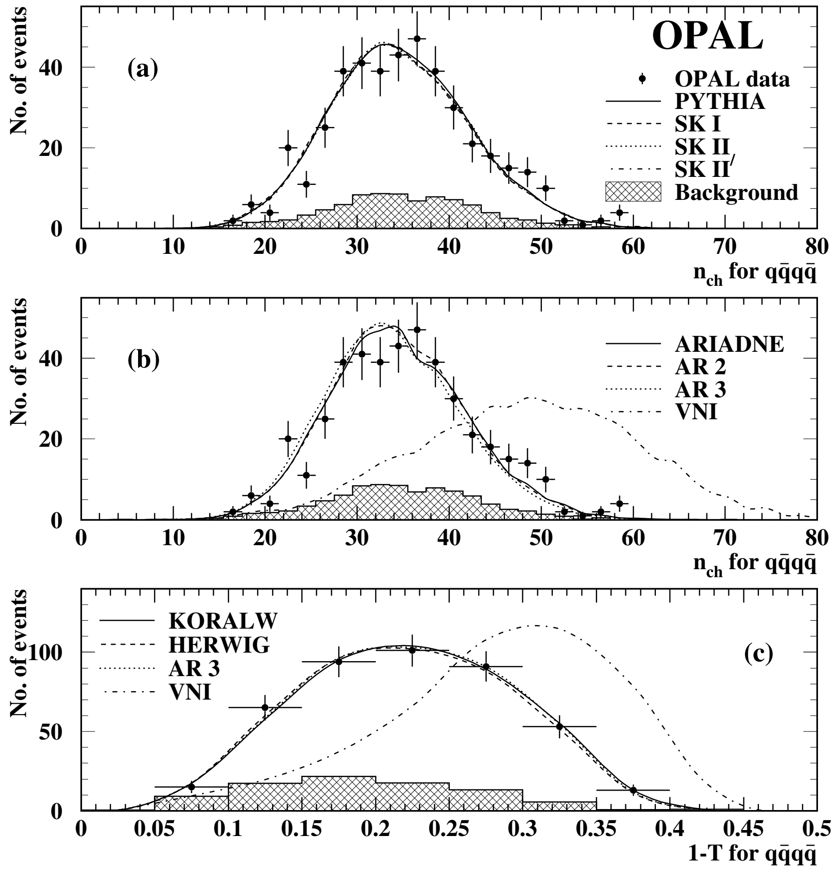
==> Statistical uncertainty of MC samples used in the reweighting method.

Bose-Einstein Correlation

1) Effects are only in 4q channel.
2) BE correlations between decay products from differnct W's might distort the Minv spectra.
3)Comparison
MC without BE vs. MC with BE
(statisticaly limited.)

Colour Reconnection

1) Effects are only in 4q channel.
2) Normal MC fragments only within each W.
3) Fragmentation between two W's might distort the Mrec spectra.
4) Various CR models implemented in MC are checked using 183 GeV DATA.
(=>ARIADNE 3 model disfavoured.)
==> Ellis-Geiger model VNI excluded.



5)ARIADNE 2 model is used to assign systematic error for CR.

ALEPH extracted Mw from W-->lv decays at 183 GeV

$$E_l = \frac{\sqrt{s}}{4} + \cos\theta_l^* \cdot \sqrt{\frac{s}{16} - \frac{Mw^2}{4}}$$

E_l = Lepton Energy

$\cos\theta_l^*$ = Angle between lepton direction in W rest frame and W flight direction in laboratory frame

E_l is sensitive to Mw

lvlv channel : E_l^{max}, E_l^{min} and E_{miss}

qqlv channel : E_l, E_ν and M^{rec}_{lv}

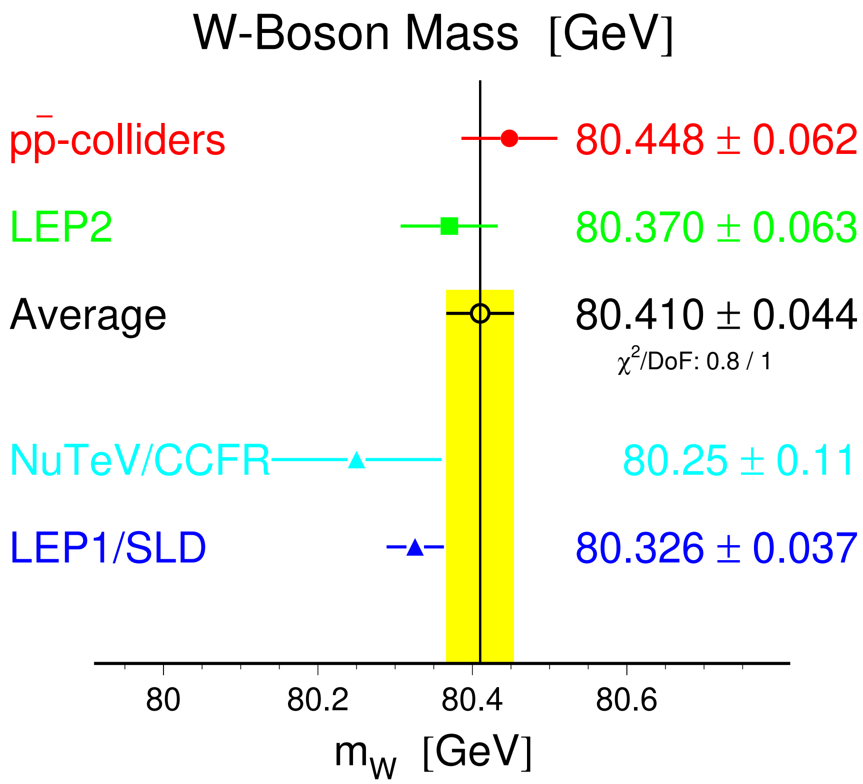
are fitted with reweighting technique.

DATA : L=57 pb-1 at 183 GeV

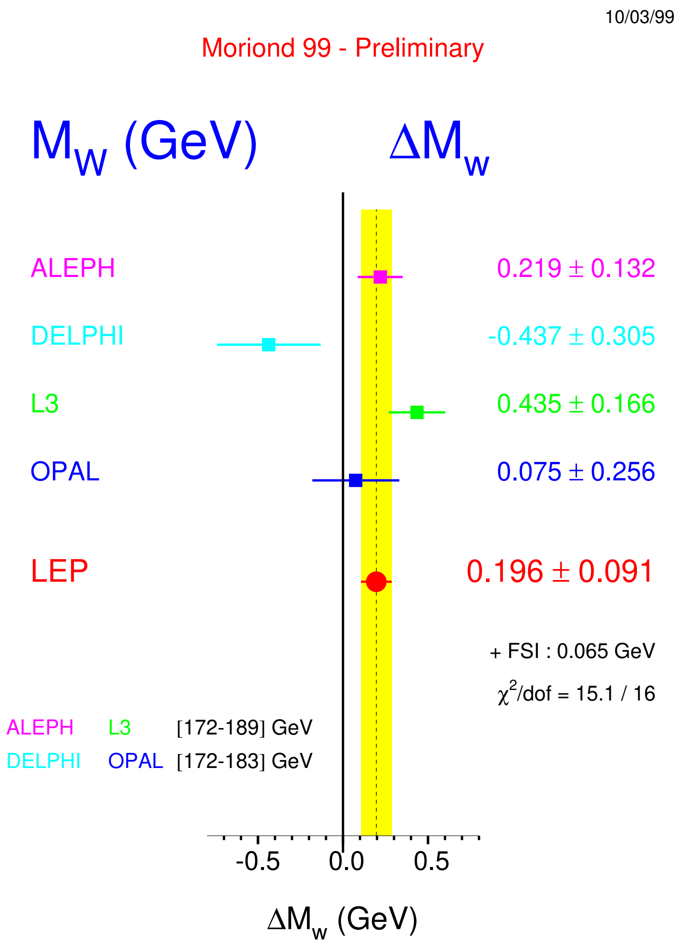
Channel	Mw +/- (stat.) +/- (syst.) GeV
lvlv	80.291 +/- 0.526 +/- 0.090
qqlv	80.119 +/- 0.207 +/- 0.089
combination	80.142 +/- 0.192 +/- 0.089

Results

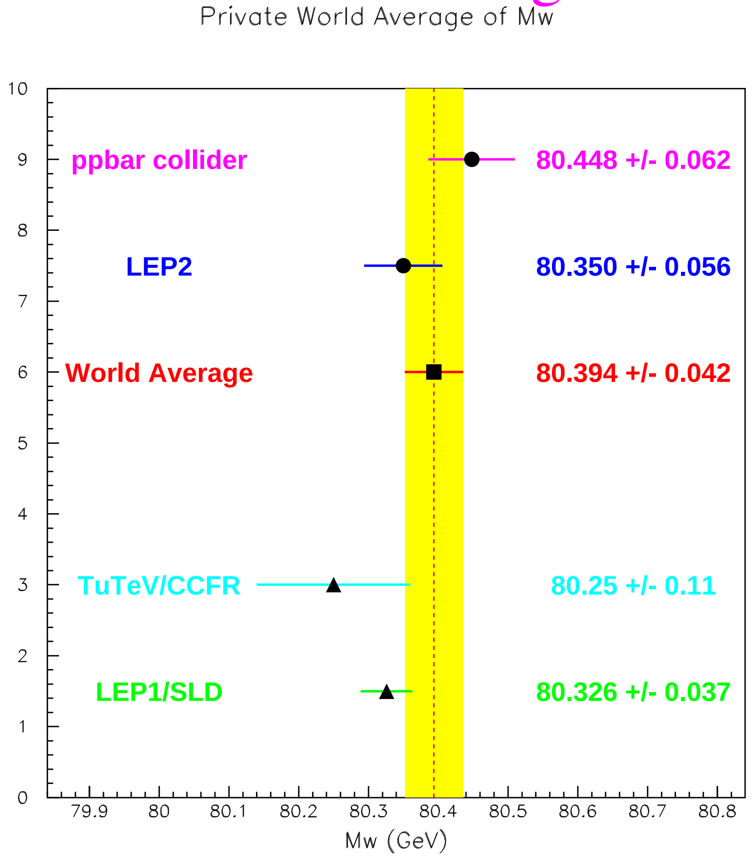
Official World Average of Mw



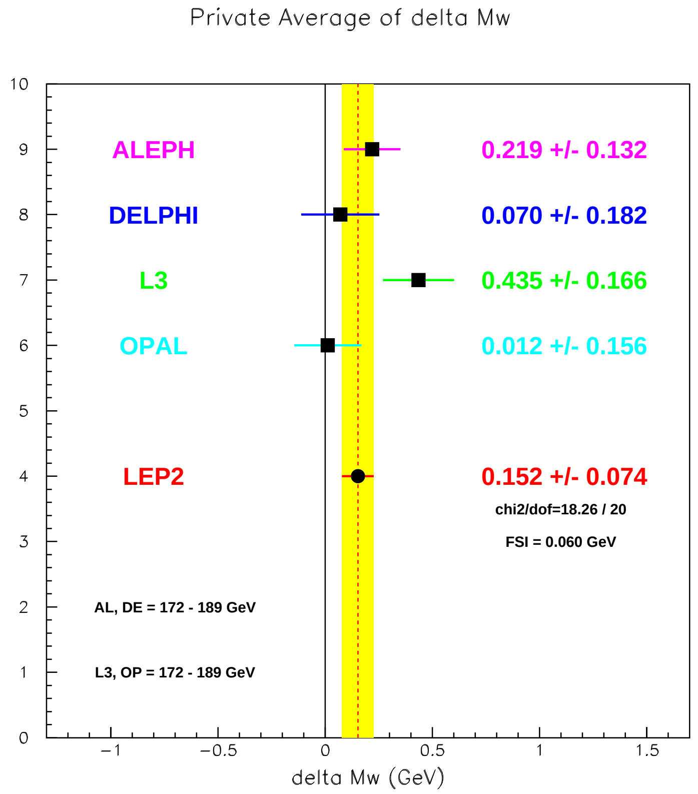
Official Average of Delta Mw (4q-qqlv)

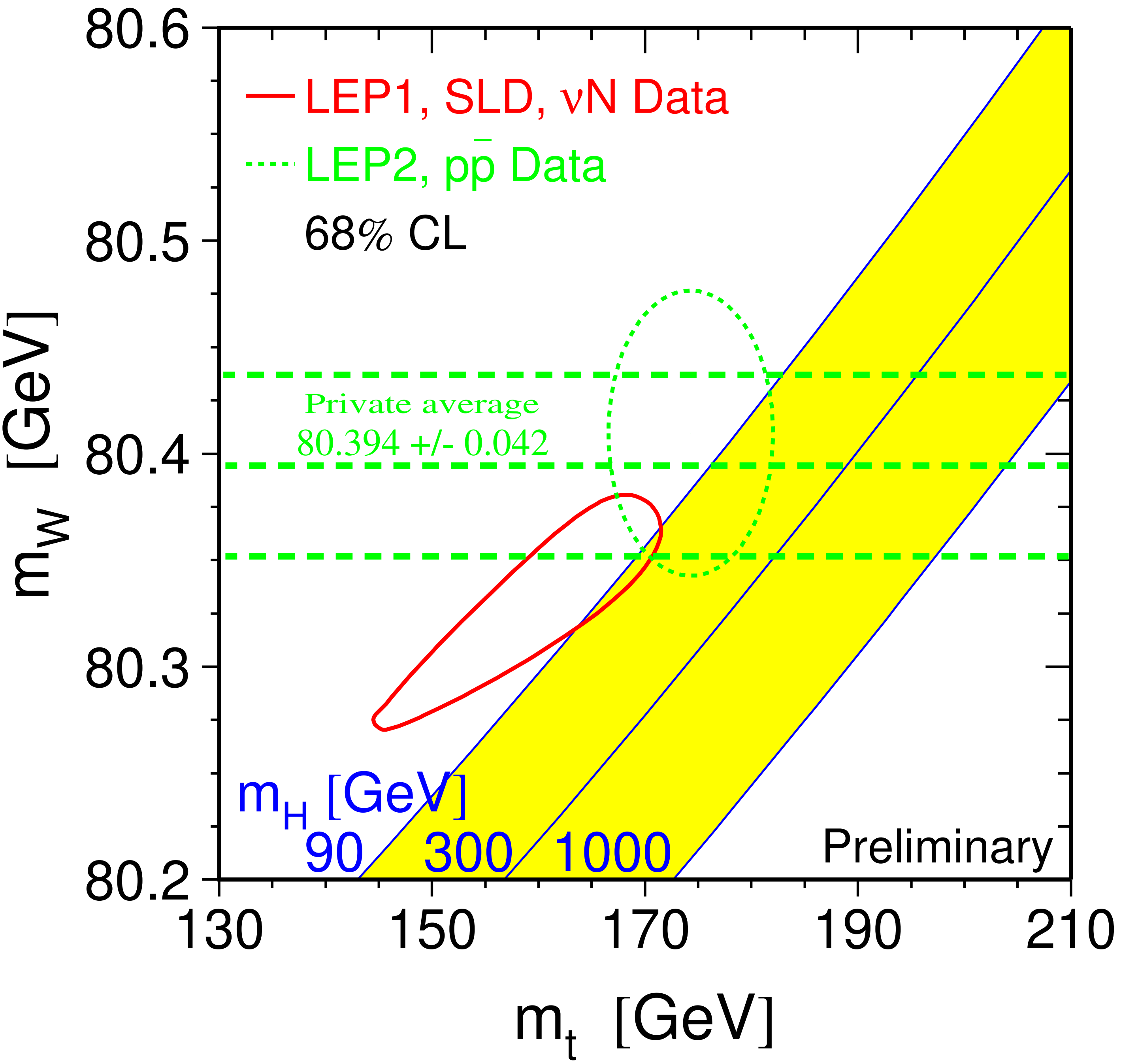


Private World Average of Mw



Private Average of Delta Mw (4q - qqlv)





80.6
80.5
80.4
80.3
80.2
130
150
170
190
210
m_W [GeV]
m_t [GeV]
LEP1, SLD, νN Data
LEP2, $p\bar{p}$ Data
68% CL
Private average
80.394 +/- 0.042
m_H [GeV]
90
300
1000
Preliminary

Conclusion

1) LEP 4 exp. (ADLO) collected data successfully at ECM of 161-189 GeV.

2) Official LEP2 average of Mw

(A+L 172 - 189 GeV, D+O 172 - 183 GeV)

Mw = 80.368 +/- 0.044(stat) +/- 0.039(syst.) +/-0.023(FSI) +/- 0.018(LEP) GeV

Combined with 161 GeV data.

Mw = 80.370 +/- 0.063 GeV

3) Private LEP2 average of Mw

(A+D+L+O 172 - 189 GeV)

Mw = 80.350 +/- 0.036(stat) +/- 0.033(syst.) +/-0.020(FSI) +/- 0.017(LEP) GeV

Combined with 161 GeV data.

Mw = 80.350 +/- 0.056 GeV

4) Statistical error < Systematic error

Need more studies on systematic errors.

(BE cor., CR effect, LEP E beam, detector effects ....)

Utilizing W --> lv decay is also useful.