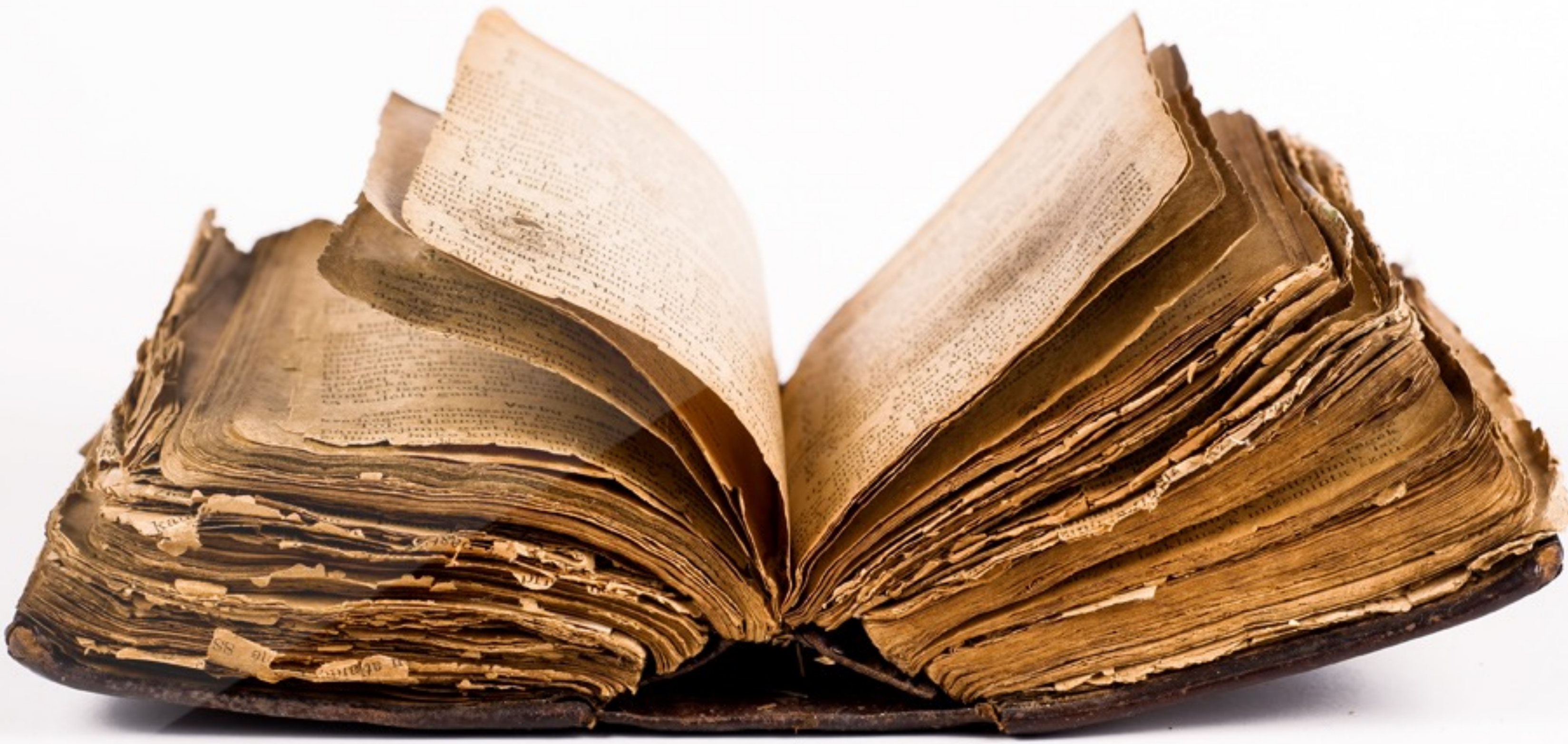
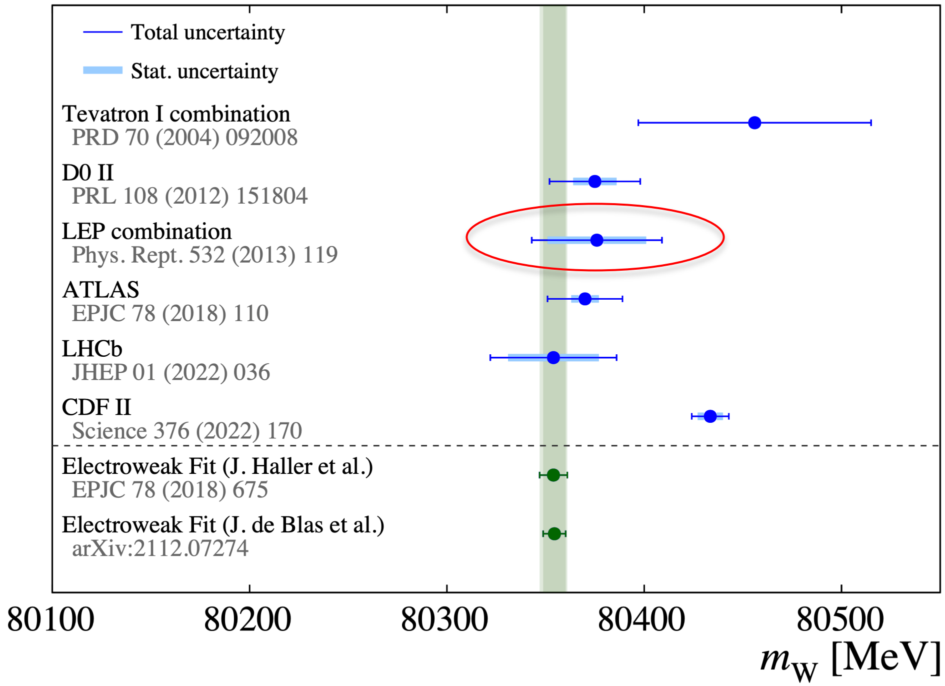
Measurement of the W-boson mass at LEP

$$m_W = 80.376 \pm 0.025\ (\text{stat.}) \pm 0.022\ (\text{syst.})\ \text{GeV}$$



Ivo van Vulpen

Precision compared to other measurements



LEP combined precision

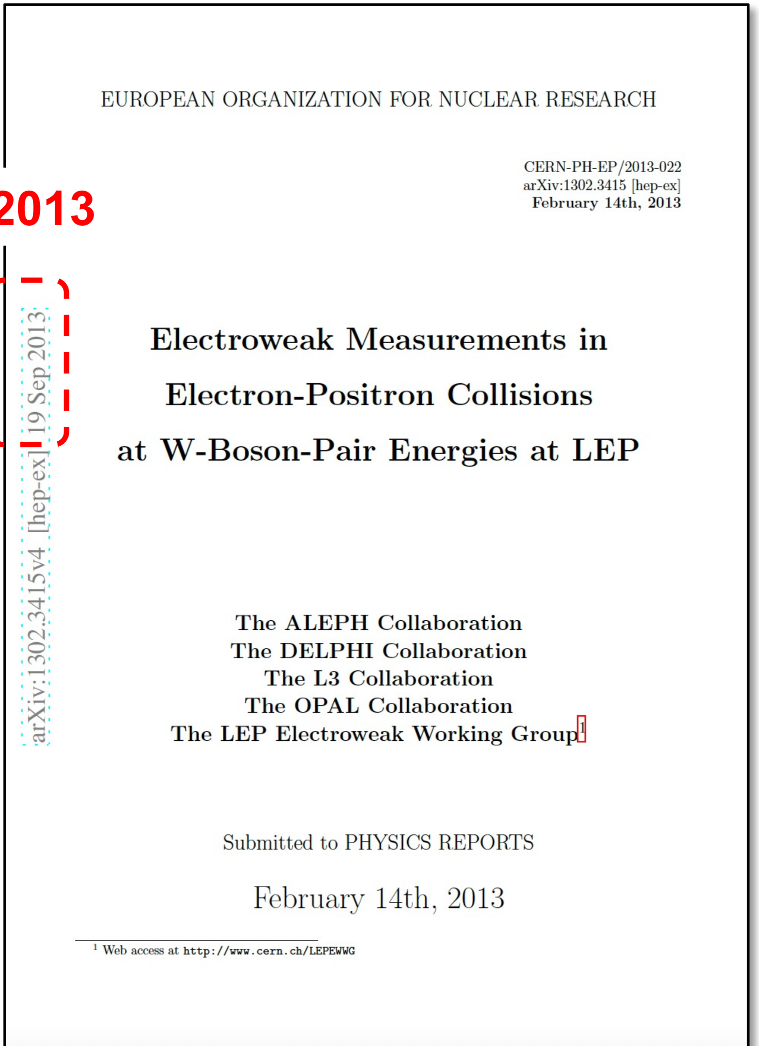
$$m_W = 80.376 \pm 0.033 \text{ GeV}$$

LEP accelerator:

- high energy electron-positron collisions
- center of mass energy: 91 (LEP 1) and 130-209 GeV (LEP 2)
- Integrated luminosity LEP 2: ~ 650 pb^{-1} per experiment

Background material used

Sep 2013



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-PH-EP/2013-022
arXiv:1302.3415 [hep-ex]
February 14th, 2013

arXiv:1302.3415v4 [hep-ex] 19 Sep 2013

Electroweak Measurements in
Electron-Positron Collisions
at W-Boson-Pair Energies at LEP

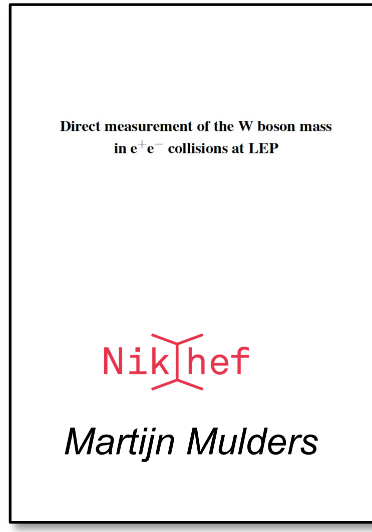
The ALEPH Collaboration
The DELPHI Collaboration
The L3 Collaboration
The OPAL Collaboration
The LEP Electroweak Working Group[1]

Submitted to PHYSICS REPORTS

February 14th, 2013

[1] Web access at http://www.cern.ch/LEPEWWG

https://arxiv.org/abs/1302.3415



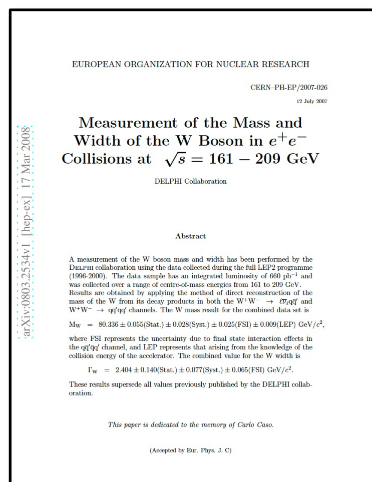
Direct measurement of the W boson mass in e^+e^- collisions at LEP

Nikhef

Martijn Mulders

PhD thesis

http://cds.cern.ch/record/517223/files/cer-002273178.pdf



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN–PH-EP/2007-026
12 July 2007

arXiv:0803.2534v1 [hep-ex] 17 Mar 2008

Measurement of the Mass and Width of the W Boson in e^+e^- Collisions at $\sqrt{s} = 161 - 209$ GeV

DELPHI Collaboration

Abstract

A measurement of the W boson mass and width has been performed by the DELPHI collaboration using the data collected during the full LEP2 programme (1996-2000). The data sample has an integrated luminosity of 660 pb^{-1} and was collected over a range of centre-of-mass energies from 161 to 209 GeV. Results are obtained by applying the method of direct reconstruction of the mass of the W from its decay products in both the $W^+W^- \to \ell\bar{\nu}_\ell q\bar{q}'$ and $W^+W^- \to q\bar{q}'\bar{q}q'$ channels. The W mass result for the combined data set is

$$M_W = 80.336 \pm 0.055(\mathrm{Stat.}) \pm 0.028(\mathrm{Syst.}) \pm 0.025(\mathrm{FSI}) \pm 0.009(\mathrm{LEP})\ \mathrm{GeV}/c^2,$$

where FSI represents the uncertainty due to final state interaction effects in the $q\bar{q}'\bar{q}q'$ channel, and LEP represents that arising from the knowledge of the collision energy of the accelerator. The combined value for the W width is

$$\Gamma_W = 2.404 \pm 0.140(\mathrm{Stat.}) \pm 0.077(\mathrm{Syst.}) \pm 0.065(\mathrm{FSI})\ \mathrm{GeV}/c^2.$$

These results supersede all values previously published by the DELPHI collaboration.

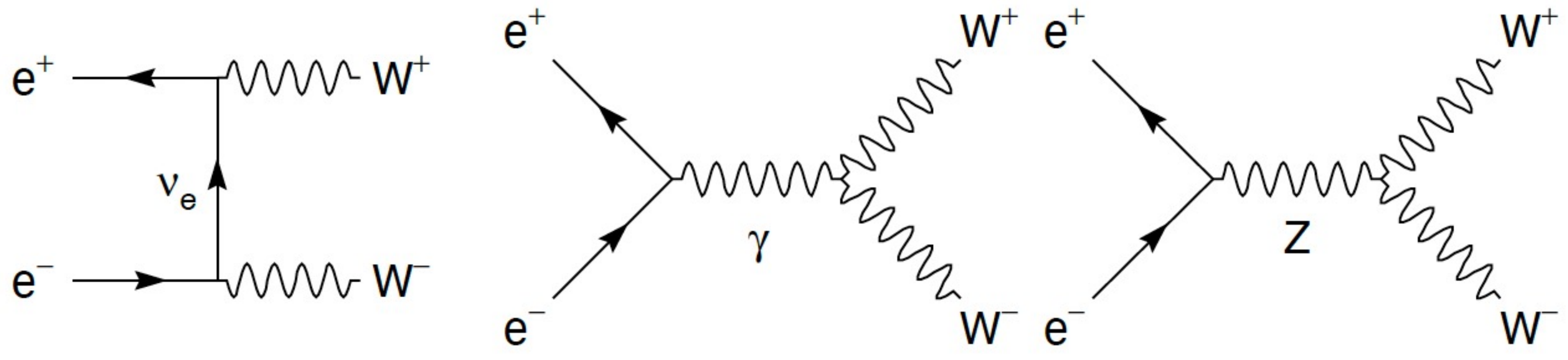
This paper is dedicated to the memory of Carlo Caso.

(Accepted by Eur. Phys. J. C)

Delphi m_W measurement

https://arxiv.org/abs/0803.2534v1

W-boson pair production at LEP



W-boson pair production:

- cross-section ~ 17 pb (→ 10k W-pairs per experiment)
- W-boson: BF's mass, width, ..

threshold scan

direct reconstruction

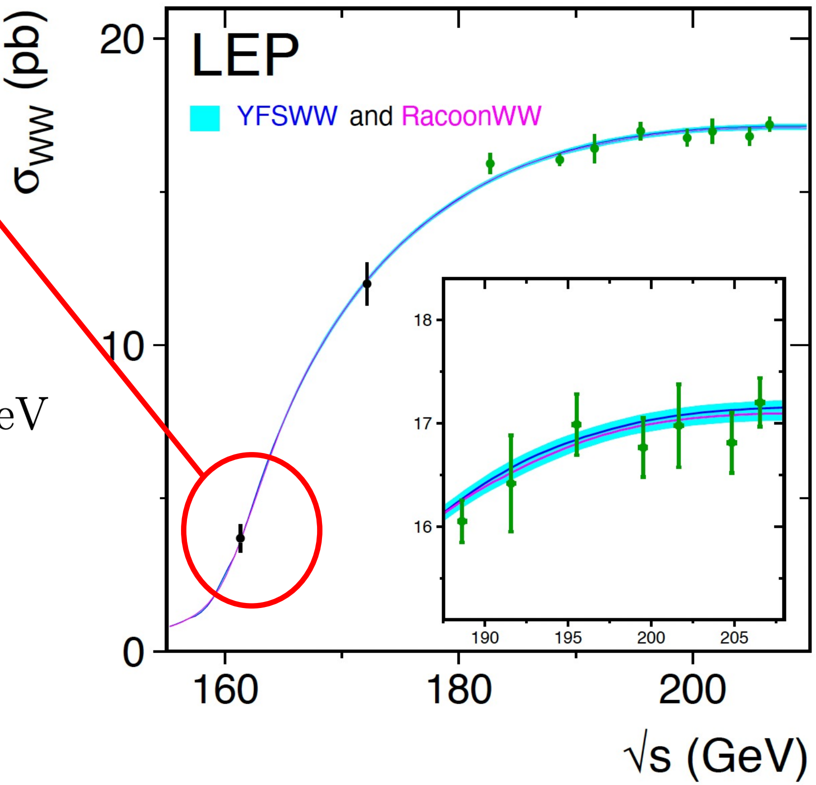
W boson mass (1): threshold scan

Dedicated run at √s = 161 GeV

$$\beta = \sqrt{1 - 4m_W^2/s}$$

$$m_W = 80.42 \pm 0.20\ (\text{stat.}) \pm 0.03(E_{LEP})\ \text{GeV}$$

Note: precision on √s ~ 20-25 MeV

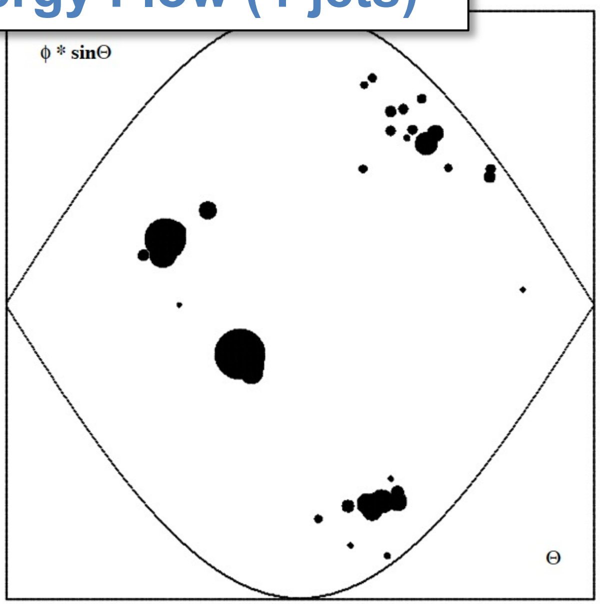


Emphasis was on increasing √s in search for the Higgs

W boson mass (2): direct reconstruction

Final states: - fully hadronic (46% - 4 jets)
- semi-leptonic (44% - 2 jets, 1 lepton, 1 neutrino)
- fully leptonic (10% - 2 leptons, 2 neutrino's) – OPAL only

Energy Flow (4-jets)

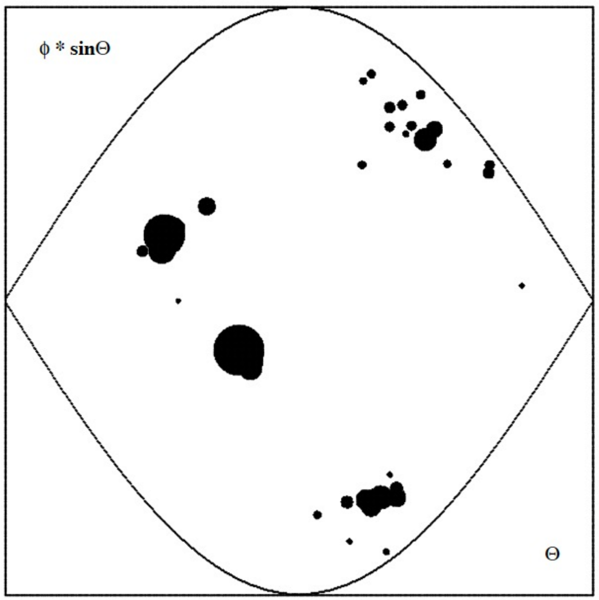


LEP event characteristics:

- clean events
- small multi-jet bckg. in WW
- **event kinematics are known: used in constrained fits**

Kinematic fit & extract m_W

Use knowledge of initial state to improve event reconstruction [energy and momentun conservation] → improved mass resolution on W-boson estimates



Typical jet energy resolution ~ 3-8 GeV

⇩

Energy and momentum conservation (4C)

⇩

$M_{W+} = M_{W-}$ (5C)

⇩

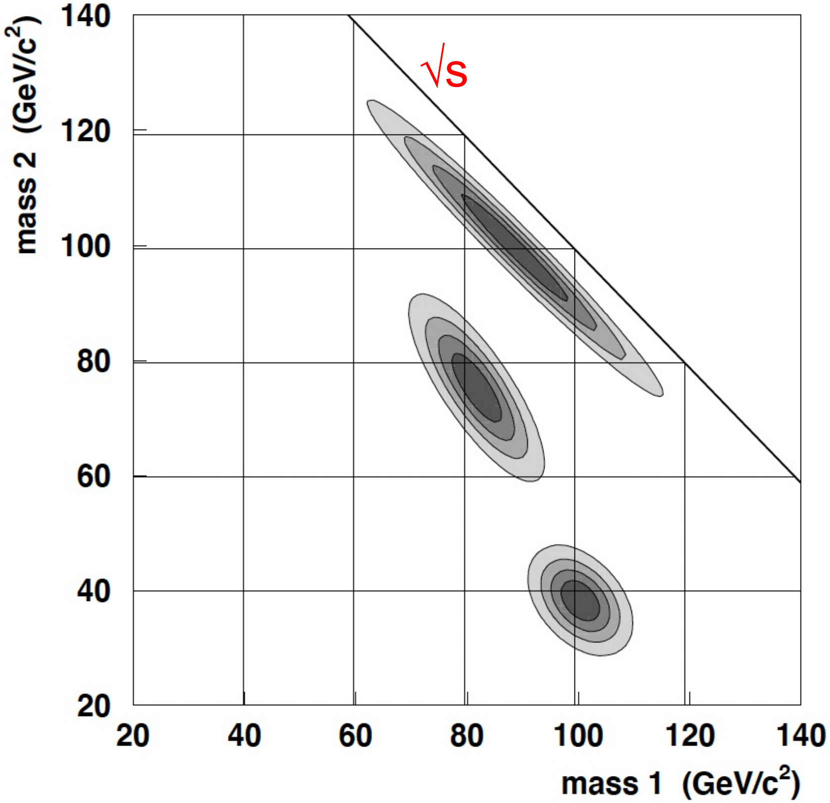
→ Mass resolution on W-mass (event) ~ 3 GeV

Note: - additional uncertainty in semi-leptonic from missing P_Z neutrino}

- mass resolution llvv better than qqqq

Di-jet invariant masses in 4 jet events

experiment



theory

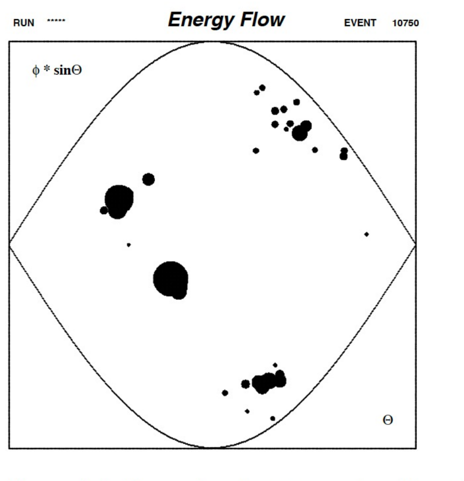
Correct pairing:
2-dim Breit-Wigner (m_W, Γ_W)

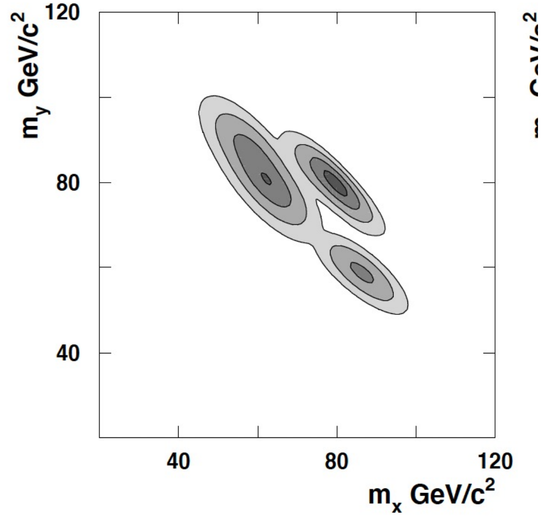
Wrong pairing: ~flat(m_1,m_2)

DELPHI: use a convolution technique to test multiple mass hypotheses

Trouble: 5 jet events

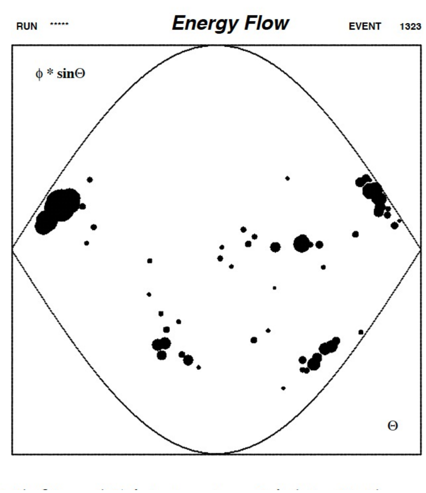
4-jet events

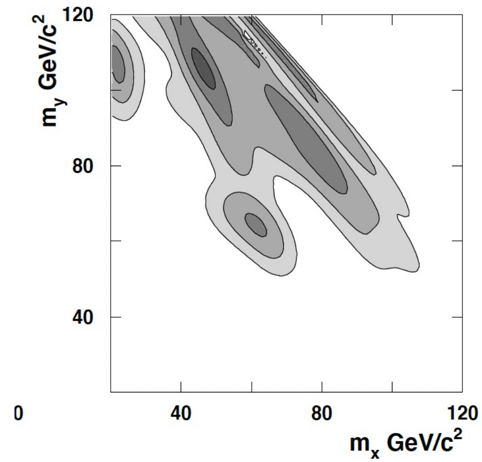




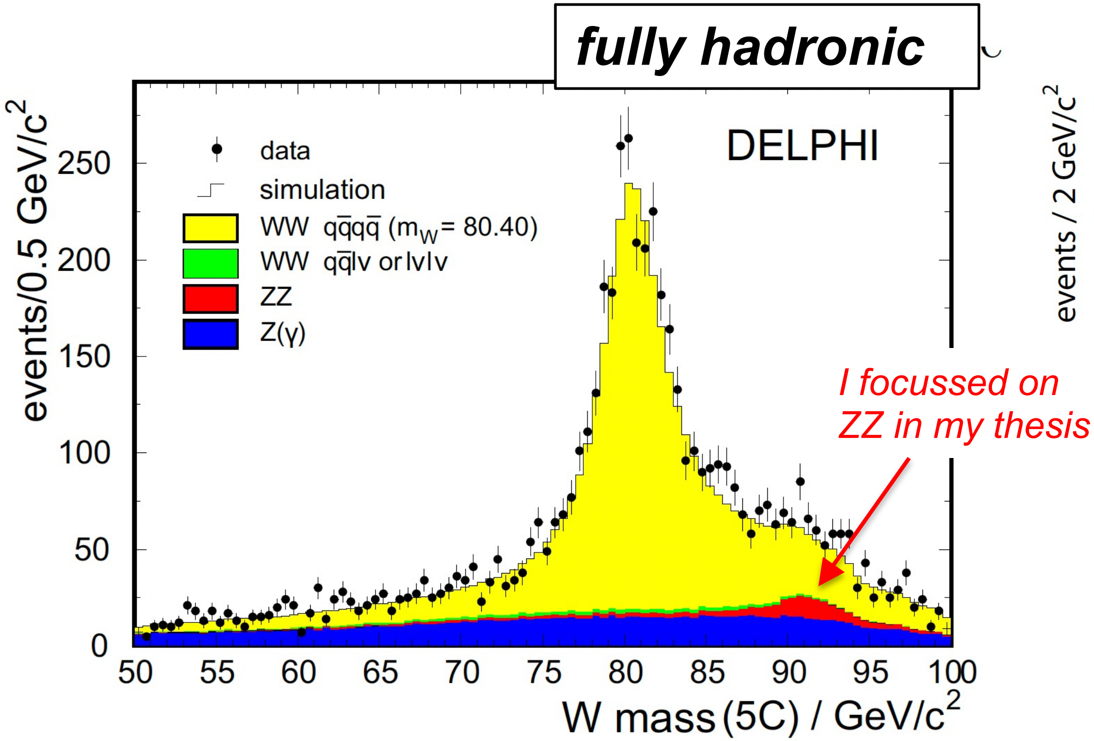
5-jet events

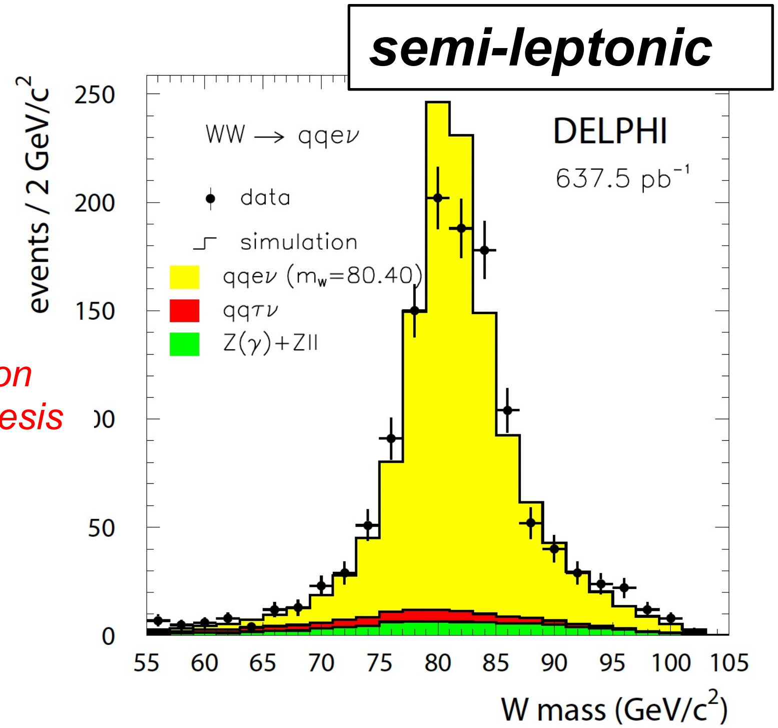
FSR → which of the 10 pairings?





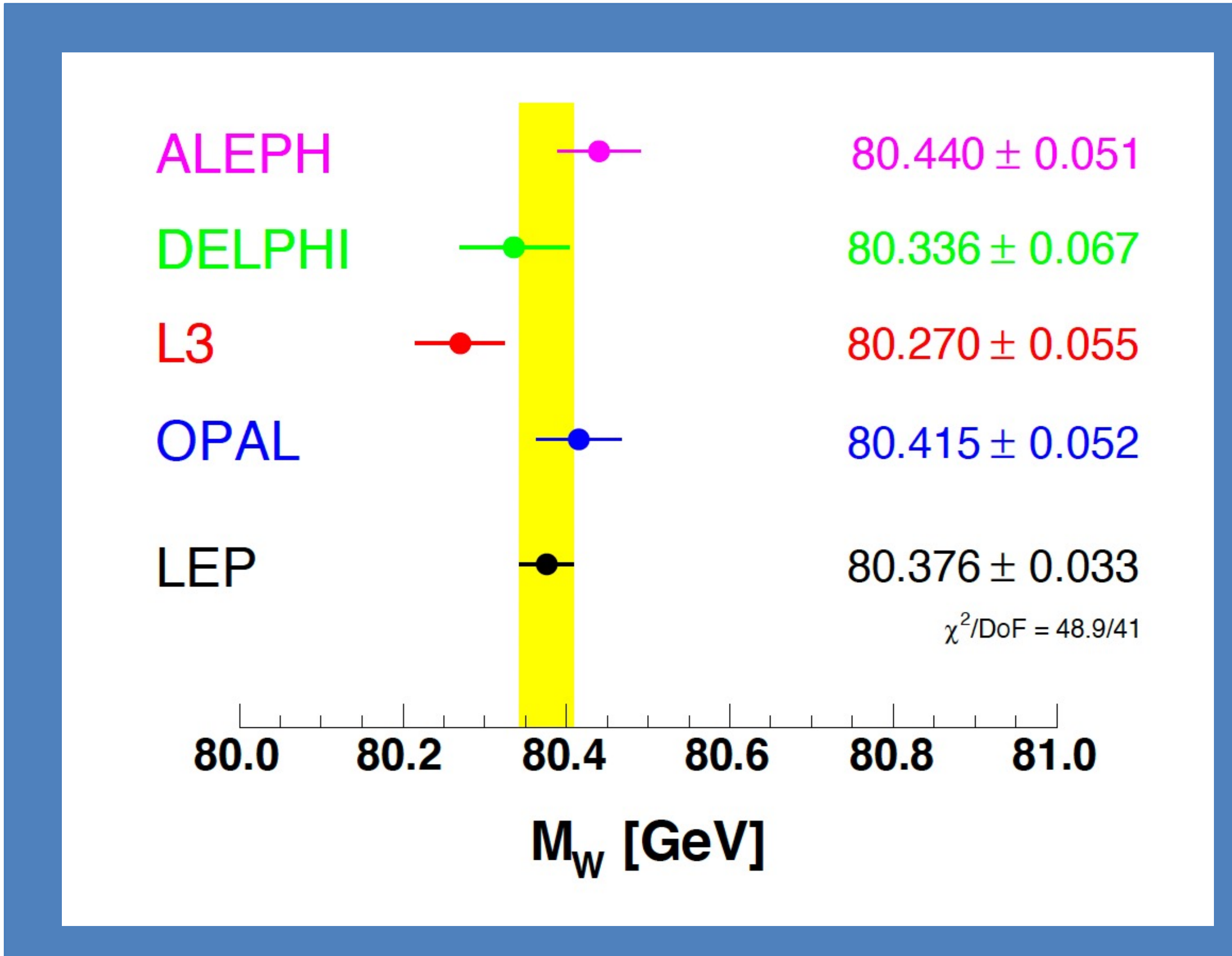
W-boson mass distributions (1 pairing)





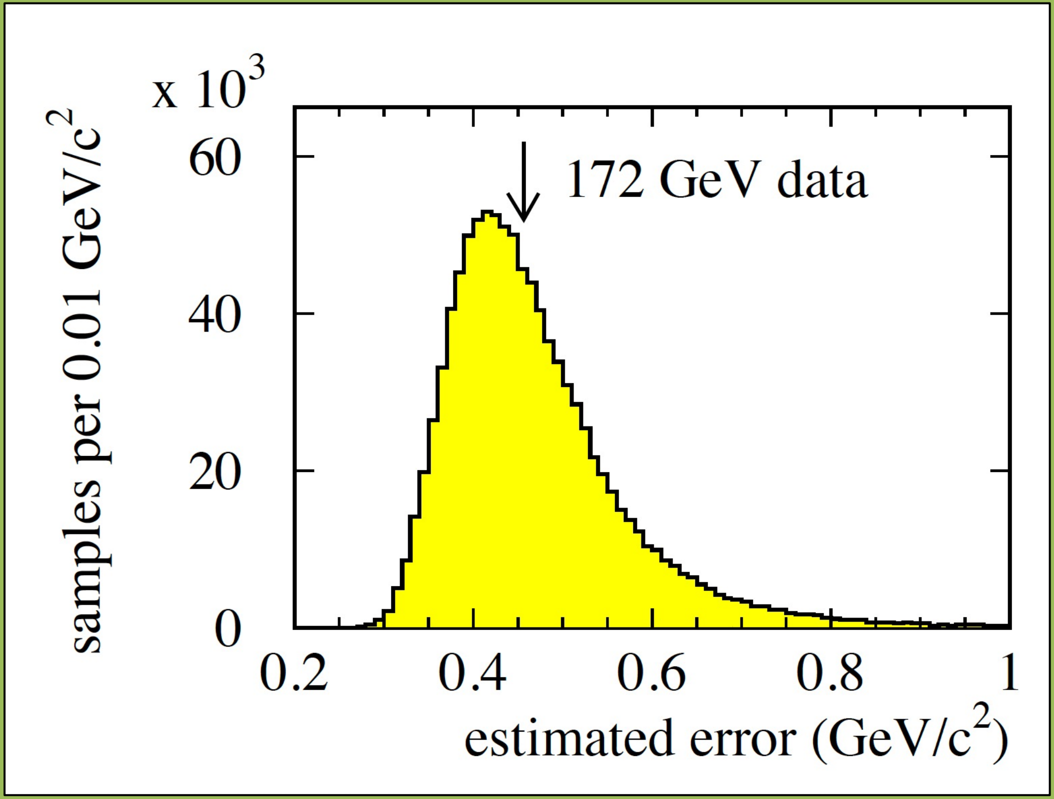
Note: - extraction W-boson mass in an unbinned maximum likelihood fit
→ this is 'just' a distribution
- ALEPH/L3 (reweighting) – DELPHI/OPAL (convolution)

W-boson mass - results



Question to theorists: what was the best (most sensitive) detector/analysis?

You can be lucky or unlucky with the data. To compare sensitivities, use expected uncertainties



DELPHI: distribution of expected uncertainty on the measurement on the sqrt(s) – 172 GeV data. Arrow indicates actual measurement

W-boson mass – LEP results

Semi-leptonic:

$$m_W = 80.372 \pm 0.030 \text{ (stat.)} \pm 0.021 \text{ (syst.) GeV}$$

Fully hadronic:

$$m_W = 80.387 \pm 0.040 \text{ (stat.)} \pm 0.044 \text{ (syst.) GeV}$$

LEP combination (including threshold scan):

$$m_W = 80.376 \pm 0.025 \text{ (stat.)} \pm 0.022 \text{ (syst.) GeV}$$

Systematic uncertainties

Source	Systematic Uncertainty in MeV			
	on m_W			on Γ_W
	$q\bar{q}\ell\nu_\ell$	$q\bar{q}q\bar{q}$	Combined	
ISR/FSR	8	5	7	6
Hadronisation	13	19	14	40
Detector effects	10	8	9	23
LEP energy	9	9	9	5
Colour reconnection	–	35	8	27
Bose-Einstein Correlations	–	7	2	3
Other	3	10	3	12
Total systematic	21	44	22	55
Statistical	30	40	25	63
Statistical in absence of systematics	30	31	22	48
Total	36	59	34	83

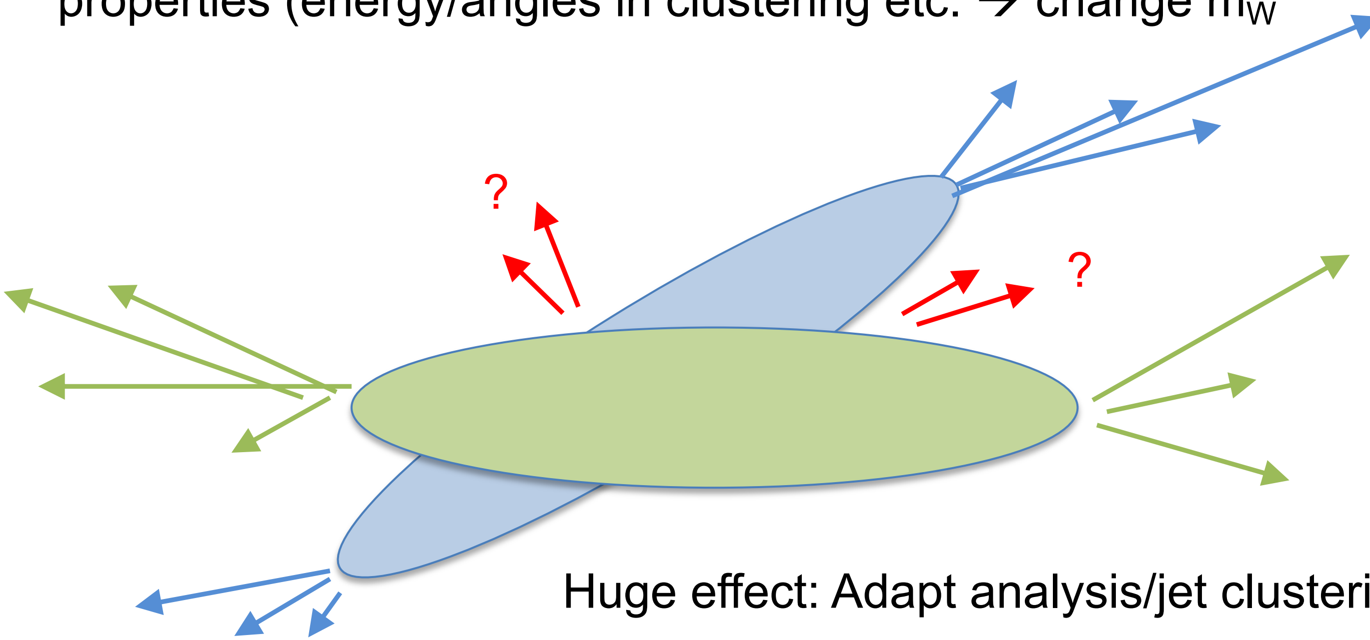
Bose Einstein Correlations & Colour reconnection

Bose Einstein correlations:

Enhances production of identical bosons close in phase space
→ BEC effects from inter-W particles?
→ Mixing method: mix hadronic W's from 2 semi-leptonic events and study differences in particle spectra → 7 MeV upper limit on shift

Colour reconnection:

Lifetime W-boson (0.1 fm) order of magnitude smaller than hadronization scales. Exchange gluons from (colour singlet) decays from individual W's. Distort properties (energy/angles in clustering etc. → change m_W



Study intra/inter-W particle flow

Huge effect: Adapt analysis/jet clustering to limit impact

ISR & beam energy

Used in constrained fit → direct bias on m_W

- ISR: MC description: test using $Z \rightarrow f\bar{f}\gamma$ events
- E_{beam}: measured every 15 min using NMR probes.
  $\Delta(\sqrt{s}) \sim 20$ MeV at $\sqrt{s} = 200$ GeV → 10^{-5} → 8 MeV on m_W

Hadronisation and fragmentation. Detector effects

Effect different Monte Carlo's (JETSET/Pythia vs HERWIG or ARIADNE)
- Parameters tuned on Z-pole (explicitly depleted in b-quarks):
  * energy scale and resolution
  * differences in heavy mesons: reconstruction assumes pion mass etc.

Test jet description using tricks like MLBZ (mixed Lorentz boosted Z bosons):
mimick WW events by using mixed hadronic Z boson decays

Measurement of the W-boson mass at LEP

$$m_W = 80.376 \pm 0.025 \text{ (stat.)} \pm 0.022 \text{ (syst.) GeV}$$