W mass and width measurement @ LEP

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On behalf of the OPAL collaboration

- W boson in SM
- Experimental methods
- Sytematic Uncertainties
- Current Results
- Outlook and conclusion

Lake Louise Winter Institute 15th –21st February 2004

Why W Boson(s)?

W^+ and W^- : SM mediators of weak interactions

Existance confirms (with Z^0) Standard Model SU(2)xU(1) gauge symmetry

Are massive: related to SM EWK symmetry breaking → Higgs

M_w and Γ_w are key parameters of SM

Precise and unbiased measurement by direct production → Stringent test of SM, constraints on SM Higgs Boson mass and on physics beyond SM (SUSY?)

LEP2 : ideal clean environment for WW studies

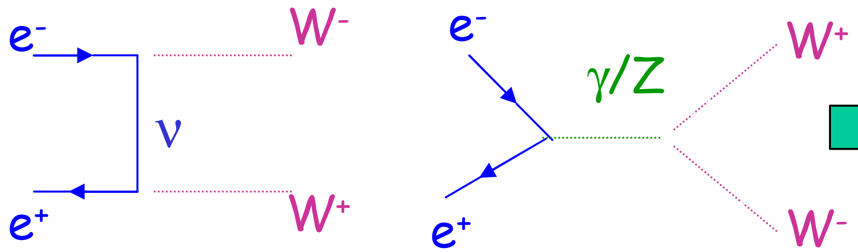
above WW threshold : direct reconstruction

@ threshold : M_w measurable from WW cross section

W physics @ LEP2

@ LEP2 : $e^+e^- \rightarrow W^+W^- \rightarrow$ 4fermions

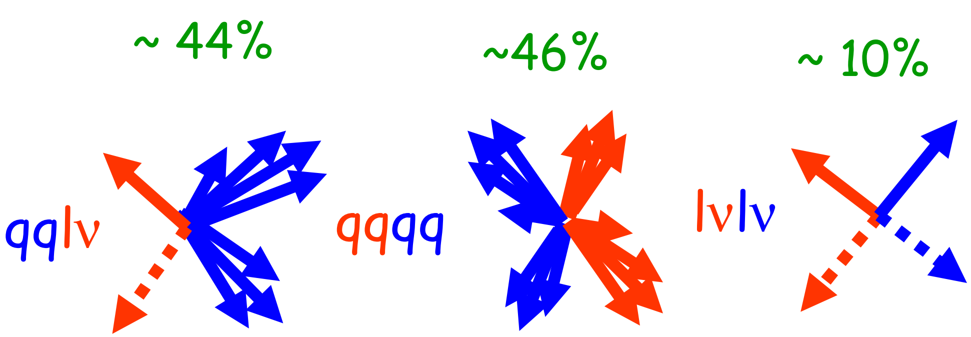
At tree level



NOT GAUGE INVARIANT
$e^+e^- \rightarrow 4f$ has other intermediate states

Add other $e^+e^- \rightarrow 4f$ for gauge invariant description also of BKG

3 final state topologies



Chan	Main Bkg
lνlν	ZZ,Zee,γγ
qqlν	Weν,qq(γ)
qqqq	qq(γ)

Add O(α) EWK corr.:**required** for precision measurement

Event selection

Total LEP2 $\int$Ldt ~ 2.8 fb^{-1}
(1997-2000) in
E_{cm} ~ 172-209 GeV
~ 40 pb^{-1} @ E_{cm} ~ 161 GeV

~10K WW

~21k 4f bkg

~63k Z/γ

per exp

Complex multi-steps event selections (cuts, likelihood discriminants, neural nets) for efficient and clean identification

Typical performance

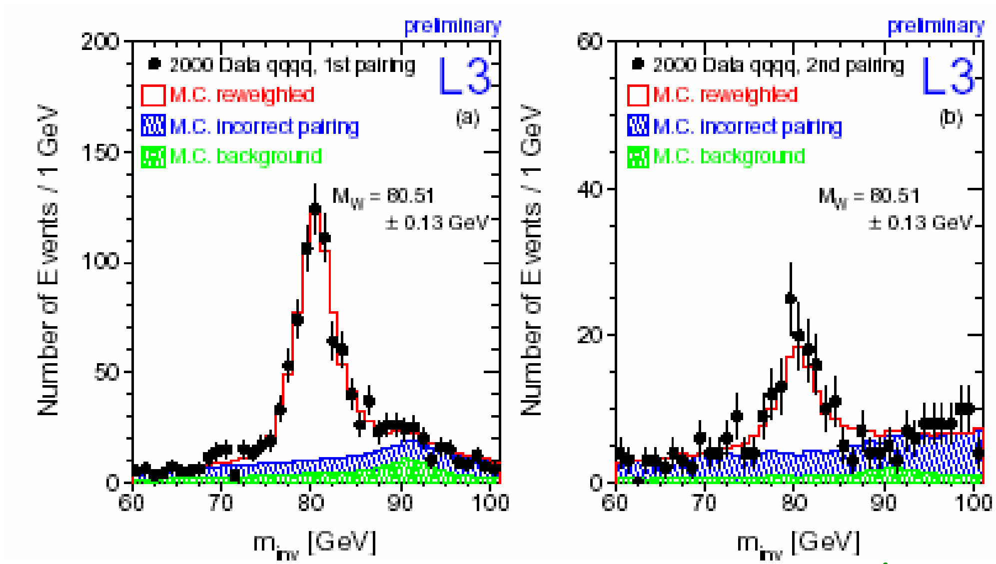
Chan	Efficiency	Purity
lνlν	70%	90%
qqlν	80%	85%
qqqq	80%	80%

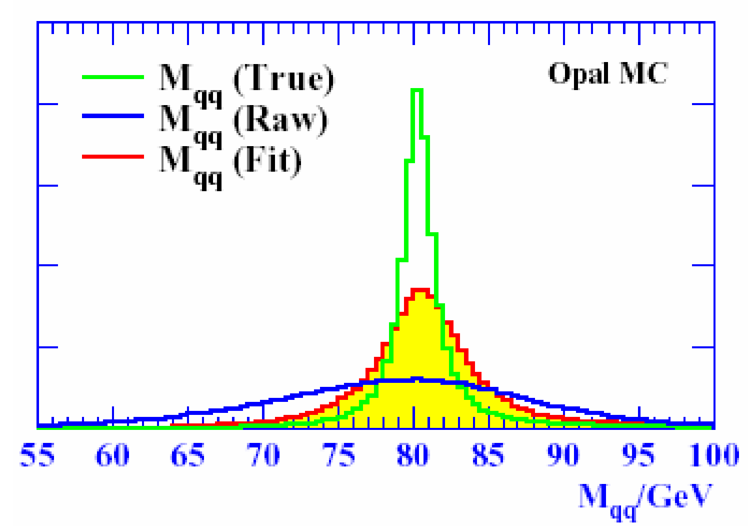
Event Reconstruction

Lepton identification in qqlν and lνlν →no rec, separate analysis (O,A)

Jet reconstruction (DURHAM): 2jets in qqlν, 4 jets in qqqq .
(D,O) allow for additional gluon jet.

Kinematic fit: beam energy knowledge to constrain total four momentum of event

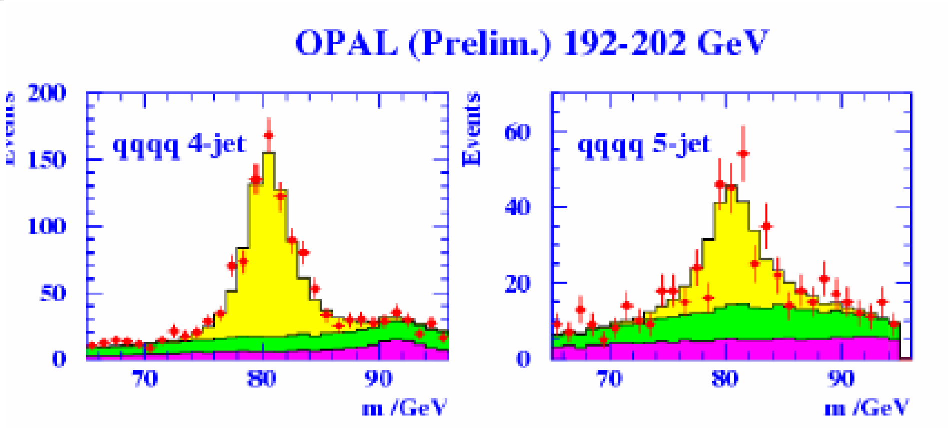


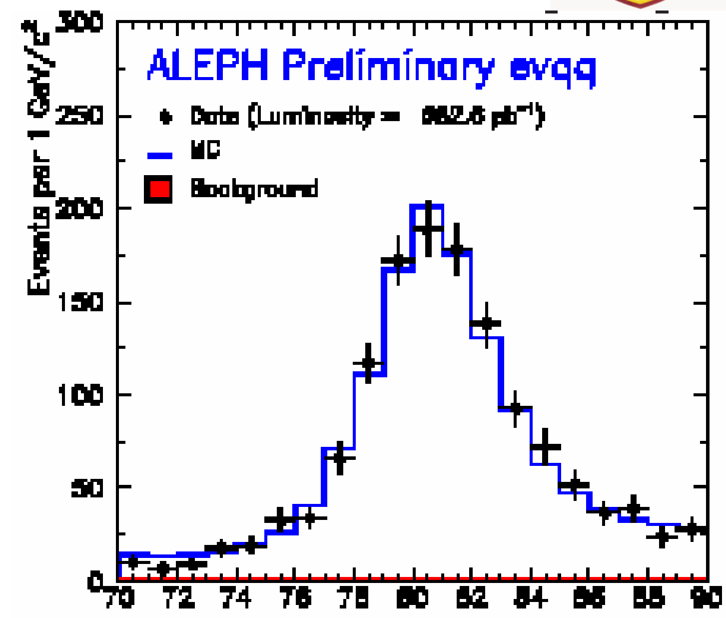


Form event-by-event invariant mass

Jet pairing in qqqq: consistency with W decay kin. (A) or multivariate sel/Kin.fit prob. (O,L) or use all pairings (D)

W mass and width extraction





Maximum Likelihood fit to extract M_W

Γ_w:from SM relation or 2 parameter Fit

Different likelihood building methods

Breit Wigner (O):
asymmetric BW,
robust for preliminary estimation

Convolution (D,O):
physics function ⊗ detector response,
statistically powerful

Reweighting (A,L,O):
MC shape reweighted for varying assumed W mass,least biased,
fully exploit MC reco

Systematic Uncertainties

Summer 2003

- full LEP sample except OPAL 2000 data (~220 pb^{-1})
- qqlν and qqqq have similar stat. uncertainty
- qqqq has only 10% weight in comb. (FSI)

Source	Systematic Error on M_W (MeV)		
	qqlν	qqqq	Combined
QED(ISR/FSR,etc)	8	8	8
Hadronisation	19	18	**18**
Detector Systematics	14	10	14
LEP Beam Energy	17	17	**17**
Colour Reconnection	-	**90**	9
Bose-Einstein Correlations	-	**35**	3
Other	4	5	4
Total Systematic	31	101	31
Statistical	32	35	29
Overall	44	**107**	**43**

LEP Beam Energy

Kinematic fit: energy scale from E_{beam} → $\delta M_W/M_W \sim \delta E_{beam}/E_{beam}$

Negligible impact on Γ_W

E_{beam} measured by:

LEP (directly)

Use 16 Nuclear Magnetic Resonance probes calibrated with Resonant Depolarisation (LEP1) and flux loop measurements (main syst. uncertainty)

Cross check with LEP spectrometer and energy loss (Q_F vs RF) method

Experiments (indirectly from physics events)

Compare Z peak position in data and MC → infer E_{beam} in $e^+e^- \rightarrow Z(\gamma)$ (Radiative Return)

All results: **consistent**

δE_{beam} = 21 Mev From direct measurement

↓

Current δM_W=17 MeV

Detector Modelling

Direct reconstruction is sensitive to detector modelling→

Use $e^+e^- \rightarrow Z^0$ @ E_{cm}=91.2 to calibrate

energy scale, resolution and linearity, angular scale and resolution for leptons and jets

→

calibration uncertainties →
δM_W= 14 MeV

Correlated amongst channels and years, not exp.

Hadronisation

Quark→hadrons: not understood mechanism → modelling → δM_W

Use hadronisation models tuned at Z^0
JETSET: Lund string model
HERWIG: singlet cluster model
ARIADNE: Lund dipole colour model

→

Models spread in M_W
→ δM_W : 18 MeV

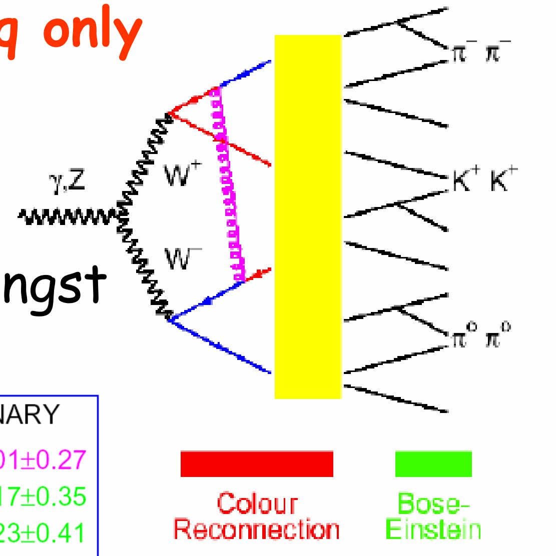
D uses Z^0data-MC comparison technique for had and det syst: careful use required

Baryon and Kaons explain part of δM_W → reduction

Bose Einstein Correlations

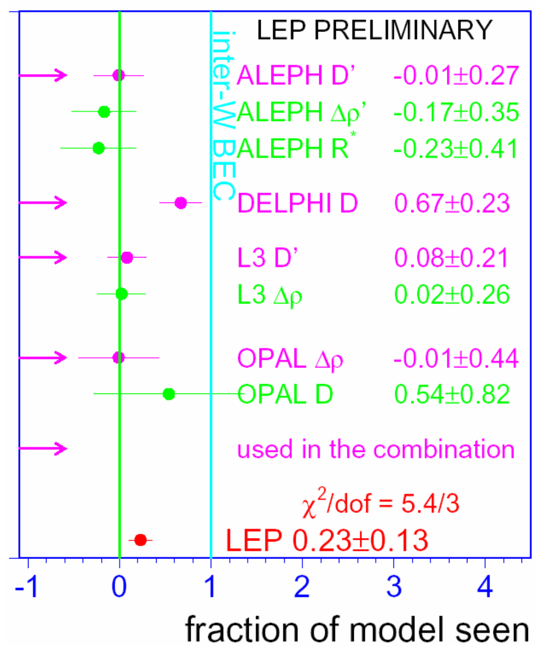
QM interference → Momentum space correlation of bosons from different W (inter-W) decays: **bias qqqq only**

Present δM_W^{4qn} =35 MeV from LUBOEI model: "with-without" inter-W cor



BEC investigated at LEP2 by Two-particle correlation studies: No evidence for inter WW BEC as predicted by LUBOEI

Correlated amongst exp and years



Data percentage of LUBOEI Inter W corr.

Linear in δM_W

Next steps: Use LEP fraction of the model to reduce δM_W: Data driven uncertainty

Colour Reconnection

Colour cross-talk between Ws: bias in qqqq but not qqlv .

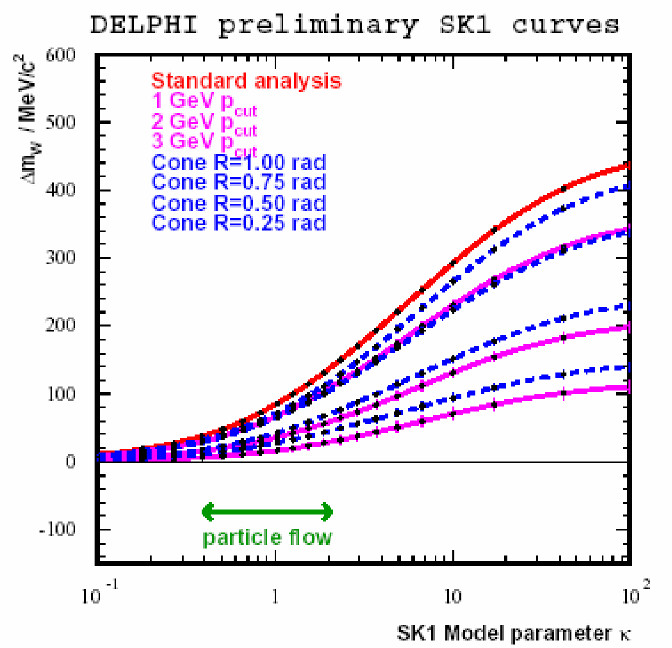
Particle Flow technique → LEP
68% CL upper limit on SK1 CR model → Data Driven δM_W

Model	δM_W^{4q}(MeV)
Herwig	30
Ariadne 2	70
SK1(k=2.1)	90

Correlated amongst exp and years

No CR,no BE: ΔM_W(4q-qqlv)=22±43 MeV

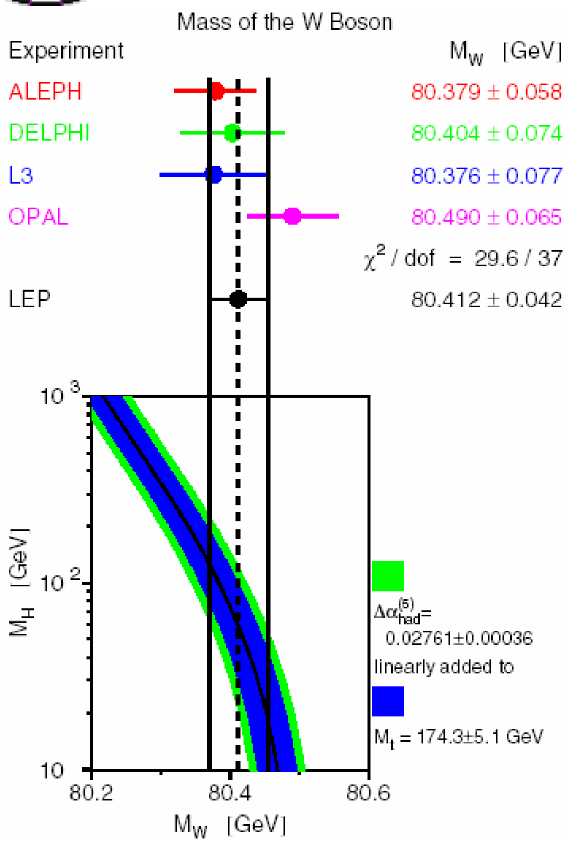
Next steps
Desensitize analysis to CR effects by changes in jet algo: cuts and/or cones



SK1 k parameter varies CR strength

LEP2 Combined Results

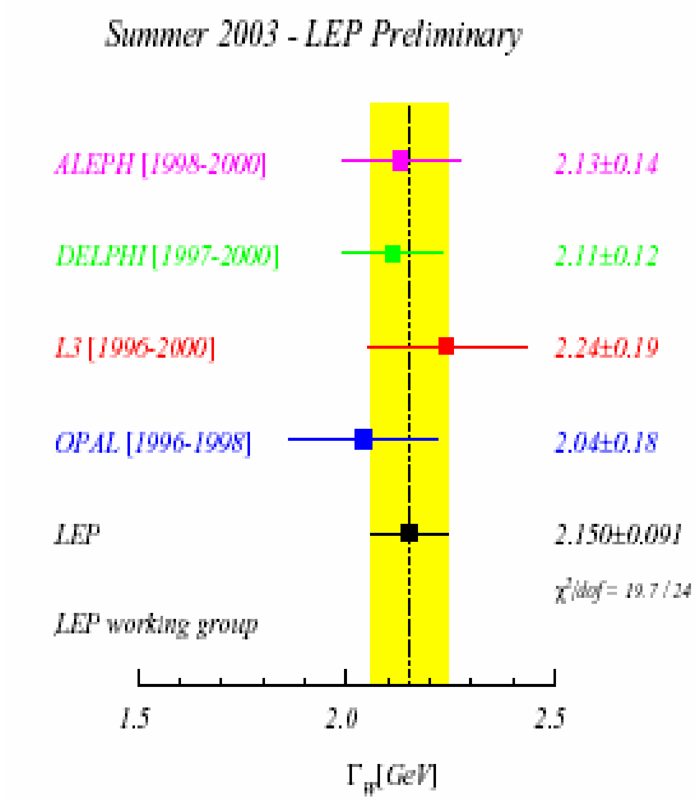
Preliminary



- full LEP sample except OPAL 2000 data

(~220 pb^{-1})

M_W from threshold included

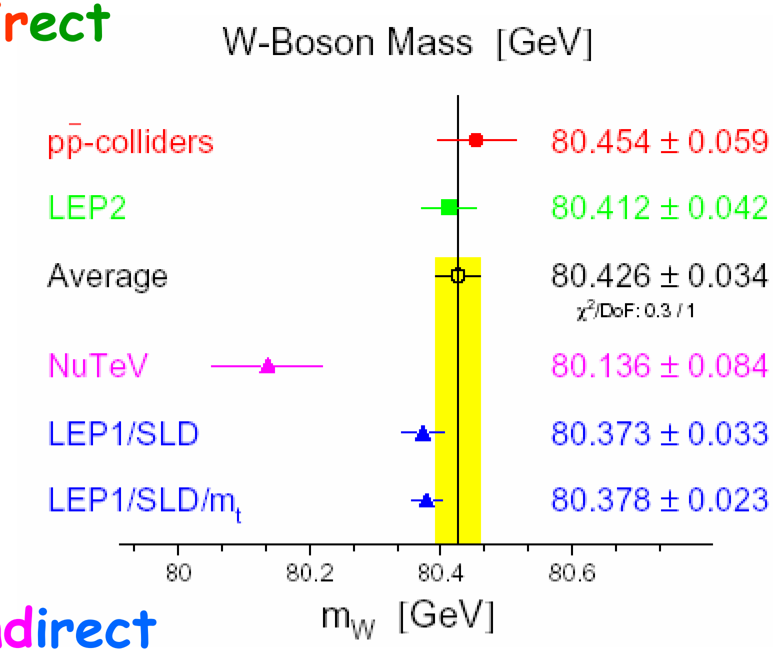


M_W(LEP)= 80.412 ± 0.029(stat.) ±0.031(syst.) GeV

Γ_W(LEP) = 2.150 ± 0.068(stat.) ± 0.060(syst.) GeV

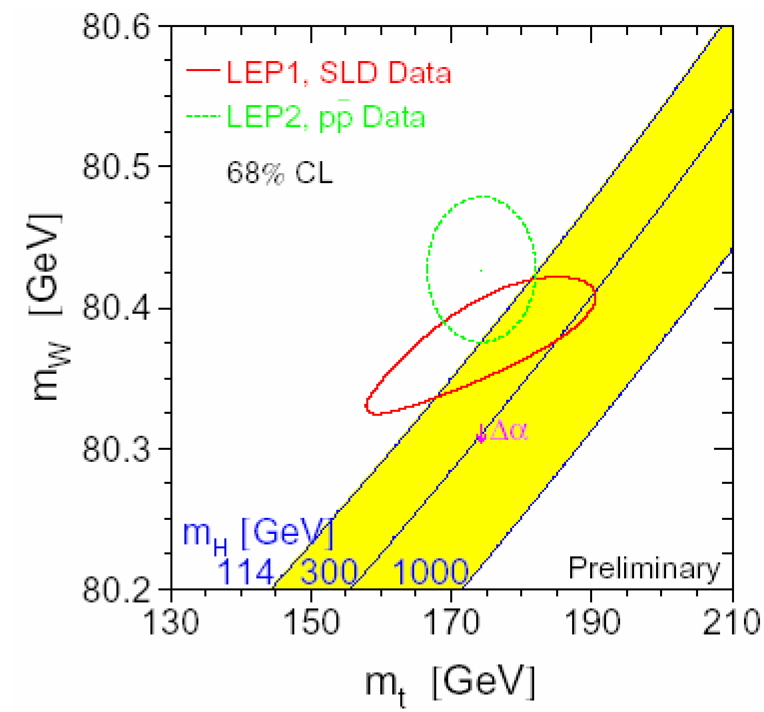
LEP2 and the others

Direct



Indirect

SM consistency



Good Direct – Indirect consistency

Low values of Higgs masses are preferred

OPAL 2000 data to be included soon

Conclusions and Outlook

M_W(LEP)=80.412 ±0.042

Γ_W(LEP)=2.150 ± 0.091

→ Favours low SM M_H
Lower M_W, higher M_H Limit

LEP possible progress

Improved analyses + add OPAL 2000 data

Better hadronisation/det sys
Lower LEP beam energy error

→ **Lower final uncertainty on M_W (42 MeV → 37 MeV)**

FSI improvements → use 4q stat. power (now only 10% weight)

Beyond LEP

Tevatron (RUNII) complementary to LEP

LHC: goal is δM_W~ 15 MeV ; consistency test if new physics is found (SUSY?)

ILC: potential to go below 10 MeV with threshold scan or direct reco