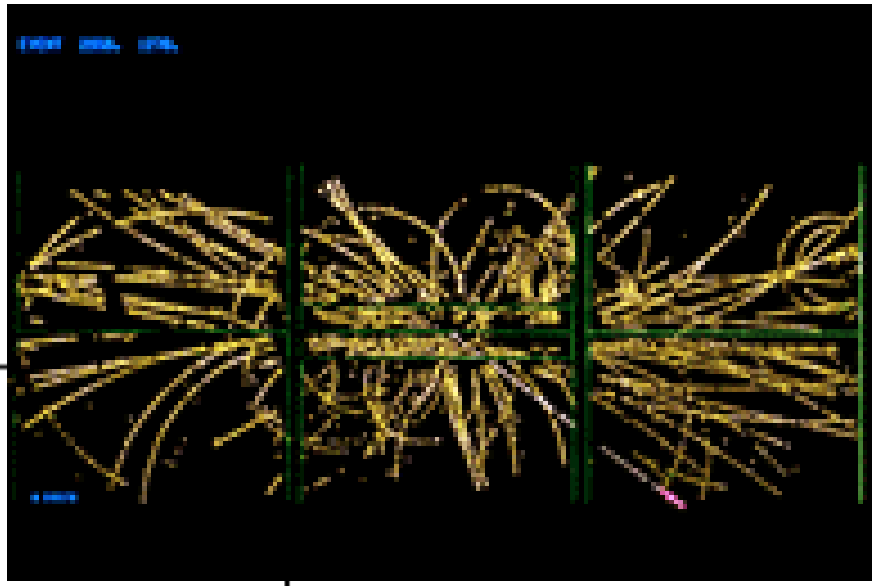
Chris Parkes

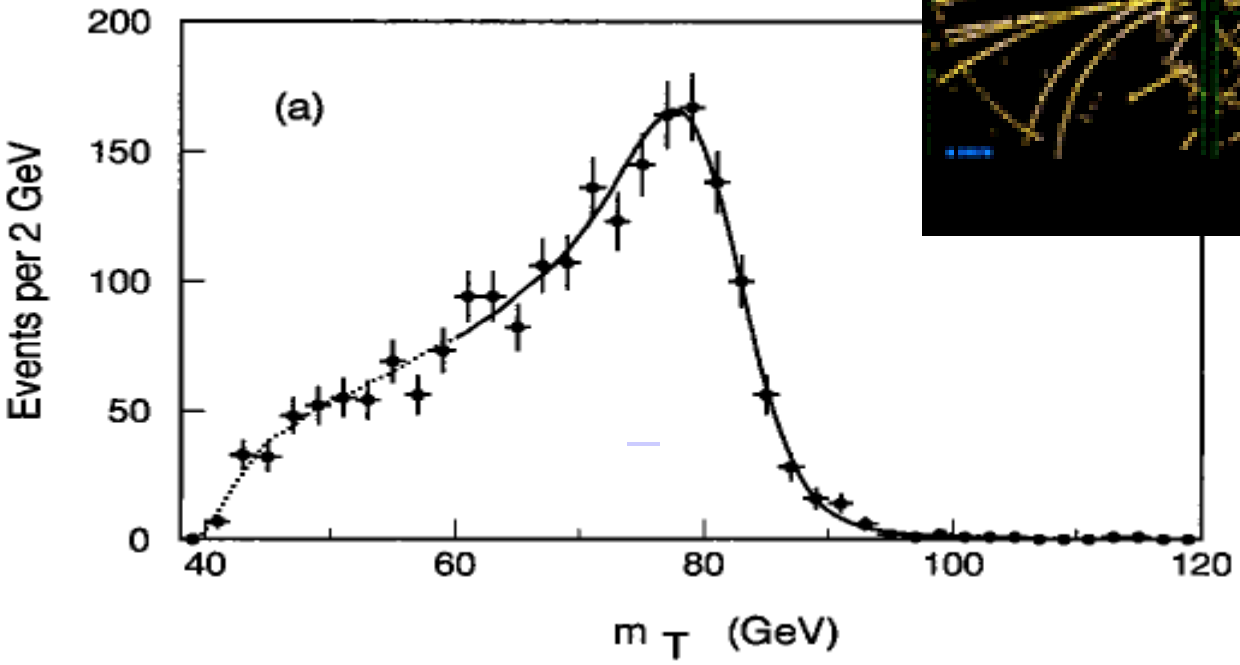
W Boson Properties at LEP

- Happy 22nd Birthday W's
  - UA1,UA2
- LEP2
  - W Boson Properties
    - **WW xsec, W BRs, V_{cs}, TGCs, QGCs, SDM, Wev**
    - **W Mass, Width**
    - → Higgs mass
- The e^+e^- Future
  - ILC

W Discovery

- UA1, UA2 1983





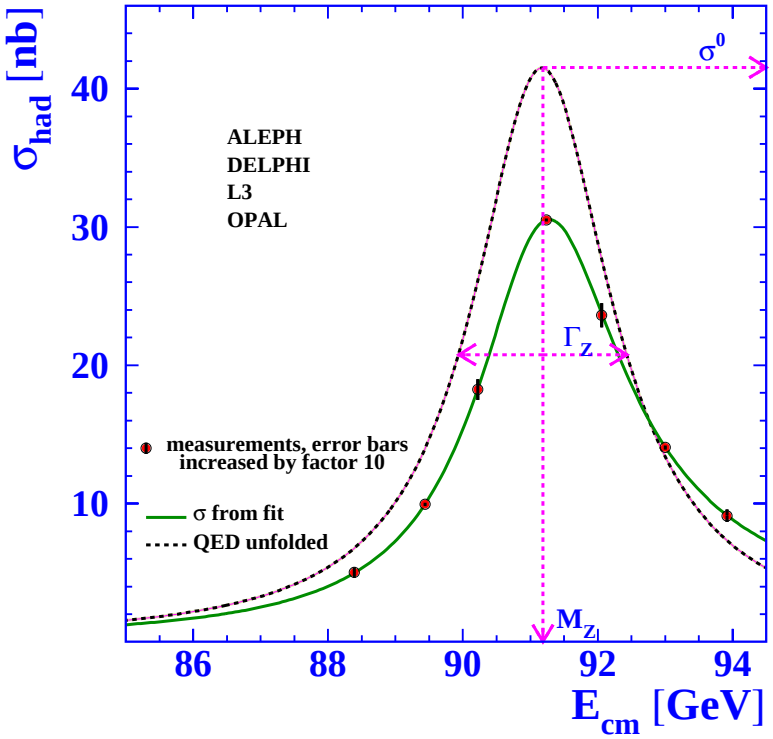
Situation pre-LEP,pre-TeVatron (see following talk for TeVatron)

UA2, Phys.Lett.B276:354-364,1992

$M_W = 80.35 \pm 0.33 \pm 0.17$ GeV

LEP's Legacy – Weighing the Bosons

- Precision measurements of the weak interactions
- The Z

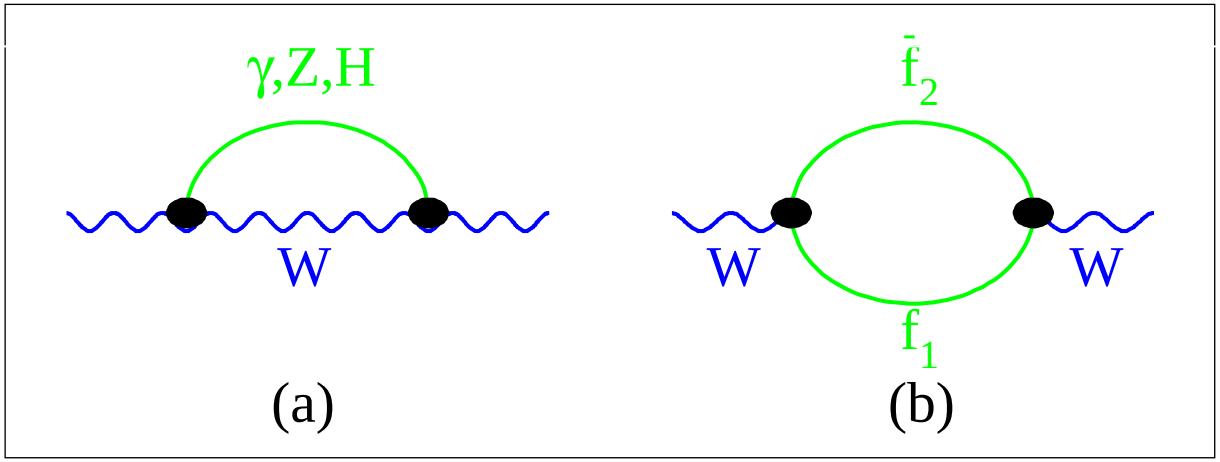


LEP 1 Phase 1989-1995

- 15 million Z's
- M_Z = 91187.5±2.1 MeV
  - 2 parts in 10^5 !
- Γ_Z=2495.2±2.3 MeV

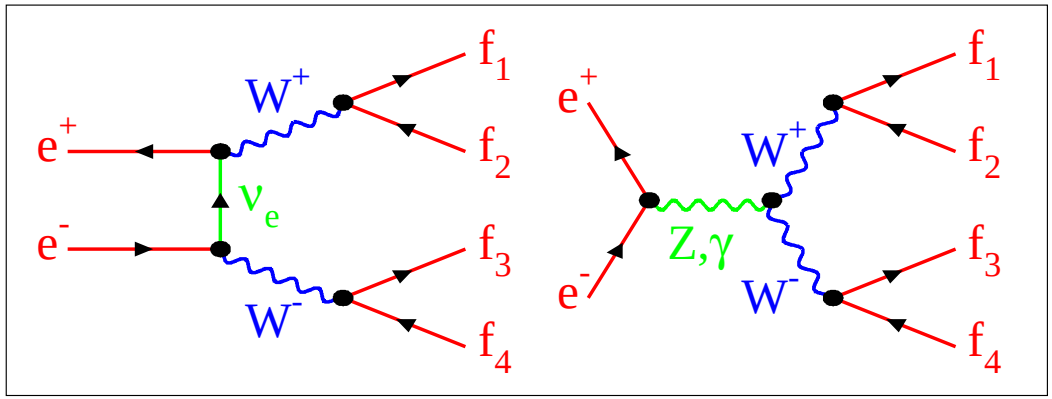
LEP 2 Phase 1996-2000

- W boson measurements
- Measuring the Higgs mass ?



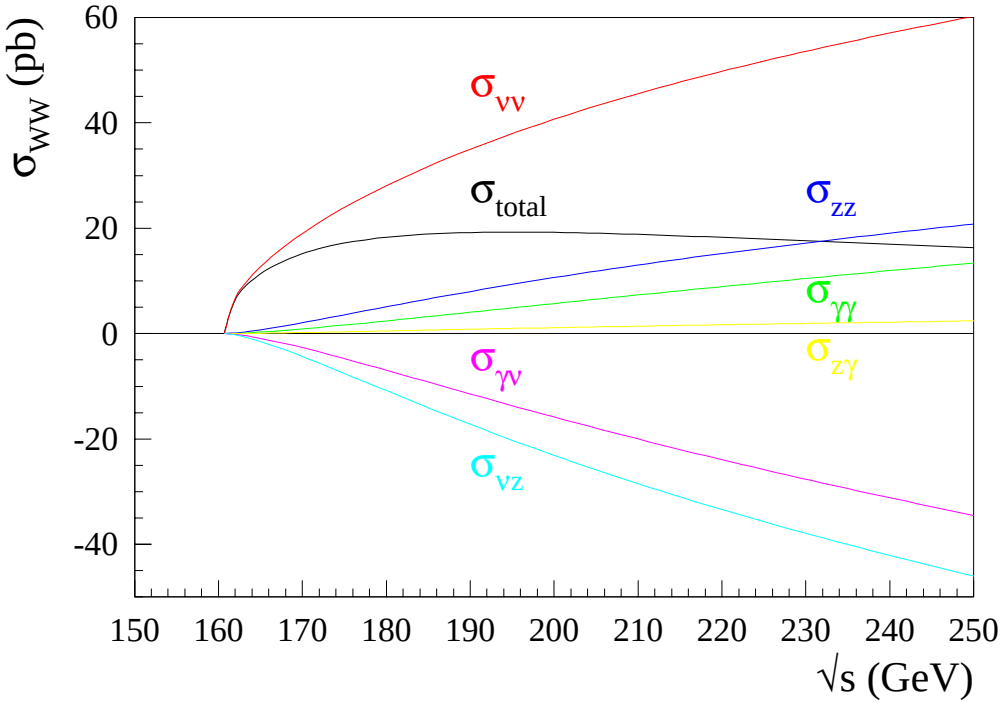
- M_W depends on $(m_{top})^2$
- M_W depends on ln (m_{higgs})

WW Production at LEP



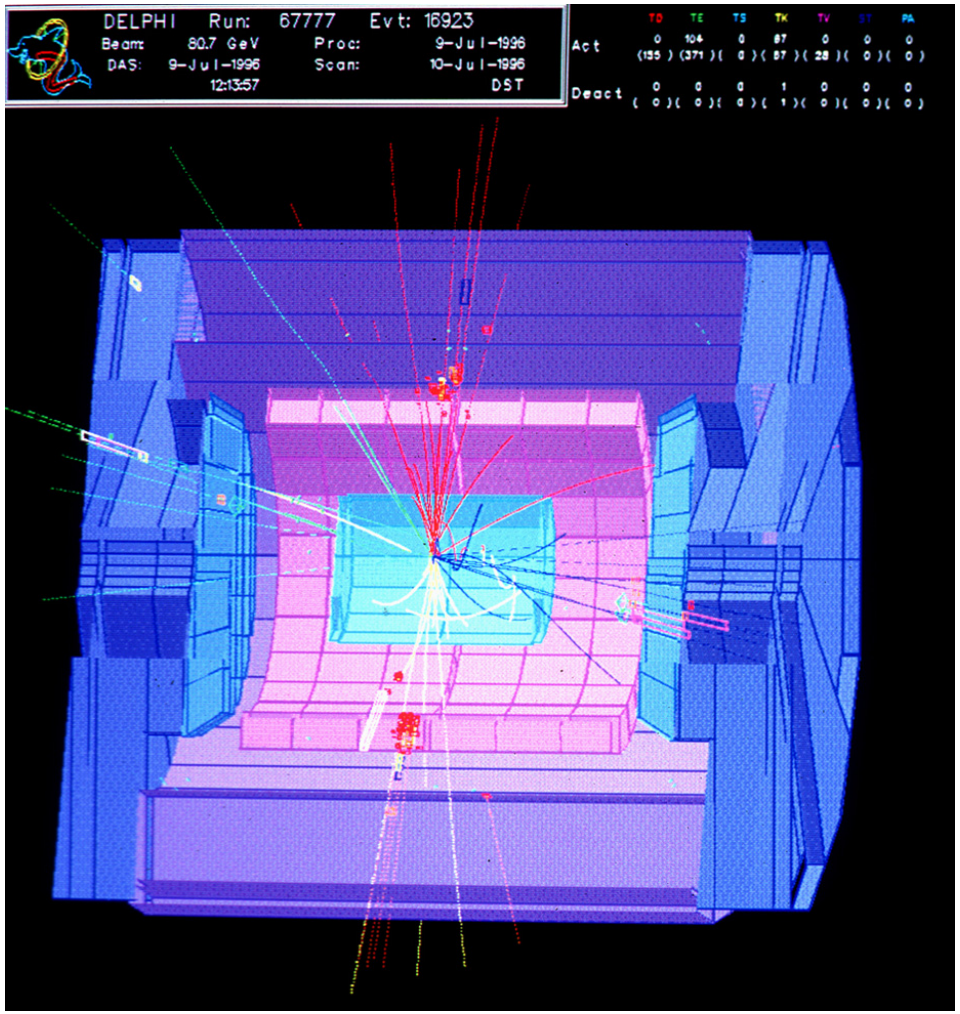
- Three Feynman graphs with interference gives Six terms
  - Only Born level shown

- Near threshold t-channel dominates
- Cancellations are consequence of SM structure



First WW Event

- 35,000 selected WW's at LEP2
- Luminosity ~700pb^{-1} per Experiment
- Energies 161 – 209 GeV

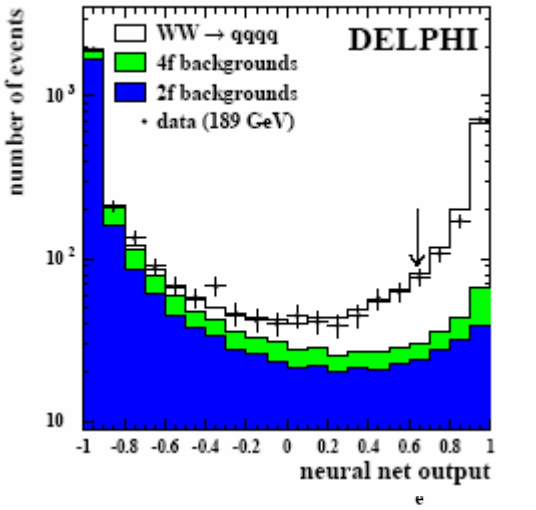


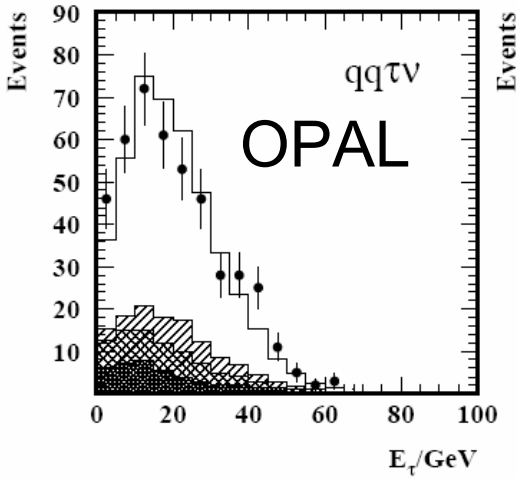
$$e^+e^- \rightarrow W^+W^- \rightarrow q\bar{q}'q\bar{q}'$$

Event Selection

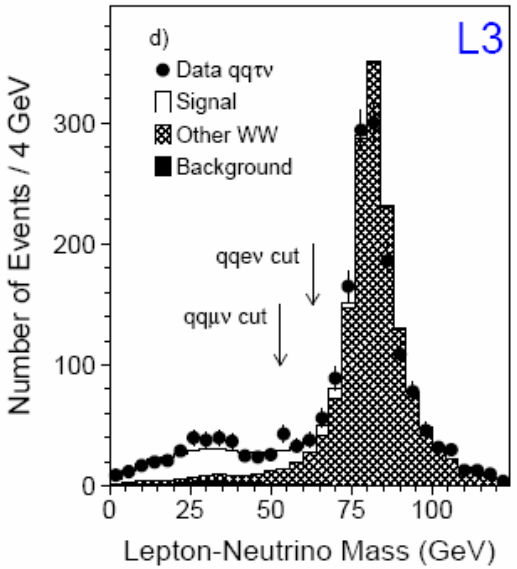
Divide events into final states:

$l\bar{\nu}_l l\bar{\nu}_l (BR = 10\%)$ $q\bar{q}'q\bar{q}' (BR = 46\%)$ $l\bar{\nu}_l q\bar{q}' (BR = 44\%)$

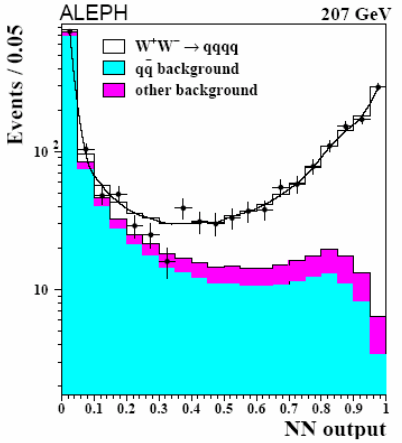




- Event characteristics:
- Jets, leptons
- Backgrounds
- Zγ, ZZ

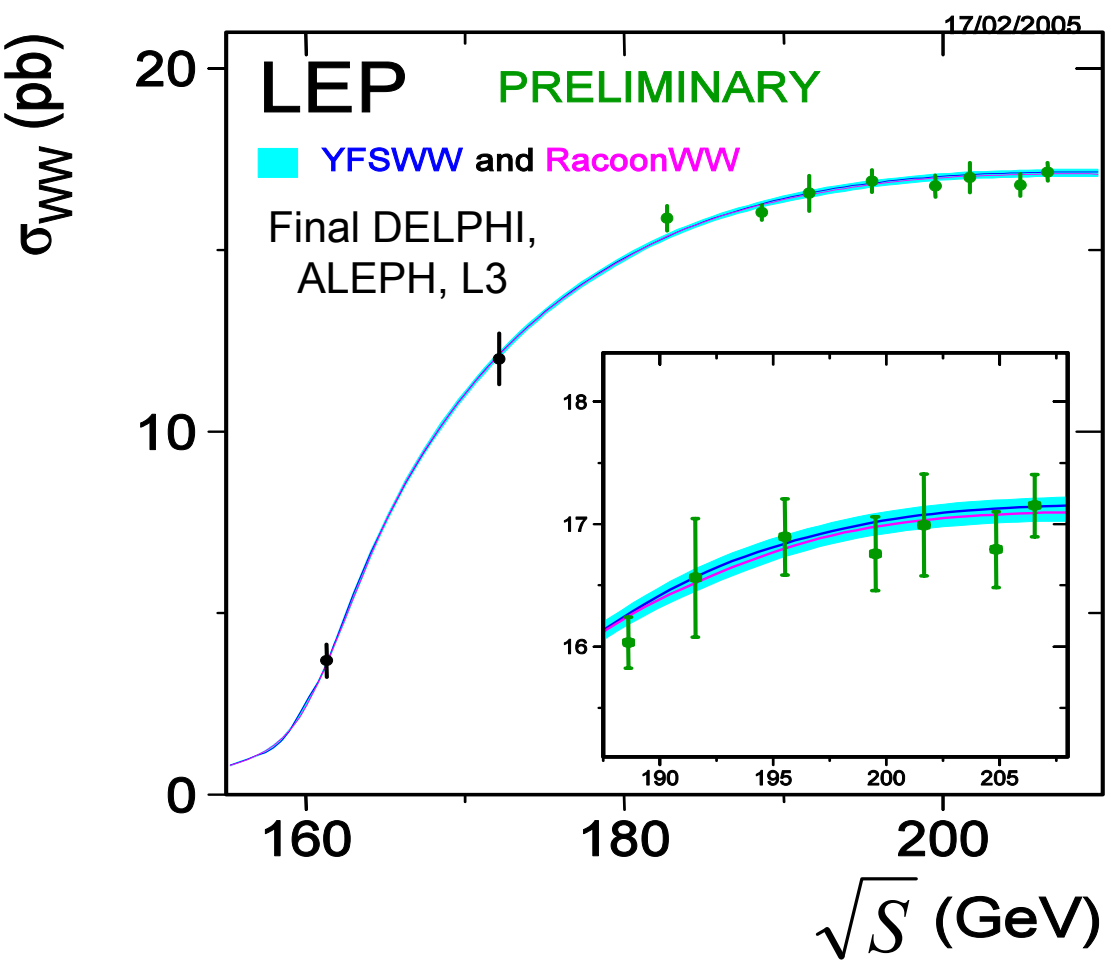


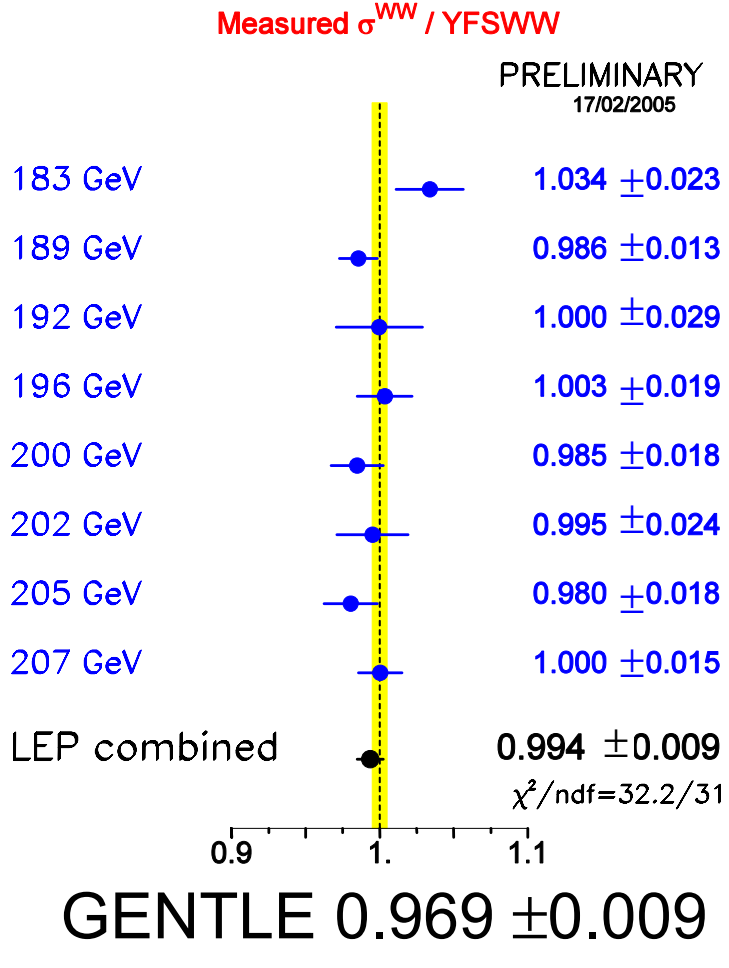
Selections typically: Neural Net, Likelihood based



Final WW cross-section:
DELPHI - Eur.Phys.J.C34:127-144,2004
L3 - Phys.Lett.B600:22-40,2004
ALEPH – CERN PH EP/2004-012

WW cross-section results



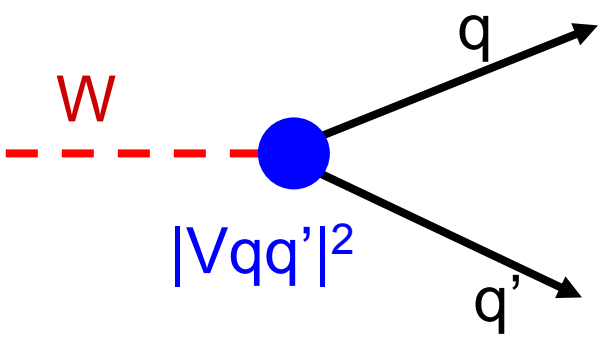


- Measured cross-sections corrected for QM interference with other processes that produce the same final state
- Theoretical error at threshold (IBA) 2%
- Theoretical error above 170 GeV (LPA/DPA) 0.7→0.4%

Winter 2005 - LEP Preliminary

Branching Ratios, Vcs

$$BR_{W\to\bar{q}q'} = \frac{\Gamma_{W\to\bar{q}q'}(|V_{cs}|)}{\Gamma_W(|V_{cs}|)}$$

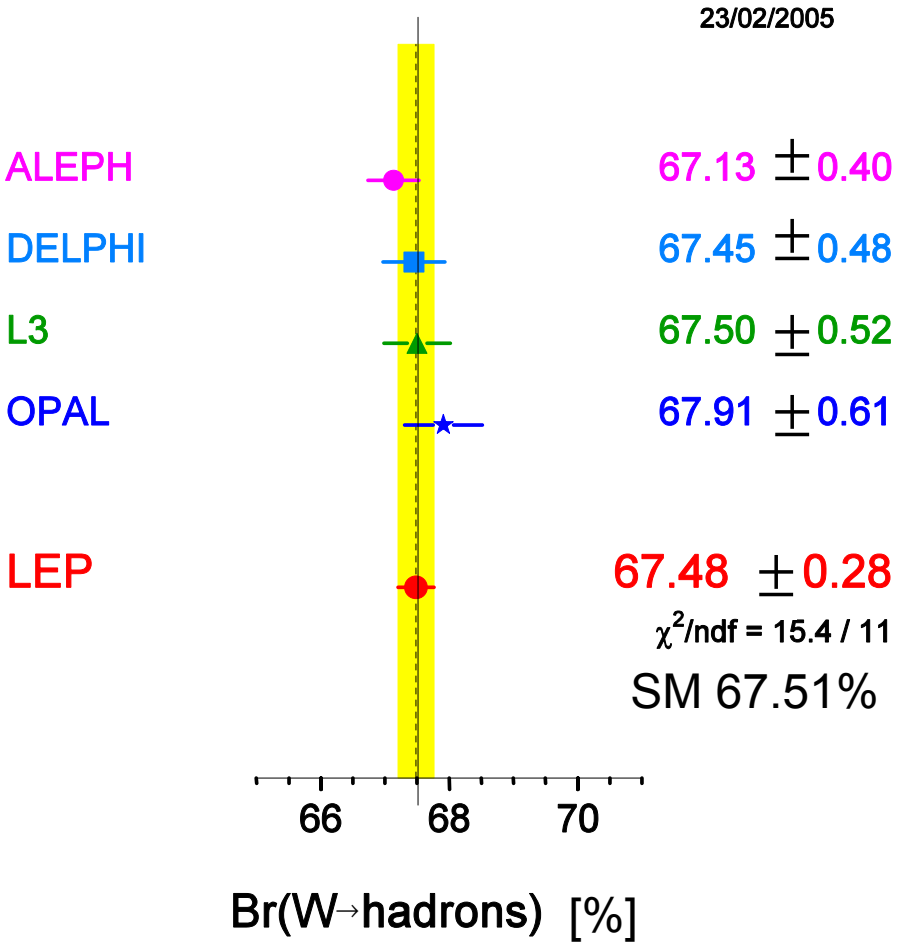


$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 + |V_{cd}|^2 + |V_{cb}|^2 + |V_{cs}|^2$$

$$|V_{cs}|^2 = 0.976 \pm 0.014$$

Assuming measurements of other elements

W Hadronic Branching Ratio

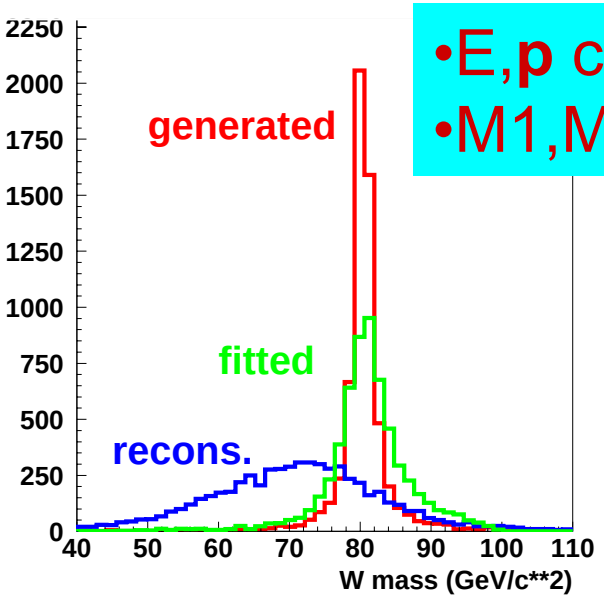


- 3.0 sigma excess in tau decays

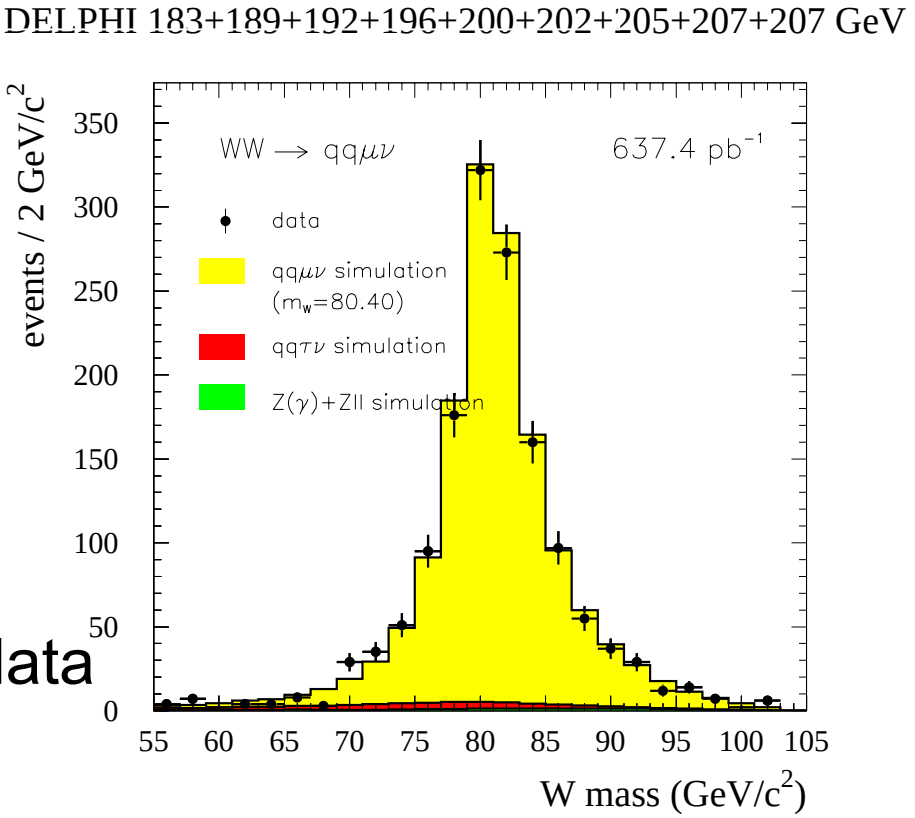
$$2B(W \to \tau\overline{\nu_\tau})/(B(W \to e\overline{\nu_e}) + B(W \to \mu\overline{\nu_\mu})) = 1.077 \pm 0.026$$

W Mass Analysis Technique

- Select Events $l\nu_l q\bar{q}'(BR=44\%), q\bar{q}'\bar{q}\bar{q}'(BR=46\%)$
- Reconstruct lepton and jets (also gluon jets)
- Impose Kinematic constraints
  - improve resolution



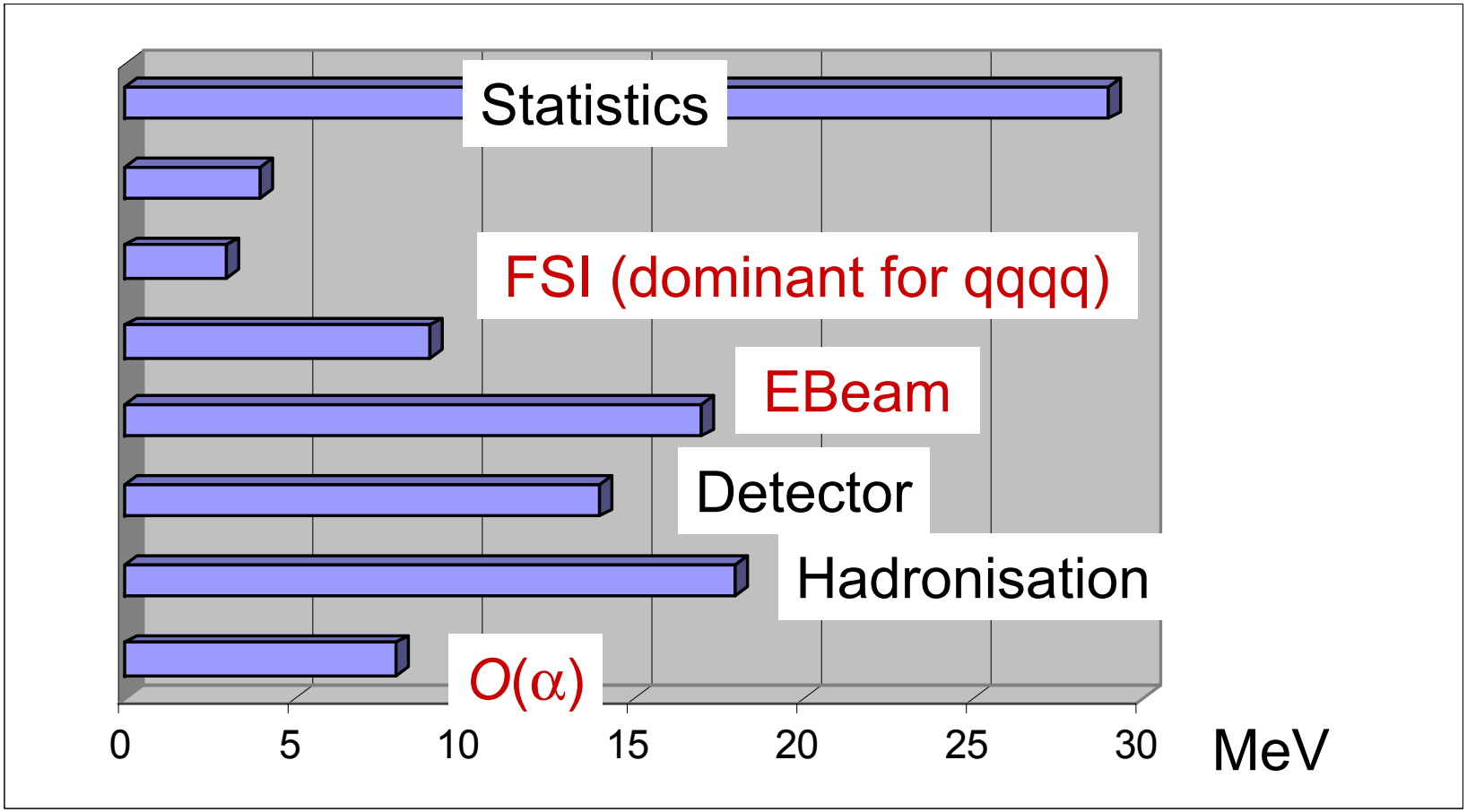
•E,**p** conservation
•M1,M2 or M1=M2



Perform maximum likelihood fit to data
- Calibrate with simulation
- Event by Event Resoultion

LEP W Mass Error Components

Breakdown of components of error



Here, discuss 3 error components

CERN-PH-EP-2004-32

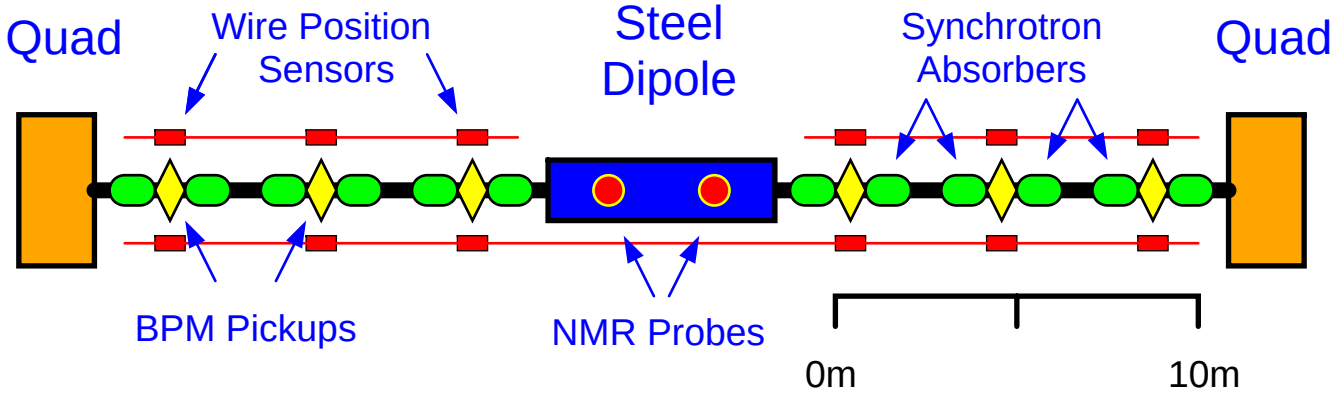
LEP Beam Energy Determination

$$\frac{\Delta M_W}{M_W} = \frac{\Delta E_{Beam}}{E_{Beam}}$$ Correlated between all experiments

- Spin precession frequency of polarised e^+e^- beams (ΔE_{BEAM}=200keV)
  - Polarisation< 60 GeV→ Calibrate other methods
- Measurement of magnetic field of LEP bending magnets
- Synchrotron tune
- Spectrometer

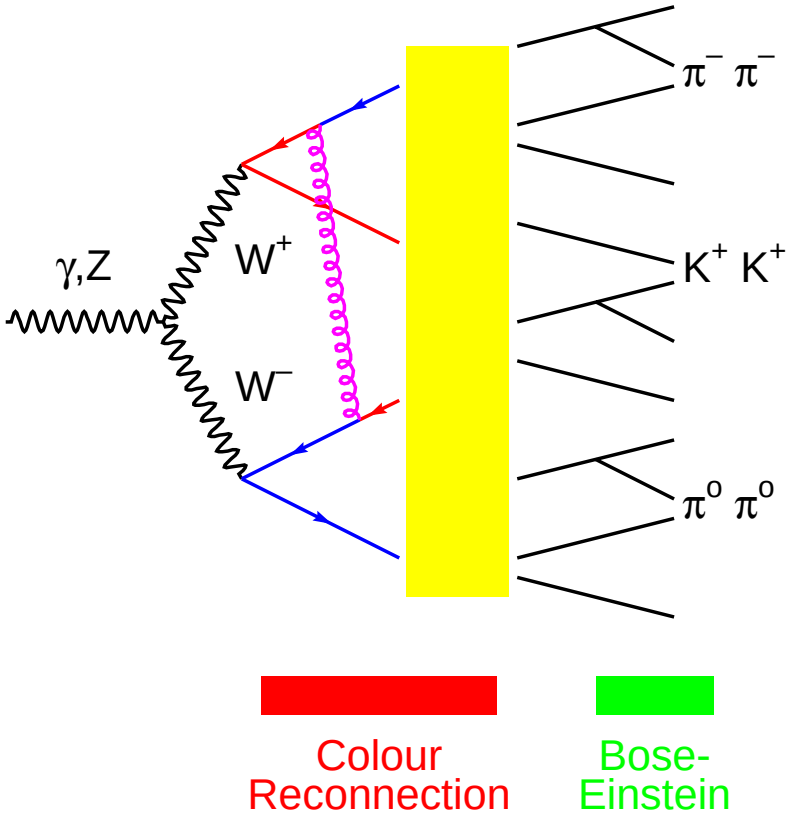
From Ebeam

$$\Delta M_W = 10 MeV$$



Final State Interactions

- W+W- decay vertices separation typically 0.1fm
- Typical hadronisation scale 1fm



BEC: between final state hadrons – identical bosons (pions) close in phase space – ±35 MeV

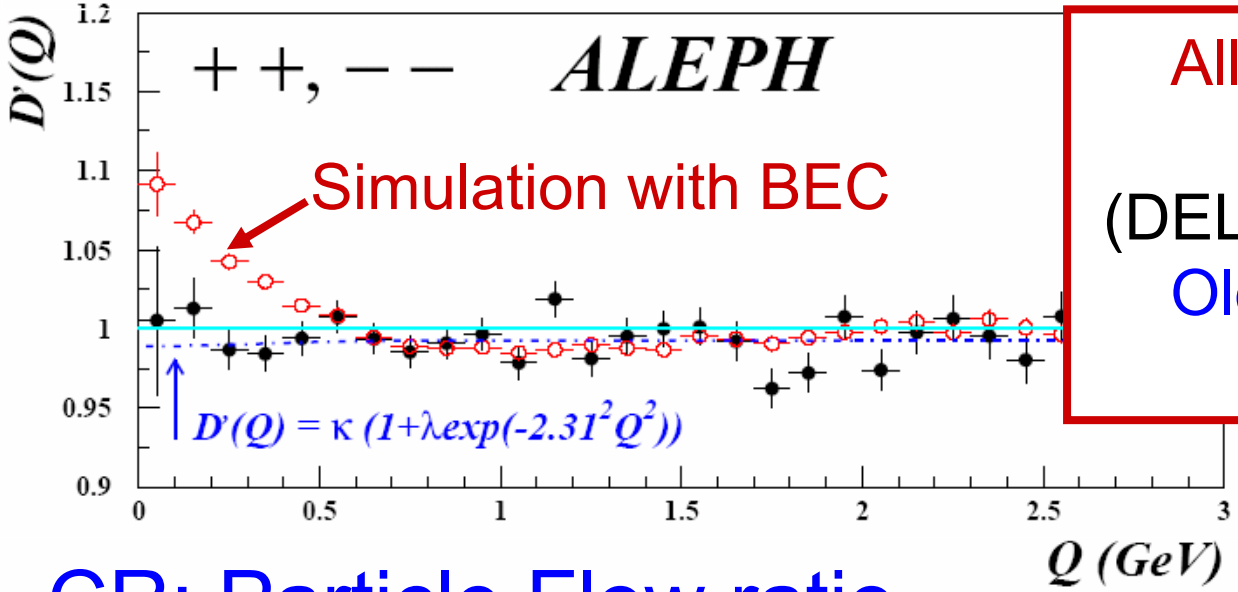
CR: cross-talk between coloured objects in non-perturbative QCD region – ±74-105 MeV

Additional systematic on W Mass for fully-hadronic decays

- Simulation
- Measurements

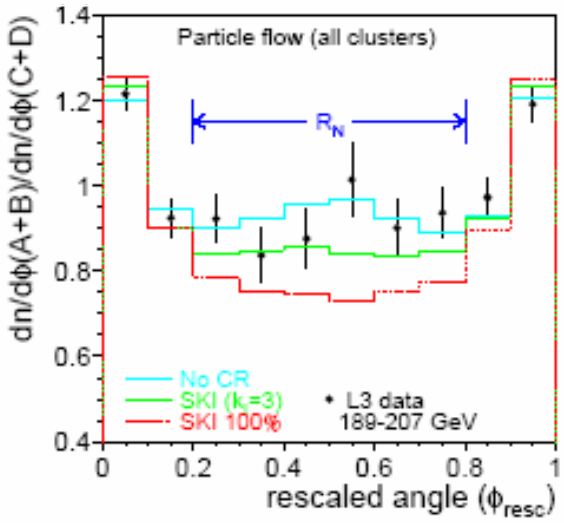
FSI Measurements

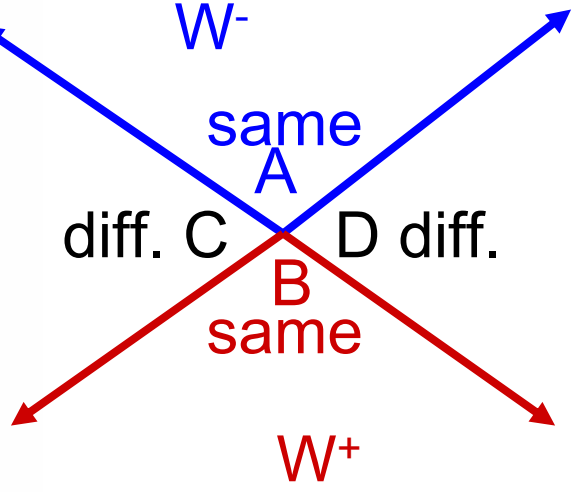
- BEC: compare $q\bar{q}'\bar{q}q'$ with mixed $l\bar{\nu}_l q\bar{q}'$



All expts see no BEC
or reduced BEC
(DELPHI observe at 2.4σ)
Old LEP combination
ΔMW=13 MeV

- CR: Particle Flow ratio

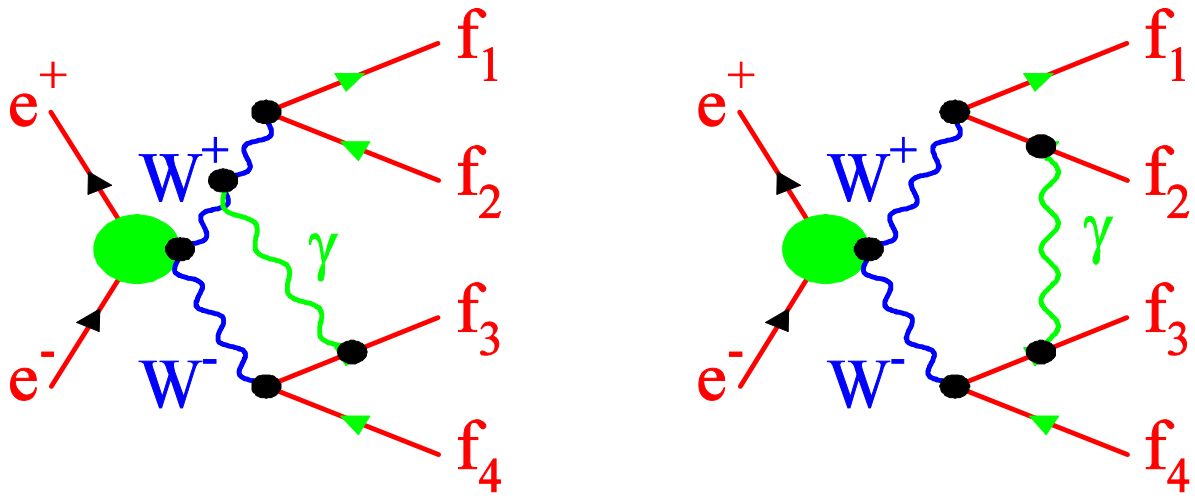




- or Cut inter-jet
  - –Reduce sensitivity of W Mass analysis to CR
  - –Measure CR

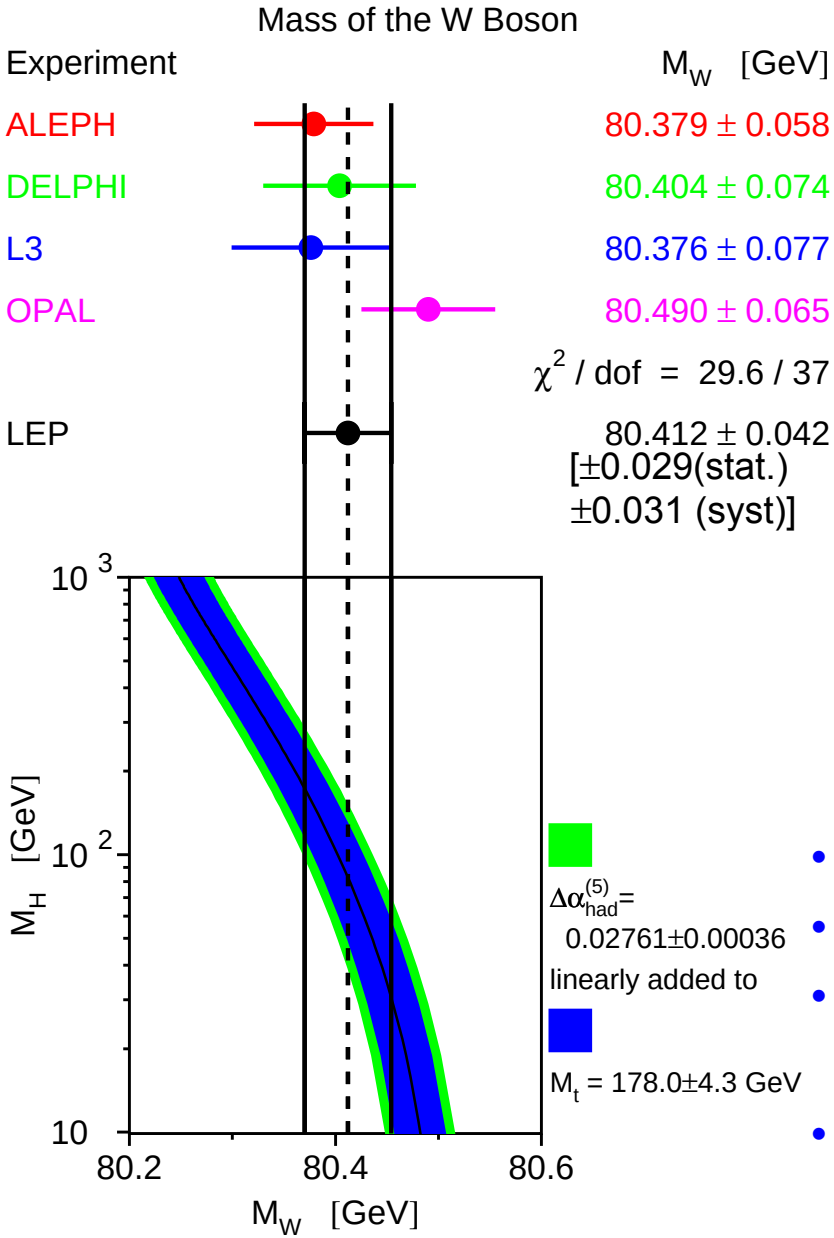
$O(\alpha)$

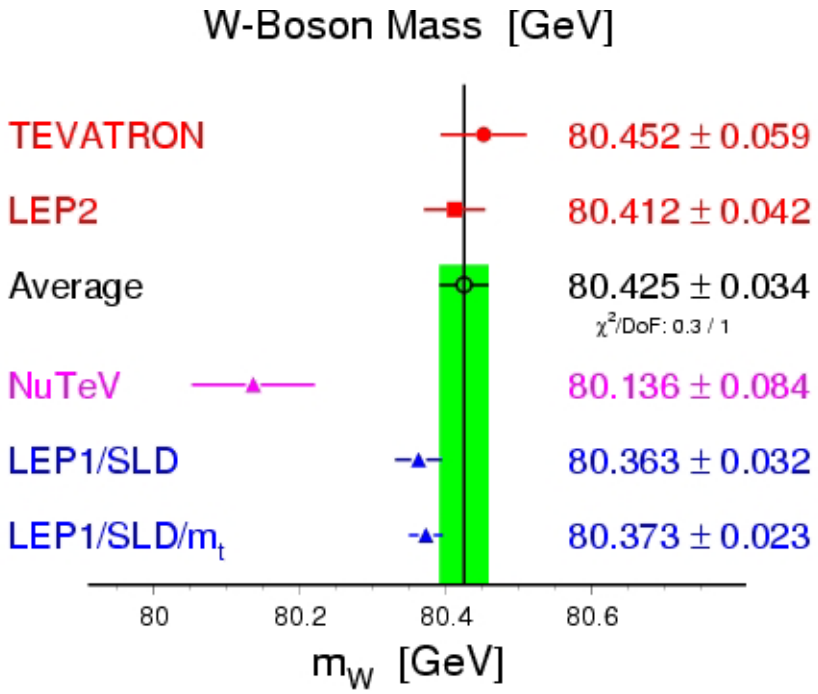
- Simple radiative corrections (IBA)
  - Not sufficient for precision required



- Full $O(\alpha)$ electroweak corrections for 4f (DPA)
  - YFSWW, Racoon WW
- Affect (see DELPHI 2004-050 PHYS 944, F. Cossutti)
  - cross-section
  - differential distributions (w mass, TGCs)
  - Study ISR, FSR, NF $O(\alpha)$ NL $O(\alpha)$, 4f background
  - ΔMW < 10 MeV

World average W Mass



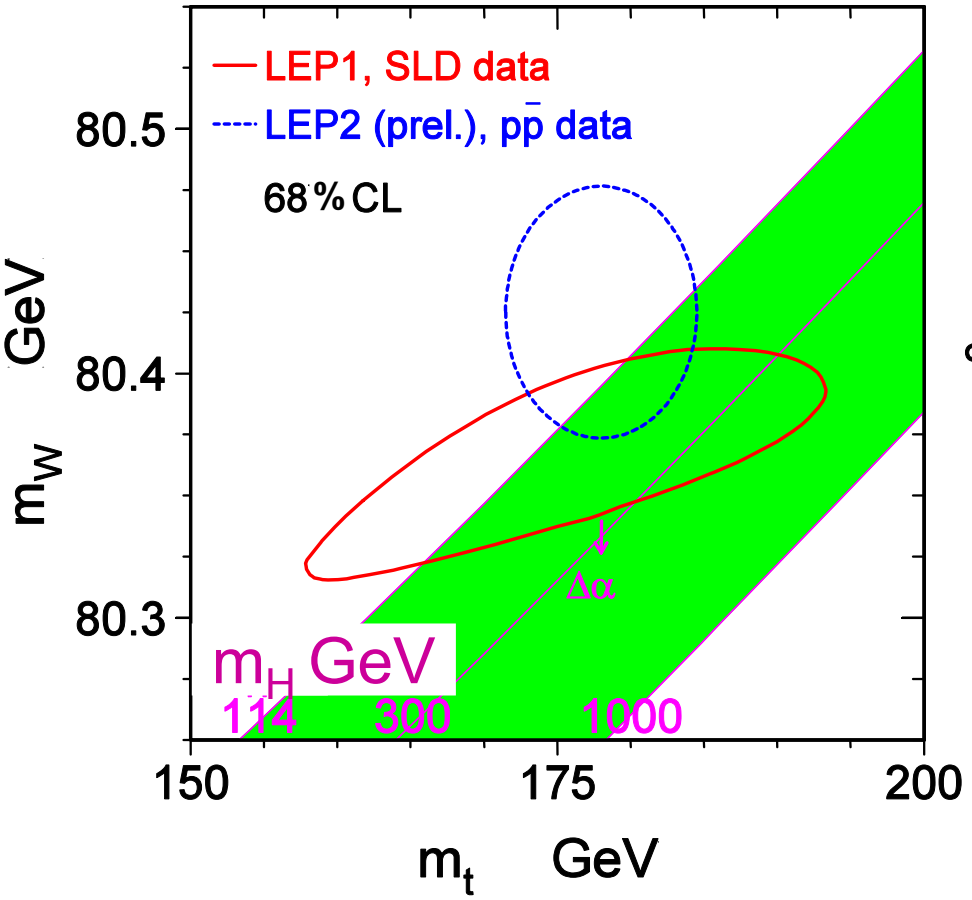


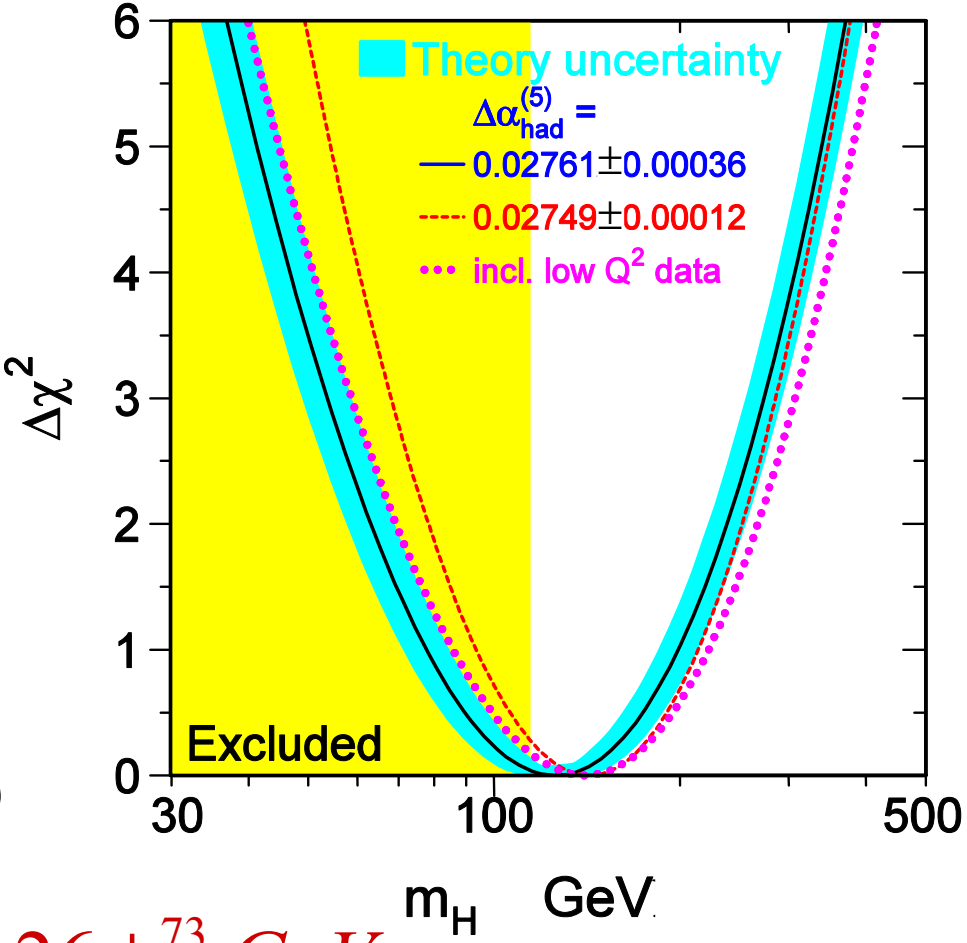
- Weight of qqqq channel in LEP fit 10%
- Mass difference (no FSI) 22±43 MeV
- Stat (no syst.) 21 MeV

- **LEP direct determination of W Width**
  - **2.150 ± 0.068(stat.) ±0.060(syst.) GeV**

Measuring the Higgs Mass

Remember LEP 1 predicted the top mass !



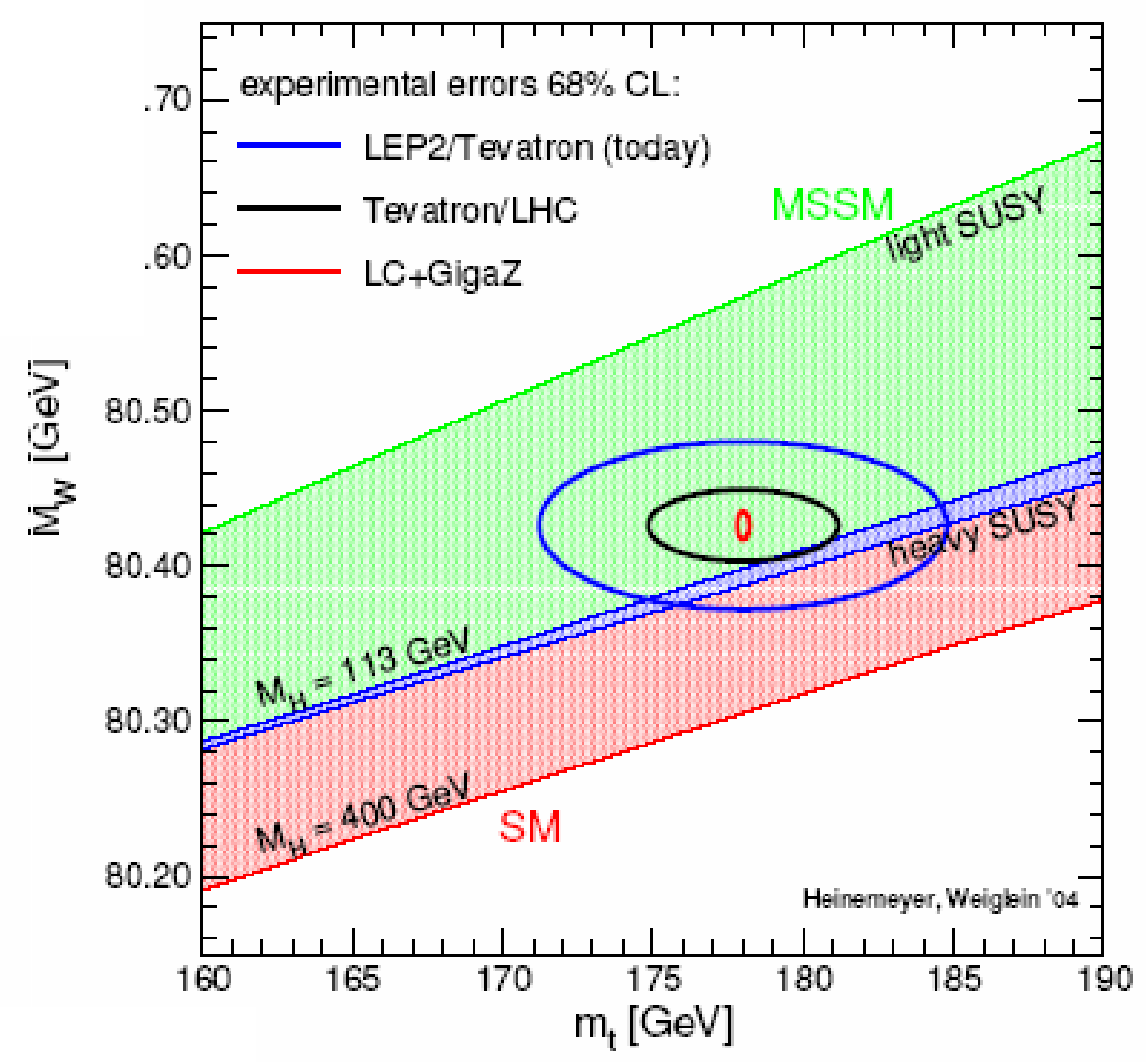


$$m_{Higgs} = 126 \pm^{73}_{48} \; GeV$$

$$m_{Higgs} < 280 \; GeV \; (95\% CL)$$

SUSY?

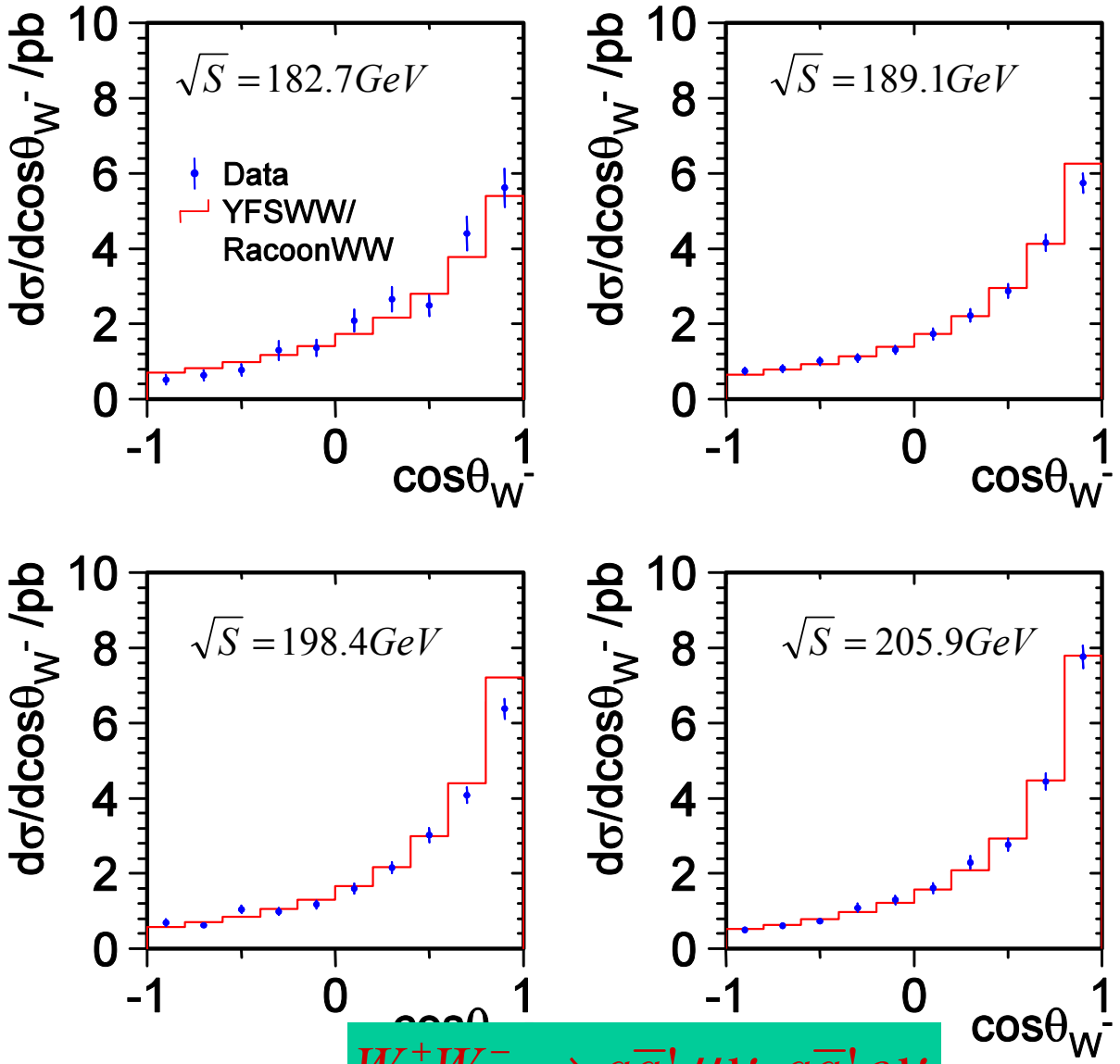
- SM MH varied
- MSSM parameters varied



W Production Polar angle

- Xsec
- Angular decay distributions
- $O(\alpha_{em})$:
  - 1-2% xsec
  - W^- production angle becomes more fwd peaked

LEP PRELIMINARY (ADL)



$W^+W^- \rightarrow q\bar{q}'\mu\nu, q\bar{q}'e\nu$

Triple Gauge Couplings

- Production and decay characterised by five angles (also use xsec)

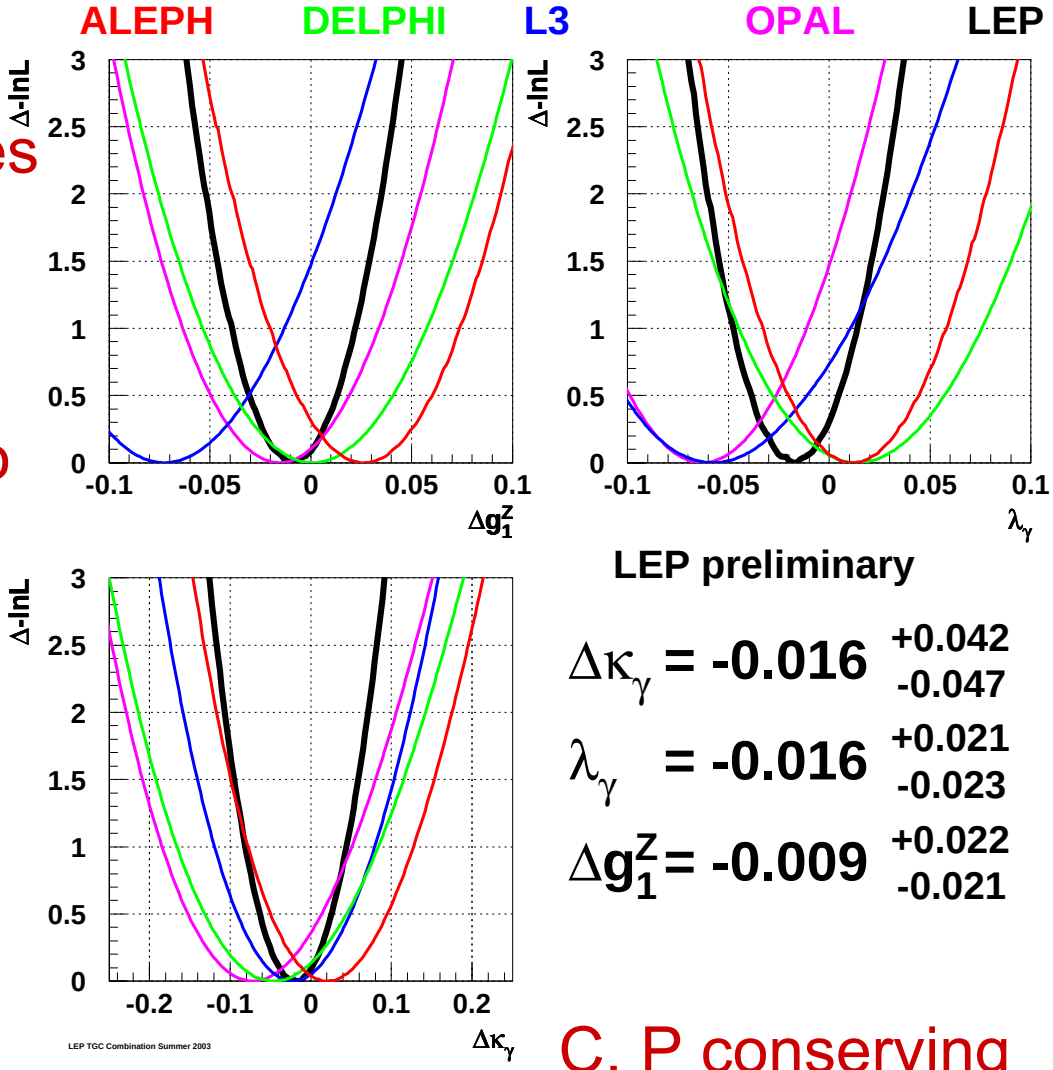
- Model as function of anomalous contributions to TGC vertex

- Can relate parameters to:

$$\mu_W = e(1+\kappa_\gamma+\lambda_\gamma)/2m_W$$

$$q_W = -e(\kappa_\gamma-\lambda_\gamma)/m_W{}^2$$

Final combination
Expected summer '05



LEP preliminary

$\Delta\kappa_\gamma$ = -0.016 $^{+0.042}_{-0.047}$

λ_γ = -0.016 $^{+0.021}_{-0.023}$

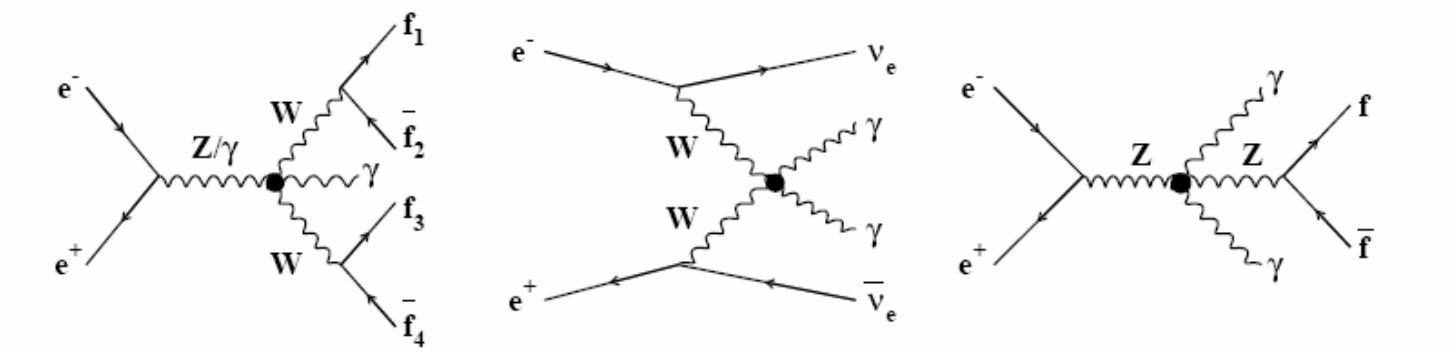
Δg_1^Z = -0.009 $^{+0.022}_{-0.021}$

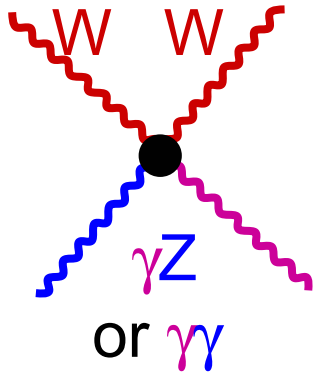
- Weυ improves sensitivity to k_γ

- LEPII Also ZZγ^*/ZZZ* TGCs

C, P conserving
emag. gauge invariant
WWZ, WWγ

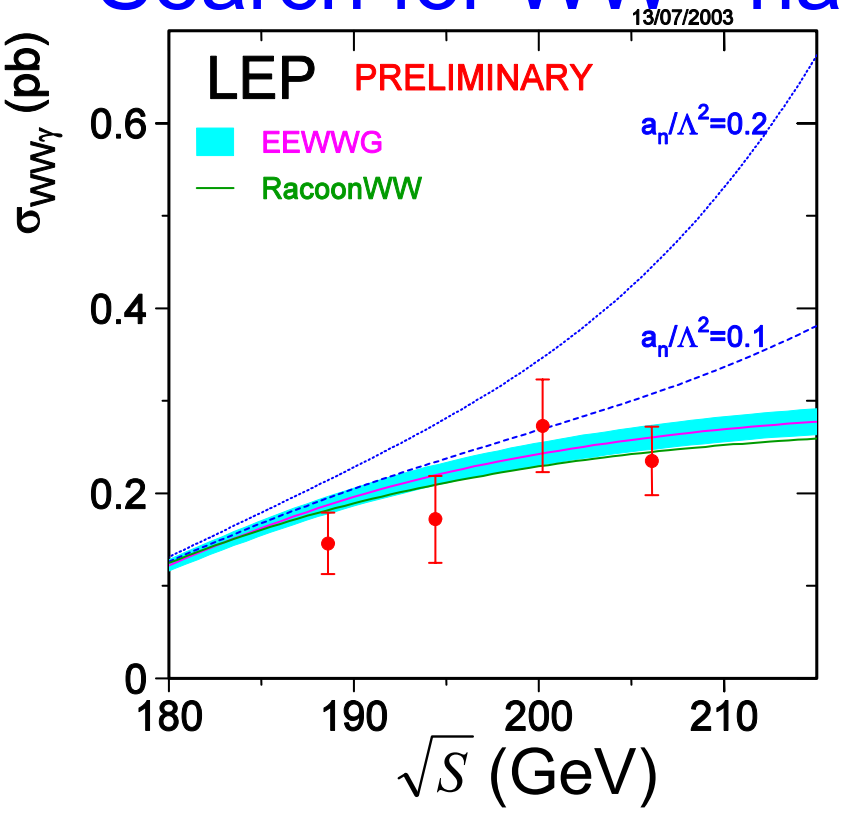
WW Quartic Couplings



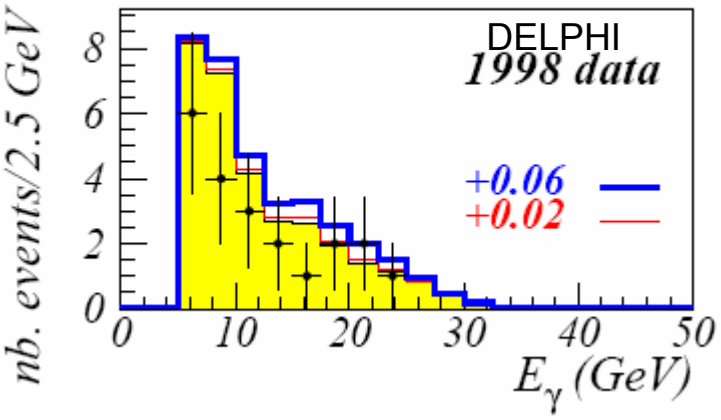


All experiments have results, combination summer '05

- Search for WW+ hard γ

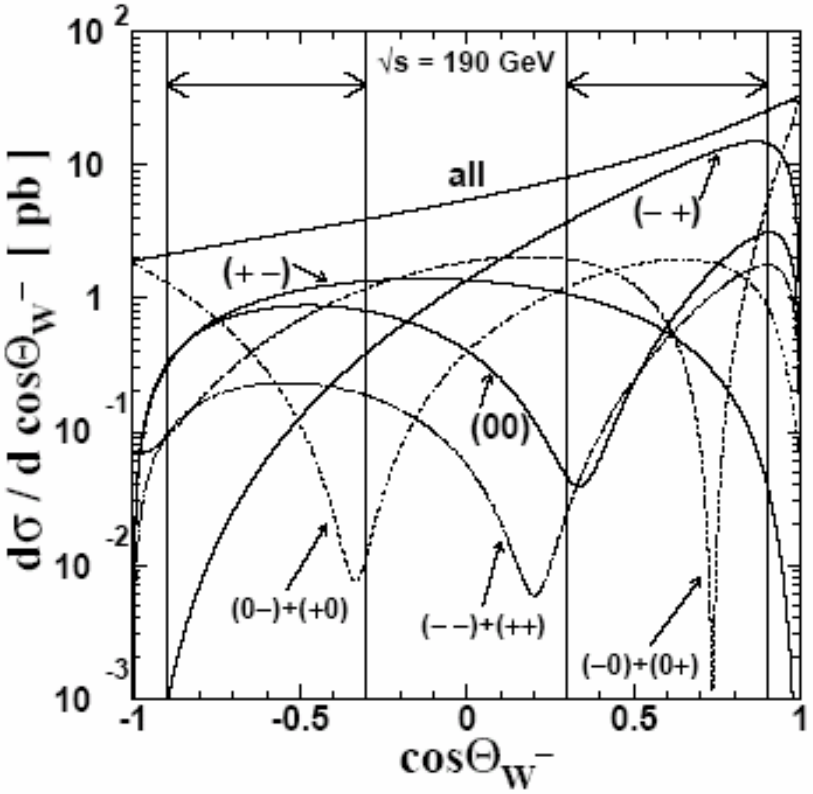


Measure cross-section
- SM QGCs below sensitivity
- Limits on anomalous QGCs

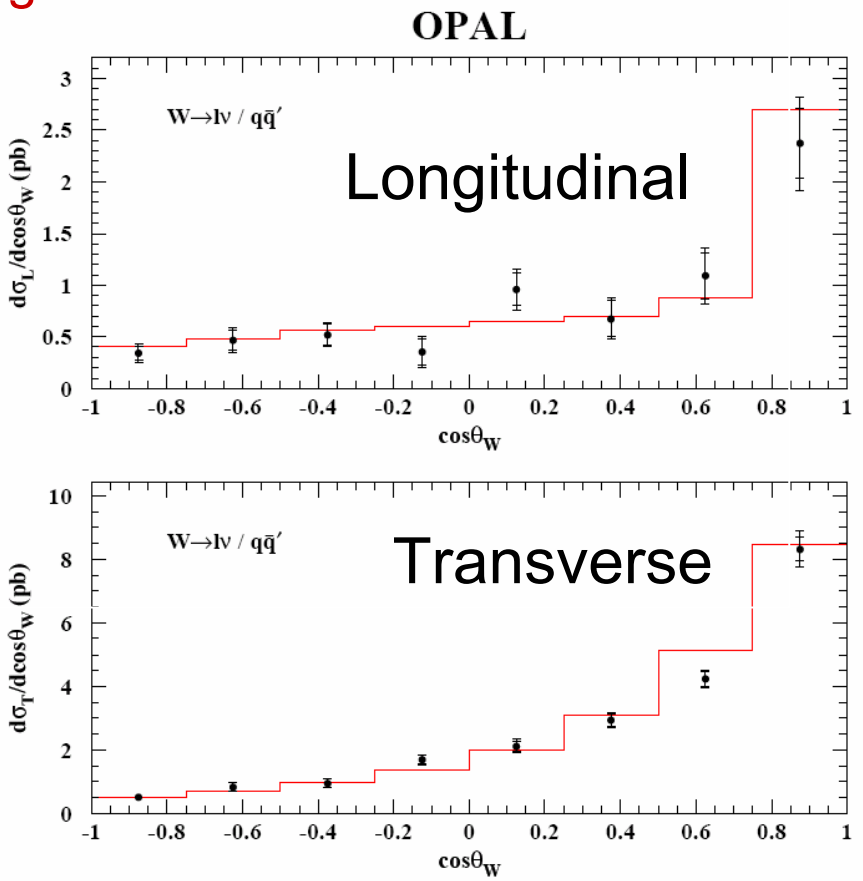


Spin States of W bosons

- Longitudinal W ←e/weak symmetry breaking
- W^- / W^+ spin state comparison sensitive to CP violation
- Use W production and decay angles

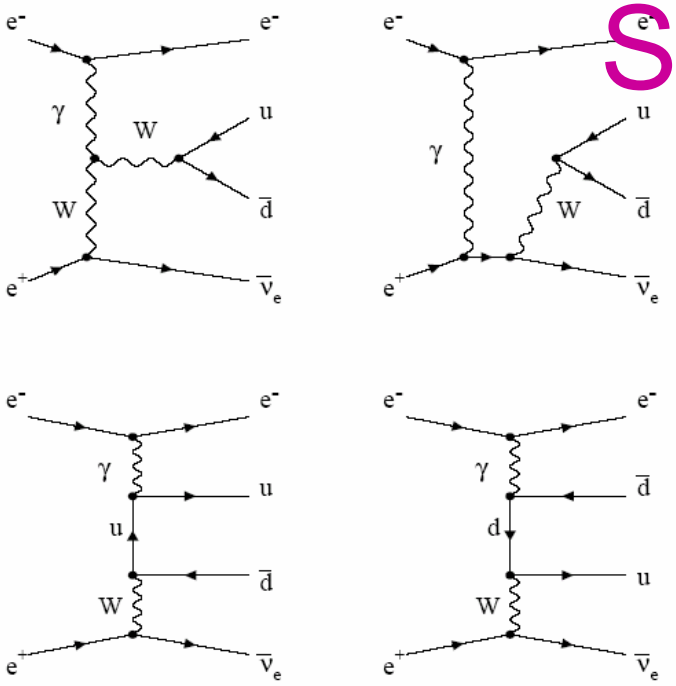


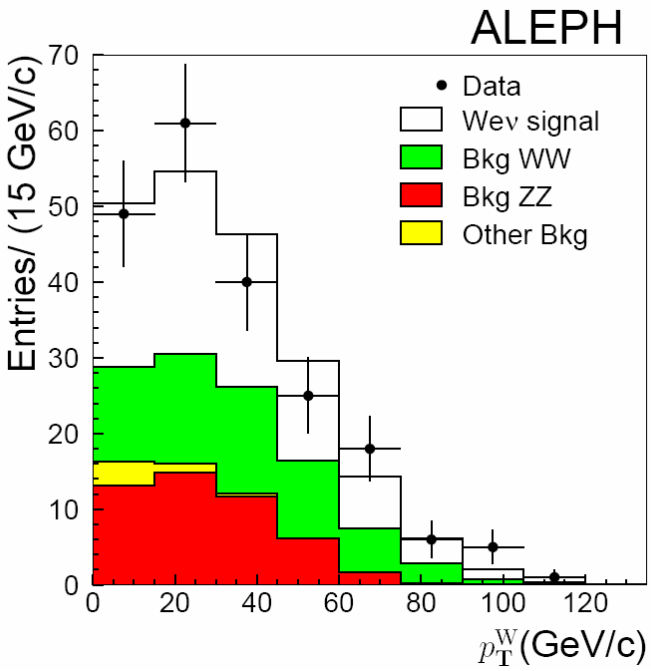
Spin Density Matrix analyses

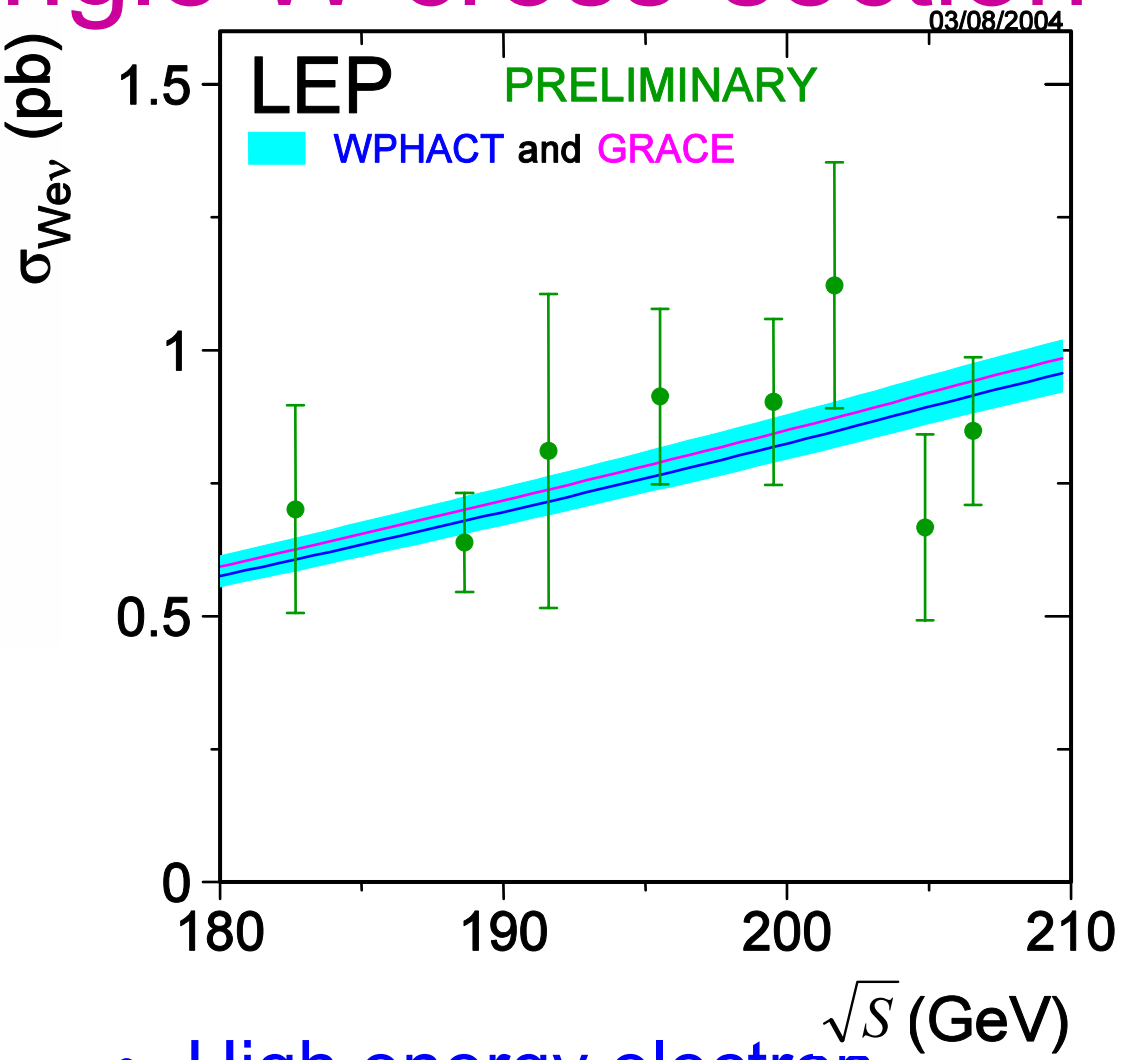


Fraction of longitudinal Ws (DLO)
23.6±1.6% (SM 24.0±0.1%)

Single W cross-section



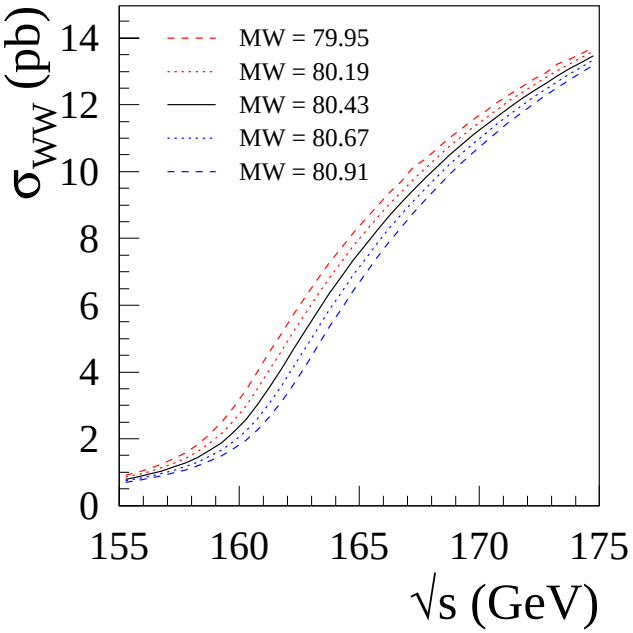




- High energy electron
- W hadronic decay or μυ or τυ, or eυ not fwd

The Far Future: ILC

G. Wilson



- $\delta MW \sim \pm 7$MeV

Measure the cross-section at threshold
→measure mass

Measurement made at LEP with 10pb^{-1}
Sensitivity ~ same at direct reconstruction

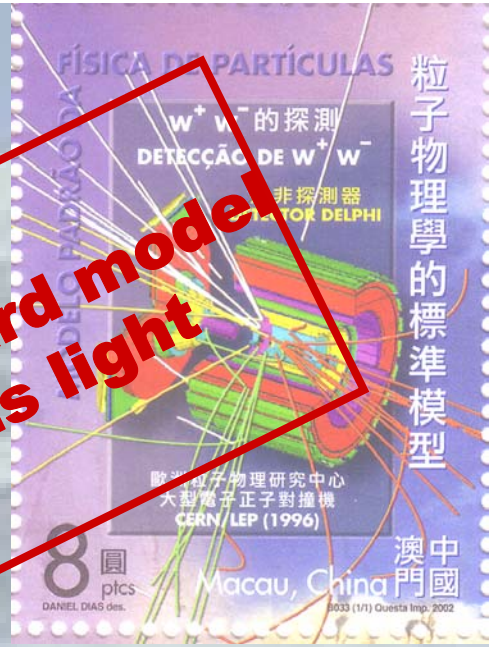
The difficulties:

- Luminosity
  - LEP 700pb^{-1}→
  - ILC 10^7 s, 100fb^{-1}
- Determine Background
  - At threshold t-channel ν diagram, $e_L^+ e_R^-$ Polarised beams can turn off signal !
- Theory: $\rightarrow \frac{\Delta\sigma}{\sigma} = 0.05\%$
  - To obtain error of 1MeV
  - GENTLE $\delta M_W = \pm 24$MeV
  - Full $O(\alpha)$ calculation in threshold region,~ 10^4 Feynman graphs
- Ebeam
  - Spectrometer, calibrate to M_z
  - $Z\gamma$ radiative return

Dear All,

Having a lovely time.

- WW cross-section, ±1%
- BR, Vcs
- TGCs, QGCs, SDM
- W Width **2.150 ±0.091 GeV**
- W Mass **80.412 ±0.042 GeV**



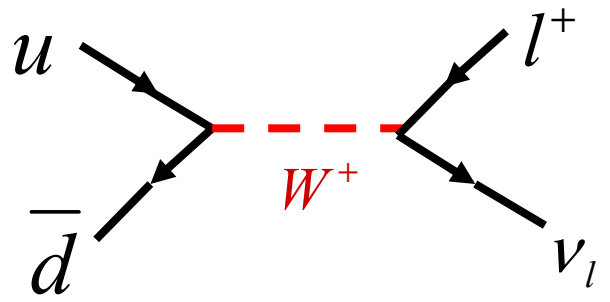
The standard model Higgs is light

m_{Higgs} < 280 GeV (95% CL)

Not sure how reliable the postal service is from a mountain top, so MW may be measured to ~7 MeV (ILC)

by the time this arrives …

The near-ish Future: TeVatron, LHC

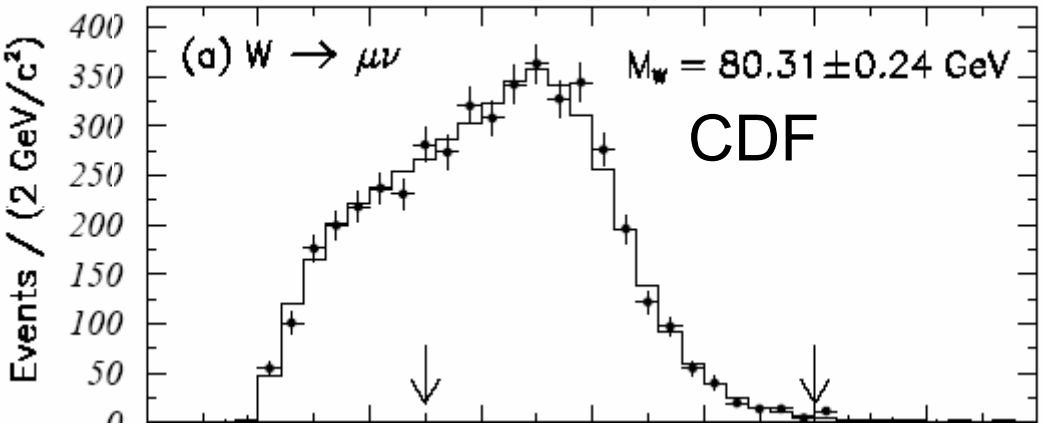


- LEP+TeVatron Run II δMW~±30 MeV
- LHC δMW~±15 MeV

Transverse mass

$$M_W^{T\,2} = (2\,p_l^T\,p_\nu^T(1-\cos\Delta\phi))$$

- No knowledge of longitudinal ν momentum
- Transverse υ momentum from missing momentum



- Systematics limited→ Statistical Error 2 MeV for 10fb^{-1}
  - –Lepton energy scale, use $Z\rightarrow l^+l^-$ i.e. measure m_W/m_Z
  - –Parton distribution functions →W longitudinal p→lepton acceptance

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W Leptonic Branching Ratios