Electro-weak precision measurements in e^+e^- annihilation into bosons

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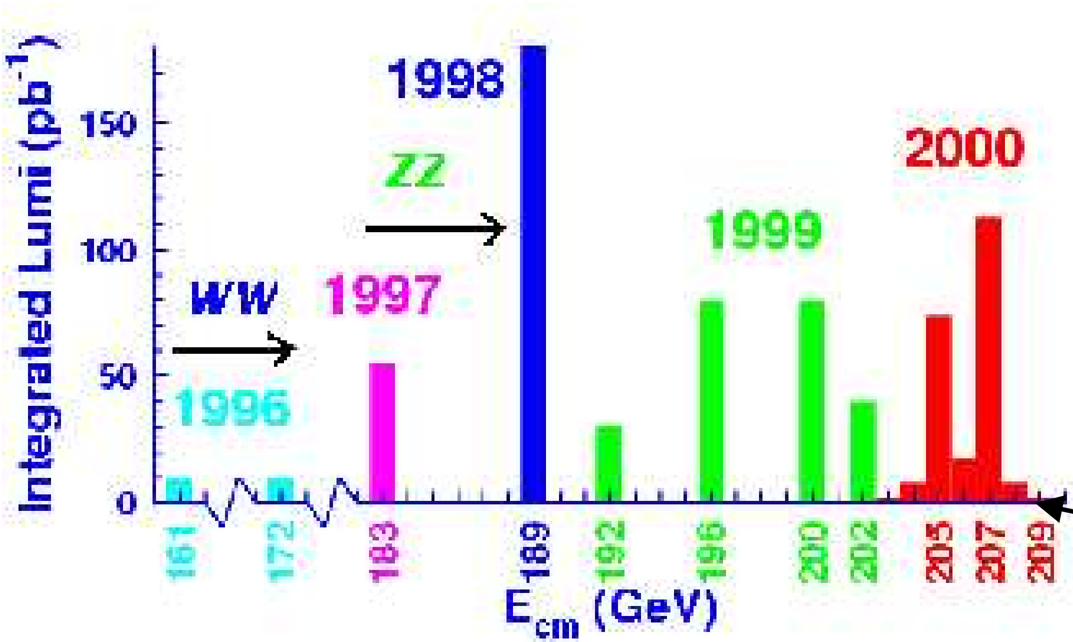
on behalf of the LEP collaborations

- Four fermion processes:
  cross-sections and boson couplings
- The W mass and the (in)direct hunt for the Higgs

RADCOR02, 10th September 2002

Collected data

Collected statistics per experiment in the period 1996-2000:



Event yield/experiment:

WW ~ 10000 (σ_{SM} ~ 17 pb)

ZZ ~ 500 (σ_{SM} ~ 1 pb)

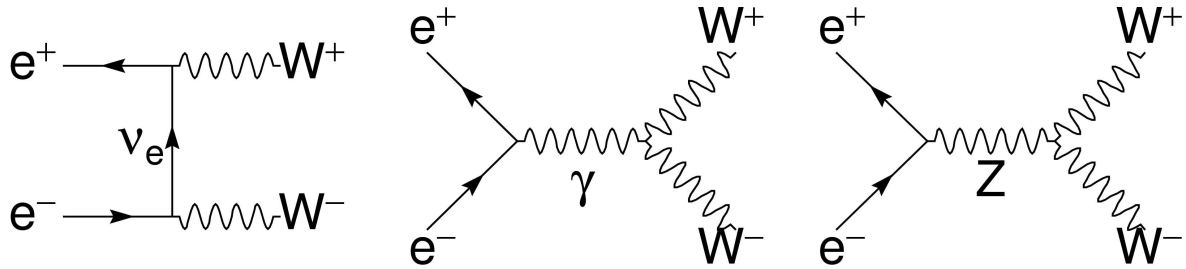
$\gamma\gamma$ ~ 4000 (σ_{SM} ~ 10 pb)

maximum energy: 209 GeV

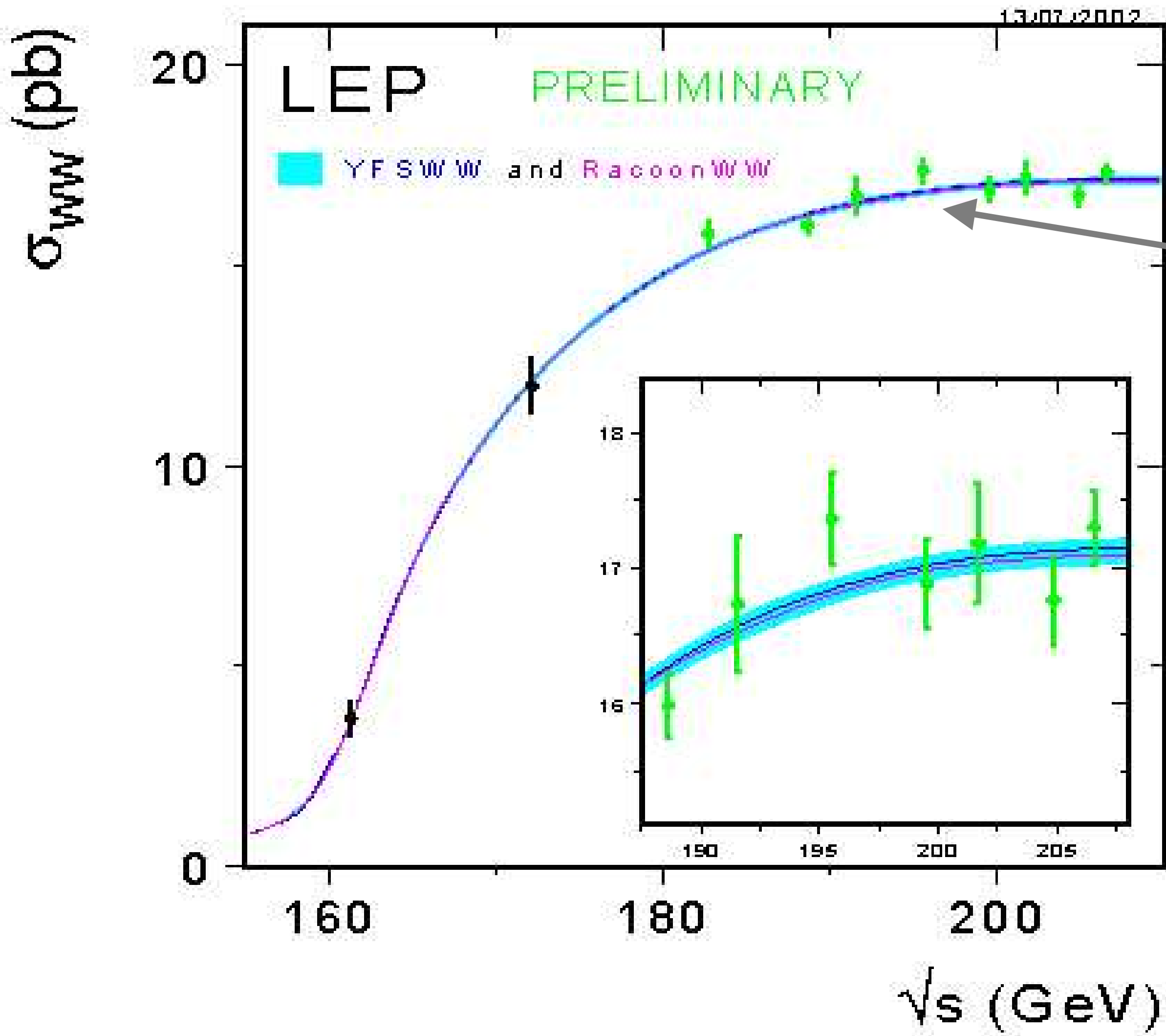
⇒ Integrated luminosity per experiment ~700 pb^{-1}

The presented results are preliminary and obtained with full statistics unless differently indicated

CC03 final states



Channel	BR(%)	ε (%)	p (%)
qqqq	**45.6**	**~85**	**~80**
qqlν	**43.8**	**~70**	**~95**
lν lν	**10.6**	**~60**	**~85**



Use O(α) EW corrections in DPA ($\delta\sigma_{WW}$ ~0.5%) (RacoonWW, YFSWW)

Excellent agreement between predictions and data

⇒ σ_{WW} measurement at LEP2 can test theory at the ≤1% level

Comparison with theory: R_{WW}

Correlated (energy/experiment) average of $R_{WW}=\sigma_{meas}/\sigma_{theory}$ gives indication of the global accuracy from data

$R_{WW}=(0.999\pm0.065_{stat}\ \pm0.090_{syst})$ -RacoonWW-

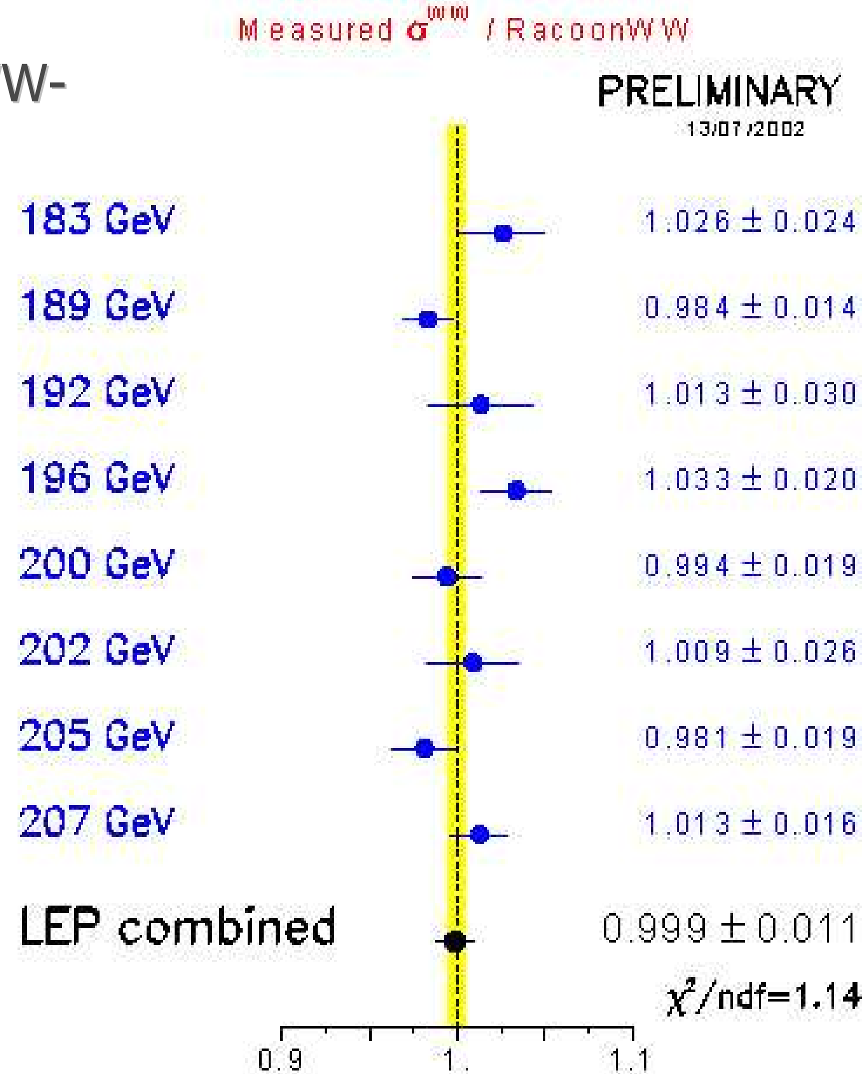
$R_{WW}=(0.978\pm0.011)$ KoralW at LEP

⇒ measurement is dominated by the systematic errors

⇒ particularly worrying are the correlated errors (fragmentation, detector)

⇒ ongoing work towards the final results 0.9% is in our reach …

⇒ final accuracy allows sensitivity to the more correct implementation of $O(\alpha)$!



YFSWW agrees at 0.2% level

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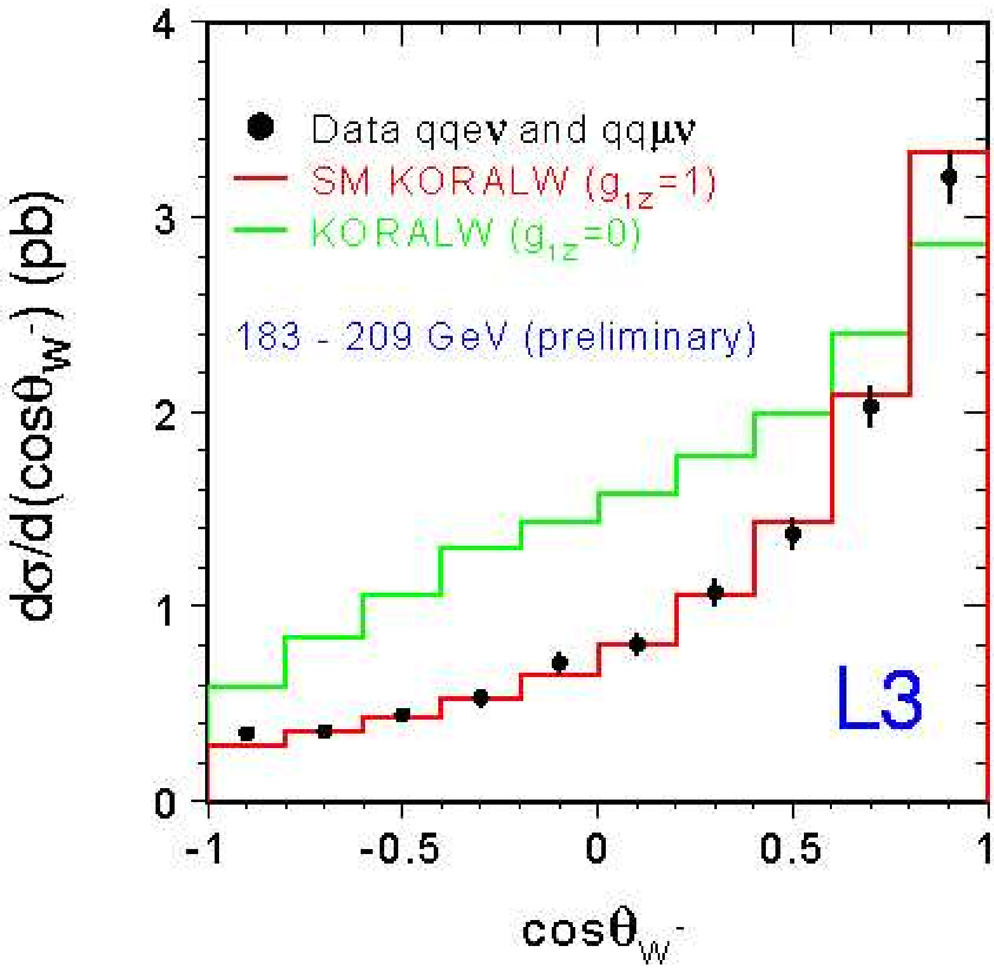
W angular distributions

O(α) corrections introduce important distortion in the W angular distributions (2% steeper slope!) ⇒ towards a LEP $d\sigma/d\vartheta_{W-}$ LEP combination



Only $qqe\nu_e$, $qq\mu\nu_\mu$ channels with $\vartheta_{e,\mu}>20^o$ are used:

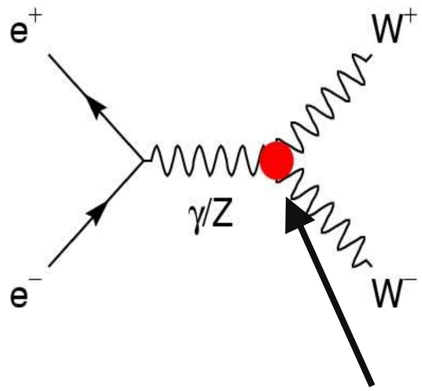
- high purity final states
- cleaner W charge reconstruction
- use only detected phase space

CALO5 photon recombination scheme used to 'define' a W

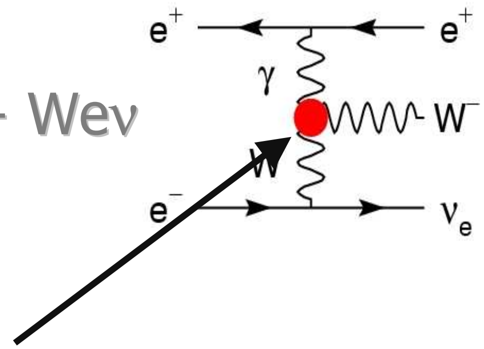
Combine in energy intervals to increase statistics

⇒ will be able to test slopes at <2% level, direct comparison with future calculations

Charged Triple Gauge Couplings



WW + Weν



To test the non-abelian structure of the SM and find signals of new physics

Single parameter fit results:

$$g_1^z = 0.998^{+0.023}_{-0.025} \quad [1]_{SM}$$

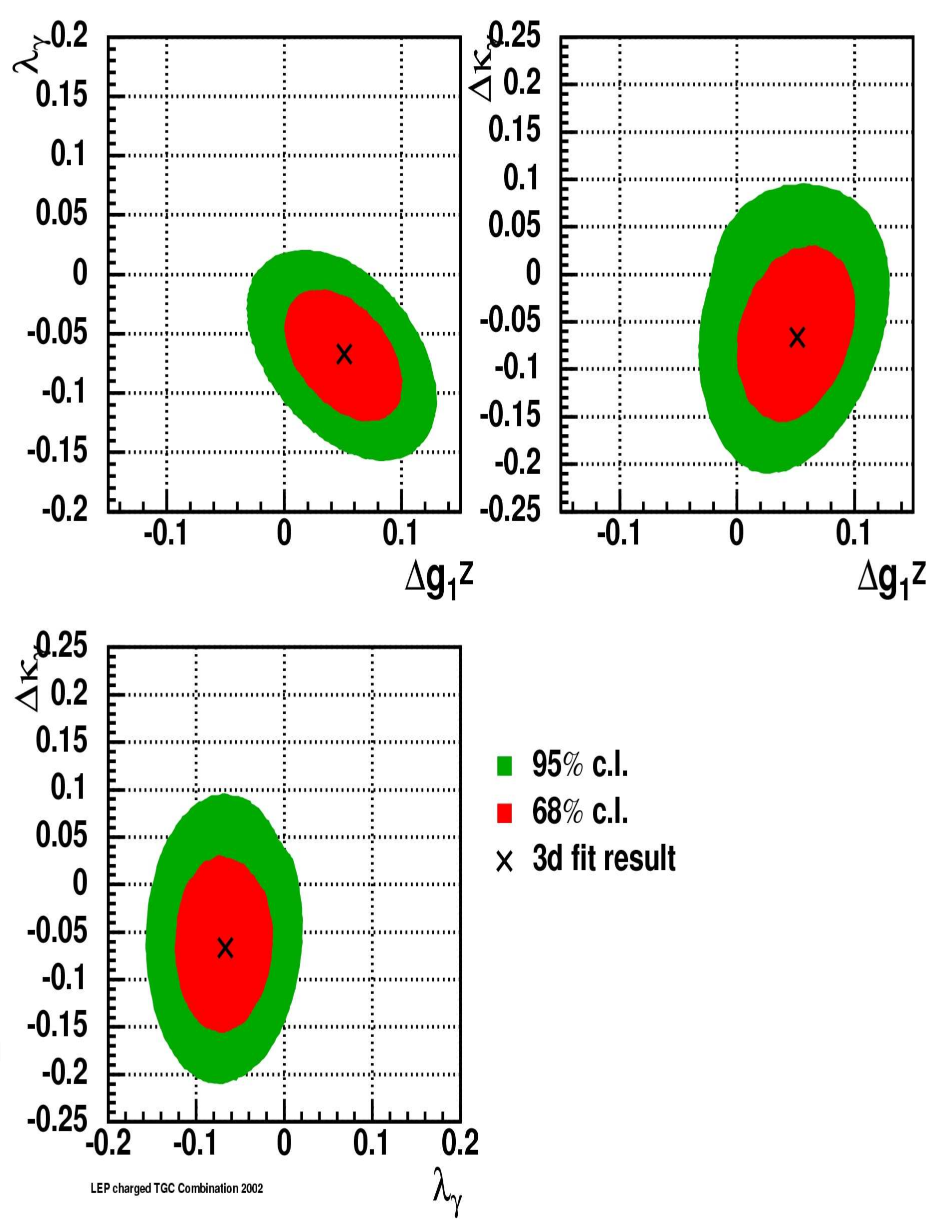
$$\lambda_\gamma = -0.020^{+0.024}_{-0.024} \quad [0]_{SM}$$

$$\kappa_\gamma = 0.943^{+0.055}_{-0.055} \quad [1]_{SM}$$

main systematic: O(α) corrections

- full effect still used as conservative estimation (δg_1^z=0.015, $\delta\lambda_\gamma$=0.015, $\delta\kappa_\gamma$=0.039)
- ongoing studies at parton and full-sim level suggest much smaller relative uncertainties

DELPHI L3 OPAL 3D Fit - Preliminary



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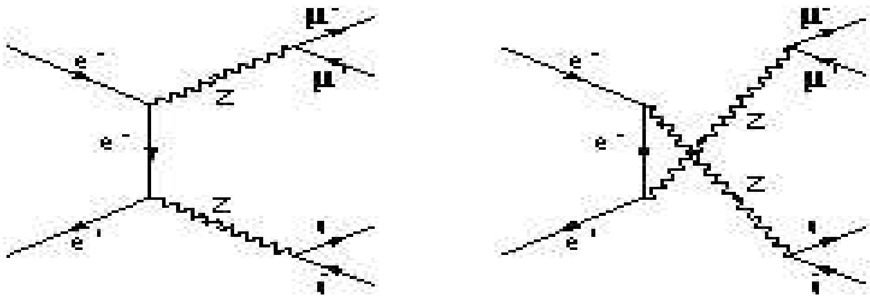
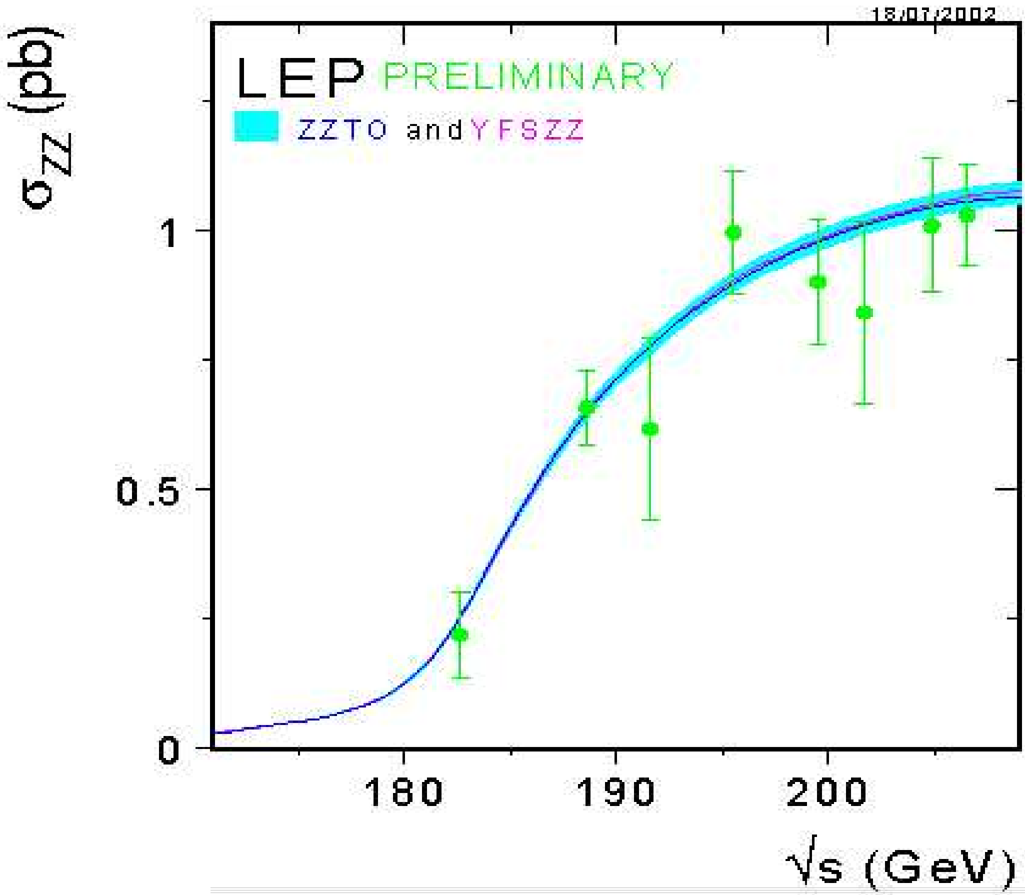
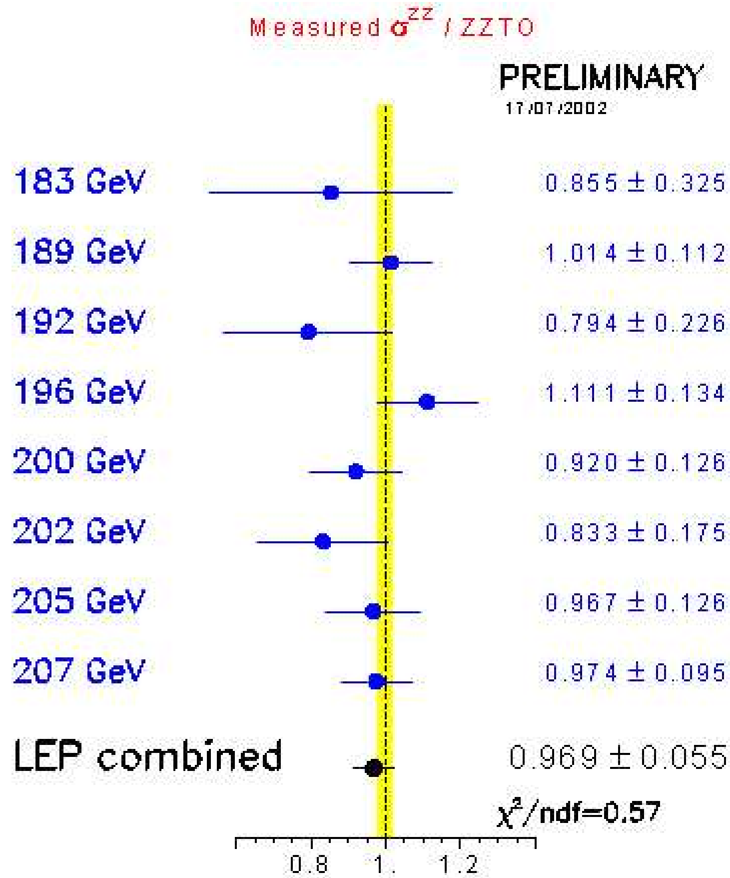
NC02 final states



Final states	qqqq	qqνν	qqll	llνν	$l_1l_1l_2l_2$
BR(%)	49%	28%	14%	4%	1%





2% theory uncertainty compares to ~5% experimental total precision

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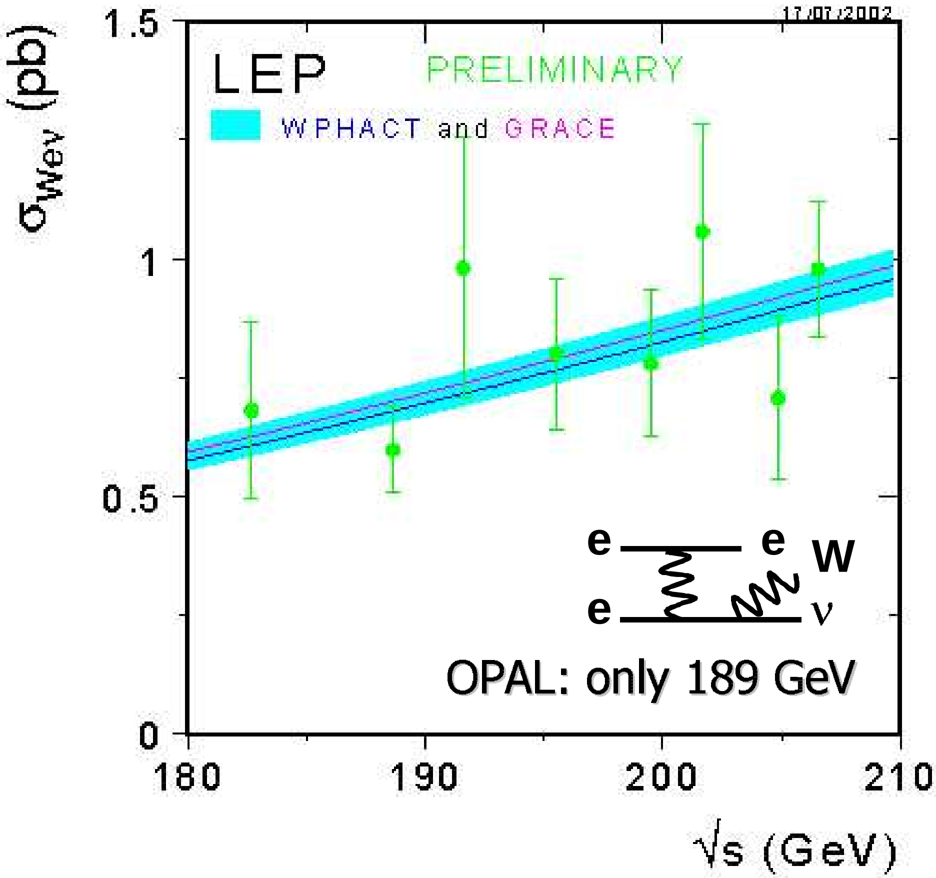
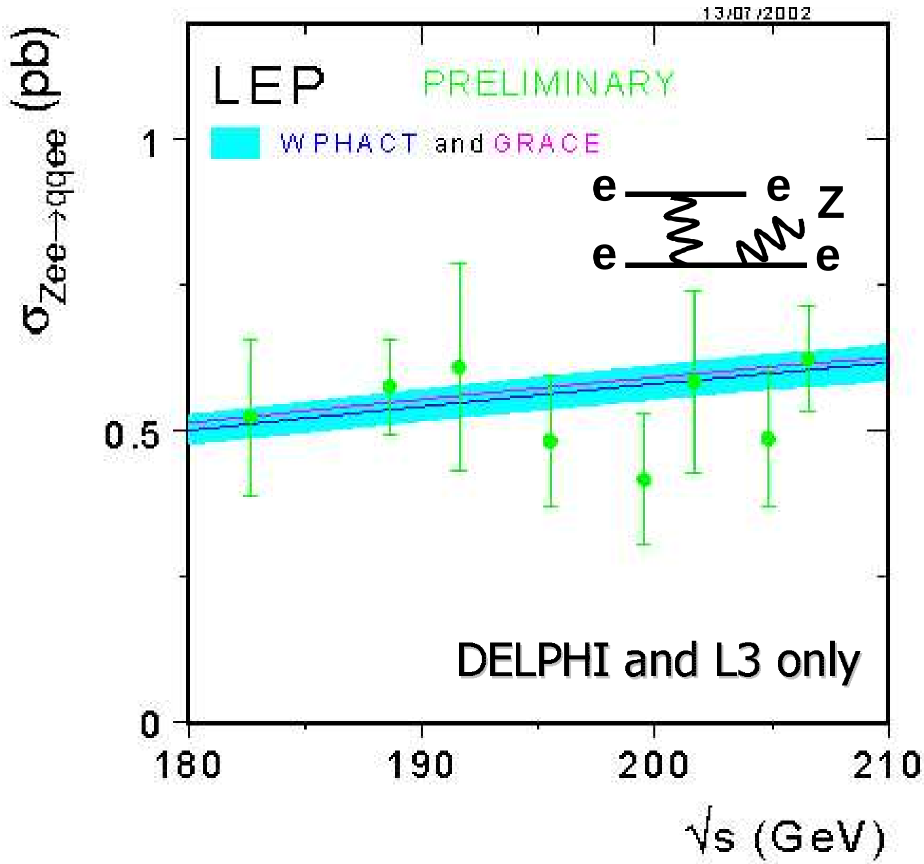
Other 4f phase space

Other regions of the phase space are studied: signals are defined with cuts



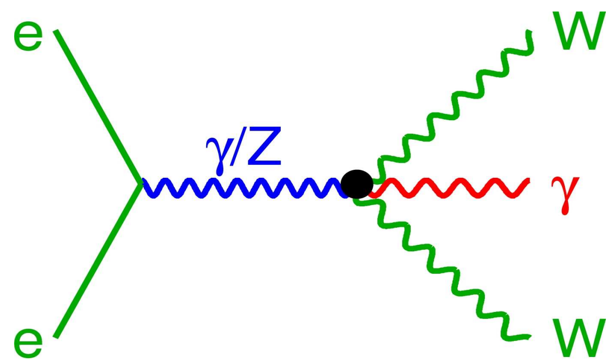


$R_{We\nu}$=0.949±0.078 (GRACE)
$R_{We\nu}$=0.978±0.080 (WPHACT)

R_{Zee}=0.928±0.088 (GRACE)
R_{Zee}=0.951±0.083 (WPHACT)

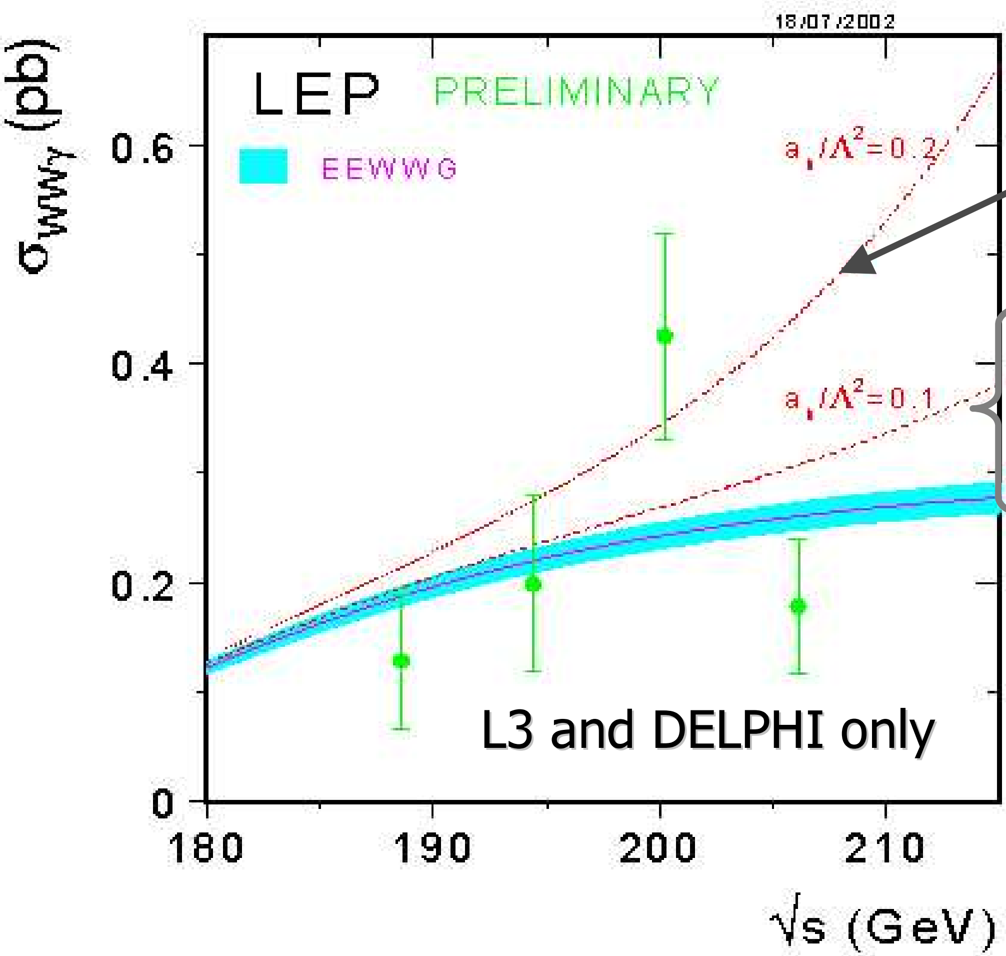
Lower cross-section SM processes can be investigated to ~5-10% accuracy

Probing the QGC



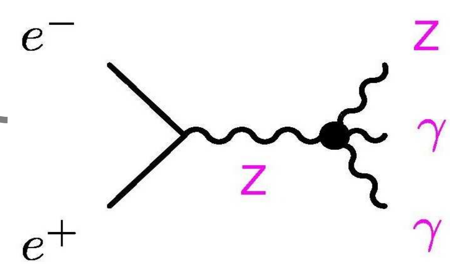
Signal definition:

- ➢E_γ> 5 GeV
- ➢$|\cos(\vartheta_\gamma)| < 0.95$
- ➢cos(γ, closest charged f) < 0.90
- ➢$|m(f,f') - m_W| < 2\Gamma_W$



E_γ, $\sigma_{WW\gamma}$ used for limits on QGC WWγγ

$a_0^W/\Lambda^2 \in$ [-0.031, 0.030] GeV^{-2} @95%
$a_c^W/\Lambda^2 \in$ [-0.069, 0.070] GeV^{-2} @95%
$a_n/\Lambda^2 \in$ [-0.45, 0.41] GeV^{-2} @95%



From Zγγ limits on ZZγγ couplings are also determined:

$a_0^Z/\Lambda^2 \in$ [-0.009, 0.026] GeV^{-2} @95%
$a_c^Z/\Lambda^2 \in$ [-0.034, 0.046] GeV^{-2} @95%

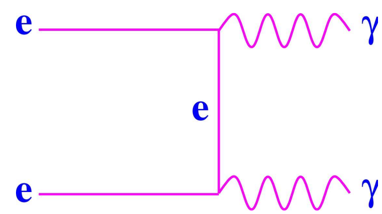
Two photon production

Pure QED, small higher order corrections

A good place to look for new physics:

- low scale gravity
- excited electrons

Straightforward selection…



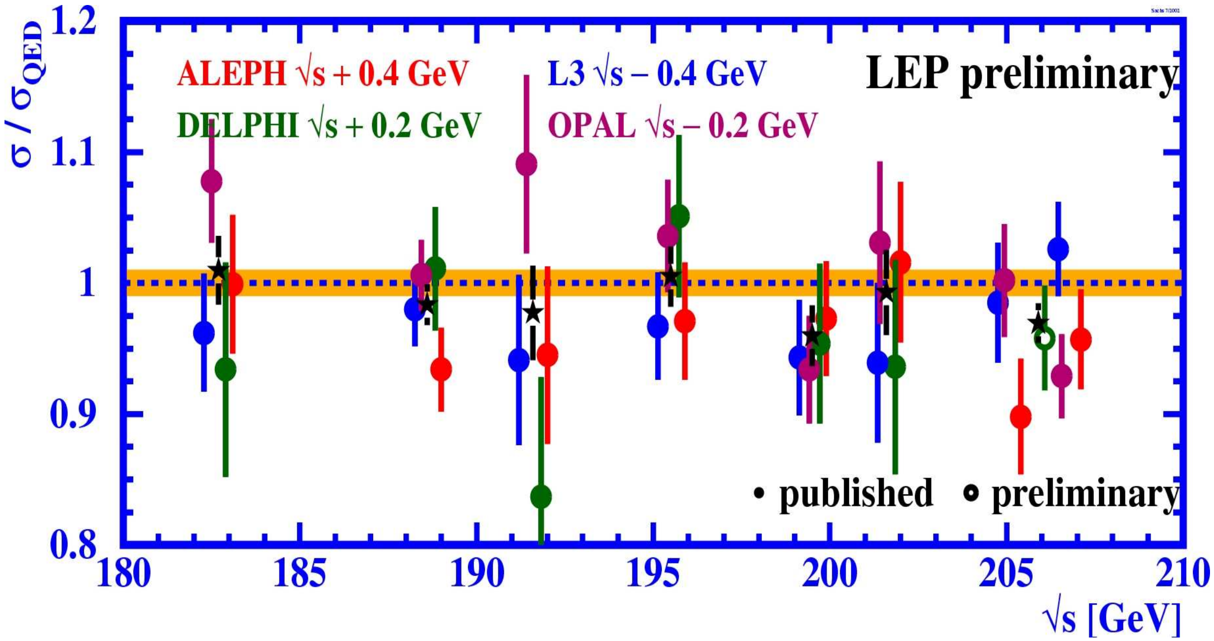
Various models can be tested by using the measured differential distributions

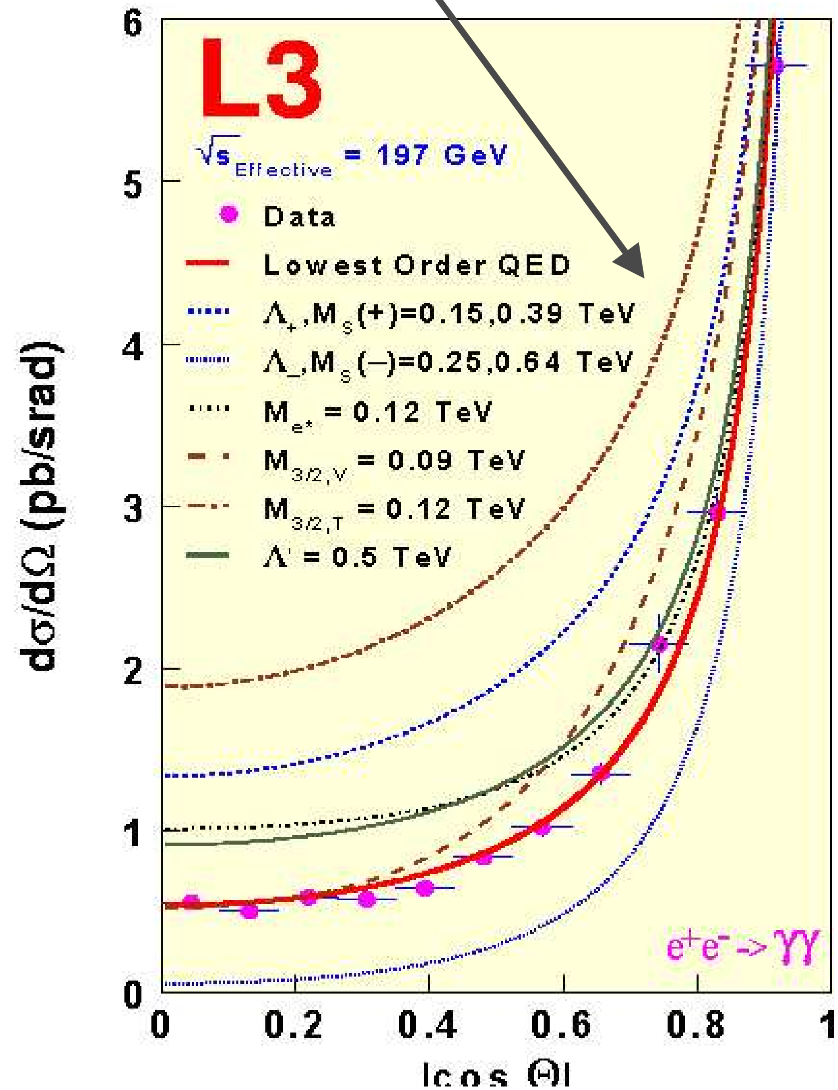
$\sigma_{meas}/\sigma_{th}$=0.982±0.010

almost final results…

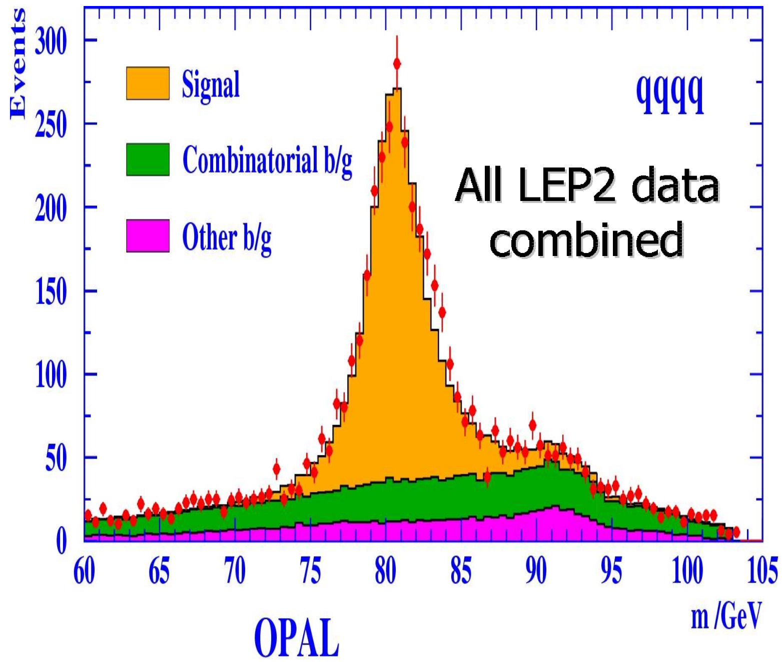
Graviton mass limit ~ 1 TeV

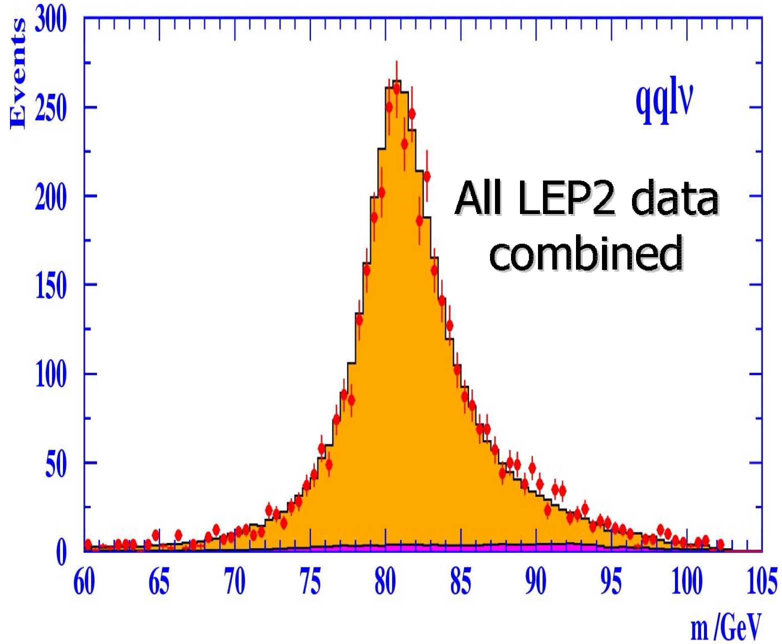
QED cut-off $\Lambda_{+,-}$>400 GeV





W mass





The W mass is extracted through direct reconstruction of the resonance via:

1. constrained kinematical fits (qqqq, qqlν)
2. lepton energy distributions ($l_1\nu_1 l_2\nu_2$)

The methods to determine m_W, Γ_W:

1. Reweighed MC fit to data
2. M-L fit with BW⊗ISR⊗resolution

(m_W is determined assuming SM $\Gamma_W(m_W)$, Γ_W in a 2-D fit)

Energies, experiments, channels are combined accounting for correlations of systematics:

- large systematics in the qqqq channel
- combination dominated by qqlv

⇒ Better accuracy on m_W relies on the ongoing work on the systematic part

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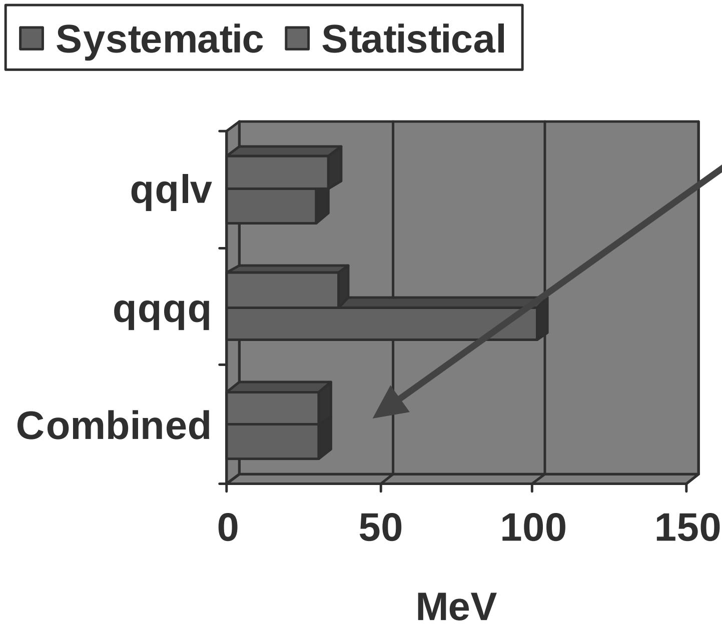
W mass error breakdown



The measurement is systematic-limited...

Total systematic ~ total statistic = 30 MeV

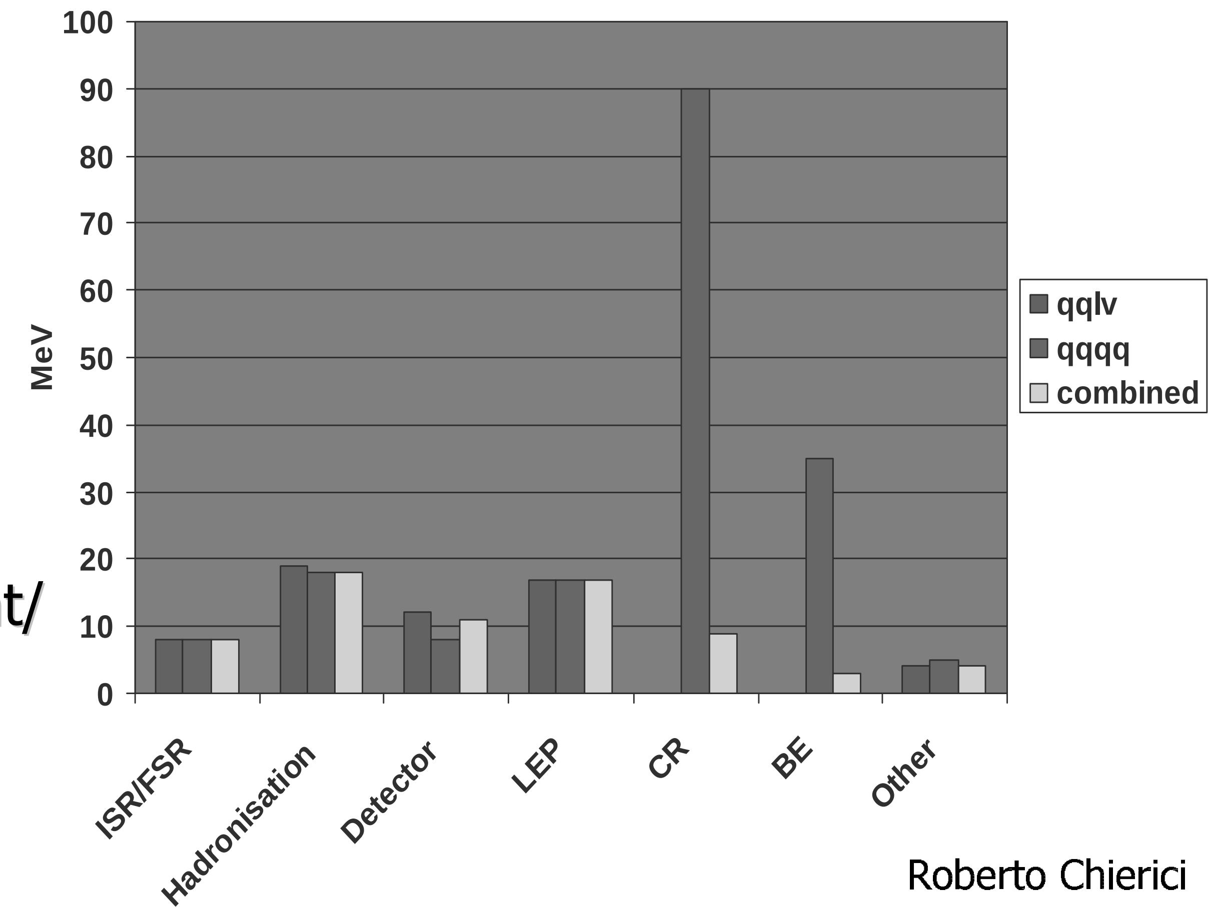
The weight of the qqqq channel is 9% only!

In absence of systematic, δm_W would be 22 MeV!

Main sources of systematics:

- FSI (qqqq only)
- hadronisation
- LEP beam energy

correlation in energy/experiment/ channels makes the rest...



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Main systematics to fight with

Hadronisation modelling: compare different models (HERWIG, JETSET, ARIADNE) and consider the largest effect as indication of the systematic error

$\Rightarrow \delta m_W$=18 MeV combined, can it be reduced?

LEP beam energy: induces a systematic error because of the kinematical fits. $\delta m_W/m_W = \delta E_b/E_b \Rightarrow \delta E_b \sim 21$ MeV $\rightarrow \delta m_W \sim 17$ MeV

(The error on the energy comes from the extrapolation to high energy of resonant depolarization beam energy measurement at 60 GeV)

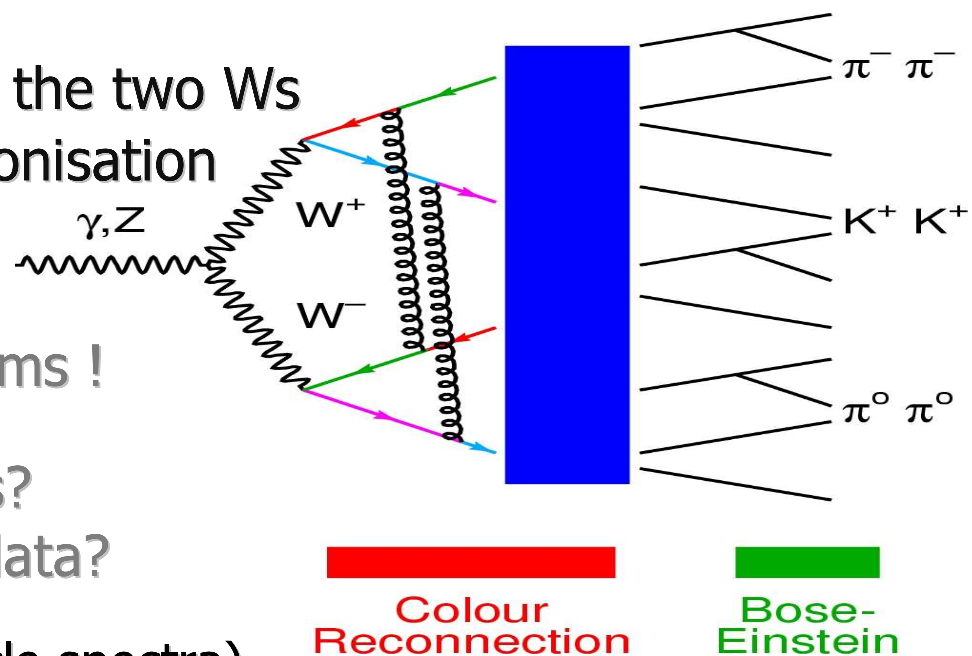
FSI: at LEP2 the decay distance between the two Ws (~0.1 fm) is smaller than the typical hadronisation scale or the radius in which BE effects start to take place

$\Rightarrow$ The two Ws are not independent systems !

how well do we know/model these effects?

can we exclude/measure them from our data?

(Mainly affect low momentum particle spectra)



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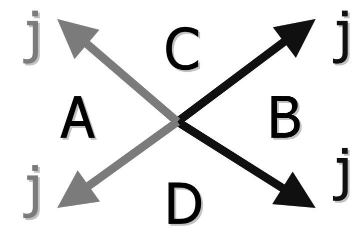
Colour Reconnection

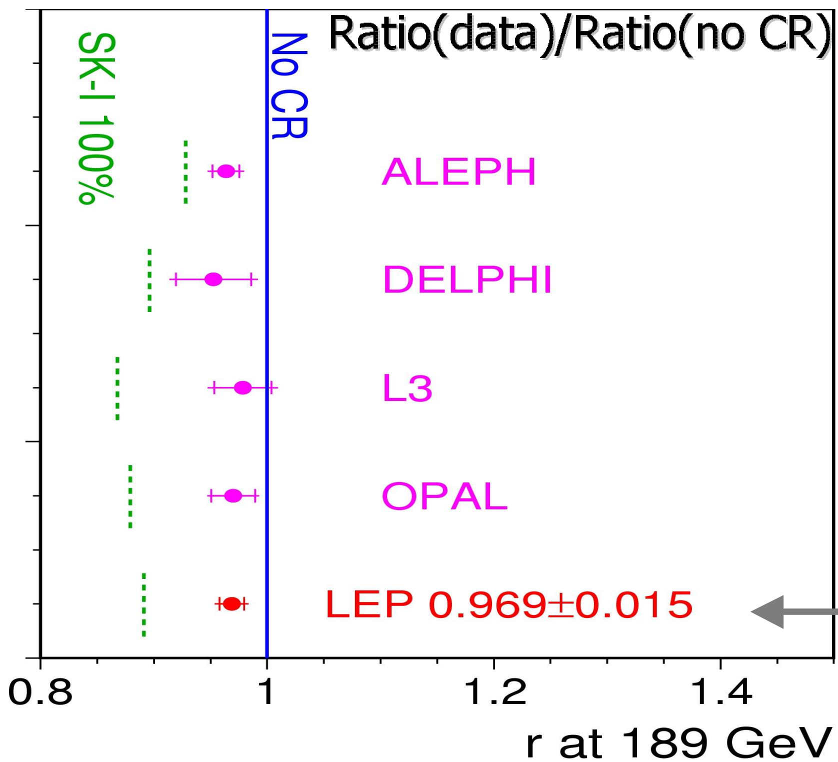
Several models: string based (SKI,II), colour dipoles (ARIADNE) , cluster based (HERWIG). Shifts on m_W(qqqq) from the models range from 30 MeV (HERWIG) to 300 MeV (SKI, 100% reconnection probability)

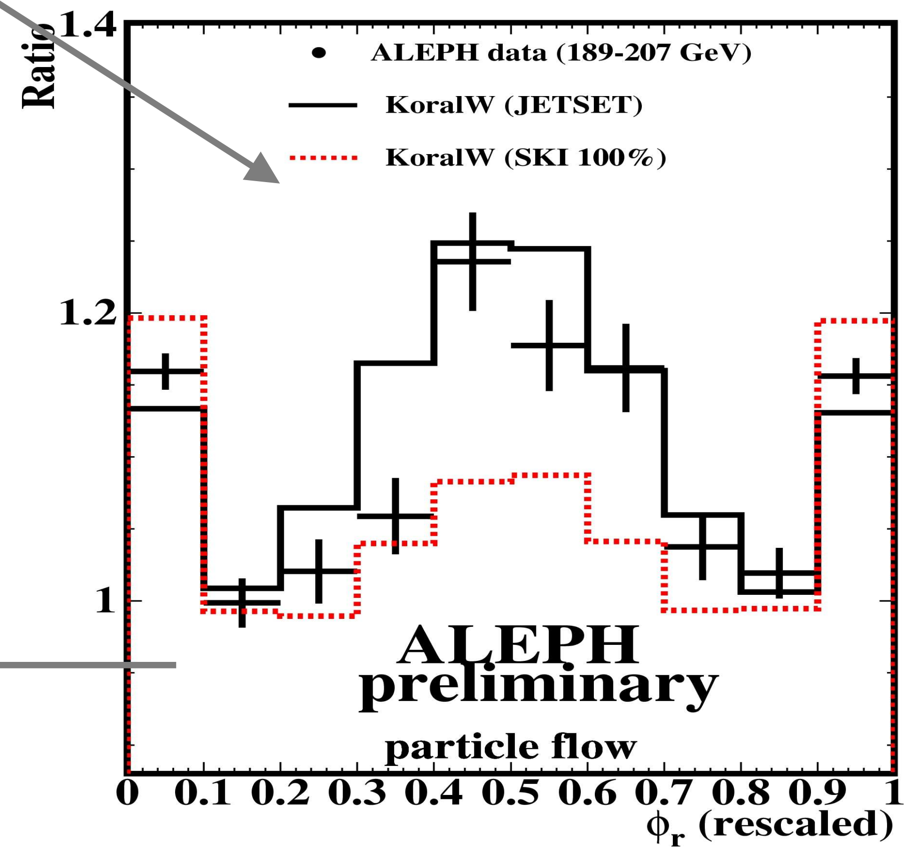
Study particle flow between jets: Ratio=(A+B)/(C+D)



Hints for observation of CR (~2σ)

⇒ δm_W(qqqq)<90 MeV @68% CL





⇒ study jet reconstruction methods less sensitive to CR effects

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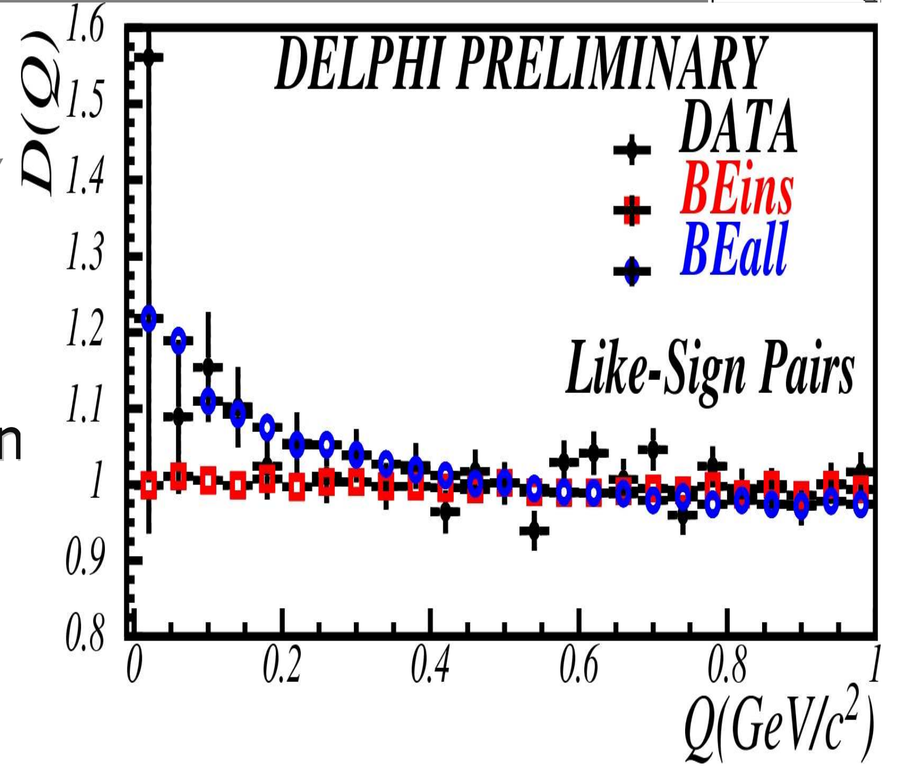
Bose-Einstein effect

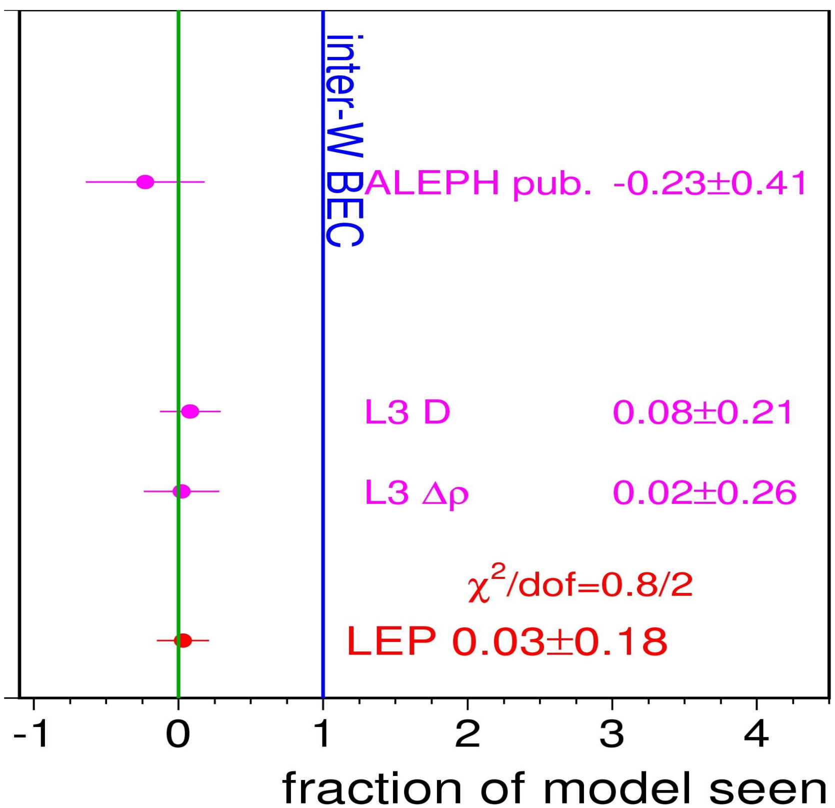
BEC are well established at the Z

For boson pair production only BEC between Ws affect the mass determination

⇒ Study two particle correlation functions



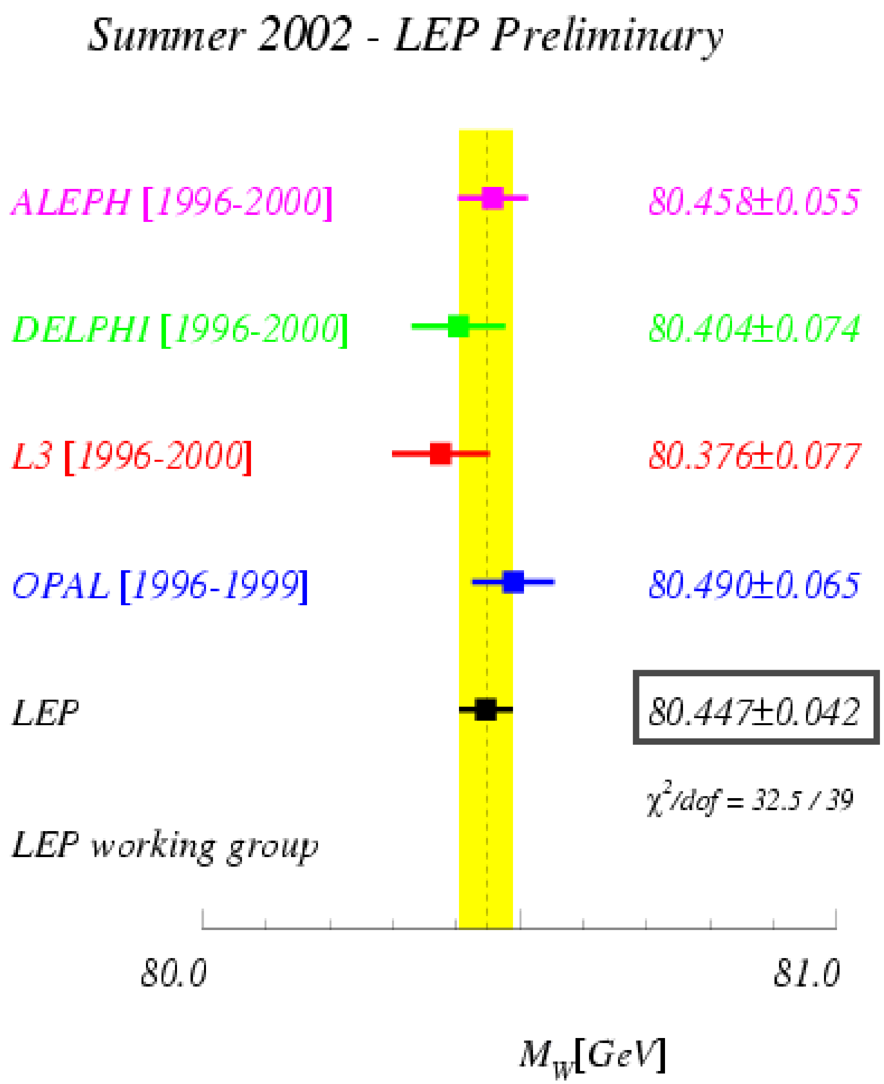
Current error is 35 MeV but no clear indication of a significant effect from the data

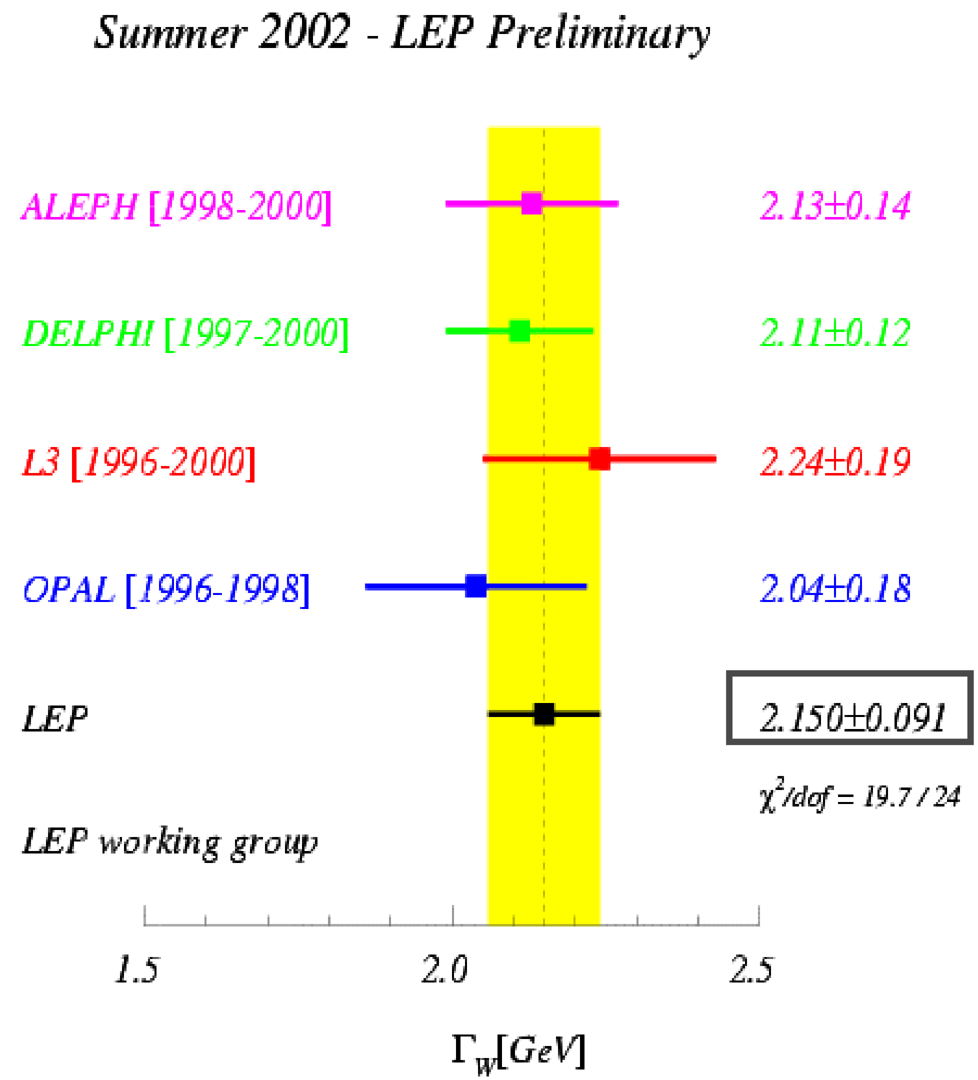


Still work to be done to reach a LEP combination on the effect $\delta m_W(qqqq)<10$ MeV?

Other BEC models need to be studied

m_W: results



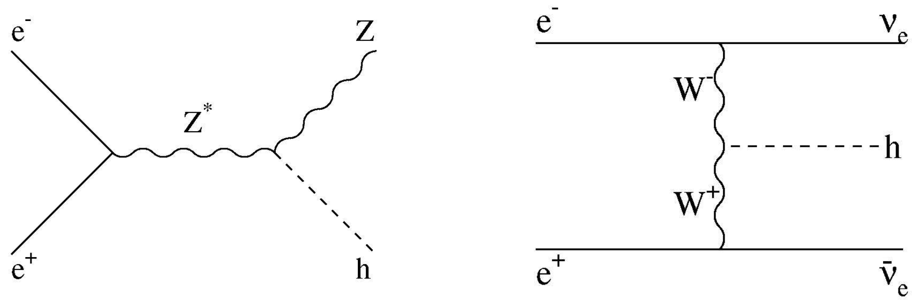


$m_W(qqqq)=(80.449\pm0.107)$ GeV
$m_W(qql\nu)=(80.448\pm0.043)$ GeV

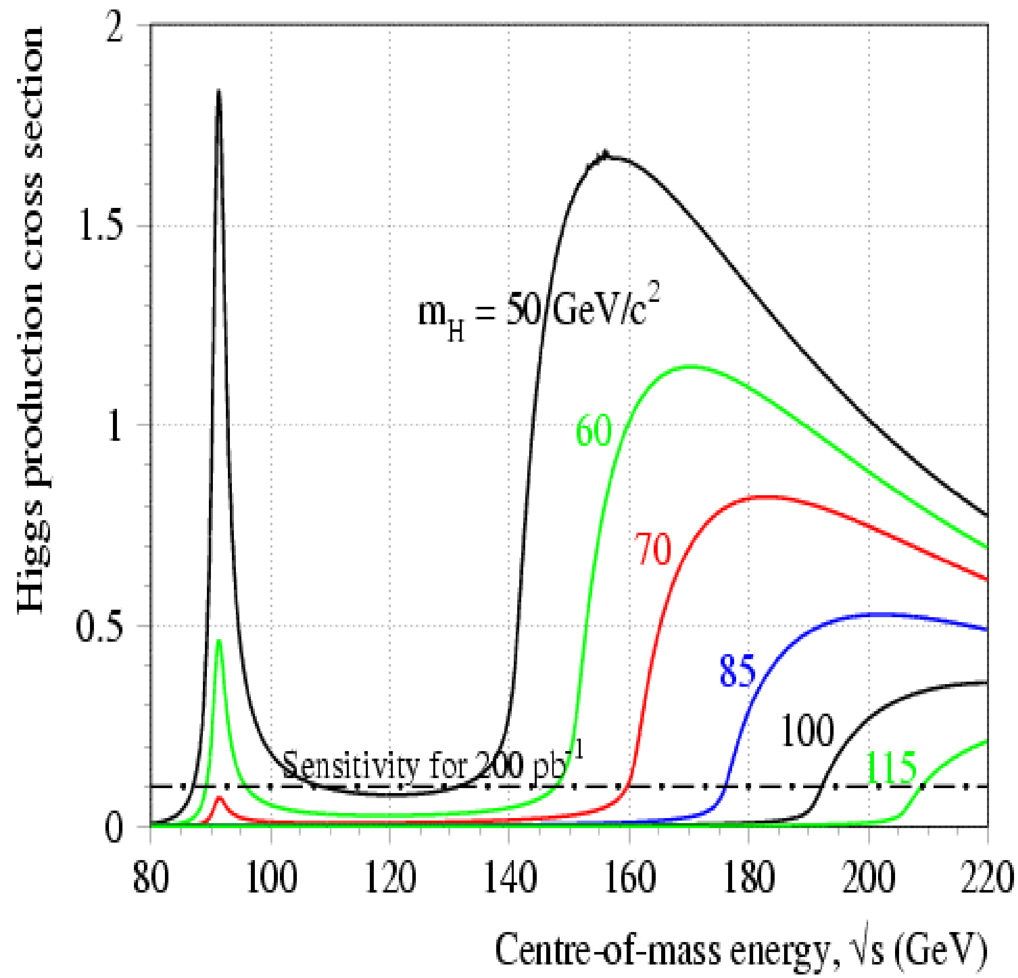
$m_W(qqqq)-m_W(qql\nu)=(9\pm44)$ MeV

Standard Model Higgs: direct search

Search mainly in ZH→ff bb



Final states	bbqq	bbνν	bbll	ττqq
BR(%)	60%	19%	6%	8%



Important ingredients of the analyses:

- High b-tagging efficiency/purity
- Kinematical reconstruction (like W mass)

⇒ Good understanding of the detector is essential (tails!)

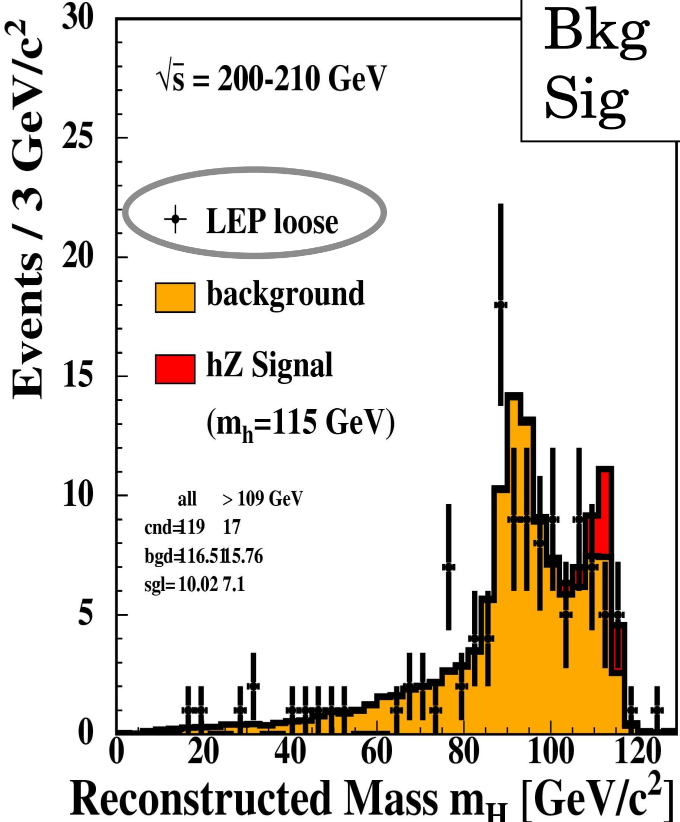
LEP final combination:

- Combine 2D distributions (m_H(rec.),discriminant variable)
- Use likelihood ratio test hypothesis:

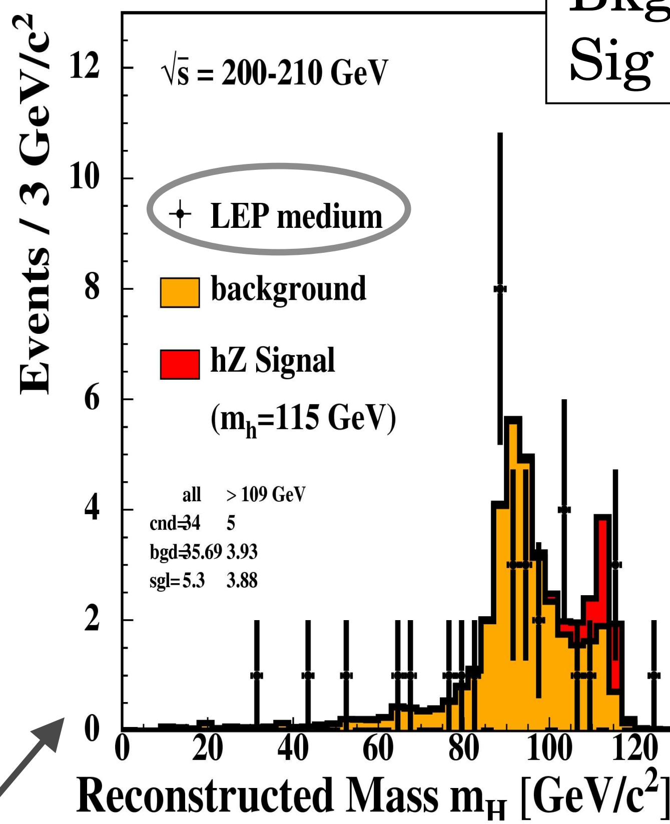
$Q(m_H)=\mathcal{L}(s+b;\ m_H)\ /\mathcal{L}(b;\ m_H)$

Standard Model Higgs: mass distributions

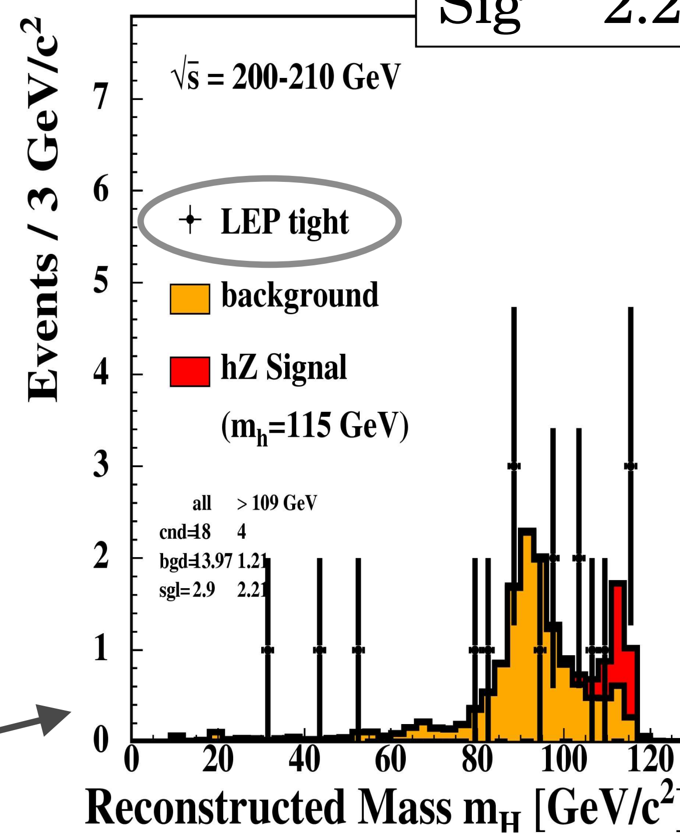
Data	17
Bkg	15.8
Sig	7.1



Data	5
Bkg	3.9
Sig	3.8



Data	4
Bkg	1.2
Sig	2.2



>0.5

>1

>2

S/N for reconstructed m_H>109 GeV/c^2

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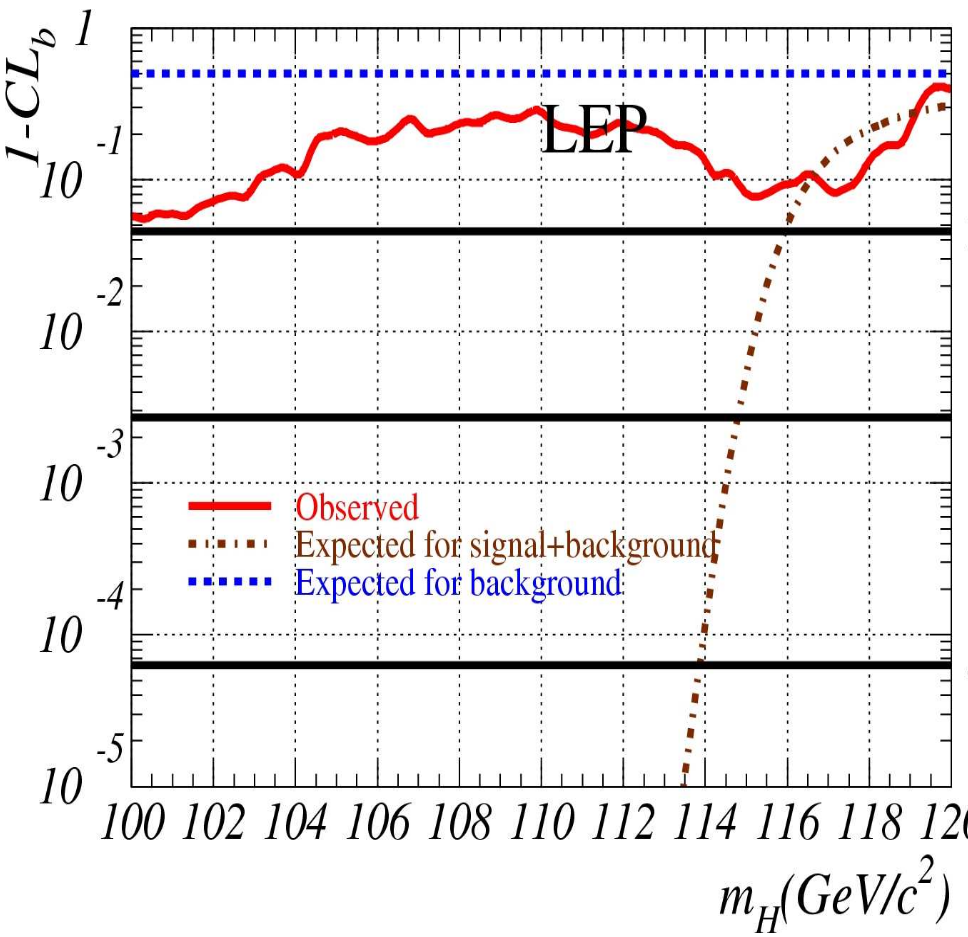
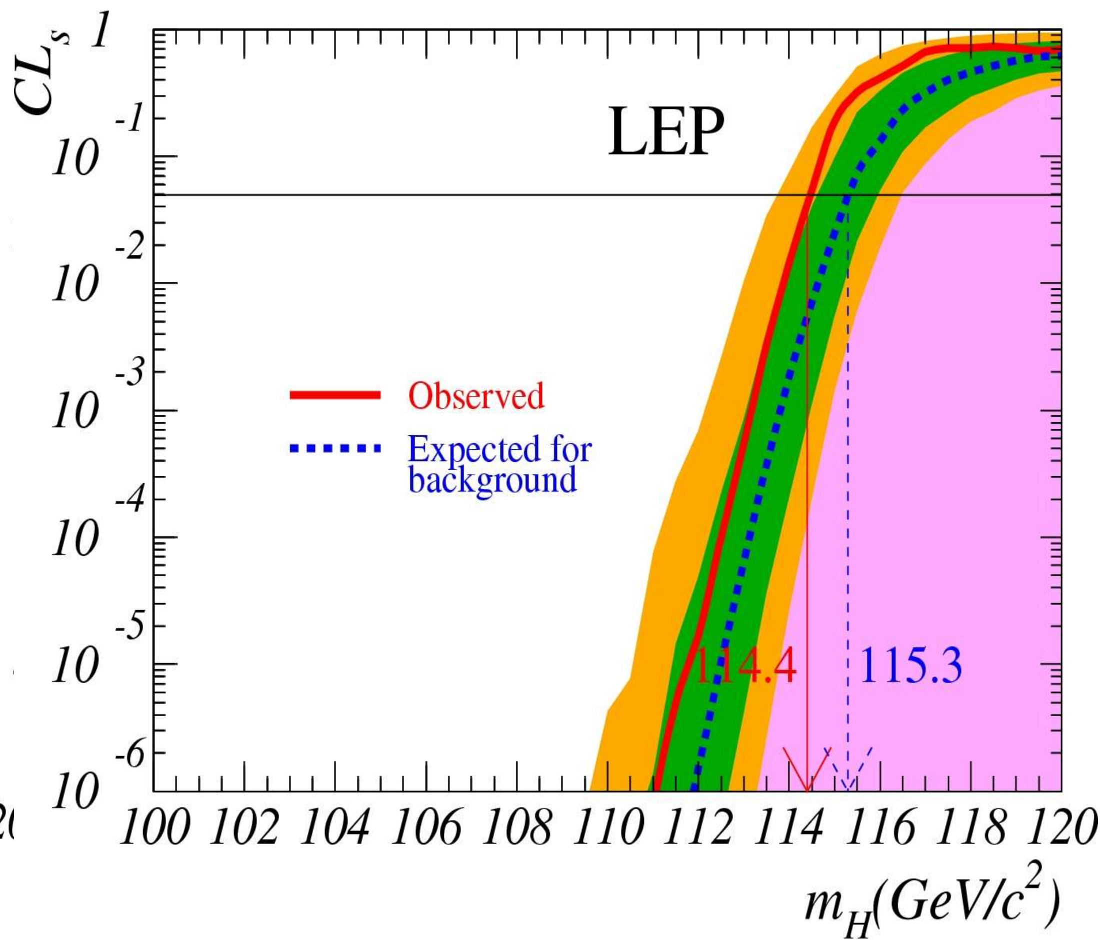
Limits on m_H

Confidence level for background and signal:





1.7σ excess (8% probability) over the background, concentrated in one channel (qqbb) and one experiment (ALEPH, ~3σ)

⇒ Final LEP2 limit: m_H>114.4 GeV @95% CL

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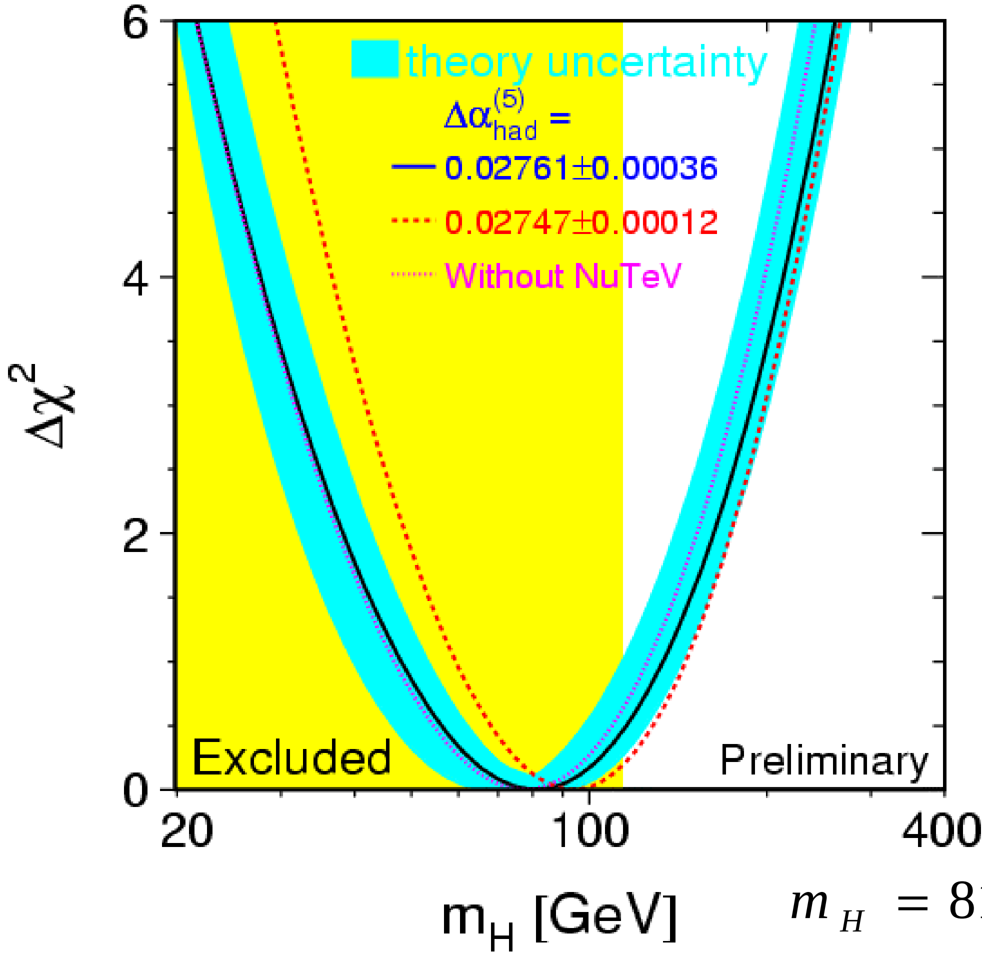
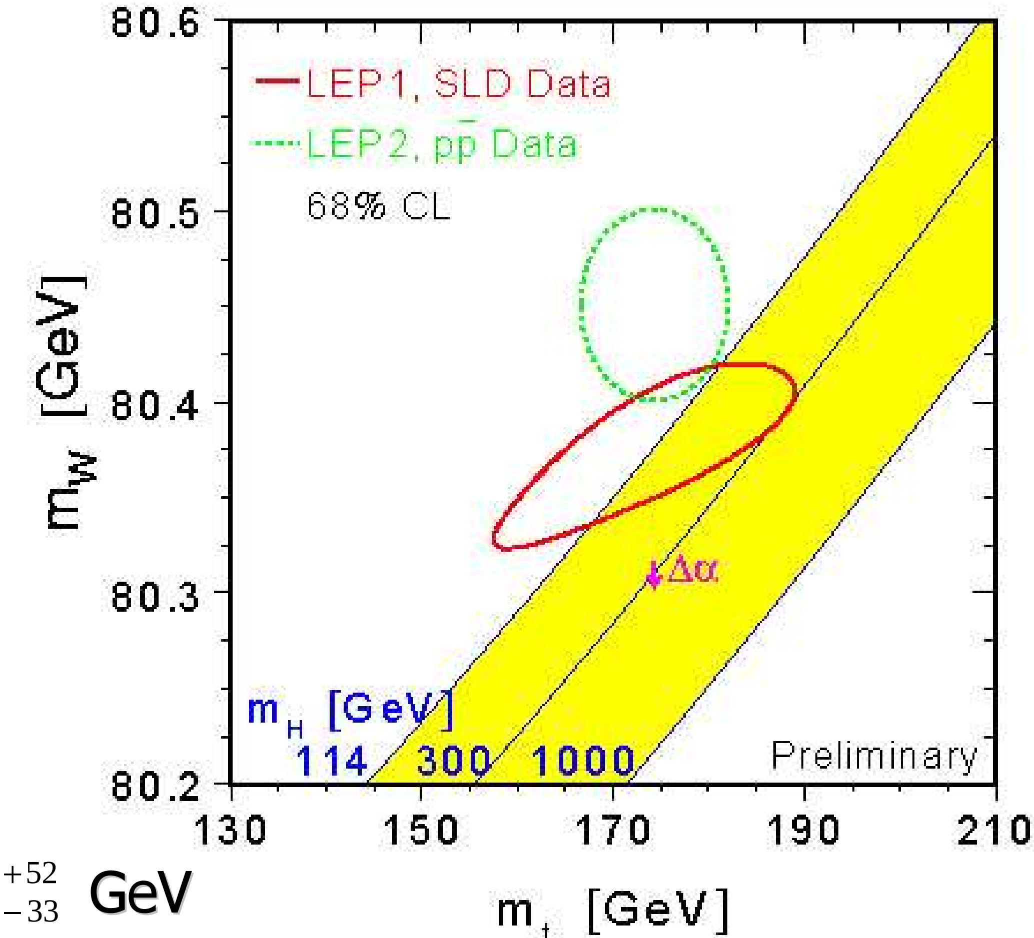
Constraints on the Standard Model

Higgs is escaping, but we can constrain it with our precise measures at LEP2
Fundamental parameters of the SM are linked through EW corrections



$$m_H = 81^{+52}_{-33} \text{ GeV}$$



$m_H \leq 193$ GeV at 95% CL

35% shift in m_H for 5 GeV shift in m_t !

direct and indirect data in agreement
both favour a light Higgs

Conclusions

The LEP2 era of 4f physics is approaching its end:

- test of the non-abelian structure of the theory
- loop sensitivity for differential and total cross-sections
- improvement of the precision on m_W by ~10

Still to do before leaving final numbers

- systematics on m_W (FSI in particular). δm_W(LEP)<35 MeV ?
- complete few combinations (4f cross-sections, $d\sigma/d\vartheta_{W-}$, TGC, QGC)

⇒ Collaborations are still active!

e+e- confirms its role in precision physics but not in discovery

- if the Higgs is there, it can't hide forever and will sooner or later become a precision measurement like all other topics of this talk
- if Higgs is not there, signals of new physics must appear at LHC/LC

LEP has allowed unprecedented tests of the SM, which might start to be under pressure. Let us be patient, but ready for surprises.

In the meanwhile m_t is the key for continuing the hunt…