Physics and Experimental Requirements at High Energy

Chamonix, January 1997

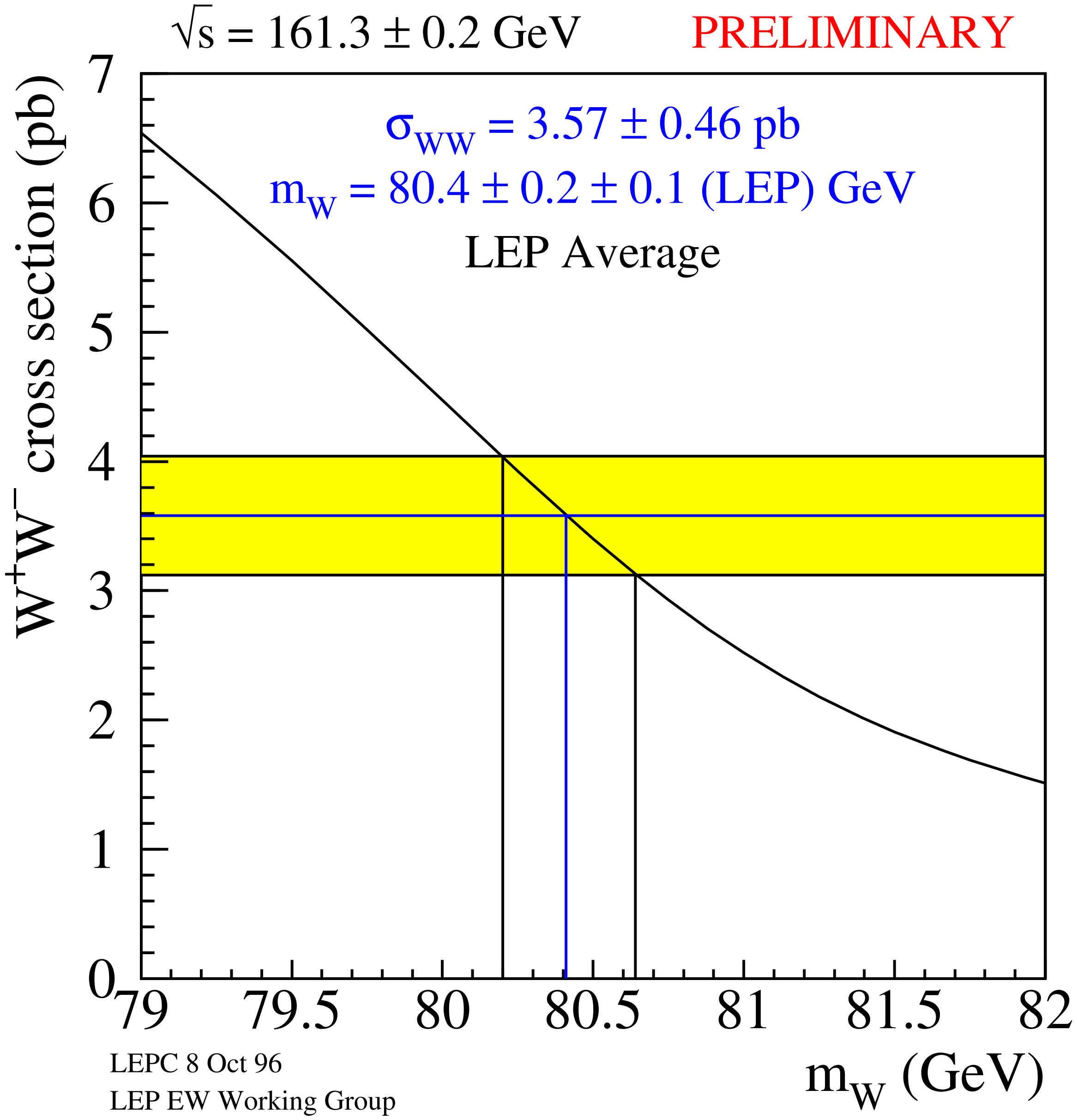
Pippa Wells

- Physics results from 161 and 172 GeV
  - W physics and other standard physics
  - Searches: Chargino, Higgs, 4 jets.
- Goals for running in 1997 and beyond (energy/luminosity)
  - W mass
  - Higgs
- Energy calibration requirements

W physics

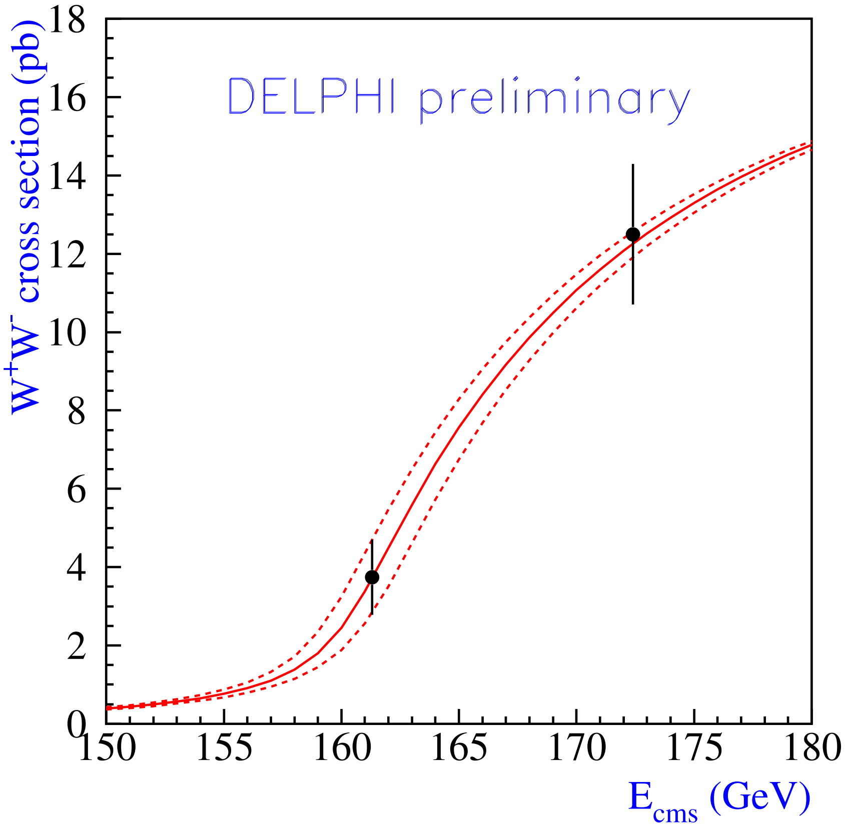
$e^+e^- \to W^+W^-$ with $W \to q\bar{q}$ (2/3) and $W \to \ell^\pm\nu$ (1/3)

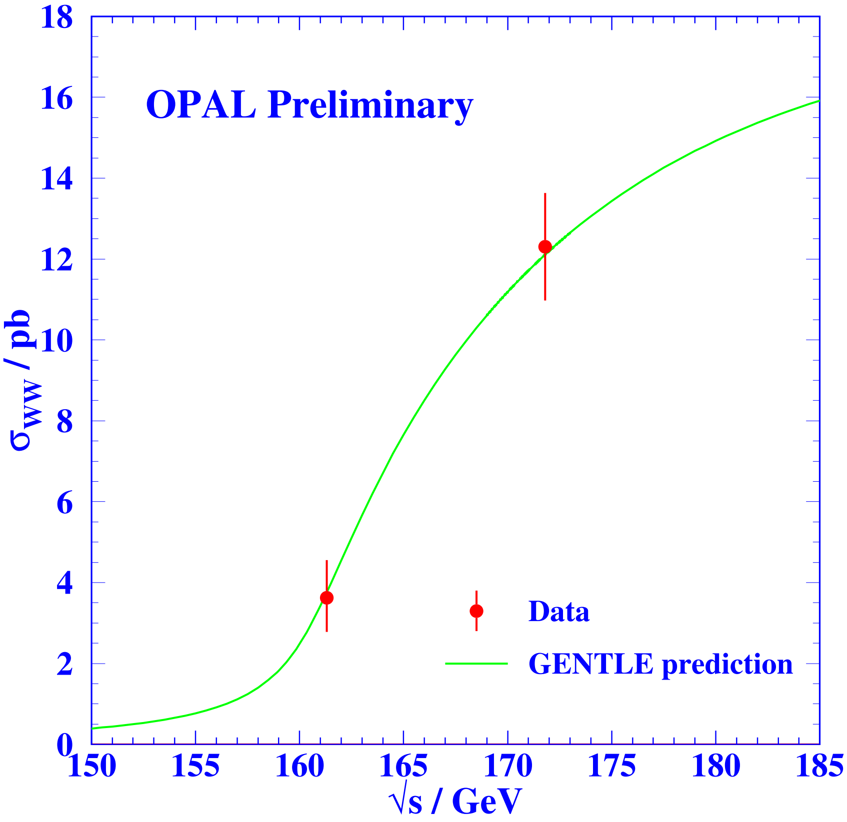
W mass from cross section at 161 GeV, threshold method



W physics

Preliminary cross section measurements at 172 GeV, eg:

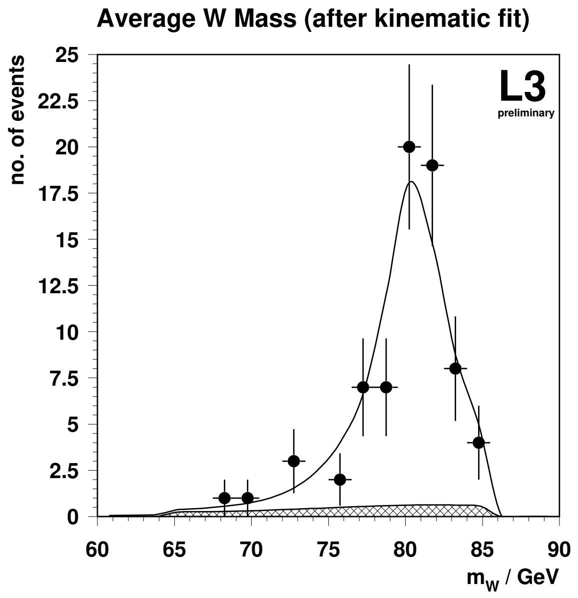


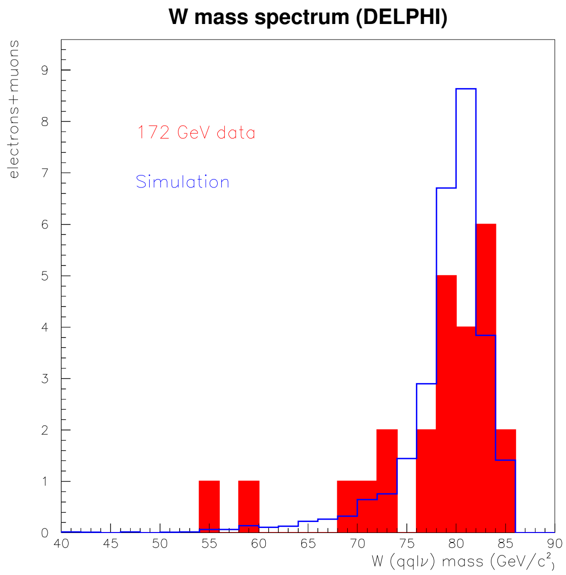


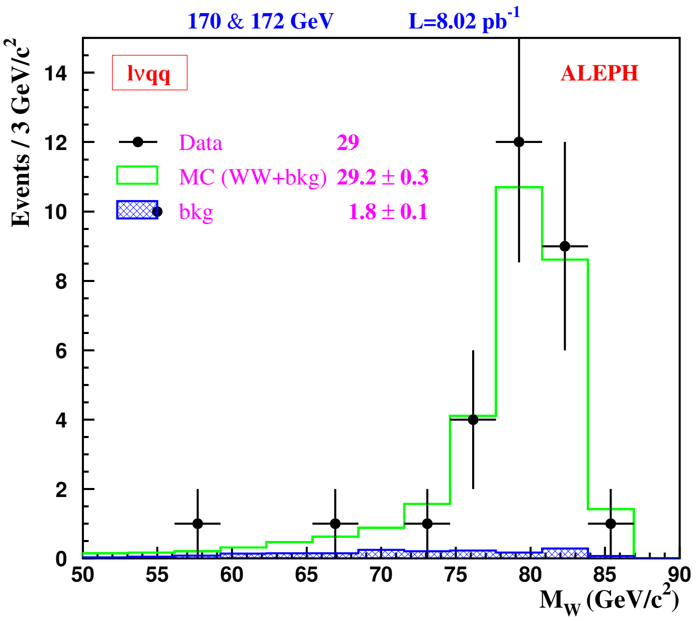
W physics

Mass from direct reconstruction of final states at 172 GeV.

(Theoretical problem with $\mathrm{WW} \rightarrow \mathrm{q\bar{q}q\bar{q}}$ due to colour reconnection)







W physics

Triple Gauge Boson Coupling

$\gamma\mathrm{WW}$ and ZWW interactions contribute to $\mathrm{e}^+\mathrm{e}^- \to \mathrm{WW}$

Constraints from cross sections and angular distributions - consistency with Standard Model so far

Parametrize anomolous coupling by $\alpha_{W\phi} \neq 0$.

95% confidence limits from 161 GeV data:

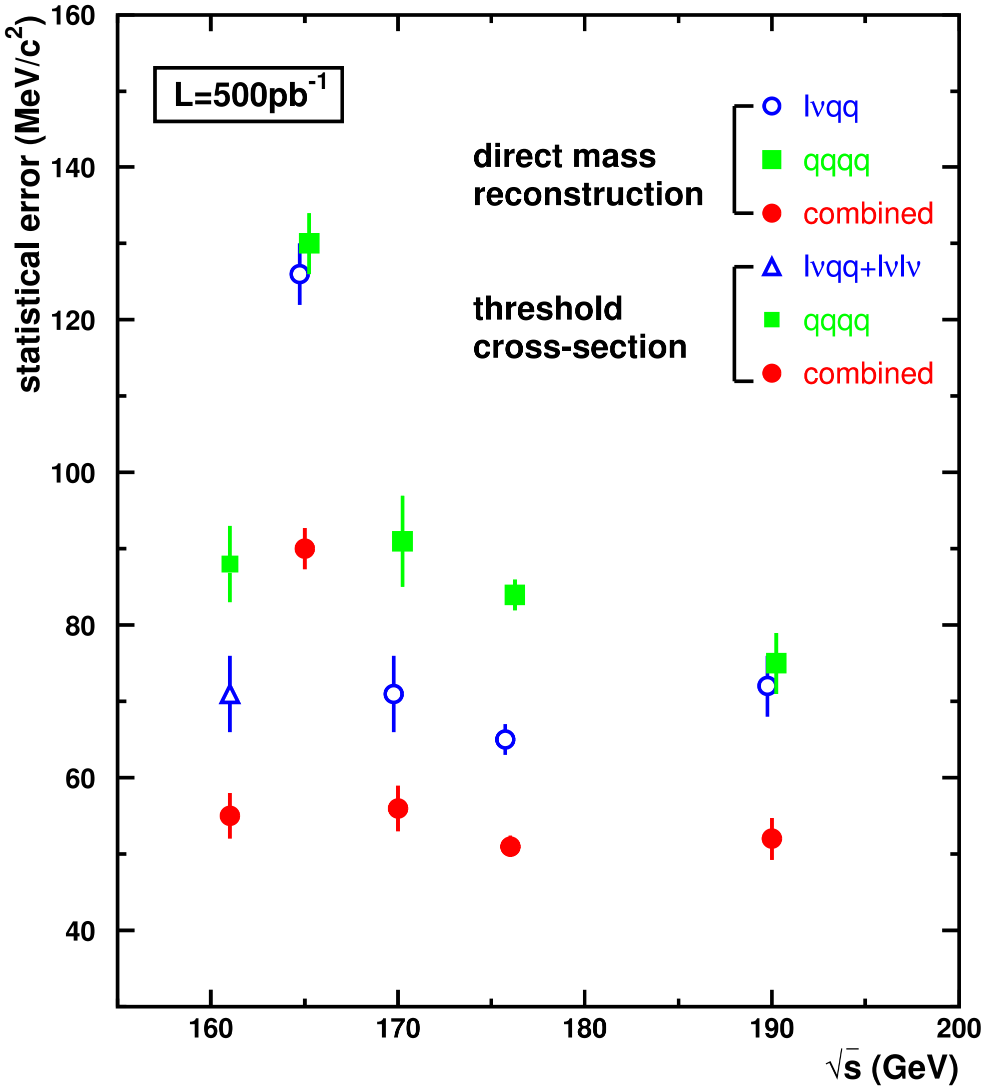
ALEPH	$-1.9 < \alpha_{W\phi} < 1.9$
DELPHI	$-1.5 < \alpha_{W\phi} < 1.8$
L3 (incl. 172 GeV)	$-0.7 < \alpha_{W\phi} < 0.8$
OPAL	$-2.1 < \alpha_{W\phi} < 1.6$

Sensitivity much greater at higher energy than at threshold

W futures

Expected W mass precision (GeV)

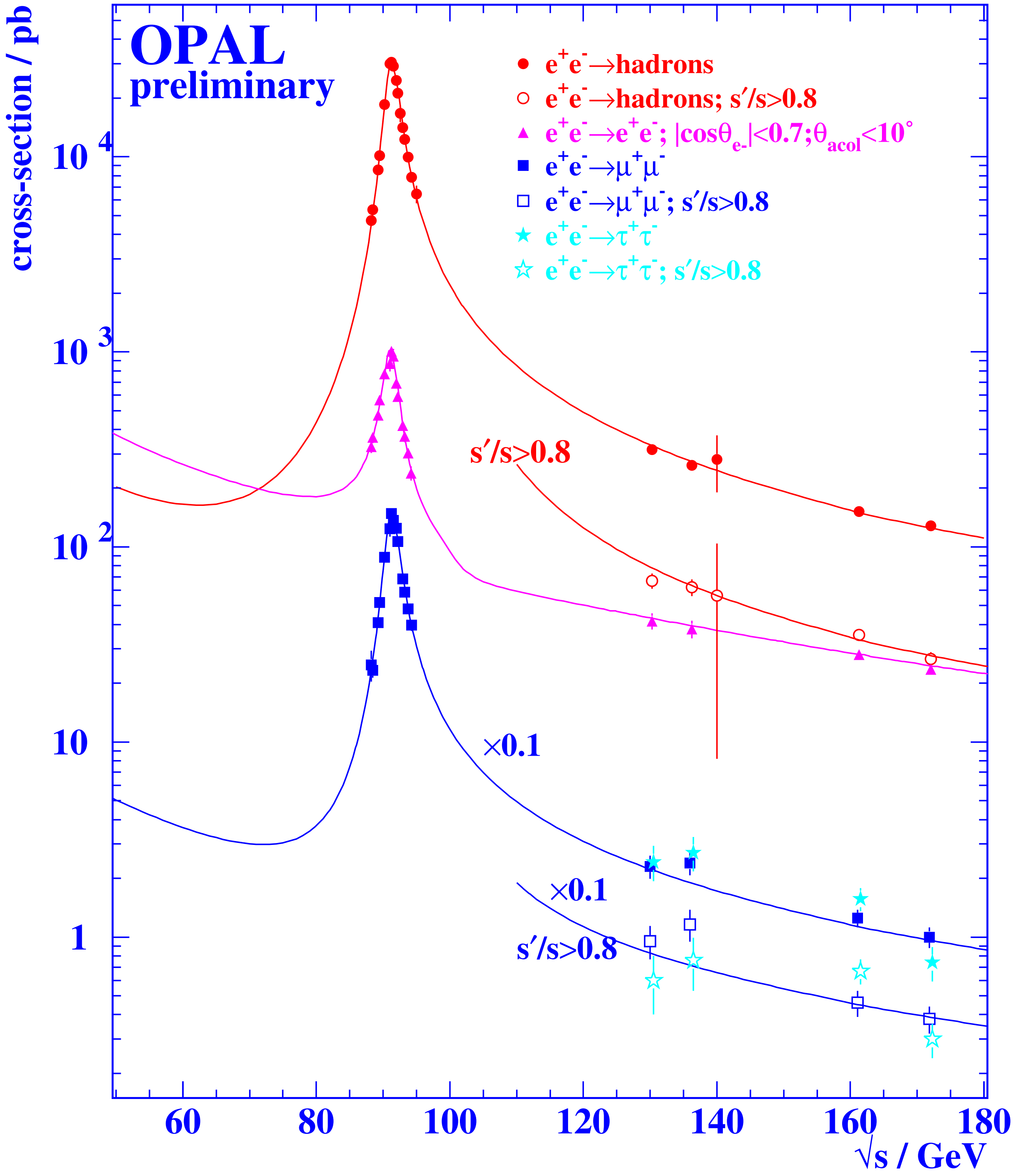
Tevatron full run 1	0.09
Electroweak fits (LEP+SLD)	0.04 $\oplus$ 0.02 (Higgs mass)
LEP 1996, 20 pb^{-1}	0.15



Taking reasonable fraction of 500pb^{-1} at 161 GeV offers small gain in total error. More importantly, offers cross check with independent errors. (Direct reconstruction method suffers from colour reconnection problem in qqqq final state.)

Other Standard Processes

Rates of other standard processes are as expected, eg:



What is SUSY?

Normal particles have "supersymmetric" partners with 1/2 unit of spin different (fermions $\leftrightarrow$ bosons)

Extra particles $\longrightarrow$ convenient cancellations in calculations.

Standard Model survives as subset of MSSM

Minimal Supersymmetric Standard Model

Spin 0	Spin 1/2		Spin 1
$\tilde{\ell}^{\pm}$, $\tilde{\nu}$ (sleptons)	ℓ, ν		
$\tilde{\mathrm{q}}$ (squarks)	q		
	$\tilde{\mathrm{g}}$ (gluinos)		g
	$\tilde{\gamma}$		γ
	$\tilde{\mathrm{Z}}$	Mix $\longrightarrow \tilde{\chi}^0_j$	Z
H^0, h^0, A^0	$\tilde{\mathrm{H}}^0_1$	(4 neutralinos)	
	$\tilde{\mathrm{H}}^0_2$		
	$\tilde{\mathrm{W}}$	Mix $\longrightarrow \tilde{\chi}^{\pm}_j$	$\mathrm{W}^{\pm}$
$\mathrm{H}^{\pm}$	$\tilde{\mathrm{H}}^{\pm}$	(2 charginos)	

SUSY particles produced in pairs ("R-Parity conservation")

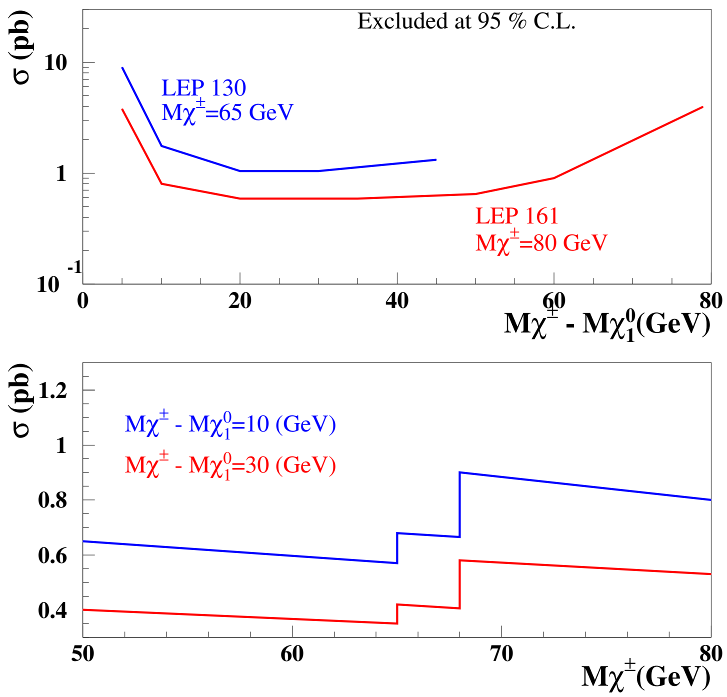
$\tilde{\chi}^0_1$ is usually Lightest Supersymmetric Particle

LSP cannot interact with normal matter $\longrightarrow$ escapes detector

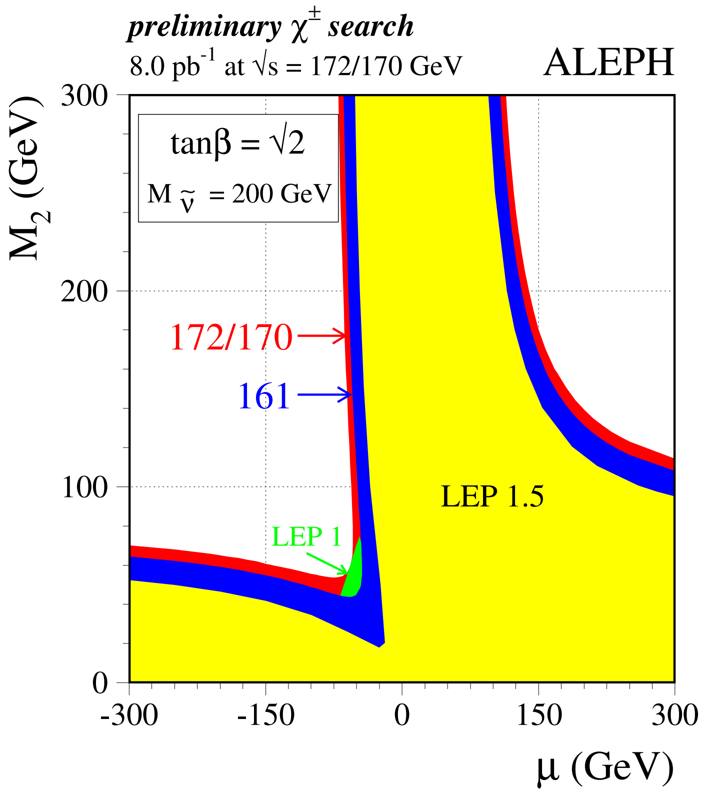
Chargino/Neutralino

Typical limits on $M(\tilde{\chi}_j^{\pm}) \gtrsim 85$ GeV, depending on $M(\tilde{\chi}_j^0)$

Example of cross section limit from L3



Example translated into SUSY parameter space from ALEPH

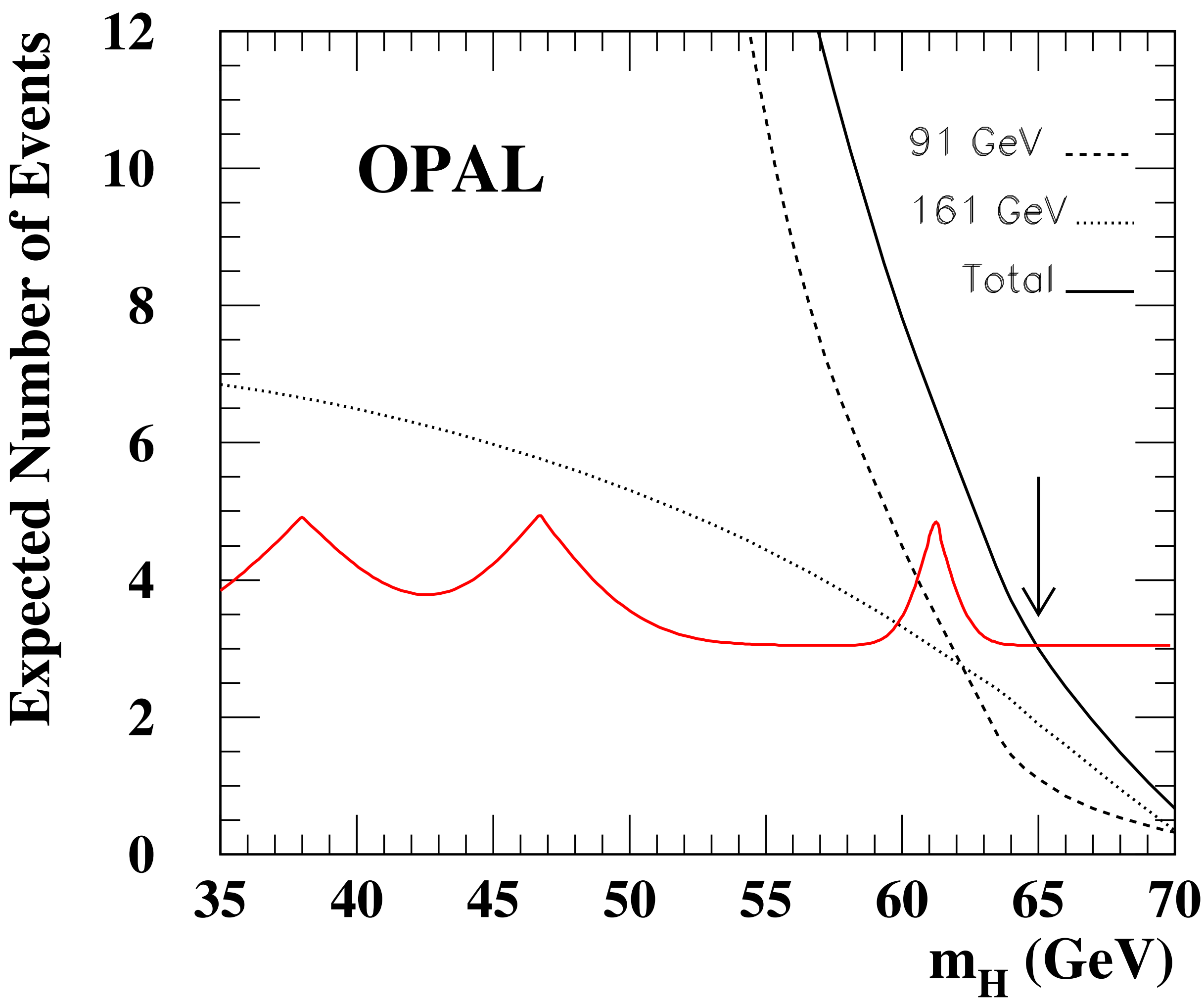


Nov 19, 1996

Standard Model Higgs

$e^+e^- \rightarrow H^0Z$, $H^0 \rightarrow b\bar{b}$ most of the time, and the Z decays to $q\bar{q}$, $\ell^+\ell^-$ or $\nu\bar{\nu}$ as usual

Example with three high mass background events:

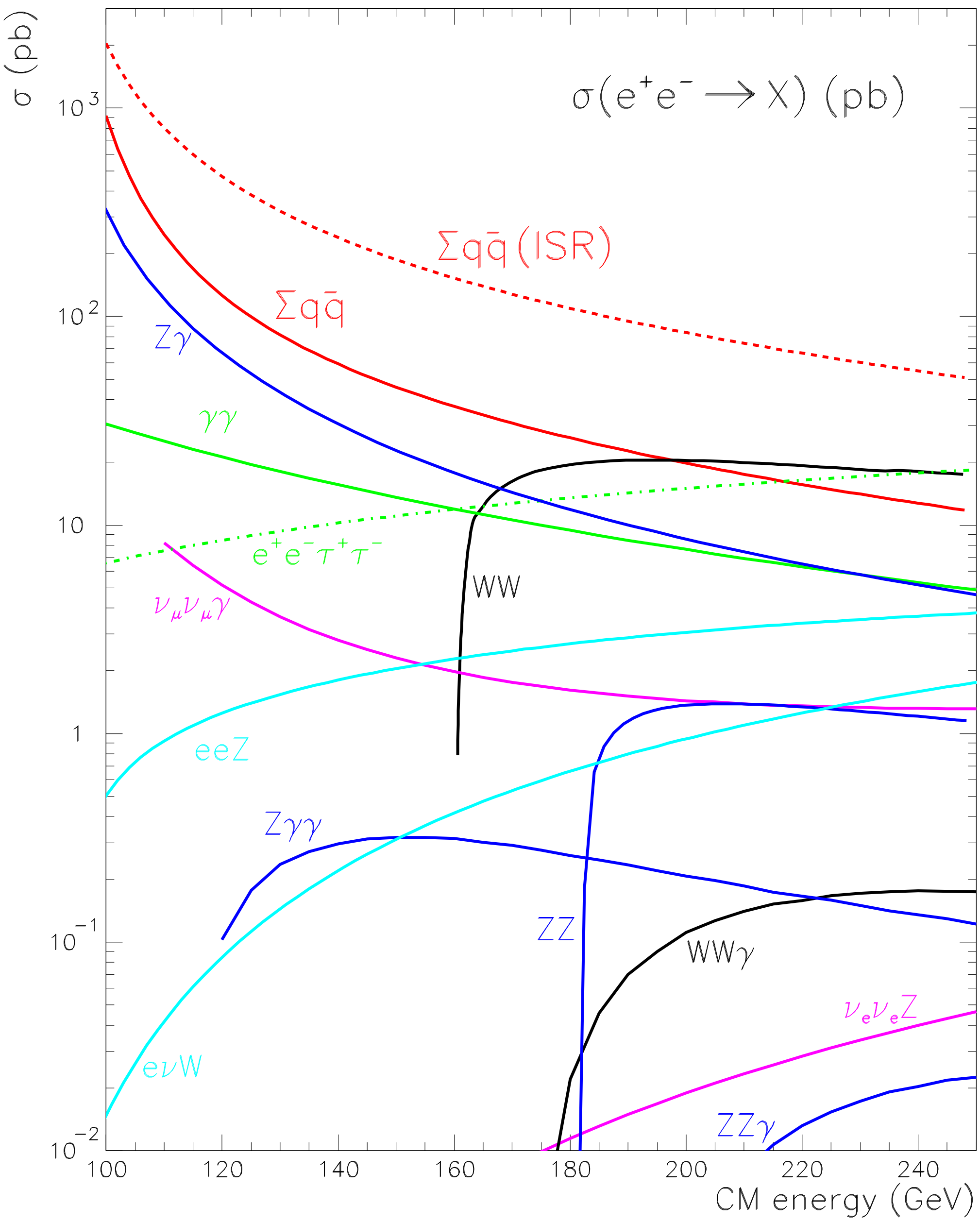


SUSY Higgs

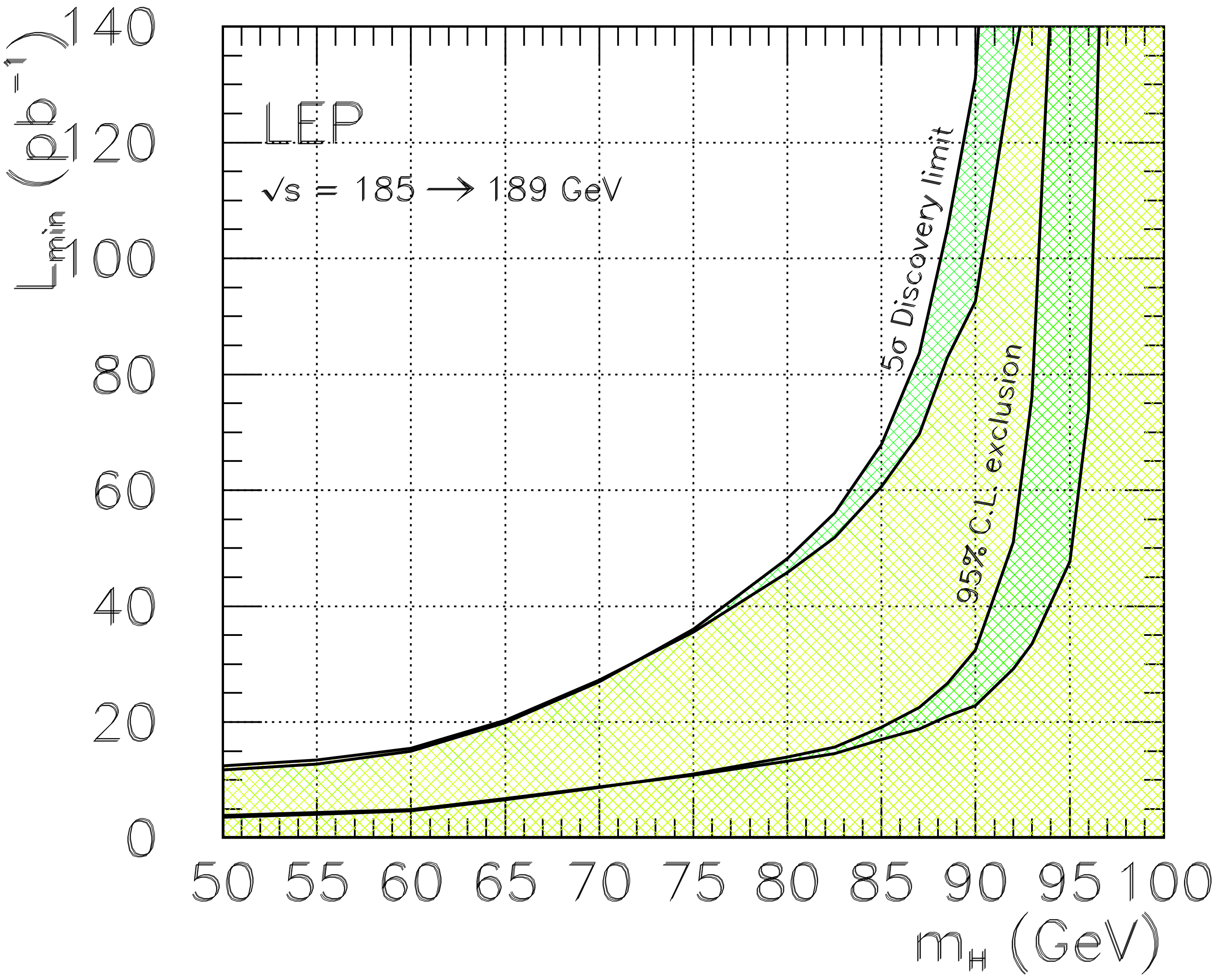
$e^+e^- \to hZ$: is very similar to the search for a Standard Model Higgs.

$e^+e^- \to hA$ is a search for 4 jet events, where the jets are all b quarks (Higgs decays to the heaviest thing it can)

Irreducible background from $e^+e^- \to ZZ \to b\bar{b}b\bar{b}$ when $M_h \approx M_Z$ or when $M_h \approx M_A \approx M_Z$



Higgs Futures - Standard Model



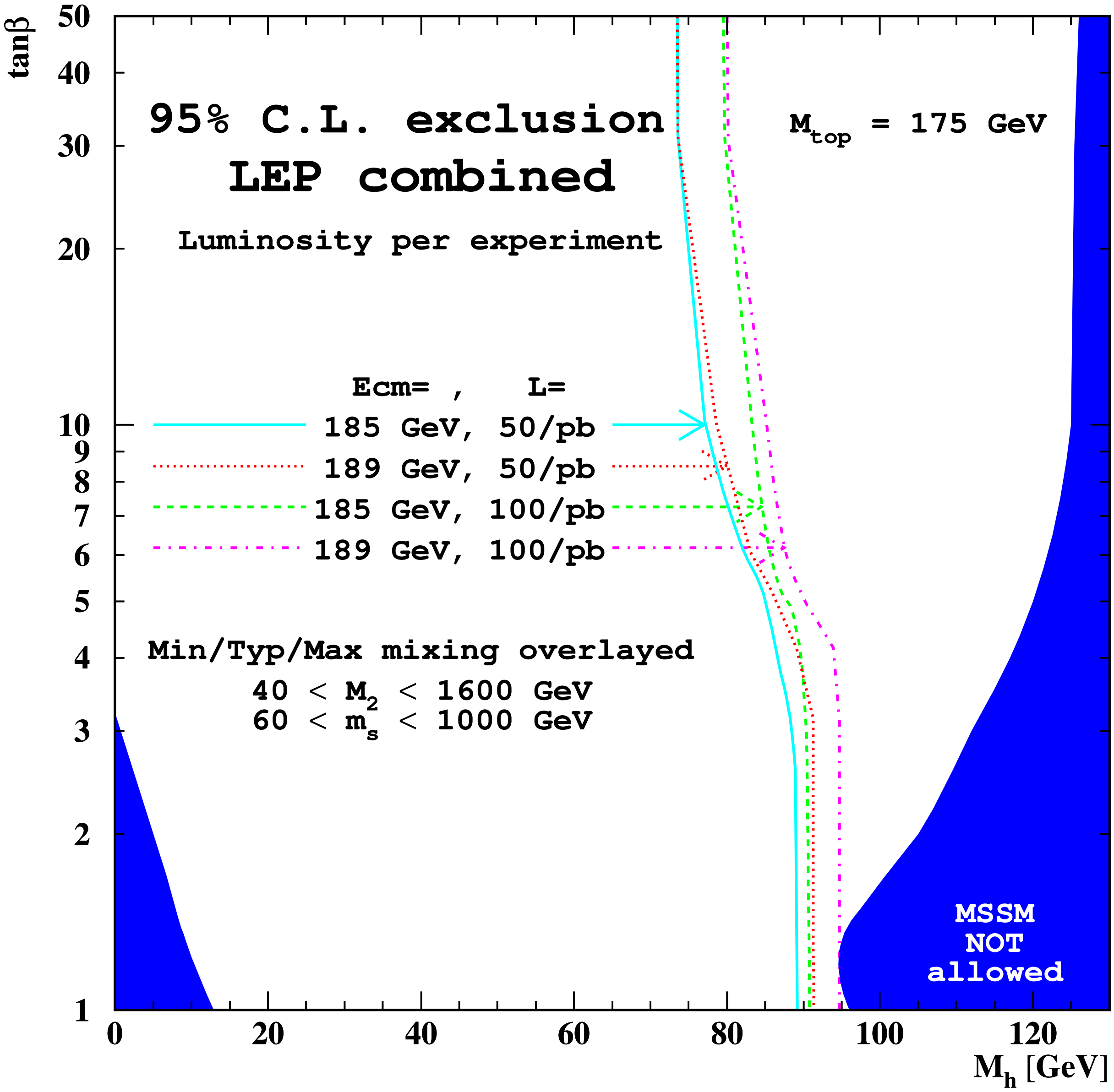
Luminosity of 50 pb^{-1} is close to saturation of exclusion

Increasing the energy allows an increase of the limit

Higgs Futures - SUSY

Plot sensitive to input assumptions, eg. top mass and squark mixing.

IR fixed point $\tan\beta \lesssim 3$. Try to close M_h gap.



LEP Higgs working group would prefer higher running efficiency with more luminosity to a small energy increase in 1997.

ALEPH 4 Jet Events

Originally motivated by Higgs search $\mathrm{e^+e^-} \rightarrow \mathrm{hA}$

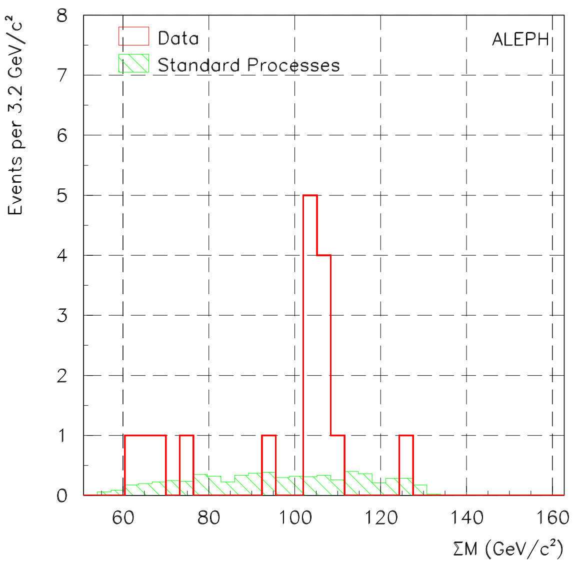
- Look for high multiplicity events with no photon
- Group the final state particles into jets. Require at least 4 jets.
- Number the jets (1,2,3,4) and make "di-jet masses" $\longrightarrow$ 3 combinations: $(m_{12}m_{34})$, $(m_{13}m_{24})$ or $(m_{14}m_{23})$
- Choose combination with smallest mass difference $(m_{ij} - m_{kl})$ and plot the mass sum $\Sigma M = (m_{ij} + m_{kl})$
- Reject WW events (NEW for 1996)

What about the new data?

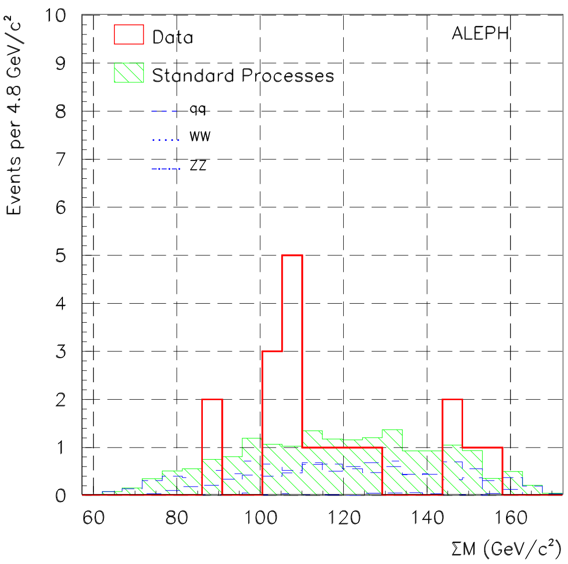
- Excess seen at 130-136 GeV also present at 161 and 172 GeV. Peak at 106.1 ± 0.8 GeV
- Total of 18 events in peak over 3.1 expected
- Properties of events at 161-172 consistent with QCD (unlike 130-136 data). No b tag excess so not Higgs.
- But still no other experiment sees them
- Working group of 4 LEP experiments established

ALEPH 4 jet events

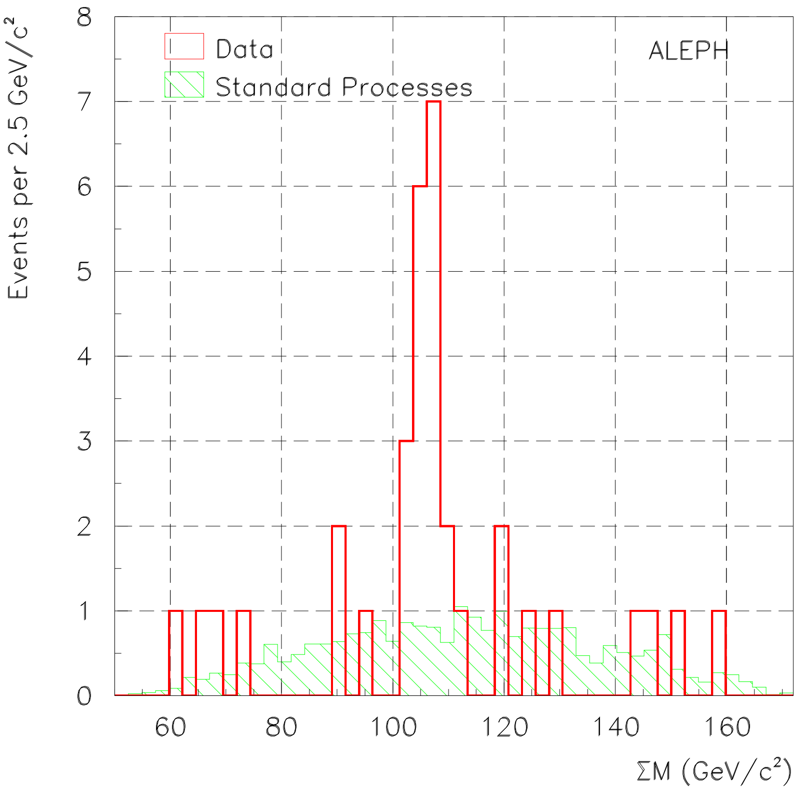
130 GeV (published)



161 + 172 GeV

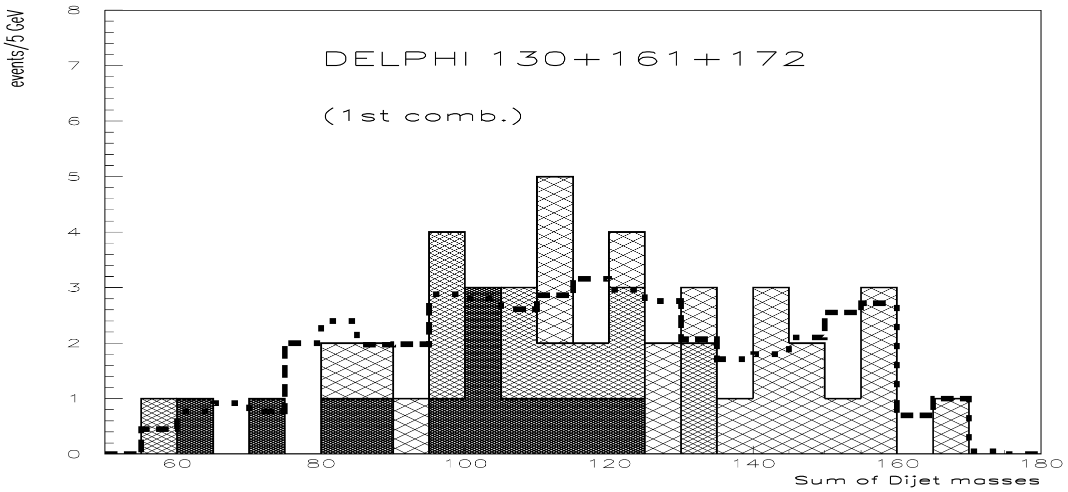


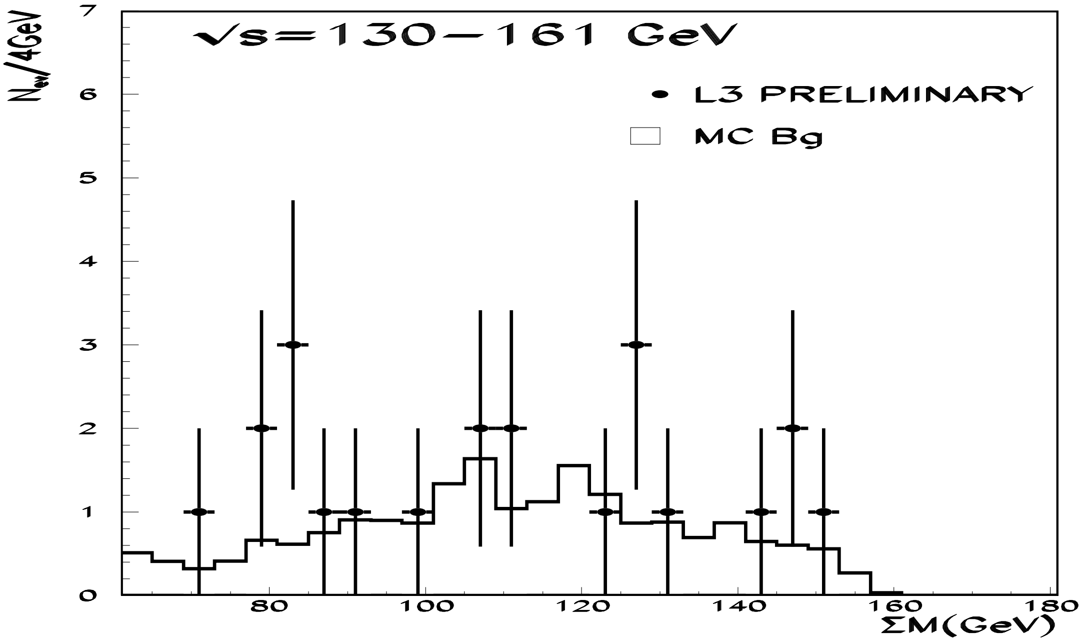
130 + 161 + 172 GeV

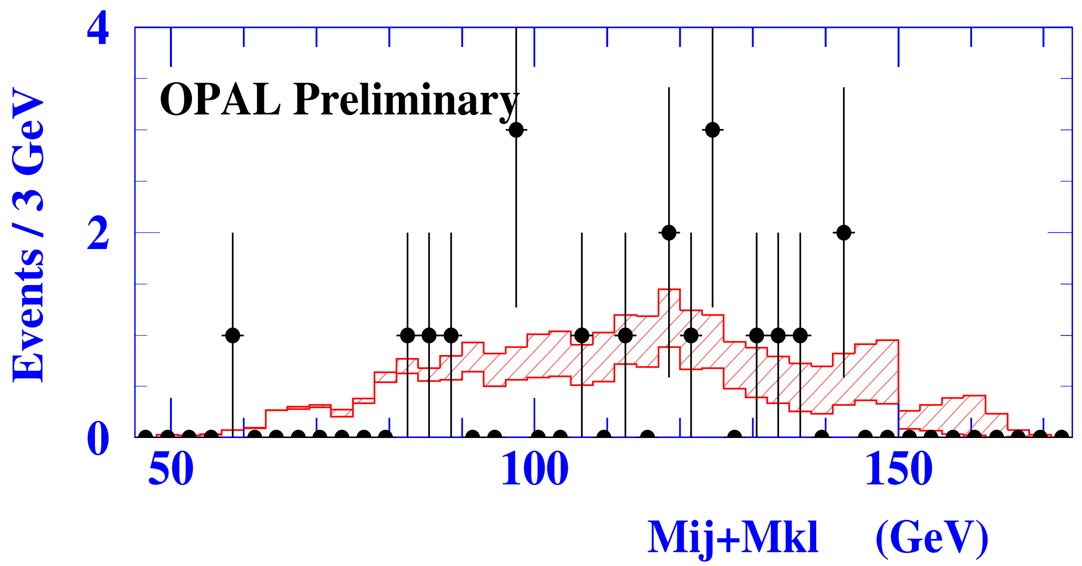


dijet mass sum

Other LEP 4 jet events







Energy Calibration – Precision needed

Z lineshape analysis – LEP combined errors from summer 1996:

$$\sigma(M_Z(\text{total})) = 2.0 \text{ MeV}$$
$$\sigma(\Gamma_Z(\text{total})) = 2.7 \text{ MeV}$$

of which

$$\sigma(M_Z(\text{LEP Energy})) = 1.5 \text{ MeV}$$
$$\sigma(\Gamma_Z(\text{LEP Energy})) = 1.7 \text{ MeV}$$

Shift in $M_Z \sim -4$ MeV from rise in fill effect deduced from NMR probes in the tunnel.

M_W in 1996:

$\sim$ 10 pb^{-1} at 161 GeV for M_W from threshold cross section plus $\sim$ 10 pb^{-1} at 172 GeV for direct reconstruction. Total error on M_W expected to be about 150 MeV so need:

$$\sigma(E_{beam}) \lesssim 50 \text{ MeV}$$

M_W for full LEP2 sample:

With 500 pb^{-1}, experimental errors on $M_W \lesssim$ 30-40 MeV, so need:

$$\sigma(E_{beam}) \lesssim 15 \text{ MeV}$$

Energy Errors for Z lineshape

Components of systematic errors on the beam energies for 1993 and 1995 (Summer 1996)

Source of error:	1993 $\sigma(M_Z)$	1993 $\sigma(\Gamma_Z)$	1995 $\sigma(M_Z)$	1995 $\sigma(\Gamma_Z)$
Rise Term from E_{pol}	**1.9**	0.6	**0.9**	0.6
Rise Term (model)	**0.8**	**0.9**	0.4	0.2
NMR_{48} Model	0.3	0.3	0.5	0.5
Temperature Coefficients	0.3	0.3	0.1	0.1
Corrector Settings	**0.8**	**1.1**	**0.8**	**1.1**
RF Corrections	0.2	0.1	0.5	0.4
Scatter of (E_{pol}-Model)	**0.9**	**1.3**	**0.3**	**0.5**
TOTAL:	**2.6**	**2.1**	**1.6**	**1.6**

1996 progress with 93–95 analysis

- Energy model developed for all years 93–95 based on 2 NMR's in LEP tunnel in 95 (NMR4 and NMR8)
- Rise per fill constrained by fills with more than one depolarization:
  - 6 dedicated fills in 1995 with mean rise of 3.9 MeV, rms of 2.8 MeV
  - 7 fills in 1993 with mean rise of 1.8 MeV, rms of 3.0 MeV
- Test dipole in ISR tunnel simulates both NMR4 & NMR8. Improved understanding of train/temperature effects.
- 16 NMR's in tunnel for 1996 $\Rightarrow$ check the beam pipe current inspired combination:

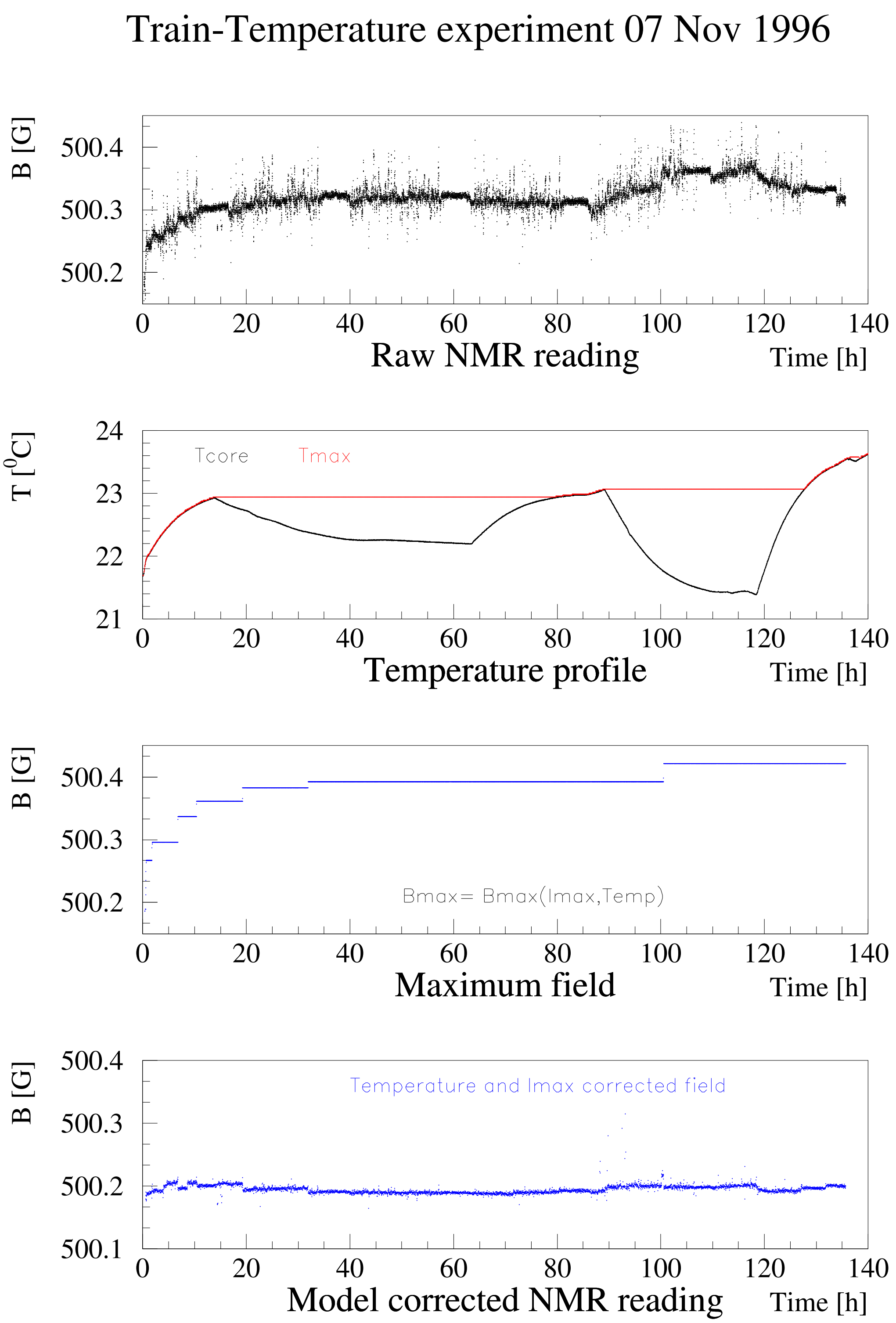
$$\mathrm{NMR}_{48} \equiv \frac{5}{8}\mathrm{NMR}_4 + \frac{3}{8}\mathrm{NMR}_8$$

- Effect of orbit corrections checked with polarization $\Rightarrow$ reduced error
- SC RF cavity alignment checked/remeasured $\Rightarrow$ reduction of errors for IP2, IP6 in 93–95. Also better measurement of path length difference between IP2-IP6 via IP4 or IP8 $\Rightarrow$ smaller errors for IP4, IP8

Temperature and Magnetic History

The dipole field depends on the temperature history and the maximum B field previously seen

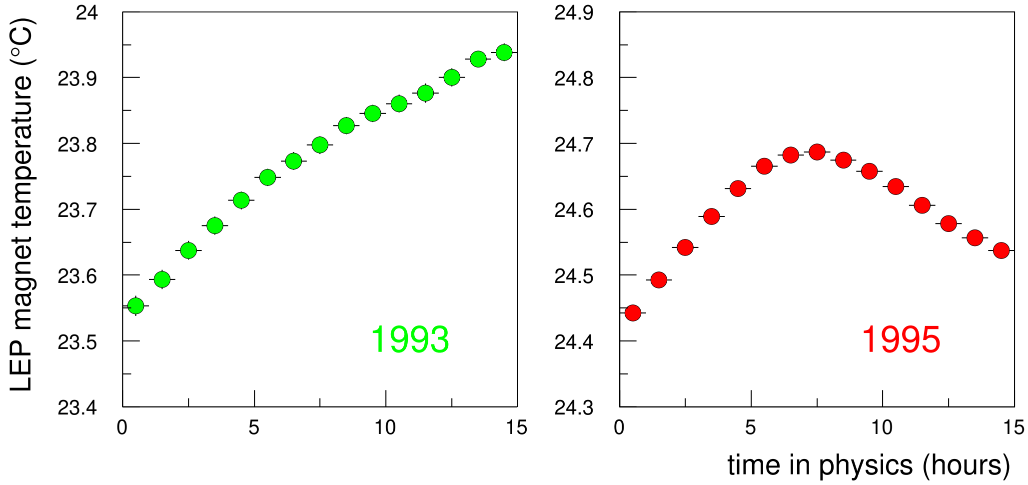
Tests in progress on effect of this on model of rise per fill



Final results for 93–95?

Correctors: Implement full corrector model for 93 and 95.

Rise per fill: Finalise temperature/train model $\Rightarrow$ move to model with two temperature coefficients. Check B_{max} effect to assign error.



RF corrections: SC RF alignment measurements still not fully understood, but without more cross checks in 1997, errors here are final.

Relative longitudinal collision point of bunchlets also mysterious, but $E_A - E_C$ is measured to be $-0.1 \pm 0.3\,\mathrm{MeV}$, which allows some constraint.

1994: Analysis must be brought up to date with 93 and 95 understanding

Trying to produce final values for Spring conferences

Status of 1996 Calibration

- Reliable logging of necessary quantities (RF, NMR...)
- NMR data quality OK for 161 GeV, very good for 172 GeV, thanks to persistent effort to maintain probes.
- 16 NMR's in the tunnel $\Rightarrow$ model of rise per fill, temperature/train effects easier. Rise per fill increased.
- Vernier scans to control collision offsets $\Rightarrow$ opposite sign vertical dispersion due to BTB no problem.
- No resonant depolarization possible at physics energy. Only two lower energies measured this year but flux loop/NMR extrapolation to physics energy looks good.

1996 Depolarization Measurements

Date	Fill	Energy	LEP Setting	$E_{pol}(GeV)$
31/10	3702	P-2	44.677	44.7000
03/11	3719	P-2	44.677	44.7009
19/08	3599	50	49.990	50.0022
03/11	3719	50	49.993	50.0015
04/11	3719	50	49.993	50.0022

- 12% polarization achieved at 50 GeV $\Rightarrow$ expect 6% at 55 GeV in same conditions
- Only 2% polarization observed at 55 GeV with 90/60 unsqueezed MD optics. Some HSM bugs found.

Summary of 1996 Energy Errors

$\sigma(E_{beam})$ [MeV] at	80.5 GeV	86 GeV
Energy Scale Errors:		
Polarisation systematic	1	1
e^+e^- energy difference	1	1
Fill-by-fill normalisation	10	5
Extrapolation	24	29
Orbit correctors	1	1
Variation within a fill:		
Tide model	1	1
NMR/temperature model	2	2
IP specific:		
Dispersion	1	1
RF	5	5
Total	27	30

Extrapolation error:

- Most measured uncertainties are at the $10 \sim 12$ MeV level
- Some larger deviations ($\approx$ 20 MeV) eg. using absolute energy scale of flux loop or using different combinations of NMR probes to compare with E_{pol}
- Only two different energies depolarized, and only one fill with two different energies measured $\Rightarrow$ no assessment of non-linearity of extrapolation from polarization data

Energy Calibration Requests for 1997

- End of fill polarization calibration during Z running at beginning of the year (fix normalisation, debug polarimeter...)
- Plus $\geq$ 6 fills with $\geq$ 2 E_{pol} energies measured, including $\geq$ 2 fills with $\geq$ 3 E_{pol} energies measured
- Increase maximum energy at which depolarization measurement possible
- k modulation to improve efficiency of this program and help increase E_{pol}^{max} (estimate about 6 days of polarization measurements in this request)
- Investigate the possibilities of a dedicated polarization optics
- Continue to maintain NMR's. (Radiation protection...?)
- Continue regular flux loop measurements
- Calibrate RF forward and reflected power. RF alignment cross checks?
- Measure opposite sign vertical dispersion
- Bend modulation at start of fill?

Conclusions

- Lots of promising new physics results from 1996 data.
- High luminosity is preferred to squeezing up the energy in 1997, since the energy will anyway increase in 1998
- L3 & DELPHI want to spend all of 1997 at top energy
ALEPH & OPAL want to leave the option open to reconsider after collecting 50 pb^{-1} (maybe take a further 50 pb^{-1} at 161 GeV during 1997 if it looks possible)
- Need 500 pb^{-1} over the next 3 years to measure M_W.
- Final reach of (some) searches will depend on maximum energy $\Rightarrow$ great interest in pushing beam energy as high as possible in the longer term.
- Other searches also require large luminoisity to be saturated (eg. hA several 100 pb^{-1})
- LEP2 can probe a large range of SUSY space
- Energy calibration requests are time consuming but are necessary to achieve the goal for LEP2 of $\lesssim 15$ MeV.