Boson-pair cross sections at LEP

WW, ZZ, $\gamma\gamma$

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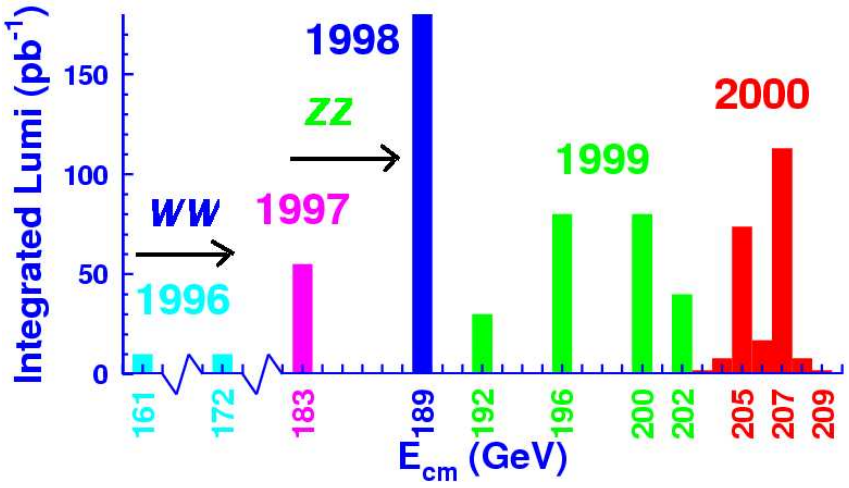
Outline:

- Data sample
- WW production
  - Definitions, selections, combination
  - Branching ratios, V_{cs} and differential cross section
- ZZ production
  - Definitions, selections, combination
- $\gamma\gamma$ production
  - Definitions, selections, combination
  - Constraints on new physics
- Conclusions

Data sample

The whole statistics collected by the 4 LEP experiments since year 1996 to year 2000:



Event yield / exp.:

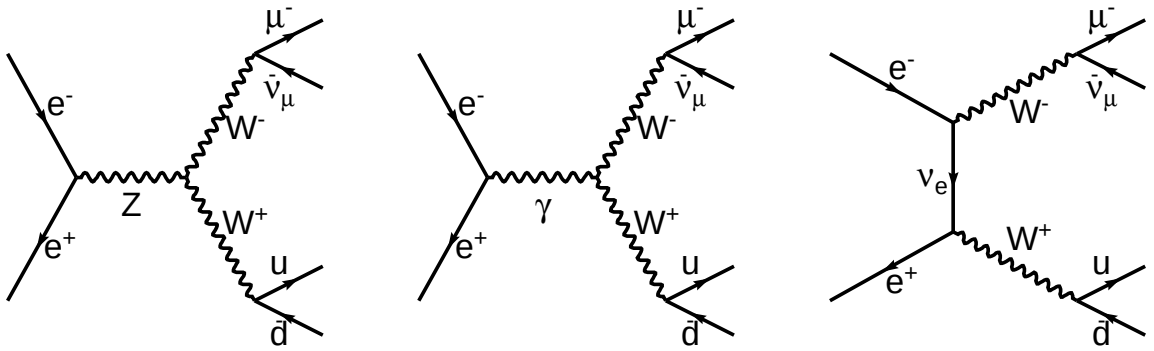
WW	$\sim$ 10000	($\sigma_{SM} \sim 17$ pb)
ZZ	$\sim$ 500	($\sigma_{SM} \sim 1$ pb)
$\gamma\gamma$	$\sim$ 4000	($\sigma_{SM} \sim 10$ pb)

Total integrated luminosity: $\int \mathcal{L} dt \simeq 700$ pb^{-1}/ exp. at center-of-mass energies in $\sqrt{s} = 161 - 209$ GeV

The following results are obtained using full statistics unless differently indicated

WW production: theory and definitions

Born level diagrams - Charged Current 03:



10 different topologies are considered

Channels	Rate
$qqqq$ (1)	45.6 %
$qq\ell\nu$ (3)	43.8 %
$\ell\nu\ell\nu$ (6)	10.6 %

The measured cross sections are corrected to CC03 + Initial State Radiation for combinations

Theoretical predictions up to $\mathcal{O}(\alpha_{em})$ corrections are available with an estimated uncertainty of ~ 0.5 %

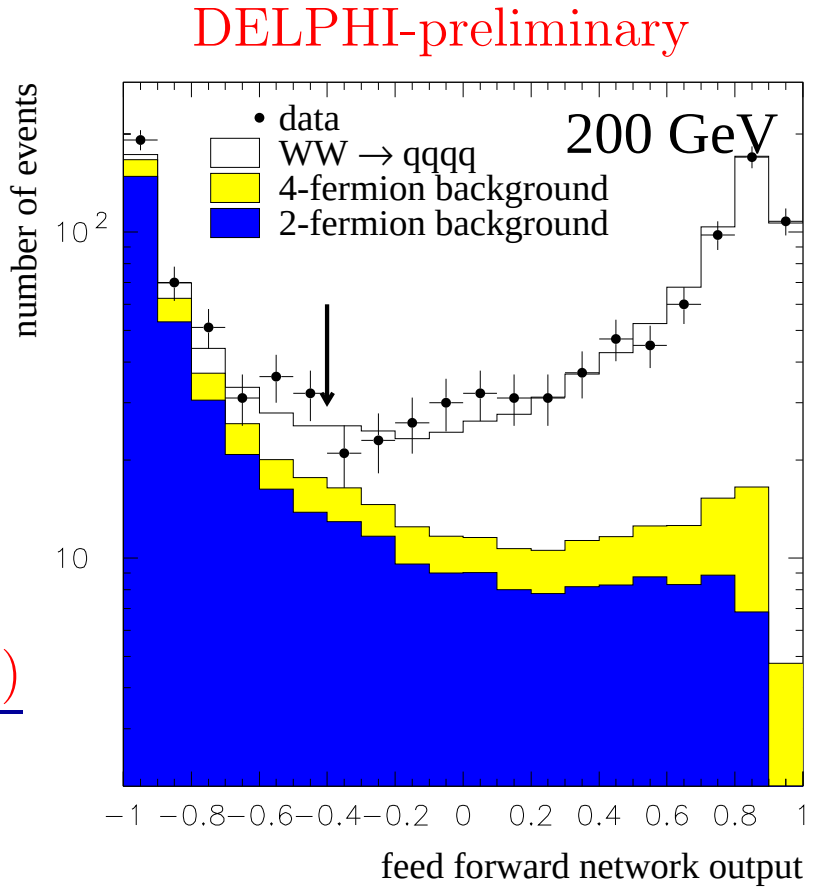
WW production: selection of $qqqq$ events

- Large multiplicity
- No missing momentum
- Multidimensional techniques used to enhance separation w.r.t. $q\bar{q}$ background

- Main systematics sources:
  - detector effects
  - hadronization models

  (correlated among experiments !)

- $\sim$ 5500 events / experiment
- Eff. $\sim$ 90 %, purity $\sim$ 85 %

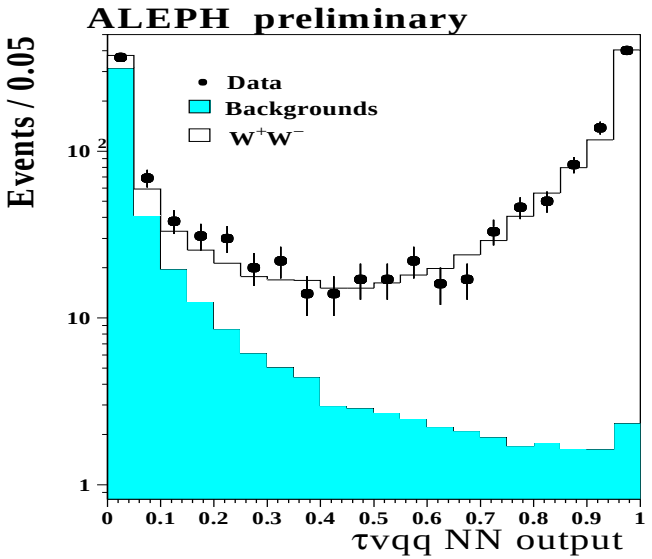


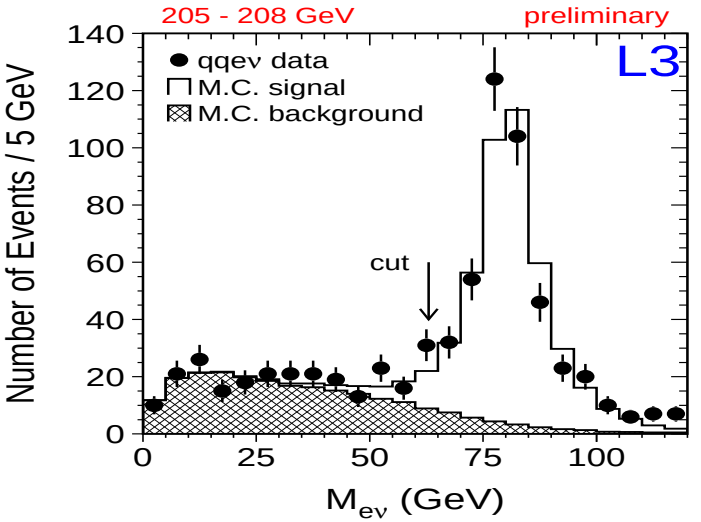
WW production: selection of $qq\ell\nu$ and $\ell\nu\ell\nu$ events

- ✸ Two jets + high energy lepton
  Two high energy leptons
- ✸ Large missing momentum

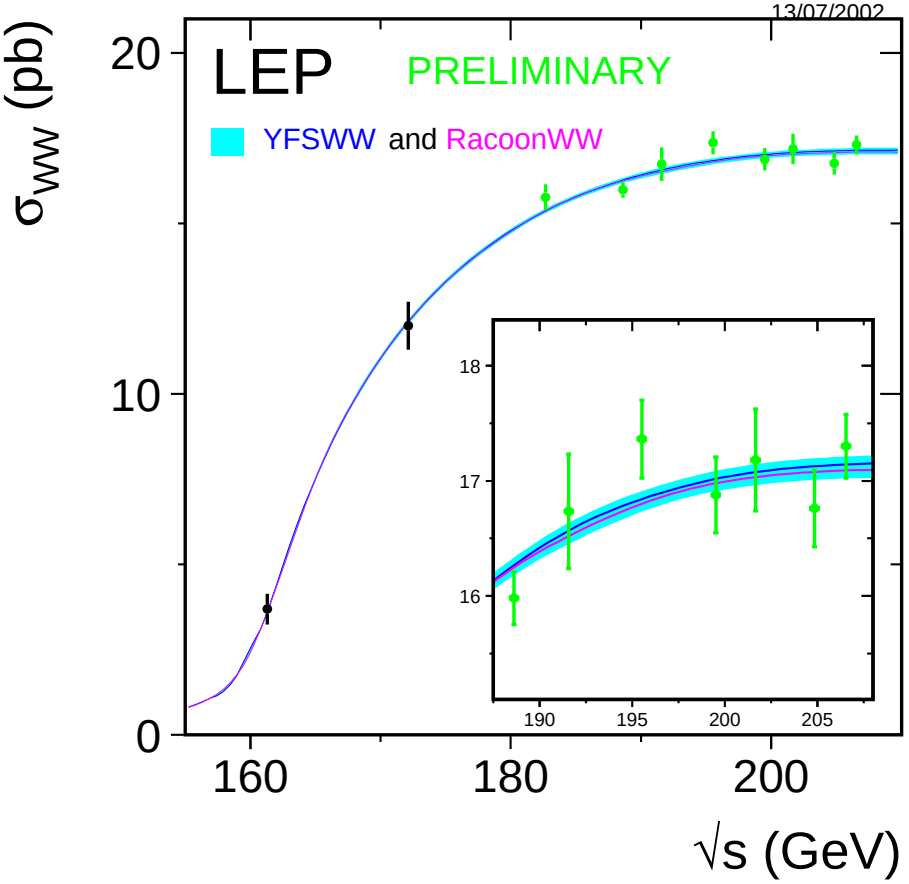
- ❖ Main systematics sources:
  - lepton identification
  - background subtraction

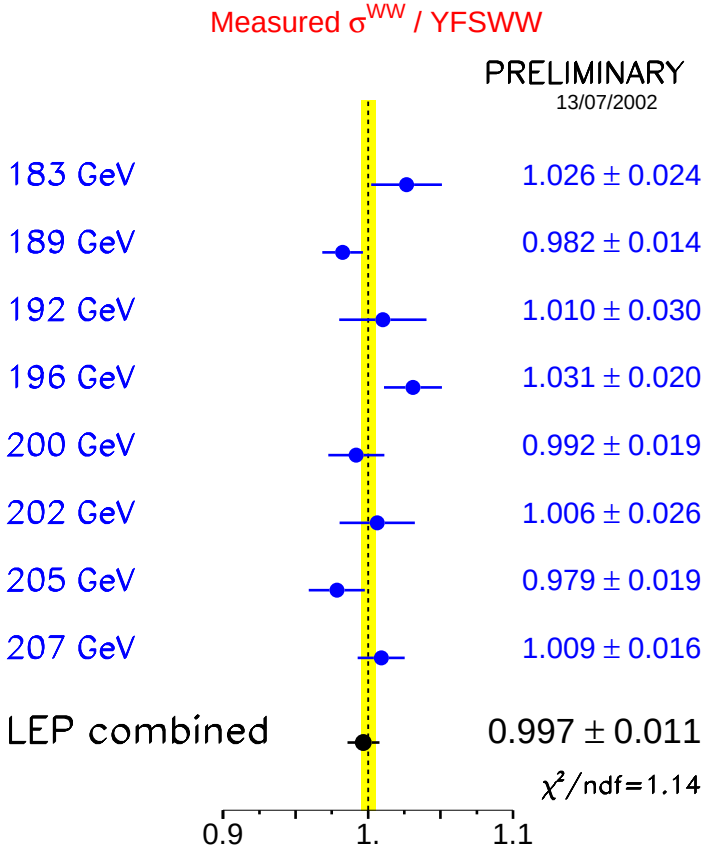
- ✚ ~ 3500 $qq\ell\nu$ events / exp.
  ~ 1000 $\ell\nu\ell\nu$ events / exp.
- ✚ Eff. $\sim 60-85$ %, purity ≥ 90 %





WW production: LEP combination





Updated results with improved combination procedure

Derived (no update): $Br(W \to \ell\nu) = 10.69 \pm 0.09\%$, $|V_{cs}| = 0.996 \pm 0.013$

Main correlated systematics coming from hadronization modeling

Total systematic uncertainty on $\sigma_{meas}/\sigma_{th} \sim 0.009$

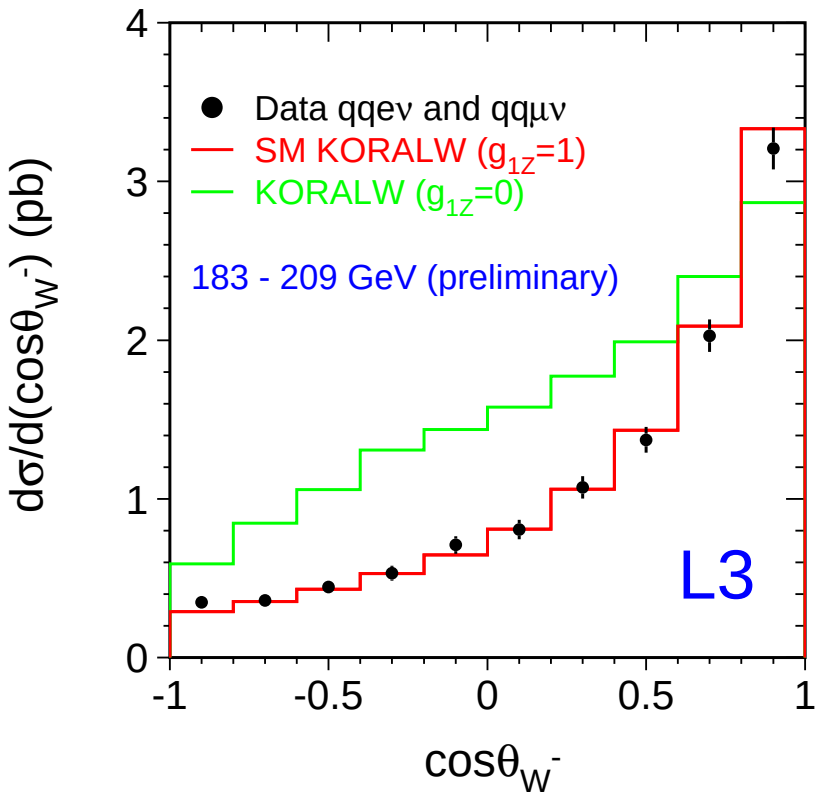
WW production: $\cos(\theta_W)$ differential distribution

Much more information (i.e. testing power) is contained in differential distributions.

The signal definition, based on clean channels, is chosen as to minimize extrapolation in undetected phase space regions:

- Only $qq\ell\nu$ events are used
- $\theta_\ell > 20°$ w.r.t. beam axis
- Final state photons recombined with parent fermion

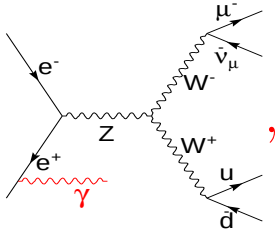
Tests of the slope at ~ 2 % will be feasible with full LEP statistics

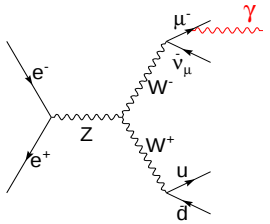


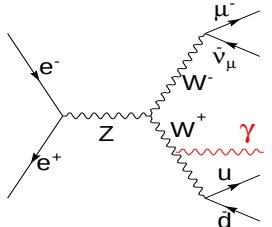
LEP combination is planned

WW production: with an additional photon

Specific final states with a detected photon are looked at.
Nice test of theoretical implementation of radiation:

ISR: 

, FSR: 

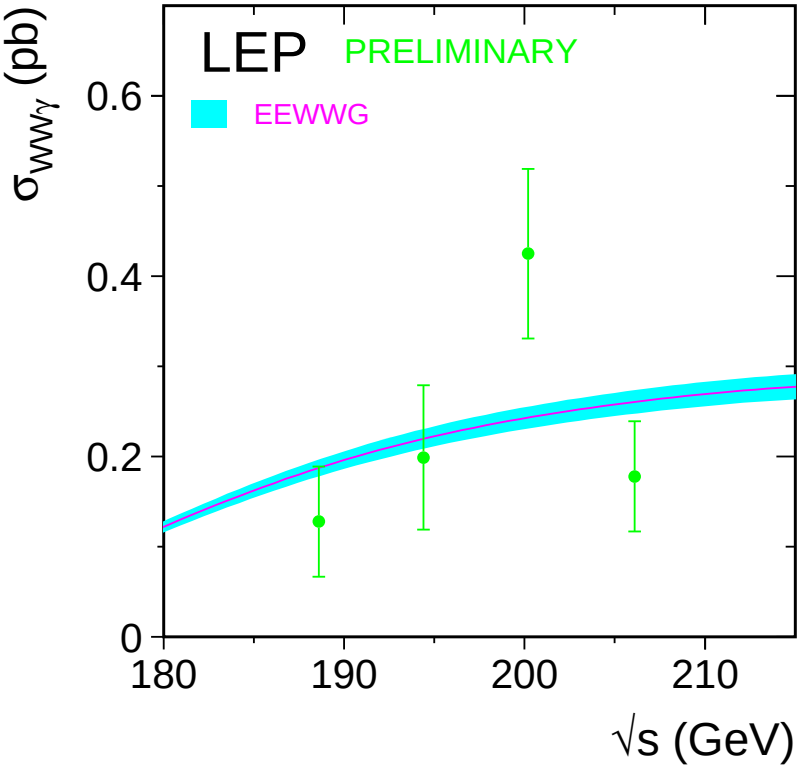
, WSR: 

Signal definition:

- $E_\gamma > 5$ GeV
- $|\cos(\theta_\gamma)| < 0.95$
- $\cos(\alpha_\gamma) < 0.90$

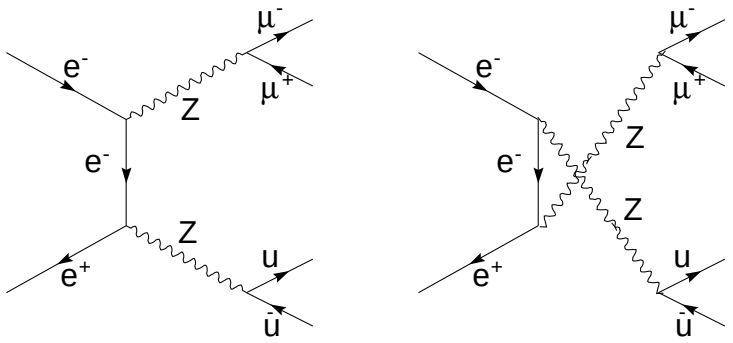
  α_γ = angle between photon and nearest charged fermion
- $M_{ff'} = M_{\mathrm{W}} \pm 2\Gamma_{\mathrm{W}}$

Used for anomalous WW$\gamma\gamma$ and WWγZ coupling searches
Only L3 and Delphi results are combined



ZZ production: theory and definition

Born level diagrams NC02:



Several topologies

Channel	N.	Rate
$\ell^+\ell^-\ell^+\ell^-$	(6)	1 %
$\ell^+\ell^-\nu\nu$	(3)	4 %
$q\bar{q}\ell^+\ell^-$	(6)*	14 %
$q\bar{q}\nu\bar{\nu}$	(2)*	28 %
$q\bar{q}q\bar{q}$	(2)*	49 %

* Light quarks are usually distinguished from b's

The measured cross sections are corrected to NC02 + ISR for combinations

Theoretical predictions are estimated to be precise at ~ 2 % level

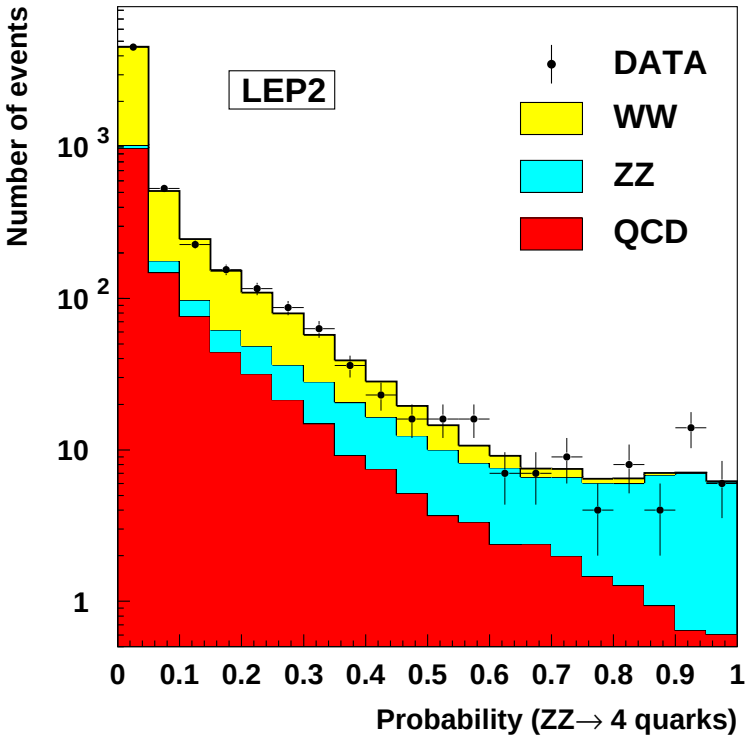
ZZ production: selection

Selection are made difficult by the low signal cross section compared to the dominant (almost irreducible) WW background

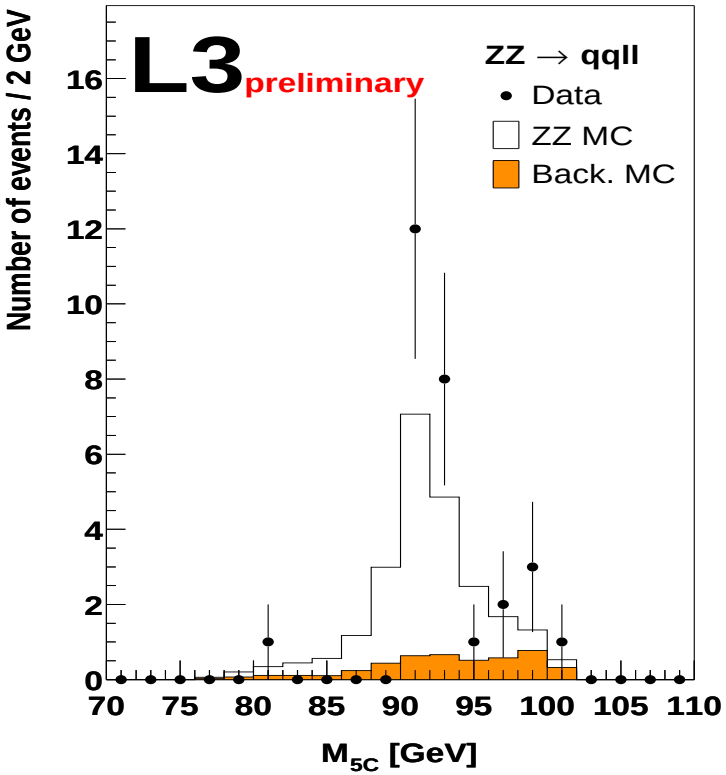
Refined multi-dim techniques are used to enhance the separation power

The $b\bar{b}q\bar{q}$ selection is an useful benchmark for Higgs searches

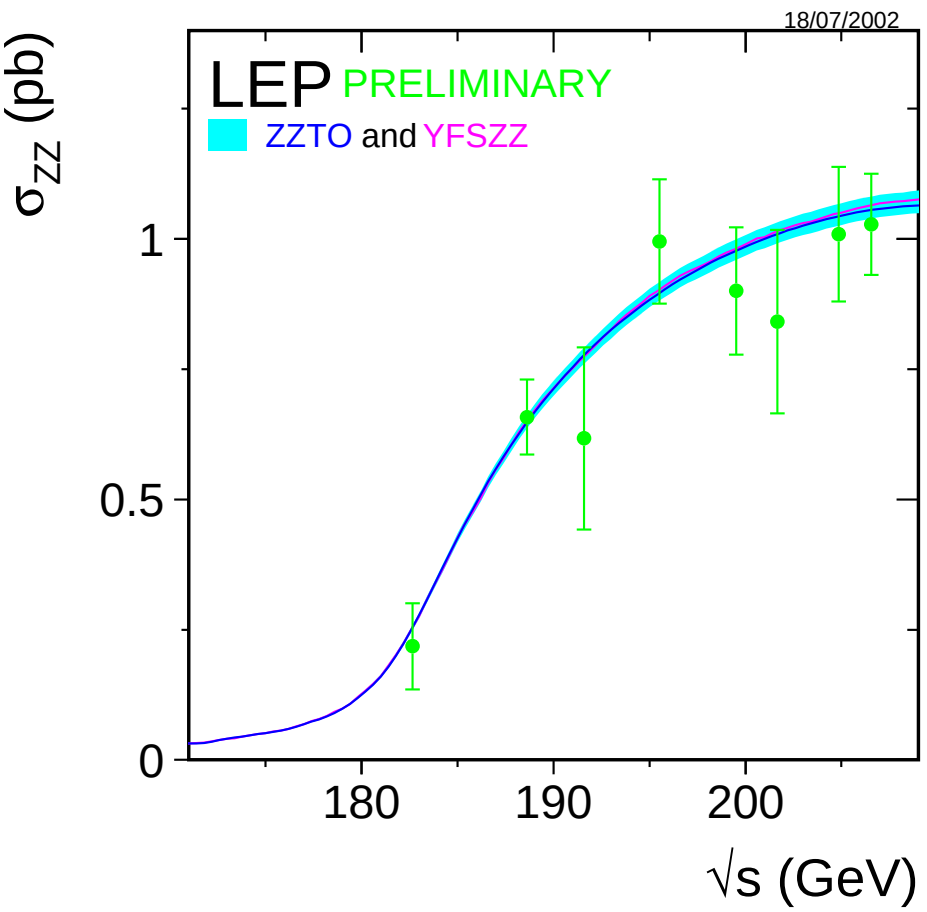
DELPHI - preliminary

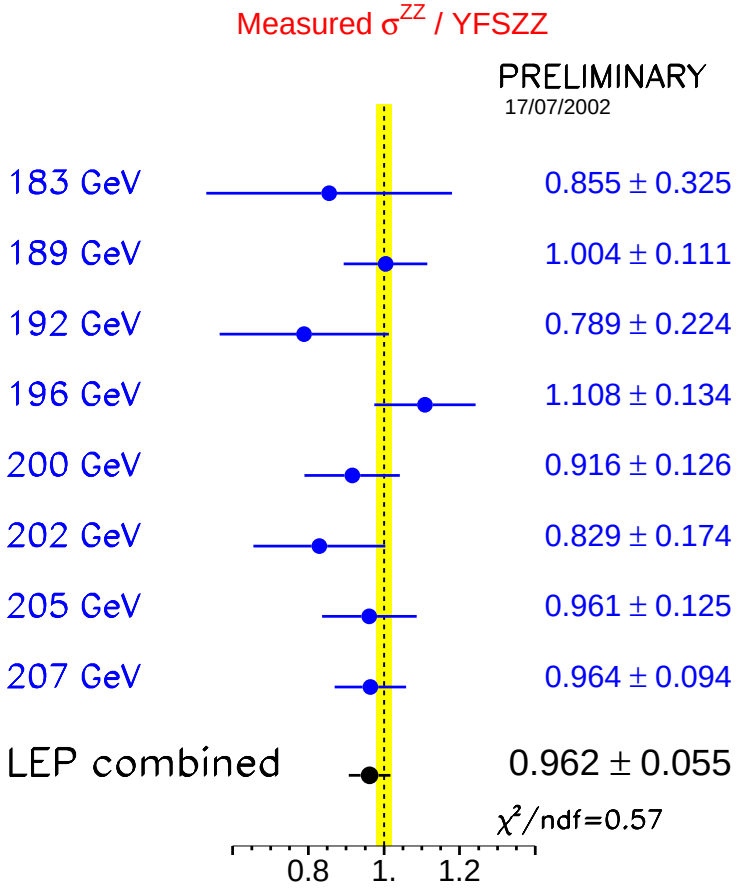


$\sqrt{s} \geq 205$ GeV



ZZ production: LEP combination





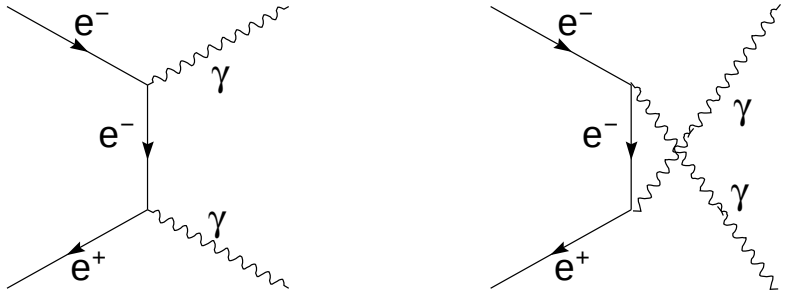
Updated results with improved combination procedure

Main correlated systematics coming from background modeling

Total systematic uncertainty on $\sigma_{meas}/\sigma_{th} \sim 0.028$

$\gamma\gamma$ production: theory and definition

Born level diagrams:



Pure QED process in the SM with small HO corrections:

$$\left.\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\right|_{Born} = \frac{\alpha^2}{s}\frac{1+\cos^2\theta}{1-\cos^2\theta}$$

A good place to look for new physics: QED cut-off, low scale gravity, spin 3/2 leptons, excited electrons, etc.

To reduce effects due to ISR the photon polar angle θ is defined as:

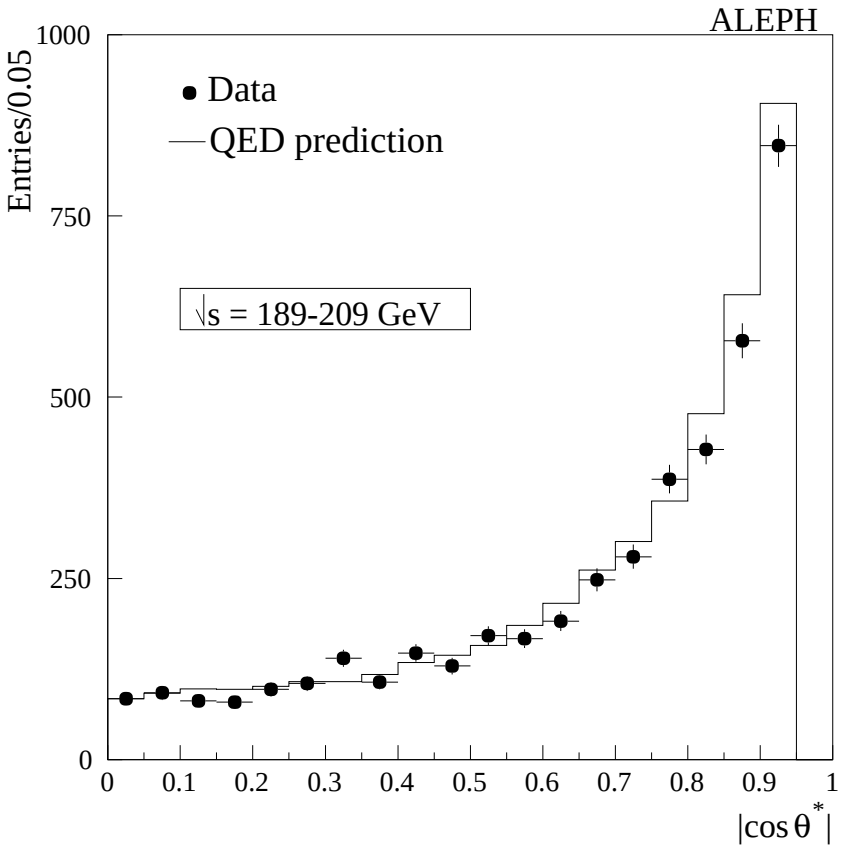
$$\cos\theta = \left|\sin\left(\frac{\theta_1-\theta_2}{2}\right)\right| / \sin\left(\frac{\theta_1+\theta_2}{2}\right)$$

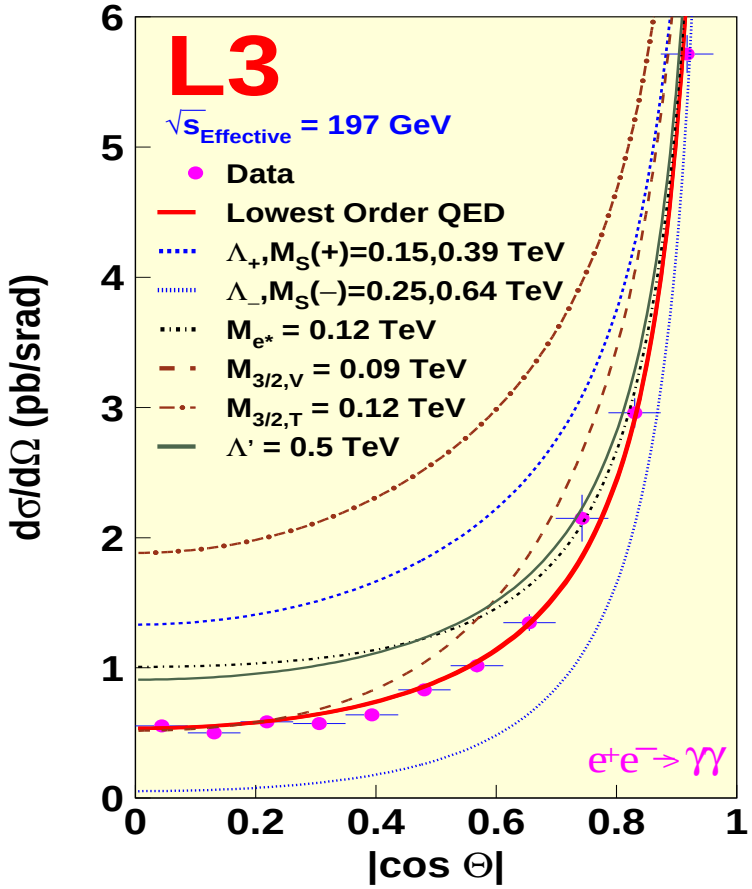
$\gamma\gamma$ production: selection and differential distribution

Straightforward selection with small background contamination: ≤ 1 %

Main systematics from detector response modeling

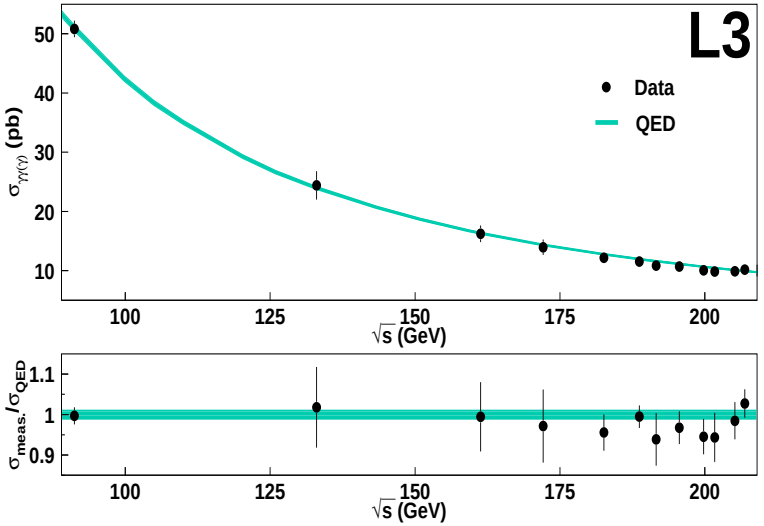
Alternative theoretical models can be tested using the differential distribution.

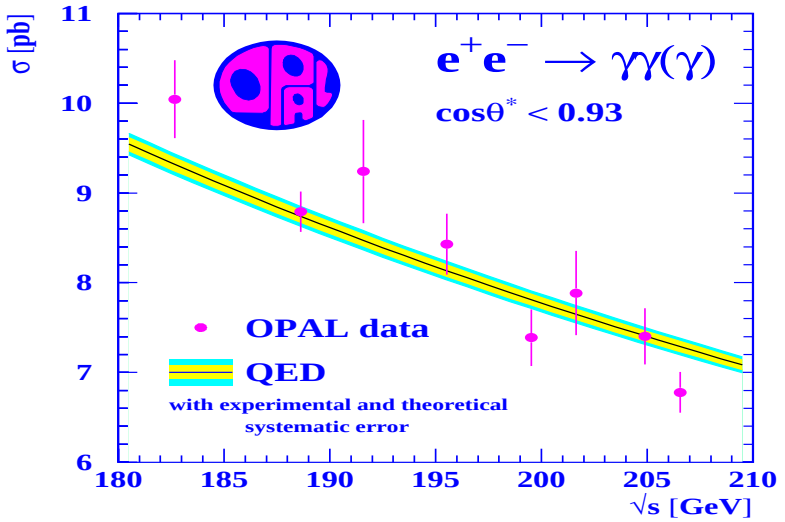




$\gamma\gamma$ production: LEP combination

Two examples:

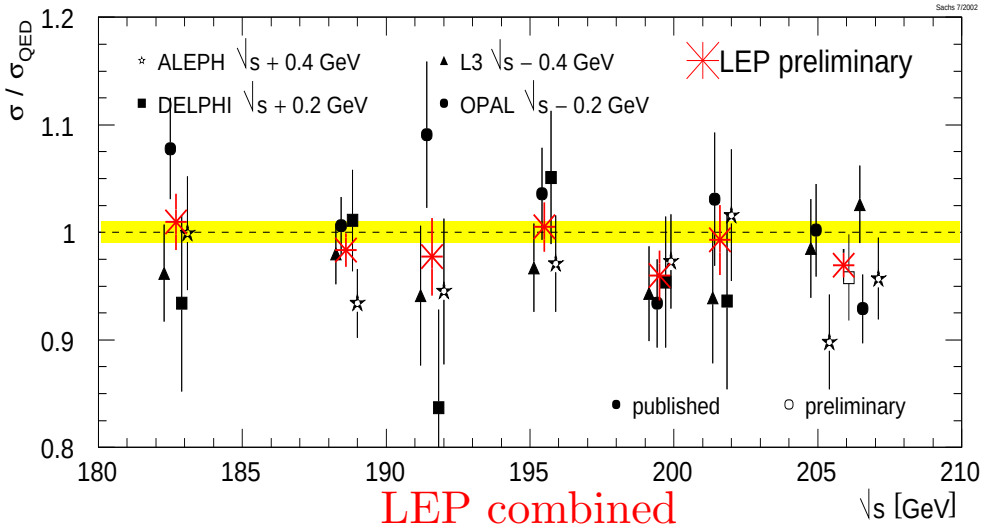




Almost final results
(DELPHI-206 GeV prelim.)

$\sigma_{meas}/\sigma_{th}(\text{LEP}) = 0.982 \pm 0.010$
Theory uncert. $(\mathcal{O}(\alpha^3)) \sim 1$ %

Graviton mass limit $\sim$ 1 TeV
QED cut-off $\Lambda_{+,-} \geq 400$ GeV



LEP combined

Conclusions

- The full LEP statistics is analyzed and final combinations are going on
- The Standard Model is tested at the percent level
- Preliminary combinations of total cross sections show no sign of deviation
- Additional combinations are envisaged (differential distributions, limits on new physics)
- LEP ready to set other long lasting milestones in the PDG