W mass and couplings with L3 at LEP

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L3 Collaboration

- W-pair-production at LEP
- W mass measurement
- W coupling to γ and Z bosons
- Conclusions

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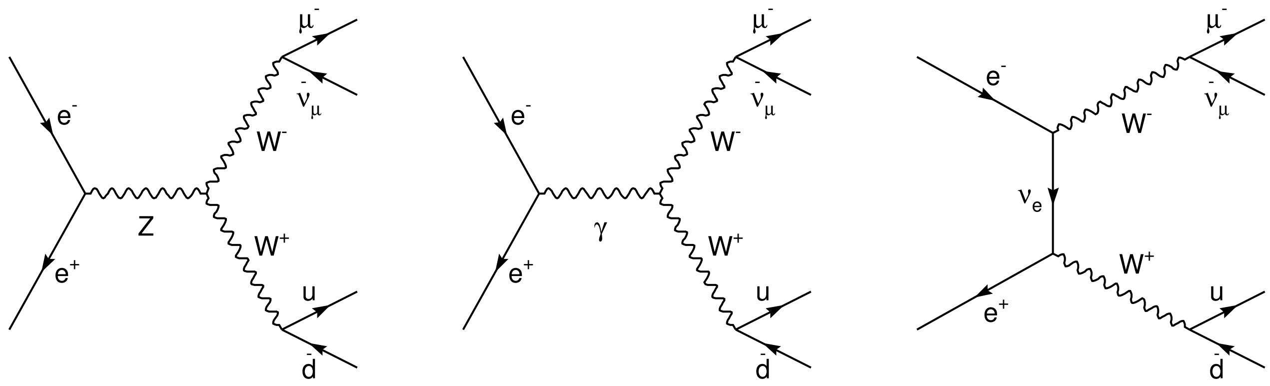
W-pair production at LEP

Main diagrams (called CC03)



	$W \rightarrow q\bar{q}$	$W \rightarrow \ell\bar{\nu}$ $(\ell = e, \mu, \tau)$
BR (%)	67.5	$3 \cdot 10.8$

$$e^+e^- \longrightarrow WW \longrightarrow q\bar{q}q\bar{q},\, e\bar{\nu}q\bar{q},\, \mu\bar{\nu}q\bar{q},\, \tau\bar{\nu}q\bar{q},\, \ell^-\bar{\nu}\ell^+\nu$$

$$\begin{aligned} DF_{WW\rightarrow qqqq} &= (BR_{W\rightarrow qq})^2 & \sim 45\% \\ DF_{WW\rightarrow qq\ell\nu} &= 2 \cdot (BR_{W\rightarrow qq}) \cdot (BR_{W\rightarrow \ell\nu}) & \sim 44\% \\ DF_{WW\rightarrow \ell\nu\ell\nu} &= (1 - BR_{W\rightarrow qq})^2 & \sim 11\% \end{aligned}$$

1996 $\sim$ 11 pb^{-1} @ 161 GeV $\longrightarrow$ 22 WW

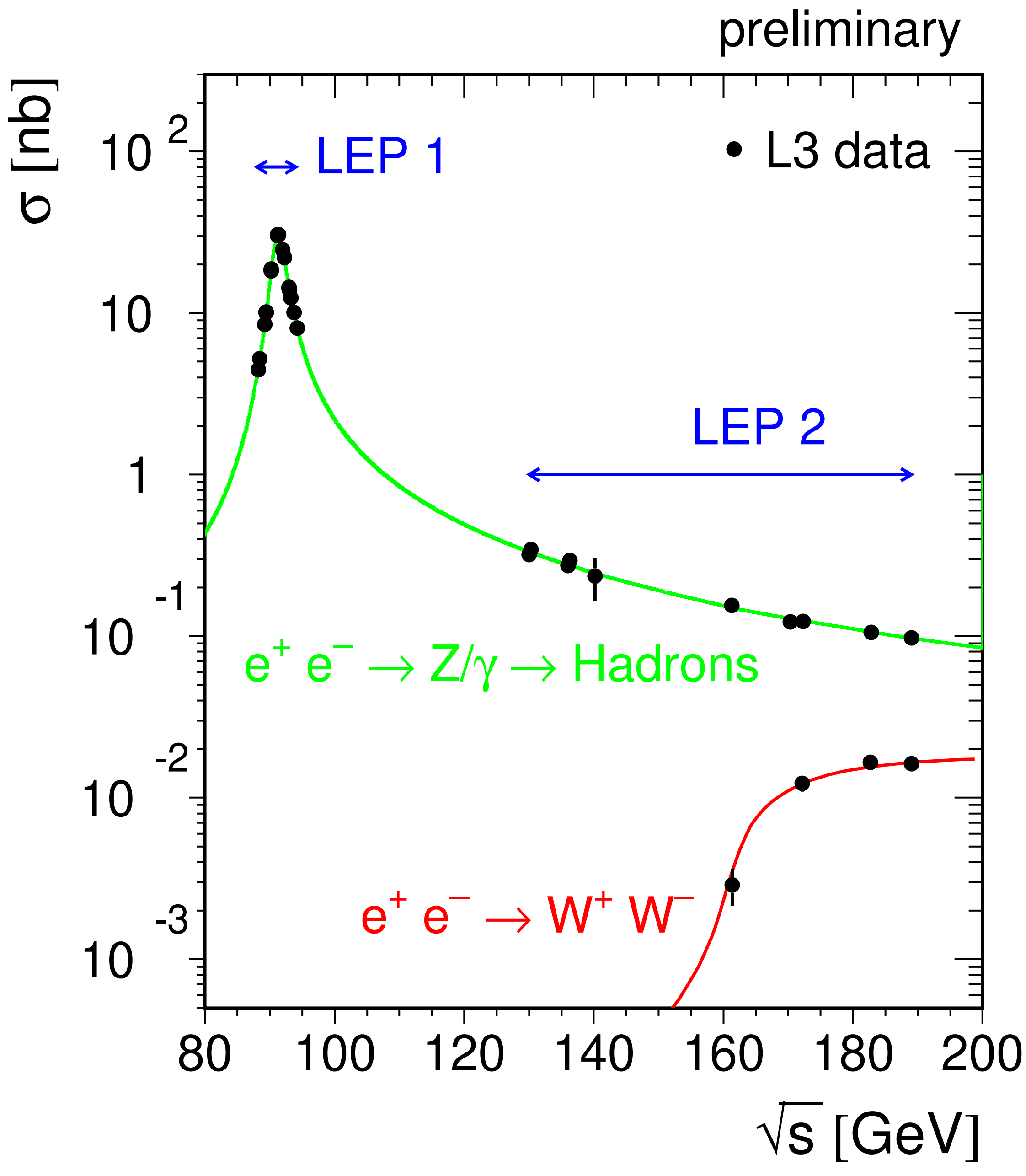
1996 $\sim$ 10 pb^{-1} @ 172 GeV $\longrightarrow$ 110 WW

1997 $\sim$ 55 pb^{-1} @ 183 GeV $\longrightarrow$ 824 WW

1998 $\sim$ 176 pb^{-1} @ 189 GeV $\longrightarrow$ 2735 WW

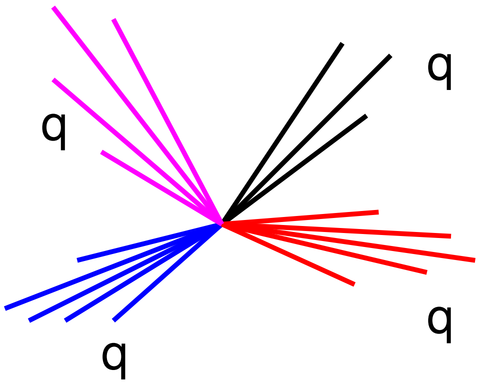
W-pair production at LEP

LEP2 phase

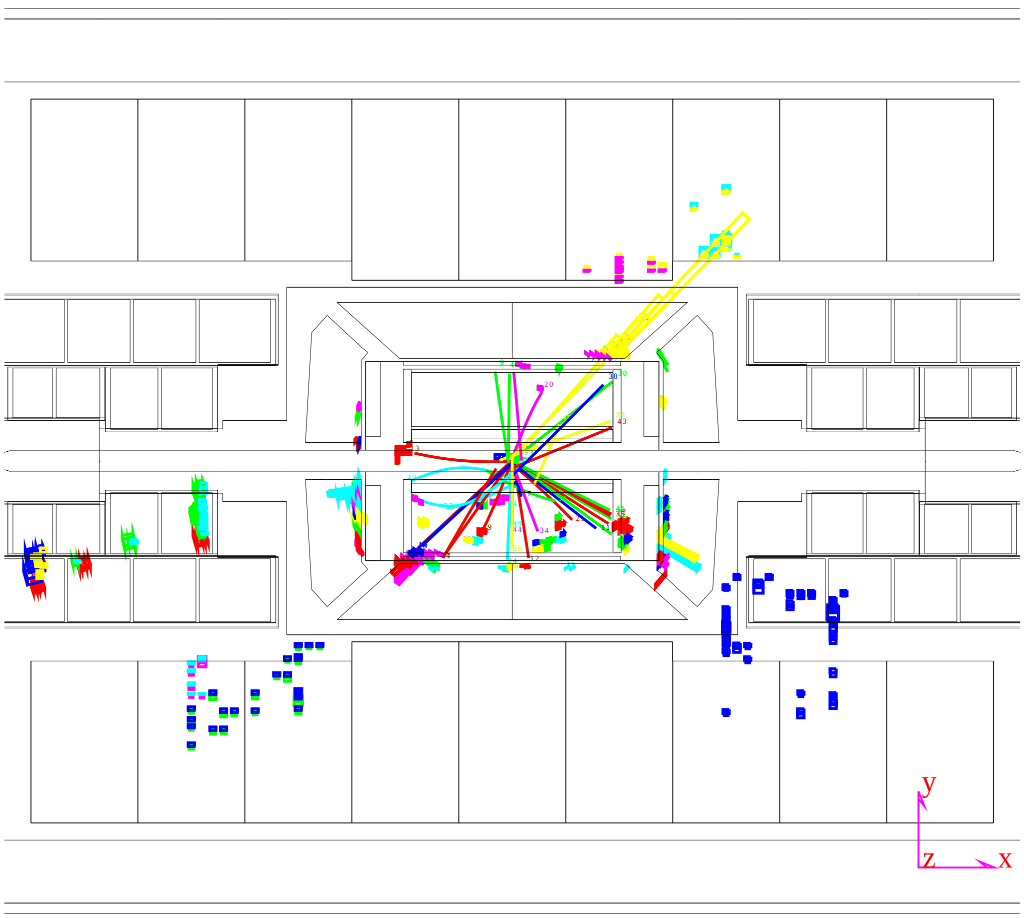


- 3691 W-pair events collected by L3

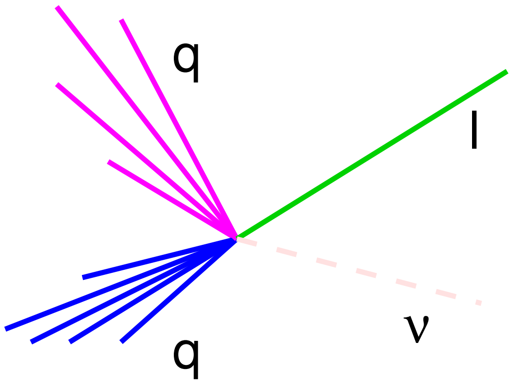
W-pair: $q\bar{q}q\bar{q}$ selection



- high multiplicity
- high visible energy and no missing momentum
- 4 jet event topology

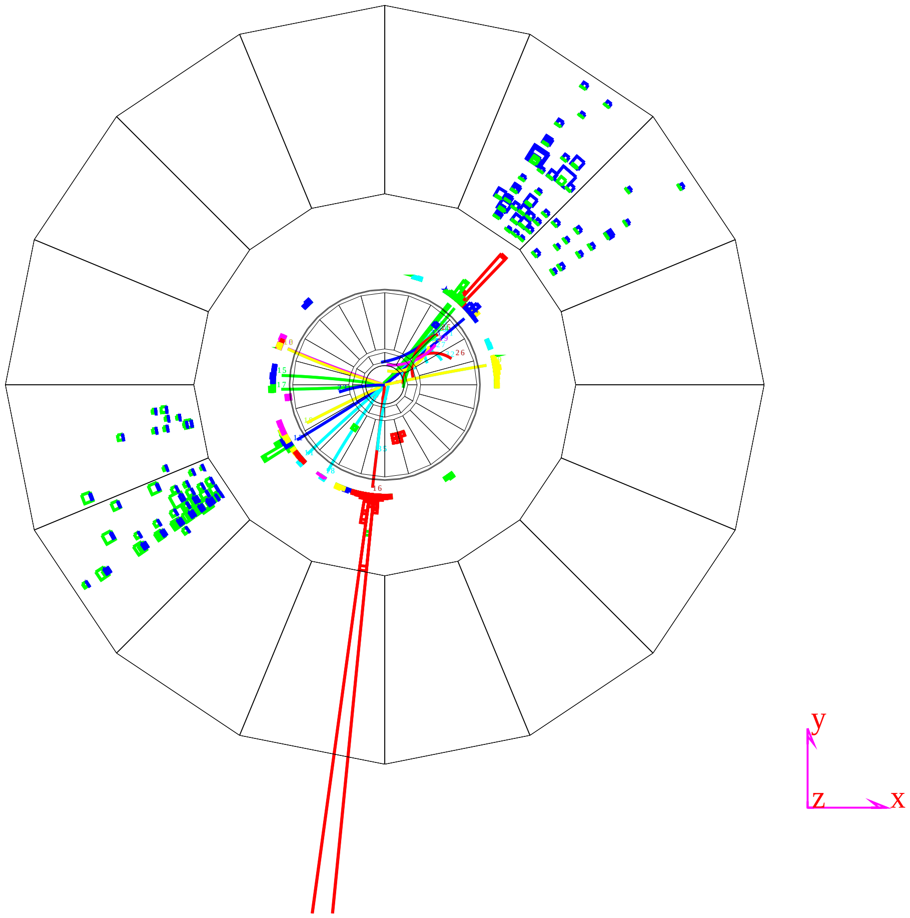


W-pair: $\ell\bar{\nu}q\bar{q}$ selection

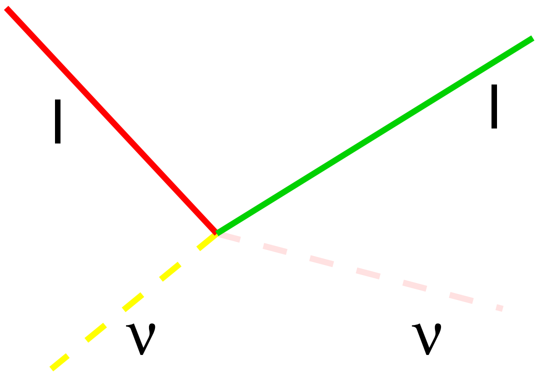


- high multiplicity
- high missing momentum due to unetected neutrino
- 1 isolated and identified lepton

- $e^+e^- \rightarrow WW \rightarrow e\bar{\nu}q\bar{q}$ event candidate

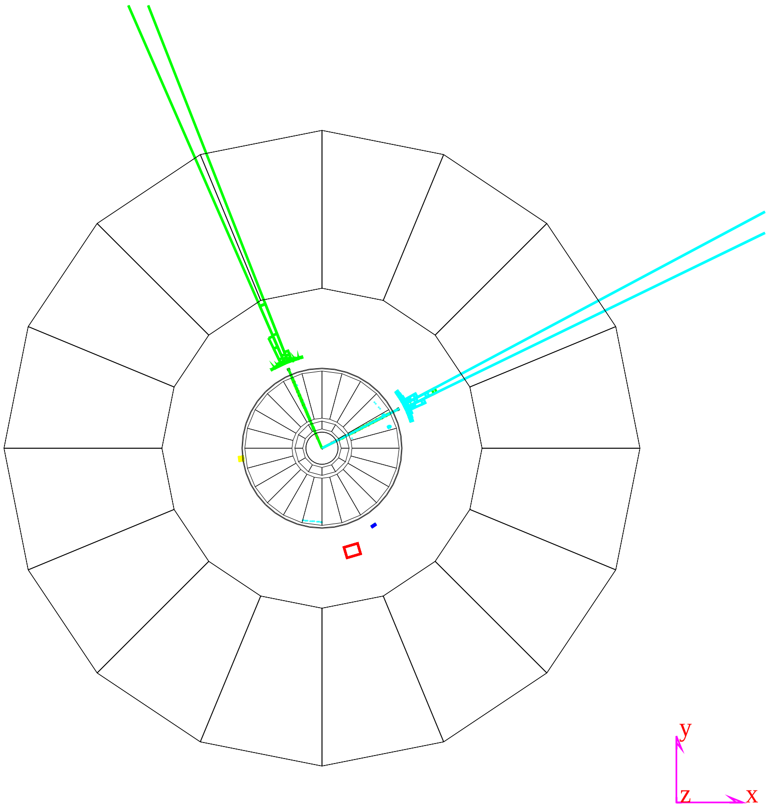


W-pair: $\ell^-\bar{\nu}\ell^+\nu$ selection

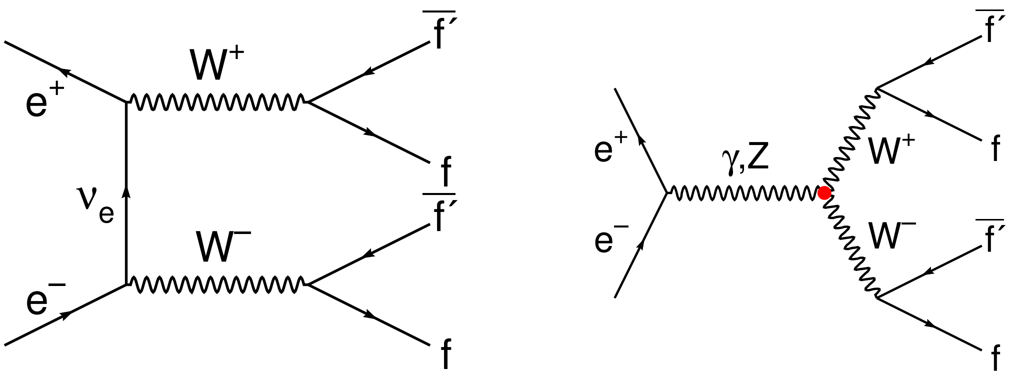


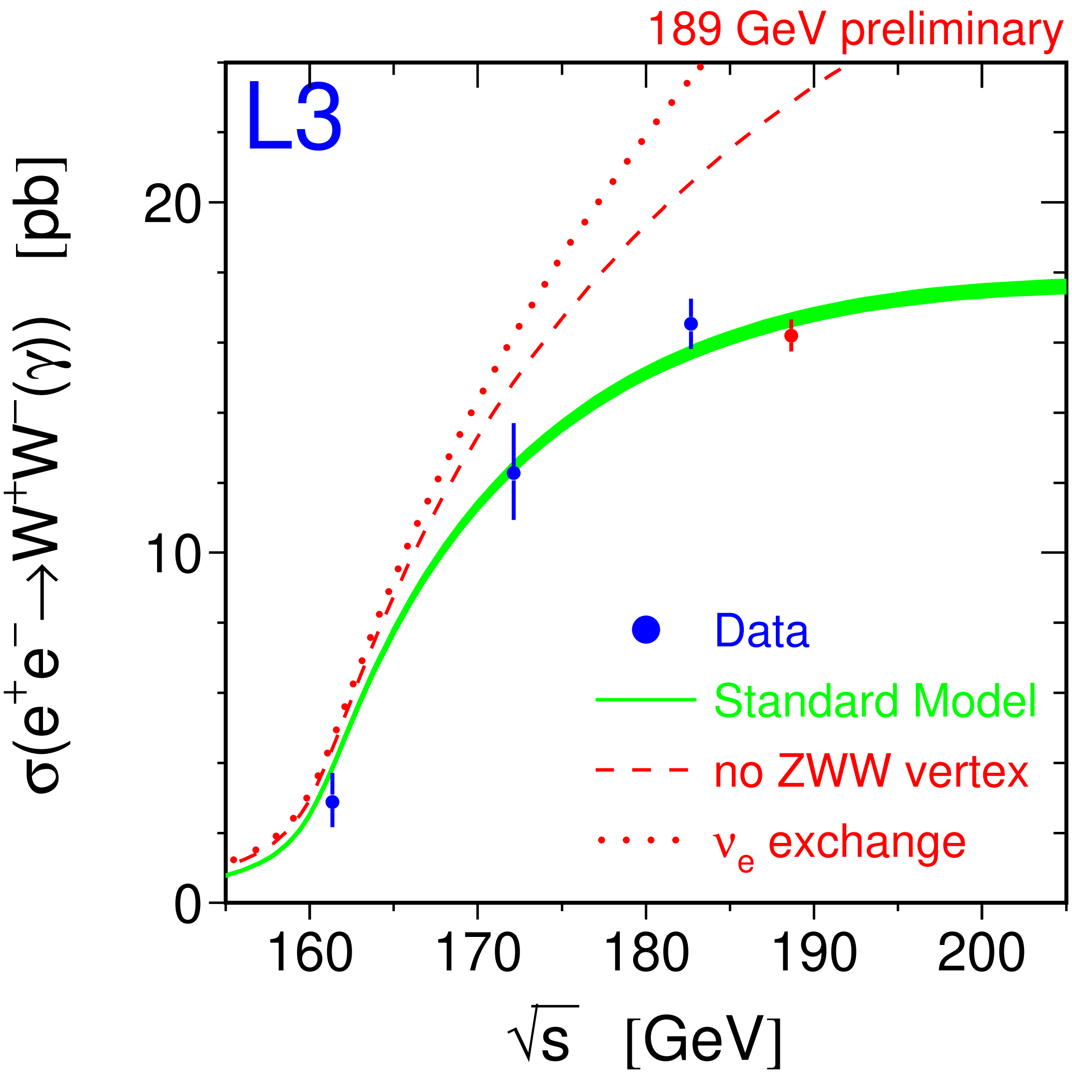
- low multiplicity
- high missing momentum due to undetected neutrinos
- 2 acoplanar identified leptons

- $e^+e^- \longrightarrow WW \longrightarrow e^+\nu e^-\bar{\nu}$ event candidate



W pair production cross section

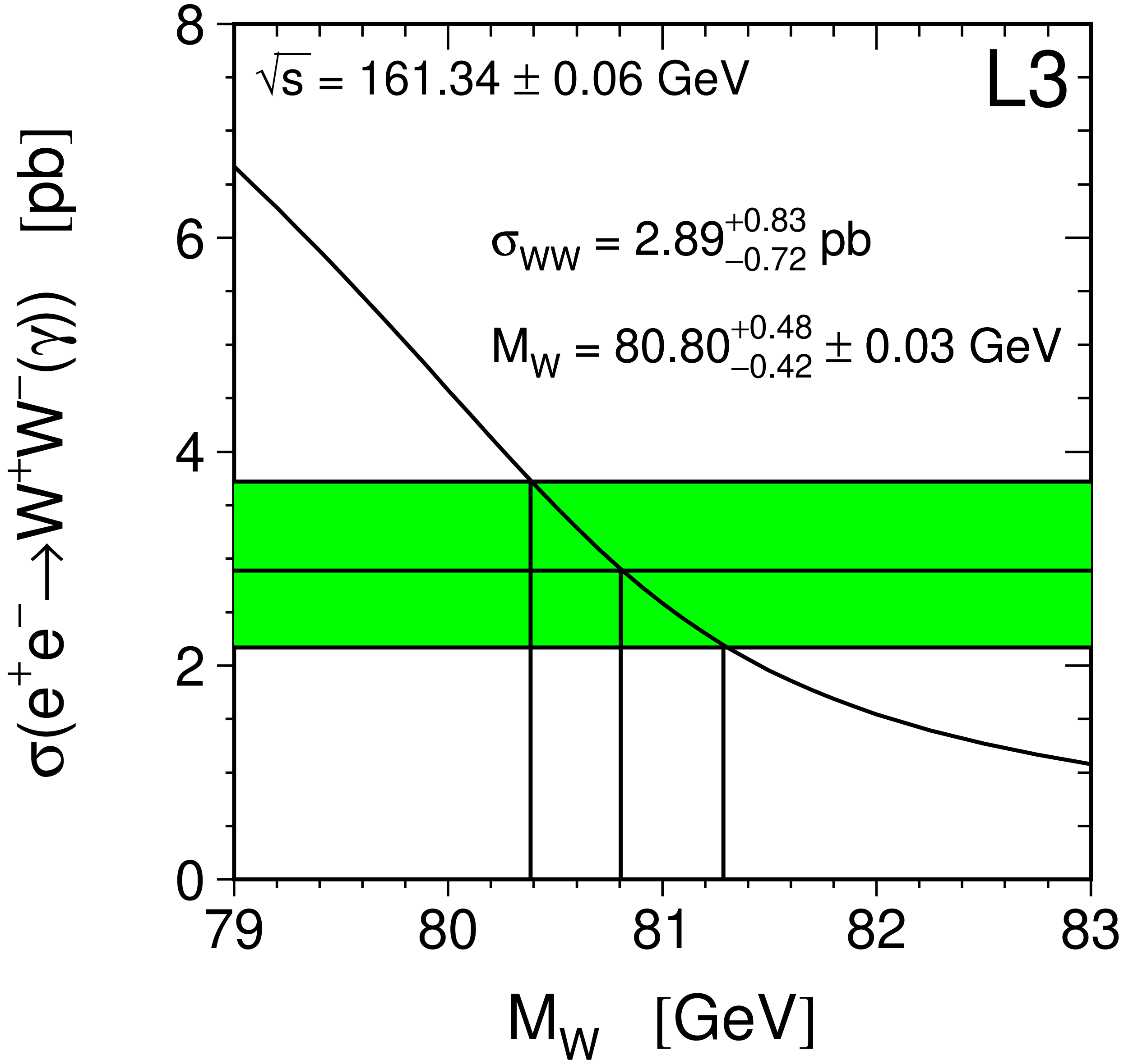




- Measurements are in agreement with Standard Model predictions
- The following models are excluded:
  models with no ZWW vertex
  models with only ν_e exchange in t channel

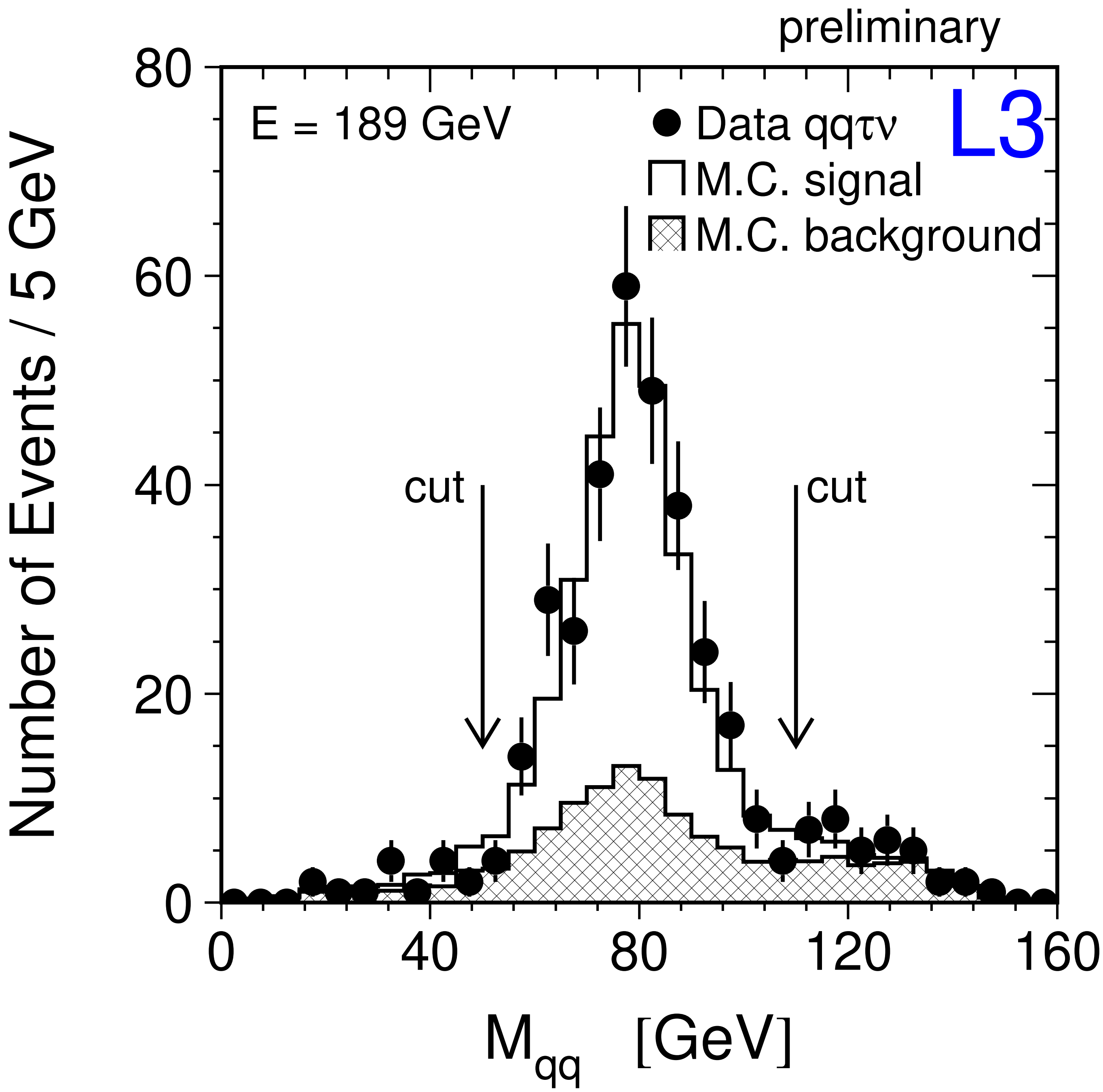
M_W from cross section measurement

- the WW cross section has a rapid increase at $\sqrt{s} \sim 2M_W$;
- the cross section measurement at $\sqrt{s} = 161$ GeV (point of highest slope) can be used derive M_W (assuming the SM couplings of W to fermions).



$$M_W = 80.80^{+0.48}_{-0.42} \pm 0.03 \ \text{GeV}$$

Direct mass reconstruction



- invariant mass of jet-pairs or lepton-neutrino is reconstructed;
- kinematical fit ($M_{W1} = M_{W2}$ constraint) is used to improve the mass resolution.

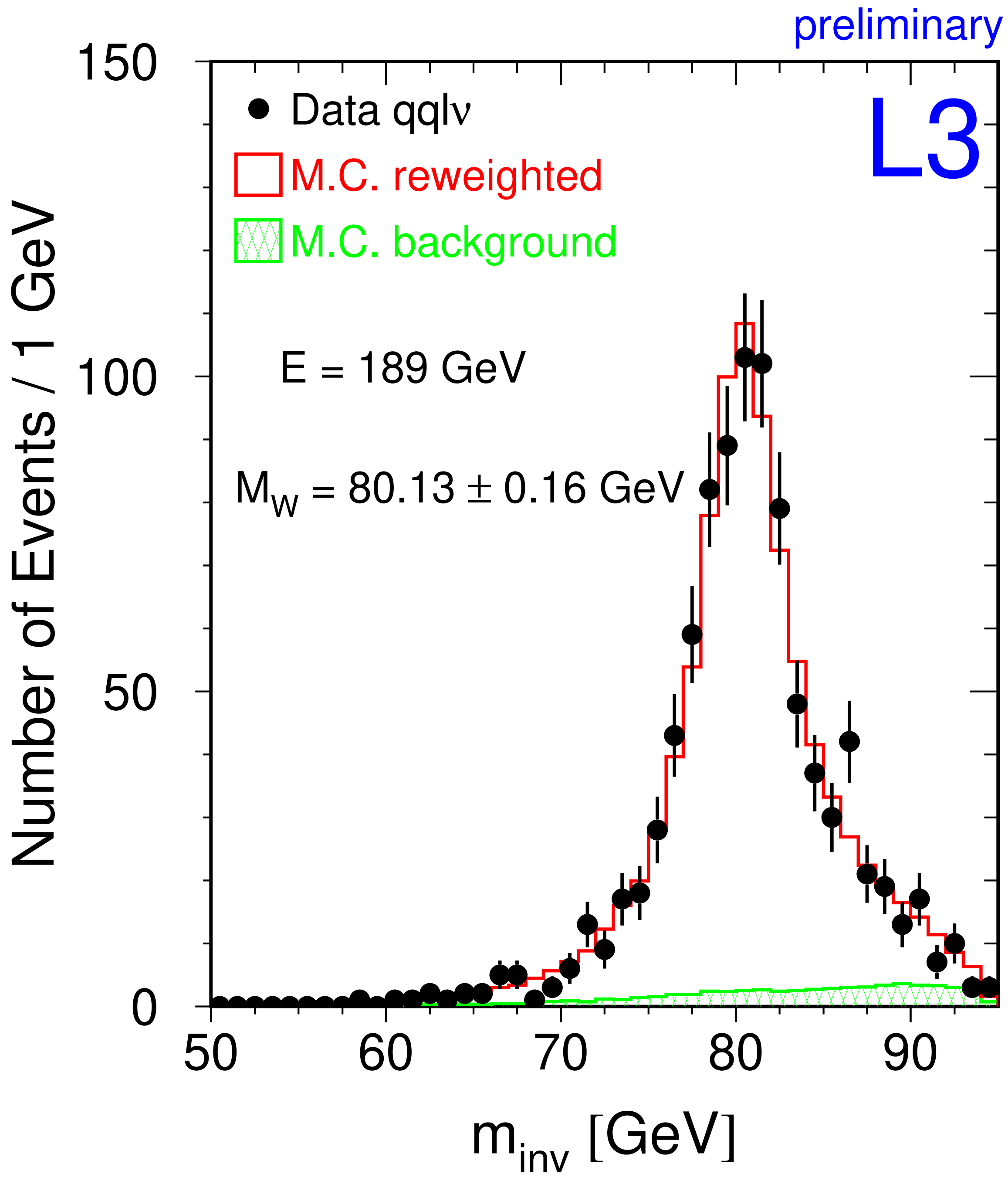
How to extract W mass from these distributions?

- reconstructed invariant mass has a Breit-Wigner distribution which is distorted by:
  - initial state radiation (ISR)
  - hadronization
  - phase space cuts
  - detector limited resolution
  - backgrounds
  - selections
- all such effects are accounted for by using the “Box & Reweighting” method.

Box & Reweighting method

- the idea is to produce several samples of Monte Carlo events with different values of M_W^{MC};
- M_W is then extracted by comparing the reconstructed invariant mass distribution in the accepted data with the MC distribution corresponding to different values of M_W^{MC}, using an unbinned maximum likelihood;
- backgrounds are included by adding the corresponding MC events and assuming that they do not depend on M_W value;
- this method corrects automatically all possible biases due to all effect considered in the MC simulation (ISR, phase space cuts, detection resolution, selections, etc.);
- the problem of generating a large amount of MC samples is solved by a reweighting procedure:
  - only one sample is generated with a fixed value of M_W, then each event is reweighted by the ω_i factor:
  $$\omega_i = \frac{|\mathcal{M}_i(M_W)|^2}{|\mathcal{M}_i(M_W^{MC})|^2}$$
  in order to construct the invariant mass distribution for different values of M_W.

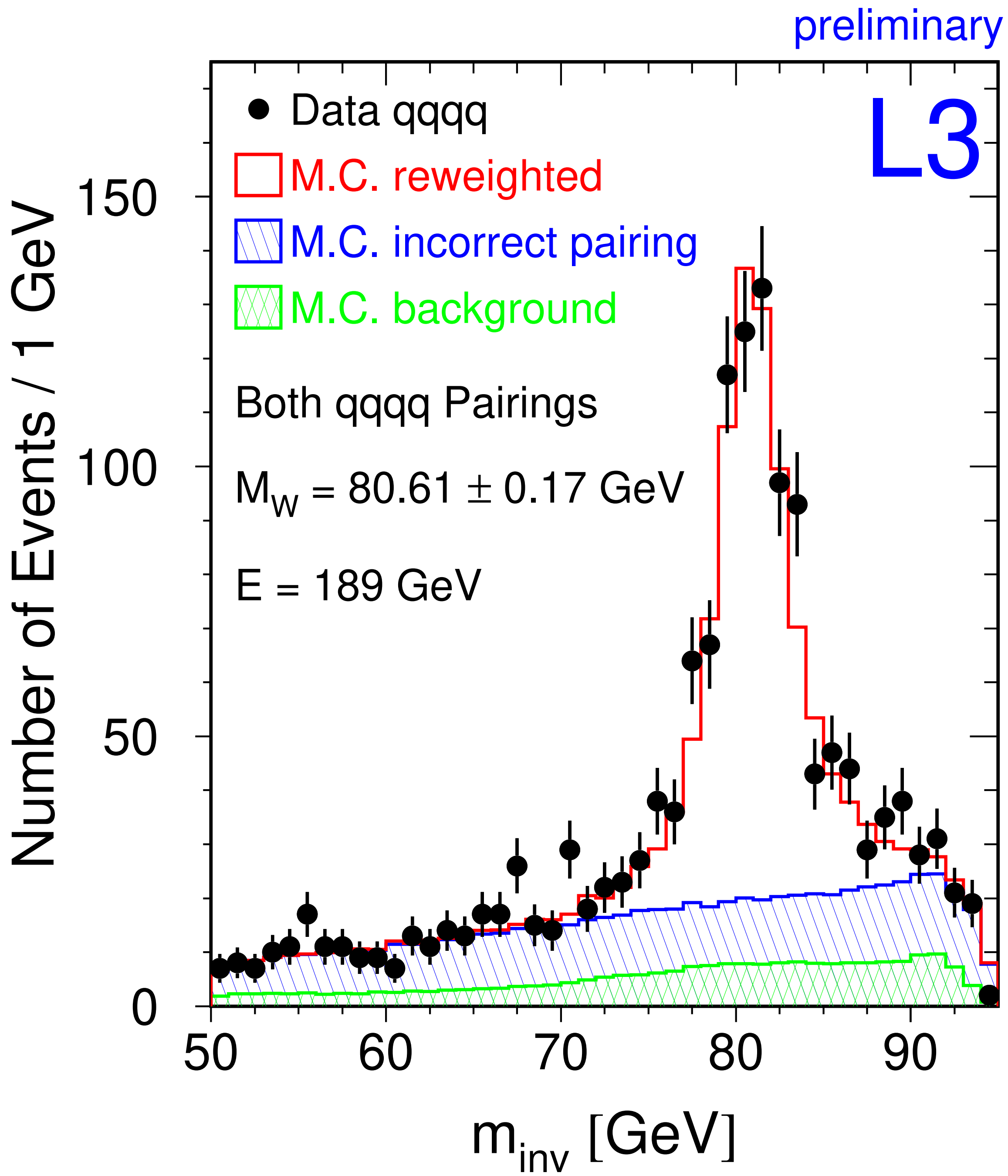
W mass measurement: $\ell\bar{\nu}q\bar{q}$ events



Reconstructed W mass from $\ell\bar{\nu}q\bar{q}$ events (including 172 and 183 GeV data):

$$M_W = 80.22 \pm 0.12(\mathrm{stat}) \pm 0.07(\mathrm{syst})\ \mathrm{GeV}$$

W mass measurement: $q\bar{q}q\bar{q}$ events



Reconstructed W mass from $q\bar{q}$ events (including 172 and 183 GeV data):

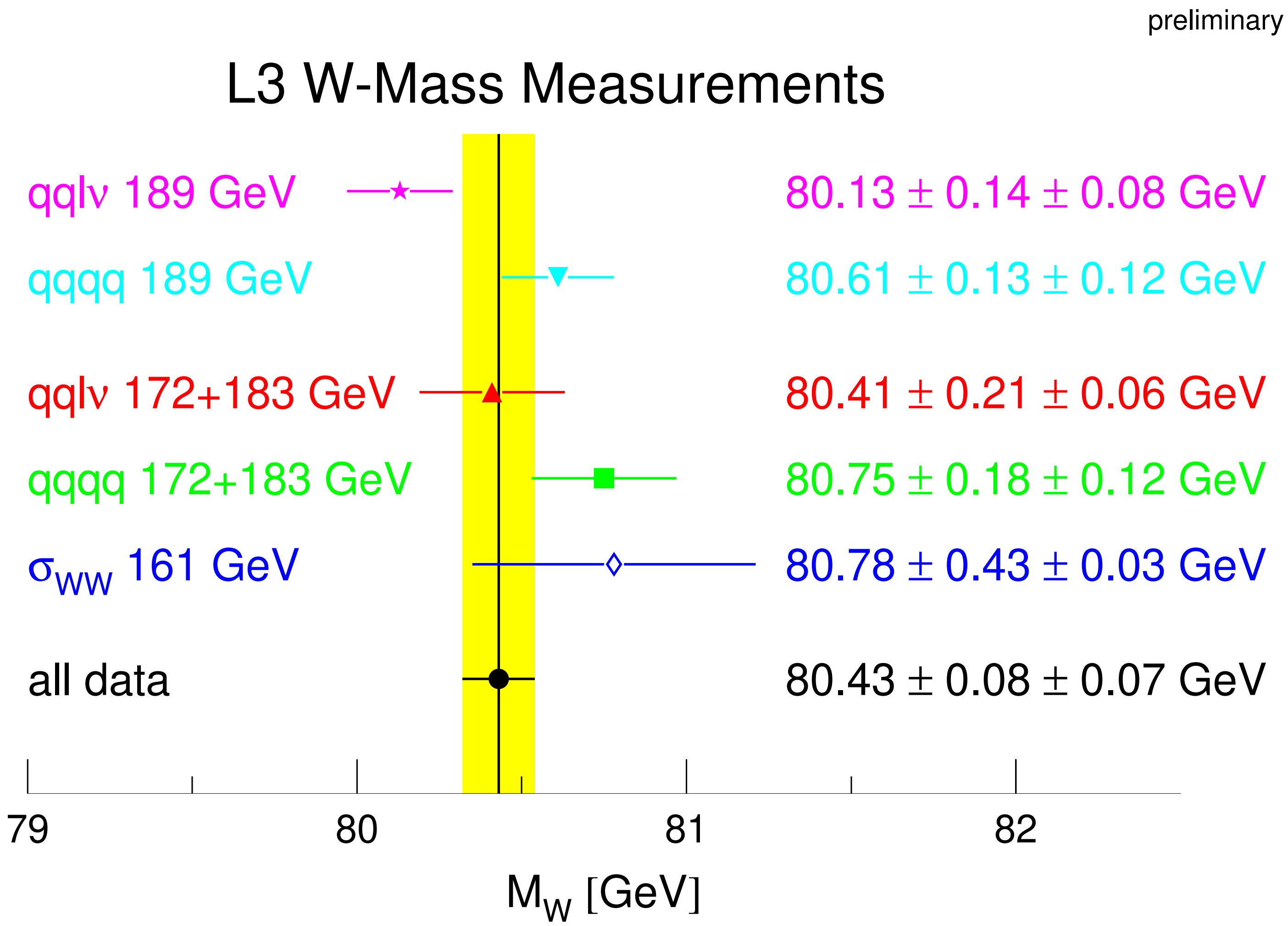
$$M_W = 80.66 \pm 0.10(\text{stat}) \pm 0.12(\text{syst})\ \text{GeV}$$

Systematic error dominated by Colour Reconnection and Bose-Einstein effects.

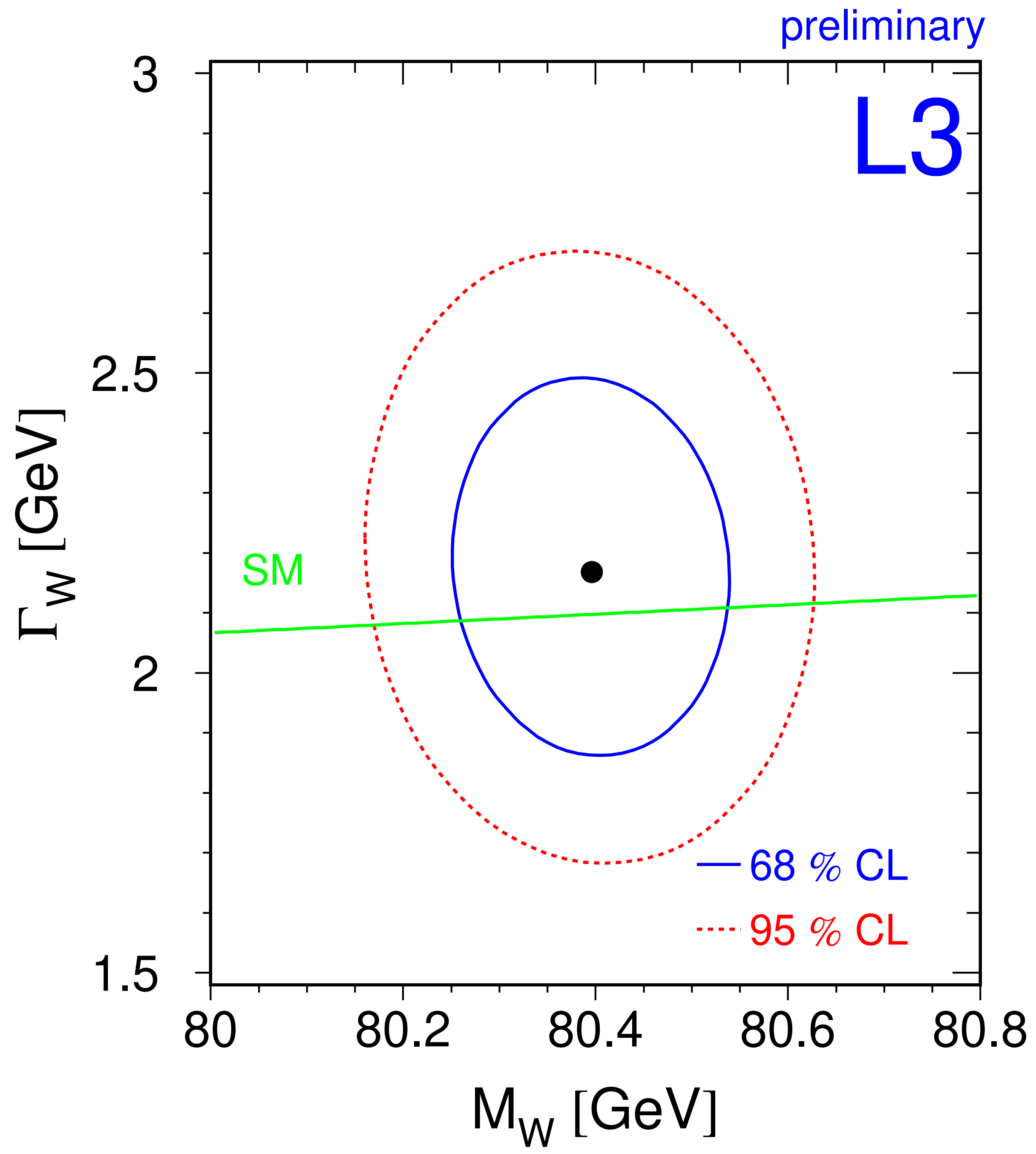
Systematics

- LEP energy $\simeq$ 20 MeV
- initial state radiation (ISR) $\simeq$ 15 MeV
- final state radiation (FSR) $\simeq$ 10 MeV
- jet measurements $\simeq$ 50 MeV
- fragmentation and decay $\simeq$ 50 MeV
- fitting method $\simeq$ 15 MeV
- MC statistics $\simeq$ 50 MeV
- selections $\simeq$ 20 MeV
- background $\simeq$ 20 MeV
- just for $q\bar{q}q\bar{q}$ channel:
  - Colour reconnection $\simeq$ 70 MeV
  - Bose-Einstein effects $\simeq$ 60 MeV

Combined results

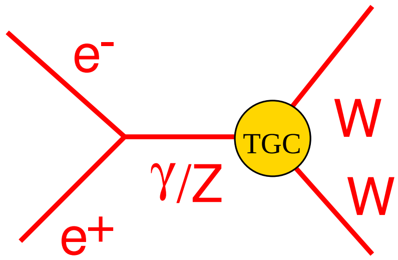


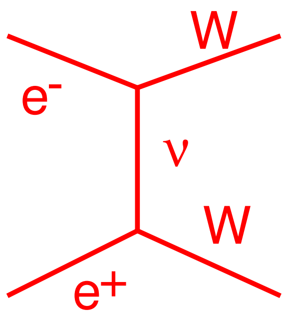
Simultaneous fit for W mass and total width:



All data ($\sqrt{s}$ from 172 to 189 GeV):

$$\Gamma_W = 2.12 \pm 0.18(\text{stat}) \pm 0.18(\text{syst})\ \text{GeV}$$





- Standard Model lagrangian for WWγ and WWZ couplings:

$$\mathcal{L}_{\text{int}}^{\text{SM}} = -ie\left[A_\mu(W^{\mu\nu}W_\nu^+ - W^{+\mu\nu}W_\nu) + F_{\mu\nu}W^{+\mu}W^\nu\right] + \\ -ie\,\cot\vartheta_W\left[Z_\mu(W^{\mu\nu}W_\nu^+ - W^{+\mu\nu}W_\nu) + Z_{\mu\nu}W^{+\mu}W^\nu\right]$$

- Effective lagrangian for WWγ and WWZ couplings (C and P conserving):

$$\mathcal{L}_{\text{eff}} = -ie\left[g_1^\gamma A_\mu(W^{\mu\nu}W_\nu^+ - W^{+\mu\nu}W_\nu) + k_\gamma F_{\mu\nu}W^{+\mu}W^\nu + \frac{\lambda_\gamma}{\mathrm{M}_{\mathrm{W}}^2}F_{\mu\nu}W_\rho^{+\nu}W^{\rho\mu}\right] \\ -ie\,\cot\vartheta_W\left[g_1^Z Z_\mu(W^{\mu\nu}W_\nu^+ - W^{+\mu\nu}W_\nu) + k_Z Z_{\mu\nu}W^{+\mu}W^\nu + \frac{\lambda_Z}{\mathrm{M}_{\mathrm{W}}^2}Z_{\mu\nu}W_\rho^{+\nu}W^{\rho\mu}\right]$$

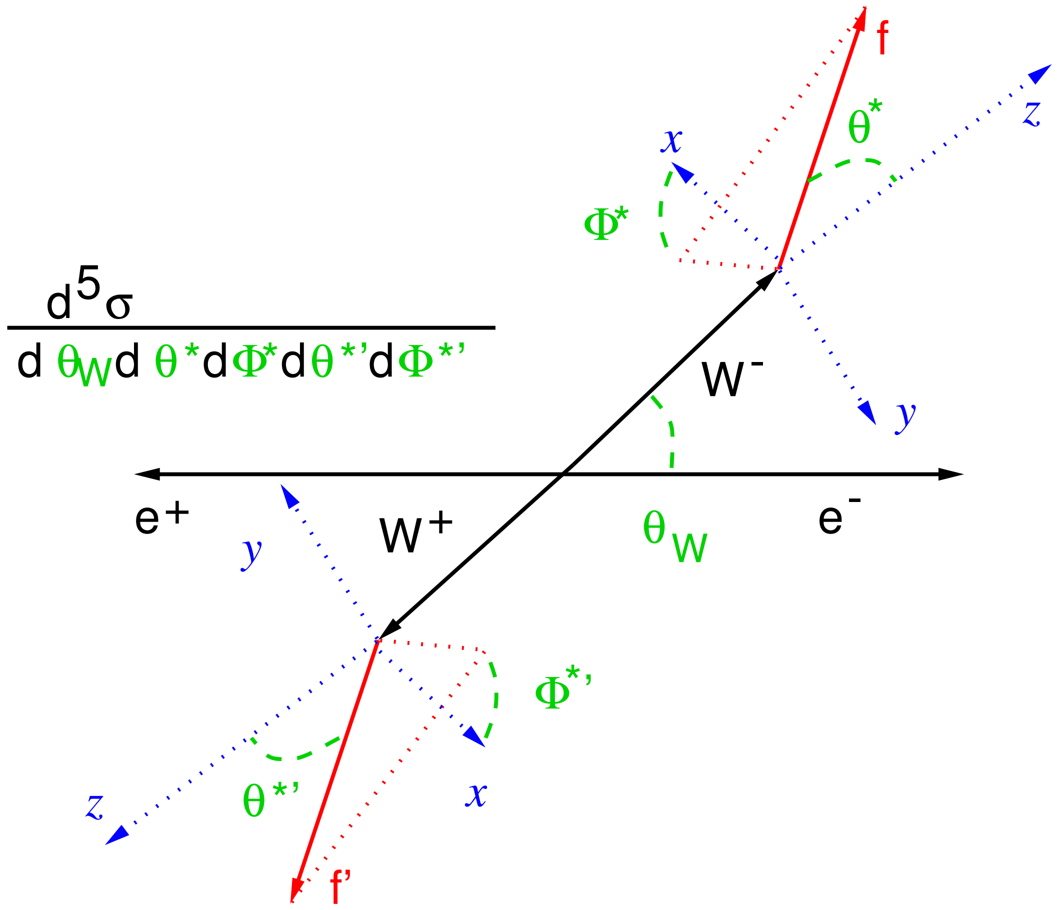
$$\text{SU(2) X U(1)} \Longrightarrow \begin{cases} g_1^\gamma = 1 \quad (q_W = e) \\ \lambda_Z = \lambda_\gamma \\ k_Z = g_1^Z - (k_\gamma - 1)\tan\vartheta_W \end{cases}$$

$\Longrightarrow$ 3 parameters: g_1^Z, k_γ, λ_γ

Triple gauge couplings in WW events

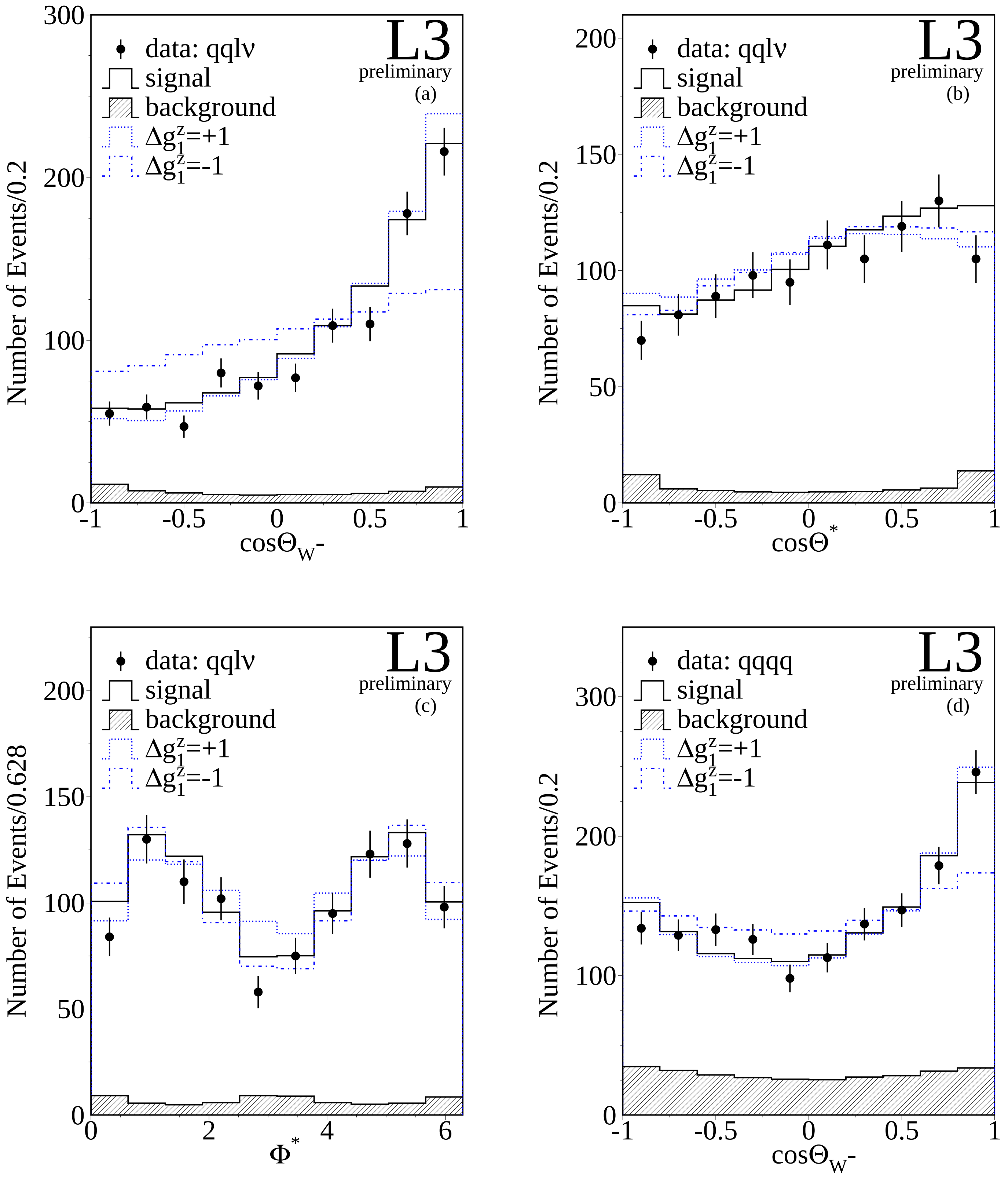
The anomalous coupling affects:

- the total cross section σ_{WW};
- the polar angle distributions of the W's (Θ_W);
- the polar and azimutal angle of the fermions in the W rest frame (Φ^*, Θ^*).



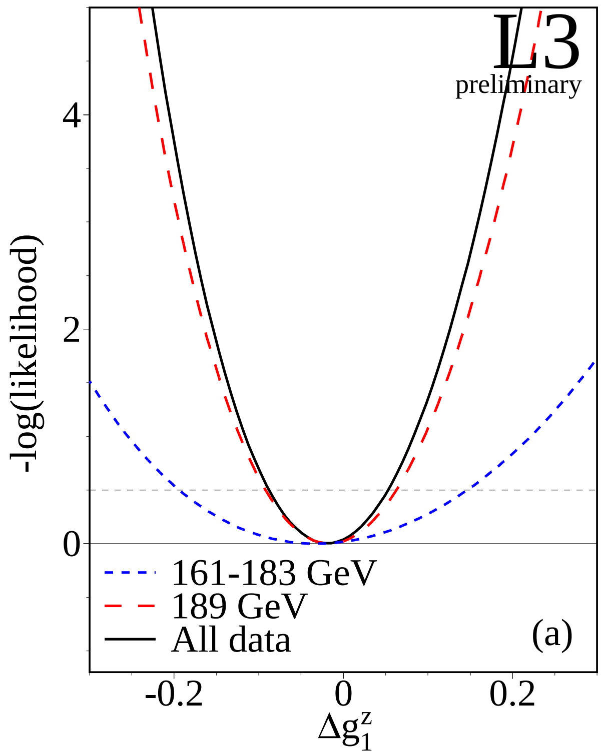
- for each data event a set of values of phase space angles Ω is reconstructed;
- anomalous couplings are extracted from an unbinned maximum likelihood of the measured differential cross section $d\sigma/d\Omega$.

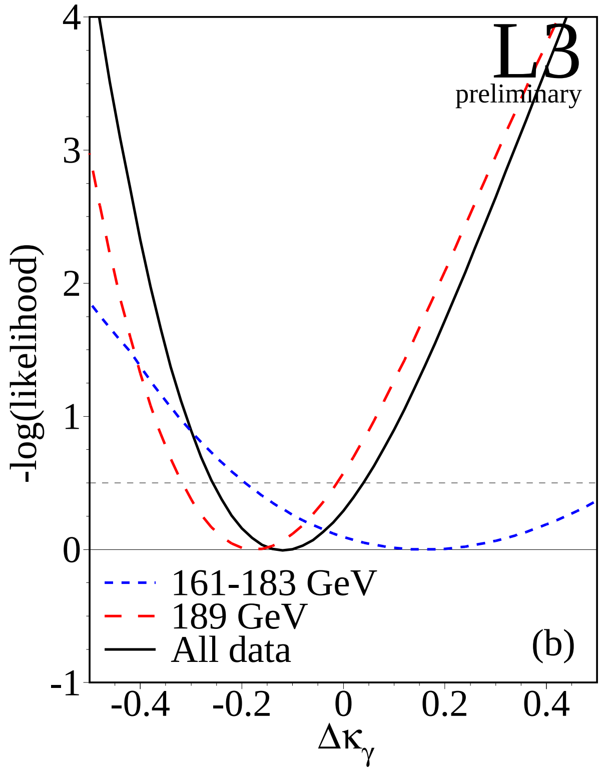
- angular distributions:

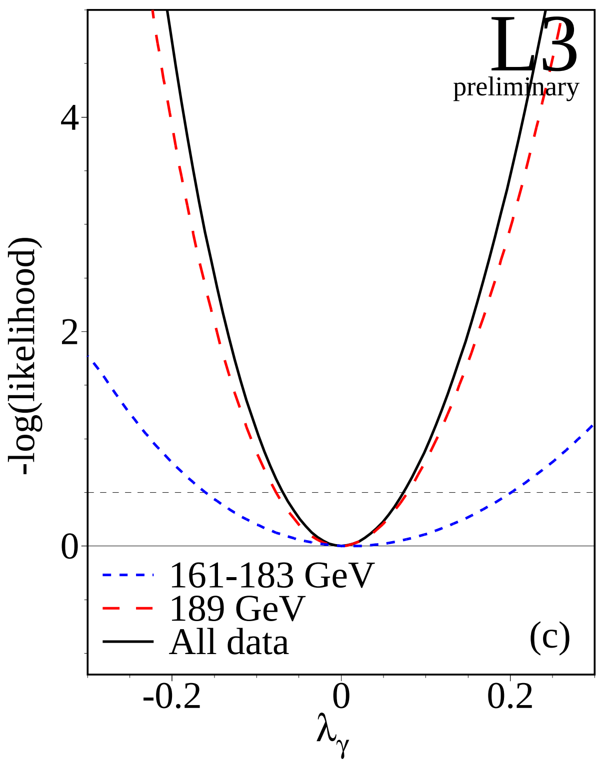


Triple gauge couplings in WW events

- single parameter fit results:

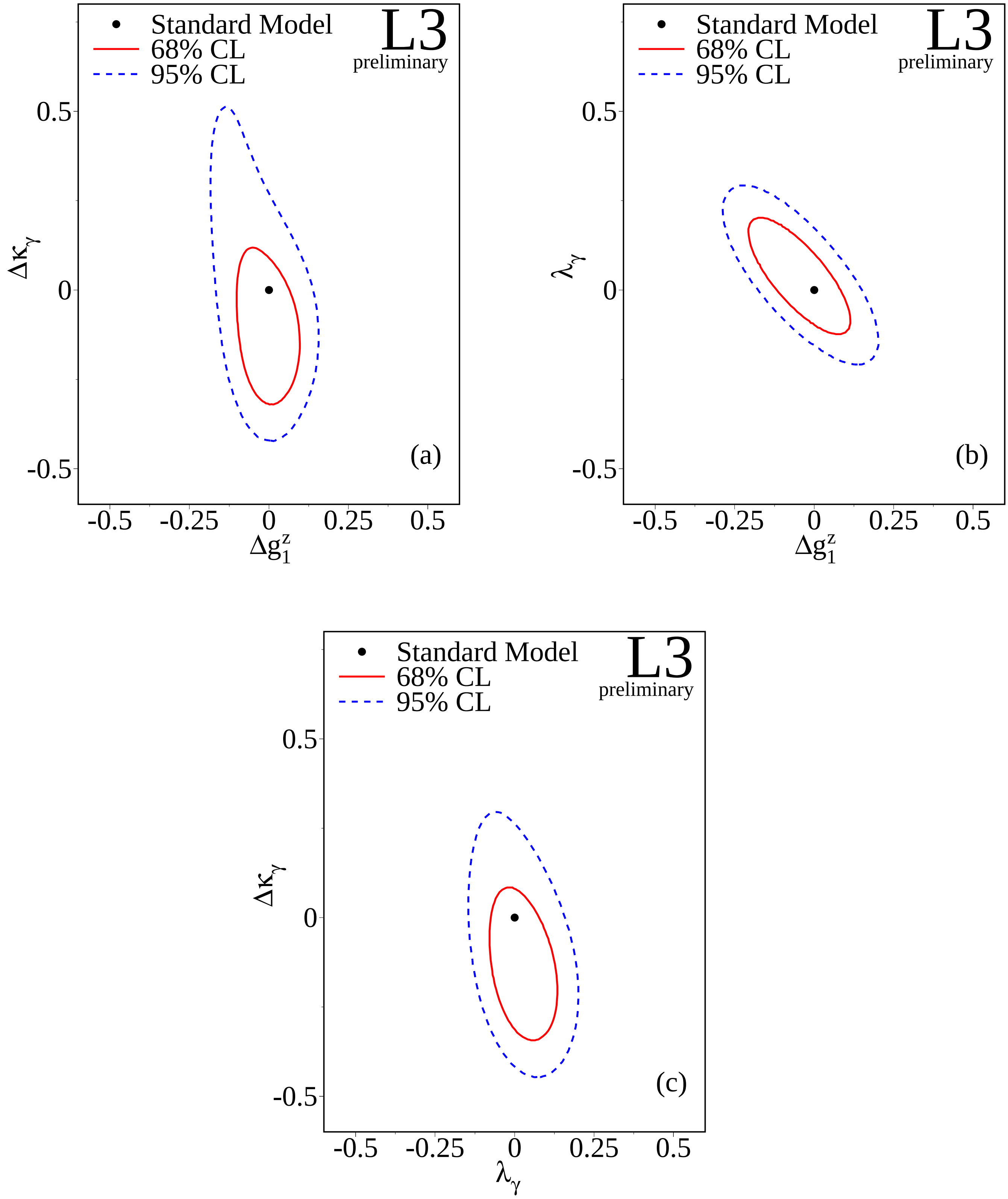




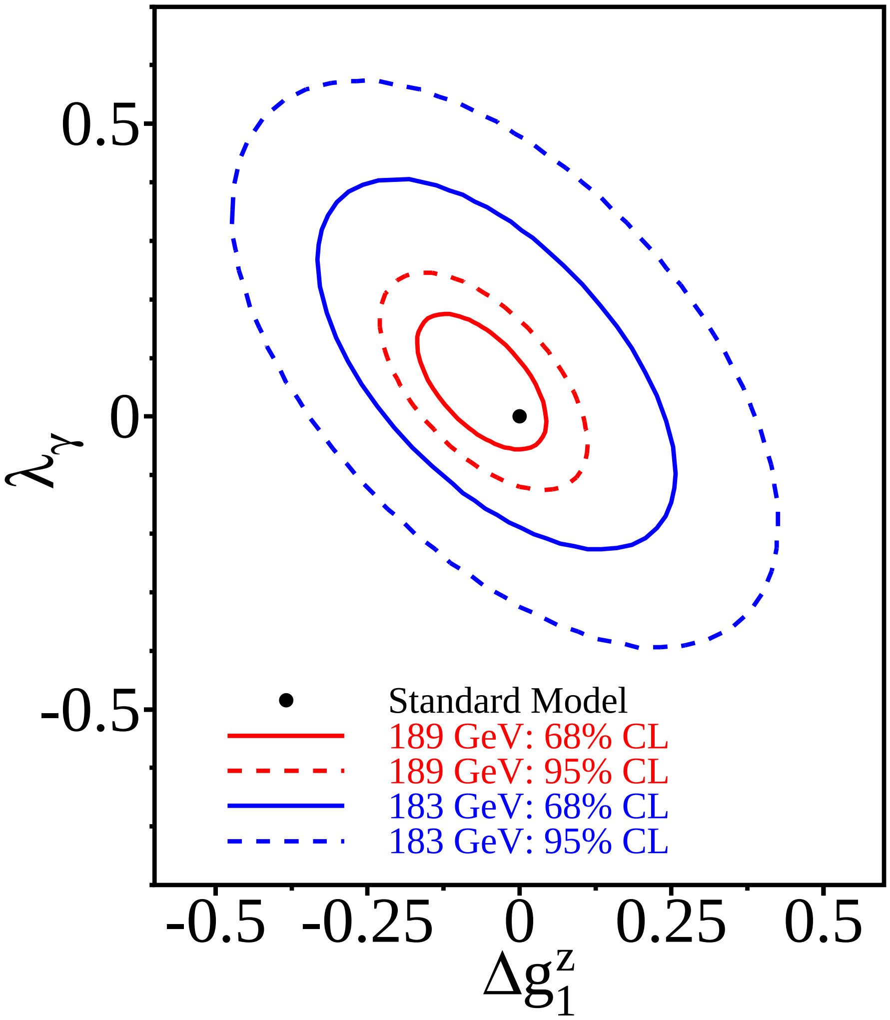


Triple gauge couplings in WW events

- bidimensional fit results:



Triple gauge couplings in WW events

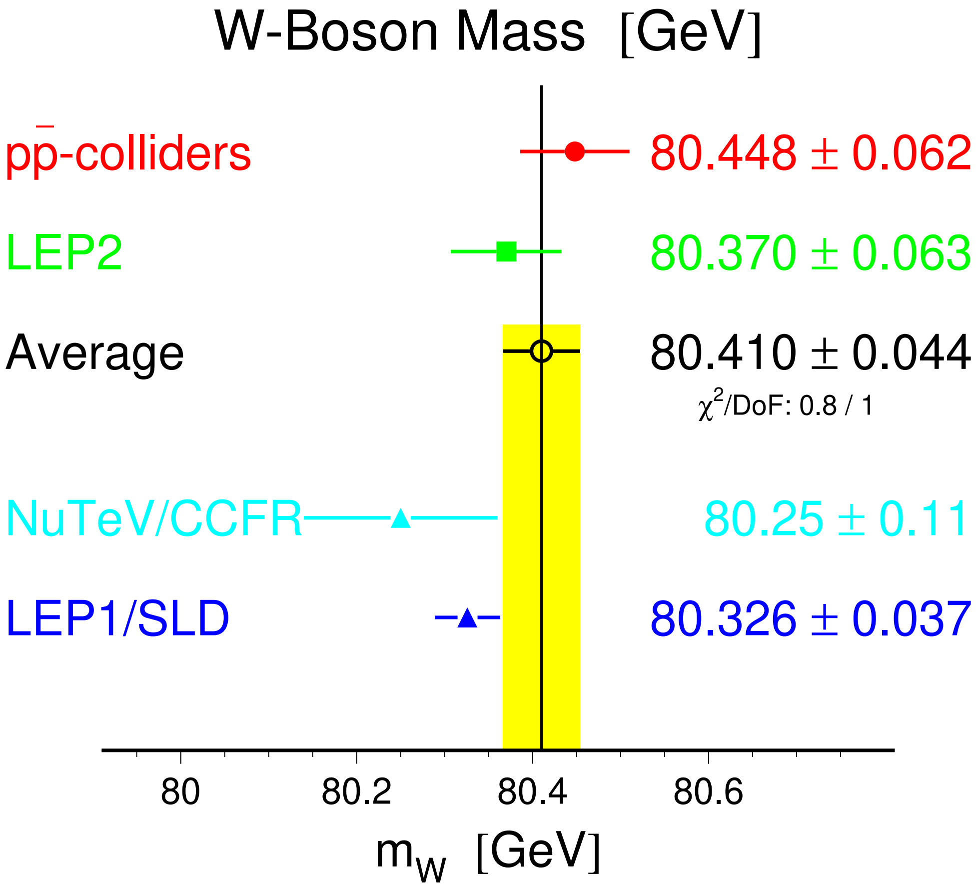


One-parameter fit results	SM value
$g_1^Z = 0.98 \pm 0.07 \pm 0.03$	1
$k_\gamma = 0.88^{+0.14}_{-0.12} \pm 0.08$	1
$\lambda_\gamma = 0.00 \pm 0.07 \pm 0.03$	0

- improvement with 1998 data : factor 3

Conclusions and outlook

- About 3700 W pairs collected by L3 have resulted in a precise measurement of M_W:
  $M_W = 80.43 \pm 0.08(\mathrm{stat}) \pm 0.07(\mathrm{syst})$ GeV
  in agreement with measurements by other experiments:



- Measured couplings of W boson to γ and Z are in agreement with Standard Model values;
- Statistical errors have been reduced by about a factor 3 with 189 GeV data;
- This year: maximum luminosity at the highest possible centre of mass energy $\sim$ 200 GeV.