Z Boson Pair Production at LEP using the L3 Detector

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Outline

- Motivation for the Study of Z Boson Pairs
- Analyzed Data Sample
- L3 Results (ZZ cross section measurements)
- Neutral Anomalous Triple Gauge Couplings
- Extra Dimensions

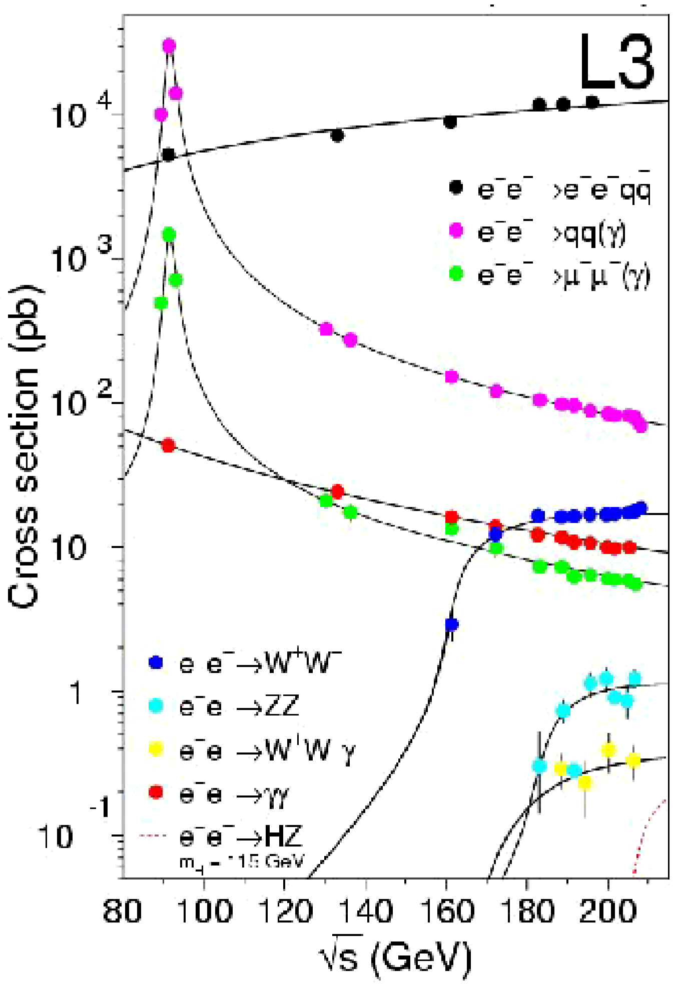
Motivation

Study of SM neutral boson sector:

- Z boson pair cross section
- irreducible background in the search for SM Higgs boson

Search for physics beyond SM:

- neutral triple guage anomalous coupling
- extra dimensions - **L**ow **S**cale **G**ravity
- new particles (heavy bosons)

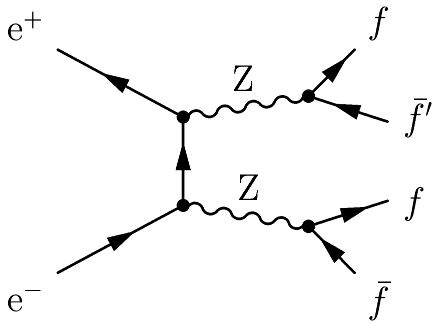


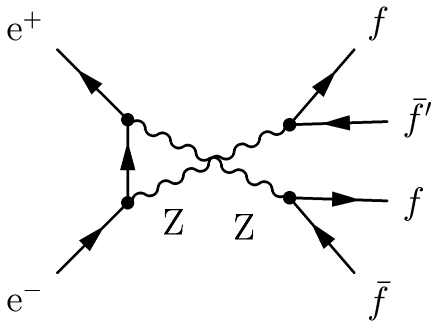
Production of ZZ competes with more copious SM processes

Feynman Diagrams

Signal: **N**eutral **C**urrent **02** diagrams = **NC02**

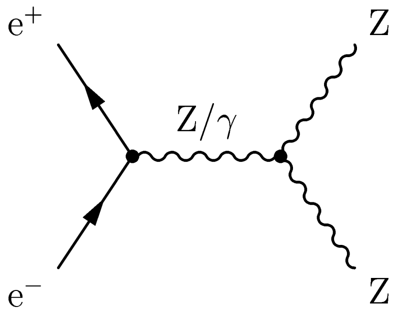
t-channel exchange only



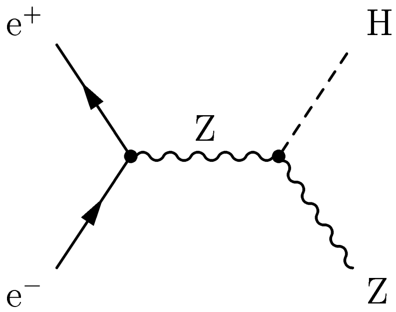


New Physics:

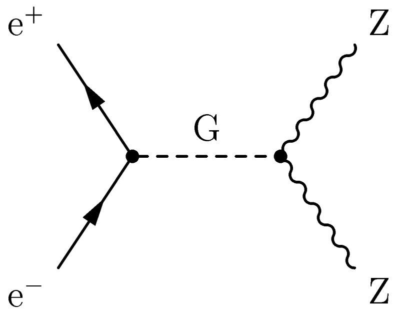
Anomalous Couplings



SM Higgs Search



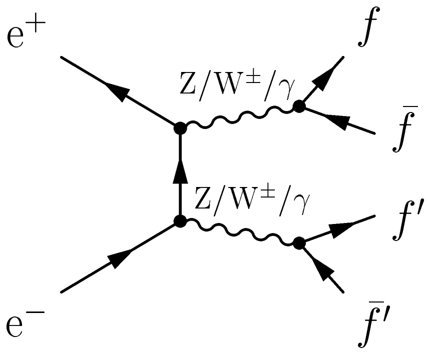
Extra Dimensions



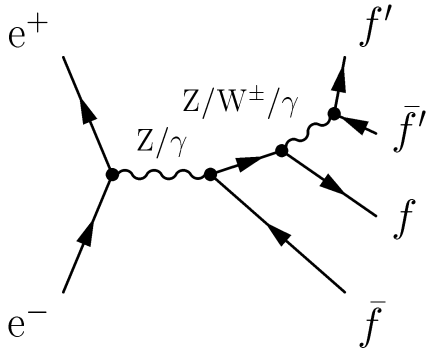
Background: other NC02-NC08 diagrams ($Z \to \gamma$)

Abelian Classes

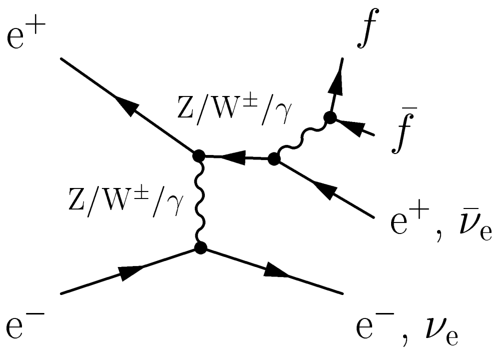
Conversion



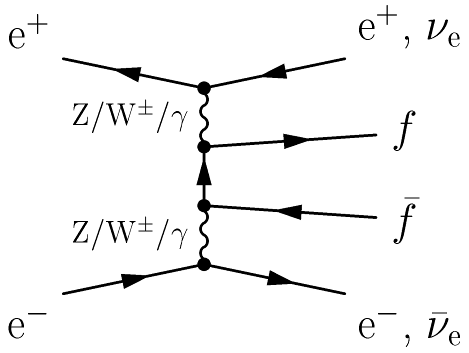
Annihilation



Bremsstrahlung

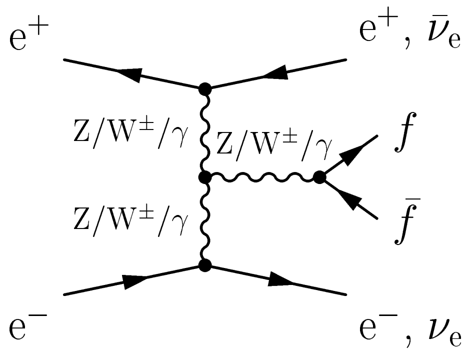


Multiperipheral

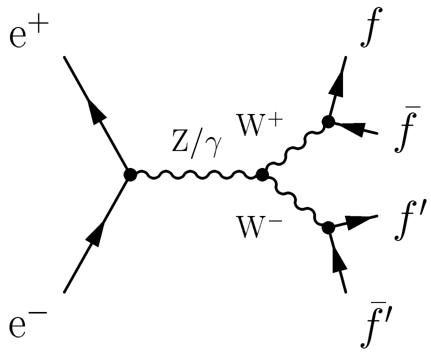


Non-Abelian Classes

Fusion

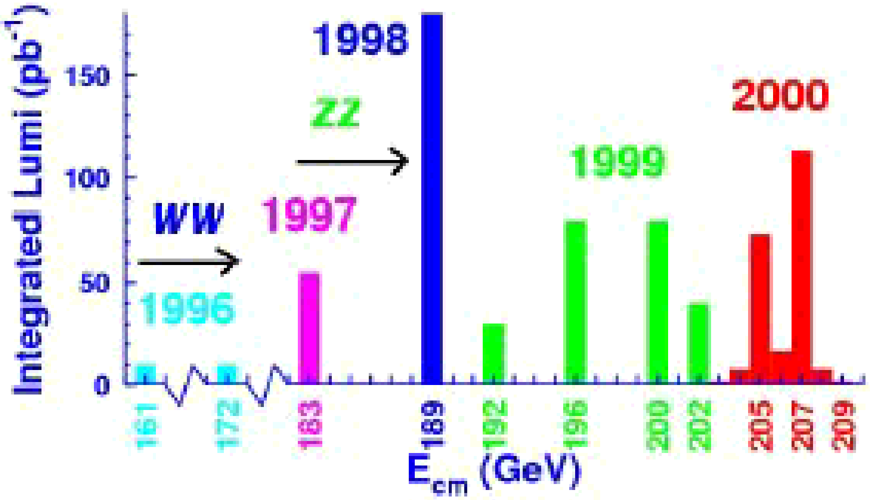


Annihilation



Data and Selections

L3 collected data amounts to $\sim$ **680 pb^{-1}** during the years **1997-2000**



ZZ Final States

Mode	**BR$_{ZZ}$ [%]**	**efficiency [%]**	**Background**
$ZZ \to q\bar{q}q'\bar{q}'$	49	65–70	WW, $q\bar{q}\gamma$
$ZZ \to q\bar{q}\nu\bar{\nu}$	28	50–55	Zee, Zγ, WW$\to q\bar{q}l\nu$
$ZZ \to l^+l^-q\bar{q}$	14	55–60	W$e\nu$, WW$\to q\bar{q}l\nu$, $q\bar{q}\gamma$
$ZZ \to l^+l^-\nu\bar{\nu}$	4	25–30	WW$\to e^+\nu e^-\bar{\nu}$, Bhabha
$ZZ \to l^+l^-l'^+l'^-$	1	35–40	non resonant 4f
$ZZ \to \nu\bar{\nu}\nu'\bar{\nu}'$	4	–	–

ZZ Final States - Selections

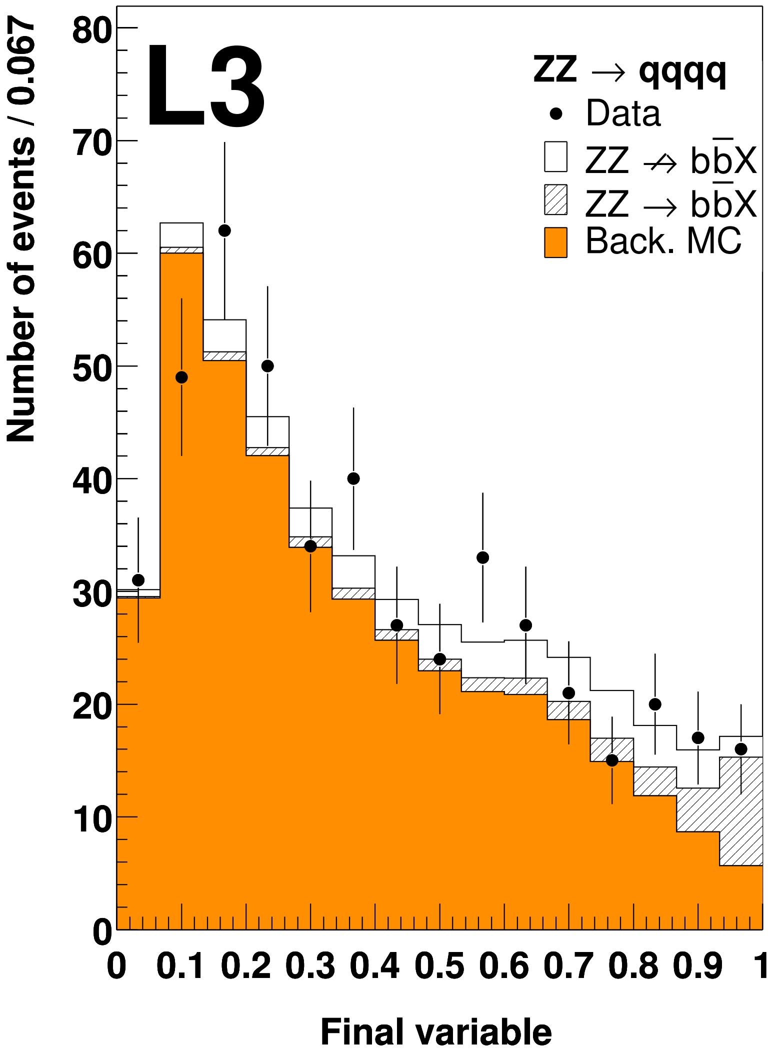
Signature:

▷ well balanced high multiplicity events, calorimetric clusters forced to form four jets

Analysis:

▷ applied 4C fit requiring conservation of four-mementum

▷ **output: Likelihood** - kinematical and topological characteristcs of selected events (di-jet mass, average # of tracks per jet, b-tag, min. jet opening angle, min. and max. jet energy, spherocity)

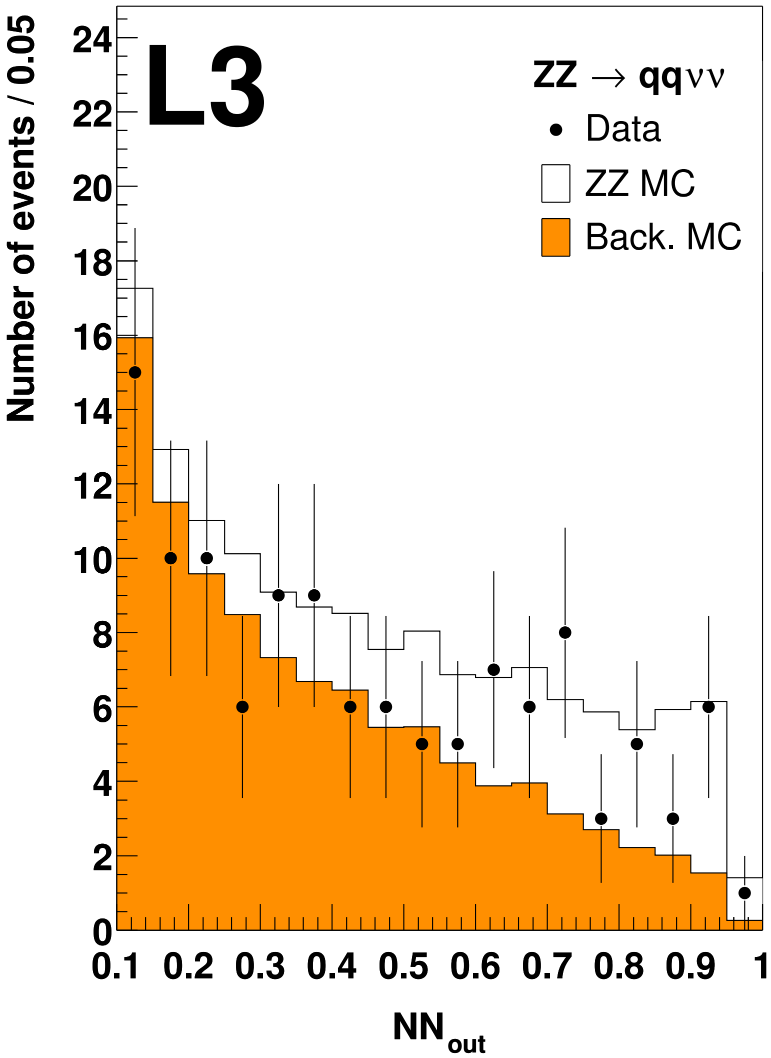


Signature:

- high multiplicity events with missing energy forced into two jets

Analysis:

- **output:** Neural Network - kinematical and topological characteristcs of selected events (missing energy, invariant and missing mass, topological variables differenciate two jet and three jet events)

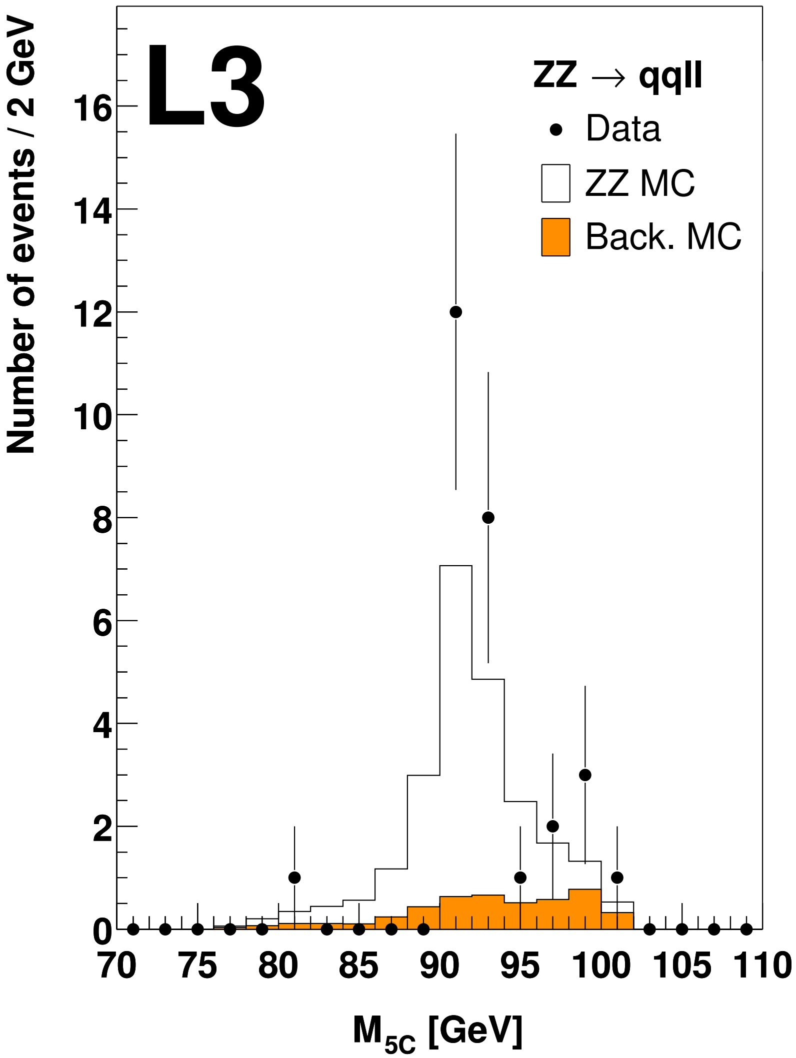


Signature:

- ▷ balanced high multiplicity events forced to two jets with two isolated same flavour leptons

Analysis:

- ▷ cut based analysis, di-jet and di-lepton invariant mass should be close to m_Z
- ▷ **output:** **5C fit of invariant mass** ($m_{l^+l^-} = m_{q\bar{q}}$)

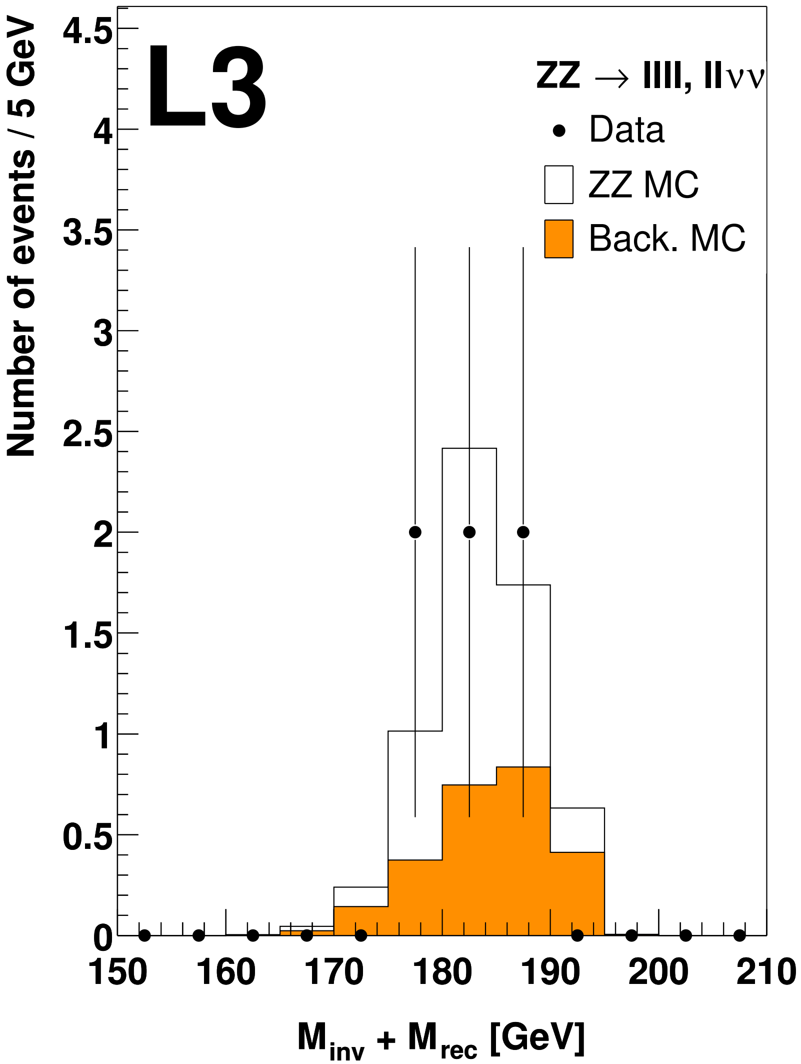


Signature:

- ▷ the cleanest channels, but with the smallest BRs

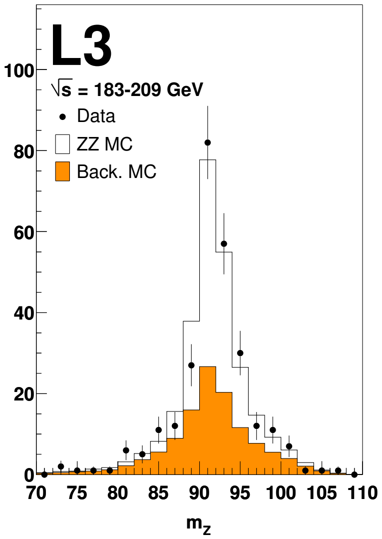
Analysis:

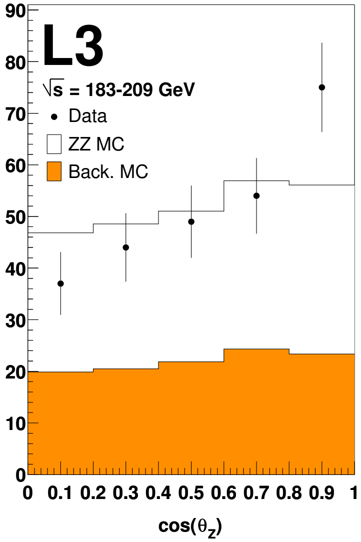
- ▷ two isolated same flavour leptons with $\not{E}$, invariant and recoil mass peaked around m_Z
- ▷ **output:** **invariant + recoil mass**
- ▷ four leptons in well balanced events (acoplanar & acolinear)
- ▷ **output:** **invariant + recoil mass** of a lepton pair with the m_{inv} closest to m_Z



ZZ Cross Sections

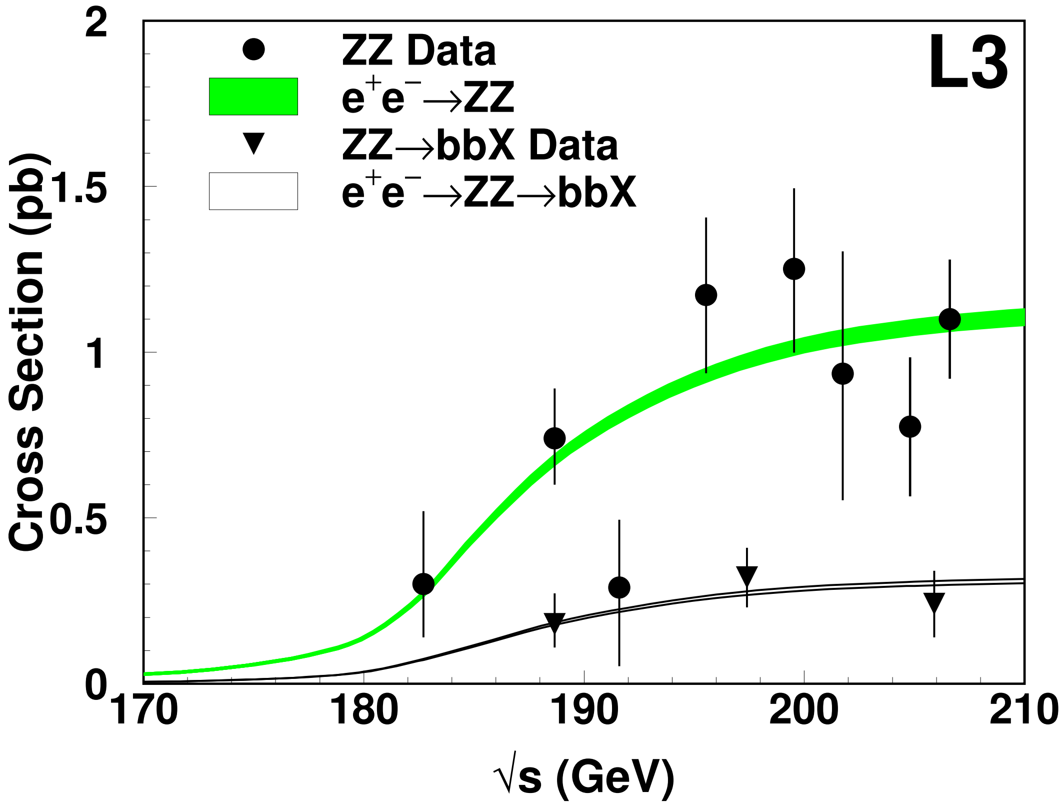
$\sqrt{s}$ [GeV]	$\sigma^{\rm SM}$ [pb]	$\sigma^{\rm measured}$ [pb]
183	0.25	$0.30^{+0.22}_{-0.16}$(stat)$^{+0.07}_{-0.03}$(syst)
189	0.66	$0.74^{+0.15}_{-0.14}$(stat)$\pm$0.04(syst)
192	0.79	0.29$\pm$0.22(stat)$\pm$0.02(syst)
196	0.92	1.17$\pm$0.24(stat)$\pm$0.09(syst)
200	1.00	1.25$\pm$0.25(stat)$\pm$0.09(syst)
202	1.03	0.93$\pm$0.38(stat)$\pm$0.07(syst)
205	1.07	0.78$\pm$0.20(stat)$\pm$0.05(syst)
207	1.08	1.10$\pm$0.17(stat)$\pm$0.07(syst)





Final Results

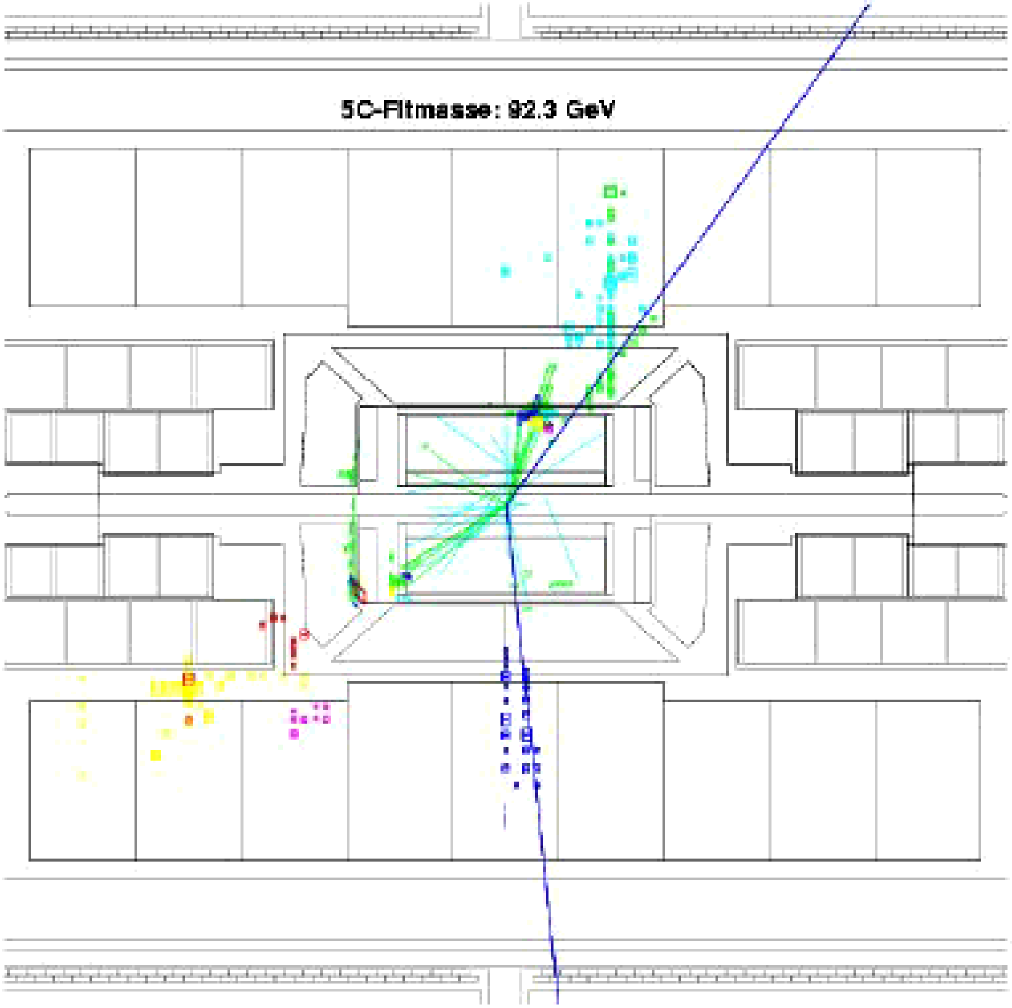
$$\mathcal{R}_{ZZ}(183-207\,\mathrm{GeV}) = \frac{\sigma_{ZZ}^{\mathrm{measured}}}{\sigma_{ZZ}^{\mathrm{SM}}} = 0.93 \pm 0.08(\mathrm{stat}) \pm 0.06(\mathrm{syst})$$



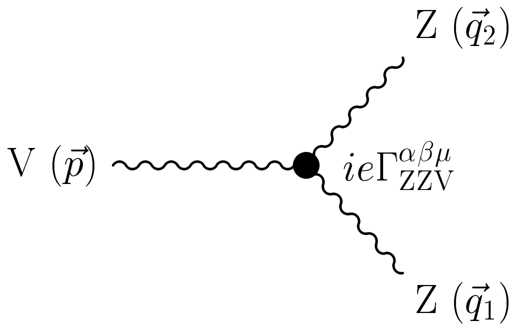
Content of b-quarks in ZZ Events

$\sqrt{s}$ [GeV]	$\sigma^{\mathrm{SM}}_{\mathrm{ZZ}\to\mathrm{b\bar{b}X}}$ [pb]	$\sigma^{\mathrm{measured}}_{\mathrm{ZZ}\to\mathrm{b\bar{b}X}}$ [pb]
189	0.18	$0.18^{+0.09}_{-0.07}$(stat)$\pm$0.02(syst)
192–202	0.27	0.31$\pm$0.09(stat)$\pm$0.03(syst)
205–207	0.30	0.24$\pm$0.09(stat)$\pm$0.03(syst)

- ▷ production of SM Higgs boson has the same final states as Z boson pair production (at this scale, the highest BR have final states with $b\bar{b}$)
- ▷ both processes have similar cross sections
- ▷ study of b-quark content in ZZ production verifies the capability of LEP detectors to detect & discover the Higgs boson


5C-Fitmasse: 92.3 GeV

Neutral Anomalous Triple Gauge Couplings (TGC)



f_4^{V} ... **CP violating**

f_5^{V} ... **CP conserving**

- Couplings vanish at tree level in SM and at one-loop level is in order of $\mathcal{O}(10^{-4})$, below the experimental sensitivity
- Possible anomalous TGCs:
  - $\Rightarrow$ **change in observed total cross section**
  - $\Rightarrow$ **modify angular distribution of Z**
  - $\Rightarrow$ **change in polarisation of Z**
- Z boson on-shell production leads to four anomalous couplings with $f_4^{\mathrm{V=Z},\gamma}$ and $f_5^{\mathrm{V=Z},\gamma}$
- to estimate TGC, $\Gamma^{\alpha\beta\mu}_{\mathrm{ZZV}}$ vertex is included in MC samples and new distribution fit is calculated for f_i^{V} while others are kept zero (SM expectation) = 1 dimensional fit

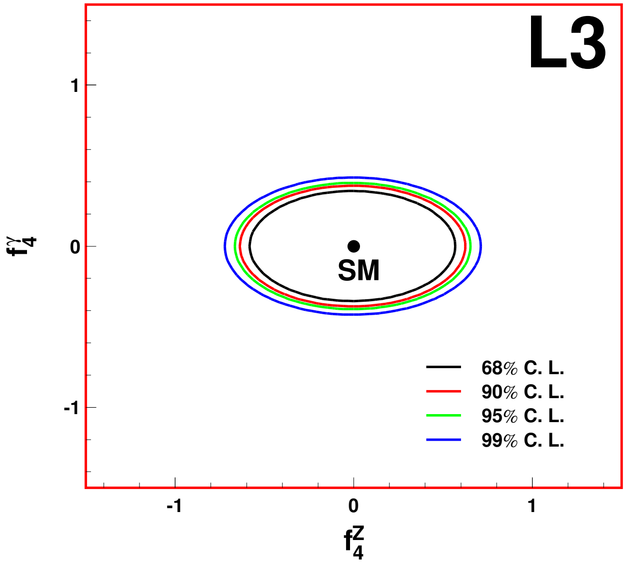
Vertex parametrization

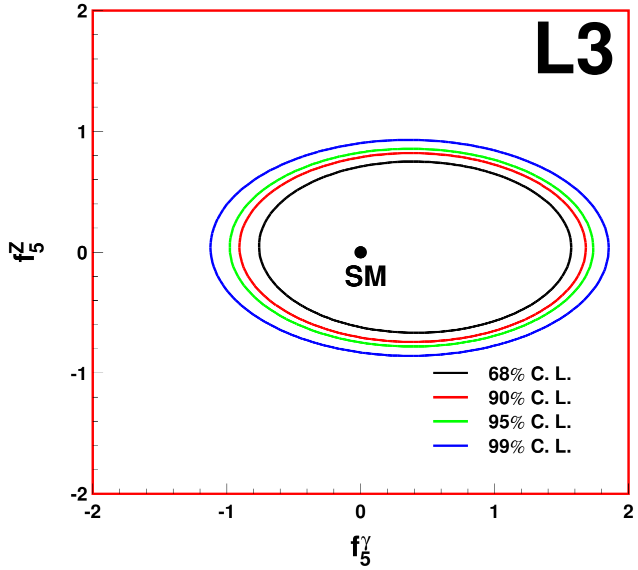
(Lorentz, $\mathrm{U(1)_{em}}$ gauge invariance + Bose symetry)

$$-i\Gamma^{\alpha\beta\mu}_{\mathrm{ZZV}} = \frac{s - m_{\mathrm{V}}^2}{m_{\mathrm{Z}}^2}\left[f_4^{\mathrm{V}}\left(p^\alpha g^{\mu\beta} + p^\beta g^{\mu\alpha}\right) + f_5^{\mathrm{V}}\varepsilon^{\mu\alpha\beta\rho}\left(q_1 - q_2\right)_\rho\right]$$

Limits set at 95 % confidence level for f_i^V:

$$-0.48 \leq f_4^Z \leq 0.46$$
$$-0.36 \leq f_5^Z \leq 1.03$$
$$-0.28 \leq f_4^\gamma \leq 0.28$$
$$-0.40 \leq f_5^\gamma \leq 0.47$$



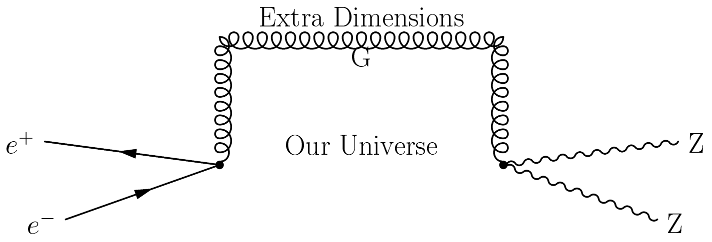


Extra Dimensions

Relative weakness of the gravitational force leads to the large gravity scale (is given by the Planck scale, $M_{Pl} \sim 10^{19}$ GeV

- ▷ SM successfully tested at the electroweak scale, $M_{ew} \sim 10^2$ GeV
- ▷ SM particles are confined to the normal world with only 3+1 dimensions

Postulation of a new scale M_S for the gravitational interaction and imposing it to be of the same order as M_{ew} predicts some deviation from the expected behaviour of gravity in theories that introduce n extra spatial dimensions of size as small as fractions of mm (R, **L**ow **S**cale **G**ravity)



$$M_{Pl}^2 \sim R^n M_S^{n+2}$$

LSG allows the graviton to couple to the Z boson which would:

⇒ **modify the Z boson cross section**

⇒ due to its different spin - **change the angular distribution of the Z boson production angle**

$$\sigma \simeq \sigma^{\rm SM} + \frac{\lambda}{M_S^4}\,\sigma_{\rm Interference} + \frac{\lambda^2}{M_S^8}\,\sigma_{\rm LSG}$$

Limits set at 95 % confidence level for M_S:

$\lambda = +\mathbf{1}$: $M_S >$ **704** GeV

$\lambda = -\mathbf{1}$: $M_S >$ **691** GeV

Conclusions

- ∘ Z boson cross sections are within SM expectation
- ∘ no evidence of neutral anomalous TGCs was found
- ∘ low limits for LSG were set