Study of ZZ Production in e^+e^- Collisions at $\sqrt{s} = 189$ GeV with the L3 Detector at LEP

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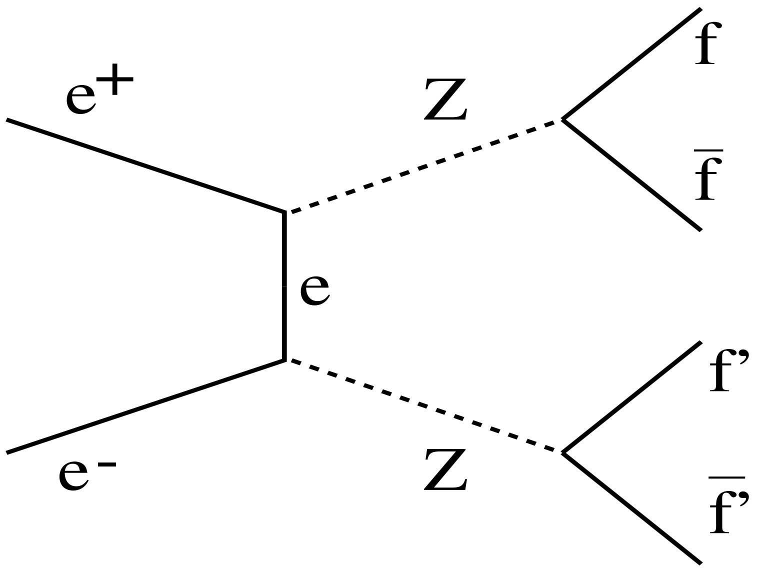
On Behalf of the L3 COLLABORATION

- Introduction
- The L3 Experiment
- ZZ Selection
- Cross Section Results
- ZZZ and ZZγ Anomalous Couplings
- Conclusions

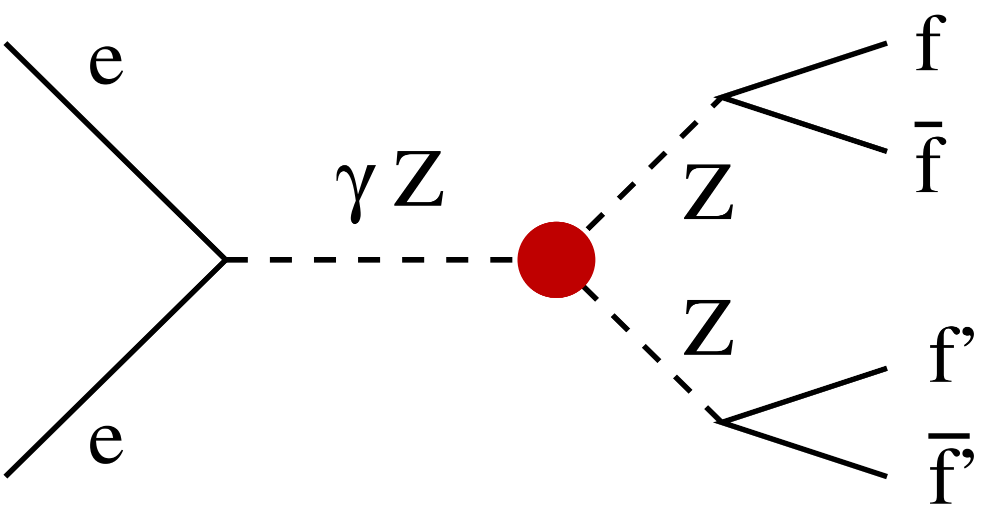
All results are preliminary!

In e^+e^- collisions at centre of mass energy above $2 * M_Z \simeq 182$ GeV the production of a pair of Z bosons as intermediate state contributes to 4-fermion final states

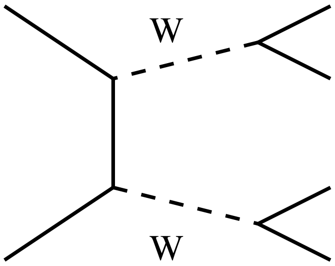


Although the production rate is low and there are large backgrounds, since 1997 it is being measured at LEP and deviations from the Standard Model are being searched for.

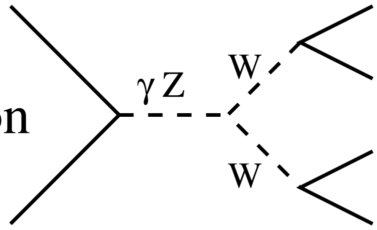
The cross section is measured, and limits on the existence of triple gauge couplings ZZZ and $ZZ\gamma$ are set.

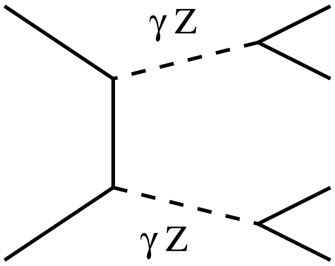


The production of four fermion final states is mediated by many different Feynman Diagrams. A few important examples are:



WW Production

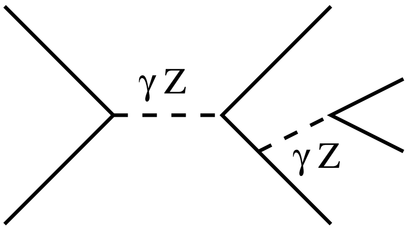




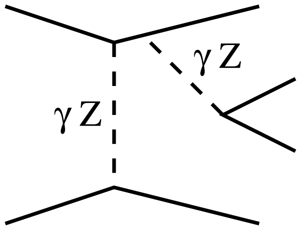
ZZ, Zγ, γγ, Production

"Conversion Diagram"

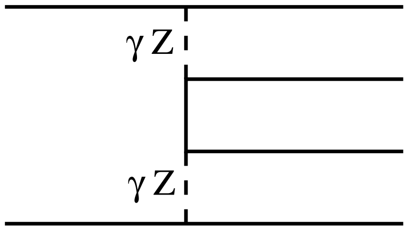
Annihilation



Bremsstrahlung



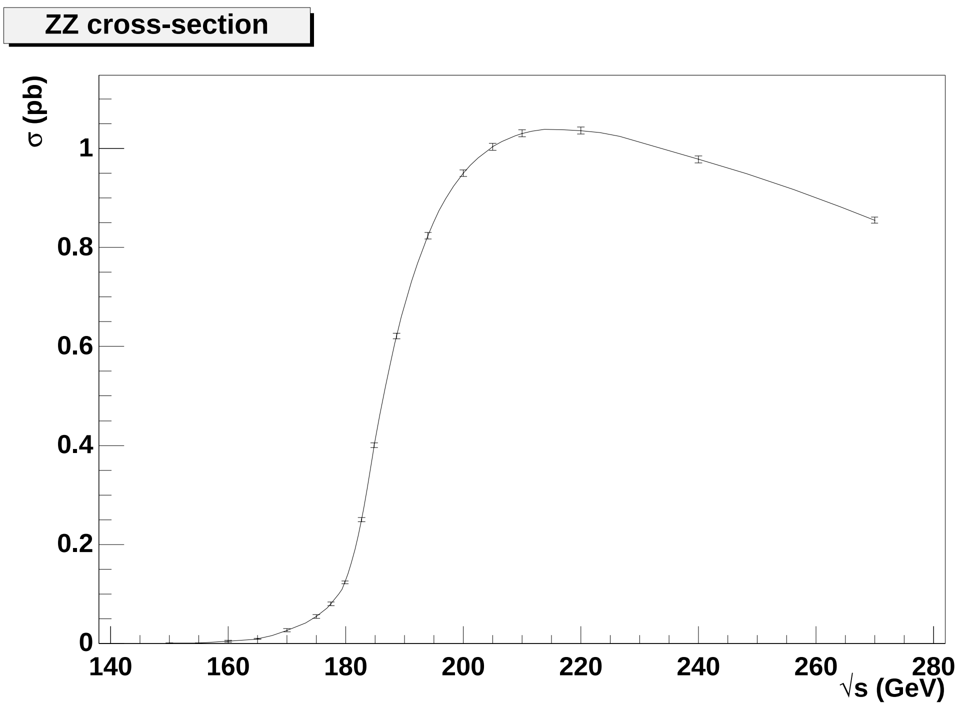
Multiperipheral



In order to maximize the contribution of the on-shell ZZ production diagram, (and minimize the others), we define our signal using the following criteria:

- Two pairs of fermion-antifermion with invariant mass in the range (70,105) GeV
- In final states with electrons, these electrons must verify $|\cos\theta_e| < 0.95$
- In final states with WW contribution, namely $\mathrm{u\bar{u}d\bar{d}}$, $\mathrm{c\bar{c}s\bar{s}}$, $\mathrm{l^+l^-}\nu\bar{\nu}$, the masses of the fermion pairs susceptible to come from W decay must be out of (75,85) GeV

Using the 4-fermion Monte Carlo generator Excalibur, the ZZ cross section has been calculated as a function of the centre of mass energy:



At $\sqrt{s} = 189$ GeV the cross sections for the different final states within our signal definition are

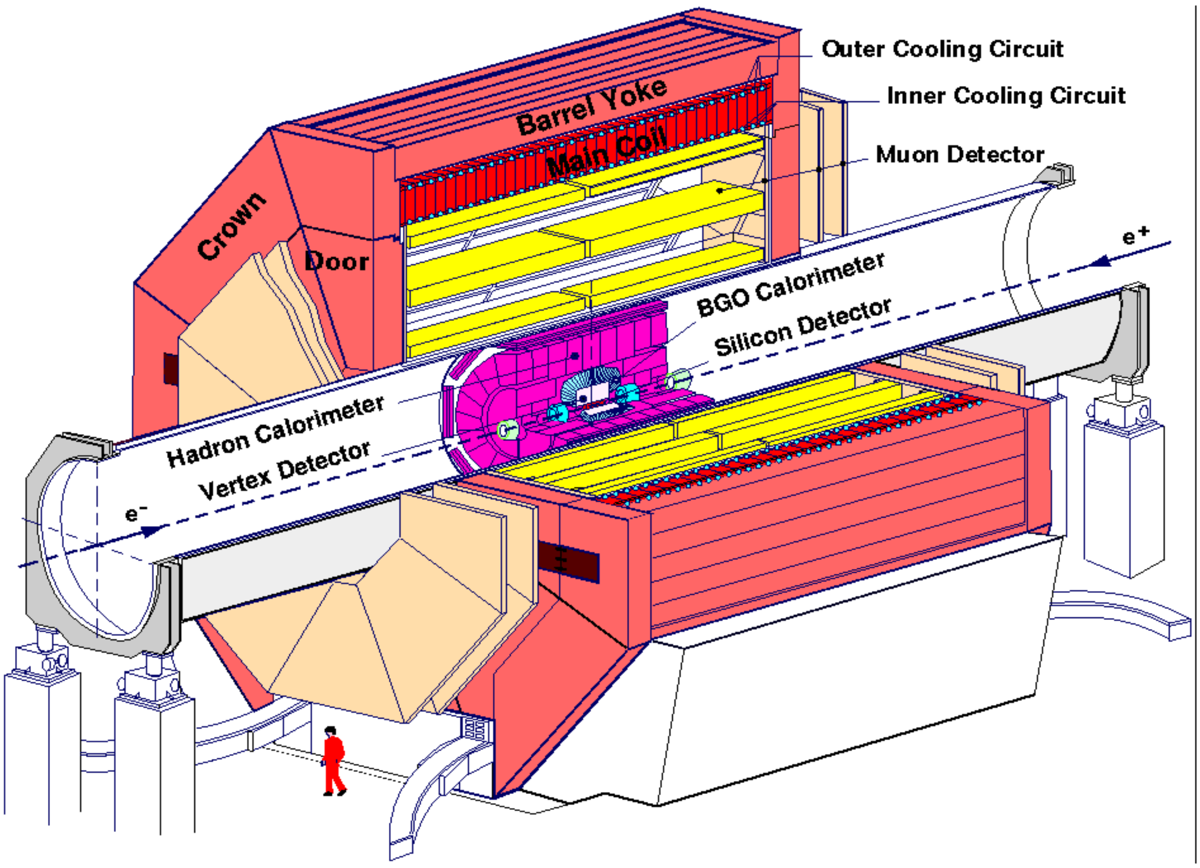
$ZZ \rightarrow$	σ (pb)	Fraction	'Naive' (B.R.)
$q_1\bar{q}_1q_2\bar{q}_2$	0.290	46.8 %	48.9 %
$q\bar{q}\nu\bar{\nu}$	0.170	27.4 %	28.0 %
$q\bar{q}l^+l^-$	0.097	15.6 %	14.1 %
$l^+l^-\nu\bar{\nu}$	0.027	4.4 %	4.0 %
$l_1^+l_1^-l_2^+l_2^-$	0.011	1.8 %	1.0 %
$\nu_1\bar{\nu}_1\nu_2\bar{\nu}_2$	0.025	4.0 %	4.0 %
ZZ	0.620	100.0 %	100.0 %

The small differences between the actual fractions and those calculated naively from the Z branching ratios are due to the contribution of non resonant Feynman Diagrams and to the signal definition itself.

L3 is one of the four detectors located at the LEP collider at CERN.

It consists of a central tracker, an electromagnetic calorimeter, a hadronic calorimeter and a muon detector.

It allows the detection, identification and measurement of energy an direction of photons, electrons, muons and hadronic jets.



Data and Monte Carlo Samples

The analysis presented here corresponds to a luminosity of $176\ \mathrm{pb}^{-1}$ collected by the L3 experiment at $\sqrt{s} \simeq 189\ \mathrm{GeV}$ during 1998.

For the background and signal efficiency estimation, different Monte Carlo generators have been used:

- EXCALIBUR: ZZ signal, $\mathrm{qqe}\nu$
- PYTHIA: $\mathrm{qq}(\gamma)$
- KORALW: WW
- BHWIDE: $\mathrm{ee}(\gamma)$
- KORALZ: $\mu\mu(\gamma)$, $\tau\tau(\gamma)$

ZZ SELECTION

ZZ events are characterized experimentally by two pairs of fermions, (leptons or hadronic jets), with high invariant masses, or a pair of fermions with large visible and recoil masses.

Channel	Statistics	Experimental Signature	Background
$\mathrm{q_1\bar{q}_1q_2\bar{q}_2}$	Large	4 hadronic jets	Large
$\mathrm{q\bar{q}}\nu\bar{\nu}$	Large	2 jets + missing energy	Large
$\mathrm{q\bar{q}l^+l^-}$	Medium	2 jets + 2 leptons	Low
$\mathrm{l^+l^-}\nu\bar{\nu}$	Low	2 leptons + missing energy	Medium
$\mathrm{l_1^+l_1^-l_2^+l_2^-}$	Low	4 leptons	Medium
$\nu_1\bar{\nu}_1\nu_2\bar{\nu}_2$		invisible!	

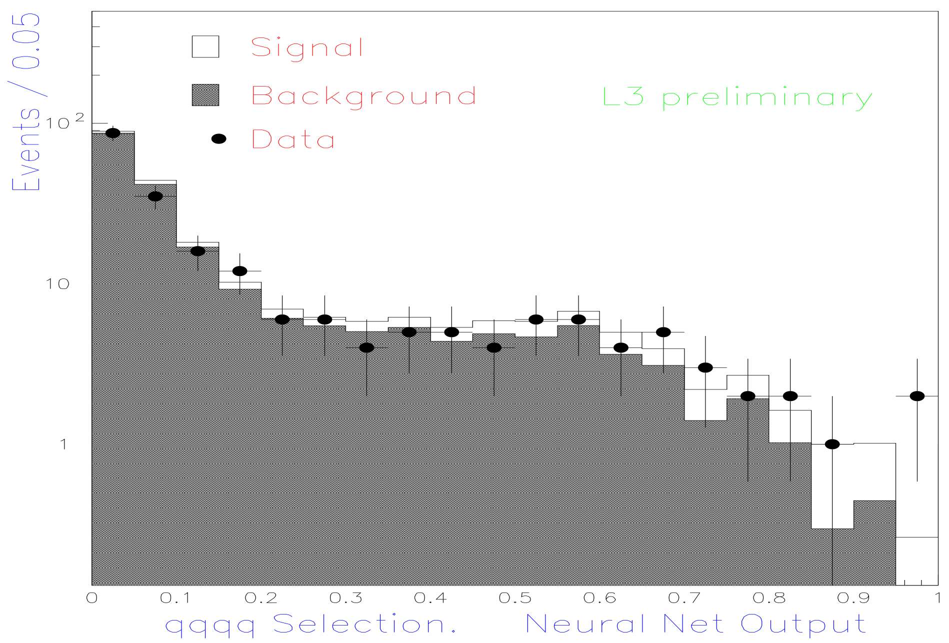
Different cut based selections as well as artificial neural networks are used to select the ZZ events, rejecting a large amount of the background.

qqqq SELECTION

- A preselection of events is done requiring high multiplicity, large visible energy, small missing energy, no energetic leptons and at least four jets ($Y_{34} > .007$)
- Then a neural network is used to distinguish among ZZ, WW and qq. The inputs are variables related to the multiplicity, the energy and direction of the jets, and kinematic variables as invariant masses of pairs of jets

The signal efficiency is $34\ \%$.

211 events are observed in data, 207.5 events are expected from background and 21.2 events are expected from $\mathrm{Z}/\gamma^*\ \mathrm{Z}/\gamma^* \to \mathrm{qqqq}$

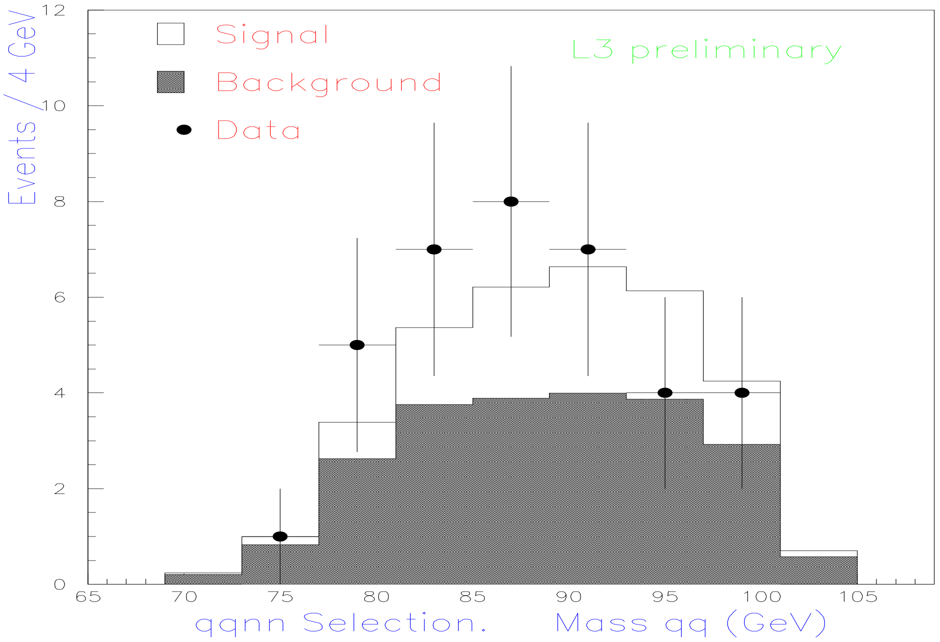


$qq\nu\nu$ SELECTION

- High multiplicity events
- $\sin\theta_{\mathrm{Pmiss}} > 0.7$
- 2 acoplanar, ($> 2.38^o$), and acollinear, ($> 2.35^o$), hadronic jets.
- $\mathrm{P_T}/\sqrt{\mathrm{s}} > 0.06$
- Visible Energy $\in (0.42, 0.56)\sqrt{s}$
- Large visible and recoil masses

The signal efficiency is 35 %

36 events are observed in data, 22.7 events are expected from background and 11.3 events are expected from $\mathrm{ZZ} \rightarrow qq\nu\nu$

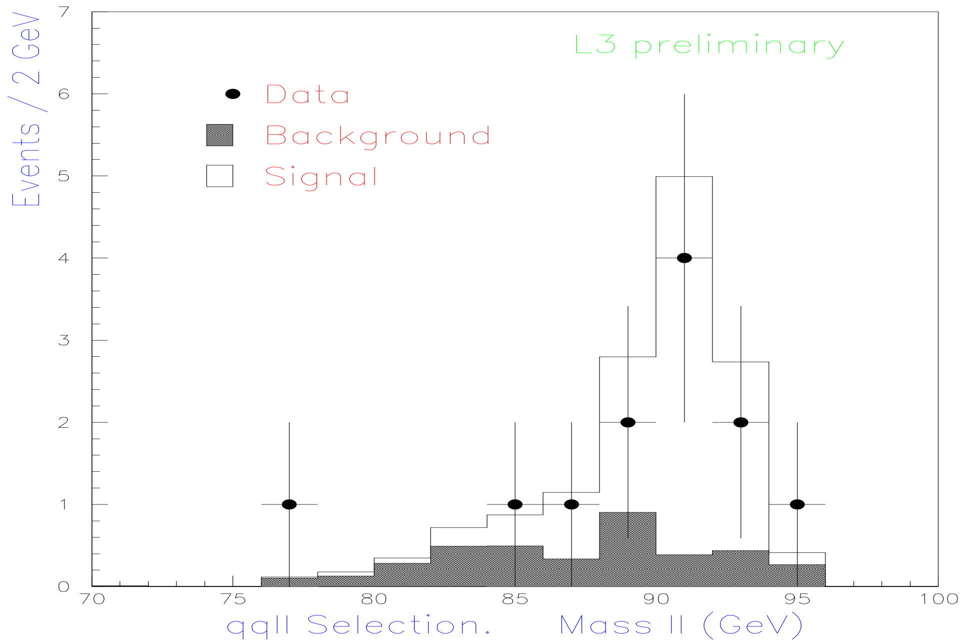


qqll SELECTION; L=e, μ, τ

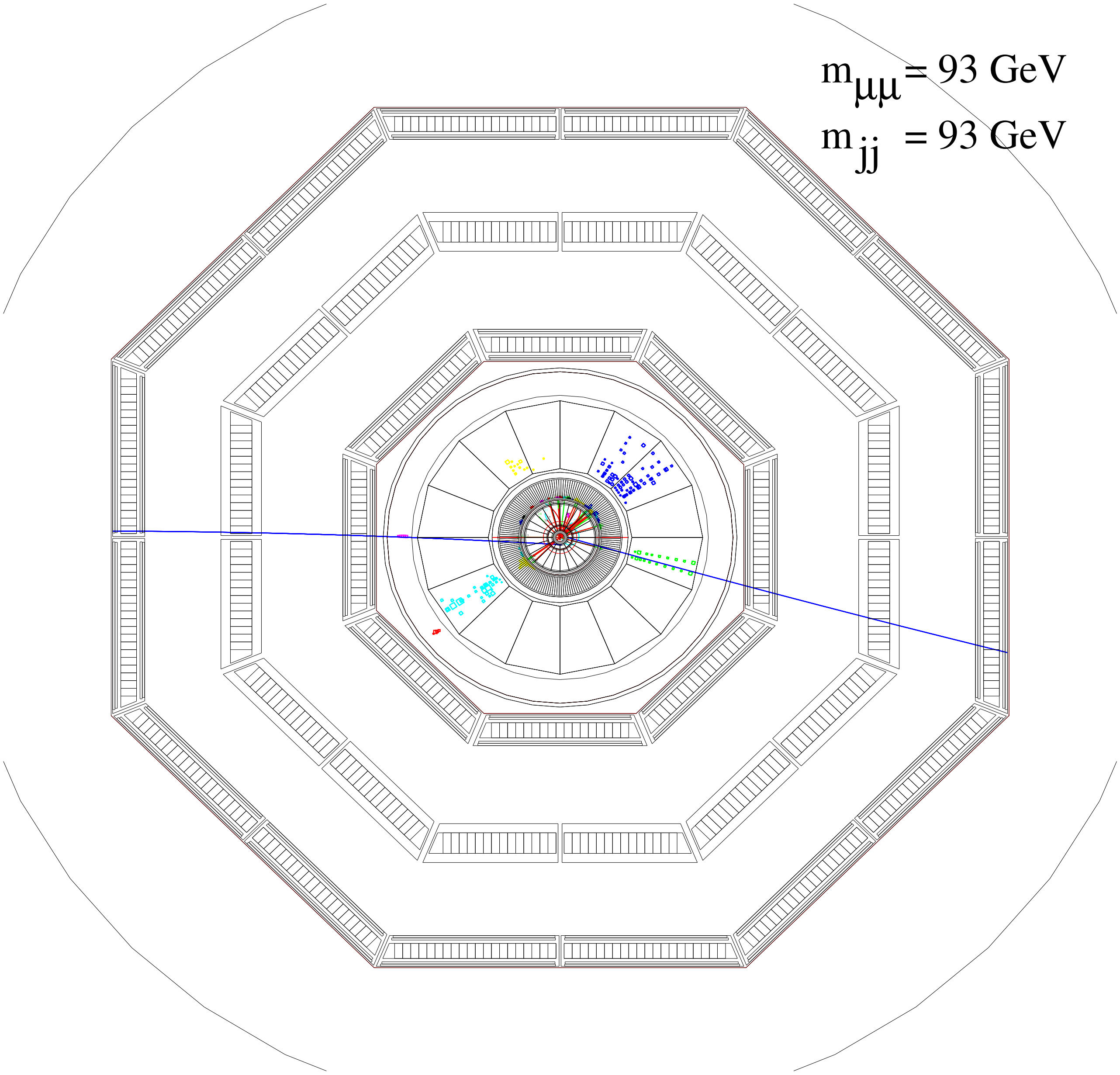
- Individual selections combined with an 'OR'
- qqee selection: 2 electrons and 2 jets with invariant masses above 50 GeV. Opening angle of the Z bosons above 130^o. Large visible energy and small missing momentum.
- $qq\mu\mu$ selection: 2 muons and 2 jets with invariant masses above 50 GeV. Opening angle of the Z bosons above 130^o.
- $qq\tau\tau$ selection: 2 low multiplicity jets and 2 high multiplicity jets with invariant masses in the range (70,120) GeV. Visible mass slightly below $\sqrt{s}$.

The signal efficiencies are $77\ \%$ for $qqee$, $61\ \%$ for $qq\mu\mu$ and $32\ \%$ for $qq\tau\tau$.

12 events are observed in data, 3.8 events are expected from background and 10.5 events are expected from ZZ $\rightarrow$ qqll



Run # 705301 Event # 24 Total Energy : 171.88 GeV



Transverse Imbalance : .0830		**Longitudinal Imbalance :** -.0744	
Thrust : .8584	**Major :** .4065		**Minor :** .1667
Event DAQ Time :	*980713 51332*		

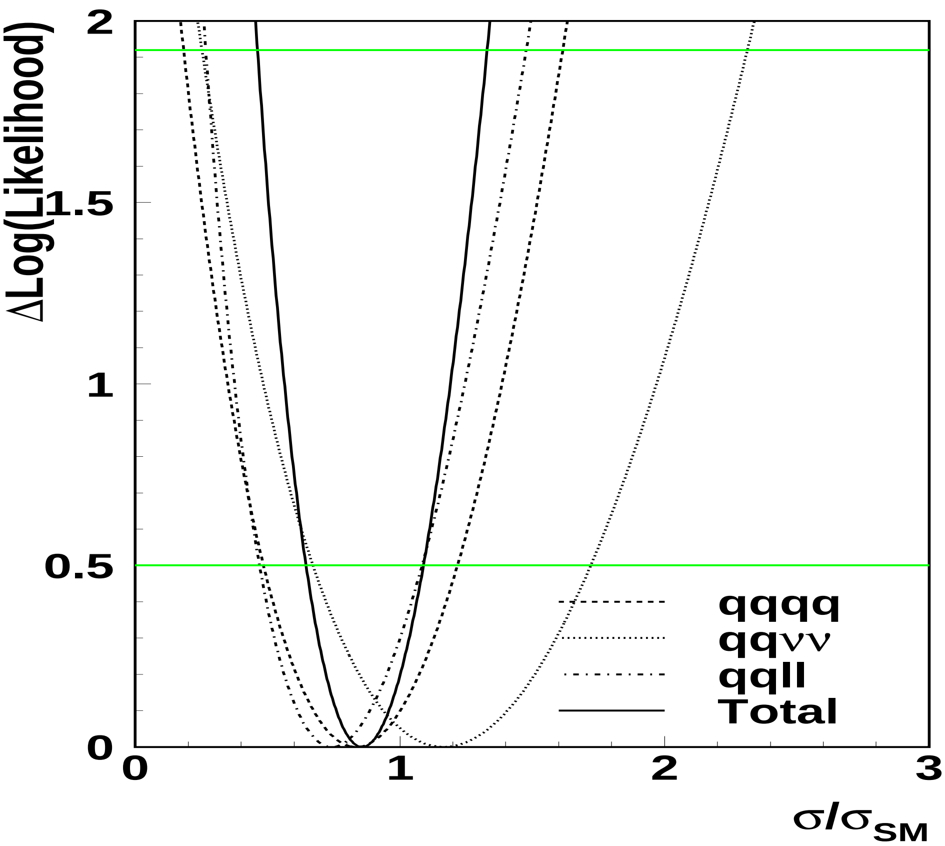
Cross Section results

Combining the results from the qqqq, $qq\nu\nu$, and qqll selections, the ZZ cross section is measured.

From the three experimental distributions shown previously, a Log Likelihood with one free parameter, the ZZ cross section, is maximized.

The measured cross section compared to the Excalibur prediction is:

Centre of Mass Energy	Measured Cross Section	S.M. Prediction
189 GeV	$0.54^{+0.16}_{-0.14}$ pb	0.62 pb
183 GeV	$0.30^{+0.22}_{-0.16}{}^{+0.07}_{-0.03}$ pb	0.25 pb

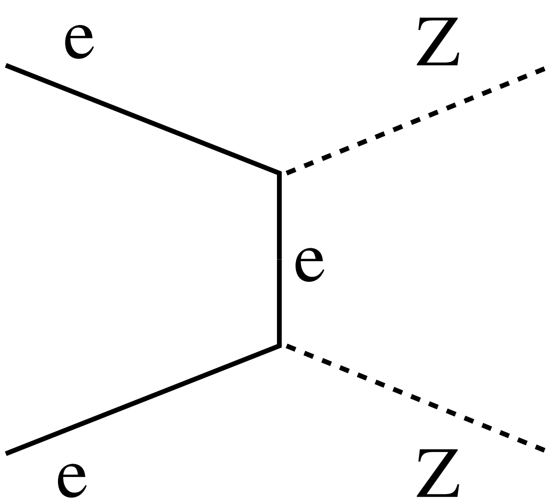


ZZZ and ZZγ Anomalous Couplings

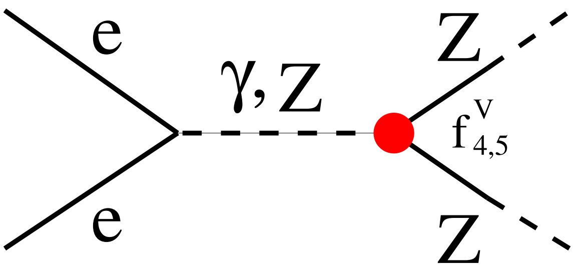
Motivation:

Look for deviations from SM in TRIPLE GAUGE BOSON COUPLINGS

ZZ Production in SM is mainly due to the conversion diagram



ANOMALOUS COUPLINGS would give rise to new diagrams



There are 4 possible couplings: f_4^Z, f_4^γ, f_5^Z and f_5^γ, all of them vanish in the Standard Model at tree level. f_4^Z and f_4^γ are CP-violating whereas f_5^Z and f_5^γ are P-violating. (Notations are from K. Hagiwara Nucl. Phys. B282, (1987) 253).

SIGNATURES OF ANOMALOUS COUPLINGS

- CHANGE IN THE TOTAL CROSS SECTION $e^+e^- \to ZZ$
- Modification of the angular distributions of the Z bosons
- Change in the average polarization of the Z's

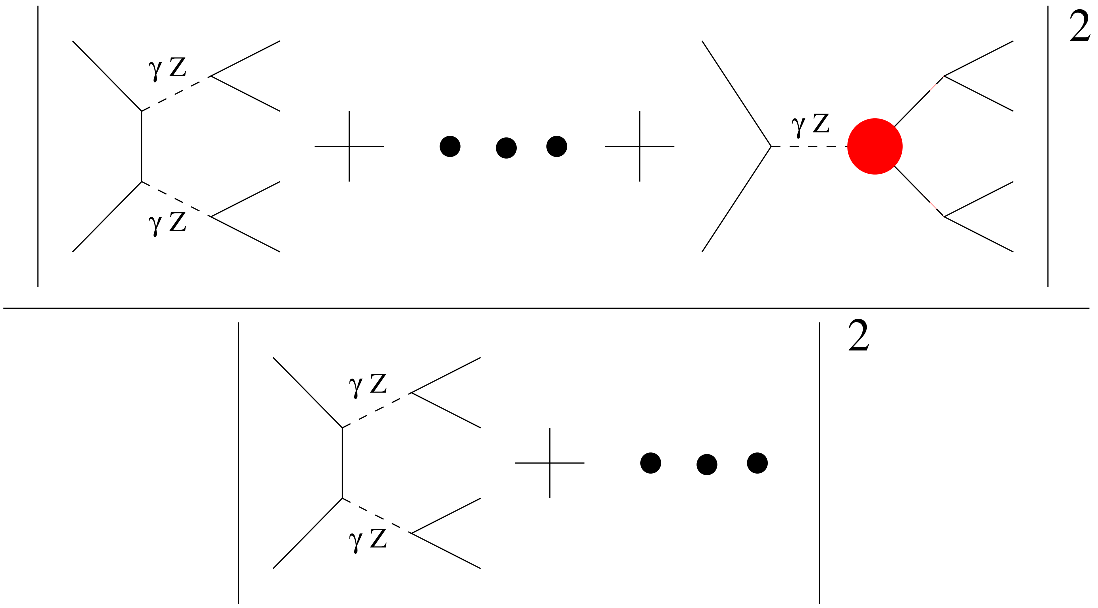
THE REWEIGHTING PROCEDURE

The amplitude for the anomalous coupling diagram has been calculated analytically, and the result has been implemented in the routine used by Excalibur including all Feynman Diagrams.

Therefore, for any 4-fermion MC event, knowing the 4 fourmomenta, the corresponding amplitude squared is calculated as a function of the anomalous couplings.

Then to obtain distributions with anomalous couplings, the SM distributions, are reweighted, event by event, according to the ratio of matrix elements:

Weight =



The histograms of the experimental variables shown previously are used to compare the measured data with the MC expectations, (which include background and ZZ signal). The value of anomalous couplings is varied, reweighting the ZZ signal events in the MC histogram, in order to maximize a binned likelihood:

$$\ln \mathcal{L} = \sum_{i=1}^{N_{BIN}} \left[N_{DATA}(i) \ln \frac{N_{MC}(i)}{N_{DATA}(i)} - (N_{MC}(i) - N_{DATA}(i)) \right]$$

where

$$N_{MC}(f_4^V, f_5^V) = N_{BKG} + N_{SIGNAL}(f_4^V, f_5^V)$$

EXPERIMENTAL RESULTS

From the qqll selection at $\sqrt{s} \simeq 189$ GeV limits are set at the 95 % confidence level, to the four possible anomalous couplings:

Limits with $\sqrt{s} \simeq 189$ GeV Data	Limits with $\sqrt{s} \simeq 183$ GeV Data
$-1.8 < f_4^Z < 1.8$	$-3.6 < f_4^Z < 3.4$
$-5.5 < f_5^Z < 5.4$	$-8.4 < f_5^Z < 7.9$
$-1.1 < f_4^\gamma < 1.0$	$-2.1 < f_4^\gamma < 2.1$
$-3.3 < f_5^\gamma < 3.2$	$-4.9 < f_5^\gamma < 4.8$

CONCLUSIONS

- The ZZ production cross section at $\sqrt{s} \simeq 189$ GeV has been measured. The result is in agreement with Standard Model expectation.

$$\sigma_{ZZ}(189\ \mathrm{GeV}) = 0.54^{+0.16}_{-0.14}\ \mathrm{pb} \qquad (0.62\ \mathrm{pb})$$

- No deviations from Standard Model have been found in the framework of an effective theory with anomalous couplings ZZZ and ZZγ. Limits have been set at the 95 % confidence level, improving our previously published results.

$$-1.8 < f_4^Z < 1.8 \qquad -5.5 < f_5^Z < 5.4$$

$$-1.1 < f_4^\gamma < 1.0 \qquad -3.3 < f_5^\gamma < 3.2$$