Study of the production of Z boson pairs in e^+e^- collisions at LEP with the L3 detector

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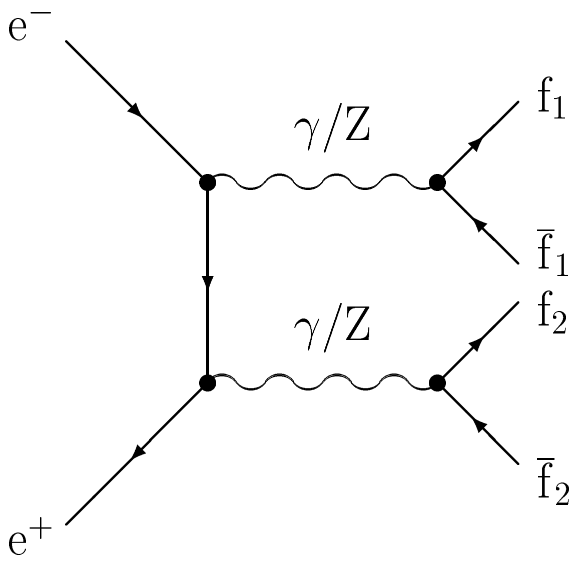
Outline

- **ZZ signal definition**
- **Analyses for**
  $\sqrt{s}$=183 GeV data, $\int\mathcal{L}$=55.3 pb^{-1}
  ZZ$\rightarrow llqq, llll, ll\nu\nu, qq\nu\nu, qqqq$
- **ZZ cross section at $\sqrt{s}$=183 GeV**
- **Anomalous coupling of ZZZ, ZZγ**
- **Preliminary results for**
  $\sqrt{s}$=189 GeV data, $\int\mathcal{L}$=175 pb^{-1}

On-shell ZZ, signal definition



Conversion diagram dominant

- **EXCALIBUR calculations**
- **1 GeV invariant mass cut for photon poles**
- **70 GeV $< m_{f_1\bar{f}_1}, m_{f_2\bar{f}_2} <$ 105 GeV**

- **e^+e^- pairs, $|\cos\theta_e| < 0.95$ to suppress multiperipheral events**
- **if $f_1 = f_2$, requires in the mass window $m_{f_1\bar{f}_1}, m_{f_2\bar{f}_2}$ OR $m_{f_1\bar{f}_2}, m_{f_2\bar{f}_1}$**

- **$u\bar{u}d\bar{d}$, $c\bar{c}s\bar{s}$, $\nu_l\bar{\nu}_l\ell^+\ell^-$ has W exchange excluded if 75 GeV $< m_{f\bar{f}} <$ 85 GeV**

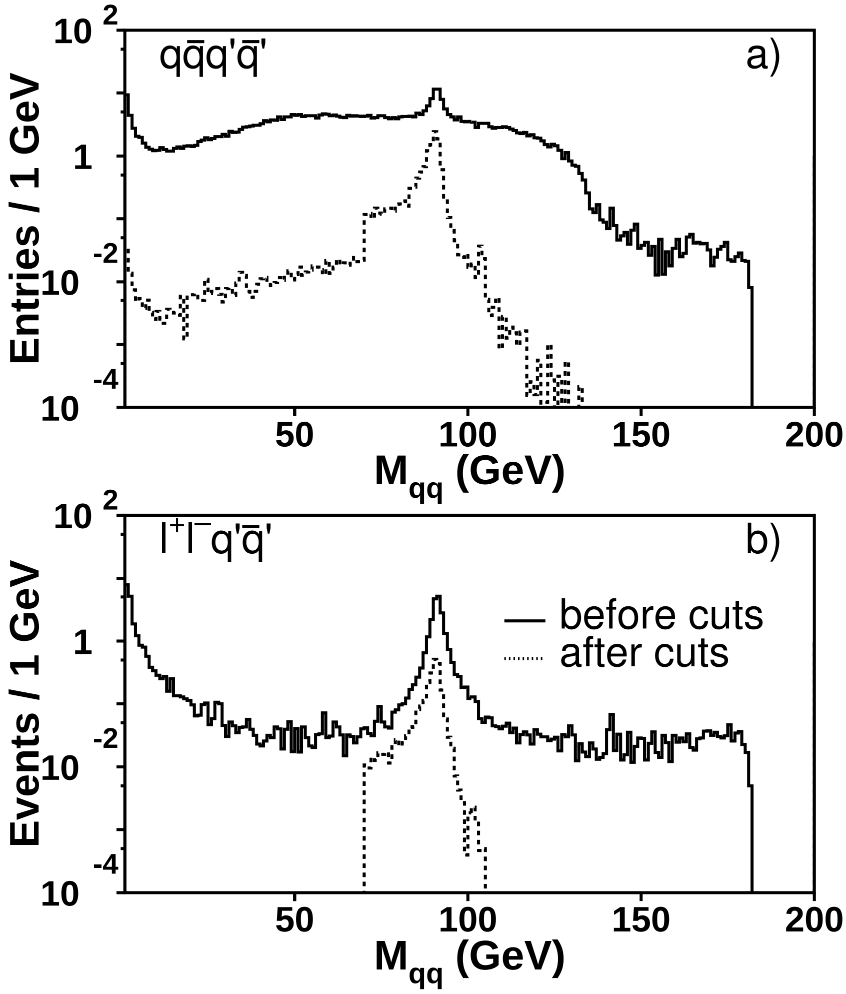
Signal definition (cont'd)

- **Total cross section at $\langle\sqrt{s}\rangle$=182.7 GeV**
  σ_{ZZ}=0.25 pb after cuts

- **Branching fractions for ZZ decays**

$qq\ell\ell$=0.17	$qq\nu\nu$=0.25	$qqqq$=0.46
$\ell\ell\ell\ell$=0.03	$\ell\ell\nu\nu$=0.05	$\nu\nu\nu\nu$=0.04

- **EXCALIBUR distributions**



ZZ $\to \ell^+\ell^- q\bar{q}$ at 183 GeV

- High multiplicity events
- Two jets plus identified leptons

Efficiencies and Events

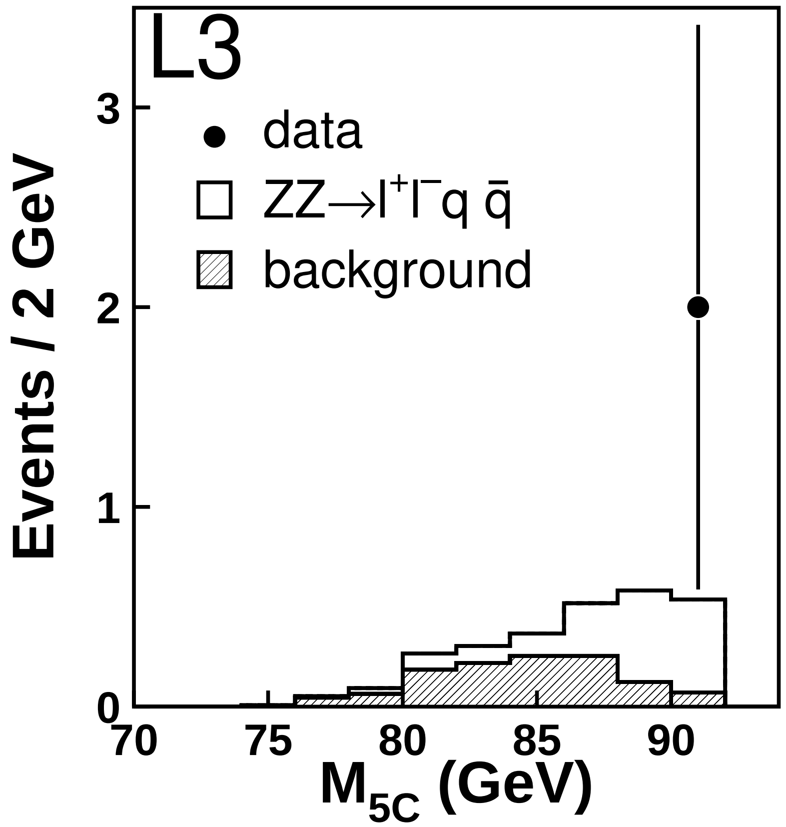
ZZ→	efficiency%	signal	background	data
$e^+e^-q\bar{q}$	79	0.79±0.03	0.29±0.04	2
$\mu^+\mu^-q\bar{q}$	58	0.42±0.01	0.09±0.01	0
$\tau^+\tau^-q\bar{q}$	36	0.26±0.01	0.85±0.13	0

Background processes :
W$^+$W$^-$55%, $qq(\gamma)$ 22%, 4-fermions 23%

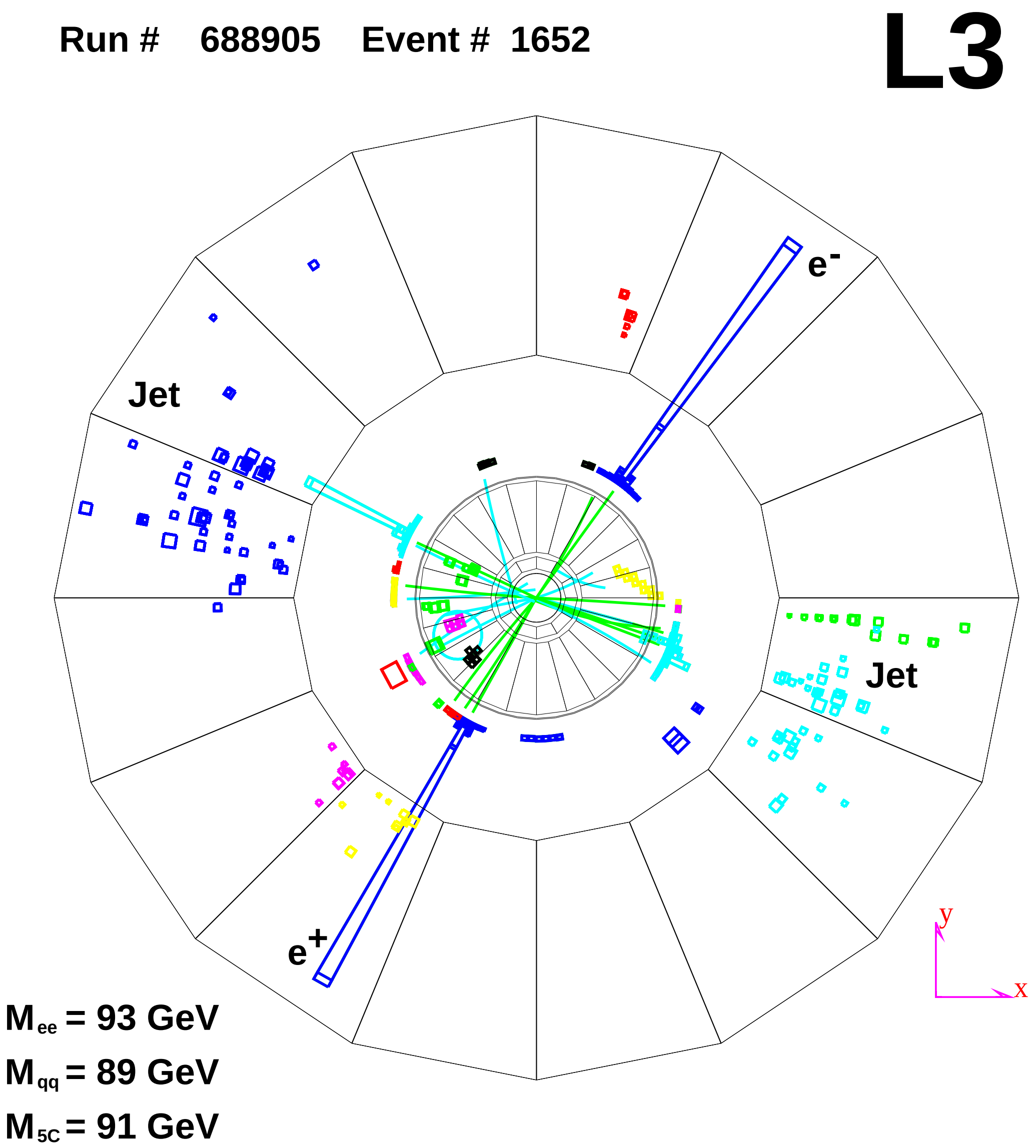
Test distributions :

M_{5C} of equal mass fit with kinematic constraints

Two $e^+e^-q\bar{q}$ candidates found



ZZ $\rightarrow e^+e^-q\bar{q}$ candidate



$ZZ \to \ell^+\ell^-\ell'^+\ell'^-$ at 183 GeV

- **Low multiplicity events**
- **Identified leptons**

Efficiencies :

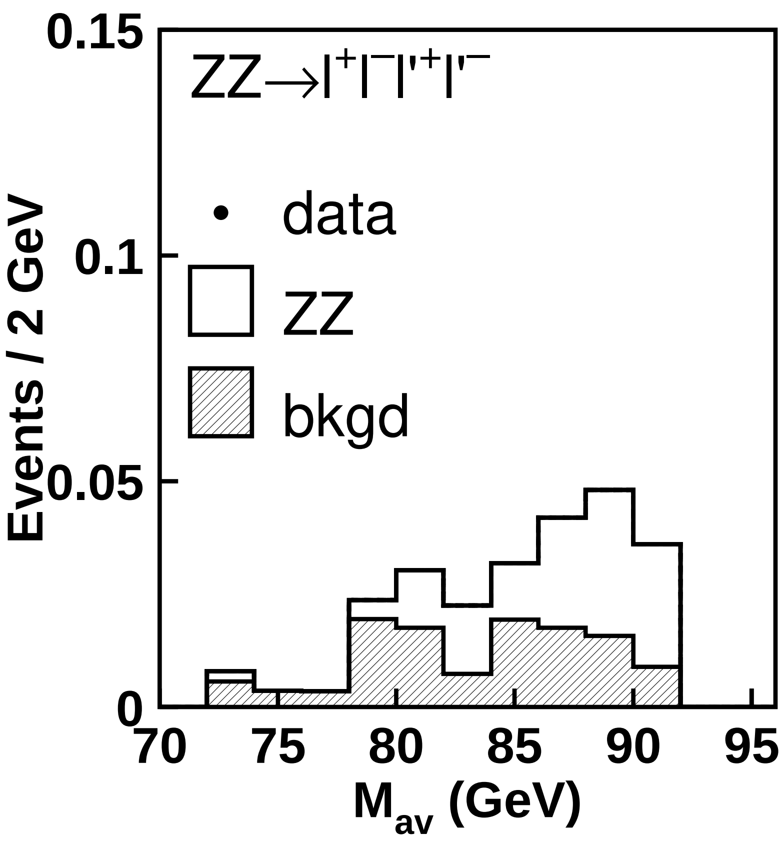
$e^+e^-e'^+e'^-$	64%	$e^+e^-\mu^+\mu^-$	78%	$e^+e^-\tau^+\tau^-$	36%
$\mu^+\mu^-\mu'^+\mu'^-$	26%	$\mu^+\mu^-\tau^+\tau^-$	15%		

Test distributions :

$M_{l^+l^-}$ of min.χ^2 to Z mass

M_{rec} the corresponding recoil mass

$M_{av}=(M_{l^+l^-}+M_{rec})/2$



Events :

$N^{SM}_{signal}=0.13\pm0.02$

$N_{bkgd}=0.12\pm0.03$

$N_{data}=0$

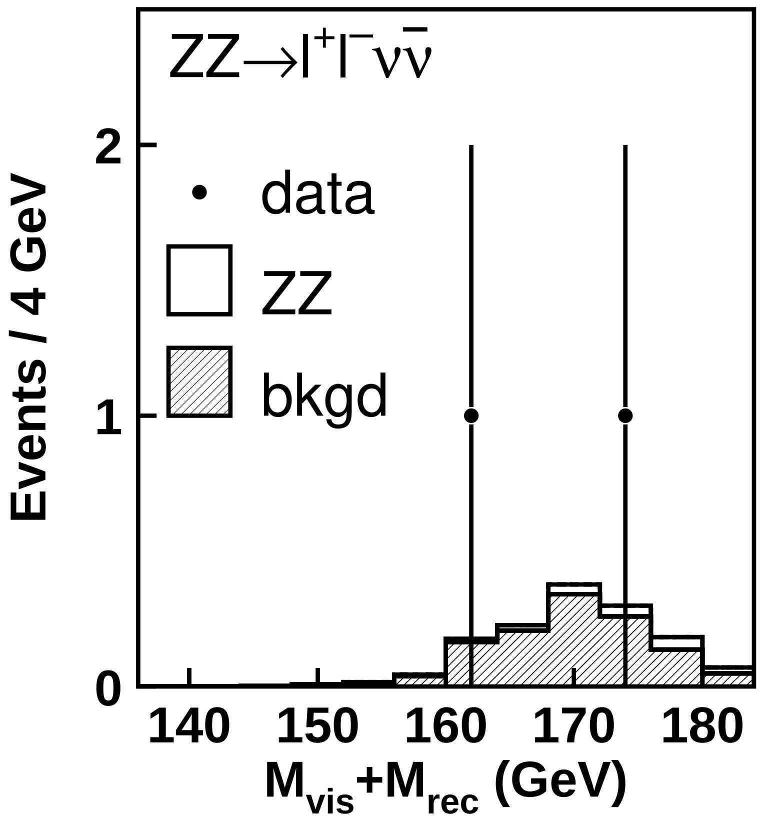
ZZ $\rightarrow \ell^+\ell^-\nu\bar{\nu}$ at 183 GeV

- Two identified leptons
- Large missing energy

Efficiencies :

$e^+e^-\nu\bar{\nu}$	37%	$\mu^+\mu^-\nu\bar{\nu}$	33%

Test distributions :
visible mass M_{vis} and recoil mass M_{rec}



Events

N^{SM}_{signal}=0.18±0.02

N_{bkgd}=1.23±0.03

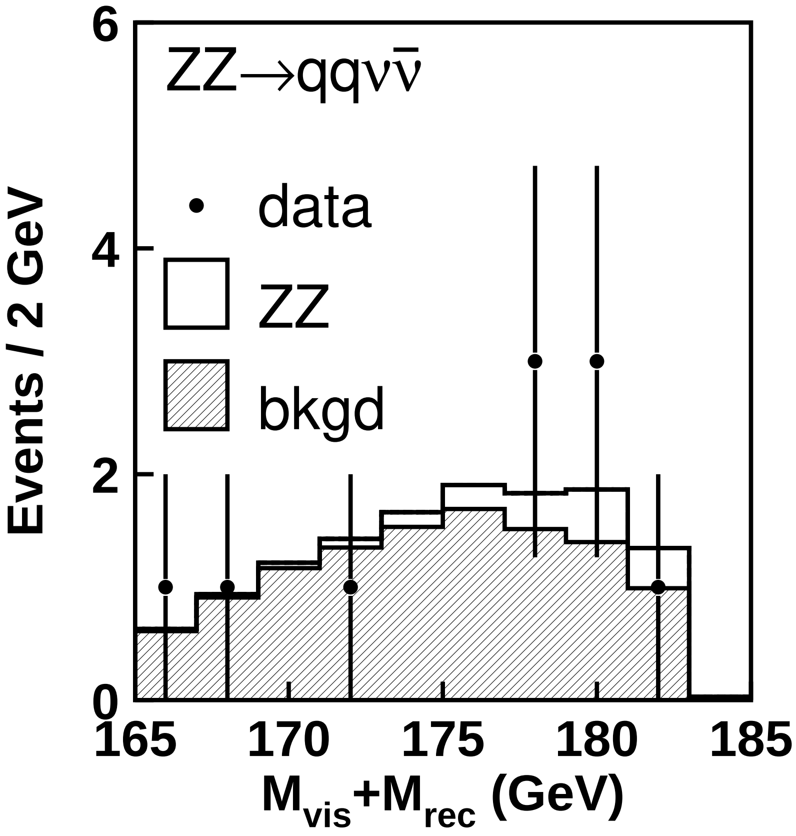
N_{data}=2

- Two acoplanar jets
- Large missing p_T

NN method
to discriminate W^+W^-background

Efficiency : 47%

Test distributions :
visible mass M_{vis} and recoil mass M_{rec}



Events

N^{SM}_{signal}=1.64±0.07

N_{bkgd}=13.0±0.06

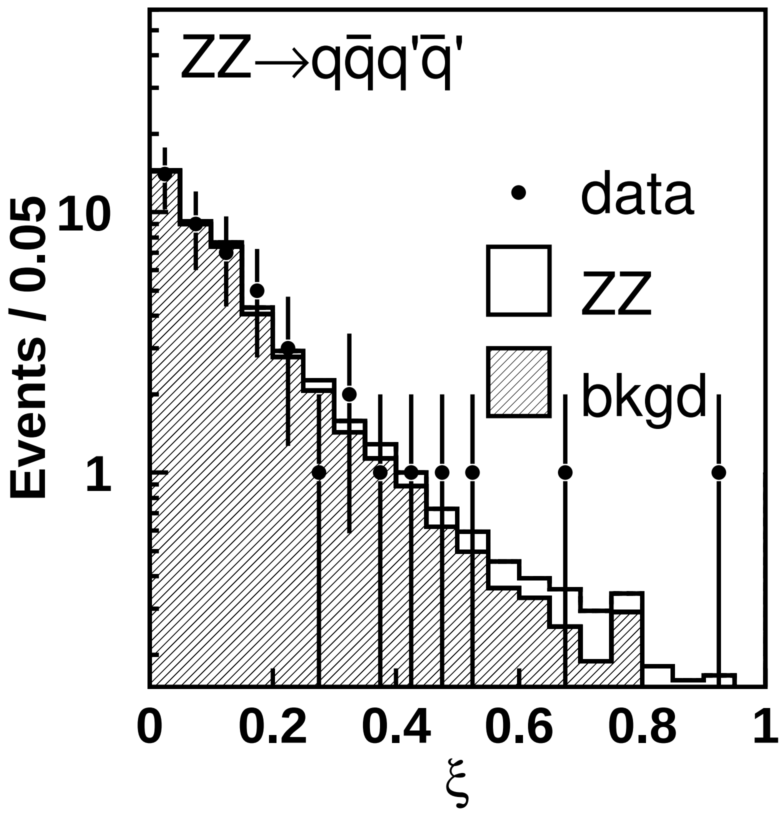
N_{data}=10

ZZ $\longrightarrow q\bar{q}q'\bar{q}'$ at 183 GeV

- High multiplicity 4 jet events
- $M_{5C} > 85$ GeV
  equal mass fit with kinematic constraints

NN method
to discriminate W^+W^-, $qq(\gamma)$ background

Test distributions :
convolution of NN outputs and M_{5C}
$\xi = NN_{ZZ}(1\text{-}NN_{WW})(1\text{-}NN_{qq})M_{5C}/M_Z$



Efficiency 34%

Events

$N^{SM}_{signal} = 2.3 \pm 0.1$

$N_{bkgd} = 46 \pm 2$

$N_{data} = 47$

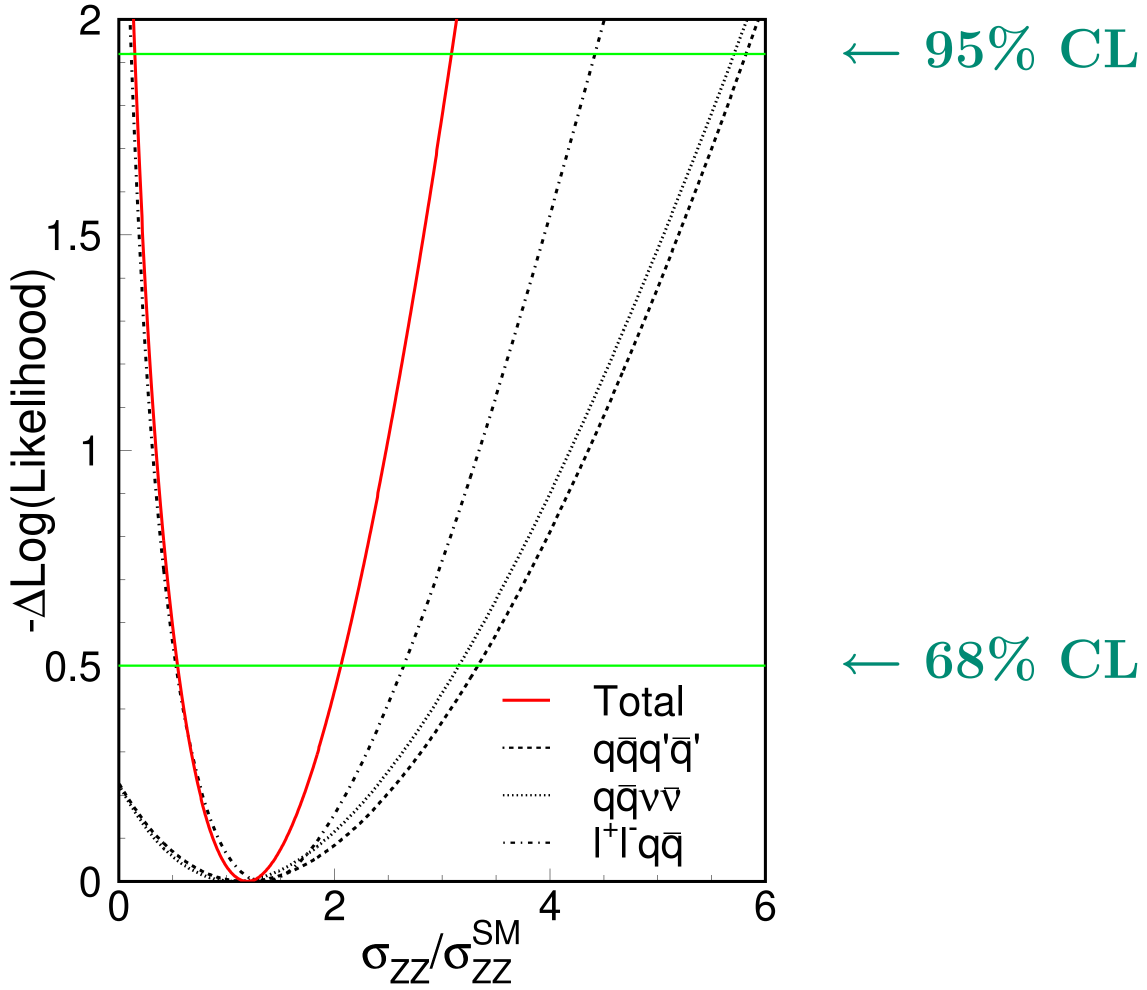
- Binned poissonian log-likelihood fit

$$P(x|N_{ij}, b_{ij}, s_{ij}) = -\log \Pi^{i}_{\mathrm{ch}} \Pi^{j}_{\mathrm{bins}} \frac{e^{-(xs_{ij}+b_{ij})} \cdot (xs_{ij} + b_{ij})^{N_{ij}}}{N_{ij}!}$$

- One fitting variable : $x = \sigma_{ZZ}/\sigma^{SM}_{ZZ}$
- All final distributions used

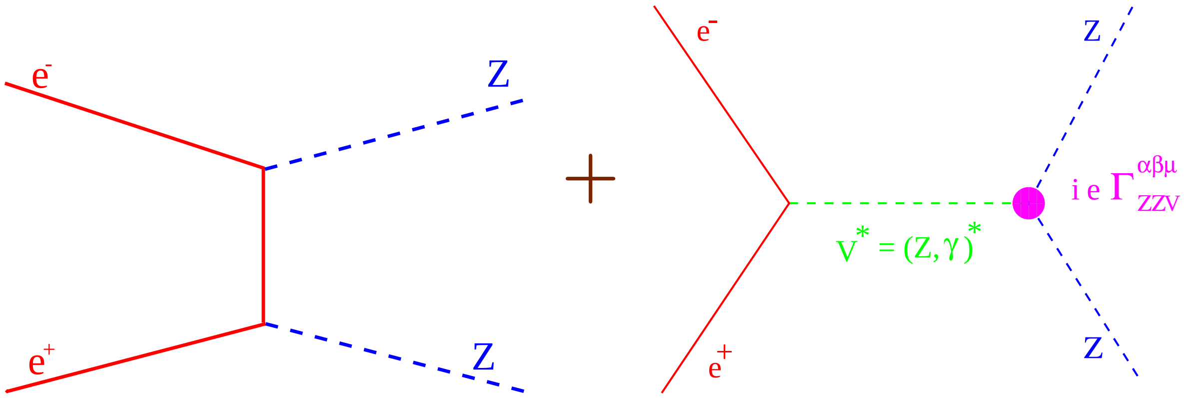
At $\sqrt{s}$=183 GeV, σ^{SM}_{ZZ}=0.25 pb

Result of the fit : $\sigma_{ZZ} = 0.30^{+0.22+0.07}_{-0.16-0.03}$ pb



Limits on ZZV anomalous Coupling

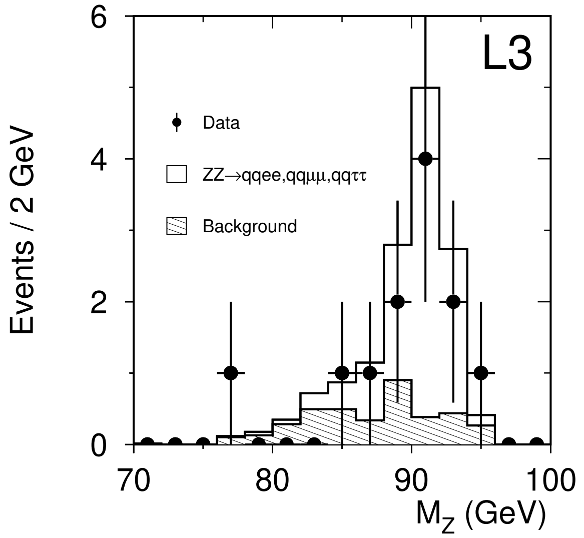
ZZ final states with non-SM couplings



- **Anomalous coupling of ZZZ, ZZγ :**
  Vertex function $\Gamma^{\alpha\beta\mu}_{ZZV}$ has coupling $f_4^{Z,\gamma}$, $f_5^{Z,\gamma}$
  for CP-violating, conserving processes
  $f_4^{Z,\gamma}$, $f_5^{Z,\gamma}=0$ at SM tree level
- **Signature :**
  σ_{ZZ} enhancement,
  angular distribution of the Z bosons
- **Deviate $f_{4,5}^{Z,\gamma}$**
  to maximize binned loglikelihood
  $\log \mathcal{L} = \sum_{\text{bins}}(N^i_{data} \cdot \log N^i_{MC} - N^i_{MC})$
  $N^i_{MC} = N^i_{ZZ}(f_{4,5}^{Z,\gamma}) + N^i_{bkgd}$
- **Results of test to final distributions :**
  $-3.6 \leq f_4^Z \leq 3.4$ $\;-2.1 \leq f_4^\gamma \leq 2.1$
  $-8.4 \leq f_5^Z \leq 7.9$ $\;-4.9 \leq f_5^\gamma \leq 4.8$

Preliminary ZZ at 189 GeV

$\int \mathcal{L}=175\ \mathrm{pb}^{-1}$

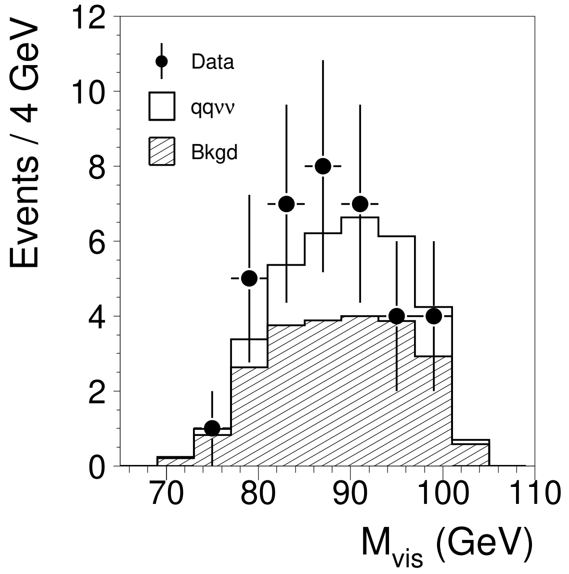


ZZ→ $\ell^+\ell^- q\bar{q}$

$N^{SM}_{signal}=10.5$

$N_{bkgd}=3.8$

$N_{data}=12$

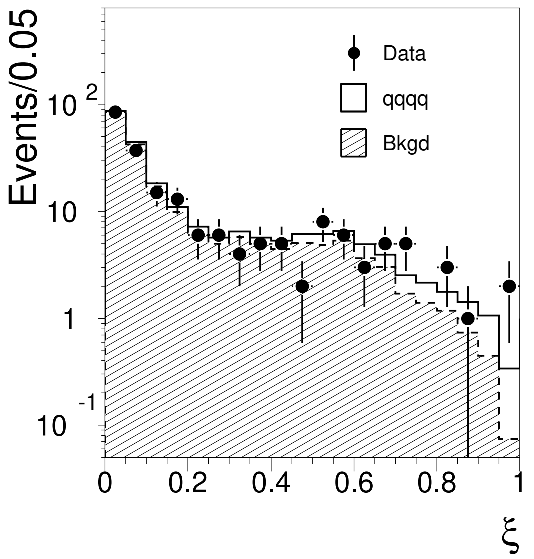


ZZ→ $q\bar{q}\nu\bar{\nu}$

$N^{SM}_{signal}=11.3$

$N_{bkgd}=22.7$

$N_{data}=36$



ZZ→ $q\bar{q}q'\bar{q}'$

$N^{SM}_{signal}=21.2$

$N_{bkgd}=207.5$

$N_{data}=211$

ZZ $\rightarrow \mu^+\mu^- q\bar{q}$ candidate

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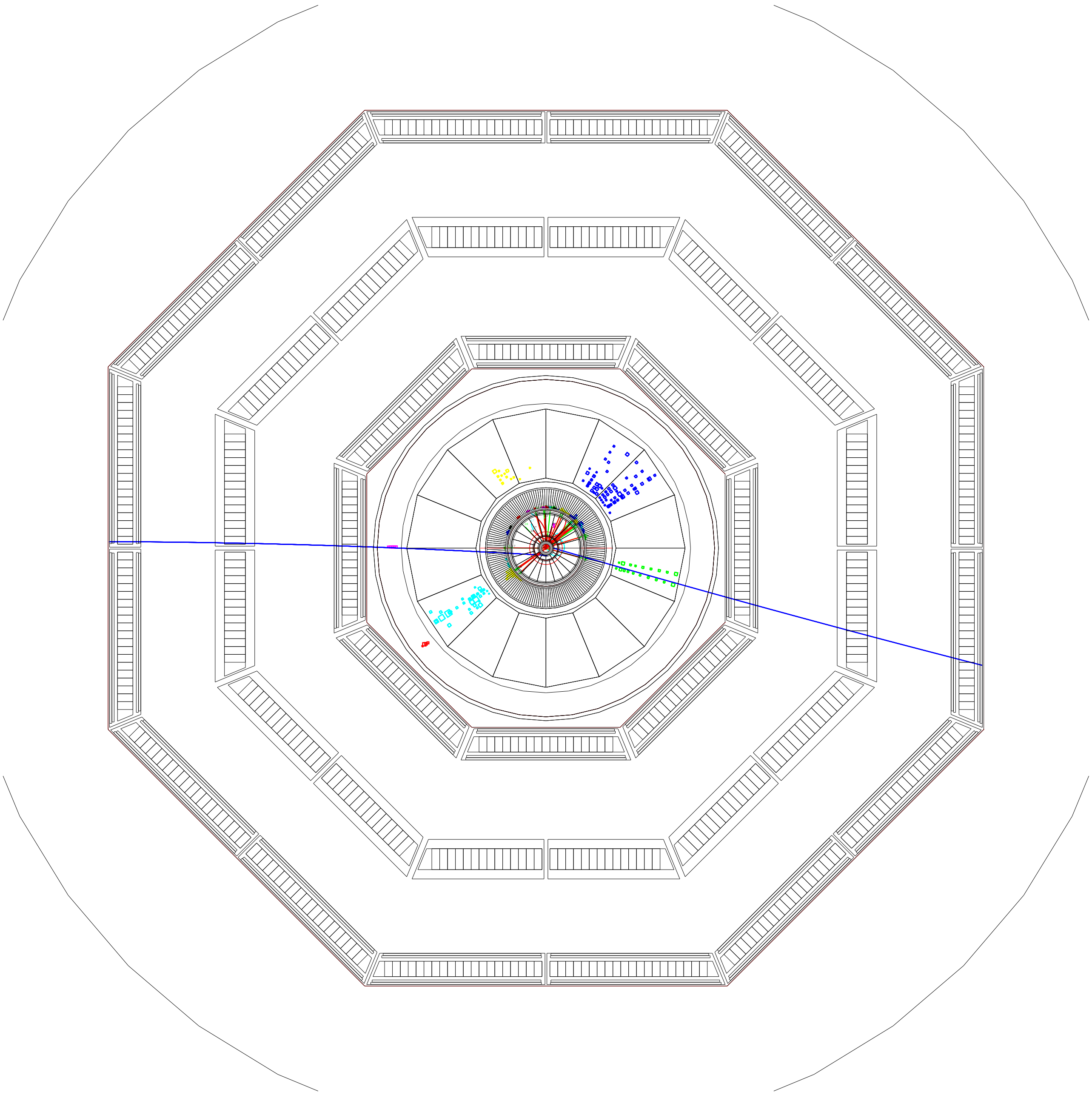

$m_{\mu\mu}$ = 93 GeV

m_{jj} = 93 GeV

Preliminary ZZ at 189 GeV

- **Total ZZ cross section at 189 GeV**

  Standard Model $\sigma_{ZZ}^{SM} = 0.62$ **pb**

  Measurement $\sigma_{ZZ} = 0.54^{+0.16}_{-0.14}$ **pb**

- **Limits on anomalous coupling**

  $$-1.8 \leq f_4^Z \leq 1.8 \quad -1.1 \leq f_4^\gamma \leq 1.0$$
  $$-5.5 \leq f_5^Z \leq 5.4 \quad -3.3 \leq f_5^\gamma \leq 3.2$$