WW scattering at TESLA

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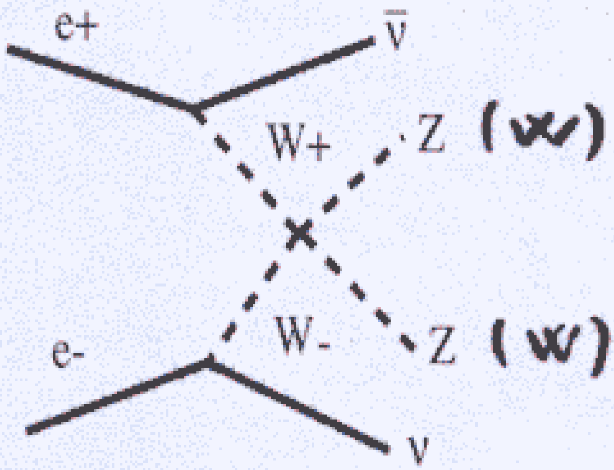
- Motivations
- Event generators
- Signal and backgrounds
- Events selections and cross sections
- Four boson couplings meauserments
- Conclusions

Motivations

- Four gauge boson interactions are an established prediction of the electroweak SM
- The measurement of the four boson couplings allows therefore an independent test of the SM at TESLA linear collider
- Furthermore, in case no light Higgs bosons exist, a new strong interaction between W,Z bosons must arise to restore unitarity, violated by WW→WW (ZZ) scattering at the TeV scale.
- Such interaction may be indicated by slight deviations from the SM prediction of 2→2 scattering of the $W^{\pm}$ and Z bosons.



Events generators

6 fermion final states $\rightarrow$ no generator was available before the LC workshop in Padova

Whizard (from W. Kilian), an omni-purpouse package for MC integration and event generation is now available and has been used in this analysis.

Whizard $\rightarrow$ unweighted events with up to 6 final state particles. Possibility to use various matrix elements: MadGraph, O'Mega (from T. Ohl) , or CompHEP

Other background processes <6 ($t\bar{t}$, $q\bar{q}$, 4-fermion) $\rightarrow$ use PYTHIA

Scheme of the analysis:

Generator $\rightarrow$ Hadronization (JETSET) $\rightarrow$ Detector simulation $\rightarrow$ Analysis

The analysis has been done for $q\bar{q}q\bar{q}\nu\bar{\nu}$ events

$ZZ\nu\nu$ signal and backgrounds

For each process, all diagrams, including interference, are generated.

$ZZ\nu\nu \rightarrow qqqq\nu\nu$ (SIGNAL) BR=49%	Signal definition: cut on di-quark masses $170<M_1+M_2<195$ and $\lvert M_1-M_2\rvert<20$ GeV Whizard + Jetset hadronization (σ =3.7 fb)
$qqqq\nu\nu$ background	$WW\nu\nu$ and other non-resonant diagrams Whizard+Jetset (σ =12.9 fb)
Other 6-fermion backgnd. $WZe\nu$, WWee,ZZee and non resonant $qqqqe\nu$, qqqqee	Whizard + Jetset hadronization (σ=32, 492, 2 fb)
4-fermion (WW,ZZ + ISR)	Pythia (σ = 5280 fb)
$t\bar{t}$	Pythia (σ =346 fb)

Detector

Optimal mass resolution and forward coverage (P_t, Emis, forward leptons ID)

- Detector simulation with SIMDET V3.1

SETUP

- Tracking: CCD 2cm+FT+TPC, $|\vec{B}|$=3T.
- TPC acceptance $\rightarrow$ 10^o, overall tracking acceptance $\rightarrow$ 5^o
- Calorimetry: EM ($0.6\%+10\%/\sqrt{E}$ resolution), HAD ($4\%+40\%/\sqrt{E}$ resolution) acceptance $\rightarrow$ 4.6^o
- Instrumented mask in the very forward region
- Instrumentation up to 23.7 mrad in SIMDET$\rightarrow$(important for WWee,WZeν background)

ZZ$\nu\nu$ analysis outline

- Force the reconstructed tracks into 4 jets

- Test the $ZZ\nu\nu$ hypotesis with a kinematic fit just constraining the two jet-pairs to have the same mass

- Likelihood method to choose the pairing (fitted mass, mass difference, fit χ^2). Very good resolution and boosted bosons allow ~95% of correct pairings.

- Apply a first preselection mainly against 4fermion+ISR and $t\bar{t}$.

- Likelihood selection to separate the ZZ$\nu\nu$ signal from 6f backgrounds

$ZZ\nu\nu$ selection

Preselection cuts

200<E_{mis}<650 GeV E^{max}_{track}<200 GeV

|cos(θ_{pmis})|<0.99 |cos(θ_{Emax})|<0.99

- Cut the event if one of the four most energetic charged tracks is isolated (less then 2 GeV in a 10 degrees cone). Effective against $t\bar{t} \rightarrow b\bar{b}l\nu l\nu$ background.

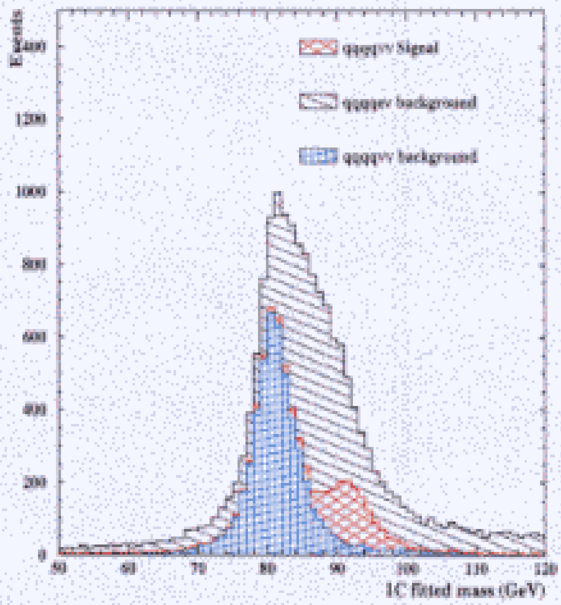
Likelihood variables

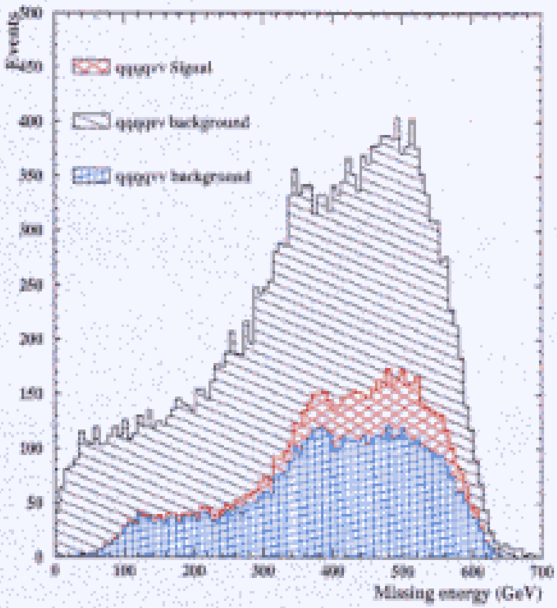
E_{mis} E^{max}_{track}

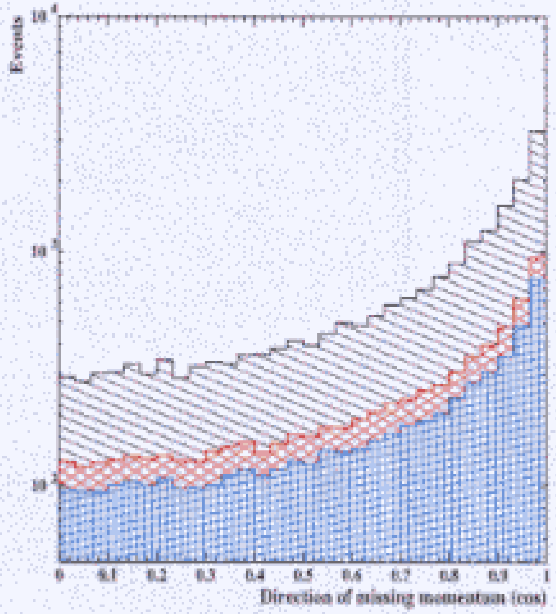
|cos(θ_{Pmis})| |cos(θ_{Emax})|

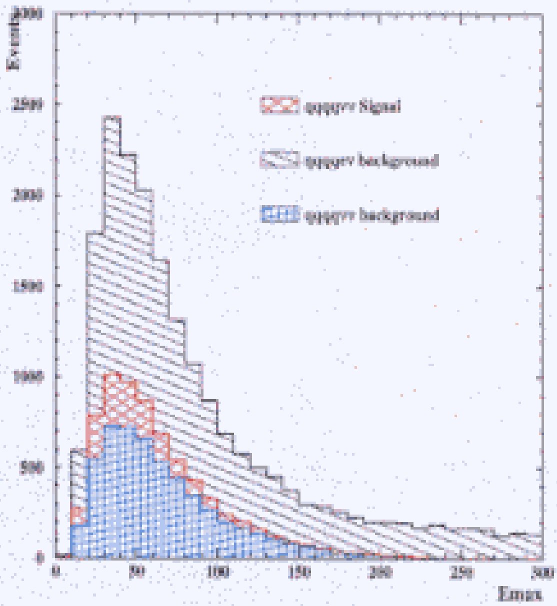
Fitted mass   Jet pairing likelihood

Selection variables



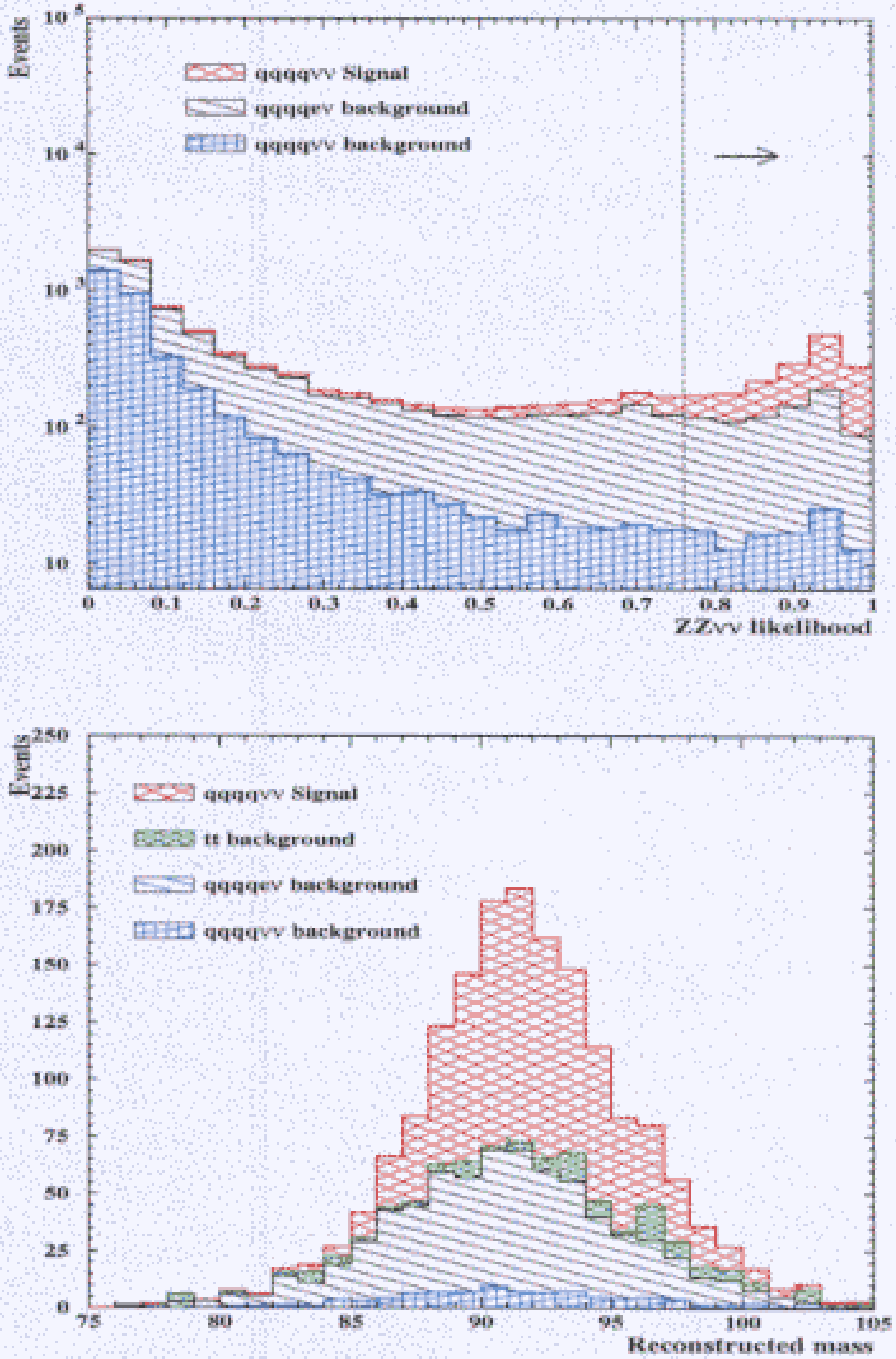






$ZZ\nu\nu$ selection results

Likelihood and mass distributions



Selection results

Expected number of events at $\sqrt{s}$ =800 GeV
1000 fb^{-1} integrated luminosity

Channel	Events	
ZZ$\nu\nu$ $\rightarrow$qqqq$\nu\nu$	844$\pm$10	$\epsilon = 52.2 \pm 0.6\%$
qqqq$\nu\nu$ backgnd	88$\pm$5	
WZeν	570 $\pm$ 20	
ZZee,WWee	$\simeq$0	
$t\bar{t}$	83 $\pm$5	
$q\bar{q}$	$\simeq$0	
4 fermion	23$\pm$10	

The purity is 52.3 %

$\rightarrow$ this results in $\frac{\Delta\sigma}{\sigma}$=3.2%

$WW\nu\nu$ selection

From R.Chierici

Event treatment

The event is forced into 4 jets (if possible)

Jet pairing chosen such that $|M_{ij}-M_W|\cdot|M_{kl}-M_W|$ is minimum

Rejection of $ee\rightarrow 2f,4f$

N_{jet} (LUCLUS, d_{join}=7GeV) = 4,5

120 GeV < E_{trans} < 600 GeV

M_{recoil} > 200 GeV (also effective for irr. $WW\nu\nu$)

Rejection of small P_T events (removes e, μ, τ ...)

P_T (WW)>40 GeV

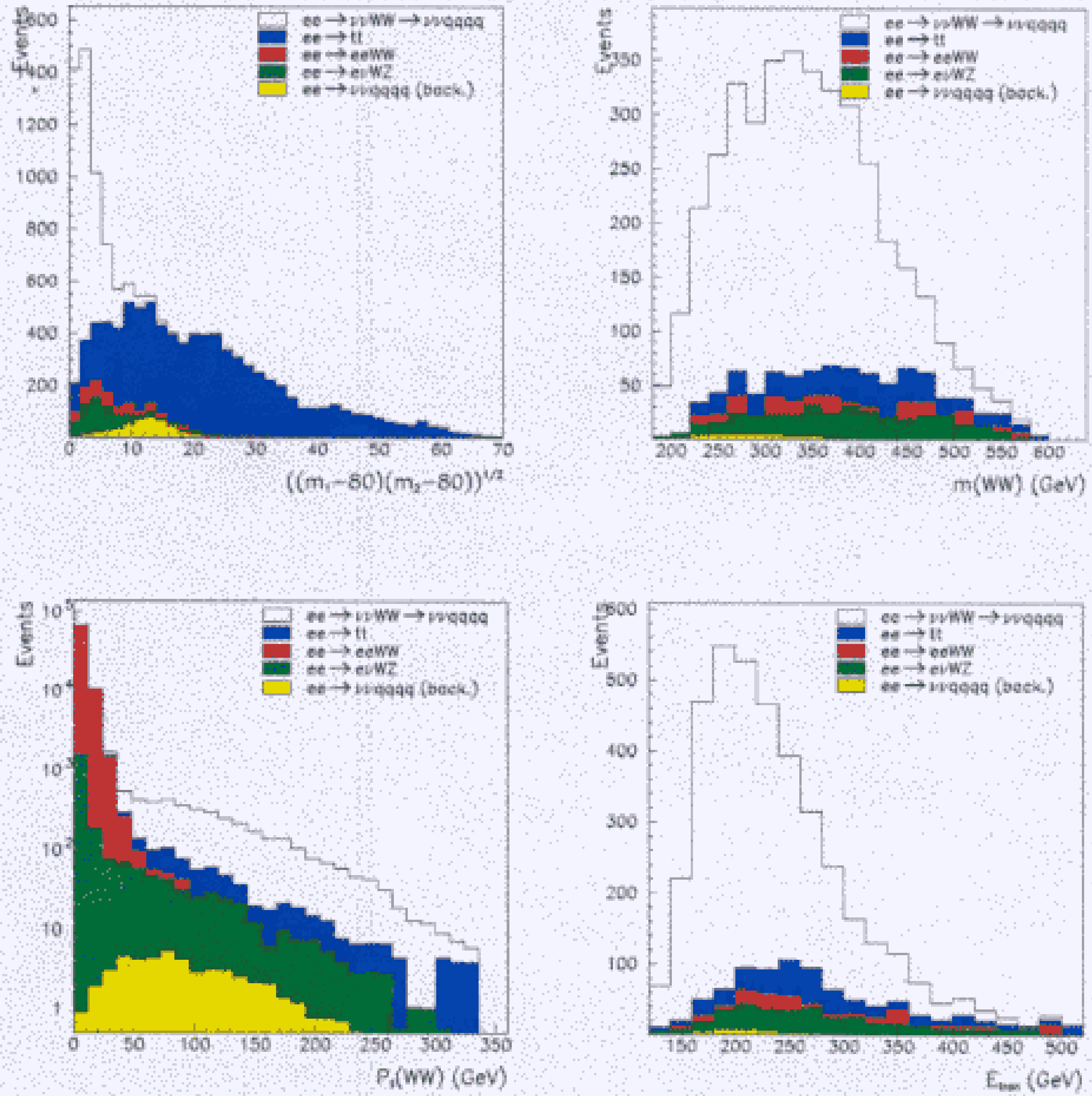
N_{ch}^{jet}(min)=3

Invariant mass (loose) cuts (very effective for $t\bar{t}$ and $ZZ\nu\nu$)

60 GeV<$M(W^+)$, $M(W^-)$<100 GeV

$|M_1-M_W|\cdot|M_2-M_W|$<50 GeV^2

AND b-TAG



Events
ee → ννWW → ννqqqq
ee → tt
ee → eeWW
ee → eνWZ
ee → ννqqqq (back.)
((m₁−80)(m₂−80))^{1/2}
m(WW) (GeV)
P_t(WW) (GeV)
E_tran (GeV)

WW$\nu\nu$ selection results

Expected number of events at $\sqrt{s}$ =800 GeV
1000 fb^{-1} integrated luminosity

Channel	Events	
WW$\nu\nu$ →qqqq$\nu\nu$	2550±30	$\epsilon = 40.1 \pm 0.4\%$
qqqq$\nu\nu$ backgnd	151±5	
WZeν	350± 10	
WWee	130±20	
$t\bar{t}$	400± 70	
$q\bar{q}$	≃0	
4 fermion	≃0	

→ this results in $\frac{\Delta\sigma}{\sigma}$=2.0%

Four Boson couplings

- Dimension-4 operators $L_{4,5}$ (E. Boos et al. hep-ph/9708310): independent contact interaction terms for W,Z bosons.

$$L_4 = \alpha_4 [\frac{g^4}{2}[(W_\mu^+ W^{-\mu})^2 + (W_\mu^+ W^{+\mu})(W_\nu^- W^{\nu -})] + \frac{g^4}{c_w^2}(W_\mu^+ Z^\mu)(W_\nu^- Z^\nu) + \frac{g^4}{4c_w^4}(Z_\mu Z^\mu)^2]$$

$$L_5 = \alpha_5 [g^4 (W_\mu^+ W^{-\mu})^2 + \frac{g^4}{c_w^2}(W_\mu^+ W^{-\mu})(Z_\nu Z^\nu) + \frac{g^4}{4c_w^4}(Z_\mu Z^\mu)^2]$$

- The two dimension-4 operators introduce all possible quartic couplings at Leading Order, compatible with charge conservation and $SU(2)_c$

- The coefficients α_4, α_5 are both 0 in SM $\rightarrow$ Evaluate the sensitivity on the coefficients that can be obtained studying WW scattering at TESLA.

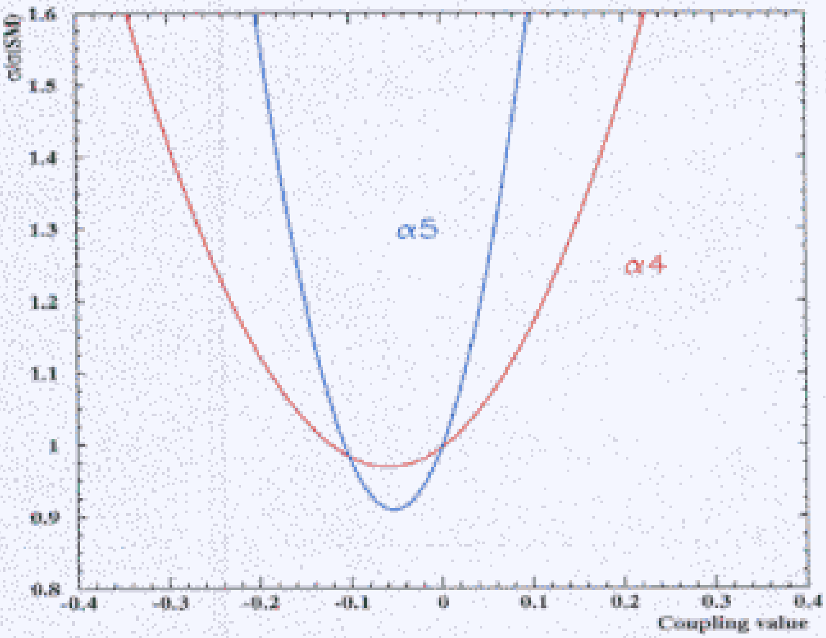
Signatures

Signatures of the quartic contributions introduced by L_4, L_5 :

- Change of the total cross section
- Change of the average polarization of bosons.

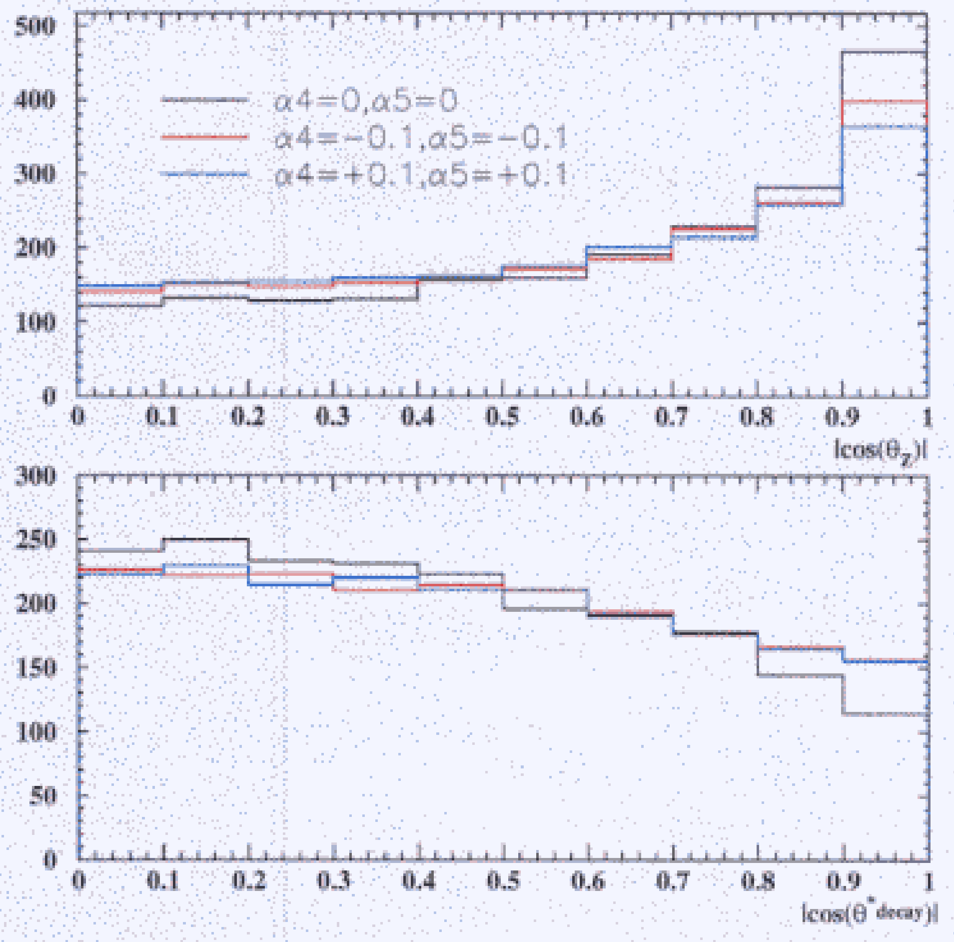
$\longrightarrow$ changes of event rate and of angular distributions of bosons and of their decay products

Relative change of ZZ$\nu\nu$ total cross section vs $\alpha 4, \alpha 5$



Angular distributions

Bosons and decay fermions angles in $ZZ\nu\nu$ events

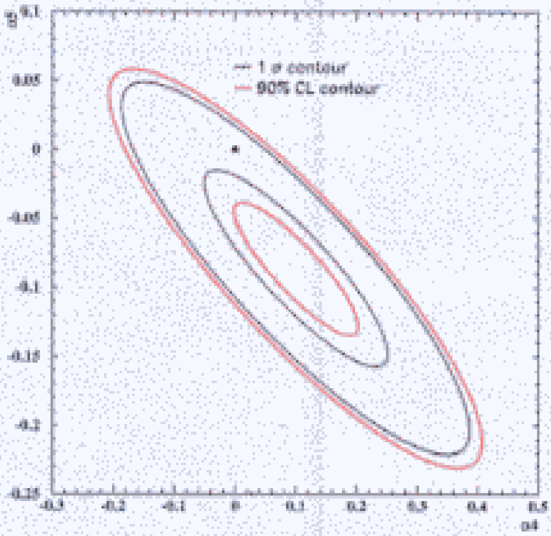


→ 2-dimensional BML fit to the couplings, using Z's θ and θ^* of decay fermions in boson frame (10x10 bins)

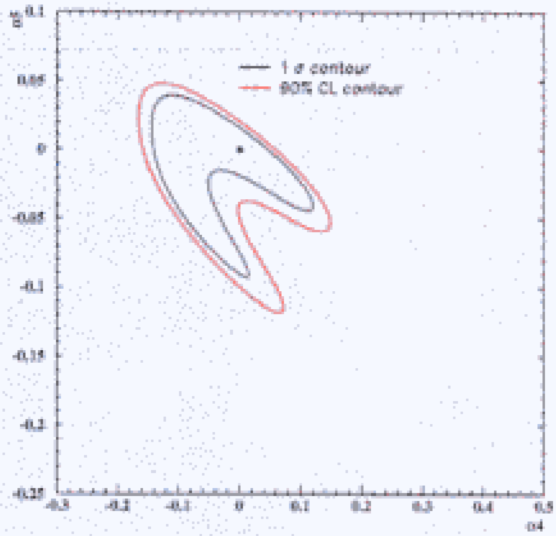
ZZ$\nu\nu$ fits

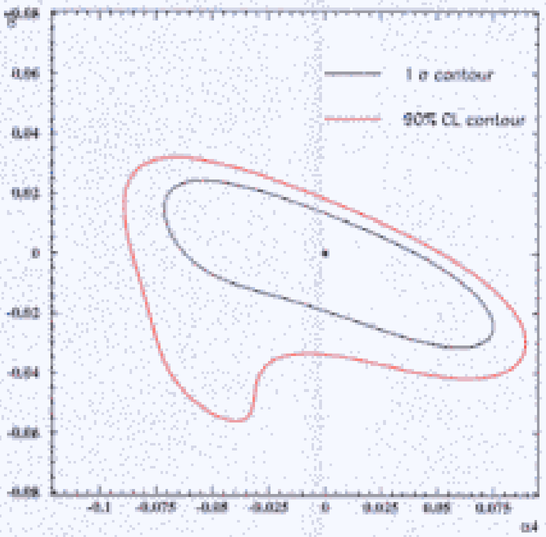
Effects of the angular distributions on the fit

EVENT RATE



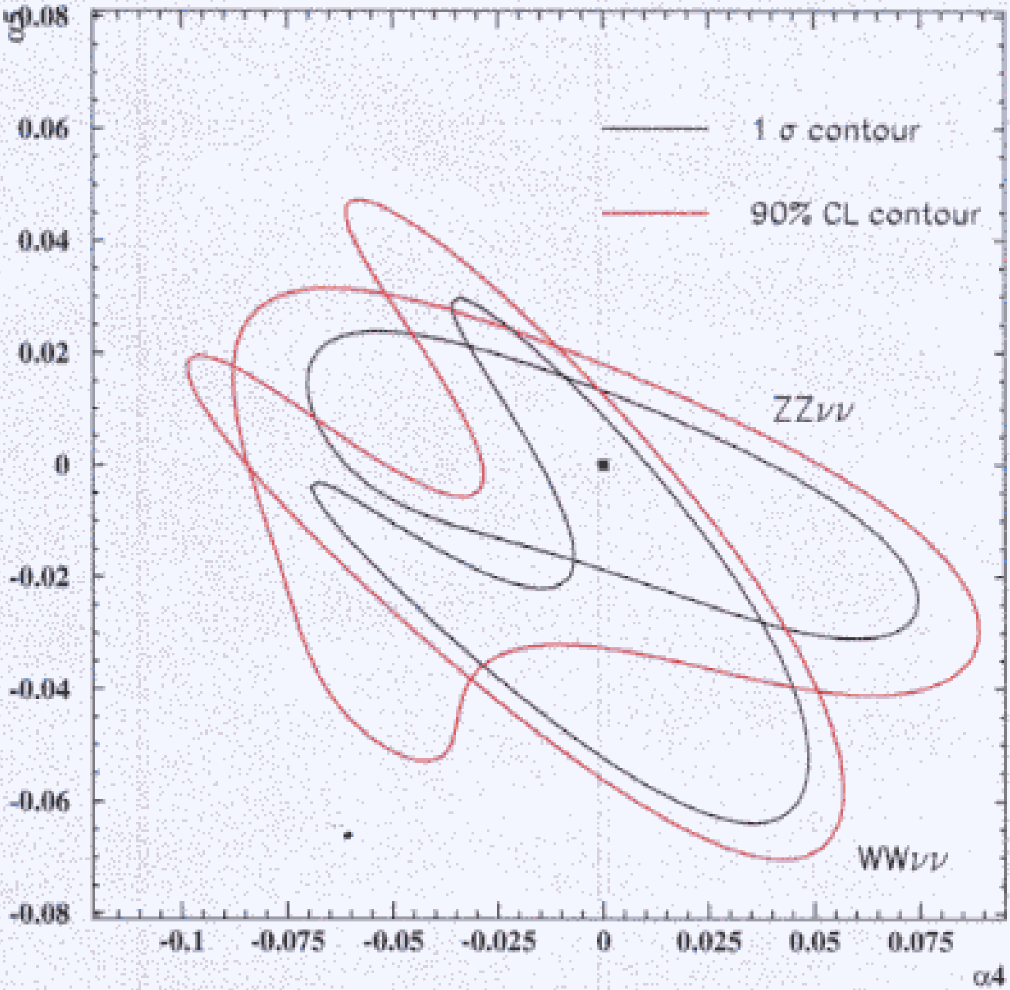
EV. RATE + Z ANGLE





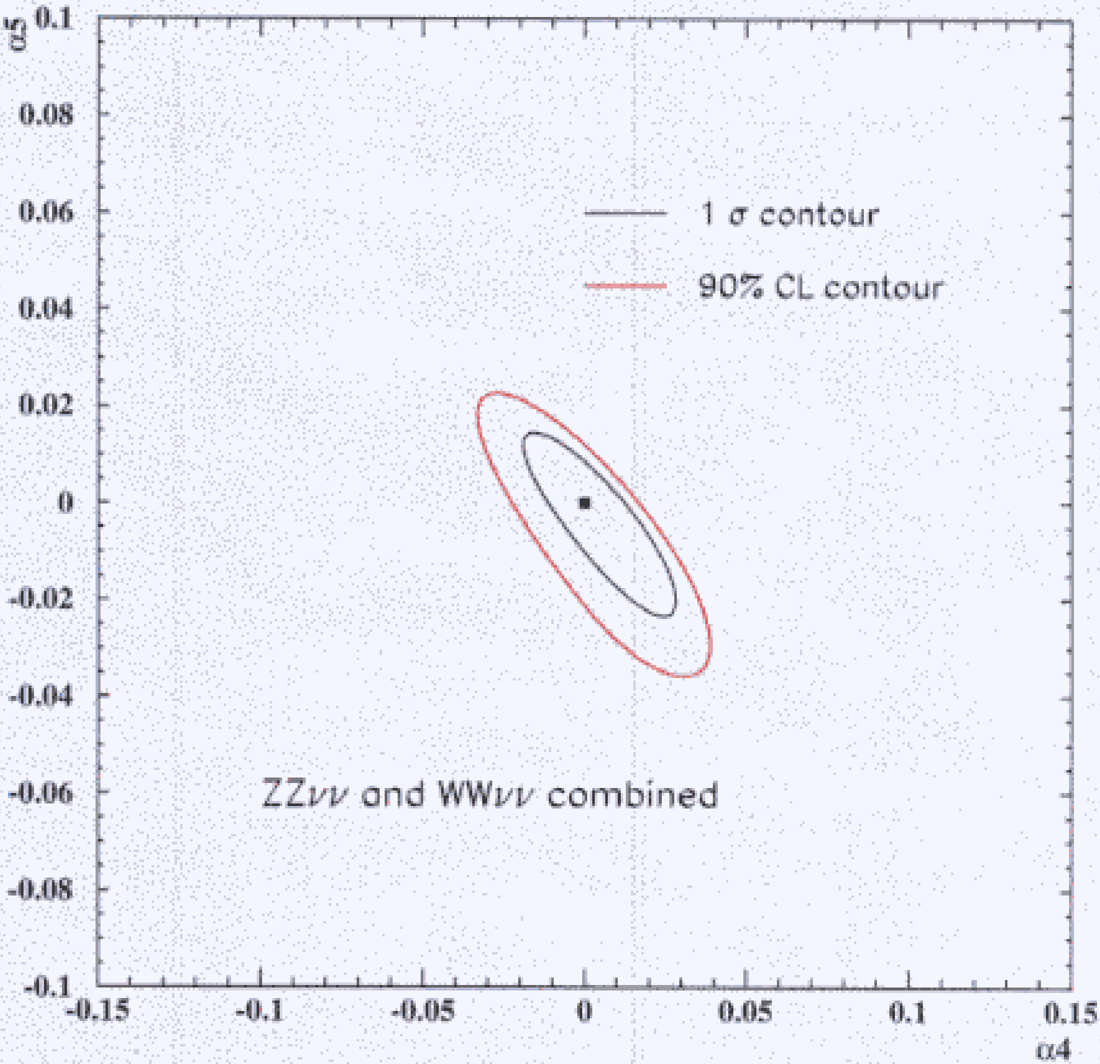
→ ALSO FERMION

Comparison of WW$\nu\nu$ and ZZ$\nu\nu$



→ expected limits on α_4 , α_5

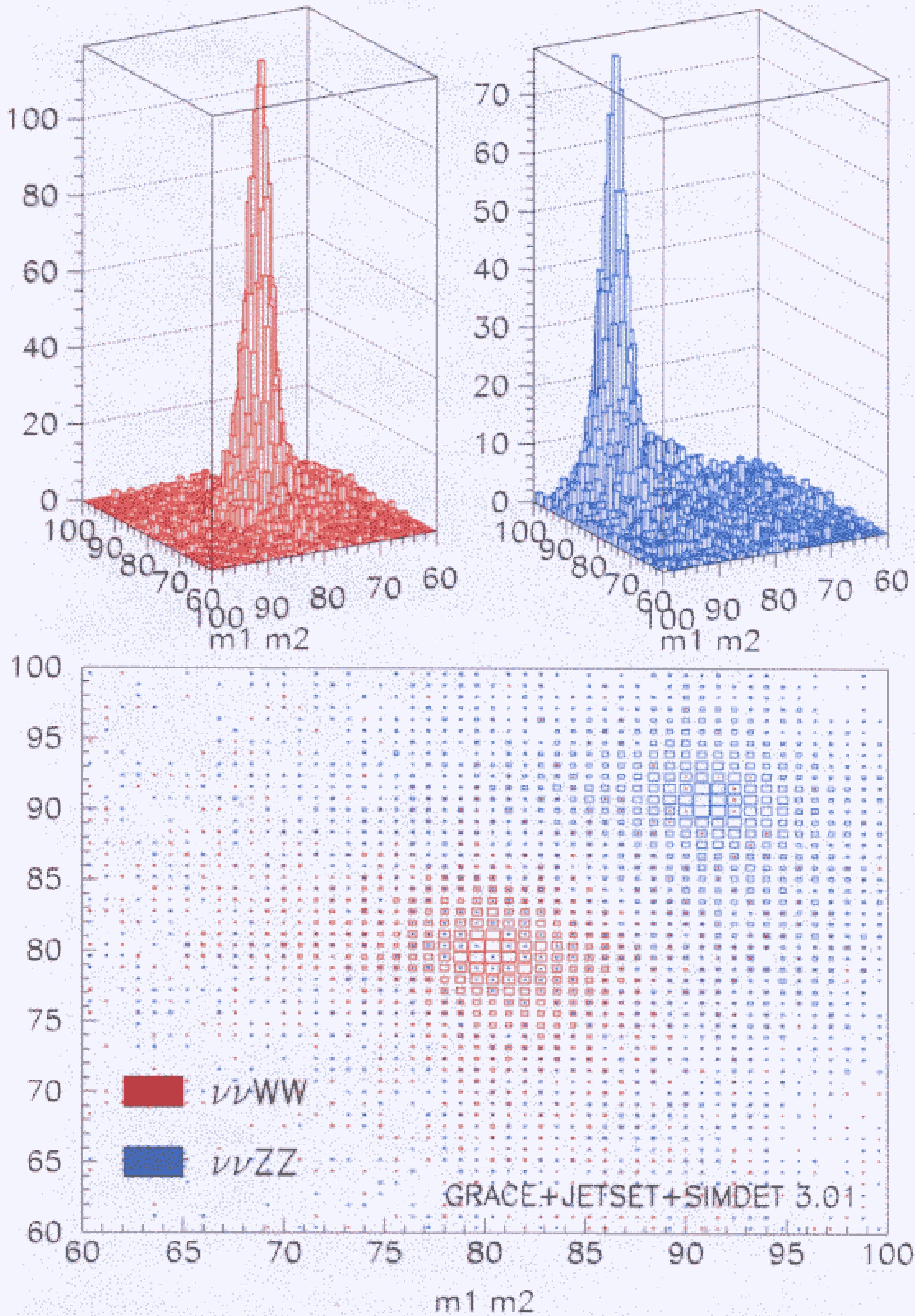
Combination of WW$\nu\nu$ and ZZ$\nu\nu$



the expected limits are $O(10^{-2})$

Conclusions

- A (still preliminary) study of WW scattering at TESLA has been done
- A complete 6-fermion generator (Whizard) has been interfaced with Simdet detector simulation and used in the analysis.
- The cross sections for WW$\nu\nu \rightarrow$ $qqqq\nu\nu$ and ZZ$\nu\nu$ $\rightarrow$ $qqqq\nu\nu$ can be measured with precisions of 2% and 3.2% (optimal mass resolution and hermeticity)
- A likelihood fit to the distributions of the bosons production angles and decay fermion angles has been performed, in order to derive the sensitivity to new 4-boson interactions.
- From the combination of the WW$\nu\nu$ and ZZ$\nu\nu$ channels the sensitivity to the parameters α_4, α_5 results O(10^{-1}).
- Possible improvements: add qqll$\nu\nu$ channels , $\sqrt{s}$ =1 TeV, polarization...



m1 m2
m1 m2
m1 m2
νν WW
νν ZZ
GRACE+JETSET+SIMDET 3.01