WW Scattering at Tesla

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- ✔ Setup of the study
- ✔ Generators
- ✔ $ee \to \nu\nu WW$
- ✔ $ee \to \nu\nu ZZ$
- ✔ Results
- ✔ Conclusions and plans

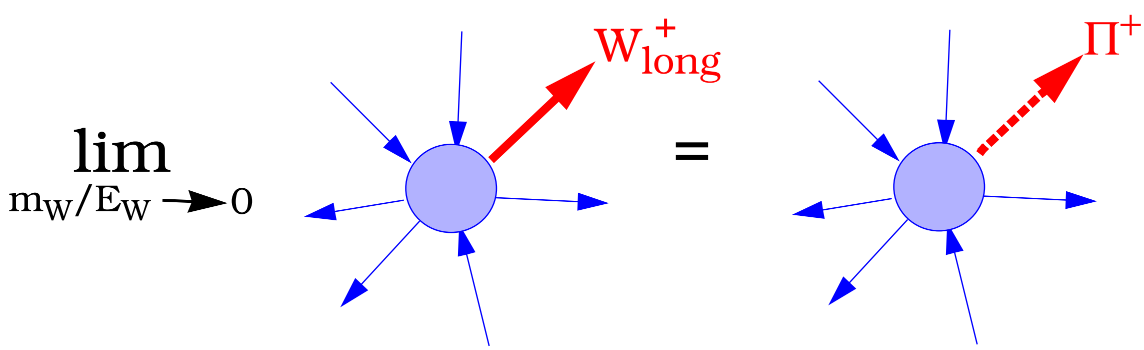
Motivations

- To give masses to W and Z, SU(2)xU(1) must be spontaneously broken. How?

SM: Scalar field with $VEV \neq 0$.
 $\Rightarrow$ 3 Goldstone bosons, absorbed to give longitudinal polarisation to W and Z $\Rightarrow$ masses.

SEWSB: No Higgs, new physics needed at the TeV scale to restore unitarity.
 $\Rightarrow$ Larger simmetry breaking down to SU(2)xU(1). providing the needed Goldstone bosons.
New strong interactions SU(2)xSU(2)xU(1). $[\pi^+,\pi^0,\pi^-]$

THE EQUIVALENCE THEOREM:



$\Rightarrow$ Scattering $W_l W_l$ gives important information about the underlying simmetry.

Formalism

- The EW interactions at low energies can be described by the EW chiral lagrangian:

⇒ effective field theory coupling the 3 Goldstones to fermions and bosons in a SU(2)xU(1) invariant way.

⇒ effective operators of increasing dimension.

- Besides the gauge interaction, the theory has only two $SU(2)_C$, 4-D interaction terms, with the following four-boson vertices:

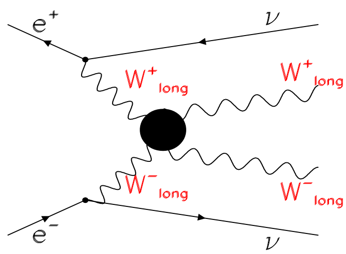
$$L_4 = \alpha_4 \left[\frac{g^4}{2} \left(W^+_\mu W^{\mu -} \right)^2 + \frac{g^4}{4 c_W^4} \left(Z_\mu Z^\mu \right)^2 + \frac{g^4}{2} W^+_\mu W^{\mu +} W^-_\nu W^{\nu -} + \right.$$
$$\left. + \frac{g^4}{c_W^2} W^+_\mu Z^\mu W^-_\nu Z^\nu \right]$$

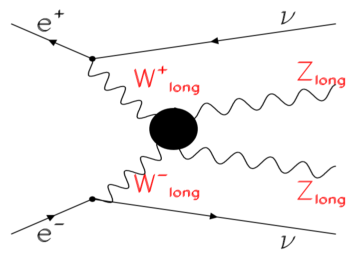
$$L_5 = \alpha_5 \left[g^4 \left(W^+_\mu W^{\mu -} \right)^2 + \frac{g^4}{c_W^2} W^+_\mu W^{\mu -} Z_\nu Z^\nu + \frac{g^4}{4 c_W^4} \left(Z_\mu Z^\mu \right)^2 \right]$$

- α_4 and α_5 (both 0 in the SM) are model dependent.

- What's the sensitivity to the αs that can be reached at TESLA?

Signals and (resonant) Backgrounds

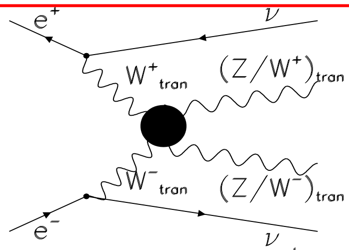




$e^+e^- \to \nu\nu W^+_l W^-_l$

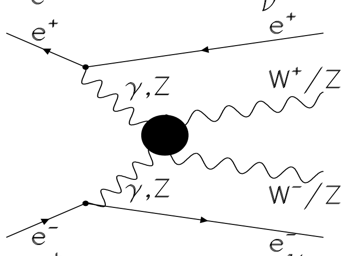
$e^+e^- \to \nu\nu Z_l Z_l$

6 fermions



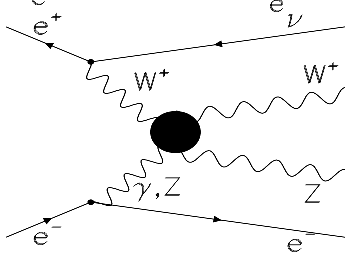
$e^+e^- \to \nu\nu W^+_t W^-_t$ — 56 diagrams

$e^+e^- \to \nu\nu Z_t Z_t$ — 55 diagrams



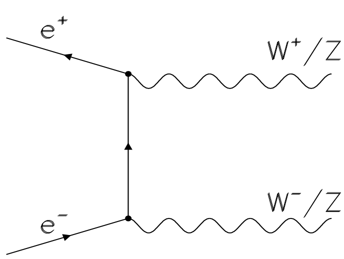
$e^+e^- \to e^+e^- W^+W^-$ — 98 diagrams

$e^+e^- \to e^+e^- Z Z$ — 42 diagrams



$e^+e^- \to e^+\nu W^- Z$ + c.c. — 160 diagrams

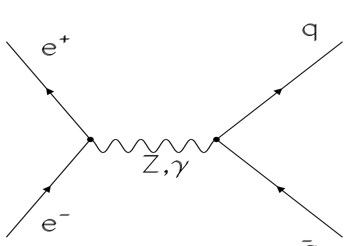
4 fermions



$e^+e^- \to W^+W^-$

$e^+e^- \to Z Z$

2 fermions

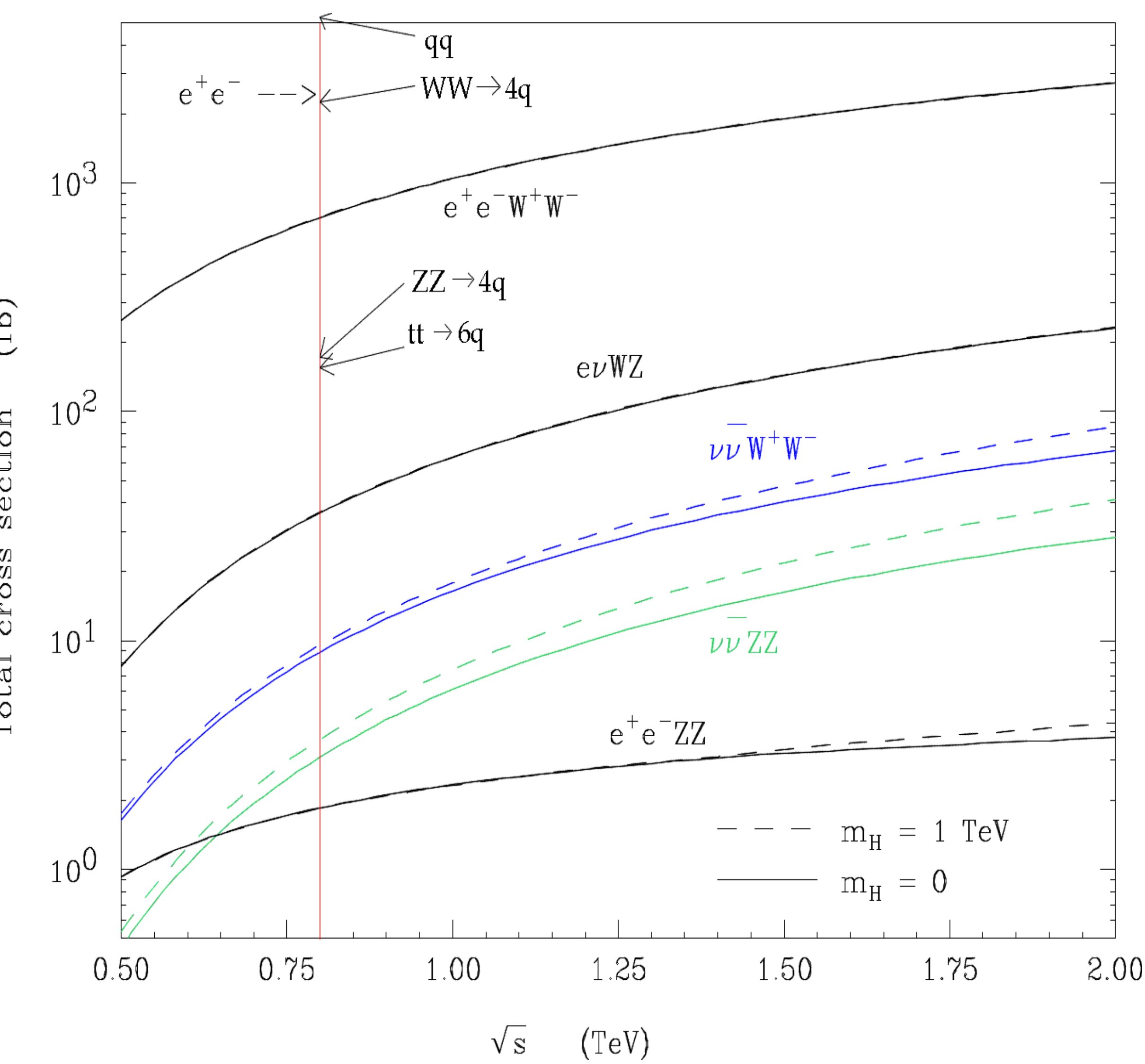


$e^+e^- \to q\bar{q}$

$t\bar{t}$ is a hidden 6f !

Cross Sections

- $\sqrt{s}$ =800 GeV and $\int \mathcal{L}$ dt=1000 fb^{-1} are assumed in this study. No beam polarisation yet.
- ISR included, beamstrahlung neglected.



Generators

- The final state of interest is $q\bar{q}q\bar{q}\nu\nu$.

$2f+4f+t\bar{t}$

- PYTHIA, but many alternatives on the market.

($ee\to q\bar{q}$, $ee\to t\bar{t}\to q\bar{q}q\bar{q}b\bar{b}, q\bar{q}l\nu b\bar{b}$, $ee\to WW,ZZ\to q\bar{q}q\bar{q}$)

6f

- Nothing usable and compete before Padova.

(SIXPHACT,SIXFAP,GRACE,PANDORA,PYTHIA)

- Nothing thought for WW scattering studies at that time.

- The situation is evolving now with WHiZard -W. Kilian-

(6f final state, with anomalous quartic couplins and e polarisation, and with the possibility of using various ME: MadGraph, CompHEP, O'Mega -T. Ohl-).

- Choice for this study:

  ✗ WHiZard for all $q\bar{q}q\bar{q}\nu\nu$ final states.
  ✗ GRACE+JETSET for $q\bar{q}q\bar{q}e\nu$ and $q\bar{q}q\bar{q}ee$ final states, through generation of $ee\to eeWW/e\nu WZ$.

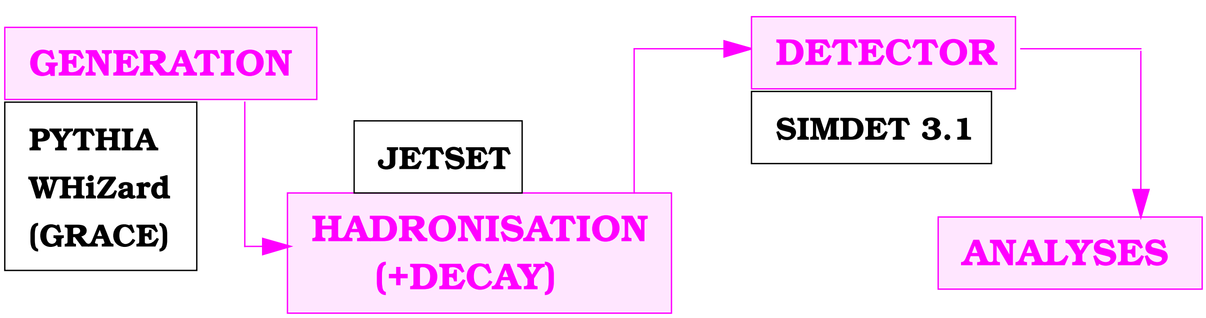
- To be updated by the use of WHiZard for all 6f final states (already started in $\nu\nu ZZ$).

Detector Setup

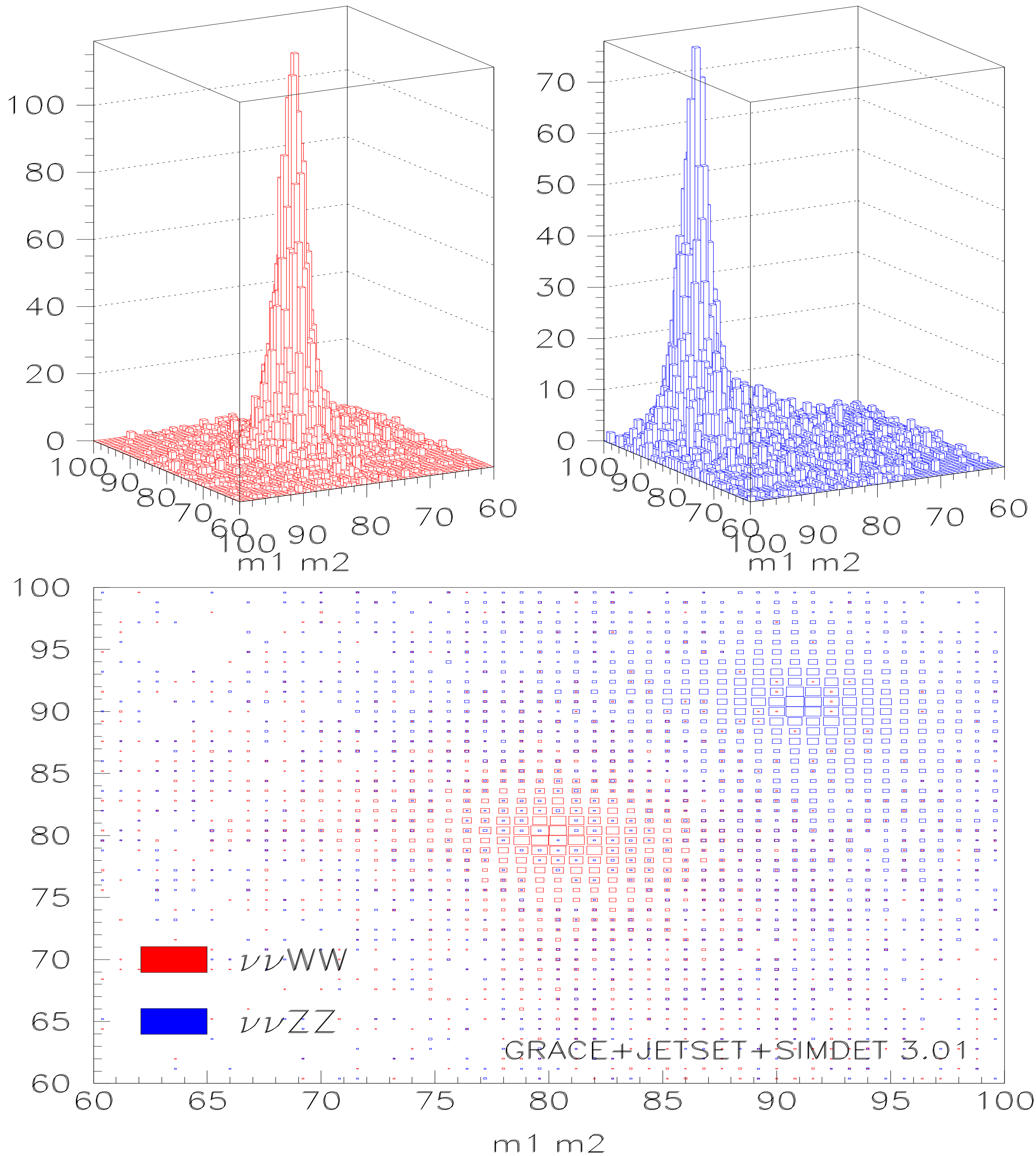
- SIMDET V3 is used (Pohl,Schreiber).
- Basic layout taken from CDR:

TRACKING:	**CCD 2 cm + FT + TPC** $\left\lvert\vec{B}\right\rvert = 3T$
	TPC coverage down to approx. 10°
	overall tracking coverage down to ~5°
CALORIMETRY:	**E.M.** $0.6\% + 10\%/\sqrt{E}$
	HAD $4\% + 40\%/\sqrt{E}$
	calorimetry acceptance down to ~5°
VERY FORWARD:	**instrumented mask from 5 to 83 mrad**
	no dead regions from 50 to 80 mrad
	LAT from 23.5 to 83.1 mrad

- Key points of these analyses:
  - ✗ hermeticity + forward coverage
    - ⇒ p_T determination, missing E, forward $e^{+/-}$
  - ✗ tracking, calorimetry
    - ⇒ excellent mass resolution, b tagging



Detector performance



- Mass resolution ~4%.

Preselection

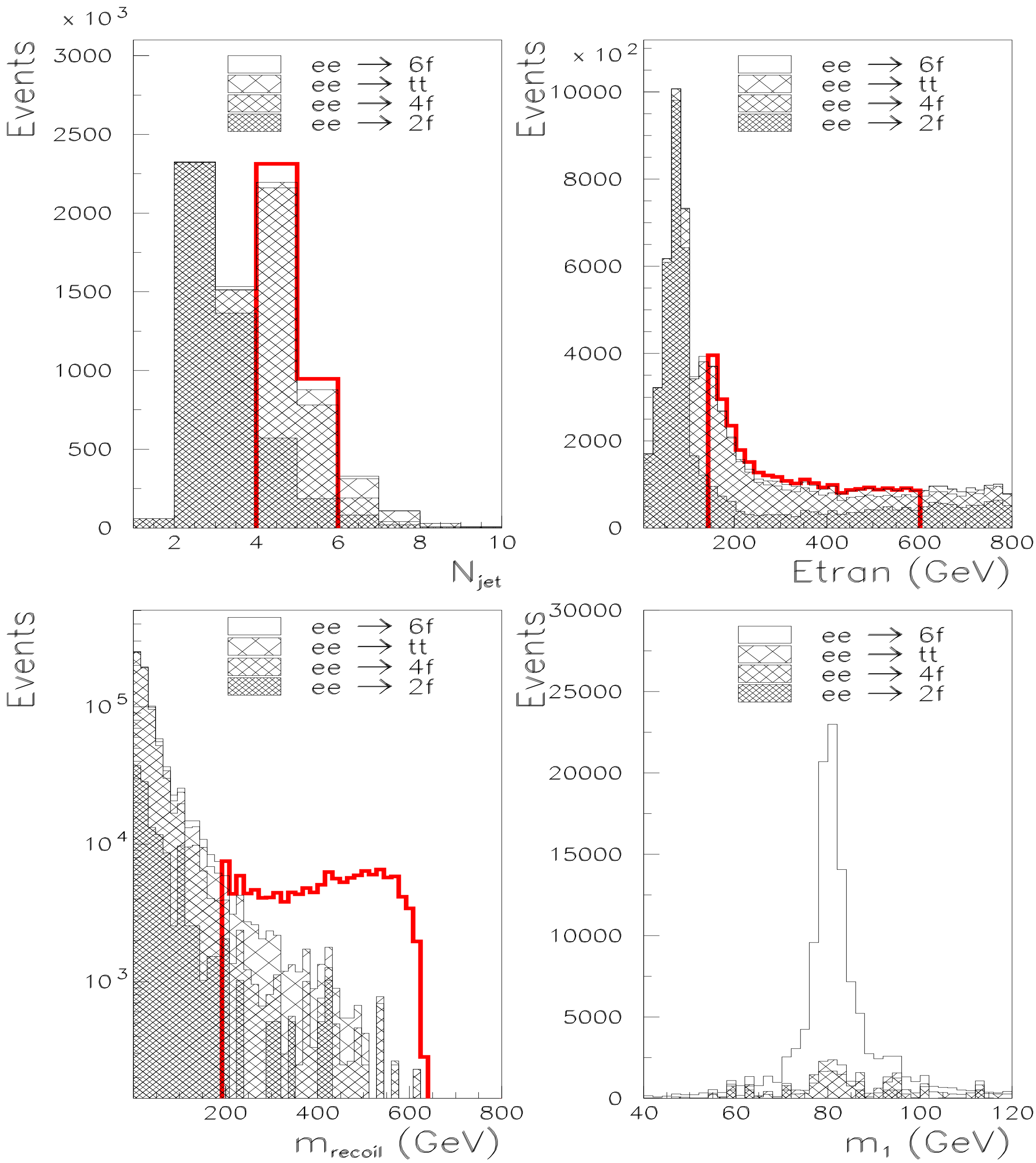
- Event handling:
  - ✗ the event is forced into 4 jets (if possible).
  - ✗ pairing chosen with a likelihood method (1C fitted mass, Δm, χ^2 of the fit) -ZZνν- or such that the value $|m_{ij}-m_W||m_{kl}-m_W|$ is minimum -WWνν-.

- Preselection (effective for 2+4f):

ZZνν	WWνν
$200<E_{mis}<650$ GeV	N_j(LUCLUS, d_{join}=7GeV)=4,5
$E_{track}^{max}<200$ GeV	$150<E_{tran}<600$ GeV
$\lvert\cos(\theta_{Pmis})\rvert<0.99$	$m_{rec}=[E_{mis}^2-p_{mis}^2]^{1/2}>200$ GeV
$\lvert\cos(\theta_{Emax})\rvert<0.99$	

- Isolated tracks **(leptonic bck, $t\bar{t}$, initial state bck)**:
  - ✗ reject events with one of the 4 most energetic tracks with less than 2 GeV ina 10^o cone -ZZνν-.
  - ✗ $N_{jet}^{ch}>2$ -WWνν-.

6f enhancement

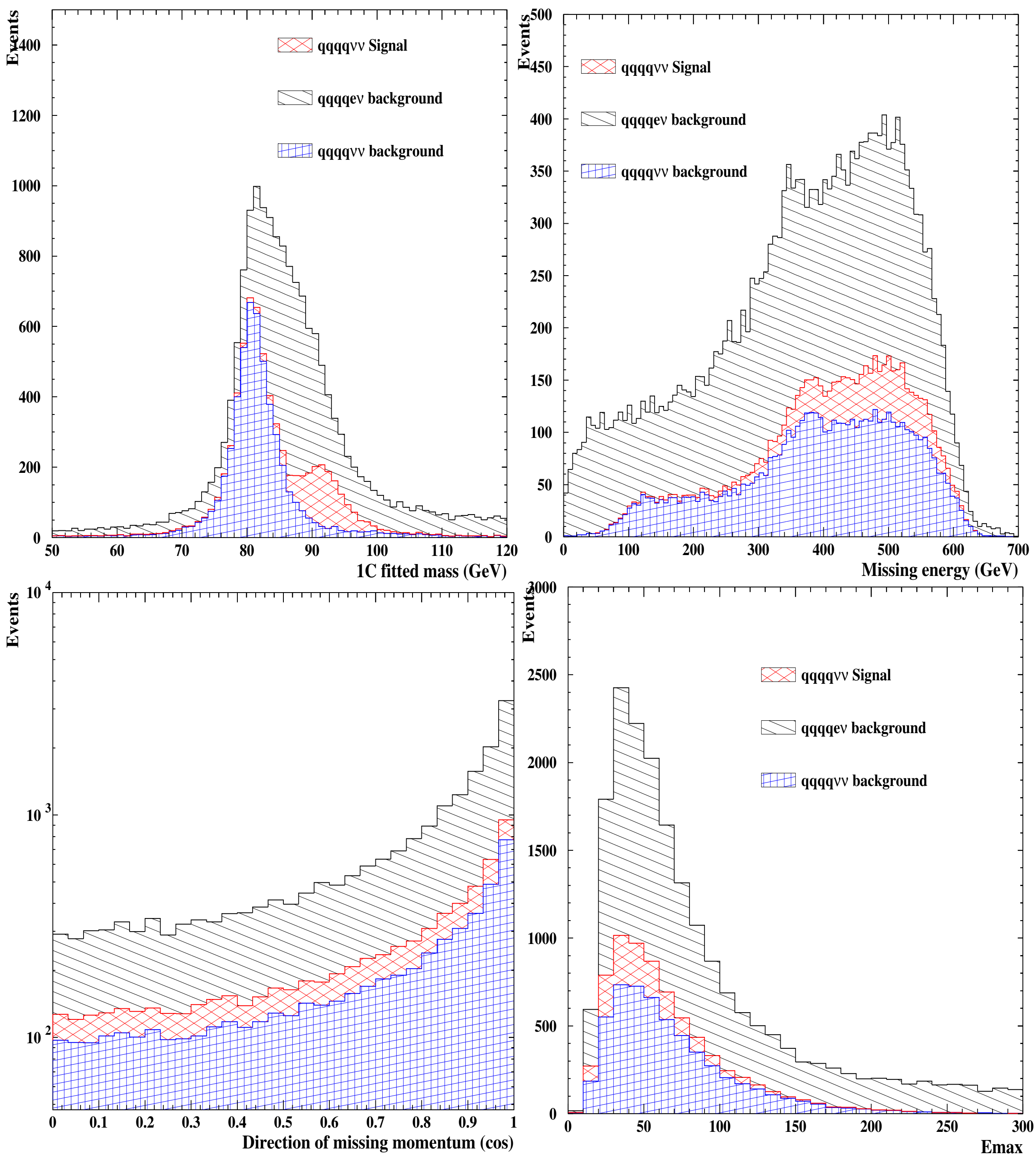


⇒ 2f+4f contamination reduced below 0.5%.

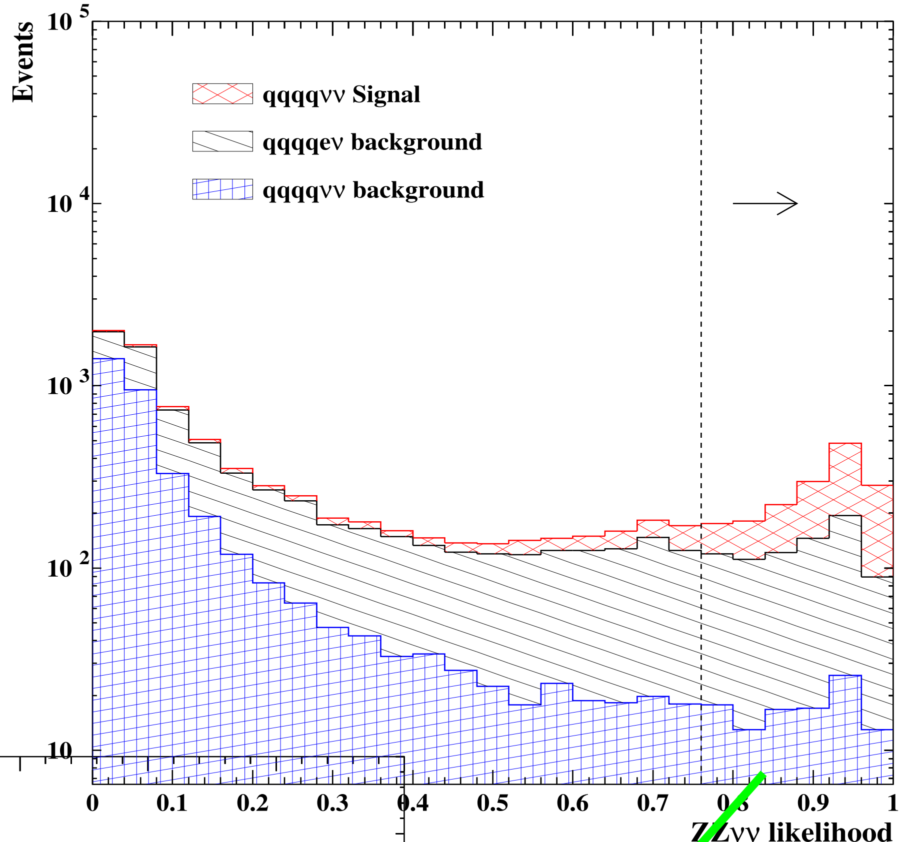
⇒ $t\bar{t}$ still very significative (usually neglected!).

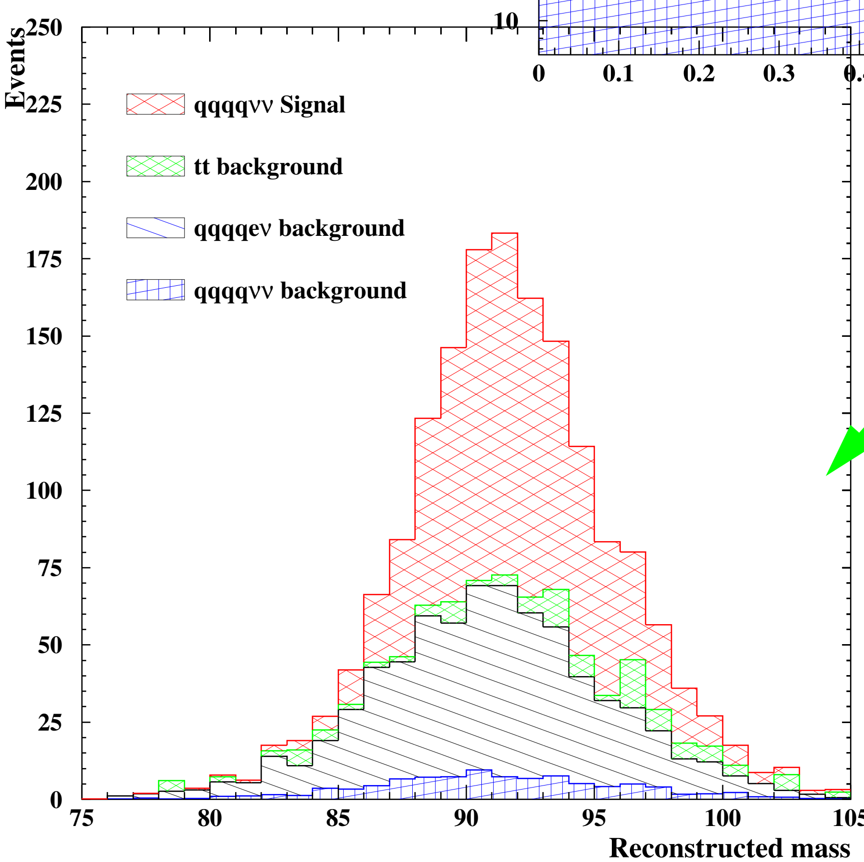
ZZνν selection

- Likelihood selection (E_{mis}, E^{max}_{track}, $|\cos(\theta_{Pmis})|$, $|\cos(\theta_{Emax})|$, 1C mass, Δm, χ^2 of the fit):



ZZνν likelihood results





WWνν selection

- Rejection of low p_T events (huge backgrounds):

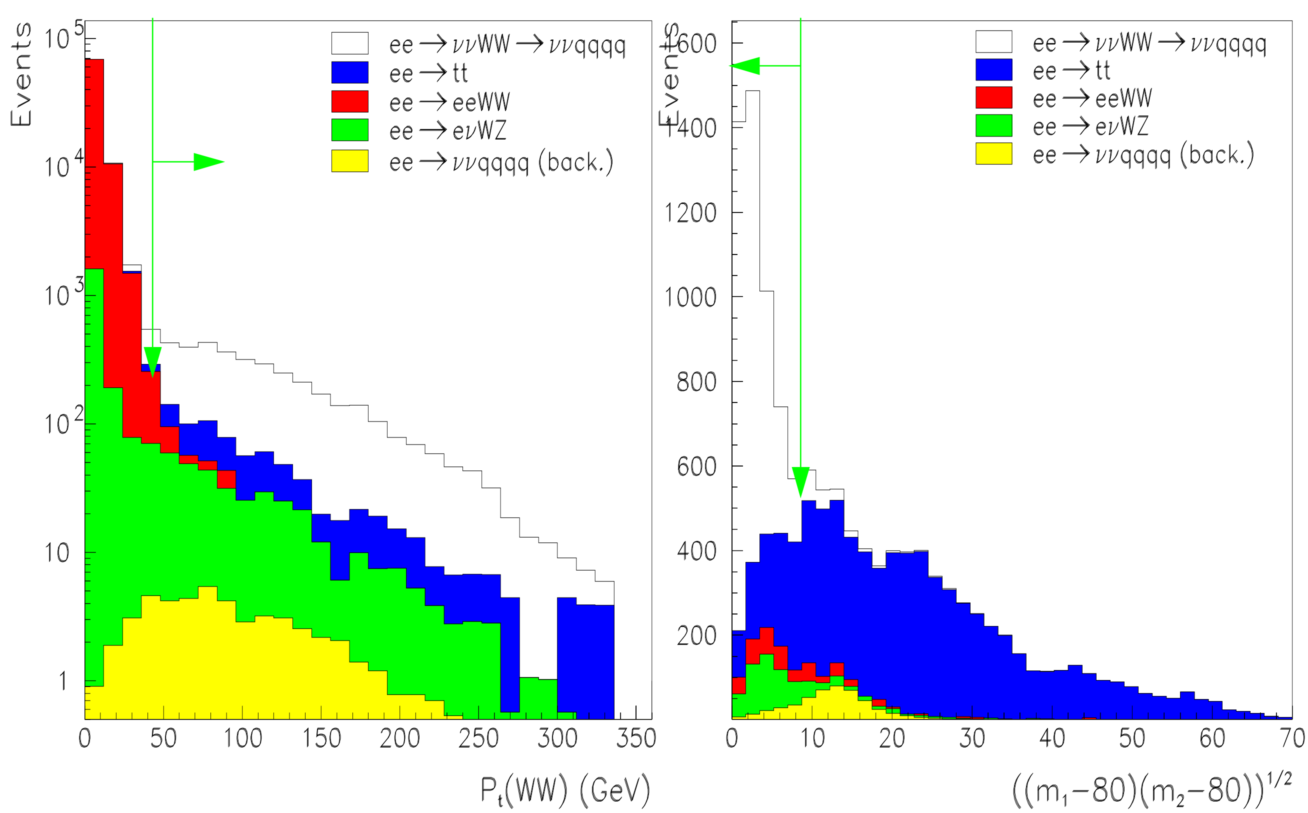
$$p_T(WW)=[(p_x^{W1}+p_x^{W2})^2+(p_y^{W1}+p_y^{W2})^2]^{1/2}>40\ \text{GeV}$$

(very effective for eeWW, eνWZ)

- Mass cuts:

$$60\ \text{GeV}<m_1,\ m_2<100\ \text{GeV}$$

$$|m_1-m_W|\,|m_2-m_W|>50\ \text{GeV}^2 \quad (t\bar{t},\ \nu\nu ZZ)$$

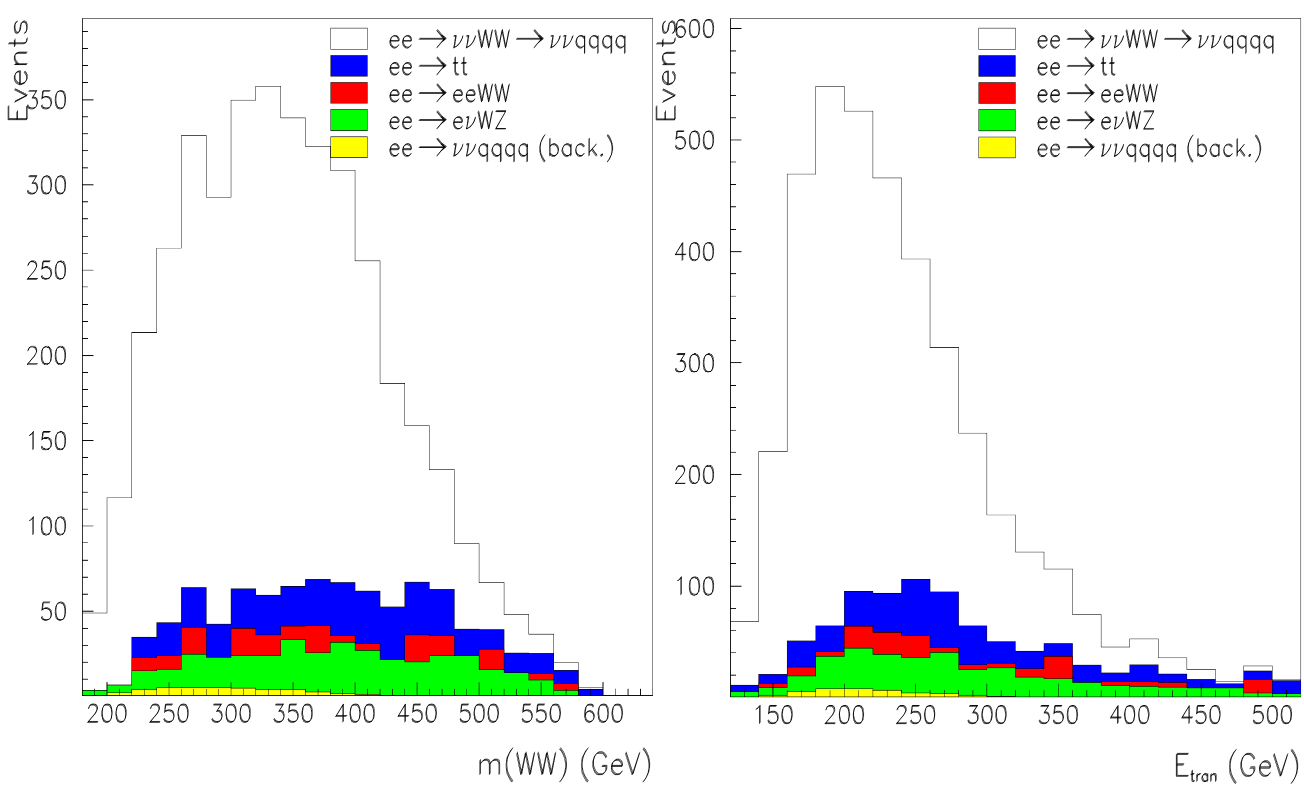


WW$\nu\nu$ results

- Still consistent contamination from tops:
  - ⇒ b tag, using Hawkings parametrisation of b tag efficiency as a function of E_{jet}.
  - ⇒ input ε_{btag}=80%, truth info are used to tag jets. Events with more than 1 tagged jet are rejected.
  - ⇒ effective for $t\bar{t}$, $\nu\nu$ZZ, eνWZ. Background reduced by ~2. Almost no effect on the signal.

- Like for $\nu\nu$ZZ, the major backgrounds come in the end from eνWZ and $t\bar{t}$.

DISTRIBUTIONS AFTER FULL SELECTION



Performance of the selections

Channel*	Exp. events** ($\nu\nu ZZ$)	Exp. events** ($\nu\nu WW$)
$ee \to \nu\nu ZZ$***	844 ± 10	
$ee \to \nu\nu WW$***		2550 ± 30
$ee \to \nu\nu q\bar{q}q\bar{q}$	88 ± 5	151 ± 5
$ee \to \nu e ZW$	570 ± 20	350 ± 10
$ee \to eeWW,ZZ$	negligible	130 ± 20
$ee \to t\bar{t}$	83 ± 5	400 ± 70
$ee \to WW,ZZ$	23 ± 10	negligible
$ee \to q\bar{q}$	negligible	negligible
efficiency***	0.522 ± 0.006	0.401 ± 0.004
purity***	52.3%	71.2%
$\Delta\sigma/\sigma$	3.2%	2.0%

(*) Only final states leading to four quarks at least are considered.

(**) A centre of mass energy of 800 GeV and an integrated luminosity of 1000 fb^{-1} are assumed.

(***) Double resonant regions of the signal are defined with the following cuts:

$\nu\nu ZZ$: 170 GeV $< m_1+m_2 <$ 195 GeV $|m_1-m_2| <$ 20 GeV
$\nu\nu WW$: 75 GeV $< m_1, m_2 <$ 85 GeV

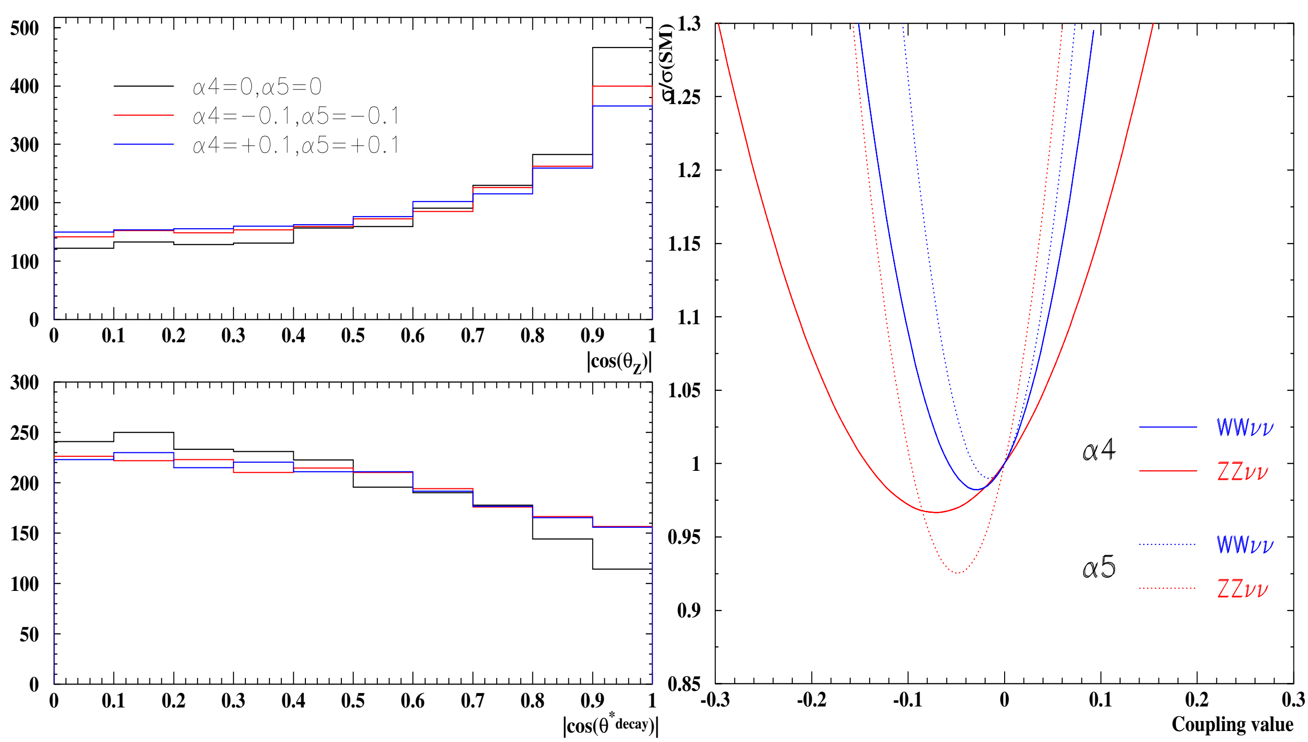
Sensitivity to the effective couplings

- Signatures of the new dinamics (α_4, $\alpha_5 \neq 0$):

  ✗ change in total WW $\rightarrow$ WW cross section.
  ✗ change in average boson polarisation.
  $\Rightarrow$ change in angular distributions.

- Interesting variables:

σ_{tot}, $d\sigma/d\theta_W$, $d\sigma/d\theta^*_q$



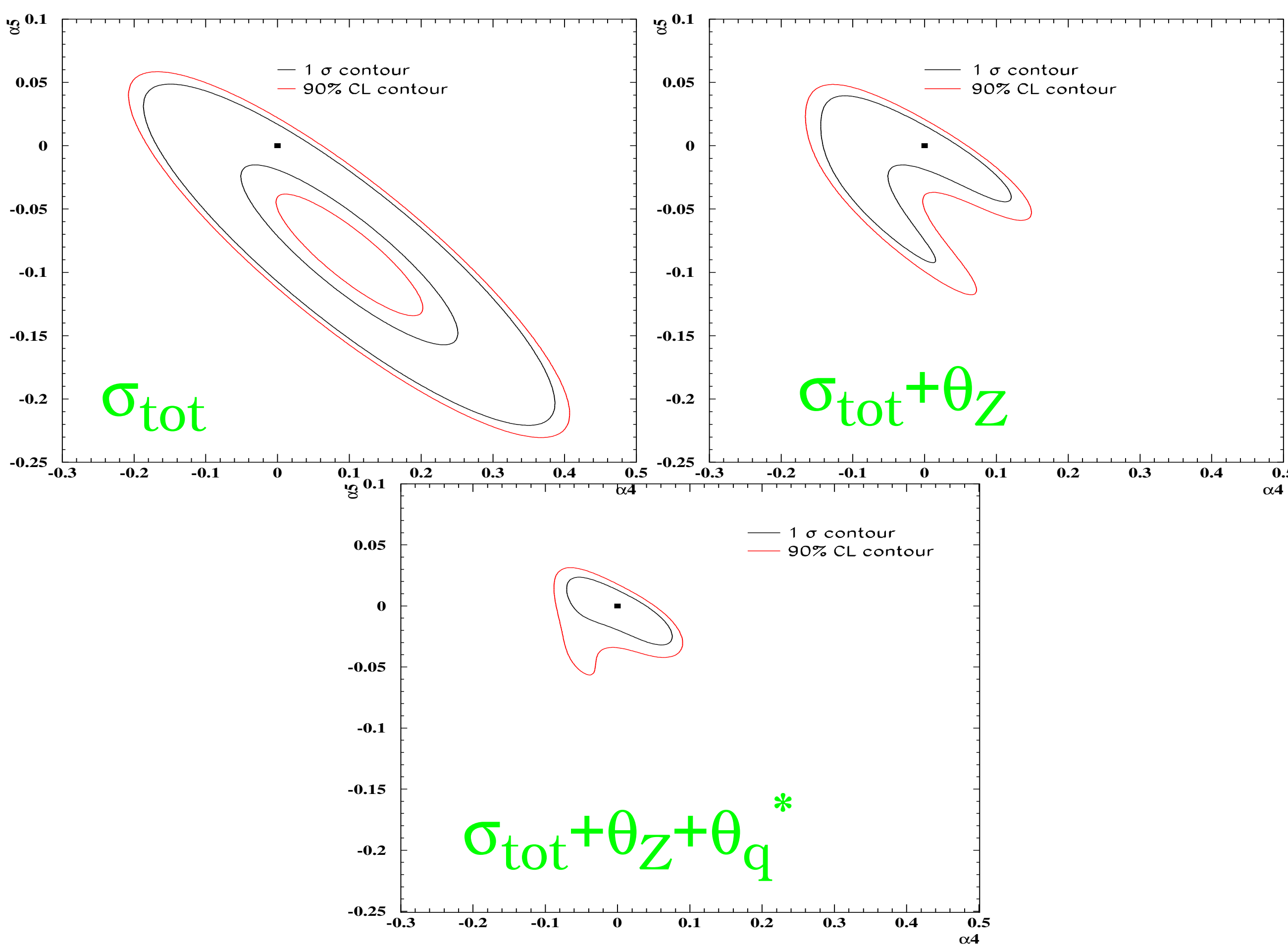
- Selection performance independent on α_4, α_5.

Experimental study

- Determine the expected $d^2\sigma/d\theta_W d\theta^*_q(\alpha_4, \alpha_5)$ after detector simulation and selection, with the proper inclusion of all backgrounds.
  - ✗ 10x10 bins distributions, function of α_4, α_5.
  - ✗ bin behaviour as a function of α_4, α_5 fitted with a paraboloid.

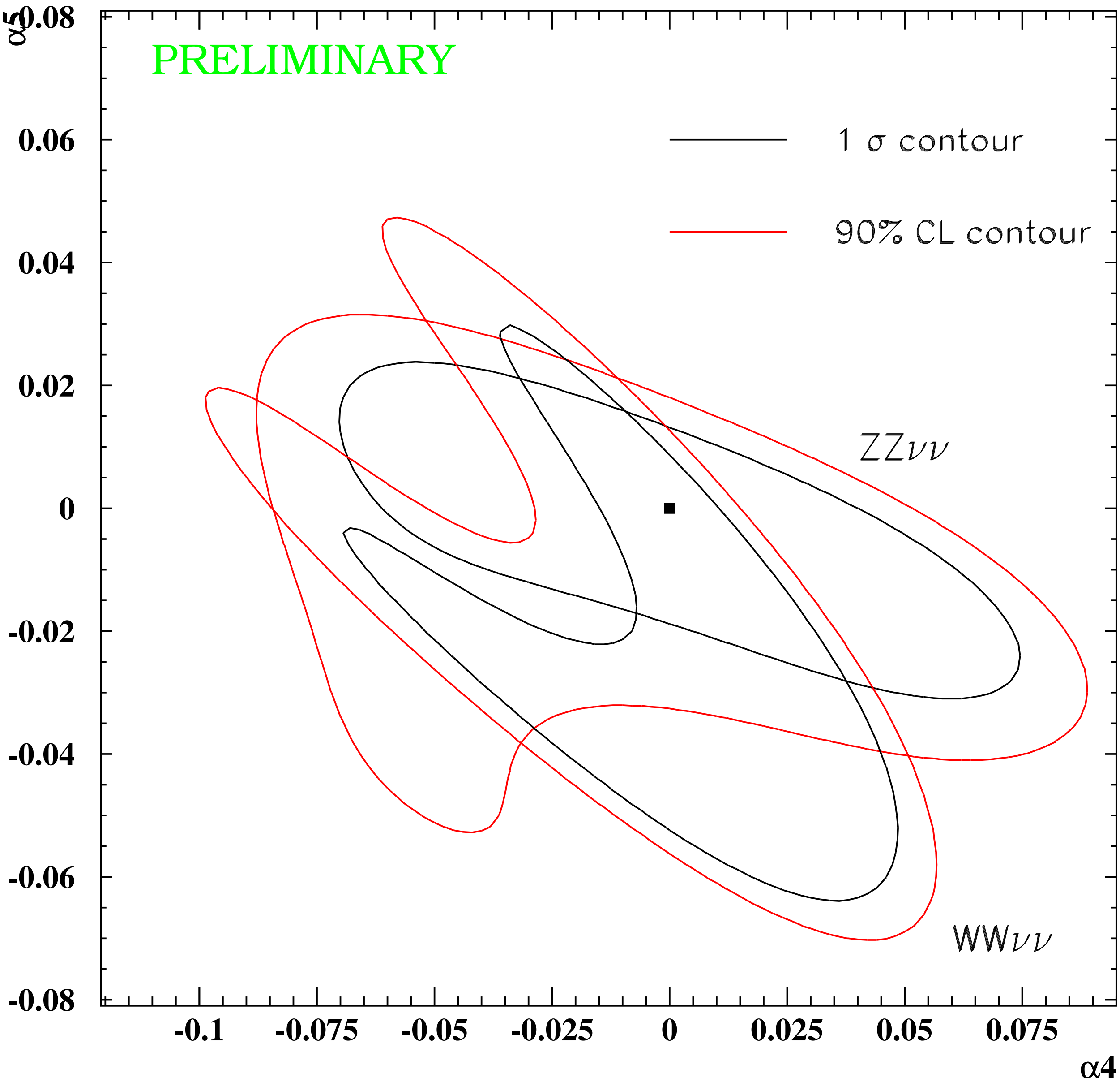
- 2D binned maximum likelihood from the bin probability $p_{bin}(N(\alpha_4, \alpha_5) | N(0,0))$.

IMPACT OF USING ANGULAR DISTRIBUTIONS (ννZZ):

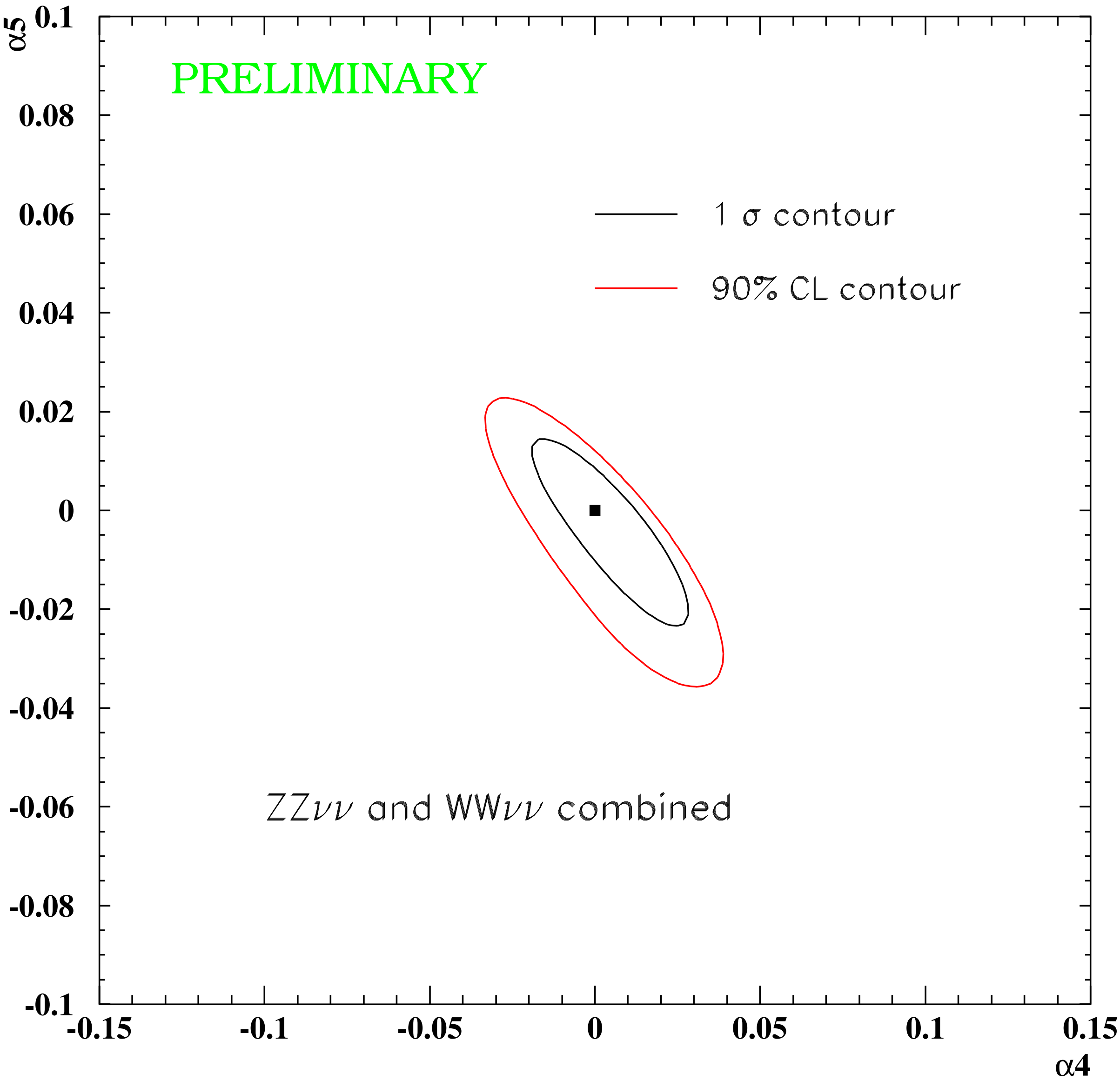


Likelihood outputs for ννZZ and ννWW

- Double minimum structures, more evident for ννWW.
  - ⇒ Effect depending upon the structure of $\sigma(\alpha_4, \alpha_5)$.



Combined Likelihood



- Expected limits are of the order of 10^{-2}.
- Not directly comparable with LHC...

Possible Improvements

- Inclusion of other final states ($\nu\nu q\bar{q}l\nu$, $\nu\nu q\bar{q}ll$).
  - ✗ different selection, cleaner signature.
- Use of other tools in the analyses.
  - ✗ lepton identification.
- Use even more information in the event.
  - ✗ W-pair invariant mass. One extra-dimension for our likelihood.
- Exploit initial state polarisation for S/N enhancement.
  - ✗ the signal is enhanced by $(1+P_+)(1+P_-)$.
  - ✗ eνWZ is enhanced by $1+(P_++P_-)/2$. The other backgrounds are not modified.

    $\Rightarrow$ polarisation of both electrons and positrons is important.

PLANS FOR A NEAR FUTURE (in time for TDR?):

- Redo everything including IS polarisation, assuming 80%e^-/40%e^+.
- Use WHiZard as unique 6f generator.
- Fit m(WW) together with the angular distributions.

Conclusions

- TESLA sensitivity to SEWSB through WW scattering was studied.
- New 6f generators (WHiZard) were used for the simulation of the signal. Backgrounds will follow.
- The current layout of TESLA allows excellent hermeticity and mass resolution, essential ingredients for ννWW analyses.
- The event selections of ννWW and ννZZ lead to errors on the total cross section of 2% and 3.2%. Major backgrounds coming from eνWZ and $t\bar{t}$!.
- The sensitivity to the α parameters was studied with likelihood fits which use angular informations of the bosons and the fermions.
- From the combinations of ννWW, ννZZ, a sensitivity to α_4, α_5 of $\sim 10^{-2}$ can be reached at 800 GeV and assuming 1000 fb-1.
- Room for improvements (polarisation, other channels...)
- Work still in progress to reach our best results in time for the TDR.