WW scattering at 1000 GeV

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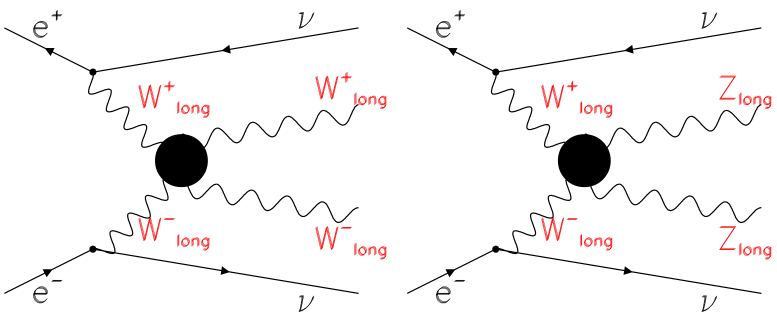
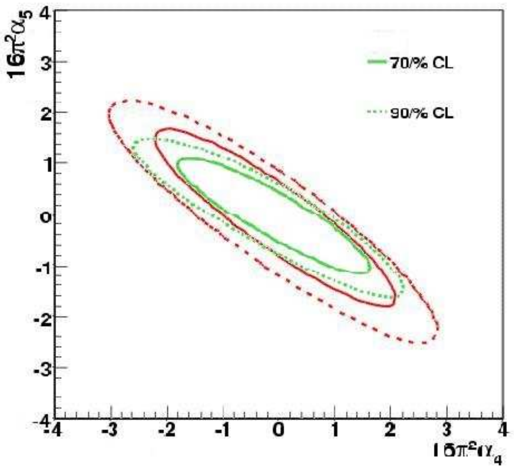
- **WW scattering**



- $W \longrightarrow q\bar{q}$; $Z \longrightarrow q\bar{q}$

- **anomalous couplings α_4 & α_5**



WW scattering

- W_LW_L scattering violates perturbative unitarity at $\sqrt{s} \sim$ 1.2 TeV. To restore unitarity
  - Light Higgs boson: weakly interacting model
    - SM + extensions
  - No light Higgs boson: strongly interacting model
    - model is non-renormalizable $\Longrightarrow$ new physics at $\Lambda = 4\pi\nu = 3.1$ TeV

- WW scattering provides information on the electroweak symmetry breaking

- EW interactions at low energies can be described by EW Chiral Lagrangian
  - has operators of higher dimensions and introduce anomalous couplings

- For WW scattering, there are two 4D operators at SU(2)$_c$ conserving case
  $L_4 = \frac{\alpha_4}{16\pi^2}tr(V_\mu V_v)tr(V^\mu V^v)$ $\qquad L_5 = \frac{\alpha_5}{16\pi^2}tr(V_\mu V^\mu)tr(V_v V^v)$

  anomalous couplings α_4 & α_5 are related to the scale of new physics. α_4 & α_5 are zero in the SM, and are model dependent

MC data samples @ 1000 GeV

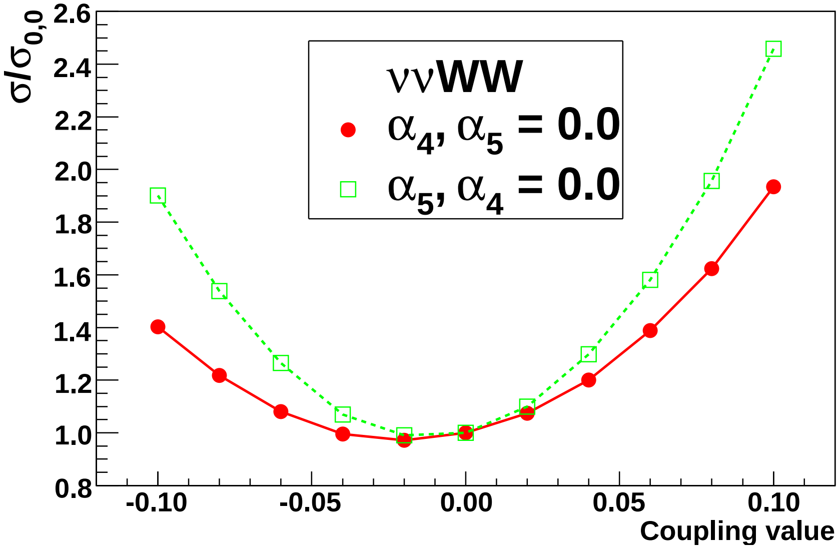
- $\sqrt{s} = $ **1000 GeV; polarization RL 30% 80%; with ISR and beamstrahlung**

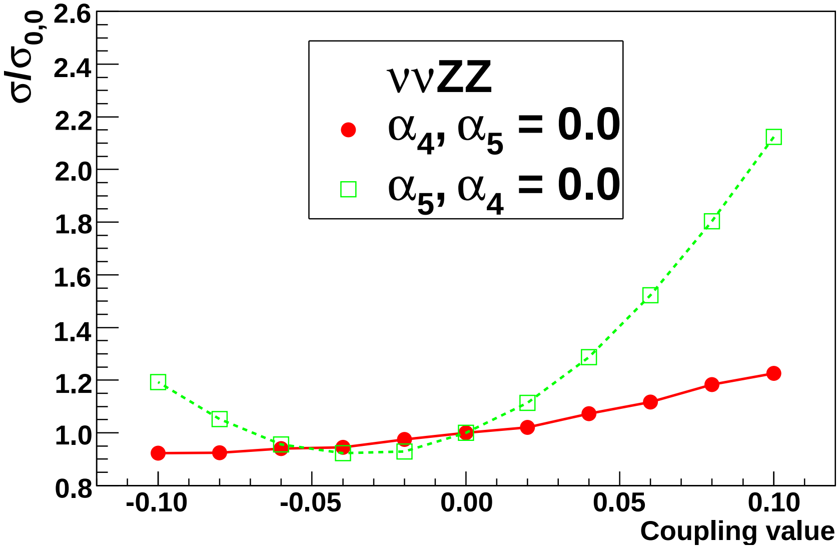
Channel	$\sigma_{1000GeV}$ (fb)	event number	Generator
$\nu_e\bar{\nu}_e\mathrm{WW} \longrightarrow \nu_e\bar{\nu}_e q\bar{q}q\bar{q}$	14.646	14646	Whizard 1.90
$\nu_e\bar{\nu}_e\mathrm{ZZ} \longrightarrow \nu_e\bar{\nu}_e q\bar{q}q\bar{q}$	6.816	6816	Whizard 1.90
$\nu_e\bar{\nu}_e q\bar{q}q\bar{q}$ (background)	6.924	6942	Whizard 1.90
$e\nu_e\mathrm{WZ} \longrightarrow e\nu_e q\bar{q}q\bar{q}$	43.104	43104	Whizard 1.90
$ee\mathrm{WW/ZZ} \longrightarrow eeq\bar{q}q\bar{q}$	109.224	109224	Whizard 1.90
$t\bar{t} \longrightarrow \mathrm{X}$	204.48	51100	PYTHIA

- **LDCPrime_02Sc @ Mokka06-06-p03: (SAME binary package for DESY mass production)**
- **event reconstruction ilcinstall v01-04**
- $t\bar{t}$ **sample at 1000GeV: no polarization and beamstrahlung**

WW/ZZ signal

- **definition of WW/ZZ Signal events**
  - $147.0 < m_{qq}^1 + m_{qq}^2 < 171.0$ **GeV: WW**
  - $171.0 < m_{qq}^1 + m_{qq}^2 < 195.0$ **GeV: ZZ**
  - $|m_{qq}^1 - m_{qq}^2| <= 20.0$ **GeV**
  - $m_{\nu_e \bar{\nu}_e} >= 100.0$ **GeV**





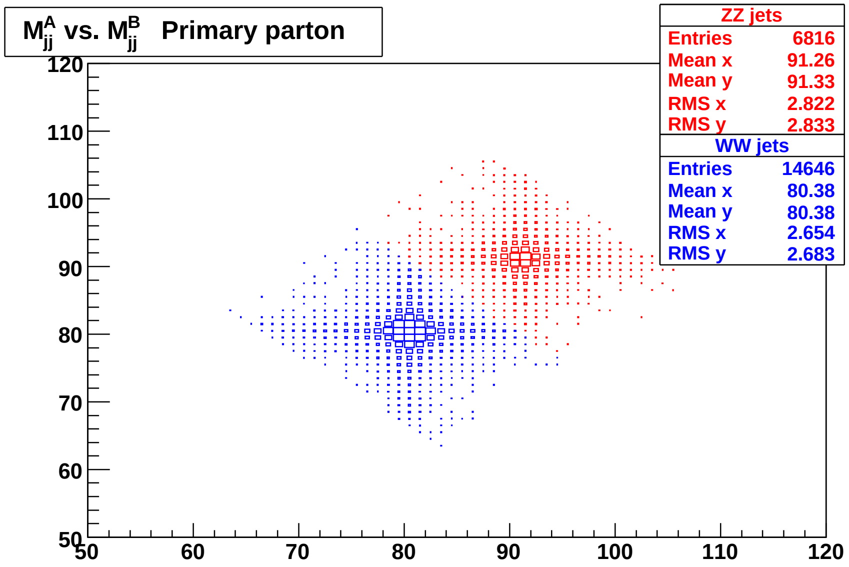
- α_5 **is more sensitive than** α_4

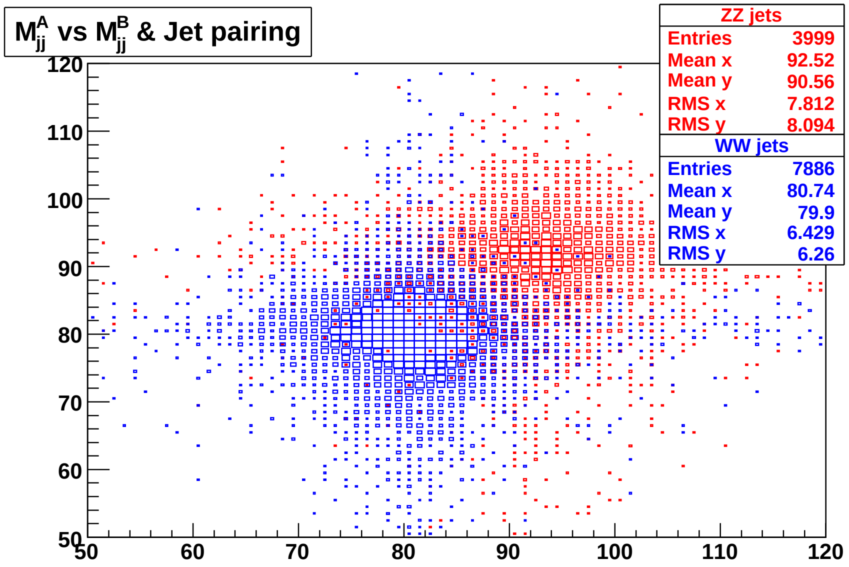
WW/ZZ event selection

- **We follow LC-PHSM-2001-038, and unify selection cuts for WW/ZZ**
- **Event selection: select events with a significant fraction of neutrinos**
  - **Recoil mass: $M_{recoil} >= 250.0$ GeV**
  - **Total transverse momentum: $P_T >= 40$ GeV**
  - **Total transverse energy: $E_T >= 150$ GeV**
  - **Total missing momentum and most energetic track: $|\cos\theta| < 0.99$**
  - **Energy in a 10^o cone of most energy track: $E_{cone} >= 2.0$ GeV**
  - **Force events to have 4 jets, and LOG10$(1/Y_{34}) < 3.5$**
    - **Jet selection: $E_{jet} > 10.0$ GeV; particles inside jets $>= 3$ and charged particles inside jets $>= 2$**
- **WW/ZZ jet pairing**
  - **WW: minimum $|M_{j_1j_2} - M_W| * |M_{j_3j_4} - M_W|$**
  - **ZZ: minimum $|M_{j_1j_2} - M_Z| * |M_{j_3j_4} - M_Z|$**
- **WW/ZZ selection**
  - **WW: $60 < M_W < 88$ GeV**
  - **ZZ: $85 < M_Z < 100$ GeV**

WW/ZZ separation

- **WW/ZZ separation @ 1000 GeV for LDCPrime_02Sc detector model**
  - **WW/ZZ: SAME selection @ detector level; without W/Z mass cut**

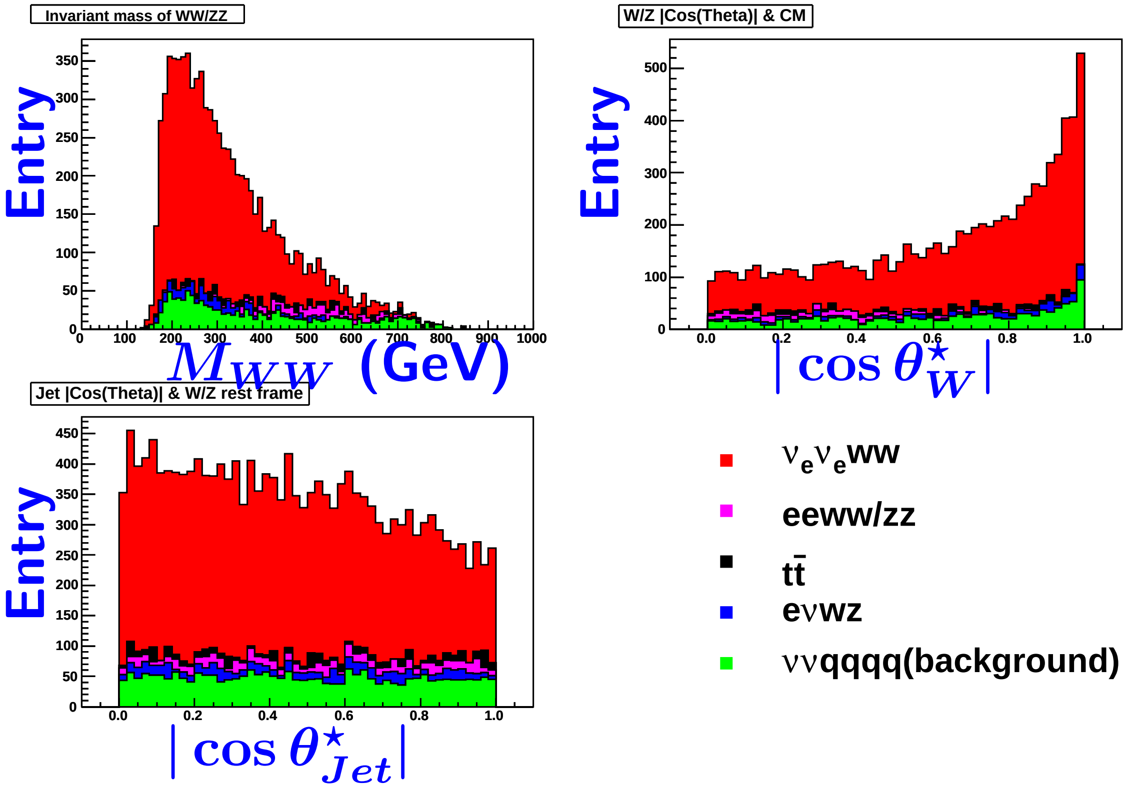




Binned maximum likelihood fit

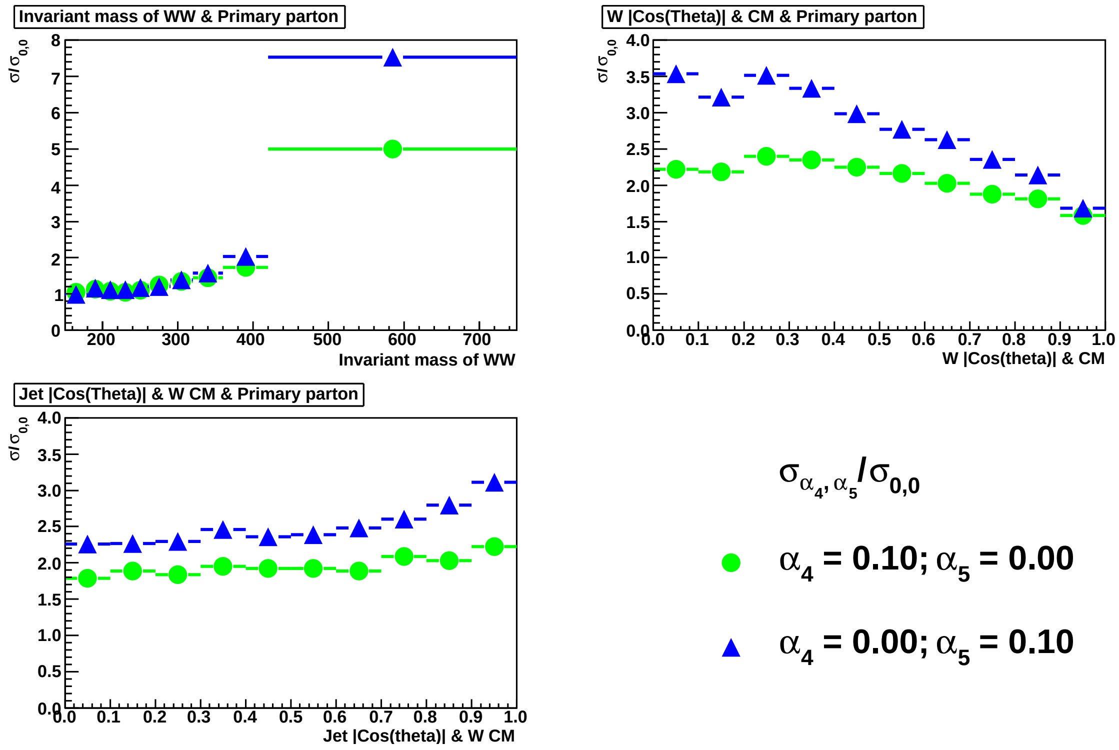
- **Fitting distributions at detector level**
  - **SM sample with (0.0, 0.0) as "data"**
  - **each bin** $p(n) = e^{-\lambda}\lambda^n/n!$
    - n: **observed number @ "data" sample and background event samples**
    - λ: **expected number;** $\lambda = m^{signal}(\alpha_4, \alpha_5) + m^{bcg1}(\alpha_4, \alpha_5) + m^{bcg2}$
  - $-\ln\mathcal{L} = -\sum \ln p(n_i) = -\sum n_i \ln\lambda_i + \sum\lambda_i + \sum\ln(n_i!)$
- $m^{signal}(\alpha_4, \alpha_5)$ **and** $m^{bcg1}(\alpha_4, \alpha_5)$
  - **Each MC event (ith event) is weighted by**
    $R_i(\alpha_4, \alpha_5) = 1.0 + A_i\alpha_4 + B_i\alpha_4^2 + C_i\alpha_5 + D_i\alpha_5^2 + E_i\alpha_4\alpha_5$
    R_i **is the ratio of matrix element to SM sample with (0.0, 0.0)**
  - **Decide** A_i, B_i, C_i, D_i, E_i **@ each event**
    - **Using generated SM sample with (0.0, 0.0), we recalculate matrix elements for each events with 20 sets of** (α_4, α_5) **value, and decide** $(A_i, B_i, C_i, D_i, E_i)$ **by TMinuit fitting to 20** R **for ith event.**
  - **Count selected events with** $R_i(\alpha_4, \alpha_5) \rightarrow m^{signal}(\alpha_4, \alpha_5)$
- **Selection performance independent of** (α_4, α_5)

Fit distributions



- $|\cos\theta^\star_W|$: W/Z boson polar angle in the reference frame of WW/ZZ pair
- $|\cos\theta^\star_{Jet}|$: jet polar angle in the reference frame of each boson W/Z
- M_{WW}: invariant mass of WW/ZZ pair

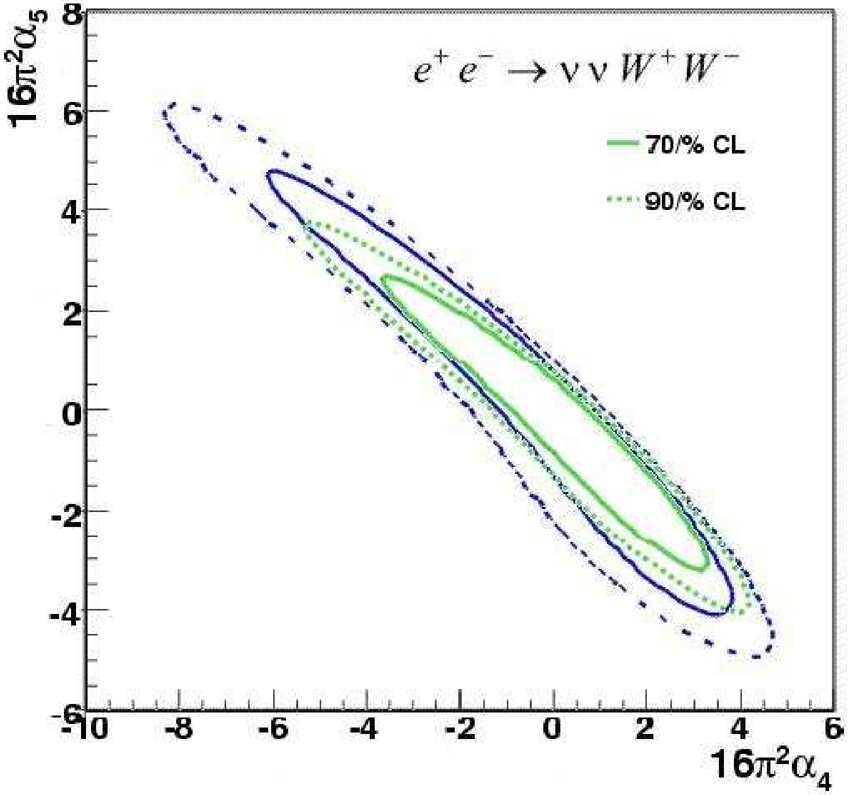
Fit distributions

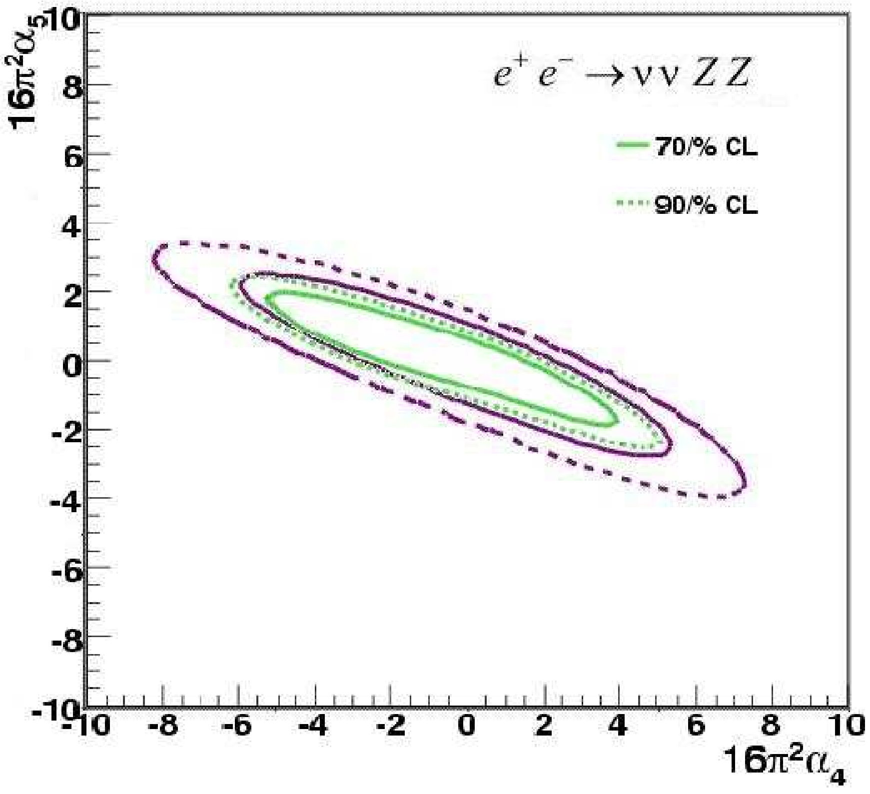


- **sensitive (α_4, α_5) at high M_{WW}, $|\cos\theta^\star_W|$ and $|\cos\theta^\star_{Jet}|$**

- **fit distributions: $d^2\sigma/(d|\cos\theta^\star_W|d|\cos\theta^\star_{Jet}|)$**

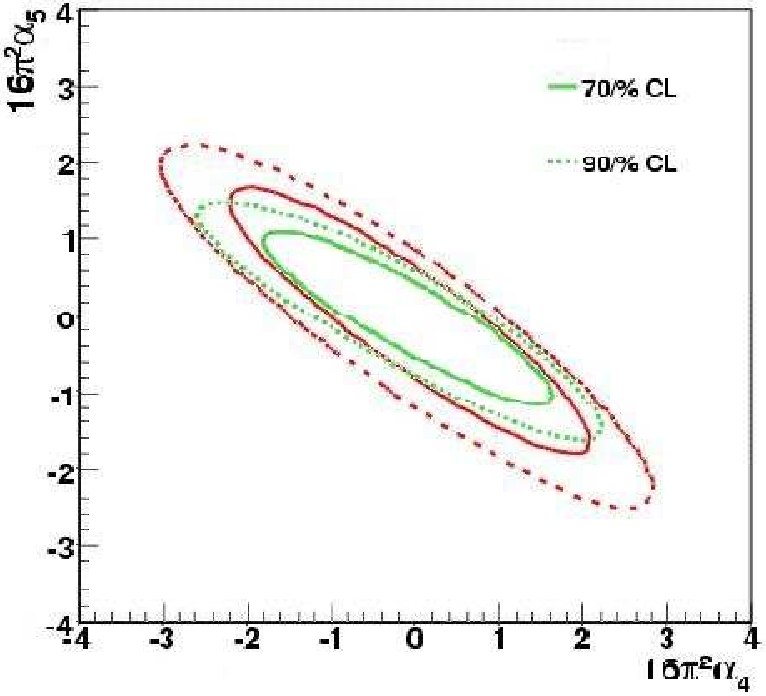
Likelihood from WW/ZZ





- **Green: full LDCPrime_02Sc; Others: TESLA fast simulation**
- **α_5 is more sensitive than α_4**

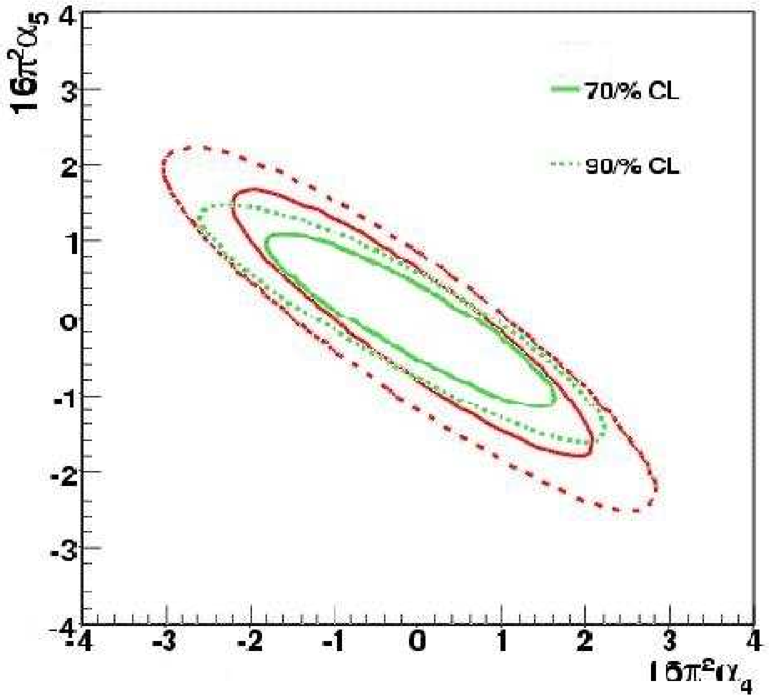
Likelihood from combined WW/ZZ



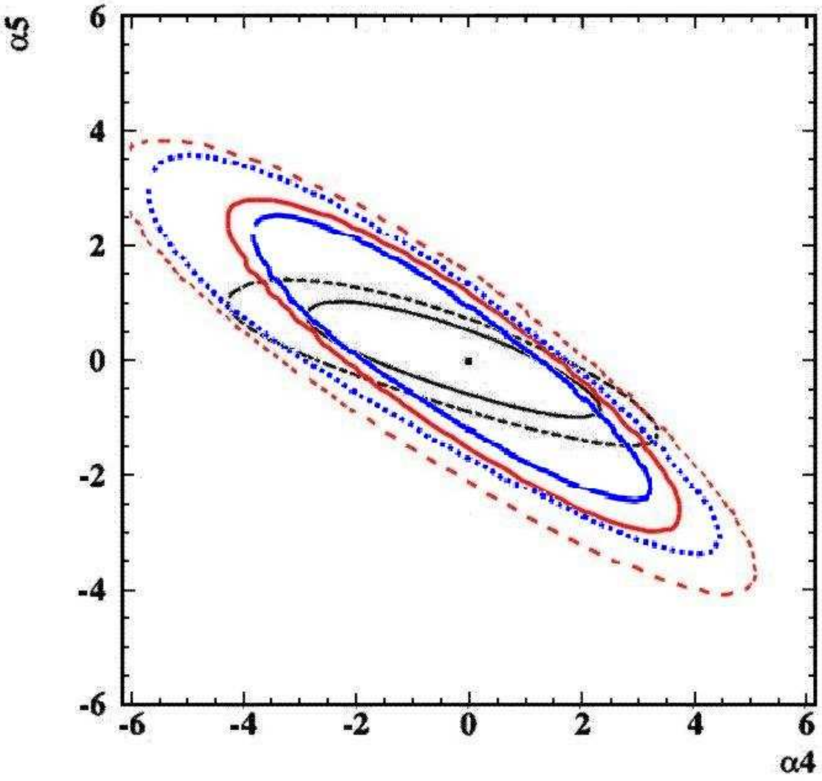
- **Green: LDCPrime_02Sc detector simulation; polarization: 80% electron; 30% positron**
- **Red: TESLA fast simulation; polarization: 80% electron; 30% positron**

Likelihood from combined WW/ZZ

- **at 1000 GeV**



- **at 800 GeV**



Summary

- **WW scattering provides information on the electroweak symmetry breaking, anomalous couplings α_4 & α_5 are related to the scale of new physics. $\Longrightarrow$ sensitivities of α_4 & α_5 at linear collider.**

- **we study WW scattering with LDCPrime_02Sc detector model, and extract α_4 & α_5, which are comparable with that of TESLA fast simulation.**

- **missing MC data samples: ongoing**
  - $t\bar{t} \longrightarrow \mathrm{X}$: **1000** fb^{-1}
  - $\nu_\mu \bar{\nu}_\mu \mathrm{WW/ZZ}$: **1000** fb^{-1}
  - $\nu_\tau \bar{\nu}_\tau \mathrm{WW/ZZ}$: **1000** fb^{-1}