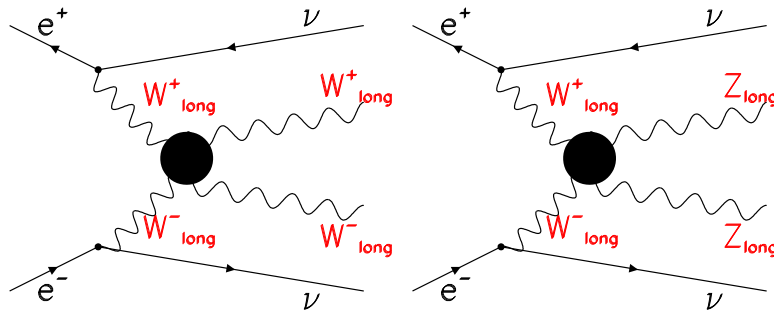


$\nu\bar{\nu}WW/ZZ$ at 1000 GeV

David Ward and Wenbiao Yan

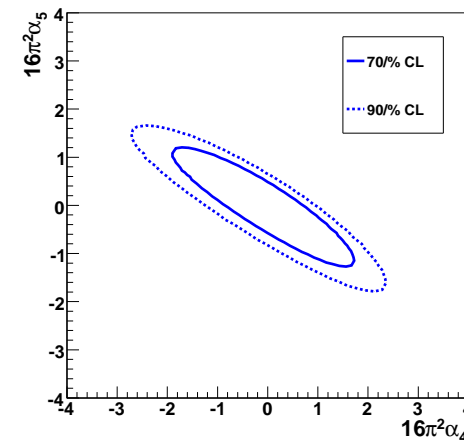


- WW scattering



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

- anomalous couplings α_4 & α_5



WW scattering

- $W_L W_L$ 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 \implies 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
$$L_4 = \frac{\alpha_4}{16\pi^2} \text{tr}(V_\mu V_\nu) \text{tr}(V^\mu V^\nu) \quad L_5 = \frac{\alpha_5}{16\pi^2} \text{tr}(V_\mu V^\mu) \text{tr}(V_\nu V^\nu)$$
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

- 80% left-handed e^- and 30% right-handed e^+ polarization; with ISR and beamstrahlung

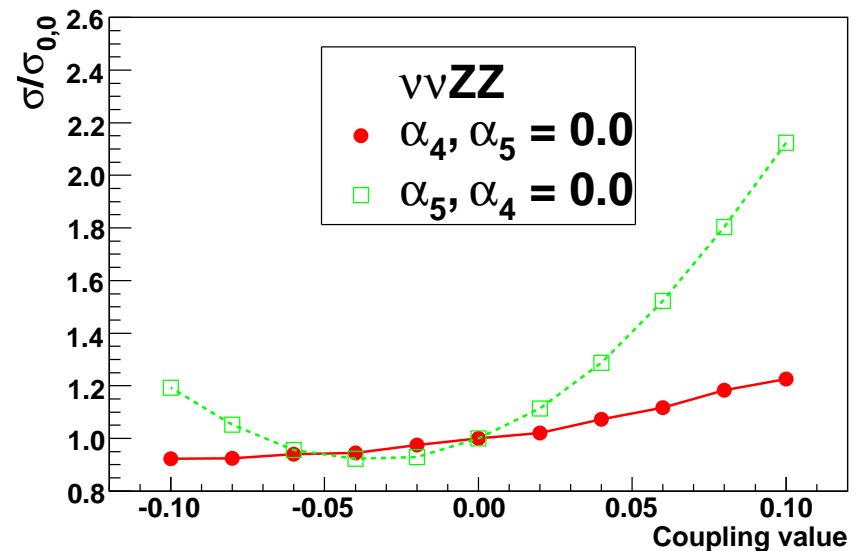
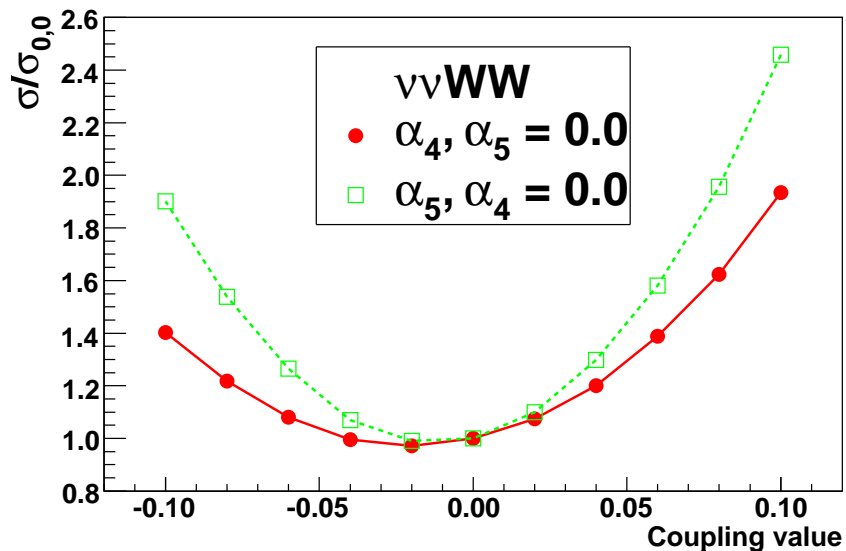
Channel	$\sigma_{1000\text{GeV}}$ (fb)	event number	Generator
$\nu_e\bar{\nu}_e WW \rightarrow \nu_e\bar{\nu}_e q\bar{q}q\bar{q}$	14.646	14646	Whizard 1.90
$\nu_e\bar{\nu}_e ZZ \rightarrow \nu_e\bar{\nu}_e q\bar{q}q\bar{q}$	6.816	6816	Whizard 1.90
$\nu_e\bar{\nu}_e q\bar{q}q\bar{q}$ (background)	6.924	6942	Whizard 1.90
$e\nu_e WZ \rightarrow e\nu_e q\bar{q}q\bar{q}$	43.104	43104	Whizard 1.90
$ee WW/ZZ \rightarrow ee q\bar{q}q\bar{q}$	109.224	109224	Whizard 1.90
$\nu_\mu\bar{\nu}_\mu WW/ZZ \rightarrow \nu_\mu\bar{\nu}_\mu q\bar{q}q\bar{q}$	3.316	4316	Whizard 1.90
$\nu_\tau\bar{\nu}_\tau WW/ZZ \rightarrow \nu_\tau\bar{\nu}_\tau q\bar{q}q\bar{q}$	4.322	4322	Whizard 1.90
$e\nu_e W \rightarrow e\nu_e q\bar{q}$	2807.196	280720	Whizard 1.90
$t\bar{t} \rightarrow X$	204.48	51100	PYTHIA

- ILD00 @ Mokka06-07-p01 and event reconstruction ilcinstall v01-06
- $t\bar{t}$ sample at 1000GeV: no polarization and beamstrahlung

WW/ZZ signal

- definition of WW/ZZ Signal events using MC truth

- $147.0 < m_{qq}^1 + m_{qq}^2 < 171.0$ GeV: WW
- $171.0 < m_{qq}^1 + m_{qq}^2 < 195.0$ GeV: ZZ
- $|m_{qq}^1 - m_{qq}^2| \leq 20.0$ GeV
- $m_{\nu_e \bar{\nu}_e} \geq 100.0$ GeV



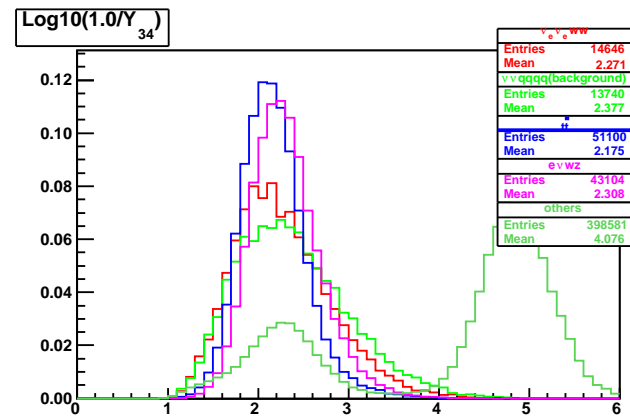
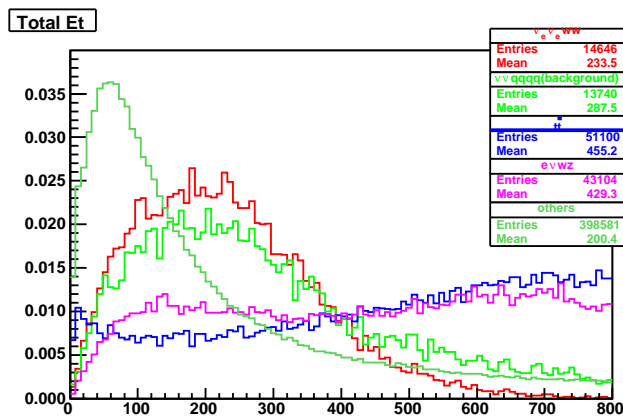
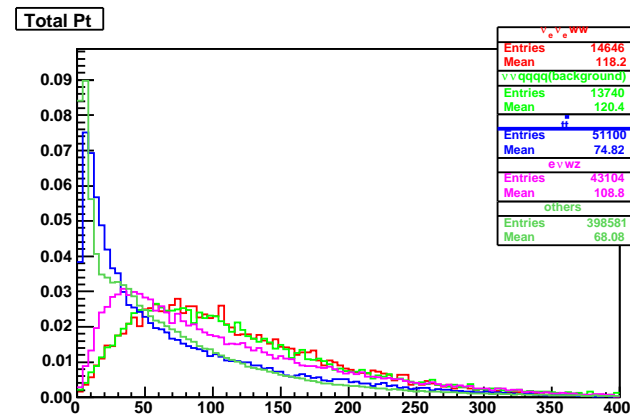
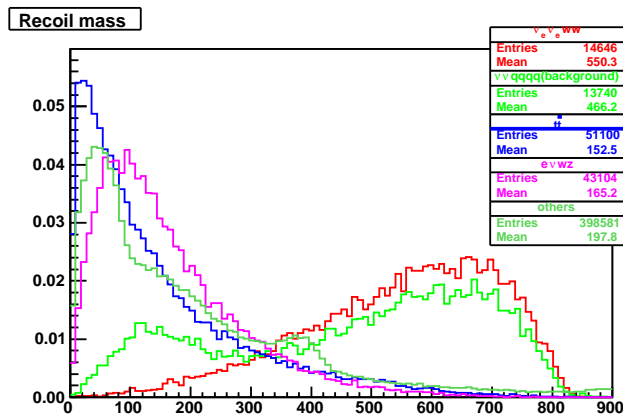
- α_5 is more sensitive than α_4

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: $M_{recoil} \geq 200.0 \text{ GeV}$
 - Total transverse momentum: $P_T \geq 40 \text{ GeV}$
 - Total transverse energy: $E_T \geq 150 \text{ GeV}$
 - Total missing momentum and most energetic track: $|\cos \theta| < 0.99$
 - Energy in a 10° cone of most energy track: $E_{cone} \geq 2.0 \text{ GeV}$
 - Force events to have 4 jets, and $\text{LOG}_{10}(1/Y_{34}) < 4.0$
 - * Jet selection: $E_{jet} > 10.0 \text{ GeV}$; 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: $60 < M_W < 88 \text{ GeV}$
 - ZZ: $85 < M_Z < 100 \text{ GeV}$

Control plots

- Histograms are normalised to one. **without cuts**

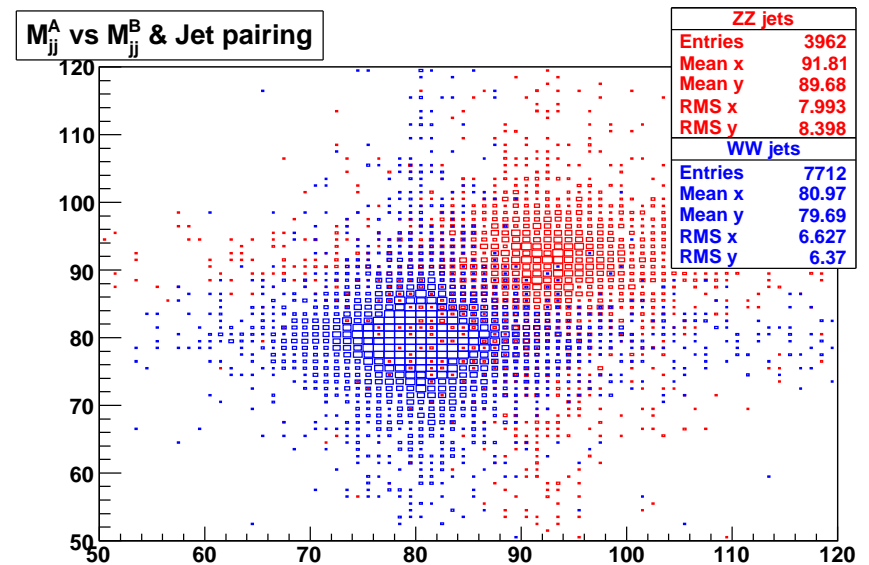
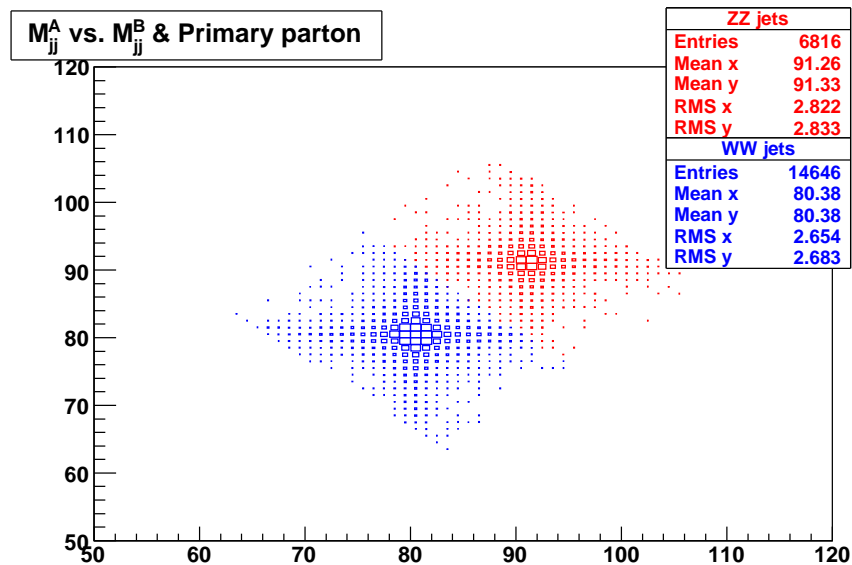


Expected signal and remaining backgrounds

Channel	$\nu_e\bar{\nu}_e WW$	$\nu_e\bar{\nu}_e ZZ$
$\nu_e\bar{\nu}_e WW \rightarrow \nu_e\bar{\nu}_e q\bar{q}q\bar{q}$	6308	
$\nu_e\bar{\nu}_e ZZ \rightarrow \nu_e\bar{\nu}_e q\bar{q}q\bar{q}$		2073
$\nu_e\bar{\nu}_e q\bar{q}q\bar{q}$ (background)	968	311
$e\nu_e WZ \rightarrow e\nu_e q\bar{q}q\bar{q}$	40	38
$ee WW/ZZ \rightarrow ee q\bar{q}q\bar{q}$	1	0
$\nu_\mu\bar{\nu}_\mu WW/ZZ \rightarrow \nu_\mu\bar{\nu}_\mu q\bar{q}q\bar{q}$	378	17
$\nu_\tau\bar{\nu}_\tau WW/ZZ \rightarrow \nu_\tau\bar{\nu}_\tau q\bar{q}q\bar{q}$	360	22
$e\nu_e W \rightarrow e\nu_e q\bar{q}$	90	0
$t\bar{t} \rightarrow X$	284	84

WW/ZZ separation

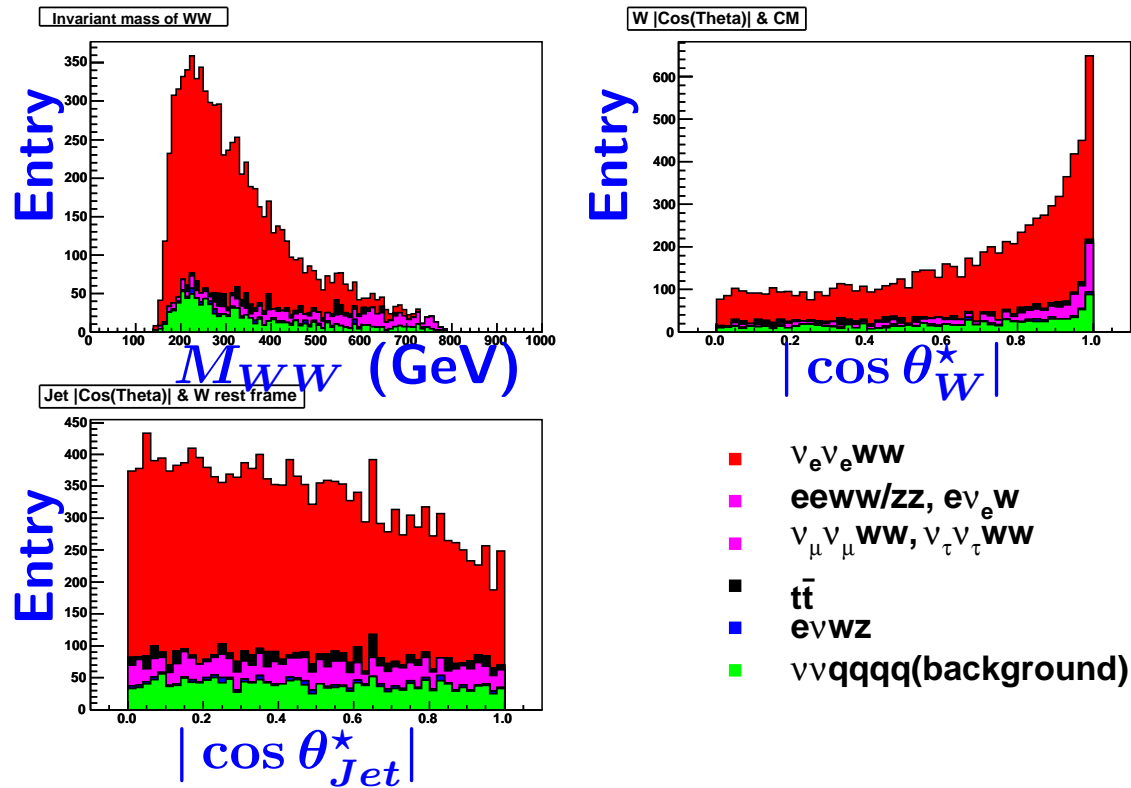
- WW/ZZ separation @ 1000 GeV for ILD00 detector model
 - WW/ZZ: SAME selection @ detector level; without W/Z mass cut



Binned maximum likelihood fit

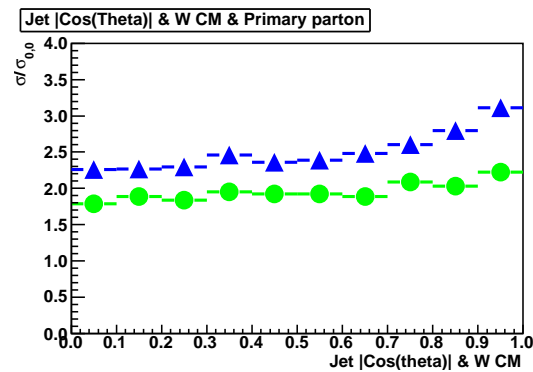
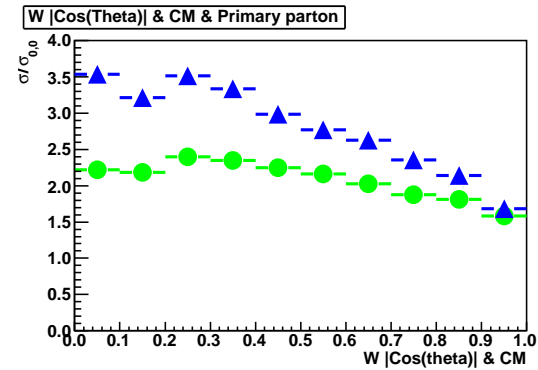
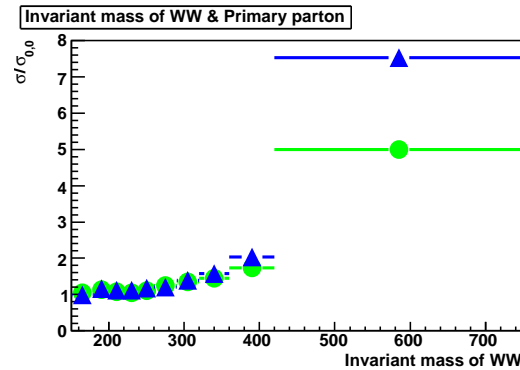
- Fitting distributions at detector level to extract α_4 and α_5
 - SM sample with (0.0, 0.0) as "data"
 - each bin $p(n) = e^{-\lambda}\lambda^n/n!$
 - * n : observed number @ "data" sample and background event samples
 - * λ : expected number; $\lambda = m^{signal}(\alpha_4, \alpha_5) + m^{bcg1}(\alpha_4, \alpha_5) + m^{bcg2}$
 - $-\ln \mathcal{L} = -\sum \ln p(n_i) = -\sum n_i \ln \lambda_i + \sum \lambda_i + \sum \ln(n_i!)$
- $m^{signal}(\alpha_4, \alpha_5)$ and $m^{bcg1}(\alpha_4, \alpha_5)$
 - Each MC event (i th 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 i th 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



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

Fit distributions



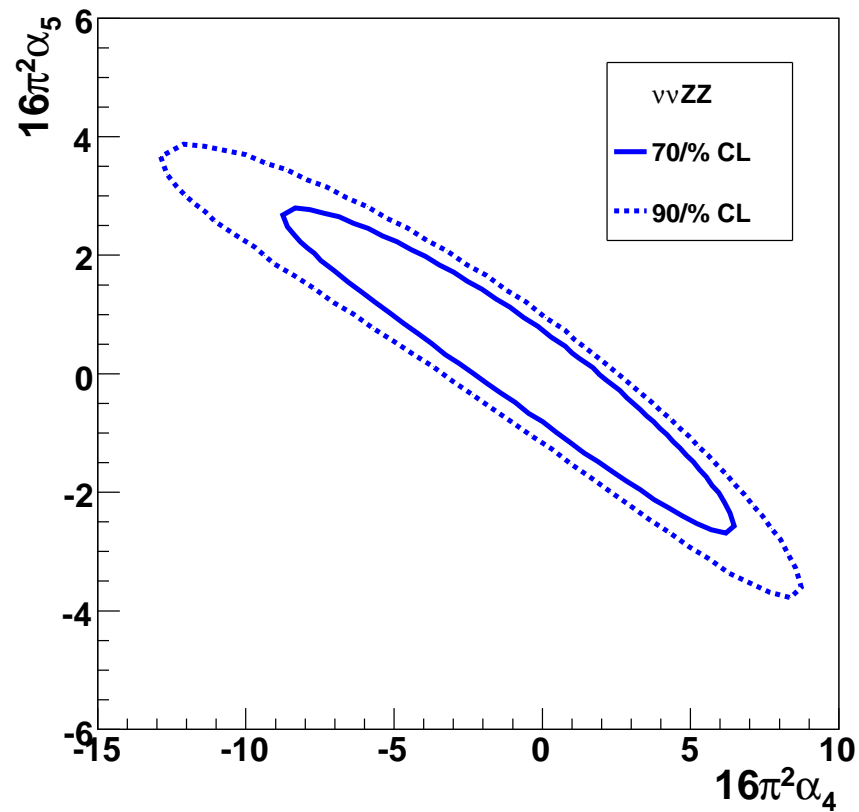
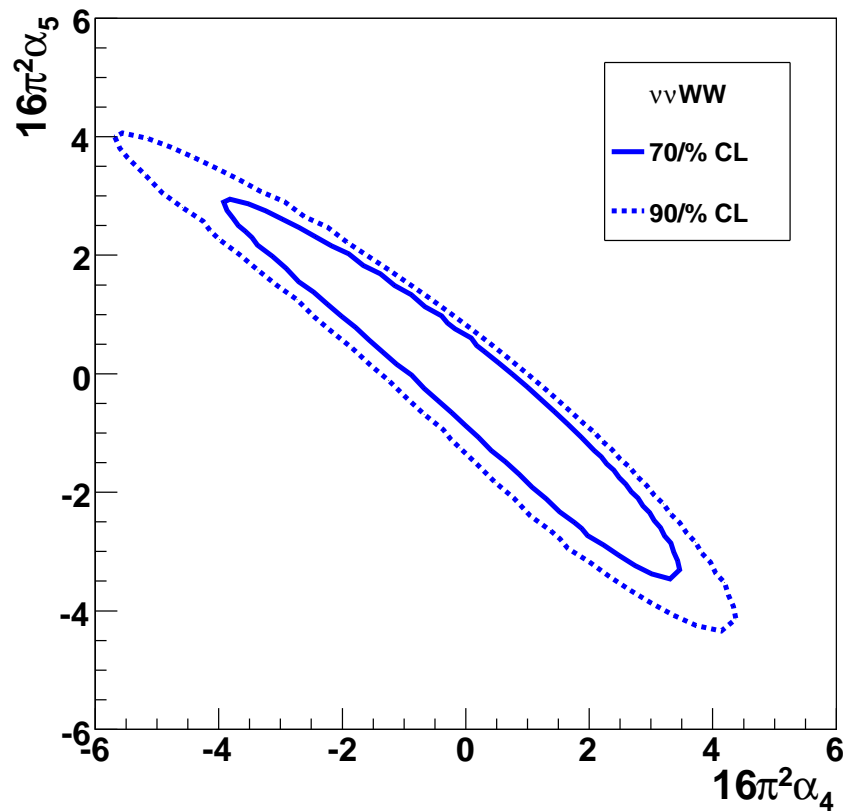
$$\sigma_{\alpha_4, \alpha_5} / \sigma_{0,0}$$

● $\alpha_4 = 0.10; \alpha_5 = 0.00$

▲ $\alpha_4 = 0.00; \alpha_5 = 0.10$

- sensitive (α_4, α_5) at high M_{WW} , $|\cos \theta_{W}^*|$ and $|\cos \theta_{Jet}^*|$
- fit distributions: $d^2\sigma / (d|\cos \theta_{W}^*| d|\cos \theta_{Jet}^*|)$

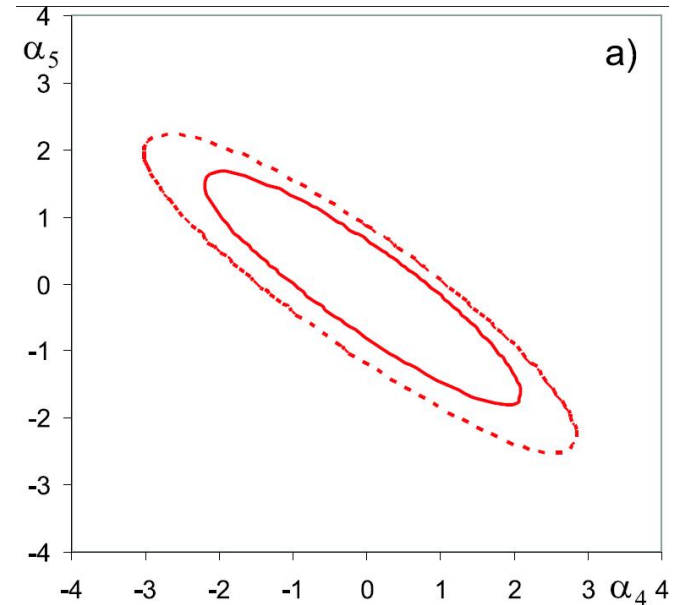
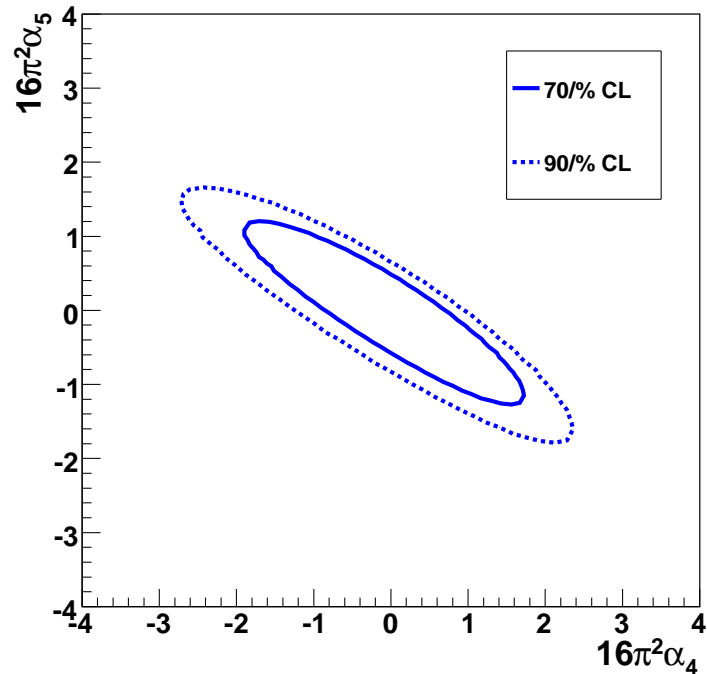
Likelihood from WW/ZZ



- α_5 is more sensitive than α_4

Likelihood from combined WW/ZZ at 1000GeV

- **ILD00: 30% (e^+) 80% (e^-)**
- **TESLA: 40% (e^+) 80% (e^-)**
- **full detector simulation**
- **fast detector simulation**
- **hep-ph/0508179**



Summary

- **WW scattering provides information on the electroweak symmetry breaking, anomalous couplings α_4 & α_5 are related to the scale of new physics. \implies sensitivities of α_4 & α_5 at linear collider.**
- **we study WW scattering with ILD00 detector model, and extract α_4 & α_5 , which are comparable with that of TESLA fast simulation.**

Useful plot

