Higgs Summary

Alexei Raspereza

On behalf of Higgs Working Group

ECFA Workshop, Warsaw 12/06/2006

Outline

- *Current Status*
- *Contributions in Warsaw*
  - *Theory (new signatures, enriched phenomenology, higher order corrections to Higgs observables)*
  - *Experiment (study of ILC potential with full simulation & reconstruction, experimentally challenging channels)*
- *Conclusions*

General Tendencies in the Field of ILC Related Higgs Studies

- Despite hard times for the ILC project we keep our optimism and continue actively working on Higgs topics
- Higher than ever anticipation of early LHC results. LHC observations will...
  - **define the destiny of the ILC project (sub-TeV machine, CLIC)**
  - **influence ILC running conditions (e.g. running @ ZH threshold)**
  - **have an impact on the analysis strategies**
- Intensified contacts between ILC & LHC communities
- Trends in theoretical field
  - **Improving prediction power of theoretical calculations (reduced uncertainties on Higgs observables; m_H, g_{VV}, g_{ff})**
  - **Exploring phenomenology outside conventional scenarios (CP properties of Higgs and CP violation, higher dimensional operators)**
- Tendencies in experimental analyses
  - **Transition to full simulation/reconstruction $\Rightarrow$ more reliable estimate of ILC potential $\oplus$ detector optimization**
  - **Addressing challenges provided by channels with extremely complex topology ee $\rightarrow$ ttH $\rightarrow$WWWWbb, ee $\rightarrow$ HHZ $\rightarrow$WWWWZ ($m_H \geq 160$GeV)**

Evolution of Higgs Activities. Contributions in Warsaw w.r.t. Previous Workshops

- Durham 2004 — 6 theoretical talks | 6 experimental talks
- Valencia 2006 — 4 theoretical talks | 6 experimental talks
- Warsaw 2008 — 6 theoretical talks | 4 experimental talks

Covered Topics

Theoretical studies (6 contributions)

- Trilinear couplings in CP-violating 2HDM (P.Osland)
- Determination of CP properties via $tt\phi$ production (R.Godbole)
- Higher dimensional operators, involving Higgs fields (K. Tsumura)
- Off-resonant background effects in ttH production (S.Szczypinski)
- Charged Higgs mass. Meeting ILC precision (S.Heinemeyer)
- Phase transitions in 2HDM in the early Universe (I.Ginzburg)

Experimental studies (4 contributions)

- ZHH with m_H=120GeV (P.Lutz)
- Recoil mass & cross sections in HZ (Hengne Li)
- Recoil mass in HZ (I.Kazutoshi)
- Analysis of 4-jet mode in ZHH (Y.Takubo)

Trilinear Self-Coupling Calculation CP Violating 2HDM

$$\lambda_{ijk} = \frac{-i\,\partial^3 V}{\partial H_i \partial H_j \partial H_k}$$

Differentiate via weak fields

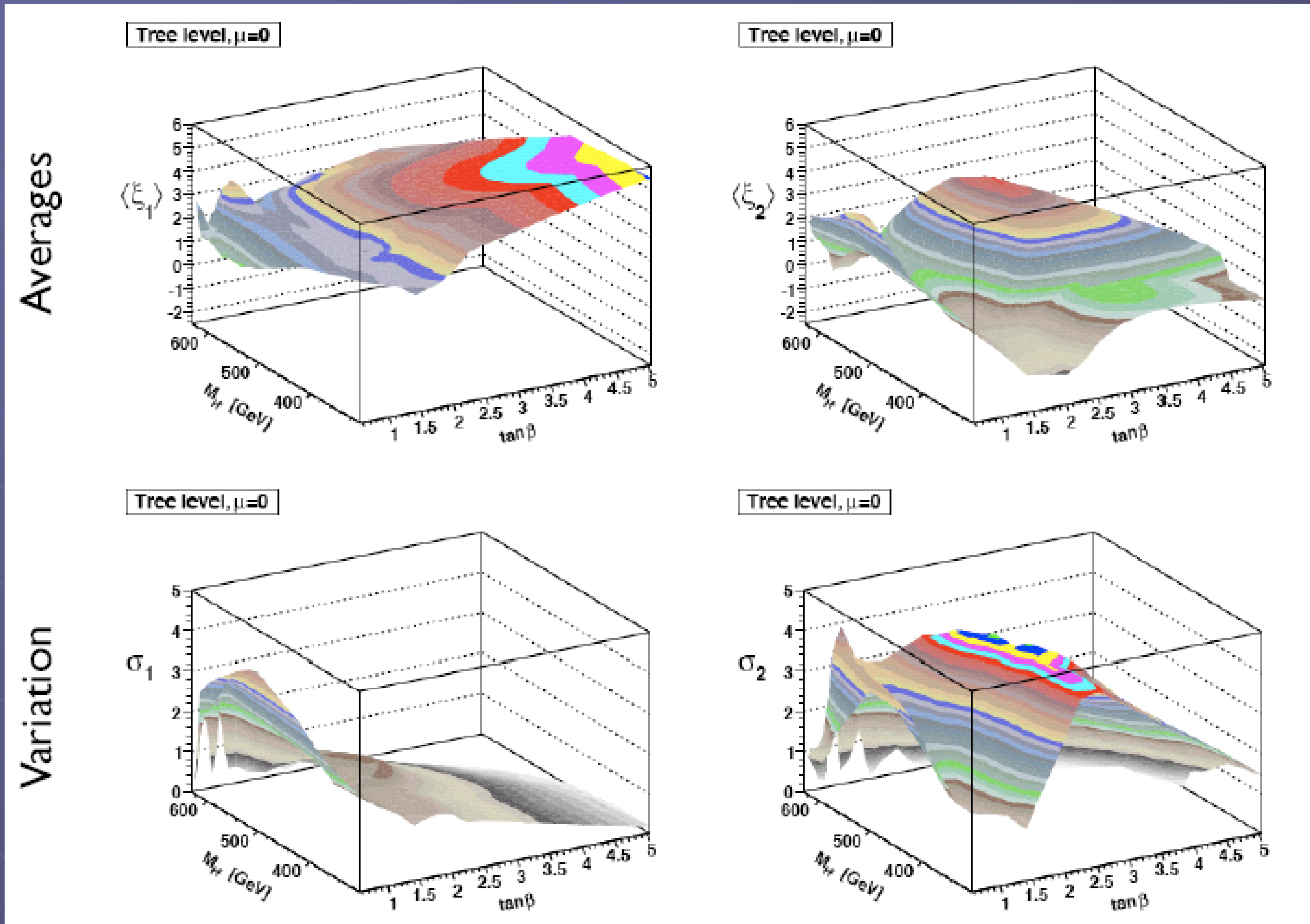
$$\lambda_{ijk} = \sum_{m \leq n \leq o = 1,2,3}^{*} R_{i'm} R_{j'n} R_{k'o} \frac{-i\,\partial^3 V}{\partial \eta_m \partial \eta_n \partial \eta_o}$$

average over some parameters $\boldsymbol{\alpha} = (\alpha_1, \alpha_2, \alpha_3)$

$$\langle \xi_1 \rangle = \frac{\langle \lambda_{111} \rangle}{\lambda_{HHH}^{\text{SM}}} \qquad \langle \xi_2 \rangle = \frac{\langle \lambda_{112} \rangle}{\lambda_{HHH}^{\text{SM}}}$$

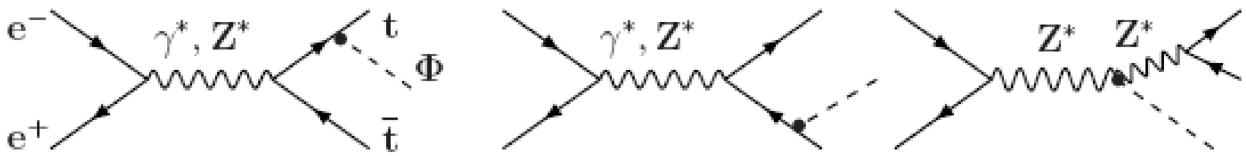
Reference mass: M_1

Results of scan over ($m_{H\pm}$, tanβ)

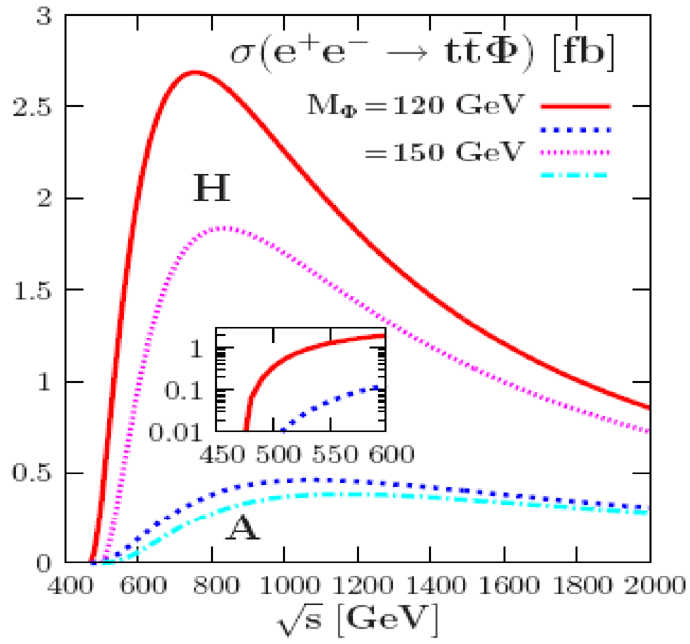


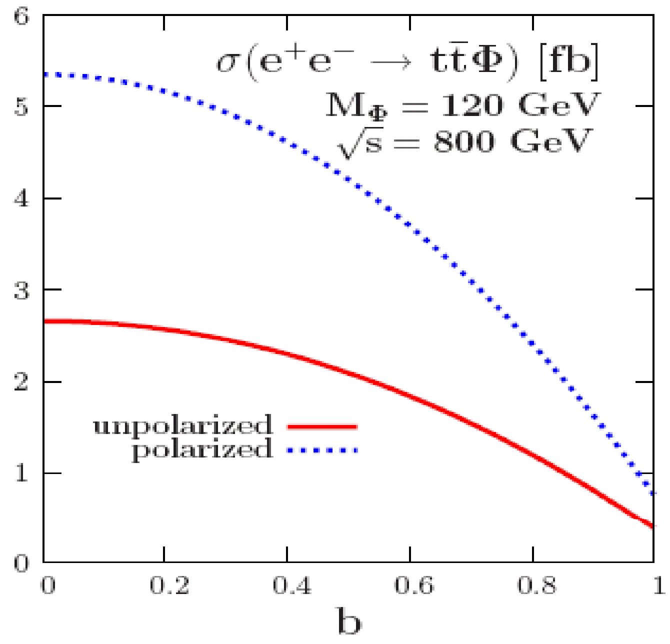
⇒Trilinear couplings in the 2HDM are typically larger than in SM
⇒They vary a lot as one scans over parameter scan even for fixed M_1 and M_2

Probing CP Properties of Higgs in $e^+e^- \to t\bar{t}\phi$



$$g_{t\bar{t}\phi} = -ig_2 \frac{m_t}{2m_W}(a + ib\gamma_5) \;.$$

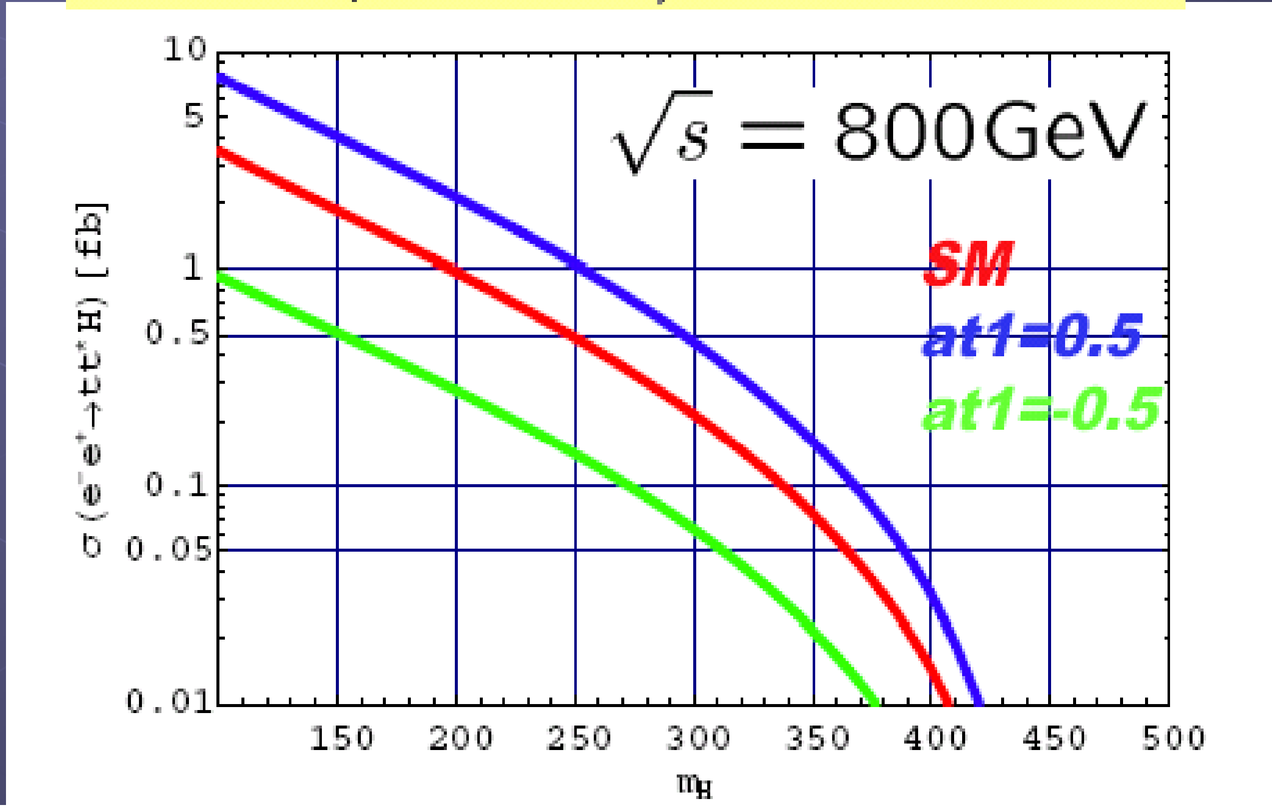




Effect of dim-6 Operators on $e^+e^-\to ttH$ Cross Section

$$\mathcal{L}^{\rm eff} = \mathcal{L}_{\rm SM} + \sum_{n>4} \frac{C_i}{\Lambda^{n-4}} \mathcal{O}_i^{(n)}$$

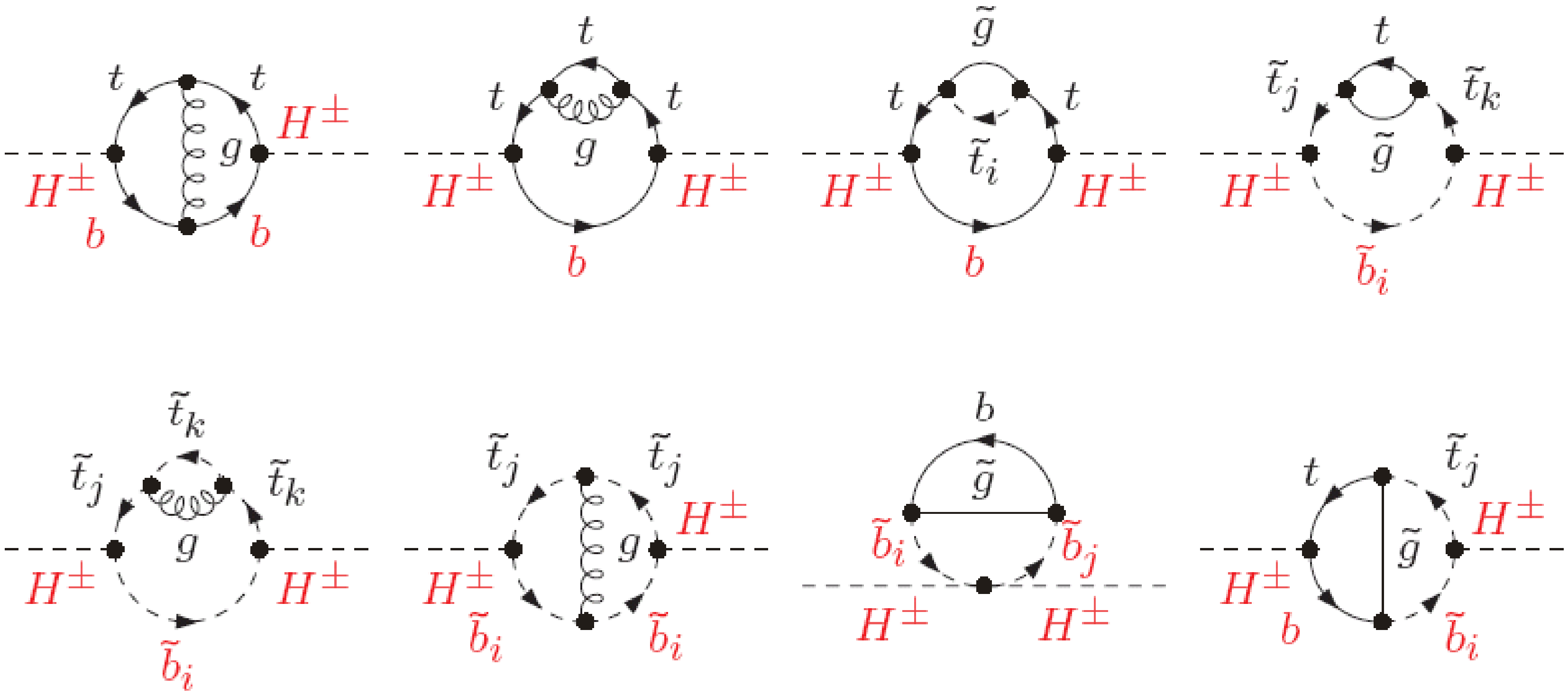
$$\mathcal{O}_{t1} = \left(\Phi^\dagger\Phi - \frac{v^2}{2}\right)\left(\bar{q}_L t_R \bar{\Phi} + \text{h.c.}\right)$$



Radiative Corrections to Charged Higgs Mass.

Contributions to the 2-loop self-energy:

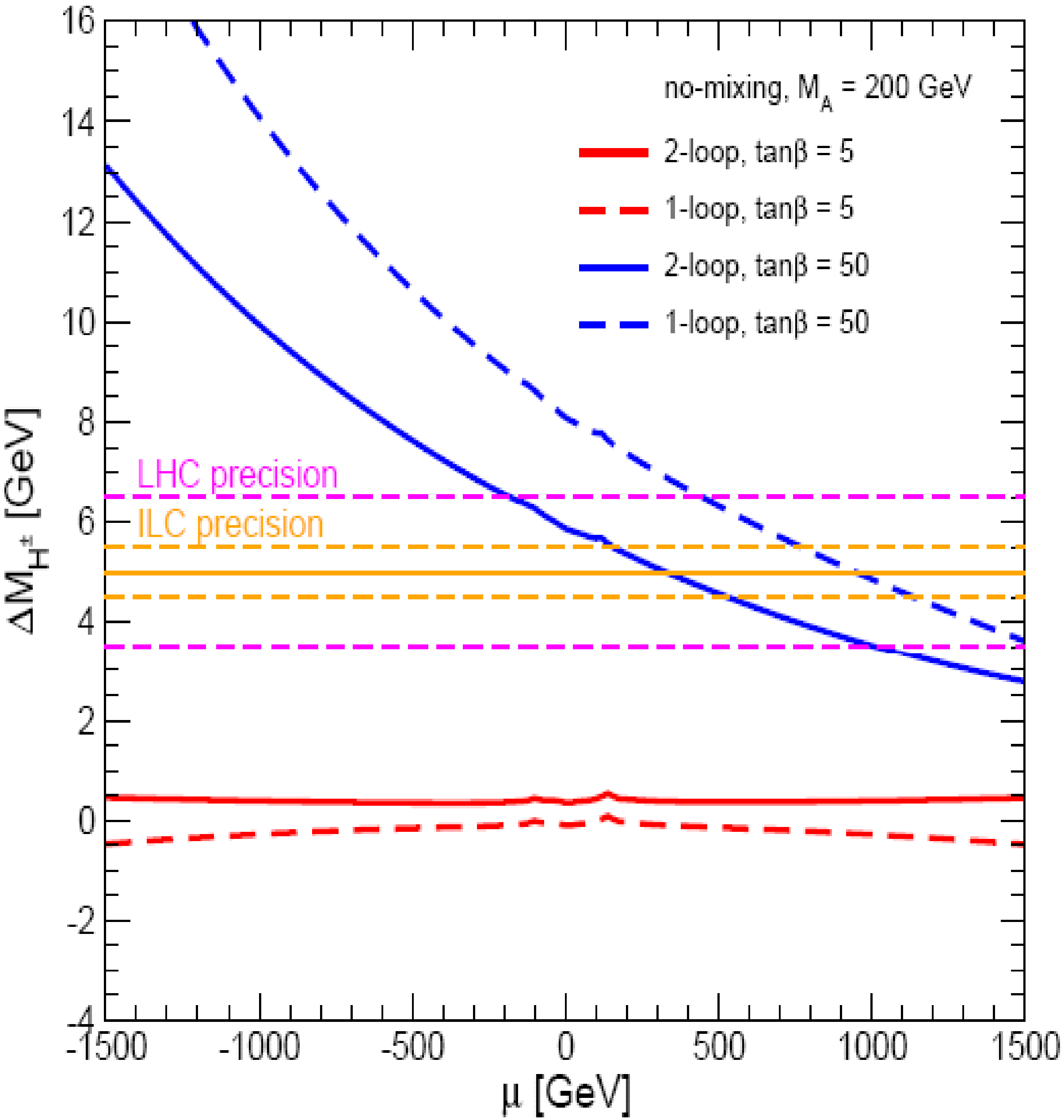
2-loop self-energy diagrams:



new: $H^{\pm}$ as external Higgs

$\Rightarrow b/\tilde{b}$ enter (even diagrams without $t/\tilde{t}$: $H^{+}H^{-}\tilde{b}_i\tilde{b}_j \sim y_t^2$)

2-loop, μ varied:



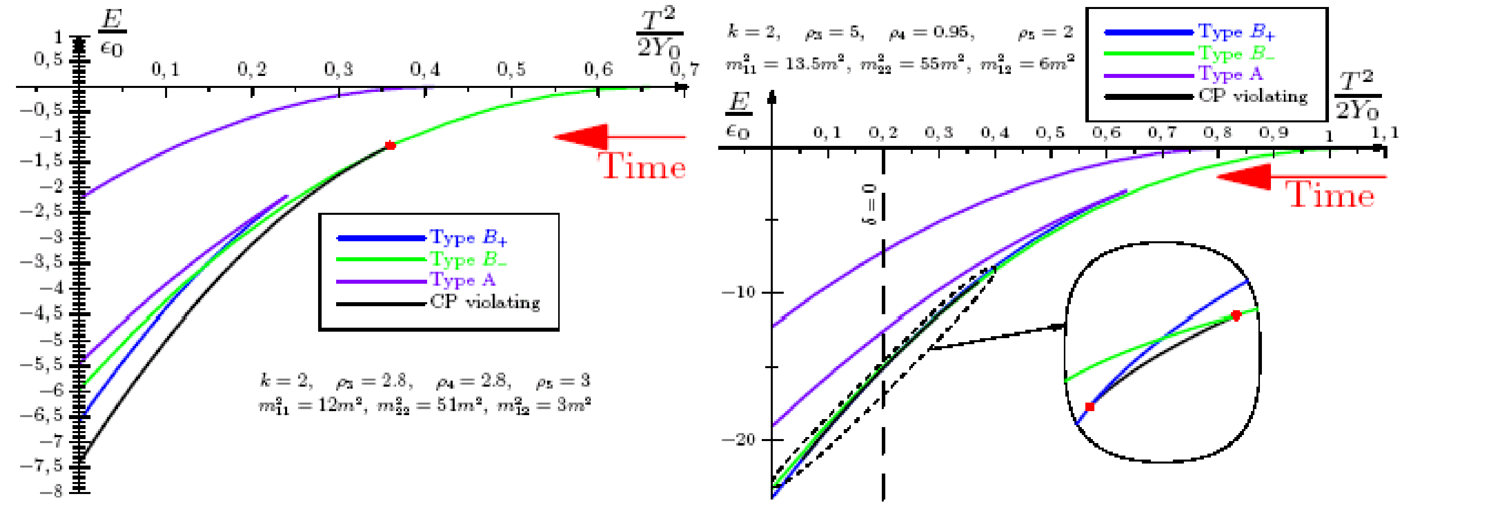
negative μ:

$\Delta M_{H^\pm} = 2 - 5$ GeV

positive μ:

$\Delta M_{H^\pm} = 0.5 - 2$ GeV

Phase Transitions in 2HDM in early Universe



Left – 2 phase transition: EWc phase → CPc phase A (2 order) → sCPv phase (2 order)

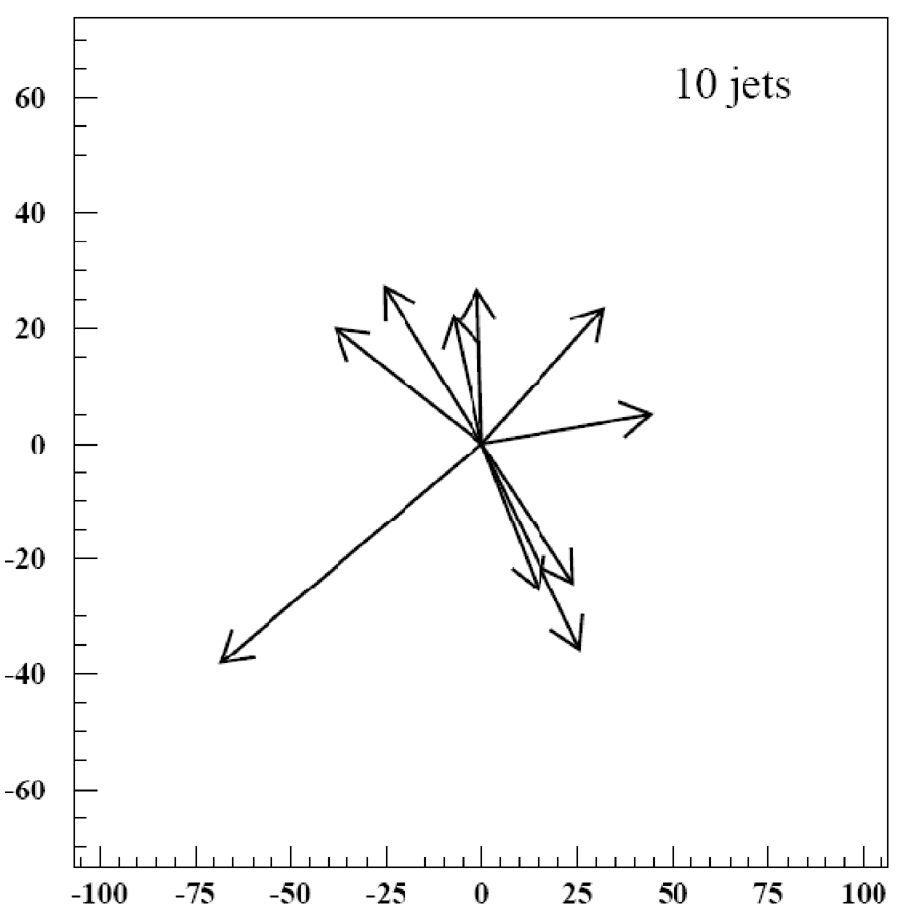
Right – 3phase transition: EWc phase → CPc phase B (2 order) → sCPv phase (2 order) → CPc phase B (2 order);
the CPC phases B at high and low temperatures are different like in the case with 1-st order transition, physical properties changes quickly.

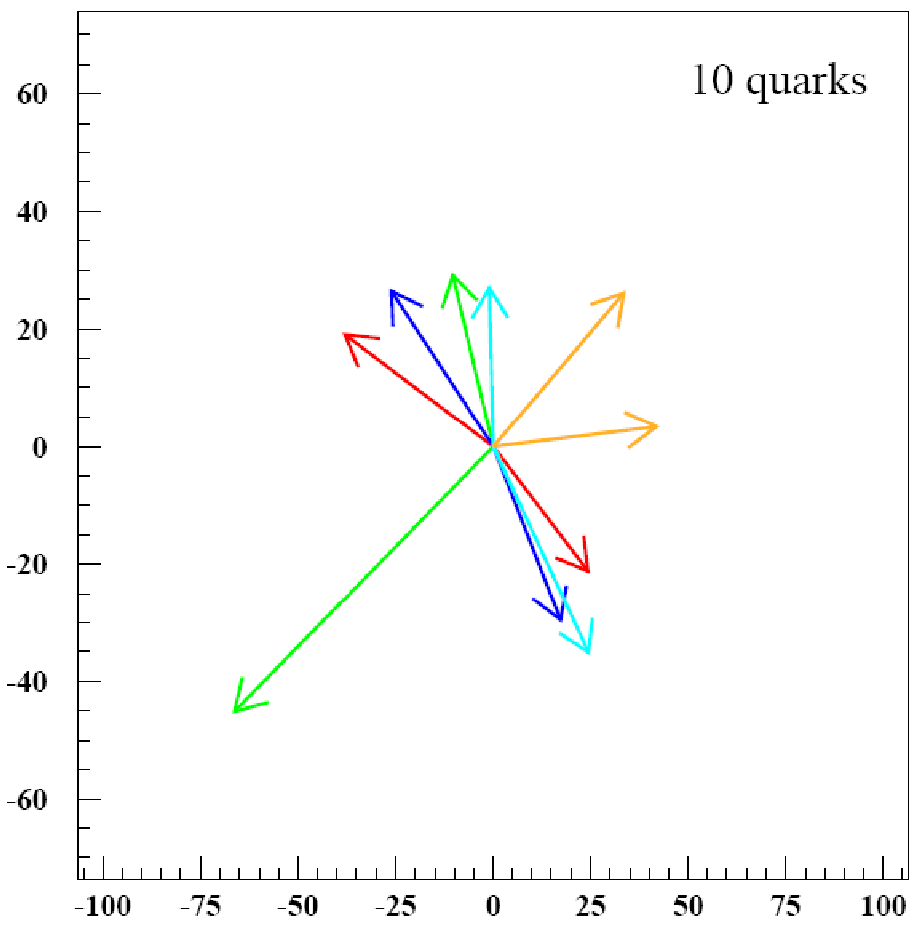
Physical observables at LHC/ILC
⇒ parameters of Higgs potential in 2HDM
⇒ probe of scenarios of Universe evolution

$e^+e^- \to ZHH$ when m(H)=170GeV

- Since long we have been asked to investigate feasibility of measuring triple Higgs self-coupling in case of heavy Higgs ($H \to WW$)
- It means that ZHH event is 5 (!) boson event resulting in 10 (!) fermions in the final state
- ZHH : Extremely challenging channel
  - Very small cross section
  - Many possible final states (10jets, 8jets+lepton+E, 6jets+2leptons+E, 4jets *etc*)
  - Combinatorics (!). 4725 ways to form 5 di-jets in $ZHH \to 10$jets
- In Valencia it was shown @ generator level that it is possible to find 5 di-jets compatible with Z4W event
  - Efficiency ≈ 47% (promising result)

Reconstruction of di-jets





Differences but no so big!

Final Results (E_{cms} = 500GeV)

Polarisation	e^- : -80% e^+ : 30%		e^- : 80% e^+ : -30%	
	Background	Signal	Background	Signal
Preselection	2155	94.2%	5128	95.3%
Z4W comp.	31250	46.3%	58820	44.2%
ZHH comp.	42200	36.4%	80000	31.7%
Ymin >5	75750	36.3%	158000	31.7%
$M_{bb} = M_Z$	500000	36.0%	833333	31.3%
for 500 fb^{-1}	1920	4.2	1120	2.5

A bit discouraging results, but improvements possible

$\Rightarrow$ ZHH cross section is higher for E_{cms}>500GeV

$\Rightarrow$ Inclusion of ee$\rightarrow$ WW$\nu\nu$$\rightarrow$ HH$\nu\nu$ (WBF) should help

Higgs Recoil Mass Analyses with Full Simulation

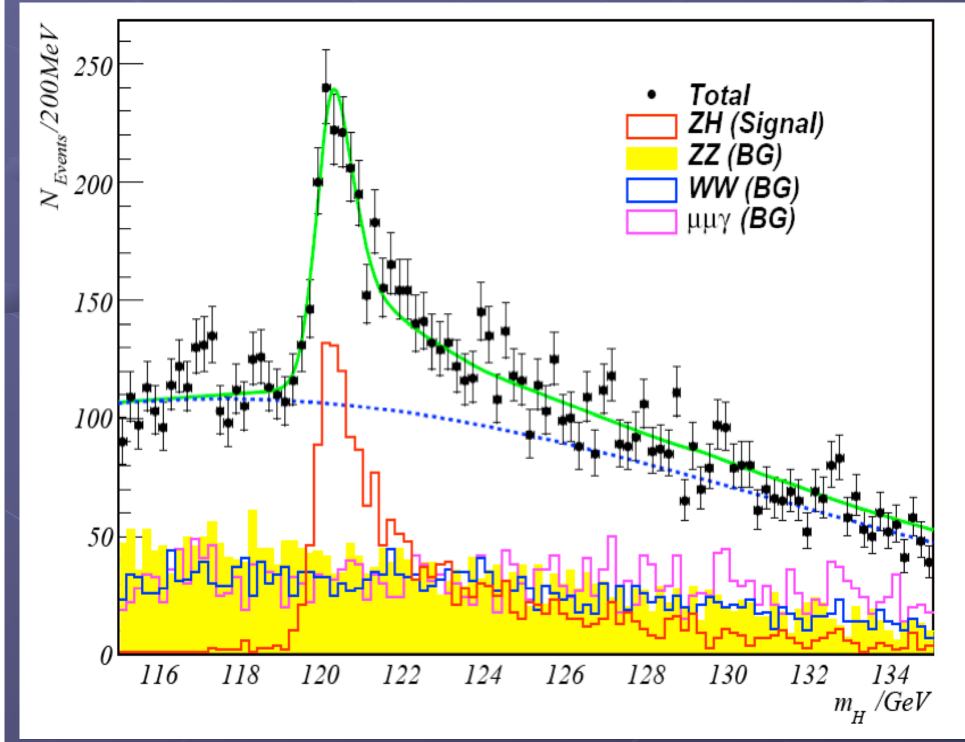
- Transition to analyses using full simulation and reconstruction tools
  - More reliable evaluation of ILC potential
  - Benchmarking detector performance
- First analyses focus on relatively „simple“ benchmark processes
  - $ZH \to eeX$
  - $ZH \to \mu\mu X$
- Optimal energy $\sqrt{s} \approx m_H + m_Z + 20$ GeV
  - Highest cross section
  - Better momentum resolution of tracker

Results of ZH Analyses

$ZH \to \mu\mu X$, L=500 fb^{-1}

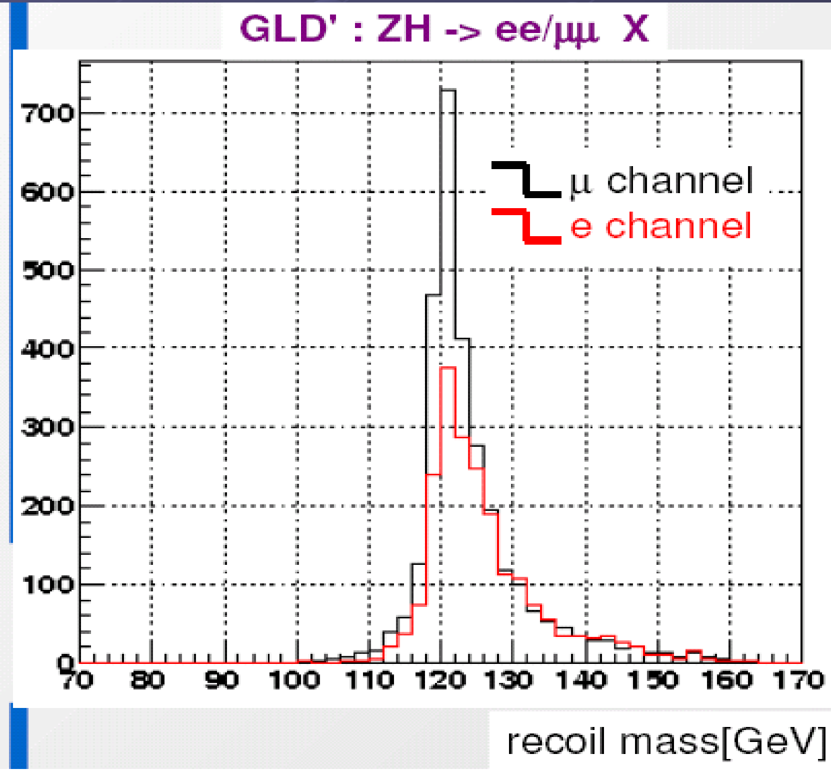
$\delta m \approx 40$ MeV

$\delta\sigma/\sigma \approx 5\%$



Electron reconstruction issue

Breamstrahlung $\Rightarrow$ degradation of di-lepton mass resolution $\Rightarrow$ reduced efficiency in $ZH \to eeX$ w.r.t. $ZH \to \mu\mu X$



Analysis of 4 jet+$\not{E}$ final state in ZHH

Higgs mass reconstruction for HHνν events

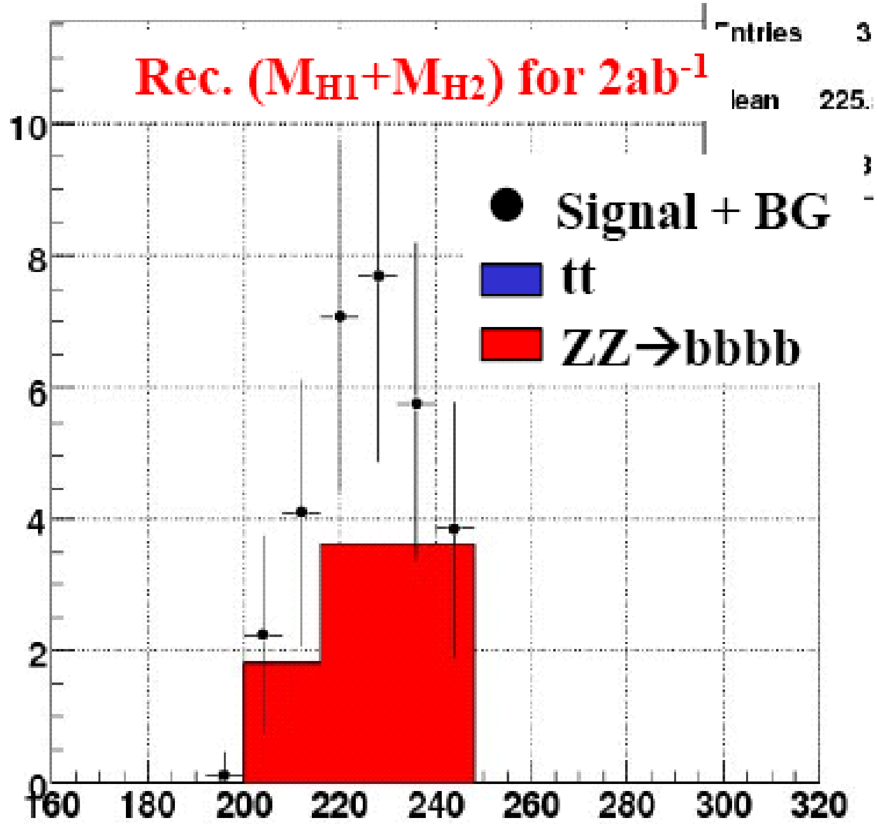
Complementary to 4jet+2leptons & 6jet channels

- M_H = 120 GeV, E_{CM} = 500GeV

The signal significance was estimated for 2ab^{-1}

- Signal : 12.8 events
- B.G. : 18.1 events

Significance : 2.3 σ



Conclusions

- Momentum and pace are kept in ILC related Higgs studies
- The strategy of real analyses will be defined by LHC data ⇒ intensified contacts with the LHC community
- With LoI being next milestone emphasis is put on the analyses based on full simulation/reconstruction
- Challenges associated with complex final states are being addressed (e.g. ZHH→Z4W→10jets)
- Trends in theoretical developments
  - $N^{(n)}LO$ order correction to Higgs observables ⇒ meeting ILC precision
  - Exploration of enriched phenomenology beyond conventional scenarios
- Despite of hard times for the ILC community we keep optimism and enthusiasm