



Higgs/EW summary

06 - 10 ОКТОБЕР '14
ИНН ВИНЧА
БЕЛГРАДЕ
СЕРБИЈА
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ЗЕМЉА

ЛЦВС14
ЛГВС14

Tim Barklow, Sven Heinemayer, Shinya Kanemura,
Markus Klute, Heather Logan, Aidan Robson, Junping Tian



Higgs/EW summary

26 talks

+ joint BSM/Higgs session
+ 2 talks scheduled in
top and BSM sessions

ДЛВС14
LGWS14

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EARTH

ILC
CLIC

updated
measurement
sensitivities

combinations

interpretations

Higgs/EW summary

26 talks

+ joint BSM/Higgs session
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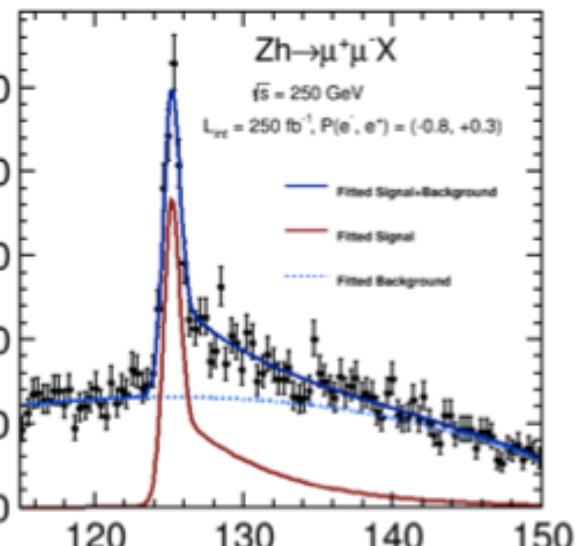
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ILCWC14
LGWS14

Shun Watanuki

work done to equalize selection efficiencies for Higgs decays

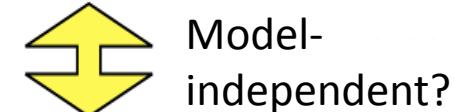


Higgs mass and cross section by recoil method

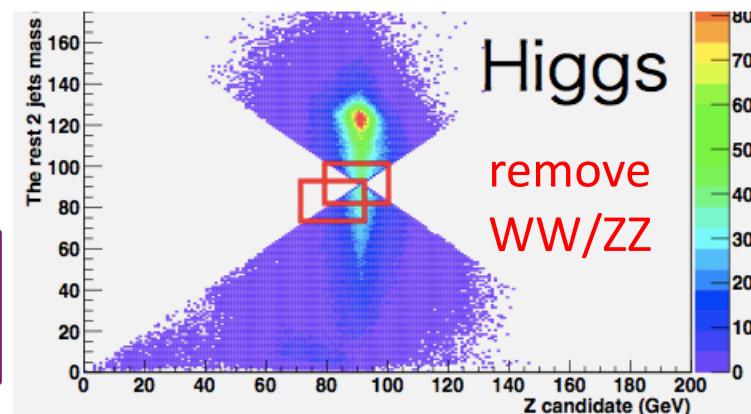
$\mu\mu h, eeh$ @250GeV		$\mu\mu h$		eeh		combined	
		Left	Right	Left	Right	Left	Right
MI	cross section	4.2%	3.8%	6.0%	6.0%	3.4%	3.2%
	mass [MeV]	34	31	231	214	34	31
semi-MI	cross section	3.8%		5.6%		3.1%	
	mass [MeV]	33		89		31	

Higgs recoil mass study using
 $ZH \rightarrow q\bar{q}H$ @ 250 GeV ILC

• More statistics



• More background



Tatsuhiko Tomita/
Taikan Suehara

- The precision of total cross section left 5.6% → 4.7%, right 4.0% → 3.3% from AWLC.
(but still not satisfactory.)
- Categorization can reduce difference of efficiency especially tautau, WW→leptonic.
- Current cut has bias for gg and WW.

Akimasa Ishikawa

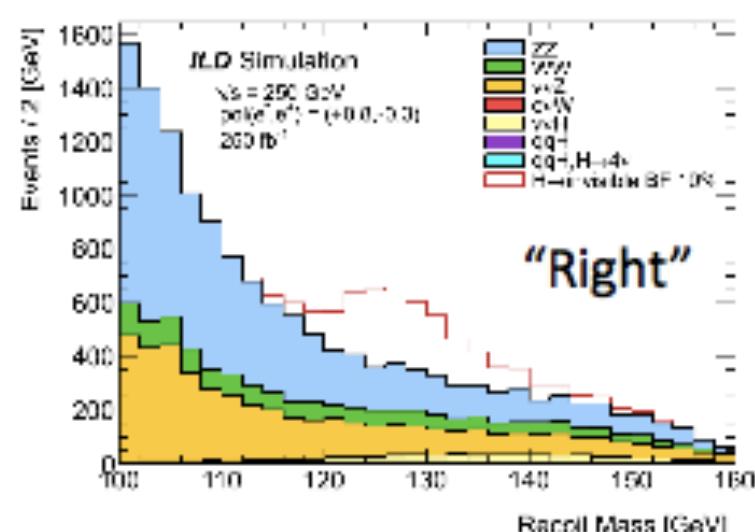
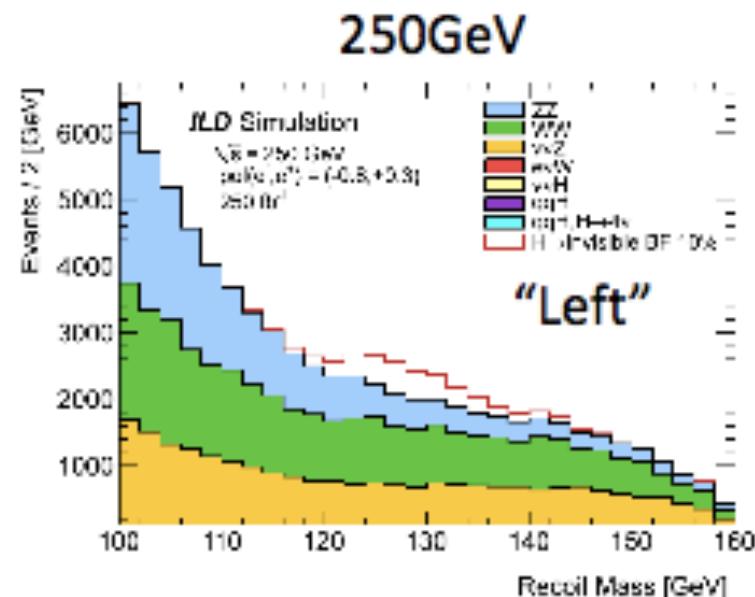
Invisible Higgs decays at the ILC

$$e^+e^- \rightarrow ZH \rightarrow qqH$$

- $Z \rightarrow qq$ decay is used ($\text{BF}(Z \rightarrow qq) = 69.9\%$)
- $E_{\text{cm}} = 250\text{GeV}$, **350GeV** and **500GeV**

New!

UL on BF [%]	“Left”	“Right”
250GeV	0.95	0.69
350GeV	1.49	1.37
500GeV	3.16	2.30

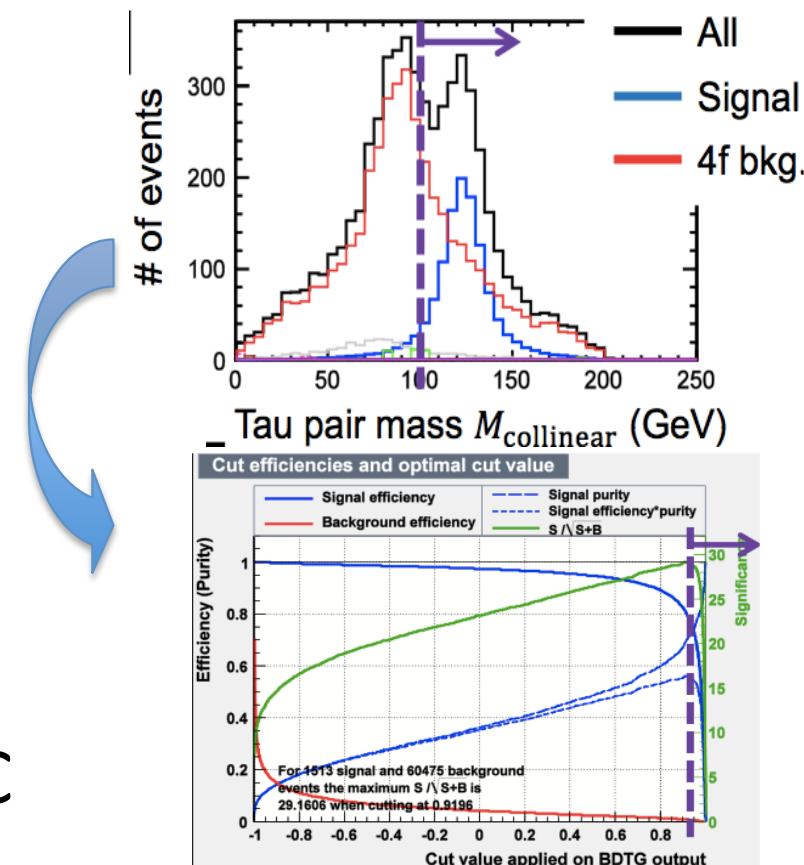




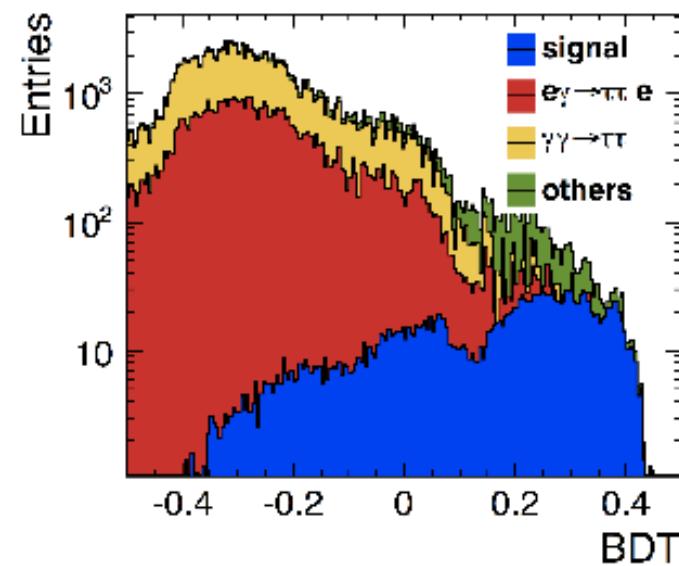
Shin-ichi Kawada

H $\rightarrow\tau\tau$ at 250GeV, ILD

250 GeV 250 fb $^{-1}$	Extrapolation from $M_h = 120 \text{ GeV}$	$M_h = 125 \text{ GeV}$
$\frac{\Delta(\sigma \times \text{BR})}{(\sigma \times \text{BR})}$	4.2% $q\bar{q}h + \ell^+\ell^-h$ (ref: LC-REP-2013-001)	3.4% $q\bar{q}h$ only
Conditions	- cut-based only - tau finder was not so optimized	- using multivariate technique - optimized tau finder



Philipp Roloff

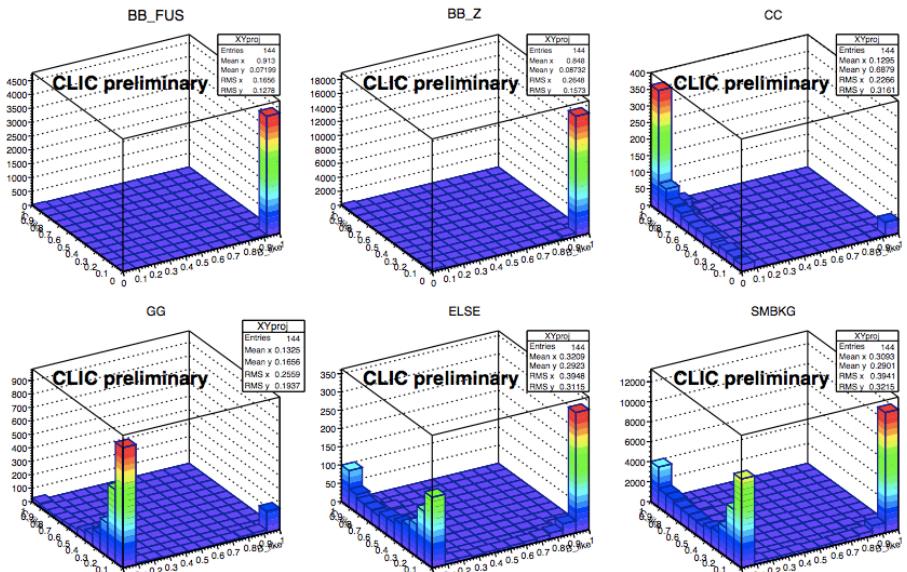
H $\rightarrow\tau\tau$ at 350GeV, 1.4 & 3TeV CLIC

redone including beam-induced backgrounds

- **350 GeV:** 6.2% precision on $\sigma \times \text{BR}(H \rightarrow \tau^+\tau^-)$ from Higgs bosons produced in Higgsstrahlung events
- **1.4 TeV:** 4.2% precision $\sigma \times \text{BR}(H \rightarrow \tau^+\tau^-)$ from Higgs bosons produced in WW fusion
- **3 TeV:** analysis to be finished soon

Marco Szalay

Templates

H \rightarrow bb/cc/gg at 350 GeV at CLIC

Preselection to classify events;

4d binned likelihood template fit

- A measurement of the Γ_H needs high precision measurements on Higgs hadronic decays, in particular $H \rightarrow bb$
- With this study, $\sigma \times BR$ for ZH: $H \rightarrow bb$ can be determined with **sub-percent** precision with 500fb^{-1} of data
- $H \rightarrow gg$ can be measured at a **5% level**
- $H \rightarrow cc$ is more problematic due to the low branching fraction, need more work to explore potential improvement

Felix Müller

Updated from LOI,
now $m_H=125$
+ tagging improvement
from LCFIVertex -> LCFIPlus
but will revisit flavour-tagging
performance for cc

Accuracies of Higgs Branching Fraction in vvh at 350 GeV

Updated results	250 GeV			350 GeV		
	$L(\text{fb}^{-1})$	$250 \text{ fb}^{-1} P(-0.8,+0.3)$	$330 \text{ fb}^{-1} P(-0.8,+0.3)$	bb	cc	gg
$\Delta\sigma\text{BR}/\sigma\text{BR}$				bb	cc	gg
wh (WW and ZH)	1.6%	14.8%	9.7%	1.1%	14.6%	4.6%
ggh (ZH)	1.6%	24.0%	18.4%	1.5%	15.0%	13.2%
eeh (ZH)	4.4%	57.4%	36.3%	6.5%	>100%	>100%
$\mu\mu h$ (ZH)	3.4%	34.0%	22.3%	4.6%	65.7%	30.9%
Combined	1.0%	11.6%	7.8%	0.9%	10.3%	4.3%
Extrapolated	1.1%	8.0%	6.8%	0.9%	6.5%	5.2%

Junping Tian

Higgs self-coupling study @ ILC

searching mode and main backgrounds: $e^+ + e^- \rightarrow ZHH$ @ 500 GeV

- llHH: llbb (ZZ, γZ , bbZ), lvbbqq ($t\bar{t}$ -bar), llbbbb (ZZZ/ZZH)
- vvHH: bbbb (ZZ, γZ , bbZ), tvbbqq ($t\bar{t}$ -bar), vvbvvv (ZZZ/ZZH)
- qqHH: bbbb (ZZ, γZ , bbZ), bbqqqq ($t\bar{t}$ -bar), qqbbbb (ZZZ/ZZH)

event selection:

$B/S \sim 10^{3-4}$

- isolated-lepton selection or rejection
- jet clustering and flavor tagging
- missing energy or visible energy requirement
- event reconstructed as from signal and dominant background
- each dominant background is suppressed by training a neural-net

- updating analysis with $m_H=125$ GeV
- impact of beam background from $\gamma\gamma \rightarrow$ hadrons
- impact of beam polarisations
- improving analysis technique / strategy

500 GeV: 500 (1600) fb^{-1}
1 TeV: 1000 (2500) fb^{-1}

$\Delta\lambda_{HHH}/\lambda_{HHH}$	500 GeV	+ 1 TeV
Baseline	83%	21%
LumiUP	46%	13%

Masakazu Kurata

HIGGS SELF COUPLING ANALYSIS USING THE EVENTS CONTAINING $H \rightarrow WW^*$ DECAY

- Effect of track energy correction using particle ID is small, but going to good direction
- Kinematic fitting will be a good tool for mass resolution improvement

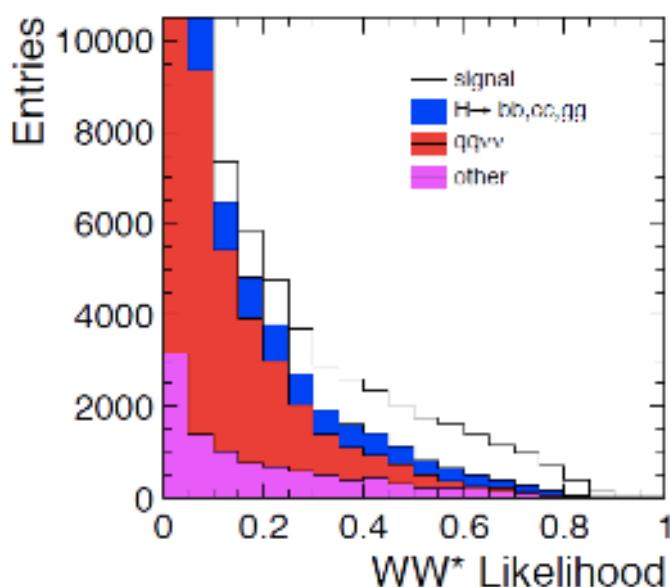
Gordana Milutinovic-Dumbelovic

H->ZZ* at 1.4 TeV CLIC

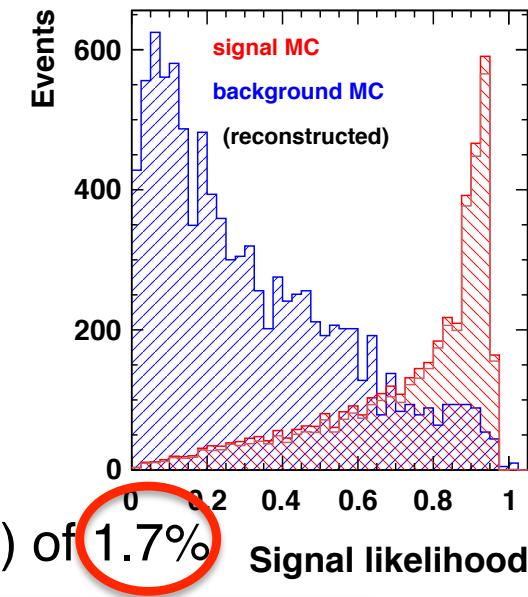
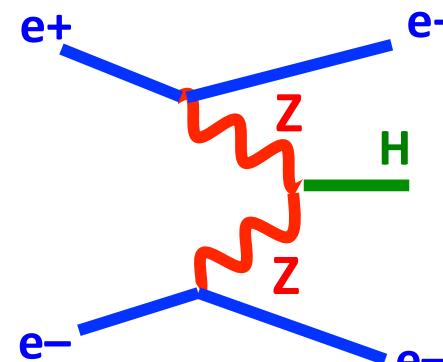
$$\begin{aligned} \delta(\sigma_{WWH} \times \text{BR}(H \rightarrow ZZ \rightarrow qqqq)) &= 18.3\% \\ \delta(\sigma_{WWH} \times \text{BR}(H \rightarrow ZZ \rightarrow qqll)) &= 6.1\% \end{aligned}$$

Mila Pandurović

H->WW* at 350 GeV and 1.4TeV CLIC



Higgs production in ZZ fusion at 1.4 TeV CLIC



Total uncertainty on $\sigma(ee \rightarrow eeH) \cdot \text{Br}(H \rightarrow bb)$ of 1.7%

Signal and background shapes so different \Rightarrow need to include constraints

Branching fractions of Higgs to bb,cc and gg are constrained to the values obtained from the independent measurements at 1.4 TeV

$$\chi^2 \sim \chi^2 + \frac{(1 - s^2_{gg})^2}{\sigma^2_{gg}} + \frac{(1 - s^2_{bb})^2}{\sigma^2_{bb}} + \frac{(1 - s^2_{cc})^2}{\sigma^2_{cc}} + \frac{(1 - b^2)^2}{\sigma^2_b}$$

$$\left. \begin{aligned} \sigma_{bb} &= 1.8\%, \quad \sigma_{cc} = 2.9\%, \\ \sigma_{bb} &= 0.3\%, \quad \sigma_b = 1.0\% \text{ (assumed)} \end{aligned} \right\}$$

FIT \Rightarrow

$$\frac{\Delta\sigma}{\sigma} = 1.4\%$$

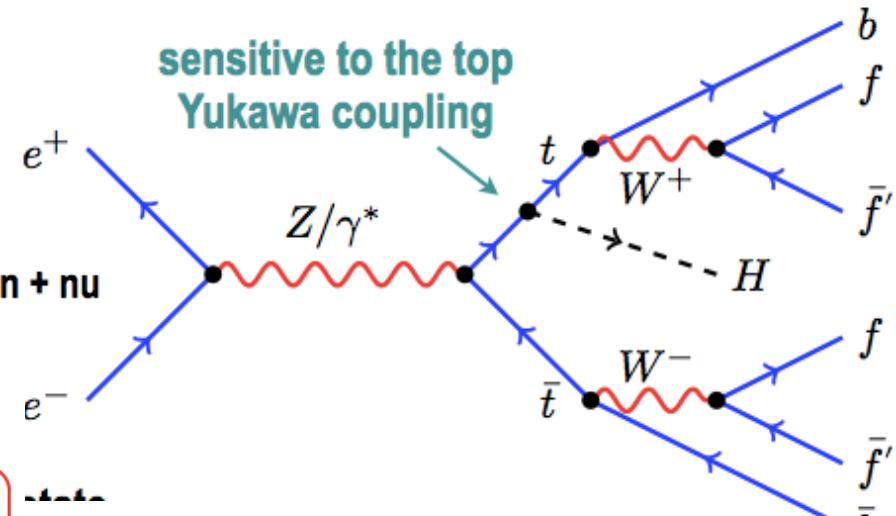
at 1.4TeV. Results from 350GeV soon.

Sophie Redford

Top Yukawa coupling at 1.4 TeV CLIC

- 1) Lepton finding
- 2) Jet clustering
- 3) Flavour tagging
 1. Fully hadronic channel: eight jets
 2. Semi-leptonic channel: six jets + lepton + nu
 - 4 b jets!
- 4) Jet grouping Choose permutation with smallest χ^2 :

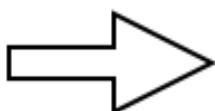
$$\chi^2 = \frac{(M_{12} - M_W)^2}{\sigma_W^2} + \frac{(M_{123} - M_t)^2}{\sigma_t^2} + \frac{(M_{45} - M_h)^2}{\sigma_h^2}$$



Updated to include non-tt+X backgrounds

- The uncertainty on the top Yukawa coupling measurement at 1.4 TeV changes from:

$$\Delta g_{ttH}/g_{ttH} = 4.3\%$$



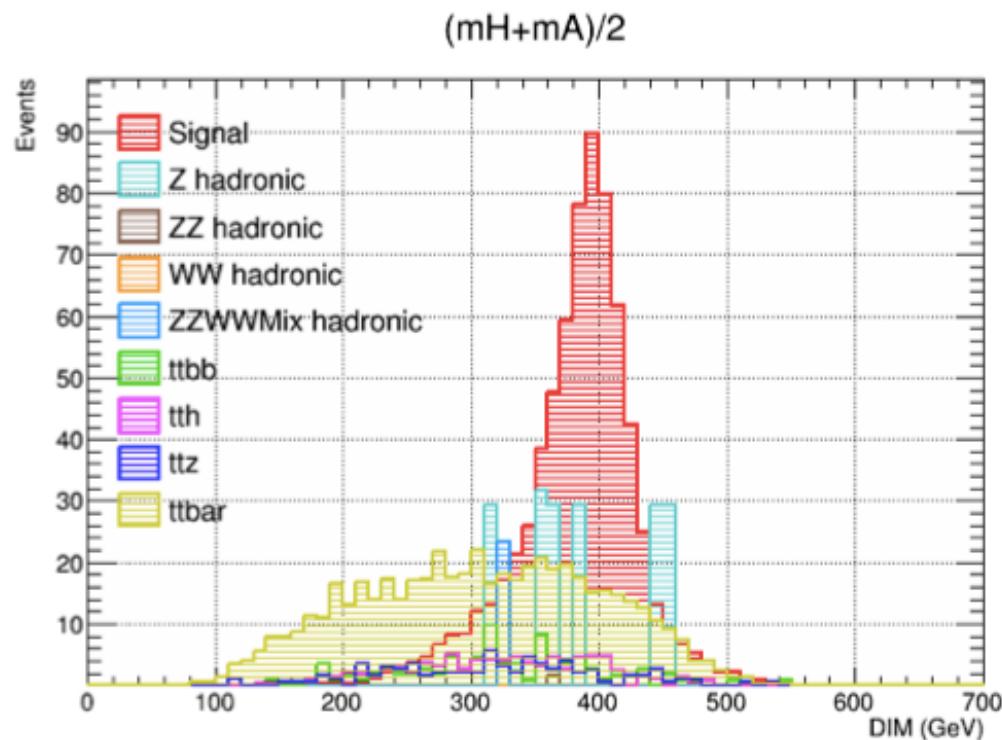
$$\Delta g_{ttH}/g_{ttH} = 4.5\%$$

- To be compared with ILC analyses at 1 TeV:
 - ILD $\Delta g_{ttH}/g_{ttH} = 4.3\%$ (LC-REP-2013-004)
 - SiD $\Delta g_{ttH}/g_{ttH} = 4.5\%$ (arXiv:1307.7644)
- Future improvements could be made by using discriminating variables based on reconstructing events as 4 jets

Abhinav Dubey/
Jan Strube

$e^+e^- \rightarrow HA \rightarrow bbbb$ at 1 TeV ILC

The ILC with $\sqrt{s} = 1$ TeV can directly study extra Higgs bosons with masses less than 500 GeV in relatively low $\tan\beta$ regions, which can't be detected easily in LHC.



same mass for both particles, 400 GeV
 $\tan\beta = 10$

x-section: $\sqrt{s} = 1$ TeV 2.38 fb
prominent decay into bb(bar)

Branching fraction for $H \rightarrow bb$ 77%

$A \rightarrow bb$ 65%

Clear separation of signal

Will set limits as function of mass / $\tan\beta$

Hiroshi Yokoya

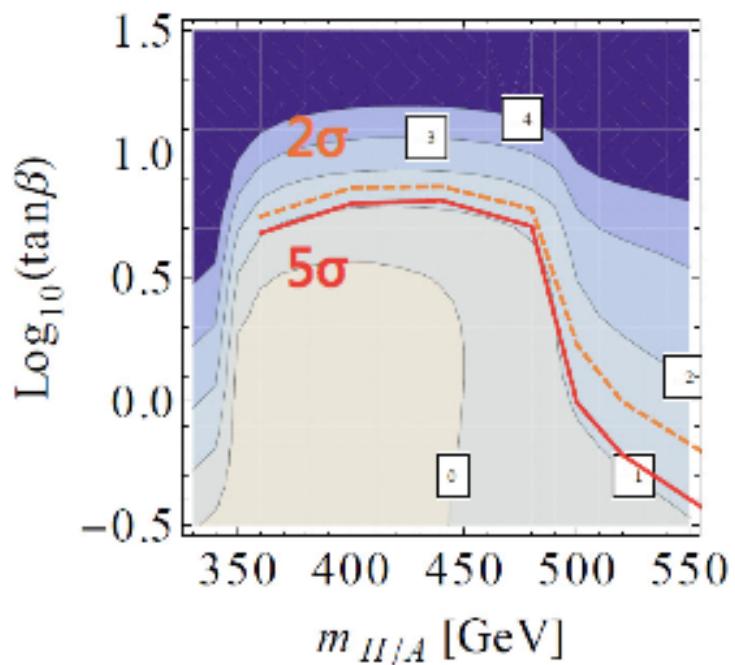
Direct Searches of 2HDM Bosons in Multi-top Events

consider the SM-like limit (alignment)

- No deviation in the couplings of light Higgs(h) with SM particles,
- Mass scale of additional Higgs bosons can be still as low as TeV scale
→ Indirect method is difficult, only the direct method is available

We focus on the parameter regions of $M_{H,A} \gtrsim 350$ GeV & small $\tan\beta$
where H/A decay into $t\bar{t}$.

- At the LHC, $pp \rightarrow H/A \rightarrow t\bar{t}$
 - At the ILC, $e^+e^- \rightarrow HA \rightarrow t\bar{t}t\bar{t}$
- Contours of $\log_{10}[\sigma_{4t}]$



difficult to find $t\bar{t}$ resonance

detectable at $\sqrt{s} = 1$ TeV stage

(Type-II(Y) Yukawa, $\sin(\beta-\alpha)=1$)

4-top cross-sections of about
0.08 (0.03) [fb] can be probed
at the **5σ(2σ) CL.**

Tim Barklow

 $\sigma(ZH)$ with $Z \rightarrow q\bar{q}$ (Mark Thomson)

$$\sigma(ZH) = \sigma(ZH) \cdot BR(\text{visible}) + \sigma(ZH) \cdot BR(\text{invisible})$$



Model Independent?

- Combining visible + invisible analysis: wanted M.I.
 - i.e. efficiency independent of Higgs decay mode

Decay mode	$\epsilon_{Z>0.65}^{\text{vis}}$	$\epsilon_{Z>0.60}^{\text{vis}}$	$\epsilon^{\text{vis}} + \epsilon^{\text{invis}}$
H \rightarrow invis.	<0.1 %	22.0 %	22.0 %
H \rightarrow $q\bar{q}/gg$	22.2 %	<0.1 %	22.2 %
H \rightarrow WW^*	21.6 %	0.1 %	21.7 %
H \rightarrow ZZ^*	20.2 %	1.0 %	21.2 %
H \rightarrow $\tau^+\tau^-$	24.7 %	0.3 %	24.9 %
H \rightarrow $\gamma\gamma$	25.8 %	<0.1 %	25.8 %
H \rightarrow $Z\gamma$	18.5 %	0.3 %	18.8 %
H \rightarrow $WW^* \rightarrow q\bar{q}q\bar{q}$	21.3 %	<0.1 %	21.3 %
H \rightarrow $WW^* \rightarrow q\bar{q}l\nu$	21.9 %	<0.1 %	21.9 %
H \rightarrow $WW^* \rightarrow q\bar{q}\tau\nu$	22.1 %	<0.1 %	22.1 %
H \rightarrow $WW^* \rightarrow l\nu l\nu$	24.8 %	0.1 %	25.0 %
H \rightarrow $WW^* \rightarrow l\nu\tau\nu$	20.5 %	0.8 %	22.1 %
H \rightarrow $WW^* \rightarrow \tau\nu\tau\nu$	16.4 %	2.5 %	18.9 %

Very similar efficiencies

Look at wide range of WW topologies

Using the Hadronic Recoil Cross Section Measurement in Higgs Coupling Fits

how much must we blow up $\Delta\sigma(ZH) \cdot BR(\text{visible})$ to account for the fact that the efficiencies differ by as much as 7%?

Propagate uncertainties on all $\sigma \cdot Br$ measurements to $\sigma(ZH) \cdot BR(\text{visible})$ -

Handle BSM contribution:

We assume that Mark's vis+invis efficiency values cover all possible BSM decays since they cover all SM decays from completely invisible to fully hadronic multi-jet decays. Assuming no knowledge of the properties of the BSM decays we can then set

$$\xi_{BSM} = 0.5 * [\xi_{\text{vis+invis}} (\text{max}) + \xi_{\text{vis+invis}} (\text{min})] = 0.5 * [0.258 + 0.188] = 0.22$$

$$\Delta\xi_{BSM} = 0.5 * [\xi_{\text{vis+invis}} (\text{max}) - \xi_{\text{vis+invis}} (\text{min})] = .035$$

obtain the error $\tau_{BSM} = \frac{\Delta\sigma \cdot BR_{BSM}}{\sigma \cdot BR_{BSM}}$

from Michael Peskin's Higgs coupling fit
only use the leptonic recoil σ_{ZH}
no $\sum_i BR_i = 1$ constraint

model independent measurement of g_{BSM}

add this new model independent hadronic recoil σ_{ZH} measurement to obtain a new error $\tau_{BSM} = 0.041$
iterate for new model-indep hadronic recoil uncertainty = 11% of stat error assuming no knowledge of BSM Higgs decays

Frank Simon

Combined Fits of Higgs Couplings at CLIC

- From the measurements of σ and $\sigma \times \text{BR}$ the couplings and the total width are determined by a global fit:

$$\chi^2 = \sum_i \frac{(C_i - 1)^2}{\Delta F_i^2}$$

ΔF_i : uncertainty of measurement
(σ or $\sigma \times \text{BR}$)

Model-independent fit - total width as a free parameter

Model-dependent fit - LHC-like constraints

New: check effect of correlations in 350GeV $H \rightarrow bb/cc/gg$
combine ZH and VBF measurements in $H \rightarrow cc/gg$

Model-independent fit:

- Including the ZH / VBF combination improves g_{Hcc} and g_{Hgg} by about 3%
- Including correlations in addition:
 - g_{Hcc} and g_{Hgg} are slightly deteriorated again
 - g_{Hbb} is deteriorated by $\sim 5\%$
 - g_{HWW} is improved by $\sim 3\%$
- total width is improved by $\sim 1.5\%$

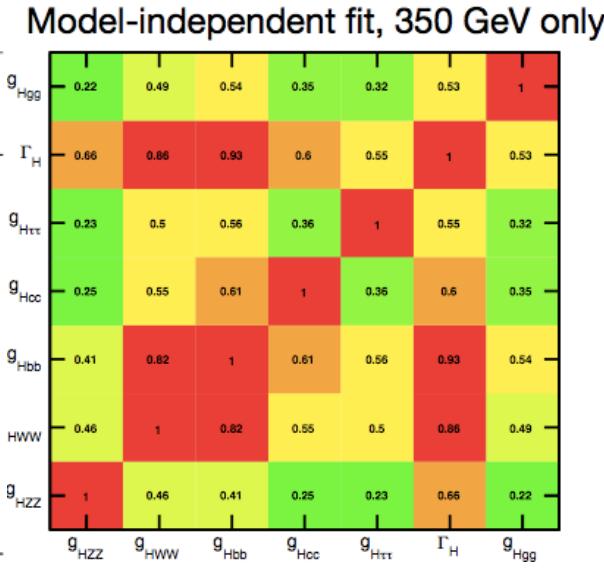
- Model-independent:

- Model-dependent:

work in progress - current status

Parameter	Measurement precision		
	350 GeV 500 fb $^{-1}$	+ 1.4 TeV +1.5 ab $^{-1}$	+3.0 TeV +2.0 ab $^{-1}$
g_{HZZ}	0.8 %	0.8 %	0.8 %
g_{HWW}	1.8 %	0.9 %	0.9 %
g_{Hbb}	2.0 %	1.0 %	0.9 %
g_{Hcc}	3.2 %	1.4 %	1.1 %
$g_{H\tau\tau}$	3.7 %	1.7 %	1.5 %
$g_{H\mu\mu}$	—	14.1 %	5.6 %
g_{Htt}	—	4.1 %	$\leq 4.1\%$
g_{Hgg}^\dagger	3.6 %	1.2 %	1.0 %
$g_{H\gamma\gamma}^\dagger$	—	5.7 %	< 5.7 %
Γ_H	5.0 %	3.6 %	3.4 %

Parameter	Measurement precision		
	350 GeV 500 fb $^{-1}$	+ 1.4 TeV +1.5 ab $^{-1}$	+3.0 TeV +2.0 ab $^{-1}$
κ_{HZZ}	0.44 %	0.31 %	0.23 %
κ_{HWW}	1.5 %	0.17 %	0.11 %
κ_{Hbb}	1.7 %	0.37 %	0.22 %
κ_{Hcc}	3.1 %	1.1 %	0.75 %
$\kappa_{H\tau\tau}$	3.7 %	1.5 %	1.2 %
$\kappa_{H\mu\mu}$	—	14.1 %	5.5 %
κ_{Htt}	—	4.0 %	$\leq 4.0\%$
κ_{Hgg}	3.6 %	0.79 %	0.55 %
$\kappa_{H\gamma\gamma}$	—	5.6 %	< 5.6 %
$\Gamma_{H,md,derived}$	1.6 %	0.32 %	0.22 %



Shinya Kanemura

Higgs couplings for
fingerprinting extended
Higgs sectors – 2HDM as
example

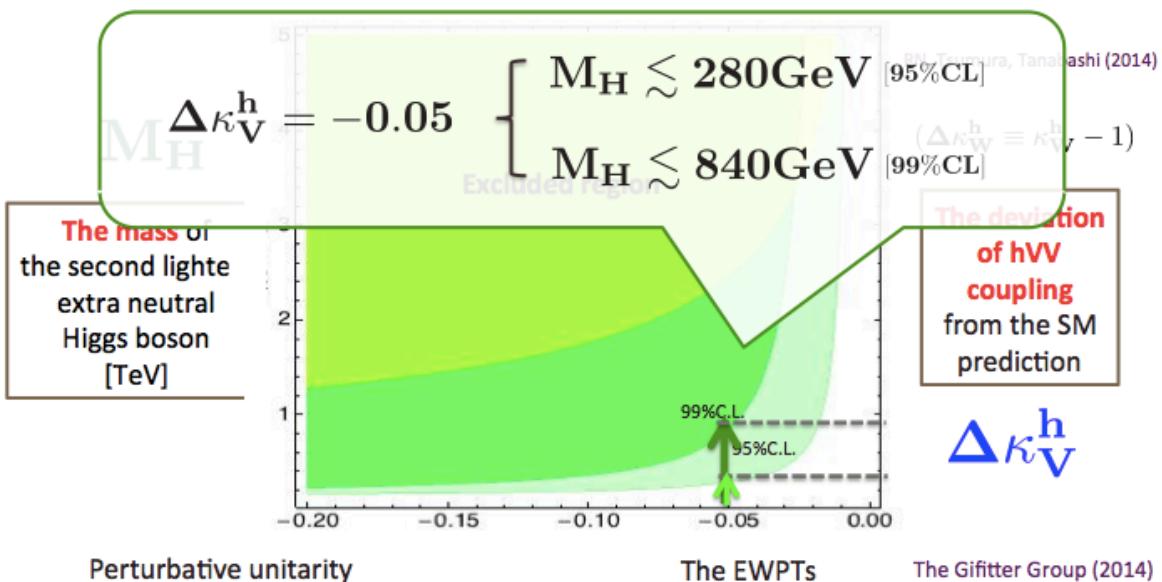
Radiative corrections to the Higgs coupling constants in extended Higgs sectors

Evaluation at one-loop

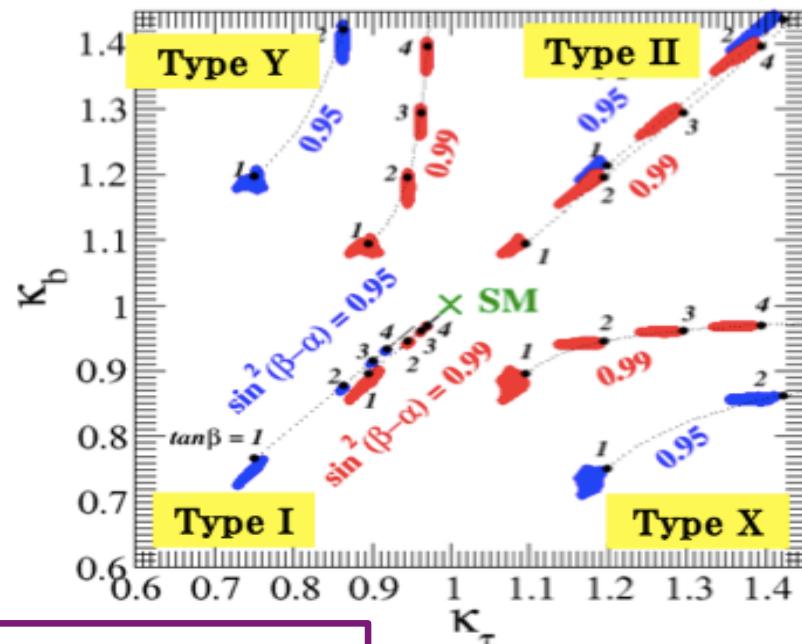
Scan of inner parameters under theoretical and experimental constraints (for each $\tan\beta$)

Ryo Nagai

We introduce arbitrary number of neutral Higgs bosons in the electroweak symmetry breaking sector.

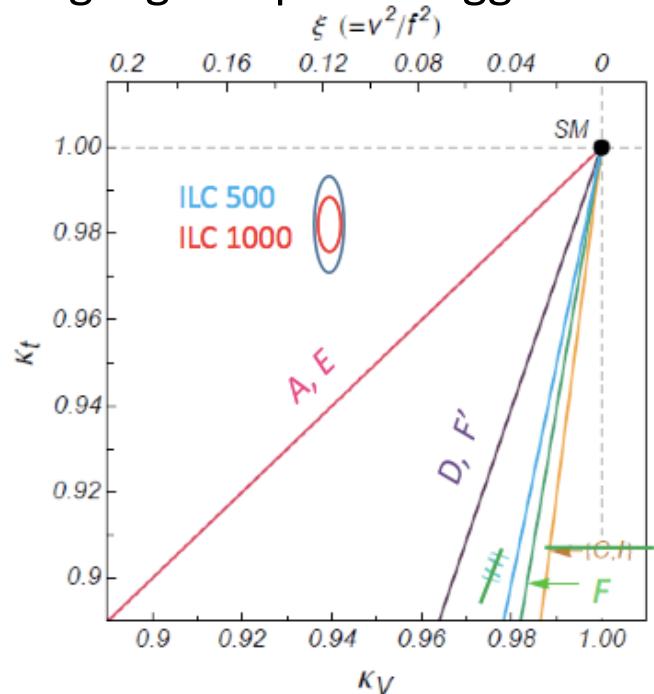


Considering unitarity and EW precision measurements gives strong constraints on mass as function of SM-coupling deviation



Naoki Machida

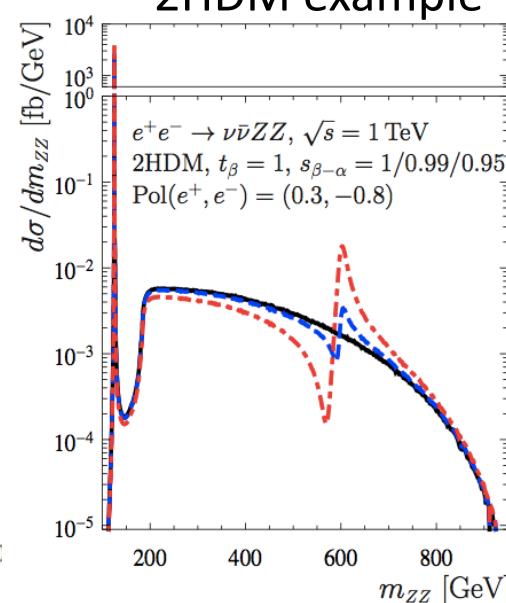
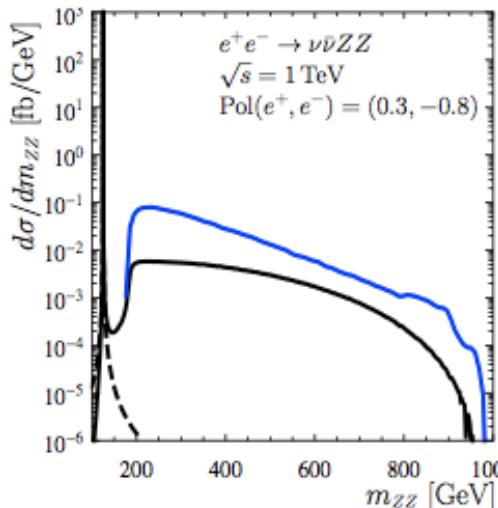
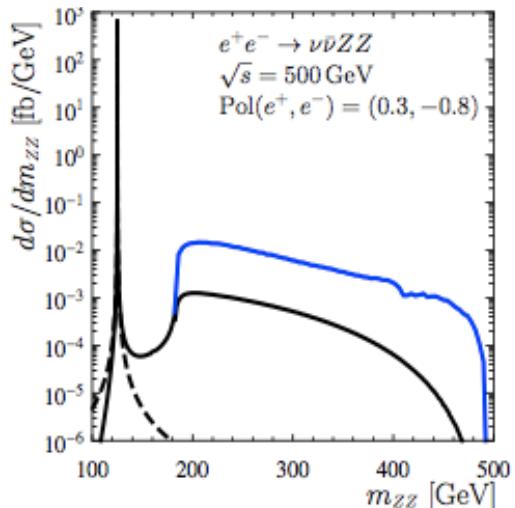
disentangling composite Higgs models



Stefan Liebler

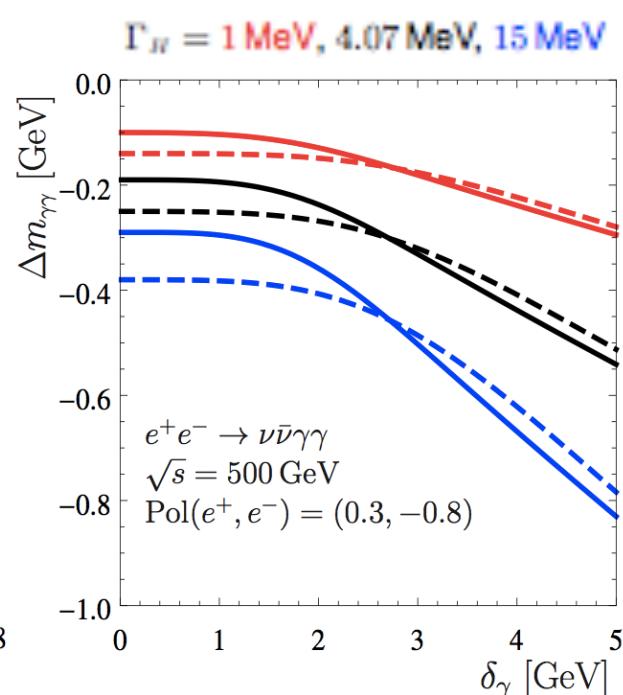
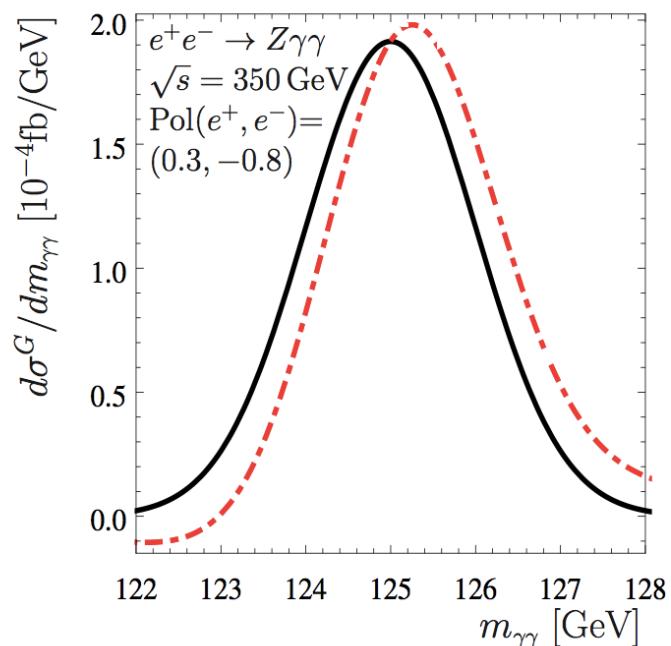
Off-shell effects in Higgs decays to gauge bosons at a LC

Off-shell contributions to $H \rightarrow VV$
 – test influence of higher-dim. operators
 – determine H width



LHC-inspired effects for linear collider!

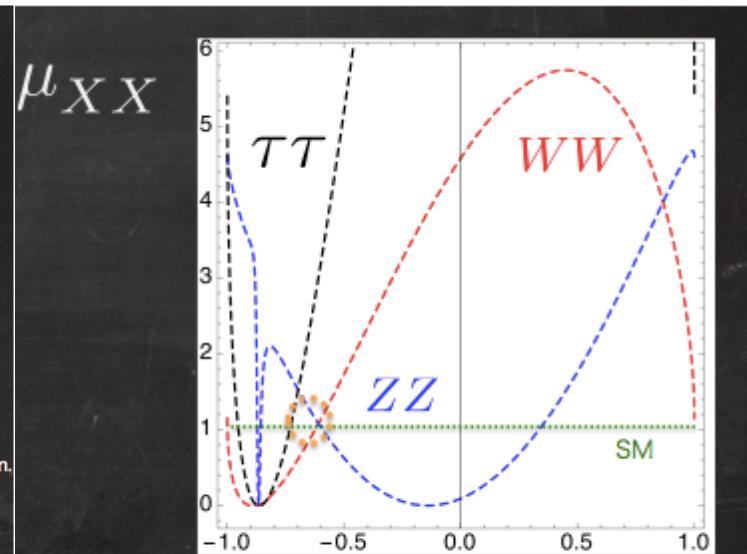
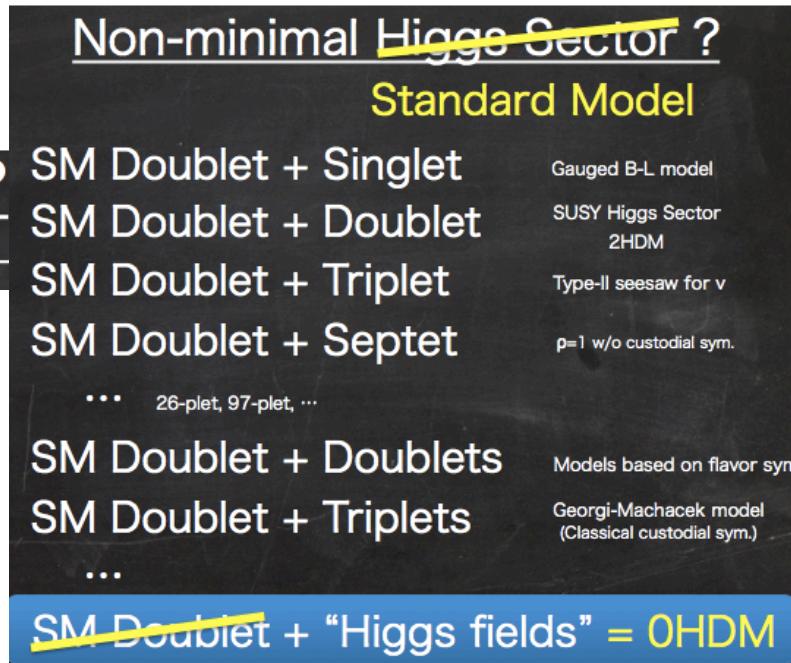
Interferometry with background in $H \rightarrow \gamma\gamma$





Koji Tsumura

What if $K_W \neq K_Z$?
- 0HDM (Zero Higgs Doublet Model) -



tau signal strength can be SM-like
but WW and ZZ deviate $\cos \theta_0$

Juergen Reuter

High-energy Vector Boson Scattering

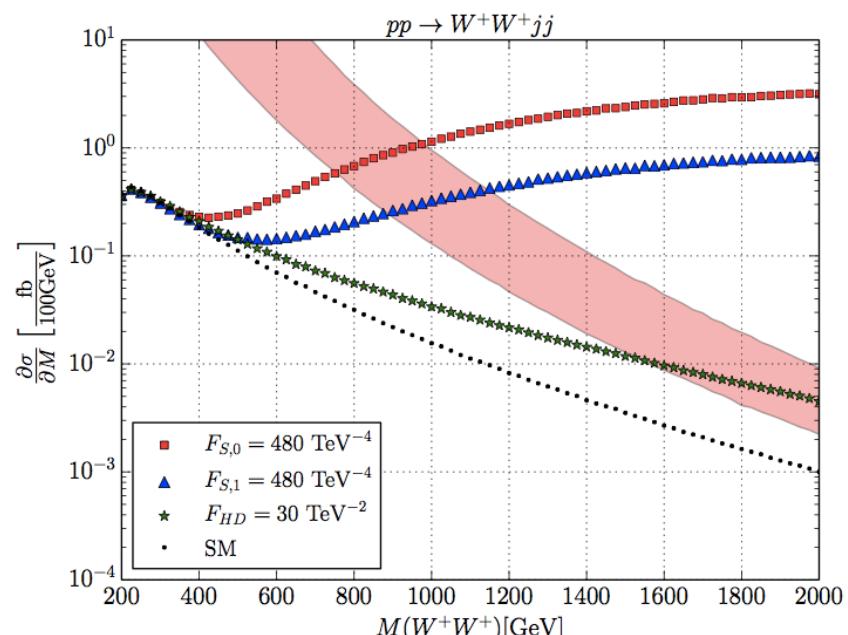
has higher-dimensional operators:

Weinberg, 1979

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \left[\frac{a_i}{\Lambda} \mathcal{O}_i^{(5)} + \frac{c_i}{\Lambda^2} \mathcal{O}_i^{(6)} + \frac{e_i}{\Lambda^4} \mathcal{O}_i^{(8)} \dots \right]$$

-> aQGC, aTGC

Had first LHC vector boson scattering results
this year – hard to compare with LEP – need
unified LHC and ILC/CLIC descriptions





Theory review talks – look at slides

Gudrid Moortgat-Pick

SUSY interpretations of the H signal: Implications for the LC

Conclusions

- Extended Higgs sectors of SUSY-type: well motivated alternative to SM
 - Search for Higgs states of extended Higgs sector: need to test compatibility with signal at 125 GeV
- Most obvious interpretation of signal, $h(125)$: lightest Higgs state
- MSSM: $M_h = 125$ GeV (lightest Higgs) implies $M_A \gg M_Z$:
 - decoupling region, SM-like Higgs; MSSM provides good fit to the data, slightly improved fit quality w.r.t. SM
- Extended Higgs sector where the second-lightest Higgs is identified with the signal at 125 GeV
 - additional light Higgs with suppressed couplings to gauge bosons
 - ‘exotic scenario’ within the MSSM, can be realized generically in the NMSSM: NMSSM fit prefers singlet-like light Higgs
- Physics potential of the LC: high precision measurement of $h(125)$ and searches for light/heavy Higgses!

Stefan Liebler

SM Higgs physics at a LC (Personal) theory overview

Conclusions:

- Higher order corrections for all SM Higgs production processes in good shape (partially since quite a bit) and needed to reach full LC potential → sufficiently accurate for LC performance predictions
- Future theory steps:
 - Event generators including higher orders (first QCD, then EW) (MadGraph5_aMC@NLO, Whizard)
 - Maybe further improvements w.r.t. $e^+e^- \rightarrow t\bar{t}(H)$ (within generators)
 - Exploit large off-shell Higgs contributions including higher order corrections (not visible at circular e^+e^- collider)
 - Distributions at higher orders and Higgs flavour violating decays
 - ...

Aidan Randle-Conde

Study of systematic errors on scalar boson mass

Adrien Caudron

Applications of matrix element methods

LHC techniques talks



Full and lively Higgs/EW sessions

Significant effort
addressing charge:

The Committee, however, expresses the desire for more compelling and articulate argument to justify the ILC project in order to search for unknown particles and the physics beyond the Standard Model, running concurrently with the upgraded LHC

Thanks to all who contributed.