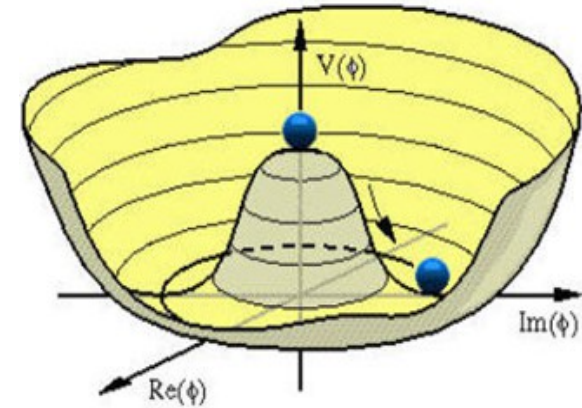


Probing the Higgs Potential

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- From the scalar potential before EWSB:

- $V(\Phi) = -\mu^2|\Phi|^2 + \lambda|\Phi|^4$

- $V(\Phi)$ after EWSB with $M_h^2 = 2\mu^2$, $v^2 = \mu^2/\lambda$

- $\Phi = (0, (v+h)/\sqrt{2})$

- $V(h) = 1/2 M_h^2 h^2 + 1/2 M_h^2/v h^3 + 1/8 M_h^2/v^2 h^4 + \text{Const}$

- Trilinear and Quartic Higgs coupling:

- $\lambda_{hhh} = 3M_h^2/v$

- $\lambda_{hhhh} = 3M_h^2/v^2$

- Within SM, the coupling is determined.

- BSM: max deviations ranging from few to 20% (arxiv:1305.6397)

- Targeted precision: <5% for both theory and experiments. We can either confirm SM or discover BSM.

Model	$\Delta g_{hhh}/g_{hhh}^{\text{SM}}$
Mixed-in Singlet	-18%
Composite Higgs	Tens of %
Minimal Supersymmetry	-2% -15%
NMSSM	-25%

Snowmass Studies

- Expected precisions on the trilinear Higgs coupling assuming all other Higgs coupling are SM-like and no other new physics contributions.

- Individual Collider:

	HL-LHC	ILC500	ILC500-up	ILC1000	ILC1000-up	CLIC1400	CLIC3000	HE-LHC	VLHC
\sqrt{s} (GeV)	14000	500	500	1000/1000	1000/1000	1400	3000	33,000	100,000
$\int \mathcal{L} dt$ (fb ⁻¹)	3000/expt	500	1000 ²	1000+1000	1000+2000 ²	1800	+2000	3000	3000
λ	10%	15%	40%	21%	15%	21%	10%	20%	8%

- Combination of colliders:

LHC	HL-LHC								
	+ILC	+ILC-up	+(TLEP)			+ILC-up		+CLIC	
			+CLIC	+HE-LHC	+VLHC	+HE-LHC	+VLHC	+HE-LHC	+VLHC
21%	12.6%	15.2/9.8%	18.6%	7.9%	10.9%	6.8%	12.5/8.9%	7.2/6.2%	

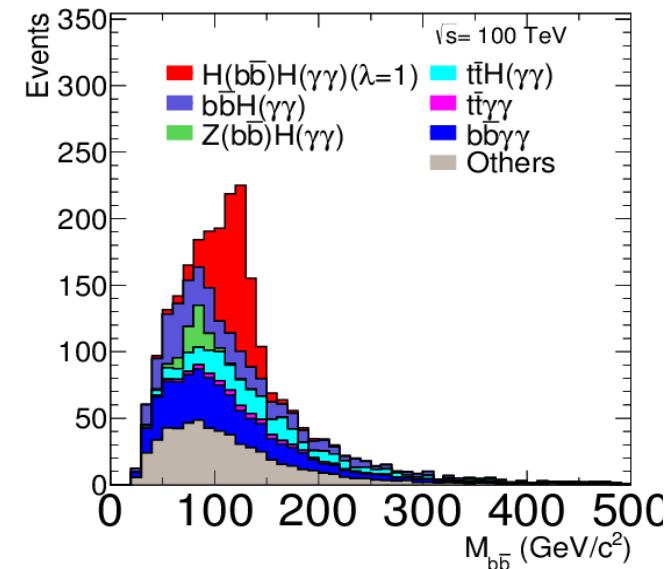
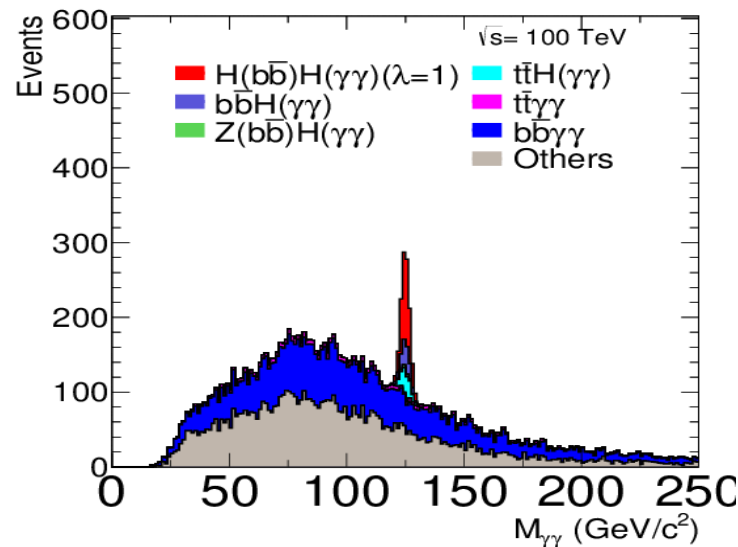
- Unfortunately, 8% for VLHC is bit optimistic:

- No fakes included and statistic error on $d\sigma/\sigma = \sqrt{(S+B)/S}$.
- The slope $d\sigma/d\lambda = -0.8$ did not correct for the acceptance.

Updating $HH \rightarrow b\bar{b}\gamma\gamma$ at Tev100

- Using Delphes 3.1.14 and the results depends on detector performance assumed.
- Including $jj\gamma\gamma$, $b\bar{b}\gamma\gamma$, $t\bar{t}\gamma\gamma$ with ATLAS $\epsilon_\gamma=0.0093e^{-(-E_t/27.5)}$ for HL-LHC
- Tighten $m_{\gamma\gamma}$ window from 10 GeV used for snowmass to 6 GeV.

Sample	$\sigma \cdot BR$ (fb)	Generated ev.	Selected ev.	Acc.	Expected (Stat.)
$H(b\bar{b})H(\gamma\gamma)(\lambda=1)$	353	10000	3925	0.04	418.8±6.6
$H(b\bar{b})H(\gamma\gamma)(\lambda=0)$	688	10000	3322	0.0322	695.7±11.8
$H(b\bar{b})H(\gamma\gamma)(\lambda=2)$	75	10000	4366	0.04566	247.1±3.6
$\bar{t}\bar{t}(\gamma\gamma)$	52.49	99611	78	0.00178	118.6±12.4
$Z(b\bar{b})H(\gamma\gamma)$	0.8346	98589	378	0.0038	142±10.7
$\bar{t}\bar{t}H(\gamma\gamma)$	37.26	23924	67	0.0010	117.2±14.8
$t\bar{t}\gamma\gamma$	322.8	15022.4	1	6.6e-3	672±6.7
$b\bar{b}\gamma\gamma$	128100	285787	0.018	6.7e-3	15.2±3.2
$b\bar{b}j\gamma\gamma$	5237	763362	11	1.4e-3	217.6±65.6
$b\bar{b}jj\gamma\gamma$	836000	1113406	0.005	4.6e-3	123.61±31.8
$jj\gamma\gamma$	121200	613277	0.056	6.8e-3	83.0±3.8
Total backg. sim.	-	-	-	-	647.3±77.1
S/\sqrt{D}	-	-	-	-	16.1



- Significance = 16.5 with 3 ab⁻¹.
- H coupling $d\lambda/\lambda=15\%$ with $d\sigma/d\lambda=-0.51$
- ArXiv:1412.7154 reported 40% using ATLAS photon ID eff.
- To achieve 5% precision, we need to combine with other channels or get more integrated luminosity (~30 ab⁻¹).
- Also start to probe Higgs coupling in VBF, $t\bar{t}HH$ channels.

