Higgs self coupling — some old man's memories

Tilman Plehn

Universität Heidelberg

Higgs Couplings, 11/2012

Higgs self coupling

The missing piece

- LHC measurements of g_{HXX} on the way
  LHC determination of coupling structure on the way
- Higgs potential
  $$V = \mu^2(\Phi^\dagger\Phi) + \lambda(\Phi^\dagger\Phi)^2 \quad \Rightarrow \quad \lambda = \frac{m_H^2}{2v^2}$$

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- including D6 operators
$$\mathcal{O}_1 = \frac{1}{2}\partial_\mu(\phi^\dagger\phi)\,\partial^\mu(\phi^\dagger\phi) \qquad \mathcal{O}_2 = -\frac{1}{3}(\phi^\dagger\phi)^3$$
- modified self couplings
$$\mathscr{L}_{\text{self}} = -\frac{m_H^2}{2v}\left[\left(1-\frac{f_1 v^2}{2\Lambda^2}+\frac{2f_2 v^4}{3\Lambda^2 m_H^2}\right)H^3 - \frac{2f_1 v^2}{\Lambda^2 m_H^2}H\,\partial_\mu H\,\partial^\mu H\right]$$
$$-\frac{m_H^2}{8v^2}\left[\left(1-\frac{f_1 v^2}{\Lambda^2}+\frac{4f_2 v^4}{\Lambda^2 m_H^2}\right)H^4 - \frac{4f_1 v^2}{\Lambda^2 m_H^2}H^2\,\partial_\mu H\partial^\mu H\right]$$
$$\text{Feynman rule} \quad -i\frac{3m_H^2}{v}\left[1-\frac{f_1 v^2}{2\Lambda^2}+\frac{2f_2 v^4}{3\Lambda^2 m_H^2}+\frac{2f_1 v^2}{3\Lambda^2 m_H^2}\sum_{j<k}^{3}(p_j p_k)\right]$$

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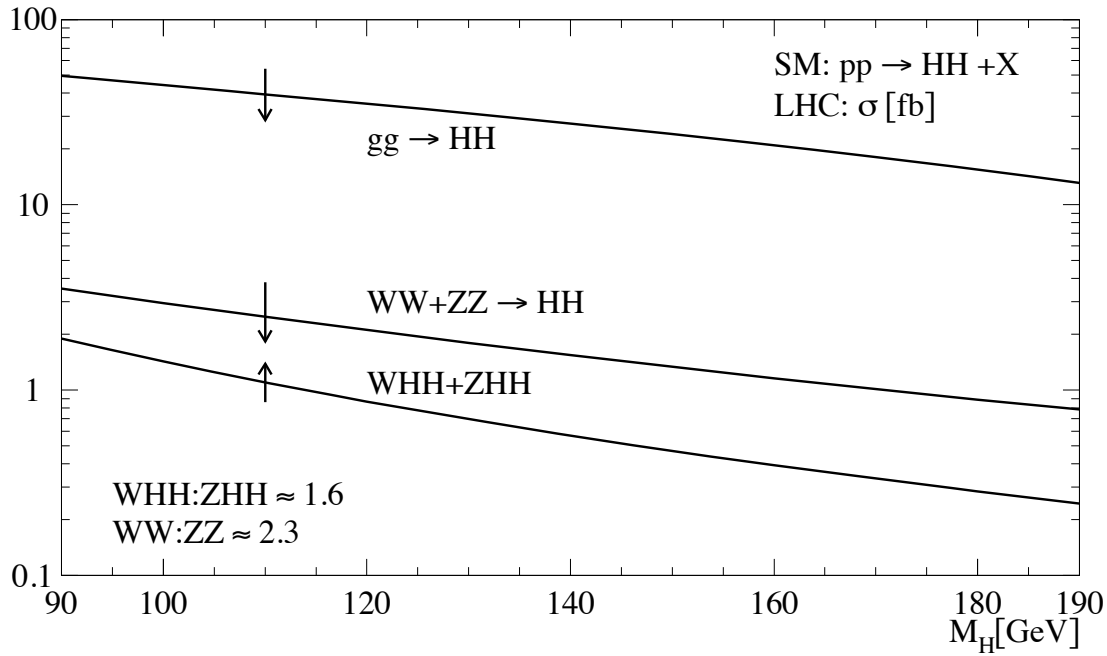
$\Rightarrow$ Higgs pair production

[Djouadi, Kilian, Mühlleitner, Zerwas]



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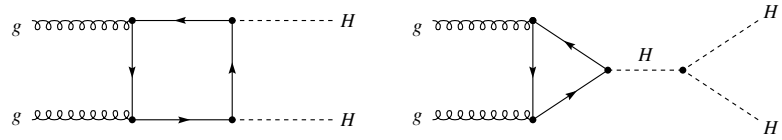
One-loop amplitude $gg \to HH$



- destructive interference: resonance–continuum
- convenient effective theory [links $ggHH$ vertex to gluon self energy for $m_H \ll m_t$]
$$\mathcal{L}_{ggH} = G^{\mu\nu}G_{\mu\nu}\,\frac{\alpha_s}{\pi}\left(\frac{H}{12v} - \frac{H^2}{24v^2} + \ldots\right) = \frac{\alpha_s}{12\pi}\,G^{\mu\nu}G_{\mu\nu}\,\log\left(1+\frac{H}{v}\right)$$
- threshold behavior
$$\left[3m_H^2\,\frac{g_{ggH}}{s-m_H^2} + g_{ggHH}\right]^2 \sim g_{ggH}\left[3m_H^2\,\frac{1}{3m_H^2} - 1\right]^2 \to 0$$

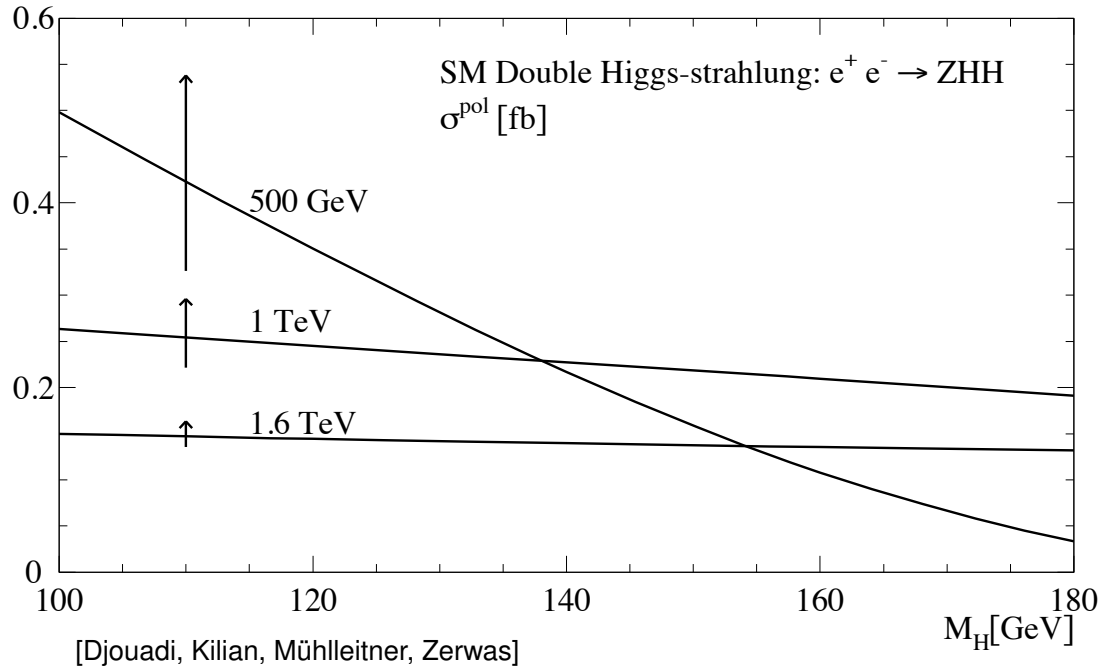
$\Rightarrow$ kinematics relevant

Linear collider

Rate at linear collider: $e^+e^- \to ZHH$

- very limited number of events
- low Higgs mass, decays $H \to b\bar{b}$ [Keisuke Fuji's talk]
- measurement of λ through total rate ($m_h = 120$ GeV)

$\Rightarrow$ hard measurement everywhere

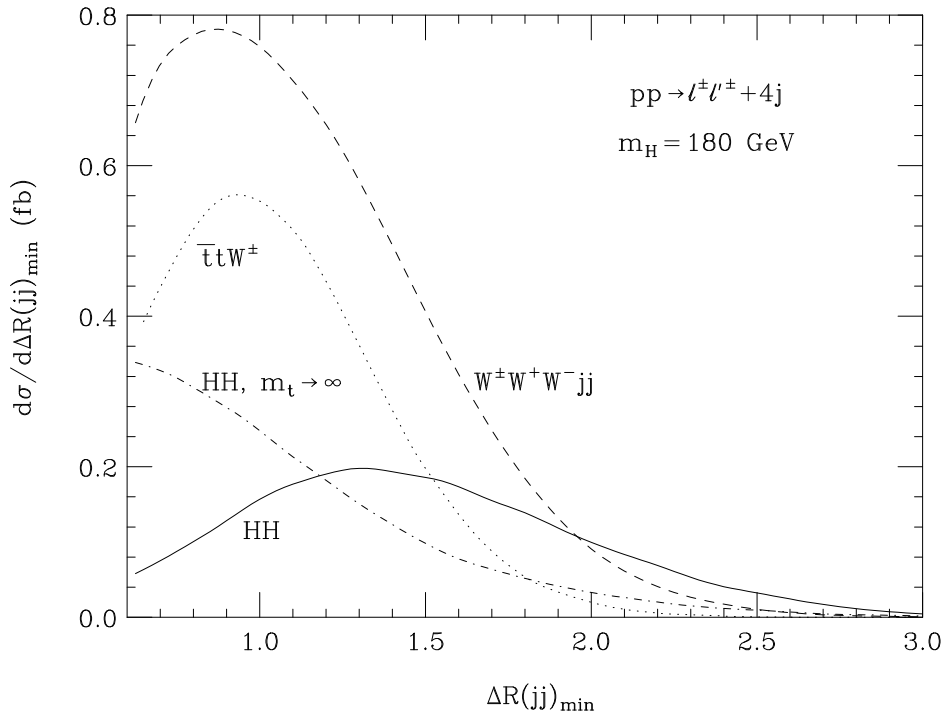


[Djouadi, Kilian, Mühlleitner, Zerwas]

Production process

Signal Extraction [Baur etal; Dolan etal]

- rates notorious at LHC [NLO: Dawson, Dittmaier, Spira]
- large top mass approximation wrong for distributions [Baur, TP, Rainwater]



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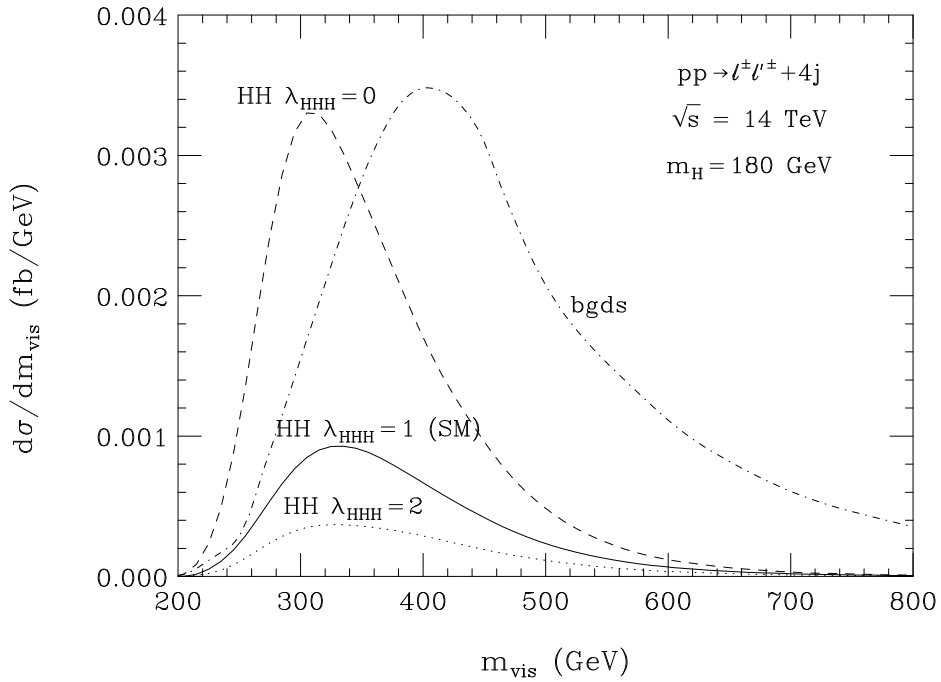

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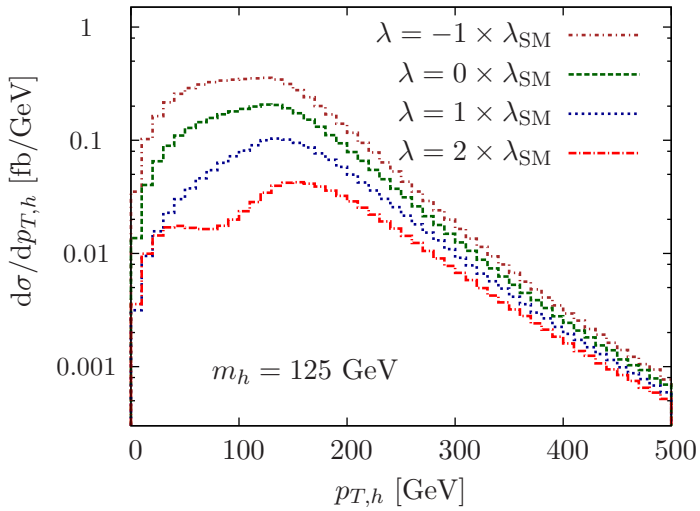

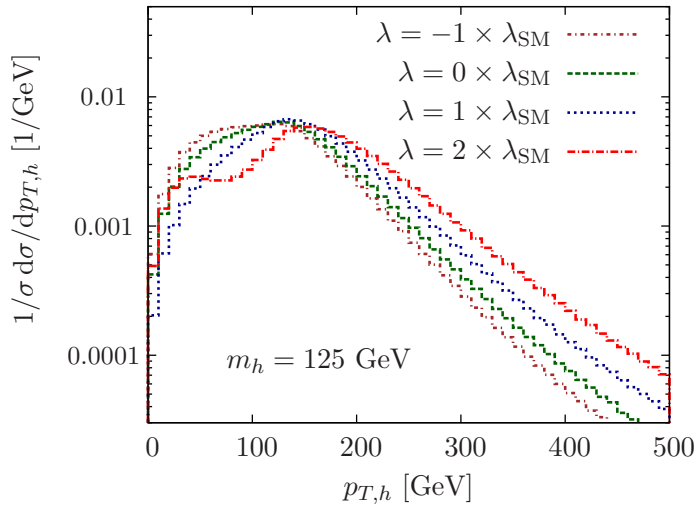

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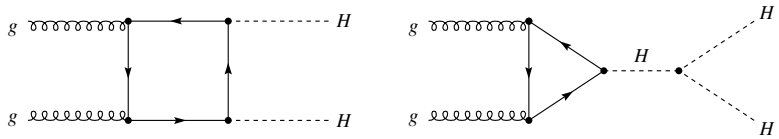
Analysis strategy [Baur etal]



- no 5σ signal for HH production
- assumption: Standard Model Higgs type scalar inducing coupling g_{ttH} from SFitter
- limits on 'anomalous' Higgs self coupling exclude $\lambda = 0$ with enhanced rate
- possibly including hard jet [Dolan etal]

Signatures

Historic channels: $HH \to 4W, b\bar{b}\gamma\gamma$ [Baur etal]

- $4W$: visible mass against backgrounds and to probe threshold $[\Sigma_{j,\ell}\, p^{\mu})^2]$
  (1) small for 2 particle final state (signal)
  (2) large for many backgrounds
- known problem: $t\bar{t}j$ background [matrix element versus shower?]
- only working for heavier Higgs?

m_h [GeV]	signal	$N^{2\times 300}$	$WWWjj$	$t\bar{t}W$	$t\bar{t}Z$	$t\bar{t}j$	$WZ4j$	$WW4j$	$t\bar{t}t\bar{t}$
150	0.074	44	0.361	0.222	0.054	0.082	0.148	0.0052	0.0018
160	0.194	116	0.486						
180	0.177	106	0.404						
200	0.083	50	0.292						

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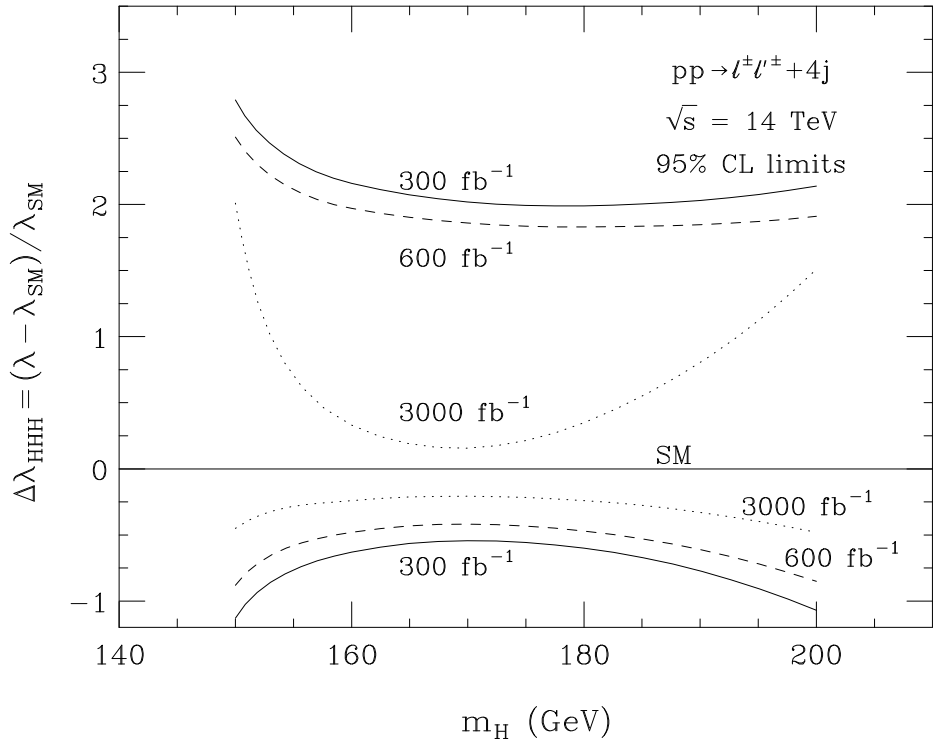

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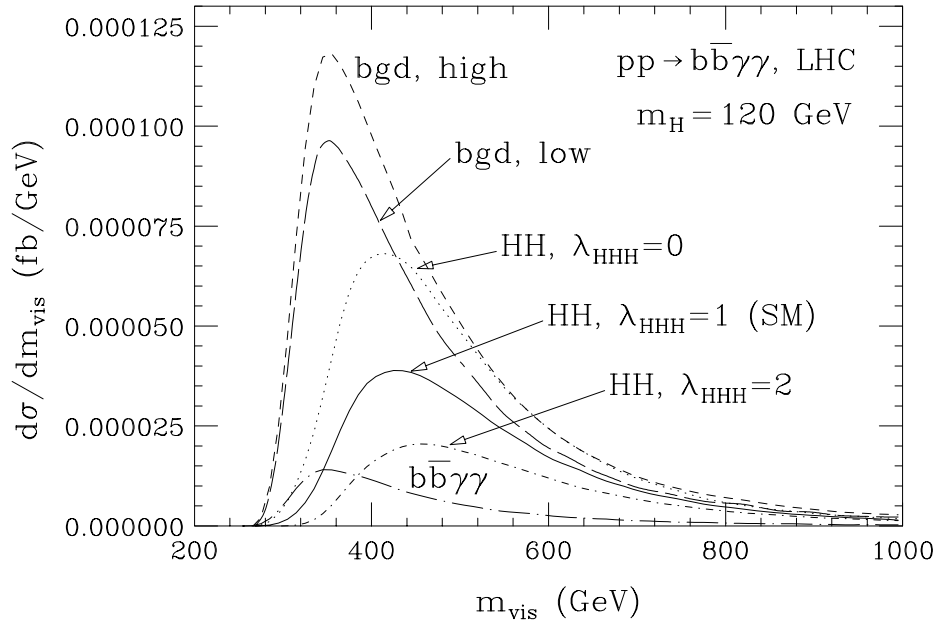

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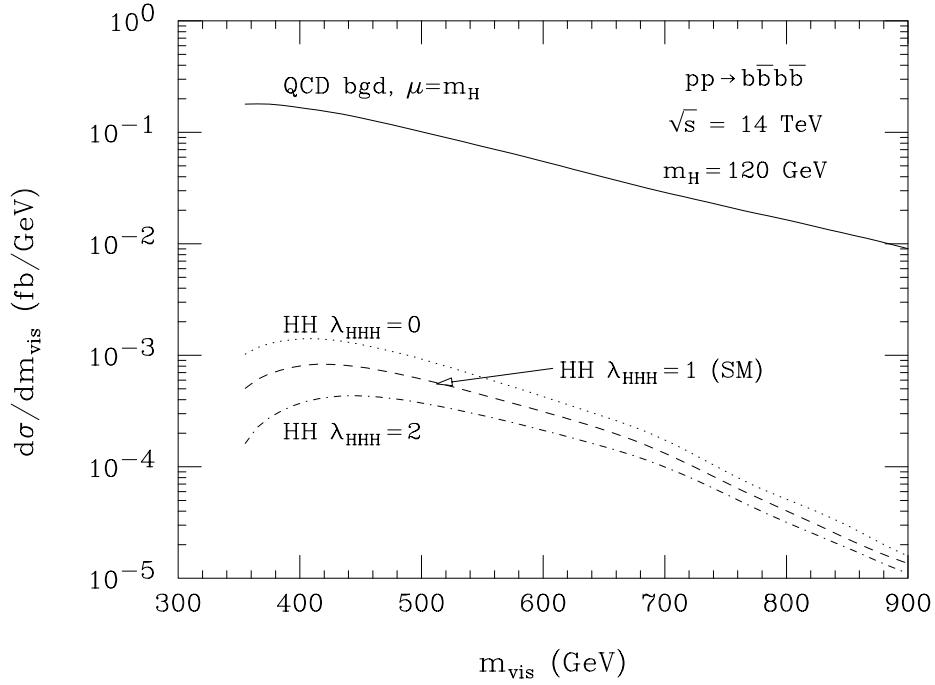

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	$\xi = 0$	$\xi = 1$	$\xi = 2$	$b\bar{b}\tau\tau$	$b\bar{b}\tau\tau$ [ew]	$b\bar{b}W^+W^-$	ratio to $\xi = 1$
before cuts	59.48	28.34	13.36	67.48	8.73	873000	$3.2 \cdot 10^{-5}$
reconstructed $m_{\tau\tau}$	4.05	1.94	0.91	2.51	1.10	1507.99	$1.9 \cdot 10^{-3}$
fatjet cuts	2.27	1.09	0.65	1.29	0.84	223.21	$4.8 \cdot 10^{-3}$
reconstructed $m_{b\bar{b}}$	0.41	0.26	0.15	0.104	0.047	9.50	$2.3 \cdot 10^{-2}$
double b-tag	0.148	0.095	0.053	0.028	0.020	0.15	0.48

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- $b\bar{b}W^+W^-$: not very promising [Dolan etal]
  maybe possible [Papaefstathiou etal]
- $t\bar{t}$ background a big challenge

$\Rightarrow$ always a good idea to try again

Outlook

Boy, that looks really hard!

Discussion on couplings

Questions on Higgs couplings

- what parametrization should we use?
  what questions do we want to ask?
- how can we test BSM physics in the Higgs sector?
- is there space for theorists' fits?
  how should an ex-th collaboration be implemented?
- what can/should the experiments publish?

Questions on future analyses

- what channels do we want to see/probe?
- what are the experimental issues for 3000 fb^{-1}?
- are there theory calculations/tools missing?
- do we want to talk about LC measurements?