Higgs physics and studies of EW symmetry breaking at 100 TeV

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Abstract
This report summarises the physics opportunities for the study of Higgs bosons and electroweak symmetry breaking at the 100 TeV pp collider.

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1 Introduction[18]

Introduction section

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2 SM Higgs[19]

We summarize here, for reference, the production rates at 100 TeV of SM Higgs bosons, including both the canonical production channels, as well as more rare channels of associated production. Associated production of Higgs bosons with other objects could allow independent tests of the Higgs boson properties, and might provide channels with improved signal over background, with possibly reduced sistematic uncertainties.

	$gg \to H$	VBF	$HW^{\pm}$	HZ	$t\bar{t}H$
σ(pb)	740	82	15.9	11.3	37.9
σ(100 TeV)/σ(14 TeV)	14.7	18.6	9.7	12.5	61

Table 1: Upper row: cross sections [1] for production of a SM Higgs boson in gg fusion, vector boson fusion, associated production with W and Z bosons, and associated production with a $t\bar{t}$ pair. Lower row: rate increase relative to 14 TeV. All results are NNLO, except ttH (NLO), with the central PDF from the MSTW2008(N)NLO set.

Table 1, extracted from the compilation produced by the LHC Higgs Cross Section working group [1], shows the rates for channels that will already be accessible and used at the LHC. The rates are typically a factor of 10-20 larger than at the LHC, except for the associate $t\bar{t}H$ production, where the gg initial state and the large mass of the final state benefit more significantly from the higher energy, leading to a rate growth by a factor of 60. The samples obtained with a luminosity of 10 ab^{-1} will therefore be a factor of 30-200 larger than what available after the completion of the HL-LHC progamme. The statistical uncertainties for the extraction of the Higgs couplings to the third generation fermions, to the charm and the muon, and to the EW gauge bosons, will become smaller than the percent level. It is difficult today to estimate how the theoretical progress will improve the theoretical systematics, and the determination of experimental systematics will require detailed simulation studies, based on realistic detector concepts. The large statistics for both signals and backgrounds will certainly help in improving the modeling systematics, which in many cases are a limitation to the precision foreseen for the HL-LHC. It is therefore not excluded that the final uncertainties, at least in some channels, may reach the percent level.

2.1 Inclusive $gg \to H$ production[20]

2.2 Higgs p_T spectrum in $gg \to H$[21]

2.3 Higgs plus jets production in $gg \to H$[22]

2.4 Associated VH production[23]

2.5 VBF Higgs production[24]

To cover

- inclusive VBF production
- VBF production in association with additional jets
- jet η spectra, jet p_T spectra at large η, detector design implications

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	HW^+W^-	$HW^{\pm}Z$	HZZ	$HW^{\pm}\gamma$	$HZ\gamma$
σ(fb)	170	100	42	78	43

Table 2: NLO cross sections for associated production of a SM Higgs boson with multiple gauge bosons [3].

– review issue of what's the best VBF selection criterion: select leading pt jets, or most fwd jets?
– shower effects and systematics

2.6 Associated ttH production[25]

Will include discussion of $t\bar{t}H/t\bar{t}Z$, as in arXiv:1507.08169

Discuss the extraction of the top Yukawa coupling y_{top} from the $t\bar{t}H$ process [2].

The large cross section at 100 TeV allows to consider boosted topologies for the hadronic decays of both the top quarks and the Higgs boson ($H \to b\bar{b}$), placing tight cuts on the emerging jets, and drastically reducing the various sources of backgrounds, while maintaining a statistical sensitivity on the production rate at the percent level. This matches the theoretical systematics, which, already today, is at the percent level [2], if one considers the ratio $\sigma(t\bar{t}H)/\sigma(t\bar{t}Z)$, which is very stable with respect to PDF and scale uncertainties. The branching ratio for the $H \to b\bar{b}$ decay, needed to extract the top Yukawa coupling from this measurement, will be known with sufficient accuracy if an e^+e^- Higgs factory (at a linear or circular collider) will be operating. Otherwise, a percent-level measurement of $y_{top} * \mathrm{BR}(H \to b\bar{b})$ will still be one of the most precise determinations of a combination of Higgs couplings, with direct sensitivity on y_{top}.

2.7 Prospects for precision measurements of Higgs properties[26]

Will include examples of precision reach for overall production$\times$decay rate, BR ratios, etc.

2.8 Rare production modes[27]

Table 2, extracted from the NLO results of the aMC@NLO code [3, 4], reports the rates for associated production of a SM Higgs with gauge boson pairs. Theoretical systematics, including scale and PDF uncertainties, are typically below 10%.

2.9 Rare SM Higgs decays[28]

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	HH	$HHjj$ (VBF)	$HHW^{\pm}$	HHZ	$HHt\bar{t}$	$HHtj$
σ(fb)	$1.2 \cdot 10^3$	81	8.1	5.5	86	4.6

Table 3: NLO cross sections for production of a SM Higgs boson pair, including associated production channels, at 100 TeV [3].

3 *HH* production[29]

3.1 Introduction

- discuss processes (double Higgs in various channels, triple Higgs)
- give cross sections
- discuss goals of analyses
    - which information can be extracted from HH production
    - estimate precision on determination of SM signal strength
    - precision on the extraction of Higgs self-couplings

Table 3, extracted from the NLO results of Ref. [3], reports the rates for SM Higgs pair production, including channels of associated production with jets, gauge bosons and top quarks. Once again, the possible implications of the measurement and study of these exotic Higgs production channels are under study.

3.2 *HH* production from gluon fusion

Rates are already discussed in introduction. Add here discussion on distributions, errors associated to approximations in beyond LO computations (mainly $m_{top} \to \infty$ limit).

Study the issue of EFT vs full m_{top} dependence, particularly at large $m(HH)$.

3.2.1 $HH \to b\bar{b}\gamma\gamma$ channel

Document the various studies [5–8] that have appeared on the determination of the Higgs self-coupling in the $HH \to b\bar{b}\gamma\gamma$ decay channel. Aim at giving a more conclusive projection for the uncertainty on the measurement of the SM coupling, in the range of $5 - 10\%$ with a total of 30 ab^{-1}.

Ongoing analysis of this channel. Main goals:

- simulate main backgrounds and signal in a consistent way
    - simulation chain: Madgraph, Pythia, Delphes
- use "adapted" analysis strategy from LHC
- first analysis with just extraction of the HH signal cross-section, see sensitivity to SM
- extraction of precision on Higgs trilinear
- analysis of dependence of the precision on detector performance. Main parameters to vary:
    - tagging efficiencies and fake rates (b and γ)
    - jet and photon energy resolution
    - detector acceptance

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3.2.2 $HH \to b\bar{b}b\bar{b}$ channel

– Contribution from Rojo.

3.2.3 Additional modes with leptons

– include analyses of $HH \to b\bar{b}WW$, $HH \to b\bar{b}ZZ$, $HH \to b\bar{b}\tau\tau$, $HH \to b\bar{b}Z\gamma$, $HH \to b\bar{b}\mu\mu$.
  Contribution from Papaefstathiou.

Include the studies of more rare decay modes, see Ref. [9].

3.3 HH production from vector boson fusion

– contribution from Rojo (ongoing analysis with Contino)
– main goals:
  – extract information on Higgs couplings to vector bosons

Discuss rates, and distributions, witj acceptance plots vs jet p_T, η, etc. Discuss optimal VBF selection cuts, also as a function of $m(HH)$.

3.4 HHH production

Include the recent studies of triple Higgs production (see Papaefstathiou etc).

– results from $4b\gamma\gamma$ channel.
  Contribution from Papaefstathiou and Fuks.
– Main goals:
  – extract precision on SM signal strength
  – extract information on Higgs quartic coupling

4 BSM aspect of Higgs physics and EWSB[30]

4.1 Electroweak Phase Transition and Baryogenesis[31]

4.2 Dark matter[32]

4.3 Naturalness[33]

4.4 Reach Projection for BSM Higgs Sectors [34]

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