Higgs self coupling at the Future Circular Collider

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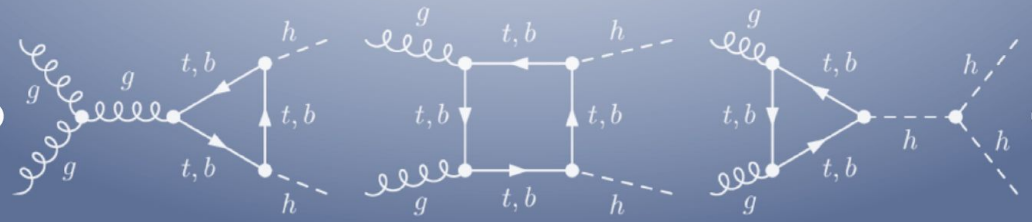
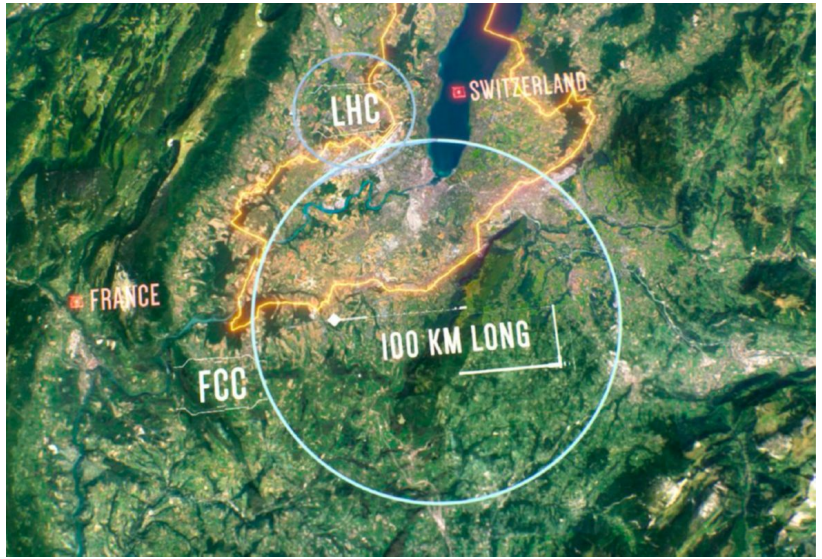


-Nikhef topical lecture project-

The FCC accelerator

Exploring new physics

- DM, neutrino masses, baryon symmetry of the universe
- Higgs properties, (self)interactions, couplings and flavor phenomena

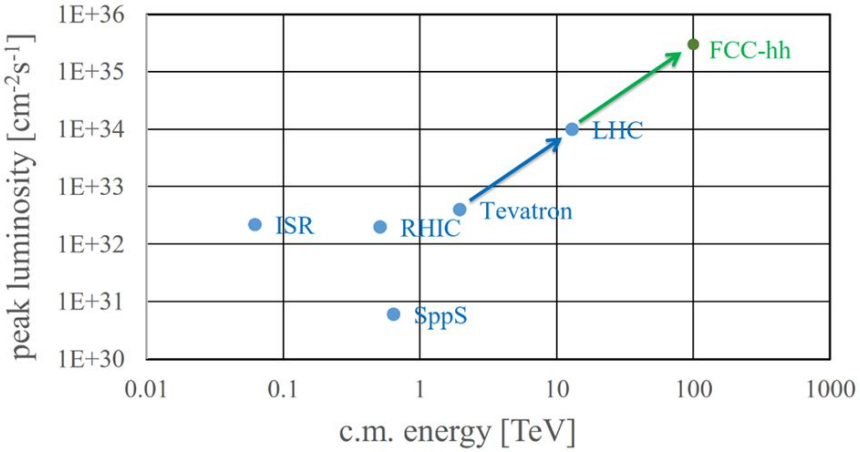


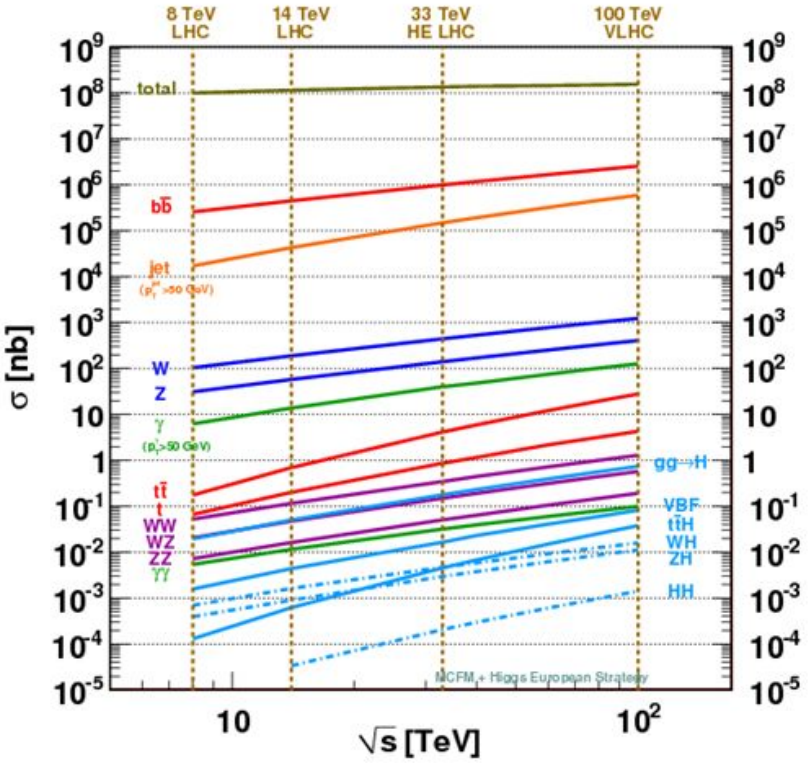
ONLY € 0.20 PER HIGGS

The FCC accelerator

Specifications

- Higgs statistics >10^{10} Higgs bosons
- Peak luminosity 30 x 10^{34} $cm^{-2}s^{-1}$
- Construction 2035-2050
- Operation 25 years





Higgs self-coupling

https://arxiv.org/pdf/2004.03505.pdf
https://arxiv.org/pdf/1305.6397.pdf
https://arxiv.org/pdf/1907.02078.pdf

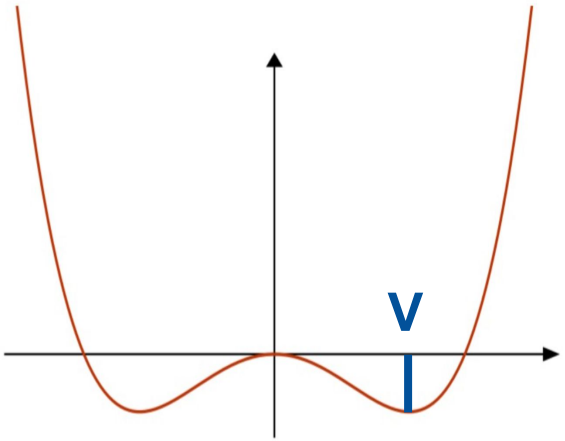
- EW symmetry breaking incorporated in the SM via the symmetric potential of a doublet Higgs field

$$V_{SM}(H) = -\mu^2 |H|^2 + \lambda |H|^4$$

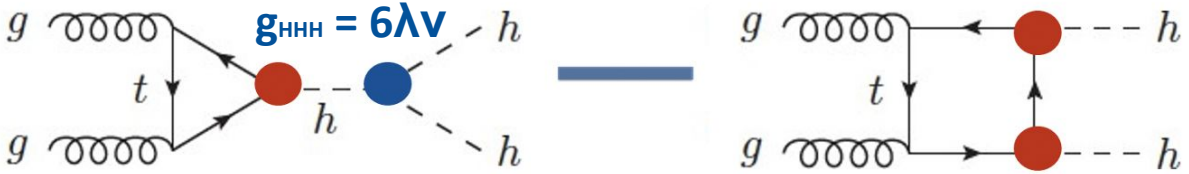
"Arbitrary terms"

- The shape of the SM Higgs potential is directly correlated to Higgs self-coupling
- Any deviation from SM λ value gives hints on new physics
  - Theories with additional scalar particles (e.g. SUSY)
  - Theories with higher-dimension operators in the Higgs potential (composite Higgs models)

SM self-coupling
$\lambda = \mu^2/(2v^2)$



Higgs self-coupling at FCC-hh

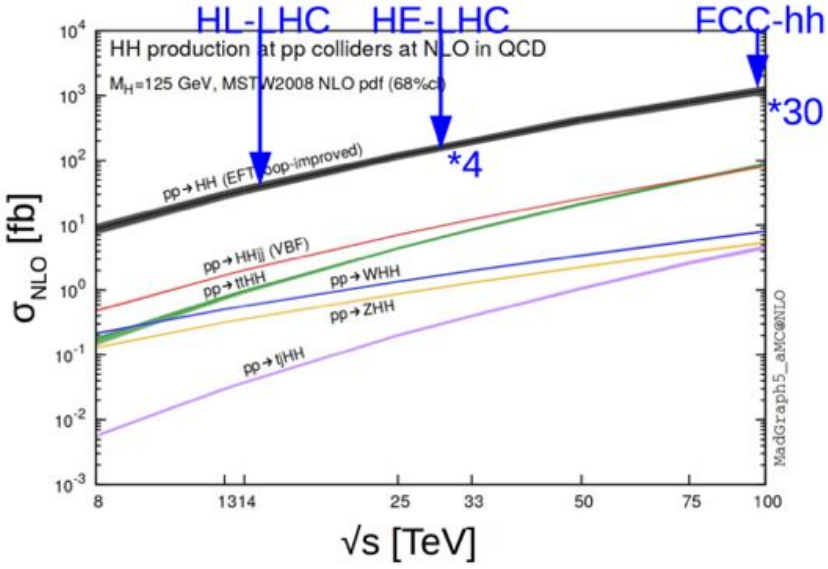


Negative interference with box diagram
- very small cross-section
- interference lower at low di-higgs invariant mass

HL-LHC expected precision: $\delta k_\lambda / k_\lambda \approx 50\%$

Huge increase of production at FCC-hh
- σ (100 TeV) / σ(14 TeV) ≅ 40
- L (FCC-hh) / L (HL-LHC) ≅ 10

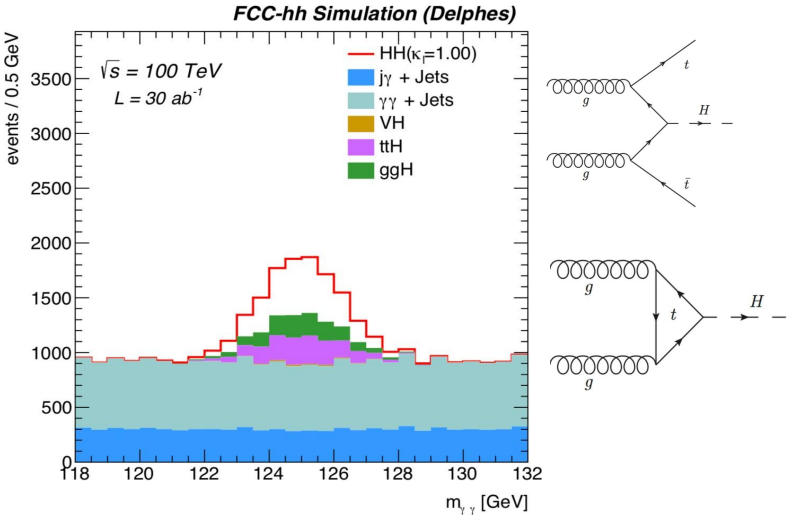
Various channels are studied:
- bbɣɣ - most sensitive channel
- bbZZ(4l) - new channel at FCC-hh
- And more: 4b+j boosted, bbττ



How do we measure it?

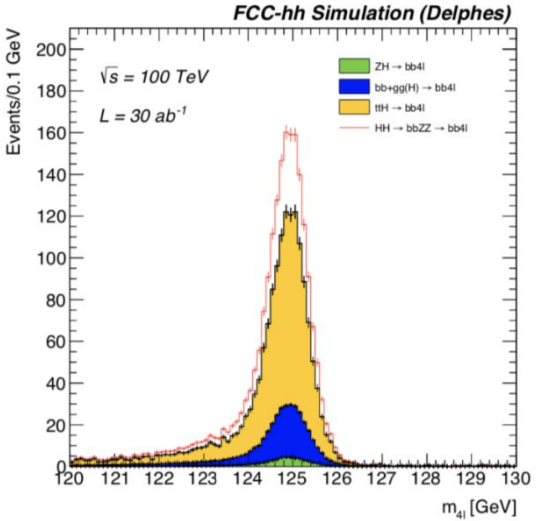
HH → bbɣɣ

- Large QCD backgrounds (jjɣɣ and ɣ+jets)
- Very large ttH background with respect to LHC
- Perform a 2D Likelihood fit in ($\mathbf{m_{\gamma\gamma}}$, $\mathbf{m_{hh}}$) plane to determine coupling modifier $\mathbf{k_\lambda}$
- Precision of this channel $\mathbf{\delta k_\lambda / k_\lambda = 5\text{-}7\%}$



HH → bb4l

- **New channel** available at FCC-hh
- Clean channel, mostly reducible **single Higgs** background
- Utilize a simple cut and count approach (4e, 4μ and 2e2μ channels)
- Precision: $\mathbf{\delta k_\lambda / k_\lambda = 15\text{-}20\%}$

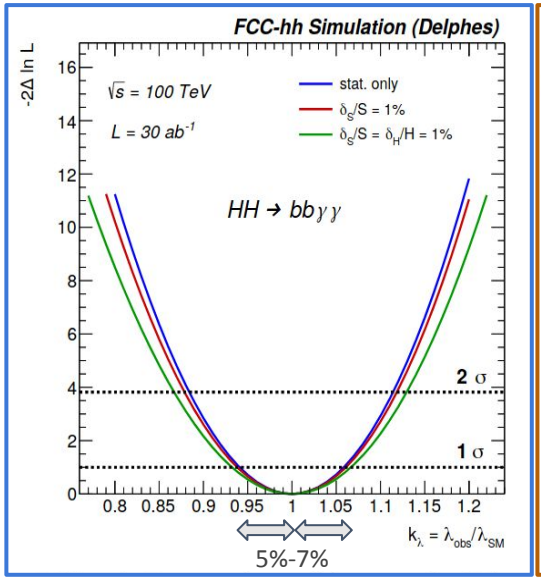


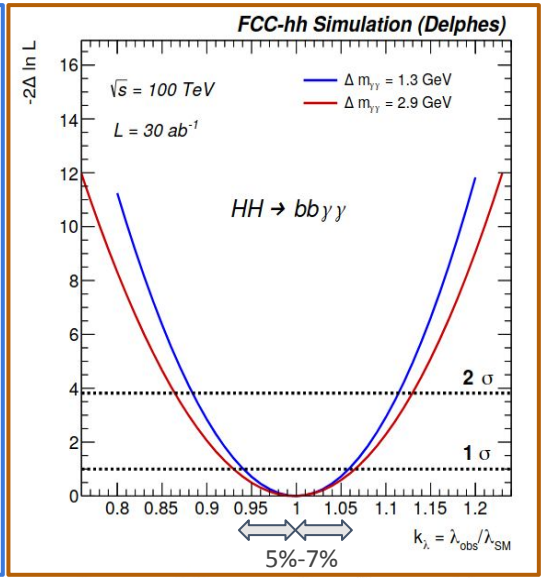
Higgs self-coupling uncertainties

- Each channel comes with specific systematic uncertainties, typically:
  a. Identification efficiencies
  b. Resolutions

HH → bbɣɣ

- Di-photon invariant mass, **$\Delta m_{\gamma\gamma}$**
  - Set by EM calorimeter E-resolution
  - Mainly influenced by pile-ups
  - Timing info + photon clustering expected to yield large improvements
- Other uncertainties:
  - b/ɣ-tagging efficiencies
  - mis-identifications





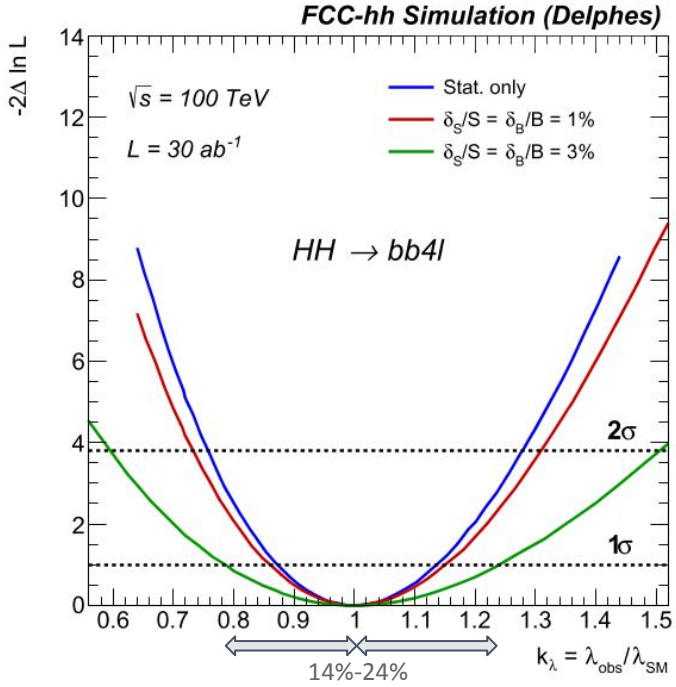
Borgonovi, L., et al. Higgs measurements at FCC-hh. No. CERN-ACC-2018-0045. FCC-DRAFT-PHYS-2018-003, 2018.

Higgs self-coupling uncertainties

- Each channel comes with specific systematic uncertainties, typically:
  a. Identification efficiencies
  b. Resolutions

HH → bbZZ (4l)

- Uncertainties driven by the **efficiency of background cuts**, specifically on:
  - B-pair and Z-candidate invariant masses
  - Lepton-pair and b-jets angular separation
  - Lepton transverse momenta



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Summary

- Higgs self-coupling ties directly to the **shape of the Higgs potential!**
- Can be studied directly via Higgs-pair production
  - **Large destructive interference** between top-quark loop and self-coupling diagrams
    - Suppresses SM rate, but enhances SM deviations at NLO
    - Self-coupling diagram contribution greatest at low invariant Higgs-pair masses
- Most promising decay-channels include **at least one b-pair**:
  - HH → bbyy
  - HH → bbZZ (4l)
- With the right techniques, **few % level precision on κ_λ** can be achieved!

	$b\bar{b}\gamma\gamma$	$b\bar{b}\tau\tau$	$b\bar{b}ZZ^*[\rightarrow 4\ell]$	$b\bar{b}WW^*[\rightarrow 2j\ell\nu]$	4b+jet
$\delta\kappa_\lambda$	6%	8%	14%	40%	30%

Borgonovi, L., et al. Higgs measurements at FCC-hh. No. CERN-ACC-2018-0045. FCC-DRAFT-PHYS-2018-003, 2018.

Send-off message

15 years of LHC statistics in just one day!

Comparison in the Higgs production via the qq → Zh channel

During a 10 hour working day the LHC produces ~20 Higgs particles

where the FCC-hh produces 108.000 Higgs particles during a single day.

Thank you for your attention!

Who dares to ask a question?

EXTRA

HH→ bbττ

- Boosted final state (high Higgs-pair invariant mass)
  - Generally causes reduced sensitivity to κ_λ
  - Higgs-pair production in association with a **jet** provides leeway
    - Jet-induced recoil decorrelates $p_{T,h}$ and m_{hh}
    - Retains high self-coupling sensitivity, whilst keeping $p_{T,h}$ large

- 3 dominant backgrounds
  - ttj with leptonic decays (t → bW → blν)
  - Pure EW backgrounds
  - Mixed QCD-EW backgrounds from jbbττ

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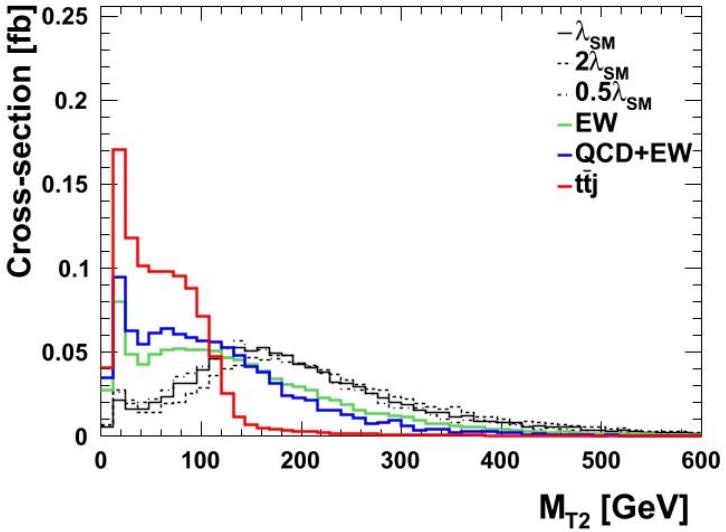
https://doi.org/10.1140/epjc/s10052-018-5788-y



- Using state-of-the-art reconstruction techniques, **~8% precision on κ_λ can be achieved!**
  - tt BG elimination based on kinematic bounding variables (arXiv:1309.6318v1)
  - BDT analysis for maximal S vs. BG discrimination despite low S/BG ratio (arXiv:1712.08895v2)
  - Jet substructure reconstruction technique (arXiv:0802.2470v2)