Higgs & EWSB @FCC-hh

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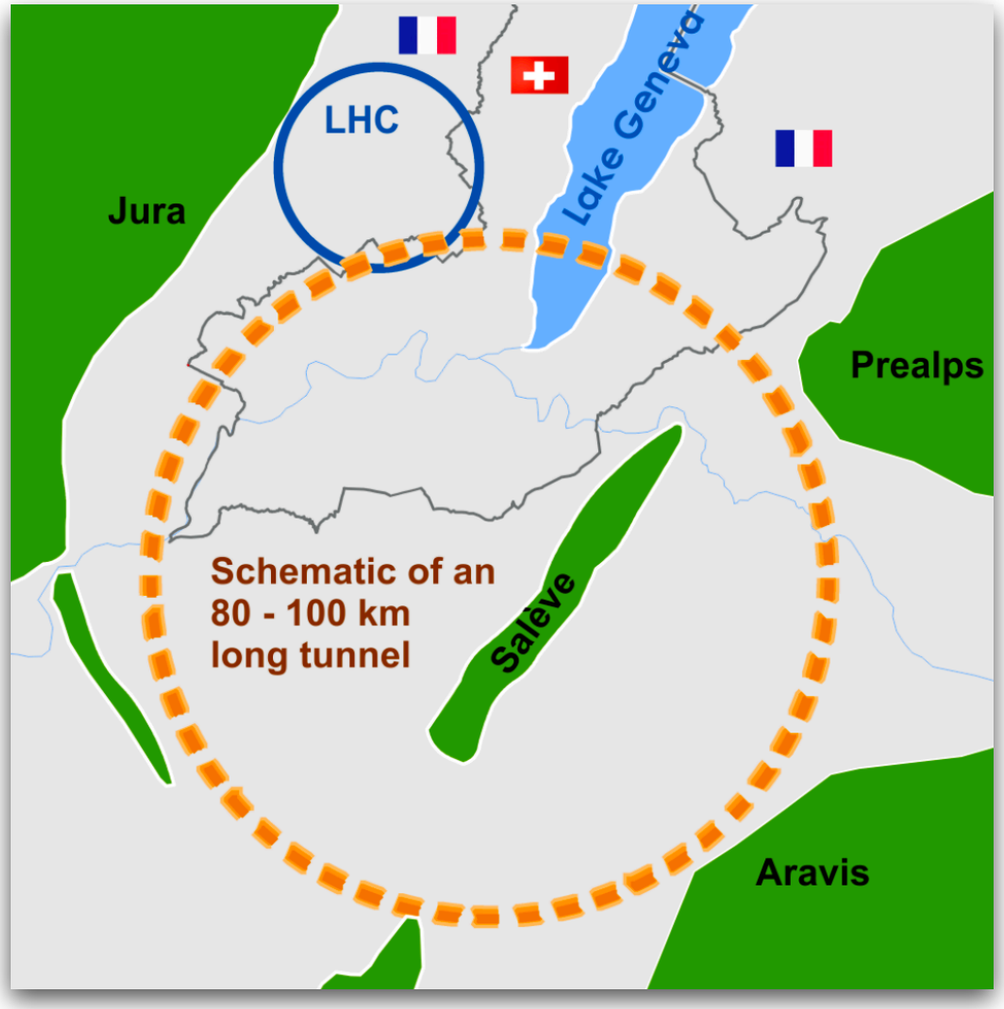
The FCC-hh

- 100 km pp collider
- E_{CM} =100 TeV
- 16T magnets

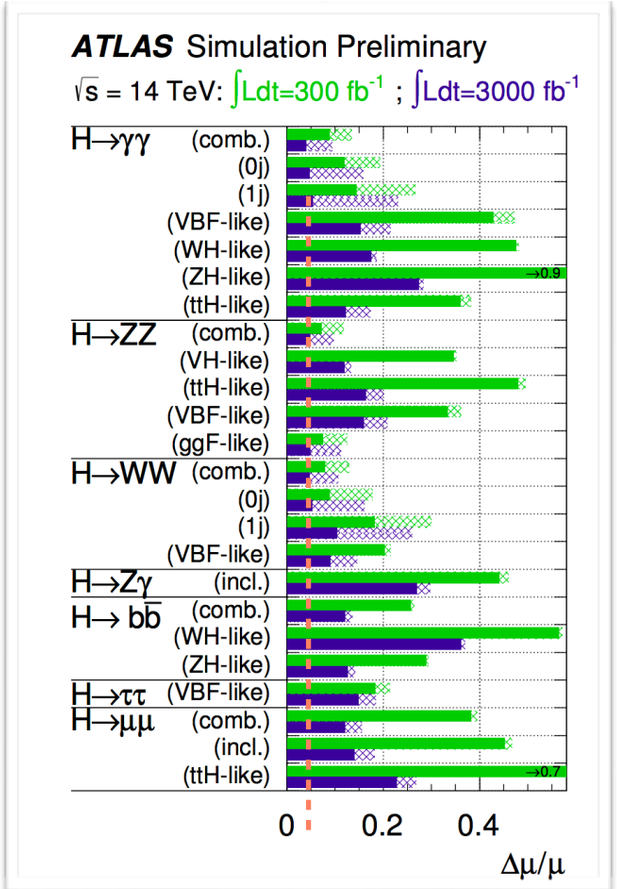
<u>Access to:</u>

- direct searches:
  - heavy Z' reach up to m ≈ 40 TeV
  - stops up to m ≈ 15 TeV
- precision SM measurements:
  - Higgs potential, self-coupling
  - Higgs, Top, EWK physics in new dynamical regimes (complementary to e^+e^-)



Why measuring Higgs @FCC-hh?

HL-LHC



5%

- Higgs precision measurements are **guaranteed deliverables**
- FCC-hh provides **unique and complementary measurements** to e^+e^- colliders:
  - Higgs **self-coupling**
  - **top Yukawa**
  - **rare decays** (BR(μμ), BR(Zɣ), ratios, ..)

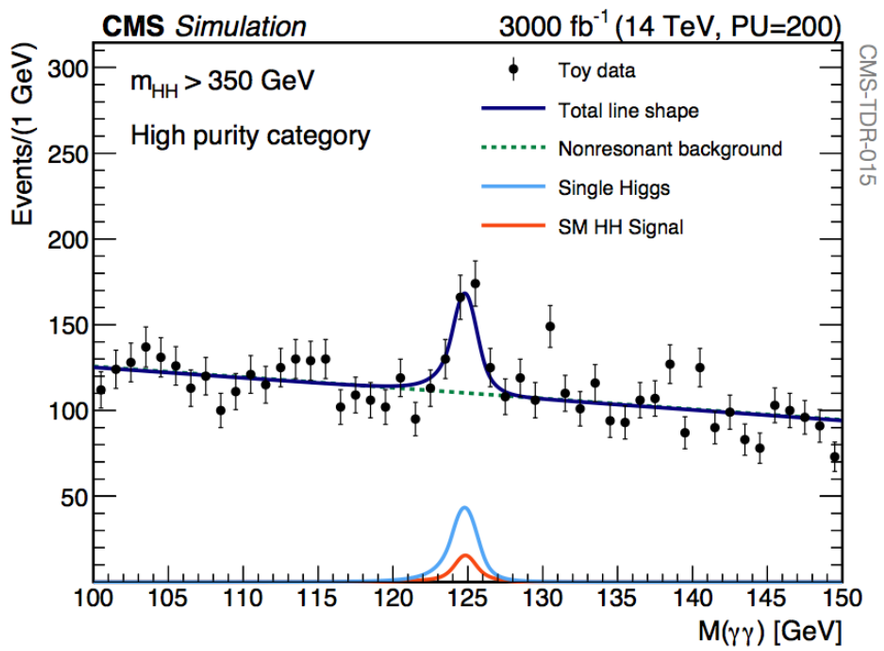
    measurements will be **statistically limited** at FCC-ee
- Directly test **unitarisation of VBS** by measuring W_LW_L and Z_LZ_L (barely observable @HL-LHC)

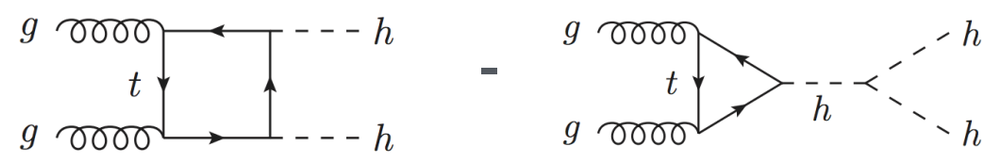
FCC-ee

δm_H (MeV)	6
$\delta\Gamma_H / \Gamma_H$(%)	1.6
$\delta g_{Hb} / g_{Hb}$ (%)	0.68
$\delta g_{HW} / g_{HW}$ (%)	0.47
$\delta g_{H\tau} / g_{H\tau}$(%)	0.80
$\delta g_{H\gamma} / g_{H\gamma}$ (%)	3.8
$\delta g_{H\mu} / g_{H\mu}$ (%)	8.6
$\delta g_{HZ} / g_{Hz}$ (%)	0.22
$\delta g_{Hc} / g_{Hc}$ (%)	1.2
$\delta g_{Hg} / g_{Hg}$ (%)	1.0
Br_{invis} (%)$_{95\%CL}$	< 0.25
BR_{EXO} (%)$_{95\%CL}$	< 1.1

Higgs self-coupling at FCC-hh

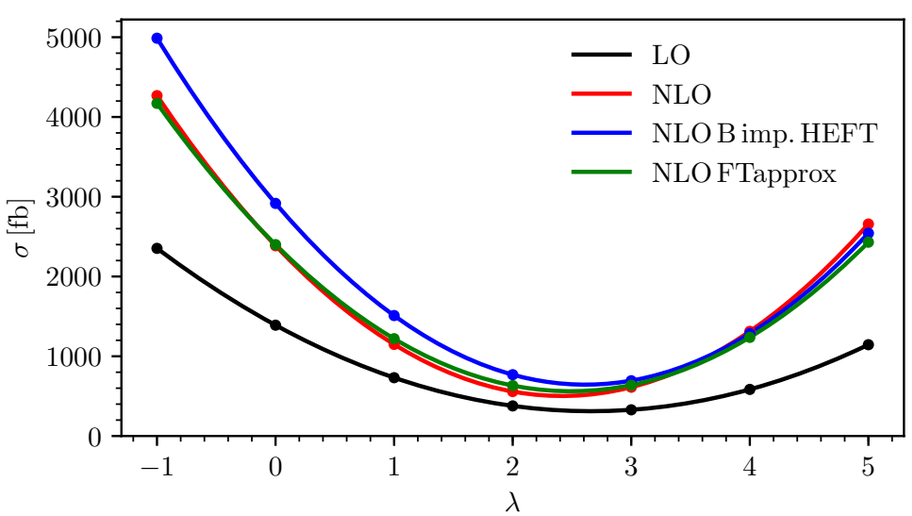
HL-LHC





- Very small cross-section due to negative interference with box diagram
- HL-LHC projections : $\delta\lambda/\lambda$ = 100%
- Expect large improvement at FCC-hh:
  - σ(100 TeV)/σ(14 TeV) ≈ 40 (and Lx10)
  - x400 in event yields and x20 in precision
- mainly 4 channels studied:
  - bbγγ (most sensitive)
  - bbZZ(4l)
  - bbbbj (boosted)
  - bbWW

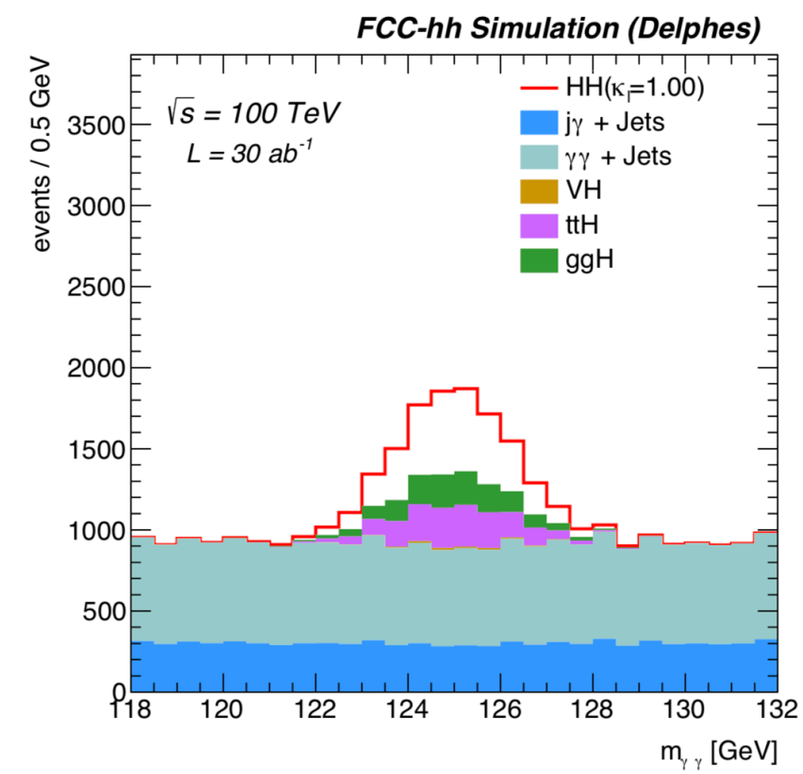
G. Heinrich et.al [1608.04798]

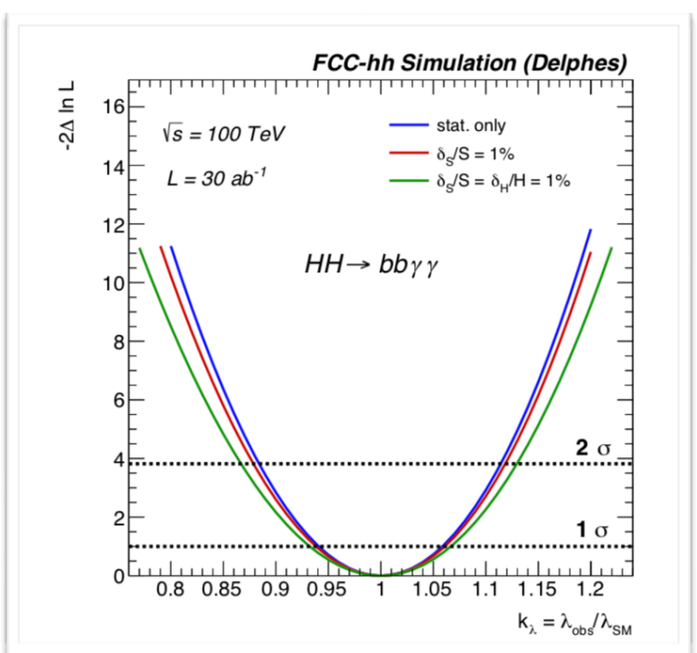


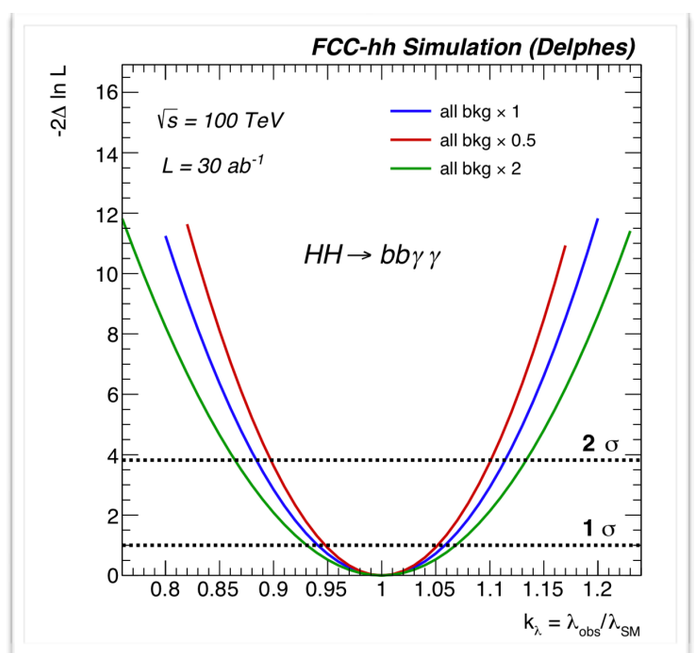
[G. Ortona, MS]

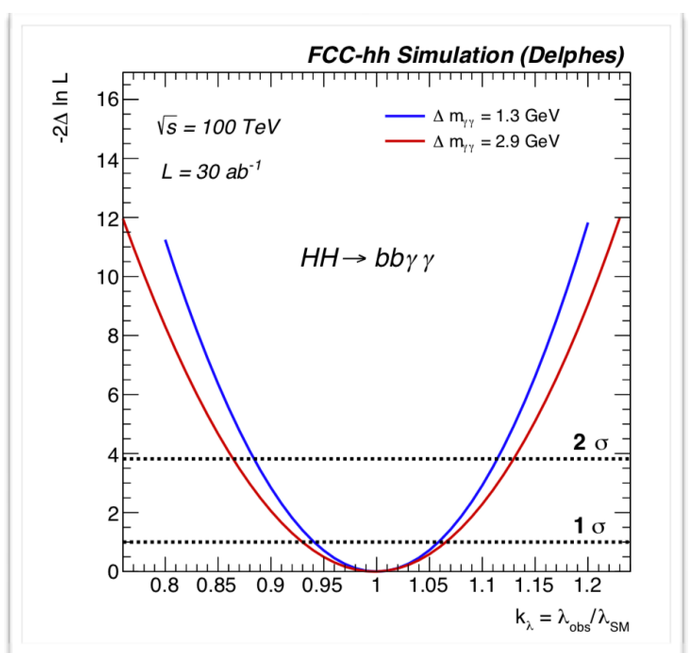
HH →bbγγ

- **Large QCD** backgrounds (jjγγ and γ+jets)
- Main difference w.r.t LHC is the very large **ttH background**
- Strategy:
  - exploit **correlation of means in ($m_{\gamma\gamma}$, m_{hh})** in signal
  - build a **parametric model in 2D**
  - perform a **2D Likelihood fit** on the coupling modifier k_λ
  - **$\delta k_\lambda / k_\lambda$ = 5%** achievable





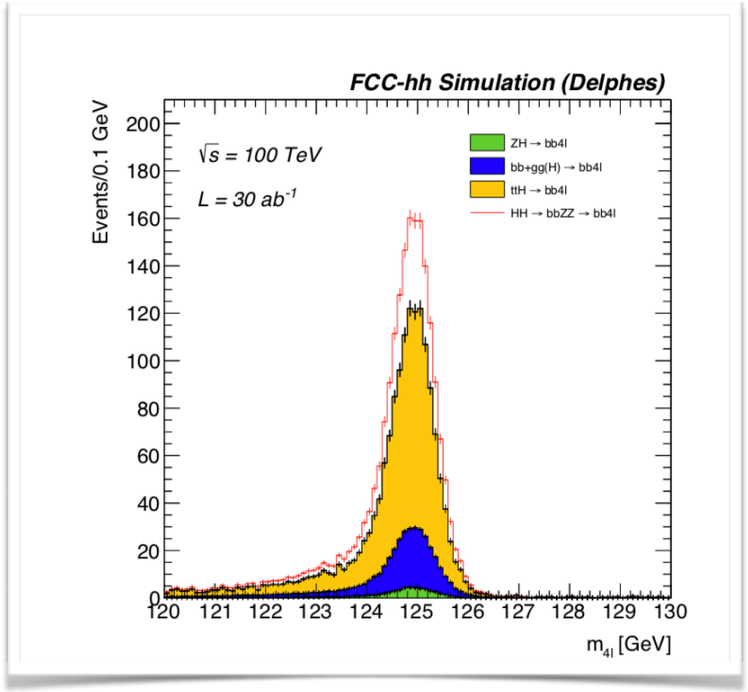


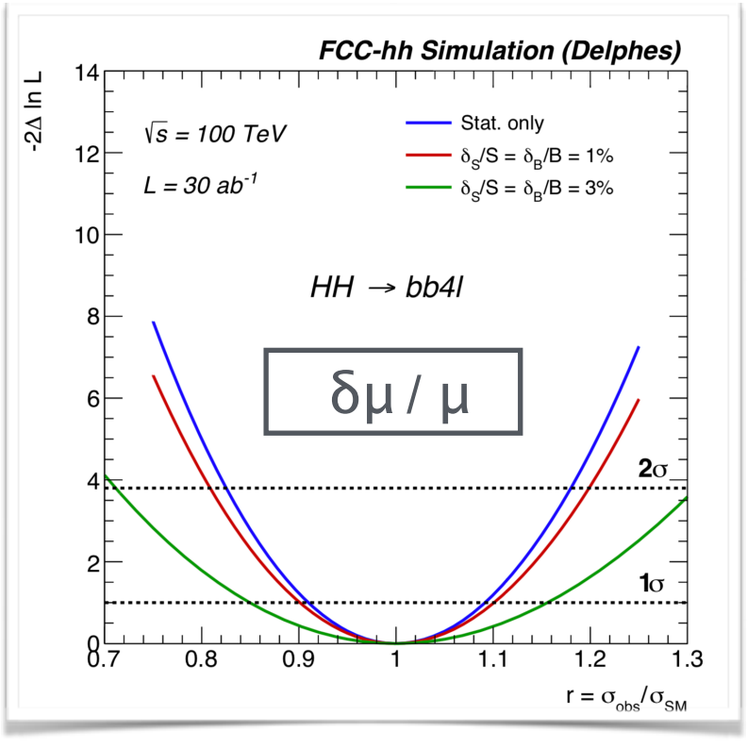


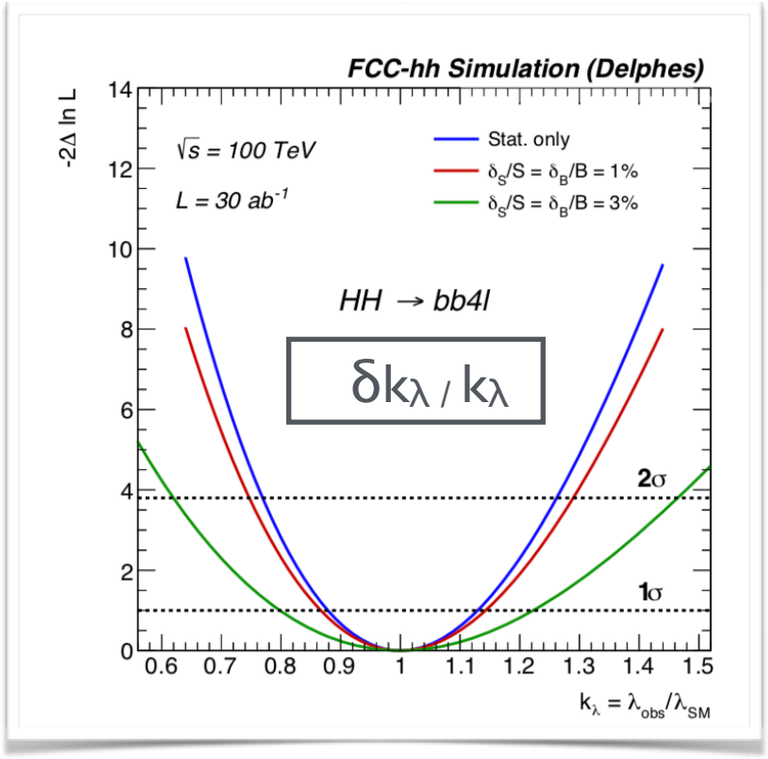
[Borgonovi, Braibant, De Filippis, Fontanesi, Ortona, MS]

HH →bb4l

- **New channel** opening at FCC-hh !!
- clean channel with mostly reducible backgrounds (**single Higgs**)
- Simple cut and count analysis on (4e, 4μ and 2e2μ channels)
- **$\delta k_\lambda / k_\lambda$ = 15-20%** depending on systematics assumptions

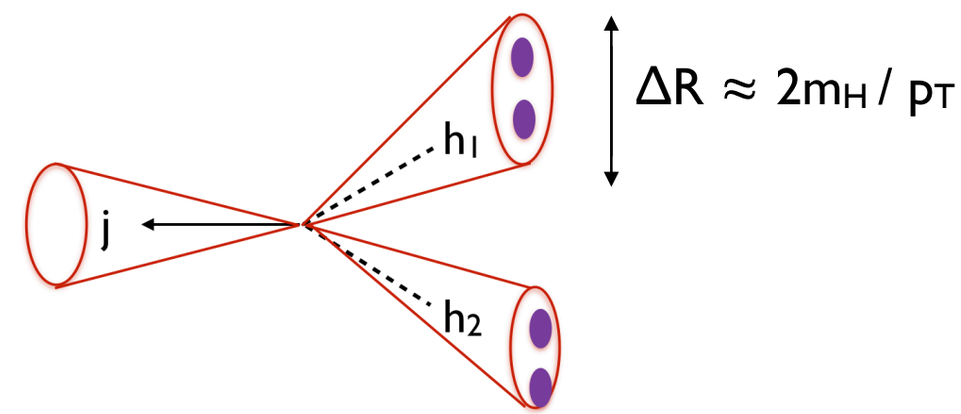


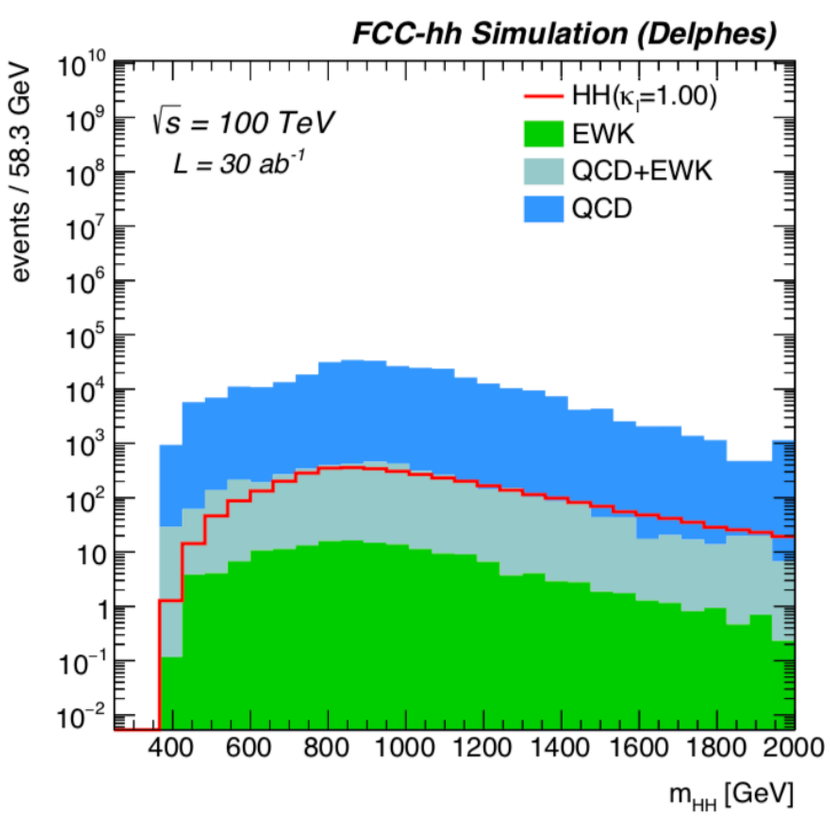


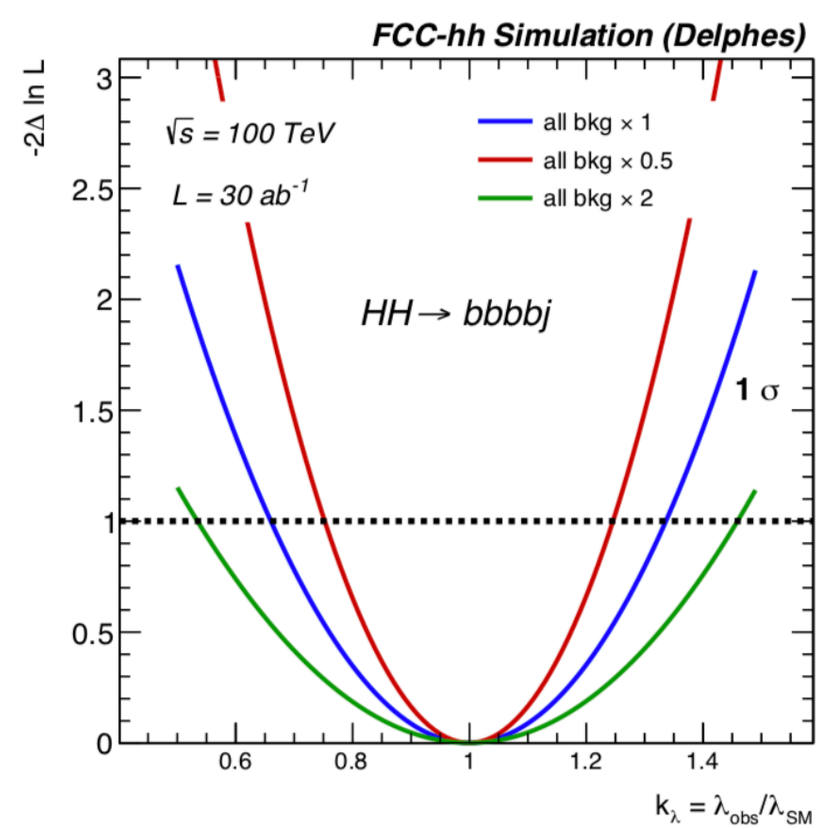


HH →4b+j boosted

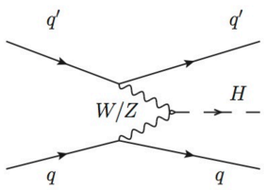
- Large rates allow to look for **boosted HH** recoiling against a jet (**low m_{HH}** drives the sensitivity)
- relies on identification **two boosted Higgs-jets**
- **fit the di-jet mass spectrum** dominated by the large QCD background
- **$\delta k_\lambda / k_\lambda$ = 20-40%** depending on assumed background rate

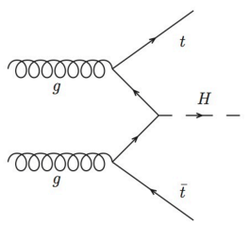




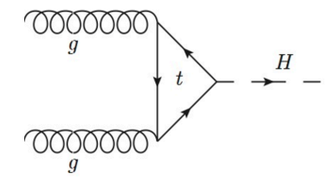


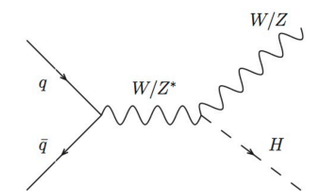
Higgs measurements @FCC-hh





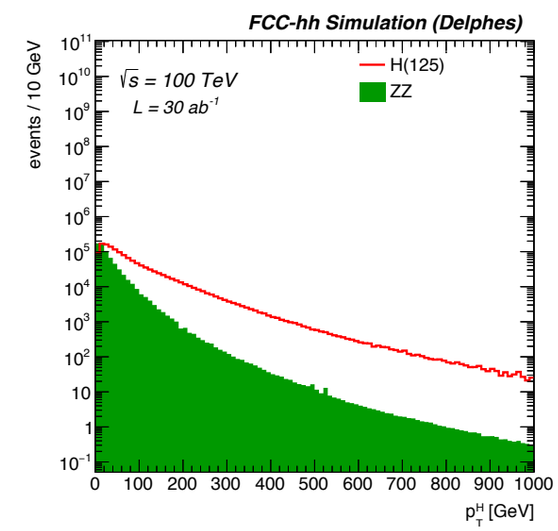
	σ(13 TeV)	σ(100 TeV)	σ(100)/σ(13)
ggH (N³LO)	49 pb	803 pb	16
VBF (N²LO)	3.8 pb	69 pb	16
VH (N²LO)	2.3 pb	27 pb	11
ttH (N²LO)	0.5 pb	34 pb	55





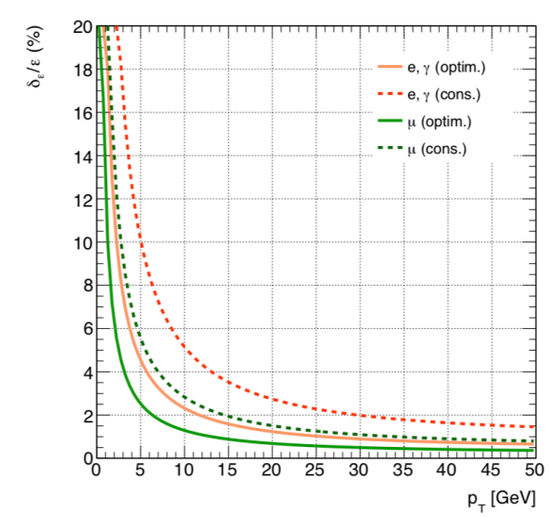
<u>Expected improvement at FCC-hh</u>:

- **20 billion Higgses** produced at FCC-hh
- **factor 10-50** in cross sections (and Lx10)
- reduction of a **factor 10-20 in statistical** uncertainties



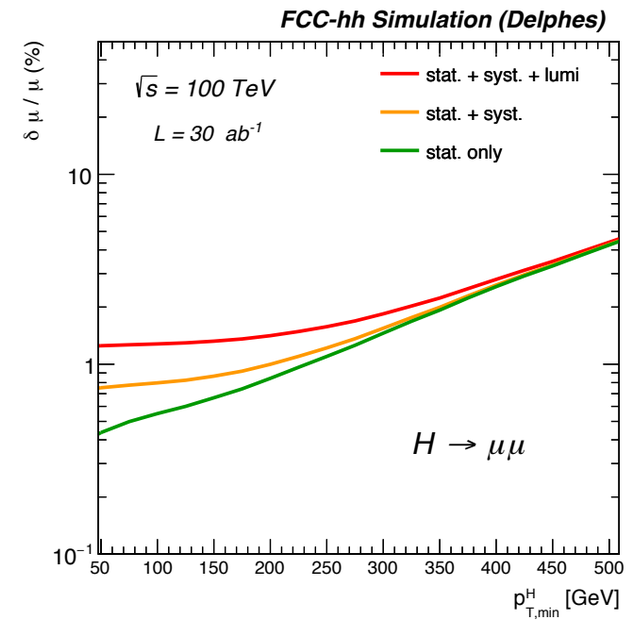
<u>Large statistics will allow:</u>

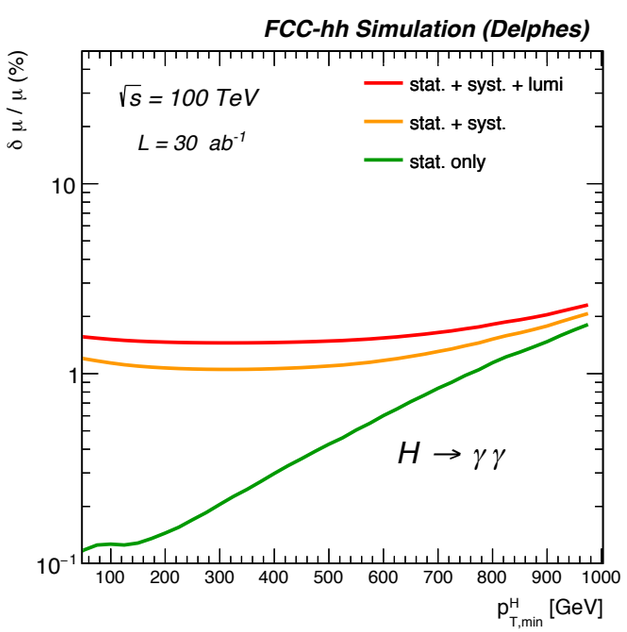
- for % - **level precision in statistically limited** rare channels (μμ, Zɣ)
- in **systematics limited** channel, to isolate **cleaner samples** in regions (e.g. @large Higgs p_T) with :
  - higher S/B
  - smaller impact of systematics

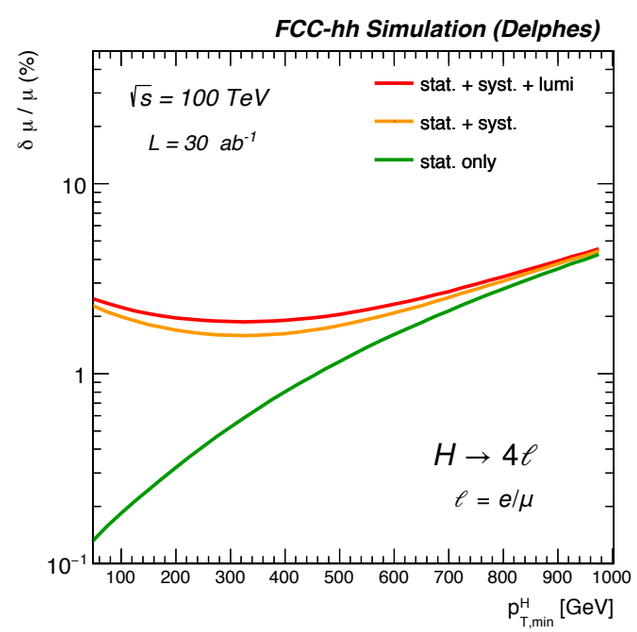


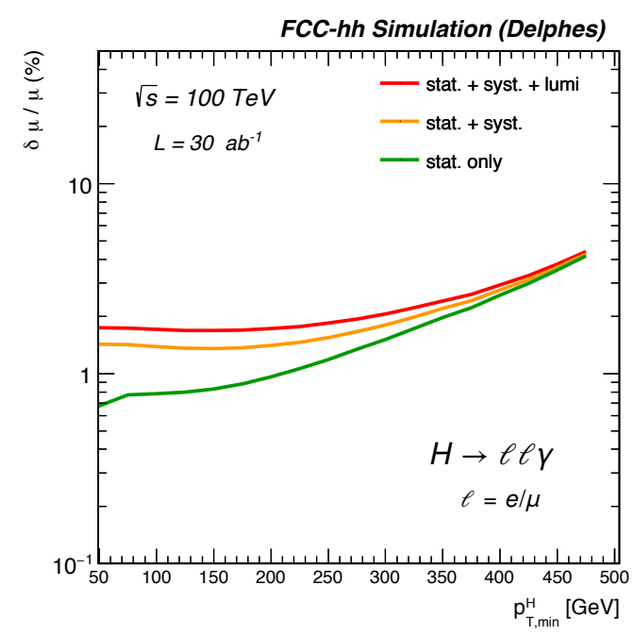
Higgs decays

- study sensitivity as a function of **minimum $p_T(H)$** requirement in the **γγ, ZZ(4l), μμ and Z(ll)γ** channels
- **low** $p_T(H)$: **small stat.** and **high syst.** unc.
- **large** $p_T(H)$: **high stat.** and **small syst.** unc.
- **O(1-2%) precision on BR** achievable up to very high p_T





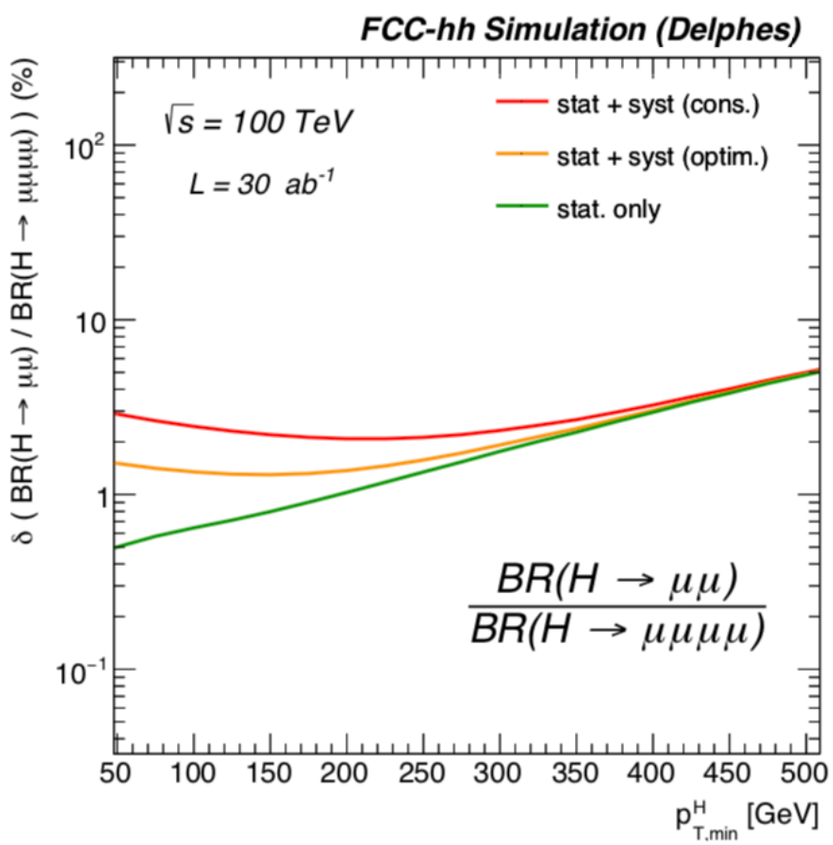


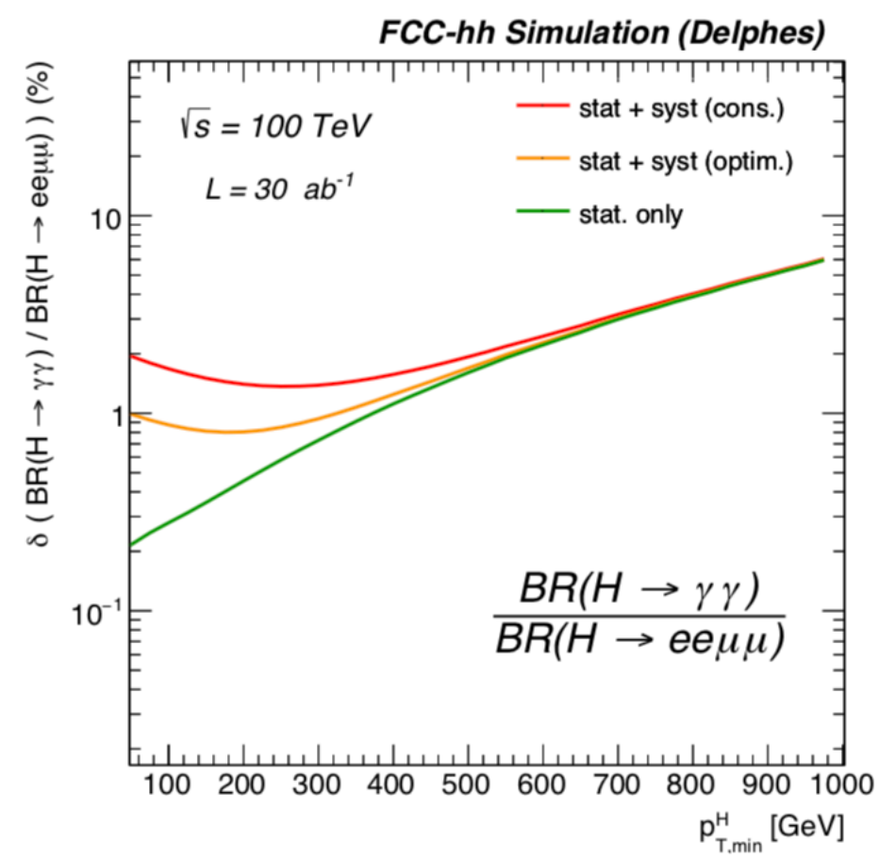


Ratios of BRs

- measure **ratios of BRs** to cancel correlated sources of systematics:
  - luminosity
  - object efficiencies
  - production cross-section (theory)
- Becomes **absolute precision** measurement in particular if combined with **H→ZZ** measurement from e^+e^- (at 0.1%)

- 1% lumi + theory uncertainty
- p_T dependent object efficiency:
  - $\delta\varepsilon(e/\gamma)$ = 0.5 (1)% at $p_T \to \infty$
  - $\delta\varepsilon(\mu)$ = 0.25 (0.5)% at $p_T \to \infty$



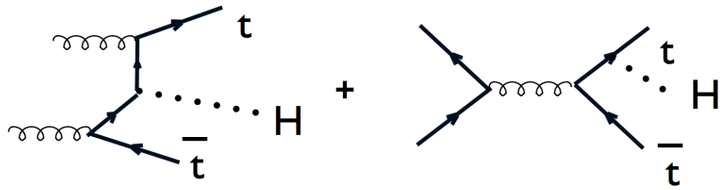


[Jamin, Helsens, MS]

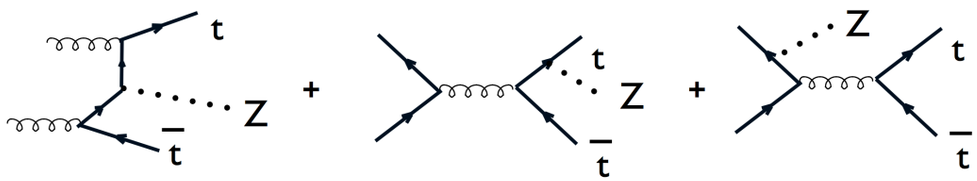
Top Yukawa

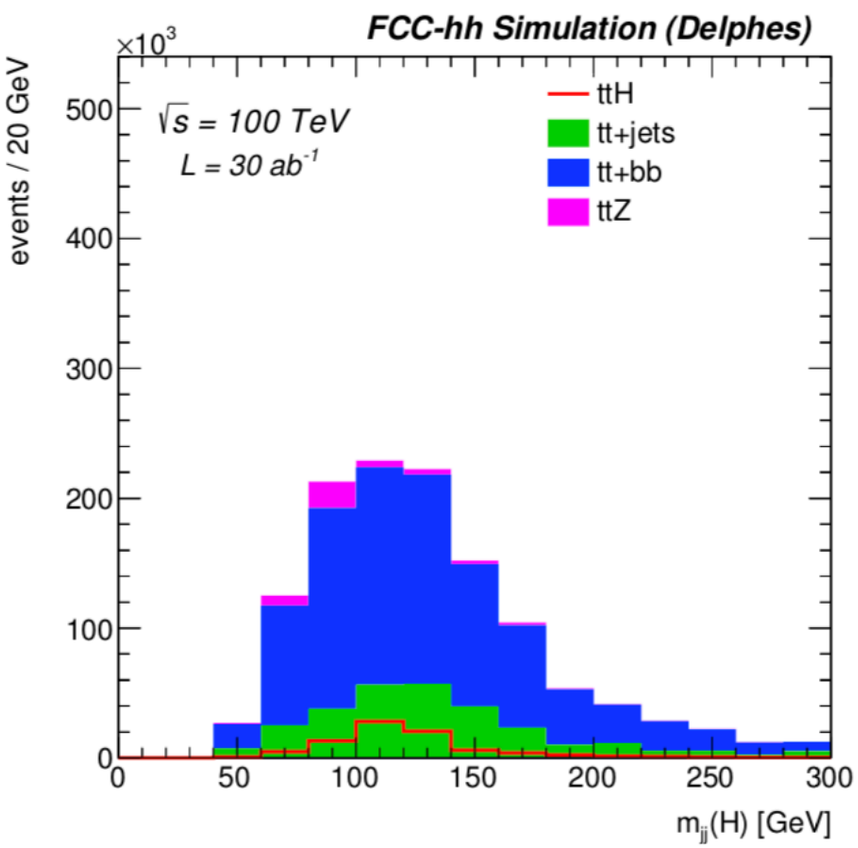
- production ratio **σ(ttH)/σ(ttZ)**
- predicted to 1% precision [1507.08169]
- measure **σ(ttH)/σ(ttZ)** in **H/Z→bb** mode in the boosted regime, in the **semi-leptonic** channel
- perform simultaneous fit of double Z and H peak

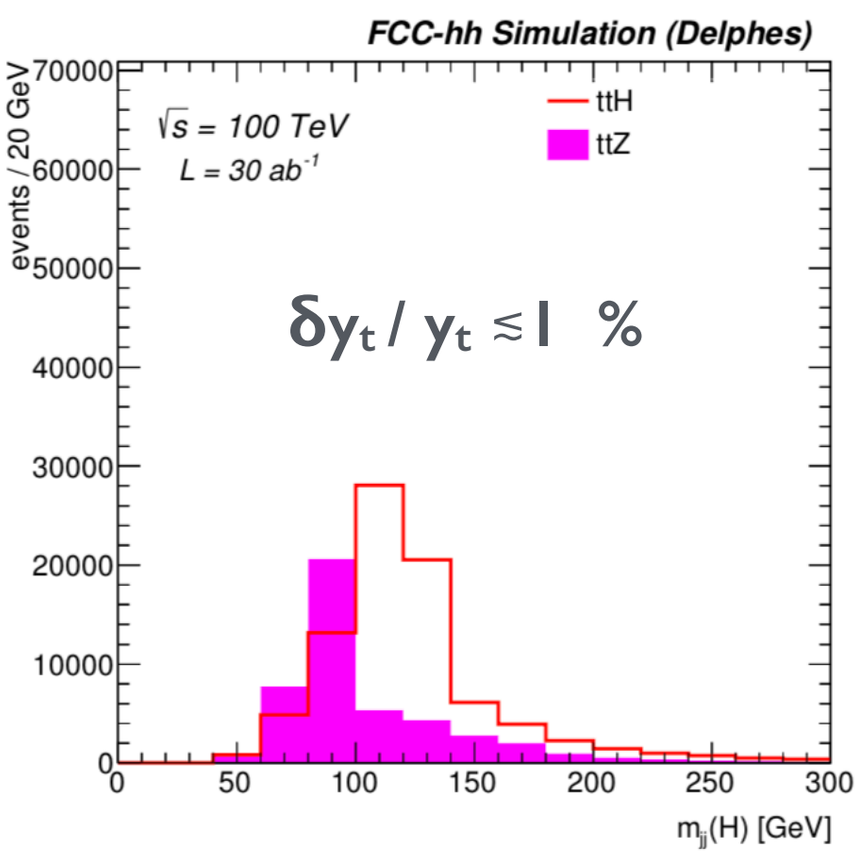
ttH



ttZ



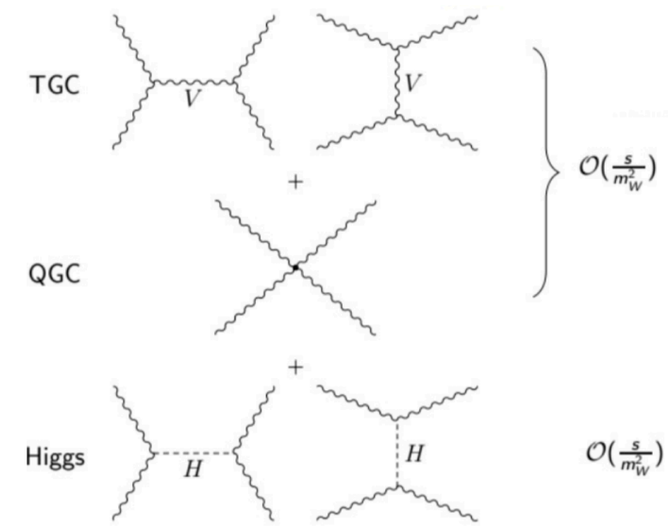


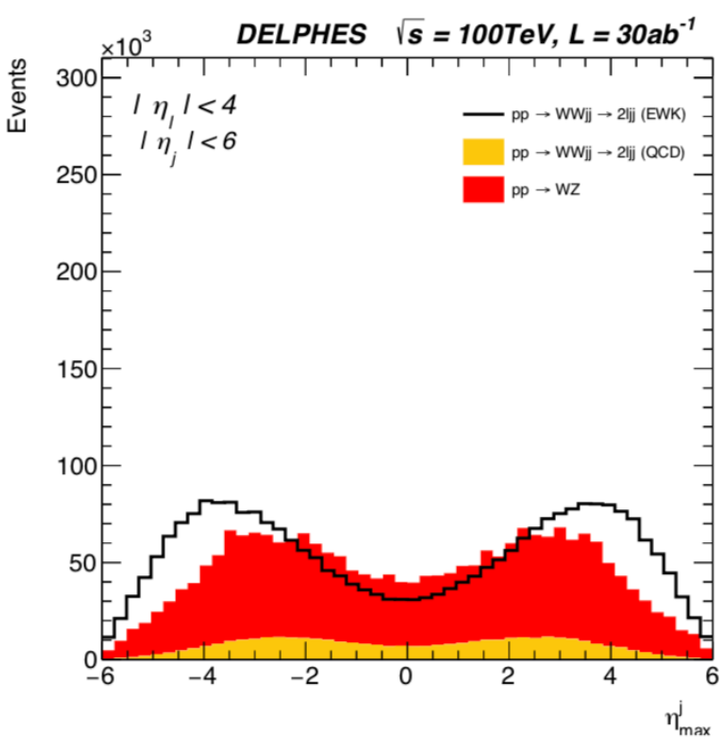


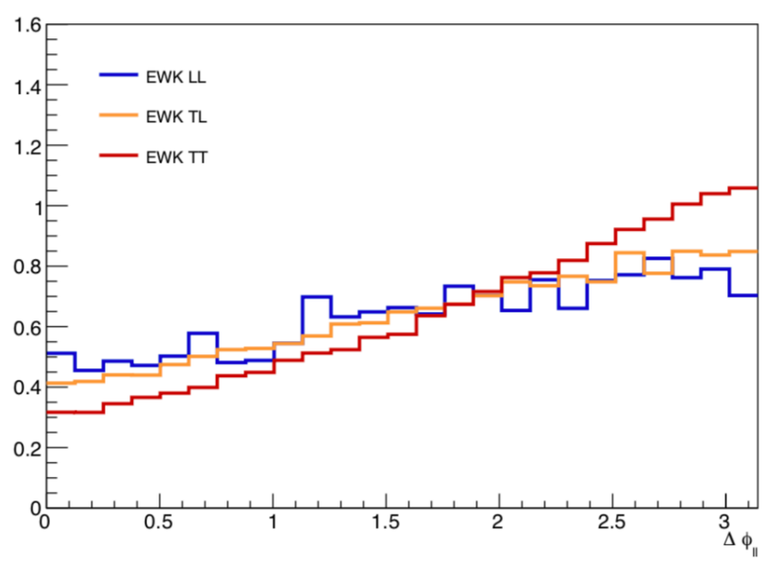
Vector Boson Scattering

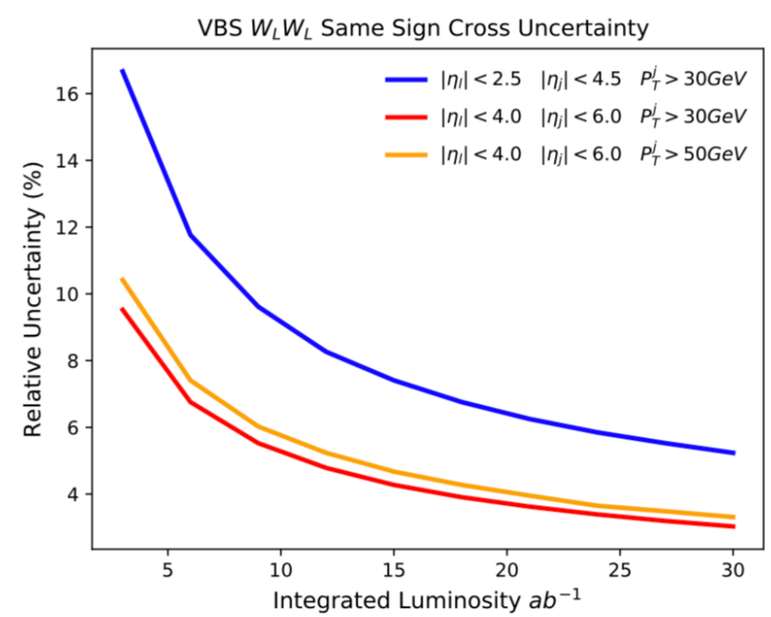
[Sznajder, MS]

- First opportunity to **measure precisely the $V_L V_L$** component that **unitarizes** VBS at high energy (barely 3σ at HL-LHC)
- Sets constraints on **detector acceptance** (fwd jets at **η≈4**)
- Study **$W^{+/-}W^{+/-}$ (same-sign)** channel
- **Large WZ** background at FCC-hh
- **3-4% precision on $W_L W_L$ scattering** achievable with full dataset!









Conclusions & outlook

- Higgs-self coupling can be measured with **$\delta\kappa_\lambda$(stat) ≈ 5%** precision at FCC-hh (best achievable precision among all future facilites)
- The FCC-hh machine will produce > **10^{10} Higgs bosons**
- Such **large statistics** open up a whole new range of possibilities, allowing for precision in new kinematic regimes
- Measuring **ratios of couplings** (or equivalently BRs), allows to cancel systematics (1% precision on "rare" couplings within reach after absolute HZZ measurement in e+e-)
- **VBS** longitudinal polarisations **$V_L V_L$** can be measured at **3-4%** precision($W_L W_L$ same sign)
- Extremely rich Higgs program at the FCC, that goes much beyond (light yukawa, Higgs off-shell width measurement, Higgs differentials) still to be studied …