Higgs & EWSB @FCC-hh

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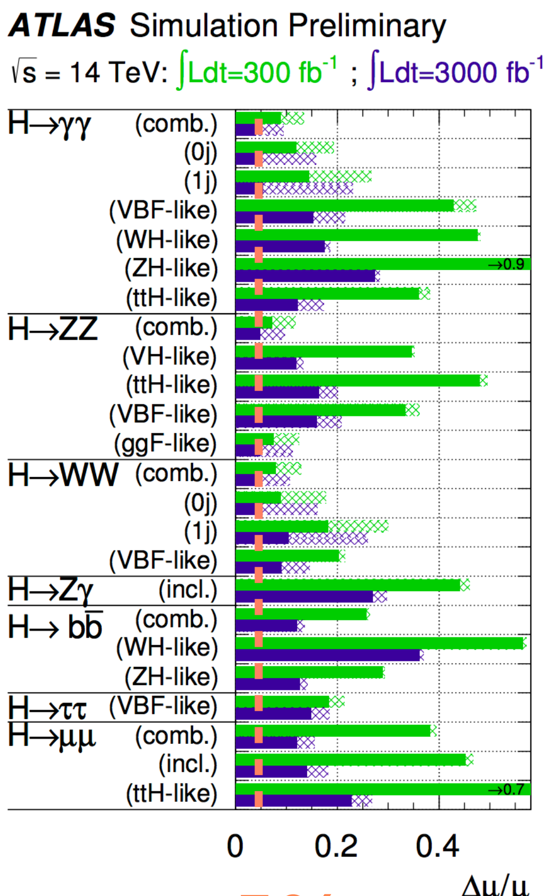
FCC week 2018 - /04/2018 - Amsterdam

Why measuring Higgs @FCC-hh?

LHC



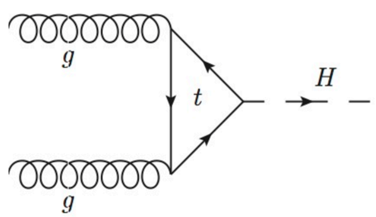
5%

- Higgs precision measurements are **guaranteed deliverables**, because we know the Higgs exists…
- Potential **deviations** on Higgs couplings might **indicate presence of new physics**
- FCC-hh provides complementary measurements to FCC-ee:
  - **rare decays** (BR(μμ), BR(Zɣ), ratios, ..) measurements will be statistically limited at FCC-ee
  - **top Yukawa and** Higgs **self-coupling**
- Directly test unitarisation of VBS by the Higgs by measuring W_LW_L and Z_LZ_L (not accessible at HL-LHC)

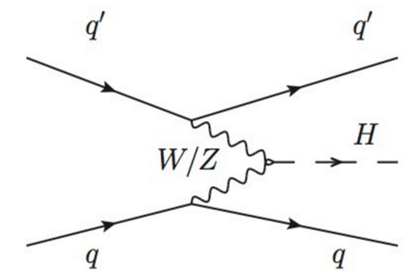
FCC-ee

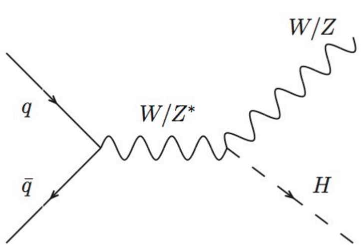
in %	FCC-ee 240 GeV	+FCC-ee 350 GeV
g_{HZ}	0.21	0.21
g_{HW}	1.25	0.43
g_{Hb}	1.25	0.64
g_{Hc}	1.49	1.04
g_{Hg}	1.59	1.18
$g_{H\tau}$	1.34	0.81
$g_{H\mu}$	8.85	8.79
$g_{H\gamma}$	2.37	2.12
Γ_H	2.61	1.55

Higgs production at FCC-hh

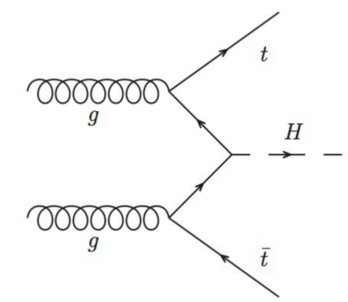


	σ(13 TeV)	σ(100 TeV)	σ(100)/σ(13)
ggH (N^3LO)	49 pb	803 pb	16
VBF (N^2LO)	3.8 pb	69 pb	16
VH (N^2LO)	2.3 pb	27 pb	11
ttH (N^2LO)	0.5 pb	34 pb	55





	N_{100}	N_{100}/N_8	N_{100}/N_{14}
$gg \to H$	16×10^9	4×10^4	110
VBF	1.6×10^9	5×10^4	120
WH	3.2×10^8	2×10^4	65
ZH	2.2×10^8	3×10^4	85
$t\bar{t}H$	7.6×10^8	3×10^5	420



$N_{100} = \sigma_{100\,\mathrm{TeV}} \times 20\ \mathrm{ab}^{-1}$
$N_8 = \sigma_{8\,\mathrm{TeV}} \times 20\ \mathrm{fb}^{-1}$
$N_{14} = \sigma_{14\,\mathrm{TeV}} \times 3\ \mathrm{ab}^{-1}$

Factor: 1/100 1/10 reduction in stat. unc.

- **Large statistics** will allow to isolate **cleaner samples** in regions with:
  - higher S/B
  - smaller impact of systematics

Outline

- Will discuss **prospects for Higgs coupling measurements** at FCC-hh, by looking at following **processes (all decays with exception on ttH)**:
  - ttH → bb boosted
  - H→γγ,
  - H→ZZ→4l
  - H→μμ
  - H→zγ

- All **signal and background samples** have been generated via the following chain (using the FCCSW):

  - **MG5aMC@NLO + Pythia8**
    - LO (MLM) matched samples (up to 1/2/3 jets) and global K-factor applied to account for $N^{2/3}LO$ corrections
    - full list of signal prod. modes simulated (ggH with finite m_{top})
  - **Delphes-3.4.2** with baseline FCC-hh detector

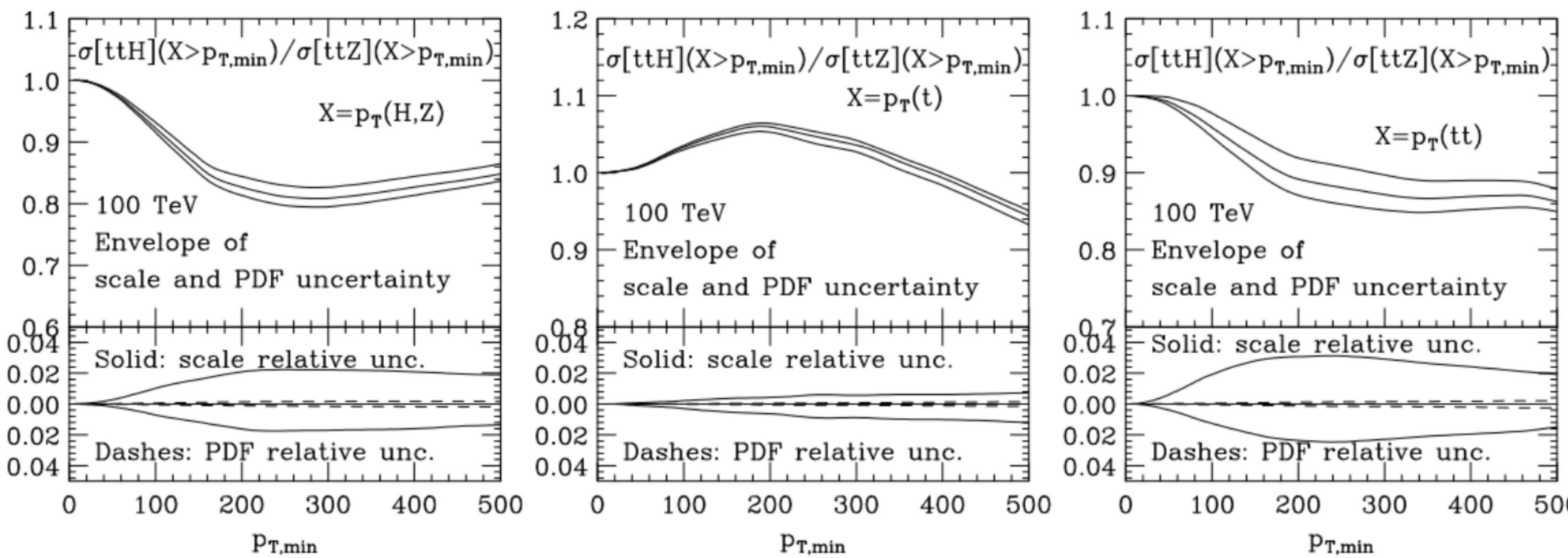
  - Full list of samples can be found here:

http://fcc-physics-events.web.cern.ch/fcc-physics-events/LHEevents.php

Top Yukawa

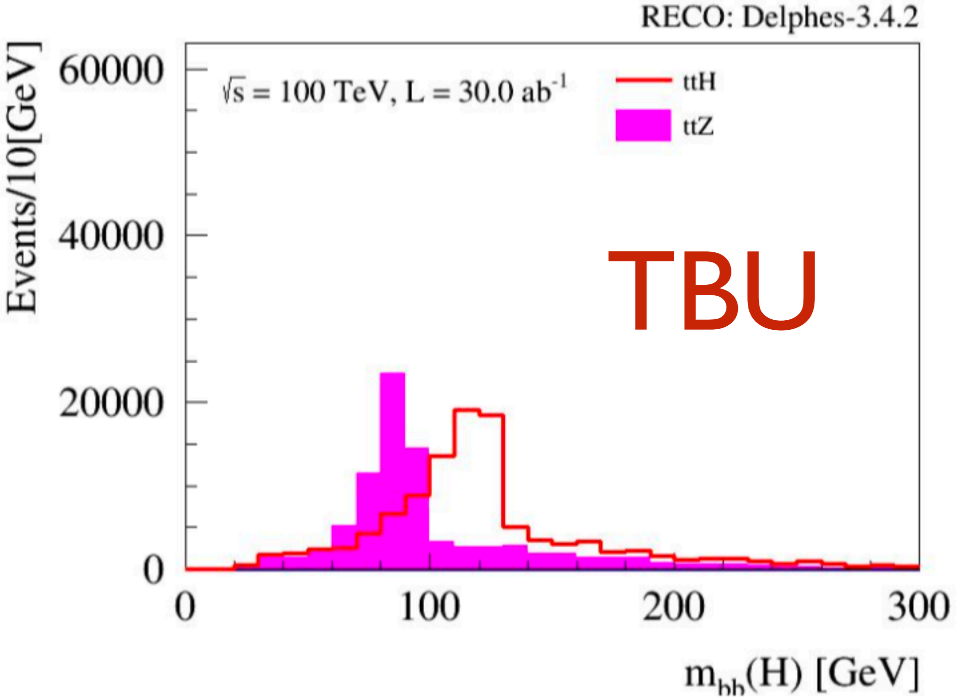
- Several possibile channels to measure top yukawa
  - **ttH → bb, boosted [arXiv:1507.08169]**
  - ttH → WW, ZZ →multileptons (in progress)
  - ttH → γγ (in progress)

- ttH and ttZ have very similar **production dynamics**, with **highly correlated** systematics:
- σ(ttH)/σ(ttZ) can be predicted with < 1% precision across a large kinematic range



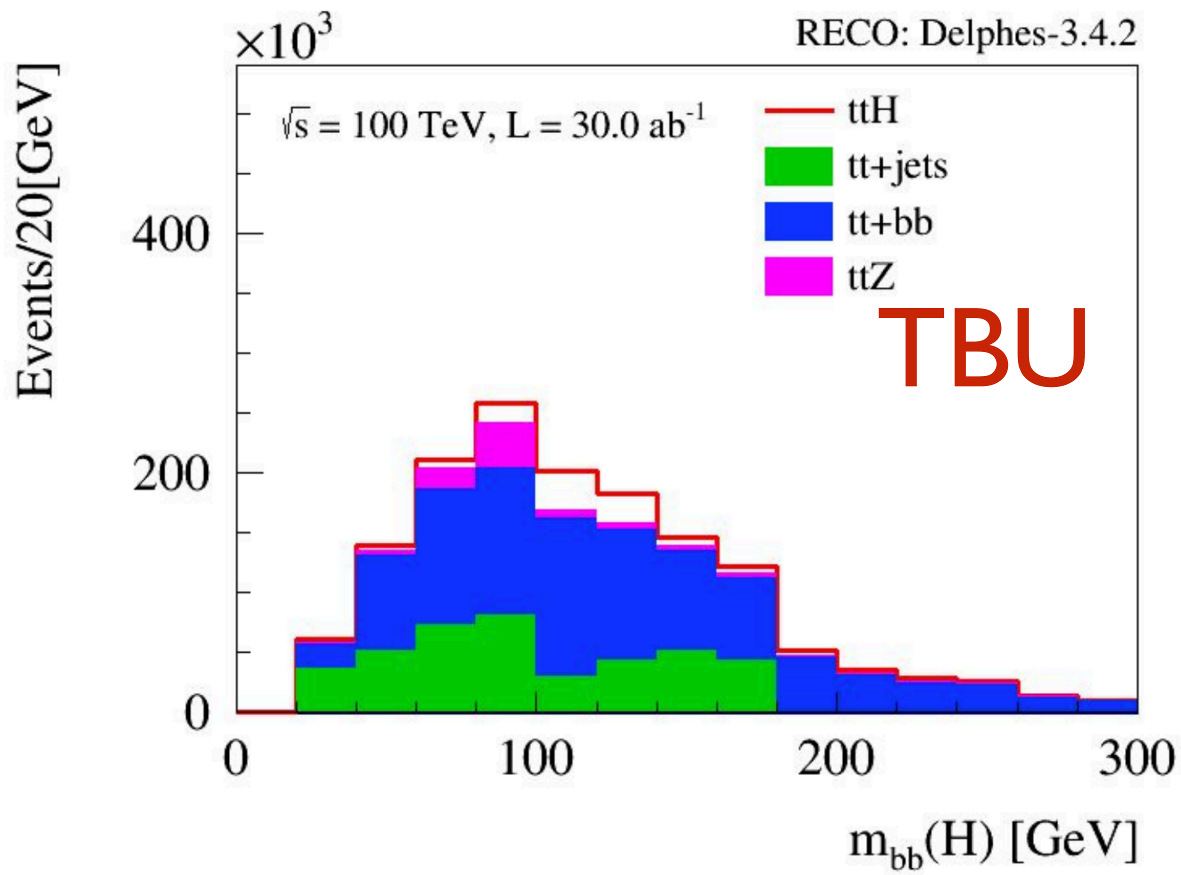
Measurement

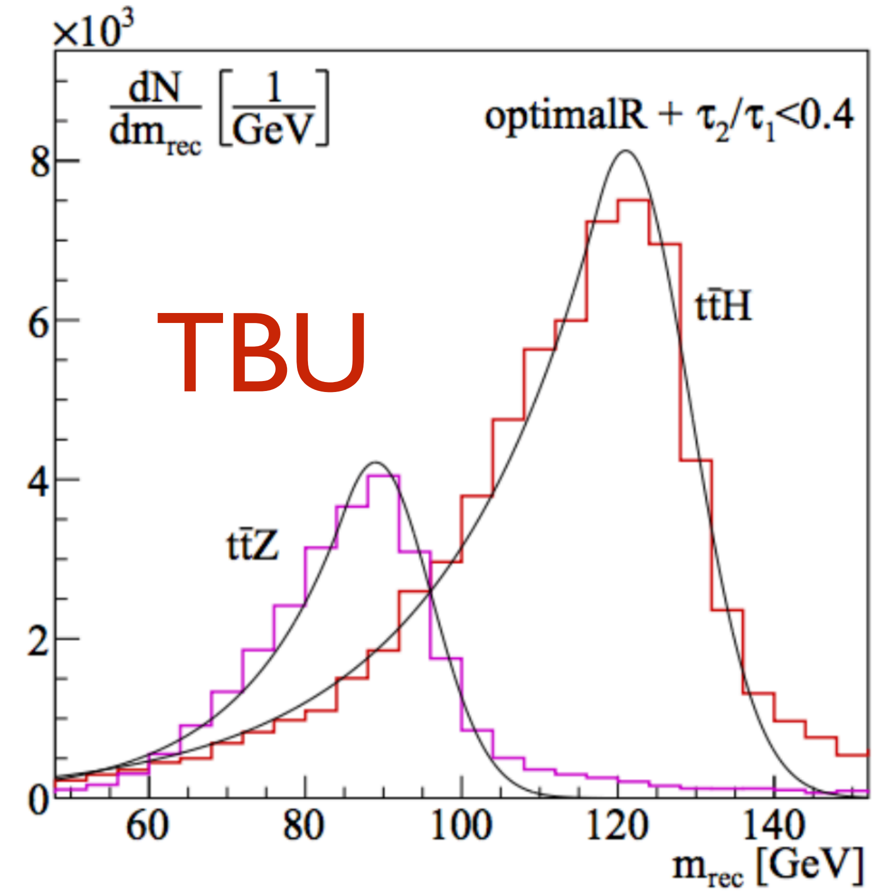
- Measure ttH/ttZ ratio in the H->bb, Z->bb channel
- Final state:
  - boosted Higgs, H-> bb
  - boosted top hadronic
  - other top leptonic decay
- Signature:
  - 2 fatjets,
  - 1 lepton,
  - MET, (+ 1 bjet)
- Backgrounds:
  - ttZ,
  - tt+jets,
  - tt+bb
  - W/Z+jets ignored for now



Top Yukawa

- Measure top Yukawa by measuring **σ(ttH)/σ(ttZ)**
- Highest sensitivity determined by **semi-leptonic boosted topology** t_{lep} t_{had} H_{had}





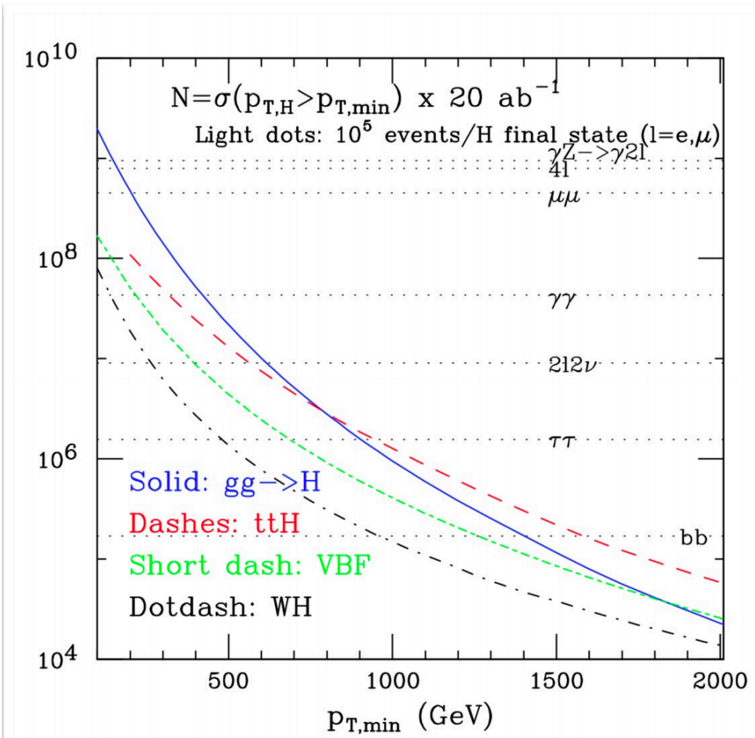
tt+jets from side bands (m_j > 160 GeV)

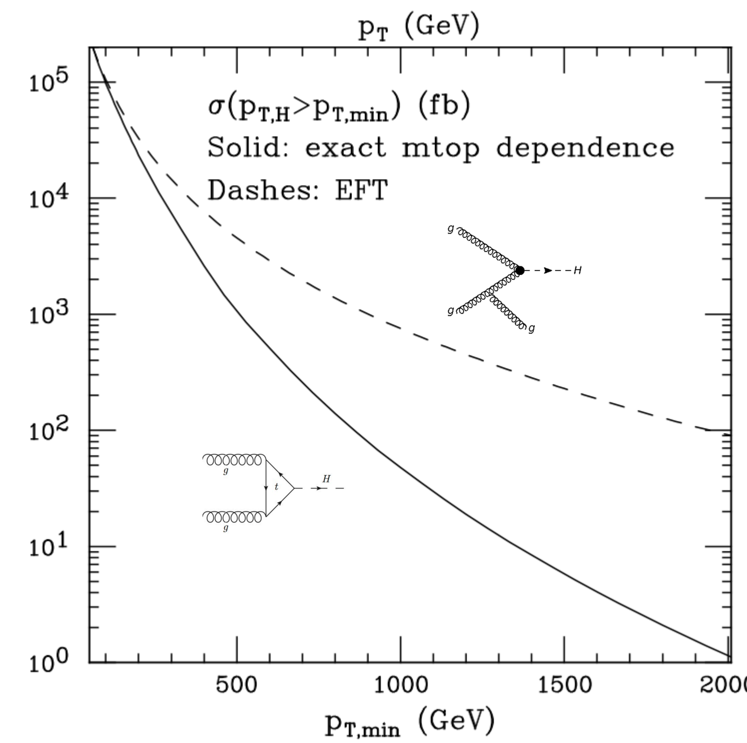
Fit and extract N_H / N_Z to ≈1% accuracy

δy_t (stat + syst $_{TH}$) ~ 1%

Higgs $N(p_T > p_{T,min})$

from MLM, 100 TeV Higgs report





- will have at disposal, $o(10^6)$ Higgs bosons at pT(H) > 1 TeV
- **ttH (VBF) overcomes ggH at p_T > 800 (2000) GeV,** distinctive signatures can be used
- Higgs pT spectrum is an indirect probe for new physics modifying, e.g. ggH coupling
  - heavy states running in the loop
  - complementary to Hgg measurement in e+ e- (how do they compare?)

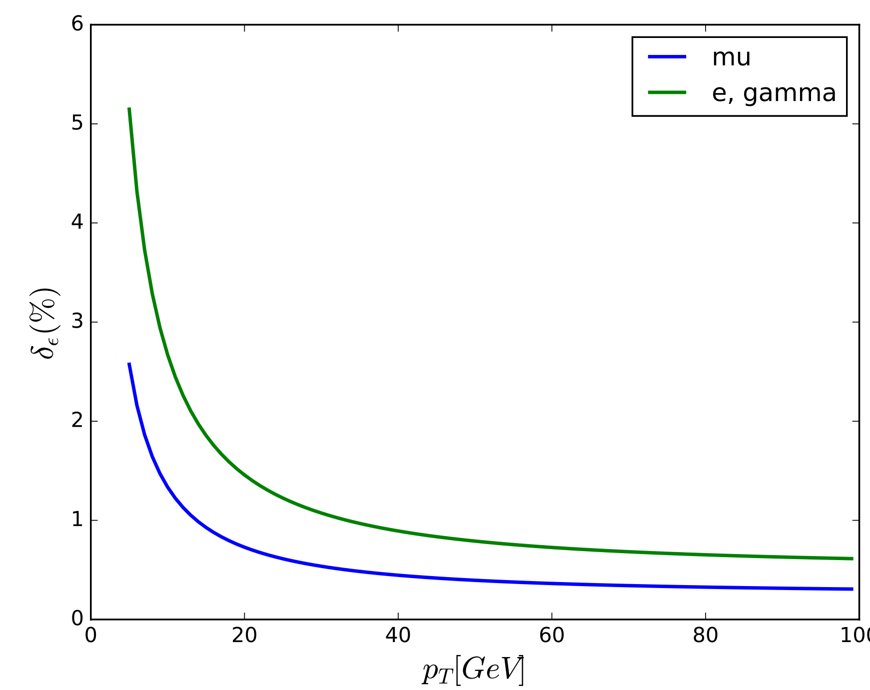
Higgs decay studies

- Will show prospects for S/B and precision on the signal strength **$\delta\mu/\mu$** in the following channels (**$H\to\gamma\gamma$, $H\to 4l$, $H\to\mu\mu$, $H\to Z\gamma$**) for various scenarios.

- Consider the following categories of uncertainties:

  - δ_{stat} = statistical
  - δ_{prod} = production + luminosity systematics
  - $\delta_{eff}^{(i)}(p_T)$ = object reconstruction (trigger+isolation+identification) systematics
  - $\delta_B = 0$, background (assume to have ∞ statistics from control regions)

  - Assume the following baseline for **reconstruction efficiency** uncertainties $\delta_{eff}^{(i)}(p_T)$



Higgs decay studies

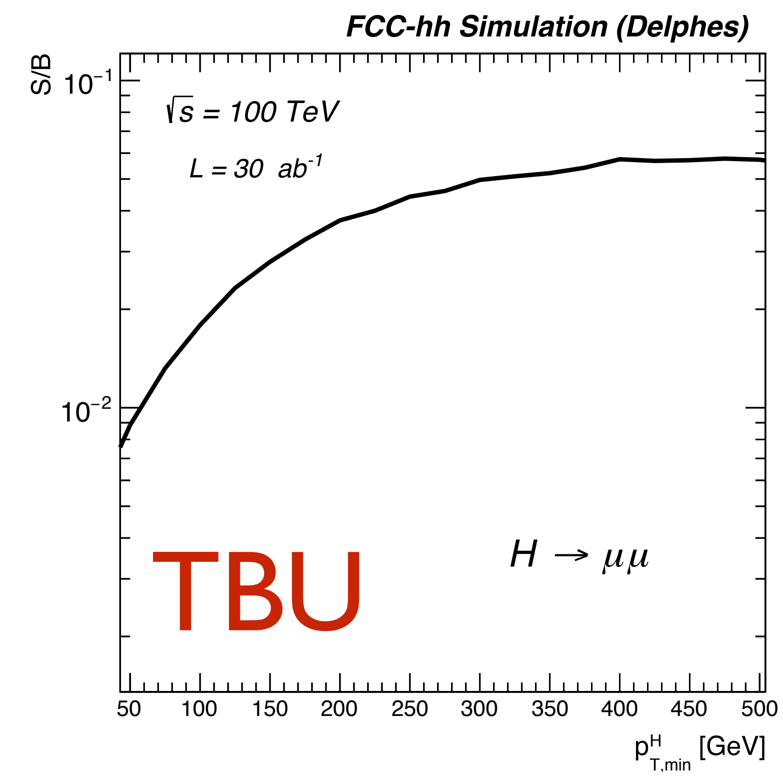
- Given how uncertainties scale with p_T, makes sense to explore sensitivity at large $p_T(H)$ (also qq induced backgrounds falls more steeply)
- Propagate systematics based on average p_T of Higgs decay product
  - ex: $H \to \mu\mu$, with $p_T(H) > 50$ GeV
    - $p_T(\mu_1) \sim 100$ GeV $\to$ $\delta_{eff}^{(\mu)} \approx 0.25\%$
    - $p_T(\mu_2) \sim 50$ GeV $\to$ $\delta_{eff}^{(\mu)} \approx 0.50\%$
- Assume (un-)correlated uncertainties for (different) same final state objects
- Following scenarios are considered:
    - δ_{stat} $\to$ stat. only (I)
    - δ_{stat} , δ_{eff} $\to$ stat. + eff. unc. (II)
    - δ_{stat} , δ_{eff} , $\delta_{prod} = 1\%$ $\to$ stat. + eff. unc. + prod (III)

H → μμ

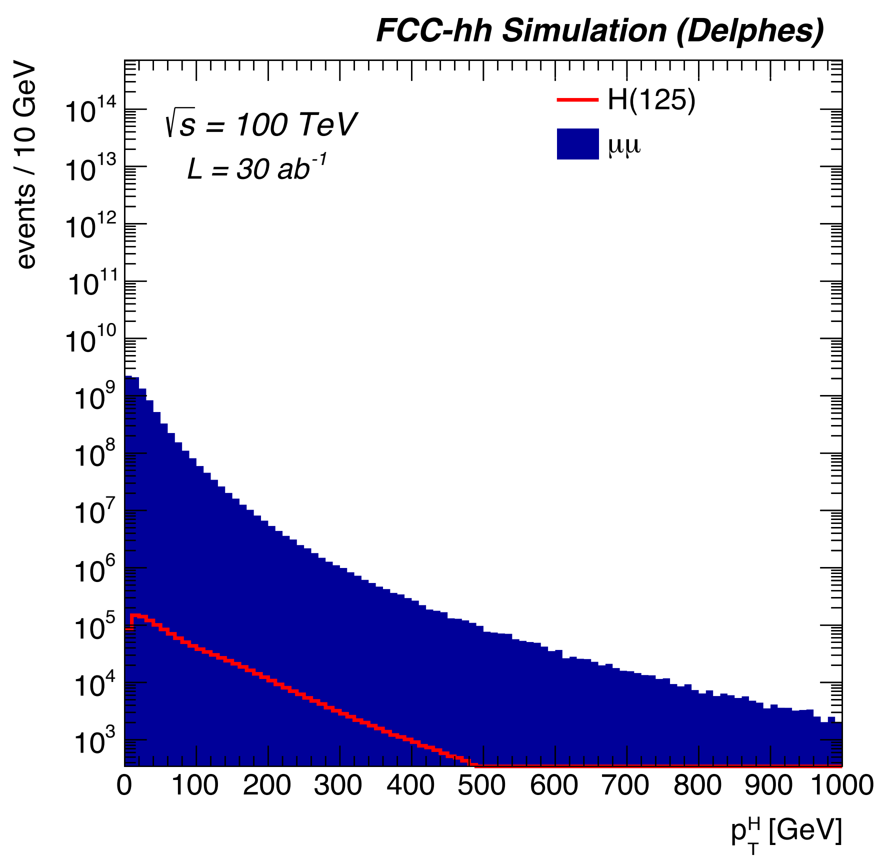
- Very small BR(H → μμ) ~ 2.18e-04,
  → %-level precision out of reach at FCC-ee

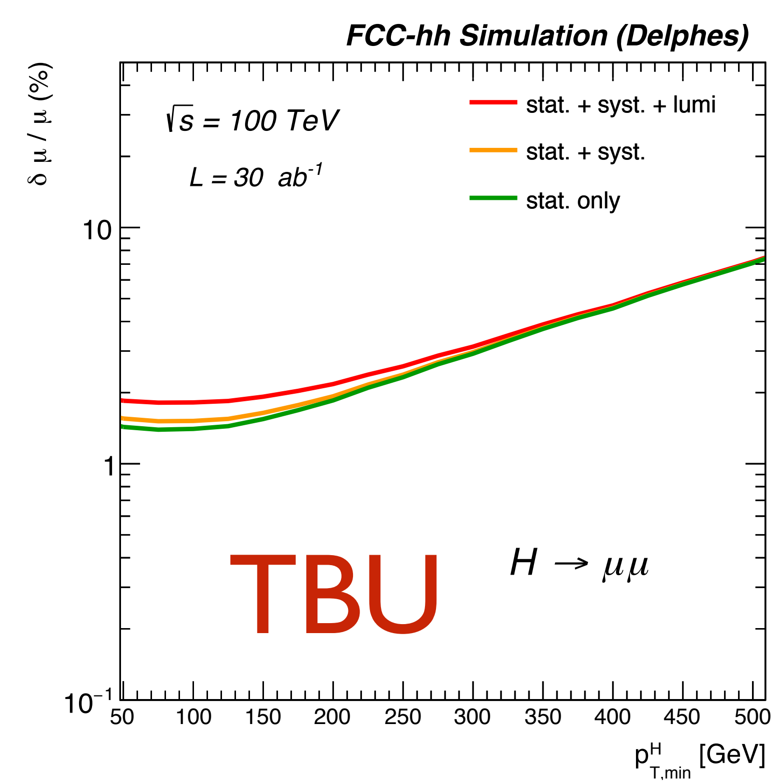
Analysis cuts

- $p_T(\mu) > 20$ GeV, $|\eta(\mu)| < 4.0$
- $|m_{\mu\mu} - m_H| < 2.5$ GeV

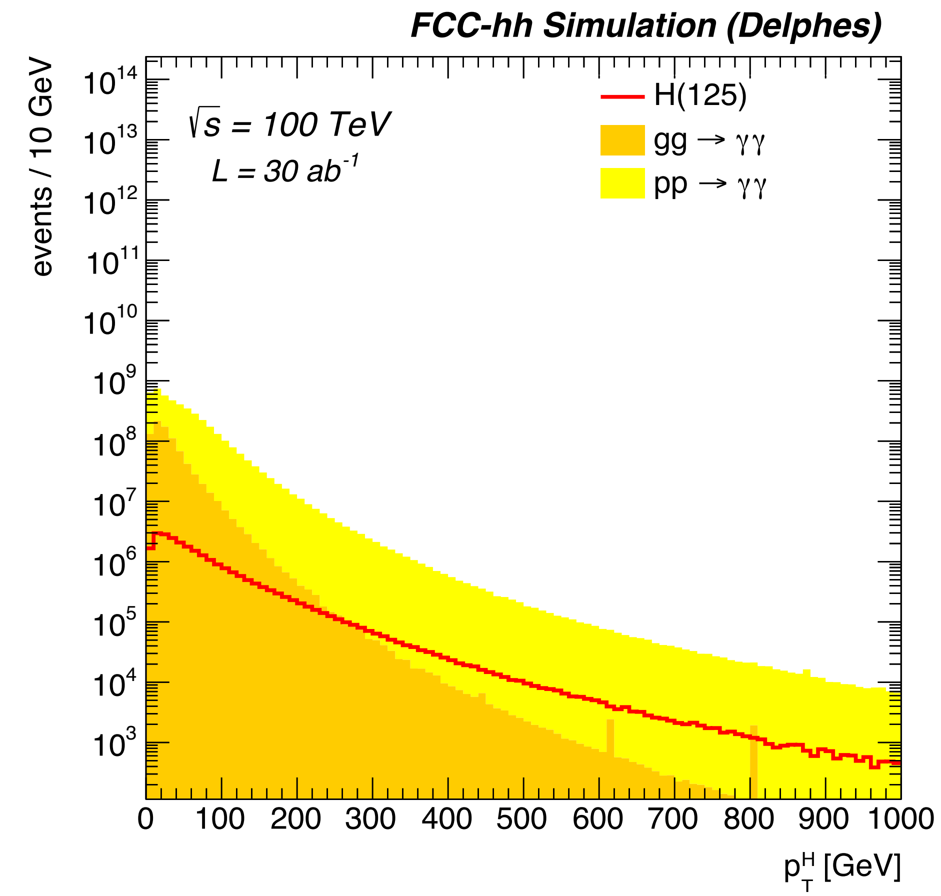


δμ/μ ≈ 1 % stat. precision
can be achieved up to p_T(H) = 200 GeV



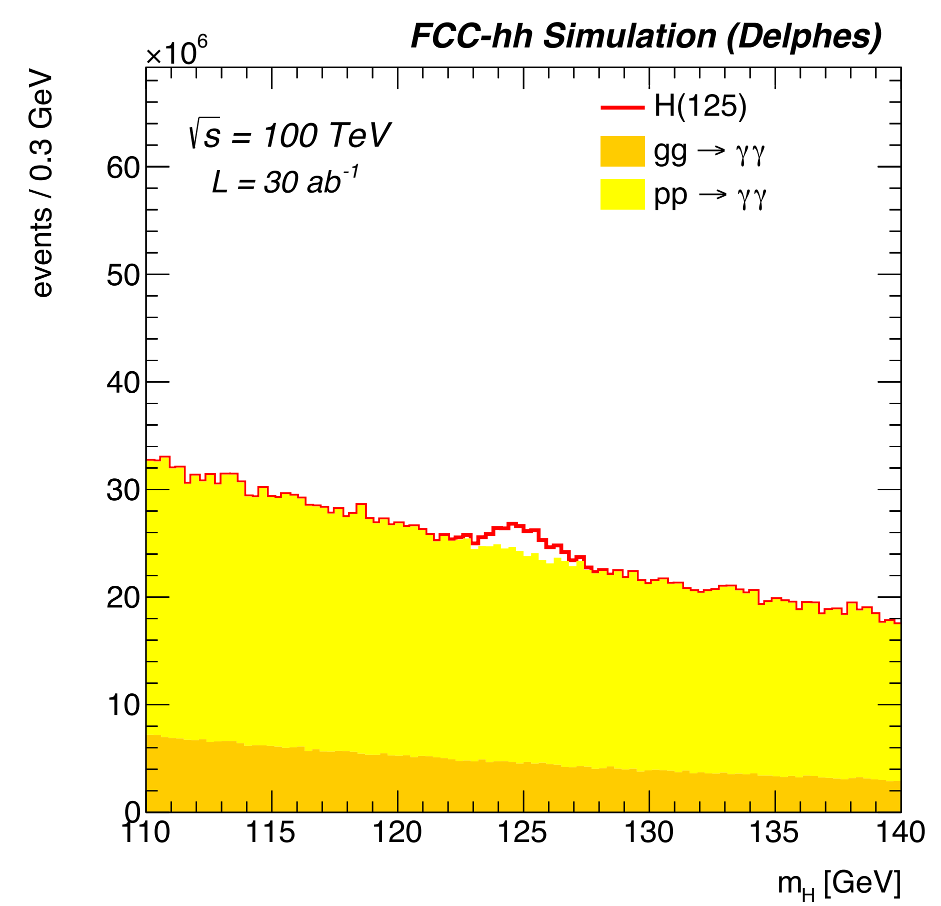


$H \to \gamma\gamma$



Backgrounds:

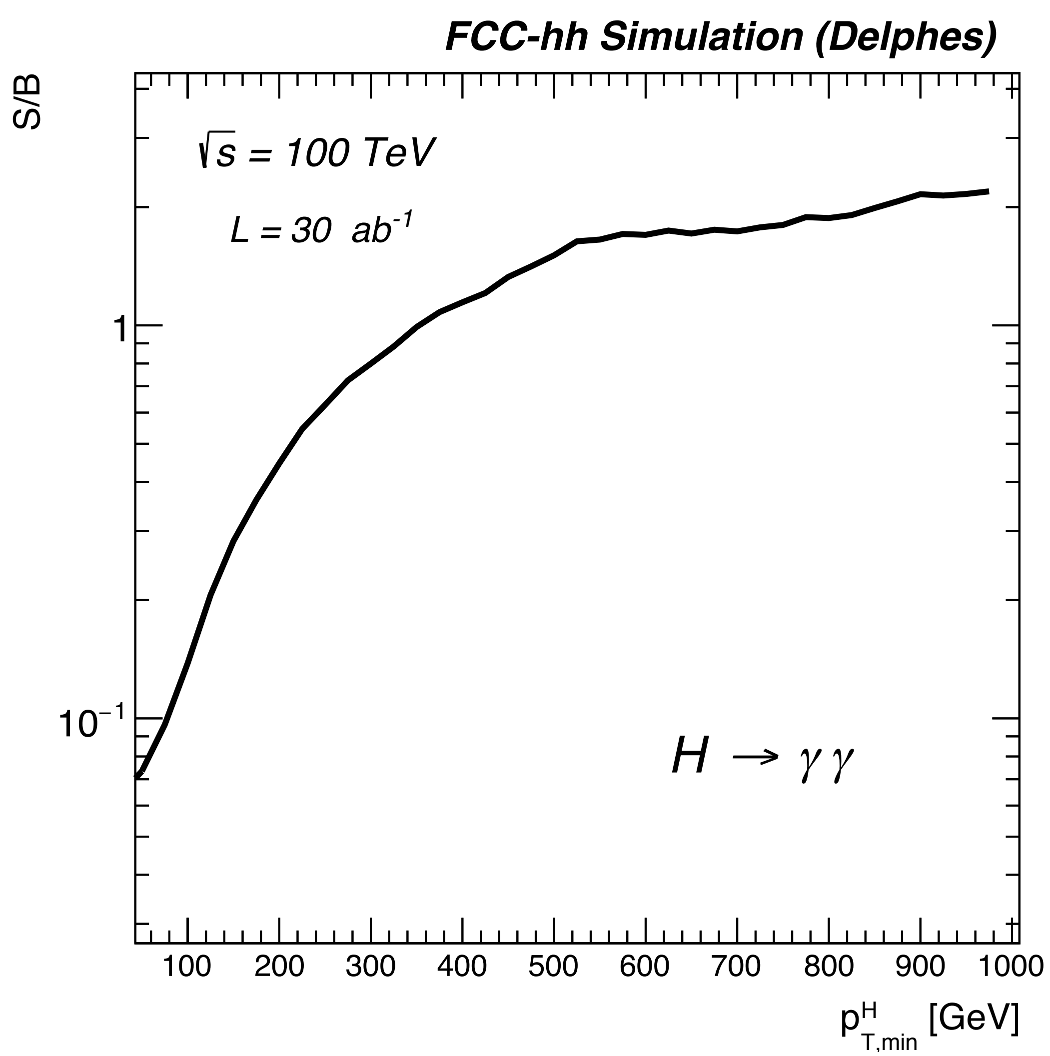
- **irreducible**: QCD $\gamma\gamma$ production
- **reducible.** : γ + jets (ignored for now)

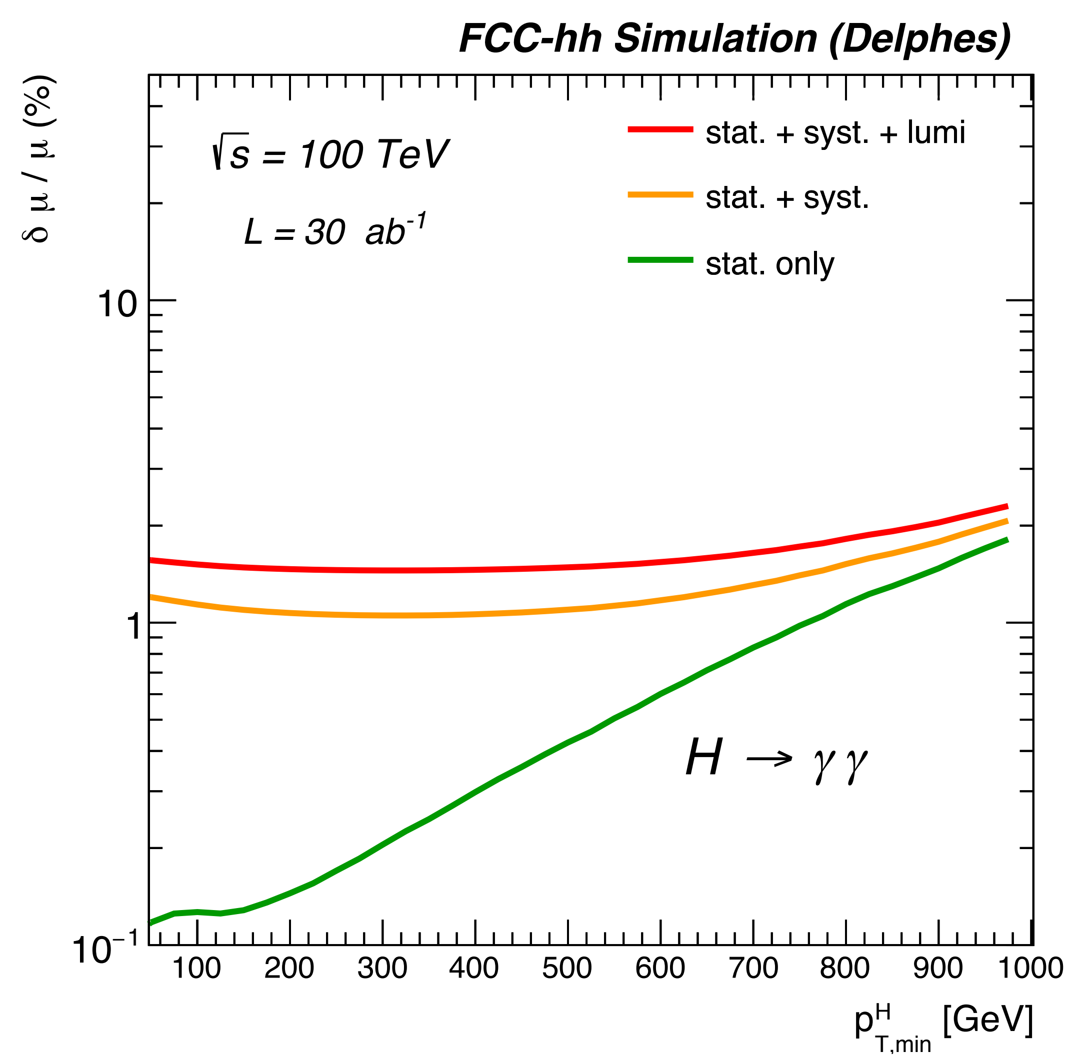


Analysis cuts

- $p_T(\gamma) > 30$ GeV, $|\eta(\gamma)| < 4.0$
- variable $p_T(H)_{min}$
- $|m_{\gamma\gamma} - m_H| < 2.5$ GeV

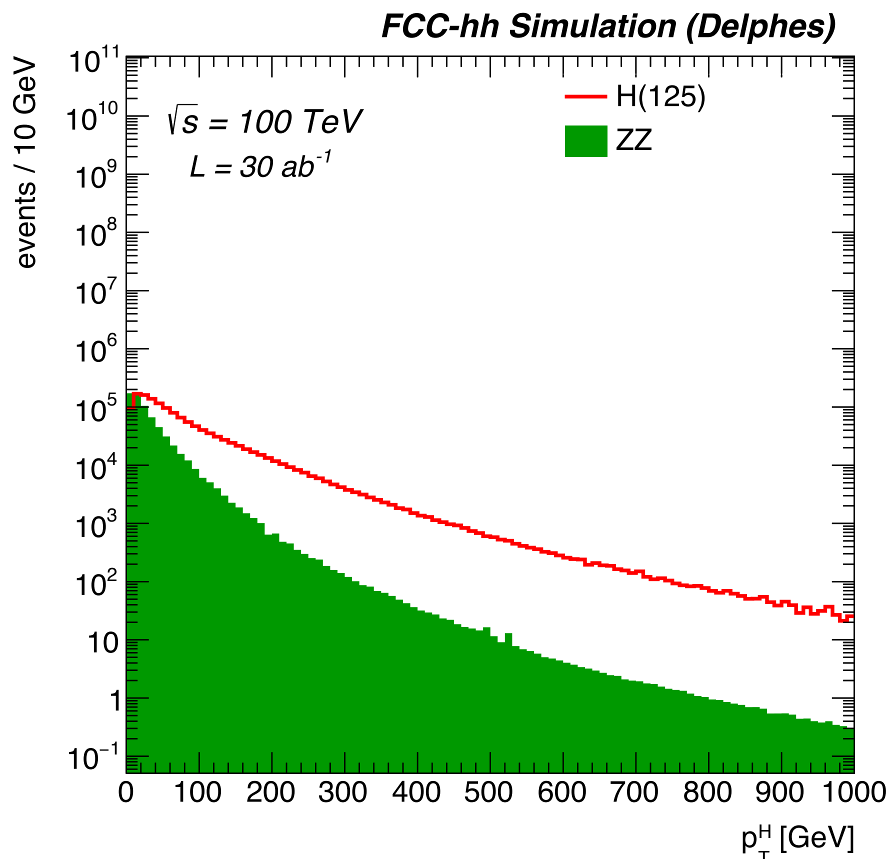
$H \to \gamma\gamma$ - Expected sensitivity





- **$\delta\mu/\mu \approx$ O(1) % precision** can be achieved up to $p_T(H)$ = 1 TeV

$H \rightarrow ZZ^* \rightarrow 4l$

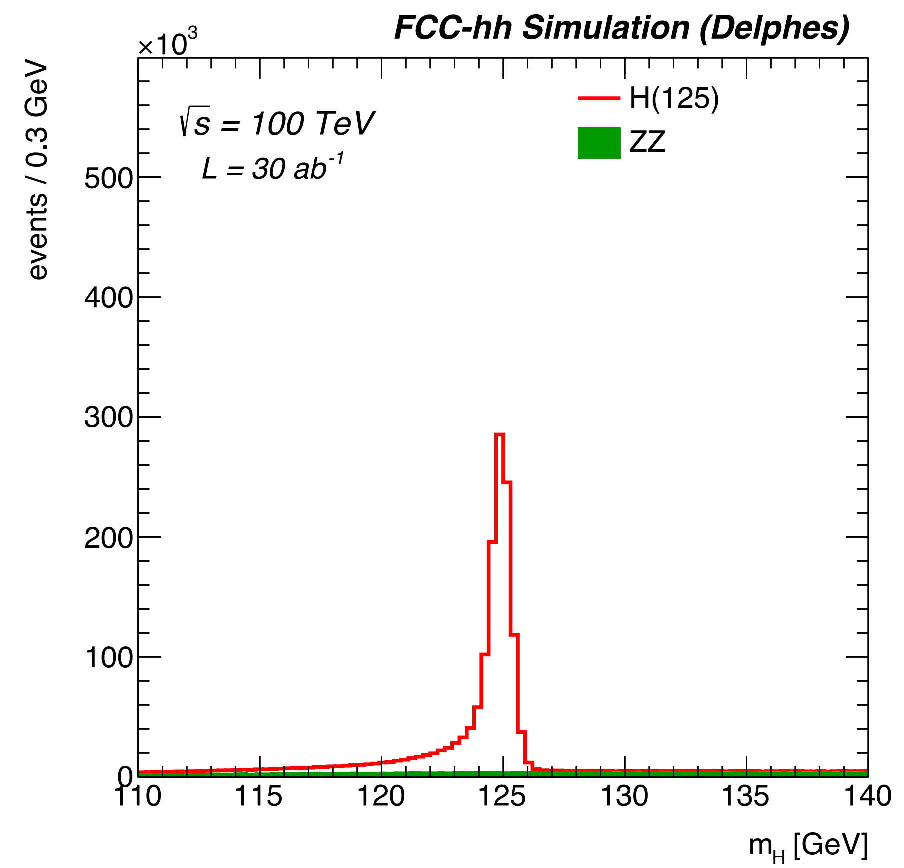


Analysis cuts:

- $40. < m_{Z1} < 120.$
- $12. < m_{Z2} < 120.$
- $p_T(l) > 10$ GeV, $|\eta(\gamma)| < 4.0$
- $120 < m_{4l} < 127.5$ GeV

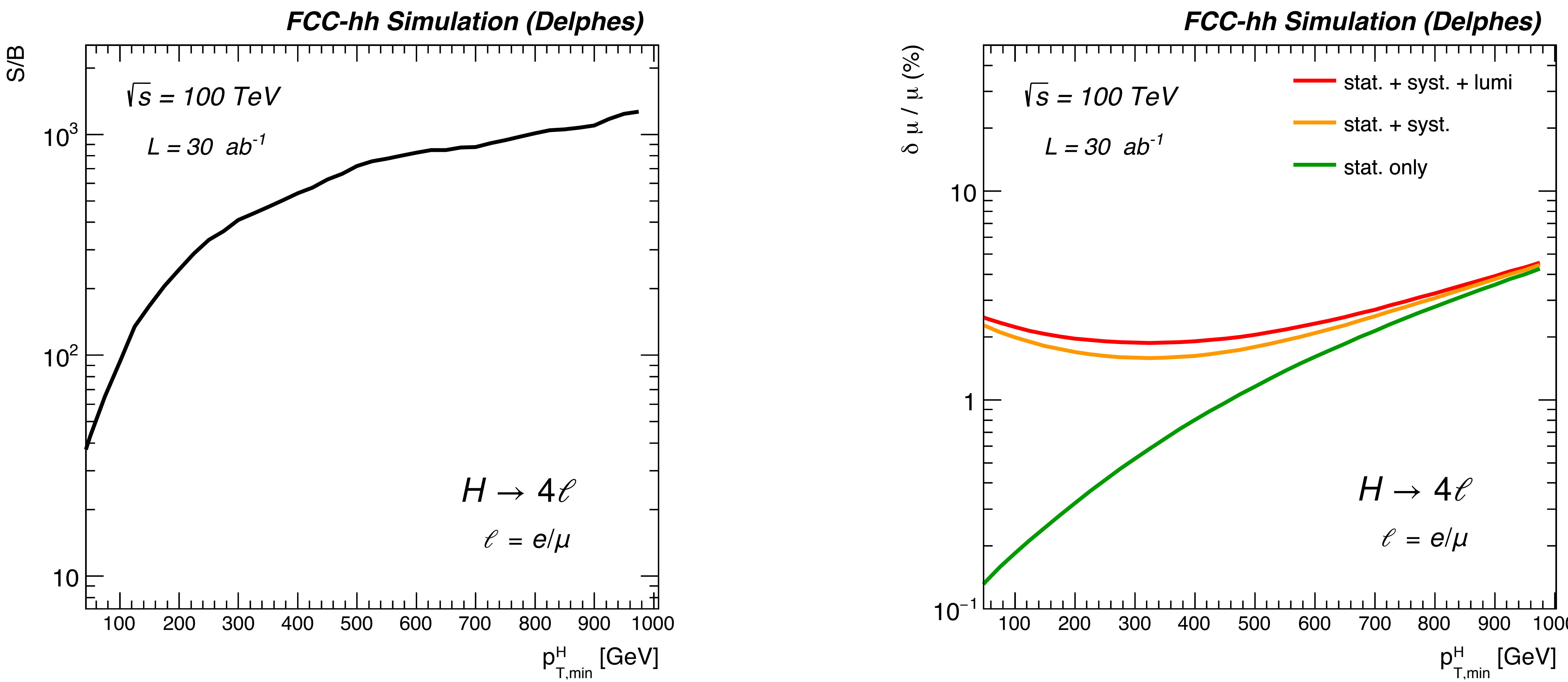
→ asymmetric cut due to FSR tail

$p_T(H) > 200$ GeV



background free analysis at
high pT !

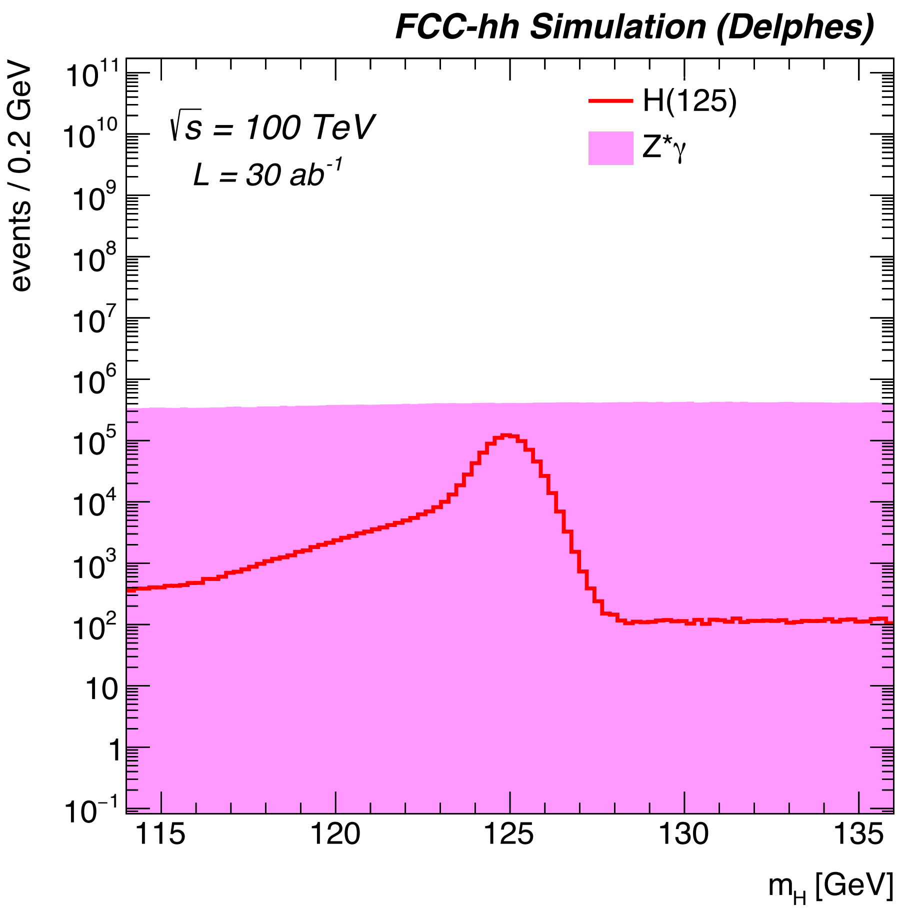
H → ZZ* → 4l - Expected sensitivity



- **δμ/μ ≈ 1 % precision** can be achieved up to $p_T(H)$ = 500
- At low p_T systematics will limit there measurement

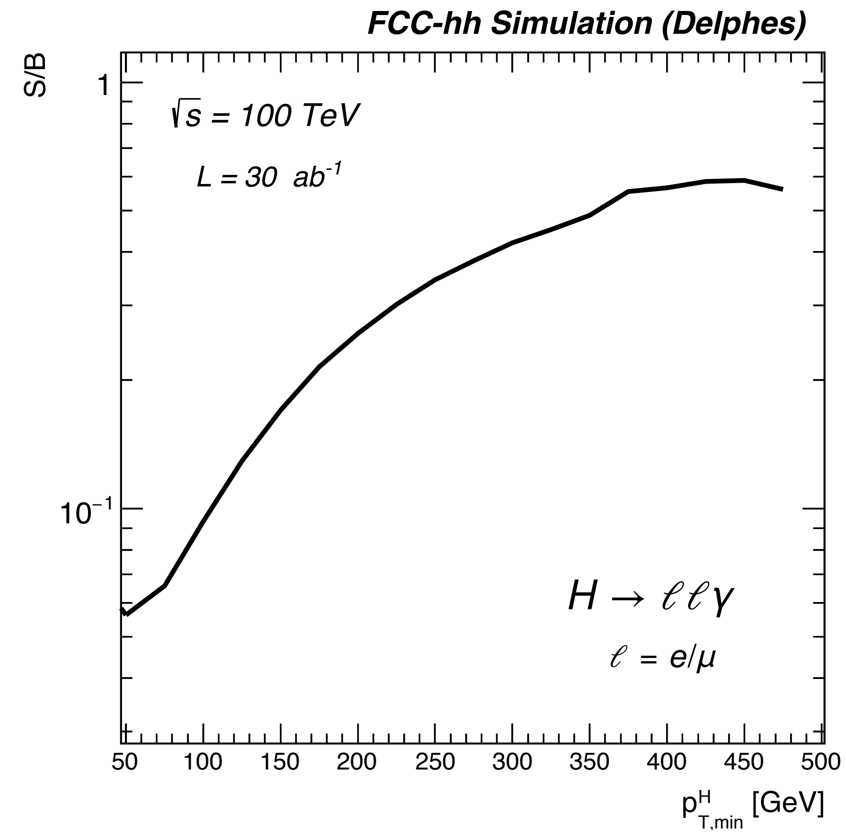
H → Zɣ → llɣ

- BR(H → Zɣ*) ~ 1.5e-03,
- irreducible: Zɣ

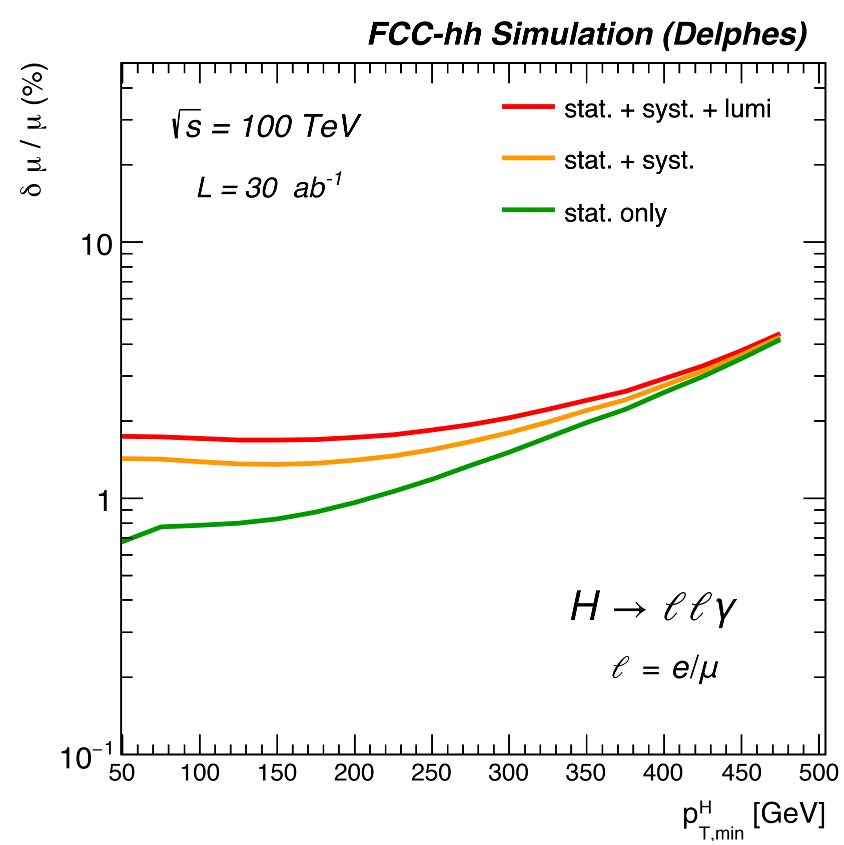


Simple cut and count strategy:

- 75 < m_{Zl} < 105.
- p_T(l) > 20 GeV, |η(l)| < 4.0
- p_T(ɣ) > 15 GeV, |η(ɣ)| < 4.0
- 122.5 < $m_{ll\gamma}$ < 127.5 GeV



δμ/μ ≈ 1 % stat. precision can be achieved up to p_T(H) = 400 GeV

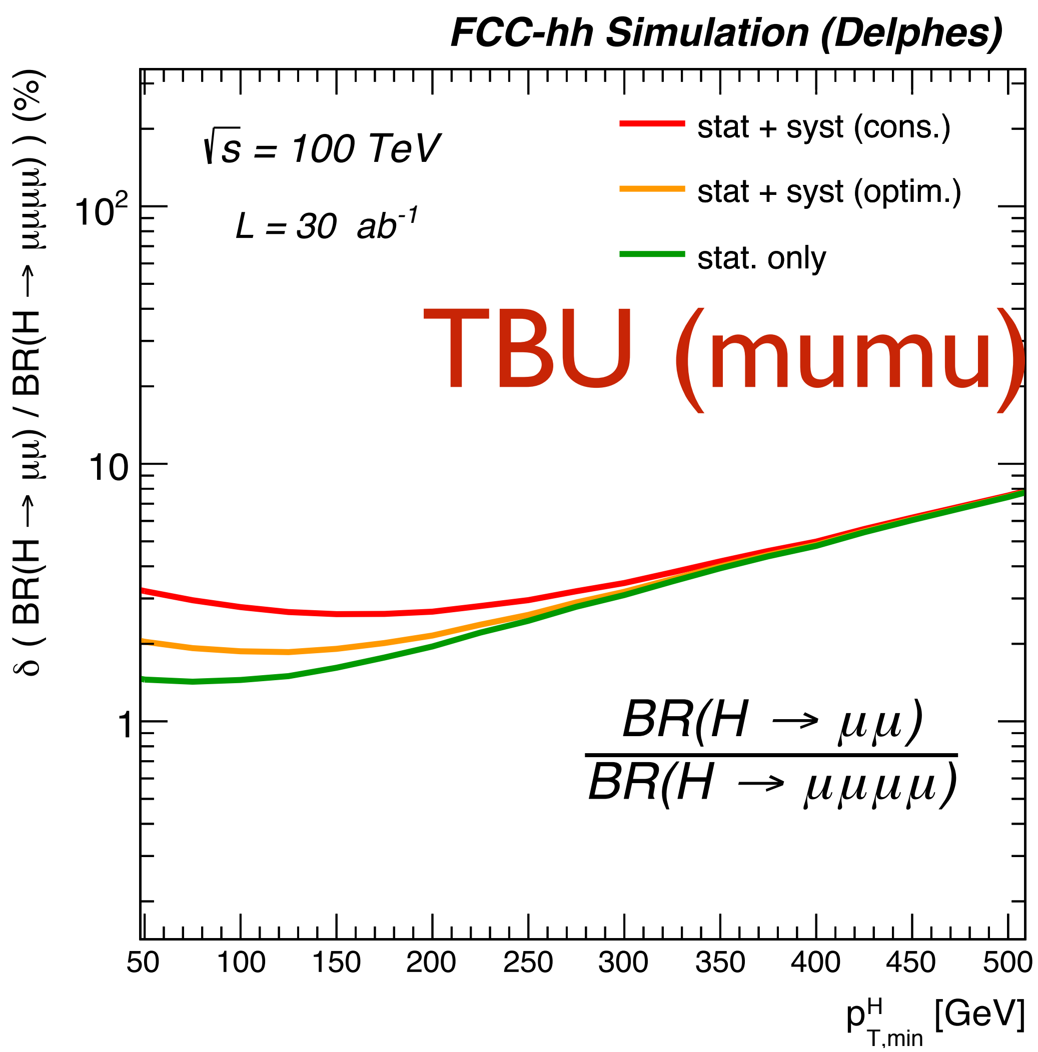


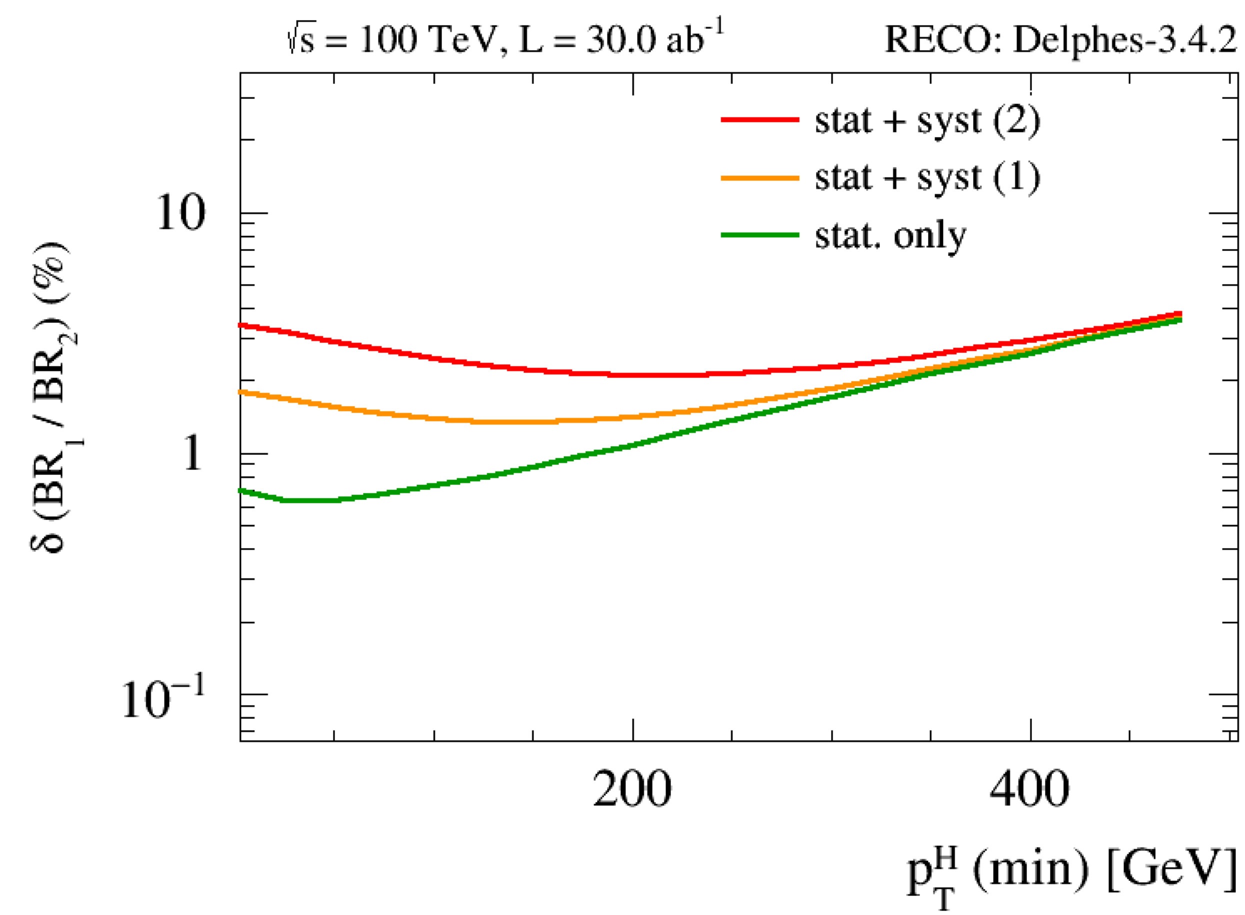
Comments

- Statistics are so **large** (even for the rare decays) is most cases that the systematics (or lumi) wall (2-3% ?) for absolute measurement will be hit well before the full 20-30 ab^{-1} @100 TeV

- In order to **cancel systematics** (from production, luminosity, etc..) a possibility is to **measure ratios of BRs**:
  - BR(μμ)/BR(4l) or BR(μμ)/BR(γγ)
  - BR(Zγ)/BR(4l) or BR(Zγ)/BR(γγ)
    → stat only **(sub)-percent precision can be reached** (provided absolute measurement given by Higgs factories)

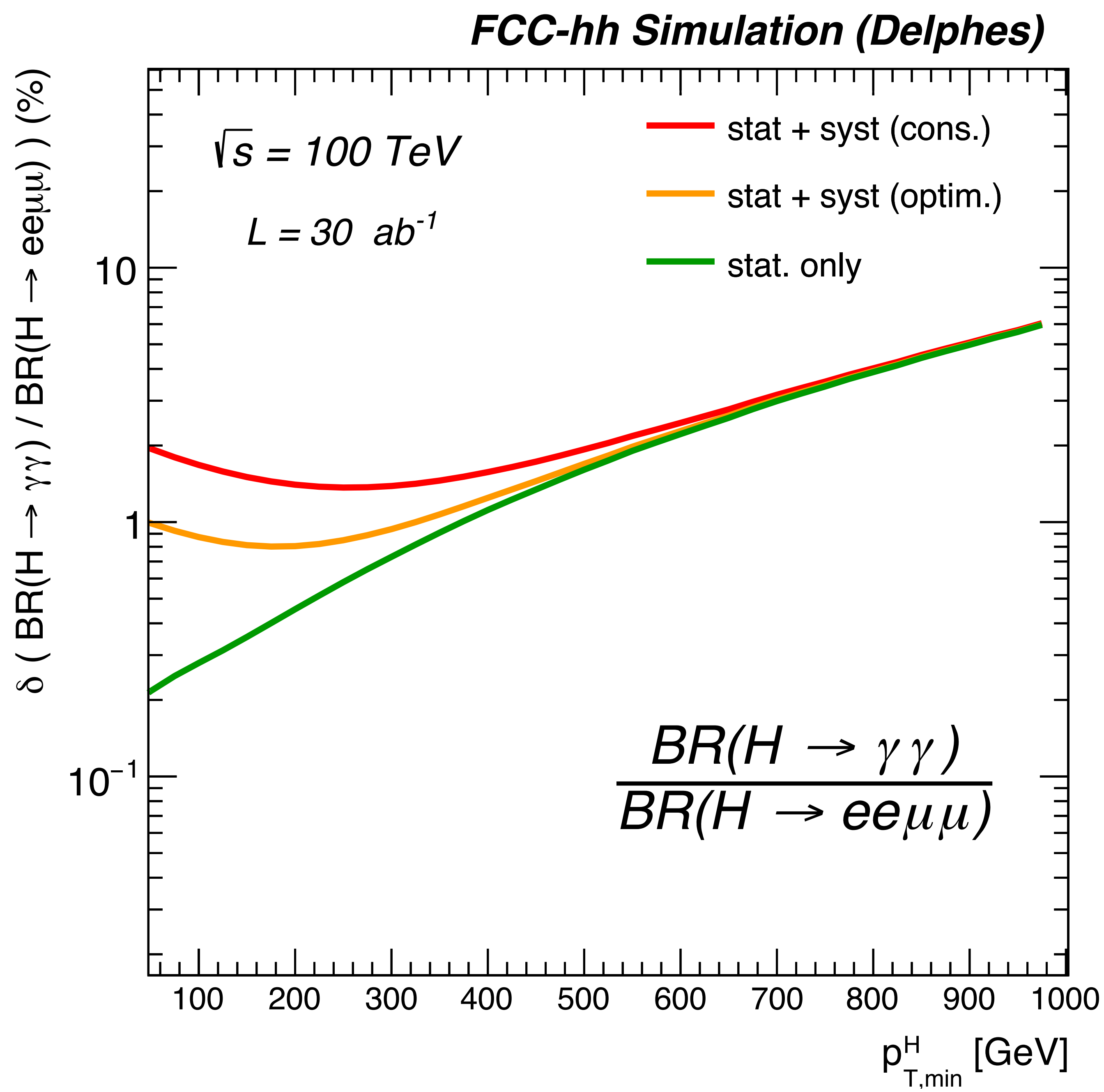
BR(H→μμ)/BR(H→4μ)





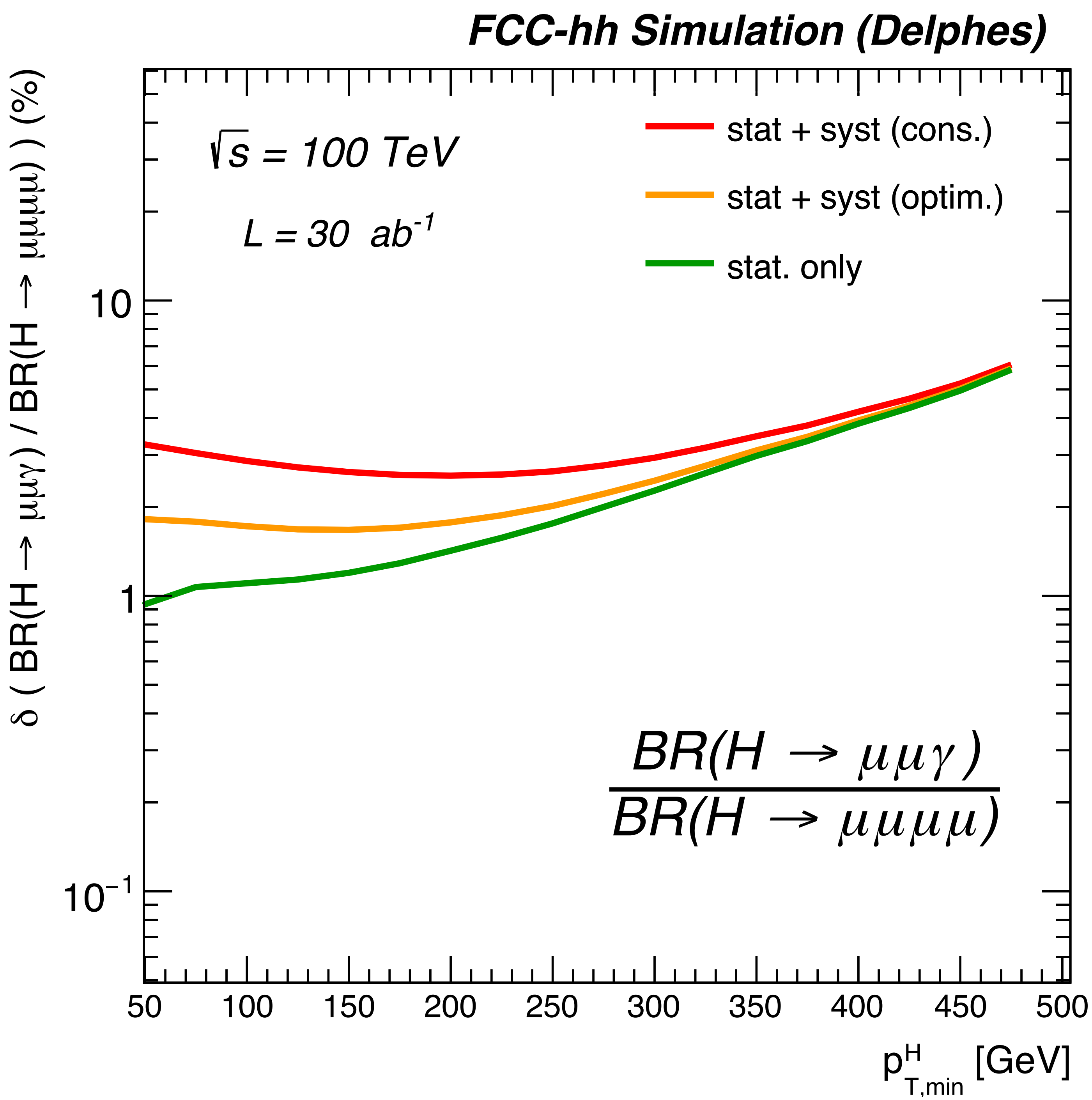
1 % precision (including systematics) within reach

BR(H→ɣɣ)/BR(H→2μ2e)



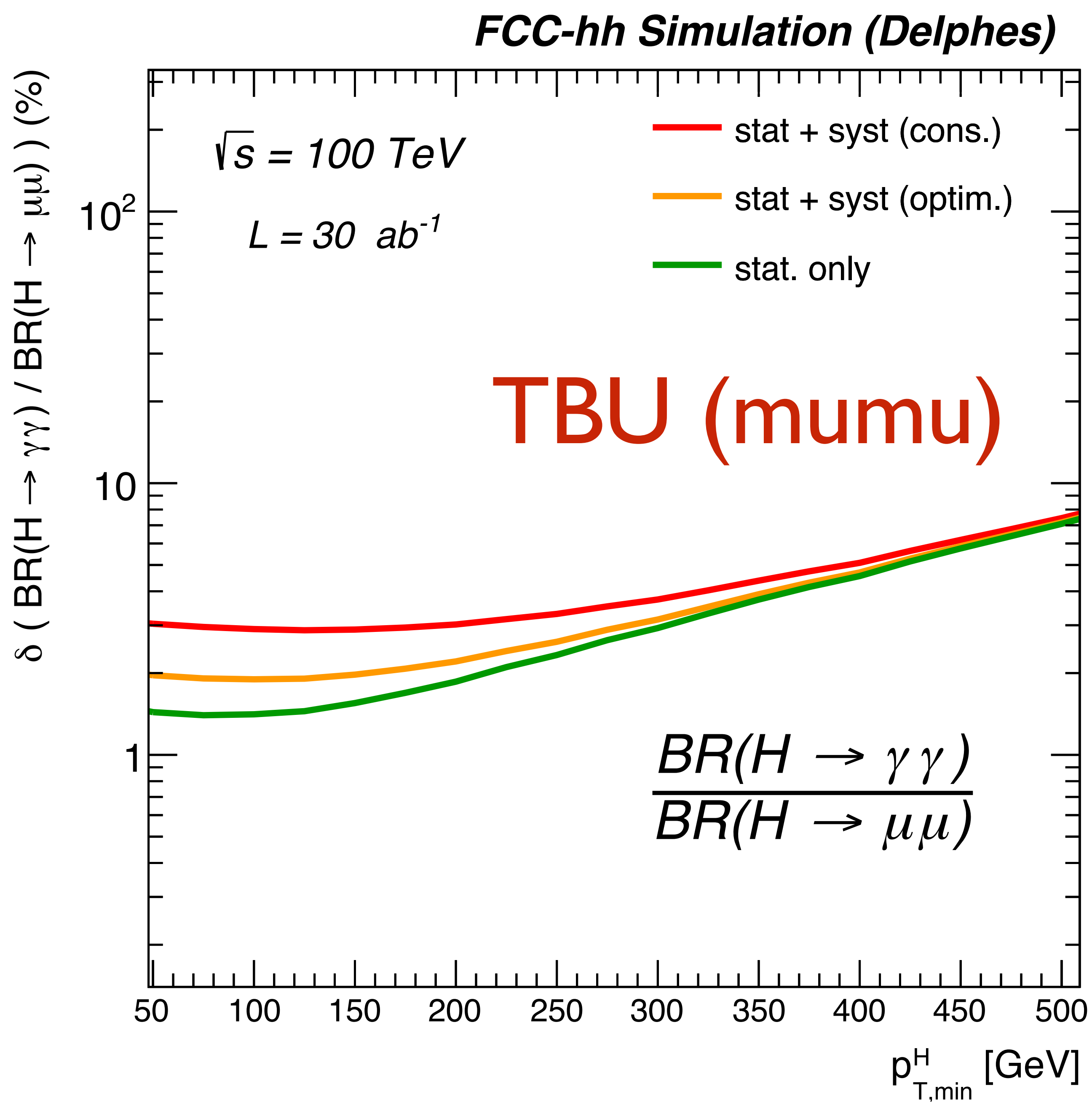
- assumes 100% between e,ɣ systematics
- **1 % precision** (including systematics) within reach

BR(H→μμγ)/BR(H→μμμμ)



1 % precision (including systematics) within reach

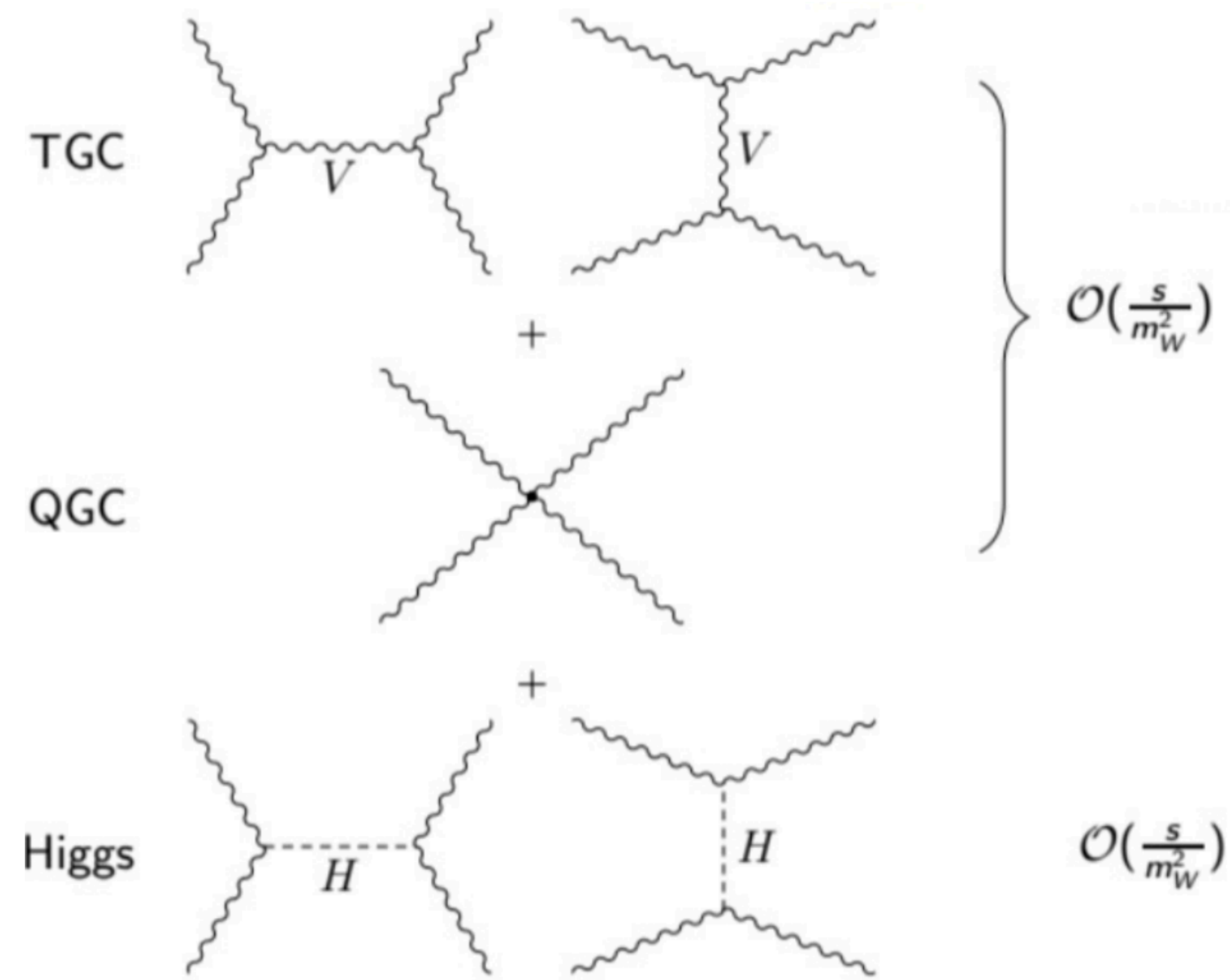
BR(H→γγ)/BR(H→μμ)



1 % precision (including systematics) within reach

VBS

- A Higgs of 125 GeV has been observed at LHC but new physics may still be hidden in EWSB
- Energy growth of (TGC+QGC) is tamed by HIGGS exchange !
- New physics could disturb this delicate unitarity balance involving longitudinally polarized VBS → rate increase

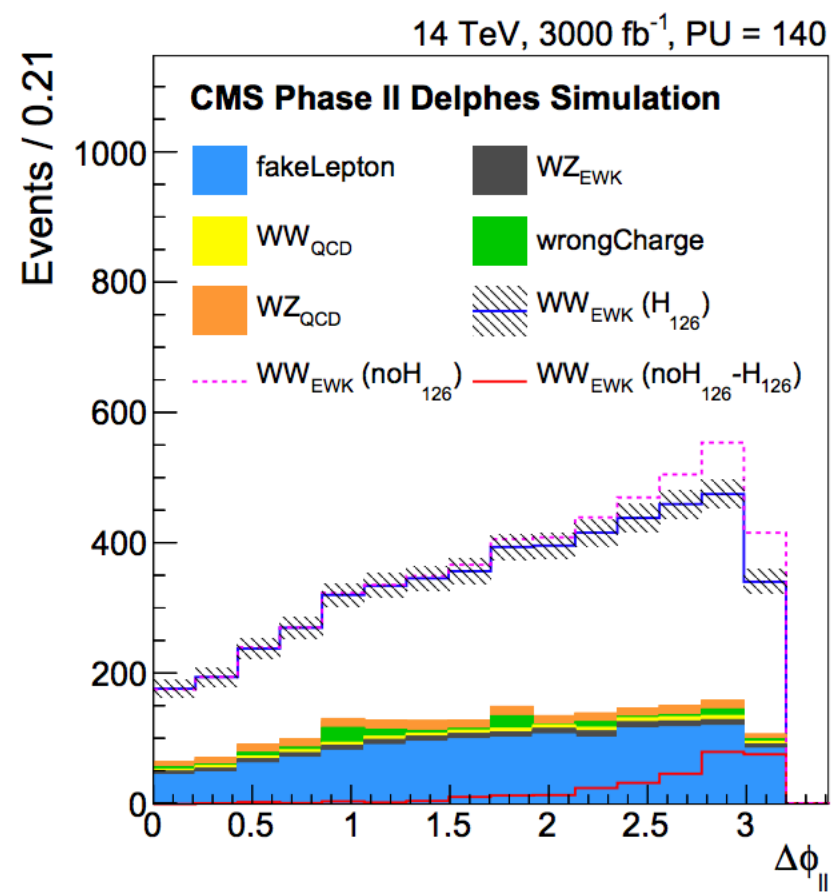


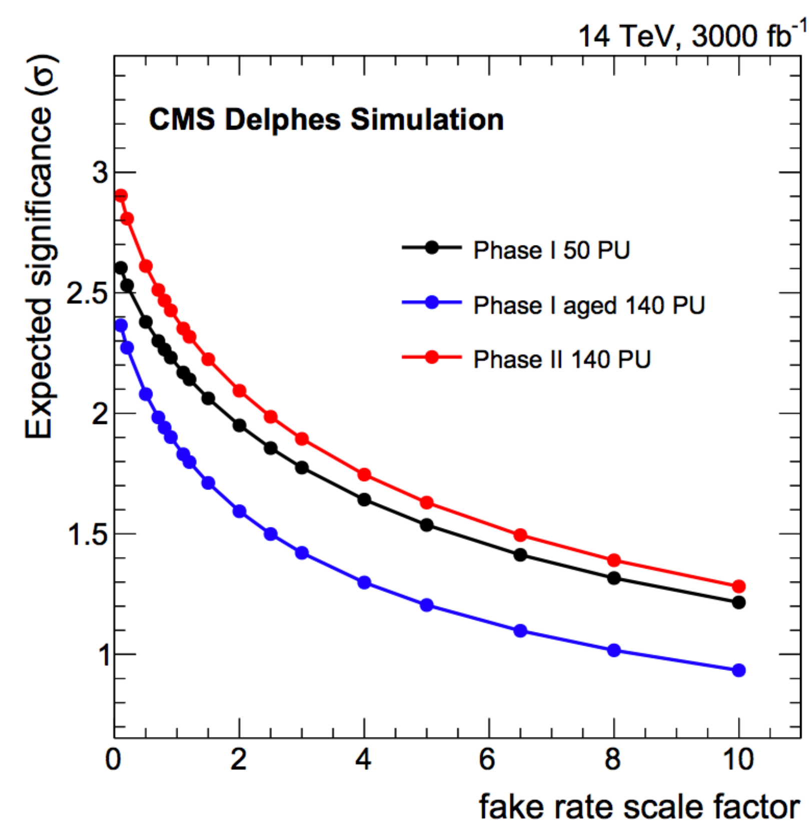
VBS

- VBS cross section for $W^{\pm}W^{\pm} \rightarrow 2l2\nu$ at FCC-hh is about 1.5pb , which gives ~107 events at FCC-hh (x1000 LHC) !!!

Assessments on the expected precision for:

- VBS cross section in $WW \rightarrow 2l2\nu$ (same sign) and $ZZ \rightarrow 4l$
- Discovery potential for longitudinal scattering
- Sensitivity at high m_{VV} (ongoing)





VBS (WW same sign)

Conclusions & outlook

- The FCC-hh machine will produce > **10^{10} Higgs bosons**
- Such **large statistics** open up a whole new range of possibilities
- First look at some Higgs **decay channels** was presented using **fast detector simulation** and simple **cut and count** analysis
- 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-)
- Comments on VBS