Higgs properties @FCC-hh

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CERN

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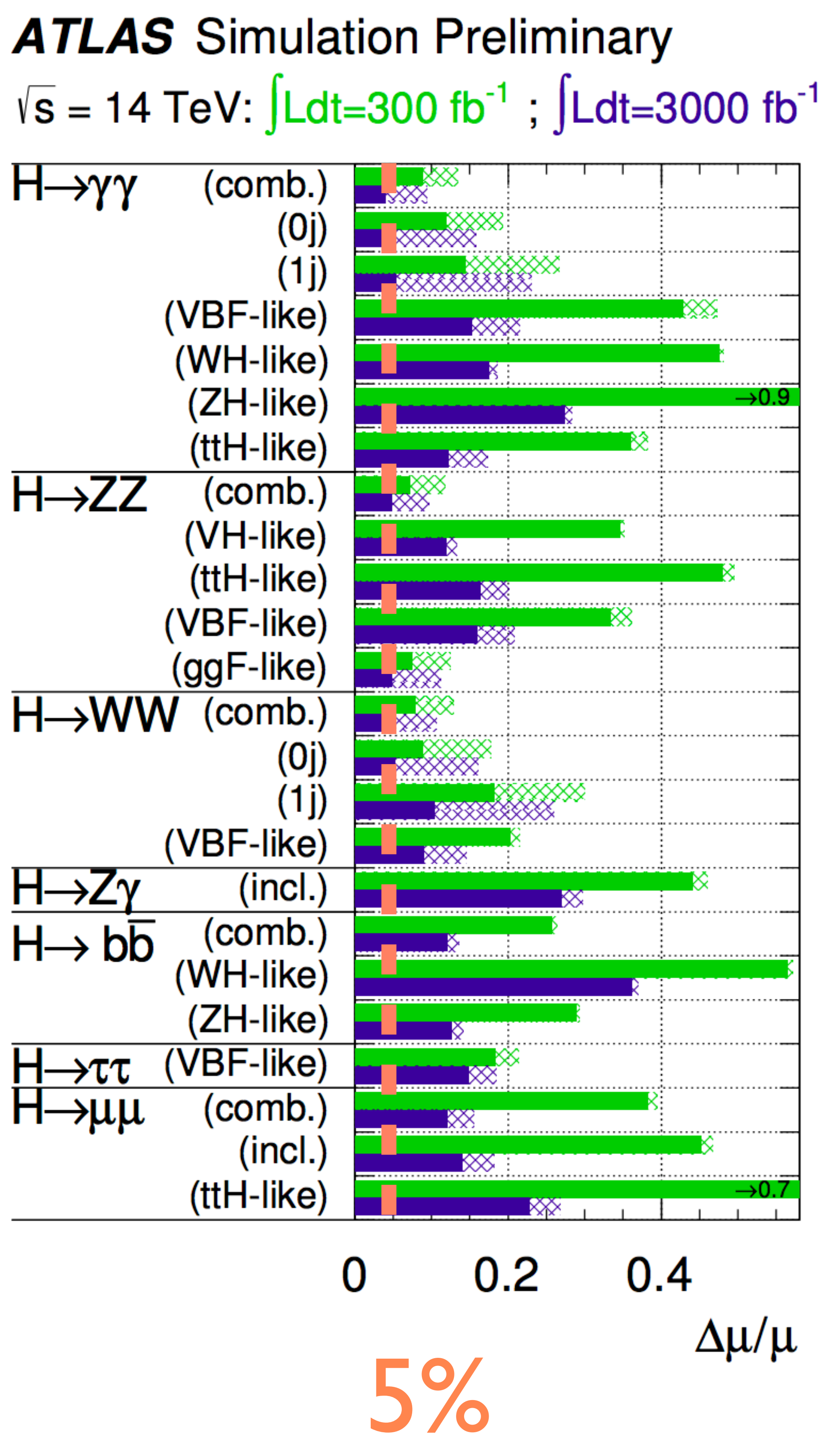
Why measuring Higgs @FCC-hh?

LHC

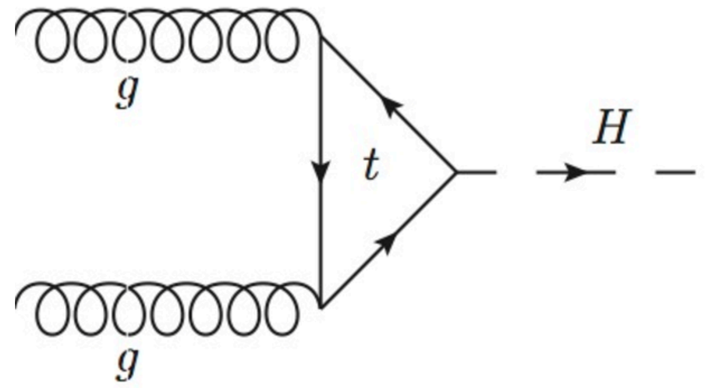


- Higgs precision measurements are **guaranteed deliverables,** because we know the Higgs exists…
- Potential **deviations** on Higgs couplings might **indicate presence of new physics**
- FCC-hh provides complementary measurements to FCC-ee:
  - **rare decays** (BR(μμ), BR(Zγ), ratios, ..) measurements will be statistically limited at FCC-ee
  - **top Yukawa and** Higgs **self-coupling** (not discussed here)
- Opportunity for testing **new analysis strategies**

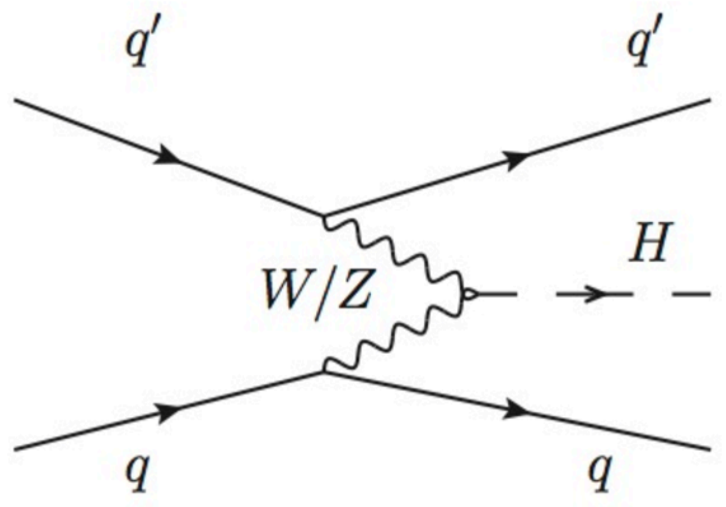
FCC-ee

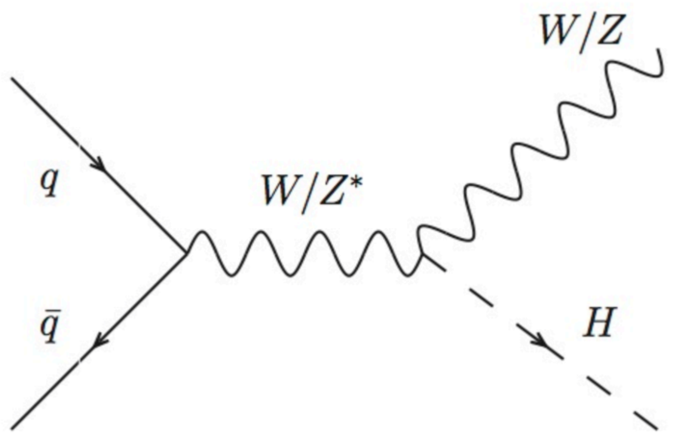
in %	FCC-ee 240 GeV	+FCC-ee 350 GeV
g_{HZ}	0.21	0.21
g_{HW}	1.25	0.43
g_{Hb}	1.25	0.64
g_{Hc}	1.49	1.04
g_{Hg}	1.59	1.18
$g_{H\tau}$	1.34	0.81
$g_{H\mu}$	8.85	8.79
$g_{H\gamma}$	2.37	2.12
Γ_H	2.61	1.55

Higgs production at FCC-hh

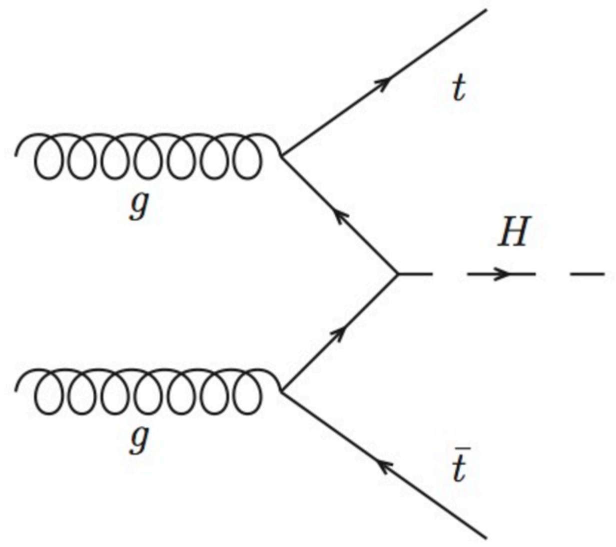


	σ(13 TeV)	σ(100 TeV)	σ(100)/σ(13)
ggH (N³LO)	49 pb	803 pb	16
VBF (N²LO)	3.8 pb	69 pb	16
VH (N²LO)	2.3 pb	27 pb	11
ttH (N²LO)	0.5 pb	34 pb	55





	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



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

$N_{100} = \sigma_{100\,\mathrm{TeV}} \times 20\ \mathrm{ab}^{-1}$

$N_{8} = \sigma_{8\,\mathrm{TeV}} \times 20\ \mathrm{fb}^{-1}$

$N_{14} = \sigma_{14\,\mathrm{TeV}} \times 3\ \mathrm{ab}^{-1}$

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

Outline

- General scope is to assess **prospects for Higgs coupling measurements** at FCC-hh, by looking at following **Higgs decay channels**:

  - $H\rightarrow\gamma\gamma$,
  - $H\rightarrow ZZ\rightarrow 4l$
  - $H\rightarrow WW^*\rightarrow 2l2\nu$
  - $H\rightarrow\mu\mu$
  - $H\rightarrow Z\gamma\rightarrow 2l\gamma$

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

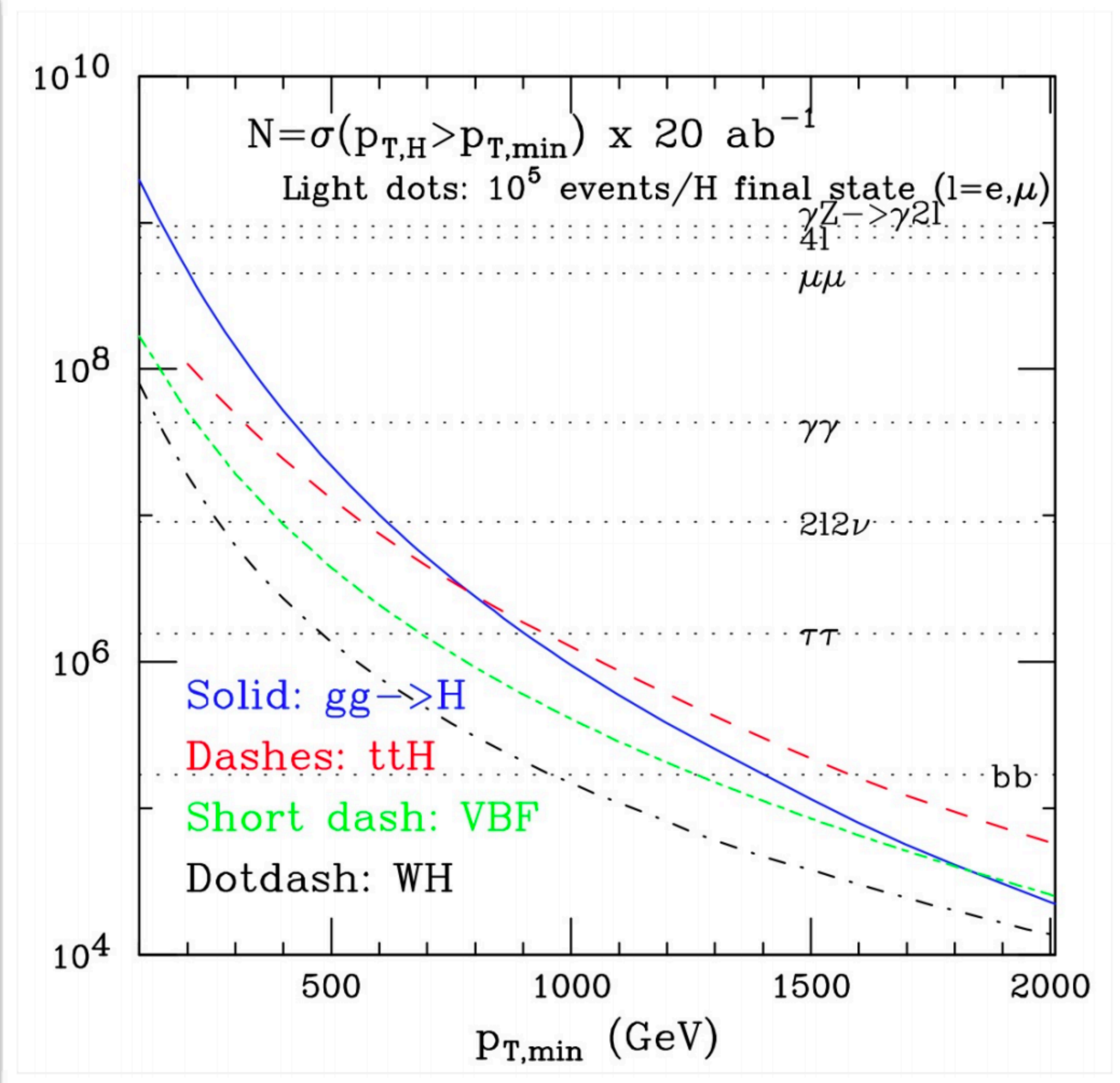
  - **MG5aMC@NLO + Pythia8**
    - LO matched samples (up to 1/2/3 jets) and global K-factor applied to account for $N^{2/3}LO$ corrections
    - full list of signal prod. modes simulated (ggH with finite m_{top})
  - **Delphes-3.4.1** with baseline FCC-hh detector

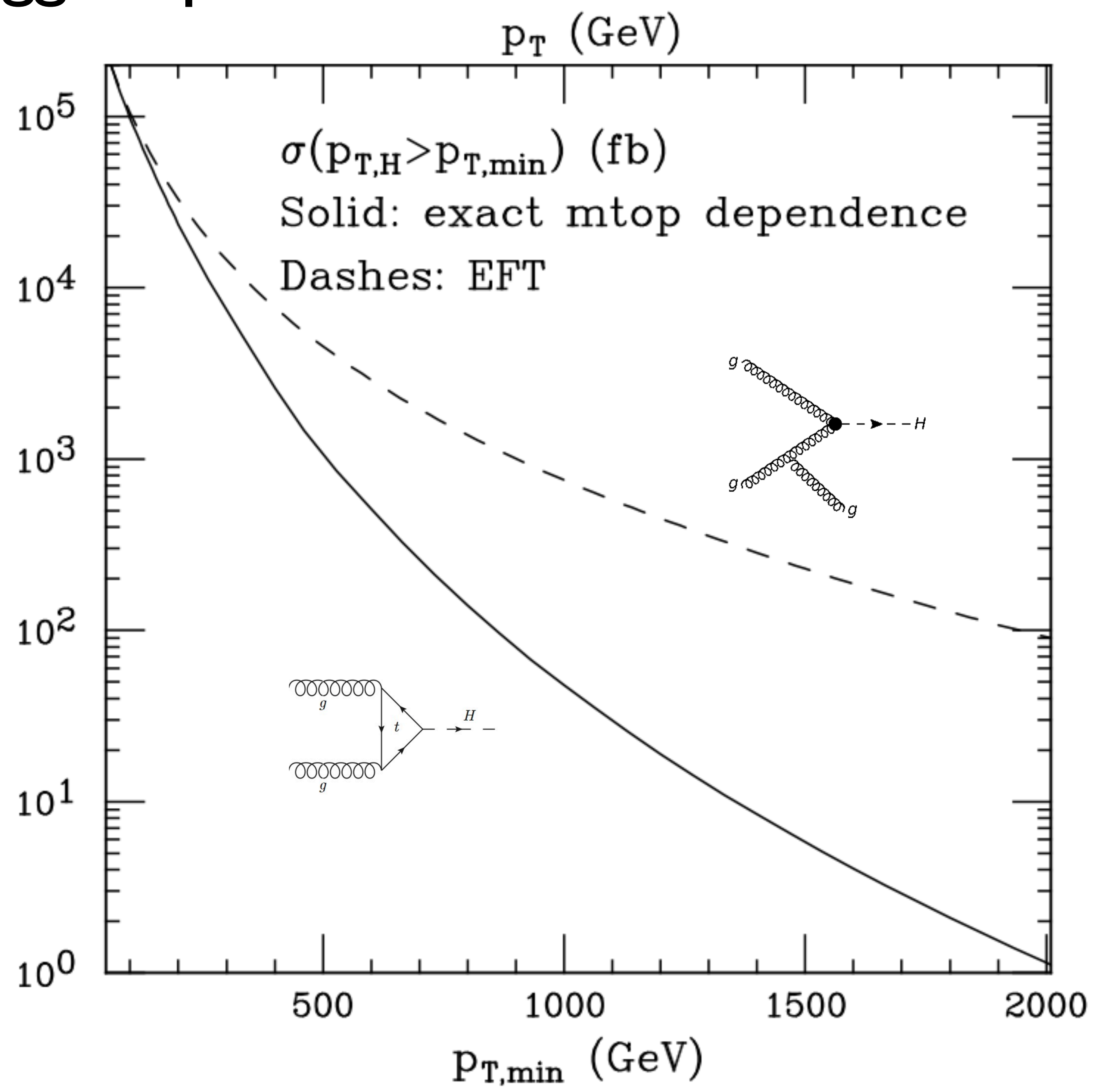
  - Full list of samples can be found here:

http://fcc-physics-events.web.cern.ch/fcc-physics-events/LHEevents.php (thanks to Clement Helsens)

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?)

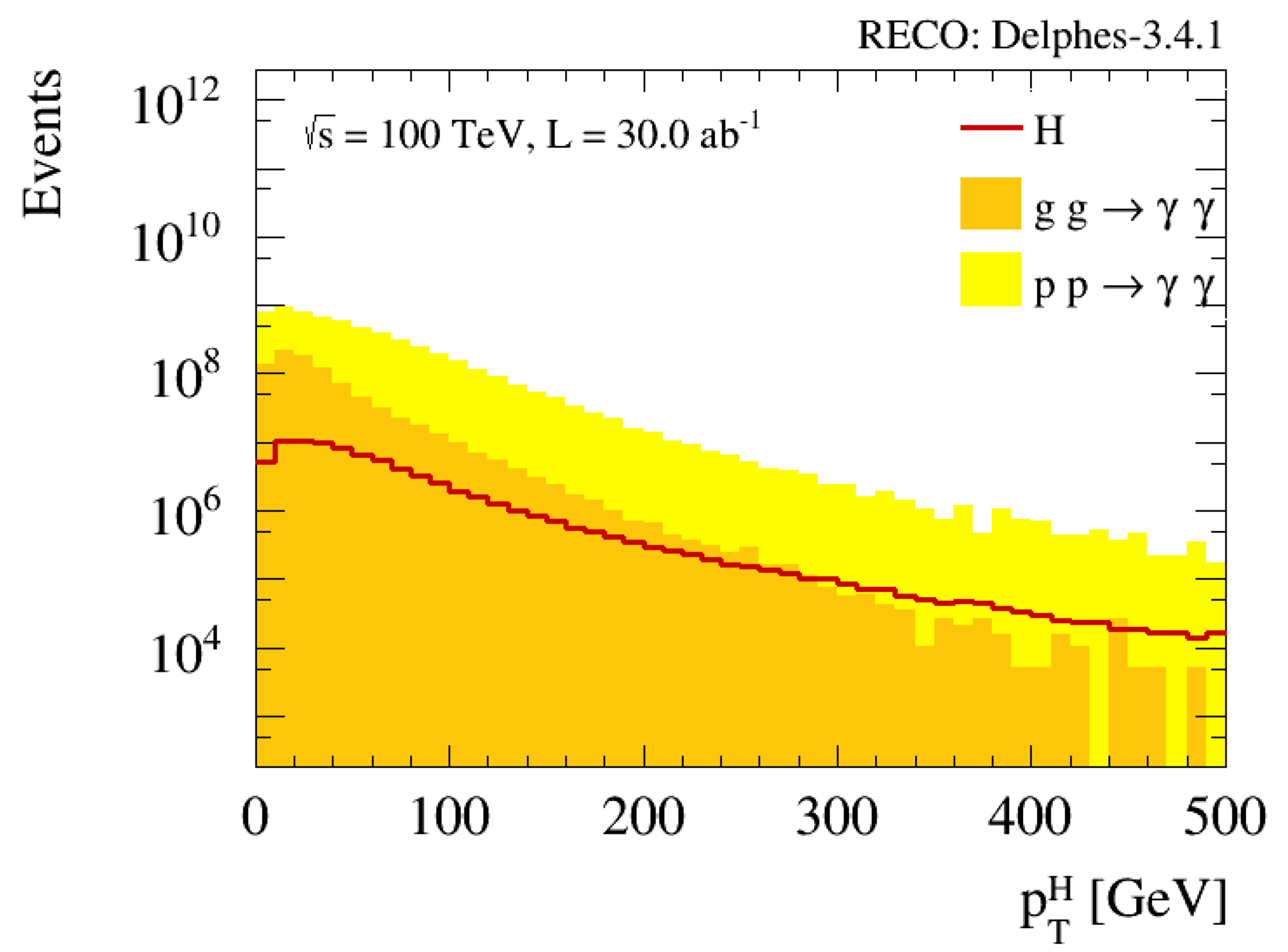
H → γγ - Selection

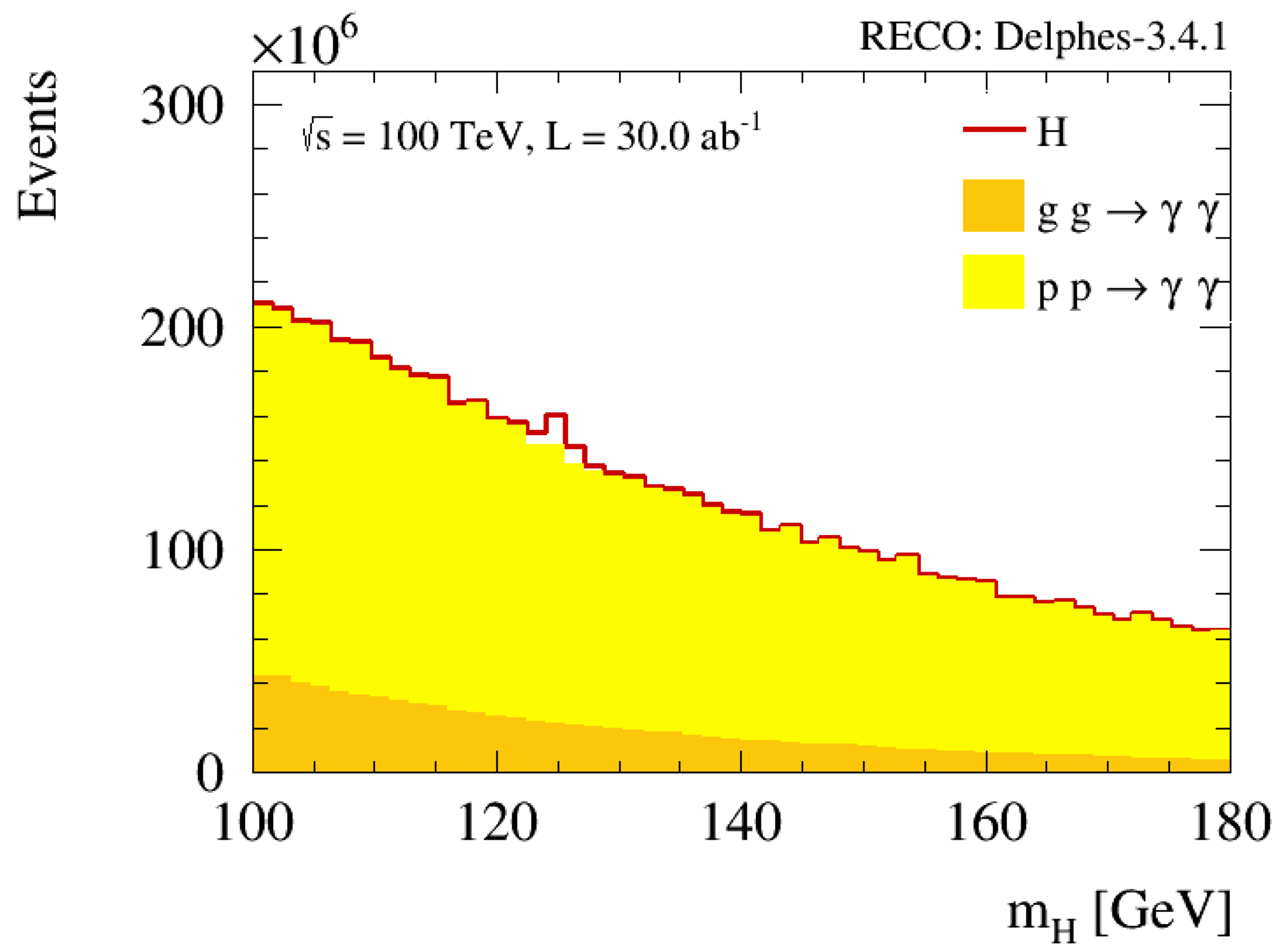
Backgrounds:

- **irreducible**: QCD γγ production
- **reducible.** : γ + jets (ignored for now)
  checked that $\sigma_{\gamma + jets}$(100 TeV) ~ 10 x $\sigma_{\gamma + jets}$(14 TeV)

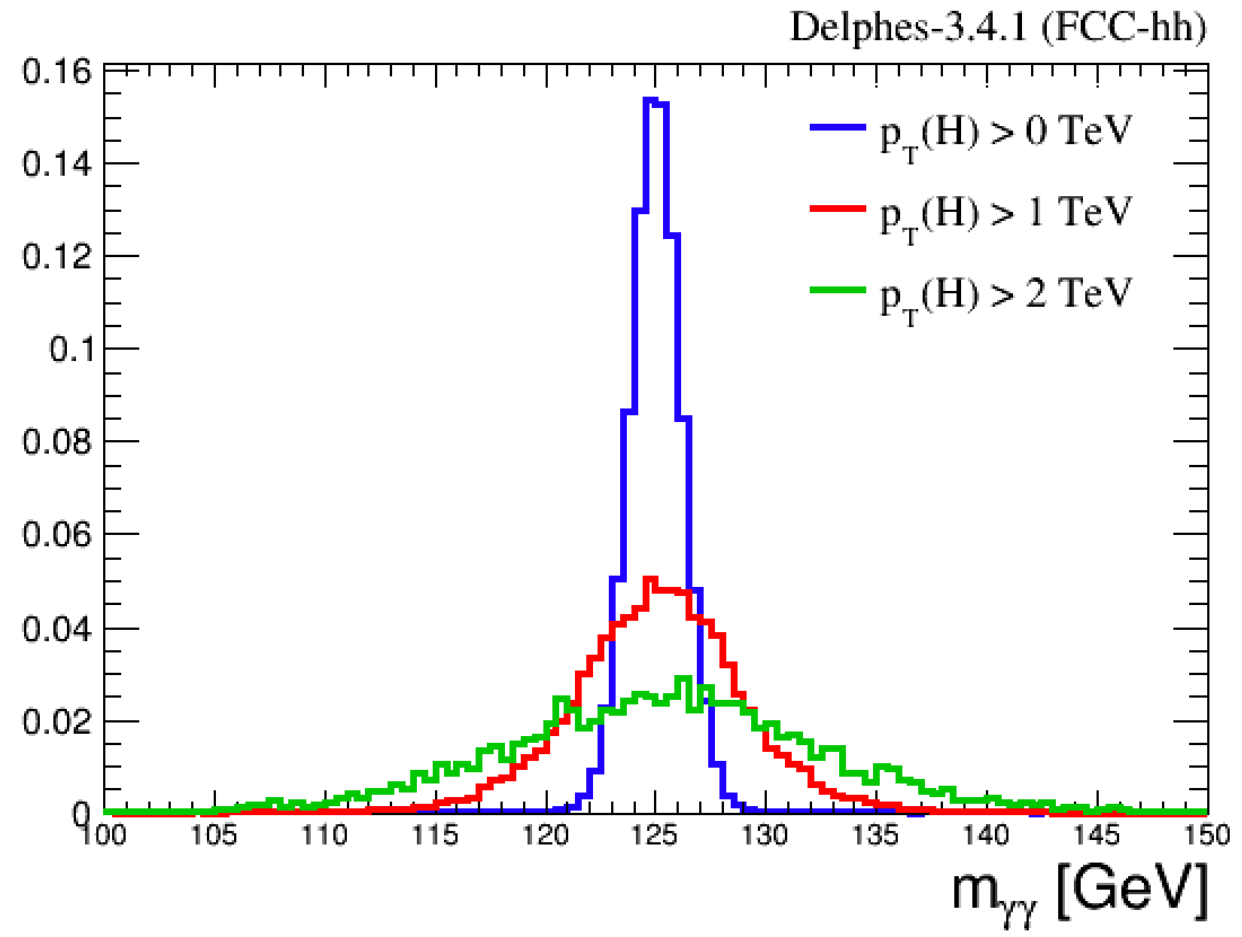
Cut and count event selection:

- $p_T(\gamma) > 30$ GeV, $|\eta(\gamma)| < 4.0$
- exploit the fact that $p_{T,\gamma\gamma}$ is harder for signal
  - variable $pT(H)_{min}$
- $|m_{\gamma\gamma} - m_H| < 2.5$ GeV + $pT(H)_{min}/200$

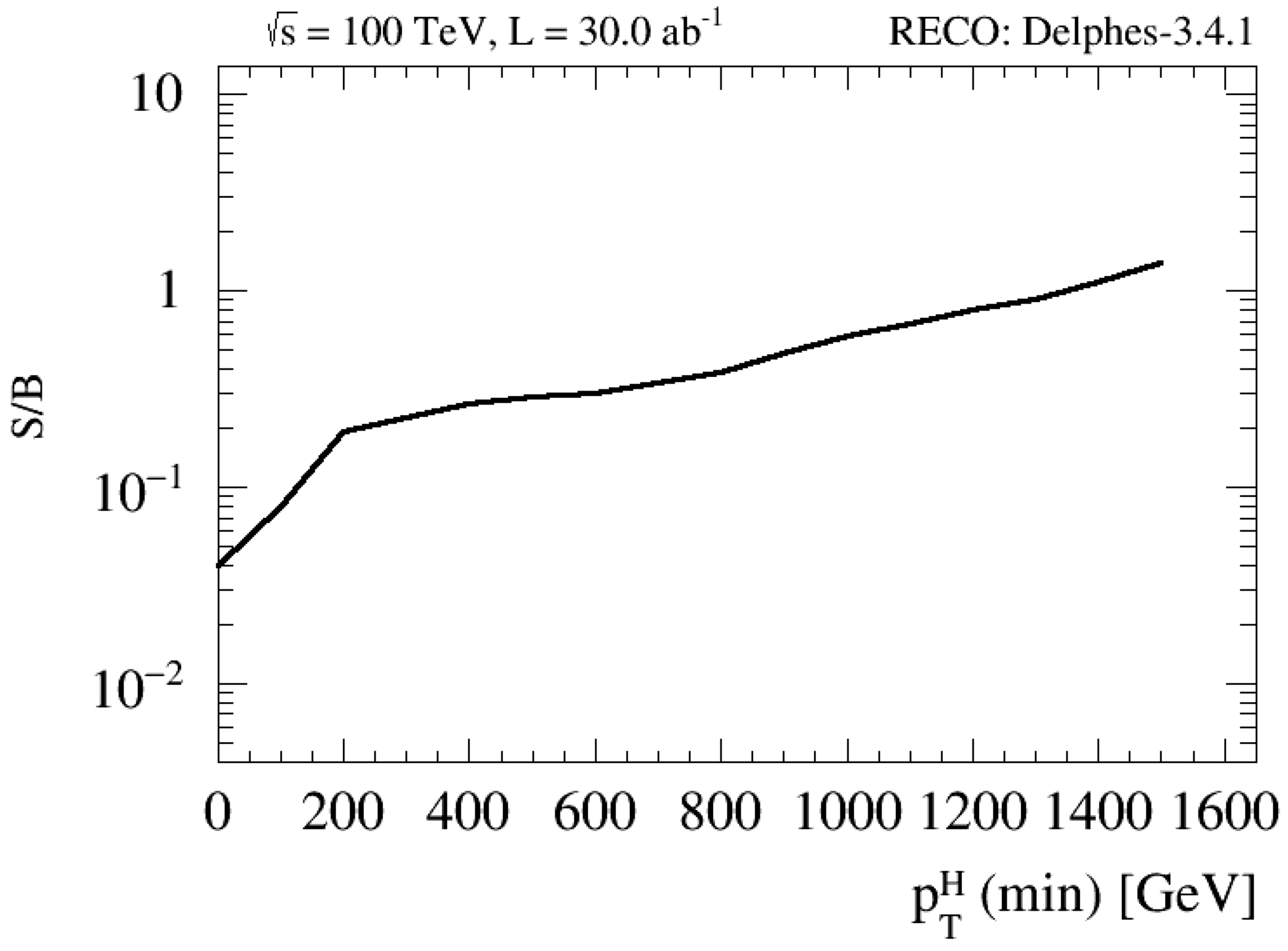


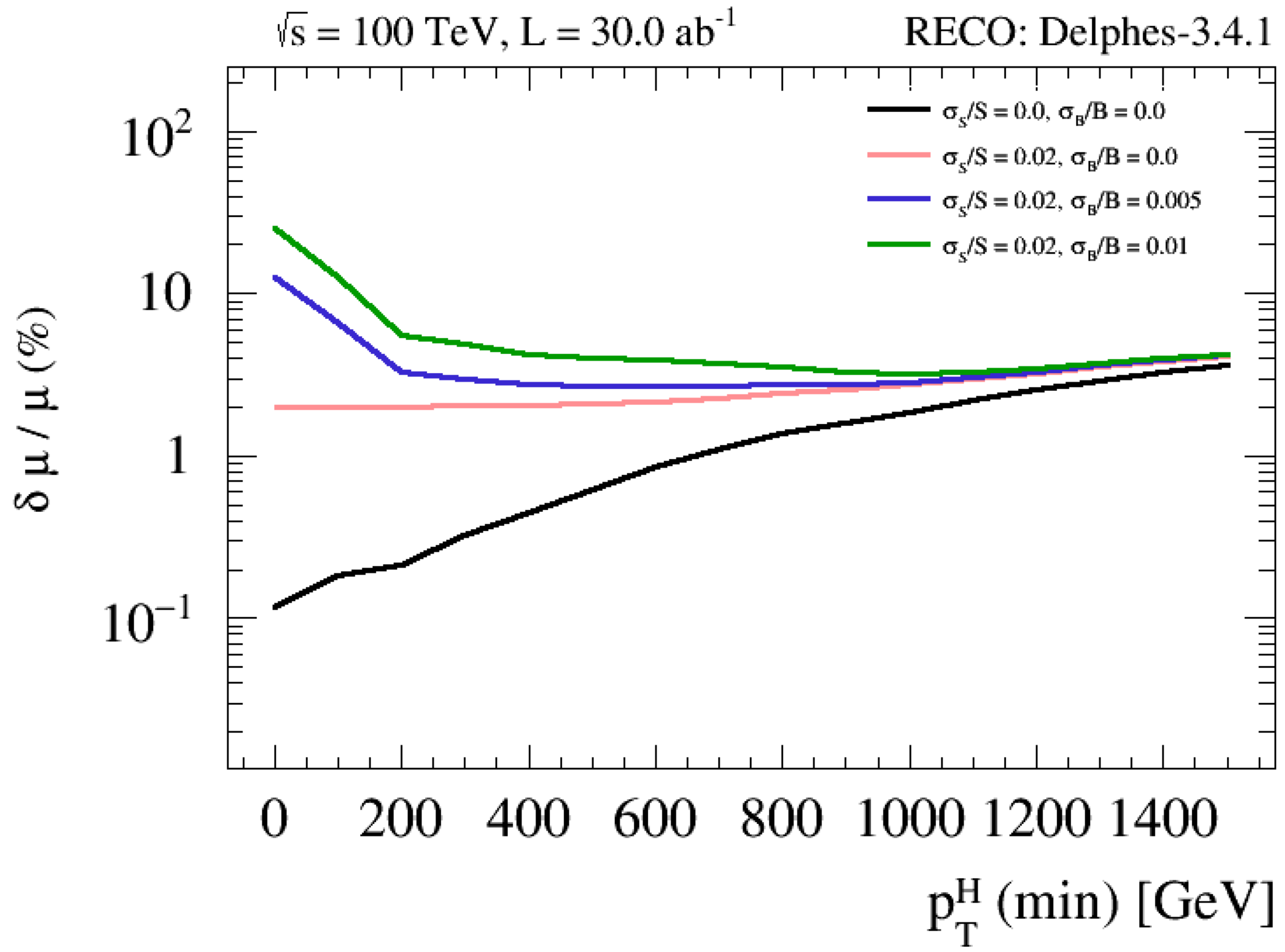


mass resolution degrades at high pT
(using unconverted photons)



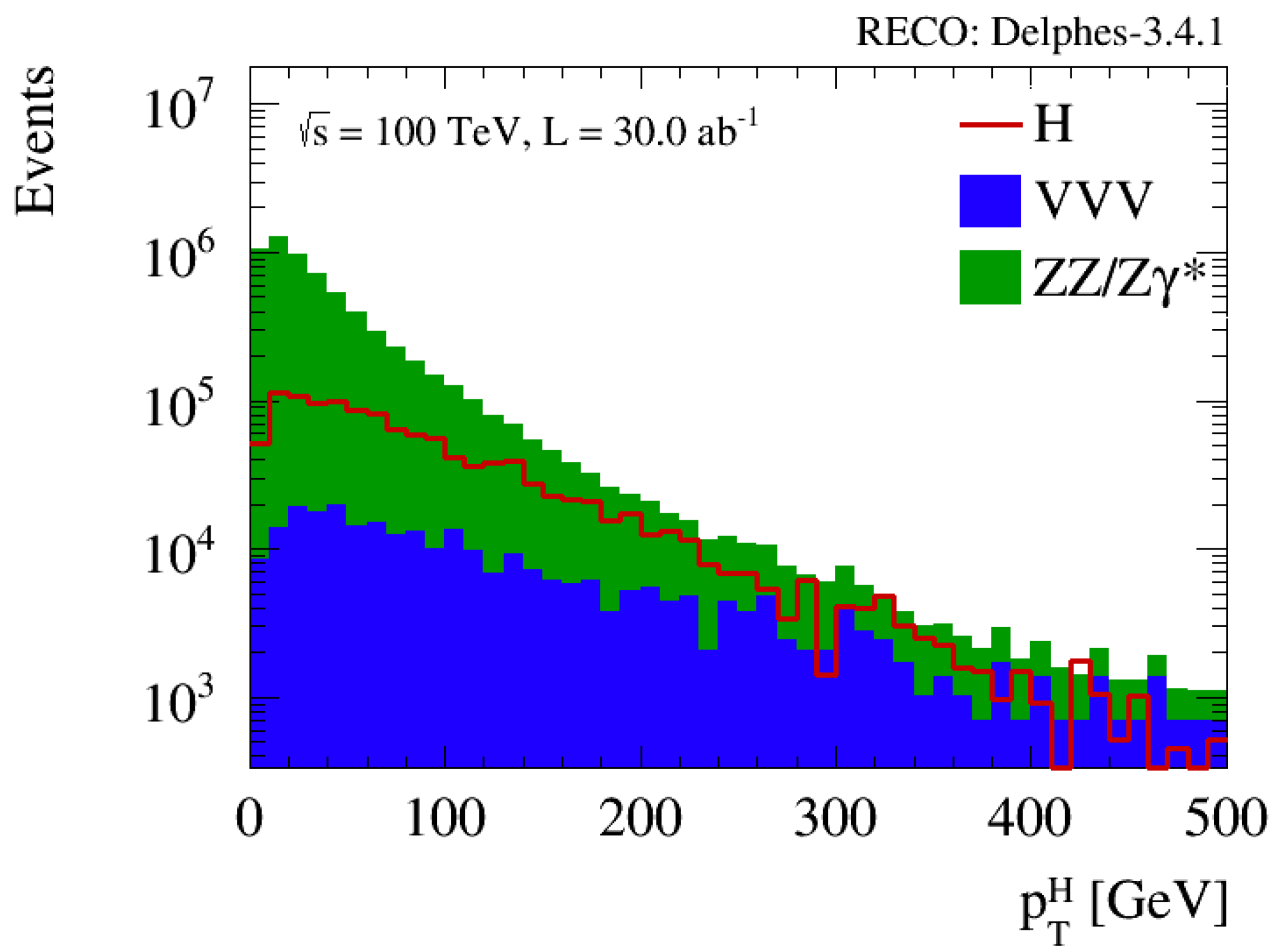
H → γγ - Expected sensitivity

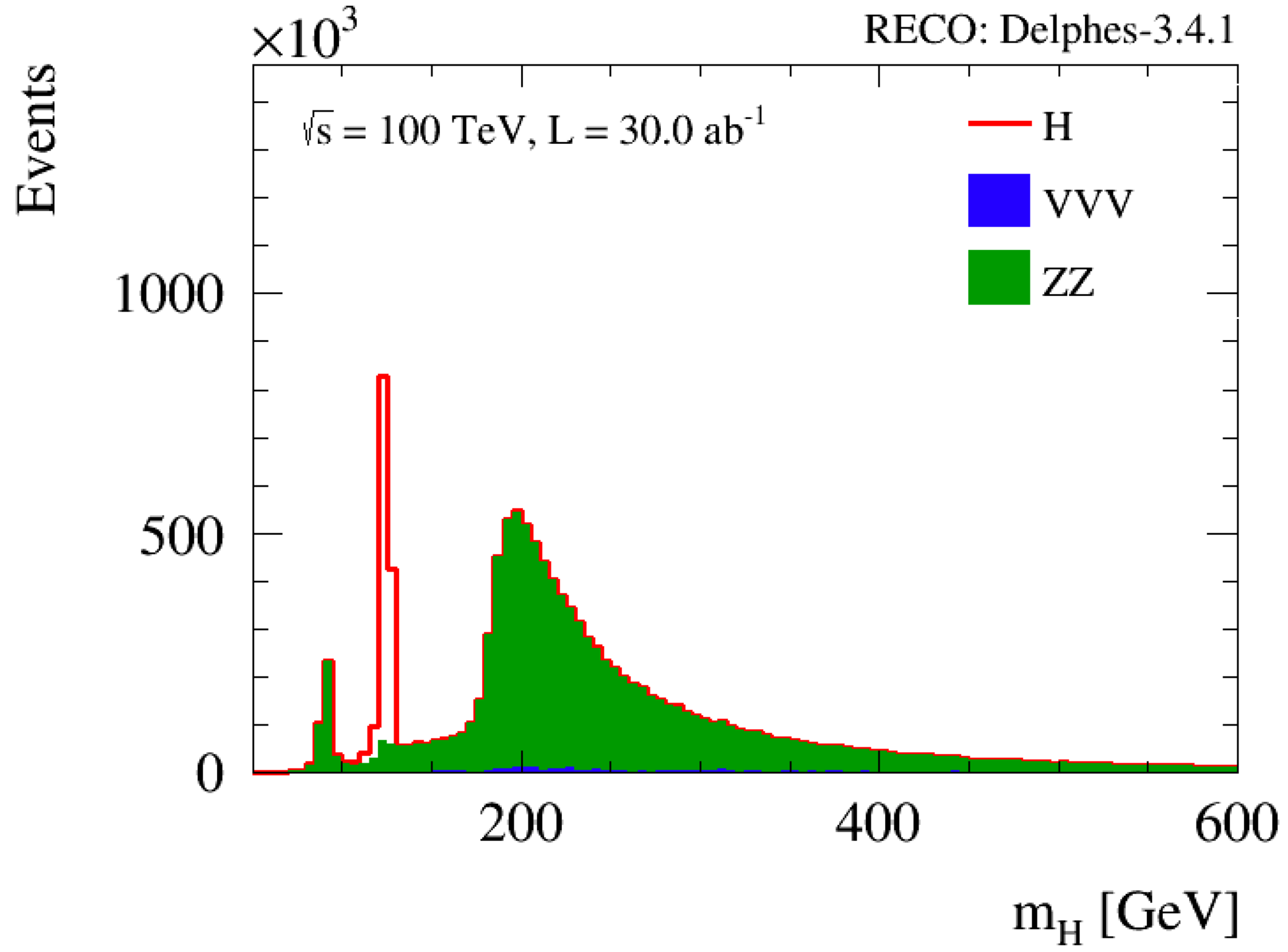




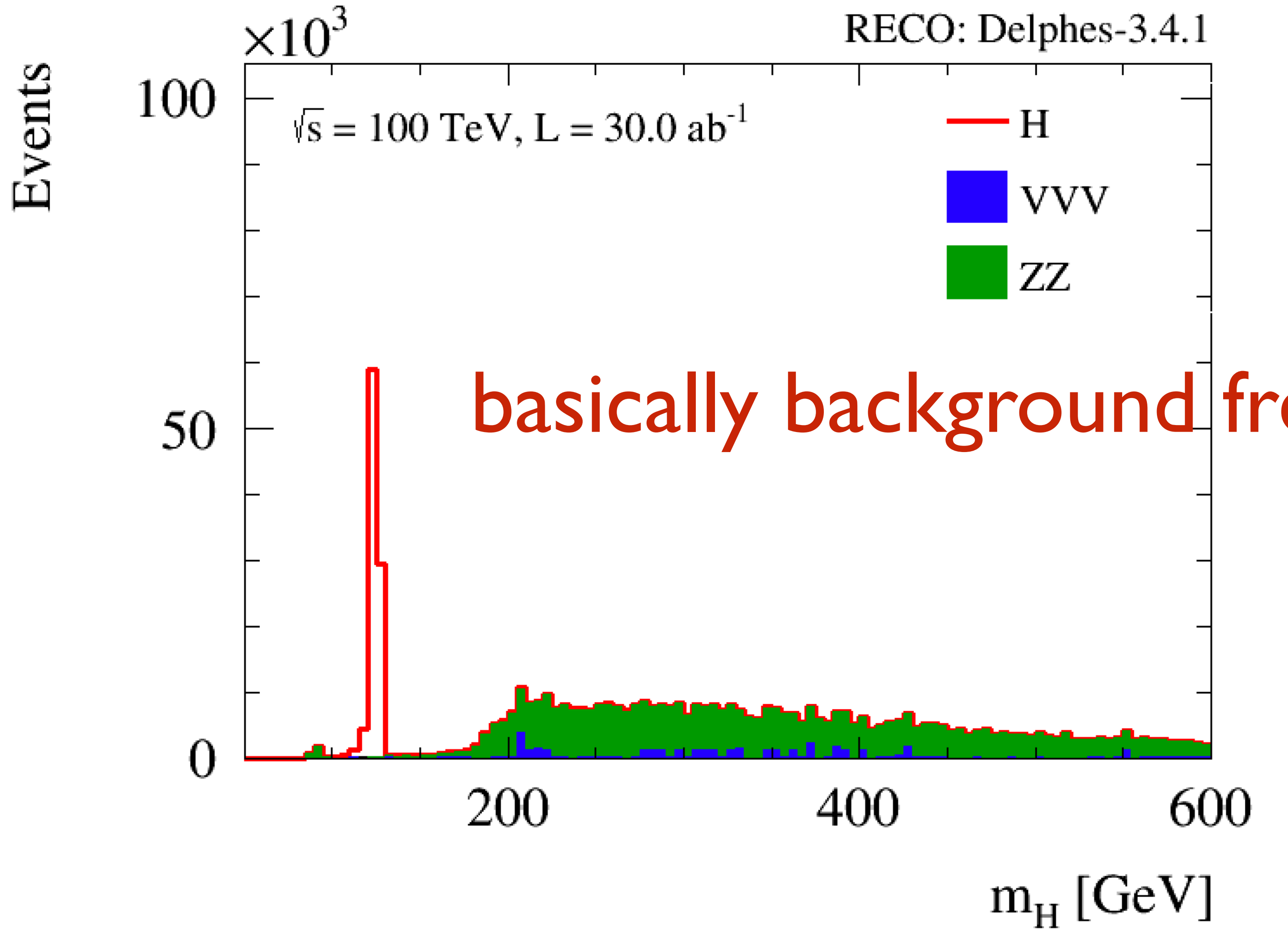
- **$\delta\mu/\mu \approx O(1)$ % precision** can be achieved up to $p_T(H) = 1$ TeV, assuming no systematics

H → ZZ* → 4l - Plots





pT(H) > 200 GeV



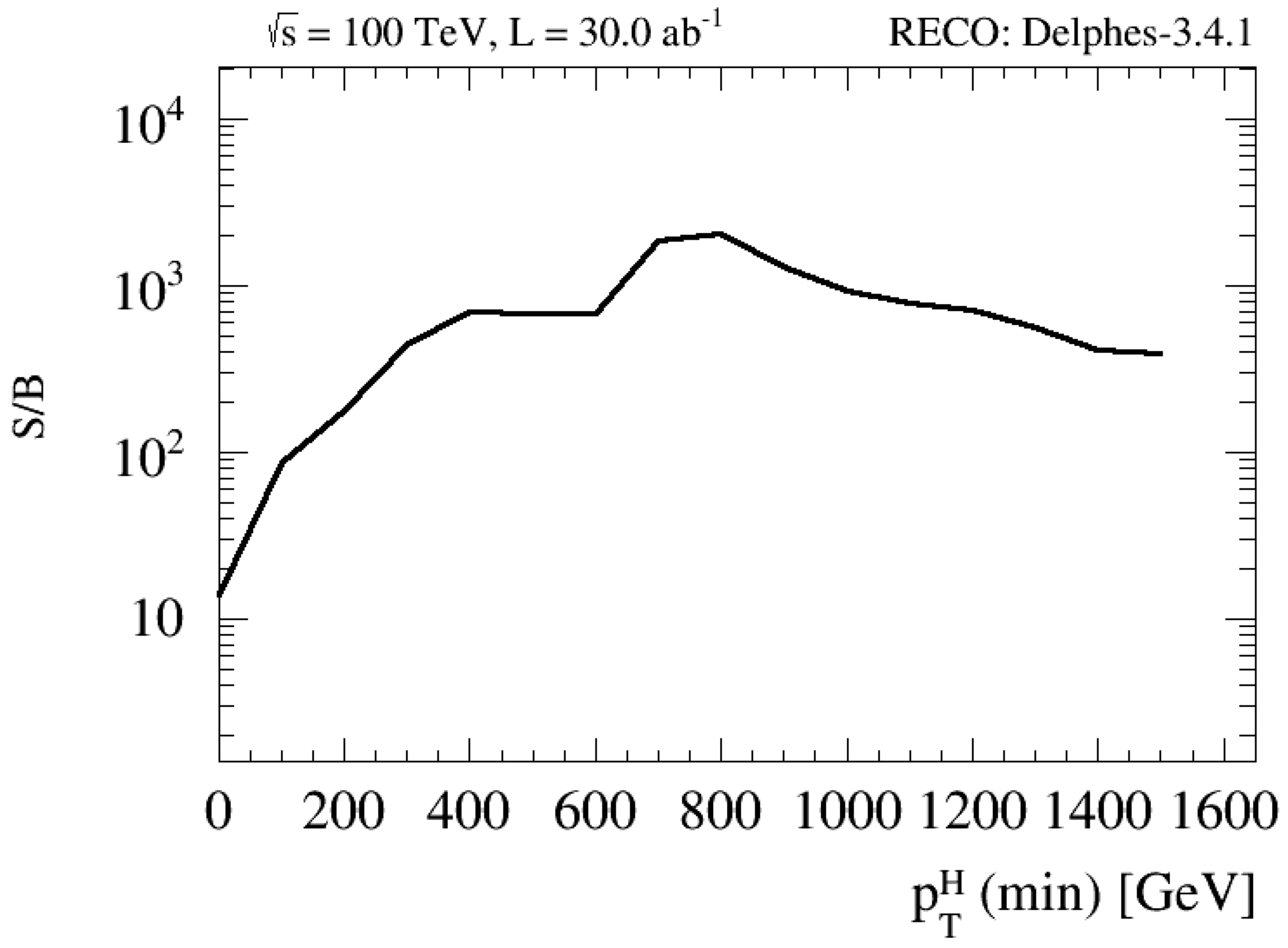
basically background free at high pT !

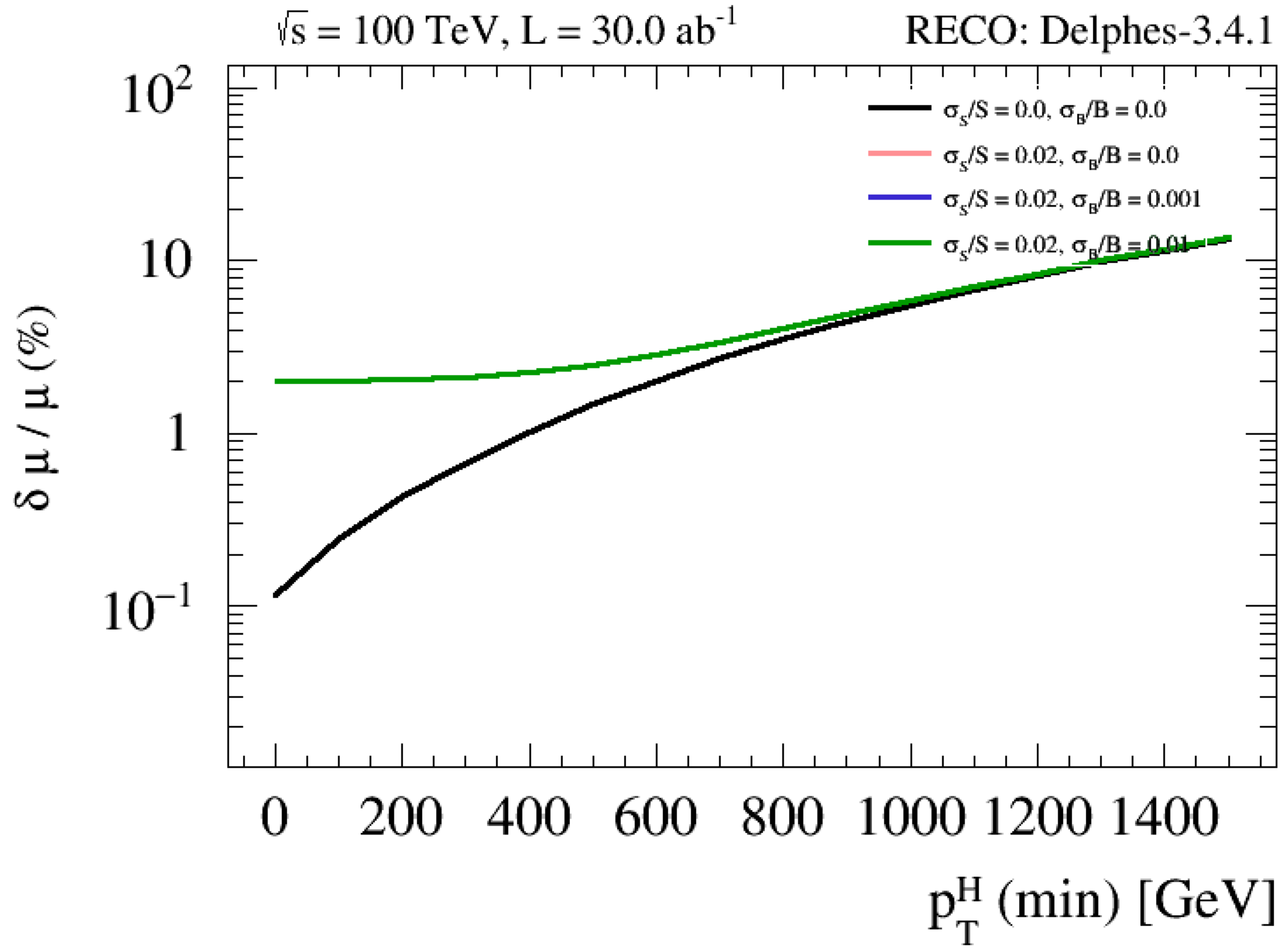
Simple cut and count strategy:

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

→ asymmetric cut due to FSR tail

$H \rightarrow ZZ^* \rightarrow 4l$ - Expected sensitivity

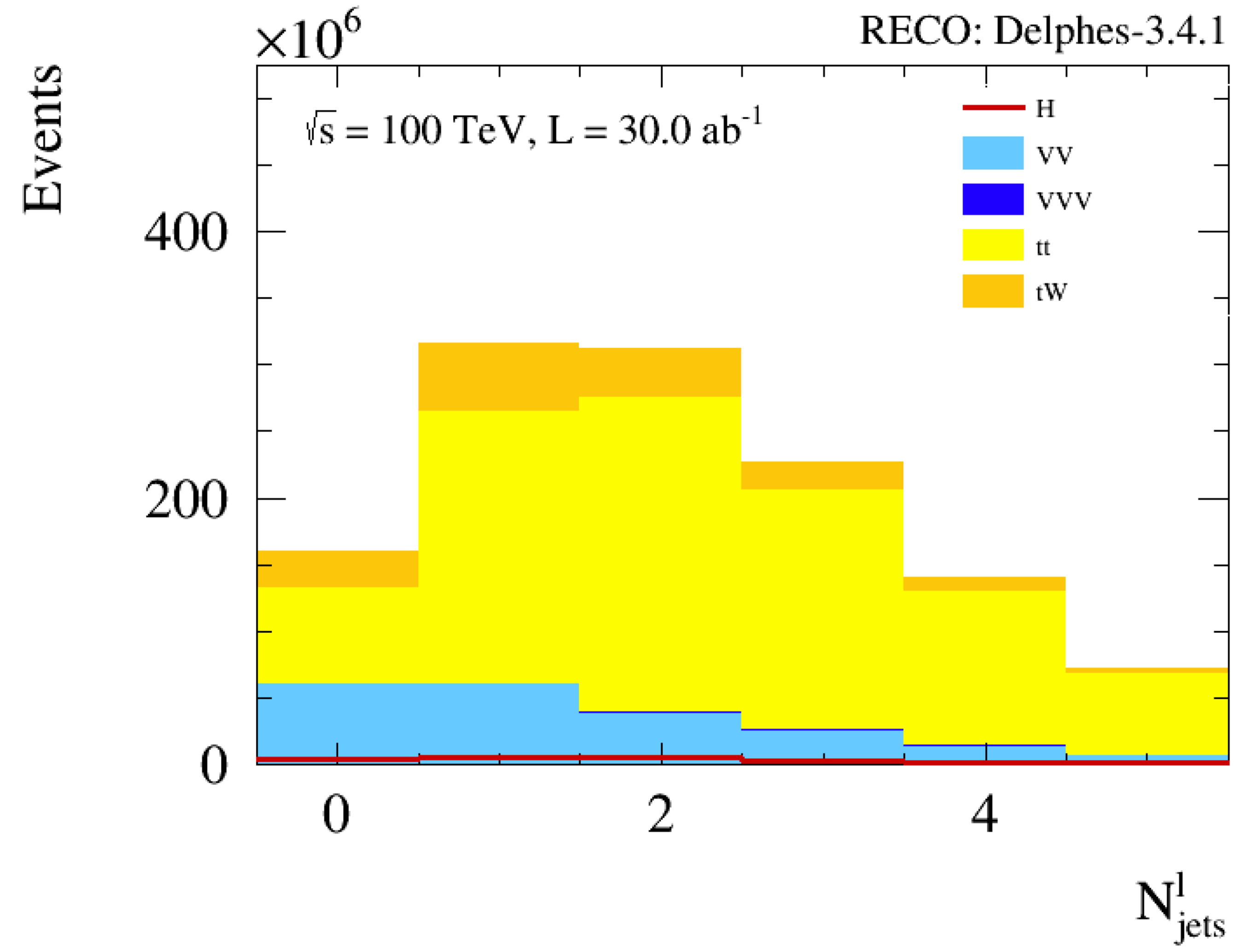




- Background free, hence uncertainty have little impact
- **$\delta\mu/\mu \approx 1$ % precision** can be achieved up to $p_T(H) = 500$ GeV, assuming no systematics
- The 4l final state can provide a very **clean sample** to measure **$d\sigma/dp_T$**.

$H \to WW^* \to 2l2\nu$ - Selection

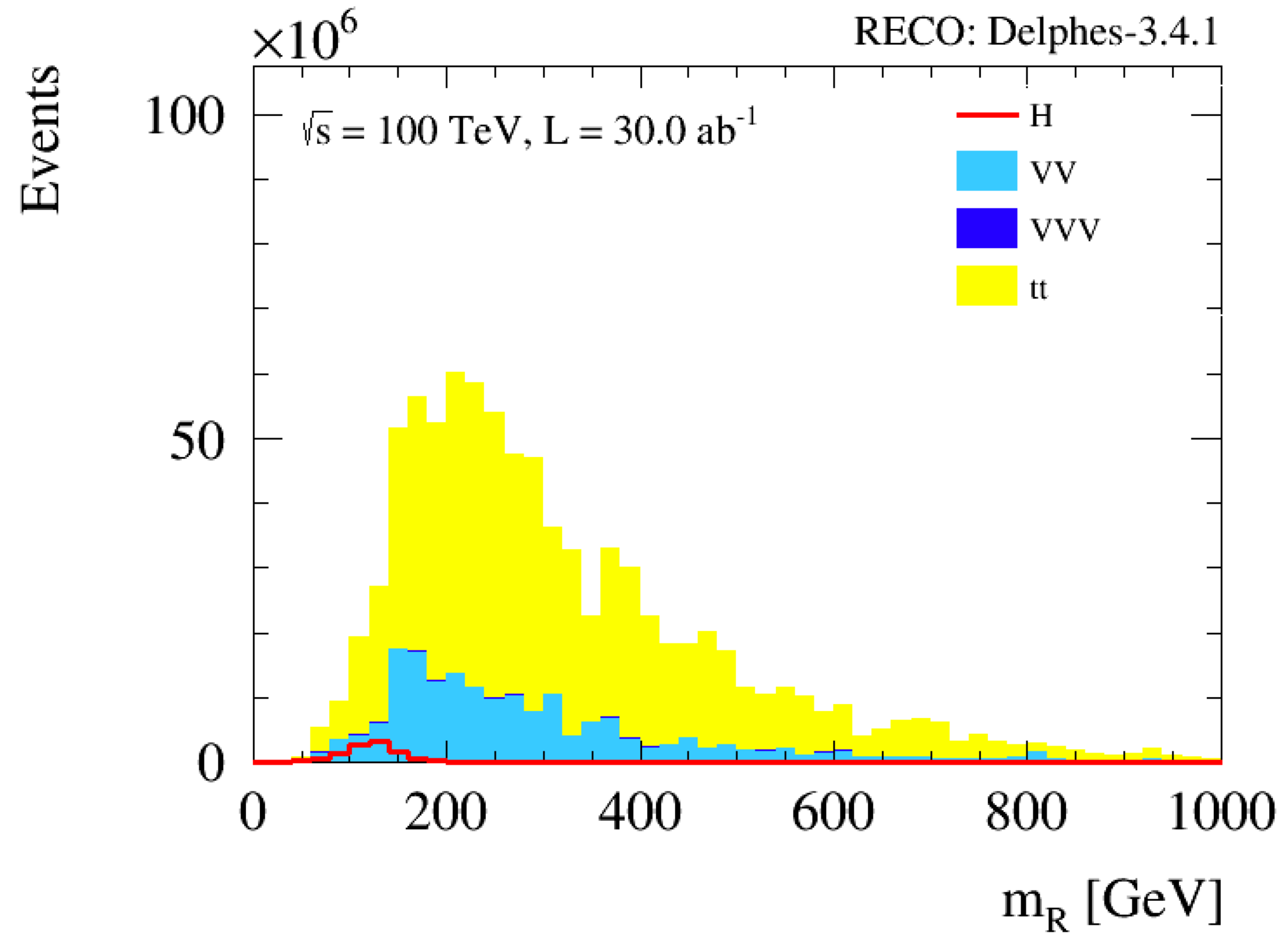
- **irreducible**: WW* (only qq WW here)
- **reducible.** : ttbar, tW, VVV, DY, W+jets (fakes, not included here)



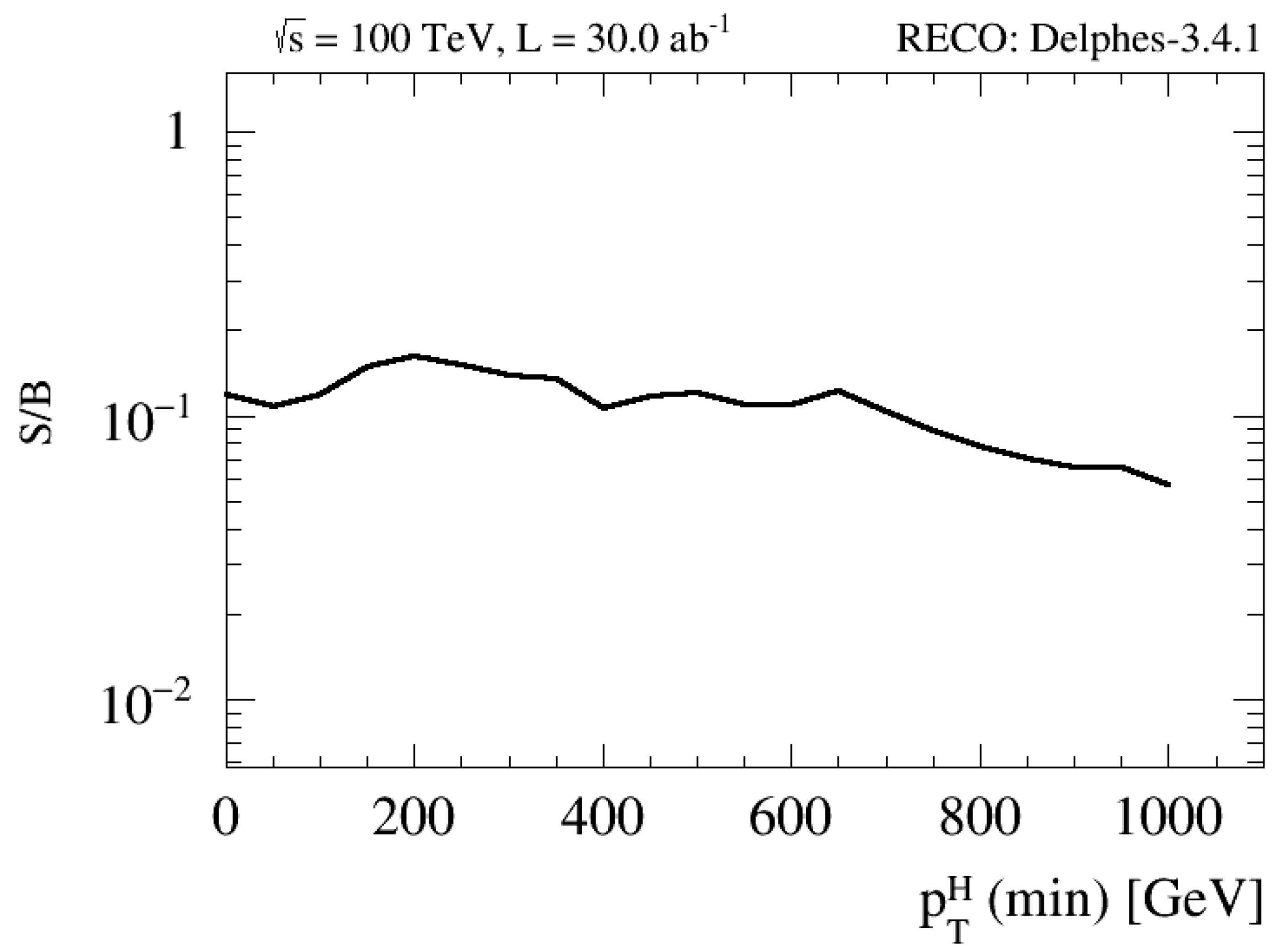
Simple cut and count strategy:

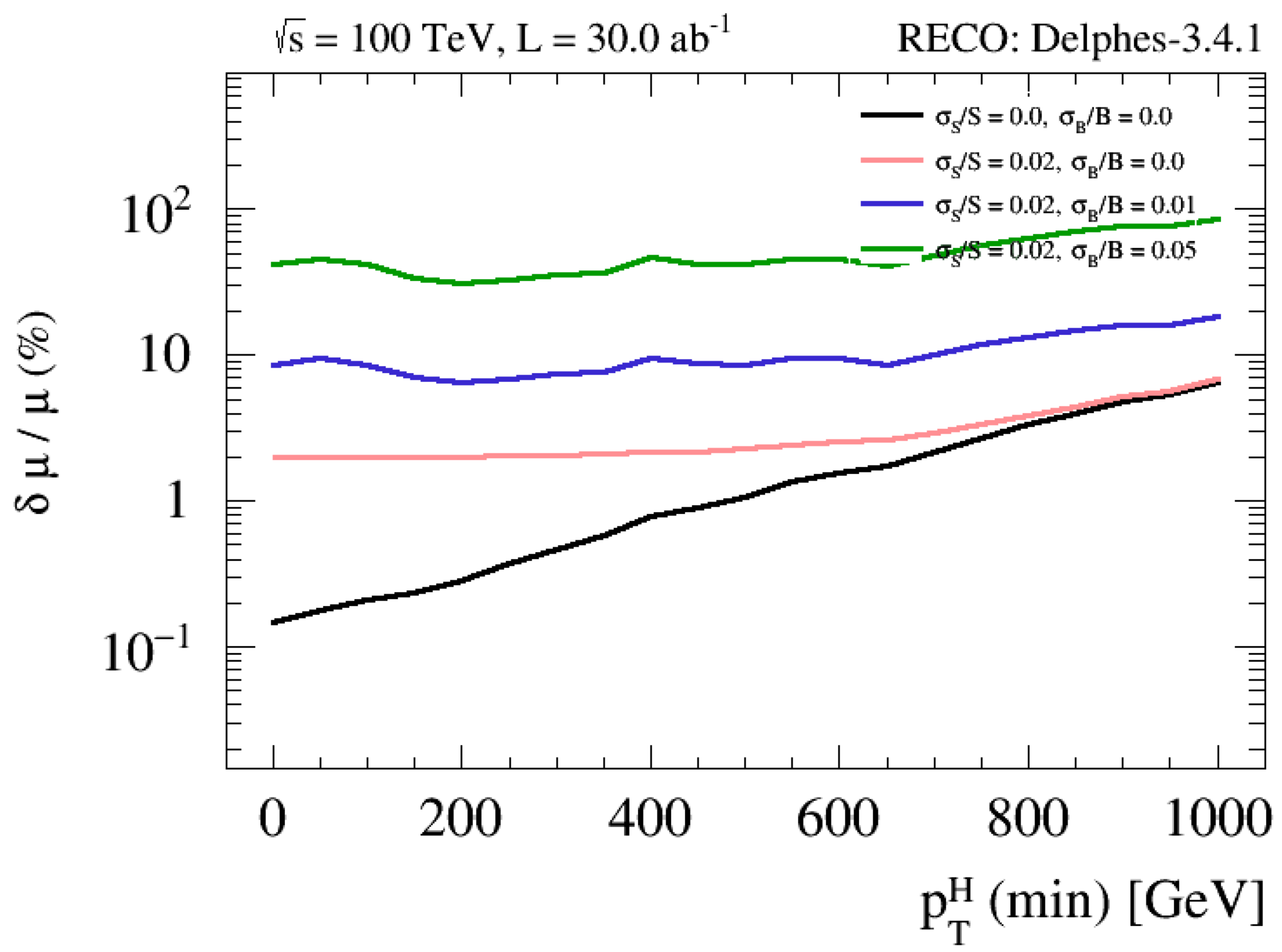
- only consider **opposite flavor eμ** final state (no DY)
- crucial part of this analysis is **jet veto** against ttbar:
  - relax jet veto and take advantage of H high pT spectrum?
  - or apply jet veto and study H at threshold?

- $p_T(l_1) > 25$ GeV, $p_T(l_2) > 15$ GeV, $|\eta(l_i)| < 4.0$, $p_T(j) > 30$ GeV
- $N_{bjets} = 0$ (bjet-veto)
- $pT_{ll} > 45.$
- $\Delta\phi_{ll} < 90$ deg.
- $100 < m_R < 150$ ("razor variable [1312.1129]")



H → WW* → 2l2ν - Expected sensitivity

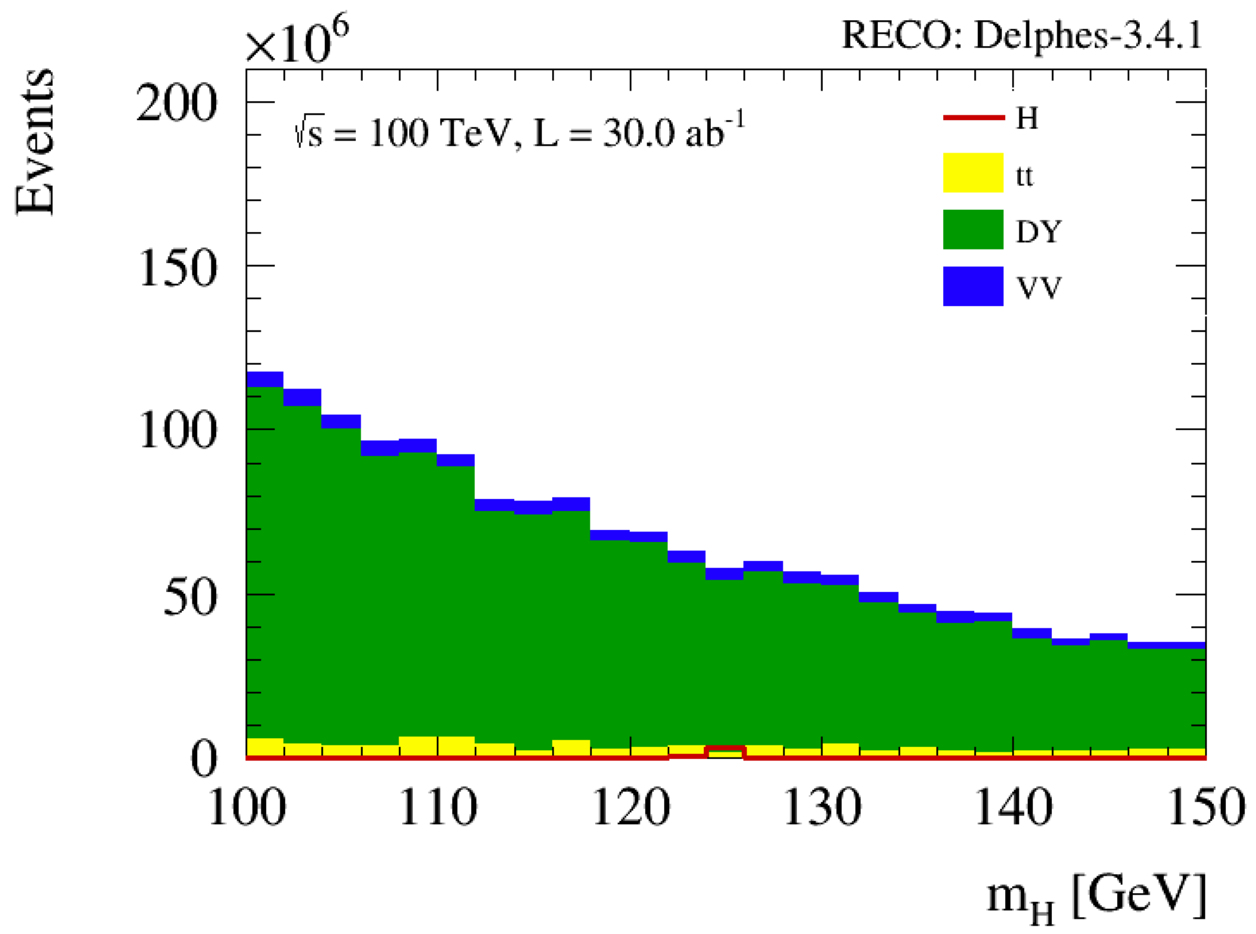




- **δμ/μ ≈ 1 % precision** can be achieved up to p_T(H) = 500 GeV, assuming no systematics (not optimal assumptions)
- do we really gain at high Higgs pT?
- Need to study further systematics

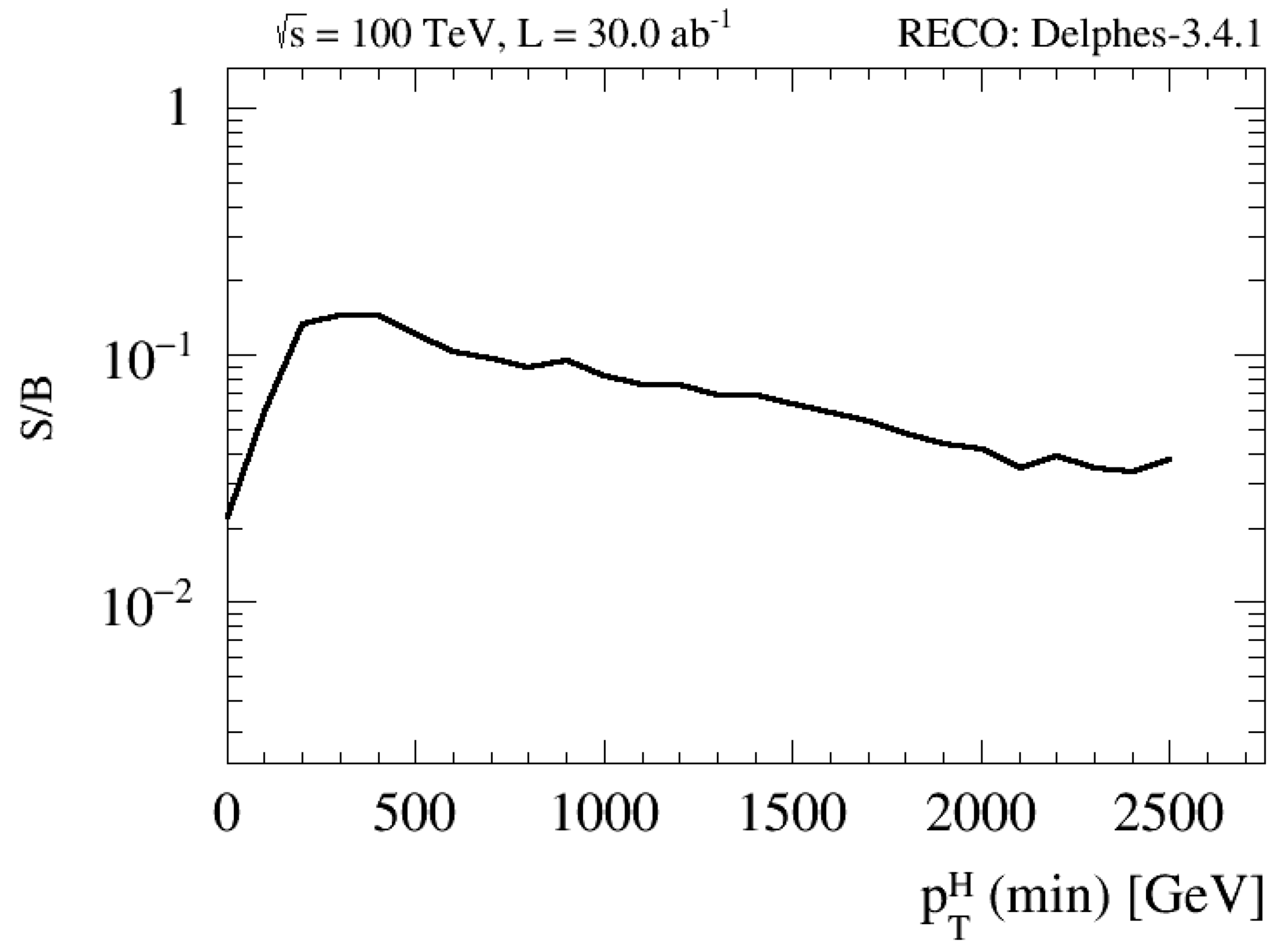
H → μμ

- Very small BR(H → μμ) ~ 2.18e-04,
  → out of reach at FCC-ee
- **irreducible**: DY
- **reducible.** : ttbar, (H →)ZZ → 2μ2ν

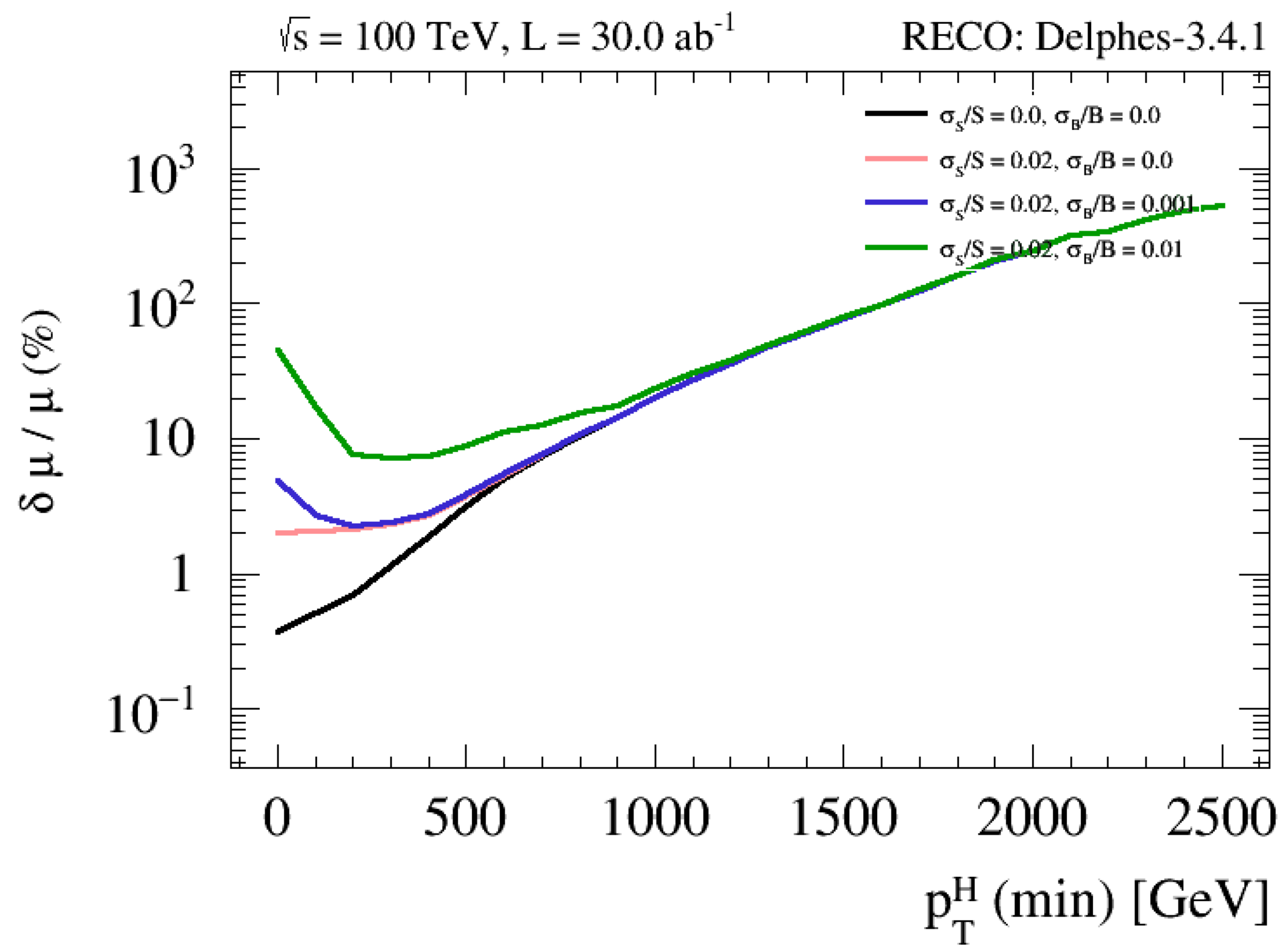


Simple cut and count strategy:

- $p_T(\mu) > 20$ GeV, $|\eta(\mu)| < 4.0$
- $E_T^{miss} < 50$ GeV (against ttbar)
- $|m_{\mu\mu} - m_H| < 2.5$ GeV
- extra-lepton veto
- exploit the fact that $p_{T,\mu\mu}$ is harder for signal

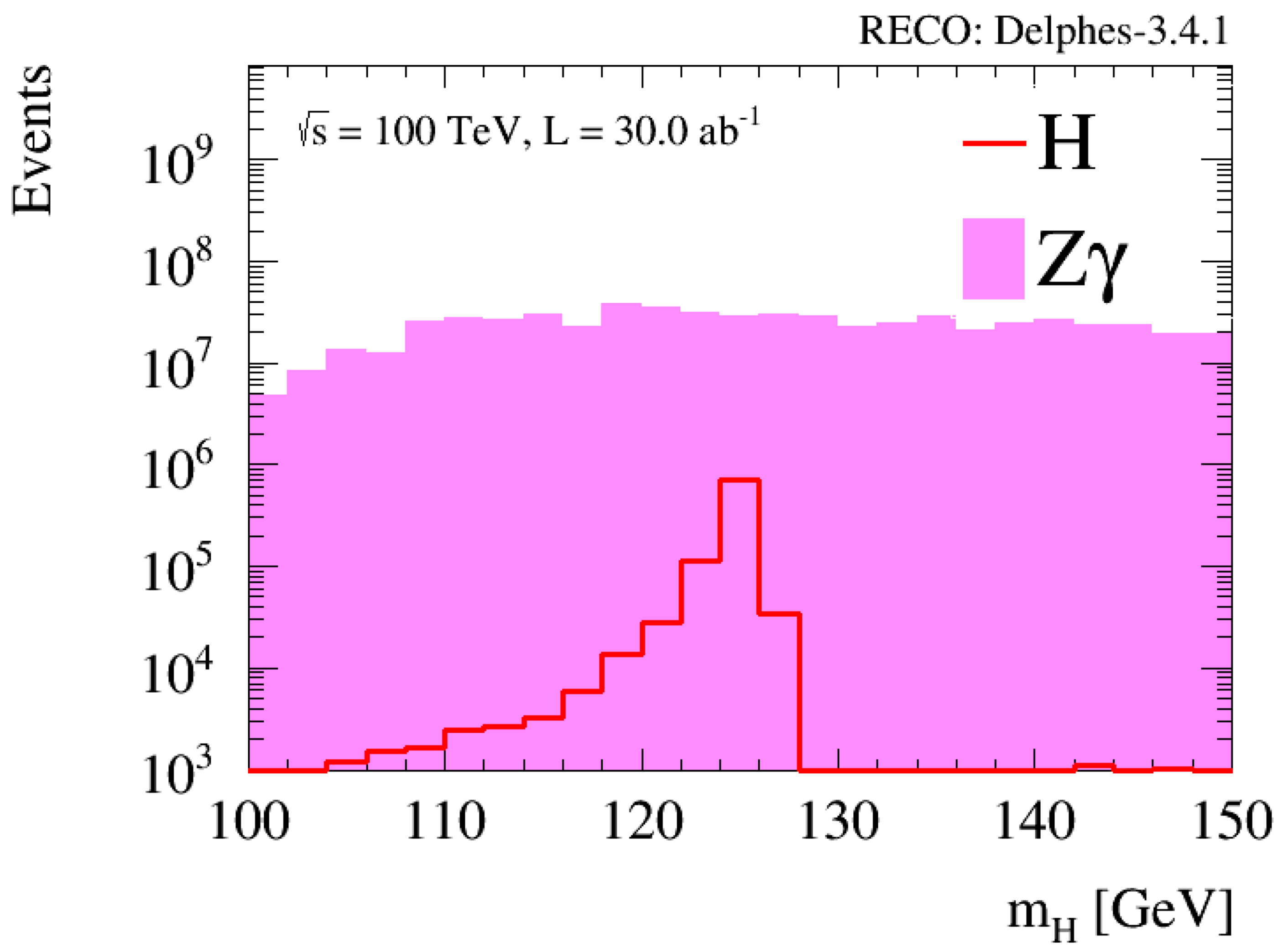


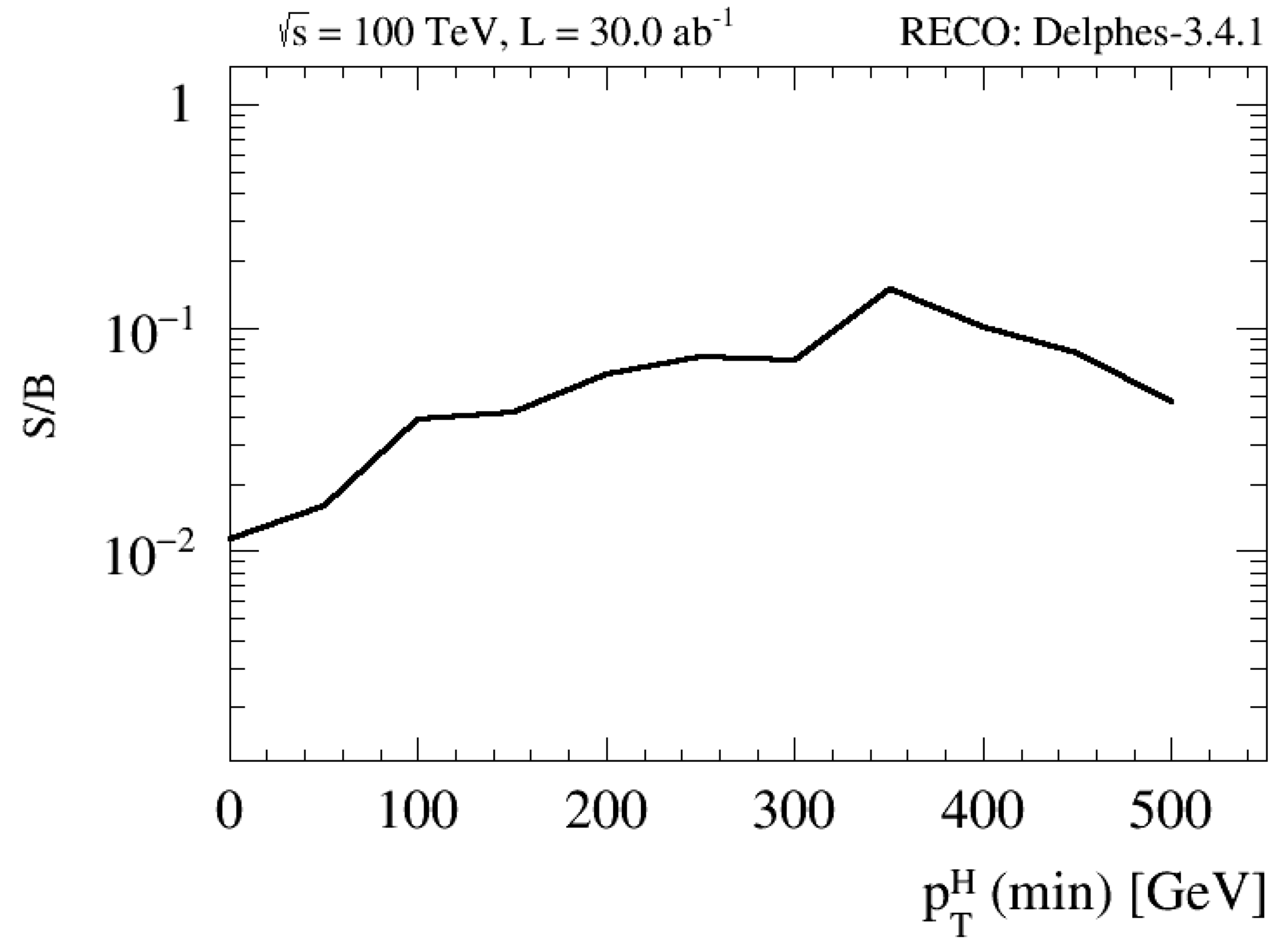
δμ/μ ≈ 1 % stat. precision
can be achieved up to $p_T(H)$ = 200 GeV



H → Zɣ → llɣ

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

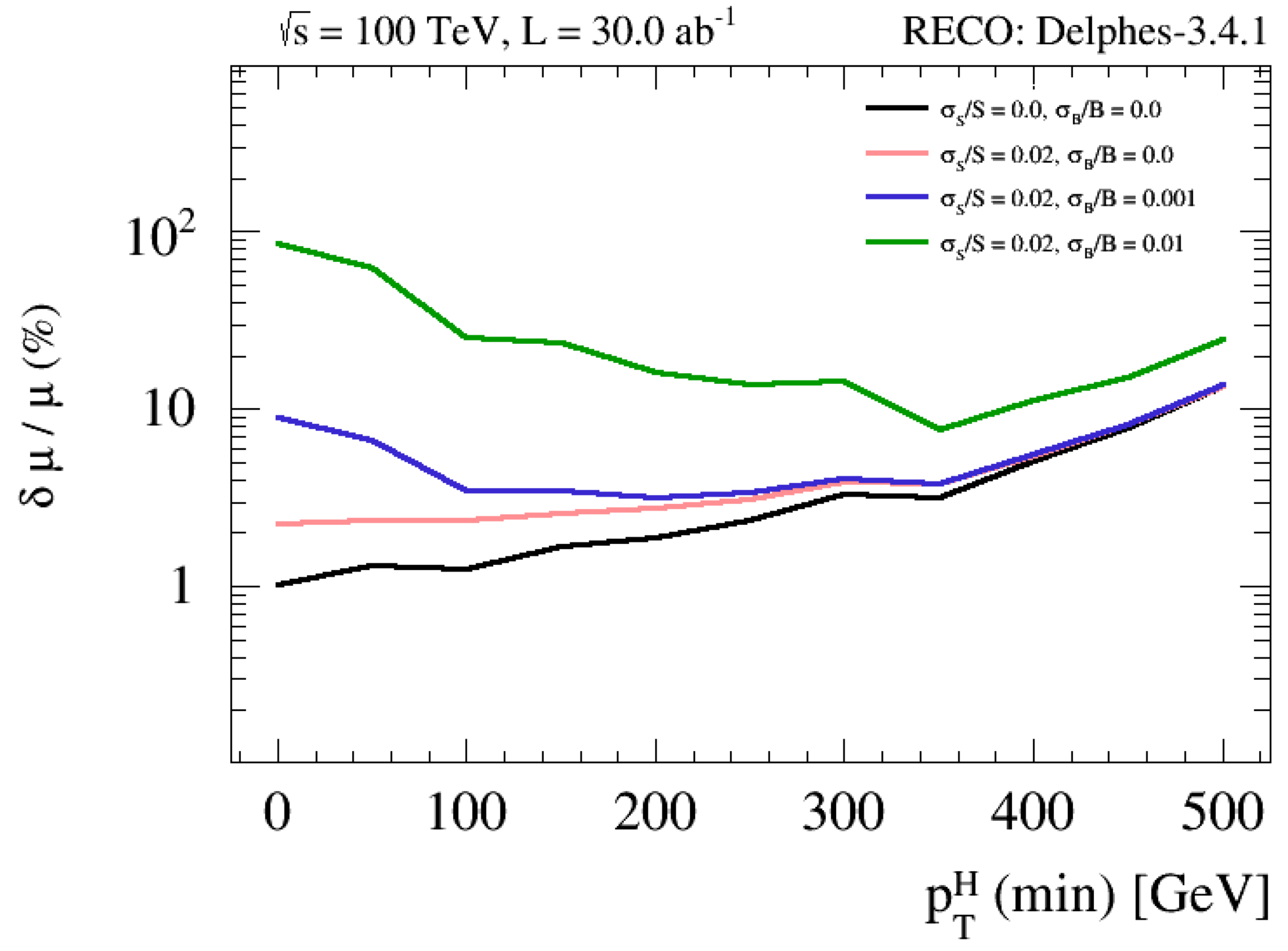




δμ/μ ≈ 1 % stat. precision
can be achieved up to $p_T(H)$ = 400 GeV

Simple cut and count strategy:

- $75 < m_{Zl} < 105.$
- $p_T(l) > 20$ GeV, $|\eta(l)| < 4.0$
- $p_T(\gamma) > 15$ GeV, $|\eta(\gamma)| < 4.0$
- $122.5 < m_{ll\gamma} < 127.5$ 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, and provided we control reconstruction efficiencies)

- Exploring **new dynamical regimes (high p_T)** gives access to:
  - enhanced SM modifications from NP
  - pure Higgs samples (e.g H→ZZ*)
  - **Higgs pT spectrum** can be potentially measured to **very high precision using 4l**, γγ (since shape, not dependent on luminosity)

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
- Remaining key channels (bb, $\tau\tau$, ttH) should be studied
- Which of the following gives more **sensitivity to new physics**?

  O(1%) precision measurement at low p_T or
  O(10%) precision at high p_T

Backup