FCC-hh Studies for the next European Strategy: kickoff meeting

100TeV → 80/120 TeV CDR projections: results so far

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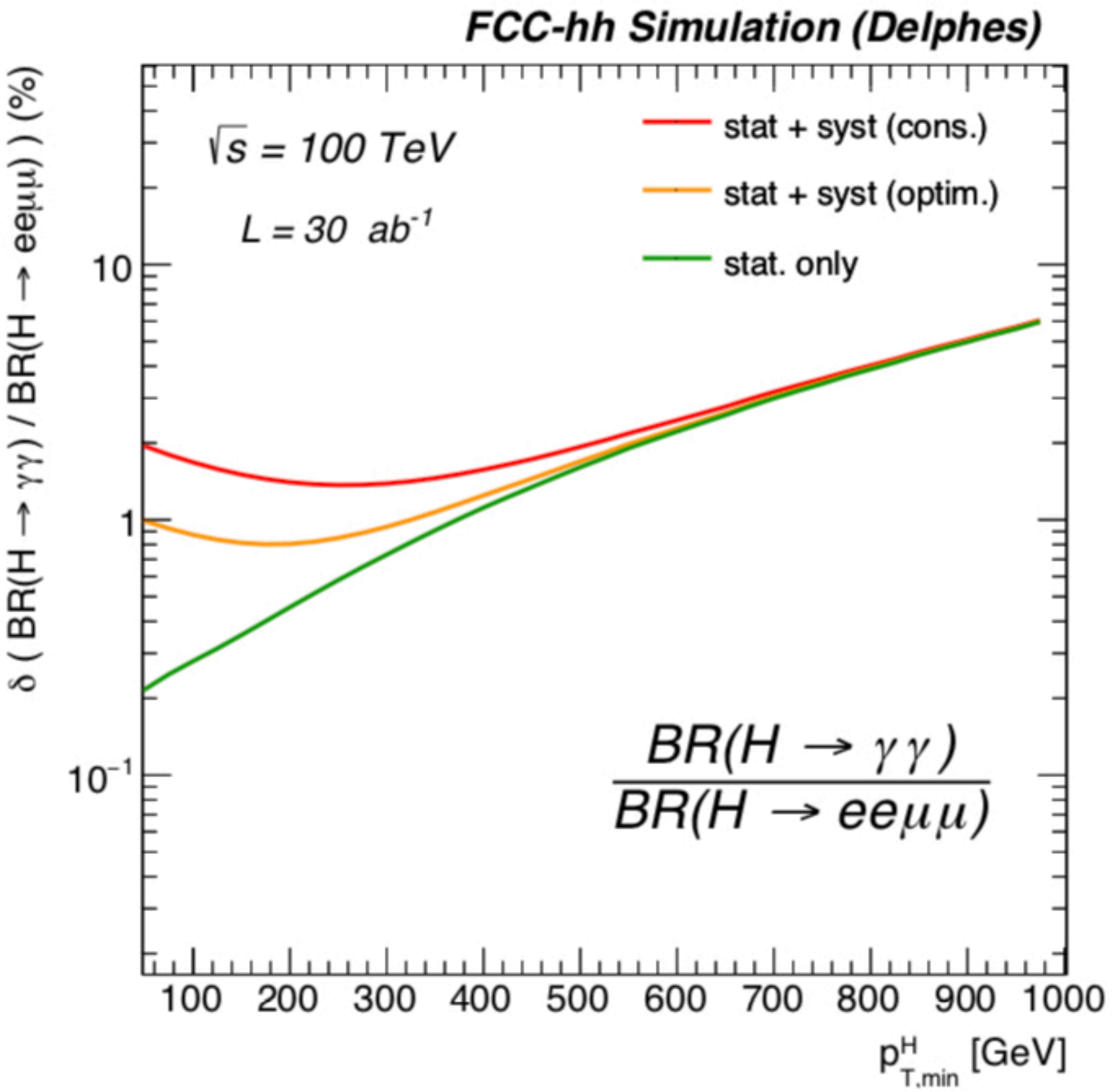
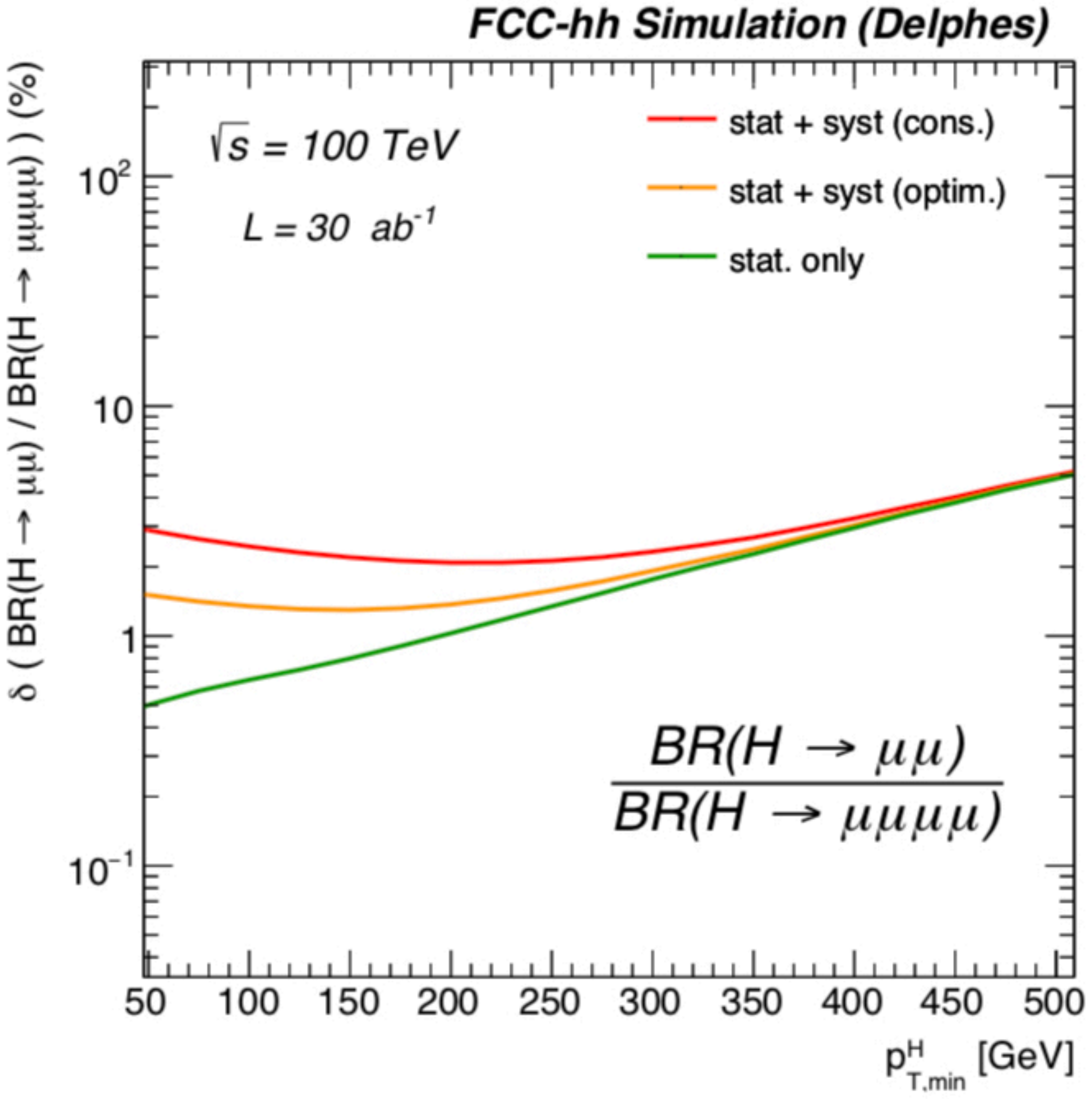
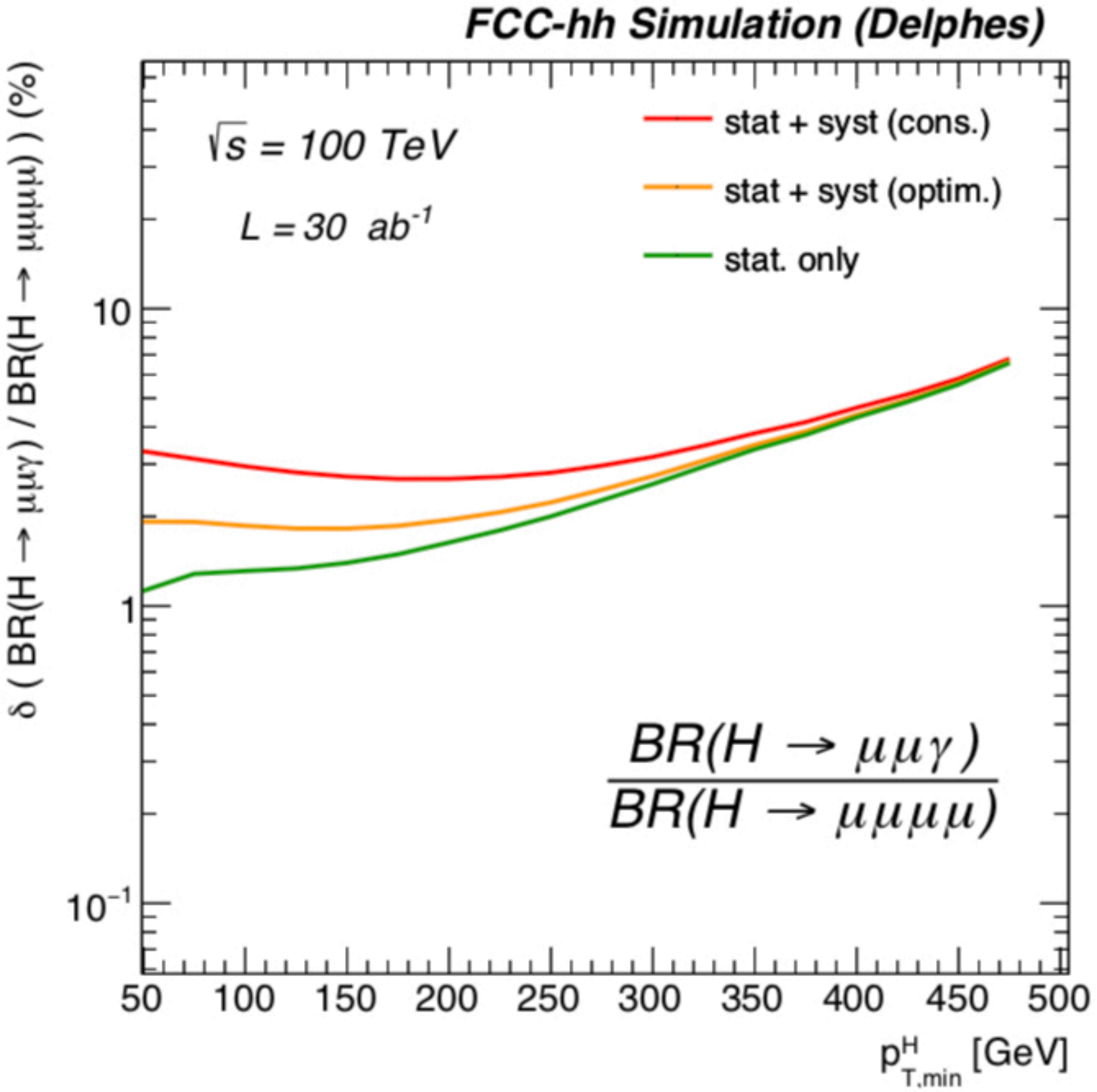
The Higgs rare decays BRs

from the CDR:







Coupling precision	**100 TeV CDR baseline**
$\delta g_{H\gamma\gamma} / g_{H\gamma\gamma}$ (%)	**0.4**
$\delta g_{H\mu\mu} / g_{H\mu\mu}$ (%)	**0.65**
$\delta g_{HZ\gamma} / g_{HZ\gamma}$ (%)	**0.9**

The Higgs rare decays BRs

Energy dependence of the Higgs pT integrated spectra:

$p_{T,min}$ (GeV)	100	140	180	220	260	300
σ(80)/σ(100)	**0.71**	**0.70**	**0.69**	**0.68**	**0.68**	**0.67**
σ(120)/σ(100)	**1.33**	**1.33**	**1.35**	**1.35**	**1.37**	**1.38**

Rescaling the statistical uncertainties (%) on the BR measurements:

100	γγ	μμ	Zγ
stat	0.4	0.8	1.3
syst	0.7	1	1.2
tot	**0.8**	**1.3**	**1.8**

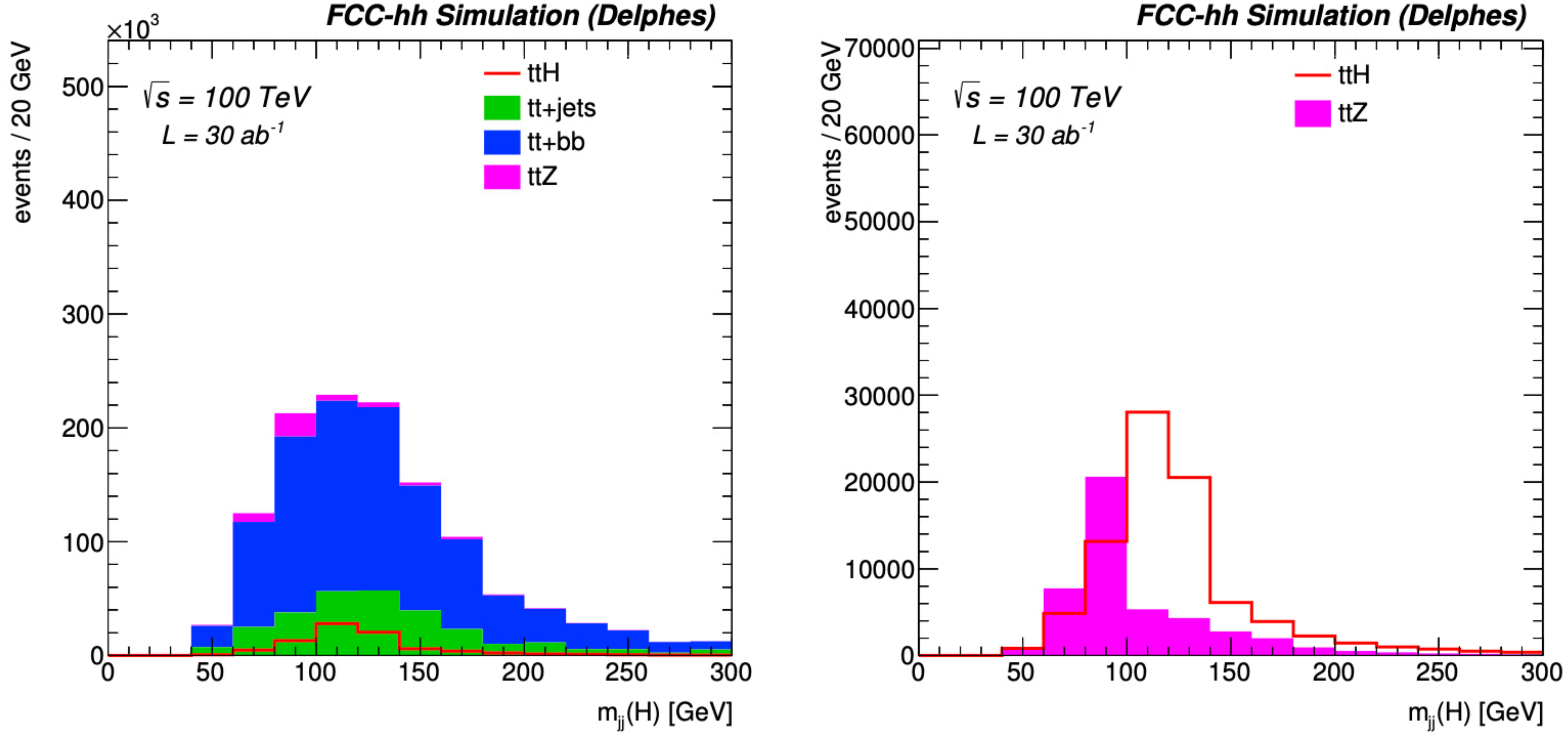
80 TeV	γγ	μμ	Zγ
stat	0.48	0.96	1.56
syst	0.7	1	1.2
tot	**0.85**	**1.39**	**1.97**

120 TeV	γγ	μμ	Zγ
stat	0.34	0.69	1.12
syst	0.7	1	1.2
tot	**0.78**	**1.21**	**1.64**

Coupling uncertainty projections:

Coupling precision	**100 TeV CDR baseline**	**80 TeV**	**120 TeV**
$\delta g_{H\gamma\gamma} / g_{H\gamma\gamma}$ (%)	**0.4**	**0.4**	**0.4**
$\delta g_{H\mu\mu} / g_{H\mu\mu}$ (%)	**0.65**	**0.7**	**0.6**
$\delta g_{HZ\gamma} / g_{HZ\gamma}$ (%)	**0.9**	**1.0**	**0.8**

ttH coupling from ttH/ttZ



- Exploit boosted top and Higgs topologies, with $p_T(H,t) \gtrsim 250$ GeV
- Assumes ttZ coupling precisely known from FCC-ee
- No bg-subtraction syst's included
- 1% stat uncertainty quoted

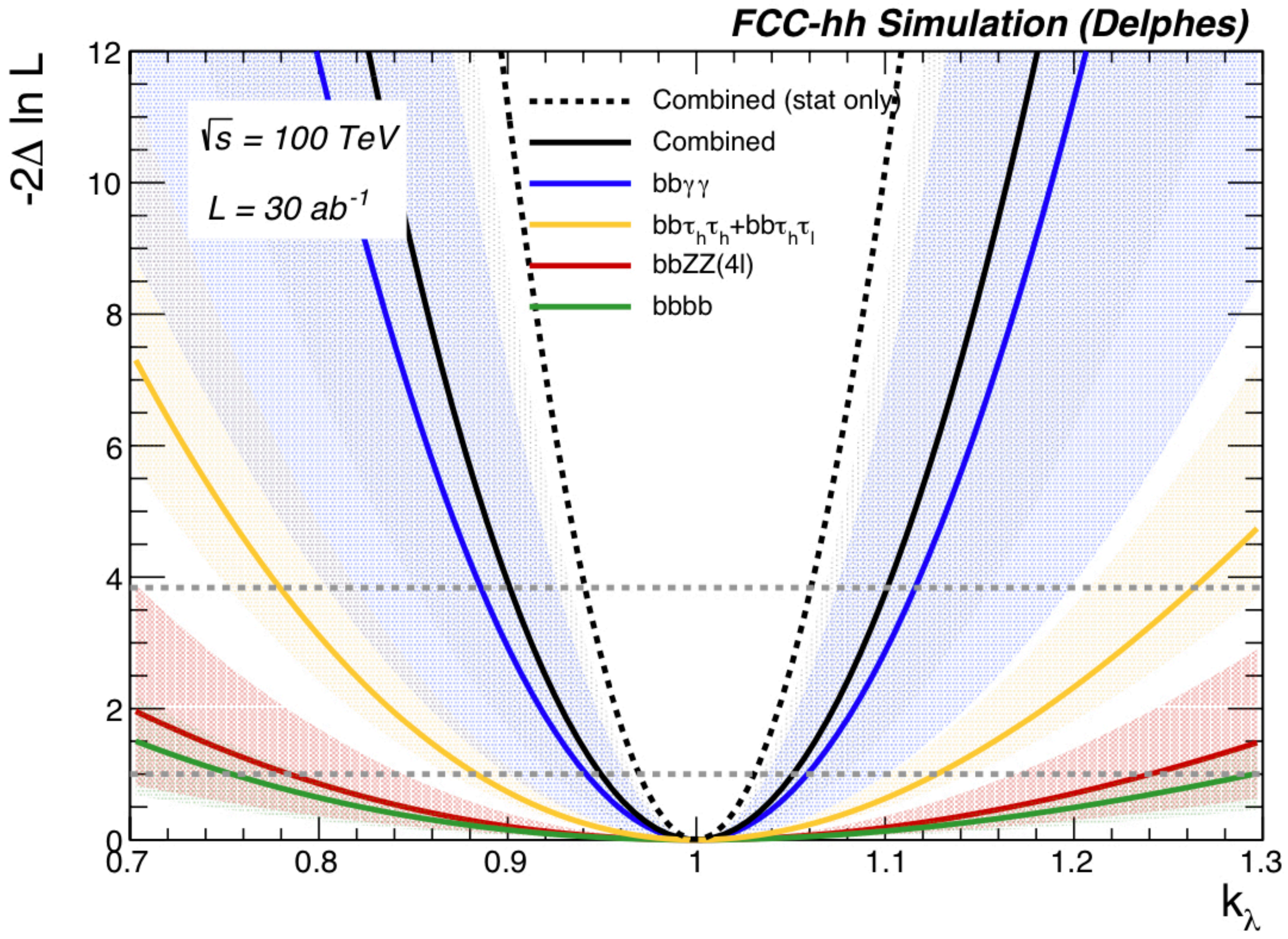
ECM dependence of rates for boosted final states [pt(H), pt(top) > ptmin]

$p_{T,min}$ (GeV)	0	100	200	400
σ(80)/σ(100)	0.68	0.67	0.67	0.57
σ(120)/σ(100)	1.36	1.38	1.38	1.48

At 80 TeV expect stat degradation of precision from 1% to 1.2% …
At 120 TeV expect stat improvement of precision from 1% to 0.85% …
But systematics will likely remain the critical item, more work, even for 100 TeV, is needed

The Higgs self-coupling

MLM, Ortona, Selvaggi https://arxiv.org/abs/2004.03505



see updates in Michele's next talk

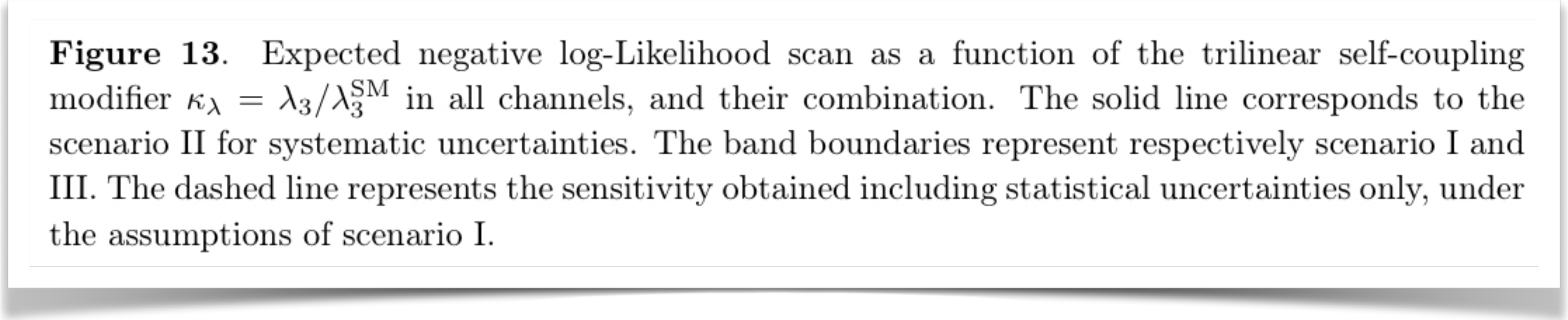
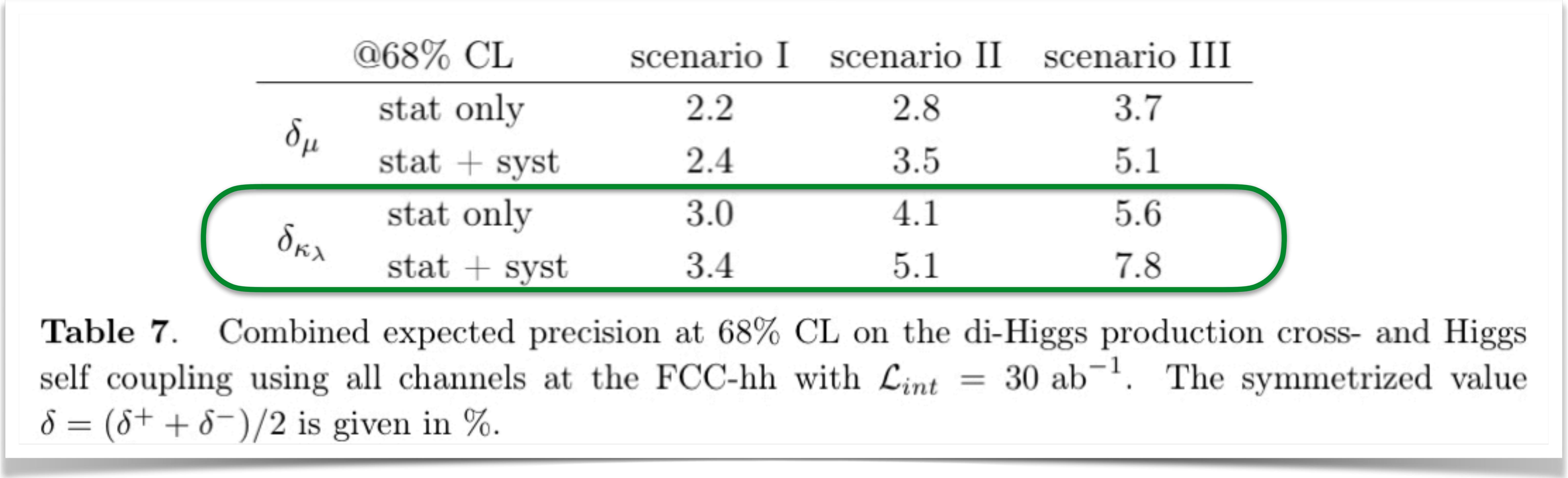


Figure 13. Expected negative log-Likelihood scan as a function of the trilinear self-coupling modifier $\kappa_\lambda = \lambda_3/\lambda_3^{SM}$ in all channels, and their combination. The solid line corresponds to the scenario II for systematic uncertainties. The band boundaries represent respectively scenario I and III. The dashed line represents the sensitivity obtained including statistical uncertainties only, under the assumptions of scenario I.

Det performance/systematics scenarios

I. Target det performance: LHC Run 2 conditions
II. Intermediate performance
III. Conservative: extrapolated HL-LHC performance, with today's algo's (eg no timing, etc)

2019



	@68% CL	scenario I	scenario II	scenario III
δ_μ	stat only	2.2	2.8	3.7
	stat + syst	2.4	3.5	5.1
δ_{κ_λ}	stat only	3.0	4.1	5.6
	stat + syst	3.4	5.1	7.8

Table 7. Combined expected precision at 68% CL on the di-Higgs production cross- and Higgs self coupling using all channels at the FCC-hh with $\mathcal{L}_{int} = 30$ ab^{-1}. The symmetrized value $\delta = (\delta^+ + \delta^-)/2$ is given in %.

The Higgs self-coupling: extrapolation

https://arxiv.org/abs/2004.03505

100 TeV	s I	s II	s III
stat	3.0	4.1	5.6
syst	1.6	3.0	5.4
tot	**3.4**	**5.1**	**7.8**

NB Statistical uncertainty depends on performance scenario (eg through γγ and bb mass resolution)

$$\frac{\sigma_{HH}(80\mathrm{TeV})}{\sigma_{HH}(100\mathrm{TeV})} \sim 0.72$$ => increase δ_{stat} by 15%

$$\frac{\sigma_{HH}(120\mathrm{TeV})}{\sigma_{HH}(100\mathrm{TeV})} \sim 1.3$$ => reduce δ_{stat} by 15%

80 TeV	s I	s II	s III
stat	3.5	4.7	6.4
syst	1.6	3.0	5.4
tot	**3.8**	**5.6**	**8.4**

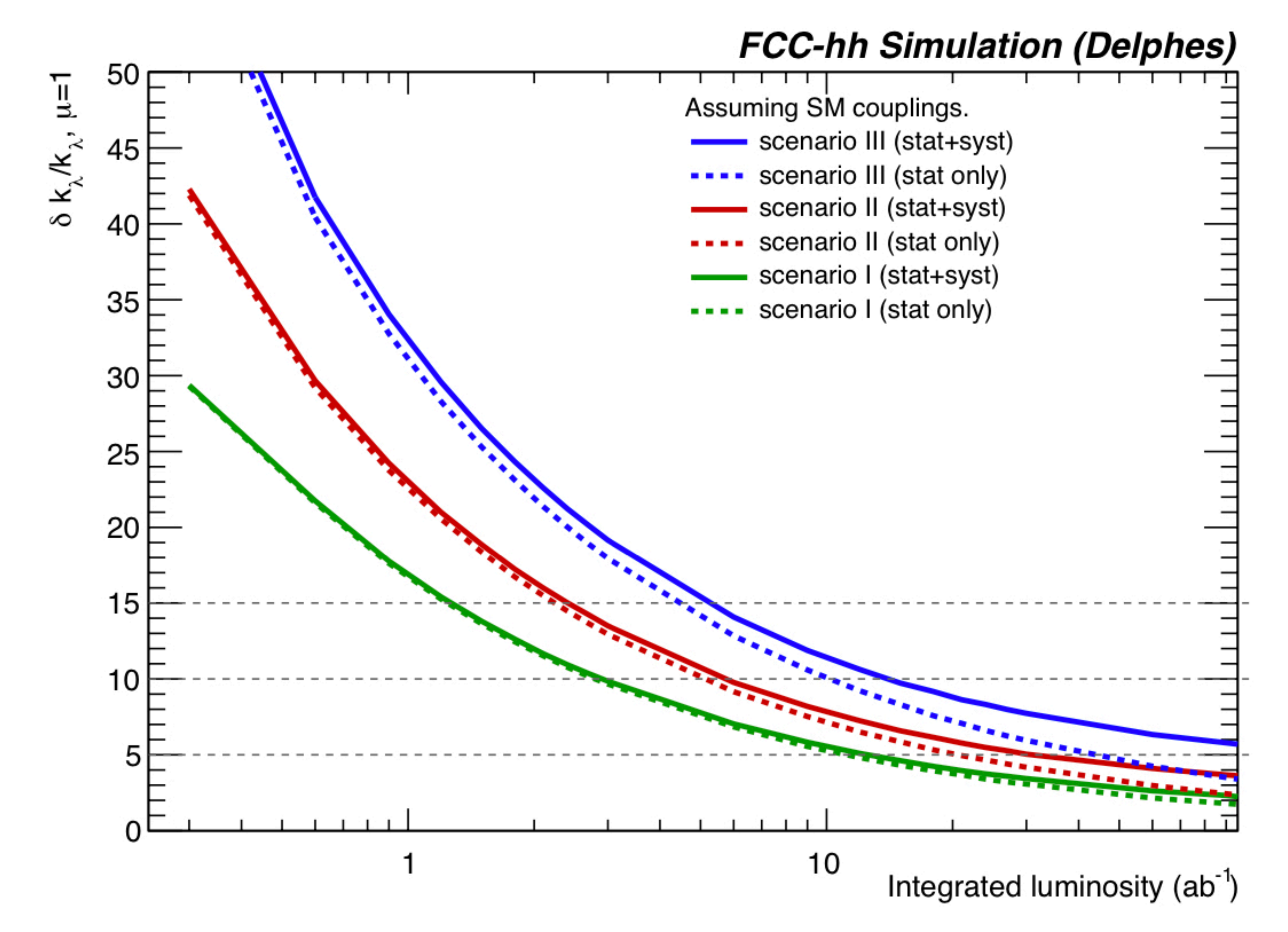
120 TeV	s I	s II	s III
stat	2.6	3.6	4.9
syst	1.6	3.0	5.4
tot	**3.1**	**4.7**	**7.3**

Bottom line: variation is within the band of uncertainty due to detector performance. Run 2 performance keeps the overall uncertainty below 5%

The Higgs self-coupling

https://arxiv.org/abs/2004.03505

The precision timeline, at 100 TeV:



Expected precision on the Higgs self-coupling as a function of the integrated luminosity.

3-5 ab^{-1} are sufficient to get below the 10% level

=> within the reach of the first 5yrs of FCC-hh running,

in the “low” luminosity / “low” pileup phase

=> the 10% precision threshold can be reached within the timescale of a similar measurement by CLIC @ 3 TeV

These conclusions remain true at 80 TeV, assuming an LHC Run 2 detector performance

More at 100 vs 80 vs 120 TeV

Disappearing charged track analyses (at ~full pileup)

Saito, Sawada, Terashi, Asai,
https://arxiv.org/abs/1901.02987 w. 80 TeV study by Saito

$$M_{wimp} \lesssim 2\ \text{TeV} \left(\frac{g}{0.3}\right)^2$$

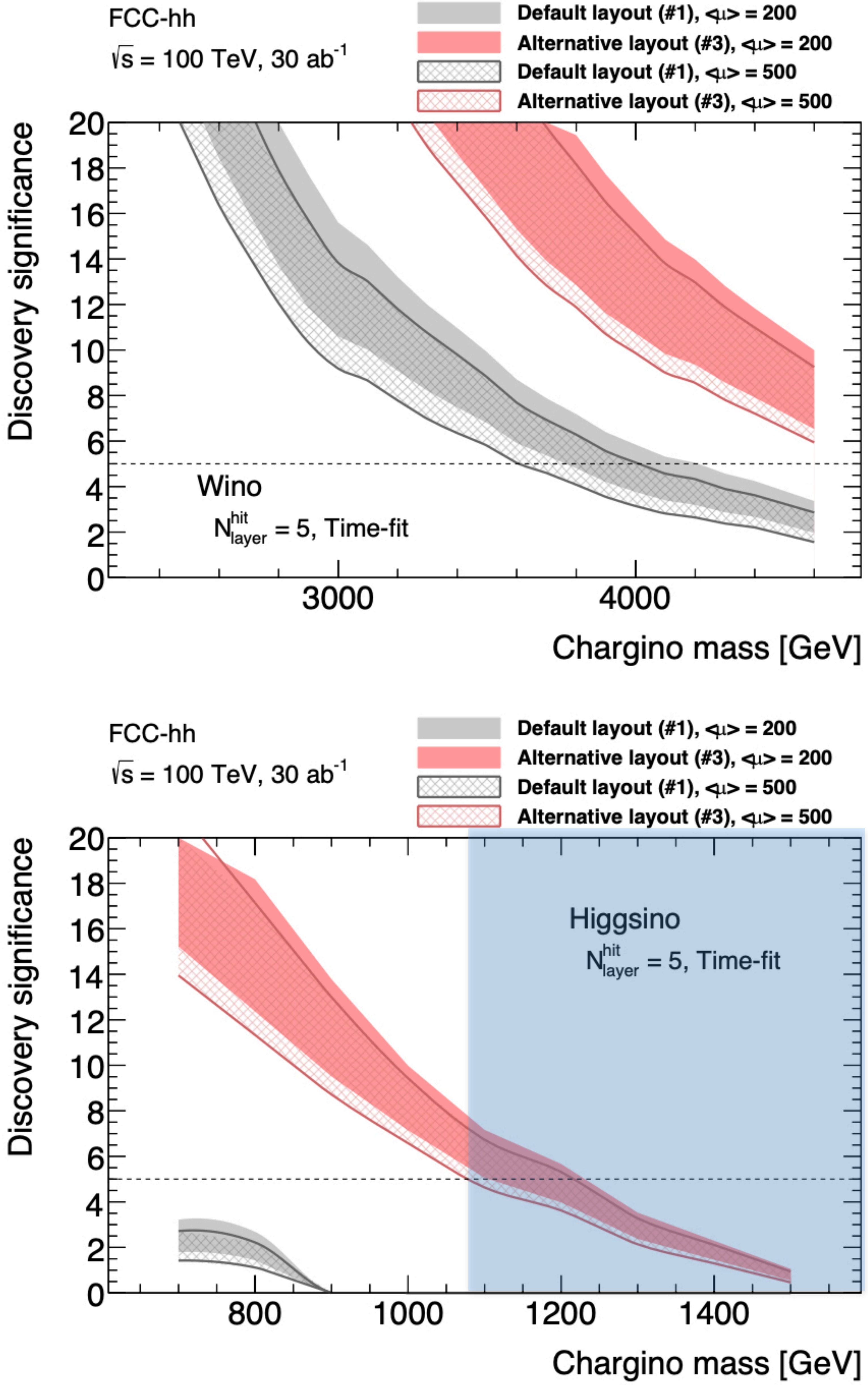
Excluded region for
thermal WIMP DM

80 TeV study, vs 100 TeV:

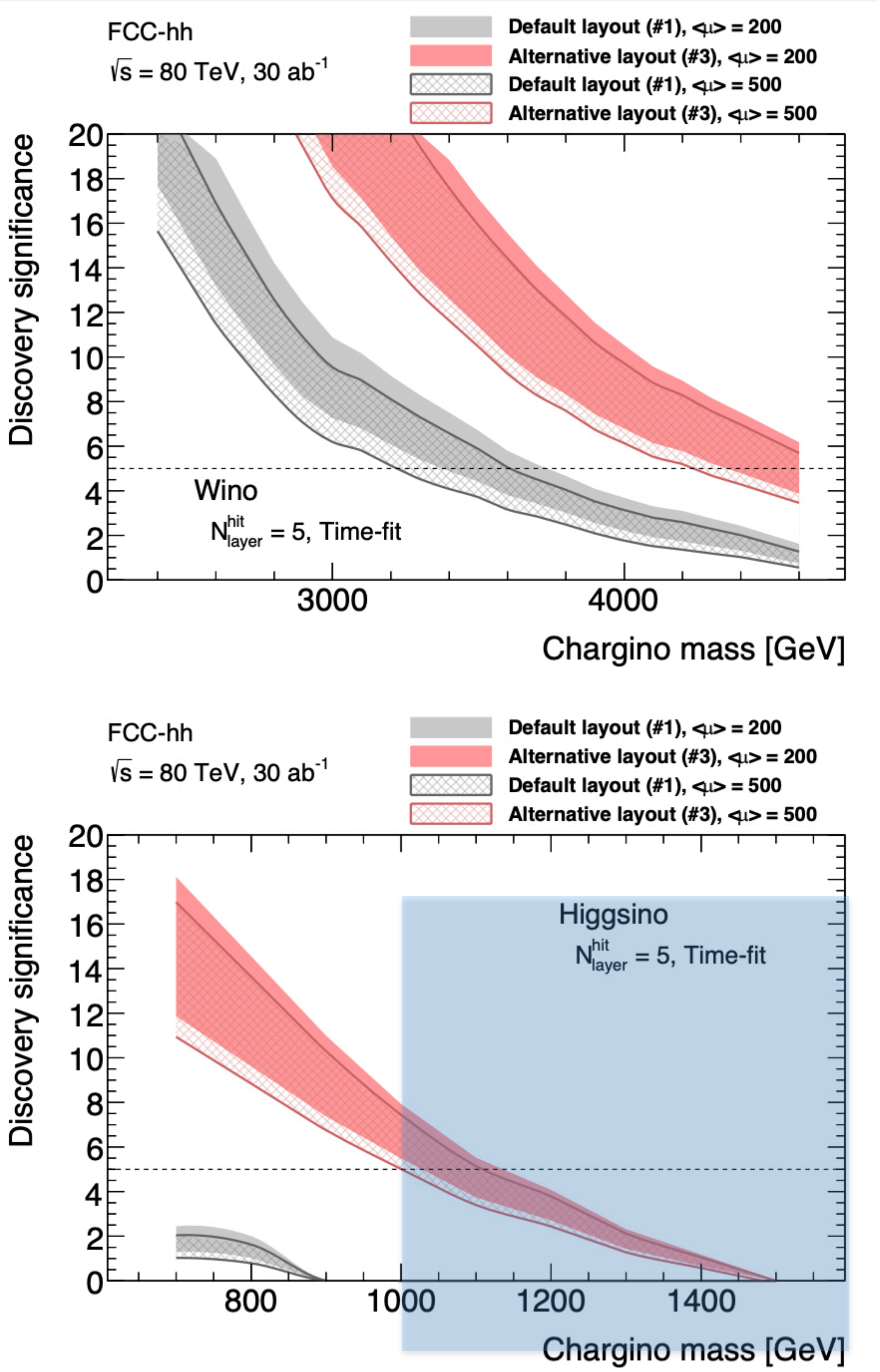
- signal rates @ 80 TeV
- kinematic selection reoptimised
- bgd rates unchanged

➡ discovery reach **conservative**

5σ higgsino reach drops from 1150 GeV to 1000 GeV

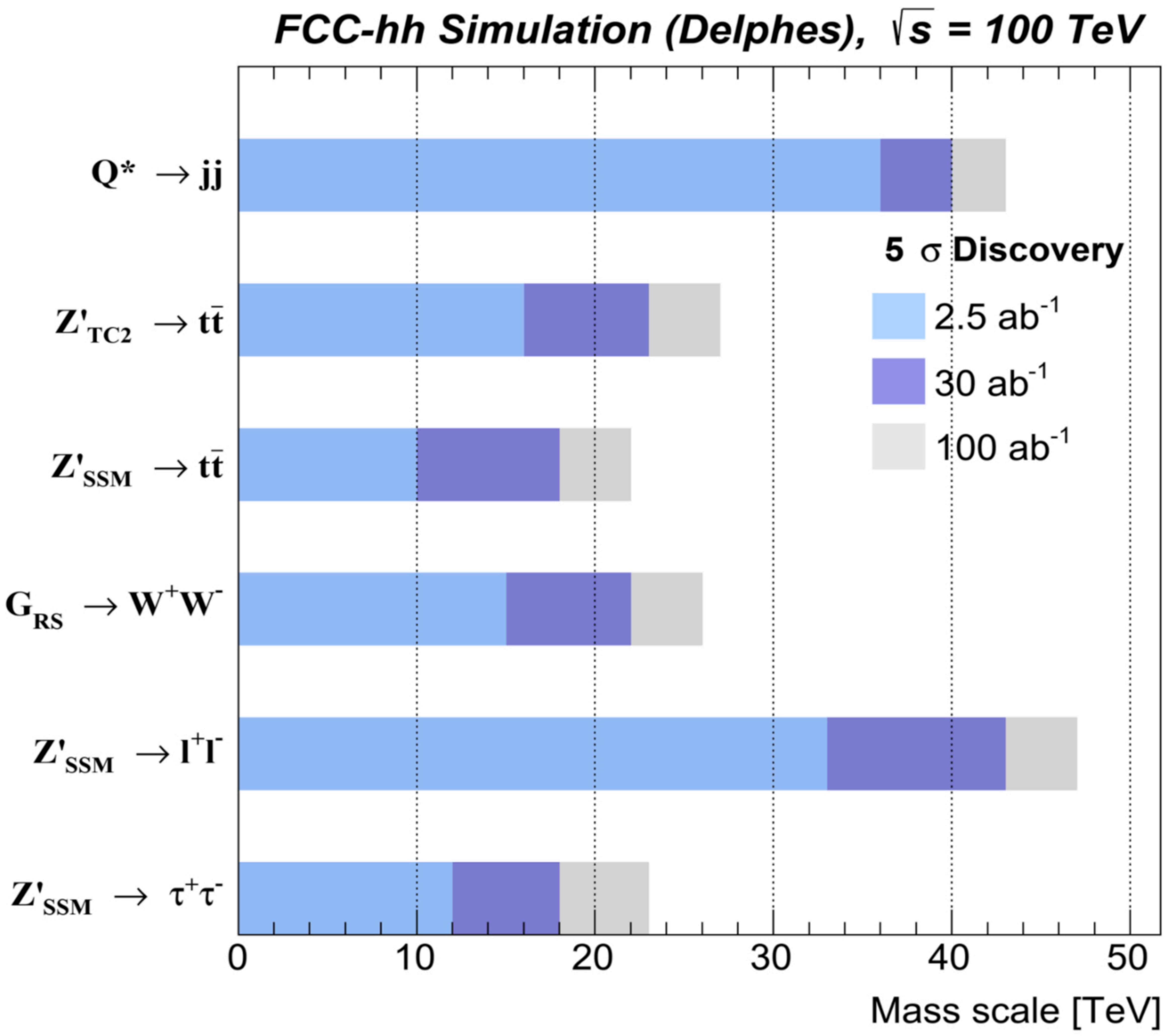


100 TeV



80 TeV

s-channel resonances



ColliderReach ECM extrapolation of 5σ
30ab^{-1} discovery reach

	100 TeV	80 TeV	120 TeV
Q*	40	33	46
$Z'_{TC2} \to tt$	23	20	26
$Z'_{SSM} \to tt$	18	15	20
$G_{RS} \to WW$	22	19	25
$Z'_{SSM} \to ll$	43	36	50
$Z'_{SSM} \to \tau\tau$	18	15	20

- **10-15% reach increase at 120 TeV**
- **15-20% reach loss at 80 TeV**

100 vs 80 vs 120: remarks

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➡ the decision of 80 vs 120 vs 100 is probably final, and unlikely to lead to an upgrade path

Further suggestions of useful studies

(see Michele's talk for more and for the detector performance perspective)

- extend the exploration of Higgs physics measurements (see Michele's talk, and beyond)
- EW precision potential
- role of non-general-purpose experiments (flavour, BSM, …) (see Juan's talk)
- Interplay of FCC-ee and FCC-hh:
  - concrete examples of how possible discrepancies for EFT operators observed at FCC-ee can be understood with direct detection at FCC-hh. Focus on concrete BSM scenarios
  - Eg: assume FCC-ee detects a 3σ discrepancy in, say, $H\to\gamma\gamma$: can FCC-hh further explore and discover the source of this anomaly, at least in the case of a few BSM model candidates ?
  - Which other concrete anomalies from FCC-ee can or cannot be explored by FCC-hh?
  - Follow up and improve on FCC-ee discoveries of HNLs, LLPs, etc
  - Mapping the FCC-hh discovery potential beyond the sensitivity of FCC-ee, also with a view to driving questions in particle physics such as naturalness.