

Physics at Future Circular Colliders

LIO international conference on
Future Colliders and the *origin of mass*

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Michelangelo L. Mangano
Theory Department,
CERN, Geneva



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Origin of mass



Future colliders

- Why do we need future colliders to probe the origin of mass?
- Why do we need future **circular** colliders?
- What can the planned future circular colliders deliver?

For examples of results, I will focus on the future 100 TeV hadron collider

For FCC-ee see Gregorio Bernardi talk on Thursday.

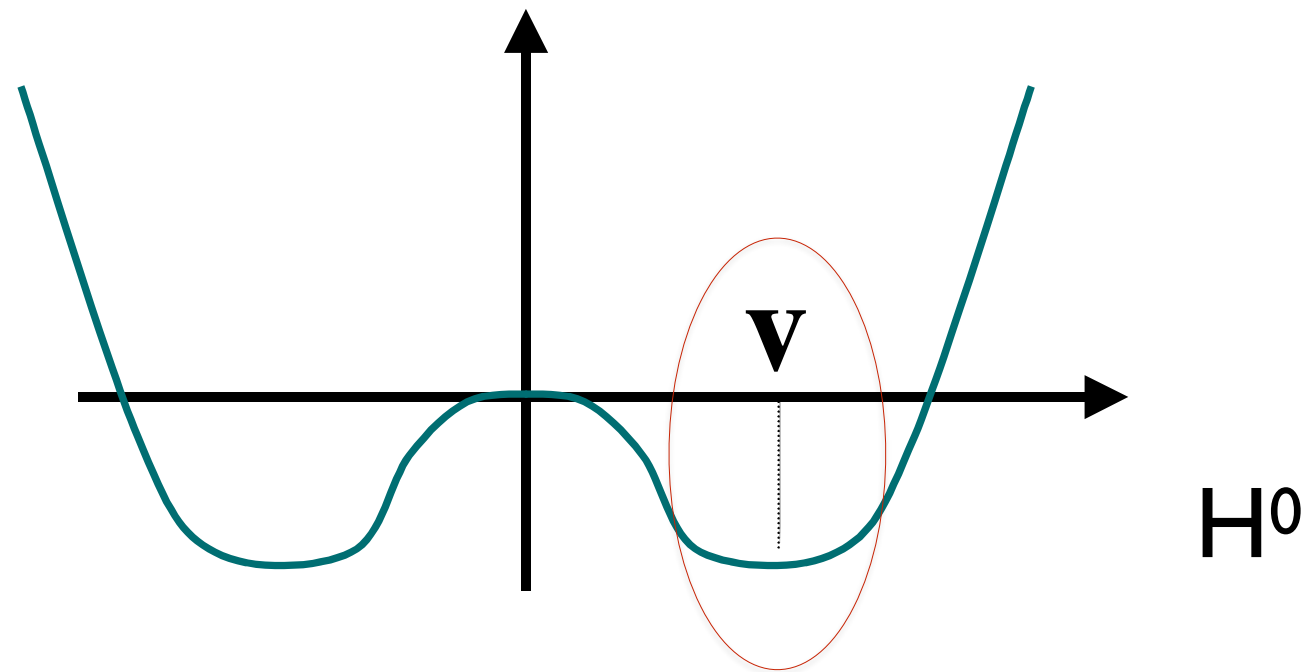
For ALP searches at the Z peak of FCC-ee, see Abhisek Iyer talk later today

Aspects of the “origin of mass” question

- What’s the origin of the diverse mass spectrum in the SM?
- What’s the origin of the neutrino mass spectrum, beyond the SM?
- Where does DM get its mass from? (Eg SUSY breaking for susy partners, ...)
- ...

We have no guarantees as to where answers to these questions will come from, and what are the experiments that will eventually answer them.

But there is one question that can only be addressed by colliders, and future collider efforts must focus on its thorough exploration



$$V(H) = -\mu^2 |H|^2 + \lambda |H|^4$$

Where does this come from?

The importance of the in-depth exploration of the Higgs properties was acknowledged by the 2020 update of the European Strategy for Particle Physics:

“An electron-positron Higgs factory is the highest-priority next collider”

Key question for the future developments of HEP:
Why don't we see the new physics we expected to be present around the TeV scale ?

- **Is the mass scale beyond the LHC reach ?**
- **Is the mass scale within LHC's reach, but final states are elusive to the direct search ?**

These two scenarios are a priori equally likely, but they impact in different ways the future of HEP, and thus the assessment of the physics potential of possible future facilities

Readiness to address both scenarios is the best hedge for the field:

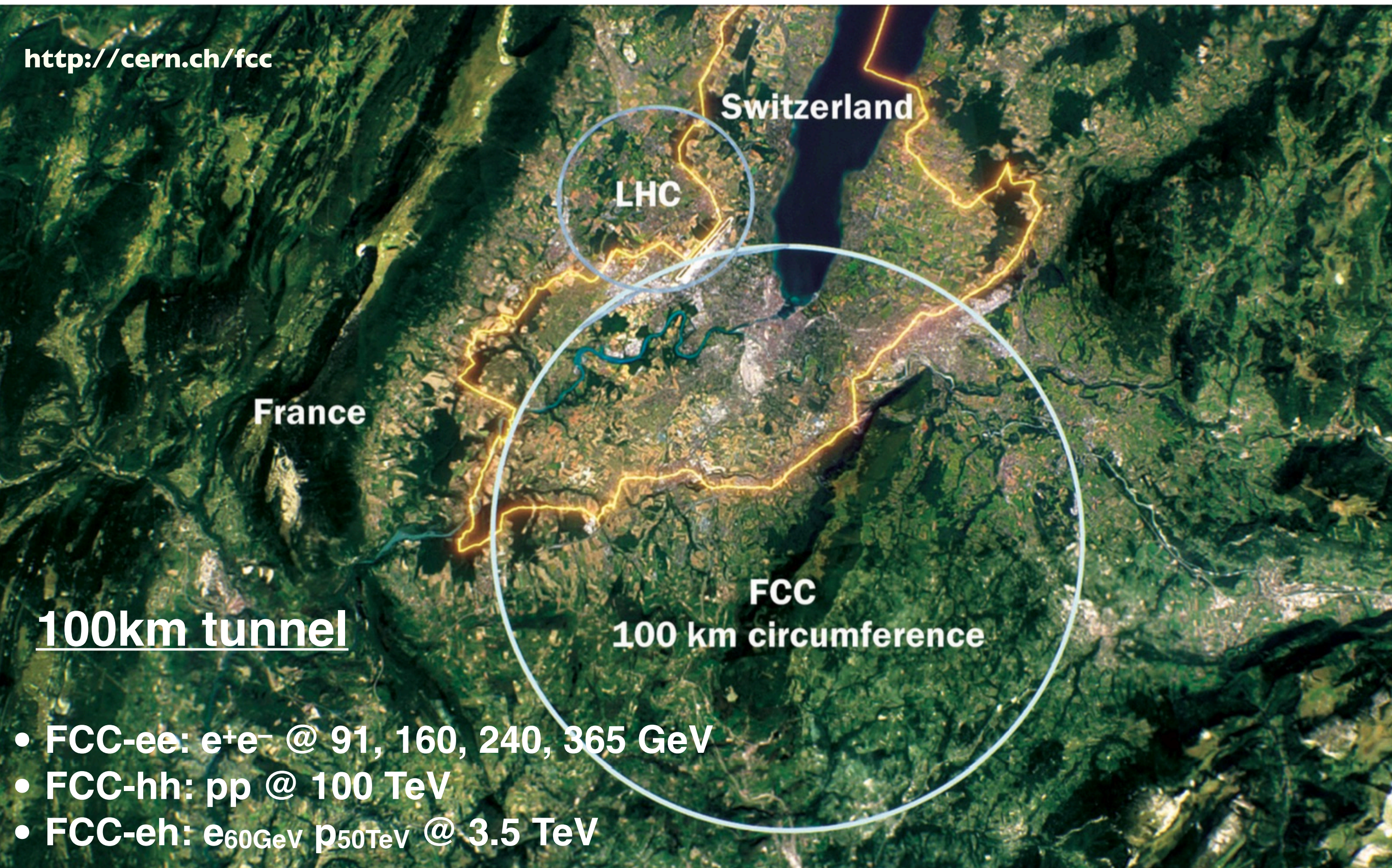
- *precision* \Rightarrow *higher statistics, better detectors and experimental conditions*
- *sensitivity (to elusive signatures)* \Rightarrow *ditto*
- ***extended energy/mass reach*** \Rightarrow ***higher energy***

From ESPP 2020:

“Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage. “

Answer to these challenges: Future Circular Collider

<http://cern.ch/fcc>



France

Switzerland

LHC

FCC

100 km circumference

100km tunnel

- FCC-ee: e^+e^- @ 91, 160, 240, 365 GeV
- FCC-hh: pp @ 100 TeV
- FCC-eh: $e_{60\text{GeV}} p_{50\text{TeV}}$ @ 3.5 TeV

What the future circular collider can offer

- Guaranteed deliverables:
 - study of Higgs and top quark properties, and exploration of EWSB phenomena, with the best possible **precision and sensitivity**
- Exploration potential:
 - exploit both direct (large Q^2) and indirect (precision) probes
 - **enhanced mass reach** for direct exploration at 100 TeV
 - *E.g. match the mass scales for new physics that could be exposed via indirect precision measurements in the EW and Higgs sector*
- Provide firm Yes/No answers to questions like:
 - is there a TeV-scale solution to the hierarchy problem?
 - is DM a thermal WIMP?
 - could the cosmological EW phase transition have been 1st order?
 - could baryogenesis have taken place during the EW phase transition?
 - could neutrino masses have their origin at the TeV scale?
 - ...

Event rates: examples

FCC-ee	H	Z	W	t	$\tau(\leftarrow Z)$	$b(\leftarrow Z)$	$c(\leftarrow Z)$
	10^6	$5 \cdot 10^{12}$	10^8	10^6	$3 \cdot 10^{11}$	$1.5 \cdot 10^{12}$	10^{12}

FCC-hh	H	b	t	$W(\leftarrow t)$	$\tau(\leftarrow W \leftarrow t)$
	$2.5 \cdot 10^{10}$	10^{17}	10^{12}	10^{12}	10^{11}

FCC-eh	H	t
	$2.5 \cdot 10^6$	$2 \cdot 10^7$

(1) guaranteed deliverables: Higgs properties

Coupling deviations for various BSM models, likely to remain unconstrained by direct searches at HL-LHC

<https://arxiv.org/pdf/1708.08912.pdf>

Model	$b\bar{b}$	$c\bar{c}$	gg	WW	$\tau\tau$	ZZ	$\gamma\gamma$	$\mu\mu$
1 MSSM [40]	+4.8	-0.8	- 0.8	-0.2	+0.4	-0.5	+0.1	+0.3
2 Type II 2HD [42]	+10.1	-0.2	-0.2	0.0	+9.8	0.0	+0.1	+9.8
3 Type X 2HD [42]	-0.2	-0.2	-0.2	0.0	+7.8	0.0	0.0	+7.8
4 Type Y 2HD [42]	+10.1	-0.2	-0.2	0.0	-0.2	0.0	0.1	-0.2
5 Composite Higgs [44]	-6.4	-6.4	-6.4	-2.1	-6.4	-2.1	-2.1	-6.4
6 Little Higgs w. T-parity [45]	0.0	0.0	-6.1	-2.5	0.0	-2.5	-1.5	0.0
7 Little Higgs w. T-parity [46]	-7.8	-4.6	-3.5	-1.5	-7.8	-1.5	-1.0	-7.8
8 Higgs-Radion [47]	-1.5	- 1.5	+10.	-1.5	-1.5	-1.5	-1.0	-1.5
9 Higgs Singlet [48]	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5



5 – 10 %



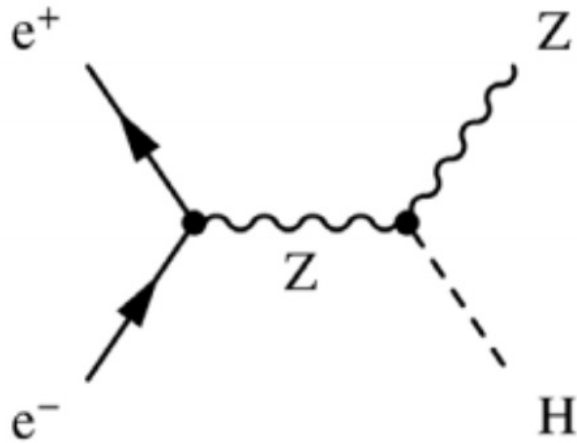
> 10%

NB: when the b coupling is modified, BR deviations are smaller than the square of the coupling deviation. Eg in model 5, the BR to b, c, tau, mu are practically SM-like

(sub)-% precision must be the goal to ensure 3-5 σ evidence of deviations, and to cross-correlate coupling deviations across different channels

The absolutely unique power of $e^+e^- \rightarrow ZH$ (circular or linear):

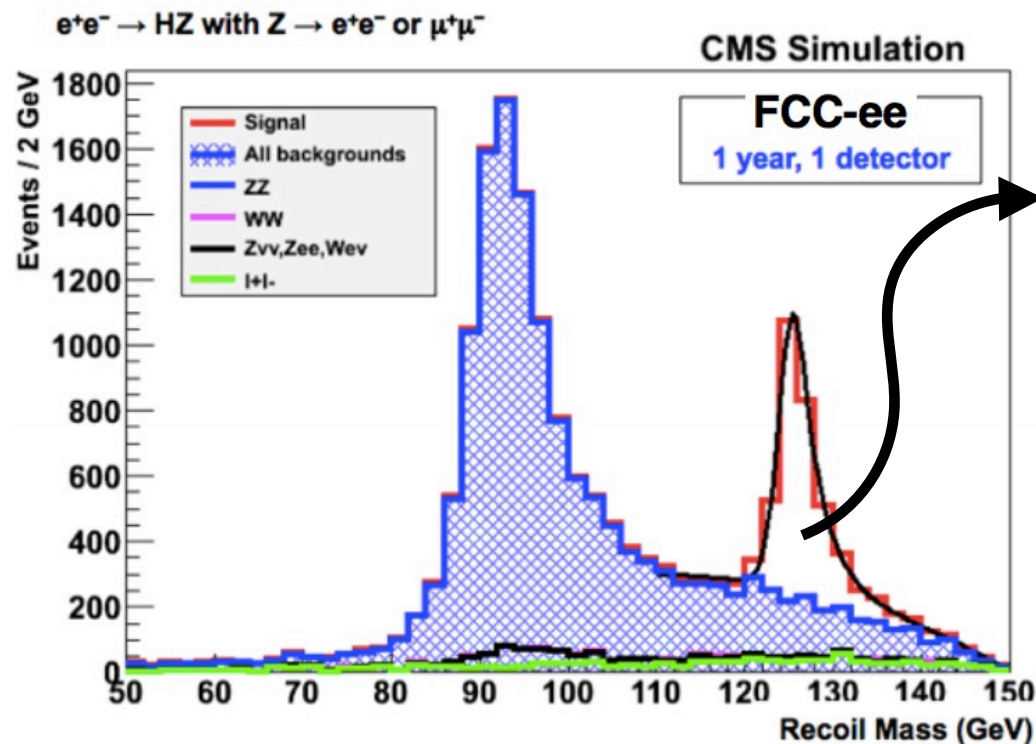
- the **model independent** absolute measurement of **HZZ** coupling, which allows the subsequent:
 - **sub-%** measurement of couplings to **W, Z, b, τ**
 - **%** measurement of couplings to **gluon and charm**



$$p(H) = p(e^-e^+) - p(Z)$$

$$\Rightarrow [p(e^-e^+) - p(Z)]^2 \text{ peaks at } m^2(H)$$

reconstruct Higgs events independently of the Higgs decay mode!



$$N(ZH) \propto \sigma(ZH) \propto g_{HZZ}^2$$

$$N(ZH[\rightarrow ZZ]) \propto$$

$$\sigma(ZH) \times \text{BR}(H \rightarrow ZZ) \propto g_{HZZ}^2 \times g_{HZZ}^2 / \Gamma(H)$$

\Rightarrow absolute measurement of width and couplings

$$m_{\text{recoil}} = \sqrt{[p(e^-e^+) - p(Z)]^2}$$

For details of Higgs program at FCC-ee, see Gregorio's talk on Thursday

The absolutely unique power of $pp \rightarrow H+X$:

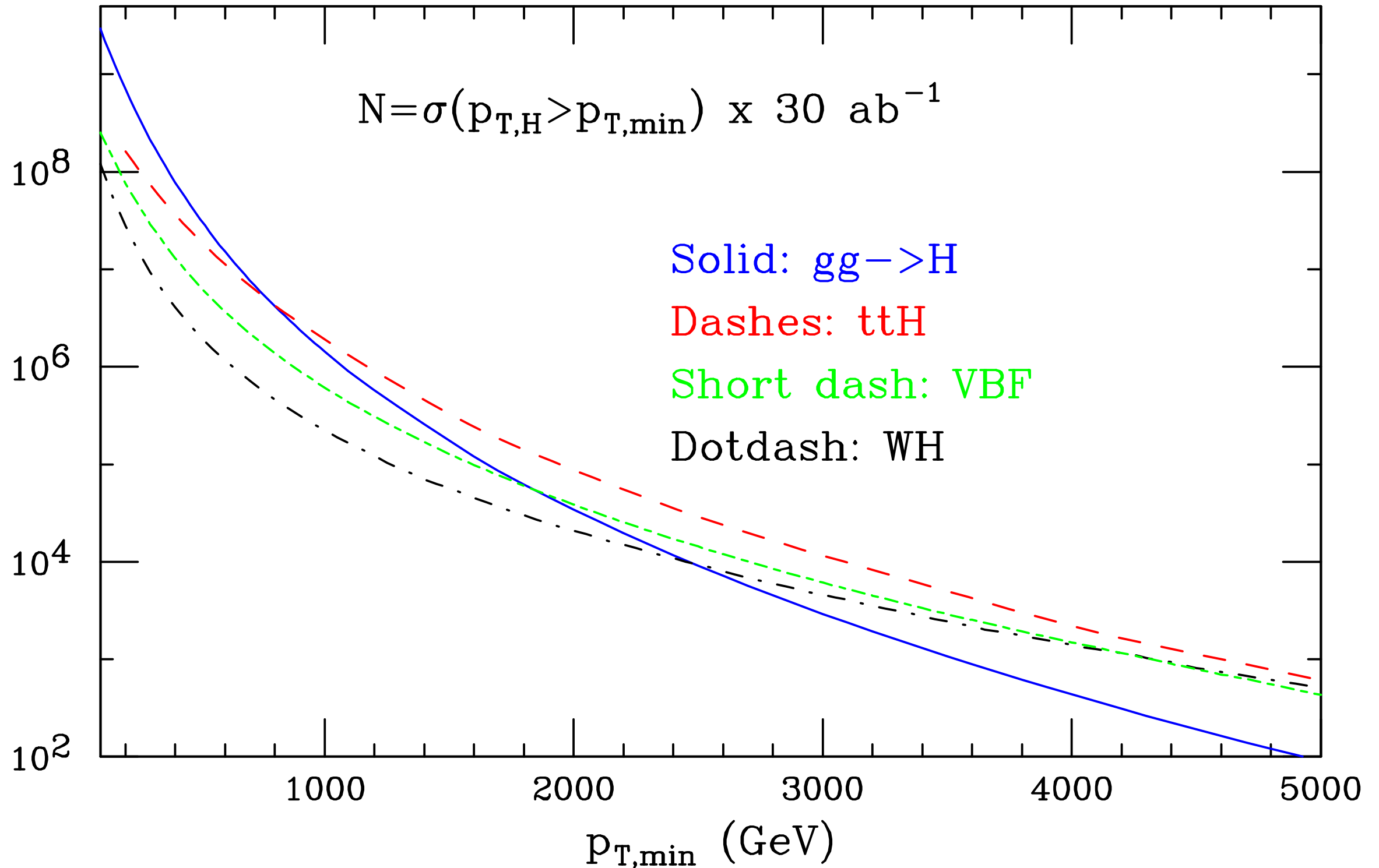
- the extraordinary statistics that, complemented by the per-mille e^+e^- measurement of eg $BR(H \rightarrow ZZ^*)$, allows
 - the sub-% measurement of rarer decay modes
 - the $\lesssim 5\%$ measurement of the Higgs trilinear selfcoupling
- the huge dynamic range (eg $pt(H)$ up to several TeV), which allows to
 - probe $d > 4$ EFT operators up to scales of several TeV
 - search for multi-TeV resonances decaying to H, or extensions of the Higgs sector

	$gg \rightarrow H$	VBF	WH	ZH	ttH	HH
N_{100}	24×10^9	2.1×10^9	4.6×10^8	3.3×10^8	9.6×10^8	3.6×10^7
N_{100}/N_{14}	180	170	100	110	530	390

$$N_{100} = \sigma_{100\text{TeV}} \times 30 \text{ ab}^{-1}$$

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

H at large p_T

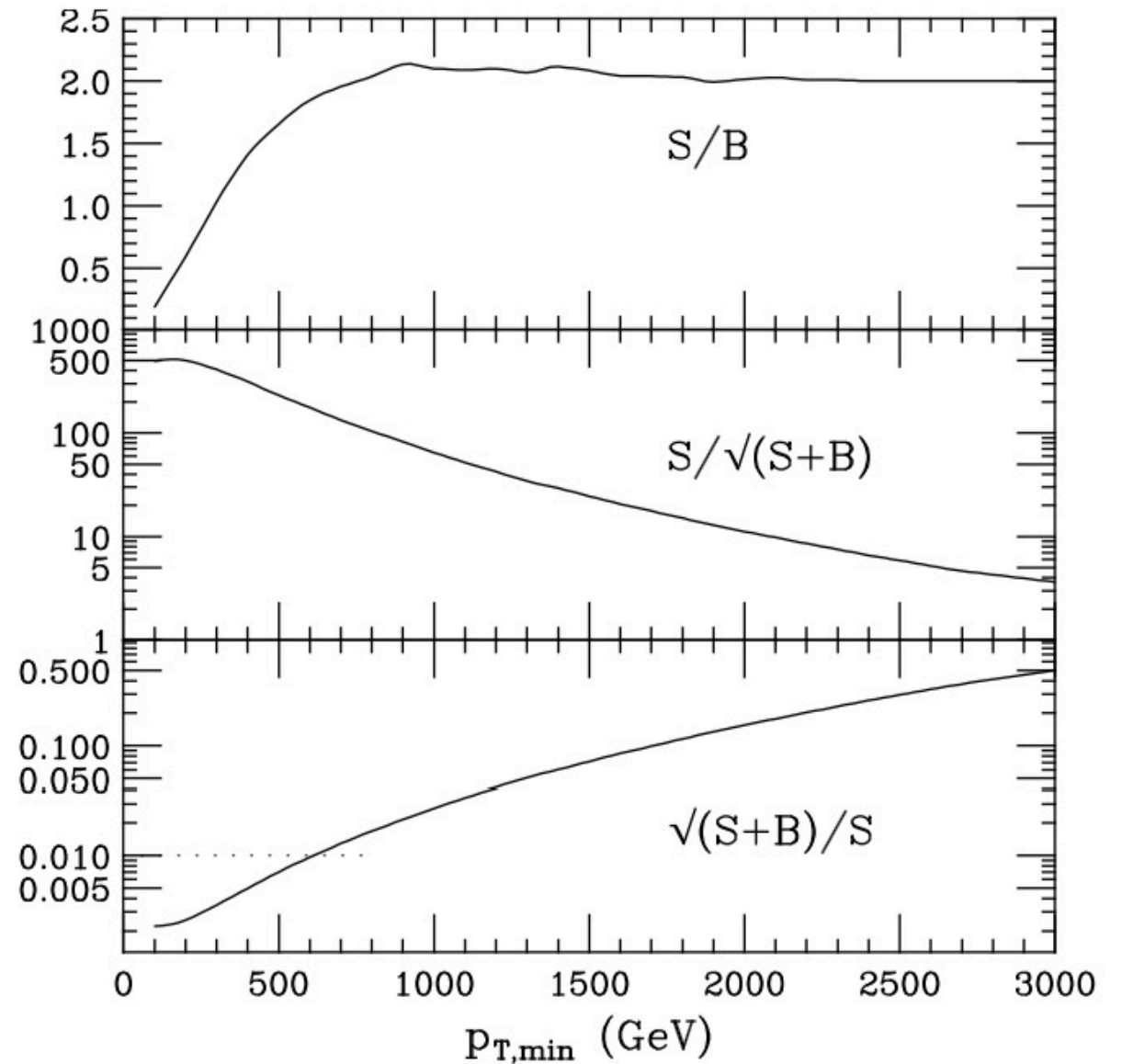
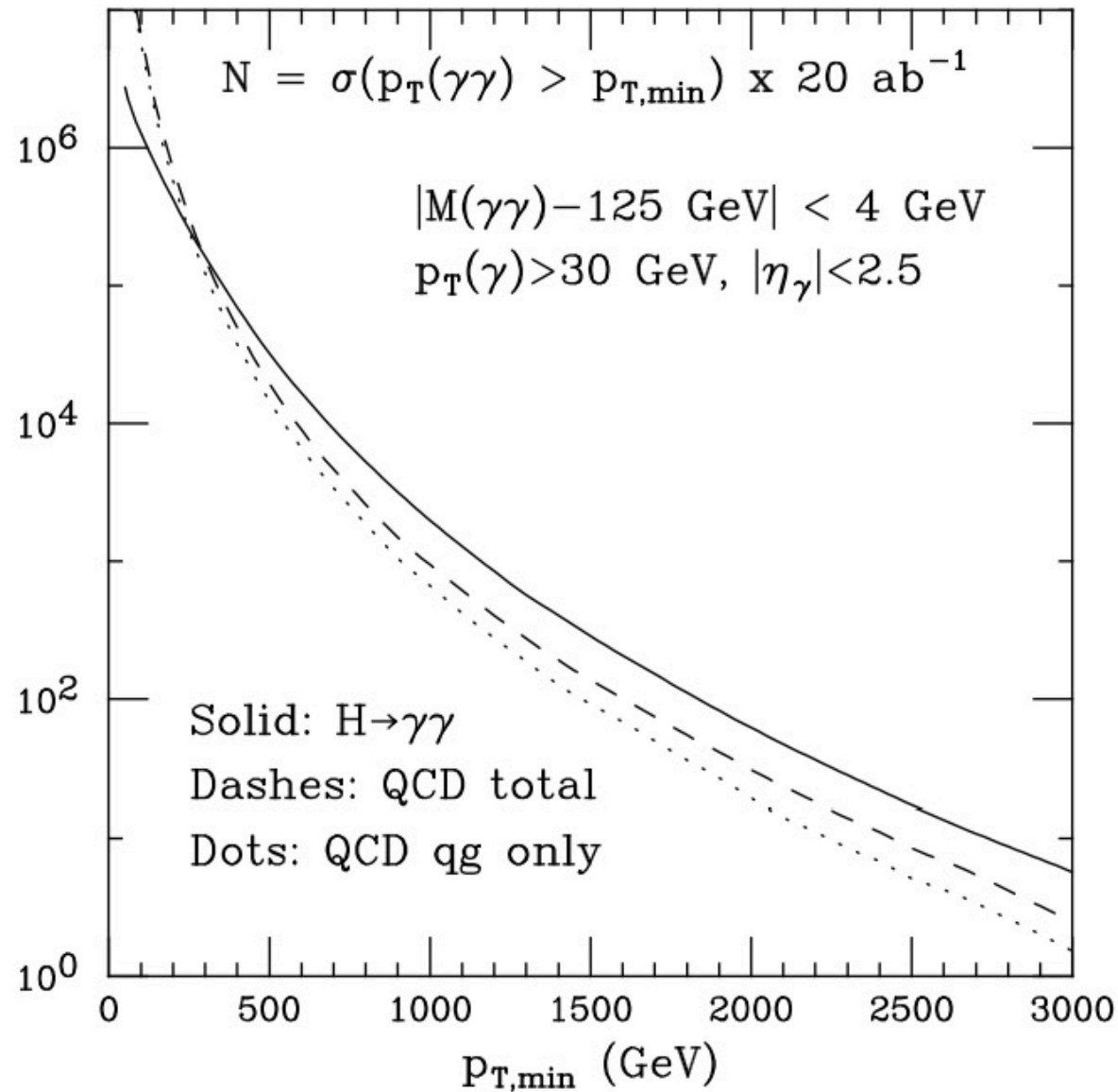


- Hierarchy of production channels changes at large $p_T(H)$:
 - $\sigma(ttH) > \sigma(gg \rightarrow H)$ above 800 GeV
 - $\sigma(VBF) > \sigma(gg \rightarrow H)$ above 1800 GeV

Three kinematic regimes

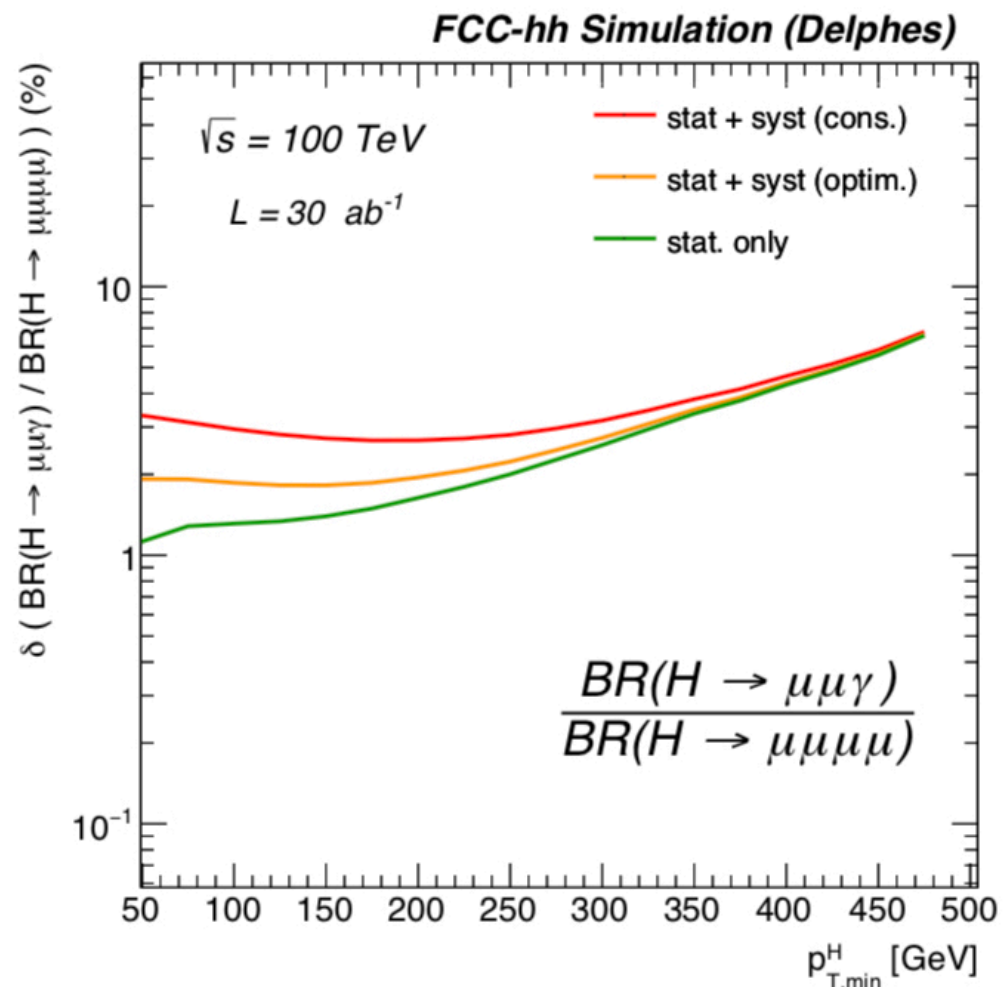
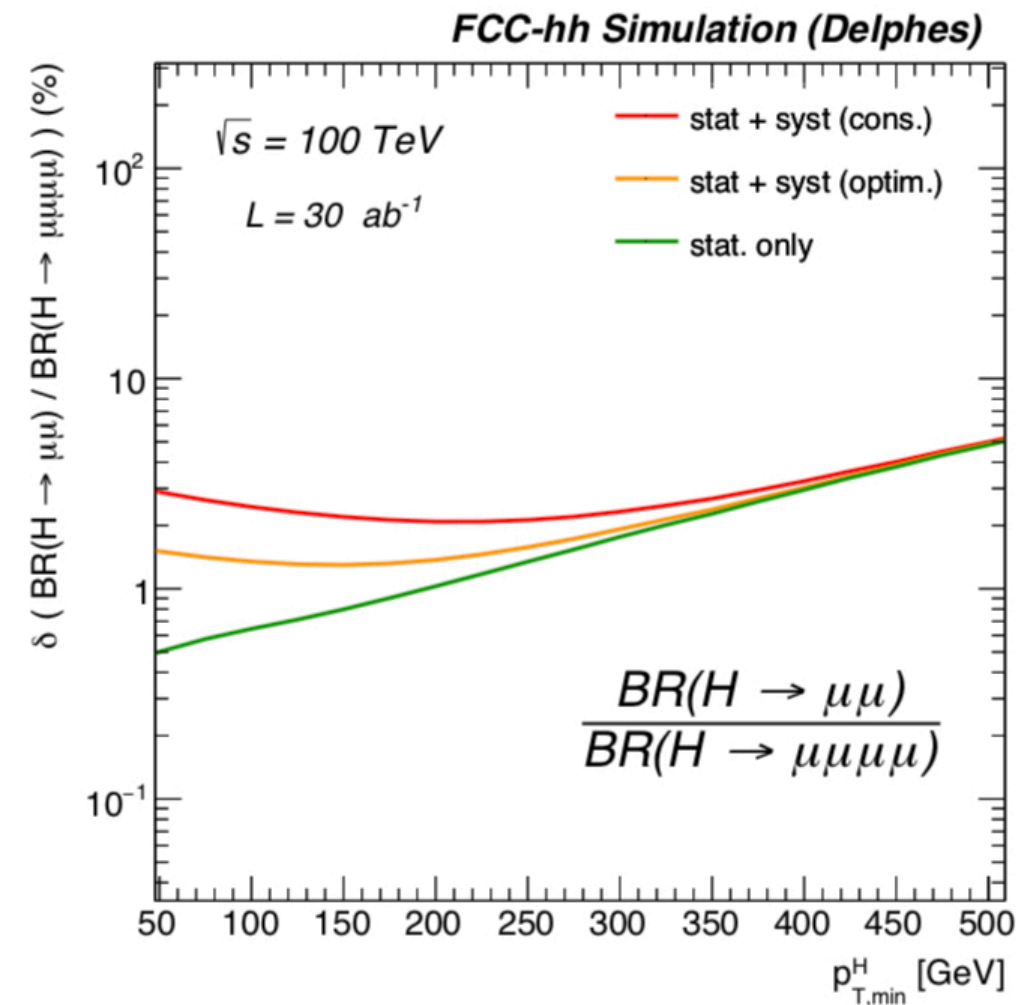
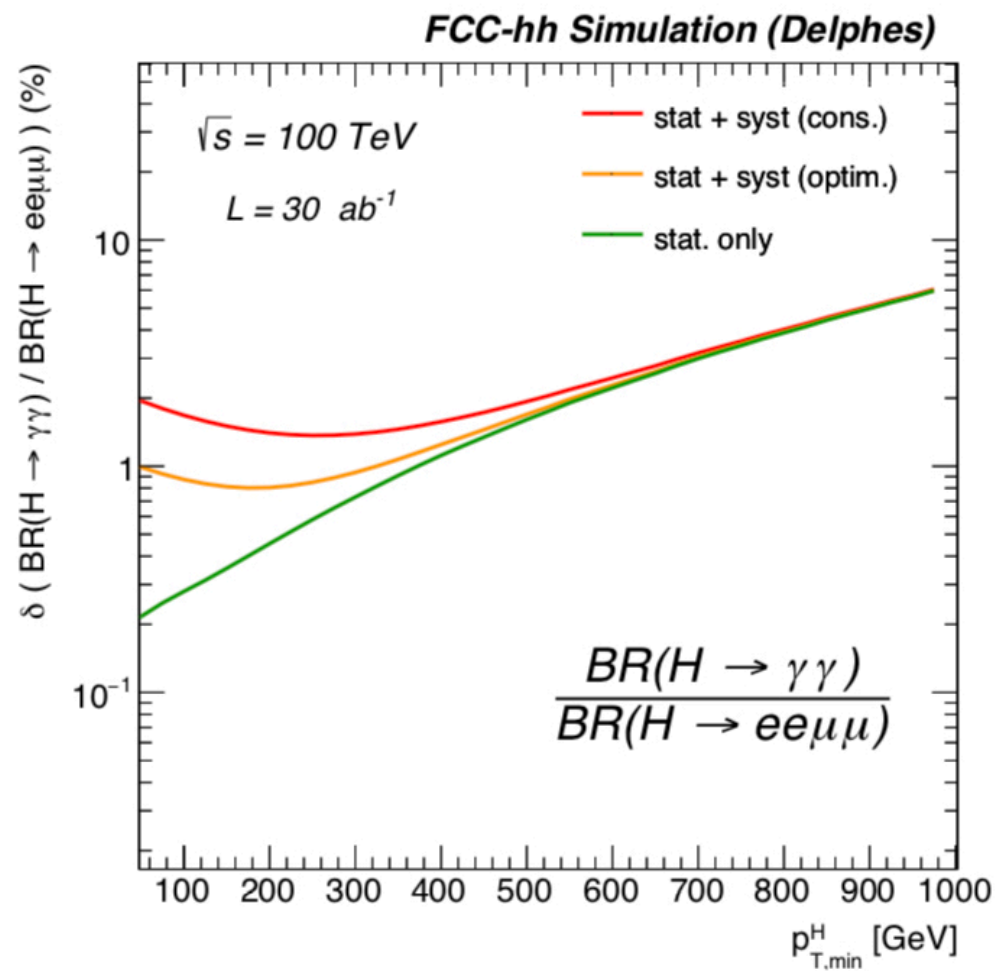
- Inclusive production, $p_T > 0$:
 - largest overall rates
 - most challenging experimentally:
 - triggers, backgrounds, pile-up \Rightarrow low efficiency, large systematics
 - ➡ det simulations challenging, likely unreliable \Rightarrow regime not studied so far
- $p_T \gtrsim 100$ GeV :
 - stat uncertainty $\sim \text{few} \times 10^{-3}$ for $H \rightarrow 4l, \gamma\gamma, \dots$
 - improved S/B, realistic trigger thresholds, reduced pile-up effects ?
 - ➡ current det sim and HL-LHC extrapolations more robust
 - ➡ focus of FCC CDR Higgs studies so far
 - ➡ sweet-spot for precision measurements at the sub-% level
- $p_T \gtrsim \text{TeV}$:
 - stat uncertainty $O(10\%)$ up to 1.5 TeV (3 TeV) for $H \rightarrow 4l, \gamma\gamma$ ($H \rightarrow bb$)
 - new opportunities for reduction of syst uncertainties (TH and EXP)
 - different hierarchy of production processes
 - indirect sensitivity to BSM effects at large Q^2 , complementary to that emerging from precision studies (eg *decay BRs*) at $Q \sim m_H$

$gg \rightarrow H \rightarrow \gamma\gamma$ at large p_T



- At LHC, S/B in the $H \rightarrow \gamma\gamma$ channel is $O(\text{few } \%)$
- At FCC, for $p_T(H) > 300 \text{ GeV}$, $S/B \sim 1$
- Potentially accurate probe of the H p_T spectrum up to large p_t

$p_{T,\min}$ (GeV)	δ_{stat}
100	0.2%
400	0.5%
600	1%
1600	10%



Normalize to BR(4l) from ee => sub-% precision for absolute couplings

Future work: explore in more depth data-based techniques, to validate and then reduce the systematics in these ratio measurements, possibly moving to lower pt's and higher stat

Higgs couplings after FCC-ee / hh

	HL-LHC	FCC-ee	FCC-hh
$\delta\Gamma_H / \Gamma_H$ (%)	SM	1.3	tbd
$\delta g_{HZZ} / g_{HZZ}$ (%)	1.5	0.17	tbd
$\delta g_{HWW} / g_{HWW}$ (%)	1.7	0.43	tbd
$\delta g_{Hbb} / g_{Hbb}$ (%)	3.7	0.61	tbd
$\delta g_{Hcc} / g_{Hcc}$ (%)	~70	1.21	tbd
$\delta g_{Hgg} / g_{Hgg}$ (%)	2.5 (gg->H)	1.01	tbd
$\delta g_{H\tau\tau} / g_{H\tau\tau}$ (%)	1.9	0.74	tbd
$\delta g_{H\mu\mu} / g_{H\mu\mu}$ (%)	4.3	9.0	0.65 (*)
$\delta g_{H\gamma\gamma} / g_{H\gamma\gamma}$ (%)	1.8	3.9	0.4 (*)
$\delta g_{Htt} / g_{Htt}$ (%)	3.4	~10 (indirect)	0.95 (**)
$\delta g_{HZ\gamma} / g_{HZ\gamma}$ (%)	9.8	—	0.9 (*)
$\delta g_{HHH} / g_{HHH}$ (%)	50	~44 (indirect)	5
BR _{exo} (95%CL)	BR _{inv} < 2.5%	< 1%	BR_{inv} < 0.025%

NB

BR(H→Zγ,γγ) ~O(10⁻³) ⇒ O(10⁷) evts for Δ_{stat}~%

BR(H→μμ) ~O(10⁻⁴) ⇒ O(10⁸) evts for Δ_{stat}~%



pp collider is essential to beat the % target, since no proposed ee collider can produce more than O(10⁶) H's

* From BR ratios wrt B(H→ZZ*) @ FCC-ee

** From pp→ttH / pp→ttZ, using B(H→bb) and ttZ EW coupling @ FCC-ee

Further work to do on decay-properties measurements:

- Apply to FCC-hh the various techniques proposed for the measurement of the total H width at the LHC: what is the precision reach?
- Consider decays to other large-BR channels, bb , WW , $\tau\tau$:
 - unlikely to improve FCC-ee measurements, but ...
 - ... can use to extend use of H as a tool (eg to reach larger p_T^H regions)
- Probes of Hcc : $H \rightarrow cc$ in boosted jets, exclusive $H \rightarrow J/\psi \gamma$ decays, ...
- Couplings to lighter quarks (exclusive decays)
- Rare/forbidden decays ($e\mu$, $\mu\tau$, $e\tau$, ..., multibodies, ...)

The Higgs self-coupling at FCC-hh

<https://arxiv.org/abs/2004.03505>

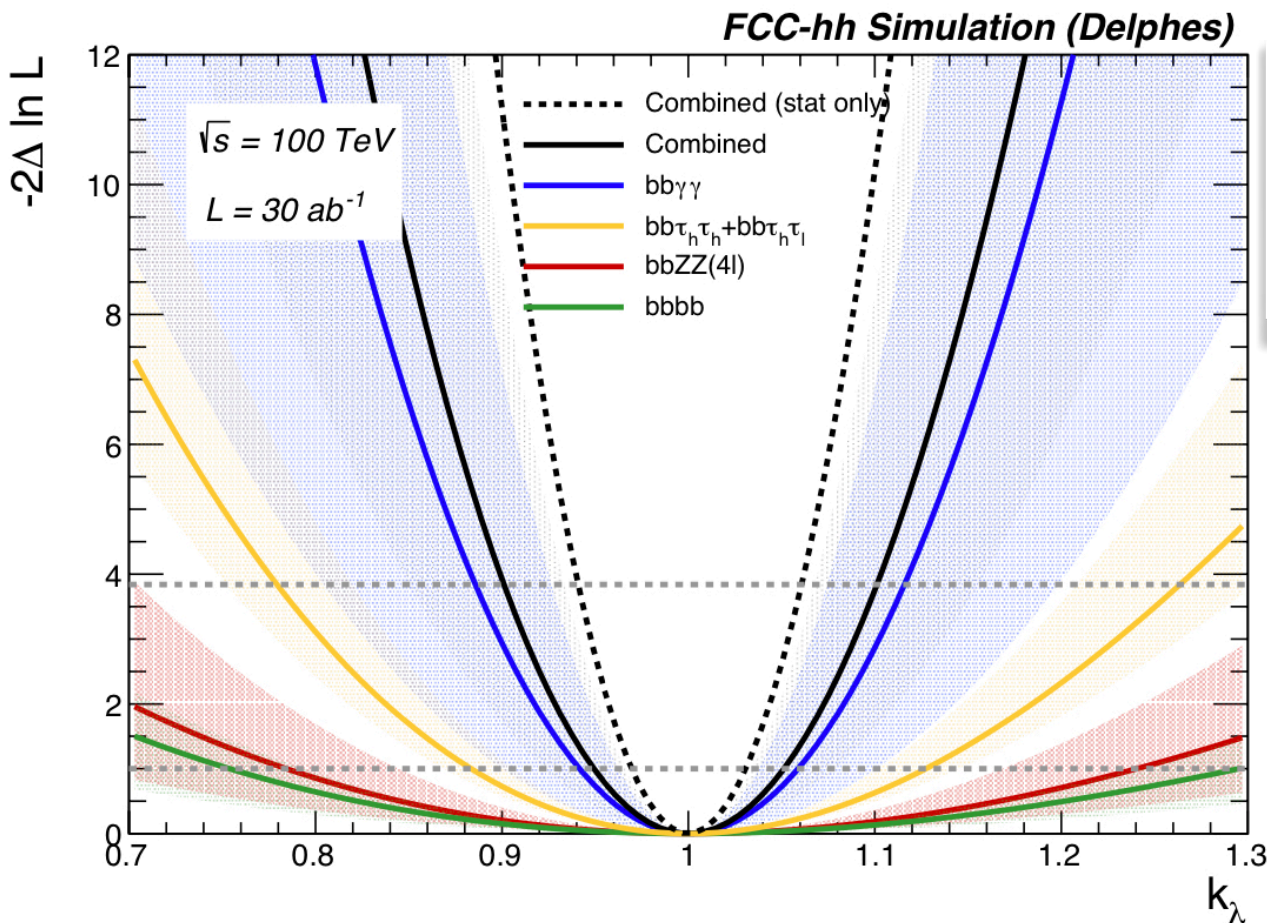
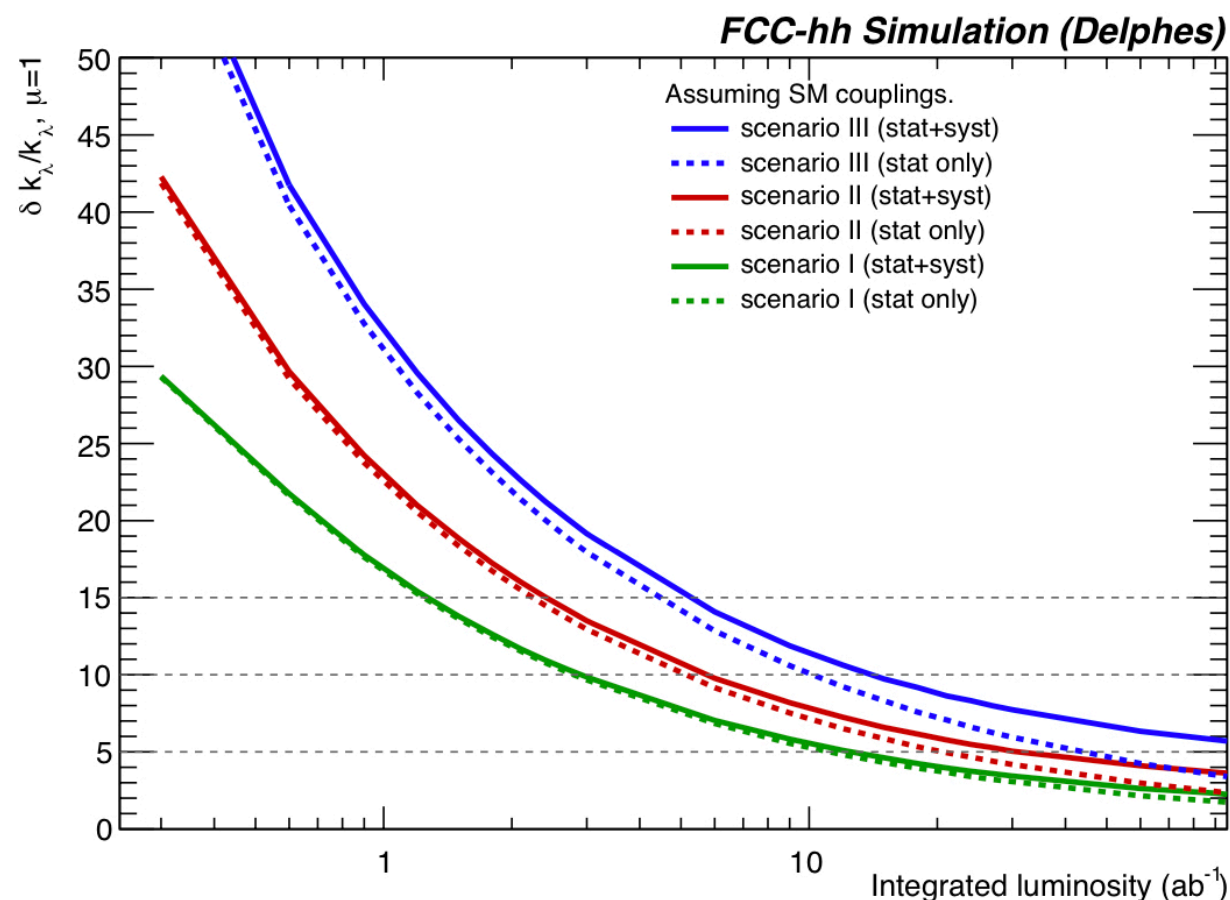


Figure 13. Expected negative log-Likelihood scan as a function of the trilinear self-coupling modifier $\kappa_\lambda = \lambda_3/\lambda_3^{\text{SM}}$ in all channels, and their combination. The solid line corresponds to the scenario II for systematic uncertainties. The band boundaries represent respectively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

Syst scenarios

	@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 $\mathcal{L}_{\text{int}} = 30 \text{ ab}^{-1}$. The symmetrized value $\delta = (\delta^+ + \delta^-)/2$ is given in %.



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

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

=> compatible with the timescale for a similar precision measurement by CLIC @ 3 TeV

- Large literature on Higgs probes of the nature of the EW phase transition, and impact of self-coupling measurement
- **TO DO:** *more systematic studies needed to explore sensitivity to BSM deviations. Eg*
 - *m_{HH} shape fits in presence of multiple EFT ops (see eg <https://arxiv.org/abs/1502.00539>, <https://arxiv.org/abs/1908.08923>)*
 - *global EFT fits including single-H and EW observables*

Higgs as a BSM probe: precision vs dynamic reach

$$L = L_{SM} + \frac{1}{\Lambda^2} \sum_k \mathcal{O}_k + \dots$$

$$O = | \langle f | L | i \rangle |^2 = O_{SM} [1 + O(\mu^2 / \Lambda^2) + \dots]$$

For H decays, or inclusive production, $\mu \sim O(v, m_H)$

$$\delta O \sim \left(\frac{v}{\Lambda} \right)^2 \sim 6\% \left(\frac{\text{TeV}}{\Lambda} \right)^2 \Rightarrow \text{precision probes large } \Lambda$$

$$\text{e.g. } \delta O = 1\% \Rightarrow \Lambda \sim 2.5 \text{ TeV}$$

For H production off-shell or with large momentum transfer Q, $\mu \sim O(Q)$

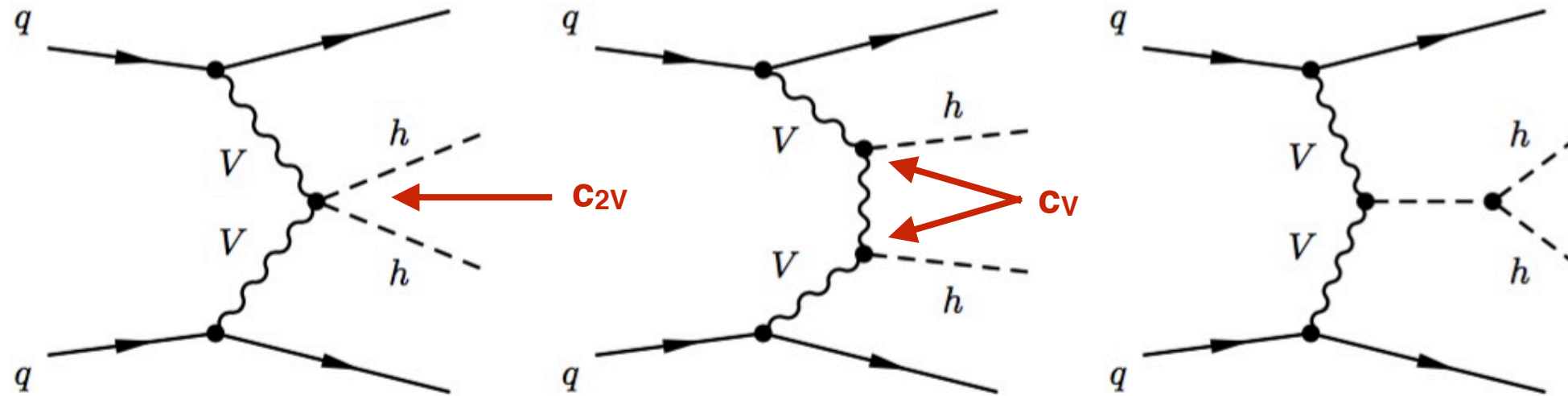
$$\delta O \sim \left(\frac{Q}{\Lambda} \right)^2 \Rightarrow \text{kinematic reach probes}$$

large Λ even if precision is low

$$\text{e.g. } \delta O = 15\% \text{ at } Q = 1 \text{ TeV} \Rightarrow \Lambda \sim 2.5 \text{ TeV}$$

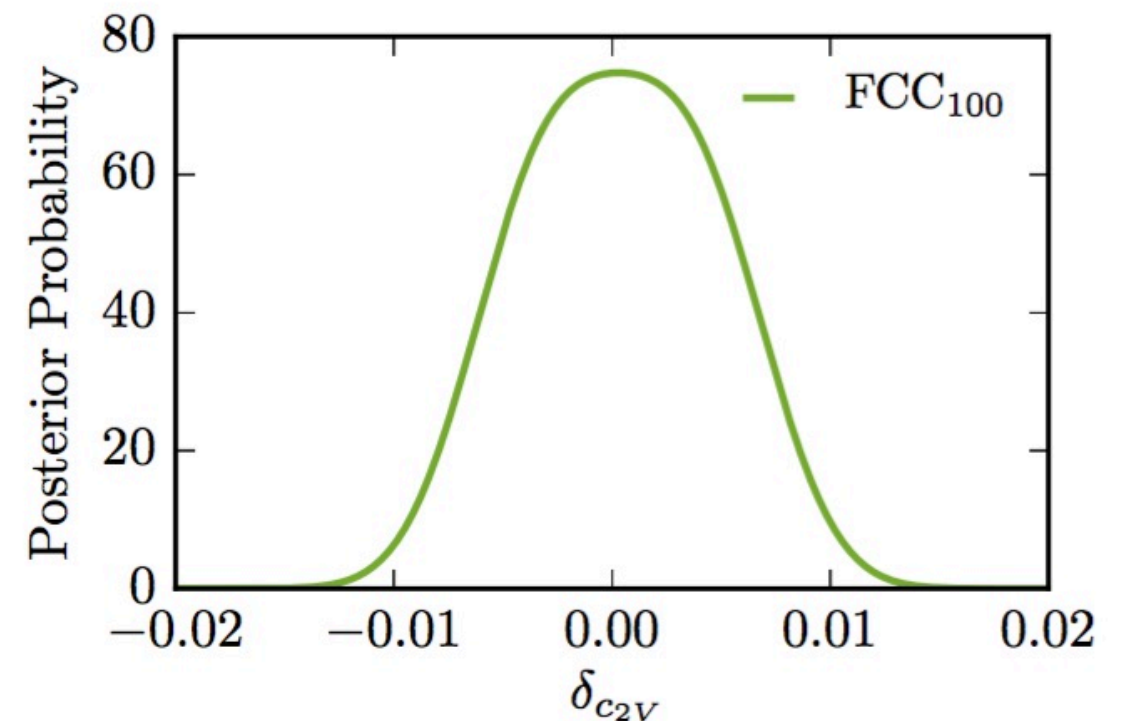
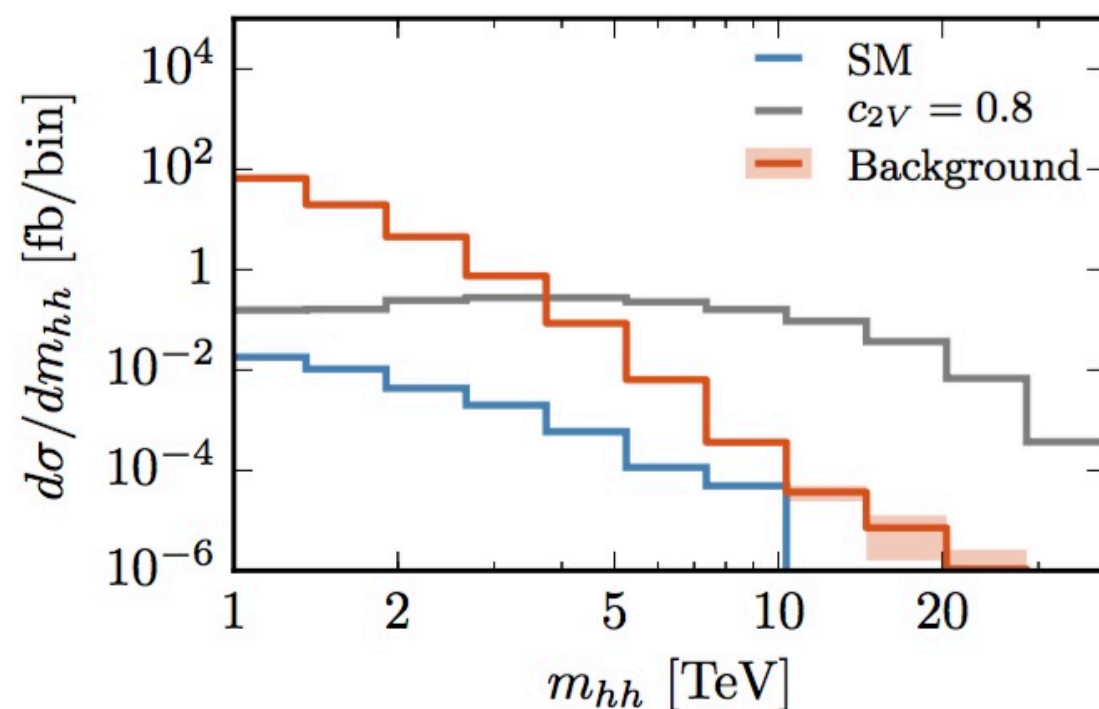
Precision and extensive kinematic reach provide unique complementarity and redundancy, crucial to interpret possible SM deviations manifest in either of these observables

Example: high mass $VV \rightarrow HH$

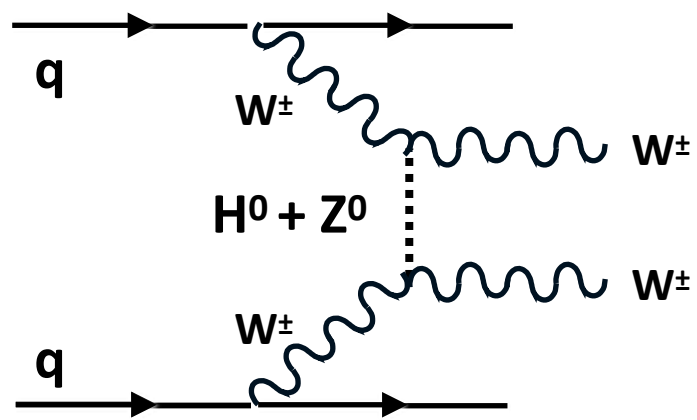


$$A(V_L V_L \rightarrow HH) \sim \frac{\hat{s}}{v^2} (c_{2V} - c_V^2) \cdot \text{where} \quad \begin{cases} c_V = g_{HVV}/g_{HVV}^{SM} \\ c_{2V} = g_{HHVV}/g_{HHVV}^{SM} \end{cases} \Rightarrow (c_{2V} - c_V^2)_{SM} = 0$$

$c_{2V} \neq c_V^2$ probes custodial symmetry breaking, extended Higgs sectors, ...



$W_L W_L$ scattering



large m_{WW}

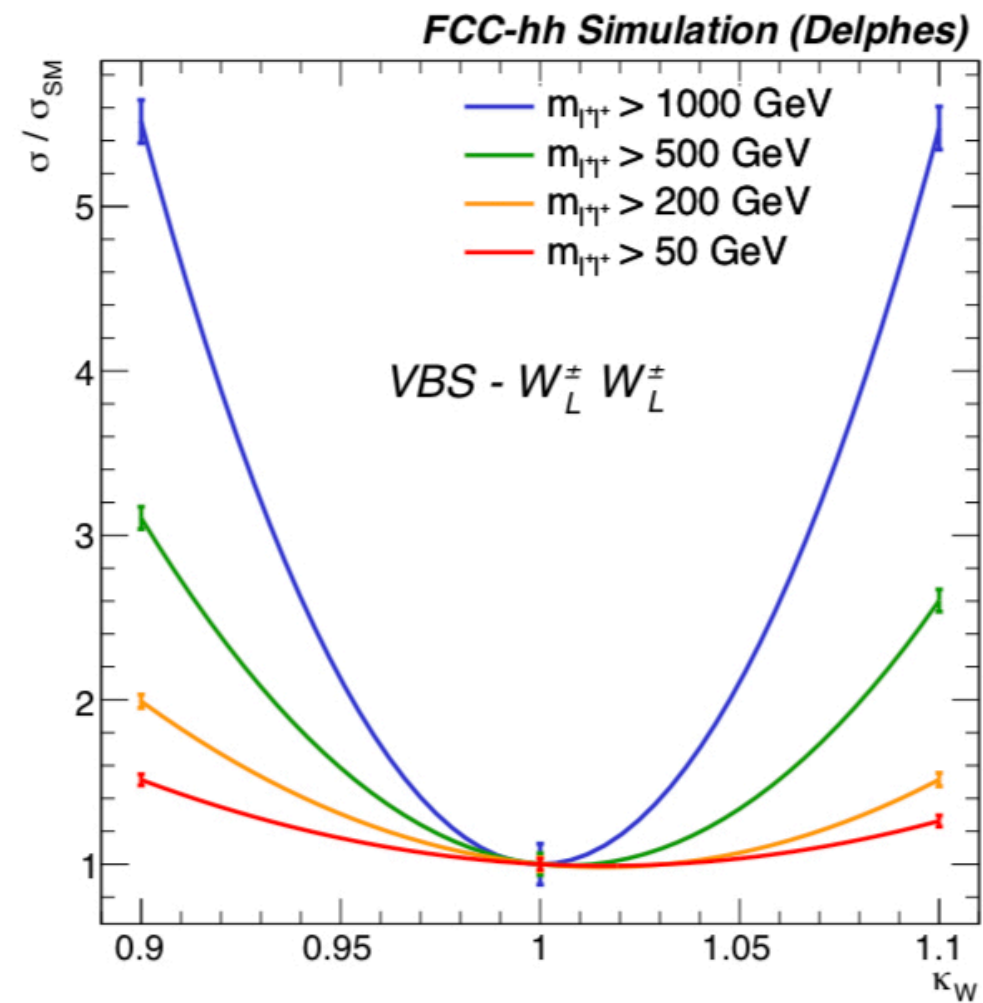
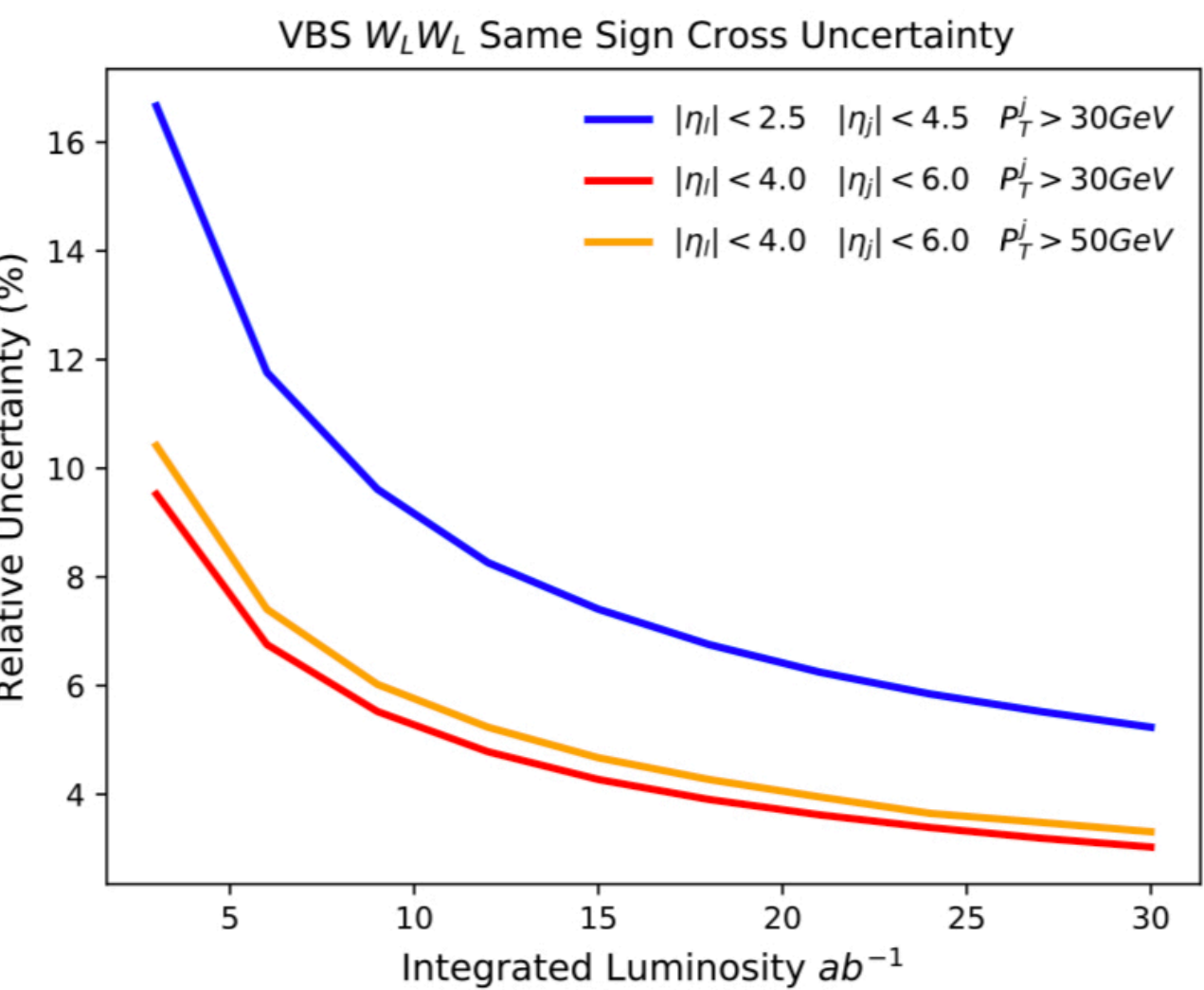


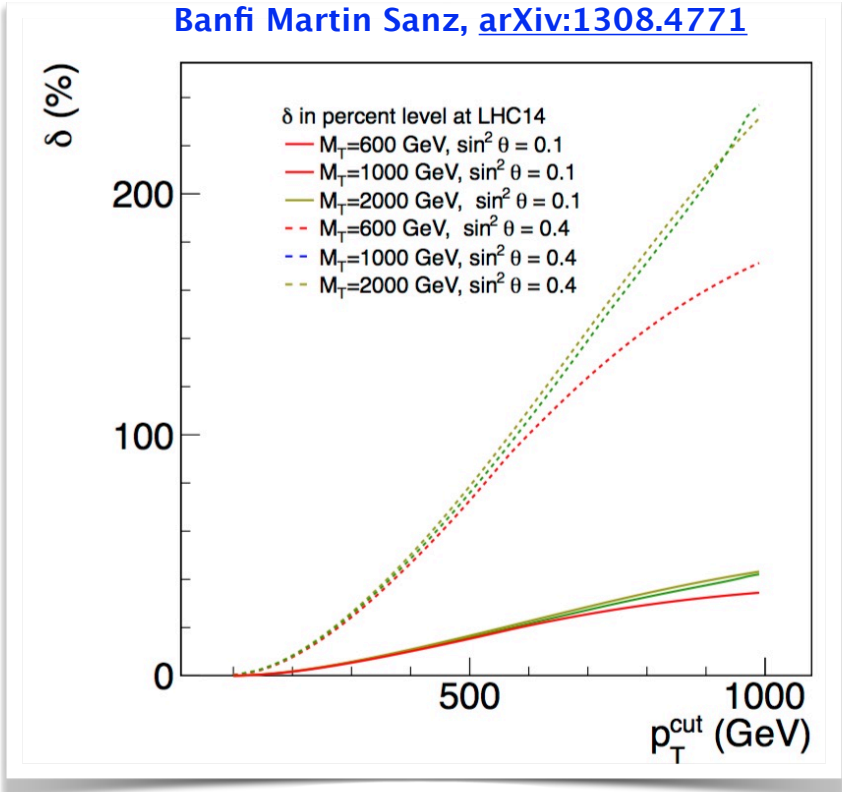
Table 4.5: Constraints on the HWW coupling modifier κ_W at 68% CL, obtained for various cuts on the di-lepton pair invariant mass in the $W_L W_L \rightarrow HH$ process.

$m_{l^+l^+}$ cut	> 50 GeV	> 200 GeV	> 500 GeV	> 1000 GeV
$\kappa_W \in$	[0.98,1.05]	[0.99,1.04]	[0.99,1.03]	[0.98,1.02]

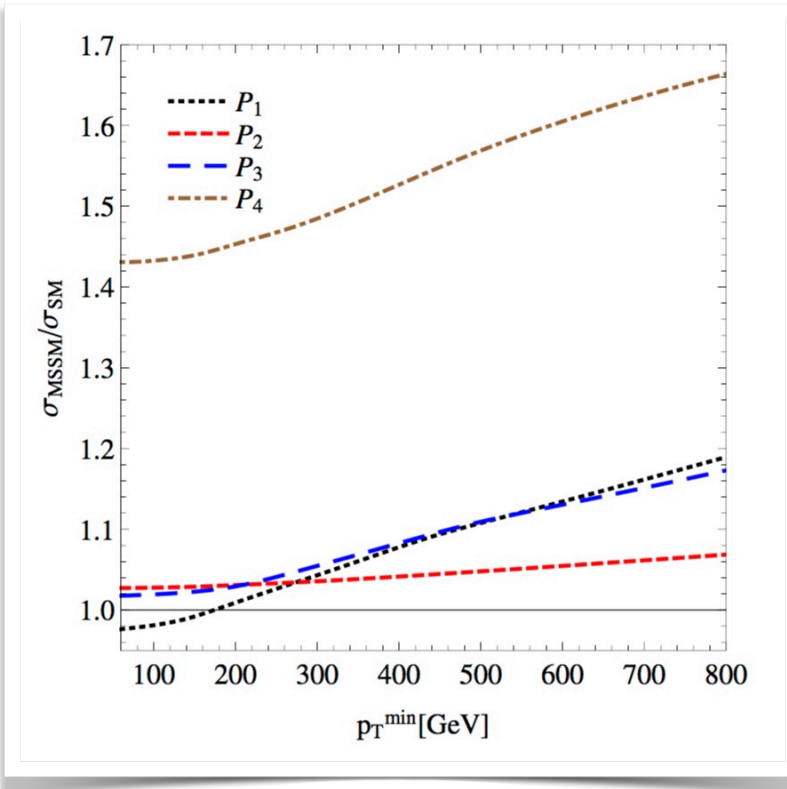
$$\kappa_W = \frac{g_{HWW}}{g_{HWW}^{SM}}$$

to do's => Re-iterate at 100 TeV the many studies done for LHC about BSM constraints from high-pT Higgs production. Eg

gg→Hg



top partners T in the loop

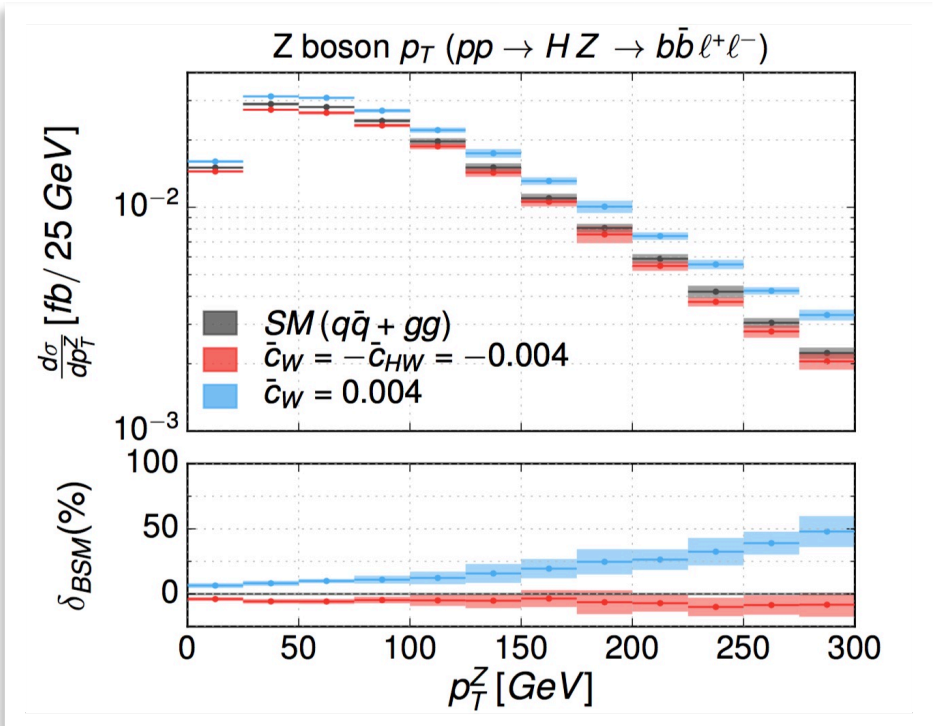
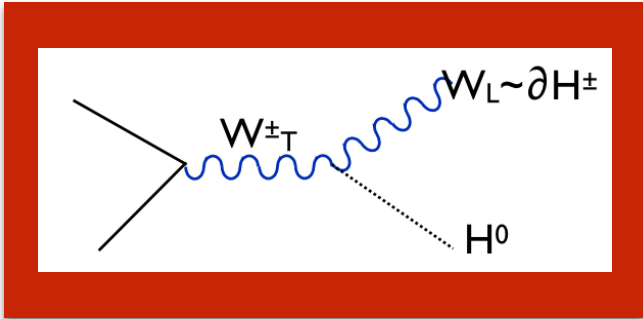


Point	$m_{\tilde{t}_1}$ [GeV]	$m_{\tilde{t}_2}$ [GeV]	A_t [GeV]	Δ_t
P_1	171	440	490	0.0026
P_2	192	1224	1220	0.013
P_3	226	484	532	0.015
P_4	226	484	0	0.18

top squarks in the loop

Grojean, Salvioni, Schlaffer, Weiler
[arXiv:1312.3317](https://arxiv.org/abs/1312.3317)

(See also
 Azatov and Paul [arXiv:1309.5273v3](https://arxiv.org/abs/1309.5273v3))



Mimasu, Sanz, Williams,
[arXiv:1512.02572v](https://arxiv.org/abs/1512.02572v)

See also
 Biekötter, Knochel, Krämer, Liu, Riva,
[arXiv:1406.7320](https://arxiv.org/abs/1406.7320)

more to do's

Quantify complementarity and synergy among

- precision measurements from FCC-ee (H and EW properties)
- Higgs/EW measurements at high- Q^2 at 100 TeV
- HH production
- direct BSM searches

In particular, consider concrete BSM scenarios, play the “inverse problem” game using all available inputs, etc...

(I) guaranteed deliverables: EW observables

The absolutely unique power of **circular** e^+e^- :

$e^+e^- \rightarrow Z$	$e^+e^- \rightarrow WW$	$\tau(\leftarrow Z)$	$b(\leftarrow Z)$	$c(\leftarrow Z)$
$5 \cdot 10^{12}$	10^8	$3 \cdot 10^{11}$	$1.5 \cdot 10^{12}$	10^{12}

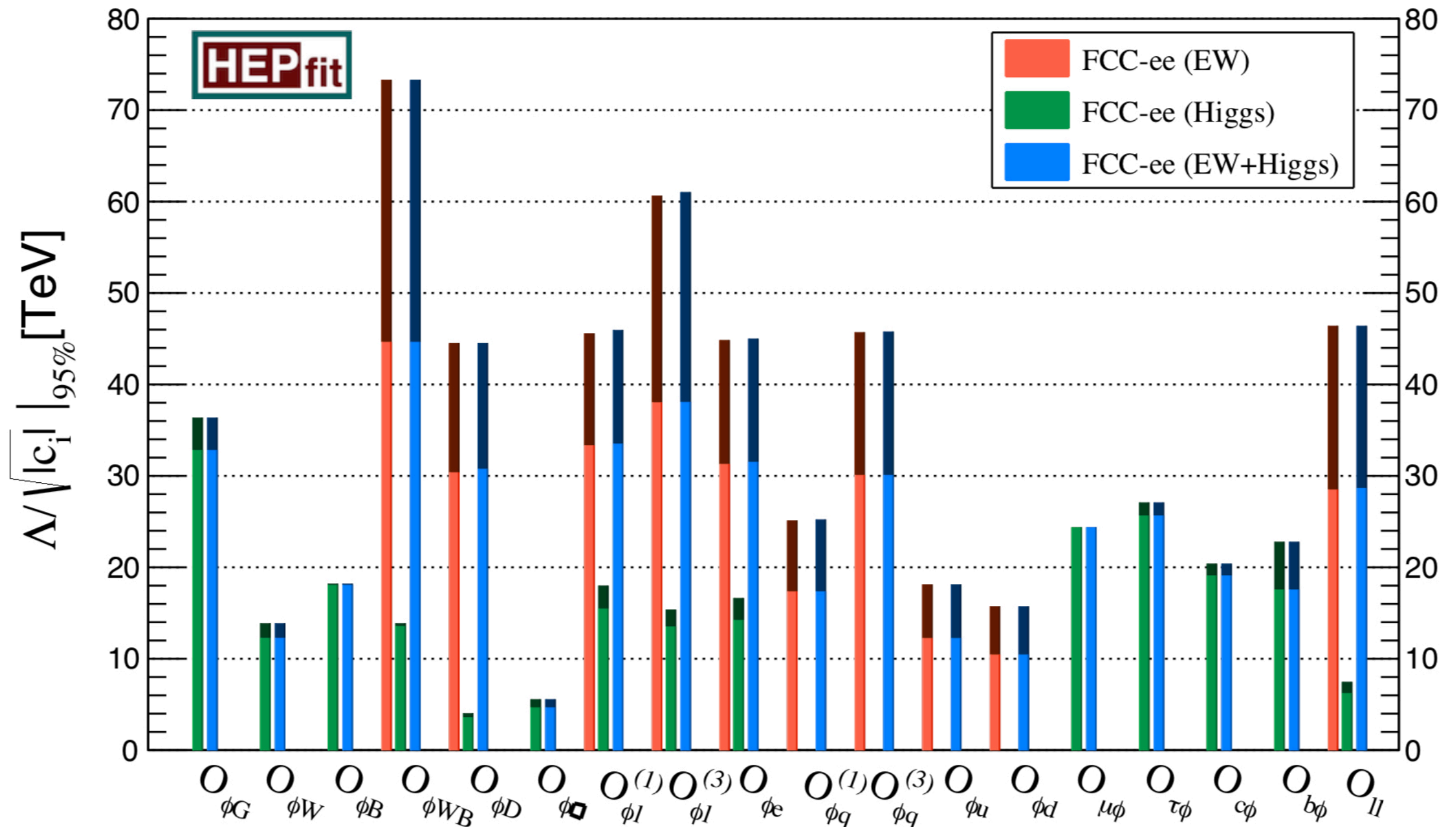
=> $O(10^5)$ larger statistics than LEP at the Z peak and WW threshold

=> see Gregorio's talk

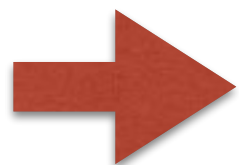
(2) Direct discovery reach at high mass: the power of 100 TeV

for the direct discovery reach at FCC-ee (eg light dark sectors, ...) see Abhishek's talk

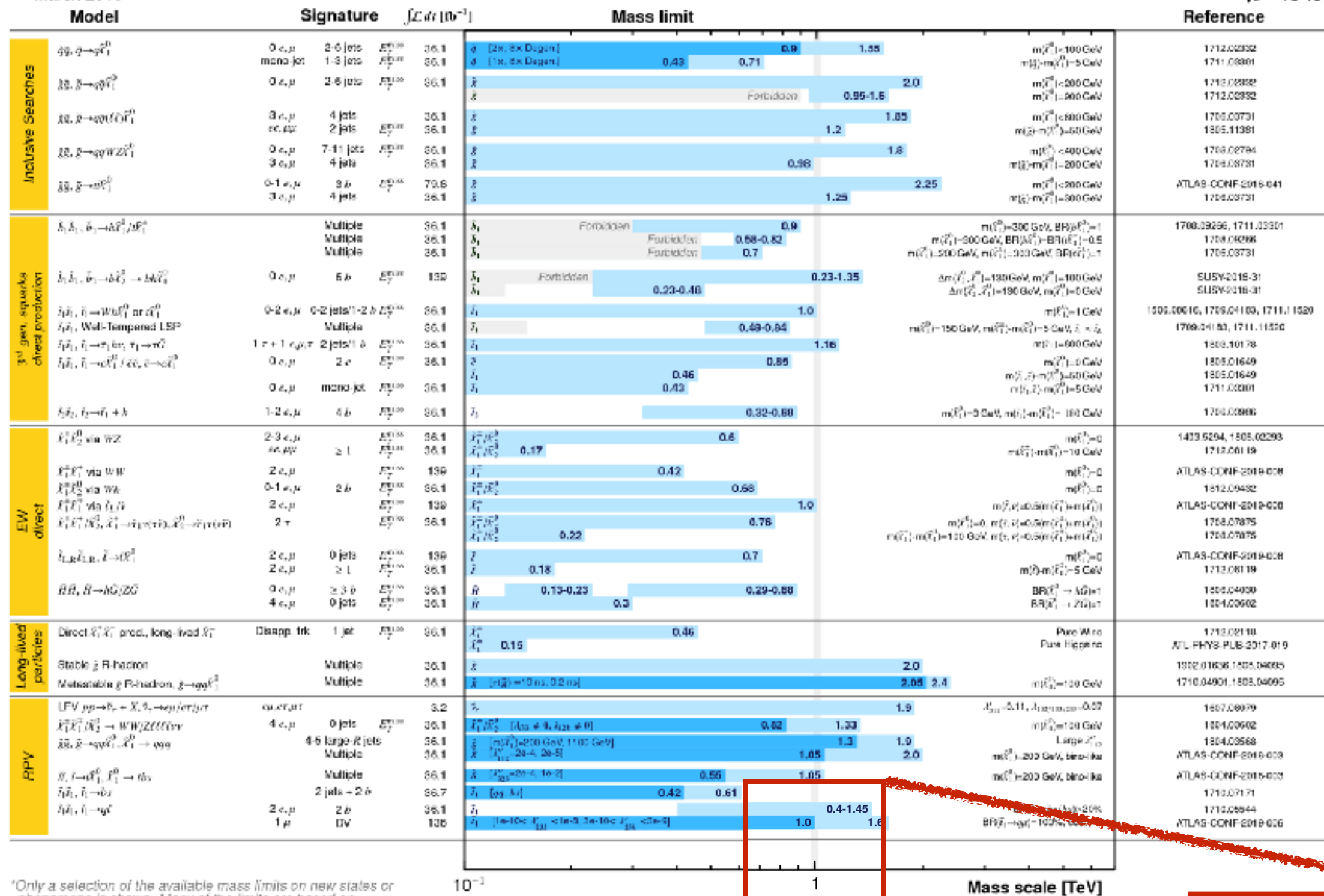
Global EFT fits to EW and H observables at FCC-ee



Constraints on the coefficients of various EFT op's from a global fit of (i) EW observables, (ii) Higgs couplings and (iii) EW+Higgs combined. Darker shades of each color indicate the results neglecting all SM theory uncertainties.



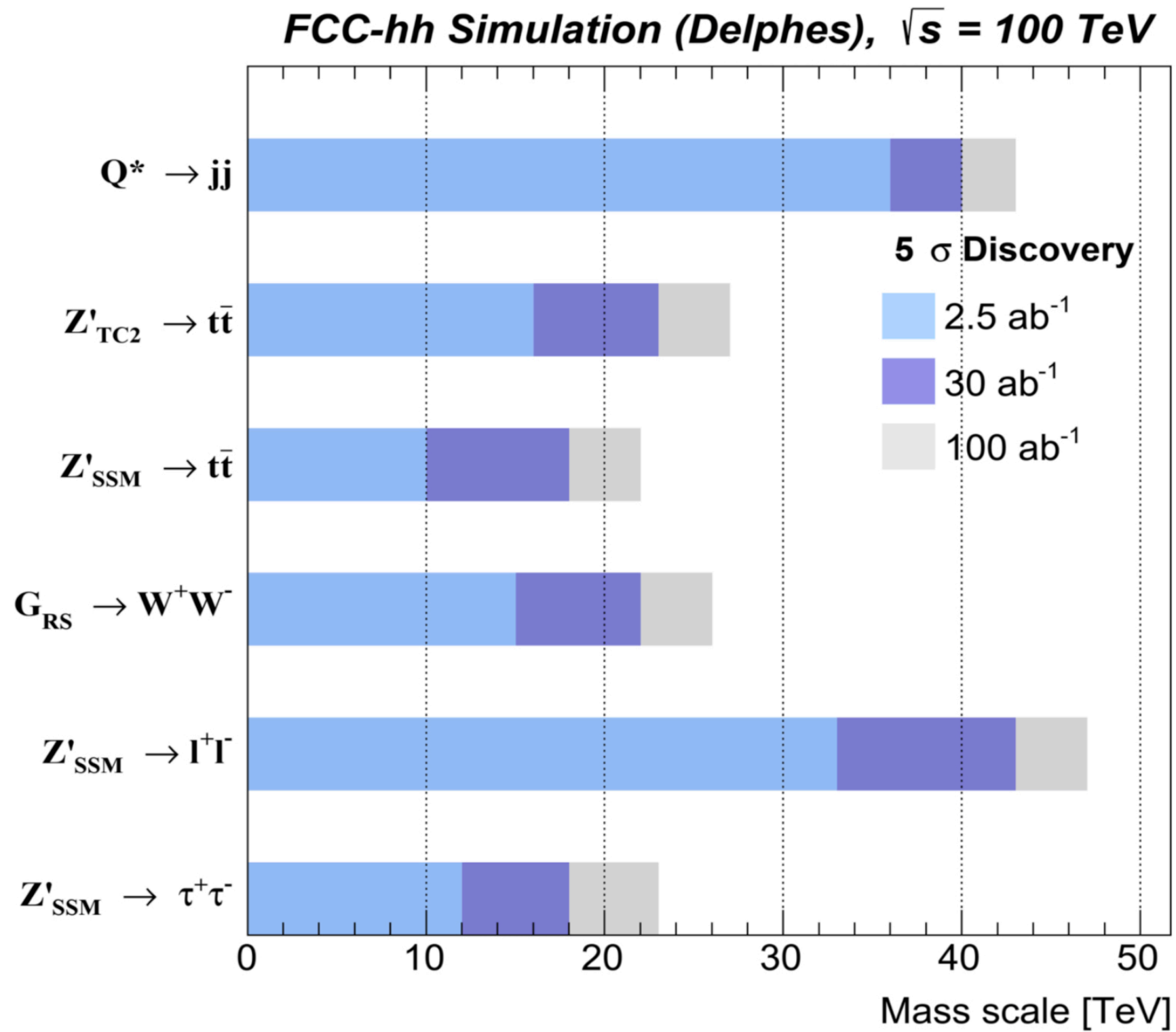
100 TeV is the appropriate CoM energy to directly search for new physics appearing indirectly through precision EW and H measurements at the future ee collider



Good rule of thumb to estimate FCC discovery reach at high mass: scale up by ~6x the LHC potential...

Explicitly verified in many examples, which helped setting detector performance targets

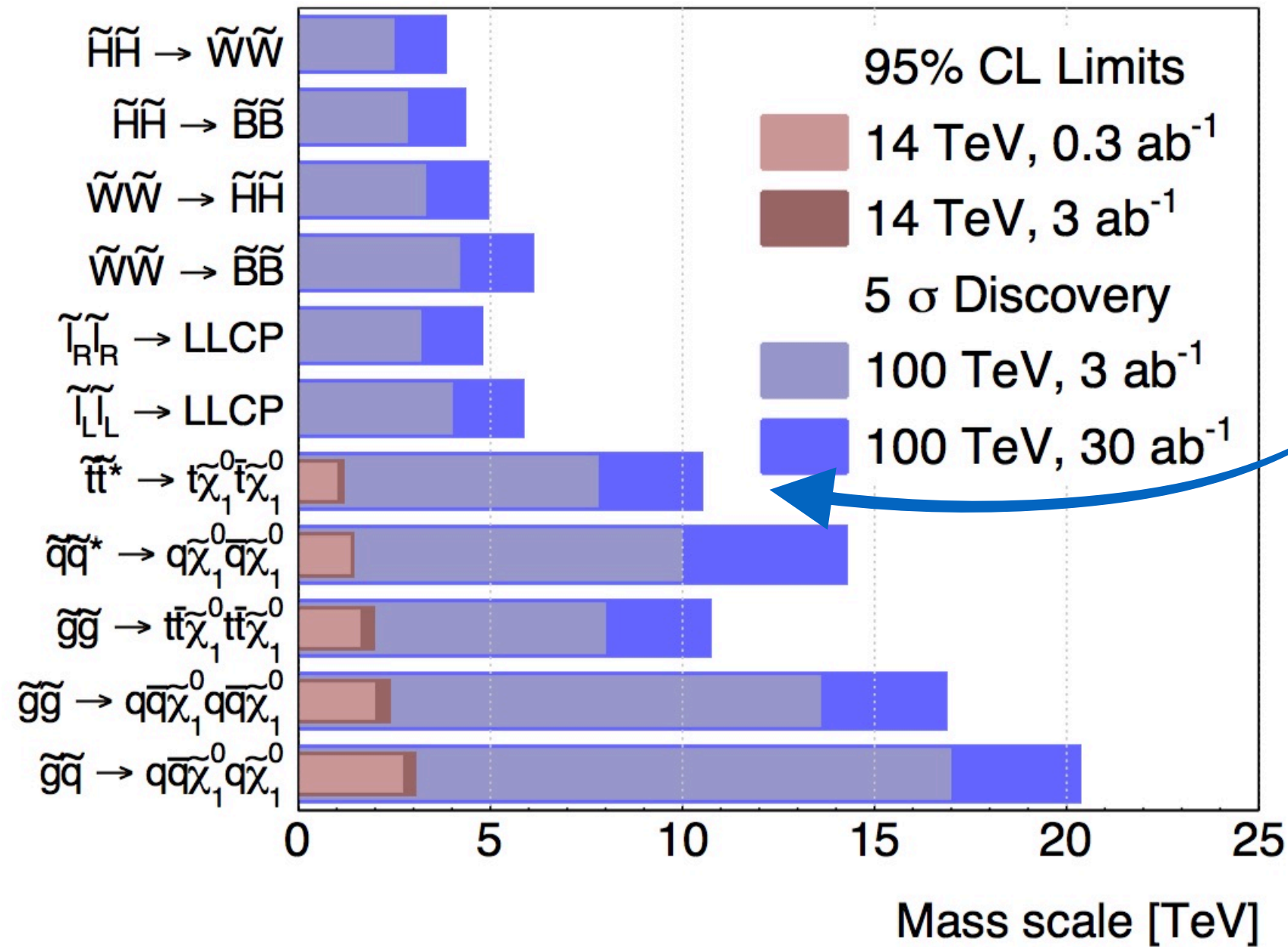
s-channel resonances



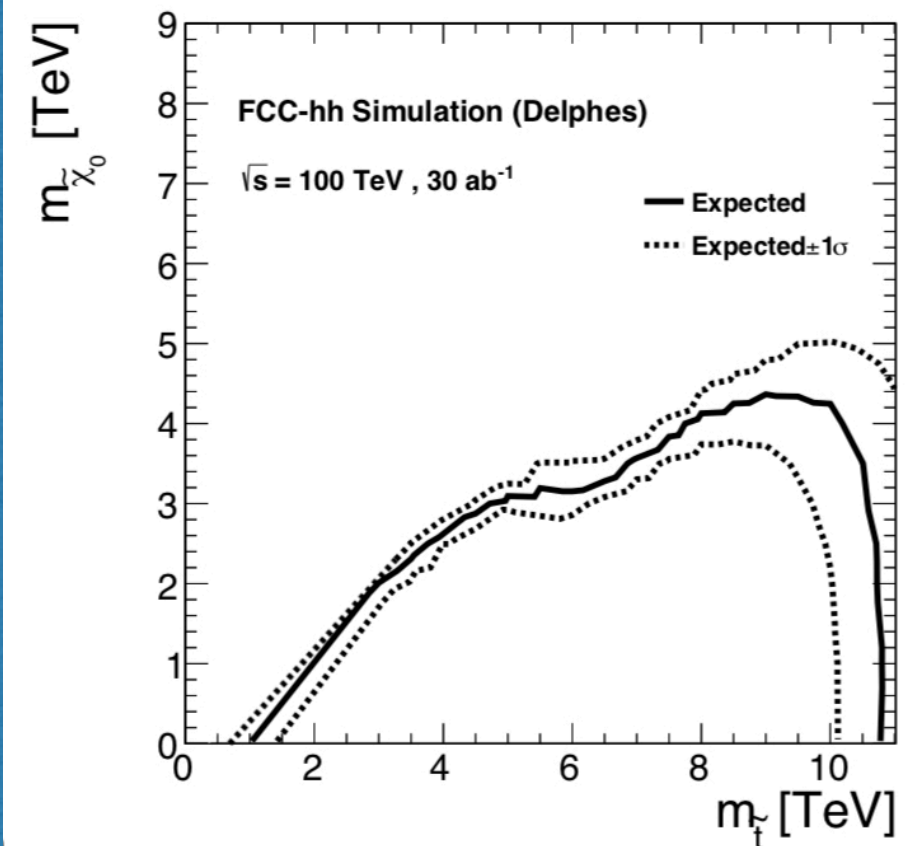
FCC-hh reach ~ 6 x HL-LHC reach

SUSY reach at 100 TeV

Early phenomenology studies



New detector performance studies



(3) The potential for yes/no answers to important questions

WIMP DM theoretical constraints

For particles held in equilibrium by pair creation and annihilation processes, ($\chi \chi \leftrightarrow \text{SM}$)

$$\Omega_{\text{DM}} h^2 \sim \frac{10^9 \text{GeV}^{-1}}{M_{\text{pl}}} \frac{1}{\langle \sigma v \rangle}$$

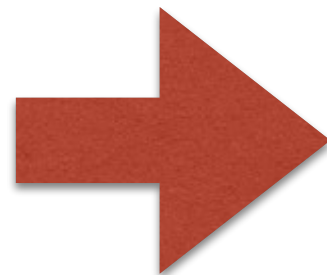
For a particle annihilating through processes which do not involve any larger mass scales:

$$\langle \sigma v \rangle \sim g_{\text{eff}}^4 / M_{\text{DM}}^2$$



$$\Omega_{\text{DM}} h^2 \sim 0.12 \times \left(\frac{M_{\text{DM}}}{2 \text{ TeV}} \right)^2 \left(\frac{0.3}{g_{\text{eff}}} \right)^4$$

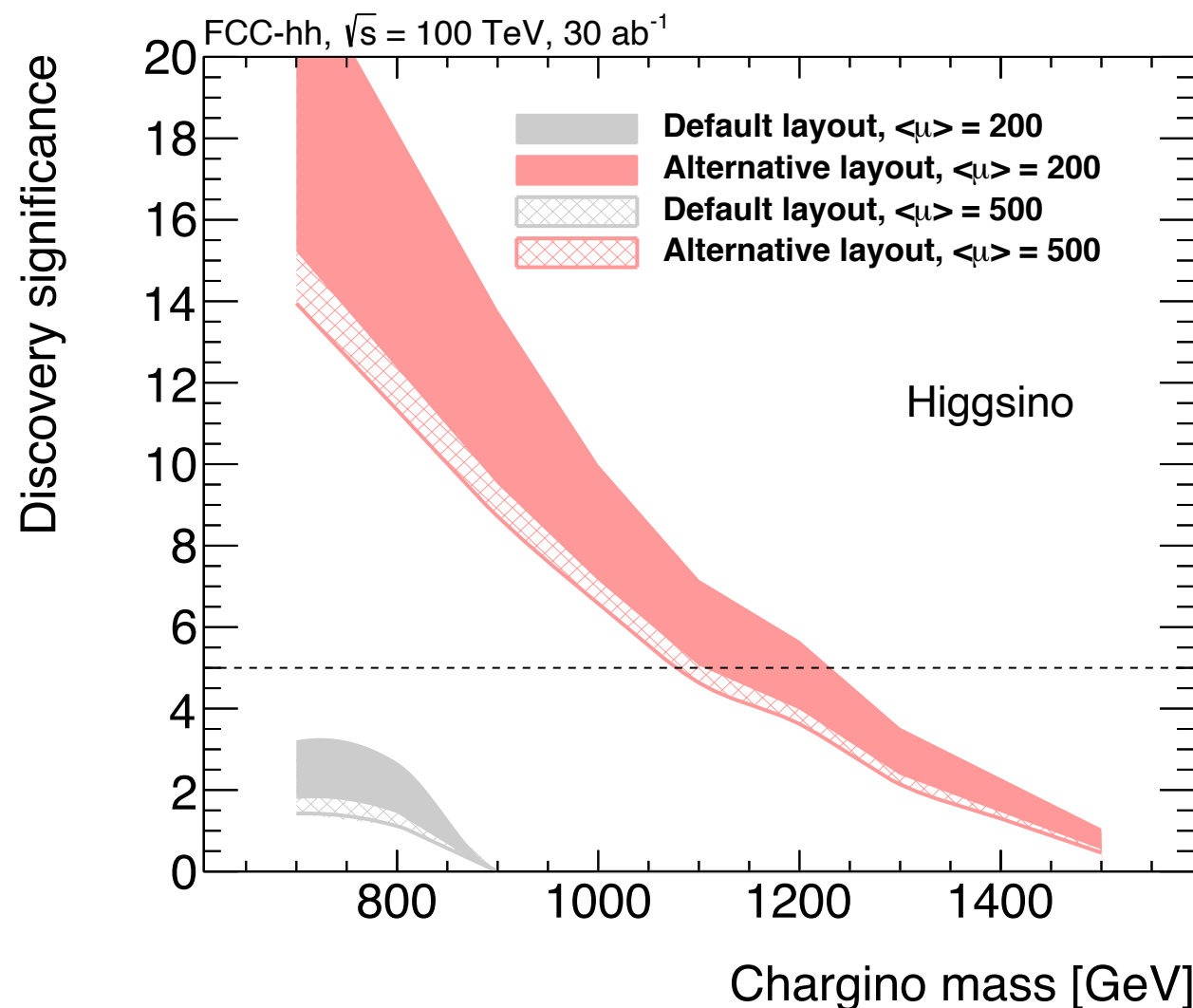
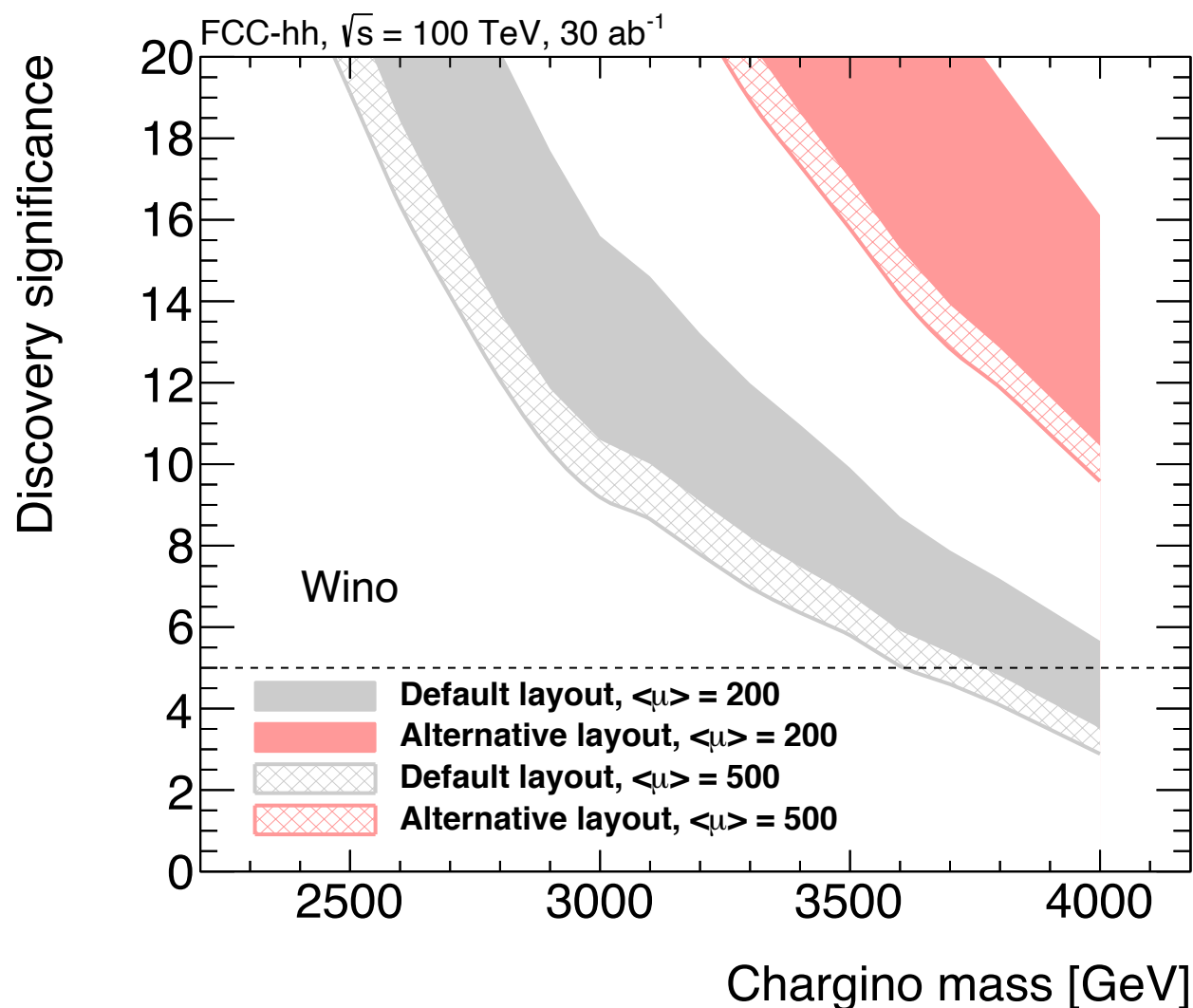
$$\Omega_{\text{wimp}} h^2 \lesssim 0.12$$



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

DM WIMP searches in the most elusive, compressed scenarios:

Disappearing charged track analyses (at ~full pileup)



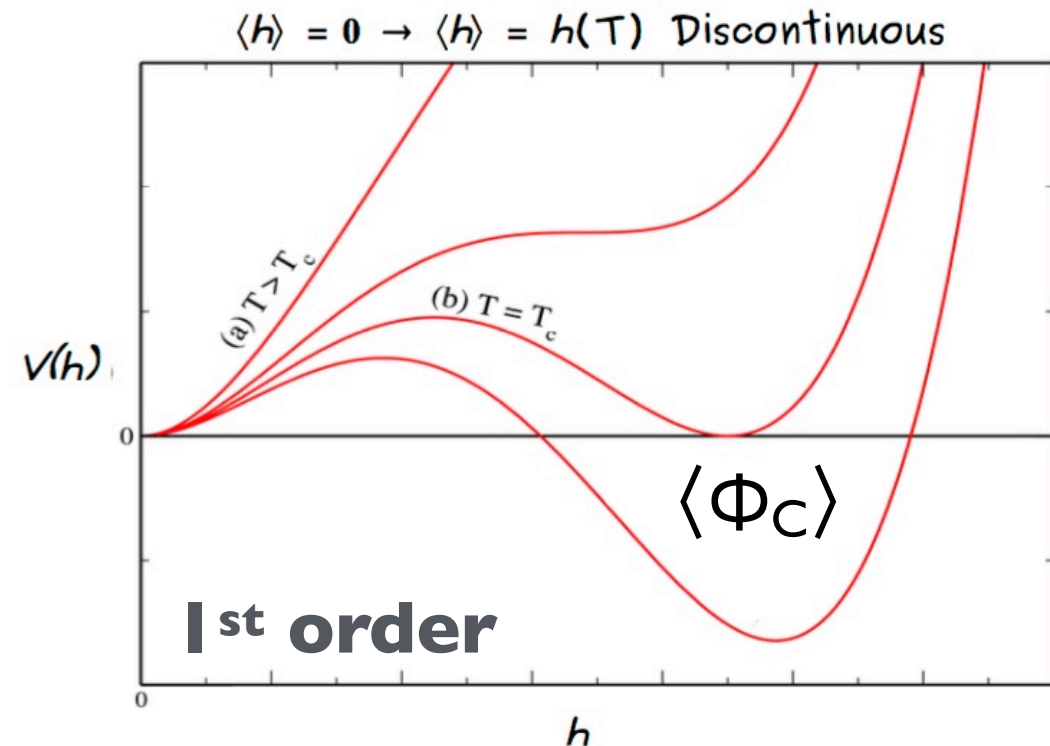
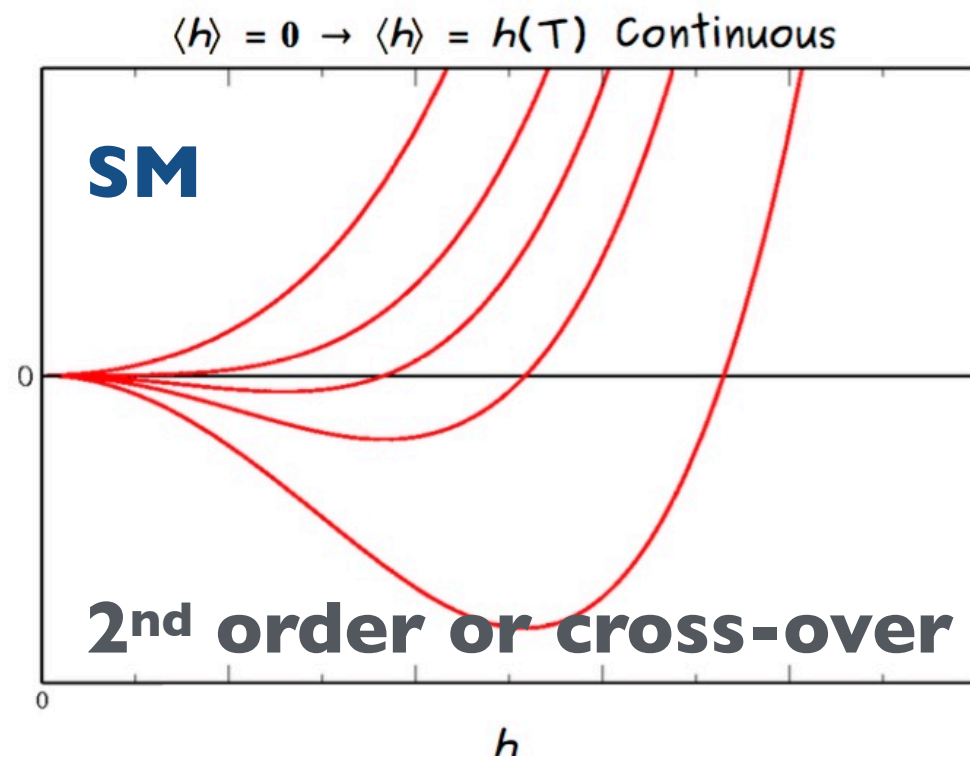
=> coverage beyond the upper limit of the thermal WIMP mass range for both higgsinos and winos !!

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

To do:

- Study more systematically the prospects to discover challenging stealthy final states, leaving no gaps in the parameter space of interesting models
- Consider opportunities for detectors dedicated and optimized to difficult BSM final states (eg Long Lived Particles)

The nature of the EW phase transition

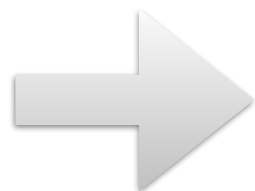


Strong 1st order phase transition is required to induce and sustain the out of equilibrium generation of a baryon asymmetry during EW symmetry breaking

Strong 1st order phase transition $\Rightarrow \langle \Phi_c \rangle > T_c$

In the SM this requires $m_H \lesssim 80$ GeV, else transition is a smooth crossover.

Since $m_H = 125$ GeV, **new physics**, coupling to the Higgs and effective at **scales $O(\text{TeV})$** , must modify the Higgs potential to make this possible

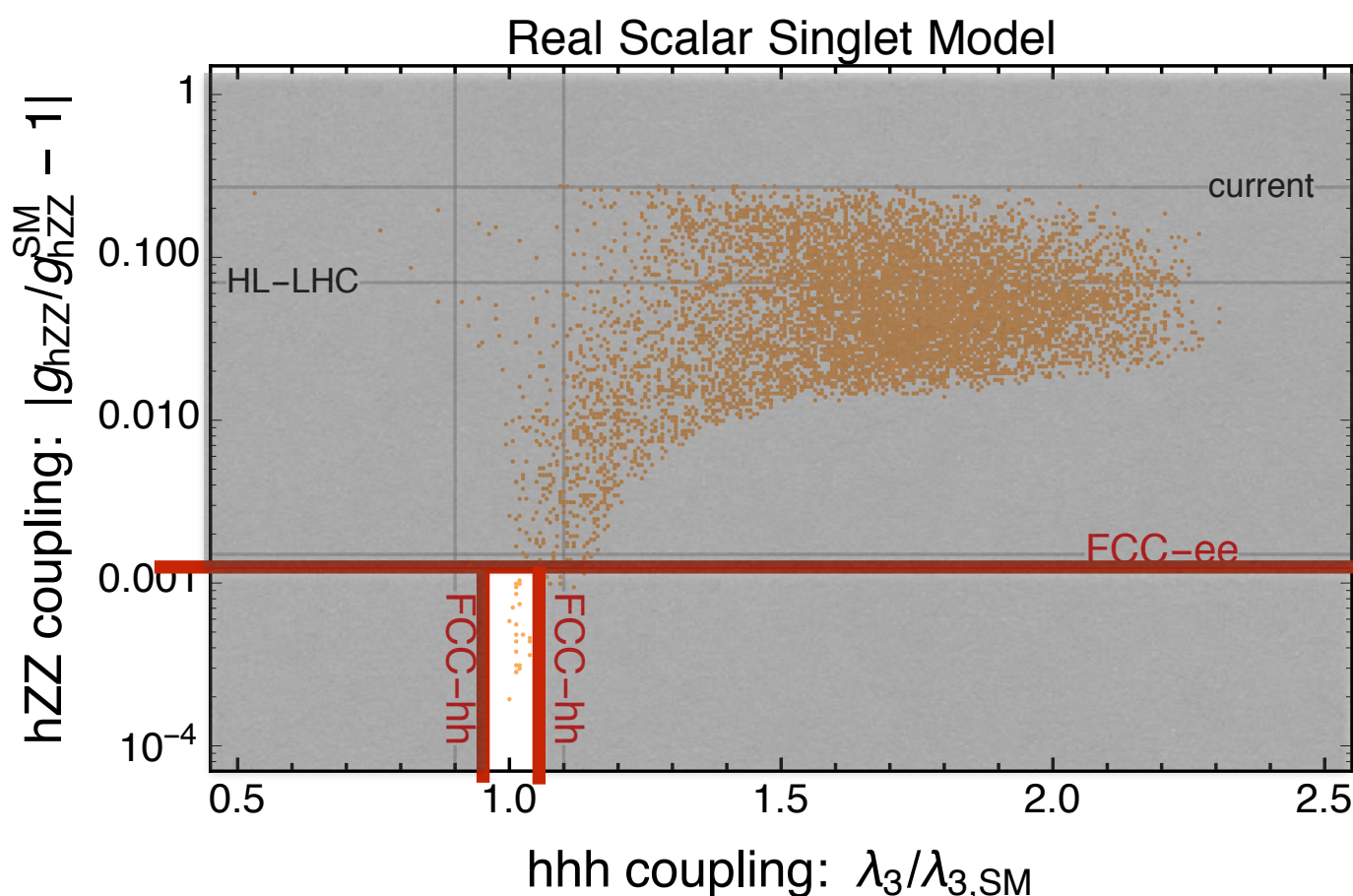


- **Probe higher-order terms of the Higgs potential (selfcouplings)**
- **Probe the existence of other particles coupled to the Higgs**

Constraints on models with 1st order phase transition at the FCC

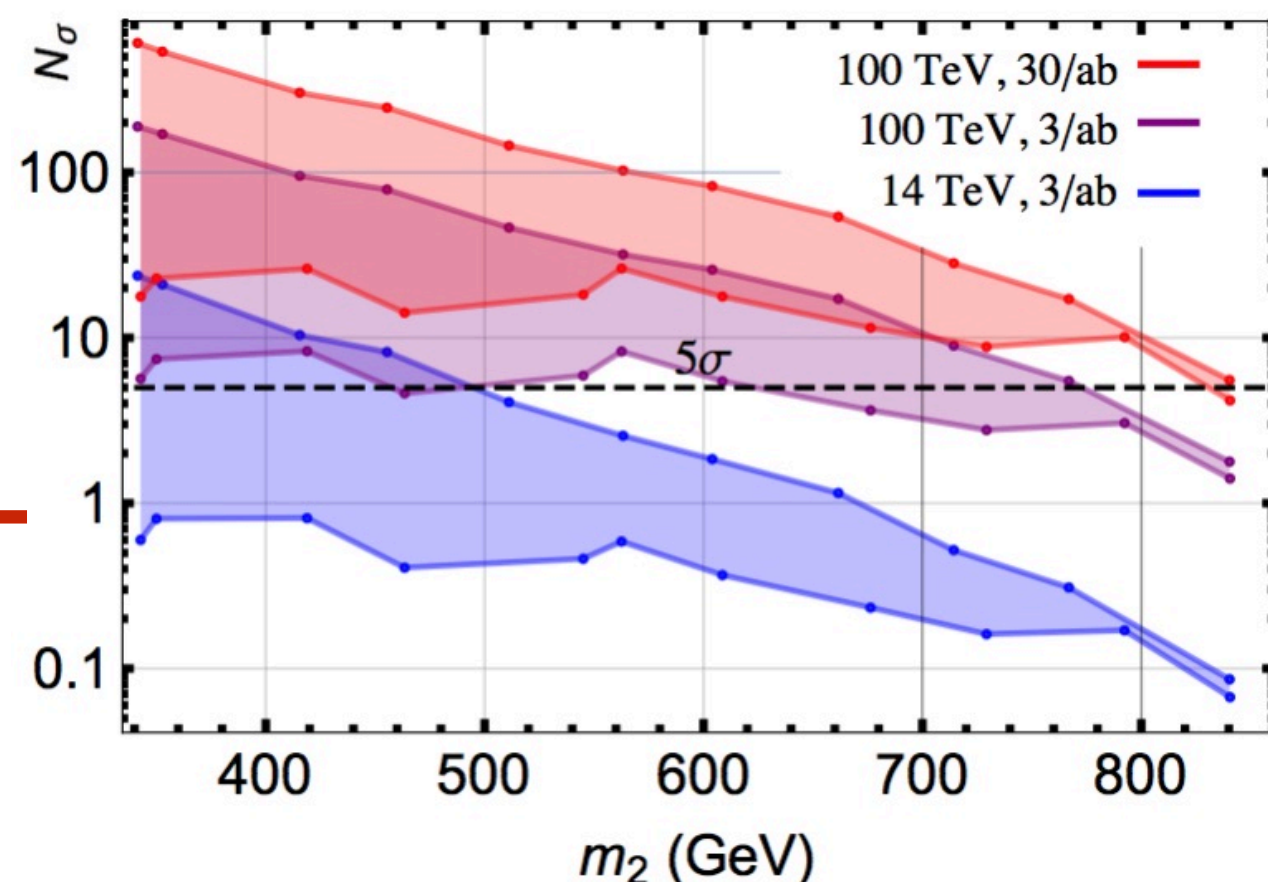
$$V(H, S) = -\mu^2 (H^\dagger H) + \lambda (H^\dagger H)^2 + \frac{a_1}{2} (H^\dagger H) S + \frac{a_2}{2} (H^\dagger H) S^2 + \frac{b_2}{2} S^2 + \frac{b_3}{3} S^3 + \frac{b_4}{4} S^4.$$

Combined constraints from precision Higgs measurements at FCC-ee and FCC-hh



Parameter space scan for a singlet model extension of the Standard Model. The points indicate a first order phase transition.

Direct detection of extra Higgs states at FCC-hh

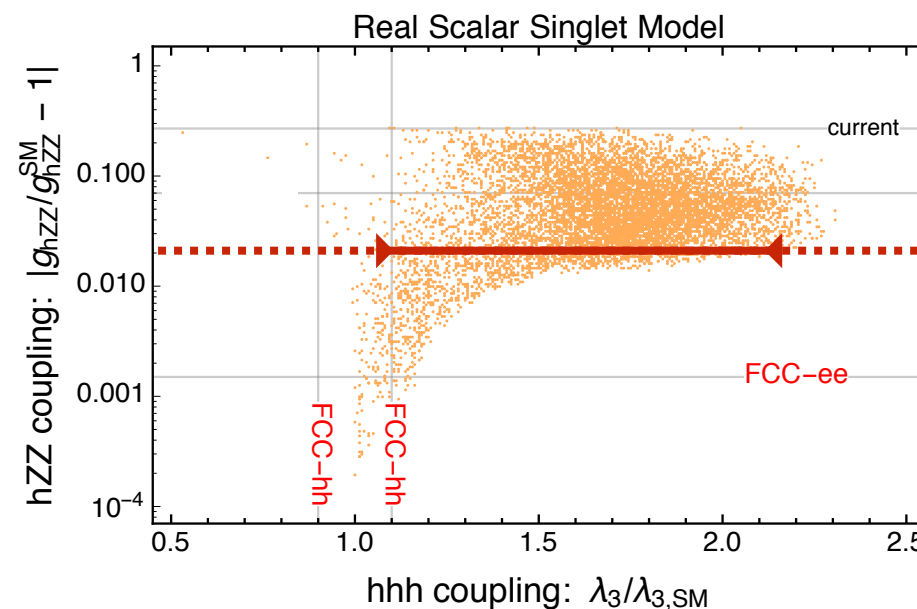


$$h_2 \rightarrow h_1 h_1 \quad (b\bar{b}\gamma\gamma + 4\tau)$$

$$(h_2 \sim S, \quad h_1 \sim H)$$

Remarks

- Apparently, adding the self-coupling constraint does not add much in terms of exclusion power, wrt the HZZ coupling measurement ...
- ... BUT, should HZZ deviate from the SM, λ_{HHH} is necessary to break the degeneracy among all parameter sets leading to the same HZZ prediction



- The concept of *“which experiment sets a better constraint on a given parameter”* is a very limited comparison criterion, which loses value as we move from *“setting limits”* to *“diagnosing observed discrepancies”*
- Likewise, it’s often said that some observable sets better limits than others: “all known model predict deviations in X larger than deviations in Y, so we better focus on X”. But once X is observed to deviate, knowing the value of Y could be absolutely crucial
- Redundancy and complementarity of observables is of paramount importance
- The full, integrated, FCC programme, is the only proposed facility capable of providing such a complementarity

Not covered

- Countless studies of discovery potential for multiple BSM scenarios, from SUSY to heavy neutrinos, from very low masses to very high masses, LLPs, DM, etcetcetc, at FCC-ee, FCC-hh and FCC-eh
- Sensitivity studies to SM deviations in the properties of top quarks, flavour physics in Z decays: huge event rates offer unique opportunities, that cannot be matched elsewhere
- ...
- Operations with heavy ions: new domains open up at 100 TeV in the study of high-T/high-density QCD. Broaden the targets, the deliverables, extend the base of potential users, and increase the support beyond the energy frontier community

ESPP 2020:

“[...] a feasibility study of the colliders and related infrastructure should be established as a global endeavour and be completed on the timescale of the next Strategy update.”

Scientific advisory
committee

Sttering committee

Collaboration board

FCC study coordination

7 pillars

Physics,
experiments
and detectors

Accelerators
ee & hh

Technical
coordination &
technical
infrastructure

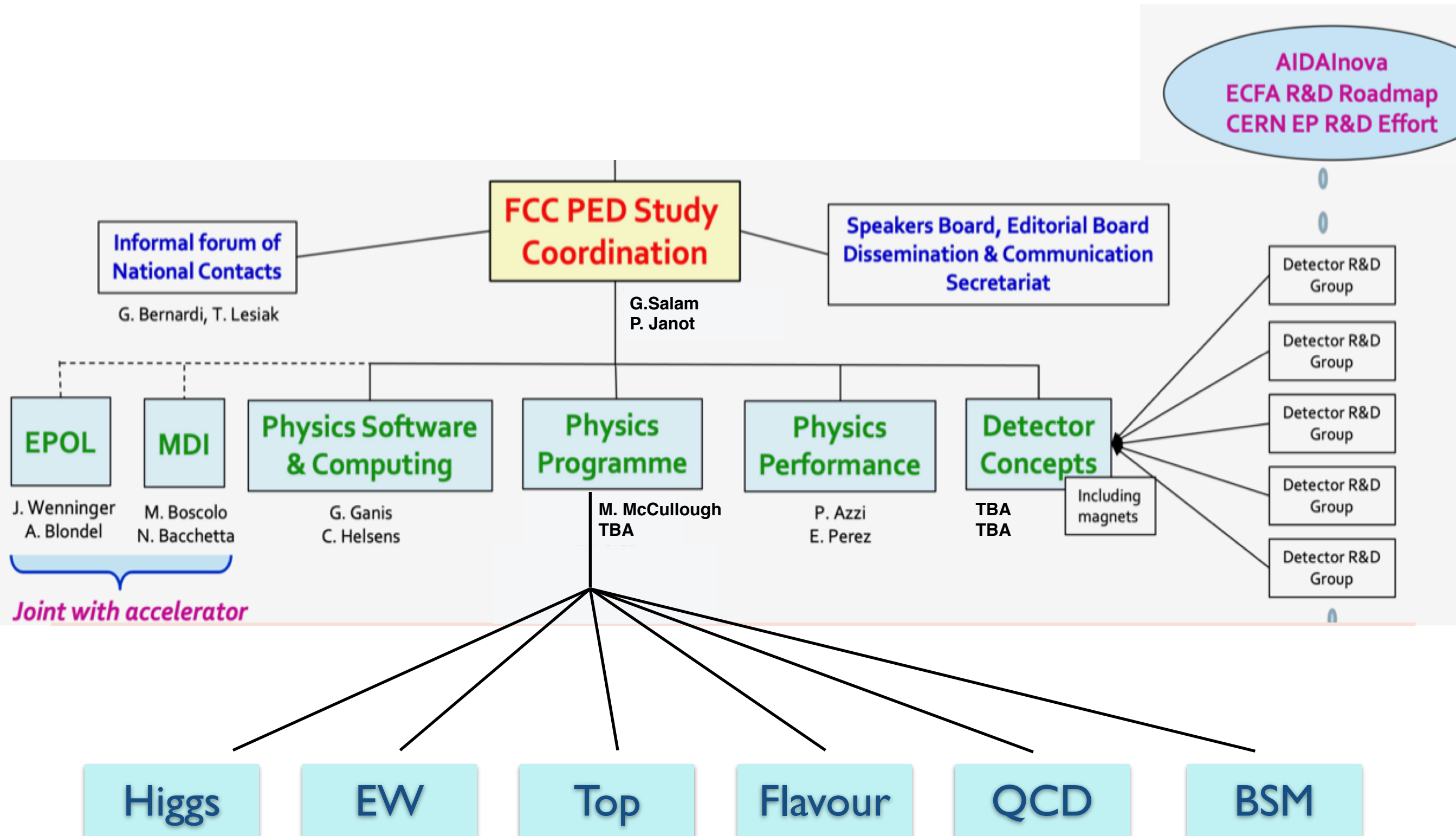
Civil
engineering

Implementation
preparations

Organization
& financing
model

Study support

Structure of physics, experiments and detectors (PED) pillar



Forthcoming events

FCC WEEK 2021

28 June – 2 July

ONLINE EVENT

Register Here:

<https://indico.cern.ch/e/fccw2021>



FCC: The Future Circular Collider under Study
This R&D project is a research and innovation action
financed under the European Union's Horizon
Framework Programme for Research and Innovation, 2019-2024

2022 Workshop on FCC Physics, Experiments and Detectors

University of Liverpool, UK

February 2022 (tentative 7-11, tbc)

**Everyone is welcome to
participate, and join the
ongoing studies**

<https://indico.cern.ch/event/995850/>

Final remarks

- The study of the SM will not be complete until we clarify the nature of the Higgs mechanism and exhaust the exploration of phenomena at the TeV scale: many aspects are still obscure, many questions are still open.
- The exptl program possible at a future collider facility, combining a versatile high-luminosity e^+e^- circular collider, with a follow-up pp collider in the 100 TeV range, offers unmatched breadth and diversity: concrete, compelling and indispensable Higgs & SM measurements enrich a unique direct & indirect discovery potential
- The technological, financial and sociological challenges are immense, and will test our community ability to build and improve on the experience of similar challenges in the past.
- The next 5-6 years, before the next review of the European Strategy for Particle Physics, will be critical to reach the scientific consensus and political support required to move forward

Additional material: recent reports on Future Circular Colliders

- **FCC CDR:**
 - Vol.1: Physics Opportunities (CERN-ACC-2018-0056) <http://cern.ch/go/Nqxx7>
 - Vol.2: The Lepton Machine (CERN-ACC-2018-0057) <http://cern.ch/go/7DH9>
 - Vol.3: The Hadron Machine (CERN-ACC-2018-0058), <http://cern.ch/go/Xrg6>
 - Vol.4: High-Energy LHC (CERN-ACC-2018-0059) <http://cern.ch/go/S9Gq>
- **"Physics at 100 TeV"**, CERN Yellow Report: <https://arxiv.org/abs/1710.06353>
- **CEPC CDR:** [Physics and Detectors](#)