Why building a muon collider

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CERN

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Why Muons?

Leptons are the ideal probes of short-distance physics:

All the energy is stored in the colliding partons
No energy “waste” due to parton distribution functions
High-energy physics probed with much smaller collider energy

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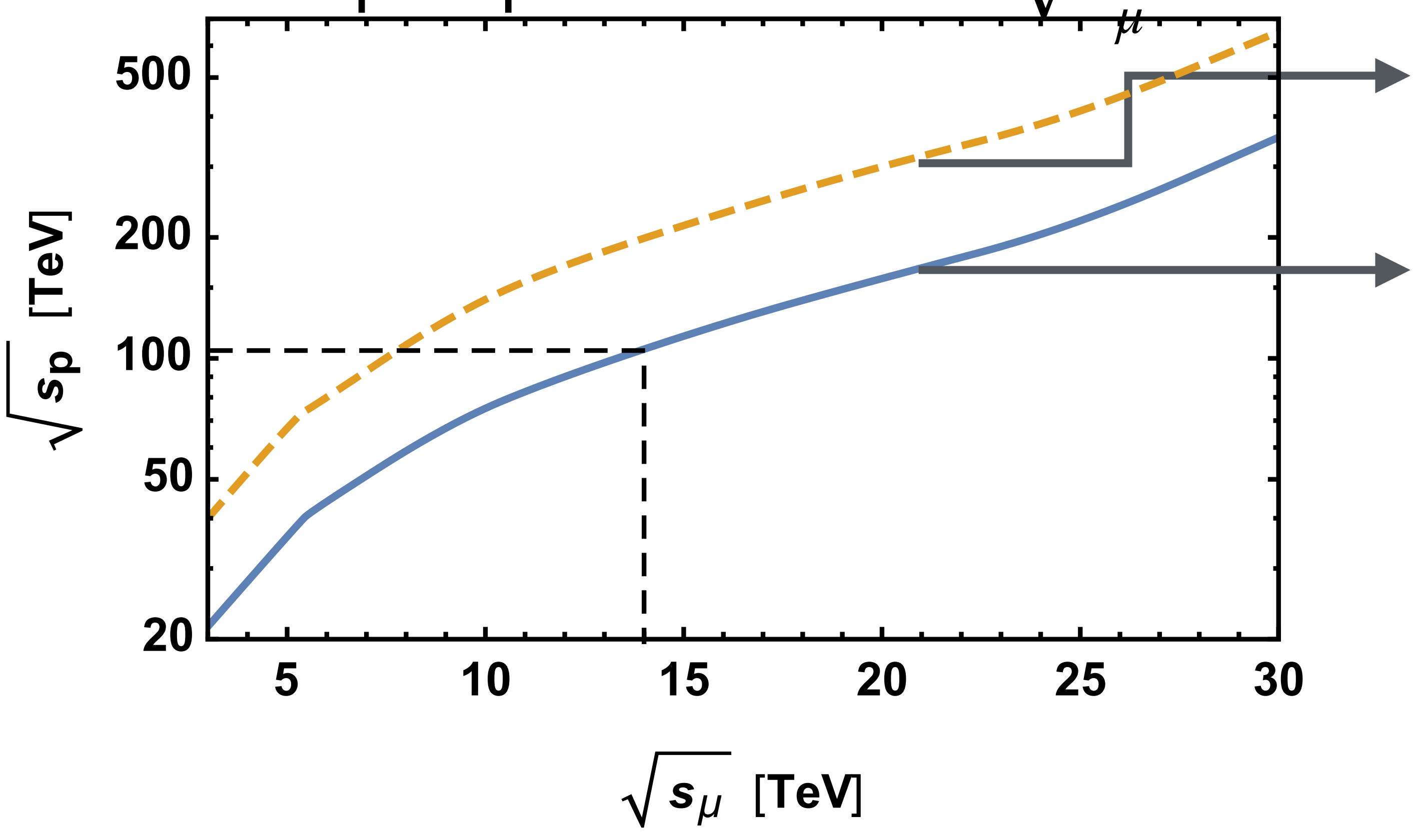
pp $\sqrt{s}$ at which $\sigma_{pp} = \sigma_{\mu\mu}$
for pair prod. with $M \sim \sqrt{s}_{\mu}$



Estimate for EWK-only charged particles

Estimate for EWK+QCD-charged particles

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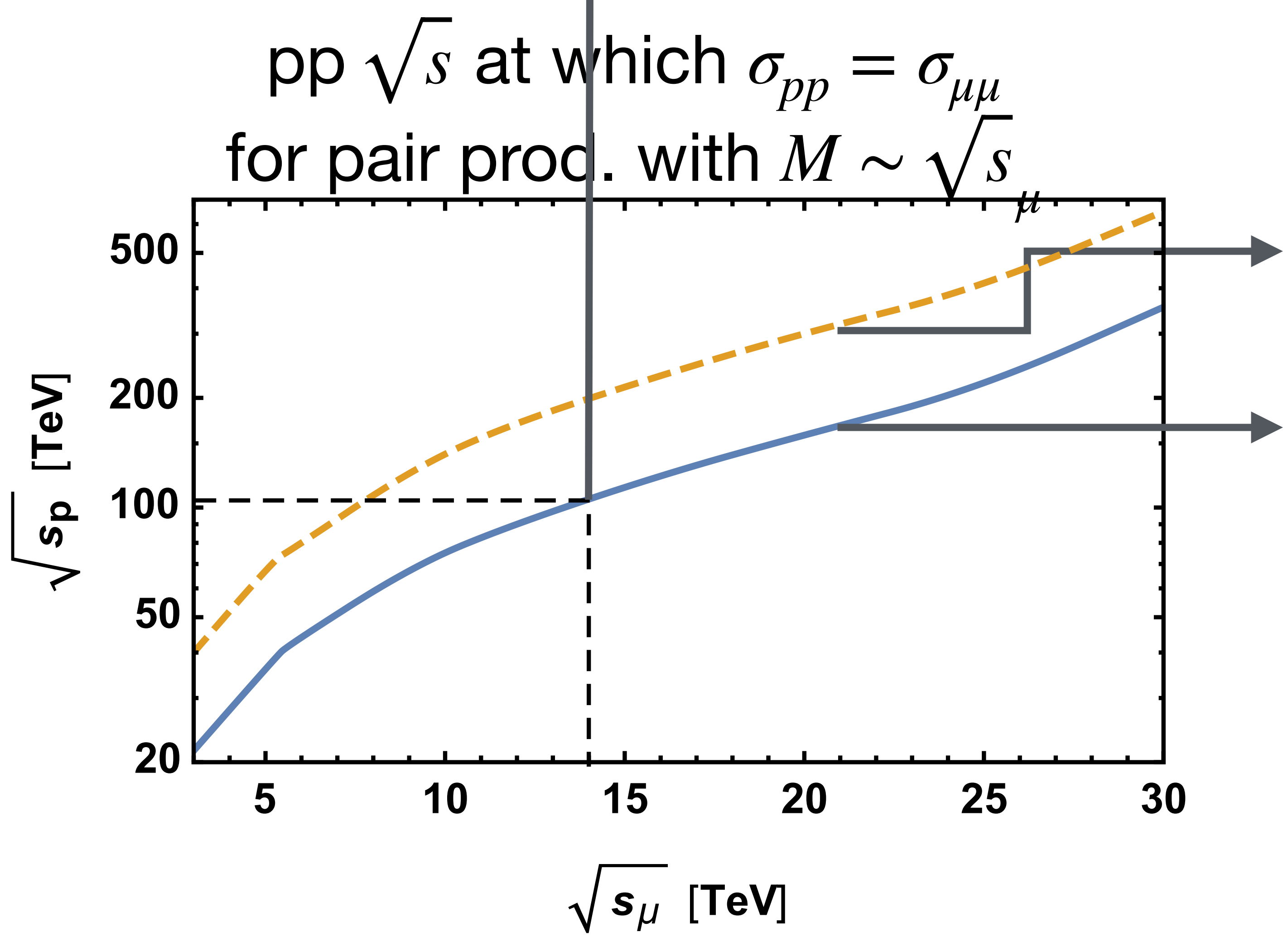

Reference Point:
14 TeV μ-collider ~ FCC@100 TeV

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Letter of Interest: Muon Collider Physics Potential Link

D. Buttazzo, R. Capedevilla, M. Chiesa, A. Costantini, D. Curtin, R. Franceschini, T. Han, B. Heinemann, C. Helsens, Y. Kahn, G. Krnjaic, I. Low, Z. Liu, F. Maltoni, B. Mele, F. Meloni, M. Moretti, G. Ortona, F. Piccinini, M. Pierini, R. Rattazzi, M. Selvaggi, M. Vos, L.T. Wang, **A. Wulzer**, M. Zanetti, J. Zurita

On behalf of the forming muon collider international collaboration [1]

We describe the plan for muon collider physics studies in order to provide inputs to the Snowmass process. The goal is a first assessment of the muon collider physics potential. The target accelerator design center of mass energies are 3 and 10 TeV or more [2]. Our study will consider energies $E_{\rm CM} = 3, 10, 14$, and the more speculative $E_{\rm CM} = 30$ TeV, with reference integrated luminosities $\mathcal{L} = (E_{\rm CM}/10 \text{ TeV})^2 \times 10\,\text{ab}^{-1}$ [3]. Variations around the reference values are encouraged, aiming at an assessment of the required luminosity of the project based on physics performances. Recently, the physics potentials of several future collider options have been studied systematically [4], which provide reference points for comparison for our studies.

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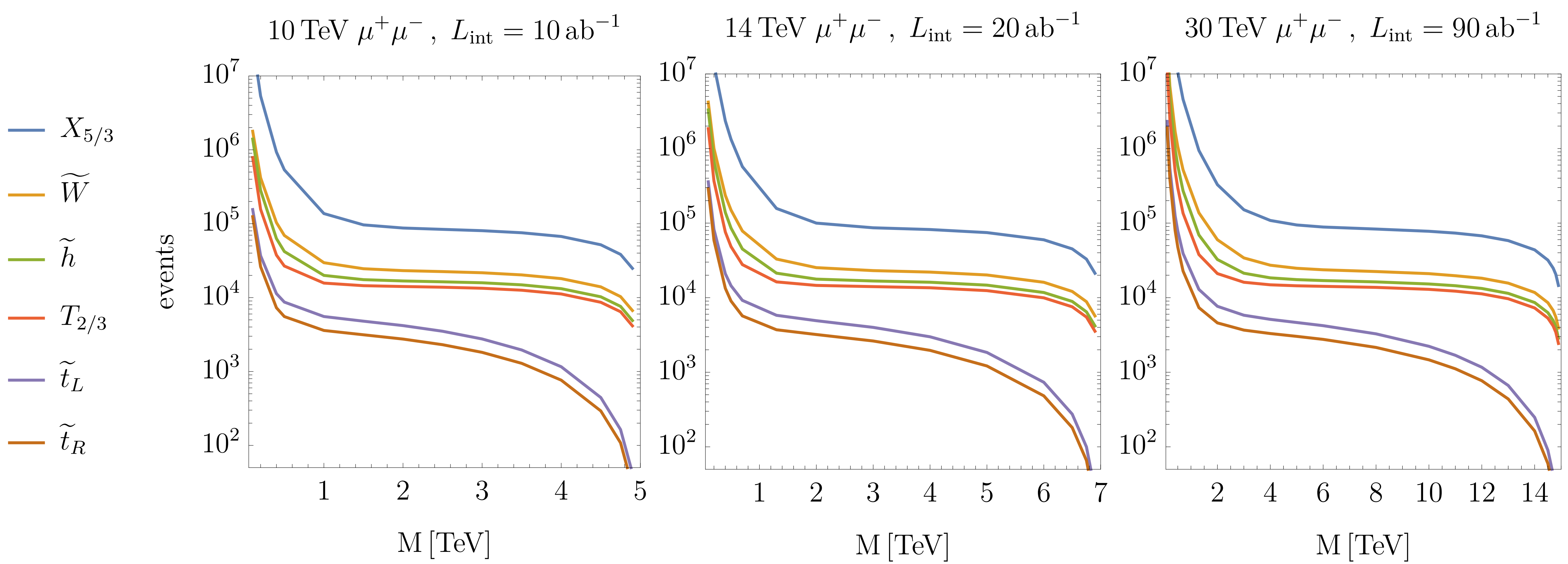
Muon Collider Physics Potential Pillars

Direct search of heavy particles	High rate indirect probes	High energy probes
SUSY-inspired, WIMP, VBF production, 2->1	Higgs single and self-couplings, rare Higgs decays, exotic decays	difermion, diboson, EFT, Higgs compositeness

The case for direct searches

EW pair-produced particles up to kinematical threshold

Striking for 10+TeV



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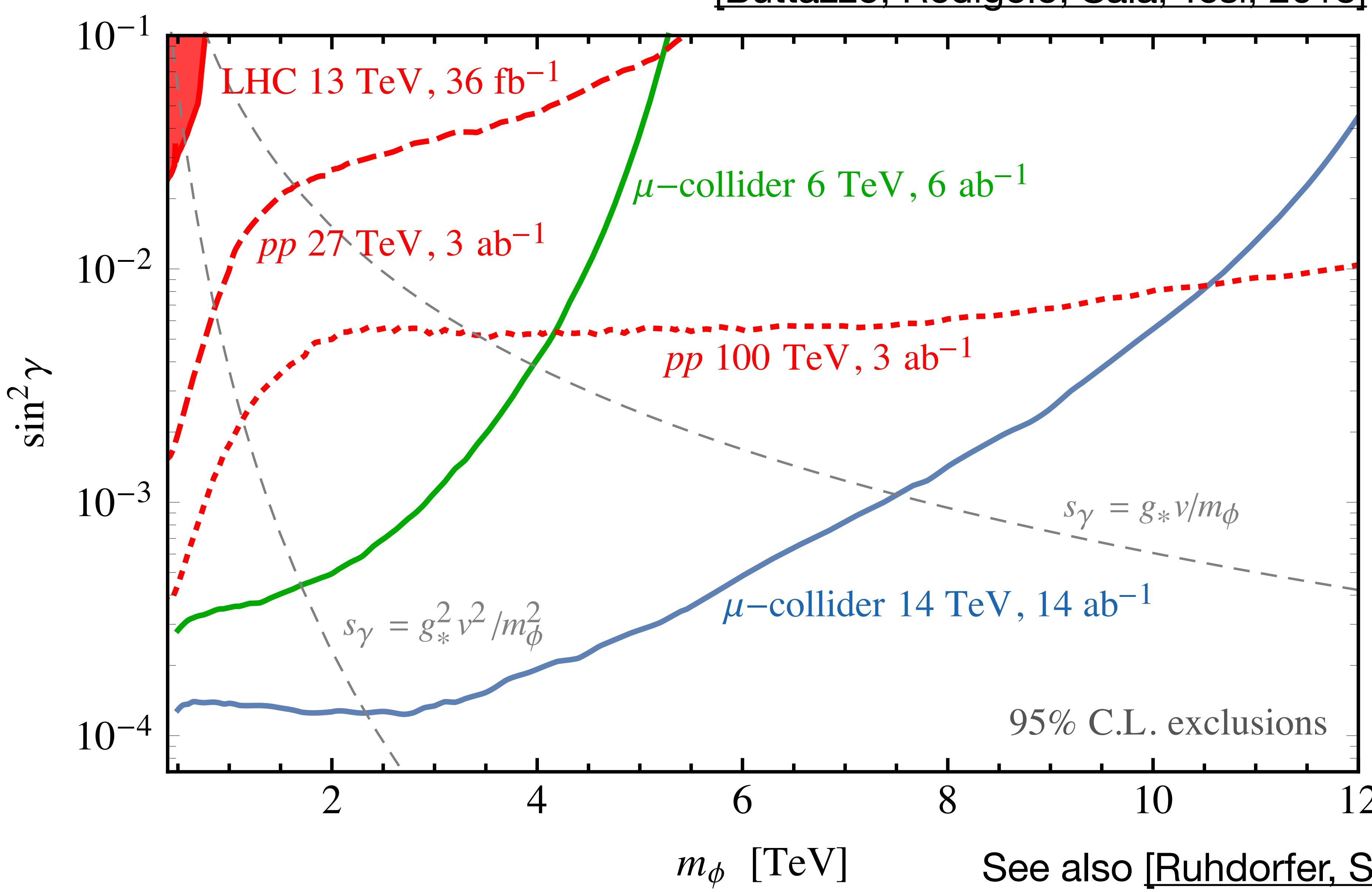
Particularly effective for **VBF-produced BSM**

[Buttazzo, Redigolo, Sala, Tesi, 2018]



See also [Ruhdorfer, Salvioni, Weiler, 2019]

[Costantini, De Lillo, Maltoni et. al., 2020]

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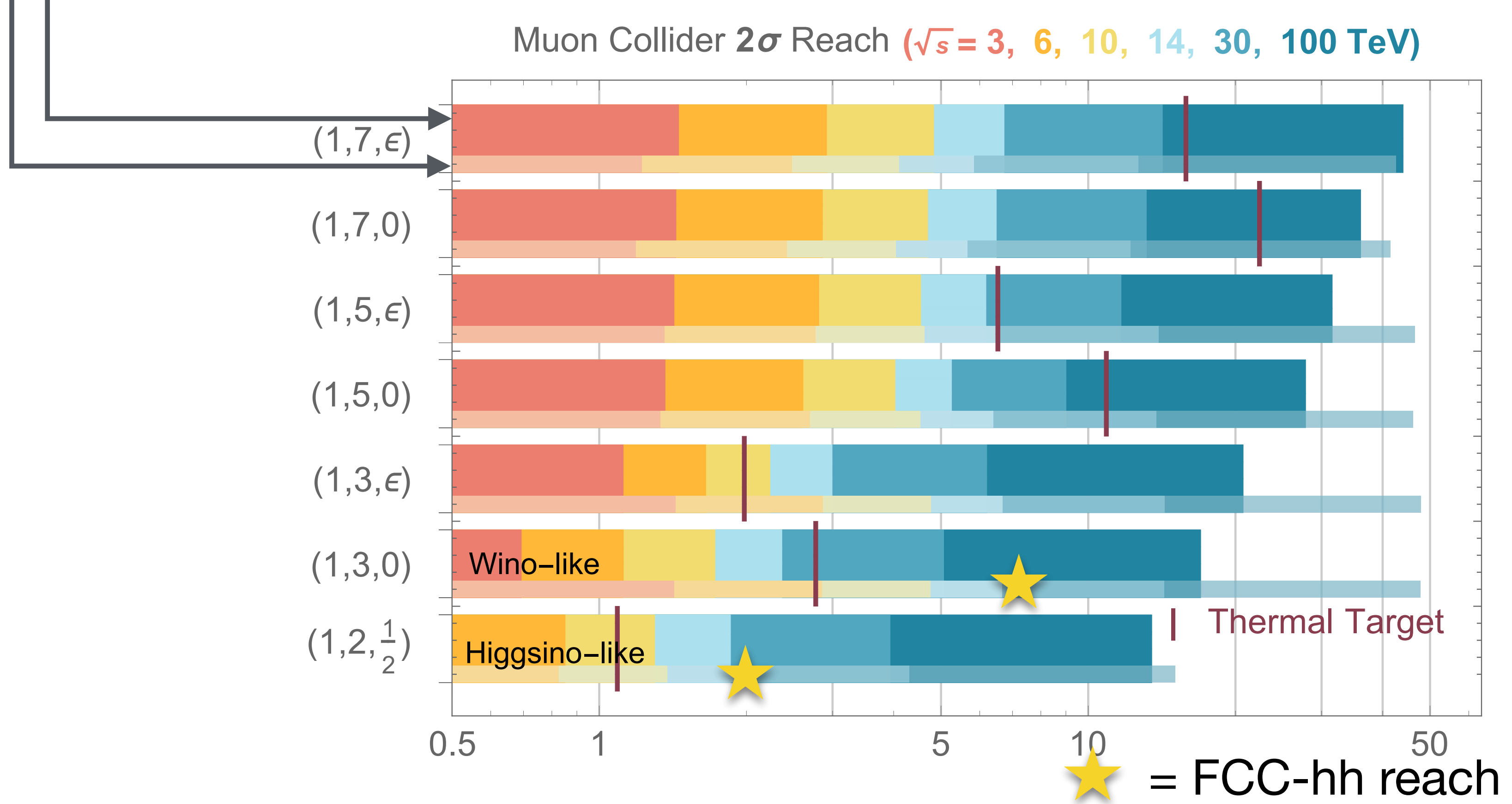
Need studies for compressed/invisible/difficult decays

WIMP DM:

- in mono-X [2009.11287 + Buttazzo, Franceschini et. al. in progress]
- disappearing tracks [2009.11287 + Meloni, Zurita et. al. in progress]



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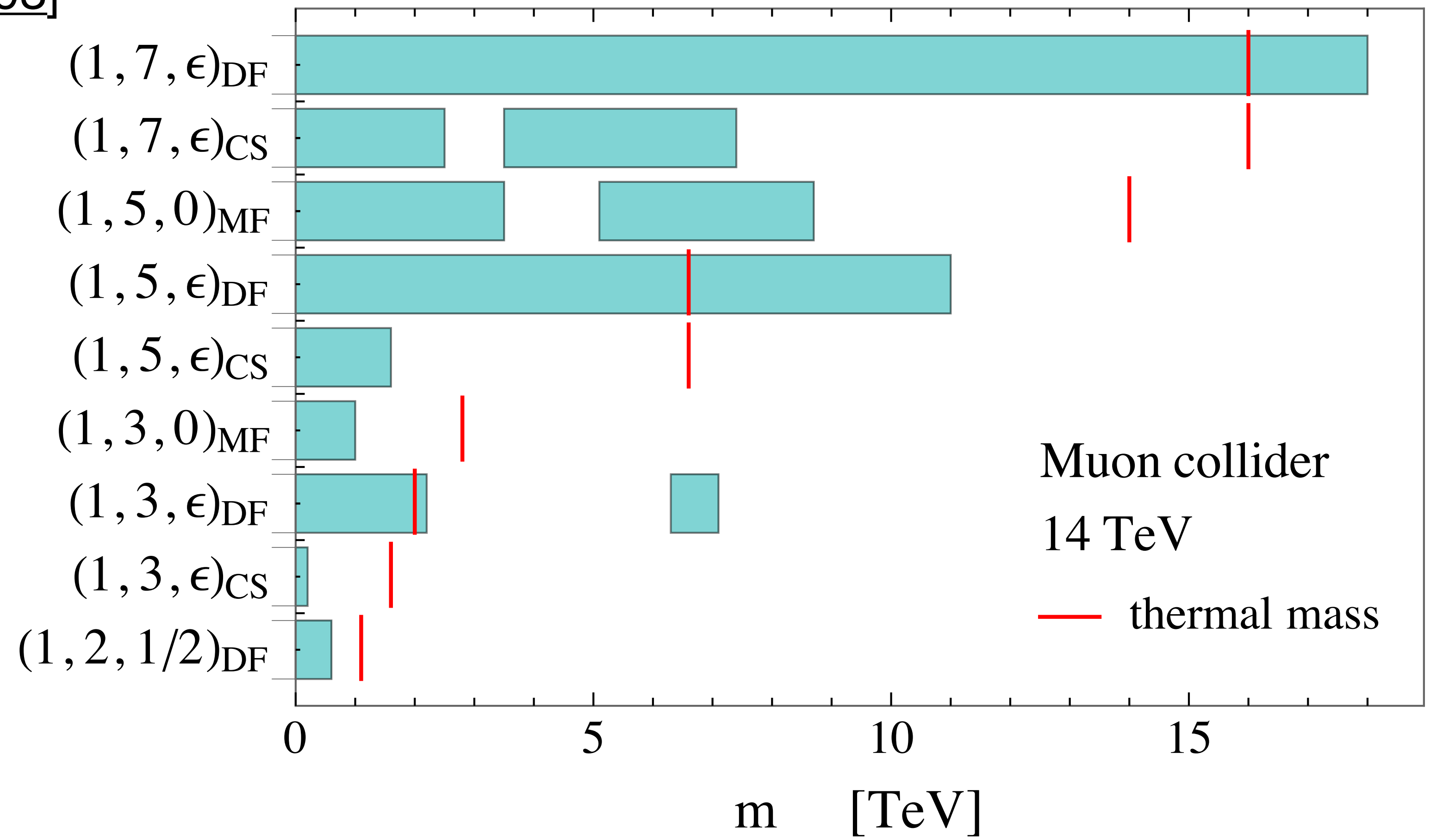
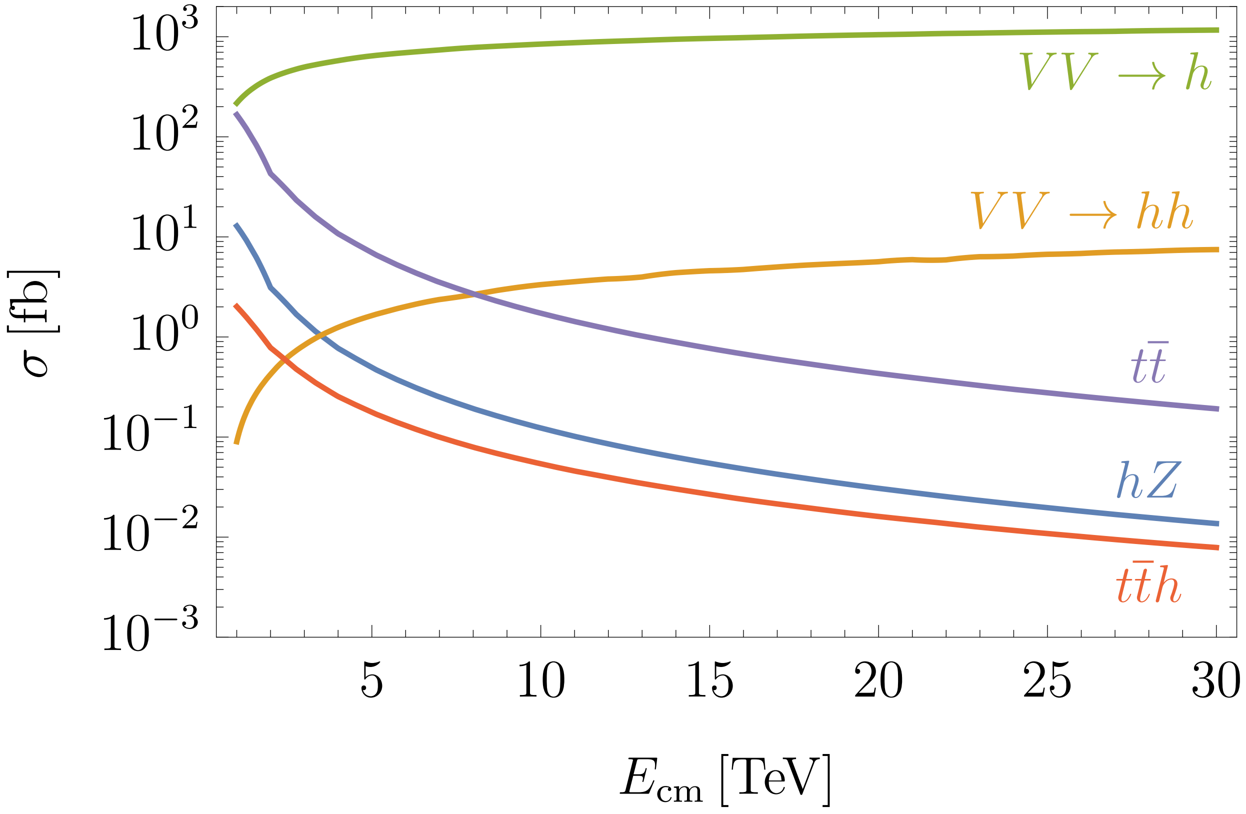
indirectly [1810.10993]

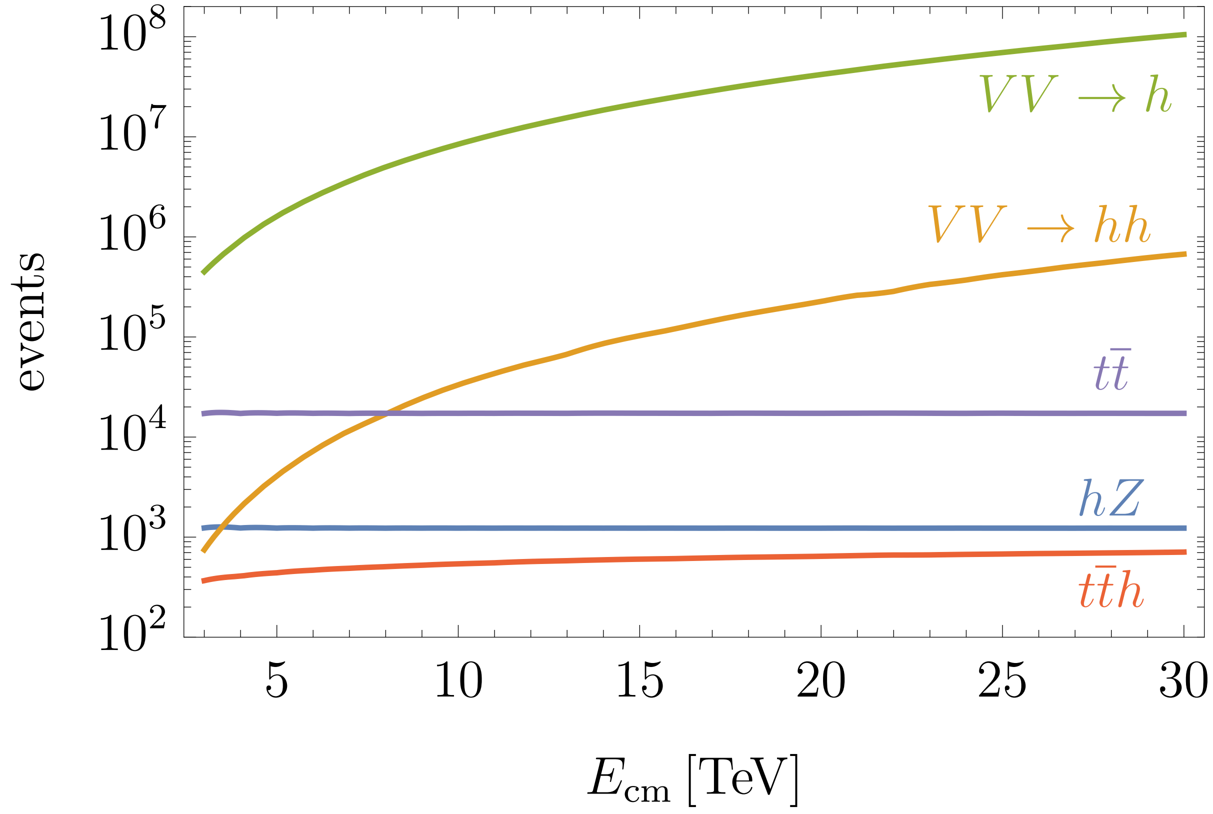


High rate indirect probes

Large single-Higgs VBF rate

Precision on Higgs couplings driven by systematics. **Could be 1‰**





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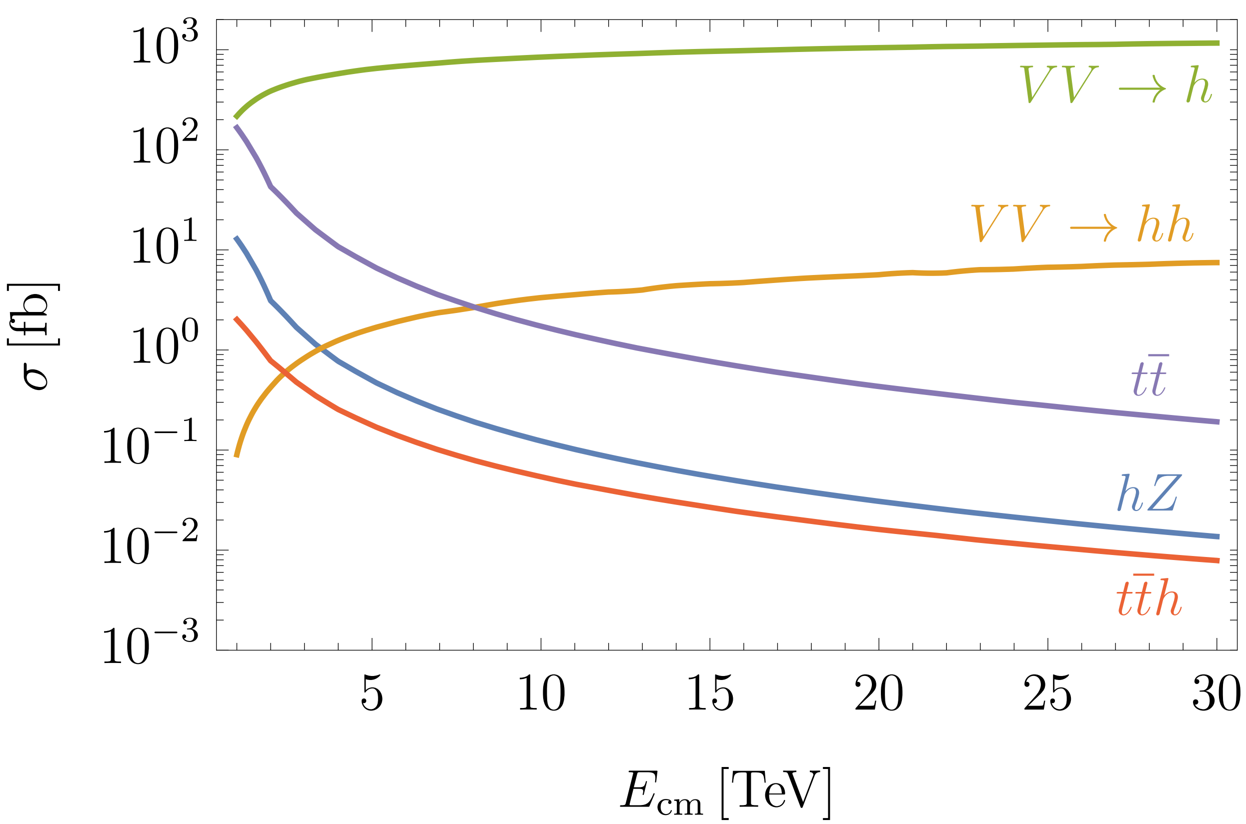
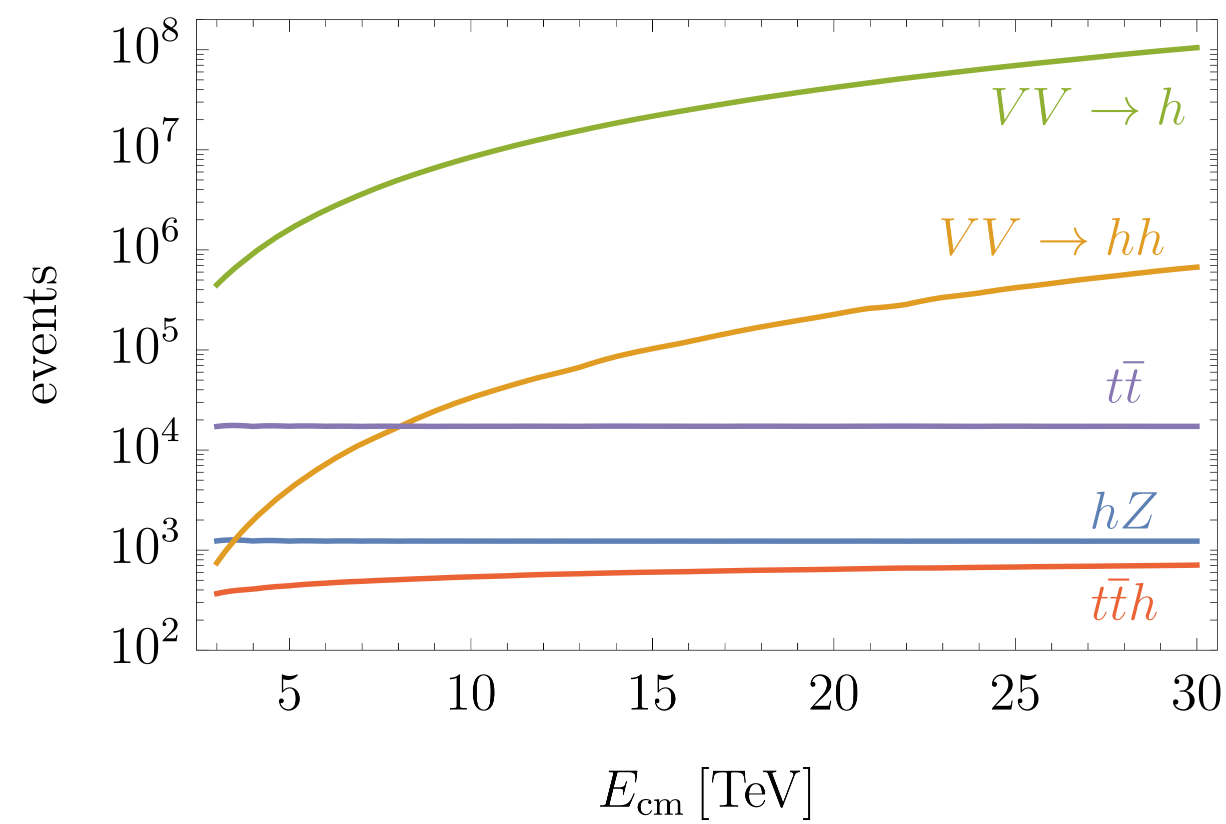
- Precision on Higgs couplings driven by systematics. **Could be 1‰**
- Rare/Exotic Higgs decay opportunities ?
  - Less Higgses than FCC-hh, but much more than FCC-ee.
  - Physics backgrounds are ee-like, what about BIB?
  - h→μμγ, h→ττγ, for determination of anomalous g-2 [2012.02769]





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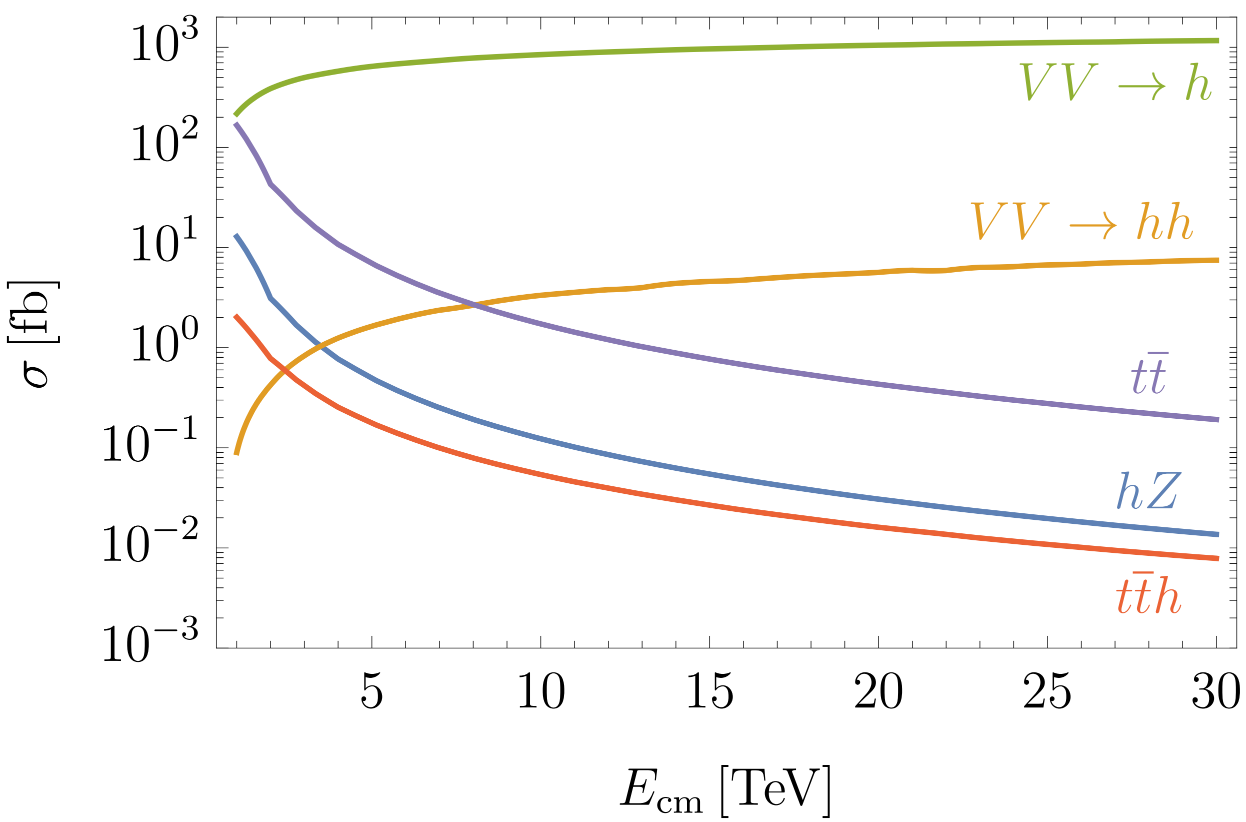
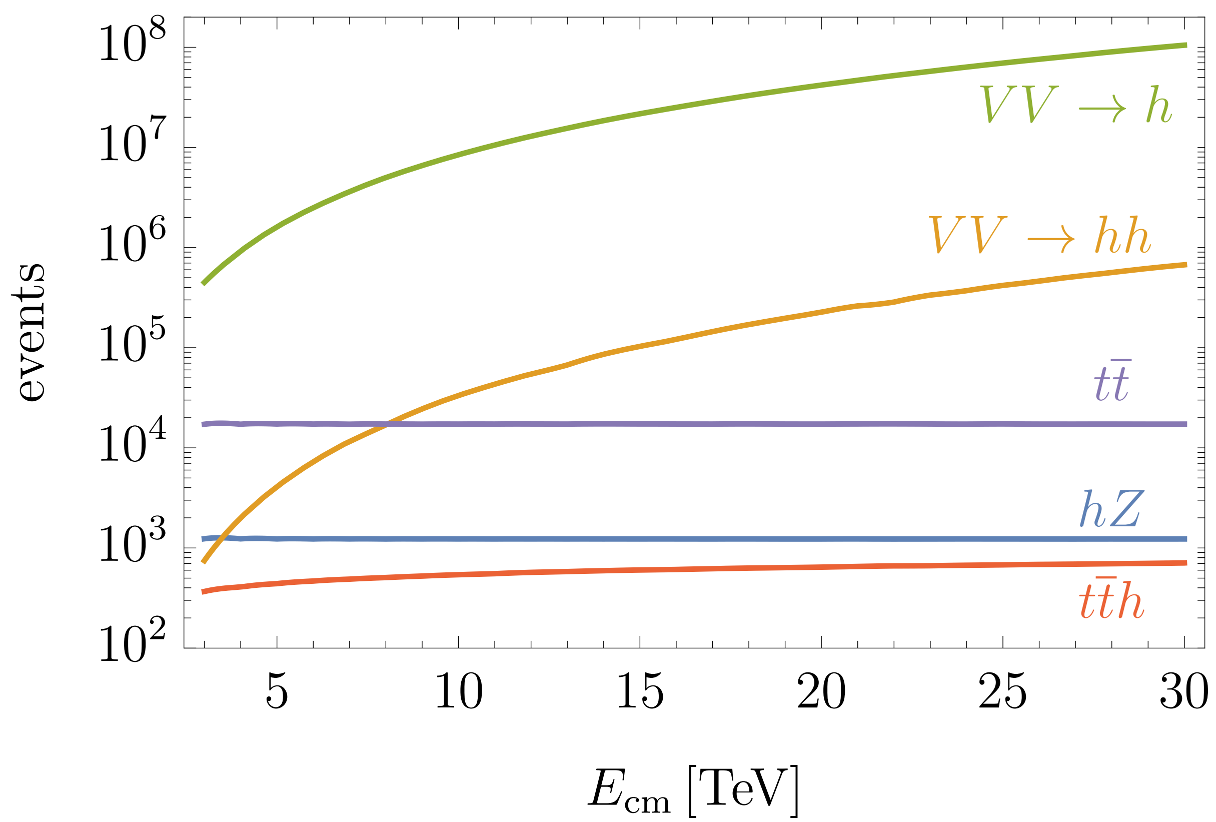
[2008.12204; 2005.10289; Buttazzo, Franceschini, AW, to appear]





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- Higgs 3-linear: **$\delta\kappa_\lambda =_{1\sigma}$ (5%, 3.5%,1.6%) for E = (10, 14, 30) TeV**

Sensitivity Projections based on:

- ✦Both Higgs → bb
- ✦Dominant backgrounds taken into account
- ✦Jet energy resolution at 10% [CLIC-like]
- ✦CLIC tight b-tagging working point
- ✦Optimisation of number of b-tags and of reconstructed Higgs mass cut
- ✦Result in perfect agreement with CLIC fullsim

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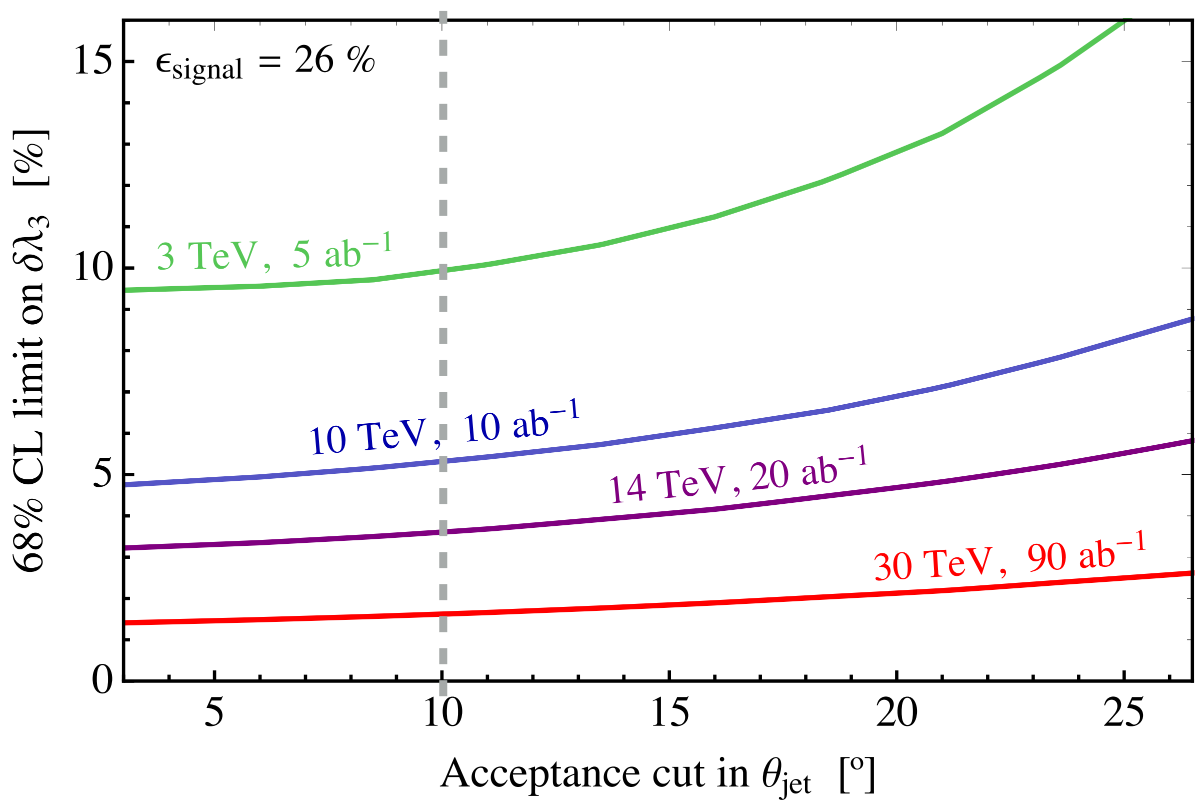
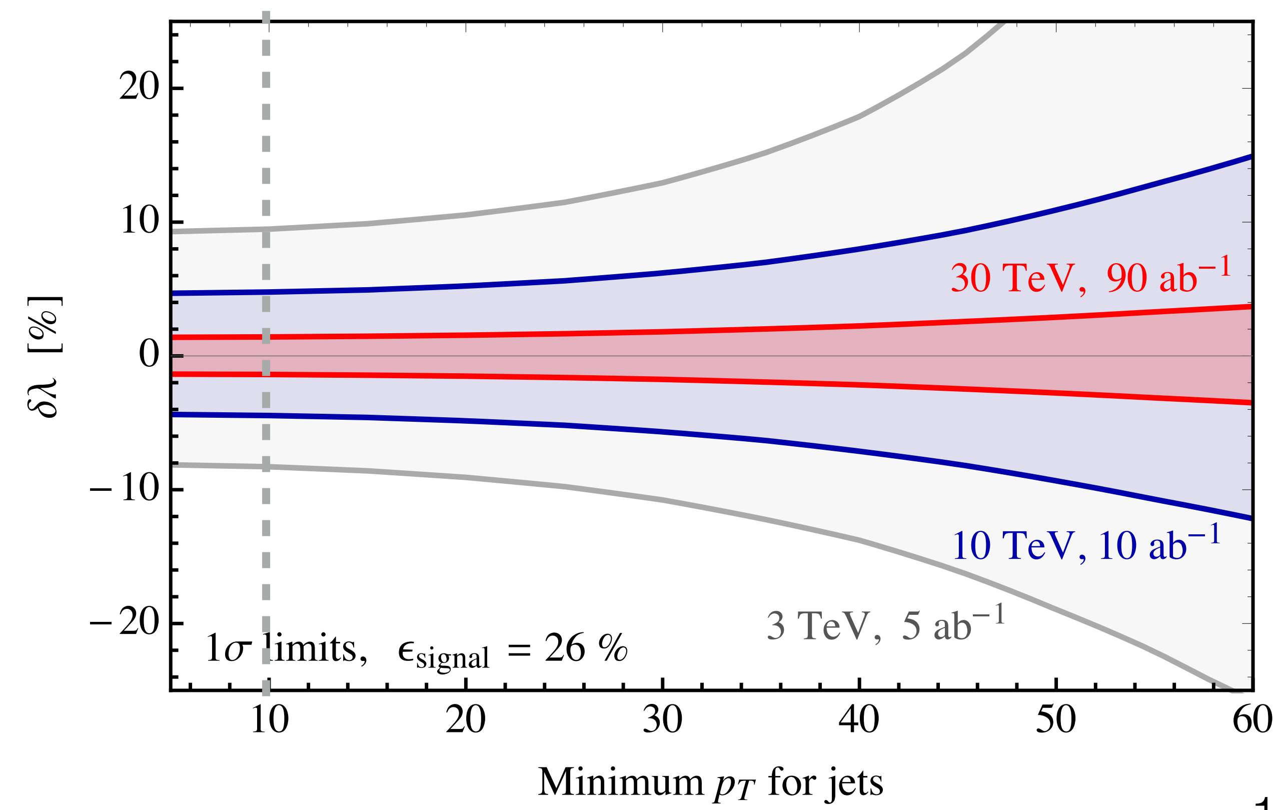
Note:

reduced angular acceptance/PT would not change much





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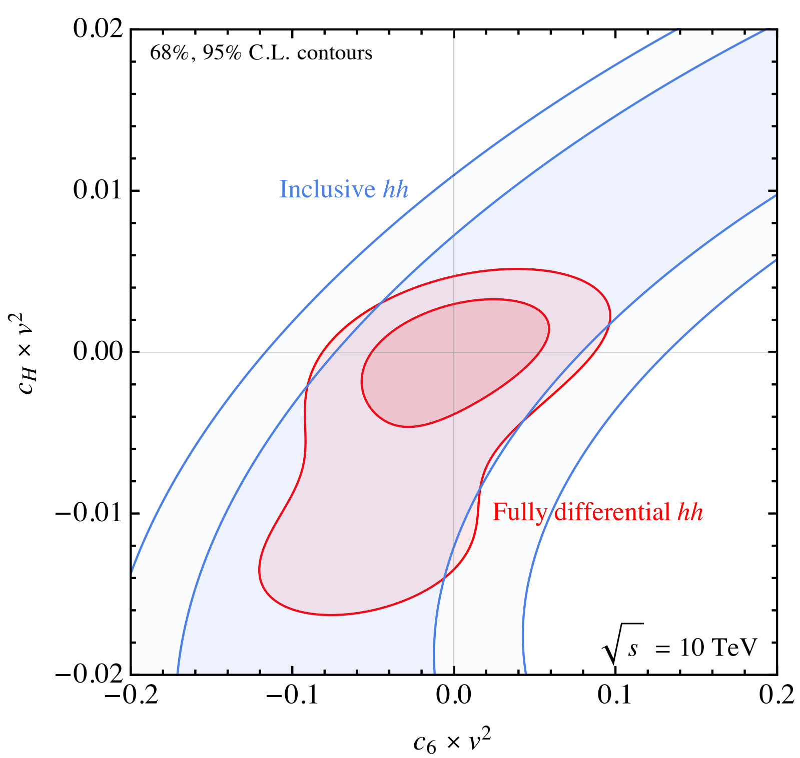
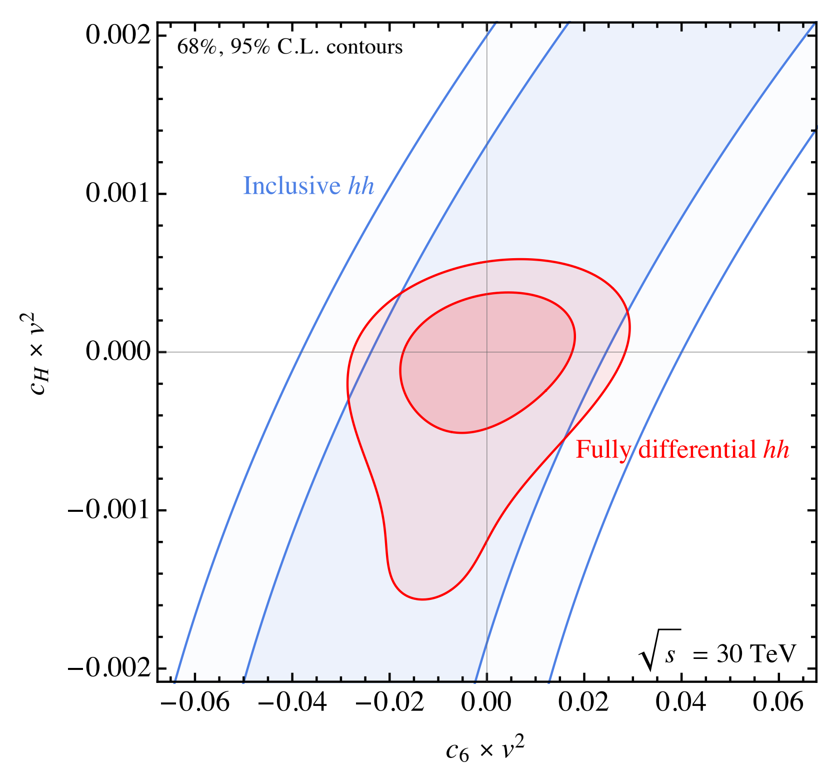
From **no-so-accurate measurements in high mass tail** [O_H energy growth]





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From **no-so-accurate measurements in high mass tail** [O_H energy growth]

FCC-all reach, from **accurate coupling** measurements, is 1.8‰

High energy probes

[Buttazzo, Franceschini, AW, to appear]

As simple as this:

$$\frac{\Delta\sigma(E)}{\sigma_{\rm SM}(E)} \propto \frac{E^2}{\Lambda^2_{\rm BSM}} \overset{\text{[say, } \Lambda_{\rm BSM} = 100\,\text{TeV]}}{=}$$

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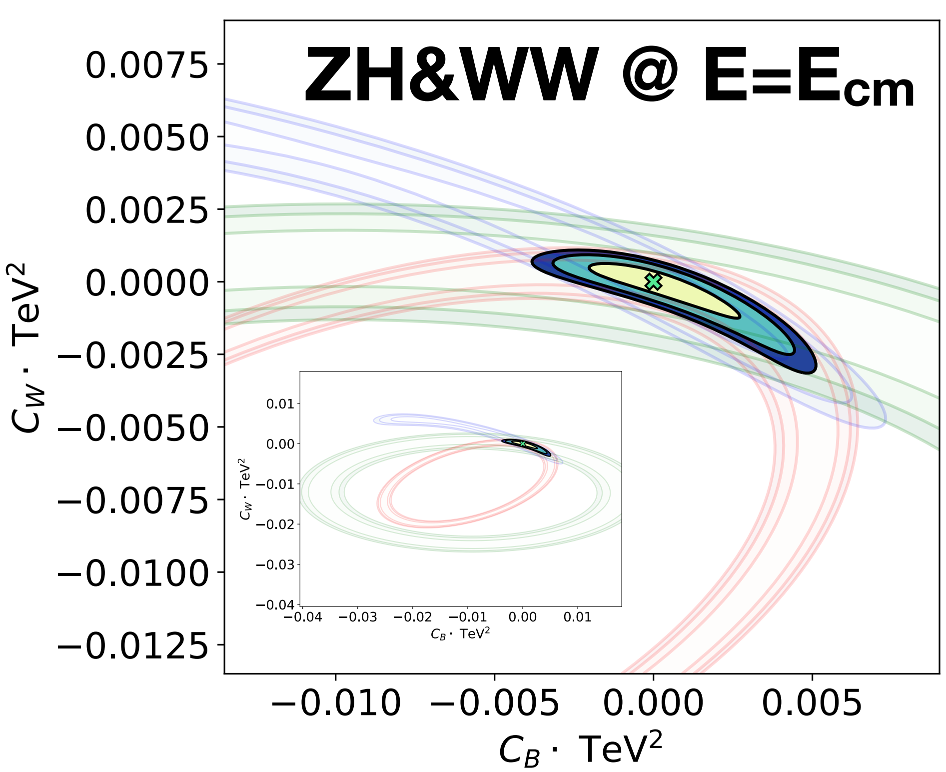
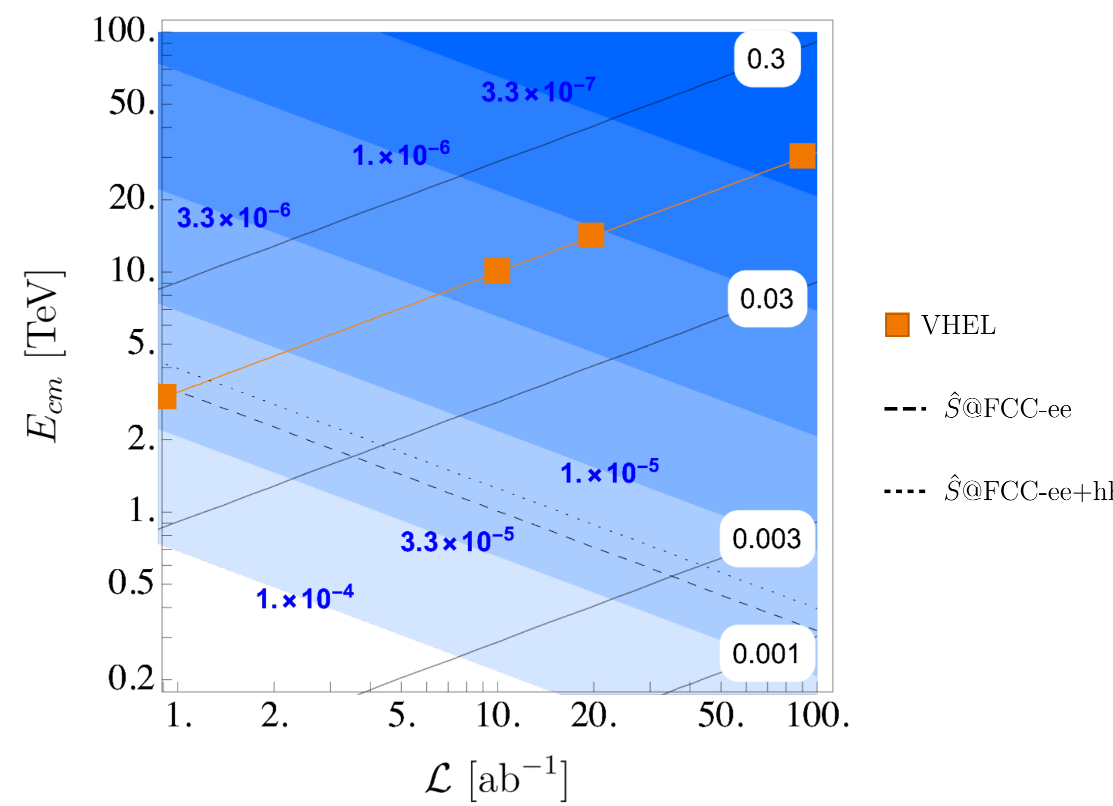
High-Energy probes are effective at HL-LHC, FCC-hh, CLIC
But they are **much more effective** at the **muon collider!**

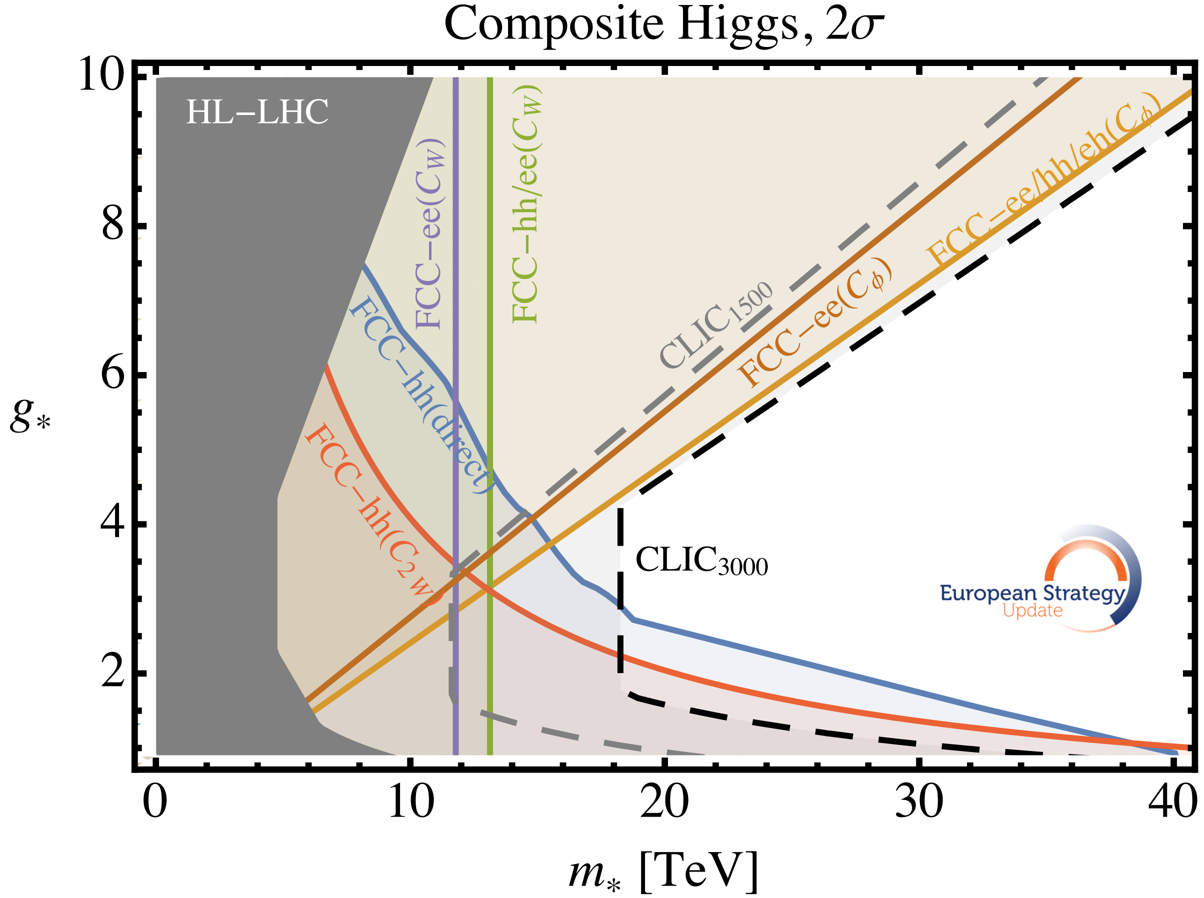




Probing Higgs compositeness

[Chen, Glioti, Ricci, Rattazzi, AW, in progress]

"Standard" Future Colliders



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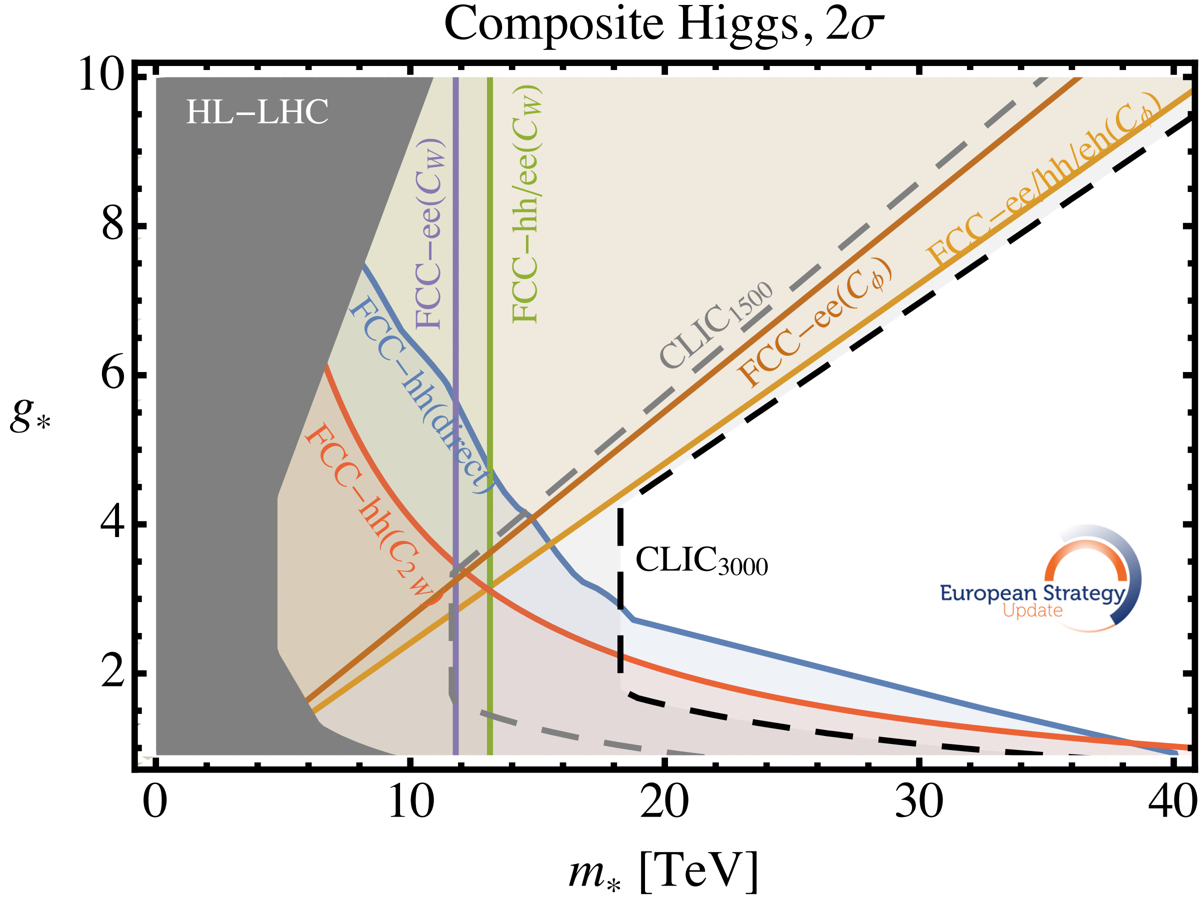
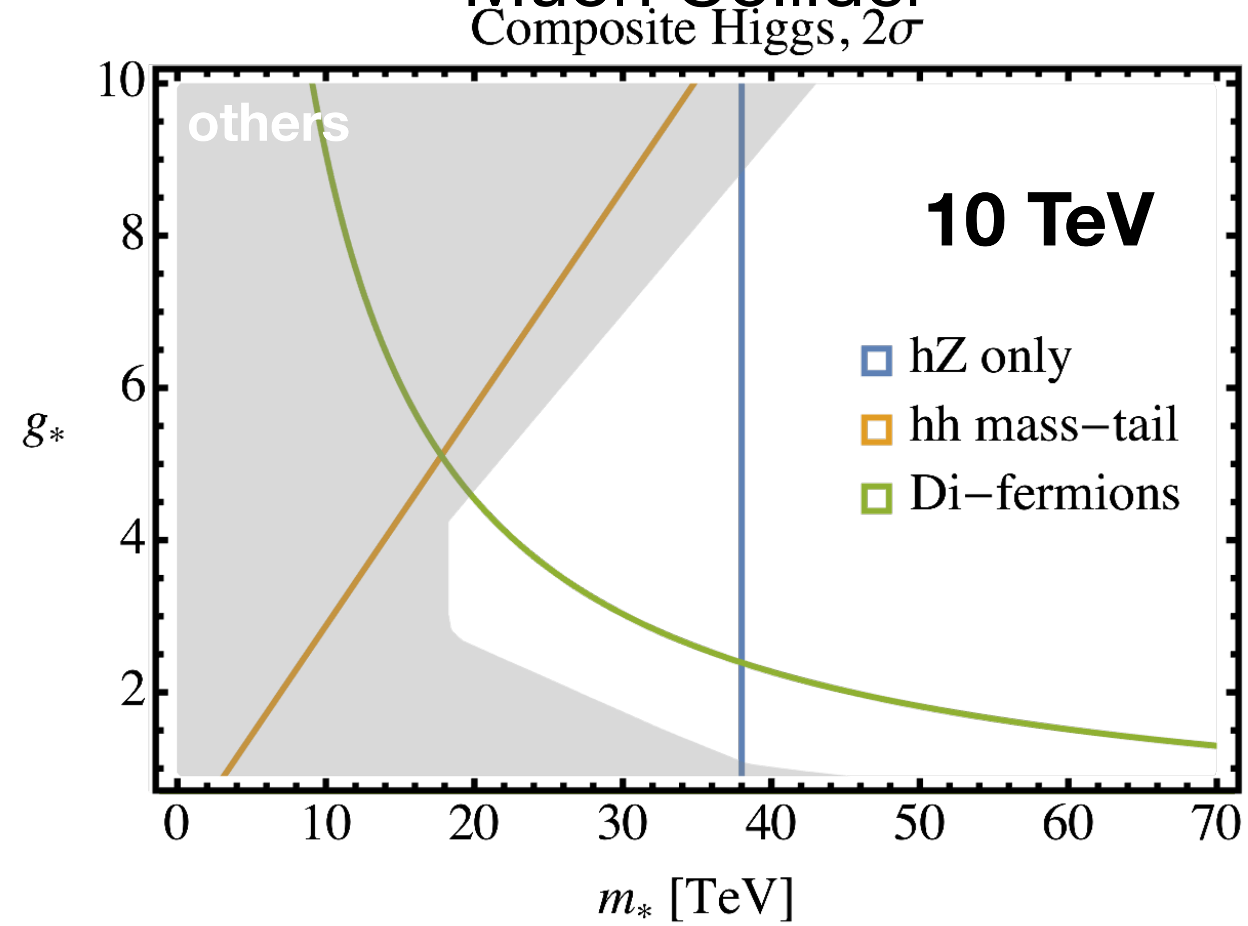


Muon Collider



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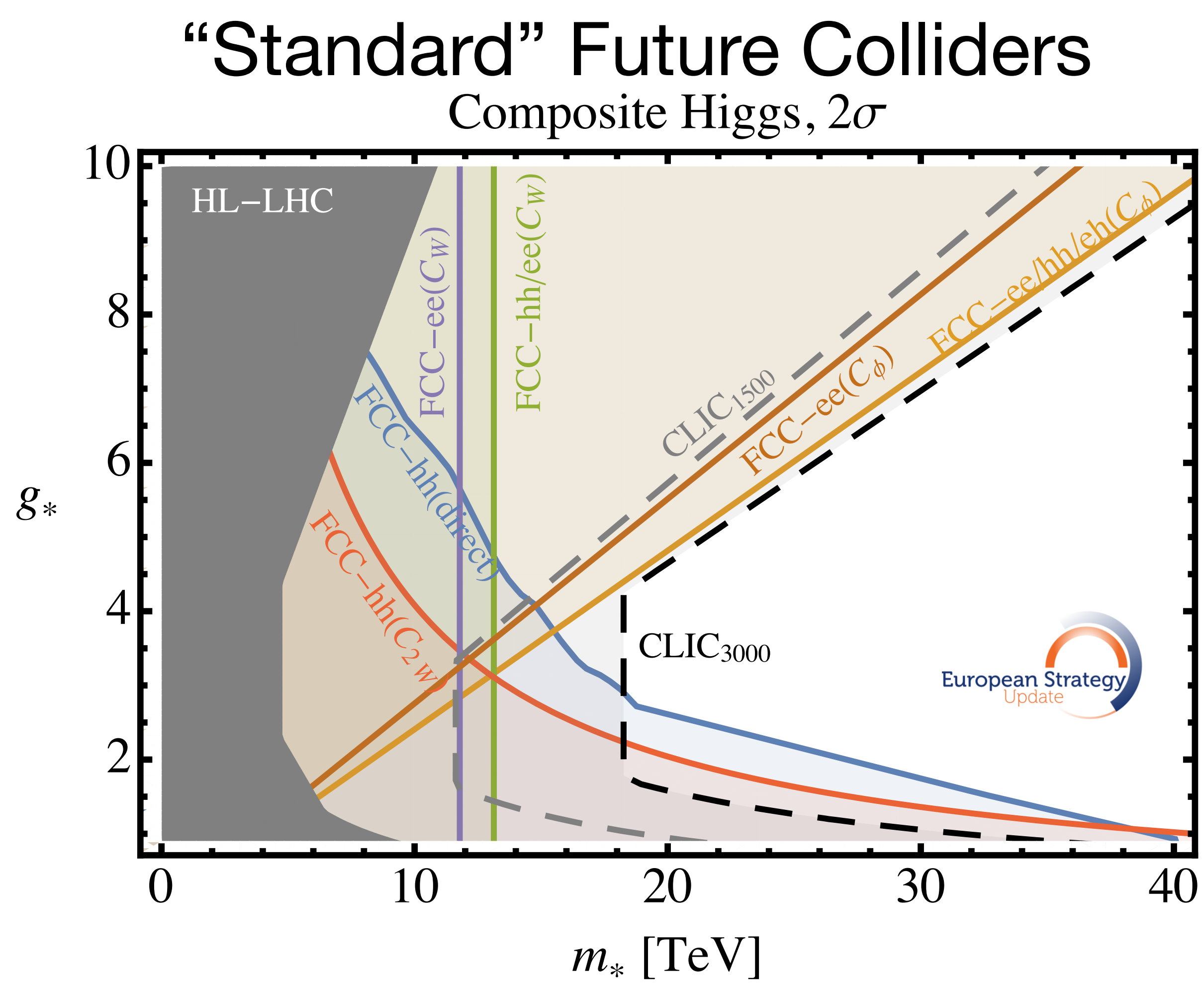

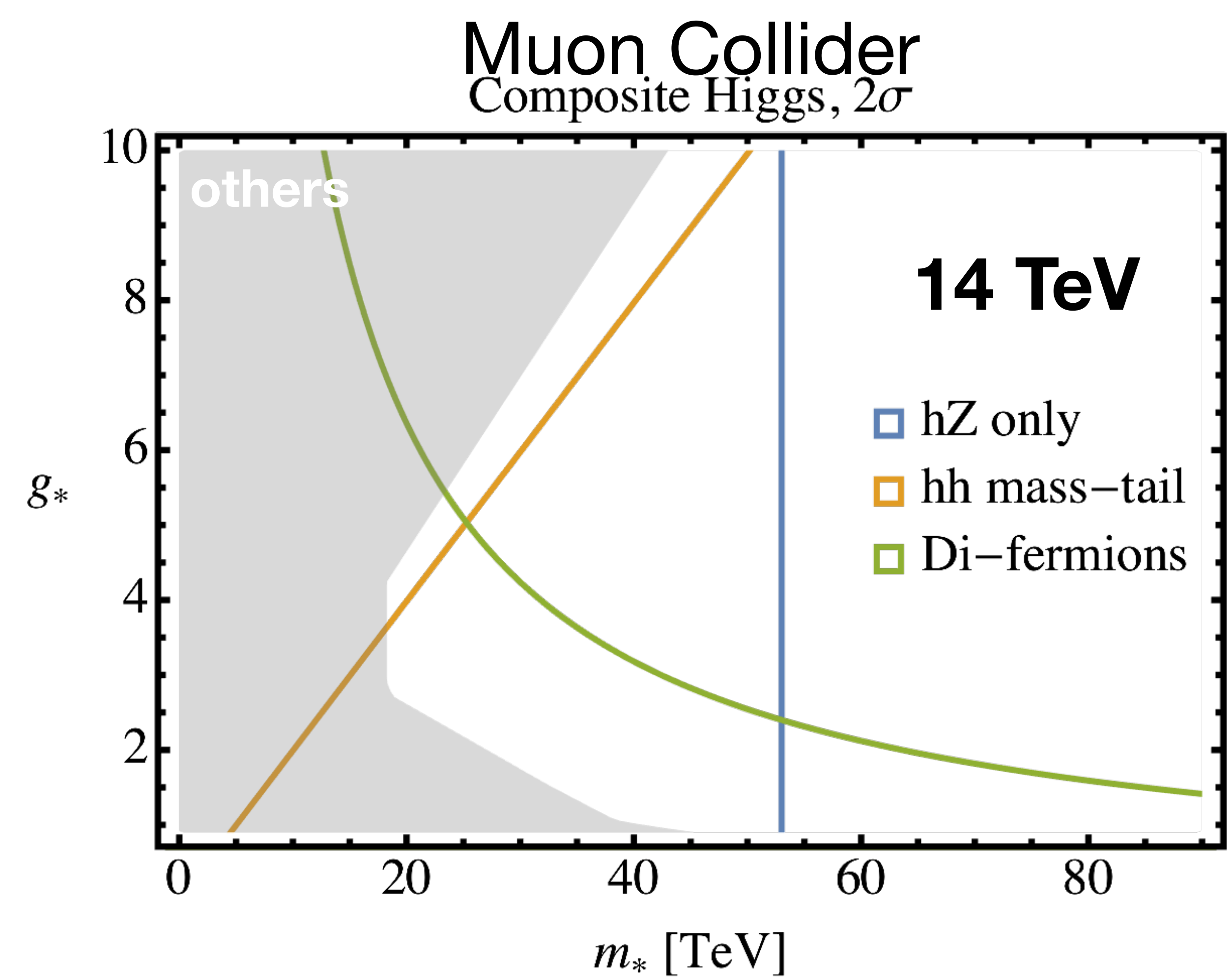

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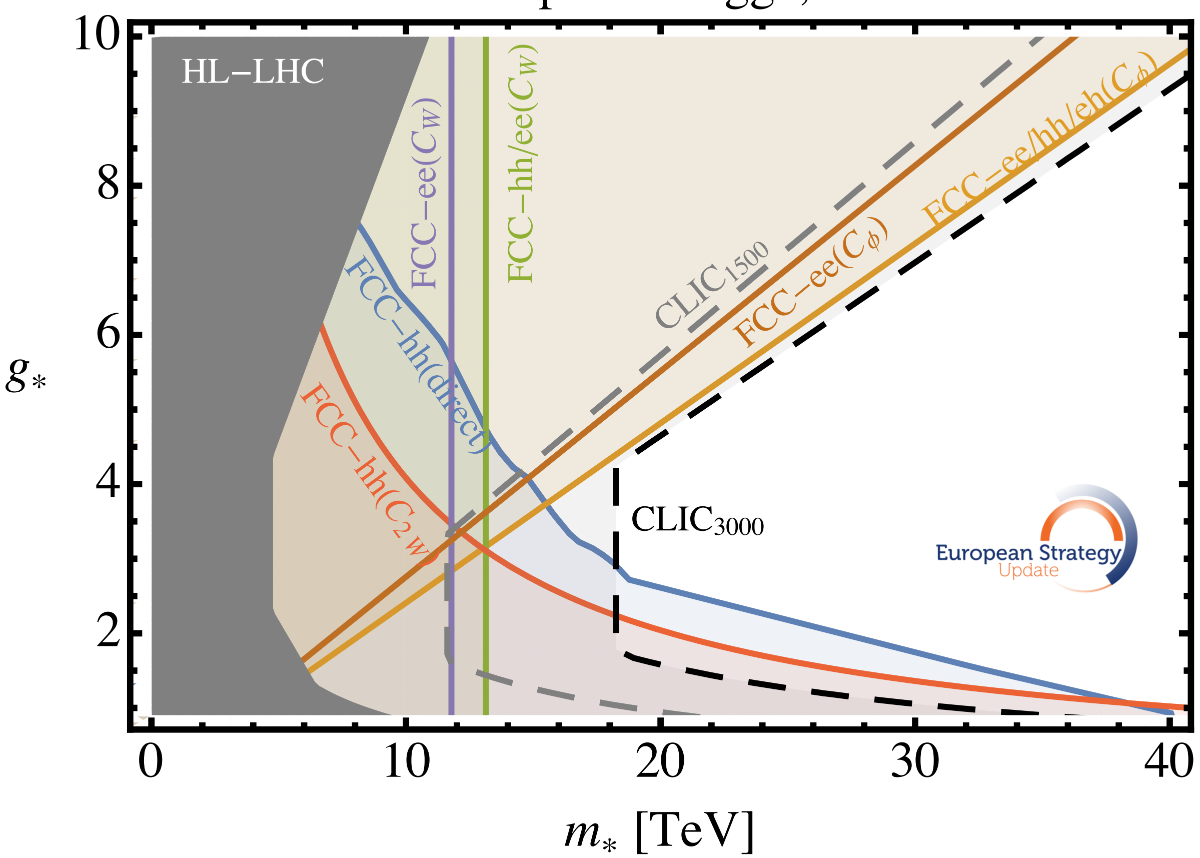

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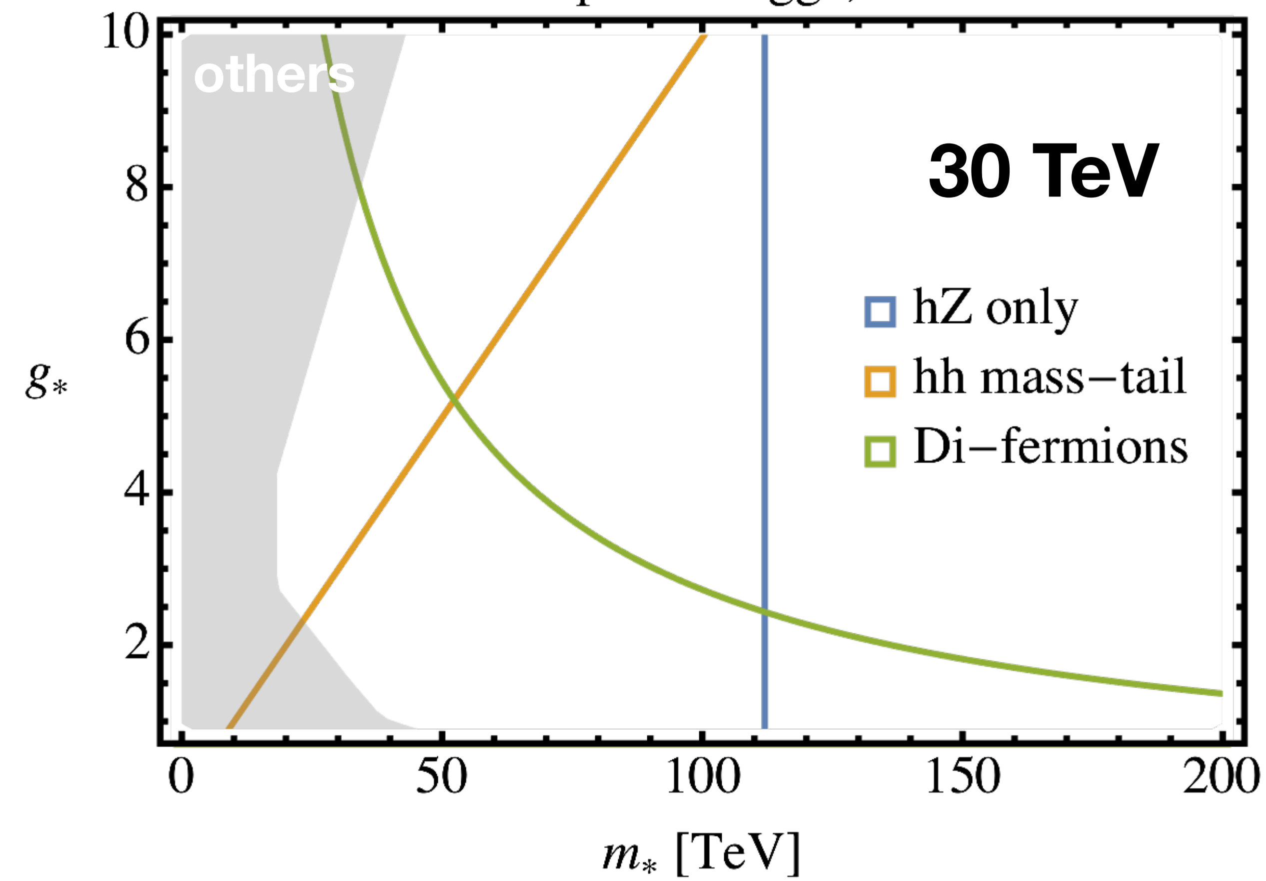

Even Simpler: Minimal Z's

[Chen, Glioti, Ricci, Rattazzi, AW, in progress]

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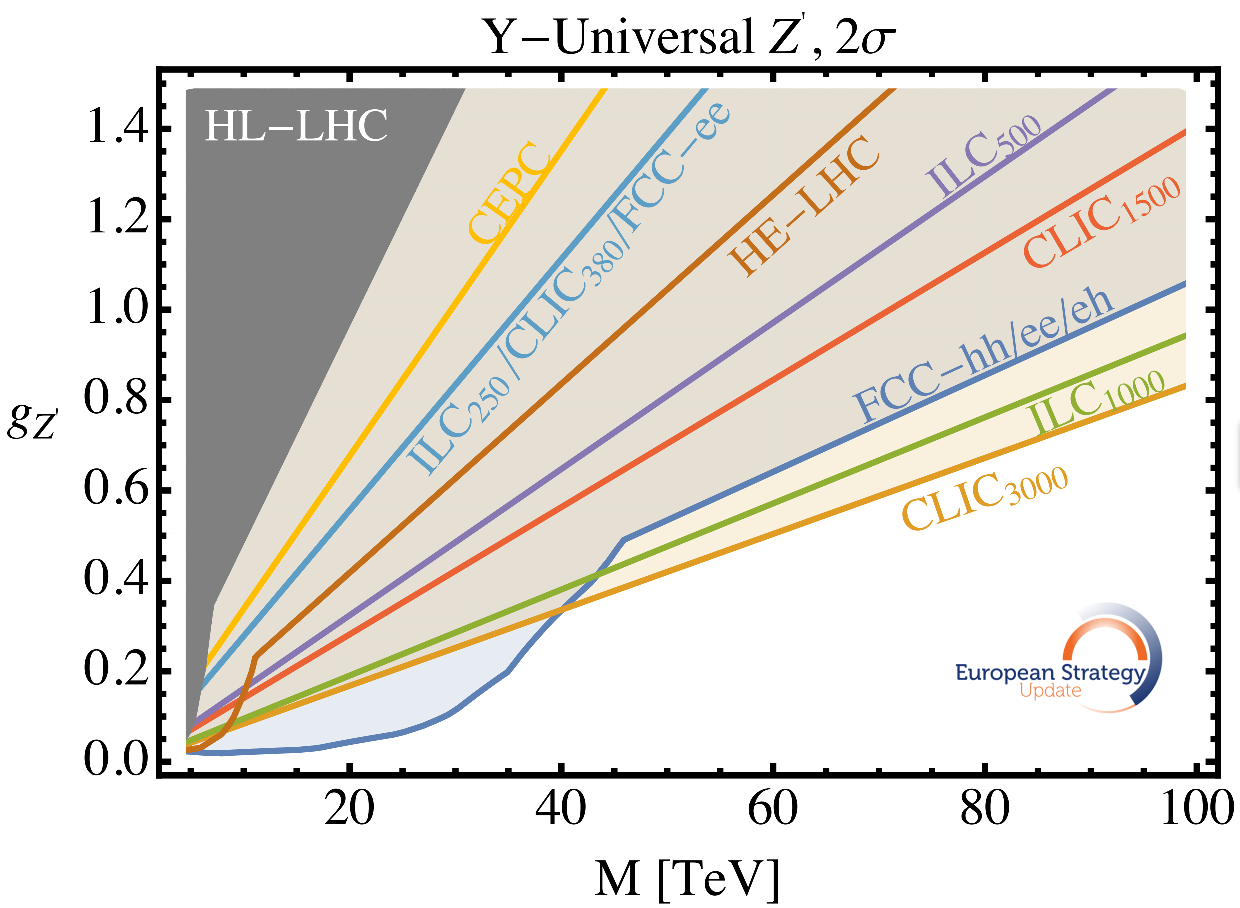

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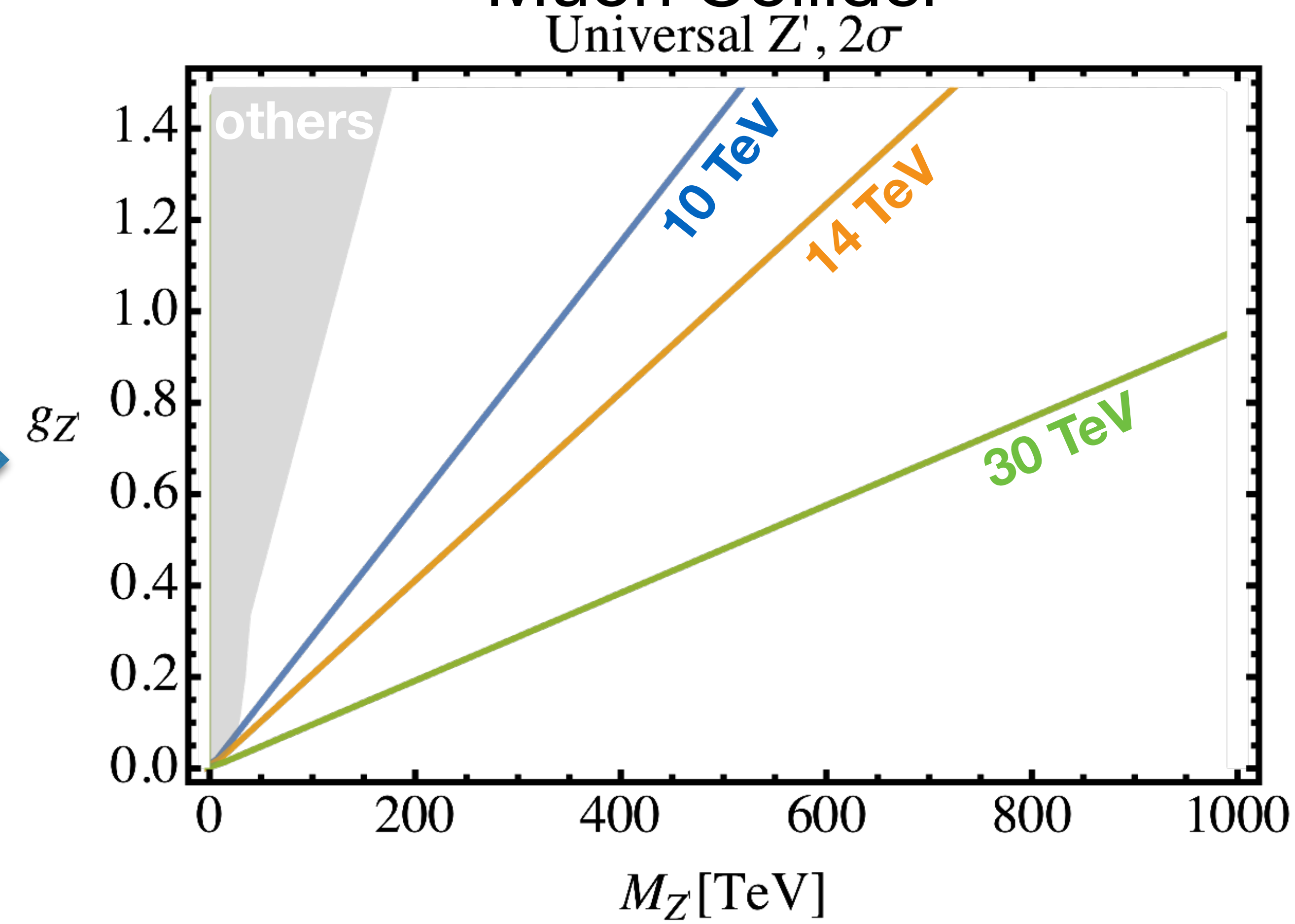

Outlook

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- It is **Important:** we might end up outlining a new possible direction for the continuation of the High Energy Physics journey
- It is **Fun:** novel BSM possibilities wait to be explored, as well as novel QFT challenges for predictions

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Goals of the Physics Potential group:

- Collect as many reach plots as possible; make them as realistic as possible
- Contribute and encourage work for **Snowmass**
- Inform Detector design of Physics needs, and get feedback
- Use the “target” μ-coll DELPHES card
- Join us! Write me, if you want to contribute to our regular meetings

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The Very High Energy Muon Collider is a Dream

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And, often, Dreams DO become Reality!

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Thank You !

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★ = FCC reach

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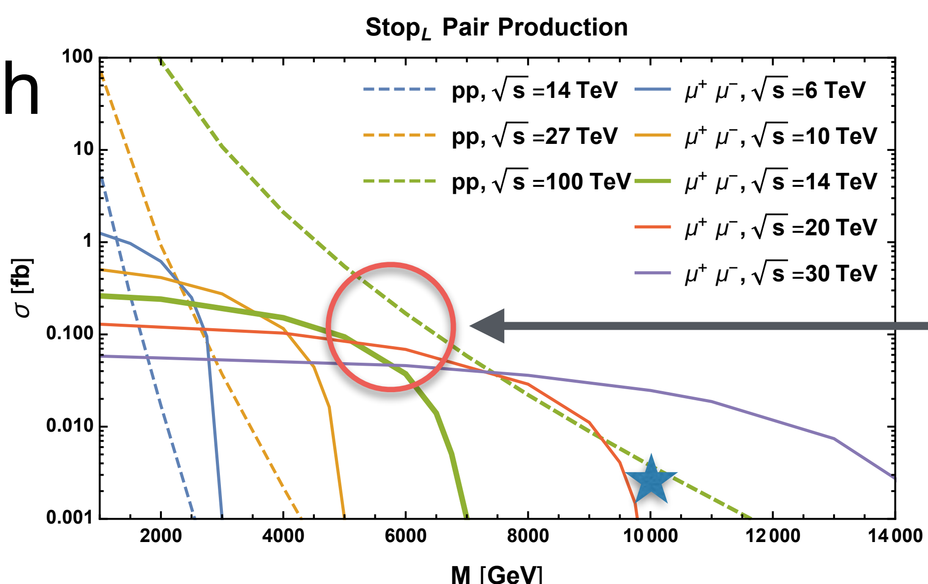
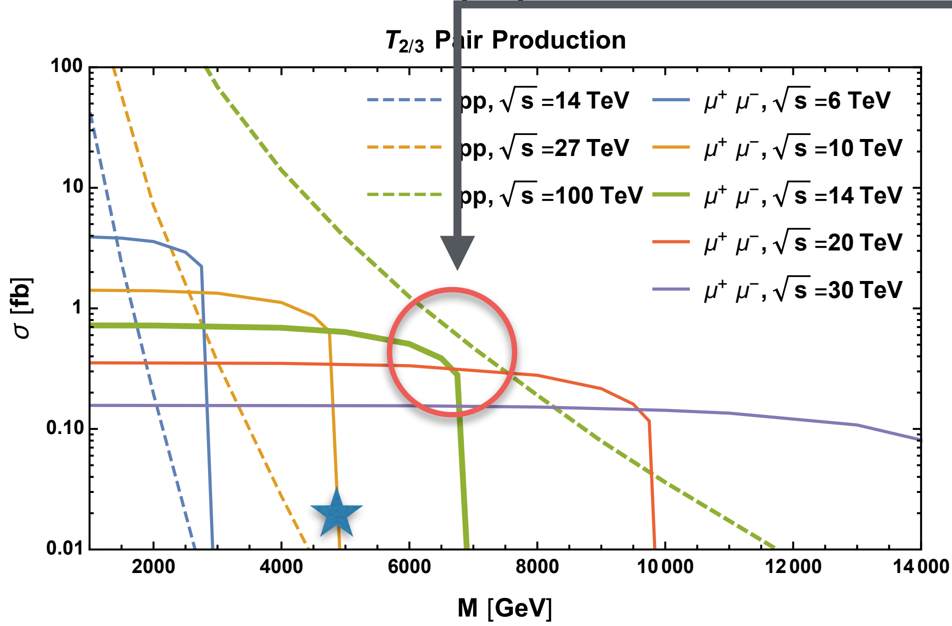
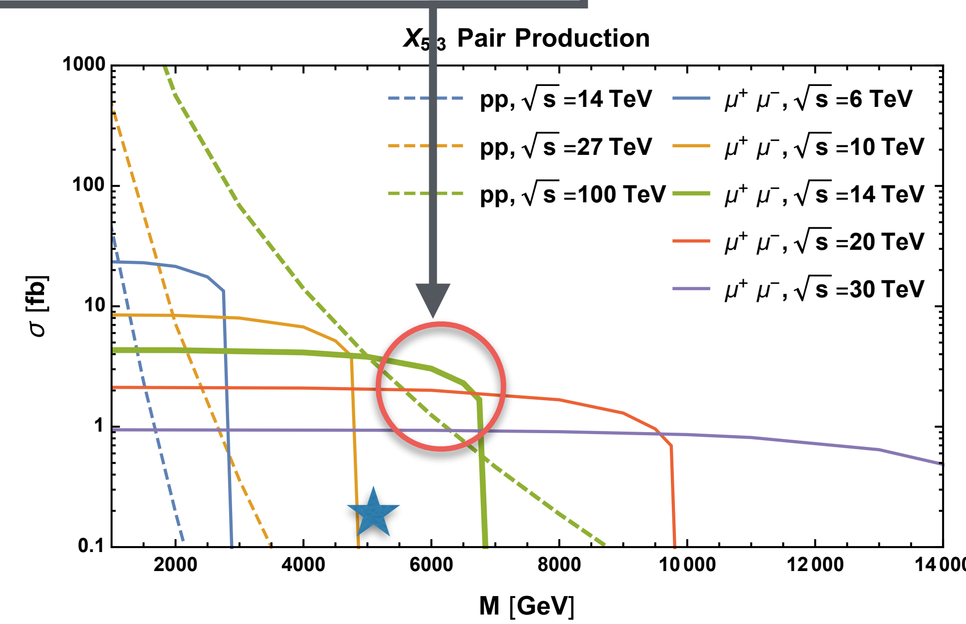
14 TeV μ-collider ~ FCC@100 TeV

Stop



Top-Partners





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Comparison even more favourable for EWK-only part. like **Higgsino** and **Wino** (potential **Dark Matter**)

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