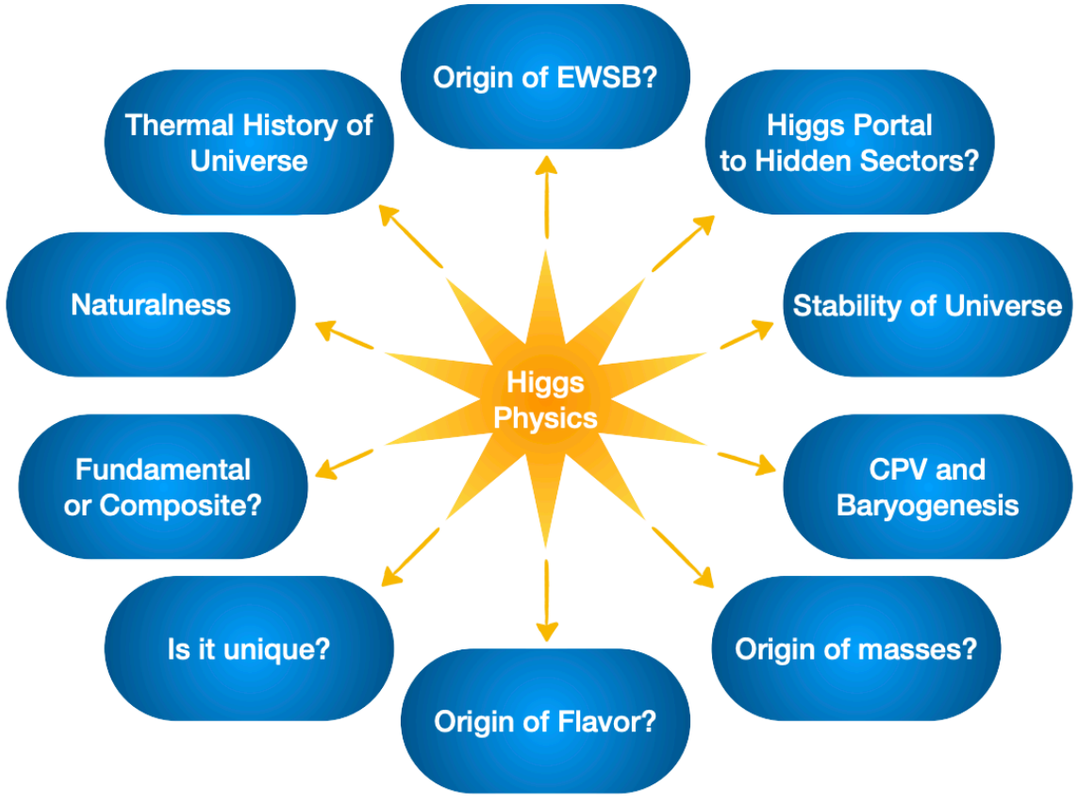
Higgs and C^3



M. E. Peskin
February 2024

outline:

Higgs IS the most important particle.

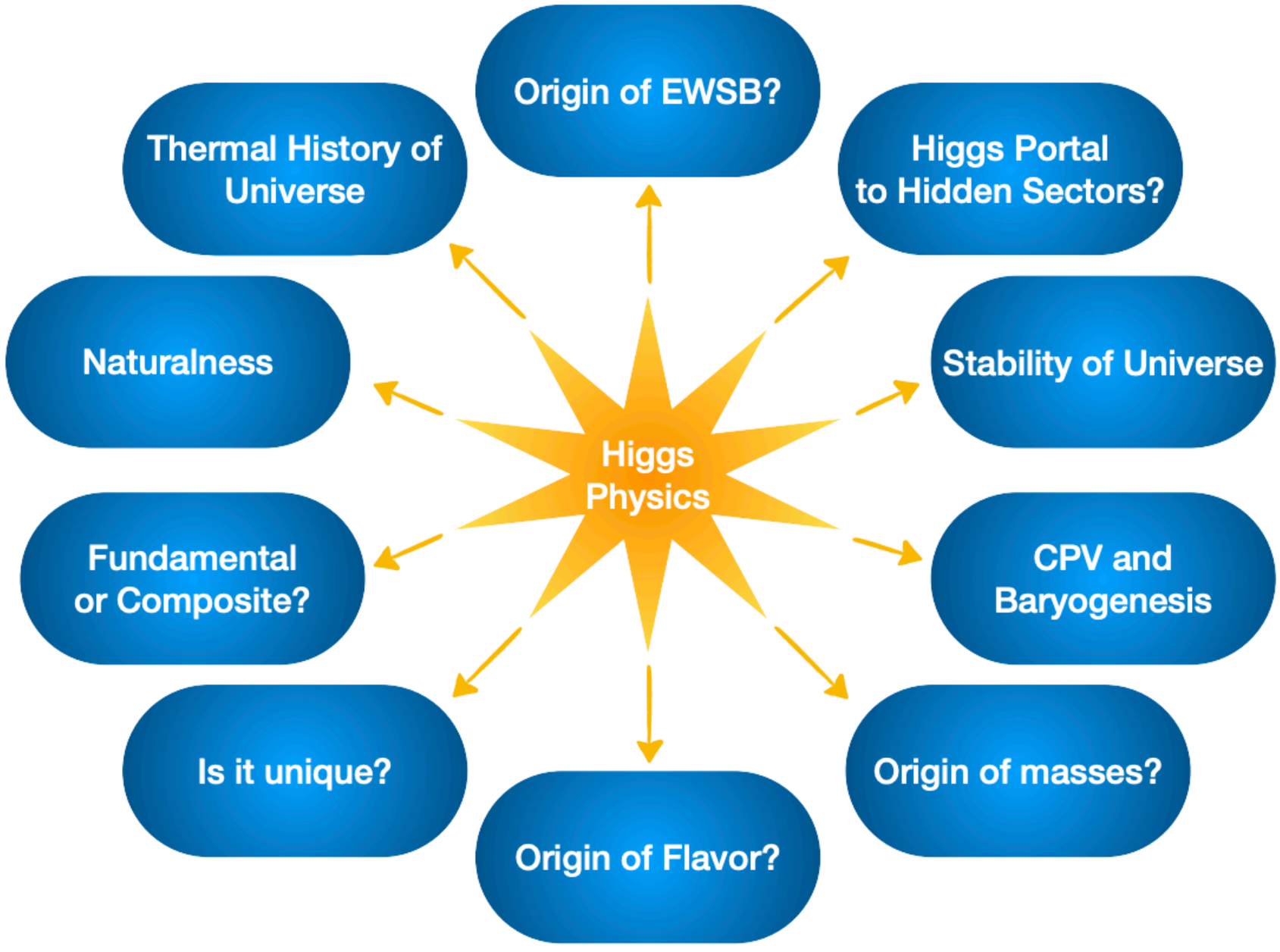
Opportunities for discovery with “ordinary” Higgs decays

Importance of reaching 550 GeV

Why C^3?

Higgs IS the most important particle

from the Snowmass Energy Frontier report:



The successes of the Standard Model depend on the gauge couplings

The mysteries of the Standard Model depend on the Higgs couplings

flavor, CP violation, neutrino masses

all go back to couplings to the Higgs

Baryogenesis, dark matter depend on new scalar couplings and new symmetry breakings

Renormalizable couplings of scalars are in principle
uncomputable.

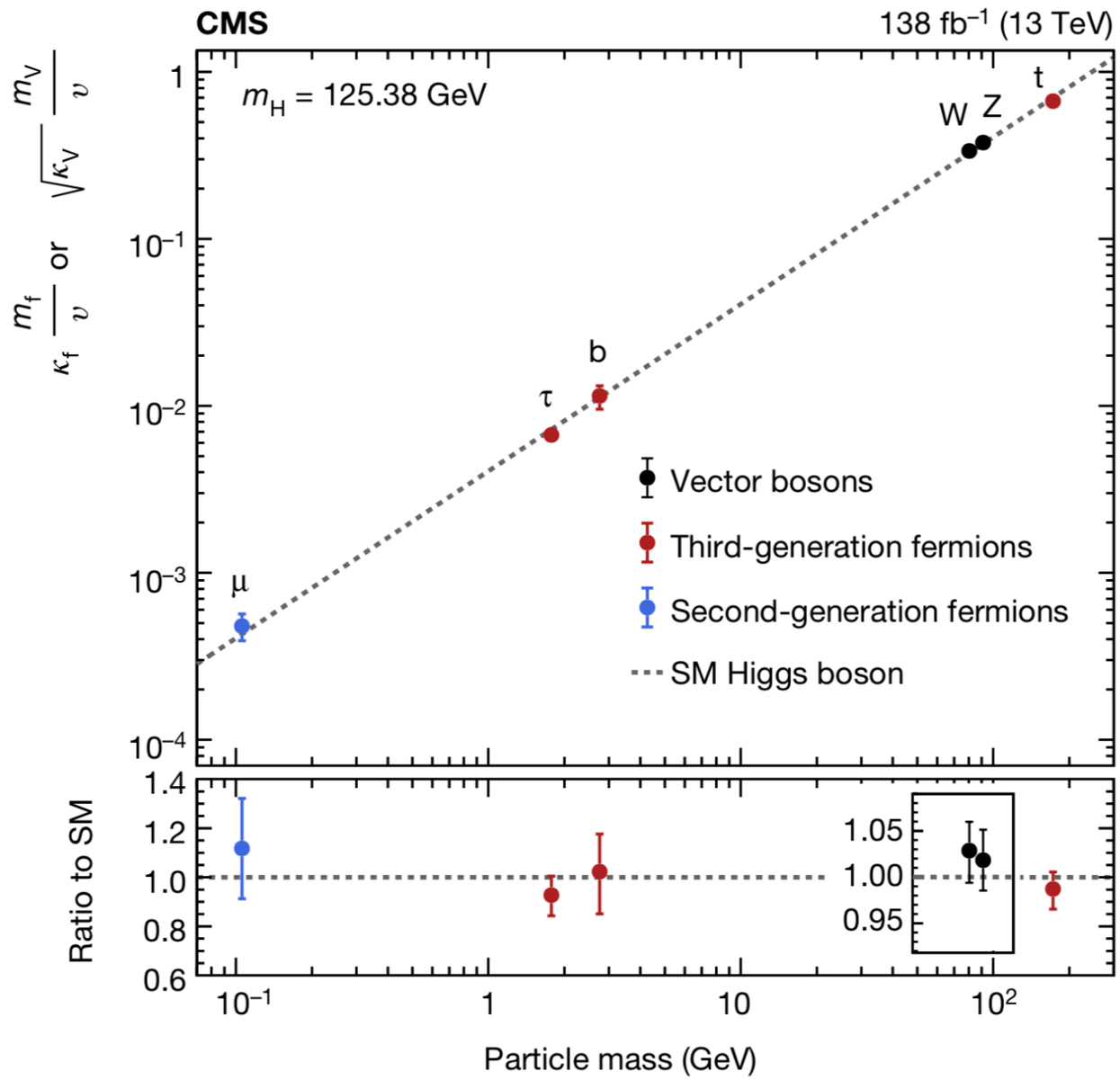
Until we can get beyond the need for these,
we cannot make progress in particle physics

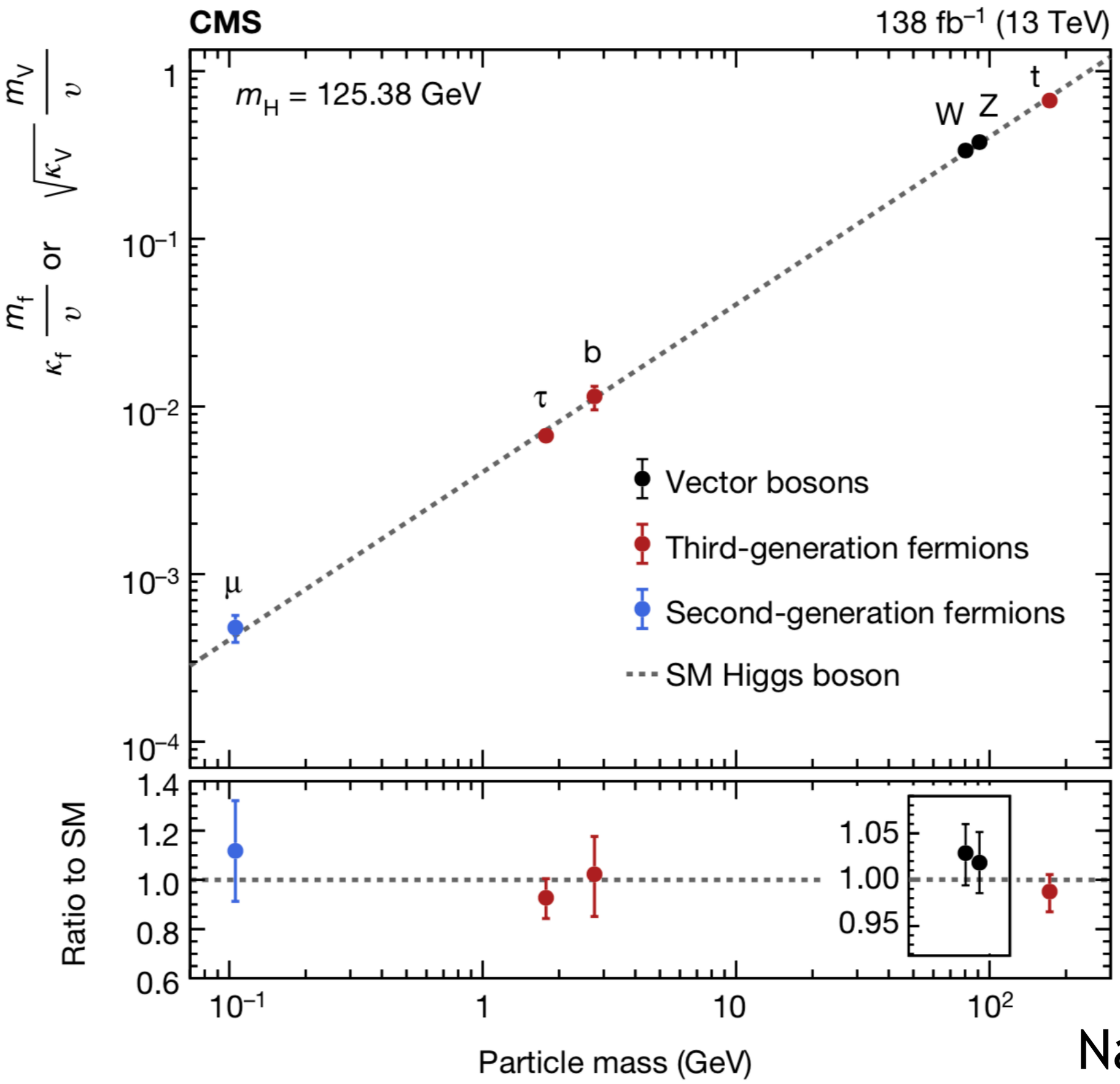
To overcome this difficulty, we need to know

why does the Higgs do what it does ?

Opportunities for discovery with “ordinary” Higgs decays

ATLAS and CMS find that the Higgs is SM-like. Is there still room for discovery?





CMS
Nature 2022

In Effective Field Theory,

deviations in Higgs couplings are of order v^2/M^2

with M ~ TeV, this is a few percent effect

ATLAS and CMS are not yet in the game.

Higgs couplings are the best place to look for new physics effects, and the last place we are looking.

In the High-Luminosity era, the LHC experiments will do better. But still,

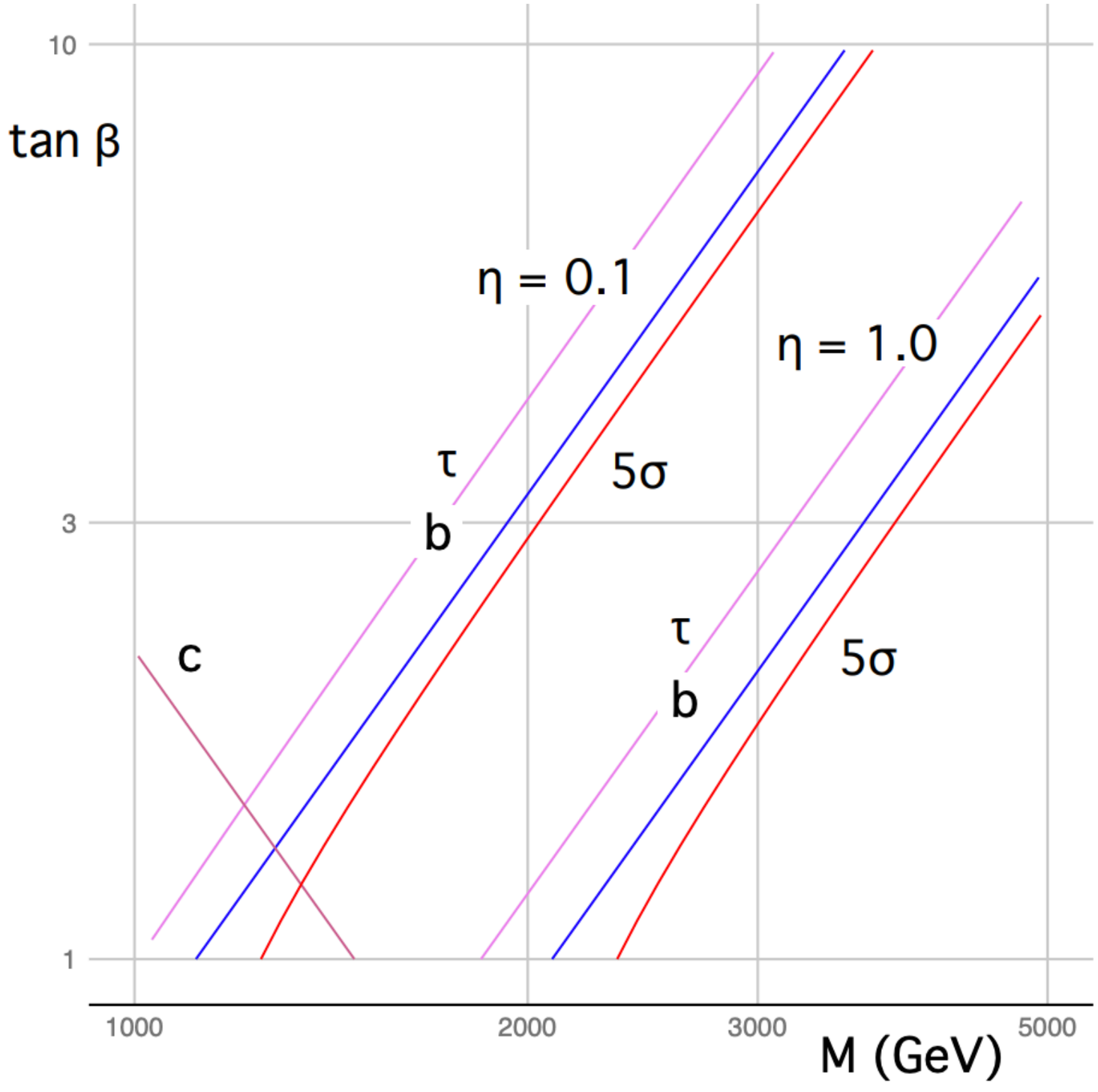
The goal is not to simply decrease the errors. The goal is to make a discovery.

The effect must be 5 σ - statistical plus systematic

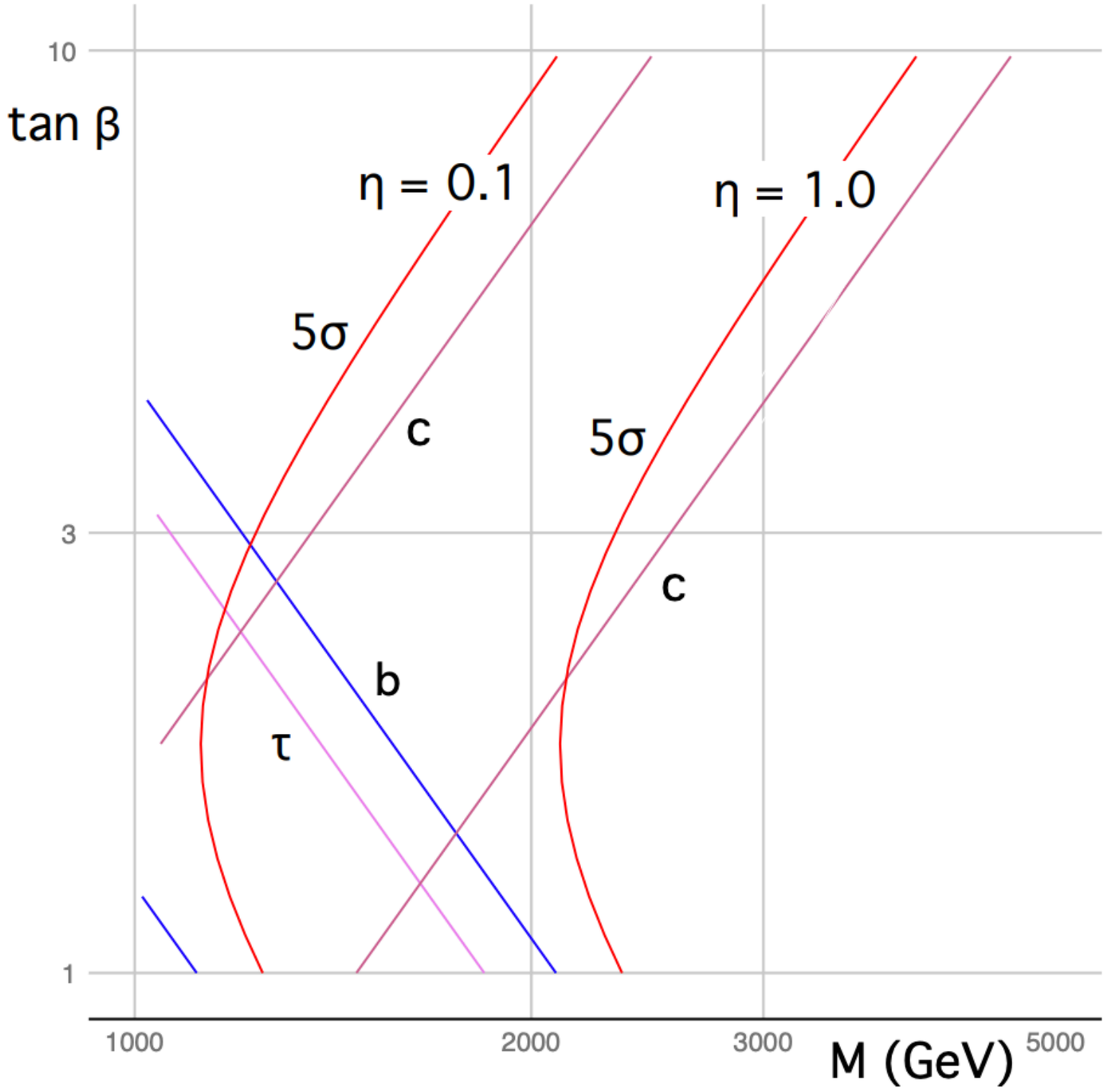
LHC analyses are complex; can they make a believable discovery ?

Not every new physics model has a large enough effect to meet the projected reach of Higgs factories, but there are many scenarios that yield discoveries:

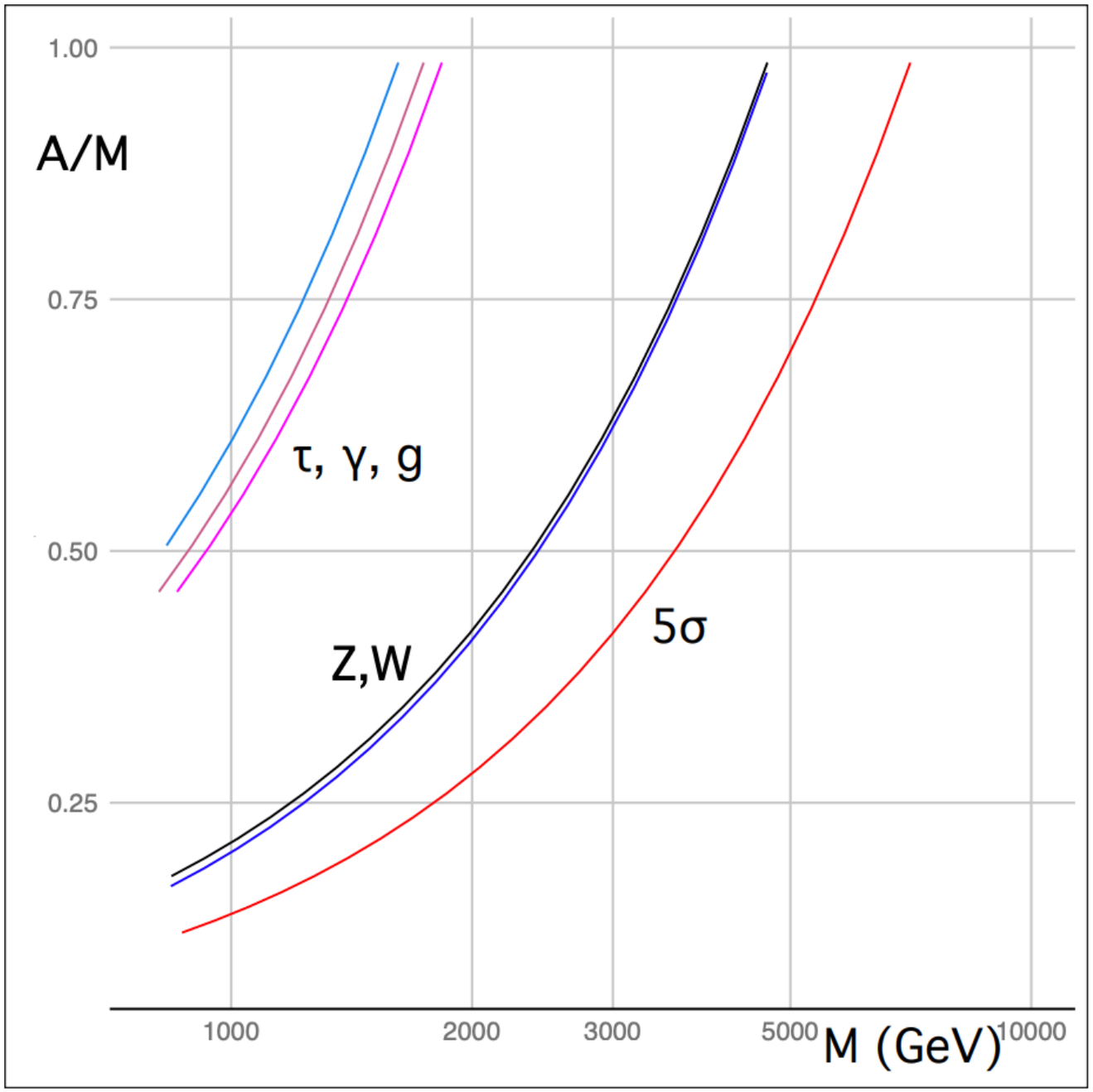
Type II two-Higgs couplet model:



flavorful THDM with enhancement of the charm Yukawa coupling:

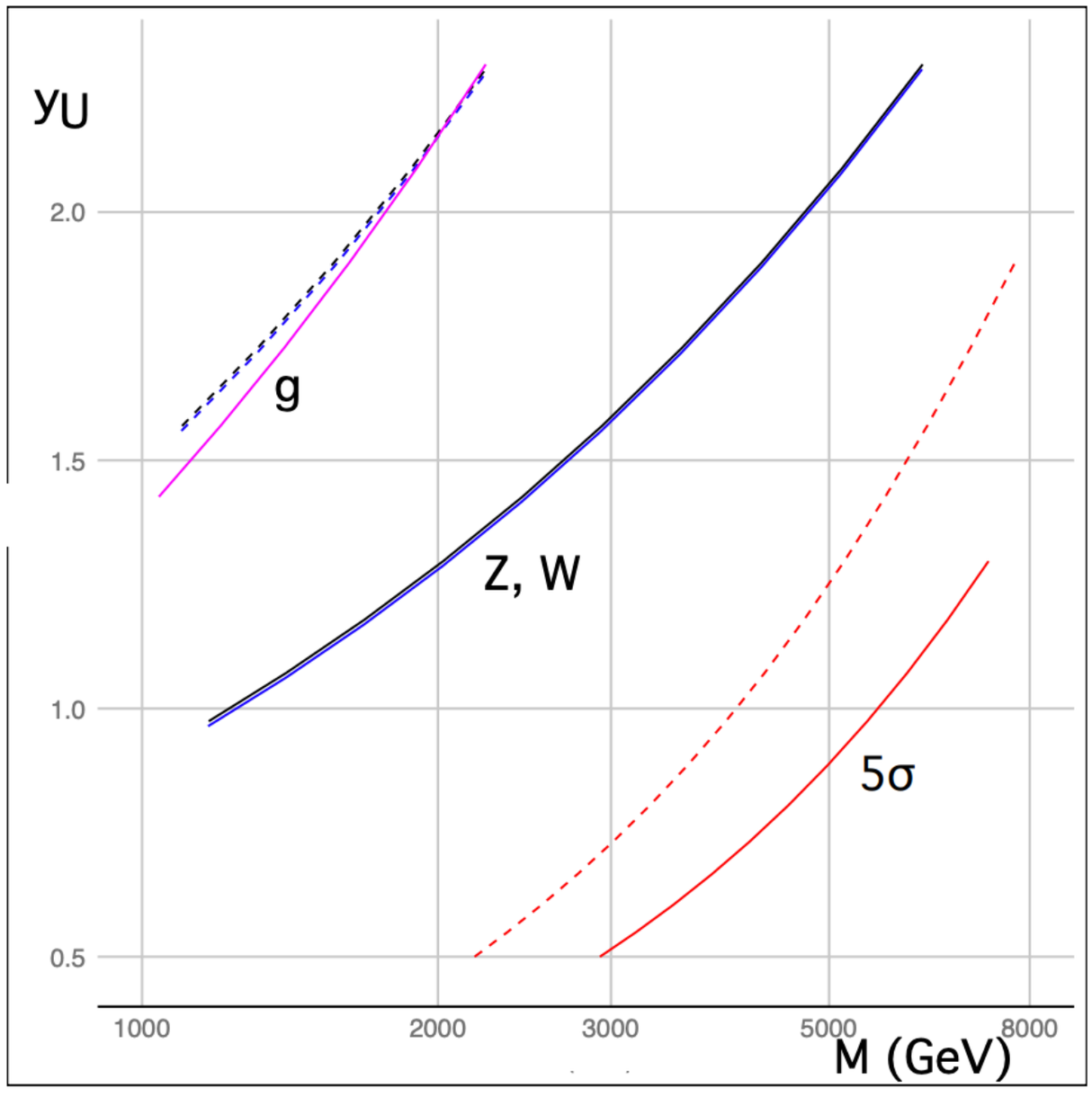


Mixing of a scalar singlet with the Higgs



This model will also show a large correction to the Higgs self-coupling.

Integrating out a vector-like quark doublet



HL-LHC reach for vectorlike quarks is ~ 1.5 TeV

This model will also show a large correction to the top quark Yukawa coupling.

Importance of reaching 550 GeV

A Higgs factory program with a top energy of 370 GeV misses two crucial Higgs observables:

$e^+e^- \to t\bar{t}H$ top quark Yukawa coupling (to 4%)

$e^+e^- \to ZHH$ Higgs self-coupling (to 20%)

It is discussed that it is possible to measure the Higgs self-coupling without measuring double Higgs production, by measuring the single Higgs processes sufficiently precisely.

The problem is that the effect is small (1.5%) and highly degenerate with a shift in the HZZ and HWW couplings. In terms of SMEFT parameters

Higgs pair production:

$$\sigma/\sigma^{SM}(ZHH) = 1 + 0.56c_6 - 4.15c_H + 15.1(c_{WW}) + 62.1(c_{HL} + c'_{HL}) -$$

Single Higgs cross section:

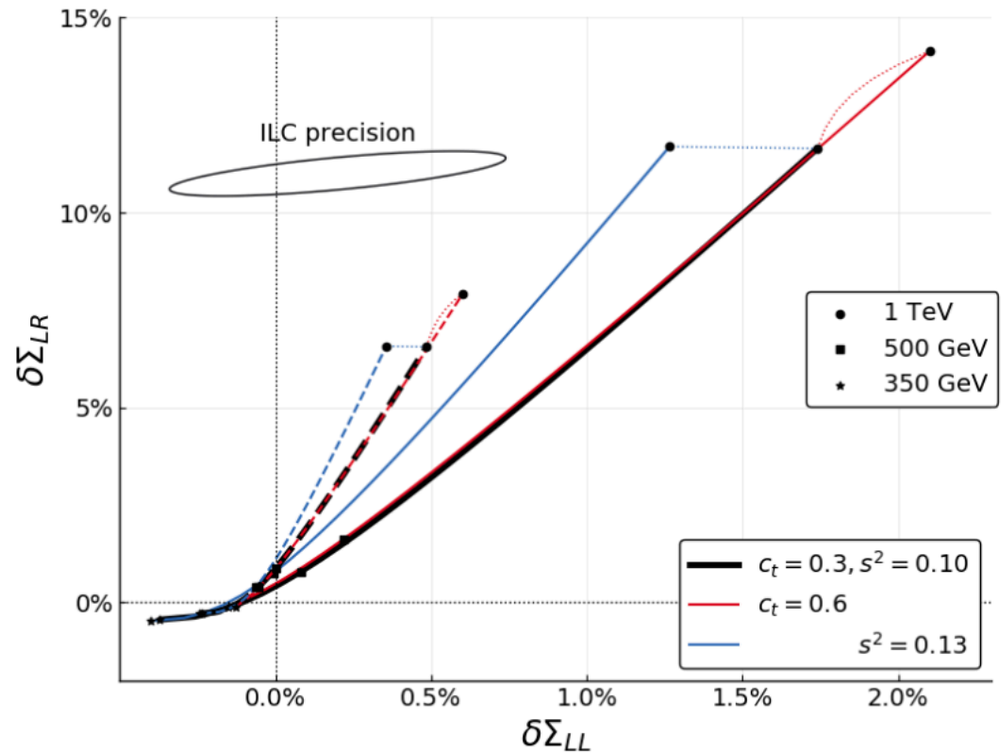
$$\sigma/\sigma^{SM}(ZH) = 1 + 0.015c_6 - c_H + 4.7(c_{WW}) + 13.9(c_{HL} + c'_{HL}) -$$

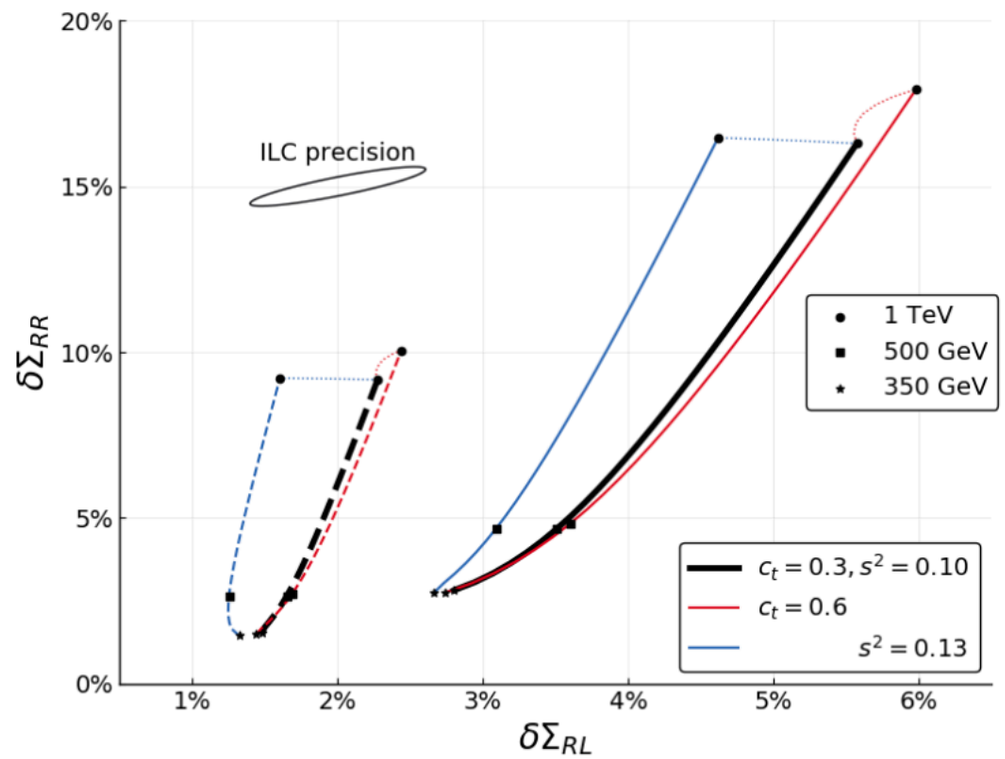
If we can go to higher energy, higher precision is possible. With running at 1 TeV:

$e^+e^- \to t\bar{t}H$ top quark Yukawa coupling (to 1%)

$e^+e^- \to \nu\bar{\nu}HH$ Higgs self-coupling (to 10%)

While we are thinking about high energies, please do not forget about the possibility to discover new physics in $e^+e^- \to t\bar{t}$





polarized cross section deviations in the 5-d model of Peskin and Yoon, arXiv:1811.07877

Why C^3?

Given the great physics opportunities for an e+e- Higgs factory and the manifest importance of learning more about the Higgs boson,

why aren't we building a Higgs factory now ?

The most important obstacle is cost. The cost of any Higgs factory is of the order of $10 B, comparable to the cost of the LHC. This will need to be sold as an world-leading collider, with global participation.

Another major reason is the apathy of the LHC experimental community. Most LHC experimenters cannot look beyond the LHC. Many of them are fully engaged with the construction of the upgrade detectors for the High Luminosity stage.

Unfortunately, the earliest that any Higgs factory could operate has now been pushed back to about 2040. A Higgs factory at CERN cannot start before 2045, and probably a start date in the 2050's is more realistic.

It is thus imperative that you impress upon your colleagues the urgency of engaging with Higgs factories now.

There is an opportunity to carry out projects within the scope of the ECFA Higgs/Top/EW study. This study is going on now and should report its findings in 2025.

P5 has requested money for both detector and accelerator R&D for Higgs factories. This gives another incentive to get involved now.

ILC has put together substantial resources for Higgs factor physics studies. See arXiv:2007.03650 , or ask me or Caterina.

How does C^3 fit into this picture?

C^3 was not recommended by P5 for US participation. However, it was recommended for R&D, with the possibility of reconsideration by a new panel in 2027-2028. Between then and now, C^3 must be converted from an R&D project to a real collider proposal.

How to do this will be an important topic of this meeting.

What are the advantages of C^3?

1. Lowest cost Higgs factory

2. Most resource-conservative Higgs factory

3. Simplest and least expensive route to 550 GeV

4. Availability of beam polarization

5. (for US and European audiences): It's not ILC.

Personally, I take this very seriously.

I believe that C ^{3} is our best chance that to actually learn more about the Higgs boson and to obtain clues to the fundamental mysteries of particle physics.

Without C ^{3}, there is a good chance that LHC will be the last collider, and our hope for knowledge will be closed off.

So we need to make this initiative succeed.