Physics case for future colliders
Activity of Gr4

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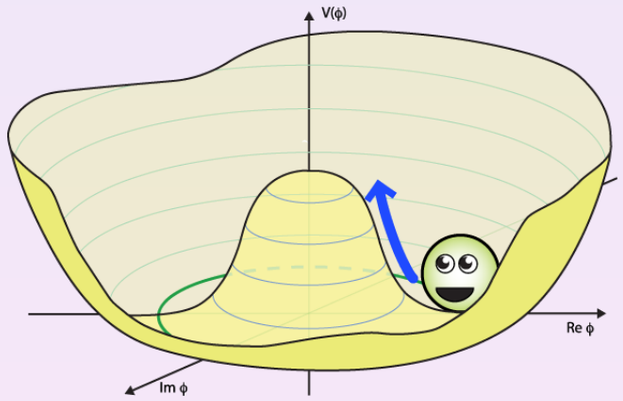
[ChatGPT on proposal of my daughter]

25/10/2024

Two main goals

Test the Standard Model

we have measured only a small part of the Higgs boson couplings



Find answers to the open questions of the Standard Model

such as neutrino masses,
matter-antimatter asymmetry of the universe,
dark matter

Search for new physics

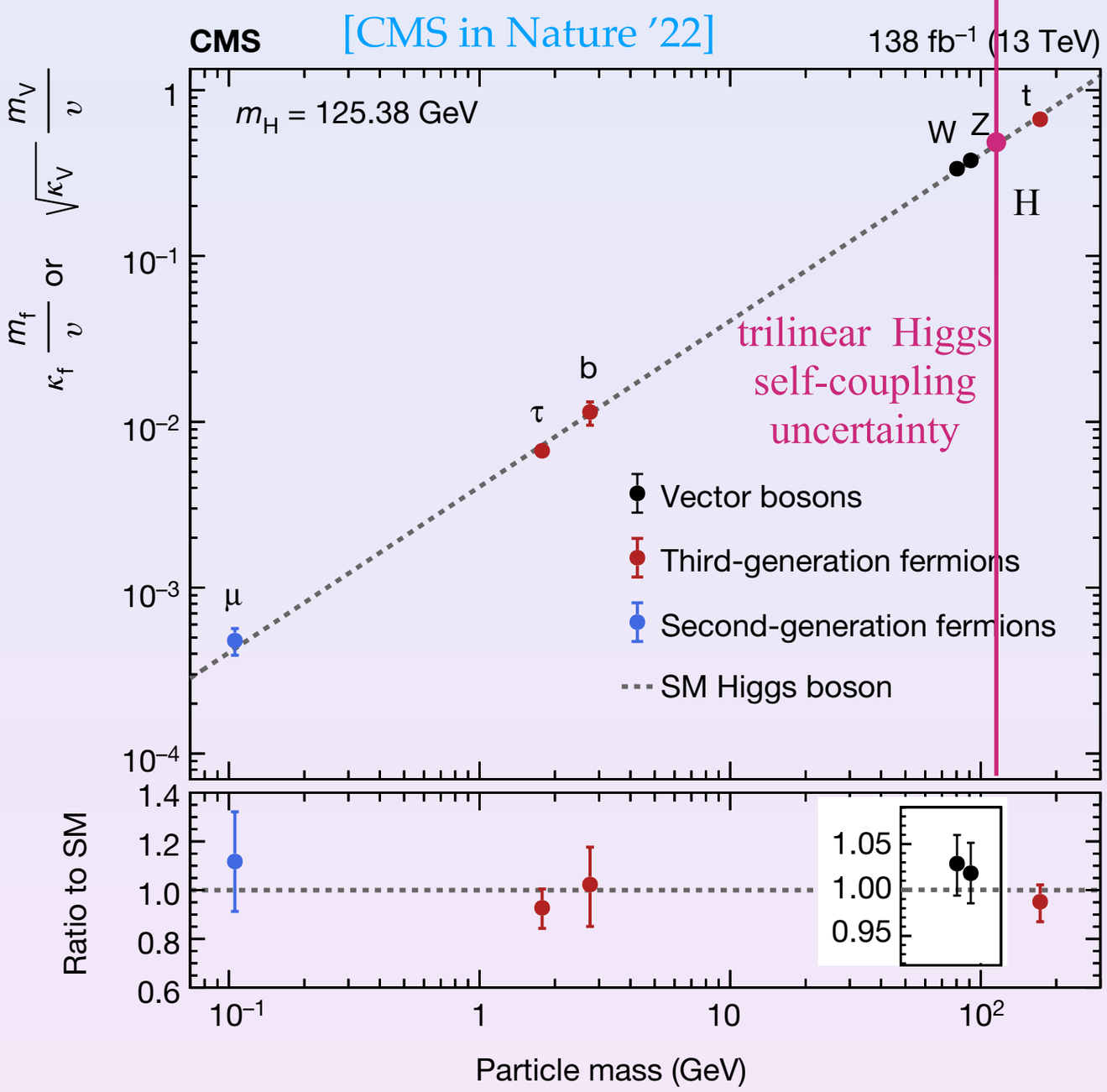
Higgs couplings

3rd generation fermion and gauge boson couplings to Higgs boson fairly good measured

2nd generation fermion couplings first results available

Higgs self-couplings?

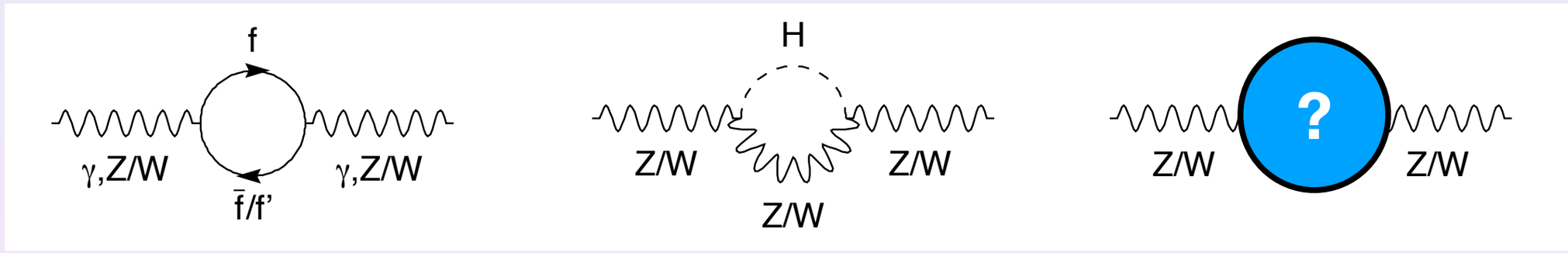
First and second generation quark Yukawa couplings?



Electroweak precision

The Standard Model is so far extremely successful! Thanks also to precise electroweak input.

Electroweak precision observables probe quantum structure of Standard Model.



The higher the precision (experimental and theoretical) the better we can probe the SM and new physics!

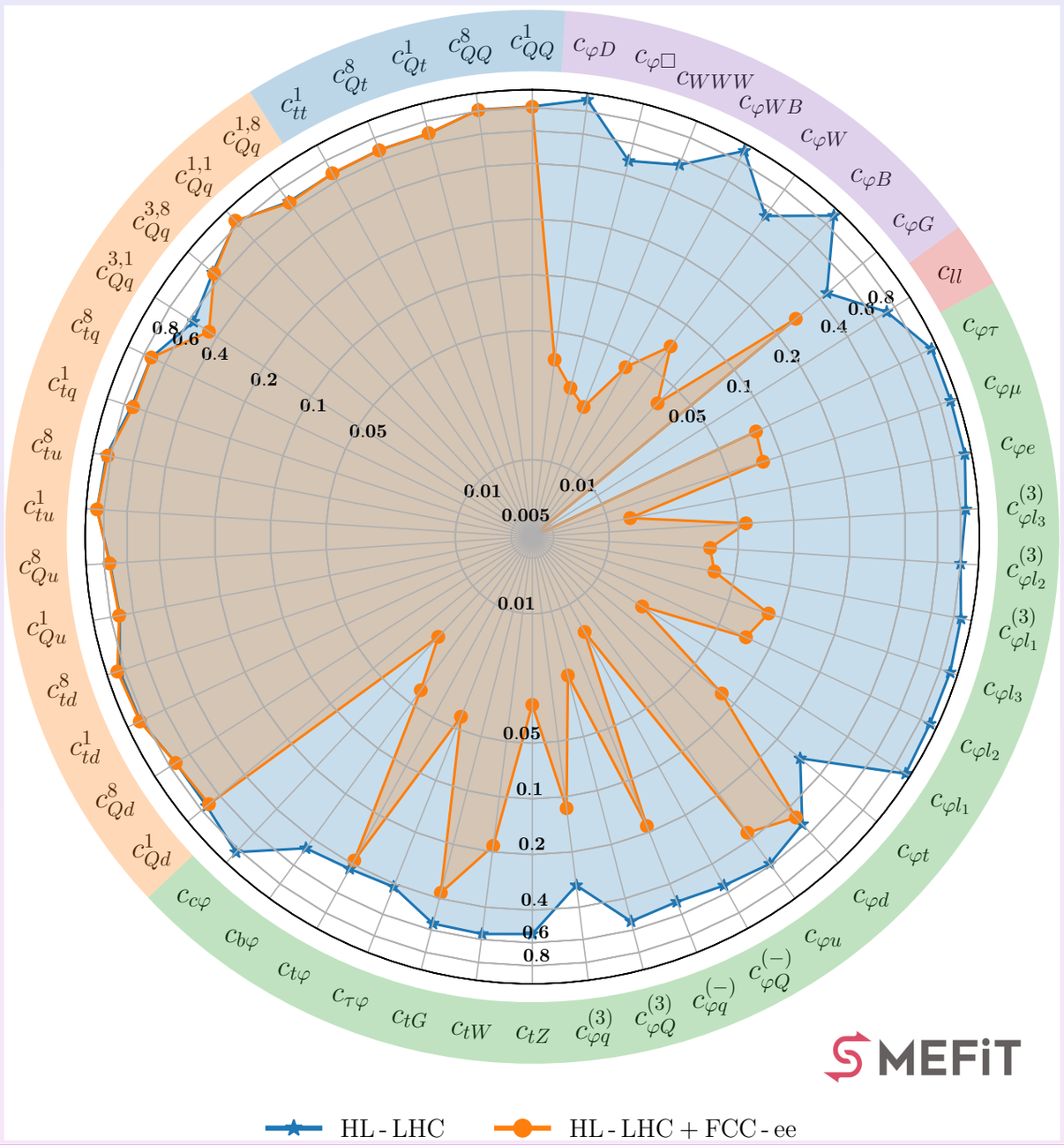
Fits in SMEFT

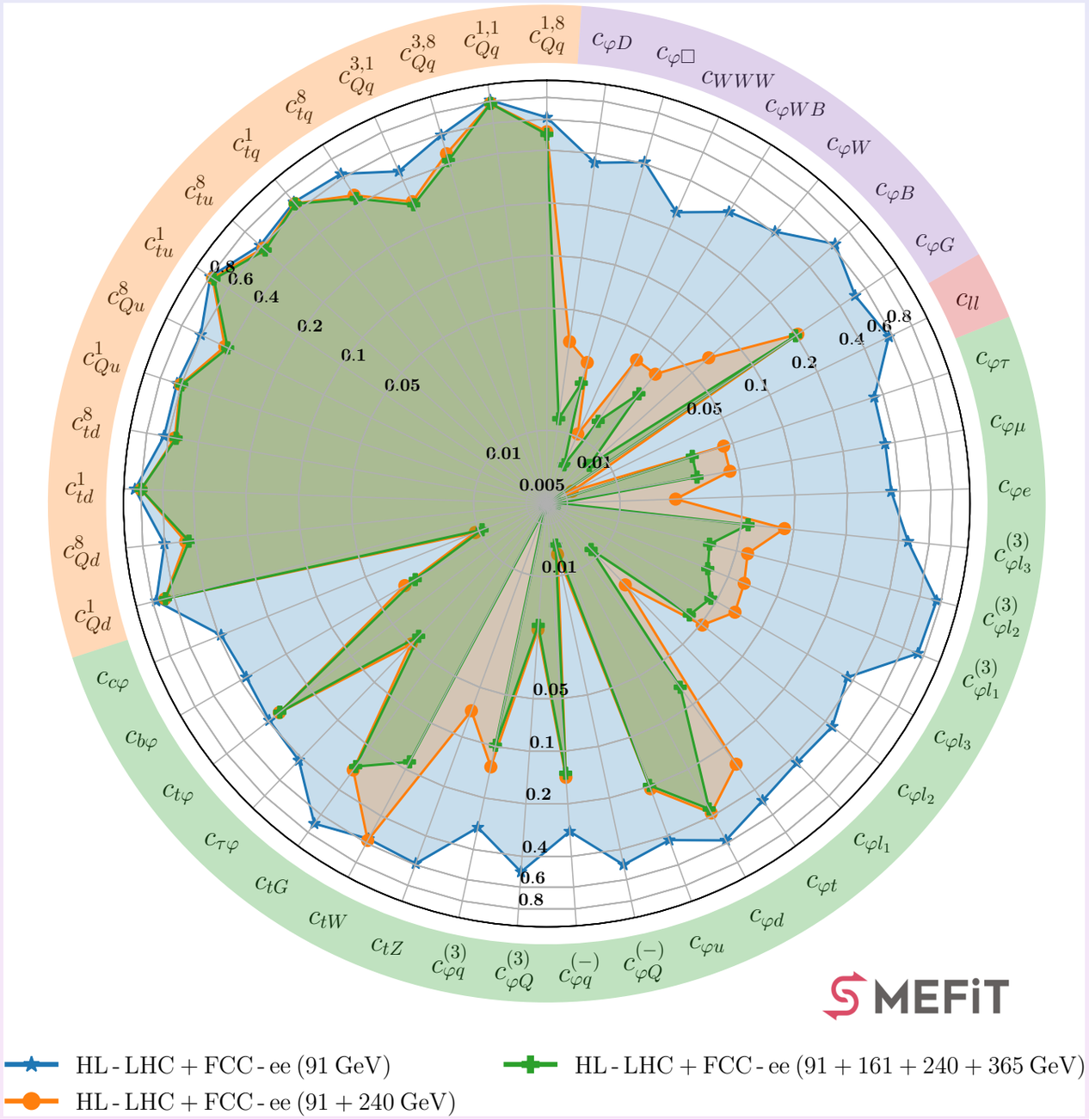
Standard Model Effective Field theory provides a model-independent framework to test new physics

contact Alejo Rossia

$$\mathscr{L} = \mathscr{L}_{SM} + \sum \frac{c_{\mathcal{O}}}{\Lambda^2}\mathcal{O} + \dots$$

[Celada et al. 24]





Fits in simplified models

Fits to simplified models that match to SMEFT at tree-level can probe all models

see also [Allwicher, McCullough, Renner '24]

[Celada et al. 24]

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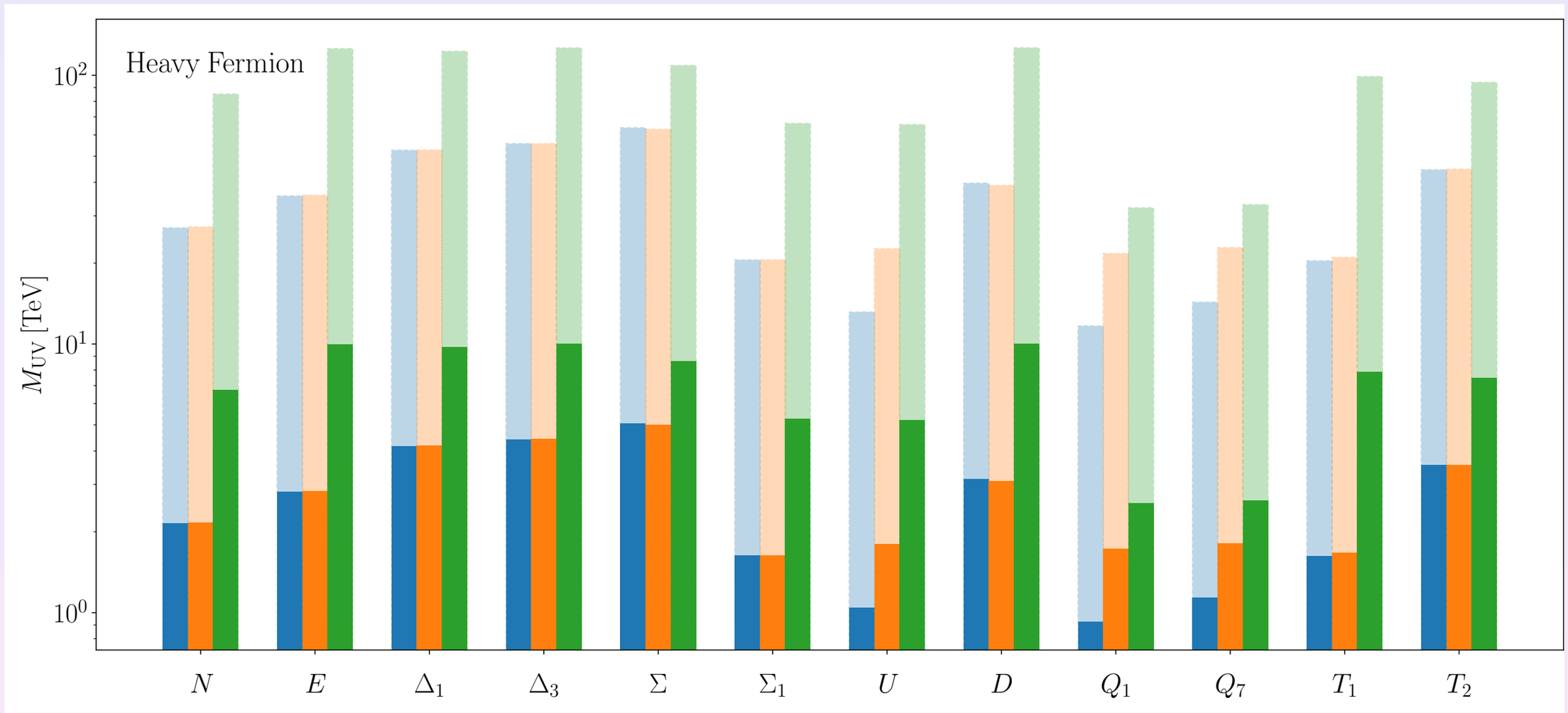


to be updated with Renormalisation group running effects

Light quark Yukawa couplings

Light quark Yukawa couplings in Standard Model Effective Field Theory modified by

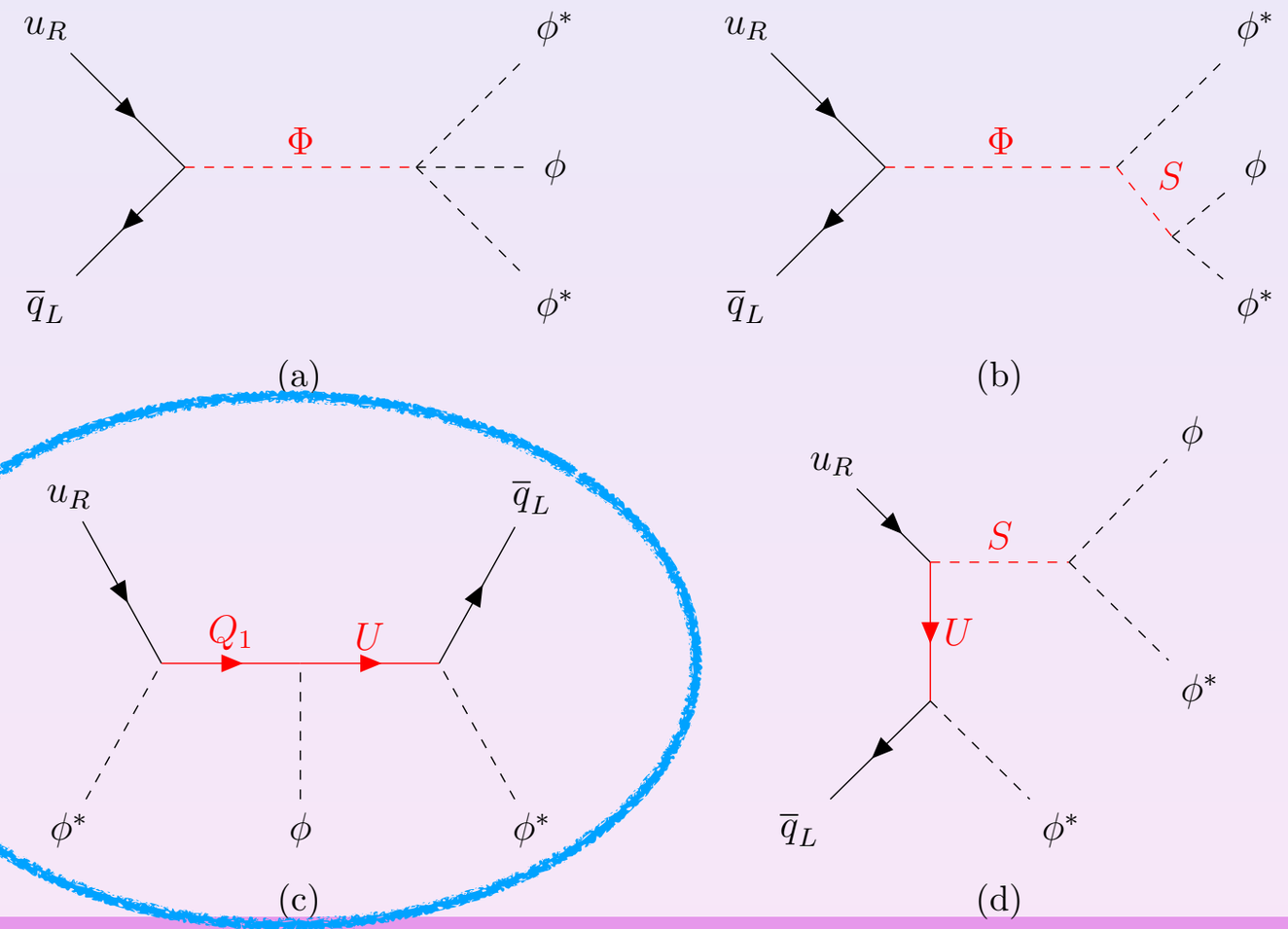
$$\mathcal{O}_{u\phi} = \bar{q}_L \tilde{\phi} u_R \phi^\dagger \phi \qquad \mathcal{O}_{d\phi} = \bar{q}_L \phi d_R \phi^\dagger \phi$$

$$g_{hq_i\bar{q}_j} = \frac{m_q}{v}\delta_{ij}\left[1 + v^2 \mathcal{C}_{\phi,\text{kin}}\right] - \frac{v^2}{\sqrt{2}}(\tilde{\mathcal{C}}_{q\phi})_{ij}$$

rescales all Higgs couplings
(hence constrained by Higgs couplings to vector bosons)

dominant modification
(mass eigenbasis)

two VLQ representations
no s channel resonance
decaying to dijets

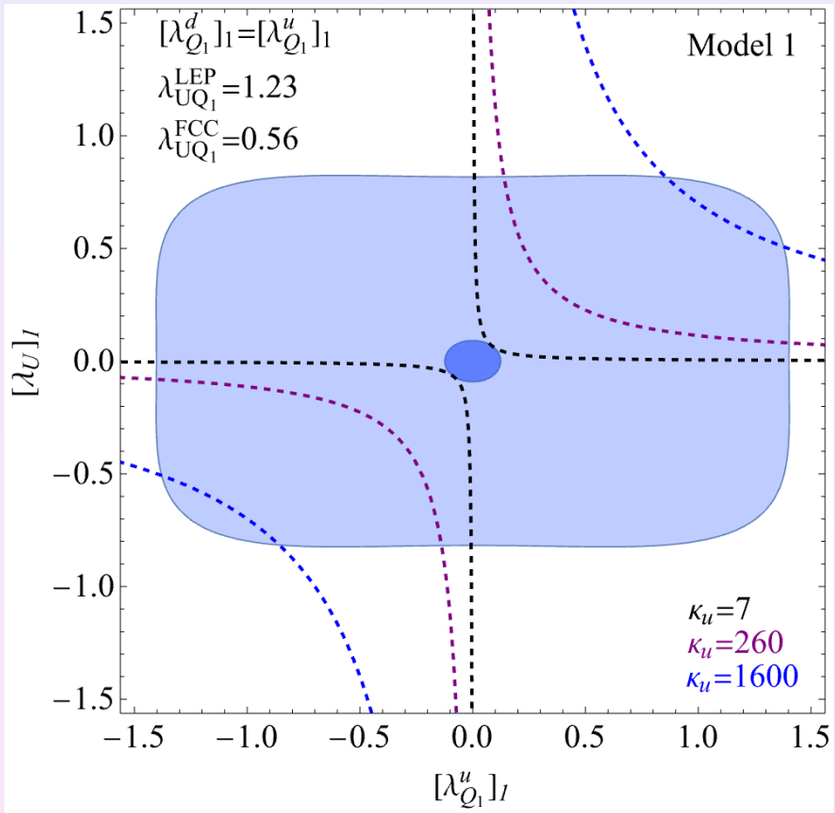


Vector-like quark Models

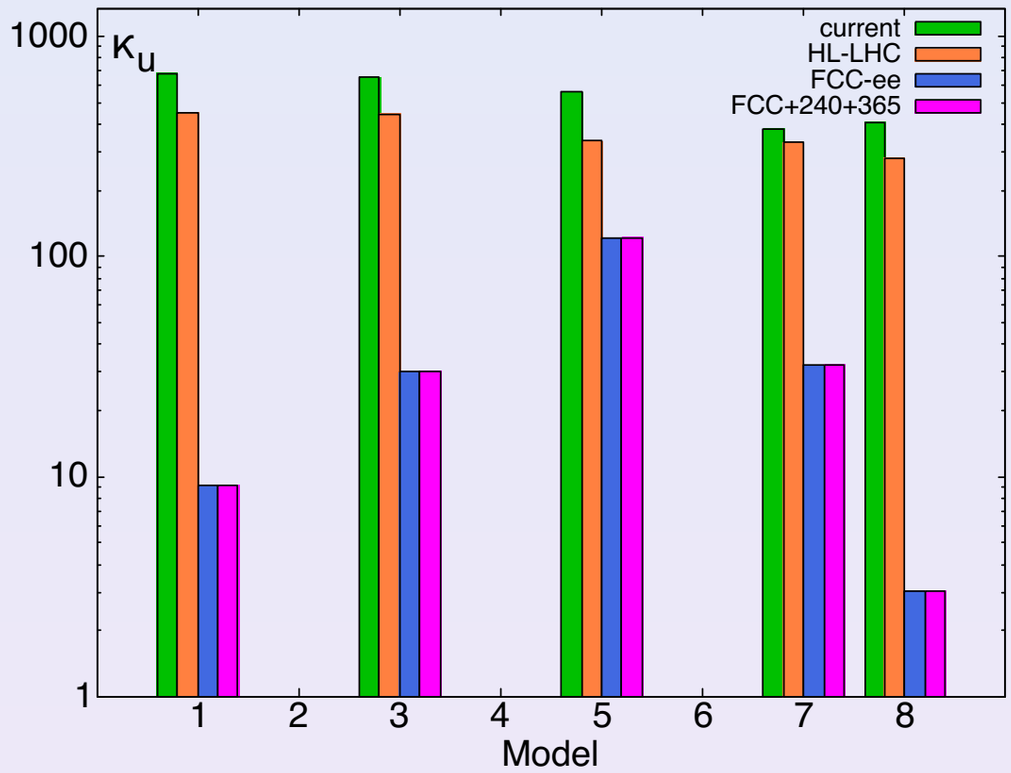
Model	VLQs	Model	VLQs	Model	VLQs
1	$(3,1)_{2/3}+(3,2)_{1/6}$	4	$(3,1)_{-1/3}+(3,2)_{-5/6}$	7	$(3,2)_{1/6}+(3,3)_{2/3}$
2	$(3,1)_{-1/3}+(3,2)_{1/6}$	5	$(3,2)_{1/6}+(3,3)_{-1/3}$	8	$(3,2)_{7/6}+(3,3)_{2/3}$
3	$(3,1)_{2/3}+(3,2)_{7/6}$	6	$(3,2)_{-5/6}+(3,3)_{-1/3}$		

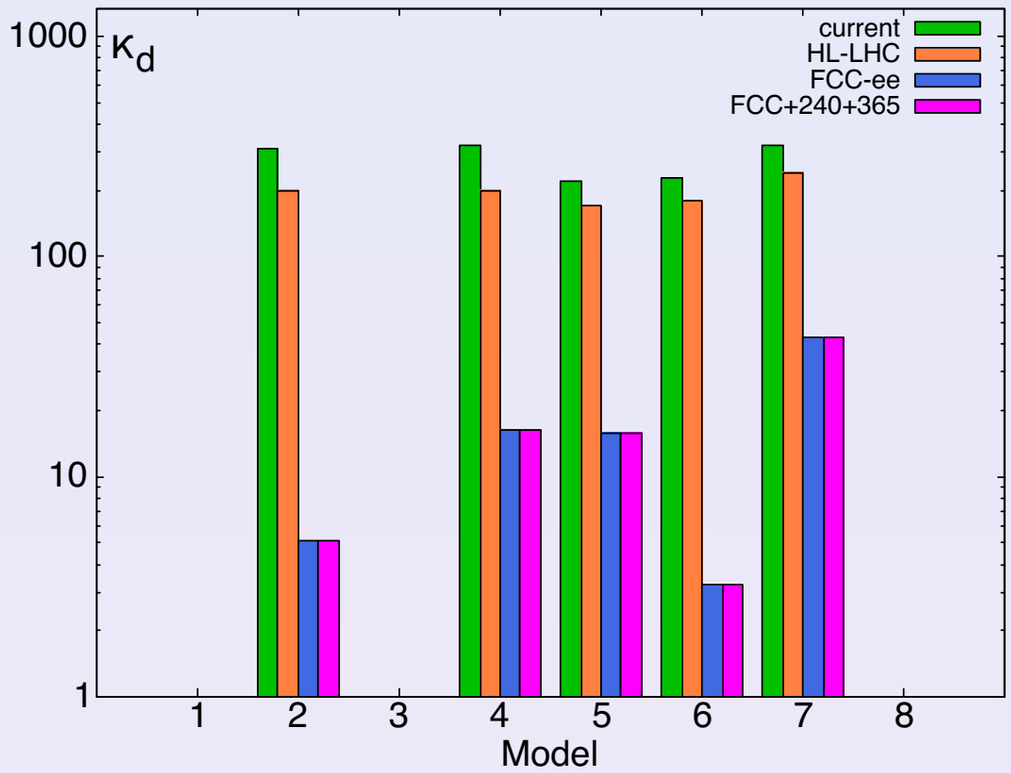
- Eight models
- they generate further operators for instance operators that modify the Z couplings to the light quarks
- are constrained by Higgs physics, flavour physics, direct searches and electroweak observables

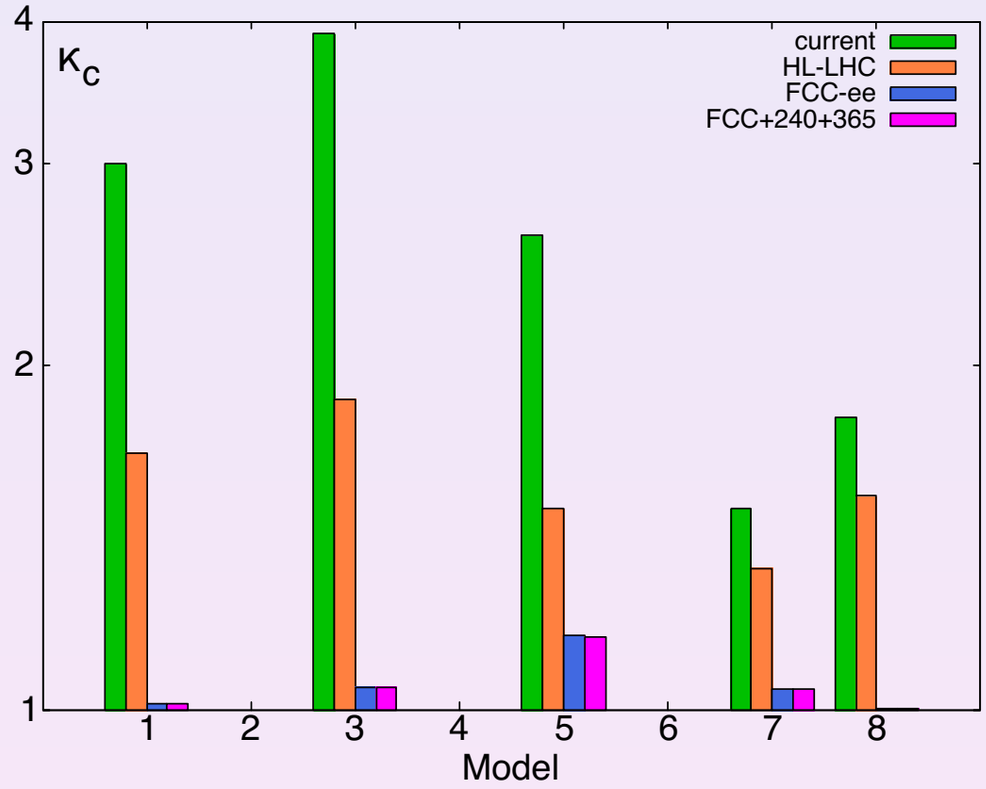
[Erdelyi, RG, Selimović, '24]

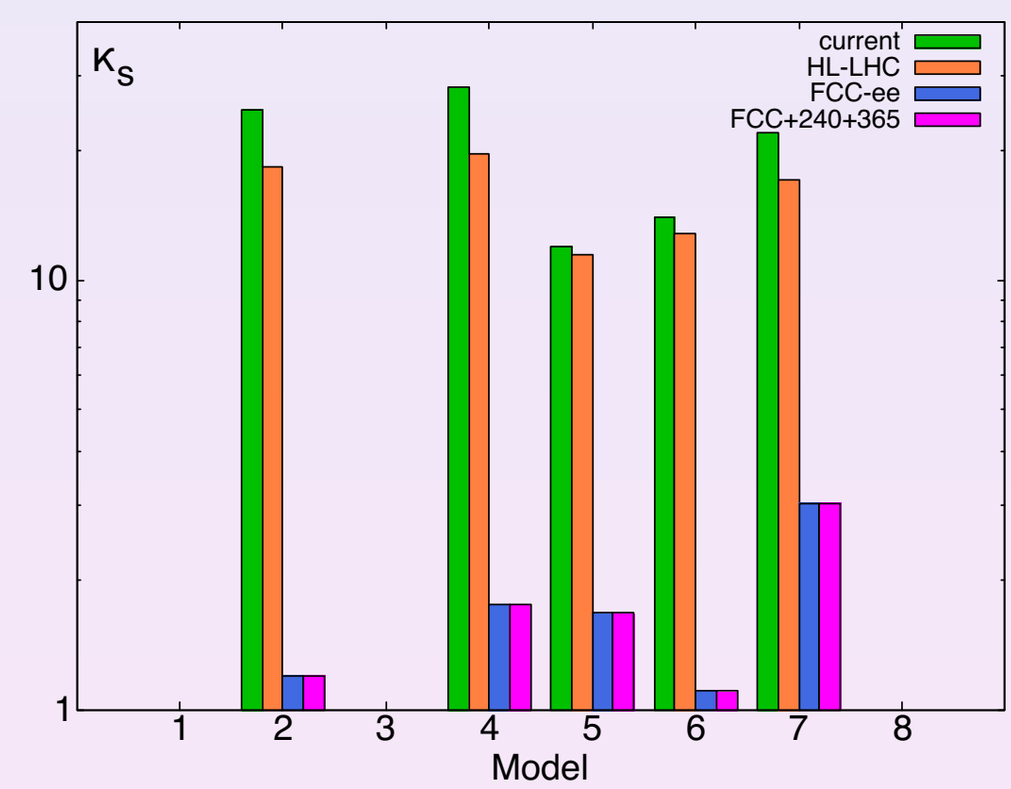


Light quark Yukawa couplings







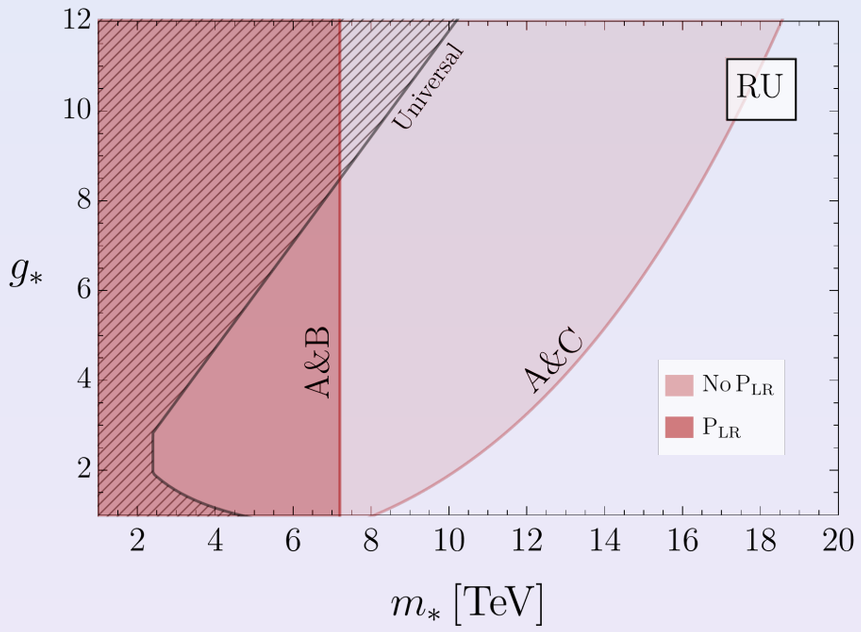


contact Barbara Erdelyi, RG, Nudžeim Selimović

Flavour and CP-violation

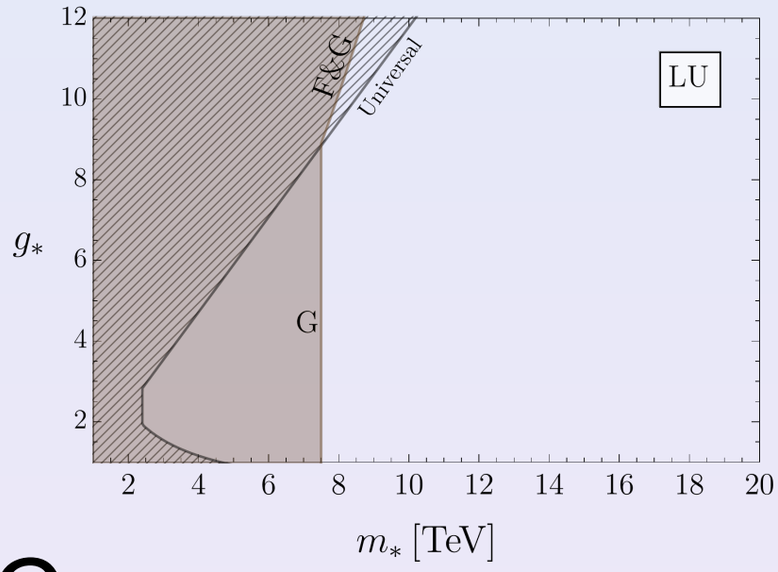
- Flavor & CP violation are and will remain a central issue for Physics Beyond the SM
- In 2402.09503, Glioti, Rattazzi, Ricci and Vecchi explored a few representative flavor scenarios for the Strongly-Interacting Light Higgs. In all of them, modified couplings of fermions to Z and W (flavour-violating as well as flavor-conserving) play a crucial role.
- In the next 10-20 years, if no discovery is made, HL-LHC and Belle II will set significant constraints in many of those scenarios, leaving only a special subclass to the next generation of detectors
- Questions for the future:
  - What is the constraining power of FCC-ee on modified vector couplings to fermions?
  - What scenarios will be left for "direct exploration" at FCC-hh?

Models with Minimal Flavour Violation

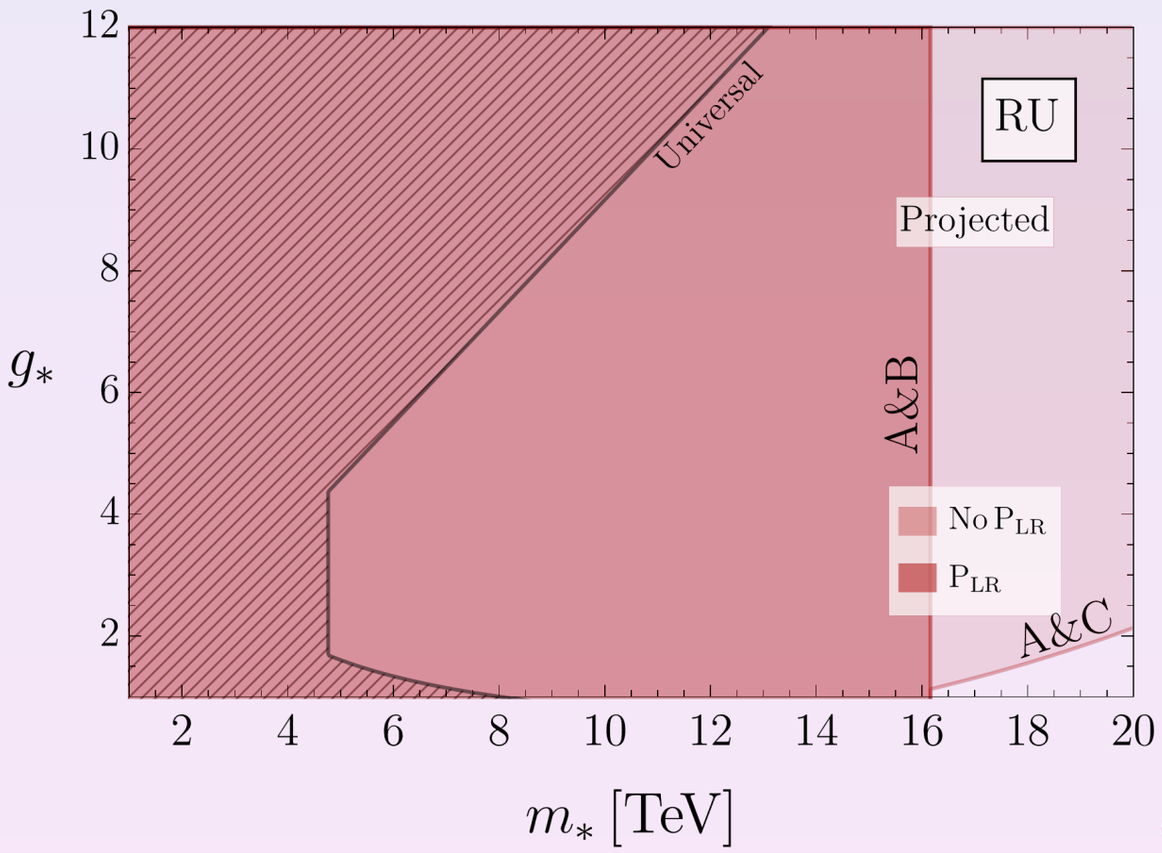


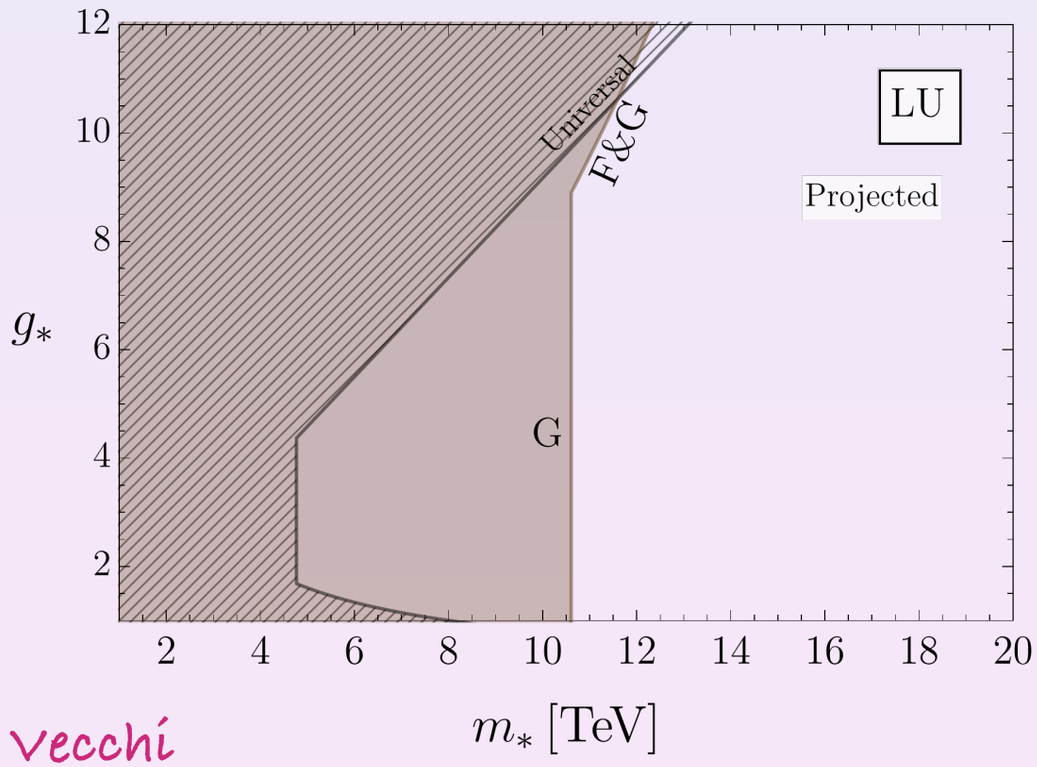
[Glioti, Rattazzi, Ricci and Vecchi '24]

Label	Observable
A	$pp \to jj$
B	$\Delta F = 2\,(B_d)$
C	$B_s \to \mu^+\mu^-$
D	nEDM
E	$B^0 \to K^{*0} e^+ e^-\ (C_7')$
F	$B \to X_s\gamma\ (C_7)$
G	W-coupling



After HL-LHC and Belle II…

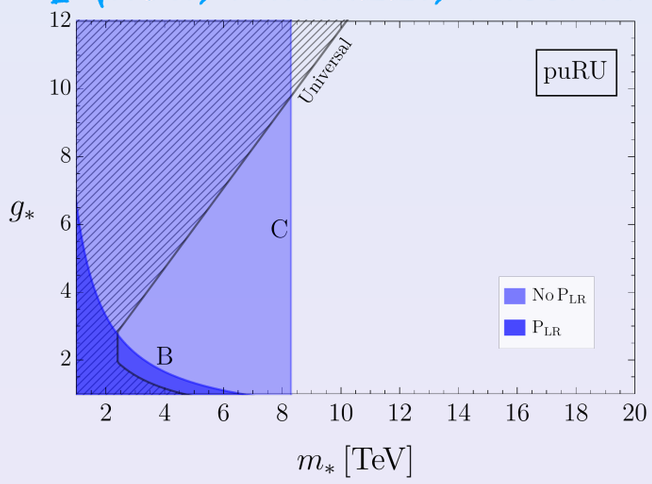


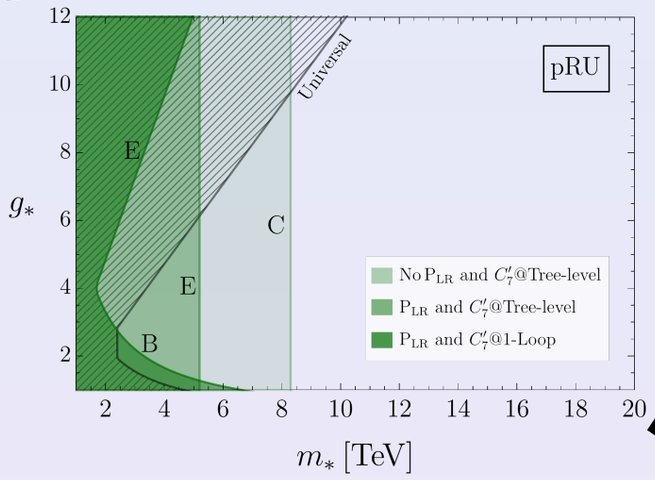


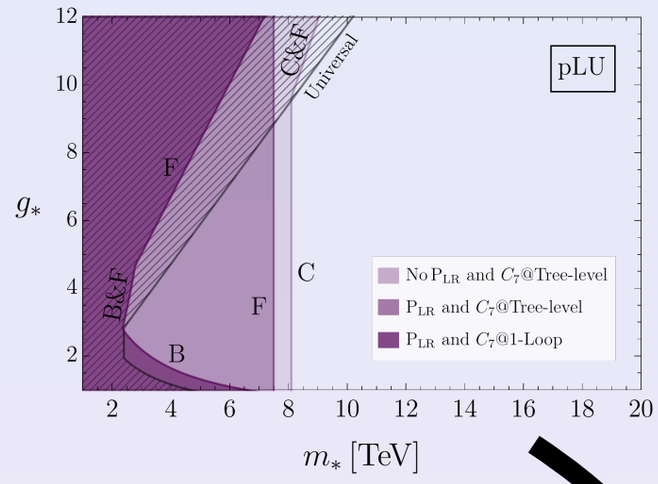
contact Luca Vecchi

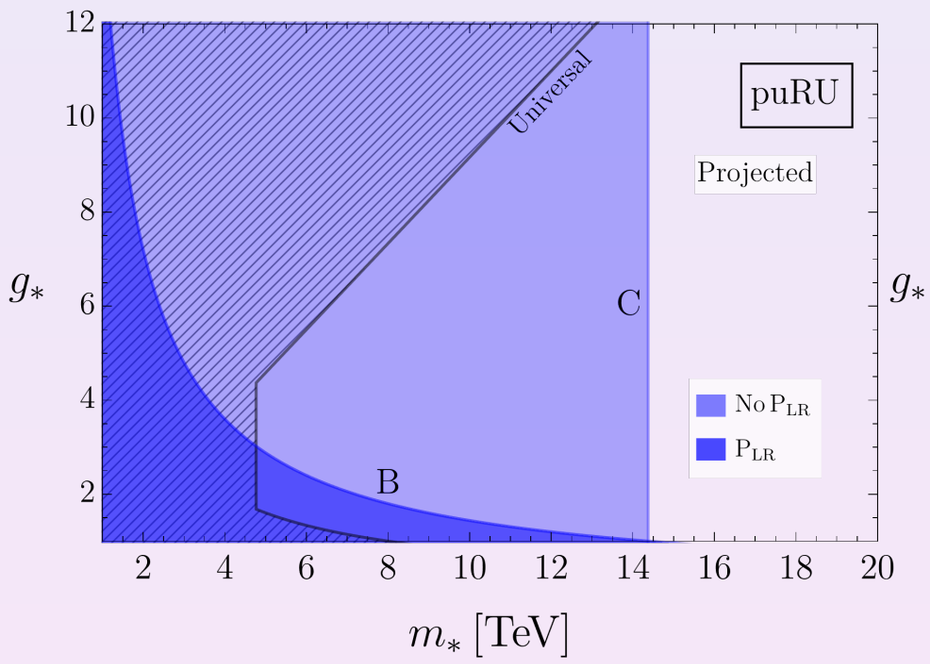
Models without MFV

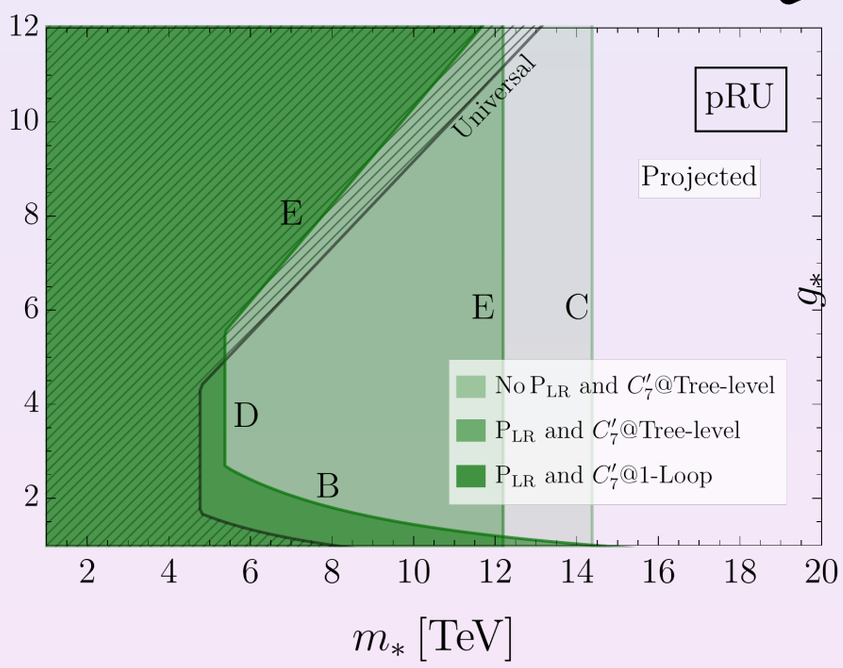
[Glioti, Rattazzi, Ricci and Vecchi '24]

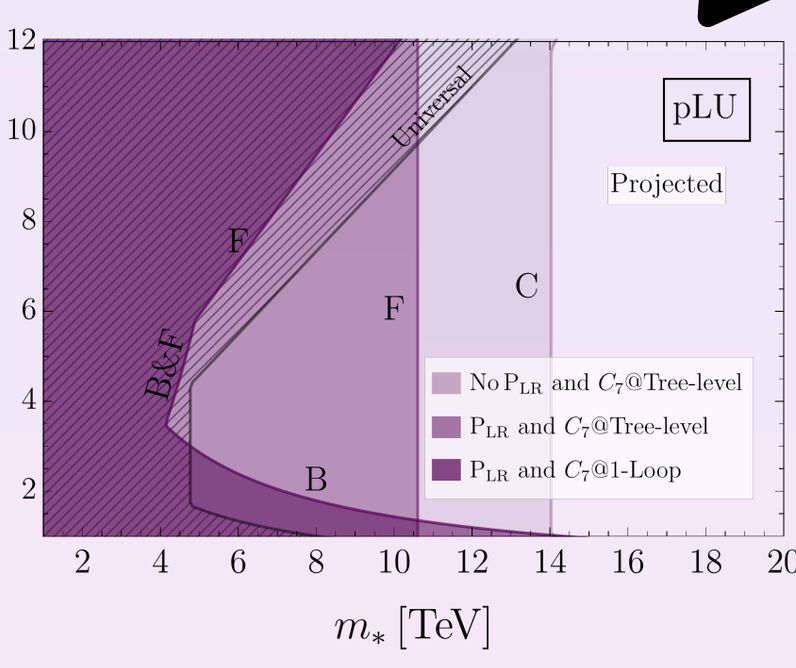












contact Luca Vecchi

Conclusion

- various activities ongoing in Gr4 in what regards future colliders

- FCC -ee whilst being a precision machine can constrain new physics by indirect effects

  examples discussed: Standard Model Effective Field Theory, light quark Yukawa couplings, flavour scenarios in Strongly-Interacting Light Higgs scenarios

- precision computations to reduce the theory uncertainty will be absolutely essential

Interest of the theory group

Luca Vecchi: Flavour scenarios/CP-violation at FCC

Stefano Rigolin: ALPs at future experiments (Belle 2 / FCC)

Paride Paradisi: interplay low energy/high energy, muon colliders

Pierpaolo Mastrolia : high -performance computing and precision computations

Ramona Gröber: Higgs physics at future colliders