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Plan de Recuperación,
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Resiliencia

AGENCIA
ESTATAL DE
INVESTIGACIÓN

UNIVERSIDAD
DE GRANADA

From loops to operators:

Driving students crazy since the 90's

AI artistic representation

HIRSCHCEPTION !!

Ricardo Cepedello

Universidad de Granada

Hirschfest

January 24th, 2024

Disclaimer

This is not a detailed talk about physics !!

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ABSTRACT:

In between anecdotes and physics, with a lot of propaganda to Martin's papers (and mine too, of course), I will talk about how Martin drove a student crazy from **radiative neutrino mass models** to **SMEFT** dimension 8 one-loop.

THIS IS A TRUE STORY.

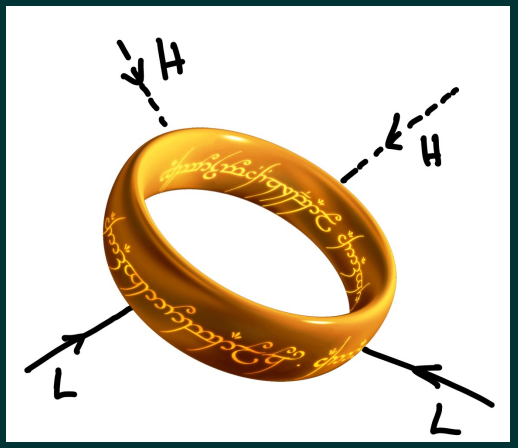
The events depicted in this talk took place (mainly) in Valencia between 2011 and 2022.

At request of the survivors, the corresponding citations will be made.

Out of respect to the researchers killed in action, the rest of the history is told (more or less) exactly as it occurred.

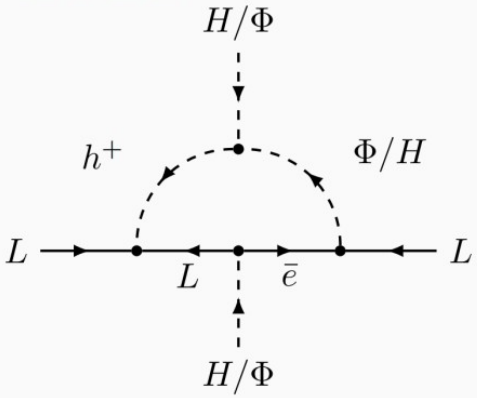
No professor, postdoc or laptop was harm during these events (only some PhD students).

The fellowship of the ~~ring~~ Loops



A professor to complete them all

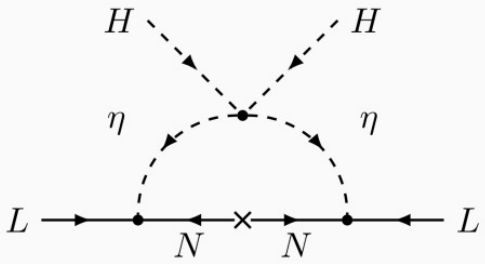
Zee model:



[Zee, Phys. Lett. B93 (1980) 389]

[Wolfenstein, Nucl. Phys. B175 (1980) 9396]

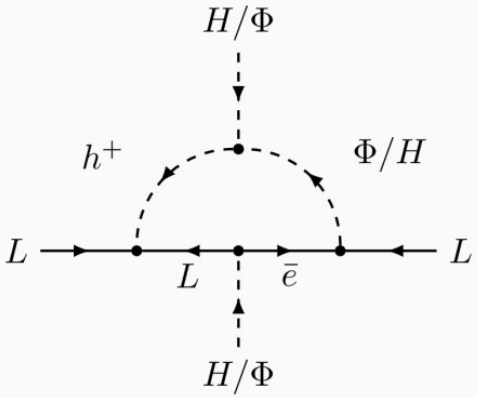
Scotogentic Model:



[Ma, Phys. Rev. D73 (2006) 077301]

A professor to complete them all

Zee model:



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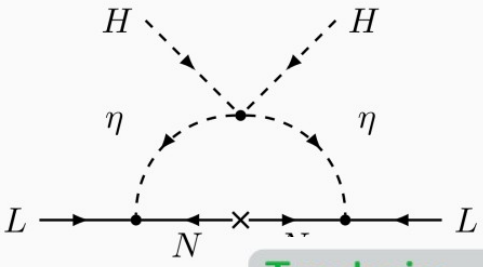
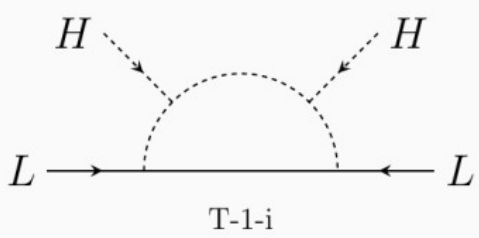


[Ma, Phys. Rev. I

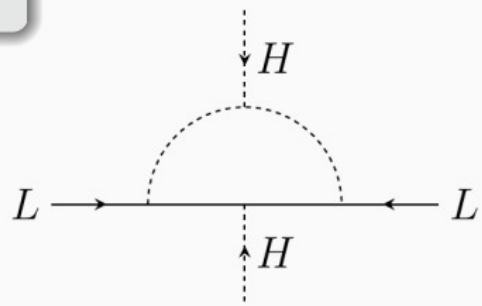
Topologies

Systematic classification by

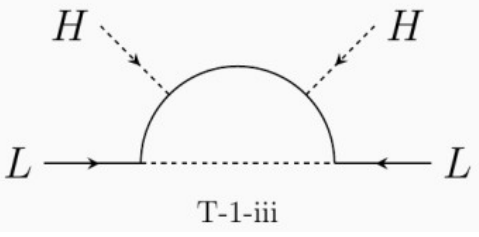
Bonet et al, JHEP 1207 (2012) 153



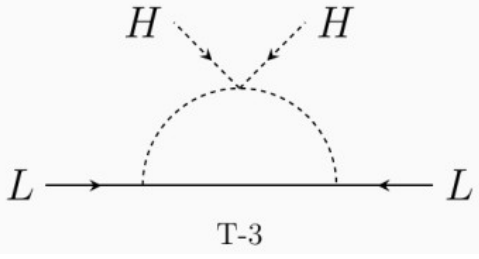
T-1-i



T-1-ii



T-1-iii

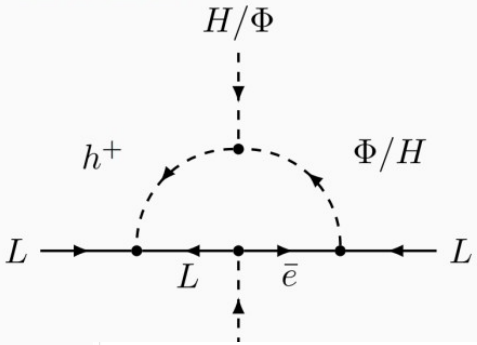


T-3

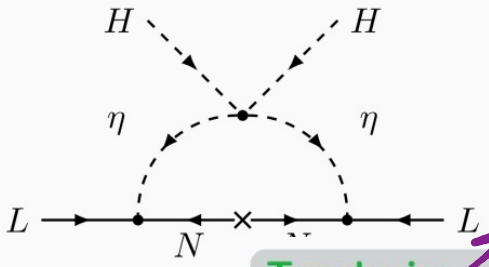
Only one integral $B_0(p^2, m_F^2, m_S^2)$

A professor to complete them all

Zee model:



Scotogentic Model:



Short answer.... a lot !!

724 models

Topologies

How many 1-loop neutrino mass models are there?

#6

Systematic classification by

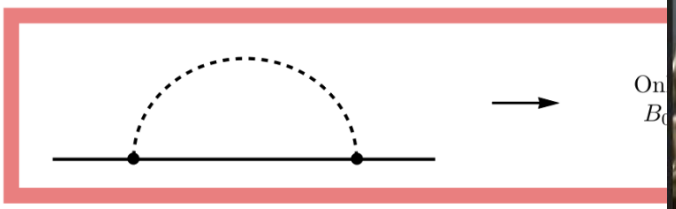
onet et al, JHEP 1207 (2012) 153

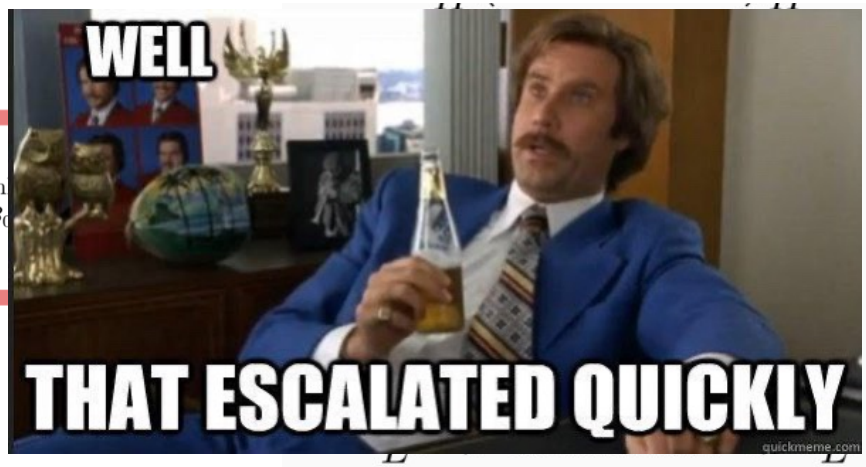
[Ze

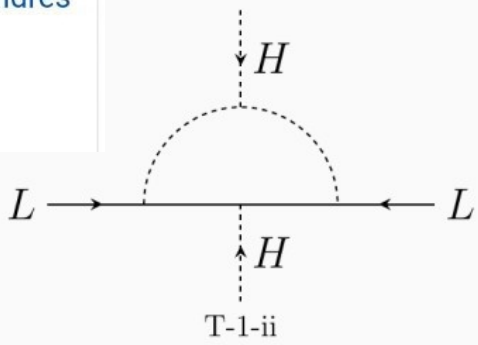
[Wolf

Carolina Arbeláez (CCTVal, Valparaiso and Santa Maria U., Valparaiso), Ricardo Cepedello (Wurzburg U.), Juan Carlos Helo (La Serena U. and Unlisted, CL), Martin Hirsch (Unlisted, CL), Sergey Kovalenko (Andres Bello Natl. U.) (May 25, 2022)

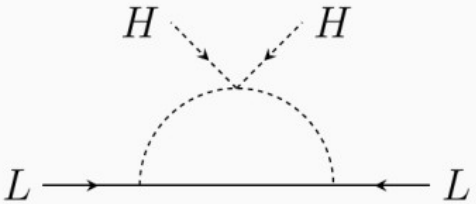
Published in: *JHEP* 08 (2022) 023 • e-Print: 2205.13063 [hep-ph]







T-1-ii



T-3

T-1-iii

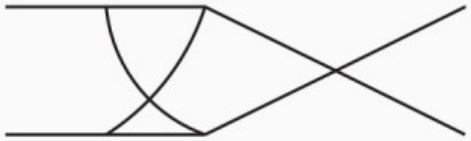
One-loop is too mainstream

Systematic classification by Aristizabal et al, JHEP 1503 (2015) 040

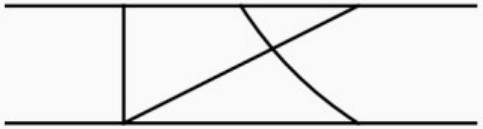
$T2_1^{\mathrm{B}}$

$T2_2^{\mathrm{B}}$

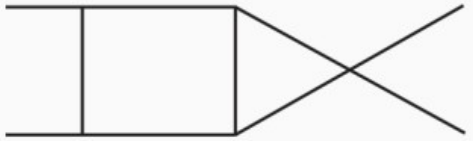
$T2_3^{\mathrm{B}}$



$T2_1^{\mathrm{T}}$



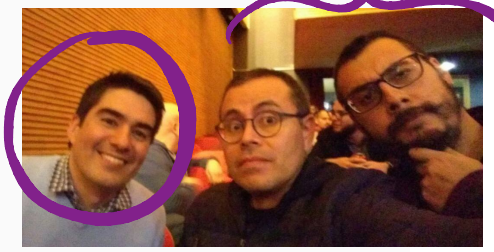
$T2_2^{\mathrm{T}}$



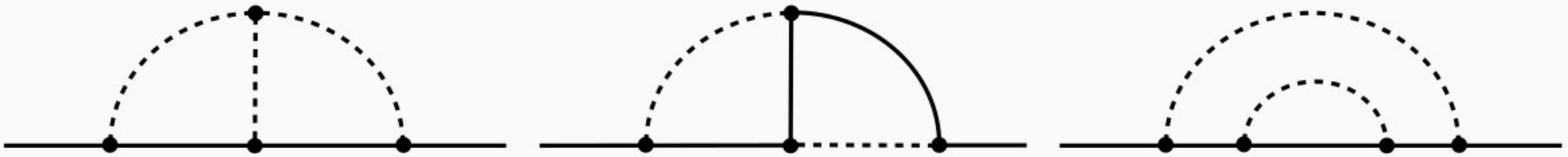
$T2_3^{\mathrm{T}}$

look innocent, but they did Sth for sure

The guilty here

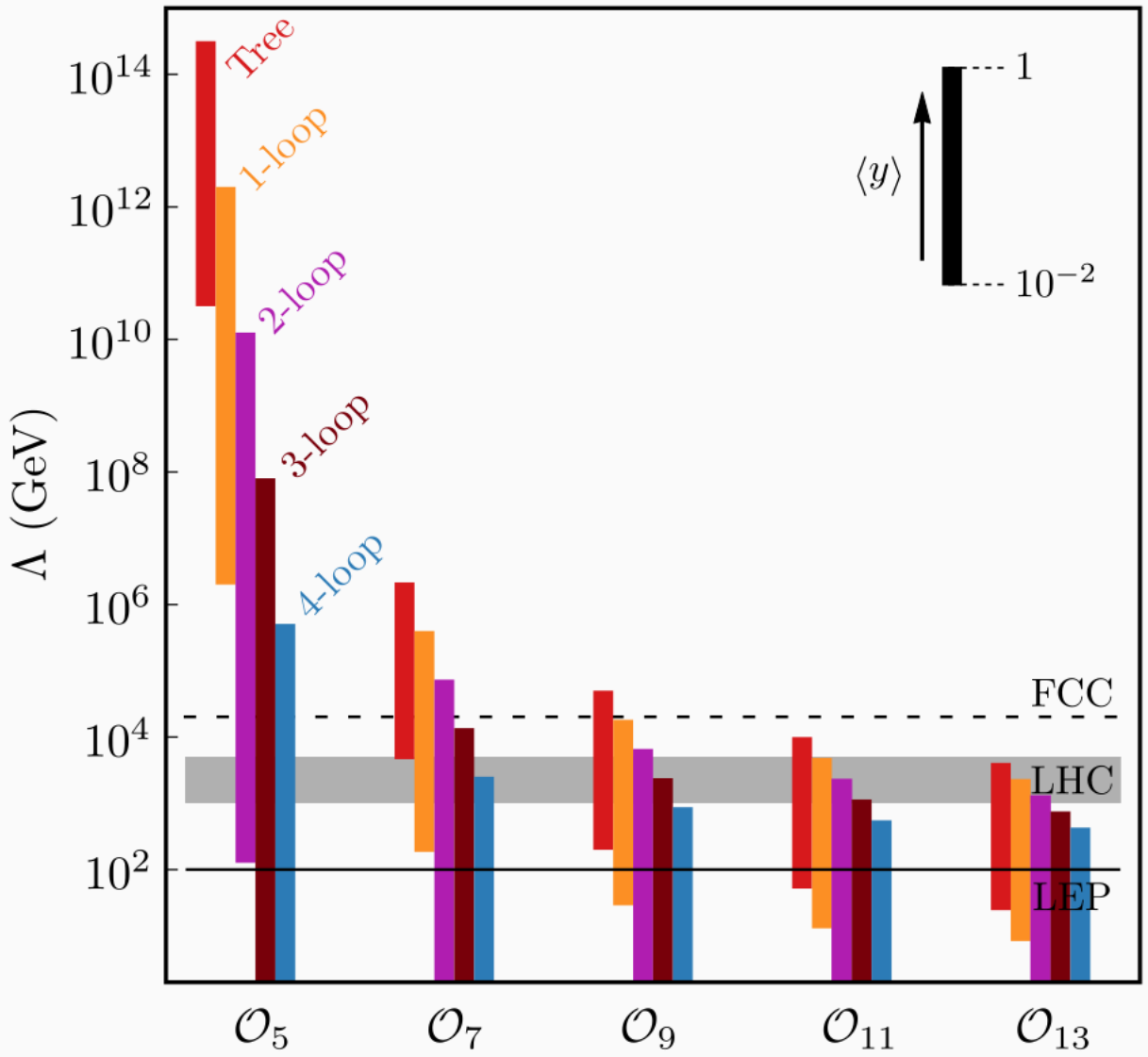


- 20 different genuine diagrams
- 3 basic classes depending on the loop integral
- All integrals can be decomposed in a basis of two master integrals



One-loop is too mainstream

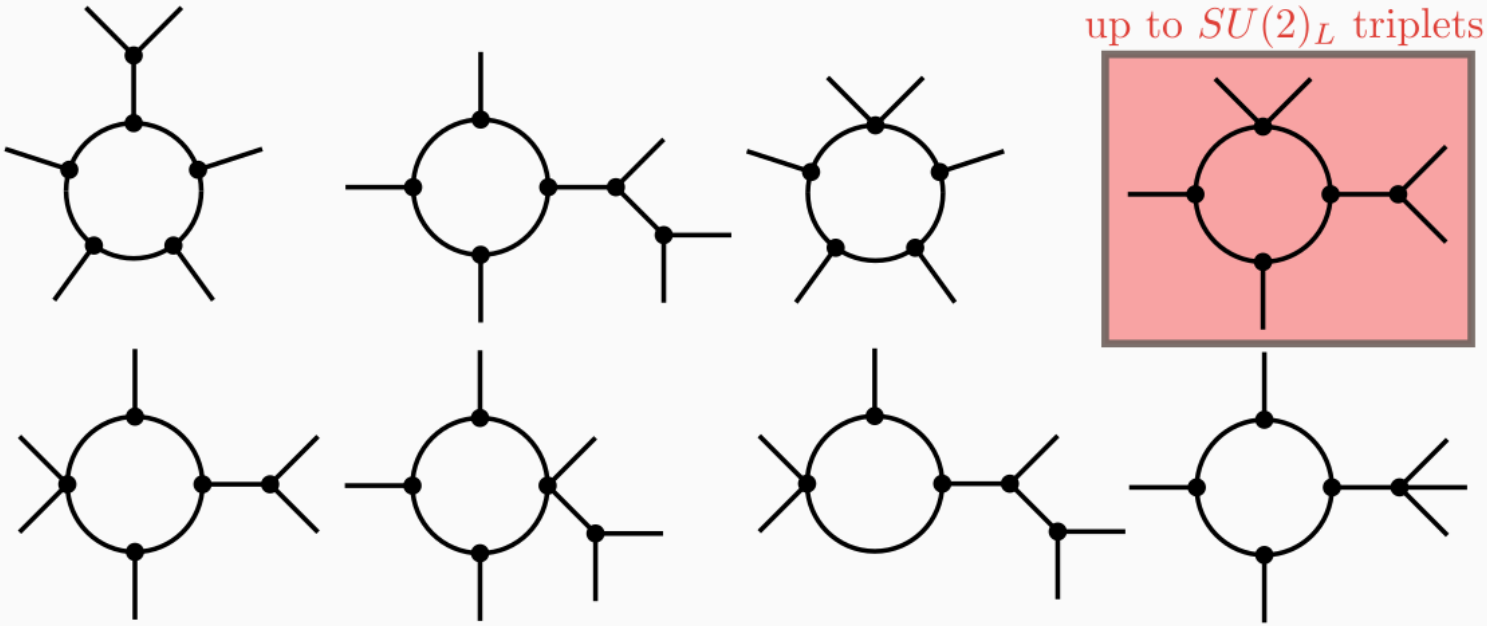
[Anamiati et al; JHEP 1812 (2018) 066]



Dim-7 to bring them all and in the darkness bind them

[JHEP 07 (2017) 079, JHEP 01 (2018) 009]

Genuine topologies:



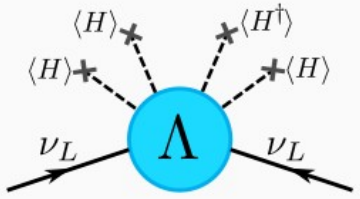
- Classification w.r.t. the maximum $SU(2)_L$ representation needed to be genuine
  - → Only **one** diagram with no representation larger than triplets
  - → The rest of the diagrams need at least one quadruplet
- All integrals can be decomposed in terms of B_0

$\Longrightarrow$ Large representations and hypercharges in order to be genuine

Dim-7 to bring them all and in the darkness bind them

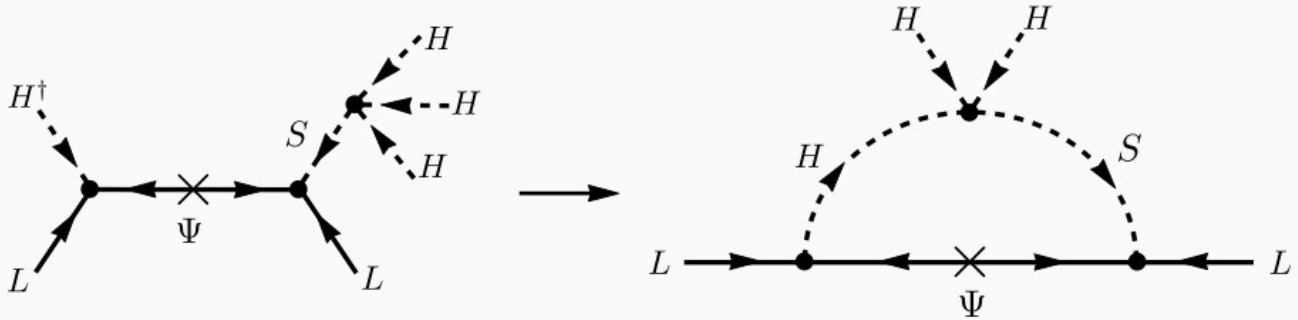
[JHEP 07 (2017) 079, JHEP 01 (2018) 009]

$$\mathcal{O}_7 = \frac{c_{\alpha\beta}}{\Lambda^3} L_\alpha L_\beta H H H^\dagger H$$



$H^\dagger H$ can be *closed* to form a loop

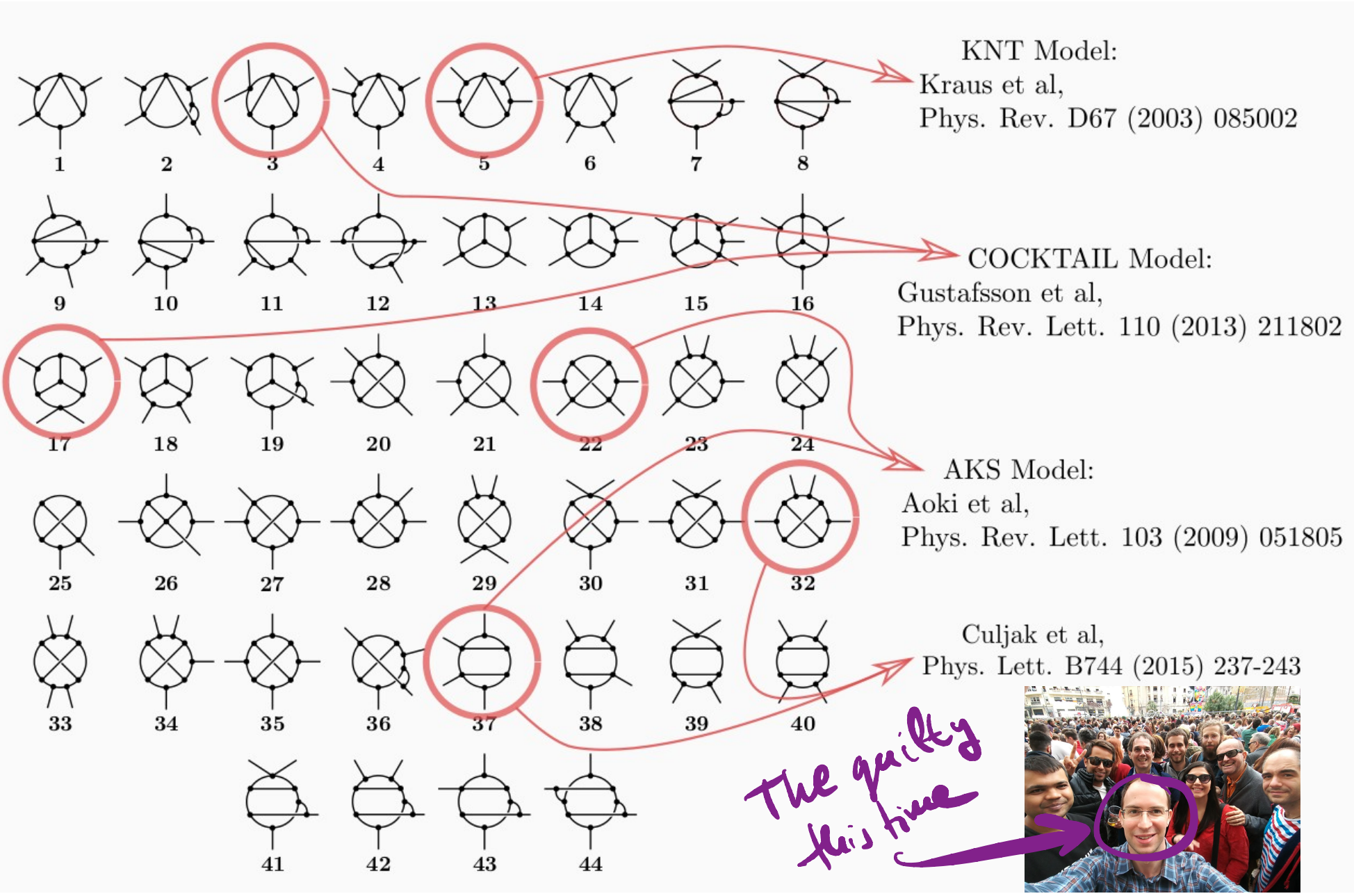
n-loops dimension 7 $\implies$ (n+1)-loops dimension 5



$m_\nu \propto \frac{v^2}{\Lambda^2}\frac{v^2}{\Lambda}$ $>$ $m_\nu \propto \frac{1}{16\pi^2}\frac{v^2}{\Lambda}$

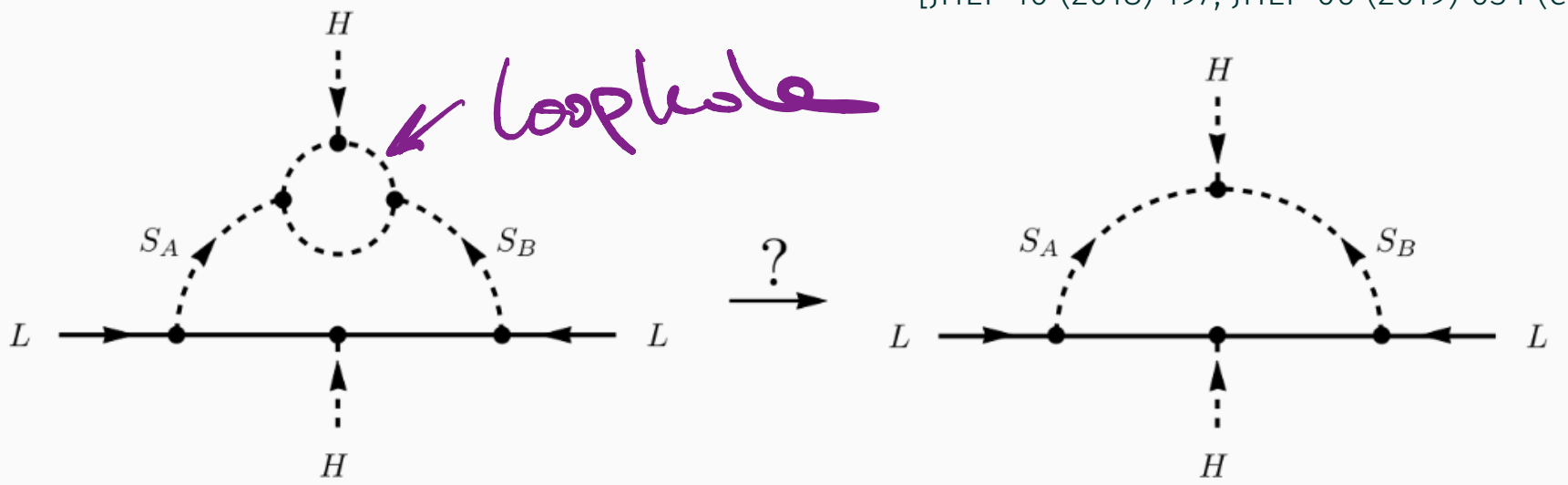
In order for the dimension 7 contribution to be dominant, $\Lambda \lesssim 2$ TeV.

Three loops... Certainty of death, small chance of success... What are we waiting for?



Three loops... Certainty of death, small chance of success... What are we waiting for?

[JHEP 10 (2018) 197, JHEP 06 (2019) 034 (erratum)]



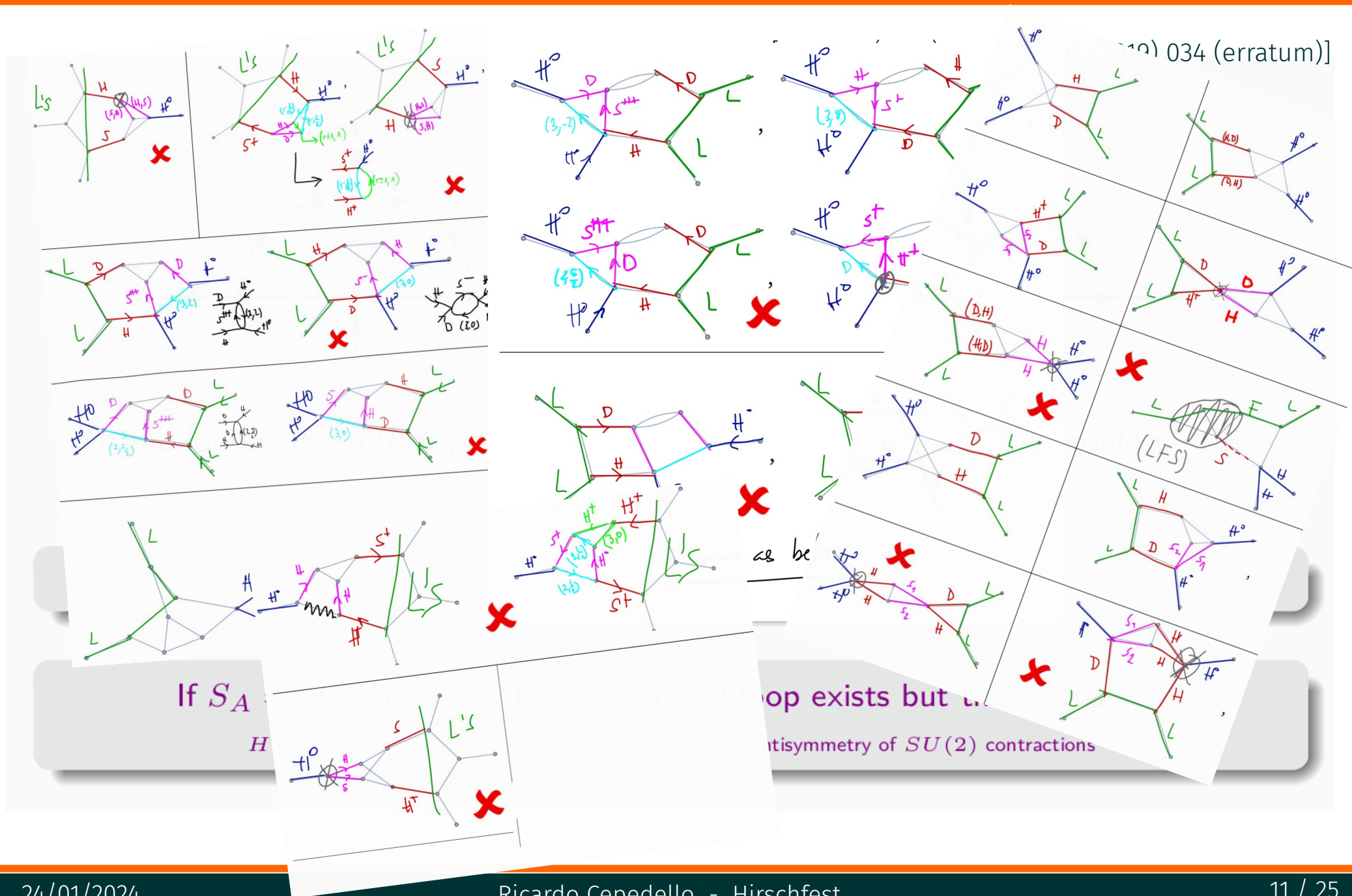
If the loop vertex (H, S_A, S_B) is allowed by the symmetries, so it should be the tree-level vertex.

But the tree-level vertex can be identically zero!

If $S_A = H$ and $S_B = (1, 1, -1)$, the 2-loop exists but the 1-loop not

$H\,H$ contraction to a singlet does not exist due to the antisymmetry of $SU(2)$ contractions

Three loops... Certainty of death, small chance of success... What are we waiting for?



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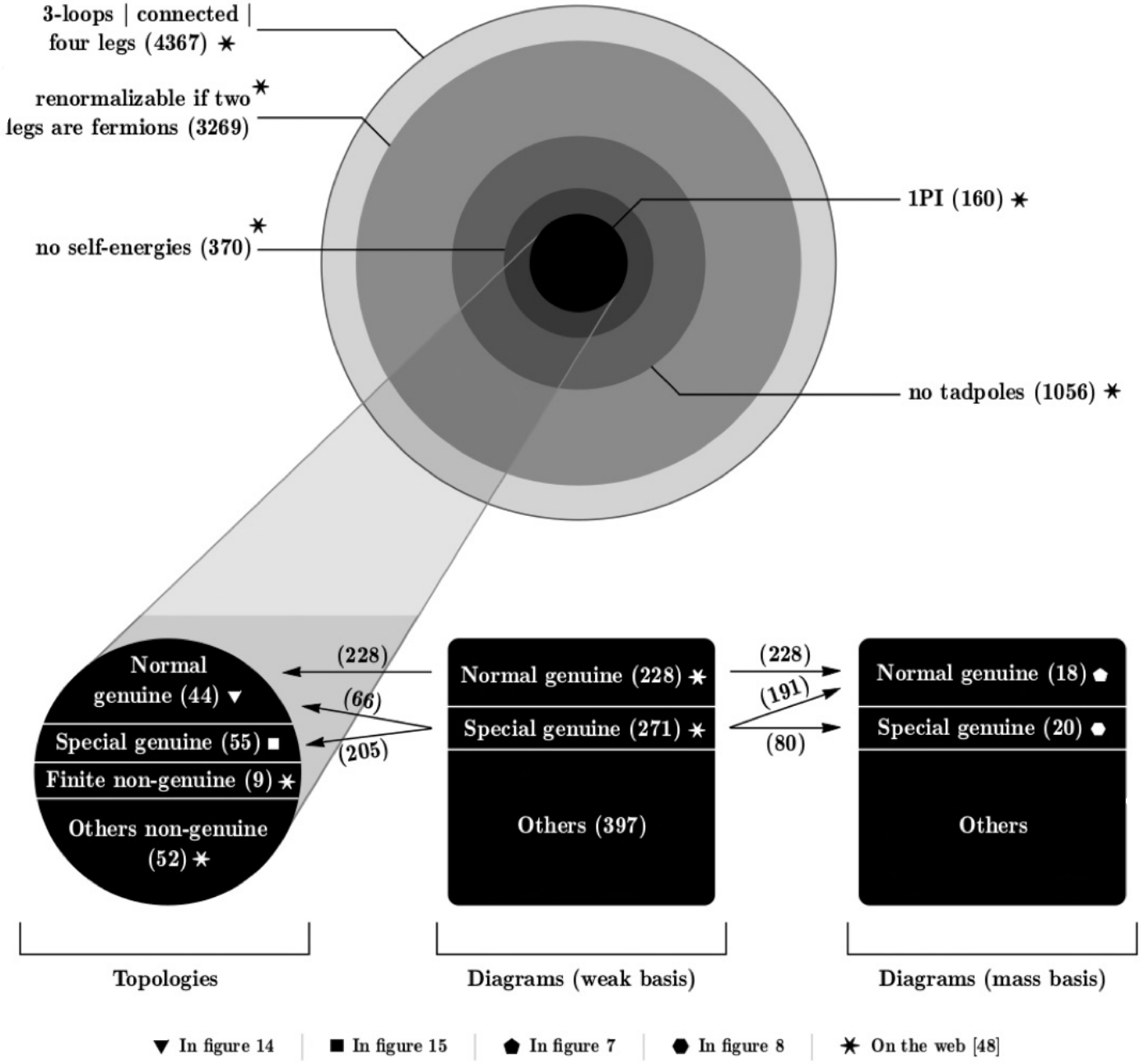
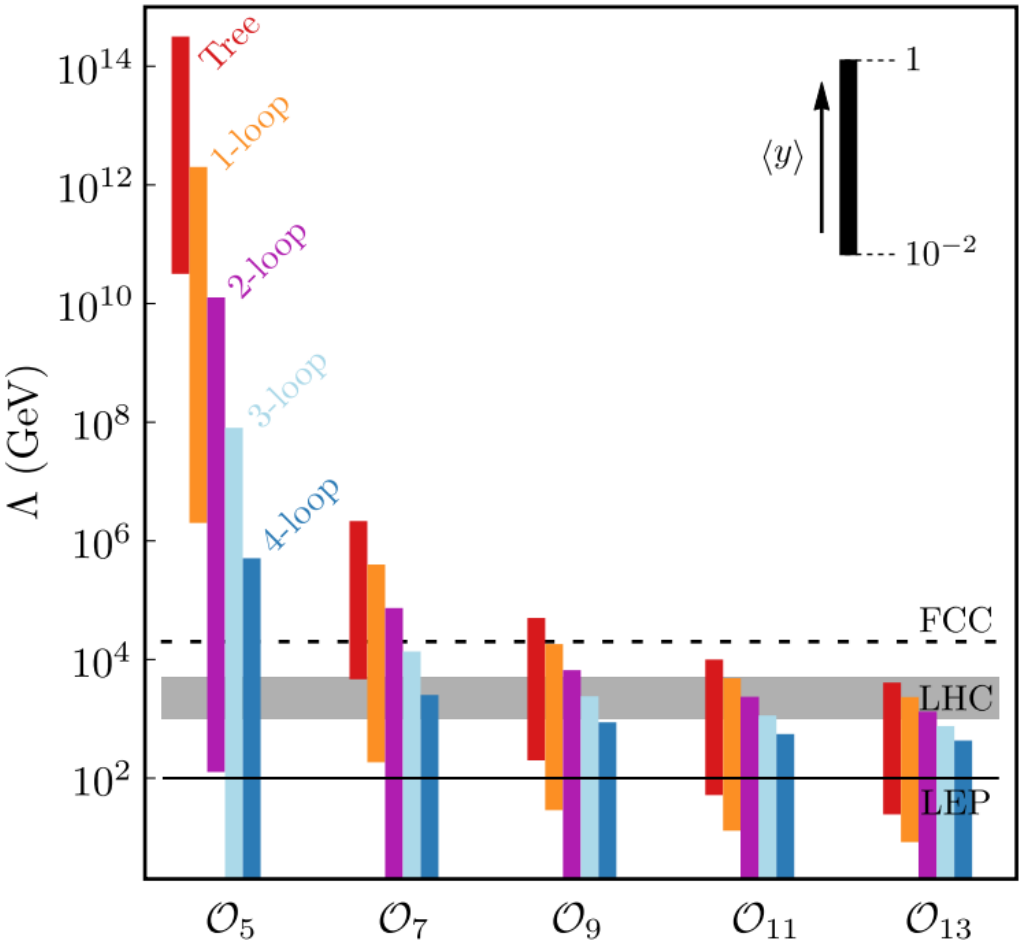


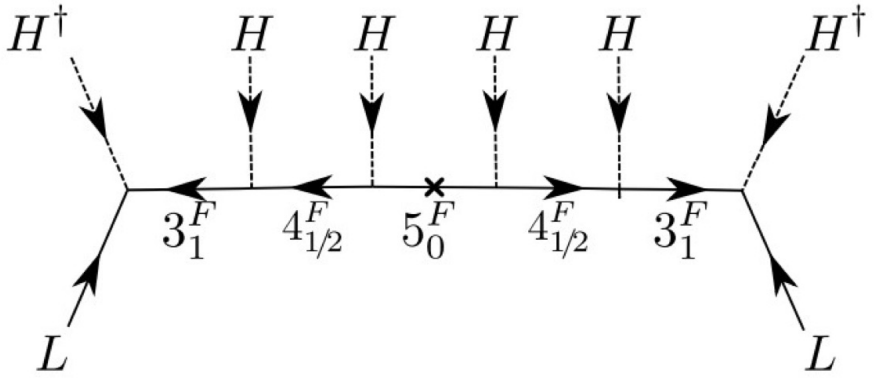
The two towers

A red sun rises. Models have been killed this night.

High-dimensional neutrino masses [JHEP 12 (2018) 066]

Gaetana Anamiati,[1,*] Oscar Castillo-Felisola,[2,3,†] Renato M. Fonseca,[4,‡] J. C. Helo,[5,3,§] and M. Hirsch[1,¶]





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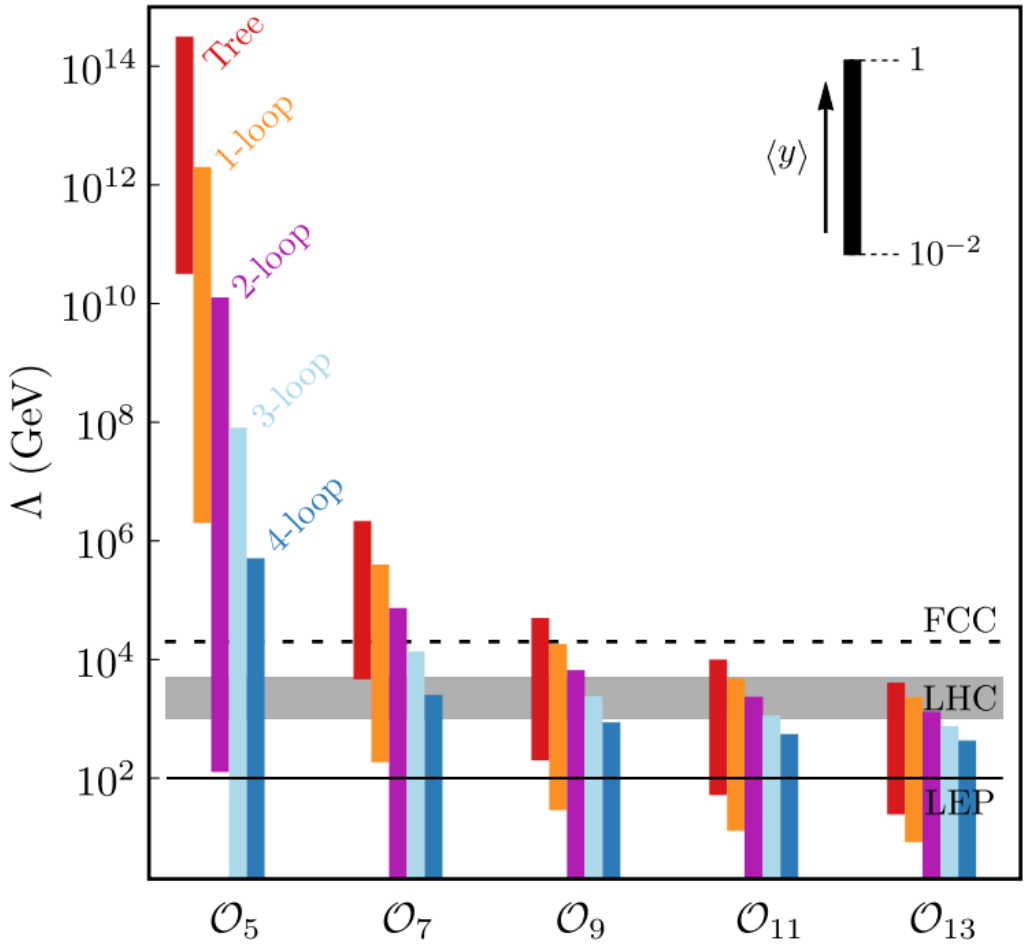
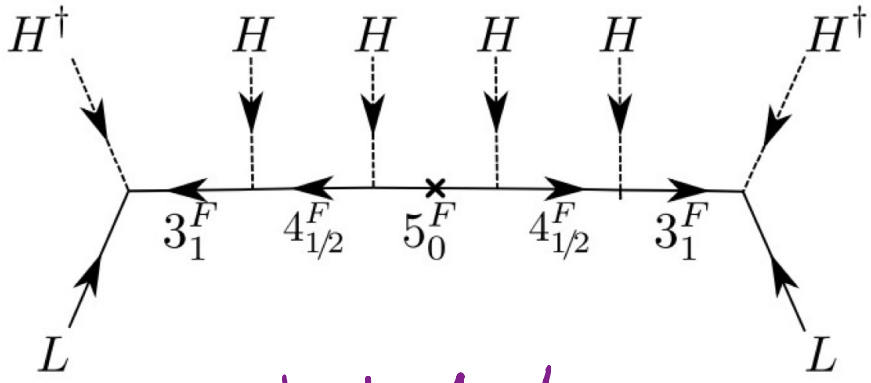
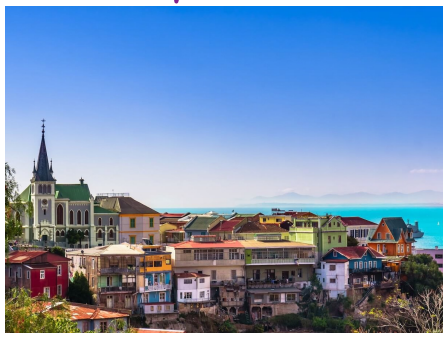




⇒ I had to run fast and fat !!



← Valparaiso (Chile)

Et tu, Brute?

Dark matter stability and Dirac neutrinos using only Standard Model symmetries

Cesar Bonilla (Munich, Tech. U.), Salvador Centelles-Chuliá (Valencia U., IFIC), Ricardo Cepedello (Valencia U., IFIC), Eduardo Peinado (Mexico U.), Rahul Srivastava (Valencia U., IFIC) (Dec 4, 2018)

Published in: *Phys.Rev.D* 101 (2020) 3, 033011 • e-Print: 1812.01599 [hep-ph]

pdf DOI cite claim reference search 63 citations

Systematic classification of two loop d = 4 Dirac neutrino mass models and the Diracness-dark matter stability connection #14

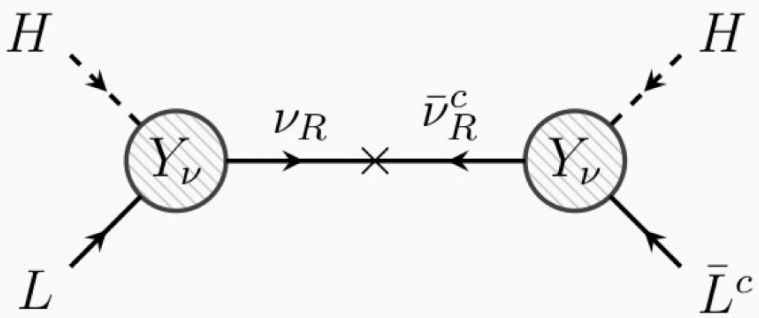
Salvador Centelles Chuliá (Valencia U., IFIC), Ricardo Cepedello (Valencia U., IFIC), Eduardo Peinado (Mexico U.), Rahul Srivastava (Valencia U., IFIC) (Jul 19, 2019)

Published in: *JHEP* 10 (2019) 093 • e-Print: 1907.08630 [hep-ph]

pdf DOI cite claim reference search 34 citations

You shall not escape

Back to low energy Marojana neutrino mass models

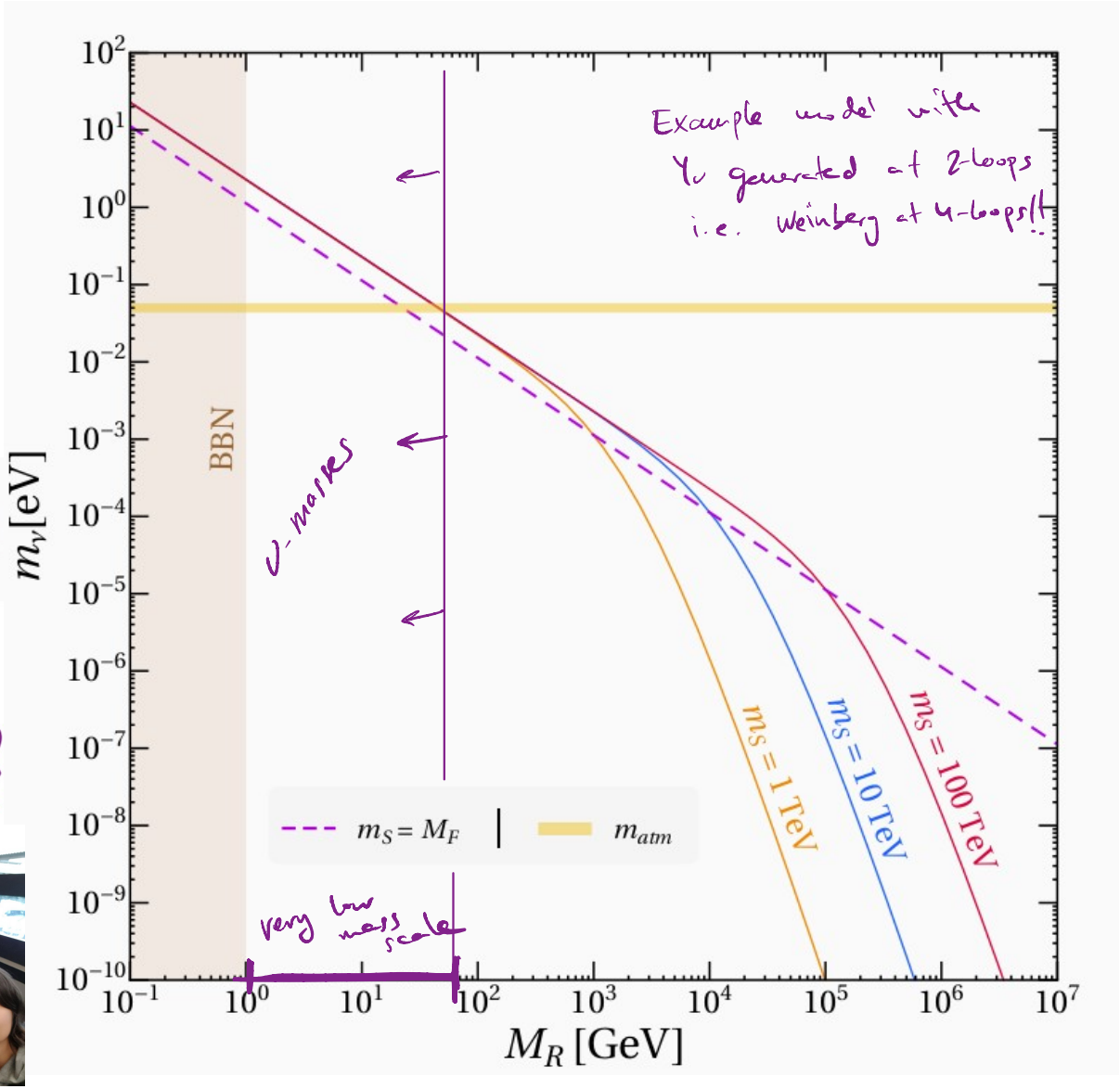


Dirac Yukawa is generated radiatively!

$$Y_\nu \sim \left(\frac{1}{16\pi^2}\right)^\ell \left(\frac{m_\tau}{v}\right)^\alpha \left(\frac{M_F}{\Lambda}\right)^\beta \left(\frac{\mu}{\Lambda}\right)^\gamma \epsilon^\delta .$$

Did I drive Martin a bit to the Dark Side?

60% of the authors



You shall not escape

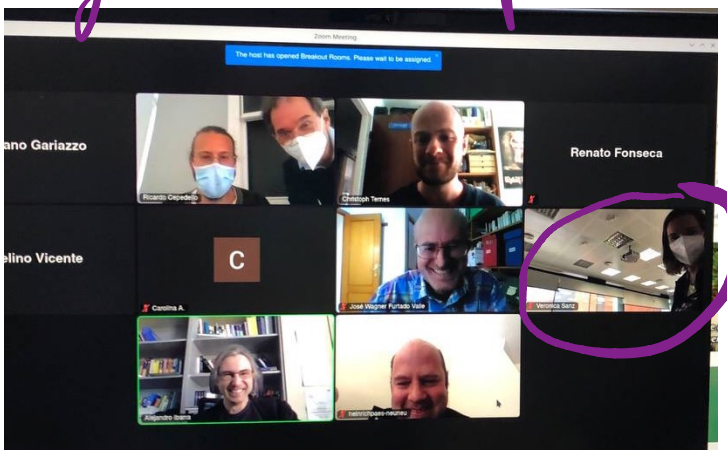
Total eclipse
Valle de Elqui
2nd July 2019

Martin practising for the eclipse

The return of the ~~ring~~ Operators

Stumbling over the same stone twice

My PhD defense:



the guilty!!

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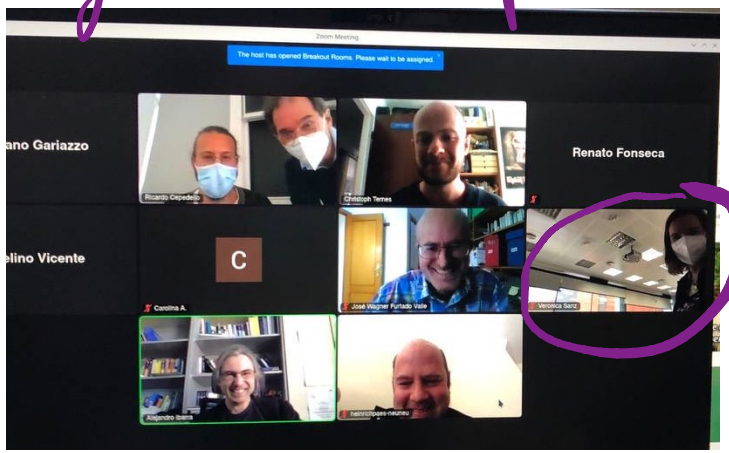

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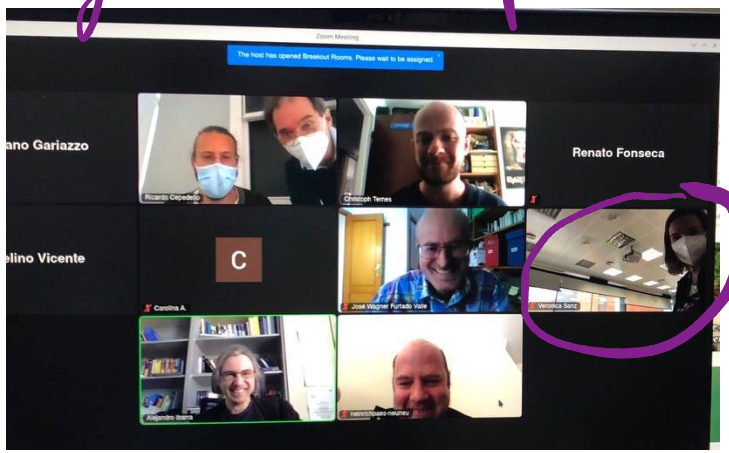

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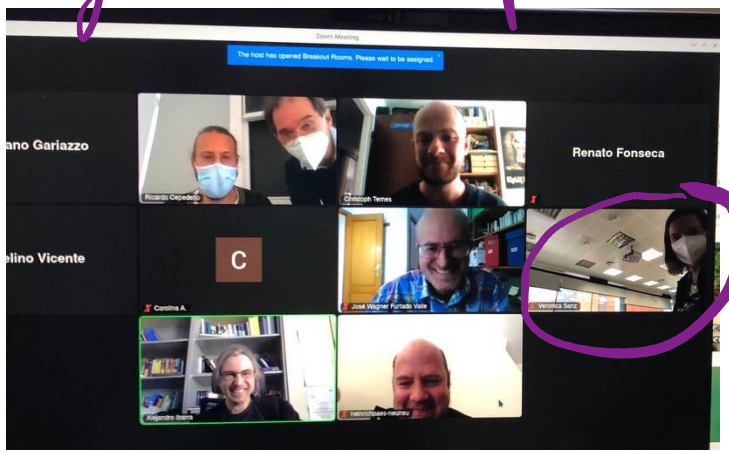

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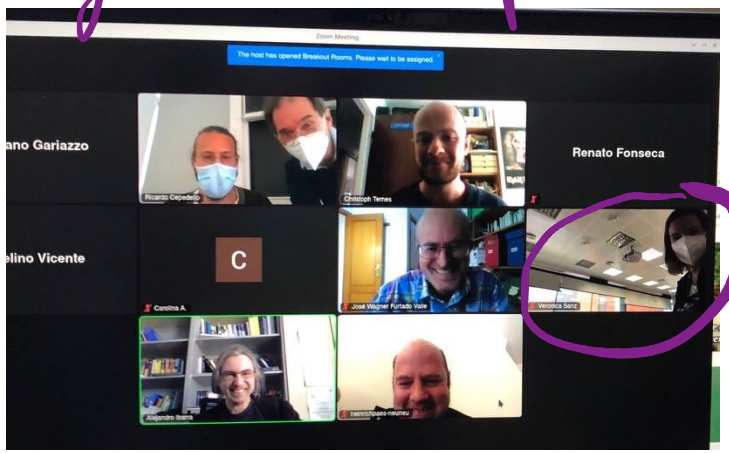

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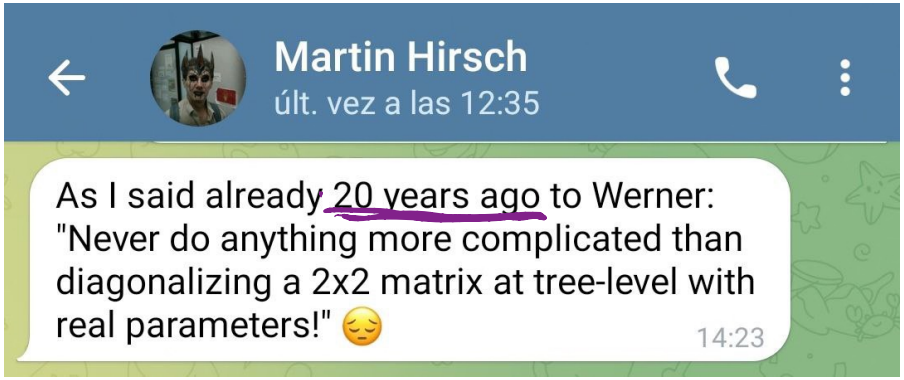

[Private communication]

Some men just want to watch my laptop burn

A code that can give us all models that can contribute to a specific experimental observable at certain order in the EFT expansion

We need to map the SMEFT (or a part of it) to UV models

Automate this approach to point towards:

- *Model discrimination*
- *Classification of models*
- *UV dictionaries* [de Blas et al 2018]
- *Find new BSM models*
- *Look for patterns in the SMEFT*

. . .

Some men just want to watch my laptop burn

A code that can give us all models that can contribute to a specific experimental observable at certain order in the EFT expansion

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as et al 2018]

dels

he SMEFT

One operator to "example" them all

Look for patterns in the SMEFT [JHEP 09 (2022) 229, JHEP 09 (2023) 081]

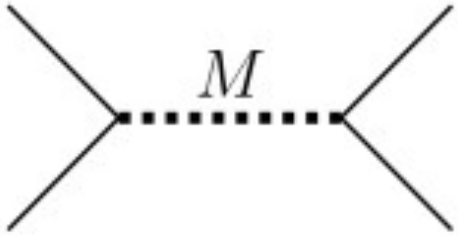
Scenarios where information from low-energy precision measurements and collider searches would be complementary

One operator to "example" them all

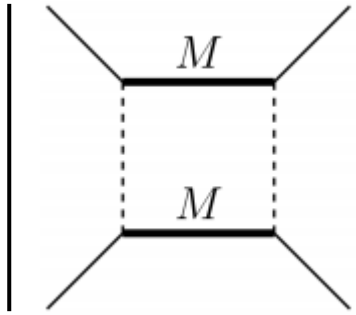
Look for patterns in the SMEFT [JHEP 09 (2022) 229, JHEP 09 (2023) 081]

Scenarios where information from low-energy precision measurements and collider searches would be complementary

The tightest SMEFT bounds come from operators involving ***four fermions (4F)***



$$c_{4F}^{tree} \propto \frac{1}{M^2}$$

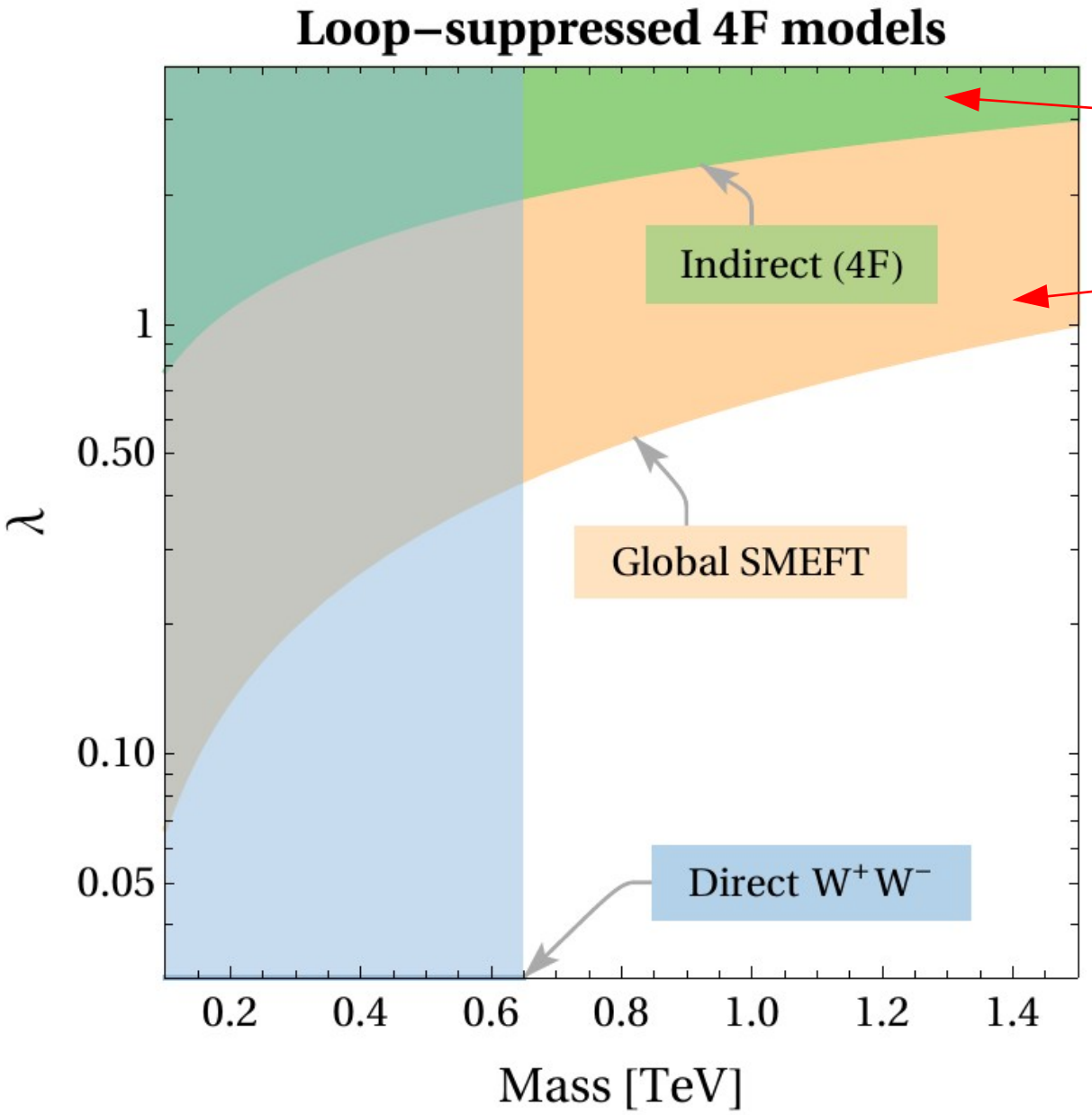


$$c_{4F}^{1l} \propto \frac{1}{16\pi^2}\frac{1}{M^2}$$

The new resonances, appearing only at 1-loop, could be much lighter, directly ***accessible at colliders***

In this class of scenarios, there is an interplay between low-energy precision measurements and collider searches

One operator to “example” them all



4F constraints at low energies:

$$m_{EU} > 0.17\,|\lambda_{EU}|^2 \text{ TeV}$$

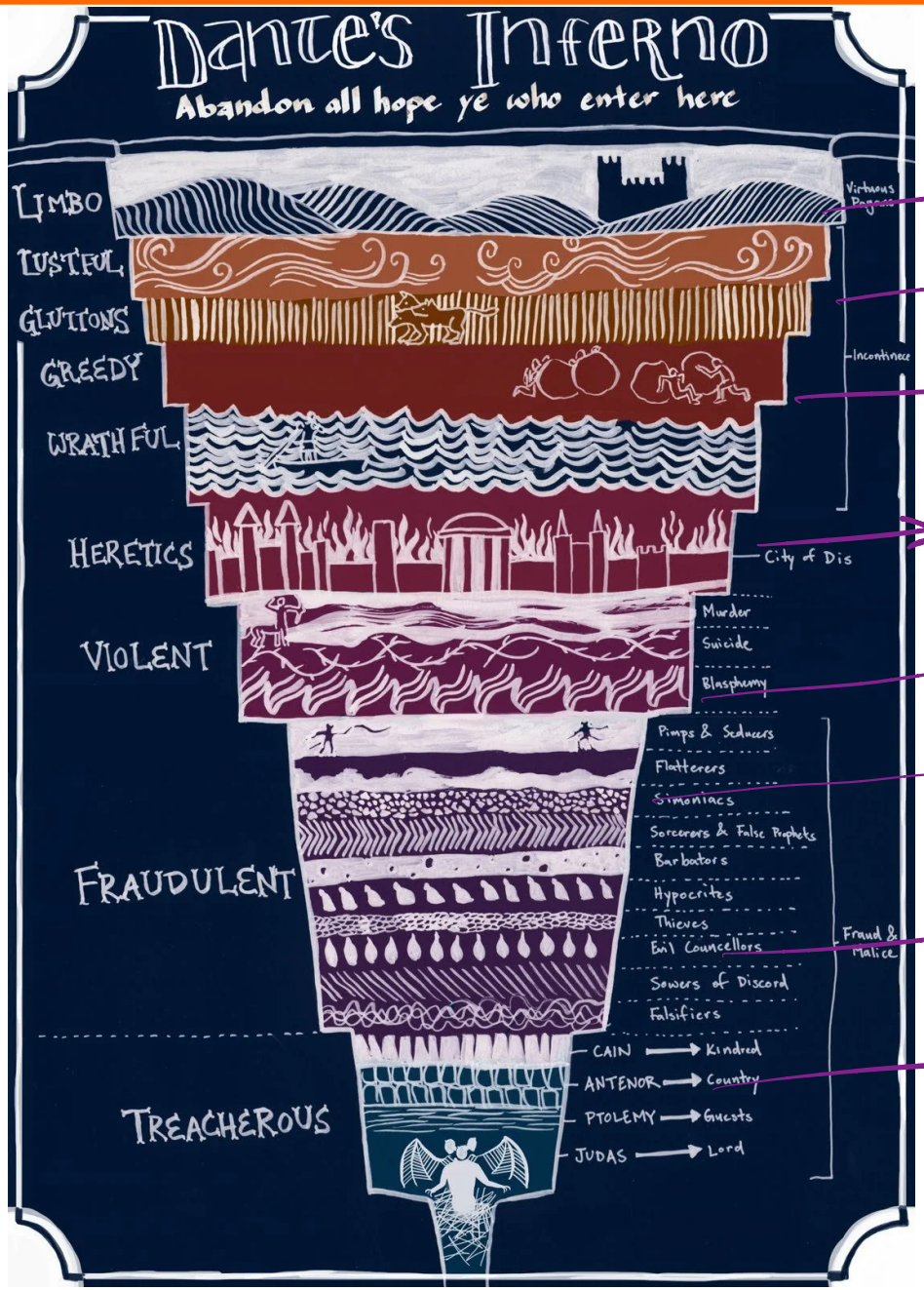
Global SMEFT fits

$$m_{EU} > |\lambda_{EU}| 1.5 \text{ TeV}$$

LHC direct probes provide a better handle on scenarios with relatively small coupling

[JHEP 09 (2022) 229, JHEP 09 (2023) 081]

Our personal levels of the Inferno



→ tree-level life (God save the seesaw's)

→ Weinberg operator at one loop
LLHH !!

→ Higher dimension neutrino masses
$LLHH(H^\dagger H)^n$

→ dim 6 SMEFT without derivatives or field tensors
$(\bar{L}\gamma_\mu\sigma^I L)(\bar{Q}\gamma^\mu\sigma^I Q)$ .... OK?

→ dim 6 Green's basis
$\bar{Q}(\sigma^I\sigma^{\mu\nu}\not{D} - \overleftarrow{\not{D}}\sigma^{\mu\nu}\sigma^I)Q W^I_{\mu\nu}$

→ NRSMEFT!

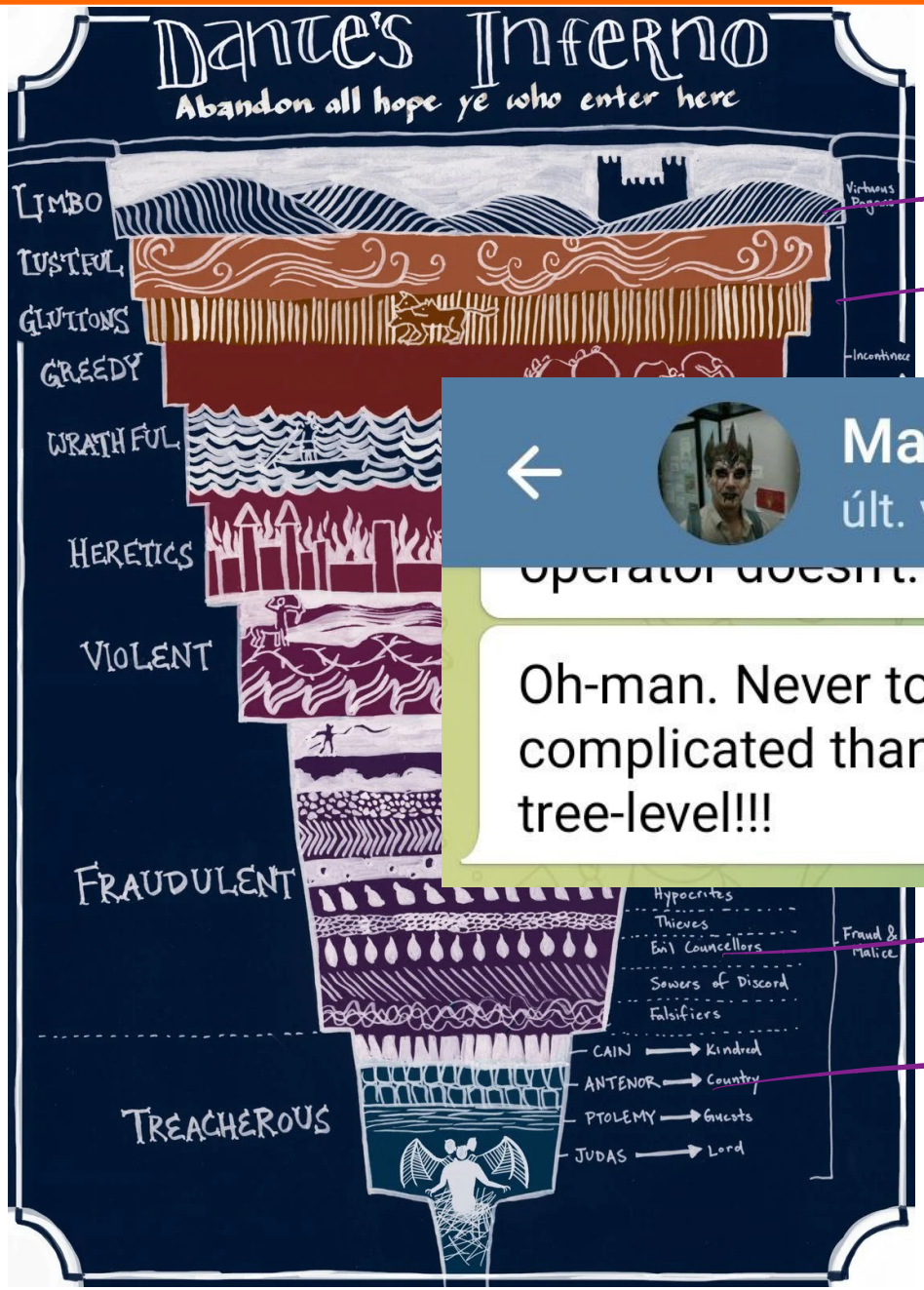
WE ARE HERE

→ dim 8 SMEFT operators !! $[H^\dagger \tilde{B}_{\mu\nu} W^{\mu\rho}\{D_\rho, D^\nu\} H]$

Are you sure it's not upside down?

→ Not sure yet ...
(Brave PhD students needed)

Our personal levels of the Inferno



tree-level life (God save the seesaw's)

Weinberg operator at one loop LLHH !!

dim 6 SMEFT operators !!

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Summary ...

Martin, trying to complete physics since the 90's.

- Corollary: send your papers to ArXiv before is too late!!

"The road goes ever on and on, down from the door where it began.
Now far ahead the road has gone, and I must follow if I can."

Tolkien, LOTR

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Martin, trying to complete physics since the 90's.

- Corollary: send your papers to ArXiv before is too late!!

Bate for potential students willing to do 4-loops Weinberg Op.

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Thank you for your attention!