Looking Forwards From 2022

Michael Ratz

8/18/2025

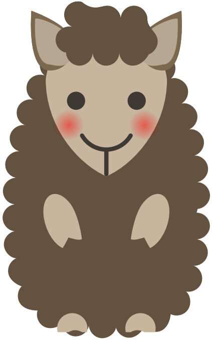
Vietnam Flavour Physics Conference
21st Recontres du Vietnam
ICISE, Quy Nhon, Vietnam

Disclaimers

&

Outline

Disclaimers & Apologies



- Some statements are oversimplified
- Some illustrations recreated (i.e. stolen) from Vincenzo Cirigliano's Snowmass talk
- Slides largely recycled from the 2022 Vietnam Flavour Physics Conference in Quy Nhon
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- The purpose of provocative statements is to provoke discussions (and not fist fights!)

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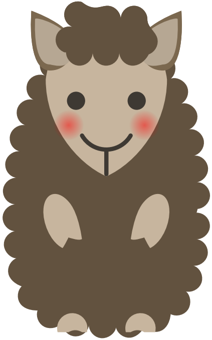

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Weinberg [1989]

"Physics thrives on crisis."

Why study flavor? (. . . my personal take)

- SM parameters
  - 3 gauge couplings

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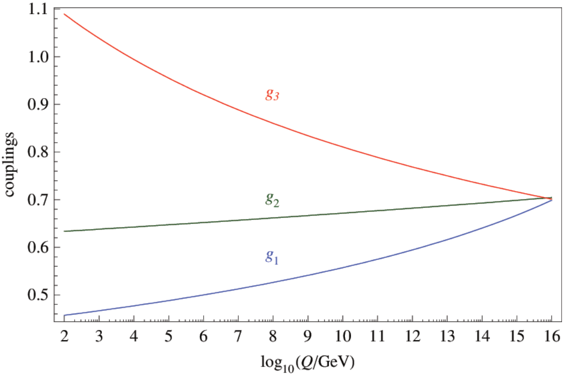
  - 3 gauge couplings (grand unification?)



Why study flavor? (. . . my personal take)

☞ SM parameters

- 3 gauge couplings
- 1 additional QCD parameter: θ_{QCD}

Why study flavor? (...my personal take)

☞ SM parameters

- 3 gauge couplings
- 1 additional QCD parameter: $\theta_{\rm QCD}$ (axion?)

Why study flavor? (. . . my personal take)

☞ SM parameters

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- 1 additional QCD parameter: θ_{QCD}
- 2 Higgs parameters

Why study flavor? (. . . my personal take)

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- 2 Higgs parameters (hierarchy problem?)

Why study flavor? (. . . my personal take)

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if neutrino masses are Majorana

Why study flavor? (. . . my personal take)

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$\left.\begin{array}{l}\text{12 masses}\\ \text{8+2 mixing parameters}\end{array}\right\}$ 20+2 flavor parameters

if neutrino masses are Majorana

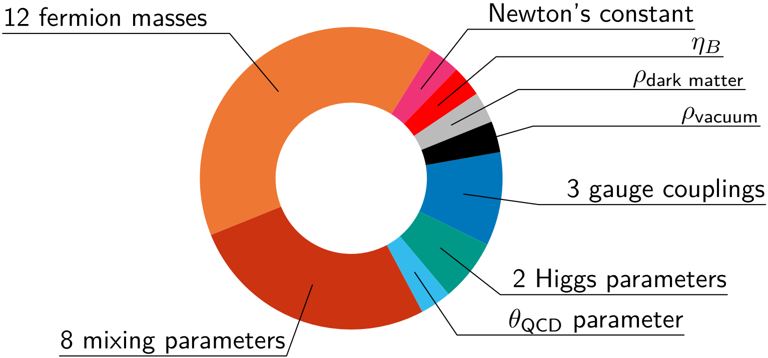
Why study flavor? (. . . my personal take)

- SM parameters
  - 3 gauge couplings
  - 1 additional QCD parameter: θ_{QCD}
  - 2 Higgs parameters
  - $\left.\begin{array}{l}\text{12 masses}\\ \text{8+2 mixing parameters}\end{array}\right\}$ 20+2 flavor parameters
- Other fundamental (?) quantities in Nature: M_{Planck} (or G_{Newton}), η_B, ρ_{vacuum} and ρ_{DM}

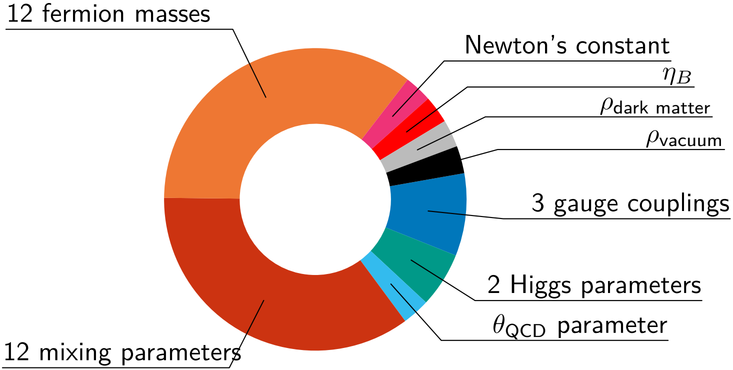
dark matter

baryon asymmetry

Parameters in Nature (Dirac νs)



Parameters in Nature (Majorana νs)



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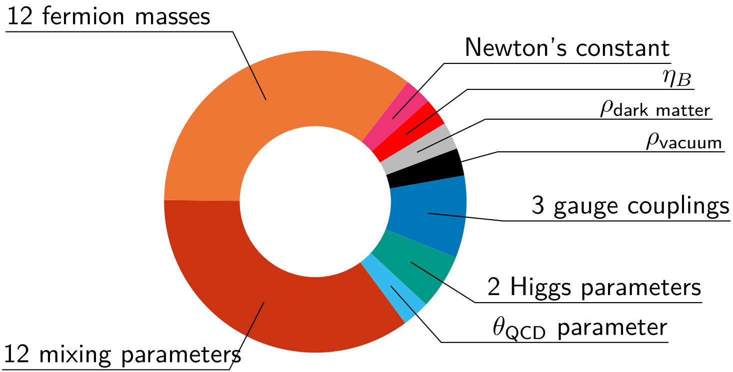


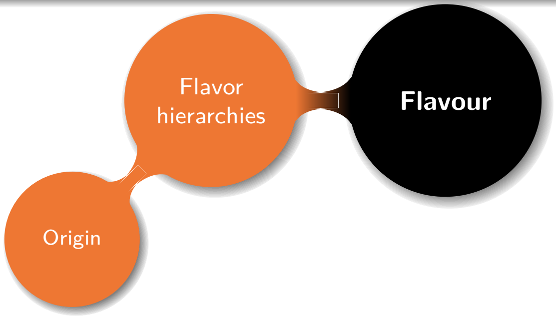
☞ The bulk of the (ununderstood) parameters of Nature resides in the flavor sector of the standard model

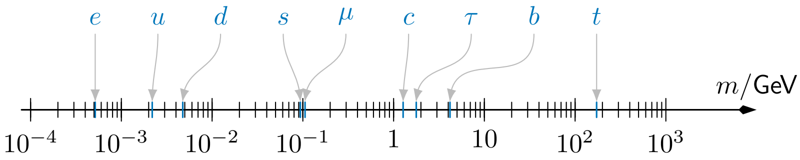
The Flavour Puzzle

(A biased selection of) Big questions

Flavour

(A biased selection of) Big questions





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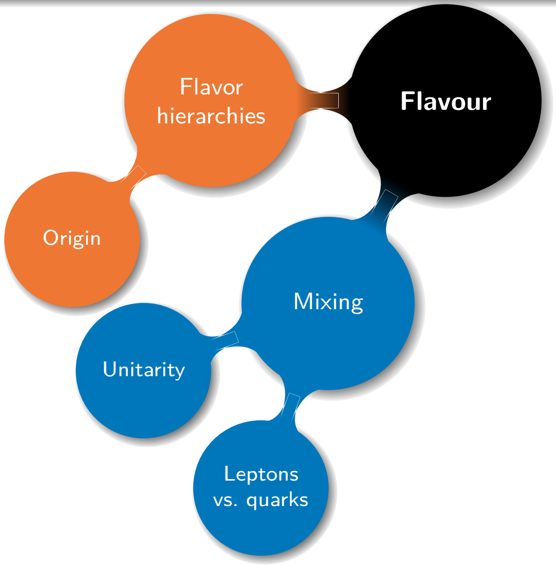

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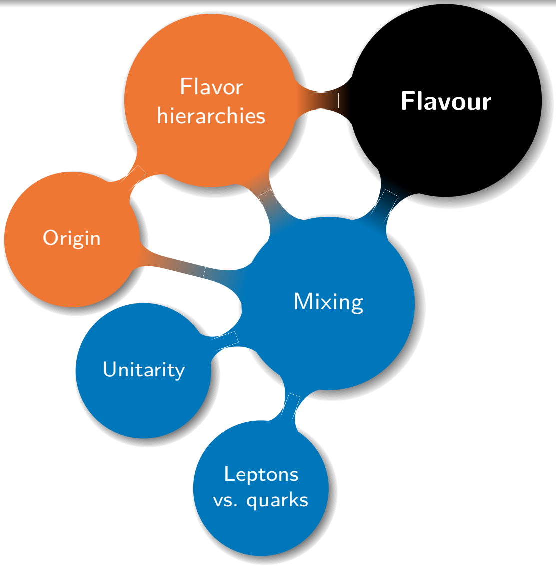

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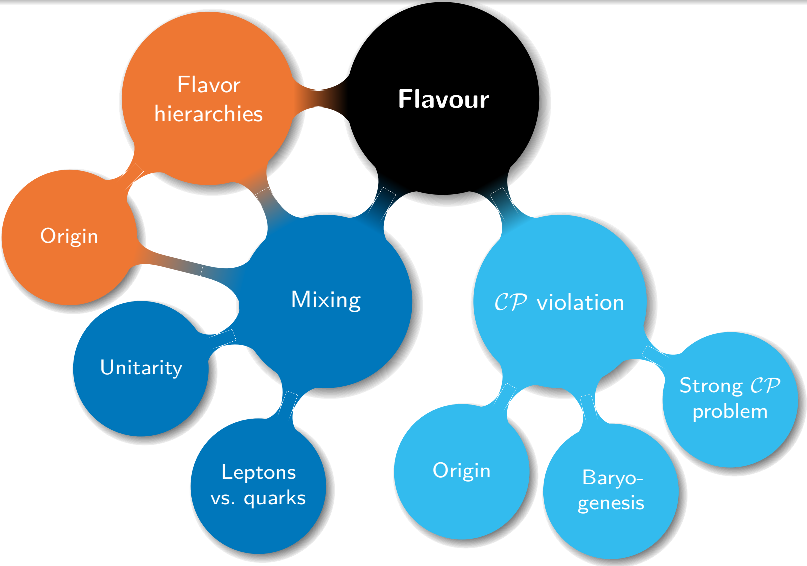

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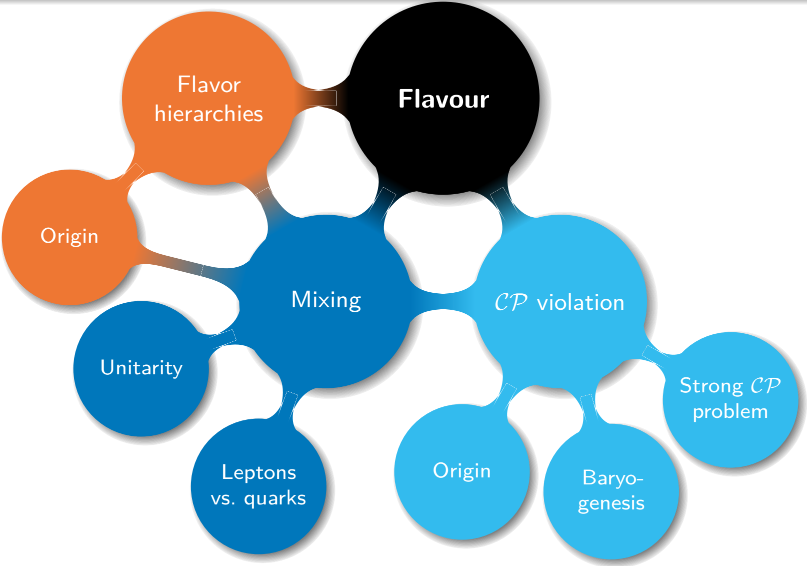

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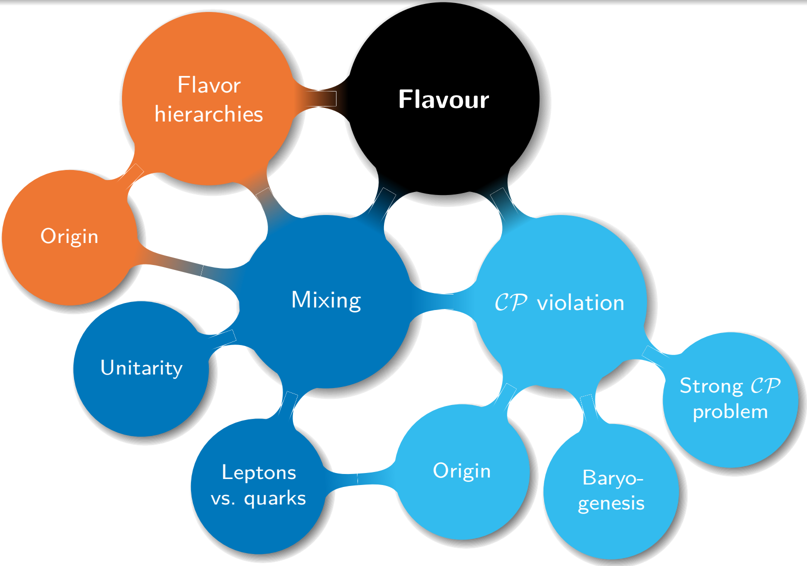

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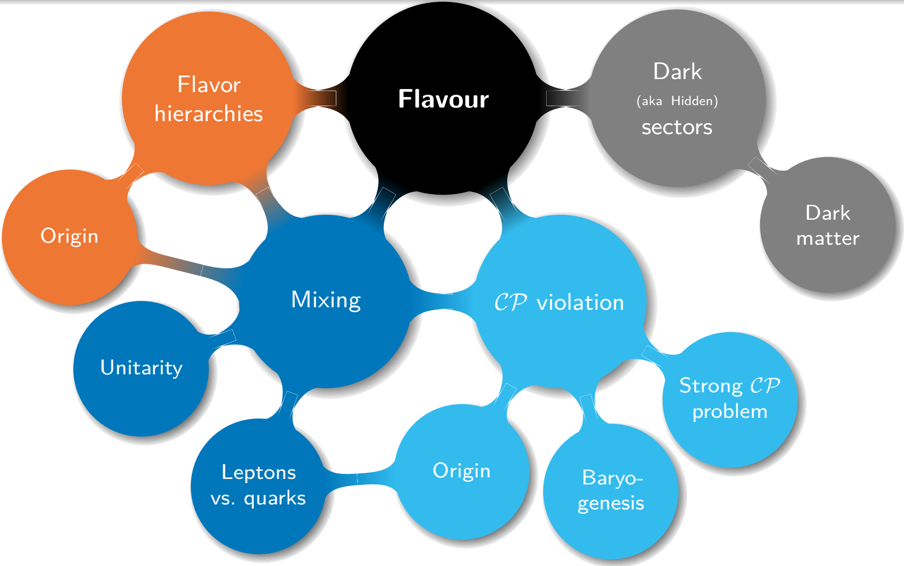

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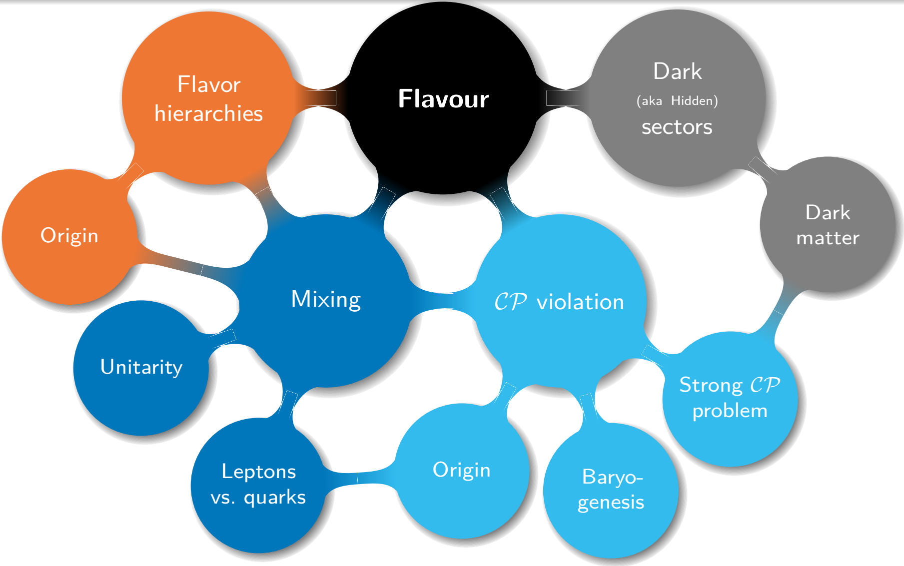
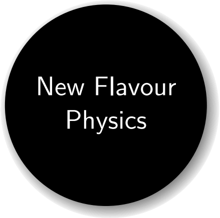


Standard ways of testing theories of flavor



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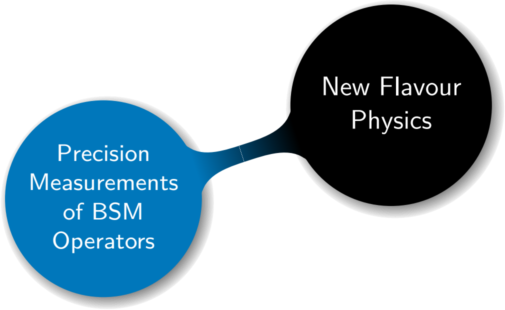
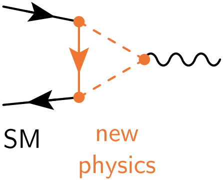


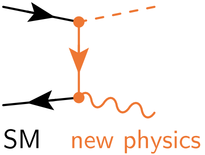


Standard ways of testing theories of flavor

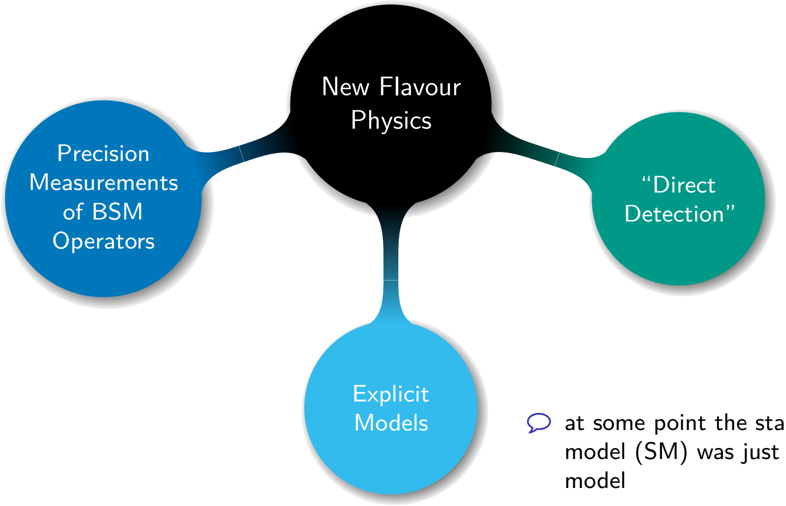
New Flavour Physics

Precision Measurements of BSM Operators

“Direct Detection”

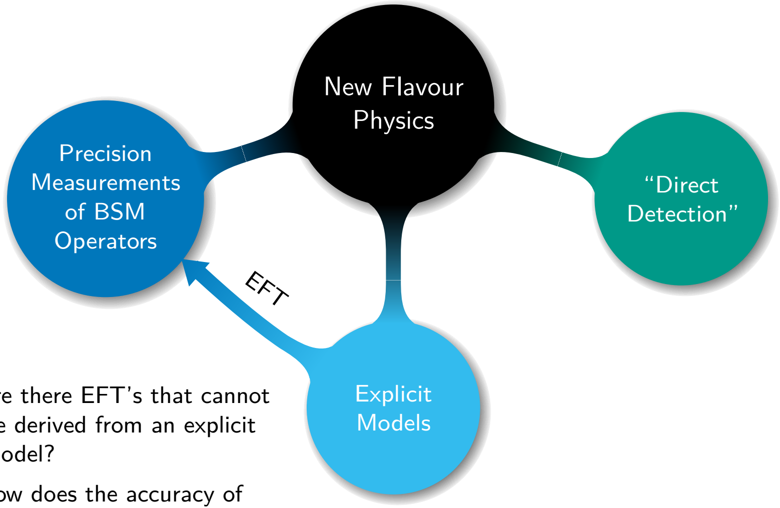


Standard ways of testing theories of flavor



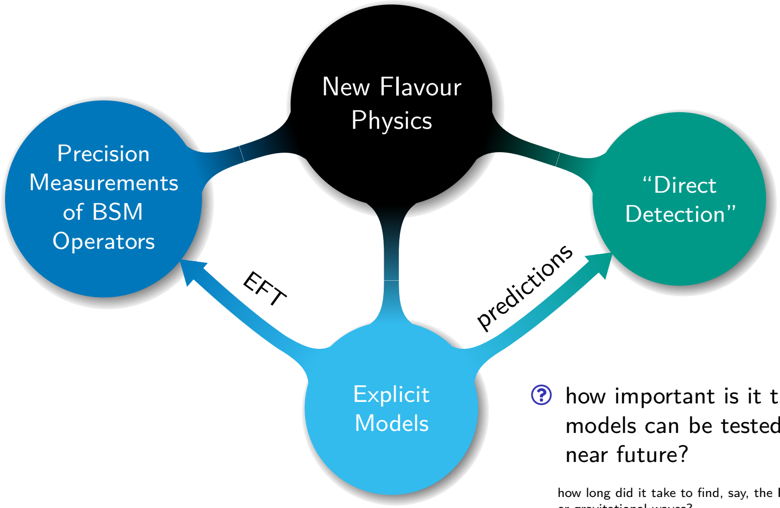
at some point the standard model (SM) was just a model

Standard ways of testing theories of flavor



- are there EFT's that cannot be derived from an explicit model?
- how does the accuracy of model predictions compare to the precision of measurements?

Standard ways of testing theories of flavor



- how important is it that models can be tested in the near future?

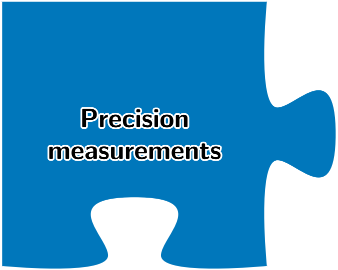
how long did it take to find, say, the Higgs or gravitational waves?

Challenges

&

Opportunities

Challenge # 1: Precision



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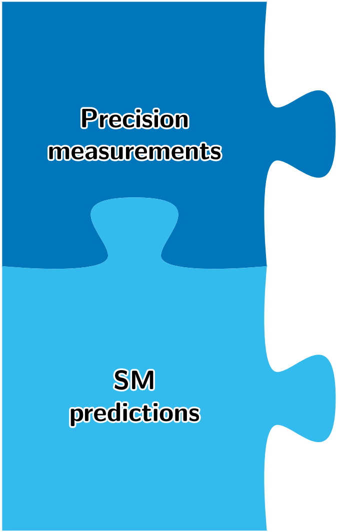

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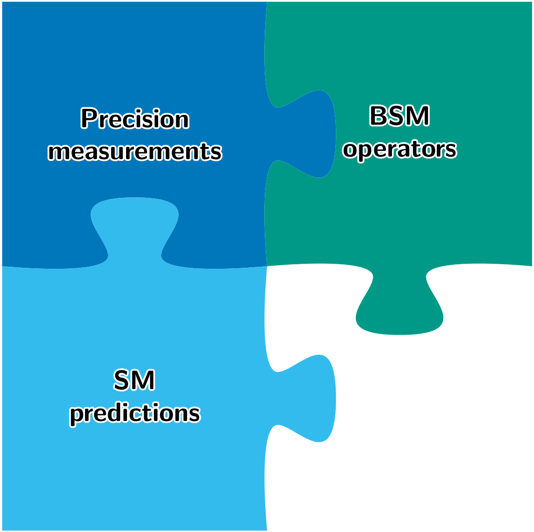

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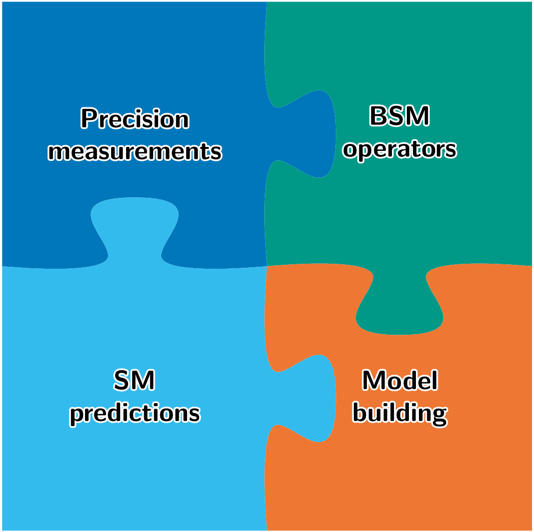

Progress in precision computations

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- ☞ Lattice QCD becoming a competetive tool
- ☞ In flavor model building some statements are more robust than others

Challenge # 1: Precision vs. convenience

https://www.redbull.com/int-en/10-mountain-huts-that-look-like-really-precarious

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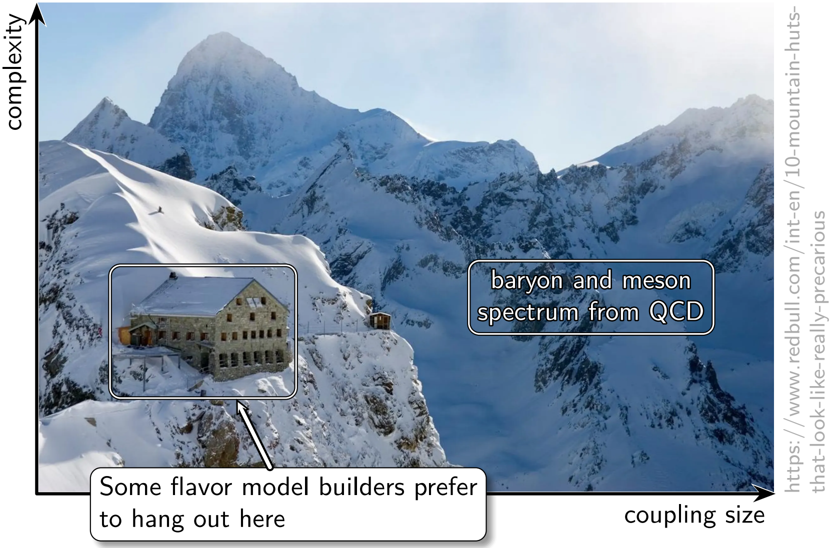

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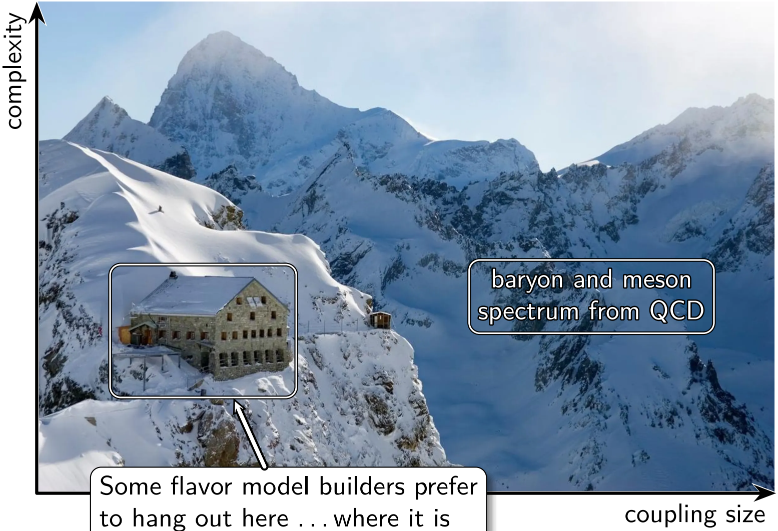

Some flavor model builders prefer to hang out here . . . where it is convenient and visibility is good

https://www.redbull.com/int-en/10-mountain-huts-that-look-like-really-precarious

Challenge # 2: Scales

☞ What is the scale of new physics?

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- Absence of large FCNCs, the longevity of the proton and the smallness of the neutrino mass scale may suggest that the scale of certain kinds of new physics is rather high

$$\tau_p \sim \frac{m_p^5}{M_X^4} \gtrsim 10^{34}\,\text{years} \qquad \curvearrowright M_X \gtrsim 10^{15}\,\text{GeV}$$

$$m_\nu^{\text{naive see-saw}} = \frac{v_{\text{EW}}^2}{M_{\text{see-saw}}} \lesssim 0.1\,\text{eV} \qquad \curvearrowright M_{\text{see-saw}} \gtrsim 10^{14}\,\text{GeV}$$

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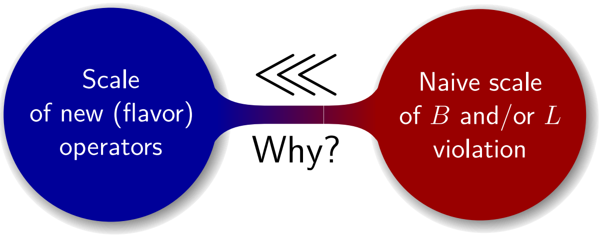

Challenge # 2: Scales (continued)

M_{np} vs. $M_{\not B}$

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M_{np} vs. $M_{\not{B}}$

New physics
accessible
in experiments

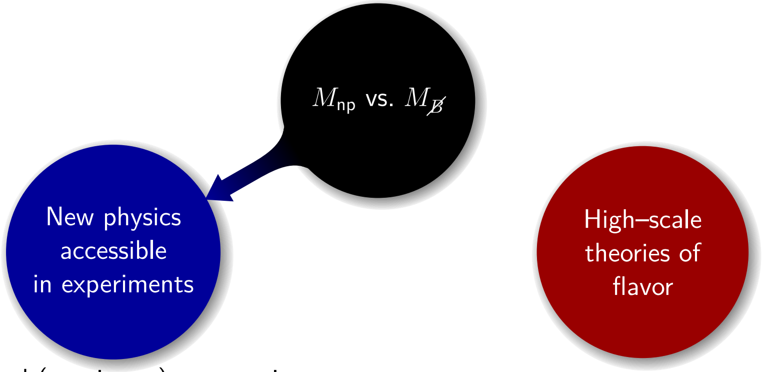
Challenge # 2: Scales (continued)

M_{np} vs. $M_{\not{B}}$

New physics accessible in experiments

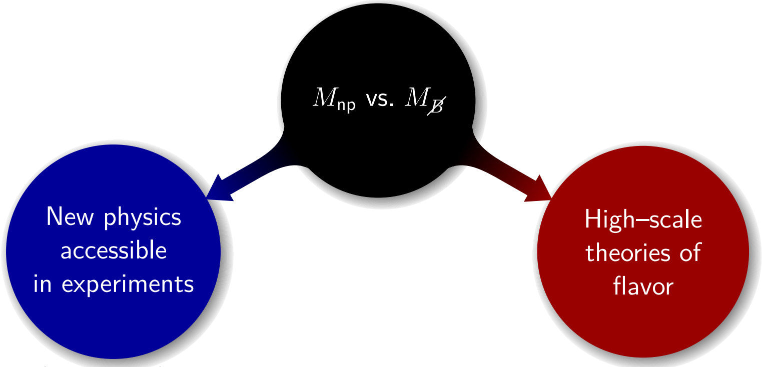
High–scale theories of flavor

Challenge # 2: Scales (continued)



- need (consistent) symmetries to tame (or forbid) offending operators
- relations between operators?

Challenge # 2: Scales (continued)



- need (consistent) symmetries to tame (or forbid) offending operators
- relations between operators?

- hard to test directly
- unequivocal/precise predictions?

Challenge # 3: Abundance and flexibility of models

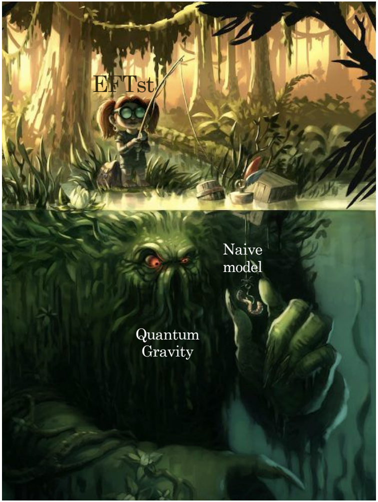
- Observation can apparently be accommodated by numerous models
  - How do we know which one (if any) is the correct one?
  - Are the only worthwhile models those which can be fully explored in the not-too-distant future?

Challenge # 3: Abundance and flexibility of models

- Observation can apparently be accommodated by numerous models
- Flexibility of some models
  - E.g. models that predicted $\theta_{13} = 0$ could be "upgraded" to accommodate a realistic θ_{13} after it has been measured
  - When do we call predictions unequivocal?

Challenge # 3: Abundance and flexibility of models

- Observation can apparently be accommodated by numerous models
- Flexibility of some models
- What are the appropriate theoretical constraints?
  - We all know that continuous gauge symmetries need to be anomaly-free but what about discrete and/or global symmetries?
  - What are reasonable restrictions on the representation content?
  - Should we take string theory and/or swampland constraints seriously?



https://workshops.ift.uam-csic.es/uploads/poster/poster_congreso_299.pdf

Can't really comment on swampland, though

D0 - Abnormally Dry

- Soil is dry; irrigation delivery begins early
- Dryland crop germination is stunted
- Active fire season begins

100.00% of Orange County (D0-D4)

D1 - Moderate Drought

- Dryland pasture growth is stunted; producers give supplemental feed to cattle
- Landscaping and gardens need irrigation earlier; wildlife patterns begin to change
- Stock ponds and creeks are lower than usual

100.00% of Orange County (D1-D4)

D2 - Severe Drought

- Grazing land is inadequate
- Fire season is longer, with high burn intensity, dry fuels, and large fire spatial extent
- Trees are stressed; plants increase reproductive mechanisms; wildlife diseases increase

100.00% of Orange County (D2-D4)

D3 - Extreme Drought

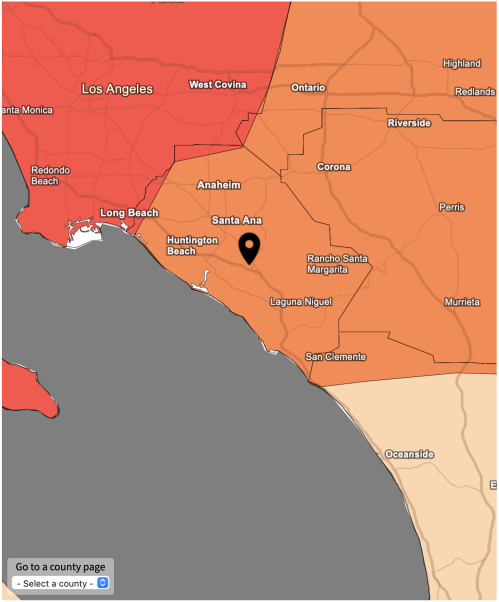
- Livestock need expensive supplemental feed; cattle and horses are sold; little pasture remains; fruit trees bud early; producers begin irrigating in the winter
- Fire season lasts year-round; fires occur in typically wet parts of state; burn bans are implemented
- Water is inadequate for agriculture, wildlife, and urban needs; reservoirs are extremely low; hydropower is restricted

4.31% of Orange County (D3-D4)

D4 - Exceptional Drought

- Fields are left fallow; orchards are removed; vegetable yields are low; honey harvest is small
- Fire season is very costly; number of fires and area burned are extensive
- Fish rescue and relocation begins; pine beetle infestation occurs; forest mortality is high; wetlands dry up; survival of native plants and animals is low; fewer wildflowers bloom; wildlife death is widespread; algae blooms appear

0.00% of Orange County (D4)



Organizing principles

Minimal
Flavour
Violation

Chivukula & Georgi [1987];
Buras, Gambino, Gorbahn, Jäger & Silvestrini [2001];
D'Ambrosio, Giudice, Isidori & Strumia [2002];...

Organizing principles

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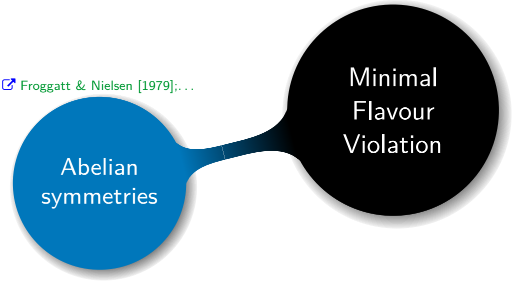
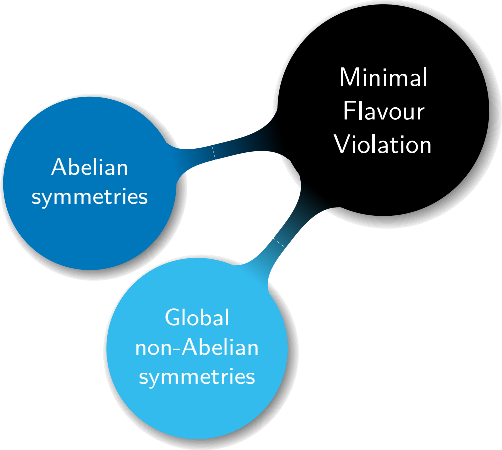
Froggatt & Nielsen [1979];...



sufficient?

Organizing principles



Goldstone bosons?

Chivukula & Georgi [1987];
Buras, Gambino, Gorbahn, Jäger & Silvestrini [2001];
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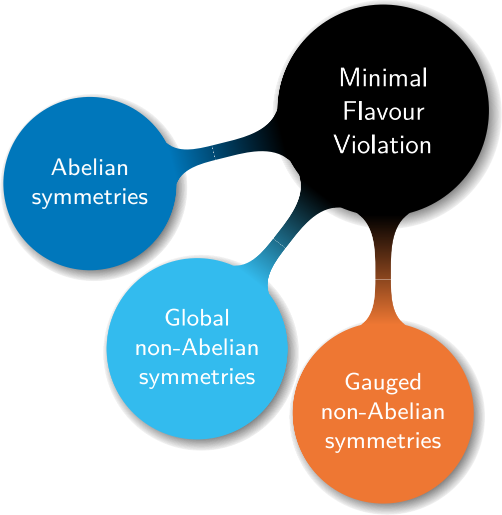
Organizing principles



anomalies?

Chivukula & Georgi [1987]; Buras, Gambino, Gorbahn, Jäger & Silvestrini [2001]; D'Ambrosio, Giudice, Isidori & Strumia [2002];. . .

Organizing principles

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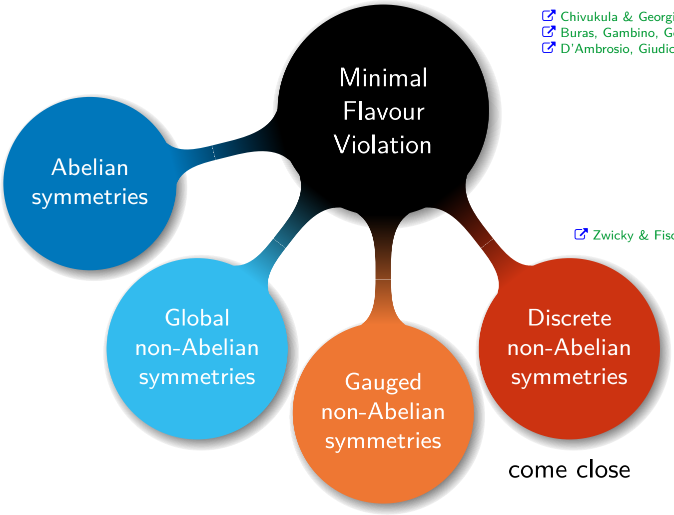


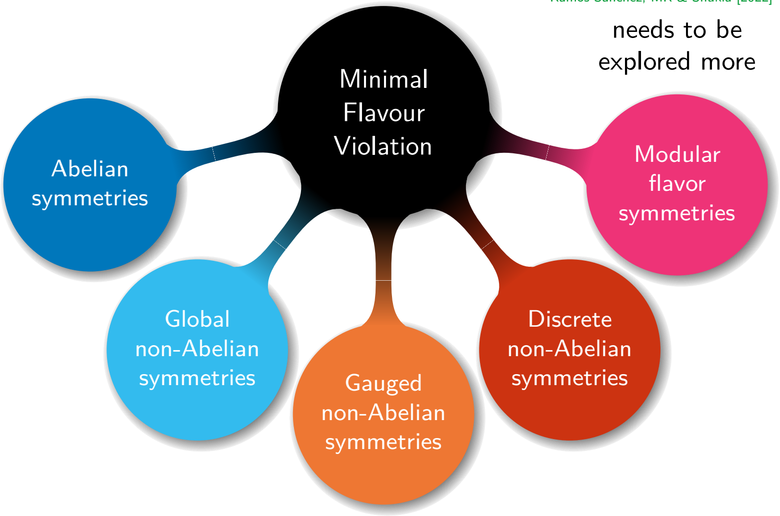
Zwicky & Fischbacher [2009]

come close

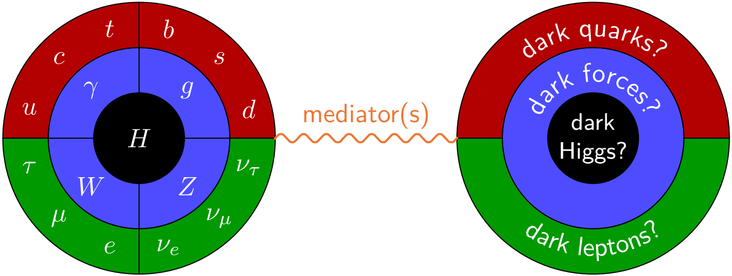
Organizing principles

Chen, Knapp–Pérez, Ramos-Hamud, Ramos-Sánchez, MR & Shukla [2022]

needs to be explored more



The dark side of ~~the Force~~ Flavour



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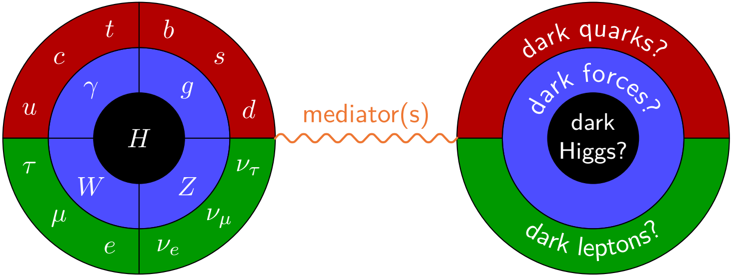

☞ 20 years ago, dark sectors were not discussed in the context of flavour

(not only because they were called hidden sectors back then)

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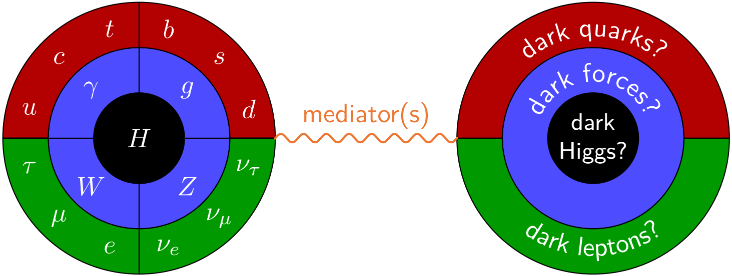

- 20 years ago, dark sectors were not discussed in the context of flavour

  (not only because they were called hidden sectors back then)

- Dark sectors may affect astrophysics and/or cosmology

Summary

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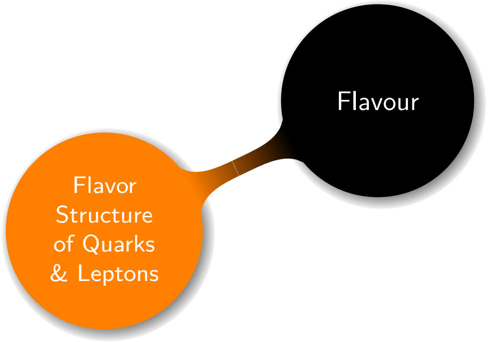
Outlook

Main insight(s)

$$\text{flavour} \neq \text{flavor}$$

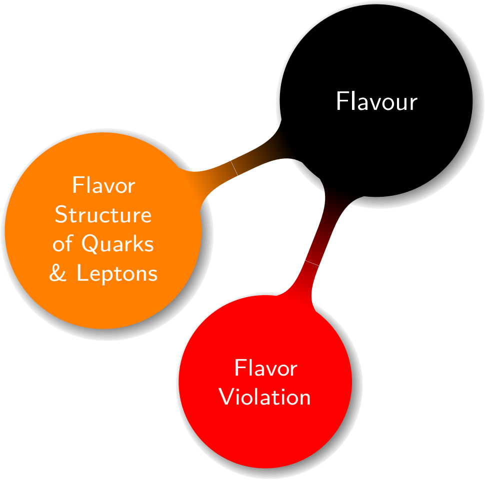
Main insight(s)

flavour $\neq$ flavor



Main insight(s)

$$\text{flavour} \neq \text{flavor}$$



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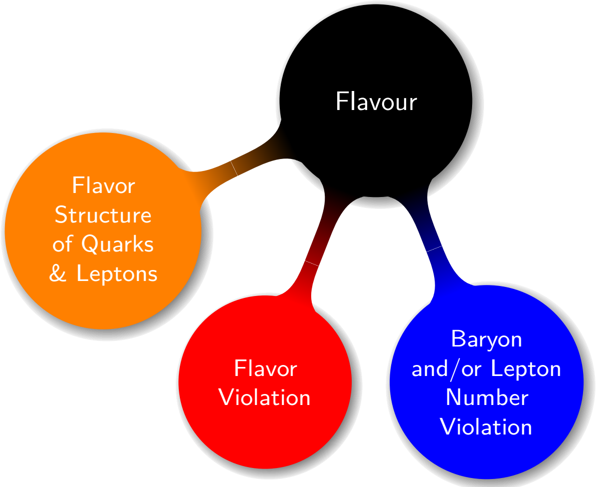

Main insight(s)

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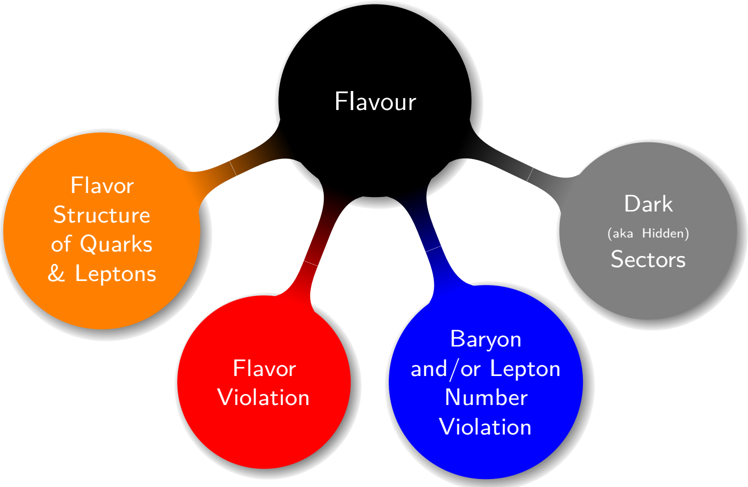

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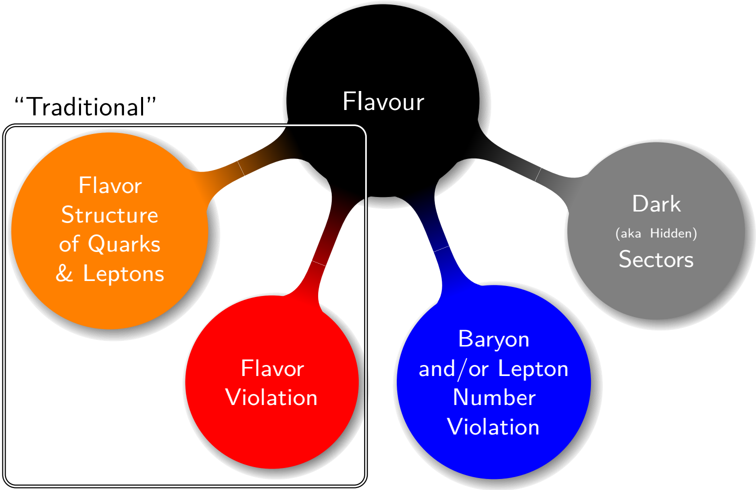

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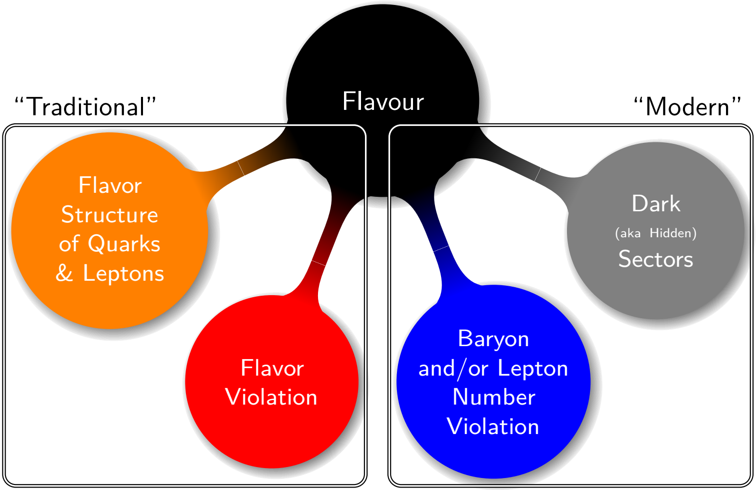

Outlook

- Stimulating talks
- Discussions
- Identify common goals

$\Bigg\}$ this week

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- New collaborations
- Neutrino 2026 in Irvine!

this week

Neutrino 2026

UC Irvine

https://sites.uci.edu/neutrino2026/

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