The flavor of the New Physics

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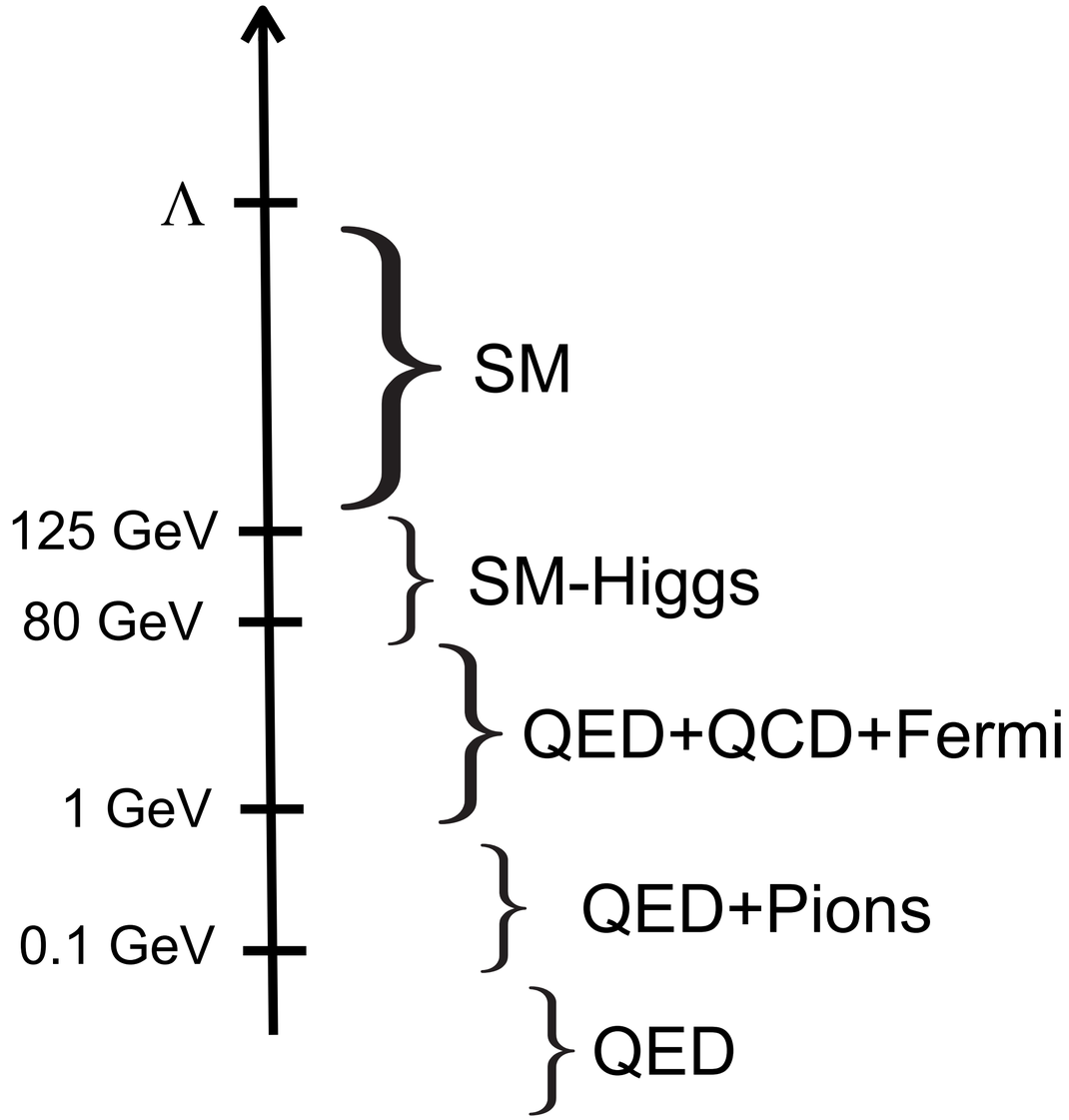
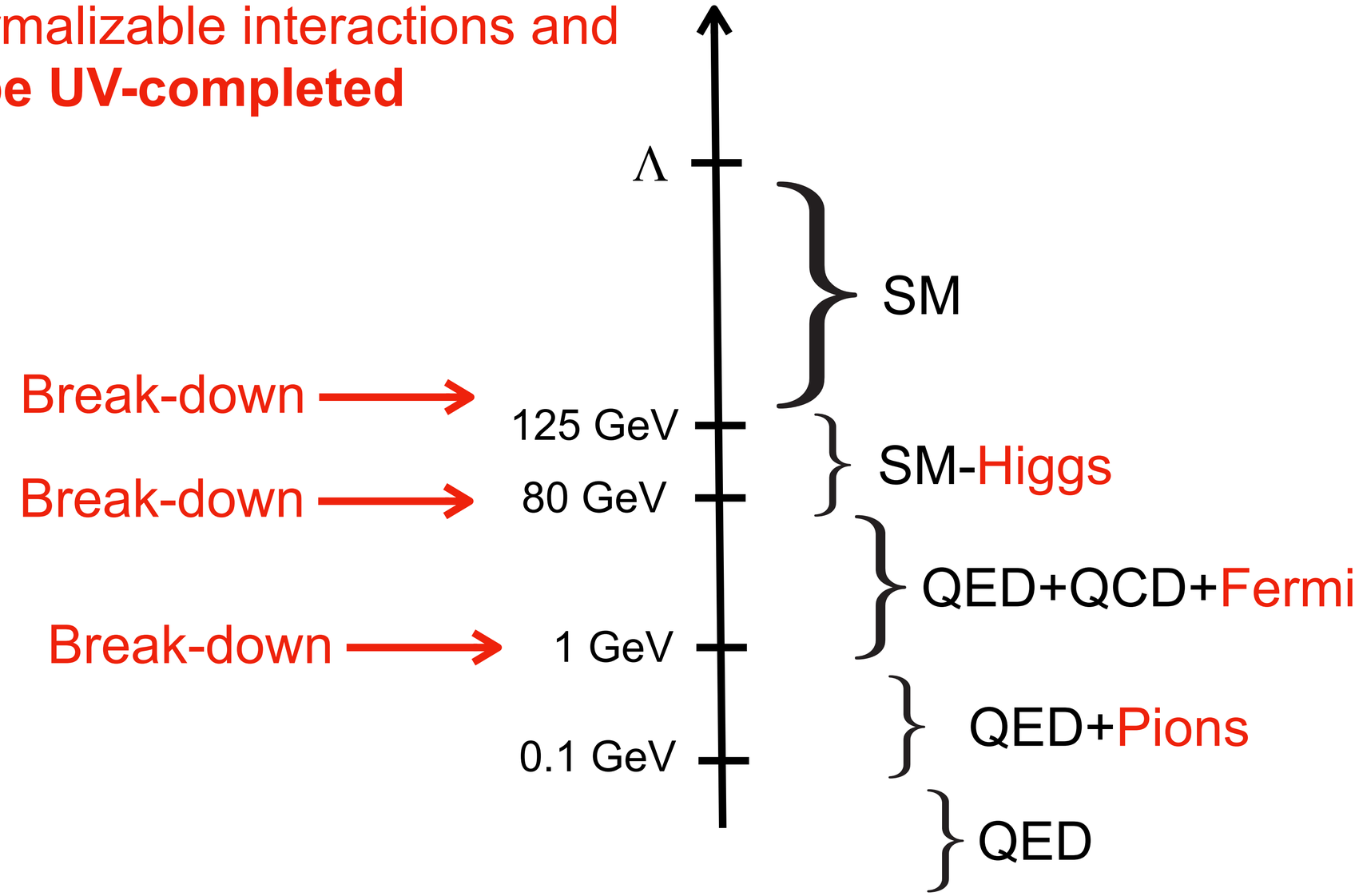
Some perspective:
What can we learn from the past?

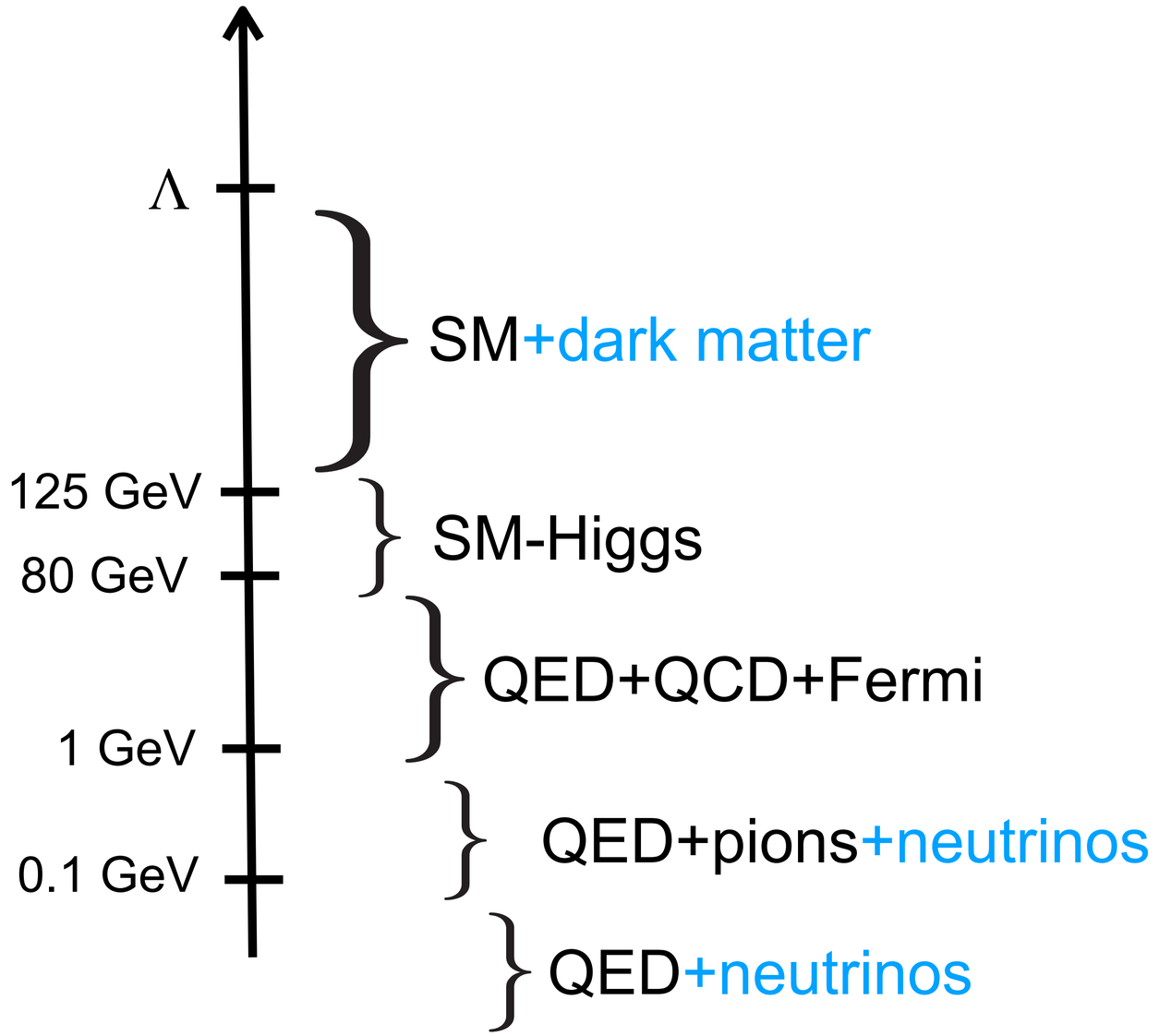
Conservatively including only accessible particles:
layers of EFTs



Some of these EFTs contain **sizable** non-renormalizable interactions and **have to be UV-completed**



Some of these EFTs include
feebly-coupled dark sectors.



Analogy between QED+ν and the SM+DM

$$\mathscr{L} = \mathscr{L}_{\text{QED}+\nu} + \mathcal{O}\left(\frac{1}{\Lambda^{\#}}\right)$$

Very weakly coupled

No sizable effective operator

$$\mathscr{L} = \mathscr{L}_{\text{SM+DM}} + \mathcal{O}\left(\frac{1}{\Lambda^{\#}}\right)$$

Very weakly coupled

No sizable effective operator

“Beyond the QED searches”

Indirect approach (QEDEFT):

$$\mathscr{L} = \mathscr{L}_{\text{QED}+\nu} + C_w(\bar{e}\gamma_\mu e)(\bar{\nu}\gamma^\mu\nu) + C_6(\bar{e}\gamma_\mu e)(\bar{e}\gamma^\mu e) + C_8 F^4 + \cdots$$

Direct approach:

$$e^+e^- \to X, \quad e\gamma \to X', \cdots$$

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What is the New Physics?

A whole new world (us!) appears
at $\Lambda = m_\pi \sim 200 m_e$ for apparently no reason!

Indirect approach:

$$\mathscr{L} = \mathscr{L}_{\text{QED}+\nu} + c_w \frac{g^2}{m_W^2}(\bar{e}\gamma_\mu e)(\bar{\nu}\gamma^\mu \nu) + c_6 \frac{e^4}{16\pi^2 m_\pi^2}(\bar{e}\gamma_\mu e)(\bar{e}\gamma^\mu e) + c_8 \frac{e^4}{16\pi^2 m_\pi^4} F^4 + \cdots$$

$10^5 m_e$ $10^4 m_e$

Direct approach:

$$\mathscr{A}(e^+e^- \to \pi^+\pi^-) \sim e^2$$

Probably a better option

Analogy between QED+ν and the SM+DM

$$\mathscr{L} = \mathscr{L}_{\text{QED+}\nu} + \mathcal{O}\left(\frac{1}{\Lambda^{\#}}\right) \qquad \mathscr{L} = \mathscr{L}_{\text{SM+DM}} + \mathcal{O}\left(\frac{1}{\Lambda^{\#}}\right)$$

Following Weinberg, if we take $\Lambda \gg m_e$ we predict that:

CP & P remain good symmetries (modulo θ) ✔

Absence of new physics up to, say, scales $\sim 100 m_e$ ✔

Analogy between QED+ν and the SM+DM

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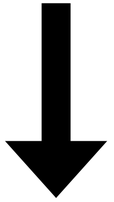

If we take $\Lambda \gg m_H$, remarkable predictions:

approximate proton stability ✔

light Majorana neutrino masses ✔

success of CKM paradigm ✔

absence of BSM signatures ✔

~~Analogy~~ between QED+ν and the SM+DM

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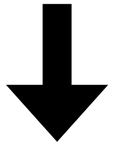

Imagine you are a theorist that computes $e^+e^- \to e^+e^-$ at 2-loops.
Observables depend on the cutoff via $\alpha \ln \Lambda^2$ (and inverse powers of Λ),
so your EFT looks fine even if Λ is large.

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Observables depend on $\alpha\Lambda^2$: reproducing data with large Λ requires fine-tuning.

Hierarchy Problem: NEW!

Lesson from the past

Indirect clues sometimes are crucial (chiral Lag., Fermi, SM-Higgs).
Sometimes they are not (QED) and Nature surprises us.
We have never seen a Hierarchy Problem.

Clues in the SM

Many, many more than in QED+ν:
the hierarchy problem (=TeV), B, L, CKM, dark matter, etc.

"Where are our pions?"

How can we have new physics at TeV?

What flavor and CP violating structures are allowed?

How will the picture evolve in 10-20 years?

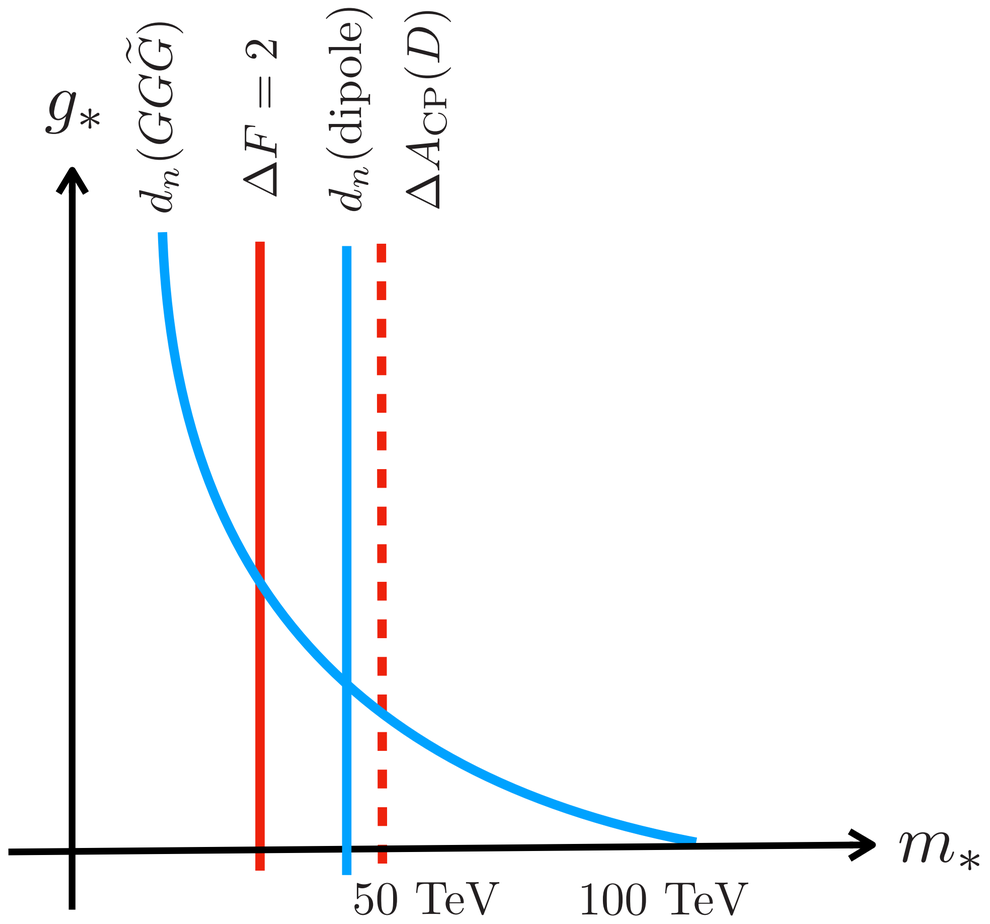
1) Pick a framework ➔ Strongly-Interacting Light Higgs + partial compositeness
2) Do the dirty work

Hypothesis:
No flavor symmetries

— qO+SO(4)+B+L

LHC ☹

FCC ☹



— qO+SO(4)+B+L
— CP
— 1-loop dipoles

LHC ☹️
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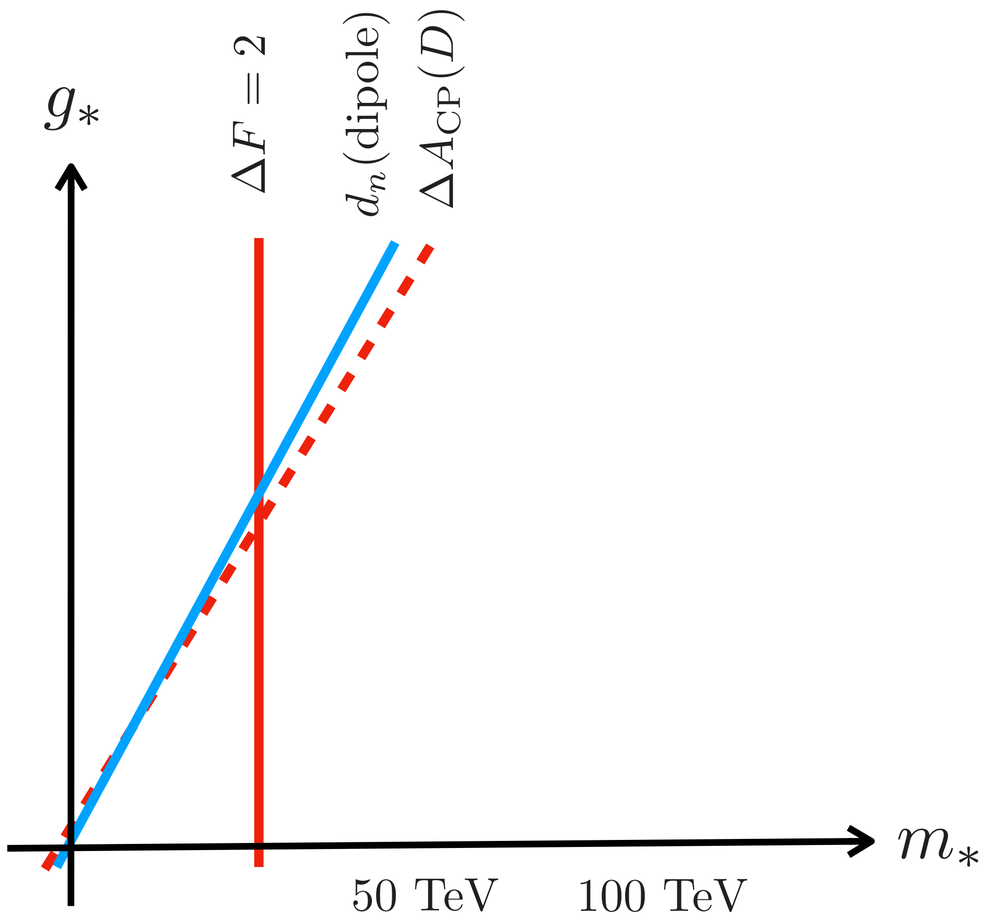
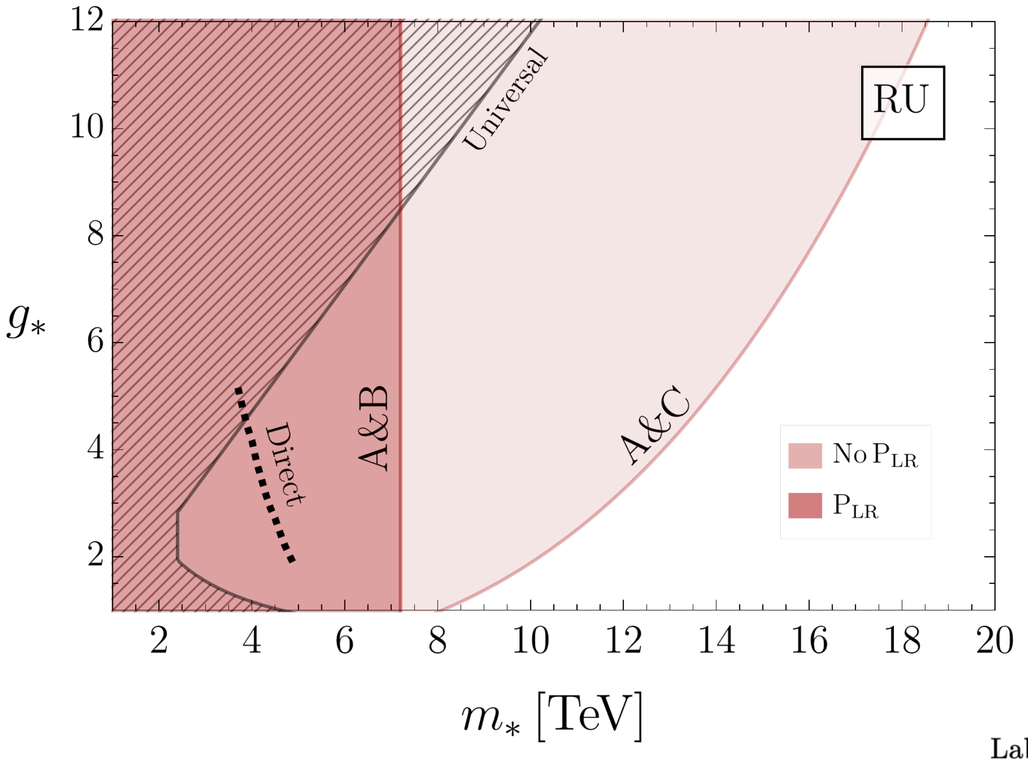
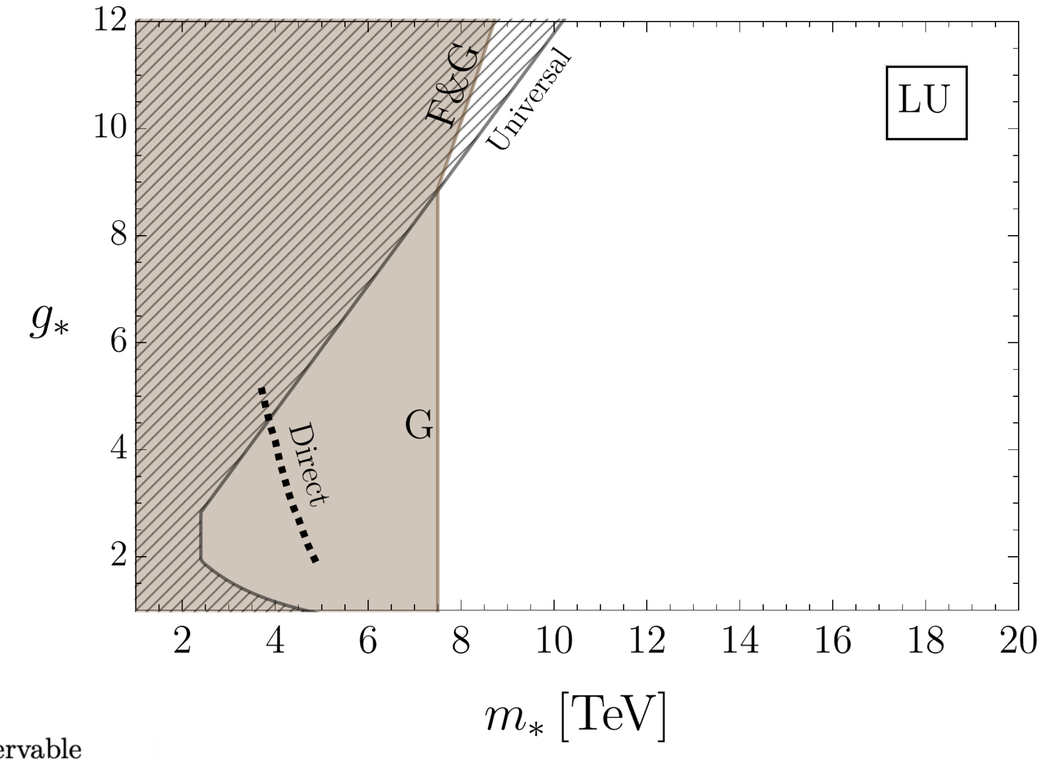


Hypothesis:
Flavor symmetries

Maximal Symmetry (MFV+CP+SO(4)+B+L)





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

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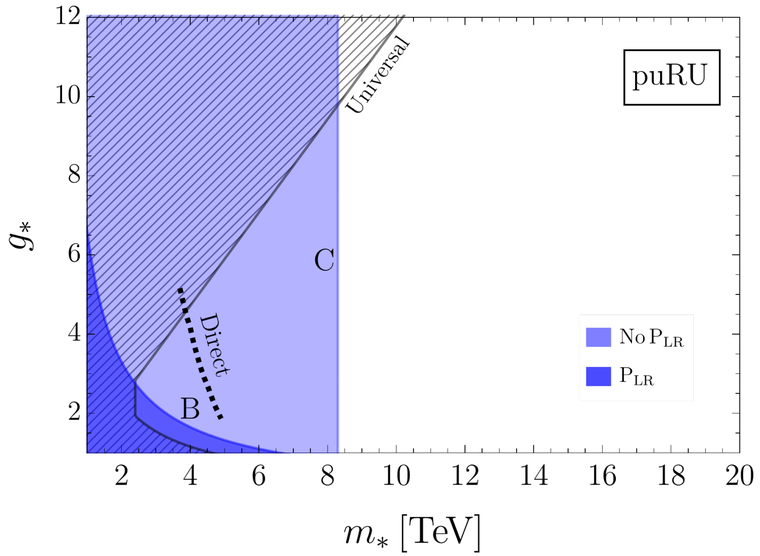
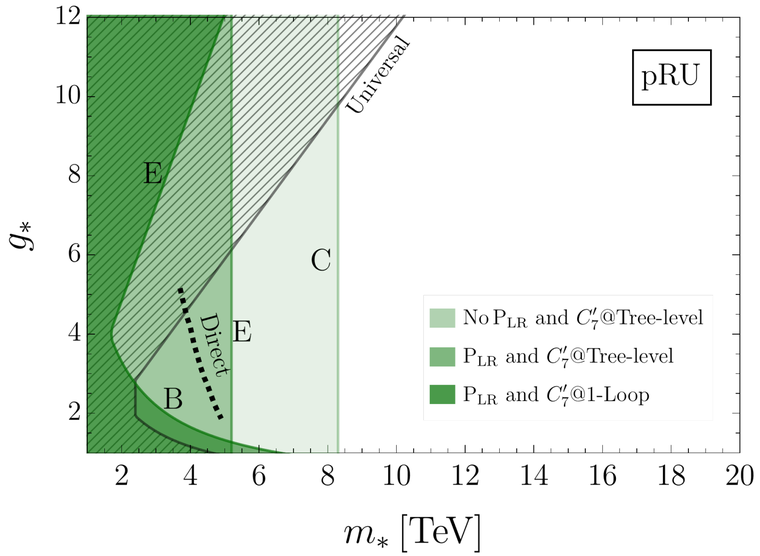
Intermediate Symmetry

LHC 😀

FCC 😀



— qO
— SO(4)+B+L
— CP
— **NMFV**
— **LR?**



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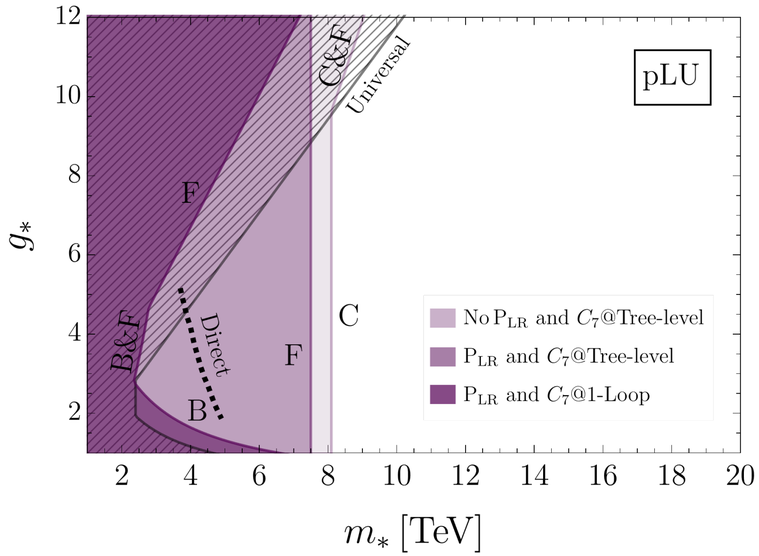

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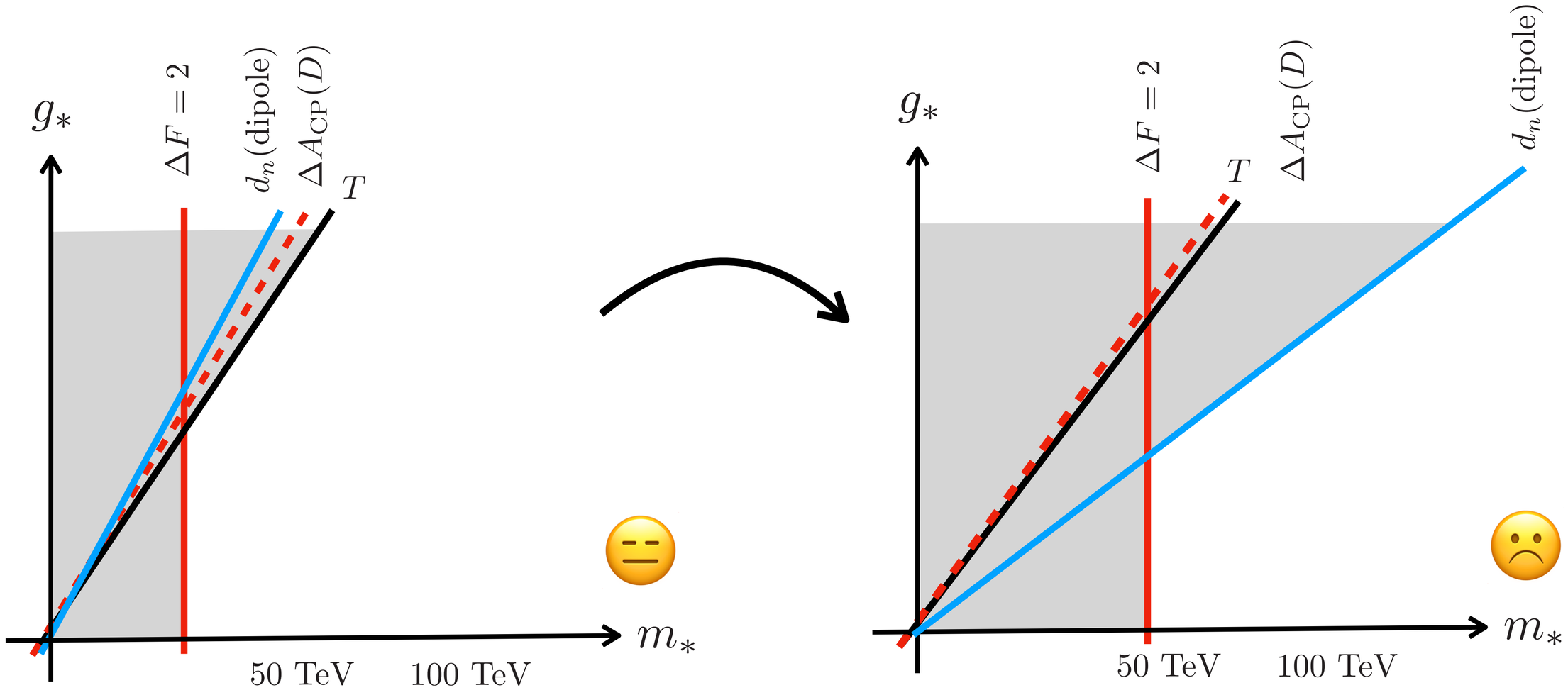
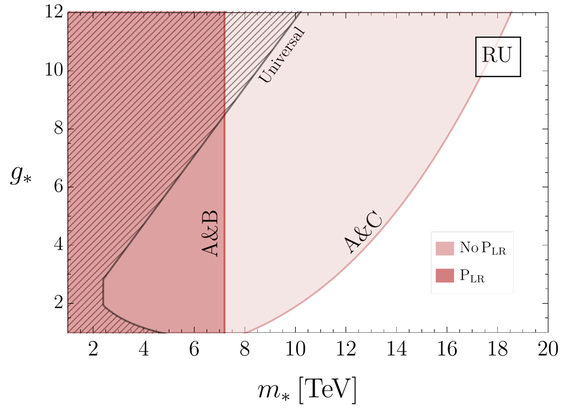
And in 10-20 years?

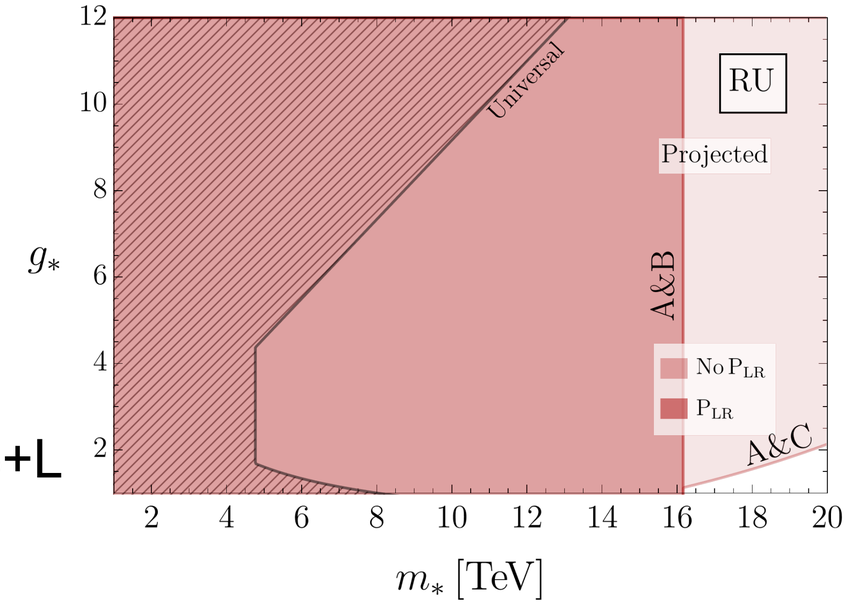
Projections (mainly HL-LHC, Belle II, nEDM)



Main FV improvements: $C_{9,10} \to 1/3$ (LHCb), $C_7 \to 1/2$ (Belle II), $C'_7 \to 1/5$ (LHCb), $C_{\Delta F=2} \to 1/4$ (HL-LHC)

LHC ☹️
FCC 😑





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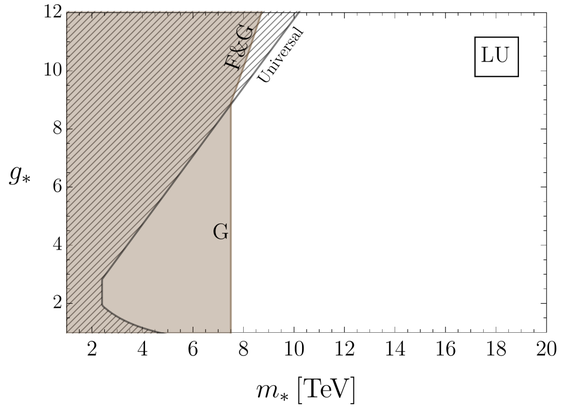

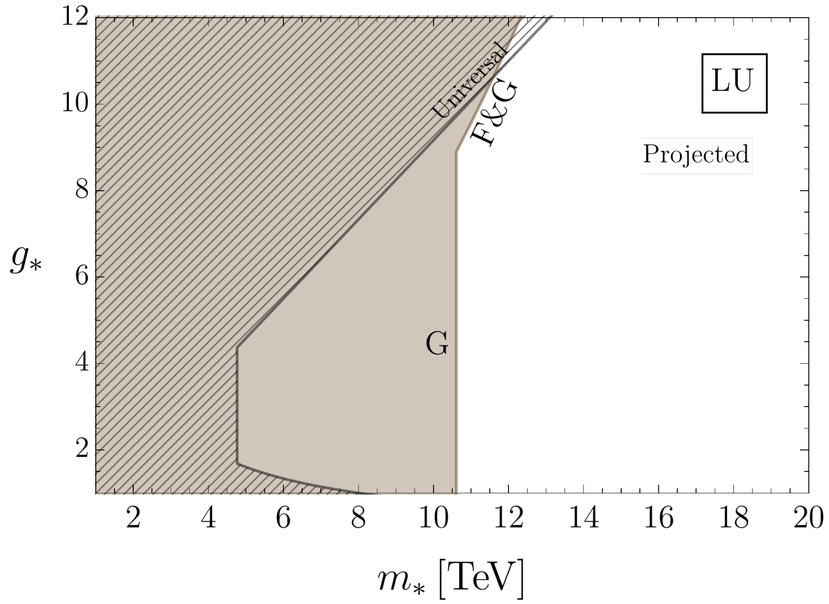

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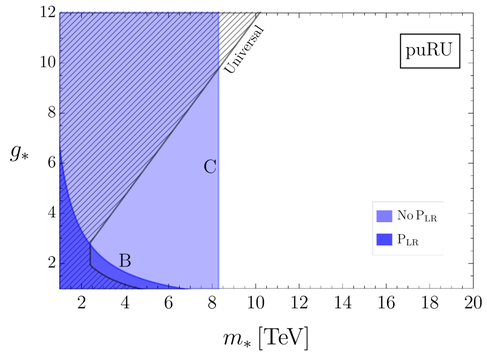

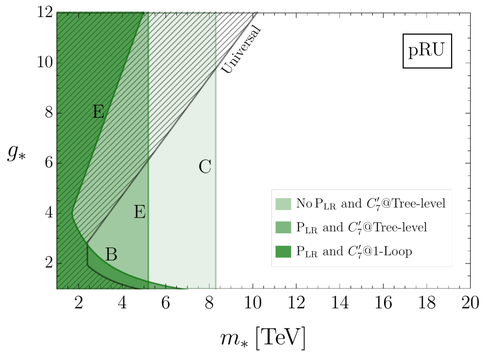

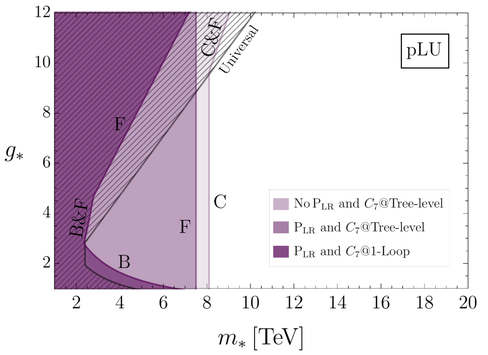

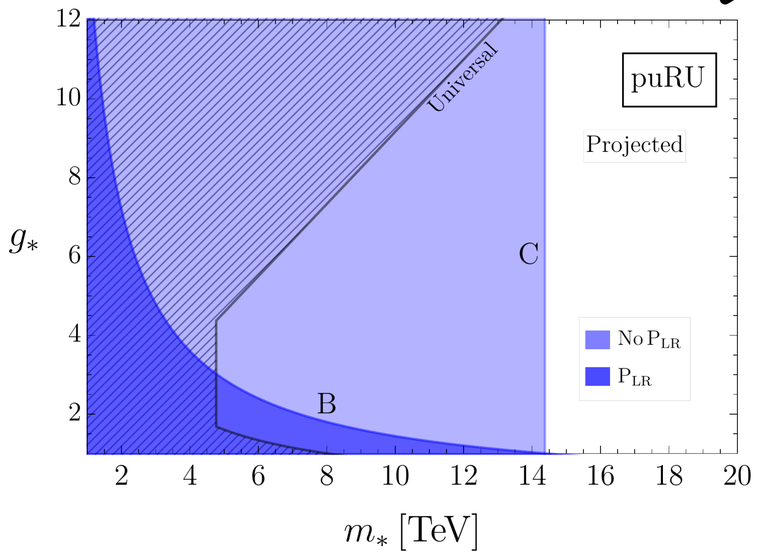

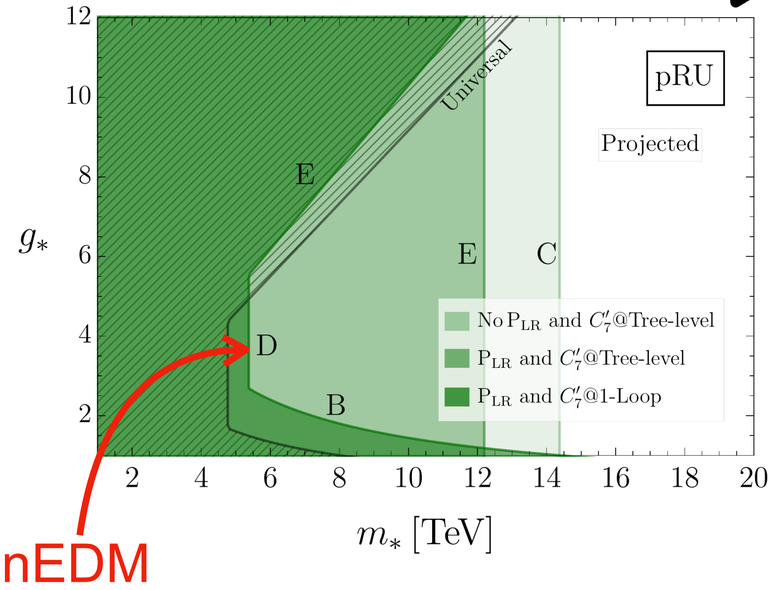

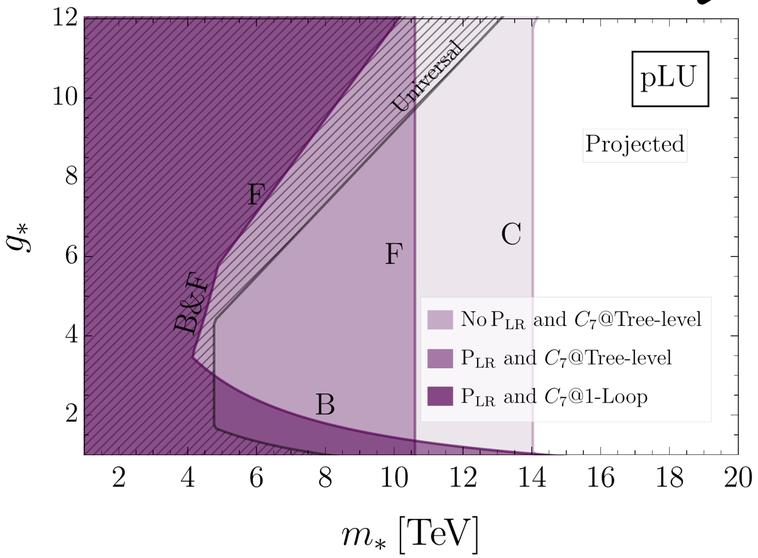

Conclusions

- Lesson from the past: **Nature gives us clues but might surprise us (=theorists can fail!)**
- SM clues (1): **the SM is a unique EFT because of the hierarchy problem**
- SM clues (2): **FV & CPV are and will remain crucial**
- **Must be interpreted**: What are we testing at LHC? What theories will a future collider explore?
- We focused on SILH with partial compositeness. **Currently:**
  - Not only B & L & custodial SO(4), but also CP is necessary
  - Accessible theories have flavor symmetries (not MFV) & Left-Right Custodial
  - Higgs-mediated transitions never relevant, but in principle $\mathrm{BR}(t \to hc) \sim 10^{-4}$ is achievable
- **In the next 10-20 years:**
  - Unless no discovery is made, flavor Anarchy removed from FCC reach
  - The "simplest accessible option" might become MFV via Left-Universality
  - Watch out for the improvement of 10-100 in nEDM