

# Flavor Physics in Composite Higgs models

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**WHY?!**

**1) Still a hierarchy problem to address.**

Little has changed, qualitatively

**2) Stronger indirect bounds on NP:**

**What scenarios are directly probed at the LHC?**

**How plausible?**

We felt the need to present a broad view  
on present and future of flavor options

# The Flavor Problem for NP:

**Why does the CKM paradigm work with NP at TeV?**

**SUSY:** MFV + CP (ex: gauge med. + B&L + CP)

**Composite Higgs:**

How to reproduce the SM?

Which flavor patterns beyond?

How plausible?

# Wish List for the SILH

- partial compositeness (qO)
- B&L symmetries
- CP in the strong sector
- SO(4) custodial
- LR parity in O(4)
- 1-loop dipoles
- Flavor symmetries [Barbieri et al.](#), [Isidori et al.](#), [Redi-Weiler](#)
- ...

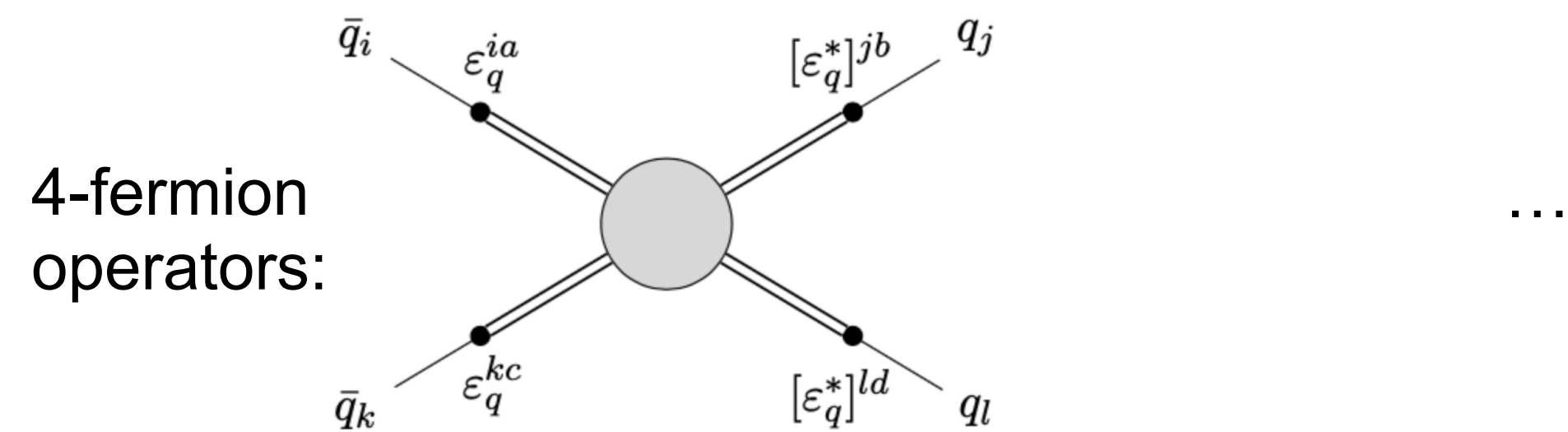
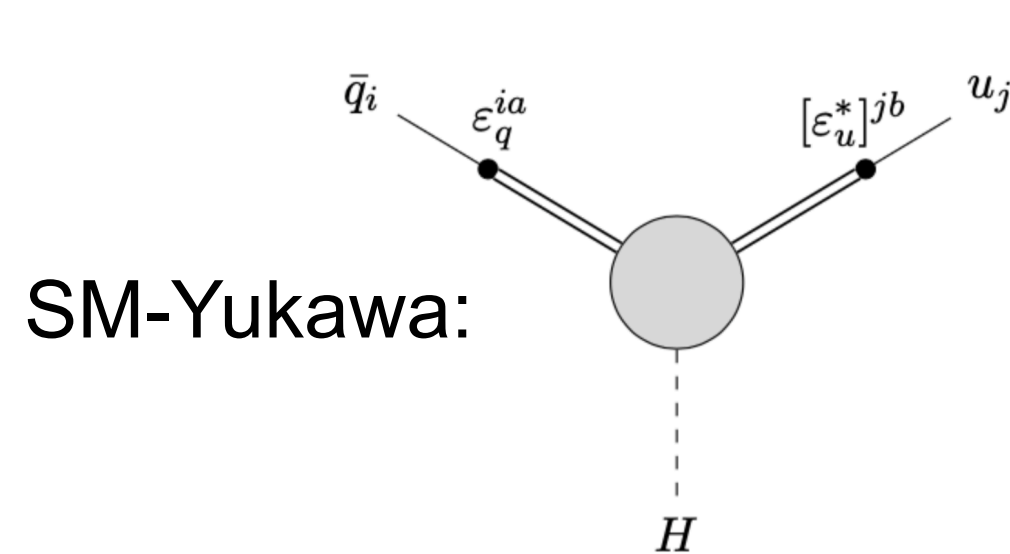
# qO: partial compositeness

Fundamental (SM) fermions

Operators of the Strong Higgs Sector

$$\mathcal{L} \supset \lambda_{ia} \bar{q}_i \mathcal{O}_a + y_{ij} \bar{q}_i q_j \mathcal{O} + c \mathcal{O} \mathcal{O}^\dagger + c' q q q q$$

Proto-Yukawa

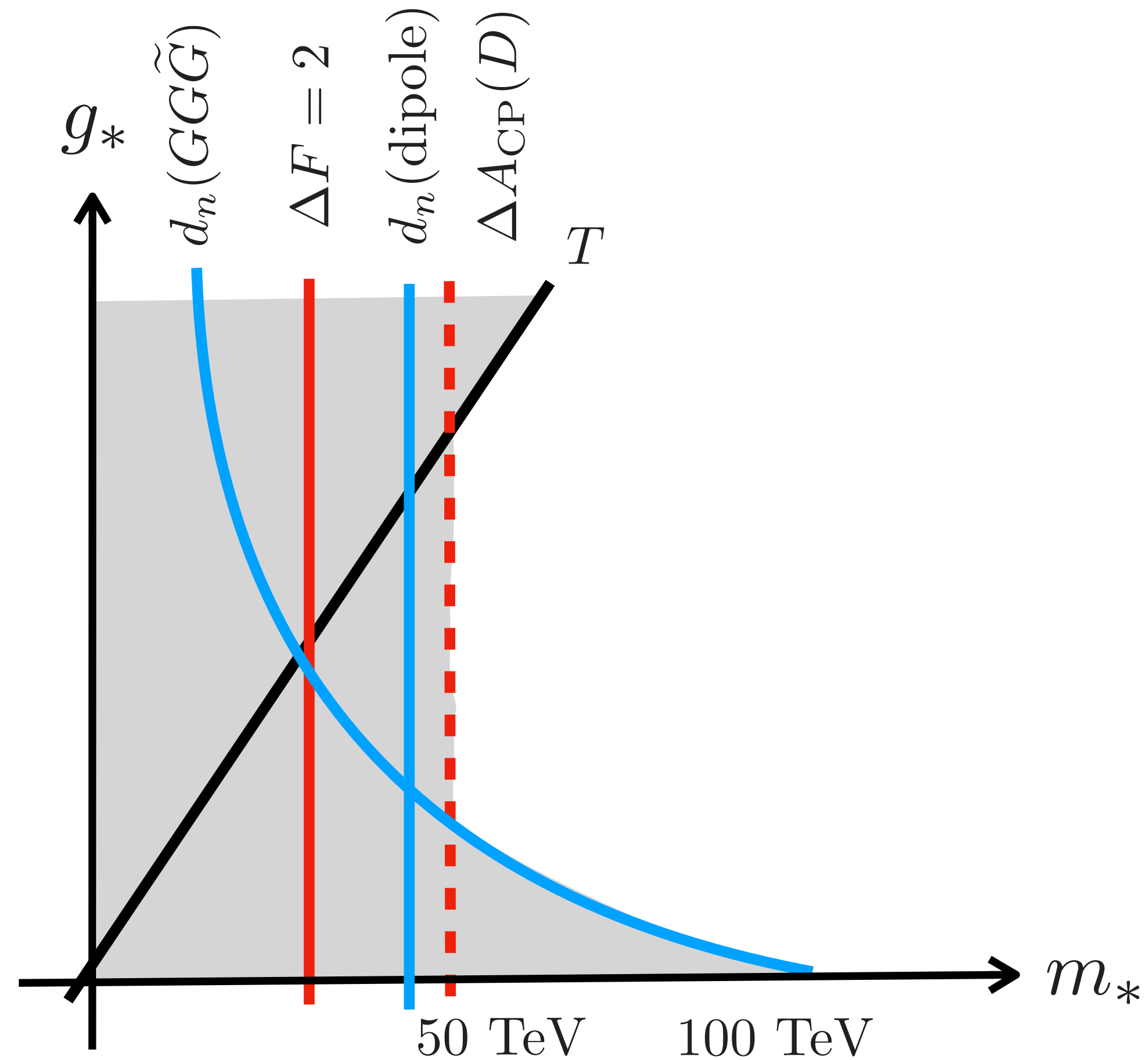


— qO

BSM couplings in  $\lambda_{ia}$  are “anarchic”

LHC 😞

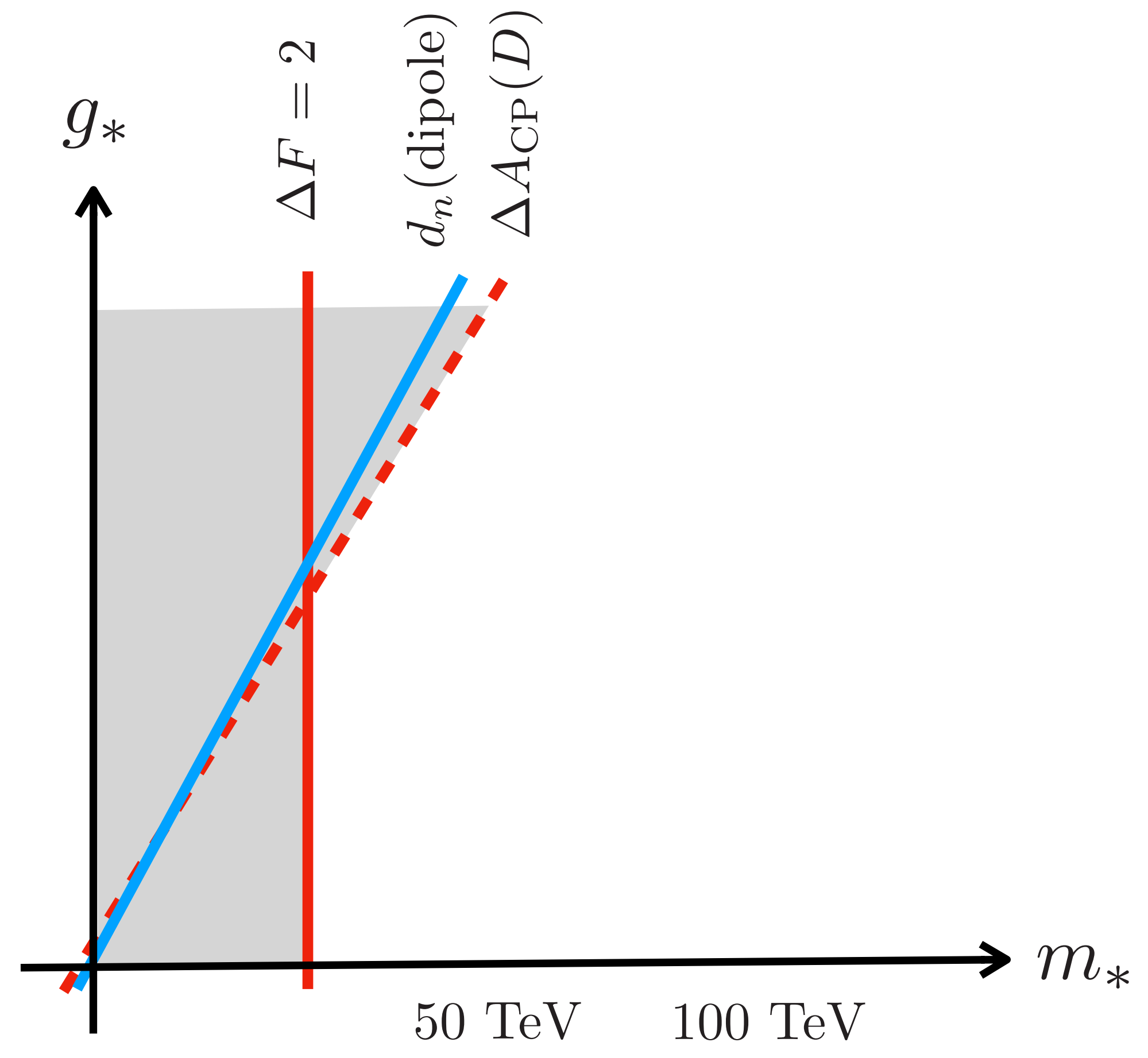
FCC 😞



This plot can be drawn only because we consider a specific class of UV completions  
More couplings  $g_*$  in the strong sector can only worsen the overall picture

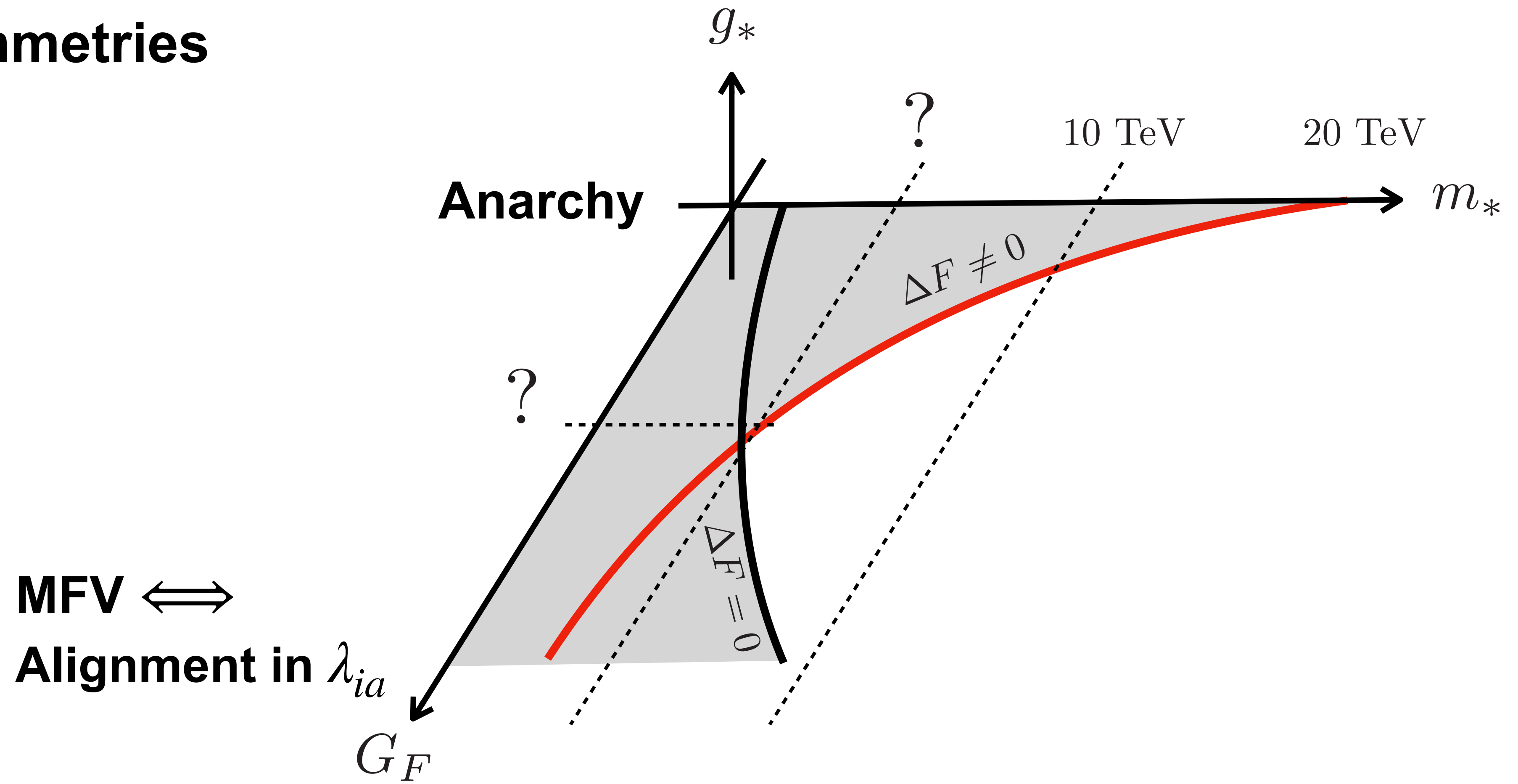
- qO
- CP
- SO(4)
- 1-loop dipoles

LHC 😞  
 FCC 😞





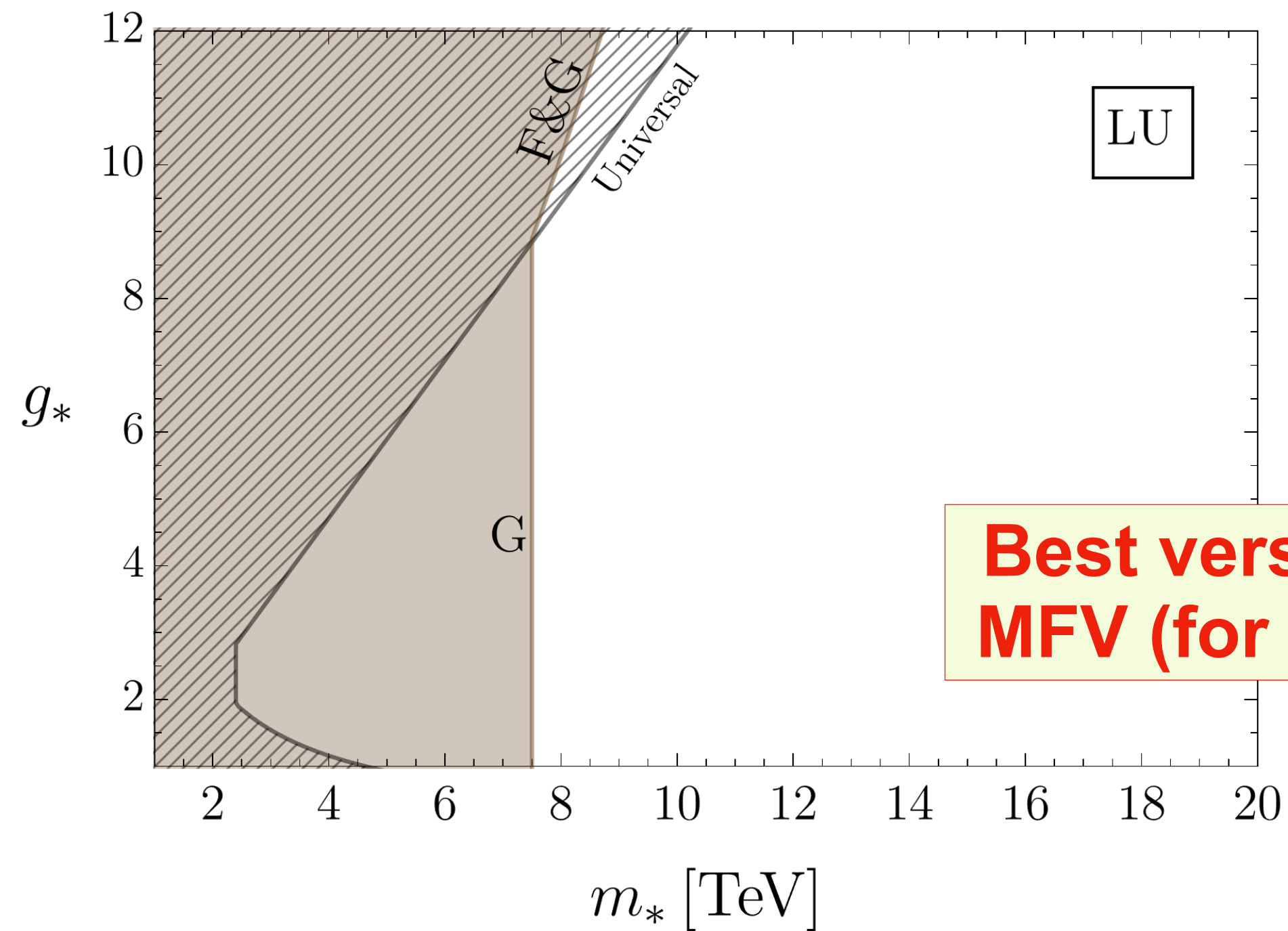
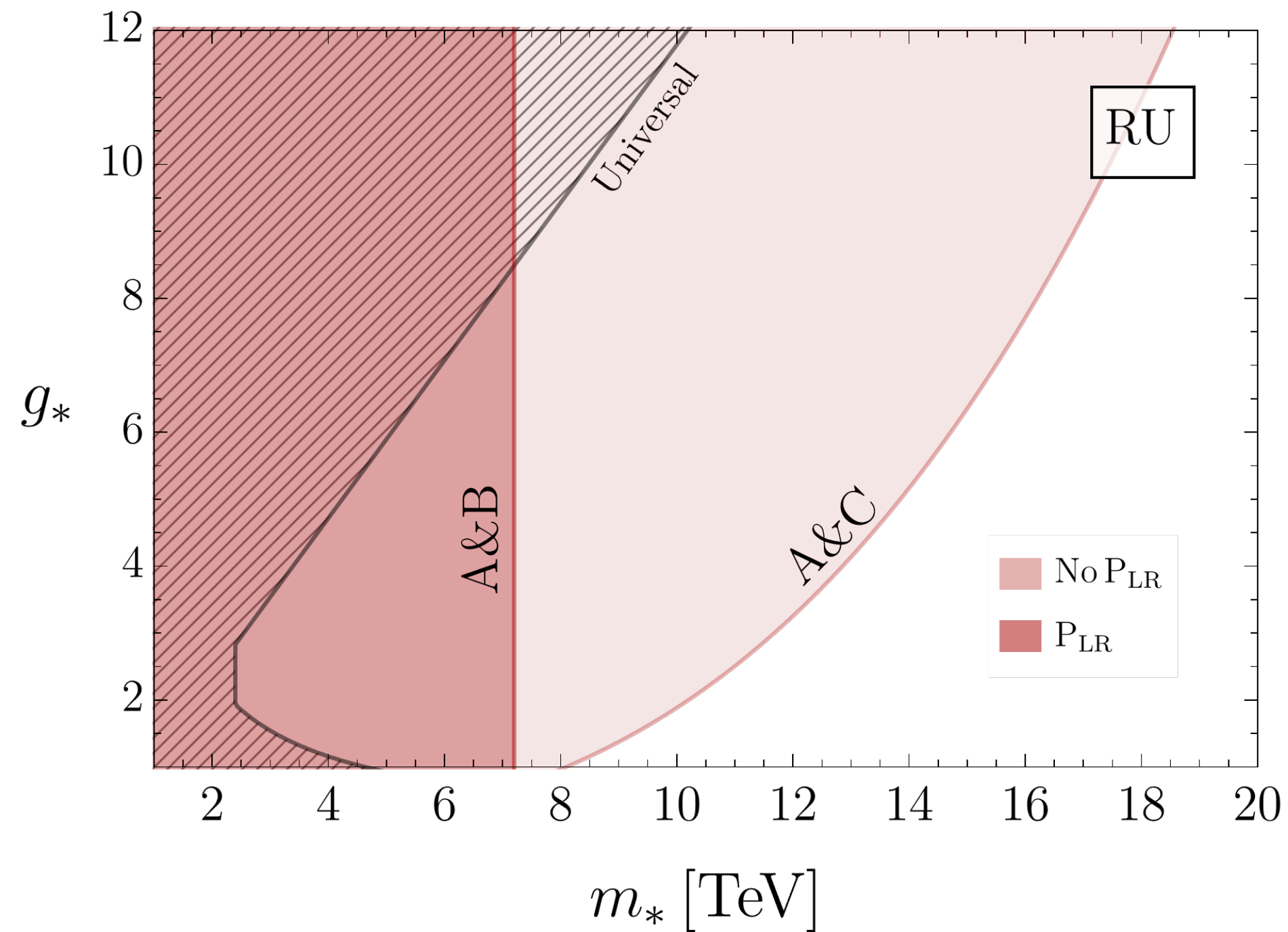
- qO
- CP
- SO(4)
- **Flavor-Symmetries**



# Maximal Symmetry

LHC 😞

FCC 😊



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

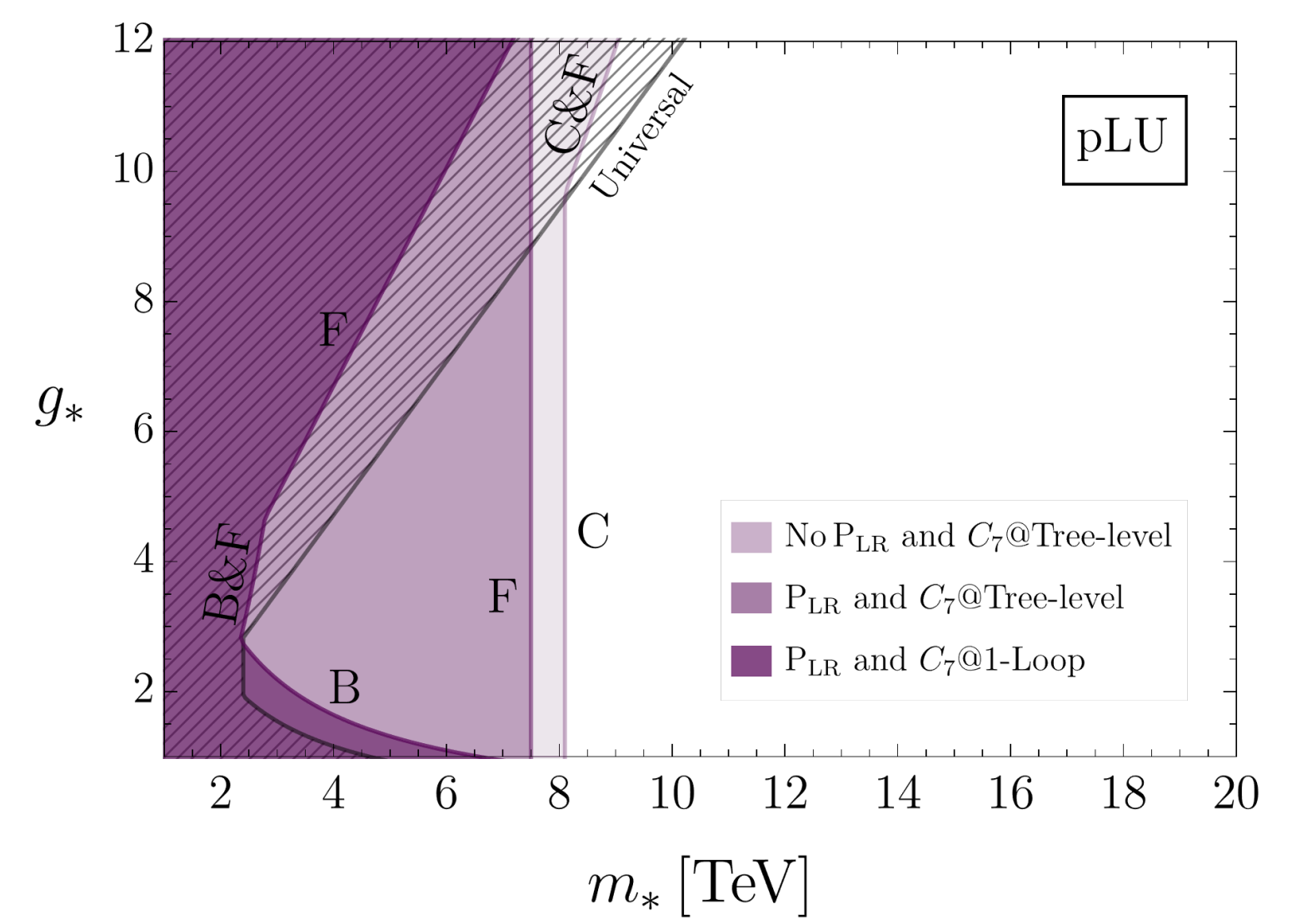
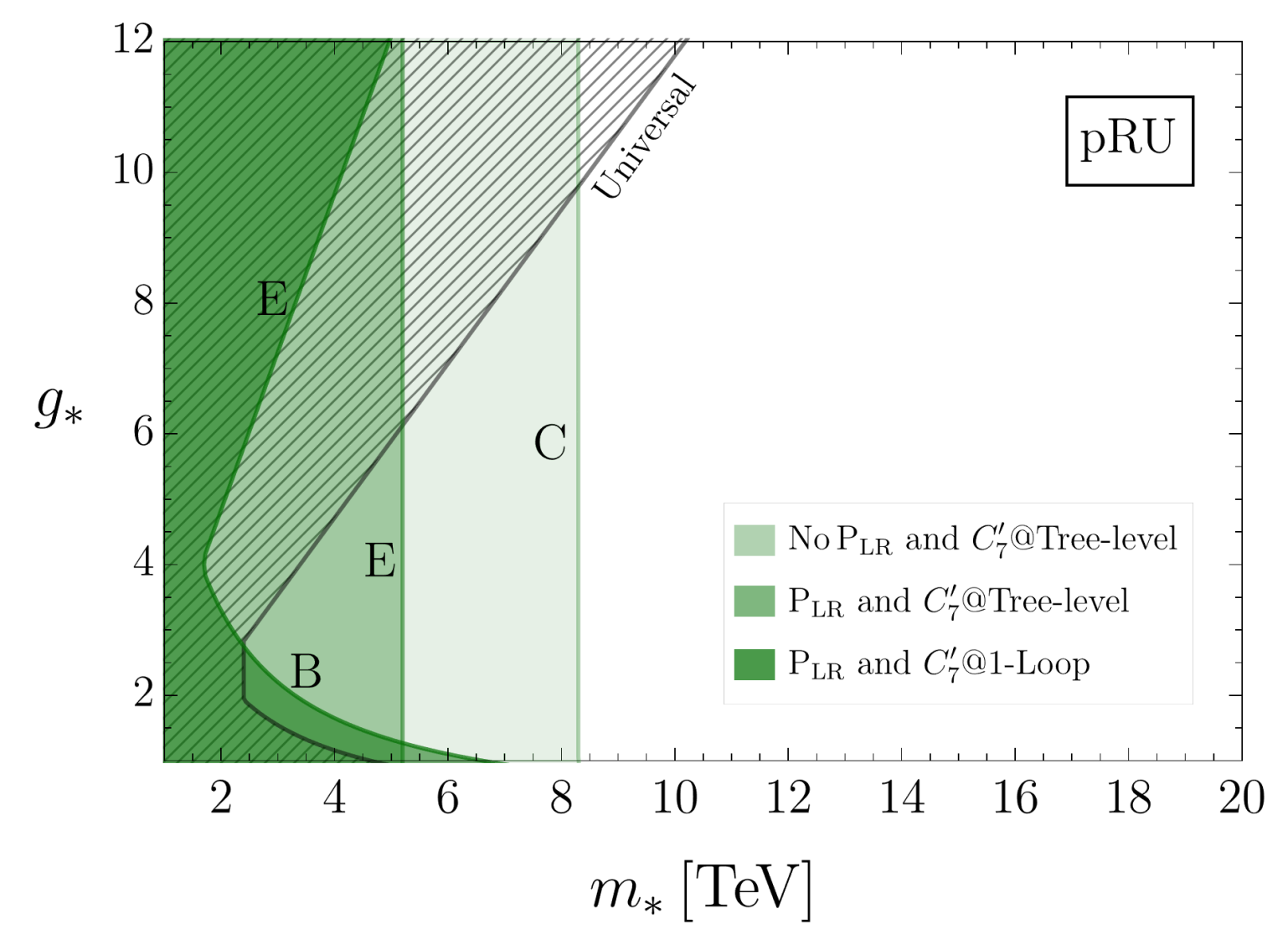
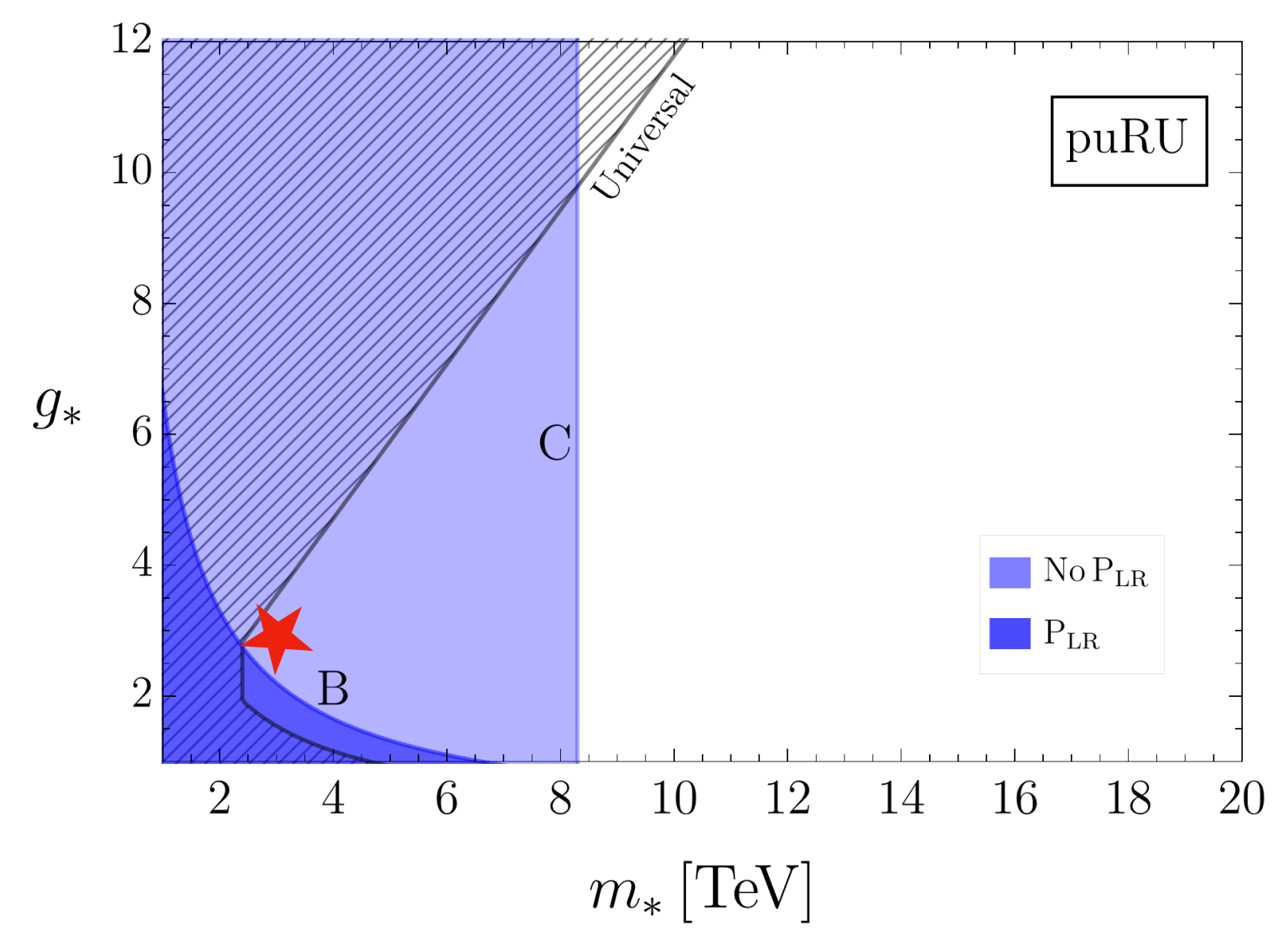
— qO	— qO
— CP	— CP
— <b>SO(4)</b>	— <b>SO(4)</b>
— <b>MFV</b>	— <b>MFV</b>
— LR?	

A  
B  
C  
D  
E  
F  
G

$pp \rightarrow jj$   
 $\Delta F = 2 (B_d)$   
 $B_s \rightarrow \mu^+ \mu^-$   
 nEDM  
 $B^0 \rightarrow K^{*0} e^+ e^- (C'_7)$   
 $B \rightarrow X_s \gamma (C_7)$   
 W-coupling

# Intermediate Symmetry

LHC 😊  
 FCC 😊



- qO
- CP
- **SO(4)**
- **NMFV**
- LR?

- qO
- CP
- **SO(4)**
- **NMFV**
- LR?
- **1-loop dipoles?**

- qO
- CP
- **SO(4)**
- **NMFV**
- LR?
- **1-loop dipoles?**

No need of “1-loop dipole”

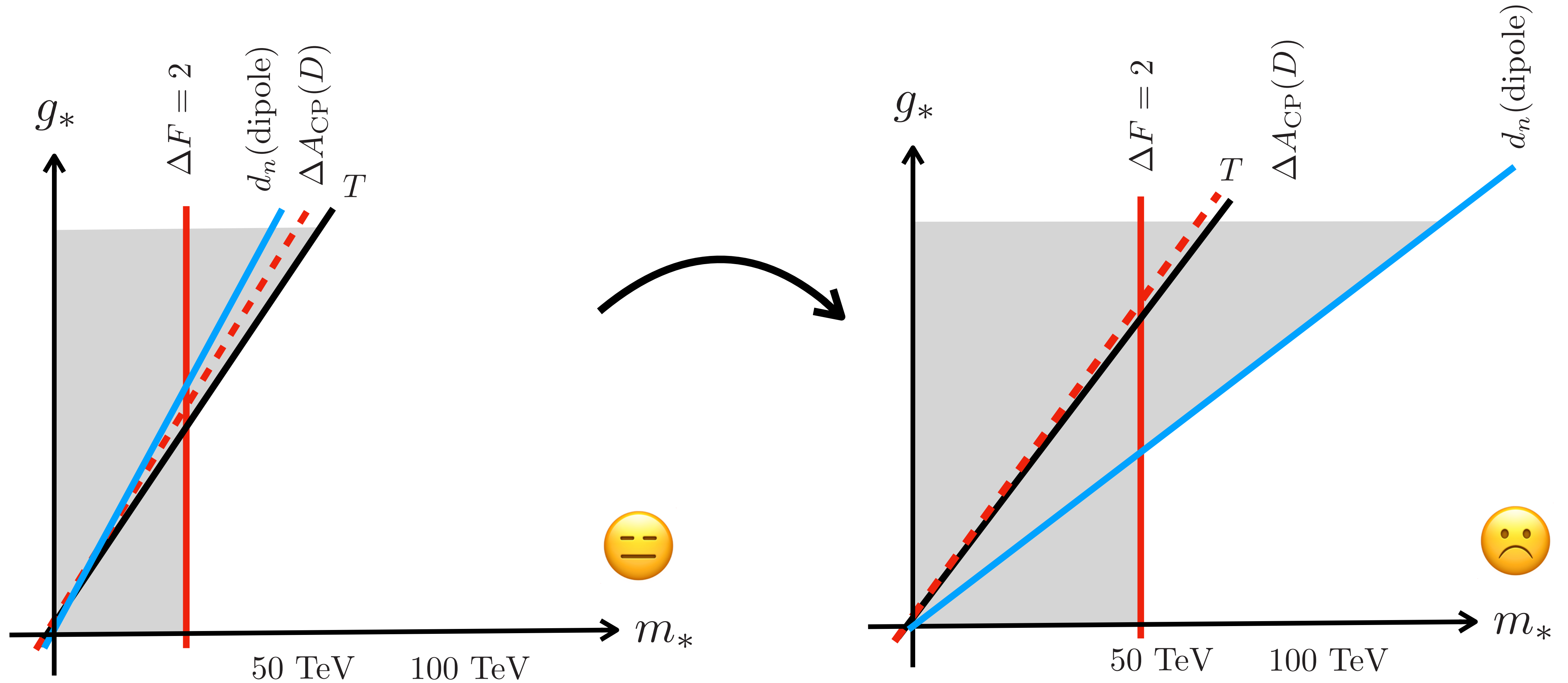
- Except LU, strongest flavor bounds from semi-leptonic B decays: “LR” is crucial to LHC
- All intermediate scenarios except puRU also need “1-loop dipoles” to suppress  $b \rightarrow s\gamma$
- Optimal regime has “maximally composite” right-handed top and  $g_* \sim 3$  (ideal for PNGB Higgs)
- “Most natural” is puRU, sizable compositeness for uR,dR makes it plausible
- Strange quark contribution to neutron EDM may (in principle) be important for pRU and pLU

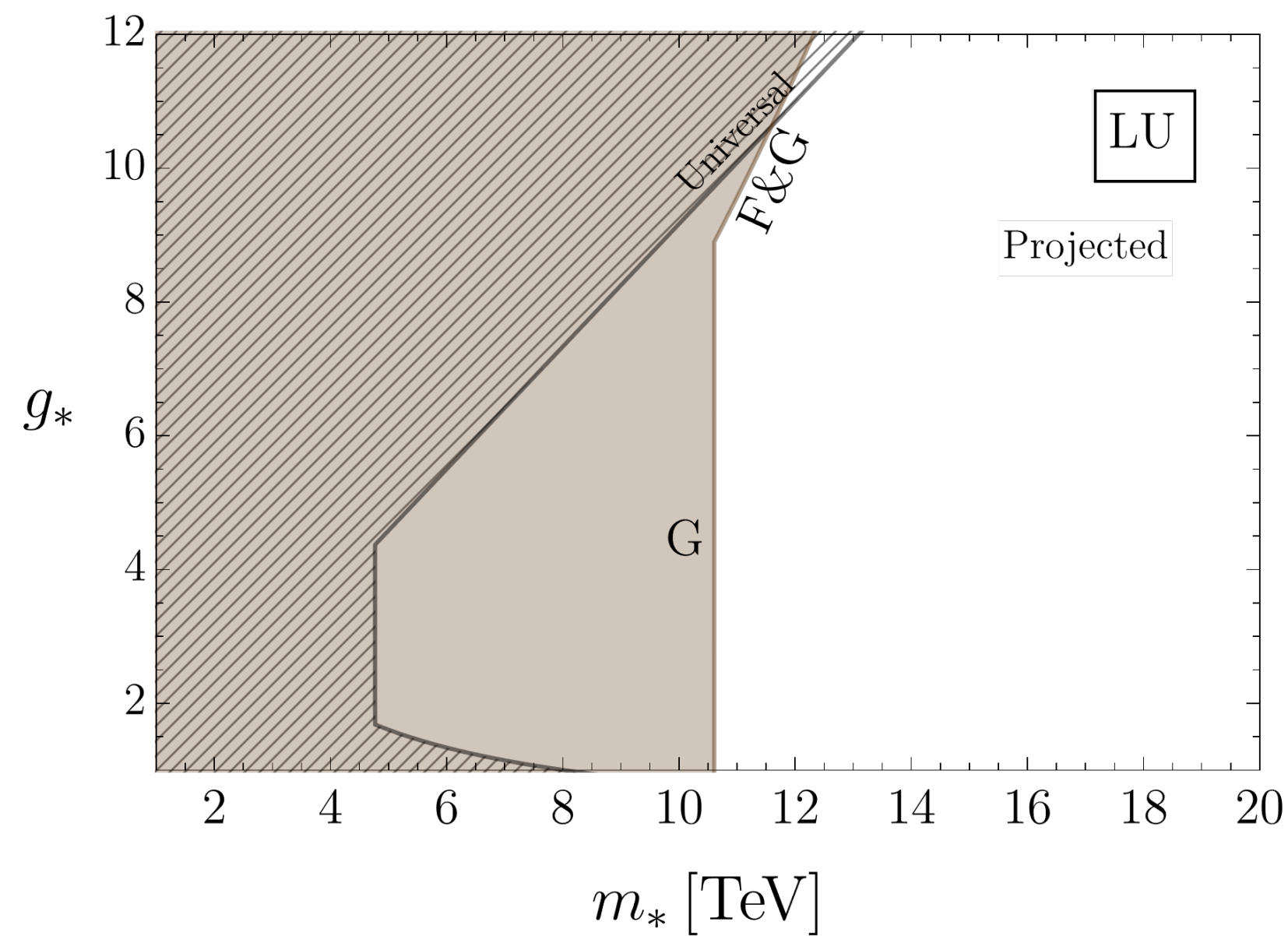
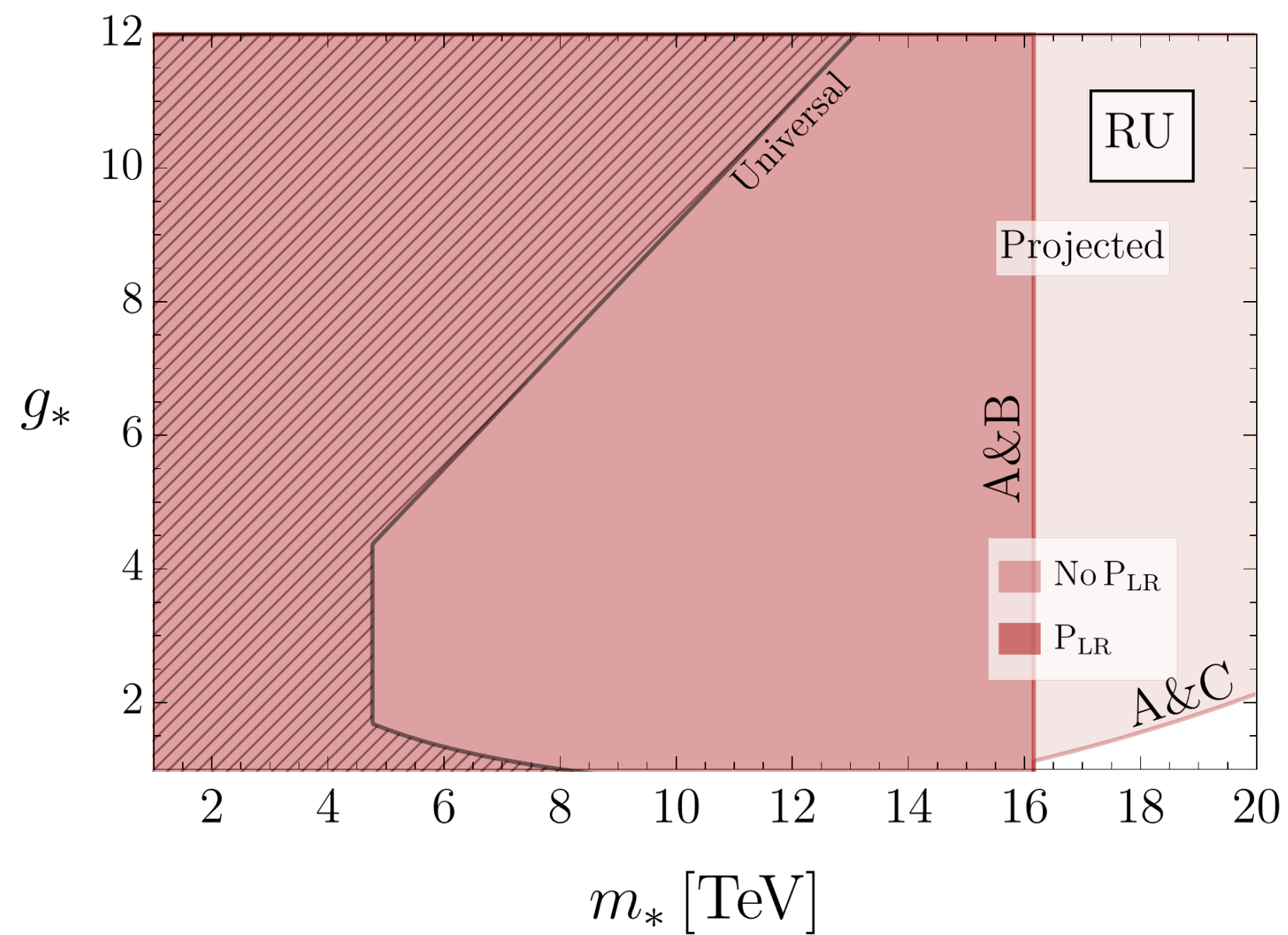
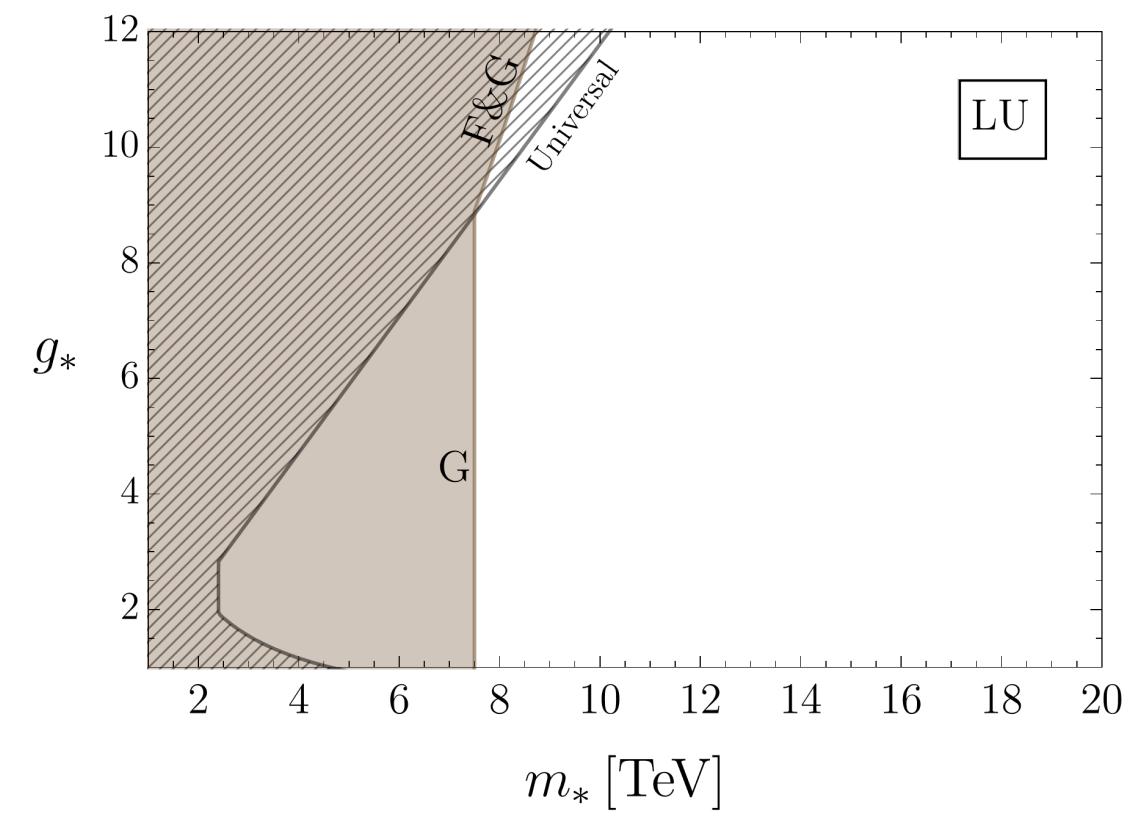
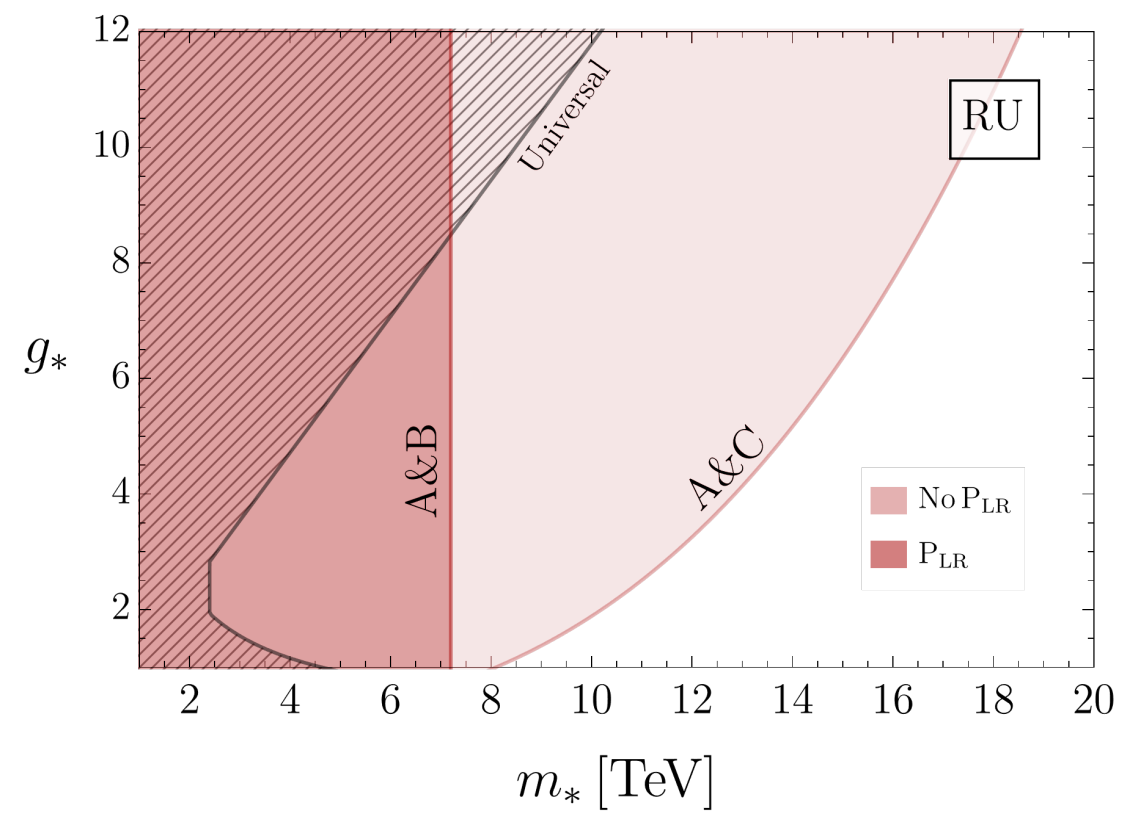
$$d_n = c_u d_u + c_d d_d + c_s \frac{1}{3} d_s + \dots$$

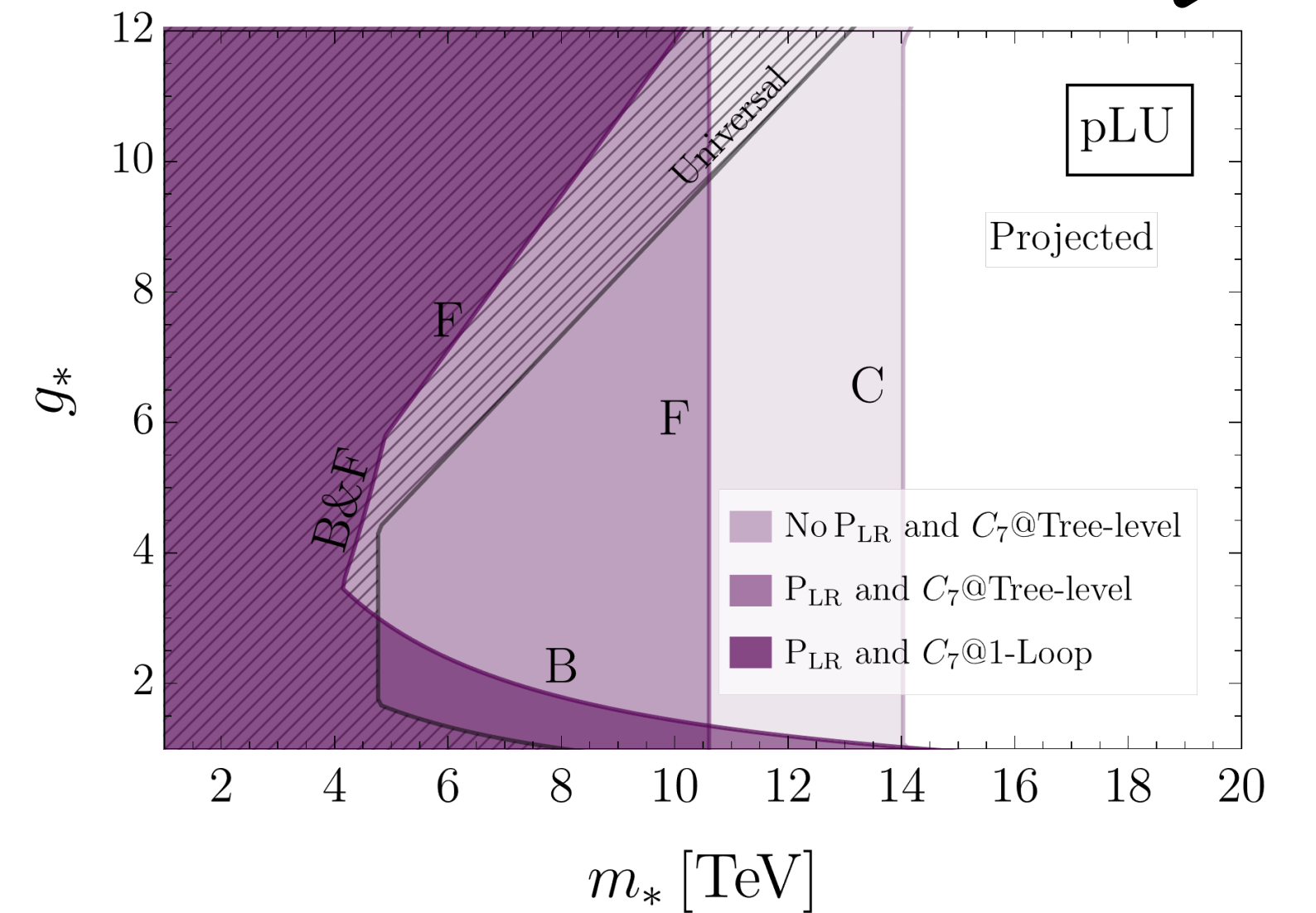
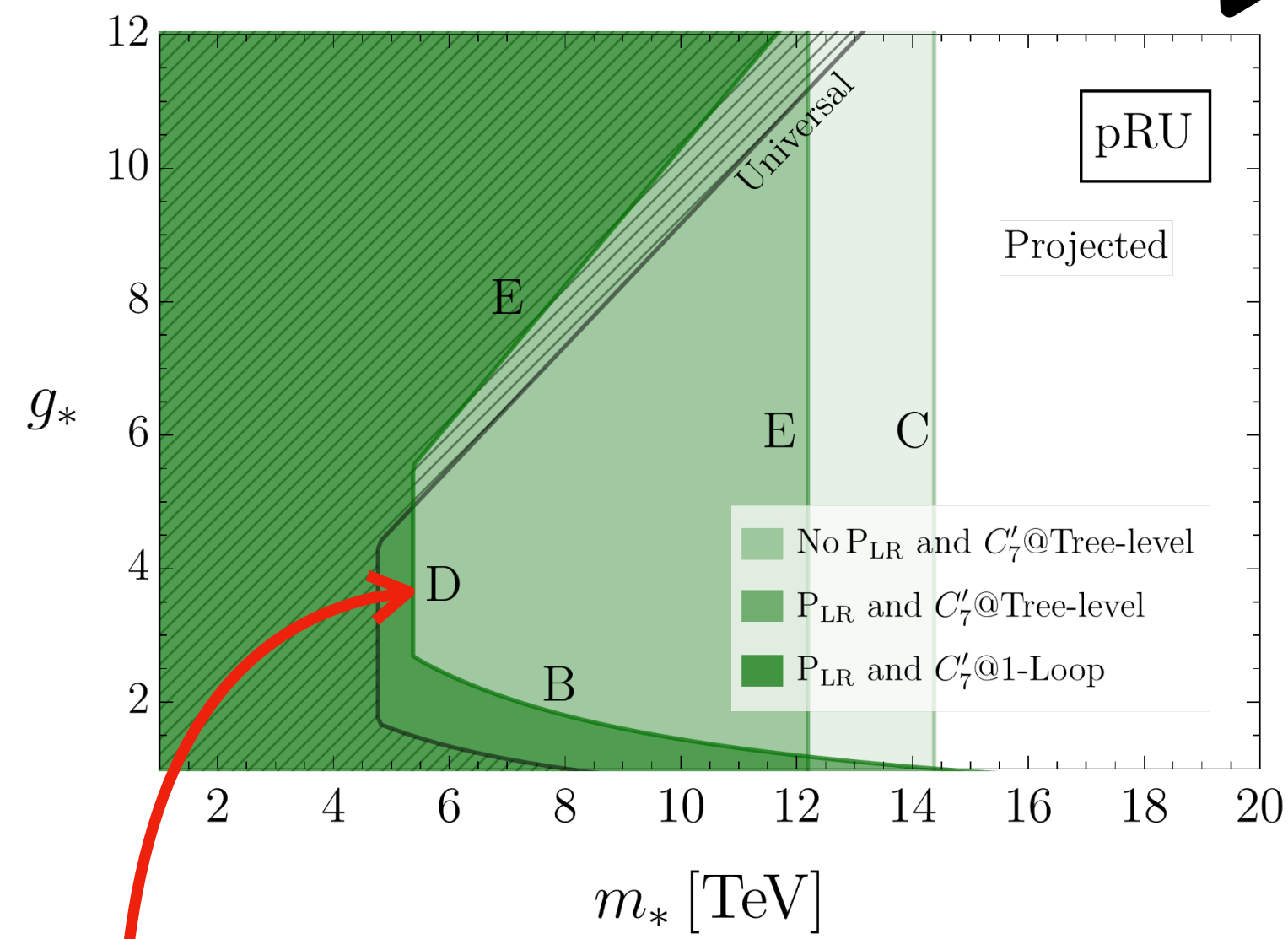
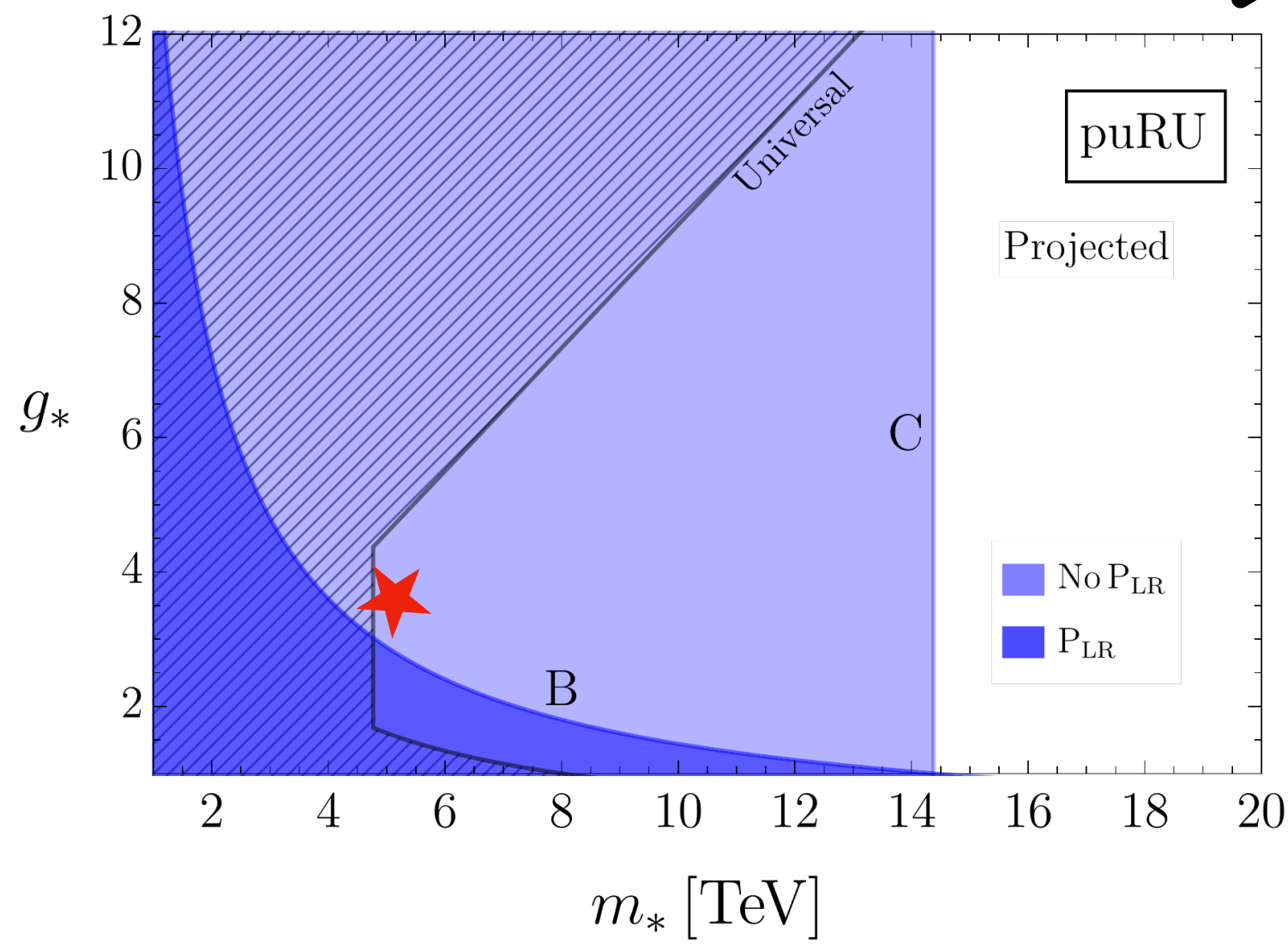
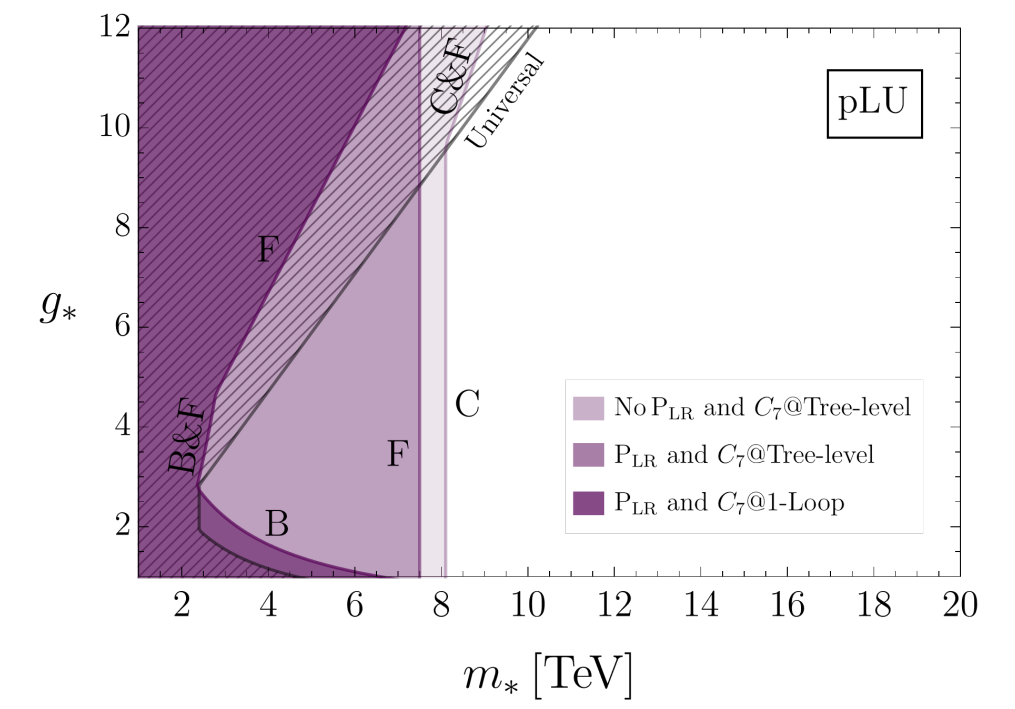
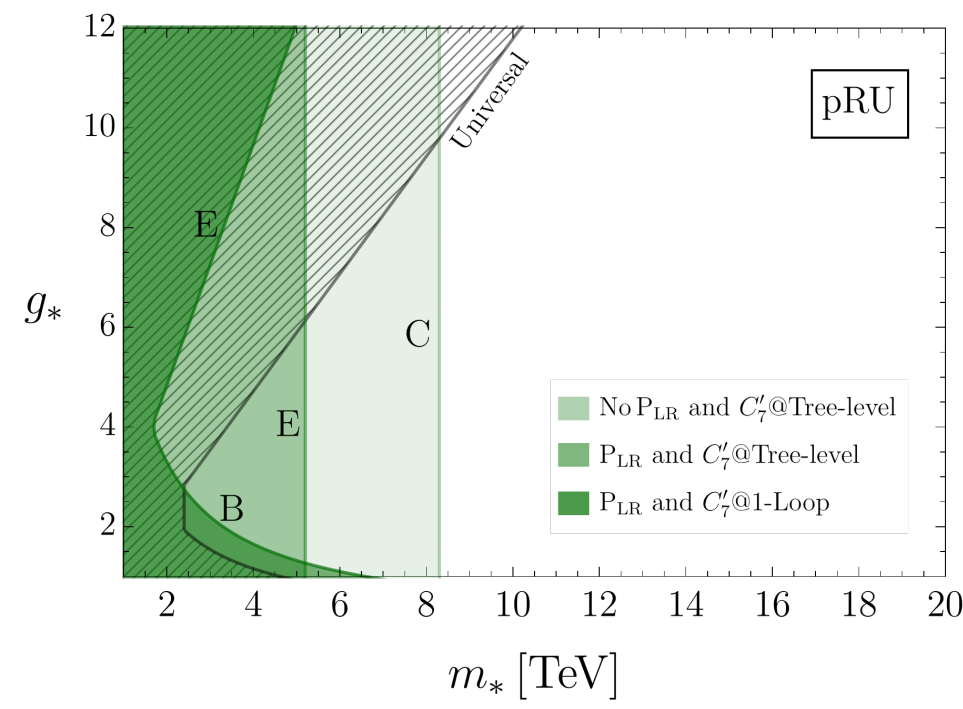
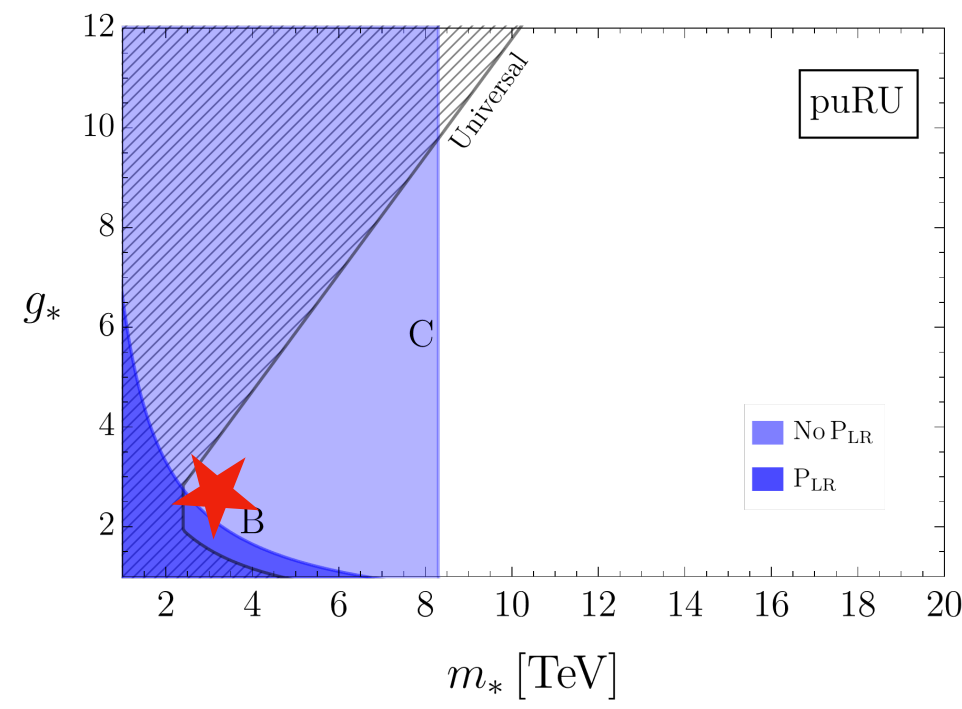
“1/N suppression” (OZI)

1/100 from lattice simulations: **WHY?!**  
 Bhattacharya et al.

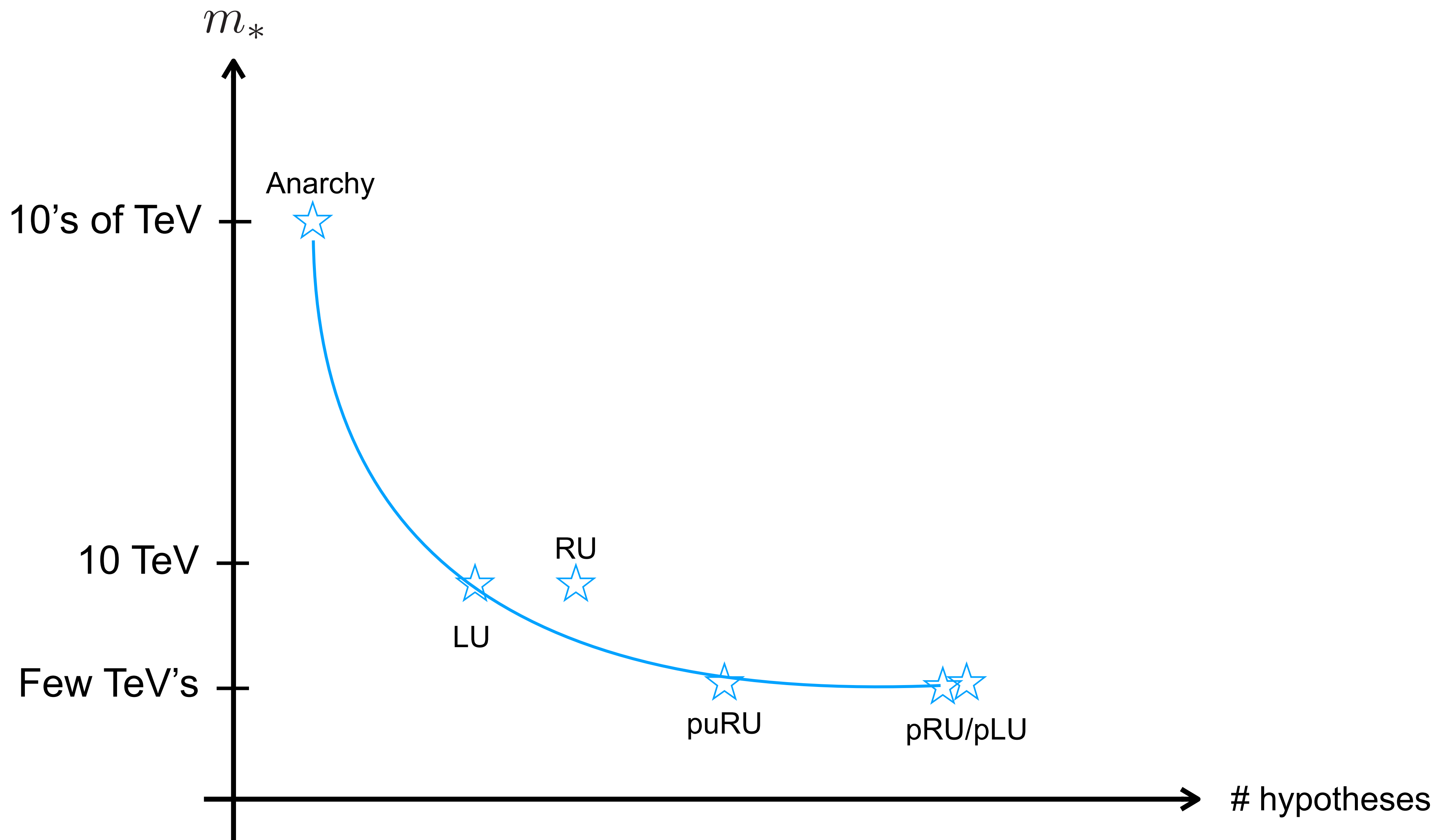
# Projections (mainly HL-LHC, Belle II, nEDM)







nEDM





# Conclusions

- **Flavor & CP violation are and will remain a central issue for “naturalness”**
- **We explored a few representative flavor scenarios for SILH with partial compositeness**
- **Currently:**
  - ◆ LHC probes only Partial Universality (some form of U(2) symmetries)
  - ◆ The options with lowest scale have a composite RH top,  $g_* \sim 3$ , and EW tuning at 5%
  - ◆ Higgs-mediated transitions never relevant, but in principle  $BR(t \rightarrow hc) \sim 10^{-4}$  is achievable
- **Projections for the next 10-20 years:**
  - ◆ Improvement of 10-100 in nEDM will basically remove Anarchy from FCC-hh reach
  - ◆ The “simplest option” might well become MFV via Left-Universality
  - ◆ The natural options will have a fine-tuning of order 2%