Synergies between UV-Safety and model building

based on works with Rigo Bause, Stefan Bissmann, Andrew Bond, Hector Gisbert, Tim Höhne, Clara Hormigos, Kamila Kowalska, Daniel Litim, Kevin Moch, Tom Steudtner

Gudrun Hiller, TU Dortmund

Dortmund-Sussex Initiative

Teaming up QFT and particle physics to explore new directions for model building $\leftrightarrow$ pheno, data

Daniel Litim and group (Sussex U), GH and group (TU Dortmund)

– 4d QFT with asymptotic safety "Top-Down"

the AS-SM: Bond, Kowalska, GH, Litim, 1702.01727 [hep-ph], PoS EPS-HEP2017 (2017) 542

towards the AS-MSSM: GH,Litim, Moch, 2202.01264 [hep-ph]

– SM-like theories, Higgs, Flavor and beyond "Bottom-up"

Safe-BSM with Higgs and Flavor: GH, Hormigos,Litim, Steudtner 2008.08606 ,1910.14062 [hep-ph]

ciollider multi-lepton signatures thereof: Bissmann, GH, Hormigos, Litim 2011.12964 [hep-ph]

B-physics and charm physics: Bause et al 2109.06201 [hep-ph], 2210.16330 [hep-ph]

stability, the gauge portal, and Higgs portal: GH, Hoehne, Litim, Steudtner 2207.07737 [hep-ph], 2401.08811 [hep-ph]

Top-Down with UV-Safety

LiSa Litim, Sannino 1406.2337: AS guaranteed in SM-like setting (gauge-yukawa-scalar theory) (talk by T.Steudtner, poster Riyaz)

$$\mathcal{L} = -\tfrac{1}{4} G_{\mu\nu} G^{\mu\nu} + \bar{\psi} i \not{D} \psi + y \bar{\psi}_i S_{ij} \psi_j - V(S)$$

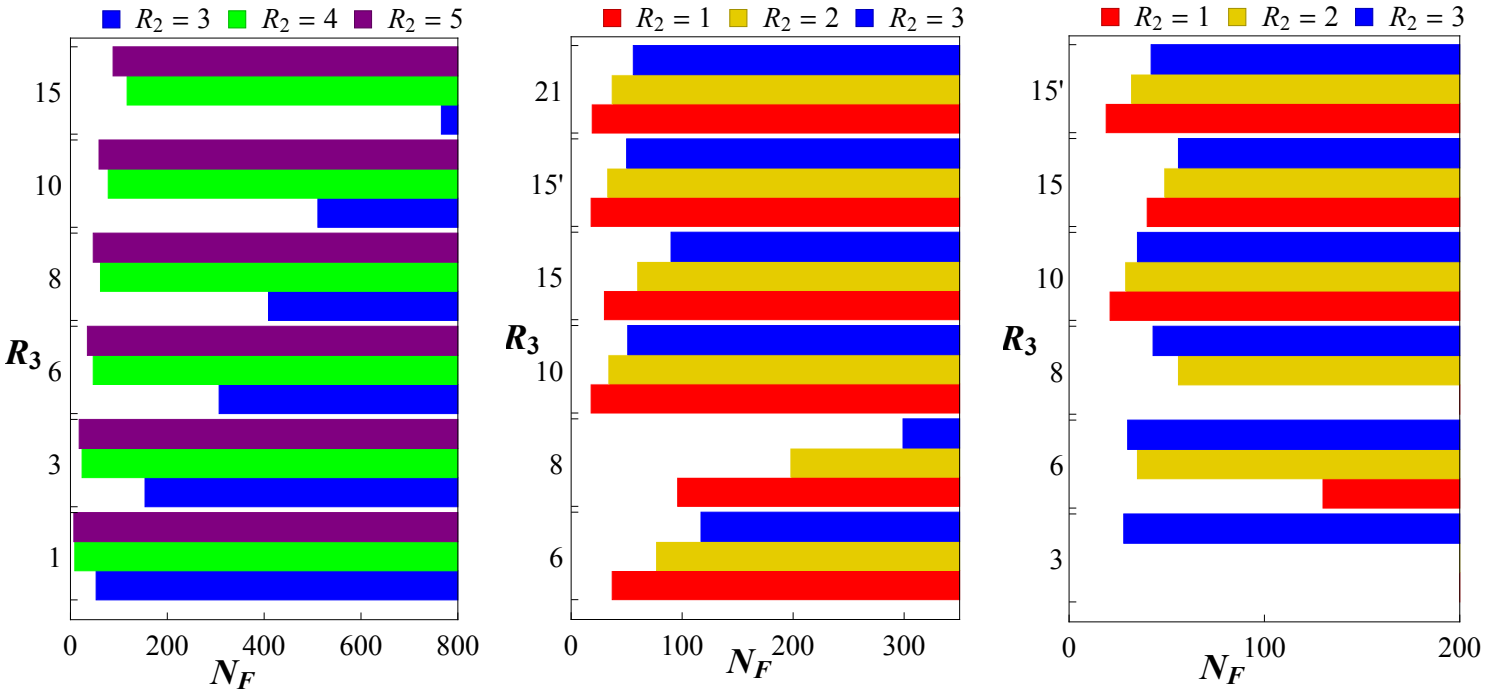
two main catches for pheno/model building:
A) Can the SM emerge at low energies from a CFT? Yes. at 2-loop,

Bond et al 1702.01727

framework has predictivity, stability, no poles (from the electroweak scale upwards) "UV complete"

Concrete SM-extensions obtained and analyzed by Bond et al '17 1702.01727 Demand for higher-order beta-functions with analytical dependence on N_F and reps. $\rightarrow$ ARGES (T.Steudtner)

New Directions from UV-Safety



$\psi(R_3, R_2, 0)$ under $SU(3)_C \times SU(2)_L \times U(1)_Y$ 1702.01727

Vector-like fermions in higher representations of QCD and $SU(2)_L$.

Due to flavor symmetry, they are long-lived; LHC: dijet searches, R-hadrons, LLP searches

Top-Down with UV-Safety

LiSa Litim, Sannino 1406.2337: AS guaranteed in SM-like setting (gauge-yukawa-scalar theory) (talk by T.Steudtner, poster Riyaz)

$\mathcal{L} = -\frac{1}{4} G_{\mu\nu} G^{\mu\nu} + \bar{\psi} i \not{D} \psi + y \bar{\psi}_i S_{ij} \psi_j - V(S)$ flavor symmetry!

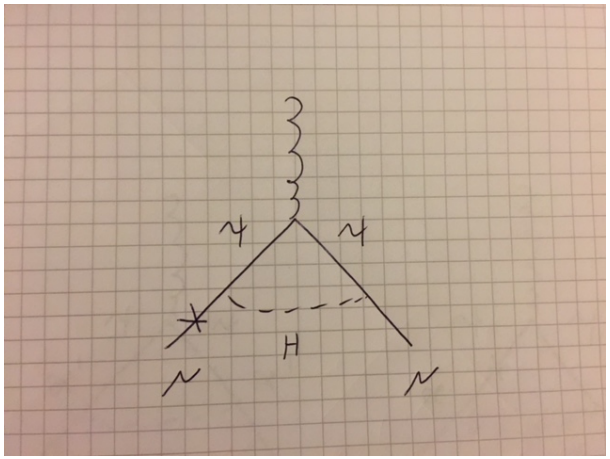
two main catches for pheno/model building:
B) new tool for flavorful model building: S_{ij} matrix scalar

application: $g-2$ of electron and muon 1910.14062 ; flavor-protection "no LFV", nor flavor non-universality needed (unique explanation)

novel multi-lepton signatures at LHC: $\psi\bar{\psi}$-production, $\psi_e^- \to S_{e\mu}\mu^- \to e^-\mu^+\mu^-$ looks LFV but isnt 2011.12964

Consider vector-like leptons with mixed Yukawas for Δa_μ: $\kappa \bar{L} H \psi$

Giudice, Wise, Ligeti, ..



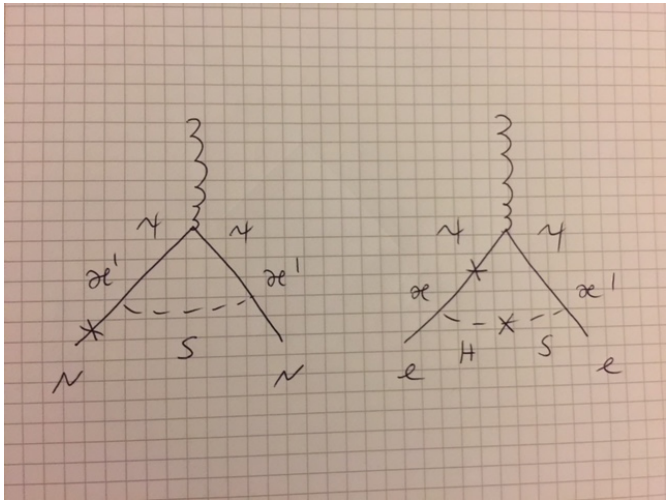
problems: Δa_e unaccounted, $Z\ell\ell$ bounds and LFV (fermions mix)

does not work

$(g-2)_{e,\mu}$ together

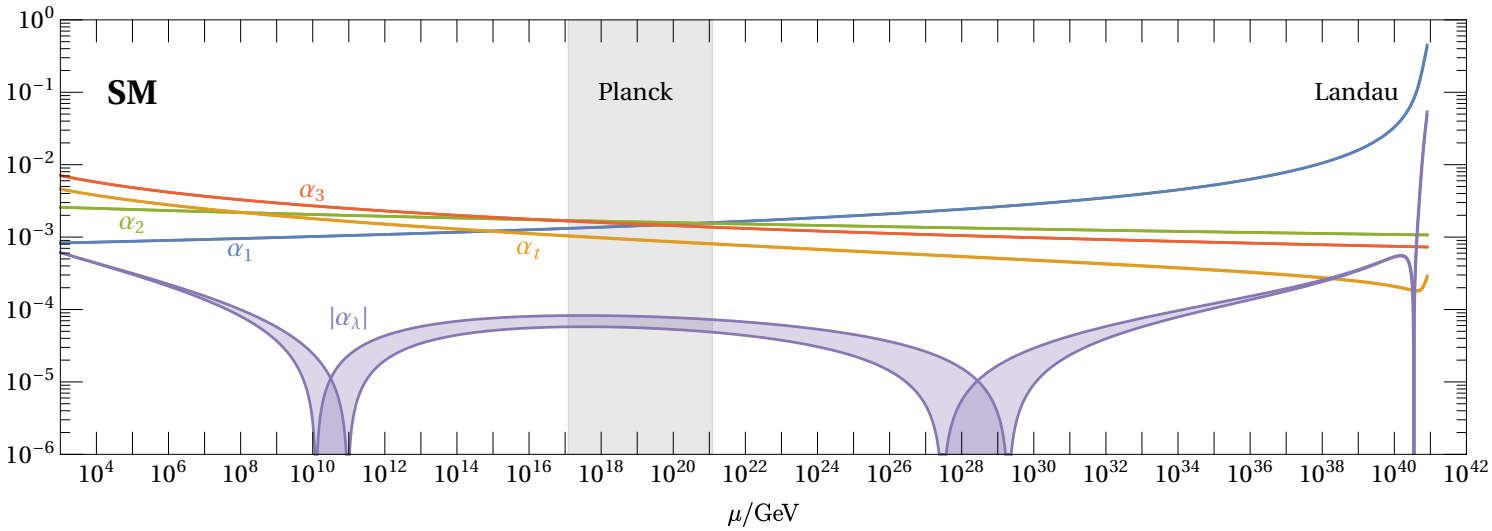
Straight-forward explanation with enlarged BSM-flavor sector: VLLs and scalar singlets with Higgs portal as in Planck-safe frameworks:

$$\kappa \bar{L} H \psi + \kappa' E S \psi + \delta S^\dagger S H^\dagger H, \quad \Delta a_\mu \sim \frac{m_\mu^2}{M_\psi^2} \frac{\kappa'^2}{16\pi^2}\,, \quad \Delta a_e \sim \frac{m_e}{M_\psi} \frac{\kappa\kappa'\delta}{16\pi^2}$$



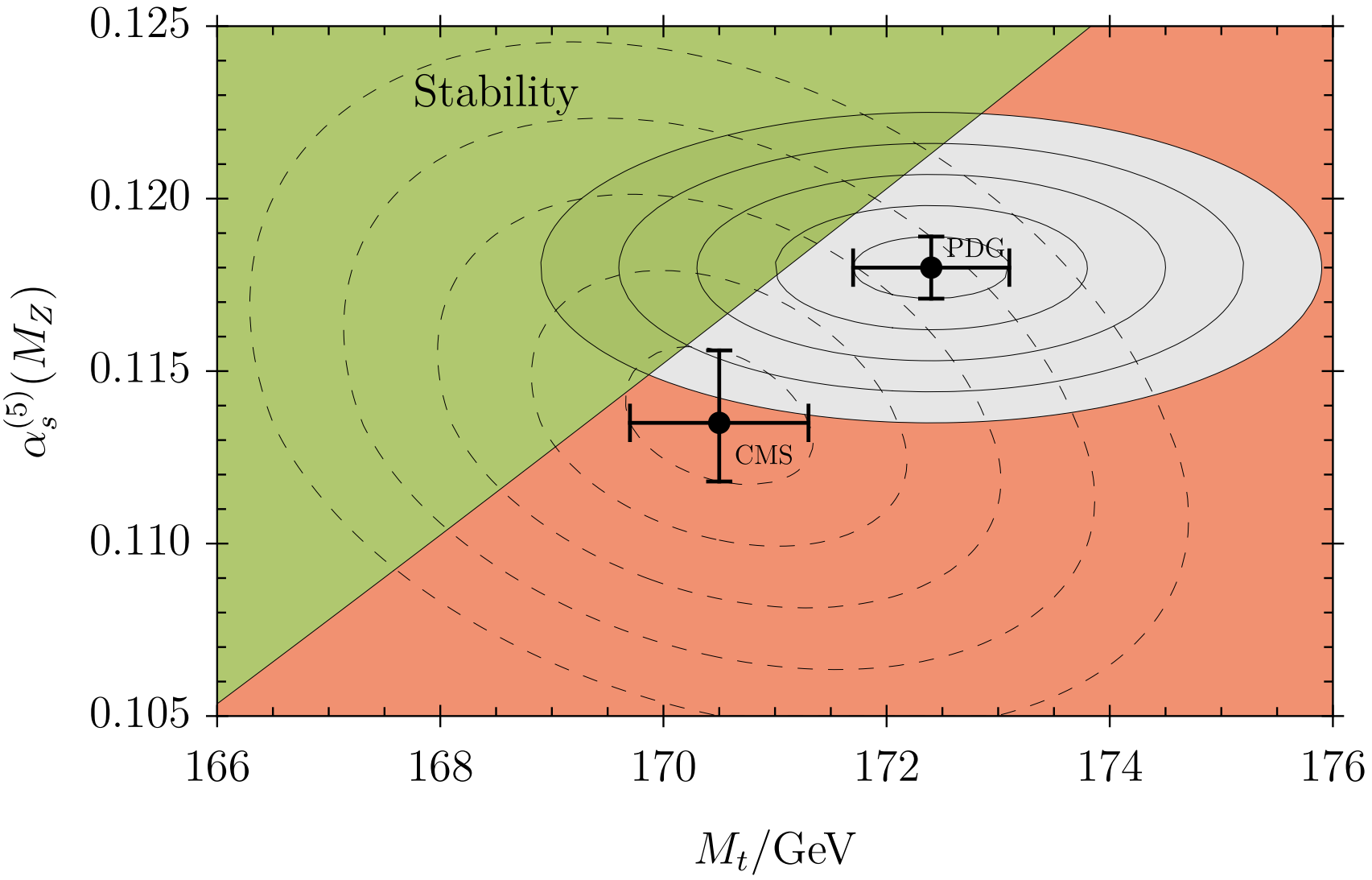
Flavorful scalar sector from asymptotic safety instrumental – $\kappa' E_i S_{ij} \psi_j$ no LFV constraints due to flavor symmetry $SU(3) \times SU(3)$.

Bottom-Up: all the way up to the Planck scale



Its intruiging that the SM is so near-critical when it comes to vacuum stability.

Bottom-Up: Vacuum Stability



Bottom-Up: Vacuum Stability

2401.08811

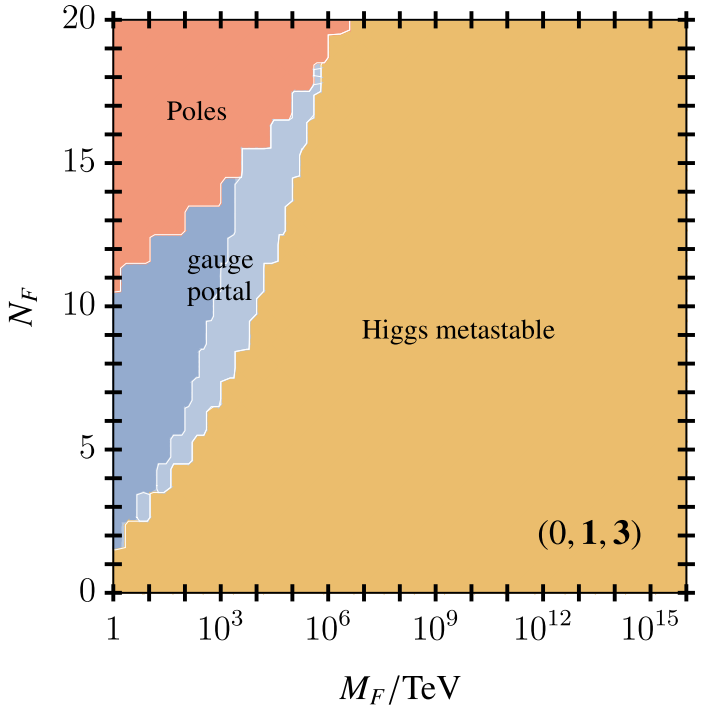
Obs.	Value	$\alpha_\lambda > 0$		$\alpha_{\lambda,\text{eff}} > 0$	
PDG 2024 :					
M_h/GeV	$125.20(11)$	127.97	$+25.2\sigma$	127.85	$+24.0\sigma$
M_t^σ/GeV	$172.4(7)$	171.04	$-\ 1.9\sigma$	171.10	$-\ 1.9\sigma$
M_t^{MC}/GeV	$172.57(29)$		$-\ 5.3\sigma$		$-\ 5.1\sigma$
m_t/GeV	$162.5(^{+2.1}_{-1.5})$	161.3	$-\ 0.8\sigma$	161.4	$-\ 0.7\sigma$
$\alpha_s^{(5)}(M_Z)$	$0.1180(9)$	0.1215	$+\ 3.9\sigma$	0.1213	$+\ 3.7\sigma$
CMS [**?**]:					
M_t/GeV	$170.5(8)$	169.25	$-\ 1.6\sigma$	169.31	$-\ 1.5\sigma$
$\alpha_s^{(5)}(M_Z)$	$0.1135(^{+21}_{-17})$	0.1167	$+\ 1.5\sigma$	0.1165	$+\ 1.4\sigma$

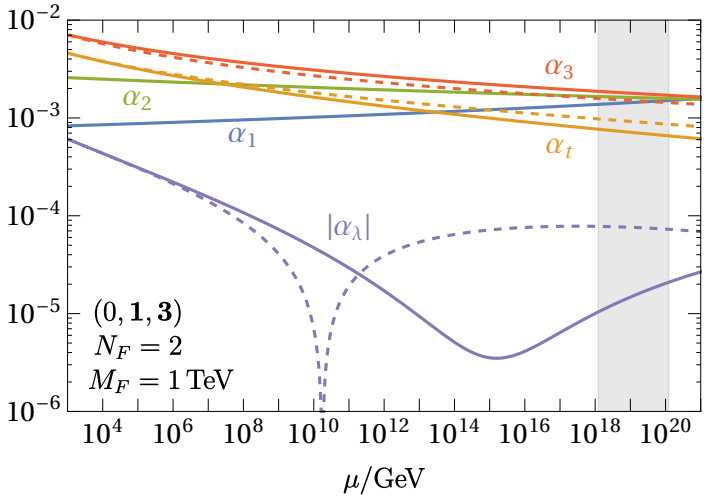
$M_t - \alpha_s$ correlations matter. M_h not relevant currently to decide fate of SM. More precise M_t needed (factor $\gtrsim 2$ ($\lesssim 300$ MeV) great)

Bottom-Up with UV-Safety

What does it take to achieve stability in SM?

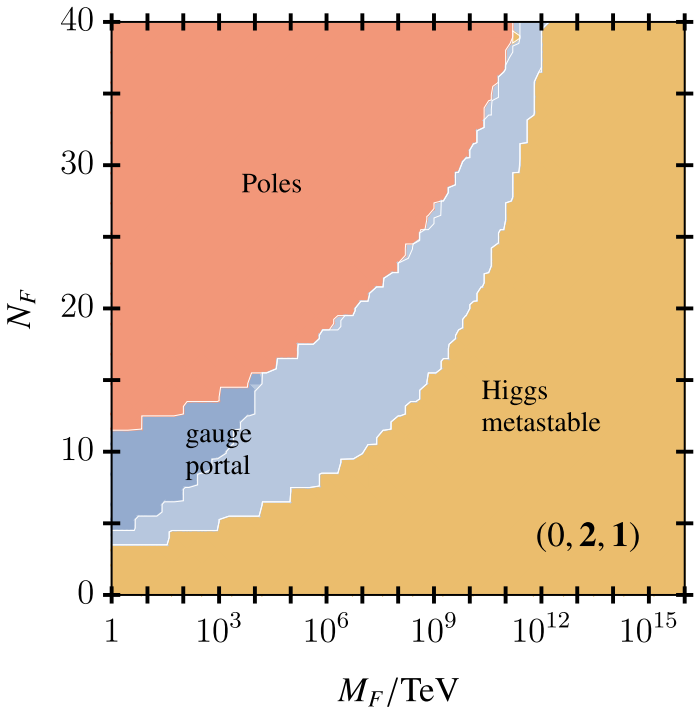
Minimal fix: the gauge portal: add VLFs. It works with charged under only QCD, $SU(2)_L$ and $U(1)_Y$ 2207.07737 Dont add too little too late

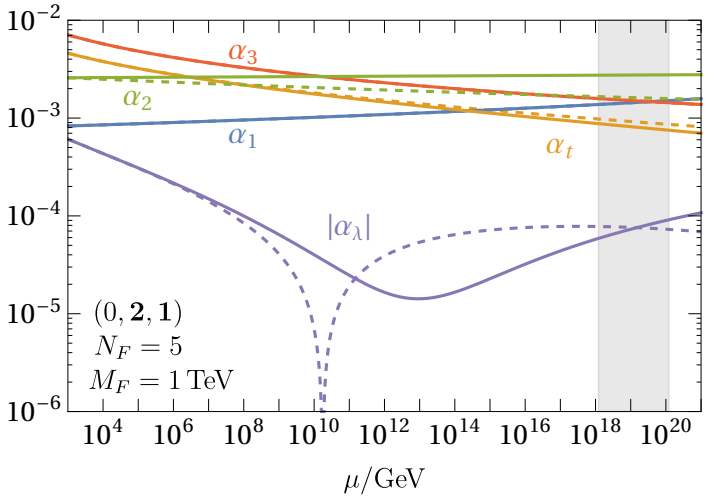




VLQs

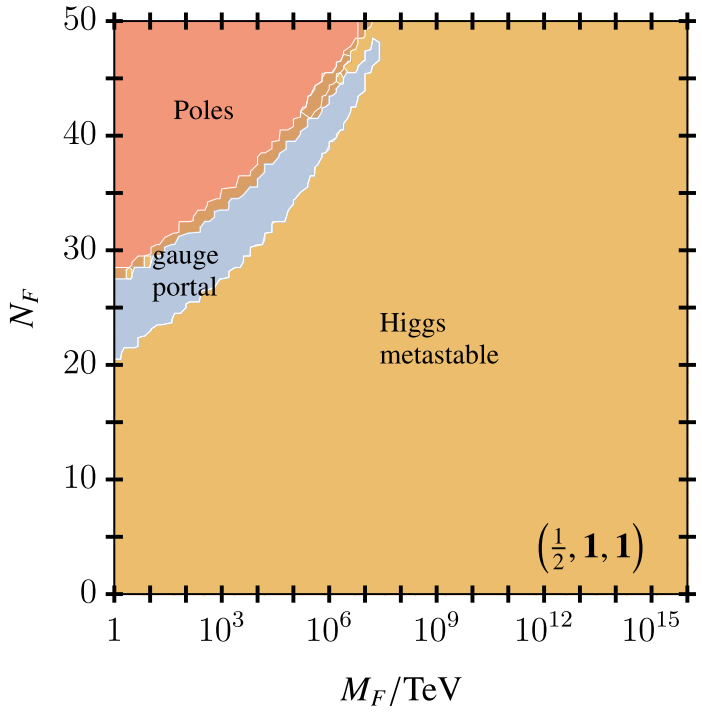
Bottom-Up with UV-Safety

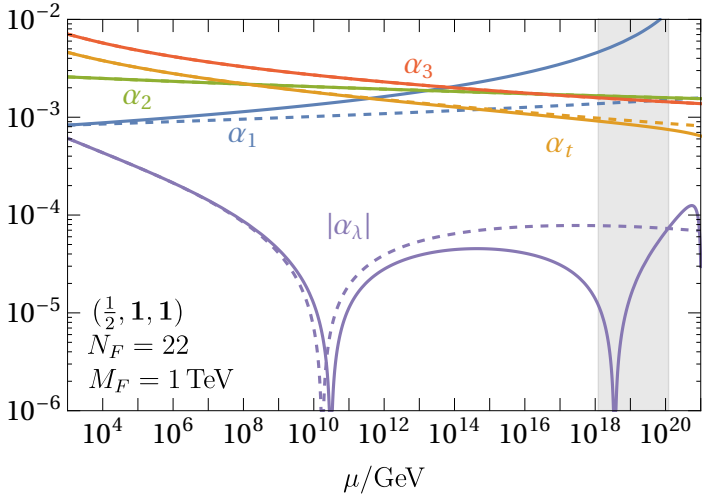




VLLs

Bottom-Up with UV-Safety

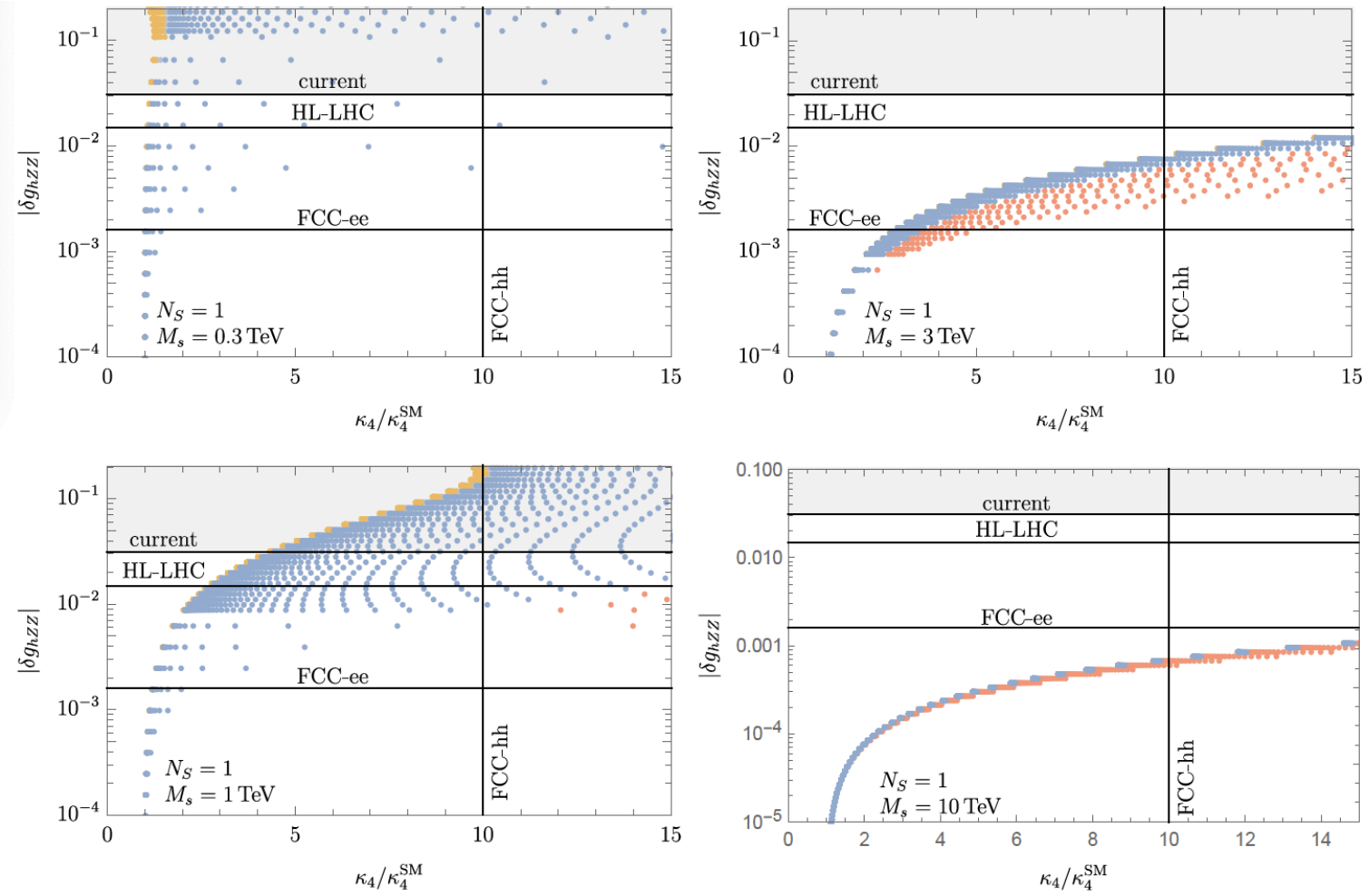




Hypercharged

Systematic study of Higgs-portal $\delta H^\dagger H S^\dagger S$ with Higgs coupling predictions for HL-LHC and FCC 2401.08811

Bottom-Up with UV-Safety



red: poles, blue: stable

Summary

- Take home message: new, concrete & testable directions from formal QFT for BSM model building beyond EFTs.
- Can explain $g-2$, flavor anomalies in beauty and charm 1910.14062, 2109.06201, 2210.16330, and stabilize the SM vaccum 2207.07737, 2305.18520 , 2401.08811
- Genuine new scalar sector: the S_{ij} matrix field; offer different ground states 2008.08606 and leads to novel flavorful signatures at the LHC "only LFV-like" 2011.12964
- Planck safety requires "no poles, no instabilities" up to Planck scale; works with or without 2207.07737 the new wonder tool S_{ij}
- Stay tuned