Multilepton signatures from vector-like fermions

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IoP Workshop @ U Sussex
15 June 2022

standard model

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local QFT for fundamental interactions

strong nuclear force
weak force
electromagnetic force

degrees of freedom

spin 0, spin 1/2, spin 1

perturbatively renormalisable & **predictive**

standard model

University of Sussex

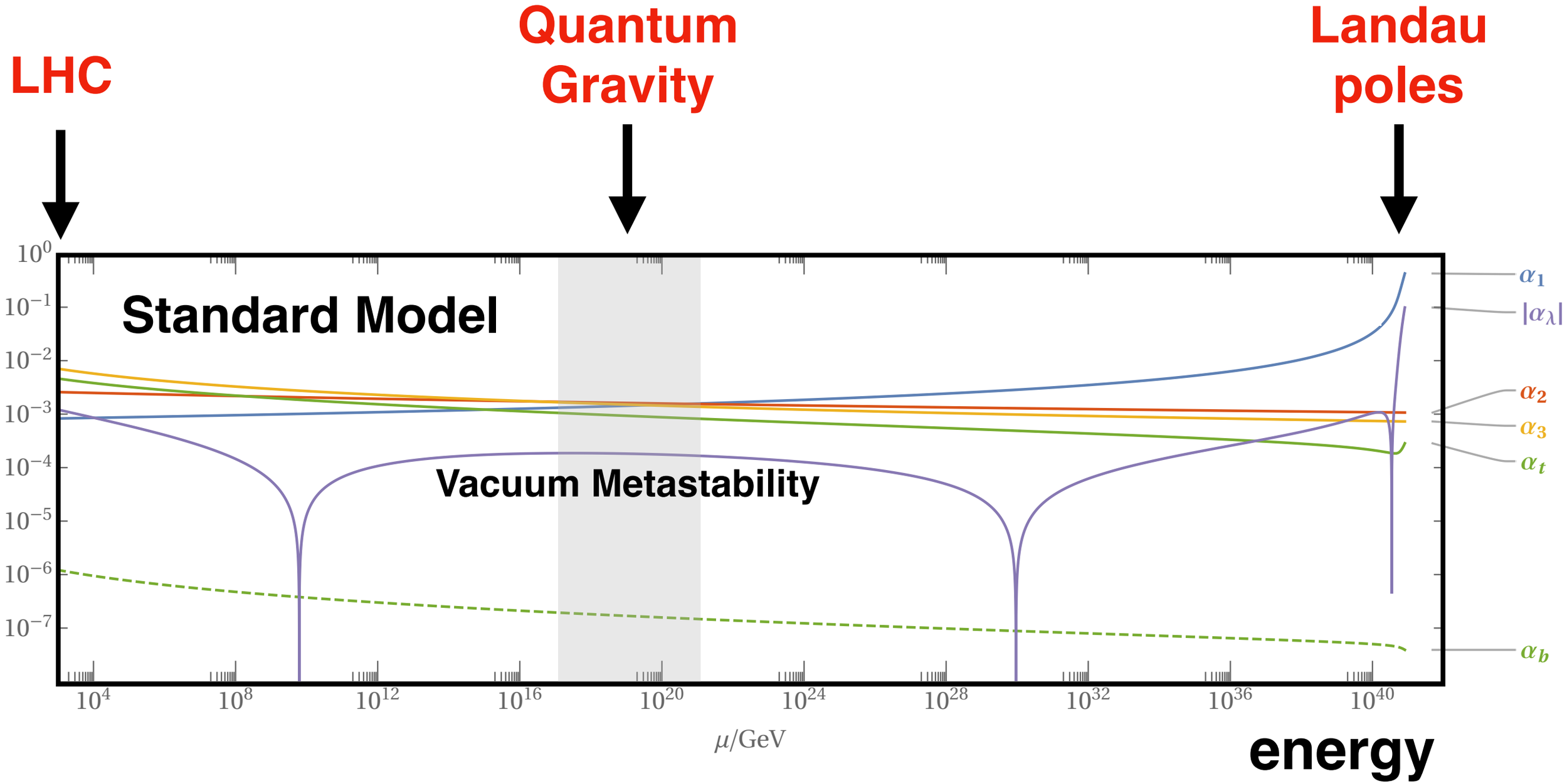
local QFT for fundamental interactions

strong nuclear force
weak force
electromagnetic force

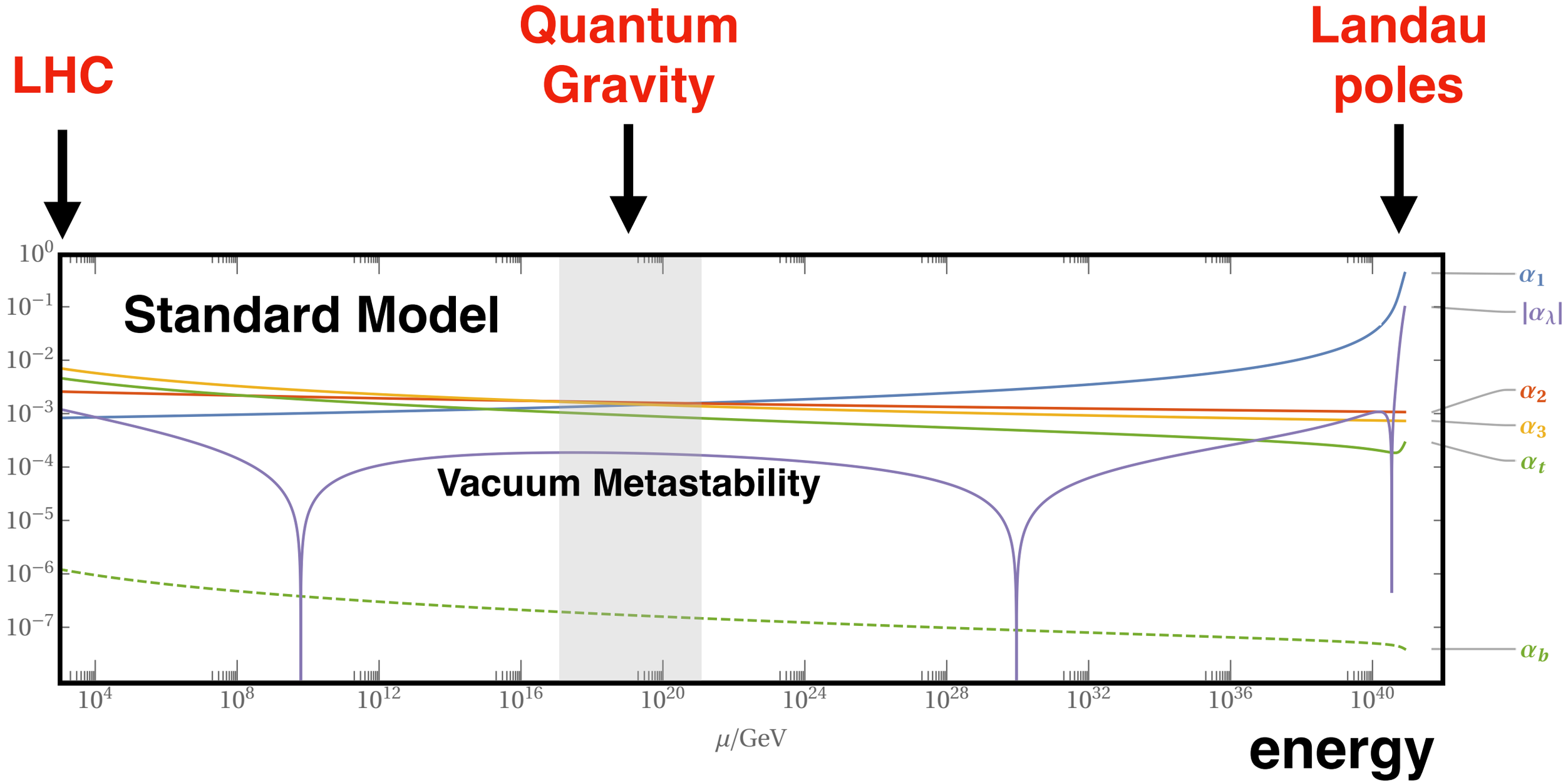
open challenges

what comes **beyond the SM**?
(how does **gravity** fit in?)

SM @ Higgs+10

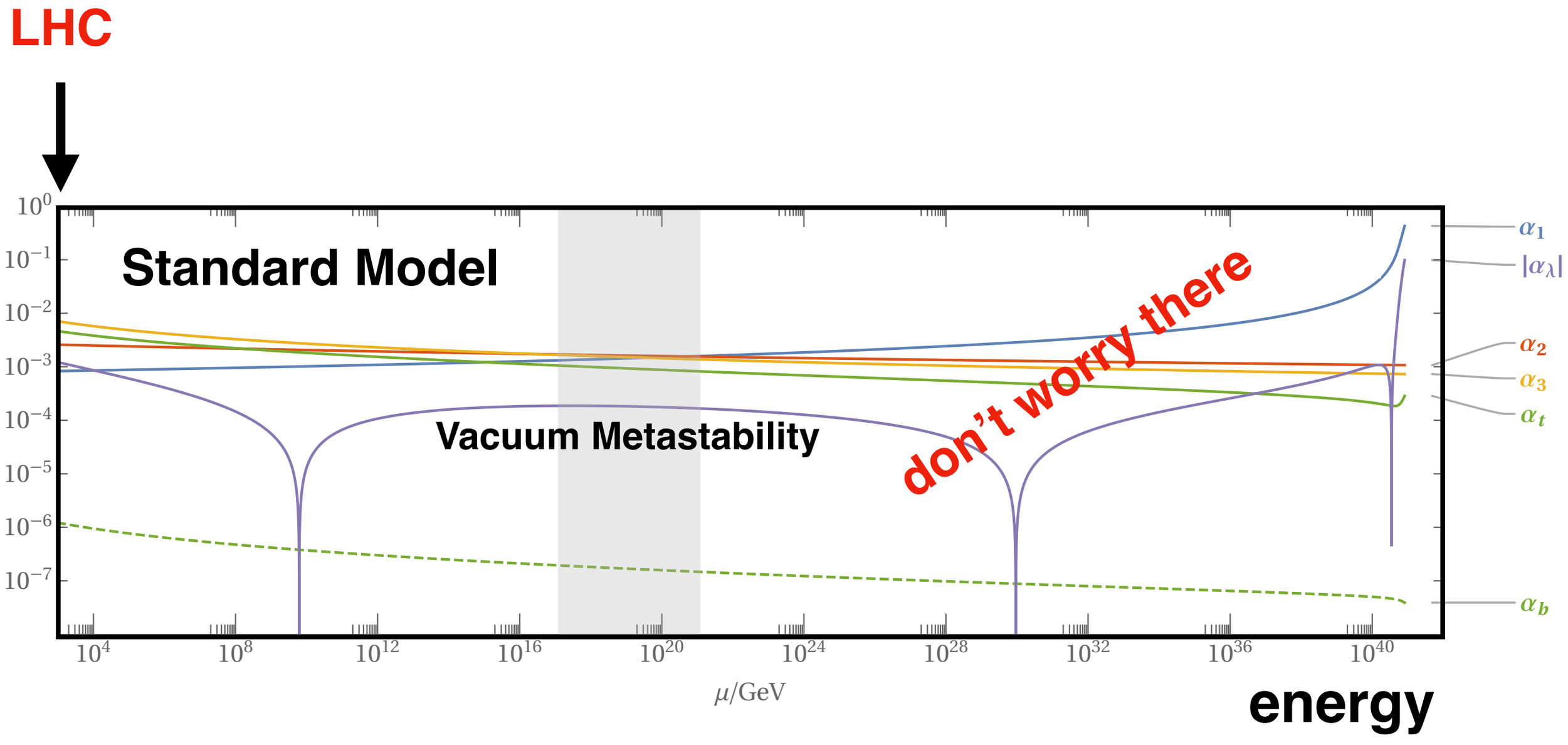

LHC
Quantum Gravity
Landau poles
Standard Model
Vacuum Metastability
α_1
$|\alpha_\lambda|$
α_2
α_3
α_t
α_b
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^4 10^8 10^{12} 10^{16} 10^{20} 10^{24} 10^{28} 10^{32} 10^{36} 10^{40}
μ/GeV
energy

SM @ Higgs+10



"The Planck scale is closer than you think"

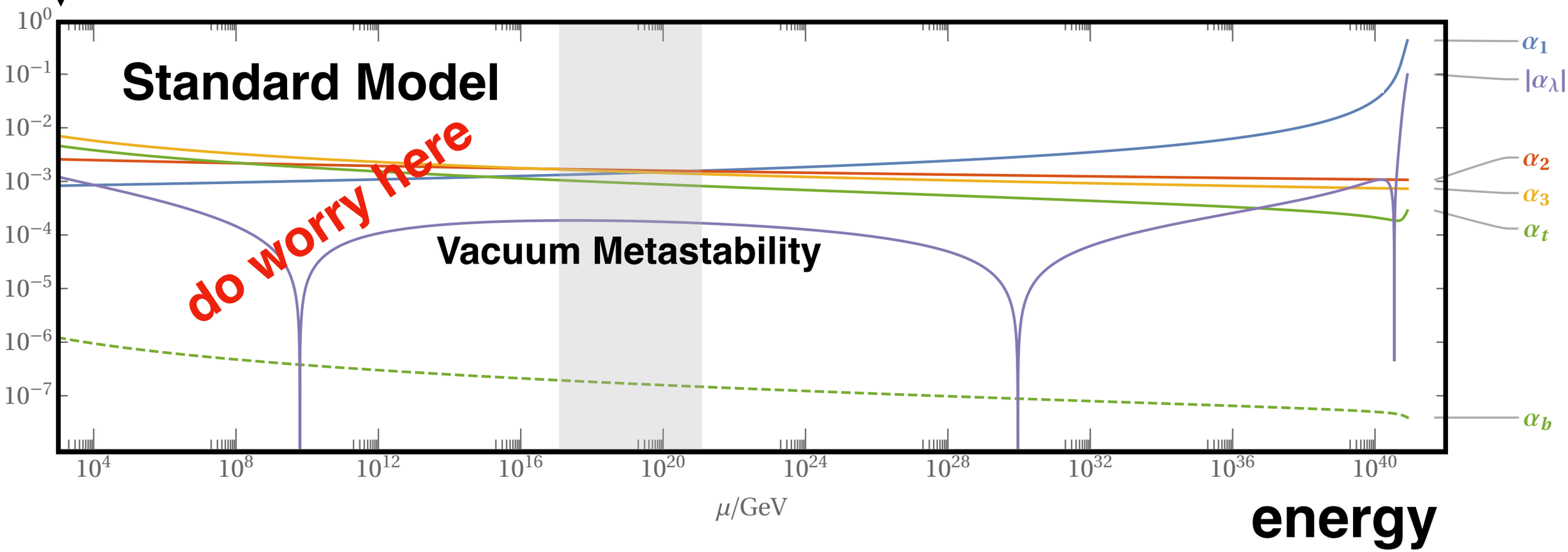
SM @ Higgs+10



"The Planck scale is closer than you think"

SM @ Higgs+10

LHC



"The Planck scale is closer than you think"

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thinking UV

idea:

improved UV behaviour - stability, predictivity

interacting UV fixed points

Wilson '71
Bailin, Love '74, Weinberg '79

offers **new directions** for BSM physics

thinking UV

asymptotic near freedom conjecture (1974)

"running couplings achieve *interacting* RG fixed point"

David Bailin

ASYMPTOTIC NEAR FREEDOM

D. BAILIN and A. LOVE
School of Mathematical and Physical Sciences, University of Sussex, Brighton, England

Received 13 February 1974

Abstract: The possibility that the asymptotic behaviour of the structure functions for electroproduction or neutrinoproduction is controlled by a renormalisation group fixed point near the origin, but not at the origin, is discussed.

Nuclear Physics B75 (1974) 159–170.

thinking UV

asymptotic near freedom guaranteed (2014)

JHEP12(2014)178

Asymptotic safety guaranteed

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Abstract: We study the ultraviolet behaviour of four-dimensional quantum field theories involving non-abelian gauge fields, fermions and scalars in the Veneziano limit. In a regime where asymptotic freedom is lost, we explain how the three types of fields cooperate to develop fully interacting ultraviolet fixed points, strictly controlled by perturbation theory. Extensions towards strong coupling and beyond the large-N limit are discussed.

Keywords: 1/N Expansion, Renormalization Group

ArXiv ePrint: 1406.2337

requires:

gauge, fermion, & scalar fields

thinking UV

Lagrangean

$$L_{\rm YM} = -\frac{1}{2}\,{\rm Tr}\, F^{\mu\nu} F_{\mu\nu}$$ **gauge fields** **gauge coupling**

$$L_F = {\rm Tr}\,(\overline{Q}\, i \not{D}\, Q)$$ **fermions**

$$L_Y = y\,{\rm Tr}\,(\overline{Q}\, H\, Q)$$ **Yukawas**

$$L_H = {\rm Tr}\,(\partial_\mu H^\dagger\, \partial^\mu H)$$ **scalar fields**

$$L_U = -u\,{\rm Tr}\,(H^\dagger H)^2$$

$$L_V = -v\,({\rm Tr}\, H^\dagger H)^2\,.$$ **quartics**

scalars are “meson-like”, H_ij

no asymptotic freedom, yet, stable and predictive “UV complete”

thinking UV

what do we know?

works for simple gauge theories with matter

works for semi-simple gauge theories with matter

works with supersymmetry

works for strongly coupled theories

thinking BSM

minimal framework:

SM gauge symmetry

AD Bond, G Hiller, K Kowalska, DF Litim, 1702.01727 (JHEP)

$$SU(3)_C \times SU(2)_L \times U(1)_Y$$

N_F **flavors of BSM fermions** $\psi_i(R_3, R_2, Y)$

BSM singlet scalars S_{ij}

features: **vector-like fermions**

global flavor symmetry $U(N_F) \times U(N_F)$

single BSM Yukawa coupling

meson-like scalar

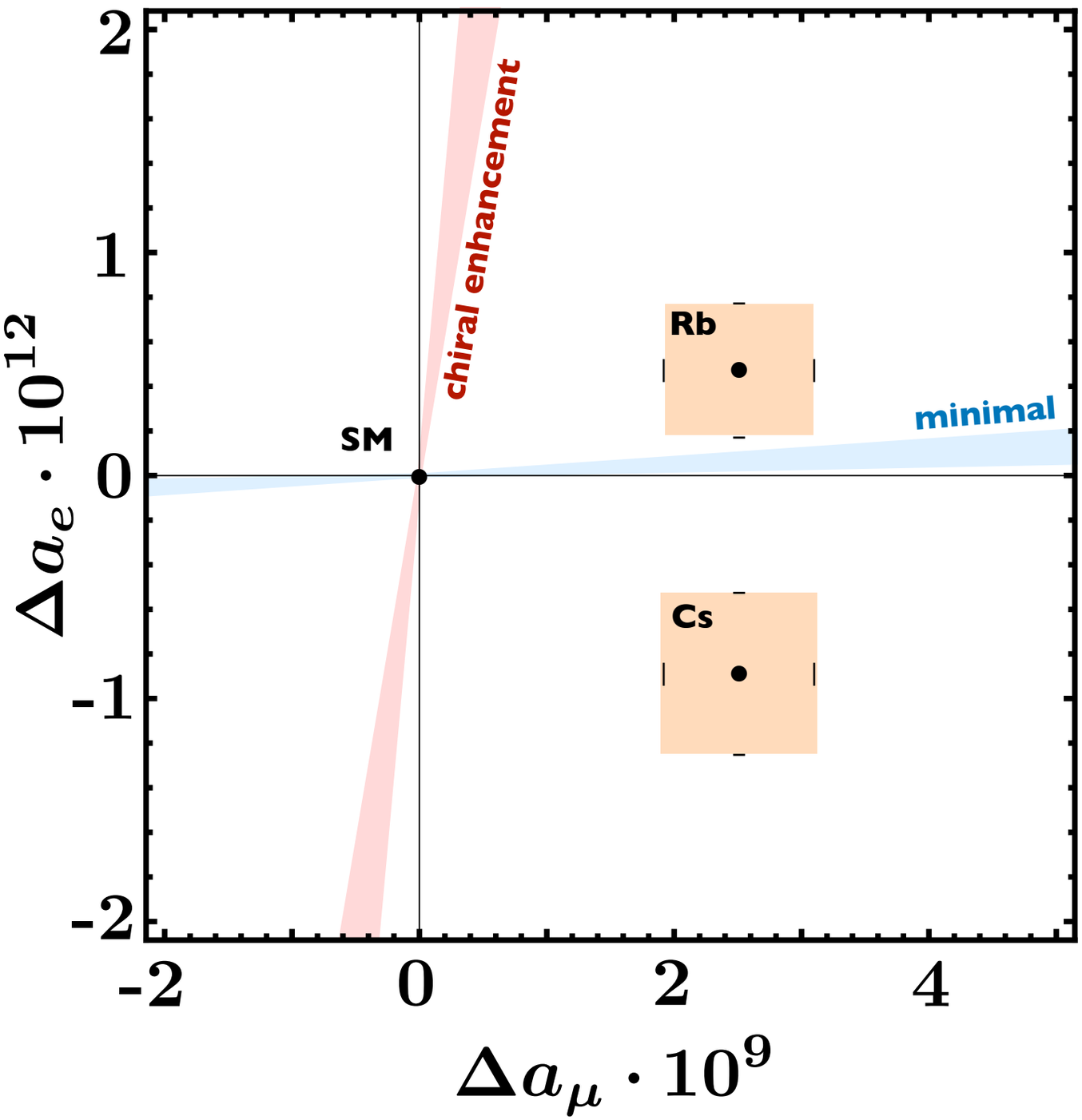
thinking BSM

anomalous magnetic moments

A Bond, G Hiller, K Kowalska, DF Litim,
Directions for model building from asymptotic safety, JHEP1708 (2017) 004

G Hiller, C Hermigos-Feliu, DF Litim, T Steudtner,
Asymptotically safe extensions of the Standard Model and their flavour phenomenology 1905.11020
Anomalous magnetic moments from asymptotic safety 1910.14062
Model building from asymptotic safety with Higgs and flavour portals 2008.08606

anomalous magnetic moments



a puzzle …

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anomalous magnetic moments

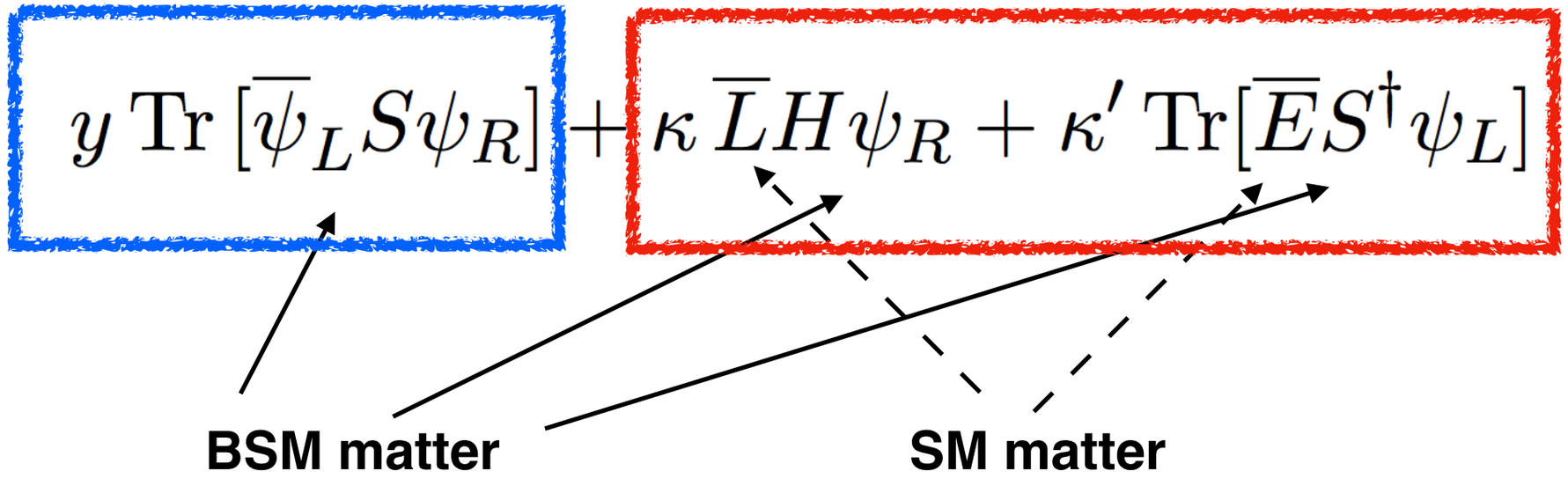
what's the new physics?

to date: about 60 BSM models can explain the data

All but two treat electrons and muons differently
i.e. lepton universality manifestly broken

thinking BSM

new vector-like BSM fermions + scalars
new Yukawas + portal interactions



lepton universality intact

Yukawas explain AMMs

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thinking BSM

new vector-like BSM fermions + scalars
new Yukawas + portal interactions

$$y\,\mathrm{Tr}\,[\overline{\psi}_L S \psi_R] + \kappa\,\overline{L} H \psi_R + \kappa'\,\mathrm{Tr}[\overline{E} S^\dagger \psi_L]$$

feature: **BSM Yukawas can explain anomalous magnetic moments**

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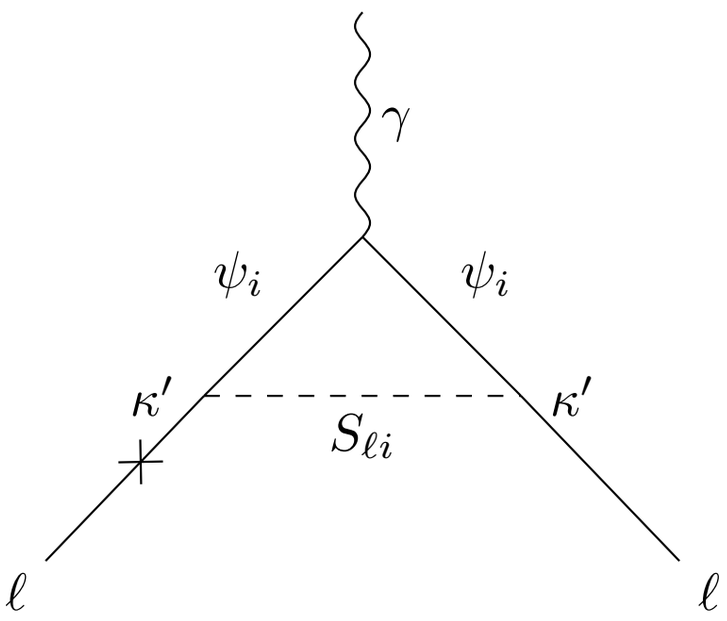
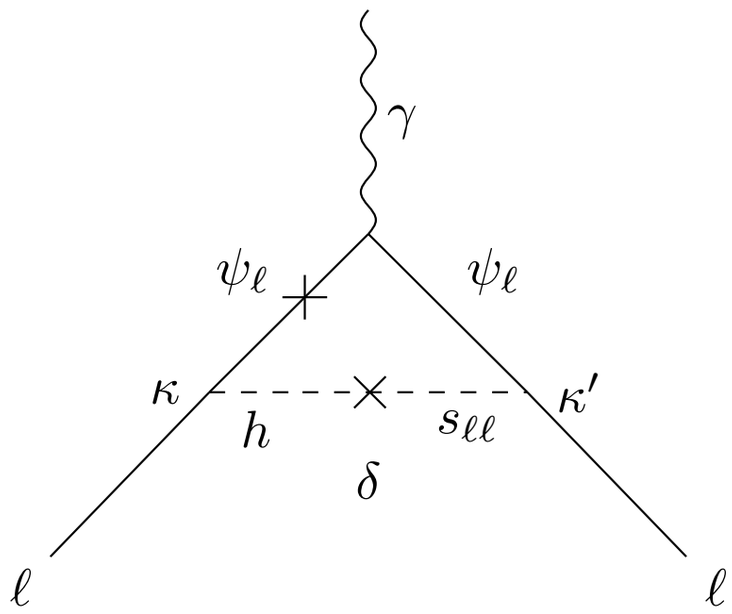
thinking BSM

new vector-like BSM fermions + scalars
new Yukawas + portal interactions



“minimal”

$$\sim (m_e/m_\mu)^2$$



“chirally enhanced”

$$\sim (m_e/m_\mu)$$

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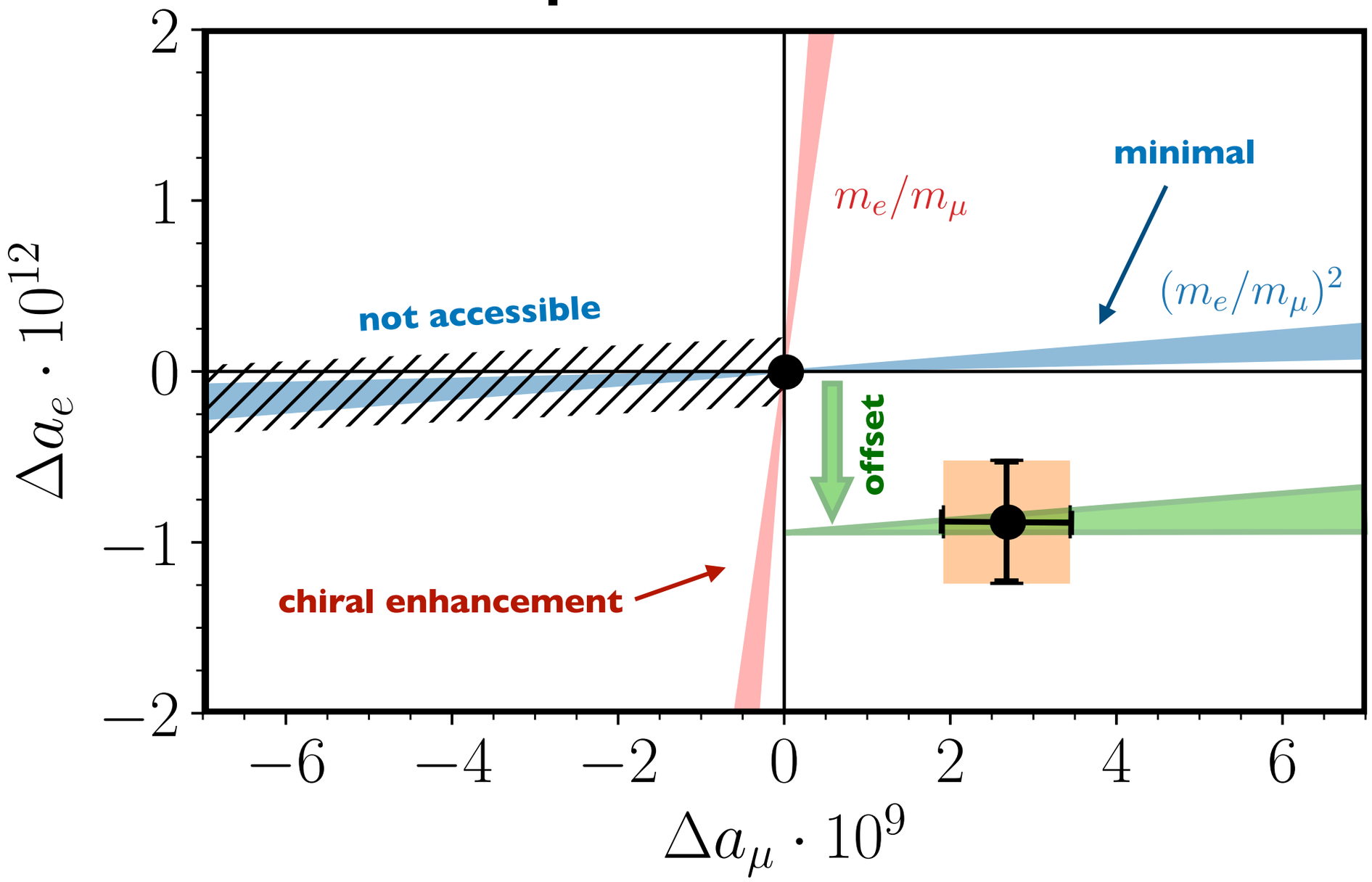
thinking BSM

natural explanation for both AMMs



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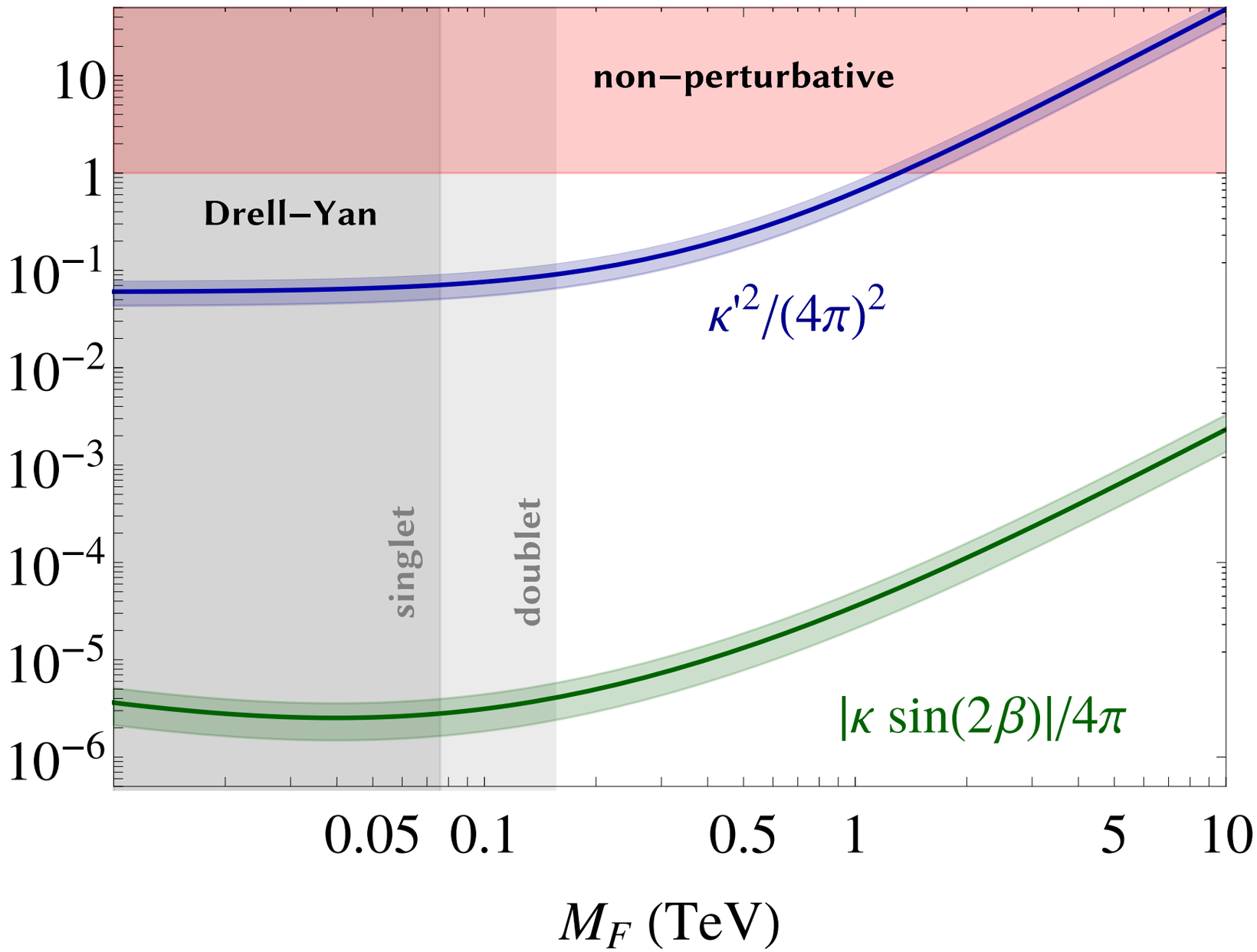
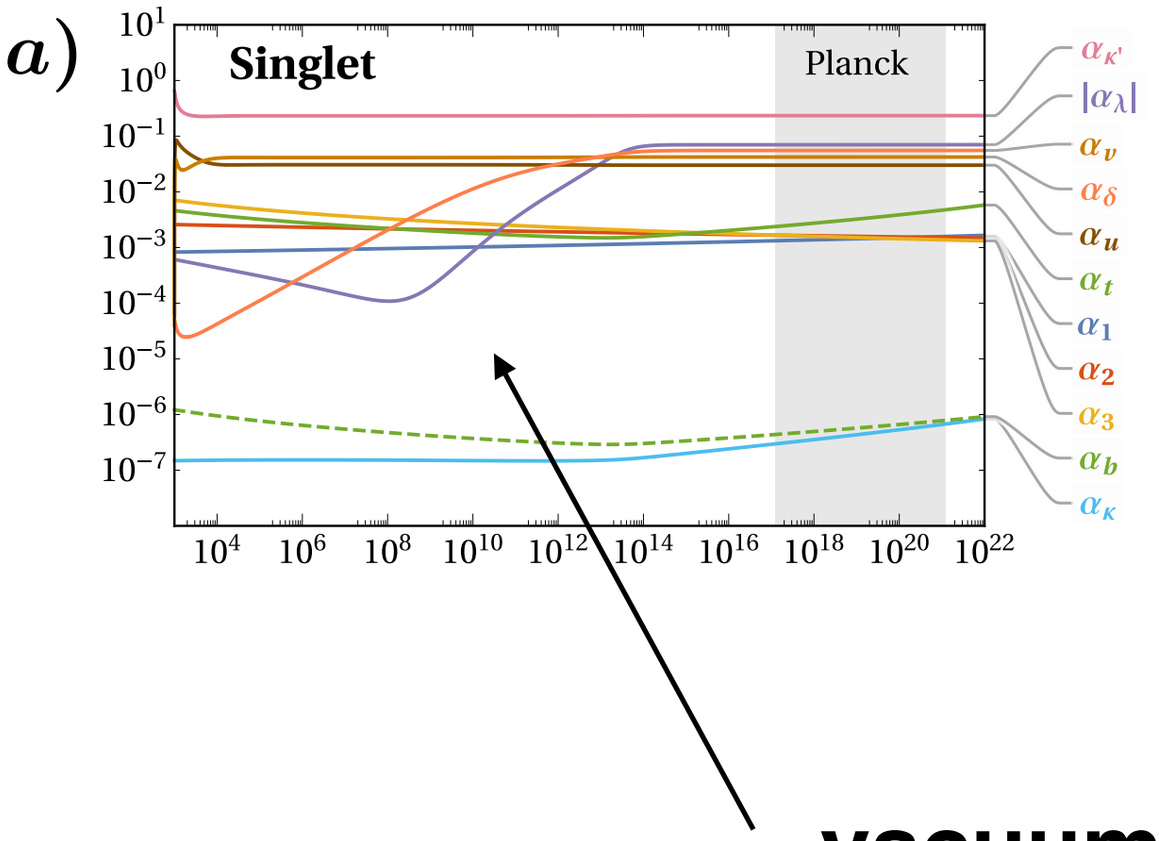
thinking BSM

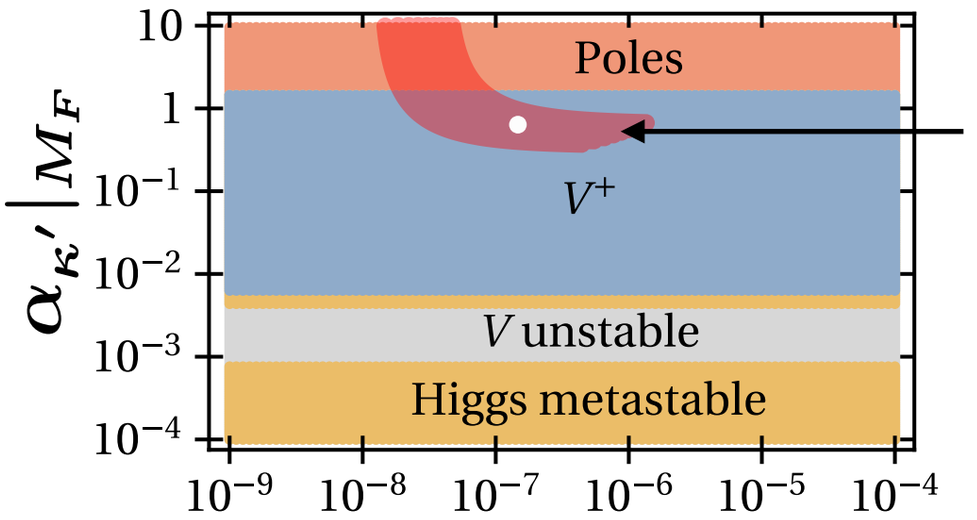
constraints



thinking BSM



vacuum stability



AMMs

G Hiller, C Hermigos-Feliu, DF Litim, T Steudtner, **Anomalous magnetic moments from asymptotic safety** 1910.14062
Model building from asymptotic safety with Higgs and flavour portals 2008.08606

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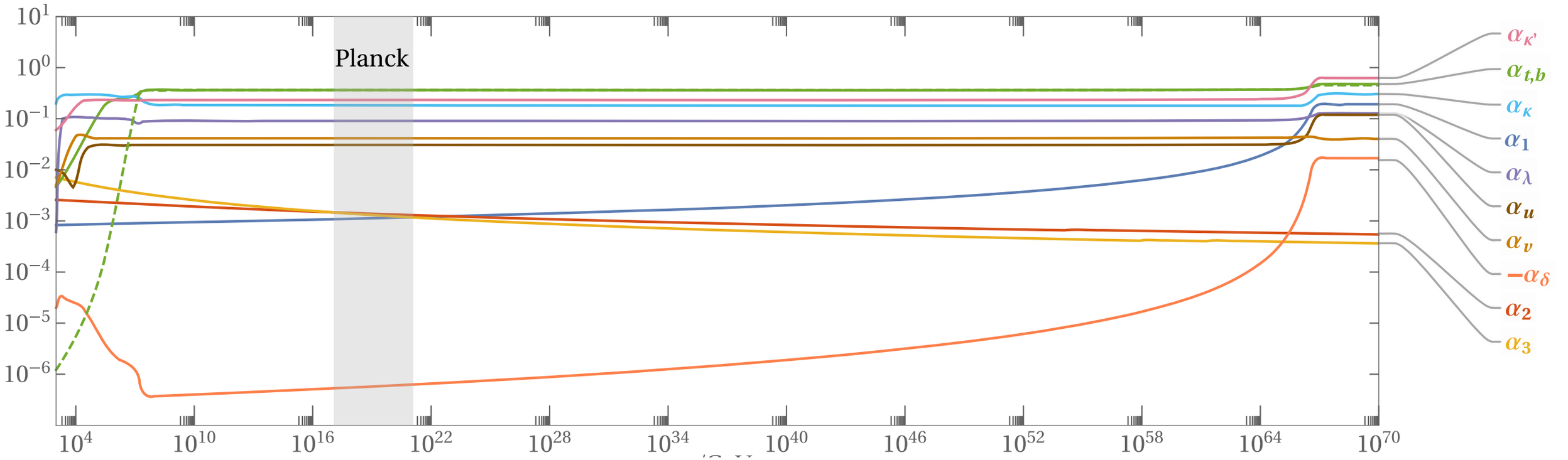
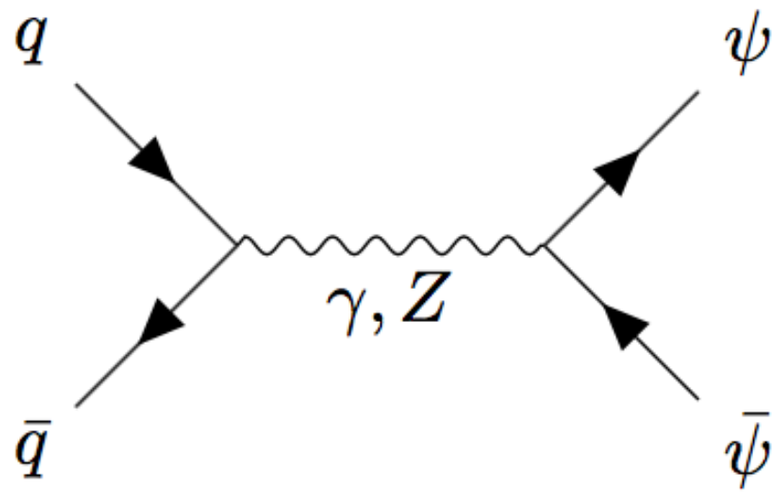
thinking BSM



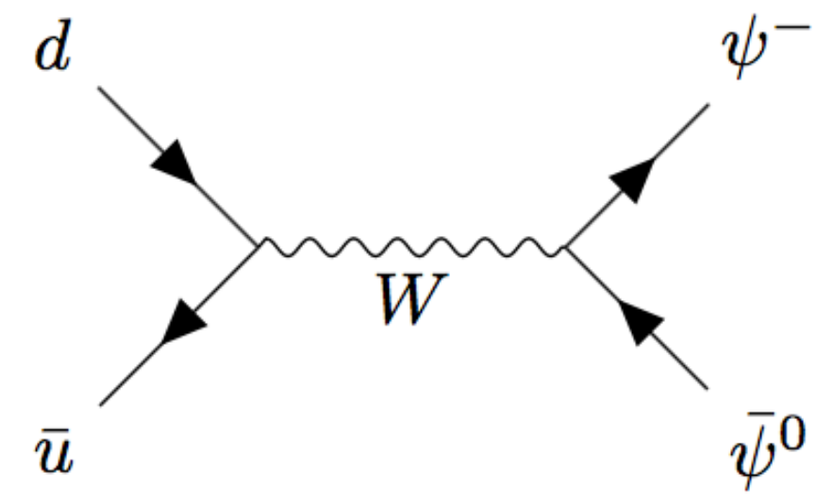
G Hiller, C Hermigos-Feliu, DF Litim, T Steudtner,
Anomalous magnetic moments from asymptotic safety 1910.14062
Model building from asymptotic safety with Higgs and flavour portals 2008.08606

new multilepton signatures

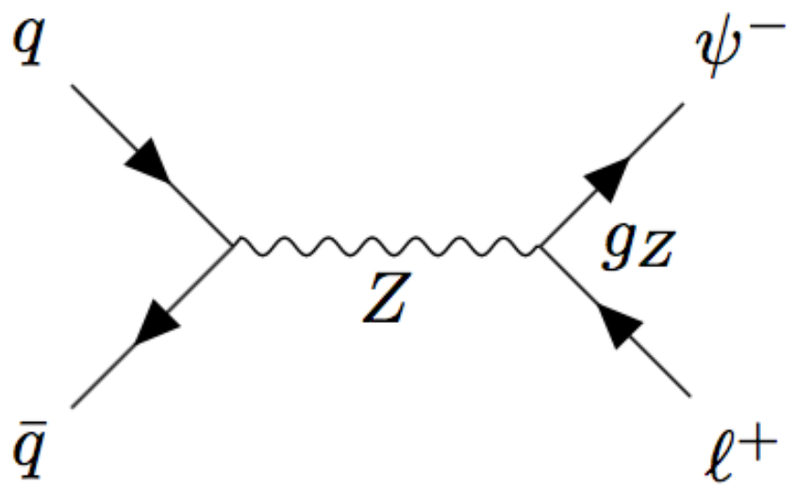
pair production



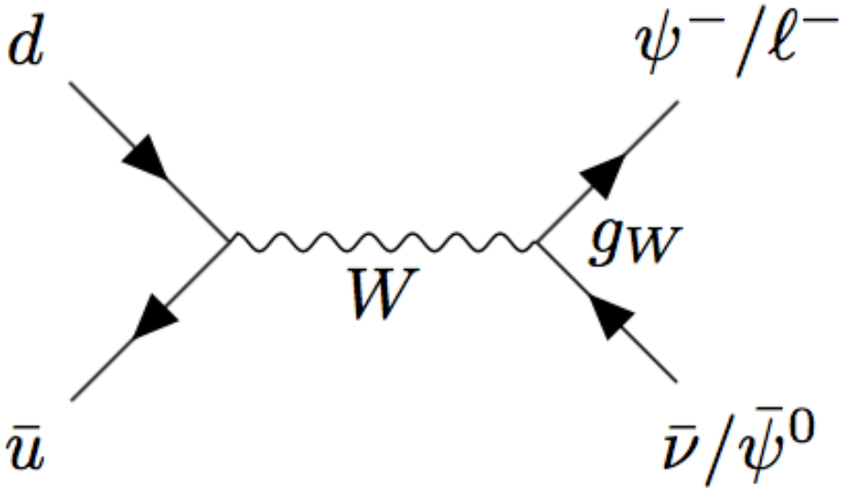
$a)$



$b)$



$c)$



$d)$

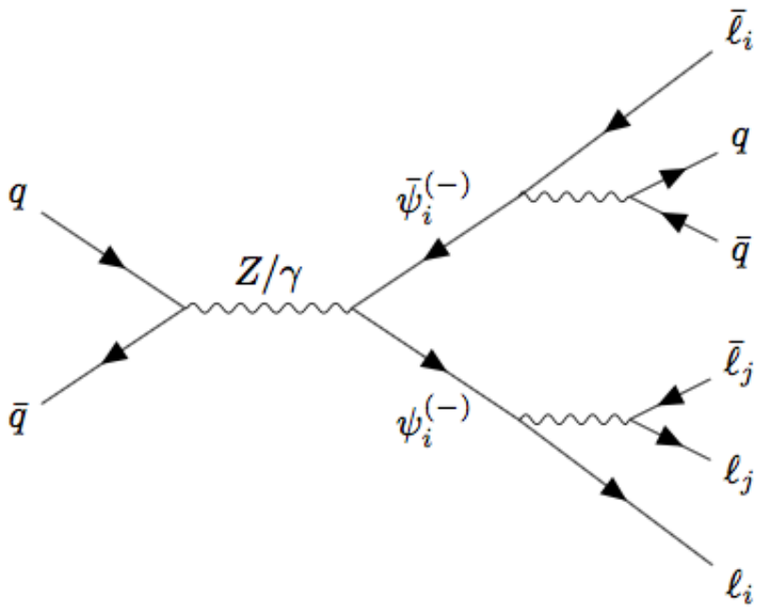
new multilepton signatures

”unusual” decay patterns

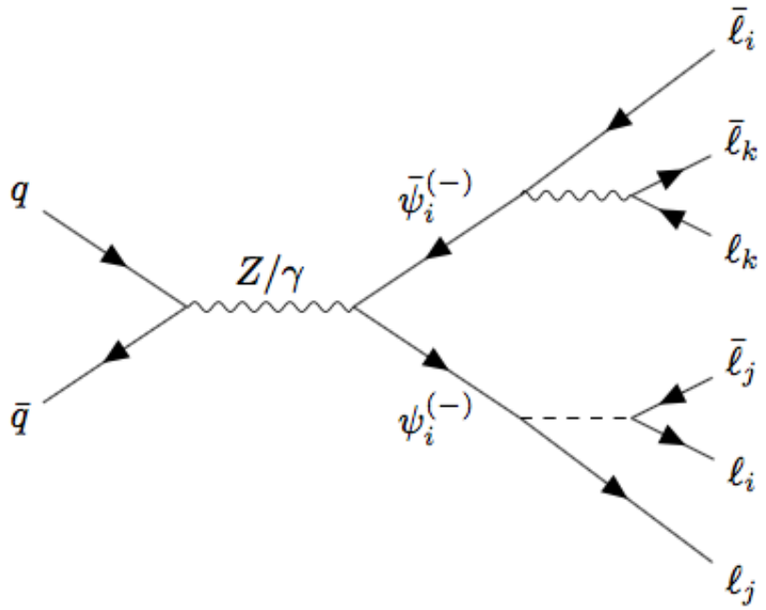
$$\psi_i \overline{\psi}_i \to \ell_j^- S_{ij}^* \ell_k^+ S_{ik} \to \ell_j^- \ell_j^+ \ell_i^- \ell_k^+ \ell_k^- \ell_i^+$$

allows SM null tests

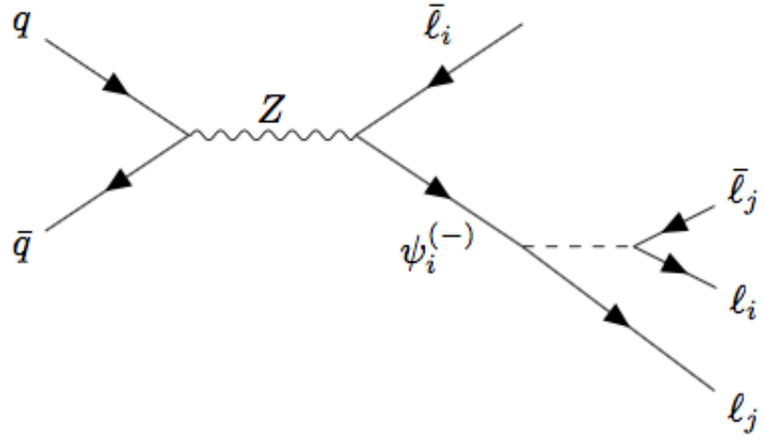
Multi leptons



$a)$



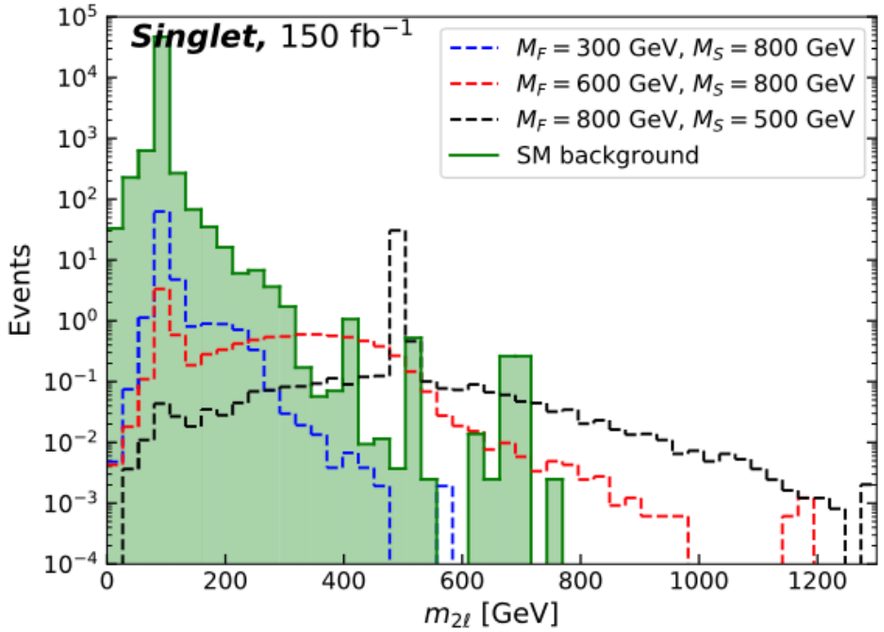
$b)$

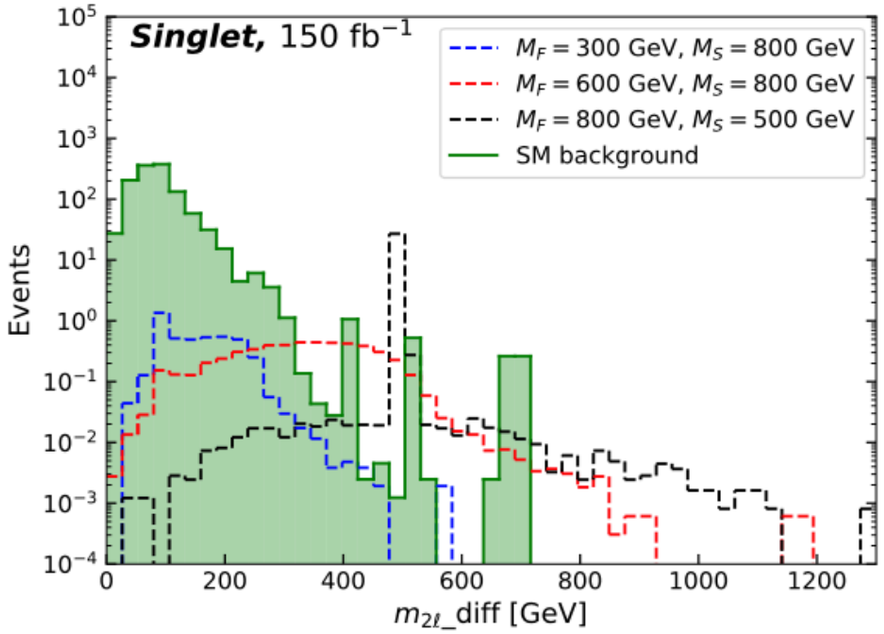


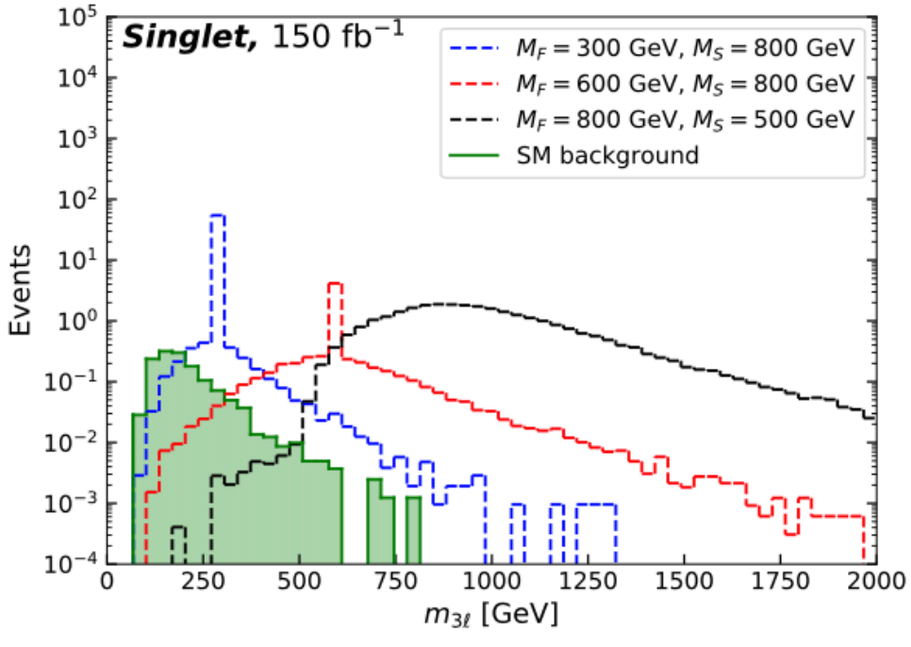
$c)$

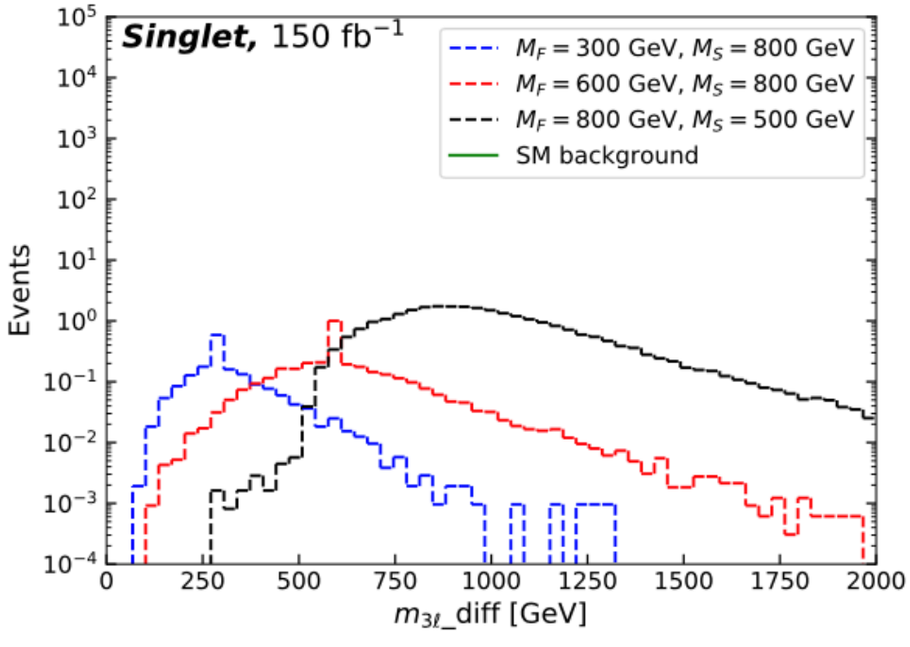
multilepton signatures

Run2

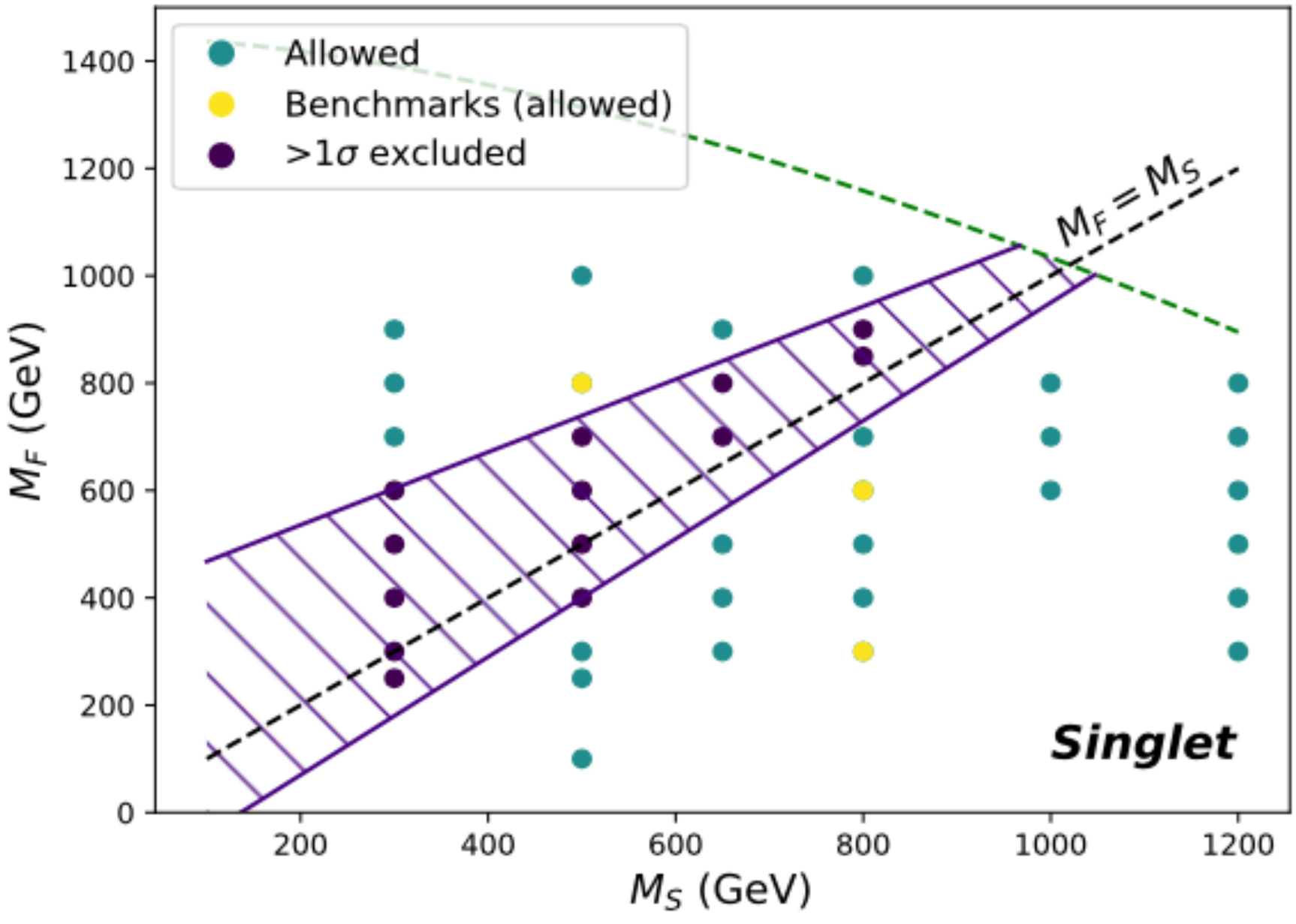




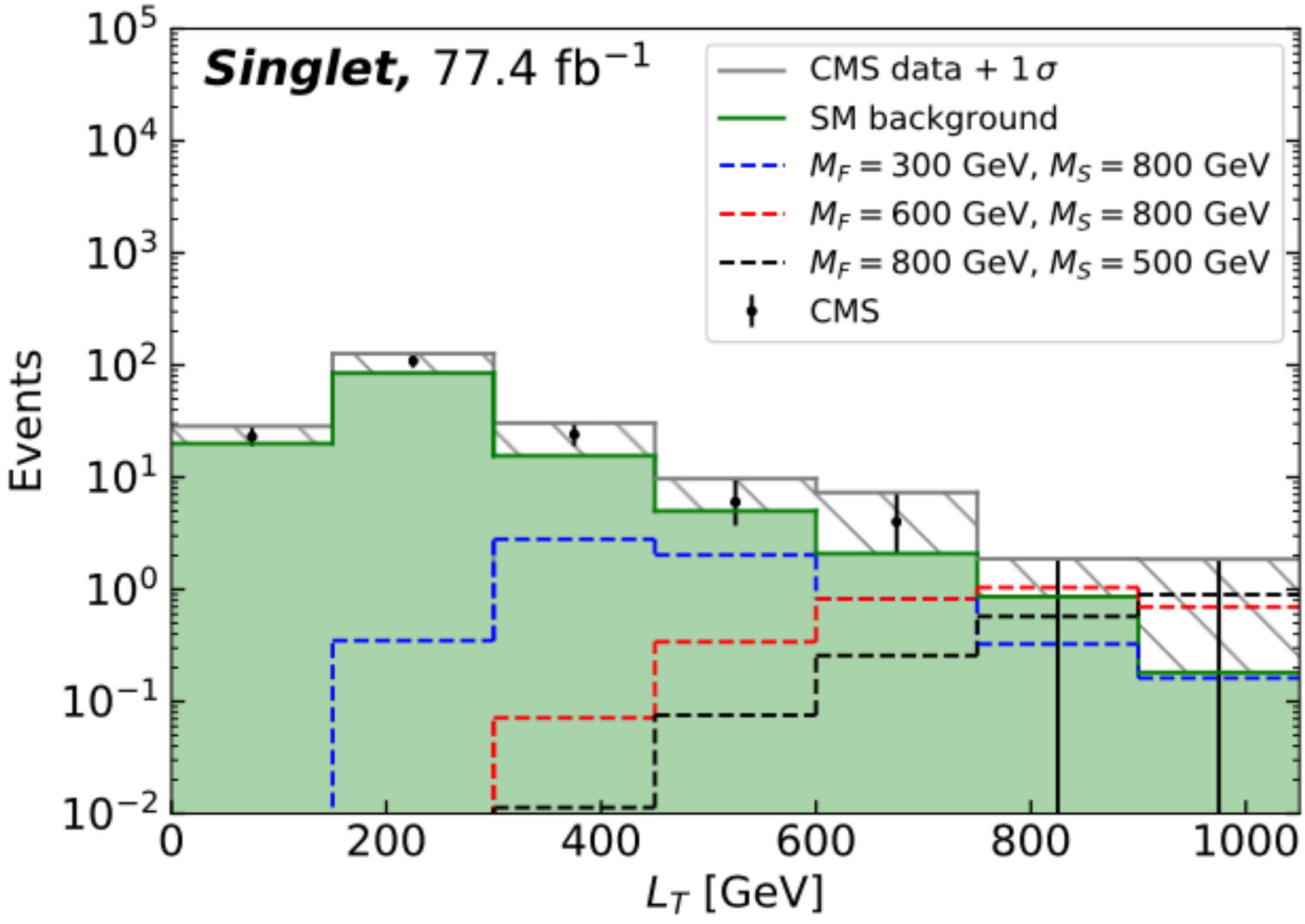




phase space

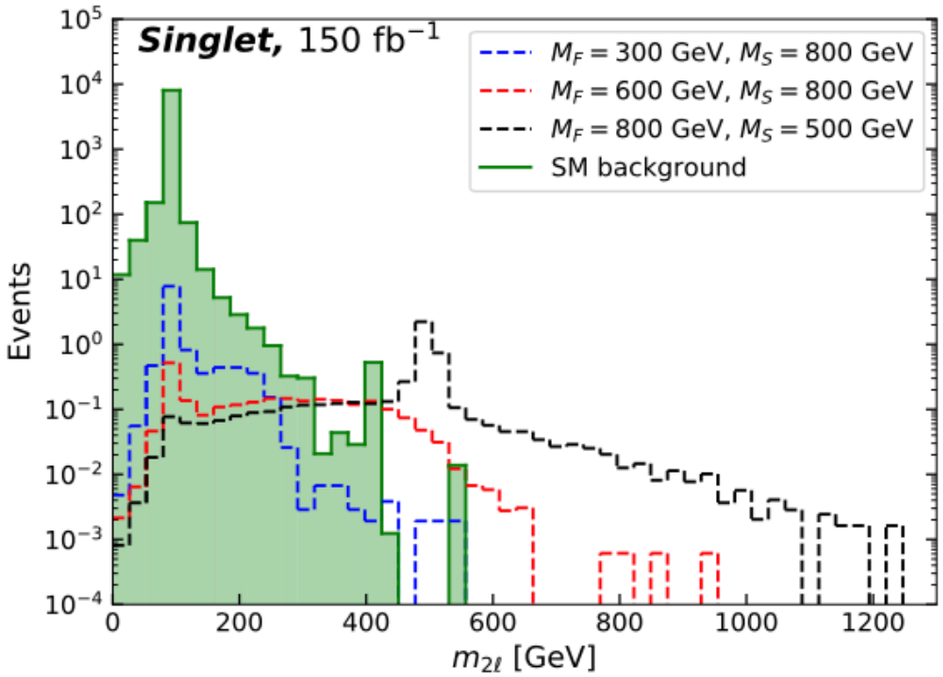

Allowed
Benchmarks (allowed)
>1σ excluded
$M_F = M_S$
Singlet
M_F (GeV)
M_S (GeV)
0
200
400
600
800
1000
1200
1400

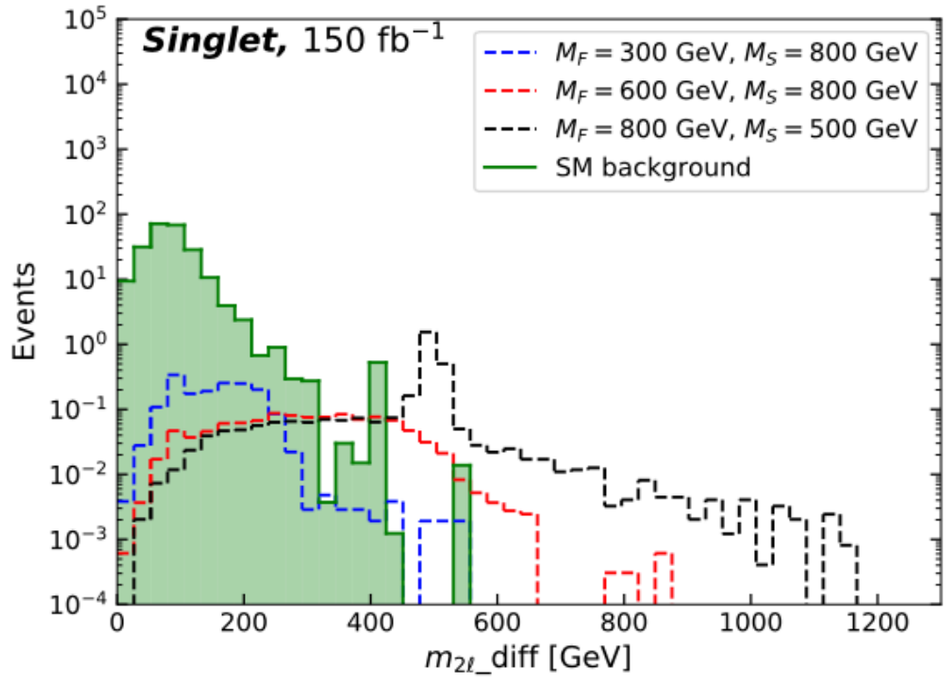
LT distribution

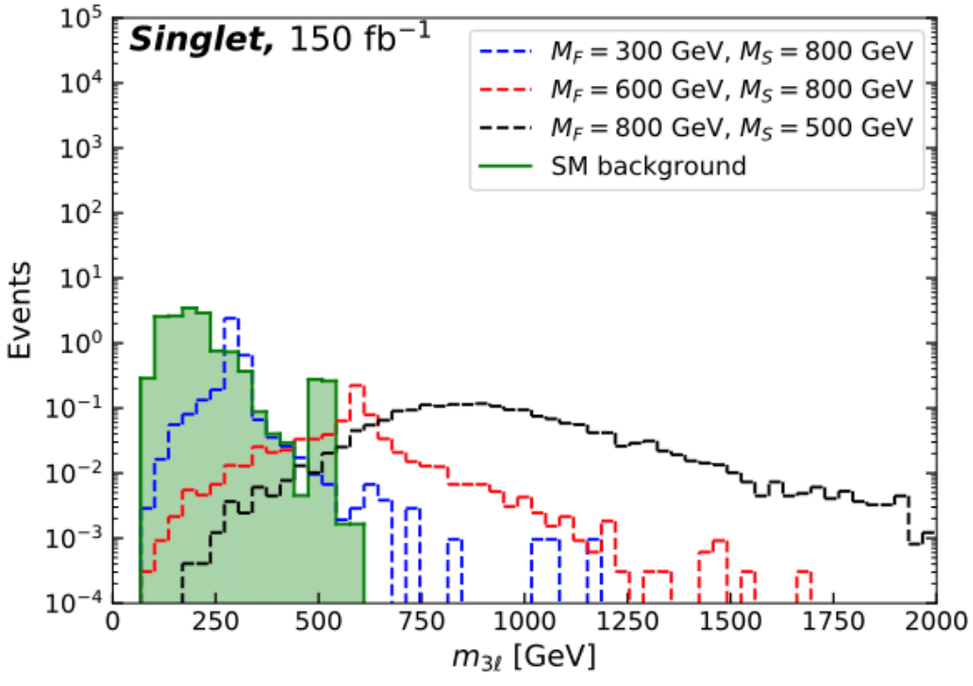


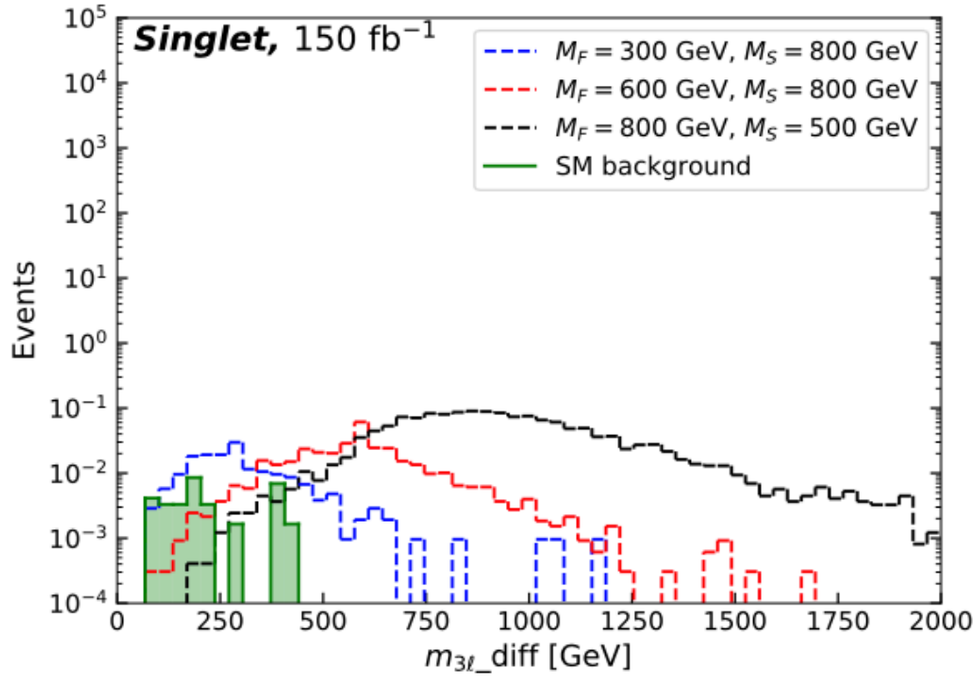
multilepton signatures

Run2



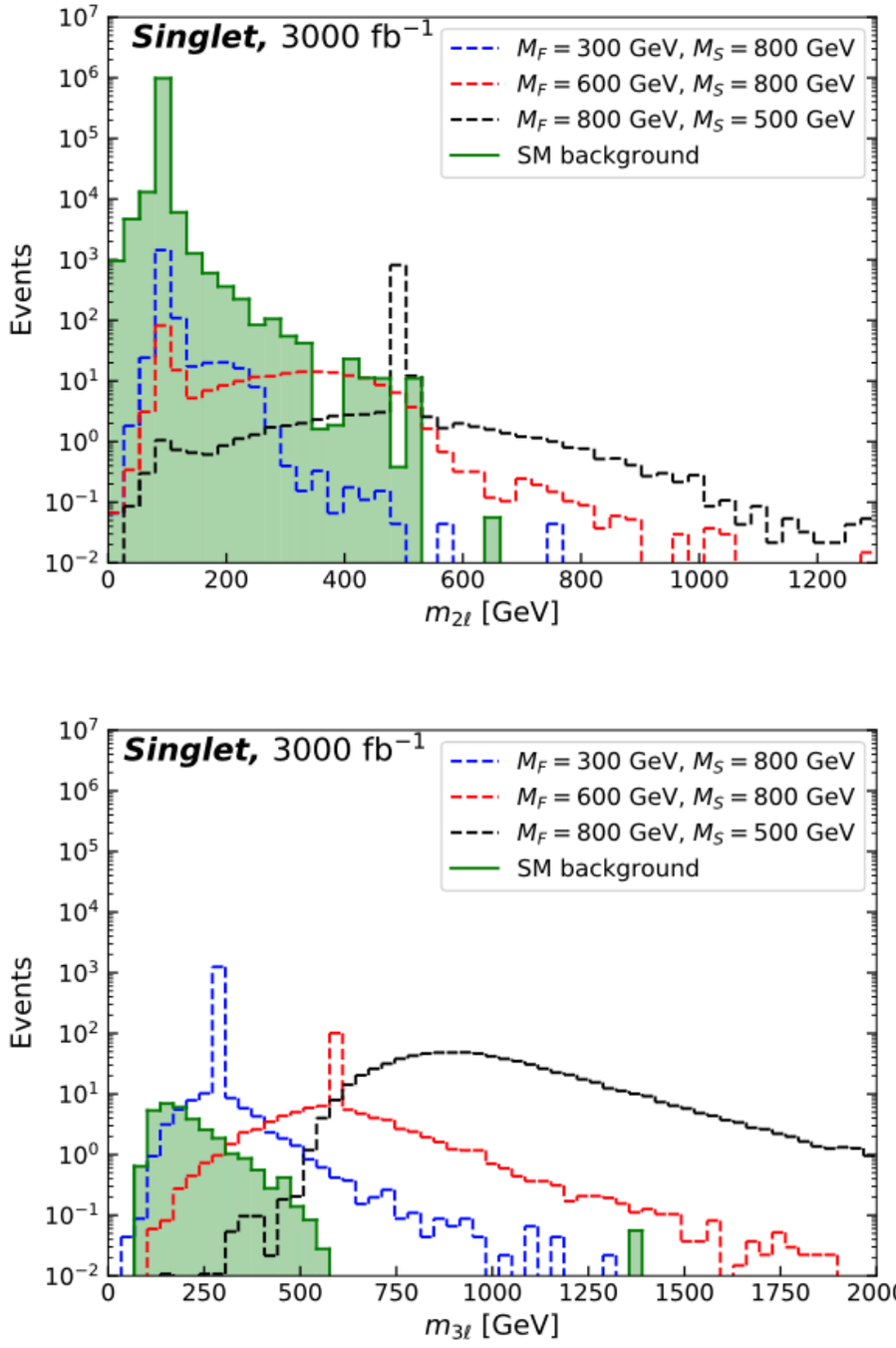


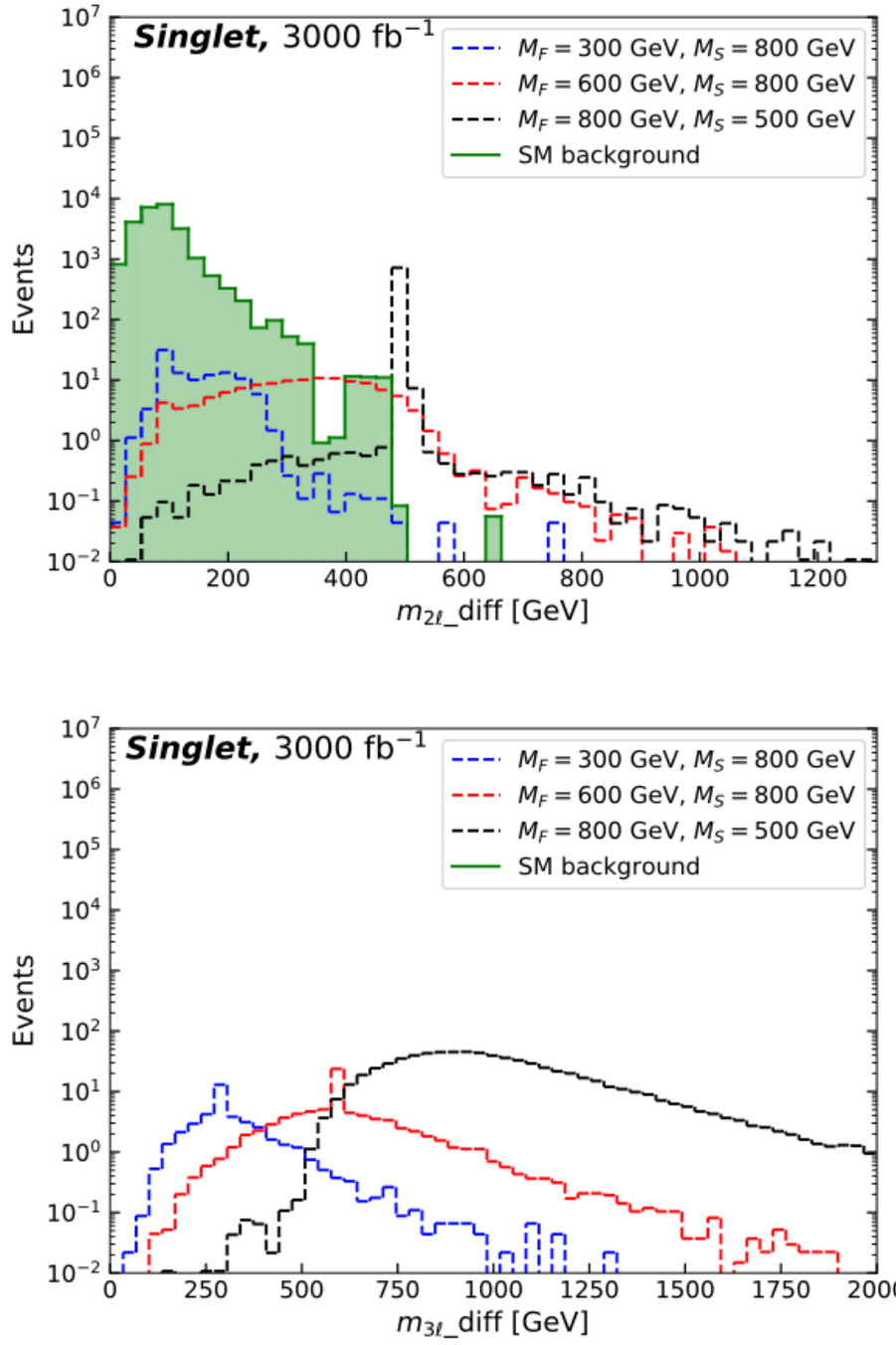




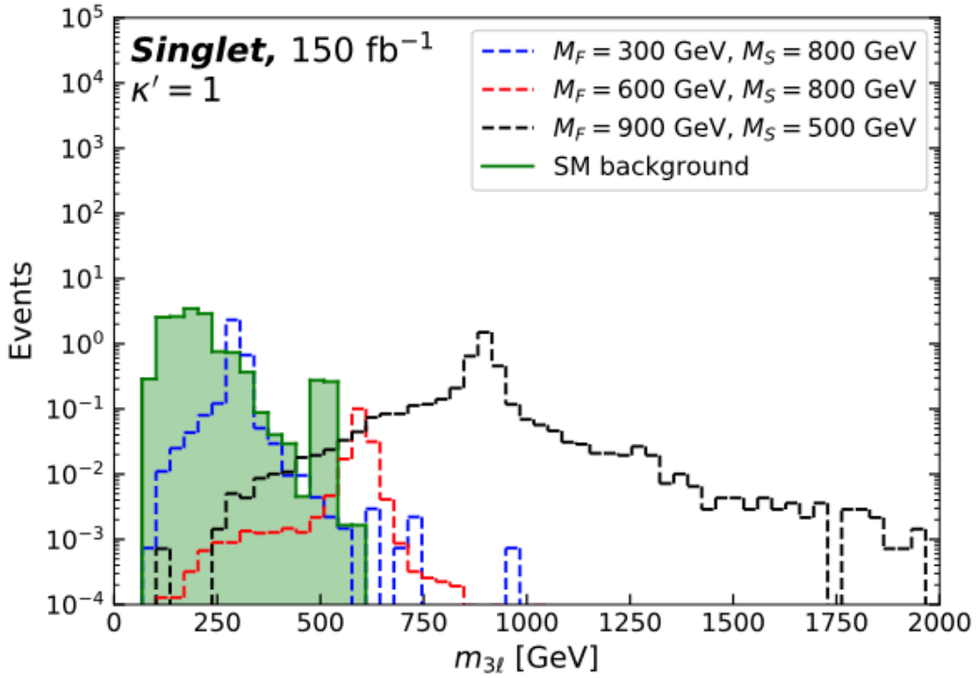
multilepton signatures

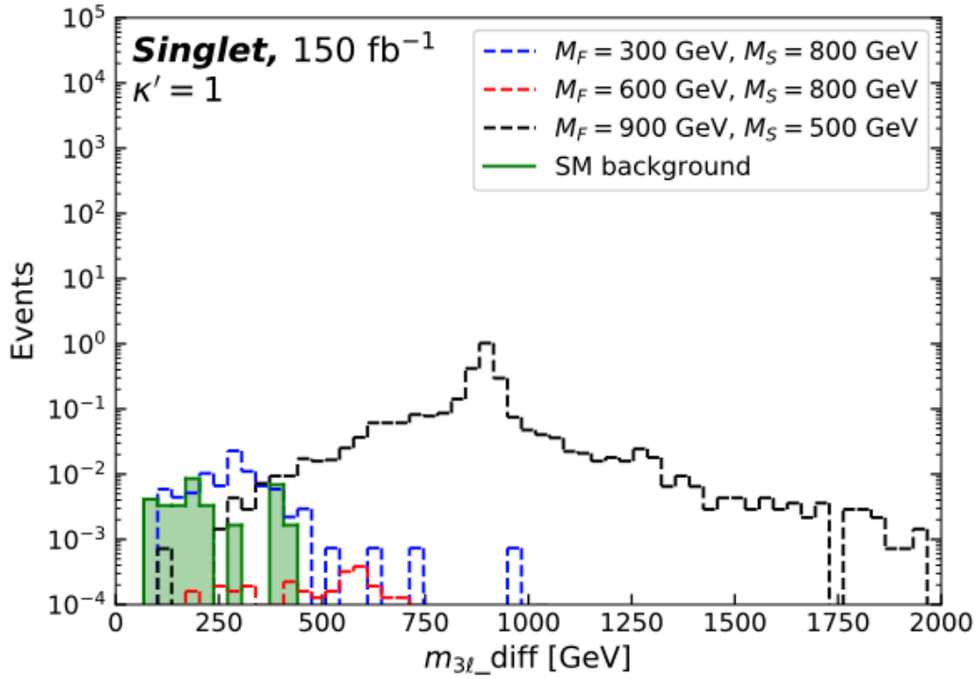
HL-LHC





m_3L


Singlet, 150 fb^{-1}
$\kappa' = 1$
$M_F = 300$ GeV, $M_S = 800$ GeV
$M_F = 600$ GeV, $M_S = 800$ GeV
$M_F = 900$ GeV, $M_S = 500$ GeV
SM background
Events
$m_{3\ell}$ [GeV]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$M_F = 600$ GeV, $M_S = 800$ GeV
$M_F = 900$ GeV, $M_S = 500$ GeV
SM background
Events
$m_{3\ell}$_diff [GeV]

Conclusions

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new model building ideas

stability
predictivity

interesting signatures at colliders

SM null tests, and more!