Surveying the Left-Right Symmetric SO(10) Landscape

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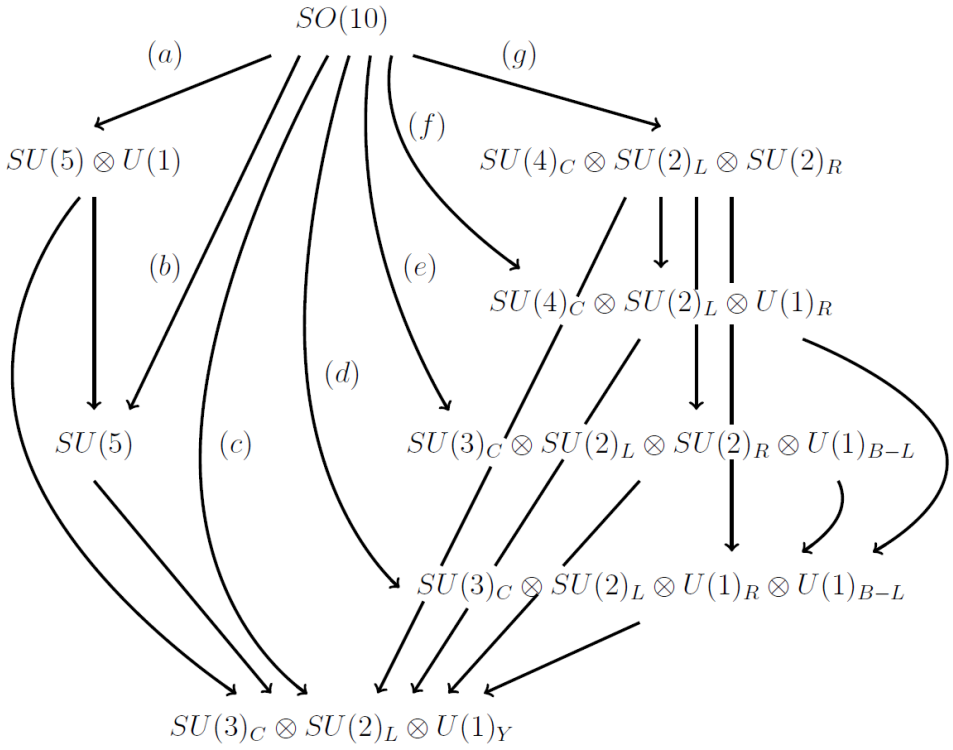
Introduction and Motivation

- current state - lack of new physics signals near the electroweak scale
- GUTs - well motivated extensions of the Standard Model
- sound way how to explore very high scales
- SO(10) - very rich framework, many free parameters $\rightarrow$ many possible scenarios, but minimal settings still phenomenologically interesting
- $\Longrightarrow$ a general, automated approach to the model building procedure

Creating a Model Landscape

- specify theory at high energies $\leftrightarrow$ symmetries + field content
- series of symmetry breaking steps reducing the symmetry down to the SM gauge group
- fermions - only $\mathbf{16}_F$
- scalars - exotics allowed, each scalar can survive or be integrated out at every breaking scale
- manageable computation $\leftrightarrow$ up to 5 scalars at every level allowing for the given breaking chain
- duplicates generated are kept, may correspond to different Lagrangians



Creating a Model Landscape

- model generating algorithm: a set of reps at GUT scale decomposed into reps of the subsequent groups of the chain
- $\implies$ all possible combinations satisfying the mentioned restrictions obtained
- for a chain $\mathcal{G} \to \mathcal{F}_1 \to \cdots \to \mathcal{F}_{m-1} \to \mathcal{G}_{SM}$ with m breaking steps the models are characterized as

$$\{\mathcal{M}\} = \left\{ \begin{array}{ll} \text{Chain: } \{\mathcal{G} \ \to \cdots \to \mathcal{G}_{SM}\}, & \text{Reps: } \{\mathcal{R}_i^{(0)}\}, \\ \text{Chain: } \{\mathcal{F}_1 \to \cdots \to \mathcal{G}_{SM}\}, & \text{Reps: } \{\mathcal{R}_i^{(1)}\}, \\ \quad \cdots & \quad \cdots \\ \text{Chain: } \{\mathcal{G}_{SM}\}, & \text{Reps: } \{\mathcal{R}_i^{(m)}\} \end{array} \right\}$$

$\{\mathcal{R}_i^{(0)}\}$ - the representations at the $SO(10)$ scale,
$\{\mathcal{R}_i^{(j)}\}$ - a combination of their decompositions at the jth step

$SO(10)$ with Intermediate Left-Right Symmetric Scale

- analysis of all possible scenarios - exhausting $\rightarrow$ test case

- LR-symmetric models - minimal realisations extensively described in literature, a lot of pheno interest

$\Longrightarrow$ consider two-step symmetry breaking

$$\begin{array}{c} SO(10) \\ \downarrow \\ SU(3)_C \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L} \\ \downarrow \\ SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \end{array}$$

- representations at $SO(10)$ scale: $\{3 \times \mathbf{16}_F, \mathbf{10}, \mathbf{45}, \mathbf{126}, \overline{\mathbf{126}}\}$

Theoretical Constraints

- chirality - complex representations needed $\rightarrow \mathbf{16}_F$
- anomalies - in our context: ABJ anomaly relevant - satisfied by construction: no exotic fermions, $\mathbf{16}_F$ of $SO(10)$ is anomaly free
- symmetry breaking - at every step we require presence of a scalar field, which can break the symmetry in the desired way
- Standard Model - last step of the chain is the SM gauge group with (at least) SM content - in addition to a Higgs doublet also extra scalar fields allowed (such that are not immediately ruled out)
- fermion mixing, CKM matrix - checking specific values beyond our scope, but enough degrees of freedom to fit the parameters must be provided (minimal choice for the LR scale: $2 \times \{\mathbf{1}, \mathbf{2}, \mathbf{2}, 0\} + \{\mathbf{1}, \mathbf{1}, \mathbf{3}, 0\}$)

Gauge Coupling Unification

- 1-loop RGE for the gauge coupling g: $\mu \frac{\mathrm{d}\alpha^{-1}}{\mathrm{d}\mu} = -\frac{b}{2\pi}$
- the slope b is given by:

$$b = \frac{2}{3} \sum_{\text{Fermions}} S(\mathcal{R}_f) d_\perp(\mathcal{R}_f) + \frac{1}{3} \sum_{\text{Scalars}} S(\mathcal{R}_s) d_\perp(\mathcal{R}_s) - \frac{11}{3} C_2(\mathcal{G})$$

- substituting $t = \frac{1}{2\pi} \log(\frac{\mu}{M_Z})$ and solving RGEs corresponding to 3 SM couplings $\rightarrow$ 3 conditions, in a matrix form:

$$\alpha^{-1} \equiv \begin{pmatrix} \alpha_3^{-1} \\ \alpha_2^{-1} \\ \alpha_1^{-1} \end{pmatrix} = \begin{pmatrix} 1 & b_1^3 & b_2^3 & \cdots & b_m^3 \\ 1 & b_1^2 & b_2^2 & \cdots & b_m^2 \\ 1 & b_1^1 & b_2^1 & \cdots & b_m^1 \end{pmatrix} \cdot \begin{pmatrix} \alpha_{GUT} \\ \Delta t_1 \\ \Delta t_2 \\ \vdots \\ \Delta t_m \end{pmatrix} \equiv B_0 \cdot \Delta t$$

- solution dependent on number of intermediate scales m
  - for $m = 2$ system gives a unique solution for scales and α_{GUT}
  - for $m > 2 \rightarrow$ underdetermined system, $m - 2$ free parameters

Pheno Constraints - ν Masses (LNV)

- 3 generations of right-handed neutrino ν^c singlet always present, assumed to live at LR scale $\rightarrow$ seesaw type I
- if Higgs triplet Δ present $\rightarrow$ seesaw type II
- current experimental bound: $m_\nu^{\text{exp}} = \sum m_{\nu_i} \lesssim 0.3$ eV; lower limit from the atmospheric mass splitting $\sqrt{\Delta m^2_{\text{atm}}} \approx 0.05$ eV
- $\rightarrow$ assume a conservative range of the masses

$$0.16 < \frac{m_\nu}{m_\nu^{\text{exp}}} \approx |\lambda_\Delta - y_\nu^2| \left(\frac{2 \times 10^{14} \text{ GeV}}{m_{LR}} \right) < 1$$

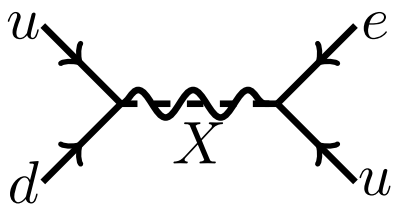
- to generate the light neutrino masses, the LR scale $\approx 10^{14}$ GeV, with couplings $\lambda_\Delta, y_\nu = \mathcal{O}(1)$

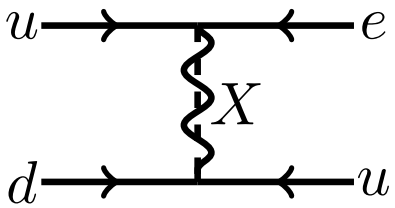
Pheno Constraints - BNV

- proton decay - typically 6D eff. operators - could be mediated by a scalar or a gauge boson and suppressed by M_X^{-2}

	SM	LR	$SO(10)$
gauge	$\{\mathbf{3},\mathbf{2},\text{-}\frac{5}{6}\}$, $\{\mathbf{3},\mathbf{2},\ \frac{1}{6}\}$	$\{\mathbf{3},\mathbf{2},\mathbf{2},\text{-}\frac{2}{3}\}$	$\mathbf{45}$, $\mathbf{54}$
scalar	$\{\mathbf{3},\mathbf{3},\text{-}\frac{1}{3}\}$, $\{\mathbf{3},\mathbf{1},\text{-}\frac{1}{3}\}$	$\{\mathbf{3},\mathbf{3},\mathbf{1},\text{-}\frac{2}{3}\}$, $\{\mathbf{3},\mathbf{1},\mathbf{3},\text{-}\frac{2}{3}\}$	$\mathbf{10}$, $\mathbf{120}$
		$\{\mathbf{3},\mathbf{1},\mathbf{1},\text{-}\frac{2}{3}\}$	$\mathbf{126}$, $\overline{\mathbf{126}}$

- decay channel $p \to e^+\pi^0$ for a gauge or scalar boson mediator X





- estimation of the p decay half-life ($\tau_p^{\text{exp}} > 1.29 \times 10^{34}$ yr):

$$\frac{\tau_p^{\text{gauge}}}{\tau_p^{\text{exp}}} \approx \frac{1}{\alpha_X^2}\left(\frac{M_X}{2.6\times 10^{16}\ \text{GeV}}\right)^4, \quad \frac{\tau_p^{\text{scalar}}}{\tau_p^{\text{exp}}} \approx \frac{1}{\bar{\lambda}^4}\left(\frac{M_X}{7.3\times 10^{15}\ \text{GeV}}\right)^4$$

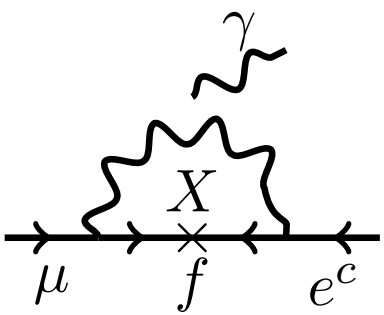
- also $n-\bar{n}$ oscillations - 9D eff. operators - scalar mediators, suppression by M_X^{-6}; less restrictive than proton decay

Pheno Constraints - LFV

- 6D eff. operators - mediated by a scalar or a gauge boson and suppressed by M_X^{-2}
- experimental limits: $\mathcal{B}(\mu \to e\gamma)_{\text{exp}} < 5.7 \times 10^{-13}$

  $\mathcal{B}(\mu \to eee)_{\text{exp}} < 1.0 \times 10^{-12}$

  $\mathcal{B}(\mu N \to eN)_{\text{exp}} < 7 \times 10^{-13}$
- dominant contributions:



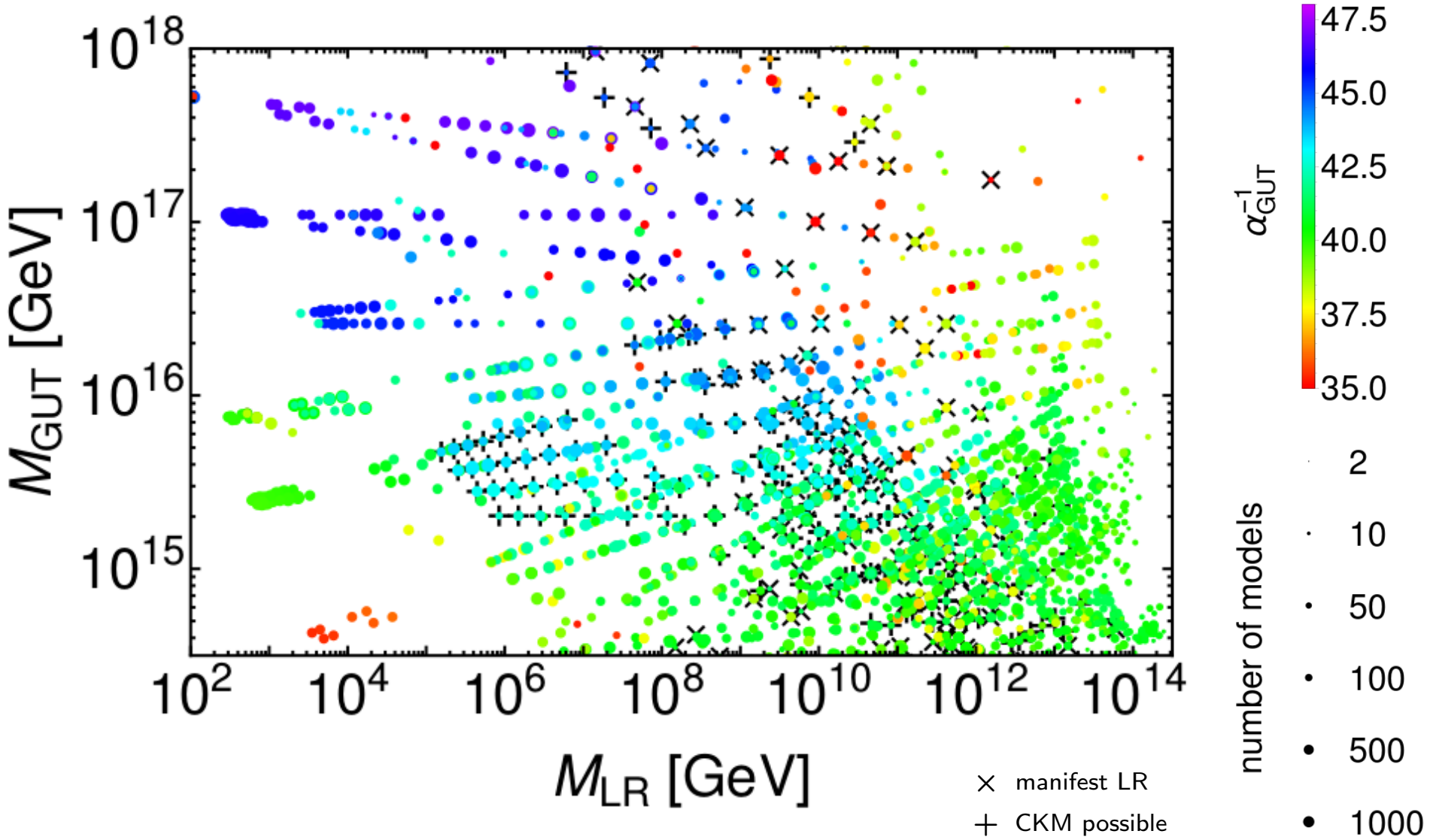
$$\frac{B(\mu \to e\gamma)}{B(\mu \to e\gamma)_{\text{exp}}} \approx |g_{e\mu}|^2 \left(\frac{g_R}{g_L}\right)^4 \left(\frac{2.3 \times 10^4 \text{ GeV}}{M_{LR}}\right)^4$$

$$\frac{B(\mu - e)}{B(\mu - e)_{\text{exp}}} \approx |g_{e\mu}|^2 \left(\frac{g_R}{g_L}\right)^4 \left(\frac{2.1 \times 10^4 \text{ GeV}}{M_{LR}}\right)^4$$

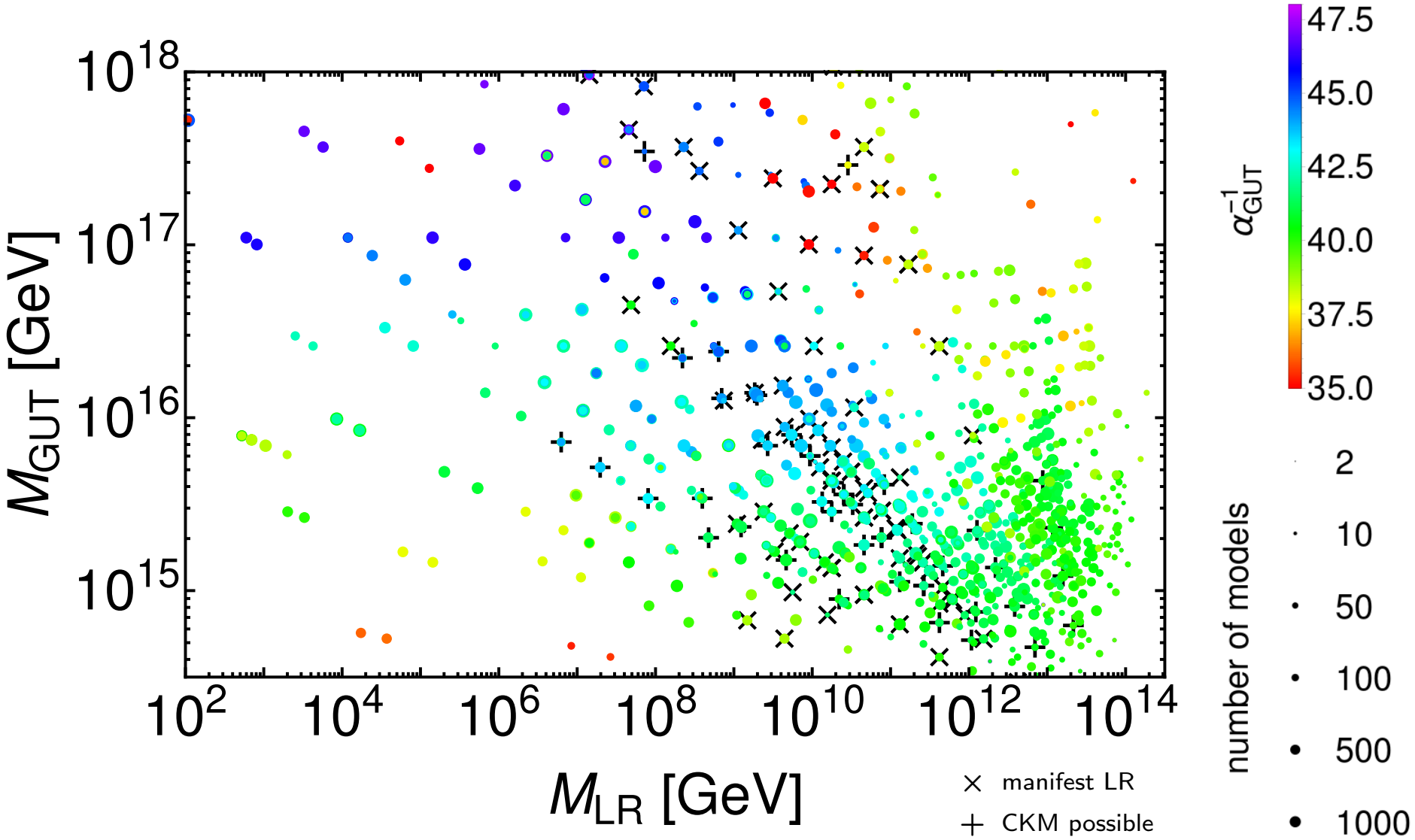
$$\frac{B(\mu \to eee)}{B(\mu \to eee)_{\text{exp}}} \approx |g_{e\mu}|^2 \left(\frac{9.1 \times 10^4 \text{ GeV}}{M_{LR}}\right)^4$$

- $\mu \to e\gamma$ and $\mu - e$ mediated dominantly by W_R
- dominant mediator for $\mu \to eee$ is the triplet Higgs

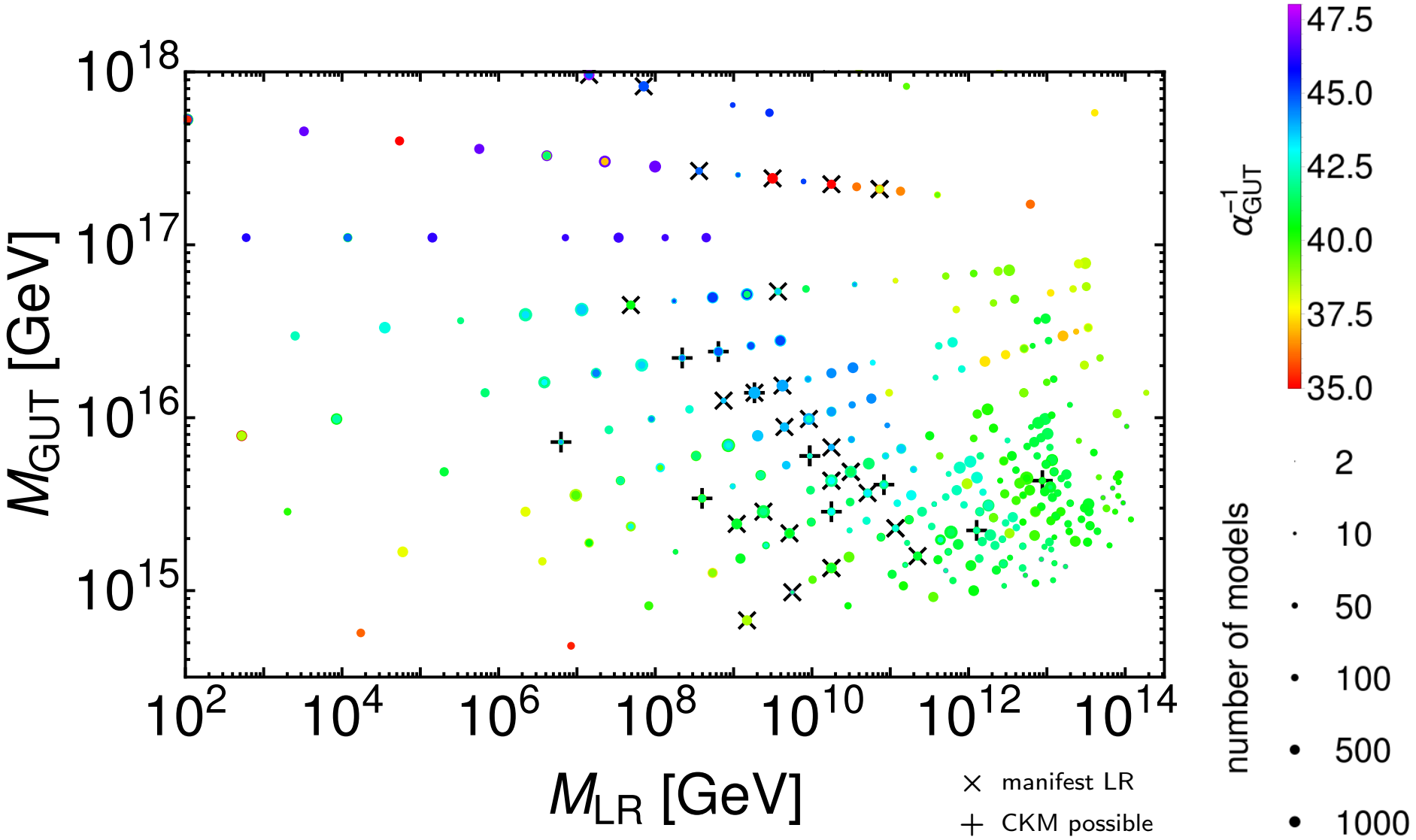
Results - $SO(10) \to$ LR $\to$ SM Models, All



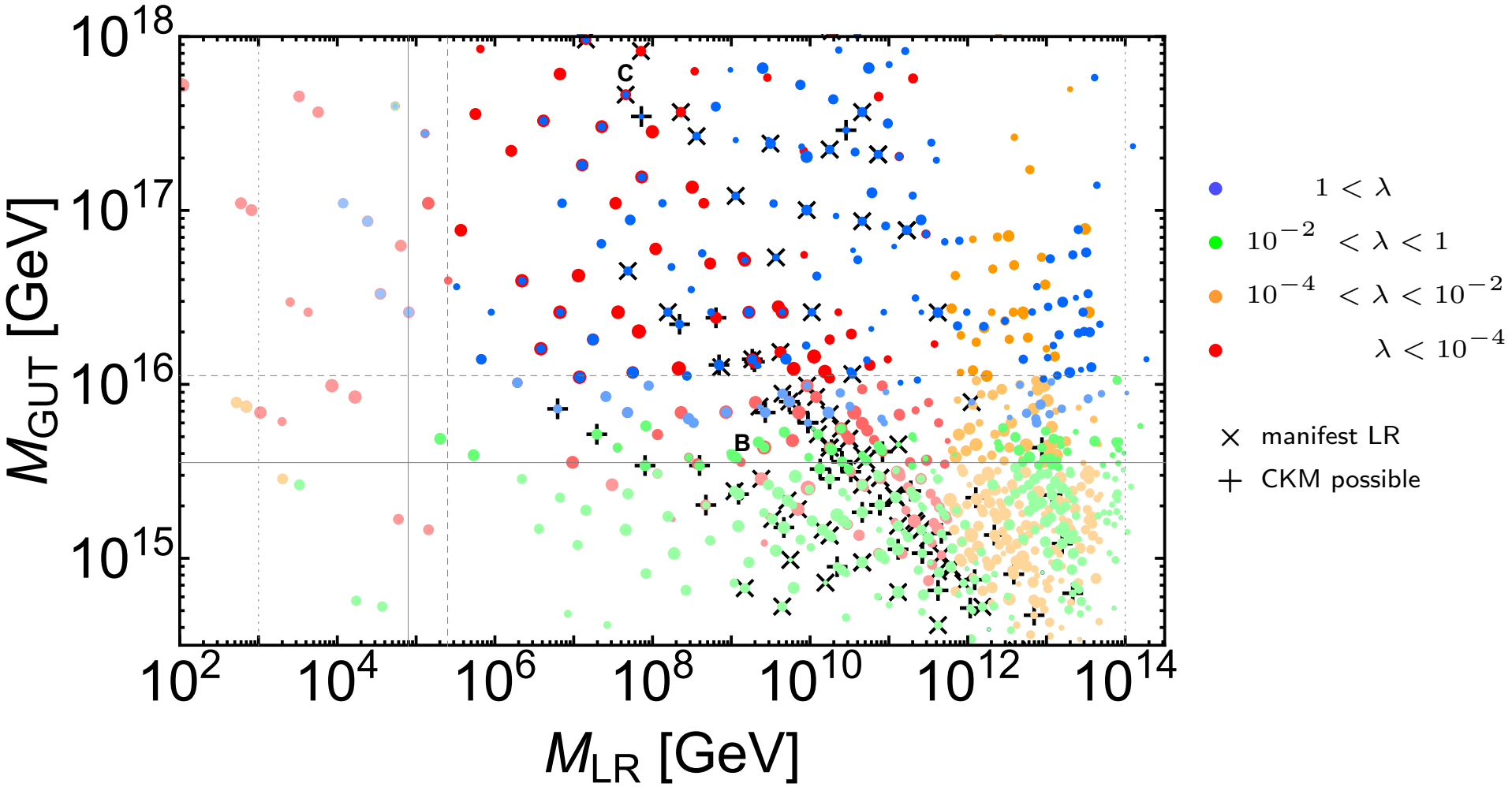
Results - Doublets & Singlets



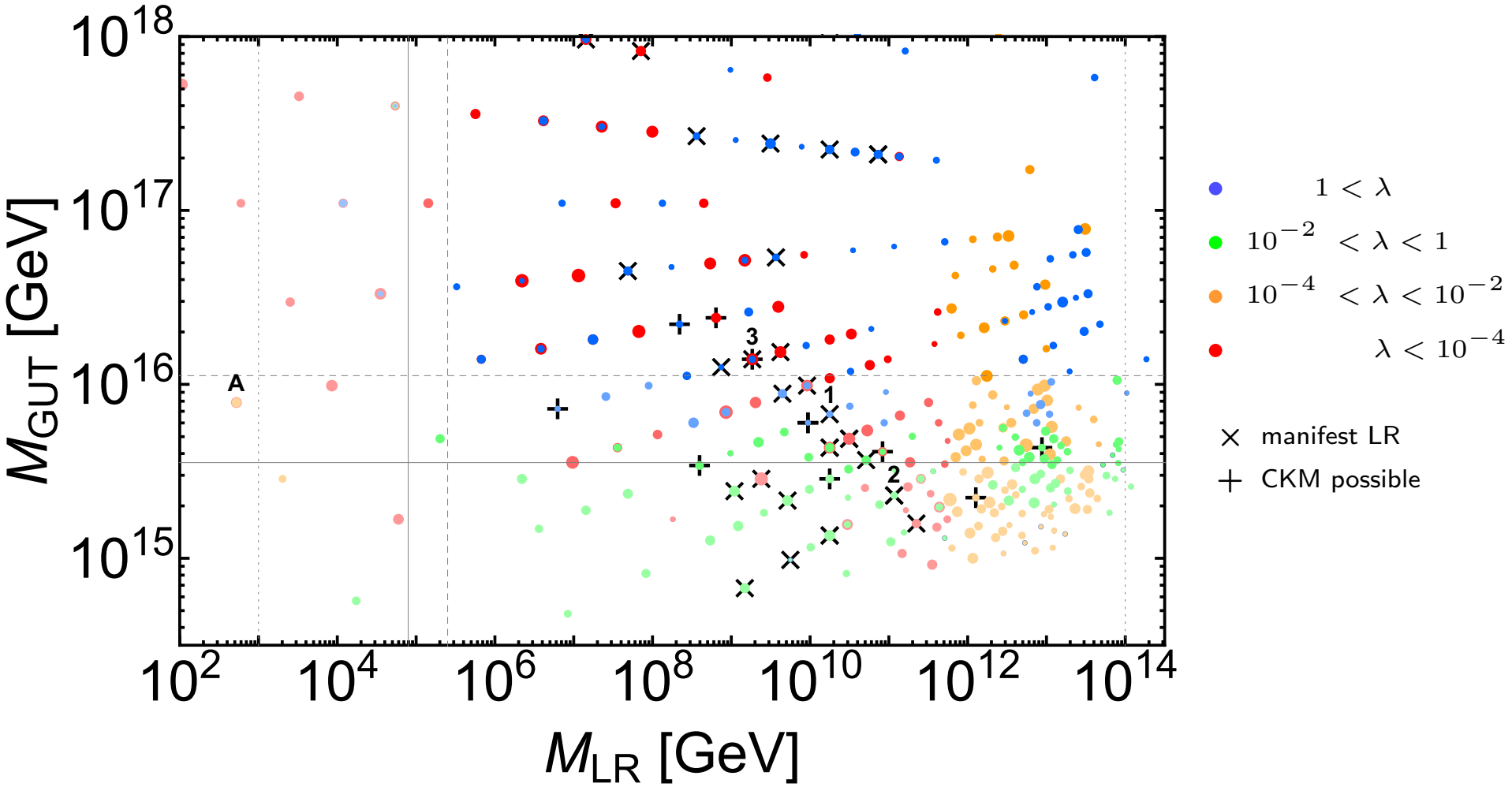
Results - No Exotics



Results - Doublets & Singlets, Constrained



Results - No Exotics, Constrained



Conclusions & Outlook

- a framework generating GUT models in an automated way developed
- aim: scanning through a large model landscapes, considering various symmetry breaking chains and field contents
- procedure applied to $SO(10)$ models with a single intermediate scale respecting the LR symmetry
- experimental bounds applied to the model landscape restricting phenomenologically incompatible scenarios
- note: a rough scan of large model landscape $\implies$ 2-loop contributions to RGEs, threshold corrections as well as model details neglected
- however, described mechanism is universal $\rightarrow$ future plans: application to different types of GUT models, more precise calculations

Thank You for attention!

based on hep-ph/1705.xxxxx, to appear within a few days

Backup Slides

Abelian Breaking

- Abelian breaking of type $U(1)_A \otimes U(1)_B \to U(1)_C$ appears in $SO(10)$

- at scale t_{mix} the boundary condition for the gauge coupling is:

$$\alpha_C^{-1}(t_{mix}) = r_A^2 \alpha_A^{-1}(t_{mix}) + r_B^2 \alpha_B^{-1}(t_{mix}),$$

where $r_{A,B} = Q^v_{A,B} / \sqrt{(Q^v_A)^2 + (Q^v_B)^2}$ such that $r_A^2 + r_B^2 = 1$

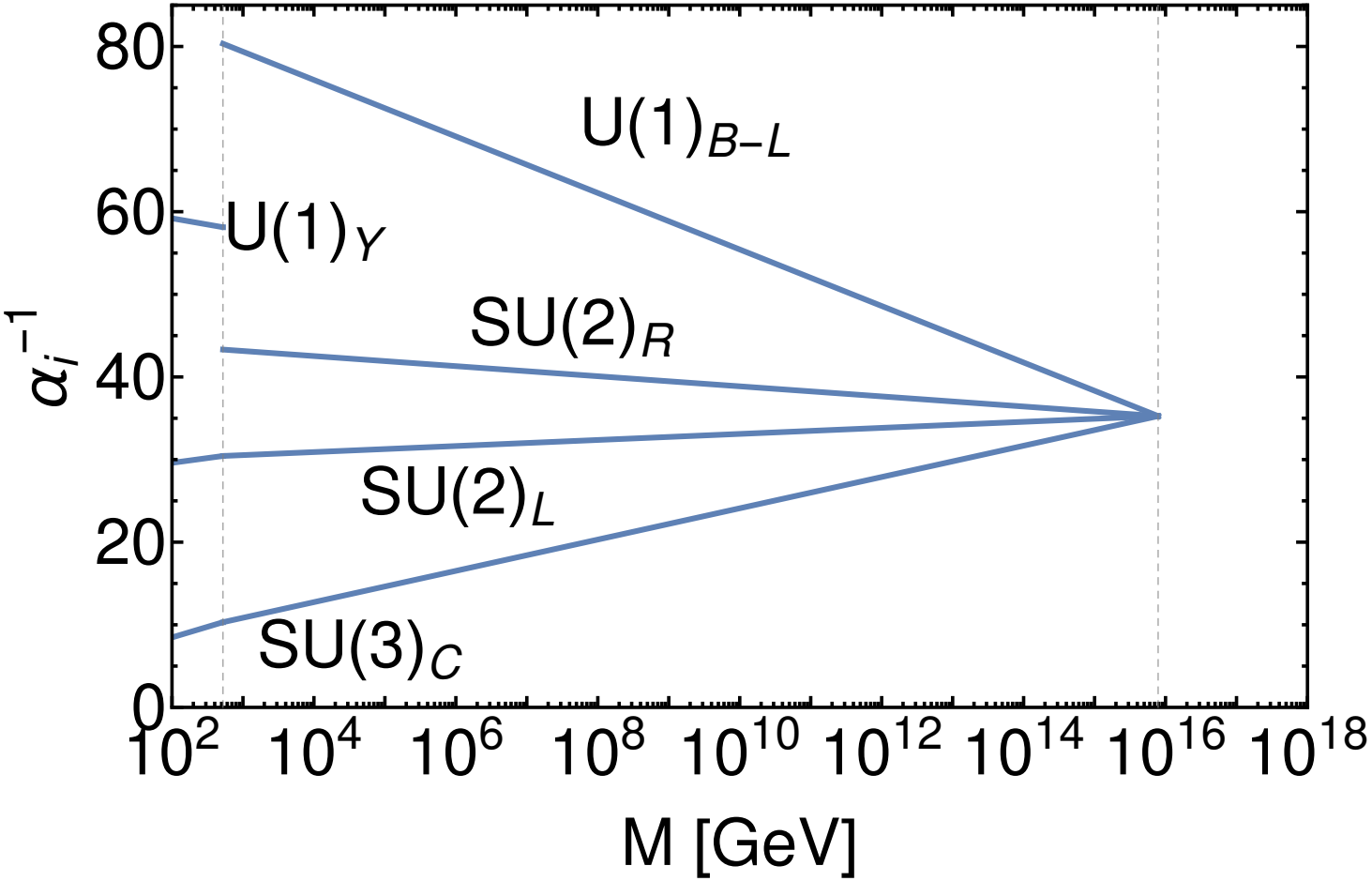
- therefore, the matrix equation takes the form

$$\begin{pmatrix} \alpha_3^{-1} \\ \alpha_2^{-1} \\ \alpha_1^{-1} \end{pmatrix} = (r_A^2 B_A + r_B^2 B_B + B_C) \cdot \Delta t.$$

Model A

$$\mathcal{R}^A_{LR} \supset \{\mathbf{1},\mathbf{2},\mathbf{2},\ 0\},\{\mathbf{3},\mathbf{2},\mathbf{2},\ \tfrac{1}{2}\},\{\bar{\mathbf{3}},\mathbf{2},\mathbf{2},\ 1\},\{\bar{\mathbf{3}},\mathbf{1},\mathbf{3},\text{-}\tfrac{1}{2}\},\{\mathbf{1},\mathbf{1},\mathbf{3},\text{-}\tfrac{3}{2}\}$$

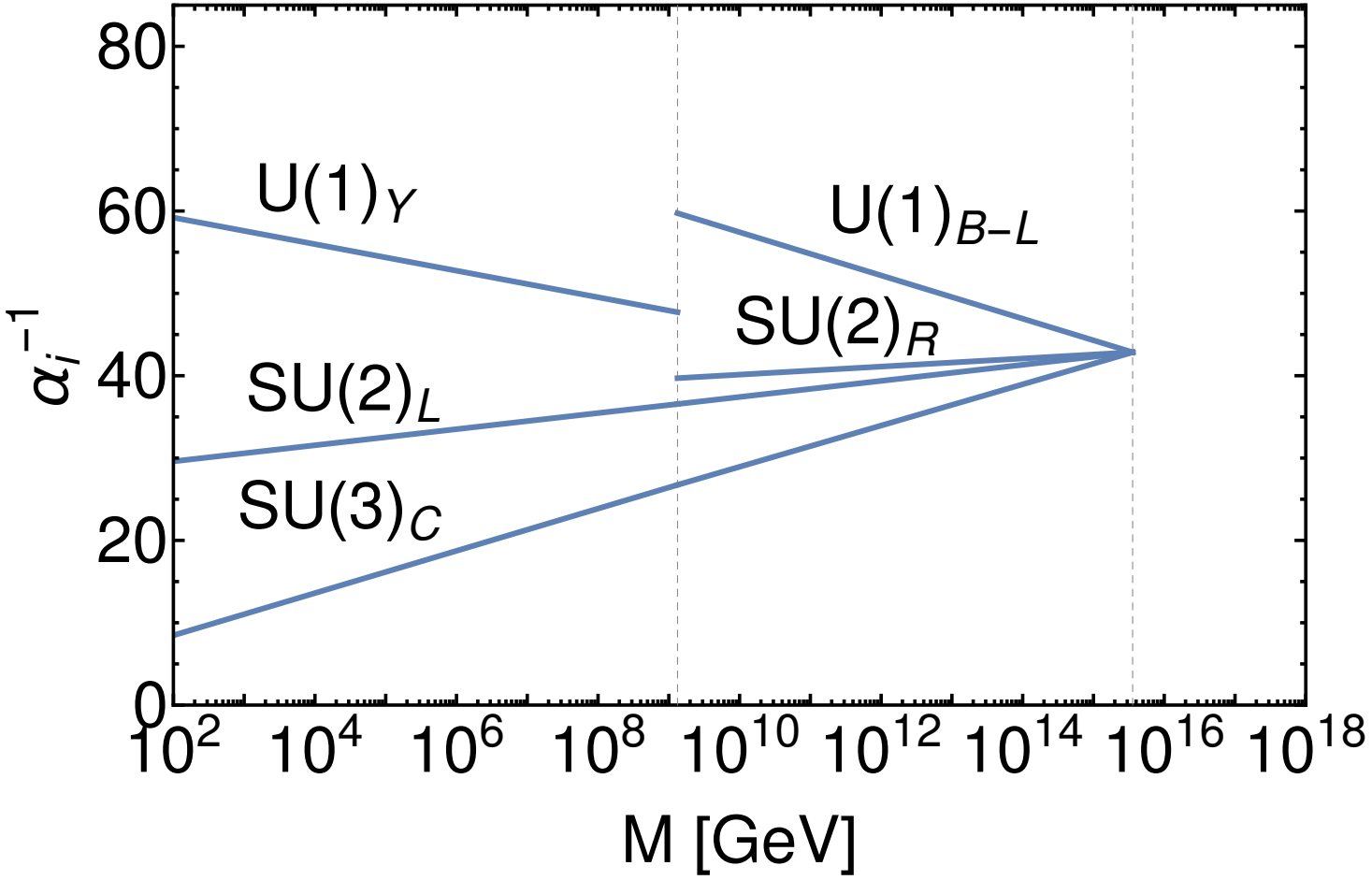
$$\mathcal{R}^A_{SM} \supset \{\mathbf{1},\mathbf{2},\text{-}\tfrac{1}{2}\}$$



Model B

$$\mathcal{R}^B_{LR} \supset \{\mathbf{1},\mathbf{2},\mathbf{2},\ 0\},\{\mathbf{3},\mathbf{2},\mathbf{2},\ \tfrac{1}{2}\},\{\mathbf{1},\mathbf{2},\mathbf{2},\ 0\},\{\mathbf{1},\mathbf{1},\mathbf{3},\text{-}\tfrac{3}{2}\},\{\mathbf{1},\mathbf{1},\mathbf{3},\ \tfrac{3}{2}\}$$

$$\mathcal{R}^B_{SM} \supset \{\mathbf{1},\mathbf{2},\ \tfrac{1}{2}\},\{\mathbf{1},\mathbf{2},\text{-}\tfrac{1}{2}\},\{\mathbf{1},\mathbf{2},\ \tfrac{1}{2}\},\{\mathbf{1},\mathbf{2},\text{-}\tfrac{1}{2}\}$$



Model C

$$\mathcal{R}^C_{LR} \supset \{\mathbf{1},\mathbf{2},\mathbf{2},\ 0\},\{\mathbf{8},\mathbf{1},\mathbf{1},\ 0\},\{\bar{\mathbf{3}},\mathbf{1},\mathbf{1},\ 1\},\{\mathbf{1},\mathbf{1},\mathbf{3},\text{-}\tfrac{3}{2}\}\{\mathbf{1},\mathbf{3},\mathbf{1},\ \tfrac{3}{2}\}$$

$$\mathcal{R}^C_{SM} \supset \{\mathbf{1},\mathbf{2},\text{-}\tfrac{1}{2}\},\{\mathbf{1},\mathbf{2},\ \tfrac{1}{2}\}$$