Quantum Gravity and Grand Unification

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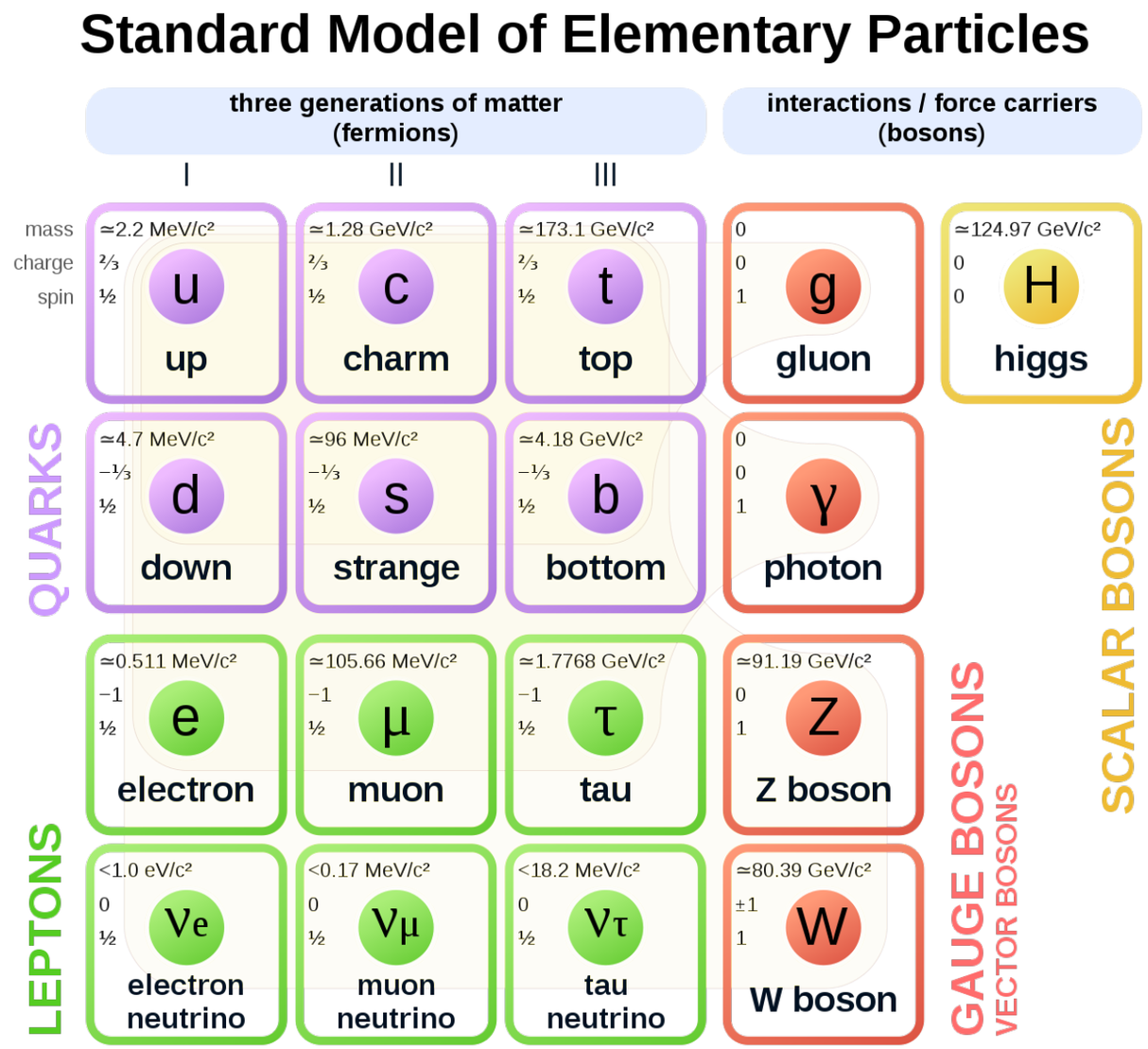
Based on work with A. Held and L. Sartore

Standard Model of Particle Physics

- SU(3)xSU(2)xU(1) symmetry
- Higgs boson
- 19 free parameters



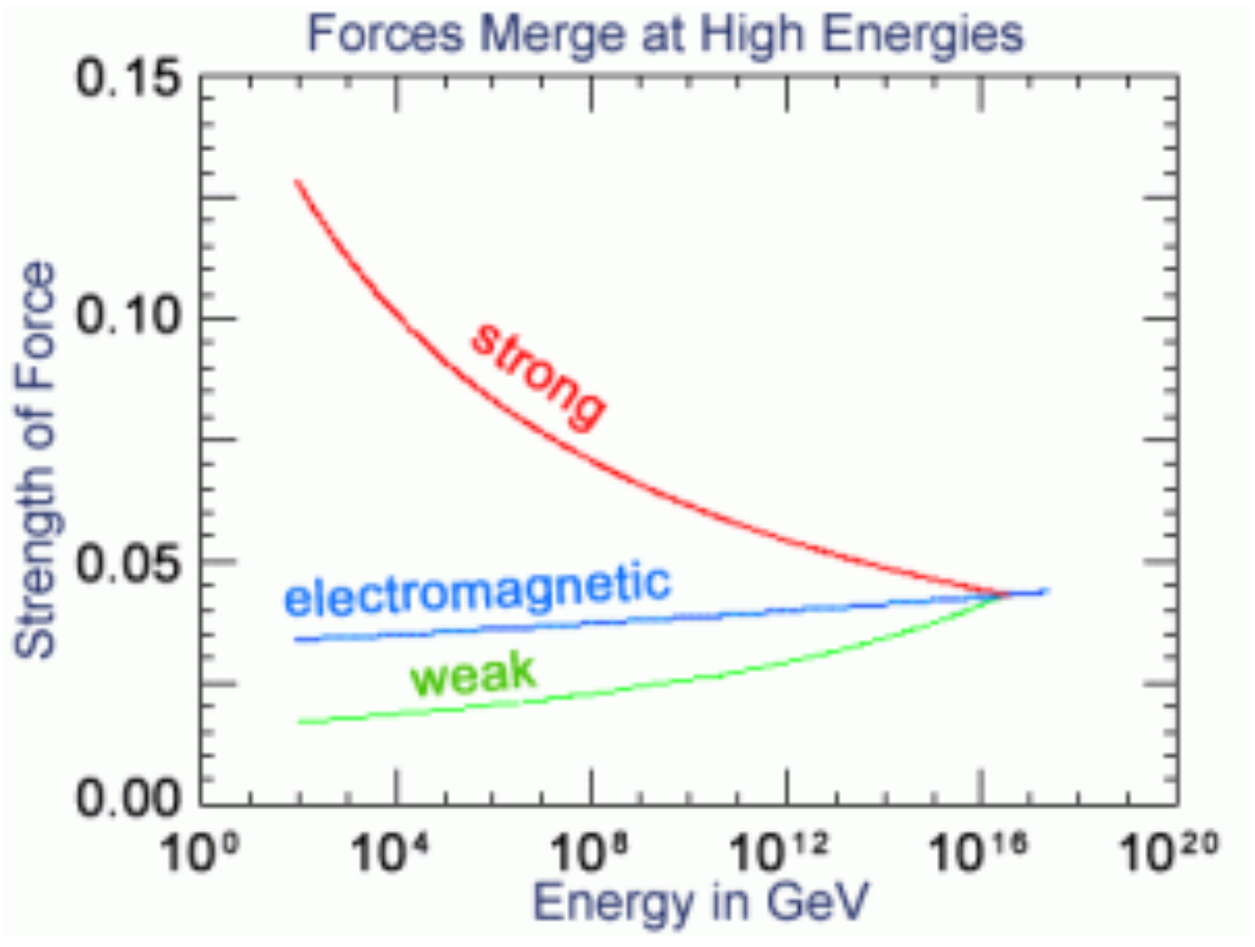
https://live-production.wcms.abc-cdn.net.au/2c70e6d5c36be4979a8f1be0e10d3810?src

How to explain the SM structure ?
Grand Unification

- Renormalisation drive the couplings to the almost equal values in the UV

- Unification provides a more symmetric picture in the higher energies

- Proton decay - highest energy observable



http://www3.fi.mdp.edu.ar/fc3/web_2010_1/Aventura/particle/grand.html

With Grand Unification comes grand number of scalars and couplings

- The Yukawa and gauge couplings are constrained experimentally

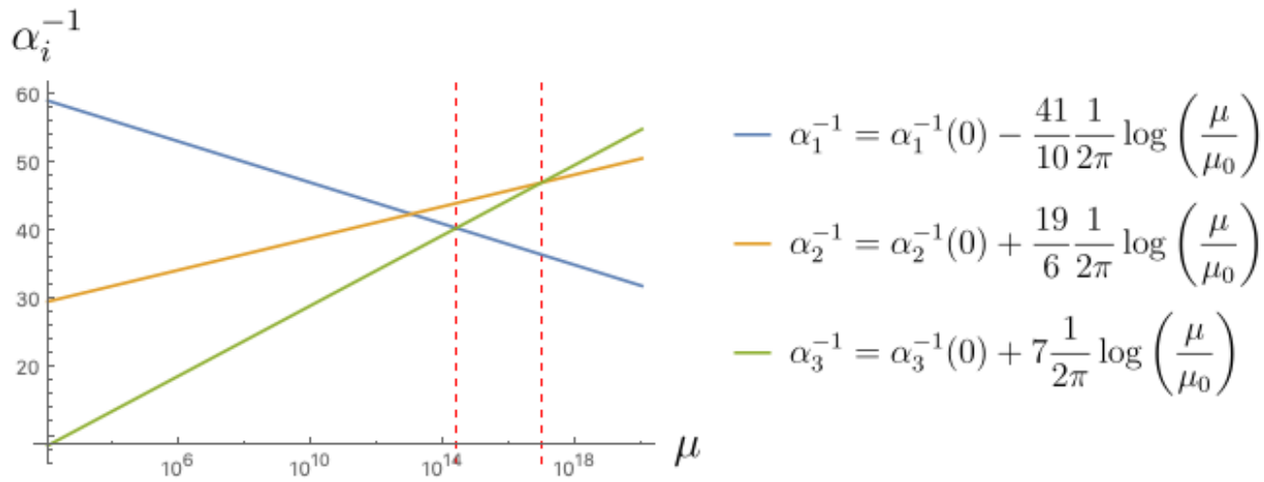
- The Quartic and the masses are not

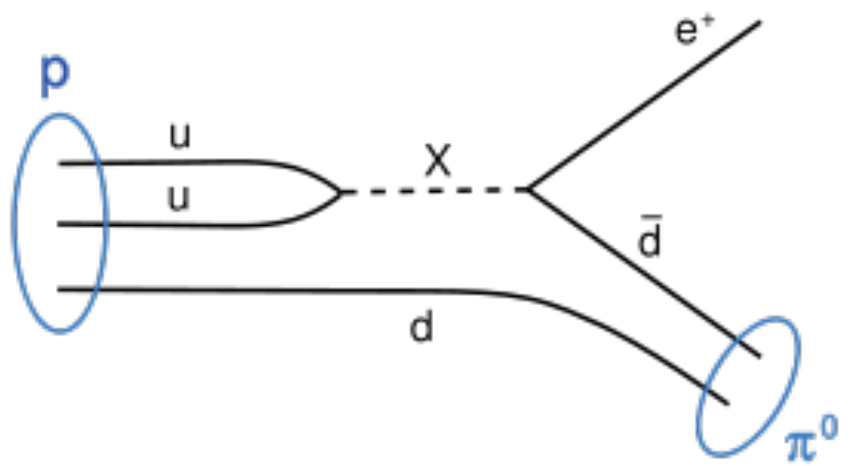
Quantum Gravity is supposed to set the values of the couplings

How big is the set of possible quartic couplings set by quantum gravity realising viable phenomenology ?

Constraints

- Unification of couplings (possibly with thresholds). No one stage breaking.
- Proton decay bounds
- SM as the deepest vacua



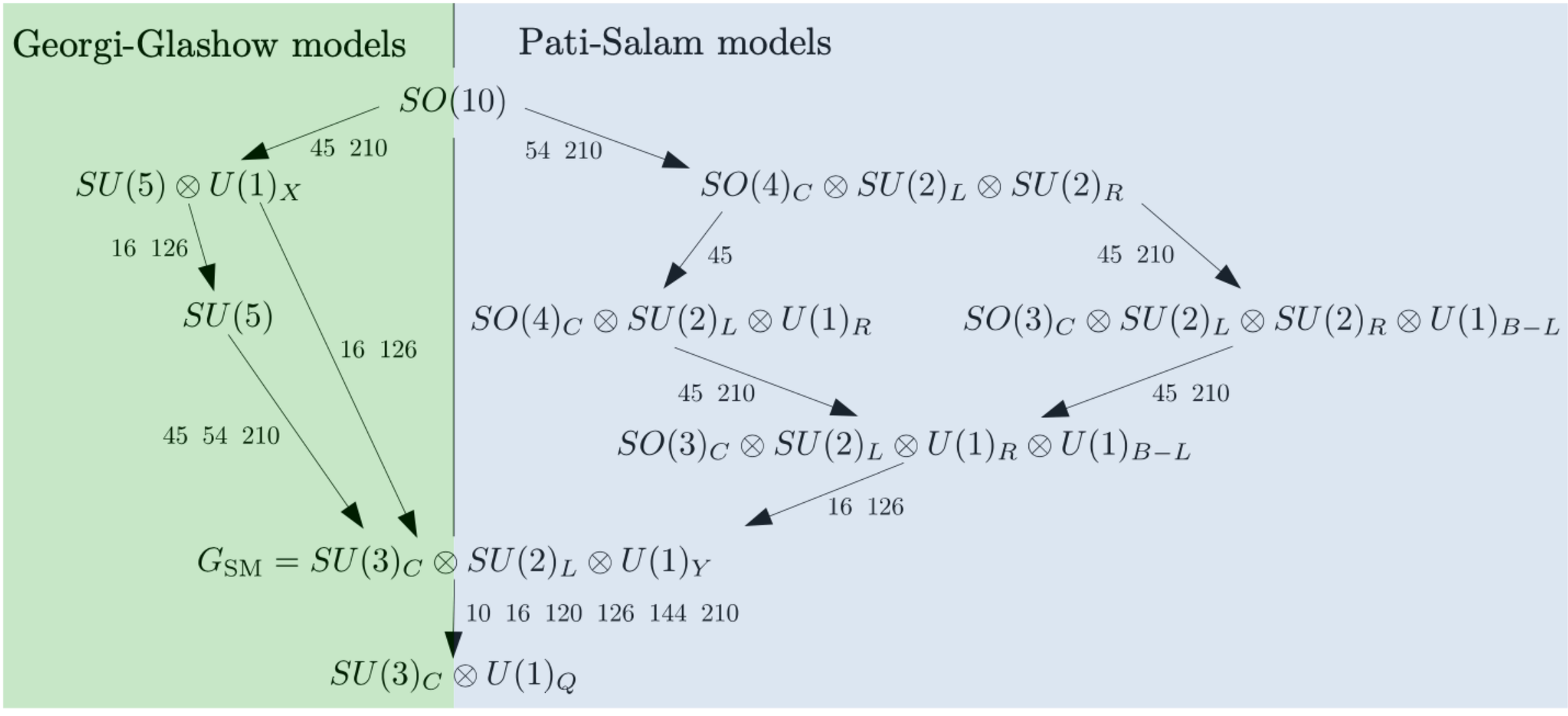


https://adamasuniversity.ac.in/proton-decay-a-candidate-for-finite-age-of-the-universe/

The Model

- $SO(10), \mathbf{16}_F, \mathbf{10}_H \oplus \mathbf{45}_H \oplus \mathbf{16}_H$
- Non-viable Yukawa sector
- Classically conformal
- Coleman-Weinberg breaking
- $\mathbf{45}_H$ appears in the Calabi-Yau compactifications and is NOT coupled to Yukawas
- In principle viable Standard Model breaking direction
- Recently revived - the non $SU(5)$ vacua are possible after quantum corrections
- Four maximal subalgebras

SO(10) possible SM breaking chains



A. Held PhD thesis

The method

- Renormalisation group beta functions PyR@TE 3.00 2007.12700
- Resummation of effective potential
- Exemplary findings for $SU(5)$

$$\beta^{(1)}(\lambda_1) = +32\lambda_1^2 + \frac{188}{5}\lambda_1\lambda_2 + \frac{336}{25}\lambda_2^2 + 10\lambda_4^2 + 4\lambda_4\lambda_5 - 60g^2\lambda_1 + 18g^4$$

$$\beta^{(1)}(\lambda_2) = +12\lambda_1\lambda_2 + \frac{64}{5}\lambda_2^2 + \lambda_5^2 - 60g^2\lambda_2 + 15g^4$$

$$\beta^{(1)}(\lambda_3) = +18\lambda_3^2 + 24\lambda_4^2 + \frac{48}{5}\lambda_4\lambda_5 + \frac{66}{25}\lambda_5^2 - \frac{144}{5}g^2\lambda_3 + \frac{198}{25}g^4$$
$$+16\lambda_3\mathbf{Tr}\left(Y_5Y_5^\dagger\right) + \frac{3}{4}\lambda_3\mathbf{Tr}\left(Y_{10}Y_{10}^*\right) - 16\mathbf{Tr}\left(Y_5Y_5^\dagger Y_5Y_5^\dagger\right)$$

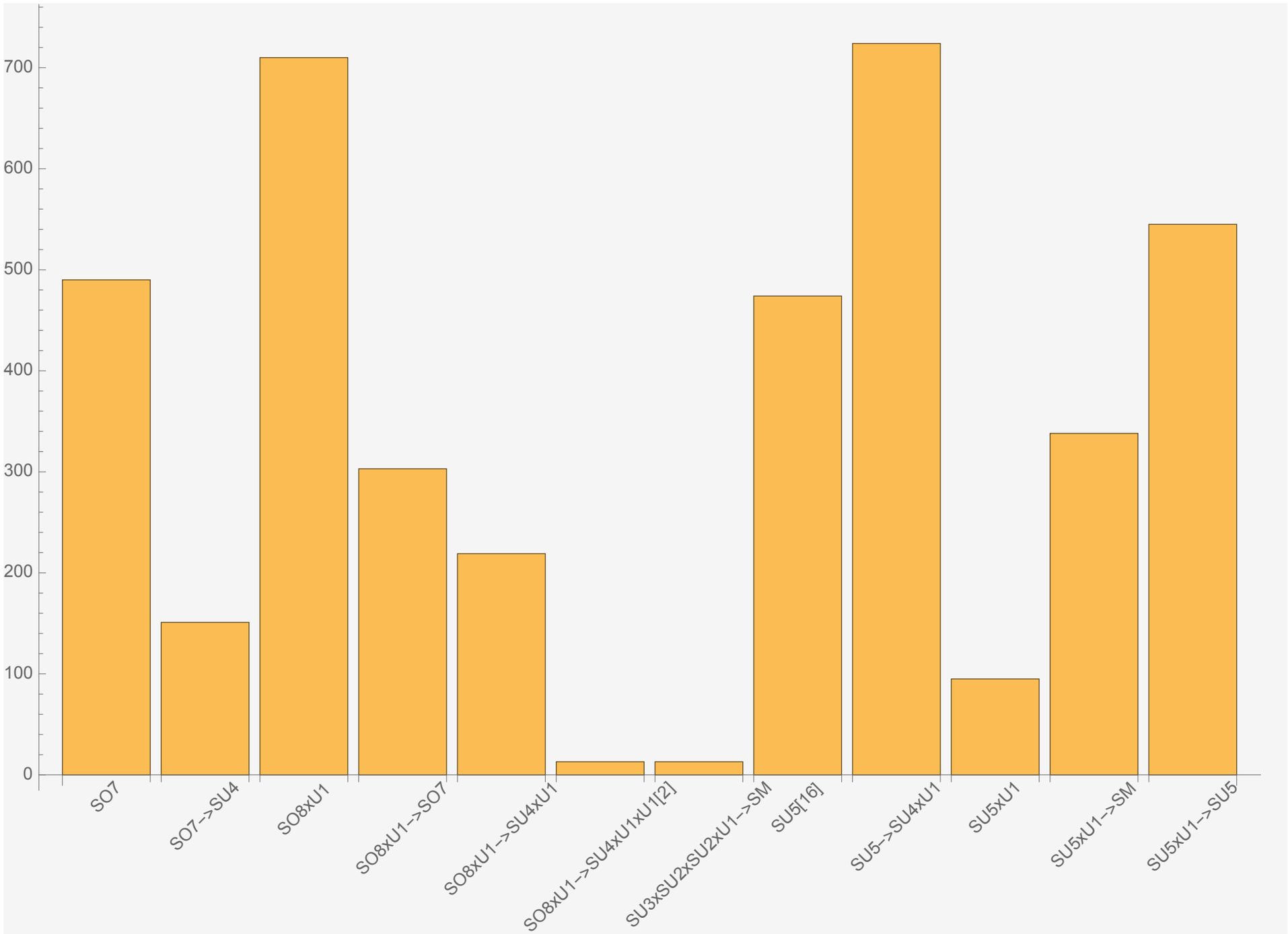
$$\beta^{(1)}(\lambda_4) = +26\lambda_1\lambda_4 + \frac{24}{5}\lambda_1\lambda_5 + \frac{94}{5}\lambda_2\lambda_4 + \frac{56}{25}\lambda_2\lambda_5 + 12\lambda_3\lambda_4 + 2\lambda_3\lambda_5 + 4\lambda_4^2 + \lambda_5^2$$
$$-\frac{222}{5}g^2\lambda_4 + 3g^4 + 8\lambda_4\mathbf{Tr}\left(Y_5Y_5^\dagger\right) + \frac{3}{8}\lambda_4\mathbf{Tr}\left(Y_{10}Y_{10}^*\right)$$

$$\beta^{(1)}(\lambda_5) = +2\lambda_1\lambda_5 + \frac{38}{5}\lambda_2\lambda_5 + 2\lambda_3\lambda_5 + 8\lambda_4\lambda_5 + \frac{21}{5}\lambda_5^2 - \frac{222}{5}g^2\lambda_5 + 15g^4$$
$$+8\lambda_5\mathbf{Tr}\left(Y_5Y_5^\dagger\right) + \frac{3}{8}\lambda_5\mathbf{Tr}\left(Y_{10}Y_{10}^*\right)$$

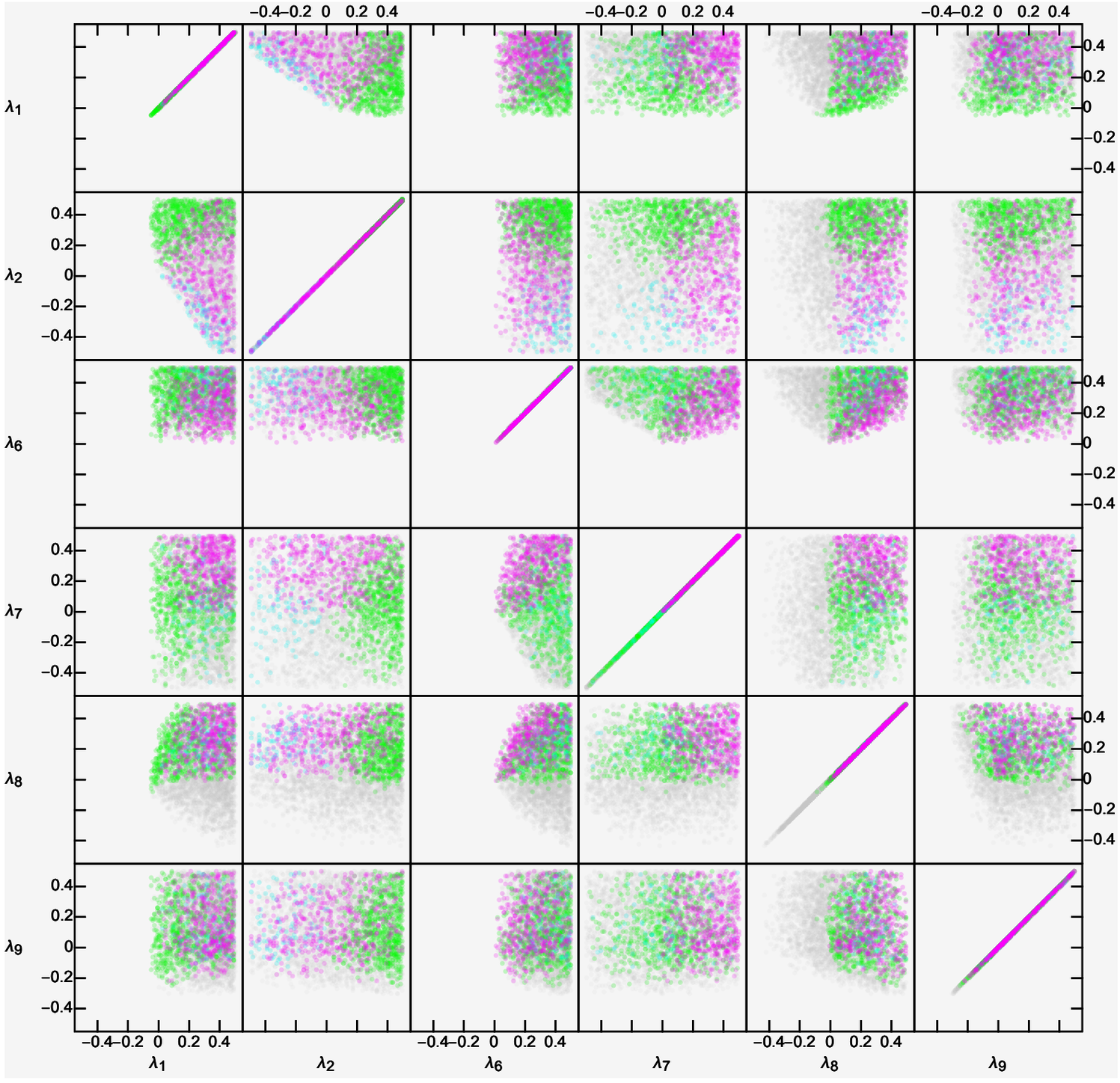
The preliminary findings

- Among the maximal subalgebras (like $SU(5) \times U(1)$, $SO(8) \times U(1)$) The Pati-Salam is disfavoured.
- Two-step breaking at once in favoured.
- Model is either non-viable or require large threshold corrections.
- More constraints can be taken into account such as leptogenesis, neutrino masses, dark matter constraints etc.

Beyond the maximal subalgebras



Parameter space scans



$SO(8) \times U(1)$

$SU(5) \times U(1)$

$SU(5)[16]$

Connection to Asymptotic Safety and String Theory

- In both the scalar quartic couplings are predictions.
- In asymptotic safety the values of couplings stem from their fixed point values.
- There is no stable non-trivial fixed point potential for the studied model in the studied truncation.
- In heterotic string theory those are tied to the gauge coupling of the string gauge group value.

Thank you for your attention!