Different candidates for grand unification theories and comparison of methods to study the first symmetry breaking

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Introduction

Grand Unified theories:

- Electroweak interaction (1960)
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- Unification point at high temperature
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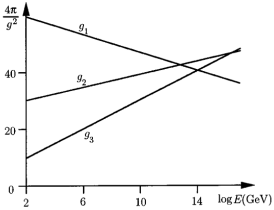

Figure: Visualization of unification point [8].

Introduction

Grand Unified theories:

- Electroweak interaction (1960)
- Unification point at high temperature
- Different candidates (SO(10), SU(5))

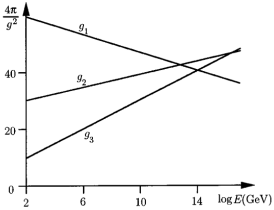

Figure: Visualization of unification point [8].

Coupling constants

In order to observe the unification a short reminder of the Coupling constants from SM.

$$\begin{aligned} \alpha_{em} &= \frac{5}{3}\frac{\alpha}{\cos^2(\Theta_{\overline{MS}})} \\ \alpha_W &= \frac{\alpha}{\sin^2(\Theta_{\overline{MS}})} \\ \alpha_s &= \frac{g_s^2}{4\pi}\,. \end{aligned} \quad (1)$$

Renormalization Group equation

In order to unify those coupling constants a renormalization group equation is tried to be solved [6].

Renormalization Group equation

$$\mu \frac{\partial \Phi}{\partial \mu} = \sum \beta_\alpha \frac{\partial \Phi}{\partial g_\alpha} \tag{2}$$

β_i are the β-functions of g_i with g_i being the coupling constants from the fine-structure constants. In this equation $\Phi(g_1, g_2, ..., g_A)$ is the wanted relation which is able to express all other terms.

Earliest phase transition

Topological defects

At a grand unification different topological defects are likely to have occurred [8].

Defects:

- domain walls
-
-
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Defects:

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- Cosmic strings
- 'textures'

The choice of potential governs the description of the formation of defects.
For cosmological strings the potential in the gauge theory is described by [8]

$$V(\phi) = \frac{1}{2}\lambda(\phi^*\phi - \frac{1}{2}\nu^2)^2 \tag{3}$$

Change into Polar Coordinates.

Topological defects

Cosmic strings

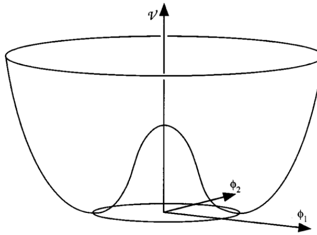

Figure: The scalar field which is considered in the field theory for cosmic strings [7].

Monopoles

Assuming a chain of symmetry breaking intermediate scale monopoles form.

Overclosure

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Monopole density of with applied constraints [5]:

$$n_m = 3 \cdot 10^3 \left(\frac{m_m}{T_R}\right)^3 n_\gamma \exp^{-\frac{2m_m}{T_R}} \quad . \tag{5}$$

Limitations due to Proton lifetime

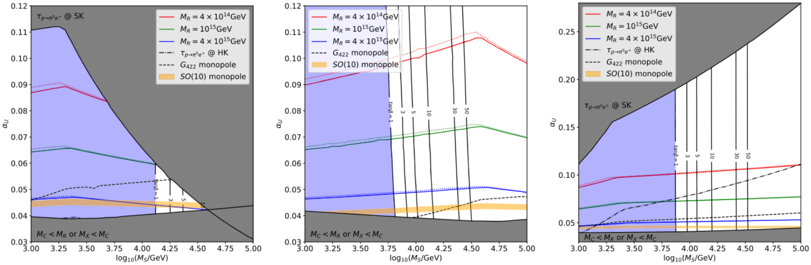


Figure: The limitations for the model parameters arising from the finite proton lifetime in a theory with various colored Higgs multiplets as a plot for M_R from α_U[5]. Left: Without threshold correction for soft masses. Middle: Typical threshold correction at GUT-scale for soft masses. Right: Threshold corrections for split SUSY spectrum with masses of gauginos fixed at 1 TeV.

Unification for MSSM

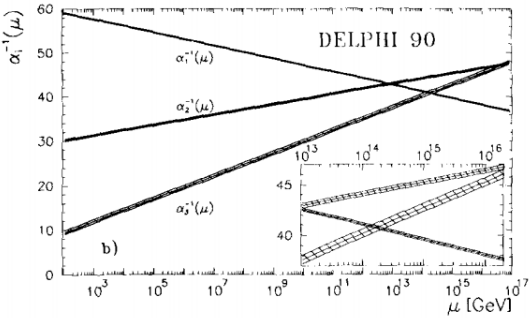


Figure: The evolution of the three coupling constants in the minimal standard model with 3 families and 1 Higgs, with α_1 for the electromagnetic, $_2$ for the weak and α_3 for the strong interaction [1].

Reducing coupling as Test for unification theories

Numerical scheme

Test agreement for Theory Candidates with **Higgs mass prediction** and **CDM relic density experimental limits**

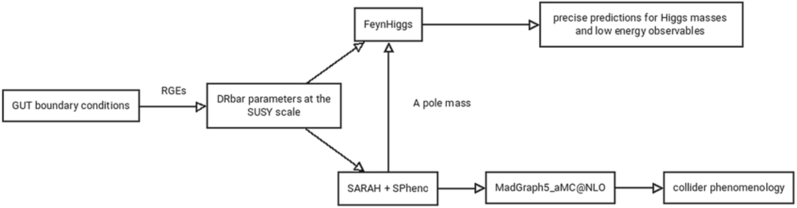
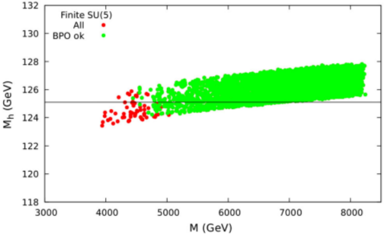


Figure: Example of computer codes used to test multiple candidates for grand unified theories [6].

Reducing coupling as Test for unification theories

Validation via Higgs mass



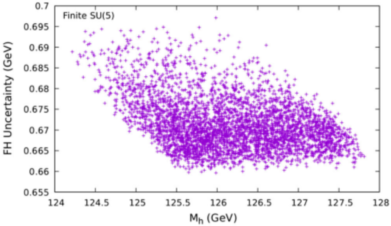


Figure: Left: lightest Higgs mass M_h plotted against mass M, right: theoretical uncertainty of Higgs mass computed with FeynHiggs for the all loop finite N=1 super symmetric model [6].

Electroweak phase transition

Electroweak Interaction:

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-
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Electroweak phase transition

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Electroweak phase transition

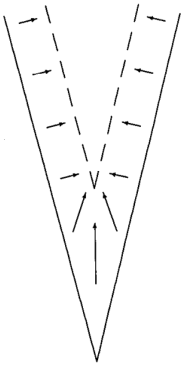

Figure: Representation of collision between two bubbles [3].

Electroweak Interaction:

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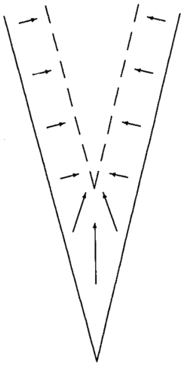
Electroweak phase transition



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Electroweak Interaction:

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- EW Baryogenesis
- Collision   Magnetic fields

Electroweak phase transition

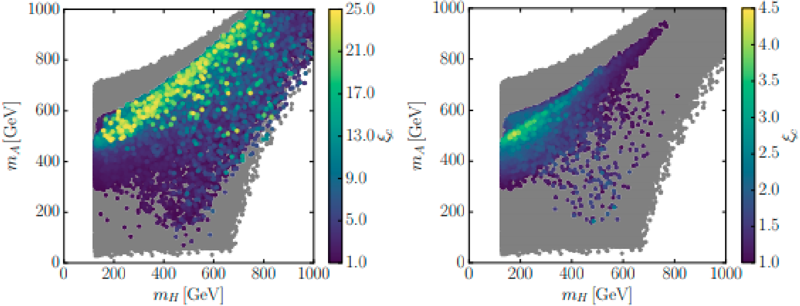

Figure: Result of the theoretical calculation and experimental findings of parameter space shown in a m_A versus m_H plane where m_H indicates the heavier of the two CP-even Higgs bosons identified with the SM-like Higgs boson. Comparison of two different methods to identify the strong first order phase transitions (in color) versus the ones passing all applied constraints (grey). Left panel: 'Parwani' method. Right panel: 'ArnoldEspinosa' method [2]

Conclusion

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  - Magnetic fields
  - Lack of Monopoles
  - Proton Lifetime
  - Dark matter candidate ...
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  - Dark matter candidate ...
- Lot of possible candidates
  $\rightarrow$ Combine experimental data and numerical simulations
- Future experiments are promising

Thank you for listening!

Do you have any questions?

Literature I

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Appendix

Gravitational waves

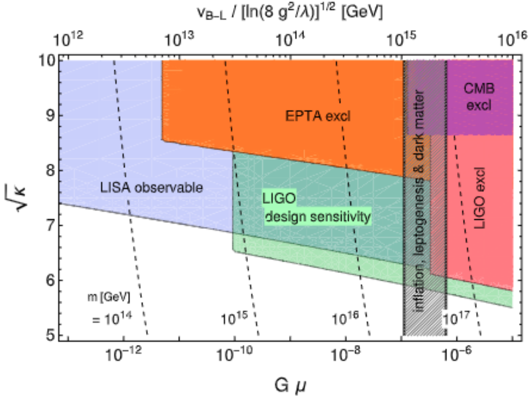

Figure: Limitation from gravitational wave experiments to cosmic string parameters by gravitational waves measuring experiments [4]. G_{μ} describes the dimensionless string tension