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Phenomenology of Physics Beyond the Standard Model

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1. Unity of All Elementary-Particle Forces

Read the pioneering paper by H. Georgi and S. L. Glashow on $SU(5)$ GUT [1].

- What is meant in the paper when stating for the SM: "lepton and hadron anomalies cancel so that the theory of weak and electromagnetic interactions is renormalizable " ? What is meant with anomaly ? What is special about the arrangement of the fermion fields in the SM ?
- According to the authors, what are the main reasons for a Grand Unified Theory ?
- Why can electromagnetic and weak interactions not be unified independently from strong interactions ? What is the solution they propose ? What is the meaning of the sentence: "What we want is not asymptotic freedom but infrared slavery" ?
- How are SM multiplets embedded in the GUT theory proposed ? Why is SU(5) suitable for doing this ? Is the new theory anomaly free ?
- What are the two main predictions of the theory that can be tested experimentally ?

2. Higgs mechanism and SUSY

Consider the Higgs Lagrangian of the standard Model:

$$\mathcal{L}_{Higgs} = |D_\mu \phi|^2 - \mu^2(\phi^\dagger \phi) - \lambda(\phi^\dagger \phi)^2 \tag{1}$$

- What is the condition for ϕ such that it develops a non-zero vacuum expectation value ?
- Looking at the plot in Figure 1 how can SUSY explain the symmetry breaking in the Standard Model ?
- According to the experimental observations, is SUSY a broken symmetry ?

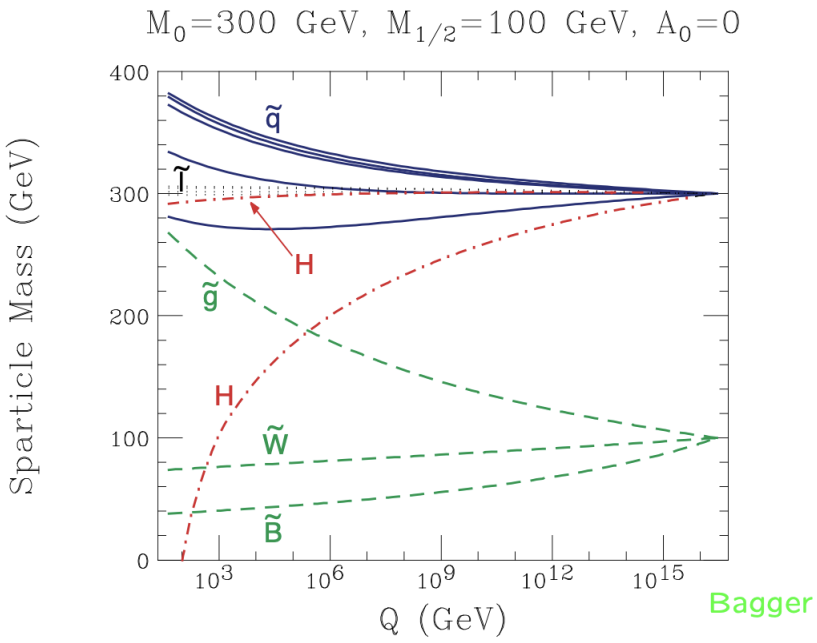


Figure 1: Running of the sparticles masses

3. Massless supermultiplets in $N = 1$ SUSY

Obtain the massless supermultiplets for $N = 1$ Supersymmetry.

- Which condition on the spin of the particles in the supermultiplets is necessary to have a renormalizable theory? And which condition for a consistent theory ? What is the maximum number of states allowed in a supermultiplet ?
- Consider a renormalisable theory, and construct accordingly the supermultiplets starting from the minimum helicity states $\lambda_{min} = -1, -1/2$ applying the creation operators $b^\dagger_{1/2} \propto \bar{Q}_{1/2}$ to the Clifford vacuum $|\lambda_{min}\rangle$ (Hint: don't forget CPT symmetry).
- For a renormalizable theory, which are the states in each supermultiplet ? Would it be possible to choose $\lambda_{min} < -1$?
- Which further supermultiplets do we get if we require the theory to be consistent ? How can we interpret the states appearing in the new supermultiplets ?

References

[1] H. Georgi and S. L. Glashow. "Unity of All Elementary Particle Forces". In: *Phys. Rev. Lett.* 32 (1974), pp. 438–441. DOI: 10.1103/PhysRevLett.32.438.