Probing Features of a Strong First-Order Electroweak Phase Transition in correlation to the Alignment Limit in the Two-Higgs-Doublet Model of Type-I

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Motivation

The baryon asymmetry of the universe (BAU) observed in nature still remains an open problem. Electroweak (EW) baryogenesis is a promising phenomenon that explains the existing matter-antimatter imbalance. Although the experimentally well-established Standard Model (SM) predicts a smooth-crossover for the mechanism of electroweak symmetry breaking, it is rather a weak phase transition that fails to follow non-equilibrium Sakharov conditions necessary for the EW baryogenesis [1].

Analysis

A scalar extension to the SM with a second doublet in the two-Higgs-doublet model (2HDM) [2] is hence very well motivated in the study of the electroweak phase transition. The 2HDM predicts additional heavy scalar degrees of freedom which contribute through loop corrections to the generation of the energy barrier required for the tunnelling of the universe from the false (symmetric) to the true (EW) vacuum state giving rise to a strong first-order electroweak phase transition (SFOEWPT) [3]. We analyse how different parameters influence the occurrence of an SFOEWPT in different parameter regions of the 2HDM of Type-I (where all fermions couple to one of the doublets), taking into account all relevant theoretical and experimental constraints. As early universe is characterised by very high temperatures, so we consider here a finite temperature effective scalar potential which accounts for the zero-temperature Coleman-Weinberg potential and thermal one-loop corrections and daisy resummations [4].

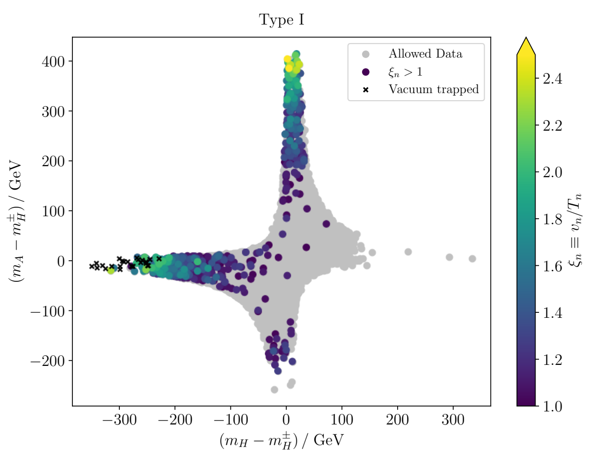

Abbildung 1: The strength of an SFOEWPT featured in the mass splitting plane $(m_A - m_{H^\pm}, m_H - m_{H^\pm})$ for our scanned parameter scan.

Two important mass configurations $m_A = m_{H^\pm}$ and $m_H = m_{H^\pm}$ trigger an SFOEWPT as shown in Figure 1, mainly constrained by electroweak precision observables. The higher the mass splittings, stronger the transitions induced. Probing in correlation to the alignment limit with respect to mass of the CP-even heavy Higgs boson, m_H, we observe for higher values of the m_H, the SFOEWPT is featured in the limit $\cos(\beta - \alpha) \to 0$ where the broken vacuum aligns with the lighter CP-even state h which behaves as $h_{SM} \approx 125$ GeV in this limit. On the other hand, for lower m_H values, the SFOEWPT occurs for larger deviations from the alignment limit where the electroweak symmetry breaking occurs in a non-SM like vacuum direction.

It is interesting to observe that transitions in the low mass region are relatively stronger than in the high mass region. Qualitatively analysing the two cases, strongest transitions are induced close to the alignment limit for higher masses compared to lower masses. As thermal corrections work on the zero-temperature potential in the high-temperature expansion, studying its depth can be useful in terms of our investigation of an SFOEWPT. A shallower potential favours easier barrier formation and therefore favours stronger transitions. We study the uplifted 2HDM vacuum with respect to the vacuum energy in the SM (for description, see Ref.[5]) and find that the amount of vacuum upliftment is correlated to the strength of the transition.

Outlook

The results show a strong possibility of an SFOEWPT within 2HDM of Type-I and we expect similar observation in Type-II in which case the parameter space is more stringently constrained. As our future outlook, it is also interesting to study the prospects of gravitational wave detection in future observatories.

References:

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