Higgs physics as a window to the electroweak epoch

The electroweak symmetry in the early universe in multi-Higgs models

Based on 2209.xxxxx (appearing TOMORROW)

in collaboration with T. Biekötter, S. Heinemeyer, J. M. No and G. Weiglein

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HELMHOLTZ

DESY.

Introduction

Motivation

- Earliest stage of the Universe experimentally probed to date:
  BBN (180 s after the Big Bang)

- Theoretical extrapolation for epochs prior to BBN increasingly uncertain in light of the shortcomings of the SM:
  - Baryon asymmetry of the Universe (BAU), DM nature, neutrino masses, quantum gravity

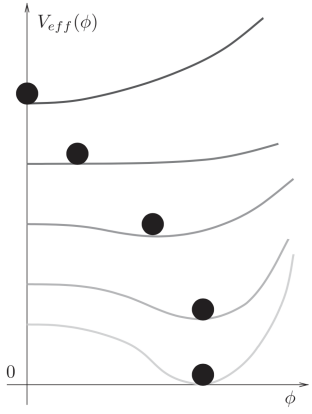
- Collider measurements + cosmological observations:
  hints on the BSM model realised in nature

- **Focus of this work**: Cosmological evolution of the vacuum structure at $T \sim O(100\,\mathrm{GeV})$
  in the CP-conserving 2HDM
  - Electroweak phase transition (EWPT)
  - More exotic phenomena such as EW symmetry non-restoration (EW SnR)

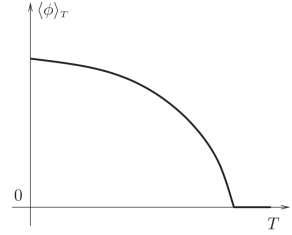
Thermal effects and thermal evolution

The EWPT in the SM

$$V_{eff}(\phi) = V_{tree}(\phi) + V_{loop}(\phi, T)$$



- Broken EW symmetry at $T = 0$ with $\langle\phi\rangle = v$
- Unbroken EW symmetry at $T \gtrsim v$
- Crossover transition at $T \sim v$
- No EW baryogenesis

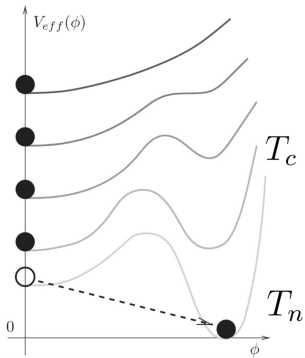


Additional scalars might change this picture!

[Images by D. Gorbunov, V. Rubakov]

Thermal effects and thermal evolution

The first-order electroweak phase transition



First-order EWPT (FOEWPT)

Specially well-motivated scenario:

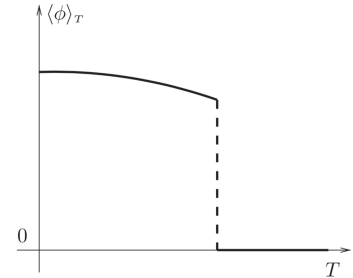
> EW baryogenesis

> New physics at the EW scale

> GW production

A hierarchical spectrum among the scalar masses in the 2HDM facilitates a FOEWPT,
i.e. $m_A \sim m_{H^\pm} > m_H$
$\rightarrow$ smoking gun signature $A \rightarrow Z\,H$

[G. Dorsch, S. Huber, K. Mimasu, J. No, hep-ph/1405.5537]



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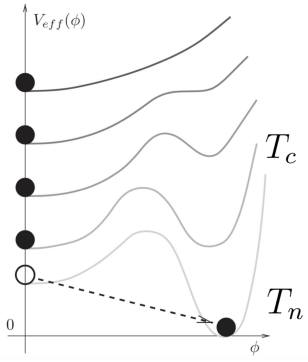

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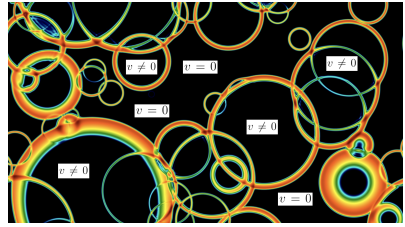
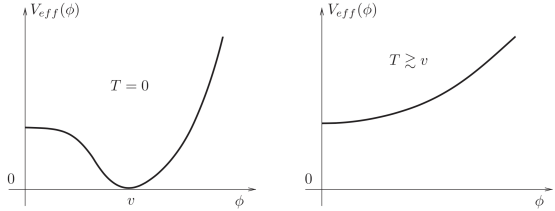


[Image by D. Weir]

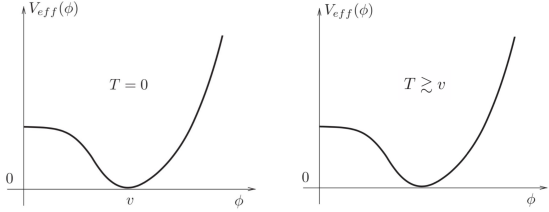
Thermal effects and thermal evolution

Electroweak symmetry non-restoration

EW symmetry restoration at high-temperature



EW symmetry **non**-restoration at high-temperature



Weinberg (1974)
Baldes, Servant (2018)
Glioti, Rattazzi, Vecchi (2018)
Meade, Ramani (2018)

[Images by D. Gorbunov, V. Rubakov]

Results

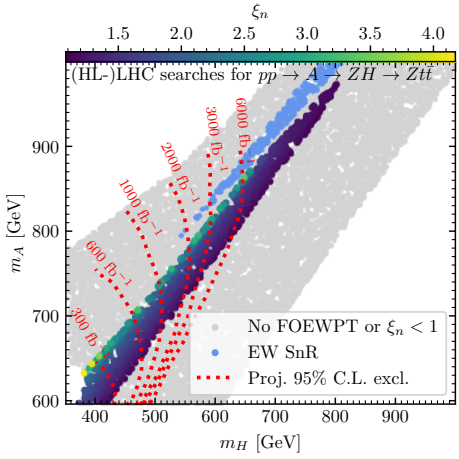
Future probes of the thermal history: the smoking gun signature

[T. Biekötter, S. Heinemeyer, J.M. No, MOOR, G. Weiglein, tbp]

2HDM type II: Alignment limit, $\tan\beta = 3$, $m_H < m_A$, $600\,\text{GeV} < m_A = m_{H^\pm} < 1000\,\text{GeV}$

- Mass of H above the di-top threshold → most promising search $A \to ZH \to Z(t\bar{t})$
- Existing searches for $A \to ZH$ with $Z(b\bar{b})$ and $Z(\tau\tau)$ final states at $\sqrt{s} = 8\,\text{TeV}$ and $13\,\text{TeV}$
- Preliminary results by CMS on the $A \to ZH \to (\mu\mu)(t\bar{t})$ search at $\sqrt{s} = 13\,\text{TeV}$ and $41\,\text{fb}^{-1}$ integrated luminosity → naive rescaling to projected luminosities during the **LHC Run 3** and **HL-LHC** operation

$\xi_n := v_n/T_n$: strength of the FOEWPT

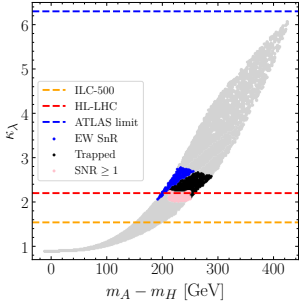


Future probes of the thermal history: the triple Higgs self-coupling

[T. Biekötter, S. Heinemeyer, J.M. No, MOOR, G. Weiglein, tbp]

2HDM type II: Alignment limit, $\tan\beta = 3$, $m_H < m_A$, $600\,\text{GeV} < m_A = m_{H^\pm} < 1000\,\text{GeV}$

Colliders: HL-LHC, ILC-500

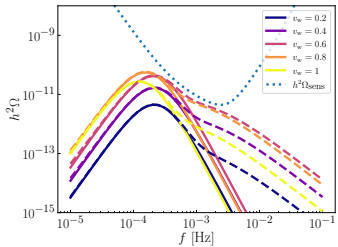


$$\kappa_\lambda := \lambda_{hhh}/\lambda_{hhh}^{\text{SM}}$$

SNR: LISA Signal-to-noise ratio of GW signal

SnR: Symmetry non-restoration

GW signals from FOEWPT: LISA



$$h^2\Omega_{\text{GW}}(f) = h^2\Omega_{\text{sw}}(f) + h^2\Omega_{\text{turb}}(f)$$

SNR $= \mathcal{O}(10 \ldots 100)$

depending on v_w: Bubble-wall velocity

Conclusions

Conclusions

- Multi-Higgs models such as the 2HDM present a **rich variety** of patterns in the evolution of the vacuum configuration
  - **EW SnR**: less explored thermal history of the Universe with related interesting phenomena (high-scale baryogenesis...)
- Scenarios in extended Higgs sectors relying on a hierarchical spectrum to trigger a FOEWPT will be probed in the upcoming years by means of collider measurements, in particular:
  - The smoking gun signature $A \to ZH$
  - Measurements of the trilinear Higgs self-coupling κ_λ
- Absence of any indications for new-physics at the LHC (in particular during the HL-LHC phase) puts severe limitations on the prospects of a detection of a GW background at LISA within the 2HDM

Thank you!

Contact

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