Universität Hamburg
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CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

DESY.

# Higgs area, Higgs phenomenology

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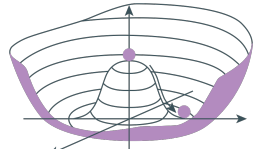
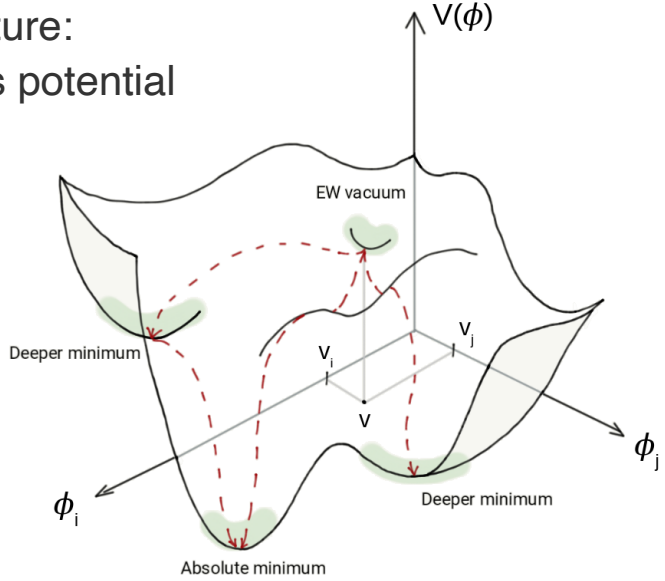
Quantum Universe Attract.Workshop, 11/2025

# H.1: Higgs potential



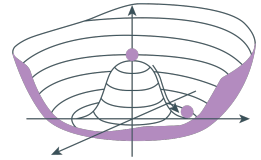
Determine the form of the Higgs potential that is realised in nature:
trilinear and quartic Higgs self-couplings, structure of the Higgs potential




Derive the implications of the Higgs sector for the evolution of the early universe

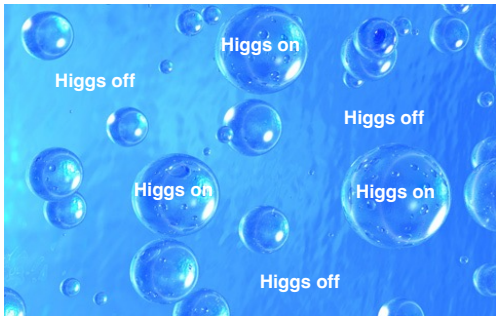
- Nature of the electroweak phase transition (EWPT)
- Stability of the vacuum
- Asymmetry between matter and anti-matter in the universe
- Inflationary phase in the early universe

# Implications for the early universe

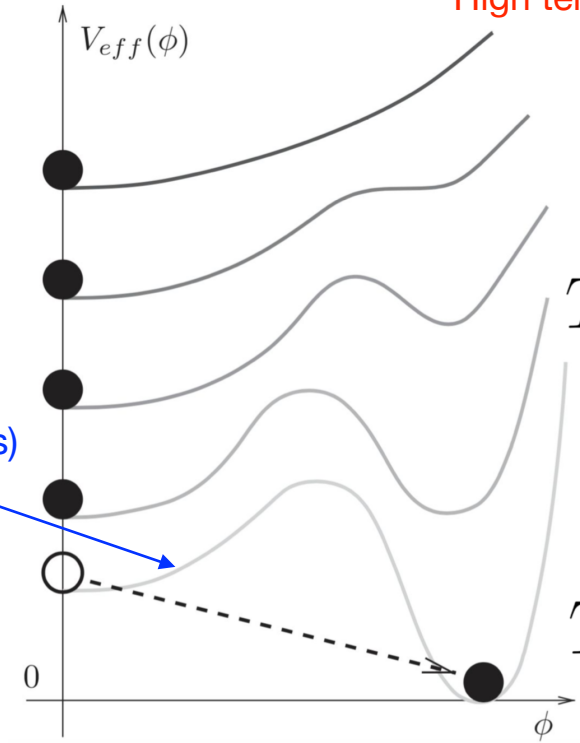


Temperature evolution of the Higgs potential in the early universe:

$$V(\phi, T) = V_0(\phi) + V^{loop}(\phi, T)$$




High temperature



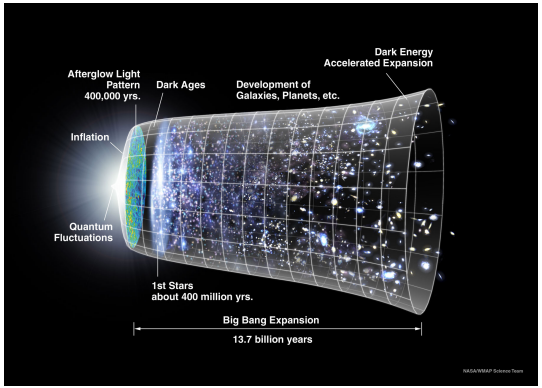

Critical temperature (degenerate minima)

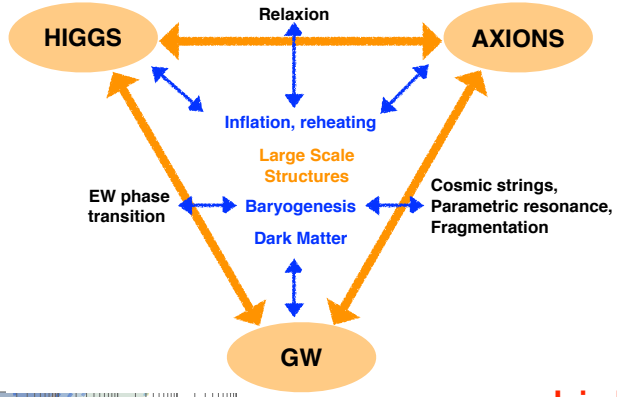
Transition temperature (strong first-order EWPT)

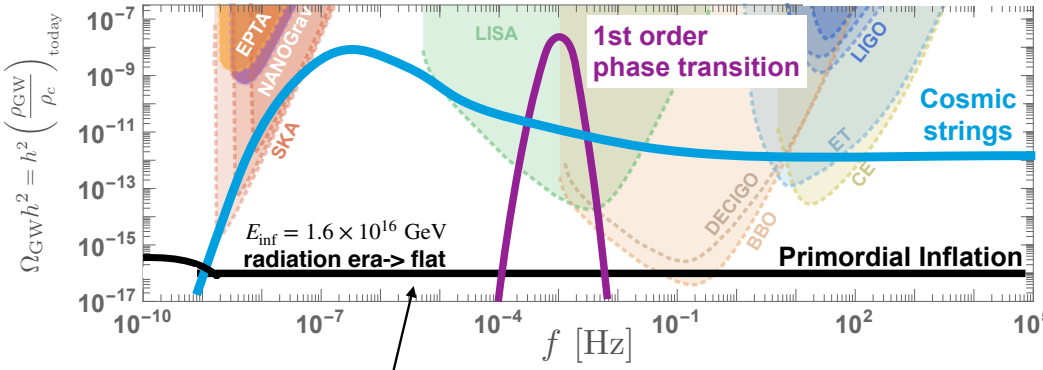
Potential barrier depends on trilinear Higgs coupling(s)

Baryogenesis: creation of the asymmetry between matter and antimatter in the universe requires strong first-order EWPT

# Implications for the early universe



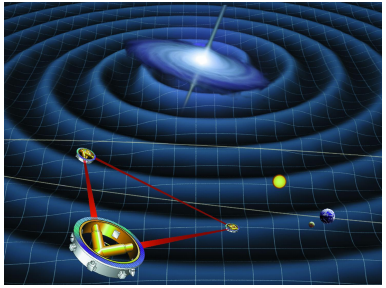



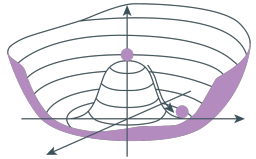

**Irreducible GW background from amplification of initial quantum fluctuations of the gravitational field**

Links to GW and DM areas of the cluster!

LISA:

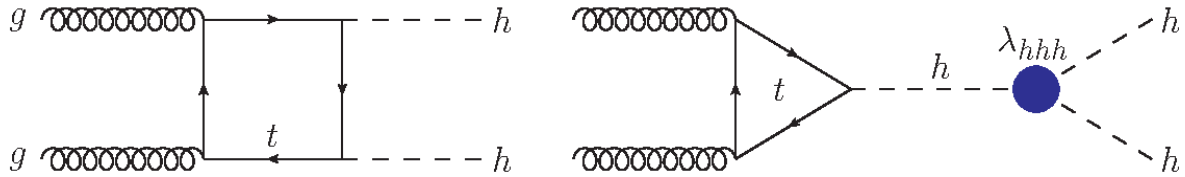


# Experimental access to the Higgs potential



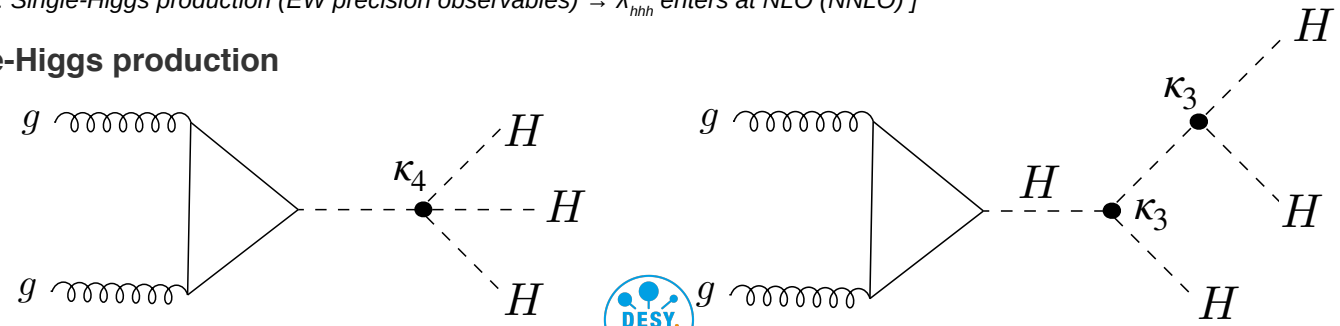
Access to triple and quartic couplings of $h_{125}$ entering the Higgs potential via di-Higgs and triple Higgs production processes at the LHC

**Double-Higgs production** → $\lambda_{hhh}$ enters at LO → **most direct probe of $\lambda_{hhh}$**

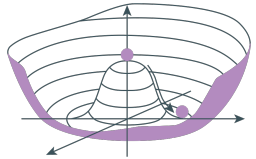



*[ Note: Single-Higgs production (EW precision observables) → $\lambda_{hhh}$ enters at NLO (NNLO) ]*

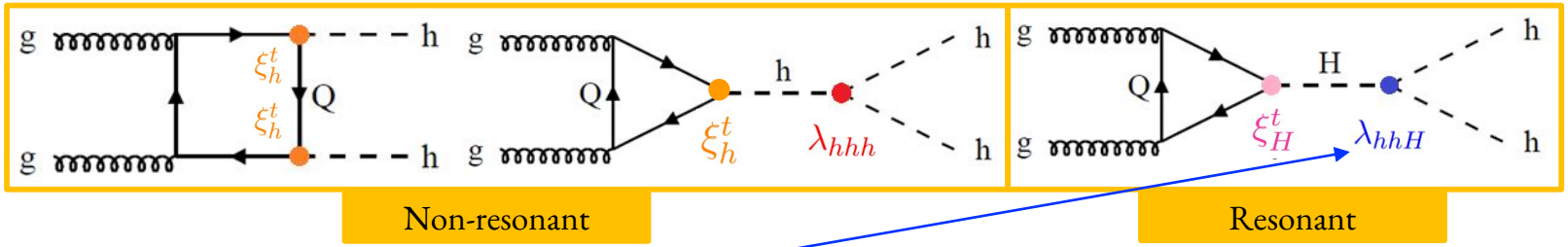
**Triple-Higgs production**



# Contribution of extra fields to the Higgs potential



Experimental access e.g. via resonant di-Higgs production

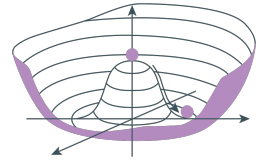



Additional trilinear Higgs coupling contributing to the Higgs potential

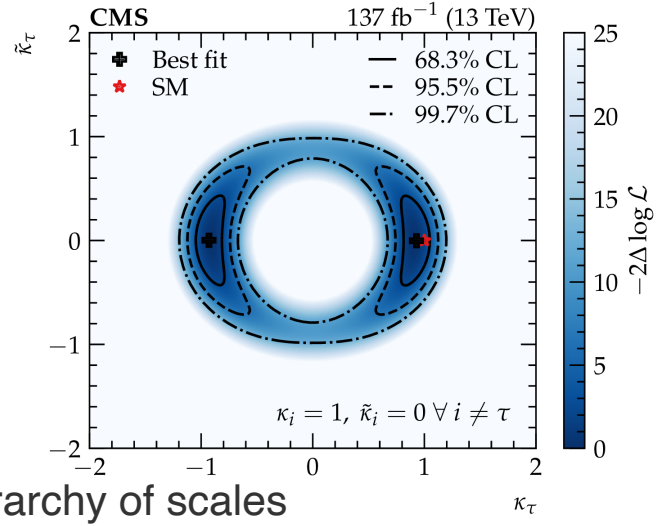
Further information from BSM Higgs searches, etc.

Constraints from vacuum stability and the thermal evolution of the early universe

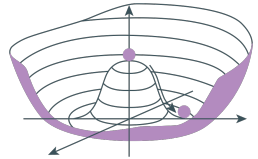
# H.2: Higgs and the Origin of Matter



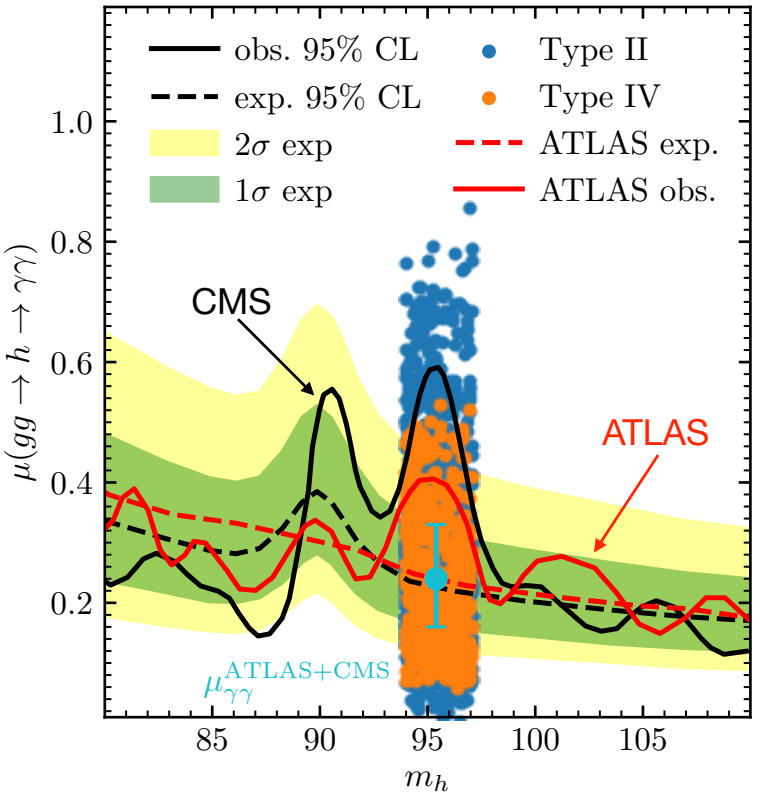
- Investigate the interplay between the Higgs and the dark sector
- Explore possible additional sources of CP violation
- Probe the underlying physics giving rise to the observed hierarchy of scales



# Extended Higgs sectors: hints at 95 GeV?

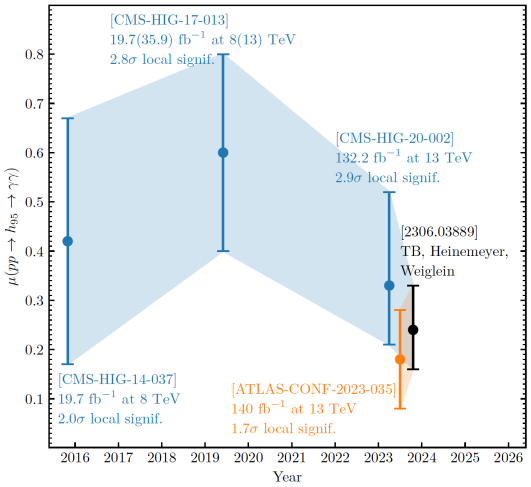


CMS + ATLAS excess in $\gamma\gamma$ channel at 95 GeV:




Example interpretation: S2HDM, type II and IV

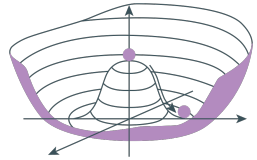
⇒Good description in extended Higgs sectors with an additional doublet and a singlet



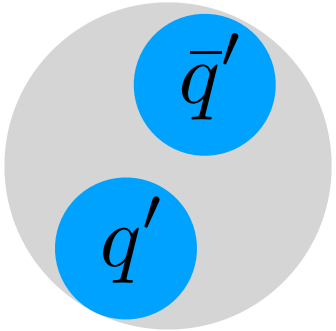

$$\mu_{\gamma\gamma}^{\text{ATLAS+CMS}} = 0.24^{+0.09}_{-0.08}$$

$3.1\,\sigma$

# EW baryogenesis in composite Higgs models



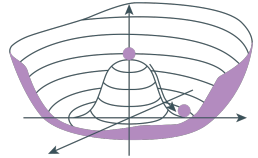
**Higgs is a bound state of new strong interactions confining at ~ 1 TeV**

$h =$ 

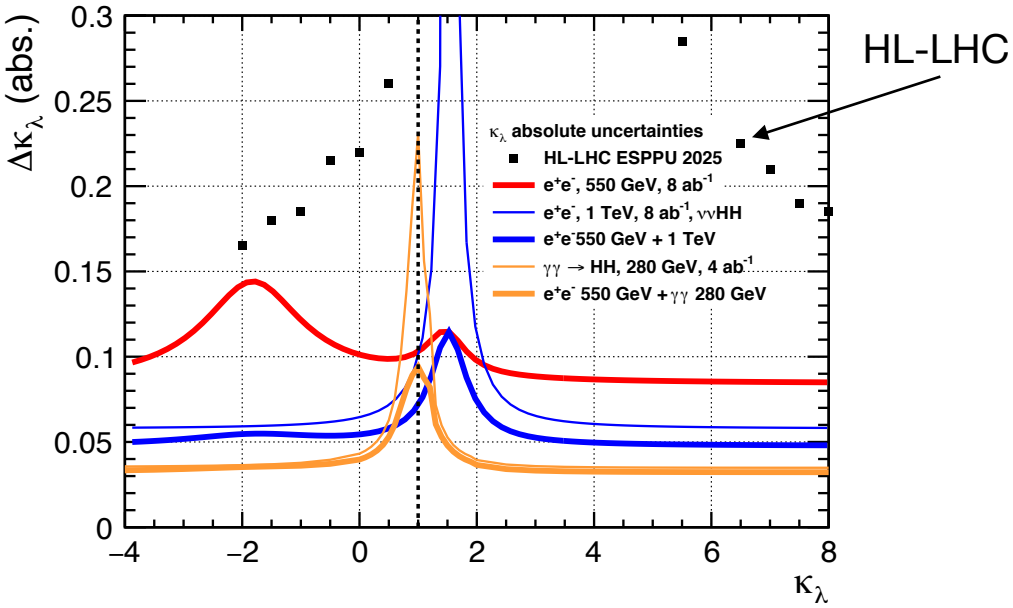

**solves the hierarchy pb.**

**The new scalar triggering the 1st-order PT is a composite dilaton (PNGB of approximate conformal invariance)**

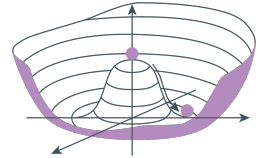
# H.3: Tools and New Facilities for Future Higgs Characterization



- AI for complex Higgs final states
- Precision predictions
- Global fits / scans
- Requirements for a future Higgs factory



# Positions in Higgs phenomenology



- Postdoctoral positions on the physics of the Higgs potential, the relation of Higgs physics to the matter / ant-matter asymmetry, precision predictions and future colliders (HALHF)
- PhD positions on the interplay of electroweak symmetry breaking and gravitational waves

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# Thanks for your attention!

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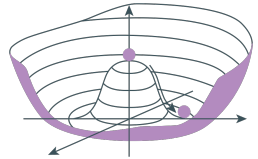
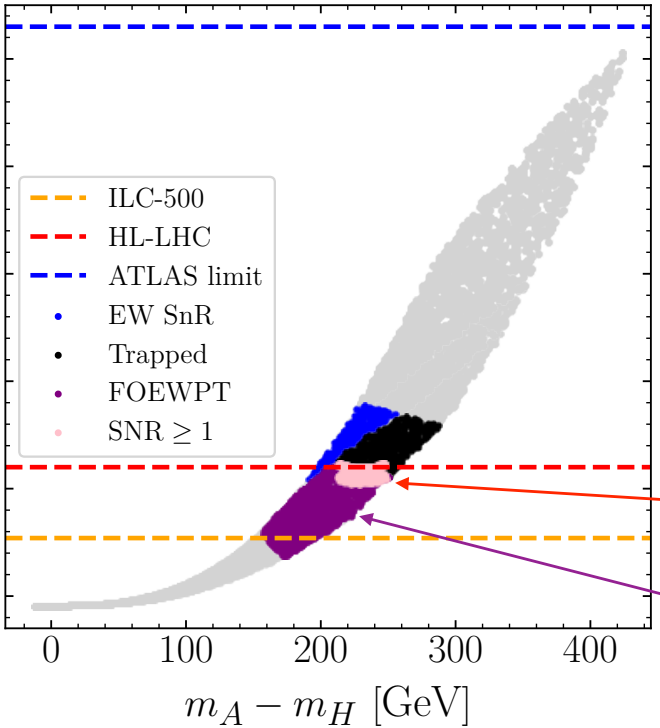
# 2HDM example: $\kappa_\lambda$, EWPT and GW signals



current bound

HL-LHC sensitivity

ILC sensitivity




alignment limit,
tanβ = 3,
1-loop prediction

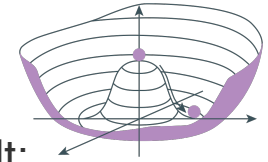
region with potentially observable gravitational wave (GW) signal

region with strong first-order EWPT

Links to GW, DM and SMART!

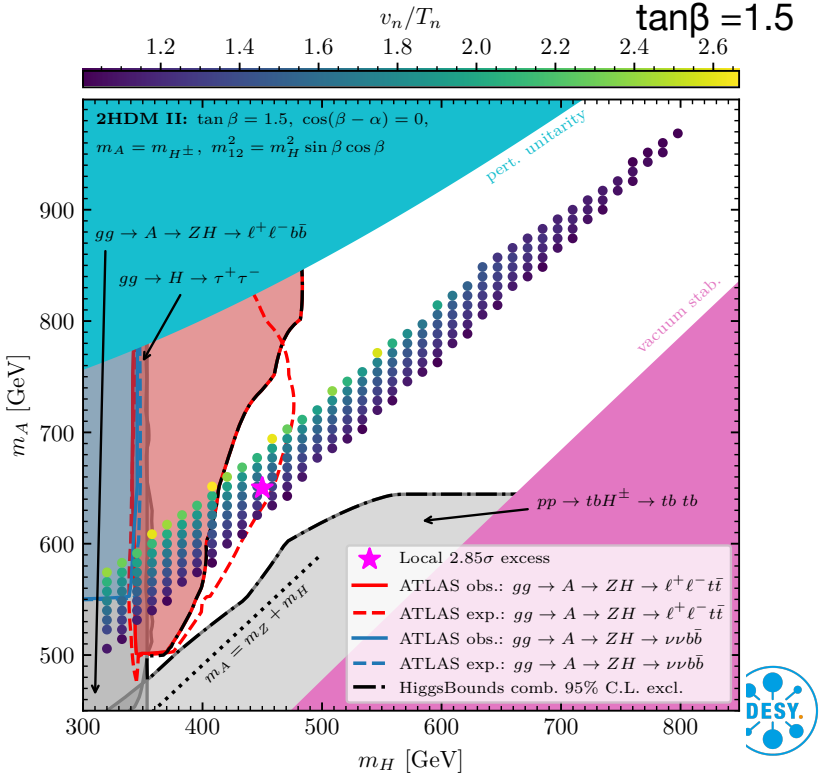
⇒ Region with strong first-order EWPT and potentially detectable GW signal is correlated with significant deviation of $\kappa_\lambda$ from SM value

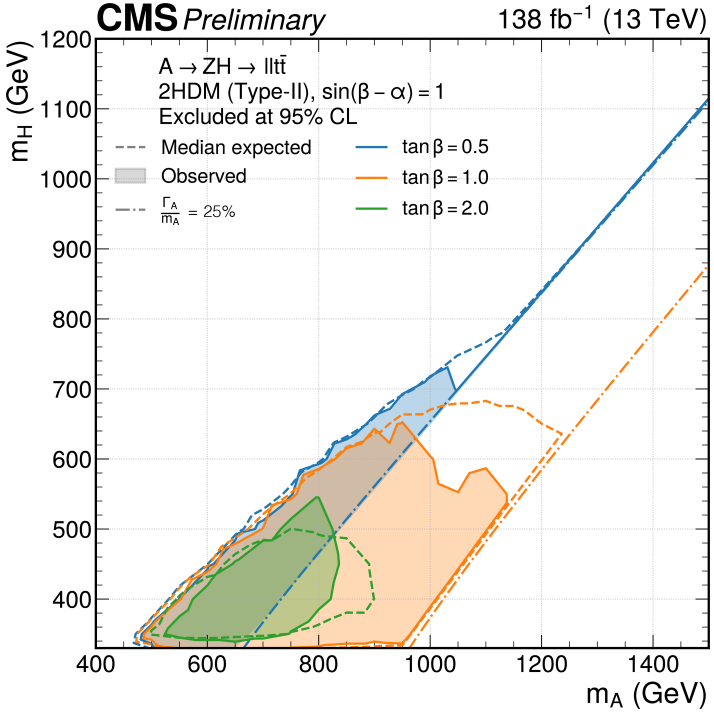
# Smoking gun searches: pp → A → ZH → Ztt



ATLAS res. vs. pref. param. region in 2HDM for SFOEWPT: Recent CMS result:

tanβ =1.5




LHC searches start probing the region giving rise to a SFOEWPT