DM searches at the LHC
+
The Higgs potential in the Early Universe

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DESY FH Fellow Meeting

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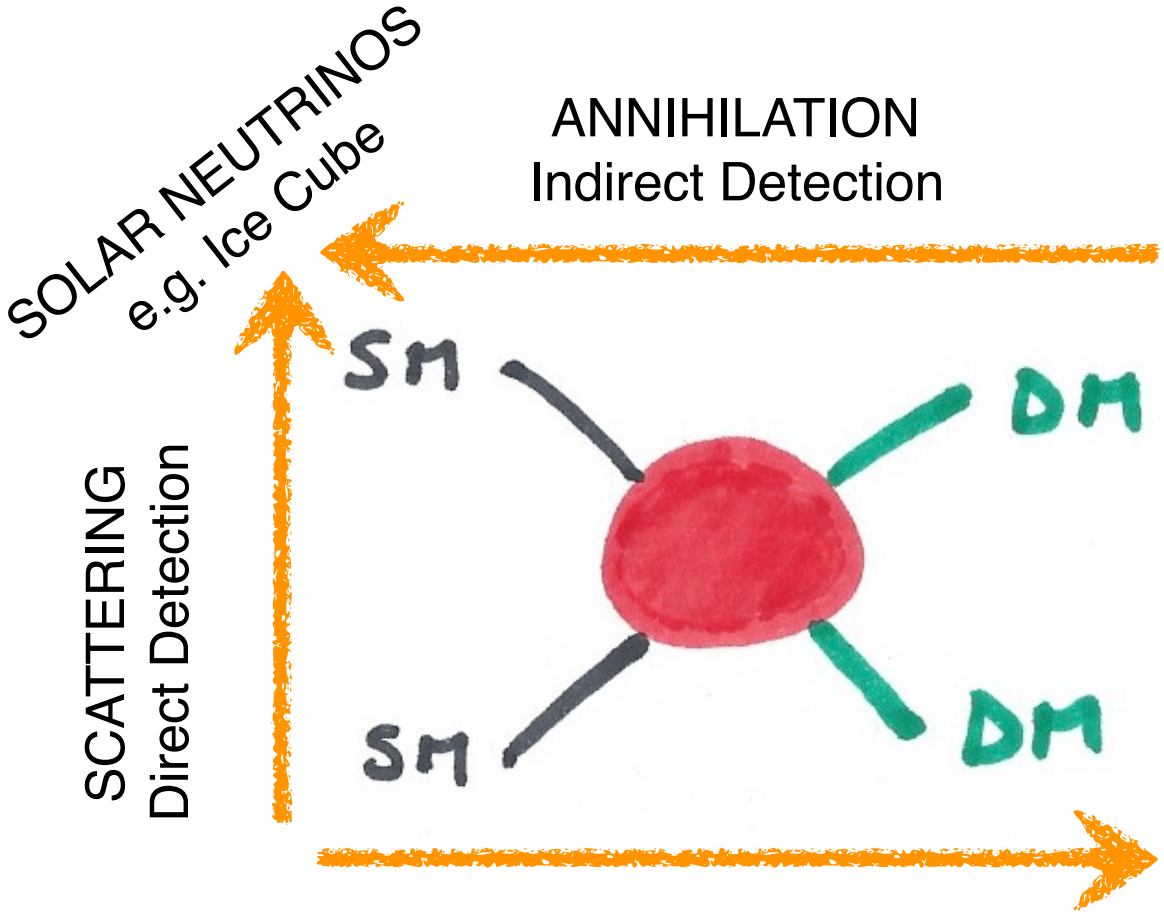
WIMP Dark Matter searches

How can we test WIMP DM interactions with the Standard Model?



Different searches cover different portions of parameter space

⇒ Importance of COMPLEMENTARITY

DM at the LHC

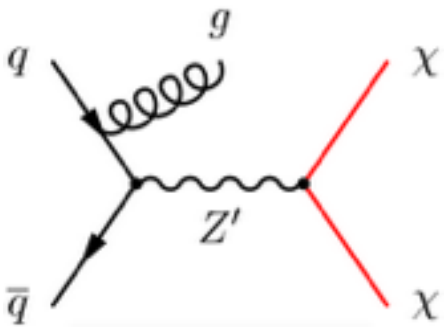
Trivial observation: WIMP particles do not interact with the detectors

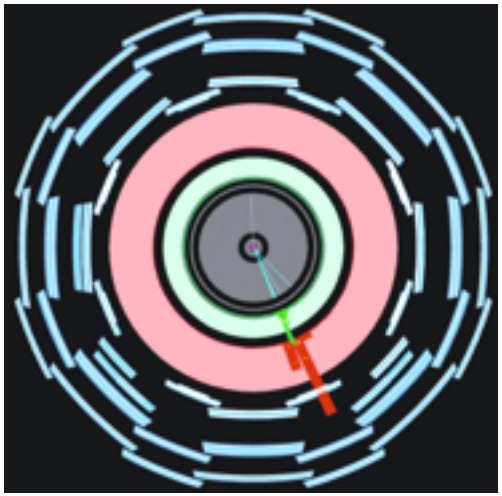
~~pp → DM DM~~

Tag DM events with some recoiling SM particle

e.g. “mono-X + MET” searches

a single SM object recoiling against some unpaired momentum in the transverse plane



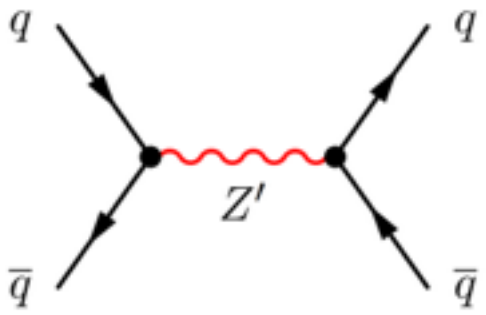


ATLAS mono-jet event, CERN courier

Study the “dark sector” independently of DM

e.g. “di-jet” searches

the mediator is produced and decays back into a quark - antiquark pair

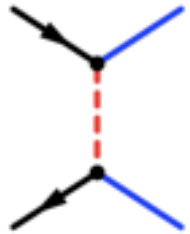


DM “models”

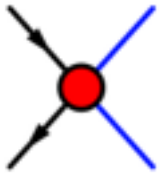
Completeness

Complexity

FULL THEORIES
- SUSY, KK…
- Many particles and parameters



SIMPLIFIED MODELS
- 2 new particles (DM + mediator)
- few parameters: M,m_{DM}, couplings

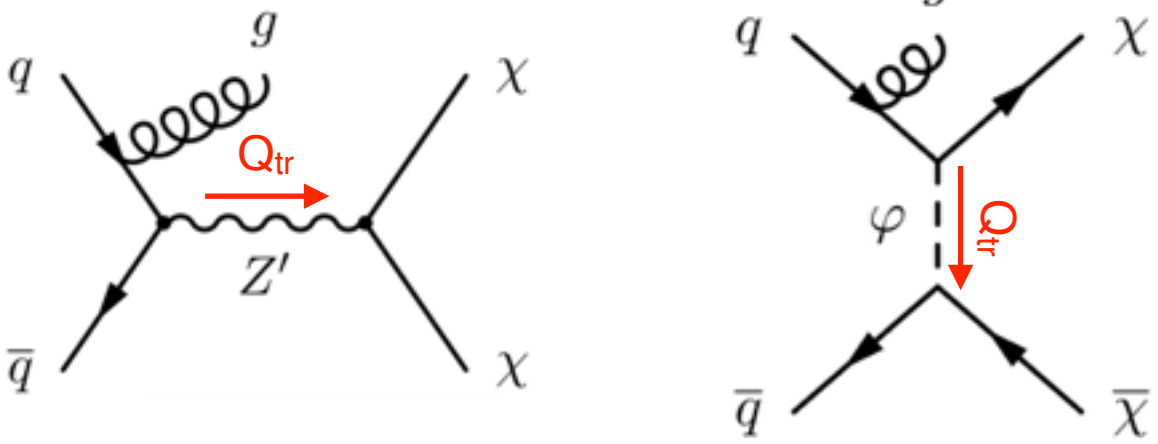


EFFECTIVE THEORIES
- 1 new particle (DM)
- 2 parameters: Λ,m_{DM}

Validity of the EFT

At the LHC, the typical momentum exchanged is close to the scales that are probed

$$\langle Q_{\rm tr}^2 \rangle \sim \mathcal{O}(1\,{\rm TeV})^2 \sim \Lambda^2$$

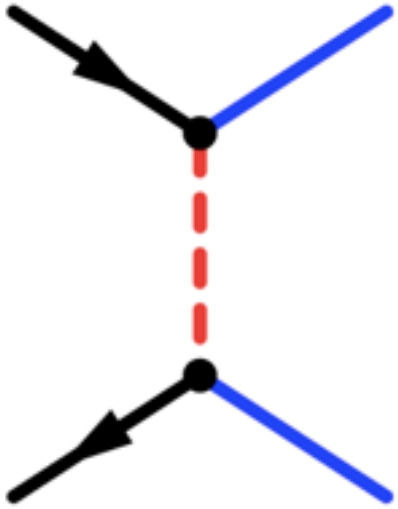


The effective description is expected to fail

[Busoni, EM, *et al.*, 1307.2253, 1402.1275, 1405.3101]

Simplified Models

Beyond EFT: consider a set of simple toy models

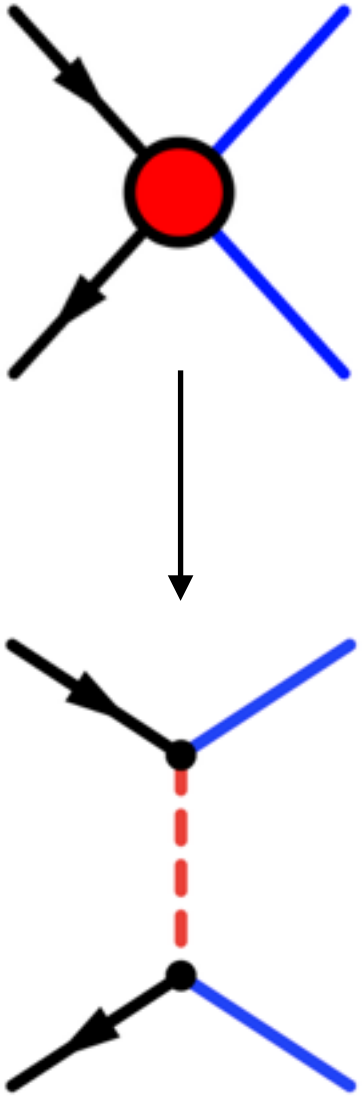


NEW PARTICLES
- DM
- Mediator

PARAMETERS
- Masses (m_{DM}, M)
- Couplings (g, g_q, $g_{\chi...}$)
- (Mixing angles)

Implementation in LHC searches for DM still in progress (DM@LHC working group)

Simplified Models



- ✓ Can grasp the most relevant physical features of a full theory including DM
- ✓ Theoretically consistent
- ✓ Richer phenomenology: other channels and searches complementary to mono-X
- ✗ More parameters (couplings) → higher dimensional space to constrain
- ✗ How to present constraints?

Interesting questions

- How to build simple but consistent simplified models
  - ✤ experimental constraints;
  - ✤ perturbative unitarity;
  - ✤ anomalies?
- How to be as model independent as possible: what is the best set of models? How not to miss interesting phenomenologies?
- Complementarity with other experiments: more assumptions are needed
- Large parameter space: can we do a clever sampling?

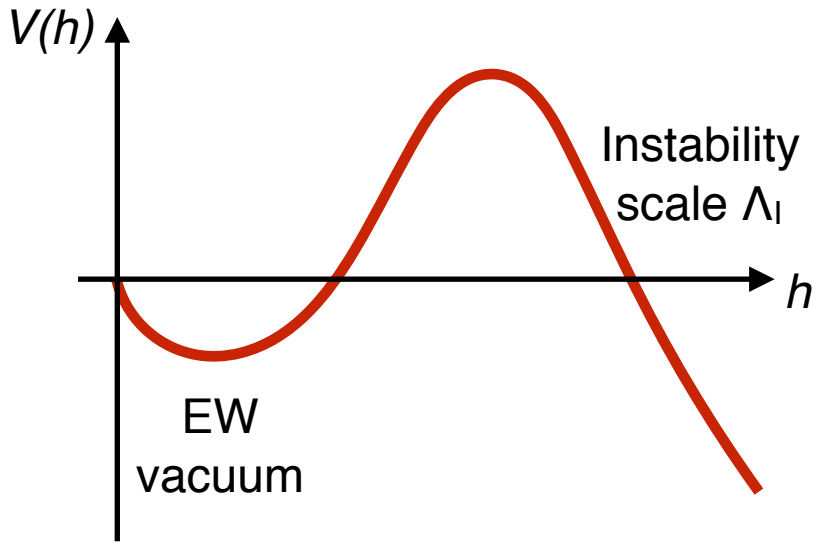
The Higgs potential in the early universe

The Higgs vacuum instability

Extrapolate SM up to Planck scale. We assume Higgs is SM like, no BSM physics.

$$V(h) = \lambda(h)\frac{h^4}{4}$$

RG running makes the potential negative at some scale $10^{10} \div 10^{11}$ GeV



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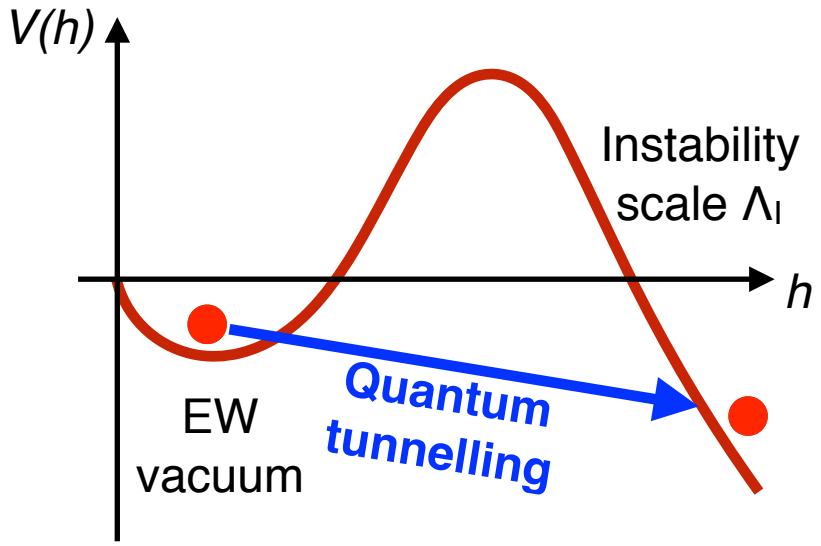
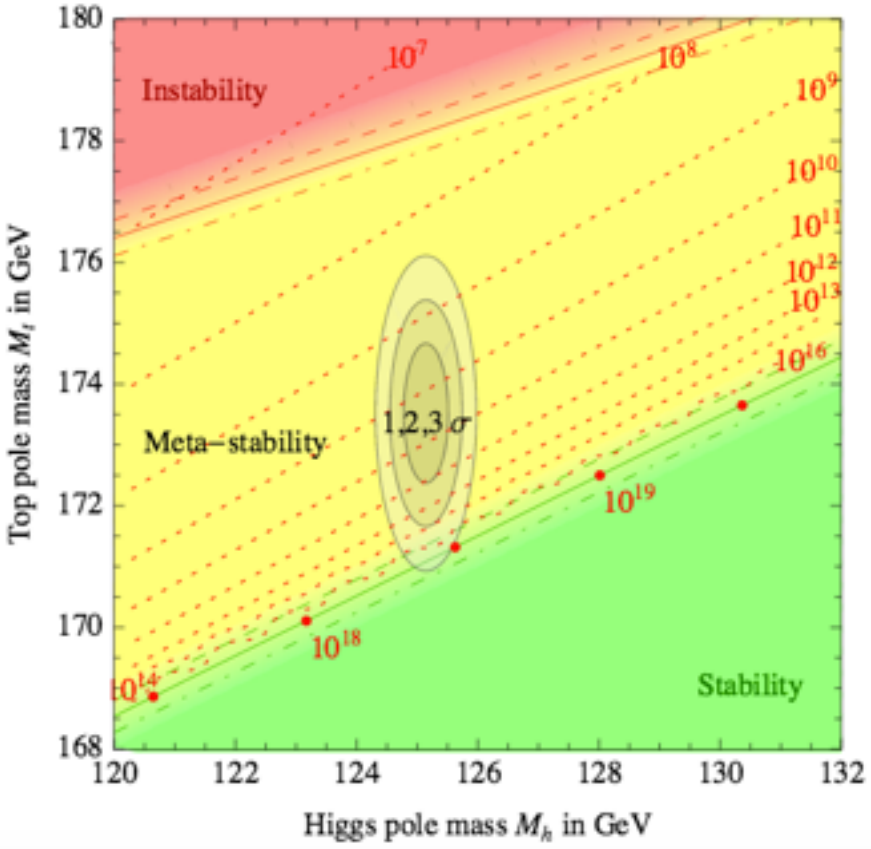
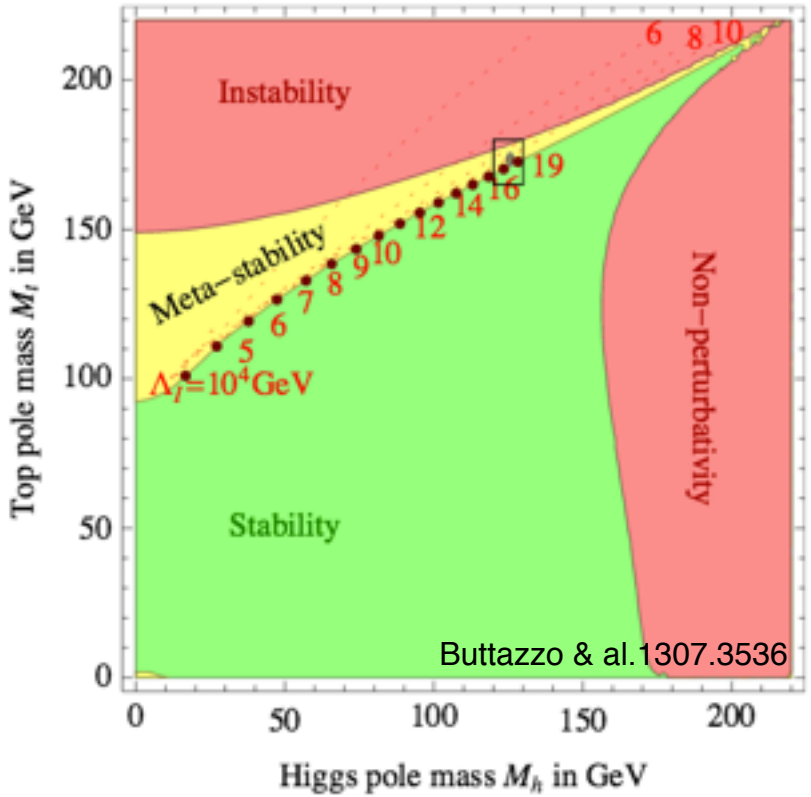


The Higgs vacuum instability

Metastability: EW vacuum lifetime is larger than the age of the Universe



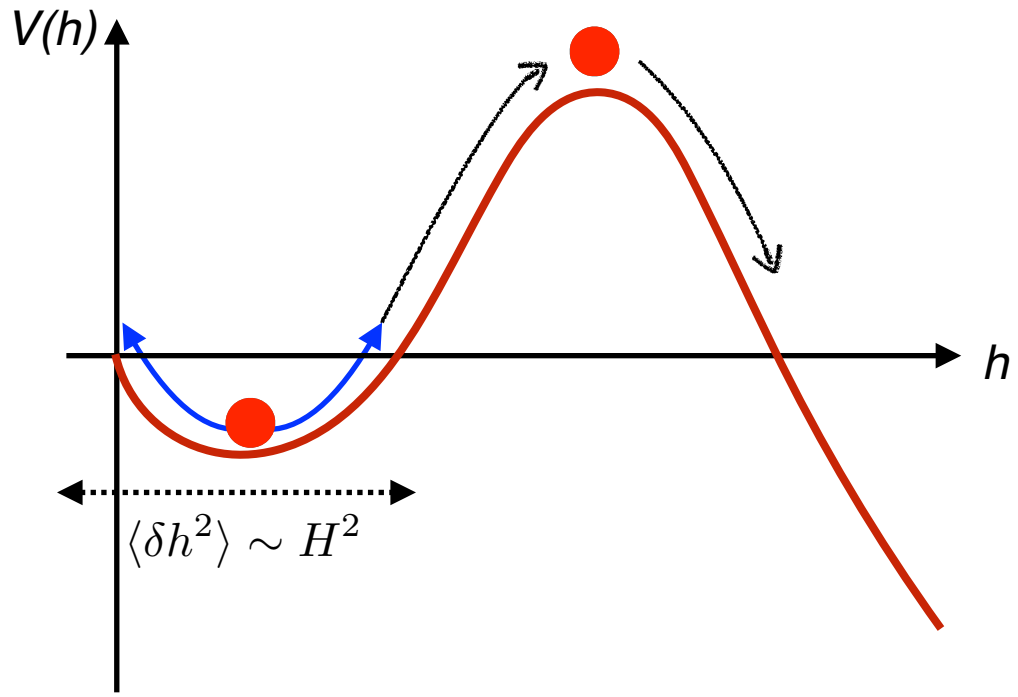


Buttazzo & al.1307.3536

Instability in the early universe

Many effects can change the situation in the early universe:

Inflation: quantum fluctuations

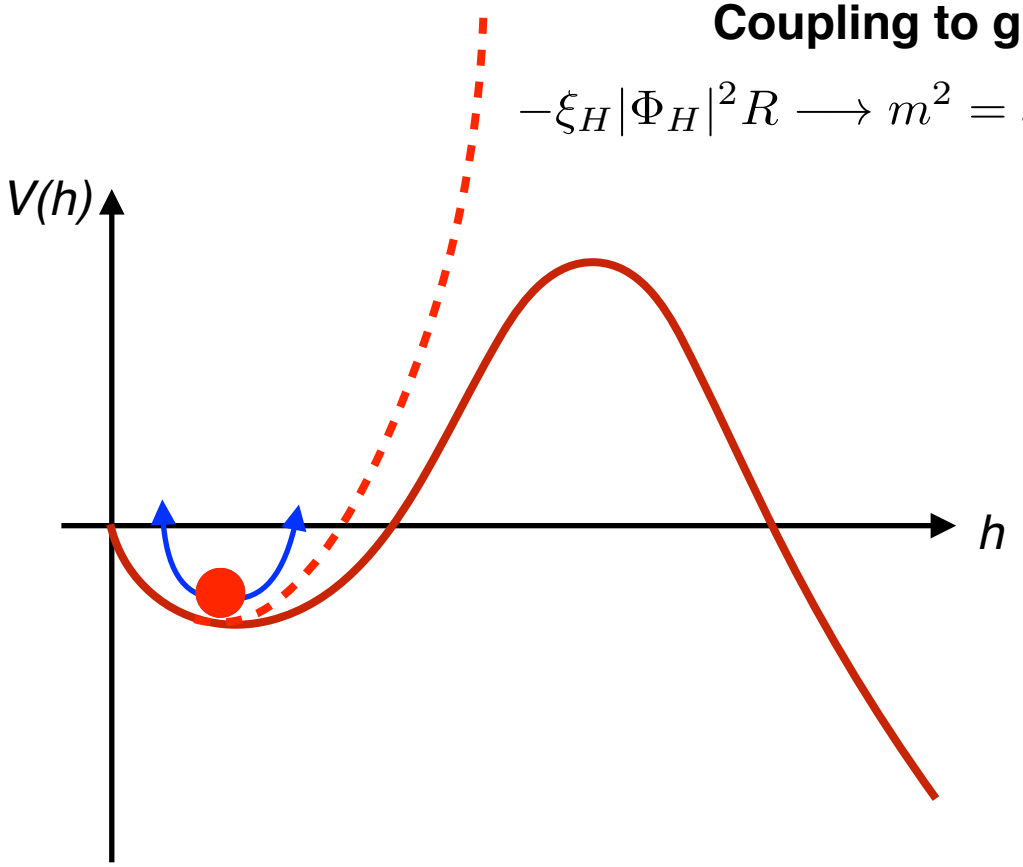


Instability in the early universe

Many effects can change the situation in the early universe:

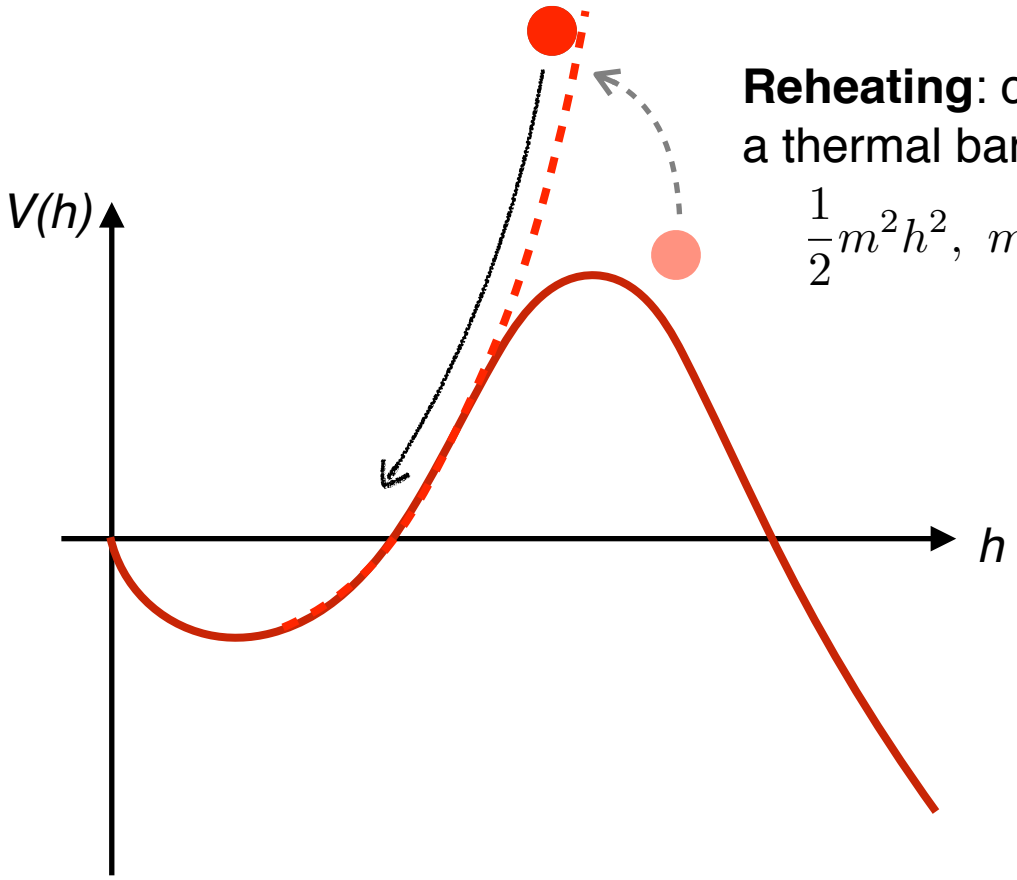
Coupling to gravity:

$$-\xi_H |\Phi_H|^2 R \longrightarrow m^2 = \xi_H R = -12\xi_H H^2$$



Instability in the early universe

Many effects can change the situation in the early universe:

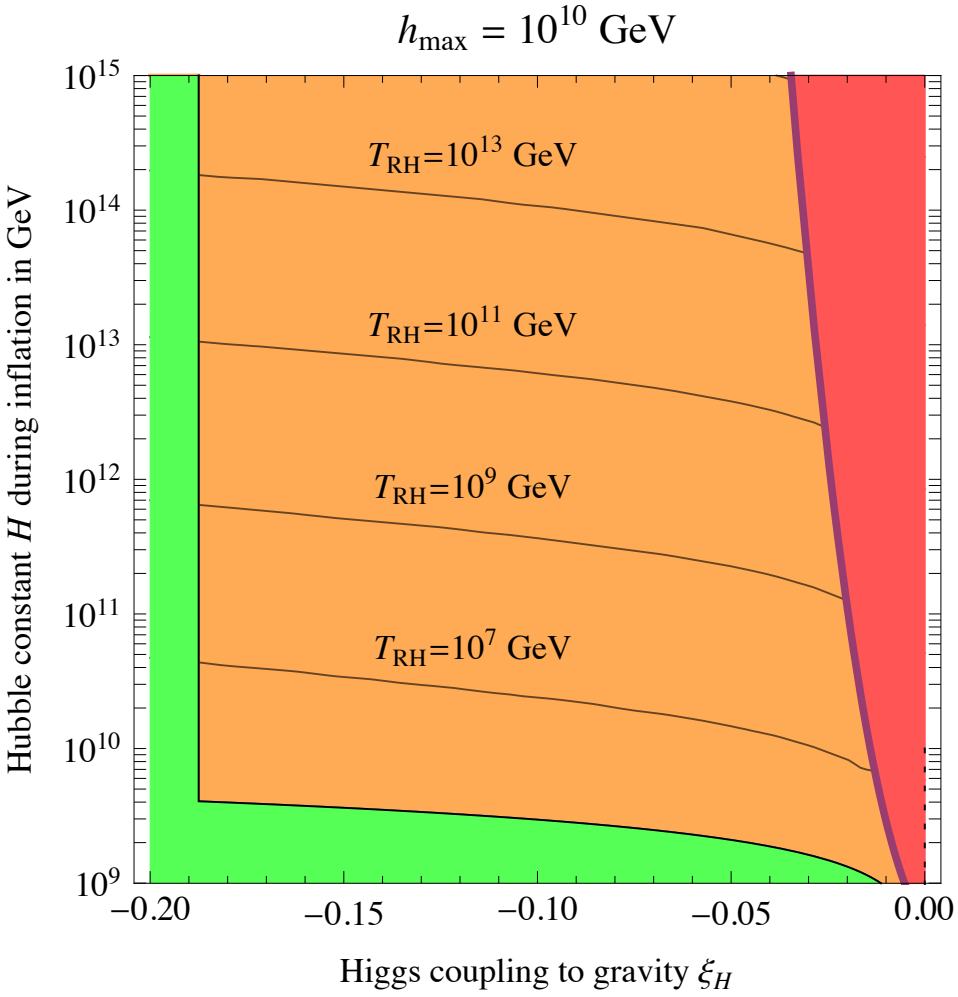


Reheating: creation of a thermal barrier

$$\frac{1}{2}m^2h^2,\ m^2 \sim T^2$$

Instability in the early universe

Lower bound on the reheating temperature



Interesting questions

- Is a gauge invariant treatment possible? What are the gauge invariant quantities involved in the process? Is the effective potential the best quantity to describe the physics?

- Sensitivity to new physics: can we use stability to exclude new physics models?

- New effects: particle productions after the tunnelling, bubble collisions, bubble formation triggered by black holes…

- Bounds on concrete realisations of cosmological history