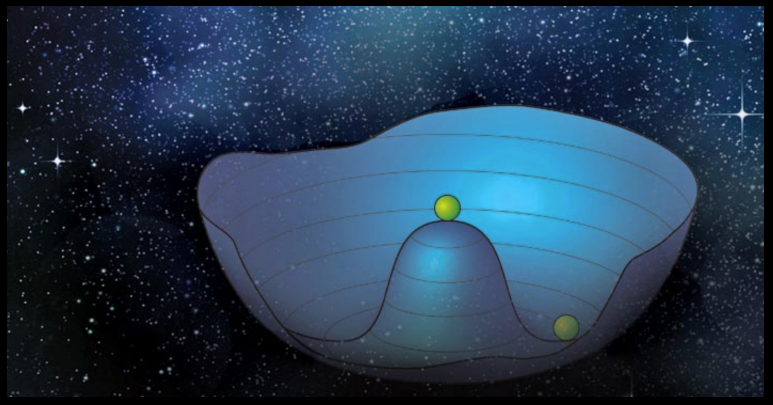
Summary:
First Order Electroweak Phase Transition from sub-GeV Physics

Hooman Davoudiasl

High Energy Theory Group, Brookhaven National Laboratory



Based on: H.D., Phys.Rev.D 103 (2021) 8, 083534; 2101.05319 [hep-ph]

Higgs 2021 (virtual), October 18-22, 2021

Introduction:

- Observed baryon asymmetry of the Universe needs a *baryogenesis* mechanism
- Baryogenesis generally requires *departure from equilibrium* Sakharov, 1967
- Could be satisfied for first order phase transition (FOPT)
- Typically assumed that EW FOPT requires

Critical temperature T_c, Higgs vev v

$$\frac{v(T_c)}{T_c} \gtrsim 1$$

- SM: thermal contributions of W, Z gauge bosons *E.g.*, Quiros, 1999

$$\frac{v(T_c)}{T_c} = \frac{2m_W^3 + m_Z^3}{3\pi\lambda_H\, v^3} \approx 0.1$$

- SM Higgs quartic coupling $\lambda_H \approx 0.13$ for $m_H \approx 125$ GeV

$v = 246$ GeV, $\langle H \rangle = v/\sqrt{2}$

- Since $m_W, m_Z \propto v$, FOPT for $\lambda_H \to \sim \lambda_H/10$ ($m_H \sim 40$ GeV)
- Motivates beyond SM (BSM) physics
- Typically, expect states near weak scale and significant coupling to Higgs

See, e.g., Ramsey-Musolf, 1912.07189, and references therein

This talk*:

Different approach with sub-GeV physics weakly coupled to Higgs

- *Basic idea: λ_H small before EWPT, grows to SM value afterwards*
- Achieved through the evolution of a light (mass $\gtrsim$ few MeV) scalar field ϕ
- Stability near weak scale suggests small top Yukawa before EWPT
- Extension: ϕ-dependent Yukawa couplings for all SM fermions *after* EWSB

- Other works considering alternative approaches include

- Using weakly coupled intermediate mass $\gtrsim$ 10 GeV scalars:
Jeong, Jung, Shin, 1806.02591; Kozaczuk, Ramsey-Musolf, Shelton, 1911.10210

- Via axion-like particles: Jeong, Jung, Shin, 1811.03294

* We do not specify a baryogenesis mechanism, but consider FOPT as a potential key ingredient

Low Energy Tests

- ϕ can appear as missing energy in rare meson decays
- Example: KOTO, measuring $K_L \to \pi^0 \bar{\nu}\nu$, to $\sim 10\%$
- SM prediction for branching fraction: $3.4 \pm 0.6 \times 10^{-11}$

Cirigliano, Ecker, Neufeld, Pich, Portoles, 2011; Egana-Ugrinovic, Homiller, Meade, 2019

- A few anomalous events were observed by KOTO Shinohara (KOTO), 2019
- ϕ-top coupling in the 1-loop penguin diagram for $K_L \to \pi^0 \phi$ can mimic the events
- ϕ-top coupling $\sim 2 \times 10^{-4}$ and $m_\phi \lesssim 50$ MeV could yield a 2σ explanation

Egana-Ugrinovic, Homiller, Meade, 2019; Kitahara, Okui, Perez, Soreq, Tobioka, 2019

- KOTO has since concluded events are consistent with background

Ahn *et al.* (KOTO), 2020

- Future KOTO measurements can potentially probe $\bar{\xi}_t \lesssim 10^{-5}$
- Generically, also expect gravitational waves from the FOPT

- Possibly detectable by *e.g.* LISA See, for example, Caprini *et al.*, 2019