First-order phase transitions and darkogenesis in Twin Higgs model

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Based on:
MB, I. Nałęcz **JHEP 02 (2023) 185**
MB, K. Harigaya, I. Nałęcz, to appear

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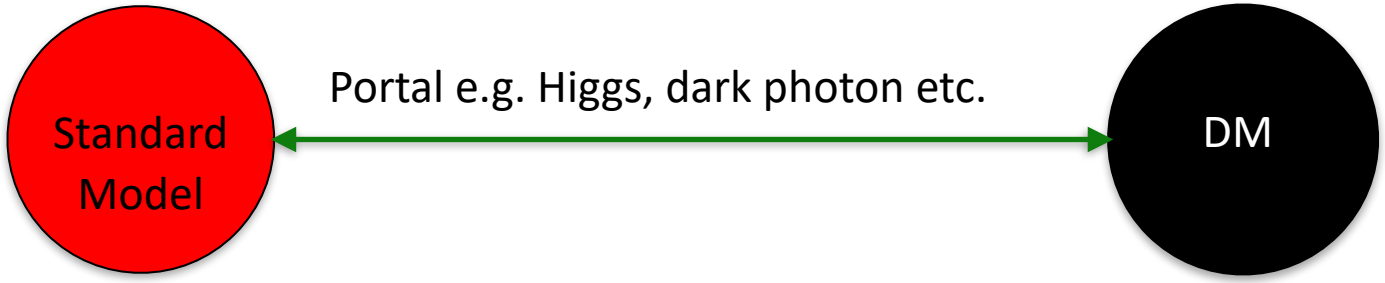
Outline

1. Motivation
2. Twin Higgs mechanism
3. Phase transitions in TH model
4. Conclusions

Simple Dark Sector

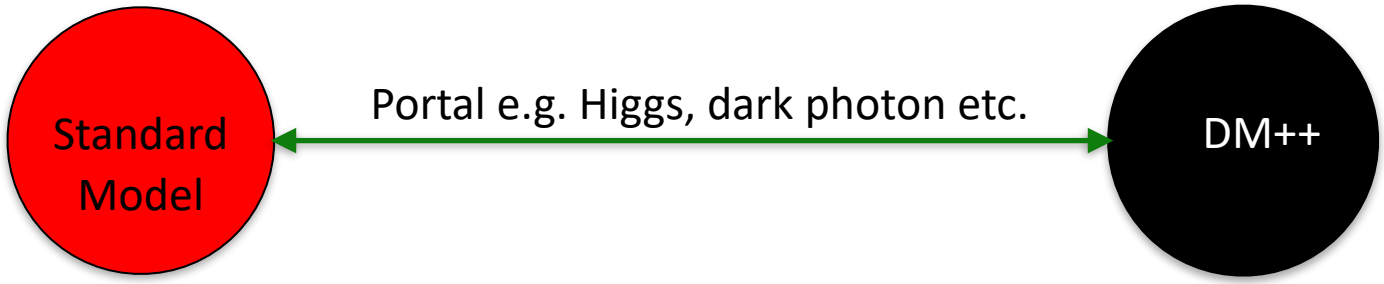
- The simplest dark sector consists of only DM particle



- DM not charged under the SM gauge group and interacts with the SM sector only via portal which relaxes exp. constraints on DM from colliders, direct detection etc.

Dark Sector to rule them all

- Dark sector may offer more than just DM particle



- Many problems of the SM may be solved in the Dark Sector at once

Twin Higgs to rule them all

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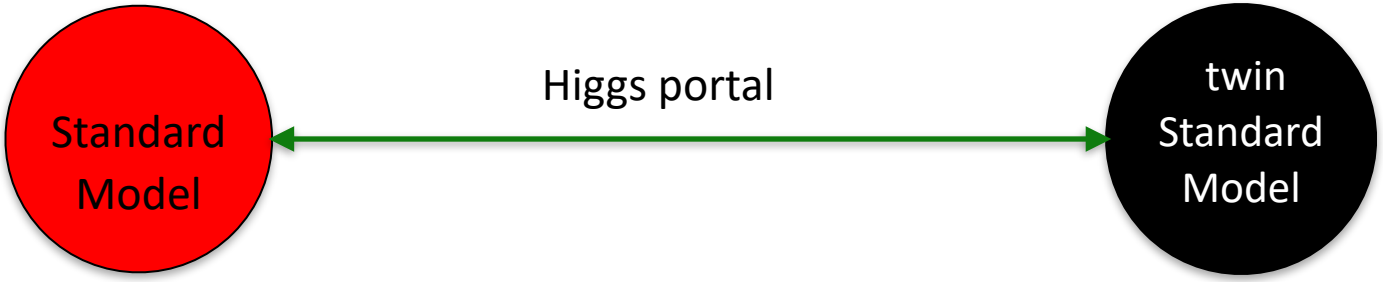

- Twin Higgs (complete model of Dark Sector):

✓ solves the hierarchy problem of the SM

✓ naturally provides dark matter candidates

✓ generates baryon asymmetry through first-order phase transition ?

This talk

Twin Higgs model in a nutshell

Chacko, Goh, Harnik '05

- The Higgs is a pNGB of a global SU(4) symmetry
- SU(4) enforced by Z_2 symmetry exchanging two copies of the SM

SM $\rightarrow H \overset{\mathbb{Z}_2}{\longleftrightarrow} H' \leftarrow$ mirror

$$V = \lambda(|H'|^2 + |H|^2)^2 - m^2(|H'|^2 + |H|^2) + \Delta\lambda(|H'|^4 + |H|^4) + \Delta m^2|H^2|$$

SU(4) symmetric

SU(4) spontaneously broken to SU(3) → 7 NGB :
6 eaten + massless Higgs

SU(4) breaking

↓

the Higgs is pNGB
maximal mixture
of H and H'

$SU(4)$ & $\mathbb{Z}_2$ breaking

↓

the Higgs with SM-like couplings

Scale of SU(4) breaking: $f^2 \equiv v^2 + v'^2 \qquad \langle H \rangle \equiv v \quad \langle H' \rangle \equiv v' \qquad \frac{v'}{v} \gtrsim 3$

Cosmological implications

TH predicts new BSM particles which are likely beyond the LHC but…

TH models have several cosmological signatures:

- New dark matter candidates in the twin sector:
  twin fermions, twin baryon, twin neutralino…

- Extended Higgs sector may allow for first-order phase transitions
  (Gravitational wave signal? Baryogenesis?)

- Twin photon and twin fermions contribute to ΔN_{eff} (dark radiation) - generically too much to be compatible with Planck satellite data but solutions to this problem exist e.g. Z_2 breaking in light Yukawa couplings reduce ΔN_{eff} below Planck sensitivity but within reach of near-future CMB experiments

  Barbieri, Hall, Harigaya '16, '17

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Rest of the talk

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Barbieri, Hall, Harigaya '16, '17

Phase transitions in TH models

If the phase transition associated with the breakdown of the ElectroWeak symmetry in the Early Universe was first-order it could lead to:

- Electroweak baryogenesis
- (Observable?) gravitational waves

In the Standard Model the EW phase transition is smooth (would be first-order only if the Higgs mass was below 70 GeV)

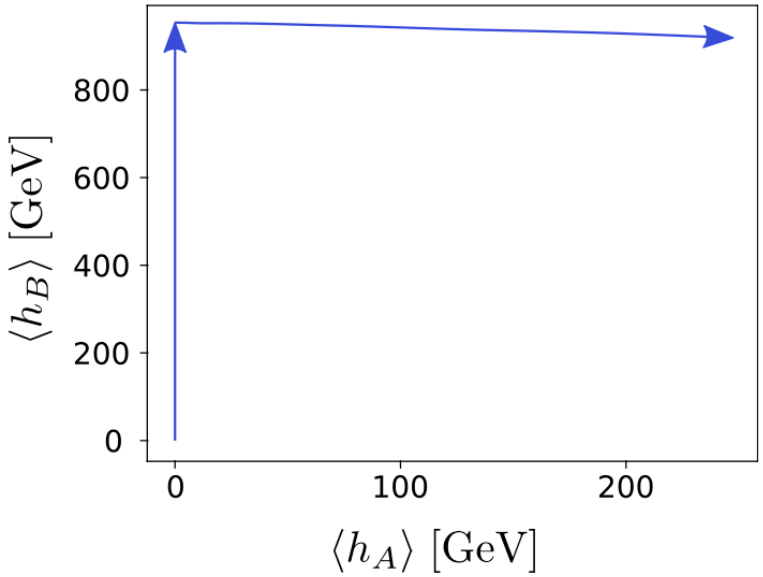
The structure of the Higgs potential in TH models is modified:

Could first-order phase transition be present in TH models?

Phase transitions in TH models

The first study of phase transitions (PT) in TH models found only smooth PT

Fujikura et al. ’18



$H \equiv h_A$

$H' \equiv h_B$

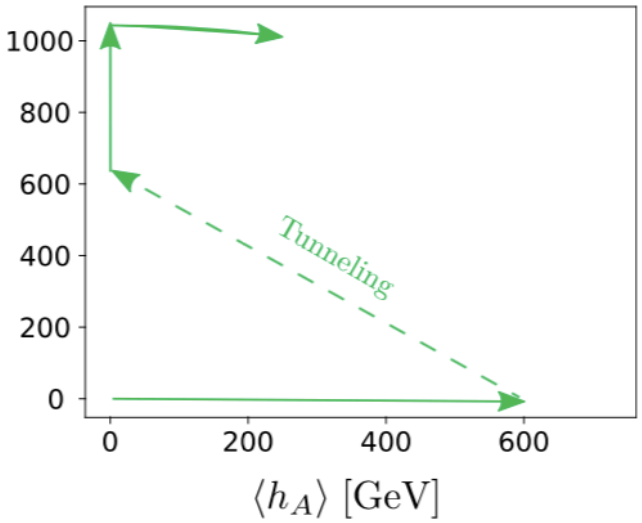
EW symmetry is broken after twin EW symmetry

First-order phase transitions in TH models

MB, Nałęcz '22

First-order phase transition can be present in TH models if the effects of Z_2 breaking between the SM and twin sector are properly taken into account

PT is 1st order if the SM Higgs gets a vev before the twin Higgs which requires additional source of Z_2 breaking



- It is crucial to take into account two-field dynamics
- EW symmetry is broken before twin EW symmetry at temperature $T \sim f \sim 1$ TeV

First-order phase transitions in TH models

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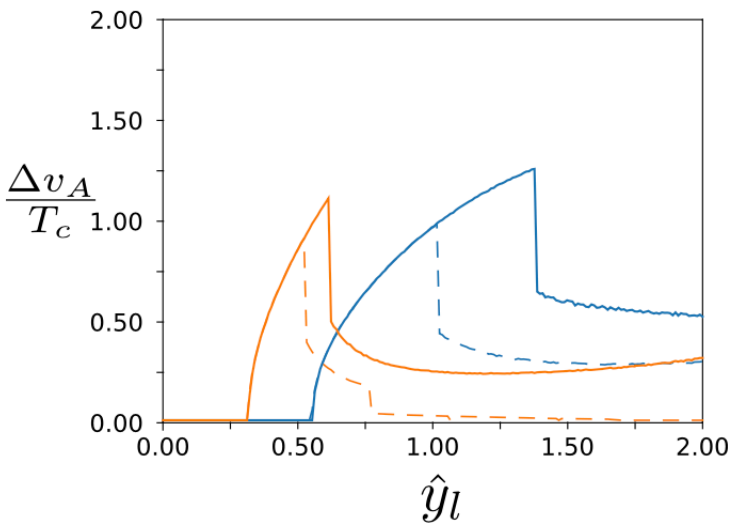
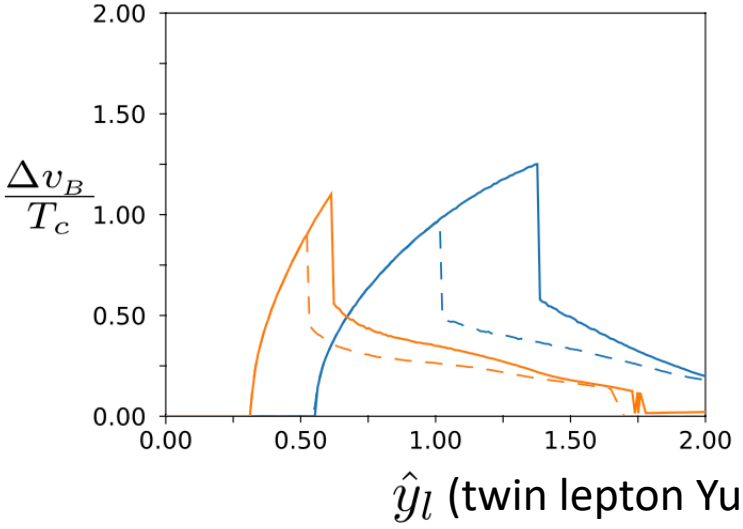
Thermally corrected masses at the origin of field space for $T \sim f$:

$$m_{h_A}^2(T) \approx \zeta_{SM} T^2 - \lambda f^2 + \Delta m^2 \quad m_{h_B}^2(T) \approx \zeta_{TS} T^2 - \lambda f^2$$

For $\zeta_{TS} \gg \zeta_{SM}$ twin EW symmetry broken before EW symmetry

e.g. Z_2 breaking in Yukawa couplings: $\zeta_{TS} = \dfrac{\sum_i \hat{n}_i \hat{y}_i^2}{12}$





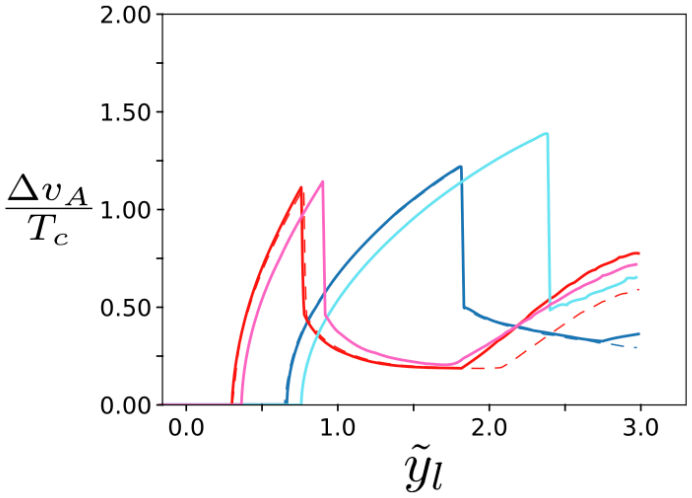
First-order phase transitions in SUSY TH

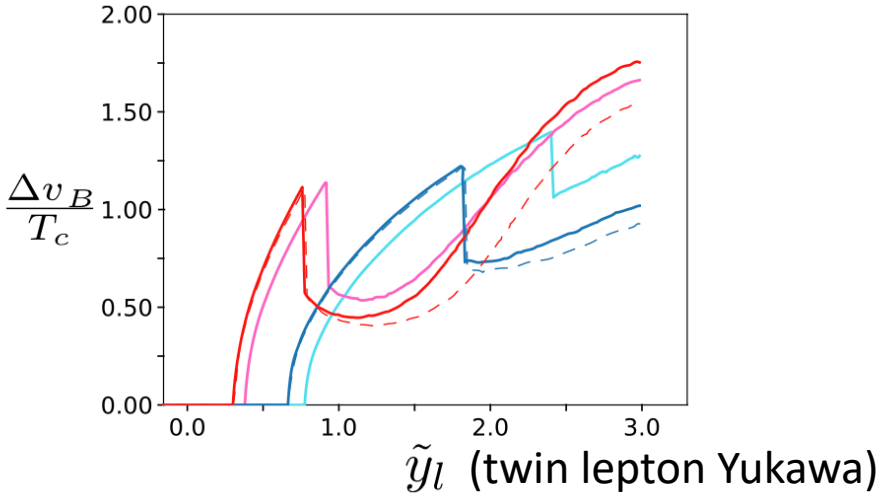
MB, Nałęcz '22

TH models can be UV completed by supersymmetry

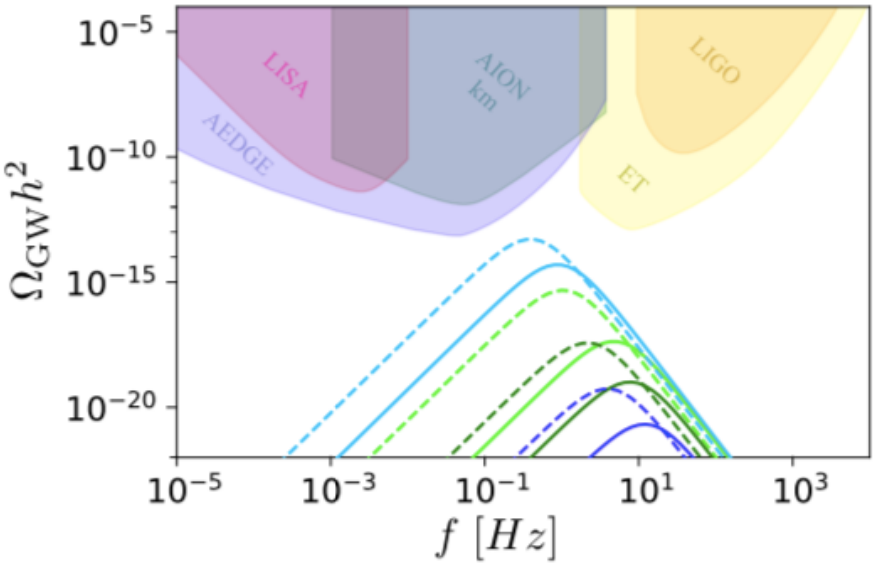
Falkowski, Pokorski, Schmaltz '06 Chang, Hall, Weiner '06
Craig, Howe '13 Katz et al. '16 MB, Harigaya '17

Introduction of light twin sleptons mitigates tuning introduced by large twin lepton Yukawa couplings and makes FOPT even stronger





GW spectra from first-order phase transitions in SUSY TH models



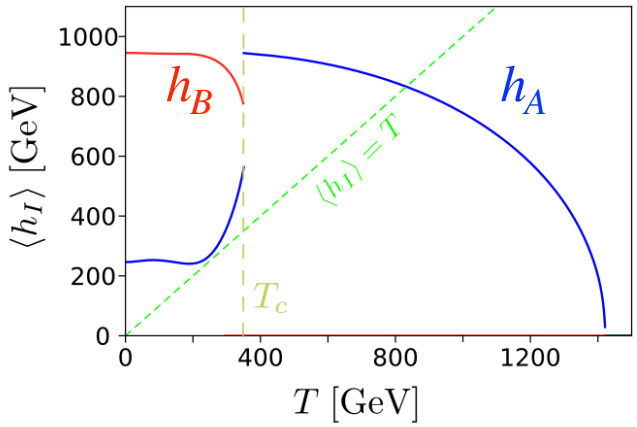
- The strongest GW signal is obtained in SUSY TH with light sleptons but is not large enough to detect it in the near future.

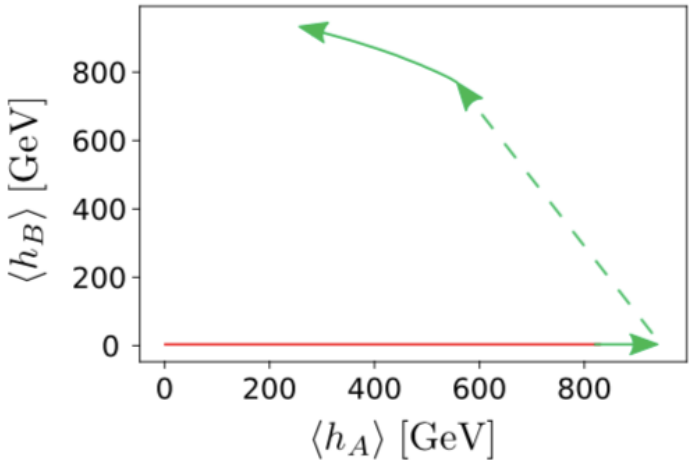
EW Symmetry Non-restoration in (SUSY) TH

MB, Harigaya, Nałęcz, to appear

- twin fermions with large Yukawa couplings lead to EW symmetry non-restoration (SNR) for $\sum_i \hat{n}_i \hat{y}_i^2 \gtrsim 5$ Matzedonsky '21

- In SUSY TH adding light twin sleptons help to achieve SNR (for smaller twin fermion Yukawas) and allow for SNR and FOPT simultaneously





Darkogenesis in TH models

MB, Harigaya, Nałęcz, in progress

- Twin EW sphalerons decouple after FOPT:

$$\frac{v_B}{T} > 1$$

- This fulfills a necessary condition for generation of twin baryon asymmetry paving the way towards darkogenesis

Shelton, Zurek '10

- To generate the SM baryon asymmetry two more ingredients needed:

1. CP violation in the twin sector e.g. from CP phases of twin soft SUSY breaking terms; EDM suppressed due to higher temperature of FOPT
2. Transfer of B' asymmetry to the SM sector e.g. neutron portal

$$\frac{1}{M^5}\bar{u}_R\bar{d}_R\bar{d}_R\hat{u}_L\hat{d}_L\hat{d}_L$$

Conclusions

- Twin Higgs is a complete model of Dark Sector which naturally explains the EW scale in spite of absence of top partners at the LHC
- Twin Higgs provides DM candidates which naturally escape detection
- Z_2 breaking in Higgs thermal masses leads to first-order phase transition at $T \sim f \sim 1\ \mathrm{TeV}$ which may lead to darkogenesis
- twin fermions with large Yukawas and light twin sfermions in SUSY TH allow for EW symmetry non-restoration up to $T \sim f \sim 1\ \mathrm{TeV}$ simultaneously with first-order phase transition