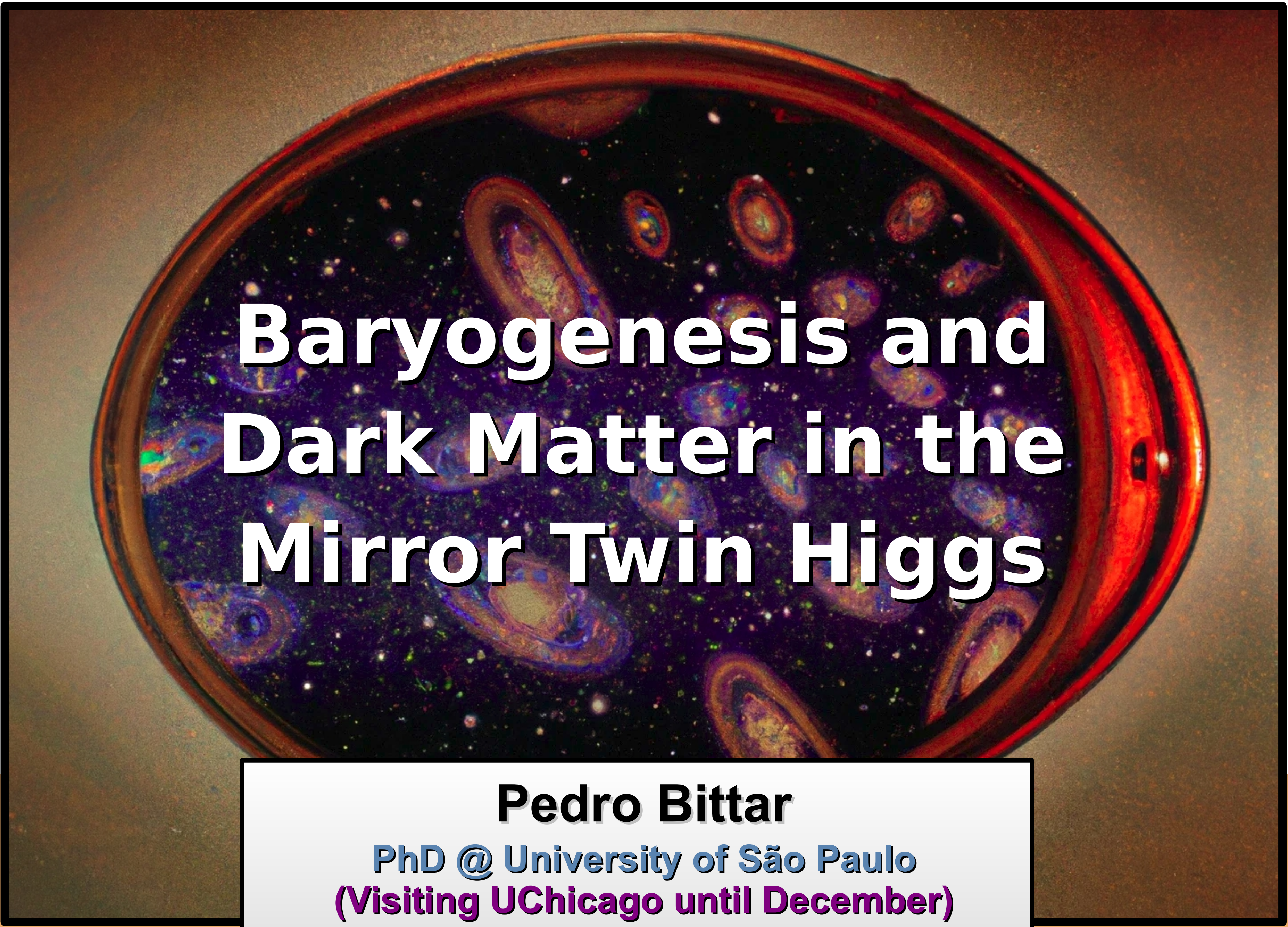
Baryogenesis and Dark Matter in the Mirror Twin Higgs



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Standard Model at the LHC Workshop – Fermilab, Batavia IL 60510, USA

Theory-driven models before

1. Electroweak scale stability: SUSY

2. Dark Matter = WIMPs

3. Gauge Unification + Baryogenesis

Theory-driven models before

1. **Electroweak scale stability: SUSY**

   → **Challenged by LHC data**

2. **Dark Matter = WIMPs**

   → **Challenged by DM detection**

3. **Gauge Unification + Baryogenesis**

   → **Challenged by proton decay experiments**

   → **High energies make difficult to look for...**

This talk: Another Option

Mirror Twin Higgs Model

1. EW Stability: Neutral Naturalness

2. DM: Asymmetric Dark Matter

3. Baryogenesis $\leftrightarrow$ Dark Matter

Mirror Twin Higgs Model

Higgs = pNGB

$$SU(4) \times U(1) \to SU(3) \times U(1) \subset [SU(2)_L \times U(1)_Y]_{\text{Local}}$$

Gauge/Yukawa generate a potential for the Higgs.

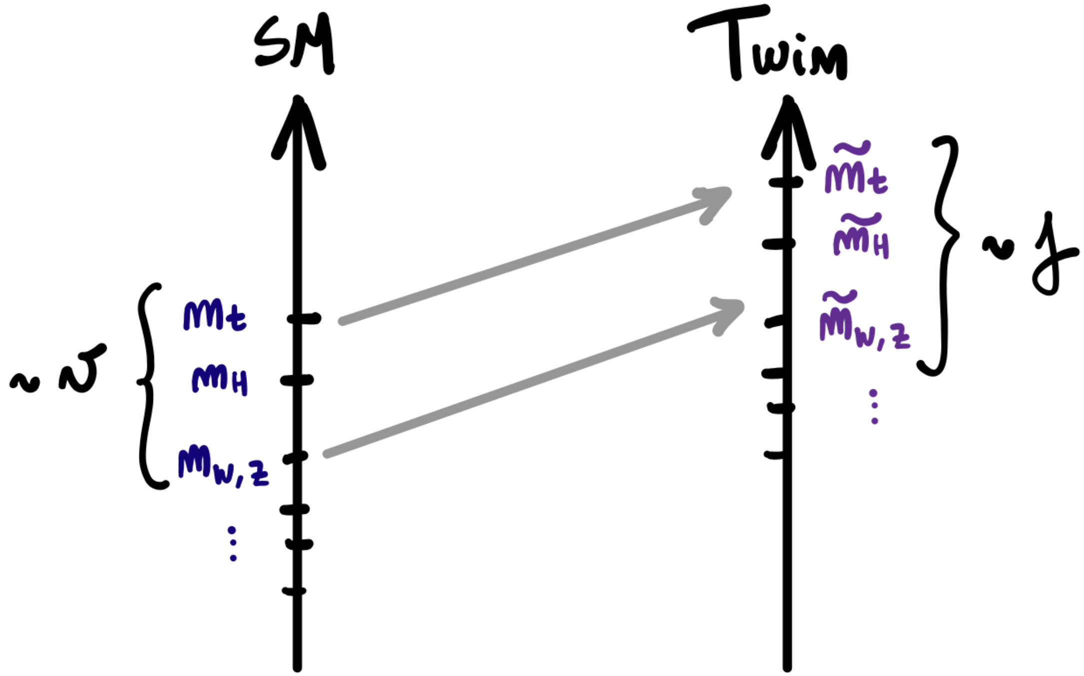
$\mathbb{Z}_2$ parity → **Restores the full SU(4) symmetry of the potential**

Consequences of the Z_2 symmetry

- **Mirror copy of the SM**
- **Hierarchy Problem → Neutral Naturalness**
- **Twin Sector → Dark Sector**
- **Cosmology, … .**

Sandbox to connect different BSM problems

The Twin Higgs Model



Measurement of the Higgs Couplings, Invisible Higgs decays @ LHC

f/v > 3

- **Soft Z_2 breaking → Safe for the HP** (Masses)
- **Hard Z_2 breaking → Reintroduces the HP** (Couplings)

Dark Matter in the Twin Higgs

Z_2 + Dark B → **Built-in candidates for DM = Twin Nucleons**

↳ **Asymmetric Dark Matter**

$$\Omega_{DM} \simeq 5\Omega_{Baryons}$$

* **Common origin of visible and dark matter**

Twin Dark Matter is naturally ADM

Dark Matter in the Twin Higgs

However …

$$\frac{\widetilde{\Lambda}_{QCD}}{\Lambda_{QCD}} = \left(\frac{f}{v}\right)^{2/9}$$

f/v ~ 3 → $\Lambda_{QCD_B} \sim 1.4\,\Lambda_{QCD_A}$

$$m_{p,\text{twin}} \simeq 1.4\, m_p$$

Twin Dark Matter cannot be much heavier than this...

$$\frac{\Omega_{DM}}{\Omega_{Baryons}} = \left(\frac{n_{DM}}{n_{VM}}\right)\frac{m_{DM}}{m_p} \neq 5$$

Whereas...

$$m_{\text{DM}} \simeq 5\, m_N$$

Dark Matter in the Twin Higgs

Our approach:
1. **Choose a baryogenesis model for the visible sector.**
2. **Use the Z_2 to copy the mechanism to the twin sector.**

[Literature]
- **Farina, JCAP 11 (2015) 017.**
- **Farina, Phys.Rev.D 94 (2016) 3, 035017.**
- **Garcia Garcia, Phys.Rev.Lett. 115 (2015) 12, 121801.**

- **Hard Z_2 breakings in QCD/Yukawa couplings**
- **Connect the two sectors with portals beyond the Higgs**

It is possible to increase the twin DM mass by brute force.

→ **But this requires hard Z_2 breaking!**

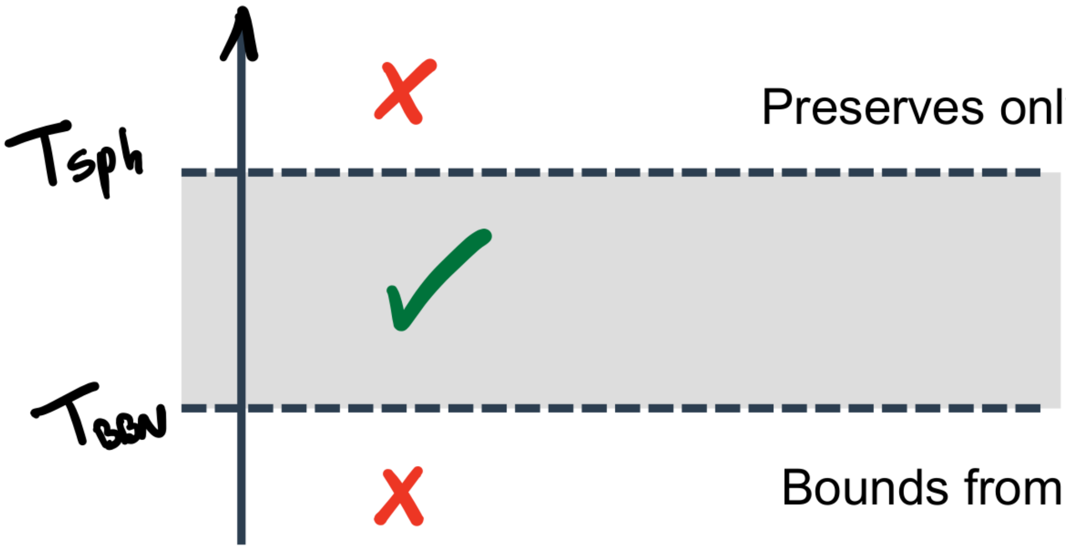
We do not want that.

Baryogenesis Model

Example: **Low-temperature Baryogenesis**

Generate the B asymmetry directly through out-of-equilibrium decays

Window: $T_{BBN} < T_{baryogenesis} < T_{Sphalerons}$



Preserves only B-L $\rightarrow$ Wash-out of ΔB

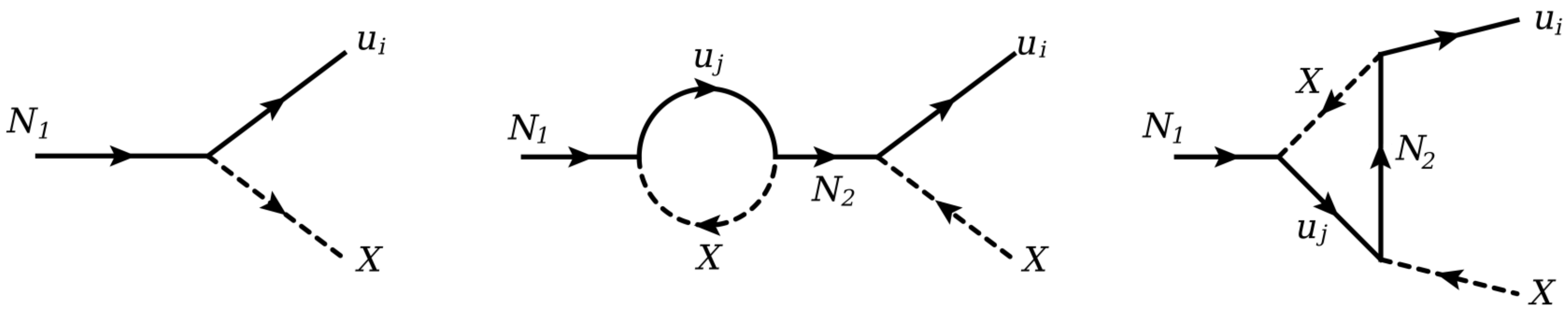
Bounds from nucleosynthesis, BBN, ...

Baryogenesis Model

Need:
- **2 flavors of N_α** α **=1,2.**
- **1 colored X**

$$\Delta\mathcal{L}_{\text{Baryogenesis}} = \lambda_{i\alpha} N_\alpha u_i^c X + \lambda'_{ij} d_i^c d_j^c \bar{X} - M_\alpha N_\alpha N_\alpha + M_X^2 X \bar{X}$$

Decay of N1 generates the baryon asymmetry



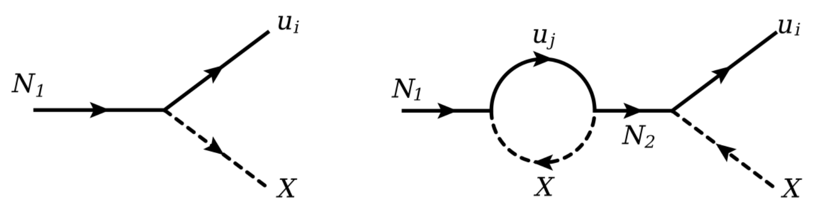
Baryogenesis Model

- **Assume that N1 was efficiently produced in the early universe.**
- **Calculate the Baryon asymmetry from N1's Yield and the CP asymmetry.**

$$Y_{\Delta B} = \frac{n_{N_1}}{s}\left(\frac{\Gamma(N_1 \to B) - \Gamma(N_1 \to \bar{B})}{\Gamma(N_1 \to \text{tot})}\right) \equiv Y_{N_1}\epsilon_{CP}^{N_1}$$

$$\frac{Y_{\Delta B}}{8.7\times 10^{-11}} = \left(\frac{213.5}{g_{*,S}(T_{FO})}\right)\left(\frac{3\mathcal{F}_S(1.5)+\mathcal{F}_V(1.5)}{15.3}\right)\left(\frac{|\lambda_{u2}|\sin^{1/2}\phi}{2.3\times 10^{-4}}\right)^2$$

$\Phi \to$ Phases of the couplings in the interference of:



Asymmetric Dark Matter

What about dark matter?

Same story: **Copy** $\Delta\mathcal{L}_{\text{Baryogenesis}}$ **with the the Z_2 symmetry**

(We do not want hard Z_2 breakings)

Allowed soft breakings:

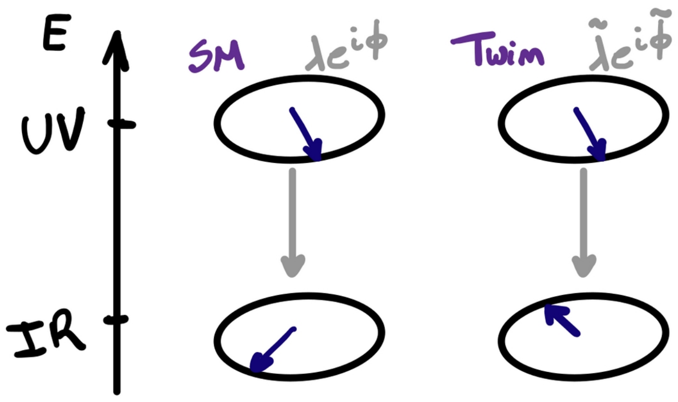
- **Soft f/v breaking:** **Twin N masses get lifted**
  - CP asymmetry depends on the ratio of twin N_1 and N_2 masses
    - **Not very effective in changing the baryon asymmetry in the twin sector**
- **Soft phase breaking:** **CP violating phase is not fixed for the twin sector**

Twin Baryogenesis

Different phases between the SM and the Twin sectors

- **Phases do not reintroduce the Hierarchy Problem**

- A priori, no reason for equal phases since we do not provide any mechanism that generate them



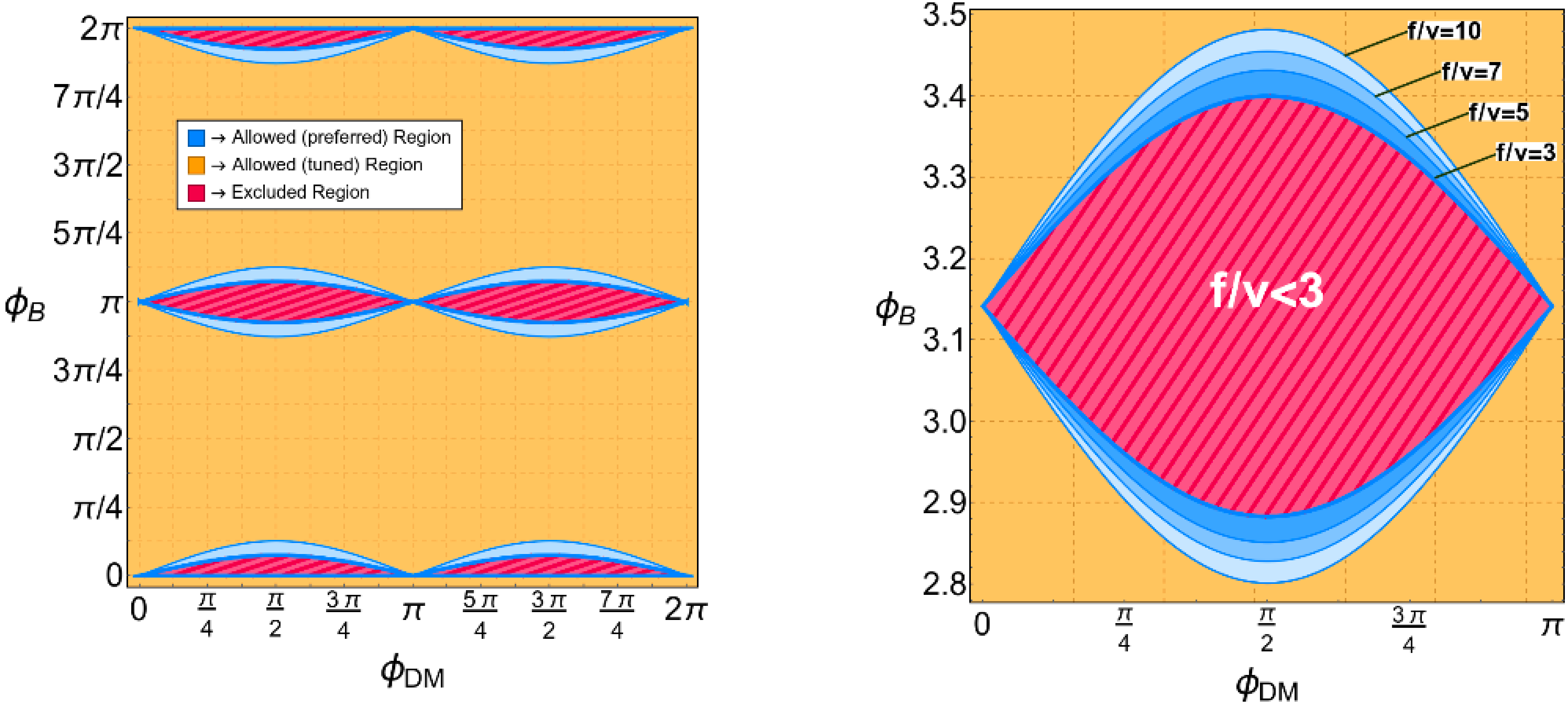
Analogies:

- "Vacuum misalignment"
- "Ferromagnets"
- "Twin CKM phase"

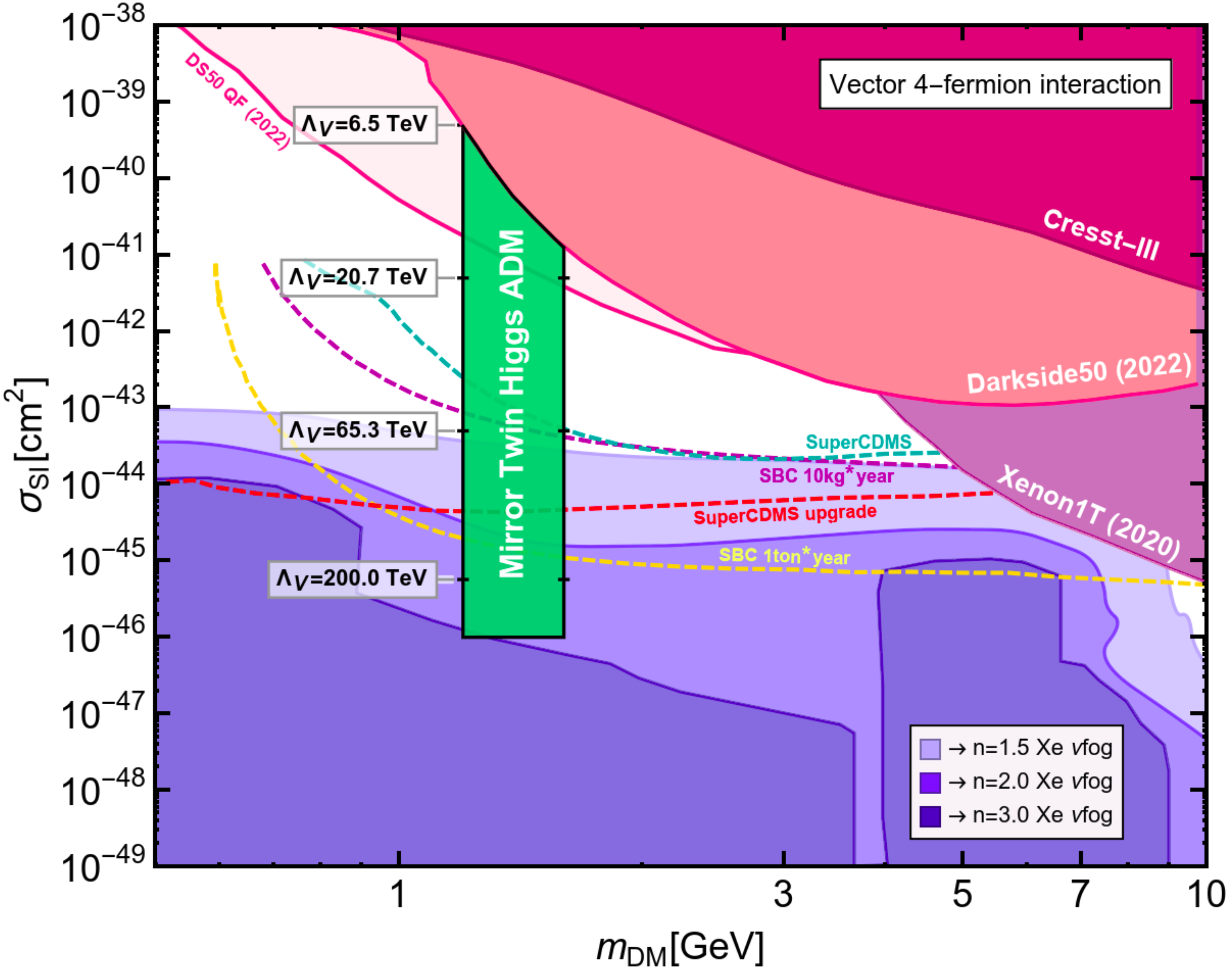
The same reasoning apply to different baryogenesis models:
i.e. High temperature Leptogenesis

Twin Baryogenesis

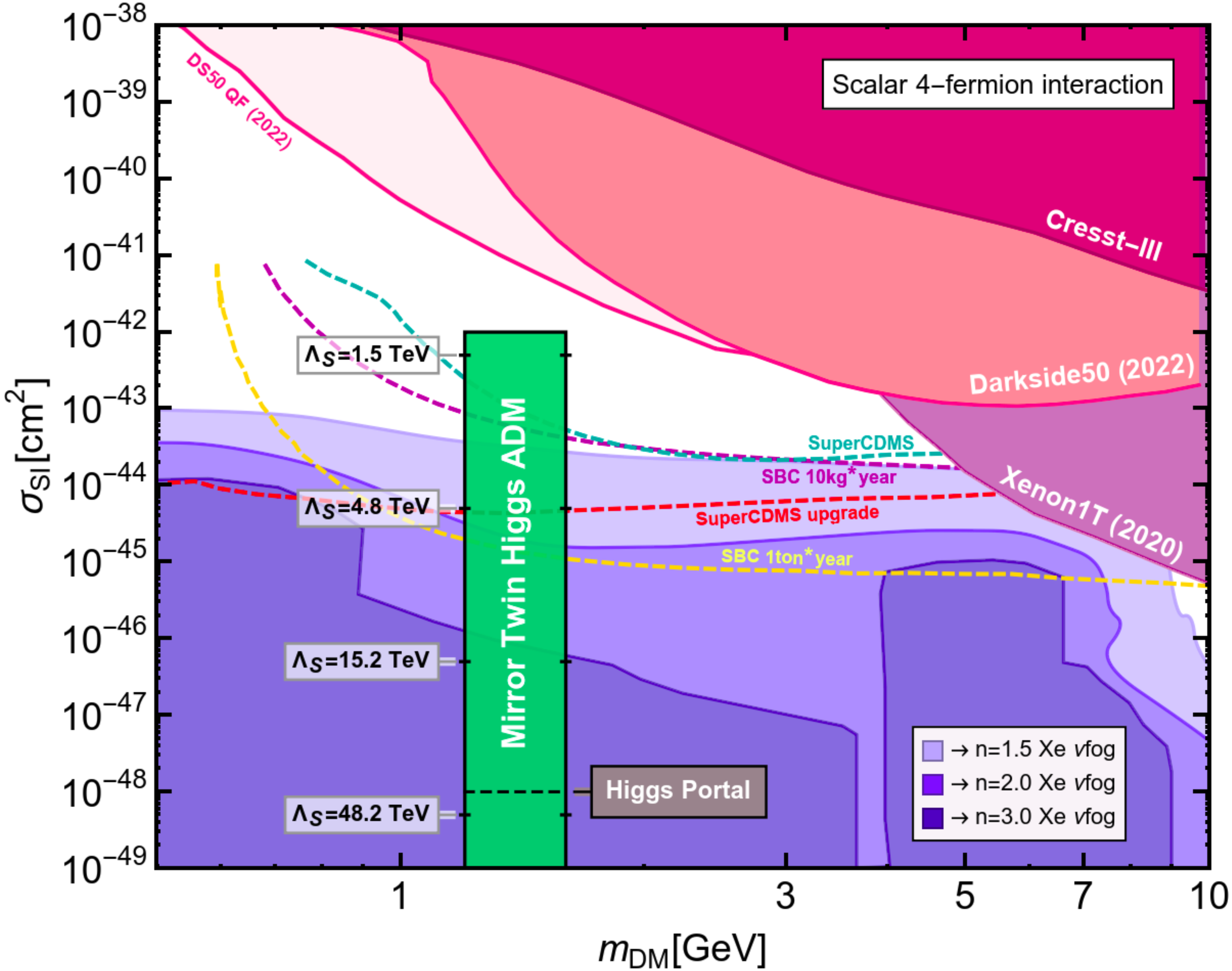
Different phases between the SM and the Twin sectors



Direct Detection: Vector interaction



Direct Detection: Scalar interaction



What about the LHC?

Low temperature Baryogenesis $\leftrightarrow$ New colored particles at TeV

- Theory-motivated models of GeV DM might start receiving attention once we reach the neutrino fog.

$\rightarrow$ Low scale baryogenesis is specially interesting for the Twin Higgs.

- Scalar di-quarks/Leptoquarks
- Hadronic displaced vertices

From the Twin Higgs side $\rightarrow$ New physics is naturally hidden

- Higgs couplings modifications
- Higgs invisible decays

Theory motivation for experiment

Summary

1. Twin Higgs as a sandbox for connecting different BSM phenomena

2. Baryogenesis model $\xrightarrow{Z_2 \text{ Copy}}$ DM genesis model

3. Phase misalignment: CP violating phases can be different in the mirrored sector

4. Look forward for direct detection around ~1 GeV!

Thank you!