



Domain Walls in extended Higgs sectors: Electric Charge Violation, CP-violation and Electroweak Symmetry Restoration

Mohamed Younes Sassi under supervision
of **Gudrid Moortgat-Pick**

CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

Domain Walls

- **Domain walls** are a type of **topological defects** that arise after a **spontaneous symmetry breaking (SSB)** of a theory with a discrete symmetry.
- After **spontaneous symmetry breaking**, different regions of the universe can **fall into different vacua** which are **degenerate** with each other.

Example:

$$V(\phi) = \mu\phi^2 + \lambda\phi^4$$
$$\mathbf{Z}_2: \phi \rightarrow -\phi$$

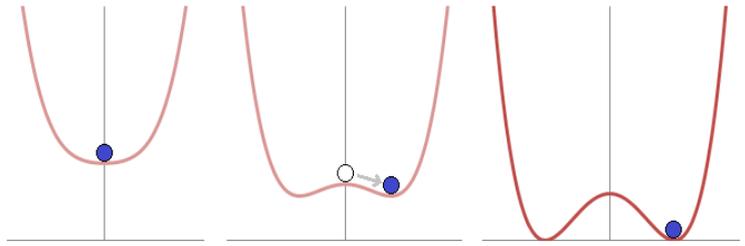
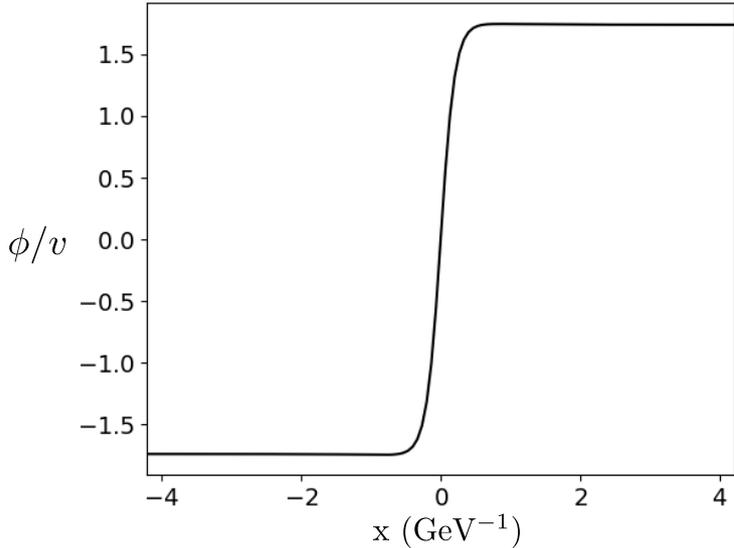
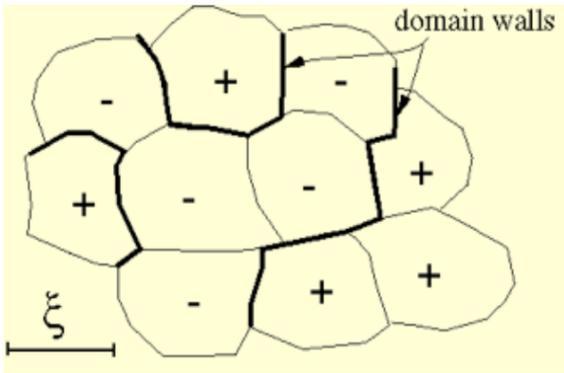


Fig. from wikipedia



The domain wall solution interpolates between the two vacua.

Fig. from https://www.ctc.cam.ac.uk/outreach/origins/cosmic_structures_two.php

We consider the (N)2HDM:

Extend the SM with an **extra Higgs doublet** and a **Higgs singlet**:

$$\begin{aligned}
 V(\Phi_1, \Phi_2, \Phi_s) = & m_{11}^2 \Phi_1^\dagger \Phi_1 + m_{22}^2 \Phi_2^\dagger \Phi_2 + m_{12}^2 (\Phi_1^\dagger \Phi_2 + h.c) + \frac{\lambda_1}{2} (\Phi_1^\dagger \Phi_1)^2 \\
 & + \frac{\lambda_2}{2} (\Phi_2^\dagger \Phi_2)^2 + \lambda_3 (\Phi_1^\dagger \Phi_1) (\Phi_2^\dagger \Phi_2) + \lambda_4 (\Phi_1^\dagger \Phi_2) (\Phi_2^\dagger \Phi_1) + \left[\frac{\lambda_5}{2} (\Phi_1^\dagger \Phi_2)^2 + h.c \right] \\
 & + \frac{m_S^2}{2} \Phi_s^2 + \frac{\lambda_6}{8} \Phi_s^4 + \frac{\lambda_7}{2} \Phi_s^2 (\Phi_1^\dagger \Phi_1) + \frac{\lambda_8}{2} \Phi_s^2 (\Phi_2^\dagger \Phi_2). \quad \text{\textit{N2HDM singlet contribution}}
 \end{aligned}$$

Z₂ symmetry

$$(m_{12}^2 = 0)$$

$$\Phi_1 \longrightarrow \Phi_1$$

$$\Phi_2 \longrightarrow -\Phi_2$$

$$\Phi_s \longrightarrow \Phi_s$$

Z'₂ symmetry

$$\Phi_1 \longrightarrow \Phi_1$$

$$\Phi_2 \longrightarrow \Phi_2$$

$$\Phi_s \longrightarrow -\Phi_s$$

Vacuum Parametrization

$$\Phi_i(x) = U(x) \hat{\Phi}_i(x)$$

$$\hat{\Phi}_1(x) = \begin{pmatrix} 0 \\ v_1(x) \end{pmatrix}, \hat{\Phi}_2(x) = \begin{pmatrix} v_+(x) \\ v_2(x) e^{i\xi(x)} \end{pmatrix}$$

$$U(x) = e^{i\theta(x)} \exp\left(i \frac{g_i(x)}{2} \sigma_i\right)$$

Possible Vacua in the 2HDM:

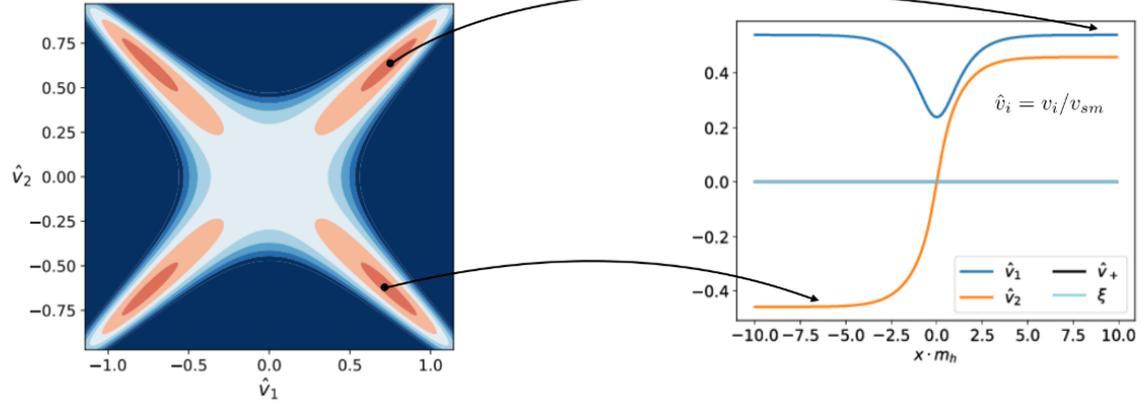
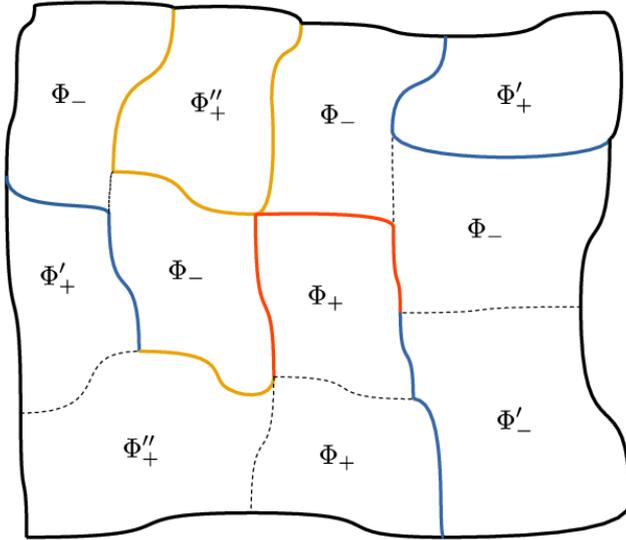
- ▶ **Neutral Vacua** $v_+ = 0, \xi = 0$
- ▶ **CP breaking Vacua** $\xi \neq 0, v_+ = 0$
- ▶ **Charge breaking Vacua** $v_+ \neq 0$

+

$$\Phi_s(x) = v_s(x)$$

Singlet VEV

After EW symmetry breaking, the universe is **seperated** into regions with **different vacua** that are degenerate. They can have **different signs** and **different Goldstone modes**.



$$\Phi_+ = (v_1, v_2, \theta_0, g_1, g_2, g_3) \quad \Phi_- = (v_1, -v_2, \theta_0, g_1, g_2, g_3)$$

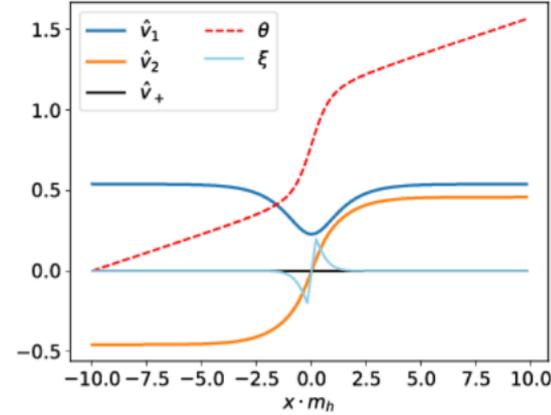
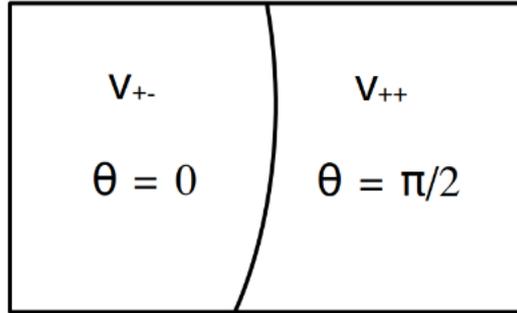
$$\Phi'_+ = (v_1, v_2, \theta', g'_1, g'_2, g'_3) \quad \Phi''_- = (v_1, -v_2, \theta'', g''_1, g''_2, g''_3)$$

Two domains Φ_+ and Φ_- having the same Goldstone modes



Vacuum inside the wall is neutral

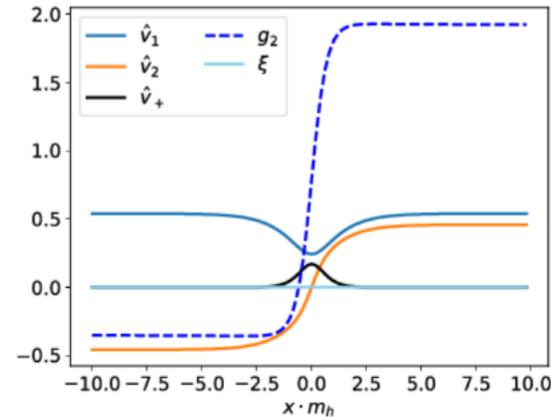
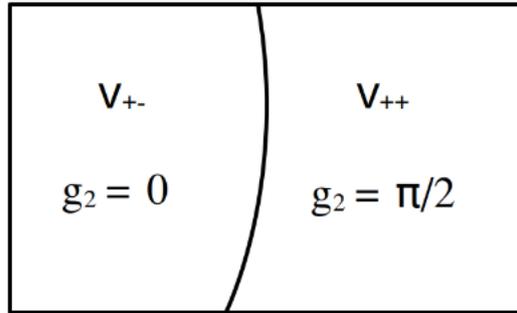
Domain wall for two vacua with different hypercharge angle θ



This leads to the **phase $\xi(x)$** between the two doublets being **non zero inside** the domain wall.

► **CP violation inside the domain wall.**

Domain wall for two vacua with different SU(2) angle g_2



$v_+(x) \neq 0$ inside the domain wall.

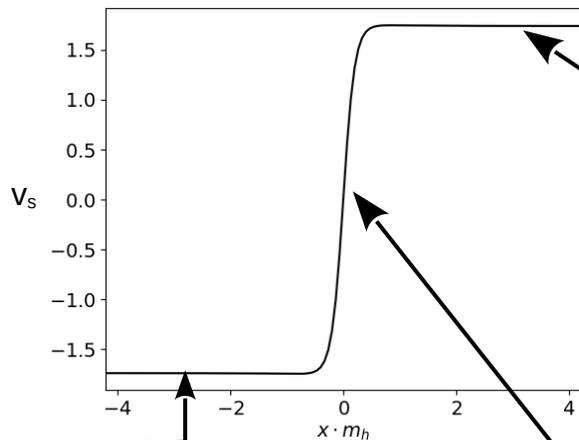
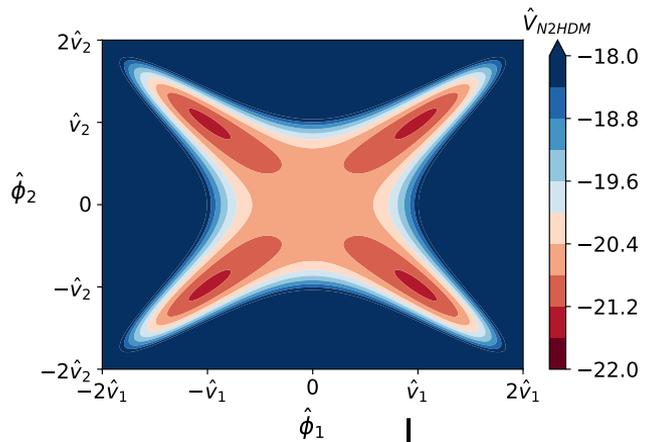
► **This leads to electric charge breaking effects and a massive photon inside the domain wall.**

Electroweak Symmetry Restoration via Domain Walls

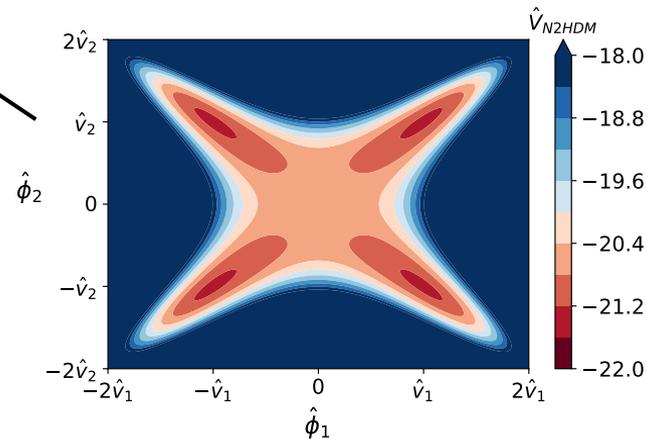
$v_1 > 0, v_2 > 0, v_s < 0$

$v_1 > 0, v_2 > 0, v_s > 0$

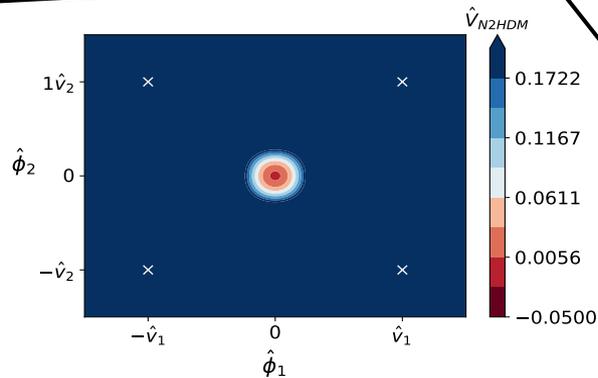
Potential of doublets at $-v_s$

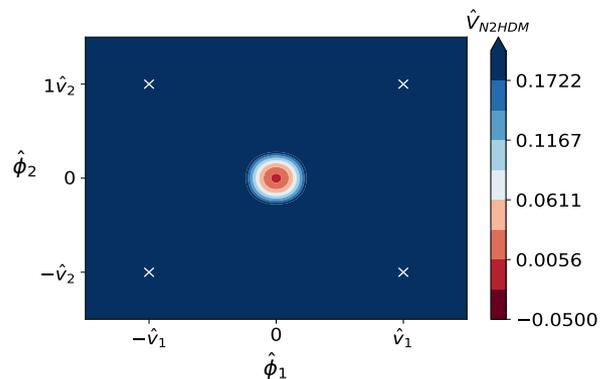
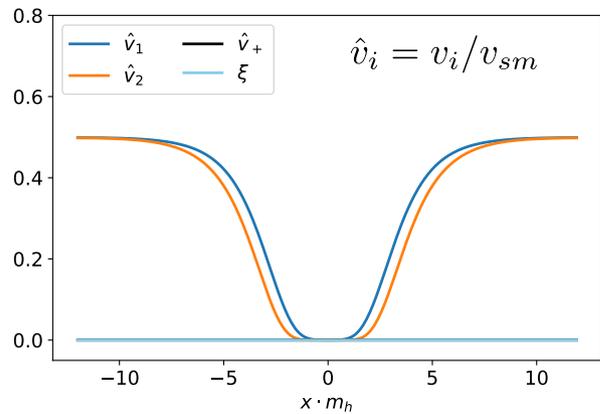


Potential of doublets at v_s

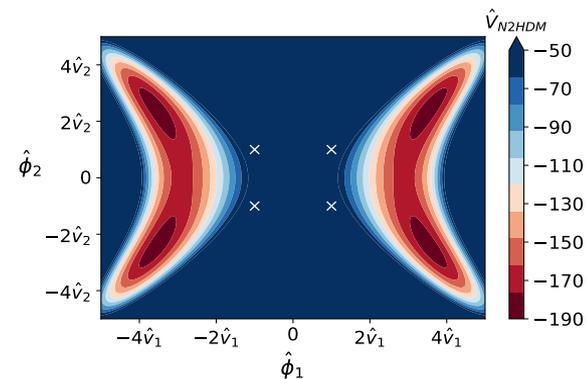
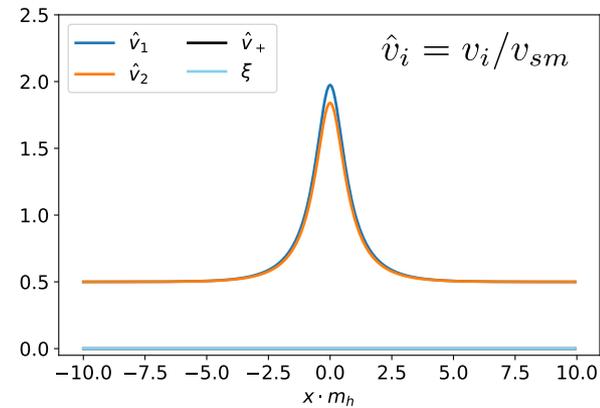


Potential of doublets at $v_s = 0$





The VEVs v_1 and v_2 **get smaller** inside the wall



The VEVs v_1 and v_2 **grow** inside the wall

Join me at my poster to know more!