BPS Cho–Maison magnetic monopole

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Magnetic monopole in the Standard Model?

Two main paradigms for a field theoretical description of a magnetic monopole:

- 't Hooft–Polyakov monopole:
  - Traditional paradigm (1974)
  - Based on topology of the vacuum manifold G/H
  - In order that it exist, it must be $\pi_2(G/H) \neq \{1\}$
  - This is, however, not the case in SM: $\pi_2(SU(2) \times U(1)/U(1)) = \{1\}$
  - $\Rightarrow$ no 't Hooft–Polyakov monopole in SM!

✗

- Cho–Maison monopole:
  - Alternative paradigm (1996)
  - Desired non-trivial topology is found in the target space of the normalized Higgs field $H = \frac{1}{\sqrt{2}}(v + \sigma)\xi$, where $\xi^\dagger \xi = 1$
  - Set of all ξ form the complex projective space $\mathbb{C}\mathrm{P}^1$ (due to $U(1)_Y$ invariance)
  - But $\pi_2(\mathbb{C}\mathrm{P}^1) = \pi_2(S^2) = \mathbb{Z}$
  - $\Rightarrow$ Cho–Maison monopole can exist SM!

✓

Infinite monopole mass and the solution

Indeed, magnetic monopole solution can be found!

- But there's a problem: It has infinite mass!
- However, this can be cured by going beyond SM and modifying the $U(1)_Y$ kinetic term (Cho, Kim, Yoon, 1997) as

$$-\frac{1}{4}B_{\mu\nu}B^{\mu\nu} \quad \longrightarrow \quad -\frac{1}{4}\epsilon\, B_{\mu\nu}B^{\mu\nu}$$

  where ϵ is some positive function of $|H|^2$
- If $\epsilon(0) = 0$, the mass of the monopole comes out finite!

However, since ϵ is in principle arbitrary, is the monopole mass also arbitrary?

- This type of questions is solved by BPS limit of a given theory:
  - Equations of motions are of the first order
  - The solutions satisfy the lower energy (Bogomolny) bound
- For the 't Hooft–Polyakov monopole obtaining a BPS limit is easy
- What about the BPS limit of the Cho–Maison monopole?

The result

We derived a whole class of BPS theories that support Cho–Maison monopole:

- Turns out that, in contrast to 't Hooft–Polyakov monopole, it is not enough just to switch off the scalar potential, but also the gauge sector has to be non-trivially modified:

$$\mathcal{L}_{\mathrm{BPS}} = |D_\mu H|^2 - \frac{v^2}{4g^2|H|^2} h^2 \left(\mathrm{Tr}\left[F_{\mu\nu}^2\right] - \frac{2}{|H|^4} \mathrm{Tr}\left[F_{\mu\nu} H H^\dagger\right]^2 \right) - \frac{1}{4}\left(\frac{h'}{g|H|^2} \mathrm{Tr}\left[F_{\mu\nu} H H^\dagger\right] + \frac{f'}{g'} B_{\mu\nu} \right)^2$$

  where h, f' are some function of $|H|^2$

- We we able to find exact solutions
- Most importantly, we found the universal lower mass bound for the Cho–Maison monopole:

$$M \geq \frac{2\pi v}{g} \approx 2.37\ \mathrm{TeV}$$

Based on:

P. B., F. Blaschke, PTEP 2018 (2018) no.7, 073B03, `arXiv:1711.04842`

GUT INSPIRED GAUGE-HIGGS UNIFICATION MODEL

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2006.02157 [hep-ph]

GAUGE-HIGGS UNIFICATION MODEL

- 5D Randall-Sundrum spacetime
- Gauge Symmetry $SU(3) \times SO(5) \times U(1)$
- Higgs boson is the fifth dimensional component of the gauge field

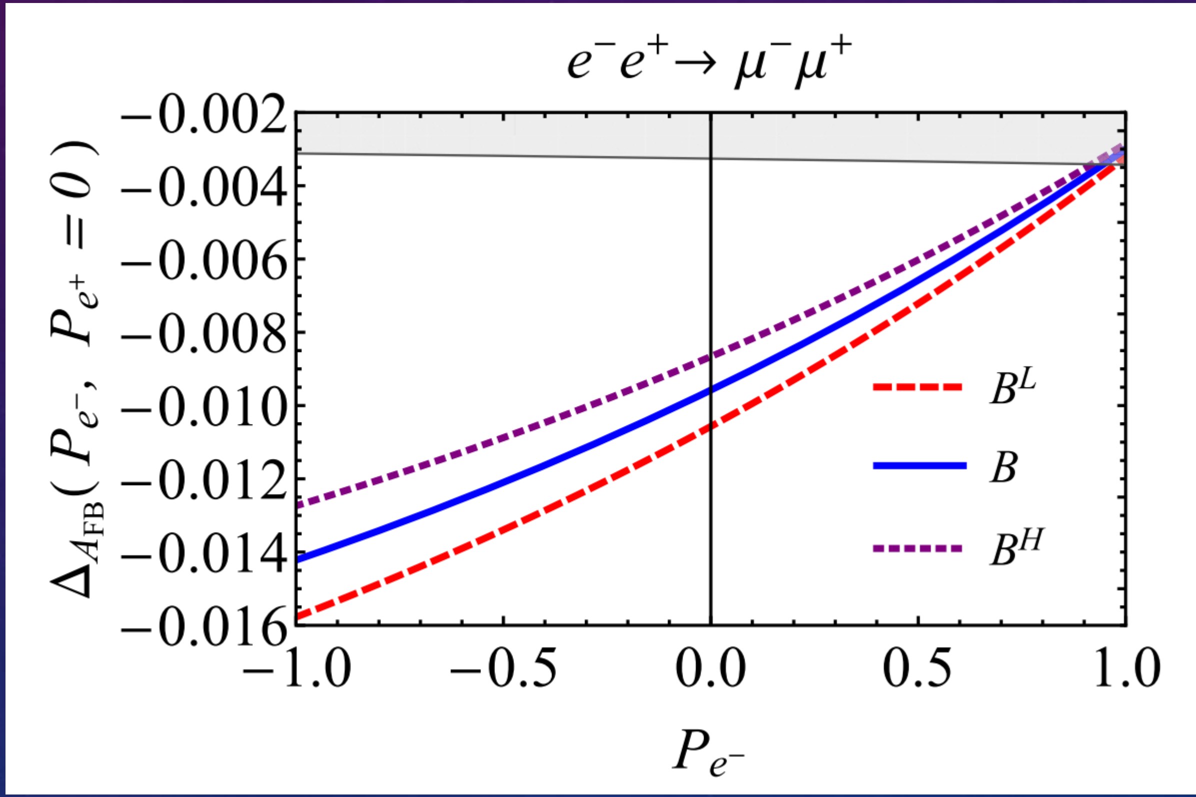
⇨ One solution of the hierarchy problem

COLLIDER

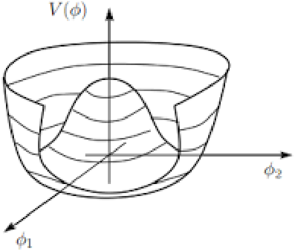
- Z′ bosons are heavy (>10 TeV)
- LHC doesn’t observe the signal
- GHU models have large parity violation

⇒ ILC can detect the asymmetry

FORWARD-BACKWARD ASYMMETRY



A gauge invariant description of phase transitions



Andreas Ekstedt

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2020.07.30
(arXiv:2006.12614)

Phase transitions via the effective potential

Transition from phase A to phase $B \implies$ Critical temperature, latent heat,...

Inconsistent power counting $\implies$ Gauge dependence, IR divergences, missing terms,...

Resummations

N-loop diagrams scale as $V_N \sim Tm^3(\frac{\lambda T^2}{m^2})^{N-1}$

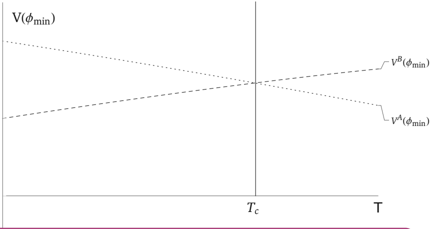
$\implies$ Needs to be resummed

Resummations must be done consistently

$V(\phi_{min})$ is physical

Should be finite and gauge independent

Must be evaluated carefully



Observables at T_c

The phase transition occurs at $T = T_c$:

$\left[V^A - V^B\right]_{T_c} = 0$

Perturbative Calculations

$$V(\phi) = V_{\text{LO}}(\phi) + \hbar V_{\text{NLO}}(\phi) + \dots$$

Only extrema of $V(\phi)$ are physical ($\partial V = 0$)

$\hbar$-expansion | Traditional method

Find V_{min} order-by-order

$$\phi_{\text{min}} = \phi_{\text{LO}} + \hbar\phi_{\text{NLO}} + \dots$$

$$[\partial V_{\text{LO}}]_{\phi=\phi_{\text{LO}}} = 0,$$

$$\left[\partial V_{\text{NLO}} + \phi_{\text{NLO}}\partial^2 V_{\text{LO}}\right]_{\phi=\phi_{\text{LO}}} = 0$$

$$\vdots$$

Critical temperature

The two phases coincide when

$$T_c = T_{\text{LO}} + \hbar T_{\text{NLO}}$$

$$\left[V^A_{\text{LO}} - V^B_{\text{LO}}\right]_{T=T_{\text{LO}},\phi=\phi_{\text{LO}}} = 0,$$

$$\vdots$$

Find V_{min} "numerically"

$$\partial V(\phi)_{\phi_{\text{min}}} = 0$$

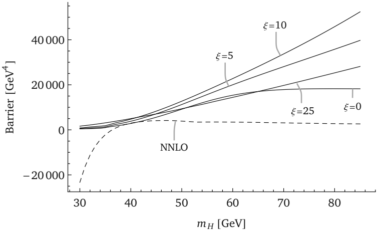
Both ϕ_{min} and $V(\phi_{\text{min}})$ are gauge dependent

Critical temperature

$$\left[V^A - V^B\right]_{T_c,\phi_{\text{min}}} = 0.$$

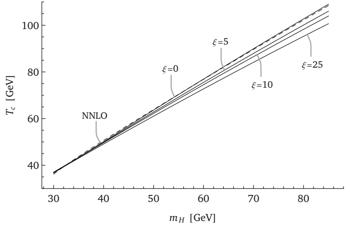
$\implies$ T_c and ϕ_{min} used to evaluate other observables

$\implies$ Spurious gauge dependence



Comparison

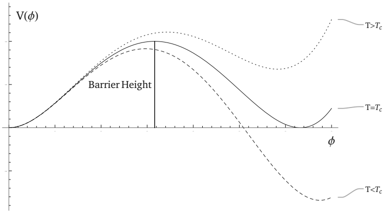
Traditional vs $\hbar$-expansion



Barrier height

Gauge dependent

Large finite pieces



Critical temperature

Result coincide with the $\hbar$-expansion

Small radiative corrections