Connecting the Swampland Program with Potential Discoveries at the LHC

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I’m Yuta Hamada at KEK. I recently work on the Swampland program.

I am asked to talk about ``what would be interesting at the LHC from my viewpoint”.

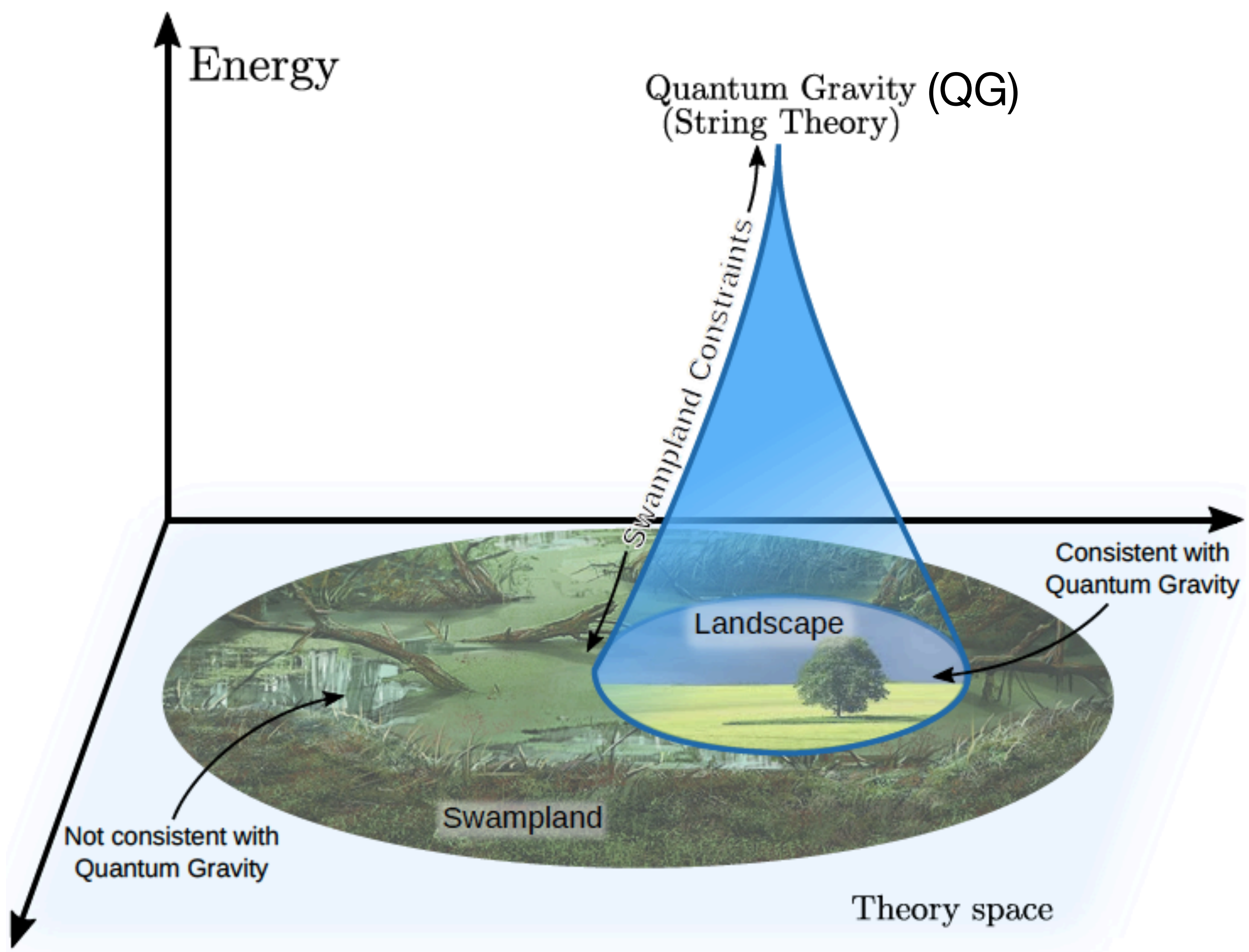
I decided to talk about:
Suppose LHC find something, (combined with Swampland conjecture) what can we from that?

More specifically,
if LHC finds $\mathbb{Z}_N$ symmetry, what can we say? → topological defect is predicted.

Swampland

Landscape: EFT compatible with Quantum Gravity.

Swampland: EFT incompatible with Quantum Gravity.



[Figure from Beest, Calderon-Infante, Mirfendereski, Valenzuela ’21]

No Global Symmetry

Statement: No Global Symmetry in QG.

[…, Banks-Dixon ’88, …, Banks-Seiberg ’10, …, Harlow-Ooguri ’18, …]

Perturbative string　　BH　　Holography

There are no discrete and continuous global symmetries.

For example, there are no $\mathbb{Z}_N$ and $SU(2)$ global symmetries.

The Conjecture also applies to new notion of symmetry such as higher form symmetry and non-invertible symmetry.

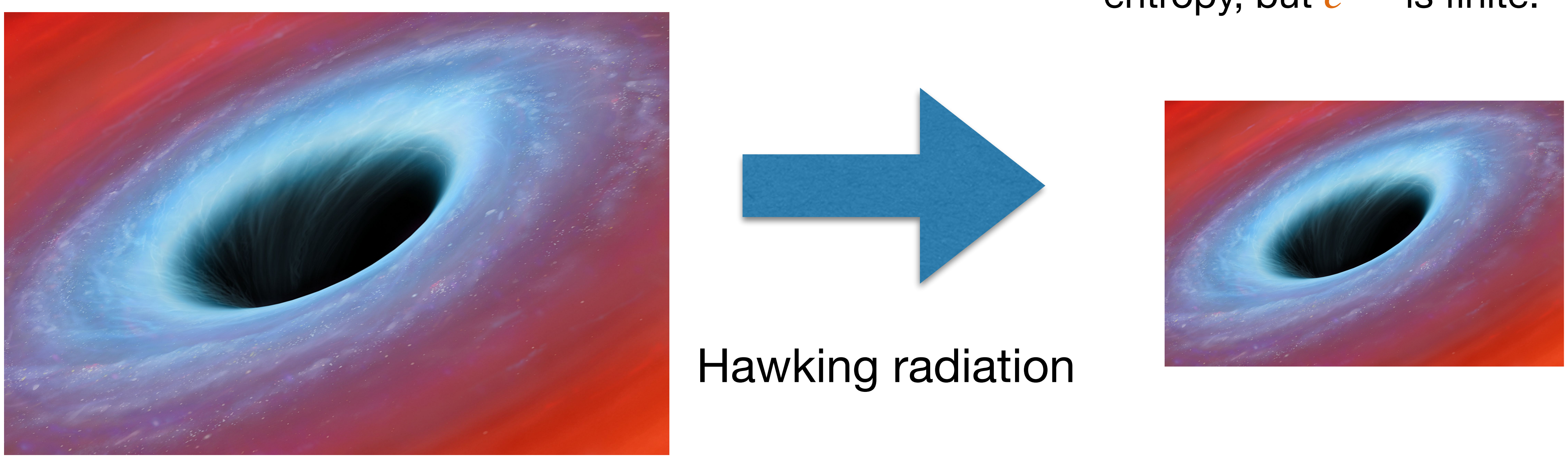
The global symmetry at the boundary of the spacetime is OK.
(e.g. AdS/CFT)

Relation to Black Hole

Suppose there is $SU(2)$ global symmetry.

By throwing Spin J matter into BH, the BH with an arbitrarily $SU(2)$ charge is constructed.

Distant observer cannot distinguish $SU(2)$ charge. The number of indistinguishable state contributes to entropy, but $e^{S_{BH}}$ is finite.



$S_{BH} = A/4.$

A: BH area.

Solutions

Solution(1) Explicit braking.

There are no global symmetries.

Solution(2) Gauging

The distance observer can see the black hole charge through the electric field.

Discovery

Suppose LHC discovers a particle charged under $\mathbb{Z}_N$.

e.g. $\mathbb{Z}_2$ odd scalar dark matter.

What can we learn from this?

From No global symmetry Conjecture,

$\mathbb{Z}_2$ is either broken or gauged.

We assume gauged option since there is something interesting in this case.

Global vs Gauge: $U(1)$

What is difference btw global and gauge symmetry?

Case of $U(1)$:

Global $U(1)$. Transformation $\phi \to e^{i\alpha}\phi$. α is constant.

Gauged $U(1)$. Transformation $\phi \to e^{i\alpha(x)}\phi$. $\alpha(x)$ depends on x.

→ gauge field A_μ is introduced for invariance.

Only gauge invariant quantities are meaningful.

Gauge symmetry is just a redundancy of description.

Global vs Gauge: $\mathbb{Z}_2$

Case of $\mathbb{Z}_2$ is puzzling.

Hard to imagine $\phi \to \pm \phi$ depends on x. If transformation is continuous, then $\phi \to +\phi$ or $\phi \to -\phi$ for all x.

Consequently, gauge field A_μ is not introduced.

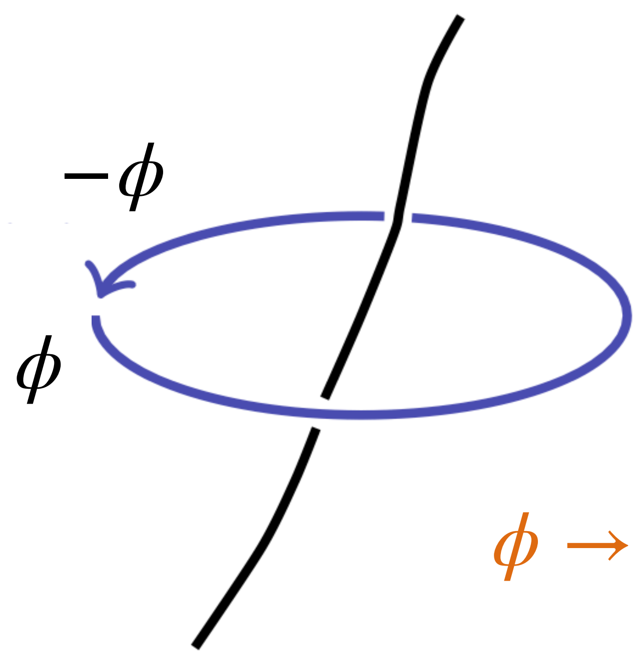
Only gauge invariant quantities are meaningful.

I do not go into detail of formulation, but just show a physical difference.

Global vs Gauge: $\mathbb{Z}_2$

What is difference btw global and gauge $\mathbb{Z}_2$ symmetry?

An answer: If $\mathbb{Z}_2$ is gauged, there is string.



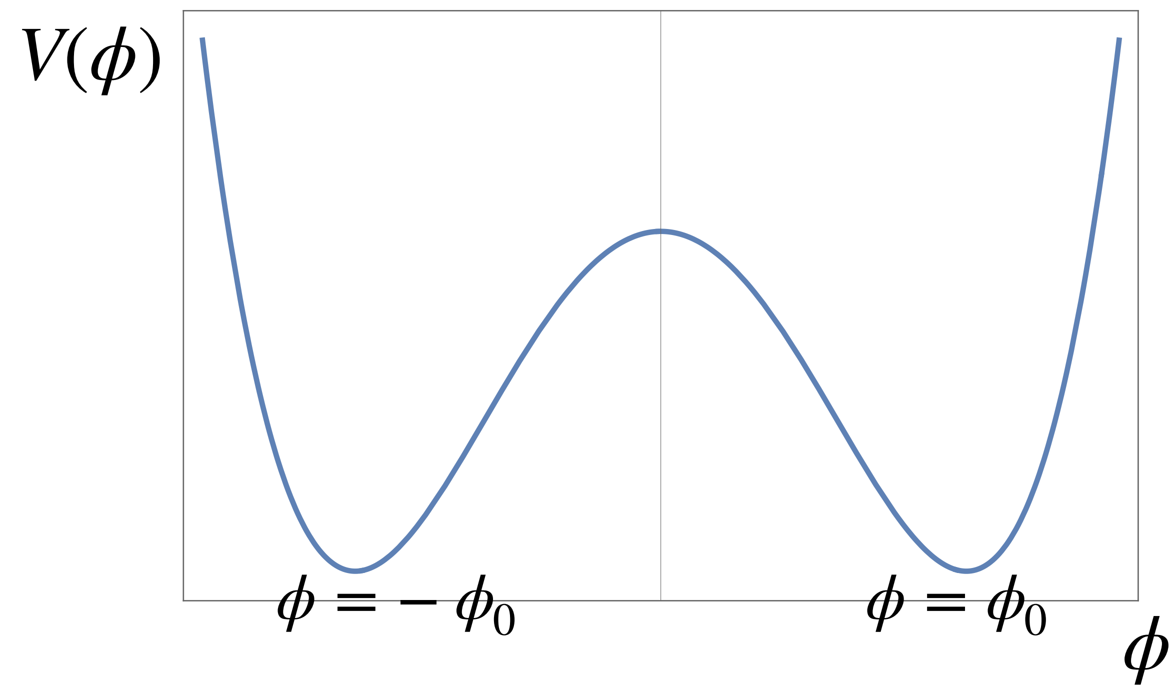
$\phi \to -\phi$ by rotating around string.

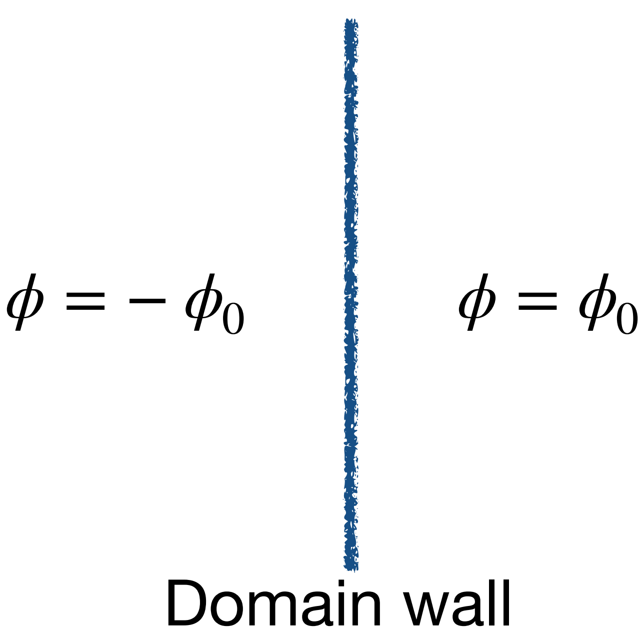
Domain wall

Why string is needed?

Suppose ϕ has a potential.

Two vacua related by $\mathbb{Z}_2$ gauge symmetry.





Domain wall and String

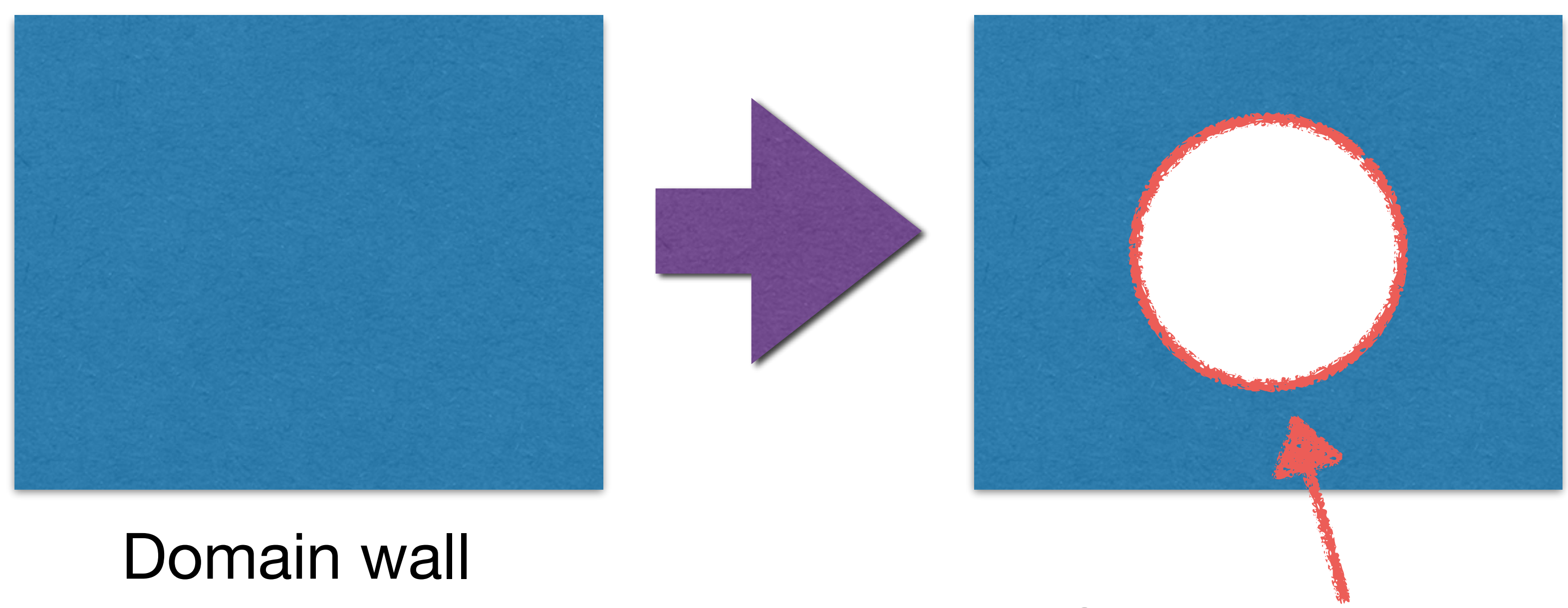
$\phi = -\phi_0$ | $\phi = \phi_0$

Domain wall

$\phi = \pm\phi_0$ is related by $\mathbb{Z}_2$ gauge sym.

$\phi = \phi_0$ and $\phi = -\phi_0$ are the same vacua.

Domain wall connecting same vacua must be unstable.



Domain wall

Creation of string

String is needed to make domain wall unstable.

Example

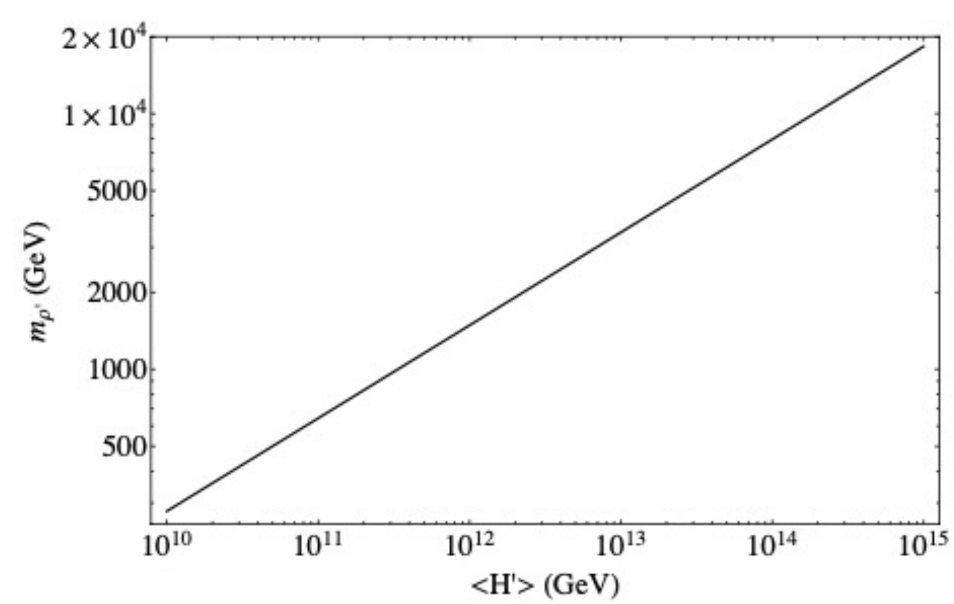
A model [Hook '14] solving the strong CP problem utilizes $\mathbb{Z}_2$ symmetry.

Standard Model ⟺ Mirror Standard Model

$\mathbb{Z}_2$

Prediction: Colored particle at TeV scale.

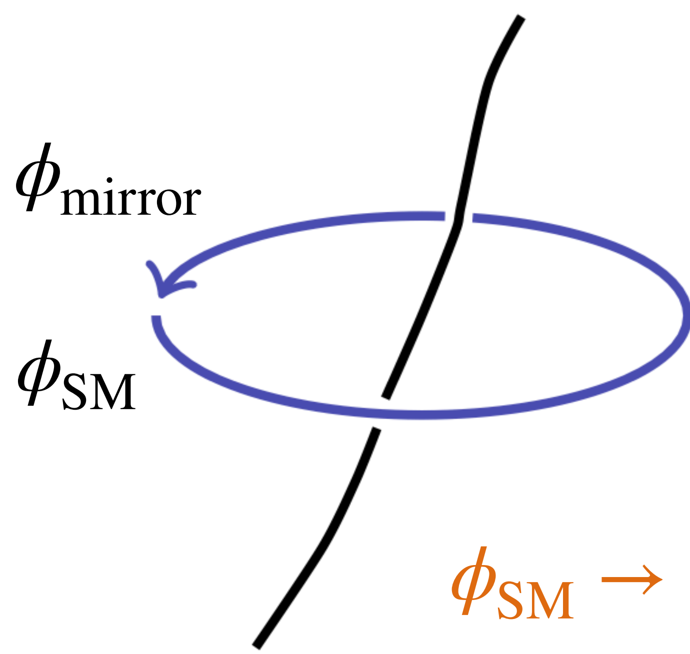
Chance to test at LHC.



$\mathbb{Z}_2$ string

Suppose this model is correct. What can we learn?

If $\mathbb{Z}_2$ exchange is gauged, there is string.



$\phi_{\mathrm{SM}} \to \phi_{\mathrm{mirror}}$ by rotating around string!

Potentially important for early cosmology?

Summary

- LHC may reveal $\mathbb{Z}_N$ symmetry.
- From Swampland Conjecture, $\mathbb{Z}_N$ is either broken or gauged.
- If gauged, new topological defect is predict, which may play a role in our world.