Higgs Coupling 2018 @ 両国
2018 Nov 26 -30

My highly-biased

Vision for High Energy Physics

- From strings to Higgs - (title given by the organizers)

Satoshi Iso (KEK & Sokendai)

The first half of my talk is

Bottom-up approach to the Higgs

Understanding Higgs sector is essential for the early universe.

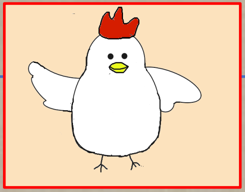
"QCD-induced EW phase transition" Serpico, Shimada, SI ('17)

The second half is

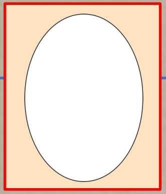
Top-down (stringy) approach to the Higgs

- an alternative view of the naturalness problem -

"Which came first, the chicken or the egg? " Kitazawa, SI ('18)
Ohta, Suyama, SI('18)



or



Bottom-up approach to the Higgs

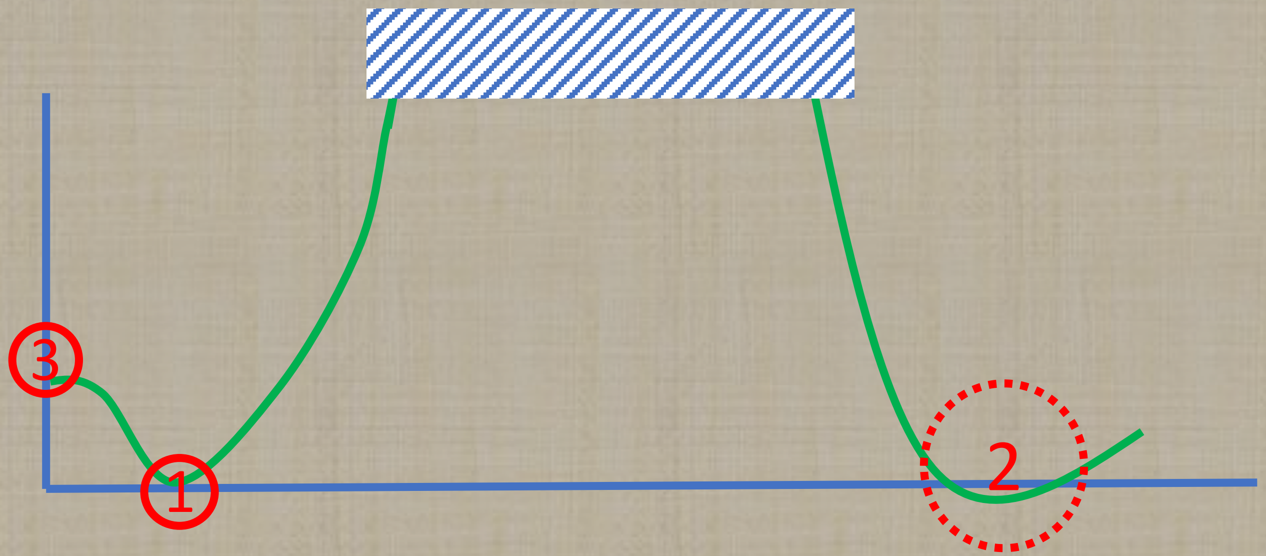
- QCD induced EW phase transition -

P. Serpico, K. Shimada, SI
PRL 119 (2017) 141301

We have now many experimental data about the Higgs sector

including Higgs mass, Higgs VEV, quartic coupling, Yukawa couplings

→ Rough picture of the Higgs potential: (at least) 3 important points



1 Higgs VEV v= 246 GeV → SM (present universe)

2 UV scale $M_{UV} > 10^{10}$ GeV or M_{Planck}

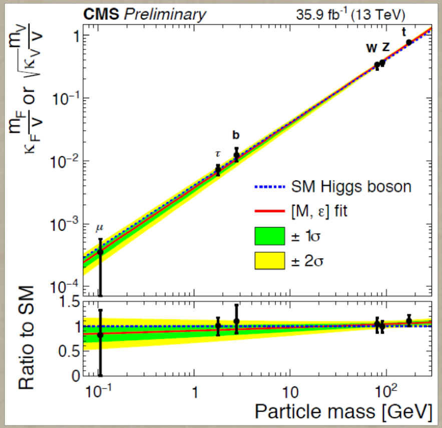
→ gravity, string theory & origin of Higgs

3 h=0 (origin) → history of the early universe

The behaviors around 2 and 3 control the early universe,
but they are only indirectly accessible by using RG and theoretical biases.

Particle physics has changed drastically after the discovery of Higgs

A. Nature seems to be much simpler than we had expected.

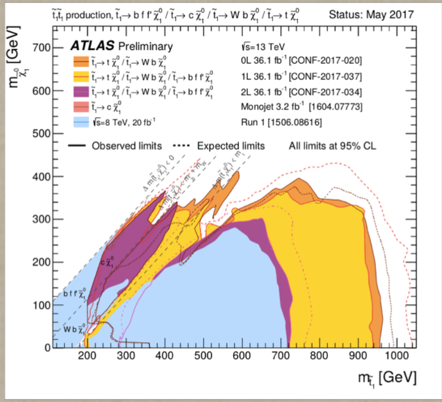


No deviations from the SM:

Higgs VEV <h>= 246 GeV seems to control almost all the properties of the SM.

B. Stringent constraints on SUSY particles

→ urges us to reconsider naturalness of EW scale M_{EW}



Naturalness against ...

M_{SUSY} = 10 TeV ?

$M_{instability}$ = 10^{10} GeV?

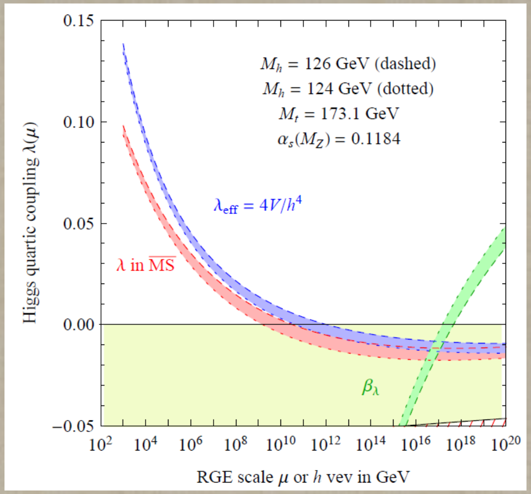
M_{GUT} = 10^{16} GeV ?

M_{Planck} = 10^{18} GeV ?

Alternative to TeV SUSY

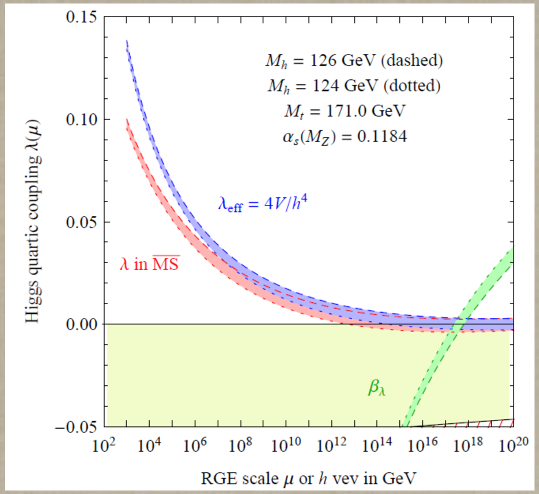
C. Higgs mass m=125 GeV indicates that

Higgs is directly connected with Planck scale physics.



or

The situation is still suble



Figures taken from Degrassi et. al (2012)

Instability of vacuum at 10^{10} GeV ?

EW scale is directly connected with the Planck scale

It is indicative that both of λ and its β-function vanish around M_{Planck} .

D. Higgs is NOT a mere "particle" but the "dictator of the vacuum".

This is the reason why Higgs is so important to be explored.

F. Higgs will be a portal to BSM.

But why do we need to go beyond SM?

The common answer is, of course,

1. SM is not complete.
   Dark matter, neutrino oscillation, Baryon asymmetry

(2. GUT is a beautiful idea; but it is not mandatory)

(3. Gravity is not included; but it is an issue of quantum gravity)

In addition, more (or most) important will be

4. We do not know anything about the origin of Higgs potential.

So at present, a good candidate of BSM will be

as *simple* as possible, but *phenomenologically viable*

and

possible to *explain the shape of the Higgs potential*.

Okada, Orikasa, SI ('09)

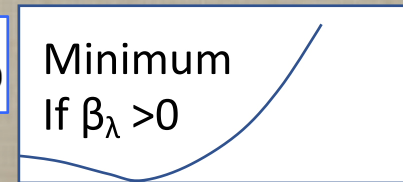
A simple solution for EW symmetry breaking is

"Classically conformal extension of SM"

no quadratic term at UV & no intermediate scales up to Planck

→ Coleman-Weinberg (radiative) symmetry breaking

$$V(\phi) \sim \frac{\lambda}{4}\phi^4 \left(\ln \frac{\phi^2}{M^2} - \frac{1}{2}\right) + V_0$$



Classically conformal (B-L) extension of SM
with flat Higgs potential at Planck

IR physics

Standard Model + **B-L sector**
- $U(1)_{B-L}$ gauge
- SM singlet scalar
- Right-handed ν

No intermediate scales

UV physics

Planck scale
V(h)=0

(1) Free from naturalness problem (since no intermediate scales)

Logarithmic corrections control the IR dynamics

Corrections from M_{pl} physics are left to string theory (discussed later)

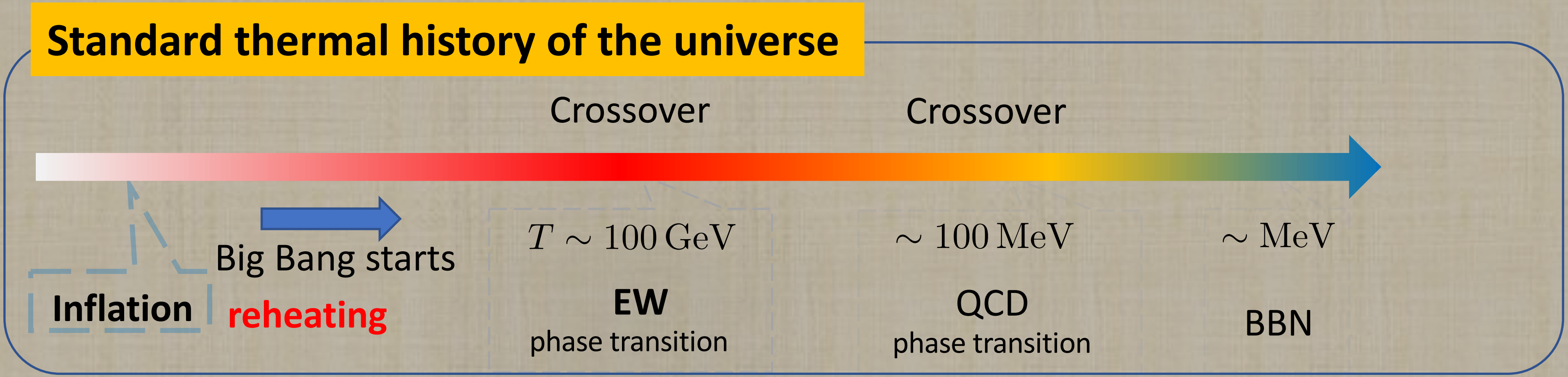
(2) Occam's razor scenario, and phenomenologically viable

neutrino oscillation, resonant leptogenesis, DM candidate (right-handed ν)

The model is very simple,

Serpico, Shimada, SI ('17)

but its cosmological consequence is drastically different.

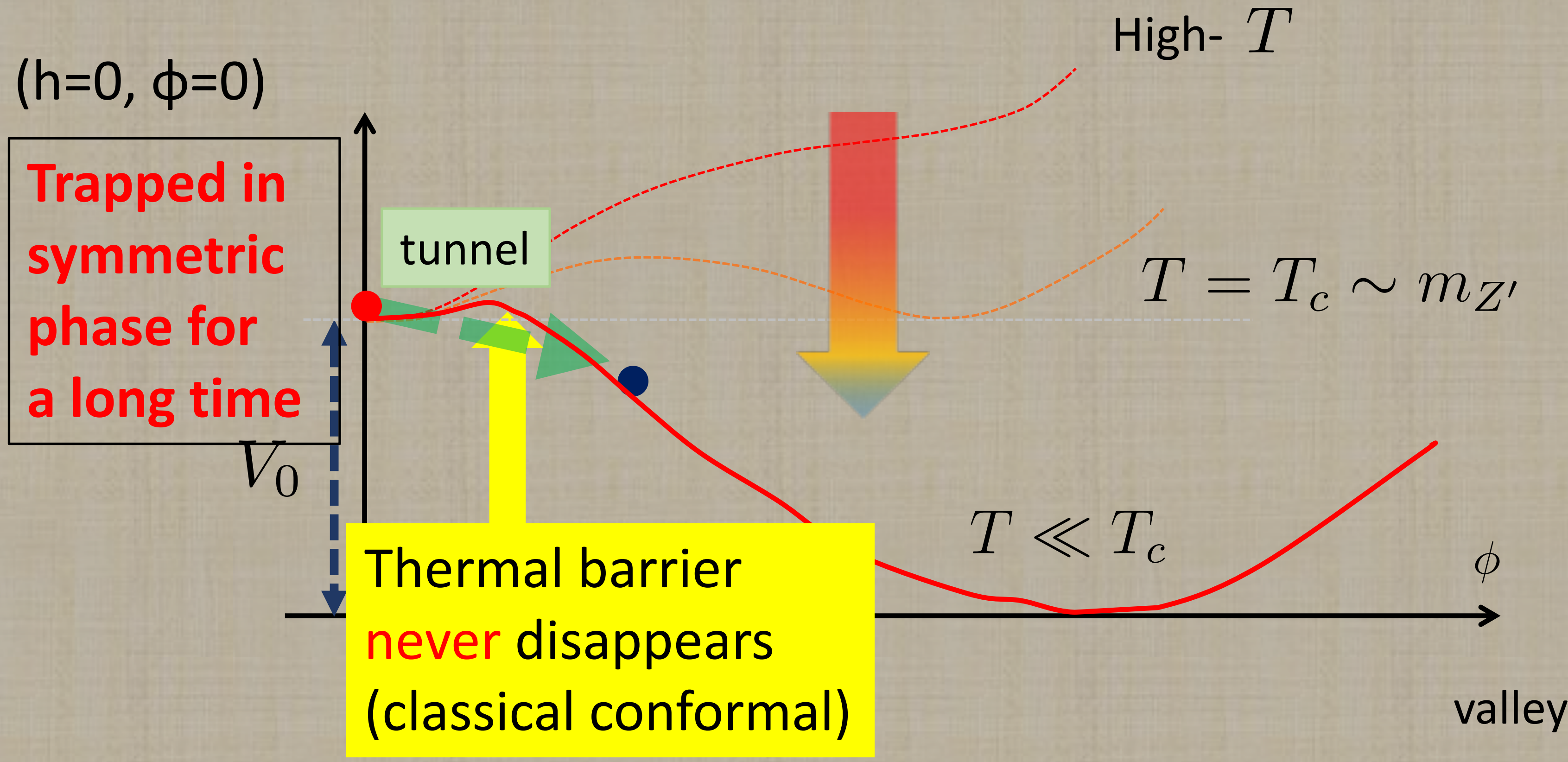


In the CW scenario, supercooling occurs in the EW sector

The vacuum is in the symmetric phase <h>=0
until T decreases to 100 MeV.

QCD χSB induces EWSB.

Supercooling of (B-L)+EW → PT much below T_C



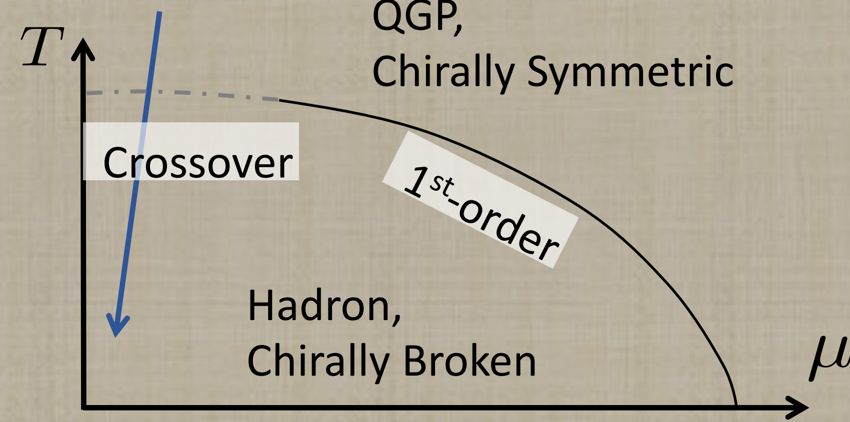
Bubble of true vacuum is created by tunneling.

Serpico, Shimada, SI ('17)

When temperature decreases down to 100 MeV at (ϕ=0, h=0)

$$\langle \bar{q}_i q_i \rangle \sim \Lambda_{\rm QCD}^3$$

In the standard scenario
with N_f =(2+1)
→ crossover



In the present case, since h=0
all N_f =6 quarks are massless !
→ 1^{st} order phase transition for $N_f \geq 3$

Pisarski Wilczek (1983)

Serpico, Shimada, SI ('17)

$$\langle \bar{q}_i q_i \rangle \sim \Lambda_{\rm QCD}^3$$

Higgs linear term is generated via Yukawa interaction

$$y_i h \langle \bar{q}_i q_i \rangle \sim (y_i \Lambda_{\rm QCD}^3) h$$

Witten (81)
Buchmuller et al (90)
Kuzmin et.al.(92)

The linear term induces EWSB.

Interesting phenomenological consequences

e.g.

(1) Stochastic gravitational waves from 1st order phase transition

Jinno, Takimoto ('17)
Hashino et.al. ('18) ...

(2) Super-cool dark matter

Hambye et.al. ('18)

Message of the first half of my talk

A simple model for Higgs potential predicts rich phenomenology.

To Understand Higgs sector = to understand the Universe.

It is why Higgs is so important !!

Top-down approach to the Higgs

- String theoretical view of our universe -

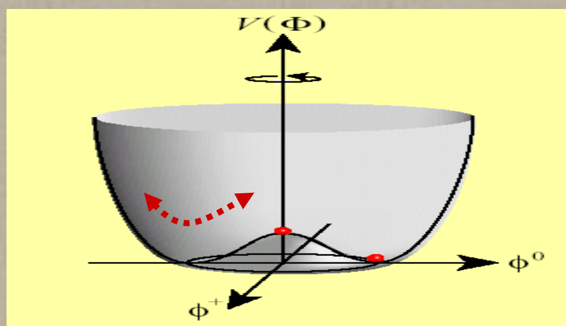
N. Kitazawa, SI ('15)
H. Ohta and T. Suyama ('18)
to appear

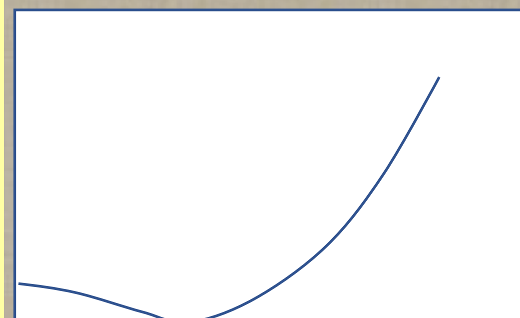
In a field theoretic approach,

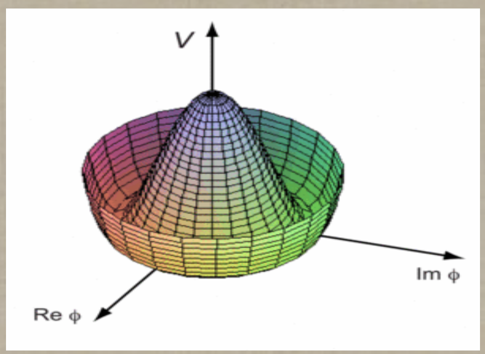
there are many different proposals to solve the hierarchy problem.

But there is one common basic assumption:

"Calculate the Higgs potential first !"



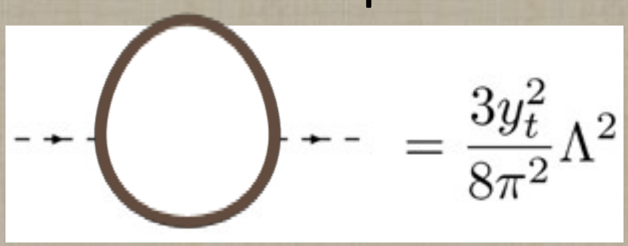




And then obtain a solution = minimum of the potential.

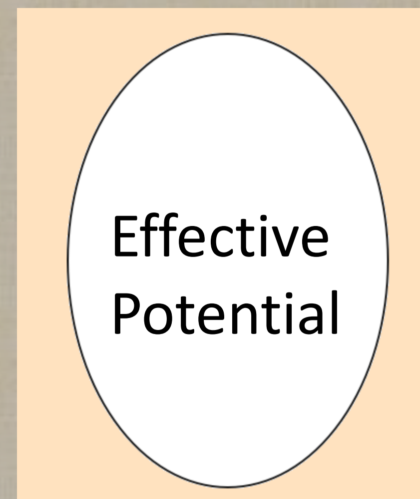
one solution to one Higgs potential

→ Then we are faced with the naturalness problem



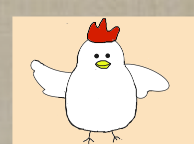
Which came first, the chicken or the egg ?

or

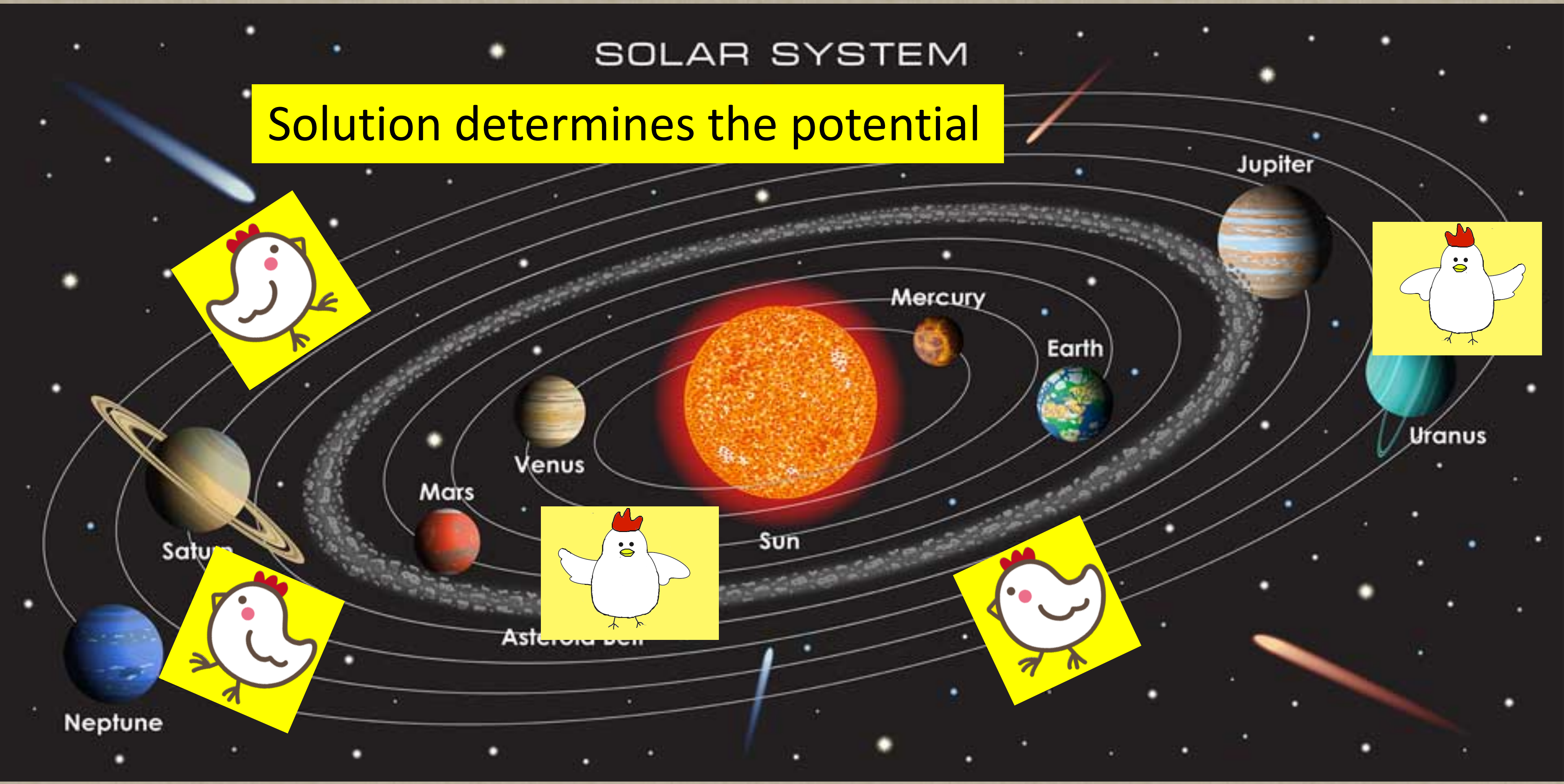


?

Usually calculate the potential first, then obtain a solution.

Instead obtain a solution first  , then calculate the potential 

A classical example of the Chicken-first approach

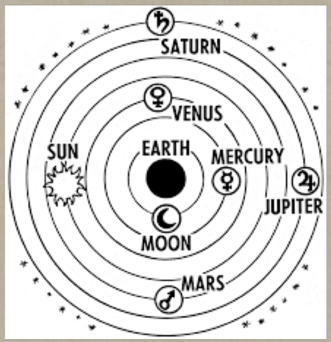


There are many orbits around the Sun;
each orbit is at the bottom of the corresponding potential.
But the underlying dynamics is the same.

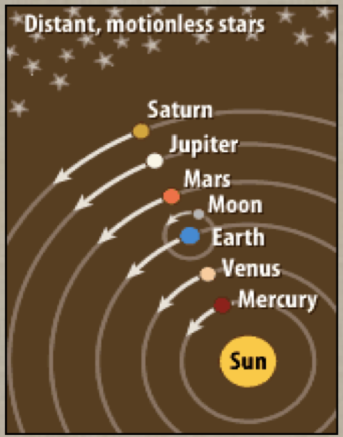
A similar mechanism
to dynamically generate the EW scale?

Our view of the universe has been expanded ... and

"Nature is always much beyond our imagination."

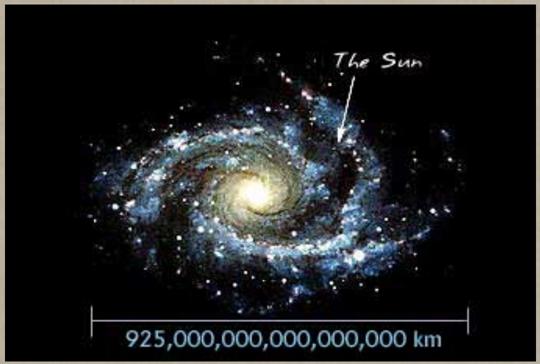


Ptolemy model



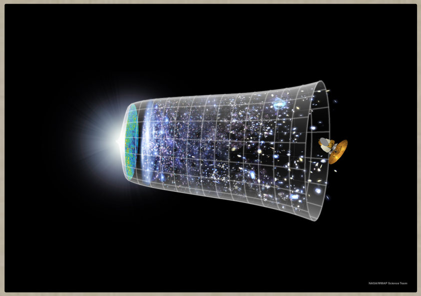
Solar system

Copernican model



Galaxy with billions of stars

Thousands of garaxies



Universe

String theory tells us that it is NOT the end.

multiverse

d=10

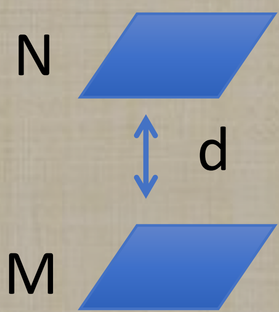
D-branes ...

Stringy view of our "universe" and "Higgs" sector:

[1] (3+1)-dimensional space-time is embedded in d=9+1.
Either compactification or brane-world scenario

[2] Higgs (scalar) field is a geometrical "moduli" field
e.g. distance between D-branes
volume / shape of extra-dimension etc.

[3] VEVs of moduli fields are proportional to the geometrical size.



D-branes

U(N+M) → U(N) × U(M)

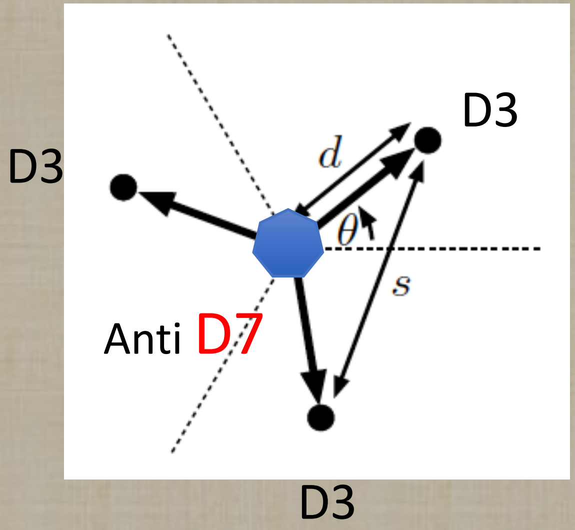
$$d = \frac{M}{M_s^2}$$

The natural scale of M should be the string scale, not the EW scale.

Hierarchy problem in string theory
= Difficulty to generate much shorter scale than the string length

([4] quantum parallel universe = multiverse, not discussed here)

An example of D-brane configurations for SM



Attractive force between D3s and anti-D7 due to open string 1-loop amplitudes

$$\mu^2 \sum_a |Z_3^{(a)}|^2$$

$$\mu^2 = \frac{1}{C^2}\frac{g^2}{16\pi^2}M_s^2$$

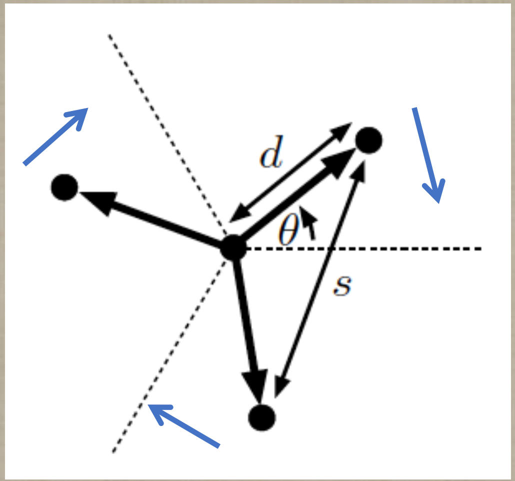
1-loop suppressed

Repulsive centrifugal force by revolution of D3s

→ **Solution:** Hierarchy of EW scale

$$M \ll M_s$$

N.Kitazawa SI PTEP,2015



High angular frequency $\omega = \mu \sim \frac{g}{4\pi}M_s$

Low velocity $v = \omega d \sim \frac{v_0}{M_s} \ll 1$

It is possible to make a classically stable state with a short distance

$$d \ll l_{string}$$

Such short distance region is described by low energy modes of open strings (D-brane EFT) instead of closed strings (supergravity).

→ Hierarchy problem can be avoided by using the chicken-first approach in string theory

But the large angular frequency causes two serious problems

$$\omega = \mu \sim \frac{g}{4\pi} M_s$$

- Lorentz symmetry is violated in the dispersion relation of Higgs field (Coriolis force) .
- closed string emission → unstable

To avoid large angular frequency, we need weaker attractive force

→ BPS configuration of D-branes

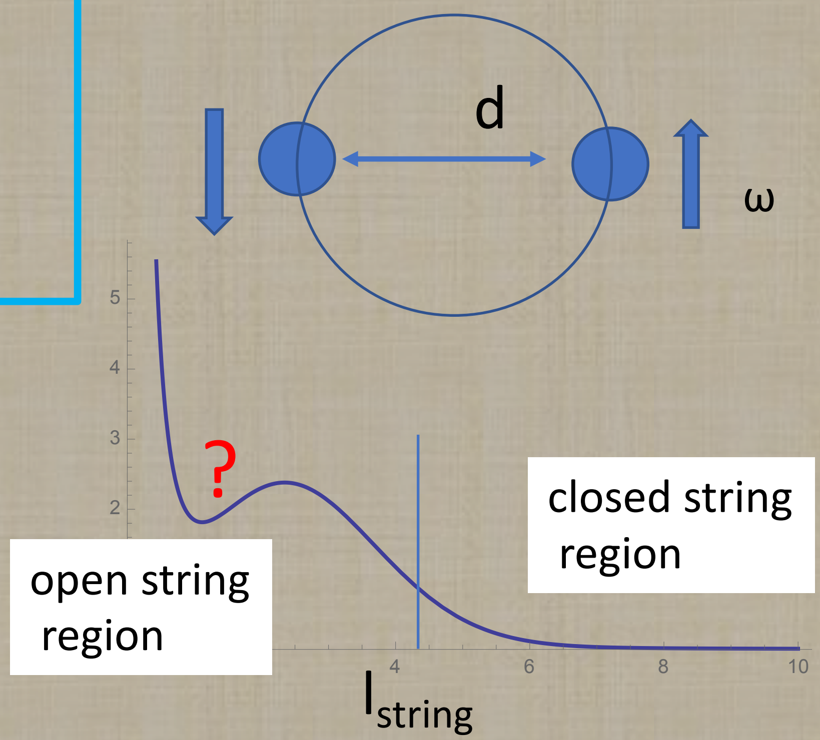
no-force (flat potential) at rest,

but attract each other when they are moving.

Is it possible to make
a "sufficiently stable resonant state"
of D-branes
with $d \ll l_{string}$ and $\omega \ll m_{string}$?

chicken-first approach.

Nothing to worry about naturalness.



H. Ohta and T. Suyama ('18) to appear

Experimental test of the "chicken-first scenario" of hierarchy problem

Lorentz violation in the Higgs sector
(Coriolis force for Higgs field since it is geometrical.)

$$\omega^2 = M^2 + (1 + \frac{4\omega_0^2}{M^2})p^2 + 16\frac{\omega_0^4}{M^6}p^4 + \cdots$$

N. Kitazawa, SI ('18)
to appear

Message of the second half of my talk

In string theory, Higgs has a geometrical meaning.
And if it is stabilized by stationary motion,
it will be tested (or falsified) by looking at
a tiny violation of Lorentz invariance in the Higgs sector.

It is another reason why Higgs is so important.

Summary

QCD-induced EW PT

Higgs physics @ LHC + ILC + ...	early universe →	String theory space-time physics
← Lorentz violation in Higgs		

naturalness
stability
Yukawa couplings

Dark matter
Baryogenesis
Inflation, PBH, ...

moduli = geometry
SUSY breaking
Dark energy

- Higgs is NOT a mere particle, but the dictator of the dark universe.
- Higgs sector may be directly connected with String.
- Scrutinizing the Higgs physics leads us to go beyond the horizon of our universe.

A final message of my talk
anything beyond our imagination can happen in the Higgs sector

That is why Higgs is so important.