Flux Compactification and SUSY Phenomenology

Komaba07

On occasion of Prof. Yoneya's 60th birthday

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Talk Plan

- Introduction : Flux compactification and KKLT set-up
- Naturalness Problem of Weak Scale
- Warped Superstring Compactification
- SUSY phenomenolog: mirage mediation

String Theory

Candidates for

1) Quantum Gravity (Yoneya)

2) Ultimate Unified Theory
   - gauge structure
   - matter representations
   - generations
   - Yukawa couplings
   - secret of weak scale

   ….

→ I will discuss possible implications to TeV scale physics.

Moduli Stabilization:
A long-standing problem

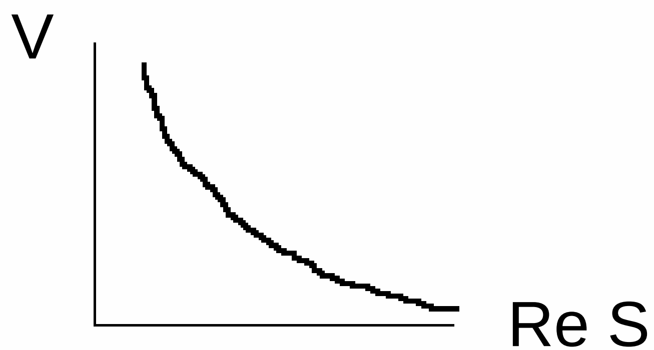
- Moduli/Dilaton Stabilization
  – Moduli have not been stabilized at tree level.
  – Non-perturbative effects important

- Why moduli?
  – structure of compact dimensions
  – gauge & matter structure
- if light moduli
  – SUSY breaking
  – Cosmological implications

Gaugino condensate: runnaway potential

$$W \sim M_{Pl}^3 \exp(-aS)$$

exponetial superpotential
→ runaway scalar potential



How to avoid runaway?
race track : multiple gaugino condensates
non-perturbative corrections to Kaehler potential
………

Flux Compactificatons

- Switch on Fluxes: $H_{(3)}$ and $F_{(3)}$ type IIB side
- Consistent solution
- Complex moduli & dilaton are stabilized

T_α:	Kaehler moduli
z_i:	complex moduli
$S = -i\tau$:	dilaton

- IIB superstring
  - 2-form potential (NS-NS, RR) $B_{(2)}, \; C_{(2)}$
  - 3-form field strength $H_{(3)} = dB_{(2)}, \; F_{(3)} = dC_{(2)}$

- superpotential for IIB theory

$$W = \int_{\mathcal{M}} \Omega \wedge G_{(3)}$$

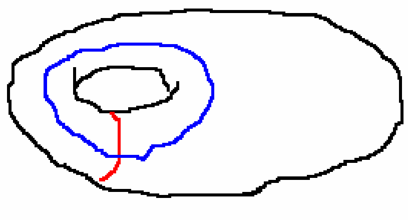
Gukov-Vafa-Witten '99

$$G_{(3)} = H_{(3)} - \tau F_{(3)}$$

$\Omega(\sim \epsilon_{abc} dx^a \wedge dx^b \wedge dx^c)$: (3,0) form

- complex moduli

$$z_i = \int_{A_i} \Omega, \quad \mathcal{G}_i(z) = \int_{B_i} \Omega$$



- quantization of fluxes

$$\frac{1}{(2\pi)^2\alpha'} \int_{A,B} H_{(3)} = \text{integer}, \quad \frac{1}{(2\pi)^2\alpha'} \int_{A,B} F_{(3)} = \text{integer}$$

$$W = \sum_i \left[\int_{A_i} \Omega \int_{B_i} G_{(3)} + \int_{B_i} \Omega \int_{A_i} G_{(3)} \right]$$

$$= \sum_i \left[z_i \int_{B_i} G_{(3)} + \mathcal{G}_i(z) \int_{A_i} G_{(3)} \right]$$

→ superpotential for complex moduli (z) and dilaton (τ)

- Consistent solution for flux compactifications in IIB
  - fluxes → warped throat (Klebanov-Strassler throat)
  - W stabilizes complex moduli as well as dilaton
  - Kaehler moduli are not stabilized by fluxes

Giddings-Kachru-Polchinski 02

KKLT set-up

Kachru-Kallosh-Linde-Trivedi 03

- Potential for Kaehler moduli:

  ← non-perturbative effects

  e.g. gaugino condensate on D7 brane

- case of single overall moduli:

  $T = R^4 + i\cdots$ R: size of compact manifold

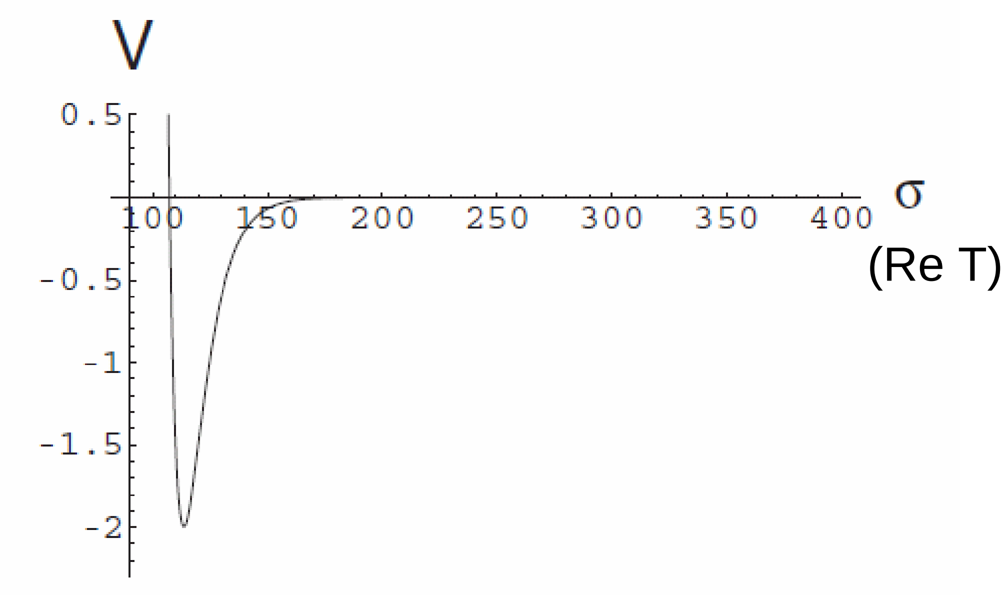
- gauge kinetic function on D7: $f = T$
- superpotential from gaugino condensate

  $$W = w_0 - Ae^{-aT}$$

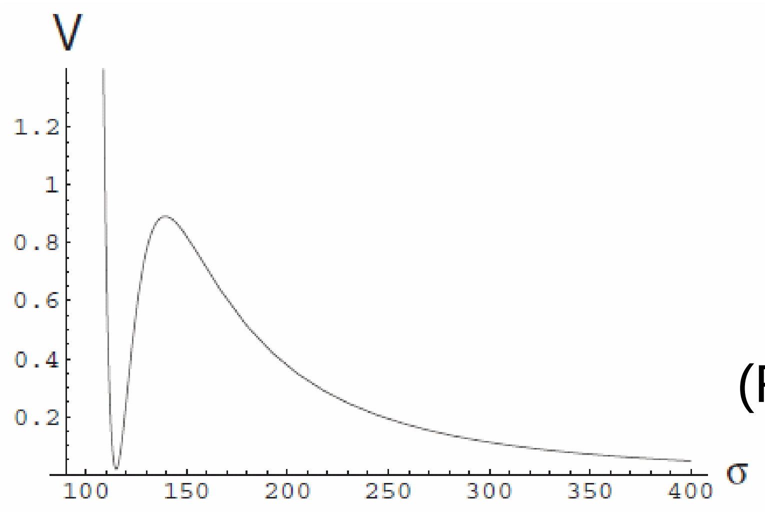
  $a \propto$ beta function coefficient

- Constant term in Superpotential
  → simplest way to avoid runnaway behavior

- T modulus stablilized but with SUSY AdS vacuum



- Up-lifting of the scalar potential
  - Adding SUSY breaking sector
  - Minkowski, SUSY broken vacuum



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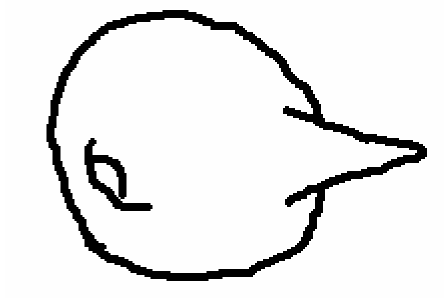


  - KKLT: anti-D3 on top of warped throat
  - Dynamical SUSY breaking sector on D-branes can also be OK

Naturalness of Weak Scale

- Why is weak scale much smaller than Planck scale?
- How is weak scale stabilized against radiative corrections?

- Proposed Solutions:
  - Low energy supersymmetry
  - Large/Warped extra dimensions
  - Unknown strong dynamics

    …..

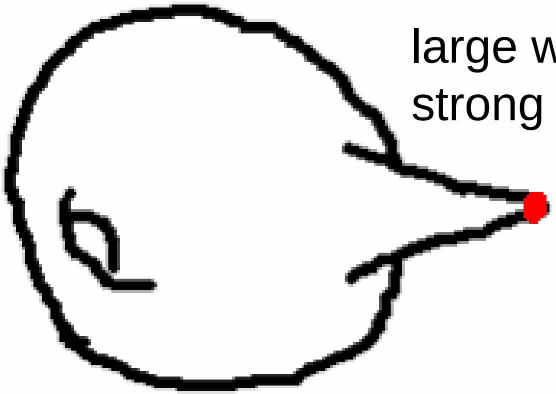
- Ingredients in string theory. Question is which plays a crucial role.

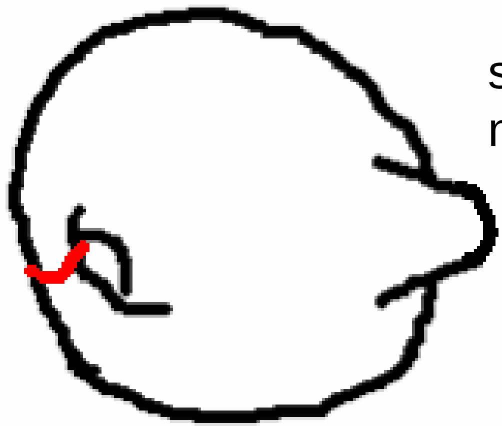
Warped Extra Dimension vs Low Energy SUSY in KKLT set-up

Similar set-up with different flux configurations and SM-brane configuration

Macroscopically (phenomenologically) important information: w_0, warp factor

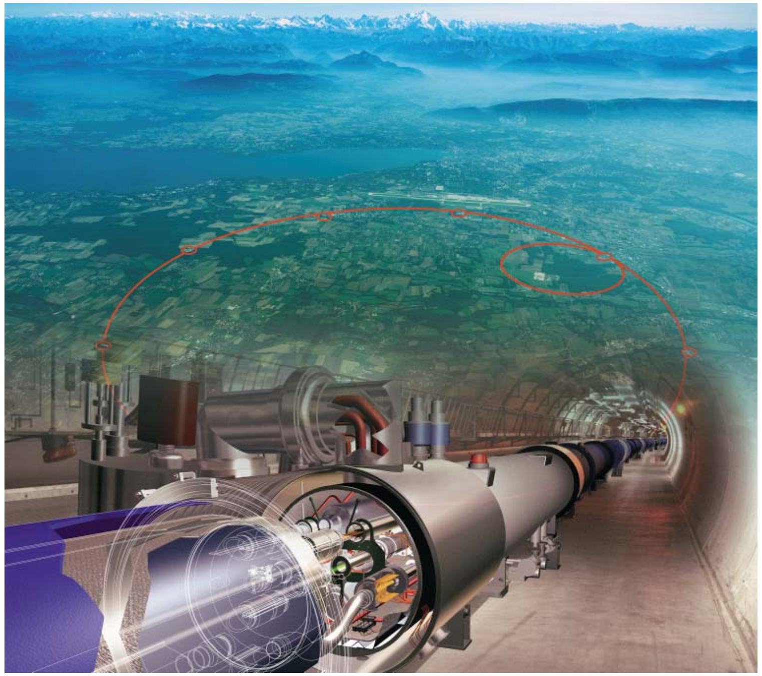
→ warped extra dim. and low-E SUSY

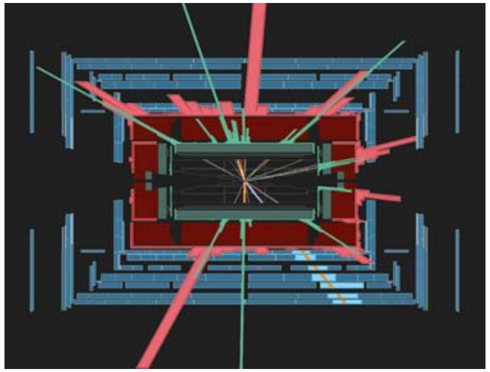




LHC (Large Hadron Collider) Experiment

pp collider at CERN
Center of mass energy =14 TeV
Starts 2007!
Expects new physics discovery at TeV scale





Warped Superstring Compactification at LHC

Noguchi,Yamashita &MY 04

- Graviton Kaluza-Klein modes
  - Masses and Couplings different from those of Randall-Sundrum model

    (Geometry of Klebanov-Strassler throat is very different from AdS_5x X near top of warped throat)
- Resonances via Drell-Yan process

→Probe of (warped) extra dimension

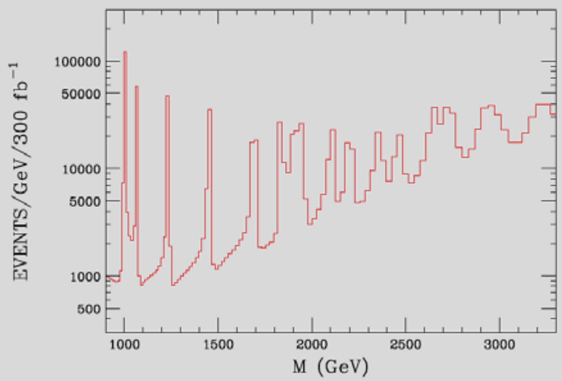


Figure 3: Binned Drell-Yan cross section for e^+e^- production at the LHC assuming $m_{10} = 1$ TeV and all other parameters as in Fig. 2. The cross section has been smeared by an electron pair mass resolution of 0.6% as might be expected at ATLAS [15].

Drell-Yan cross section at LHC for AdS_5 x S^1/Z_2

Davoudiasl-Hewett -Rizzo '02

Implications to Low-E SUSY

- Original Motivation of KKLT:
  realization of dS vacuum in string theory

- Simple KKLT set-up can also provide a new mediation mechanism of SUSY breaking.

Choi-Falkowski-Nilles
-Olechowski-Pokorski 04,05
Endo-MY-Yoshioka 05
Choi-Jeong-Okumura 05

- mixed modulus anomaly mediation

= mirage mediation

Phenomenology with KKLT-like model

$$K = -n \ln(T + T^*) \quad W = w_0 - Ae^{-aT}$$

SUSY breaking sector added to uplift potential

Overall SUSY breaking characterized by gravitino mass: $m_{3/2} \approx w_0$

SUSY breaking effect of Moduli T: $F_T / ReT \approx m_{3/2}/(8\pi^2)$

suppressed by one-loop factor

Gaugino Masses

Consider SM on D7 brane

Gauge kinetic function $f_7 = T$

Gaugino Mass

$$M_i = \frac{F_T}{2T_R} + \frac{\beta_{gi}}{g_i} F_\phi = \frac{F_T}{2T_R} + \frac{\beta_i g_i^2}{16\pi^2} F_\phi$$ @GUT scale

$F_\phi \simeq m_{3/2}$ chiral compensator

$\beta_i = (-3, 1, 33/5)$

moduli+anomaly mediation:

two contributions comparable

Gaugino Masses

$$R \equiv \frac{F_\phi}{F_T/2ReT}$$

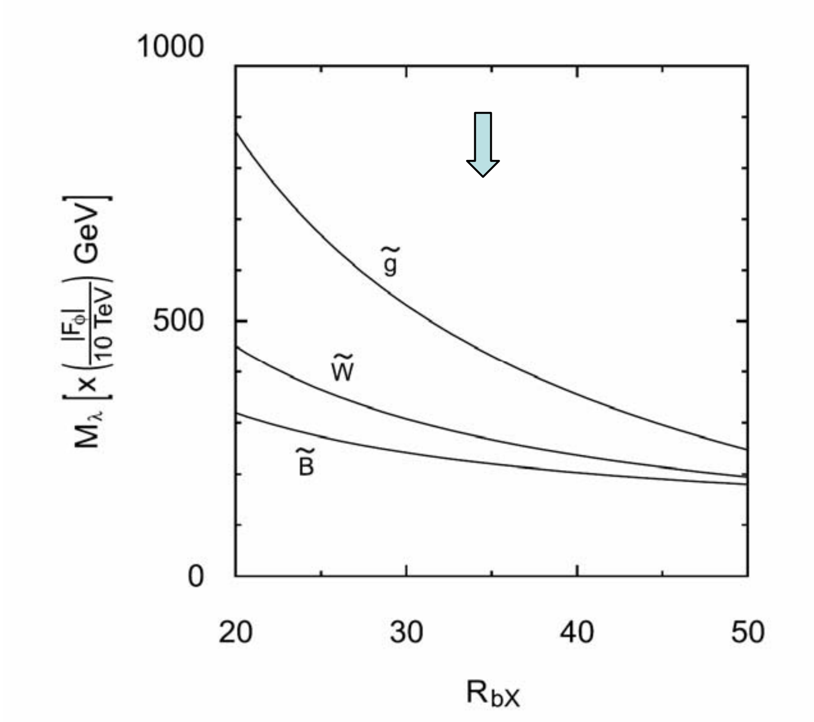
For R~35 (KKLT),

$M_1 : M_2 : M_3 \sim 1 : 1.3 : 2$

cf.

$M_1 : M_2 : M_3 \sim 1 : 2 : 7$

(mSUGRA)

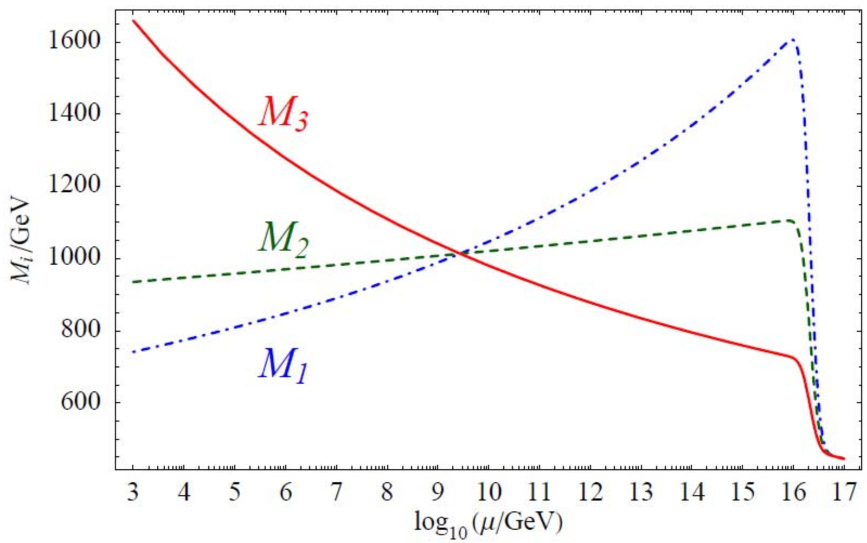


Mirage Mediation

Choi, Jeong, Okumura 05

RG properties: Gaugino masses (as well as scalar masses) are unified at a mirage scale.

$$M_a(\mu) = M_0 \left[1 - \frac{1}{4\pi^2} b_a g_a^2(\mu) \ln \left(\frac{M_{GUT}}{(M_{Pl}/m_{3/2})^{\alpha/2} \mu} \right) \right].$$



from Lebedev, Nilles, Ratz 05

General Features of Mirage Mediation

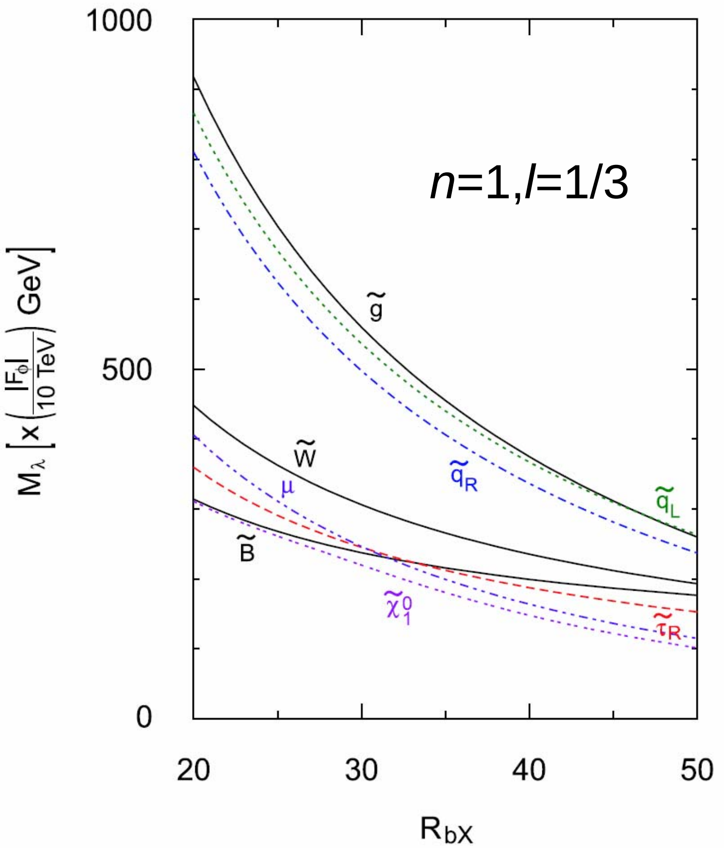
Endo-MY-Yoshioka 05
Choi-Jeong-Okumura 05

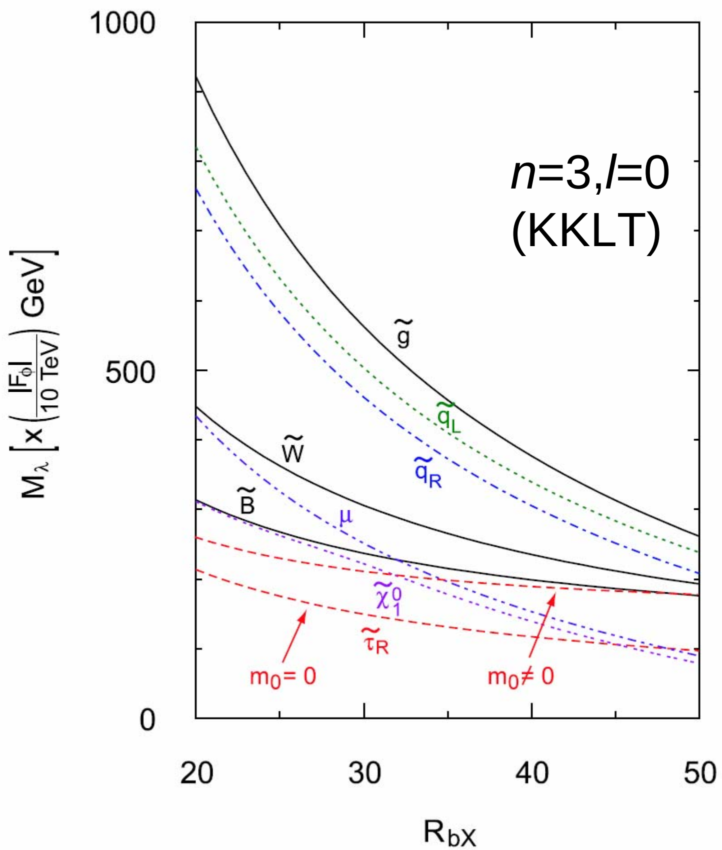
- Compact Sparticle Mass Spectrum
- small μ parameter ($\sim M_1$)
  ← small gluino mass/ RGE
- LSP(lightest superparticle): neutralino
  – admixture of gauginos and higginos
- stau: tends to be light

- Mass Spectrum is very different from mSUGRA (CMSSM).
  gauge mediation & anomaly mediation
- Testable at future collider experiments (LHC/ILC)

Mass Spectrum: Case Study

Endo,MY,Yoshioka 05





Conclusions

- Moduli Stabilization: Flux compactification
- Implications to Weak Scale Stabilization
- warped superstring compactification
- low-E SUSY: mirage mediation

- LHC will provide crucial information beyond SM, and hopefully structure of unified theory.