Non-SUSY theories in CEPC & SppC

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Outline

- The use of CEPC & SppC
- Models overview
- Signal based classification & search strategy: Core signal with theory motivations or easy to discover
- Plans

The use of CEPC & SppC

CEPC

Cicular e^+ e^- collider with center of mass energy 350 GeV

What can it go beyond the LEP?

- Higgs precision
- Tri-gauge boson precision
- (Unlikely) Very low mass particles

SppC

Cicular pp collider with center of mass energy 50 ~ 70 TeV

Could it be ppbar (essentially increase the energy and helps for CP searches)?

- Di Higgs related process
- multi-gauge boson / top production
- (Likely) High mass particles

Models Overview

I assume neutrino models reviewed by Prof. Yi Liao

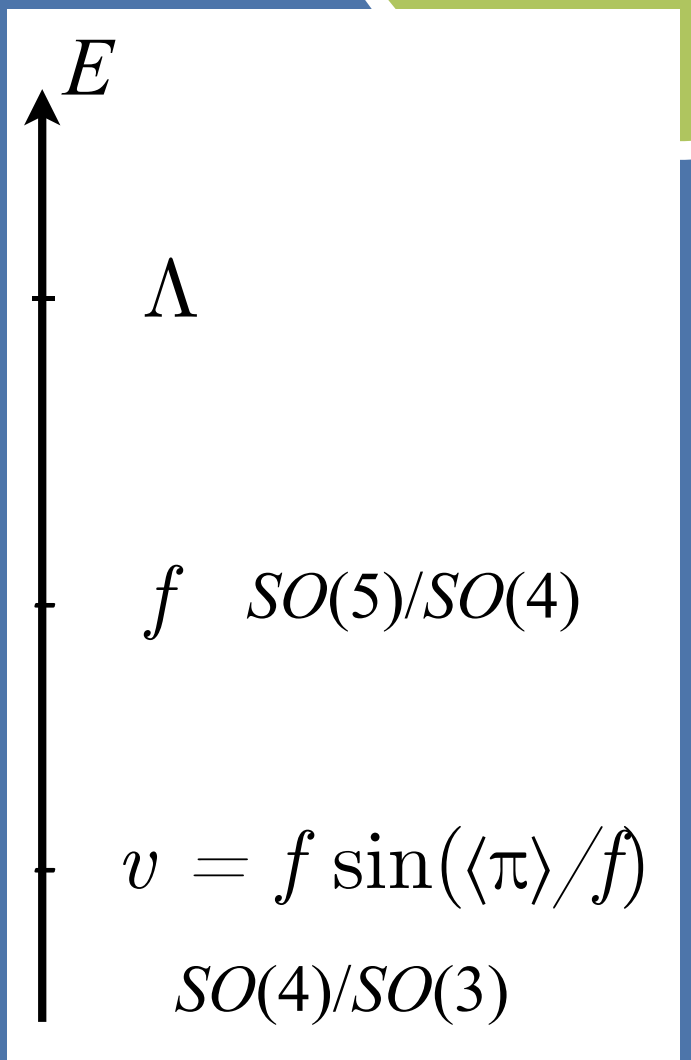
Moose Models

By saying moose, I mean what ever models with extended symmetries that are global, local or even emergent

Moose Models

- 4D Composite Higgs
- Little Higgs (with collective symmetry breaking)
- RS with gauge Higgs unification (deconstructed)

Higgs as a pNGB from G/H:
Higgs properties based on G/H



Nonlinear parametrization

Consider the most general Goldstone interaction which has a custodial symmetry

(only the gauge sector) $SU(2)_L \times SU(2)_R$

$\Sigma(x) = \exp(i\sigma^a \chi^a(x)/v)$ Goldstone interaction

$\mathcal{L} = \frac{v^2}{4} Tr[(D_\mu \Sigma)^\dagger D^\mu \Sigma]$ Consider a physical singlet scalar h

$$\mathcal{L}_H = \frac{1}{2}(\partial_\mu h)^2 + V(h) + \frac{v^2}{4} Tr[(D_\mu \Sigma)^\dagger (D_\mu \Sigma)](1 + 2a\frac{h}{v} + b\frac{h^2}{v^2} + ...)$$
$$-\frac{v}{\sqrt{2}}\Sigma[1 + c_j \frac{h}{v} + \cdots] \begin{pmatrix} y^u_{ij} u^j_R \\ y^d_{ij} d^j_R \end{pmatrix} + h.c.$$

Higgs from EFT

Some times I use a different parametrization variable

Everything should be parametrized by effective theory.

$$\begin{aligned}\mathcal{L}_{eff} = & \; c_V \frac{2m_W^2}{v} h W_\mu^+ W_\mu^- + c_V \frac{m_Z^2}{v} h Z_\mu Z_\mu - c_b \frac{m_b}{v} h \bar{b}b - c_\tau \frac{m_\tau}{v} h \bar{\tau}\tau - c_c \frac{m_c}{v} h \bar{c}c \\ & + c_g \frac{\alpha_s}{12\pi v} h G_{\mu\nu}^a G_{\mu\nu}^a + c_\gamma \frac{\alpha}{\pi v} h A_{\mu\nu} A_{\mu\nu} - c_{inv} h \bar{\chi}\chi \; .\end{aligned}$$

Integrating out particles heavier than higgs

top already in cg, cgammma

Higgs properties

Universal Higgs properties at the leading order

$$f^2 \sin^2 \frac{h}{f} = f^2 \left[\sin^2 \frac{\langle h \rangle}{f} + 2 \sin \frac{\langle h \rangle}{f} \cos \frac{\langle h \rangle}{f} \left(\frac{h}{f} \right) + \left(1 - 2 \sin^2 \frac{\langle h \rangle}{f} \right) \left(\frac{h}{f} \right)^2 + \dots \right]$$
$$= v^2 + 2v\sqrt{1-\xi}\, h + (1-2\xi)\, h^2 + \dots$$

W & Z boson mass

modification of hVV coupling

$a = \sqrt{1-\xi}$ $b = 1-2\xi$

Similarly for fermions.

$m_f(h) \propto \sin\left(\frac{2h}{f}\right)$ $c = \frac{1-2\xi}{\sqrt{1-\xi}}$ 5, 10

$m_f(h) \propto \sin\left(\frac{h}{f}\right)$ $c = \sqrt{1-\xi}$ Spinorial 4

Higgs properties

MCHM5 in 350 GeV CEPC

Higgs production

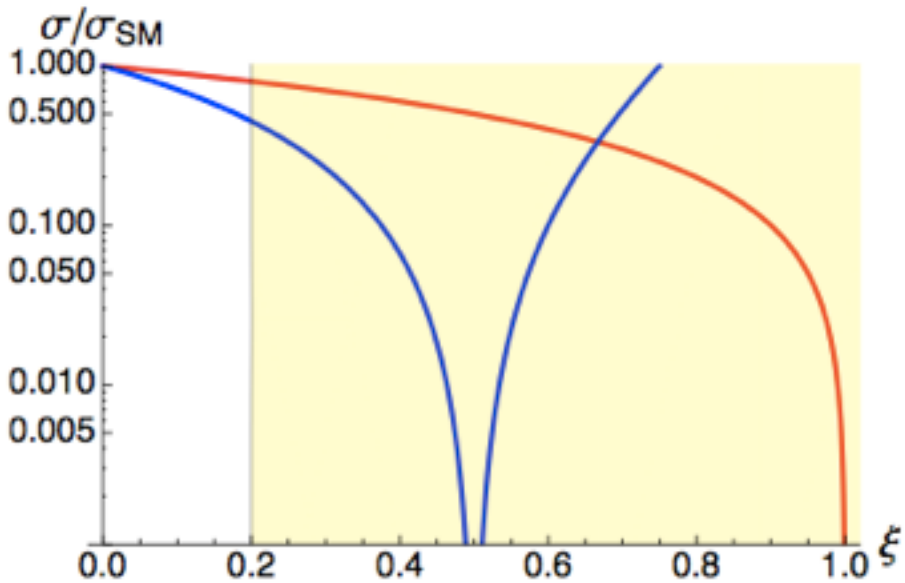


FIG. 1: The production rate ratio between the composite Higgs and the SM Higgs. The red line stands for weak boson fusion and associate production channel while the blue line stands for the gluon fusion channel. The yellow region $\xi > 0.2$ are not preferred by the electroweak precision test.

Higgs decay

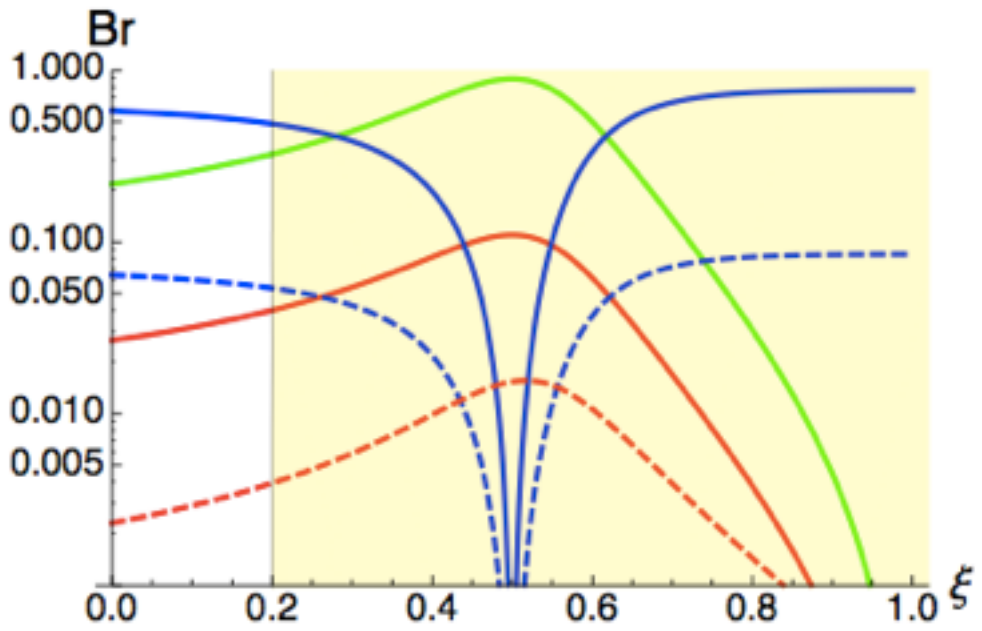
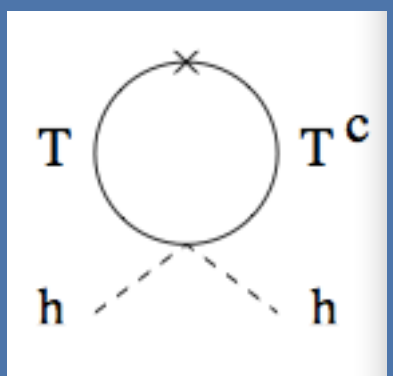


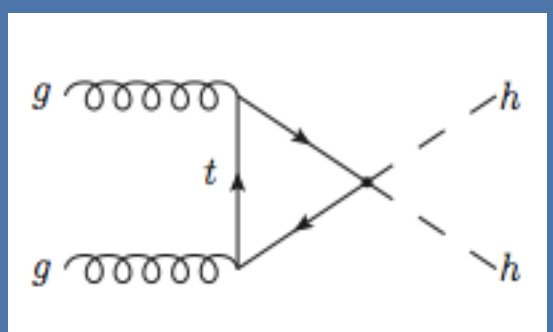
FIG. 2: The decay branching ratio for 125 GeV composite Higgs in MCHM5. The red solid, green solid, blue solid, blue dashed and red dashed lines stand for ZZ, WW, $b\bar{b}$, $\tau\bar{\tau}$ and $\gamma\gamma$ decay channels. The yellow region $\xi > 0.2$ are not preferred by the electroweak precision test.

Other operators

Here I mention an important one:



Cancel the Higgs quadratic divergence from top



Therefore, the di-higgs production from the left diagram it is inevitably there and the size is large:
Good for SppC

Other aspects

- Resonance searches (Z', W', f', etc)
- WW Strong phase measurements
- WW scattering
- Field extended objects (skymion, etc)

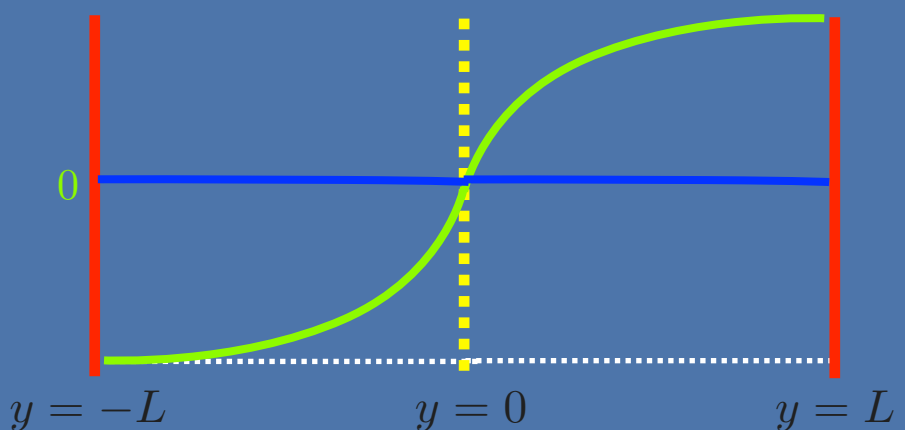
RS models

If no gauge higgs unification, then the Higgs sector is trival except for radion-Higgs mixing

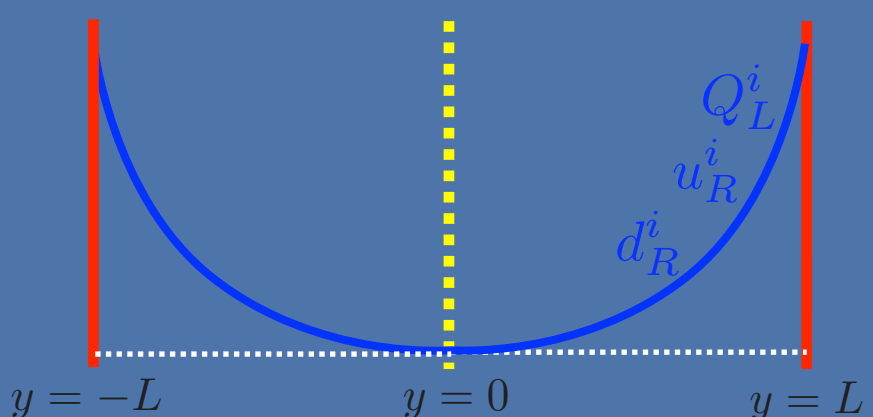
- Radion pheno
- KK gauge bosons / fermions (much better in SppC)
- KK gravitons (much better in SppC)

UED models

We all lives in the flat EDs:



Gauge fields



Fermion fields

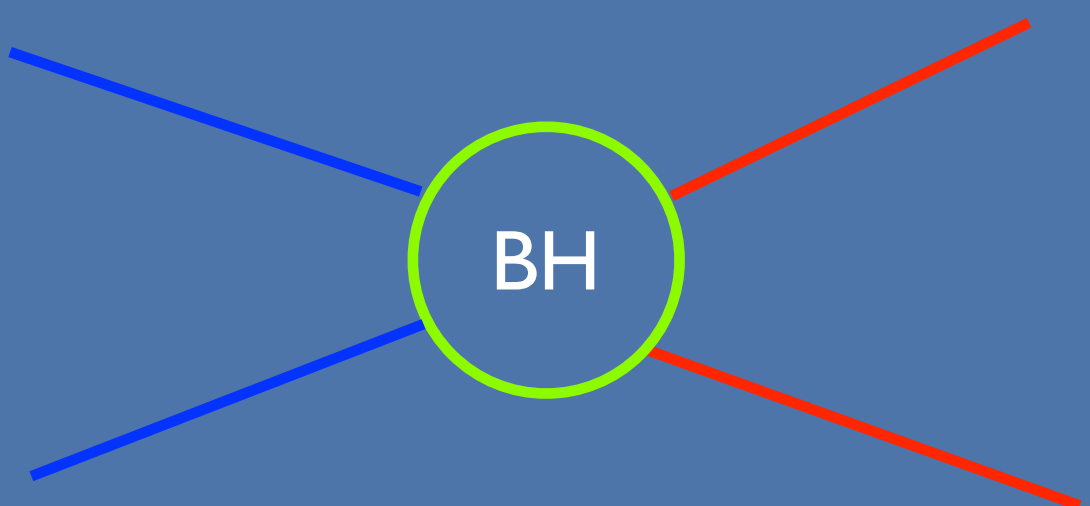
UED models

We all lives in the flat EDs:

- KK even gauge bosons
- KK even fermions
- Pair produced KK odd particles

BHs, ADD, Exotic SD

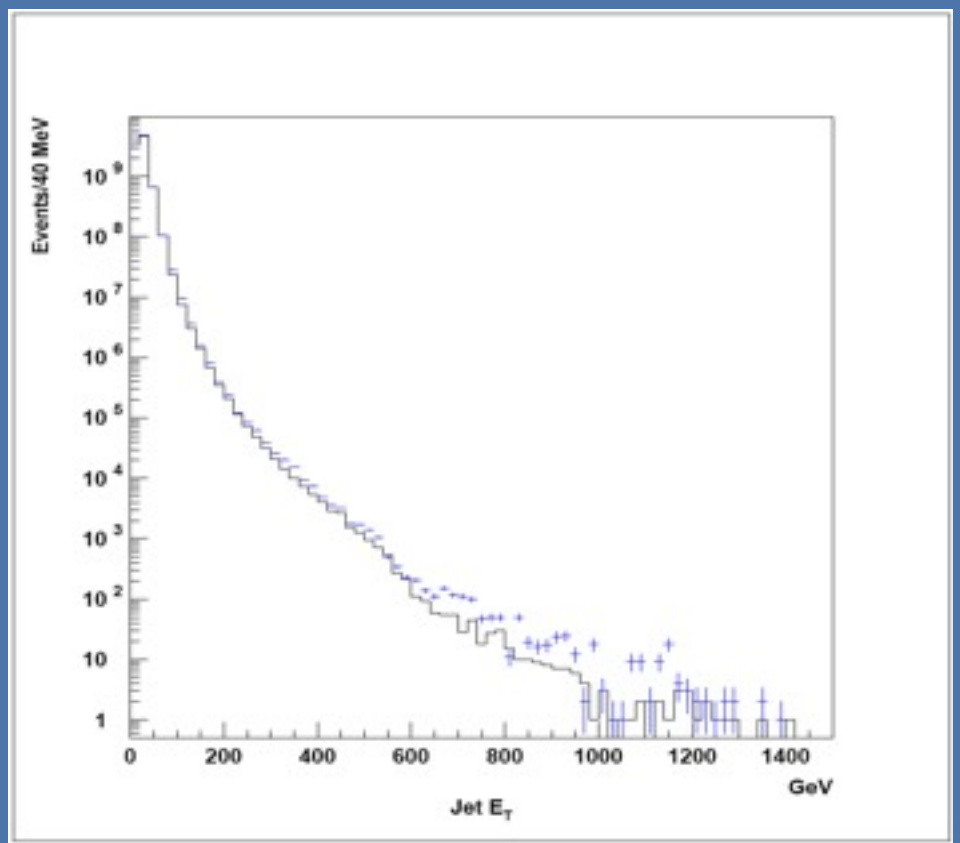
Essentially a form factor

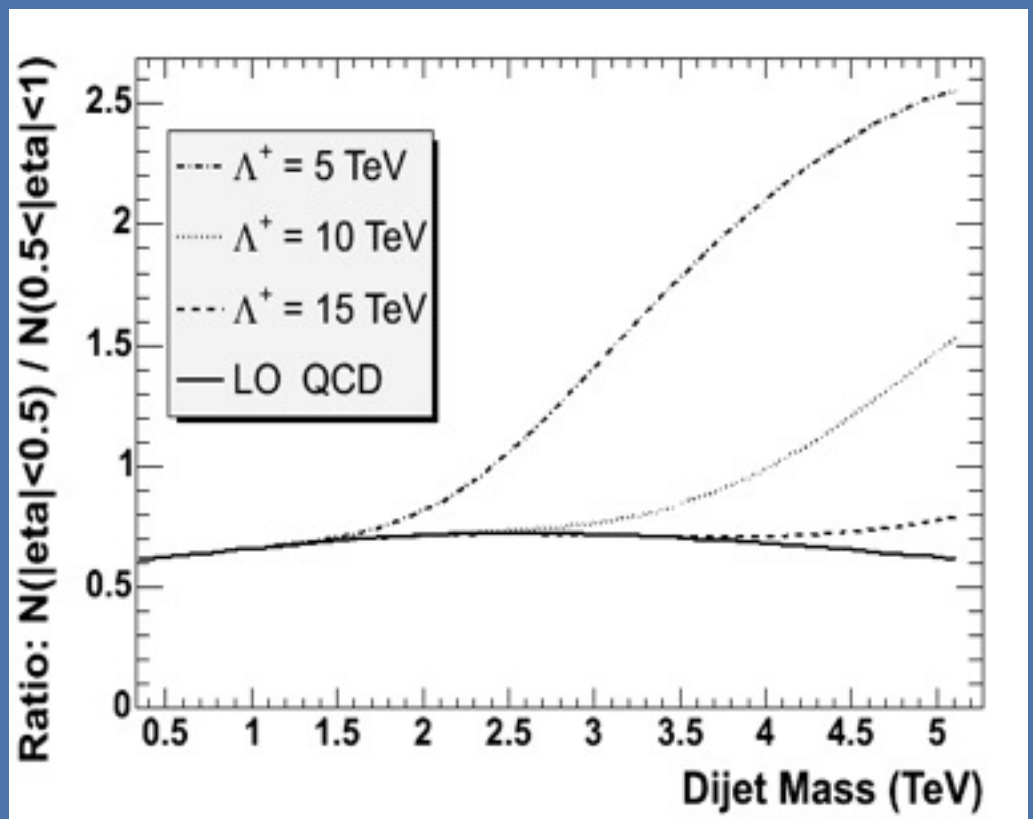


Angular distribution of the two final particles

BHs, ADD, Exotic SD

$$\frac{g^2}{\Lambda^2}\,[\bar{q}\gamma^{\mu}q]\,[\bar{q}\gamma_{\mu}q]$$





Other exotic models

- Chiral 4th generation (almost dead)
- 2HDM (Type 2 mostly in SUSY)
- Gauge extensions (2-2-1, 3-3-1, 2-1-1, etc): Resonce searches, pretty much the same)
- Other models with particular motivation, like Higgs portal, darkon, colored scalars, etc. (better

Particle based signals and search strategy

Spin zero

What are the particles aside from a "discovered" Higgs?

Dilaton/radion:

$$c_{V,\chi} = \frac{v}{f},$$

$$c_{t,\chi} = \frac{v}{f}(1+\gamma_t), \quad c_{b,\chi} = \frac{v}{f}(1+\gamma_b), \quad c_{\tau,\chi} = \frac{v}{f}(1+\gamma_\tau),$$

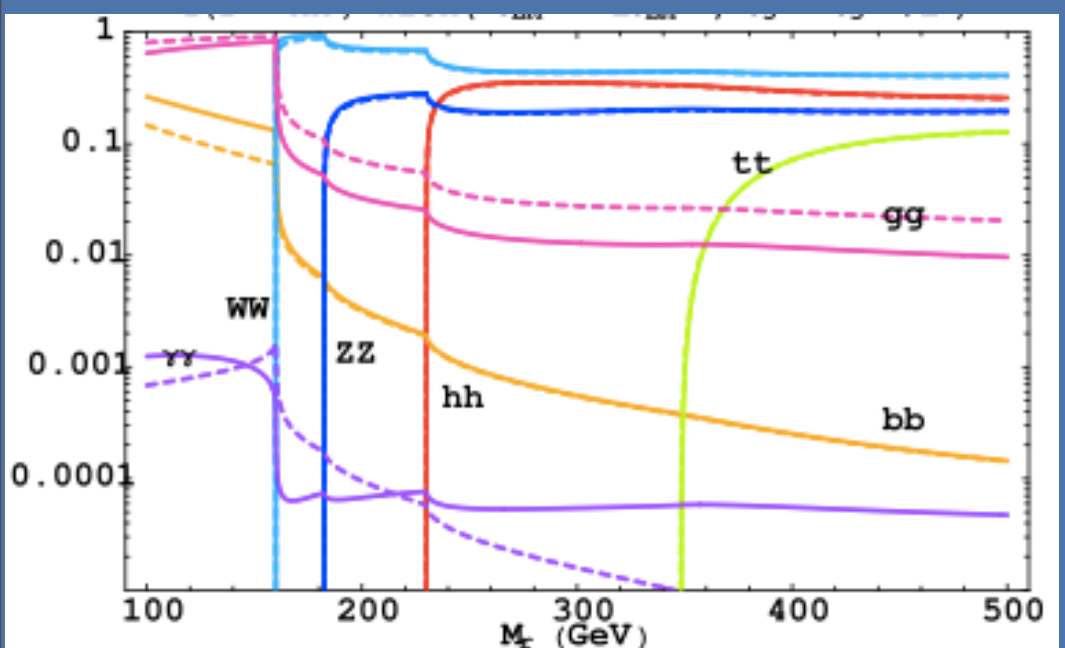
$$c_{g,\chi} = \frac{v}{f}(b^{(3)}_{IR} - b^{(3)}_{UV}), \quad c_{\gamma,\chi} = \frac{v}{f}(b^{(EM)}_{IR} - b^{(EM)}_{UV}).$$

\gamma: anomalous dimension for the Yukawa

b: QCD/QED beta function

Spin zero

Typical radion/dilaton decay branching:



Can we miss it at LHC while see it at CEPC?

One can tune the UV part of QCD beta function (suppress gluon coupling)

CEPC associate production VS: LHC VBF

Needs more careful work

Spin zero

Other possibilities

- Scalars not directly couples to electron: CEPC associate production VS: LHC VBF
- Inert scalars directly couple to electrons (For instance, Byproducts of leptonic DM). Just so easy for CEPC

Spin one

- Lepton philic Z' (Split UED explanation for leptonic DMs)

At the SppC, we have much more opportunities (Z', W, etc):

Current S parameter constrains require super collider

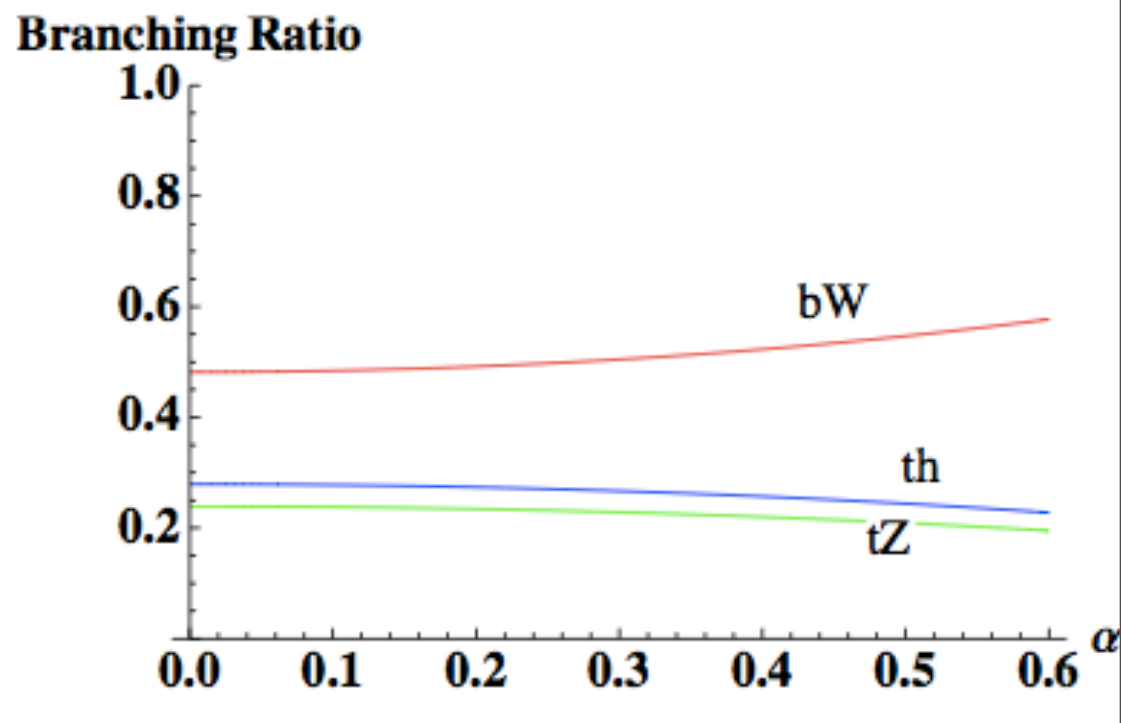
$$S \sim 4\pi v^2 / m_\rho^2$$

- Needs separate simulation
- Needs more access for the boosted top, W tagging if they are in the final states

Spin 1/2

- Top / Light fermion partners

Heavy states pair produced at SppC (much better than LHC)



$$\mathrm{BR}(t' \to th) \approx \mathrm{BR}(t' \to tZ) \approx \mathrm{BR}(t' \to bW)/2 \approx 0.25$$

Spin two

- RS KK gravitons: (Good for SppC)

Very heavy: Similar arguments like
Z' from S parameter

- Needs separate simulation
- Needs more access for the boosted top, W tagging if they are in the final states

Extended Objects

- Magnetic Monopoles

Monopoles pair produced by gauge force then annilates into multi-hard photons

- Skymions:

Models	G	H	$\pi_3(G/H)$
Minimal Moose [20]	$SU(3)^2$	$SU(3)$	$\mathbf{Z}$
Littlest Higgs [21]	$SU(5)$	$SO(5)$	$\mathbf{Z_2}$
$SO(5)$ Moose [22]	$SO(5)^2$	$SO(5)$	$\mathbf{Z}$

Like e^+ e^- ---> hadrons at 2 ~ 3 GeV

SU(4)/SO(4): Z2 (minimal skymion)

Extended Objects

- Non-topological: from extra U(1), like Q balls

Energy frontier is also so good!

Plans

Re-organize

- The drafts in the past are quire separated
- Framework on what is needed to be done and explore
- Needs discussion, communication and working.
- I am considering organize small discussion groups