Solving cosmological problems in Universal Extra Dimension models by introducing Dirac neutrino

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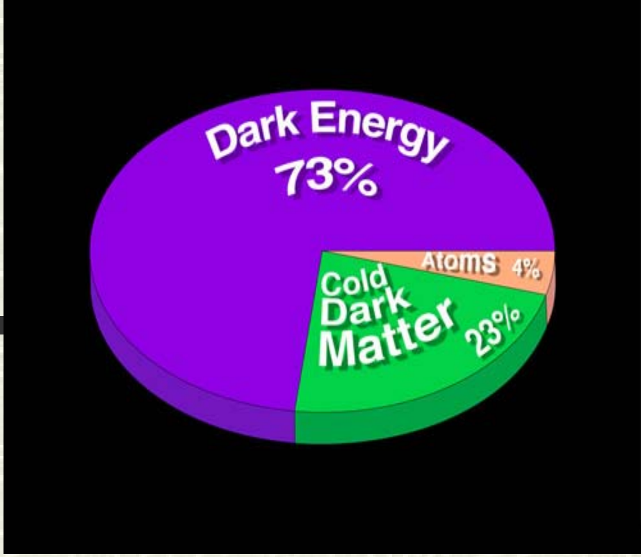
hep-ph/0607331

Introduction

CMB, rotating curve, and so on

There is a dark matter in our universe !



http://map.gsfc.nasa.gov

- candidate:Weakly Interacting Massive Particles(WIMPs)

Universal Extra Dimension model provides a good candidate for WIMPs
However this model has two shortcomings

Introducing right-handed neutrino

These two problems can be solved simultaneously !

Today’s story

- What is Universal Extra Dimension model ?
- Radiative correction
- Cosmological problems
- Solving cosmological problems
  by introducing Dirac neutrino
- Summary and discussion

What is Universal Extra Dimension (UED) model ? 1

Extra dimension model

Candidate for the theory beyond the standard model

- **Hierarchy problem**

  Large extra dimensions [Arkani-hamed, Dimopoulos, Dvali PLB429(1998)]

  Warped extra dimensions [Randall, Sundrum PRL83(1999)]

- **Existence of dark matter**

  LKP dark matter due to KK parity [Servant, Tait NPB650(2003)]

- **etc.**

What is Universal Extra Dimension (UED) model ? 2

Universal Extra Dimension

Appelquist, Cheng, Dobrescu PRD67 (2000)

characteristics of UED model

- 5-dimensions (time 1 + space 4)
- all SM particles propagate spatial extra dimension and has the excitation mode called KK particle
- compactified on an S^1/Z_2 orbifold
- typical scale : 1/R = order[100 GeV]

R : compactification scale (S^1 radius)

What is Universal Extra Dimension (UED) model ? 3

5th dimension momentum conservation

↓

For S^1 compactification ➡ $P_5 = n/R$

R : S^1 radius   n : 0,1,2,….

↓

KK number (= n) conservation at each vertex

↓

S^1/Z_2 orbifolding $P_5 = -P_5$

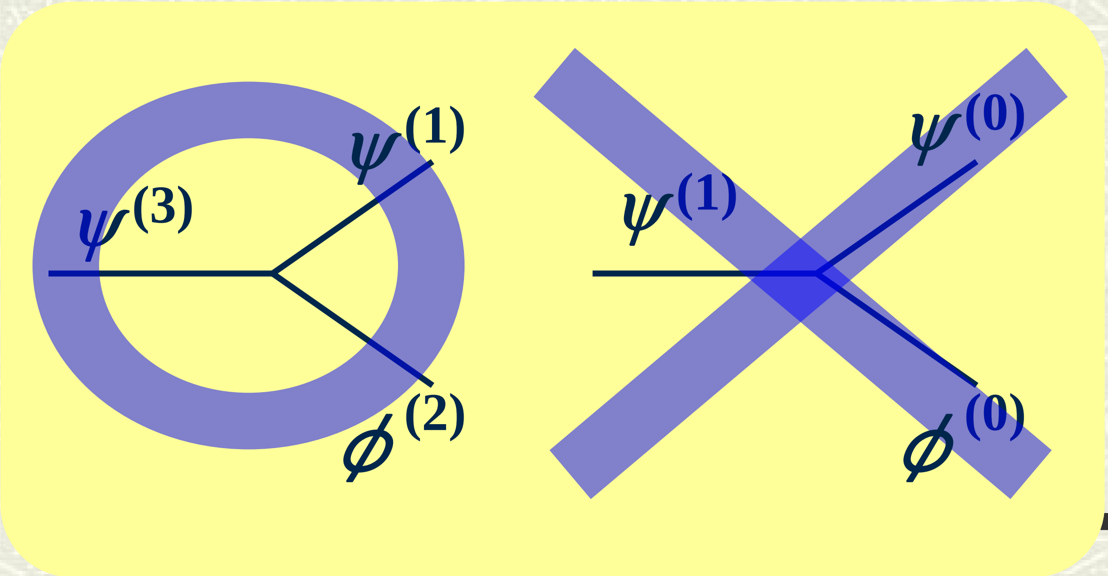
↓

KK-parity conservation

n = 0,2,4,… ➡ +1

n = 1,3,5,… ➡ −1

At each vertex the product of the KK parity is conserved



What is Universal Extra Dimension (UED) model ? 4

5th dimension momentum conservation

compactification & orbifolding

KK parity conservation at each vertex

Lightest Kaluza-Klein Particle(LKP) is stable

(c.f. R-parity and the LSP in SUSY)

If LKP is neutral and massive,
LKP can be the dark matter candidate

radiative correction 1

[Cheng, Matchev, Schmaltz PRD66 (2002)]

Radiative corrections are crucial for determining the LKP in extra dimension models

↓ **Why ?**

Tree level KK particle mass : $m^{(n)} = \left(n^2/R^2 + m_{SM}^2 \right)^{1/2}$

m_{SM}^2 : corresponding SM particle mass

Since $1/R \gg m_{SM}$, all KK particle masses are highly degenerated around n/R

→ **Mass differences among KK particles dominantly come from radiative corrections**

radiative correction 2

Important things :

- Colored KK particles are heavier than other KK particles
- The masses of U(1) gauge boson and right-handed leptons still remain ～n/R

⇓

The candidate for the neutral LKP

- KK B boson $B^{(1)}$
- KK graviton $G^{(1)}$

➡ Dark matter candidate

radiative correction 3

Mass of the KK graviton

$$m_{G^{(1)}} = \frac{1}{R}$$

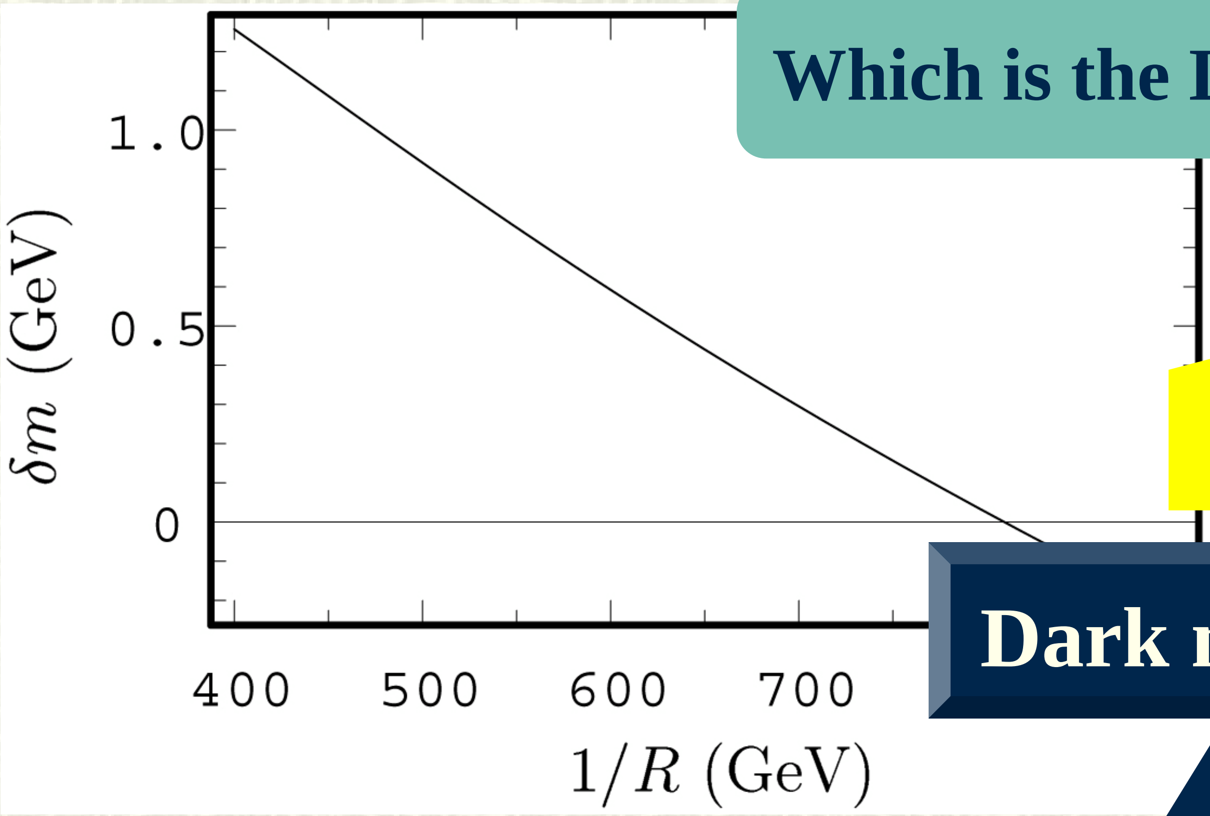
Mass matrix of the U(1) and SU(2) gauge boson

$$\begin{pmatrix} 1/R^2 + \delta m^2_{B^{(1)}} + g'^2 v^2/4 & g' g\, v^2/4 \\ g' g\, v^2/4 & 1/R^2 + \delta m^2_{W^{(1)}} + g^2 v^2/4 \end{pmatrix}$$

$$\delta m^2_{B^{(1)}} = -\frac{39}{2}\frac{g'^2 \zeta(3)}{16\pi^4 R^2} - \frac{1}{6}\frac{g'^2}{16\pi^2 R^2}\ln(\Lambda^2 R^2)$$

$$\delta m^2_{W^{(1)}} = -\frac{5}{2}\frac{g^2 \zeta(3)}{16\pi^4 R^2} + \frac{15}{2}\frac{g^2}{16\pi^2 R^2}\ln(\Lambda^2 R^2)$$

Λ : cut off scale   v : vev of the Higgs field



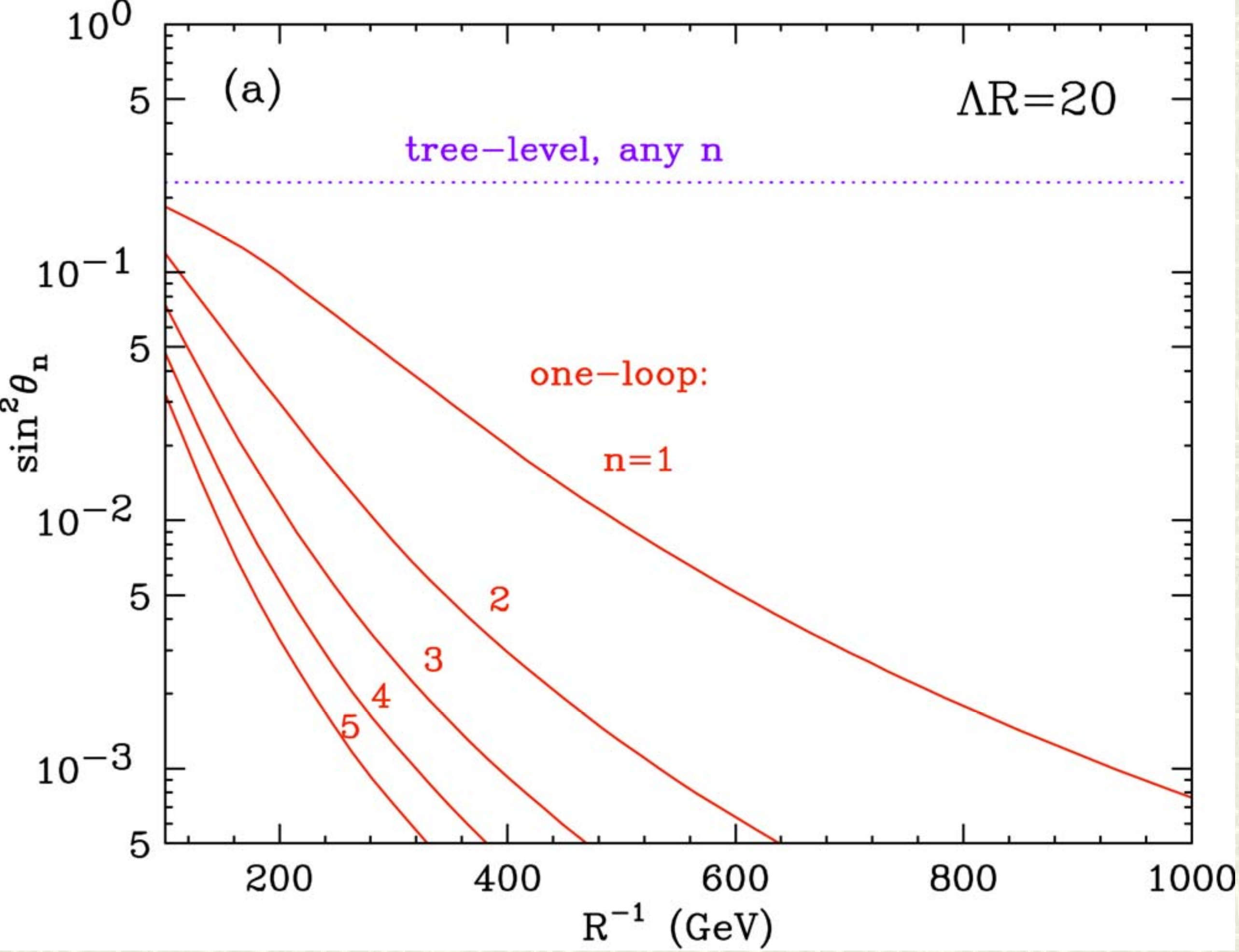
Which is the LKP, $B^{(1)}$ or $G^{(1)}$?

$\delta m = m_{B^{(1)}} - m_{G^{(1)}}$

Dark matter candidate

- **For $1/R \lesssim 800$ GeV** — **LKP : $G^{(1)}$** — NLKP : $B^{(1)}$
- **For $1/R \gtrsim 800$ GeV** — **LKP : $B^{(1)}$** — NLKP : $G^{(1)}$

NLKP : Next Lightest Kaluza-Klein Particle



Dependence of the ‘‘Weinberg’’ angle

[Cheng, Matchev, Schmaltz (2002)]

$\sin^2\theta_W \approx 0$ due to $1/R$ >> (EW scale) in the mass matrix

→ $B^{(1)} \approx \gamma^{(1)}$

Cosmological problems

For the case of $G^{(1)}$ LKP

Gravitational coupling is extremely weak

$\gamma^{(1)}$ decays into γ and $G^{(1)}$ after the recombination

The emitted γ distorts the Cosmic Microwave Background (CMB) spectrum !

Hu, Silk PRL70(1993) , Feng, Rajaraman, Takayama PRL91(2003)

Even if $G^{(1)}$ is the NLKP, these problems are replaced with the problems caused by the $G^{(1)}$ late time decay

Cosmological problems
(For the Big-Bang Nucleosynthesis)

decouple

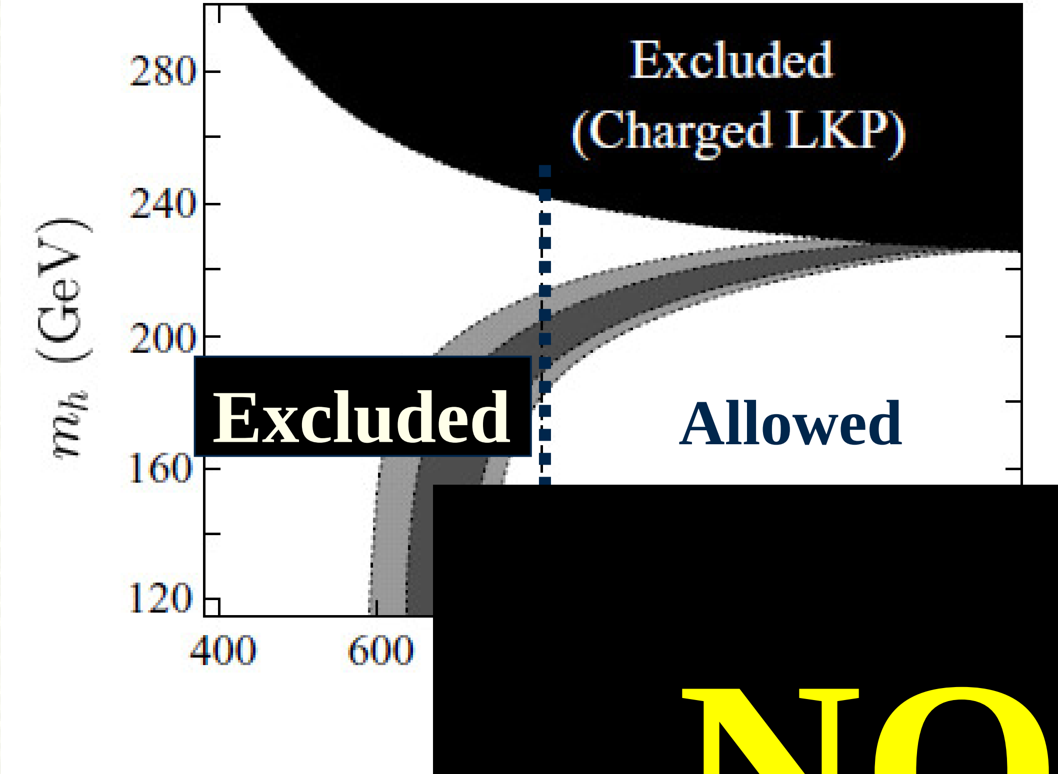
Thermal bath → $\gamma^{(1)}$ → $G^{(1)}$

decay

The cause of the problem → photon

Big Bang Nucleosynthesis prediction ⟷ Present observation

Inconsistent !



[Kakizaki, Matsun[redacted] PRD68(2003)]

NLKP : $G^{(1)}$

1/R > 800 GeV

Constraining the reheating temperature

[redacted]d the

[redacted] problems

[redacted]araman,

NO !

As shown in[redacted]arrow· ·

Really ?

If the light (∼150 GeV) Higgs is discovered, does the UED model entirely be excluded ?

Solving cosmological problems by introducing Dirac neutrino

Key point

Careful treatment of the neutrino mass in the UED model

In the UED model, the SM neutrino is regarded as massless particle

From measurements, we know that neutrino is massive

We must introduce the neutrino mass into the UED model

Solving cosmological problems by introducing Dirac neutrino

UED model + **small Dirac mass type neutrino**

→ **We can extend the allowed region !!**

$N^{(1)}$: KK right handed neutrino

Mass of the KK right-handed neutrino

$$m_{N^{(1)}} \cong \frac{1}{R} + \mathrm{order}\left(\frac{m_\nu^2}{1/R}\right)$$

Solving cosmological problems by introducing Dirac neutrino

For excluded region (1/R < 800 GeV)

- **Before introducing Dirac neutrino**

$$m_{\gamma^{(1)}} > m_{G^{(1)}}$$

⟶ **Problematic γ is always emitted from $\gamma^{(1)}$ decay**

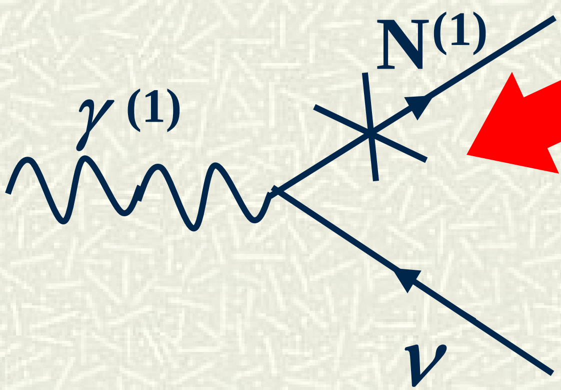
- **After introducing Dirac neutrino**

$$m_{\gamma^{(1)}} > m_{N^{(1)}} > m_{G^{(1)}}$$

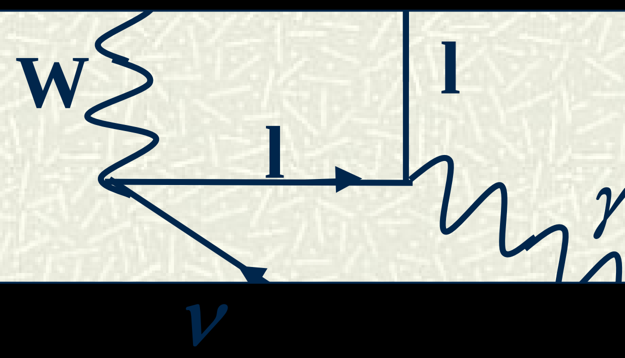
⟶ **There is no γ emission !!**

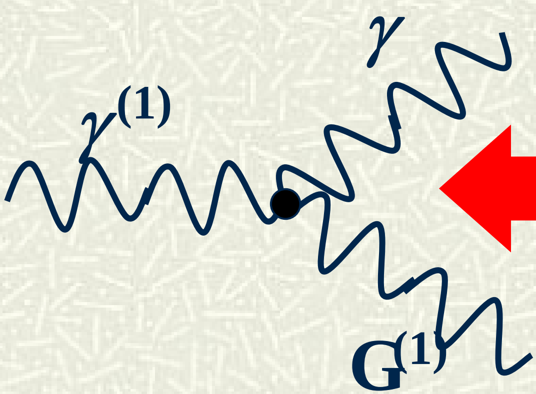
Solving cosmological problems by introducing Dirac neutrino

We investigated some $\gamma^{(1)}$ decay mode



Dominant decay mode from $\gamma^{(1)}$

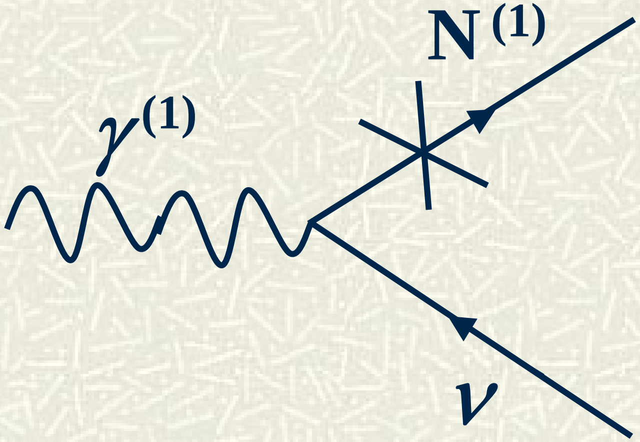




Dominant photon emission decay mode from $\gamma^{(1)}$

Solving cosmological problems by introducing Dirac neutrino

Decay rate for $\gamma^{(1)} \longrightarrow N^{(1)}\nu$

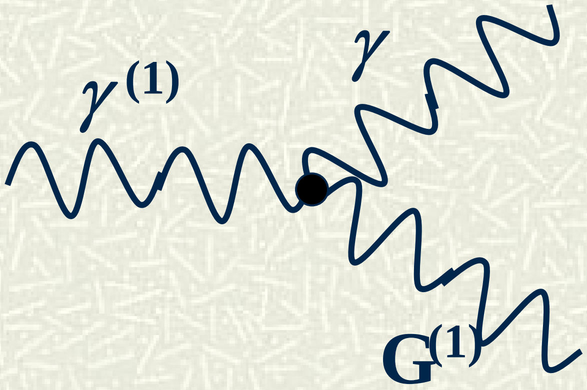


$$\Gamma \cong 2\times 10^{-9}[\mathrm{sec}^{-1}]\left(\frac{500\mathrm{GeV}}{m_{\gamma^{(1)}}}\right)^3\left(\frac{m_\nu}{10^{-2}\mathrm{eV}}\right)^2\left(\frac{\delta m}{1\ \mathrm{GeV}}\right)^2$$

$\delta m = m_{\gamma^{(1)}} - m_{N^{(1)}}$ m_ν : SM neutrino mass

Solving cosmological problems by introducing Dirac neutrino

Decay rate for $\gamma^{(1)} \longrightarrow G^{(1)}\gamma$



$$\Gamma \cong 10^{-15}[\mathrm{sec}^{-1}]\left(\frac{\delta m'}{1\ \mathrm{GeV}}\right)^3$$

[Feng, Rajaraman, Takayama PRD68(2003)]

$$\delta m' = m_{\gamma^{(1)}} - m_{G^{(1)}}$$

Solving cosmological problems by introducing Dirac neutrino

Branching ratio of the $\gamma^{(1)}$ decay

$$\mathrm{Br}(\gamma^{(1)}) = \frac{\Gamma(\gamma^{(1)} \longrightarrow G^{(1)}\gamma)}{\Gamma(\gamma^{(1)} \longrightarrow N^{(1)}\bar{\nu})}$$

$$= 5 \times 10^{-7} \left(\frac{1/R}{500\mathrm{GeV}}\right)^{3} \left(\frac{0.1\ \mathrm{eV}}{m_\nu}\right)^{2} \left(\frac{\delta m}{1\ \mathrm{GeV}}\right)$$

$\gamma^{(1)}$ decay associated with a photon is very suppressed !!

Total injection photon energy from $\gamma^{(1)}$ decay

$$\varepsilon \, \mathrm{Br}(\gamma^{(1)}) Y_{\gamma^{(1)}} < 3 \times 10^{-18}\ \mathrm{GeV}$$

$$\times \left(\frac{1/R}{500\mathrm{GeV}}\right)^2 \left(\frac{0.1\ \mathrm{eV}}{m_\nu}\right)^2 \left(\frac{\delta m}{1\ \mathrm{GeV}}\right)^2 \left(\frac{\Omega_{DM} h^2}{0.10}\right)$$

ε : typical energy of emitted photon

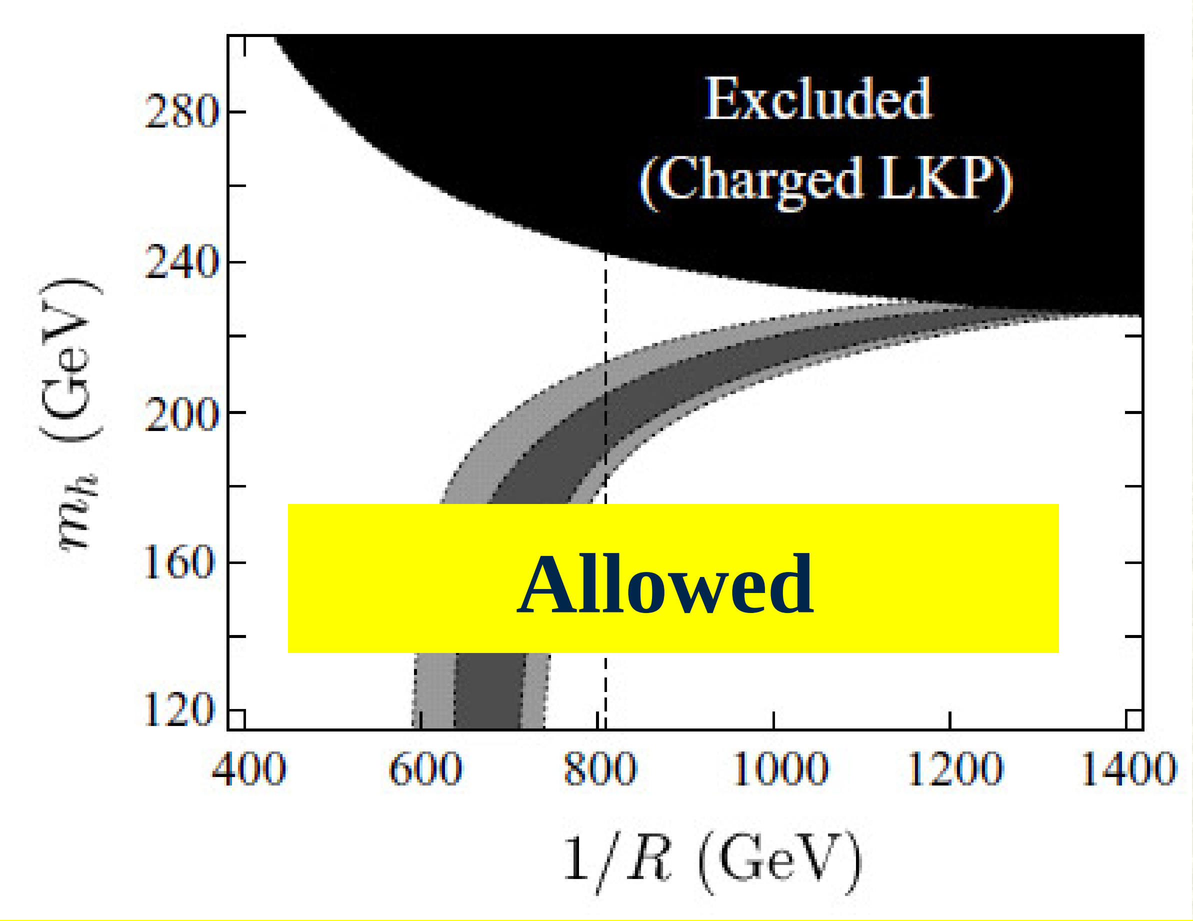
$Y_{\gamma^{(1)}}$: number density of the KK photon normalized by that of background photons

The successful BBN and CMB scenarios are not disturbed unless this value exceeds 10^{-9} - 10^{-13}GeV

[Feng, Rajaraman, Takayama (2003)]

Cosmological problems has been solved by introducing the Dirac type mass neutrino

As a result・・・・



There is no excluded region in our model !

Summary and discussion

Connection between collider experiment and determination of the neutrino mass type

In the case of UED model

There will be no evidence of the extra dimension existence for $1/R < 800$ GeV

In the case of UED model with right-handed neutrino

KK particles can be discovered at lower energy ($\leqq$ 800 GeV)

Neutrino mass type can be indirectly determined as Dirac at collider experiment !!

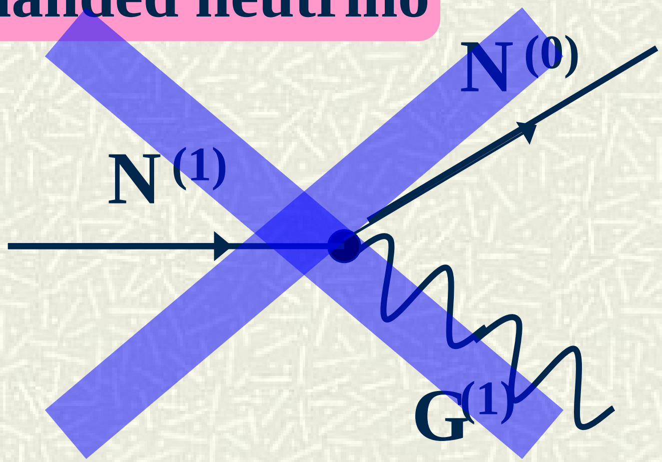
Summary

- We have introduced the Dirac type neutrino into the UED model
- We have solved cosmological problems by satisfying the necessary condition, i.e. no γ emission
- We have shown the possibility that neutrino mass type (Dirac or Majorana) can be indicated at future collider experiments
- Our idea is applicable to extended UED model

Future work

Mass of the KK right-handed neutrino

$$m_{N^{(1)}} \cong \frac{1}{R} + \text{order}\left(\frac{m_\nu^2}{1/R}\right)$$



$N^{(1)}$ decay is impossible !

stable, neutral, massive, weakly interaction

KK right handed neutrino can be dark matter !

We are calculating the dark matter relic abundance in UED model including right-handed neutrino

Appendix

What is Universal Extra Dimension (UED) model ?

S^1: compactification on circle $\psi(x^\mu, y) = \psi(x^\mu, y+2\pi R)$

Z_2 : reflection symmetry under $y \longrightarrow -y$

y : extra dimension coordinate

S^1/Z_2 compactification produces chiral theory corresponding to the SM

$$\Psi_L(x^\mu, y) = \frac{1}{\sqrt{2\pi R}}\Psi_L^{(0)}(x^\mu) + \sum_{n=1}^{\infty}\frac{1}{\sqrt{\pi R}}\Psi_{L+}^{(n)}(x^\mu)\cos\frac{ny}{R},$$

$$\Psi_R(x^\mu, y) = \sum_{n=1}^{\infty}\frac{1}{\sqrt{\pi R}}\Psi_{R-}^{(n)}(x^\mu)\sin\frac{ny}{R}.$$