Models with radiative neutrino masses and minimal dark matter

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Outline

1. Introduction and Motivation
2. Construction of Models
3. Conclusion

1. Introduction and Motivation

July 4th 2012
The discovery of a new particle

International Herald Tribune

Discovery upends world of physics

The New York Times

Physicists Find Elusive Particle Seen as Key to Univers

Oil Backed Up, Iranians Put It On Idled Ships

ROMNEY NOW SAYS HEALTH MANDATE BY OBAMA IS A TAX

The Economist

A giant leap for science

Finding the Higgs boson

ッグス粒子発見か

年内に結論

新粒子検出

Milhares de moradores de bairros sociais em risco de perderem RSI

Science : la matière dévoilée

The Gazette

EL PAIS

allada la partícula clave para a comprensión del universo

В ТЕАТРЫ БУДУТ ПУСКАТЬ ПО МОБИЛЬНЫМ ТЕЛЕФОНАМ

MK

ПОСЛЕДНИЙ КИРПИЧ В СТЕНУ МИРОЗДАНИЯ

«КРЕМЛЕВСКИЕ» САМОЛЕТЫ ПРИШЛОСЬ МЕНЯТЬ НА ПЕРЕПРАВЕ

МЕТРО СПУСТЯТ НА ВОДУ

AD ALGEMEEN DAGBLAD

EINDELIJK GELIJK NA 48 JAAR

Frankfurter Allgemeine

CHINA DAILY

THE TIMES OF INDIA

Big bang moment: Scientists may have found 'God particle'

THE HINDU

Elusive particle found, looks like Higgs boson

CORRIERE DELLA SERA

Nomine Rai bloccate Scontro Fini-Schifani

La particella che può svelare i segreti dell'universo

gazeta

BOSKA MASA

আনন্দবাজার পত্রিকা

বিজ্ঞানের 'ঈশ্বর' দর্শন

'পেয়েছি, যা খুঁজছিলাম'

PPT from J. Ellis's talk

2013 NOBEL PRIZE IN PHYSICS

PPT from Q.H. Cao's talk

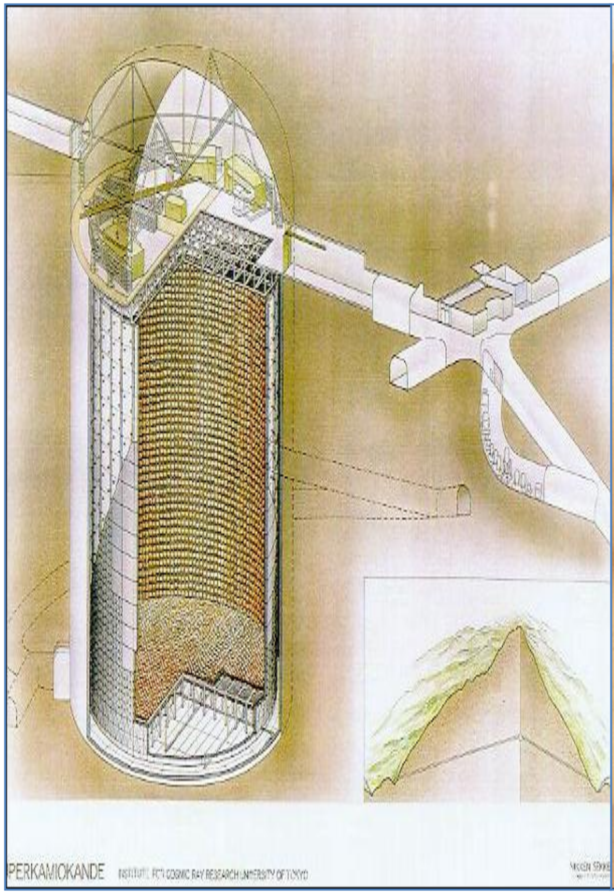
Francois Englert **Peter W. Higgs**

"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"

SM is not the whole story

neutrino mass, DM ……

Oscillation experiments



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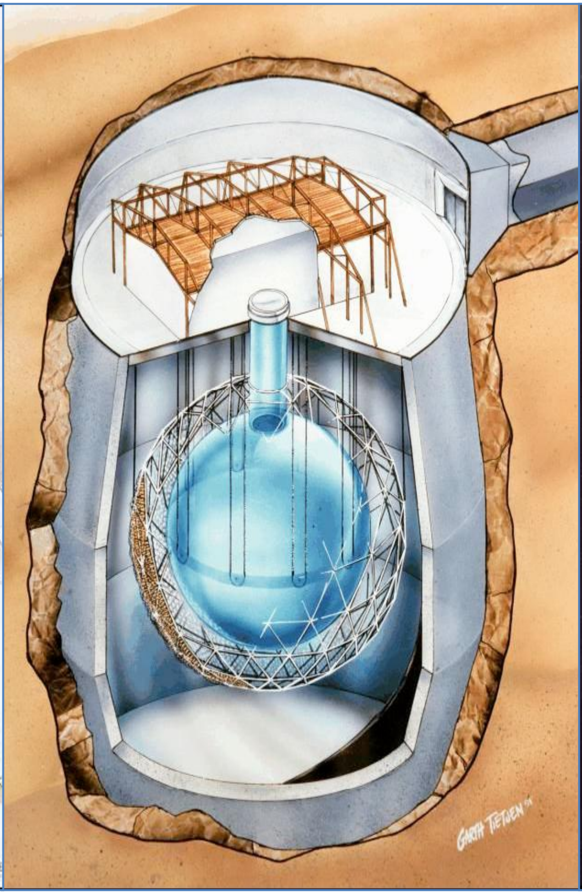


SNO

KamLAND

other atmospheric, solar, accelerator, and reactor neutrino experiments

Neutrino have tiny mass and flavor violation

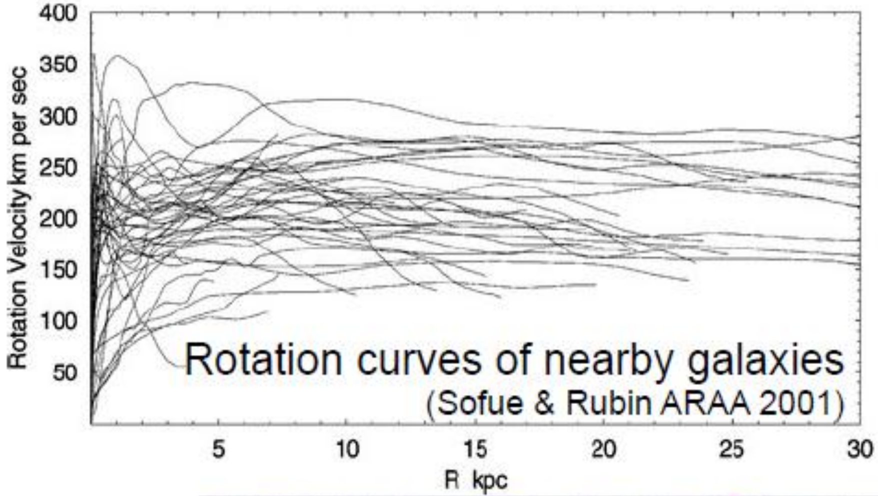
Evidence for Dark Matter

at Different Astrophysics Scales

Spiral Galaxies Scale: ~10^{21} m

Rotation curves remain flat far beyond the edge of the visible disk.

$$\left.\begin{array}{lcl} v(R) & = & \sqrt{GM(R)/R} \\ v(R) & \approx & const \end{array}\right\} \Rightarrow \left\{\begin{array}{lcl} M(R) & \propto & R \\ \rho(R) & \propto & R^{-2} \end{array}\right.$$



Rotation curves of nearby galaxies (Sofue & Rubin ARAA 2001)

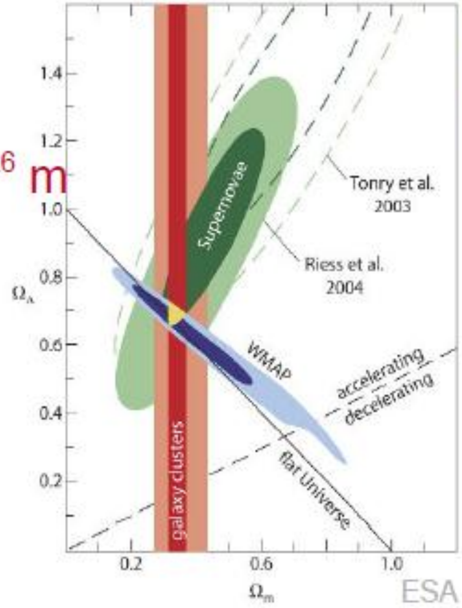
Galaxy Clusters Scale: ~10^{22} m

- Orbital velocities of galaxies (Zwicky's discovery in 1933)
- X-ray gas
- Gravitational lensing

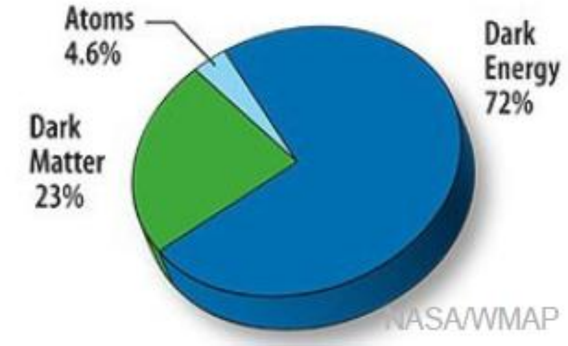
W.Couch, R. Ellis/NASA

The Dark Universe - Scale: ~10^{26} m

- CMB: Ω_{tot}=1.0
- CMB, BBN: Ω_b=0.045
- Galaxy clusters: Ω_m=0.27
- Supernovae Ia: Ω_m, Ω_Λ
- Structure formation: cold DM



ESA



NASA/WMAP

Physics beyond SM!

Neutrino in the SM and beyond

In SM, neutrino is massless :

(1) Gauge symmetry; (2) Renormalization;

(3) Minimal particle spectrum; No RH neutrino, only one Higgs doublet

Possible corresponding ways to extend:

(1) Extension of gauge group: eg. SUSY, Grand Unification.

(2) Effective operator: eg. Weinberg operator.

(3) Extension of particle spectrum:

(a) Canonical seesaw; (b) Quantum effects.

Radiative neutrino mass

DM: a model view

(1) Relic density;

WIMP: a particle with weak interaction naturally give relic desity with mass at electroweak scale

(2) Stable Or decay lifetimes larger than the age of the Universe;

Symmetry, higher dimensional operator……

Stabilization mechanism in SM

Photon: U(1)QED;
Neutrino: Lorentz invariance;

electron: lightest charged particle;
proton: baryon number conservation

No DM candidate in SM

(3) Others;

(a) electroneutrality;

(b) Y=0 from DM direct detection experiment;

(c) Non-baryonic;

One stone two birds

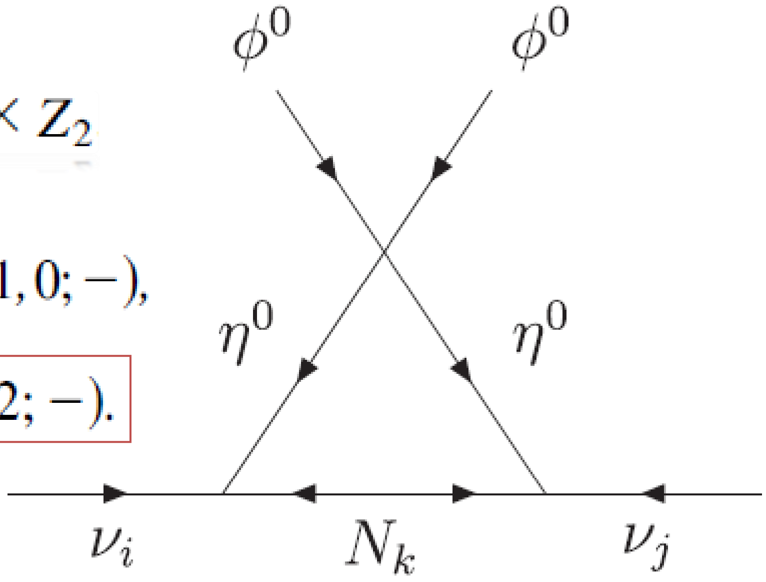
Radiative neutrino mass + symmetry

Scotogenic model $SU(2)_L \times U(1)_Y \times Z_2$

(E. Ma, PRD 73 (2006) 077301)

$$(\nu_i, l_i) \sim (2, -1/2; +), \quad l_i^c \sim (1, 1; +), \quad N_i \sim (1, 0; -),$$

$$\boxed{(\phi^+, \phi^0) \sim (2, 1/2; +), \qquad (\eta^+, \eta^0) \sim (2, 1/2; -).}$$



Comment:

(1) Additional Z2 is imposed to keep the stability of DM;

Minimal DM may work for this problems

(2) A relatively small number of paramters due to (accident) symmetry;

Minimal DM

(M. Cirelli et al, NPB 753(2006)178, NPB 787(2007)152, NJP 11(2009)105005)

Basic idea:

Add to SM one extra multiplets with minimal spin, isospin and hypercharge quantum numbers, and satisfy :

(1) The lightest component is automatically stable;

(2) The DM is still allowed by DM searches;

Higher isospin

hyperchargeless

Main conclusions:

(1) $n \geq 5$, for fermions, $n \geq 7$ for scalars;

(2) Small number of parameters:

(a) For fermions, gauge type interactions and one new parameter(the tree-level mass);

(b) For scalars, quartic couplings with the Higgs fields besides the same thing like the case in fermions.

Motivation

Radiative neutrino mass + Minimal DM

(1) Radiative neutrino mass :

With the help of higher isospin multiplets we do a systematic investigation, from dimensional-5 Weinberg operator, on the neutrino mass generated at one loop.

(2) The Stability of DM:

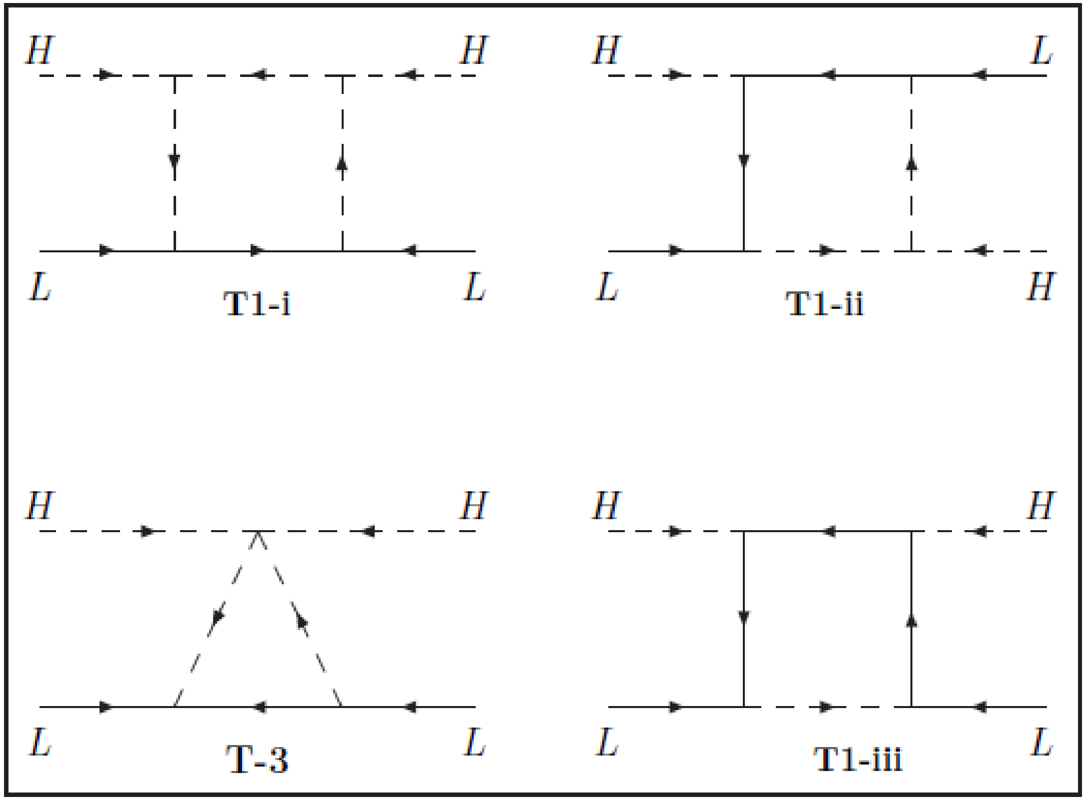
Analysis of the symmetry lead by the assignments of the quantum number of new fields. eg. Z2 symmetry

2. Construction of models

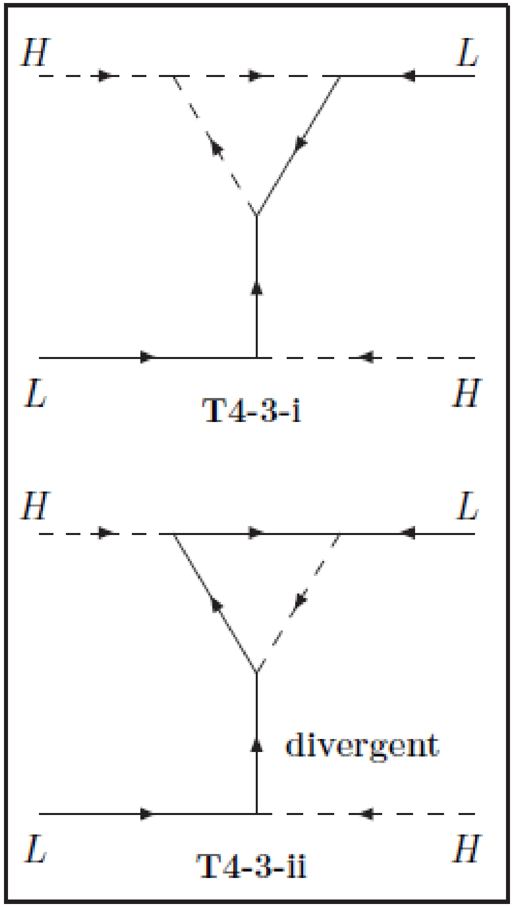
One-loop realization of Weinberg operator

(F. Bonnet et al.,JHEP 07(2012)153)

Other mechanism

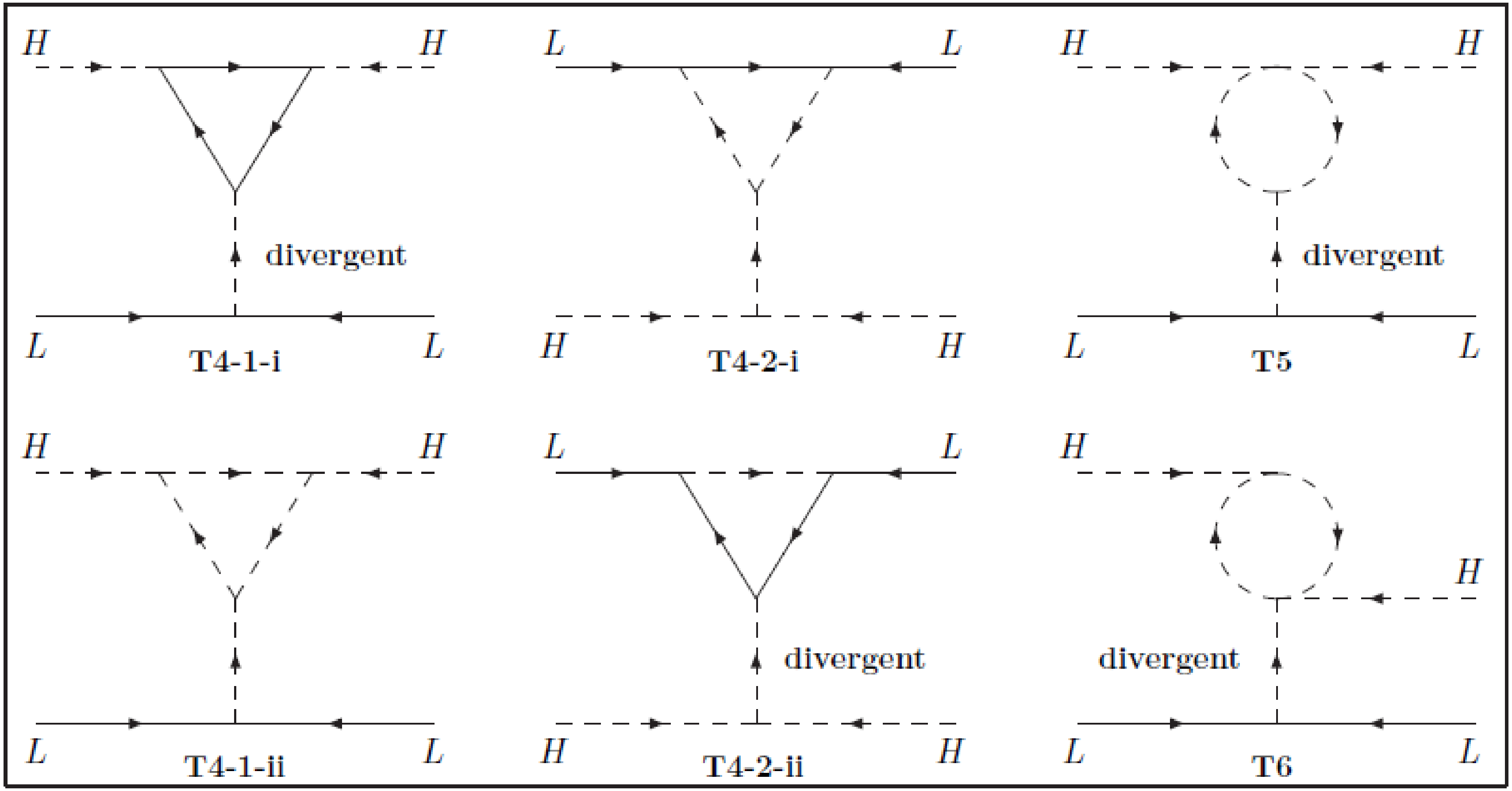


Analogous Type I/III



Only considerate fermions and scalars running in the loop, not include color particles and vector bosons.

Analogous Type II



(1) The divergence can be absorbed by the tree level counter-terms coming from the regular tree level Type II (Type II-like) seesaw;

(2) To link DM, the fields running in the loop should have neutral component.

Lesson from minimal DM model

Fermion multiplets Mass term, gauge interactions

$T \geq \frac{3}{2}, n = 2T + 1 \geq 4,\ U(1)$ Symmetry; → $T \geq 2, n \geq 5, U(1)$

Neutrality and Y=0 $\boxed{Q = T3 + Y, T3 \subset [-T, T]}$

Scalar multiplets Mass term, gauge interactions, scalar potential

$T \geq \frac{5}{2}, n = 2T + 1, Y = 0,$ Z2 Symmetry;

Neutrality and Y=0 → $T \geq 3, n \geq 7, Z2$

Generalization on Scalar multiplets

(1) $Y = 0, T \geq 3, T$ odd integer, Z2

(2) $T \geq Y \geq 1, T \geq 2, Y, T$ integer, U(1)

(3) $T \geq Y \geq 1, T \geq 5/2, Y, T$ half integer, U(1)

(part of results: K. Earl et al. arxiv:1311.3656)

Notice: Y can be nonzero in generalization

Constraints on multilplets

Perturbativity of SU(2)L gauge coupling

Model dependent

$n \leq 5$, for Majorana fermions

$n \leq 8$, for real scalars (Planck scale)

$n \leq 6$, for complex scalar

$n \leq 7$, for real scalars (TeV scale)

Perturbative unitarity

Generally applicable

$n \leq 8$, for complex scalar

$n \leq 9$, for real scalars (TeV scale)

New fields in our analysis

$$\boxed{Q = T3 + Y, T3 \subset [-T, T]}$$

Scalars (1) $Y = 0, T = 3$, for real scalar; (2) $Y \neq 0, \frac{1}{2}, T = \frac{5}{2}, \frac{7}{2}$, for complex scalar;

(3) $Y \neq 0, T = 2{,}3{,}4$, for complex scalar.

fermions $T = \frac{3}{2}, 2, \frac{5}{2},$ for real scalar;

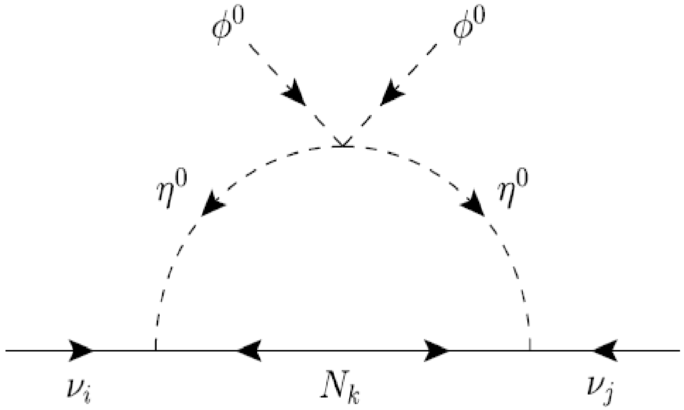
Y can set any values only if there exists neutral component in multiplets

An elaborate example

Lepton number violation in the mass term

$$N\!: T = 2, Y = 0;$$

$$\eta\!: T = \frac{5}{2}, \frac{3}{2}, Y = \frac{1}{2};\ \widetilde{H}\eta\eta\tilde{\eta}$$



Lepton number violation in the Yukawa coupling

$$N\!: T = 2, Y = 2,1;$$

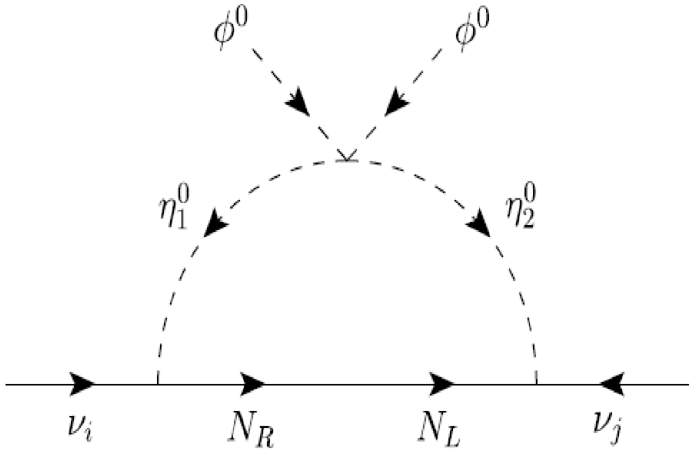
$$\eta_1\!: T = \frac{5}{2}, Y = \frac{5}{2}, \frac{3}{2};$$

$$\eta_2\!: T = \frac{5}{2}, Y = \frac{3}{2}, \frac{1}{2};\ \widetilde{H}\eta_2\eta_2\widetilde{\eta_1}$$

$$N\!: T = \frac{5}{2}, Y = \frac{5}{2}, \frac{3}{2}, \frac{1}{2};$$

$$\eta_1\!: T = 3, Y = 3,2,1;$$

$$\eta_2\!: T = 3, Y = 2,1,0;\ \widetilde{H}\eta_2\eta_2\widetilde{\eta_1}$$



Careful: When more than one new scalar fields are introduced, we must make sure that the new interactions brought by them don't break the pre-existing symmetry.

Relevant phenomenology

(1) Flavor physics will be relevant if new fermion is not to heavy and coupling can be large;

(2) New scalar may have influence in Higgs physics ;

(3) Due to exotic charge, new fields will have rich collider phenomenology if their masses are not heavy ;

3. Conclusion

Conclusion

(1) A systematic investigation has been done for the models with radiative neutrino masses and minimal dark matter;

(2) radiative neutrino masses and minimal dark matter can be achieved in a simple model except hyperchargeless;

(3) These models will have rich phenomenology if the new fields is not too heavy and its couplings with SM particles not too weak ;

Thanks for your attention !!!