Mitchell Workshop on Collider and Dark Matter Physics

Dark Matter, Neutrino Mass Gauge Coupling Unification and LHC

Ilia Gogoladze

Bartol Research Institute
University of Delaware

Work in progress with Adeel Ajaib and Qaisar Shafi

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What we know about neutrinos

- Global fit to neutrino mass and mixing parameters:

Quantity	Value
$\Delta m^2_{21}(\mathrm{eV}^2)$	$(7.59 \pm 0.21) \times 10^{-5}$
$\Delta m^2_{31}(\mathrm{eV}^2)$	$(2.53^{+0.13}_{-0.08}) \times 10^{-3}$ (NH) $-(2.4^{+0.1}_{-0.07}) \times 10^{-3}$ (IH)
$\sin^2\theta_{12}$	$0.320^{+0.015}_{-0.017}$
$\sin^2\theta_{23}$	$0.49^{+0.08}_{-0.05}$ $0.53^{+0.08}_{-0.07}$
$\sin^2\theta_{13}$	$0.026^{+0.003}_{-0.004}$ $0.027^{+0.003}_{-0.004}$

Forero, Tórtola, & Valle (2012)

K.S. Babu, talk at the LHC Theory Workshop , 2012

Neutrino Mass Generation Mechanisms

1) Seesaw (I, II & III)
2) Inverse Seesaw (d > 5)
3) Radiative Mass (1, 2 and 3 loops)

Dark Matter

❖ Nature of Dark Matter

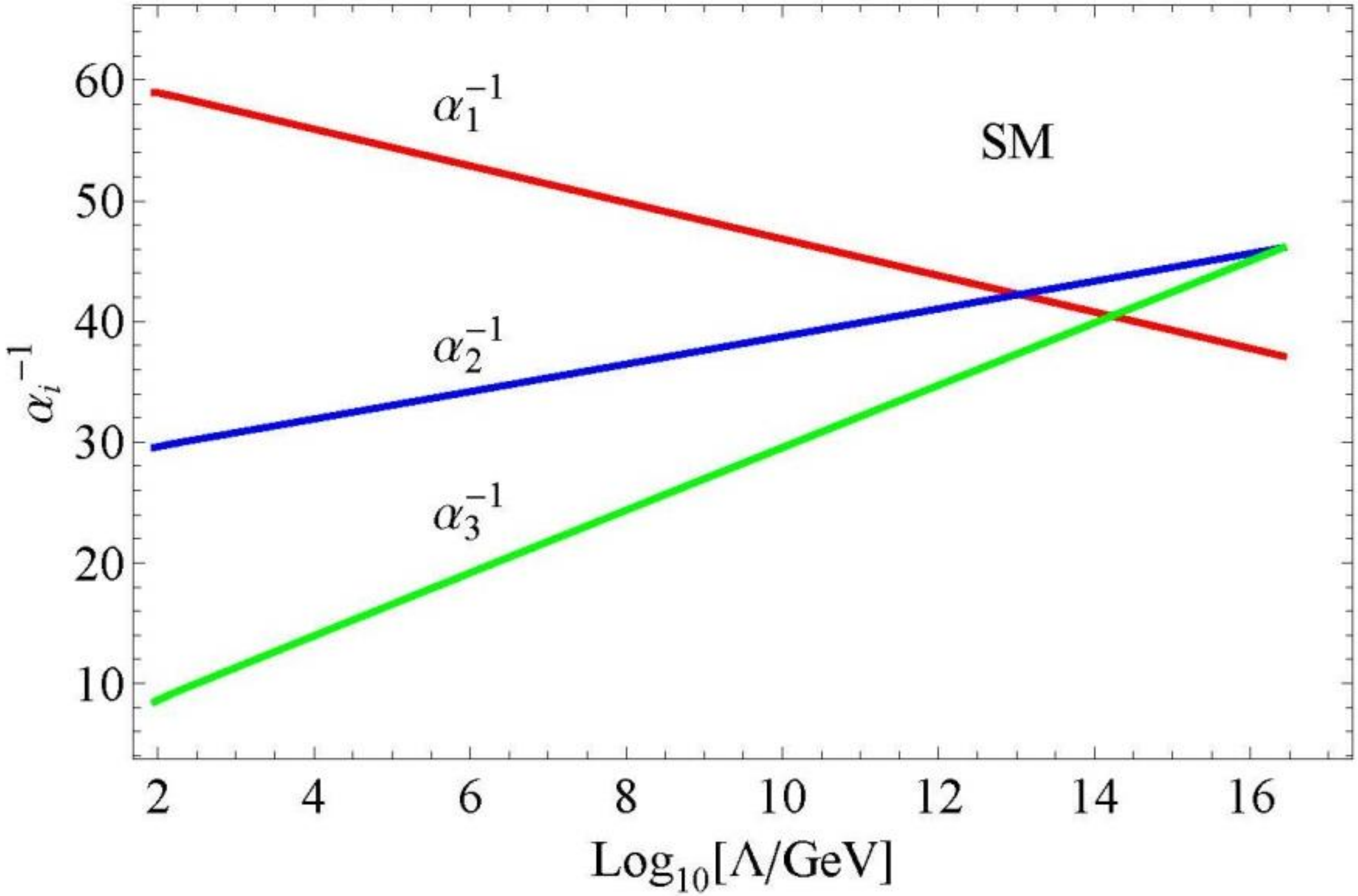
- Stable (or long live > 10^{26} sec)
- electrically neutral
- non-relativistic particle

❖ DM candidate

- In order to include DM we have to stabilize a particle → Z_2 (Z_3, …) parity
- Neutralino, Right-handed neutrino, Gravitino, Axion, inert scalar doublet etc..

Jiang-Hao Yu talk

Gauge Coupling Unification



$$\Delta B_{23} \approx 0, \quad \Delta \mathrm{B}_{12} \approx \Delta B_{13} \approx 2 \left(\pm \frac{1}{6}\right)$$

Additional Vector-like Particles

$SU(3)_C$ x $SU(2)_L$ x $U(1)_Y$

Fermions (one Scalars)

$$A = (1,2)_{-1/2} + (1,2)_{1/2}$$
$$B = (\bar{3},1)_{1/3} + (3,1)_{-1/3}$$
$$C = (3,2)_{1/6} + (\bar{3},2)_{-1/6}$$
$$D = (\bar{3},1)_{-2/3} + (3,1)_{2/3}$$
$$E = (1,1)_{-1} + (1,1)_{1}$$

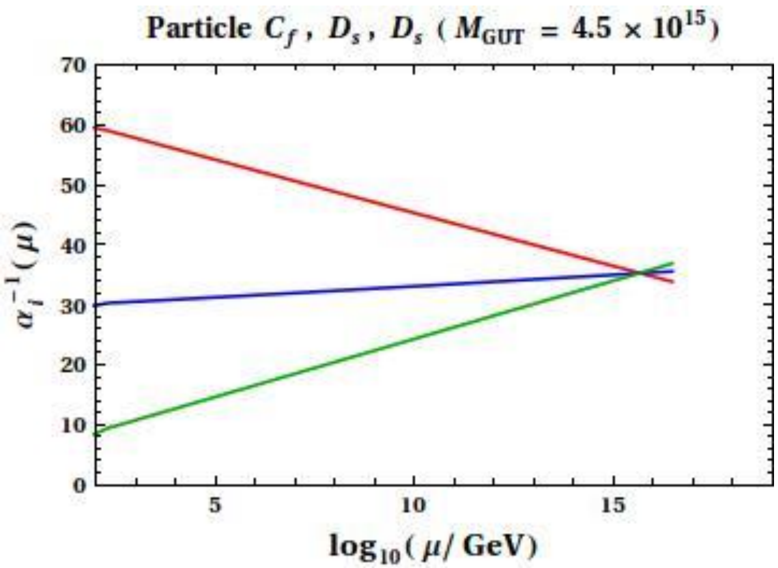
Pyungwon Ko talk

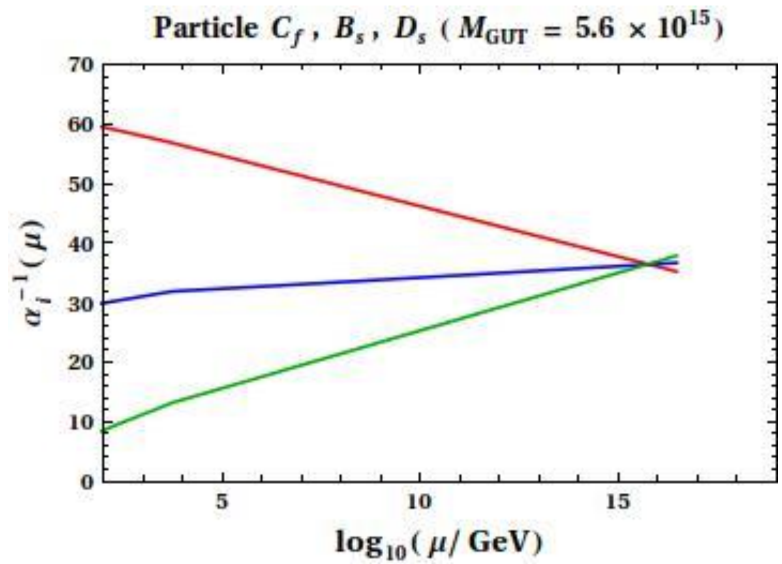
Radiative Neutrino Mass and Unification

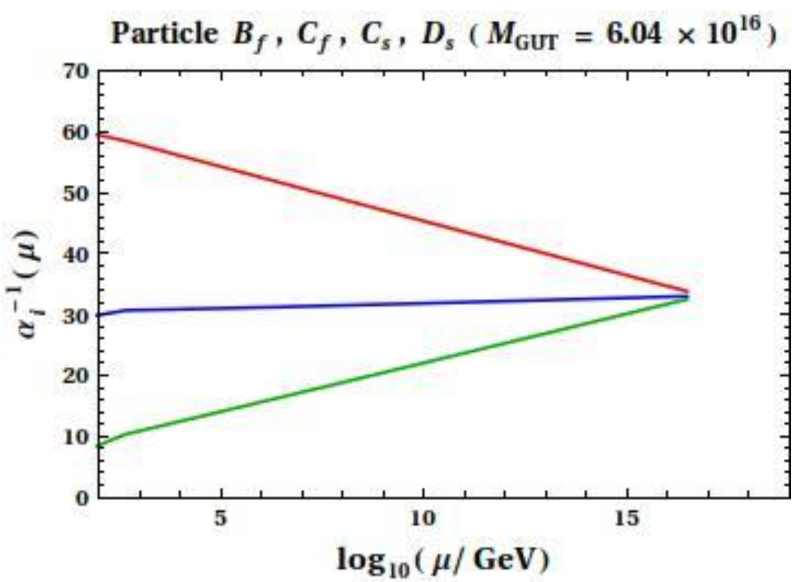
Fermions					Scalars							
A	B	C	D	E	A	B	C	D	E	# of irr reps	M_{GUT}	α_{GUT}^{-1}
0	0	1	0	0	0	1	0	1	0	3	7.12×10^{15}	36.13
0	1	1	0	0	0	0	1	1	0	4	5.51×10^{16}	33.35
0	1	1	0	0	0	1	1	0	1	5	5.63×10^{16}	33.38
0	1	1	0	0	1	0	0	0	0	3	2.00×10^{16}	35.28
0	1	1	0	0	1	0	0	0	1	4	1.06×10^{16}	34.78
0	1	1	0	0	1	0	1	1	1	6	2.19×10^{16}	32.63
0	1	1	0	0	1	1	1	1	0	6	5.62×10^{16}	32.45
1	1	1	0	0	0	1	0	1	0	5	8.08×10^{15}	32.83
1	1	1	1	0	1	0	1	0	0	6	5.36×10^{15}	29.10

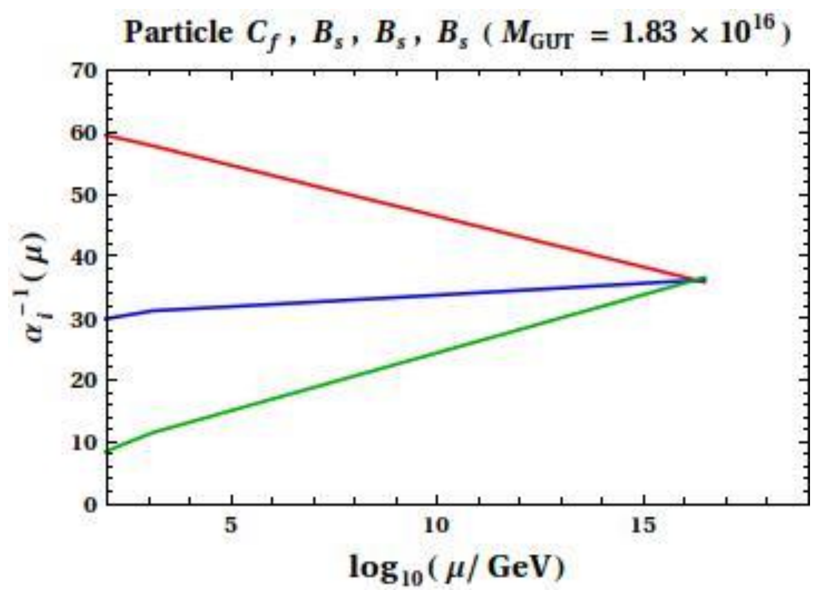
Table 1: Table of additional vector like particles. The maximum number of particles allowed of a particular type is 1. The threshold scale for all the cases is $M_{\text{threshold}} = 1$ TeV.

Gauge Coupling Unification



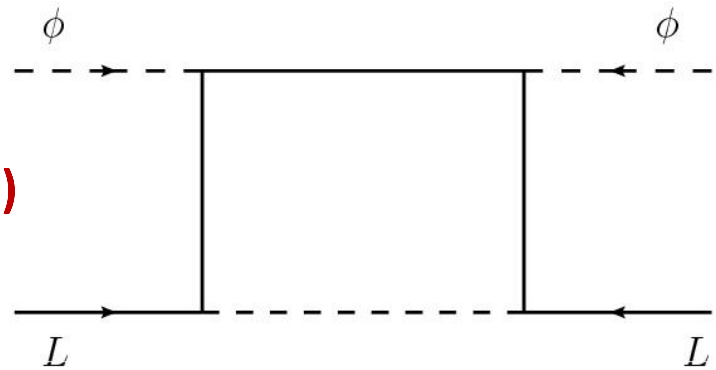




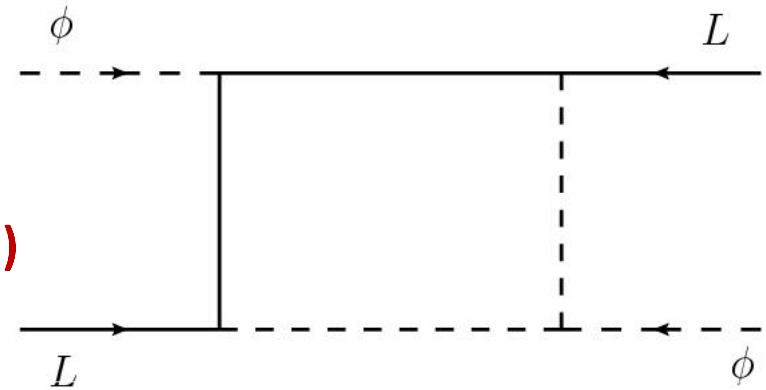


Neutrino Mass Generation at one Loop Order

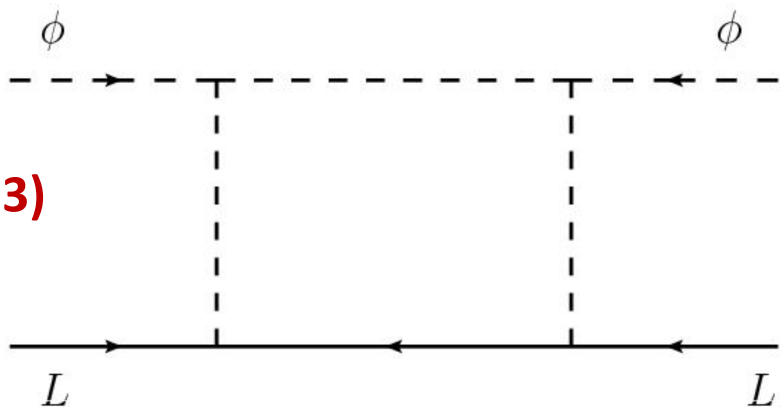
1)



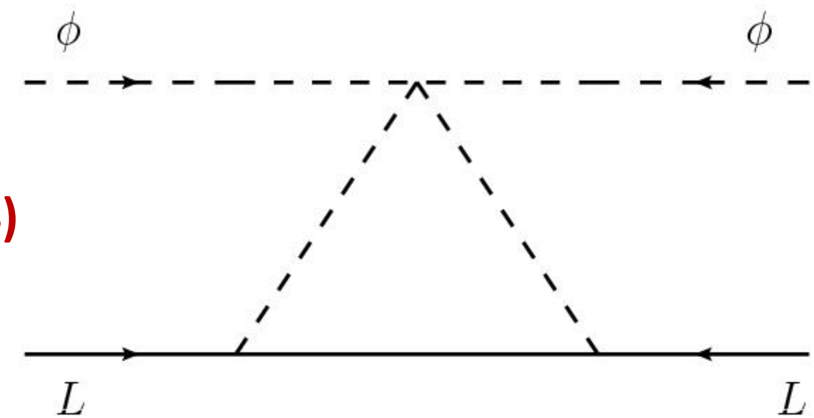
2)



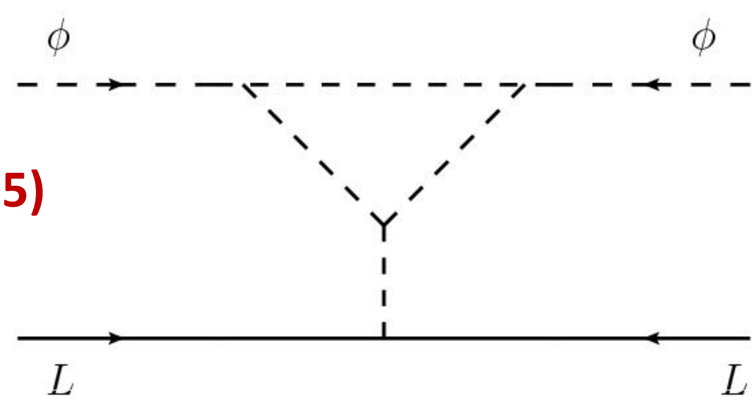
3)



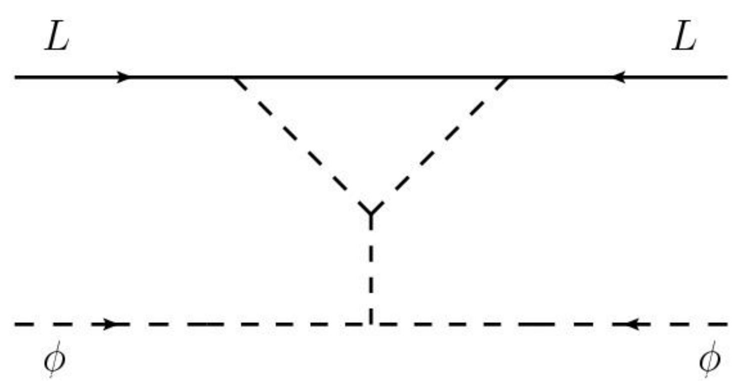
4)



5)

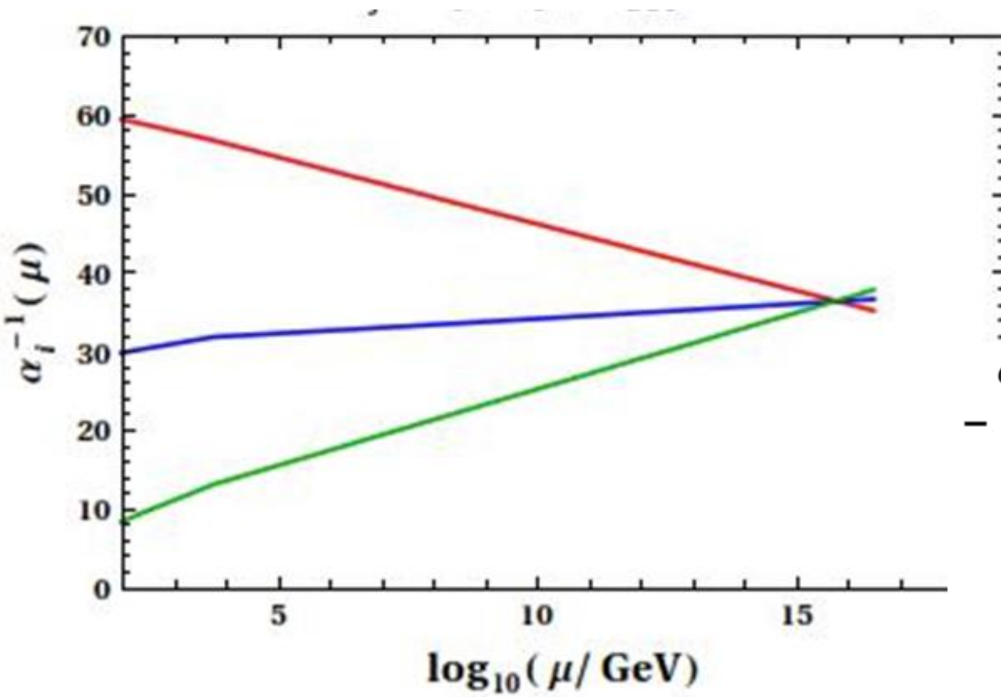


6)



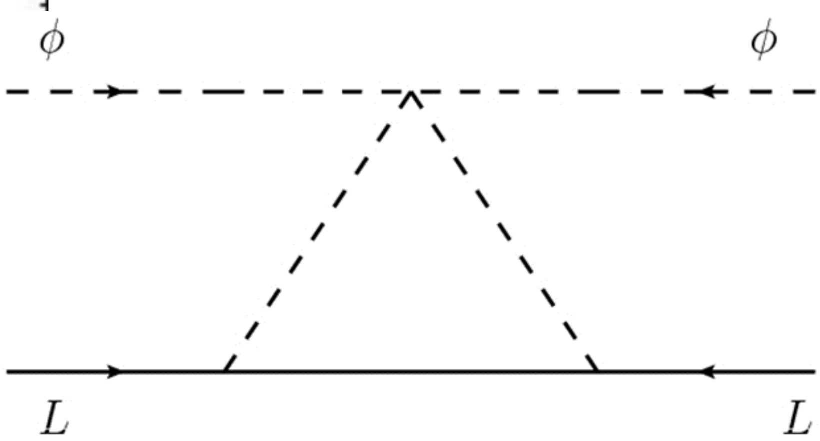
Gauge coupling unification and neutrino mass

$$(3,2)^f{}_{1/6} + (\overline{3},2)^f{}_{-1/6} + (\overline{3},1)^s{}_{1/3} + (\overline{3},1)^s{}_{-2/3}$$



$$M_{GUT} = 7 \times 10^{15}\ GeV$$

$$\alpha_{GUT}^{-1} = 36$$

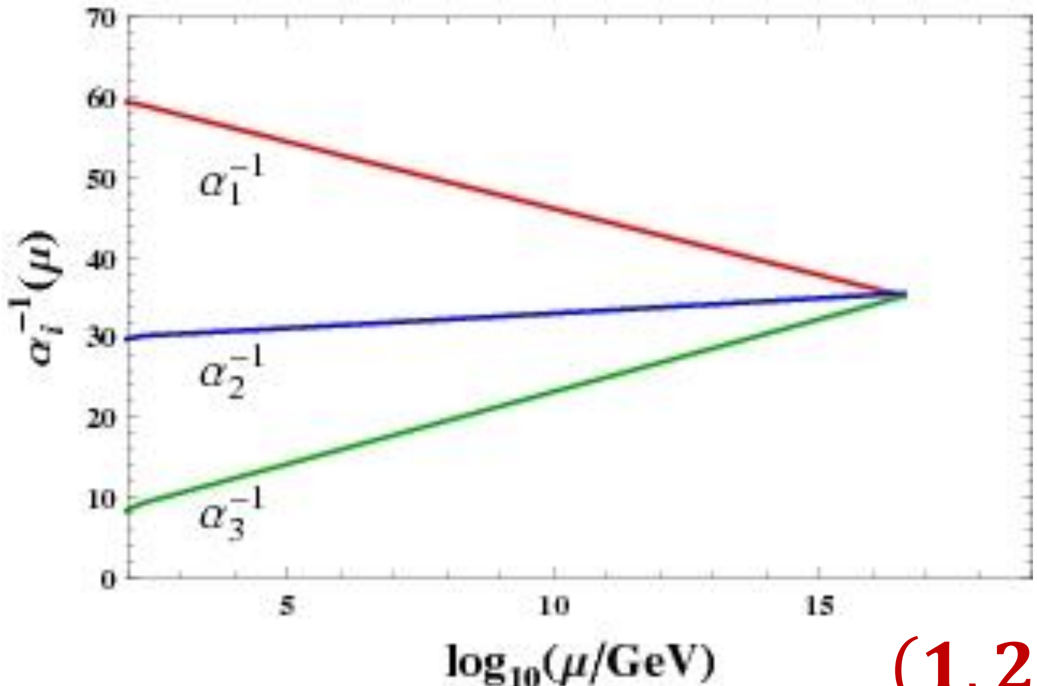


$$(\mathcal{M}_\nu)_{\alpha\beta} = \sum_i \frac{h_{\alpha i} h_{\beta i} M_i}{16\pi^2} \left[\frac{m_R^2}{m_R^2 - M_i^2} \ln \frac{m_R^2}{M_i^2} - \frac{m_I^2}{m_I^2 - M_i^2} \ln \frac{m_I^2}{M_i^2} \right].$$

K. S. Babu and J. Julio, Phys. Rev. D 85, 073005 (2012)

Gauge coupling unification and Dark Matter

$$(3,2)^f{}_{1/6} + (\bar{3},2)^f{}_{-1/6} + (\bar{3},1)^f{}_{1/3} + (3,1)^f{}_{-1/3} + (1,2)^s{}_{-1/2}$$



$$M_{GUT} = 2 \times 10^{16}\ \mathrm{GeV}$$

$$\alpha_{GUT}^{-1} = 35$$

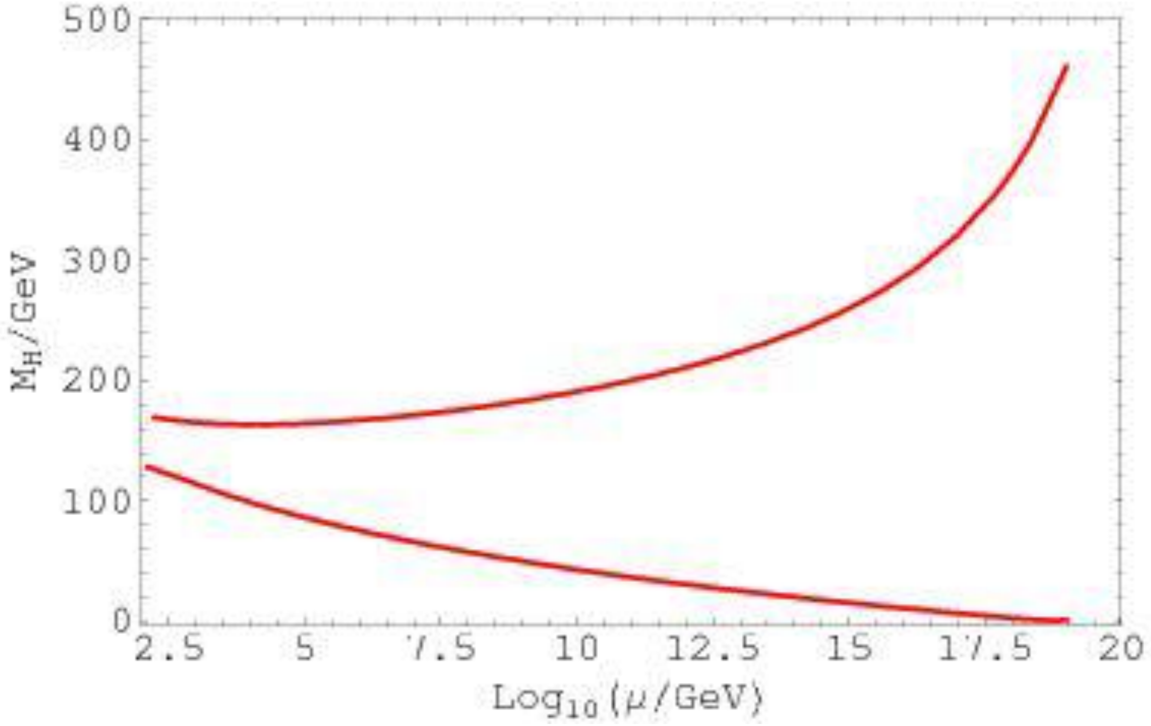
$(1,2)^s{}_{-1/2}$ is odd under Z_2

We can have the inert doublet model of dark matter.

L. Lopez Honorez and C. E. Yaguna, JHEP 1009, 046 (2010)

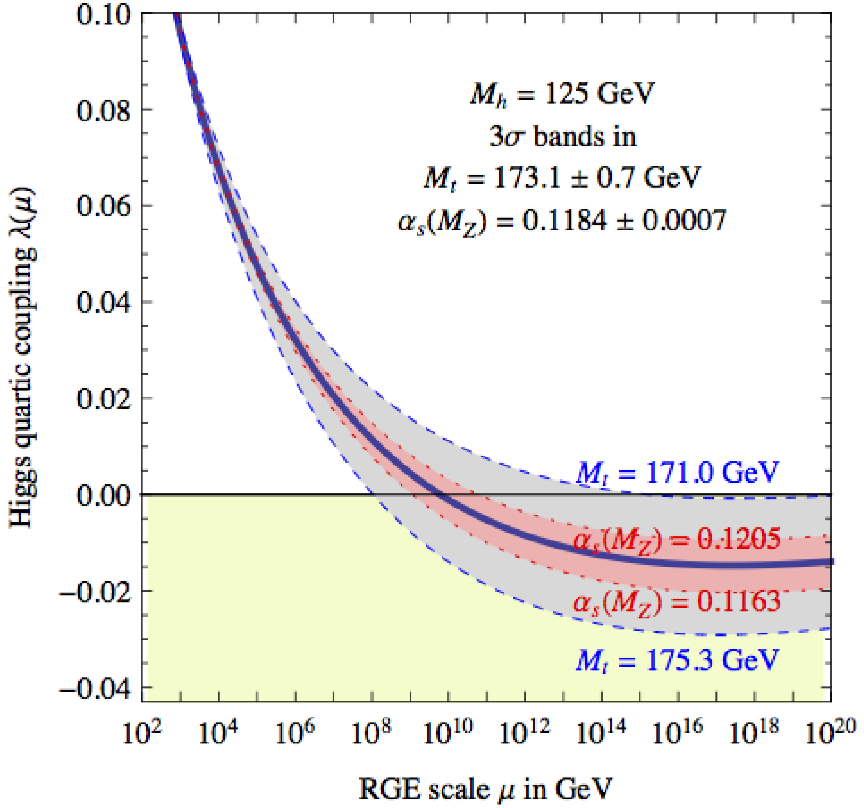
Higgs mass bound in the SM

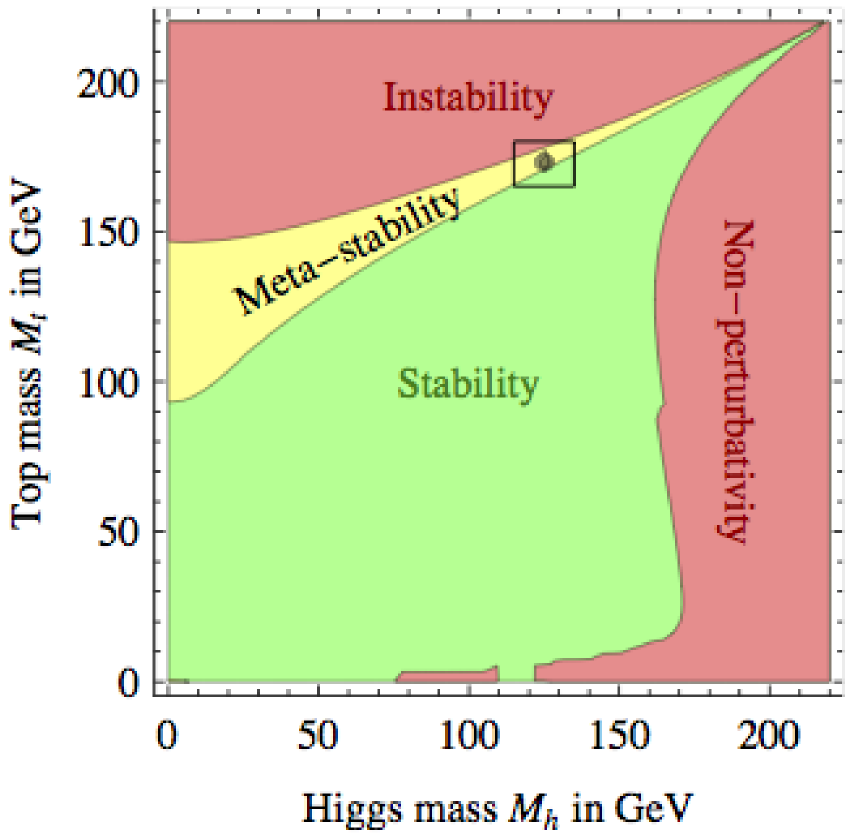
$$\frac{d}{dt}\lambda = \frac{\lambda}{16\pi^2}\left(12\,\lambda^2 - 12h_t^4 + \ \ldots\right)$$



$$130 < m_h < 176$$

125 GeV Higgs and Vacuum meta-stability

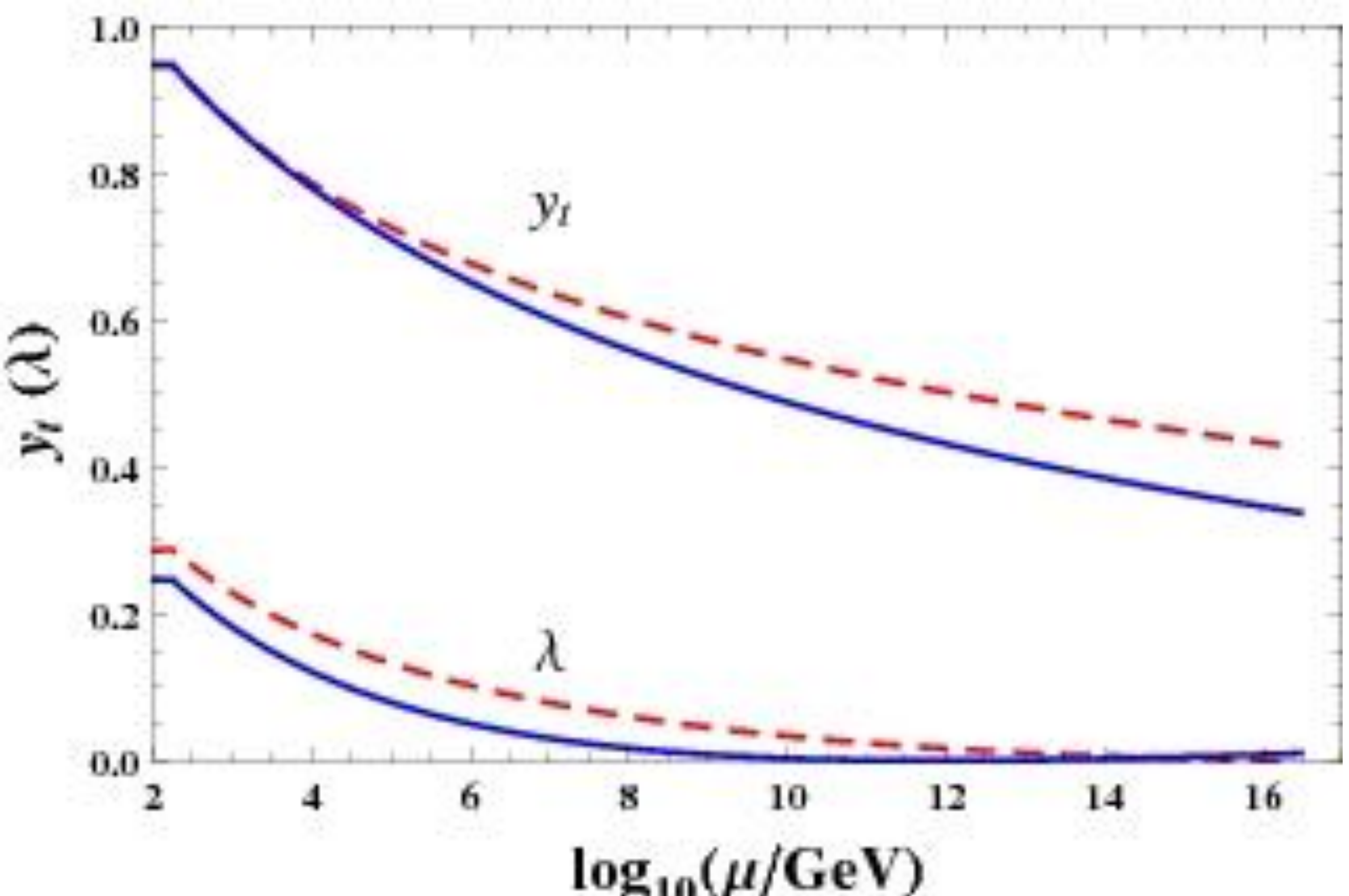




G. Degrassi, S. Di Vita, J. Elias-Miro, J. R. Espinosa, G. F. Giudice, G. Isidori and A. Strumia, JHEP 1208, 098 (2012)

Gauge Coupling Unification and Higgs vacuum stability

$$\frac{d}{dt}\lambda = \frac{\lambda}{16\pi^2}\left(12\,\lambda^2 - 12h_t^4 + \,\ldots\right)$$



Conclusion

We show that around TeV scale we can have particles which can generate Neutrino mass, accommodate correct dark matter relic abundance, leads to the perfect gauge coupling unification and predicts testable lifetime for the proton.