Lepton Flavour Violating Minimal Dark Matter

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Meeting of the Belgian Inter-University Attraction Pole network on fundamental interactions.
18 December 2015
University of Antwerp

BSM New Physics

BSM New Physics

- Neutrino Masses!

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- Neutrino Masses!
- Baryon Asymmetry

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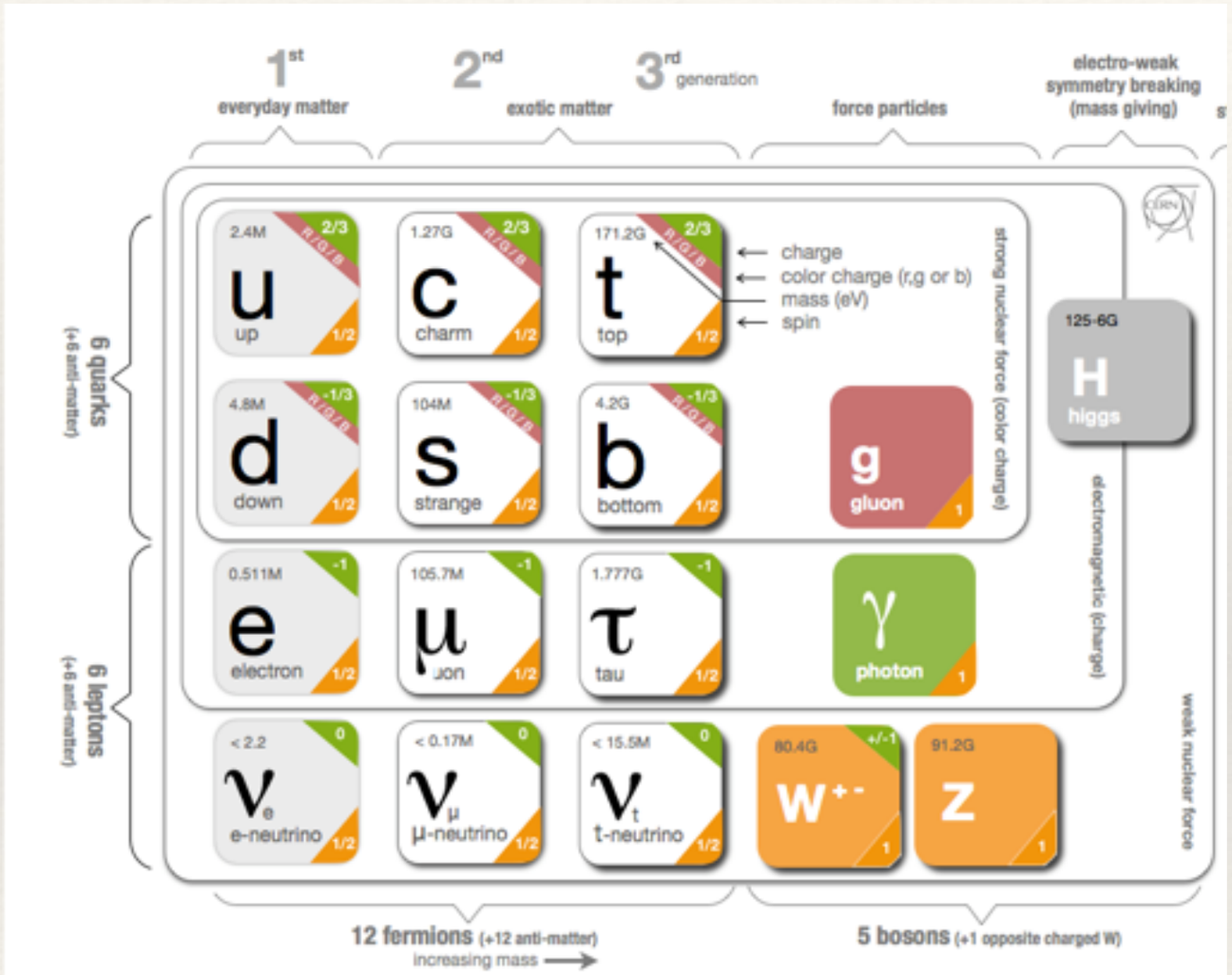
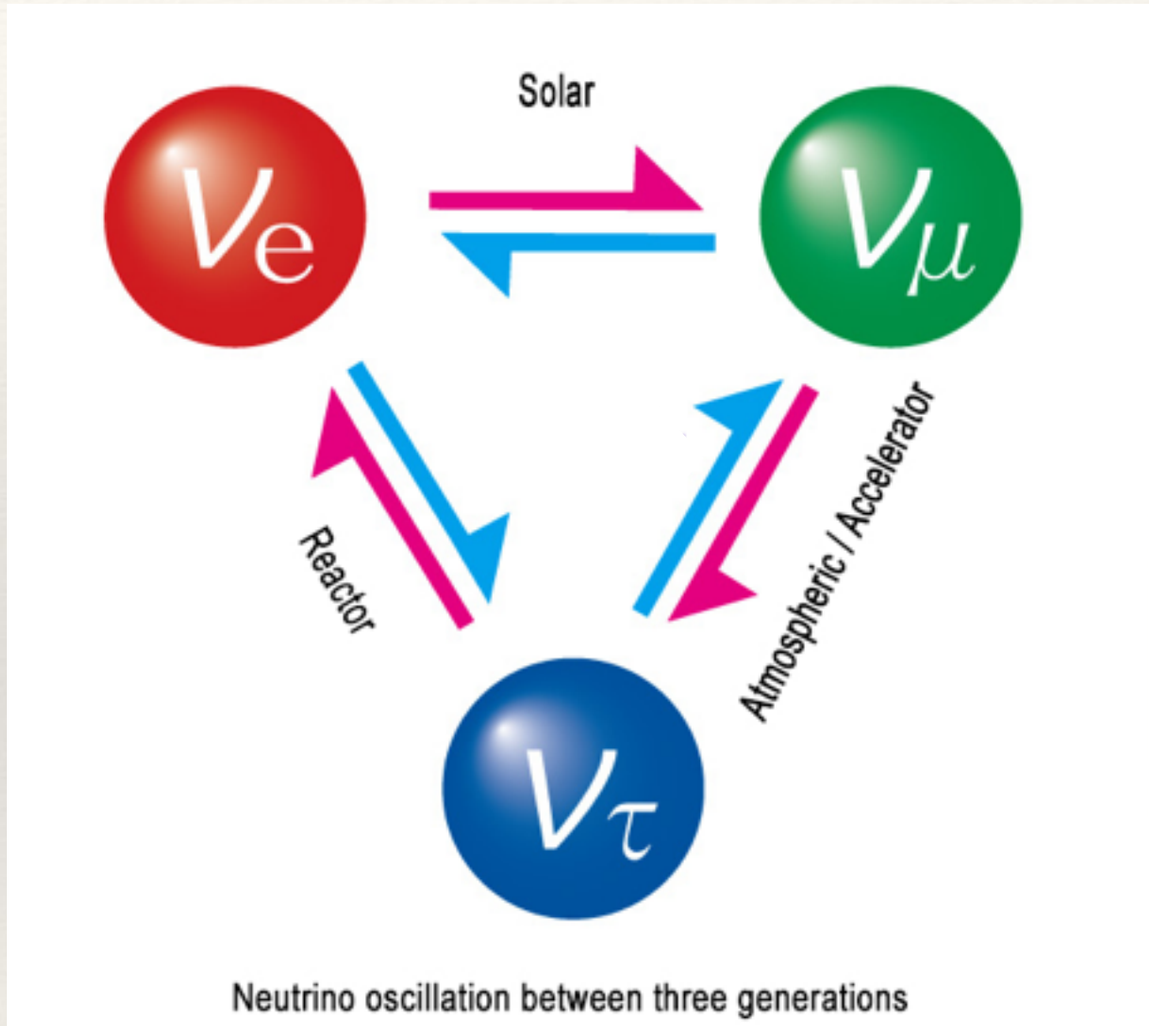
- Baryon Asymmetry
- Dark Matter?

BSM New Physics

- Neutrino Masses!
- Baryon Asymmetry
- Dark Matter?
- ???

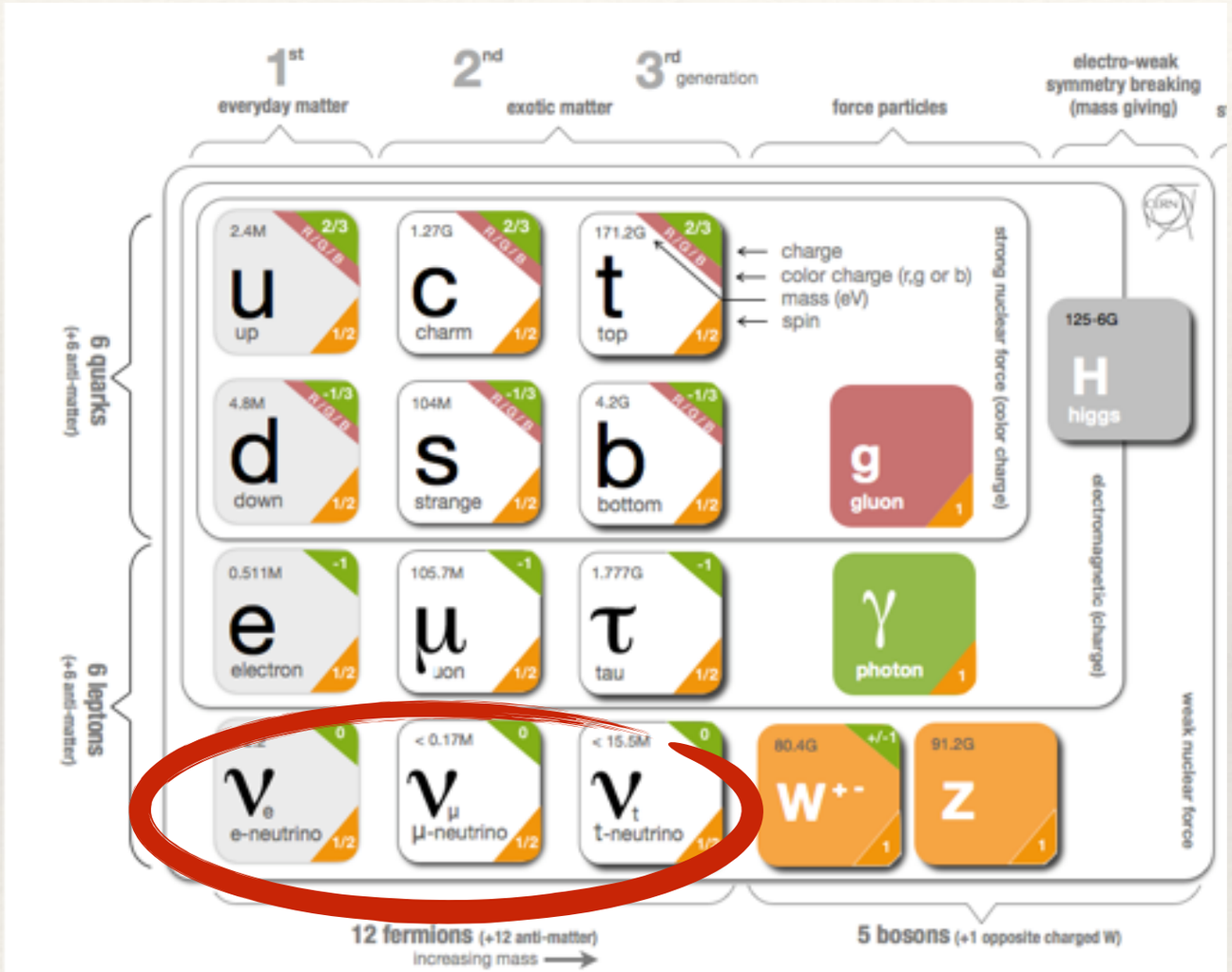
Neutrino Masses

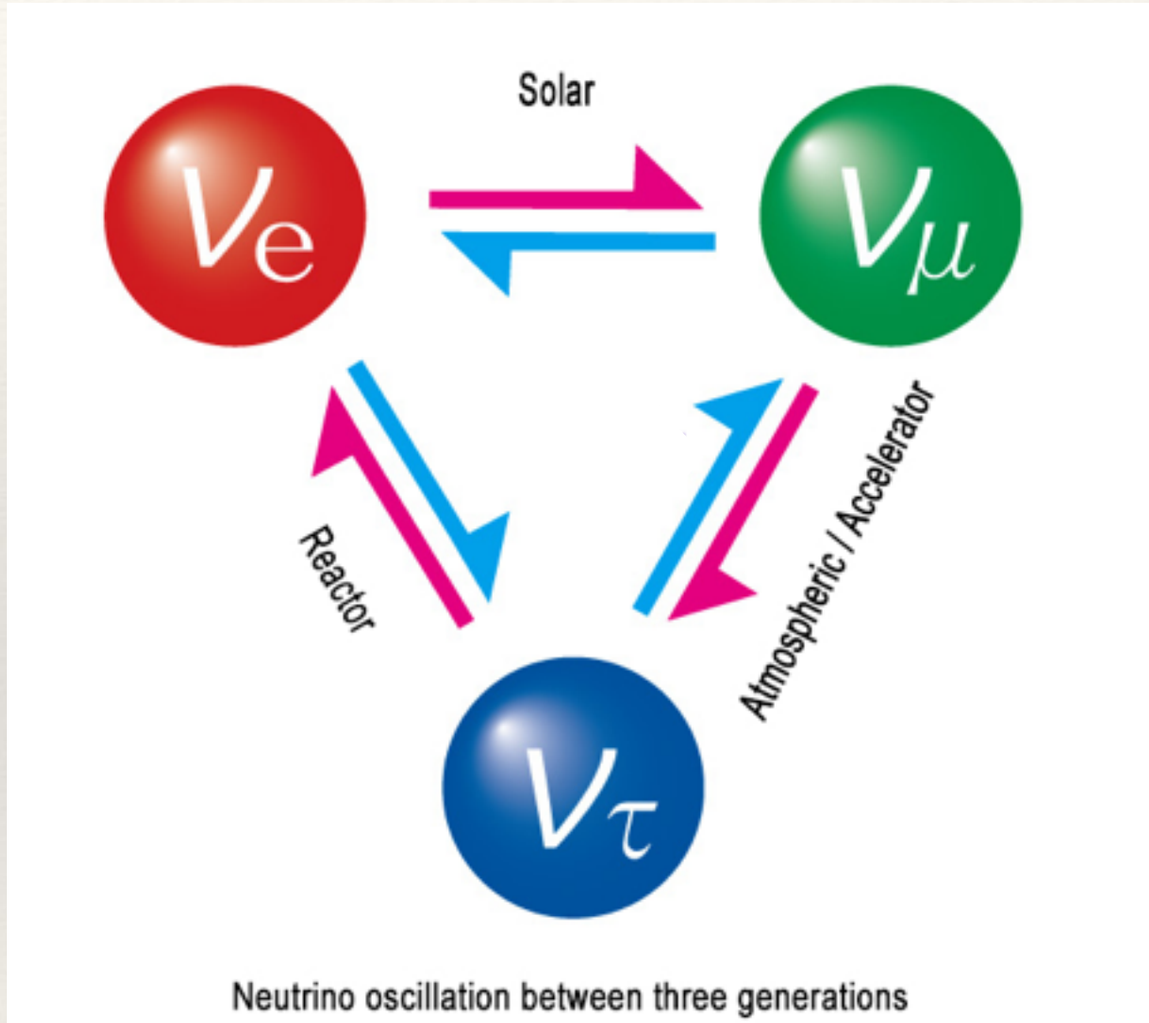




Neutrino oscillation between three generations

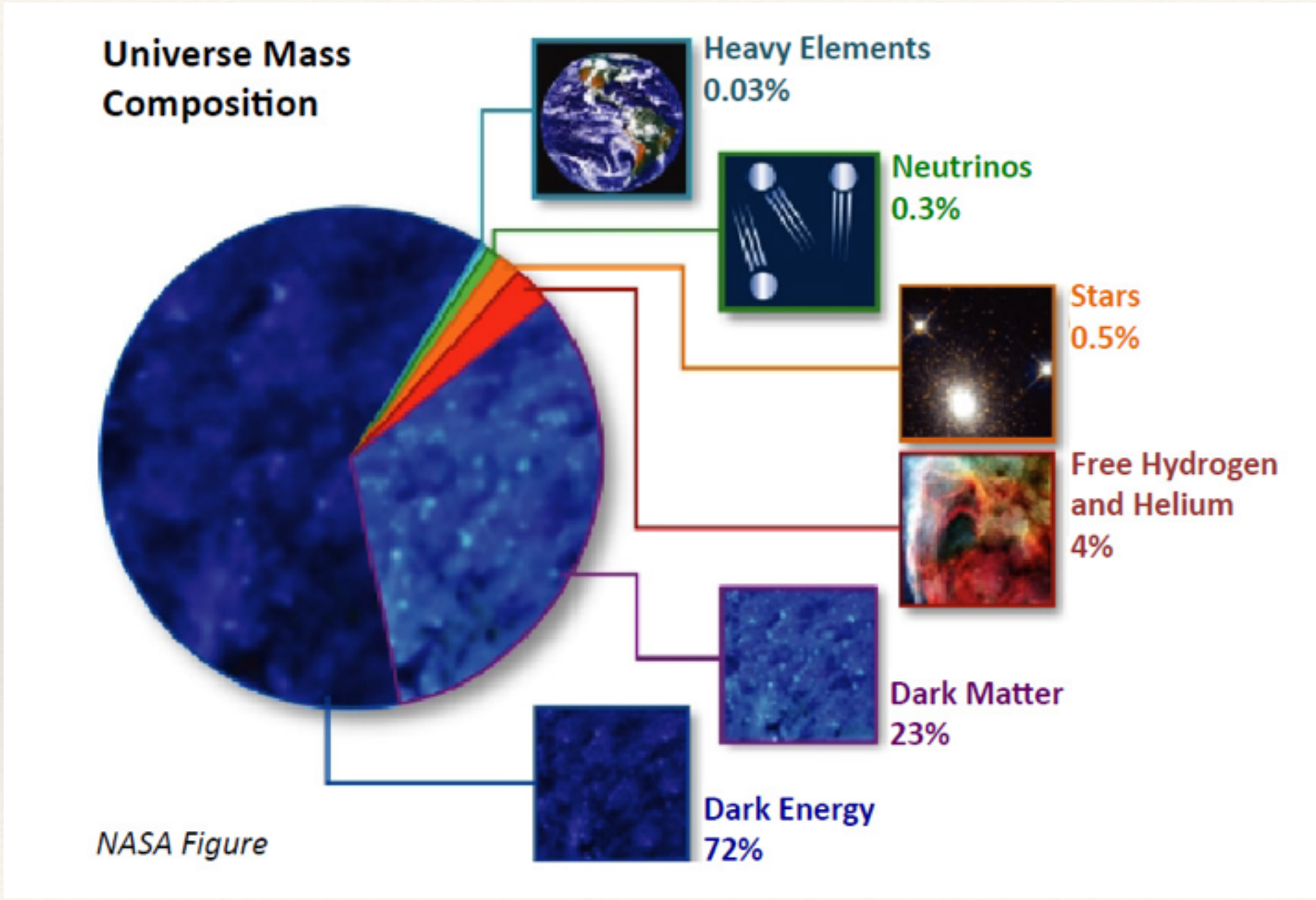
Neutrino Masses





Neutrino oscillation between three generations

Dark Matter



http://scienceblogs.com/startswithabang/2012/07/26/empty-space-has-more-energy-than-everything-in-the-universe-combined/

“Stable” Dark Matter

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- No decay

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- No decay
  - Discrete Symmetry

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  - Accidental Symmetry

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- Long decay

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  - Discrete Symmetry
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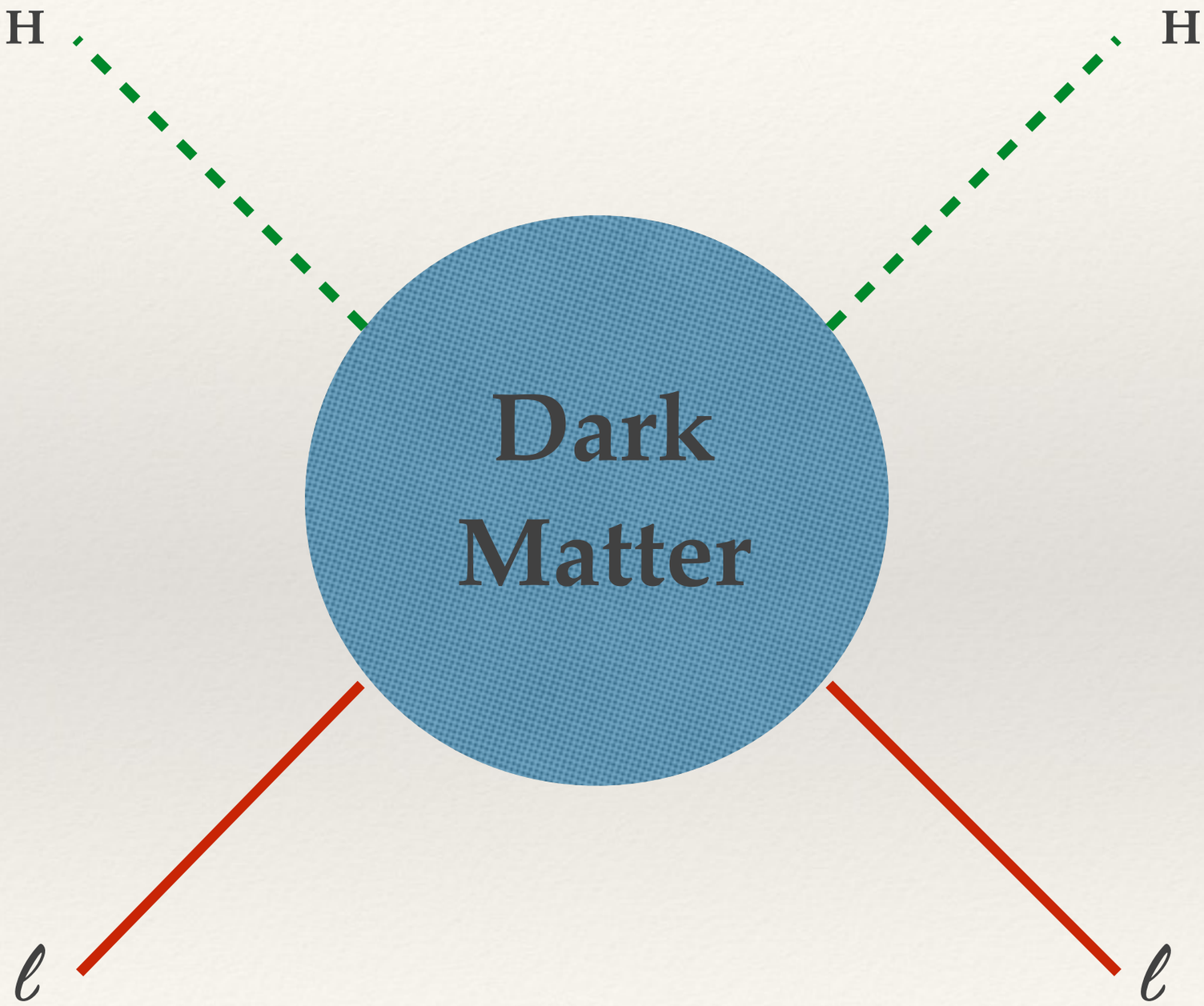
  - $\boldsymbol{\tau} > 10^{26}$ sec

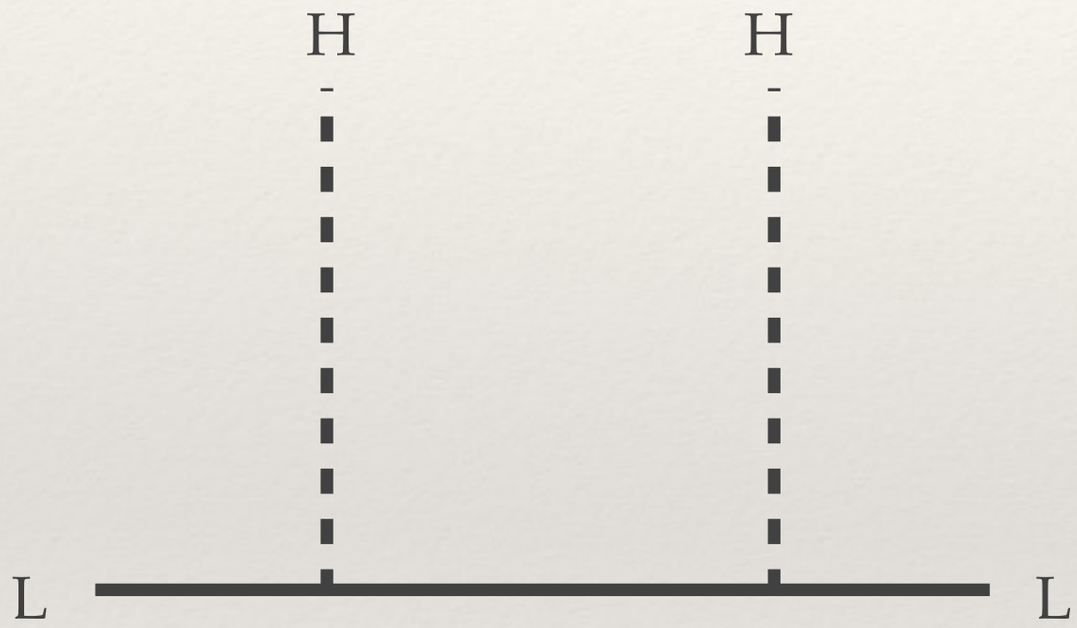
“Stable” Dark Matter

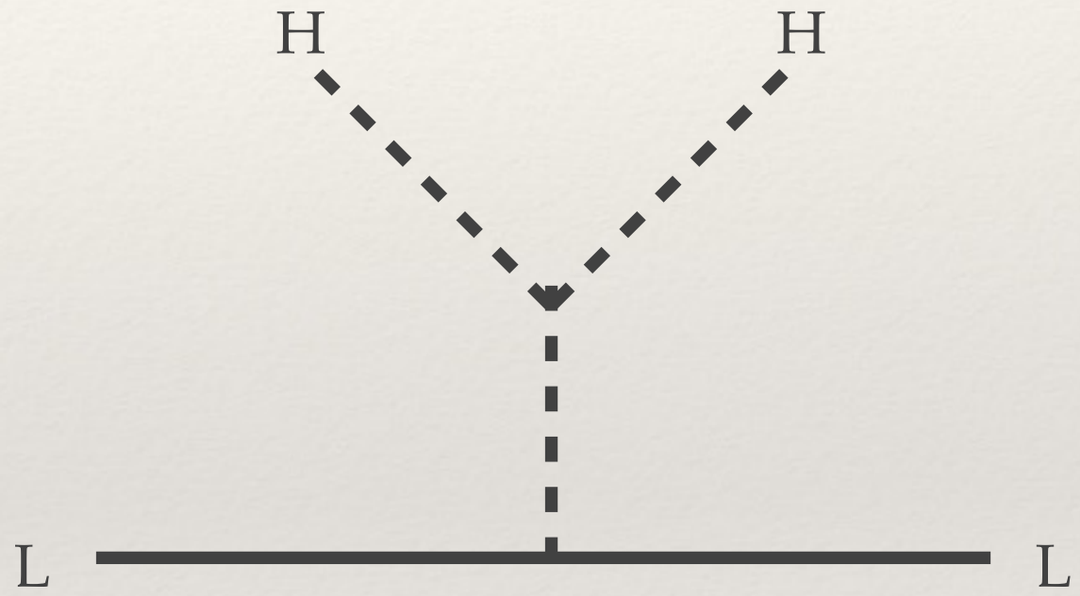
- No decay
  - Discrete Symmetry
  - Accidental Symmetry
- Long decay
  - $\boldsymbol{\tau} > 10^{26}$ sec
  - Parameter Space.

DM ⟷ Neutrinos

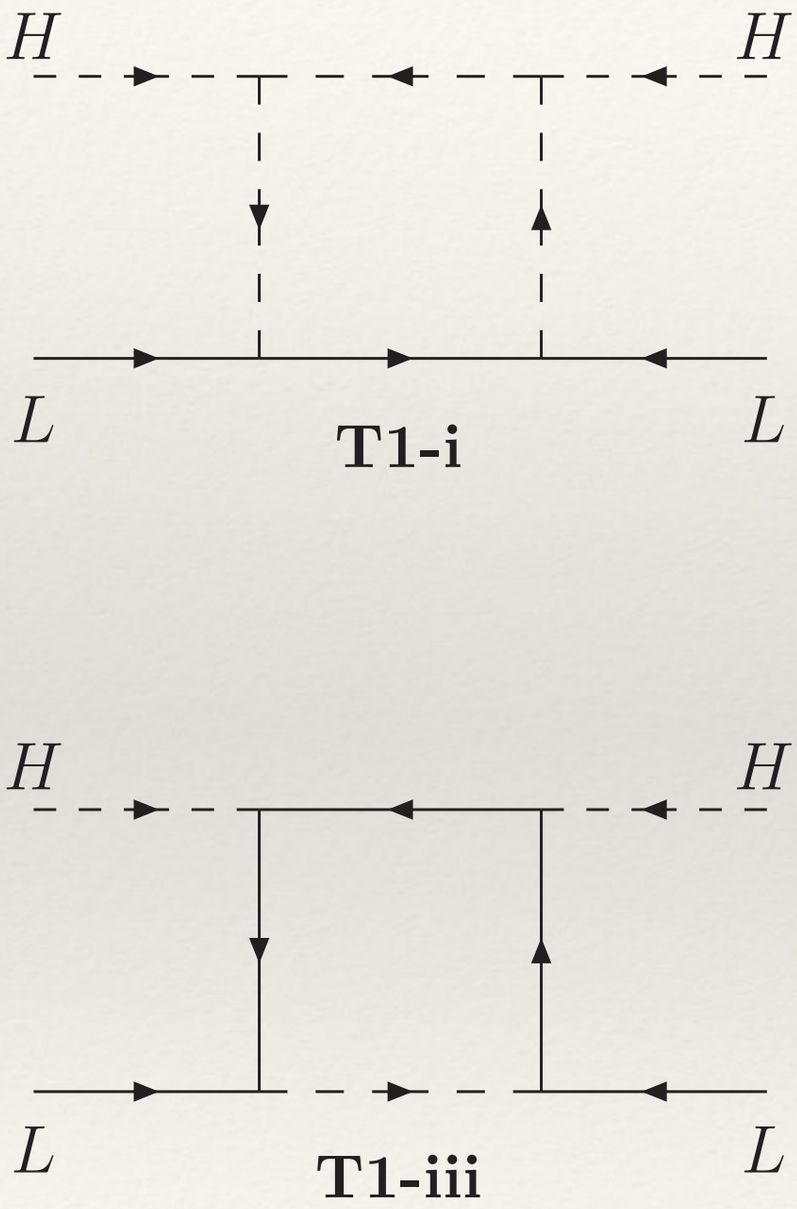


Seesaw Masses

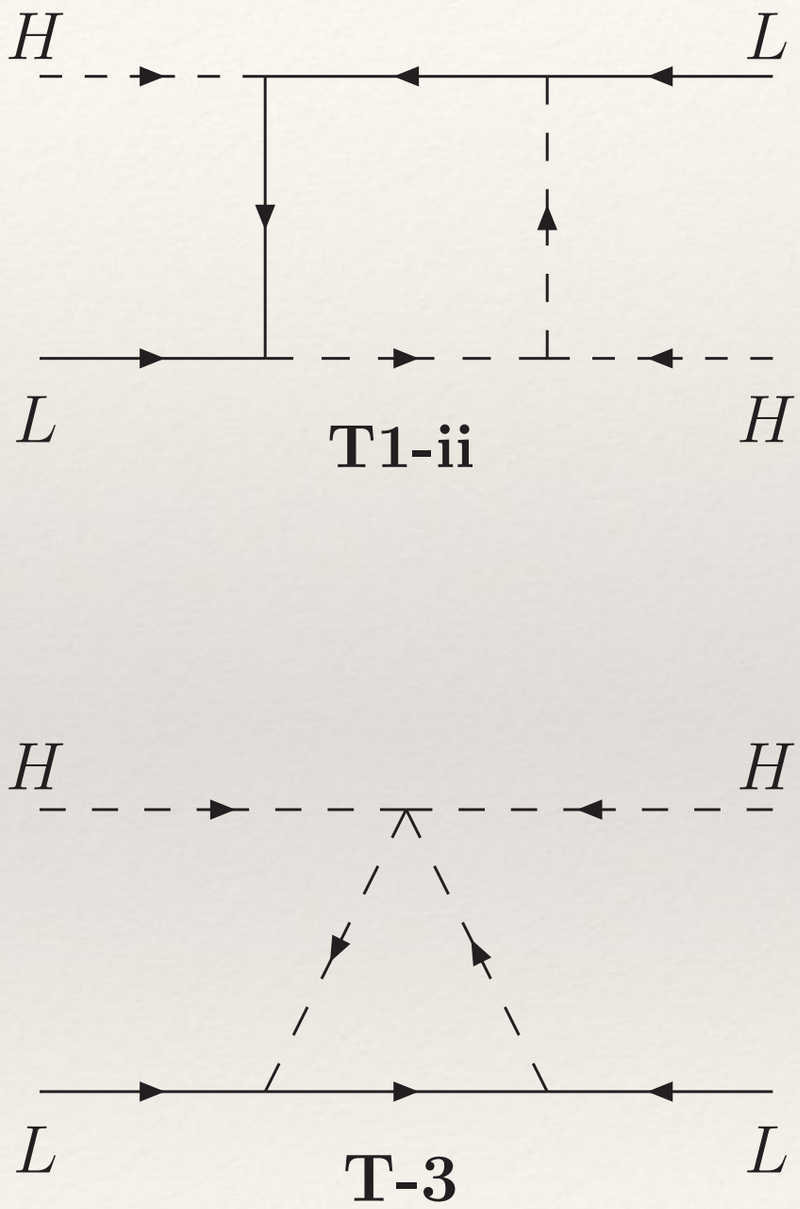




One Loop Neutrino Masses



T1-i



T1-ii

T1-iii

T-3

Minimal Dark Matter

- Minimal DM rely on the fact that neutral particles belonging to higher-order SU(2) representations, are automatically stable, without the need to add any new symmetry. While still matching DM cosmological constraints.

M. Cirelli and A. Strumia, Minimal Dark Matter: Model and results, New J. Phys. 11, 105005 (2009) [arXiv:0903.3381 [hep-ph]].

SU(2) Multiplication

$$2 \times 2 = 1 + 3$$
$$3 \times 2 = 2 + 4$$
$$3 \times 3 = 1 + 3 + 5$$
$$4 \times 2 = 3 + 5$$
$$4 \times 3 = 2 + 4 + 6$$
$$4 \times 4 = 1 + 3 + 5 + 7$$
$$5 \times 2 = 4 + 6$$
$$5 \times 3 = 3 + 5 + 7$$
$$5 \times 4 = 2 + 4 + 6 + 8$$
$$5 \times 5 = 1 + 3 + 5 + 7 + 9$$
$$6 \times 2 = 5 + 7$$
$$6 \times 3 = 4 + 6 + 8$$
$$6 \times 4 = 3 + 5 + 7 + 9$$
$$6 \times 5 = 2 + 4 + 6 + 8 + 10$$
$$6 \times 6 = 1 + 3 + 5 + 7 + 9 + 11$$
$$7 \times 2 = 6 + 8$$
$$7 \times 3 = 5 + 7 + 9$$
$$7 \times 4 = 4 + 6 + 8 + 10$$
$$7 \times 5 = 3 + 5 + 7 + 9 + 11$$
$$7 \times 6 = 2 + 4 + 6 + 8 + 10 + 12$$
$$7 \times 7 = 1 + 3 + 5 + 7 + 9 + 11 + 13$$
$$8 \times 2 = 7 + 9$$
$$8 \times 3 = 6 + 8 + 10$$
$$8 \times 4 = 5 + 7 + 9 + 11$$
$$8 \times 5 = 4 + 6 + 8 + 10 + 12$$
$$8 \times 6 = 3 + 5 + 7 + 9 + 11 + 13$$
$$8 \times 7 = 2 + 4 + 6 + 8 + 10 + 12 + 14$$
$$8 \times 8 = 1 + 3 + 5 + 7 + 9 + 11 + 13 + 15$$
$$9 \times 2 = 8 + 10$$
$$9 \times 3 = 7 + 9 + 11$$
$$9 \times 4 = 6 + 8 + 10 + 12$$
$$9 \times 5 = 5 + 7 + 9 + 11 + 13$$
$$9 \times 6 = 4 + 6 + 8 + 10 + 12 + 14$$
$$9 \times 7 = 3 + 5 + 7 + 9 + 11 + 13 + 15$$
$$9 \times 8 = 2 + 4 + 6 + 8 + 10 + 12 + 14 + 16$$
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SU(2)~4: 4 X 2=3, 3 X 2=2, 2 x 2=1

4 X 2 X 2 X 2=1

S H H H* ——> Dim 4

F L H H* ——> Dim 5

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SU(2)~4: 4 X 2=3, 3 X 2=2, 2 x 2=1

4 X 2 X 2 X 2=1

S H H H* ——> Dim 4

F L H H* ——> Dim 5

SU(2)~5: 5 X 2=4, 4 X 2=3, 3 X 2=2, 2 x 2=1

5 X 2 X 2 X 2 X 2=1

S H H H* H* ——> Dim 5

F L H H H ——> Dim 6

DM Candidates?

Quantum numbers $SU(2)_L$	$U(1)_Y$	Spin	DM can decay into	DD bound?	Stable?
2	1/2	S	EL	×	×
2	1/2	F	EH	×	×
3	0	S	HH^*	√	×
3	0	F	LH	√	×
3	1	S	HH, LL	×	×
3	1	F	LH	×	×
4	1/2	S	HHH^*	×	×
4	1/2	F	(LHH^*)	×	×
4	3/2	S	HHH	×	×
4	3/2	F	(LHH)	×	×
5	0	S	(HHH^*H^*)	√	×
5	0	F	–	√	√
5	1	S	$(HH^*H^*H^*)$	×	×
5	1	F	–	×	√
5	2	S	$(H^*H^*H^*H^*)$	×	×
5	2	F	–	×	√
6	1/2, 3/2, 5/2	S	–	×	√
7	0	S	–	√	√
8	1/2, 3/2 ...	S	–	×	√

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2	1/2	F	EH	×	×
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3	0	F	LH	√	×
3	1	S	HH, LL	×	×
3	1	F	LH	×	×
4	1/2	S	HHH^*	×	×
4	1/2	F	(LHH^*)	×	×
4	3/2	S	HHH	×	×
4	3/2	F	(LHH)	×	×
5	0	S	(HHH^*H^*)	√	×
5	0	F	–	√	√
5	1	S	$(HH^*H^*H^*)$	×	×
5	1	F	–	×	√
5	2	S	$(H^*H^*H^*H^*)$	×	×
5	2	F	–	×	√
6	1/2, 3/2, 5/2	S	–	×	√
7	0	S	–	√	√
8	1/2, 3/2 ...	S	–	×	√

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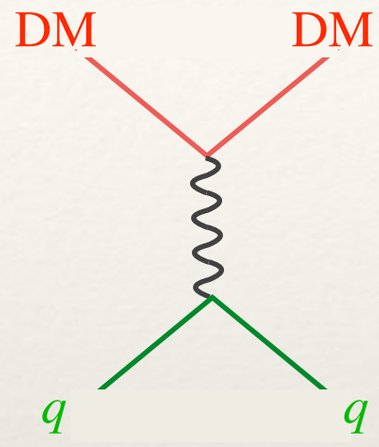
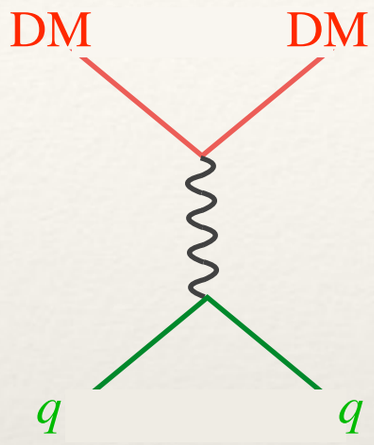
MDM Direct Detection



$$\sigma(\mathrm{DM}\,\mathcal{N} \to \mathrm{DM}\,\mathcal{N}) = c\frac{G_\mathrm{F}^2 M_\mathcal{N}^2}{2\pi} Y^2 (N - (1 - 4s_\mathrm{W}^2)Z)^2$$

MDM Direct Detection



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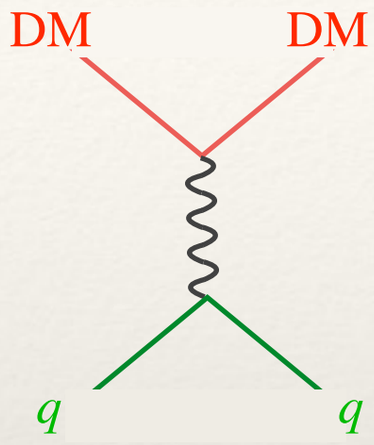
Y=0

MDM Direct Detection



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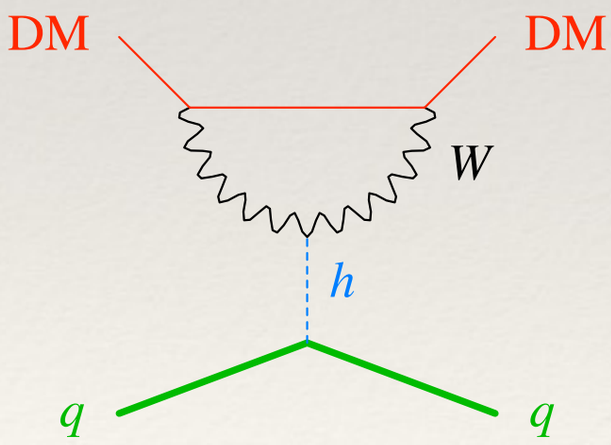
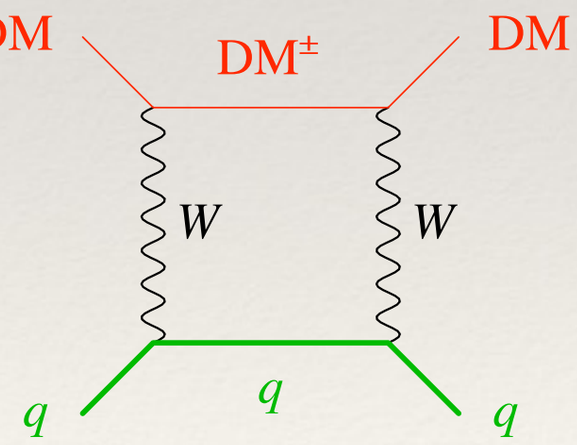
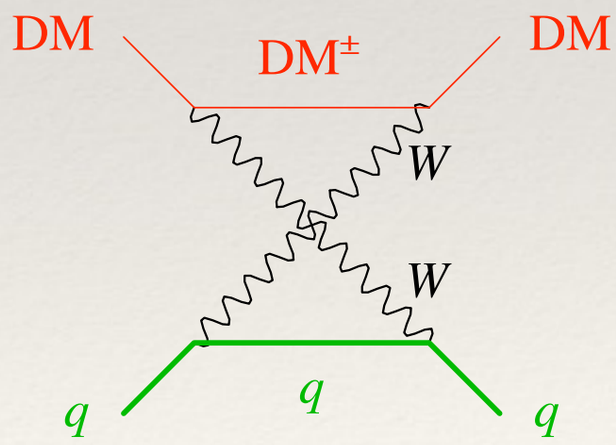




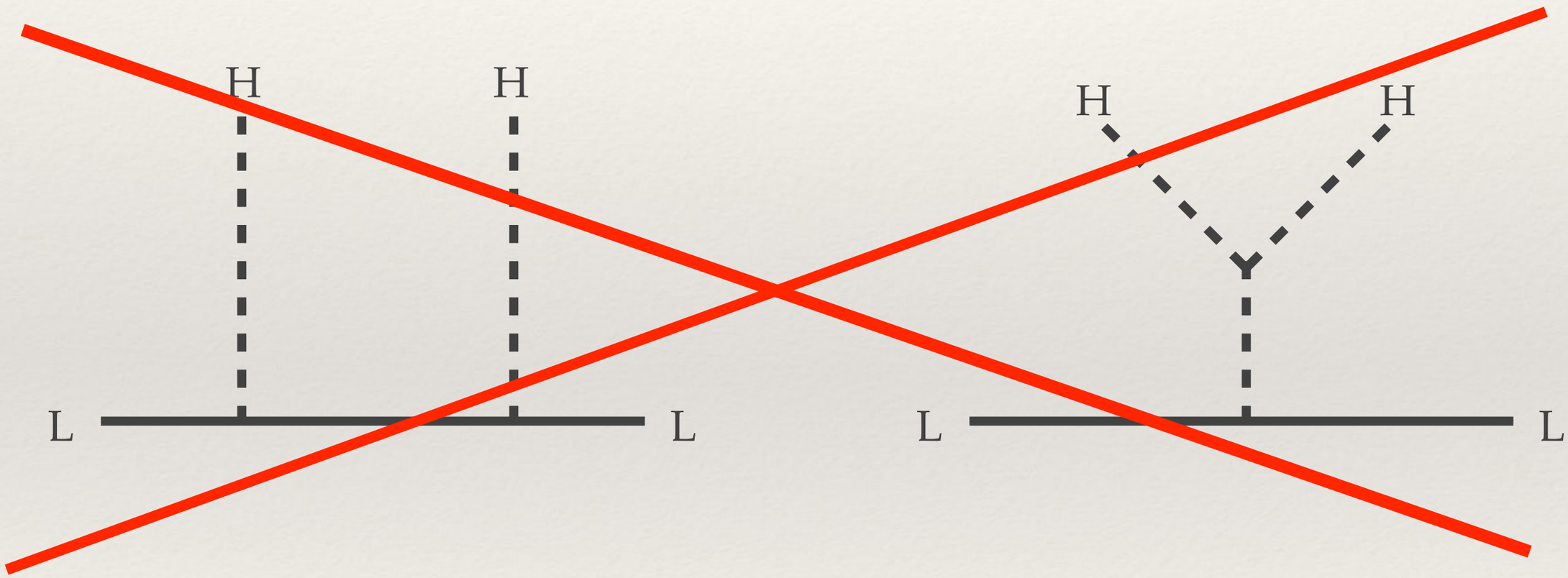


$$\sigma_\mathrm{SI}(\mathrm{DM}\,\mathcal{N} \to \mathrm{DM}\,\mathcal{N}) = (n^2-1)^2 \frac{\pi \alpha_2^4 M_\mathcal{N}^4 f^2}{64 M_W^2} \left(\frac{1}{M_W^2} + \frac{1}{m_h^2}\right)^2 .$$

Seesaw Masses

$$2 \times 2 = 1 + 3$$

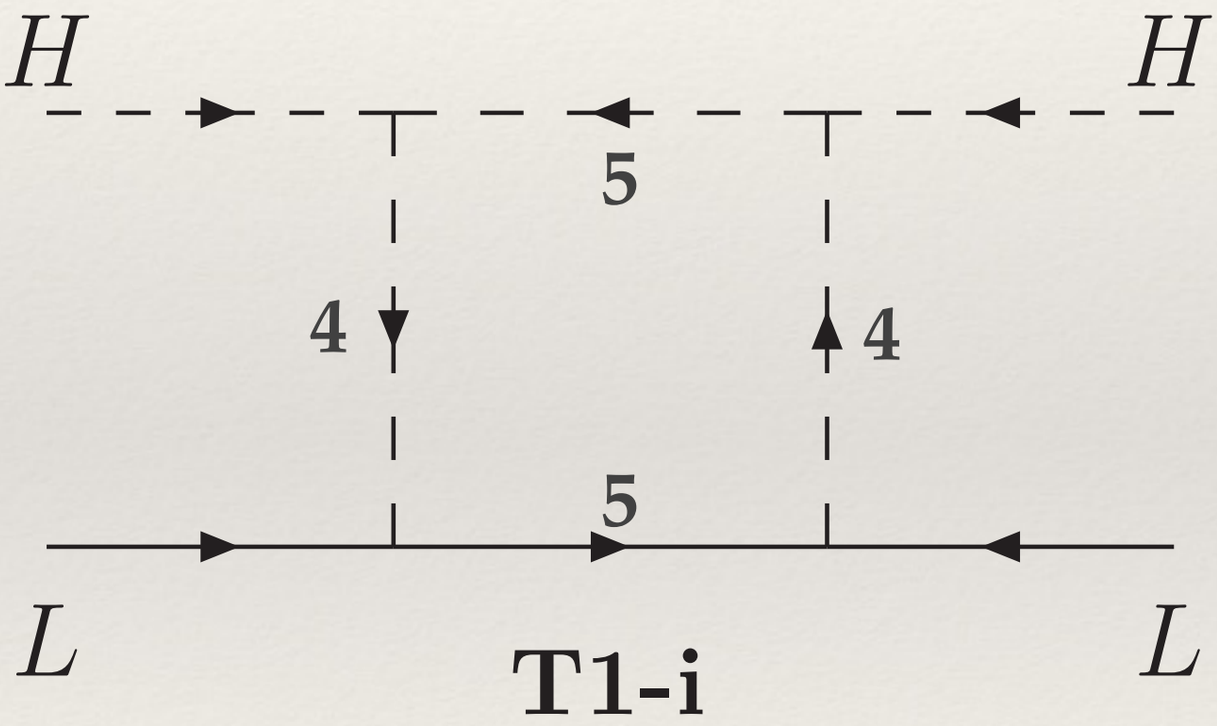
Seesaw Masses



$$2 \times 2 = 1 + 3$$

One Loop Example

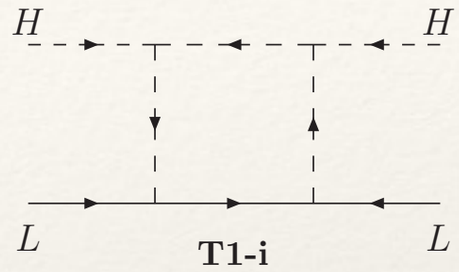
$$5 \times 4 \times 2 = 1$$

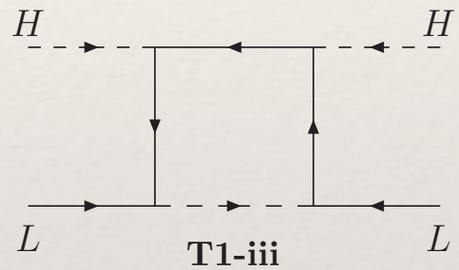


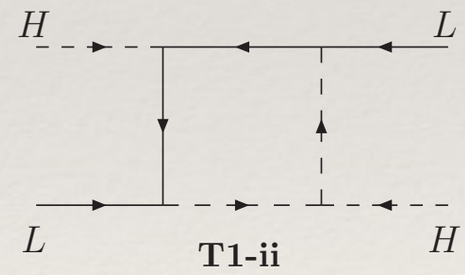
Fermonic 5plet

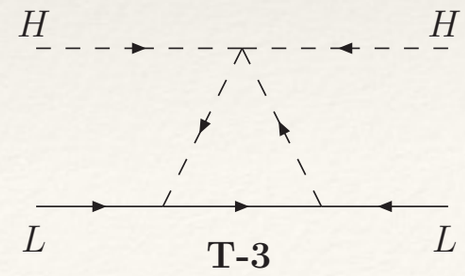
DM~(5,0)

T-3	(4,1)	(6,1)	(4,1) (6,1)			
T3, T1-i	(4,1)(3,0)	(4,1) (5,0)	(4,1)(5,0) (6,1)	(6,1) (5,0)	(6,1) (7,0)	
T3, T1-i, T1-ii	(4,1) (4,1)(3,0)	(4,1) (4,1) (5,0)	(6,1) (4,1)(5,0)	(4,1) (6,1) (5,0)	(6,1) (6,1) (5,0)	(6,1) (6,1) (7,0)
T1-iii	(4,1) (3,0)	(4,1) (5,0)	(6,1) (5,0)	(4,1) (6,1) (5,0)	(6,1) (7,0)	
T3, T1-iii	(4,1) (3,2) (4,1)	(4,1) (5,2) (4,1)	(6,1) (5,2) (4,1)	(4,1) (5,2) (6,1)	(6,1) (5,2) (6,1)	(6,1) (7,2) (6,1)





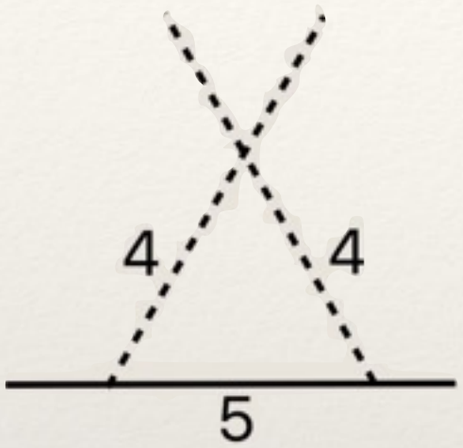




Fermion Scalar

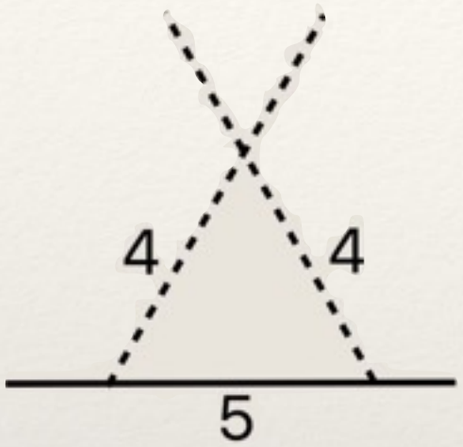
Example

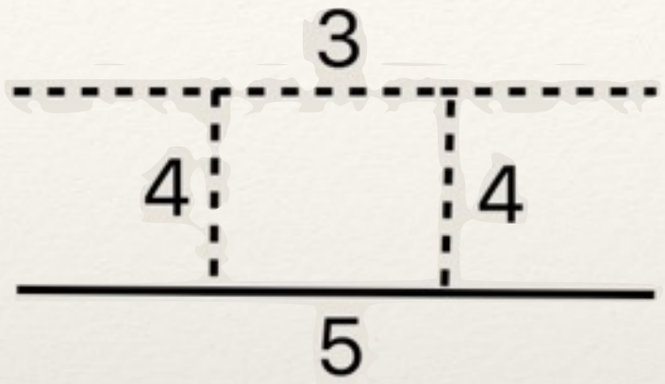
(5,0)(4,1)



Example

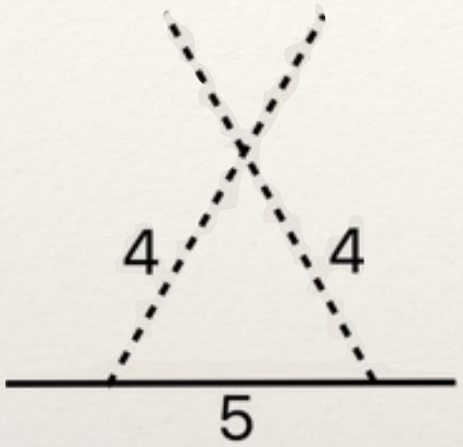
(5,0)(4,1)(3,0)

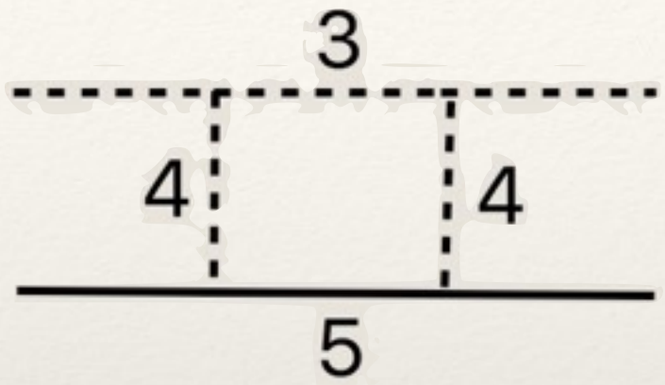


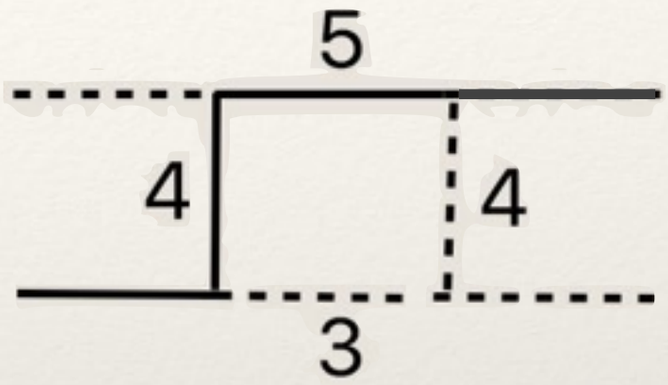


Example

(5,0)(4,1)(3,0)(4,1)







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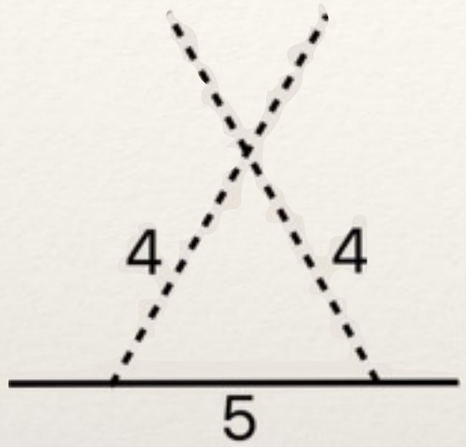
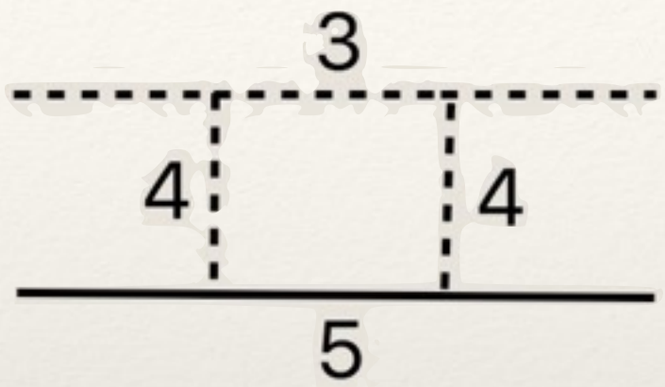
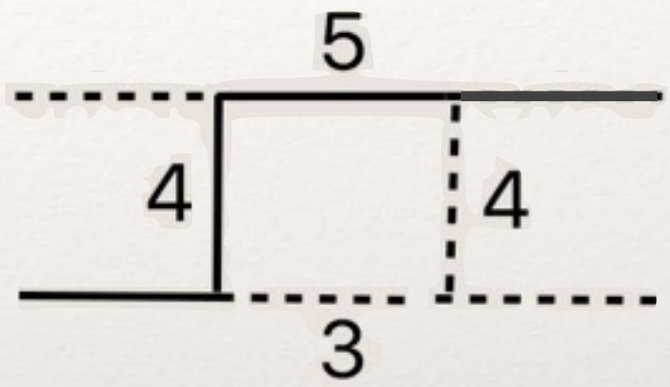
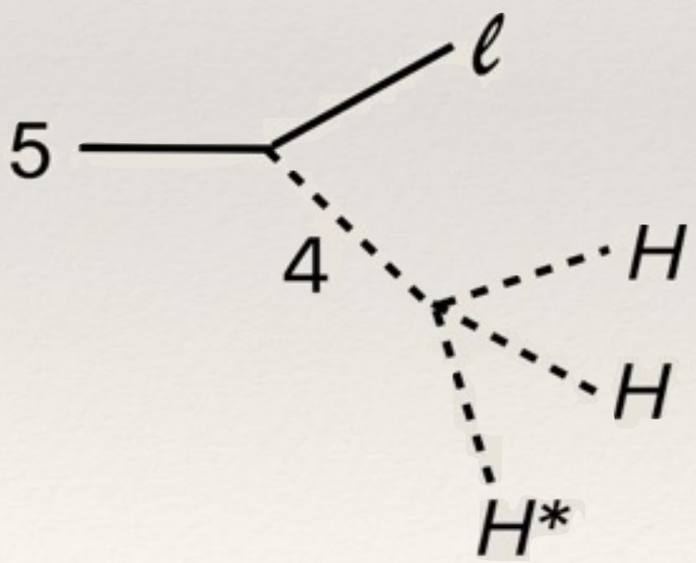


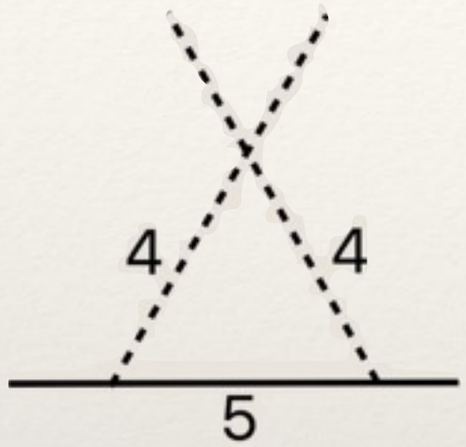


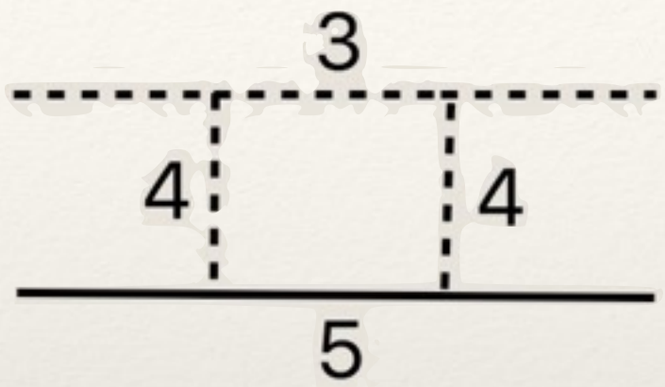


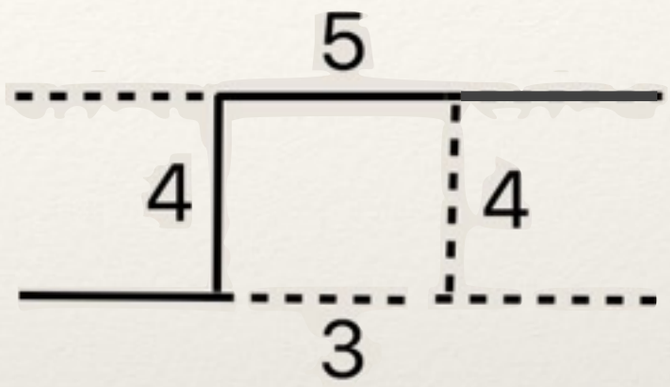


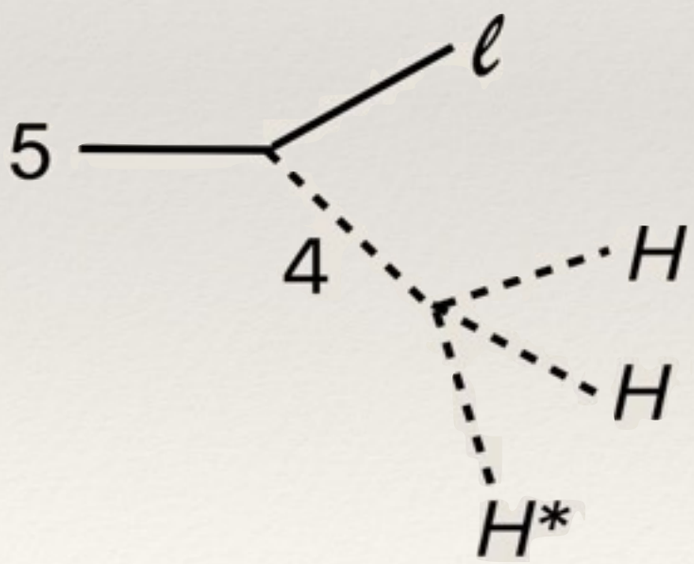
Example

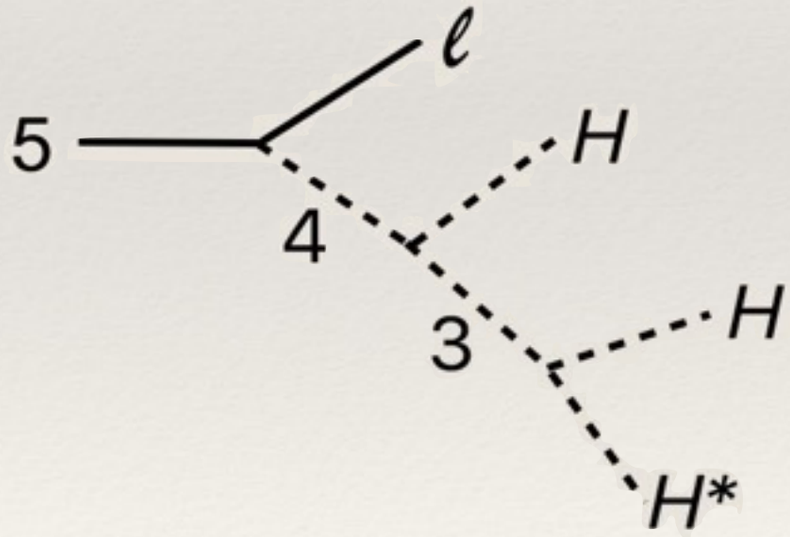
(5,0)(4,1)(3,0)(4,1)





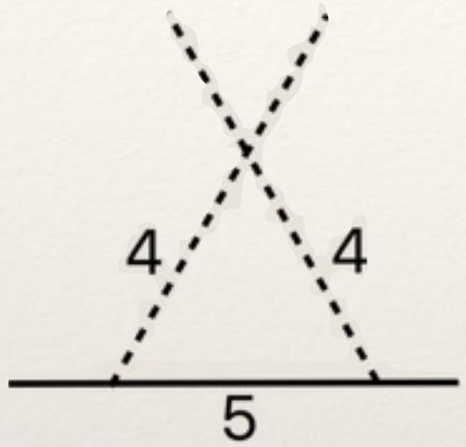


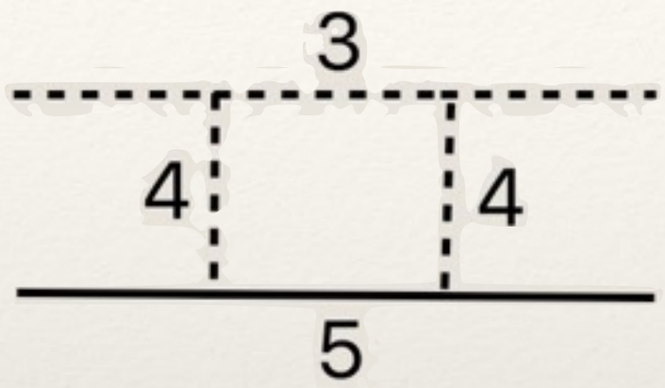


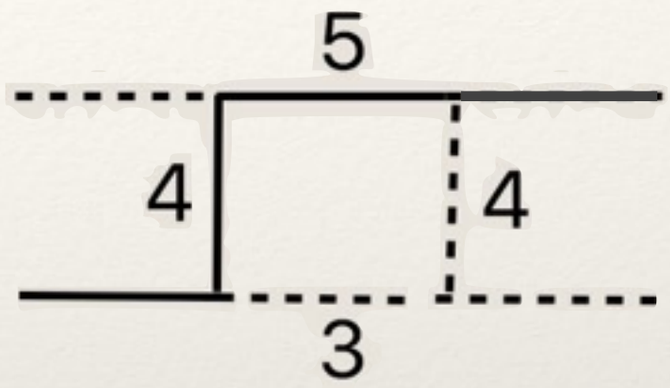


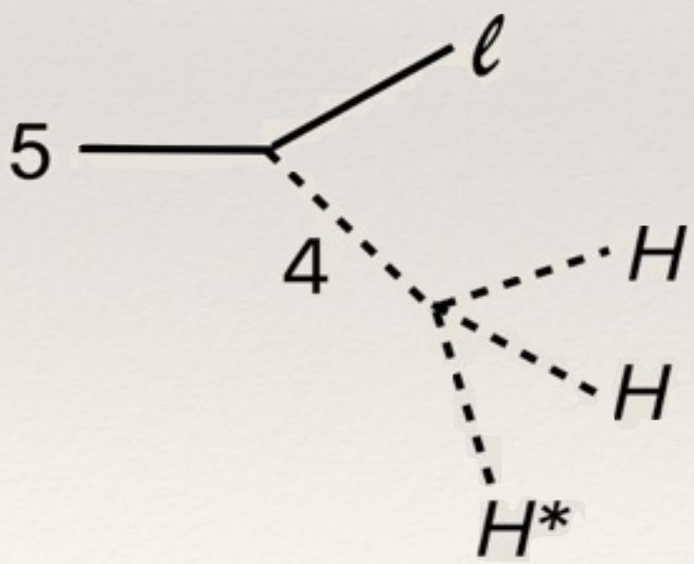
Example

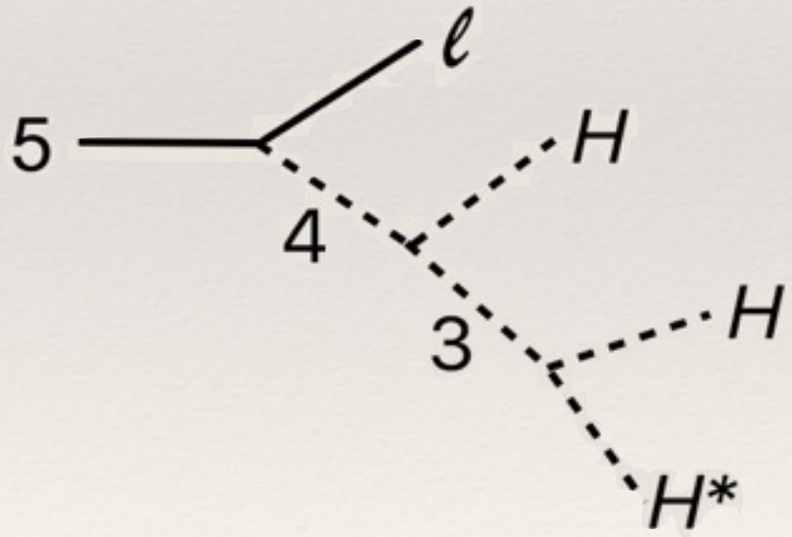
(5,0)(4,1)(3,0)(4,1)

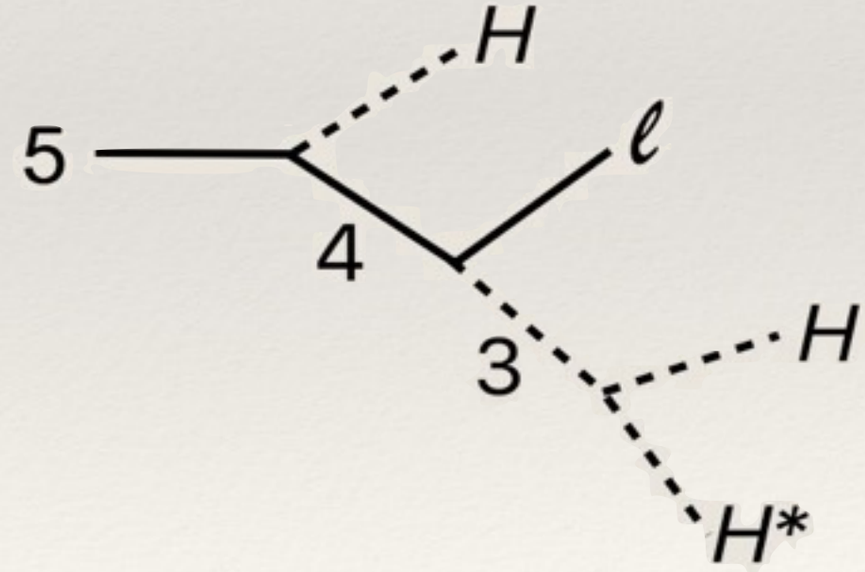






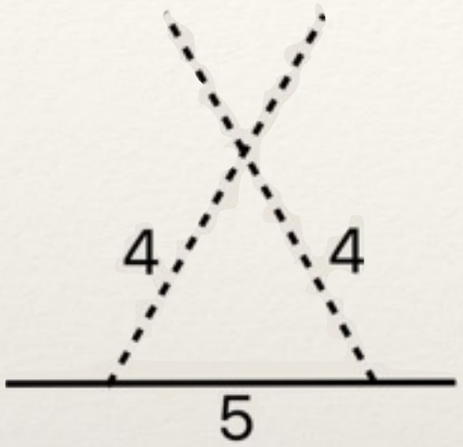


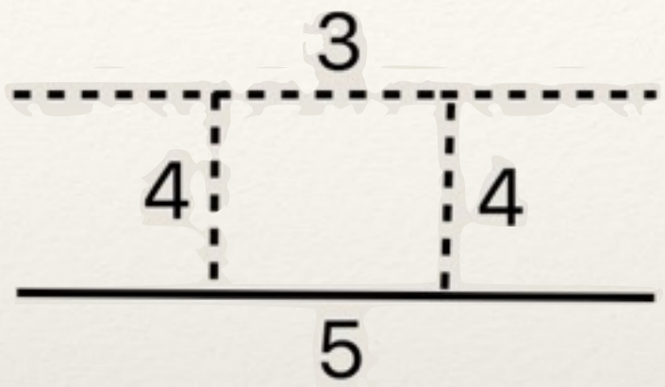


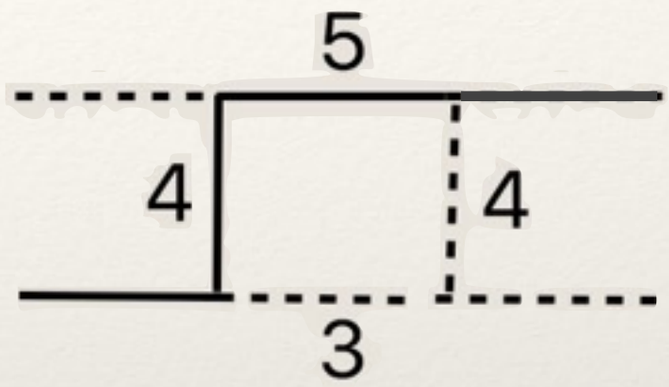


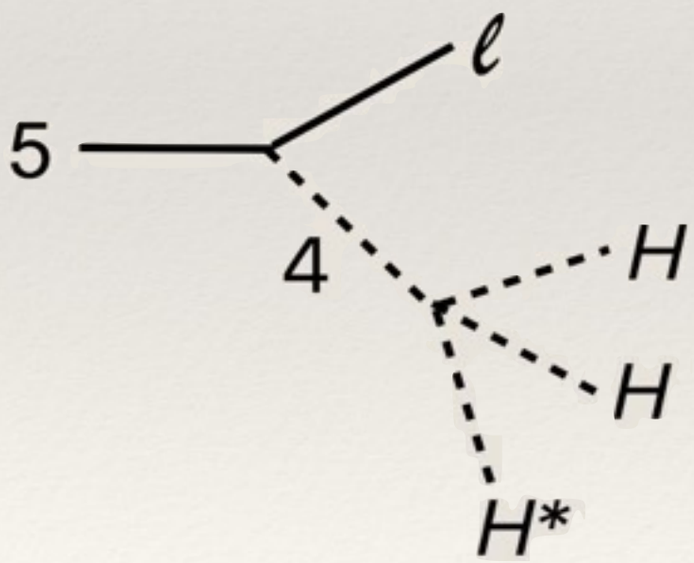
Example

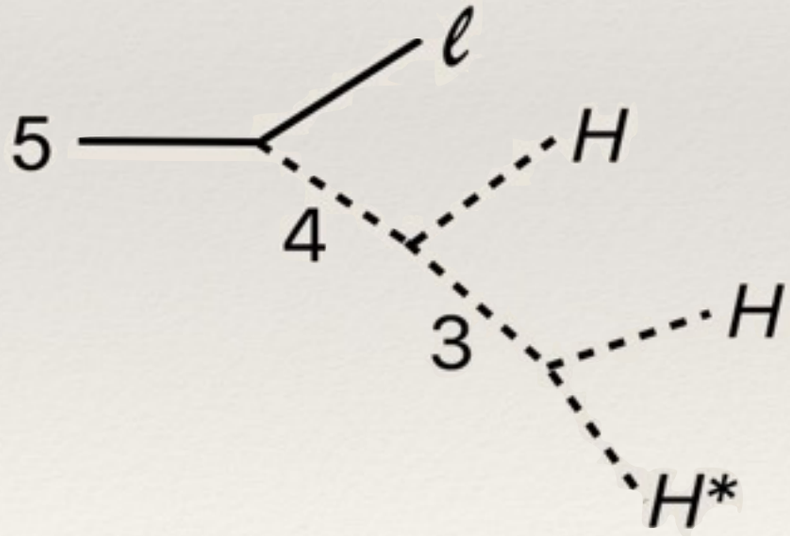
(5,0)(4,1)(3,0)(4,1)

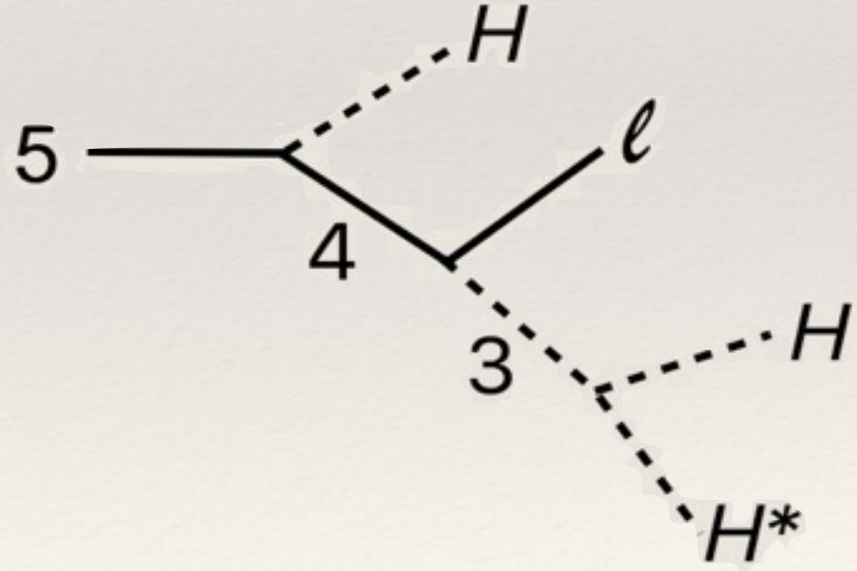






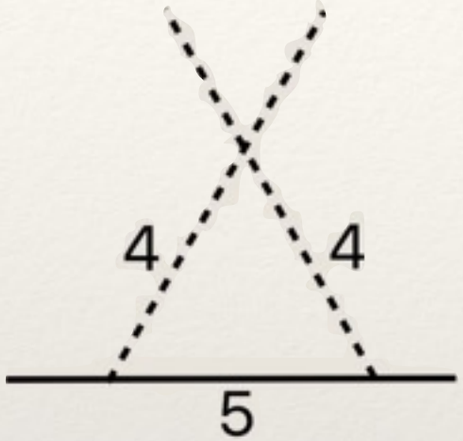


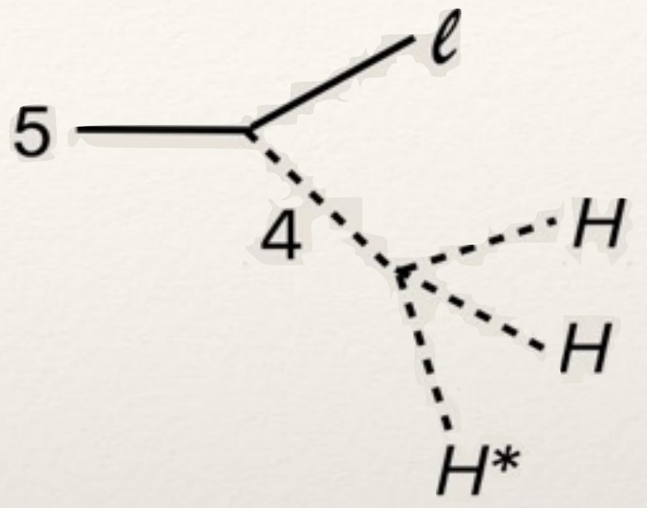




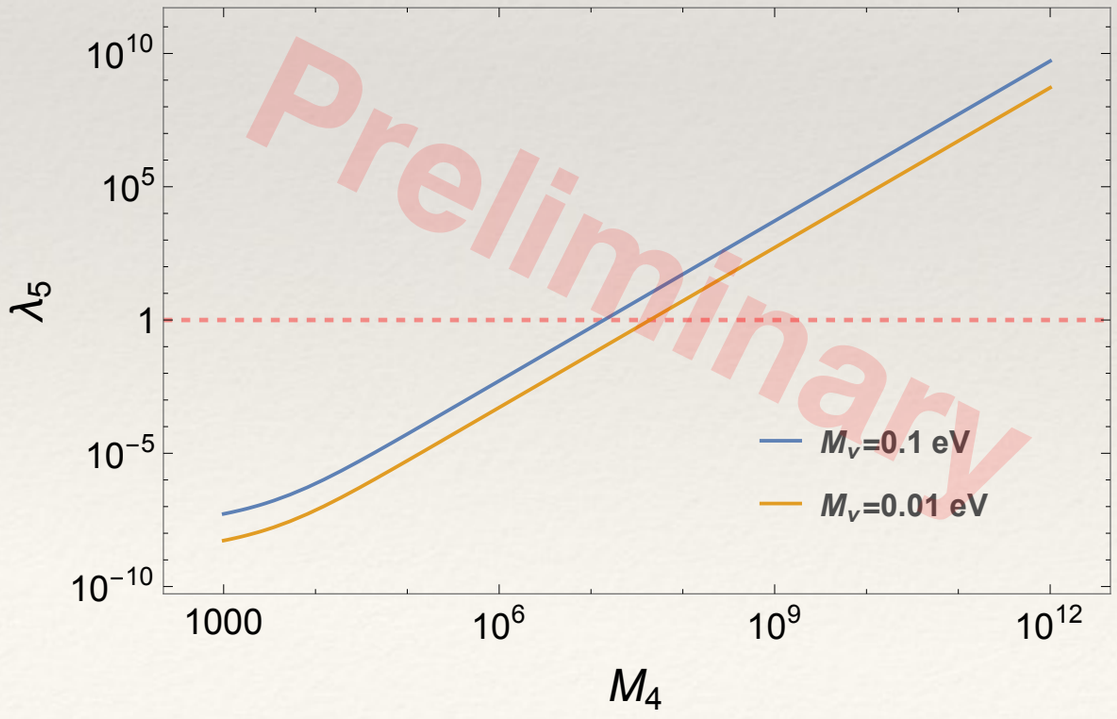
Dim 5

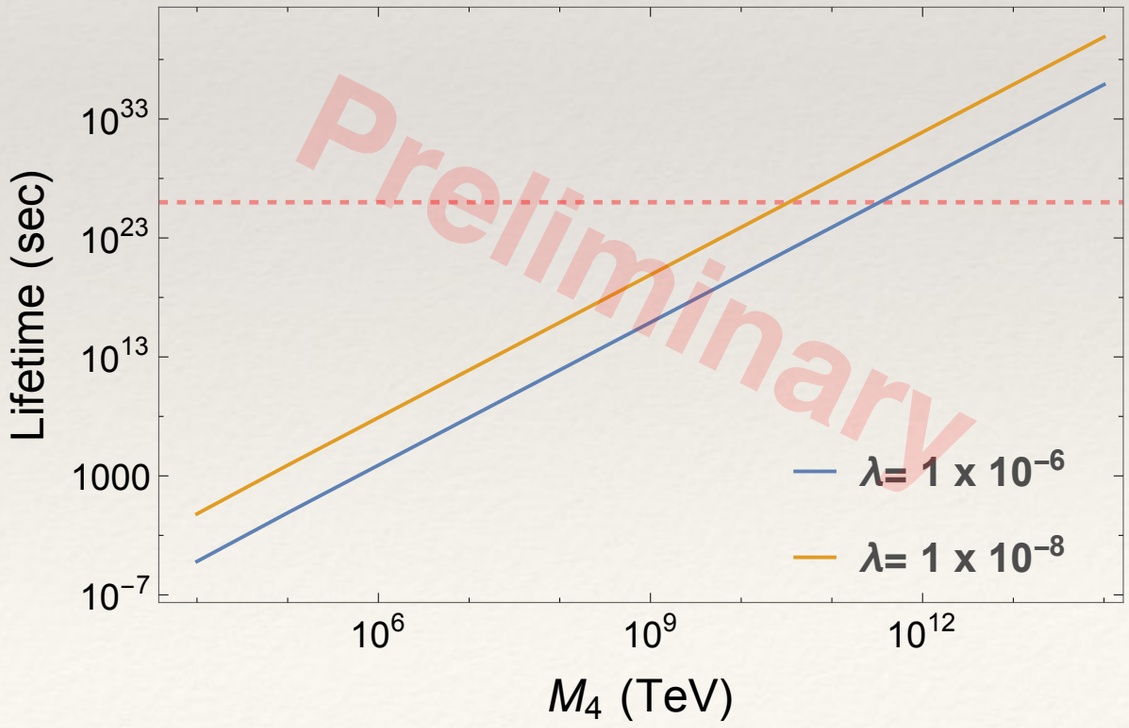
Parameter Space in Decay Cascades



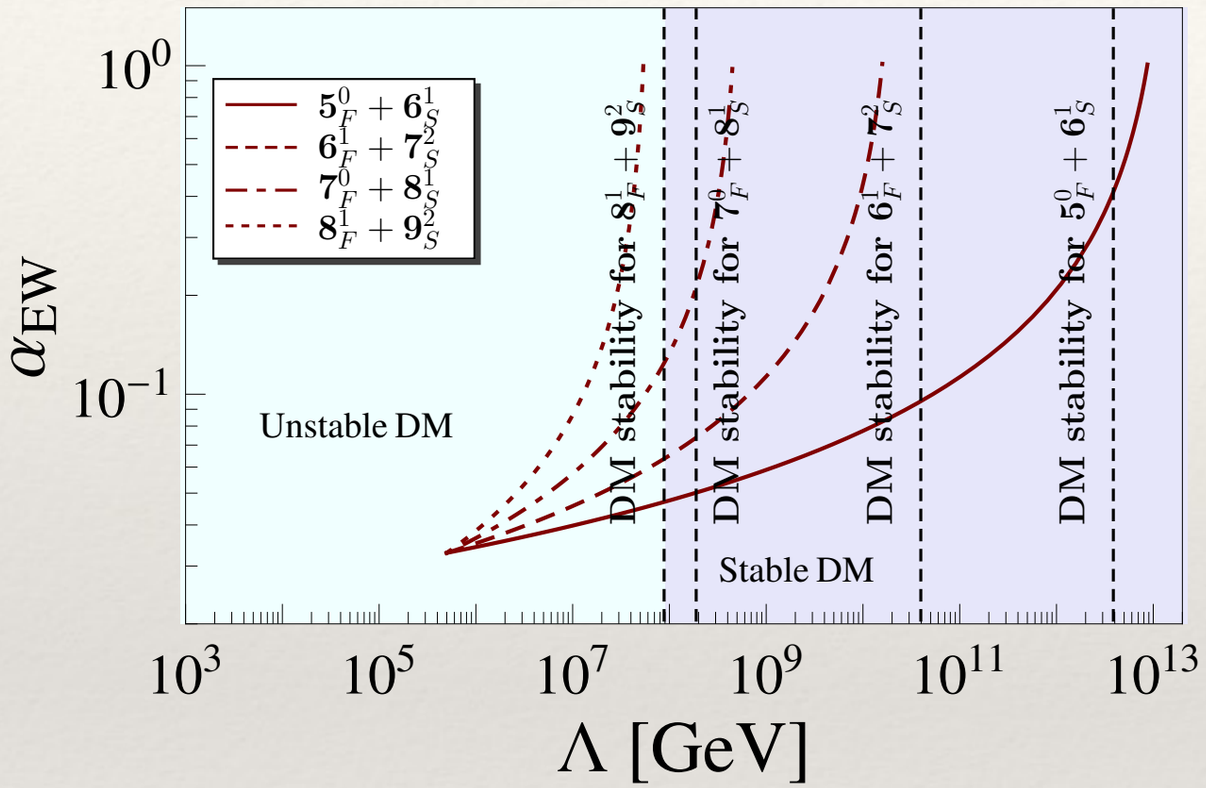


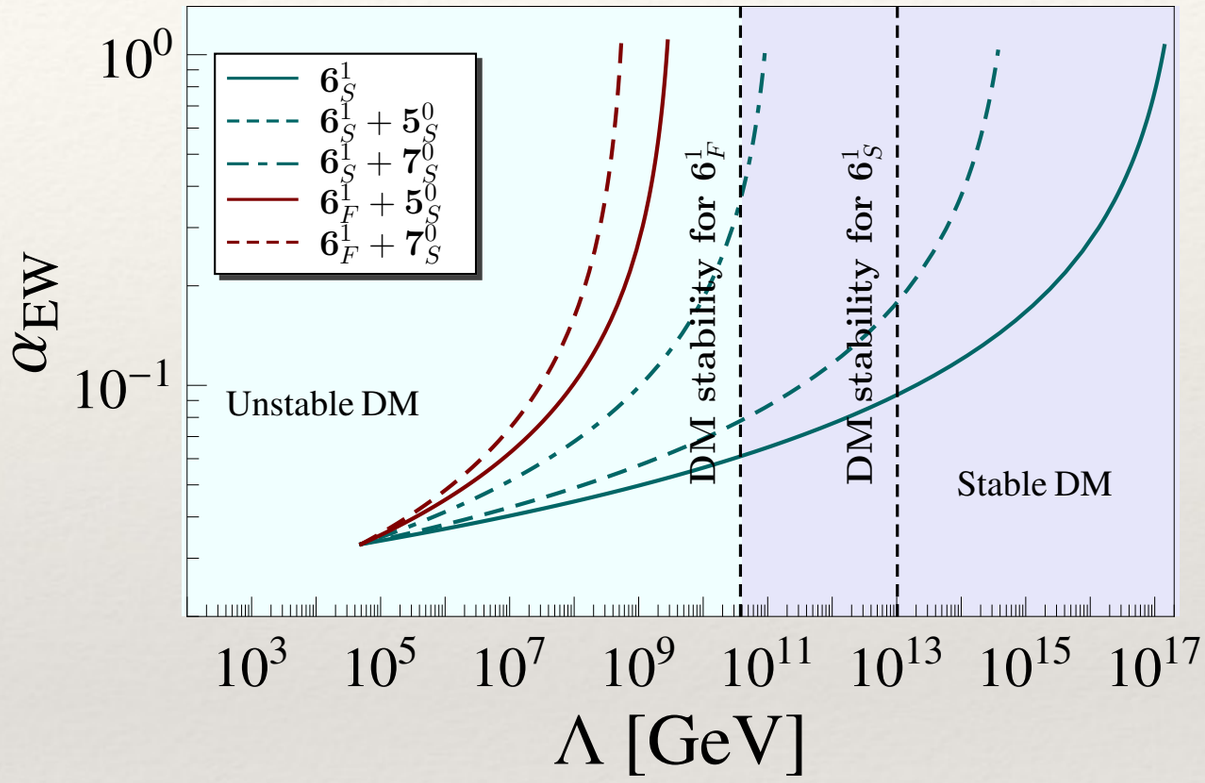
M_5= 5 TeV, Y=0.1



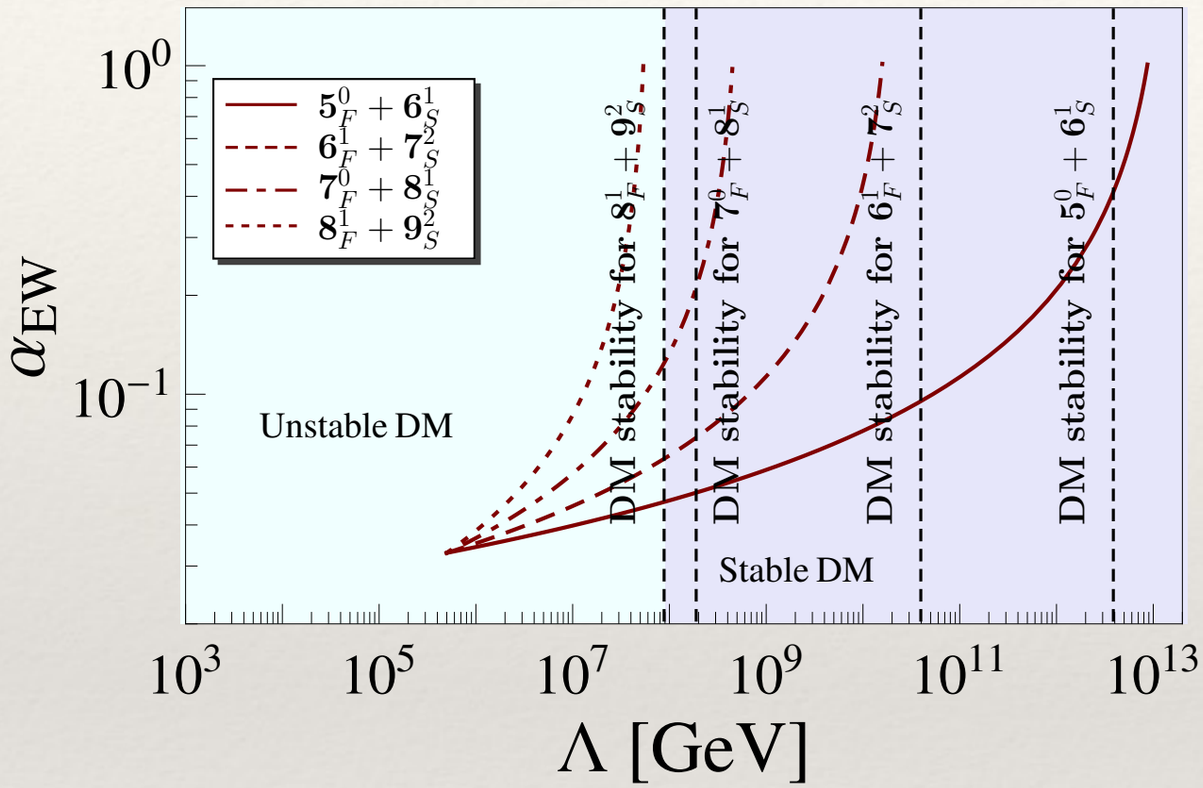


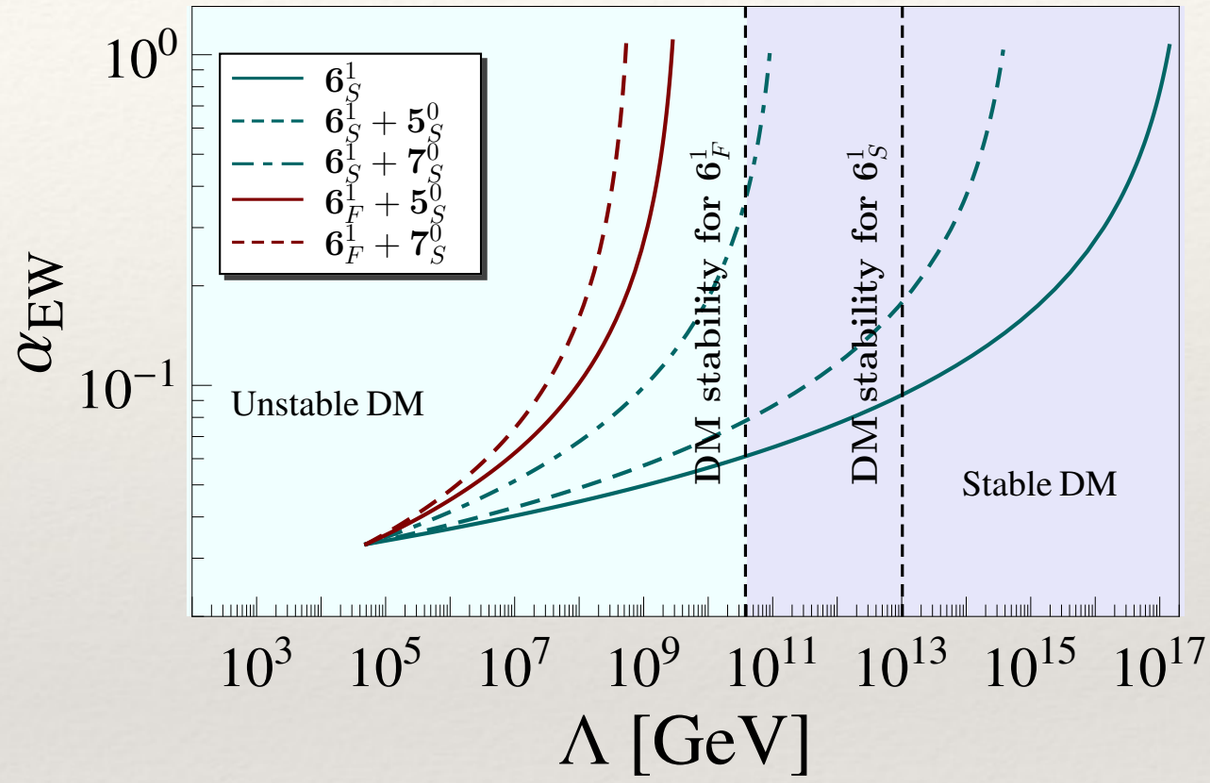
Perturbativity





Perturbativity





Careful: Quartic coupling running goes faster than $\alpha_{\rm EW.}$

(Hamada, Kawana,Tsumara. hep-ph 1505.01772)

Scalar 7plet

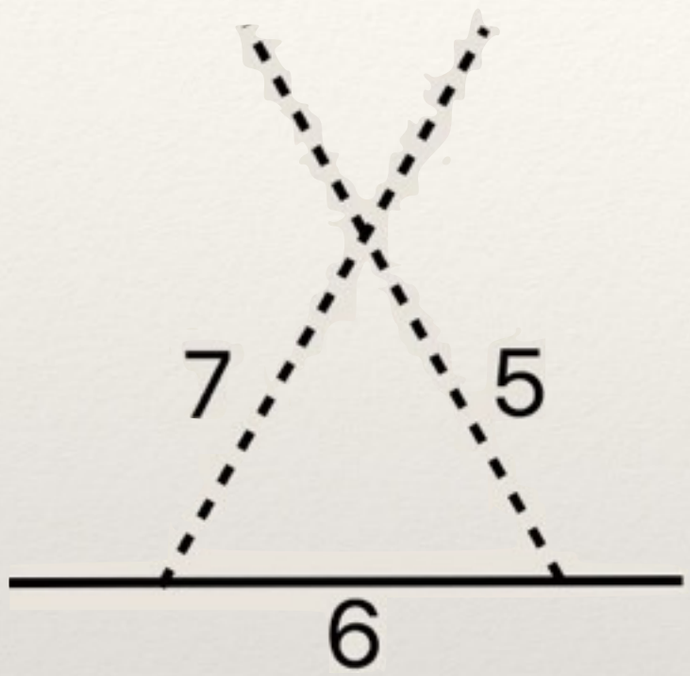
DM~(7,0)

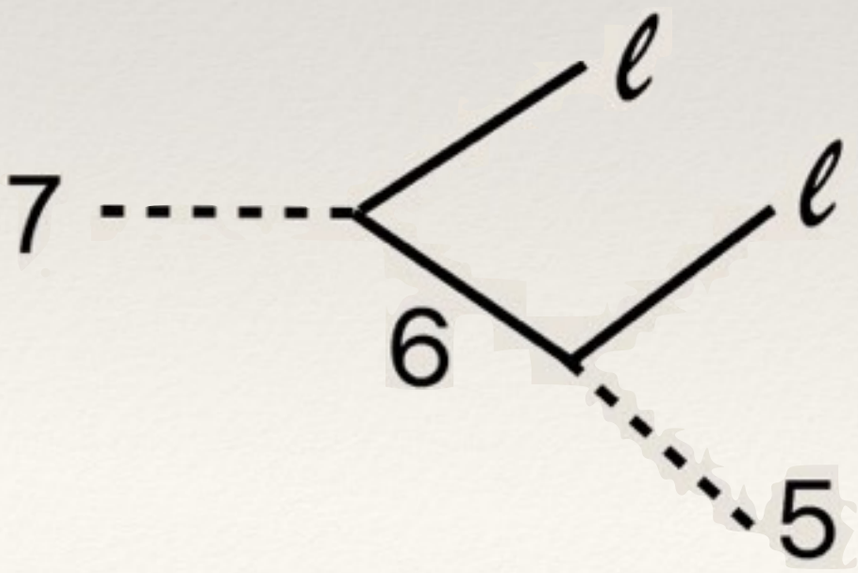
T-3	(6,1) (5,2)	(6,1) (7,2)	(8,1) (7,2)	(8,1) (9,2)			
T1-i	(5,0) (6,1)	(7,0) (6,1)	(7,0) (6,1) (8,1)	(7,0) (8,1)	(9,0) (8,1)		
T3, T1-i	(6,1) (5,2) (6,1)	(6,1) (5,2) (6,1)	(6,1) (7,2) (6,1)	(6,1) (7,2) (8,1)	(8,1) (7,2) (6,1)	(8,1) (7,2) (8,1)	(8,1) (9,2) (8,1)
T1-iii	(6,1) (5,0)	(6,1) (7,0)	(6,1) (7,0) (8,1)	(8,1) (7,0)	(8,1) (9,0)		
T1-i, T2-ii, T3-iii	(6,1) (5,0) (6,1)	(6,1) (7,0) (6,1)	(6,1) (7,0) (8,1)	(8,1) (7,0) (6,1)	(8,1) (7,0) (8,1)	(8,1) (9,0) (8,1)	

Fermion Scalar

Example 2

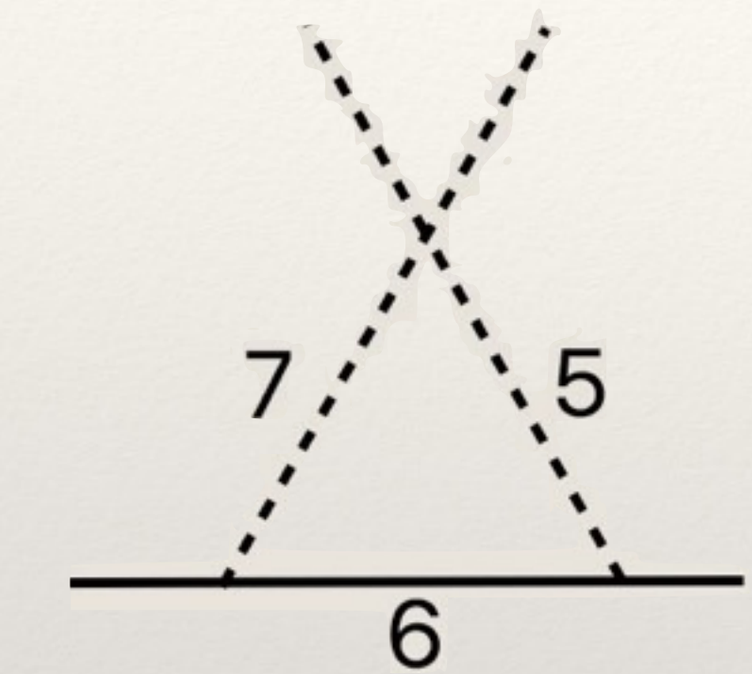
(7,0)(6,1)(5,2)

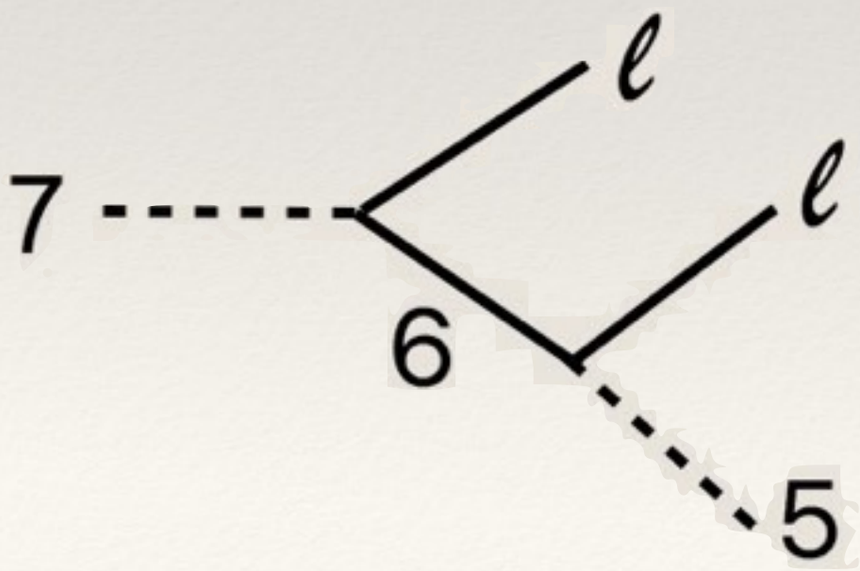




Example 2

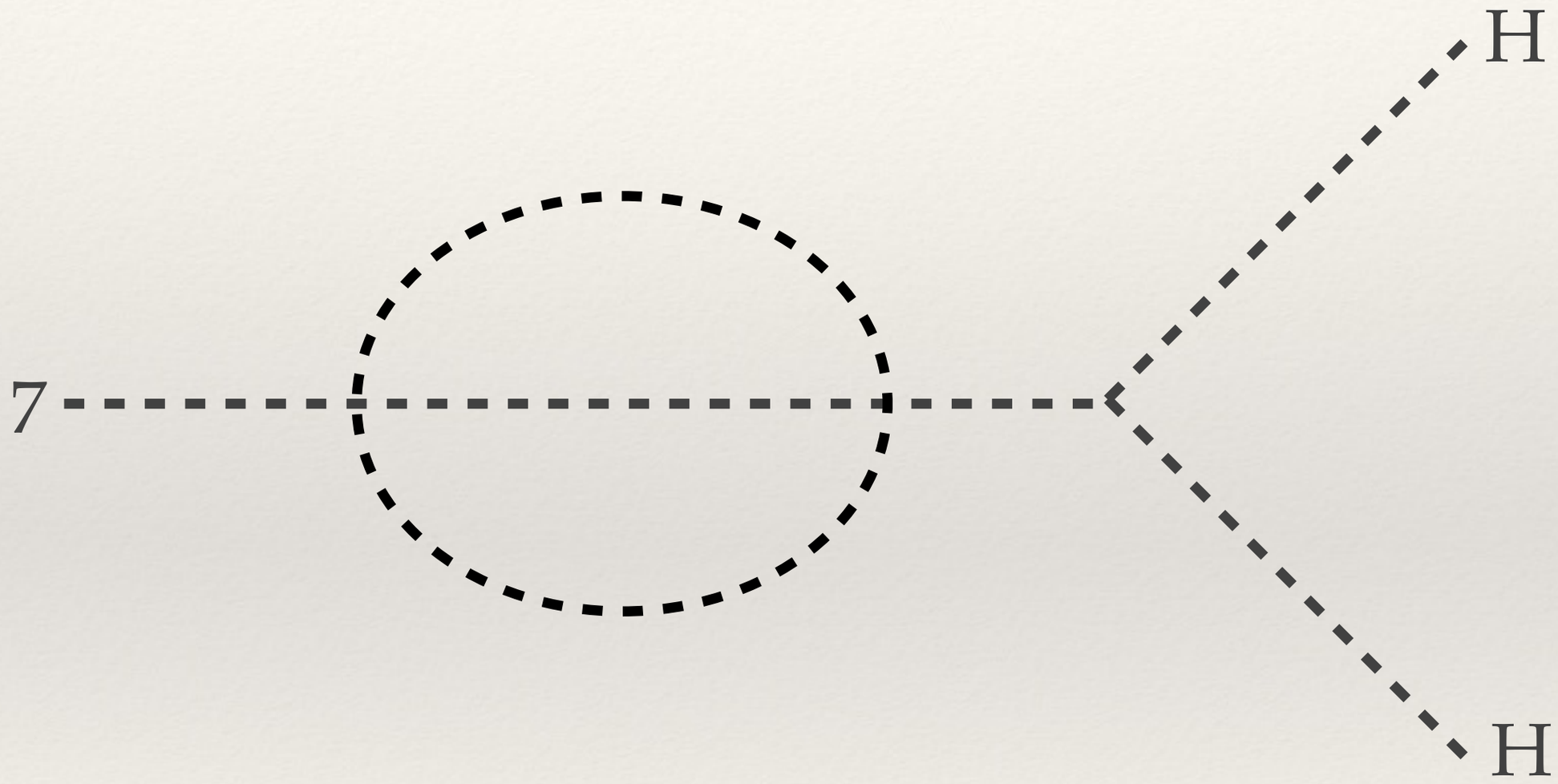
(7,0)(6,1)(5,2)





Only models with an SU(2)~3 or a ~4 can decay into all SM particles.

In Progress: Decays With a Loop



Dim 4

Conclusions

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