

# Gods of SMALL things

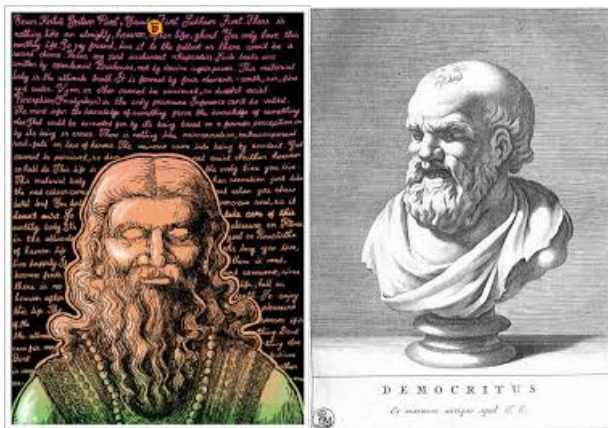
Madhu K

<sup>1</sup>Department of Physics  
Union Christian College, Aluva.

September 30, 2017

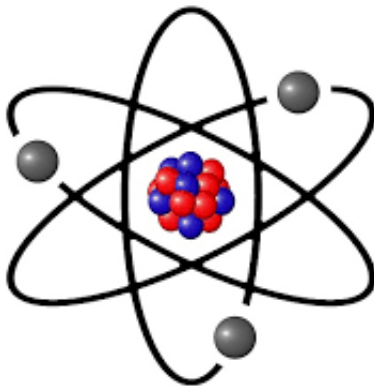
# Smallest part of matter

A question that churned minds for millenia



# Atom

- Smallest part retaining chemical properties - known since 1800 - due to John Dalton



- Organized as

# Periodic Table of the Elements

1 H Hydrogen 1.008																	2 He Helium 4.003																														
3 Li Lithium 6.941	4 Be Beryllium 9.012																	5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180																								
11 Na Sodium 22.990	12 Mg Magnesium 24.305																	13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948																								
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798																														
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.294																														
55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [209]	85 At Astatine 209	86 Rn Radon 222.018																														
87 Fr Francium 223	88 Ra Radium 226	89-103	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [271]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Nh Nihonium [284]	114 Fl Flerovium [289]	115 Mc Moscovium [288]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]																														
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Alkali Metal		Alkaline Earth		Transition Metal		Rare Earth		Semimetal		Nonmetal		Halogen		Noble Gas		Lanthanide		Actinide																													

# Crushing atoms

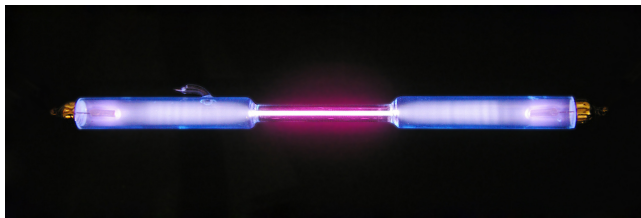
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# Crushing atoms

- Inside atoms?
- First observed in gas discharge tubes, later in vacuum tubes

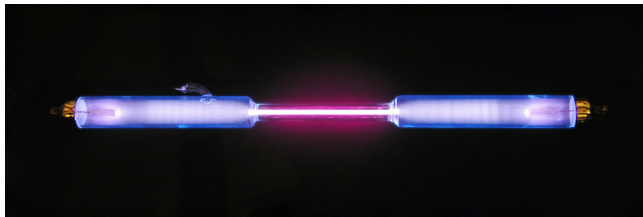
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- Crash atom into atom, it breaks open





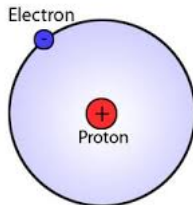
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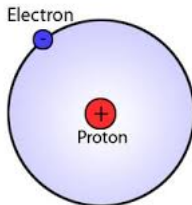
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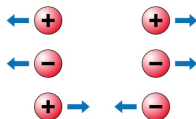
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- Electron is now recognized as one of the **leptons**

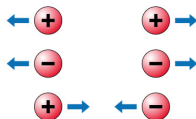
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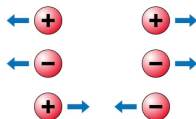
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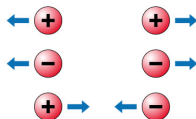
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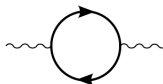
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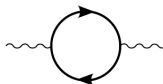
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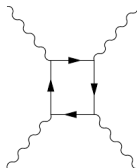


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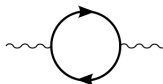


- Now the photon scatter with itself !

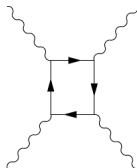


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- Photon remain massless

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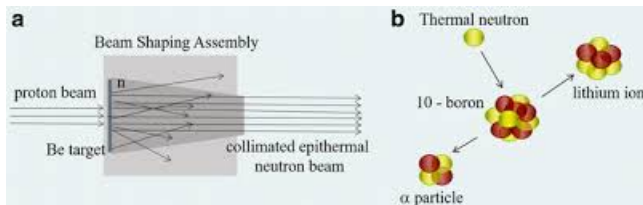
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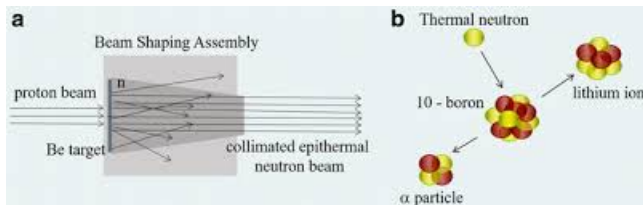
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- No charge? Then how did the protons feel them?

- They feel each other through WEAK force :  $W^+$ ,  $W^-$ , Z-BOSONS

# Weak force

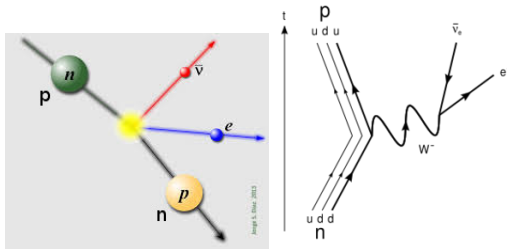
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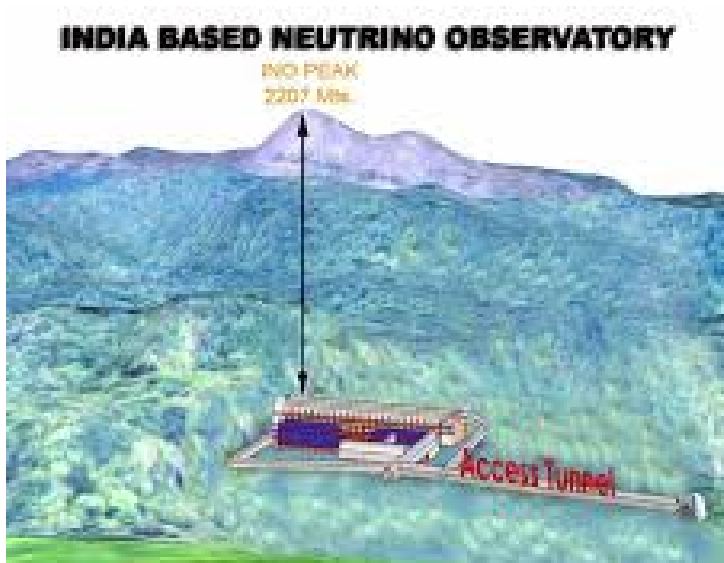


- Cannot be really massless
- Neutrinos pass through everything - Can't "see" us

# Indian Neutrino Observatory

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Organized as Periodic table



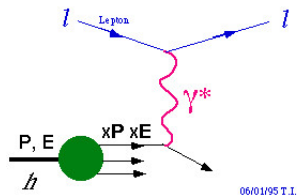
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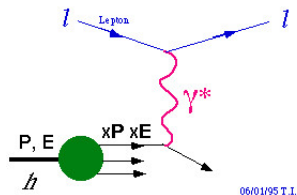


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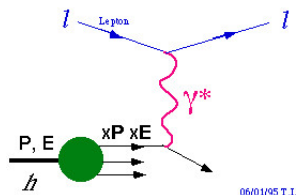


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- Charged, Massive, weakly interacting particles 1.5MeV – 175GeV

# Strong interaction

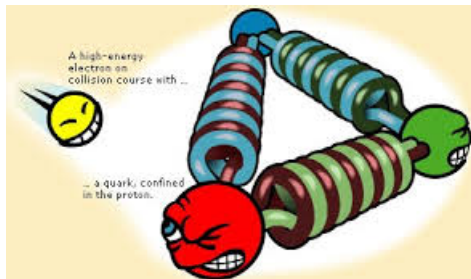
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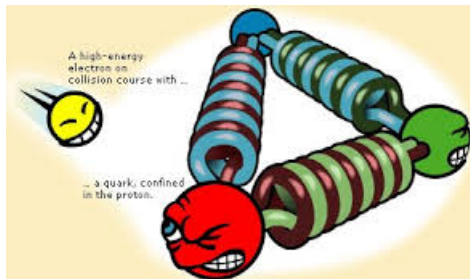
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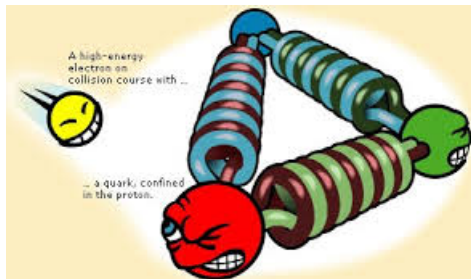
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- Quarks are the only particles that feel all the 4 forces - including Gravity

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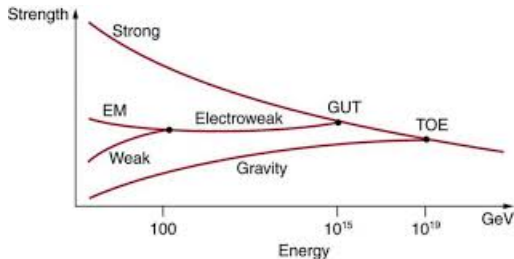


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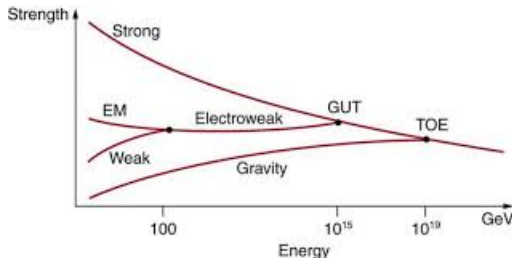
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- Then why do they behave differently at lower energies?

- The question was addressed here

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# Higgs

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- Centre of mass energy  $\approx 14\text{ TeV}$

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- Centre of mass energy  $\approx 14\text{ TeV}$
- Proton-Proton, Proton-Lead ion collisions

- There is something that breaks their unity !



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# How particles acquire mass : Higgs mechanism

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- Higgs has mass  $\approx 125\text{GeV}$

# To sum up

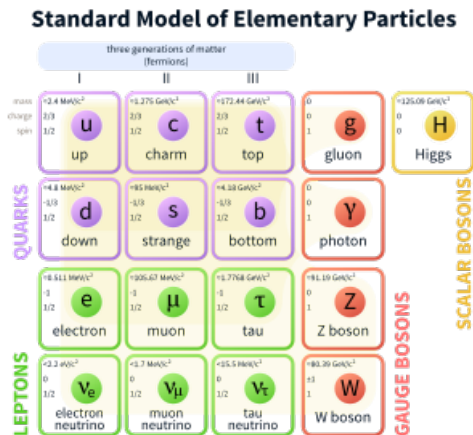
- A "particle" table

Standard Model of Elementary Particles					
three generations of matter (fermions)					
	I	II	III		
mass	$\approx 2.4 \text{ MeV}/c^2$	$\approx 1.275 \text{ GeV}/c^2$	$\approx 172.44 \text{ GeV}/c^2$	0	$\approx 125.09 \text{ GeV}/c^2$
charge	$2/3$	$2/3$	$2/3$	0	0
spin	$1/2$	$1/2$	$1/2$	1	0
QUARKS	<b>u</b> up	<b>c</b> charm	<b>t</b> top	<b>g</b> gluon	<b>H</b> Higgs
	<b>d</b> down	<b>s</b> strange	<b>b</b> bottom	<b><math>\gamma</math></b> photon	
	<b>e</b> electron	<b><math>\mu</math></b> muon	<b><math>\tau</math></b> tau	<b>Z</b> Z boson	
LEPTONS	<b><math>\nu_e</math></b> electron neutrino	<b><math>\nu_\mu</math></b> muon neutrino	<b><math>\nu_\tau</math></b> tau neutrino	<b>W</b> W boson	
				GAUGE BOSONS	SCALAR BOSONS



# To sum up

- A "particle" table



- Theoretical description in terms of point particles: **Quantum field theory**

# Why Gravity is different

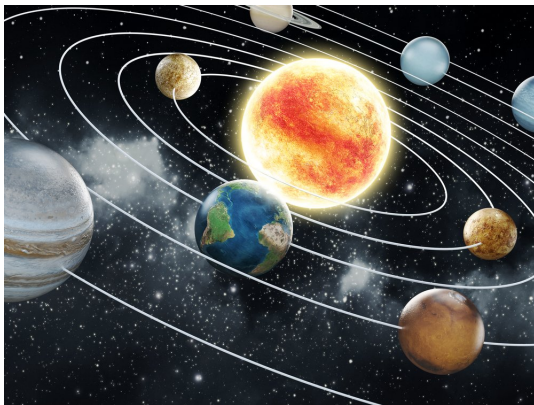
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- Newton's gravity explains very accurately the motion of planets



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- What mediates Gravity cannot be point particles

# What is NOTHING?

- Lambda requires us to know the energy of the vacuum

# What lies beyond?

- Any more work left?

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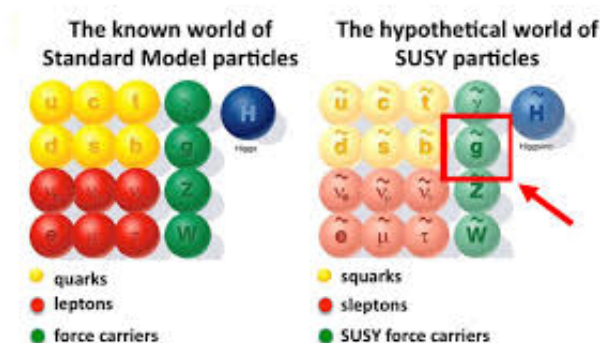
- Any more work left?
- Higgs is not the end of the story

# What lies beyond?

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- Higgs is not the end of the story
- Mass of Higgs as envisaged in Standard model is very unstable - Higgs hierarchy problem

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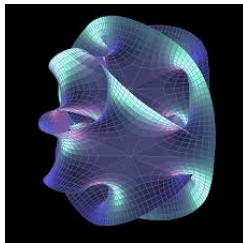
- Any more work left?
- Higgs is not the end of the story
- Mass of Higgs as envisaged in Standard model is very unstable - Higgs hierarchy problem
- Supersymmetry : Do these elementary particle have pairs





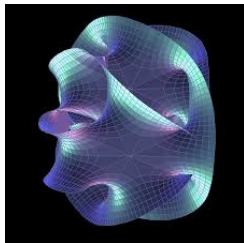
# What lies beyond?

- Extra dimensions



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- Strings



# Paradigms

- Description of physical phenomena are organized by length scales

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# Paradigms

- Description of physical phenomena are organized by length scales



- No! That's not a bunch of hadrons and leptons chasing another bunch
- Frameworks: point particles, unification and symmetry

THANK YOU