

# Introduzione al Modello Standard delle particelle elementari



hands on particle physics

Perugia, 10 Marzo 2015

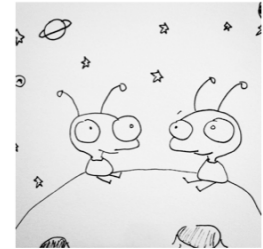


Elisa Manoni

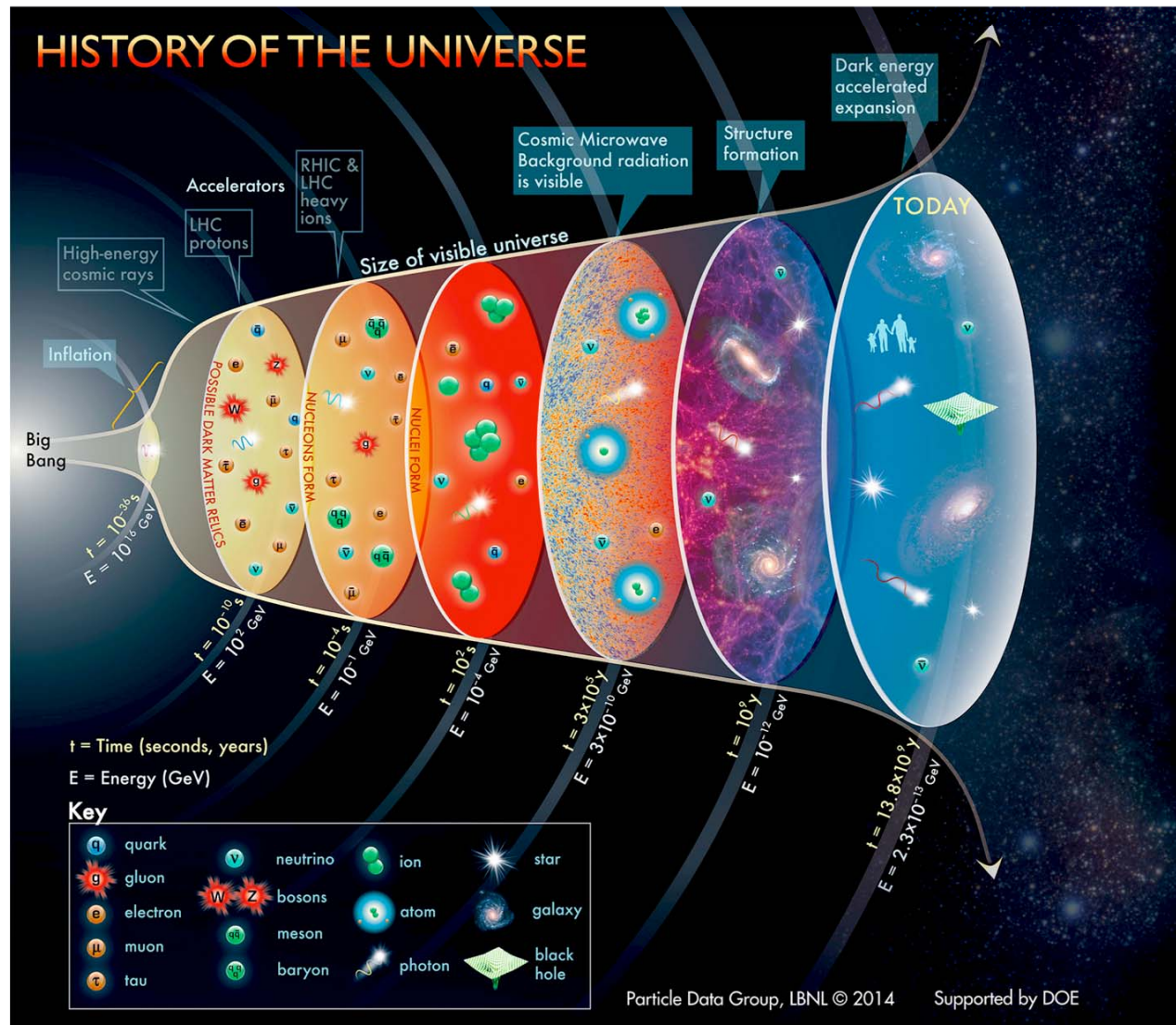
Dipartimento di Fisica e Geologia, UniPG  
Istituto Nazionale di Fisica Nucleare, Sezione Perugia



# "We're all made of stars"



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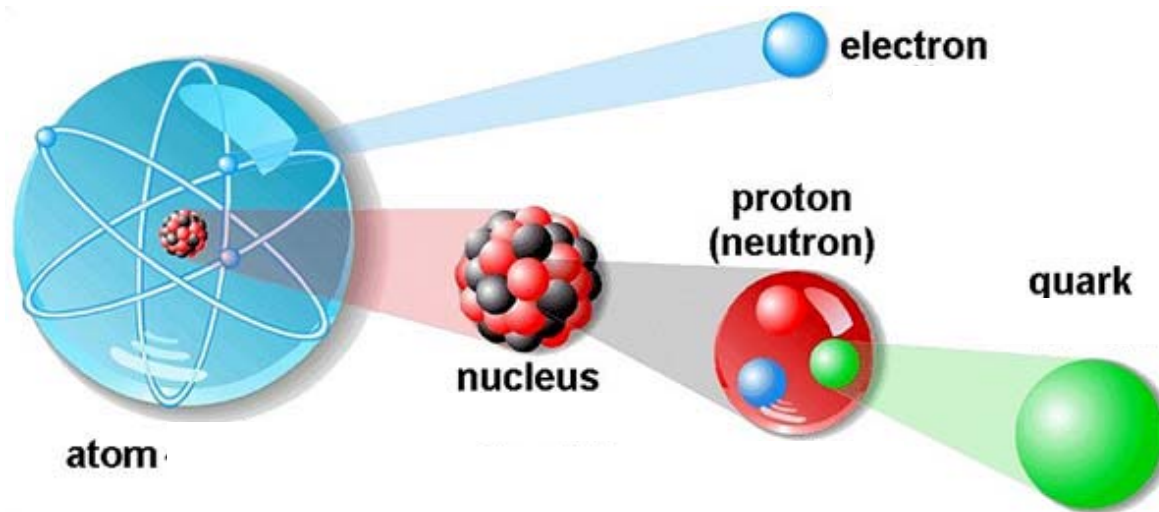


# Known elements: from atoms ....

## Periodic Table of the Elements

<div> <div>Group</div> <div>1 1A</div> <div>2 2A</div> <div>3 3B</div> <div>4 4B</div> <div>5 5B</div> <div>6 6B</div> <div>7 7B</div> <div>8 8B</div> <div>9 9B</div> <div>10 10B</div> <div>11 11B</div> <div>12 12B</div> <div>13 3A</div> <div>14 4A</div> <div>15 5A</div> <div>16 6A</div> <div>17 7A</div> <div>18 8A</div> </div>																	
<div> <div>1</div> <div>2</div> <div>3</div> <div>4</div> <div>5</div> <div>6</div> <div>7</div> <div>8</div> <div>9</div> <div>10</div> <div>11</div> <div>12</div> <div>13</div> <div>14</div> <div>15</div> <div>16</div> <div>17</div> <div>18</div> </div>																	
<div> <div>H</div> <div>He</div> <div>Li</div> <div>Be</div> <div>B</div> <div>C</div> <div>N</div> <div>O</div> <div>F</div> <div>Ne</div> <div>Na</div> <div>Mg</div> <div>Al</div> <div>Si</div> <div>P</div> <div>S</div> <div>Cl</div> <div>Ar</div> </div>																	
<div> <div>Hydrogen</div> <div>Helium</div> <div>Lithium</div> <div>Beryllium</div> <div>Boron</div> <div>Carbon</div> <div>Nitrogen</div> <div>Oxygen</div> <div>Fluorine</div> <div>Neon</div> <div>Sodium</div> <div>Magnesium</div> <div>Aluminum</div> <div>Silicon</div> <div>Phosphorus</div> <div>Sulfur</div> <div>Chlorine</div> <div>Argon</div> </div>																	
<div> <div>1.0078</div> <div>4.0026</div> <div>6.938</div> <div>9.0122</div> <div>10.806</div> <div>12.009</div> <div>14.006</div> <div>15.999</div> <div>18.998</div> <div>20.180</div> <div>22.990</div> <div>24.305</div> <div>26.982</div> <div>28.084</div> <div>30.974</div> <div>32.059</div> <div>35.446</div> <div>39.948</div> </div>																	
<div> <div>Atomic number</div> <div>Element symbol</div> <div>Element name</div> <div>Atomic weight</div> </div>																	
<div> <div>Alkali metals</div> <div>Alkaline earth metals</div> <div>Lanthanides</div> <div>Actinides</div> <div>Transition metals</div> <div>Unknown properties</div> <div>Post-transition metals</div> <div>Metalloids</div> <div>Other nonmetals</div> <div>Halogens</div> <div>Noble gases</div> </div>																	
<div> <div>Period</div> <div>1</div> <div>2</div> <div>3</div> <div>4</div> <div>5</div> <div>6</div> <div>7</div> </div>																	
<div> <div>Scandium</div> <div>Titanium</div> <div>Vanadium</div> <div>Chromium</div> <div>Manganese</div> <div>Iron</div> <div>Cobalt</div> <div>Nickel</div> <div>Copper</div> <div>Zinc</div> <div>Gallium</div> <div>Germanium</div> <div>Arsenic</div> <div>Selenium</div> <div>Bromine</div> <div>Krypton</div> <div>Rubidium</div> <div>Strontium</div> </div>																	
<div> <div>44.956</div> <div>47.867</div> <div>50.942</div> <div>51.996</div> <div>54.938</div> <div>55.845</div> <div>58.933</div> <div>58.693</div> <div>63.546</div> <div>65.38</div> <div>69.723</div> <div>72.63</div> <div>74.922</div> <div>78.96</div> <div>79.904</div> <div>83.798</div> <div>85.468</div> <div>87.62</div> </div>																	
<div> <div>Yttrium</div> <div>Zirconium</div> <div>Niobium</div> <div>Molybdenum</div> <div>Technetium</div> <div>Ruthenium</div> <div>Rhodium</div> <div>Palladium</div> <div>Silver</div> <div>Cadmium</div> <div>Indium</div> <div>Tin</div> <div>Antimony</div> <div>Tellurium</div> <div>Iodine</div> <div>Xenon</div> <div>Rubidium</div> <div>Strontium</div> </div>																	
<div> <div>88.906</div> <div>91.224</div> <div>92.906</div> <div>95.96</div> <div>98.9062</div> <div>101.07</div> <div>102.91</div> <div>106.42</div> <div>107.87</div> <div>112.41</div> <div>114.82</div> <div>118.71</div> <div>121.76</div> <div>127.60</div> <div>126.90</div> <div>131.29</div> <div>85.468</div> <div>87.62</div> </div>																	
<div> <div>Hafnium</div> <div>Tantalum</div> <div>Tungsten</div> <div>Rhenium</div> <div>Osmium</div> <div>Iridium</div> <div>Platinum</div> <div>Gold</div> <div>Mercury</div> <div>Thallium</div> <div>Lead</div> <div>Bismuth</div> <div>Polonium</div> <div>Astatine</div> <div>Radon</div> <div>Cesium</div> <div>Barium</div> </div>																	
<div> <div>178.49</div> <div>180.95</div> <div>183.84</div> <div>186.21</div> <div>190.23</div> <div>192.22</div> <div>195.08</div> <div>196.97</div> <div>200.59</div> <div>204.38</div> <div>207.2</div> <div>208.98</div> <div>(209)</div> <div>(210)</div> <div>(222)</div> <div>132.91</div> <div>137.33</div> </div>																	
<div> <div>Francium</div> <div>Radium</div> <div>Rutherfordium</div> <div>Dubnium</div> <div>Seaborgium</div> <div>Bohrium</div> <div>Hassium</div> <div>Meitnerium</div> <div>Darmstadtium</div> <div>Roentgenium</div> <div>Copernicium</div> <div>Ununtrium</div> <div>Flerovium</div> <div>Ununpentium</div> <div>Livermorium</div> <div>Ununseptium</div> <div>Ununoctium</div> </div>																	
<div> <div>(223)</div> <div>(226)</div> <div>(261)</div> <div>(262)</div> <div>(266)</div> <div>(264)</div> <div>(269)</div> <div>(268)</div> <div>(268)</div> <div>(268)</div> <div>(268)</div> <div>(268)</div> <div>(268)</div> <div>(268)</div> <div>(268)</div> <div>(268)</div> <div>(268)</div> </div>																	
<div> <div>Lanthanides</div> <div>Actinides</div> <div>Lanthanum</div> <div>Cerium</div> <div>Praseodymium</div> <div>Neodymium</div> <div>Promethium</div> <div>Samarium</div> <div>Europium</div> <div>Gadolinium</div> <div>Terbium</div> <div>Dysprosium</div> <div>Holmium</div> <div>Erbium</div> <div>Thulium</div> <div>Ytterbium</div> <div>Lutetium</div> </div>																	
<div> <div>138.91</div> <div>140.12</div> <div>140.91</div> <div>144.24</div> <div>(145)</div> <div>150.36</div> <div>151.96</div> <div>157.25</div> <div>158.93</div> <div>162.50</div> <div>164.93</div> <div>167.26</div> <div>168.93</div> <div>173.04</div> <div>174.97</div> <div>(227)</div> <div>232.04</div> </div>																	
<div> <div>Actinium</div> <div>Thorium</div> <div>Protactinium</div> <div>Uranium</div> <div>Neptunium</div> <div>Plutonium</div> <div>Americium</div> <div>Curium</div> <div>Berkelium</div> <div>Californium</div> <div>Einsteinium</div> <div>Fermium</div> <div>Mendelevium</div> <div>Nobelium</div> <div>Lawrencium</div> <div>Actinium</div> <div>Thorium</div> </div>																	
<div> <div>(227)</div> <div>232.04</div> <div>231.04</div> <div>238.03</div> <div>(237)</div> <div>(244)</div> <div>(243)</div> <div>(247)</div> <div>(247)</div> <div>(251)</div> <div>(252)</div> <div>(257)</div> <div>(258)</div> <div>(259)</div> <div>(262)</div> <div>(227)</div> <div>232.04</div> </div>																	

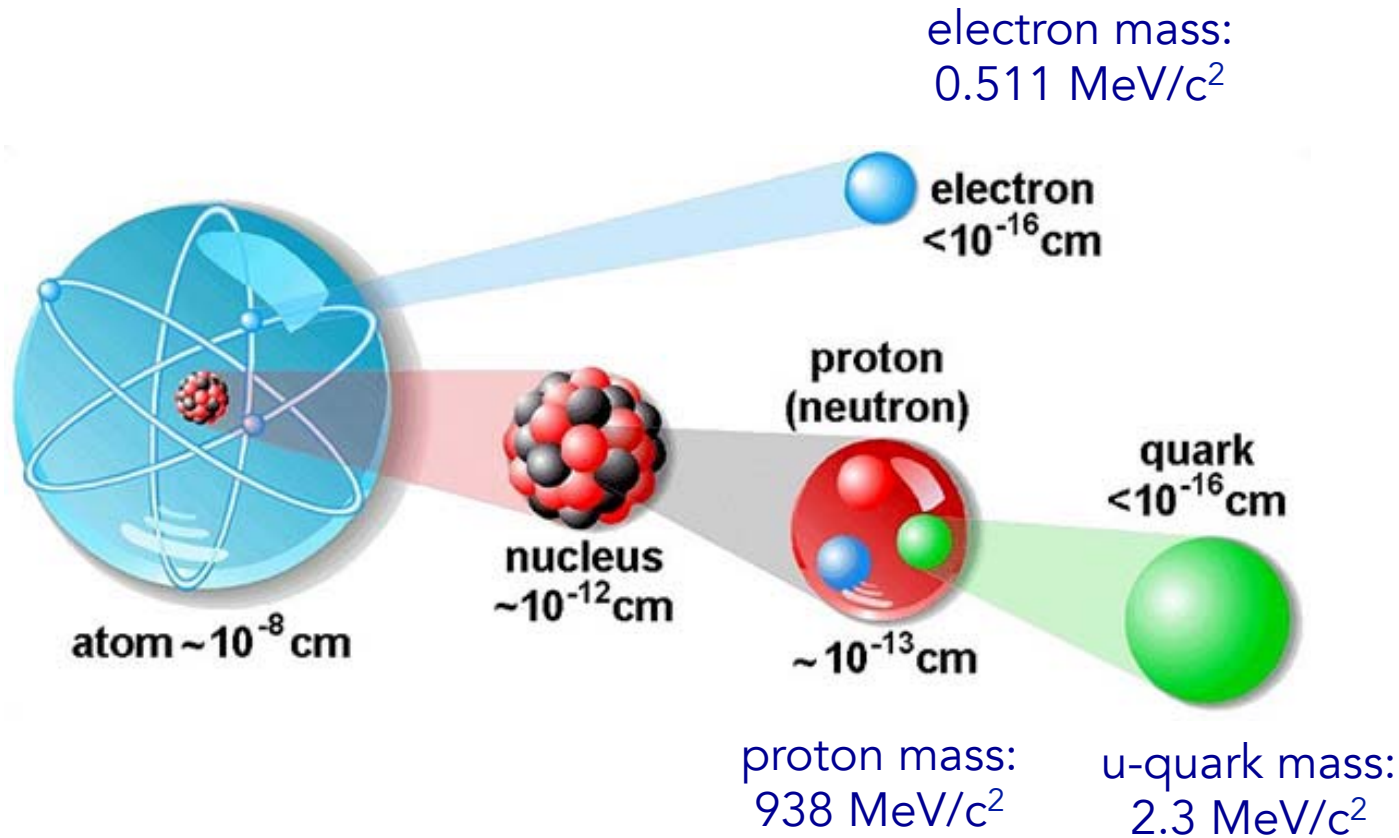
# ..to their building blocks



mass →	$\approx 2.3 \text{ MeV}/c^2$	<b>u</b> up
charge →	$2/3$	
spin →	$1/2$	
<b>QUARKS</b>		
	$\approx 4.8 \text{ MeV}/c^2$	<b>d</b> down
	$-1/3$	
	$1/2$	
	$0.511 \text{ MeV}/c^2$	<b>e</b> electron
	$-1$	
	$1/2$	



# How small (and light) are the smallest?



mass $\rightarrow$	$\approx 2.3 \text{ MeV}/c^2$	<div>u</div> <div>up</div>
charge $\rightarrow$	$2/3$	
spin $\rightarrow$	$1/2$	
QUARKS	$\approx 4.8 \text{ MeV}/c^2$	<div>d</div> <div>down</div>
	$-1/3$	
	$1/2$	
	$0.511 \text{ MeV}/c^2$	<div>e</div> <div>electron</div>
	$-1$	
	$1/2$	

n.b.:  $1 \text{ MeV}/c^2 \sim 2 \times 10^{-30} \text{ Kg}$

# But there's much more

mass →	$\approx 2.3 \text{ MeV}/c^2$	$\approx 1.275 \text{ GeV}/c^2$	$\approx 173.07 \text{ GeV}/c^2$	0	$\approx 126 \text{ GeV}/c^2$
charge →	$2/3$	$2/3$	$2/3$	0	0
spin →	$1/2$	$1/2$	$1/2$	1	0
	<b>u</b> up	<b>c</b> charm	<b>t</b> top	<b>g</b> gluon	<b>H</b> Higgs boson
	$\approx 4.8 \text{ MeV}/c^2$	$\approx 95 \text{ MeV}/c^2$	$\approx 4.18 \text{ GeV}/c^2$	0	
	$-1/3$	$-1/3$	$-1/3$	0	
	$1/2$	$1/2$	$1/2$	1	
	<b>d</b> down	<b>s</b> strange	<b>b</b> bottom	<b><math>\gamma</math></b> photon	
	$0.511 \text{ MeV}/c^2$	$105.7 \text{ MeV}/c^2$	$1.777 \text{ GeV}/c^2$	$91.2 \text{ GeV}/c^2$	
	-1	-1	-1	0	
	$1/2$	$1/2$	$1/2$	1	
	<b>e</b> electron	<b><math>\mu</math></b> muon	<b><math>\tau</math></b> tau	<b>Z</b> Z boson	
	$< 2.2 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 15.5 \text{ MeV}/c^2$	$80.4 \text{ GeV}/c^2$	
	0	0	0	$\pm 1$	
	$1/2$	$1/2$	$1/2$	1	
	<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	

QUARKS

LEPTONS

GAUGE BOSONS

# But there's much more

matters'  
building  
blocks

<div> <div>QUARKS</div> <div>LEPTONS</div> </div>	<div> <div> <div>mass → <math>\approx 2.3 \text{ MeV}/c^2</math></div> <div>charge → <math>2/3</math></div> <div>spin → <math>1/2</math></div> </div> <div> <div>u</div> <div>up</div> </div> </div>	<div> <div> <div>mass → <math>\approx 1.275 \text{ GeV}/c^2</math></div> <div>charge → <math>2/3</math></div> <div>spin → <math>1/2</math></div> </div> <div> <div>c</div> <div>charm</div> </div> </div>	<div> <div> <div>mass → <math>\approx 173.07 \text{ GeV}/c^2</math></div> <div>charge → <math>2/3</math></div> <div>spin → <math>1/2</math></div> </div> <div> <div>t</div> <div>top</div> </div> </div>	<div> <div> <div>mass → 0</div> <div>charge → 0</div> <div>spin → 1</div> </div> <div> <div>g</div> <div>gluon</div> </div> </div>	<div> <div> <div>mass → <math>\approx 126 \text{ GeV}/c^2</math></div> <div>charge → 0</div> <div>spin → 0</div> </div> <div> <div>H</div> <div>Higgs boson</div> </div> </div>
	<div> <div> <div>mass → <math>\approx 4.8 \text{ MeV}/c^2</math></div> <div>charge → <math>-1/3</math></div> <div>spin → <math>1/2</math></div> </div> <div> <div>d</div> <div>down</div> </div> </div>	<div> <div> <div>mass → <math>\approx 95 \text{ MeV}/c^2</math></div> <div>charge → <math>-1/3</math></div> <div>spin → <math>1/2</math></div> </div> <div> <div>s</div> <div>strange</div> </div> </div>	<div> <div> <div>mass → <math>\approx 4.18 \text{ GeV}/c^2</math></div> <div>charge → <math>-1/3</math></div> <div>spin → <math>1/2</math></div> </div> <div> <div>b</div> <div>bottom</div> </div> </div>	<div> <div> <div>mass → 0</div> <div>charge → 0</div> <div>spin → 1</div> </div> <div> <div><math>\gamma</math></div> <div>photon</div> </div> </div>	
	<div> <div> <div>mass → <math>0.511 \text{ MeV}/c^2</math></div> <div>charge → -1</div> <div>spin → <math>1/2</math></div> </div> <div> <div>e</div> <div>electron</div> </div> </div>	<div> <div> <div>mass → <math>105.7 \text{ MeV}/c^2</math></div> <div>charge → -1</div> <div>spin → <math>1/2</math></div> </div> <div> <div><math>\mu</math></div> <div>muon</div> </div> </div>	<div> <div> <div>mass → <math>1.777 \text{ GeV}/c^2</math></div> <div>charge → -1</div> <div>spin → <math>1/2</math></div> </div> <div> <div><math>\tau</math></div> <div>tau</div> </div> </div>	<div> <div> <div>mass → <math>91.2 \text{ GeV}/c^2</math></div> <div>charge → 0</div> <div>spin → 1</div> </div> <div> <div>Z</div> <div>Z boson</div> </div> </div>	
	<div> <div> <div>mass → <math>&lt; 2.2 \text{ eV}/c^2</math></div> <div>charge → 0</div> <div>spin → <math>1/2</math></div> </div> <div> <div><math>\nu_e</math></div> <div>electron neutrino</div> </div> </div>	<div> <div> <div>mass → <math>&lt; 0.17 \text{ MeV}/c^2</math></div> <div>charge → 0</div> <div>spin → <math>1/2</math></div> </div> <div> <div><math>\nu_\mu</math></div> <div>muon neutrino</div> </div> </div>	<div> <div> <div>mass → <math>&lt; 15.5 \text{ MeV}/c^2</math></div> <div>charge → 0</div> <div>spin → <math>1/2</math></div> </div> <div> <div><math>\nu_\tau</math></div> <div>tau neutrino</div> </div> </div>	<div> <div> <div>mass → <math>80.4 \text{ GeV}/c^2</math></div> <div>charge → <math>\pm 1</math></div> <div>spin → 1</div> </div> <div> <div>W</div> <div>W boson</div> </div> </div>	<div>GAUGE BOSONS</div>

# But there's much more

mass →	$\approx 2.3 \text{ MeV}/c^2$	$\approx 1.275 \text{ GeV}/c^2$	$\approx 173.07 \text{ GeV}/c^2$	0	$\approx 126 \text{ GeV}/c^2$
charge →	$2/3$	$2/3$	$2/3$	0	0
spin →	$1/2$	$1/2$	$1/2$	1	0
	<b>u</b> up	<b>c</b> charm	<b>t</b> top	<b>g</b> gluon	<b>H</b> Higgs boson
<b>QUARKS</b>	$\approx 4.8 \text{ MeV}/c^2$	$\approx 95 \text{ MeV}/c^2$	$\approx 4.18 \text{ GeV}/c^2$	0	
	$-1/3$	$-1/3$	$-1/3$	0	
	$1/2$	$1/2$	$1/2$	1	
	<b>d</b> down	<b>s</b> strange	<b>b</b> bottom	<b><math>\gamma</math></b> photon	
	$0.511 \text{ MeV}/c^2$	$105.7 \text{ MeV}/c^2$	$1.777 \text{ GeV}/c^2$	$91.2 \text{ GeV}/c^2$	
	-1	-1	-1	0	
	$1/2$	$1/2$	$1/2$	1	
	<b>e</b> electron	<b><math>\mu</math></b> muon	<b><math>\tau</math></b> tau	<b>Z</b> Z boson	
<b>LEPTONS</b>	$< 2.2 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 15.5 \text{ MeV}/c^2$	$80.4 \text{ GeV}/c^2$	
	0	0	0	$\pm 1$	
	$1/2$	$1/2$	$1/2$	1	
	<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	
				<b>GAUGE BOSONS</b>	

Produced  
in nuclear  
 $\beta$  decay



But there's much more

mass →	$\approx 2.3 \text{ MeV}/c^2$	$\approx 1.275 \text{ GeV}/c^2$	$\approx 173.07 \text{ GeV}/c^2$	0	$\approx 126 \text{ GeV}/c^2$
charge →	$2/3$	$2/3$	$2/3$	0	0
spin →	$1/2$	$1/2$	$1/2$	1	0
	<b>u</b> up	<b>c</b> charm	<b>t</b> top	<b>g</b> gluon	<b>H</b> Higgs boson
	$\approx 4.8 \text{ MeV}/c^2$	$\approx 95 \text{ MeV}/c^2$	$\approx 4.18 \text{ GeV}/c^2$	0	
	$-1/3$	$-1/3$	$-1/3$	0	
	$1/2$	$1/2$	$1/2$	1	
	<b>d</b> down	<b>s</b> strange	<b>b</b> bottom	<b><math>\gamma</math></b> photon	
	$0.511 \text{ MeV}/c^2$	$105.7 \text{ MeV}/c^2$	$1.777 \text{ GeV}/c^2$	$91.2 \text{ GeV}/c^2$	
	-1	-1	-1	0	
	$1/2$	$1/2$	$1/2$	1	
	<b>e</b> electron	<b><math>\mu</math></b> muon	<b><math>\tau</math></b> tau	<b>Z</b> Z boson	
	$< 2.2 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 15.5 \text{ MeV}/c^2$	$80.4 \text{ GeV}/c^2$	
	0	0	0	$\pm 1$	
	$1/2$	$1/2$	$1/2$	1	
	<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	

QUARKS

LEPTONS

GAUGE BOSONS

two more copies of matter particles

But there's much more

mass →	$\approx 2.3 \text{ MeV}/c^2$	$\approx 1.275 \text{ GeV}/c^2$	$\approx 173.07 \text{ GeV}/c^2$	0	$\approx 126 \text{ GeV}/c^2$
charge →	$2/3$	$2/3$	$2/3$	0	0
spin →	$1/2$	$1/2$	$1/2$	1	0
	<b>u</b> up	<b>c</b> charm	<b>t</b> top	<b>g</b> gluon	<b>H</b> Higgs boson
	$\approx 4.8 \text{ MeV}/c^2$	$\approx 95 \text{ MeV}/c^2$	$\approx 4.18 \text{ GeV}/c^2$	0	
	$-1/3$	$-1/3$	$-1/3$	0	
	$1/2$	$1/2$	$1/2$	1	
	<b>d</b> down	<b>s</b> strange	<b>b</b> bottom	<b><math>\gamma</math></b> photon	
	$0.511 \text{ MeV}/c^2$	$105.7 \text{ MeV}/c^2$	$1.777 \text{ GeV}/c^2$	$91.2 \text{ GeV}/c^2$	
	-1	-1	-1	0	
	$1/2$	$1/2$	$1/2$	1	
	<b>e</b> electron	<b><math>\mu</math></b> muon	<b><math>\tau</math></b> tau	<b>Z</b> Z boson	
	$< 2.2 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 15.5 \text{ MeV}/c^2$	$80.4 \text{ GeV}/c^2$	
	0	0	0	$\pm 1$	
	$1/2$	$1/2$	$1/2$	1	
	<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	

QUARKS

LEPTONS

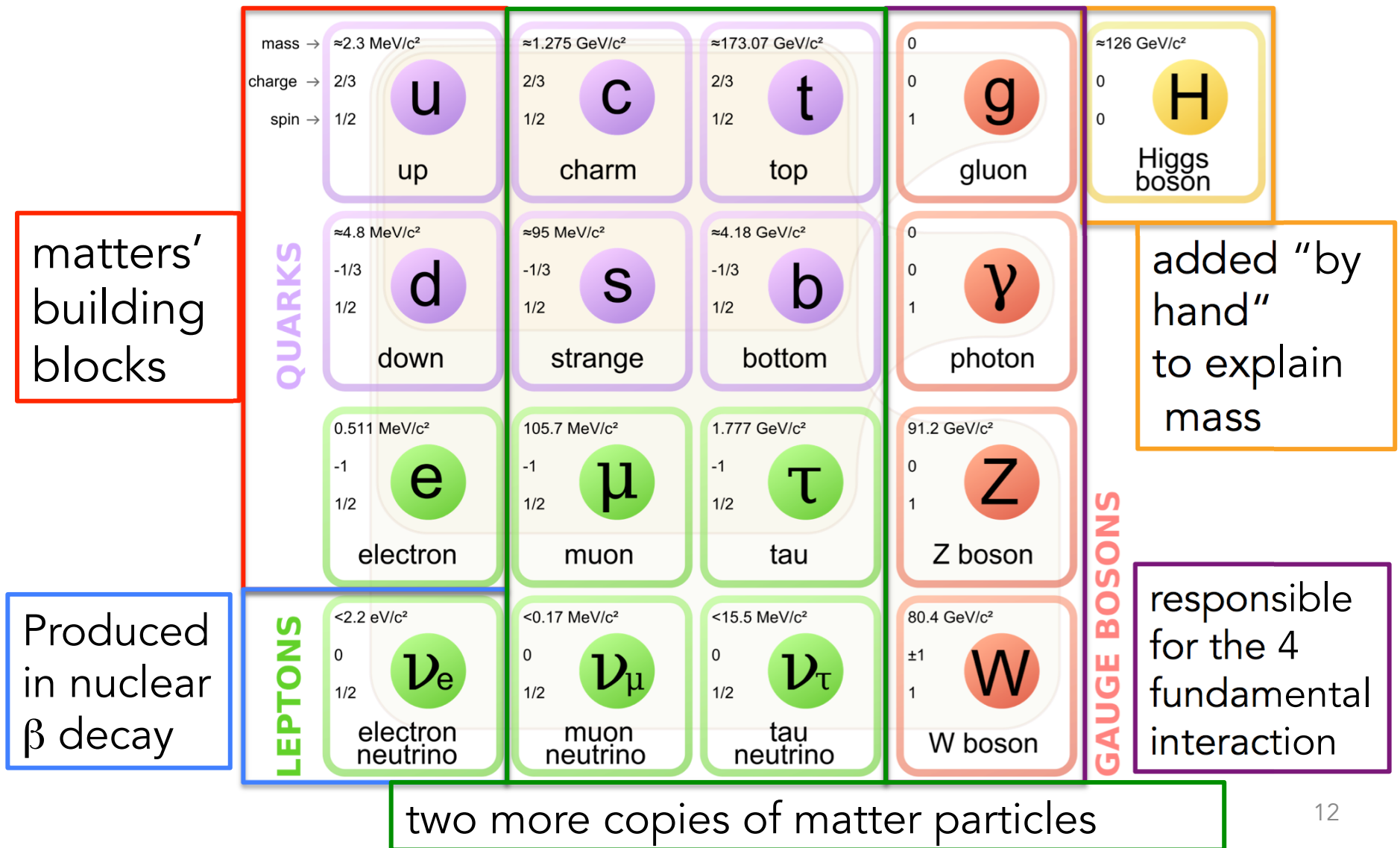
GAUGE BOSONS

responsible  
for the 4  
fundamental  
interaction

# But there's much more

LEPTONS	QUARKS	mass → charge → spin →	$\approx 2.3 \text{ MeV}/c^2$ $2/3$ $1/2$ <b>u</b> up	$\approx 1.275 \text{ GeV}/c^2$ $2/3$ $1/2$ <b>c</b> charm	$\approx 173.07 \text{ GeV}/c^2$ $2/3$ $1/2$ <b>t</b> top	0 0 1 <b>g</b> gluon	$\approx 126 \text{ GeV}/c^2$ 0 0 0 <b>H</b> Higgs boson
			$\approx 4.8 \text{ MeV}/c^2$ $-1/3$ $1/2$ <b>d</b> down	$\approx 95 \text{ MeV}/c^2$ $-1/3$ $1/2$ <b>s</b> strange	$\approx 4.18 \text{ GeV}/c^2$ $-1/3$ $1/2$ <b>b</b> bottom	0 0 1 <b><math>\gamma</math></b> photon	added "by hand" to explain mass
			$0.511 \text{ MeV}/c^2$ -1 $1/2$ <b>e</b> electron	$105.7 \text{ MeV}/c^2$ -1 $1/2$ <b><math>\mu</math></b> muon	$1.777 \text{ GeV}/c^2$ -1 $1/2$ <b><math>\tau</math></b> tau	0 0 1 <b>Z</b> Z boson	
			$< 2.2 \text{ eV}/c^2$ 0 $1/2$ <b><math>\nu_e</math></b> electron neutrino	$< 0.17 \text{ MeV}/c^2$ 0 $1/2$ <b><math>\nu_\mu</math></b> muon neutrino	$< 15.5 \text{ MeV}/c^2$ 0 $1/2$ <b><math>\nu_\tau</math></b> tau neutrino	$80.4 \text{ GeV}/c^2$ $\pm 1$ 1 <b>W</b> W boson	
						GAUGE BOSONS	

But there's much more

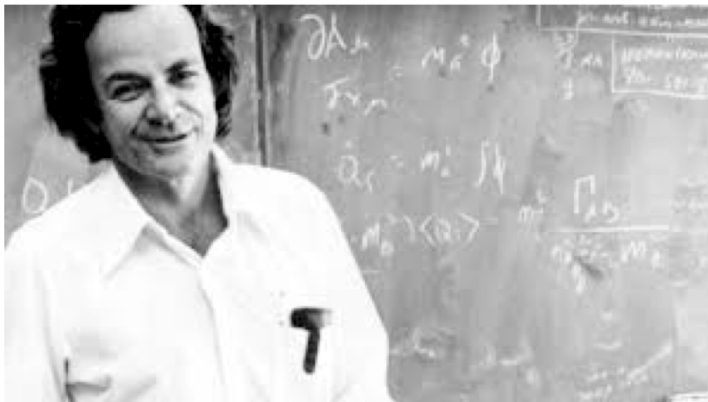
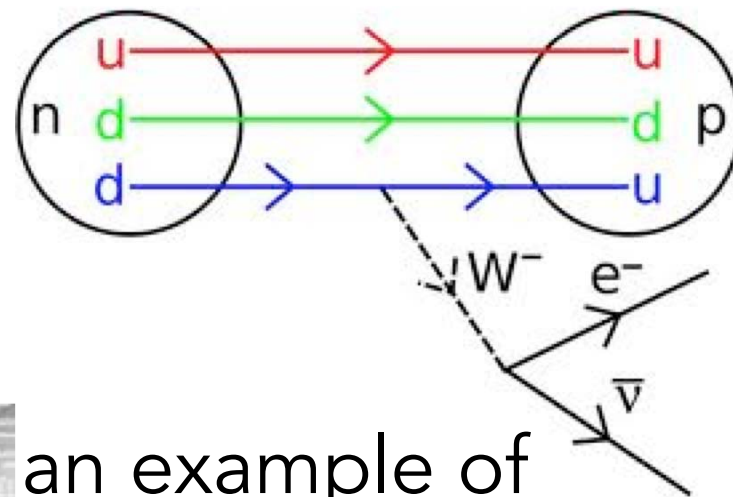




# An example of particle interaction: Nuclear- $\beta$ decay

- neutron decay to proton + electron + electronic neutrino

$$n \rightarrow p e^- \bar{\nu}_e$$



an example of  
Feynman diagram

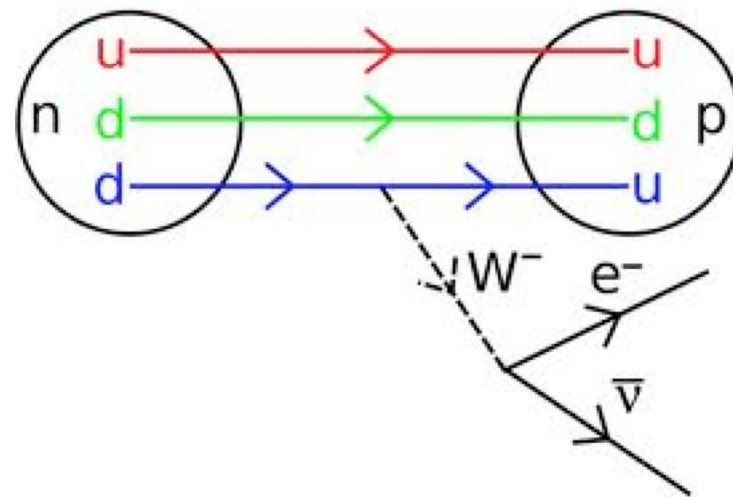
## An example of particle interaction: Nuclear- $\beta$ decay

- neutron decay to proton + electron + electronic neutrino

$$n \rightarrow p e^- \bar{\nu}_e$$

- Nature is obedient to **CONSERVATION LAWS**

- electric charge
- leptonic number
- baryon number
- energy

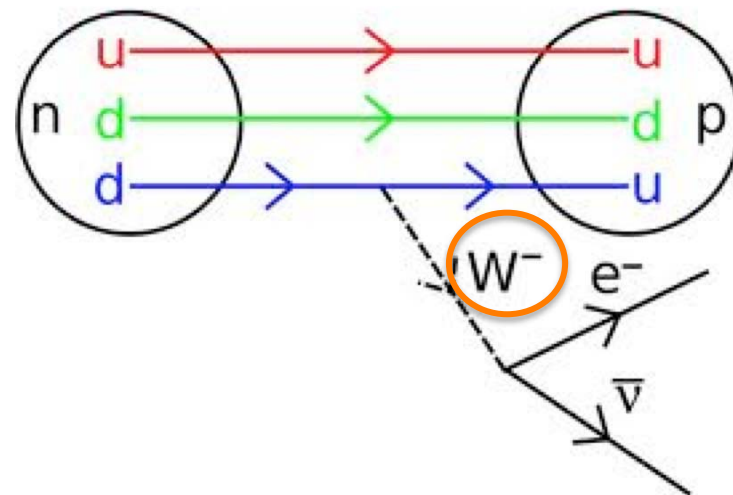


## An example of particle interaction: Nuclear- $\beta$ decay

- neutron decay to proton + electron + electronic neutrino

$$n \rightarrow p e^- \bar{\nu}_e$$

- Decay happens through  $W^\pm$  bosons exchange, charged **weak forces** carriers

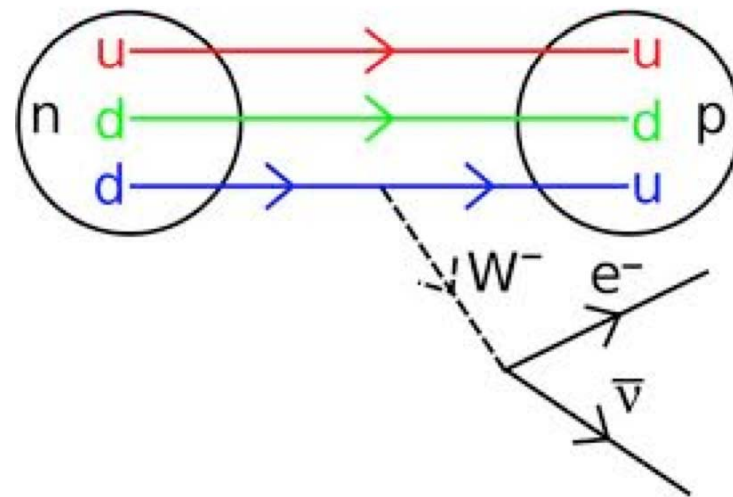


## An example of particle interaction: Nuclear- $\beta$ decay

- neutron decay to proton + electron + electronic neutrino

$$n \rightarrow p e^- \bar{\nu}_e$$

- Quarks are “glued” inside the nucleons by **gluons**, strong forces carriers
  - an additional quantum numbers related to strong forces: **COLOR**

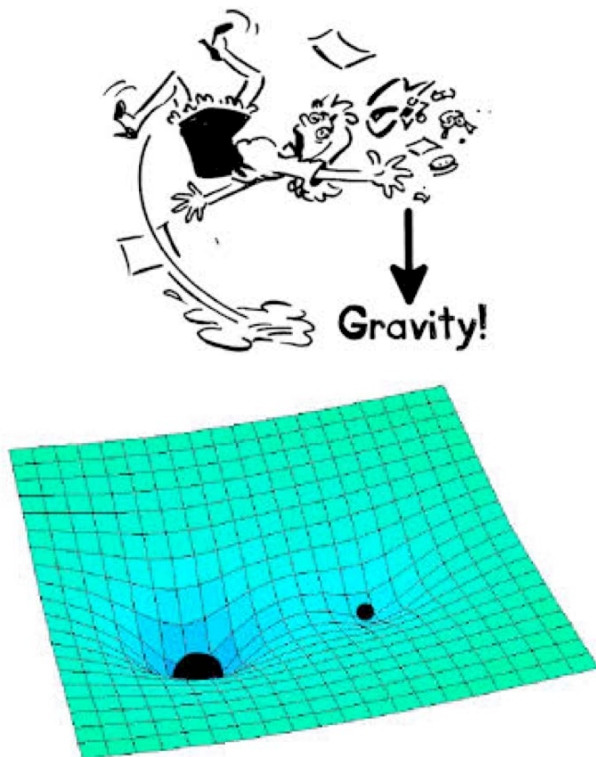




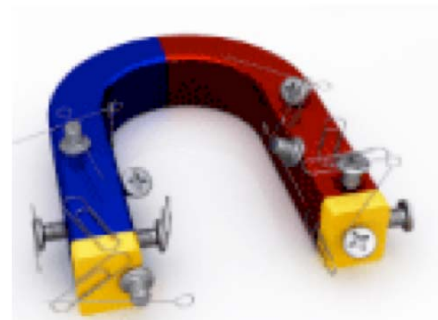
# Fundamental interactions

- Other than weak and strong forces, we have 2 more fundamental interaction

GRAVITATIONAL FORCE



ELECTROMAGNETIC FORCE



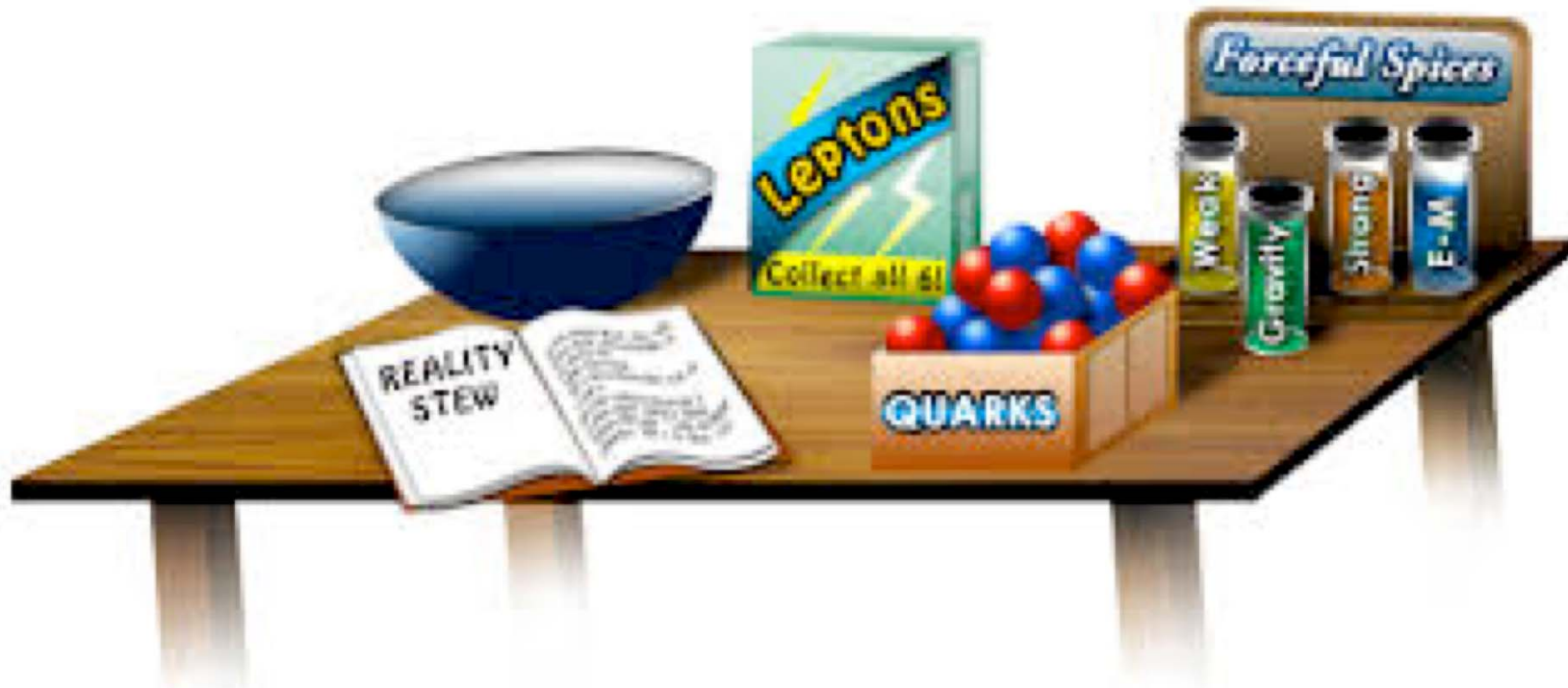
$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

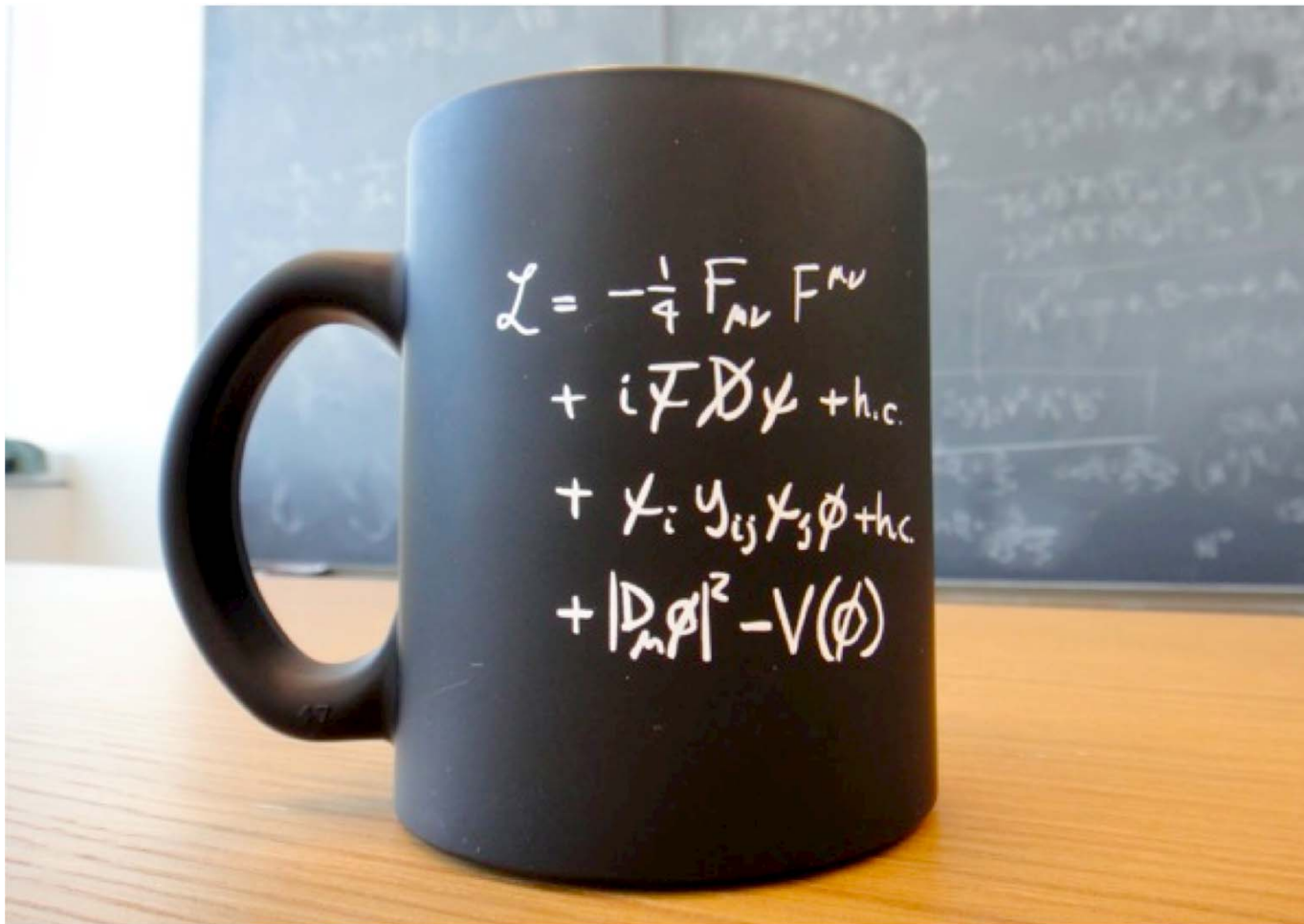
$$\frac{1}{\mu_0} \nabla \times \mathbf{B} = \mathbf{J} + \epsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$

# Particles and Forces: summary

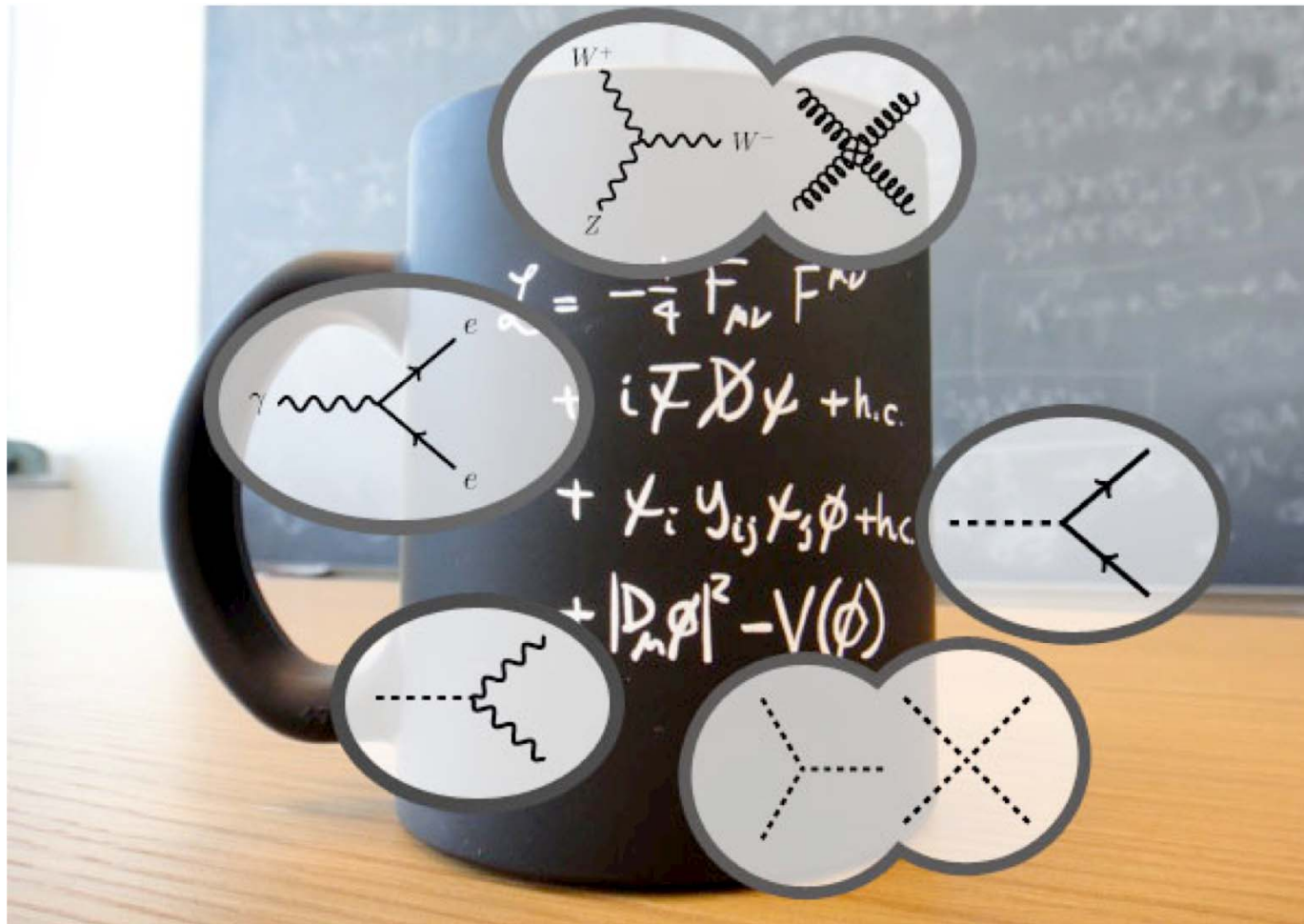


- There's a theory which tries to describe elementary particle properties and they interactions: **THE STANDARD MODEL OF PARTICLE PHYSICS**

# The Standard Model Lagrangian



# The Standard Model Lagrangian





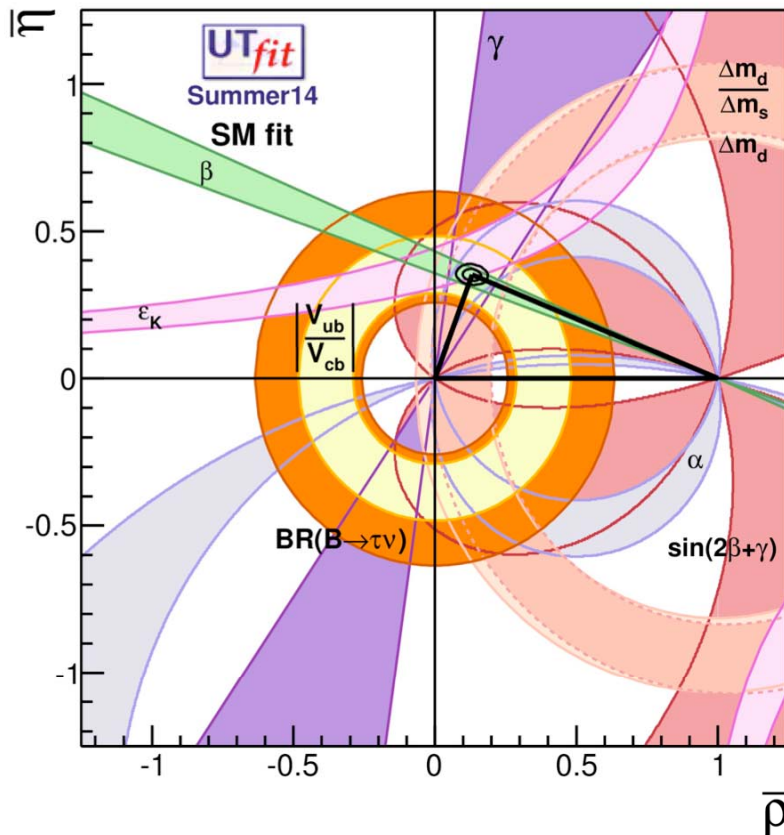
# SM it's a working theory!

We have observed a new  
boson with a mass of

**$125.3 \pm 0.6 \text{ GeV}$**

at

**$4.9 \sigma$**  significance



...but not the ultimate one!

- Why 3 generations ?
- Why mass/mixing hierarchy?
- What is the origin of CP violation ? (can the SM explain the matter-antimatter asymmetry in the Universe ? )
- Which particle(s) are responsible for dark matter ?
- What about gravity ?
- .....

# What's beyond?

- Theorists at work



- Experimentalist at work

**THANKS FOR YOUR  
ATTENTION!**