arXiv:1201.0537 (Standard Model)
arXiv:1512.08749 (Higgs Physics)
arXiv:1805.08597 (Flavour Physics)

Flavour Physics

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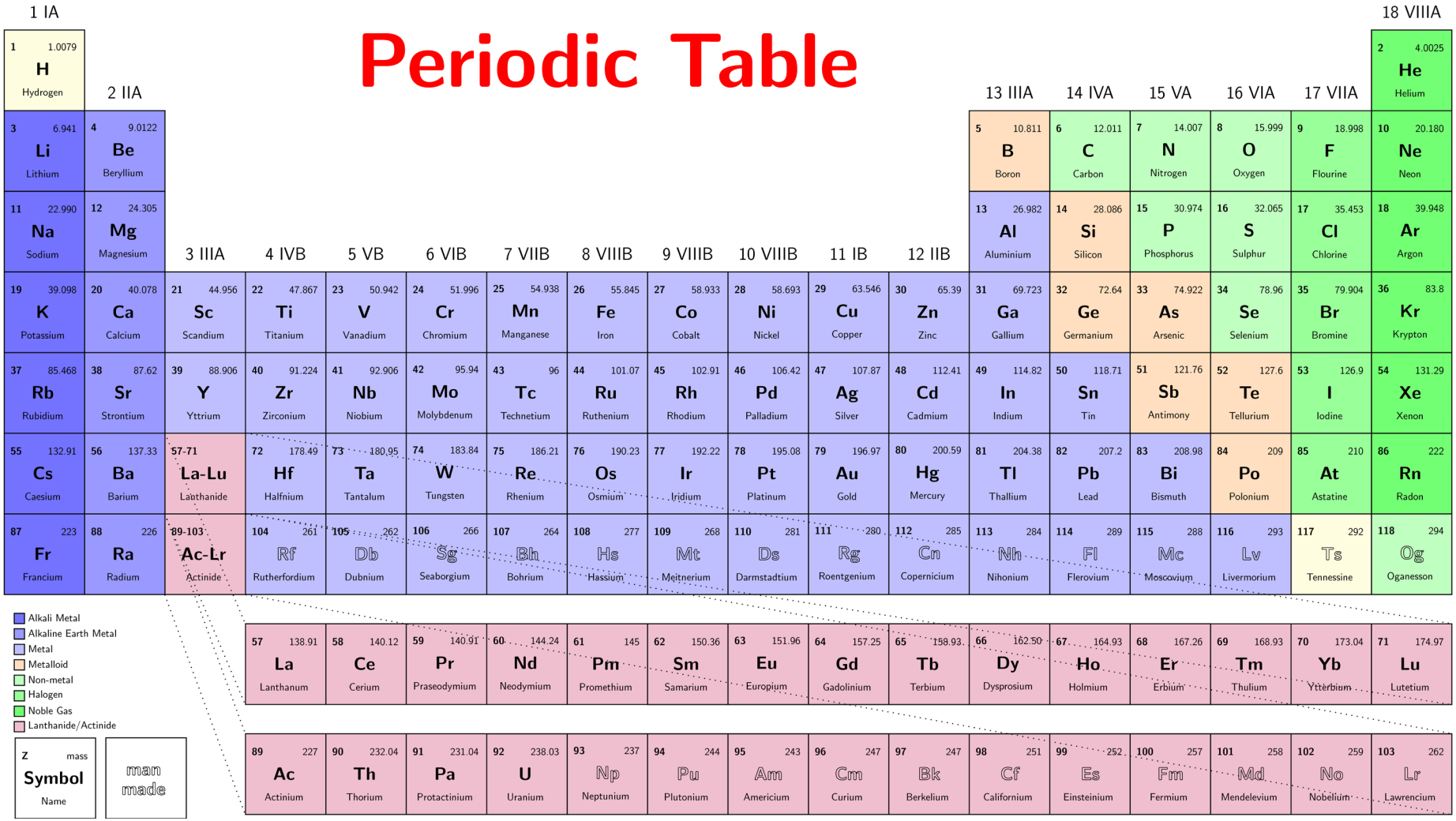
1. Elementary constituents & fundamental interactions
2. Flavour-changing phenomena
3. Meson mixing & CP violation

2021 JENNIFER2 Summer School, 19-27 July 2021

Periodic Table



Periodic Table

	1 IA												13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 1.0079 H Hydrogen	2 IIA																2 4.0025 He Helium
2	3 6.941 Li Lithium	4 9.0122 Be Beryllium											5 10.811 B Boron	6 12.011 C Carbon	7 14.007 N Nitrogen	8 15.999 O Oxygen	9 18.998 F Flourine	10 20.180 Ne Neon
3	11 22.990 Na Sodium	12 24.305 Mg Magnesium	3 IIIA	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9 VIIIB	10 VIIIB	11 IB	12 IIB	13 26.982 Al Aluminium	14 28.086 Si Silicon	15 30.974 P Phosphorus	16 32.065 S Sulphur	17 35.453 Cl Chlorine	18 39.948 Ar Argon
4	19 39.098 K Potassium	20 40.078 Ca Calcium	21 44.956 Sc Scandium	22 47.867 Ti Titanium	23 50.942 V Vanadium	24 51.996 Cr Chromium	25 54.938 Mn Manganese	26 55.845 Fe Iron	27 58.933 Co Cobalt	28 58.693 Ni Nickel	29 63.546 Cu Copper	30 65.39 Zn Zinc	31 69.723 Ga Gallium	32 72.64 Ge Germanium	33 74.922 As Arsenic	34 78.96 Se Selenium	35 79.904 Br Bromine	36 83.8 Kr Krypton
5	37 85.468 Rb Rubidium	38 87.62 Sr Strontium	39 88.906 Y Yttrium	40 91.224 Zr Zirconium	41 92.906 Nb Niobium	42 95.94 Mo Molybdenum	43 96 Tc Technetium	44 101.07 Ru Ruthenium	45 102.91 Rh Rhodium	46 106.42 Pd Palladium	47 107.87 Ag Silver	48 112.41 Cd Cadmium	49 114.82 In Indium	50 118.71 Sn Tin	51 121.76 Sb Antimony	52 127.6 Te Tellurium	53 126.9 I Iodine	54 131.29 Xe Xenon
6	55 132.91 Cs Caesium	56 137.33 Ba Barium	57-71 La-Lu Lanthanide	72 178.49 Hf Halfnium	73 180.95 Ta Tantalum	74 183.84 W Tungsten	75 186.21 Re Rhenium	76 190.23 Os Osmium	77 192.22 Ir Iridium	78 195.08 Pt Platinum	79 196.97 Au Gold	80 200.59 Hg Mercury	81 204.38 Tl Thallium	82 207.2 Pb Lead	83 208.98 Bi Bismuth	84 209 Po Polonium	85 210 At Astatine	86 222 Rn Radon
7	87 223 Fr Francium	88 226 Ra Radium	89-103 Ac-Lr Actinide	104 261 Rf Rutherfordium	105 262 Db Dubnium	106 266 Sg Seaborgium	107 264 Bh Bohrium	108 277 Hs Hassium	109 268 Mt Meitnerium	110 281 Ds Darmstadtium	111 R Roentg							

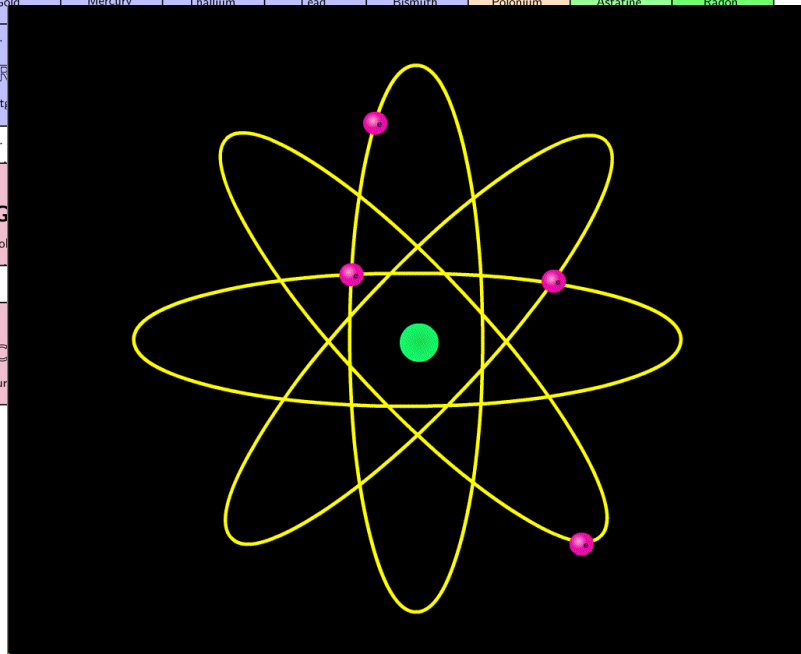
	57	58	59	60	61	62	63	64
	138.91 La Lanthanum	140.12 Ce Cerium	140.91 Pr Praseodymium	144.24 Nd Neodymium	145 Pm Promethium	150.36 Sm Samarium	151.96 Eu Europium	G Gadol

	89	90	91	92	93	94	95	96
	227 Ac Actinium	232.04 Th Thorium	231.04 Pa Protactinium	238.03 U Uranium	237 Np Neptunium	244 Pu Plutonium	243 Am Americium	C Cur

- Alkali Metal
- Alkaline Earth Metal
- Metal
- Metalloid
- Non-metal
- Halogen
- Noble Gas
- Lanthanide/Actinide

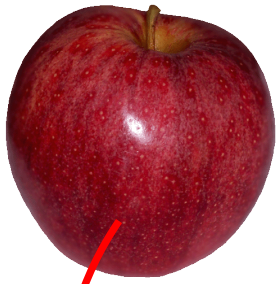
Z mass Symbol Name

man made



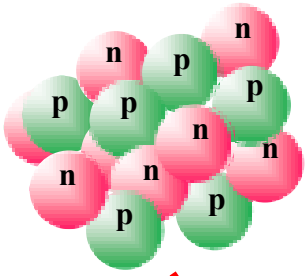
E.M. interaction

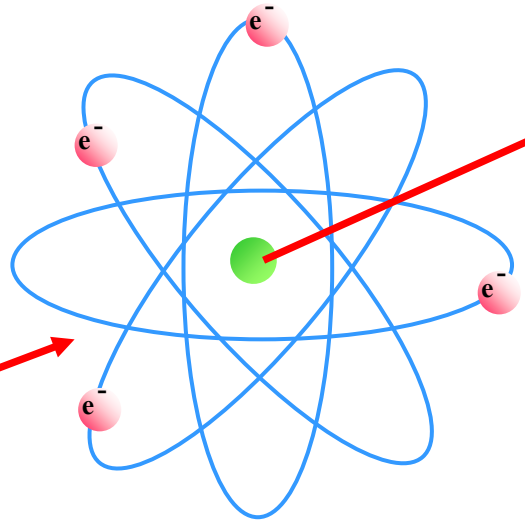
Z = # electrons



Matter

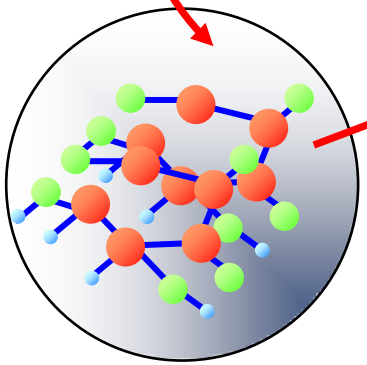
Nucleus



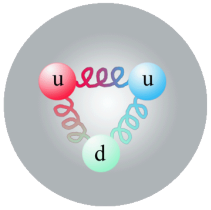


Electron

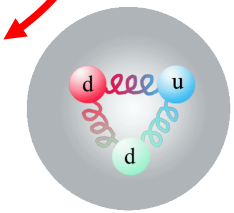
Atom



Molecules



Proton



Neutron

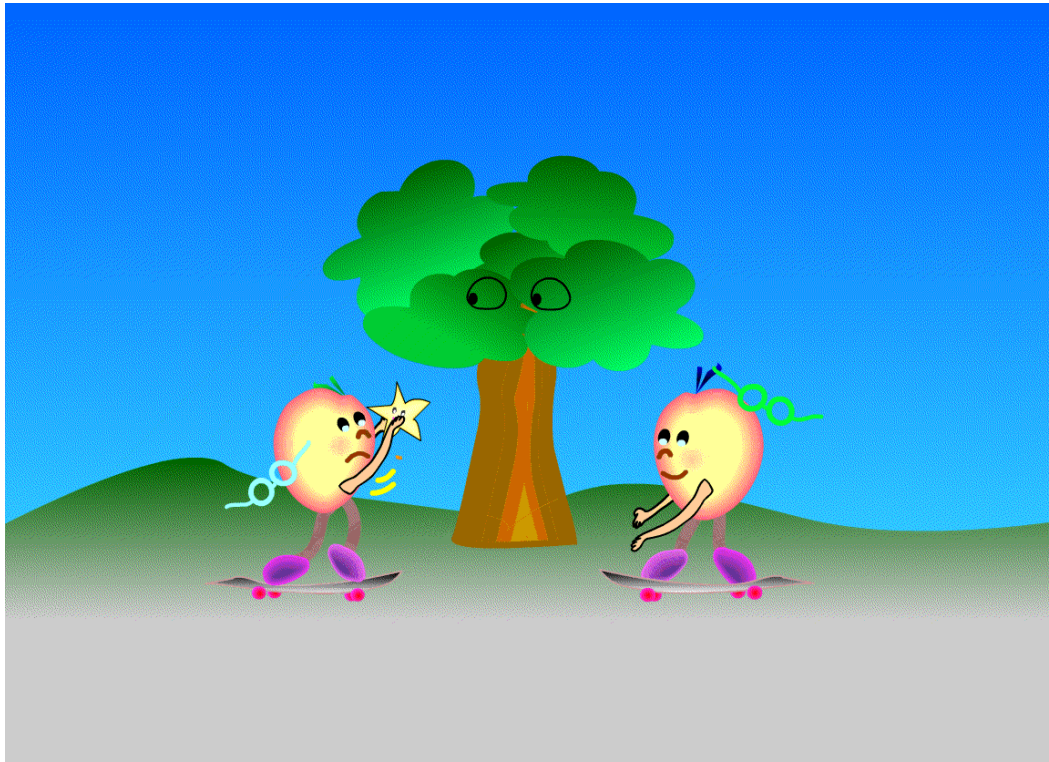
Quarks

$$Q_u = +\frac{2}{3} \quad , \quad Q_d = -\frac{1}{3}$$

Fundamental Interactions

Type	Intensity	Intermediate Particle	Physical System
Strong	≈ 1	Gluons (m = 0)	Atomic Nucleus
Electromagnetic	≈ 10^{-3}	Photon (m = 0)	Atom
Weak	≈ 10^{-5}	$W^{\pm}$, Z (M ≠ 0)	Radioactivity β
Gravitation	≈ 10^{-38}	Graviton ?	Massive Bodies

The exchange of particles generates the interaction



RADIOACTIVITY

$$^{14}_{6}C \to {}^{14}_{7}N + e^- + \bar{\nu}_e$$

(β decay)

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

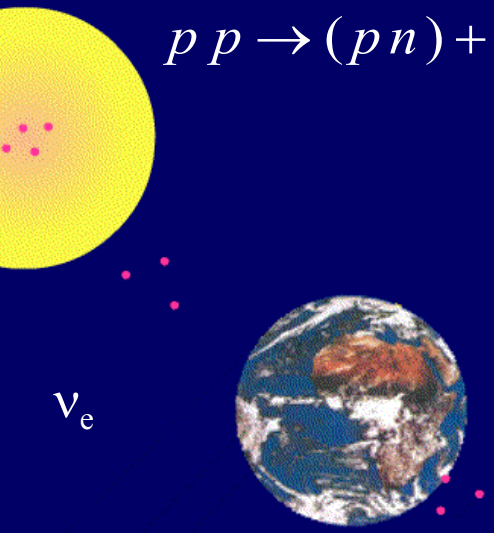
$$"\, p \to n + e^+ + \nu_e\,"$$

$$Q_{\nu_e} = Q_{\bar{\nu}_e} = 0$$

$$m_{\nu_e} = m_{\bar{\nu}_e} \approx 0$$

$\nu_e \equiv$ Neutrino ; $\bar{\nu}_e \equiv$ Anti-Neutrino

$$p\,p \to (p\,n) + e^+ + \nu_e$$



Weak Interaction

$$W^{\pm},\ Z^0$$

$$M_W \sim M_Z \approx 100\, m_p$$

NEUTRINOS

ν_e

- Interact very weakly
- Very abundant in the Universe
- Each second your body is crossed by

$\sim 10^{14}$ ν_e coming from the Sun

$$p\,p \to d\,e^+\,\nu_e \;,\; \ldots$$

NEUTRINOS

Each second your body is crossed by

$\sim 10^{14}$ ν_e coming from the Sun

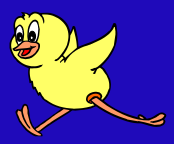
$$p\,p \rightarrow d\,e^{+}\nu_e \;,\; \ldots$$

They also come from below!

ν_e

Matter (Fermions , $J = \frac{1}{2}$)

Quarks

$Q = 2/3$	$Q = -1/3$
	
up (u)	down (d)

Leptons

$Q = 0$	$Q = -1$
	
neutrino e (ν_e)	electron (e)

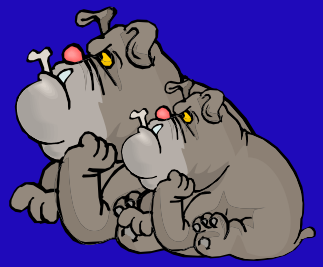
Forces

Bosons

$J = 1$

photon

gluons



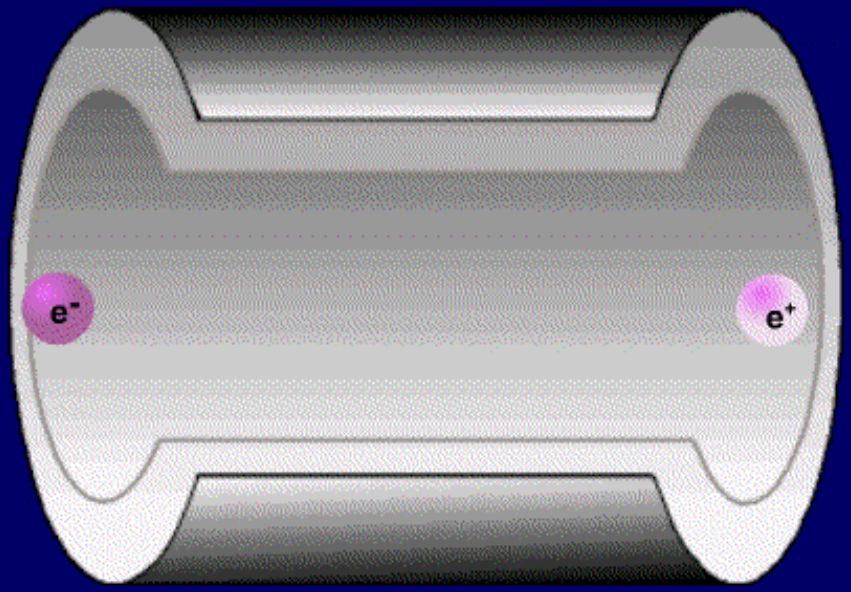
Z^0 $W^{\pm}$

Quantum Mechanics + Relativity → Antiparticles

(Dirac)

ANTIMATTER

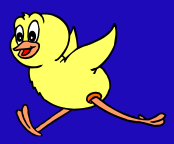
u	d	ν_e	e^-
$\bar{u}$	$\bar{d}$	$\bar{\nu}_e$	e^+



$$E = m\,c^2$$

Matter (Fermions , $J = \frac{1}{2}$)

Quarks

$Q = 2/3$	$Q = -1/3$
0.003  up (u)	0.005  down (d)
1.3  charm (c)	0.1  strange (s)
173  top (t)	4.2  beauty (b)

Leptons

$Q = 0$	$Q = -1$
< 0.000002  neutrino e (ν_e)	0.0005  electron (e)
< 0.000002  neutrino μ (ν_μ)	0.105  muon (μ)
< 0.000002  neutrino τ (ν_τ)	1.777  tau (τ)

Forces

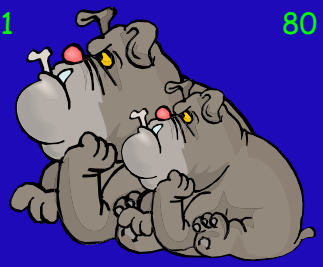
Bosons

0  $J = 1$

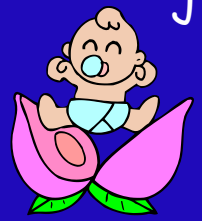
Photon

0 

gluons

91 80 

Z^0 $W^\pm$

125 $J = 0$ 

Higgs

STANDARD MODEL

Quantum Mechanics $(\hbar)$ + Special Relativity (c)

➡ **Quantum Field Theory**

- **Quantum Electrodynamics (QED)**

  Electricity + Magnetism + Light: γ

- **Quantum Chromodynamics (QCD)**

  Strong interaction: 8 Gluons

- **Electroweak Theory** $\mathbf{SU(2)_L \otimes U(1)_Y}$

  QED + Weak Interactión: $\gamma,\ Z,\ W^{\pm}$

Quantum Mechanics Wave Equations $(\hbar = c = 1)$

- **Non Relativistic:** **Schrödinger equation**

$$E = i\frac{\partial}{\partial t} \;\; ; \;\; \vec{p} = -i\vec{\nabla} \qquad E = \frac{\vec{p}^{\,2}}{2m} \;\Rightarrow\; \boxed{i\frac{\partial}{\partial t}\Psi = -\frac{\vec{\nabla}^2}{2m}\Psi}$$

- **Relativistic:** **Klein-Gordon equation**

$$p^\mu \equiv (E, \vec{p}) = i\partial^\mu = i g^{\mu\nu}\frac{\partial}{\partial x^\nu} \qquad E^2 = \vec{p}^{\,2} + m^2 \;\Rightarrow\; \boxed{(\Box + m^2)\,\phi = 0}$$

$$\Box \equiv \partial^\mu \partial_\mu = g^{\mu\nu}\partial_\mu\partial_\nu = \frac{\partial^2}{\partial t^2} - \vec{\nabla}^2$$

- **Spin $\frac{1}{2}$:** $\boxed{(i\gamma^\mu\partial_\mu - m)\,\psi = 0}$ **Dirac equation**

$$-(i\gamma^\nu\partial_\nu + m)\,[(i\gamma^\mu\partial_\mu - m)\,\psi] = 0 \;\equiv\; (\Box + m^2)\,\psi \;\Rightarrow\; \{\gamma^\mu, \gamma^\nu\} = 2g^{\mu\nu}$$

Spin matrices $(D = 4)$

Dirac Algebra

$$\gamma^\mu \gamma^\nu + \gamma^\nu \gamma^\mu = 2 g^{\mu\nu}$$

$$\gamma^0 = \begin{pmatrix} I_2 & 0 \\ 0 & -I_2 \end{pmatrix} \quad ; \quad \vec{\gamma} = \begin{pmatrix} 0 & \vec{\sigma} \\ -\vec{\sigma} & 0 \end{pmatrix}$$

$$\sigma^1 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \; ; \; \sigma^2 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix} \; ; \; \sigma^3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

$$\left\{\sigma^i, \sigma^j\right\} = 2\delta^{ij} \; ; \; \left[\sigma^i, \sigma^j\right] = 2i\varepsilon^{ijk}\sigma^k$$

$$\psi = \begin{pmatrix} \varphi \\ \chi \end{pmatrix}$$

Particle

Antiparticle

} **Spinors**

Chirality Projectors:

$$\gamma_5 \equiv i\gamma^0\gamma^1\gamma^2\gamma^3 = \begin{pmatrix} 0 & I_2 \\ I_2 & 0 \end{pmatrix} \quad ; \quad (\gamma_5)^2 = I_4$$

$$P_R \equiv \frac{1+\gamma_5}{2} \; ; \; P_L \equiv \frac{1-\gamma_5}{2}$$

$$P_R^2 = P_R \; ; \; P_L^2 = P_L \; ; \; P_R P_L = P_L P_R = 0$$

$$\psi = (P_R + P_L)\psi \equiv \psi_R + \psi_L$$

Chirality (~ helicity) components

Lagrangian Formalism

$$S = \int d^4x \;\; \mathcal{L}(\phi, \partial_\mu \phi)$$

$$\delta S = 0 \quad \Rightarrow \quad \frac{\partial \mathcal{L}}{\partial \phi} - \partial^\mu \left(\frac{\partial \mathcal{L}}{\partial (\partial^\mu \phi)} \right) = 0$$

Eq. Motion

Klein-Gordon: (spin 0)

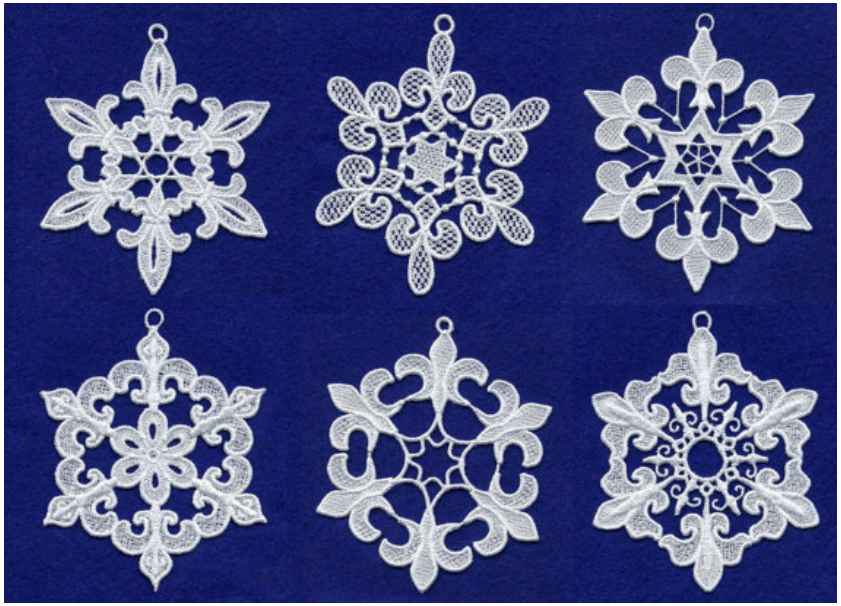
$$\mathcal{L} = \partial^\mu \phi^* \, \partial_\mu \phi - m^2 \, \phi^* \, \phi \quad \Rightarrow \quad (\Box + m^2)\, \phi = 0$$

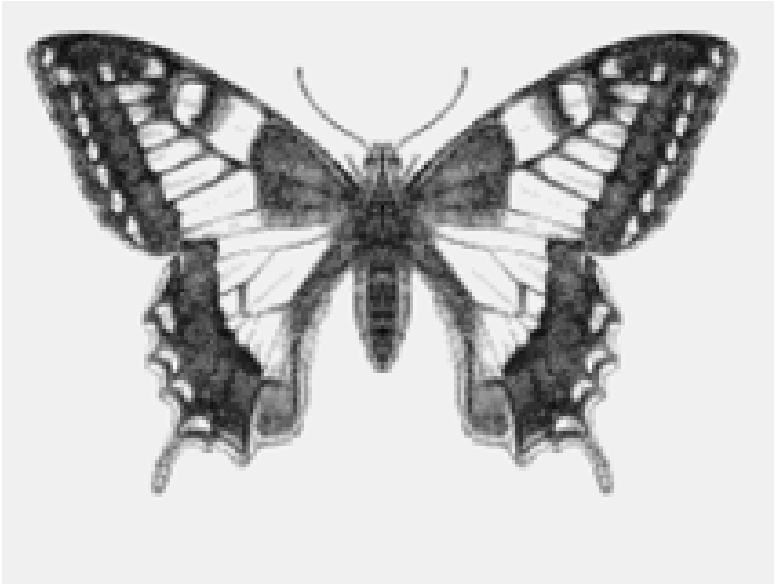
Dirac: (spin $\frac{1}{2}$)

$$\bar{\psi} \equiv \psi^\dagger \gamma^0$$

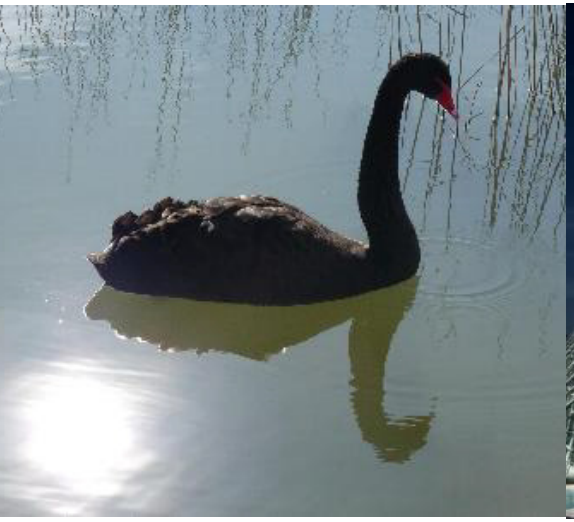
$$\mathcal{L} = \bar{\psi} \, (i \gamma^\mu \, \partial_\mu - m) \, \psi \quad \Rightarrow \quad (i \gamma^\mu \, \partial_\mu - m) \, \psi = 0$$

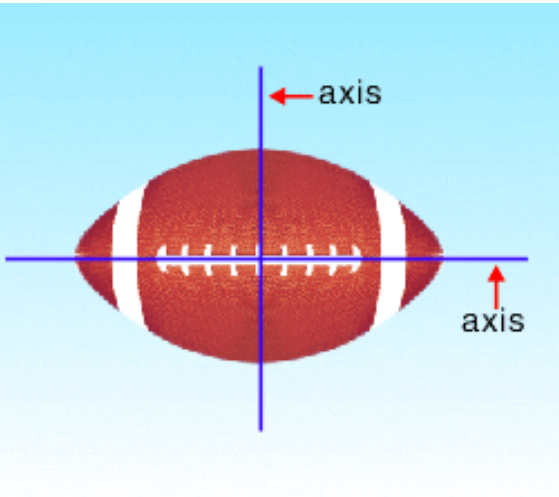
Fields create, annihilate and propagate (anti)particles





SYMMETRIES





Free Dirac Fermion: $\mathcal{L} = \bar{\psi}\,(i\,\gamma^\mu\,\partial_\mu - m)\,\psi$

Phase Invariance: $\psi \to \psi' = e^{iQ\theta}\,\psi \quad ; \quad \bar{\psi} \to \bar{\psi}' = e^{-iQ\theta}\,\bar{\psi}$

Absolute phases are not observable in Quantum Mechanics

GAUGE PRINCIPLE: $\theta = \theta(x)$

Phase Invariance should hold LOCALLY

BUT $\partial_\mu\psi \to e^{iQ\theta}\,(\partial_\mu + i\,Q\,\partial_\mu\theta)\,\psi$

SOLUTION: Covariant Derivative

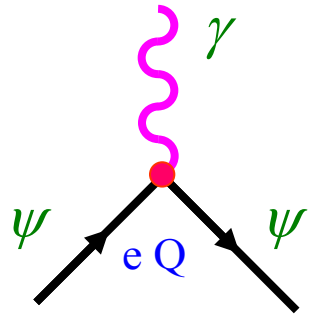
$$D_\mu\psi \equiv (\partial_\mu + i\,e\,Q\,A_\mu)\,\psi \to e^{iQ\theta}\,D_\mu\psi$$

One needs a spin-1 (gauge) field A_μ **satisfying** $A_\mu \to A_\mu - \frac{1}{e}\,\partial_\mu\theta$

Quantum Electrodynamics (QED)

$$\mathcal{L} = \bar{\psi}\,(i\,\gamma^\mu D_\mu - m)\,\psi$$

$$= \bar{\psi}\,(i\,\gamma^\mu \partial_\mu - m)\,\psi - e\,Q\,A_\mu\,(\bar{\psi}\,\gamma^\mu \psi)$$



Kinetic term: $F^{\mu\nu} \equiv \partial^\mu A^\nu - \partial^\nu A^\mu$

$$\mathcal{L}_K = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} \quad \Rightarrow \quad \partial_\mu F^{\mu\nu} = eQ\,(\bar{\psi}\,\gamma^\nu\,\psi) \equiv J^\nu$$

Maxwell

Mass term: [exp: $m_\gamma < 1 \times 10^{-18}$ eV]

$$\mathcal{L}_M = \frac{1}{2} m_\gamma^2\, A^\mu A_\mu$$

Not Gauge Invariant $\Rightarrow$ $m_\gamma = 0$

Gauge Symmetry $\Rightarrow$ **QED Dynamics**

GAUGE THEORIES

The symmetries determine the interactions

(locally in each space-time point)

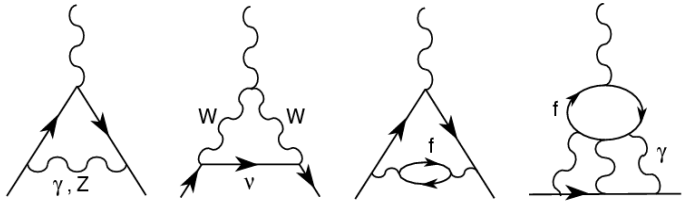
- **Electrodynamics:** 1 parameter $\alpha \equiv \frac{e^2}{4\pi}$ (interaction strength)

  Phase symmetry ➡ QED ➡ Maxwell Eqs.

Anomalous Magnetic Moment

$$\mu_l \equiv g_l \frac{e}{2\,m_l} \qquad a_l \equiv \frac{1}{2}\,(g_l - 2)$$

$$\alpha^{-1}_{\text{Rb2020}} = 137.035\,999\,206\,(11)$$



$$a_e^{\text{th}} = 0.001\,159\,652\,180\,252\ \ (95)$$

$$a_e^{\text{exp}} = 0.001\,159\,652\,180\,91\ \ (26)$$

- **Electroweak Theory:** 2 parameters α, θ_W
- **Quantum Chromodynamics:** 1 parameter α_s

Quantum Chromodynamics (QCD)

Free Quarks: $N_C = 3$ colours

$$\mathcal{L} = \bar{\mathbf{q}} \, [\, i \gamma^\mu \partial_\mu - m \,] \, \mathbf{q} \qquad \mathbf{q} \equiv \begin{pmatrix} q \\ q \\ q \end{pmatrix}$$

$SU(3)_C$ Colour Symmetry:

$$[\lambda^a, \lambda^b] = 2 i \, f^{abc} \, \lambda^c$$

$$\mathbf{q} \to \mathbf{U}\, \mathbf{q} = \exp\left\{ i \, \frac{\lambda^a}{2} \, \theta_a \right\} \mathbf{q}$$

Gauge Principle: **Local Symmetry** $\theta_a = \theta_a(x)$

$$\mathbf{D^\mu q} \equiv (\mathbf{I}_3 \, \partial^\mu + i \, g_s \, \mathbf{G}^\mu) \, \mathbf{q} \to \mathbf{U} \; \mathbf{D^\mu q}$$

$$\mathbf{D}^\mu \to \mathbf{U} \; \mathbf{D}^\mu \; \mathbf{U}^\dagger \qquad \mathbf{G}^\mu \to \mathbf{U} \, \mathbf{G}^\mu \, \mathbf{U}^\dagger + \frac{i}{g_s} (\partial^\mu \mathbf{U}) \; \mathbf{U}^\dagger$$

$$[\mathbf{G}^\mu]_{\alpha\beta} \equiv \frac{1}{2} \, (\lambda^a)_{\alpha\beta} \; G_a^\mu(x)$$

8 Gluon Fields

Kinetic Term:

$$\mathbf{G}^{\mu\nu} \equiv -\frac{i}{g_s}\,[\mathbf{D}^\mu, \mathbf{D}^\nu] = \partial^\mu \mathbf{G}^\nu - \partial^\nu \mathbf{G}^\mu + i\, g_s\,[\mathbf{G}^\mu, \mathbf{G}^\nu] \quad \to \quad \mathbf{U}\ \mathbf{G}^{\mu\nu}\ \mathbf{U}^\dagger$$

$$\mathbf{G}^{\mu\nu} \equiv \frac{\lambda^a}{2} G_a^{\mu\nu} \quad ; \quad G_a^{\mu\nu} = \partial^\mu G_a^\nu - \partial^\nu G_a^\mu - g_s\, f^{abc}\, G_b^\mu\, G_c^\nu$$

$$\mathcal{L}_K = -\frac{1}{2}\,\mathrm{Tr}\,(\mathbf{G}^{\mu\nu}\mathbf{G}_{\mu\nu}) = -\frac{1}{4}\,G_a^{\mu\nu}\,G^a_{\mu\nu}$$

Mass Term:

$$\mathcal{L}_M = \frac{1}{2}\,m_G^2\,G_a^\mu\,G^a_\mu$$

Not Gauge Invariant → $m_G = 0$

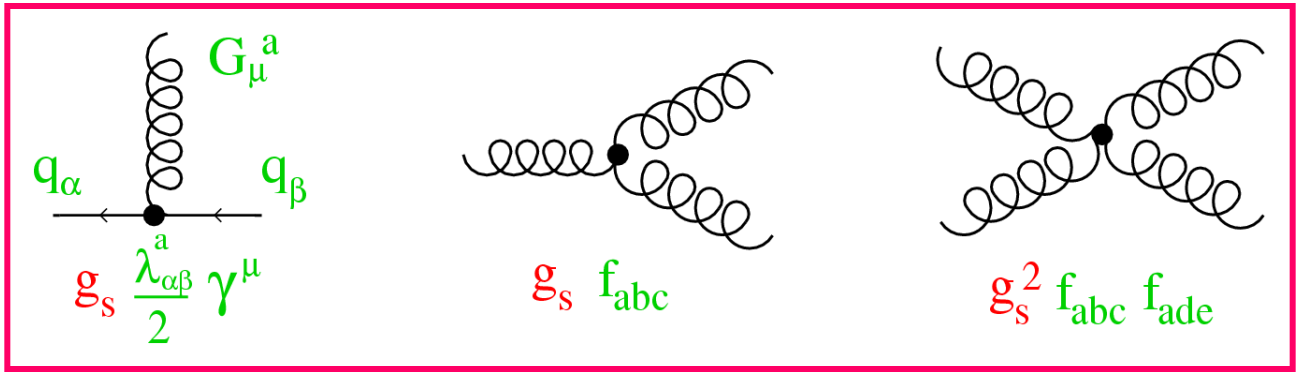
Massless Gluons

$$\mathcal{L}_{QCD} = -\frac{1}{2}\,\mathrm{Tr}\,(\mathbf{G}^{\mu\nu}\,\mathbf{G}_{\mu\nu}) + \bar{\mathbf{q}}\,[\,i\,\gamma^{\mu}\,\mathbf{D}_{\mu} - m_q\,]\,\mathbf{q}$$

$$= -\frac{1}{4}\left(\partial^{\mu}G_a^{\nu} - \partial^{\nu}G_a^{\mu}\right)\left(\partial_{\mu}G_{\nu}^{a} - \partial_{\nu}G_{\mu}^{a}\right) + \sum_q \bar{q}_{\alpha}\,[\,i\,\gamma^{\mu}\partial_{\mu} - m_q\,]\,q_{\alpha}$$

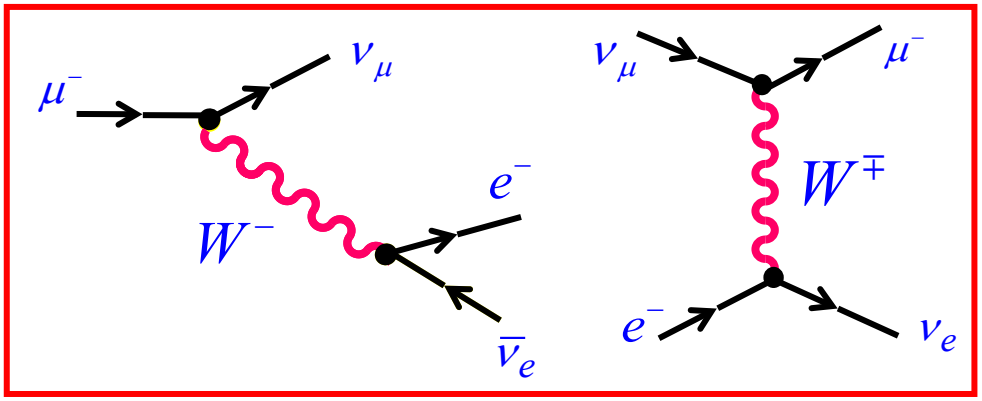
$$- \frac{1}{2}\sum_q g_s\,[\bar{q}_{\alpha}\,(\lambda^{a})_{\alpha\beta}\,\gamma^{\mu}q_{\beta}]\,G_{\mu}^{a}$$

$$+ \frac{1}{2}\,g_s\,f_{abc}\,(\partial_{\mu}G_{\nu}^{a} - \partial_{\nu}G_{\mu}^{a})\,G_b^{\mu}\,G_c^{\nu} - \frac{1}{4}\,g_s^2\,f_{abc}\,f_{ade}\,G_b^{\mu}\,G_c^{\nu}\,G_{\mu}^{d}\,G_{\nu}^{e}$$

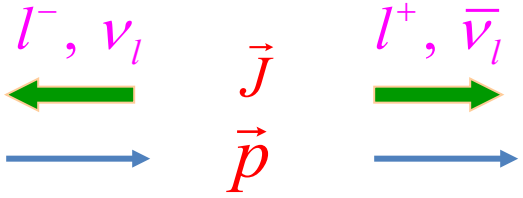


- **Gluon Self – interactions: G^3 , G^4**
- **Universal Coupling g_s** **(No Colour Charges)**

Experimental Facts on Weak Transitions



- **Left-handed leptons (Right-handed antileptons)**



- **Doublet partners:** $l_L^- \Leftrightarrow (\nu_l)_L \quad , \quad d_L \Leftrightarrow u_L$

$$\nu_\mu X \to \mu^- X' \quad ; \quad \nu_\mu X \not\to e^- X' \quad ; \quad d \to u\, e^- \bar{\nu}_e \quad ; \quad u \to d\, e^+ \nu_e$$

- **Three families:**

$$\begin{bmatrix} \nu_e & u \\ e^- & d' \end{bmatrix} \quad , \quad \begin{bmatrix} \nu_\mu & c \\ \mu^- & s' \end{bmatrix} \quad , \quad \begin{bmatrix} \nu_\tau & t \\ \tau^- & b' \end{bmatrix}$$

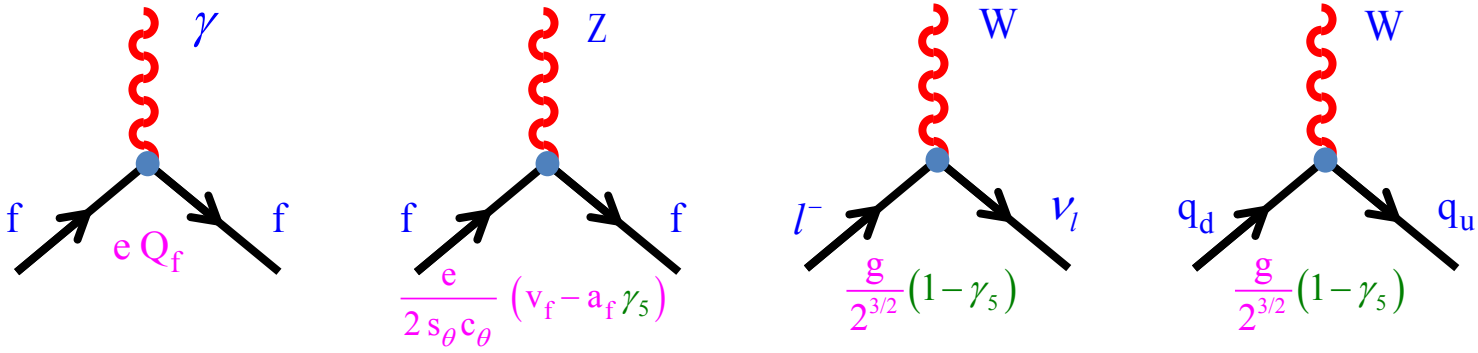
Family Structure

$$\begin{bmatrix} \nu_l & q_u \\ l^- & q_d \end{bmatrix} \equiv \left\{ \begin{pmatrix} \nu_l \\ l^- \end{pmatrix}_L , (\nu_l)_R , l_R^- \right\} \; ; \; \left\{ \begin{pmatrix} q_u \\ q_d \end{pmatrix}_L , (q_u)_R , (q_d)_R \right\}$$

$SU(2)_L \otimes U(1)_Y$ Electroweak Gauge Theory

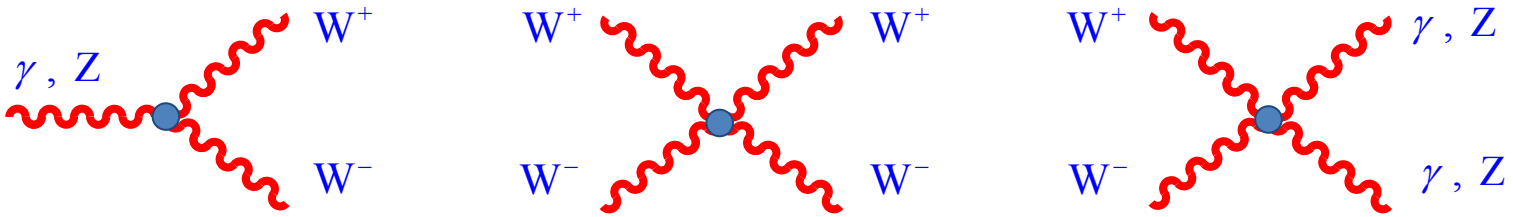
3 + 1 gauge bosons: $W^{\pm}$, Z , γ ; **2 gauge couplings:** g , g'

Fermion Interactions



$$g \sin\theta_W = g' \cos\theta_W = e \quad , \quad v_f = T_3^f = \pm\frac{1}{2} \quad , \quad a_f = T_3^f \left(1 - 4\,|Q_f|\,\sin^2\theta_W\right)$$

Gauge Self-Interactions



PROBLEM WITH MASSES

The same symmetry that determines the interactions requires all elementary particles to be massless

$$\mathcal{L}_{m_f} \equiv -m_f\, \bar{f}\, f = -m_f\, (\bar{f}_L\, f_R + \bar{f}_R\, f_L)$$ Not gauge invariant ➡ $m_f = 0$

$$m_\gamma = m_G = 0$$

$$M_W = 80.38\ \text{GeV}$$

$$M_Z = 91.19\ \text{GeV}$$

$$m_t = 173\ \text{GeV}$$

?

Mass is the only difference among the 3 families of quarks and leptons

PROBLEM WITH MASSES

- If $M_W = M_Z = 0$ the weak force would not be suppressed

  Stars (Sun) would consume much faster their nuclear fuel

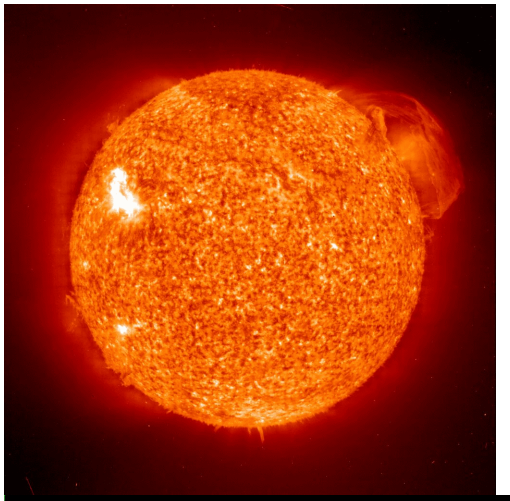
  The Universe would be different

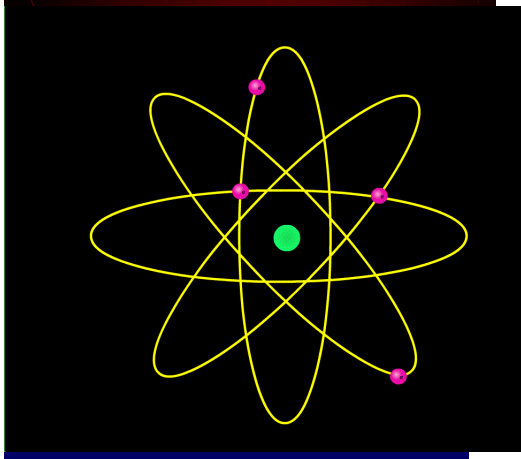
- Massless electrons would travel at the speed of light

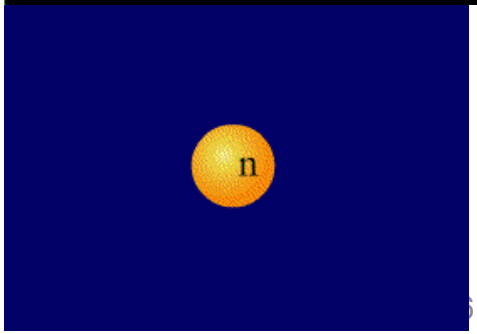
  Atoms would not exist

- If $m_u > m_d$ protons would decay

  Many atomic nuclei would not be stable



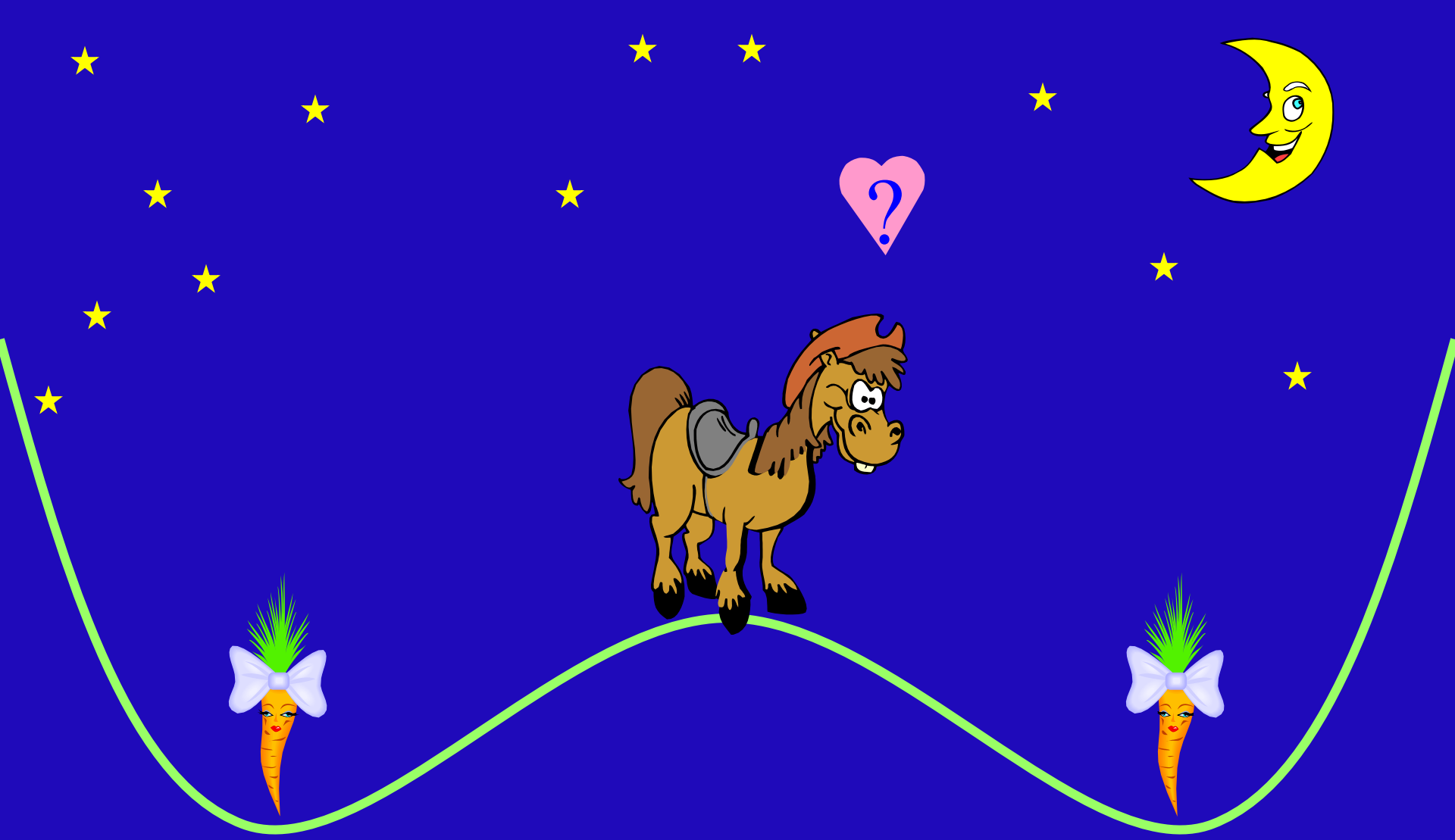


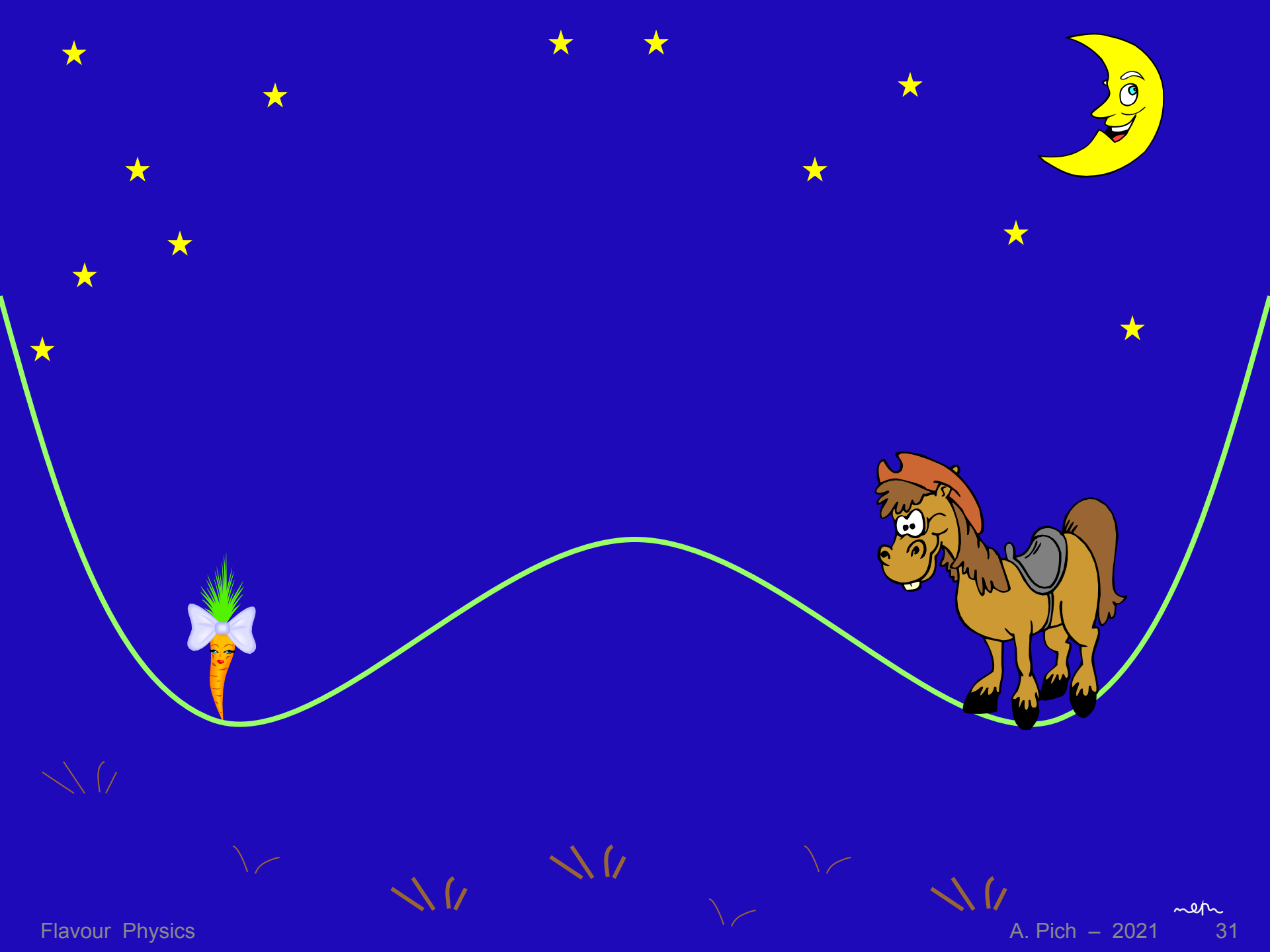


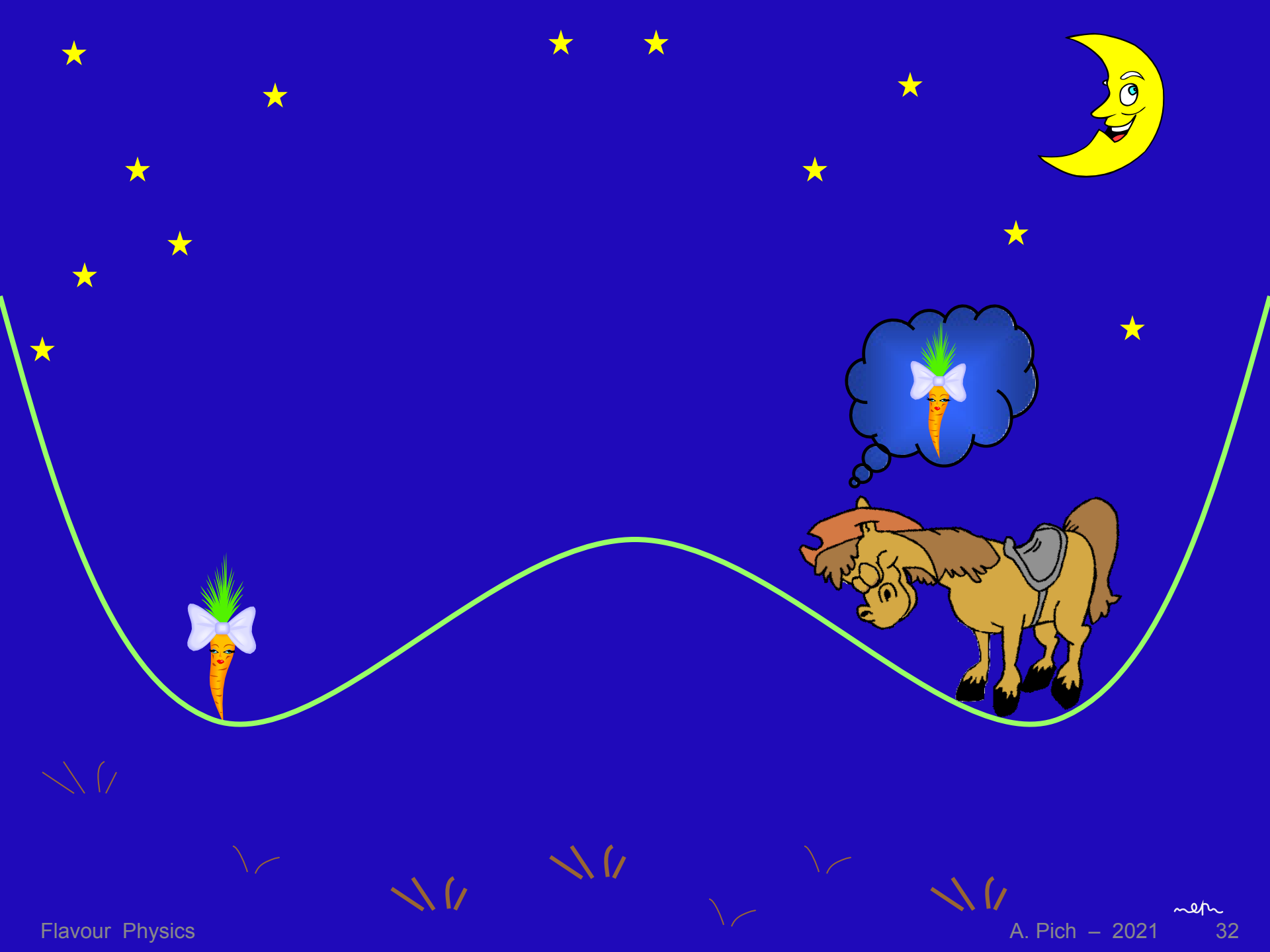
Masses cannot be added by hand: the quantum theory becomes ill-defined when gauge symmetry is broken

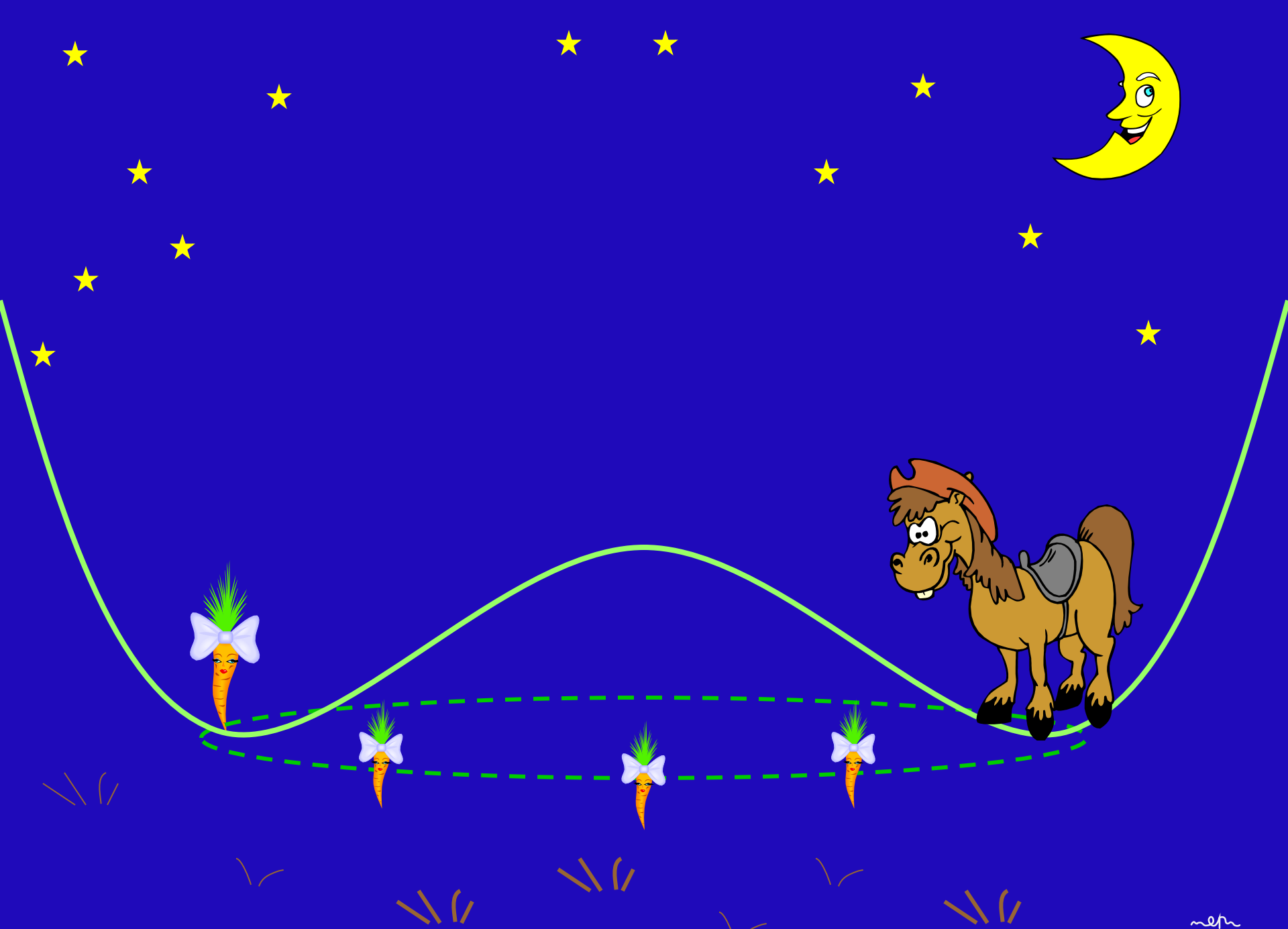
Spontaneous Symmetry Breaking

Spontaneous Symmetry Breaking





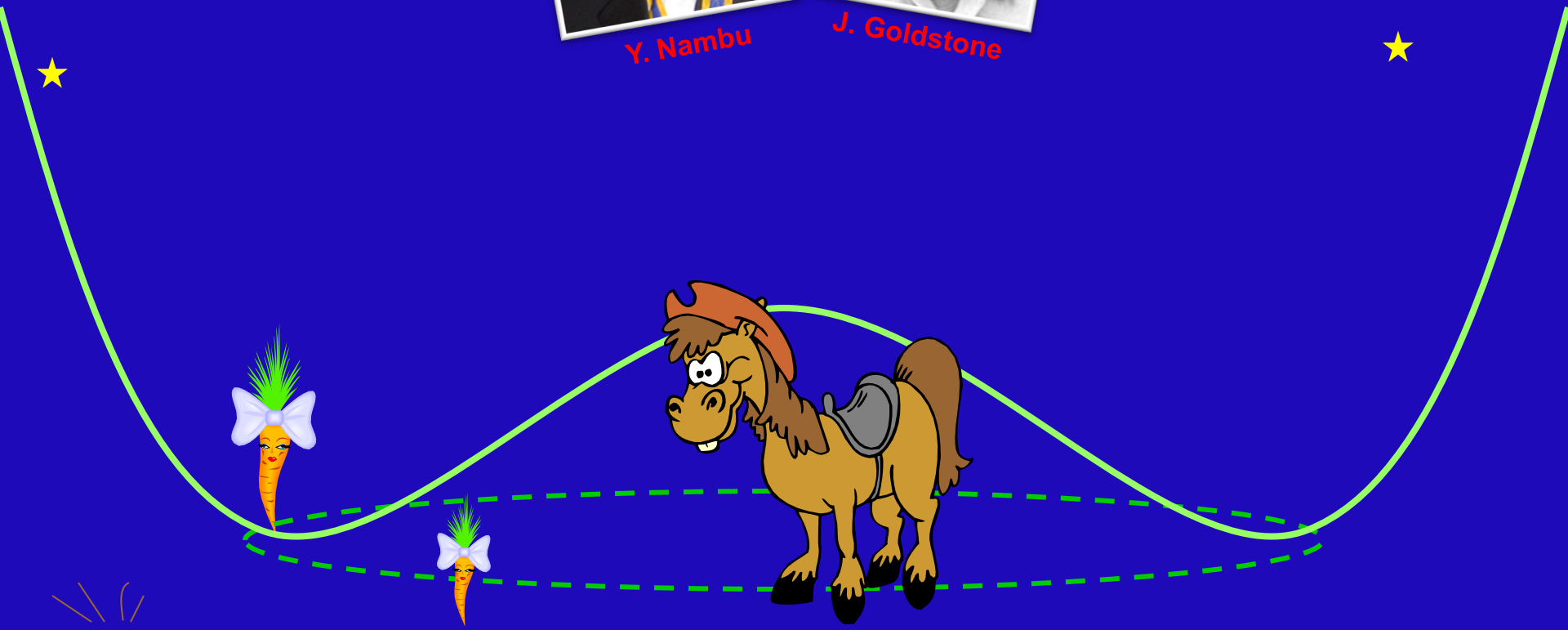




Nobel Prize 2008

Y. Nambu

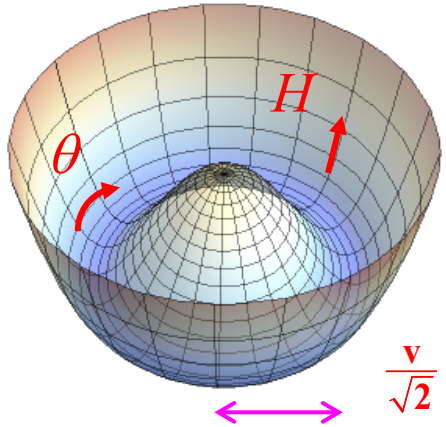
J. Goldstone



Higgs Mechanism

$$V(\phi) = -\mu^2 \phi^\dagger \phi + \lambda \left(\phi^\dagger \phi\right)^2 \quad , \quad \mathrm{v} \equiv \sqrt{\mu^2/\lambda}$$

Nobel Prize 2013



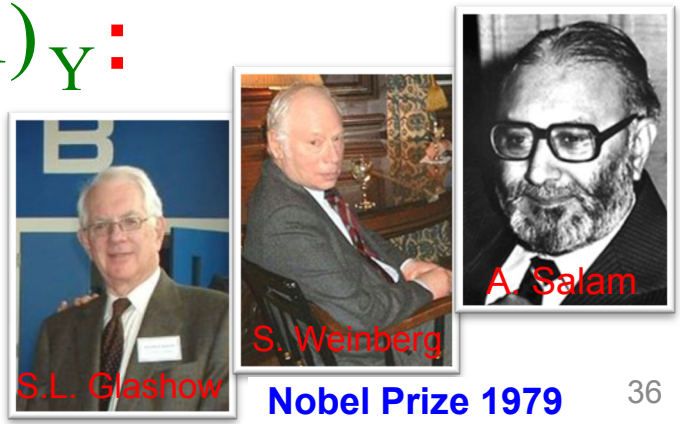
- **Scalar field (without spin) coupled to the gauge field**
- **θ(x) + Gauge Field = Massive Gauge Field**
- **H(x) = Higgs Field**

$$\phi(x) = \frac{1}{\sqrt{2}} e^{i\theta(x)} \left[\mathrm{v} + \mathrm{H}(x)\right]$$

Standard Theory $SU(2)_L \otimes U(1)_Y$:

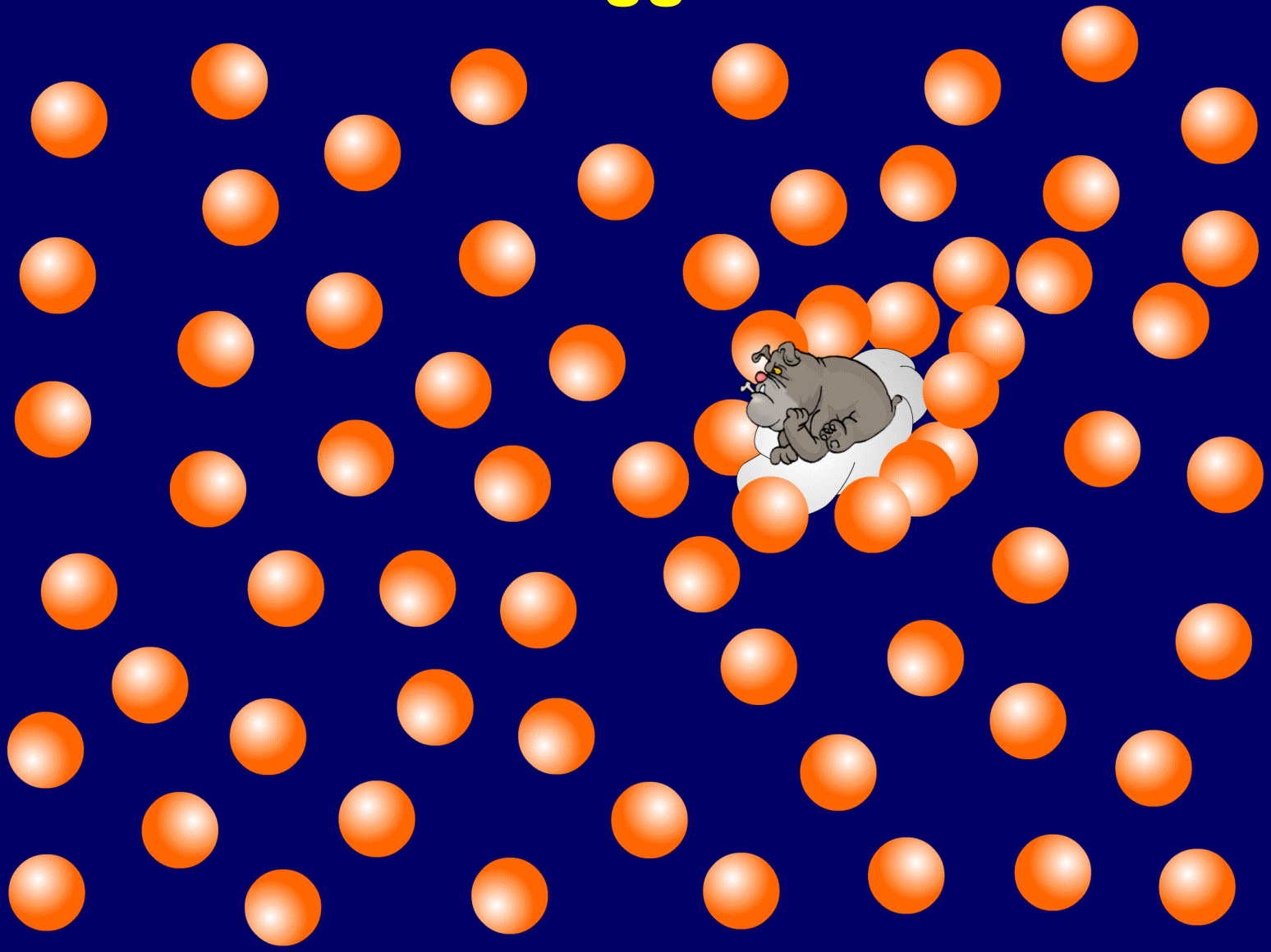
$$M_Z \cos\theta_W = M_W = \frac{1}{2} \mathrm{v}\, g$$

v = 246 GeV



Nobel Prize 1979

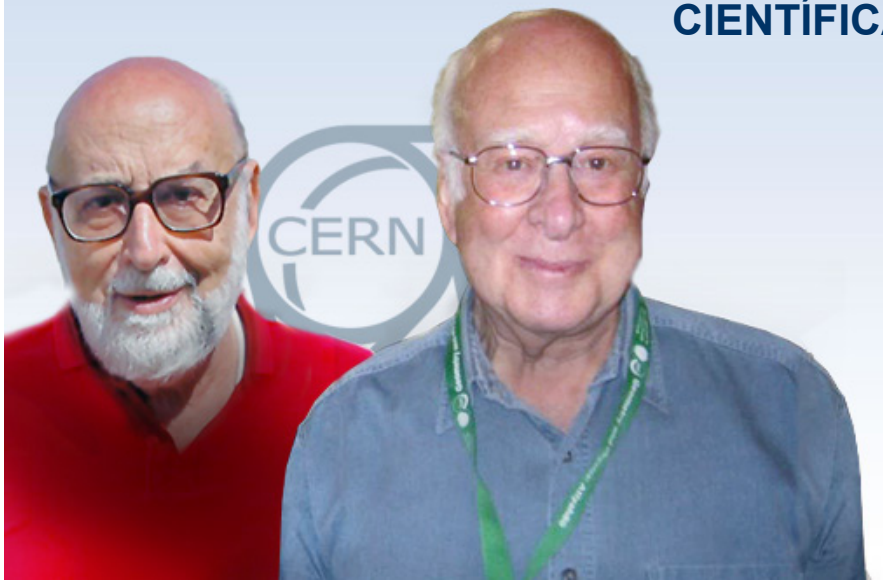
Masses generated through the interaction with the Higgs field



The discovery of the Higgs Boson

PREMIO PRÍNCIPE DE ASTURIAS DE INVESTIGACIÓN CIENTÍFICA Y TÉCNICA 2013

Fundación Príncipe de Asturias



The Nobel Prize in Physics 2013: François Englert, Peter 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"

A Higgs field indeed

Interaction proportional to mass