

Roxana Zus

Facultatea de Fizică

Universitatea din București



Fizica particulelor pentru elevii de liceu

„CERN Romanian Teacher Programme 2024 “

11 iunie 2024

Platforma București-Măgurele

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Parcul Institutului de Fizică

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Stăție electrică

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- cel mai important centru pentru cercetări științifice și tehnologice din țară -

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➤ Institutul Național de Cercetare-Dezvoltare pentru Fizica Materialelor

➤ Institutul Național de Cercetare-Dezvoltare pentru Fizica Laserilor, Plasmei și Radiației

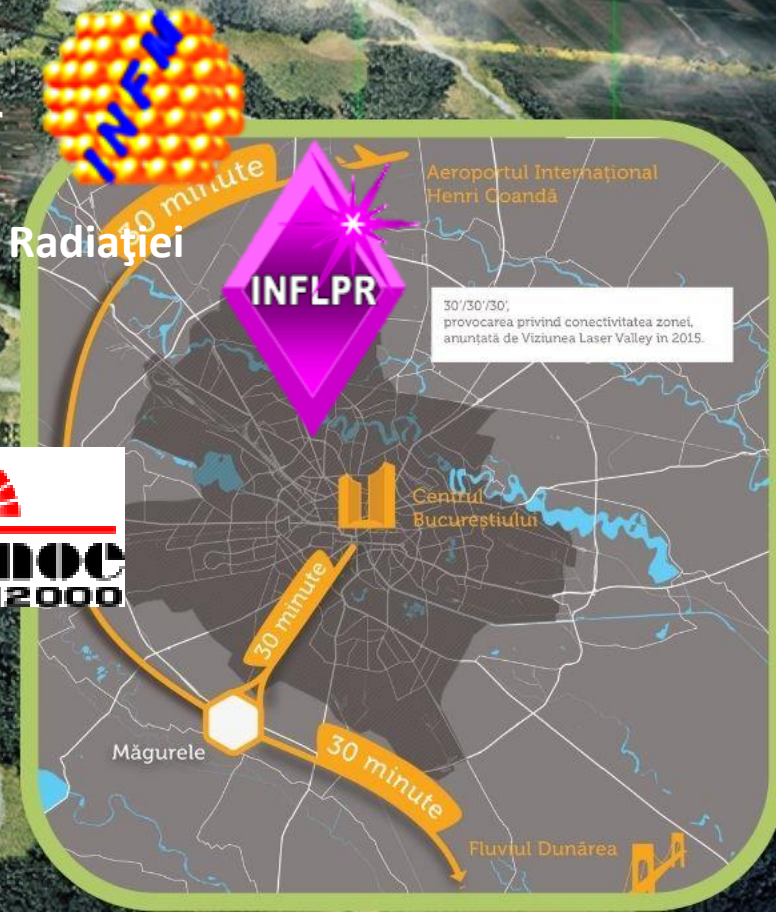
➤ Institutul de Științe Spațiale



➤ Institutul Național de Cercetare-Dezvoltare pentru Optoelectronică



➤ Institutul Național pentru Fizica Pământului





UNIVERSITATEA DIN BUCUREȘTI FACULTATEA DE FIZICĂ



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Facultatea de Fizică

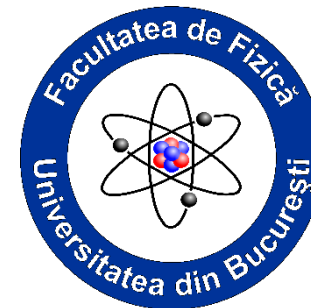
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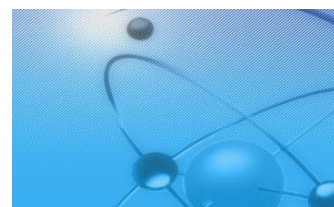
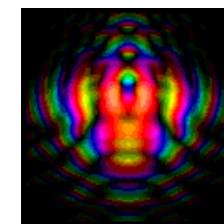
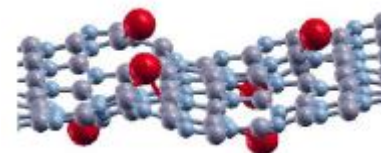
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Fax: +40 (0)21 457 4521, +40 (0)21 457 4418



Structura:

- ◆ Departamentul de Electricitate, Fizica Solidului și Biofizică;
- ◆ Departamentul de Fizică Teoretică, Matematici, Optică, Plasmă, Laseri;
- ◆ Departamentul de Structura Materiei, Fizica Atmosferei și a Pământului, Astrofizică;
- ◆ Scoala Doctorală de Fizică;



Centre de Cercetare:

- ◆ Biofizică Moleculară;
- ◆ Fizică Atomică și Astrofizică;
- ◆ Fizică Cuantică Avansată;
- ◆ Fizică Teoretică;
- ◆ Fonică, Spectroscopie, Plasmă, Laseri;
- ◆ Materia Nucleară în condiții extreme;
- ◆ Materiale și Dispozitive Electronice și Optoelectronice;
- ◆ Materiale Polimere, Mezofaze și Metode Neconvenționale de Protecție a Mediului
- ◆ Nanoștiințe, Surse Alternative de Energie

Programe de studiu

Licență

- Fizică (în limba română)
- Physics (în limba engleză)
- Fizică informatică
- Fizică medicală
- Fizică tehnologică
- Robotică

<https://fizica.unibuc.ro/Fizica/Studii/Licenta/>

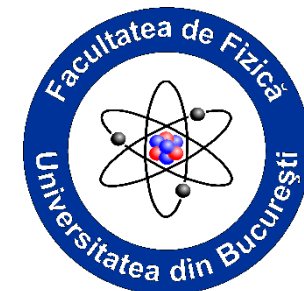
Master

- Theoretical and computational physics (în limba engleză)
- Physics of advanced materials and nanostructures (în limba engleză)
- Fizica atomului, nucleului, particulelor elementare, astrofizică și aplicații
- Fizica mediului și a polimerilor ecologici
- Optică, laseri și aplicații
- Fizică medicală
- Surse de energie regenerabile și alternative



Doctorat

- Fizică teoretică și computațională
- Fizică atomică, Fizică nucleară, Fizica particulelor elementare, Astrofizică și aplicații
- Biofizică și fizică medicală
- Fizica stării condensate
- Fizică educațională
- Optică, spectroscopie, plasmă și laseri
- Fizica atmosferei și a pământului; surse regenerabile de energie





<https://www.ifa-mg.ro/cern/programul-cern-ro.php>

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Descoperă Universul cu Romania@CERN

CERN Romanian Teacher Programme 2024

9-15 iunie 2024

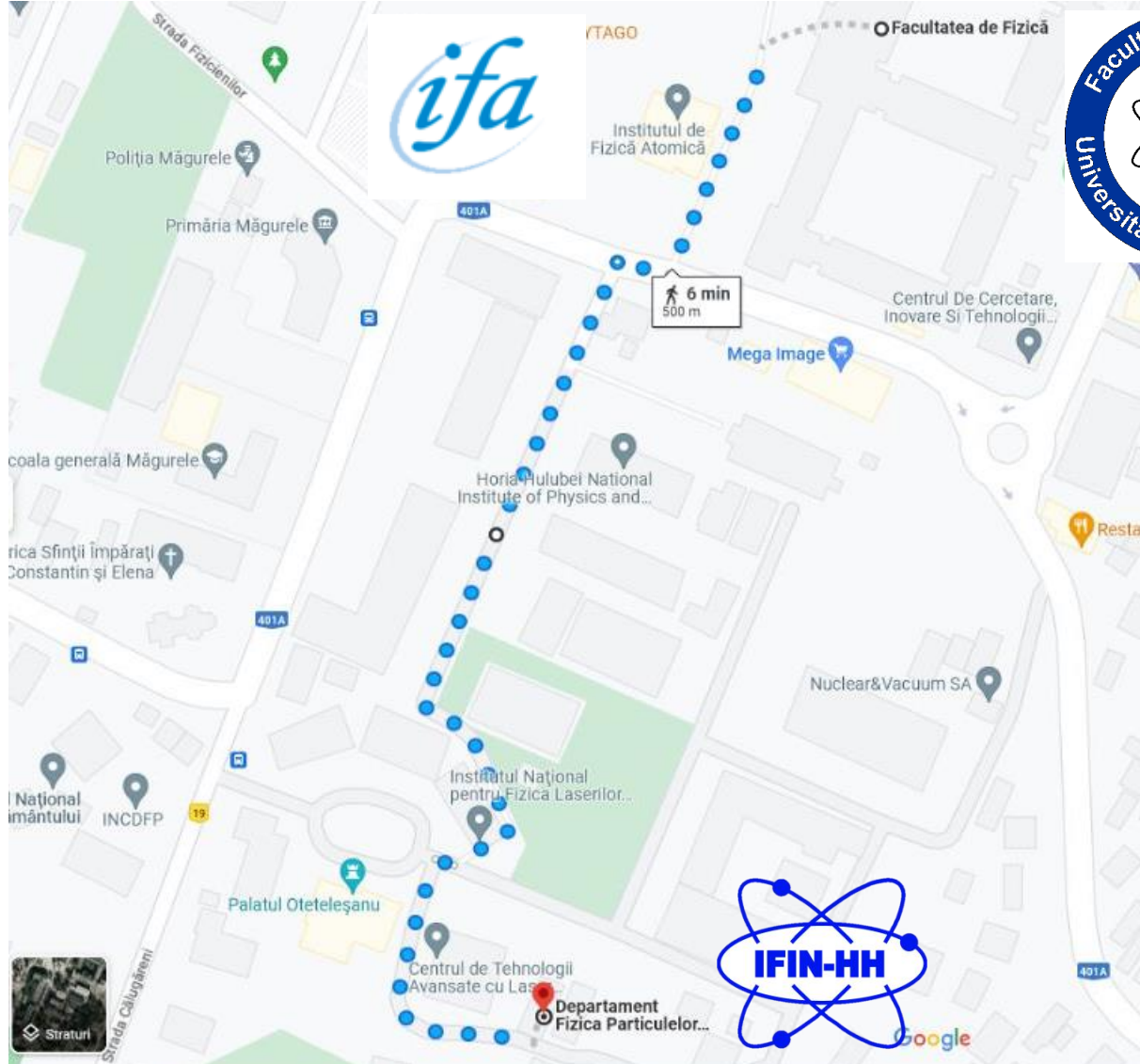
Facultatea de Fizică, Universitatea din București

Institutul Național de Cercetare-Dezvoltare
pentru Fizică și Inginerie Nucleară - Horia
Hulubei (IFIN-HH)

- Echipa din România:**

Călin ALEXA (calin.alex@cern.ch), *IFIN-HH*
Roxana ZUS (roxana.zus@g.unibuc.ro), *FF-UB*
Alexandra TUDORACHE, *IFIN-HH*
Valentina TUDORACHE, *IFIN-HH*
Ioana DUMINICĂ, *FF-UB & IFIN-HH*
Marina ROTARU, *IFIN-HH*
Mădălina BOCA, *FF-UB*
Raluca Sibinescu, *UB*
Andreea Cârstea, *UB*
Cristina Melinte, *IFA*

edu@fizica.unibuc.ro

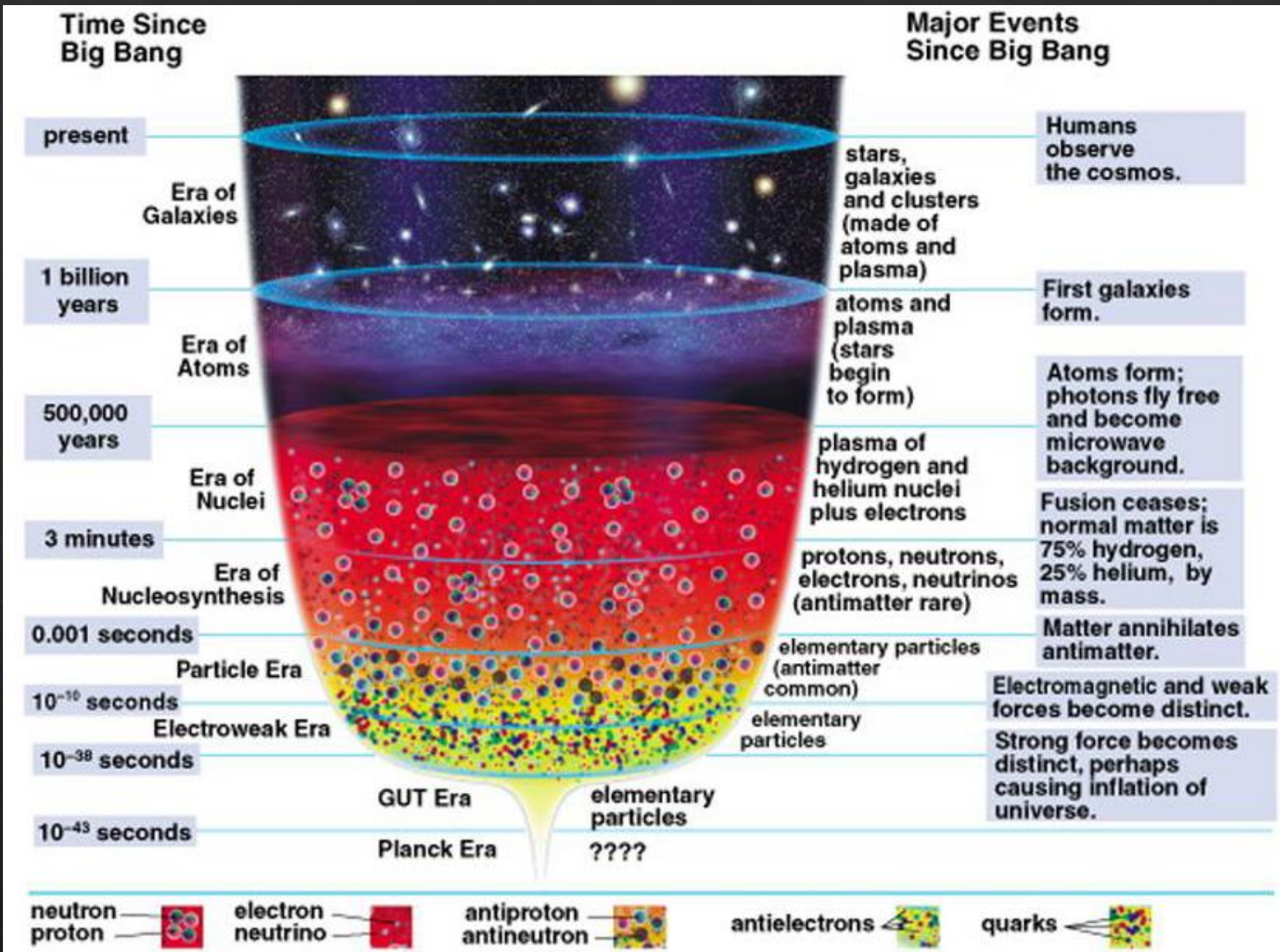


Fizica particulelor pentru elevii de liceu

Introducere

Întrebări pentru elevi

- ? Din ce este constituită materia?
- ? Din ce este compus universul?
- ? Care este originea universului și cum a evoluat?
- ? De ce se comportă așa universul?
- ? Cum va evolua?
- ?



neutron — [diagram] electron — [diagram] antiproton — [diagram] antielectrons — [diagram] quarks — [diagram]
 proton — [diagram] neutrino — [diagram] antineutron — [diagram]

Care sunt elementele din care este constituita materia?



(c) Andy Brice 1998

Empedocles 492-432 BC

By convention there is color,
by convention sweetness,
by convention bitterness,
but in reality there are
atoms and space.

Democritus 400 BC

Periodic Table of the Elements

IA																										0
1																2										
H																He										
3	4											5	6	7	8	9	10									
Li	Be											B	C	N	O	F	Ne									
11	12											13	14	15	16	17	18									
Na	Mg											Al	Si	P	S	Cl	Ar									
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36									
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr									
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54									
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe									
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86									
Cs	Ba	*La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn									
87	88	89	104	105	106	107	108	109	110	111	112	113														
Fr	Ra	+Ac	Rf	Ha	Sg	Ns	Hs	Mt	110	111	112	113														

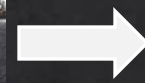
* Lanthanide Series	58	59	60	61	62	63	64	65	66	67	68	69	70	71
	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
* Actinide Series	90	91	92	93	94	95	96	97	98	99	100	101	102	103
	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Mendeleev, 1869

Scurt istoric

- sfârșitul secolului XIX:
 - mecanică clasică;
 - electromagnetism;
 - termodinamică.

Electricitate și magnetism



electromagnetism

m

**ecuațiile
MAXWELL**

$$\operatorname{div} \vec{E} = \frac{\rho}{\epsilon_0}$$

$$\operatorname{rot} \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\operatorname{div} \vec{B} = 0$$

$$\operatorname{rot} \vec{B} = \frac{\vec{j}}{\epsilon_0 c^2} + \frac{1}{c^2} \frac{\partial \vec{E}}{\partial t}$$



Scurt istoric

- sfârșitul secolului XIX:
 - mecanică clasică;
 - electromagnetism;
 - termodinamică.
- începutul secolului XX:
 - **domeniul relativist** (mecanica Newtoniană nu poate fi folosită la viteze foarte mari)
 - **domeniul microscopic** (fizica clasică nu poate fi folosită la nivel microscopic – e.g. pentru descrierea atomilor și moleculelor, a interacției cu câmpul electromagnetic etc.)

Ce legi folosim?

Ce mecanică folosim?

Legea atracției universale

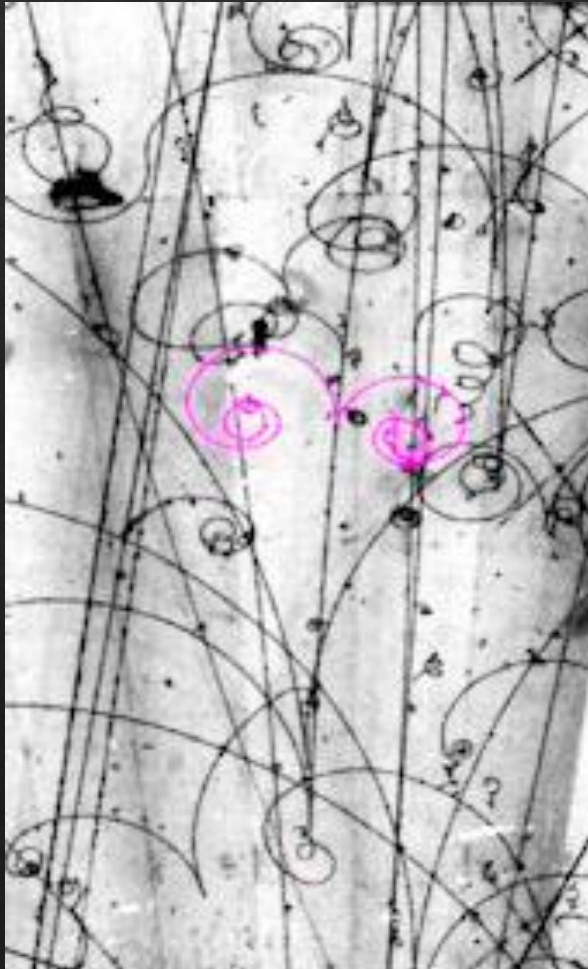


**Legile de mișcare ale lui
Newton – mecanica clasică**



Dirac – particulă - antiparticulă

sarcină electrică
de semn opus



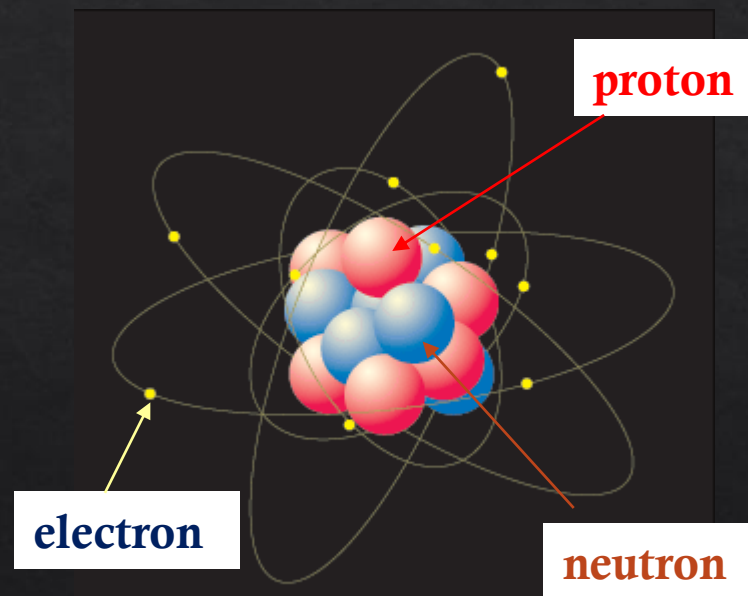
- Pereche electron-positron creată din fotoni într-o cameră cu bule.
- Energia fotonului este transformată în
• materie și anti-materie.
- Energia și impulsul se conservă (dar nu și masa de repaus)

Resurse: <https://home.cern/science/physics/antimatter>

Atomii

Atomii:

- **protoni** și **neutroni** în nucleu
- **electroni**



Sunt **protonii** și **neutronii** particule elementare?

Fizica particulelor elementare

1. Care sunt particulele elementare (ce proprietăți au – masă, sarcină electrică, spin, ...)?
2. Cum interacționează?
3. Cum producem particule elementare?
4. Cum detectăm particule elementare?

Yukawa – 1934

- Ce ține **protonii** și **neutronii** în nucleul?

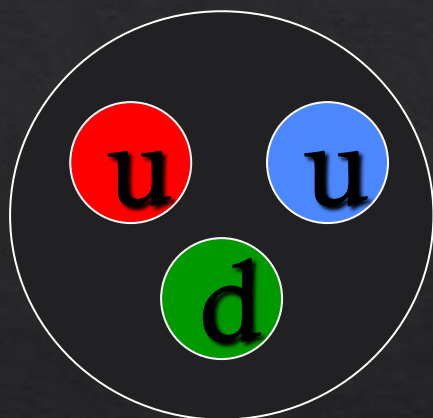
INTERACȚIA TARE

- De ce nu o experimentăm în viața de zi cu zi?

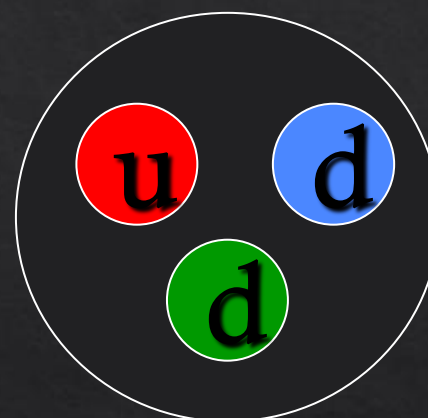
acționează la distanțe scurte

Protonii și neutronii – modelul cuarcilor (1964)

proton (sarcină +1)



neutron (sarcină 0)



Cuarcii au sarcini electrice fracționare

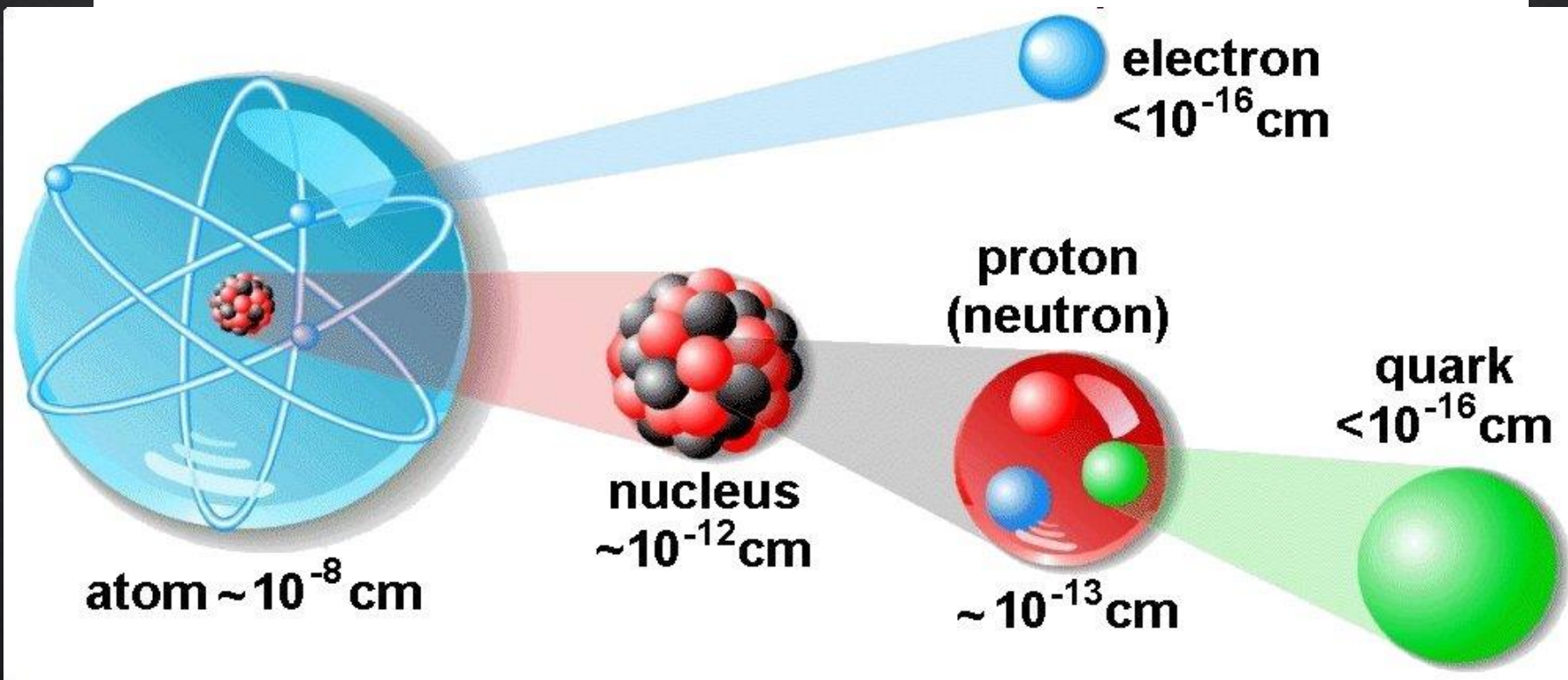
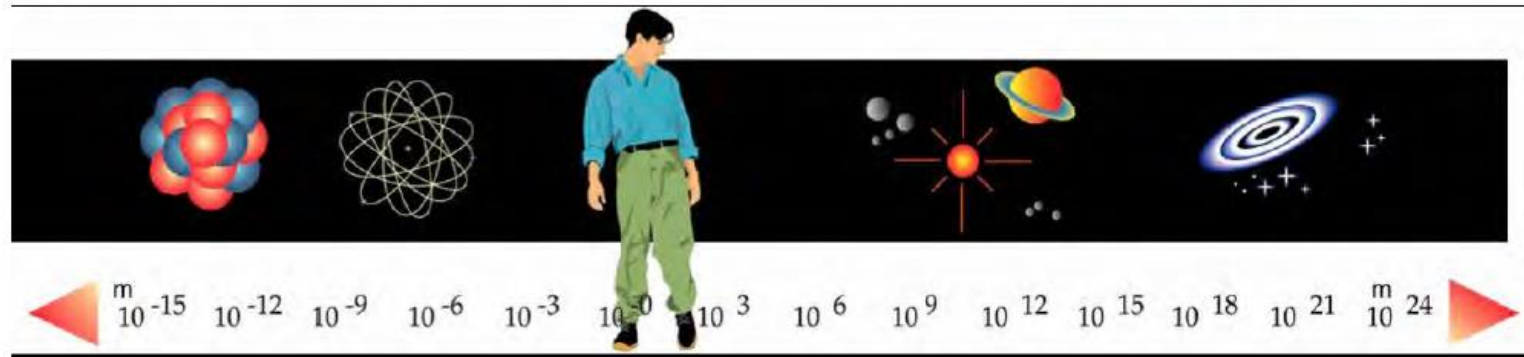
u - cuarcul up – sarcină electrică + 2/3

d - cuarcul down – sarcină electrică -1/3

$$u\left(+\frac{2}{3}\right)u\left(+\frac{2}{3}\right)d\left(-\frac{1}{3}\right) = p(+1)$$

$$u\left(+\frac{2}{3}\right)d\left(-\frac{1}{3}\right)d\left(-\frac{1}{3}\right) = n(0)$$

Structura materiei (astăzi!)

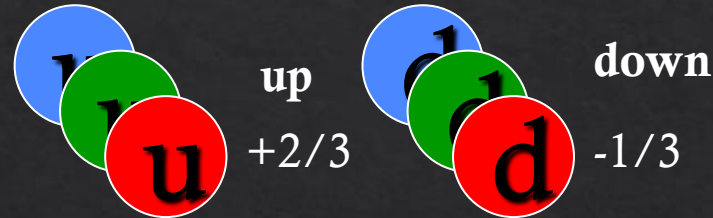




Cuarzii și culorile

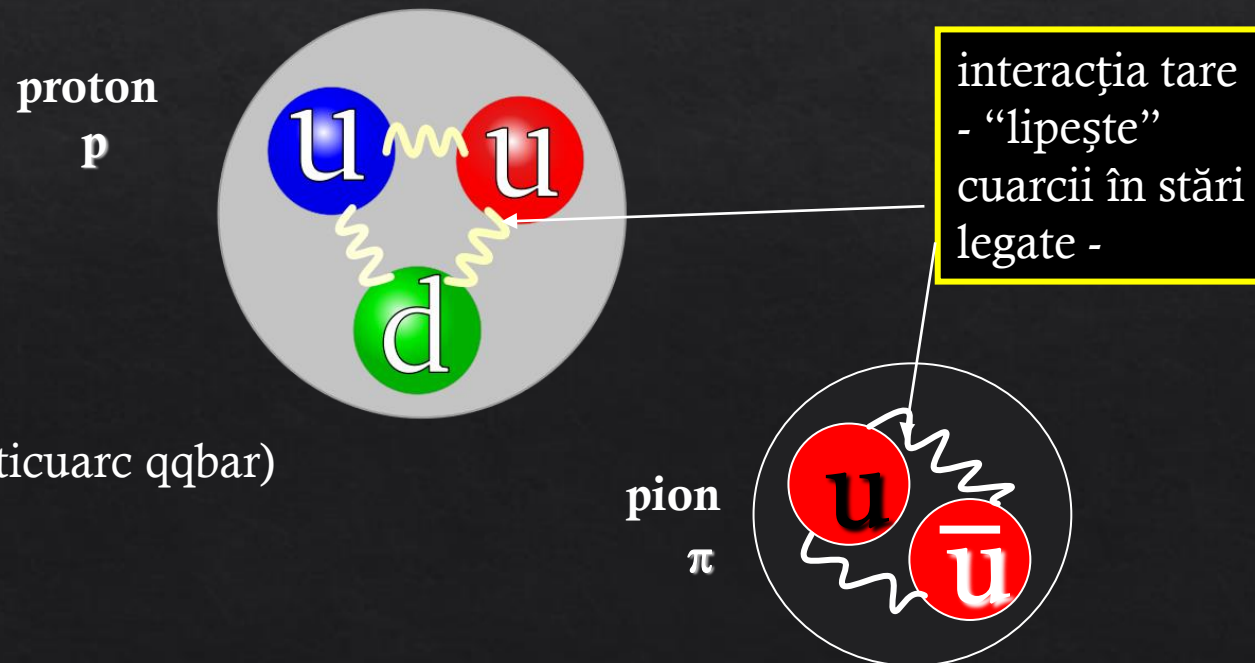
QCD – Quantum
chromodynamics

Fiecare cuarc poate avea 3 “culori”



Cuarzii se combină în așa fel încât să formeze particule „incolore” (confinare).

-Barioni (3 cuarci qqq: roșu + verde + albastru = alb)



-Mezoni (cuarc-anticuarc qqbar)

PDG – Particle Data Group

STRANGE MESONS		CHARMED MESONS		$c\bar{c}$ MESONS		LIGHT BARYONS		BOTTOM BARYONS	
K_L^0	130	D^+	411	$\eta_c(1S)$	441	p	2212	Λ_b^0	5122
K_S^0	310	D^0	421	$\chi_{c0}(1P)$	10441	n	2112	Σ_b^-	5112
K^0	311	$D_0^*(2400)^+$	10411	$\eta_c(2S)$	100441	Δ^{++}	2224	Σ_b^0	5212
K^+	321	$D_0^*(2400)^0$	10421	$J/\psi(1S)$	443	Δ^+	2214	Σ_b^+	5222
$K_0^*(800)^0$	9000311*	$D^*(2010)^+$	413	$h_c(1P)$	10443	Δ^0	2114	Σ_b^{*-}	5114
$K_0^*(800)^+$	9000321*	$D^*(2007)^0$	423	$\chi_{c1}(1P)$	20443	Δ^-	1114	Σ_b^{*0}	5214
$K_0^*(1430)^0$	10311	$D_1(2420)^+$	10413	$\psi(2S)$	100443	STRANGE BARYONS			
$K_0^*(1430)^+$	10321	$D_1(2420)^0$	10423	$\psi(3770)$	30443	Λ	3122	Σ_b^{*+}	5224
$K(1460)^0$	100311	$D_1(H)^+$	20413	$\psi(4040)$	9000443	Σ^+	3222	Ξ_b^-	5132
$K(1460)^+$	100321	$D_1(2430)^0$	20423	$\psi(4160)$	9010443	Σ^0	3212	Ξ_b^0	5232
$K(1830)^0$	9010311*	$D_2^*(2460)^+$	415	$\psi(4415)$	9020443	Σ^-	3112	$\Xi_b^{\prime-}$	5312
$K(1830)^+$	9010321*	$D_2^*(2460)^0$	425	$\chi_{c2}(1P)$	445	Σ^{*+}	3224 ^d	$\Xi_b^{\prime0}$	5322
$K_0^*(1950)^0$	9020311*	D_s^+	431	$\chi_{c2}(2P)$	100445*	Σ^{*0}	3214 ^d	Ξ_b^{*-}	5314
$K_0^*(1950)^+$	9020321*	$D_{s0}^*(2317)^+$	10431	$b\bar{b}$ MESONS				Ξ^0	3322
$K^*(892)^0$	313	D_s^{*+}	433	$\eta_b(1S)$	551	Ξ^-	3312	Ξ_b^{*0}	5324
$K^*(892)^+$	323	$D_{s1}(2536)^+$	10433	$\chi_{b0}(1P)$	10551	Ξ^{*0}	3324 ^d	Ω_b^-	5332
$K_1(1270)^0$	10313	$D_{s1}(2460)^+$	20433	$\eta_b(2S)$	100551	Ξ^{*-}	3314 ^d	Ω_b^{*-}	5334
$K_1(1270)^+$	10323	$D_{s2}^*(2573)^+$	435	$\chi_{b0}(2P)$	110551	Ω^-	3334	Ξ_{bc}^0	5142
$K_1(1400)^0$	20313	BOTTOM MESONS		$\eta_b(3S)$	200551	CHARMED BARYONS			
$K_1(1400)^+$	20323	B^0	511	$\chi_{b0}(3P)$	210551	Λ_c^+	4122	$\Xi_{bc}^{\prime0}$	5412
$K^*(1410)^0$	100313	B^+	521	$\Upsilon(1S)$	553	Σ_c^{++}	4222	$\Xi_{bc}^{\prime+}$	5422
$K^*(1410)^+$	100323	B_0^{*0}	10511	$h_b(1P)$	10553	Σ_c^+	4212	Ξ_{bc}^{*0}	5414
$K_1(1650)^0$	9000313*	B_0^{*+}	10521	$\chi_{b1}(1P)$	20553	Σ_c^0	4112	Ξ_{bc}^{*+}	5424
$K_1(1650)^+$	9000323*	B^{*0}	513	$\Upsilon_1(1D)$	30553	Σ_c^{*++}	4224	Ω_{bc}^0	5342
$K^*(1680)^0$	30313					Σ_c^{*+}	4214	$\Omega_{bc}^{\prime0}$	5432

Universul este alcătuit numai din cuarci și electroni?

Există și neutrini!



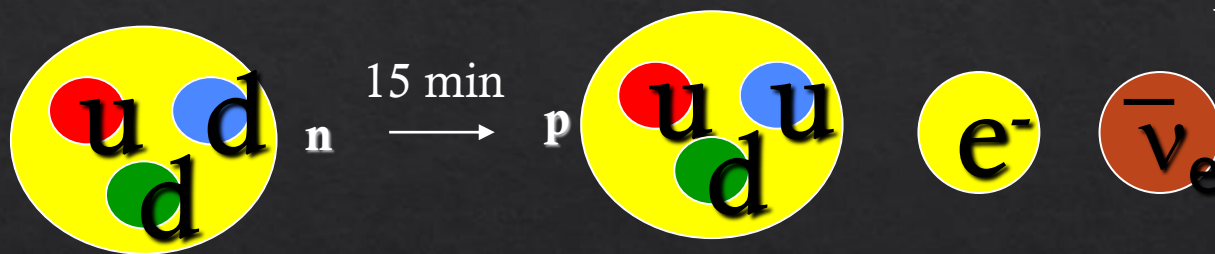
Electronul, protonul și neutronul sunt rari!
Pentru fiecare dintre ei, există 1 billion neutrini.

Neutrini sunt cele mai abundente particule ale materiei în univers.



Dezintegrarea β

La nivelul cuarcilor: $d \rightarrow u e^- \bar{\nu}_e$

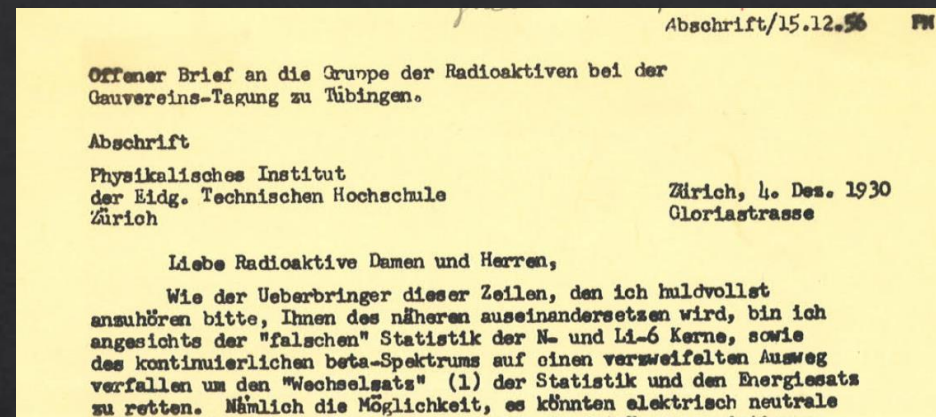


Un neutron se dezintegrează în 15 minute.

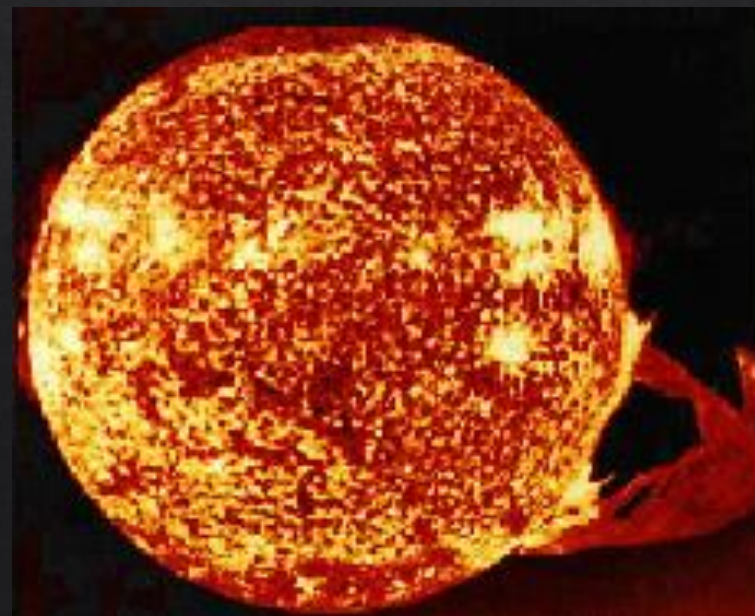
interacție „slabă”!

QFD – Quantum flavordynamics

!



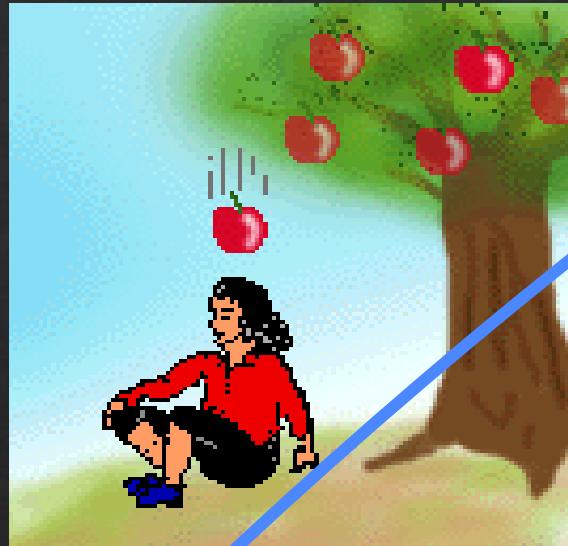
W.Pauli - 1930



Tipuri de interacție

Gravitațională

masa

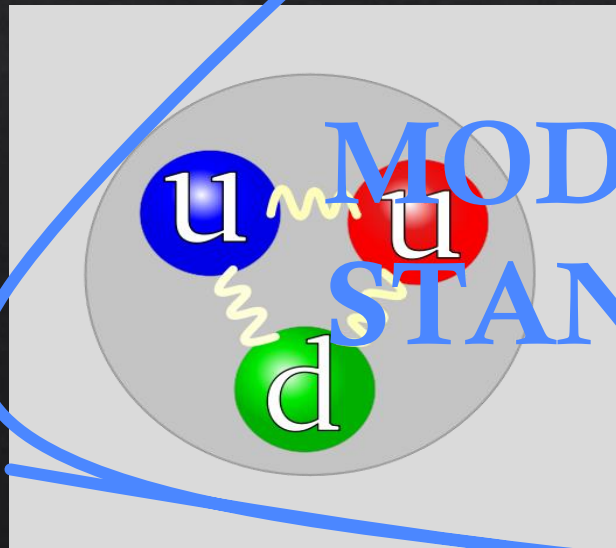


Electromagnetică

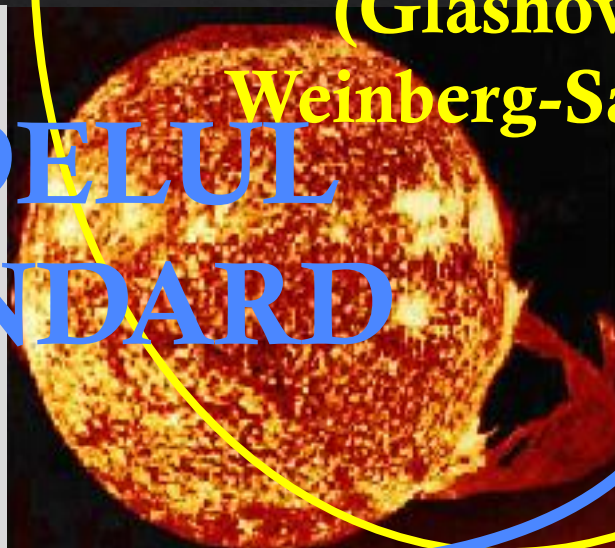


ELECTROSLABĂ
(Glashow-
Weinberg-Salam)

Tare



MODELUL
STANDARD



Slabă

Cine mediază interacțiile?

bozonii

Gravitațională
? graviton ?



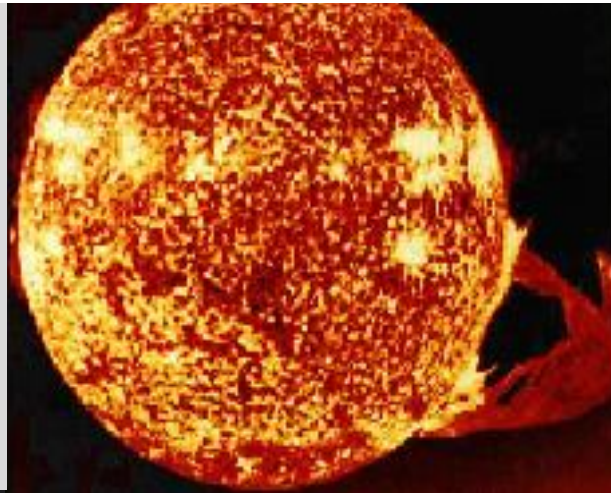
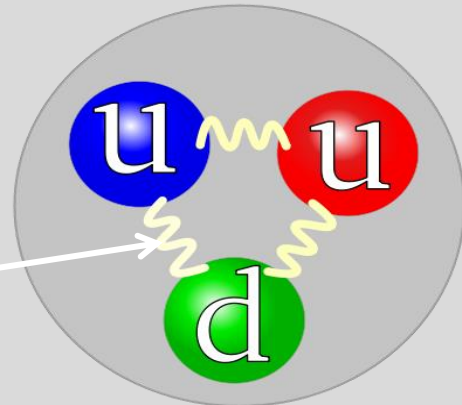
QED – Quantum
Electrodynamics

Electromagnetică
 γ - fotonul

$$G_{SM} = SU(3)_C \times SU(2)_L \times U(1)_Y \rightarrow SU(3)_C \times U(1)_Q$$

Tare

gluonii



QCD – Quantum
chromodynamics

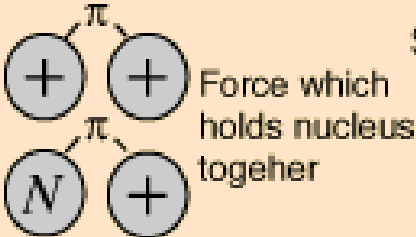
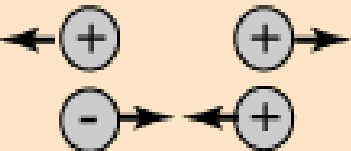
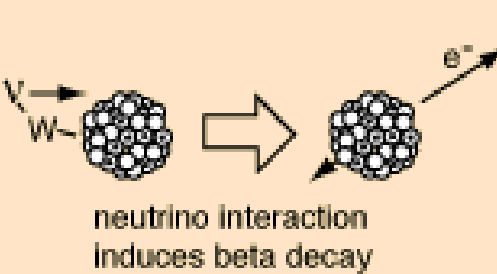
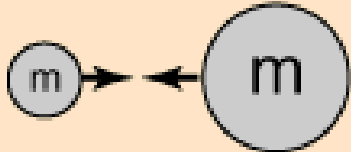
QFD – Quantum
flavordynamics

Slabă

W^+ , W^- , Z

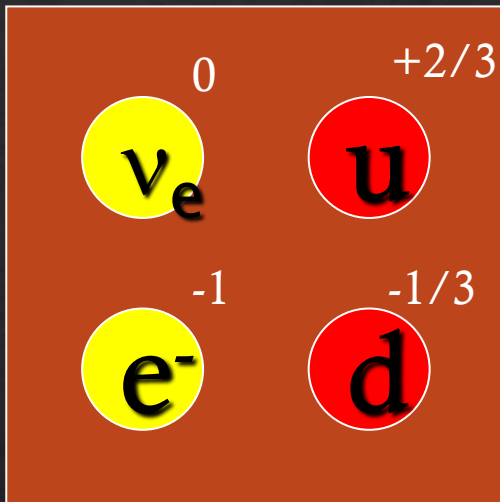
Fundamental Forces

<http://hyperphysics.phy-astr.gsu.edu/hbase/Forces/funfor.html>

<i>Strong</i>		Strength 1	Range (m) 10^{-15} (diameter of a medium sized nucleus)	Particle gluons, π (nucleons)
<i>Electro-magnetic</i>		Strength $\frac{1}{137}$	Range (m) Infinite	Particle photon mass = 0 spin = 1
<i>Weak</i>		Strength 10^{-6}	Range (m) 10^{-18} (0.1% of the diameter of a proton)	Particle Intermediate vector bosons W^+ , W^- , Z_0 , mass > 80 GeV spin = 1
<i>Gravity</i>		Strength 6×10^{-39}	Range (m) Infinite	Particle graviton ? mass = 0 spin = 2

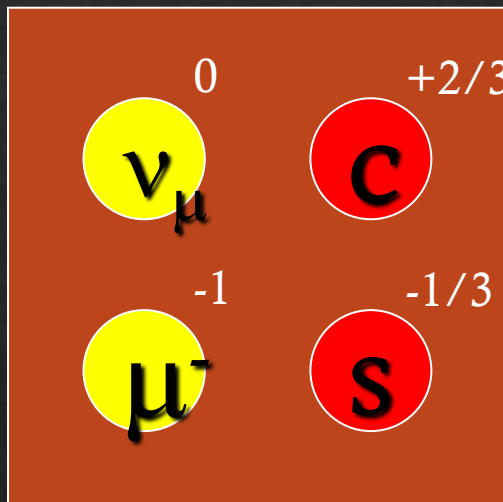
3 FAMILII (ASTĂZI!)

prima generație



materie „obișnuită”

a doua generație



radiație cosmică

a treia generație



acceleratori

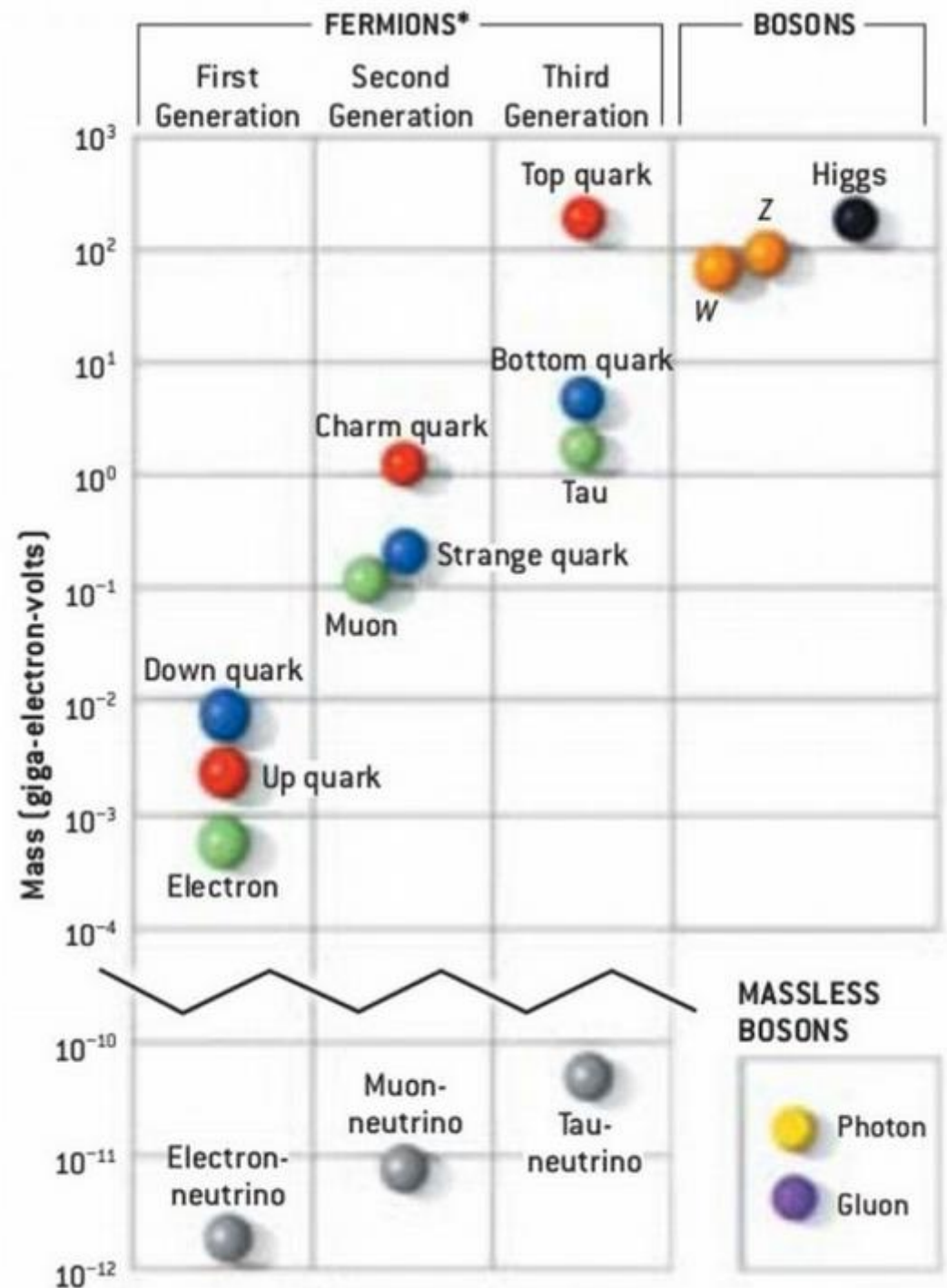
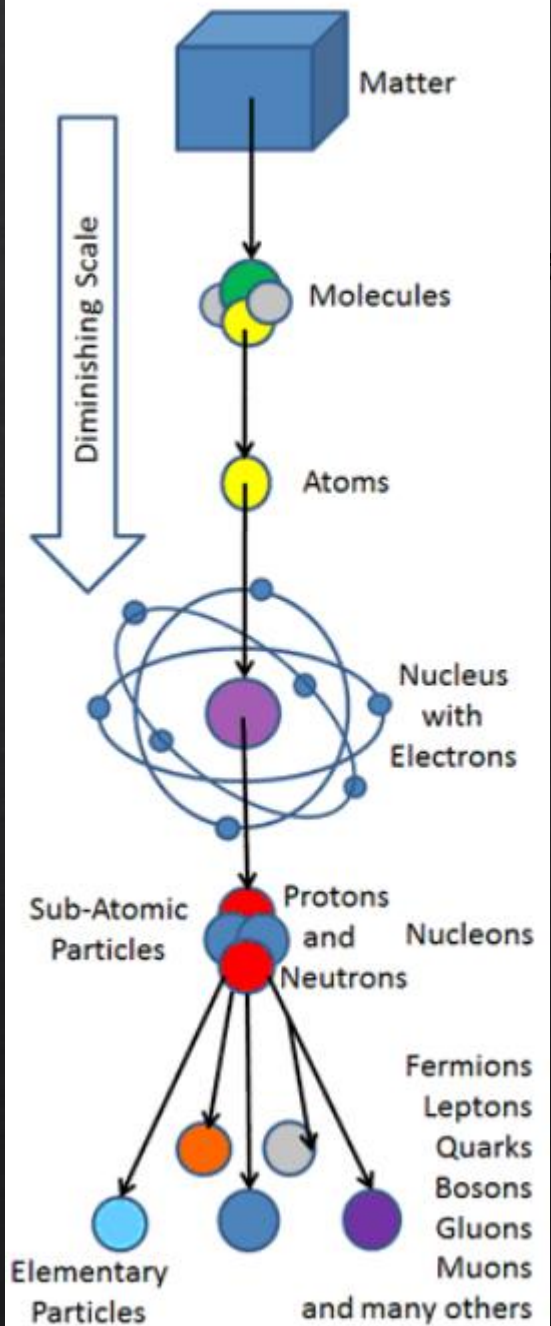
cele 3 generații diferă prin masă!

Three Generations of Matter (Fermions)

	I	II	III	
mass→	2.4 MeV	1.27 GeV	171.2 GeV	0
charge→	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0
spin→	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
name→	u up	c charm	t top	γ photon
Quarks	4.8 MeV	104 MeV	4.2 GeV	0
	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	0
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
	d down	s strange	b bottom	g gluon
Leptons	<2.2 eV	<0.17 MeV	<15.5 MeV	91.2 GeV
	0	0	0	0
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	Z⁰ weak force
	0.511 MeV	105.7 MeV	1.777 GeV	80.4 GeV
	-1	-1	-1	± 1
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
	e electron	μ muon	τ tau	W[±] weak force

Bosons (Forces)


Particle Hierarchy



număr asociat sarcinii electrice (Q)

număr barionic B

număr leptonic L (L_e, L_μ, L_τ)



	Gravity	Weak (Electroweak)	Electromagnetic	Strong
Carried By	Graviton (not yet observed)	$W^+ W^- Z^0$	Photon	Gluon
Acts on	All	Quarks and Leptons	Quarks and Charged Leptons and $W^+ W^-$	Quarks and Gluons

interacție slabă

interacție tare (cuarcii)

(cuarcii și leptonii) interacție electromagnetică

(particule cu sarcină electrică: cuarci, leptoni cu sarcină electrică)

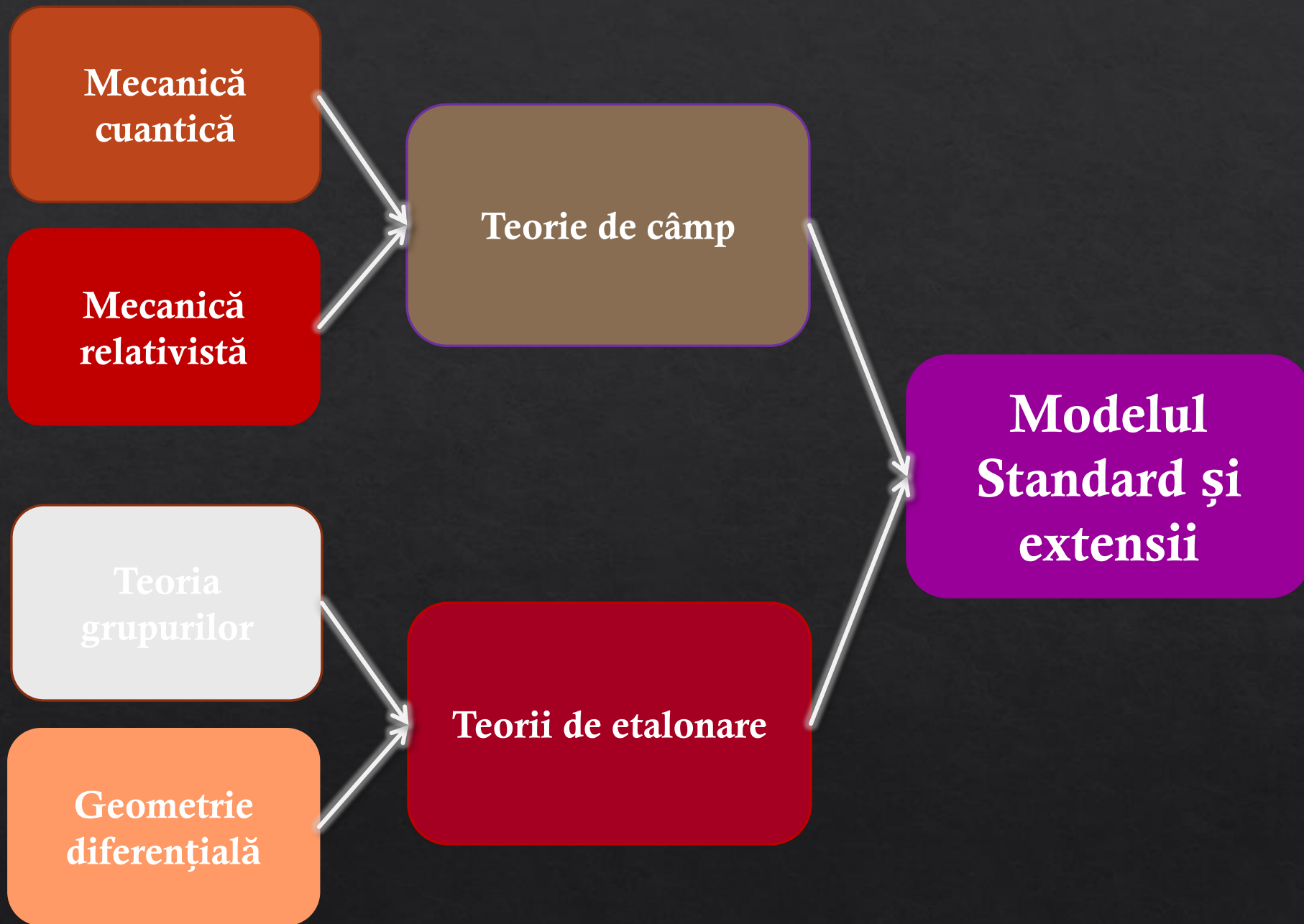
indiscernabilitatea
particulelor identice

statistică cuantică

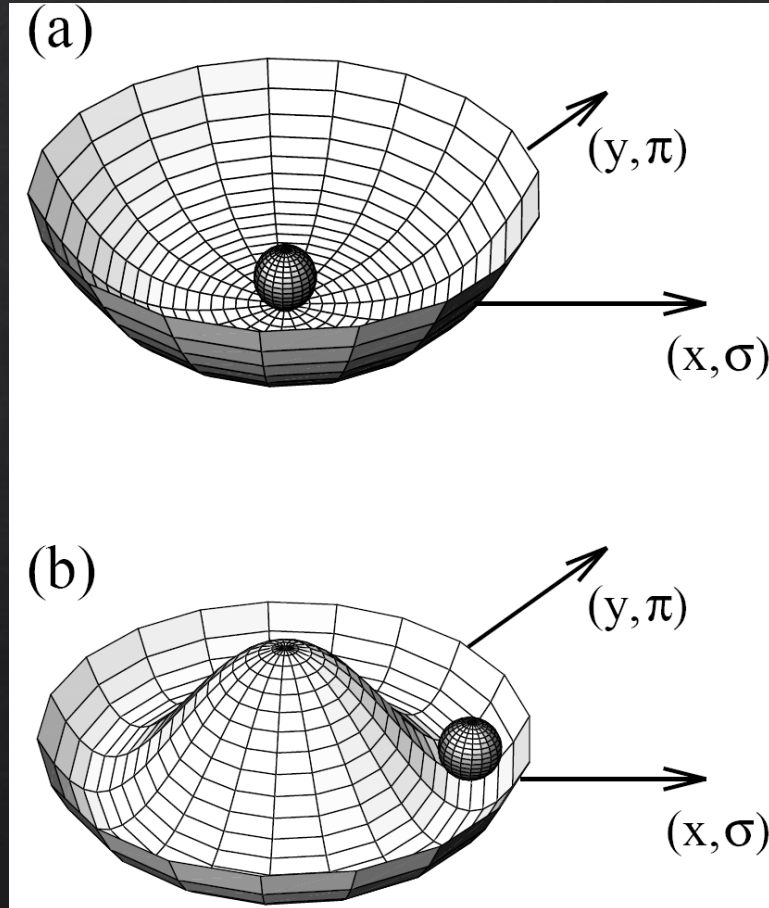
existența antiparticulelor

**procese de creare și
anihilare a particulelor**

interacție cu schimb de particule

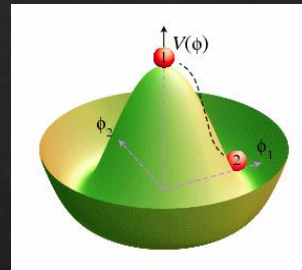


De unde apare masa particulelor în teorie?



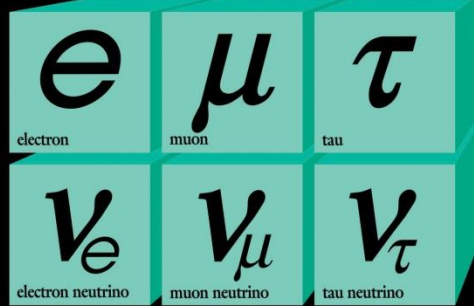
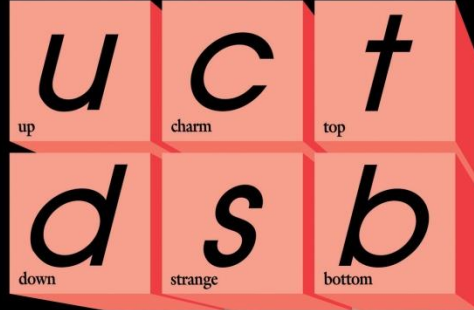
W^+ , W^- , Z – au masă
- rezultă **bozonul Higgs**

fără rupere spontană
de simetrie



rupere spontană de simetrie

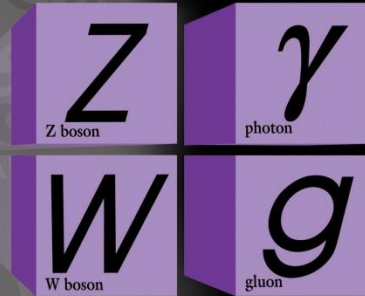
Quarks



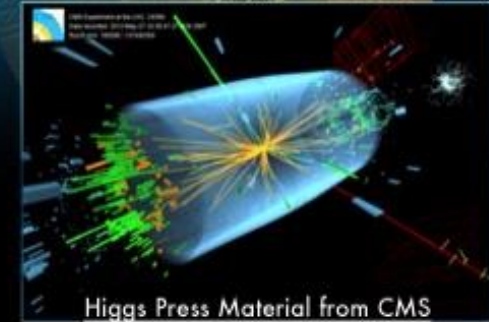
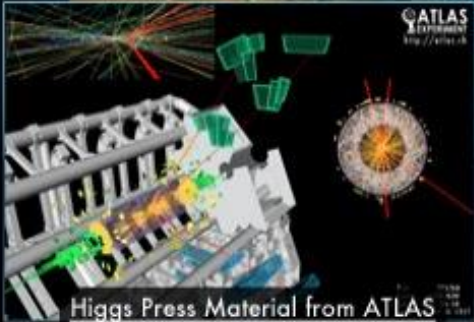
Leptons



Forces



Congratulations to Professors
François Englert & Peter Higgs
for the
2013 Nobel Prize in Physics



The ATLAS and CMS experiments at CERN congratulate Professors François Englert and Peter Higgs for their pioneering work in identifying the electro-weak-symmetry-breaking mechanism. CMS and ATLAS independently announced the discovery of a new particle on 4 July 2012, later identified as a Higgs boson, confirming the predictions of Professors Higgs, Englert and others in seminal papers published in 1964. We join in this celebration of the triumph of human curiosity and ingenuity.

Higgs boson discovery was the culmination of the decades of dedicated and intense work by so many collaborators in designing, building and operating ATLAS, and in understanding and analysing the data. None of it would have been possible without the huge dedication also of the LHC accelerator team, the worldwide distributed computing teams, and the continuing support of the governments and funding agencies of the 38 countries home to our 177 member institutes.

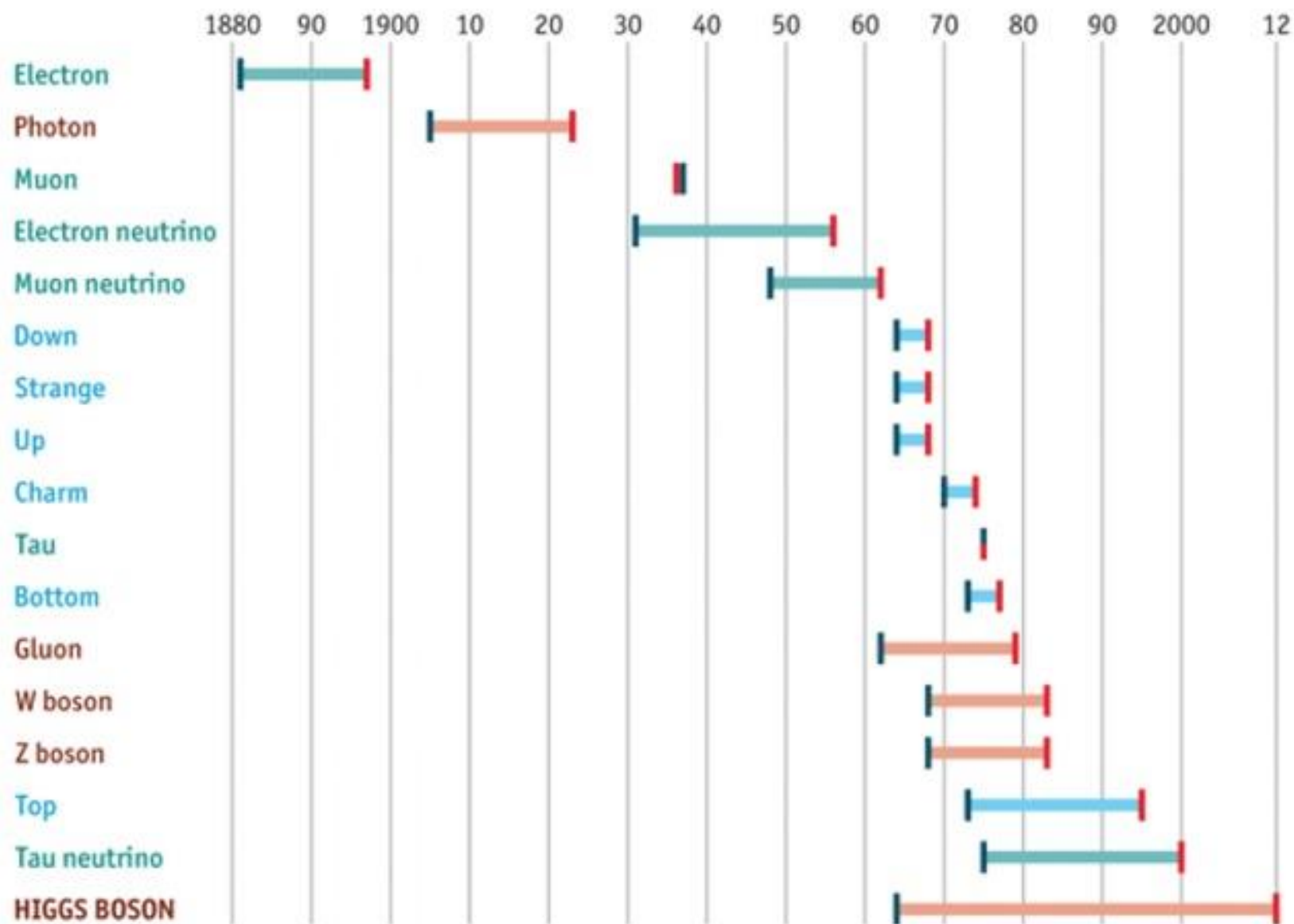
We can all feel proud that our experimental observations demonstrated that the insights rewarded by the Nobel prize are realised in nature.

The Standard Model of particle physics

Years from concept to discovery

Leptons
Bosons
Quarks

Theorised/explained
Discovered



Modelul Standard

Câte particule sunt în Modelul Standard?

	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
QUARKS		u up	c charm	t top	g gluon	H Higgs boson
		$-1/3$	$-1/3$	$-1/3$	0	0
		d down	s strange	b bottom	γ photon	
		$1/2$	$1/2$	$1/2$	1	
LEPTONS		$0.511 \text{ MeV}/c^2$	$105.7 \text{ MeV}/c^2$	$1.777 \text{ GeV}/c^2$	$91.2 \text{ GeV}/c^2$	
		-1	-1	-1	0	
		e electron	μ muon	τ tau	Z Z boson	
		$1/2$	$1/2$	$1/2$	1	
	$< 2.2 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 15.5 \text{ MeV}/c^2$	$80.4 \text{ GeV}/c^2$		
	0	0	0	± 1		
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson		
	$1/2$	$1/2$	$1/2$	1		

+ antiparticule
(Q, L, B opus)!

Standard Model of Elementary Particles

	three generations of matter (elementary fermions)			three generations of antimatter (elementary antifermions)			interactions / force carriers (elementary bosons)	
	I	II	III	I	II	III		
mass	$\approx 2.2 \text{ MeV}/c^2$	$\approx 1.28 \text{ GeV}/c^2$	$\approx 173.1 \text{ GeV}/c^2$	$\approx 2.2 \text{ MeV}/c^2$	$\approx 1.28 \text{ GeV}/c^2$	$\approx 173.1 \text{ GeV}/c^2$	0	$\approx 124.97 \text{ GeV}/c^2$
charge	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	$-\frac{2}{3}$	$-\frac{2}{3}$	$-\frac{2}{3}$	0	0
spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	0
	u up	c charm	t top	\bar{u} antiup	\bar{c} anticharm	\bar{t} antitop	g gluon	H higgs
	d down	s strange	b bottom	\bar{d} antidown	\bar{s} antistrange	\bar{b} antibottom	γ photon	
	e electron	μ muon	τ tau	e^+ positron	$\bar{\mu}$ antimuon	$\bar{\tau}$ antitau	Z Z^0 boson	
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	$\bar{\nu}_e$ electron antineutrino	$\bar{\nu}_\mu$ muon antineutrino	$\bar{\nu}_\tau$ tau antineutrino	W^+ W^+ boson	W^- W^- boson

QUARKS

LEPTONS

GAUGE BOSONS
VECTOR BOSONS

SCALAR BOSONS

Resurse: <https://home.cern/science/physics>



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Physics

The research programme at CERN covers topics from the basic structure of matter to cosmic rays, and from the Standard Model to supersymmetry



Fizica particulelor elementare

1. Care sunt particulele elementare (ce proprietăți au – masă, sarcină electrică, spin, ...)?
2. Cum interacționează? - De unde obținem informații?
3. Cum producem particule elementare?
4. Cum detectăm particule elementare?

The Review of Particle Physics (2023)

R.L. Workman *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. 2022, 083C01 (2022) and 2023 update

<p>Gauge & Higgs Bosons reviews</p> <ul style="list-style-type: none"> γ gluon graviton W Z H Neutral Higgs Bosons, Searches for Charged Higgs Bosons (H^\pm, $H^{\pm\pm}$) Heavy Bosons Axions 	<p>Leptons reviews</p> <ul style="list-style-type: none"> e μ τ Heavy Charged Lepton Neutrino Properties Number of Neutrino Types Double β-Decay Neutrino Mixing Heavy Neutral Leptons 	<p>Quarks reviews</p> <ul style="list-style-type: none"> Light quarks (u, d, s) c b t b' t' Free quark
<p>Mesons reviews</p> <ul style="list-style-type: none"> Light Unflavored Strange Charmed Charmed, Strange (incl. possibly non-$q\bar{q}$ states) Bottom Bottom, Strange Bottom, Charmed $c\bar{c}$ (incl. possibly non-$q\bar{q}$ states) $b\bar{b}$ (incl. possibly non-$q\bar{q}$ states) Other Mesons 	<p>Baryons reviews</p> <ul style="list-style-type: none"> N Baryons Δ Baryons Λ Baryons Σ Baryons Ξ Baryons Ω Baryons Charmed Baryons Doubly-Charmed Bottom Baryons Exotic Baryons 	<p>Other Searches reviews</p> <ul style="list-style-type: none"> Magnetic Monopole Supersymmetric Particles Technicolor Quark and Lepton Compositeness Extra Dimensions WIMPs Other Particle Searches <p>Conservation Laws reviews</p> <ul style="list-style-type: none"> Discrete Space-Time Symm. Number Conservation Laws

Quantity	Symbol, equation	Value	Uncertainty (ppb)
speed of light in vacuum	c	299 792 458 m s ⁻¹	exact
Planck constant	h	6.626 070 15×10 ⁻³⁴ J s (or J/Hz) [‡]	exact
Planck constant, reduced	$\hbar \equiv h/2\pi$	1.054 571 817... × 10 ⁻³⁴ J s = 6.582 119 569... × 10 ⁻²² MeV s	exact* exact*
electron charge magnitude	e	1.602 176 634×10 ⁻¹⁹ C	exact
conversion constant	$\hbar c$	197.326 980 4... MeV fm	exact*
conversion constant	$(\hbar c)^2$	0.389 379 372 1... GeV ² mbarn	exact*
electron mass	m_e	0.510 998 950 00(15) MeV/c ² = 9.109 383 7015(28)×10 ⁻³¹ kg	0.30
proton mass	m_p	938.272 088 16(29) MeV/c ² = 1.672 621 923 69(51)×10 ⁻²⁷ kg = 1.007 276 466 621(53) u = 1836.152 673 43(11) m_e	0.053, 0.060
neutron mass	m_n	939.565 420 52(54) MeV/c ² = 1.008 664 915 95(49) u	0.57, 0.48
deuteron mass	m_d	1875.612 942 57(57) MeV/c ²	0.30
unified atomic mass unit**	$u = (\text{mass } ^{12}\text{C atom})/12$	931.494 102 42(28) MeV/c ² = 1.660 539 066 60(50)×10 ⁻²⁷ kg	0.30
permittivity of free space	$\epsilon_0 = 1/\mu_0 c^2$	8.854 187 8128(13) × 10 ⁻¹² F m ⁻¹	0.15
permeability of free space	$\mu_0/(4\pi \times 10^{-7})$	1.000 000 000 55(15) N A ⁻²	0.15
fine-structure constant	$\alpha = e^2/4\pi\epsilon_0\hbar c$	7.297 352 5693(11)×10 ⁻³ = 1/137.035 999 084(21) [†]	0.15
classical electron radius	$r_e = e^2/4\pi\epsilon_0 m_e c^2$	2.817 940 3262(13)×10 ⁻¹⁵ m	0.45
(e^- Compton wavelength)/2 π	$\lambda_e = \hbar/m_e c = r_e \alpha^{-1}$	3.861 592 6796(12)×10 ⁻¹³ m	0.30
Bohr radius ($m_{\text{nucleus}} = \infty$)	$a_\infty = 4\pi\epsilon_0\hbar^2/m_e e^2 = r_e \alpha^{-2}$	0.529 177 210 903(80)×10 ⁻¹⁰ m	0.15
wavelength of 1 eV/c particle	$hc/(1 \text{ eV})$	1.239 841 984... × 10 ⁻⁶ m	exact*
Rydberg energy	$hcR_\infty = m_e e^4/2(4\pi\epsilon_0)^2\hbar^2 = m_e c^2 \alpha^2/2$	13.605 693 122 994(26) eV	1.9×10 ⁻³
Thomson cross section	$\sigma_T = 8\pi r_e^2/3$	0.665 245 873 21(60) barn	0.91
Bohr magneton	$\mu_B = e\hbar/2m_e$	5.788 381 8060(17)×10 ⁻¹¹ MeV T ⁻¹	0.3
nuclear magneton	$\mu_N = e\hbar/2m_p$	3.152 451 258 44(96)×10 ⁻¹⁴ MeV T ⁻¹	0.31
electron cyclotron freq./field	$\omega_{\text{cycl}}^e/B = e/m_e$	1.758 820 010 76(53)×10 ¹¹ rad s ⁻¹ T ⁻¹	0.30
proton cyclotron freq./field	$\omega_{\text{cycl}}^p/B = e/m_p$	9.578 833 1560(29)×10 ⁷ rad s ⁻¹ T ⁻¹	0.31

gravitational constant [‡]	G_N	$6.674\ 30(15)\times 10^{-11}\ \text{m}^3\ \text{kg}^{-1}\ \text{s}^{-2}$ $= 6.708\ 83(15)\times 10^{-39}\ \text{hc}\ (\text{GeV}/c^2)^{-2}$	2.2×10^4 2.2×10^4
standard gravitational accel.	g_N	$9.806\ 65\ \text{m}\ \text{s}^{-2}$	exact
Avogadro constant	N_A	$6.022\ 140\ 76\times 10^{23}\ \text{mol}^{-1}$	exact
Boltzmann constant	k	$1.380\ 649\times 10^{-23}\ \text{J}\ \text{K}^{-1}$ $= 8.617\ 333\ 262\dots\times 10^{-5}\ \text{eV}\ \text{K}^{-1}$	exact exact*
molar volume, ideal gas at STP	$N_A k (273.15\ \text{K})/(101\ 325\ \text{Pa})$	$22.413\ 969\ 54\dots\times 10^{-3}\ \text{m}^3\ \text{mol}^{-1}$	exact*
Wien displacement law constant	$b = \lambda_{\text{max}} T$	$2.897\ 771\ 955\dots\times 10^{-3}\ \text{m}\ \text{K}$	exact*
Stefan-Boltzmann constant	$\sigma = \pi^2 k^4/60\hbar^3 c^2$	$5.670\ 374\ 419\dots\times 10^{-8}\ \text{W}\ \text{m}^{-2}\ \text{K}^{-4}$	exact*
Fermi coupling constant ^{‡‡}	$G_F/(\hbar c)^3$	$1.166\ 378\ 7(6)\times 10^{-5}\ \text{GeV}^{-2}$	510
weak-mixing angle	$\sin^2 \hat{\theta}(M_Z) (\overline{\text{MS}})$	$0.231\ 22(4)^{\dagger\dagger}$	1.7×10^5
W^\pm boson mass	m_W	$80.379(12)\ \text{GeV}/c^2$	1.5×10^5
Z^0 boson mass	m_Z	$91.1876(21)\ \text{GeV}/c^2$	2.3×10^4
strong coupling constant	$\alpha_s(m_Z)$	$0.1179(10)$	8.5×10^6
$\pi = 3.141\ 592\ 653\ 589\ 793\ 238\dots$		$e = 2.718\ 281\ 828\ 459\ 045\ 235\dots$	$\gamma = 0.577\ 215\ 664\ 901\ 532\ 860\dots$

$1\ \text{in} \equiv 0.0254\ \text{m}$	$1\ \text{G} \equiv 10^{-4}\ \text{T}$	$1\ \text{eV} = 1.602\ 176\ 634 \times 10^{-19}\ \text{J}$ (exact)	kT at 300 K = $[38.681\ 740(22)]^{-1}\ \text{eV}$
$1\ \text{Å} \equiv 0.1\ \text{nm}$	$1\ \text{dyne} \equiv 10^{-5}\ \text{N}$	$(1\ \text{kg})c^2 = 5.609\ 588\ 603\dots \times 10^{35}\ \text{eV}$ (exact*)	$0\ ^\circ\text{C} \equiv 273.15\ \text{K}$
$1\ \text{barn} \equiv 10^{-28}\ \text{m}^2$	$1\ \text{erg} \equiv 10^{-7}\ \text{J}$	$1\ \text{C} = 2.997\ 924\ 58 \times 10^9\ \text{esu}$	$1\ \text{atmosphere} \equiv 760\ \text{Torr} \equiv 101\ 325\ \text{Pa}$

[‡] CODATA recommends that the unit be J/Hz to stress that in $h = E/\nu$ the frequency ν is in cycles/sec (Hz), not radians/sec.

* These are calculated from exact values and are exact to the number of places given (*i.e.* no rounding).

** The molar mass of ^{12}C is 11.999 999 9958(36) g.

[†] At $Q^2 = 0$. At $Q^2 \approx m_W^2$ the value is $\sim 1/128$.

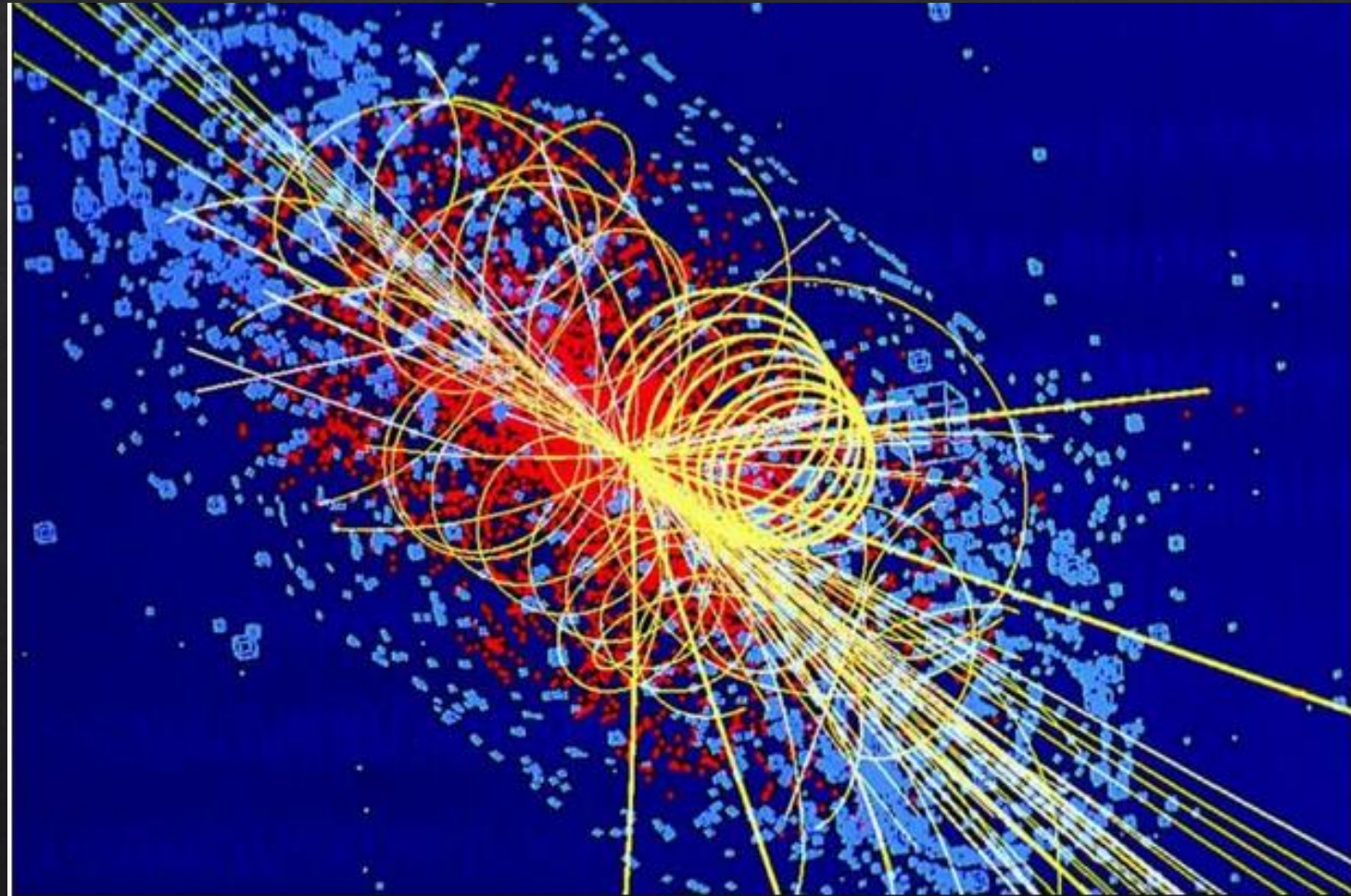
[‡] Absolute laboratory measurements of G_N have been made only on scales of about 1 cm to 1 m.

^{‡‡} See the discussion in Sec. 10, “Electroweak model and constraints on new physics.”

^{††} The corresponding $\sin^2 \theta$ for the effective angle is 0.23155(4).

2. De unde obținem informații despre particule?

- ◇ ciocniri
- ◇ dezintegrări
- ◇ stări legate



Simulation of a particle collision in which a Higgs boson is produced (Image: Lucas Taylor/CMS)

particle physics collisions: cross section σ_{fi}
 ciocniri: secțiune eficace de împrăștiere

$$= \frac{W_{fi}}{(\text{initial flux})} \text{ (number of final states)}$$

$$d\sigma = \frac{|M|^2}{F} dQ$$

M – amplitudine de tranziție

$$\begin{aligned} \sigma_{\text{tot}}(\mathbf{a}_1 + \mathbf{a}_2 \rightarrow \mathbf{b}'_1 + \dots + \mathbf{b}'_m) &= \frac{1}{2w(s, m_1^2, m_2^2)} \\ &\cdot \int \prod_{i=1}^m \left(\frac{d^3 p'_i}{(2\pi)^3} \delta_+(p_i'^2 - m_i'^2) \right) (2\pi)^4 \delta(p'_1 + \dots + p'_m - p_1 - p_2) \\ &\cdot |\langle \mathbf{b}_1(p'_1) \dots \mathbf{b}_m(p'_m) | \mathbf{T} | \mathbf{a}_1(p_1) \mathbf{a}_2(p_2) \rangle|^2. \end{aligned}$$

dezintegrări: rata de dezintegrare

$$\begin{aligned} d\Gamma(\mathbf{a}(p) \rightarrow \mathbf{b}_1(p'_1) + \dots + \mathbf{b}_m(p'_m)) &= \frac{1}{2m_a} (2\pi)^4 \delta(p'_1 + \dots + p'_m - p) \\ &\cdot \prod_{i=1}^m \frac{d^3 p'_i}{(2\pi)^3 2p_i'^0} |\langle \mathbf{b}_1(p'_1) \dots \mathbf{b}_m(p'_m) | \mathbf{T} | \mathbf{a}(p) \rangle|^2. \end{aligned}$$

Cum interacționează?

$$\begin{aligned}
 & -\frac{1}{2}\partial_\nu g_\mu^a \partial_\nu g_\mu^a - g_s f^{abc} \partial_\mu g_\nu^a g_\mu^b g_\nu^c - \frac{1}{4}g_s^2 f^{abc} f^{ade} g_\mu^b g_\nu^c g_\mu^d g_\nu^e + \\
 & \frac{1}{2}i g_s^2 (\bar{q}_i^\alpha \gamma^\mu q_j^\alpha) g_\mu^a + \bar{G}^a \partial^2 G^a + g_s f^{abc} \partial_\mu \bar{G}^a G^b g_\mu^c - \partial_\nu W_\mu^+ \partial_\nu W_\mu^- - \\
 & M^2 W_\mu^+ W_\mu^- - \frac{1}{2}\partial_\nu Z_\mu^0 \partial_\nu Z_\mu^0 - \frac{1}{2c_w^2} M^2 Z_\mu^0 Z_\mu^0 - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - \frac{1}{2}\partial_\mu H \partial_\mu H - \\
 & \frac{1}{2}m_h^2 H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - M^2 \phi^+ \phi^- - \frac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \frac{1}{2c_w^2} M \phi^0 \phi^0 - \beta_h \left[\frac{2M^2}{g^2} + \right. \\
 & \left. \frac{2M}{g} H + \frac{1}{2}(H^2 + \phi^0 \phi^0 + 2\phi^+ \phi^-) \right] + \frac{2M^4}{g^2} \alpha_h - igc_w [\partial_\nu Z_\mu^0 (W_\mu^+ W_\nu^- - \\
 & W_\nu^+ W_\mu^-) - Z_\nu^0 (W_\mu^+ \partial_\nu W_\mu^- - W_\mu^- \partial_\nu W_\mu^+) + Z_\mu^0 (W_\nu^+ \partial_\nu W_\mu^- - \\
 & W_\nu^- \partial_\nu W_\mu^+)] - ig s_w [\partial_\nu A_\mu (W_\mu^+ W_\nu^- - W_\nu^+ W_\mu^-) - A_\nu (W_\mu^+ \partial_\nu W_\mu^- - \\
 & W_\nu^- \partial_\nu W_\mu^+) + A_\mu (W_\nu^+ \partial_\nu W_\mu^- - W_\nu^- \partial_\nu W_\mu^+)] - \frac{1}{2}g^2 W_\mu^+ W_\mu^- W_\nu^+ W_\nu^- + \\
 & \frac{1}{2}g^2 W_\mu^+ W_\nu^- W_\mu^+ W_\nu^- + g^2 c_w^2 (Z_\mu^0 W_\mu^+ Z_\nu^0 W_\nu^- - Z_\mu^0 Z_\nu^0 W_\mu^+ W_\nu^-) + \\
 & g^2 s_w^2 (A_\mu W_\mu^+ A_\nu W_\nu^- - A_\mu A_\nu W_\mu^+ W_\nu^-) + g^2 s_w c_w [A_\mu Z_\nu^0 (W_\mu^+ W_\nu^- - \\
 & W_\nu^+ W_\mu^-) - 2A_\mu Z_\mu^0 W_\nu^+ W_\nu^-] - g\alpha [H^3 + H\phi^0 \phi^0 + 2H\phi^+ \phi^-] - \\
 & \frac{1}{8}g^2 \alpha_h [H^4 + (\phi^0)^4 + 4(\phi^+ \phi^-)^2 + 4(\phi^0)^2 \phi^+ \phi^- + 4H^2 \phi^+ \phi^- + 2(\phi^0)^2 H^2] - \\
 & g M W_\mu^+ W_\mu^- H - \frac{1}{2}g \frac{M}{c_w^2} Z_\mu^0 Z_\mu^0 H - \frac{1}{2}ig [W_\mu^+ (\phi^0 \partial_\mu \phi^- - \phi^- \partial_\mu \phi^0) - \\
 & W_\mu^- (\phi^0 \partial_\mu \phi^+ - \phi^+ \partial_\mu \phi^0)] + \frac{1}{2}g [W_\mu^+ (H \partial_\mu \phi^- - \phi^- \partial_\mu H) - W_\mu^- (H \partial_\mu \phi^+ - \\
 & \phi^+ \partial_\mu H)] + \frac{1}{2}g \frac{1}{c_w} (Z_\mu^0 (H \partial_\mu \phi^0 - \phi^0 \partial_\mu H) - ig \frac{2c_w}{c_w} M Z_\mu^0 (W_\mu^+ \phi^- - W_\mu^- \phi^+) + \\
 & ig s_w M A_\mu (W_\mu^+ \phi^- - W_\mu^- \phi^+) - ig \frac{1-2c_w^2}{2c_w} Z_\mu^0 (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) + \\
 & ig s_w A_\mu (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) - \frac{1}{4}g^2 W_\mu^+ W_\mu^- [H^2 + (\phi^0)^2 + 2\phi^+ \phi^-] - \\
 & \frac{1}{4}g^2 \frac{1}{c_w^2} Z_\mu^0 Z_\mu^0 [H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2 \phi^+ \phi^-] - \frac{1}{2}g^2 \frac{s_w^2}{c_w} Z_\mu^0 \phi^0 (W_\mu^+ \phi^- + \\
 & W_\mu^- \phi^+) - \frac{1}{2}ig^2 \frac{s_w^2}{c_w} Z_\mu^0 H (W_\mu^+ \phi^- - W_\mu^- \phi^+) + \frac{1}{2}g^2 s_w A_\mu \phi^0 (W_\mu^+ \phi^- + \\
 & W_\mu^- \phi^+) + \frac{1}{2}ig^2 s_w A_\mu H (W_\mu^+ \phi^- - W_\mu^- \phi^+) - g^2 \frac{s_w}{c_w} (2c_w^2 - 1) Z_\mu^0 A_\mu \phi^+ \phi^- - \\
 & g^1 s_w^2 A_\mu A_\mu \phi^+ \phi^- - \bar{e}^\lambda (\gamma \partial + m_e^\lambda) e^\lambda - \bar{\nu}^\lambda \gamma \partial \nu^\lambda - \bar{u}_j^\lambda (\gamma \partial + m_u^\lambda) u_j^\lambda - \bar{d}_j^\lambda (\gamma \partial + \\
 & m_d^\lambda) d_j^\lambda + ig s_w A_\mu [-(\bar{e}^\lambda \gamma e^\lambda) + \frac{2}{3}(\bar{u}_j^\lambda \gamma u_j^\lambda) - \frac{1}{3}(\bar{d}_j^\lambda \gamma d_j^\lambda)] + \frac{ig}{4c_w} Z_\mu^0 [(\bar{\nu}^\lambda \gamma^\mu (1 + \\
 & \gamma^5) \nu^\lambda) + (\bar{e}^\lambda \gamma^\mu (4s_w^2 - 1 - \gamma^5) e^\lambda) + (\bar{u}_j^\lambda \gamma^\mu (\frac{4}{3}s_w^2 - 1 - \gamma^5) u_j^\lambda) + \\
 & (\bar{d}_j^\lambda \gamma^\mu (1 - \frac{8}{3}s_w^2 - \gamma^5) d_j^\lambda)] + \frac{ig}{2\sqrt{2}} W_\mu^+ [(\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) e^\lambda) + (\bar{u}_j^\lambda \gamma^\mu (1 + \\
 & \gamma^5) C_{\lambda\kappa} d_j^\kappa)] + \frac{ig}{2\sqrt{2}} W_\mu^- [(\bar{e}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (\bar{d}_j^\kappa C_{\lambda\kappa}^\dagger \gamma^\mu (1 + \gamma^5) u_j^\lambda)] + \\
 & \frac{ig}{2\sqrt{2}} \frac{m_\lambda^2}{M} [-\phi^+ (\bar{\nu}^\lambda (1 - \gamma^5) e^\lambda) + \phi^- (\bar{e}^\lambda (1 + \gamma^5) \nu^\lambda)] - \frac{g}{2} \frac{m_\lambda^2}{M} [H (\bar{e}^\lambda e^\lambda) + \\
 & i\phi^0 (\bar{e}^\lambda \gamma^5 e^\lambda)] + \frac{ig}{2M\sqrt{2}} \phi^+ [-m_d^\kappa (\bar{u}_j^\lambda C_{\lambda\kappa} (1 - \gamma^5) d_j^\kappa) + m_u^\lambda (\bar{u}_j^\lambda C_{\lambda\kappa} (1 + \\
 & \gamma^5) d_j^\kappa)] + \frac{ig}{2M\sqrt{2}} \phi^- [m_d^\lambda (\bar{d}_j^\kappa C_{\lambda\kappa}^\dagger (1 + \gamma^5) u_j^\kappa) - m_u^\lambda (\bar{d}_j^\kappa C_{\lambda\kappa}^\dagger (1 - \gamma^5) u_j^\kappa) - \\
 & \frac{g}{2} \frac{m_\lambda^2}{M} H (\bar{u}_j^\lambda u_j^\lambda) - \frac{g}{2} \frac{m_\lambda^2}{M} H (\bar{d}_j^\lambda d_j^\lambda) + \frac{ig}{2} \frac{m_\lambda^2}{M} \phi^0 (\bar{u}_j^\lambda \gamma^5 u_j^\lambda) - \frac{ig}{2} \frac{m_\lambda^2}{M} \phi^0 (\bar{d}_j^\lambda \gamma^5 d_j^\lambda) + \\
 & \bar{X}^+ (\partial^2 - M^2) X^+ + \bar{X}^- (\partial^2 - M^2) X^- + \bar{X}^0 (\partial^2 - \frac{M^2}{c_w^2}) X^0 + \bar{Y} \partial^2 Y + \\
 & igc_w W_\mu^+ (\partial_\mu \bar{X}^0 X^- - \partial_\mu \bar{X}^+ X^0) + ig s_w W_\mu^+ (\partial_\mu \bar{Y} X^- - \partial_\mu \bar{X}^+ Y) + \\
 & igc_w W_\mu^- (\partial_\mu \bar{X}^- X^0 - \partial_\mu \bar{X}^0 X^+) + ig s_w W_\mu^- (\partial_\mu \bar{X}^- Y - \partial_\mu \bar{Y} X^+) + \\
 & igc_w Z_\mu^0 (\partial_\mu \bar{X}^+ X^- + \partial_\mu \bar{X}^- X^+) + ig s_w A_\mu (\partial_\mu \bar{X}^+ X^- - \partial_\mu \bar{X}^- X^+) - \\
 & \frac{1}{2}g M [\bar{X}^+ X^+ H + \bar{X}^- X^- H + \frac{1}{c_w} \bar{X}^0 X^0 H] + \frac{1-2c_w^2}{2c_w} ig M [\bar{X}^+ X^0 \phi^+ - \\
 & \bar{X}^- X^0 \phi^-] + \frac{1}{2c_w} ig M [\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + ig M s_w [\bar{X}^0 X^- \phi^+ - \\
 & \bar{X}^0 X^+ \phi^-] + \frac{1}{2}ig M [\bar{X}^+ X^+ \phi^0 - \bar{X}^- X^- \phi^0]
 \end{aligned}$$



interacția
particulelor

interacția
dintre particule
asociate
materiei

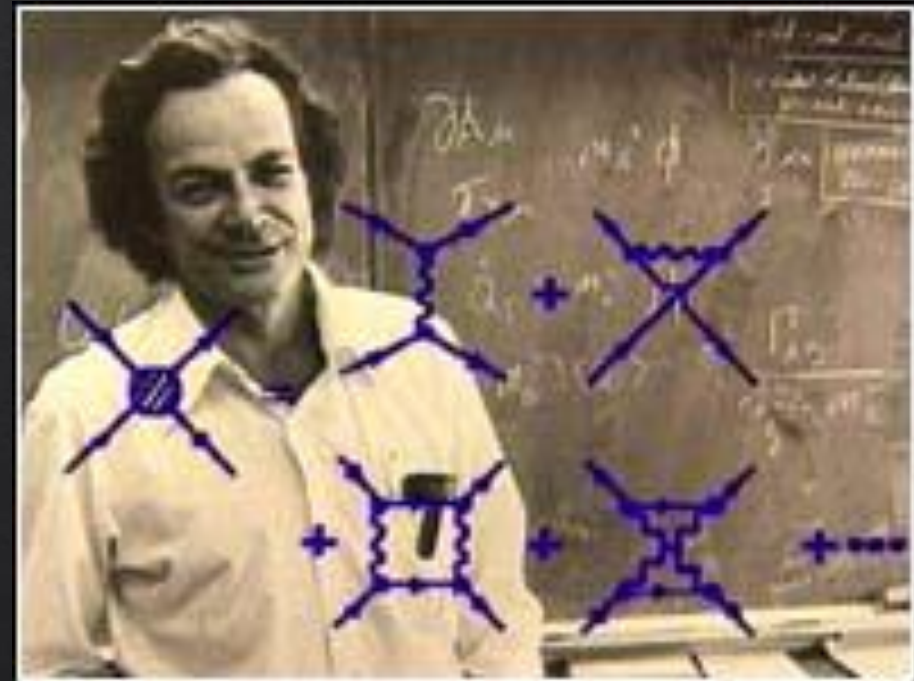
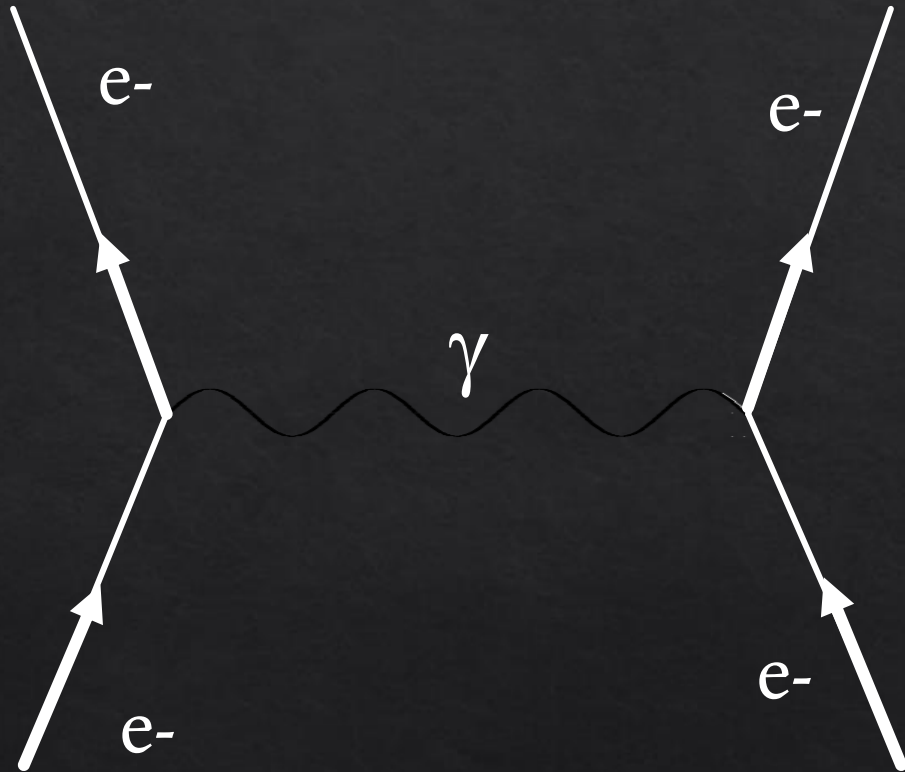
masa
particulelor
asociate
materiei

masa anti-
particulelor

masa particulelor
care mediază
interacțiile

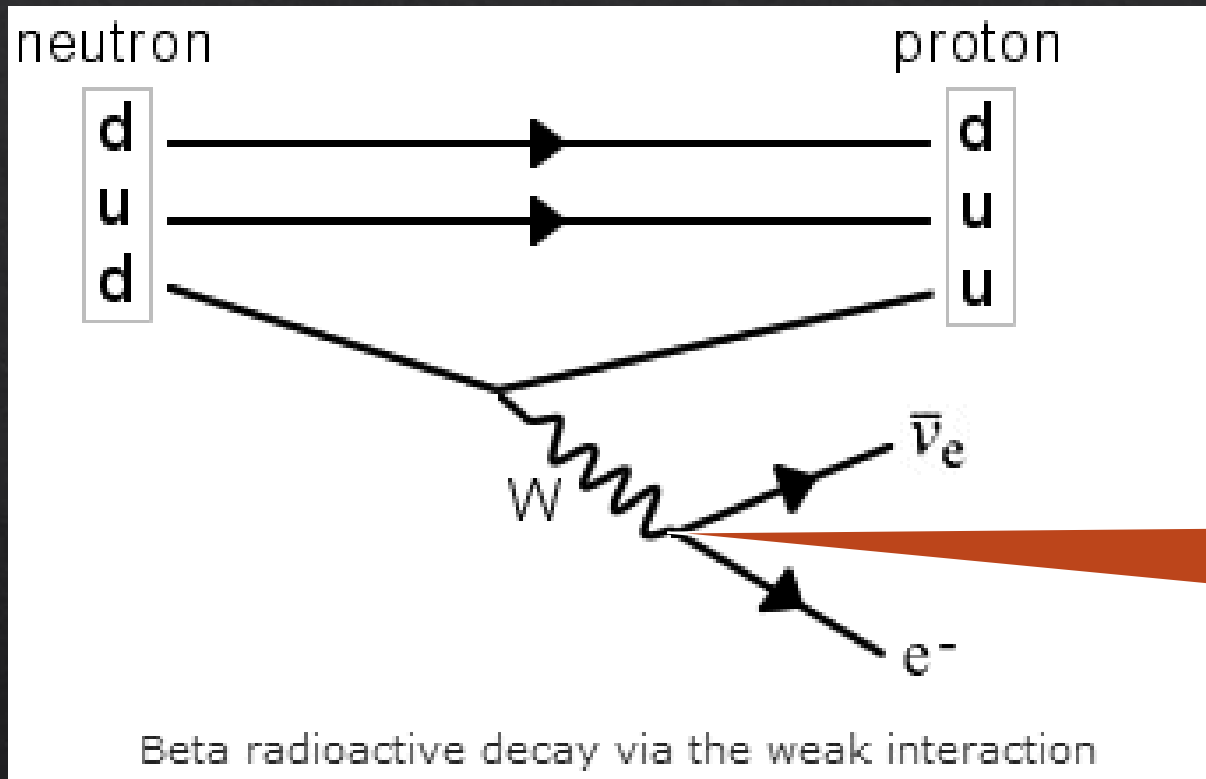
Higgs - interacții

Feynman – diagrame și reguli



Feynman earned his Nobel for creating these diagrams
(Courtesy Auckland University)

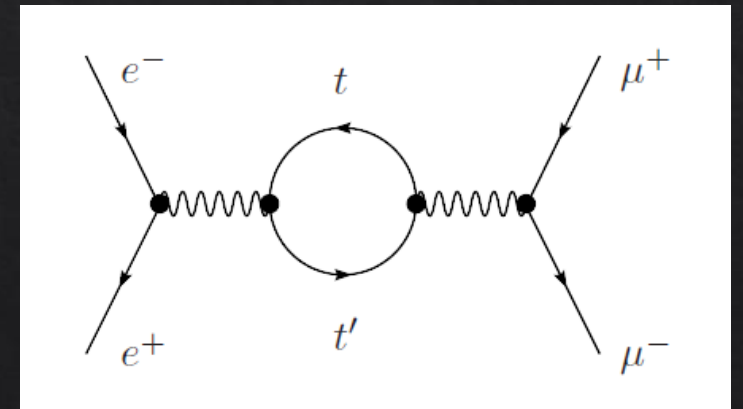
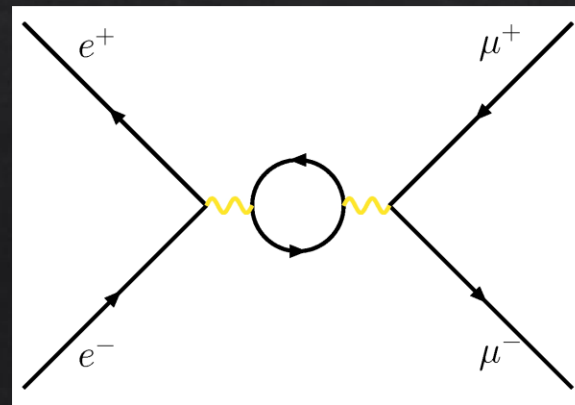
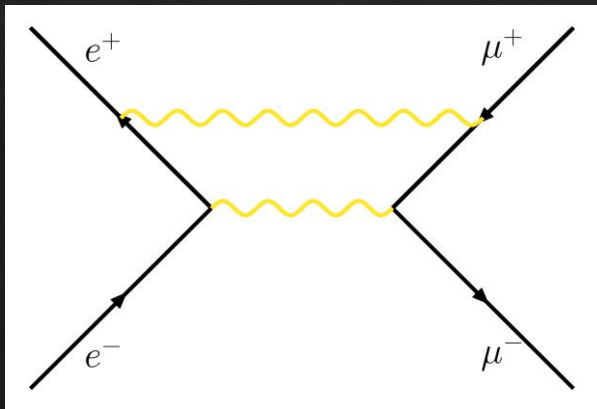
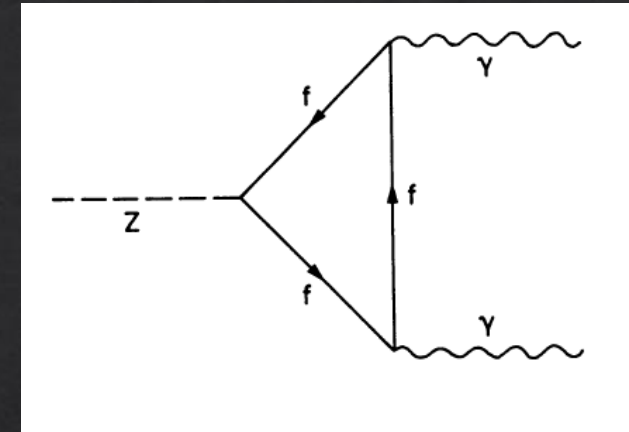
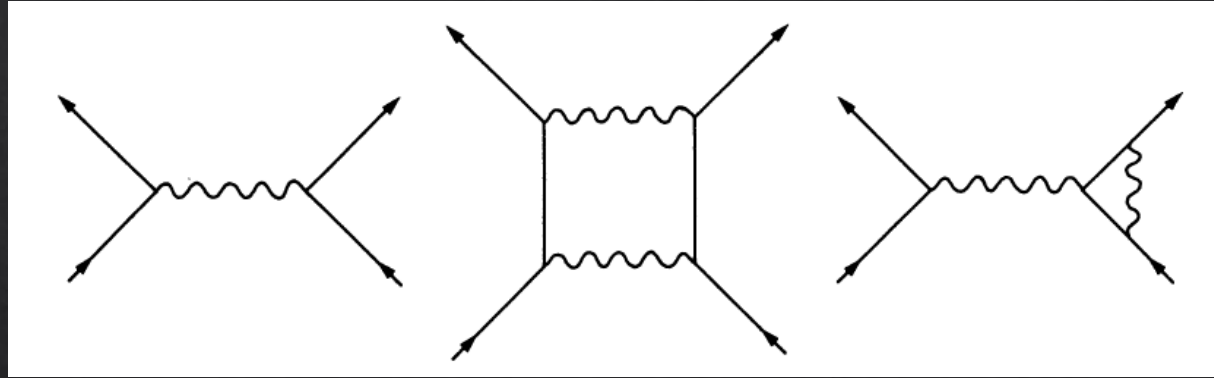
Feynman – diagrame și reguli



Sarcina electrică
se conservă la
fiecare vertex

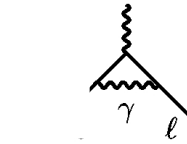
...și mai multe!

Teoria perturbațiilor – corecții

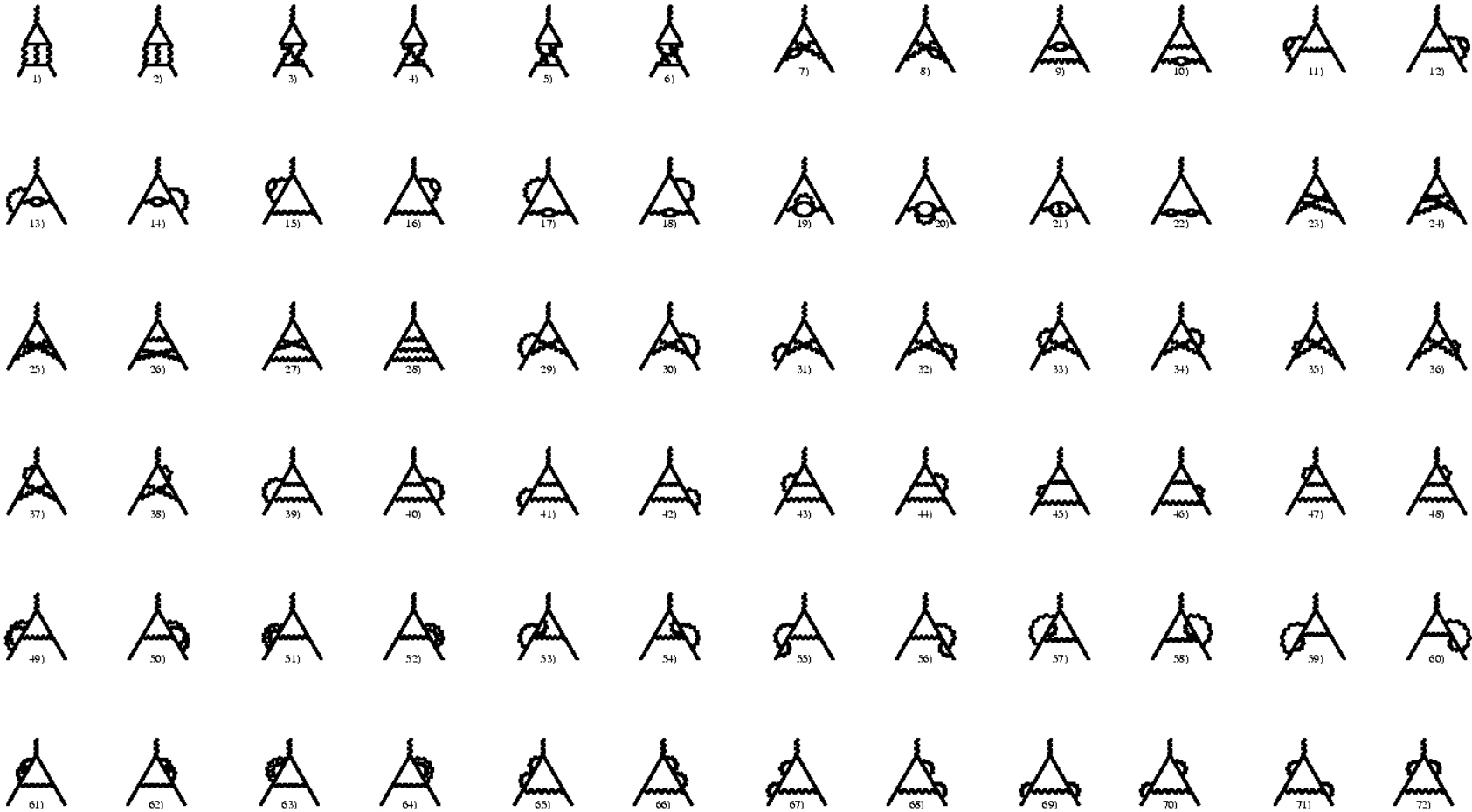


$(g-2)_\ell$

$\ell=e,\mu,\tau$



$$a_e = a_\mu = a_\tau = \frac{\alpha}{2\pi}$$



Fizica particulelor

1. Care sunt particulele elementare (ce proprietăți au – masă, sarcină electrică, spin, ...)?
2. Cum interacționează? - De unde obținem informații?
3. Cum producem particule elementare?
4. Cum detectăm particule elementare?

- **Particle Physics @Calin Alexa**
- **Particle Detectors @Calin Alexa**

3. Cum producem particule elementare?

- ◇ metode simple pentru electroni, protoni (e.g. ionizări)
- ◇ radiații cosmice
- ◇ reactori nucleari
- ◇ acceleratori de particule



Accelerating Science and Innovation

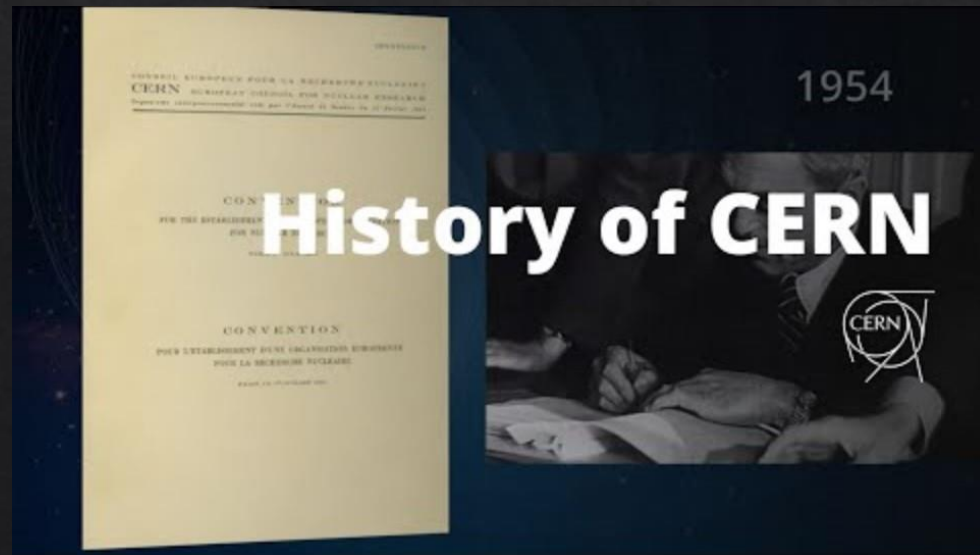


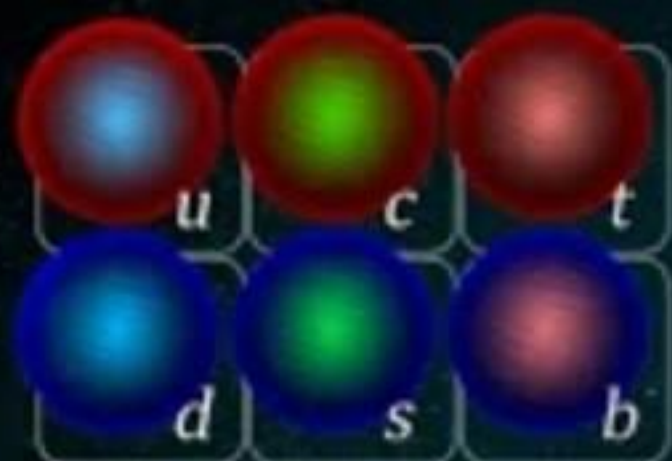
CERN – materiale video, postere etc

<https://home.cern/events/science-gateway-facilities-training> (de exemplu pentru educators: <https://home.cern/resources?audience=21>)

<https://design-guidelines.web.cern.ch/guidelines/70yrs-exhibitions>

<https://cern70.cern/multimedia/>





Quarks



Leptons



Higgs boson

70 years of unveiling the Universe

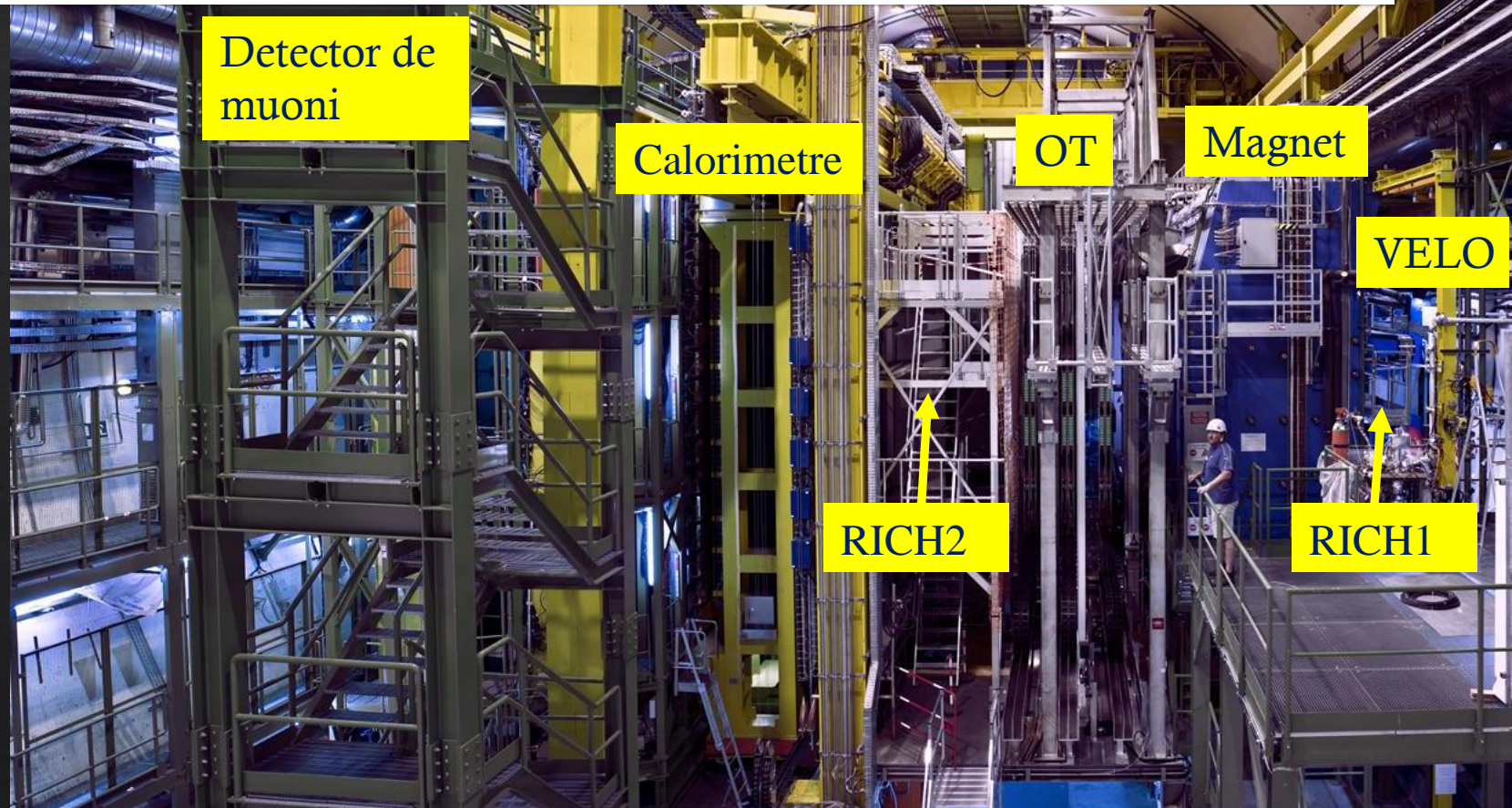


Forces



4. Cum detectăm particule elementare?

◆ ansamblu format din diferiți detectori



Muon Spectrometer

Hadronic Calorimeter

Electromagnetic Calorimeter

Solenoid magnet

Tracking

Transition Radiation Tracker

Pixel/SCT detector

Proton

Neutron

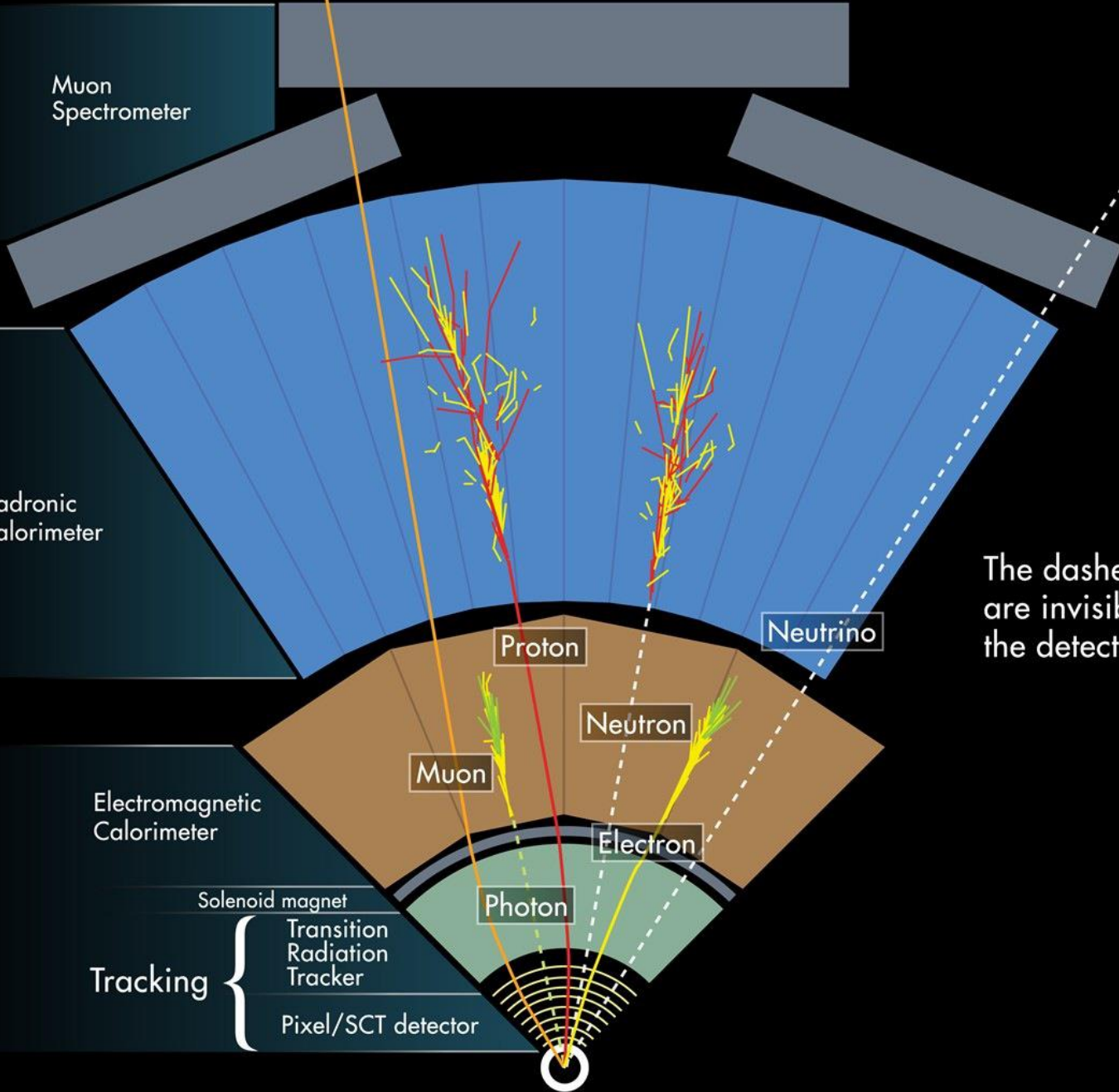
Muon

Electron

Photon

Neutrino

The dashed tracks are invisible to the detector

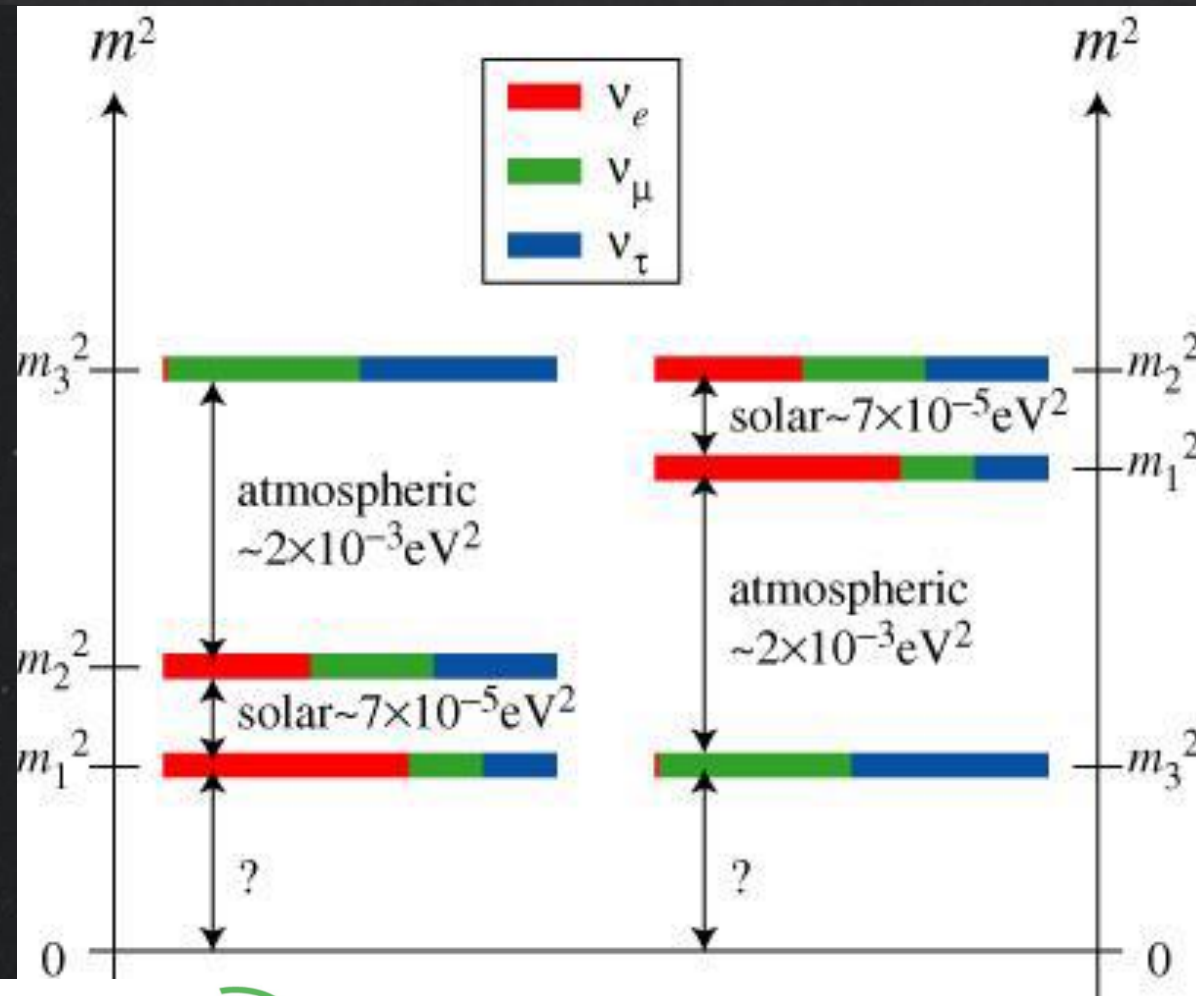


- ? Din ce este constituită materia?
- ? Din ce este compus universul?
- ? Care este originea universului și cum a evoluat?
- ? De ce se comportă așa universul?
- ? Cum va evolua?
- ?

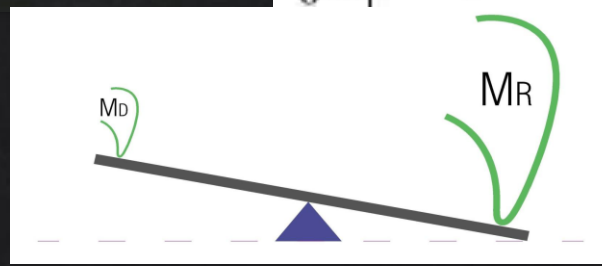
Modelul Standard –
răspunsul la toate întrebările?

◆ **NU!**

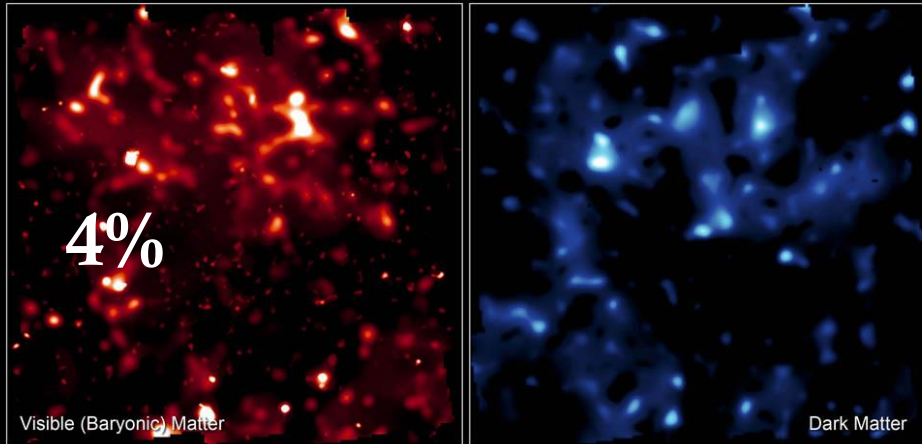
Cum acomodăm în teorie masa neutrinilor?



matricea de mixing a neutrinilor?



Ce este „dark matter”?



Visible (Baryonic) Matter

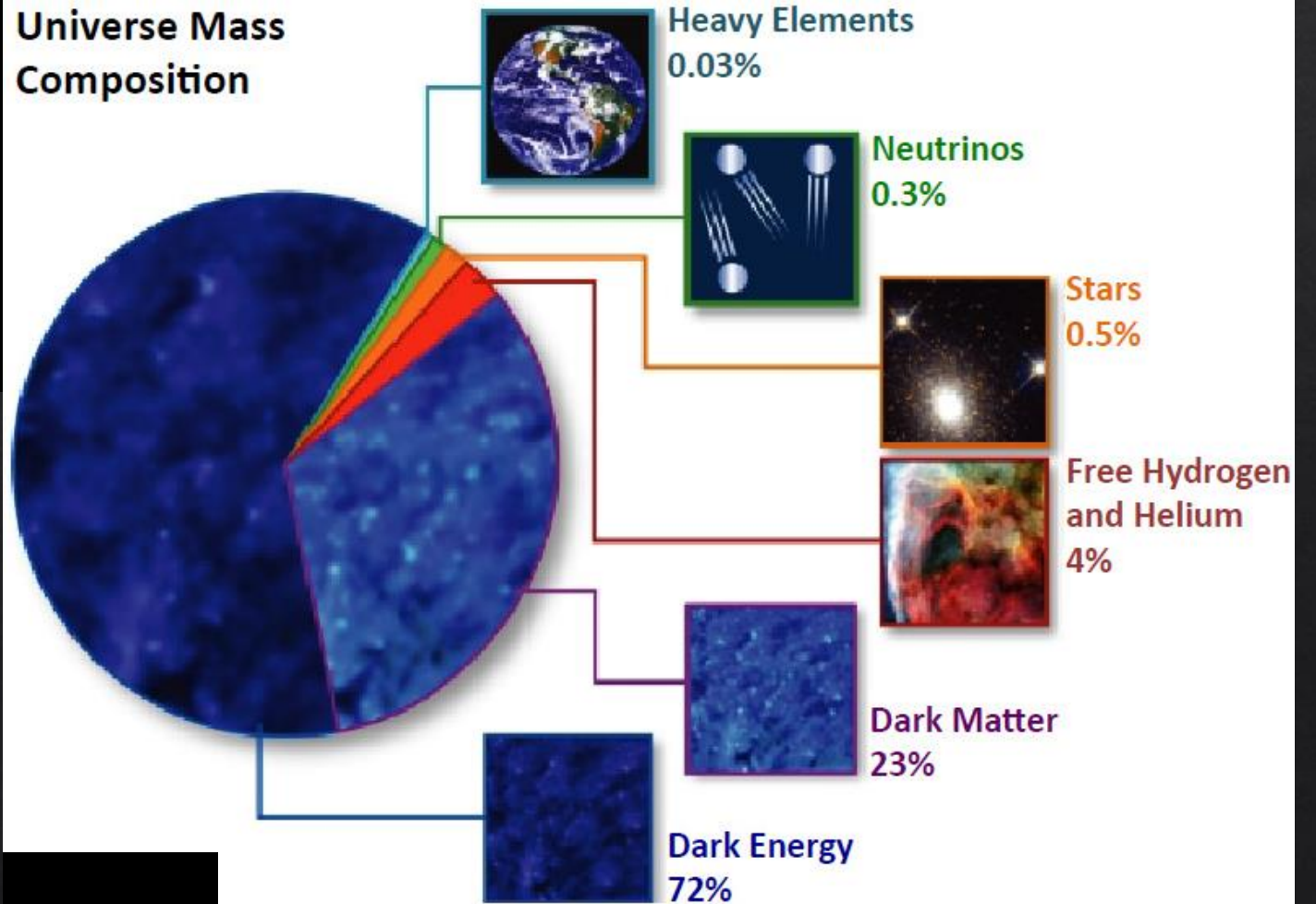
Dark Matter

Distribution of Visible and Dark Matter • Cosmic Evolution Survey
Hubble Space Telescope • Advanced Camera for Surveys

NASA, ESA, and R. Massey (California Institute of Technology)

STScI-PRC07-01b

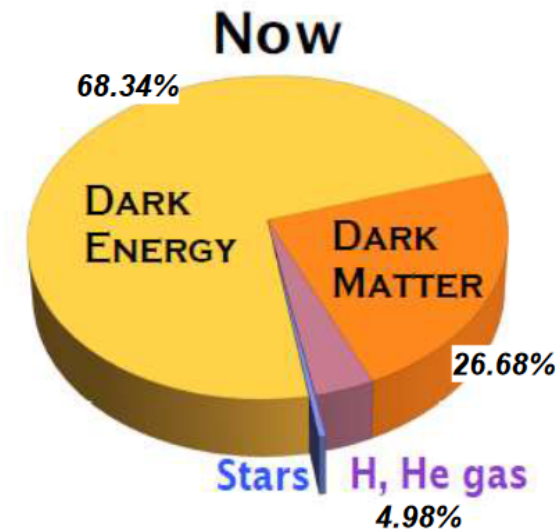
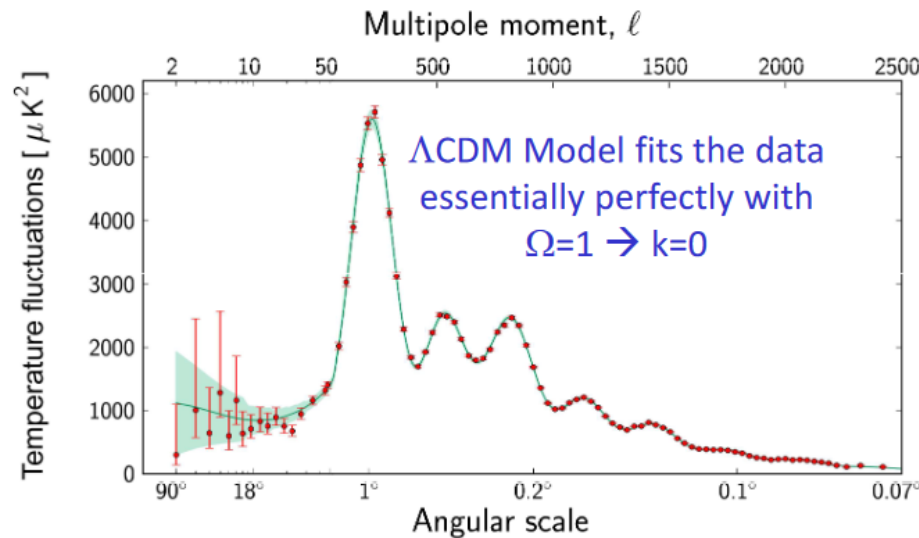
Universe Mass Composition



Vezi: Pascal Pralavorio's on Dark matter

Cosmic microwave background

- Use this photon flux to know the composition of the Universe
 - Decompose data in spherical harmonics
 - Amplitude and position of “acoustic” peaks gives the composition of the Universe



Cosmology is making precision measurements ... and we don't know 95% of the Universe and 85% of the matter !

De ce în univers există mai multă materie decât antimaterie?

- ◇ Există cantități mari de materie, dar nu și dovada unor cantități mari de antimaterie.

violarea conservării sarcinii și parității
CP – charge-parity

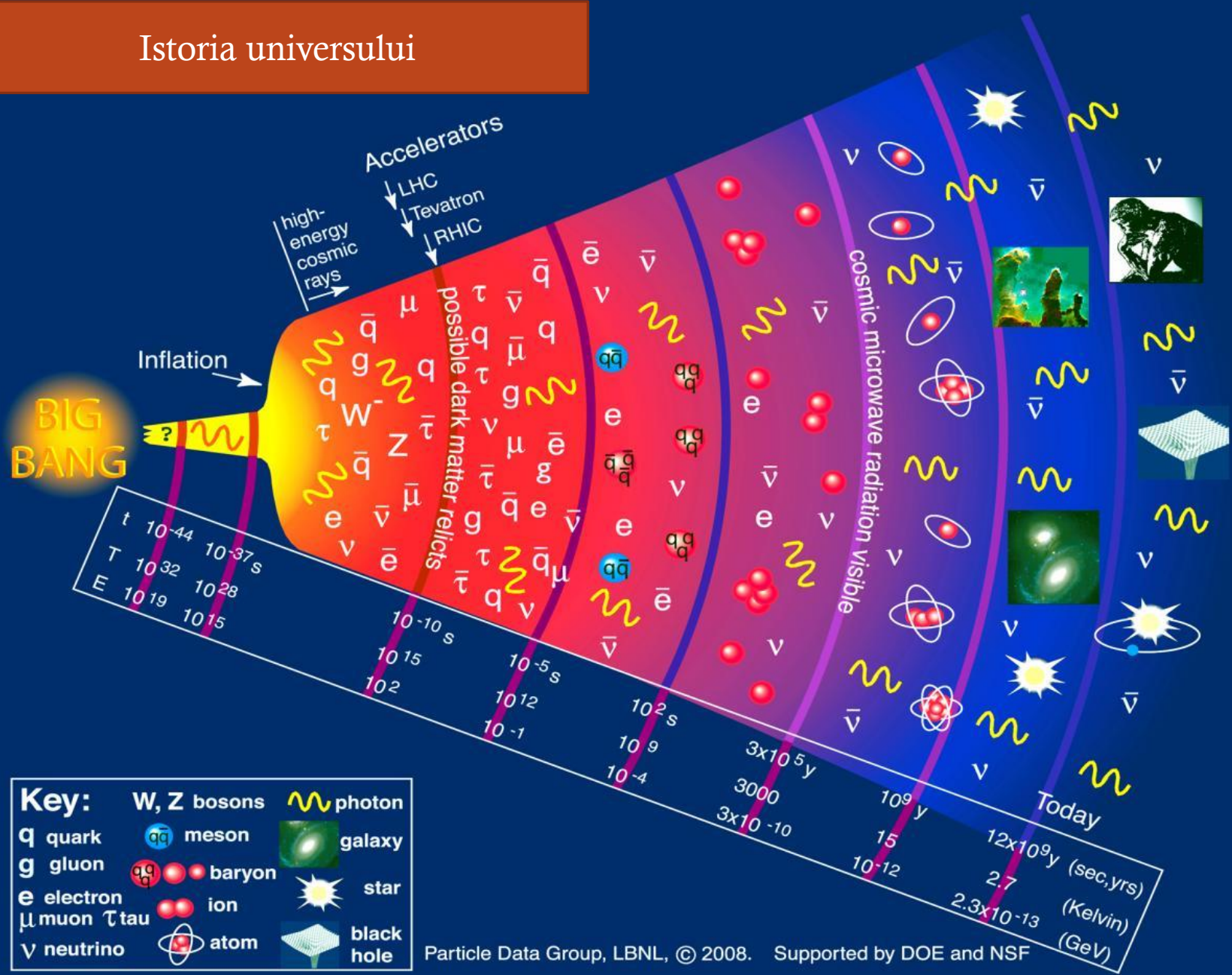


beauty
 B^0

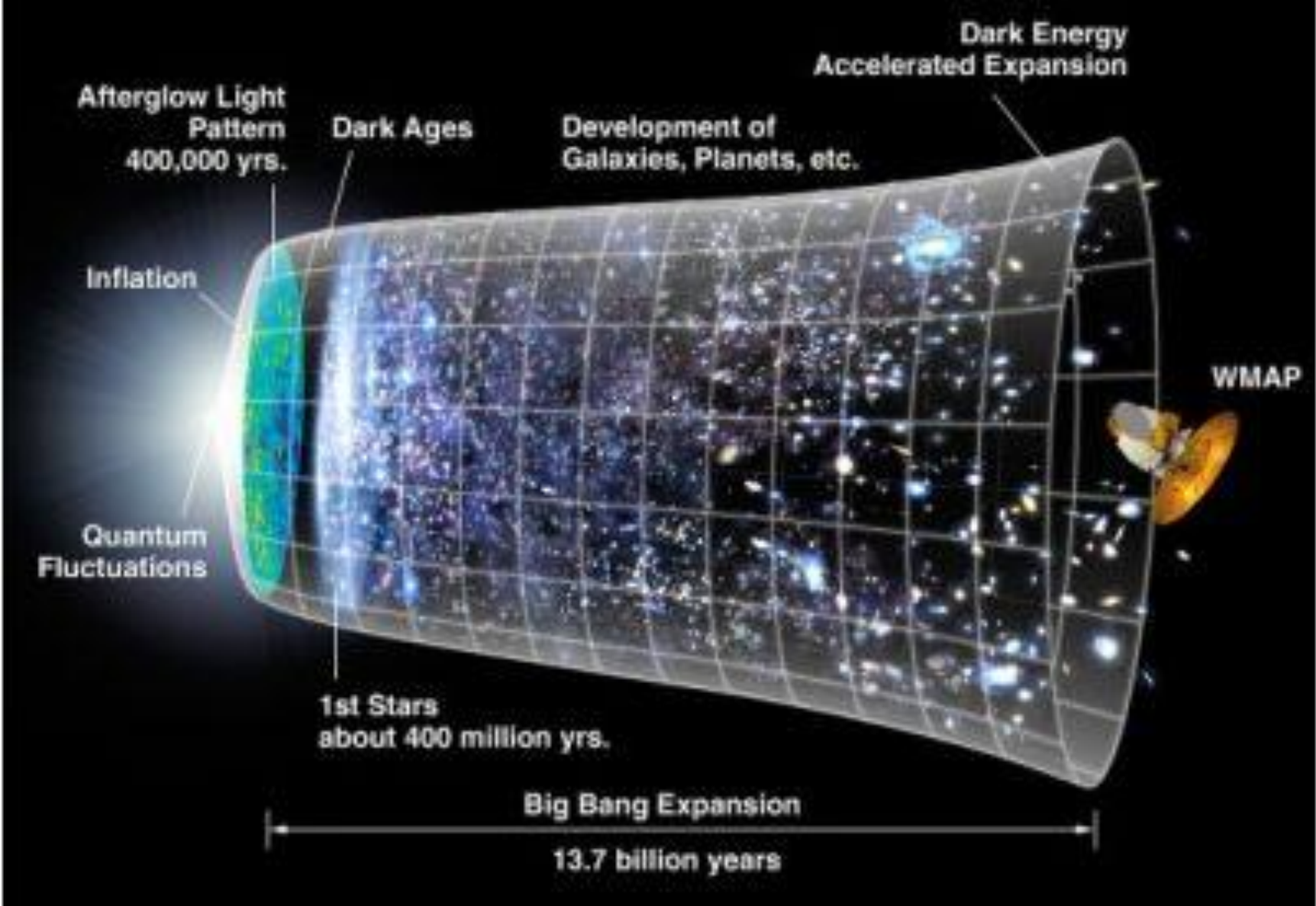


anti-beauty
 $\overline{B^0}$

Istoria universului



Ce face universul astăzi și cum va evolua?




Modelul Standard –
răspunsul la toate întrebările?

◇ **NU!**

- **Extensions of the Standard Model of elementary particles**

Particle Listings

R.L. Workman *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. **2022**, 083C01 (2022) and 2023 update

Cut-off date for Listings/Summary Tables was Jan. 15, 2023. Files can be downloaded directly by clicking on the icon: . For a key to the listings [click here](#).

Expand/Collapse All

Gauge & Higgs Bosons

gamma

g (gluon)

graviton

W boson

Z boson

H

Neutral Higgs Bosons, Searches for

Charged Higgs Bosons (H^\pm and $H^{\pm\pm}$), Searches for

Heavy Bosons, Other Than Higgs Bosons, Searches for

Axions (A^0) and Other Very Light Bosons, Searches for

Leptons (e, mu, tau, neutrinos, heavy leptons ...)

electron



[pdg Live](#)

muon



[pdg Live](#)

tau



[pdg Live](#)

Heavy Charged Lepton Searches



[pdg Live](#)

Neutrino Properties



[pdg Live](#)

Number of Neutrino Types



[pdg Live](#)

Double-beta Decay



[pdg Live](#)

Neutrino Mixing



[pdg Live](#)

Heavy Neutral Leptons, Searches for



[pdg Live](#)

Quarks (u,d,s,c,b,t...)

LIGHT QUARKS --- u, d, s



[pdg Live](#)

c quark



[pdg Live](#)

b quark



[pdg Live](#)

t quark



[pdg Live](#)

b' quark (4**th Generation)



[pdg Live](#)

t' quark (4**th Generation)



[pdg Live](#)

Free Quark Searches



[pdg Live](#)

Fizica particulelor

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- Particle Physics @Calin Alexa
- Particle Detectors @Calin Alexa & co.