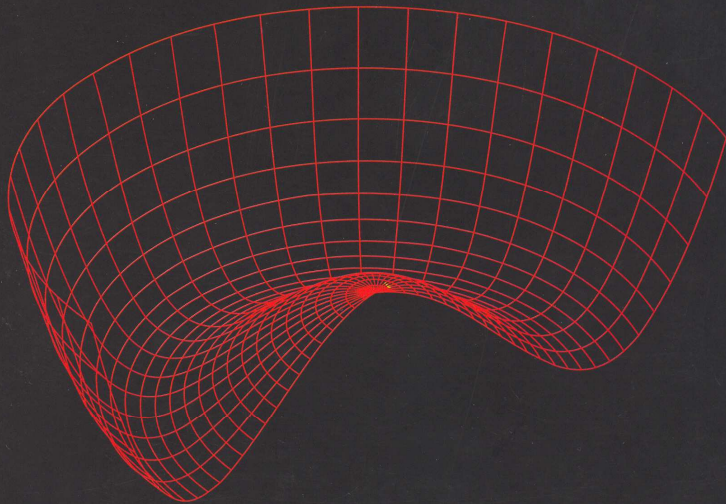


Ivica Picek

FIZIKA

elementarnih

ČESTICA



I. UVODNO PREDAVANJE

- Fizika realnog svijeta, §1.1
- Čestice na kvantnom stepeništu, §1.2
- Razotkrivanje fundamentalnih skala
- Fundamentalne konstante i jedinice
- Program ujedinjenja sila i standardni model



Što je fizika elementarnih čestica?

- "Particle physics is a modern name for the long quest to understand the laws of nature" (E.Witten, Split'08)
- Postignuće: STANDARDNI MODEL temeljnih čestica i sila
- "The Standard Model is the most complete mathematical THEORY ever developed" (F.Wilczek)

DZ 1.1:
Opiši
ukratko
“svoje
otkriće” s
liste pola
stoljeća
Nobelovih
nagrada
vezanih uz
standardni
model

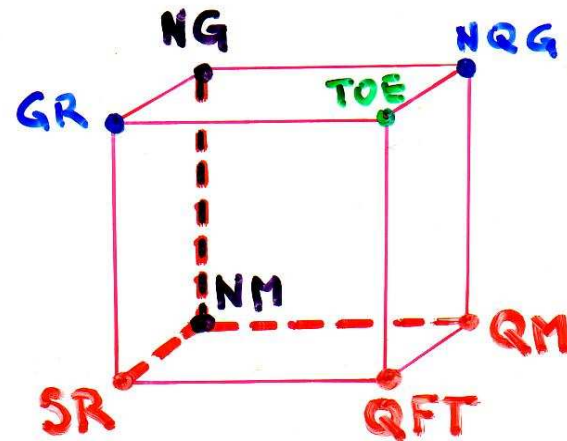
Year	Recipient(s)	Subject
1957	T. D. Lee and C. N. Yang	Parity violation
1960	D. A. Glaser	Bubble chamber
1965	R. P. Feynman, J. S. Schwinger, and S. I. Tomonaga	Quantum electrodynamics
1968	L. W. Alvarez	Discovery of resonances
1969	M. Gell-Mann	Particle classification
1976	B. Richter and S. C. C. Ting	J/ψ discovery
1979	S. L. Glashow, A. Salam, and S. Weinberg	Electroweak unification
1980	J. W. Cronin and V. L. Fitch	CP violation
1982	K. G. Wilson	Critical phenomena
1984	C. Rubbia and S. Van Der Meer	W and Z discovery via $S\bar{p}pS$ collider
1988	L. M. Lederman, M. Schwartz, and J. Steinberger	Discovery that $\nu_\mu \neq \nu_e$
1990	J. I. Friedman, H. W. Kendall, and R. E. Taylor	Deep inelastic electron scattering
1992	G. Charpak	Particle detectors
1995	M. L. Perl F. Reines	τ lepton Neutrino detection
1999	G. 't Hooft and M. J. G. Veltman	Electroweak interactions
2002	R. Davis and M. Koshiba R. Giacconi	Cosmic neutrinos Cosmic X-rays

Novije Nobelove nagrade (opisane u MFL-u)

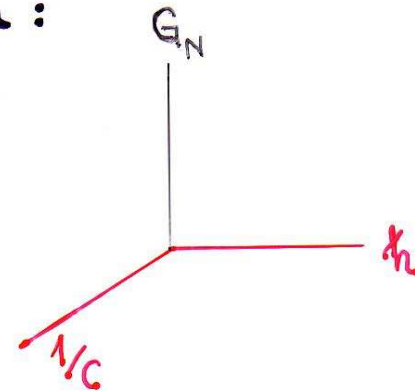
- **G.'t Hooft & M. Veltman 1999.** "za rad koji je rasvijetlio kvantnu strukturu elektroslabih međudjelovanja u fizici"; **MFL 2/198, 74**
- **R. Davis & M. Koshiba 2002.** "za pionirske doprinose astrofizici, posebice za detekciju kozmičkih neutrina"; **MFL 3/211, 176**
- **D. Gross, D. Politzer & F. Wilczek 2004.** "za otkriće asimptotske slobode u teoriji jakog međudjelovanja"; **MFL 2/218, 91 (poster HFD-a)**
- **& G. Smoot 2006.** "za otkriće da kozmička mikrovalna **J. Mather** pozadina ima oblik zračenja crnog tijela, te za otkriće njezine anizotropije; **MFL 2/226, 104**
- **Yoichiro Nambu 2008.** "za otkriće mehanizma spontanog narušenja simetrije u subatomske fizici" & **Makoto Kobayashi i Toshihide Maskawa** "za otkriće porijekla narušene simetrije koja predviđa postojanje barem triju obitelji kvarkova u prirodi" ; **MFL 3/235, 208**

DZ 1.2: Pomoću
tri
fundamentalne
konstante, h , c i
 G_N izvrijednite
 L_P , M_P i T_P

Bronshtein - Želmanovljeva
KOCKA FIZIKALNIH TEORIJA

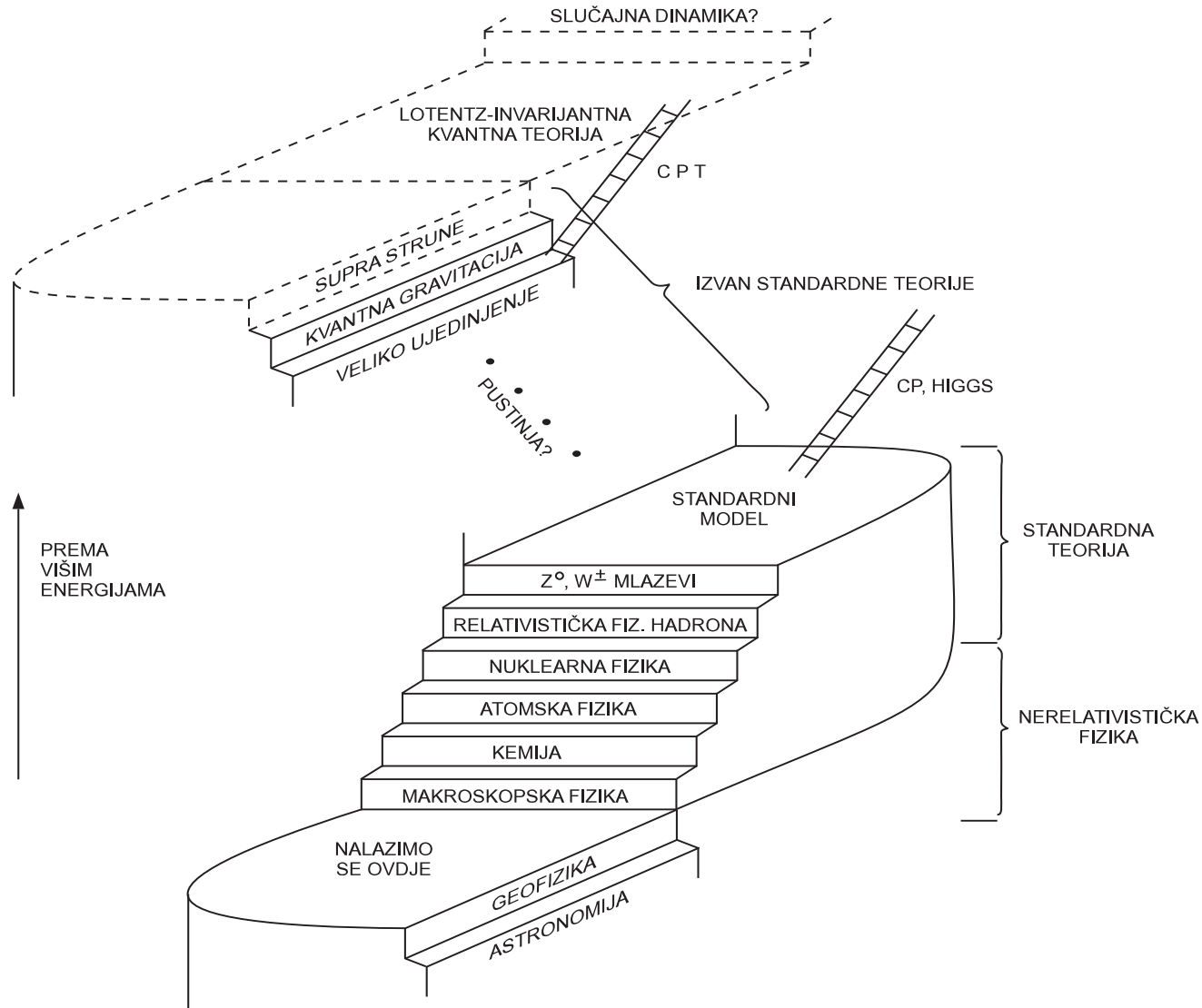


na
osima :



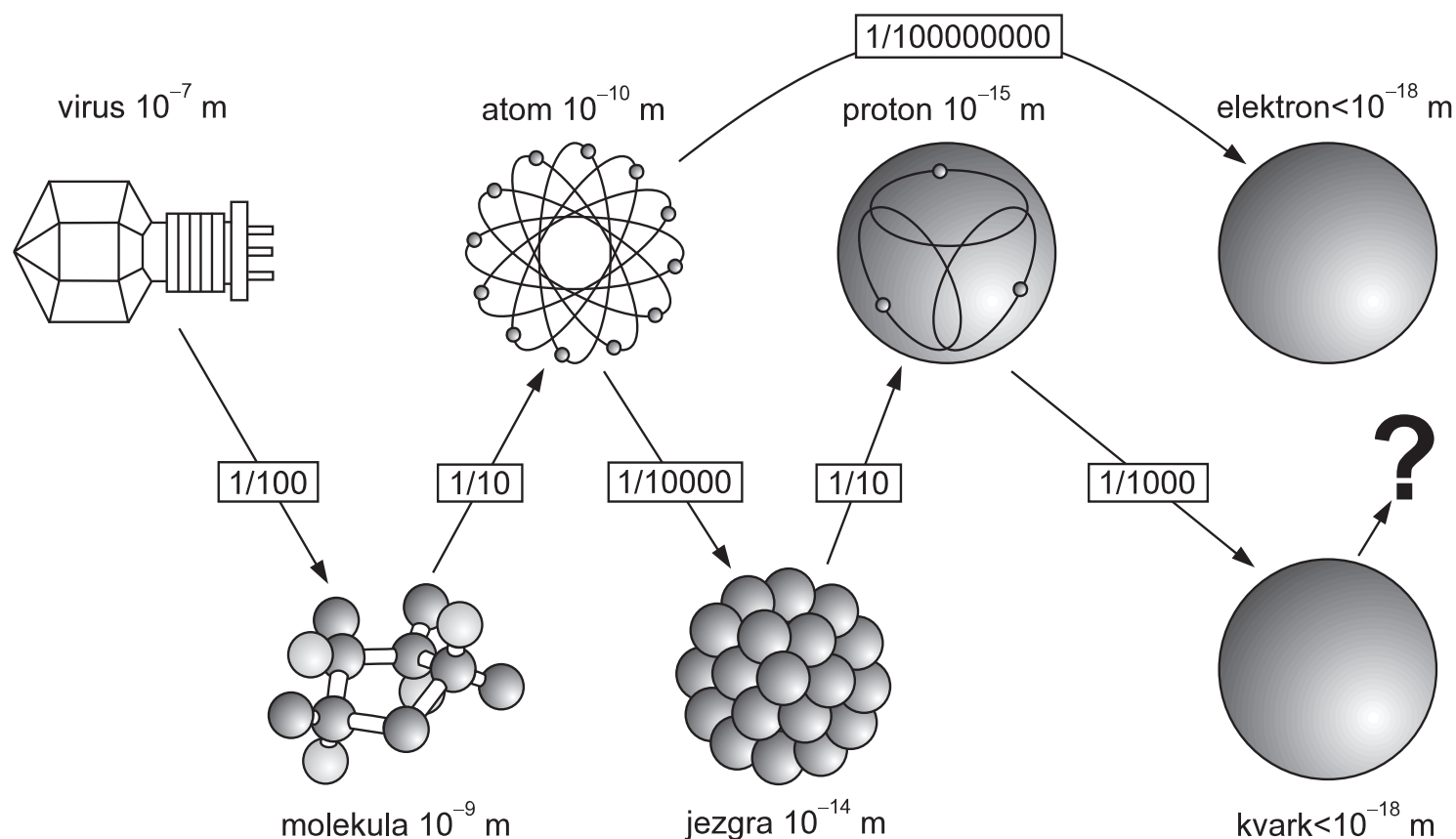
Kvantno stepenište

- od "makro" do subatomske razina

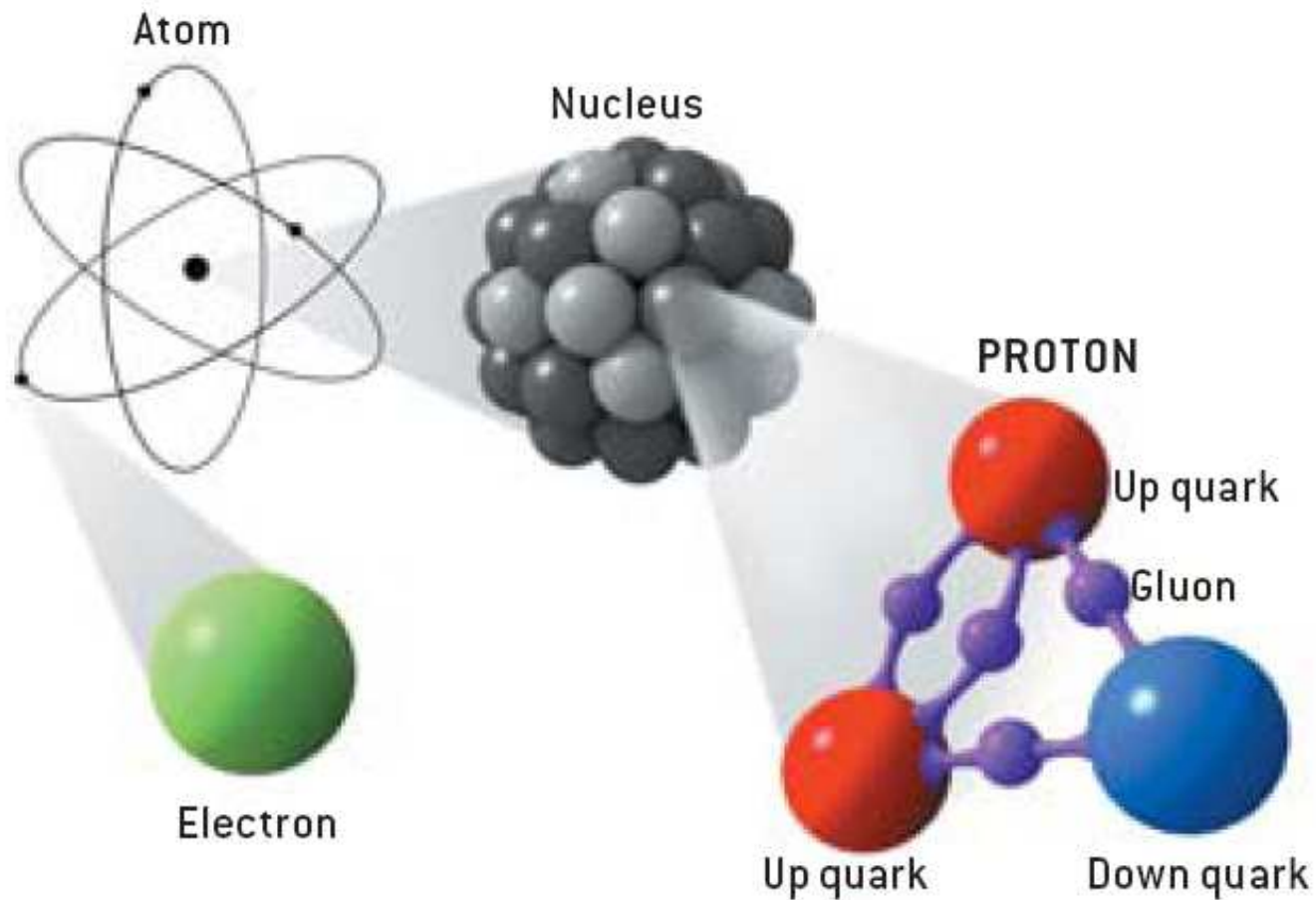


Programom redukcionizma

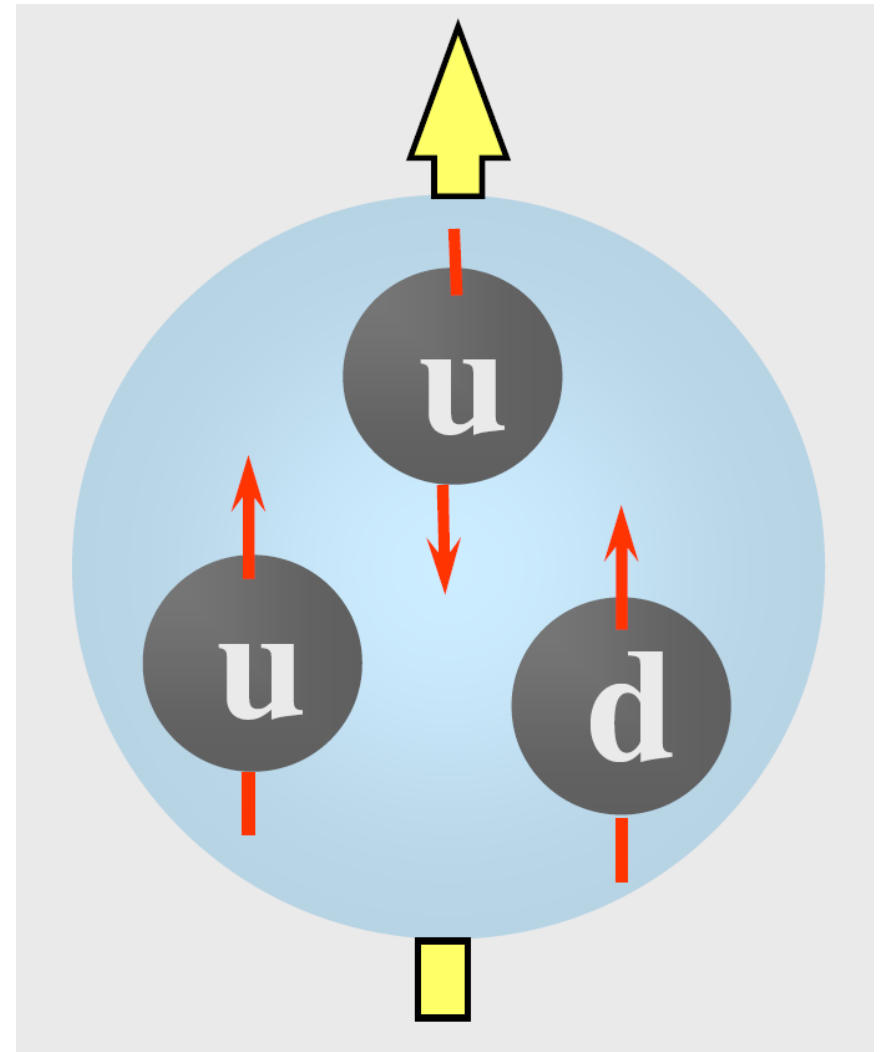
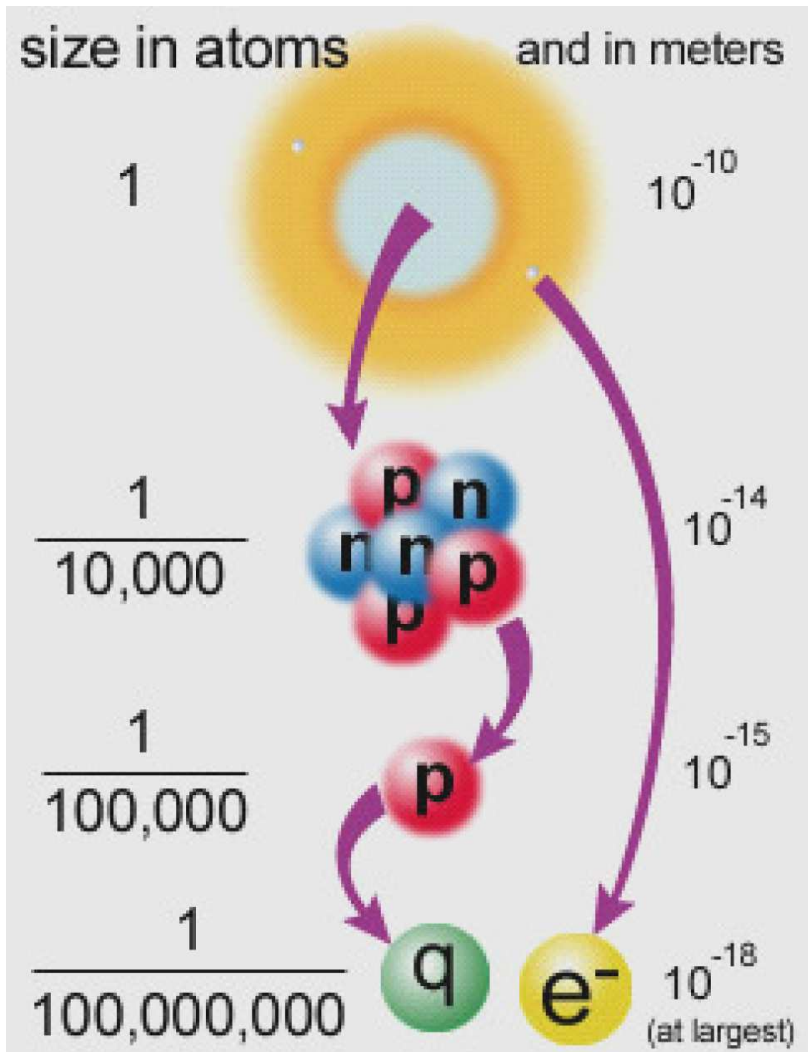
- do subatomskih temeljnih čestica



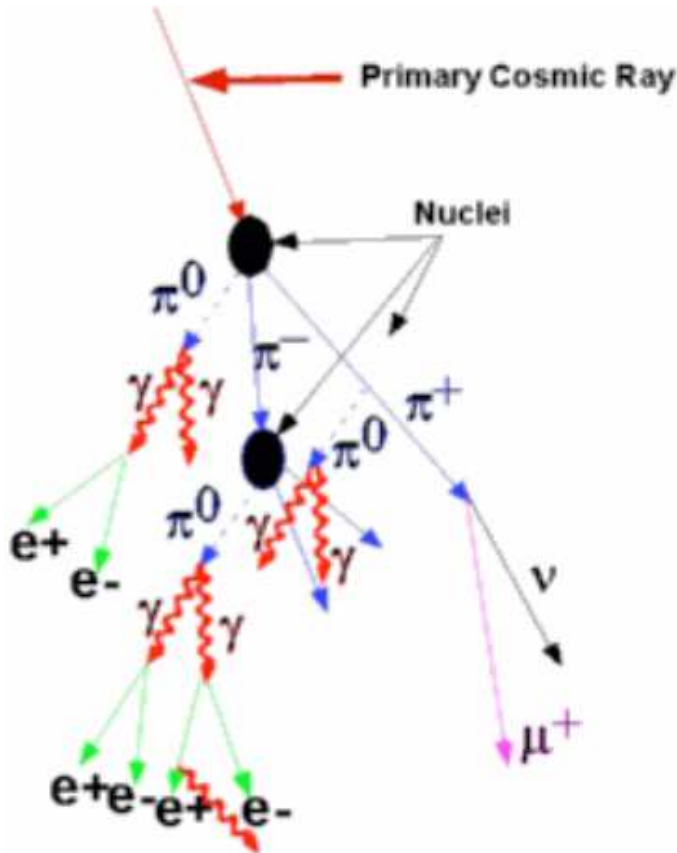
Temeljne čestice obične tvari



Svođenje na svijet kvarkova i leptona



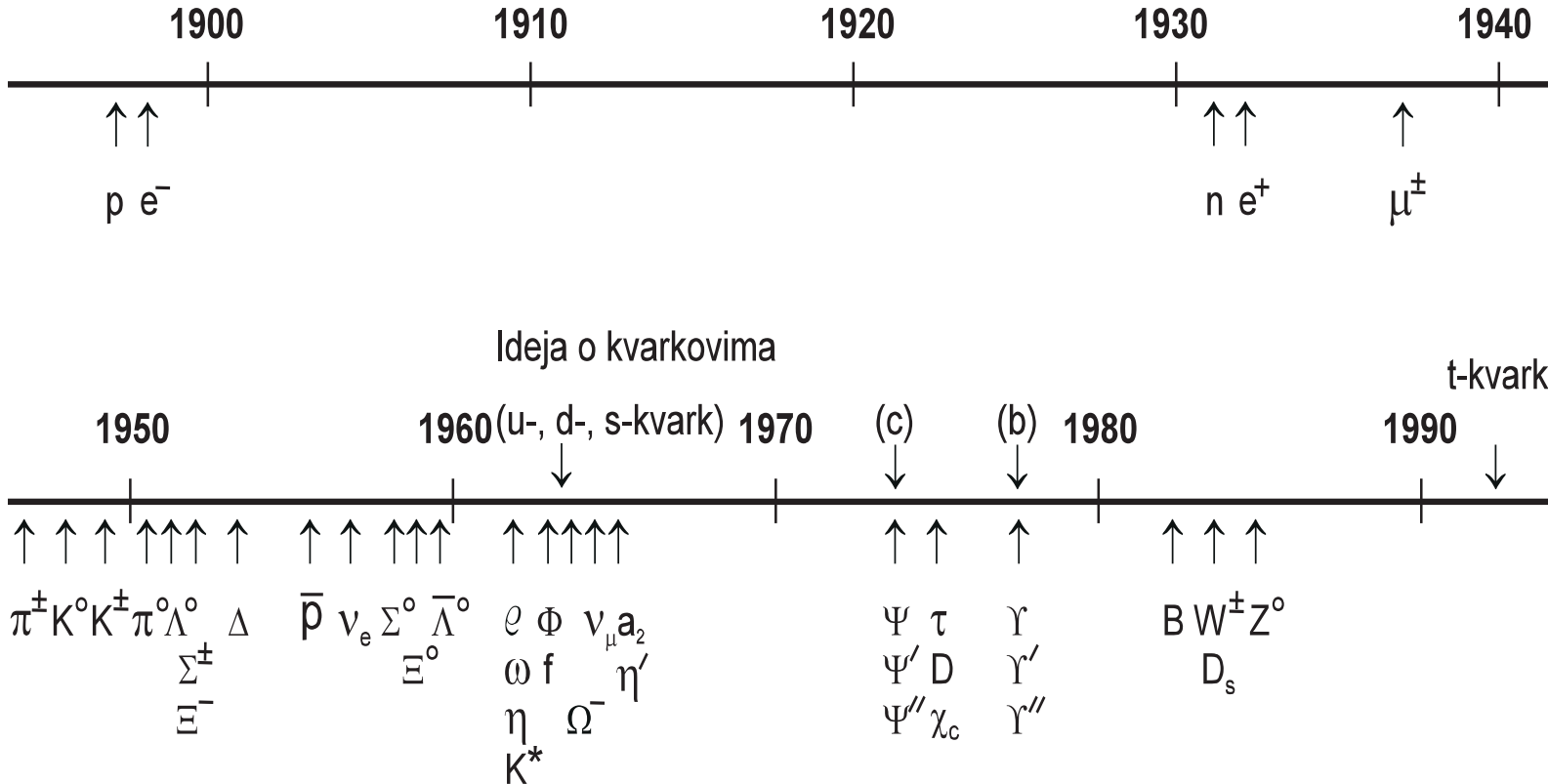
Era otkrića elementarnih čestica u kozmičkom zračenju



Particle	Year	Discoverer (Nobel Prize)	Method
e^-	1897	Thomson (1906)	Discharges in gases
p	1919	Rutherford	Natural radioactivity
n	1932	Chadwick (1935)	Natural radioactivity
e^+	1933	Anderson (1936)	Cosmic Rays
μ^\pm	1937	Neddermeyer, Anderson	Cosmic Rays
π^\pm	1947	Powell (1950) , Occhialini	Cosmic Rays
K^\pm	1949	Powell (1950)	Cosmic Rays
π^0	1949	Bjorklund	Accelerator
K^0	1951	Armenteros	Cosmic Rays
Λ^0	1951	Armenteros	Cosmic Rays
Δ	1932	Anderson	Cosmic Rays
Ξ^-	1932	Armenteros	Cosmic Rays
Σ^\pm	1953	Bonetti	Cosmic Rays
p^-	1955	Chamberlain, Segre' (1959)	Accelerators
anything else	1955 \implies today	various groups	Accelerators
$m_\nu \neq 0$	2000	KAMIOKANDE	Cosmic rays

Eksplzija otkrića čestica po uvođenju akceleratora

KALENDAR OTKRIĆA ČESTICA



Gdje je tu elementarnost?

LIGHT UNFLAVORED (S = C ± B = 0)		STRANGE (S = ±1, C = B = 0)		BOTTOM (B = ±1)	
$J^P(J^{PC})$	$J^P(J^{PC})$	$J^P(J^{PC})$	$J^P(J^{PC})$	$J^P(J^{PC})$	$J^P(J^{PC})$
<ul style="list-style-type: none"> π^\pm $1^-(0^-)$ π^0 $1^-(0^-)$ η $0^+(0^-)$ $\eta(600)$ $0^+(0^+)$ $\rho(770)$ $1^+(1^-)$ $\omega(782)$ $0^-(1^-)$ $\eta(958)$ $0^+(0^+)$ $\eta(980)$ $0^+(0^+)$ $a_0(980)$ $1^-(0^+)$ $\phi(1020)$ $0^-(1^-)$ $h_1(1170)$ $0^-(1^+)$ $b_1(1235)$ $1^+(1^-)$ $a_1(1260)$ $1^-(1^+)$ $f_2(1270)$ $0^+(2^+)$ $f_1(1285)$ $0^+(1^+)$ $\eta(1295)$ $0^+(0^+)$ $\pi(1300)$ $1^-(0^-)$ $a_2(1320)$ $1^-(2^+)$ $f_0(1370)$ $0^+(0^+)$ $h_1(1380)$ $?^-(1^+)$ $\pi_1(1400)$ $1^-(1^-)$ $\eta(1405)$ $0^+(0^+)$ $f_1(1420)$ $0^+(1^+)$ $\omega(1420)$ $0^-(1^-)$ $f_2(1430)$ $0^+(2^+)$ $a_0(1450)$ $1^-(0^+)$ $\rho(1450)$ $1^+(1^-)$ $\eta(1475)$ $0^+(0^+)$ $f_0(1500)$ $0^+(0^+)$ $f_1(1510)$ $0^+(1^+)$ $f_2'(1525)$ $0^+(2^+)$ $f_2(1565)$ $0^+(2^+)$ $h_1(1595)$ $0^-(1^+)$ $\pi_1(1600)$ $1^-(1^-)$ $a_1(1640)$ $1^-(1^+)$ $f_2(1640)$ $0^+(2^+)$ $\eta_2(1645)$ $0^+(2^-)$ $\omega(1650)$ $0^-(1^-)$ $\omega_3(1670)$ $0^-(3^-)$ 	<ul style="list-style-type: none"> $\pi_2(1670)$ $1^-(2^+)$ $\phi(1680)$ $0^-(1^-)$ $\rho_3(1690)$ $1^+(3^-)$ $\rho(1700)$ $1^+(1^-)$ $a_2(1700)$ $1^-(2^+)$ $f_0(1710)$ $0^+(0^+)$ $\eta(1760)$ $0^+(0^+)$ $\pi(1800)$ $1^-(0^+)$ $f_2(1810)$ $0^+(2^+)$ $X(1835)$ $?^?(?^-)$ $\phi_3(1850)$ $0^-(3^-)$ $\eta_2(1870)$ $0^+(2^+)$ $\rho(1900)$ $1^+(1^-)$ $f_3(1910)$ $0^+(2^+)$ $f_2(1950)$ $0^+(2^+)$ $\rho_3(1990)$ $1^+(3^-)$ $f_2(2010)$ $0^+(2^+)$ $f_0(2020)$ $0^+(0^+)$ $a_4(2040)$ $1^-(4^+)$ $f_4(2050)$ $0^+(4^+)$ $\pi_2(2100)$ $1^-(2^-)$ $f_0(2100)$ $0^+(0^+)$ $f_2(2150)$ $0^+(2^+)$ $\rho(2150)$ $1^+(1^-)$ $f_0(2200)$ $0^+(0^+)$ $f_3(2220)$ $0^+(2^+)$ $\eta(2225)$ $0^+(0^+)$ $\rho_3(2250)$ $1^+(3^-)$ $f_2(2300)$ $0^+(2^+)$ $f_4(2300)$ $0^+(4^+)$ $f_2(2340)$ $0^+(2^+)$ $\rho_3(2350)$ $1^+(5^-)$ $a_6(2450)$ $1^-(6^+)$ $f_6(2510)$ $0^+(6^+)$ 	<ul style="list-style-type: none"> K^\pm $1/2(0^-)$ K^0 $1/2(0^-)$ K_S^0 $1/2(0^-)$ K_L^0 $1/2(0^-)$ $K_S^*(800)$ $1/2(0^+)$ $K^*(892)$ $1/2(1^-)$ $K_1(1270)$ $1/2(1^+)$ $K_1(1400)$ $1/2(1^+)$ $K^*(1410)$ $1/2(1^-)$ $K_0^*(1430)$ $1/2(0^+)$ $K_2^*(1430)$ $1/2(2^+)$ $K(1460)$ $1/2(0^-)$ $K_2(1580)$ $1/2(2^-)$ $K(1630)$ $1/2(2^?)$ $K_1(1650)$ $1/2(1^+)$ $K^*(1680)$ $1/2(1^-)$ $K_2(1770)$ $1/2(2^-)$ $K_3^*(1780)$ $1/2(3^-)$ $K_2(1820)$ $1/2(2^-)$ $K(1830)$ $1/2(0^+)$ $K_0^*(1950)$ $1/2(0^+)$ $K_2^*(1980)$ $1/2(2^+)$ $K_4^*(2045)$ $1/2(4^+)$ $K_2(2250)$ $1/2(2^-)$ $K_3(2320)$ $1/2(3^+)$ $K_4^*(2380)$ $1/2(5^-)$ $K_4(2500)$ $1/2(4^-)$ $K(3100)$ $?^?(?^?)$ 	<ul style="list-style-type: none"> B^\pm $1/2(0^-)$ B^0 $1/2(0^-)$ B^\pm/B^0 ADMIXTURE $B^\pm/B^0/B_S^0/b$-baryon AD-MIXTURE V_{cb} and V_{ub} CKM Matrix Elements B^* $1/2(1^-)$ B_s^*(5732) $?^?(?^?)$ 	<p>BOTTOM, STRANGE (B = ±1, S = ±1)</p> <ul style="list-style-type: none"> B_s^0 $0(0^-)$ B_s^+ $0(1^-)$ $B_{s,J}^*$(5850) $?^?(?^?)$ 	<p>BOTTOM, CHARMED (B = C = ±1)</p> <ul style="list-style-type: none"> B_c^\pm $0(0^-)$
		<p>CHARMED (C = ±1)</p> <ul style="list-style-type: none"> D^\pm $1/2(0^-)$ D^0 $1/2(0^-)$ $D^*(2007)^0$ $1/2(1^-)$ $D^*(2010)^\pm$ $1/2(1^-)$ $D_0^*(2400)^0$ $1/2(0^+)$ $D_0^*(2400)^\pm$ $1/2(0^+)$ $D_1(2420)^0$ $1/2(1^+)$ $D_1(2420)^\pm$ $1/2(2^?)$ $D_1(2430)^0$ $1/2(1^+)$ $D_2^*(2460)^0$ $1/2(2^+)$ $D_2^*(2460)^\pm$ $1/2(2^+)$ $D^*(2640)^\pm$ $1/2(2^?)$ 		<p>CHARMED, STRANGE (C = S = ±1)</p> <ul style="list-style-type: none"> D_s^\pm $0(0^-)$ $D_s^{*\pm}$ $0(2^?)$ $D_{s0}^*(2317)^\pm$ $0(0^+)$ $D_{s1}(2460)^\pm$ $0(1^+)$ $D_{s1}(2536)^\pm$ $0(1^+)$ $D_{s2}(2573)^\pm$ $0(2^?)$ 	
OTHER LIGHT				<p>$c\bar{c}$</p> <ul style="list-style-type: none"> $\eta_c(1S)$ $0^+(0^-)$ $J/\psi(1S)$ $0^-(1^-)$ $\chi_{c0}(1P)$ $0^+(0^+)$ $\chi_{c1}(1P)$ $0^+(1^+)$ $\chi_{c2}(1P)$ $?^?(2^?)$ $\chi_{c0}(1P)$ $0^+(2^+)$ $\eta_c(2S)$ $0^+(0^+)$ $\psi(2S)$ $0^-(1^-)$ $\psi(3770)$ $0^-(1^-)$ $X(3872)$ $0^?(2^?)$ $\chi_{c2}(2P)$ $0^+(2^+)$ $Y(3940)$ $?^?(?^?)$ $\psi(4040)$ $0^-(1^-)$ $\psi(4160)$ $0^-(1^-)$ $Y(4260)$ $?^?(1^-)$ $\psi(4415)$ $0^-(1^-)$ 	
Further States				<p>$b\bar{b}$</p> <ul style="list-style-type: none"> $\eta_b(1S)$ $0^+(0^-)$ $\Upsilon(1S)$ $0^-(1^-)$ $\chi_{b0}(1P)$ $0^+(0^+)$ $\chi_{b1}(1P)$ $0^+(1^+)$ $\chi_{b2}(1P)$ $0^+(2^+)$ $\Upsilon(2S)$ $0^-(1^-)$ $\Upsilon(2S)$ $0^-(2^-)$ $\chi_{b0}(2P)$ $0^+(0^+)$ $\chi_{b1}(2P)$ $0^+(1^+)$ $\chi_{b2}(2P)$ $0^+(2^+)$ $\Upsilon(3S)$ $0^-(1^-)$ $\Upsilon(4S)$ $0^-(1^-)$ $\Upsilon(10860)$ $0^-(1^-)$ $\Upsilon(11020)$ $0^-(1^-)$ 	
				NON-q \bar{q} CANDIDATES	

p	P_{11} ****	$\Delta(1232)$	P_{33} ****	Λ	P_{01} ****	Σ^+	P_{11} ****	Ξ^0	P_{11} ****
n	P_{11} ****	$\Delta(1600)$	P_{33} ***	$\Lambda(1405)$	S_{01} ****	Σ^0	P_{11} ****	Ξ^-	P_{11} ****
$N(1440)$	P_{11} ****	$\Delta(1620)$	S_{31} ****	$\Lambda(1520)$	D_{03} ****	Σ^-	P_{11} ****	$\Xi(1530)$	P_{13} ****
$N(1520)$	D_{13} ****	$\Delta(1700)$	D_{33} ****	$\Lambda(1600)$	P_{01} ***	$\Sigma(1385)$	P_{13} ****	$\Xi(1620)$	*
$N(1535)$	S_{11} ****	$\Delta(1750)$	P_{31} *	$\Lambda(1670)$	S_{01} ****	$\Sigma(1480)$	*	$\Xi(1690)$	***
$N(1650)$	S_{11} ****	$\Delta(1900)$	S_{31} **	$\Lambda(1690)$	D_{03} ****	$\Sigma(1560)$	**	$\Xi(1820)$	D_{13} ***
$N(1675)$	D_{15} ****	$\Delta(1905)$	F_{35} ****	$\Lambda(1800)$	S_{01} ***	$\Sigma(1580)$	D_{13} *	$\Xi(1950)$	***
$N(1680)$	F_{15} ****	$\Delta(1910)$	P_{31} ****	$\Lambda(1810)$	P_{01} ***	$\Sigma(1620)$	S_{11} **	$\Xi(2030)$	***
$N(1700)$	D_{13} ***	$\Delta(1920)$	P_{33} ***	$\Lambda(1820)$	F_{05} ****	$\Sigma(1660)$	P_{11} ***	$\Xi(2120)$	*
$N(1710)$	P_{11} ***	$\Delta(1930)$	D_{35} ***	$\Lambda(1830)$	D_{05} ****	$\Sigma(1670)$	D_{13} ****	$\Xi(2250)$	**
$N(1720)$	P_{13} ****	$\Delta(1940)$	D_{33} *	$\Lambda(1890)$	P_{03} ****	$\Sigma(1690)$	**	$\Xi(2370)$	**
$N(1900)$	P_{13} **	$\Delta(1950)$	F_{37} ****	$\Lambda(2000)$	*	$\Sigma(1750)$	S_{11} ***	$\Xi(2500)$	*
$N(1990)$	F_{17} **	$\Delta(2000)$	F_{35} **	$\Lambda(2020)$	F_{07} *	$\Sigma(1770)$	P_{11} *		
$N(2000)$	F_{15} **	$\Delta(2150)$	S_{31} *	$\Lambda(2100)$	G_{07} ****	$\Sigma(1775)$	D_{15} ****	Ω^-	****
$N(2080)$	D_{13} **	$\Delta(2200)$	G_{37} *	$\Lambda(2110)$	F_{05} ***	$\Sigma(1840)$	P_{13} *	$\Omega(2250)^-$	***
$N(2090)$	S_{11} *	$\Delta(2300)$	H_{39} **	$\Lambda(2325)$	D_{03} **	$\Sigma(1880)$	P_{11} **	$\Omega(2380)^-$	**
$N(2100)$	P_{11} *	$\Delta(2350)$	D_{35} *	$\Lambda(2350)$	**	$\Sigma(1915)$	F_{15} ****	$\Omega(2470)^-$	**
$N(2190)$	G_{17} ****	$\Delta(2390)$	F_{37} *	$\Lambda(2585)$	H_{09} **	$\Sigma(1940)$	D_{13} ***		
$N(2200)$	D_{15} **	$\Delta(2400)$	G_{39} **			$\Sigma(2000)$	S_{11} *	Λ_c^+	****
$N(2220)$	H_{19} ****	$\Delta(2420)$	$H_{3,11}$ ****			$\Sigma(2030)$	F_{17} ****	$\Lambda_c(2593)^+$	***
$N(2250)$	G_{19} ****	$\Delta(2750)$	$h_{3,13}$ **			$\Sigma(2070)$	F_{15} *	$\Lambda_c(2625)^+$	***
$N(2600)$	$h_{1,11}$ ***	$\Delta(2950)$	$K_{3,15}$ **			$\Sigma(2080)$	P_{13} **	$\Lambda_c(2765)^+$	*
$N(2700)$	$K_{1,13}$ **					$\Sigma(2100)$	G_{17} *	$\Lambda_c(2880)^+$	**
		$\Theta(1540)^+$	*			$\Sigma(2250)$	***	$\Sigma_c(2455)$	****
						$\Sigma(2455)$	**	$\Sigma_c(2520)$	***
						$\Sigma(2620)$	**	$\Sigma_c(2520)$	***
						$\Sigma(3000)$	*	Ξ_c^+	***
						$\Sigma(3170)$	*	Ξ_c^0	***
								Ξ_c^+	***
								Ξ_c^0	***
								$\Xi_c(2645)$	***
								$\Xi_c(2790)$	***
								$\Xi_c(2815)$	***
								Ω_c^0	***
								Ξ_{cc}^+	*
								Λ_b^0	***
								Ξ_{bb}^0, Ξ_{bb}^-	*

ČAROBNI OKUS u slijedu uspostavljanja simetrije KVARKOVA i LEPTONA

- ZEMALJSKA TVAR
- ETERIČNA (STRANA)
- 1937 mion
- 1947 stranost
- ČAROBNI OKUS
(Niu, Mikumo, Maeda'71
-Kobayashi&Maskawa'74)
- .. OKUS LJEPOTE ..

$$\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} \nu_e \\ e^- \end{pmatrix}$$

$$\begin{pmatrix} \mu^- \end{pmatrix}$$

$$\begin{pmatrix} \nu \\ s \end{pmatrix}$$

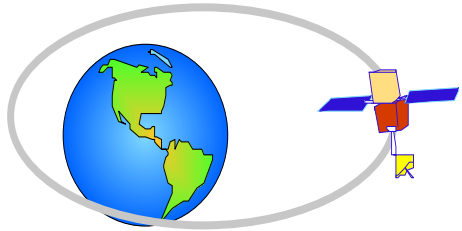
"c" :

Sam Thing $p + Be \rightarrow e^+ e^- + X$

Burton Richter $e^+ e^- \rightarrow \psi / \Upsilon$

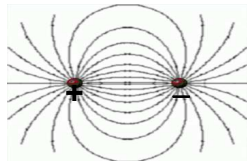
$$\begin{pmatrix} b \end{pmatrix} \begin{pmatrix} \tau^- \end{pmatrix}$$

Ujedinjenje sila

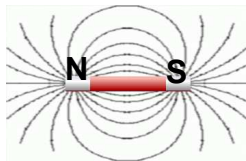


Zemaljska mehanika

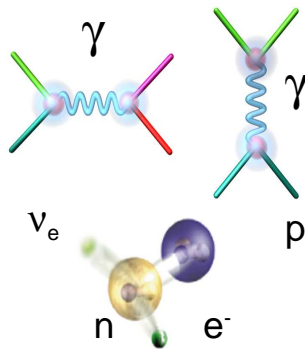
Nebeska mehanika



Elektricitet



Magnetizam



Elektromagnetizam

Slaba sila

Univerzalna gravitacija

Inercijalna odn. Gravitacijska masa

(I. Newton, 1687.)

Elektromagnetizam

Elektromagnetski valovi (foton)

(J.C. Maxwell, 1860.)

Elektroslaba

Intermedijalni bozoni W, Z

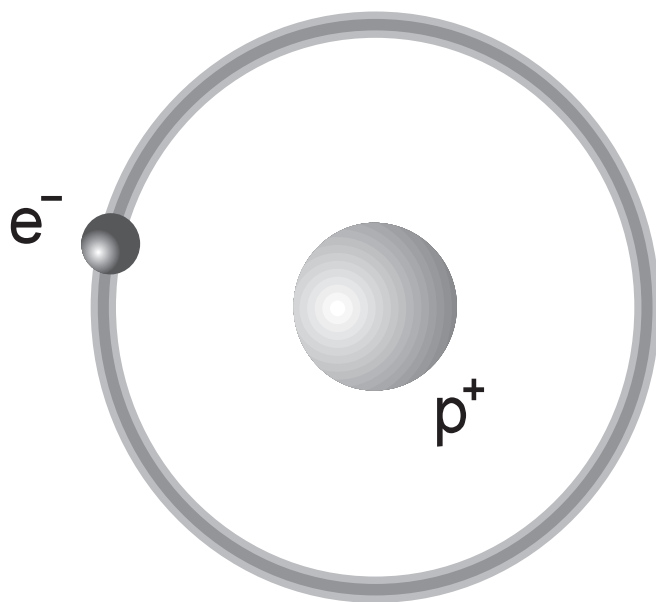
(1970.-83.)

?

Ispitivanje sve manjih
dimeznija

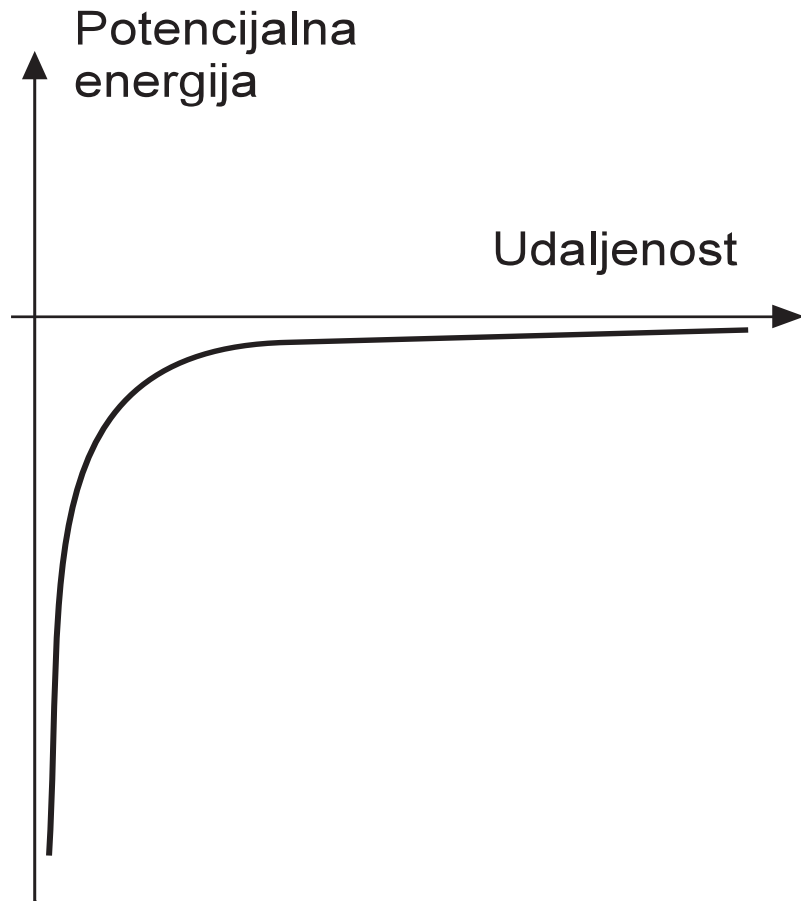
UJEDINJENI OPIS

Atomska domena (Bohrov polumjer) rođenje kvantne fizike (čestica ili val?)

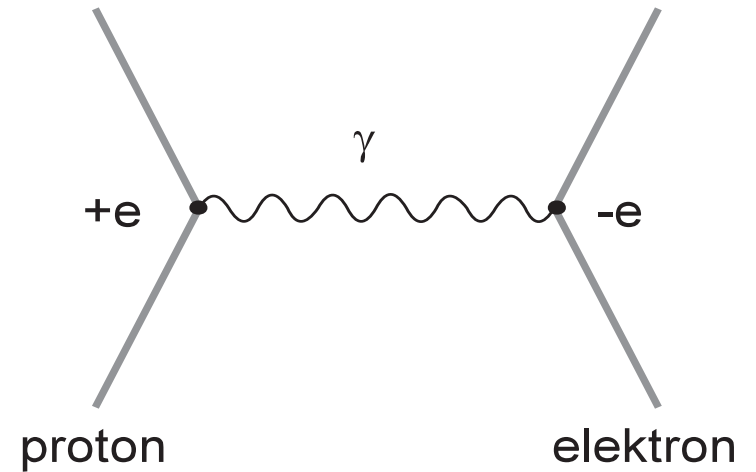


Bohrov polumjer

Kulonski potencijal od izmjene fotona



(a)



(b)

Nuklearna i subnuklearna domena

Yukawini prijenosnici sila

struktura atoma

kvark $<10^{-18}$ m

elektron $<10^{-18}$ m

jezgra 10^{-14} m

atom 10^{-10} m

neutron 10^{-15} m

proton 10^{-15} m

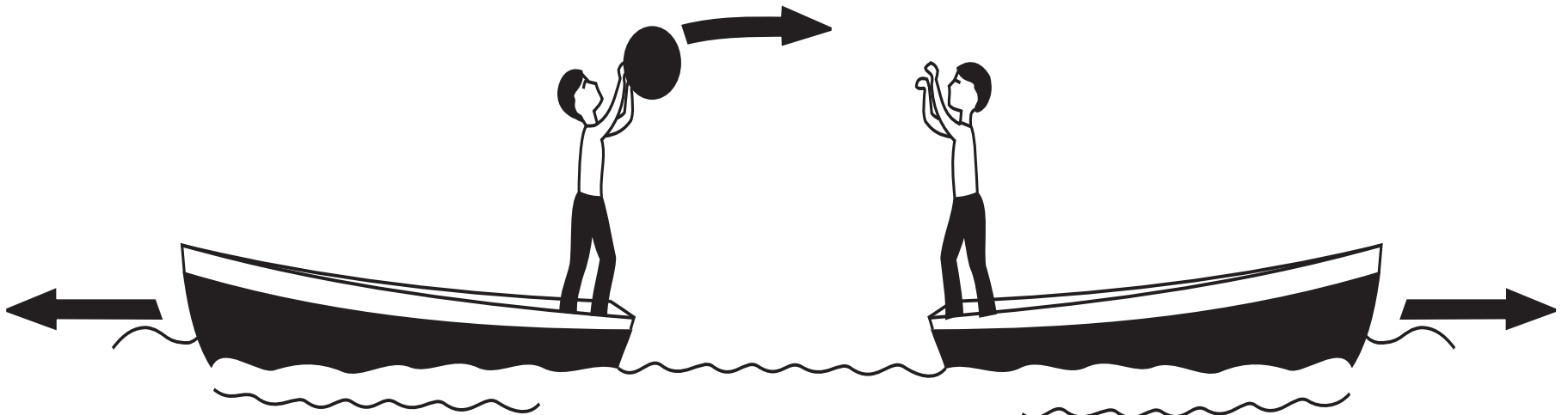
BOZONI

Unificirani elektroslabi spin = 1	Masa GeV/c ²	Elektr. naboj
γ foton	0	0
W^-	80.33	-1
W^+	80.33	+1
Z^0	91.19	0

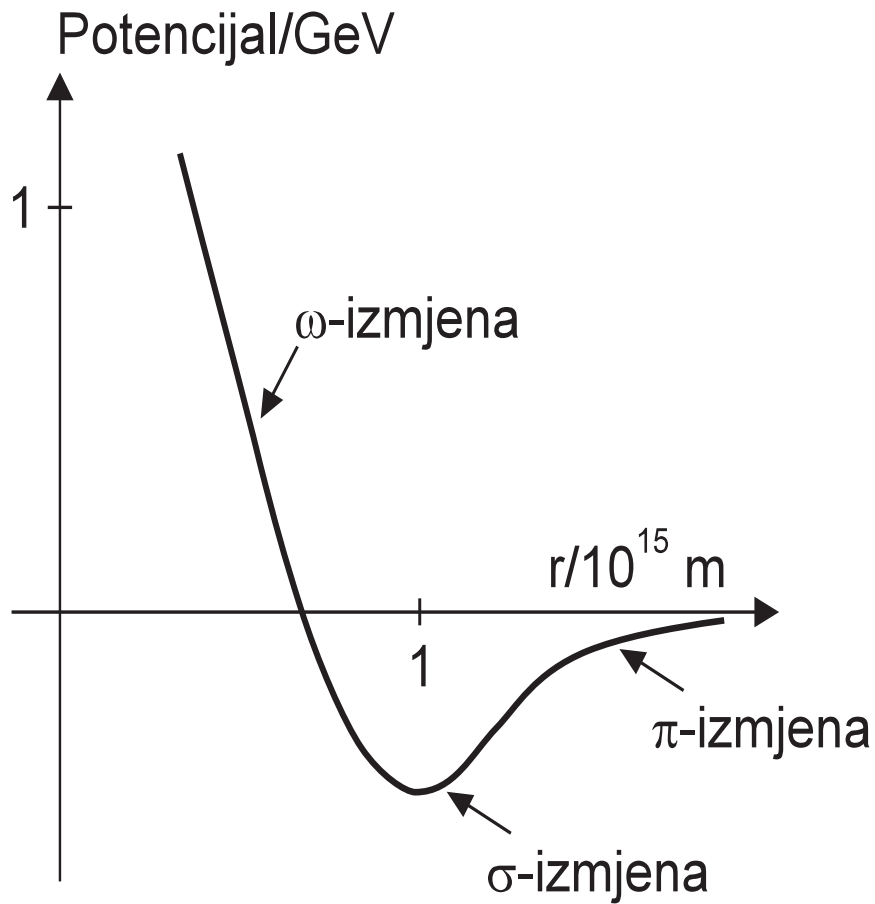
prijenosnici sile
spin 0, 1, 2 ...

Boja	Masa GeV/c ²	Električni naboj
g gluon	0	0

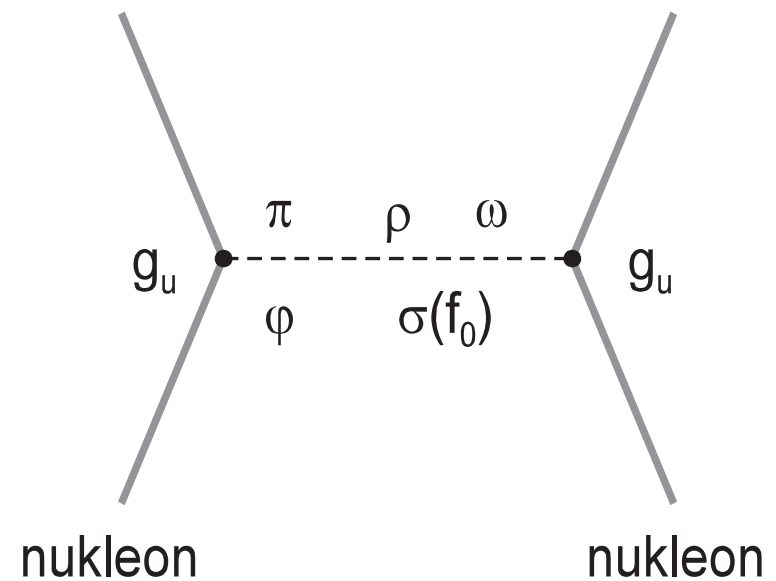
Izmjena (loptanje) česticom Yukawinim prijenosnikom sile



Nukleonsko međudjelovanje od izmjene mezona (rezidualna jaka sila)



(a)



(b)

Dva bitna načela: kvantno i relativističko

QED involved principles

◇ QUANTUM MECHANICS

◇ RELATIVITY

recovered through dilemmas / new scales

particle or wave ?

Bohr radius
 $r_B \approx 5 \cdot 10^{-11} \text{ m}$

particle or field ?

Compton w-length
 $r_C \approx 4 \cdot 10^{-13} \text{ m}$

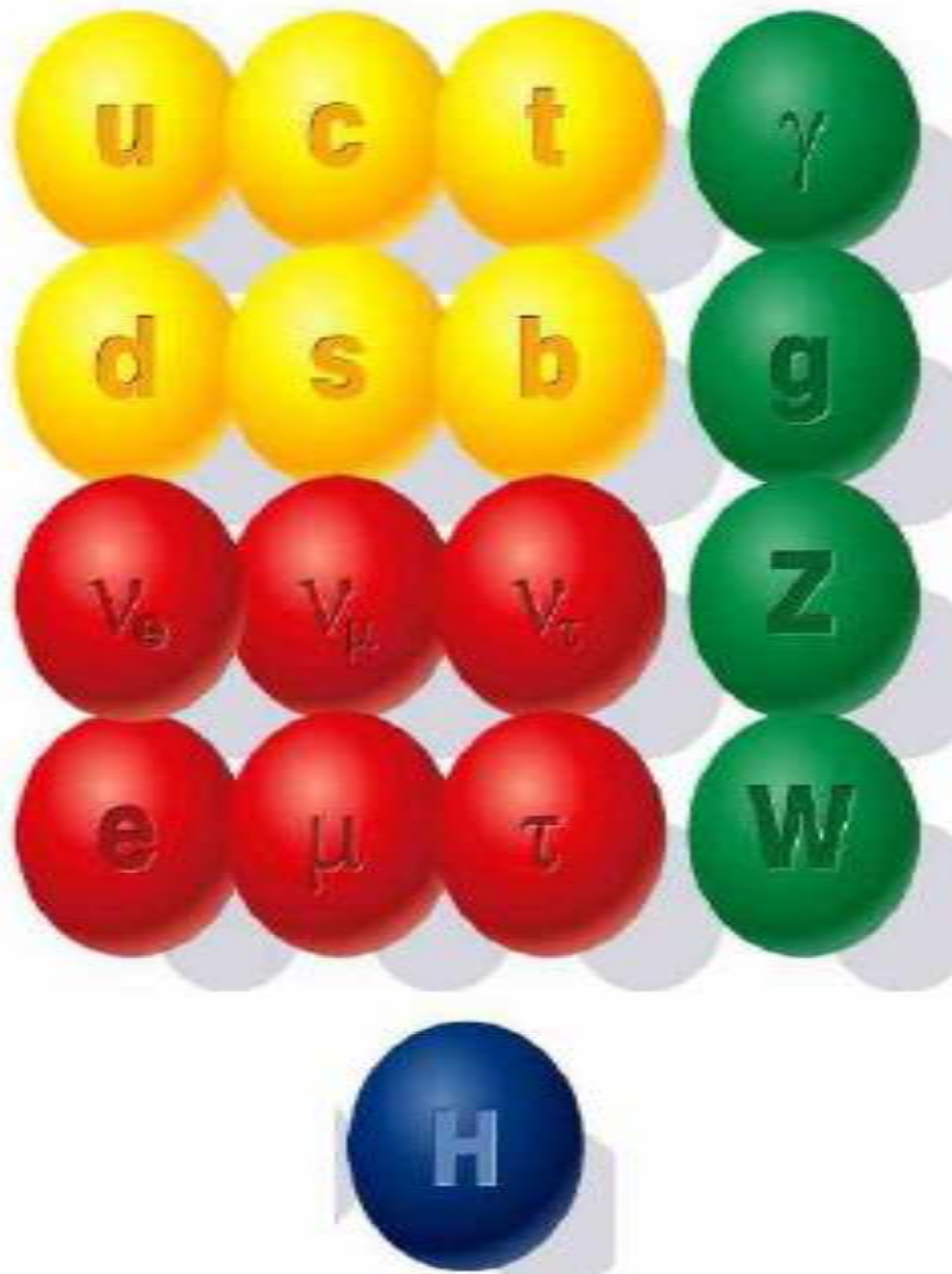


Razotkrivanje novog, baždarnog načela

- Baždarna prethistorija (Boškovićeви točkasti izvori sila)
- Ideal QED-a
- EW ujedinjenje kao novi iskorak
- QCD kao zasebni sektor SM-a

STANDARDNI MODEL ČESTICA I SILA oslanja se na

- 6 KVARKOVA i
- 6 LEPTONA (12 ČESTICA TVARI)
- 12 PRIJENOSNIKA SILA
- ZAGONETNI HIGGSOV BOZON (PROBLEM TeV SKALE KAO IZAZOV ZA LHC)



THE DALMATIAN PROPHET

A final note on this first stage, the age of mechanics, the great era of classical physics. The phrase “ahead of his time” is overused. I’m going to use it anyway. I’m not referring to Galileo or Newton. Both were definitely right on time, neither late nor early. Gravity, experimentation, measurement, mathematical proofs . . . all these things were in the air. Galileo, Kepler, Brahe, and Newton were accepted — heralded! — in their own time, because they came up with ideas that the scientific community was ready to accept. Not everyone is so fortunate.

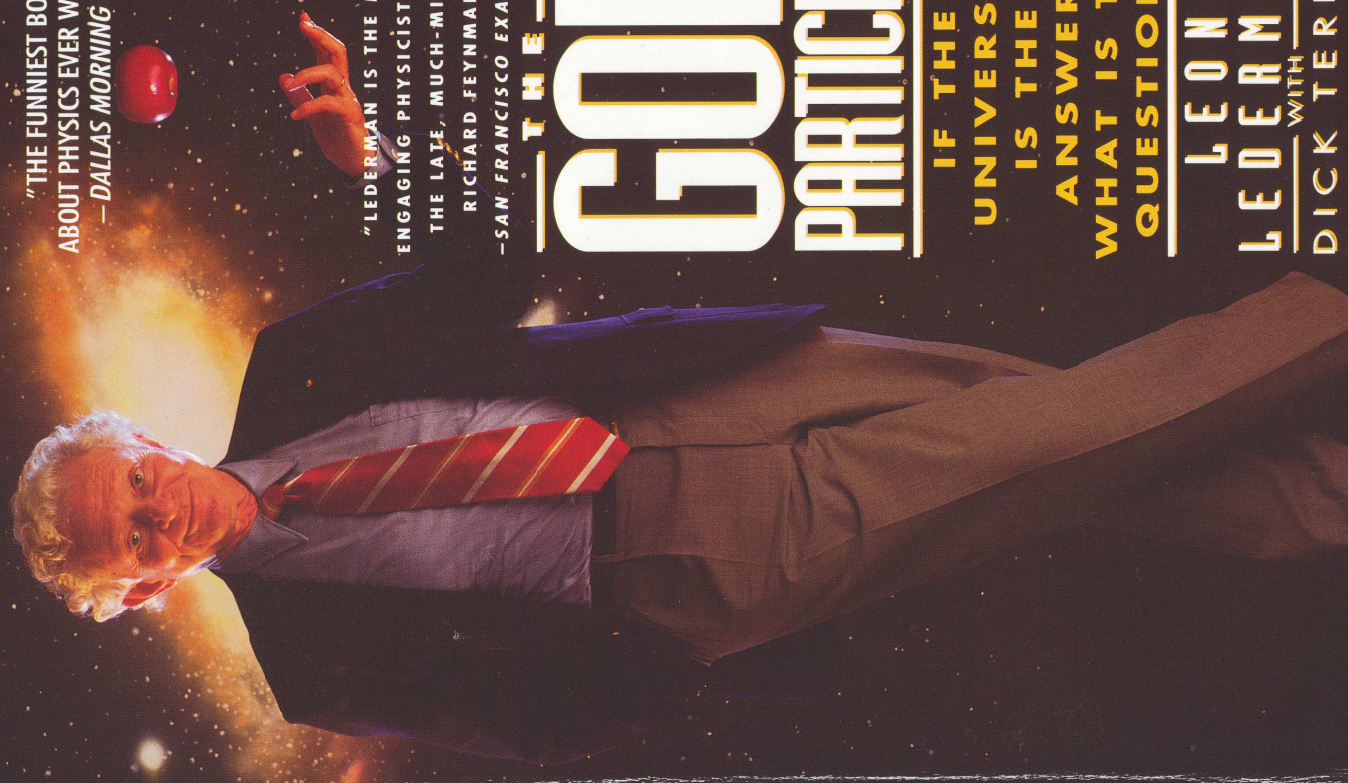
Roger Joseph Boscovich, a native of Dubrovnik who spent much of his career in Rome, was born in 1711, sixteen years before Newton’s death. Boscovich was a great supporter of Newton’s theories, but he had some problems with the law of gravitation. He called it a “classical limit,” an adequate approximation where distances are large. He said that it was “very nearly correct but that differences from the law of inverse squares do exist even though they are very slight.” He speculated that this classical law must break down altogether at the atomic scale, where the forces of attraction are replaced by an oscillation between attractive and repulsive forces. An amazing thought for a scientist in the eighteenth century.

Boscovich also struggled with the old action-at-a-distance problem. Being a geometer more than anything else, he came up with the idea of *fields of force* to explain how forces exert control over objects at a distance. But wait, there’s more!

Boscovich had this other idea, one that was real crazy for the eighteenth century (or perhaps any century). Matter is composed of indivisible, indivisible a-toms, he said. Nothing particularly new there. Leucippus, Democritus, Galileo, Newton, and others would have agreed with him. Here’s the good part: Boscovich said these particles had no size; that is, they were geometrical points. Clearly, as with so many ideas in science, there were precursors to this — probably in ancient Greece, not to mention hints in Galileo’s works. As you may recall from high school geometry, a point is just a place; it has no dimensions. And here’s Boscovich putting forth the proposition that matter is composed of particles that have no dimensions! We found a particle just a couple of decades ago that fits such a description. It’s called a quark.

We’ll get back to Mr. Boscovich later.

“THE FUNNIEST BOOK ABOUT PHYSICS EVER WRITTEN.”
—DALLAS MORNING NEWS



“LEDERMAN IS THE MOST ENGAGING PHYSICIST SINCE THE LATE, MUCH-MISSED RICHARD FEYNMAN.”
—SAN FRANCISCO EXAMINER

THE
GOD PARTICLE

IF THE
UNIVERSE
IS THE
ANSWER,
WHAT IS THE
QUESTION?

LEON
LEDERMAN
WITH
DICK TERESI

THEORIA PHILOSOPHIÆ NATURALIS

REDACTA AD UNICAM LEGEM VIRIUM
IN NATURA EXISTENTIUM,

AUCTORE

P. ROGERIO JOSEPHO BOSCOVICH

SOCIETATIS JESU,

NUNC AB IPSO PERPOLITA, ET AUCTA,

Ac a plurimis præcedentium editionum
mendis expurgata.

EDITIO VENETA PRIMA

IPSO AUCTORE PRÆSENTE, ET CORRIGENTE.



V E N E T I I S,

MDCCLXIII.

EX TYPOGRAPHIA REMONDINIANA.
SUPERIORUM PERMISSU, ac PRIVILEGIO.

GAUGE-THEORY PREHISTORY

◇ Rudjer Bošković
(1711-1787)

"Theoria Philosophiæ
Naturalis" (1763)



force acting
-- between particles of matter

◇ John Leslie
(Edinburgh)

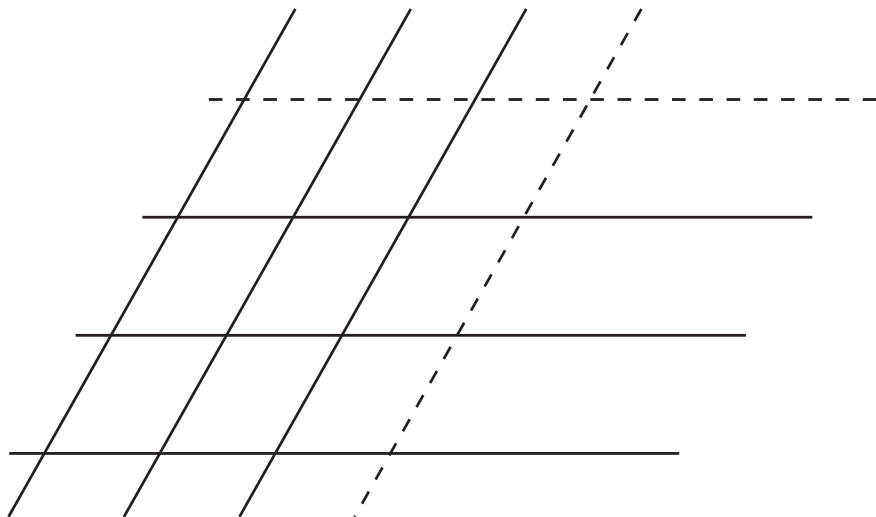
besides lecturing from 1785
on Bošković's theory

introduced separate forces acting
-- between two particles of light
-- between particle of matter
and particle of light

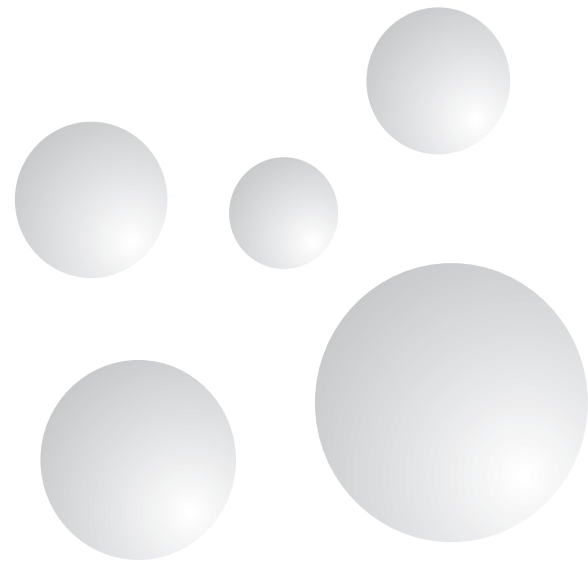
basic ingredients in the SM of forces !



Prilagodba sustava jedinica



(a)



(b)

Heaviside-Lorentzove jedinice

- **Electron charge** defined by Force equation:

$$F = \frac{e^2}{4\pi\epsilon_0 r^2}$$

- In Heaviside-Lorentz units set

$$\boxed{\epsilon_0 = 1}$$

and $F \rightarrow \frac{e^2}{4\pi r^2}$

NOTE: electric charge
has dimensions

$$[EL]^{\frac{1}{2}} = [\hbar c]^{\frac{1}{2}}$$

- Since $c = (\epsilon_0 \mu_0)^{-\frac{1}{2}} = 1$

$$\rightarrow \boxed{\mu_0 = 1}$$

$$\boxed{\hbar = c = \epsilon_0 = \mu_0 = 1}$$

Prirodni sustav jedinica

- From Quantum Mechanics - the unit of action : \hbar
- From relativity - the speed of light: c
- From Particle Physics - unit of energy: **GeV** (1 GeV ~ proton rest mass energy)

Units become:

Energy	GeV	Time	$(\text{GeV}/\hbar)^{-1}$
Momentum	GeV/c	Length	$(\text{GeV}/\hbar c)^{-1}$
Mass	GeV/c^2	Area	$(\text{GeV}/\hbar c)^{-2}$

Simplify by choosing: $\hbar = c = 1$

- Now all quantities expressed in powers of **GeV**

Energy	GeV	Time	GeV^{-1}
Momentum	GeV	Length	GeV^{-1}
Mass	GeV	Area	GeV^{-2}

Jedinice,
koje po
Plancku,
vrijede
"za sve
civilizacije
i za sva
vremena"

Our experience of the
matter in space-time

reflected in basic UNITS

[M] [L] [T]



kg m s

everyday's (human choice)

w.r.t.

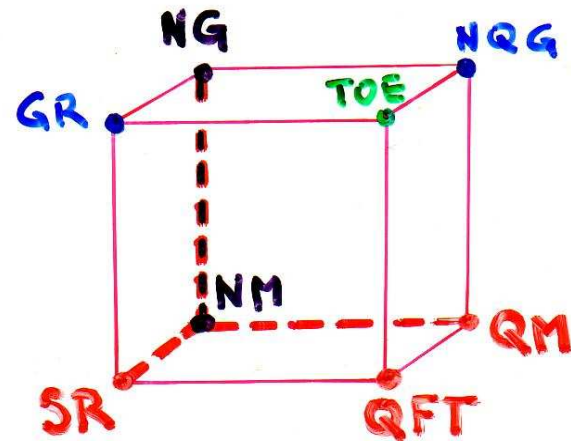


Nature's choice :

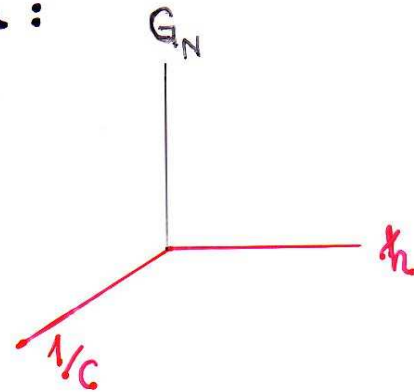
- $c = 2.998 \cdot 10^8 \text{ m s}^{-1}$ STR
- $\hbar = 1.055 \cdot 10^{-34} \text{ J s}$ QM

Zanemariva gravitacija u svijetu elementarnih čestica

Bronshtein - Želmanovljeva
KOCKA FIZIKALNIH TEORIJA

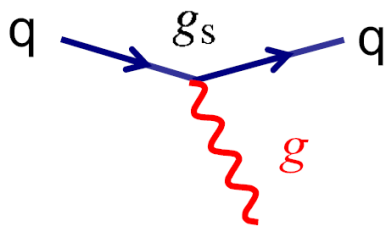


na osima :



Konstante fine strukture

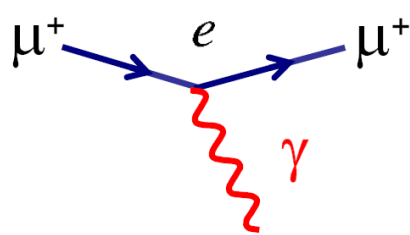
STRONG



Only quarks
Never changes
flavour

$$\alpha_s \sim 1$$

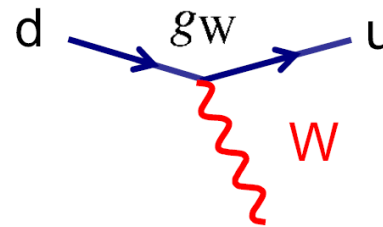
EM



All charged
fermions
Never changes
flavour

$$\alpha \simeq 1/137$$

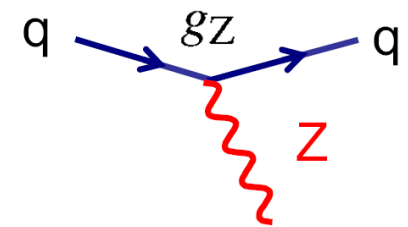
WEAK CC



All fermions
Always changes
flavour

$$\alpha_{W/Z} \sim 1/40$$

WEAK NC



All fermions
Never changes
flavour

Ilustracija za α & α_G