

Čo je to častica?

Ivan Melo, Katedra fyziky FEIT, Žilinská univerzita

Group	→ 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Period	↓																		
1	1 H																	2 He	
2	3 Li	4 Be										5 B	6 C	7 N	8 O	9 F	10 Ne		
3	11 Na	12 Mg										13 Al	14 Si	15 P	16 S	17 Cl	18 Ar		
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr	
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe	
6	55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn	
7	87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og	
				* 58 Ce	* 59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu		
				* 90 Th	* 91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr		

- prednáška
- kvíz

	2.4 MeV $+\frac{2}{3}$ $+\frac{2}{3}$	1.27 GeV $\frac{2}{3}$ $\frac{2}{3}$	171.3 GeV $\frac{2}{3}$ $\frac{2}{3}$	0 0 1
	u up	c charm	t top	γ photon
Quarks	4.8 MeV $-\frac{1}{3}$ $\frac{1}{3}$	104 MeV $-\frac{1}{3}$ $\frac{1}{3}$	4.2 GeV $-\frac{1}{3}$ $\frac{1}{3}$	0 0 1
	d down	s strange	b bottom	g gluon
	<2.2 eV 0 $\frac{1}{2}$	<0.17 MeV 0 $\frac{1}{2}$	<15.5 MeV 0 $\frac{1}{2}$	91.2 GeV 0 1
	ν _e electron neutrino	ν _μ muon neutrino	ν _τ tau neutrino	Z weak force
Leptons	0.511 MeV -1 $\frac{1}{2}$	105.7 MeV -1 $\frac{1}{2}$	1.777 GeV -1 $\frac{1}{2}$	80.4 GeV ±1 1
	e electron	μ muon	τ tau	W [±] weak force
				Bosons (Forces)

Krájanie jablka – veľká otázka

Keď budeme krájať jablko,
bude to krájanie mať koniec?

Ak to bude mať koniec,
koľko zvislých prekrojení bude
treba?



Je hmota zrnitá
alebo spojitá?



Bude to mať koniec
a treba 30 prekrojení

$10 \text{ cm} / 2^{30} = \text{rozmer atómu}$

Čo je to atóm?

1. tabuľka atómov a ich vlastnosti
2. ako atómy vidí experiment
3. akú majú o atómoch predstavu vedci

Čo je to atóm? - tabuľka atómov a ich vlastnosti



PERIODIC TABLE OF ELEMENTS

<https://www.webelements.com/>

PERIOD	GROUP 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	H Hydrogen 1.008																	He Helium 4.003
2	Li Lithium 6.941	Be Beryllium 9.012											B Boron 10.81	C Carbon 12.01	N Nitrogen 14.01	O Oxygen 15.99	F Fluorine 18.99	Ne Neon 20.18
3	Na Sodium 22.99	Mg Magnesium 24.31											Al Aluminum 26.98	Si Silicon 28.09	P Phosphorus 30.97	S Sulfur 32.06	Cl Chlorine 35.45	Ar Argon 39.95
4	K Potassium 39.10	Ca Calcium 40.08	Sc Scandium 44.96	Ti Titanium 50.94	V Vanadium 50.94	Cr Chromium 52.00	Mn Manganese 54.94	Fe Iron 55.85	Co Cobalt 58.93	Ni Nickel 58.69	Cu Copper 63.55	Zn Zinc 65.39	Ga Gallium 69.72	Ge Germanium 72.64	As Arsenic 74.92	Se Selenium 78.96	Br Bromine 79.90	Kr Krypton 83.79
5	Rb Rubidium 85.47	Sr Strontium 87.62	Y Yttrium 88.91	Zr Zirconium 91.22	Nb Niobium 92.91	Mo Molybdenum 95.96	Tc Technetium (98)	Ru Ruthenium 101.1	Rh Rhodium 102.9	Pd Palladium 106.4	Ag Silver 107.9	Cd Cadmium 112.4	In Indium 114.8	Sn Tin 118.7	Sb Antimony 121.8	Te Tellurium 127.6	I Iodine 126.9	Xe Xenon 131.3
6	Cs Cesium 132.9	Ba Barium 137.3	57-71 Lanthanides	Hf Hafnium 178.5	Ta Tantalum 180.9	W Tungsten 183.9	Re Rhenium 186.2	Os Osmium 190.2	Ir Iridium 192.2	Pt Platinum 195.1	Au Gold 197.0	Hg Mercury 200.5	Tl Thallium 204.38	Pb Lead 207.2	Bi Bismuth 209.0	Po Polonium (209)	At Astatine (210)	Rn Radon (222)
7	Fr Francium 223	Ra Radium 226	89-103 Actinides	Rf Rutherfordium 261	Db Dubnium 268	Sg Seaborgium (271)	Bh Bohrium 270	Hs Hassium 277	Mt Meitnerium 276	Ds Darmstadtium 285	Rg Roentgenium 280	Cn Copernicium (285)	Nh Nihonium 284	Fl Flerovium 289	Mc Moscovium 288	Lv Livermorium 293	Ts Tennessine 294	Og Oganesson 294

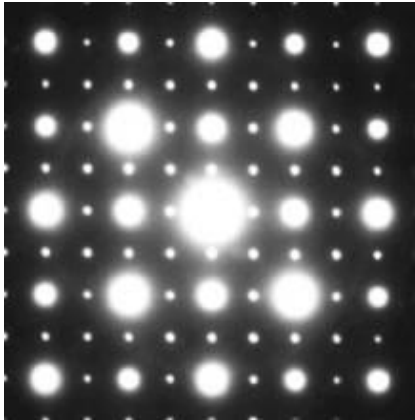
1700: 13 prvkov

1869: 60 prvkov

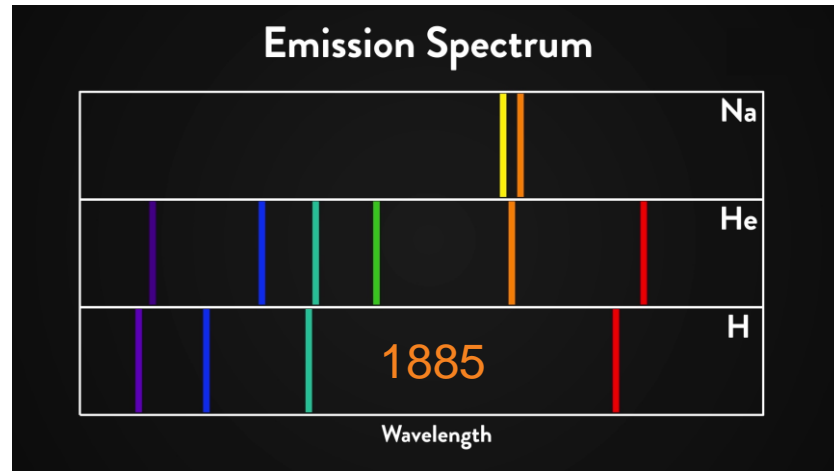
2022: 118 prvkov,
z toho 35 rádioaktívnych

La Lanthanum 138.9	Ce Cerium 140.1	Pr Praseodymium 140.9	Nd Neodymium 144.2	Pm Promethium (145)	Sm Samarium 150.4	Eu Europium 152.0	Gd Gadolinium 157.2	Tb Terbium 158.9	Dy Dysprosium 162.5	Ho Holmium 164.9	Er Erbium 167.3	Tm Thulium 168.9	Yb Ytterbium 173.0	Lu Lutetium 175.0
Ac Actinium (227)	Th Thorium 232.0	Pa Protactinium 231.0	U Uranium 238.0	Np Neptunium (237)	Pu Plutonium (244)	Am Americium (243)	Cm Curium (247)	Bk Berkelium (247)	Cf Californium (251)	Es Einsteinium (252)	Fm Fermium (257)	Md Mendelevium (258)	No Nobelium (259)	Lr Lawrencium (262)

Ako atómy vidíme v experimente



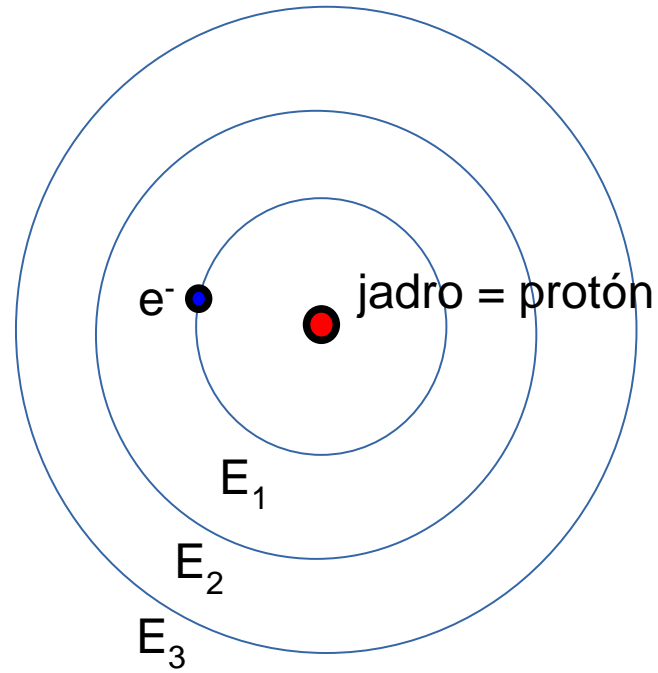
Pohľad na atómy cez
elektrónový mikroskop



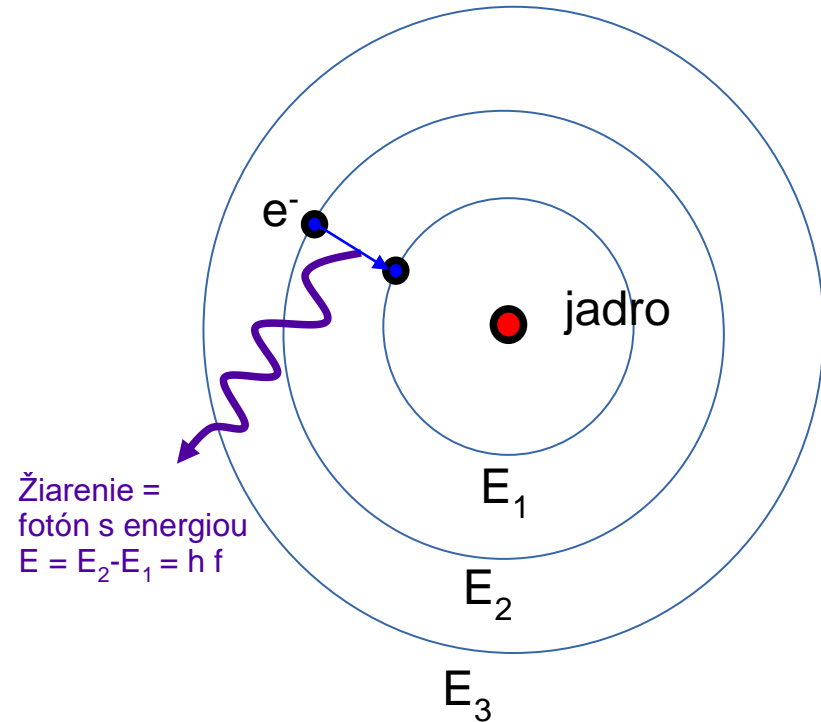
vnútorná štruktúra atómov vyplýva zo spektier

Akú majú predstavu o atóмоch študenti (Bohrov model)

Atóm vodíka v základnom stave



Excitovaný atóm vodíka



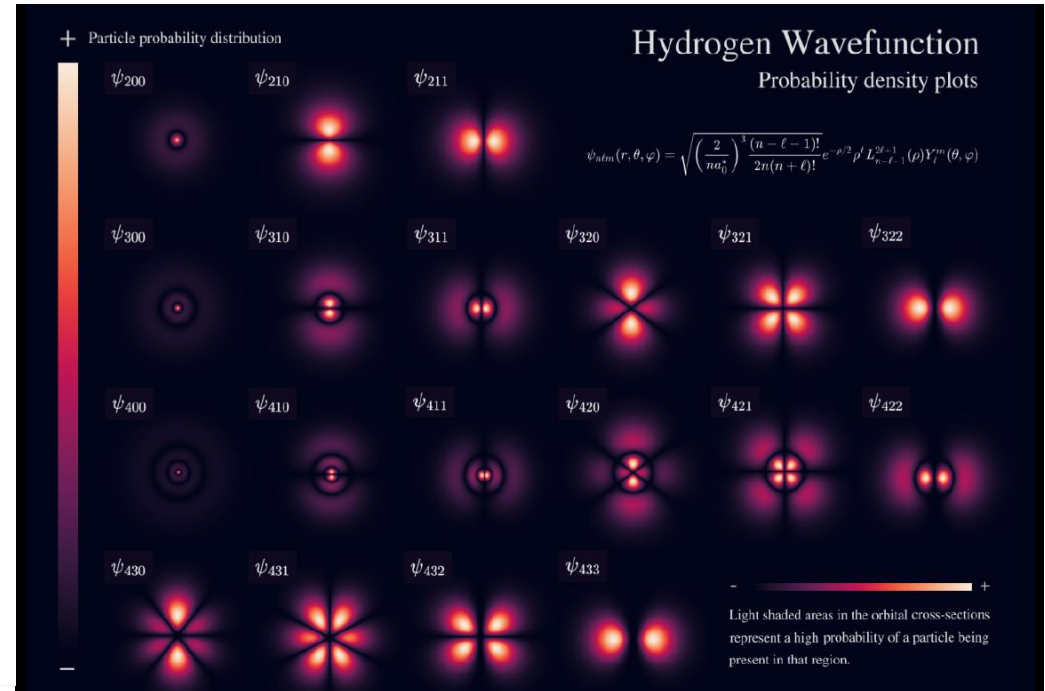
Akú majú predstavu o atómoch vedci (Schrodingerova rovnica)

$$i\hbar \frac{\partial}{\partial t} \psi(r, t) = \hat{H} \psi(r, t)$$

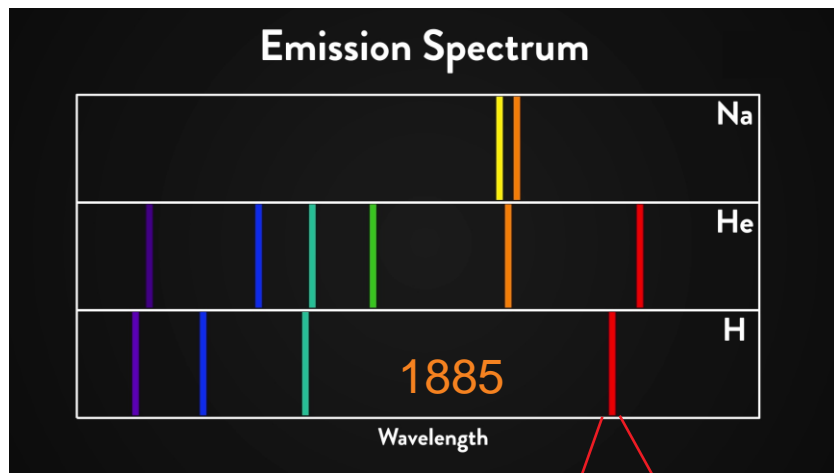


n	l	m_l	$\Phi_{m_l}(\phi)$	$\Theta_{lm_l}(\theta)$	$R_{nl}(r)$
1	0	0	$\frac{1}{\sqrt{2\pi}}$	$\frac{1}{\sqrt{2}}$	$\frac{2}{a_0^{3/2}} e^{-\frac{r}{a_0}}$
2	0	0	$\frac{1}{\sqrt{2\pi}}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{2\sqrt{2}a_0^{3/2}} (2 - \frac{r}{a_0}) e^{-\frac{r}{2a_0}}$
2	1	0	$\frac{1}{\sqrt{2\pi}}$	$\frac{\sqrt{6}}{2} \cos \theta$	$\frac{1}{2\sqrt{6}a_0^{3/2}} \frac{r}{a_0} e^{-\frac{r}{2a_0}}$
2	1	± 1	$\frac{1}{\sqrt{2\pi}} e^{\pm i\phi}$	$\frac{\sqrt{3}}{2} \sin \theta$	$\frac{1}{2\sqrt{6}a_0^{3/2}} \frac{r}{a_0} e^{-\frac{r}{2a_0}}$
3	0	0	$\frac{1}{\sqrt{2\pi}}$	$\frac{1}{\sqrt{2}}$	$\frac{2}{81\sqrt{3}a_0^{3/2}} (27 - 18\frac{r}{a_0} + 2\frac{r^2}{a_0^2}) e^{-\frac{r}{3a_0}}$
3	1	0	$\frac{1}{\sqrt{2\pi}}$	$\frac{\sqrt{6}}{2} \cos \theta$	$\frac{4}{81\sqrt{6}a_0^{3/2}} (6 - \frac{r}{a_0}) \frac{r}{a_0} e^{-\frac{r}{3a_0}}$
3	1	± 1	$\frac{1}{\sqrt{2\pi}} e^{\pm i\phi}$	$\frac{\sqrt{3}}{2} \sin \theta$	$\frac{4}{81\sqrt{6}a_0^{3/2}} (6 - \frac{r}{a_0}) \frac{r}{a_0} e^{-\frac{r}{3a_0}}$
3	2	0	$\frac{1}{\sqrt{2\pi}}$	$\frac{\sqrt{10}}{4} (3 \cos^2 \theta - 1)$	$\frac{4}{81\sqrt{30}a_0^{3/2}} \frac{r^2}{a_0^2} e^{-\frac{r}{3a_0}}$
3	2	± 1	$\frac{1}{\sqrt{2\pi}} e^{\pm i\phi}$	$\frac{\sqrt{15}}{2} \sin \theta \cos \theta$	$\frac{4}{81\sqrt{30}a_0^{3/2}} \frac{r^2}{a_0^2} e^{-\frac{r}{3a_0}}$
3	2	± 2	$\frac{1}{\sqrt{2\pi}} e^{\pm 2i\phi}$	$\frac{\sqrt{15}}{4} \sin^2 \theta$	$\frac{4}{81\sqrt{30}a_0^{3/2}} \frac{r^2}{a_0^2} e^{-\frac{r}{3a_0}}$

Table 3.1: Eigenfunctions $\psi = R_{nl} \Theta_{lm_l} \Phi_{m_l}$ for the hydrogen atom for $n = 1, 2$ and 3.



Akú majú predstavu o atóмоch vedci (pokračovanie)



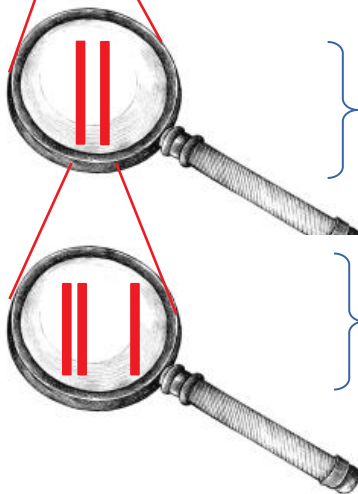
Schrodingerova rovnica

jemná štruktúra

1887

Lambov posun

1947

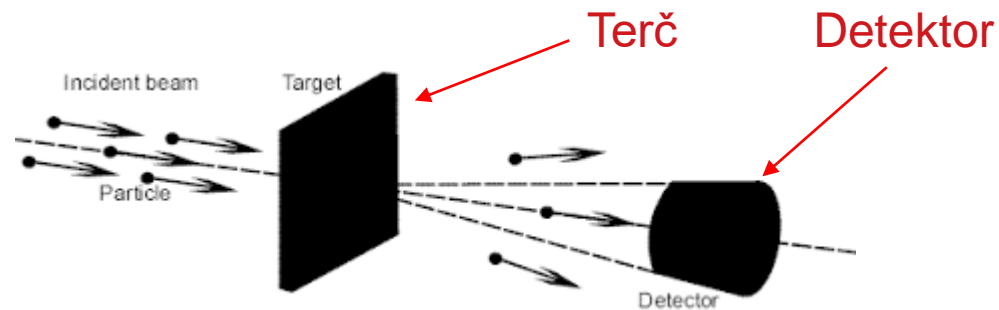


Spin, Diracova rovnica

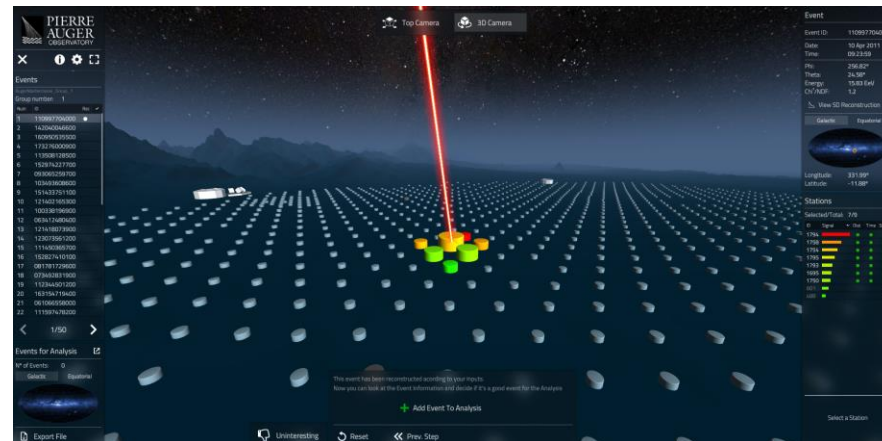
Kvantová elektrodynamika

Čo je to častica?

Atómy sú nesmierne užitočné, nie sú ale najmenšie stavebné prvky nášho sveta. Tými sú elementárne častice. Koľko ich je? Aké majú vlastnosti? Čo je to častica?



urýchľovače



kozmičné žiarenie

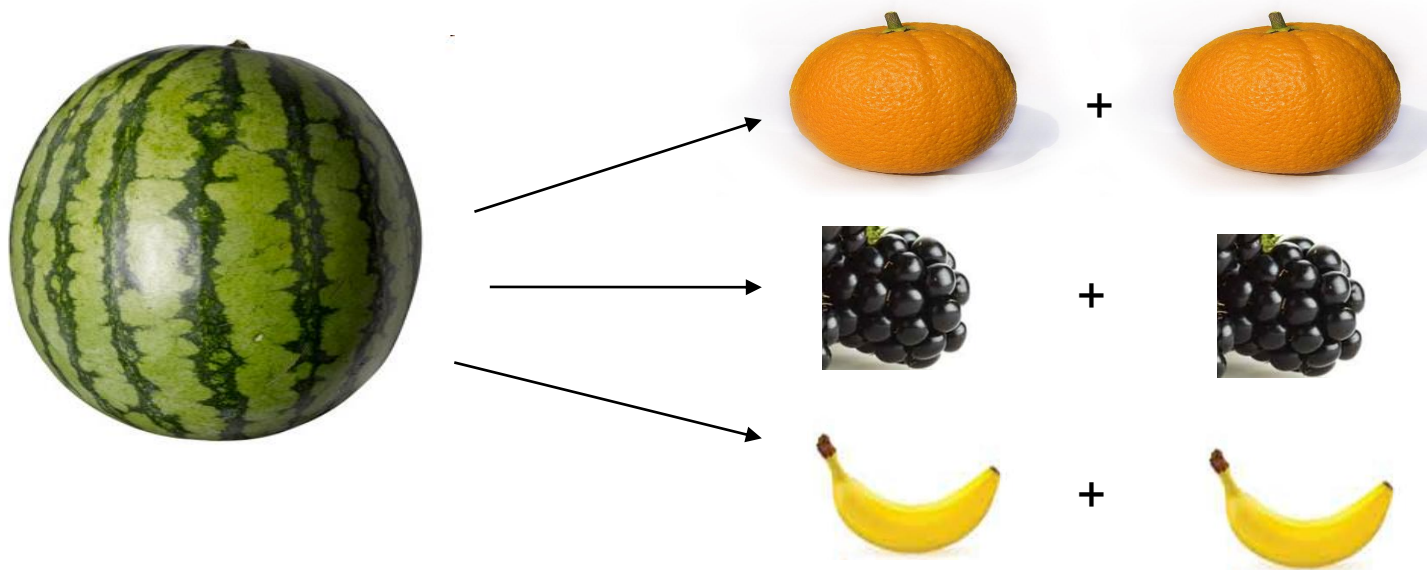
Urýchľovače – továrne na nové častice

Klasitoko

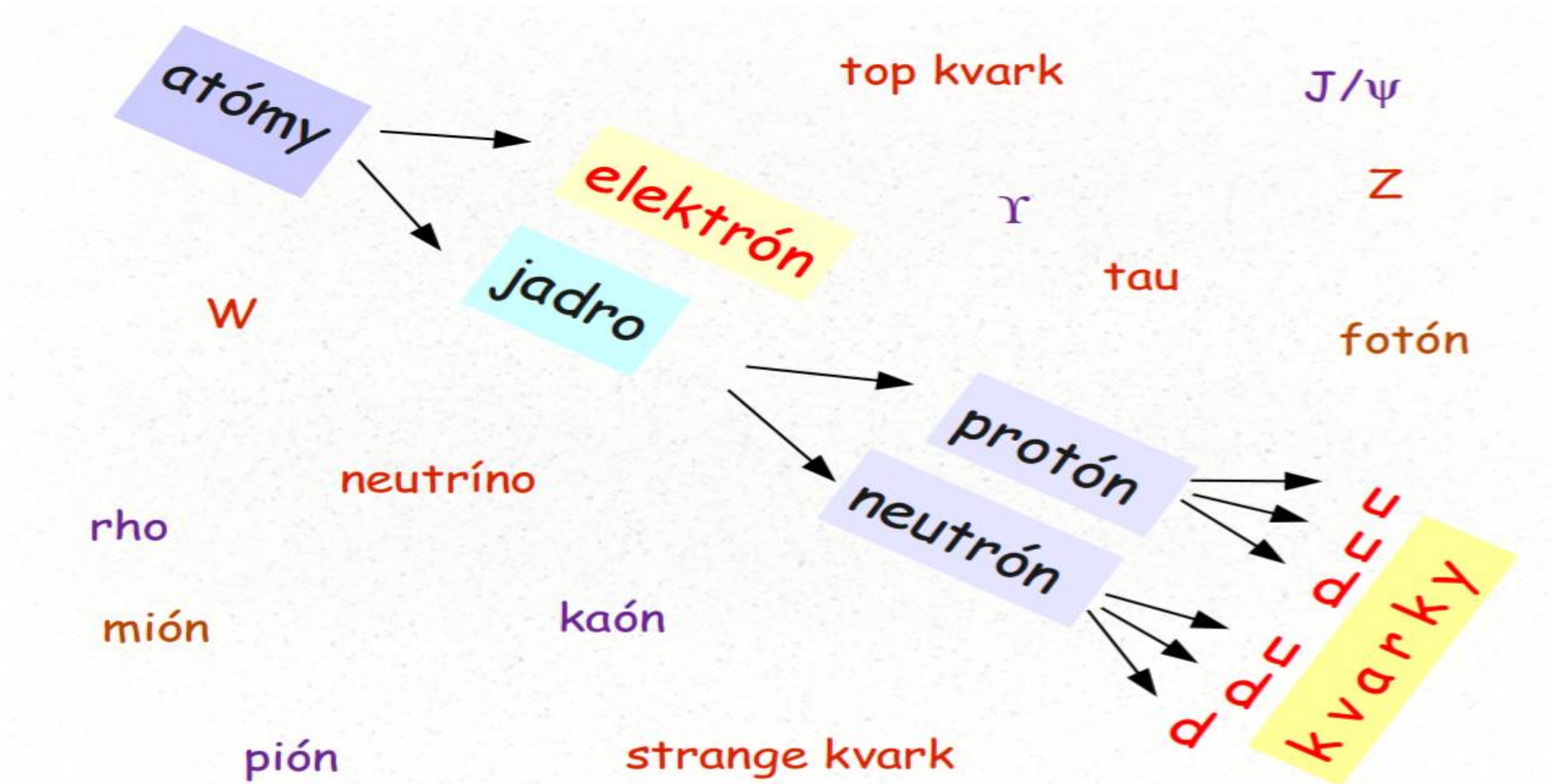


$$E = mc^2$$

Rozpad částic



Od atómov ku kvarkom



Čo je to častica?



1. tabuľka častíc a ich vlastnosti
2. ako vidí častice experiment
3. akú majú o časticiach predstavu fyzici

Tabuľka elementárnych častíc - Štandardný model

Quarks	2.4 MeV $\frac{2}{3}$ $\frac{1}{2}$ u up	1.27 GeV $\frac{2}{3}$ $\frac{1}{2}$ c charm	171.2 GeV $\frac{2}{3}$ $\frac{1}{2}$ t top	0 0 1 γ photon
	4.8 MeV $-\frac{1}{3}$ $\frac{1}{2}$ d down	104 MeV $-\frac{1}{3}$ $\frac{1}{2}$ s strange	4.2 GeV $-\frac{1}{3}$ $\frac{1}{2}$ b bottom	0 0 1 g gluon
Leptons	< 2.2 eV 0 $\frac{1}{2}$ ν_e electron neutrino	< 0.17 MeV 0 $\frac{1}{2}$ ν_μ muon neutrino	< 15.5 MeV 0 $\frac{1}{2}$ ν_τ tau neutrino	91.2 GeV 0 1 Z weak force
	0.511 MeV -1 $\frac{1}{2}$ e electron	105.7 MeV -1 $\frac{1}{2}$ μ muon	1.777 GeV -1 $\frac{1}{2}$ τ tau	80.4 GeV ±1 1 W weak force
				Bosons (Forces)

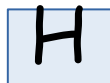
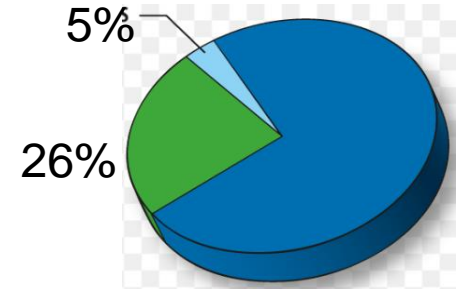
Interakcie

← elektromagnetická

← silná

← slabá

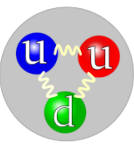
vesmír



Higsov bozón (objavený 2012 v CERNe)

nemá spin

1. generácia



Častice, ktoré nie sú elementárne: Hadróny



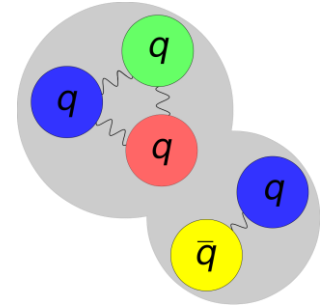
Table of Baryons

Particle	Symbol	Makeup	Rest mass MeV/c ²	Spin	B	S	Lifetime (seconds>)	Decay Modes
Proton	p	uud	938.3	1/2	+1	0	Stable	...
Neutron	n	ddu	939.6	1/2	+1	0	920	pe ⁻ ν _e
Lambda	Λ ⁰	uds	1115.6	1/2	+1	-1	2.6 x10 ⁻¹⁰	pπ ⁻ , nπ ⁰
Sigma	Σ ⁺	uus	1189.4	1/2	+1	-1	0.8 x10 ⁻¹⁰	pπ ⁰ , nπ ⁺
Sigma	Σ ⁰	uds	1192.5	1/2	+1	-1	6x10 ⁻²⁰	Λ ⁰ γ
Sigma	Σ ⁻	dds	1197.3	1/2	+1	-1	1.5 x10 ⁻¹⁰	nπ ⁻
Delta	Δ ⁺⁺	uuu	1232	3/2	+1	0	0.6 x10 ⁻²³	pπ ⁺
Delta	Δ ⁺	uud	1232	3/2	+1	0	0.6 x10 ⁻²³	pπ ⁰
Delta	Δ ⁰	udd	1232	3/2	+1	0	0.6 x10 ⁻²³	nπ ⁰
Delta	Δ ⁻	ddd	1232	3/2	+1	0	0.6 x10 ⁻²³	nπ ⁻
Xi Cascade	Ξ ⁰	uss	1315	1/2	+1	-2	2.9 x10 ⁻¹⁰	Λ ⁰ π ⁰
Xi Cascade	Ξ ⁻	dss	1321	1/2	+1	-2	1.64 x10 ⁻¹⁰	Λ ⁰ π ⁻
Omega	Ω ⁻	sss	1672	3/2	+1	-3	0.82 x10 ⁻¹⁰	Ξ ⁰ π ⁻ , Λ ⁰ K ⁻
Lambda	Λ ⁺ _c	udc	2281	1/2	+1	0	2x10 ⁻¹³	...

Mesons

Particle	Symbol	Anti-particle	Makeup	Rest mass MeV/c ²	S	C	B	Lifetime	Decay Modes
Pion	π ⁺	π ⁻	u \bar{d}	139.6	0	0	0	2.60 x10 ⁻⁸	μ ⁺ ν _μ
Pion	π ⁰	Self	$\frac{u\bar{u} - d\bar{d}}{\sqrt{2}}$	135.0	0	0	0	0.83 x10 ⁻¹⁶	2γ
Kaon	K ⁺	K ⁻	u \bar{s}	493.7	+1	0	0	1.24 x10 ⁻⁸	μ ⁺ ν _μ , π ⁺ π ⁰
Kaon	K ⁰ _s	K ⁰ _s	1*	497.7	+1	0	0	0.89 x10 ⁻¹⁰	π ⁺ π ⁻ , 2π ⁰
Kaon	K ⁰ _L	K ⁰ _L	1*	497.7	+1	0	0	5.2 x10 ⁻⁸	π ⁺ e ⁻ ν _e
Eta	η ⁰	Self	2*	548.8	0	0	0	<10 ⁻¹⁸	2γ, 3μ
Eta prime	η ⁰ _{prime}	Self	2*	958	0	0	0	...	π ⁺ π ⁻ η
Rho	ρ ⁺	ρ ⁻	u \bar{d}	770	0	0	0	0.4 x10 ⁻²³	π ⁺ π ⁰
Rho	ρ ⁰	Self	u \bar{u} , d \bar{d}	770	0	0	0	0.4 x10 ⁻²³	π ⁺ π ⁻
Omega	ω ⁰	Self	u \bar{u} , d \bar{d}	782	0	0	0	0.8 x10 ⁻²²	π ⁺ π ⁻ π ⁰
Phi	φ	Self	s \bar{s}	1020	0	0	0	20 x10 ⁻²³	K ⁺ K ⁻ , K ⁰ K ⁰
D	D ⁺	D ⁻	c \bar{d}	1869.4	0	+1	0	10.6 x10 ⁻¹³	K ⁺ + ₋ , e ⁺ + ₋
D	D ⁰	D ⁰	c \bar{u}	1864.6	0	+1	0	4.2 x10 ⁻¹³	[K, μ, e] + ₋
D	D ⁺ _s	D ⁻ _s	c \bar{s}	1969	+1	+1	0	4.7 x10 ⁻¹³	K + ₋
J/Psi	J/ψ	Self	c \bar{c}	3096.9	0	0	0	0.8 x10 ⁻²⁰	e ⁺ e ⁻ , μ ⁺ μ ⁻ ...
B	B ⁻	B ⁺	b \bar{u}	5279	0	0	-1	1.5 x10 ⁻¹²	D ⁰ + ₋
B	B ⁰	B ⁰	d \bar{b}	5279	0	0	-1	1.5 x10 ⁻¹²	D ⁰ + ₋
Bs	B ⁰ _s	B ⁰ _s	s \bar{b}	5370	-1	0	-1	...	B ⁻ _s + ₋
Upsilon	Υ	Self	b \bar{b}	9460.4	0	0	0	1.3 x10 ⁻²⁰	e ⁺ e ⁻ , μ ⁺ μ ⁻ ..

Pentaquarks



P⁺_c(4380), P⁺_c(4450)



J/ψ + p

1* The neutral [Kaons](#) K⁰_s and K⁰_L represent symmetric and antisymmetric mixtures of the quark combinations down-antistrange and antidown-strange.

2* The neutral eta meson is considered to be a quark combination

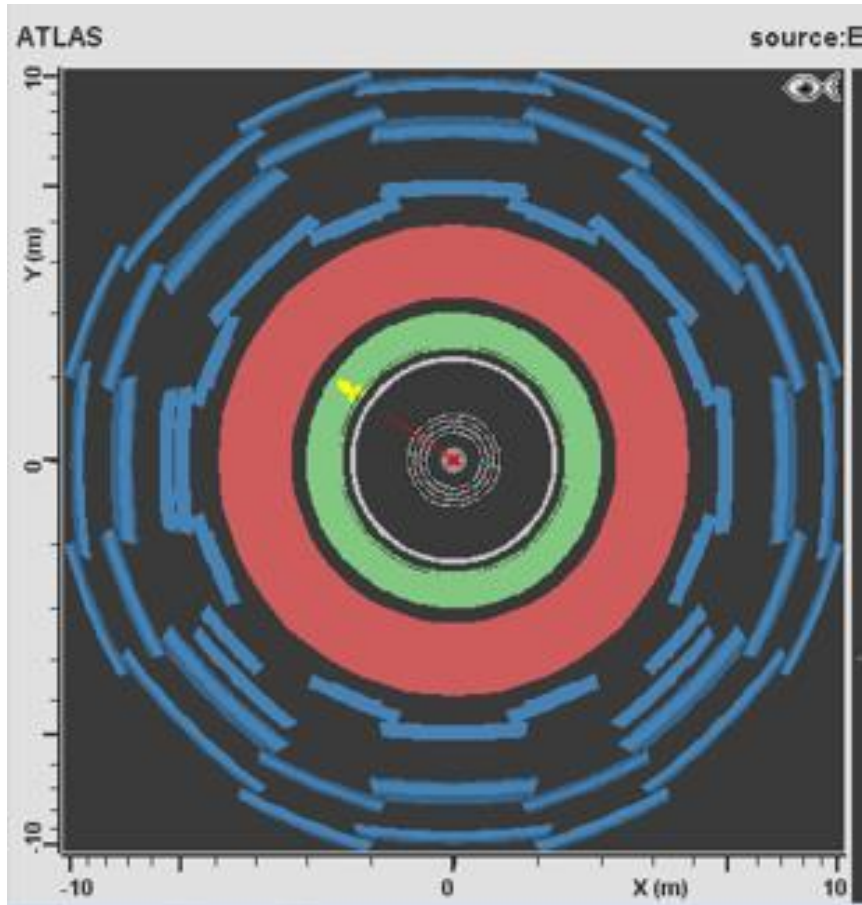
$$\frac{u\bar{u} + d\bar{d} - 2s\bar{s}}{\sqrt{6}}$$

Ako vidí častice experiment? (hmlová komora)

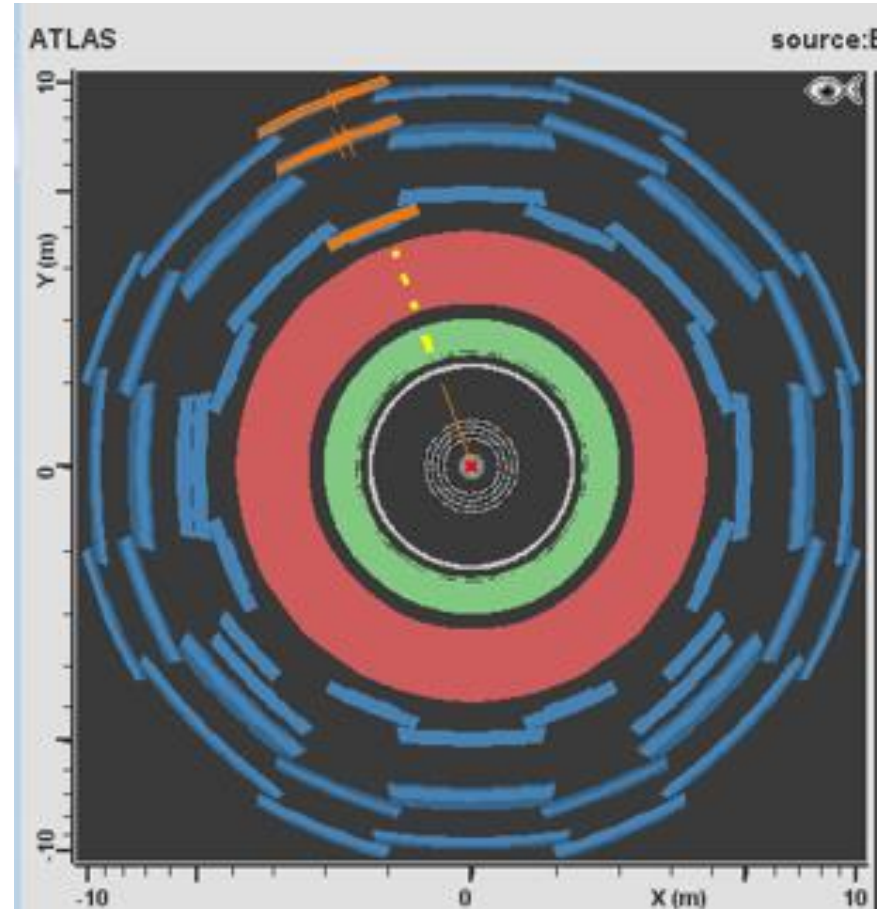


Ako vidí častice experiment? (ATLAS)

elektrón



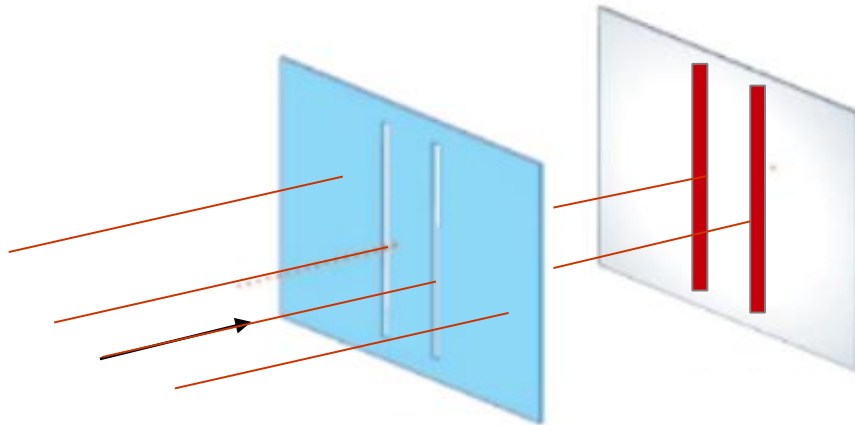
mión



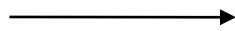


Akú majú o časticiach predstavu fyzici?

2 – štrbinový experiment (svetlo ako lúče)

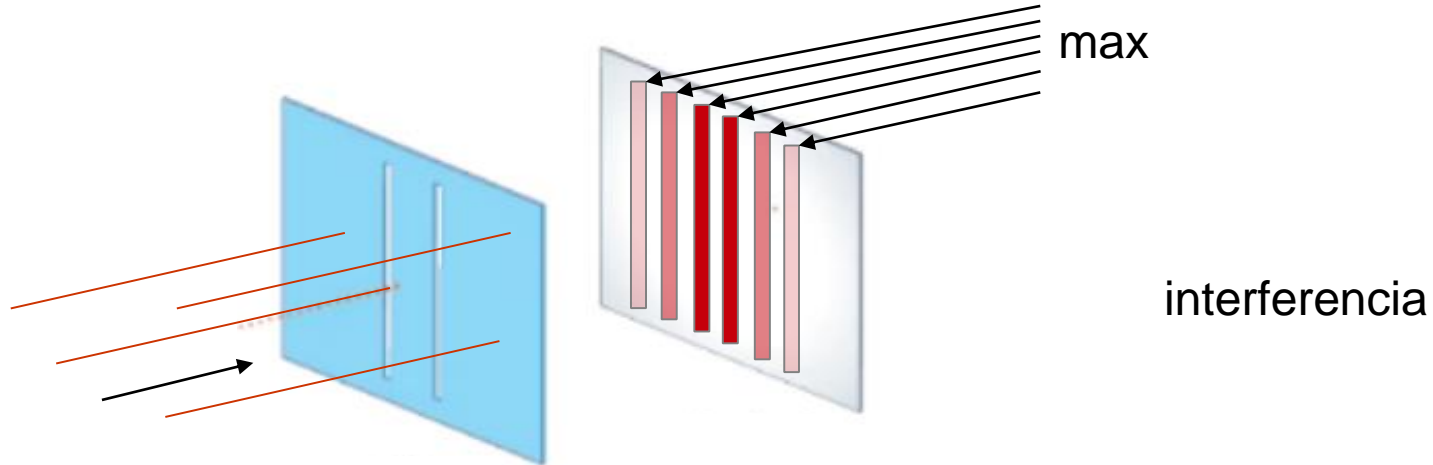


vzdialenosť štrbín \gg vlnová dĺžka svetla



Newton: svetlo sú častice

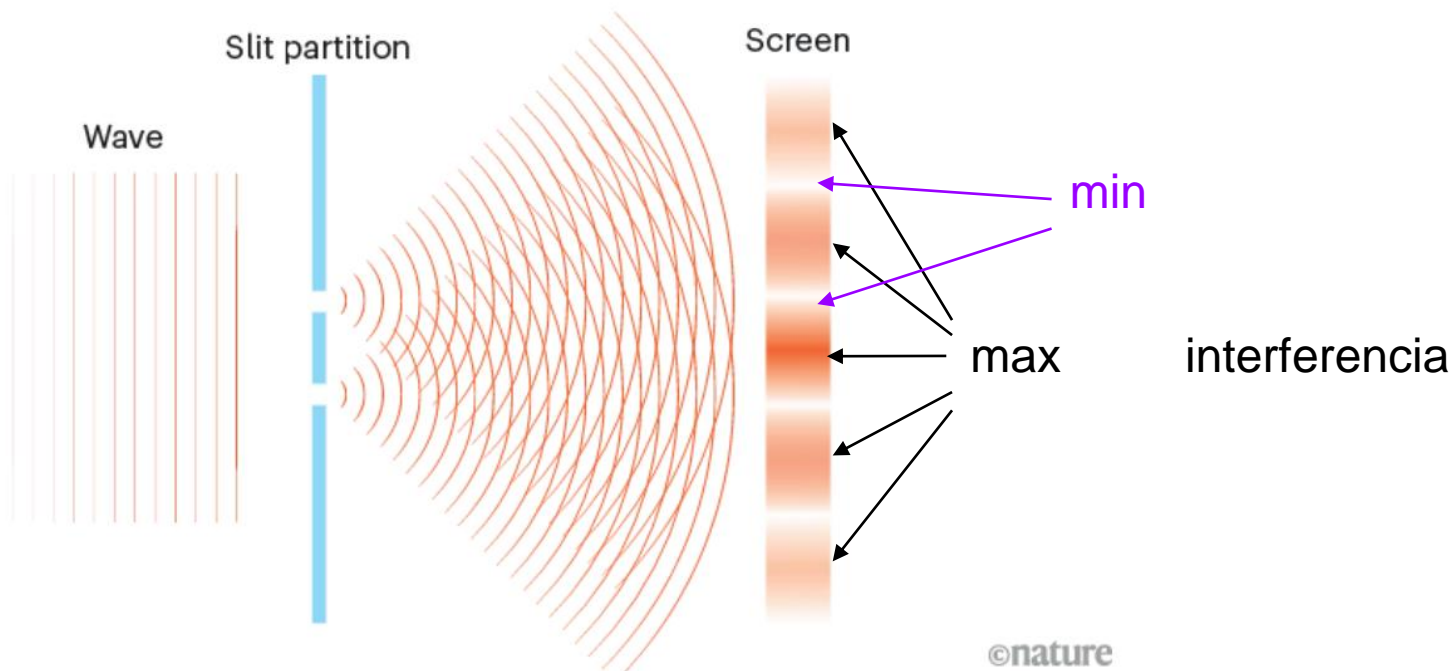
2 – štrbinový experiment (svetlo ako vlna)



Young 1805

Vzdialenosť štrbín ~ vlnová dĺžka svetla

2 – štrbinový experiment (svetlo ako vlna)

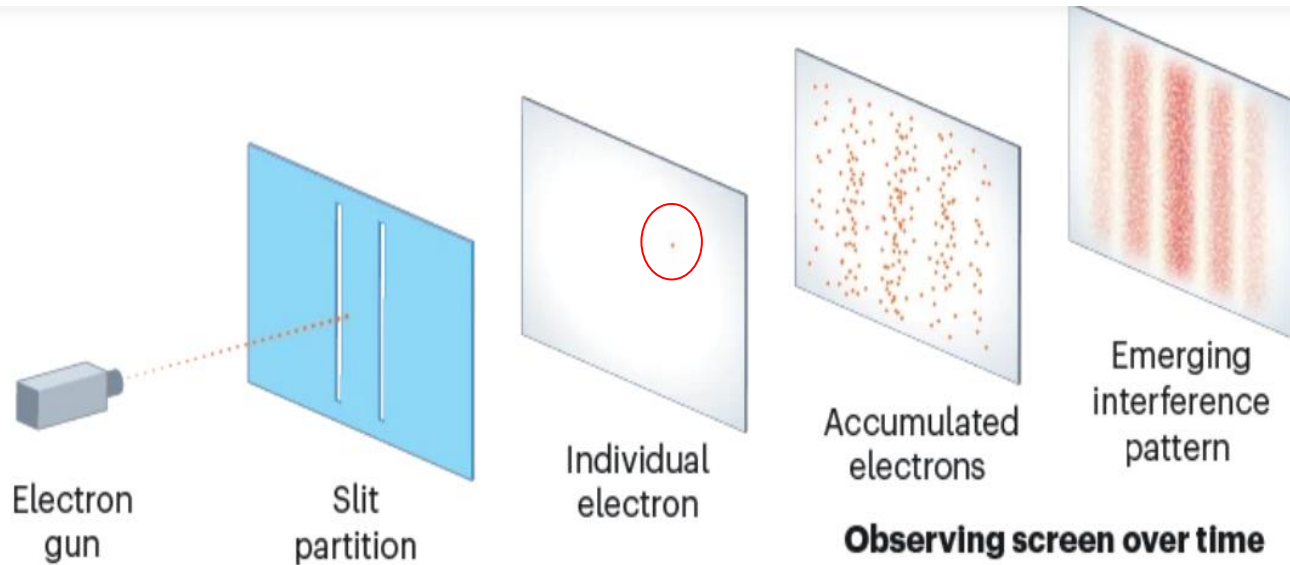


Young 1805

vzdialenosť štrbín ~ vlnová dĺžka svetla

2 – štrbinový experiment (elektróny a fotóny)

Vzdialenosť štrbín ~ vlnová dĺžka elektrónu/fotónu

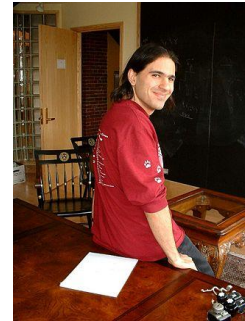


Elektrón/fotón sa správa ako vlna aj ako častica

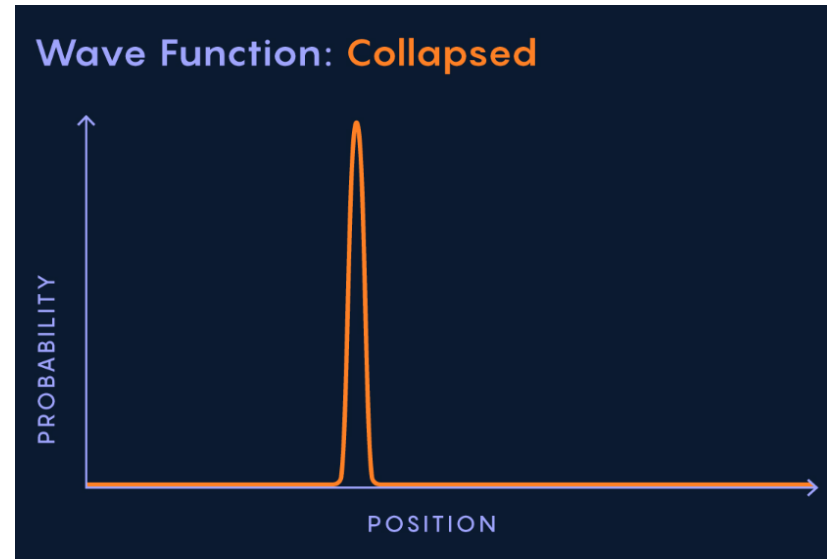
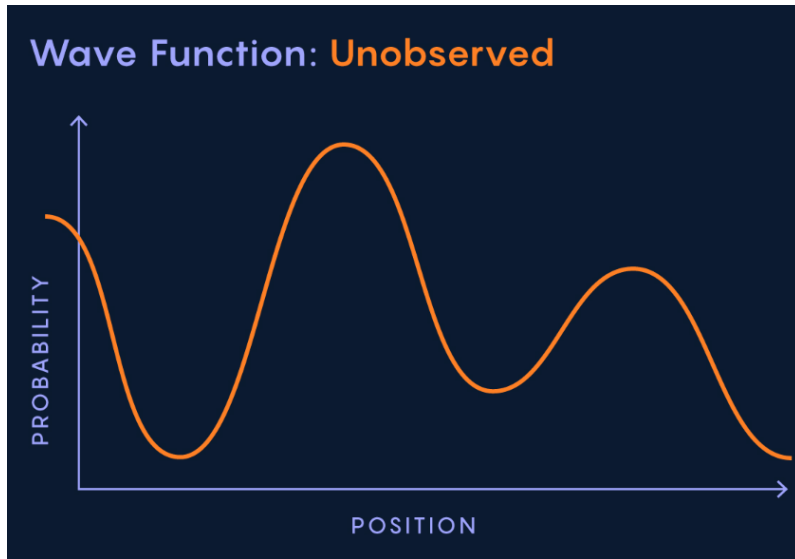
Feynman: svetlo sú častice



Arkani-Hamed: častice sú vlny



Kolaps vlny (vlnovej funkcie) pri meraní



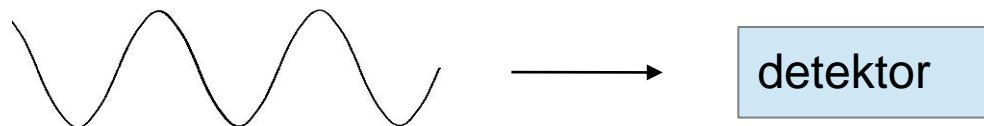
Častice sú v našej bežnej predstave

1. lokalizované
2. pri prúde častíc sa energia v detektore mení skokom



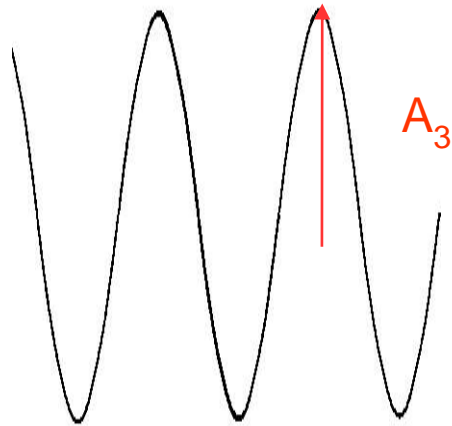
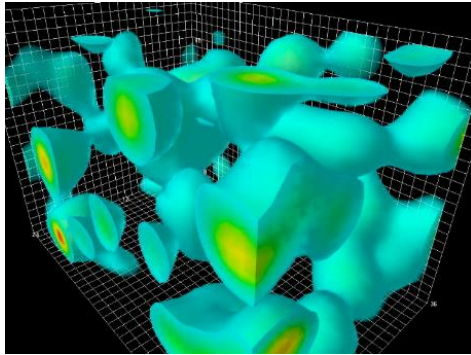
Vlna je

1. nelokalizovaná
2. pri dopadajúcej vlne sa energia v detektore mení spojit

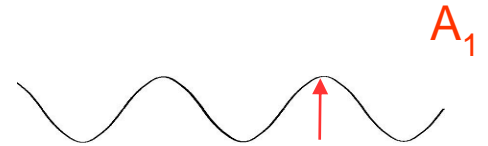
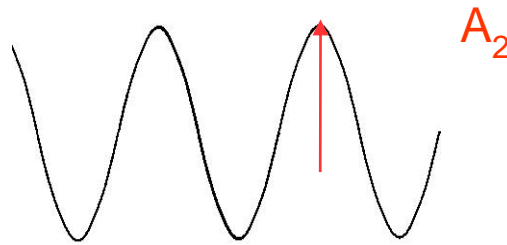


Častica ako excitácia kvantového poľa

vákuum



Amplitúdy sa menia skokom

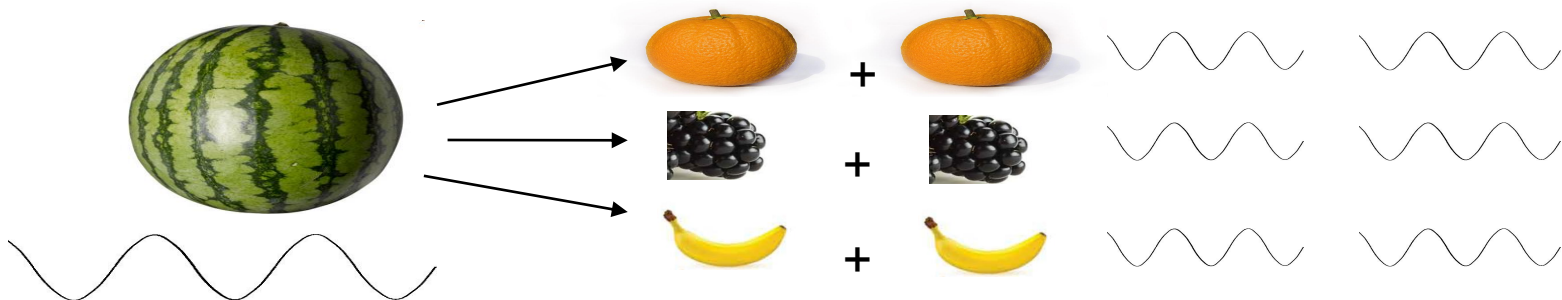


Častica je vlna s najmenšou možnou priemernou amplitúdou

Rozpad častíc

Disipácia alebo rozpad vln

- časť energie struny sa premení na vibrovanie vzduchu (zvuk)
- časť sa premení trením na teplo, čo sú vibrácie molekúl v strune



Back - up

Čo sa vlastne vlní?

Klasické vlny: prostredie



voda

Kvantové vlny: - žiadne prostredie
- šíria sa v kvantovom poli

Pr. Elektromagnetické vlny: éter
sa nenašiel

- šíria sa v kvantovom
elektromagnetickom poli