

Úvod do částicové fyziky

část' 2: Antihmota

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Pozitrón - teoretický objav

Diracova rovnica

$$\left(\not{p} - \frac{eA}{c} - mc \right) \psi(x) = 0$$



Paul Adrien Maurice Dirac
odvodenie 1928 (26 rokov)
Nobelova cena 1933

Diracova rovnica podrobne

$$\left(\not{p} - \frac{eA}{c} - mc \right) \psi(x) = 0$$

$$\not{p} = i\hbar \left(\frac{1}{c} \gamma^0 \frac{\partial}{\partial t} + \gamma^1 \frac{\partial}{\partial x} + \gamma^2 \frac{\partial}{\partial y} + \gamma^3 \frac{\partial}{\partial z} \right)$$
$$\not{A} = \gamma^0 A^0 - \gamma^1 A^1 - \gamma^2 A^2 - \gamma^3 A^3 \quad \psi(x) = \begin{pmatrix} \psi_0(x) \\ \psi_1(x) \\ \psi_2(x) \\ \psi_3(x) \end{pmatrix}$$

$$\gamma^0 = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix} \quad \gamma^2 = \begin{pmatrix} 0 & 0 & 0 & -i \\ 0 & 0 & i & 0 \\ 0 & i & 0 & 0 \\ -i & 0 & 0 & 0 \end{pmatrix}$$

$$\gamma^1 = \begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{pmatrix} \quad \gamma^3 = \begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

Rozpísaná Diracova rovnica

$$i\hbar \frac{1}{c} \frac{\partial \psi_0}{\partial t} - \frac{e}{c} A^0 \psi_0 - mc\psi_0 + i\hbar \frac{\partial \psi_2}{\partial z} - \frac{e}{c} A^3 \psi_2 + i\hbar \left(\frac{\partial}{\partial x} - i \frac{\partial}{\partial y} \right) \psi_3 - \frac{e}{c} (A^1 - iA^2) \psi_3 = 0$$

$$i\hbar \frac{1}{c} \frac{\partial \psi_1}{\partial t} - \frac{e}{c} A^0 \psi_0 - mc\psi_1 - i\hbar \frac{\partial \psi_3}{\partial z} + \frac{e}{c} A^3 \psi_3 + i\hbar \left(\frac{\partial}{\partial x} + i \frac{\partial}{\partial y} \right) \psi_2 - \frac{e}{c} (A^1 + iA^2) \psi_2 = 0$$

$$-i\hbar \frac{1}{c} \frac{\partial \psi_2}{\partial t} + \frac{e}{c} A^0 \psi_2 - mc\psi_2 - i\hbar \frac{\partial \psi_0}{\partial z} + \frac{e}{c} A^3 \psi_0 - i\hbar \left(\frac{\partial}{\partial x} - i \frac{\partial}{\partial y} \right) \psi_1 + \frac{e}{c} (A^1 - iA^2) \psi_1 = 0$$

$$-i\hbar \frac{1}{c} \frac{\partial \psi_1}{\partial t} + \frac{e}{c} A^0 \psi_0 - mc\psi_1 + i\hbar \frac{\partial \psi_1}{\partial z} + \frac{e}{c} A^3 \psi_1 - i\hbar \left(\frac{\partial}{\partial x} + i \frac{\partial}{\partial y} \right) \psi_0 + \frac{e}{c} (A^1 + iA^2) \psi_0 = 0$$

Rozpísaná Diracova rovnica

$$i\hbar \frac{1}{c} \frac{\partial \psi_0}{\partial t} \left(-\frac{e}{c} A^0 \psi_0 - mc\psi_0 + i\hbar \frac{\partial \psi_2}{\partial z} - \frac{e}{c} A^3 \psi_2 + i\hbar \left(\frac{\partial}{\partial x} - i\frac{\partial}{\partial y}\right) \psi_3 - \frac{e}{c} (A^1 - iA^2) \psi_3 = 0\right.$$

$$i\hbar \frac{1}{c} \frac{\partial \psi_1}{\partial t} \left(-\frac{e}{c} A^0 \psi_0 - mc\psi_1 - i\hbar \frac{\partial \psi_3}{\partial z} + \frac{e}{c} A^3 \psi_3 + i\hbar \left(\frac{\partial}{\partial x} + i\frac{\partial}{\partial y}\right) \psi_2 - \frac{e}{c} (A^1 + iA^2) \psi_2 = 0\right.$$

$$-i\hbar \frac{1}{c} \frac{\partial \psi_2}{\partial t} \left(+\frac{e}{c} A^0 \psi_2 - mc\psi_2 - i\hbar \frac{\partial \psi_0}{\partial z} + \frac{e}{c} A^3 \psi_0 - i\hbar \left(\frac{\partial}{\partial x} - i\frac{\partial}{\partial y}\right) \psi_1 + \frac{e}{c} (A^1 - iA^2) \psi_1 = 0\right.$$

$$-i\hbar \frac{1}{c} \frac{\partial \psi_1}{\partial t} \left(+\frac{e}{c} A^0 \psi_0 - mc\psi_1 + i\hbar \frac{\partial \psi_1}{\partial z} + \frac{e}{c} A^3 \psi_1 - i\hbar \left(\frac{\partial}{\partial x} + i\frac{\partial}{\partial y}\right) \psi_0 + \frac{e}{c} (A^1 + iA^2) \psi_0 = 0\right.$$

- v 3. a 4. riadku je pri e iné znamienko ako v 1. a 2. riadku
- rovnica popisuje aj časticu s opačným nábojom a rovnakou hmotnosťou, ako má elektrón

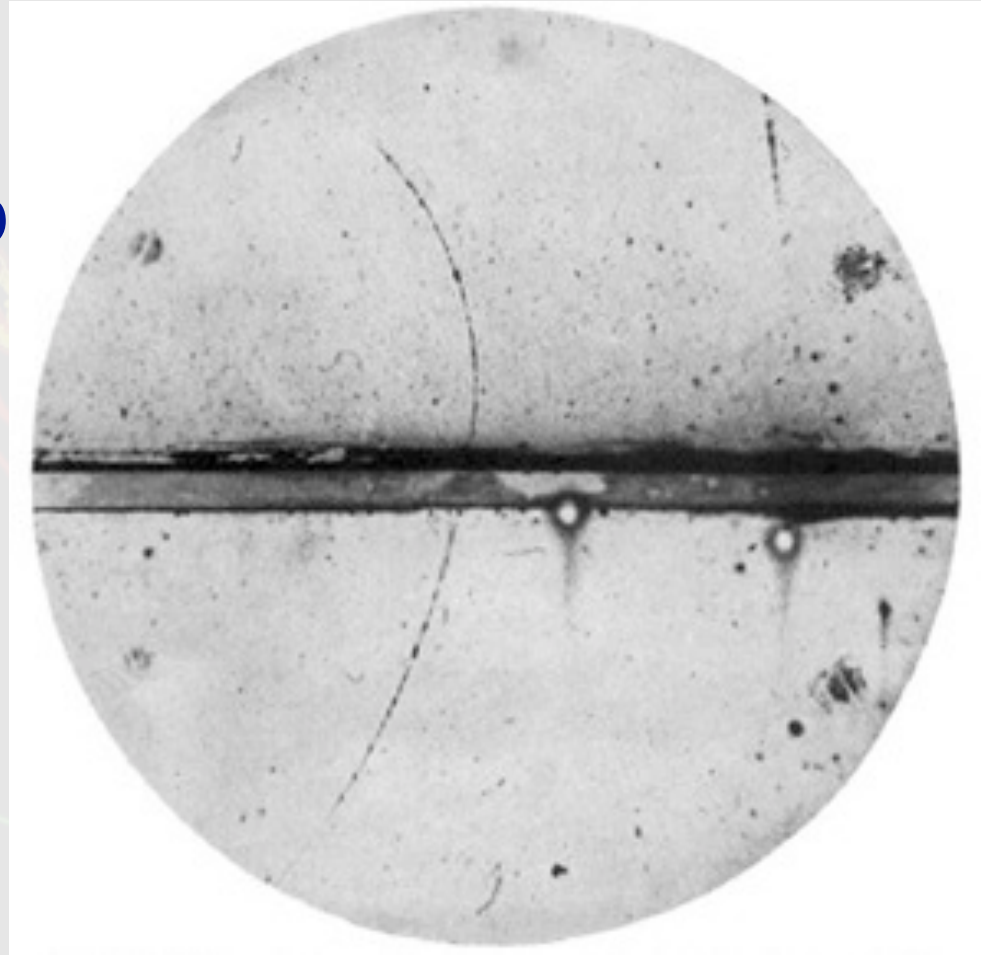
Pozitrón - experimentálny objav

Carl Anderson

- pozorovanie kozmického žiarenia
- hmlová komora v magnetickom poli

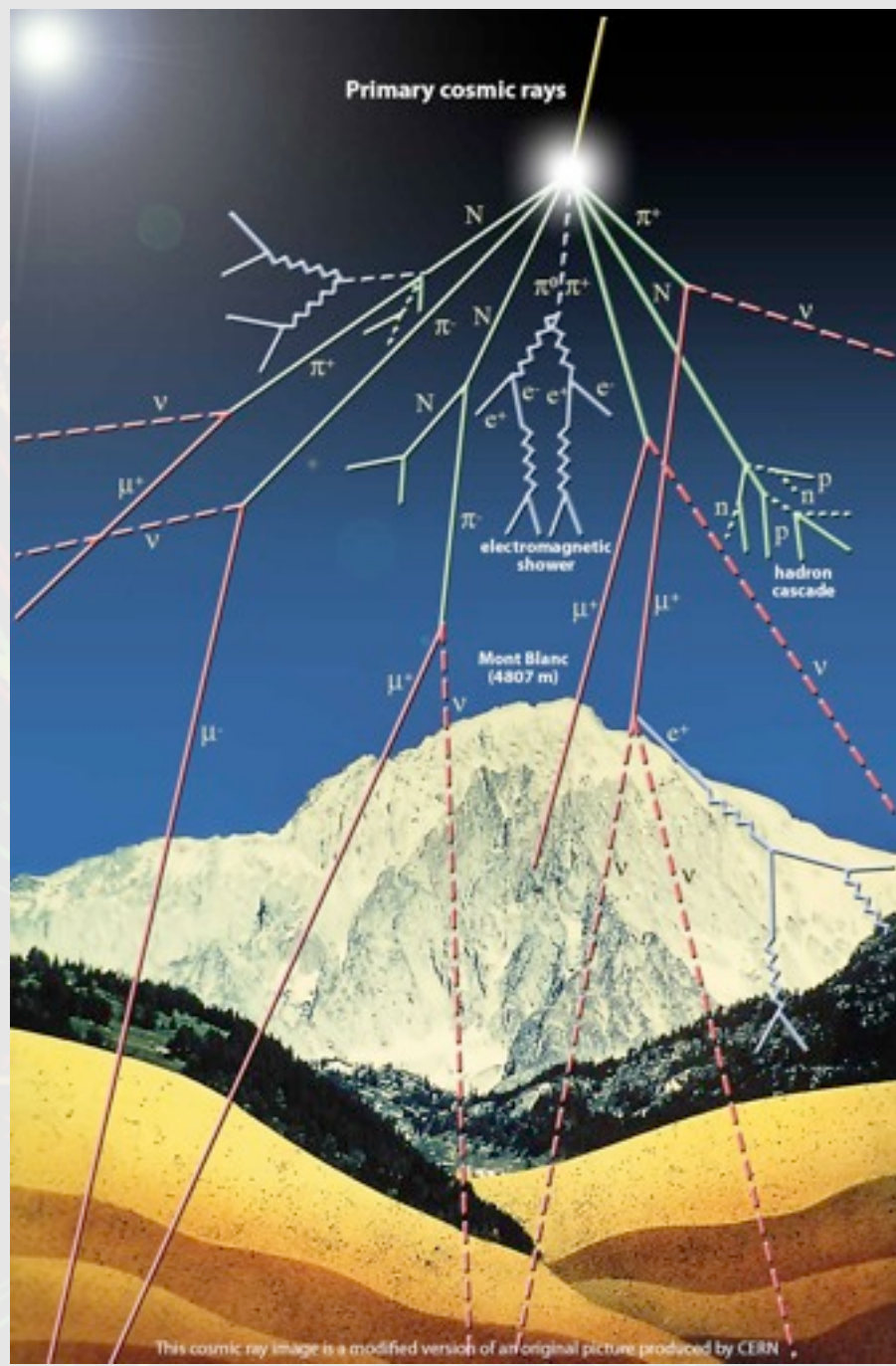


Carl David Anderson
Objav 1933 (28 rokov)
Nobelova cena 1936



Kozmické žiarenie

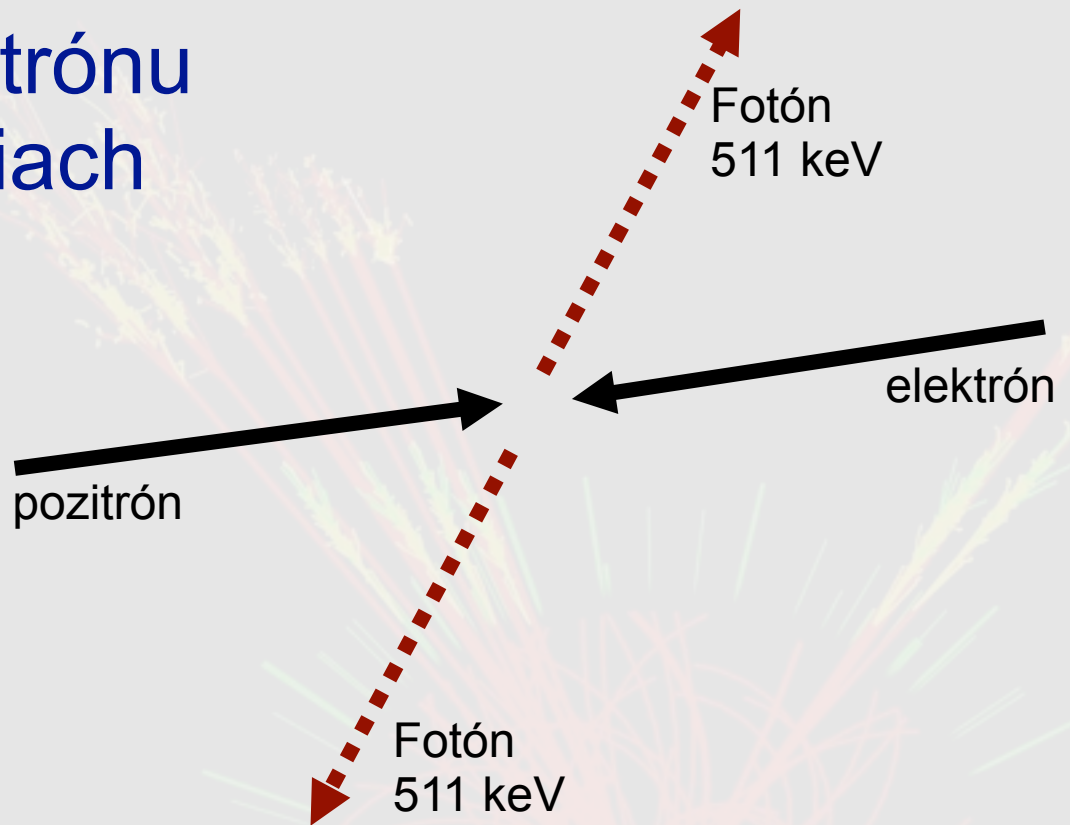
- prúd protónov a jadier prilietajúcich z vesmíru
- odtienené v stratosfére
- zrážkami s jadrami vo vzduchu vznikajú spršky
- väčšie dávky vo veľkých výškach
- na povrchu Zeme 1 mión/min/cm²



Anihilácia pozitrónu

stret elektrónu a pozitrónu
pri malých hybnostiach

=> vznik 2 fotónov

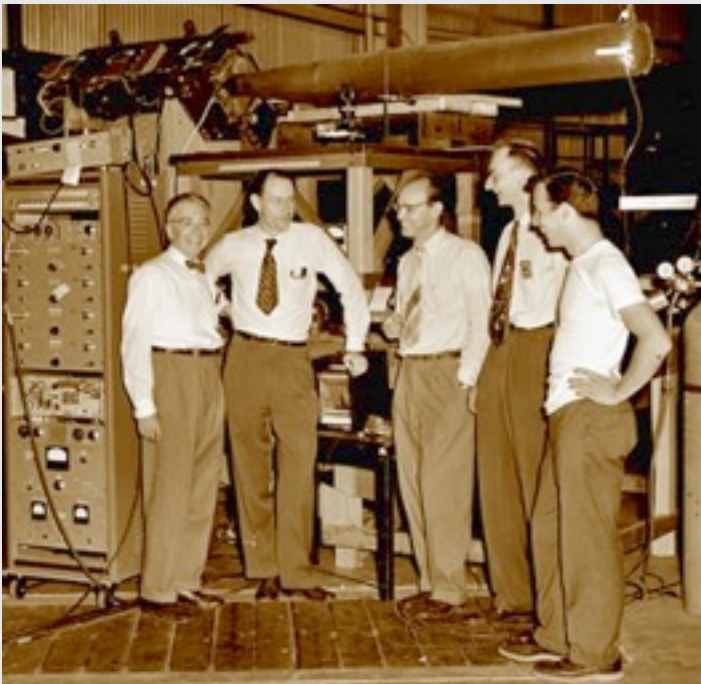


zákon zachovania energie

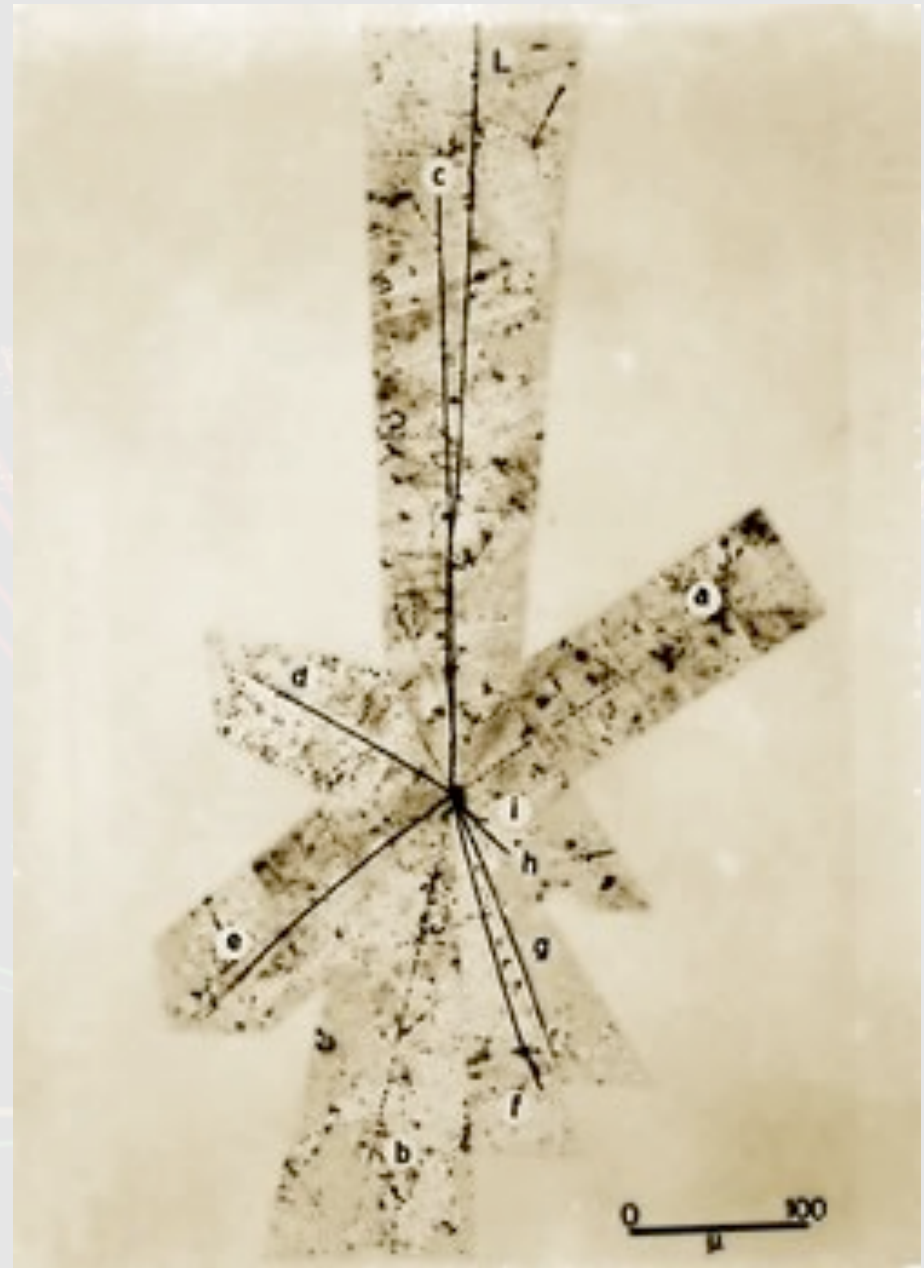
zákon zachovania hybnosti

Antiprotón

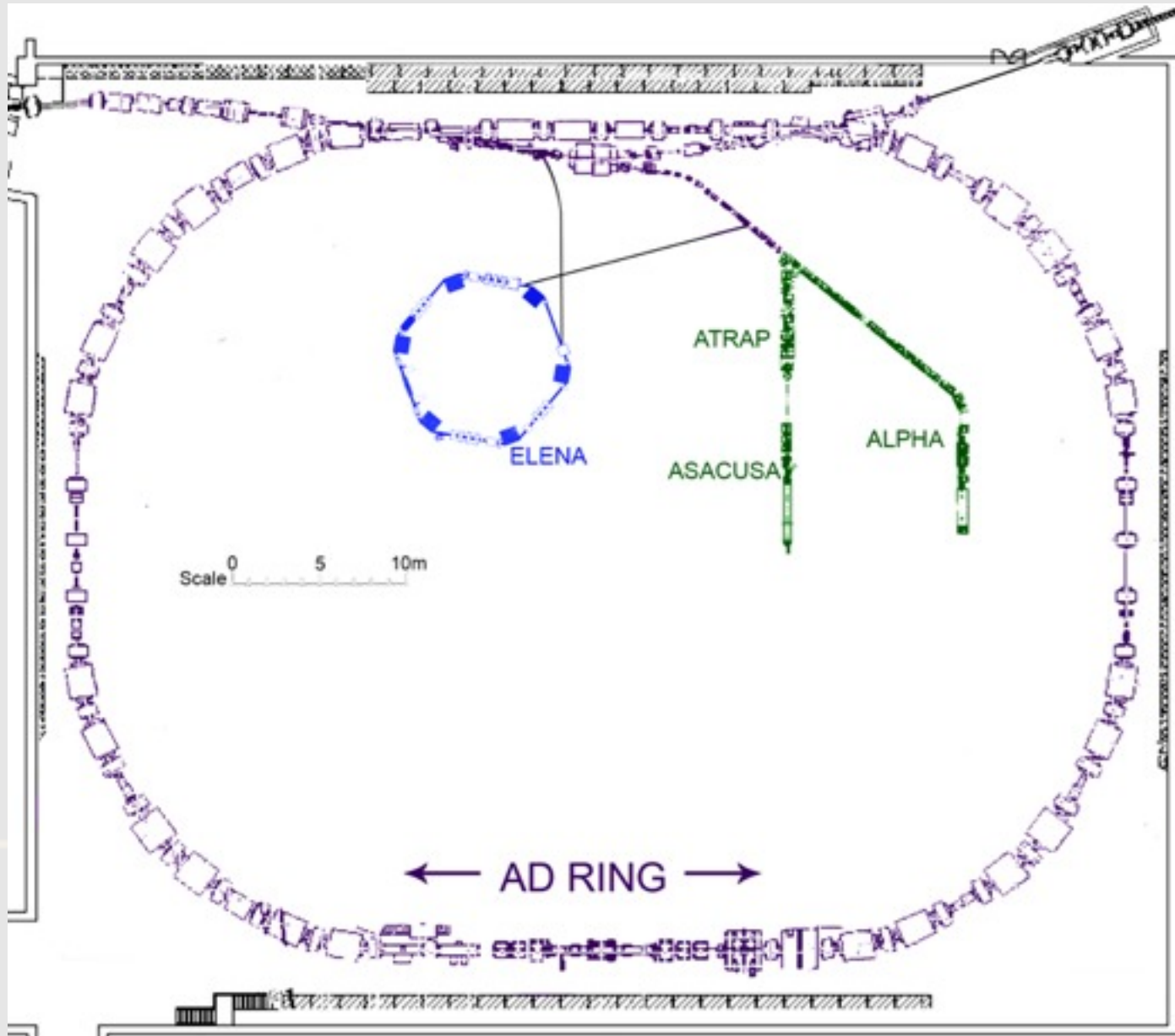
Antiprotón prilieta zhora,
zráža sa s protónom a
anihiluje na 9 piónov



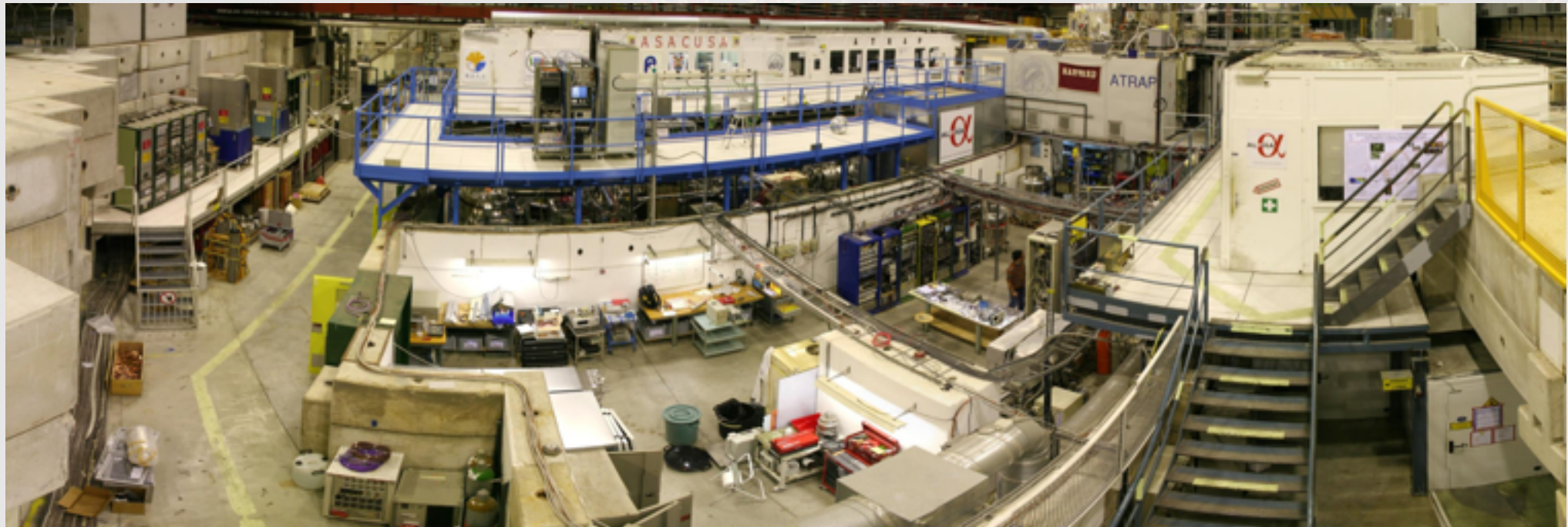
Emilio Gino Segre
objav 1955 (50 rokov)
Nobelova cena 1959



AD - Antiprotonový decelerátor

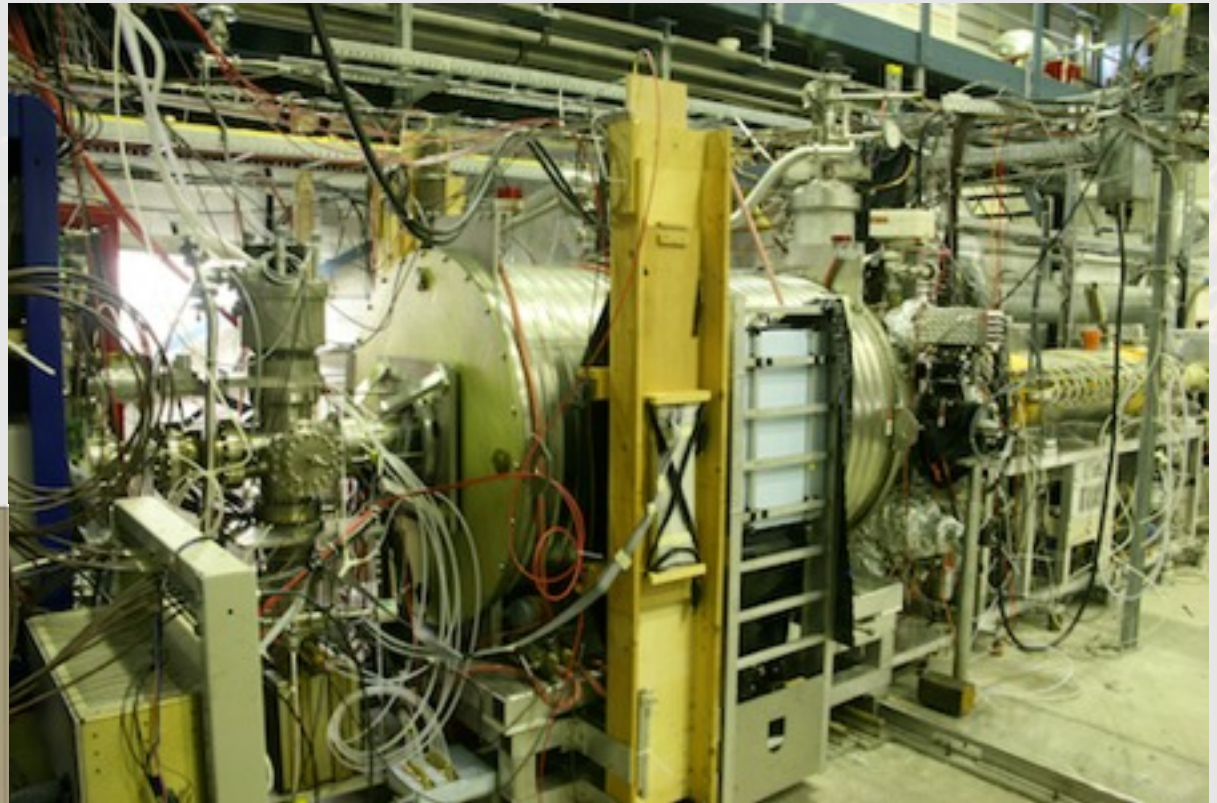


AD - Antiprotónový decelerátor



Antivodík

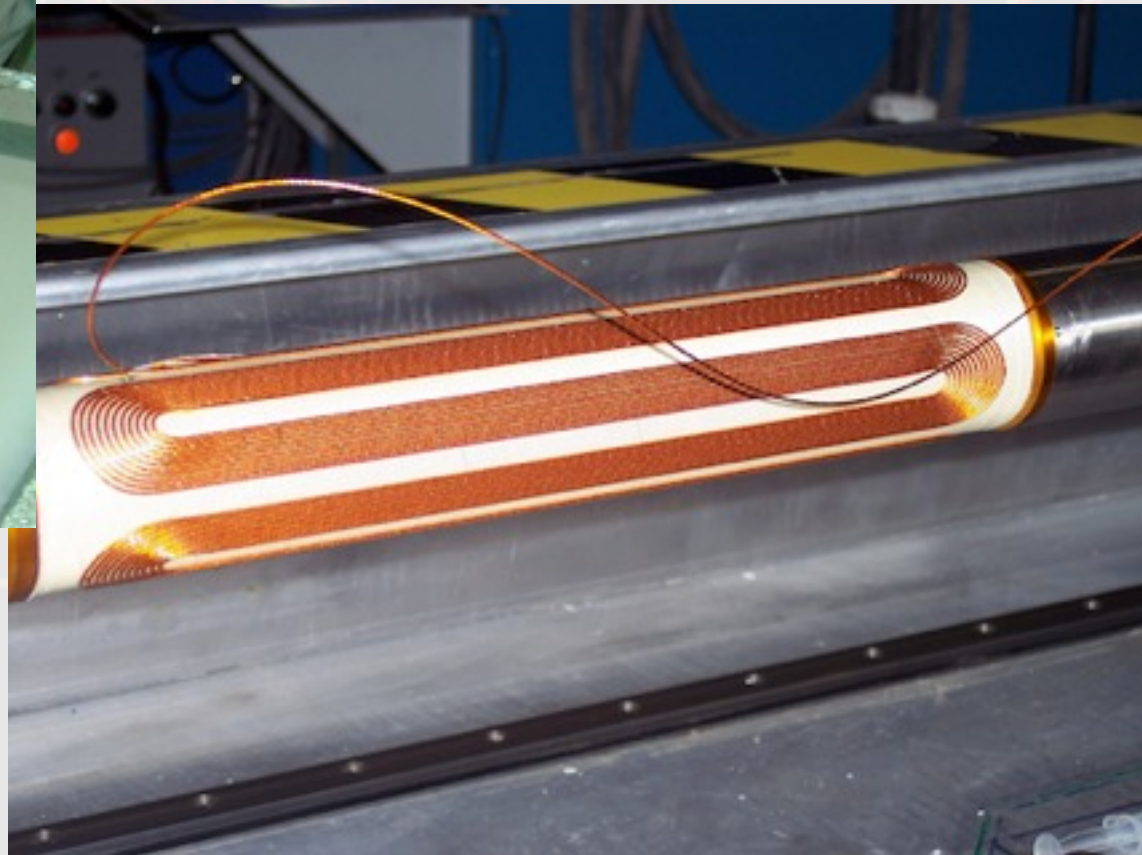
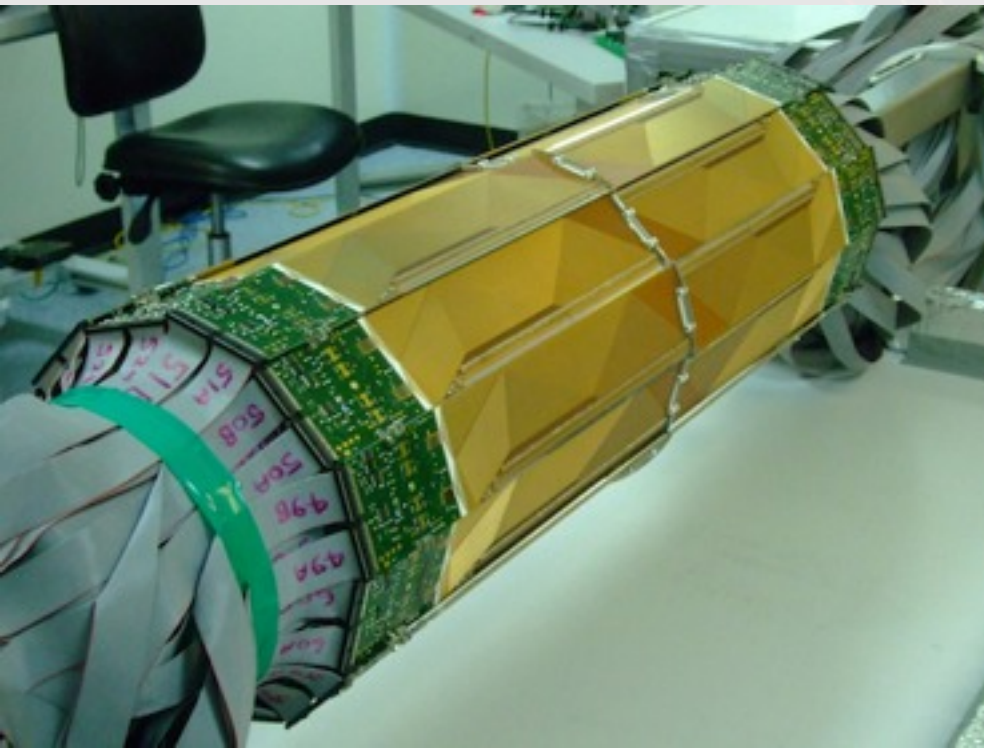
Viazaný stav antiprotónu a pozitronu



Experiment ALPHA

Antivodík na niekoľko minút

Antivodík je držaný v Ioffeho pasci



Jadro antihélie

Experiment STAR,
Brookhaven National
Laboratory

