DIRIGE: ALEXIS MAURICIO

Search for sterile neutrinos at the DANSS experiment

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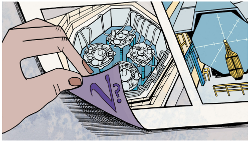
JUEVES 23
1 - 3 P.M.
R1 225A FAC. CIENCIAS - UNI

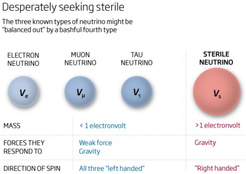
Temas a discusión:
Neutrinos estériles
Oscilaciones de neutrinos

***Este evento es gratis y abierto al público**

Motivación

Existen los neutrinos estériles?



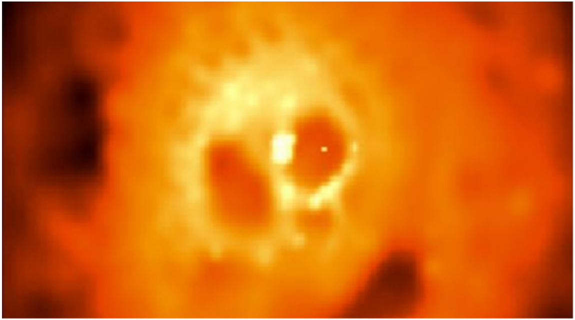


Desperately seeking sterile

The three known types of neutrino might be "balanced out" by a bashful fourth type

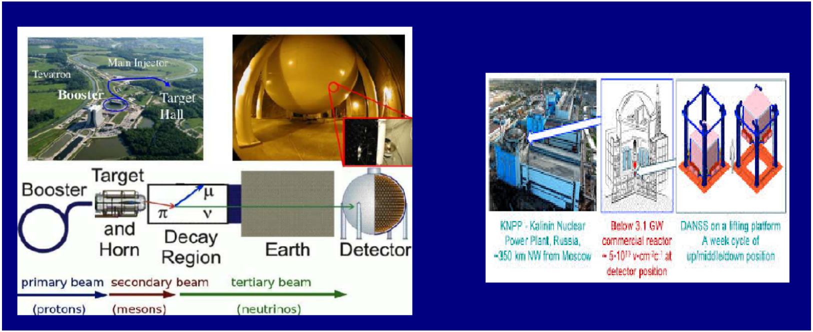
	ELECTRON NEUTRINO	MUON NEUTRINO	TAU NEUTRINO	**STERILE NEUTRINO**
	ν_e	ν_μ	ν_τ	ν_s
MASS	< 1 electronvolt			>1 electronvolt
FORCES THEY RESPOND TO	Weak force Gravity			Gravity
DIRECTION OF SPIN	All three "left handed"			"Right handed"

Motivación

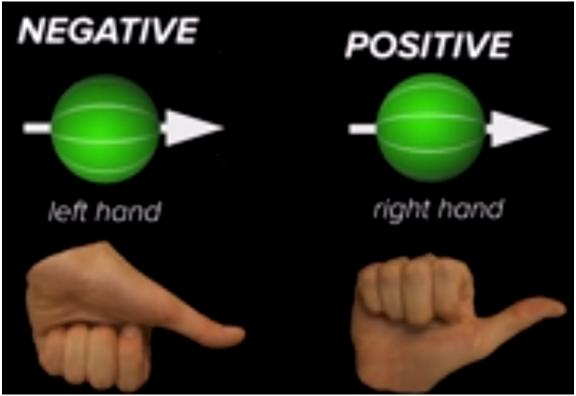


A. Fabian (IoA Cambridge) *et al.* /NASA

Motivación


Main Injector
Tevatron
Booster
Target Hall
Booster
Target and Horn
μ
π
ν
Decay Region
Earth
Detector
primary beam
(protons)
secondary beam
(mesons)
tertiary beam
(neutrinos)
KNPP - Kalinin Nuclear Power Plant, Russia, ~350 km NW from Moscow
Below 3.1 GW commercial reactor ~ $5\cdot 10^{13}$ $\nu\cdot cm^{-2}c^{-1}$ at detector position
DANSS on a lifting platform A week cycle of up/middle/down position

Motivación



Motivación

The RH neutrinos can play a crucial role:

- In the generation of **neutrino masses and mixing**.
- In understanding the remarkable **disparity** between the magnitudes of **neutrino masses and the masses of the charged leptons and quarks**.
- In the generation of the observed **matter-antimatter asymmetry of the Universe (via the leptogenesis mechanism)**.

Objetivo:

Por medio de la **detección de** $\overline{\nu}_e$ a través de una reacción de **decaimiento beta inverso**, evidenciar la **distorsión del espectro de energía del** $\overline{\nu}_e$.

Introducción:

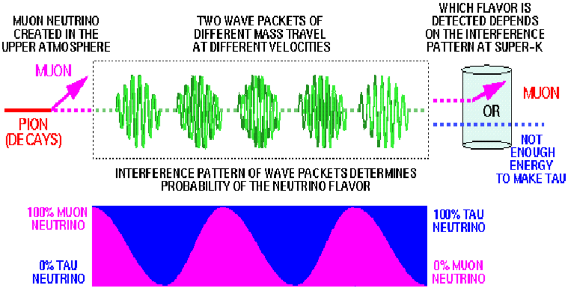
Entendemos por **neutrino estéril** como aquella partícula que **no interactúa con la fuerza nuclear fuerte, electromagnética y nuclear débil**; este tipo hipotético de partícula tan solo **interactúa con la fuerza gravitacional.**

Introducción:

Los neutrinos poseen una propiedad fundamental **chirality o quiralidad**. La quiralidad, en una partícula, **determina con qué tipo de fuerza interactúa la partícula**. En el caso de los **neutrinos, la quiralidad es del tipo left-handed**, mientras que para su **antipartícula es del tipo right-handed**.

Introducción:

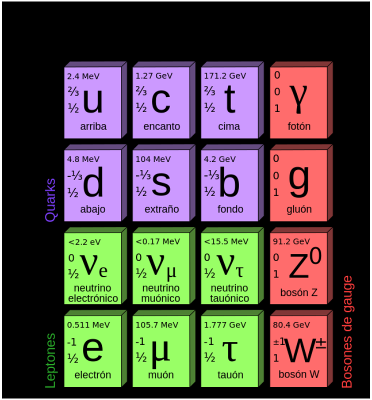
En cuanto al fenómeno de **oscilación de neutrinos**, consiste en que en el **proceso de medición de un neutrino**, se registra un **flavour o sabor inicial**, ya sean $\nu_e,\ \nu_\mu\ o\ \nu_\tau$, que posteriormente se mide con un **sabor final diferente**. La observación de **este fenómeno indica que el neutrino experimenta el flujo del tiempo, lo cual significa que posee una masa, aunque muy pequeña, ésta es diferente de cero.**

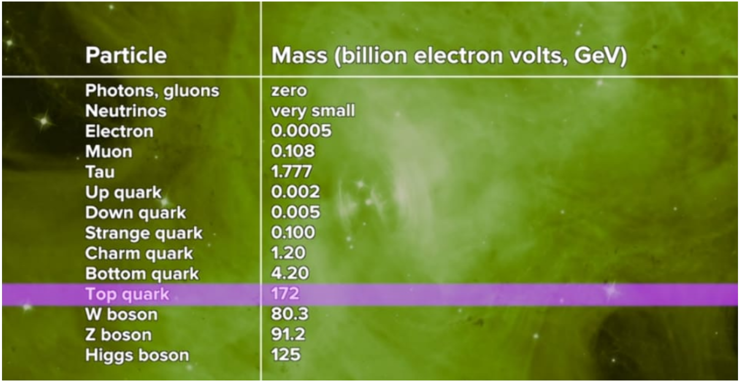


Introducción:

Del modelo estándar de partículas

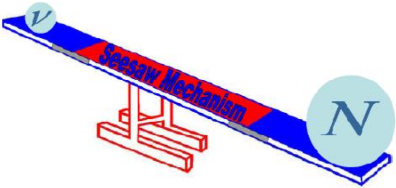
Según el **modelo estándar de partículas**, tenemos los **bosones, gluones, fotones**, de los cuales estos **dos últimos no poseen masa**; además de los **quarks (partículas masivas en el orden de cientos de millones)** y finalmente los **leptones**.

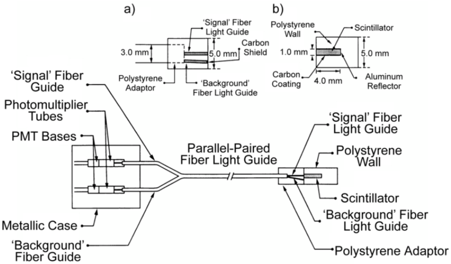




Particle	Mass (billion electron volts, GeV)
Photons, gluons	zero
Neutrinos	very small
Electron	0.0005
Muon	0.108
Tau	1.777
Up quark	0.002
Down quark	0.005
Strange quark	0.100
Charm quark	1.20
Bottom quark	4.20
Top quark	172
W boson	80.3
Z boson	91.2
Higgs boson	125

Introducción:



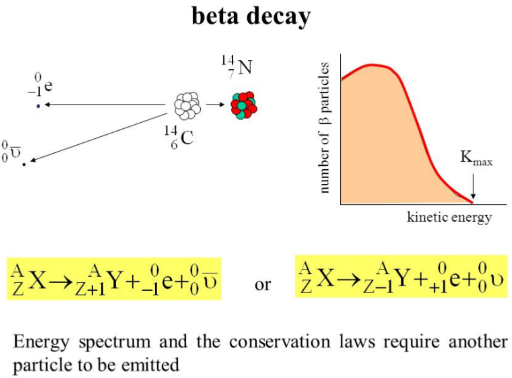


Metodología:

Beta decay reaction:

$${}^{1}_{0}n \longrightarrow {}^{1}_{1}p + e^{-}$$

$${}^{1}_{0}n \longrightarrow {}^{1}_{1}p + e^{-} + \overline{\nu}_{e}$$


beta decay

$${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e + {}^{0}_{0}\overline{\upsilon}$$

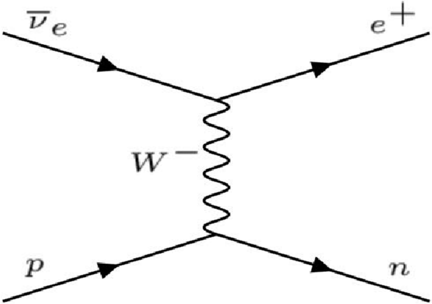
or

$${}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}e + {}^{0}_{0}\upsilon$$

Energy spectrum and the conservation laws require another particle to be emitted

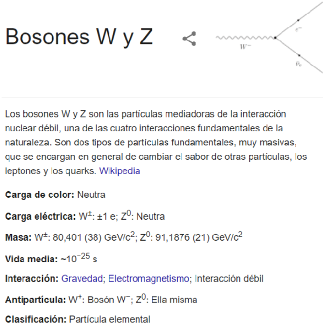
Metodología:

Inverse beta decay:



Metodología:

MC simulation (Monte Carlo simulation):



Bosones W y Z

Los bosones W y Z son las partículas mediadoras de la interacción nuclear débil, una de las cuatro interacciones fundamentales de la naturaleza. Son dos tipos de partículas fundamentales, muy masivas, que se encargan en general de cambiar el sabor de otras partículas, los leptones y los quarks. Wikipedia

Carga de color: Neutra

Carga eléctrica: $W^{\pm}$: ±1 e; Z^0: Neutra

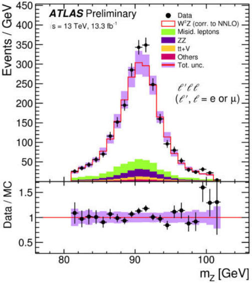
Masa: $W^{\pm}$: 80,401 (38) GeV/c^2; Z^0: 91,1876 (21) GeV/c^2

Vida media: ~10^{-25} s

Interacción: Gravedad; Electromagnetismo; Interacción débil

Antipartícula: W^+: Bosón W^-; Z^0: Ella misma

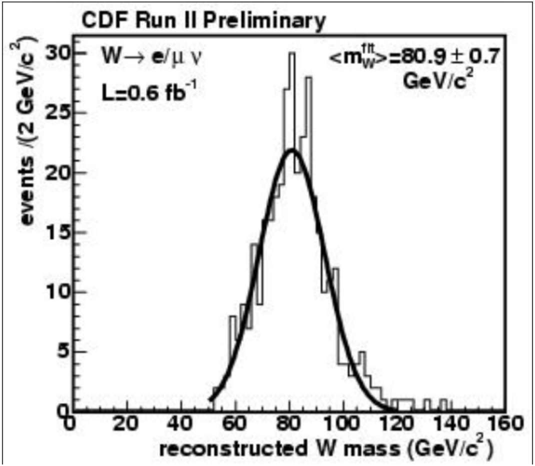
Clasificación: Partícula elemental



Metodología:

MC simulation (Monte Carlo simulation):

$$\begin{array}{cccccc} n & \longrightarrow & W & + & p \\ W & \longrightarrow & e^{-} & + & \overline{\nu}_e \\ W_{mass} & = & 156000 & eV & \end{array}$$



Metodología:

More about neutrino oscillations:

The Cabbibo angle

Quark transitions in the weak decays indeed are observed predominantly within a family but also, to a lesser degree, **from one family to another**. For charged currents, the partner of the flavour eigenstate $|u>$ is therefore not the flavour eigenstate $|d>$, but a **linear combination of** $|d>$ **and** $|s>$**.We call this linear combination** $|d'>$. Similarly the partner of the c-quark is a linear combination of $|s>$ and $|d>$, orthogonal to $|d'>$, which we call $|s'>$. **The coefficients of these linear combinations can be written as the cosine and sine of an angle called the Cabibbo angle** θ.

$$\begin{aligned} |d'> &= \cos\theta|d> + \sin\theta|s> \\ |s'> &= \cos\theta|s> - \sin\theta|d> \end{aligned}$$

Metodología:

More about neutrino oscillations:

$$\begin{pmatrix} |d' > \\ |s' > \end{pmatrix} \quad = \quad \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} |d > \\ |s > \end{pmatrix}$$

In view of neutrino oscillations, we emphasise here that **only the eigenstates $|d>$ and $|s>$ of the strong interaction have a well defined mass, but not the states $|d'>$ and $|s'>$.**

Metodología:

More about neutrino oscillations:

The flavour states $|\nu_e>$, $|\nu_\mu>$ and $|\nu_\tau>$ **are not identical to the states** $|\nu_1>$, $|\nu_2>$ and $|\nu_3>$, which possess a **well-defined mass**. However, **in analogy to the quarks, we can write the flavour states as orthogonal linear combinations of the mass states**:

$$\begin{pmatrix}|\nu_e>\\|\nu_\mu>\\|\nu_\tau>\end{pmatrix} = \begin{pmatrix}U_{e1} & U_{e2} & U_{e3}\\U_{\mu1} & U_{\mu2} & U_{\mu3}\\U_{\tau1} & U_{\tau2} & U_{\tau3}\end{pmatrix}\begin{pmatrix}|\nu_1>\\|\nu_2>\\|\nu_3>\end{pmatrix}$$

In particular, U **it is unitary and contains three mixing angles and one phase**. The possibility of **neutrino mixing** was investigated theoretically very early. **Pontecorvo** was the first to consider **neutrino-antineutrino oscillations.Maki, Nakagawa and Sakata** have discussed **flavour mixing of two neutrinos** (interestingly already before the Cabibbo angle for quark mixing was introduced). Therefore **U is called the PMNS matrix**.

Metodología:

More about neutrino oscillations:

To understand **how the elements of U can be determined**, consider two generations of neutrinos, $|\nu_e>$ and $|\nu_\mu>$, they are written as

$$\begin{pmatrix} |\nu_e> \\ |\nu_\mu> \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} \\ U_{\mu 1} & U_{\mu 2} \end{pmatrix} \begin{pmatrix} |\nu_1> \\ |\nu_2> \end{pmatrix}$$

The time evolution of the mass states leads after a time t to the following **wave function of the electron neutrino**:

$$|\nu_e(t)> = \cos\theta e^{-iE_{\nu_1}t/\hbar}|\nu_1> + \sin\theta e^{-iE_{\nu 2}t/\hbar}|\nu_2>$$

$$E_{\nu_i} = \sqrt{p^2c^2 + m_{\nu_i}^2c^4} \approx pc(1 + \frac{1}{2}\frac{m_{\nu_i}^2c^4}{p^2c^2})$$

The probability to find an electron neutrino after the time t is therefore

$$P_{\nu_e \longrightarrow \nu_e} = |\langle\nu_e(t)|\nu_e\rangle|^2 =$$
$$\cos^4\theta + \sin^4\theta + 2\cos^2\theta\sin^2\theta\cos\left(\frac{\Delta m_{21}^2c^4}{2\hbar c}\frac{L}{pc}\right)$$

Metodología:

More about neutrino oscillations:

$$
\begin{aligned}
P_{\nu_e \longrightarrow \nu_e} &= 1 - \sin^2 2\theta \sin^2 \left(\frac{\Delta m_{21}^2 c^4}{4\hbar c} \frac{L}{pc}\right) \\
\Delta m_{21}^2 &= m_{\nu_2}^2 - m_{\nu_1}^2
\end{aligned}
$$

$L =$ *distance that travels the neutrino from the source to the point of detection.*

It follows that **by measuring the survival probability one can determine the amplitude** $\sin^2 2\theta$ (hence the elements of the mixing matrix) and the **mass-squared difference** Δm_{21}^2, which is proportional to the **oscillation frequency**.

$$P_{\nu_e \longrightarrow \nu_\mu} = 1 - P_{\nu_e \longrightarrow \nu_e} = \sin^2 2\theta \sin^2 \left(\frac{\Delta m_{21}^2 c^4}{4\hbar c} \frac{L}{pc}\right)$$

$$\frac{\Delta m_{21}^2 c^4}{4\hbar c} \frac{L}{pc} = 1.27\left(\frac{\Delta m_{21}^2}{eV^2/c^4}\right)\left(\frac{MeV}{pc}\right)\left(\frac{L}{m}\right), \quad L_{osc} = 4\pi \frac{\hbar p c^2}{\Delta m_{21}^2 c^4}$$

Metodología:

More about neutrino oscillations:

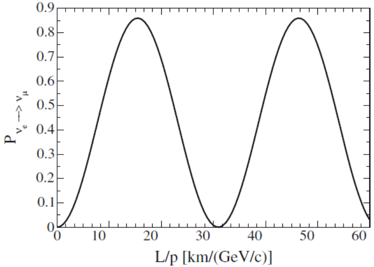


Fig. 11.1 Typical oscillation curve for the transition probability of electron neutrinos in muon neutrinos, see (11.7). The chosen parameters are $\theta = 34^\circ$ and $m_{\nu_2}^2 - m_{\nu_1}^2 = 8 \cdot 10^{-5}\,\mathrm{eV}^2/c^4$. Hence the transition probability is zero for $L/p \approx 31\,\mathrm{km}/(\mathrm{MeV}/c)$ and maximal ($\sin^2 2\theta = 0.86$) for half this value. The oscillation length for a momentum of $3\,\mathrm{MeV}/c$ is $L_{\mathrm{osc}} \approx 93\,\mathrm{km}$

Metodología:

More about neutrino oscillations:

A full **3+1 model**, however, has a 4 4 matrix that connects **all three active plus single sterile flavor states** to the four mass states:

$$U_{3+1} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} \end{bmatrix}.$$

Thus, for these oscillations, one can make the approximations that

$$\Delta m^2_{41} \approx \Delta m^2_{42} \approx \Delta m^2_{43} \text{ and } \Delta m^2_{21} \approx \Delta m^2_{32} \approx 0$$

$$P_{\alpha\beta} = \delta_{\alpha\beta} - 4(\delta_{\alpha\beta} - U_{\alpha 4} U^*_{\beta 4}) U^*_{\alpha 4} U_{\beta 4} \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$