A TINY BIT OR REALITY

J.J. Gómez Cadenas
IFIC-CSIC-U.Valencia

CERN Summer Student Lectures
2008

Hundred billion (10^{11})

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the number of sand grains in all the beaches on Earth

Hundred billion (10^{11})

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The number of stars in our galaxy

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Hundred billion (10^{11})

the number of sand grains in all the beaches on Earth

The number of stars in our galaxy

The number of galaxies in the universe

How many neutrinos cross your finger nail every second?

The world according to the Aristotle

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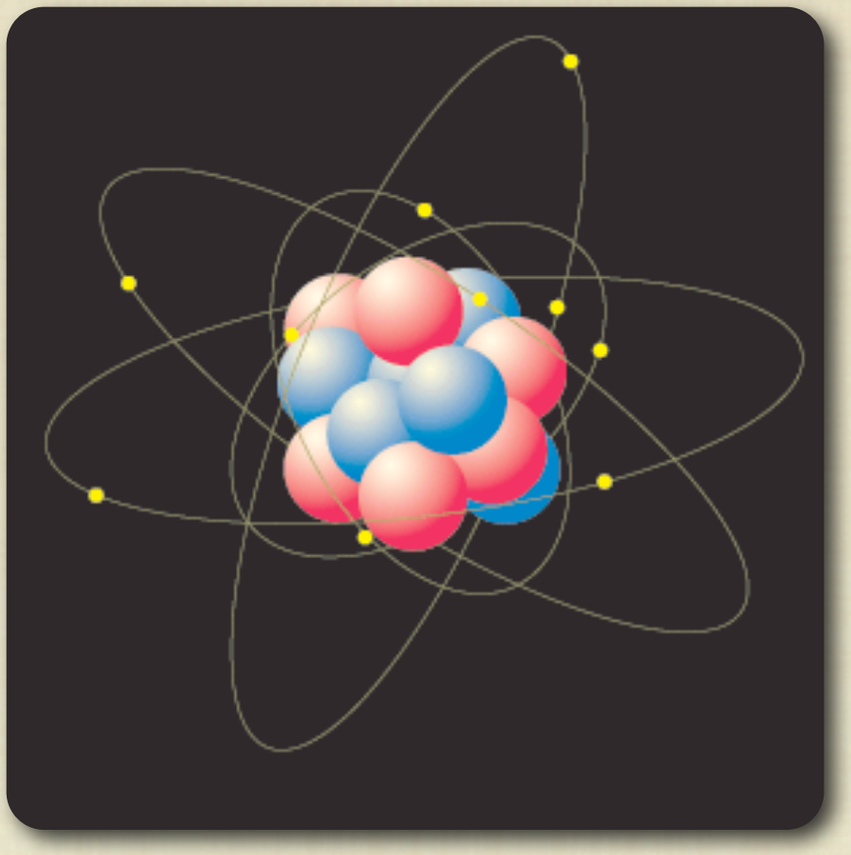
The world according to the Aristotle

The world in the XXth century



Protons and neutrons in the nucleus
electrons orbiting around

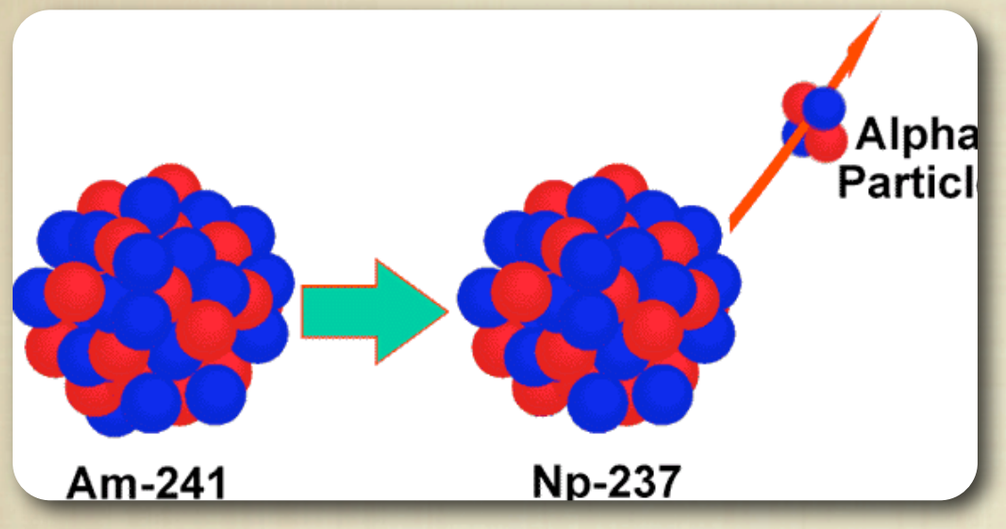
Circa 1900

Universal exposition
Paris

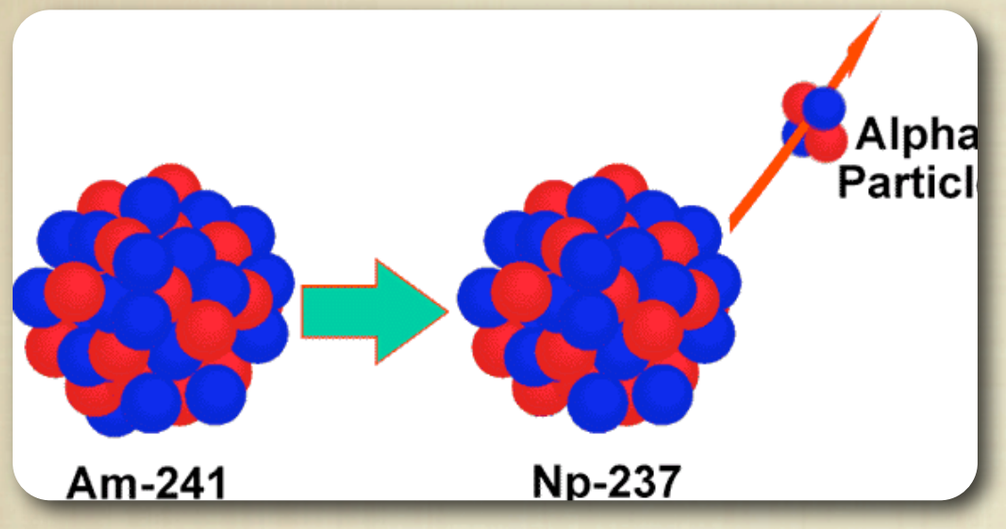
New York

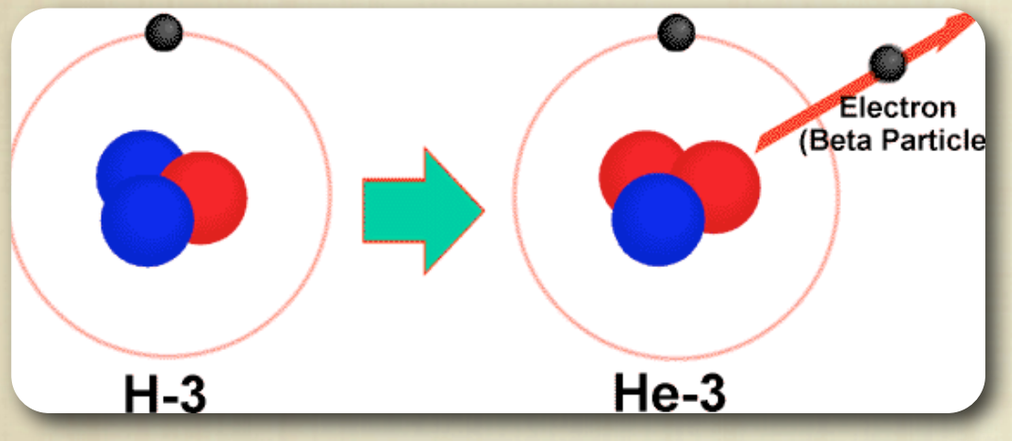
Radioactivity

Radioactivity



Radioactivity





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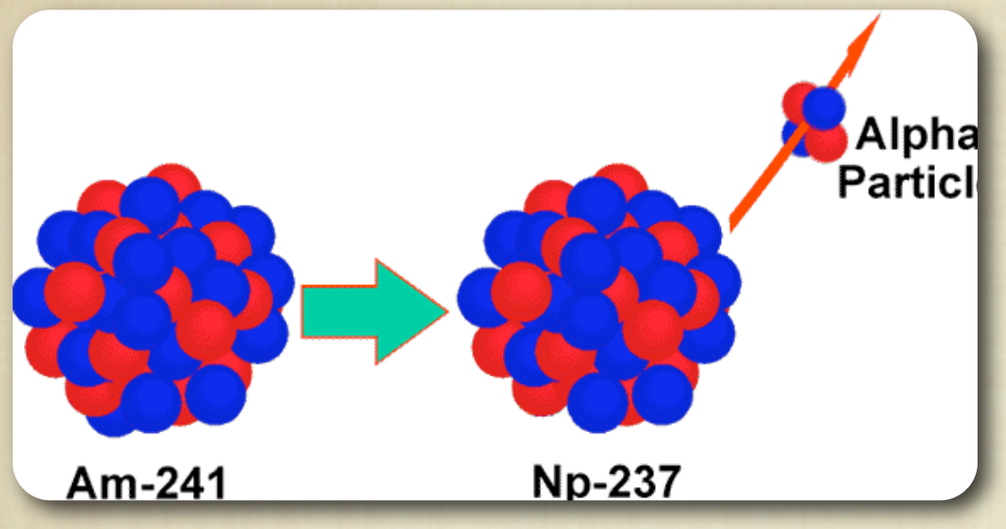
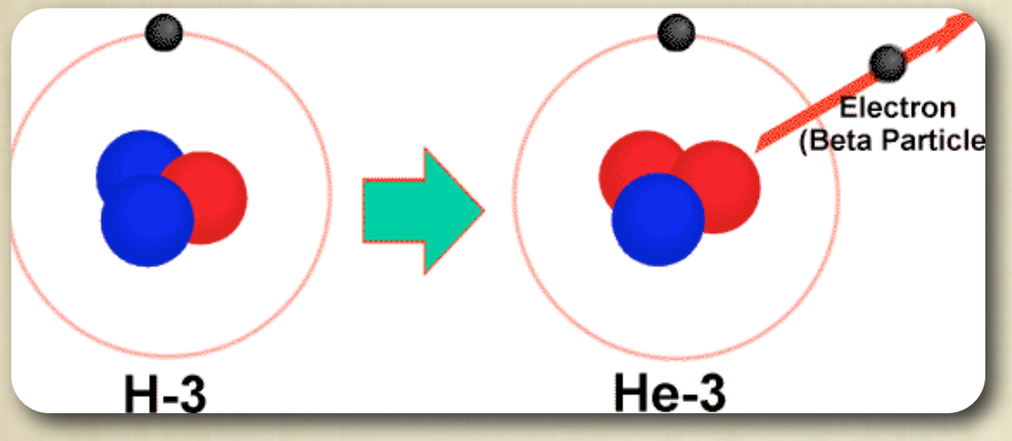
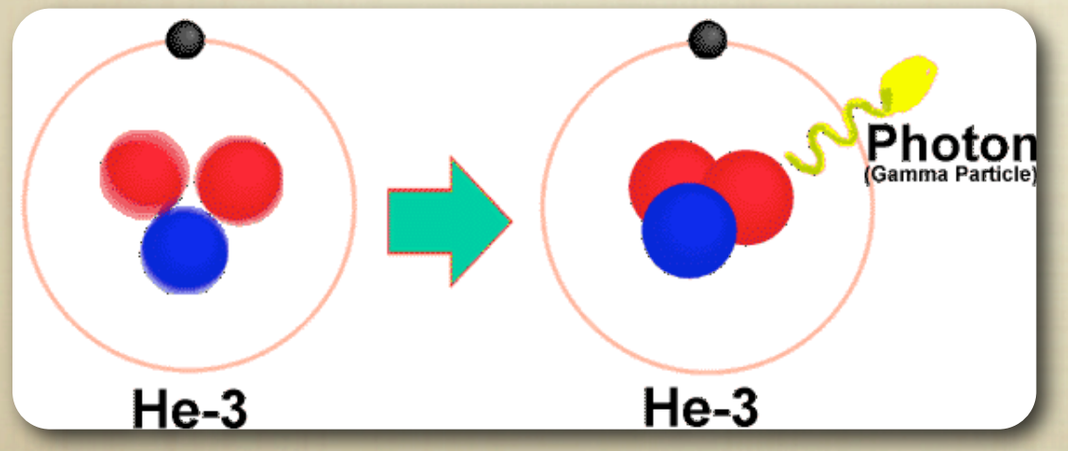
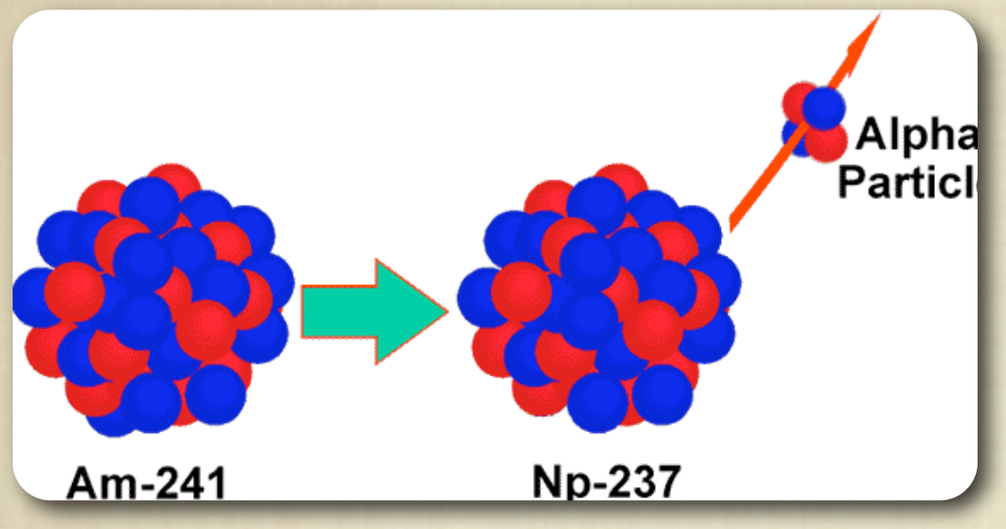
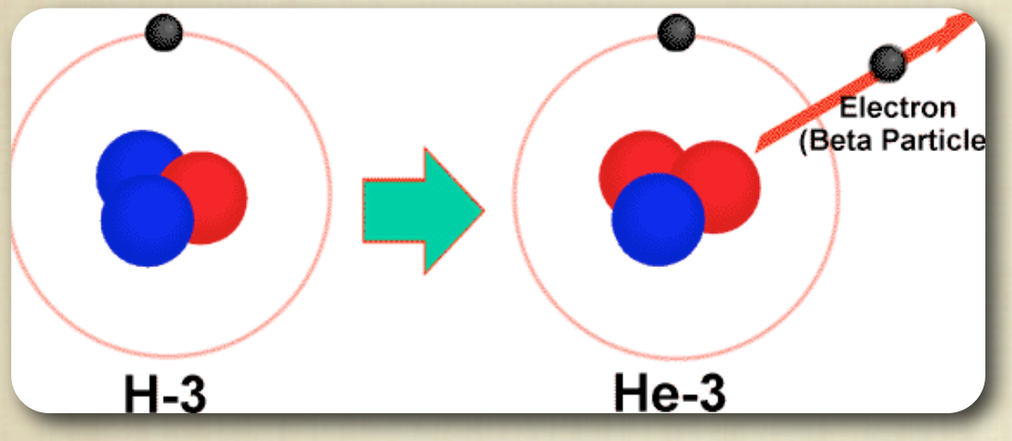


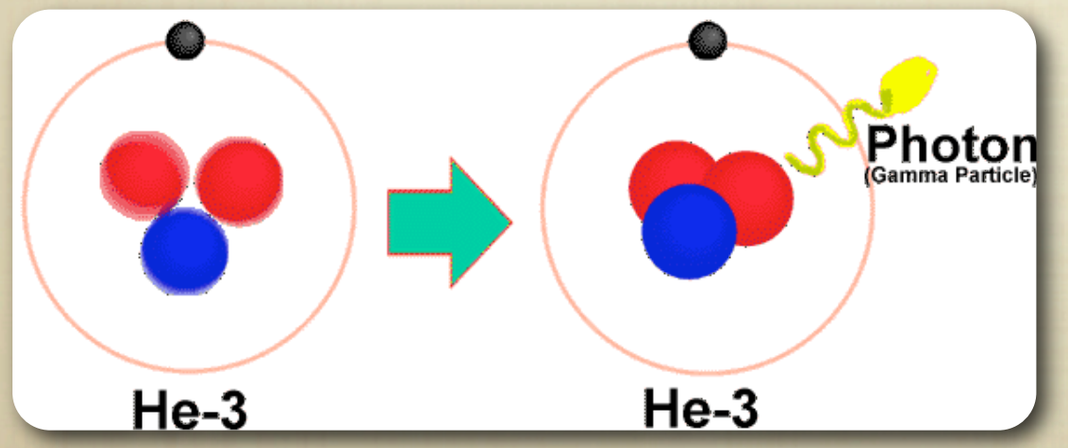




Radioactivity







BETA DECAY

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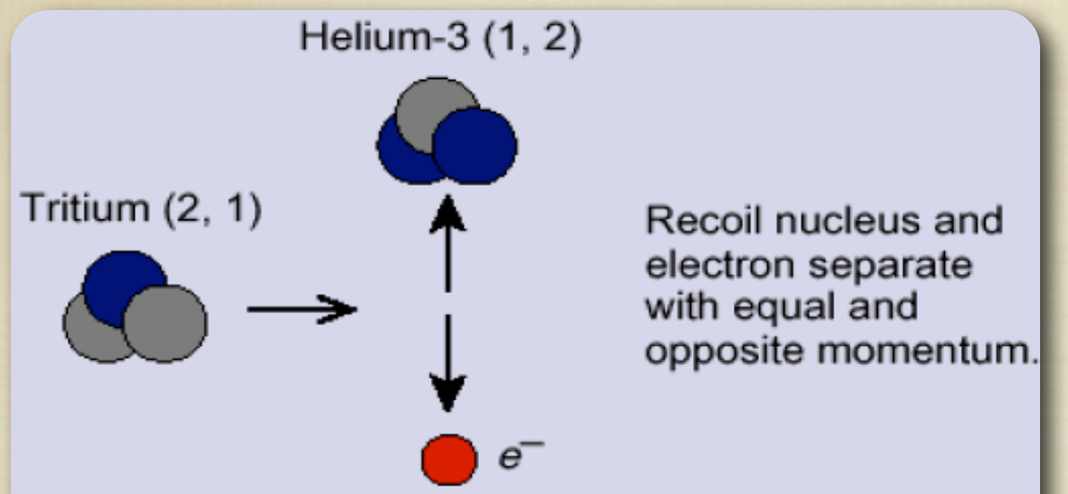
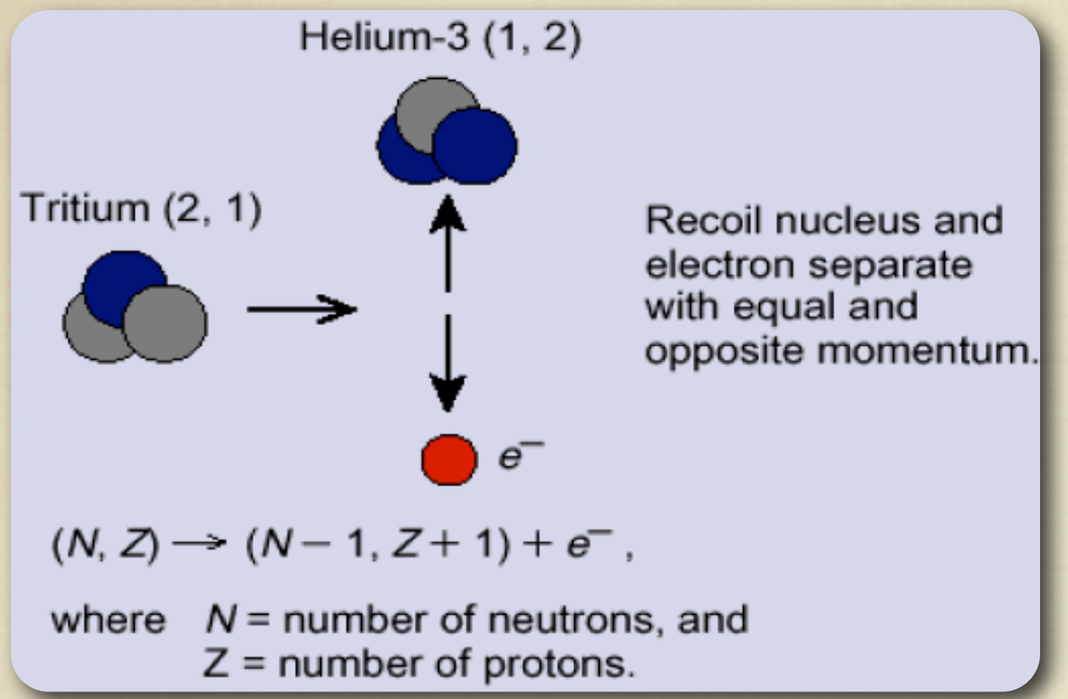

Helium-3 (1, 2)
Tritium (2, 1)
Recoil nucleus and electron separate with equal and opposite momentum.
e^-
$(N, Z) \longrightarrow (N-1, Z+1) + e^-$,
where N = number of neutrons, and
Z = number of protons.

BETA DECAY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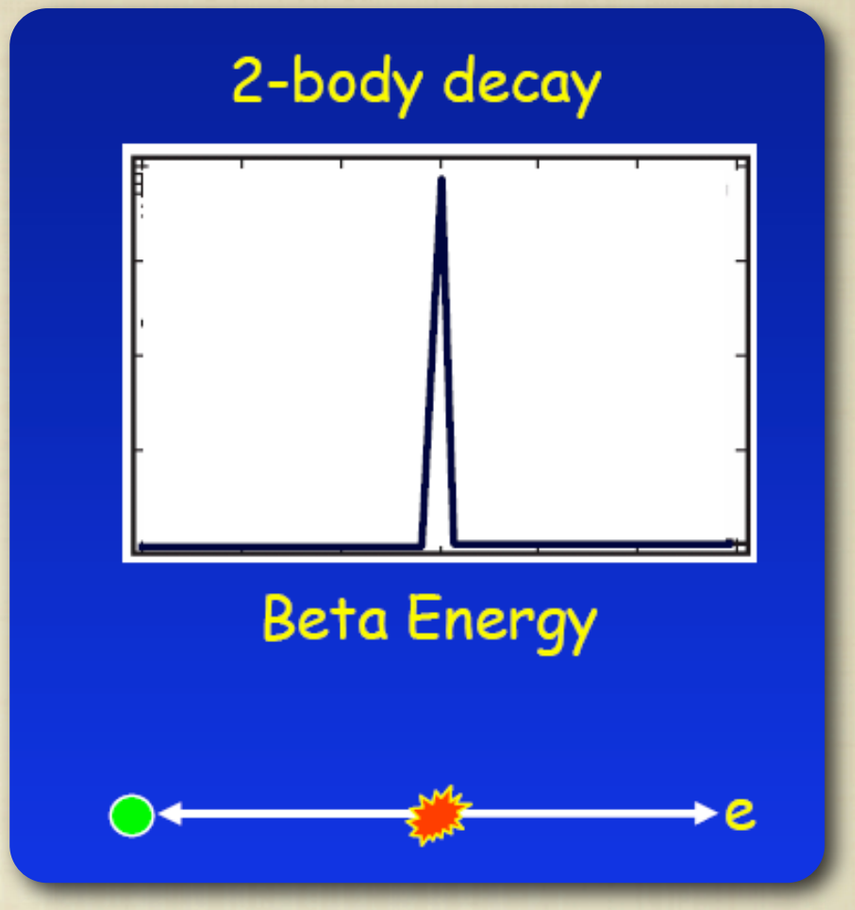
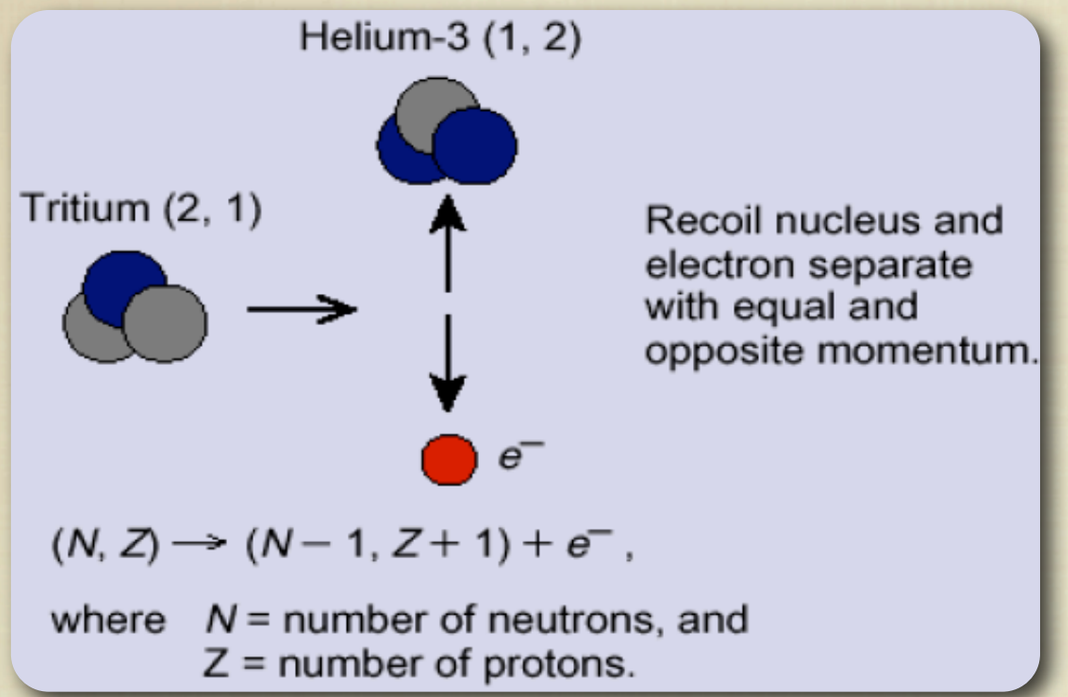

2-body decay
Beta Energy
e

BETA DECAY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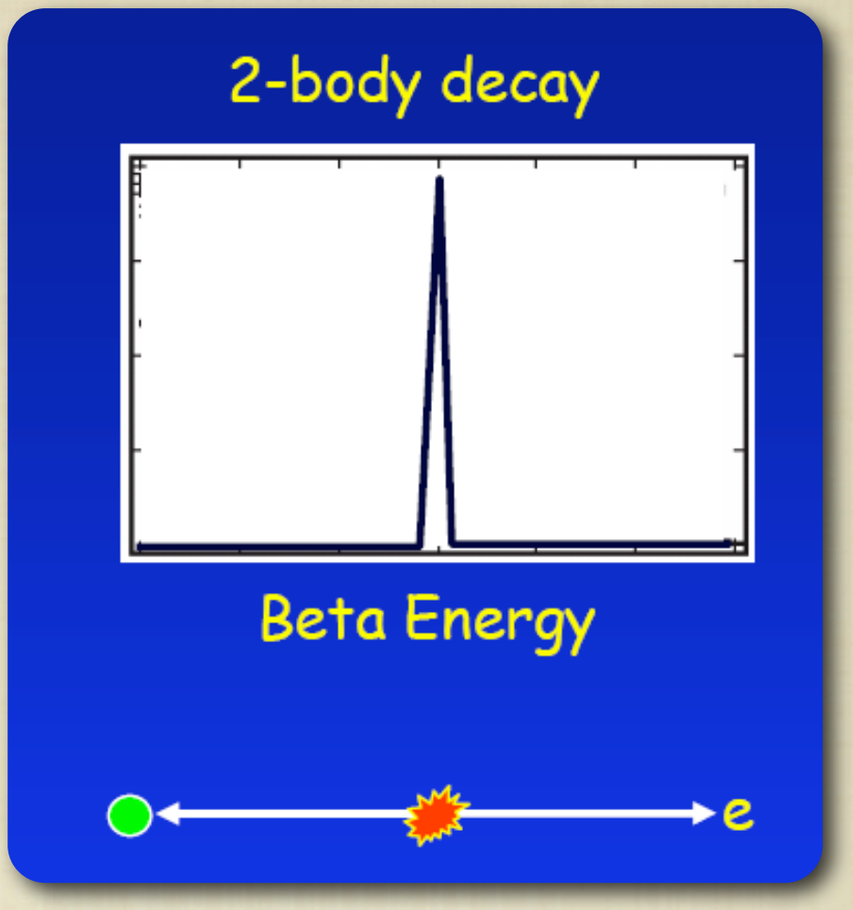
2-body decay
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Energy conservation?

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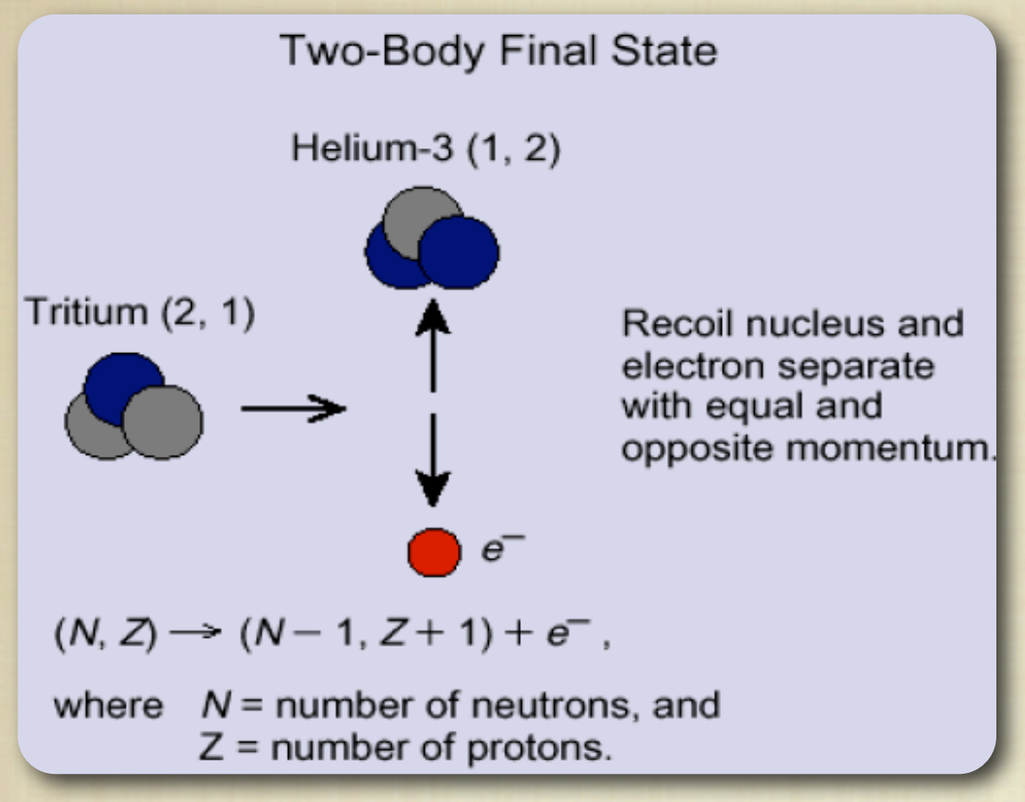
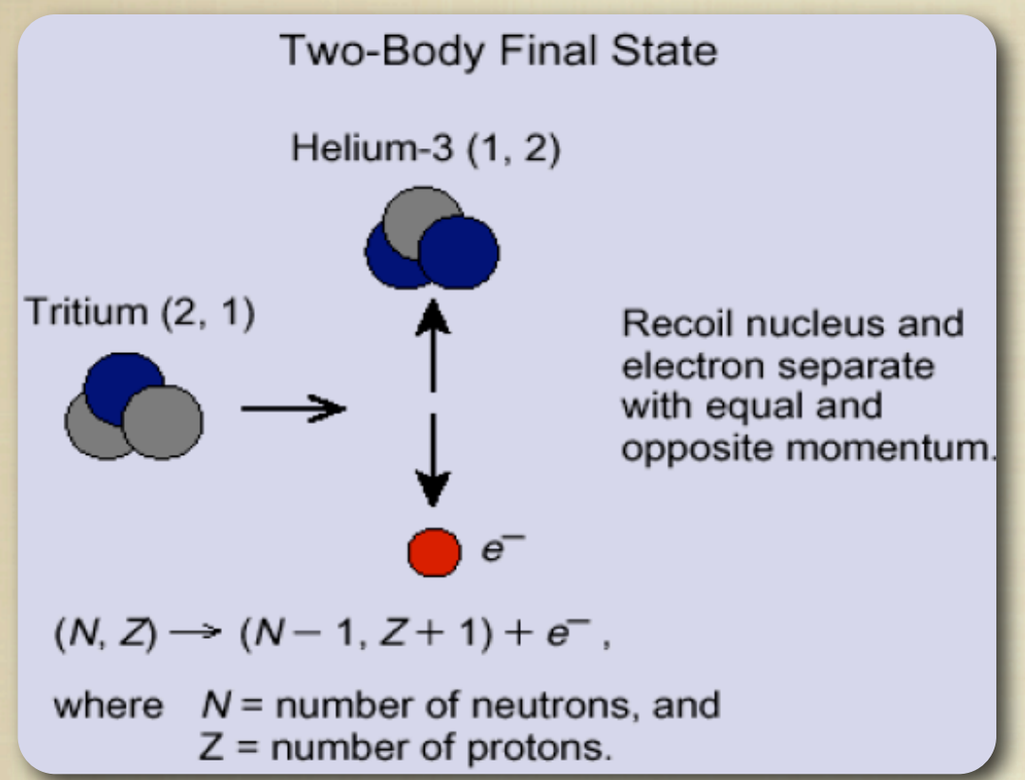
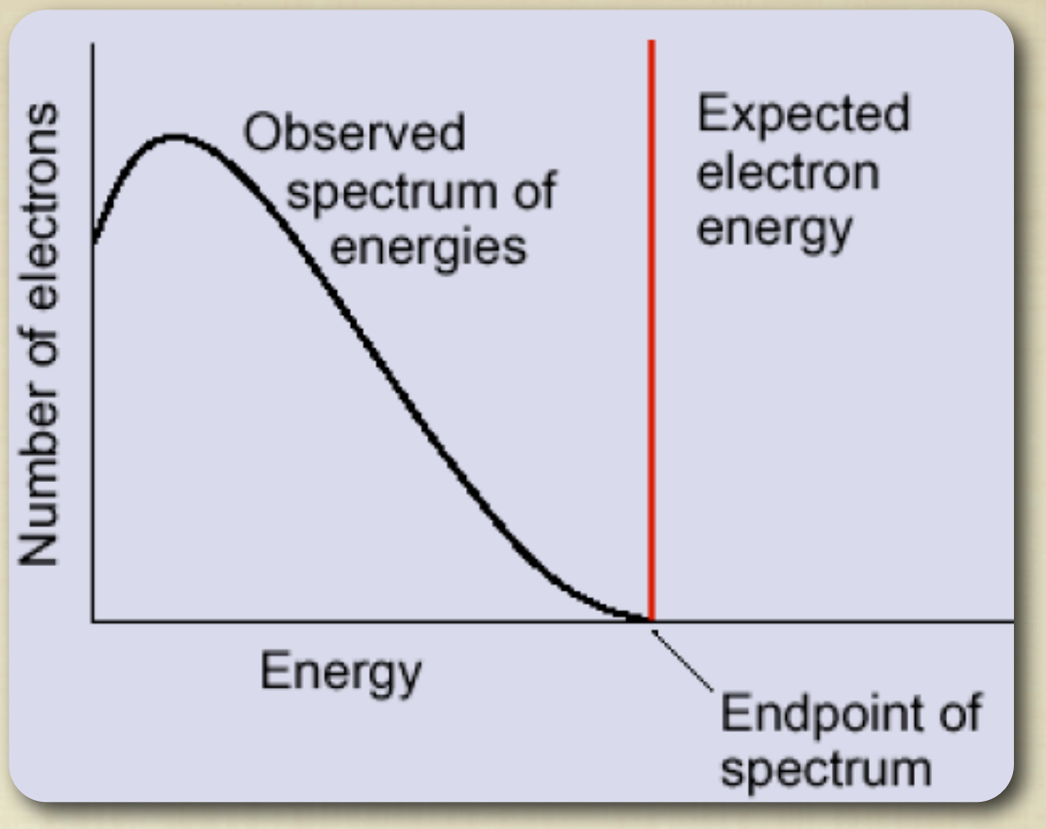


Energy conservation?





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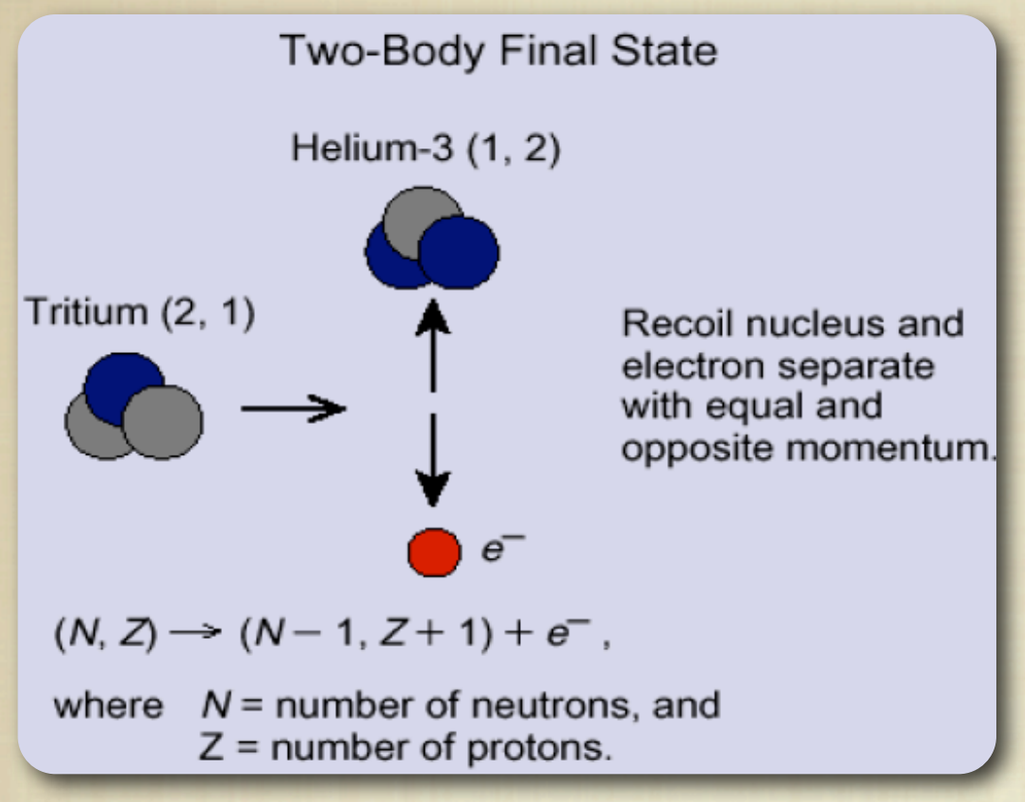
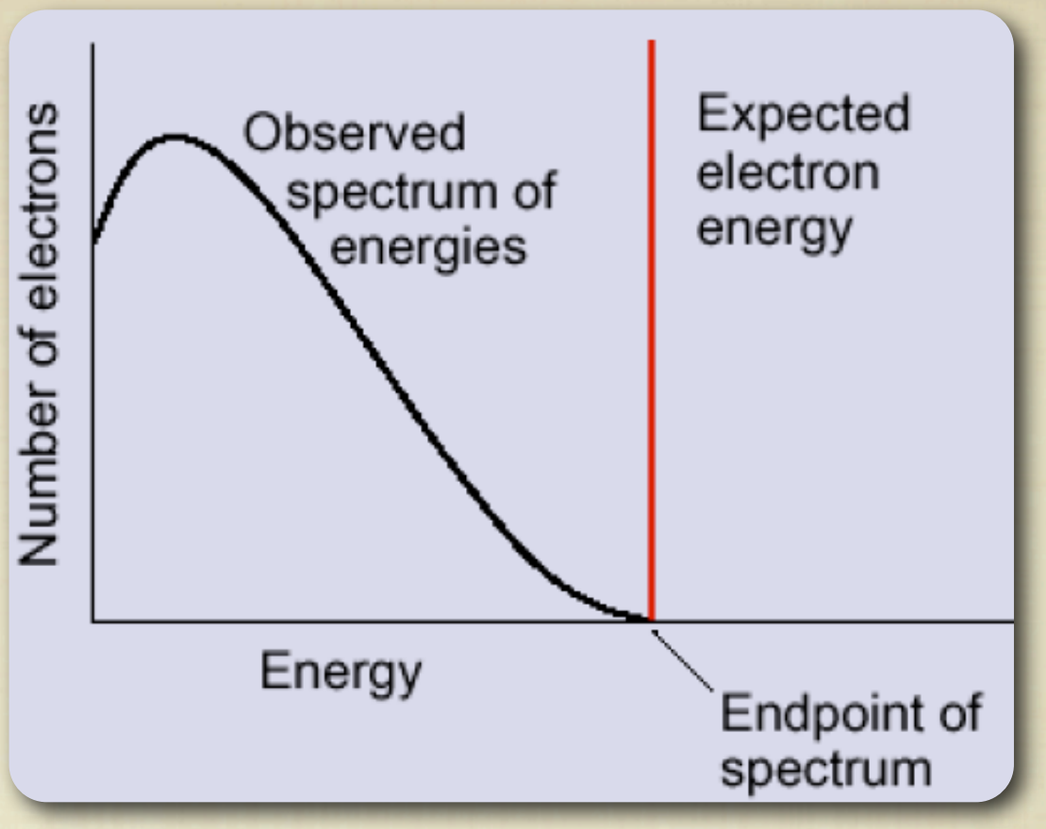




Abschrift/15.12.[illegible]

Offener Brief an die Gruppe der Radioaktiven bei der Gauvereins-Tagung zu Tübingen.

Abschrift

Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

Zürich, 4. Dez. 1930
Oloriastrasse

Liebe Radioaktive Damen und Herren,

Wie der Ueberbringer dieser Zeilen, den ich huldvollst anzuhören bitte, Ihnen des näheren auseinandersetzen wird, bin ich angesichts der "falschen" Statistik der N- und Li-6 Kerne, sowie des kontinuierlichen beta-Spektrums auf einen verzweifelten Ausweg verfallen um den "Wechselsatz" (1) der Statistik und den Energiesatz zu retten. Nämlich die Möglichkeit, es könnten elektrisch neutrale Teilchen, die ich Neutronen nennen will, in den Kernen existieren, welche den Spin 1/2 haben und das Ausschliessungsprinzip befolgen und sich von Lichtquanten ausserdem noch dadurch unterscheiden, dass sie nicht mit Lichtgeschwindigkeit laufen. Die Masse der Neutronen müsste von derselben Grössenordnung wie die Elektronenmasse sein und jedenfalls nicht grösser als 0,01 Protonenmasse.- Das kontinuierliche beta-Spektrum wäre dann verständlich unter der Annahme, dass beim beta-Zerfall mit dem Elektron jeweils noch ein Neutron emittiert wird, derart, dass die Summe der Energien von Neutron und Elektron konstant ist.

Dear Radioactive Ladies and Gentlemen,

As the bearer of these lines, to whom I graciously ask you to listen, will explain to you in more detail, how because of the "wrong" statistics of the N and Li^6 nuclei and the continuous beta spectrum, I have hit upon a desperate remedy to save the "exchange theorem" of statistics and the law of conservation of energy. Namely, the possibility that there could exist in the nuclei electrically neutral particles, that I wish to call neutrons, which have spin 1/2 and obey the exclusion principle and which further differ from light quanta in that they do not travel with the velocity of light. The mass of the neutrons should be of the same order of magnitude as the electron mass and in any event not larger than 0.01 proton masses. The continuous beta spectrum would then become understandable by the assumption that in beta decay a neutron is emitted in addition to the electron such that the sum of the energies of the neutron and the electron is constant...

I agree that my remedy could seem incredible because one should have seen these neutrons much earlier if they really exist. But only the one who dare can win and the difficult situation, due to the continuous structure of the beta spectrum, is lighted by a remark of my honoured predecessor, Mr Debye, who told me recently in Bruxelles: "Oh, It's well better not to think about this at all, like new taxes". From now on, every solution to the issue must be discussed. Thus, dear radioactive people, look and judge.

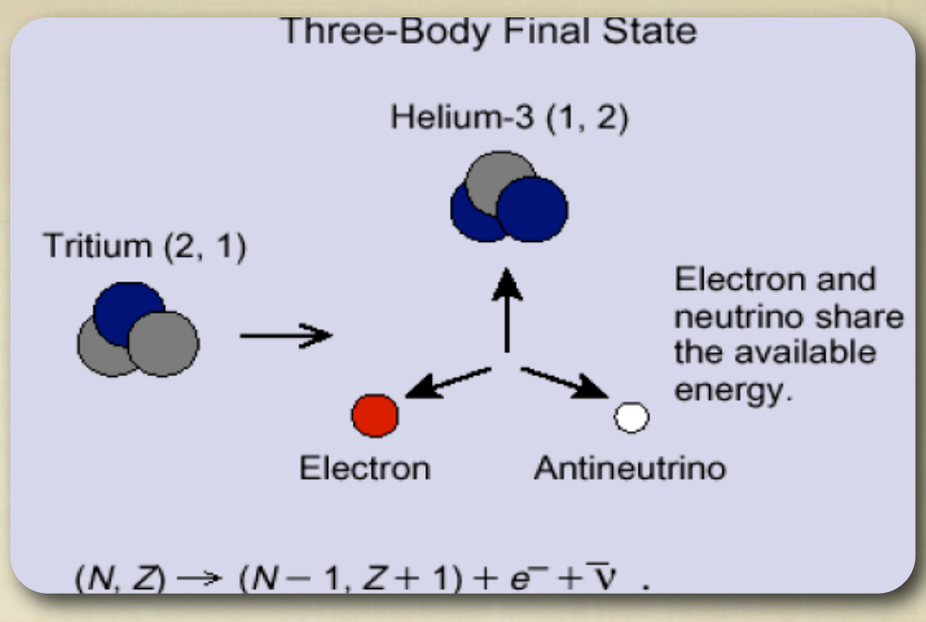
Unfortunately, I cannot appear in Tubingen personally since I am indispensable here in Zurich because of a ball on the night of 6/7 December. With my best regards to you, and also to Mr Back.

Your humble servant,

W. Pauli

I have made a terrible thing
Proposing a particle that
can't be detected...

This is something no theorist
should ever do...



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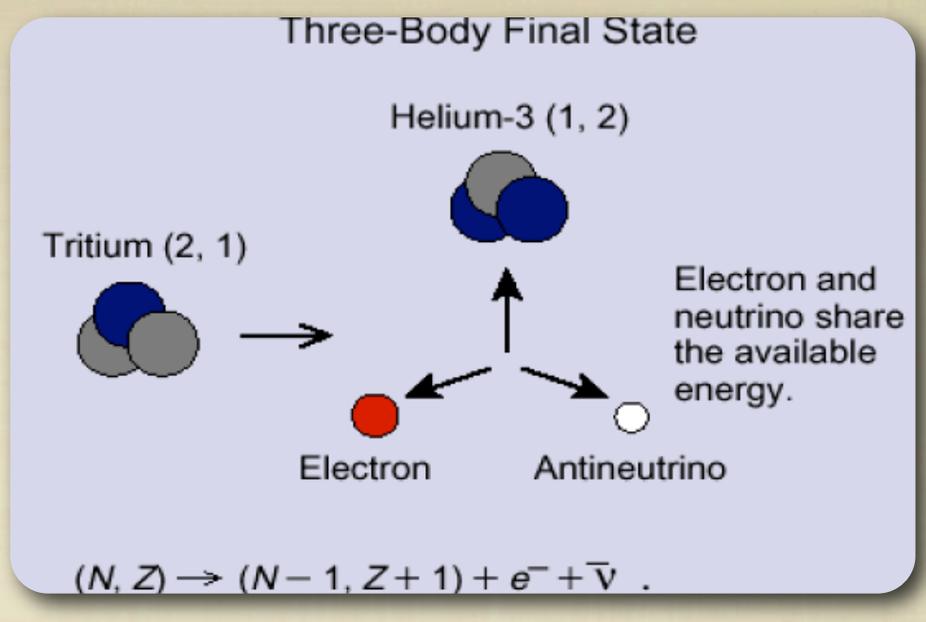

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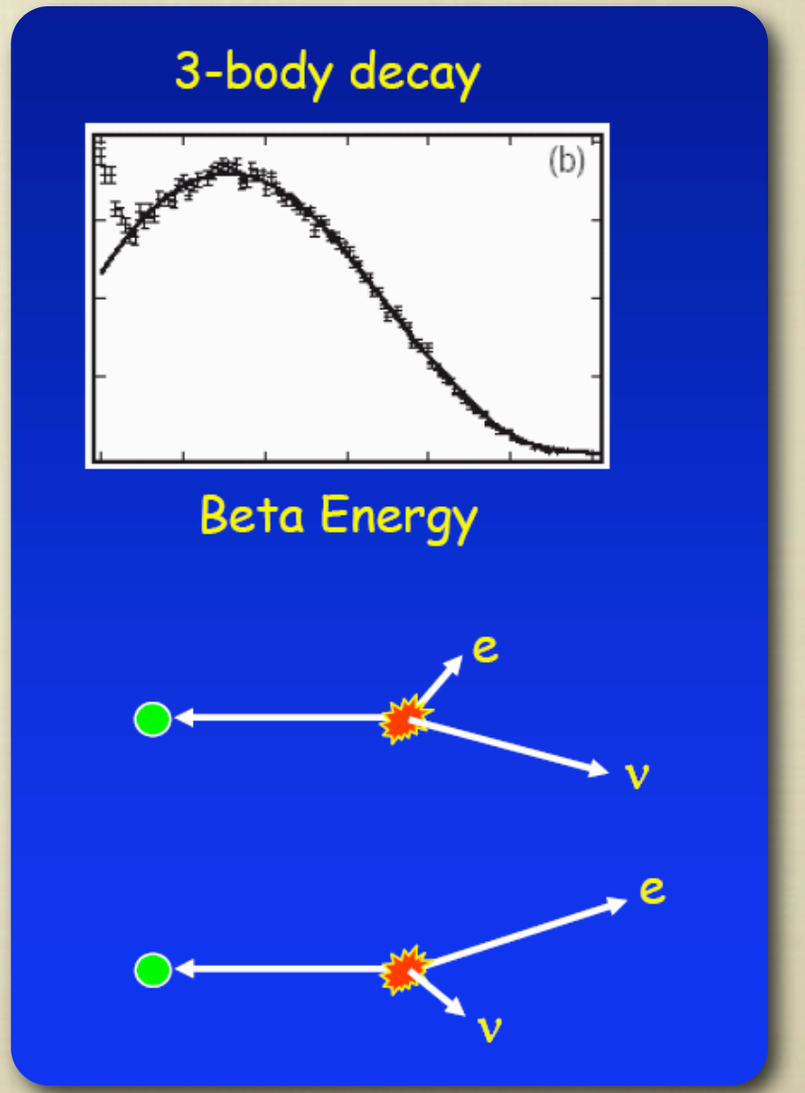
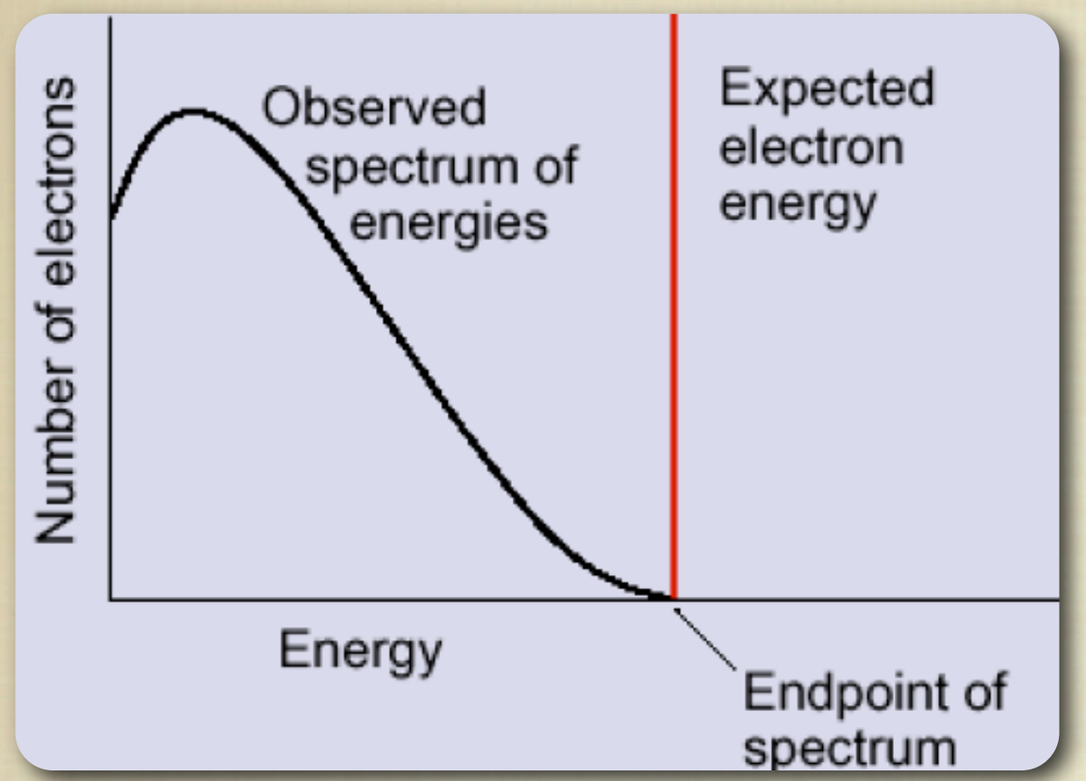


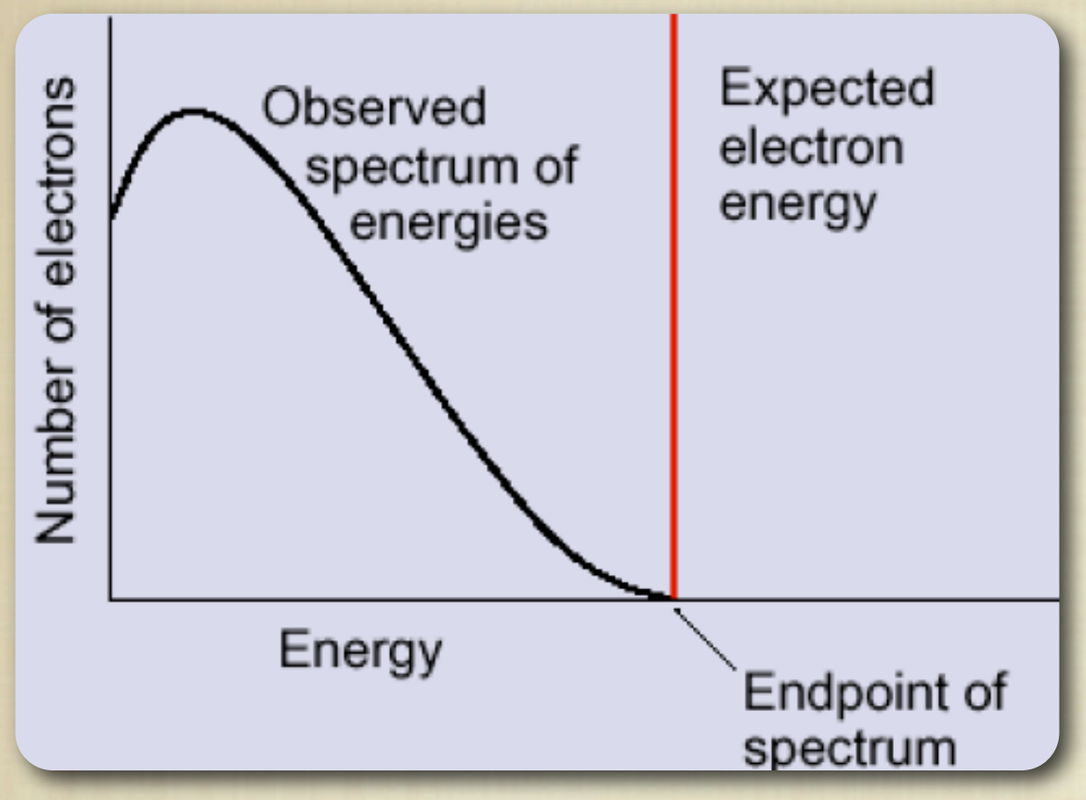
Pauli's neutrino

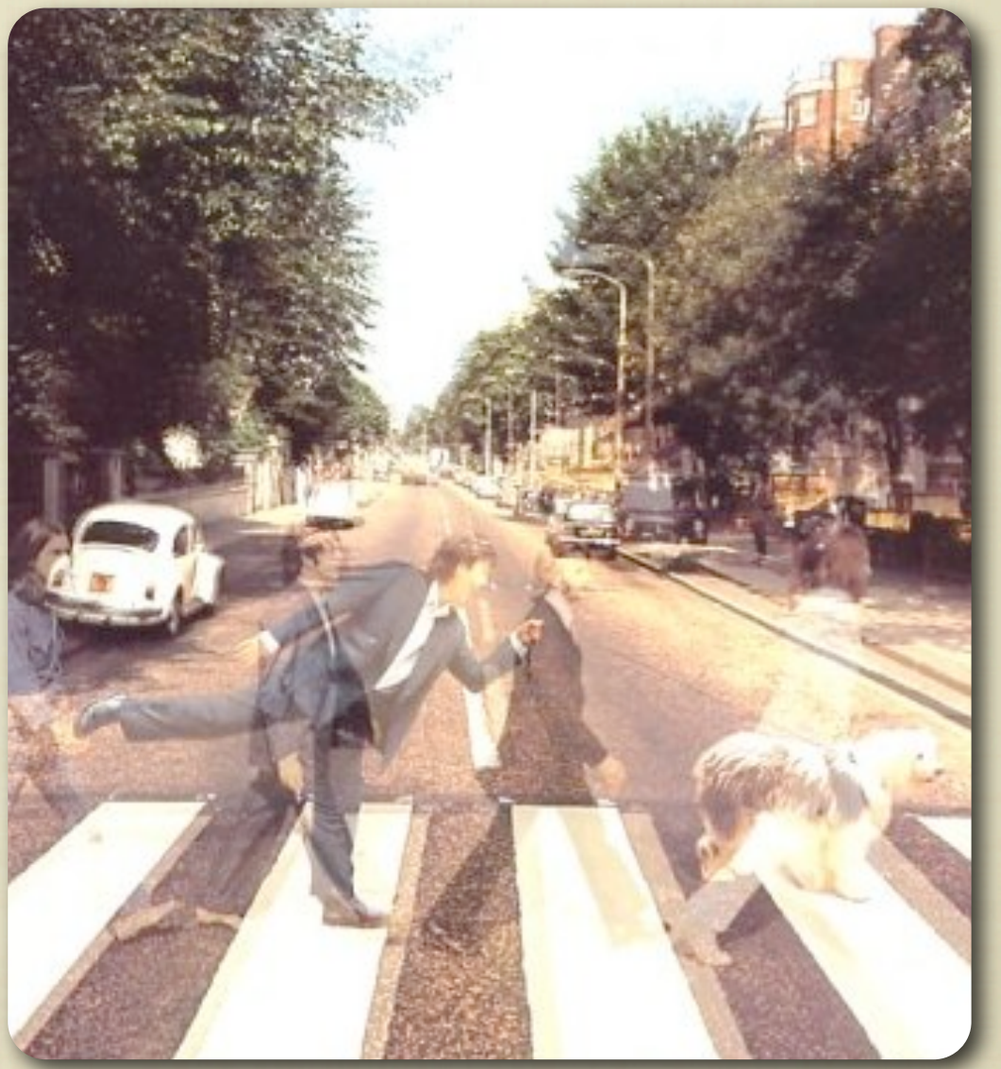


Pauli had good reasons to feel guilty

He had predicted the existence of a ghost!

Pauli's neutrino





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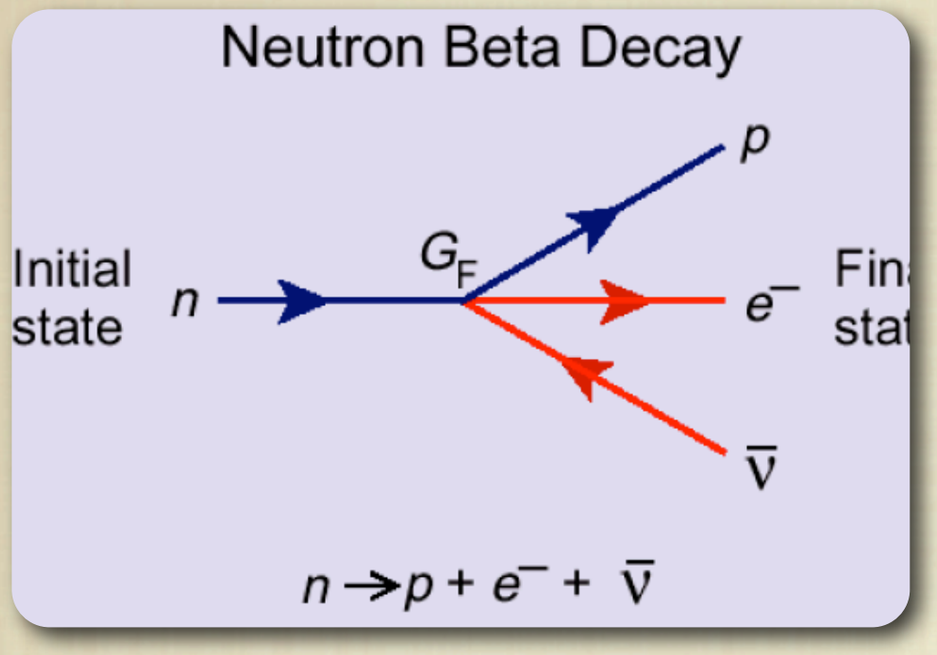
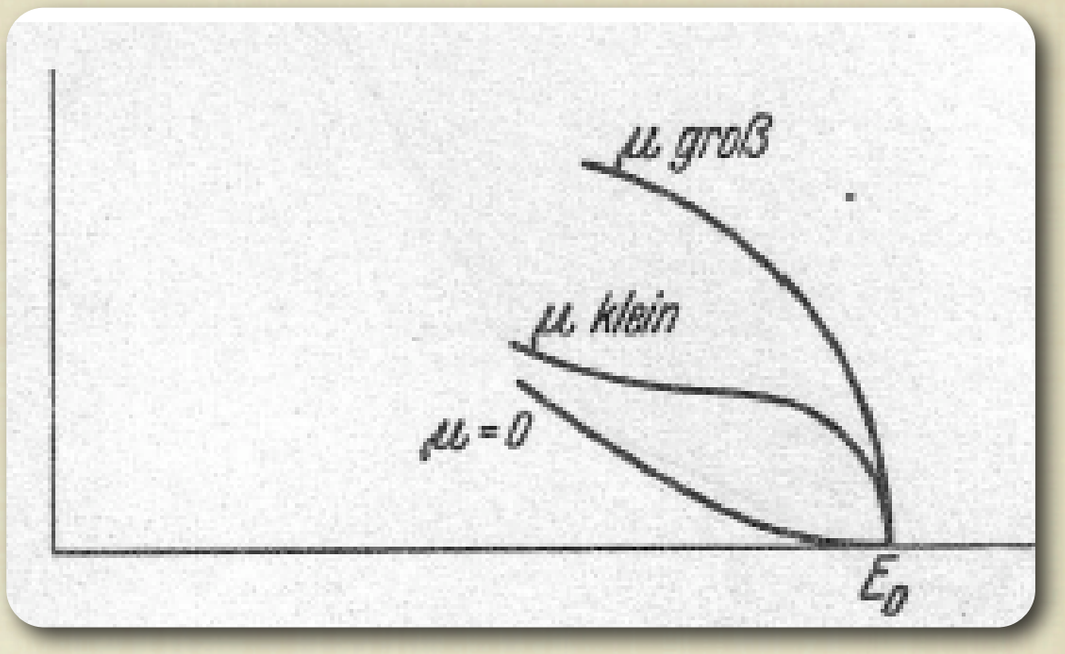
Versuch einer theorie der b-strahlen (Fermi, 1936)





Point interaction among four spin 1/2 particles. Theory is relativistic. Wave functions are spinors satisfying Dirac equation. Particles are created at the instant of decay.

Prediction of decay rates and electron energy spectra depends only of one constant, G_F, determined experimentally. Energy spectrum depends of neutrino mass . Measurable distortions near end-point of spectrum if >0.

The discovery of neutrinos

Sir Arthur Eddington

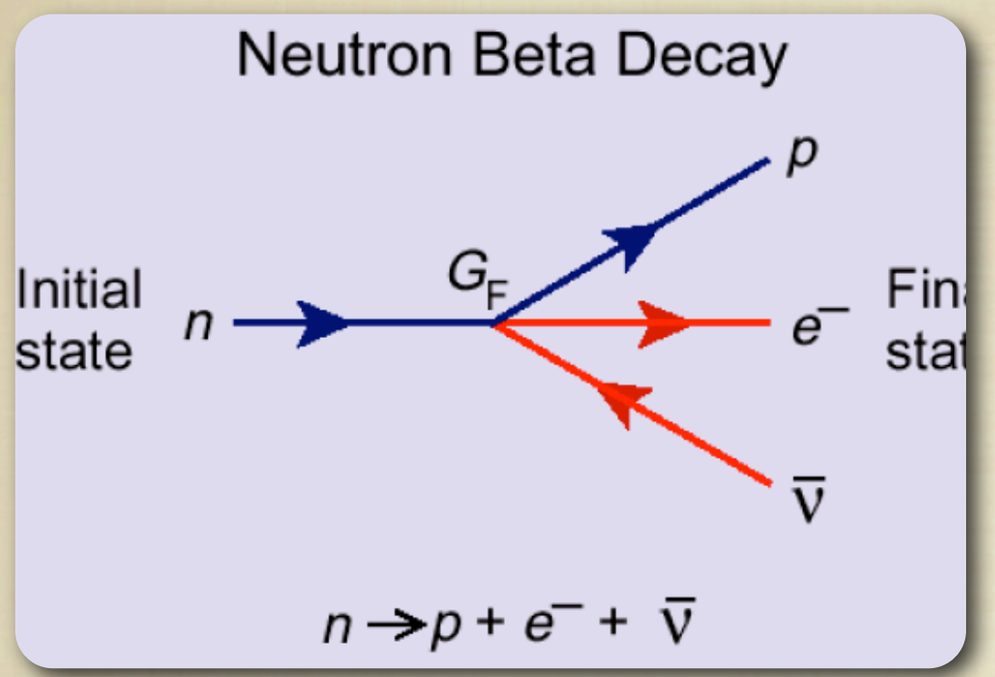
The discovery of neutrinos

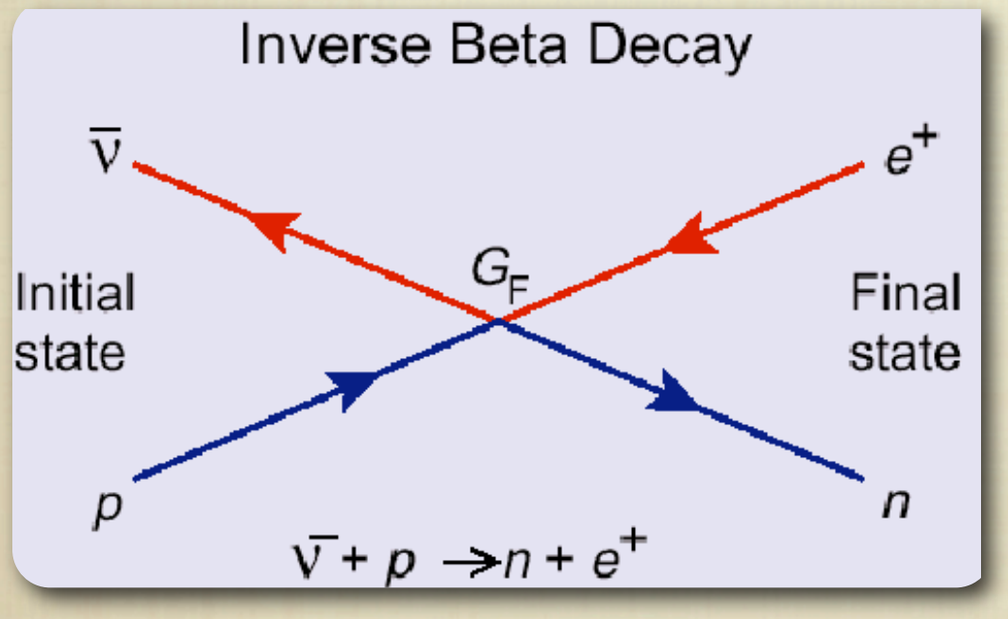
In an ordinary way I might say that I do not believe in neutrinos. Dare I say that experimental physicists will not have sufficient ingenuity to make neutrinos..

Sir Arthur Eddington

How to detect neutrinos

How to detect neutrinos





If n are produced by b decay, they can be detected using the inverse reaction.

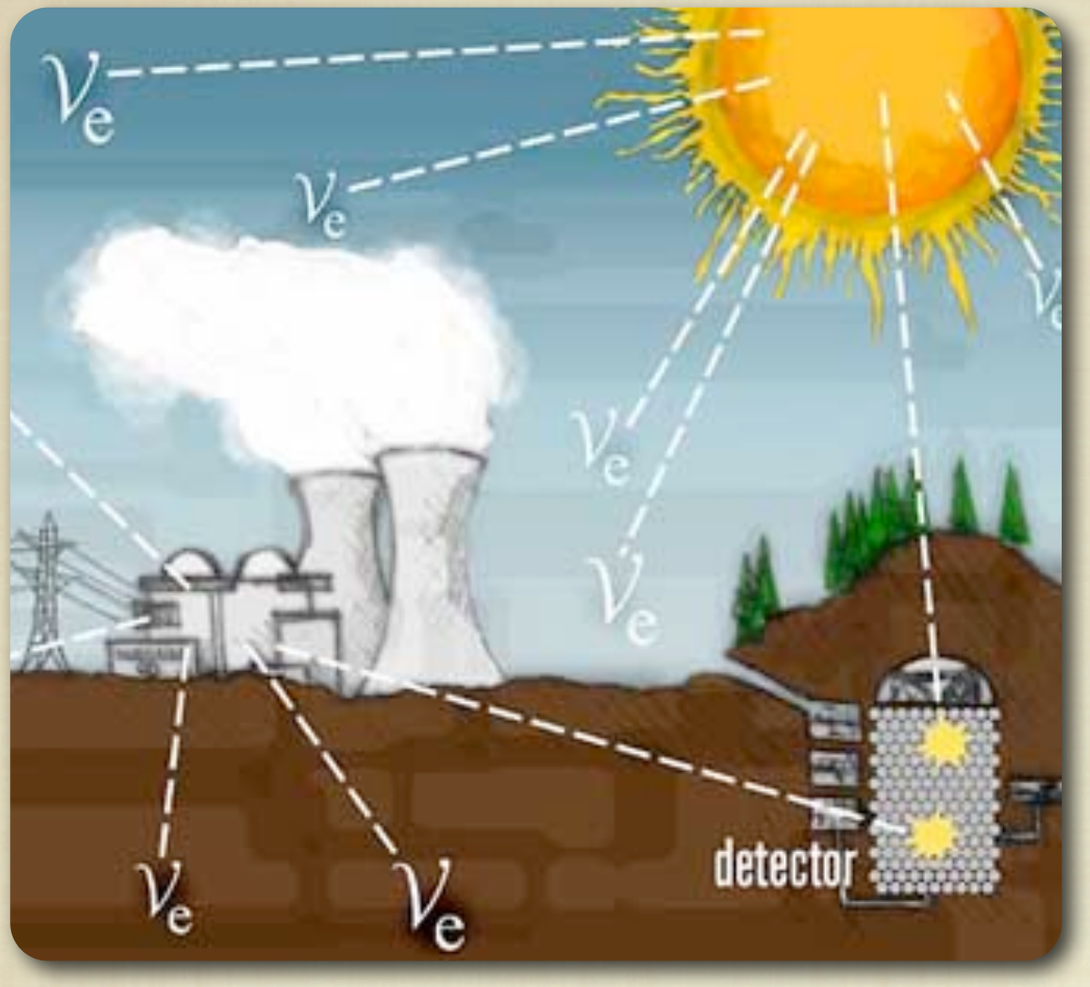
$$\sigma(\bar{\nu}p) \approx 10^{-43}\, cm^2 \qquad E_\nu \sim 3\ MeV$$

$$\lambda = \frac{1}{N_A \rho \sigma}$$

$$\lambda(Pb) \sim \frac{1}{610^{23}(nucleon/g)(7.9\ g/cm^3)(10^{-43}\ cm^2)}$$

$\sim$ 4 *light years*!

So one needs



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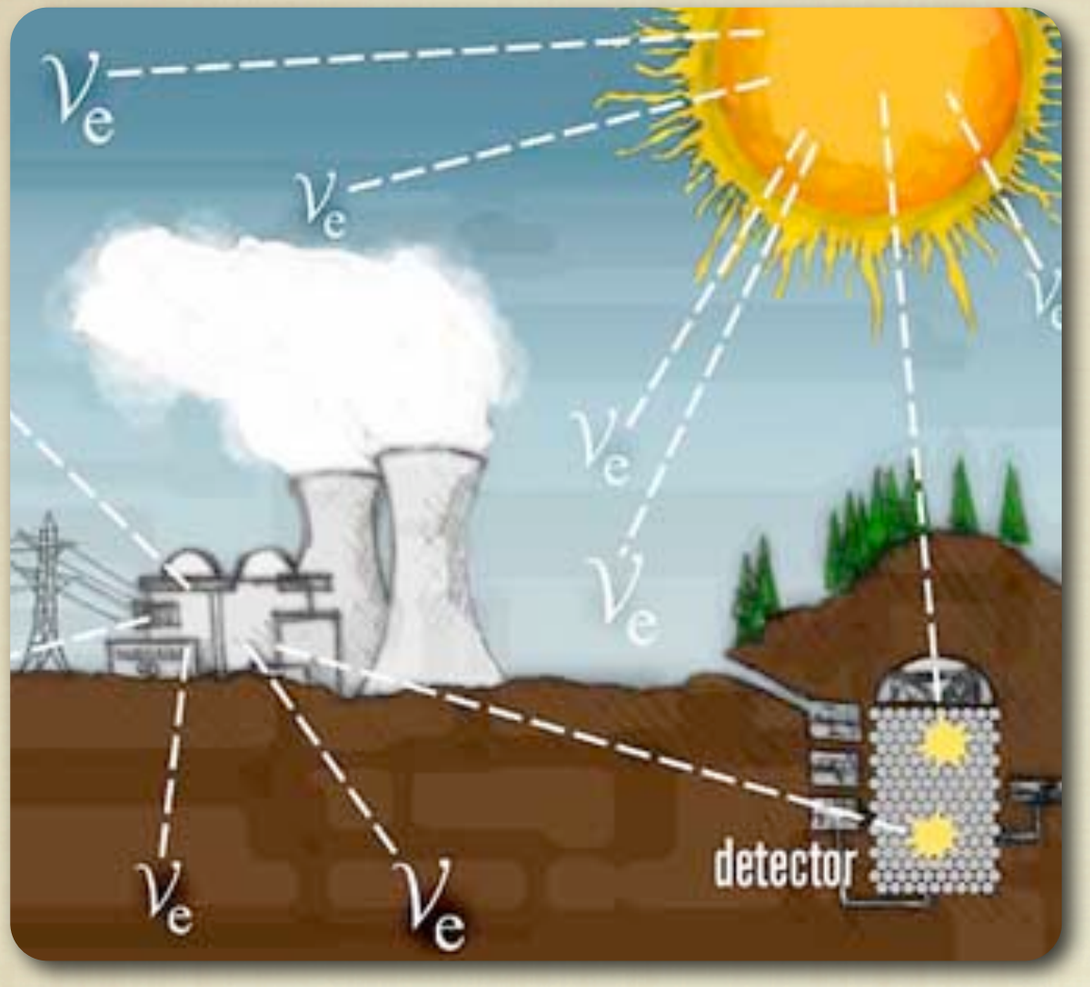
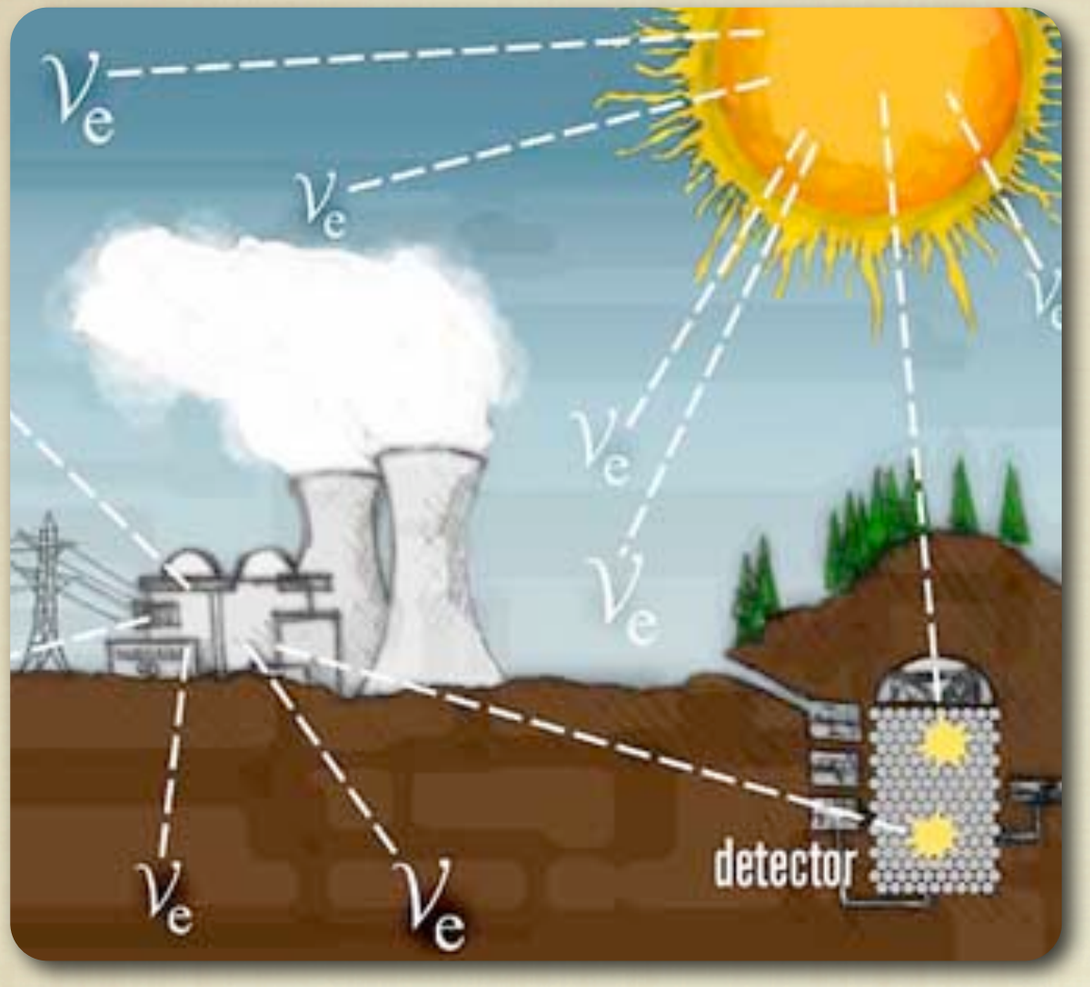


Intense neutrino sources

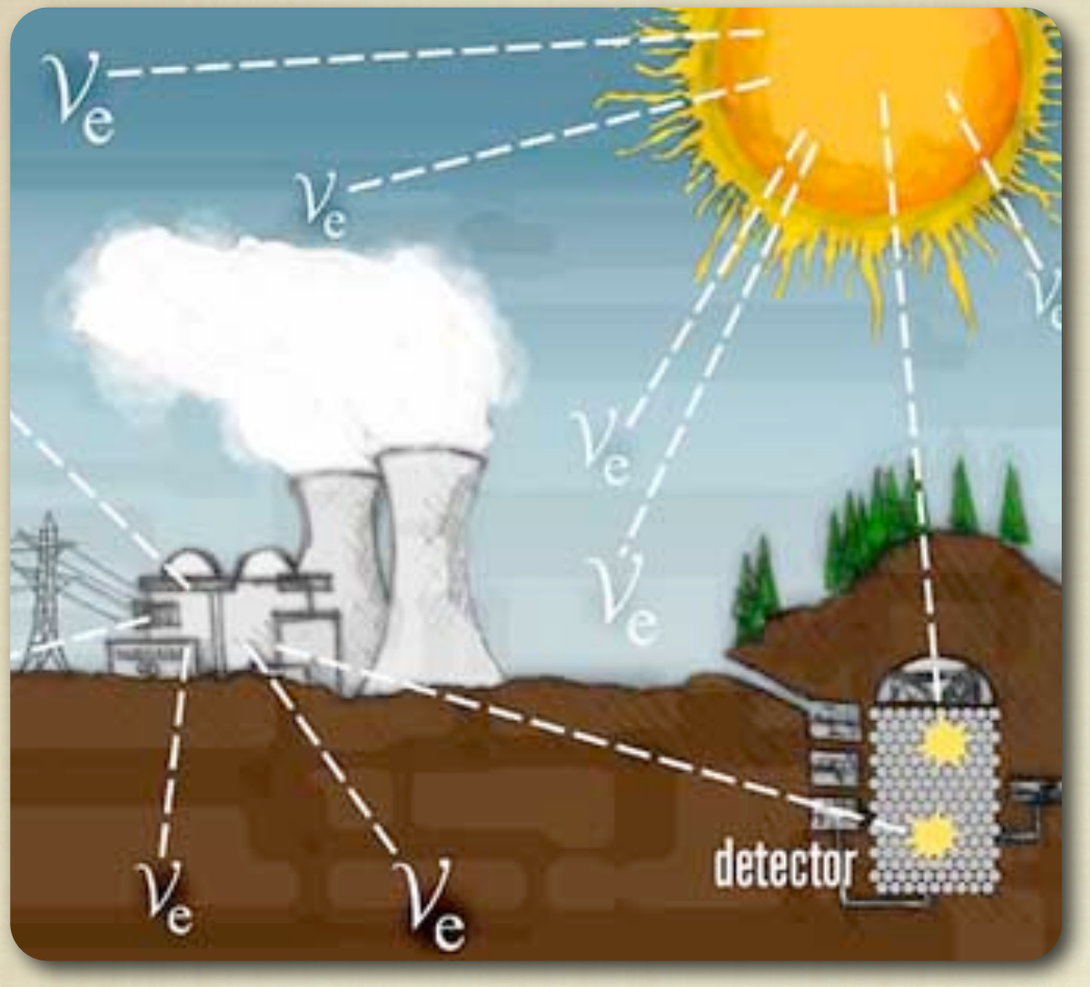
So one needs



Intense neutrino sources

Massive detectors

So one needs

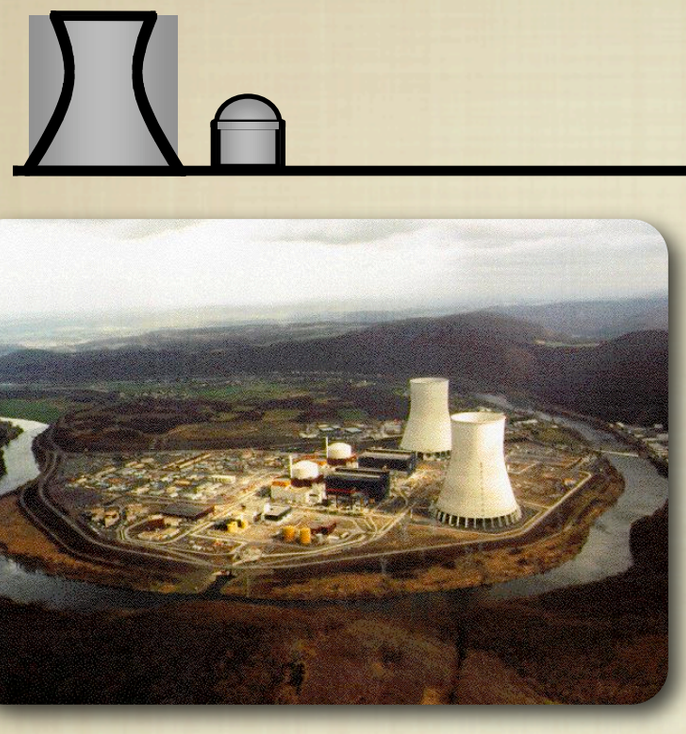


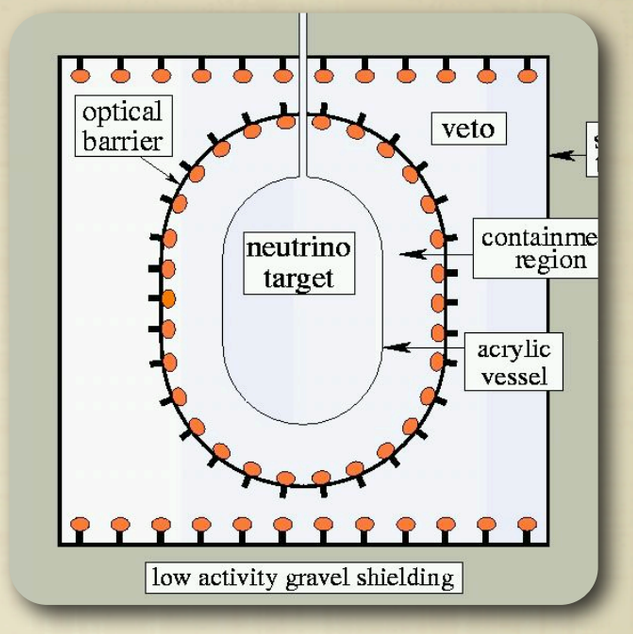
Long exposures (lots of patience)

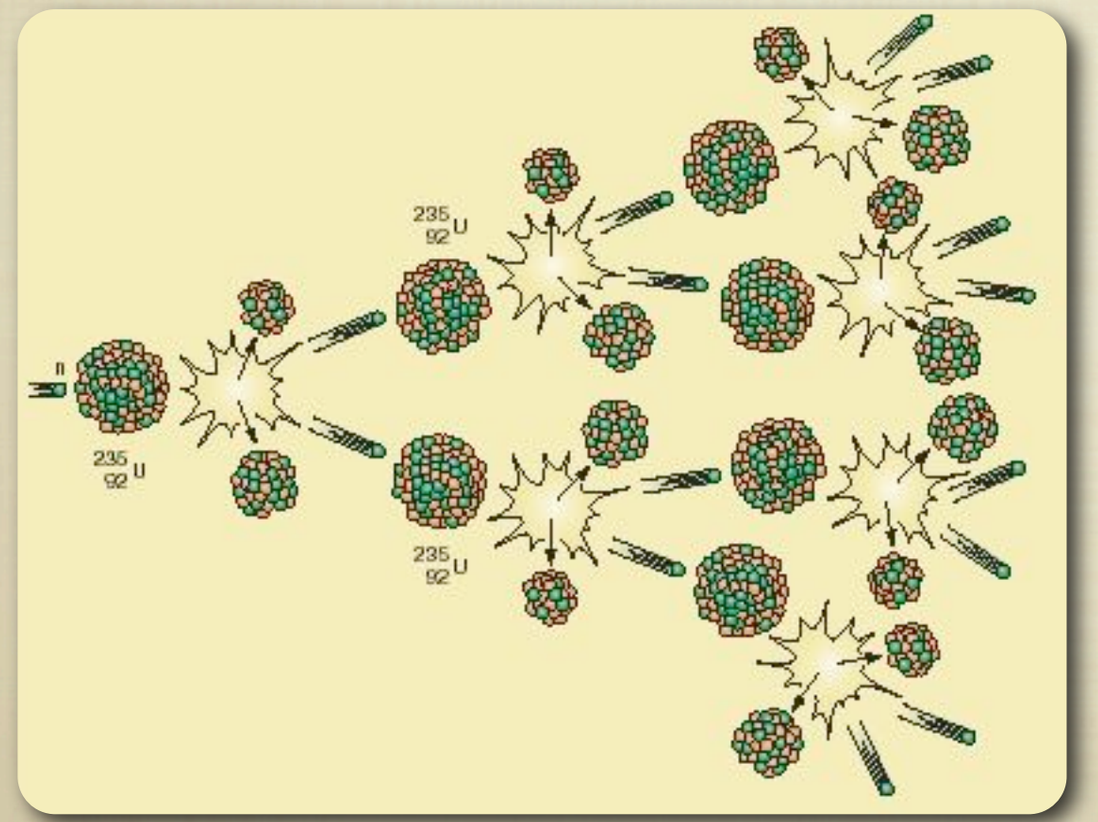
Intense neutrino sources

Massive detectors

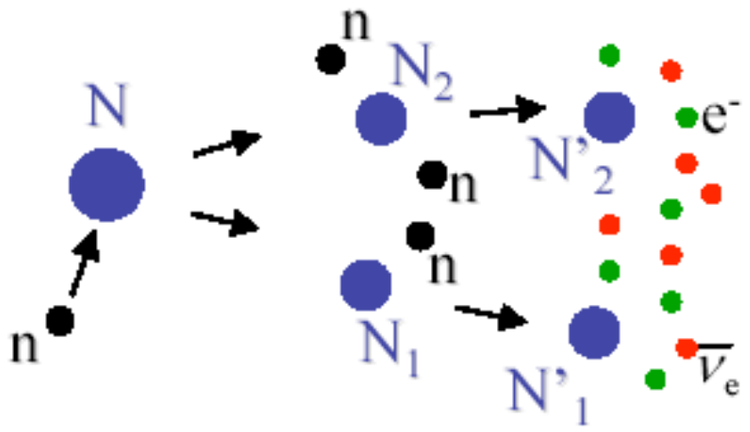
Intense neutrino sources = nuclear reactors







Nuclear reactors are very intense sources of $\bar{\nu}_e$ deriving from beta-decay of the neutron-rich fission fragments



$$Yield:$$
$$200\,MeV\ /\ fission$$
$$6\bar{\nu}_e\ /\ fission$$

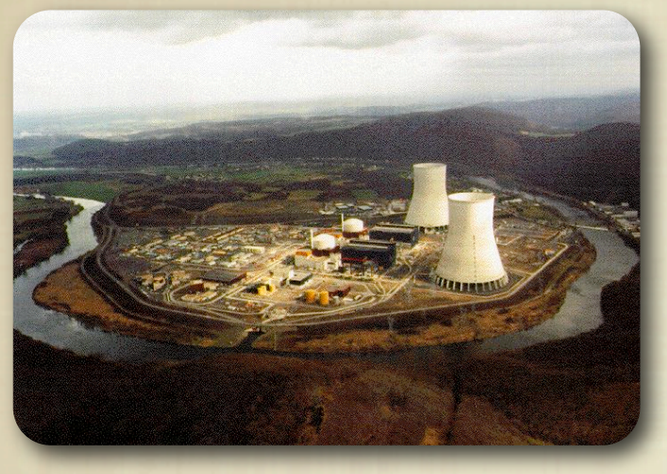
$$\bar{\nu}\text{ production rate} = \frac{6P_t}{200\text{ MeV} \times \underbrace{1.6\times10^{-13}}_{\text{conversion factor MeV} \rightarrow \text{J}}} = 1.87\times10^{11}\,P_t\ \bar{\nu}/\text{s}$$

P_t: reactor thermal power [W]

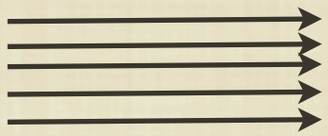
For a typical reactor: P_t = 3 x 10^9 W $\Rightarrow$ 5.6 x 10^{20} $\bar{\nu}$ / s (isotropic)

Continuous $\bar{\nu}$ energy spectrum – average energy ~3 MeV

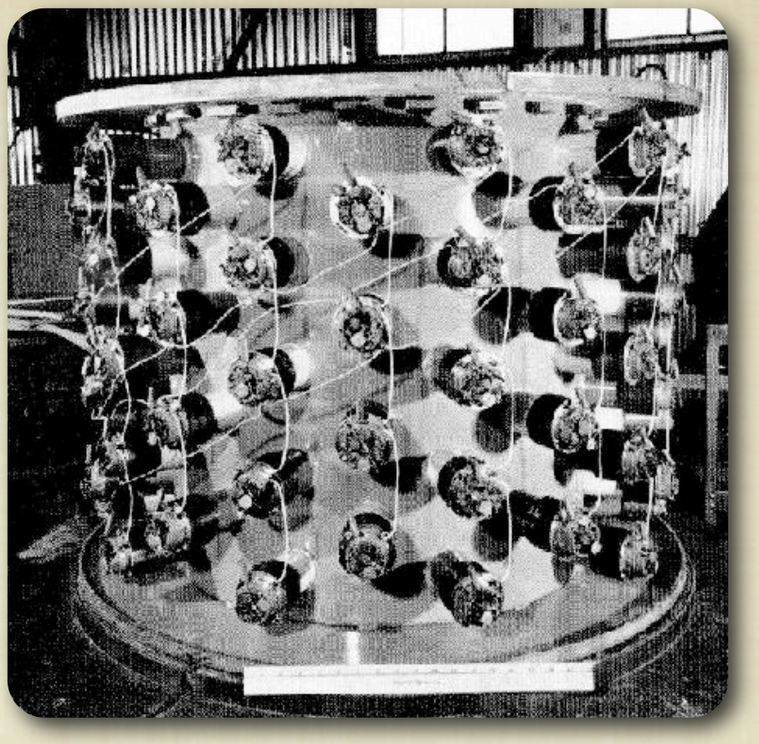
Reines y Cowan, 1953

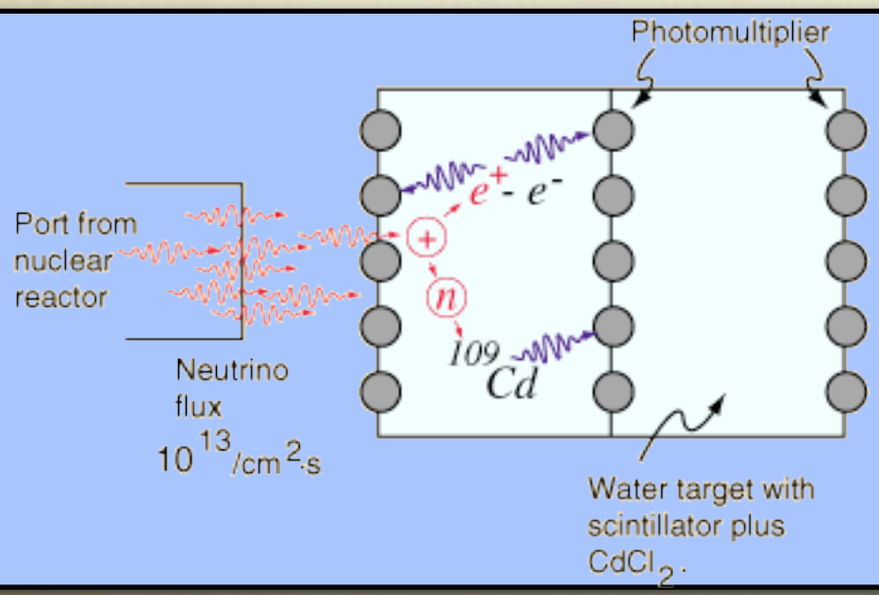


Savanah River



$\bar{\nu}_e$



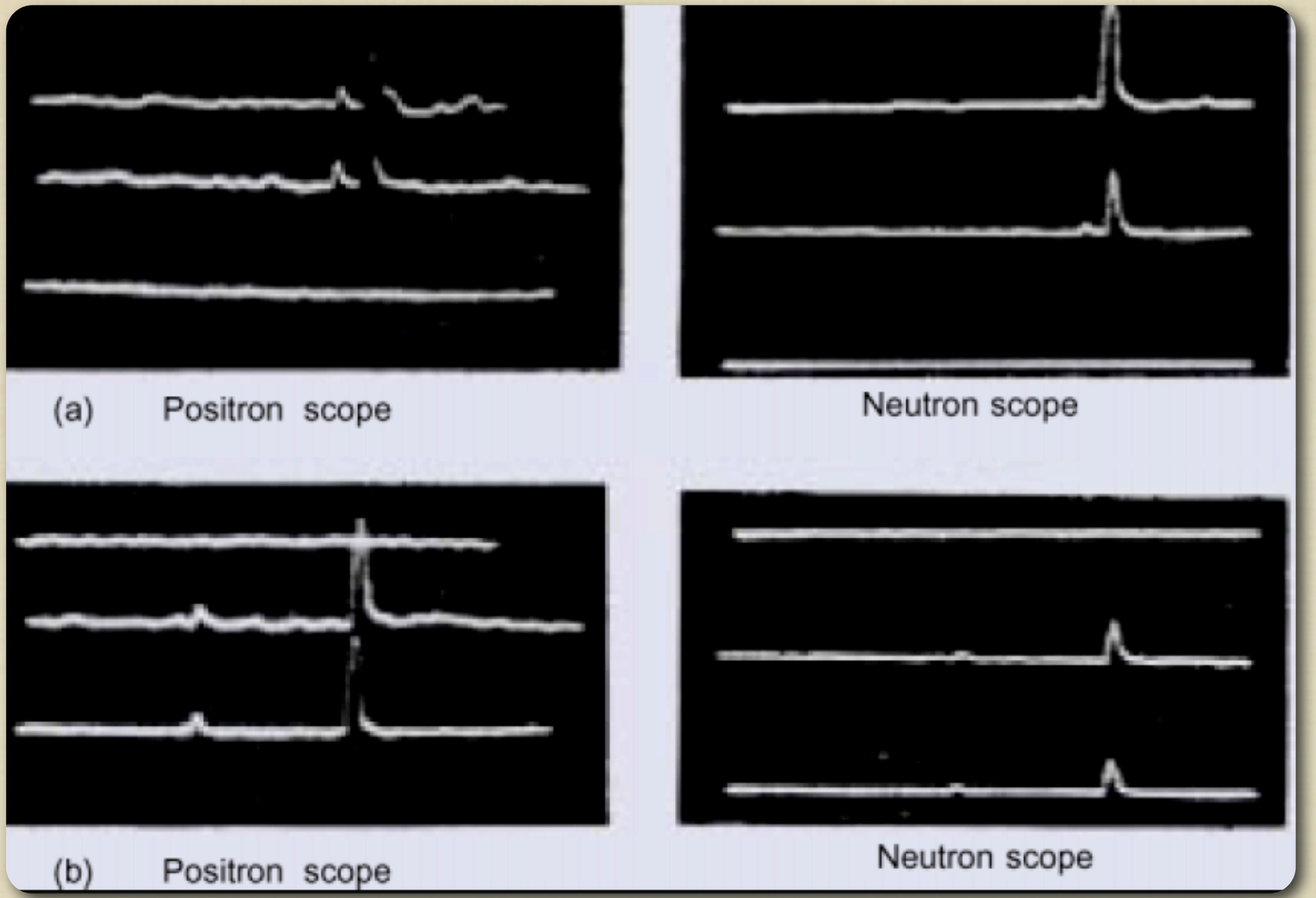


Delayed coincident detection of γ from ^{109}Cd with pair of γ's from $e^+ - e^-$ annihilation.

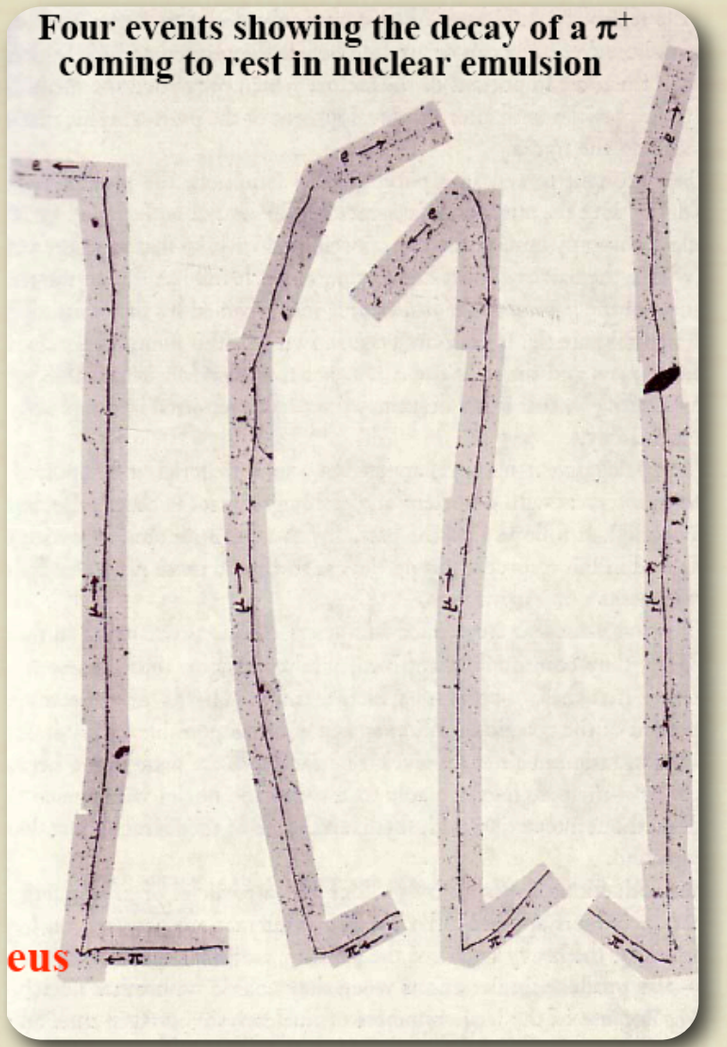
$$\bar{\nu}_e + p \rightarrow n + e^+$$

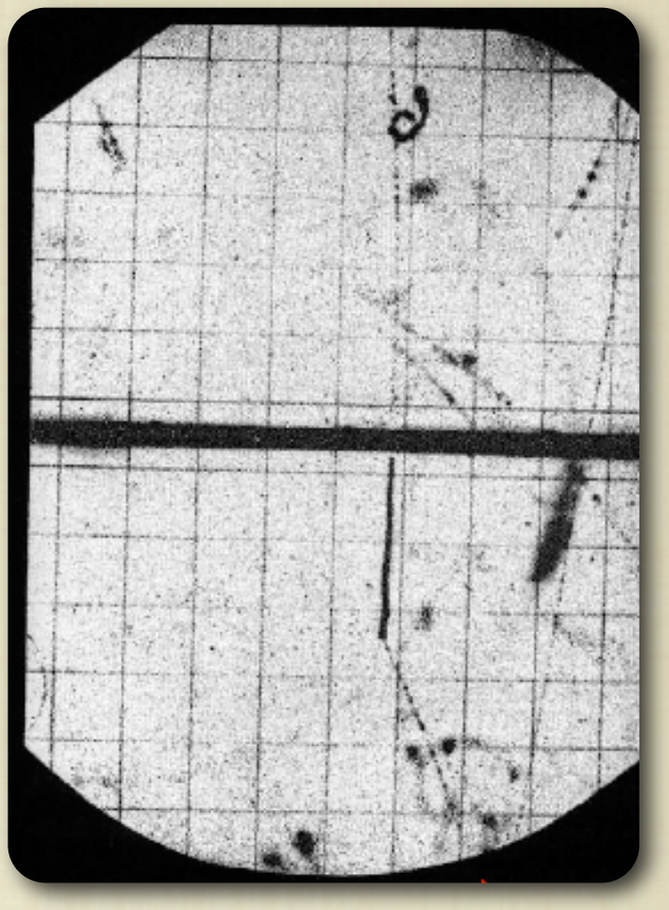
$$n + {}^{108}Cd \rightarrow {}^{109}Cd^* \rightarrow {}^{109}Cd + \gamma$$

Experimental signature



Who ordered that?



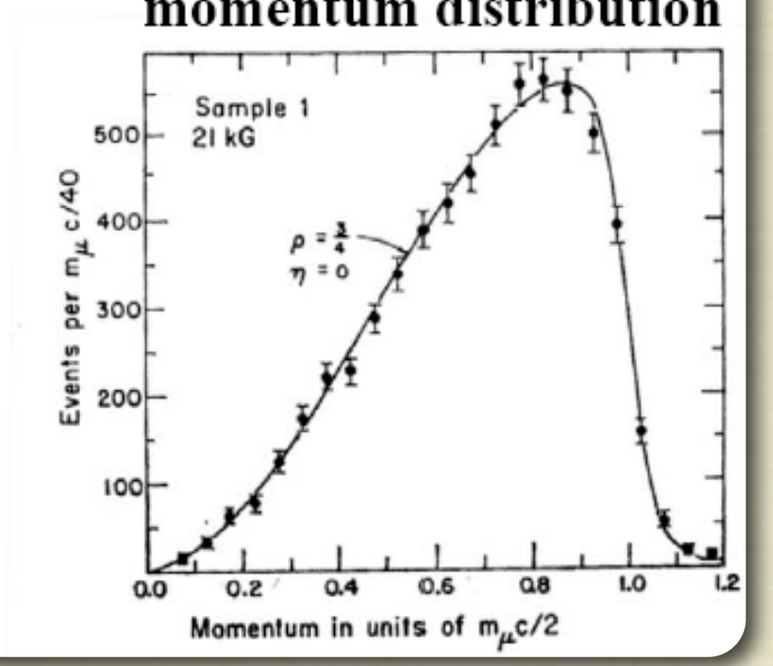


$\pi^+ \rightarrow \mu^+ \rightarrow e^+$ decay chain

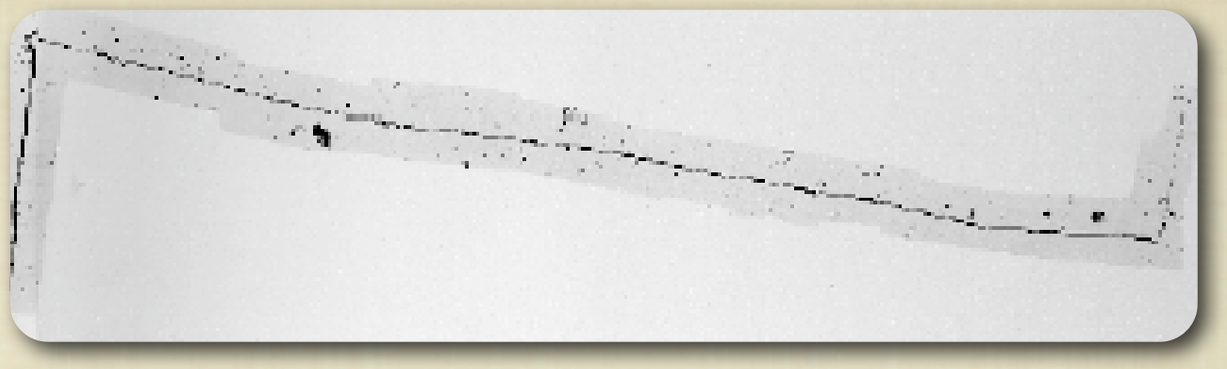
Cosmic ray muon stopping in a cloud chamber and decaying to an electron

Muon decay

$\mu^{\pm} \rightarrow e^{\pm} + \nu + \bar{\nu}$



$\pi \rightarrow \mu + \nu$

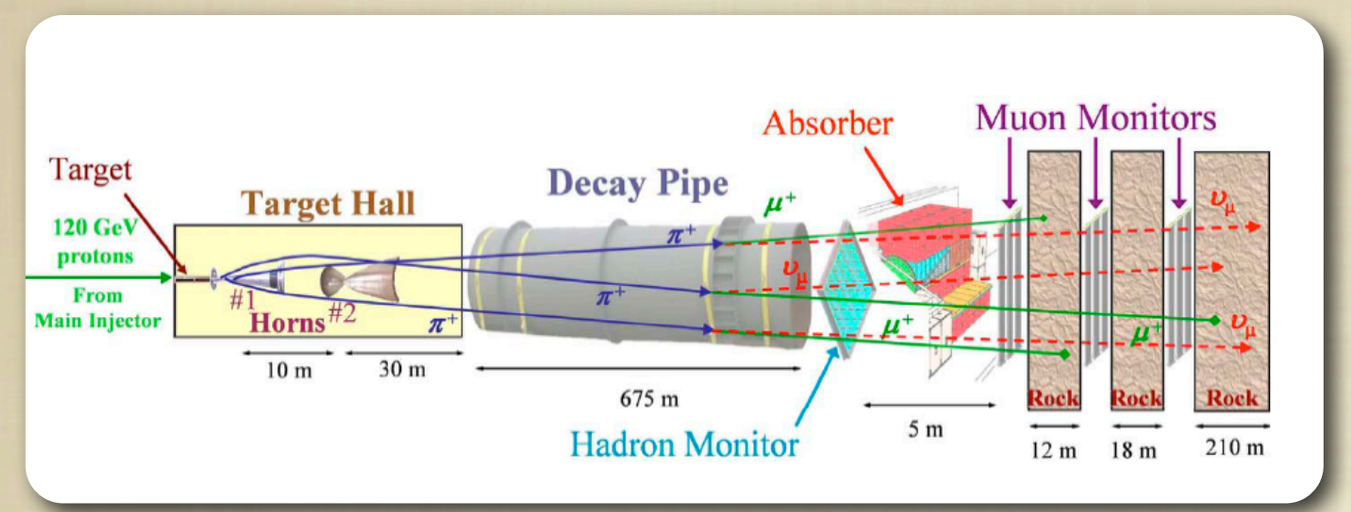


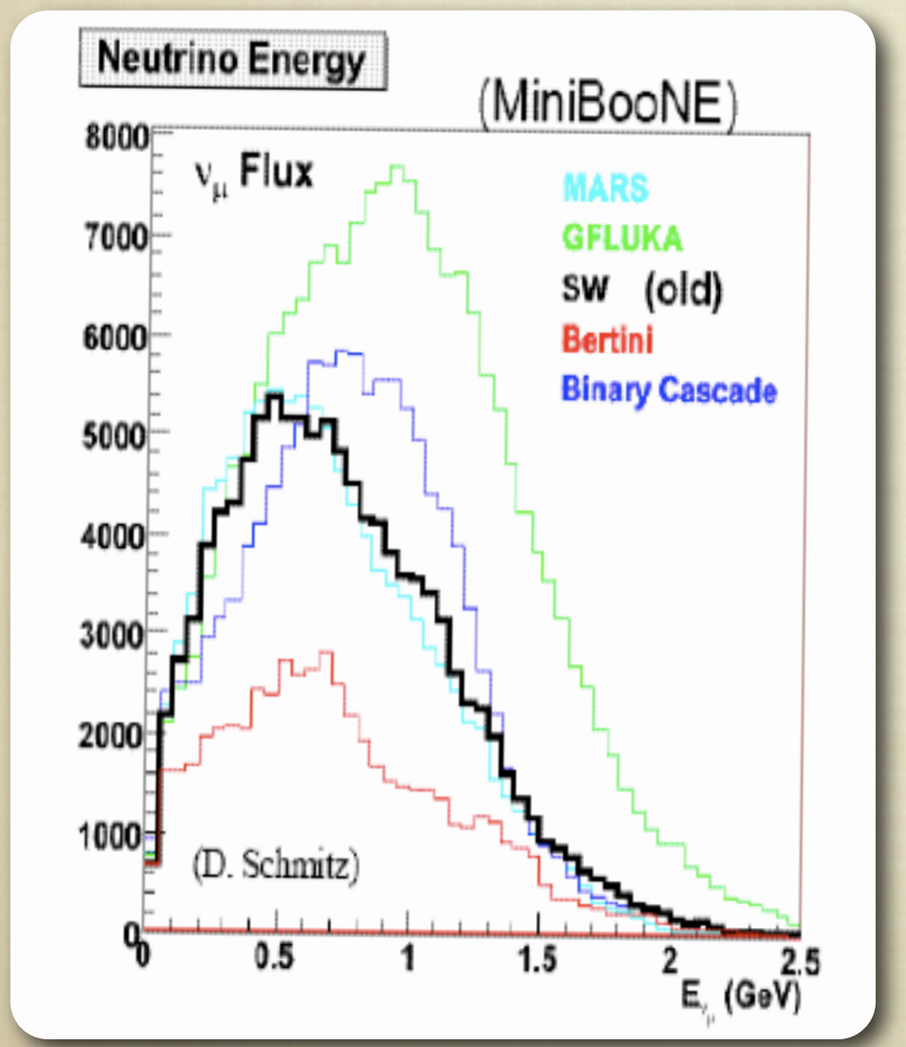
π decay is a two body process (muon has always the same energy when pion decays at rest). One undetected particle (kink in emulsion) signals the presence of a neutrino

μ decay is a three body process (observed electron has a continuous spectrum). One needs two neutrinos

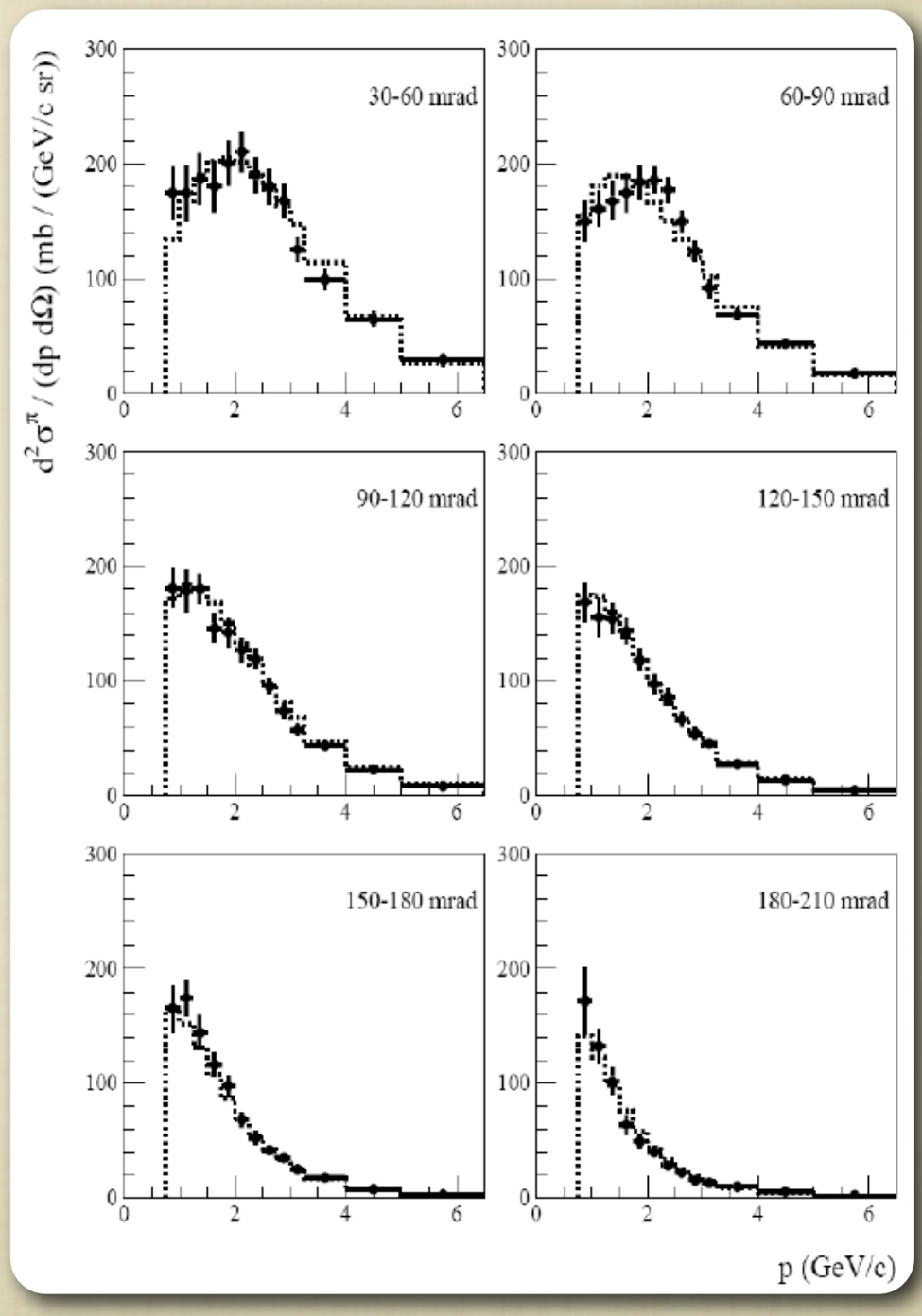
Are all those neutrinos the same than the one emitted in β decay?

How to build a neutrino beam

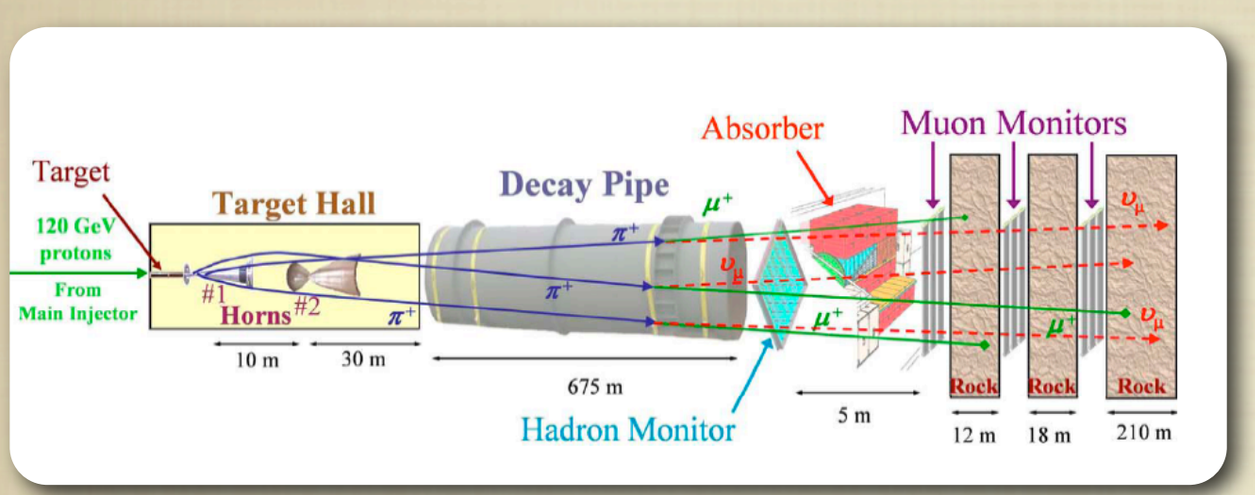




HARP BE Target DATA

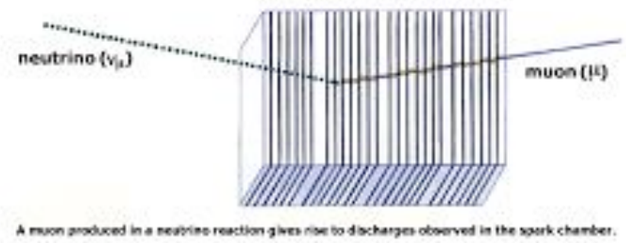


Discovery of the muon neutrino



Muon Neutrino

2nd kind of neutrino discovered - muon neutrino (1962)
produces a muon instead of electron

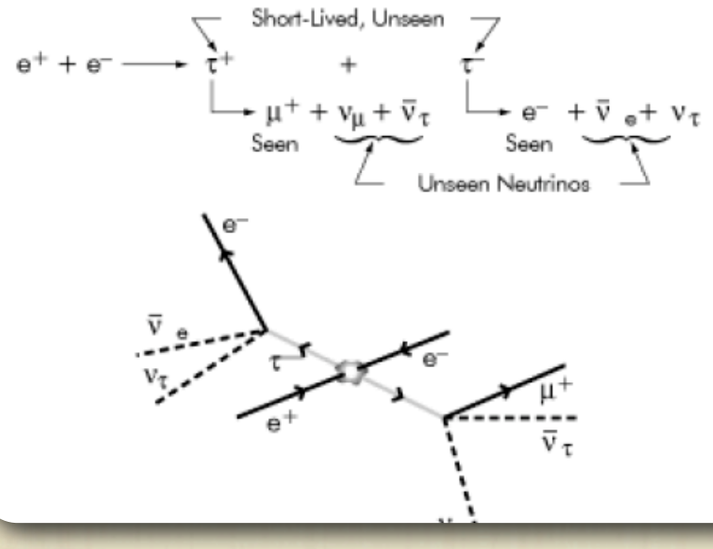


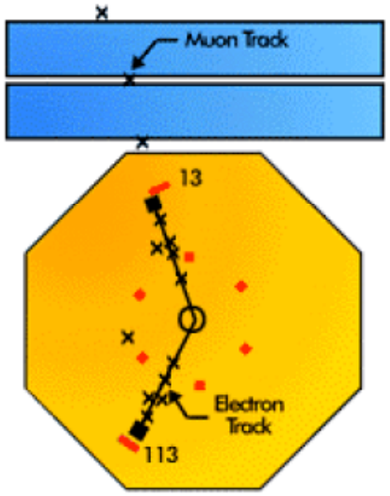
A muon produced in a neutrino reaction gives rise to discharges observed in the spark chamber.

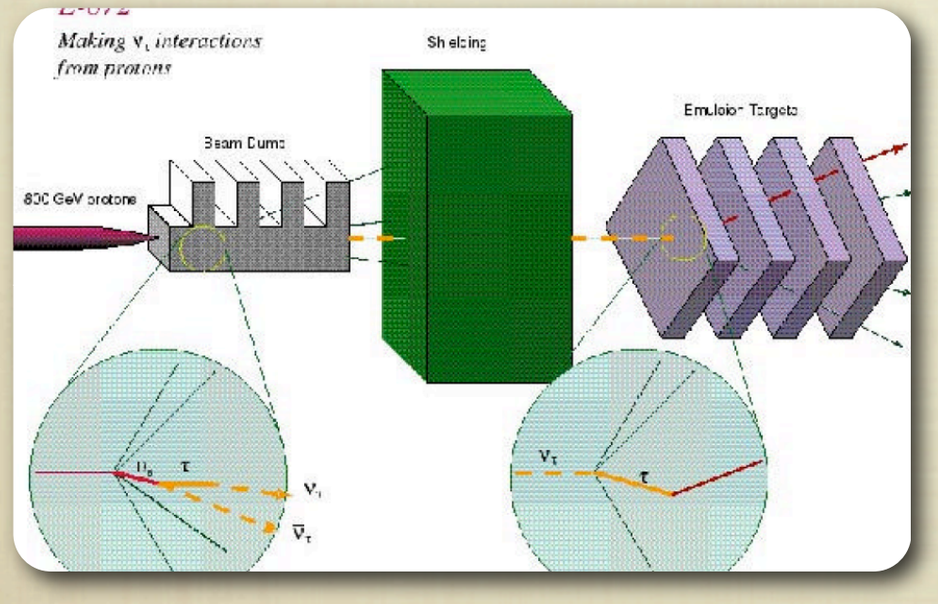
Neutrino beam produced by decay of particles produced by Particle accelerator

Discovery of the tau neutrino

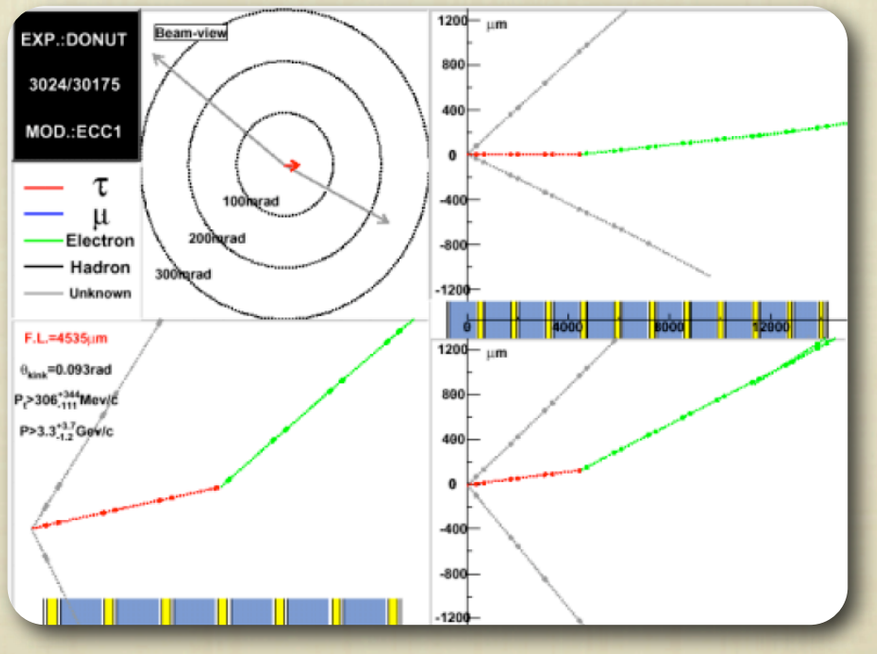
The third heavy electron, tha tau was discovered by M. Perl and collaborators in 1975 at SLAC







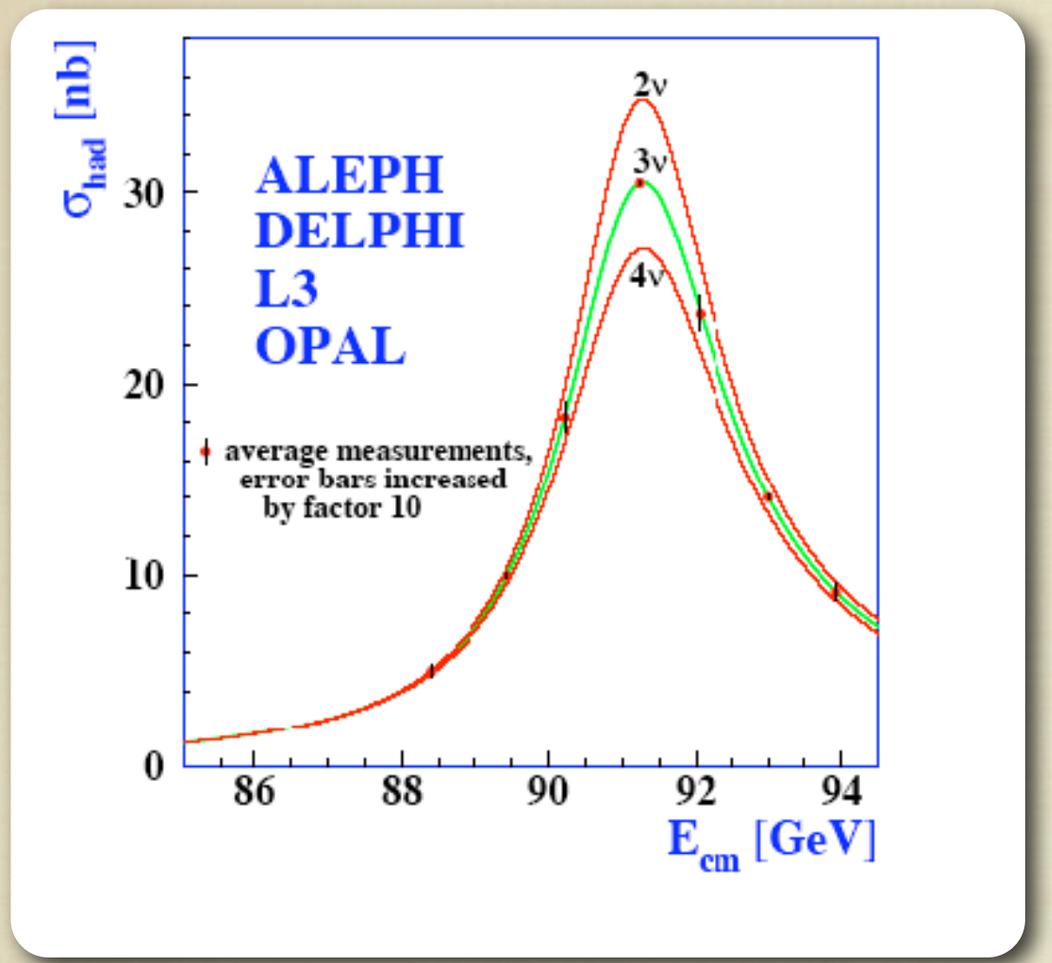
$$D_s \rightarrow \tau \nu_\tau$$



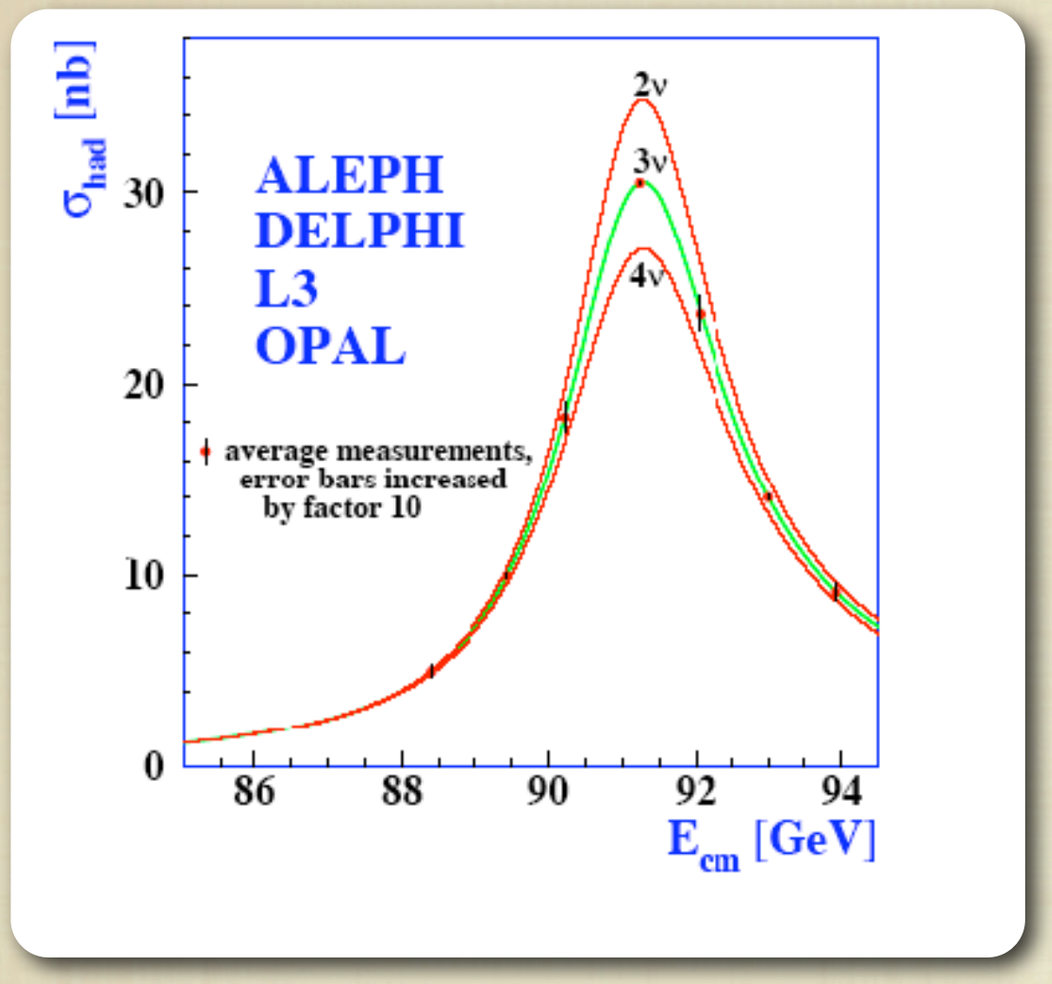
$$\nu_\tau + N \rightarrow \tau + X$$

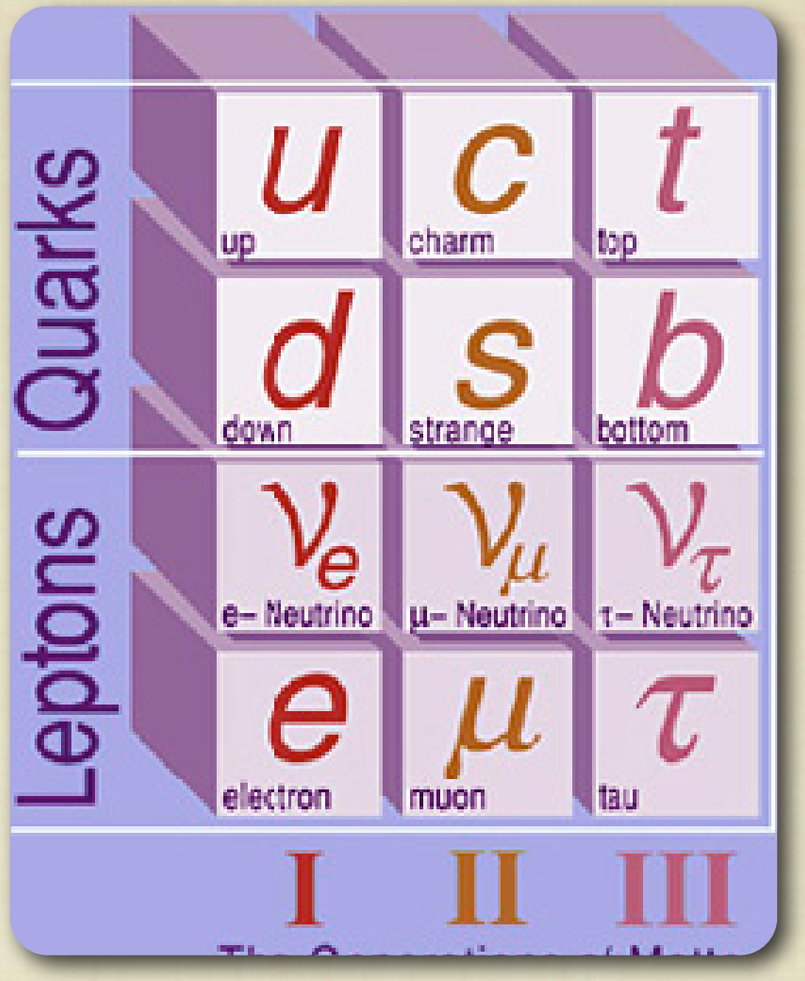
There are only three light neutrinos

There are only three light neutrinos



There are only three light neutrinos





The world according to the Aristotle

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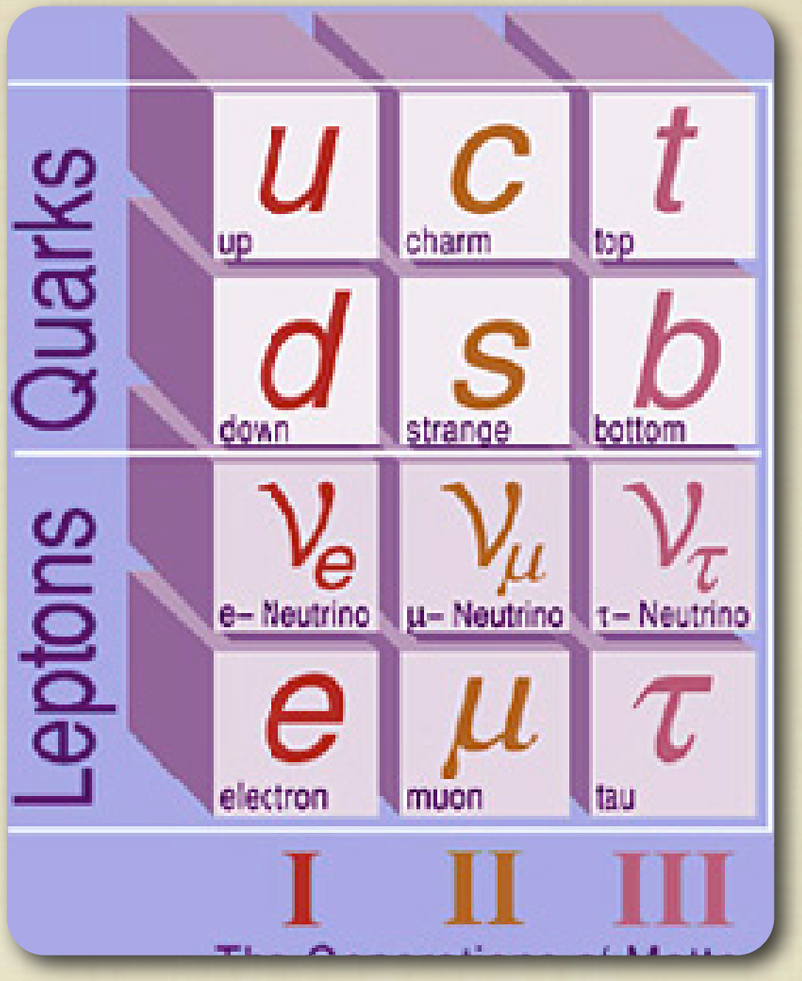

sir Arthur & the neutrinos

Sir Arthur would not have made a living as a prophet.
Physicists have got ingenuity enough to detect not only electron neutrinos but also muon and tau neutrinos.
Furthermore neutrinos coming from the sun, from the atmosphere from supernovae (1987A) have been observed.
Some experiments (NOMAD) have registered millions of neutrino interactions.

Pauli can reast in peace. His beast has been detected and exhaustively studied!