REAÇÕES NUCLEARES E A FÍSICA ALÉM DO MODELO PADRÃO

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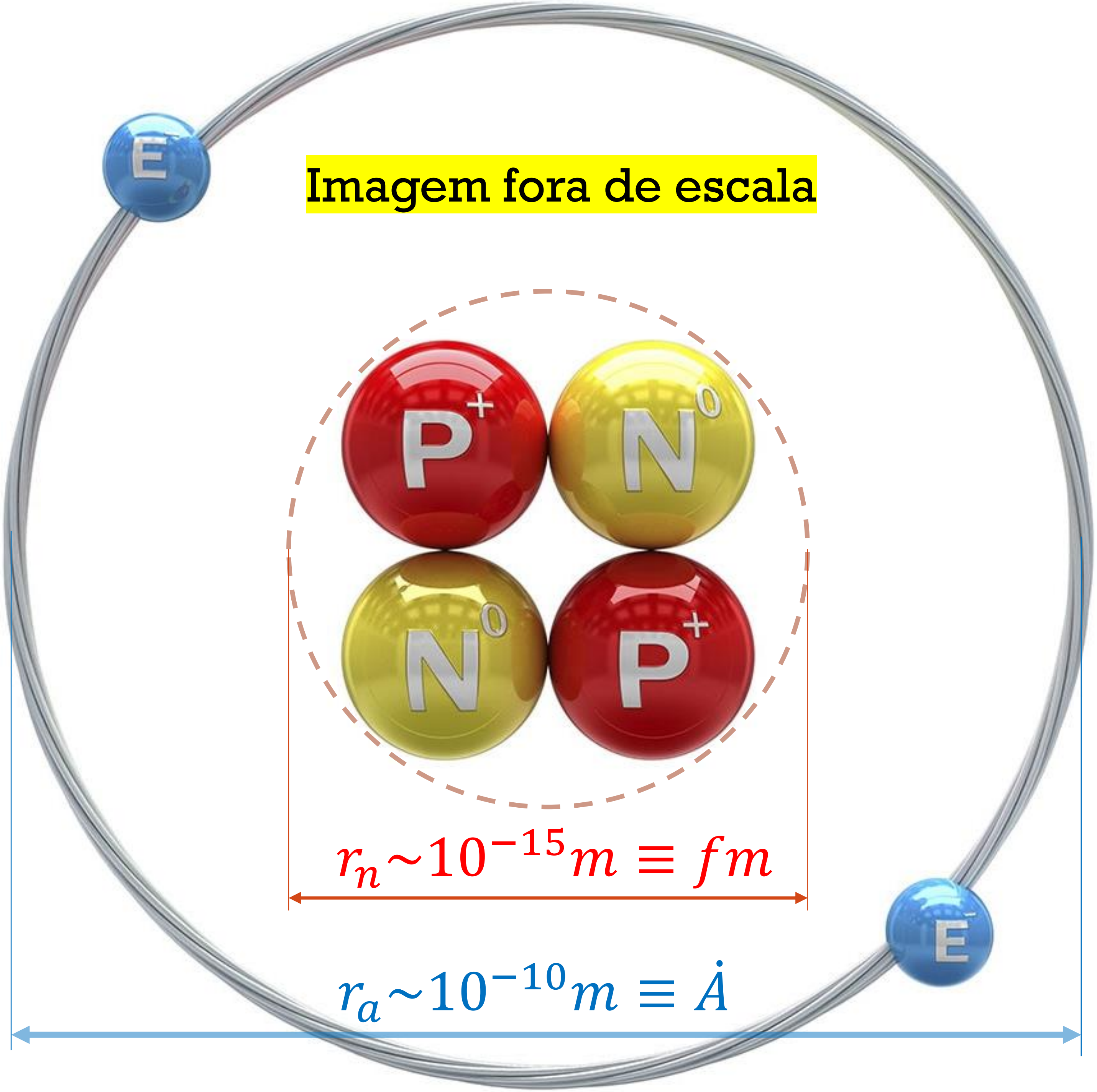
Panoramas da física 2°/2018

CONTEÚDO

- Núcleo atômico
- Decaimentos nucleares
  - Especificamente, decaimentos beta
- Noções do modelo padrão
  - Leis de conservação
  - What´s next? Decaimento beta duplo sem a emissão de neutrino
- Reações nucleares
  - Transferência de partículas e troca de carga



NÚCLEO ATÔMICO

- Nêutrons
- Prótons

PROPRIEDADES DO NÊUTRON E PRÓTON

Próton

- Massa $\approx 938\ ^{MeV}/_{c^2} \cong 1{,}671 \times 10^{-27} kg$
- Carga elétrica $= +e \equiv +1{,}60 \times 10^{-19} C$
- Spin $= {}^{1}/_{2}$

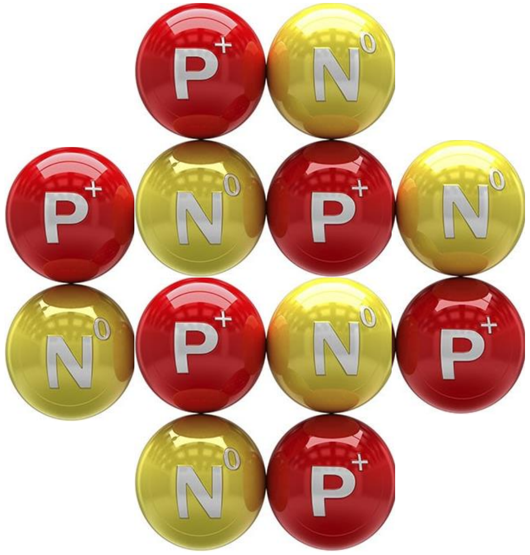
Nêutron

- Massa $\approx 939\ ^{MeV}/_{c^2} \cong 1{,}675 \times 10^{-27} kg$
- Carga elétrica $= 0$
- Spin $= {}^{1}/_{2}$

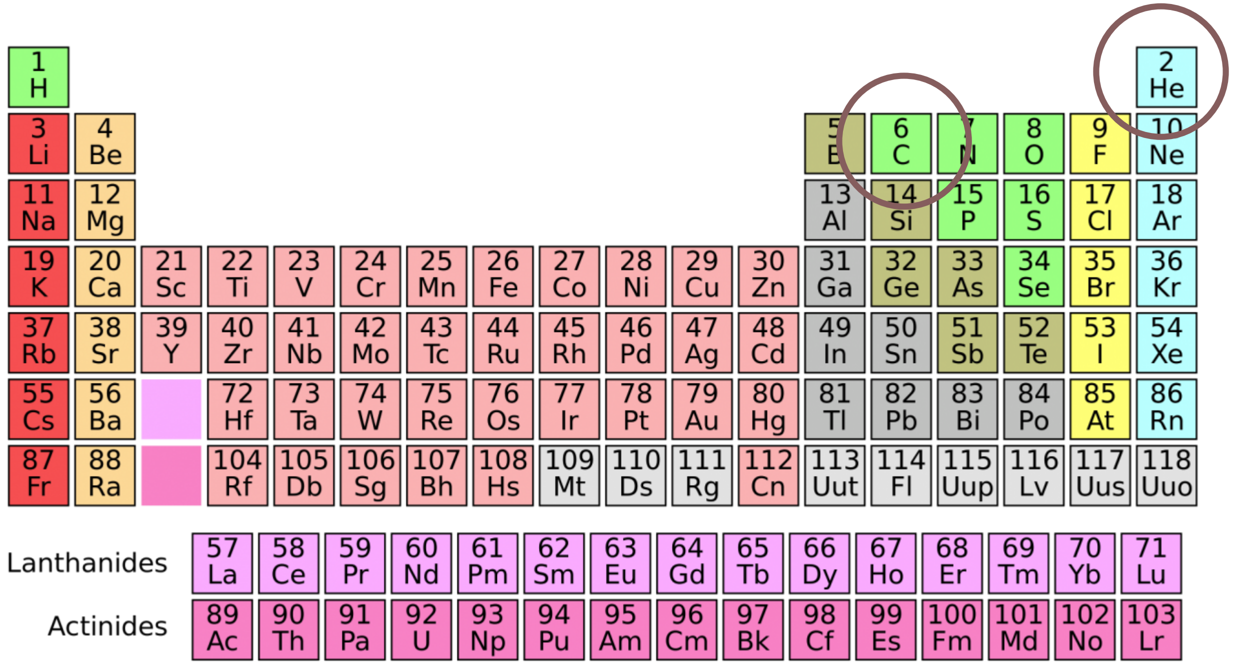
Partículas de spin ½ → férmions

NÚCLEOS

^{4}He

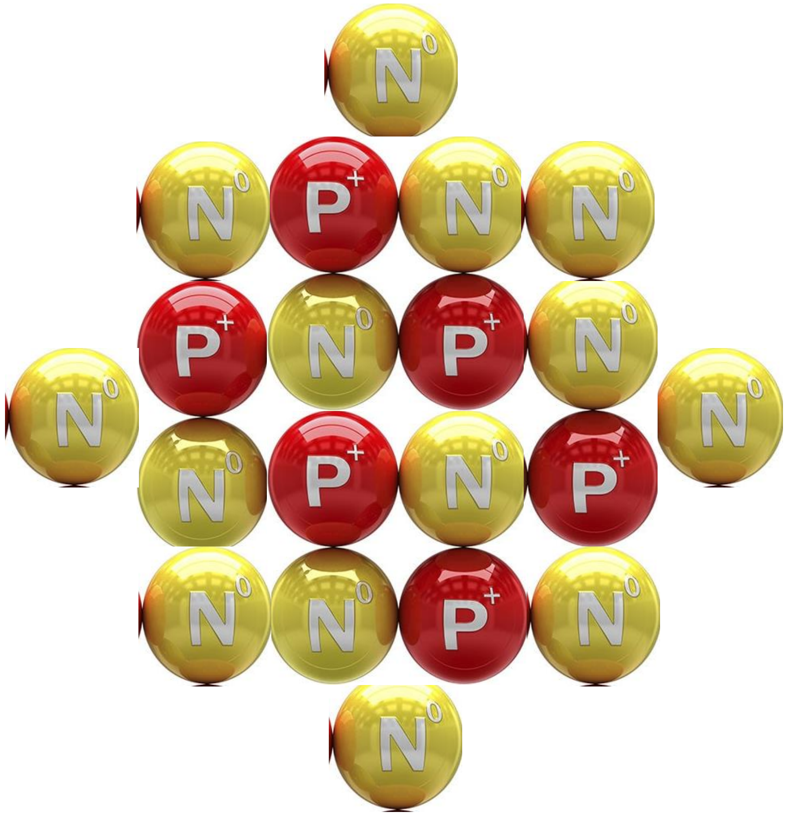


^{12}C

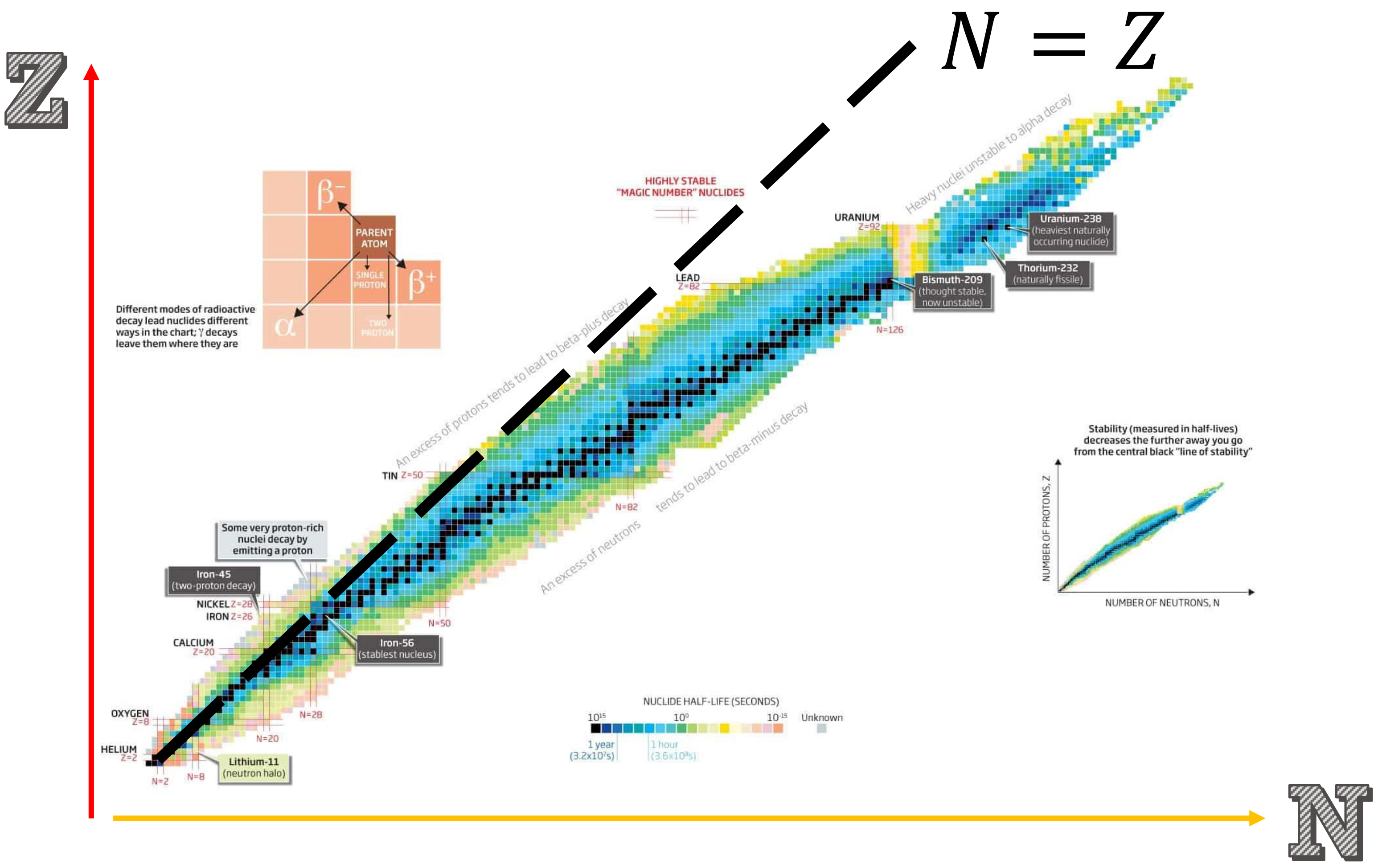


ISÓTOPOS

Núcleos atômicos com mesmo número atômico (mesmo número de prótons)



~300 núcleos estáveis e >3.000 núcleo instáveis

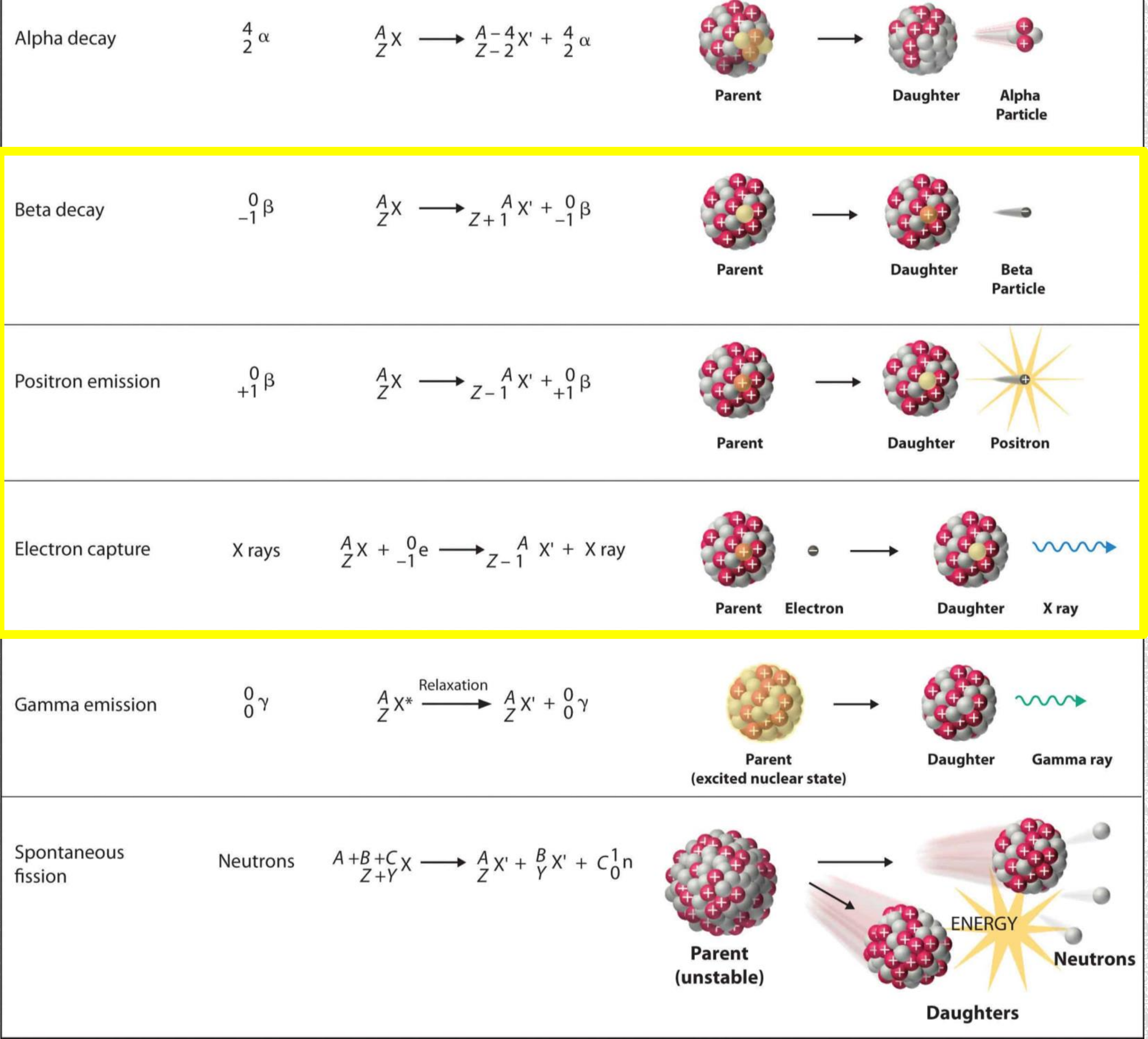


ESTABILIDADE NUCLEAR

NÚCLEOS INSTÁVEIS

- Dada uma quantidade inicial de núcleos estáveis (N_i), após 1 meia-vida metade desses núcleos decaem.

Núcleo instável	Isotópos estáveis	Meia-vida
^{6}He	^{3}He, ^{4}He	~0,81 s
^{8}Li	^{6}Li, ^{7}Li	~0.84 s
^{14}C	^{12}C, ^{13}C	~5.700 a
^{26}Al	^{27}Al	~0,72 Ma (milhão de ano)
^{210}Bi	^{209}Bi (estável mais pesado)	~5,01 d (dias)
^{238}U	não tem	~4,47 Ga (bilhões de anos)

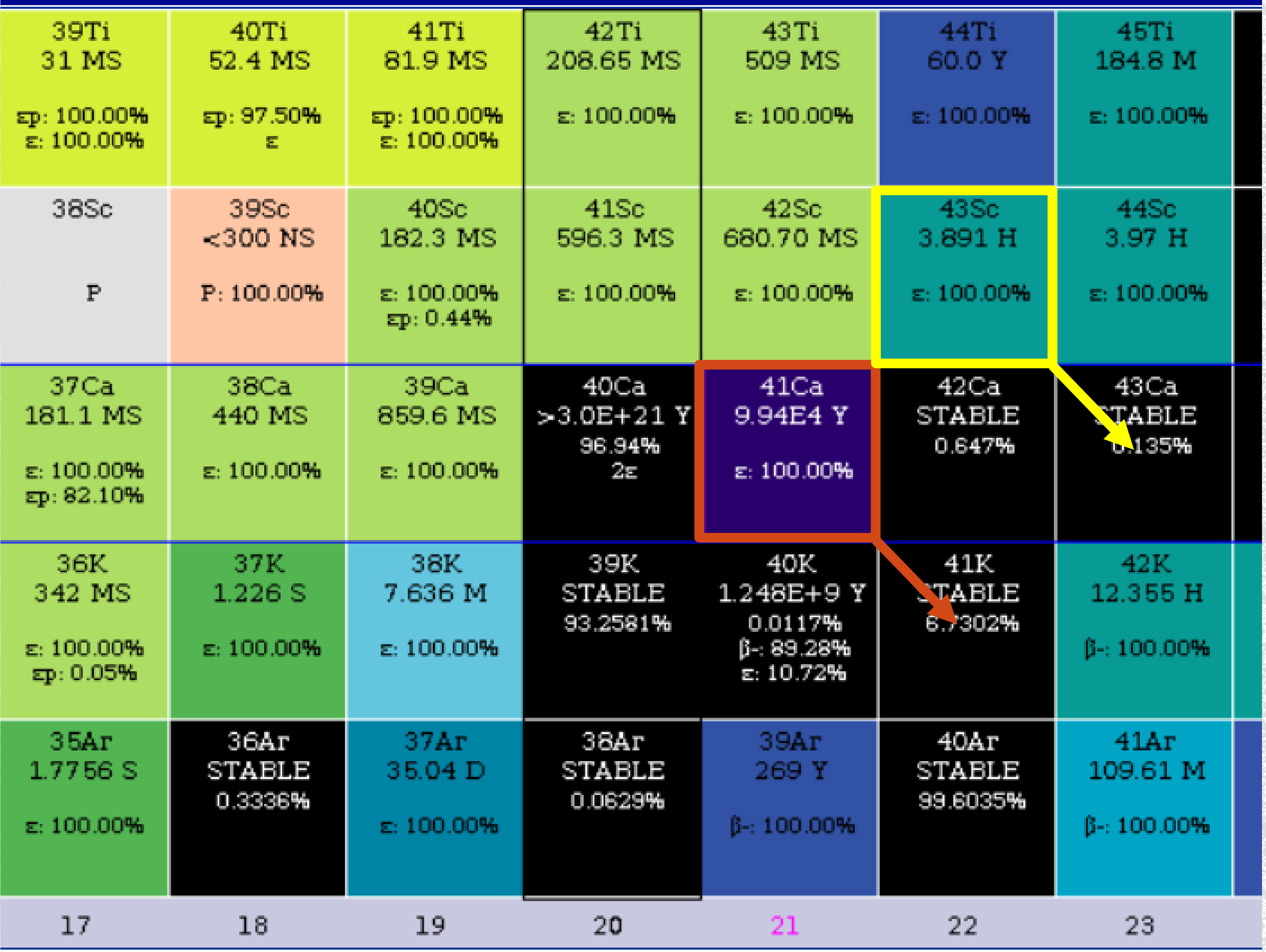


DECAIMENTOS

- Decaimento beta não altera a massa atômica e, sim, as quantidades de protons e neutrons
- **Pósitron** é uma partícula com massa idêntica a do elétron mas carga elétrica oposta

POR QUÊ NÚCLEOS ATÔMICOS DECAEM?

- Núcleos instáveis buscam o "vale da estabilidade"

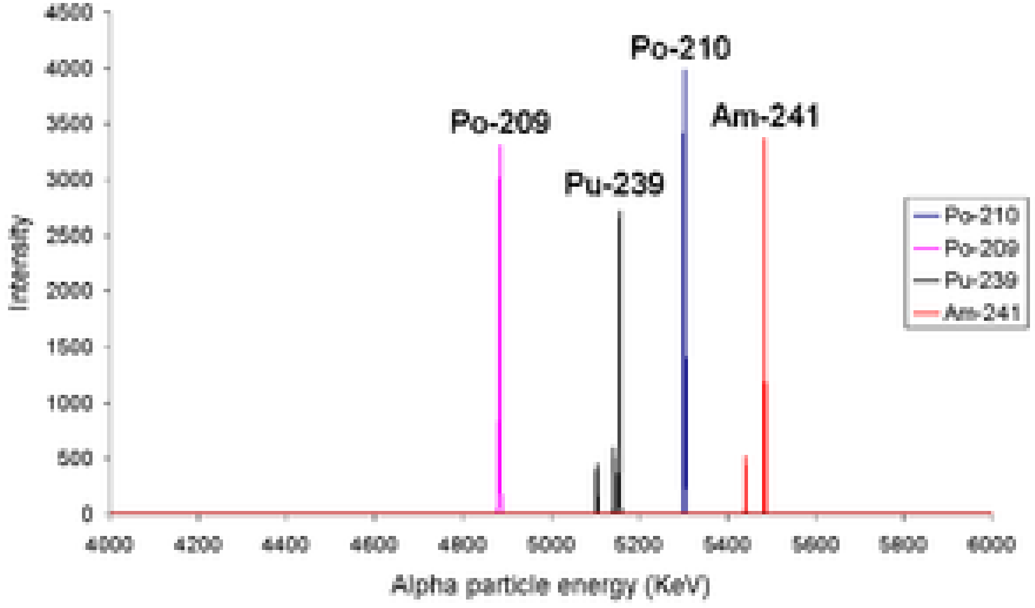


Ground and isomeric state information for $^{41}_{20}Ca$

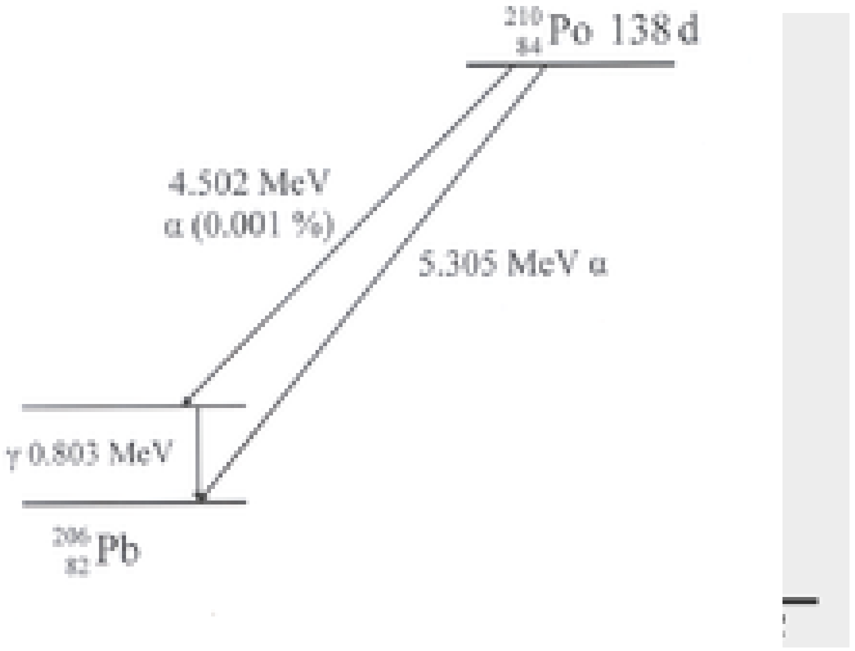
E(level) (MeV)	Jπ	Δ(MeV)	$T_{1/2}$	Decay Modes
0.0	7/2-	-35.137890625	9.94E4 y *15*	ε : 100.00 %

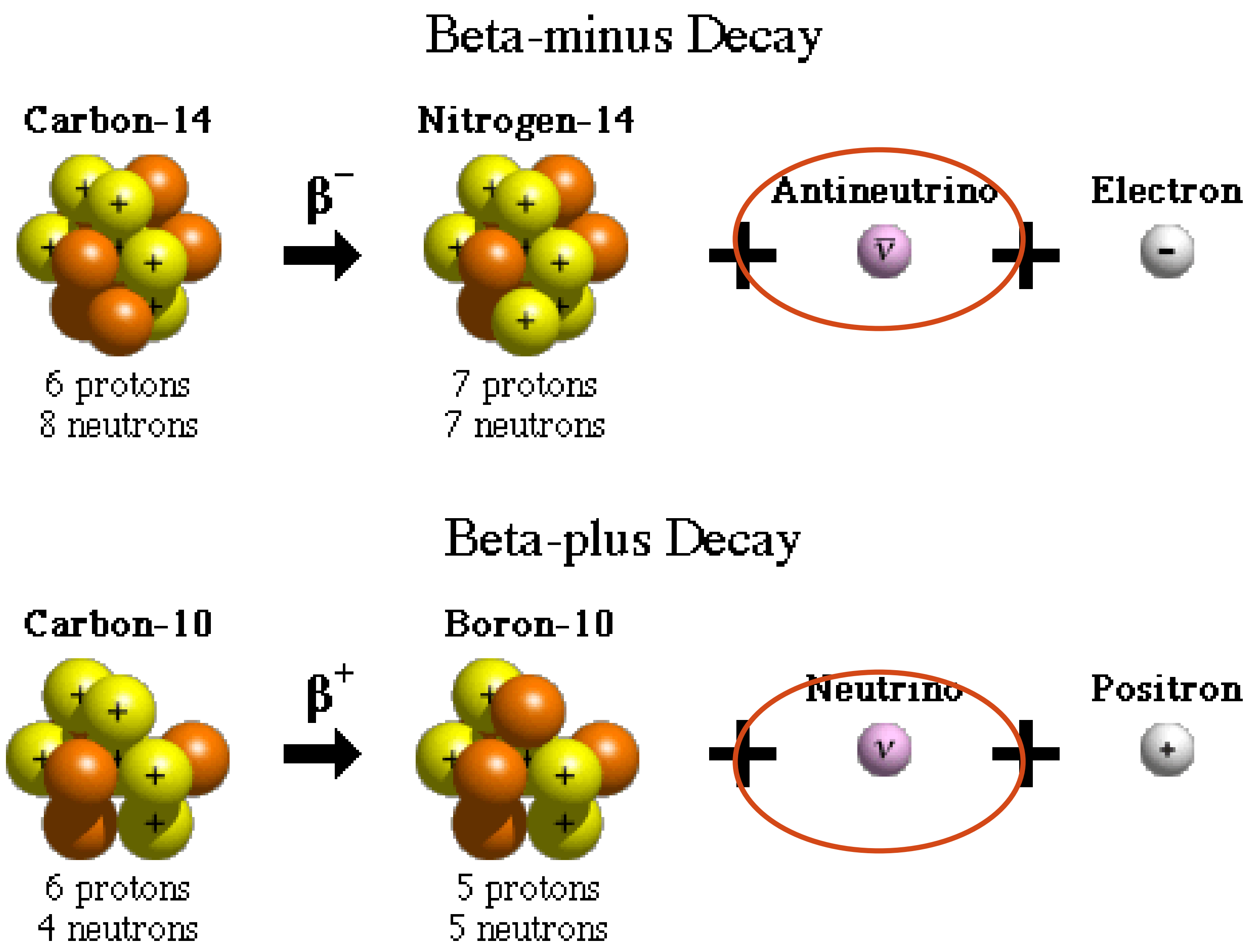
ESPECTROS DE EMISSÃO ALPHA E BETA

Decaimento alfa = discretizado



Decaimento beta = contínuo



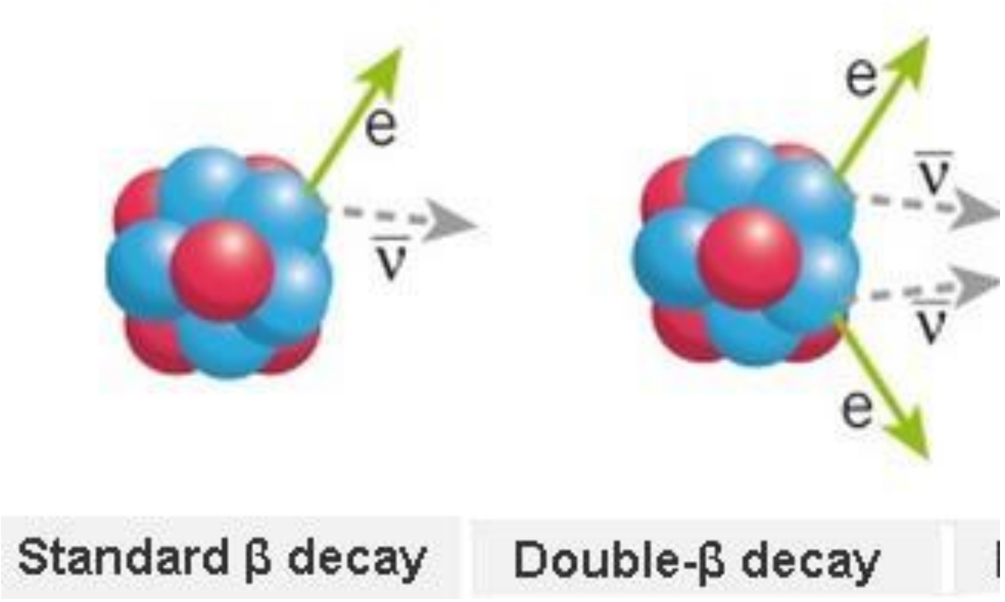


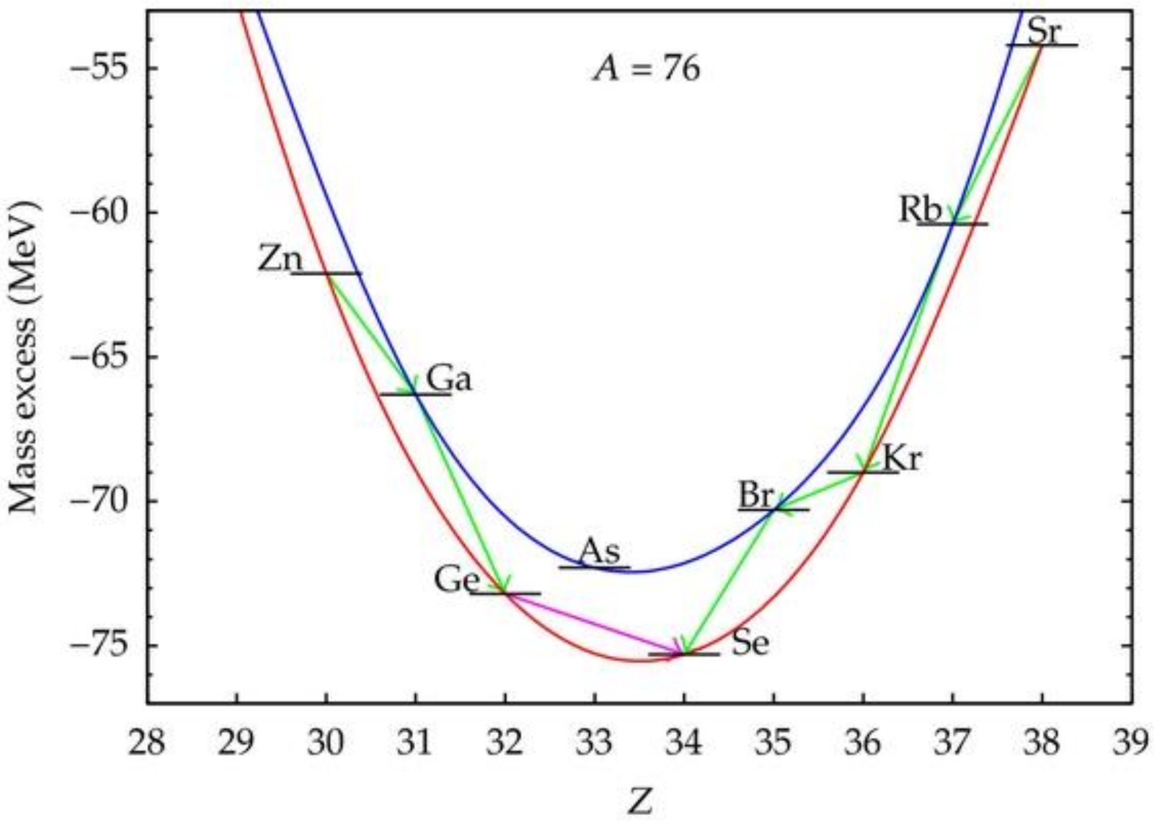
A HIPÓTESE DO NEUTRINO

- Uma partícula sem carga elétrica, leve e pouco interagente

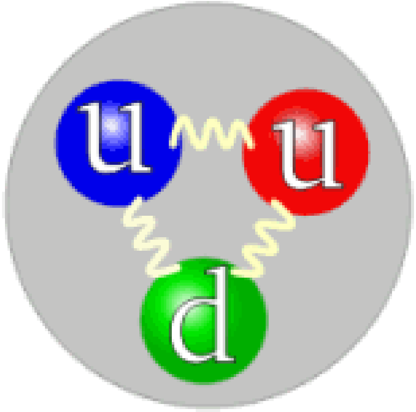
DECAIMENTO BETA SIMPLES E DUPLO

Emissão de anti-neutrino

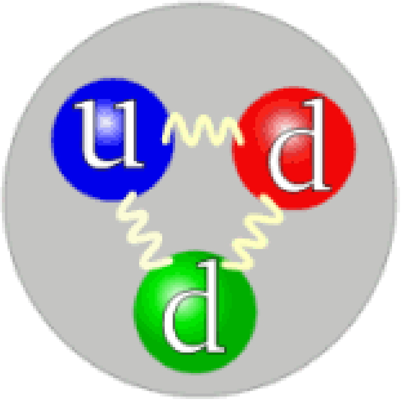




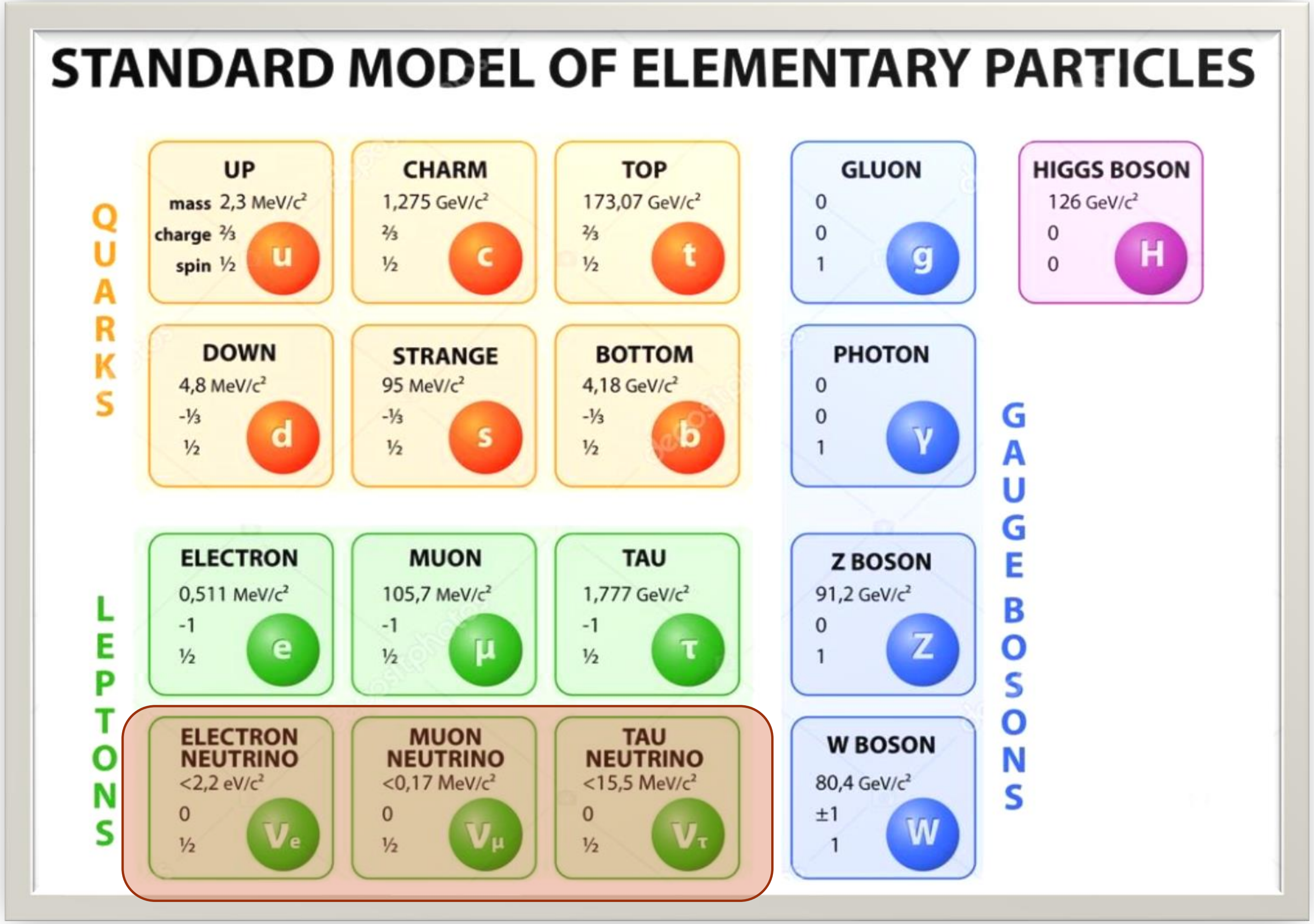
PARTÍCULAS FUNDAMENTAIS



Proton

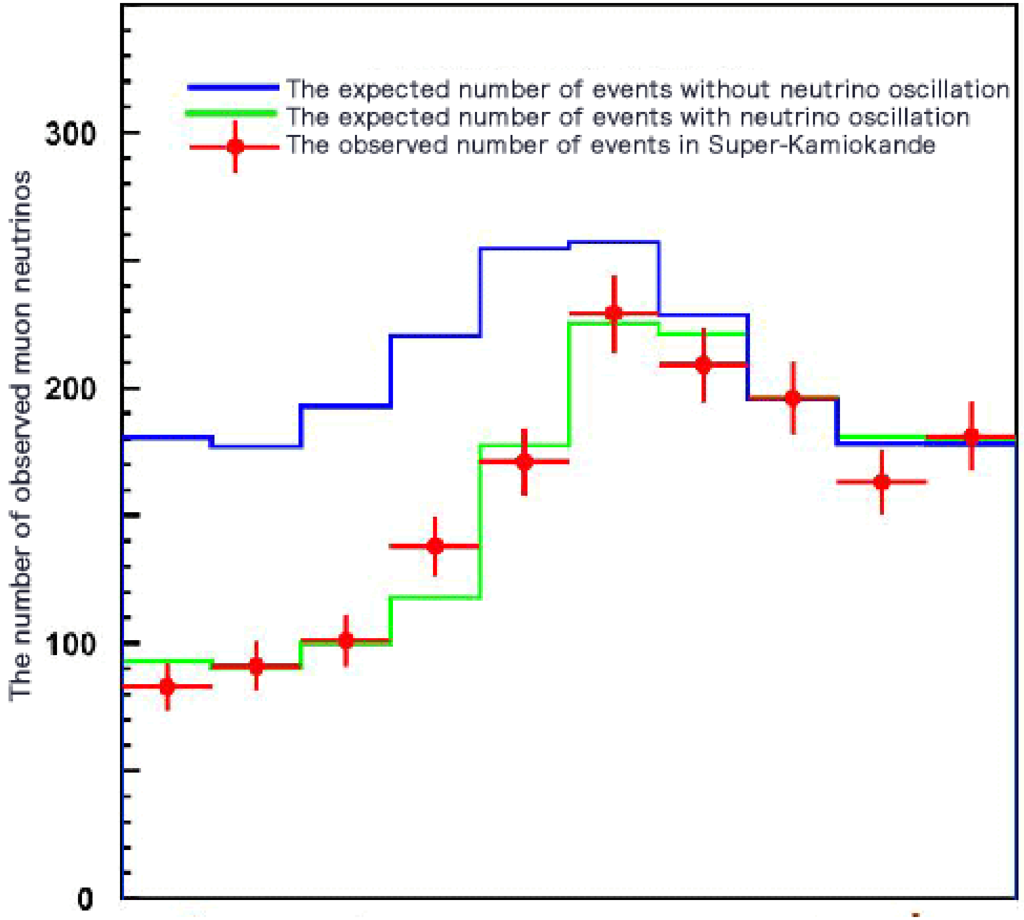


Neutron



NEUTRINOS: PARTÍCULAS MUTANTES

- Neutrinos são partículas sem massa dentro do Modelo Padrão
- Extensões ao modelo permitem acomodar neutrinos massivos (também permitido dentro da teoria de Fermi-Dirac do decaimento beta)
- Oscilação de neutrinos confirmam que possuem massa



IDÉIAS GERAIS DO MODELO PADRÃO

- O Modelo Padrão também assume leis de conservação:
  - Número Leptônico (L)
    - Léptons $L = +1$
    - Anti-léptons $L = -1$
  - Número Bariônico (B)
    - $B = \frac{1}{3}(n_q - n_{\bar{q}})$

$$^{14}C \rightarrow {}^{14}N + e + \overline{\nu_e}$$

Levam a simetria de matéria e anti-matéria no universo.

TEORIA DO DECAIMENTO BETA DUPLO COM A EMISSÃO DE NEUTRINOS

- Em 1935, paper de Maria Goeppert-Mayer

SEPTEMBER 15, 1935 PHYSICAL REVIEW VOLUME 48

Double Beta-Disintegration

M. Goeppert-Mayer, *The Johns Hopkins University*

(Received May 20, 1935)

From the Fermi theory of β-disintegration the probability of simultaneous emission of two electrons (and two neutrinos) has been calculated. The result is that this process occurs sufficiently rarely to allow a half-life of over 10^{17} years for a nucleus, even if its isobar of atomic number different by 2 were more stable by 20 times the electron mass.

https://doi.org/10.1103/PhysRev.48.512

A symmetric theory of electrons and positrons(*)

Ettore Majorana

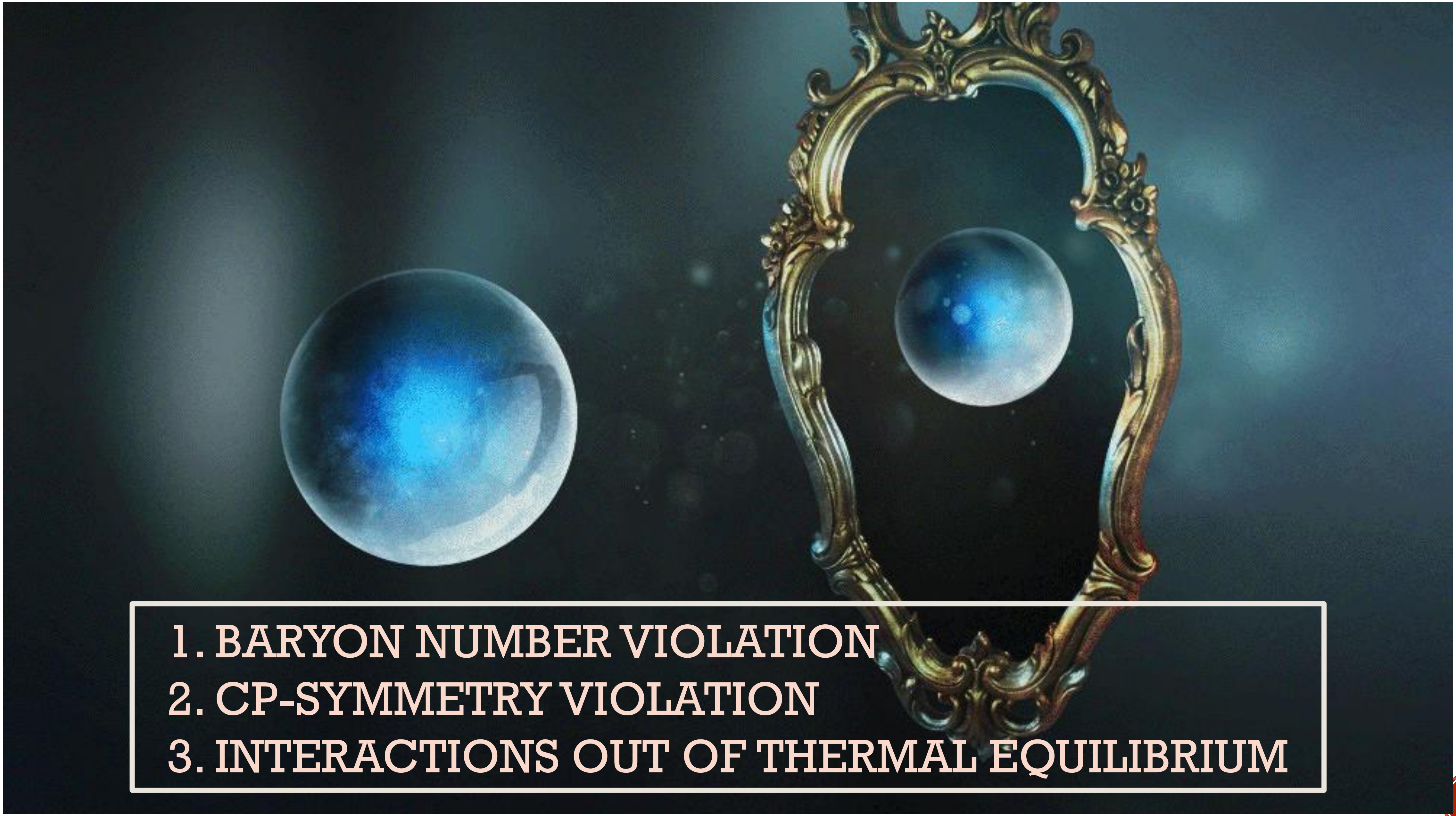
Summary. — It is shown that it is possible to achieve complete formal symmetrization in the electron and proton quantum theory by means of a new quantization process. The meaning of Dirac equations is somewhat modified and there is no longer any reason to speak of negative-energy states nor to assume, for any other types of particles, especially neutral ones, the existence of antiparticles, corresponding to the "holes" of negative energy.

INTRODUÇÃO

Em 1937, o paper de E. Majorana

PARTÍCULAS DE MAJORANA

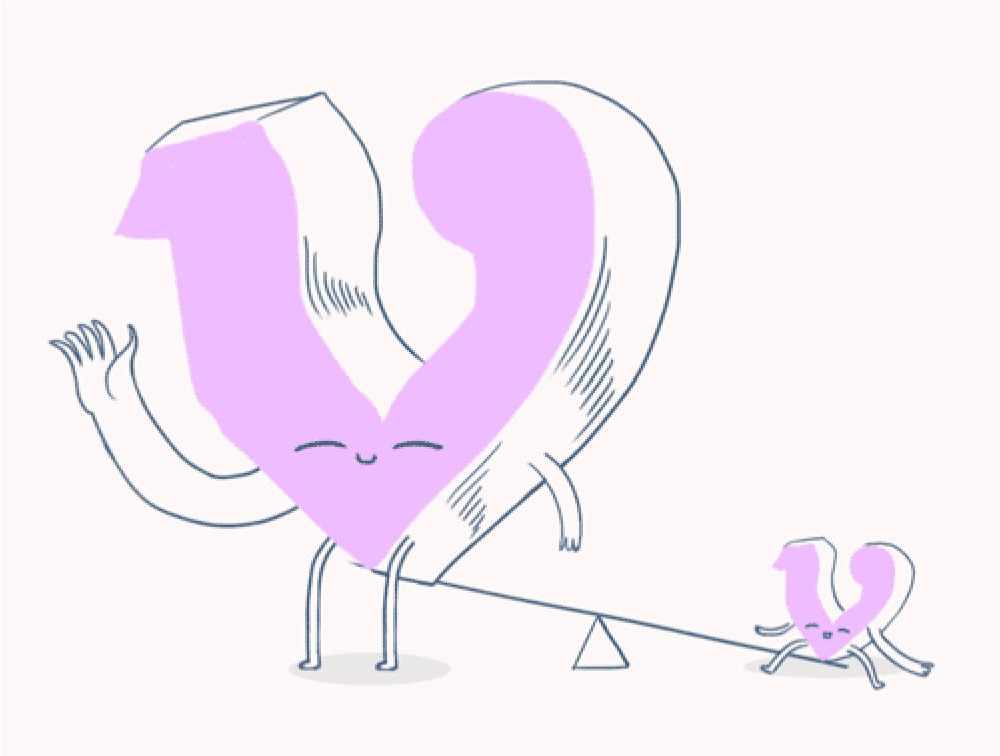
- O que são partículas de Majorana?
  - Férmions (spin semi-inteiro)
  - Com massa
  - Idênticas às suas anti-partículas (conjugação de carga)
    - Sendo assim, devem ser eletricamente neutras
- Considerando partículas de spin ½ , apenas neutrinos são candidatos a serem partículas de Majorana



1. BARYON NUMBER VIOLATION
2. CP-SYMMETRY VIOLATION
3. INTERACTIONS OUT OF THERMAL EQUILIBRIUM

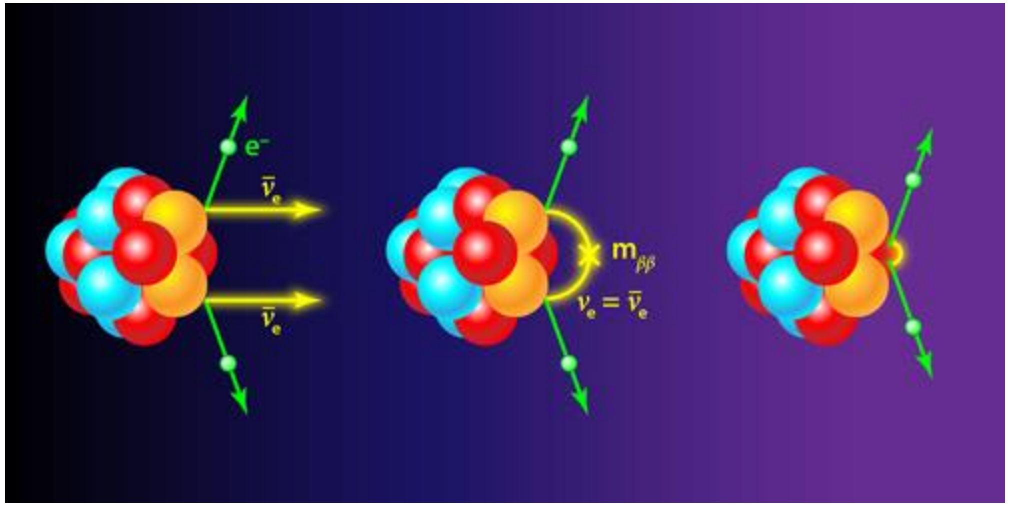
UMA FÍSICA ALÉM DO MODELO PADRÃO

- Se o decaimento $0\nu\beta\beta$ ocorre
  - Confirma o neutrino como uma fermion de Majorana elementar
  - Fornece uma explicação para a pequena massa do ν_e
  - Justifica a assimetria de matéria e anti-matéria no Universo



UMA FÍSICA ALÉM DO MODELO PADRÃO

- The Leptogenesis mechanism



“Do we all descend from neutrinos?”

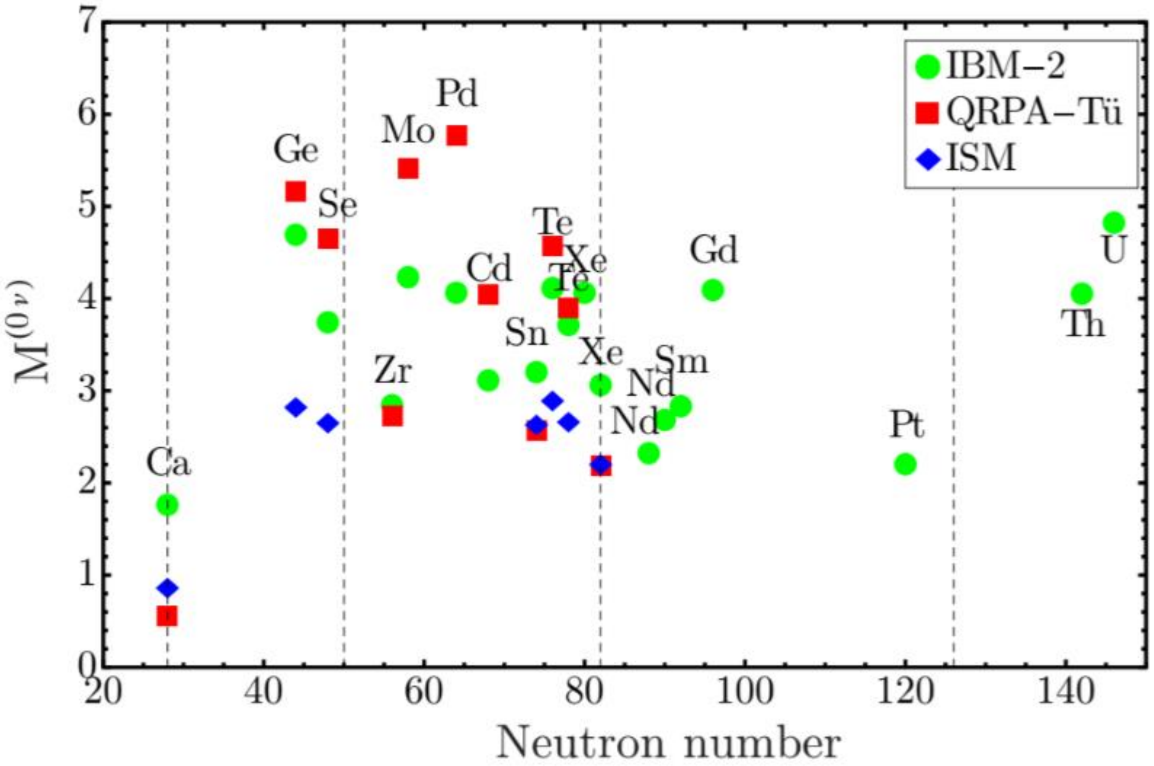
1. Partícula de Majorana (RH)
2. Assimetria Leptônica
3. Violação B + L

Assimetria bariônica

O PAPEL DA FÍSICA NUCLEAR

- A meia-vida do decaimento $0\nu\beta\beta$

$$[t^{1/2}]^{-1} = G_{0\nu}\,|\mathcal{M}|^2\,|f(m_i, U_{ei})|^2$$



NUMEN

BUSCA EXPERIMENTAL DO $0\nu\beta\beta$

- 4 Possíveis mecanismos

$$
\begin{aligned}
(A,Z) &\rightarrow (A,Z+2) + 2e^- && (\beta^-\beta^-)\\
(A,Z) &\rightarrow (A,Z+2) + 2e^+ && (\beta^+\beta^+)\\
(A,Z) + 2e^- &\rightarrow (A,Z-2) && (EC\,EC)\\
(A,Z) + e^- &\rightarrow (A,Z-2) + e^+ && (EC\,\beta^+).
\end{aligned}
$$

TABLE V. Isotopic abundance and Q-value for the known $2\nu\beta\beta$ emitters [175].

Isotope	isotopic abundance (%)	$Q_{\beta\beta}$ [MeV]
^{48}Ca	0.187	4.263
^{76}Ge	7.8	2.039
^{82}Se	9.2	2.998
^{96}Zr	2.8	3.348
^{100}Mo	9.6	3.035
^{116}Cd	7.6	2.813
^{130}Te	34.08	2.527
^{136}Xe	8.9	2.459
^{150}Nd	5.6	3.371

BUSCA EXPERIMENTAL DO $0\nu\beta\beta$

- Sensibilidade e alta resolução

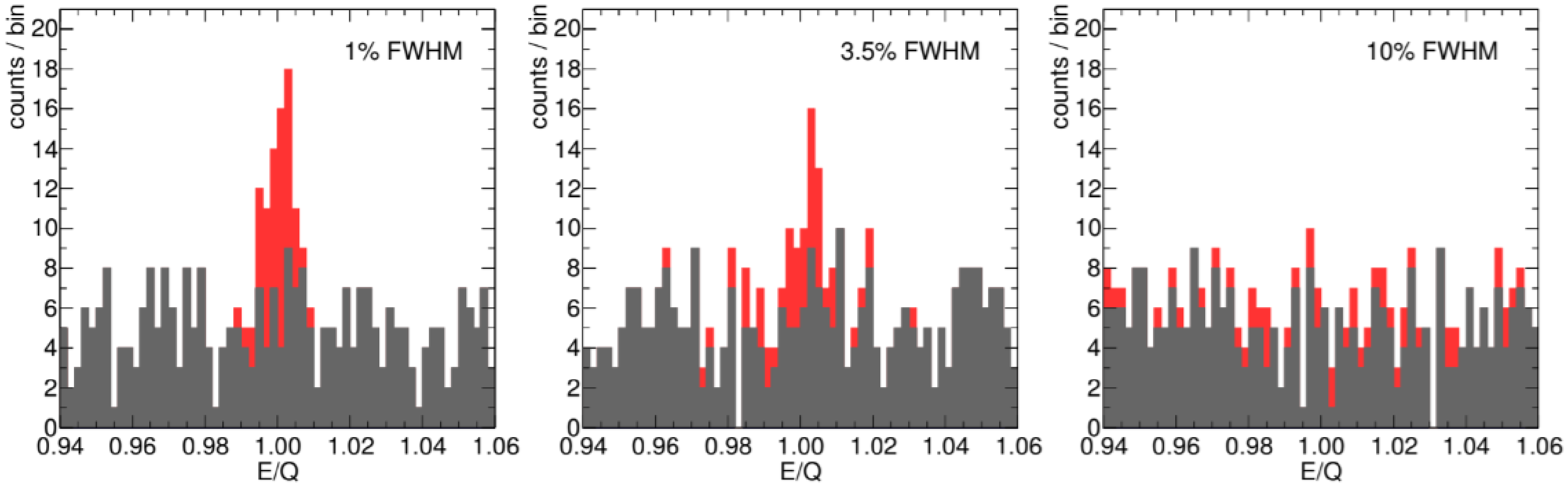


FIG. 15. Signal and background (red and grey stacked histograms, respectively) in the region of interest around $Q_{\beta\beta}$ for 3 Monte Carlo experiments with the same signal strength (50 counts) and background rate (1 count keV^{-1}), but different energy resolution: top: 1% FWHM, centre: 3.5% FWHM, bottom: 10% FWHM. The signal is distributed normally around $Q_{\beta\beta}$, while the background is assumed flat. Figure from Ref. [177].

GERDA EXPERIMENT

Editors' Suggestion | Featured in Physics

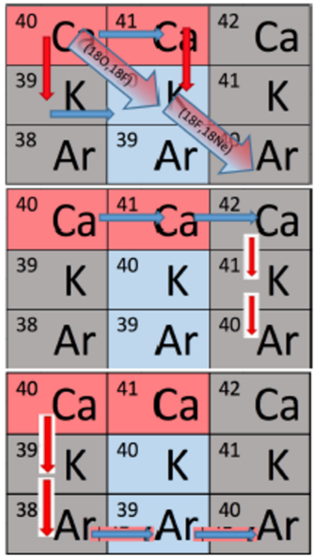
Improved Limit on Neutrinoless Double-β Decay of ^{76}Ge from GERDA Phase II

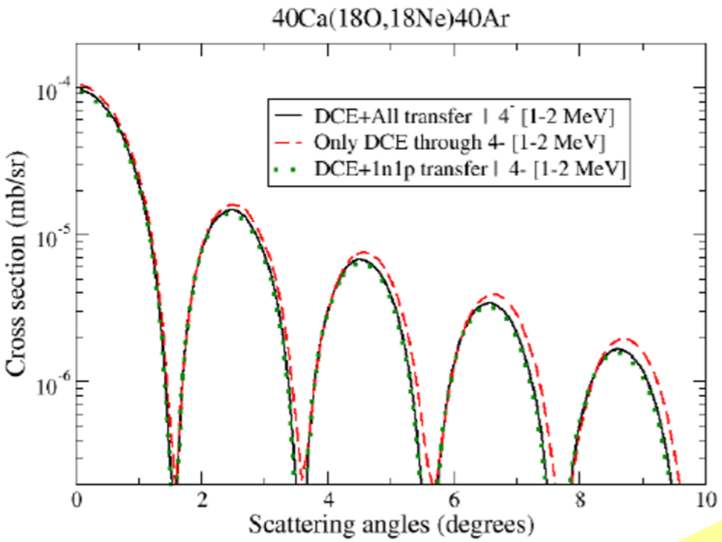
M. Agostini,[1,b] A. M. Bakalyarov,[14] M. Balata,[1] I. Barabanov,[12] L. Baudis,[20] C. Bauer,[8] E. Bellotti,[9,10] S. Belogurov,
A. Bettini,[17,18] L. Bezrukov,[12] J. Biernat,[4] T. Bode,[16] D. Borowicz,[6,d] V. Brudanin,[6] R. Brugnera,[17,18] A. Caldwe

The GERDA experiment searches for the lepton-number-violating neutrinoless double-β deca ^{76}Ge ($^{76}\mathrm{Ge} \rightarrow {}^{76}\mathrm{Se} + 2e^-$) operating bare Ge diodes with an enriched ^{76}Ge fraction in liquid argon. The exposure for broad-energy germanium type (BEGe) detectors is increased threefold with respect to our previous data release. The BEGe detectors feature an excellent background suppression from the analysis of the time profile of the detector signals. In the analysis window a background level of $1.0^{+0.6}_{-0.4} \times 10^{-3}$ counts/(keV kg yr) has been achieved; if normalized to the energy resolution this is the lowest ever achieved in any $0\nu\beta\beta$ experiment. No signal is observed and a new 90% C.L. lower limit for the half-life of 8.0×10^{25} yr is placed when combining with our previous data. The expected median sensitivity assuming no signal is 5.8×10^{25} yr.

REAÇÕES NUCLEARES PARA A FÍSICA ALÉM DO MODELO PADRÃO

Preliminary results: DCE vs transfer





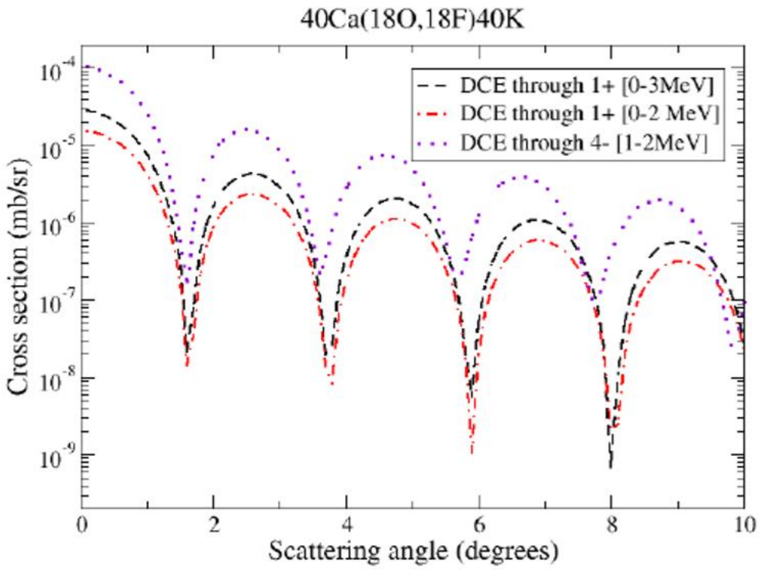
Preliminary results

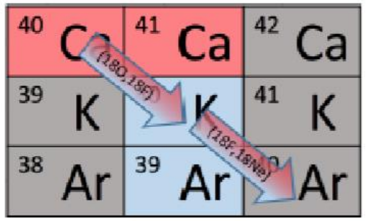
- Only ground states in 2n/2p transfers

FRESCO code: *J.A. Lay*

REAÇÕES NUCLEARES PARA A FÍSICA ALÉM DO MODELO PADRÃO

DCE cross section (DWBA): preliminary results





Preliminary results

FRESCO code:
Calculations by *J.A. Lay*
(LNS and Sevilla Univ.)