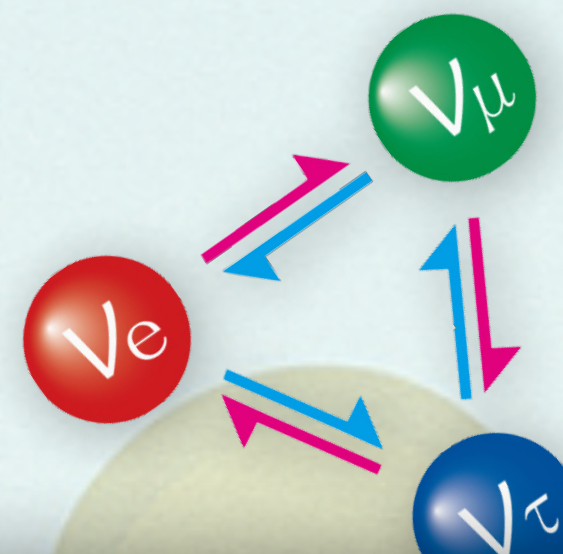


(2)

(1)

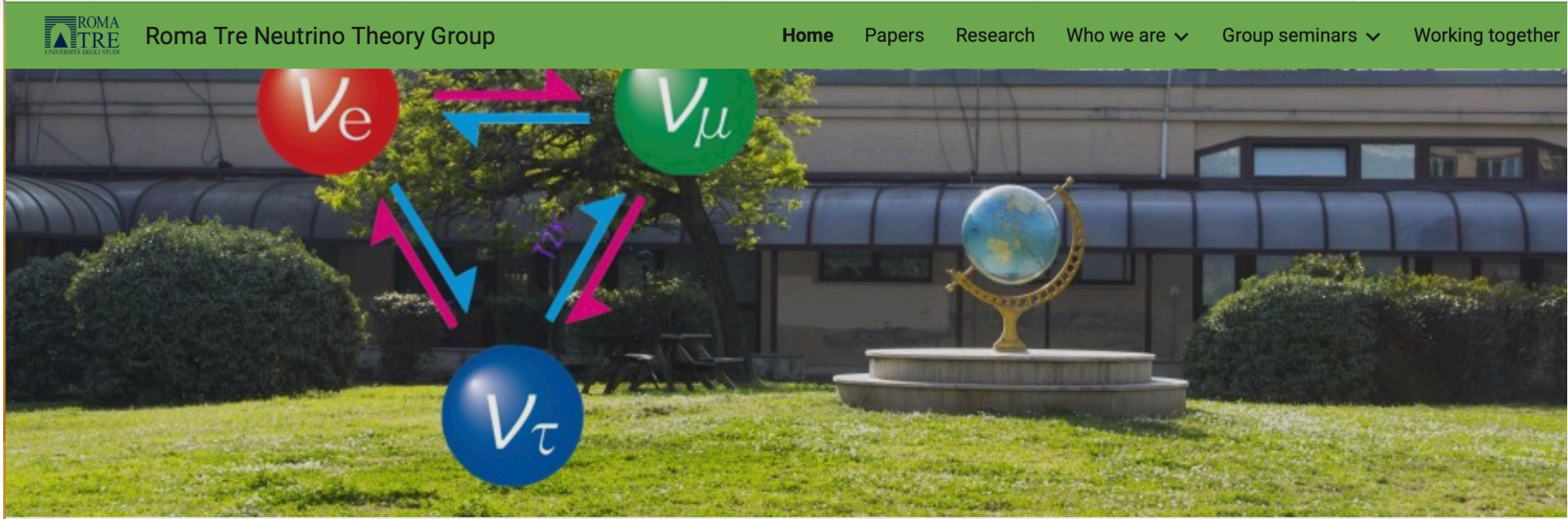


Introduzione al mondo dei neutrini

Matteo Parriciatu ⁽¹⁾₍₂₎

Giornata tematica del neutrino - Roma Tre - Dipartimento di Matematica e Fisica

12 maggio 2025





Roma Tre
Neutrino Theory Group

Università degli Studi Roma Tre,
Dipartimento di Matematica e Fisica & INFN Sezione Roma Tre







Davide Meloni

Professor
[Inspire](#)

[Short bio](#)



Alessio Giarnetti

Postdoctoral Researcher
[Inspire](#)

[Short bio](#)



Joao Penedo 

Postdoctoral Researcher
[Inspire](#)

[Short bio](#)



Matteo Parriciatu

PhD Student
[Inspire](#)

[Short bio](#)



Mirko Rettaroli

PhD Student

[Short bio](#)



Marco Carducci

PhD Student

[Short bio](#)

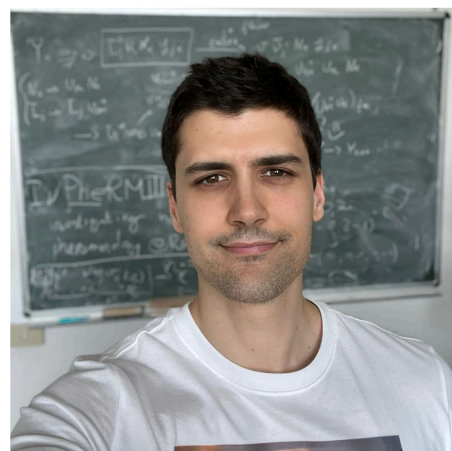
Master students



Gabriele Battimelli



Davide Russo



Simone Marciano
(Founding member)

Postdoctoral Researcher
[Inspire](#)

Former members



Anish Ghoshal

[Inspire](#)



Andrea Di Iura

[Inspire](#)

et al.



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Theory
Group

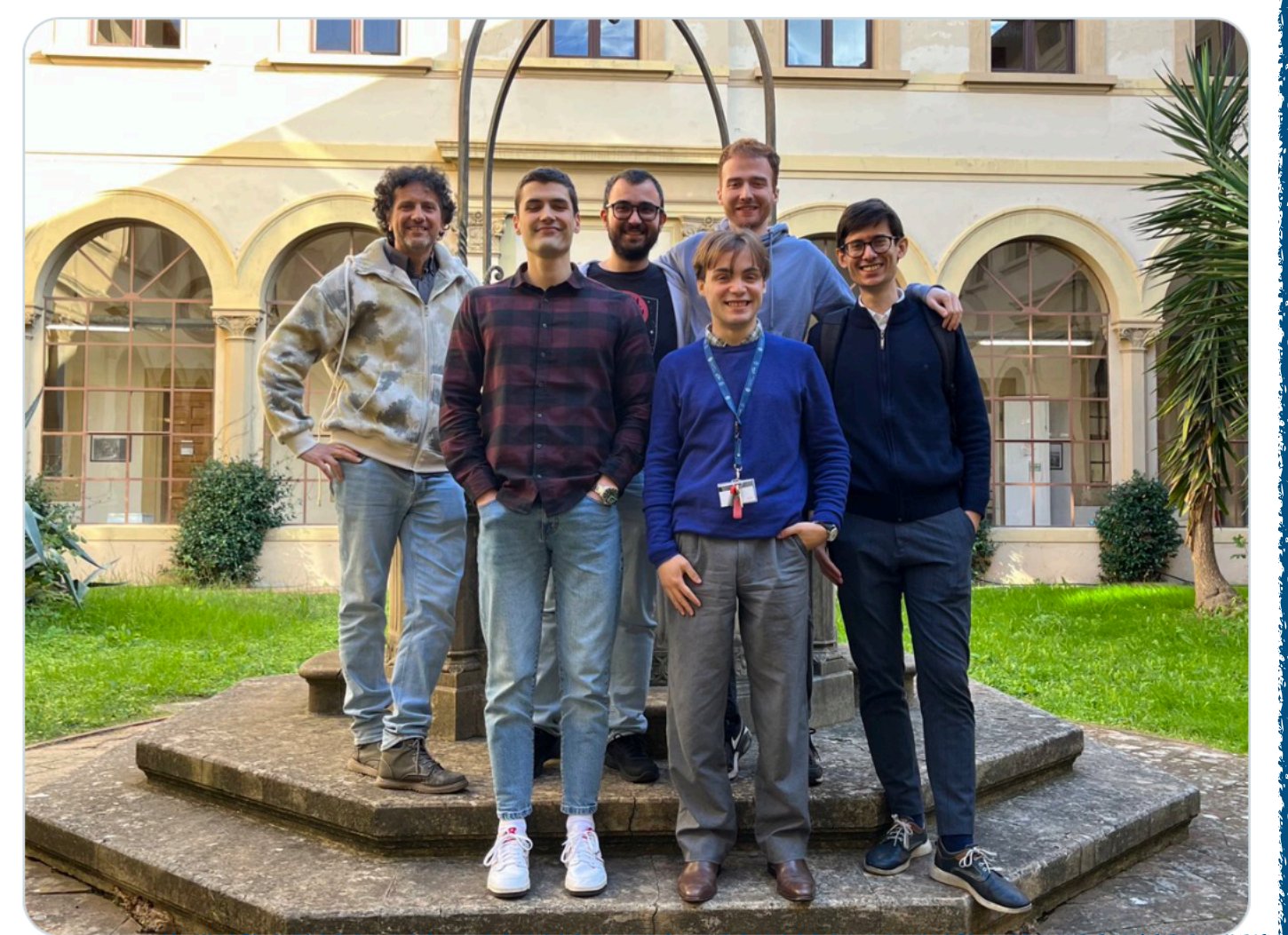
**Roma Tre Neutrino Group** @romatreneutrino · Mar 14

Yesterday, we had the pleasure of hosting our friend Tommaso Chiarusi, who gave a talk on “High energy neutrino telescopes, under ice and under water challenges and new findings”, with emphasis on the recent ultra high energetic neutrino discovered by KM3NeT 🌟
#neutrinos



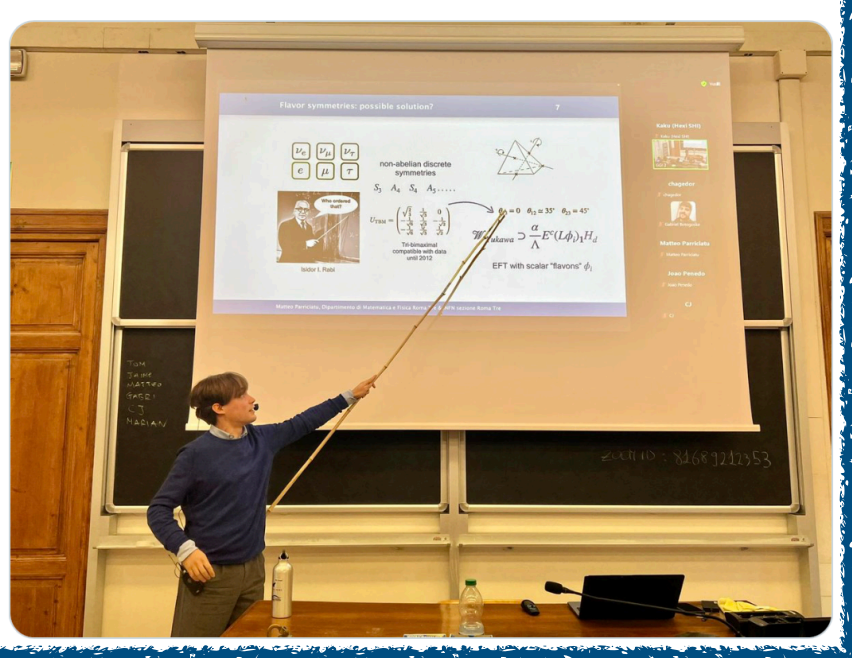
**Roma Tre Neutrino Group** @romatreneutrino · Nov 15, 2024

Roma Tre Neutrino Theory Group is at the Galileo Galilei Institute in Arcetri. Our Matteo Parriciatu and Mirko Rettaroli are attending the school on neutrinoless double beta decay, in which our João Penedo is a tutor lecturer, and Davide Meloni one of the organizers 🙌🙌



**Roma Tre Neutrino Group** @romatreneutrino · Nov 21, 2024

Today our Matteo Parriciatu gave a talk at the Galileo Galilei Institute for theoretical physics (GGI), for the school “Theory Meets Experiment: neutrinoless double beta decay”.
Topic: “Modular Symmetries”.
@MParriciatu #GGI



**Roma Tre Neutrino Group** @romatreneutrino · Oct 3, 2024

Today we had our friend Alessandro Granelli (Università di Bologna) as a guest in Roma Tre! For the occasion, our Simone Marciano (@marciano1219) held a journal club about Axions in Flavour theories 🍷
#physics #romatre

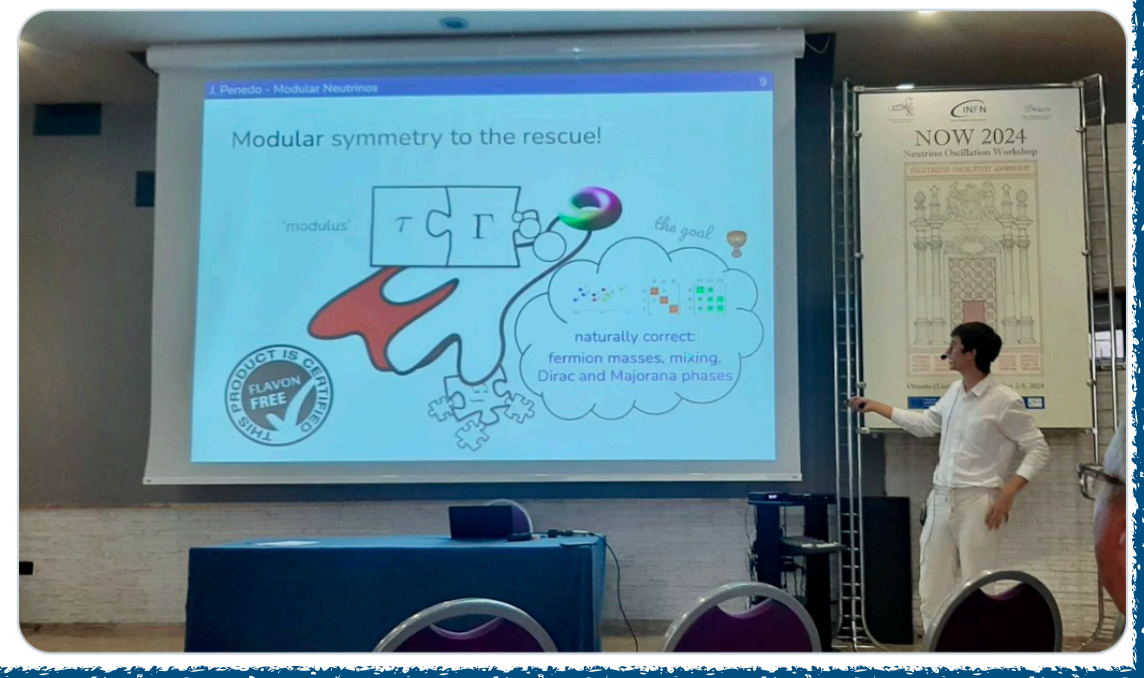


Matteo Parriciatu and Mirko Rettaroli

1 7 11 436

**Roma Tre Neutrino Group** @romatreneutrino · Sep 6, 2024

Today our Joao Penedo gave a talk at the Neutrino Oscillation Workshop (NOW 2024) in Otranto, with the title “Modular neutrinos” 🌟🌟
#physics #neutrinos #now2024



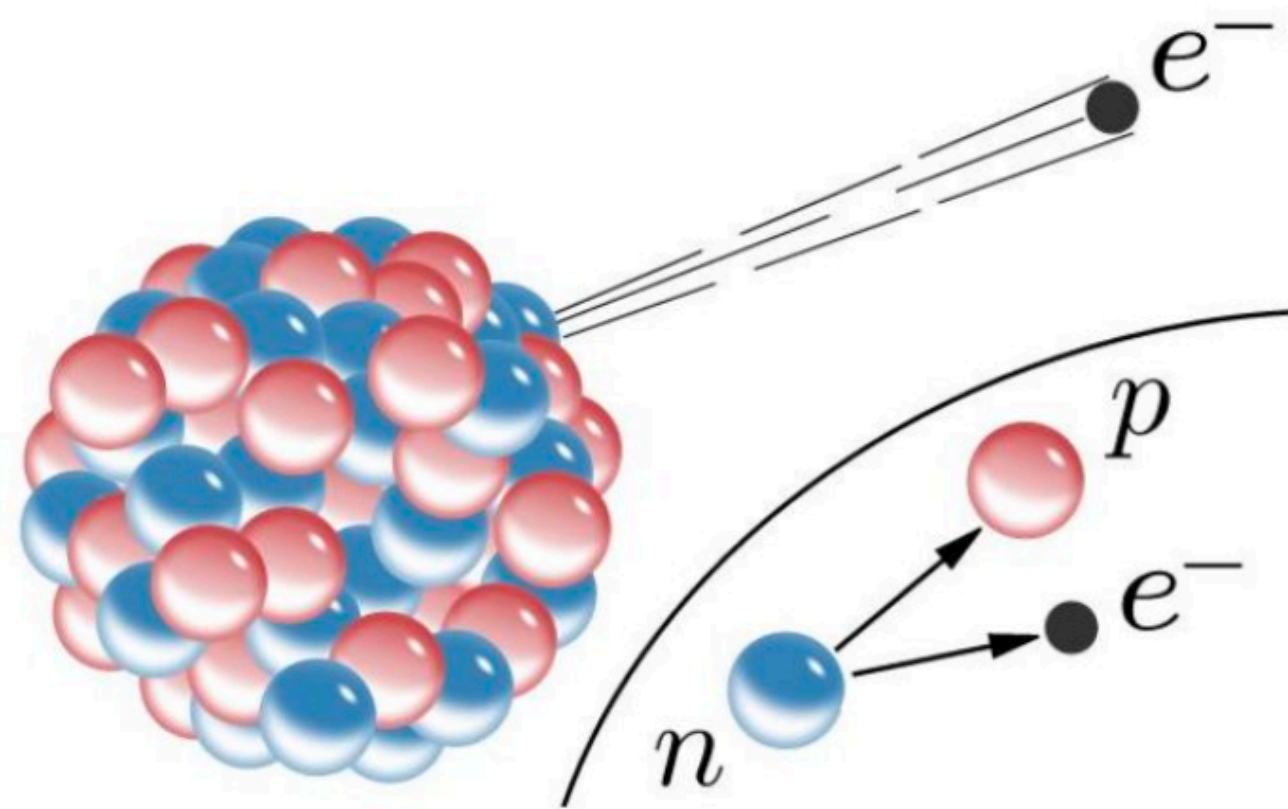
**Roma Tre Neutrino Group** @romatreneutrino · Jul 20, 2024

Today our Alessio Giarnetti gave a talk on behalf of ESSnuSB+ collaboration at ICHEP 2024, in Prague 🌟
Title: “The European Spallation Source neutrino Super Beam plus Project”.
#Physics @ichep2020 @essnusb

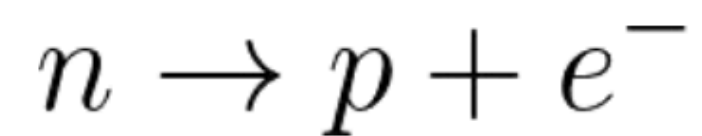


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beta-decay



UNICHE particelle conosciute nei primi anni '30

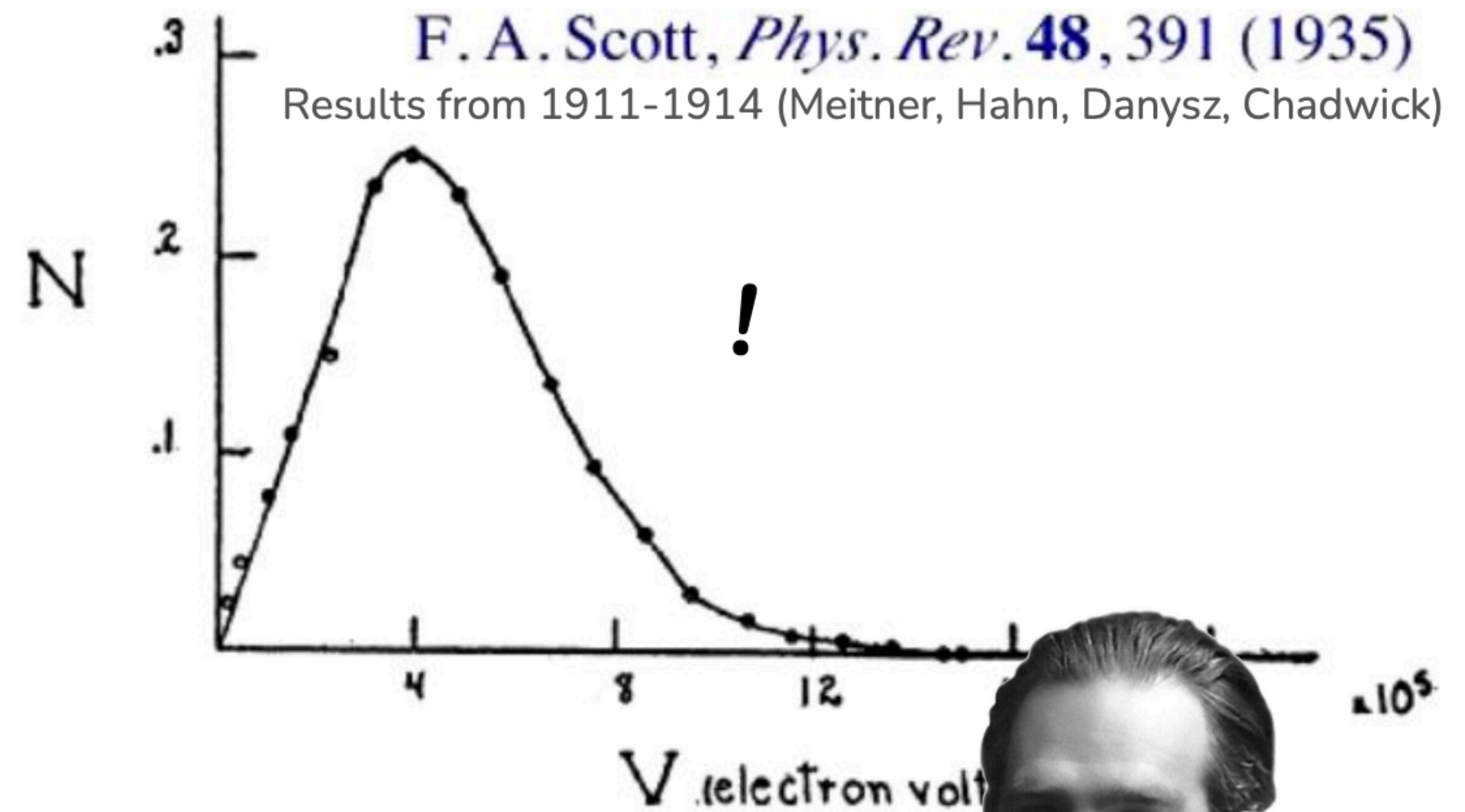
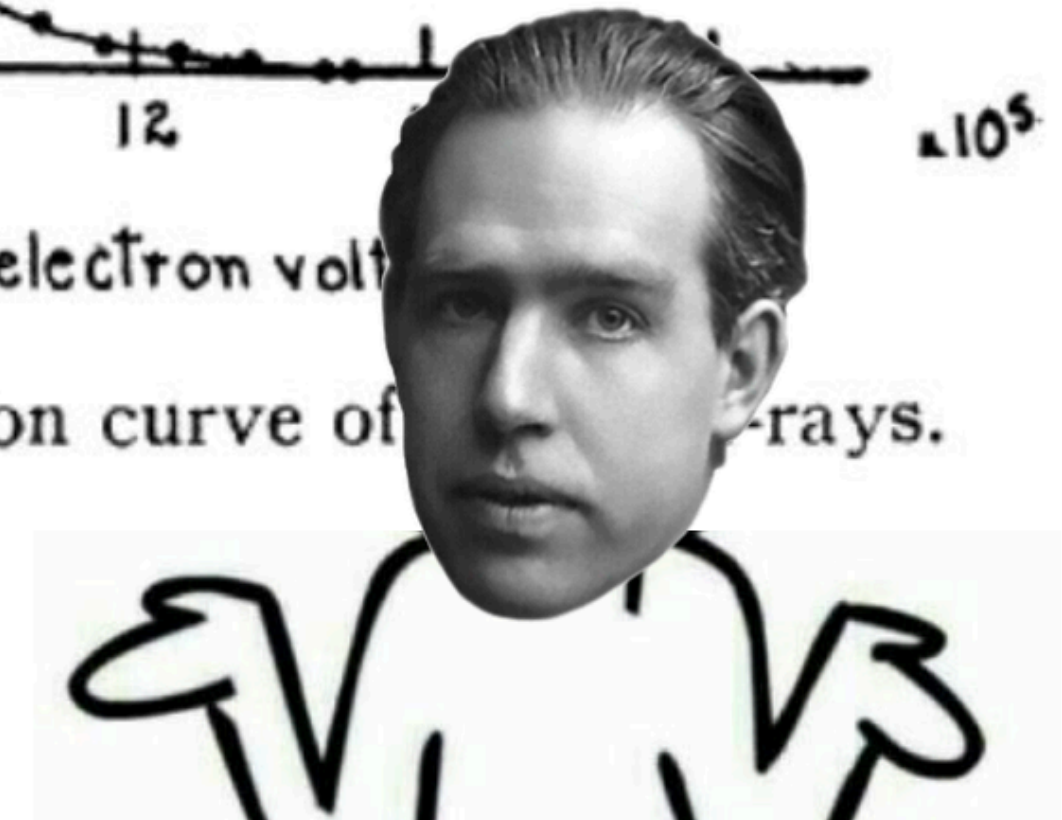
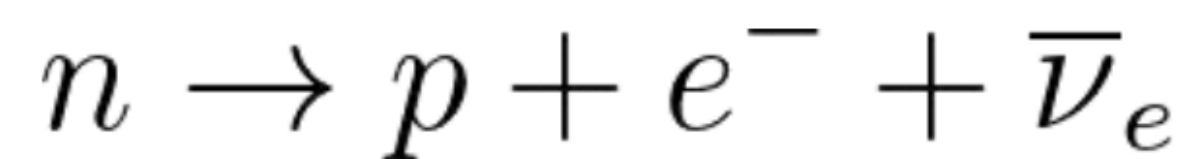
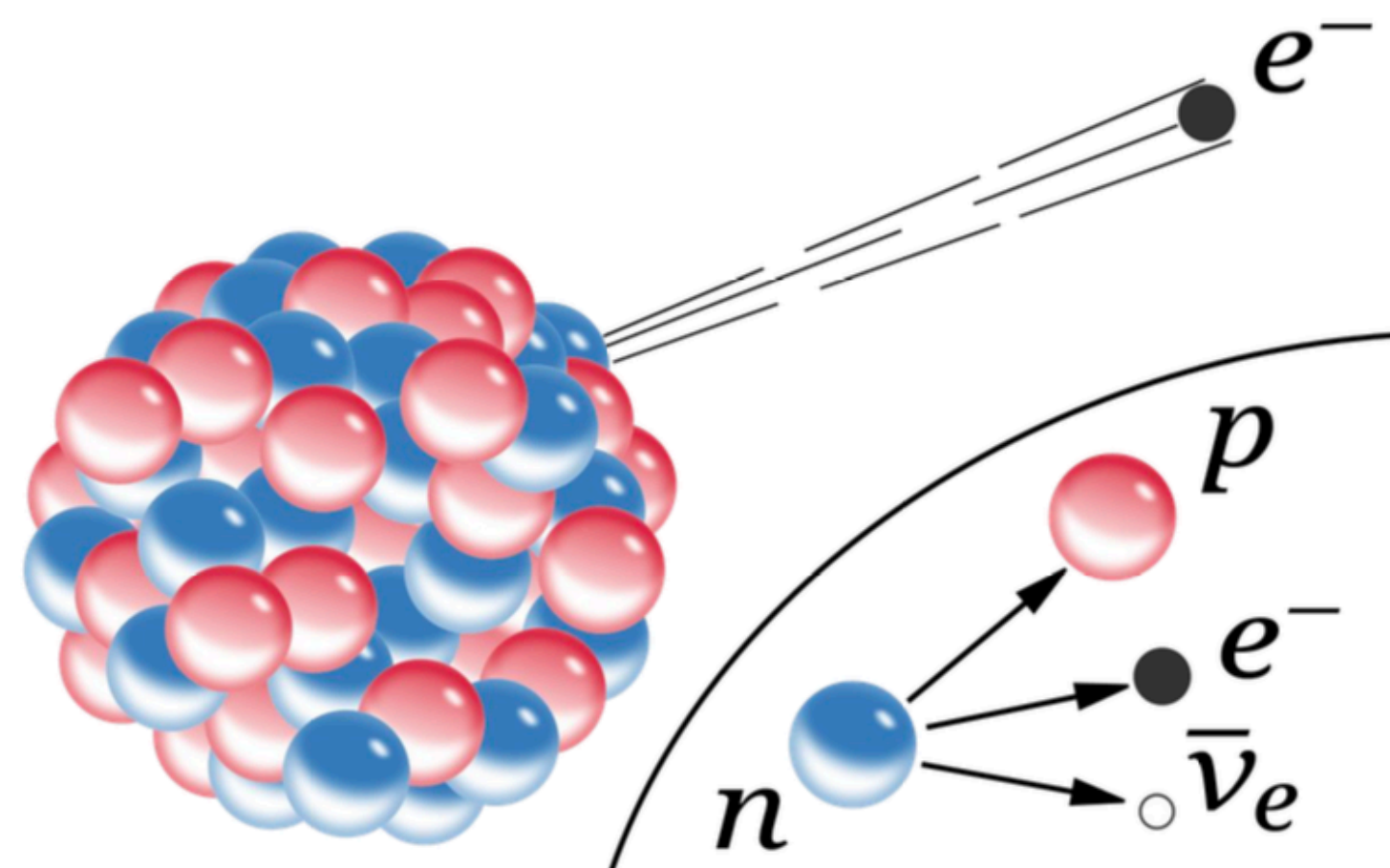


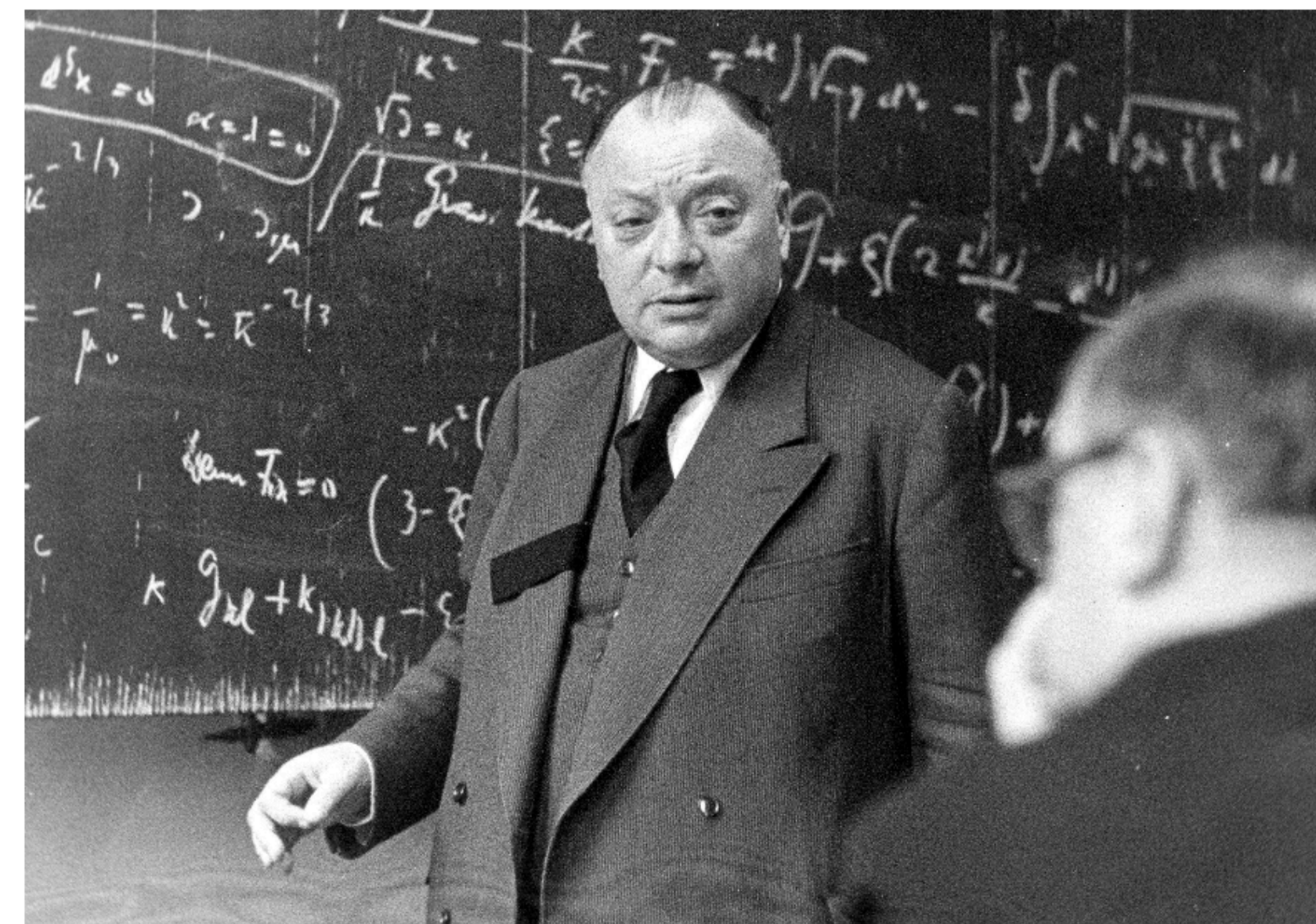
FIG. 5. Energy distribution curve of beta-rays.





Enrico Fermi suggerisce il nome "Neutrino"

Wolfgang Pauli



"Ho fatto una cosa terribile. Ho postulato l'esistenza di una particella che non può essere rilevata."

1934

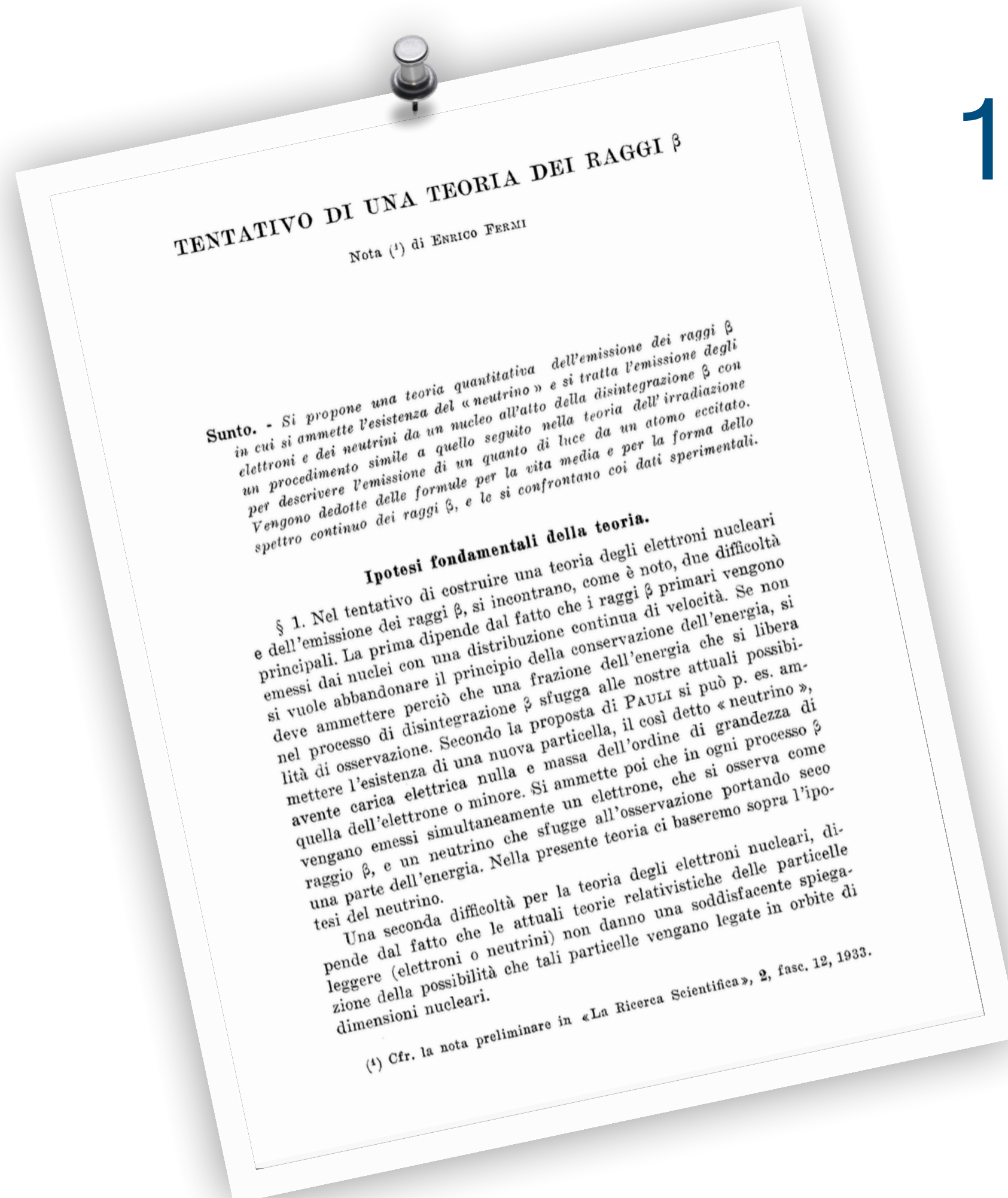
Enrico Fermi



$$m_\nu \rightarrow 0 !!$$

“Il neutrino di Pauli aiuta a spiegare gli spettri dei raggi β ”

Nasce la moderna teoria quantistica dei campi



H. Bethe and R. Peierls,
Nature 133 (1934) 532

where A has the dimension $\text{cm}^2 \text{ sec}$. The longest length and time which can possibly be involved are $\hbar/mc$ and $\hbar/mc^2$. Therefore

$$\sigma < \frac{\hbar^3}{m^3 c^4 t}$$

For an energy of 2.3×10^6 volts, t is 3 minutes and therefore $\sigma < 10^{-44} \text{ cm}^2$ (corresponding to a penetrating power of 10^{16} km . in solid matter). It is therefore absolutely impossible to observe processes of this kind with the neutrinos created in nuclear transformations.

With increasing energy, σ increases (in Fermi's model³ for large energies as $(E/mc^2)^2$) but even if one assumes a very steep increase, it seems highly improbable that, even for cosmic ray energies, σ becomes large enough to allow the process to be observed.

If, therefore, the neutrino has no interaction with other particles besides the processes of creation and annihilation mentioned—and it is not necessary to assume interaction in order to explain the function of the neutrino in nuclear transformations—one can conclude that there is no practically possible way of observing the neutrino.

Physical Laboratory,
University,
Manchester.
Feb. 20.

H. BETHE.
R. PEIERLS.

Particelle fantasma



$$\sigma \sim 6 \times 10^{-44} \text{ cm}^2$$

mean free path of a
few-MeV neutrino in lead?

~1 light-year!

Direct detection of a neutrino
Cowan-Reines experiment (1956)



(1995)

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

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



(1988)

Muon neutrino (1962)
Lederman, Schwartz,
Steinberger

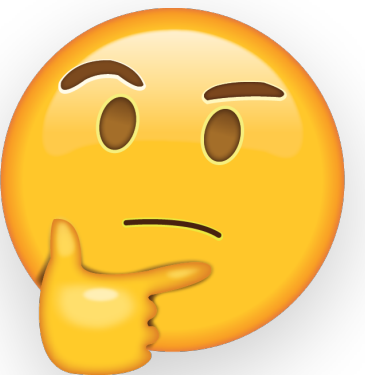
Tau neutrino (2000)
DONUT collaboration

TRE SAPORI DIVERSI



“Muone e Tau: i cugini pesanti dell’elettrone”

$$m_e/m_\mu \simeq \frac{1}{200} \quad m_\mu/m_\tau \simeq \frac{1}{17}$$

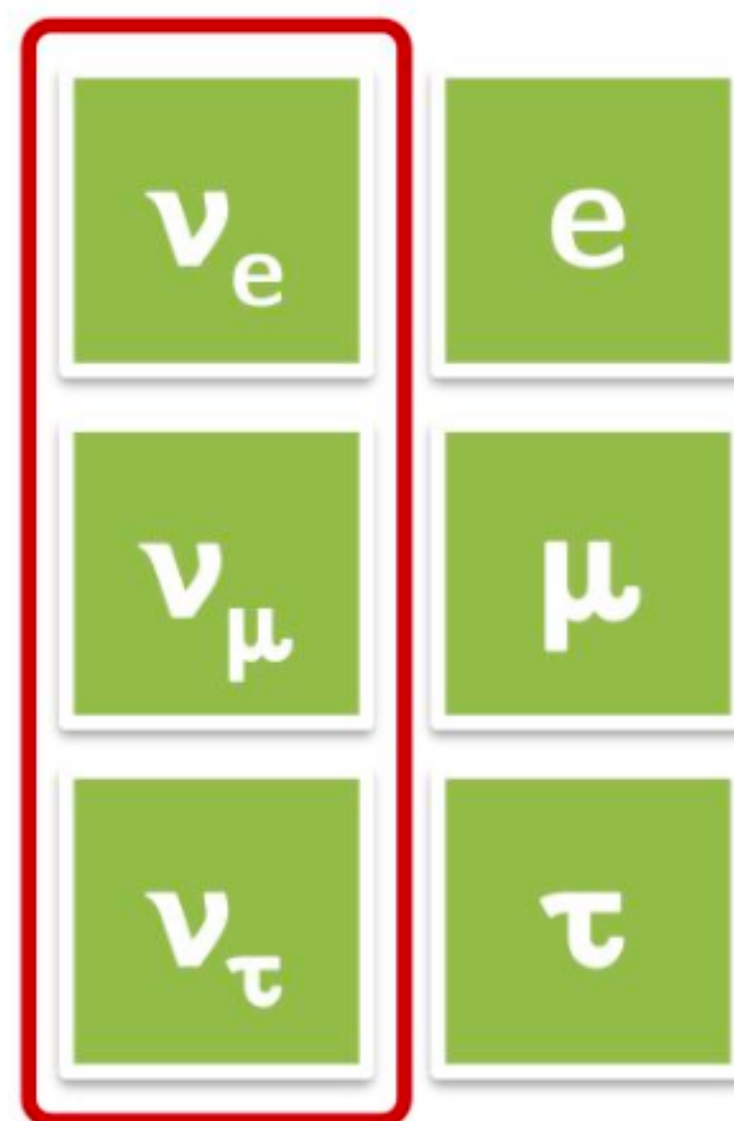


Direct detection of a neutrino
Cowan-Reines experiment (1956)



(1995)

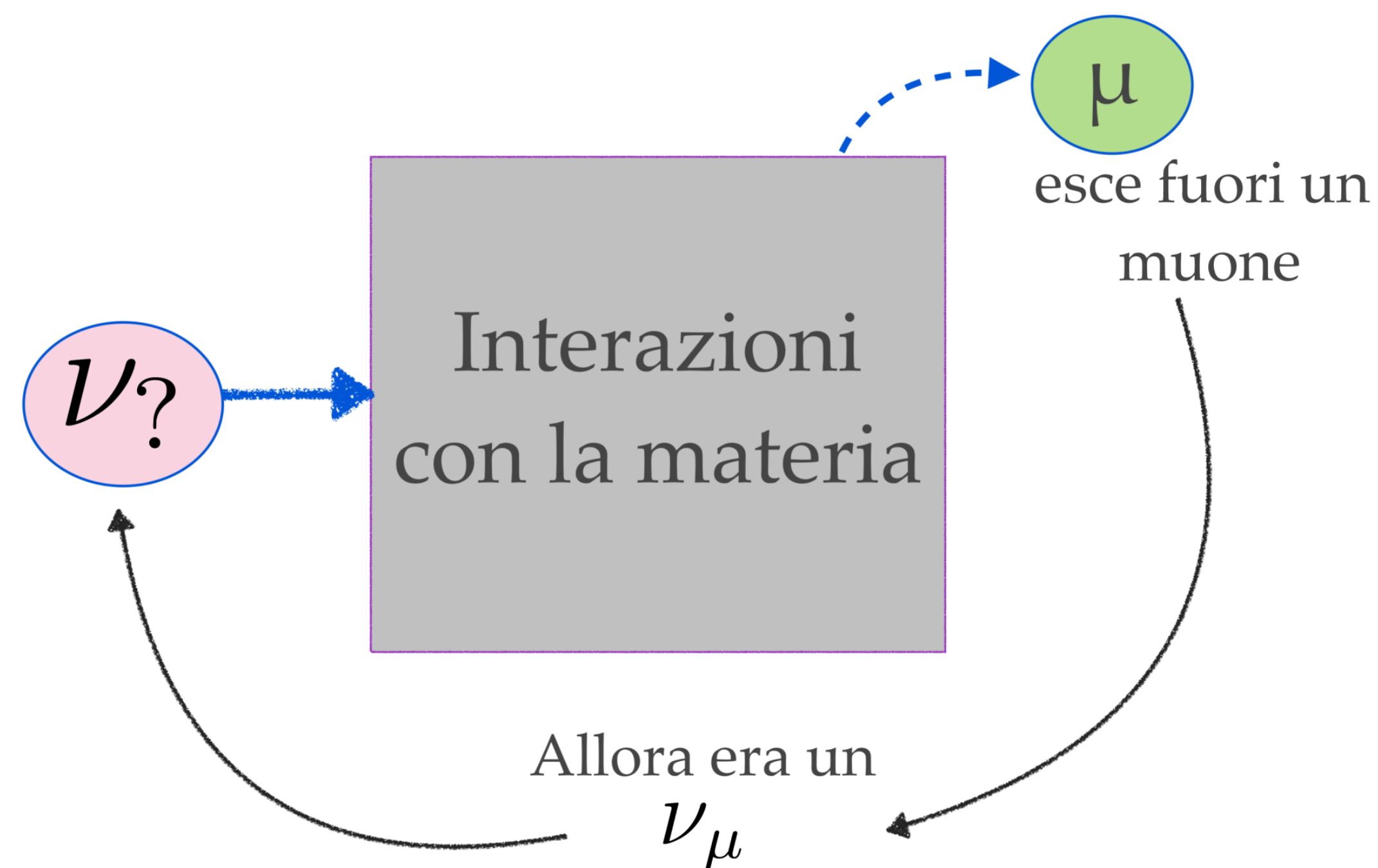
TRE SAPORI DIVERSI



(1988)

Muon neutrino (1962)
*Lederman, Schwartz,
Steinberger*

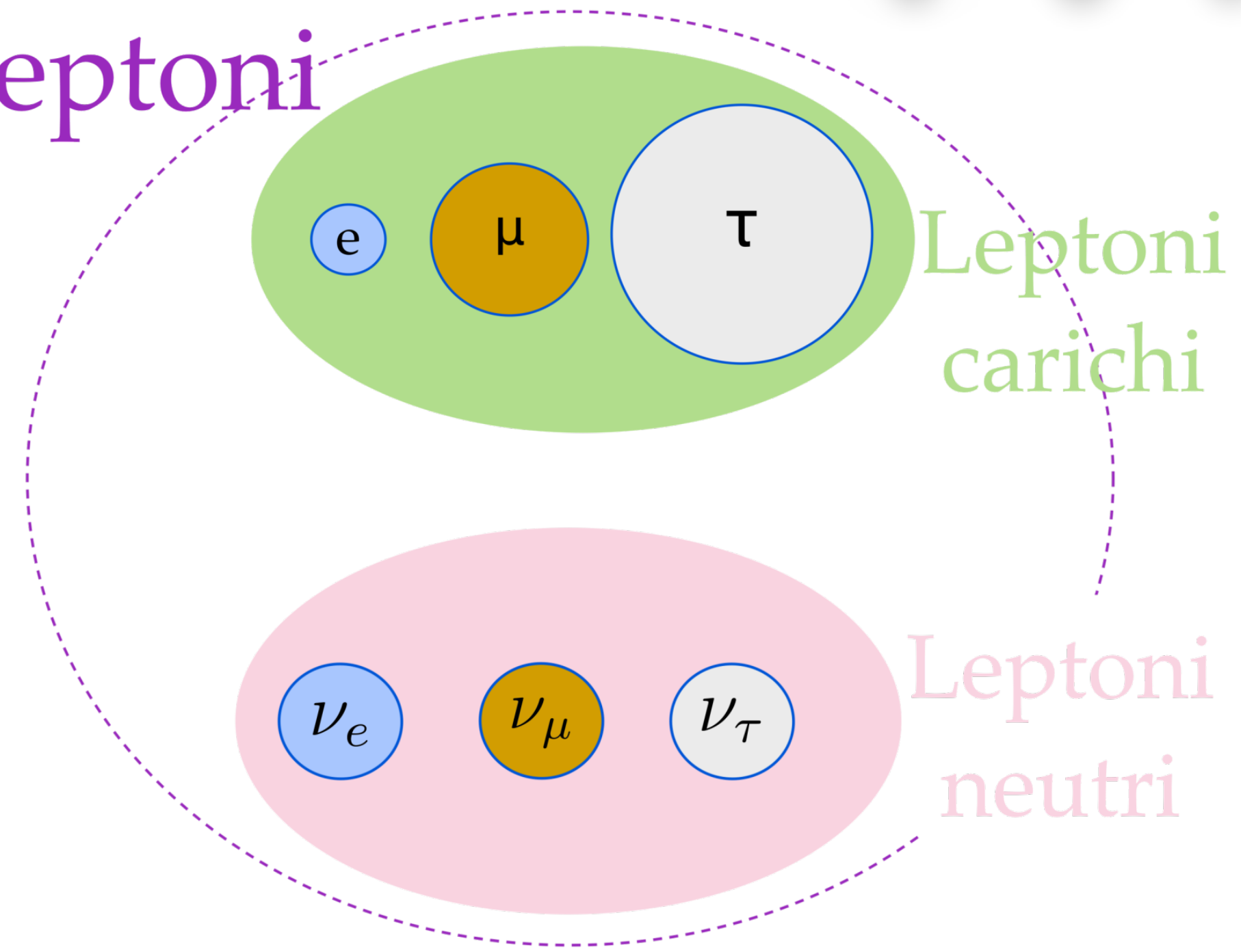
Tau neutrino (2000)
DONUT collaboration



TRE SAPORI DIVERSI



Leptoni



Oscillazioni dei neutrini: possono
cambiare sapore mentre si propagano!

$$m_\nu = 0 ?$$



Bruno Pontecorvo

Oscillazione di sapore



$$\underbrace{|\nu_\alpha\rangle}_{\text{Interaction basis}} = \sum_{i=1}^3 U_{\alpha i}^* \underbrace{|\nu_i\rangle}_{\text{Mass basis}}$$

Oscillazioni dei neutrini: possono cambiare sapore mentre si propagano!

$$m_\nu \neq 0 ?$$

$$|\nu_e\rangle = U_{e1}^* |\nu_1\rangle + U_{e2}^* |\nu_2\rangle + U_{e3}^* |\nu_3\rangle$$

$$|\nu_\mu\rangle = U_{\mu 1}^* |\nu_1\rangle + U_{\mu 2}^* |\nu_2\rangle + U_{\mu 3}^* |\nu_3\rangle$$

$$|\nu_\tau\rangle = U_{\tau 1}^* |\nu_1\rangle + U_{\tau 2}^* |\nu_2\rangle + U_{\tau 3}^* |\nu_3\rangle$$

$U_{\alpha i} \rightarrow$ matrice che diagonalizza le masse dei neutrini

$$\underbrace{|\nu_\alpha\rangle}_{\text{Interaction basis}} = \sum_{i=1}^3 U_{\alpha i}^* \underbrace{|\nu_i\rangle}_{\text{Mass basis}}$$

$$\begin{pmatrix} \theta_{12} & \theta_{13} \\ \delta_{CP} & \theta_{23} \end{pmatrix}$$

Pontecorvo - Maki - Nakagawa - Sakata

$$U_{\text{PMNS}} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta_{CP}} \\ -s_{12}c_{23} - c_{12}s_{13}s_{23}e^{i\delta_{CP}} & c_{12}c_{23} - s_{12}s_{13}s_{23}e^{i\delta_{CP}} & c_{13}s_{23} \\ s_{12}s_{23} - c_{12}s_{13}c_{23}e^{i\delta_{CP}} & -c_{12}s_{23} - s_{12}s_{13}c_{23}e^{i\delta_{CP}} & c_{13}c_{23} \end{pmatrix}$$

$$c_{ij} \equiv \cos \theta_{ij}, \quad s_{ij} \equiv \sin \theta_{ij}$$

Oscillazioni dei neutrini: possono
cambiare sapore mentre si propagano!

$$m_\nu = 0 ?$$

$$P_{\nu_e \rightarrow \nu_\mu} = \sin^2(2\theta) \sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

Oscillazioni dei neutrini rilevata a
40 σ !!!

$$\Delta m^2 \neq 0$$

Devono essere massivi
almeno due neutrini su tre!!!

Oscillazioni dei neutrini rilevata a
 40σ !!!

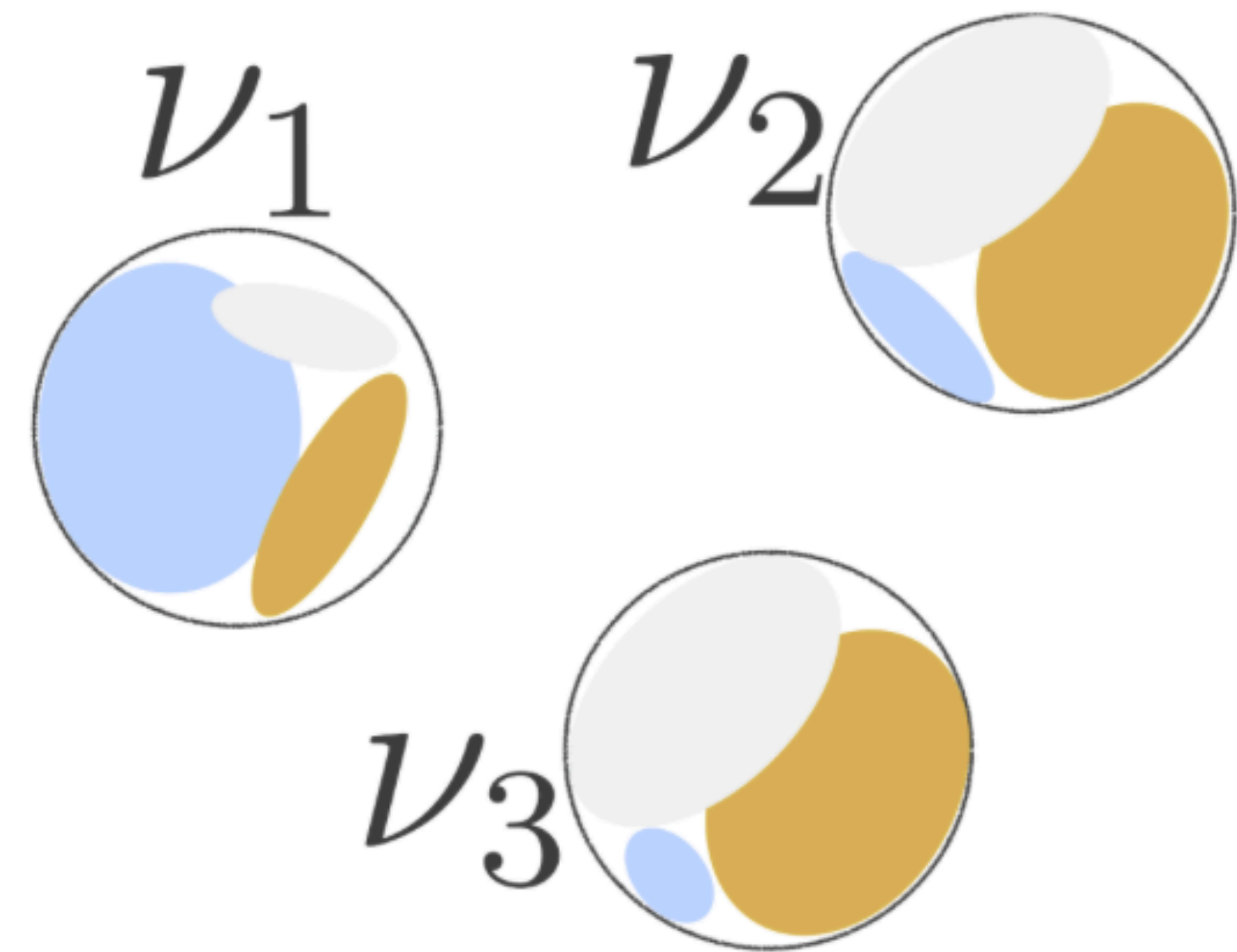
$$\Delta m^2 \neq 0$$

Devono essere massivi
almeno due neutrini su tre!!!

$$|\nu_e\rangle = U_{e1}^* |\nu_1\rangle + U_{e2}^* |\nu_2\rangle + U_{e3}^* |\nu_3\rangle$$

$$|\nu_\mu\rangle = U_{\mu 1}^* |\nu_1\rangle + U_{\mu 2}^* |\nu_2\rangle + U_{\mu 3}^* |\nu_3\rangle$$

$$|\nu_\tau\rangle = U_{\tau 1}^* |\nu_1\rangle + U_{\tau 2}^* |\nu_2\rangle + U_{\tau 3}^* |\nu_3\rangle$$

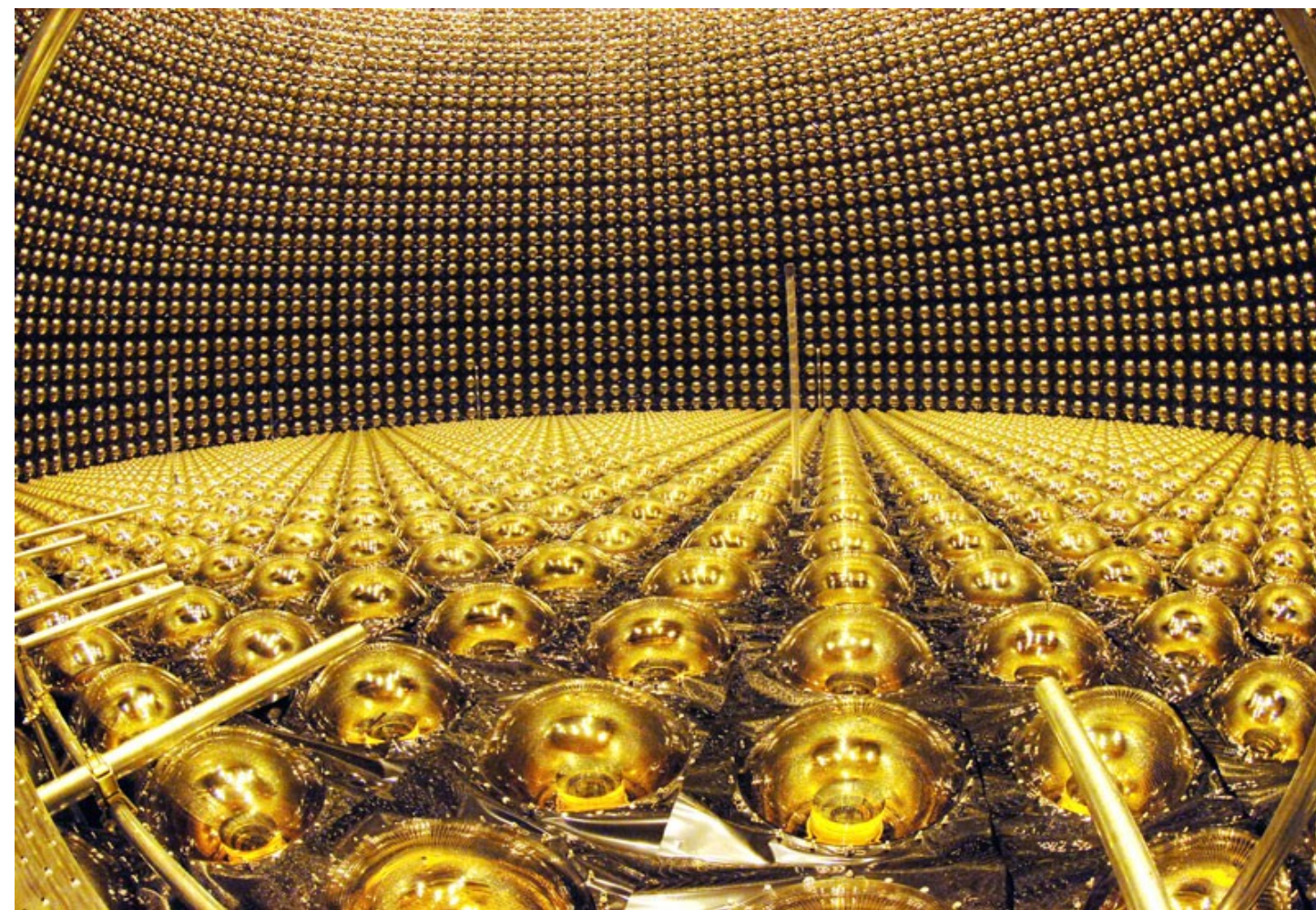


*Gli autostati di massa dei neutrini con al loro interno il
mixing dei sapori.*

Celeste: ν_e , Marroncino: ν_μ , Grigio: ν_τ .

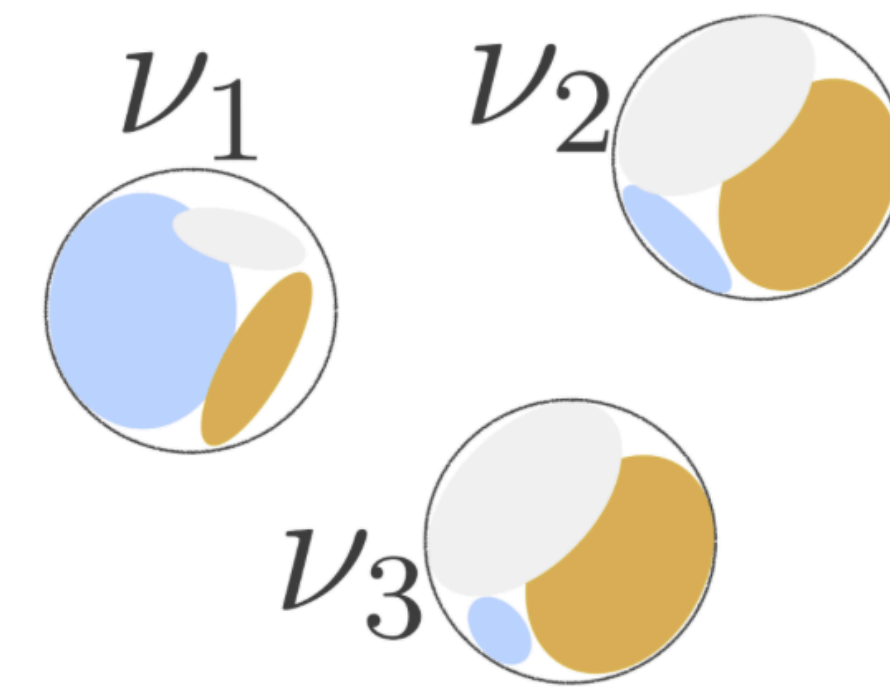
Oscillazioni dei neutrini rilevata a 40σ !!!

Scoperta delle oscillazioni dei
neutrini (1998)

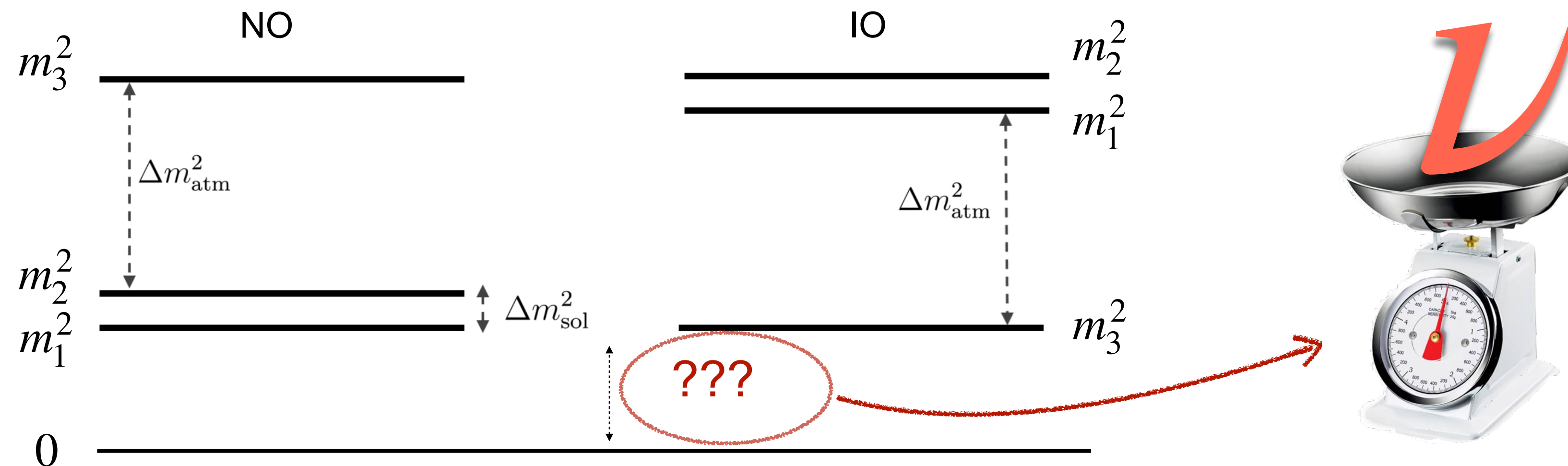


(Super-kamiokande)
(2015)

Kajita, McDonald

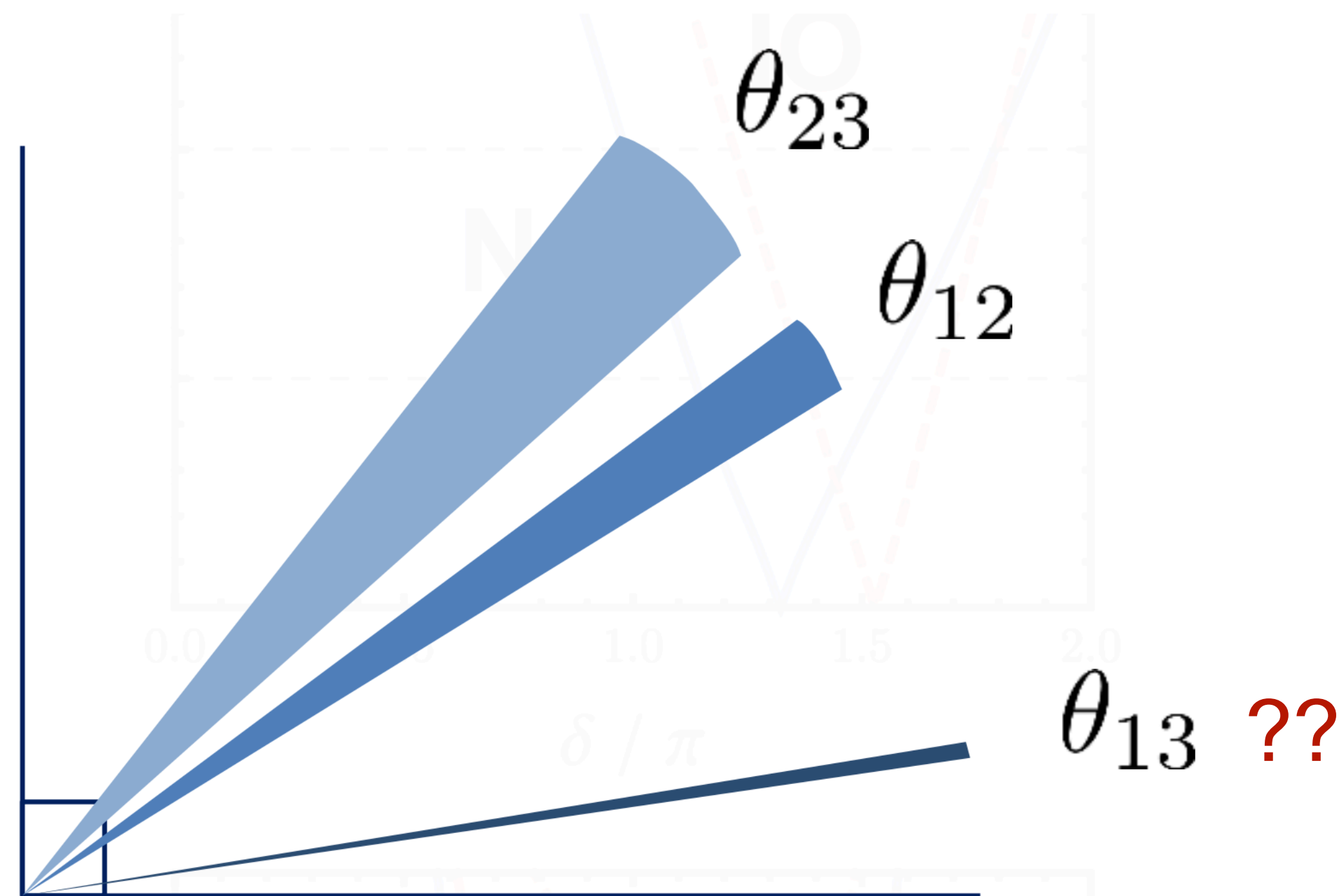
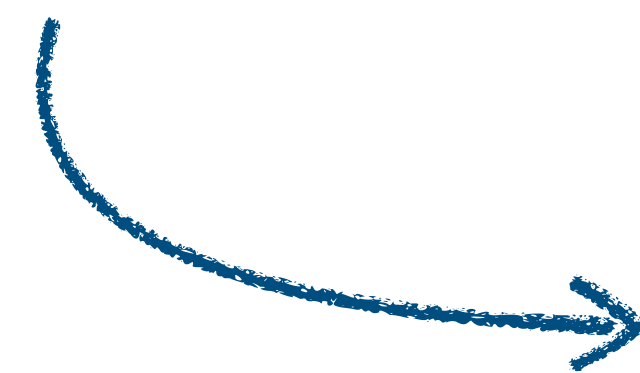


I misteri dei neutrini



I misteri dei neutrini

Dai dati sperimentali



Nel Modello Standard i neutrini non hanno massa

(electroweak part of the Lagrangian)

$$\mathcal{L}_{\text{SM}} = (D^\mu \phi)^\dagger (D_\mu \phi) - V(\phi) - \frac{1}{4} A_{\mu\nu}^i A^{i\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu}$$

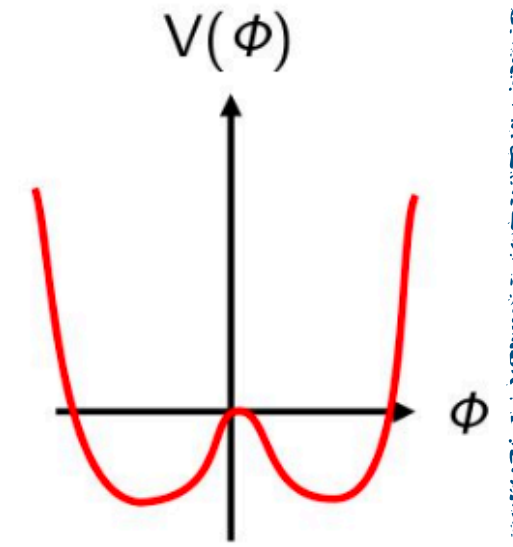
“Higgs field exists” “W, Z, γ exist (W and Z have mass)”

$$+ i \bar{\ell}_{\alpha L} \not{D} \ell_{\alpha L} + i \bar{q}_{\alpha L} \not{D} q_{\alpha L} + i \bar{l}_{\alpha R} \not{D} l_{\alpha R} + i \bar{u}_{\alpha R} \not{D} u_{\alpha R} + i \bar{d}_{\alpha R} \not{D} d_{\alpha R}$$

“electrons, neutrinos and quarks exist”

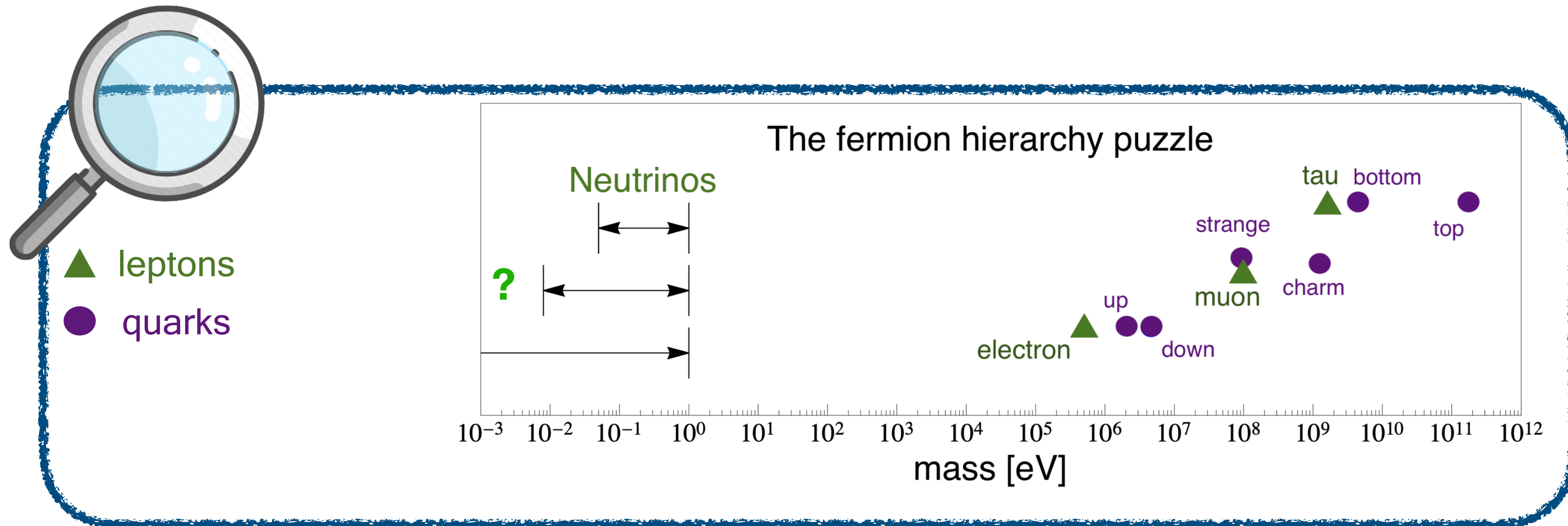
$$- (\mathbf{Y}_{\alpha\beta}^l \bar{\ell}_{\alpha L} \phi l_{\beta R} + \text{H.c.}) - (\mathbf{Y}_{\alpha\beta}^u \bar{q}_{\alpha L} \tilde{\phi} u_{\beta R} + \text{H.c.}) - (\mathbf{Y}_{\alpha\beta}^d \bar{q}_{\alpha L} \phi d_{\beta R} + \text{H.c.}).$$

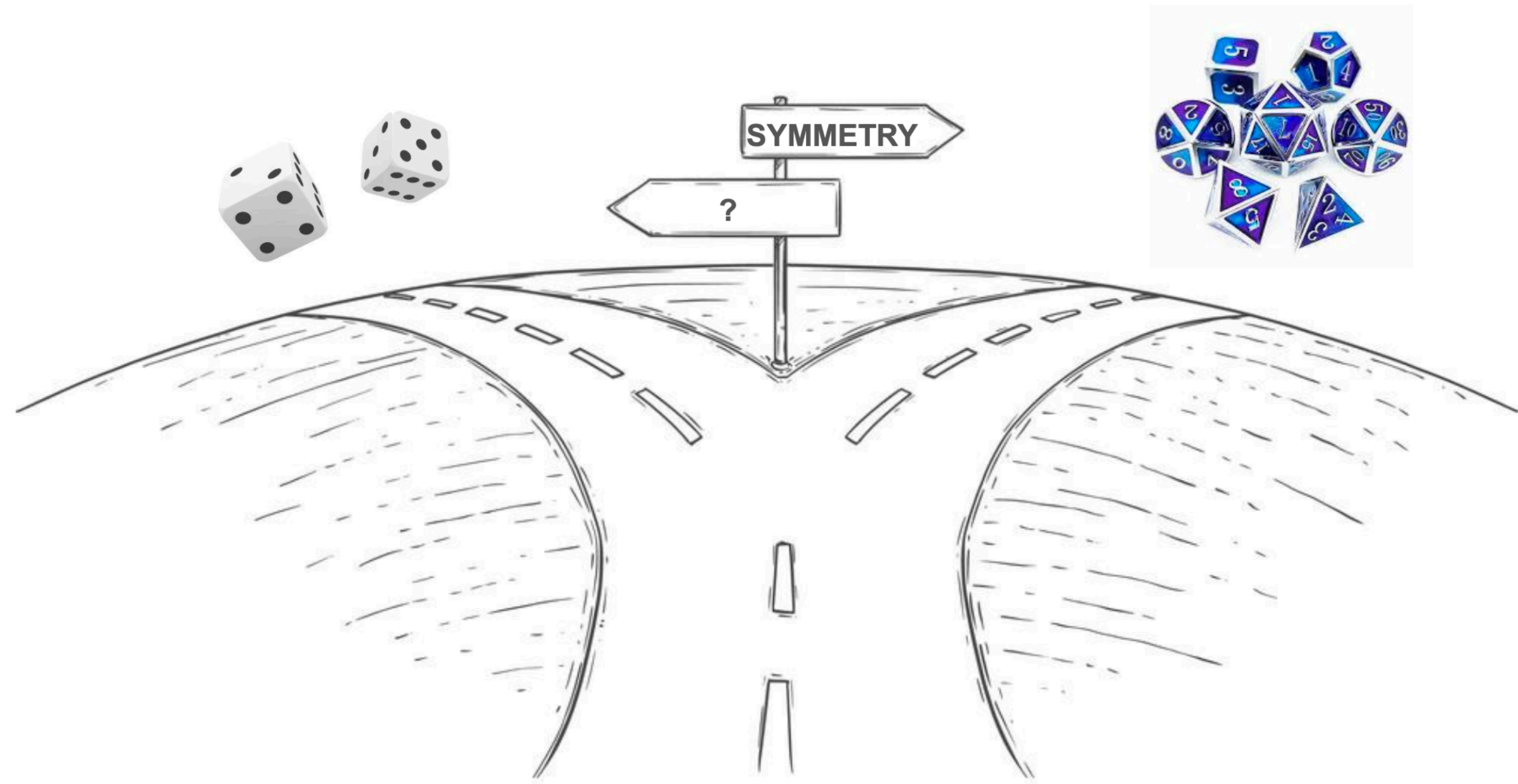
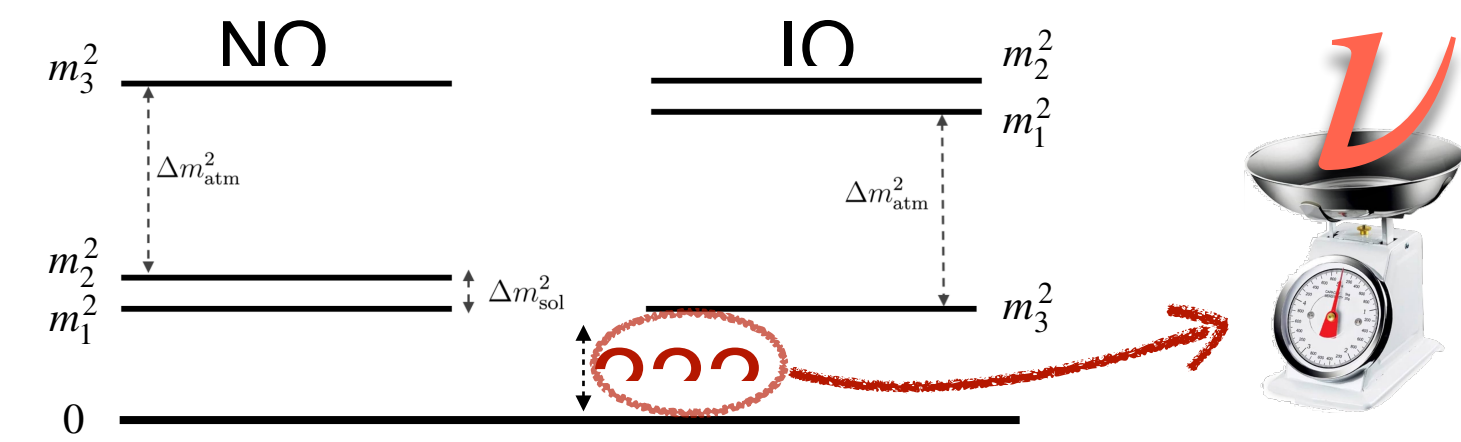
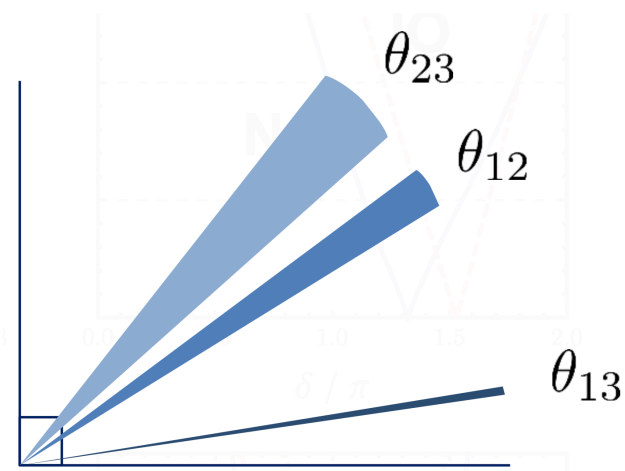
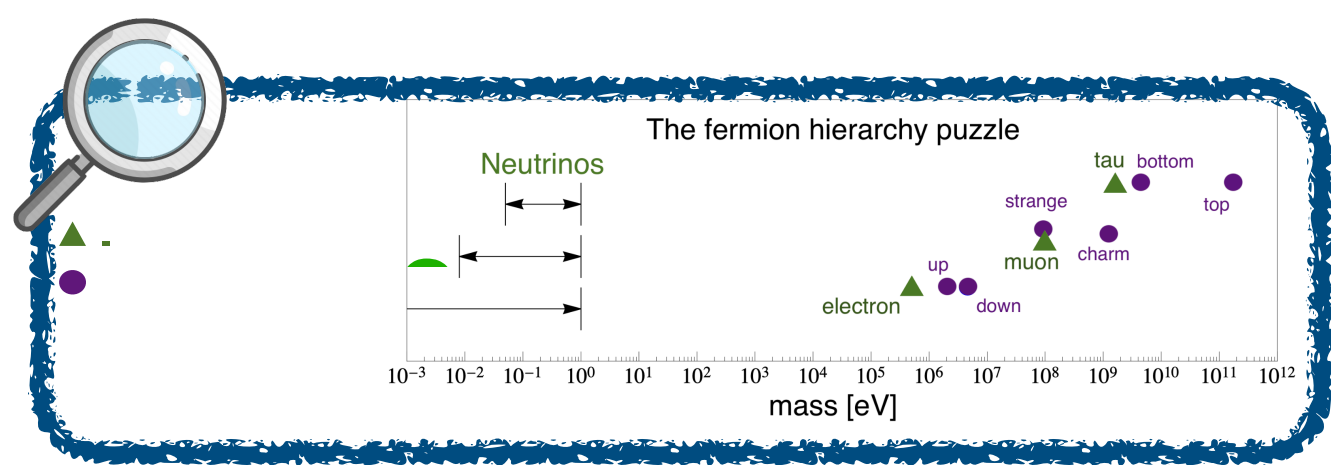
“electrons and quarks have a (Dirac-type) mass”

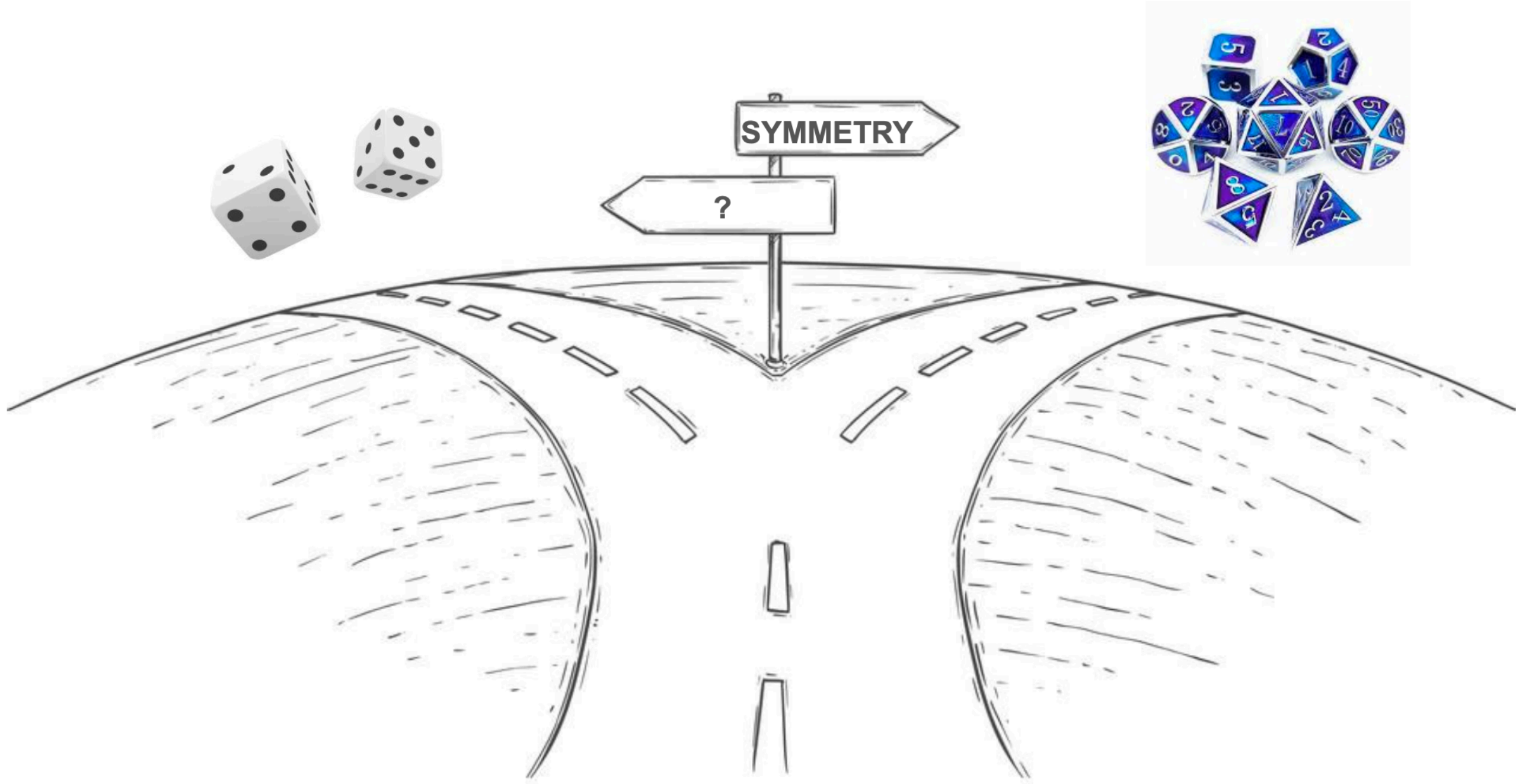
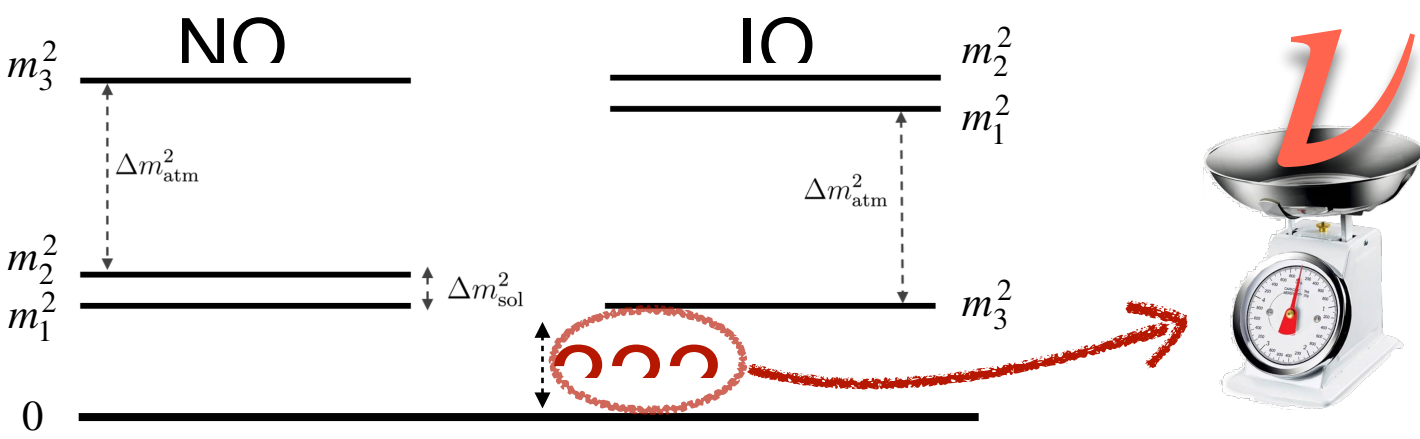
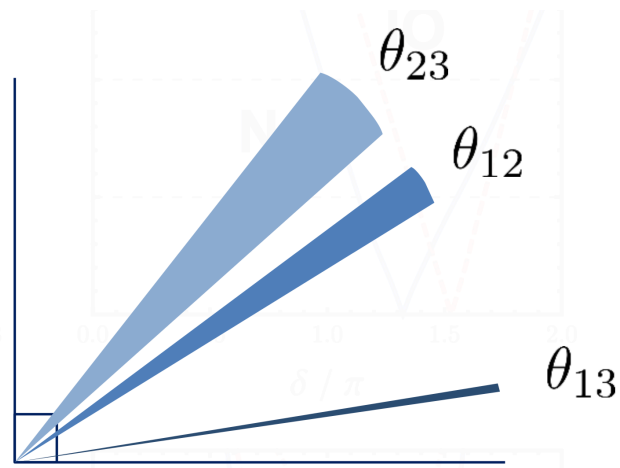
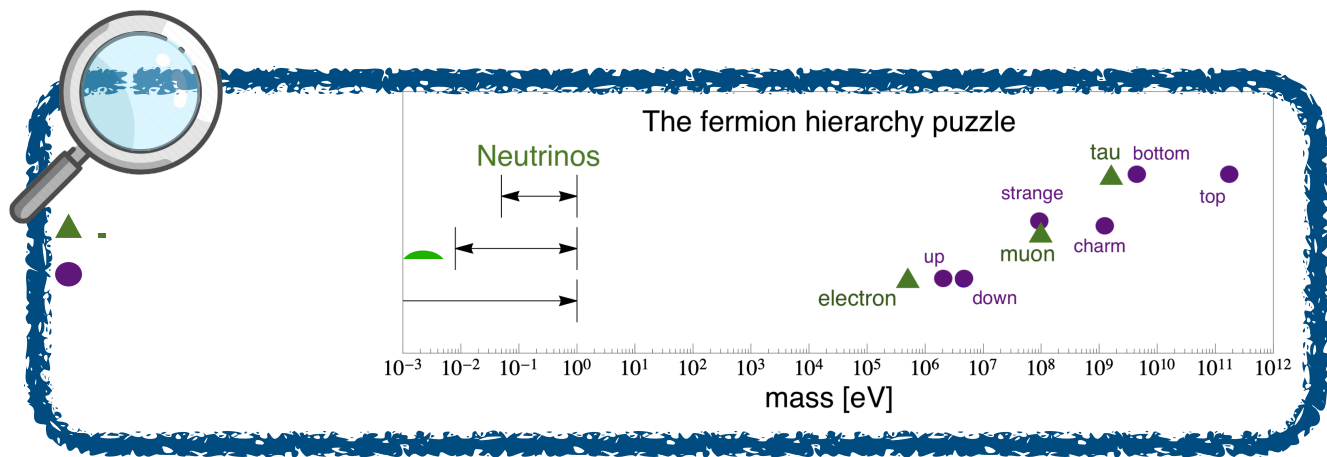


$m_\nu \neq 0 \longrightarrow$ Nuova fisica!

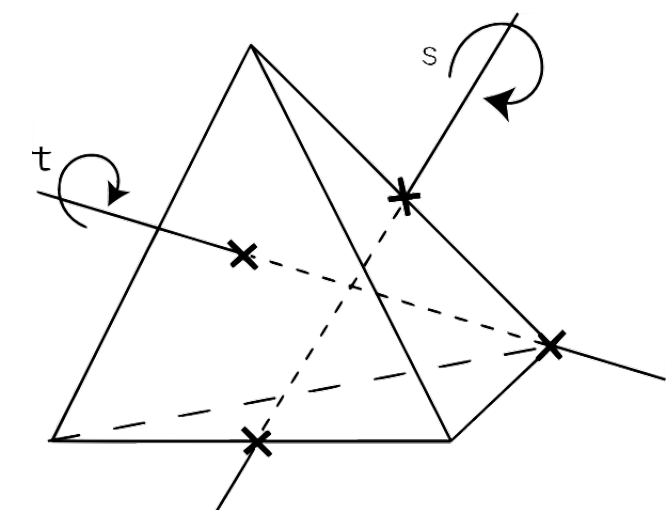
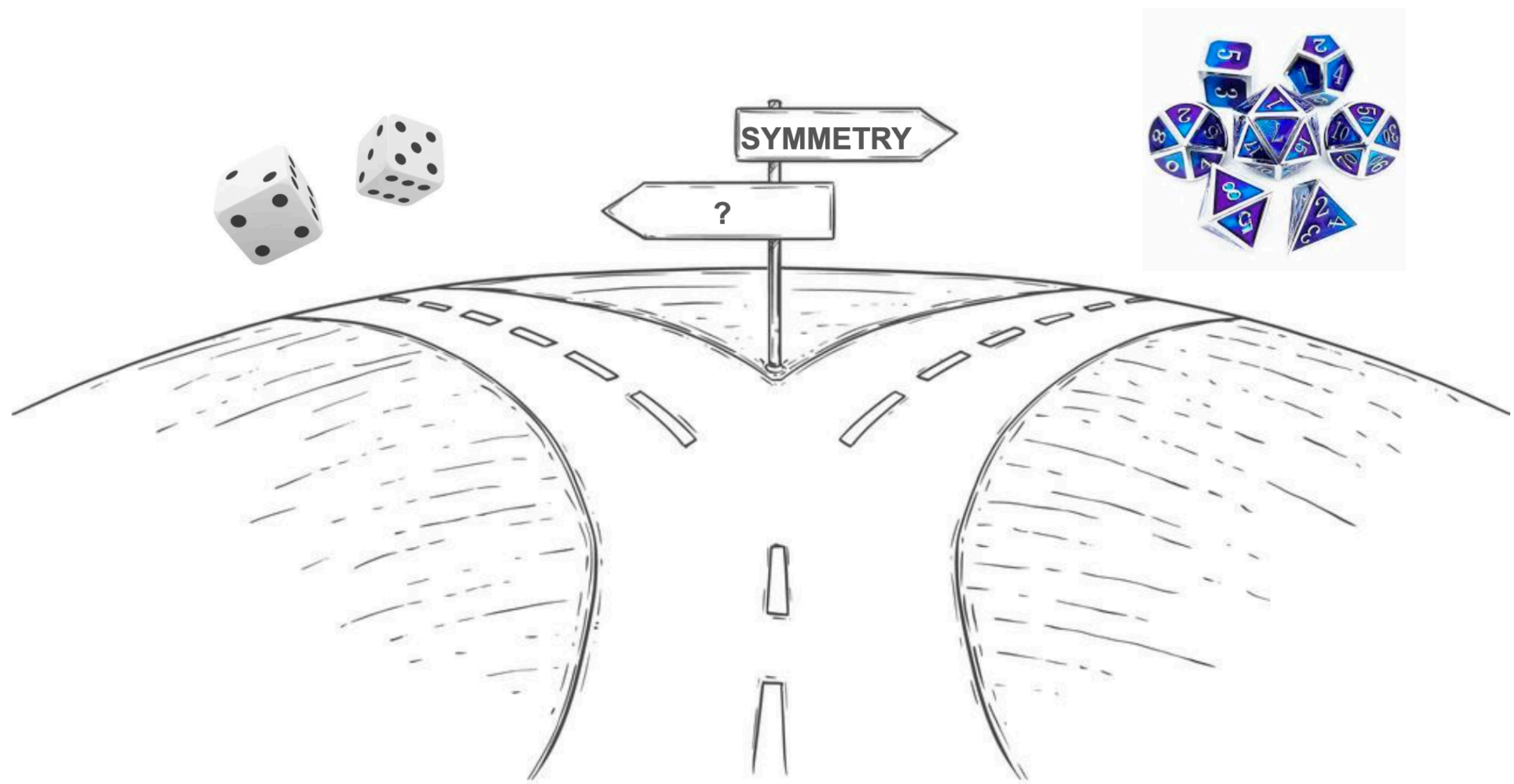
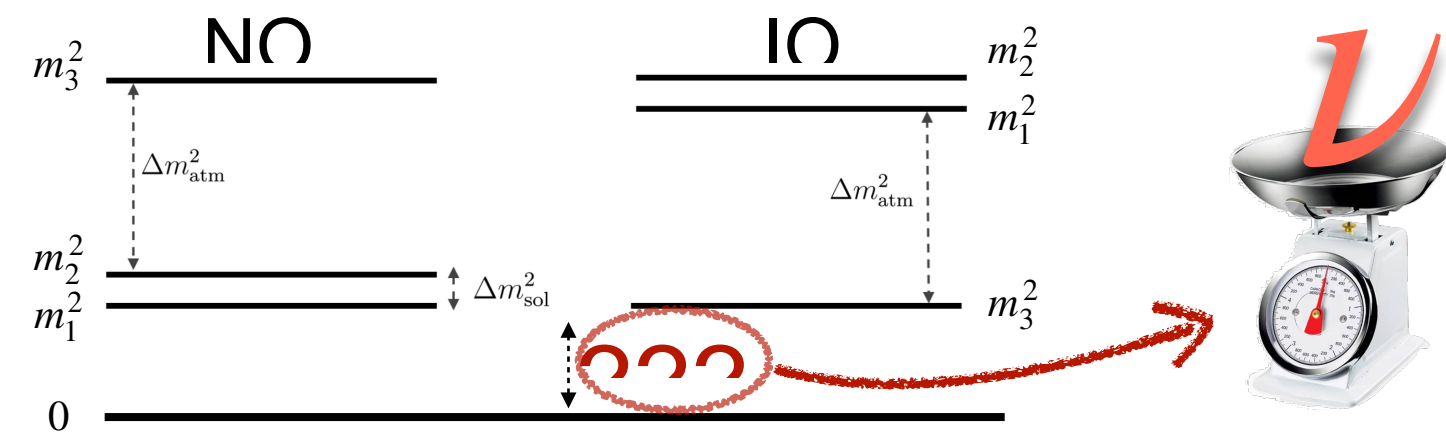
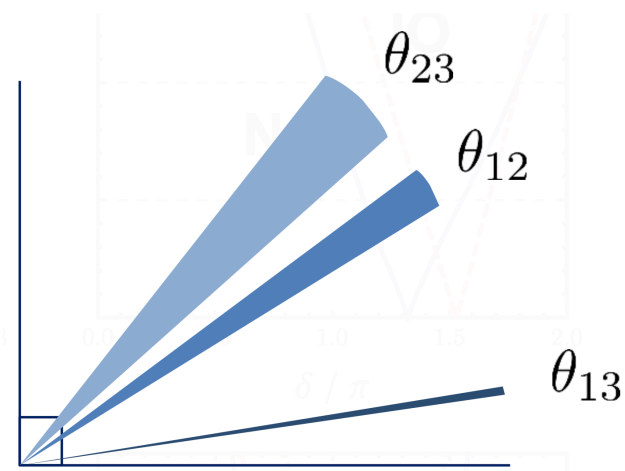
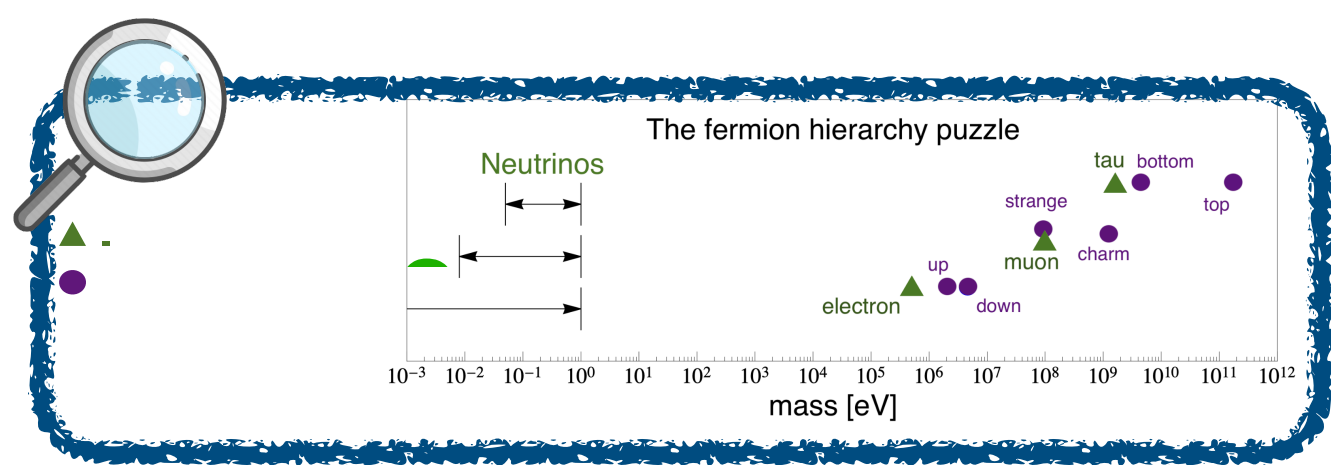
(Vedi) Talk di Mirko Rettaroli







Roma Tre
Neutrino
Theory
Group



(Vedi) Talk di Marco Carducci

(Vedi) Talk di Gabriele Battimelli

Grazie per l'attenzione

Roma Tre
Neutrino  Group

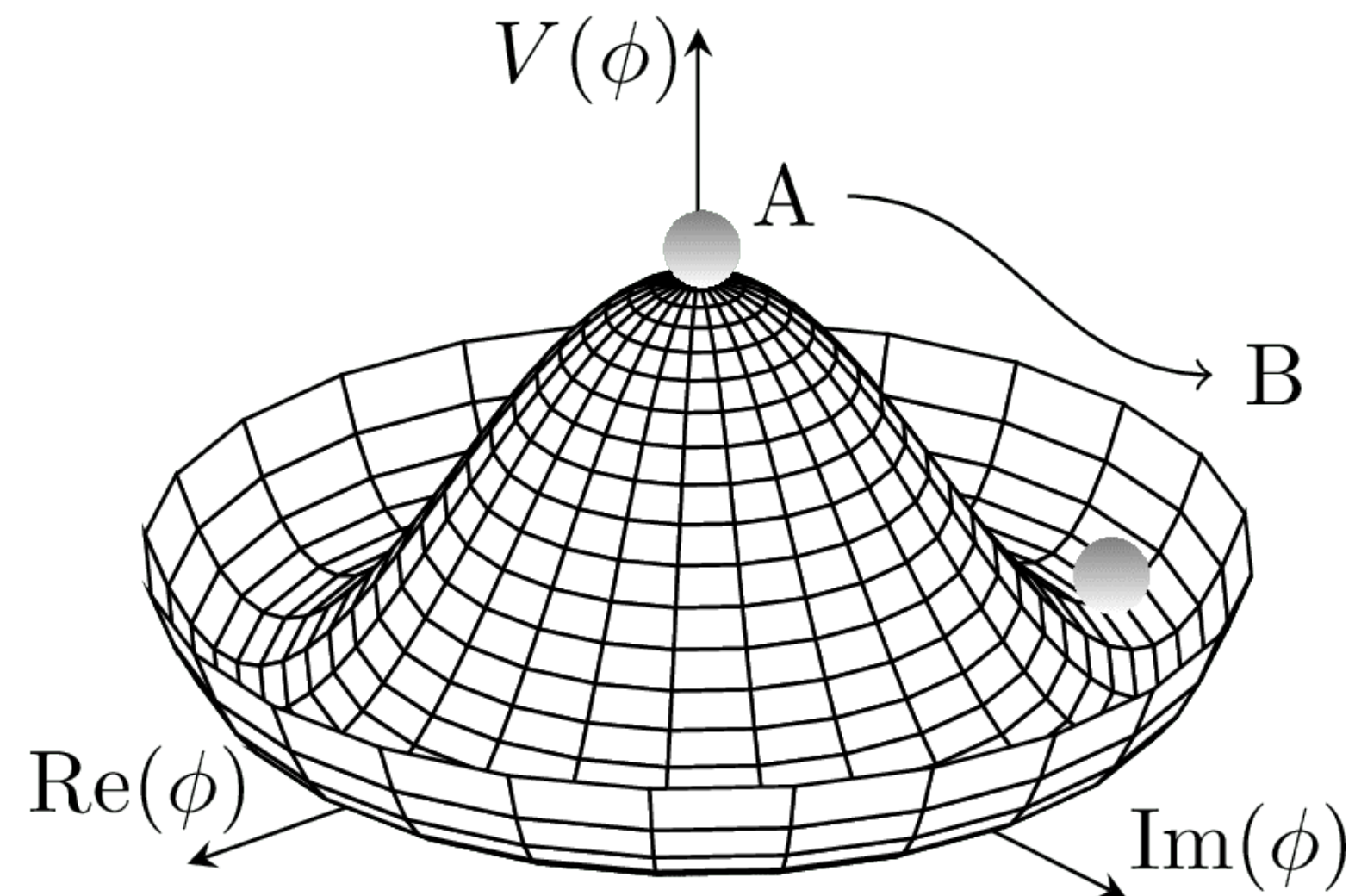
SCAN ME



BACKUP SLIDES

Termine di massa nel Modello Standard

Campo di Higgs fornisce la massa



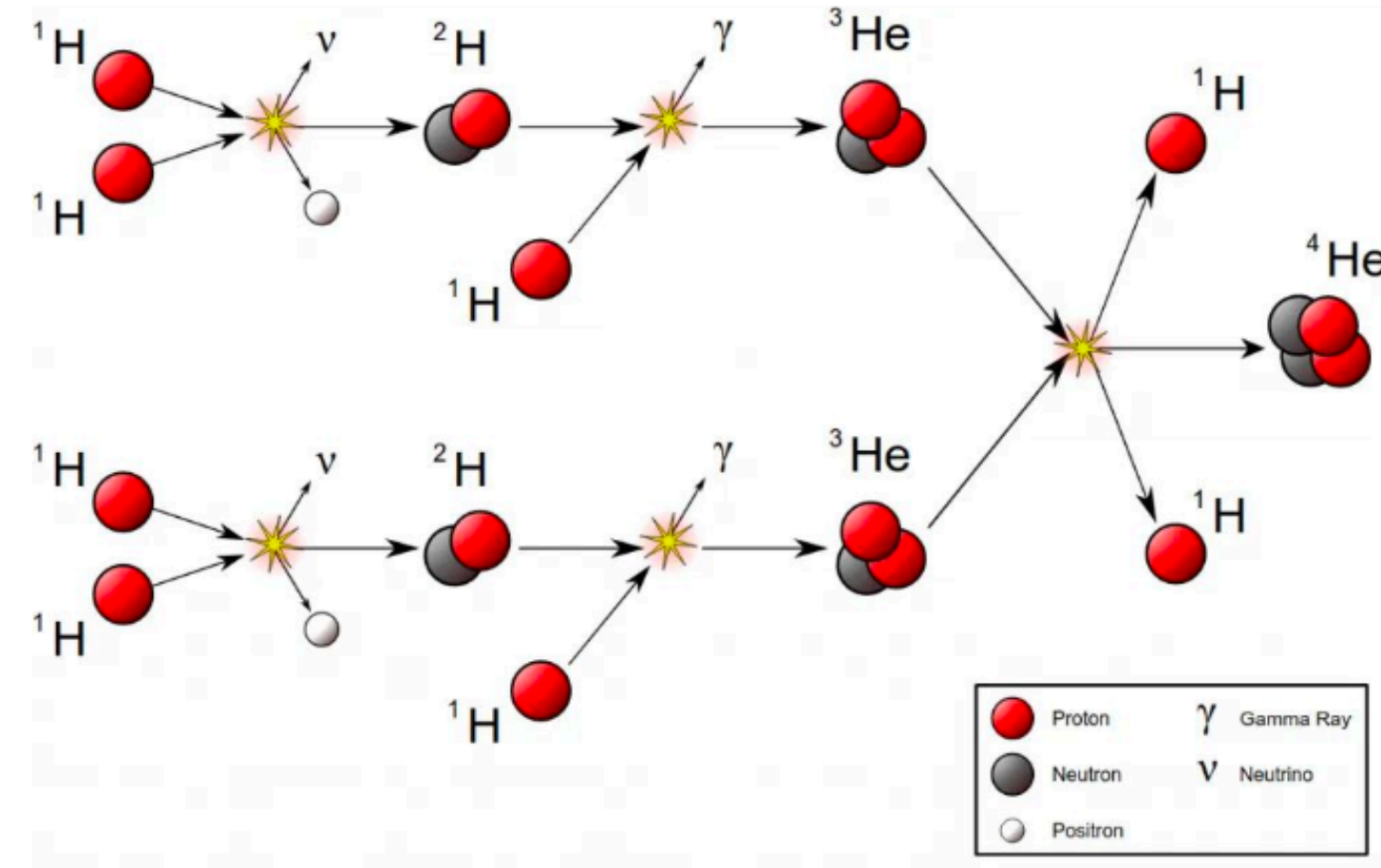
$$y_e \bar{e}_L H e_R$$



$$m_e \bar{e}_L e_R$$

Nel Modello Standard la chiralità
destra ν_R dei neutrini è
completamente
non-rilevabile

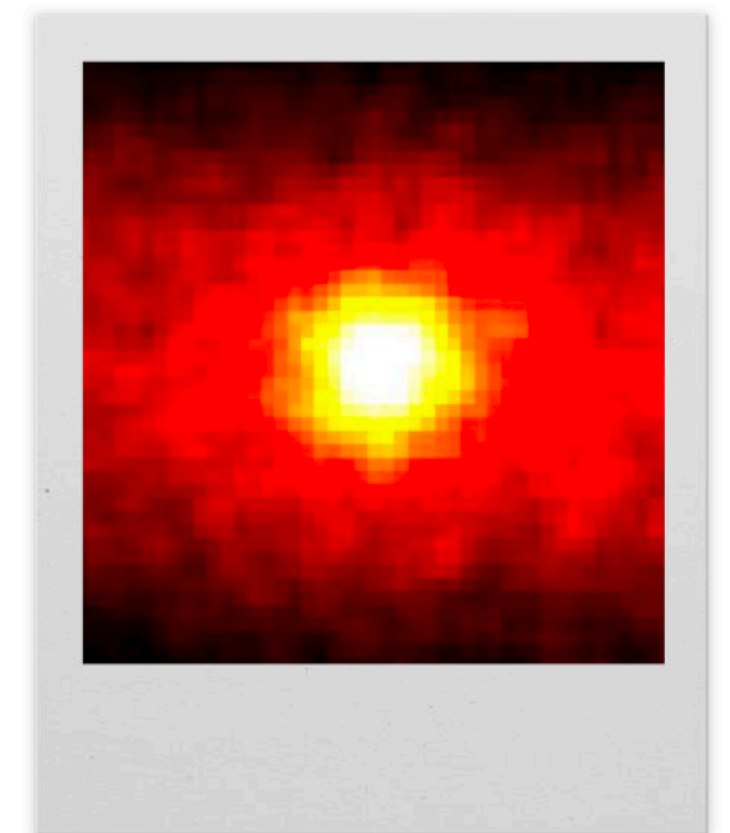
Copiosamente prodotti nel Sole



0.04 s

$\sim 7 \times 10^{10} \text{ cm}^{-2} \text{ s}^{-1}$

Grande flusso di fantasmini



Fotografia del Sole vista coi neutrini di Super-Kamiokande