An Appraisal of Some Concepts of Neutrino Physics

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The discussions of superluminal neutrinos and other recent events witness the importance of a critical appraisal of the adopted theoretical concepts. We examine how some hypotheses have been put forward and then widely adopted. The emerging impression is that the role of discussions in neutrino physics, in particular those concerning hypotheses and concepts, could be usefully strengthened.

SUPERLUMINAL NEUTRINOS

The road to superluminal neutrinos

⋆ Gonzalez-Mestres '97 proposes that the dispersion relation for hadrons is

$$\mathbf{E}=\sqrt{\mathbf{m^2} + [\ \sin(\mathbf{p\ a})/\mathbf{a}\ ]^{\mathbf{2}}} \quad \textbf{with} \quad \mathbf{a} \sim \frac{1}{M_{\textsf{Planck}}} \equiv \sqrt{G_N}$$

arguing that GZK cutoff can be wiped out in this manner.

⋆ Amelino-Camelia, Ellis, Mavromatos, Nanopoulos, Sarkar '97 suggest testing

$$\mathbf{p^2} = \mathbf{E^2}(\mathbf{1} + \xi \mathbf{E}/\mathbf{E}_{\textsf{QG}}) \Rightarrow \mathbf{v} = \mathbf{1} - \xi \mathbf{E}/\mathbf{E}_{\textsf{QG}} \Rightarrow \mathbf{\Delta t}/\mathbf{t} = \xi \mathbf{E}/\mathbf{E}_{\textsf{QG}}$$

namely, a non-Einsteinian dispersion relation, using γ rays from GRB.

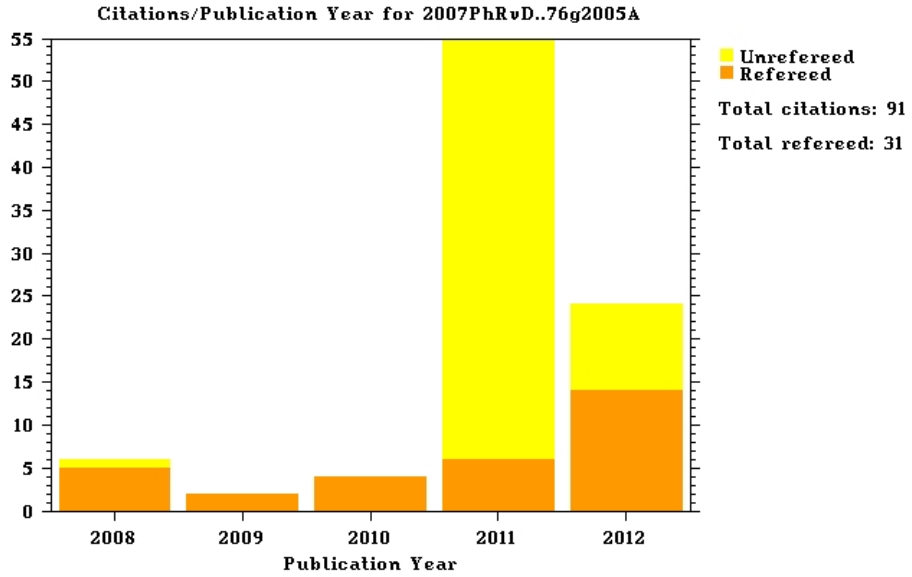
⋆ Coleman and Glashow '98, parameterize the energy of a particle with

$$\mathbf{E_i} = \mathbf{c_i}\sqrt{\mathbf{p^2} + (\mathbf{m_i c_i})^{\mathbf{2}}}$$

where c_i = constant $\neq 1$ is a quantity that depends on the particle.

The measurement at MINOS

The recent campaign of measurement of neutrino velocity in longbaseline experiments has been opened by MINOS 2007, whose upper bound was considered of limited interest till past year.



For our discussion, it is important to examine the theoretical motivations for the measurement they performed.

Let us read Phys. Rev. D 76 (2007) 072005

theories have been proposed to allow some or all neutrinos to travel along "shortcuts" off the brane through large extra dimensions [5], and thus have apparent velocities different than the speed of light. Some of these theories [6–8] allow $|v - c|/c \sim 10^{-4}$ at neutrino energies of a few GeV. Terrestrial neutrino beams could measure an

[5] R. N. Mohapatra and A. Y. Smirnov, Annu. Rev. Nucl. Part. Sci. **56**, 569 (2006).
[6] G. G. Volkov, Ann. Fond. Broglie **31**, 227 (2006).
[7] V. Ammosov and G. Volkov arXiv:hep-ph/0008032.
[8] G. S. Asanov, arXiv:hep-ph/0009305.

Ref. [5] discusses 'branes' and 'extra dimensions' but does not mention 'shortcuts'. The paper where this is mentioned, H. Päs, S. Pakvasa, T. J. Weiler, STERILE-ACTIVE NEUTRINO OSCILLATIONS AND SHORTCUTS IN THE EXTRA DIMENSION, *Phys. Rev. D* **72** *(2005) 095017, is not quoted by any of these works – including MINOS's.*

The scenery of OPERA

In the past years, several suggestive but vague theoretical arguments have been collected, that helped to accept superluminal neutrinos.

This is reflected in the excitement expressed by outstanding physicists. See e.g., the declarations to the newspaper *Messaggero* on Sept 23, 2011,

> **Potrebbe esistere una nuova costante dell'universo**: potrebbe essere questa una delle conseguenze dirompenti dei dati annunciati oggi. La percezione, ha detto il presidente dell'Istituto Nazionale di Fisica Nucleare (Infn) Roberto Petronzio, è che «si possa cominciare a ragionare su una nuova scala e che si entri in un territorio sconosciuto della fisica, nel quale si potrebbero incontrare, per esempio nuove dimensioni o addirittura una nuova costante fondamentale dell'universo».

which fits well the expectations on large extra dimensions or TeV scale gravity described several times in the theoretical section of *Piano Triennale*.

A LOOK TO THEORY AFTER θ_{13} MEASUREMENT

Tri-bimaximal mixing

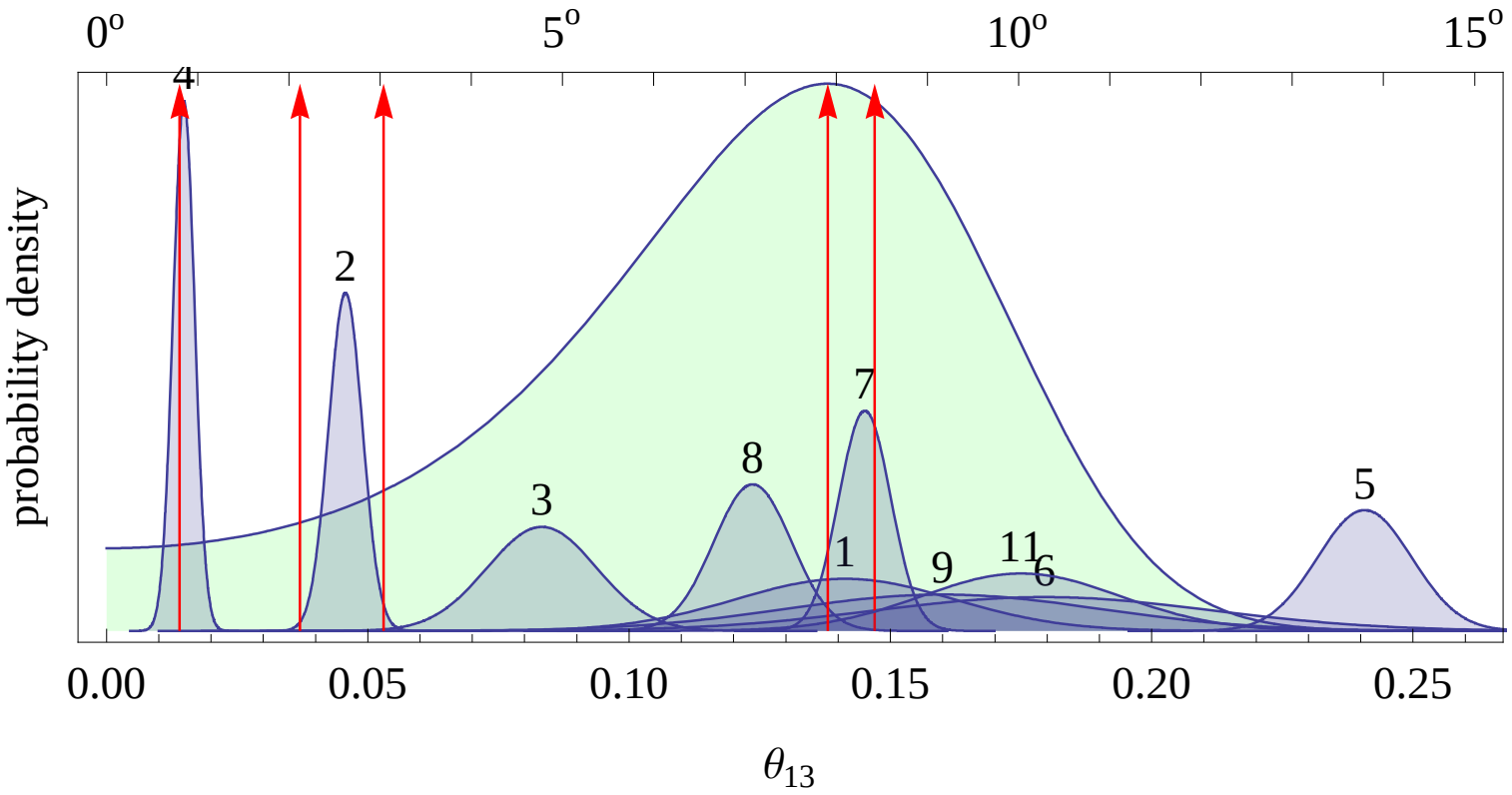
Harrison, Perkins, Scott 2002 posit a mixing matrix that has $\theta_{13} = 0$. It led to many papers. Among those who quoted it more often

S King 48 [Neutrino 02 & 08], Z-Z Xing 37, E Ma 35, W Rodejohann 29, S Morisi 28, G Altarelli 27 [Neutrino 04], L Merlo 23, S Antusch 22 [Neutrino 12], F Feruglio 20 [Neutrino 04], J Valle 21, Y Koide 20, M Hirsch 18, C Hagedorn 18, X-G He 18, M Tanimoto 17, M-C Chen 13 [Neutrino 08], D Meloni 13, A Zee 14, R Mohapatra 14 [Neutrino 06], F Bazzocchi 13, A Smirnov 12 [IAC Neutrino, many talks], W Scott & P Harrison 12, W Grimus 12, S Petcov 11 [PDG review on neutrino], P Frampton 11

I wonder what are the reasons why this proposals has received such an enormous attention–more than 800 citations. Personally, I am inclined to doubt that we will learn something useful from its failure.

A compilation of other cases

This picture (from Strumia & FV) **shows that θ_{13} measurements rules out many proposals. However, even the successful cases should examined, to assess whether they are valid and convincing from a theoretical point of view.**



One scheme that could be still of some use

In 2001 I tried to guess the gross structure of the neutrino matrix by

$$M_\nu \propto \text{diag}(\varepsilon, 1, 1) \cdot \begin{pmatrix} \texttt{rnd()} & \texttt{rnd()} & \texttt{rnd()} \\ & \texttt{rnd()} & \texttt{rnd()} \\ & & \texttt{rnd()} \end{pmatrix} \cdot \text{diag}(\varepsilon, 1, 1)$$

finding that the most promising value was

$$\varepsilon = \theta_C = 13^\circ \sim \sqrt{m_\mu / m_\tau} = 14^\circ$$

it gave significant preference for LMA (before it was confirmed) and suggested

$$\theta_{13} = 12^\circ \pm 6^\circ \quad \text{or } 6^\circ \pm 3^\circ \text{ if charged leptons are diagonal}$$

Similar results for type I seesaw, with more random matrices. While this scheme is not ruled out, it leaves us several difficult tasks, as its inclusion in a more complete setup, and in last analysis, the theory of the $\mathcal{O}(1)$ coefficients.

ON NEUTRINOLESS DOUBLE BETA DECAY

Violations of global numbers

Various higher-dimensional operators, that respect the SM gauge symmetry, however violate the baryon and lepton numbers:

$$\mathcal{L}_{\text{SM}} + \frac{(\ell H)^2}{M} + \frac{\ell qqq}{M'^2} + \frac{(\ell q d^c)^2}{M''^5}$$

Dark matter, sterile neutrinos, or generally light states may require to extend this scheme proposed by Weinberg and Wilczek-Zee.

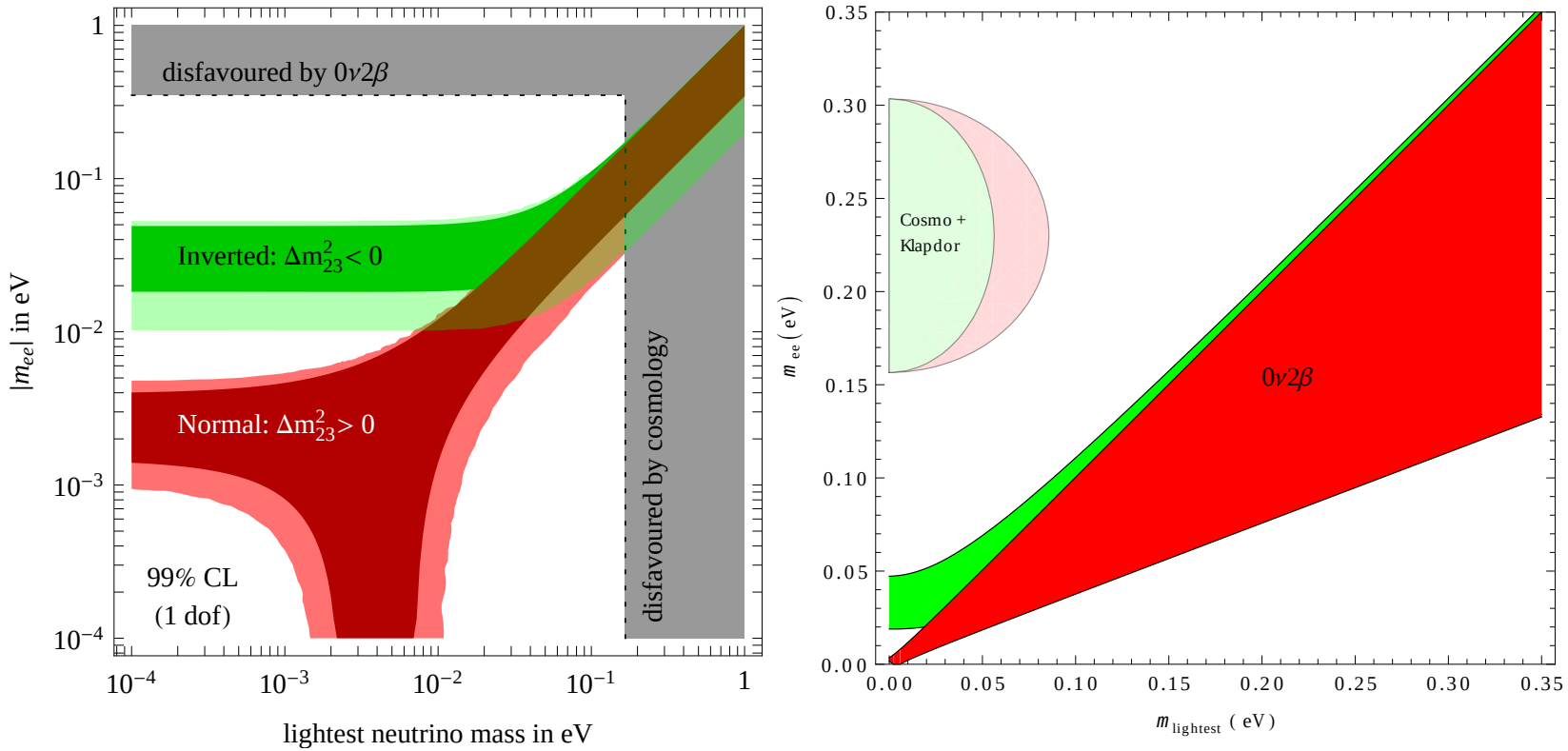
From the available experimental information, we find

$$\begin{cases} M < 10^{14} \text{ GeV} & \text{from neutrino masses} \\ M' > 10^{15} \text{ GeV} & \text{from matter stability} \\ M'' > 5 \text{ TeV} & \text{from neutrinoless double beta decay} \end{cases}$$

Note that a large effective mass could stem from small couplings, e.g., $1/M = \lambda^2/\mu$

Neutrinoless double beta decay $(A, Z) \to (A, Z+2) + 2e^-$, can be induced by the dim.5 operator but also by the dim.9. So one can ask, which is the leading source?

Left, prediction for neutrinoless double beta decay based on the hypothesis that the only relevant operator is the one of dim.5, thus neutrino masses have Majorana nature (Strumia, FV). Right, the same but emphasizing the clash with Klapdor findings and newest cosmological constraints (Mitra, FV)–thus, something is wrong.



In my intentions, these plots define the *minimal* case that should be tested.

Next steps (and past ones)

Next, one can consider well-defined models for the physics that extends the SM, and that predict, e.g., observable signals at LHC besides neutrinoless double beta decay.

However, a "black-box theorem", that should imply a tight connection between the observation of neutrinoless double beta decay and Majorana neutrinos, is still often mentioned, even when it is known that the connection is quite loose or just absent in several models with lepton violation at a low energy scale.

Similar reluctance to analyze critically the views to which we are accustomed can be perceived also from the language. When we speak of neutrinoless double beta decay, we use a terminology for initiates and define a reaction for the absence of neutrinos. A quite precise, alternative definition is just creation of electrons in a nuclear transition.

ON SN1987A

Notable features of a 25 years long discussion

The epochal observation of SN1987A neutrino begun a new chapter of astronomy.

After the first years the discussion focussed strongly on neutrino properties; e.g., Smirnov, Spergel & Bahcall 94 discuss whether SN1987A contradicts LMA.

A diffuse opinion was that the neutrino emission was the average energy was too low to be standard (?). Now, the simulations agree with the measured average energy.

Comparably, the open question of the neutron star, and the possible presence of multiple neutrino emissions, received (and receives) only a small attention.

A major focus was the importance of SN1987A for particle physics, morever neglecting the astrophysical aspects and related uncertainties. The discussion in astrophysics proceeds independently, the SN1987A events being usually ignored.

Summary and discussion

⋆ We considered superluminal neutrinos [1,2], models for θ_{13} [3,4]; neutrinoless double beta decay [5-10]; interpretations of SN1987A events [11,12]; examining conceptual aspects and related discussions.

⋆ In several cases, ideas that became popular and attracted consensus (as measured by conferences, publications, and citations) do not correspond to valid concepts. A natural question is whether we can avoid this type of polarization.

⋆ IMHO, the problem is not only lack of data. I think that concepts, hypotheses and results should be severely judged and subjected to critical analyses.

⋆ Moreover, I feel that open, frank and extensive scientific discussions among experts could still play an important role in neutrino physics.

Grazie per l'attenzione!

Riferimenti bibliografici

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[2] See my talk at the meeting http://agenda.infn.it/materialDisplay.py?materialId=slides&confId=4896

[3] A. Strumia and FV, online review: "Neutrino masses and mixings and...," hep-ph/0606054 V3

[4] FV, "Expected properties of massive neutrinos [...] random coefficients order unity," PLB **508** (2001) 79

[5] S. Weinberg, "Baryon and Lepton Nonconserving Processes," PRL **43** (1979) 1566 and PRD **22** (1980) 1694

[6] F. Wilczek and A. Zee, "Operator Analysis of Nucleon Decay," PRL **43** (1979) 1571

[7] FV, "Signal of neutrinoless double beta decay, neutrino spectrum and oscillation scenarios," JHEP **9906** (1999) 022, see Fig.4

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