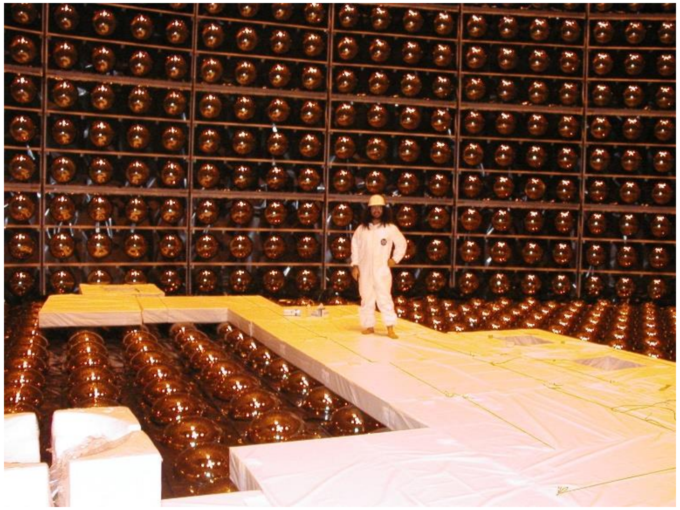
MAREK ZRAŁEK

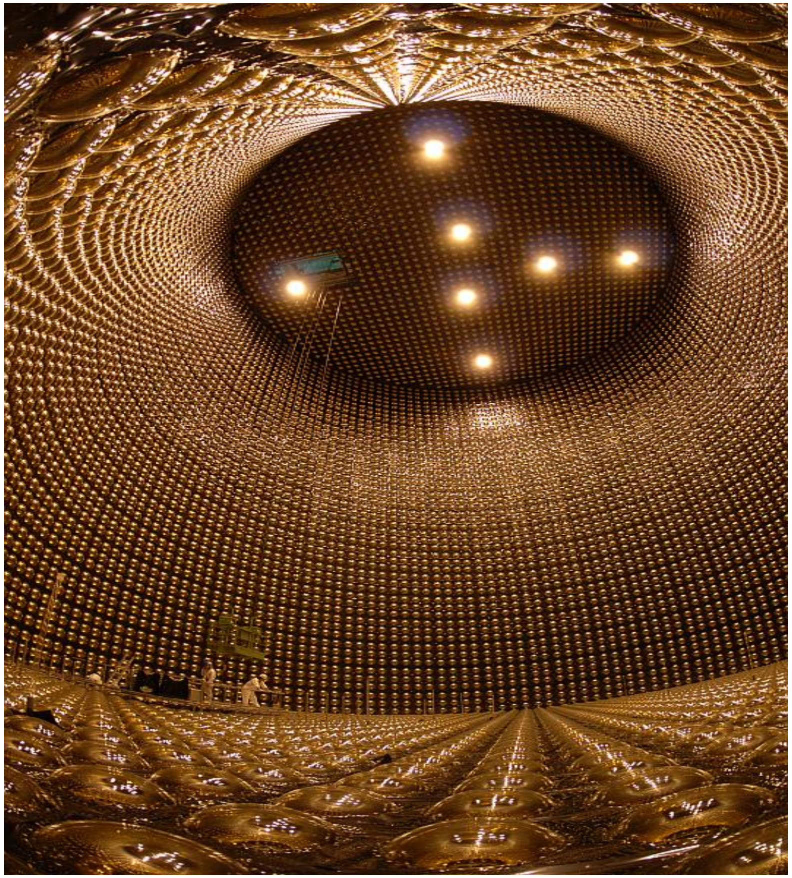
Rector, Scientist and Friend

On the occasion of 70th birthday

A portrait of Ettore Majorana


20

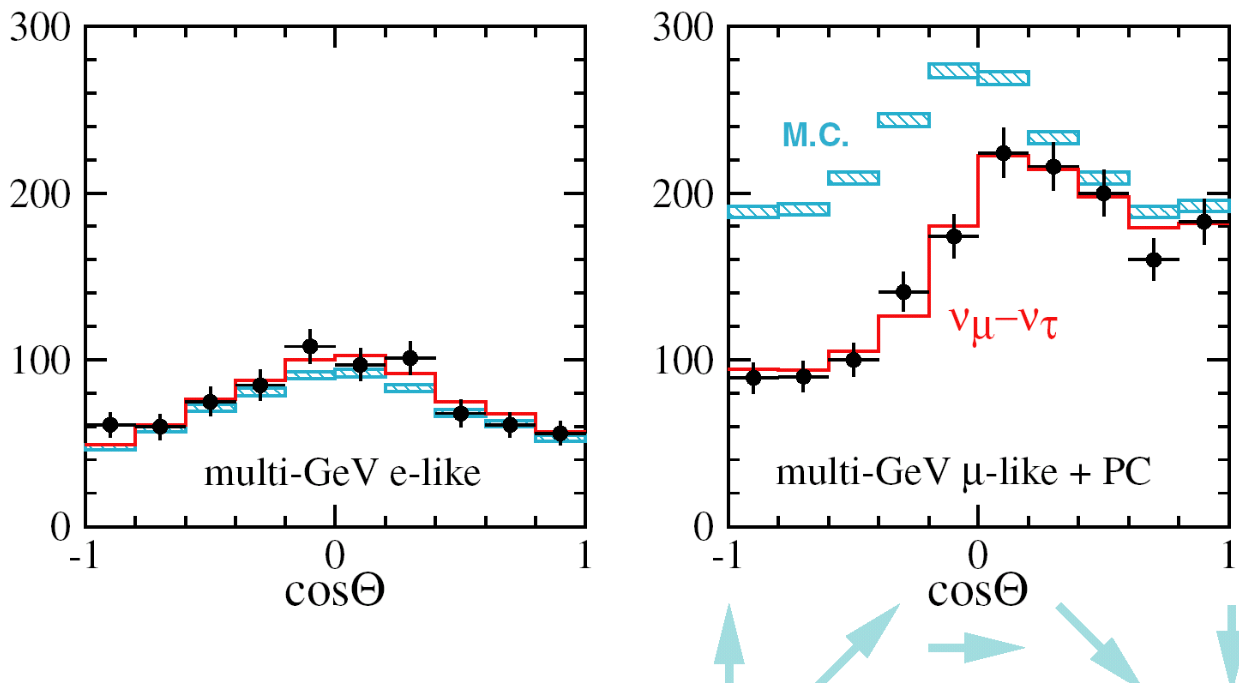




$$\nu_\mu \rightarrow \nu_\tau$$

multi-GeV: $\left(\dfrac{N_{UP} - N_{DOWN}}{N_{UP} + N_{DOWN}}\right)_{\mu\text{-like}} = -0.303 \pm \underset{\text{stat.}}{0.030} \pm \underset{\text{sys.}}{0.004}$

> 10σ deviation!



1489 day
Super-K
preliminary

Neutrino travel distance: 12800 6200 700 40 15 km

ELSEVIER

19 November 1998

PHYSICS LETTERS B

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Neutrino mixing and see-saw mechanism

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Abstract

Models of neutrino masses are discussed capable of explaining in a natural way the maximal mixing between ν_μ and ν_τ observed by the Super-Kamiokande Collaboration. For three generations of leptons two classes of such models are found implying: a) $\Delta m^2_{23} \ll \Delta m^2_{12} \approx \Delta m^2_{13}$ and a small mixing between ν_e and the other two neutrinos, b) $\Delta m^2_{12} \ll \Delta m^2_{13} \approx \Delta m^2_{23}$ and a nearly maximal mixing for solar neutrino oscillations in vacuum.

Torn between identities – tau-, electron- or muon-neutrino?

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Effects of neutrino mixing on high-energy cosmic neutrino flux

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Several cosmologically distant astrophysical sources may produce high-energy cosmic neutrinos ($E \geqslant 10^6$ GeV) of all flavors above the atmospheric neutrino background. We study the effects of vacuum neutrino mixing in the three flavor framework on this cosmic neutrino flux. We also consider the effects of possible mixing between the three active neutrinos and the (fourth) sterile neutrino with or without big-bang nucleosynthesis constraints and estimate the resulting final high-energy cosmic neutrino flux ratios on Earth compatible with currently existing different neutrino oscillation hints in a model independent way. Further, we discuss the case where the intrinsic cosmic neutrino flux does not have the standard ratio.

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}, \quad U \equiv \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}.$$

In the limit $L \to \infty$, we have

$$P(\nu_\alpha \to \nu_\beta; L = \infty) = \delta_{\alpha\beta} - \sum_{j \neq k} U^*_{\alpha j} U_{\beta j} U_{\alpha k} U^*_{\beta k}$$

$$= \sum_j |U_{\alpha j}|^2 |U_{\beta j}|^2, \tag{5}$$

where we have averaged over rapid oscillations.

Thus, we can represent the oscillation probability as a symmetric matrix P and P can be written as a product of a matrix A:

$$P \equiv \begin{pmatrix} P_{ee} & P_{e\mu} & P_{e\tau} \\ P_{e\mu} & P_{\mu\mu} & P_{\mu\tau} \\ P_{e\tau} & P_{\mu\tau} & P_{\tau\tau} \end{pmatrix} \equiv AA^T, \quad (6)$$

with

$$A \equiv \begin{pmatrix} |U_{e1}|^2 & |U_{e2}|^2 & |U_{e3}|^2 \\ |U_{\mu 1}|^2 & |U_{\mu 2}|^2 & |U_{\mu 3}|^2 \\ |U_{\tau 1}|^2 & |U_{\tau 2}|^2 & |U_{\tau 3}|^2 \end{pmatrix}. \quad (7)$$

Now, the cosmic neutrino flux in the far distance can be expressed as a product of P and the intrinsic flux $F^0(\nu_\alpha)$ $(\alpha = e, \mu, \tau)$:

$$\begin{pmatrix} F(\nu_e) \\ F(\nu_\mu) \\ F(\nu_\tau) \end{pmatrix} = P \begin{pmatrix} F^0(\nu_e) \\ F^0(\nu_\mu) \\ F^0(\nu_\tau) \end{pmatrix} = AA^T \begin{pmatrix} F^0(\nu_e) \\ F^0(\nu_\mu) \\ F^0(\nu_\tau) \end{pmatrix} . \qquad (8)$$

$$A^T\begin{pmatrix} F^0(\nu_e) \\ F^0(\nu_\mu) \\ F^0(\nu_\tau) \end{pmatrix} = \begin{pmatrix} |U_{e1}|^2 & |U_{\mu 1}|^2 & |U_{\tau 1}|^2 \\ |U_{e2}|^2 & |U_{\mu 2}|^2 & |U_{\tau 2}|^2 \\ |U_{e3}|^2 & |U_{\mu 3}|^2 & |U_{\tau 3}|^2 \end{pmatrix} \begin{pmatrix} 1 \\ 2 \\ 0 \end{pmatrix} F^0(\nu_e)$$

$$= \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} F^0(\nu_e) + \begin{pmatrix} |U_{\mu 1}|^2 - |U_{\tau 1}|^2 \\ |U_{\mu 2}|^2 - |U_{\tau 2}|^2 \\ |U_{\mu 3}|^2 - |U_{\tau 3}|^2 \end{pmatrix} F^0(\nu_e), \tag{9}$$

$$\begin{pmatrix} F(\nu_e) \\ F(\nu_\mu) \\ F(\nu_\tau) \end{pmatrix} \simeq A \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} F^0(\nu_e) \simeq \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} F^0(\nu_e),$$

Happy Birthday Marek

Best wishes from Cracow