

# Neutrino oscillations: personal memories

Francesco Ronga

Istituto Nazionale di Fisica Nucleare INFN, LNF Frascati, Italy  
francesco.ronga@lnf.infn.it

This short neutrino oscillations history is focused to the period up to June 1998, from the point of view of a researcher working in the past MACRO experiment at the Gran Sasso Laboratory, scheduled to talk at the Takayama conference just before the historical Tataaki Kajita's talk.

## References:

F. Ronga: "A story of neutrino oscillations in the book" Neutrino the mutant particle" Aracne editions  
<http://www.aracneeditrice.it/index.php/pubblicazione.html?item=9788854895805>  
also in  
[http://www.dmf.unisalento.it/~gpc0/lthaca\\_VI\\_2015.pdf](http://www.dmf.unisalento.it/~gpc0/lthaca_VI_2015.pdf) (english version)

In the spring of 2015 (before the neutrino Nobel prizes) Giampaolo Co' planned a special number of the online magazine Ithaca dedicated to neutrino. G. Co' and Paolo Bernardini asked me to write an article on the neutrino history. Later in 2016 a book was published by Aracne editions



## NEUTRINO: THE MUTANT PARTICLE

A cura di Elena Canovi, Giampaolo Co', Daniele Montanino, Francesco Vissani  
Maria Benedetta Barbaro, Omar Benhar, Paolo Bernardini, Vincenzo Flaminio, Carlotta Giusti, Eligio Lisi, Giampiero Mangano, Camillo Mariani, Alessandro Mirizzi, Francesco Ronga, Francesco Terranova

MI piace 48 Condividi Tweet G+

### SINTESI

On October 2015 the Royal Swedish Academy of Sciences announced that the Nobel Prize in Physics 2015 was assigned to Takaaki Kajita and Arthur B. McDonald for the discovery of neutrino oscillations, which shows that neutrinos have mass. This is the academic acknowledgement of a result which has deeply modified our understanding of fundamental physics. In about twenty years of exciting discoveries neutrino physics has changed from a pioneering discovery activity into a mature precision science. In this volume we collect a set of articles presenting modern issues of neutrino physics.

## 1968 beginning of the solar neutrino anomaly. Why more than 30 years to establish neutrino oscillations?

Question to McDonald (raised by Cabibbo) during a meeting at the Accademia dei Lincei organized by Milla Baldo Ceolin in 2003  
Several reasons

- **sociological**: difficult to admit that particle physics could be done with astrophysical sources
- **theoretical** prejudice : **small oscillation amplitude** predicted (similar to quarks), **large neutrino mass** preferred (dark matter)
- **experimental**: discrepancy between atmospheric neutrino experiments

### Consequences :

- second generation solar neutrino experiments were **delayed**, Gallium solar neutrino experiment not approved in USA and moved to Europe (GallEx Italy, SAGE Russia)
- CERN-Gran Sasso neutrino beam (planned from the beginning of the Gran Sasso laboratory), **approved only in Dec 1999**. Some CERN countries voted against the beam (even if most of the money was INFN)

## 1986 Start of the atmospheric neutrino anomalies

IMB and later Kamiokande  
In 1992 a result on the IMB stopping muons excluded oscillations

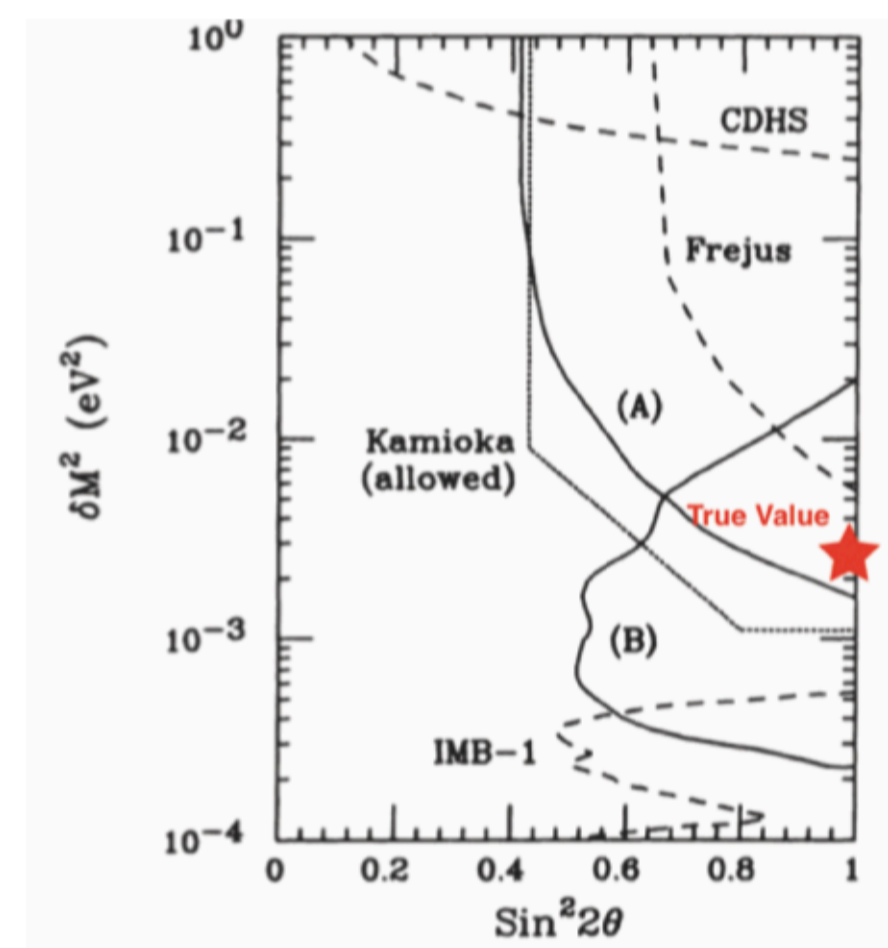
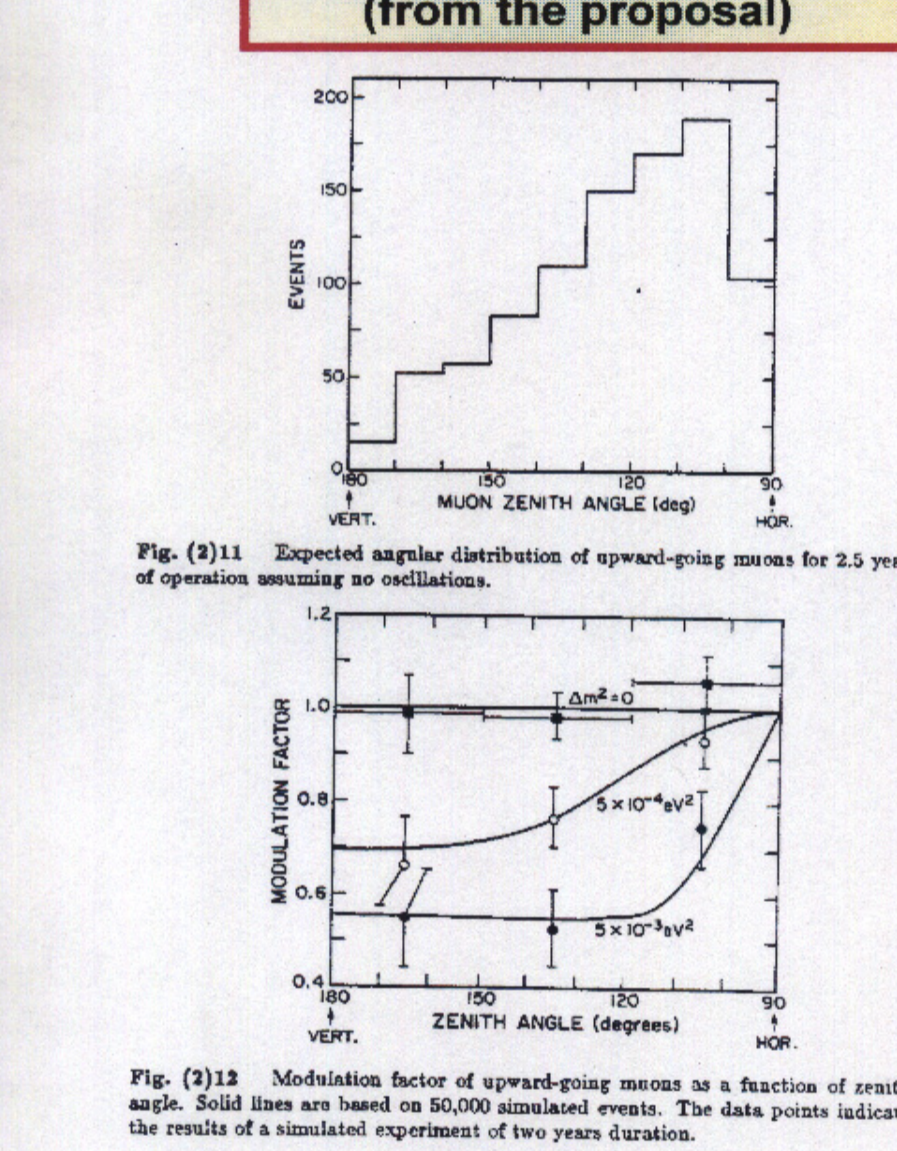


Figure 1. Figure analogous to that of the IMB paper published on Physics Review Letters in 1992 [8]. All the curves include excluded regions, except that of Kamiokande, which defines the allowed region. One should notice that the curve B of IMB completely excludes the red star that represents the presently accepted oscillation values. This wrong result generated great confusion and slowed down the claim of the discovery

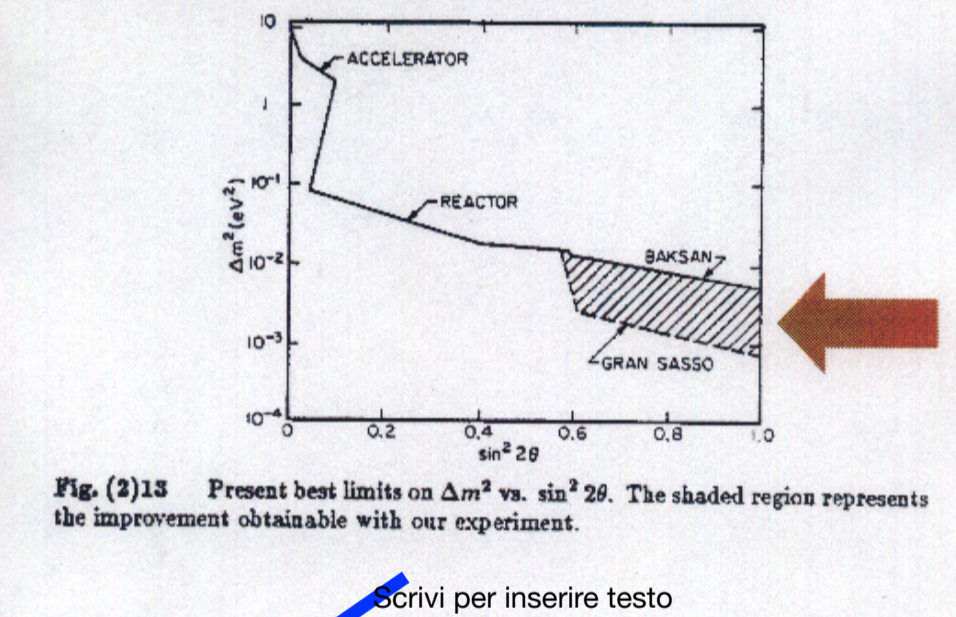
## Atmospheric Neutrino study in the MACRO, magnetic monopole search, proposal (1984)

### Neutrino Oscillation Studies (from the proposal)



### In 1984, proposal anticipates MACRO sensitivity and contribution to neutrino oscillations ...

After, in two years of operation, our experiment can set a 3σ limit for neutrino oscillations for mass differences in excess of 10^-3 eV^2 for maximal mixing. In Fig. (112), this limit (shaded region) is compared with the present limits set by other neutrino oscillation experiments. For sin^2 2θ > 0.5, the experiment should yield nearly an order of magnitude improvement for the limit on Δm^2.



## Takayama neutrino 1998 conference, agenda June 5

9.10 Contained events and Soudan2 (E. Peterson) main result the **muon deficit in iron in agreement with water detector and in agreement with oscillations**

9.35 Upward-going muons and MACRO (F.Ronga) I was quite nervous. Our results **different from the one** of Kamiokande. Possibility to have an immediate denial by a much better experiment like Superkamiokande. Paolo Bernardini already presented our results to the Vulcano workshop.

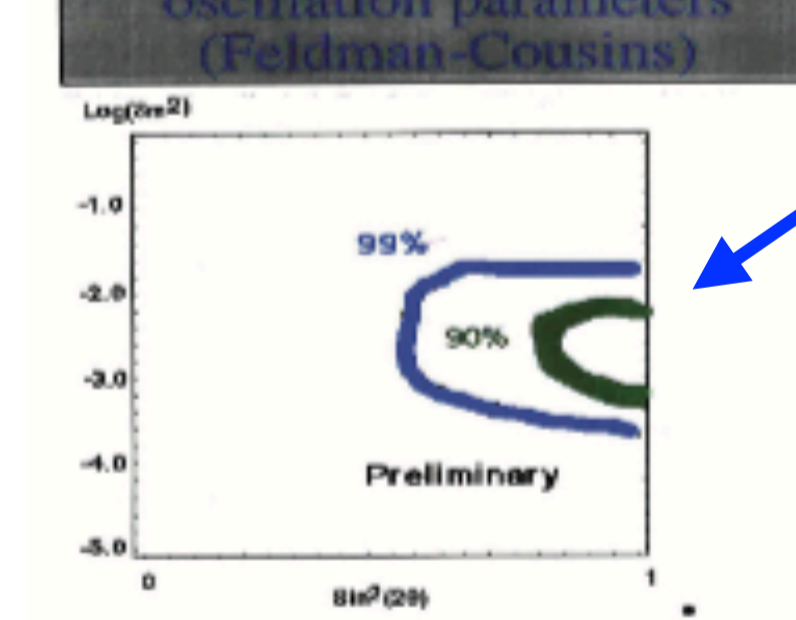
9.55 Results from Kamiokande and SuperKamiokande (T.Kajita)

I was very happy after the Kajita talk. **Our results were in complete agreement with SK** and new Kamiokande data. Of course the statistical evidence was much lower (3 σ in 1998 ==> 5 σ with the full data set in 2000)

## Takayama

### NEUTRINO 98 MACRO (F. RONGA)

#### Confidence regions for oscillation parameters (Feldman-Cousins)



• Note : In this kind of plots there is no information on the goodness of the agreement of data with the hypothesis. You assume that the model is correct (Pbest=17%).

• The regions are smaller than the one expected from the "sensitivity" (statistical fluctuation?)

#### Conclusions

MACRO Upgoing Muons (Through-going) :  
Eν=100 GeV  
• Peak probability νμ → ντ 17%  
• Probability for No oscillations 0.1%  
• Peak Probability νμ → ν sterile 2%

Low energy events:  
Eν=5 GeV  
R=Data/Predict  
No oscillations With oscillations  
10^-3 cm^2 < 10^-2

Internal Up	0.53±0.15	1	0.56
Internal Down	0.71±0.21	1	0.73

Stopping Up  
Conclusion: a νμ → ντ oscillation with maximum mixing and Δm^2 = a few units in 10^-3 eV^2 is consistent with all the MACRO Data

Only Warning :  
The peak probability for the angular distributions of the Upgoing Muons (Through-going) is low (4.6%)  
=>>> Statistical Fluctuation or Hidden Physics?

Figure 3. Slides of the MACRO presentation at "neutrino 1998". The slides are still on the conference link <http://www-sk.icrr.u-tokyo.ac.jp/nu98/scan/index.html>. Similar slides had already been shown by Paolo Bernardini six days earlier at the Vulcano workshop 1998

### NEUTRINO 1998 SUPERKAMIOKANDE (T. KAJITA)

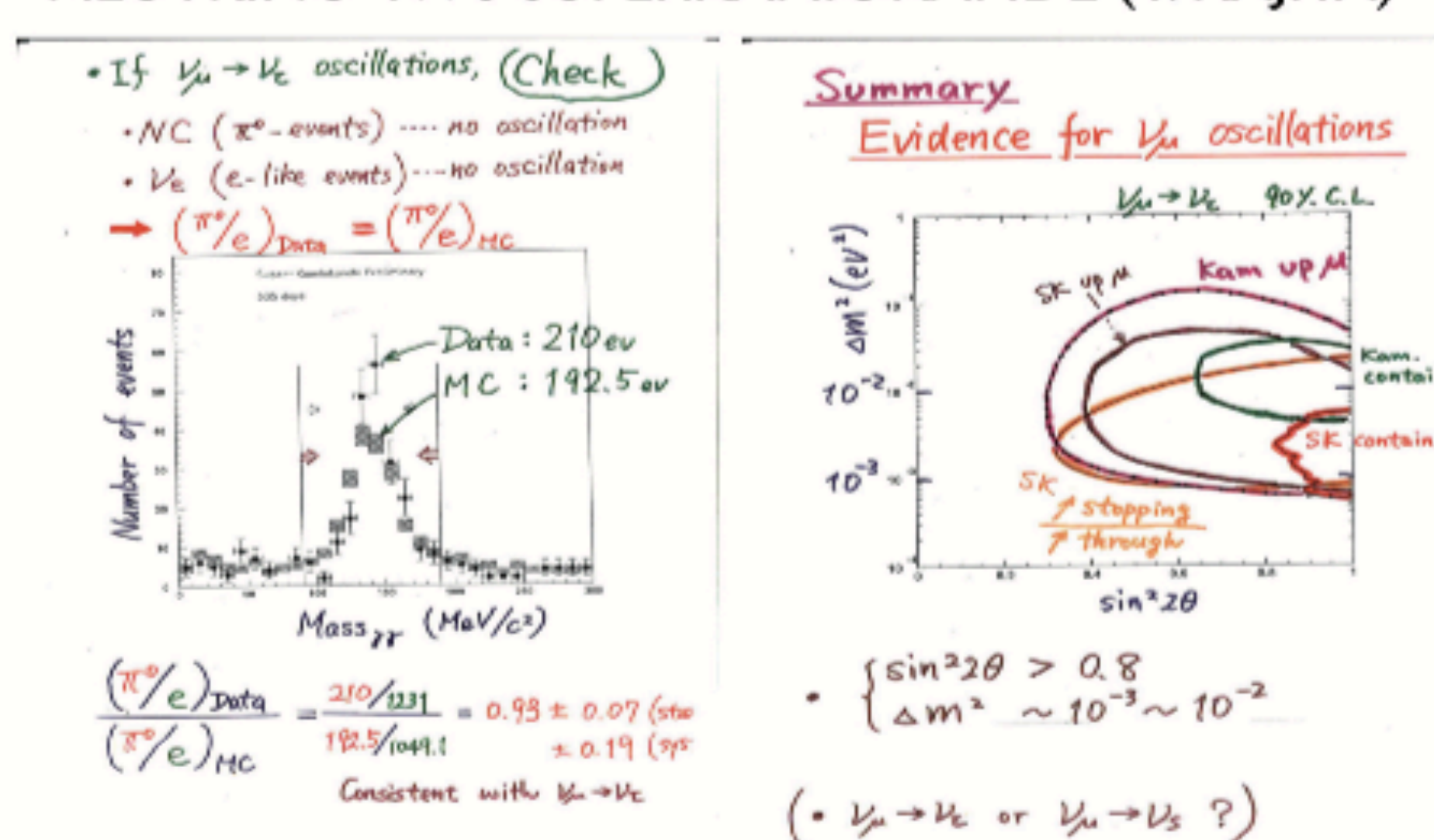


Figure 4. Slides of the Super-Kamiokande presentation at neutrino 1998.

## 1998 papers after Takayama

M. Ambrosio et al. [MACRO Collaboration], "Measurement of the atmospheric neutrino induced upgoing muon flux using MACRO," Phys. Lett. B 434, 451 (1998) [hep-ex/9807005]

Y. Fukuda et al. [Super-Kamiokande Collaboration], "Evidence for oscillation of atmospheric neutrinos," Phys. Rev. Lett. 81, 1562 (1998) [hep-ex/9807003].

Note the preprint numbers **9807003** (Superkamiokande) **9807005** (MACRO). Our paper was **ready** before that of SK, but Giorgio Giacomelli (co-spokesman together B. Barish) waited for the green light from his colleague and friend Koshiba to submit to the arXiv the paper soon after that of SK