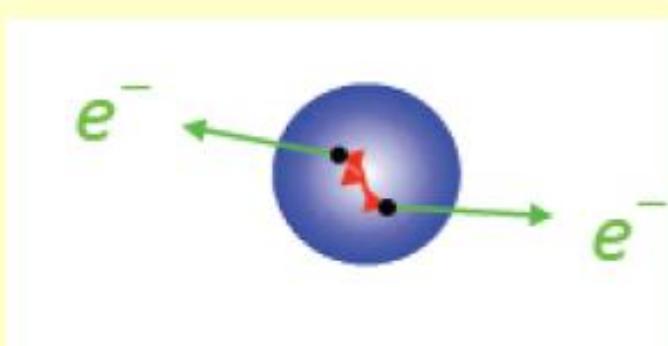
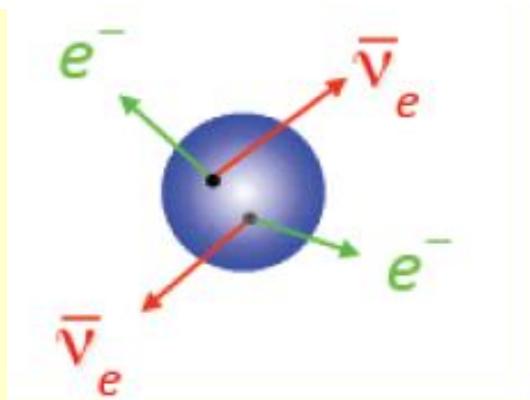
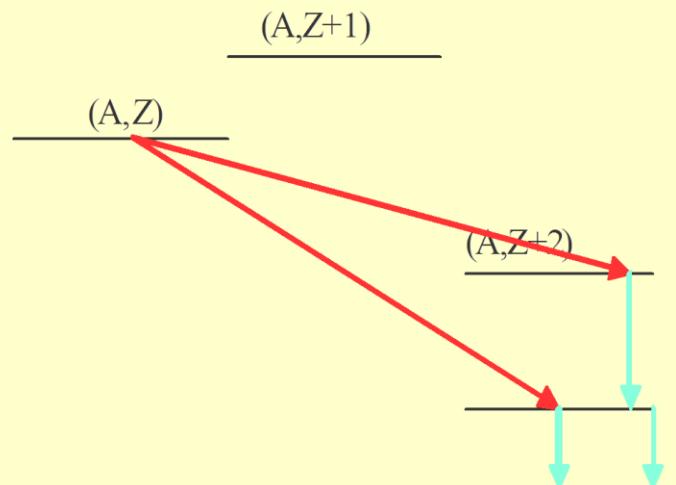
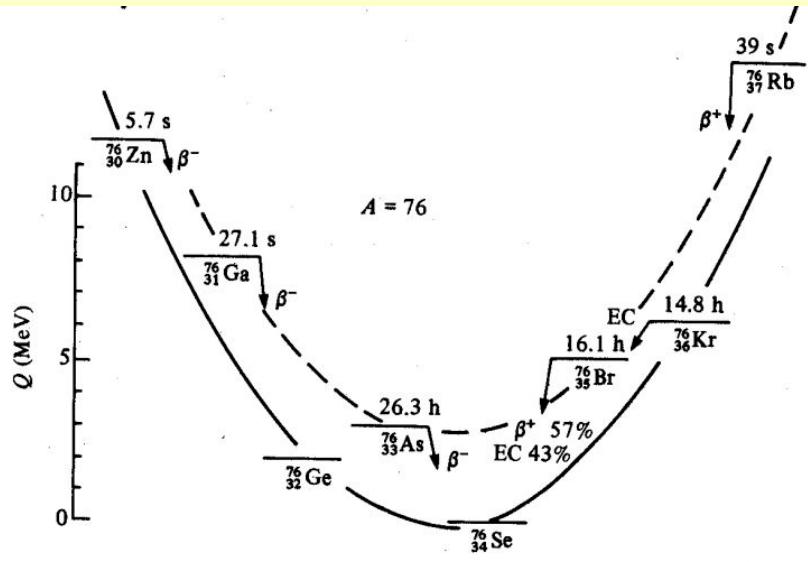


# My debts to Bruno

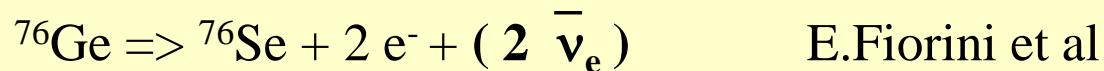
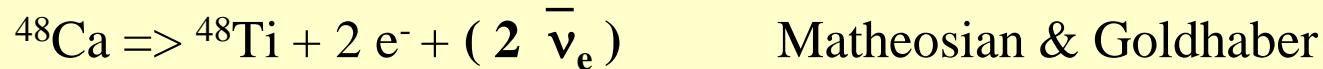
## 1. Double beta decay



Then not “**on fashion**” (Few believed on lepton number non conservation)

But **important** for the two of us

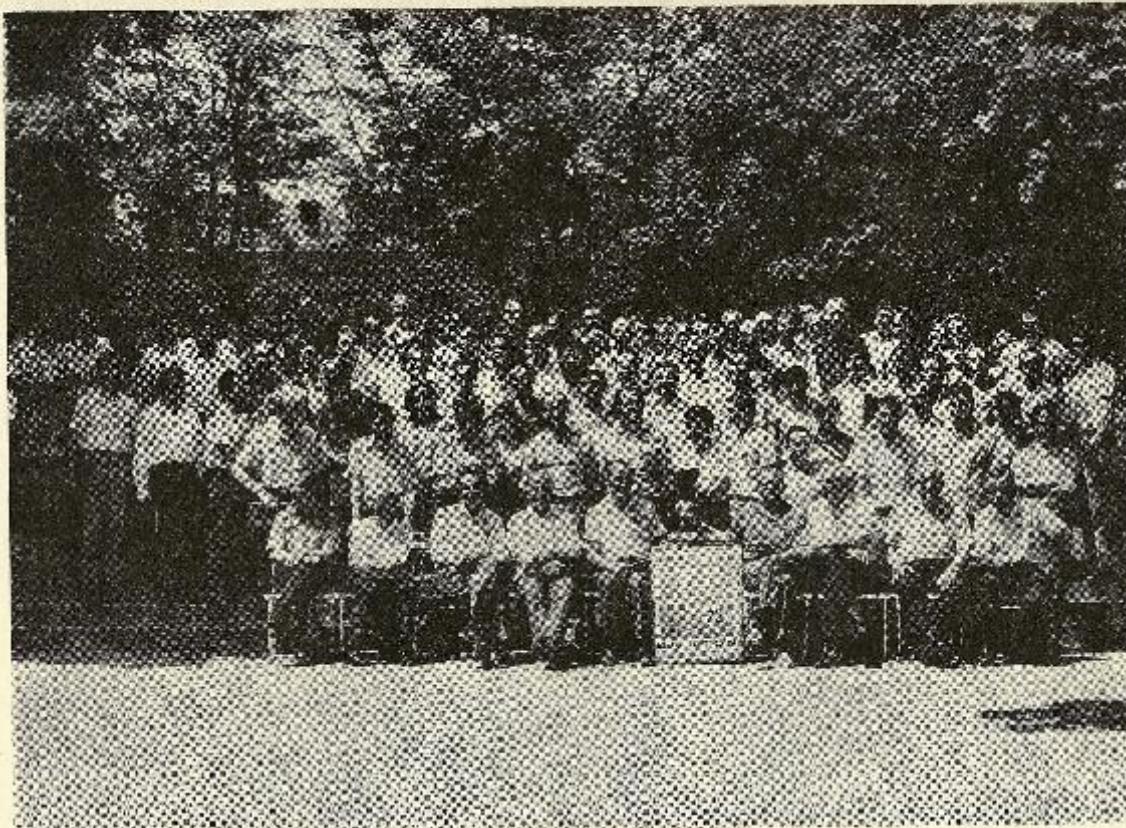
Experiments **source = detector**



Bruno =.<> **DSDL =2 vs =2**

A comment by **Mrs. Wu**

# The Meeting in **KIEV** and **Balatonfured**



Sitting: T. D. Lee, G. L. Radicati, R. P. Feynman, B. Pontecorvo, G. Marx,  
V. F. Weisskopf, F. Reines, C. L. Cowan and P. Budini

## 2. My first approach to a Reactor



**Neutrino oscillations?**

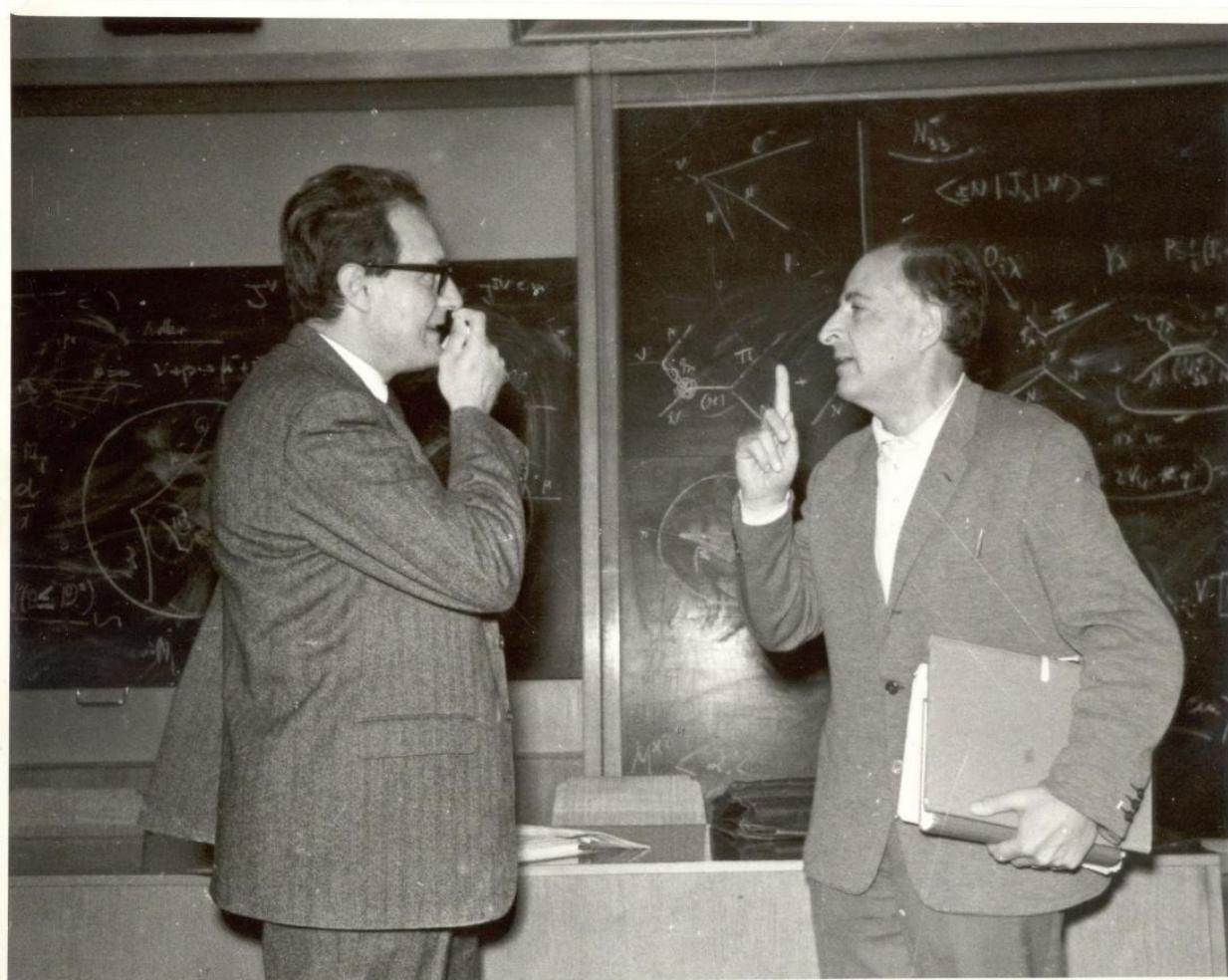
**A proposal for the Caorso reactor => no nuclear energy in Italy**

### 3.Discussion on weak neutral currents in Balatonfured and Milano

In Gargamelle some skeptical Carlo Franzitetti;

Le correnti neutre le lascio a Fiorini

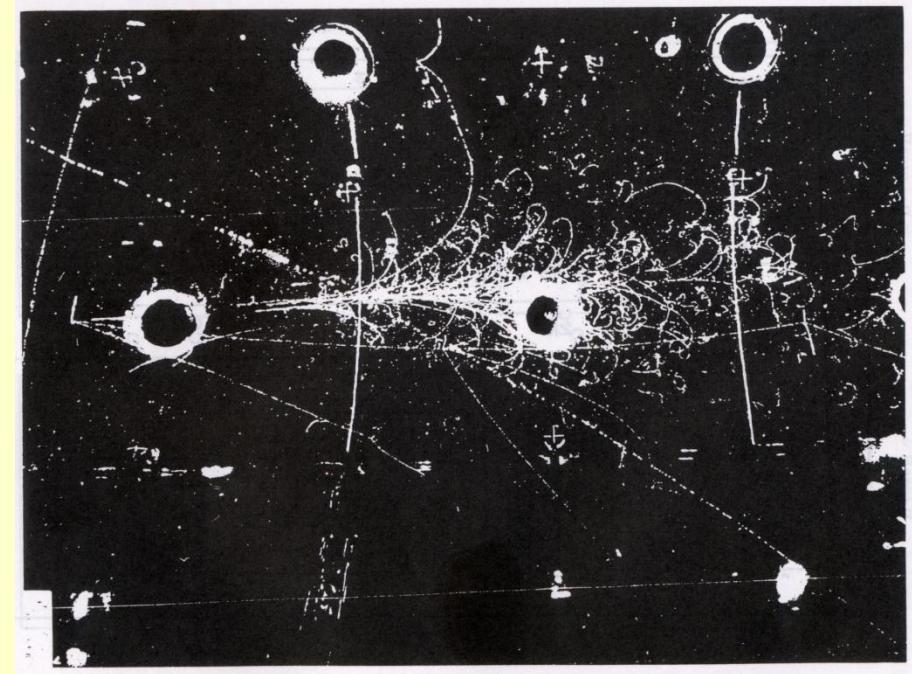
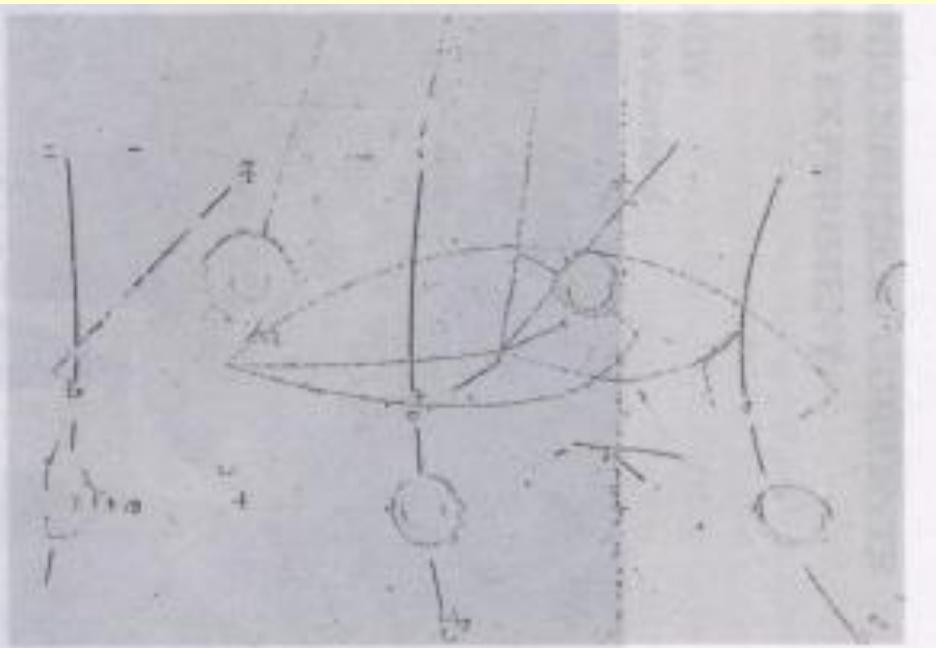
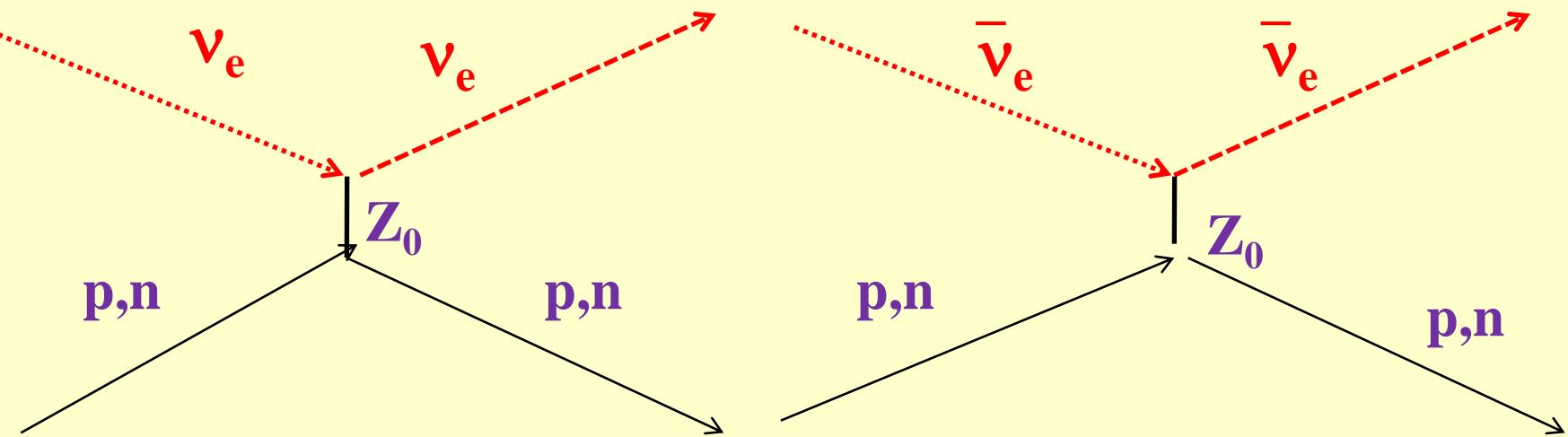
Cabibbo & Maiani



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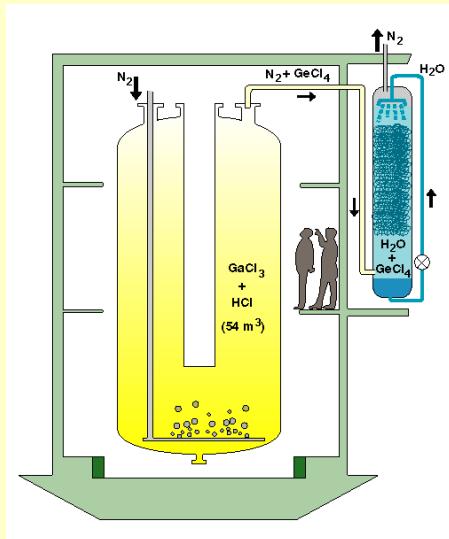
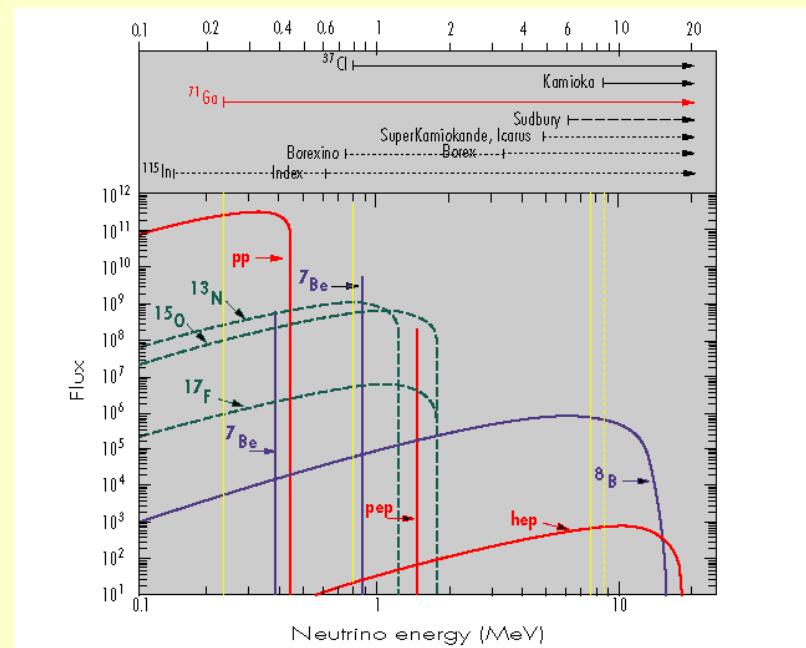
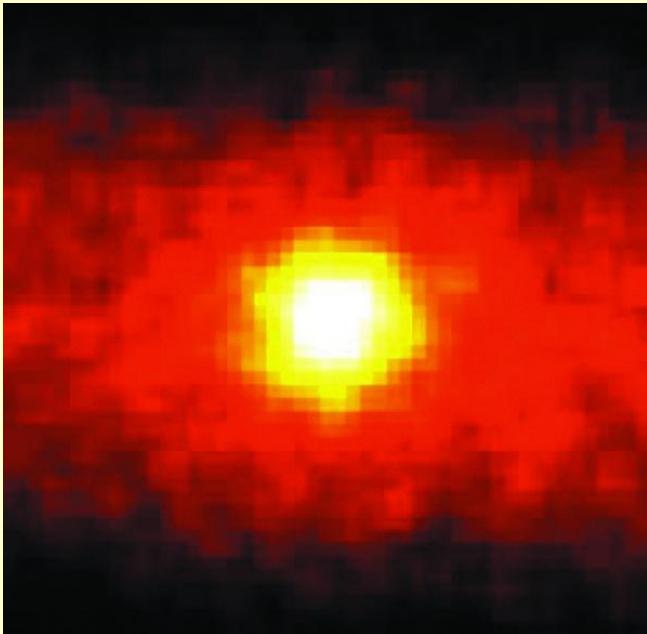
Ettore Fiorini My debts to Bruno

### 3. The discovery of *weak neutral currents*



#### 4.Solar neutrinos => the **GALLEX** experiment





# Presentation at neutrino **with Bruno**



# BRUNO returns to Italy !



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**Scanned at the American  
Institute of Physics**

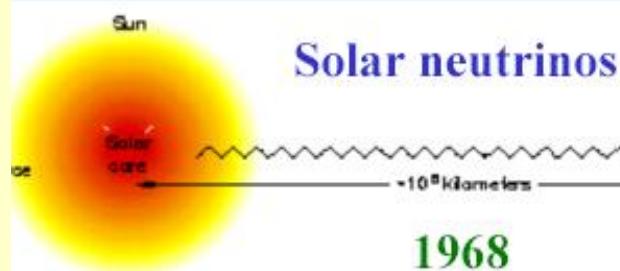
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# The great suggestion of Bruno => Neutrino oscillations

Reactor neutrinos



1968



Бруно Понтекорво

## Atmospheric neutrinos

Cosmic Rays  
p, He, etc.  
  
air molecules  
  
 $\pi^+$

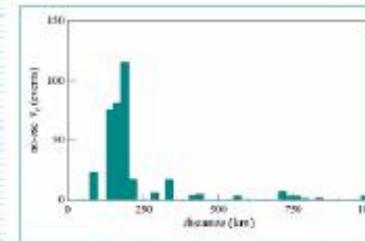
$\nu_\mu \sim 66\%$   
 $\nu_e \sim 33\%$

$\mu^+$   
 $e^-$   
 $\nu_\mu$   
 $\bar{\nu}_\mu$



6/12/2006

Fedor S.



## Accelerator neutrinos



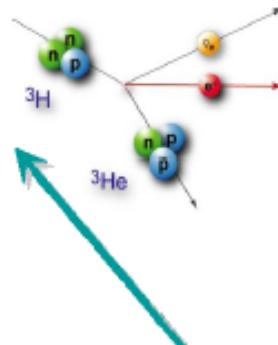
# Neutrino oscillations => $M_{\nu_a} - M_{\nu_b} \neq 0$



## Neutrino mass: status and perspectives



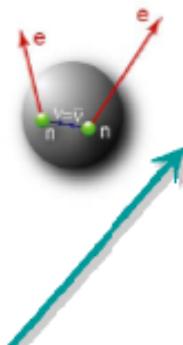
kinematics of  $\beta$ -decay  
absolute  $\nu_e$ -mass:  $m_\nu$



**model-independent**  
status:  $m_\nu < 2.3$  eV  
potential:  $m_\nu = 200$  meV  
KATRIN (MARE-II)



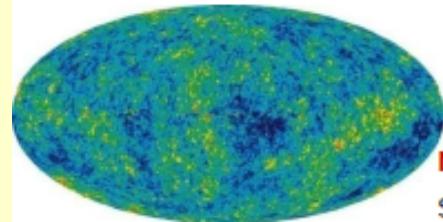
search for  $0\nu\beta\beta$   
eff. Majorana mass  $m_{\beta\beta}$



**model-dependent (CP-phases)**  
status:  $m_{\beta\beta} < 0.35$  eV, evidence?  
potential:  $m_{\beta\beta} = 20-50$  meV  
GERDA, EXO, CUORE



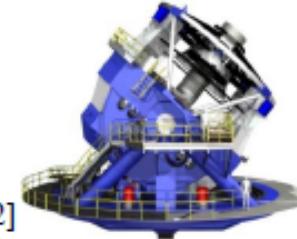
neutrino masses  
experimental techniques:  
status & potential

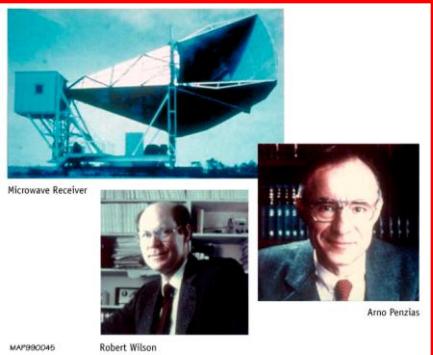


cosmology  
 $\sum \Sigma m_i$ , HDM  $\Omega_\nu$

**model-dependent (multi-parameter fits)**

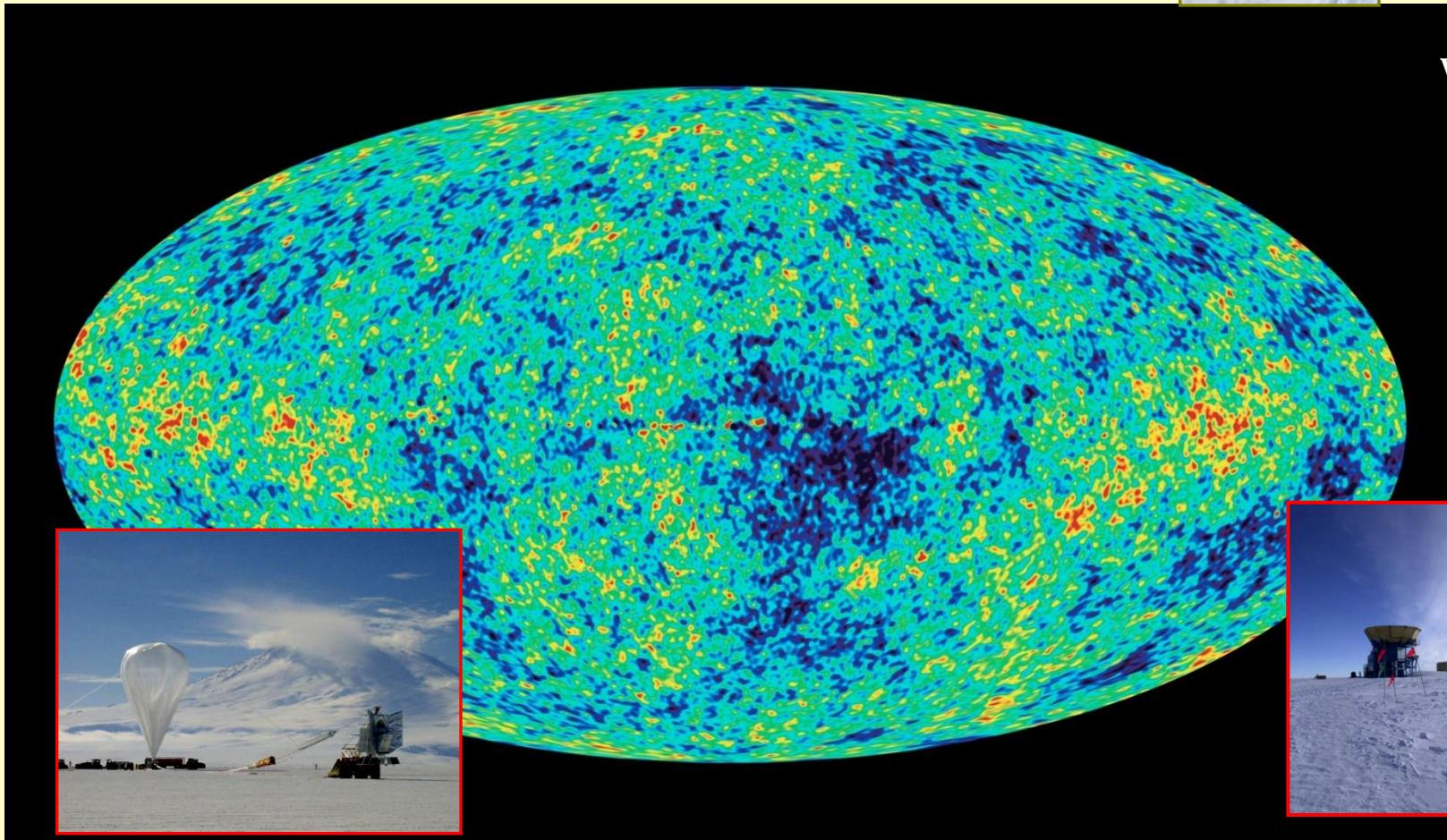
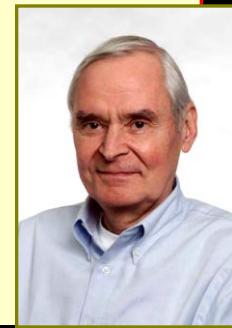
status:  $\sum m_i < 1$  eV [Hannestad et al., arXiv:0803.1585v2]  
potential:  $\sum m_i = 20-50$  meV  
Planck, LSST, weak lensing





# CMB Anisotropy

## $\langle m_\nu \rangle$ from cosmology

$$\mu\text{K} \rightarrow \text{nK}$$


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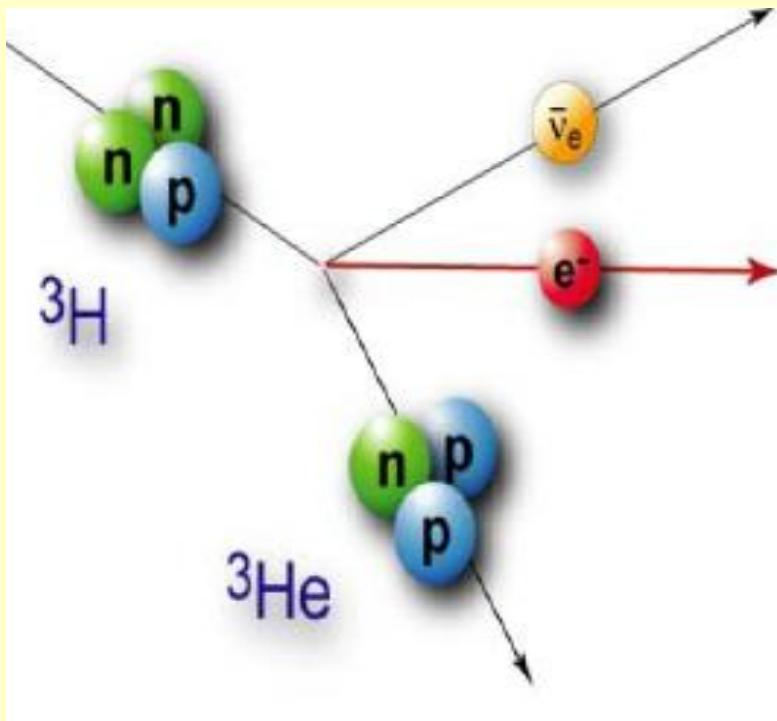
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DASI

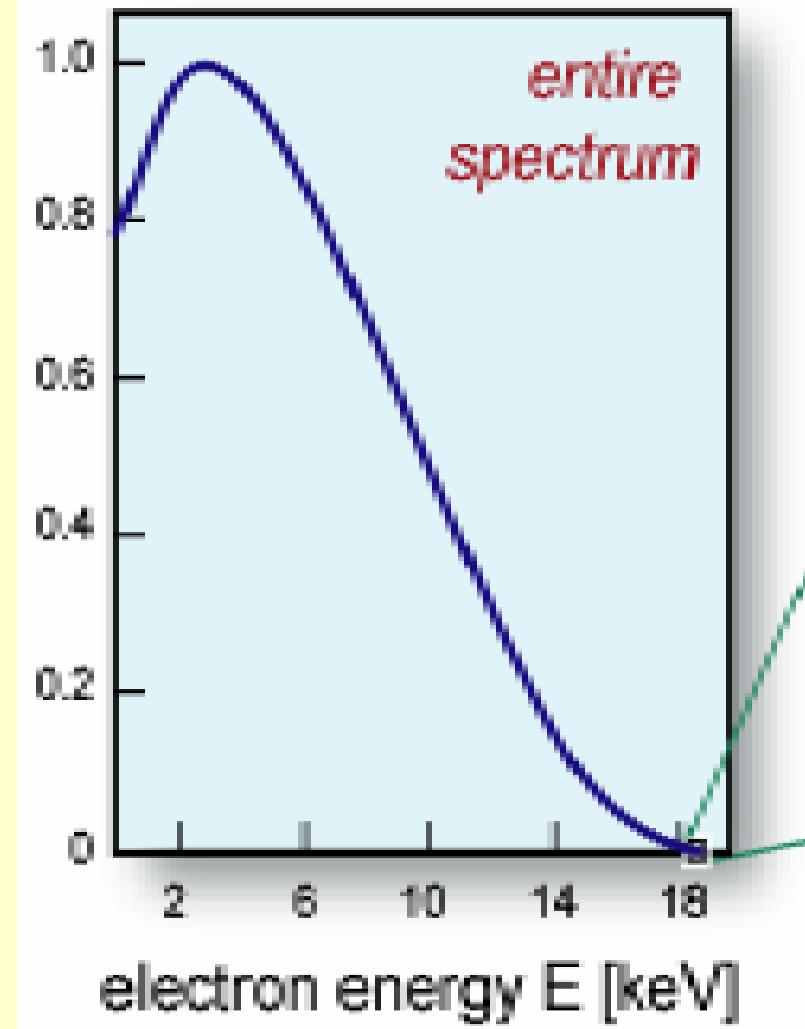
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# Direct measurement of the neutrino mass

$\beta$  decay



Limite attuale < 2 eV



# The second mystery of Ettore Majorana

## Teoria simmetrica dell'elettrone e del positrone

NOTA DI ETTORE MAJORANA

"Il Nuovo Cimento", vol. 14, 1937, pp. 171-184.

**Sunto.** — Si dimostra la possibilità di pervenire a una piena simmetrizzazione formale della teoria quantistica dell'elettrone e del positrone facendo uso di un nuovo processo di quantizzazione. Il significato delle equazioni di DIRAC ne risulta alquanto modificato e non vi è più luogo a parlare di stati di energia negativa; né a presumere per ogni altro tipo di particelle, particolarmente neutre, l'esistenza di "antiparticelle" corrispondenti ai "vuoti" di energia negativa.

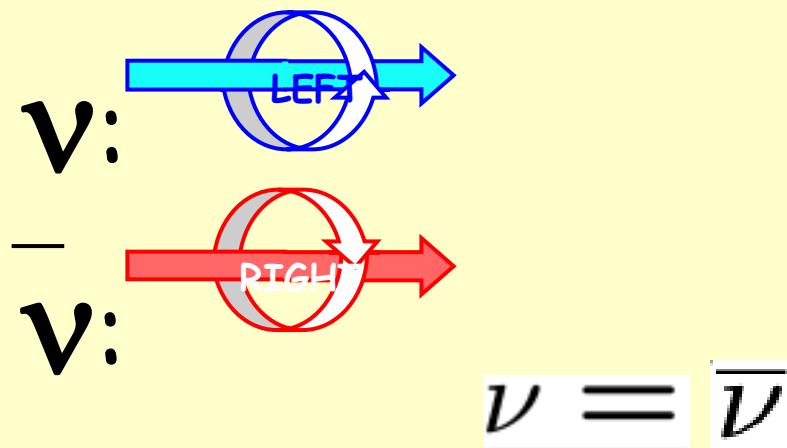
# Dirac or Majorana neutrino?

$$\nu \neq \bar{\nu}$$

$\rightarrow$   
 $\Leftarrow$        $\rightarrow$   
 $\Rightarrow$

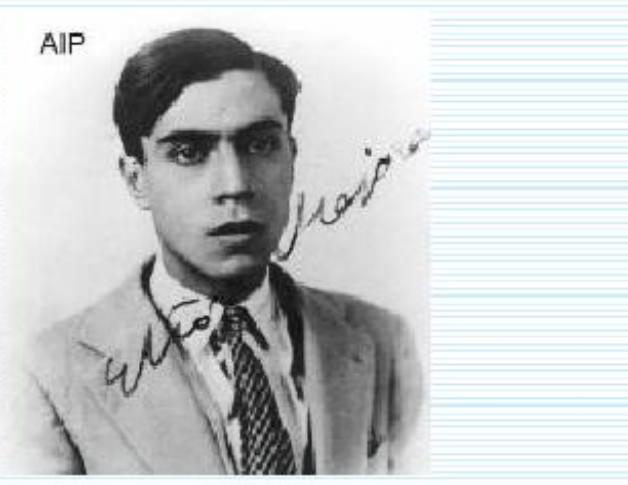


Dirac particle



Majorana  
=>1937

Majorana particle



# *Chi l'ha visto?*



Ettore Majorana, ordinario di fisica teorica all'Università di Napoli, è misteriosamente scomparso dagli ultimi di marzo. Diametri 31, alto metri 1,70, snello, con capelli neri, occhi scuri, una lunga cicatrice sul dorso di una mano. Chi ne sapesse qualcosa è pregato di scrivere al R. P. E. Maria-

Becci, Viale Regina Margherita 66 - Roma.



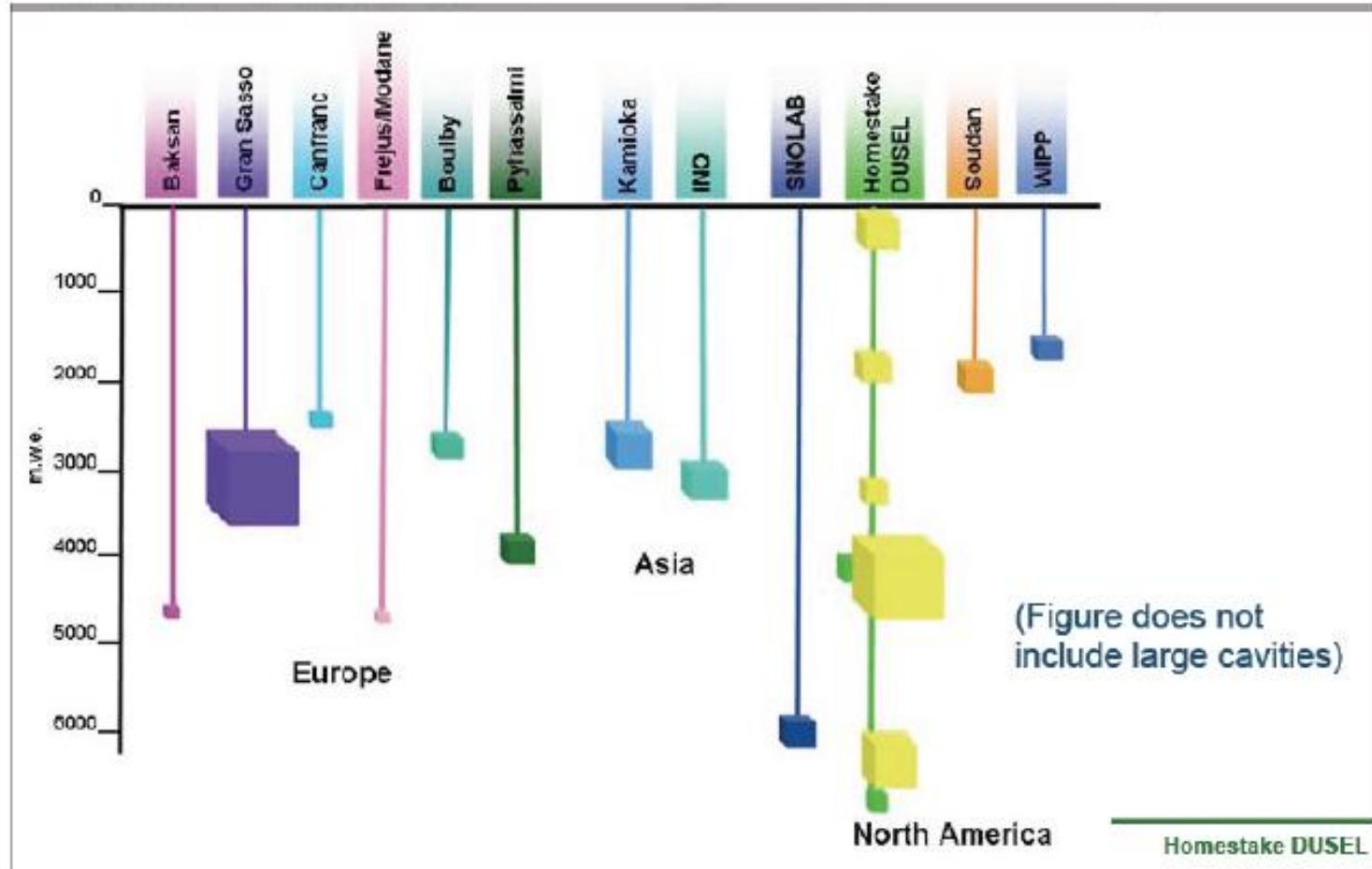
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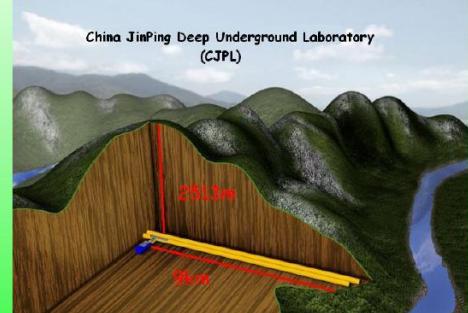
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# Where to go ?

## INTERNATIONAL UNDERGROUND LABORATORIES (Present and Planned)

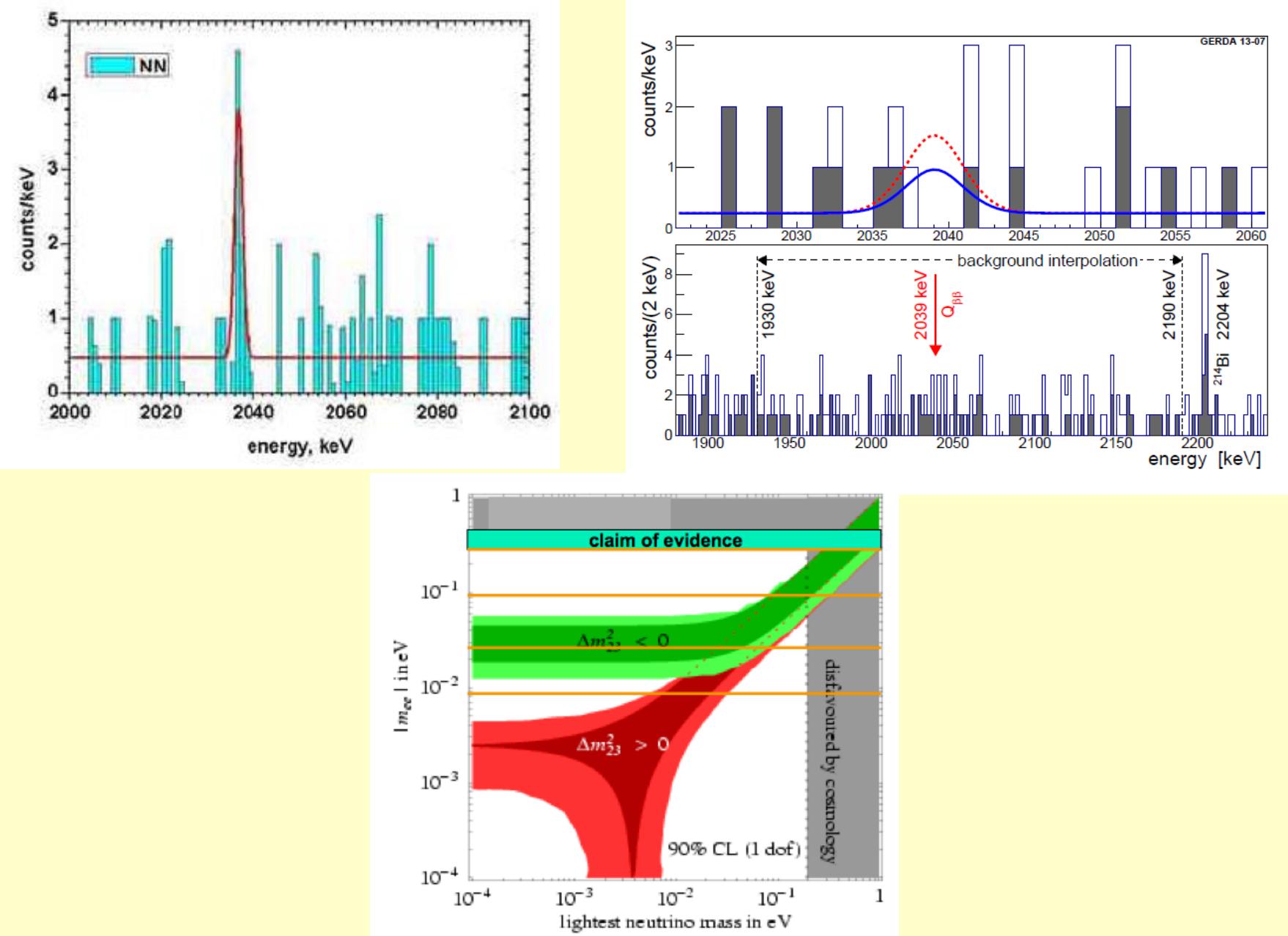




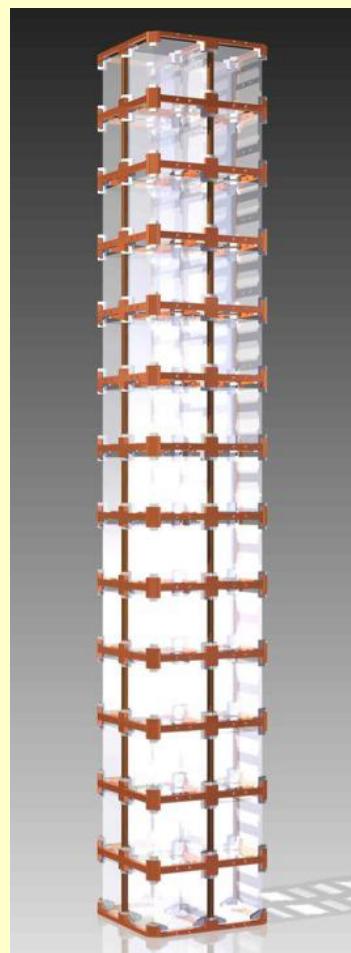
**Table I: present results on neutrinoless DBD**

Nucleus	Experiment	%	$Q_{\beta\beta}$	Enrich	Technique	$T_{0\nu}$ (y)	$\langle m_\nu \rangle$
48Ca	Elegant IV	0.19	4271		scintillator	$>1.4 \times 10^{22}$	20-28
76Ge	IGEX	7.8	2039	87	Ionization	$>1.6 \times 10^{25}$	.23 – .64
76Ge	Klapdor et al	7.8	2039	87	ionization	$1.2 \times 10^{25}$	.29-.81
82Se	NEMO 3	9.2	2995	97	tracking	$>1.1 \times 10^{23}$	1.7-4.5
100Mo	NEMO 3	9.6	3034	95-99	tracking	$>1 \times 10^{24}$	.46-1.1
116Cd	Solotvina	7.5	3034	83	scintillator	$>1.7 \times 10^{23}$	1.2 – 2.7
128Te	Bernatovitz	34	2529		geochem	$>7.7 \times 10^{24}$	.82-1.9
130Te	Cuoricino	33.8	2529		bolometric	$>2.8 \times 10^{24}$	.3-.7
136Xe	DAMA	8.9	2476	69	scintillator	$>1.2 \times 10^{24}$	.64 -1.6
150Nd	Irvine	5.6	3367	91	tracking	$>1.2 \times 10^{21}$	14 - ?

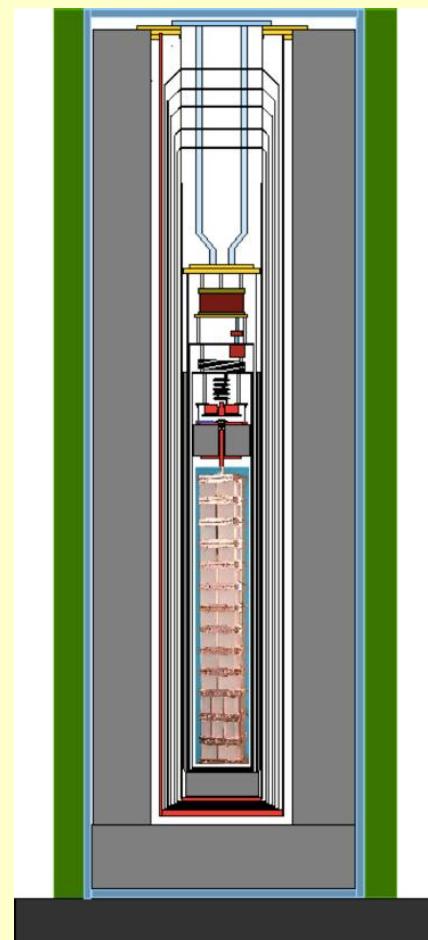
**EXO  $T_{1/2}^{0\nu}$  (136Xe)  $> 1.6 \times 10^{25}$  yr correspond  $\langle m_\nu \rangle$  140–380me**  
**KAMLAND-ZEN  $> 3.4 \times 10^{25}$  yr (Fukushima) 120-250**  
**GERDA I => 0.2 -0.4 eV**



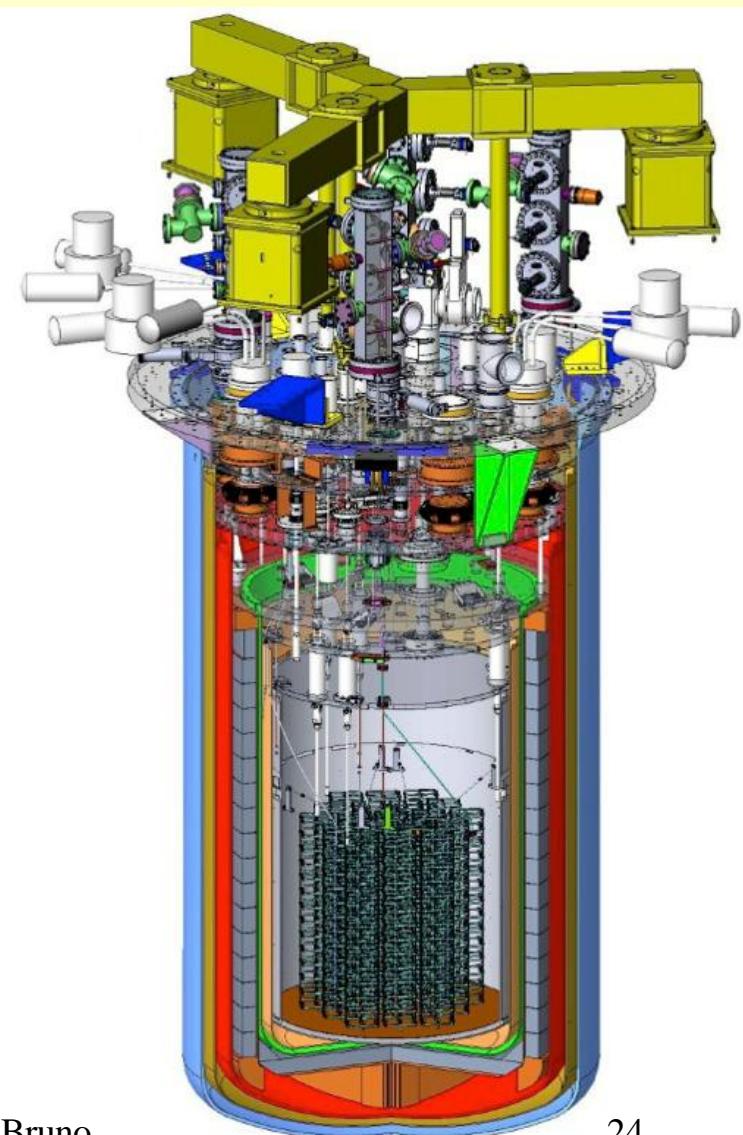
**CUORICINO**



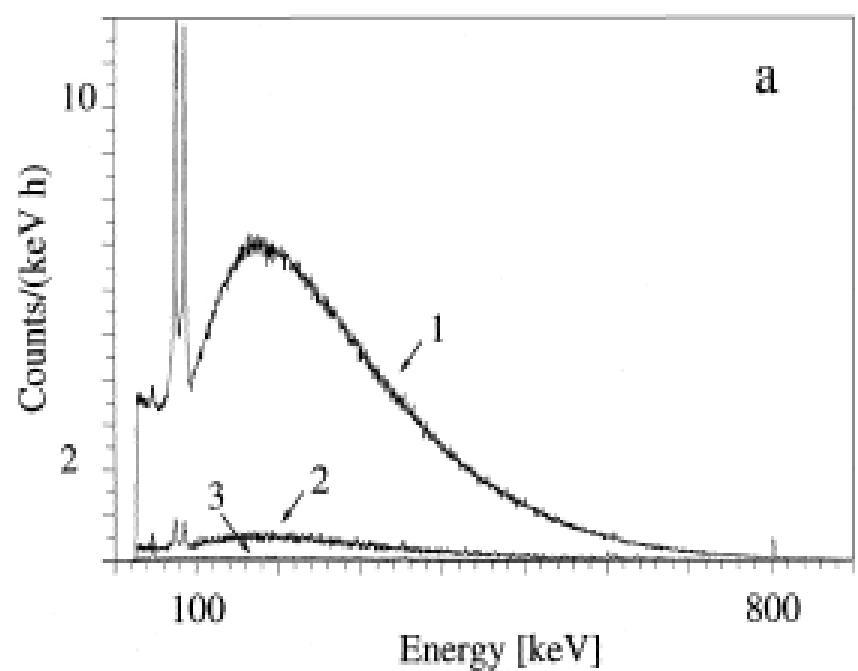
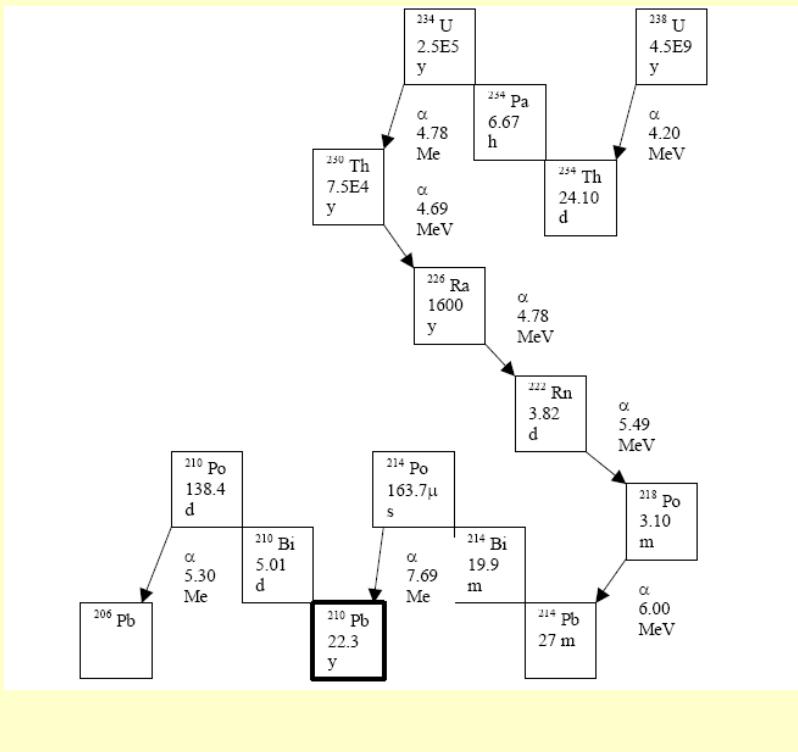
**CUORE0**



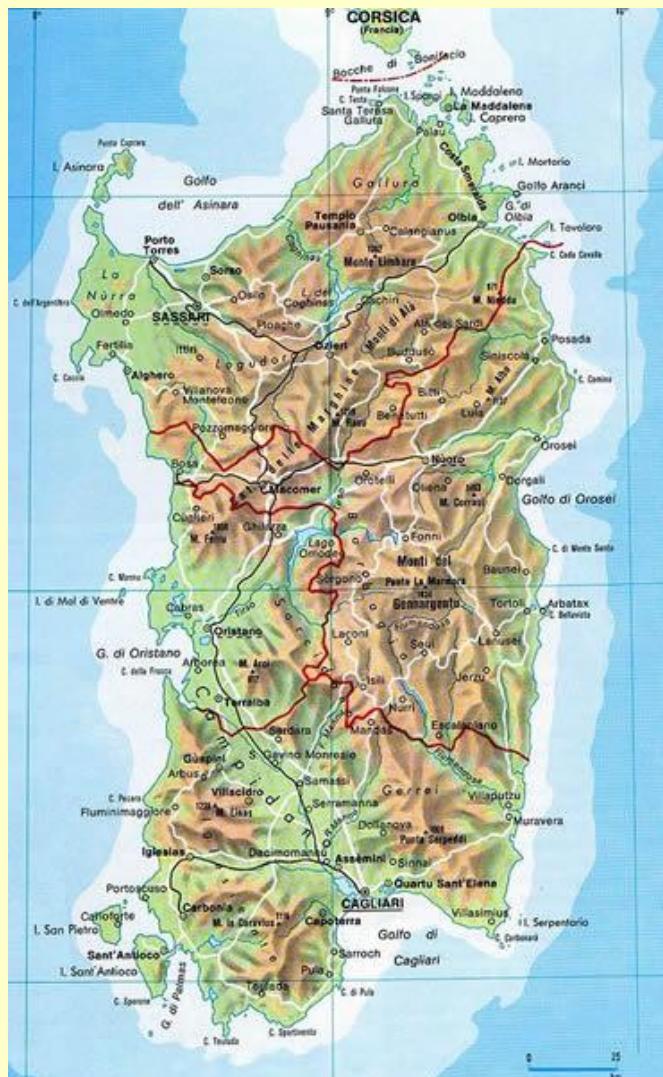
**CUORE**



# But Bruno was interested also in our problem of the Roman lead



# A Roman “*navis oneraria*” sunk in Sardinia

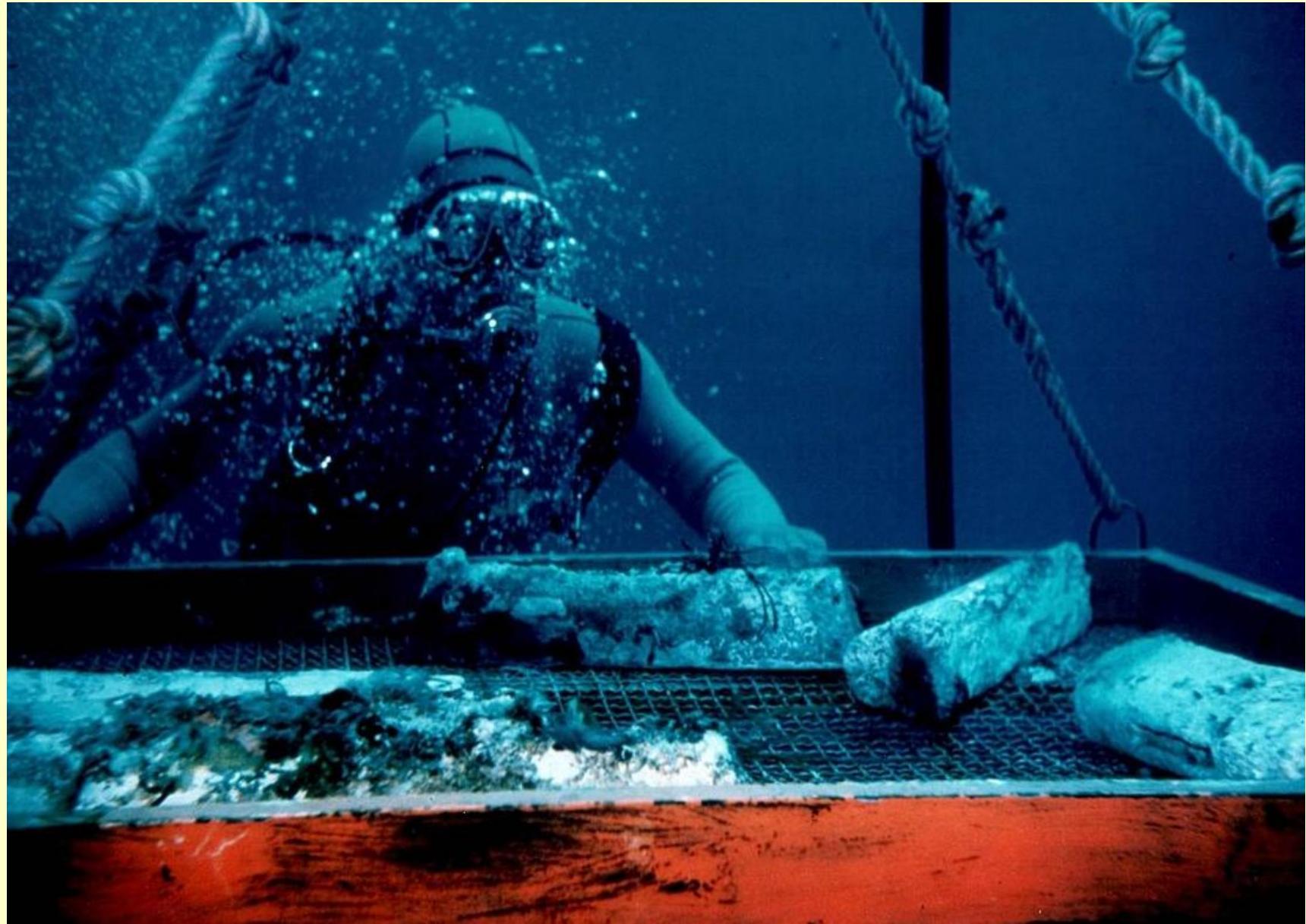




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# AN IMPORTANT RECENT RESULT ON NEUTRINO OSCILLATIONS

$$P(v_a - v_b) = \sin^2 \theta [1.27 \Delta m^2 L(km)/E(GeV)]$$

Only  $\theta_{13}$  was missing !

After an indication by Double Chooz e Japan Results  
from Orient: Daya Bay (China) and RENO (South  
Corea)

$$\sin^2 \theta_{13} = 0.092 \pm 0.016(\text{stat}) \pm 0.005(\text{syst})$$

$$\sin^2 \theta_{13} = 0.103 \pm 0.013(\text{stat}) \pm 0.011(\text{syst})$$

If Bruno would still be alive what a triumph for him!

# A non conventional conclusion

## An Italian and a Russian

**Two examples :**

1. The cabbage
2. The pioneers house

**The best week of my life**

Mail by Samoel :

“Dear Ettore,  
Bruno died yesterday night in the Dubna Hospital. It is a great  
loss for our science and his friends. I worked with him for 22  
years and still thank God for that”