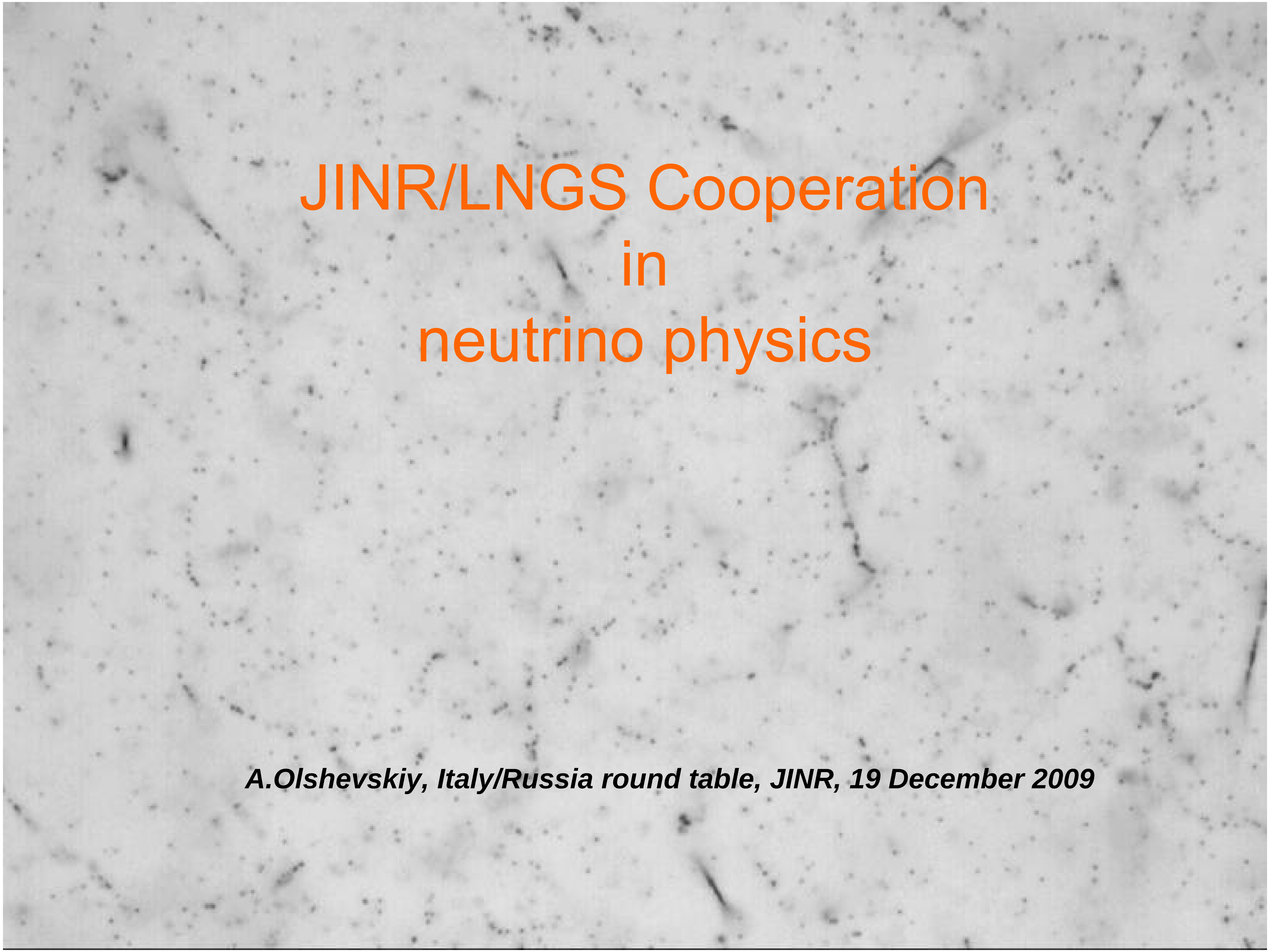
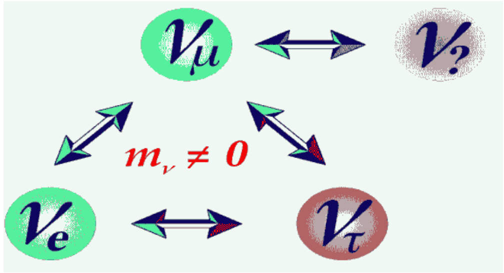


JINR/LNGS Cooperation in neutrino physics

A.Olshevskiy, Italy/Russia round table, JINR, 19 December 2009

50 years of ν oscillations

Бруно Понтекорво

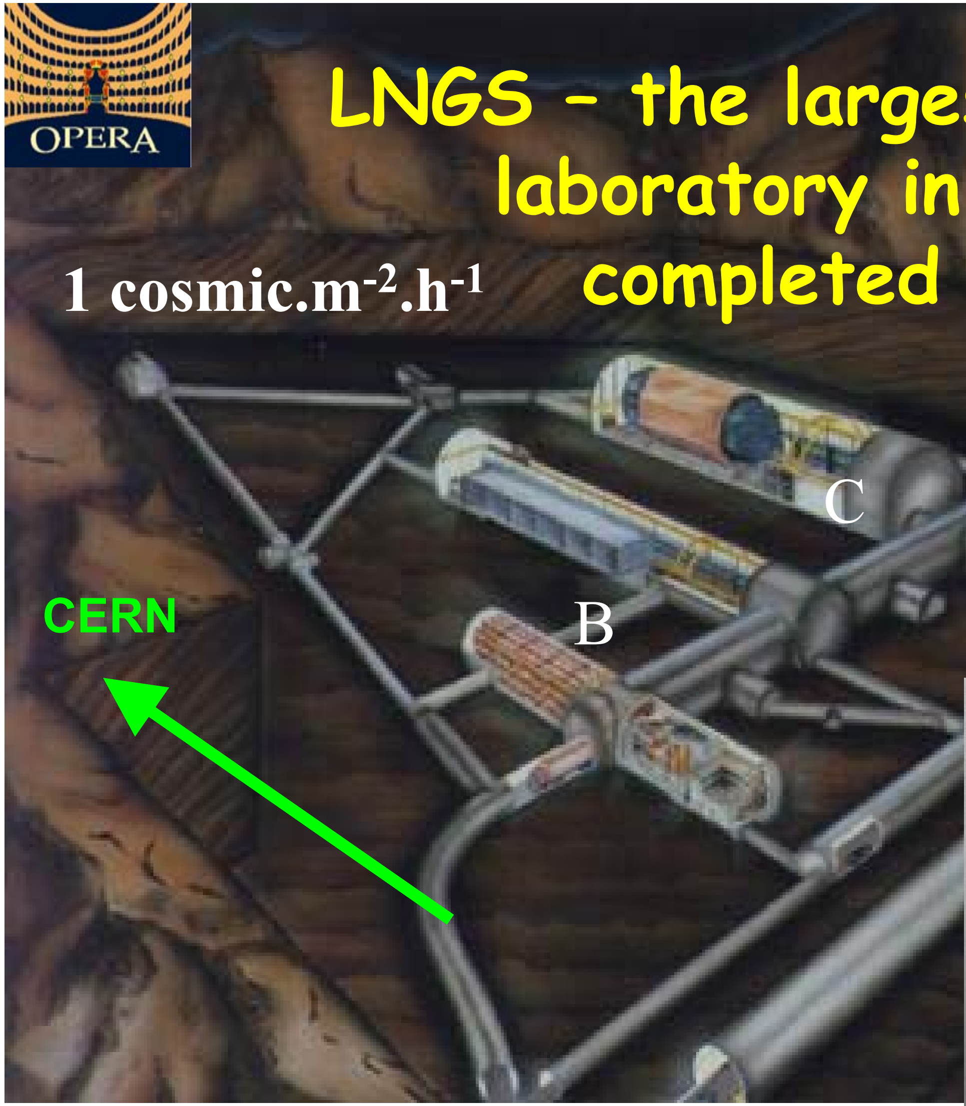


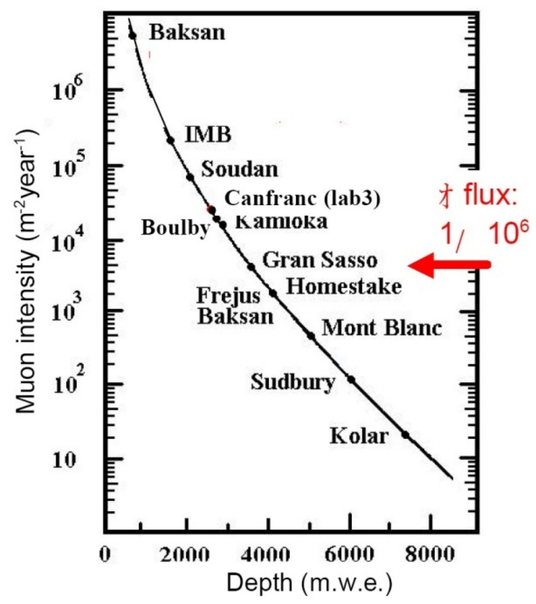
Pontecorvo-Maki-Nakagava-Sakata matrix

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

LNGS – the largest underground laboratory in the world completed in 1987

1 cosmic.$m^{-2}.h^{-1}$

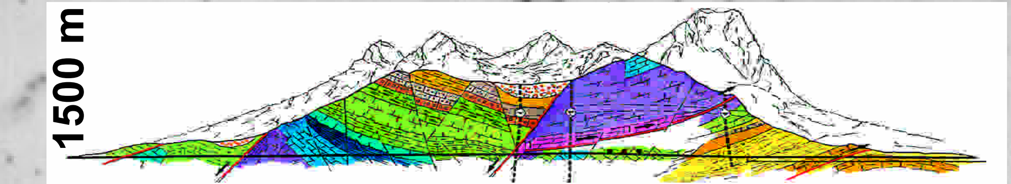


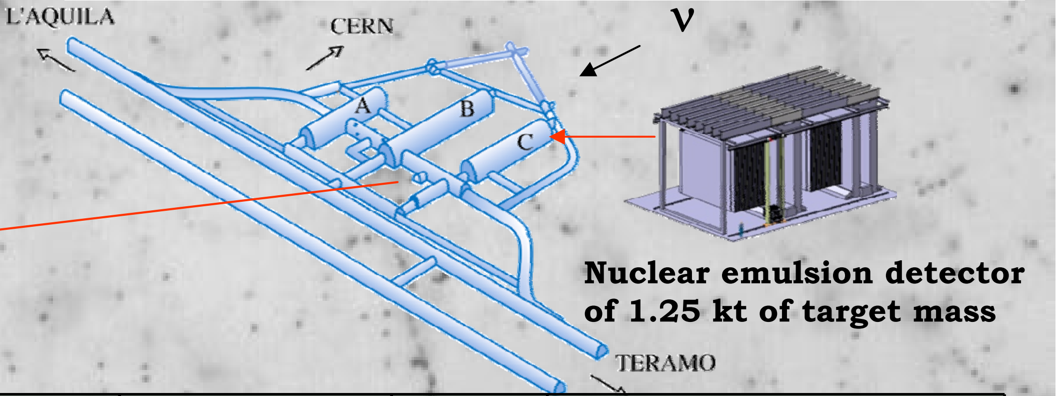


μ flux: 1/ 10^6

OPERA Experiment

OPERA - Direct search for ν oscillations by looking at the appearance of ν_τ in a pure ν_μ beam to explain atmospheric neutrinos anomaly and results of K2K and MINOS





Nuclear emulsion detector of 1.25 kt of target mass

Experiment is taking data now

2006	0.076×10^{19} pot	0 int.	Commissioning
2007	0.082×10^{19} pot	38 int.	Commissioning
2008	1.78×10^{19} **pot**	**1663 int.**	**First physics run**
2009	3.52×10^{19} **pot**	**3715 int.**	**Full physics run. (~**2 tau
Nominal	**4.5×10^{19} pot x 5 year. total 22.5×10^{19} pot**		

Expected produced interactions (22.5×10^{19}):
~25400 ν_μ CC + NC
~170 $\nu_e + \overline{\nu}_e$ CC
~125 ν_τ CC ($\Delta m^2 = 2.5 \times 10^{-3}$ eV^2)

~10 tau decays are expected
to be observed
Less than 1 background
after 5 years running

The OPERA detector

Veto plane
(RPC)

High precision tracker
- 6 4-fold layers of drift tubes

Instrumented dipole magnet
- 1.53 T
- 22 XY planes of RPC in both arms

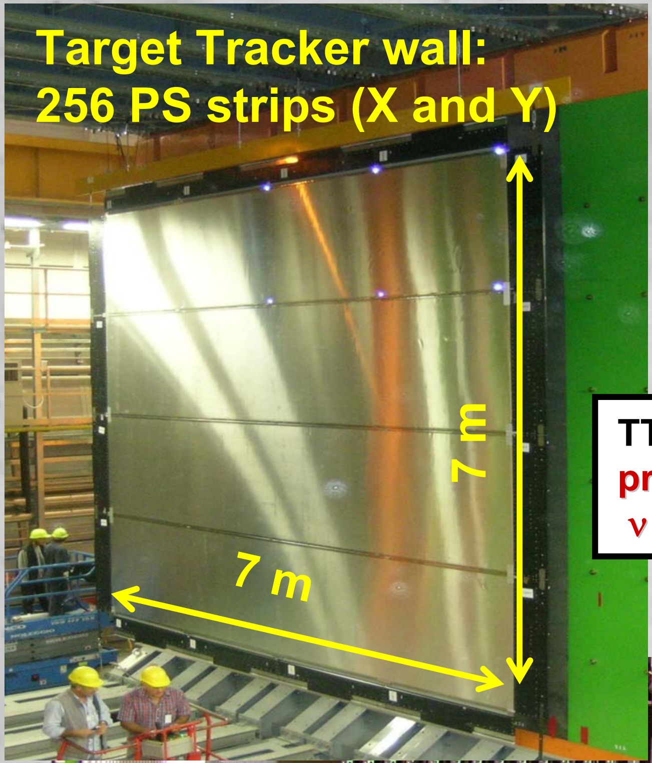
Muon spectrometer (8×10 m^2)

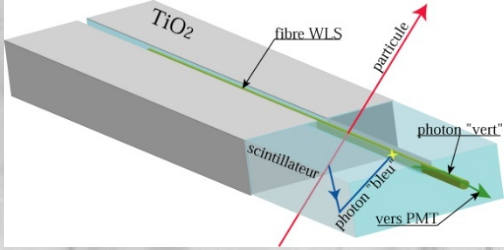
Target and Target Tracker ($6.7m$)^2

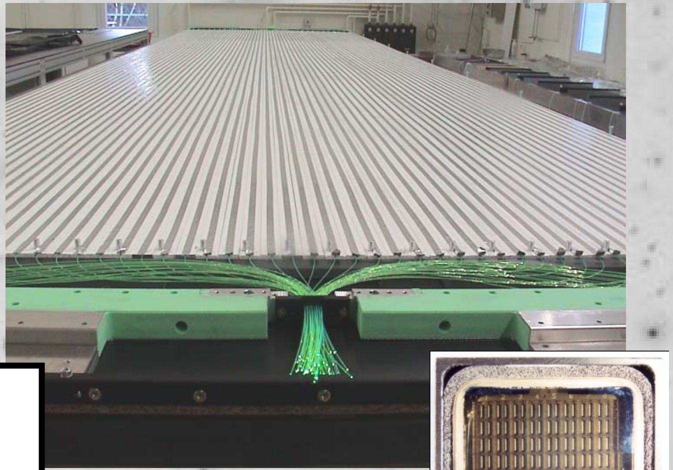
- Target : 77500 bricks, 29 walls

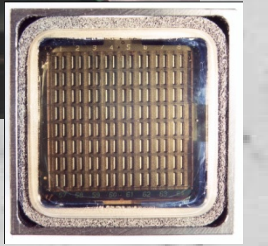
- Target tracker : 31 XY doublets of 256 scintillator strips + WLS fibres + multi-anodes PMT for
  - Brick selection
  - Calorimetry

Target Tracker



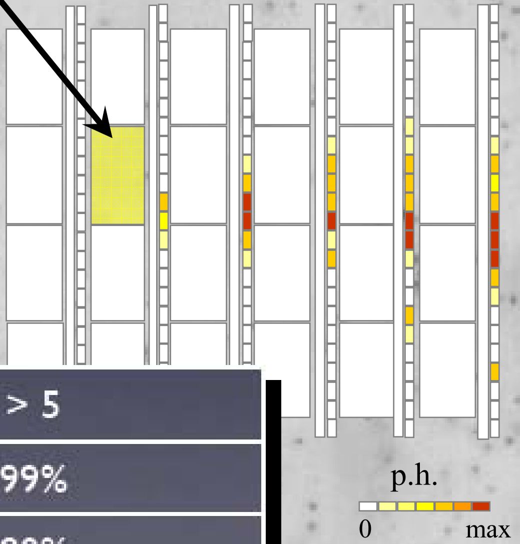


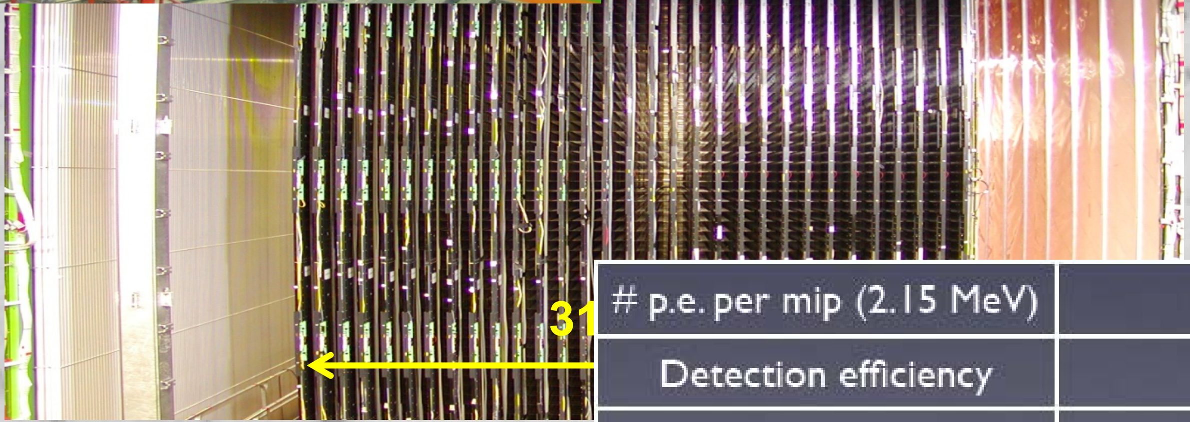




Hamamatsu M64

TT built of PS strips
provides information for
ν interaction brick identification





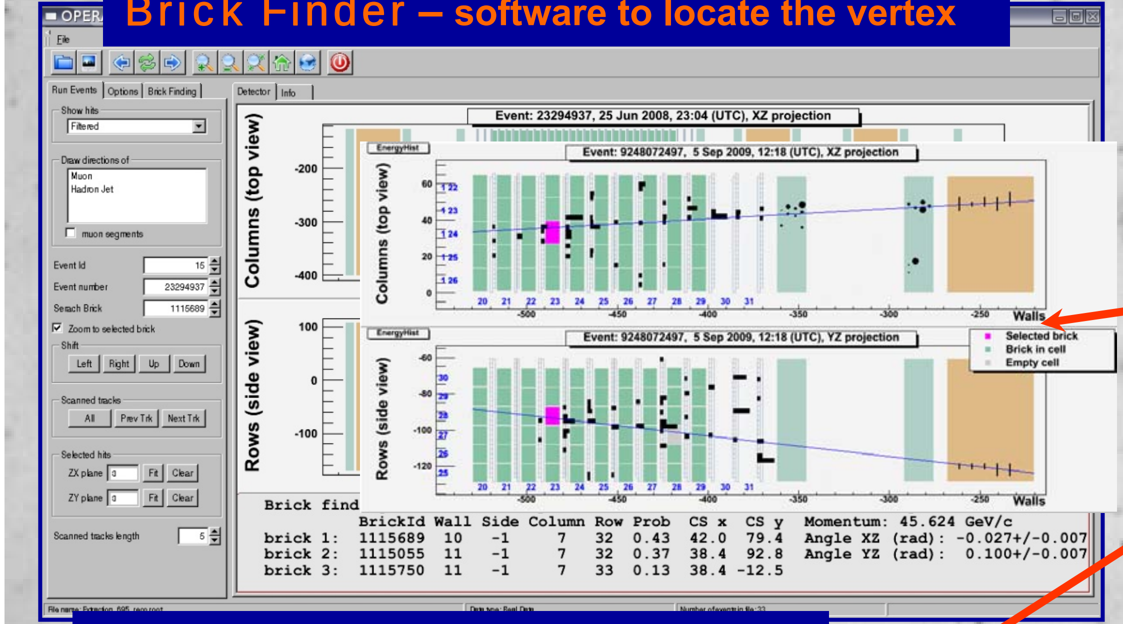
# p.e. per mip (2.15 MeV)	> 5
Detection efficiency	99%
Brick finding efficiency	80%

JINR's responsibilities in OPERA:

8 participants (3 PhD students)

- Target Tracker maintenance and TT data analysis
- Brick Finding software development to select the bricks for extraction and processing
- Emulsion scanning in Dubna
- Physics analysis

Brick Finder – software to locate the vertex



Show hits: Filtered

☐ muon segments

Event Id: 15

Event number: 23294937

Serach Brick: 1115689

☑ Zoom to selected brick

ZX plane: 0

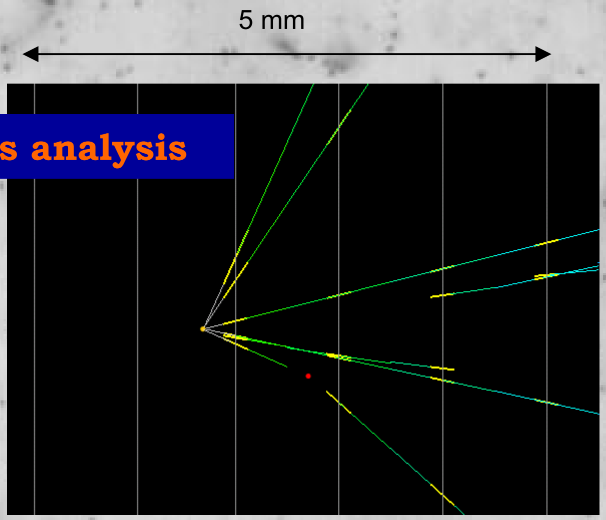
ZY plane: 0

Scanned tracks length: 5

```
Brick find
            BrickId Wall  Side Column Row Prob   CS x   CS y   Momentum: 45.624 GeV/c
brick 1:   1115689  10    -1       7   32  0.43  42.0   79.4   Angle XZ (rad): -0.027+/-0.007
brick 2:   1115055  11    -1       7   32  0.37  38.4   92.8   Angle YZ (rad):  0.100+/-0.007
brick 3:   1115750  11    -1       7   33  0.13  38.4  -12.5
```

Emulsion scanning in Dubna

Data physics analysis



BOREXINO Experiment

BOREXINO Collaboration

BOREXINO GRAN SASSO

INFN

Genova

Perugia

Milano

APC Paris

Princeton University

Princeton University

VirginiaTech
Invent the Future

Virginia Tech. University

ISTITUTO NAZIONALE DI FISICA NUCLEARE INFN
LNGS Laboratori Nazionali del Gran Sasso

JINR 1956-2006 DUBNA

Dubna JINR
(Russia)

Kurchatov
Institute
(Russia)

Jagiellonian U.
Cracow
(Poland)

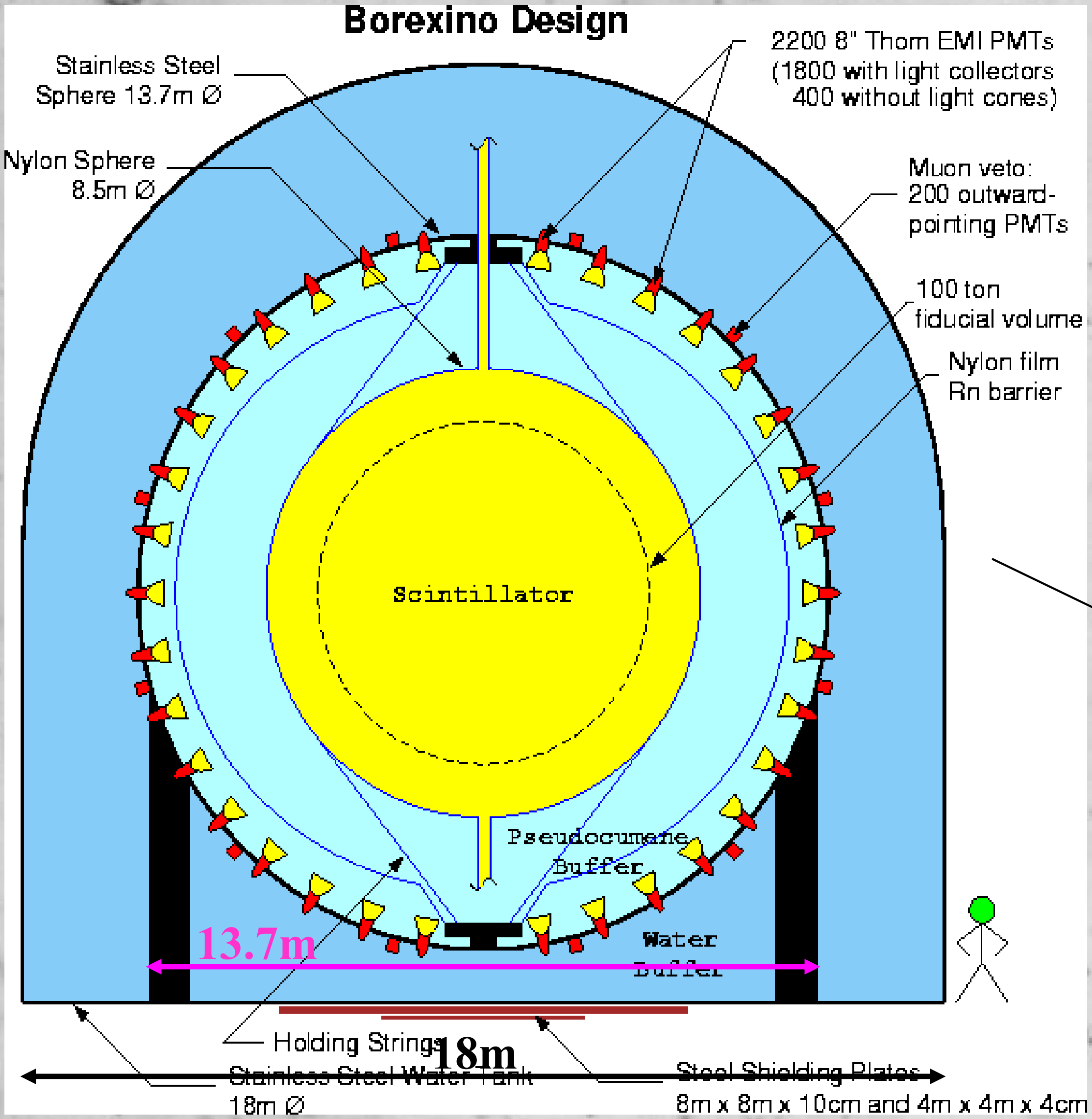
Max-Planck-Institut
für Kernphysik

Heidelberg
(Germany)

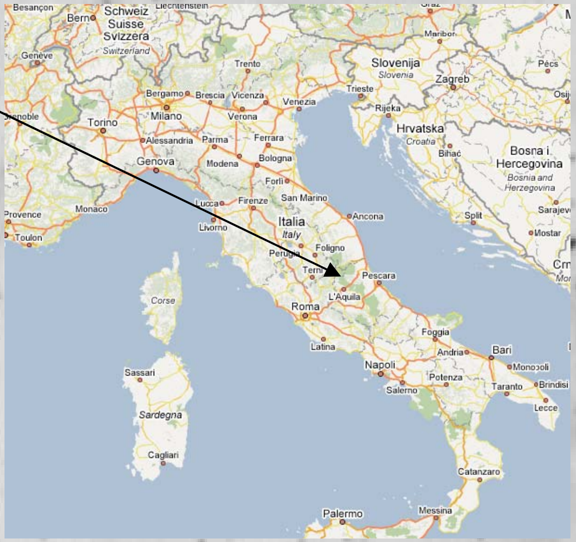
TUM TECHNISCHE UNIVERSITÄT MÜNCHEN

Munich
(Germany)

BOREXINO



- •278 t of liquid organic scintillator PC + PPO (1.5 g/l)
- • (ν,e)-scattering with 200 keV threshold
- •Outer muon detector



A touch of History

1990 A group of physicists started a project having as main goal the detection in real time of the solar ν below 2 MeV (no experimental data on this flux till the start of Borexino in 2007)

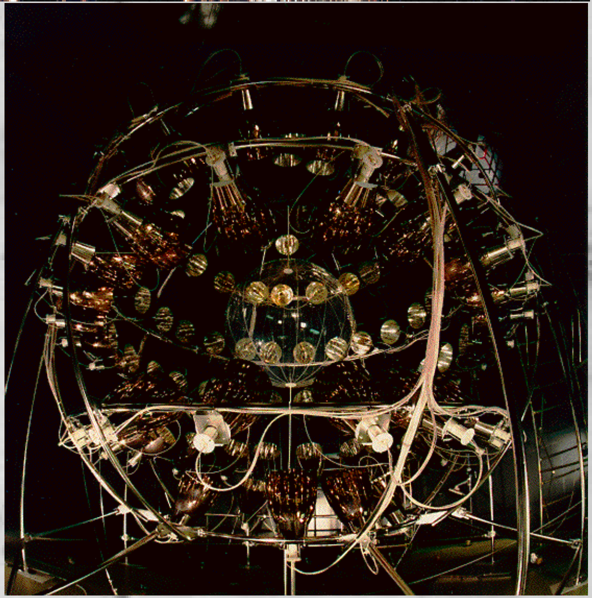
Main choice: use liquid organic scintillator to have more light

Main problem: natural radioactivity: levels $\leq 10^{-16}$g/g : Th, U;

$^{14}C/^{12}C \approx$10-18.

1992-1995 To check ultralow rad. levels the Counting Test Facility (CTF) has been installed, a very high sensitivity detector: sensitivity down to 5 10^{-16} g/g U,Th equiv (still in operation)

1995 The CTF results showed the feasibility, in principle, of the project. (Borex Coll. Phys.Let. B422,1998; Astrop. Phys. 8, 1998; Astrop.Phys.18,2002)



1998 Borexino approved by the funding Agencies

2002-2004 The project blocked for the well known local problems (50 l of LS spill)

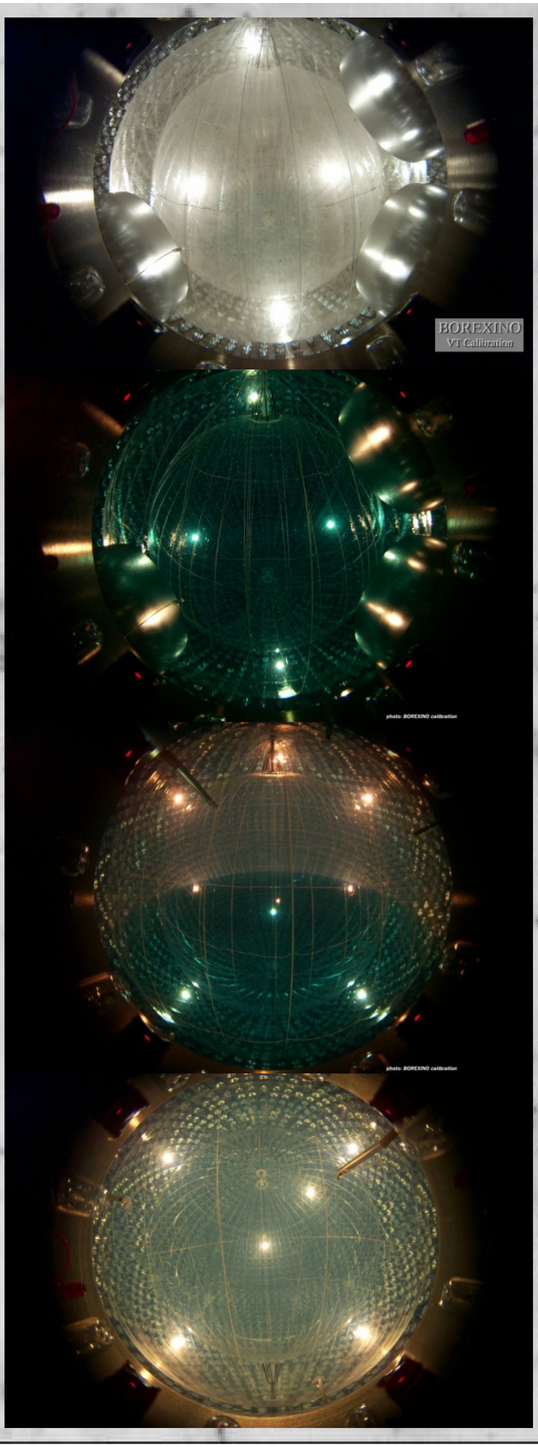
2005 Recommissioning of all setups

Late spring 2006 Restart of all operations, detector filled with purified water

2007 Detector filled with purified scintillator (PC+1.5 g/l PPO), PC plus quencher(5.0 g/l), purified water

May 15th 2007- Borexino starts the data taking with the detector completely filled.

Aug 2007 – first results on 7Be neutrino appeared



Main contributions of Dubna group

In collaboration since 1991

On-line software for CTF; participation in the CTF construction;

PMT test facility and all PMTs tests;

CTF energy scale calibration. CTF data analysis (including rare processes study);

Participated in Borexino off-line code development;

Borexino data analysis (energy calibration, ^{7}Be neutrino analysis, antineutrino detection, rare processes);

Rare processes studied with CTF

1. **Electron decay mode $e \rightarrow \gamma + \nu$:**

   $\tau \geq 4.6 \times 10^{26}$ y
2. **Nucleon and dinucleon “disappearance” ($N \rightarrow 3\nu$, $NN \rightarrow 2\nu$):**

   $\tau \geq (10^{25} - 10^{26})$ y
3. **Magnetic moment of pp- and ^{7}Be-neutrinos:**

   $\mu_{\nu} \leq 5.5 \times 10^{-10}\ \mu_{B}$
4. **Neutrino radiative decay $\nu_H \rightarrow \nu_L + \gamma$:**

   $\tau / m_{\nu} \geq 4.2 \times 10^{3}$ s eV^{-1}
5. **Limits on the Solar antineutrino flux**

   $\varphi < 0.02\varphi$
6. **Emission of heavy neutrino in ^{8}B-decay**

   $|U_{eH}|^{2} \leq 10^{-3} - 10^{-5}$ for $m_{\nu H} = (1 \div 12)$ MeV
7. **Check of the Pauli principle for (n,p) in ^{12}C and ^{16}O nuclei**

   $\tau \geq (10^{26} - 10^{27})$ y
8. **Limits on the 478 keV solar axions emitted in the M1-transition of ^{7}Li*.**

all limits for 90% c.l.

Citation: S. Eidelman *et al.* (Particle Data Group), Phys. Lett. B **592**, 1 (2004) (URL: http://pdg.lbl.gov)

LEPTONS

e

$J = \frac{1}{2}$

Mass $m = (548.57990945 \pm 0.00000024) \times 10^{-6}$ u

Mass $m = 0.51099892 \pm 0.00000004$ MeV

$\left| m_{e^+} - m_{e^-} \right| / m < 8 \times 10^{-9}$, CL = 90%

$\left| q_{e^+} + q_{e^-} \right| / e < 4 \times 10^{-8}$

Magnetic moment $\mu = 1.001159652187 \pm 0.000000000004\ \mu_B$

$(g_{e^+} - g_{e^-})\ /\ g_{\text{average}} = (-0.5 \pm 2.1) \times 10^{-12}$

Electric dipole moment $d = (0.07 \pm 0.07) \times 10^{-26}\ e\,\text{cm}$

Mean life $\tau > 4.6 \times 10^{26}$ yr, CL = 90% [a]

Borexino current results/future

- Borexino operates at purity levels never achieved before, it demonstrated the feasibility of the neutrino flux measurement in sub-MeV region, under the natural radioactivity threshold (4.2 MeV);
- Solar ^{7}Be-ν flux has been measured with 10% accuracy;
- a first measurement of ^{8}B-ν in LS with threshold below 5 MeV (2.8 MeV);
- Borexino results are compatible with MSW/LMA;
- strong limit on neutrino effective magnetic moment is obtained;
- extremely high sensitivity to electron antineutrino has been experimentally confirmed, waiting for more statistics.
- Further calibration and reduction of the error on the ^{7}Be flux down to 5% (further improvements if constraining ^{85}Kr, in this case also the limits on the effective magnetic moment will be improved);
- Seasonal variations of the neutrino fluxes (detector stability, more statistics); other time variations
- More precise measurement of the oscillation probability in the transition region (either due to the higher statistics or due to increase of the FV);
- The CNO and pep-neutrino fluxes measurement (requires cosmogenic ^{11}C tagging);
- The feasibility of the pp-neutrino flux measurement is under study (better understanding of the detector at low energies and the precise spectral shape of ^{14}C is needed);
- Antineutrino studies: geo, reactor, supernova.

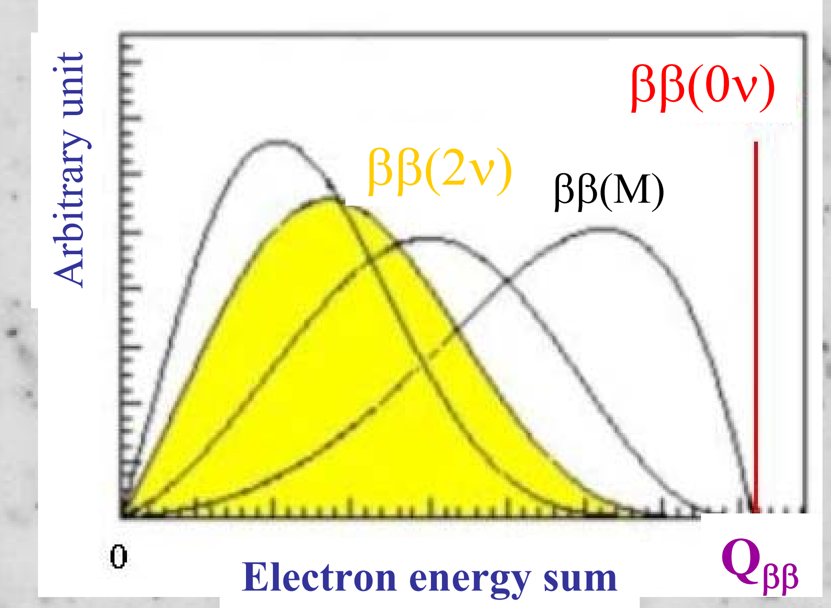
GERDA Experiment

Neutrinoless double beta decay

$$(A,Z) \longrightarrow (A,Z+2) + 2\, e^-$$

Discovery implies $\Delta L=2$ and Majorana neutrino

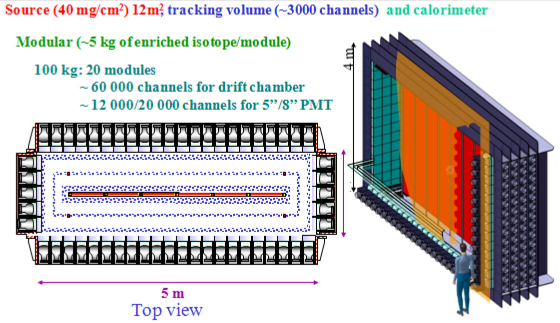
Process:	parameters
Light neutrino exchange	$\langle m_\nu \rangle$
(V+A) current	$\langle m_\nu \rangle, \langle \lambda \rangle, \langle \eta \rangle$
Majoron emission	$\langle g_M \rangle$
SUSY	$\lambda'_{111}, \lambda'_{113} \lambda'_{131}, \ldots$



New generation of experiments

aimed to search for neutrinoless ββ decay

NEMO



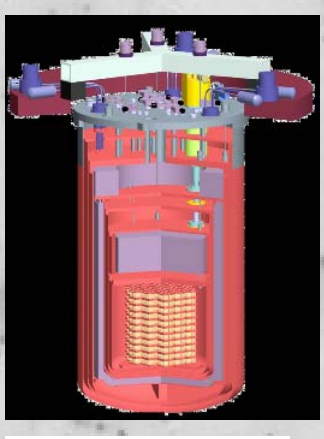
Source (40 mg/cm^2) 12m^2, tracking volume (~3000 channels) and calorimeter

Modular (~5 kg of enriched isotope/module)

100 kg: 20 modules
~ 60 000 channels for drift chamber
~ 12 000/20 000 channels for 5”/8” PMT

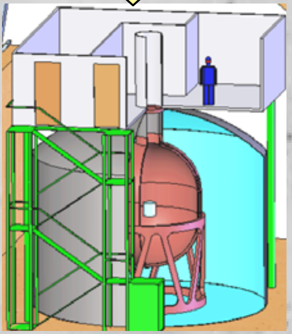
Super NEMO

CUORICINO

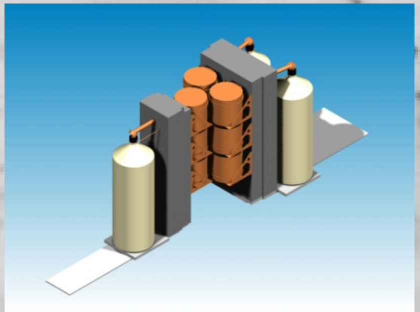


CUORE

HdM & IGEX



GERDA



MAJORANA

GERDA Plans

The commissioning of the main **GERDA** setup at LNGS is scheduled for the end of **2009**.

Phase I (2009 – 2011):

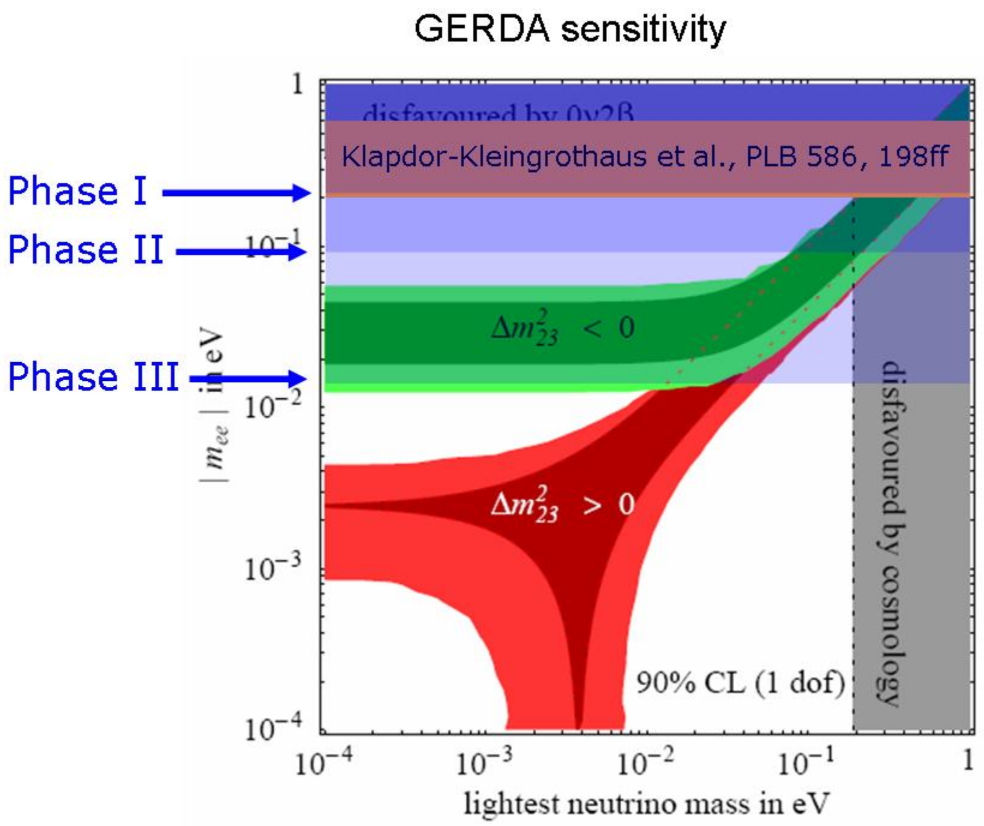
After 2 years of data taking (an exposure of 30 kg x years),
with the background **10^{-2} counts/(keV kg y),**
the GERDA can either confirm the claimed observation of $\beta\beta0\nu$ decay
or refute it at the high statistical level without problems with uncertainties in NME.
If no events will observed, the limit on the half life would amount to **$T_{1/2} > 3 \times 10^{25}$ y**
or, tranlated into an effective neutrino mass, **$m_\nu < 0.3$ eV**, depending on NME used.

Phase II (2012 – 2016):

The total mass with the new types of 76Ge detectors will be 40 kg.
After exposure of 100 kg x years
and with the background reduced up to **10^{-3} counts/(keV kg y),**
the limit on $T_{1/2}$ would improve to **$> 1.5 \times 10^{26}$ y.**
This translates to an upper limit on the effective neutrino mass of **0.07 - 0.17 eV.**

*Phase I will cover the area of sensitivity **required to scrutinize the claim***
*and Phase II will cover **the degenerate neutrino mass hierarchy**.*

Expected sensitivity of the **GERDA** experiment



GERDA

will probe **Majorana nature of neutrino**

with sensitivity at

GERDA phase I :

with background **0.01 cts / (**kg·keV·y)

► to **scrutinize KKDC result within 1 year**

GERDA phase II :

with background **1 cts** / (**ton !**·keV·y)

► to cover **the degenerate neutrino mass hierarchy ($<m_{ee}> < 0.08 – 0.29$ eV)**

phase III :

world wide **GERDA –MAJORANA** collaboration

background **0.1 cts** / (**ton**·keV·y)

► to cover **the inverted neutrino mass hierarchy $<m_{ee}>$ ~10 meV**

Installation of the GERDA

Construction of the GERDA set up started in 2007 in the INFN Gran Sasso National Laboratory (LNGS), Italy. The “nested type” assembly has already installed in the deep underground facility (Hall A) at 3500 m w.e.

Detector string

Glove box & lock

Clean room

Cryostat & μ-veto

Heat exchanger & pipes

Contribution of the JINR team
to the GERDA project

The JINR team contributions to the collaboration tasks in the experiment preparation steps include, in particular,

1. **Modification of existing Ge detectors and testing them in liquid argon for a long term operation;**

2. **Production of the effective veto shields on the base of plastic scintillators;**

3. **Development of new methods of background reduction including active LAr scintillation veto;**

4. **Design and construction of the GERDA test facility LArGe with 1 ton of liquid argon;**

5. **Measurements of radioactive contamination of the construction materials by using low-background Ge gamma-spectrometers;**

6. **Production of specific alpha sources to perform calibrations in LAr scintillators and the system for coordinate manipulation with the sources inside the LAr.**

Conclusion

- JINR/Italy cooperation in neutrino physics at LNGS represents very valuable field of research at the frontier of modern particle physics.

- We are looking forward for realization of our plans and extending Collaboration.