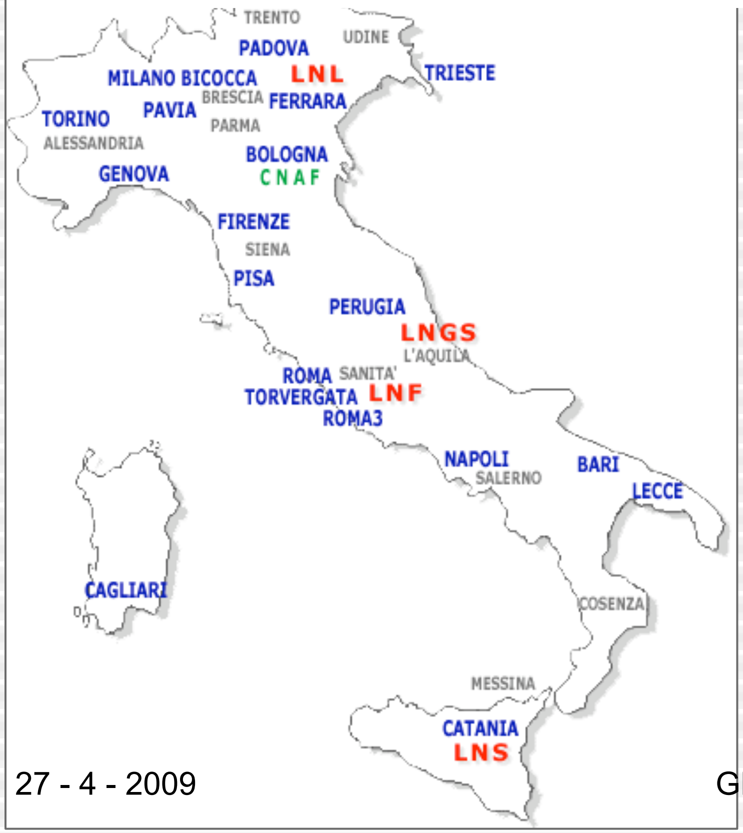
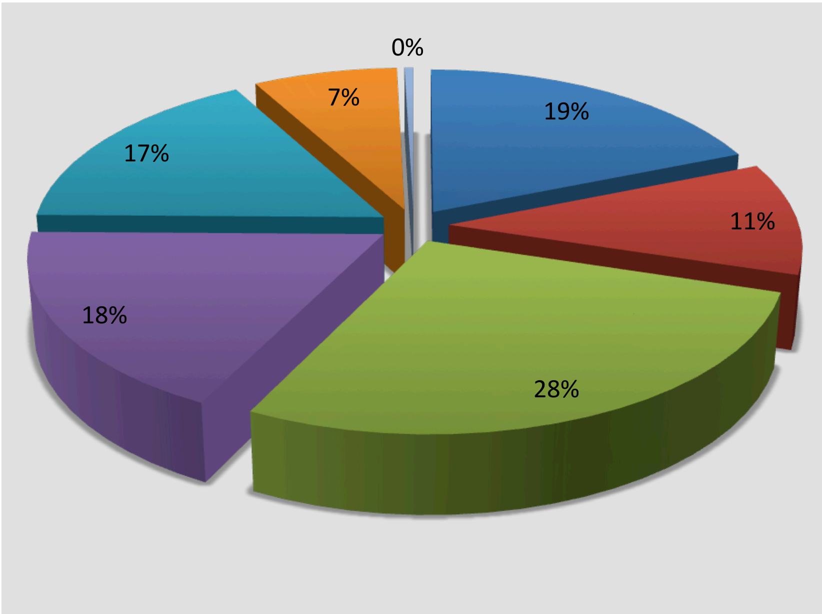
Neutrino Physics in Italy

In Italy activities in Neutrino Physics are funded mainly by the **INFN (Istituto Nazionale di Fisica Nucleare)**
(others are Universities, EU)
The **INFN Scientific Commission 2 (CSN2)** is the coordinating and reviewing body of all activities in Neutrino and Astroparticle Physics

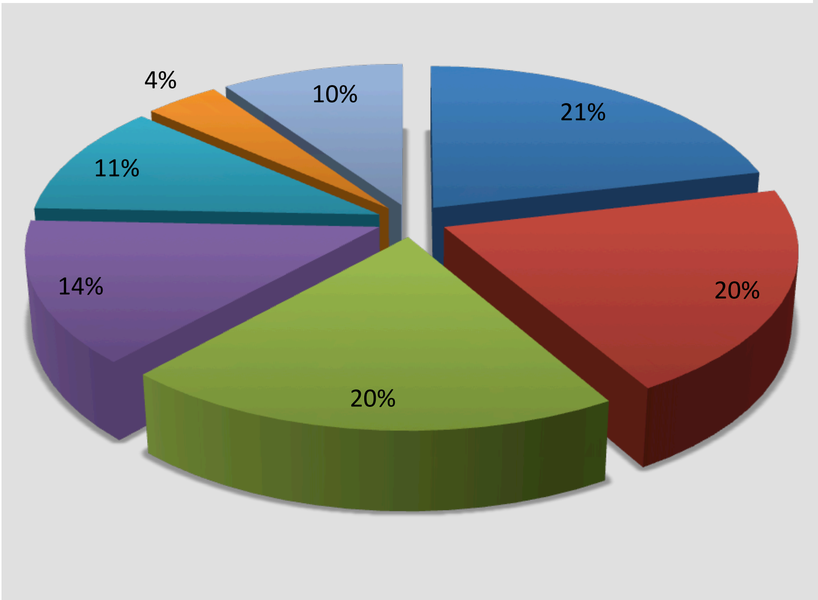


INFN –CSN2 Astroparticle and Neutrino Physics	2009 Budget sharing
Neutrino physics (mainly at LNGS)	25 %
Search for rare processes (DM, $0\nu2\beta$ decay, SNν) (mainly at LNGS)	22 %
Study of the cosmic rays by ground based and underwater experiments	23 %
Study of the cosmic rays by experiments in the space	15 %
Search for gravitational waves	13 %
General physics	2 %

FTE



- Line 1 Neutrino Physics
- Line 2 Rare Processes (Dark matter, 0v2β decays, SN v)
- Line 3 Cosmic rays by ground based and underwater experiments
- Line 4 Study of the cosmic rays by experiments in the space
- Line5 Search for gravitational waves
- Line 6 General Physics
- Others



FUNDING

FTE	674
PEOPLE	857

2008 Funding 16 M€

INFN –Scientific Commission 2 (CSN2)

www.inf.it/csn2/

Neutrino physics (mainly at LNGS)

BOREXINO	ICARUS	OPERA	T2K
GERDA	CUORE	MARE-RD	SciBoone
			BENE

R&D
Running
Construction
Completed in 2008

35% of the 2008 budget of the CSN2 sector
230 Ricercatori
150 FTE Ric (20% CSN2)

The Old Questions	The Search for Answers
How small is the neutrino mass? (Pauli, Fermi, in the 1930s)	*MI-BETA, MANU precursors of* **MARE R&D**
Can a neutrino transform into its own anti-particle? (Majorana, in the 1930s)	CUORICINO **CUORE, GERDA**
Do neutrino flavors transform (“oscillate”) into each other? (Pontecorvo, Maki-Nakagawa-Sakata in the 1960s)	*GALLEX , MACRO (in the 1990s)* **BOREXINO,** **OPERA, ICARUS**

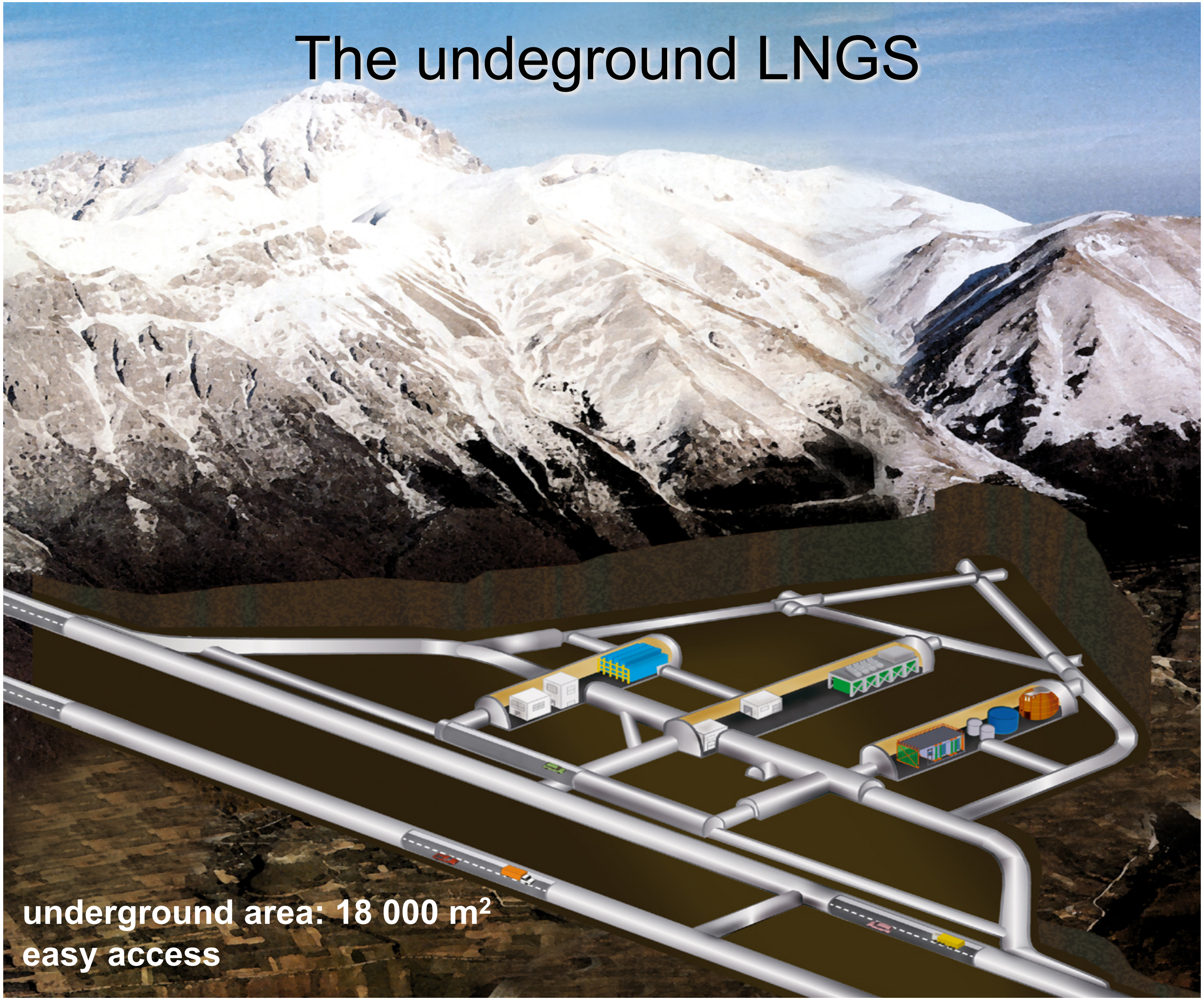
The INFN LNGS, 900 m asl (Abruzzo, Italy)

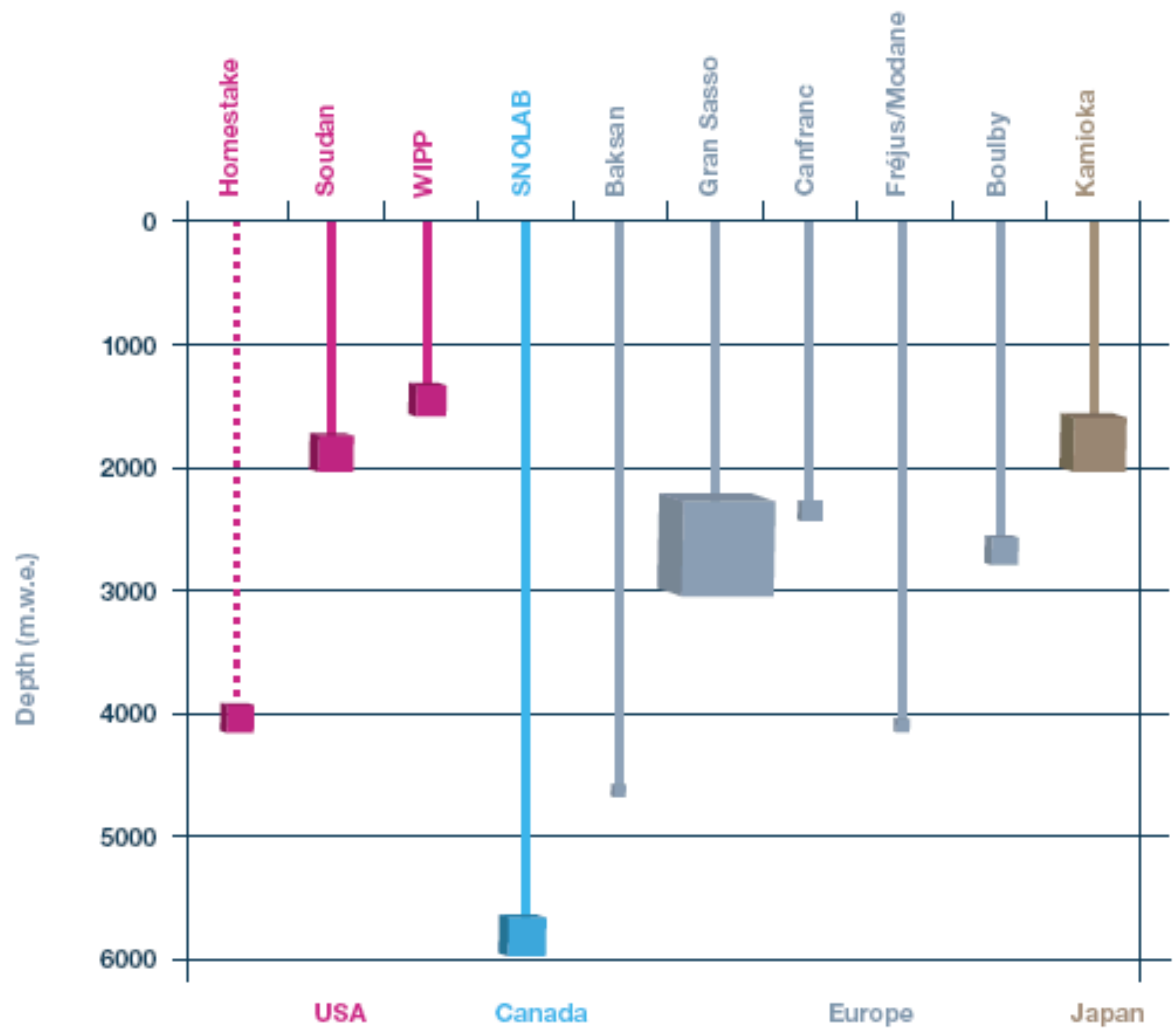
15 km from the epicenter

LNGS News:

1-The dramatic earthquake which hit Abruzzo …caused no damage to the people or the equipment of the Gran Sasso Laboratory. All the running experiments are working smoothly, and the external buildings have been essentially untouched.

2- The date of the regular restart of the activity of the LNGS staff is Monday, May 4th

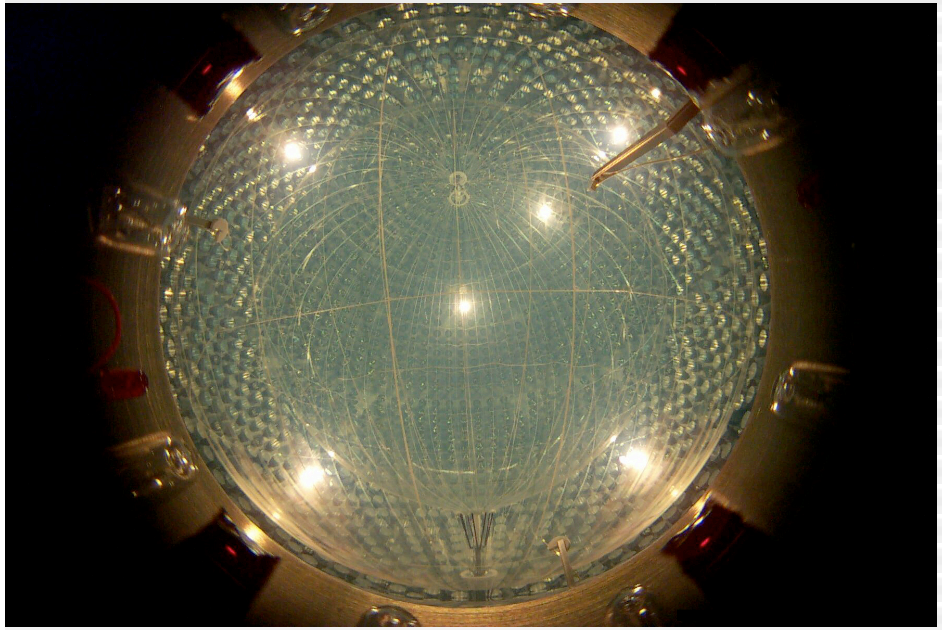

The undeground LNGS
underground area: 18 000 m²
easy access

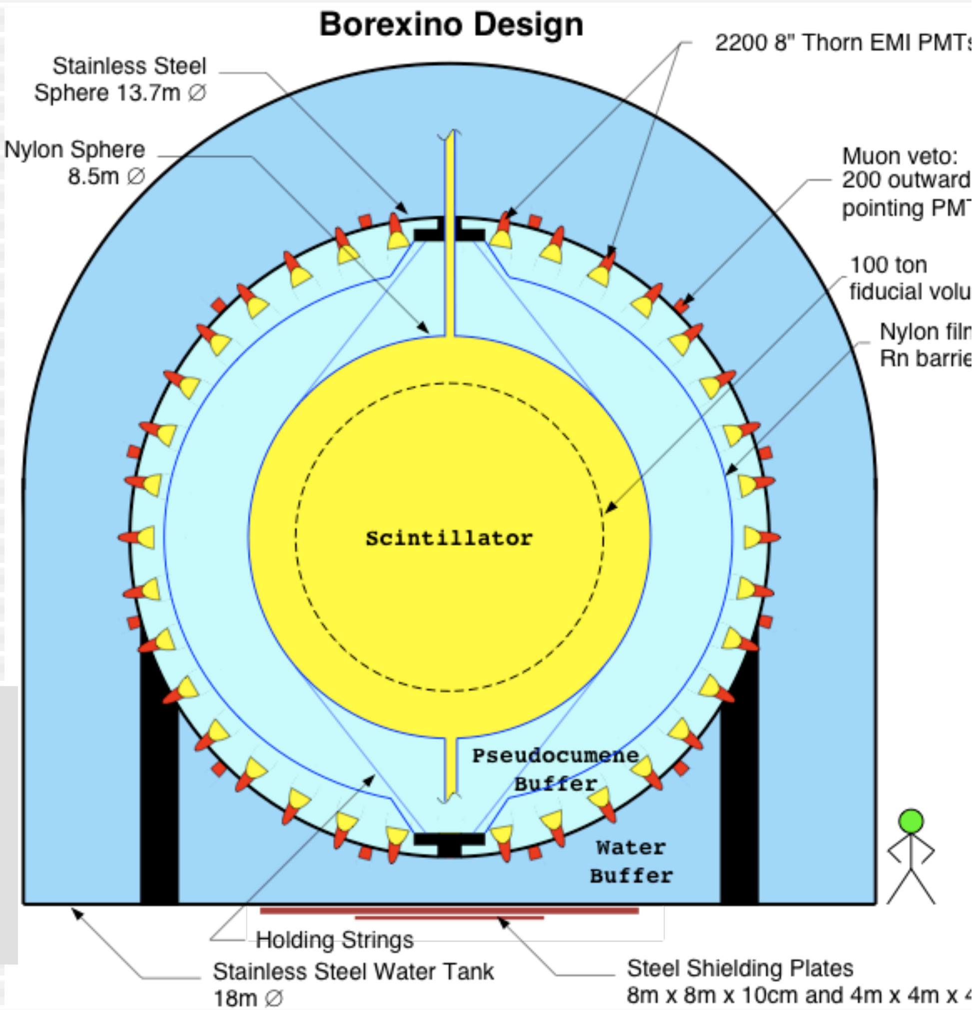

Homestake
Soudan
WIPP
SNOLAB
Baksan
Gran Sasso
Canfranc
Fréjus/Modane
Boulby
Kamioka
0
1000
2000
3000
4000
5000
6000
Depth (m.w.e.)
USA
Canada
Europe
Japan

Borexino @ LNGS

Funding 2009: 820 k€

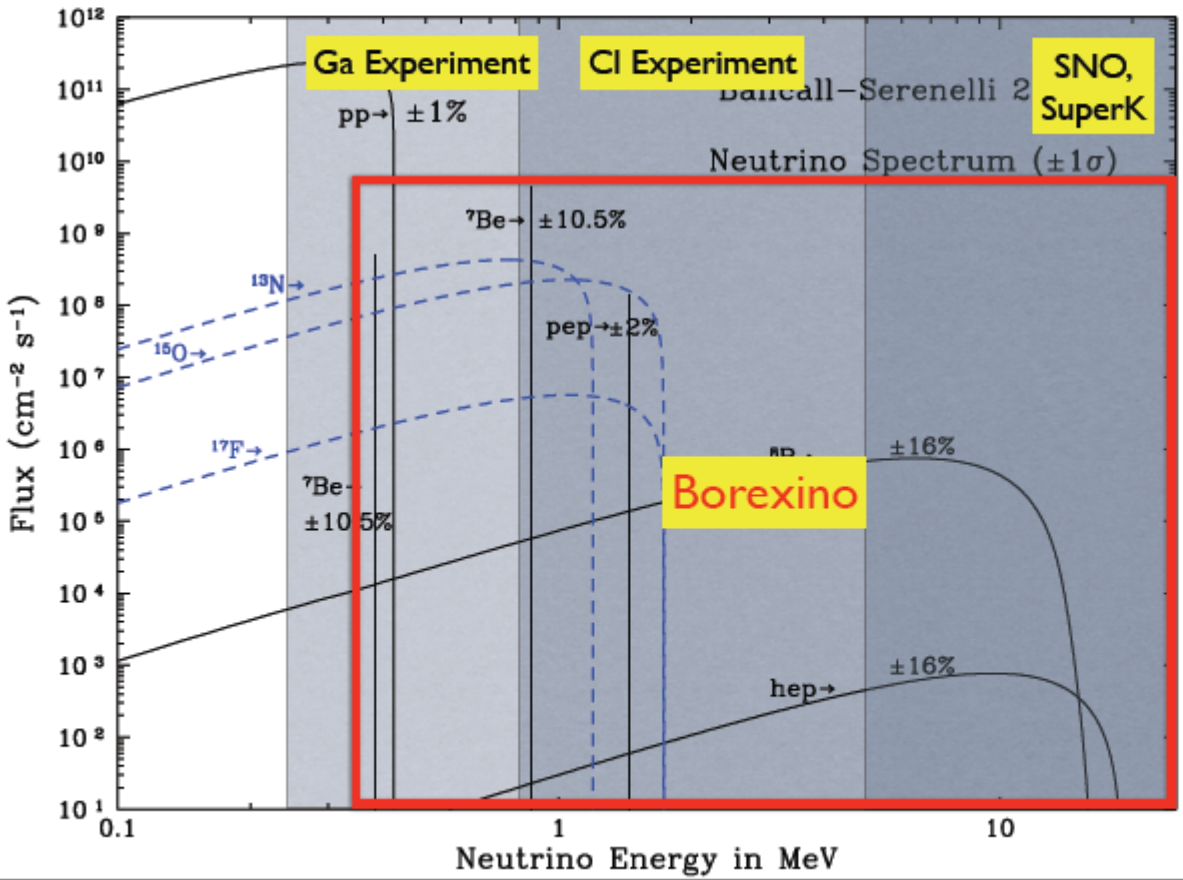
FTE: 22 (29 people)





Main measurement: real time detection of solar ^{7}Be
Borexino Collaboration Phys. Lett. B 658 (2008) :
after 2 months of data taking
Borexino Collaboration PRL 101 (2008) :
192 days of live time

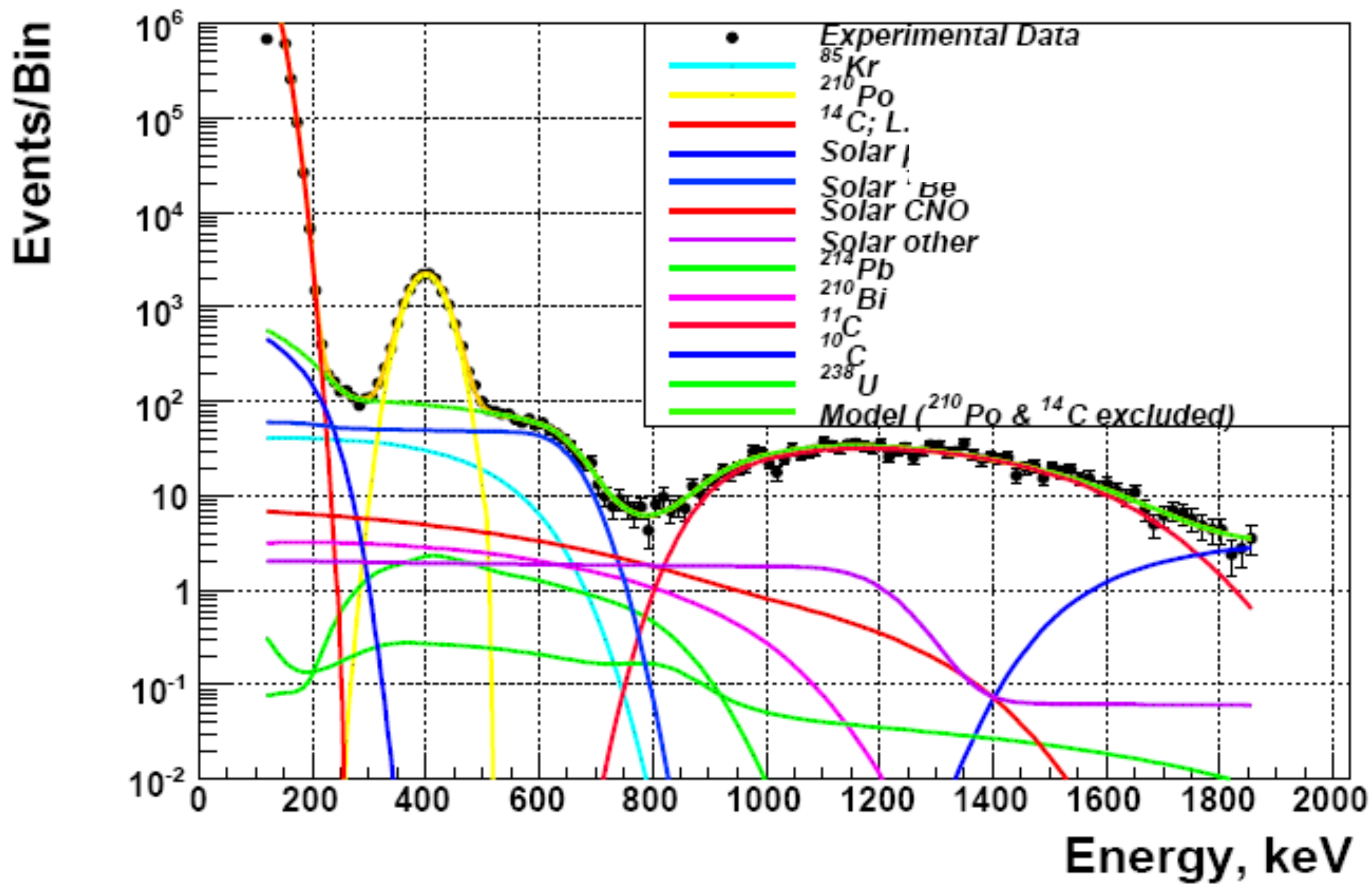
Solar Neutrinos Spectrum



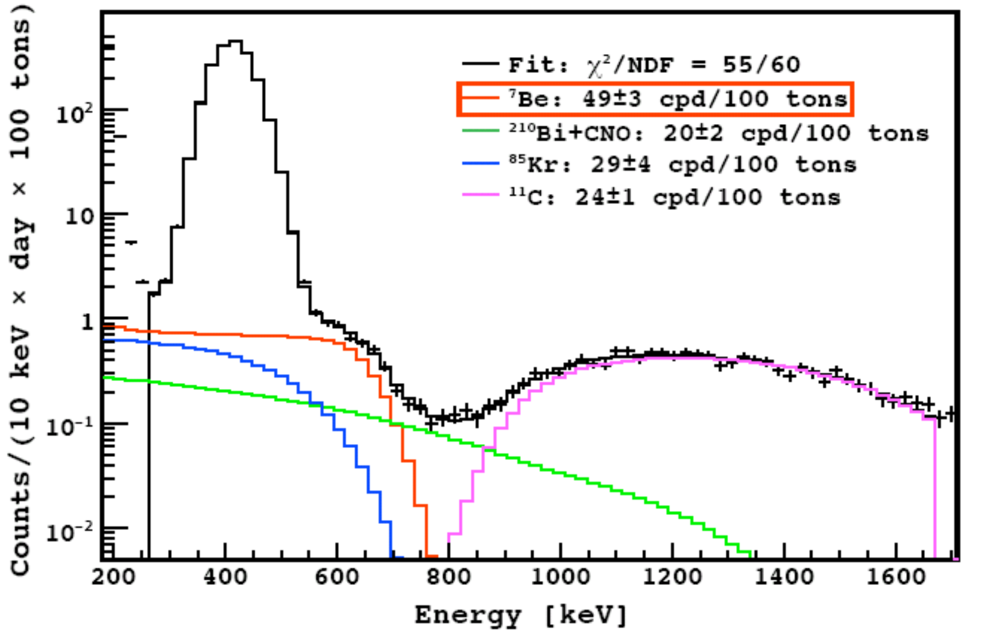
Liquid scintillator purity

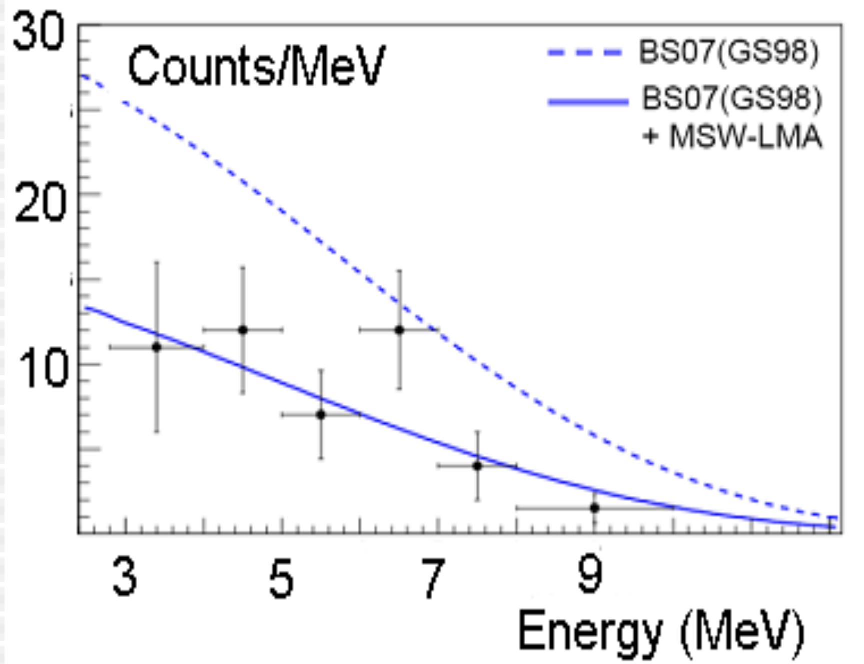
Background	Typical abundance (source)	Borexino goals	Borexino measured
$^{14}C/^{12}C$	10^{-12} (cosmogenic) g/g	10^{-18} g/g	~ 2 10^{-18} g/g
^{238}U (by ^{214}Bi-^{214}Po)	2 10^{-5} (dust) g/g	10^{-16} g/g	(1.6±0.1) 10^{-17} g/g
^{232}Th (by ^{212}Bi-^{212}Po)	2 10^{-5} (dust) g/g	10^{-16} g/g	(5±1) 10^{-18} g/g
^{222}Rn (by ^{214}Bi-^{214}Po)	100 atoms/cm^3 (air) emanation from materials	10^{-16} g/g	~ 10^{-17} g/g (~1 cpd/100t)
^{210}Po	Surface contamination	~1 c/d/t	May 07 : 80 c/d/t Now : few c/d/t
^{40}K	2 10^{-6} (dust) g/g	~ 10^{-14} g/g	< 3 10^{-18} (90%) g/g
^{85}Kr	1 Bq/m^3 (air)	~1 c/d/100t	(28±7) c/d/100t (fast coinc.)
^{39}Ar	17 mBq/m^3 (air)	~1 c/d/100t	<< ^{85}Kr

The measured energy spectrum: May07 – Oct08



^{7}Be and ^{8}B flux measurements





R_{7Be} = 49 ± 3_{stat} ± 4_{sys} cpd/100 tons

Rate>2.8MeV = 0.26 ± 0.04_{stat} ± 0.02_{sys} cpd/100 tons

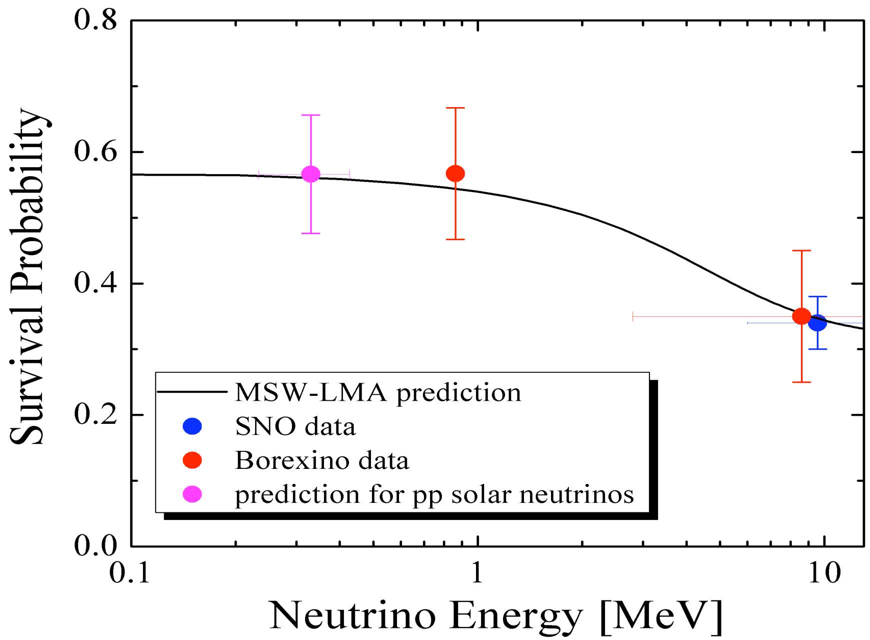
No-oscillation hypothesis rejected at 4 σ level

- **^{8}B flux above 5 MeV agrees with existing data**
- **Neutrino oscillation confirmed by ^{8}B data at 4.2 σ**

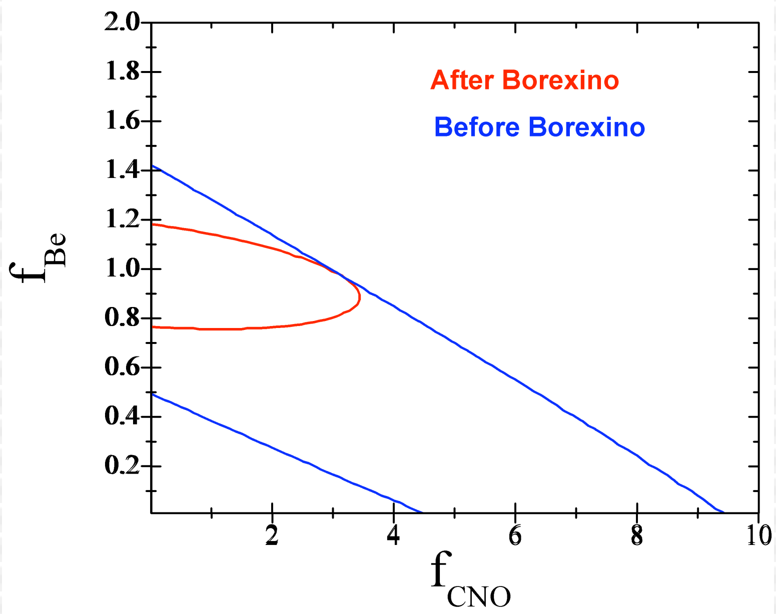
Direct test of MSW mechanism

$\overline{P}_{ee}(^8B) = 0.35 \pm 0.10$ (8.6 MeV)

$P_{ee}(^7Be) = 0.56 \pm 0.10$ (0.862 MeV)

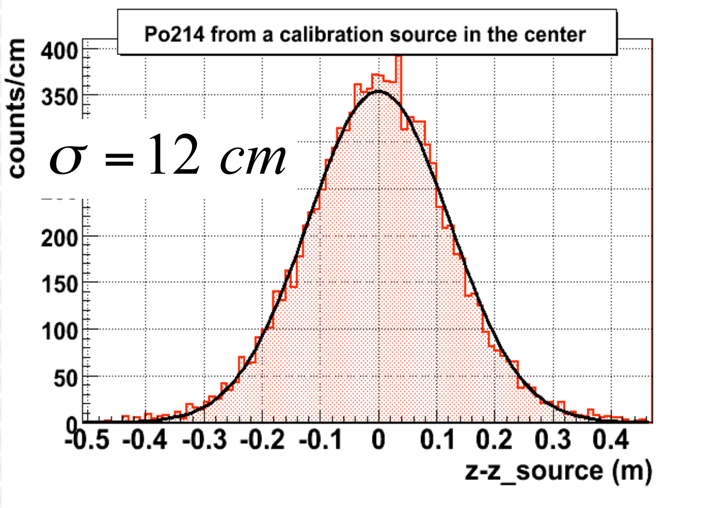


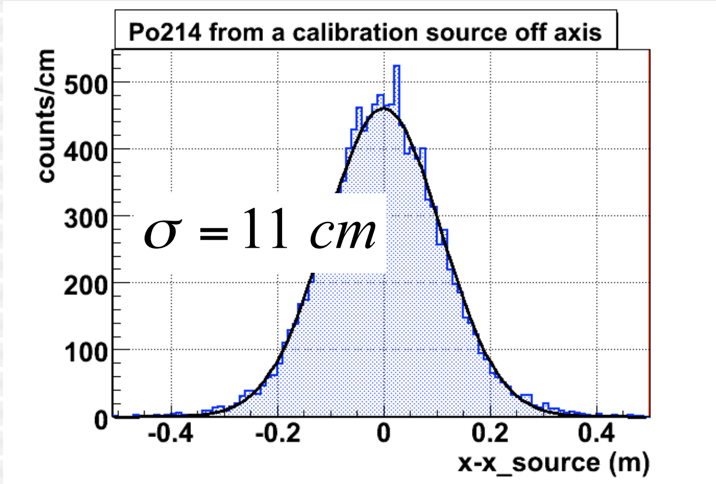
Constraints on pp + CNO flux



ν magnetic moment	
Experiment	90% C.L. 10^{-11} m_B
^{8}B above 5 MeV (SK)	< 11
Reactor n (GEMMA)	<5.8
^{7}Be (BOREXINO)	**<5.4**

Calibration with radioactive sources

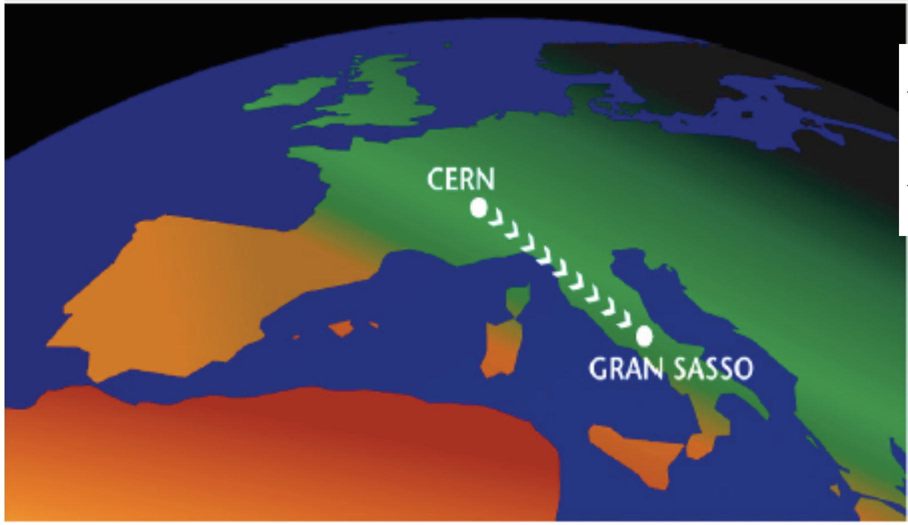




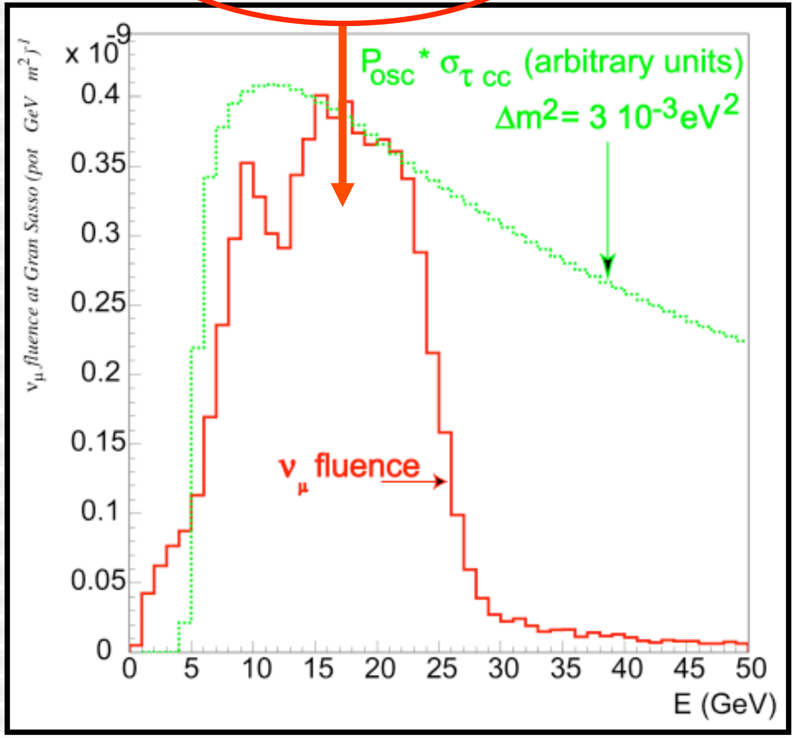
What Next:

- ^{7}Be flux at % level accuracy (SSM precision test)
- pep and CNO (relevant for the sun metallicity "controversy"): limited by ^{11}C background
- ^{8}B increase in statistics
- Supernova neutrinos: Borexino is joining the SNEW community
- Geo-neutrinos. Low Background from reactor neutrino. Expected 7-17 ev/year in 300 t S/N=1.2 . Long term program (~4 anni)

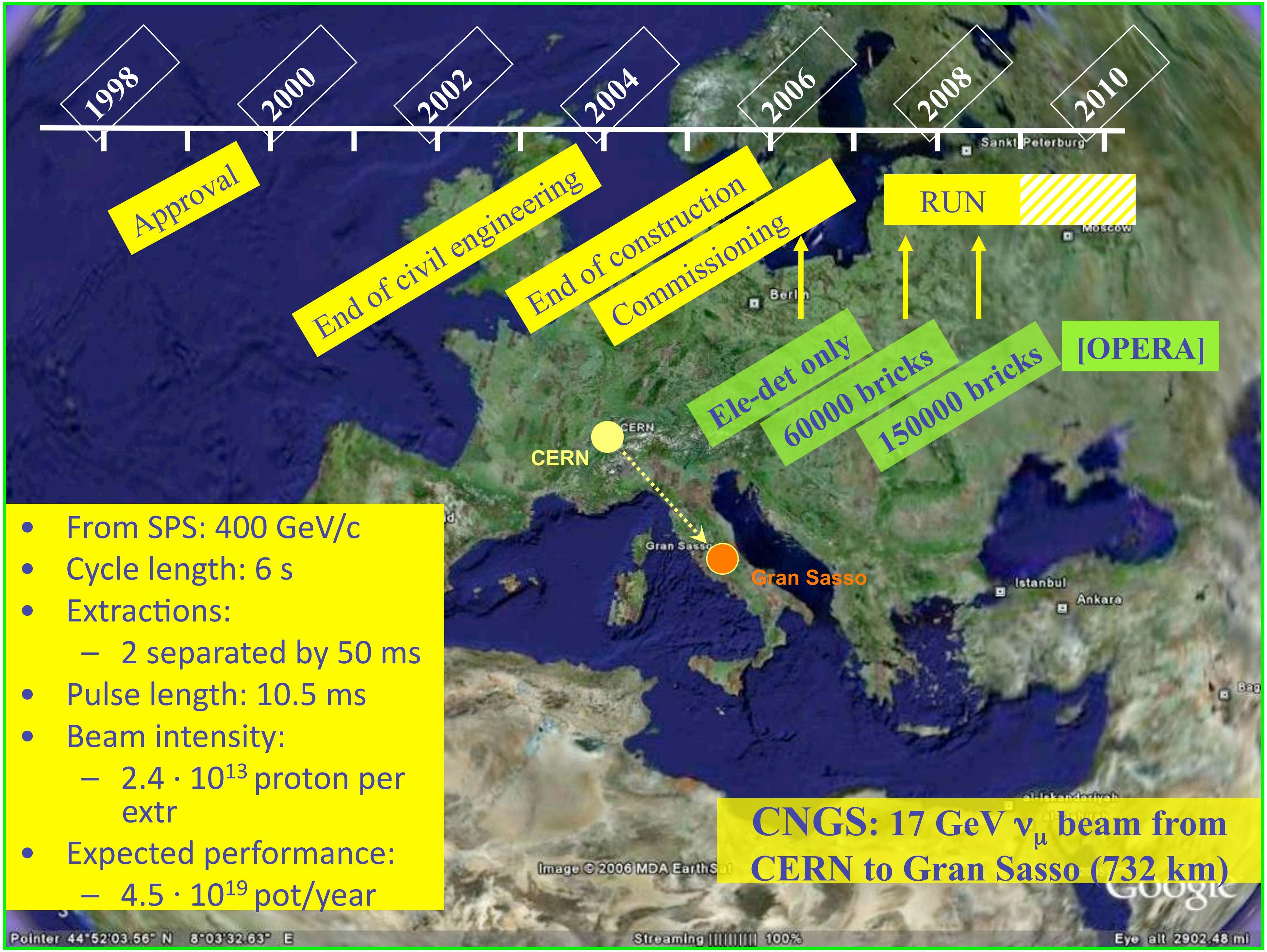
The CNGS program



$$N_\tau = N_A M_D \int \phi_{\nu_\mu}(E) P_{\nu_\mu \to \nu_\tau}(E) \sigma_{\nu_\tau}^{CC}(E) \varepsilon(E) dE$$



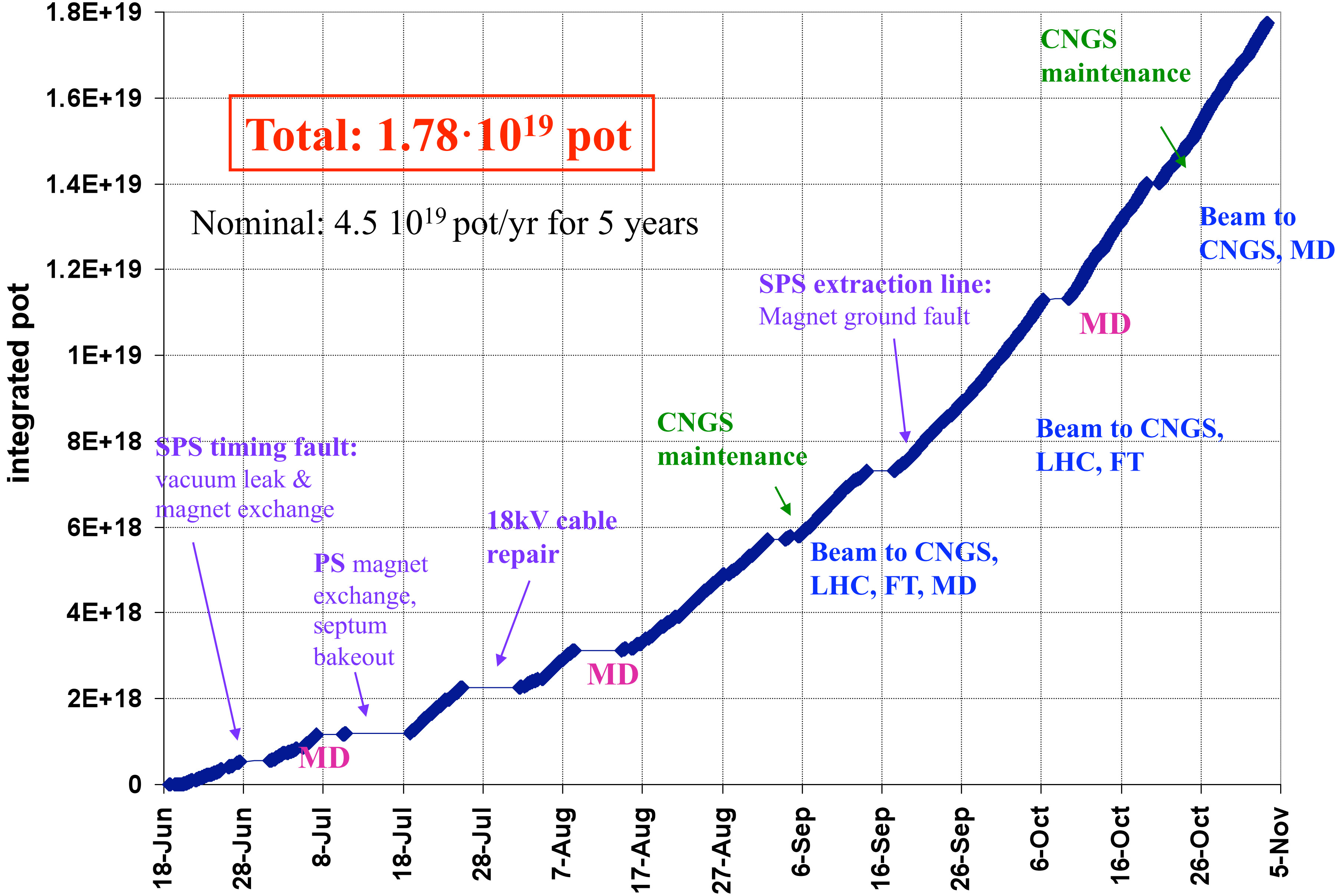
ν_μ CC / kton	2900
ν_μ NC / kton	875
< E_ν> GeV)	17
$(\bar{\nu}_e + \nu_e) / \nu_\mu$	0.85 %
$\bar{\nu}_\mu / \nu_\mu$	2.1 %
ν_τ prompt	negligible
proton/year	$4.5\,10^{+19}$



CNGS: 17 GeV ν_μ beam from CERN to Gran Sasso (732 km)

- From SPS: 400 GeV/c
- Cycle length: 6 s
- Extractions:
  - 2 separated by 50 ms
- Pulse length: 10.5 ms
- Beam intensity:
  - $2.4 \cdot 10^{13}$ proton per extr
- Expected performance:
  - $4.5 \cdot 10^{19}$ pot/year

CNGS Run 2008: 18 June - 03 Nov 2008



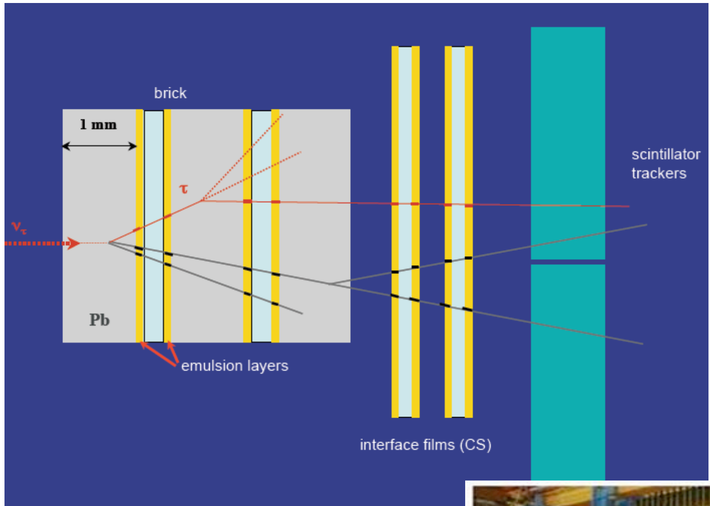
OPERA

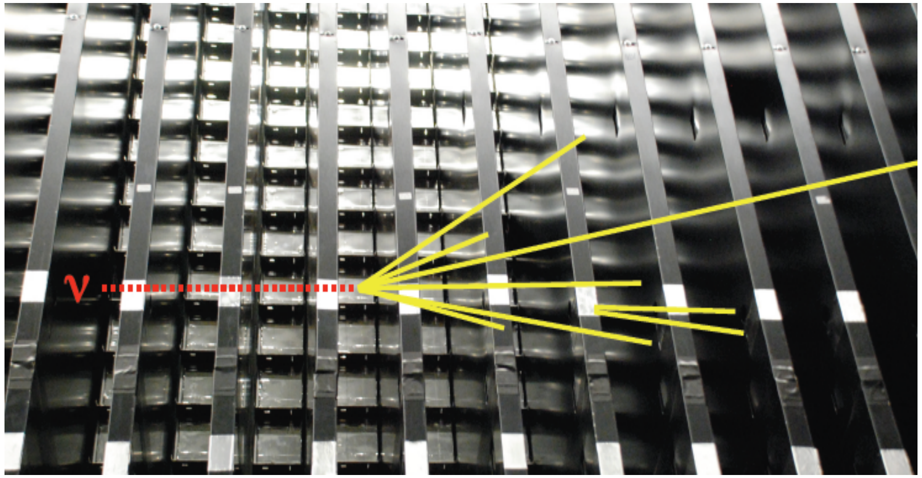
Funding 2009: 1630 kE

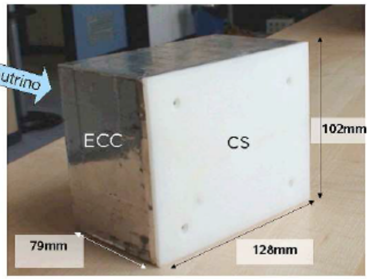
FTE: 53.4 (66 people)

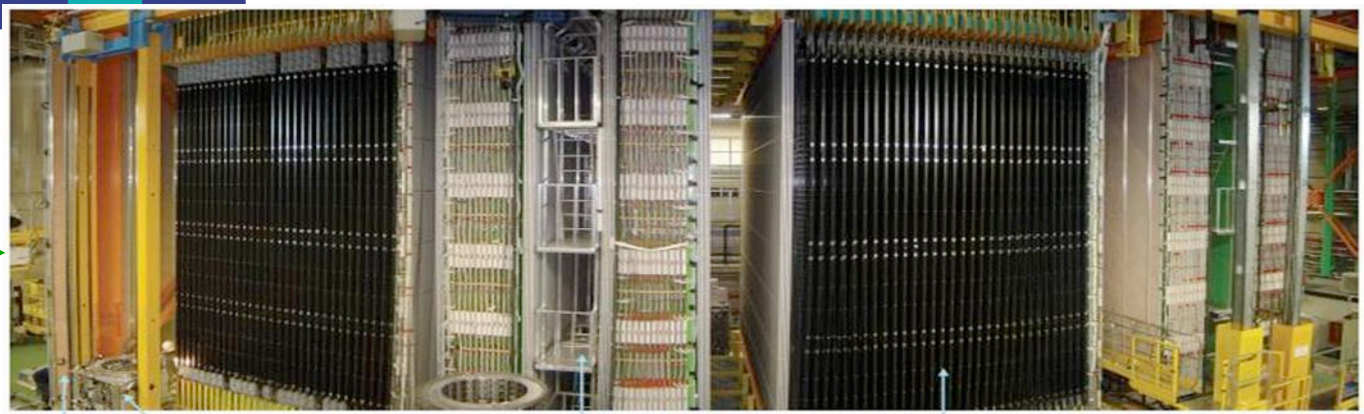
OPERA is based on the only proven technology (DONUT) to identify ν_τ on an event-by-event

It will be firstly celebrated as a **major engineering achievement** since it brought such technology to an **immense size** (1.25 kton)







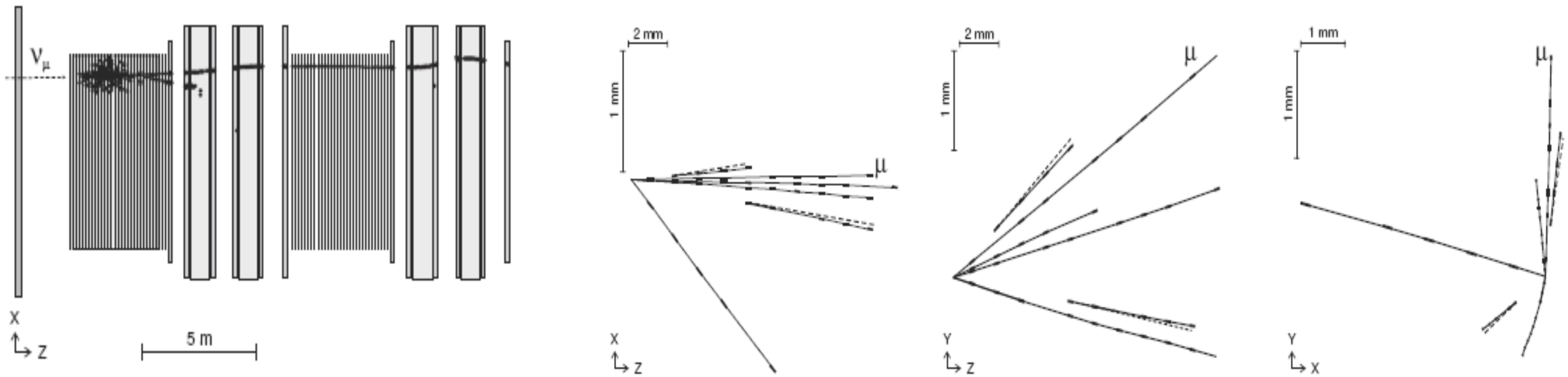


*) R.Acquafredda et al., "The Opera experiment in the CERN to GS ν beam"; submitted to JINST

OPERA as a hybrid detector

• Prediction of the brick where the interaction occurred	**Part. validated (*)**
• Alignment and development of the Changeable Sheets	**Fully validated**
• Scanning of the Changable Sheets	**Fully validated**
• Extraction of the Bricks at the rate of CNGS events	**Fully validated**
• Identification of the primary vertex	**In progress (**)**
• Kinematic reconstruction and decay search	**In progress (**)**

arXiv:0903.2973v1 [hep-ex].



(*) Extr. of 1° brick nearly completed. 2° in progress.
(**) First results on a subsample of ~200 events

F. Terranova NeuTel 2009

- With a beam intensity of 22.5 x 10^{19} pot, a target mass of 1300 tons and $\Delta m^2_{23}=2.5\times10^{-3}$ eV^2 :
  - ~25000 neutrino interactions
  - ~120 ν_τ interactions
  - ~10 ν_τ identified
  - < 1 background events

- **Forecast for 2009:**

  173 days of running: ~3.5×10^{19} pot

  Integrated statistics sufficient for candidate events (~2 tau events)

  Precise evaluation of efficiencies, backgrounds and sensitivity

OPERA future depends critically on CNGS performances. It is crucial to have the beam asap at its nominal intensity

The ICARUS experiment

A multi-kton detector based on a new powerful detection technique:

the Liquid Argon Time Projection Chamber

[C. Rubbia: CERN-EP/77-08 (1977)]

first proposed to INFN in 1985

[ICARUS: Imaging Cosmic And Rare Underground Signals: INFN/AE-85/7]

capable of providing a 3D imaging of any ionizing event ("electronic bubble chamber") with in addition:

- high granularity (~mm)
- excellent calorimetric properties
- particle identification (through dE/dx vs range)
- continuously sensitive

ICARUS -T600

Funding 2009 476 k€
FTE: 27.1 44 people

It is a necessary intermediate technical step towards a much more massive LAr detector

T600 Physics

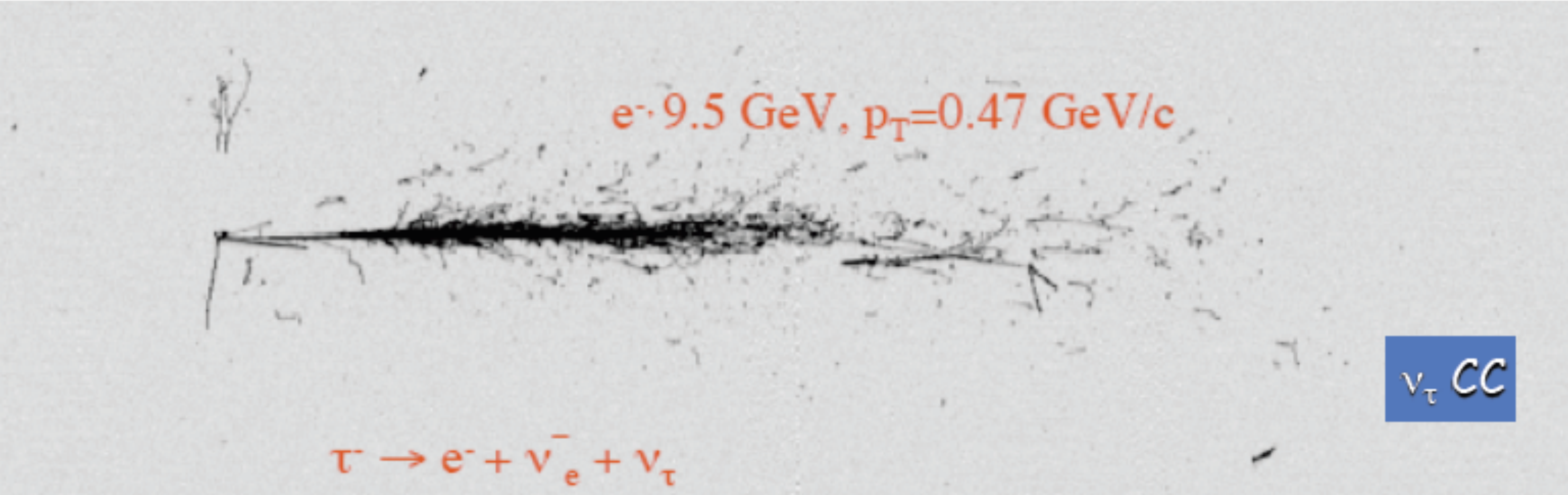
- ≈ 100 ev/year of individually recorded atmospheric CC neutrinos.
- Solar neutrino electron rates > 5 MeV.
- Supernova neutrinos.
- proton decay with 3 x 10^{32} nucleons.
- CNGS beam related neutrino events:

In 2009 ICARUS will be ready to enter the game

Installations and infrastructures in 2004-2008
May 2009 Final Tests of cryogenic plant and control systems (redundancy)
Then: start of the filling with LAr

ICARUS T600

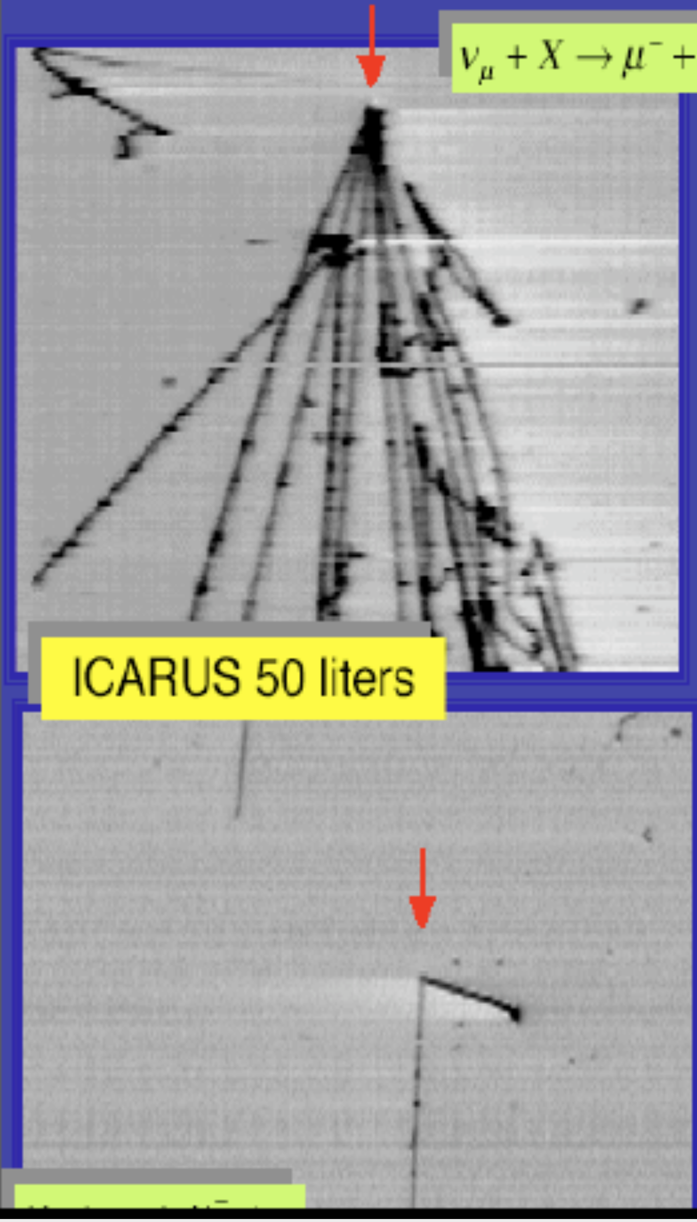
τ search based on **kinematical criteria**
main reaction: ντ + Ar -> τ + jet (gold candidate is the τ electron decay)

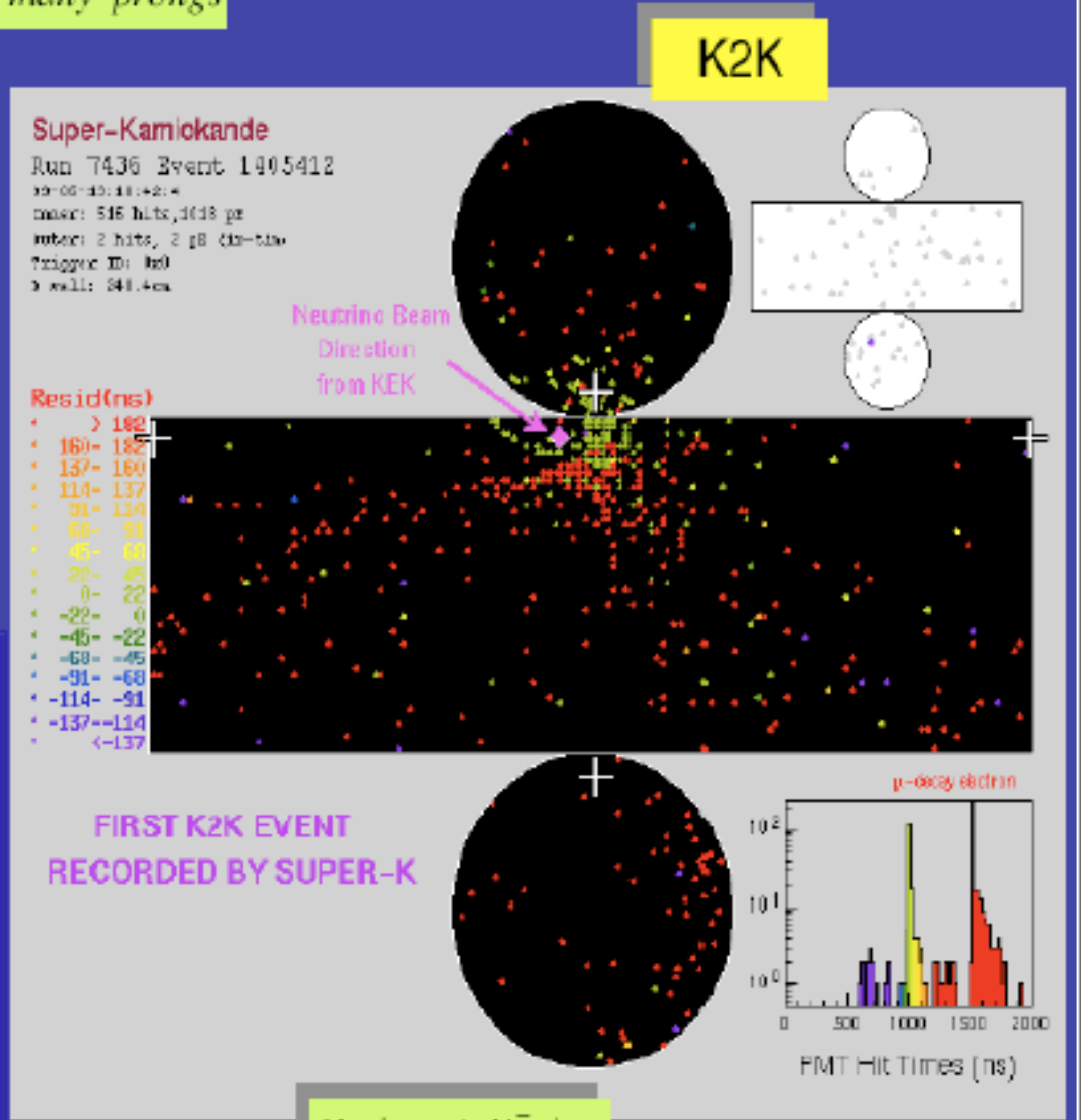


in 5 years running ~ 2 events and 0.1 events as background

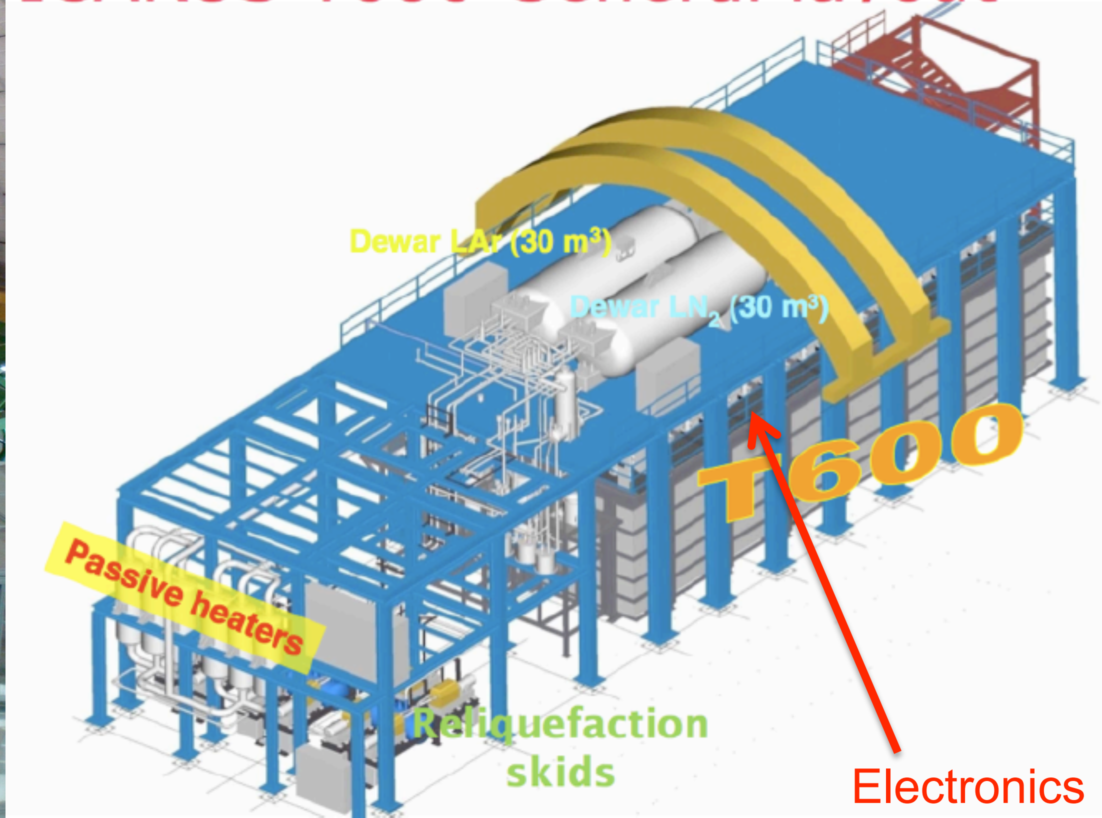
The main importance of this detector is in the technological developments for future large mass liquid Argon detectors.

Real neutrino events observed by LAr TPC and water Cerenkov





ICARUS T600 General layout



Electronics

ICARUS in Hall B

WARP (DarkMatter)

The neutrino mass

Tritium Experiments
Mainz + Troitsk: $\mathbf{m_\beta < 2}$ **eV**
KATRIN: O(10) improvement

Possible results with KATRIN ([eV]):

$m_\beta = 0.35 \pm 0.07$ 5 sigma , discovery
$m_\beta = 0.30 \pm 0.10$ 3 sigma , evidence
$m_\beta < 0.2$ at 90% CL

Need for new ideas in order to go below ~0.2 eV.
MARE ?

MARE experiment

Funding 2009: 160 k€
FTE: 12.2 (27 people)

Microcalorimeter **A**rrays for a **R**henium **E**xperiment

^{187}Re as ß-emitter: isotopic abundance 62.8%

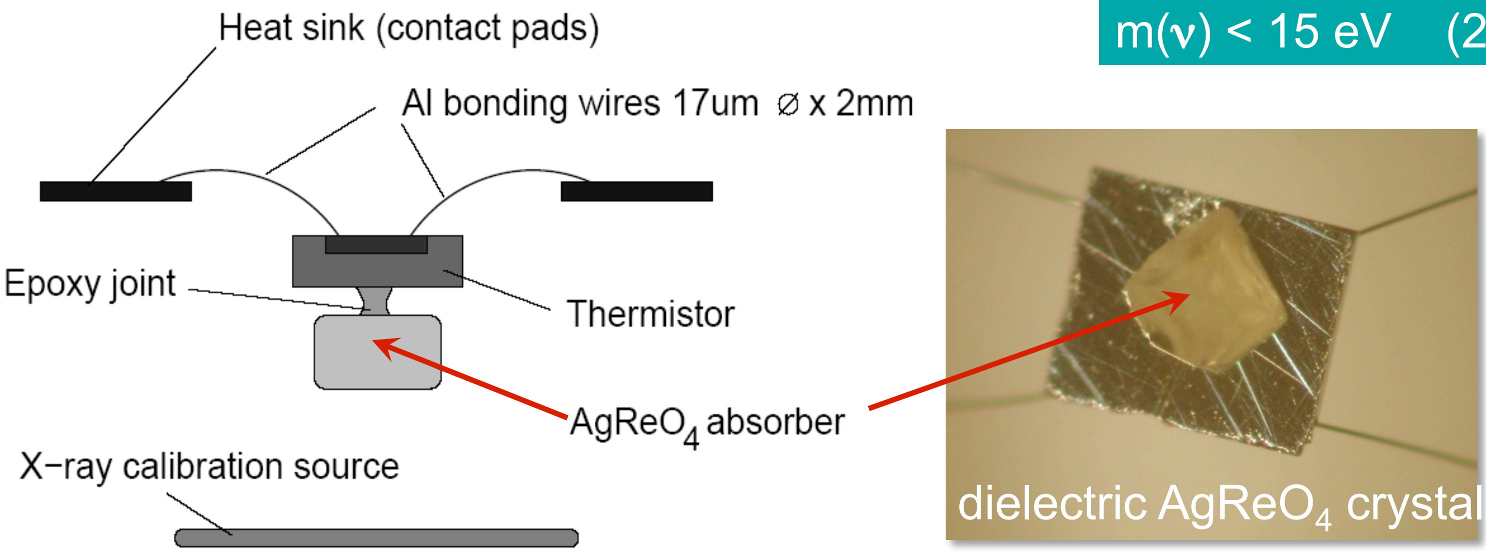
$$^{187}_{85}\text{Re} \rightarrow ^{187}_{86}\text{Os} + e^- + \bar{\nu}_e$$

$5/2^+ \rightarrow 1/2^-$ unique first forbidden transition (shape factor)

previous experiments:

Genova: metallic Re (MANU)
Milano: $AgReO_4$ (MIBETA)

6.2 ×10^6 ^{187}Re ß-decays:
m(ν) < 15 eV (2004)



MIBETA:
10 crystals

MARE experiment: Phase-I

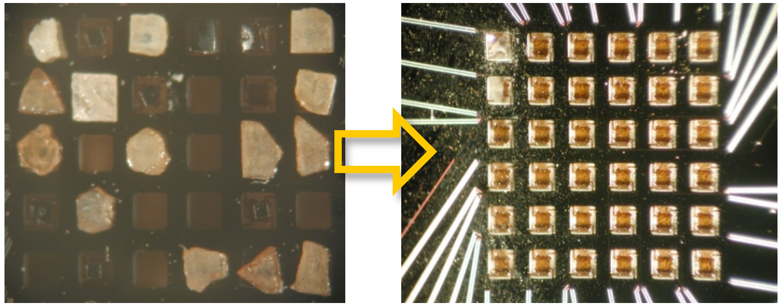
Phase-I objective: improve sensitivity for $m(\nu)$ by factor 10
increase statistics to 10^{10} ß-decays ⇨ $m(\nu) \sim 2$ eV

Phase-I detectors: Genova: metallic Re, superconducting at T = 1.6 K
absorber mass 1 mg

Milan: new $AgReO_4$ crystals, dielectric perrhenates
absorber mass 500 µg at T ~ 85 mK, τ_{rise} ~200 µs
6 × 6 pixel arrays: 1st operational, 2nd: funded
energy resolution: ΔE = 34 eV @ 2.5 keV

ΔE = 15 eV
Δt = 50 µs
3 years

Genova: Re metal



Milano: pixel arrays of $AgReO_4$

MARE-I cryostat for 288 elements (4×72) under construction

MARE experiment: Phase-II

Phase-II objective: improve sensitivity for m(ν) by another factor 10

increase statistics to 10^{14} ß-decays ⇨ m(ν) ~ 0.2 eV

Phase-II detectors: R&D efforts for new detectors

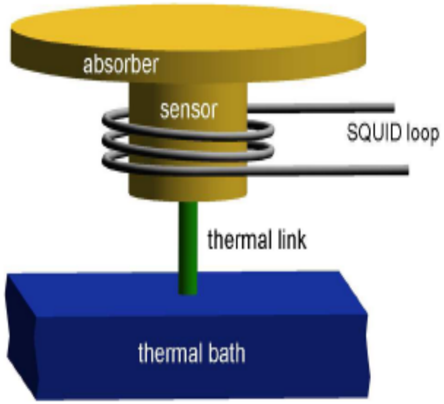
magnetic micro-calorimeters with paramagnetic sensor

δT in absorber ⇨ change in magnetism δM of sensor

ΔE = 5 eV
Δt = 1 μs
> 5 years

$$\delta M = \frac{\partial M}{\partial T} \cdot \delta T$$

read out by SQUID

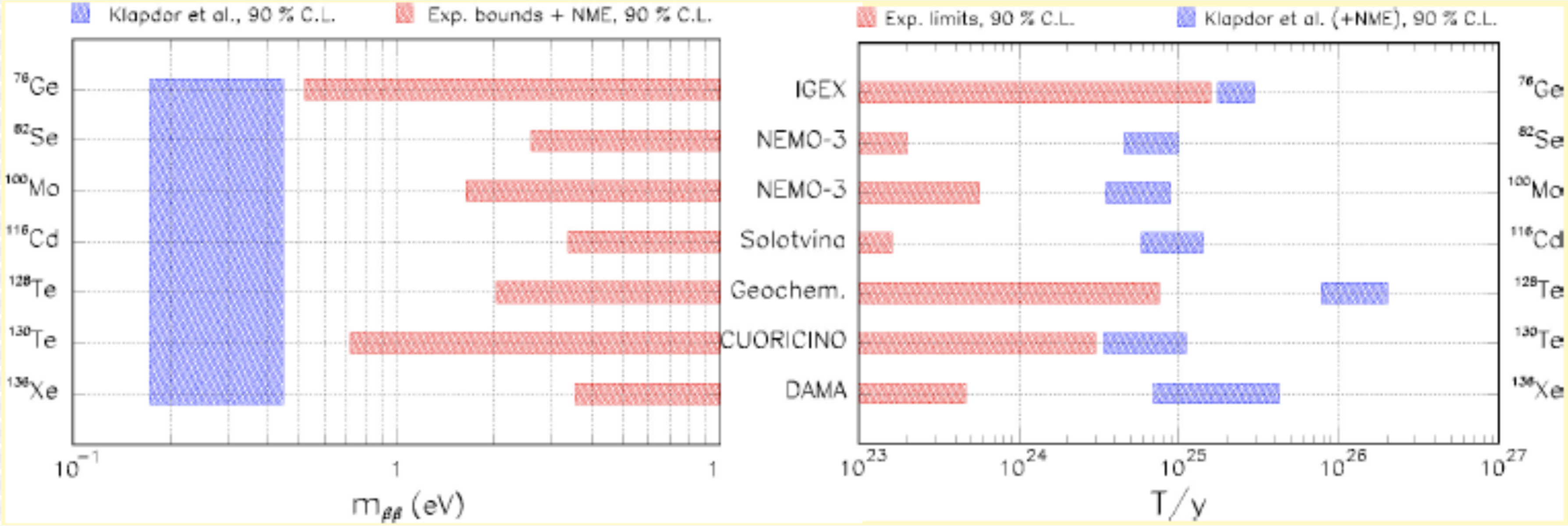


if R&D for MMC or other detectors successful:

- operate a pilot array with 5000 bolometers
- sensitivity of m(ν) = 0.2 eV would require an array of ~50.000 bolometers in several cryostats and a measuring time of > 5 years

$0\nu-2\beta$ decay

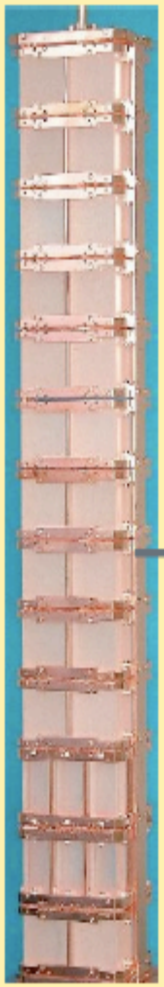
The present situation :only upper limits, besides a controversial result form the most sensitive experiment so far (Klapdor et al).



From E. Lisi, IFAE 2009

CUORICINO last result (PRELIMINARY !)

CUORICINO was decommissioned during summer 2008

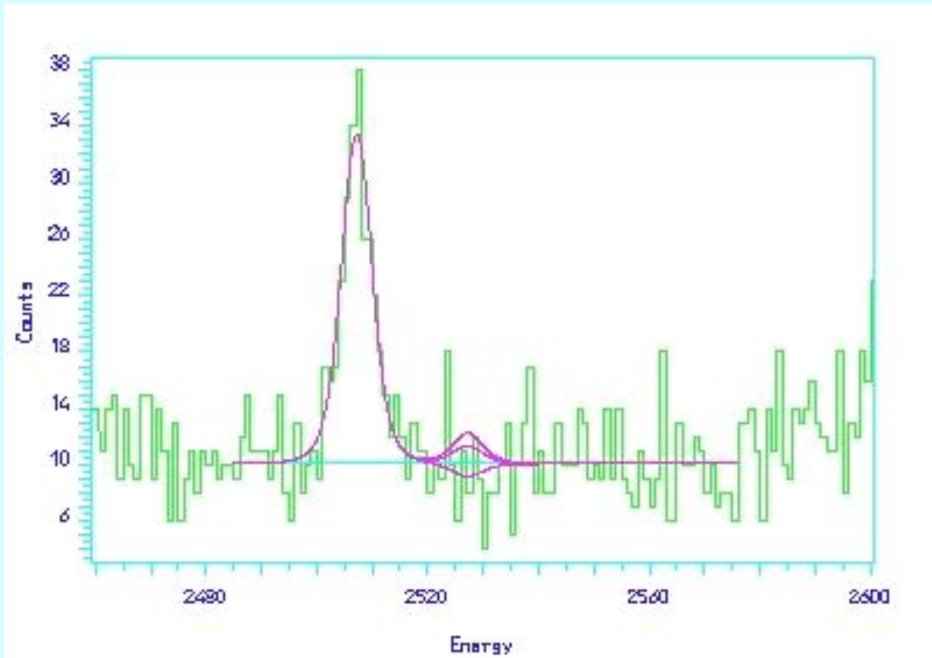


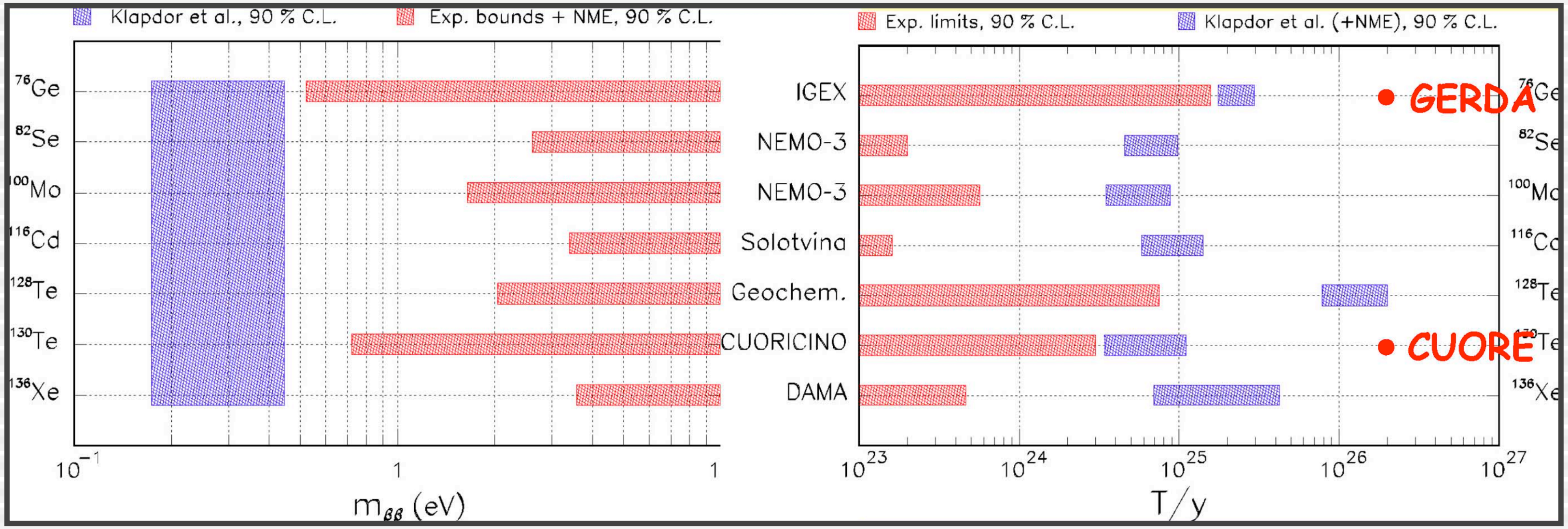
Isotope: ^{130}Te	Modules
•High natural abundance (33.9%) •High Q-value (2530keV) almost out of γ-bkg	•11 modules of 4 crystals each 5x5x5 cm^3 •2 modules for 9+9 3x3x6 cm^3 crystasls

Absorber: TeO_2	Active Mass
• Low thermal capacity • Big crystals available • Very high radiopurity	•40.7 kg TeO_2 • 11.2 kg ^{130}Te • 5 x 10^{25} nuclei ^{130}Te

Updated statistics: 18 kg·y ^{130}Te
Q-Value: 2527.2 +/- 0.5
(recent update)

New limit for DBD0n ^{130}Te:
$T_{1/2} > 2.94 \cdot 10^{24}$ y

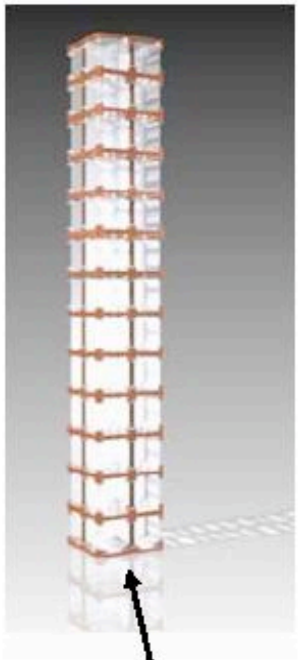



Klapdor et al., 90 % C.L.
Exp. bounds + NME, 90 % C.L.
^{76}Ge
^{82}Se
^{100}Mo
^{116}Cd
^{128}Te
^{130}Te
^{136}Xe
10^{-1}
1
1
$m_{\beta\beta}$ (eV)
Exp. limits, 90 % C.L.
Klapdor et al. (+NME), 90 % C.L.
IGEX
NEMO-3
NEMO-3
Solotvina
Geochem.
CUORICINO
DAMA
10^{23}
10^{24}
10^{25}
10^{26}
10^{27}
T/y
GERDA
CUORE

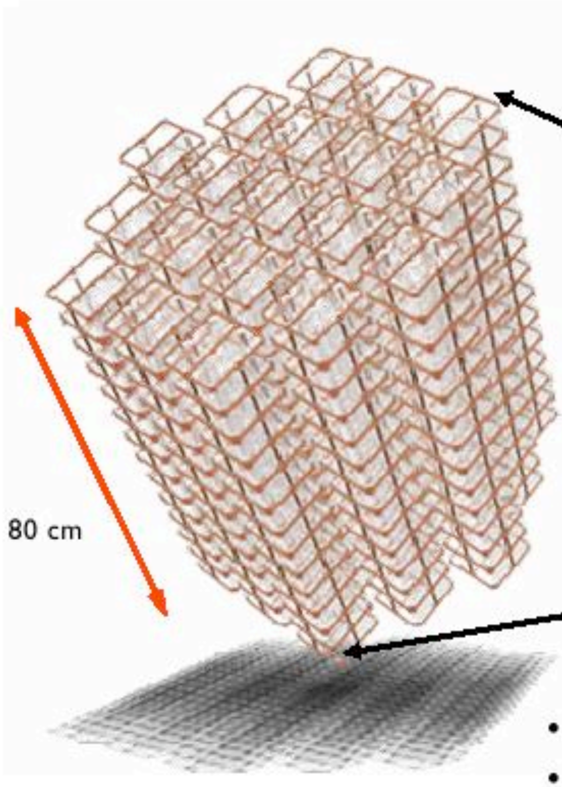
CUORE

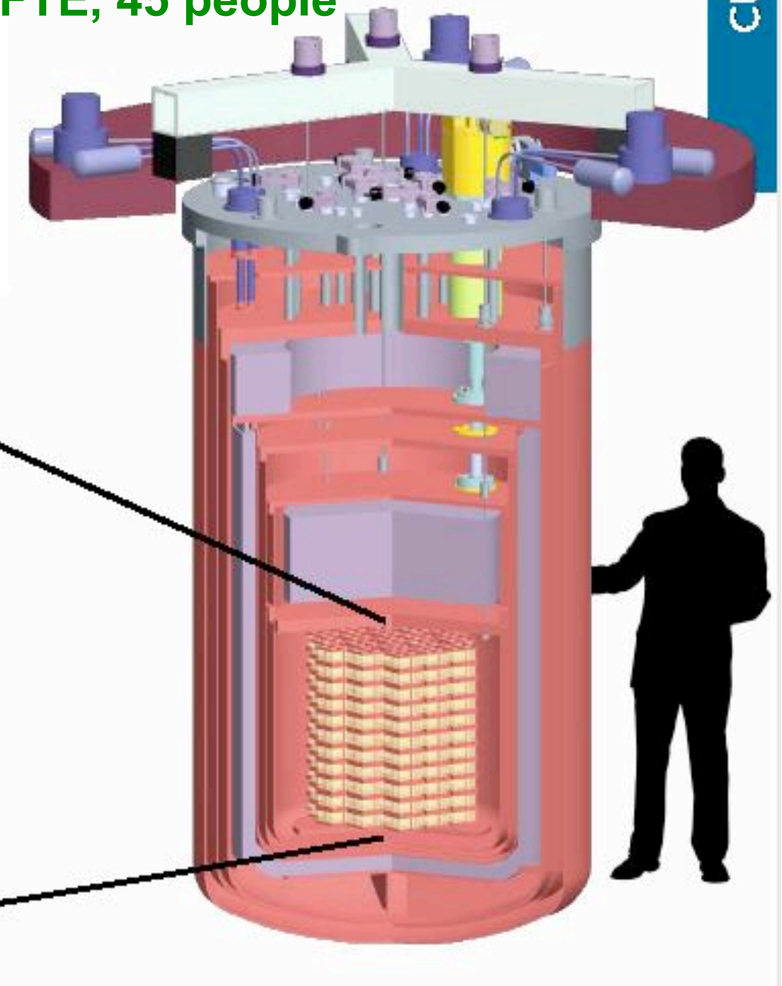
Funding 2009 1400 k€
32 FTE, 45 people

CUORE: **C**ryogenic **U**nderground **O**bservatory for **R**are **E**vents will be a tightly packed array of 988 bolometers - M ~ 200 kg of ^{130}Te



19 Cuoricino-like towers with 13 planes of 4 crystals each





- Operated at Gran Sasso laboratory
- Special cryostat built w/ selected materials
- Cryogen-free dilution refrigerator
- Shielded by several lead shields

Projected Sensitivity for CUORE in 5 years

Bkg=0.01 c/kev/kg/y
FWHM@DBD = 5 keV

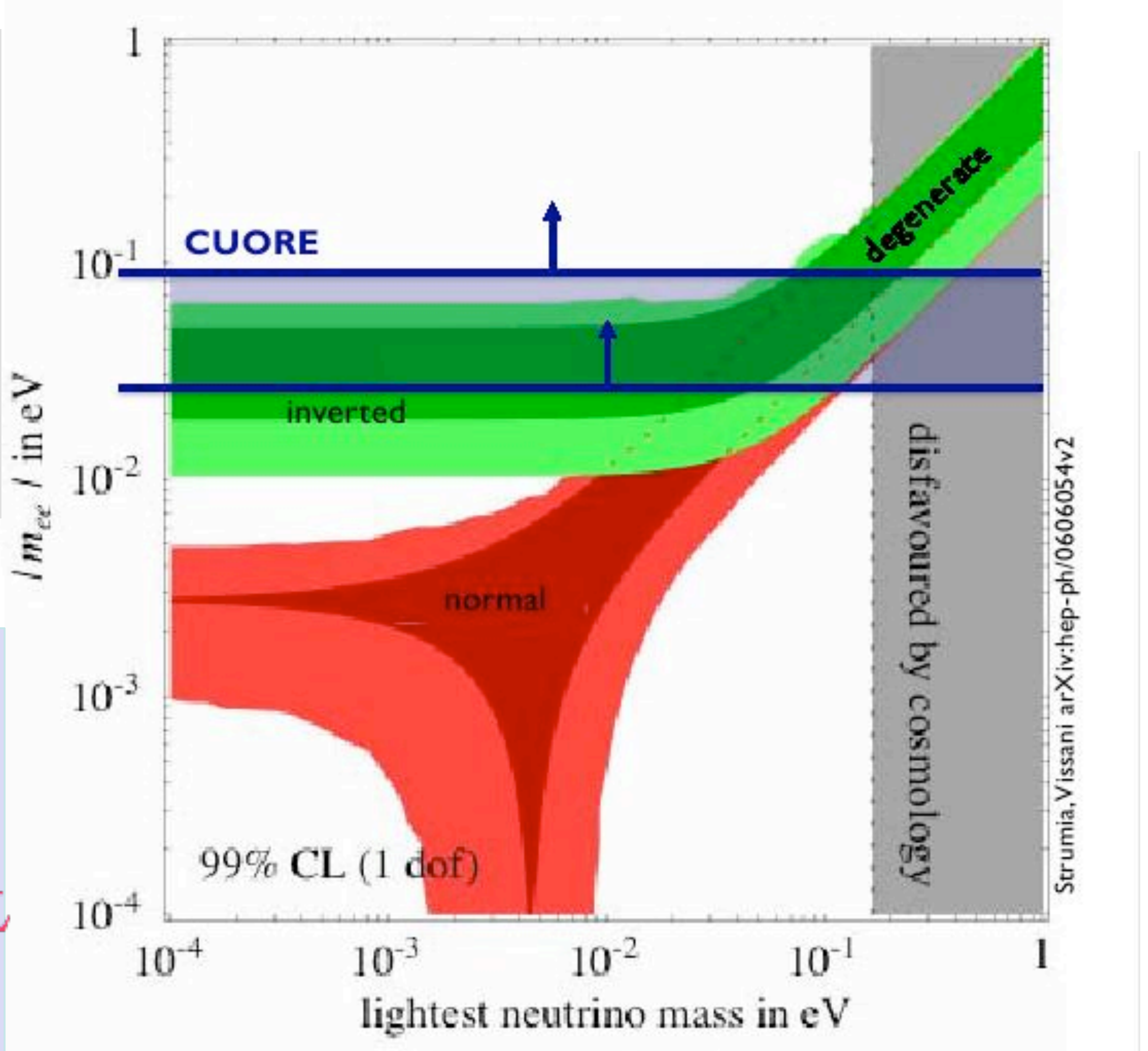
$$\tau^{0\nu}_{1/2} > 2.1 \cdot 10^{26}\,\mathrm{y}\ @90\%CL$$

$$m_{\beta\beta} < 20 \div 100\,\mathrm{meV}$$

Bkg=0.001 c/kev/kg/y
FWHM@DBD = 5 keV

$$\tau^{0\nu}_{1/2} > 6.5 \cdot 10^{26}\,\mathrm{y}\ @90\%CL$$

$$m_{\beta\beta} < 11 \div 60\,\mathrm{meV}$$



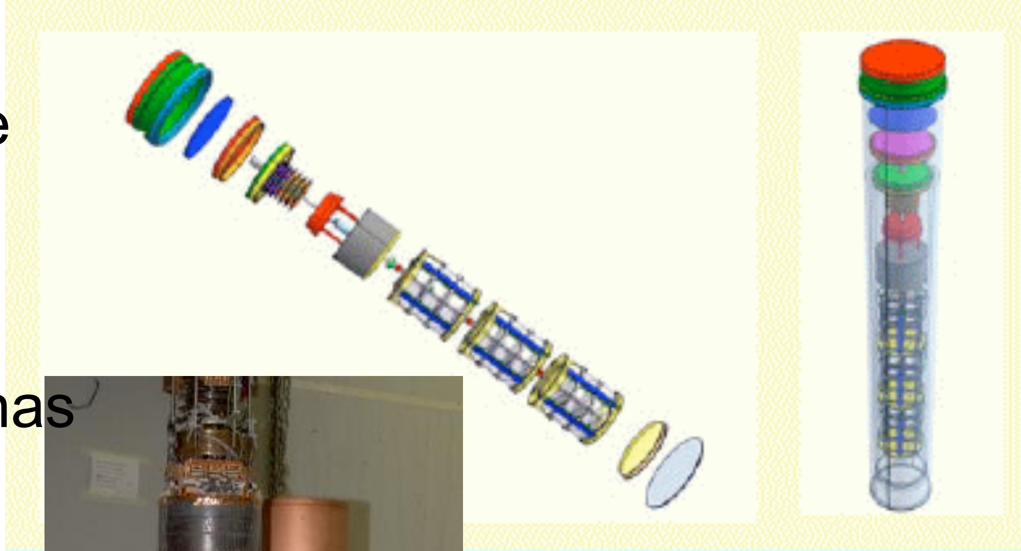
CUORE Status: Three Tower test

- Test to finalize copper surface treatment with respect to radiopurity constraints

- Three towers whose copper has been subject to 3 different surface treatments:
  1. Plasma Cleaning
  2. Chemistry
  3. Polyethylene sheets

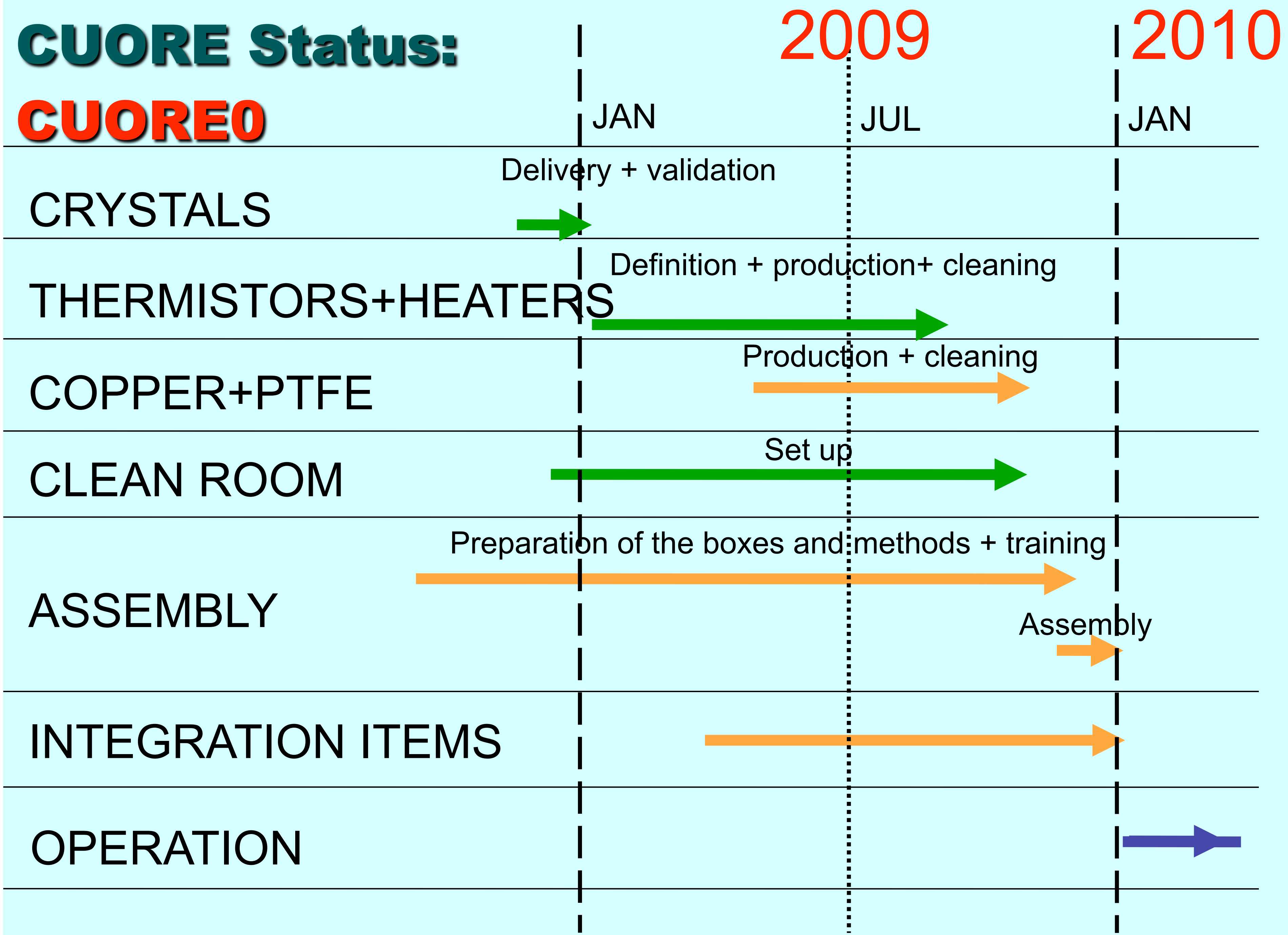
- 3 plane of 4 TeO_2 crystals each

- Crystals completely reprocessed according to CUORE standards



Data taking is going to start in a few days

CUORE Status:
CUORE0



Goals and distinctive features of GERDA
(GERmanium Detector Array)

- Investigation of $0\nu\beta\beta$ decay of ^{76}Ge. Location:
  - Staged Approach (Phase I + Phase II+ …).

- Build a setup having a background @ $Q_{\beta\beta} \leq 10^{-3}$ cts/(kg·keV·y) adopting passive/active shielding.

- Use of bare diodes in cryogenic liquid (LAr) of very high radiopurity. Technique proposed by G. Heusser (Ann. Rev. Nucl. Part. Sci. 45(1995)543) and tested by KK in GENIUS_TF @ LNGS (GENIUS proposed in 2000) with non encouraging results (NIM2004) . Problems reported have been overcome by GERDA collaboration.

8 FTE, 13 people
2009 Funding 142 k€

Phases of GERDA

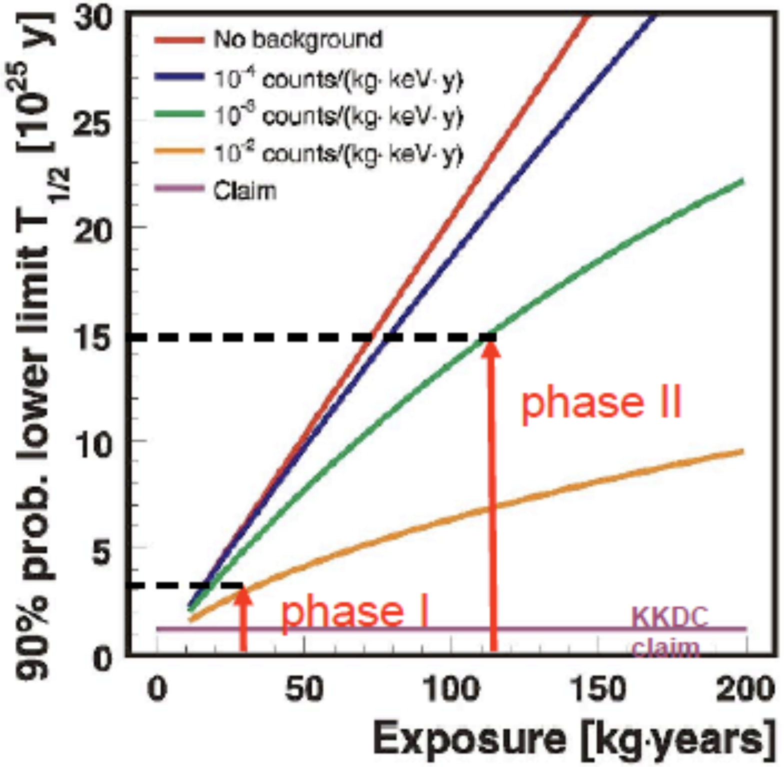
- Phase I:
  - Use of existing ^{76}Ge-diodes from Heidelberg-Moscow and IGEX-experiments
  - 8 detectors for 17.9 Kg of ^{enr}Ge
  - Expected Background ~ 10^{-2} count/(kg·keV·y) dominated by crystal internal backg. → KKDC evidence verified in an external background-free setup.

- Phase II:
  - Add new diodes (+22 kg, total: ~40 kg ^{enr}Ge) able to discriminate SSE/MSE.
  - Demonstration of bkg-level $<10^{-3}$ count/(kg·keV·y)

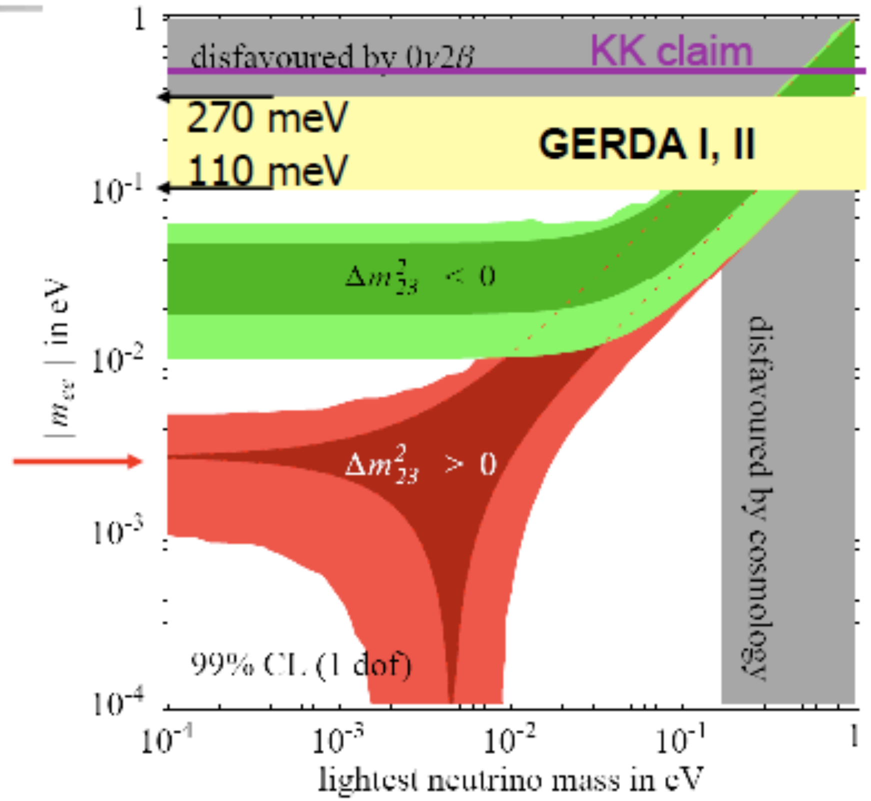
- Eventually Phase III:
  - If background OK
  - If KKDC-evidence not confirmed: $\mathcal{O}$(1 ton) experiment by a worldwide collaboration with Majorana

GERDA: Sensitivity

Assumed E resolution: ΔE = 4 keV



From Vissani, Strumia hep-ph/0606054v2

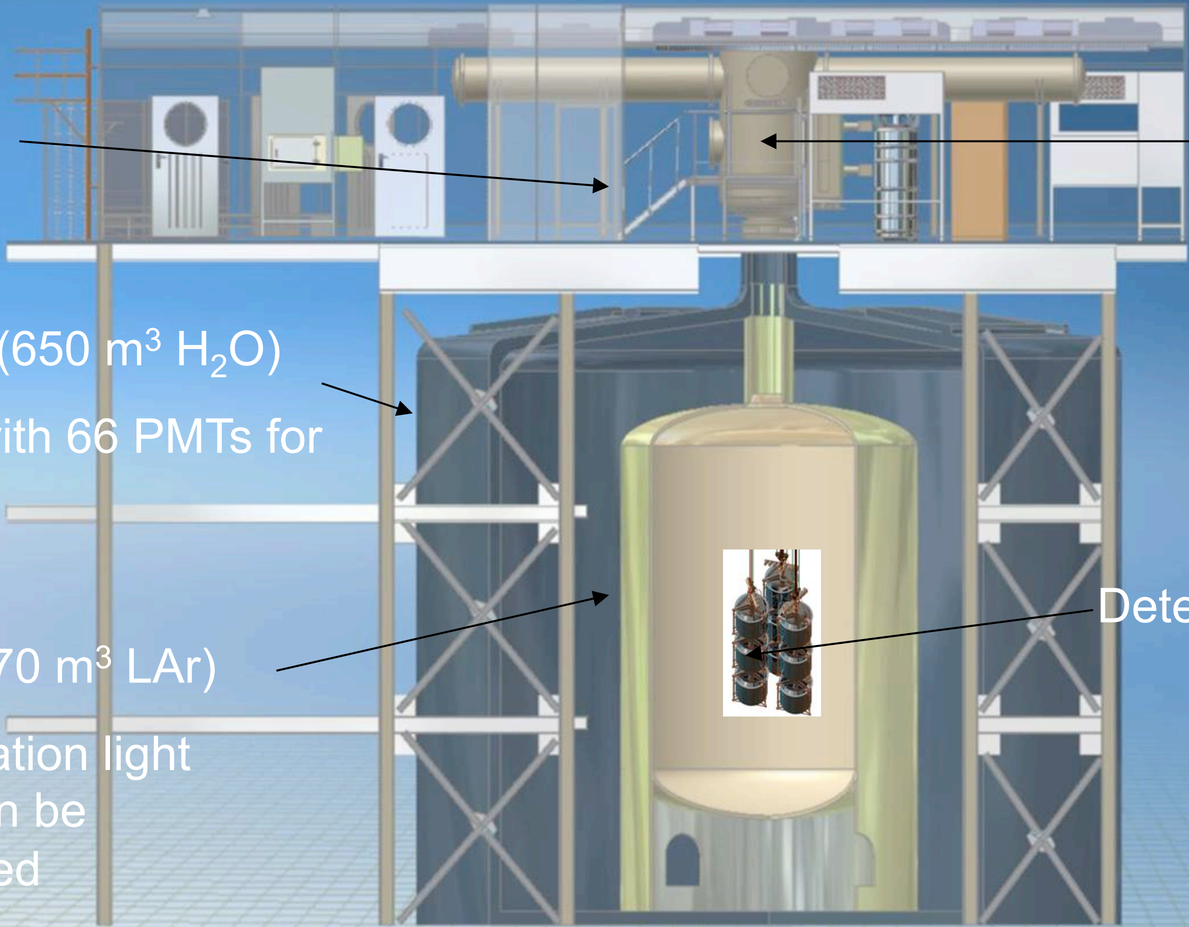


→ if signal found in HM by KK is true ββ decay, this would produce in ~ 1 year GERDA I data taking (assuming 18 kg y exposure) 7 cts, above bckg of 0.5 cts → probability that bckg simulate signal ~ 10^{-5}

Shielding requirements make these detectors large...

GERDA design

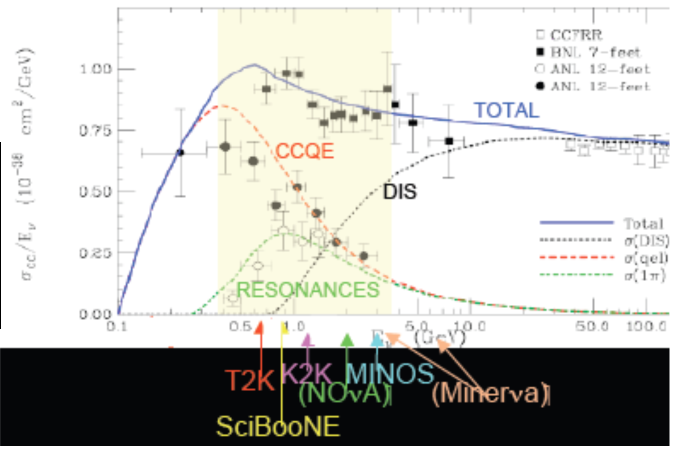
The setup is conceved and constructed to have a B @ $Q_{\beta\beta} \leq 10^{-3}$ cts/(kg·keV·y) adopting passive/active shielding, and suitable to host > 500 kg Ge detectors

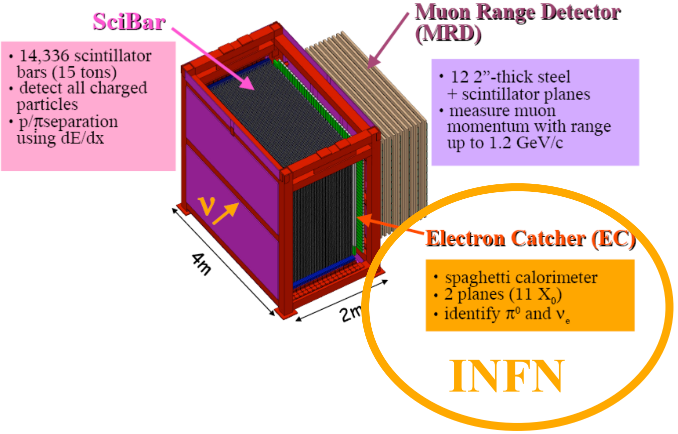


Sciboone (FNAL E954):

First results: K.Hiraide et al, PRD 78 (2008) 112004 etc.

Stage 1 approval	14 Dec. 2005
Start excavation	20 Sep. 2006
First (anti)nu logged	30 May 2007
Data run completed	18 Aug. 2008

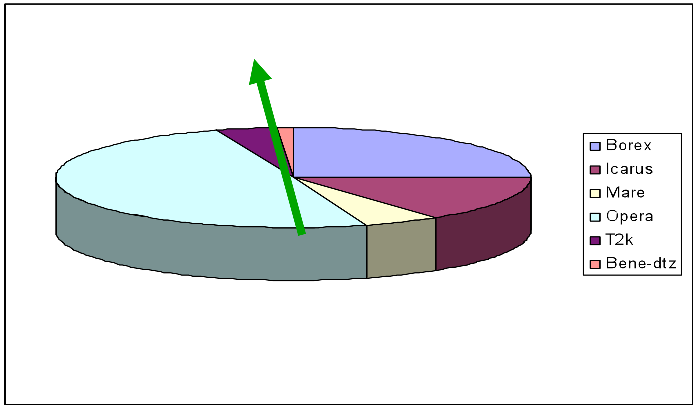




T2K

Fiunding 2009: 137 kE

FTE: 5.1 (9 people)



Italian (and European) contribution limited to the Near Detector

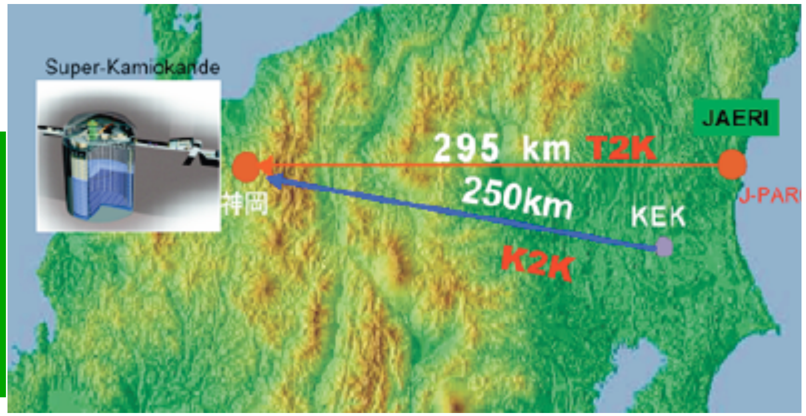
✓Micromegas and TPC calibration

✓Ancillary equipments

Far detector: SK

Near detector: new (mainly EU)

ν beamline: new (**main cost:** mainly JP)



Future : Possible improvements in the CNGS beam intensity

CNGS facility was designed to deliver **4.5 x10^{19} pot per year** for 5 years.

(200 days, 55% efficiency, 60% of the SPS users)

M. Meddahi, E. Shaposhnikova **CERN-AB-2007-013 PAF**

Table *7: Protons on target per year [x10^{19}] for 200 days of operation with 80% machine availability*

	SPS cycle length	6 s		4.8 s	
	Injection momentum	14 GeV/c		26 GeV/c	
	Beam sharing / Max SPS intensity @400GeV [x10^{13}]	0.45	0.85	0.45	0.85
Present injectors + machines' improvement	4.8 – "Nominal CNGS"	5	9.4		
	5.7- "Max. SPS"	5.9	11.1		
Future injectors + SPS RF upgrade	7 – "Ultimate CNGS"			9	17.1
Future injectors + new SPS RF system + CNGS new equipment design	10 – "Max. PS2"			12.9	24.5

34

Units 10^{19} pot

factor ~ 5 possible

"short term" multi-turn extraction ecc

after 2016

The MODULAr project

Astroparticle Physics 29 (2008) 174-187 and 2009 Jinst 4 P02003

- 21.5 kton of Liquid Argon in 4 modules "600 ton" like.
- At shallow depth, 7 or 10 km off-axis from CNGS.
- Modified CNGS optics and target to lower the mean ν_μ energy.
- Assume $1.2 \cdot 10^{20}$ pot/yr (CNGS-1, 0.5 MW) or $4.4 \cdot 10^{20}$ pot/yr (CNGS-2, 1.6 MW). At present, CNGS: $4.5 \cdot 10^{19}$ pot/yr.

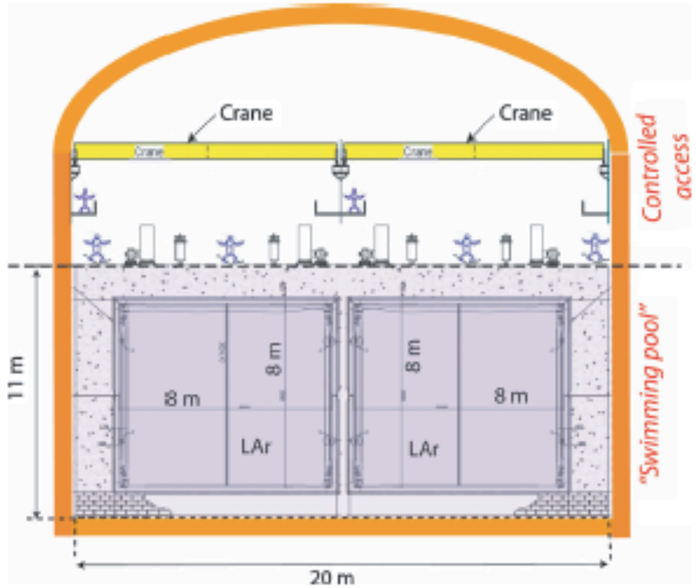
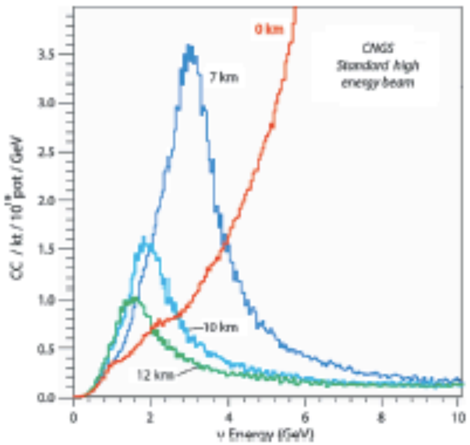
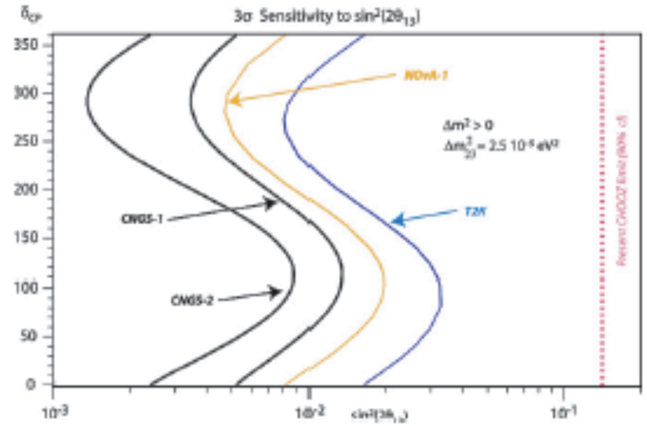


Fig. 1. Indicative cross-section of the T600 "clone " in the dedicated "swimming pool like" underground hall. The lower part is made of two twin separate LAr containers made of aluminum extruded structures, thermally stabilized with forced N2 circulation. Outside the structure an about 1.5 m thick per wall provides spontaneous, passive heat insulation. The region on top of the "swimming pool" is accessible to auxiliary equipments. Personnel access is strictly controlled.



7 km Off axis Detector on surface



The future *(only a personal/trivial consideration)*

A general consensus exist that any further generation experiment in this sector, will be no more affordable at national/regional level

[Super ββ experiments (1-10 ton)

- Superbeams
- Beta-Beams
- Neutrino Factories

New large infrastructure for a detector 10^5-10^6 ton scale, ...]

The need is to integrate the efforts by making also the best use of existing facilities/know how's... (but shall we be "capable" of this?)

and/or (if f.e. no signal from T2K) new (à la MARE) R&Ds