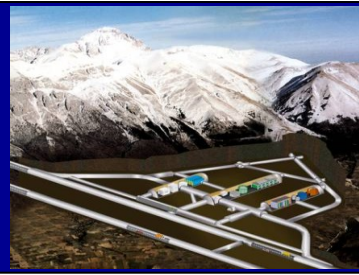


# Gran Sasso Laboratory – Status and perspectives

**Luciano Pandola – INFN Gran Sasso National Laboratory**

Aspera Workshop on Next Generation Projects in Deep  
Underground Laboratories, Zaragoza, July 1<sup>st</sup>, 2011

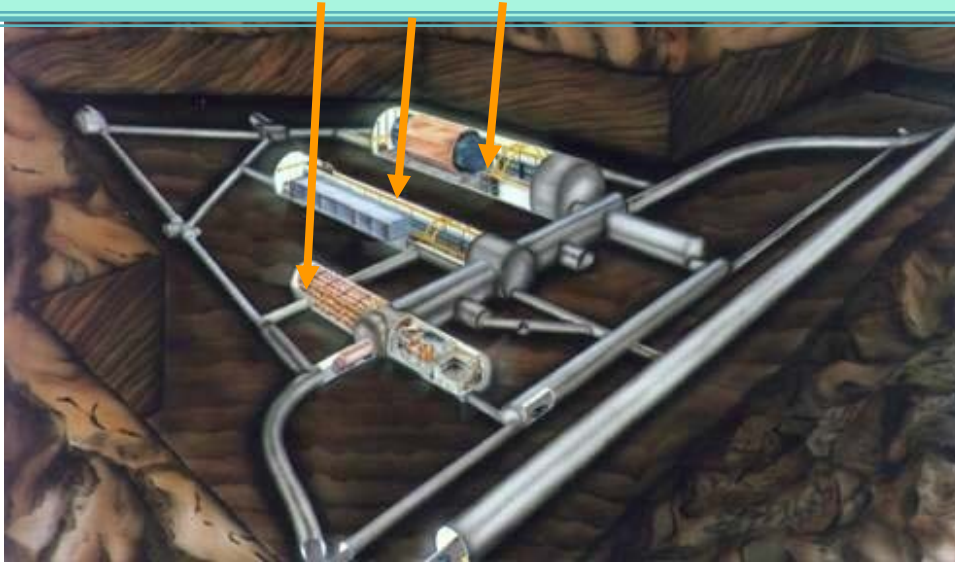
# Highlights from Gran Sasso Laboratory



- **Largest** underground laboratory in the world
  - Run by **INFN** under the Gran Sasso Mountain, Italy
  - 120 km far from Rome, completed 1987
  - International scientific community (1000 users per year)
  - Permanent staff: 82 + 19 temporary positions
- **Neutrino physics**
  - Neutrinoless double beta decay
  - Solar, geo and supernova neutrinos
  - CNGS neutrinos
- **Dark matter searches**
- **Nuclear Astrophysics**
  - Geophysics and environmental physics
  - Biology

# Gran Sasso Laboratory

3 main halls A B C  $\sim 100 \times 20 \text{ m}^2$  (h 20 m)



## Muon Flux

$$3.0 \cdot 10^{-4} \mu \text{ m}^{-2} \text{ s}^{-1}$$

## Neutron Flux

$$2.92 \cdot 10^{-6} \text{ n cm}^{-2} \text{ s}^{-1} \quad (0-1 \text{ keV})$$

$$0.86 \cdot 10^{-6} \text{ n cm}^{-2} \text{ s}^{-1} \quad (> 1 \text{ keV})$$

Depth: 1400 m (**3800 m w.e.**)

Surface: 17800  $\text{m}^2$

Volume: **180000**  $\text{m}^3$

Rn in air: 20-80  $\text{Bq/m}^3$

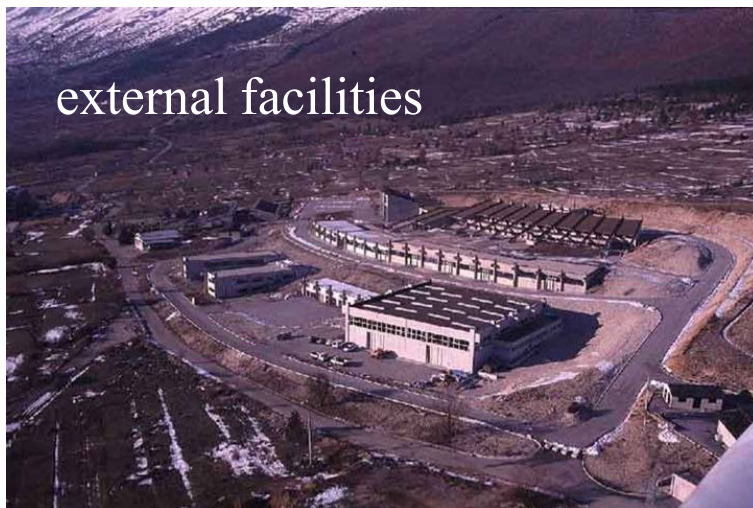
ISO 14001

Ventilation: 1 Lab volume/3 h

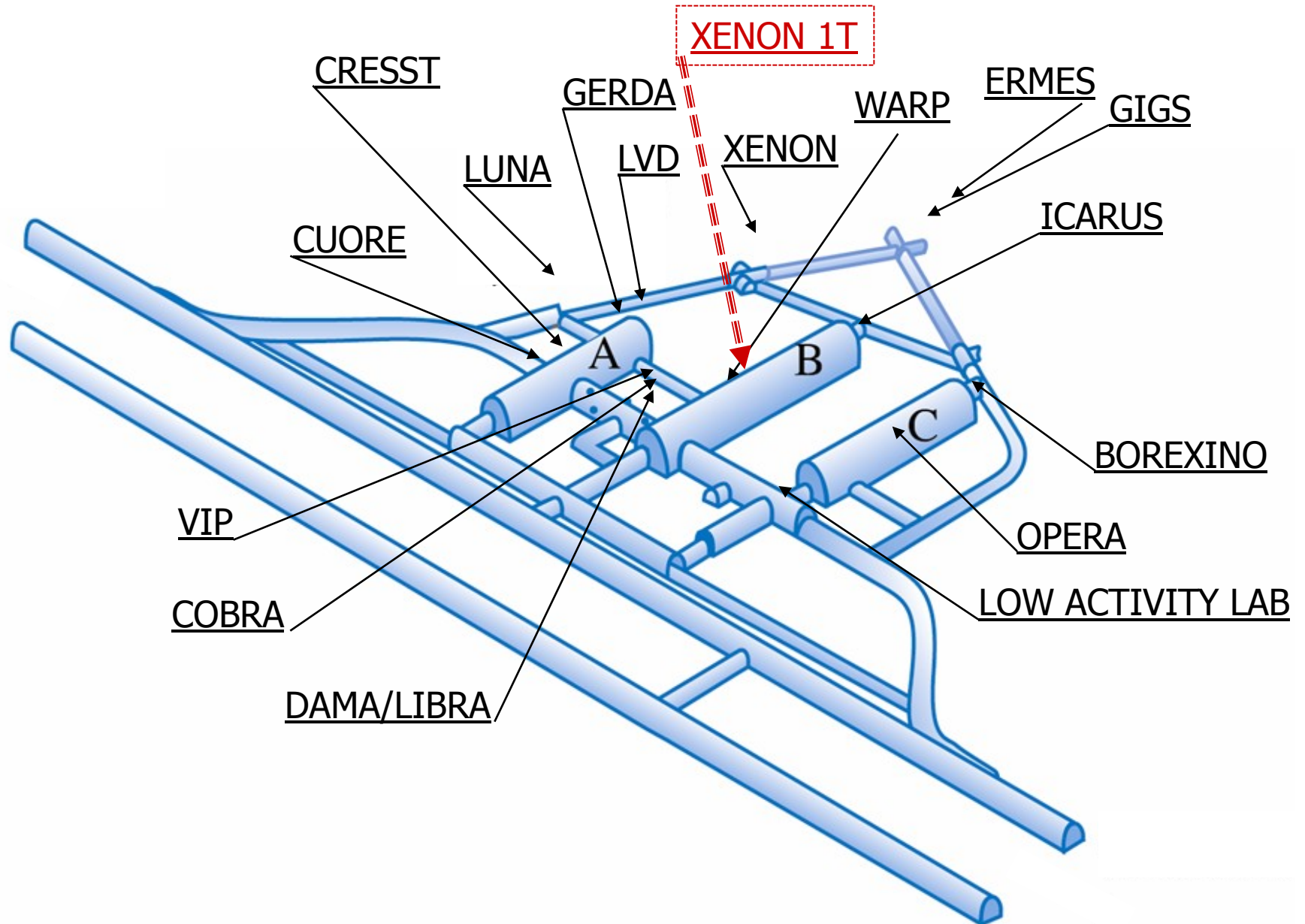
Electrical power: 1300 kW

Access: horizontal

external facilities



# OCCUPANCY



# Neutrinoless Double Beta Decay

- LNGS program: complementary approaches concerning isotopes and techniques
- **GERDA**: HPGe detectors enriched in  $^{76}\text{Ge}$ 
  - commissioning run with  $^{\text{nat}}\text{Ge}$  detectors
  - start data taking with  $^{\text{enr}}\text{Ge}$  detectors during the summer
- **CUORE**:  $\text{TeO}_2$  bolometers ( $^{130}\text{Te}$ )
  - construction phase. Expect data taking in 2014
  - among the firsts able to probe the inverted neutrino mass hierarchy
  - Lucifer R&D project to further suppress background: scintillating bolometers
- **COBRA R&D**: CdZnTe detectors



clean room – rdy

phase I lock –

single-string arm installed

cryo-mu-lab

control room

water plant  
Rn monitor

phase I array  
rdy (scaled:)

FE electronics

$\mu$  veto  
rdy

cryostat - rdy

water tank - rdy

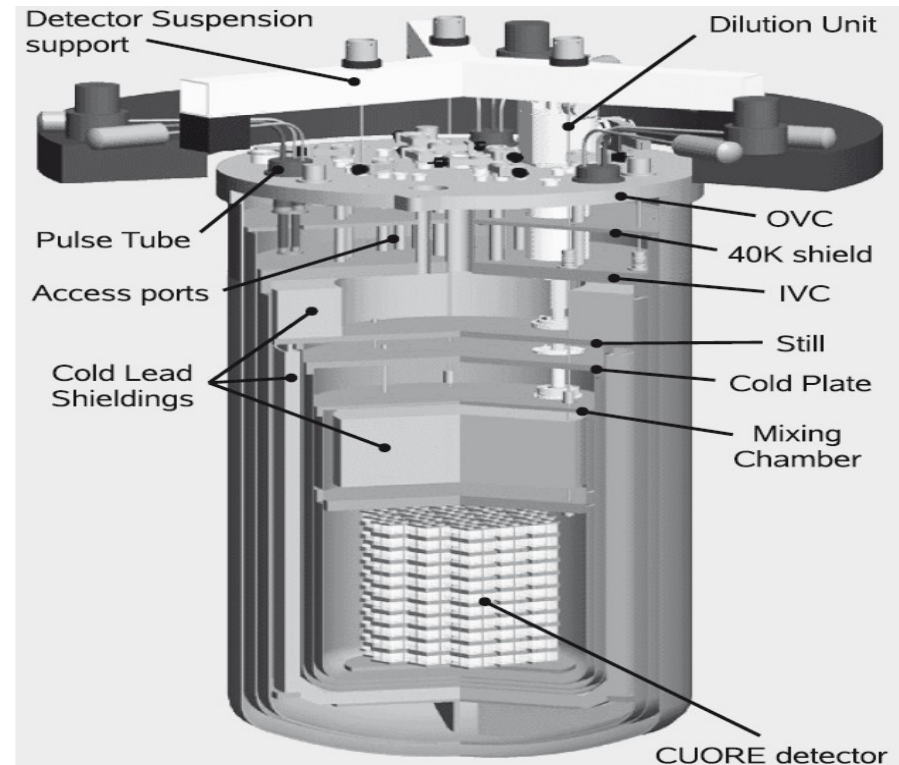
GERDA bldg - rdy

LAr fill : Nov/Dec 09

# The CUORE experiment

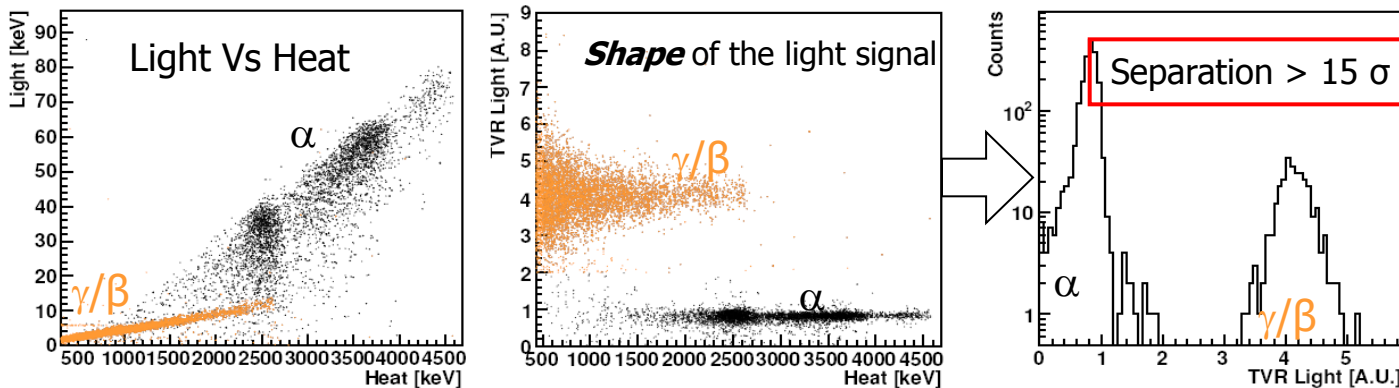
The CUORE experiment is able to detect  $\beta\beta$  decay of  $^{130}\text{Te}$  by using cryogenic detectors made of  $\text{TeO}_2$  crystals

The **prototype** CUORICINO, already installed at LNGS, demonstrated the feasibility of the large scale detector **CUORE** that will be **in operation in 2014**

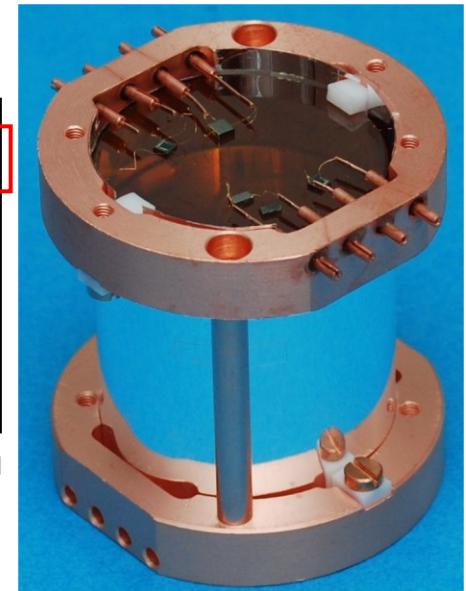


# The Lucifer R&D Project

The **Lucifer Project** is an EU Advanced Grant aiming to the construction of a  $\beta\beta$  Scintillating bolometer experiment  
Lucifer will consist of an array of **enriched ZnSe crystals**, total  $^{82}\text{Se}$  mass of  $\sim 10$  kg  
ZnSe is a “puzzling” promising **scintillating crystal**, being the only scintillator with an “**inverse**” Scintillating QF (approx. 4)



*C. Arnaboldi et al., Astropart. Phys. 34 (2011) 344.*

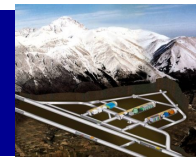


The **enriched  $^{82}\text{Se}$**  production (Urenco) is starting and the delivery of the 10 kg is foreseen for end of 2013

**Expected background** in the ROI (2995 keV) dominated by environmental  $^{214}\text{Bi}$  is expected to be  $\leq 0.006$  counts/(keV kg y)

Lucifer will be **hosted in the CUORICINO cryostat**, once the CUORE-0 tower will finish data taking (2014-2015)

# Dark matter @ LNGS



Different **methods and techniques** towards a “smoking gun” signature

**Ionization**

*Noble liquids*

XENON100  
WARP100  
DarkSide R&D

**Scintillation**

*Crystals NaI 250 kg*

DAMA/LIBRA

**Heat**

*Bolometric*  
*Cryogenic  $\text{CaWO}_4$*

CRESST

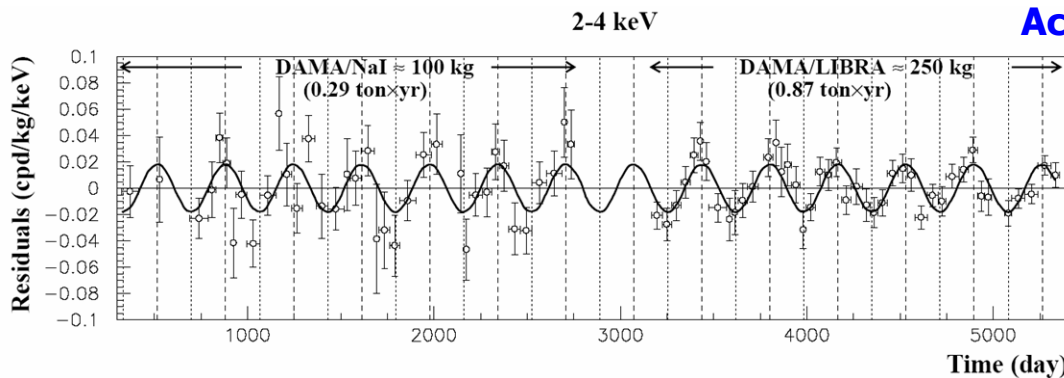
# Model Independent Annual Modulation Result

DAMA/NaI (7 years) + DAMA/LIBRA (6 years) Total exposure: 425428 kg·day = 1.17 ton·yr

experimental single-hit residuals rate vs time and energy

EPJC67(2010)39; see also refs therein

$\text{Acos}[w(t-t_0)]$ ; continuous lines:  $t_0 = 152.5$  d,  
 $T = 1.00$  y



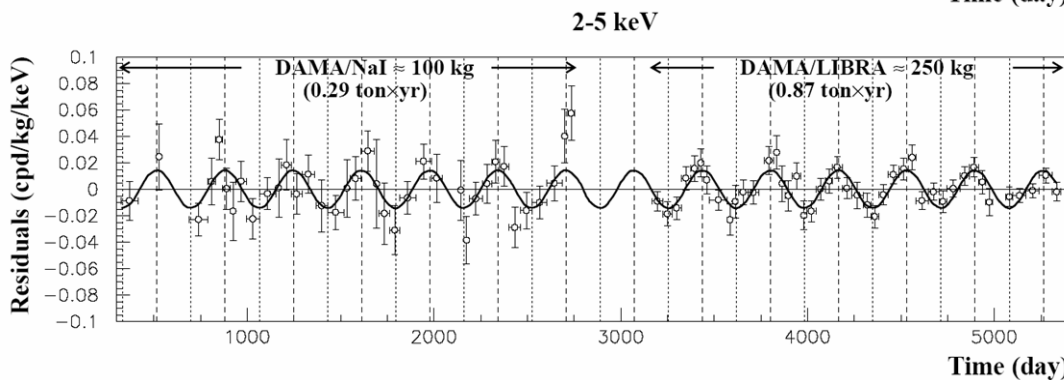
**2-4 keV**

$$A = (0.0183 \pm 0.0022) \text{ cpd/kg/keV}$$

$$\chi^2/\text{dof} = 75.7/79 \quad \mathbf{8.3 \sigma \text{ C.L.}}$$

Absence of modulation? No

$$\chi^2/\text{dof} = 147/80 \rightarrow P(A=0) = 7 \cdot 10^{-6}$$



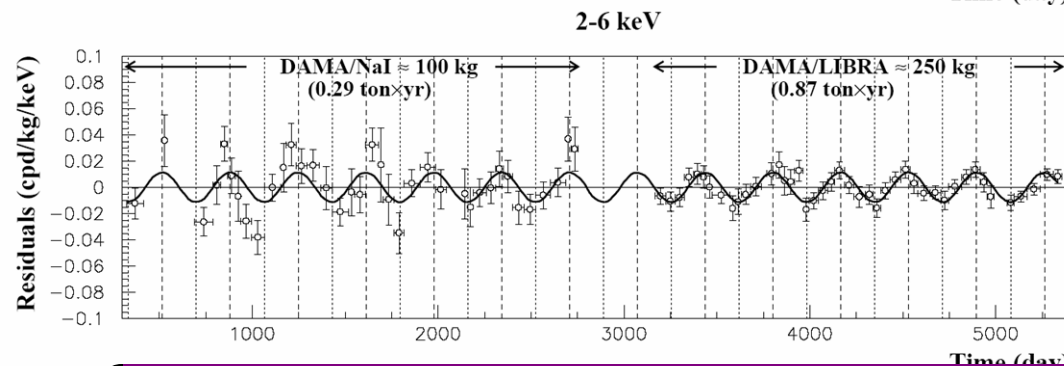
**2-5 keV**

$$A = (0.0144 \pm 0.0016) \text{ cpd/kg/keV}$$

$$\chi^2/\text{dof} = 56.6/79 \quad \mathbf{9.0 \sigma \text{ C.L.}}$$

Absence of modulation? No

$$\chi^2/\text{dof} = 135/80 \rightarrow P(A=0) = 1.1 \cdot 10^{-4}$$



**2-6 keV**

$$A = (0.0114 \pm 0.0013) \text{ cpd/kg/keV}$$

$$\chi^2/\text{dof} = 64.7/79 \quad \mathbf{8.8 \sigma \text{ C.L.}}$$

Absence of modulation? No

$$\chi^2/\text{dof} = 140/80 \rightarrow P(A=0) = 4.3 \cdot 10^{-5}$$

The data favor the presence of a **modulated behavior** with proper features at **8.8 $\sigma$  C.L.**

# Summarizing

The new annual cycles DAMA/LIBRA-5,6 have further **confirmed a peculiar annual modulation** of the ***single-hit events*** in the (2-6) keV energy region which satisfies the many requests of the DM annual modulation signature.

The total exposure by former DAMA/NaI and present DAMA/LIBRA is **1.17 ton·yr** (13 annual cycles)

In fact, **as required** by the DM annual modulation signature:

1)

The ***single-hit events*** show a clear cosine-like modulation

2)

Measured period is equal to  $(0.999 \pm 0.002)$  yr, well compatible with the 1 yr period,

3) Measured phase  $(146 \pm 7)$  days

is well compatible with the roughly about 152.5 days

4)

The modulation is present only in the low energy (2—6) keV energy interval and not in other higher energy regions

5)

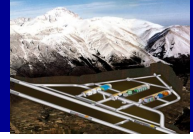
The modulation is present only in the ***single-hit events***, while it is absent in the ***multiple-hit ones***

6)

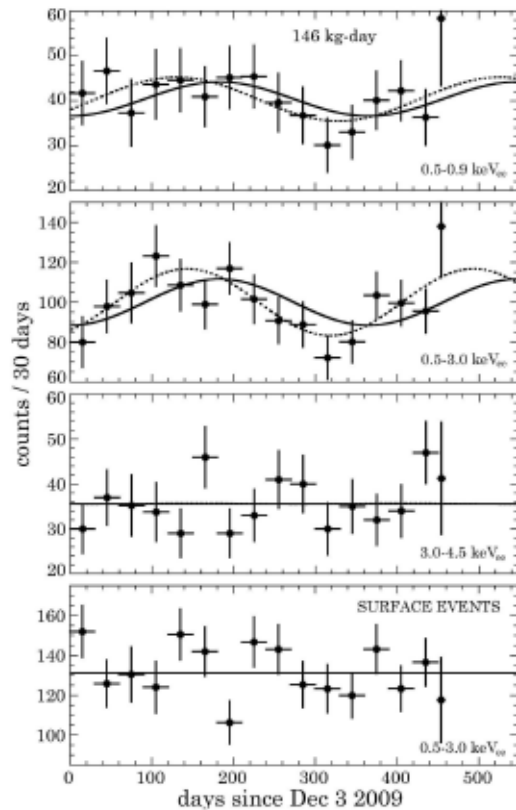
The measured modulation amplitude in NaI(Tl) of the ***single-hit events*** in the (2-6) keV energy interval is:  $(0.0116 \pm 0.0013)$  cpd/kg/keV ( $8.9\sigma$  C.L.).

**No systematic** or side process able to **simultaneously satisfy** all the many peculiarities of the signature and to account for the whole measured modulation amplitude is available

# Dark Matter

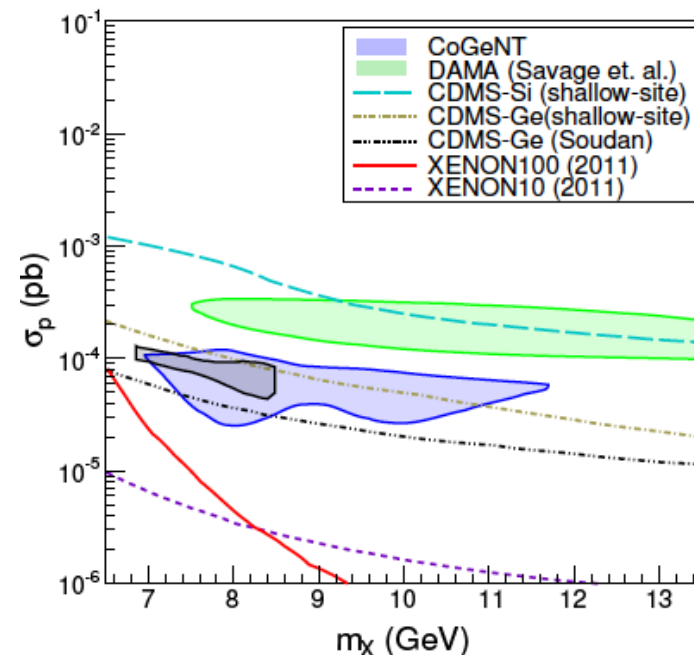


Very recently great excitement in DM field produced by the **CoGeNT (SUL)** results of **15 months of data** showing indication at  $2.8\sigma$  of annual modulation in a **P-type Ge-detector**



DAMA and CoGeNT results **consistent** with a **DM particle** with mass  $m_\chi$  in the range  $\approx 10$  **GeV** and elastic  $s \approx 10^{-40} \text{ cm}^2$ . Phase, period and amplitude are also consistent.

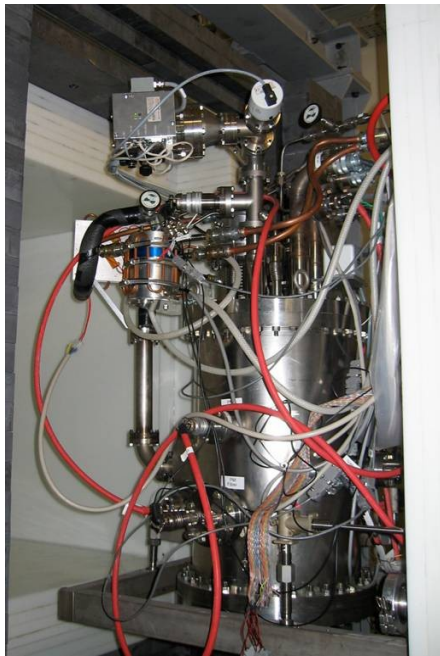
This simple interpretation is excluded by other null results mostly by Xenon100 (LNGS) and CDMS (SUL)



# The XENON Dark Matter Program



**past (LNGS)  
(2005 - 2007)**



**XENON10**

*Achieved (2007)  $\sigma_{SI} = 8.8 \times 10^{-44} \text{ cm}^2$*

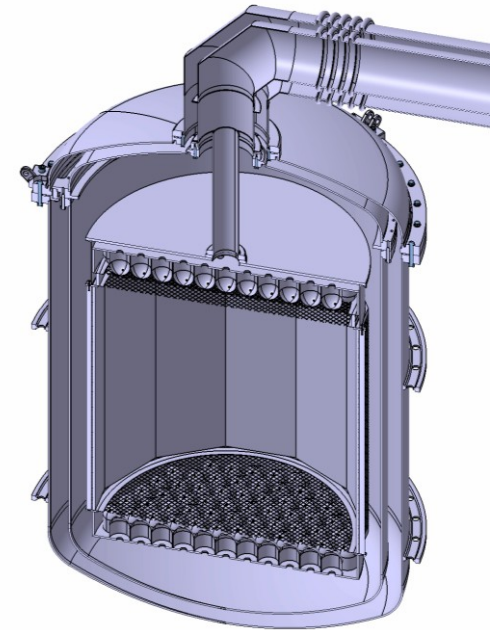
**current (LNGS)  
(2008-2011)**



**XENON100**

*Achieved (2010)  $\sigma_{SI} = 2.4 \times 10^{-44} \text{ cm}^2$   
Achieved (2011)  $\sigma_{SI} \sim 7 \times 10^{-45} \text{ cm}^2$*

**future  
(2011-2015)**



**XENON1T**

*Projected (2015)  $\sigma_{SI} \sim 10^{-47} \text{ cm}^2$*



**Approved by INFN and by the LNGS Scientific Committee**

# XENON100 Dark Matter

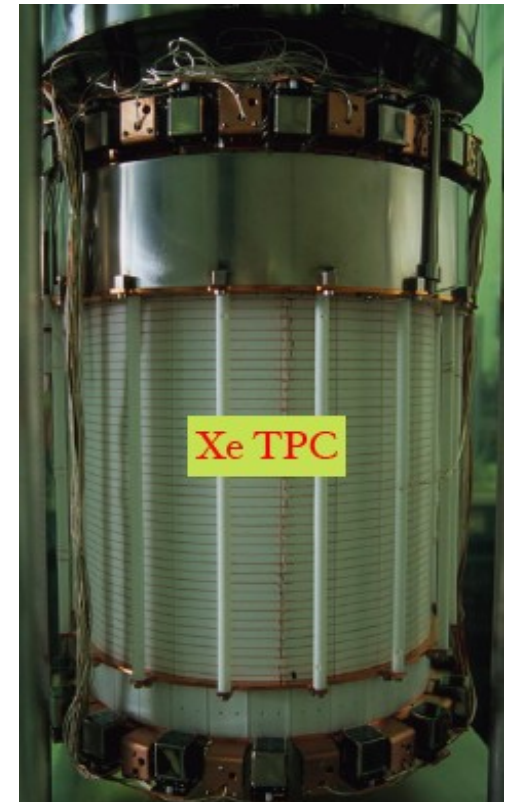
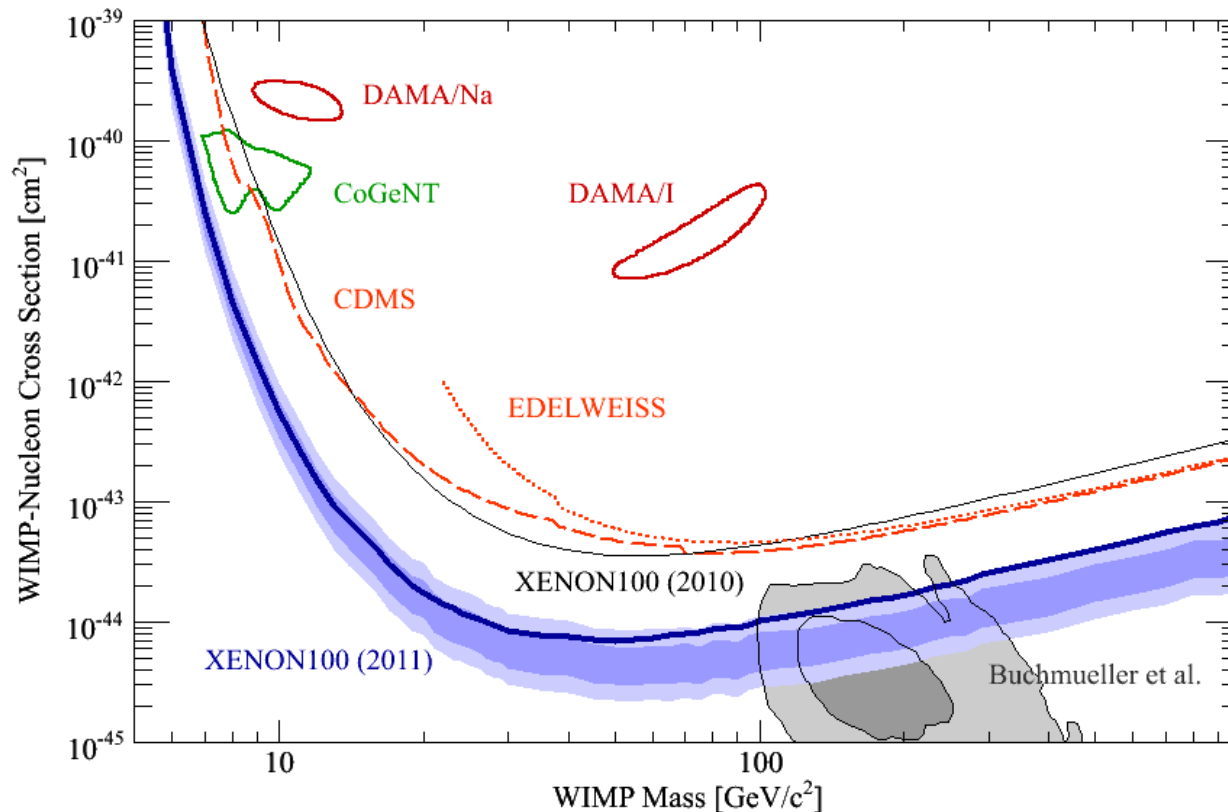


900 events observed in 4800 kg·day: 3 in the WIMP window

Expected total Gamma Leakage:  $1.8 \pm 0.6$

Expected Neutron Background:  $0.1 + 0.08 - 0.04$

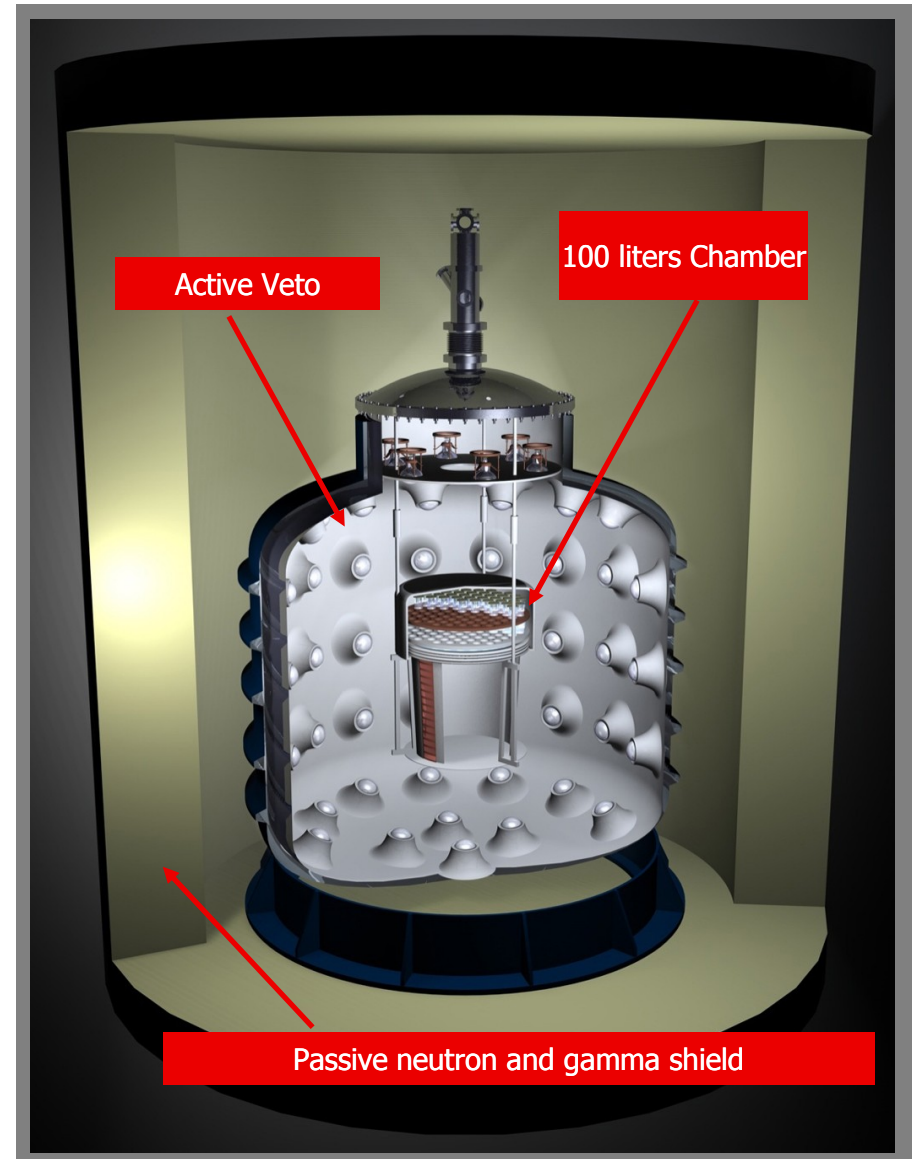
Expectation validated on unblinded side band (30 - 130 phe)



Minimum at  $7 \times 10^{-45} \text{ cm}^2$  and 50 GeV

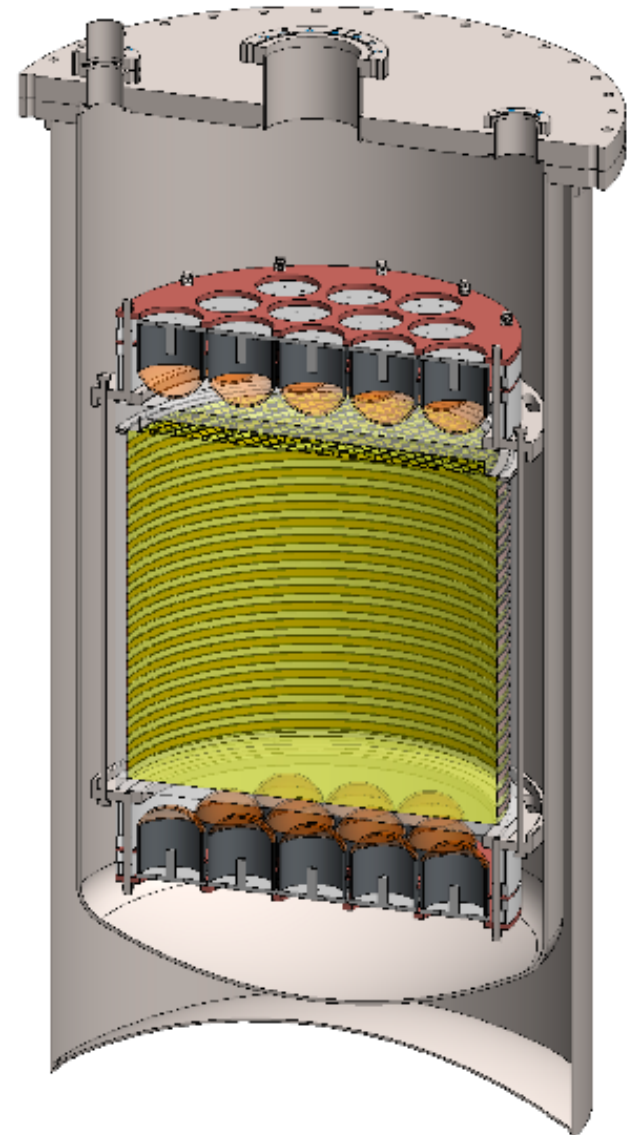
# WARP 100 detector

- WARP 140-kg detector **installed** at **LNGS**. Liquid argon filling completed, **technical run** ongoing
  - complete neutron shield
- **4n active neutron veto** (9 tons Liquid Argon, 300 PMTs), allowing active control on **nuclear-recoil background**
- **3D event localization** and definition of fiducial volume for surface background rejection
  - Detector designed for **positive confirmation** of a possible WIMP discovery (**annual modulation, neutron background subtraction**)
  - Cryostat designed to **allocate** a possible **1400 kg** detector



# Dark Side - 50

- first implementation of **new technologies**
  - **depleted argon, QUPIDs, organic scintillator based neutron veto**
- **dual-phase TPC** à la WARP
- **50 kg<sup>dep</sup>Ar active mass**
- sensitivity  **$10^{-45}$  cm<sup>2</sup>** in 3-yrs background-free operation
- **demonstrate** potential of the **technology** for **multi-ton year** background-free sensitivity



# Dark matter – Future perspectives



- **Rich experimental program** for dark matter searches at LNGS in the next years
  - many **complementary techniques** and **target materials** available
- **DAMA/LIBRA**
  - continue **observations** on **annual modulation**
  - **improved** set-up (**lower energy threshold**)
- **XENON 1T**
  - recently **approved** by INFN and LNGS Scientific Committee
  - location: **Hall B**
- **Liquid Argon** Technology
  - **pursue** with both **WARP100** and **Dark Side R&D**
- **CRESST**
  - precursor of the **next-generation** dark matter project **EURECA**

# Neutrino physics

## ➤ Solar neutrinos

- ${}^7\text{Be}$  was the main target for Borexino
- Future:  ${}^8\text{B}$ , CNO, pep and possibly pp

## ➤ Geo anti-neutrinos

## ➤ SuperNova neutrinos

- LVD, Borexino and ICARUS
- LVD and Borexino are in the SNEWS network

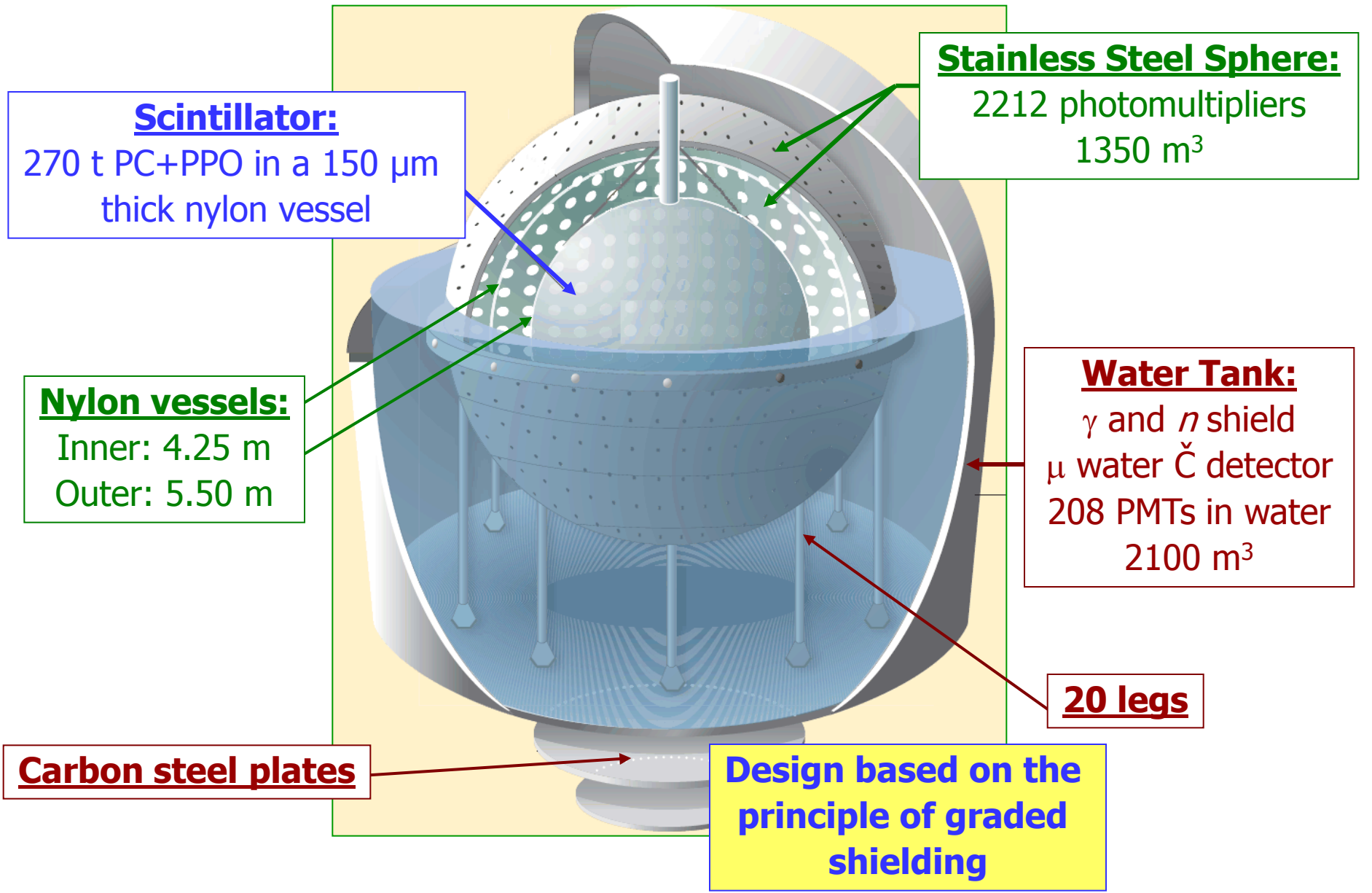
## ➤ CNGS neutrinos

- OPERA and ICARUS

## ➤ Basic neutrino properties

- design dedicated experimental activities to probe models predicting sterile neutrinos

# BOREXINO: a real time detector for solar neutrinos



# $^7\text{Be}$ solar neutrino flux measurement

1<sup>st</sup> result (30% - 2007)  $^7\text{Be}$  Rate =  $47 \pm 7_{\text{stat}} \pm 12_{\text{syst}}$  cpd/100t (47.4 days)

2<sup>nd</sup> result (10% - 2008)  $^7\text{Be}$  Rate =  $49 \pm 3_{\text{stat}} \pm 4_{\text{syst}}$  cpd/100 t (192 days)

**3<sup>rd</sup> result: at 4.3 % precision**

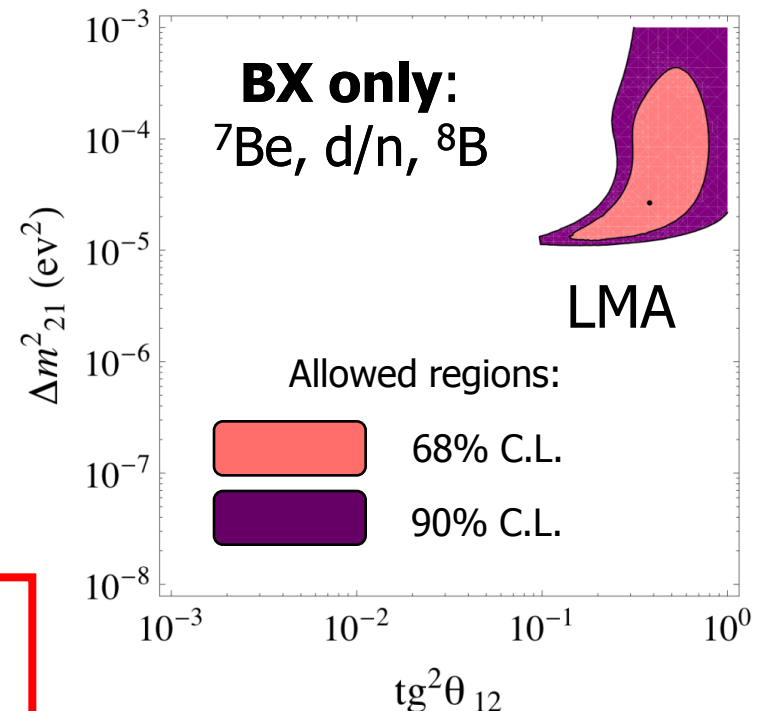
$^7\text{Be}$   $\nu$  Rate:

**$46 \pm 1.5_{\text{STAT}} \pm 1.3_{\text{SYS}}$  cpd/100 t in 750 days of data**

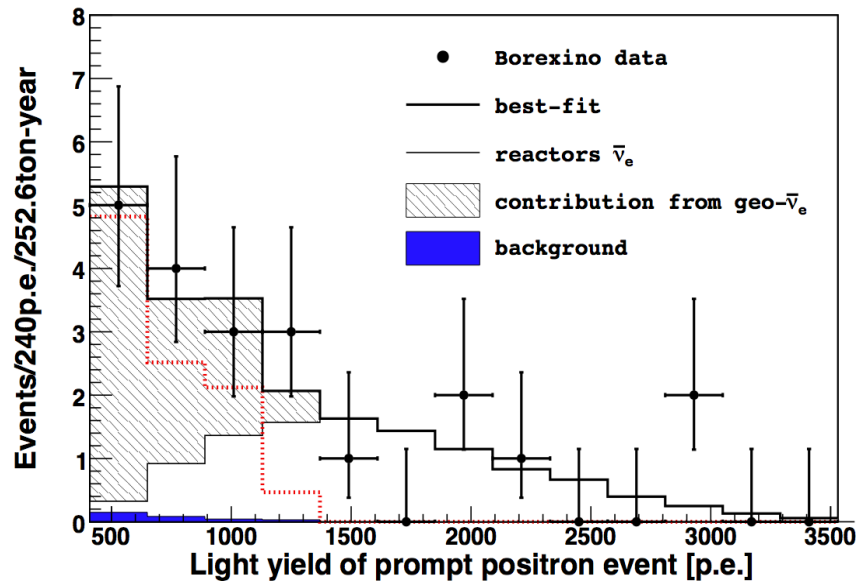
Measured also **day-night asymmetry**:  $A_{\text{dn}} = 0.001 \pm 0.012$  (stat)  $\pm 0.007$  (syst)

Hypothesis	Exp. Rate (cpd/100t)
<b>No oscillation + High Z</b>	<b><math>74 \pm 4</math></b>
<b>No oscillation + Low Z</b>	<b><math>67 \pm 4</math></b>
<b>Oscillation MSW + High Z</b>	<b><math>48 \pm 4</math></b>
<b>Oscillation MSW + Low Z</b>	<b><math>44 \pm 4</math></b>

BX measurement **confirms oscillations** but cannot discriminate High vs. Low metallicity



# Geo-v: observation of the geo- ν signal

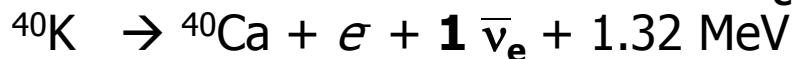
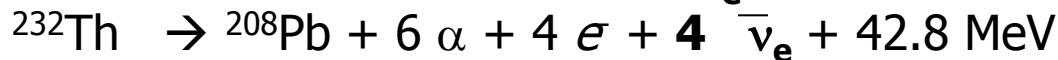
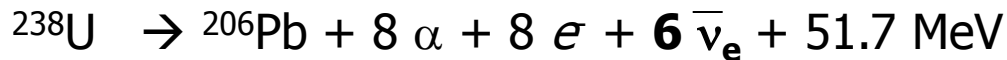


$$N_{geo} = 9.9^{+4.1}_{-3.4}^{+14.6}_{-8.2} \quad @ \text{99.73\% C.L.}$$

$$N_{react} = 10.7^{+4.3}_{-3.4}^{+15.8}_{-8.0} \quad @ \text{68.3\% C.L.}$$

**Null geo-ν hypothesis rejected at 4.2 σ**

**Background** in the geo-ν energy window:  $0.31 \pm 0.05$



S/B  $\approx$  4:1 in Borexino

S/B  $\approx$  1:7 in Kamland

Relevance of geoneutrinos study  $\rightarrow$  A new probe of the Earth interior: the movement of the heat within the Earth is central in the theory of plate tectonics

# CNGS beam: CERN Neutrino to Gran Sasso

**Energy:**

**optimized for  $\nu_\tau$  appearance mode**

**Goal:**

**prove definitely the neutrino oscillations**

Project INFN-CERN: approved in 1999, started in 2006

$\nu_\mu$  beam produced at CERN and detected at LNGS

Experimental halls designed in the CERN direction

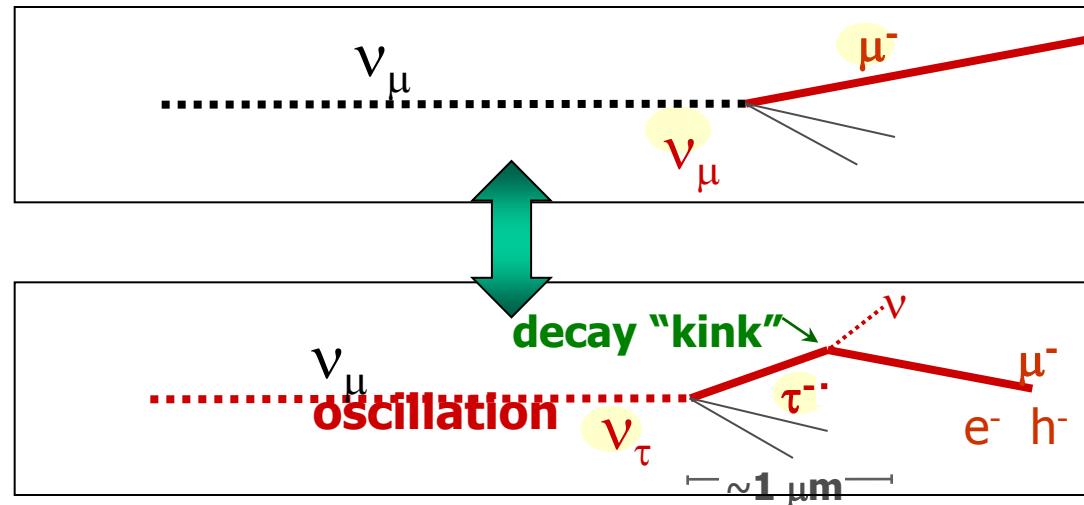
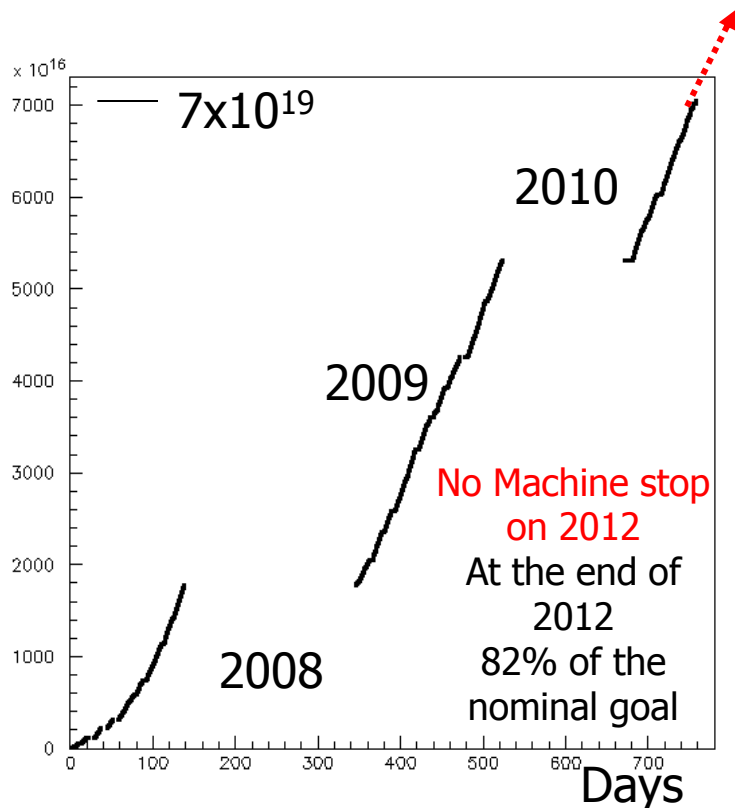


**OPERA** running since 2006  
**ICARUS** running since 2010

# OPERA: Oscillation Project with Emulsion-tRacking Apparatus

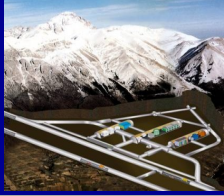
## The direct detection of neutrino oscillations in appearance mode

Requires: (1) long baseline, (2) high neutrino energy, (3) high beam intensity, (4) detect short lived  $\tau$ 's



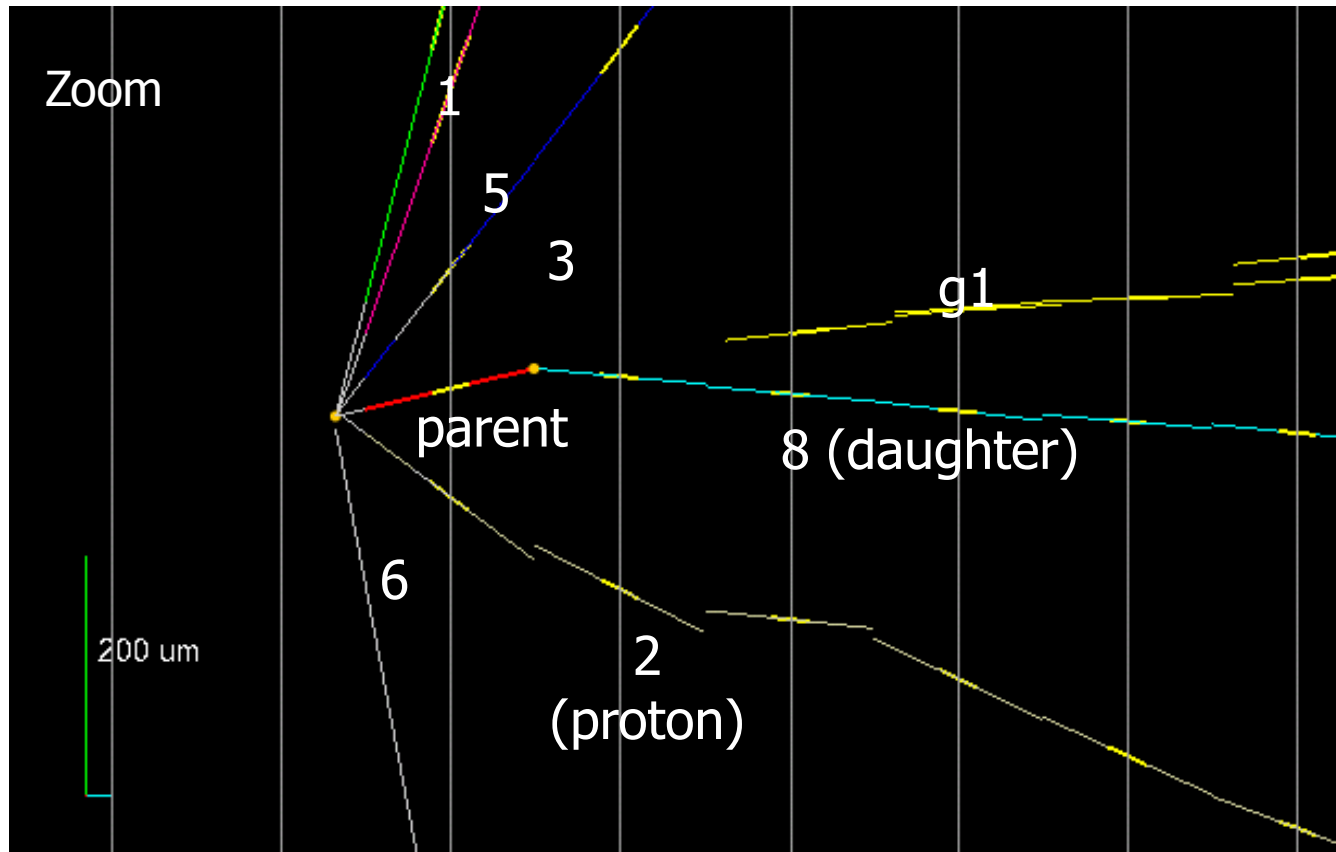
	Signal	Background
	$\Delta m^2 = 2.5 \times 10^{-3} \text{ eV}^2$	
Counts for $22.5 \times 10^{19}$ pot	10.4	0.75

# Neutrino Oscillations: OPERA



➤ Recently at LNGS

the first evidence of direct detection of  $\nu_\mu \rightarrow \nu_\tau$  oscillation in appearance mode



# ICARUS T600 in LNGS Hall B

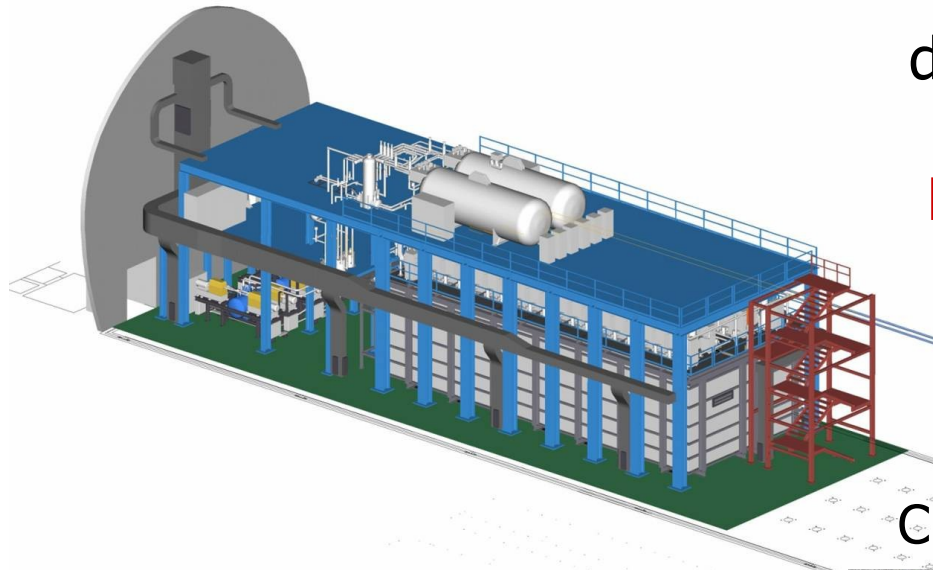
Two identical modules  
 $3.6 \times 3.9 \times 19.6 \approx 275 \text{ m}^3$  each  
Liquid Ar active mass:  $\approx 476 \text{ t}$

**Multi-purpose detector:**  
atmospheric, solar ( $>8 \text{ MeV}$ ),  
supernovae neutrinos, nucleon  
decay searches in “exotic” channels,  
CNGS beam

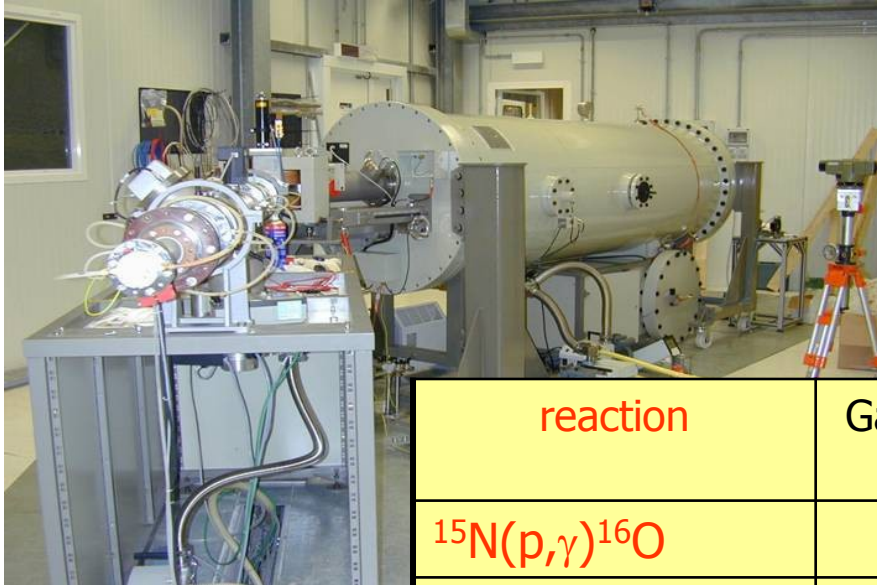
**Milestone** towards a **multi-kton LAr detector** with unique imaging capability, and spatial/calorimetric resolutions

CNGS neutrino event (May 28<sup>th</sup> 2010)

Inaugurated on **March 29<sup>th</sup>, 2011**. Preliminary results available on  $\nu_\mu$  interactions from the CNGS beam



# Laboratory for Underground Nuclear Astrophysics



400 kV Accelerator :

$E_{\text{beam}}$  : 50 – 400 keV

$I_{\text{max}} \approx 500 \mu\text{A}$  protons

$I_{\text{max}} \approx 250 \mu\text{A}$  alphas

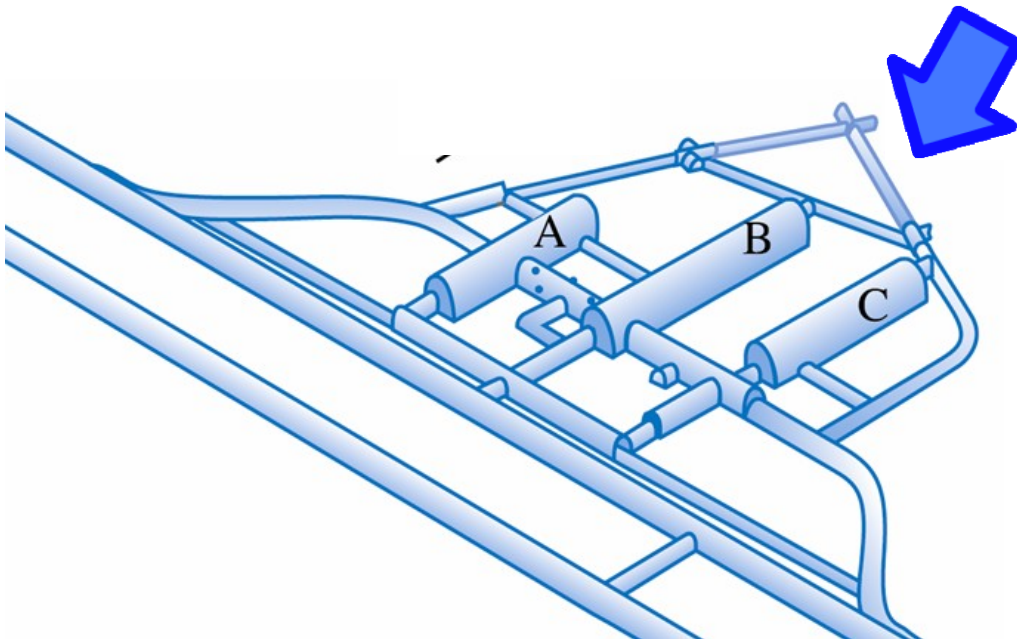
3 reactions  
still to be  
studied:  
probably  
3-4 years  
from now

reaction	Gamow energy (keV)	Lowest meas. Energy (keV)	LUNA limit
$^{15}\text{N}(p,\gamma)^{16}\text{O}$	10-300	130	50
$^{17}\text{O}(p,\gamma)^{18}\text{F}$	35-260	300	65
$^{18}\text{O}(p,\gamma)^{19}\text{F}$	50-200	143	89
$^{23}\text{Na}(p,\gamma)^{24}\text{Mg}$	100-200	240	138
$^{22}\text{Ne}(p,\gamma)^{23}\text{Na}$	50-300	250	68
$\text{D}(\alpha,\gamma)^6\text{Li}$	50-300	700(direct) 50(indirect)	50

# LUNA MV LoI : key reactions of the He burning and neutron sources for the s-process

$^{12}\text{C}(\alpha,\gamma)^{16}\text{O}$ ,  $^{13}\text{C}(\alpha,n)^{16}\text{O}$ ,  $^{22}\text{Ne}(\alpha,n)^{25}\text{Mg}$ ,  $(\alpha,\gamma)$  reactions on  $^{14,15}\text{N}$  and  $^{18}\text{O} \rightarrow$  reactions relevant at higher temperatures than reactions belonging to the hydrogen-burning studied so far at LUNA

 higher energy machine required: 3 MV



Location underground  
has been identified:  
**interferometric area**

An *ad hoc* committee was appointed to evaluate impact of accelerator **n production** to other experiments  $\rightarrow$  **no major impact** in the foreseen position

# LUNA MV Project: Status

- **Positive recommendation** by the **LNGS Scientific Committee** following the report from the *ad-hoc* neutron committee
- Real **feasibility study** started
  - finalize the **design** of the **accelerator** (LUNA Collaboration + INFN-LNF)
  - finalize the **design** of the neutron shielding
  - prepare the **refurbishment** of the **underground area** (ventilation, floor sealing, security system)
    - estimated time: 1 year, cost: 400 k€
- A **Round Table** was organized at LNGS (Feb 10<sup>th</sup>-11<sup>th</sup>) to collect **interest** among **new groups**
  - slides and proceedings available at <http://luna.lngs.infn.it/luna-mv>

# Conclusions

- INFN-Gran Sasso laboratory is the **largest underground laboratory** in the **world**
  - **Leadership** in **massive experiments** with record performance and **low-level background**
- The **present scientific program** of LNGS includes a very **broad spectrum** of competitive experiments (astroparticle, particle and nuclear physics)
  - **16 experiments** + R&D activities, including world-leading in the fields of solar neutrinos, accelerator neutrinos, double beta decay, dark matter and nuclear astrophysics
- Plan to **maintain** the **scientific excellence** in the next years by an **extensive physics program** (**new experiments** and **upgrades** of the present ones)
- After the **end** of the **CNGS program** (2013-2015), **underground space** (OPERA and ICARUS) could be **made available**
  - laboratory still **open to proposals** for new and innovative experiments

**BACKUP**

# Physics at LNGS

The inventory of Universe and the dark matter

DAMA/LIBRA  
CRESST  
WARP  
XENON  
Dark Side R&D

LBL - CNGS

OPERA  
Icarus T600

Properties of neutrinos and their role in cosmic evolution

$2\beta 0\nu$

CUORE  
GERDA  
COBRA  
Lucifer R&D

What about the interior of the Sun and the Earth

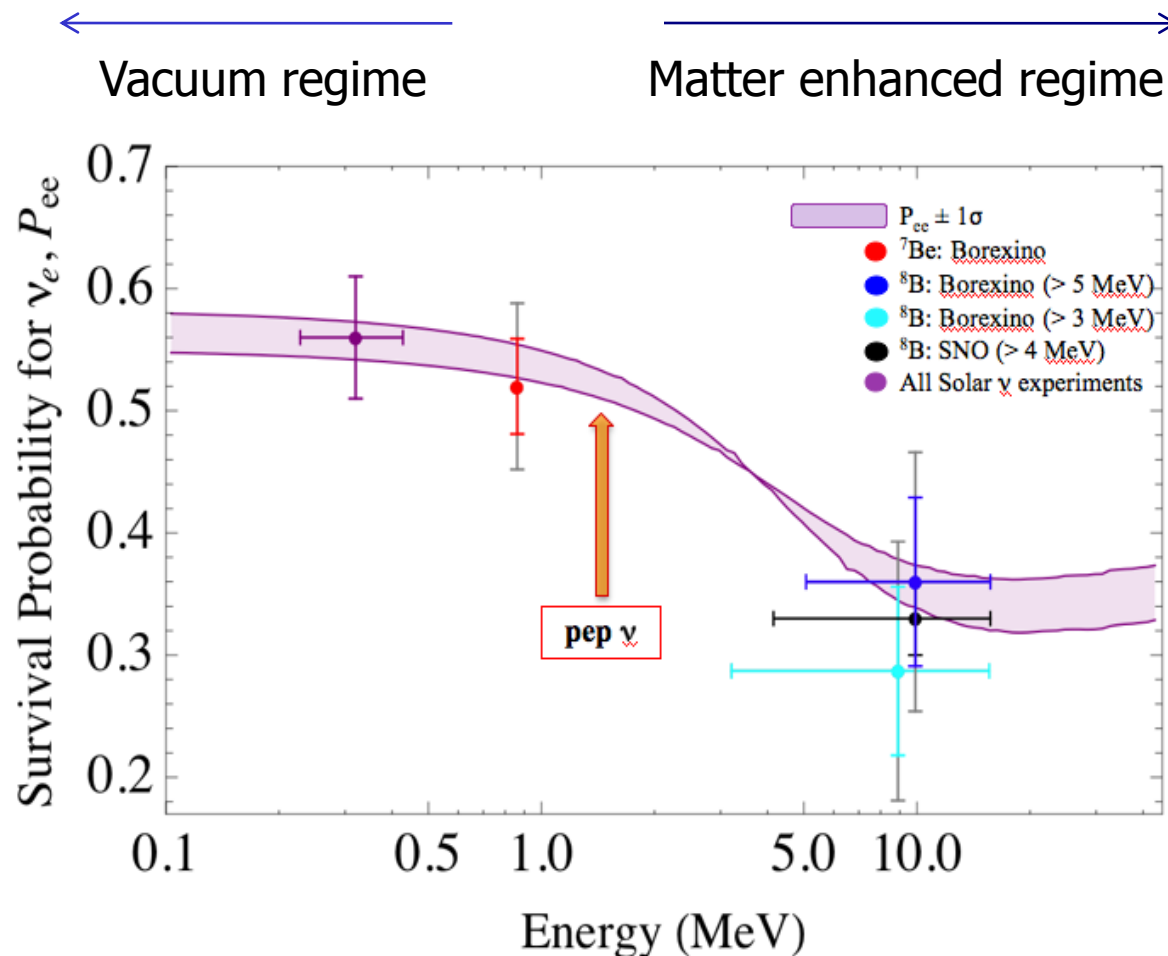
BOREXINO  
LUNA

LVD

What about the supernova explosions

# Impact of Borexino results

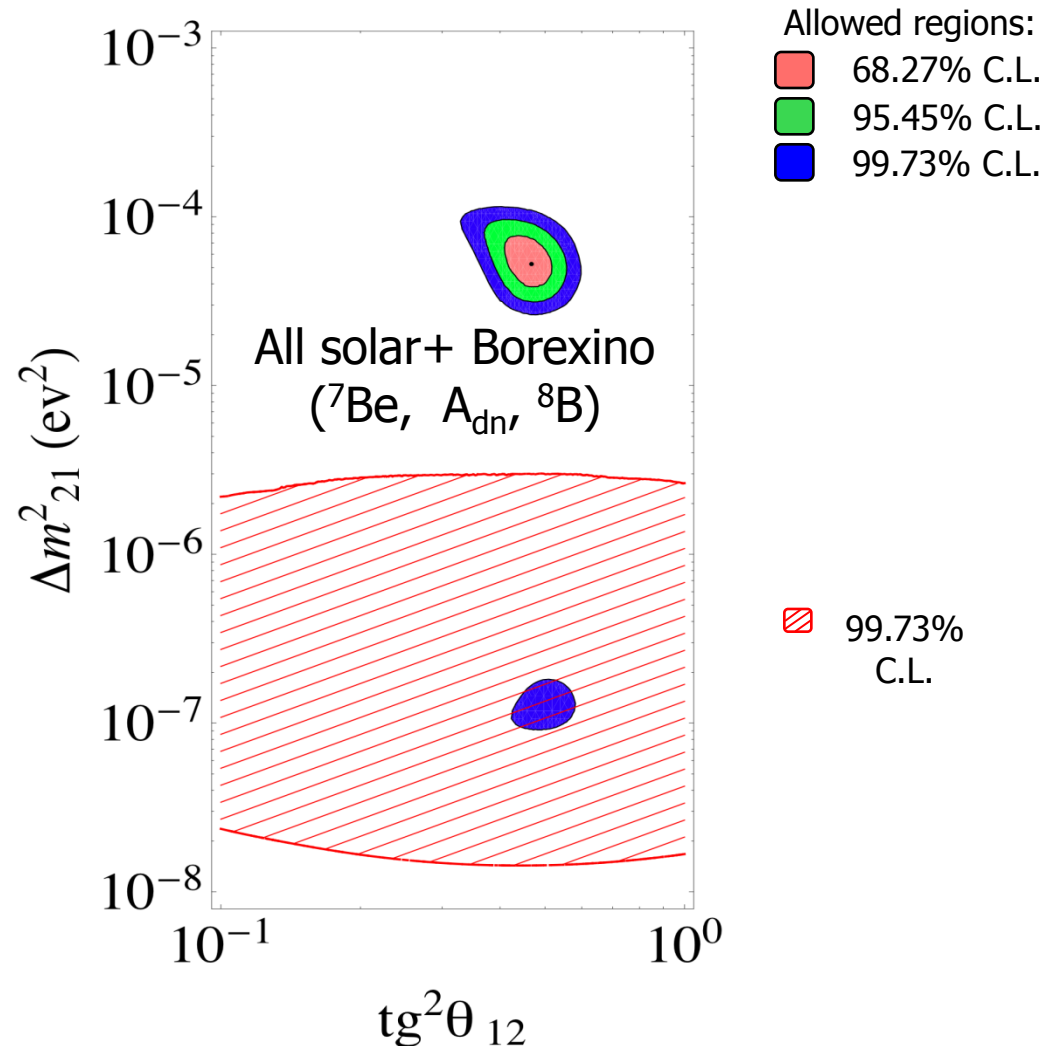
$^7\text{Be}$  flux and  $P_{ee}$ : validation of the LMA  
MSW model in the vacuum regime



# Impact of Borexino results

The LOW region  
is ruled out at  
 $8.5 \sigma$  by solar n  
only (not anti  $\nu$ )  
when Borexino  
data are included

No need for CPT



# Impact of Borexino results

The Borexino data ( ${}^7\text{Be}$ ,  $D/N$ ,  ${}^8\text{B}$  rate and spectrum)  
(without the others solar data and without KamLand)  
identify the LMA region at 90% CL

