HIGHLIGHTS FROM INFN

Fernando Ferroni
INFN & Universita' Sapienza Roma

The Future of our Physics including new Frontiers

Erice 53st Course: June 24-July 3 2015

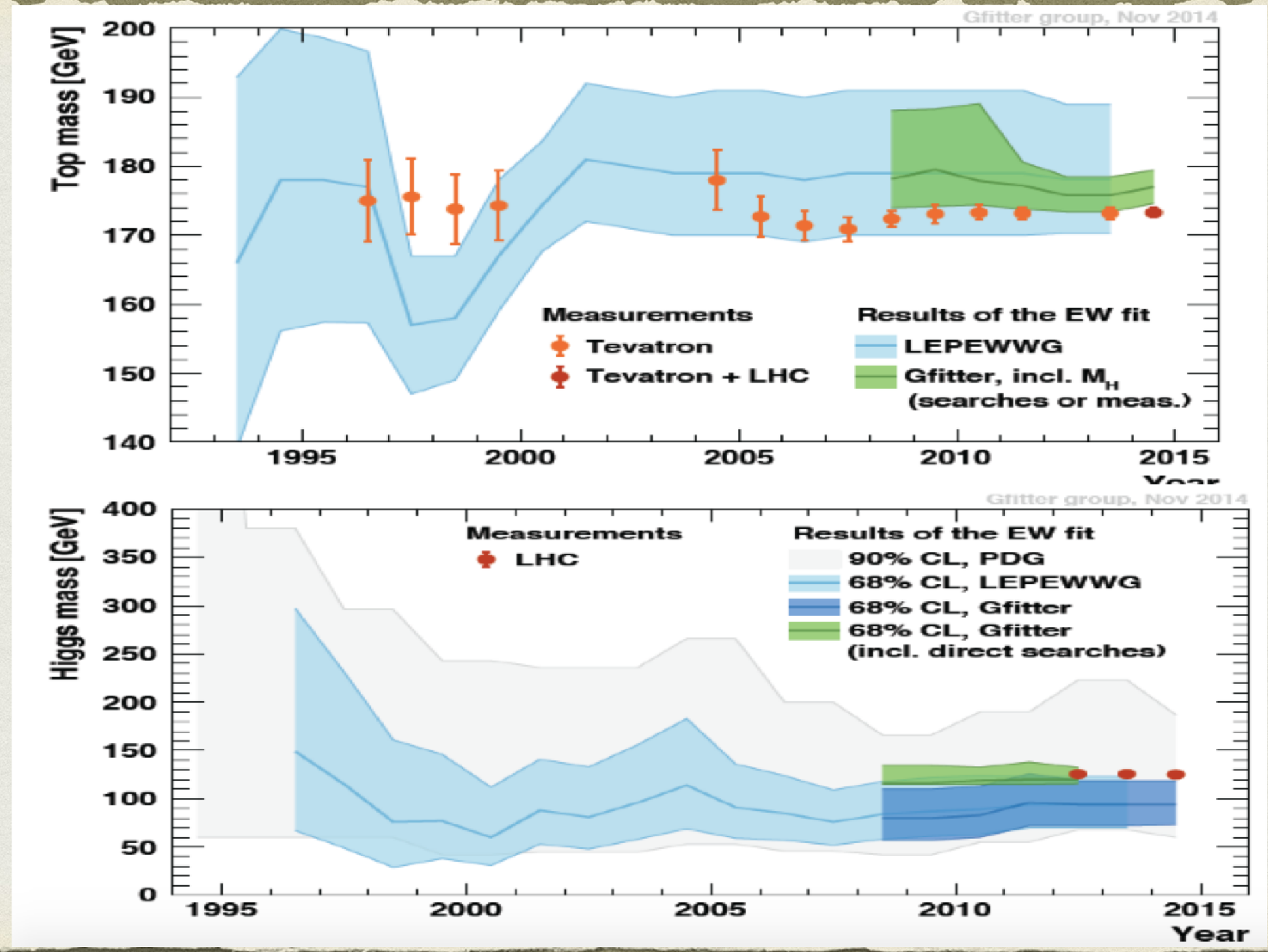
INTERESTING TIMES

- at the border between the glorious past of Standard Model and the uncertain future of New Physics

- the extraordinary success of LHC in finding the long awaited Higgs boson exhausts the roads, that although impervious, were somewhat marked

- we are in front of a list of questions, none of which has a guaranteed answers from the experiments we are doing, the accelerators we have, the technology we exploit

WHAT I MEAN...


Gfitter group, Nov 2014
Top mass [GeV]
200
190
180
170
160
150
140
1995
2000
2005
2010
2015
Measurements
Tevatron
Tevatron + LHC
Results of the EW fit
LEPEWWG
Gfitter, incl. M_H
(searches or meas.)
Gfitter group, Nov 2014
Higgs mass [GeV]
400
350
300
250
200
150
100
50
0
Measurements
LHC
Results of the EW fit
90% CL, PDG
68% CL, LEPEWWG
68% CL, Gfitter
68% CL, Gfitter
(incl. direct searches)
Year

JUST TO REMIND

(AN INCOMPLETE

- DarkMatter exists, but what is made of ?
- Dark Energy is a total mystery
- Our existence in the broader context of Flavour Physics is a puzzle
- Neutrino sector is a vibrant field of research since it is little understood

INFN IN SHORT

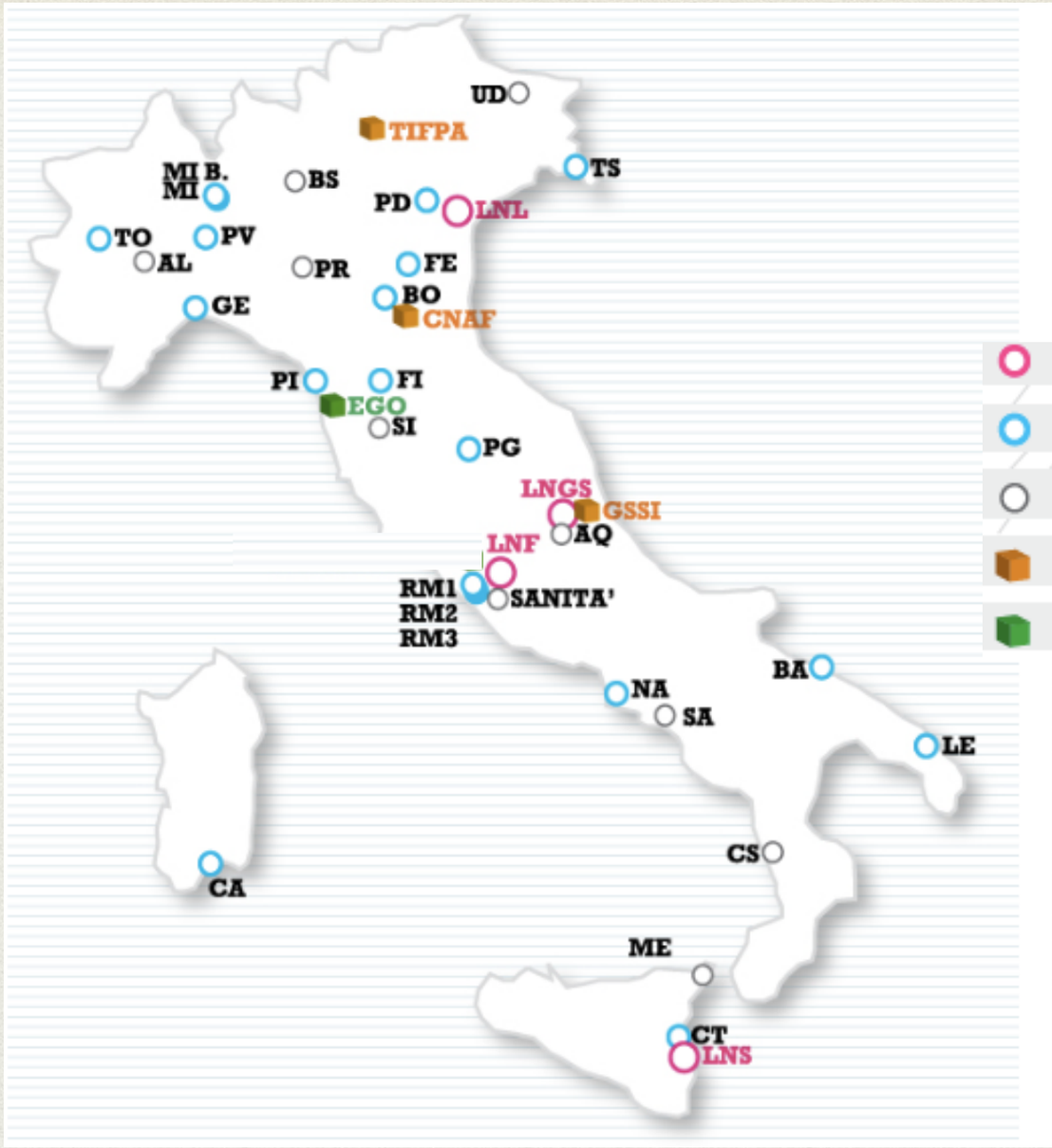
- a research institute diffused all over the country, leaving mostly in a blessed symbiotic relation with universities

- 4 national labs, 3 specialised centres (computer centre- applied physics- Ph.D. school), an infrastructure for GW search, 1 lab for Cultural Heritage and 1 for Superconductivity

- a couple of thousand people (staff and university associates)

- a budget in the 300 MEuro range

INFN GEOGRAPHICALLY



laboratories	4
divisions	20
associated groups	10
national centres	3
consortia	2

LNS

LNF

INFN-HUMAN

DG

Researcher

Engineers

Tech

Administration

Post-Doc

Researcher (full time)

Engineers

Researcher (part time)

Ph. D. students, Post-Doc

Researcher (part time) from other Research Institutions

Retired (still active)

Senior (emeritus)

Foreigner Instituions

Others (unexplicable !)

INFN

1 Dirigente
610 Ricercatori
230 Tecnologi
692 Tecnici
301 Amministrativi
197 Associati Borsisti, Assegnisti

UNIVERSITÀ

843 Associazioni con incarico di ricerca
109 Associazioni con incarico di collaborazione tecnica
651 Associazioni scientifiche/tecnologiche/tecniche
1280 Laureandi, Dottorandi, Borsisti, Assegnisti

ALTRI ENTI

158 Associazioni scientifiche/tecnologiche/tecniche

SENIOR

217 Associazioni scientifiche/tecnologiche/tecniche

ATTRIBUITI DAL PRESIDENTE

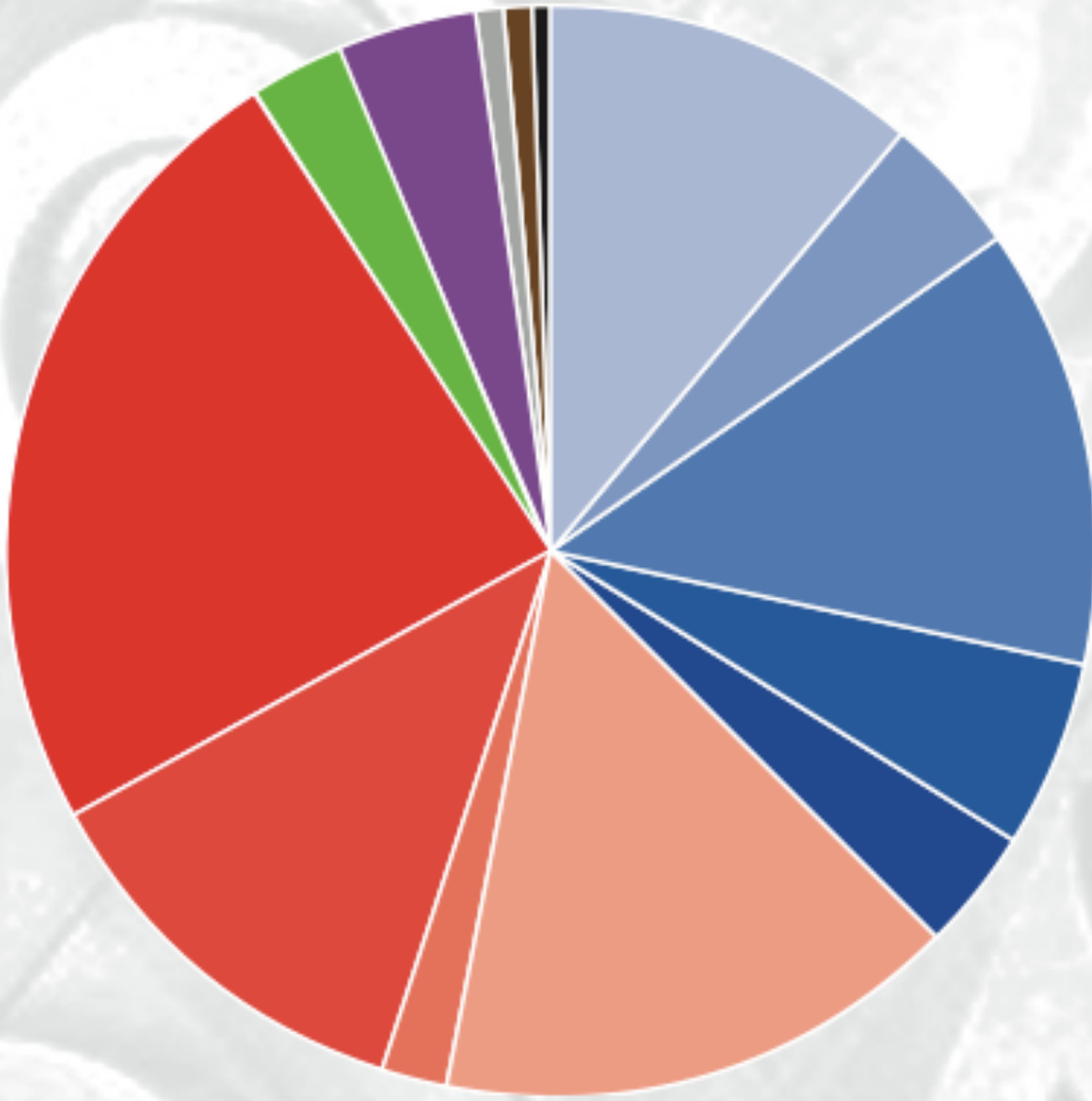
56 Incarichi di ricerca e associazioni scientifiche

STRANIERI

41 Associazioni

ALTRE ASSOCIAZIONI

23 Associazioni scientifiche/tecnologiche E.P. e contratti art. 19



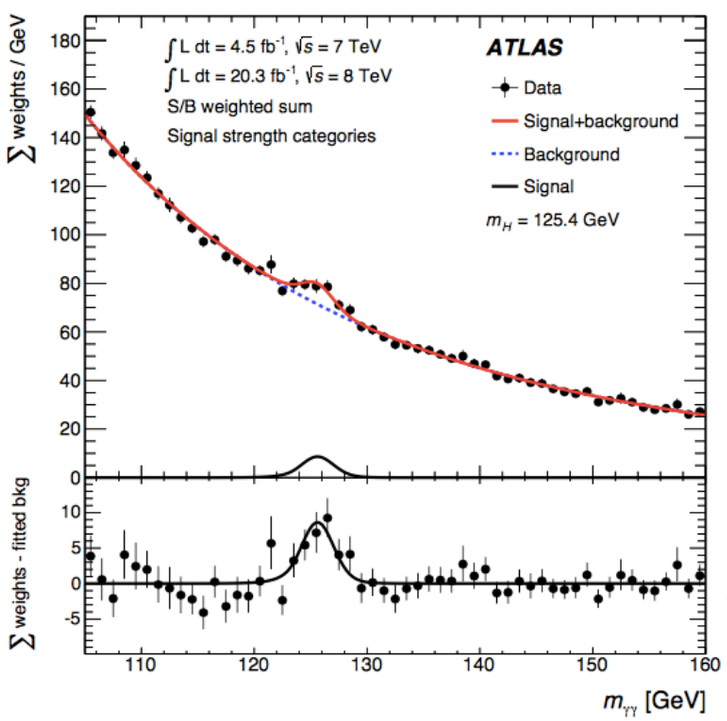
BALANCING A ROBUST PRESENT WITH A VISION FOR A POSSIBLE FUTURE

BASELINE TODAY

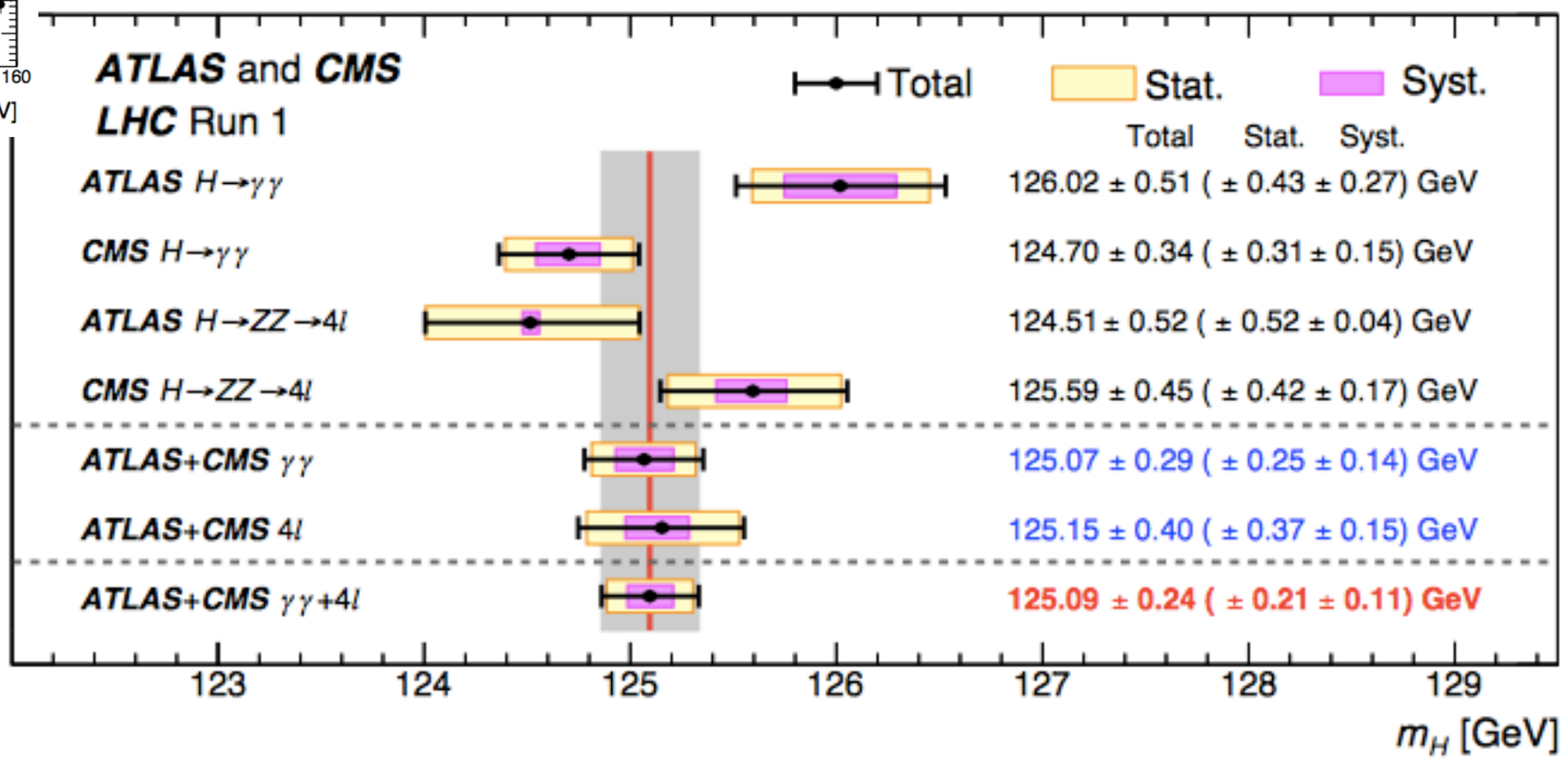
- LHC at CERN
- Dark Matter searches at LNGS
- Neutrino Physics at LNGS
- Gravitational Wave search at EGO (Cascina)
- Accelerator Physics at LNF, LNL, LNS
- Cosmic rays in space, on ground, underground and underwater

LHC

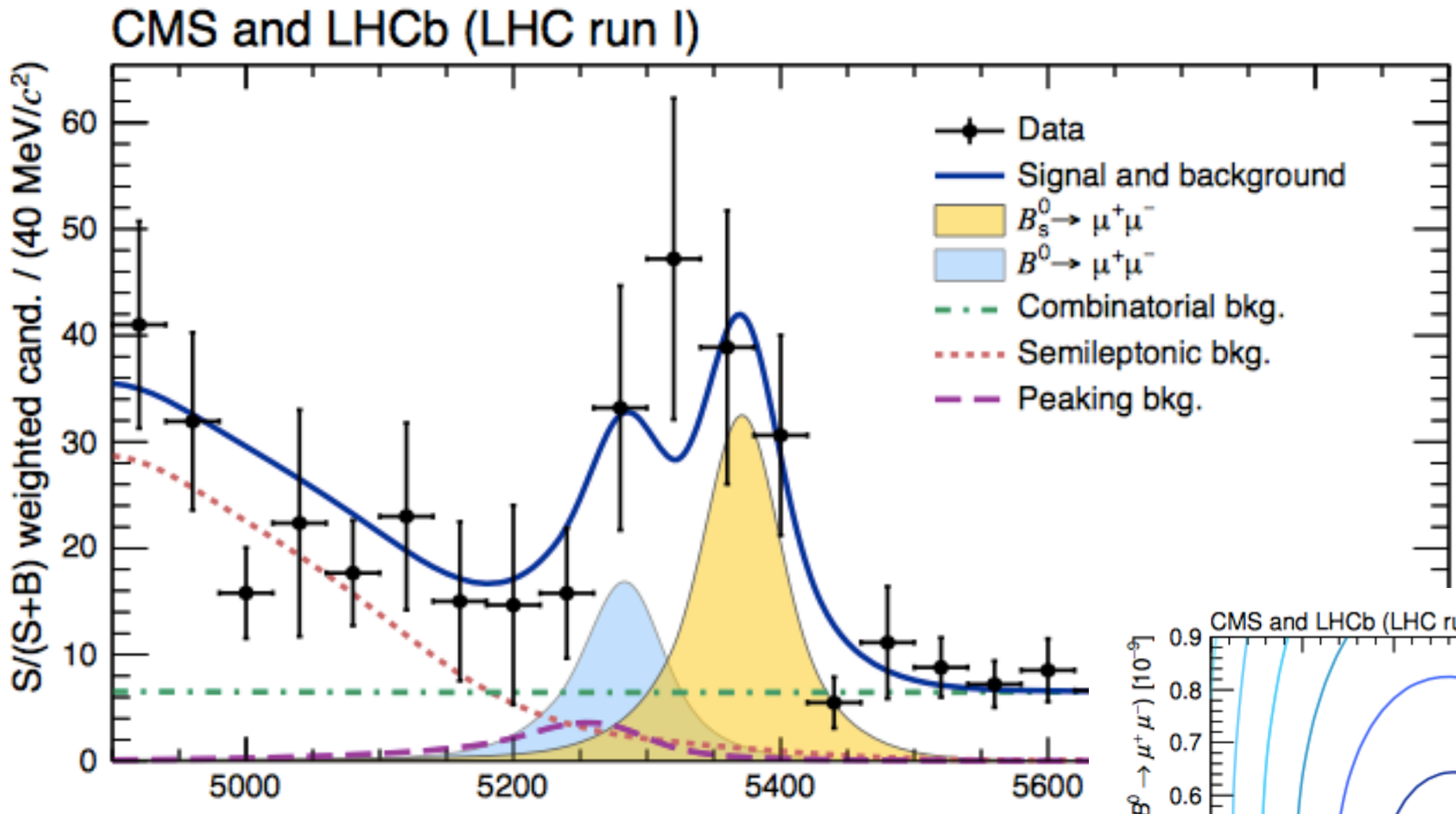
LHC (HIGGS)

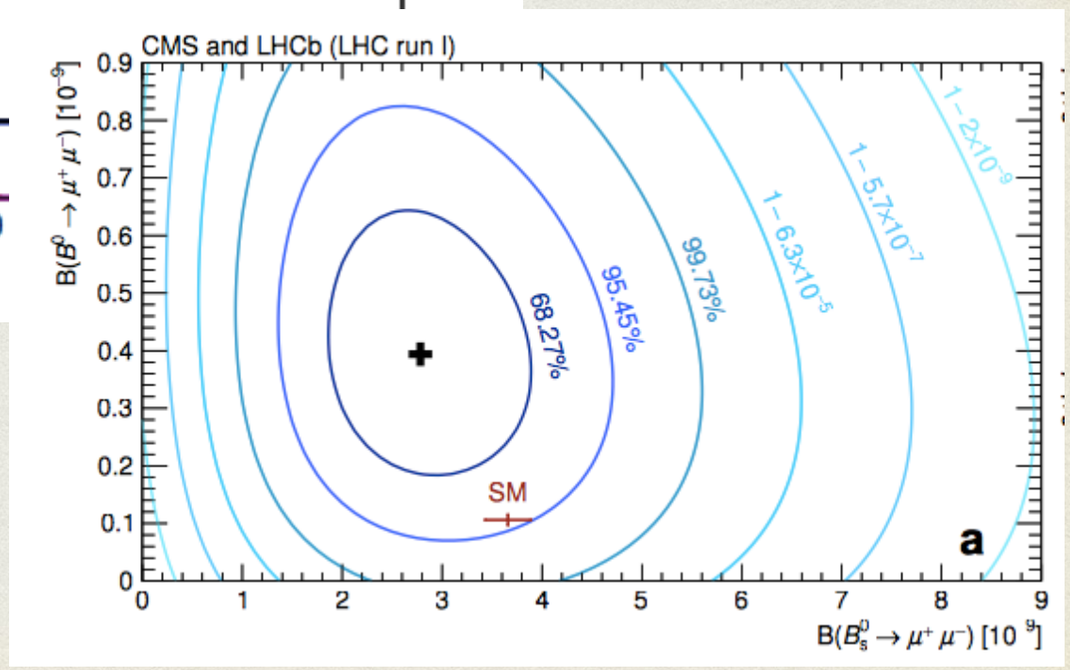


$$m_H = 125.09 \pm 0.24 \text{ GeV}$$
$$= 125.09 \pm 0.21 \text{ (stat.)} \pm 0.11 \text{ (syst.) GeV}$$



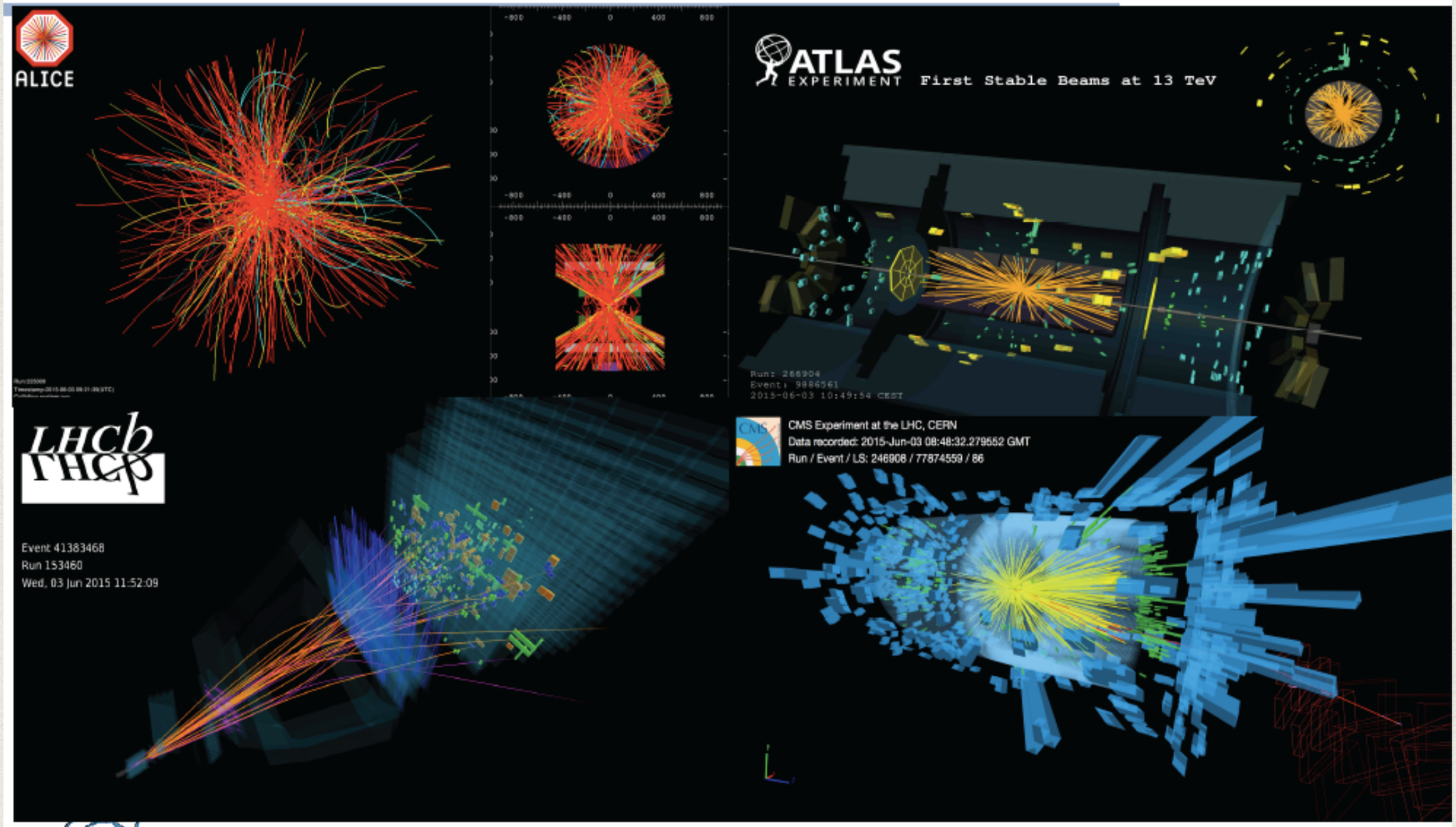
LHC (FLAVOUR)


CMS and LHCb (LHC run I)
S/(S+B) weighted cand. / (40 MeV/c^2)
0
10
20
30
40
50
60
5000
5200
5400
5600
Data
Signal and background
$B_s^0 \to \mu^+\mu^-$
$B^0 \to \mu^+\mu^-$
Combinatorial bkg.
Semileptonic bkg.
Peaking bkg.


CMS and LHCb (LHC run I)
$B(B_s^0 \to \mu^+\mu^-)$ [10^{-9}]
$B(B^0 \to \mu^+\mu^-)$ [10^{-9}]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2
3
4
5
6
7
8
9
68.27%
95.45%
99.73%
$1 - 6.3\times10^{-5}$
$1 - 5.7\times10^{-7}$
$1 - 2\times10^{-9}$
SM
a

AND NOW !

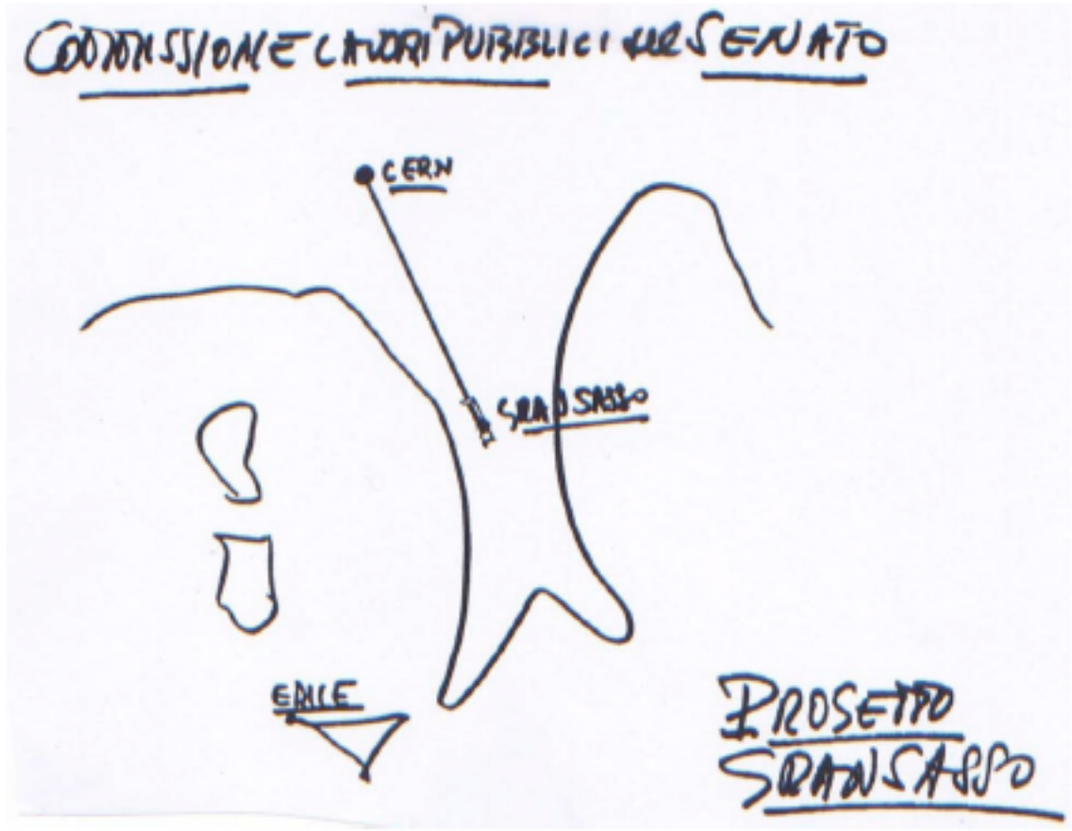
June 3rd: Physics @ 13 Tev



LNGS

THE IDEA OF COSMIC SILENCE

from dream to reality !



Note manoscritte di A. Zichichi presentate nella Seduta della Commissione Lavori Pubblici del Senato convocata con urgenza dal Presidente del Senato per discutere la proposta del Progetto Gran Sasso (1979).

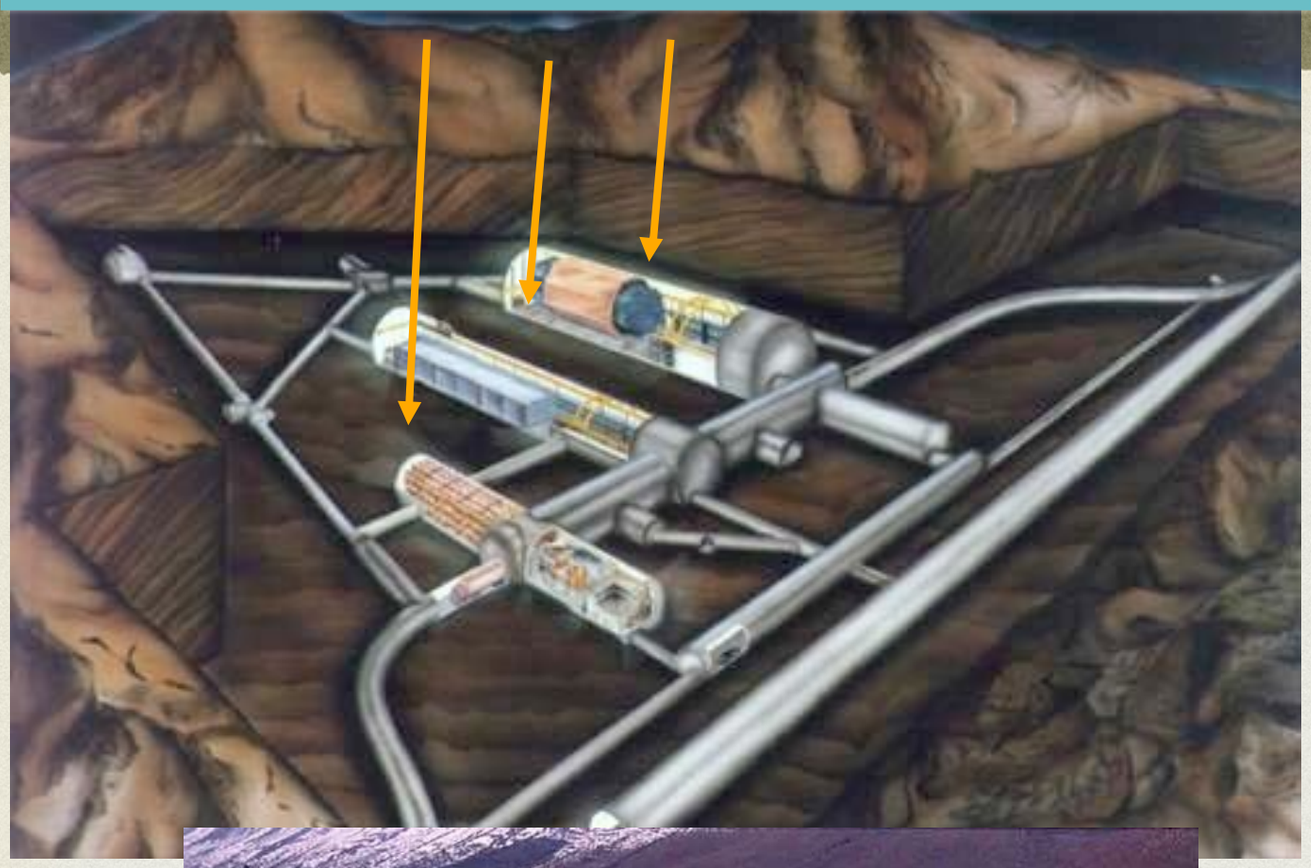
To summarize, the scientific aims of the "Gran Sasso" laboratory are the study of:

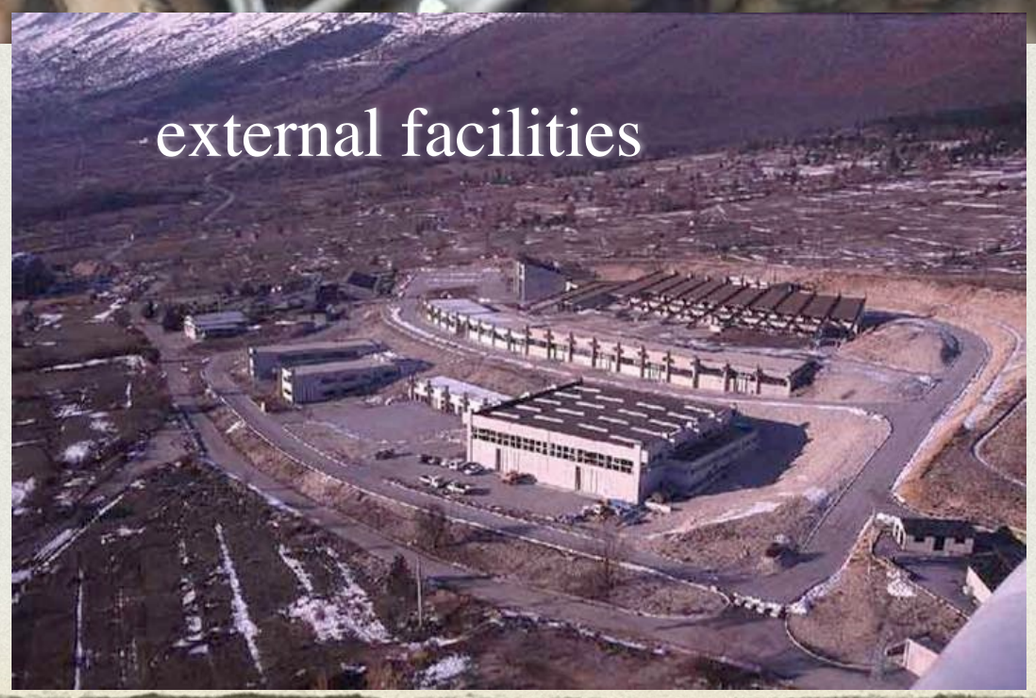
1) nuclear stability;
2) neutrino astrophysics;
3) new cosmic phenomenology;
4) neutrino oscillations;
5) biologically active matter;
6) ground stability.

NOT only $\tau_p \neq \infty$

GRAN SASSO LABORATORY

3 main halls A B C ~100 x 20 m² (h 20 m)





Muon Flux
3.0 10^{-4} μ m^{-2} s^{-1}

Neutron Flux	
2.92 10^{-6} n cm^{-2} s^{-1}	(0-1 keV)
0.86 10^{-6} n cm^{-2} s^{-1}	(> 1 keV)

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

Surface: 17800 m²

Volume: **180000** m³

Rn in air: 20-80 Bq/m³

ISO 14001

Ventilation: 1 Lab volume/3 h

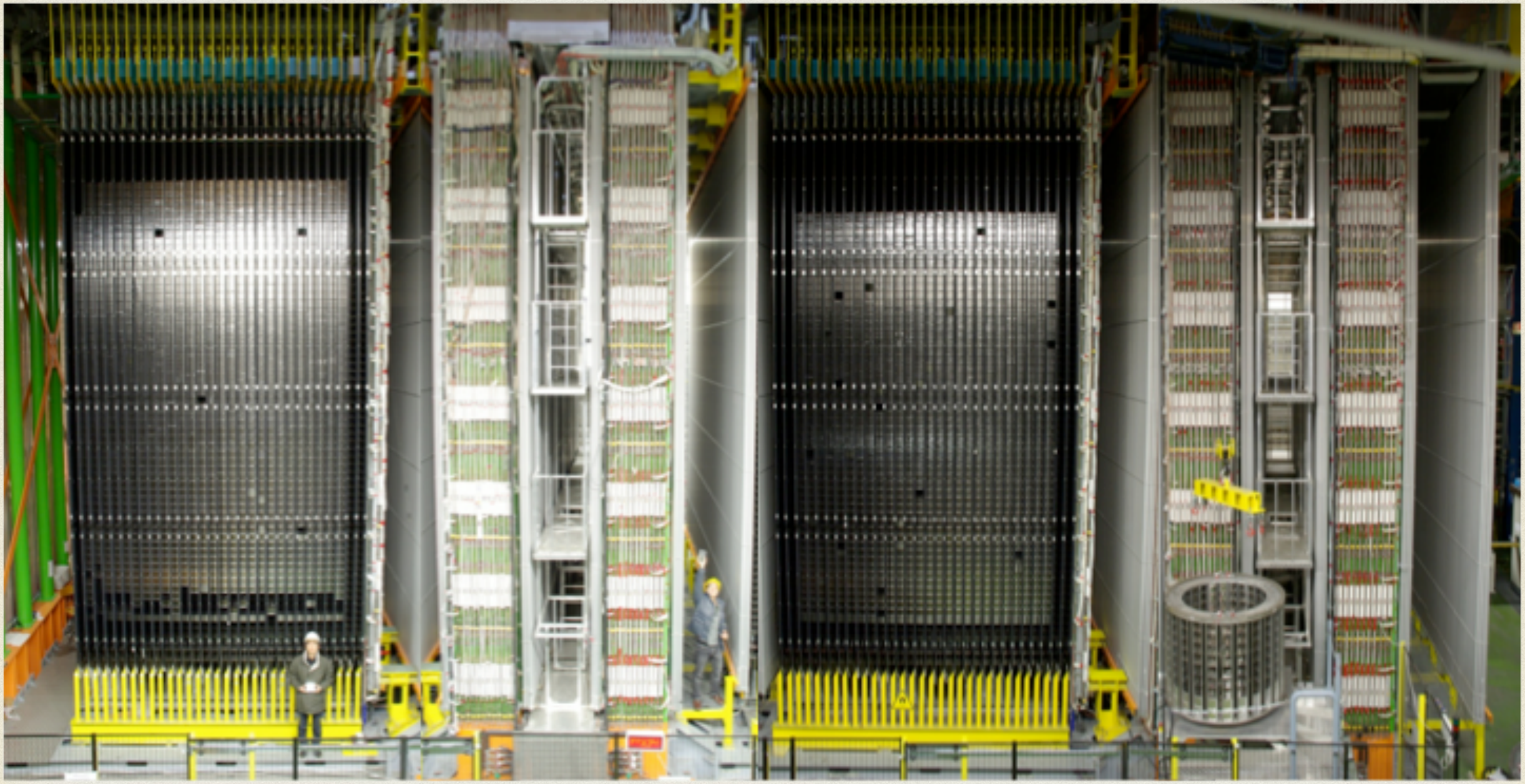
Electrical power: 1300 kW

Access: horizontal

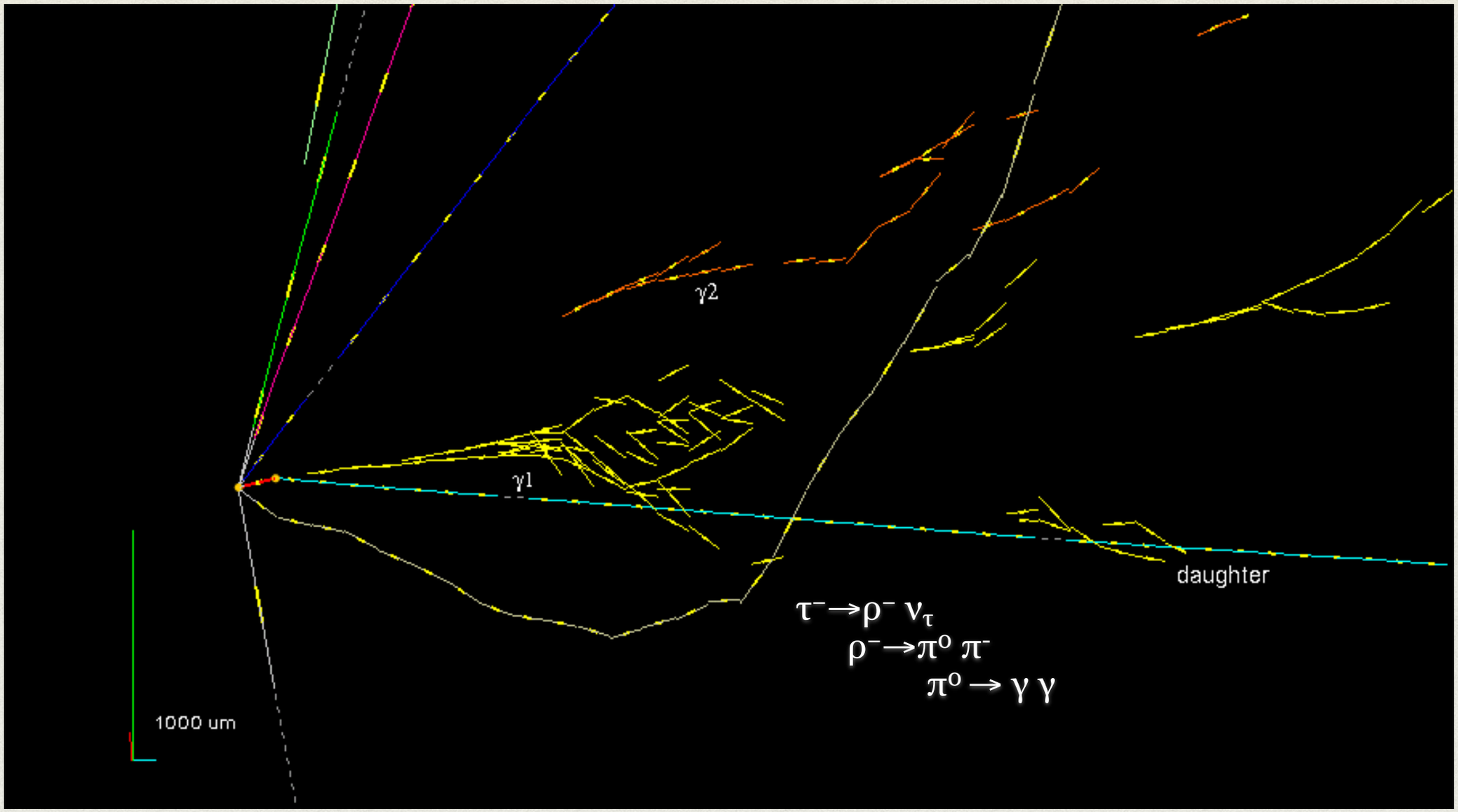
NEUTRINO

- The appearance of tau neutrino from a muon neutrino beam (OPERA)
- The study of the neutrinos travelling from the Sun to Earth (Borexino)
- The quest for Majorana neutrinos (GERDA & CUORE)
- The proof that LAr is a perfect detector for the future of neutrino physics at accelerators (ICARUS)

OPERA



LOOKING AT WHAT THE EMULSIONS ARE GOOD



OVER 5 SIGMA: TAU APPEARANCE IS A MISSION ACCOMPLISHED

Channel	Expected background				Expected signal	Observed
	Charm	Had. re-interac.	Large μ-scat.	Total		
$\tau \to 1h$	0.017 ± 0.003	0.022 ± 0.006	–	0.04 ± 0.01	0.52 ± 0.10	3
$\tau \to 3h$	0.17 ± 0.03	0.003 ± 0.001	–	0.17 ± 0.03	0.73 ± 0.14	1
$\tau \to \mu$	0.004 ± 0.001	–	0.0002 ± 0.0001	0.004 ± 0.001	0.61 ± 0.12	1
$\tau \to e$	0.03 ± 0.01	–	–	0.03 ± 0.01	0.78 ± 0.16	0
Total	0.22 ± 0.04	0.02 ± 0.01	0.0002 ± 0.0001	0.25 ± 0.05	2.64 ± 0.53	5

$\Delta m^2 = 2.44 \cdot 10^{-3}$ eV^2

Two statistical methods:
- Fisher combination of single channel p-values
- Profile likelihood ratio

5 observed events with 0.25 background events expected

Probability to be explained by background { Fisher = 1.10×10^{-7} ; Profile likelihood = 1.07×10^{-7}

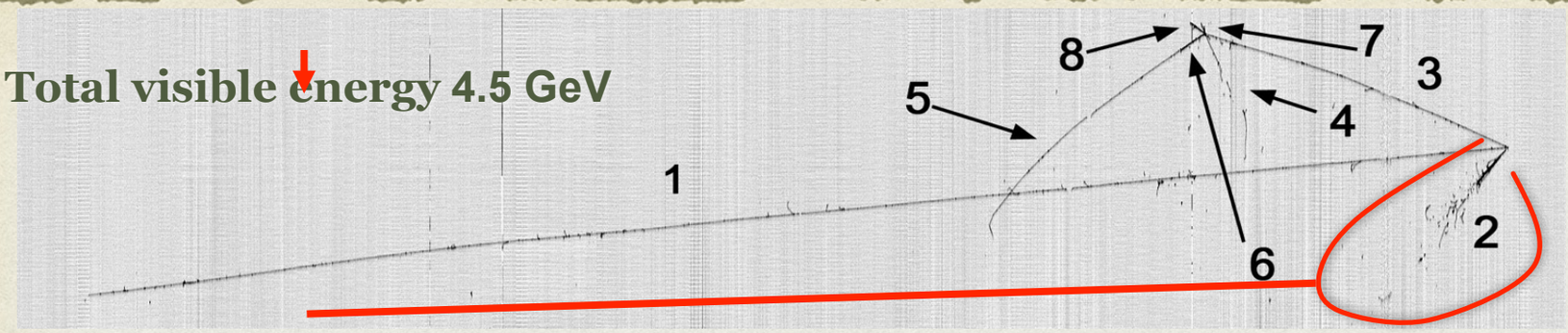
This corresponds to 5.1 σ significance of non-null observation

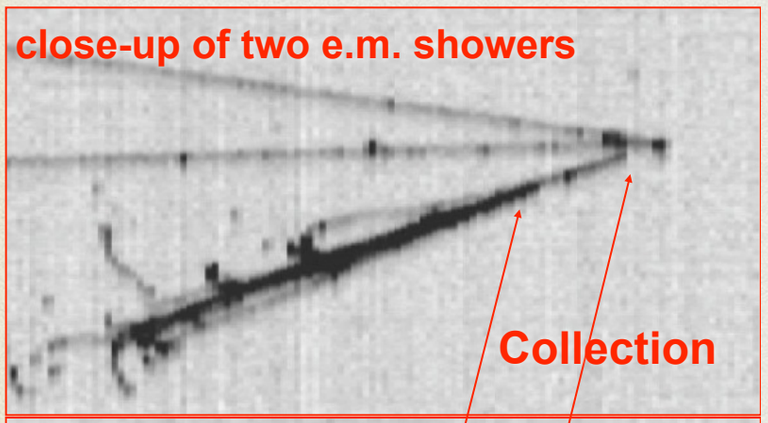
$P(n \geq 5 \mid \mu = 2.9) = 16.6\ \%$

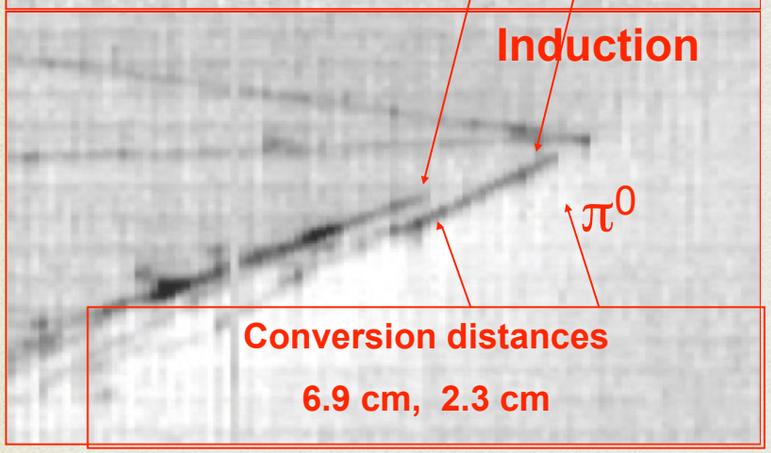
$P^{\dagger} = 6.4\%$

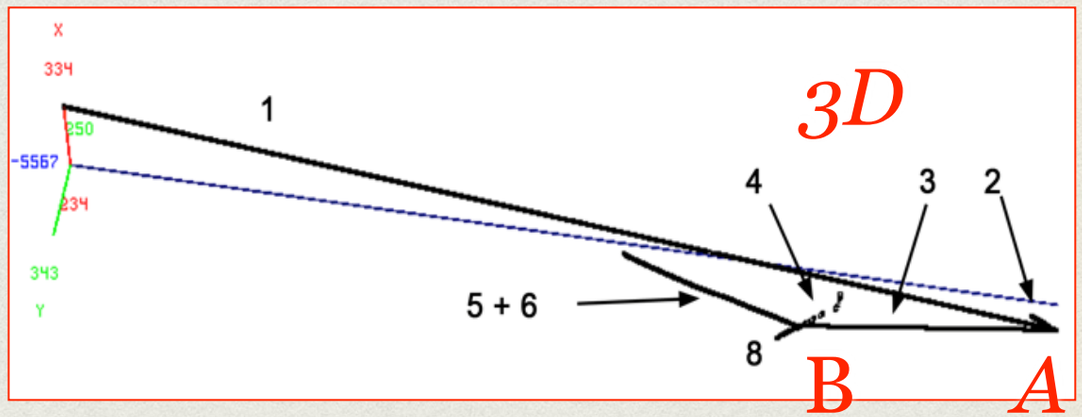
$P^{\dagger}$ = probability to obtain a configuration less likely than (3, 1, 1, 0)

THE LAR-TPC
THE ELECTRONIC BUBBLE CHAMBER









Primary vertex (A):

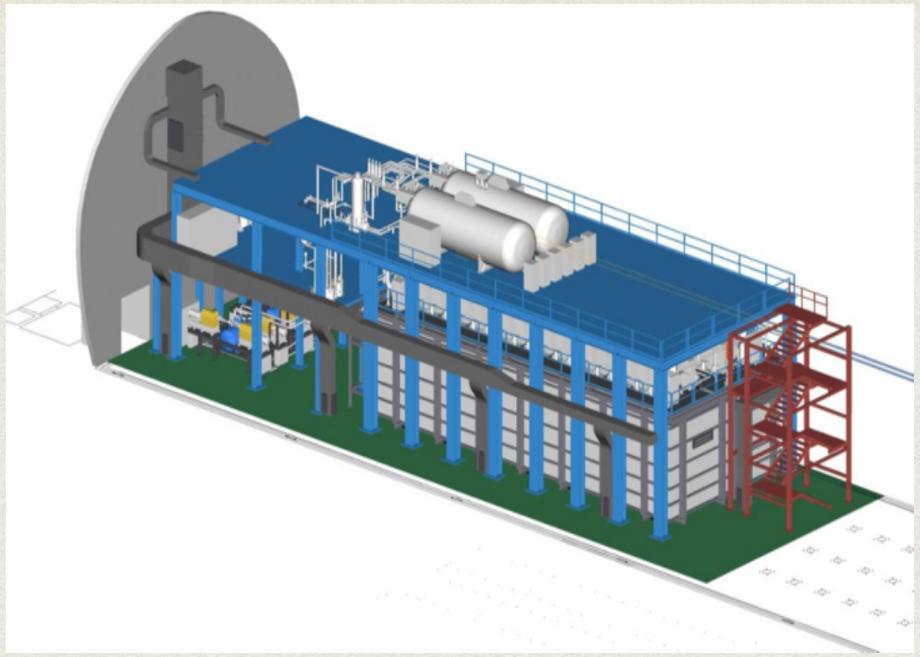
very long μ (1), e.m.cascades(2), π (3)

Secondary vertex (B):

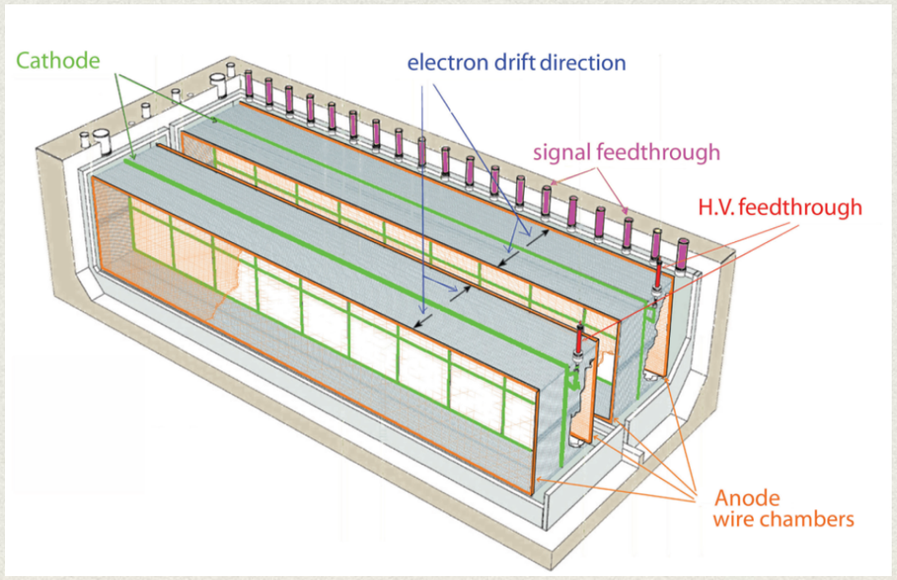
longest track (5) is a μ from stopping K (6)

μ decay is observed

ICARUS-T600 @ LNGS

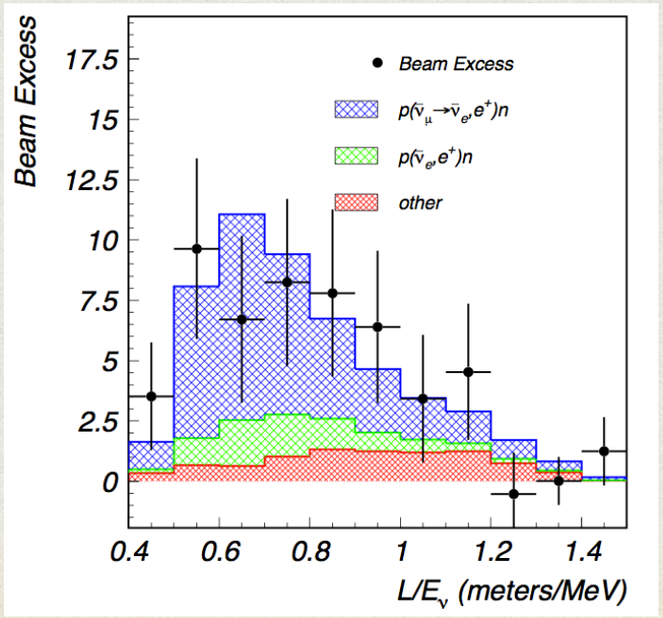


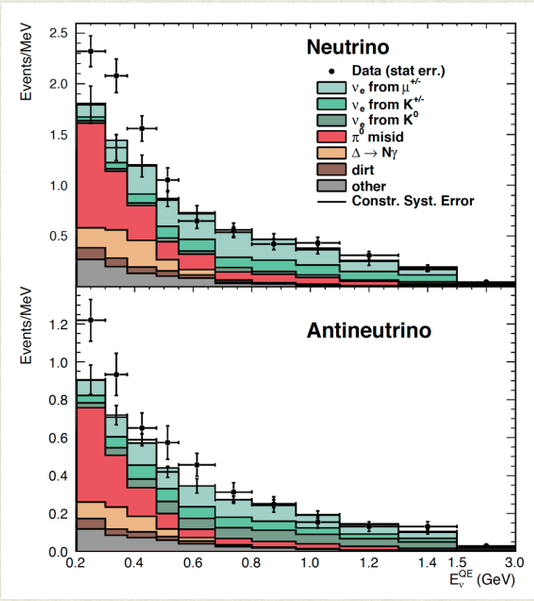
0.77 kton LAr-TPC



STERILE NEUTRINO QUEST

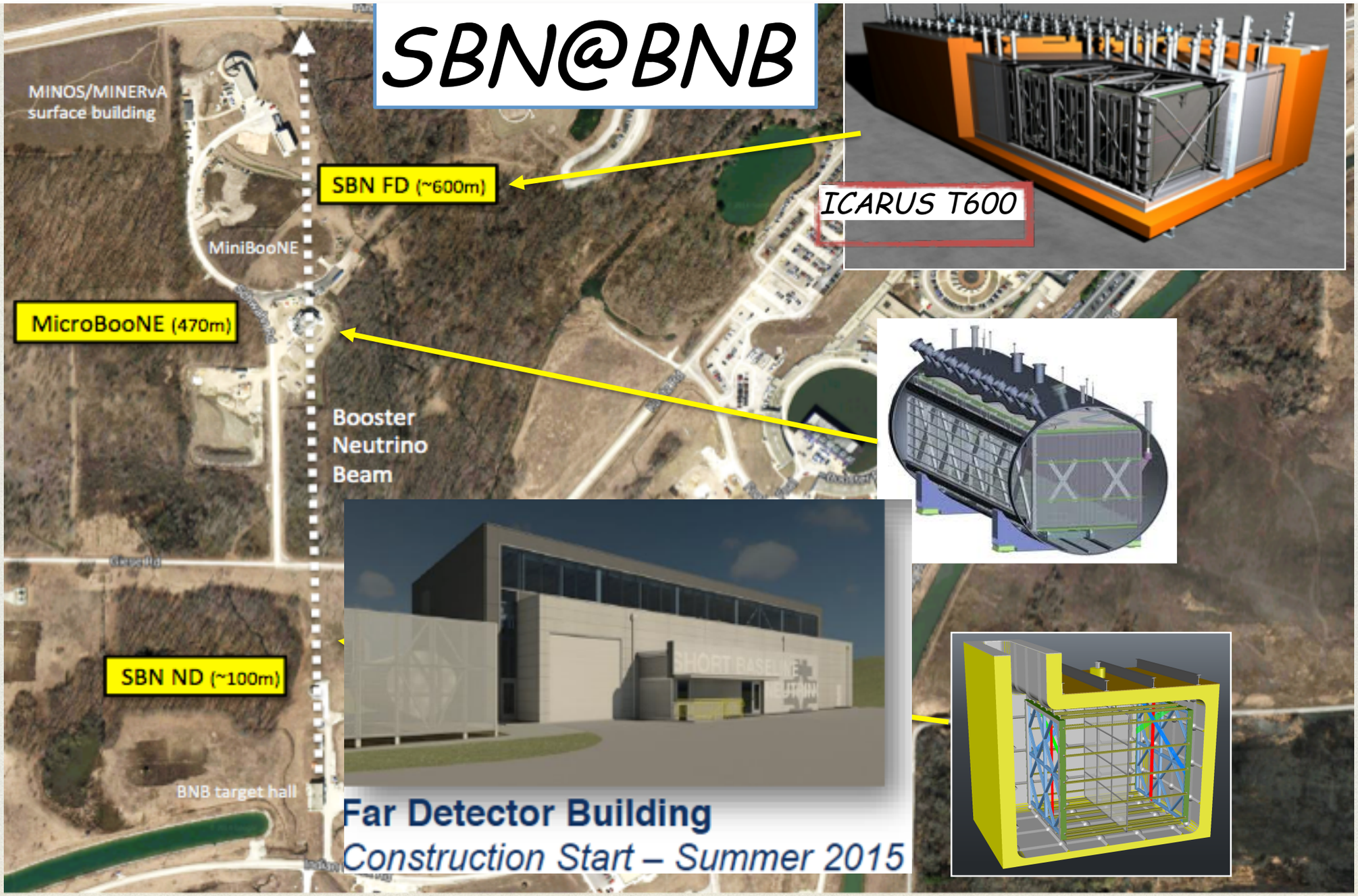
- Triggered by anomalies (none of which really outstanding) in several experiments (LNDS, Mini-Boone, reactors)
- a final (!?) word is needed (the manual of good experimentalist)
- different possibilities: we have chosen neutrino sources (VSBL) and SBL





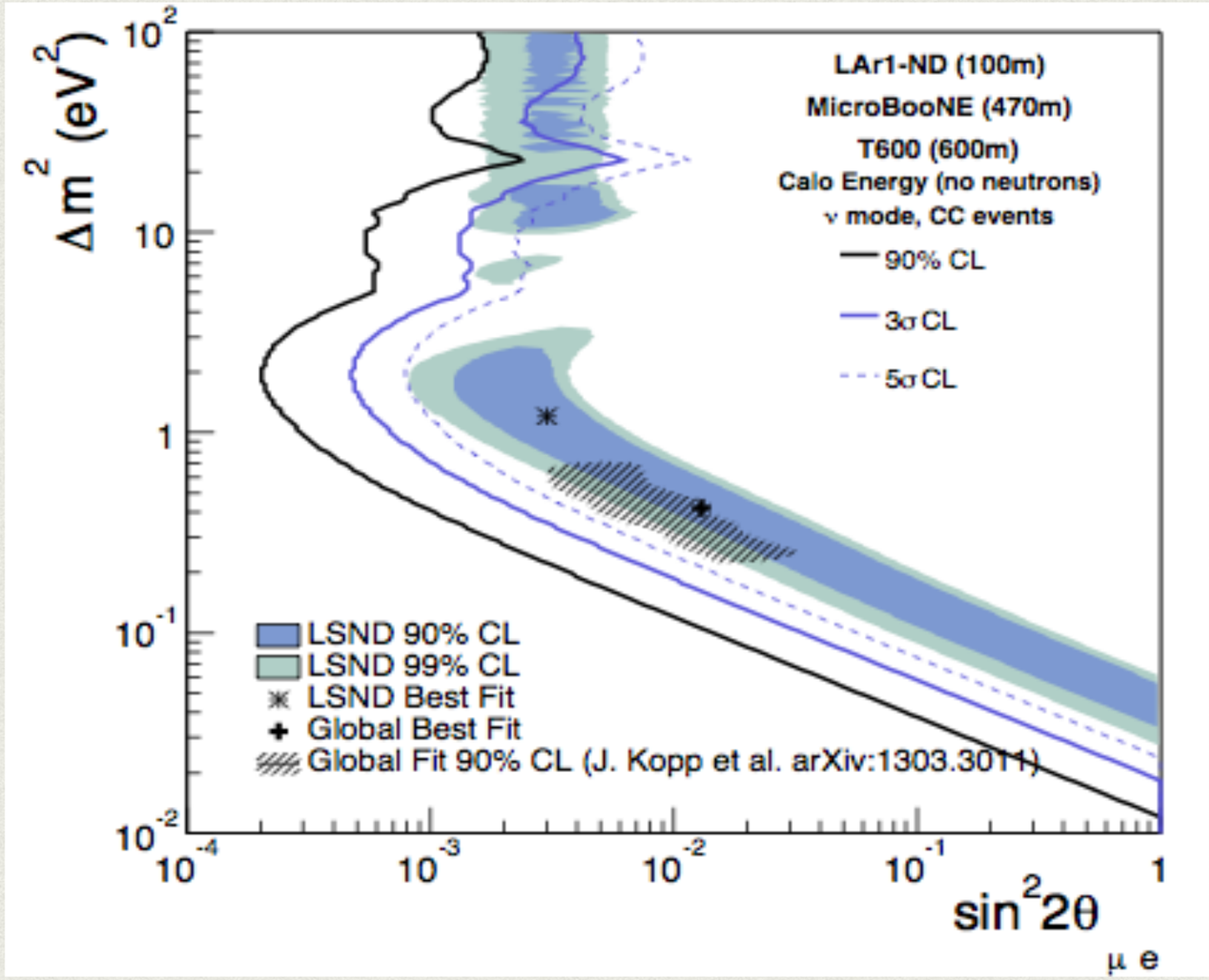
THE FUTURE HOME FOR ICARUS BEING BUILT

Fermilab short baseline neutrino program…roaring ahead



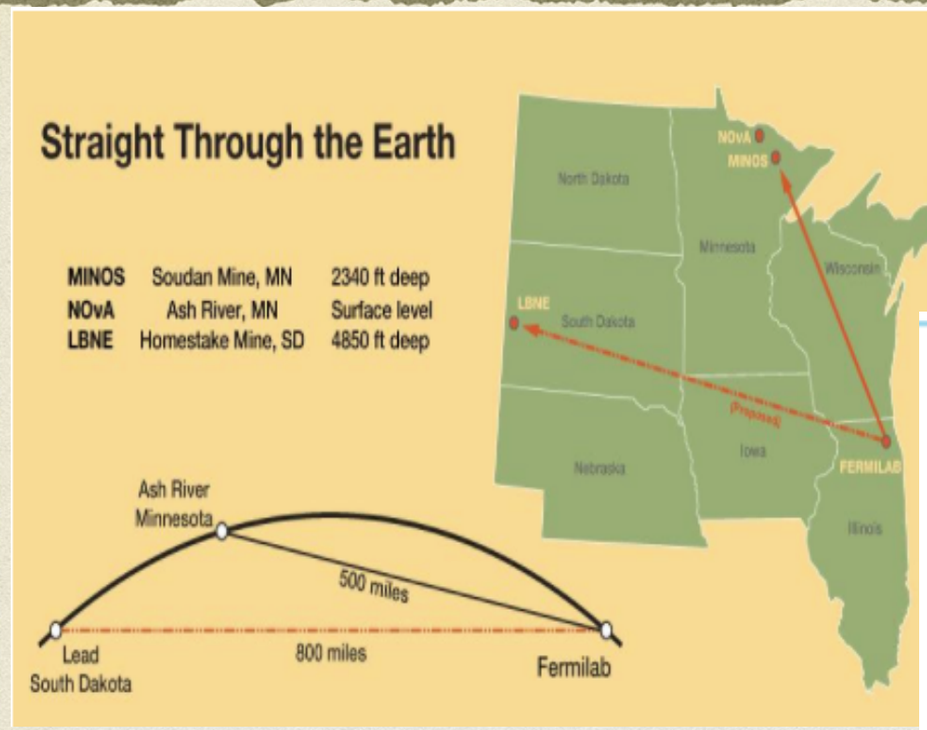
END OF A STORY OR PERHAPS START OF AN ADVENTURE

$\nu_\mu \rightarrow \nu_e$ Appearance



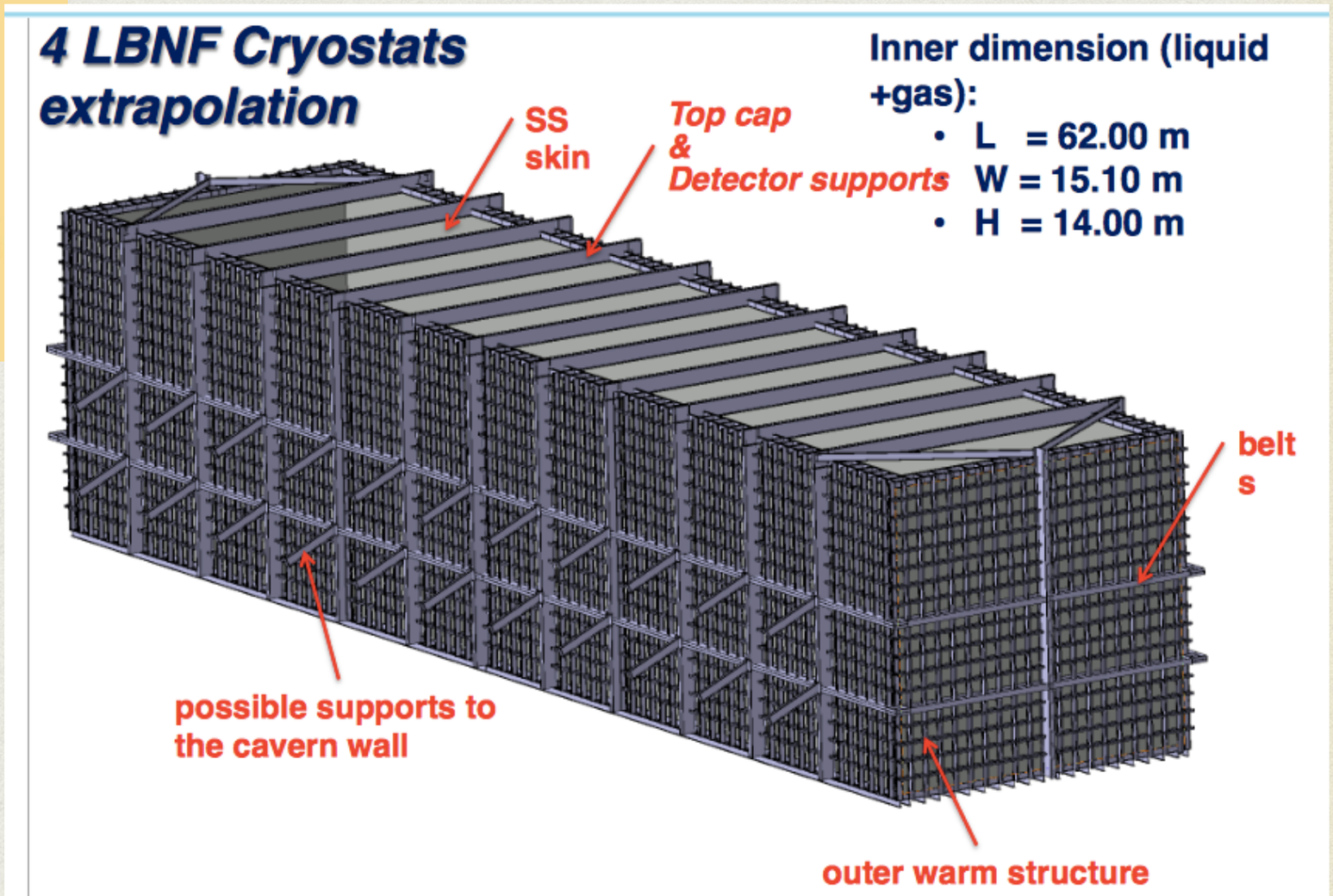
but…beware…very difficult experimental conditions.

LOOKING AT DUNE



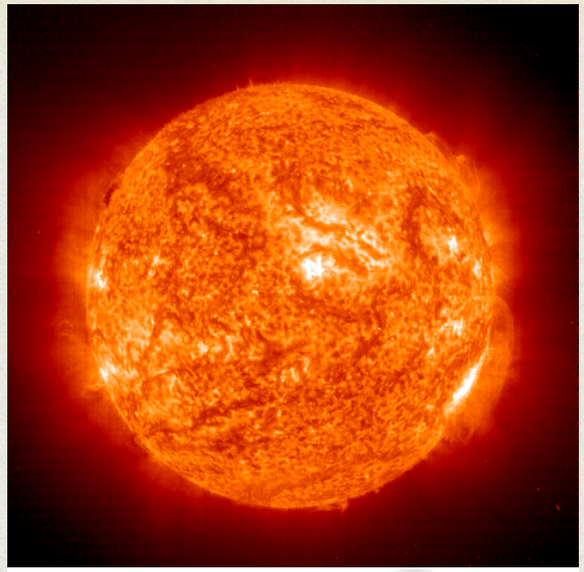
Neutrino tunnels are becoming popular!

CP or not CP

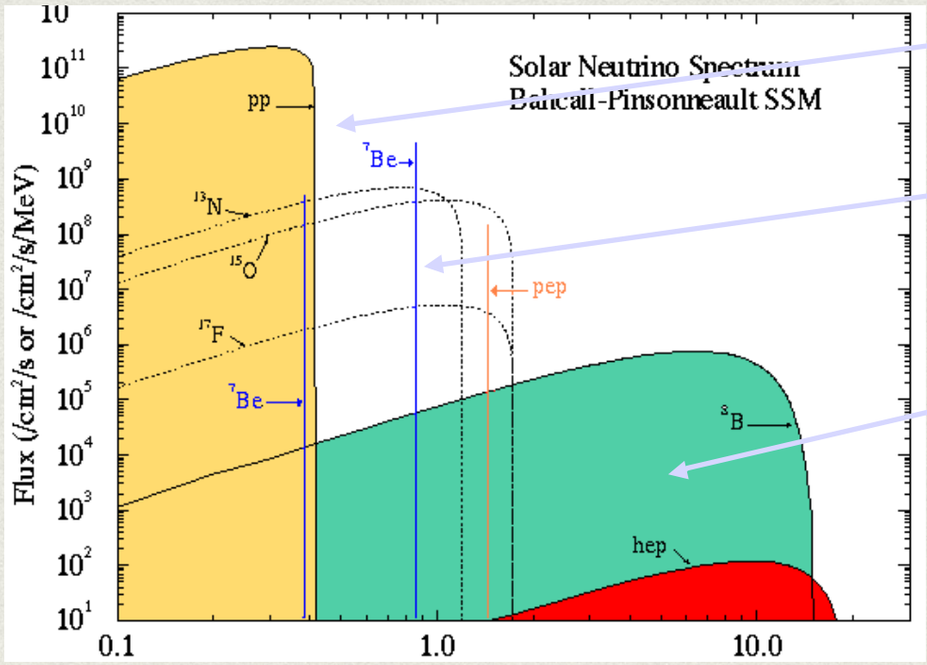


SOLAR NEUTRINOS

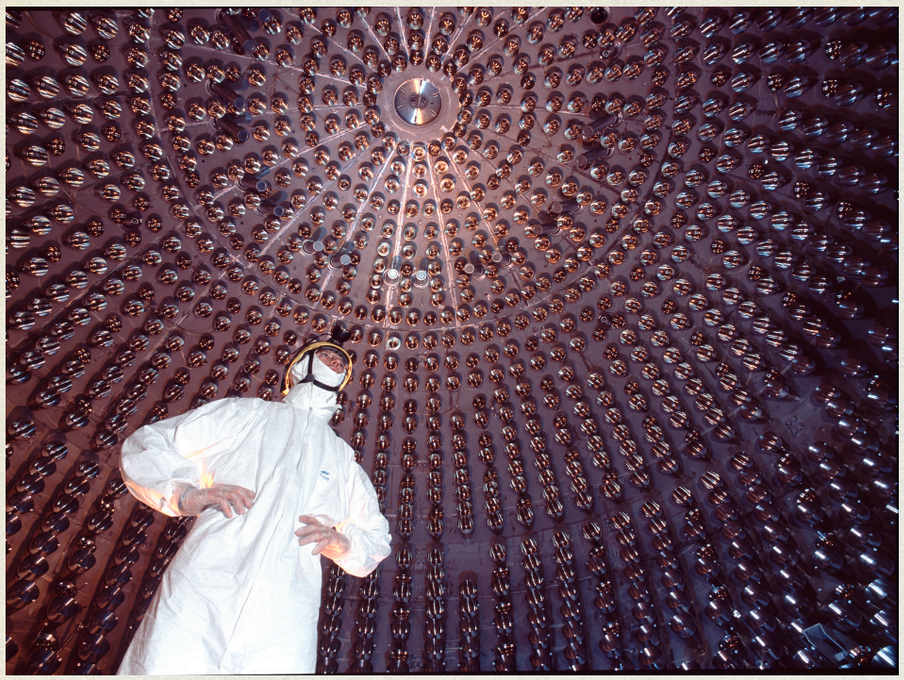
Sun is a precious source of neutrinos. They are studied thoroughly on Earth !

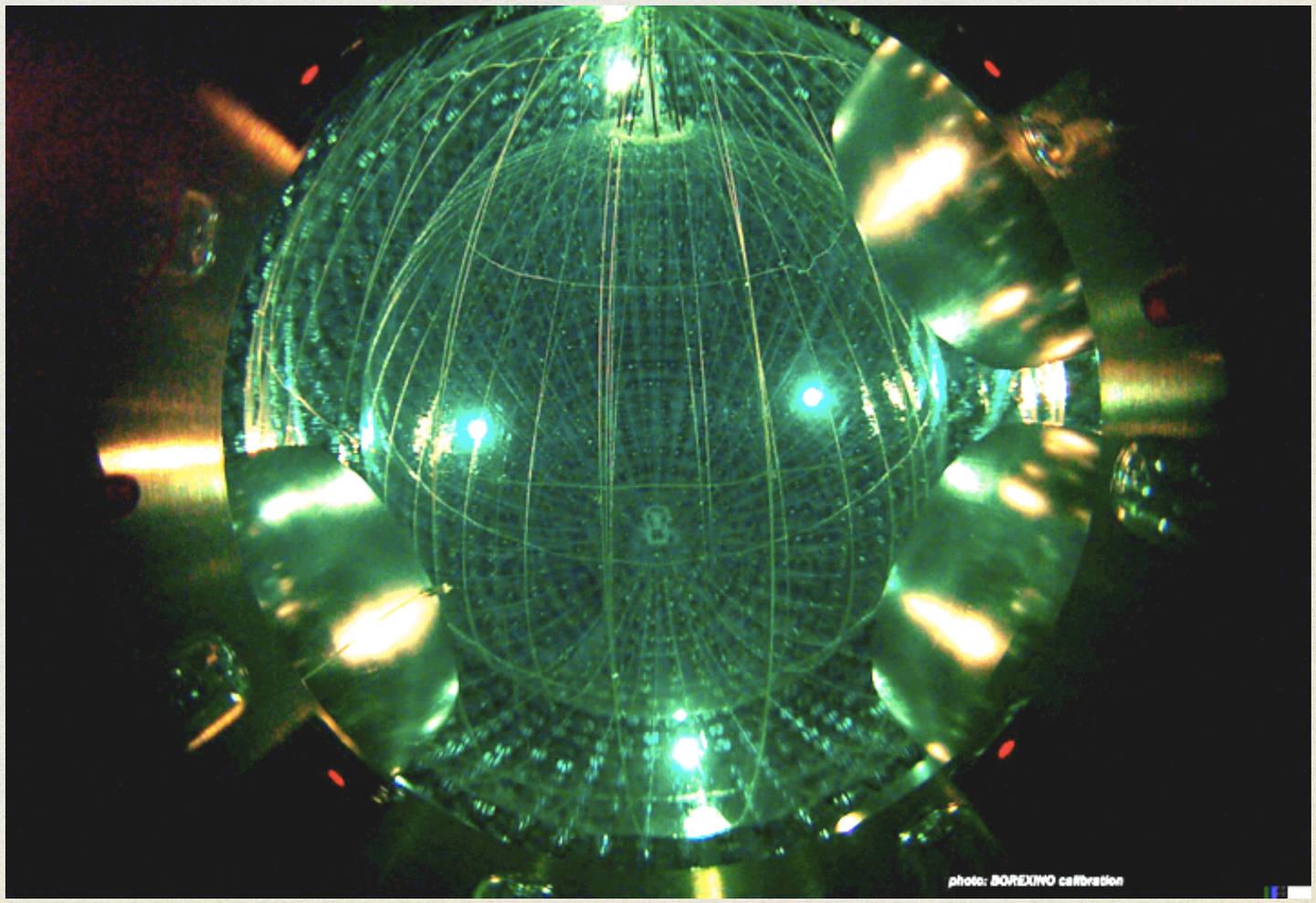


pp	$\rightarrow$	$^2H + e^+ + \nu_e$	
$^2H + p$	$\rightarrow$	$^3He + \gamma$	
$^3He + {}^3He$	$\rightarrow$	$^4He + 2p$	85%
$^3He + {}^4He$	$\rightarrow$	$^7Be + \gamma$	15%
$e^- + {}^7Be$	$\rightarrow$	$^7Li + \nu_e$	
$^7Li + p$	$\rightarrow$	$2\,^4He$	
$p + {}^7Be$	$\rightarrow$	$^8B + \gamma$	0.02%
^8B	$\rightarrow$	$^8Be^* + e^+ + \nu_e$	
$^8Be^*$	$\rightarrow$	$2\,^4He$	

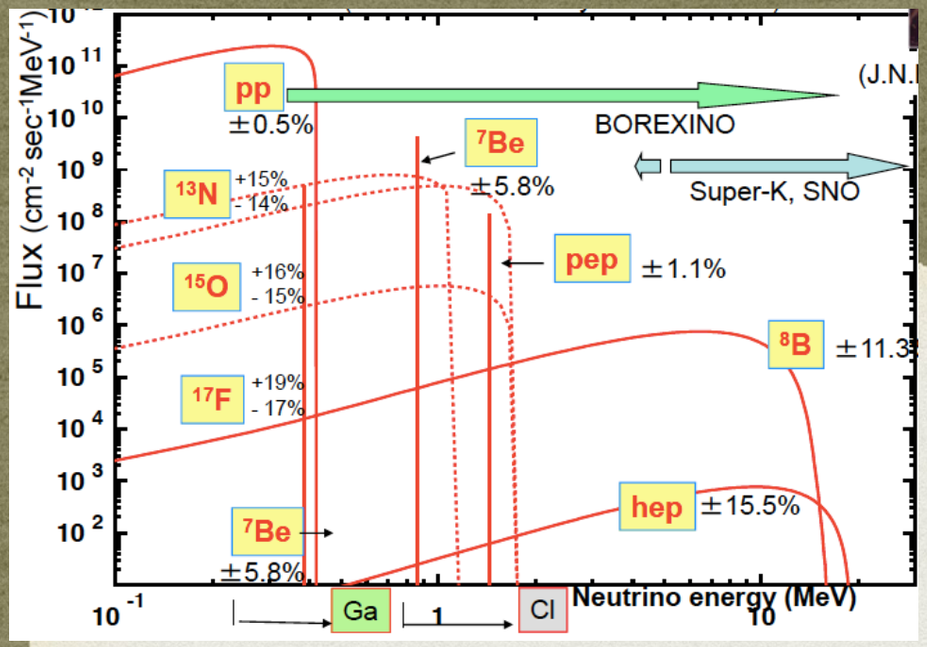


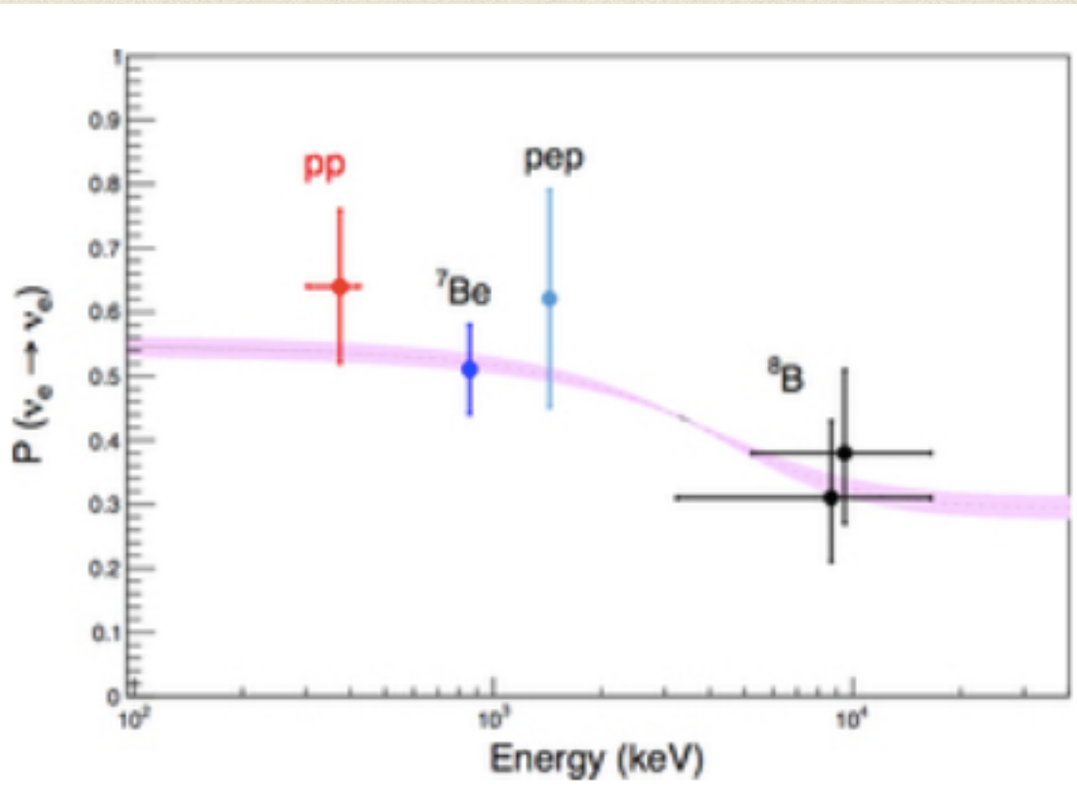
BOREXINO @ LNGS

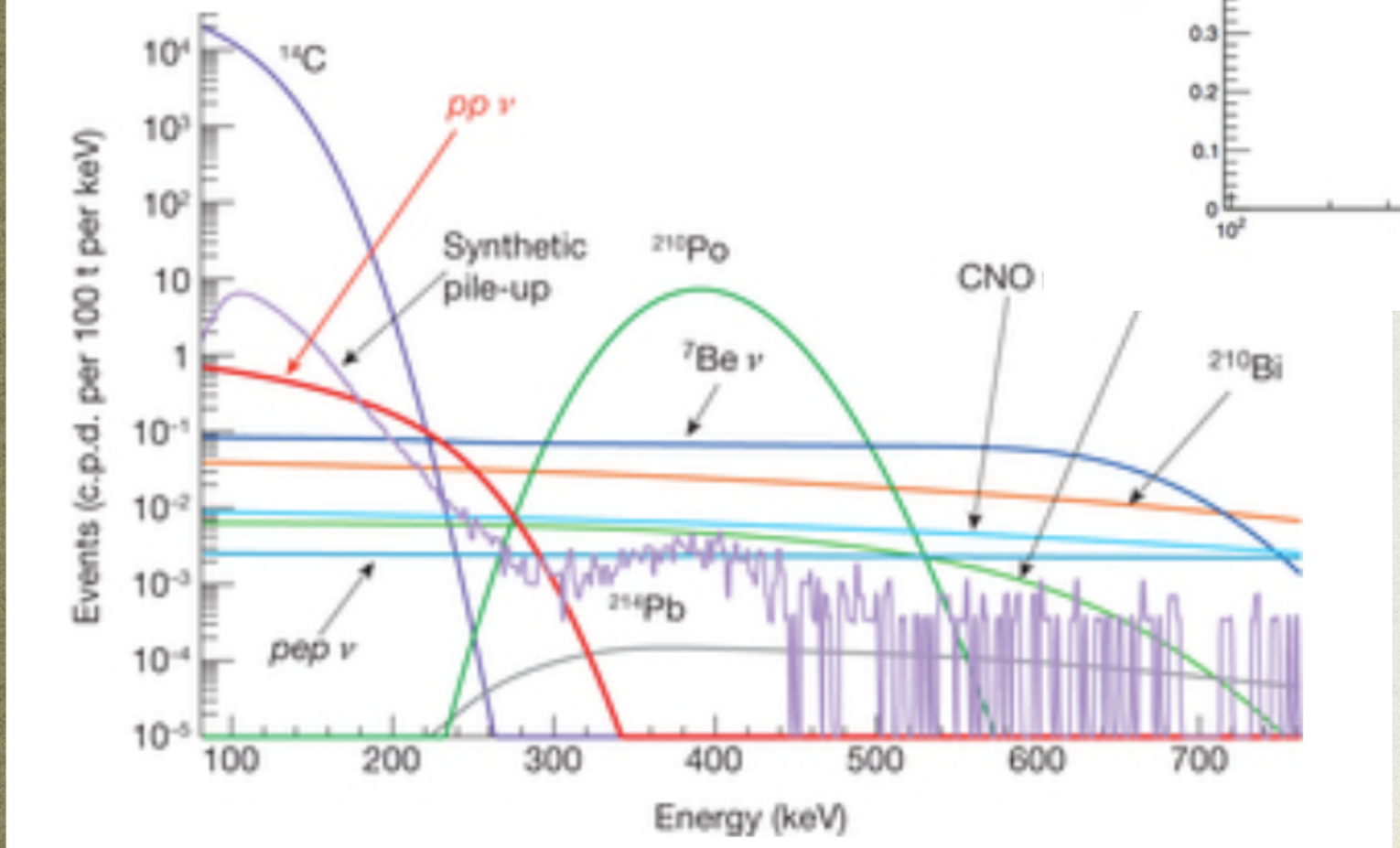




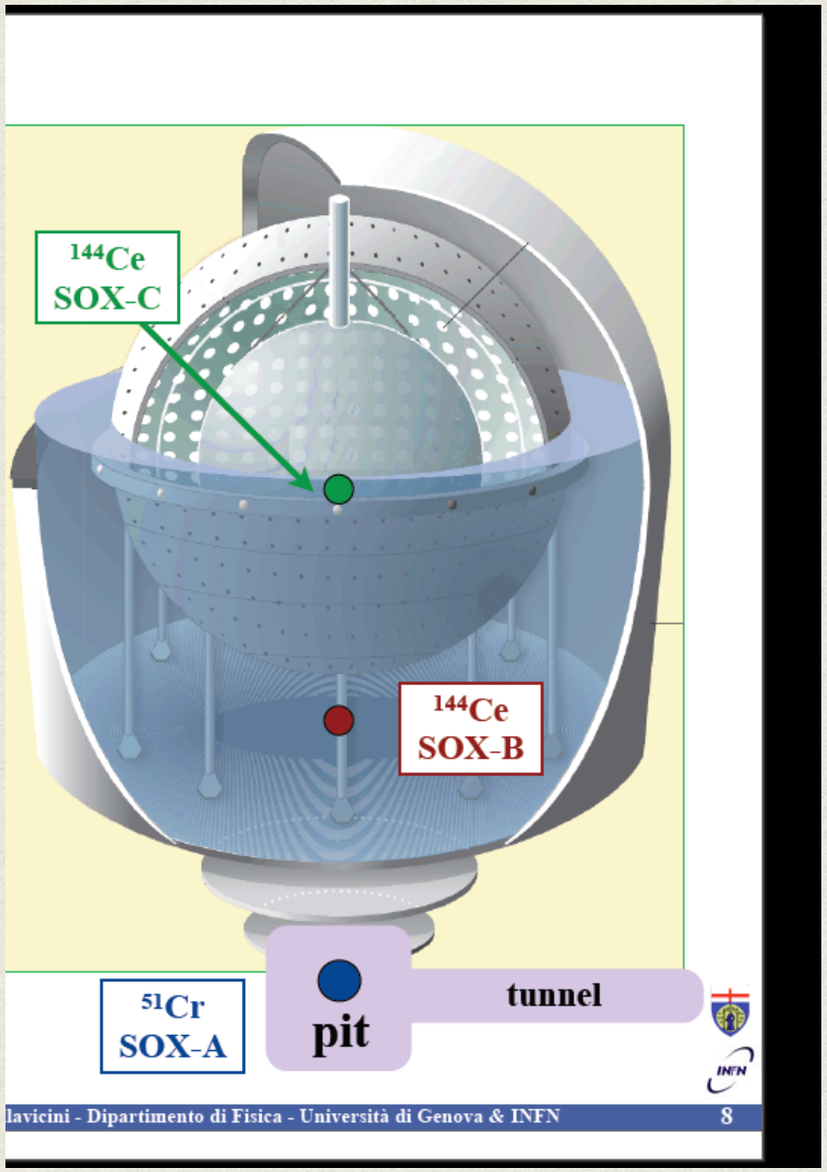
BOREXINO CONTRIBUTION TO SOLAR NEUTRINO UNDERSTANDING





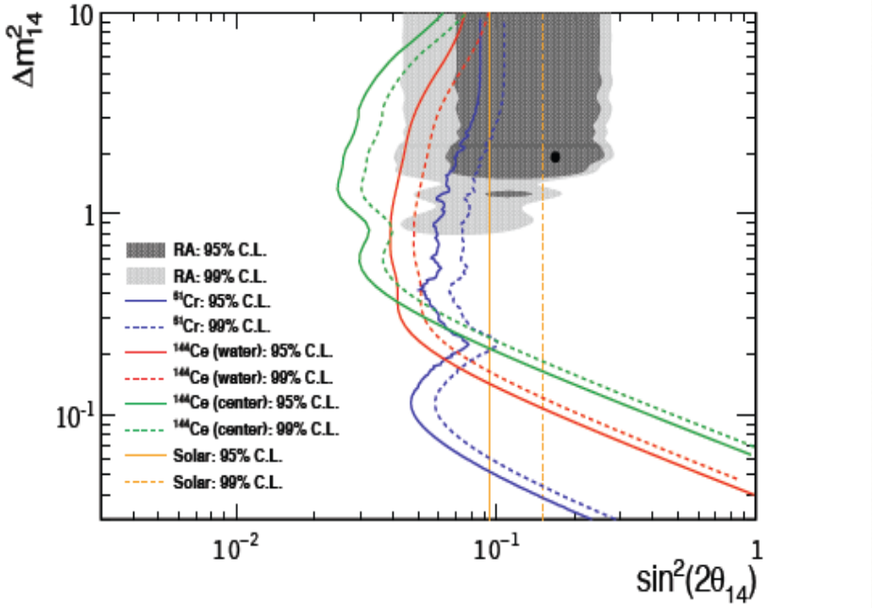


BOREXINO REINCARNATES IN

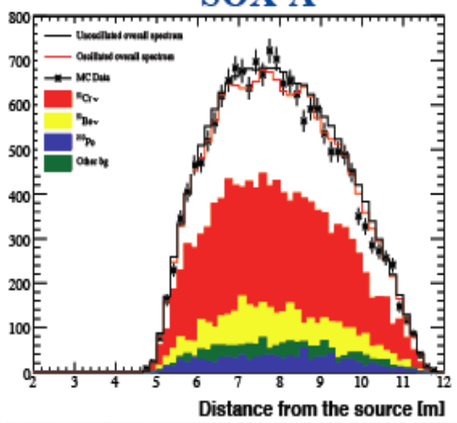


anti-neutrino sources

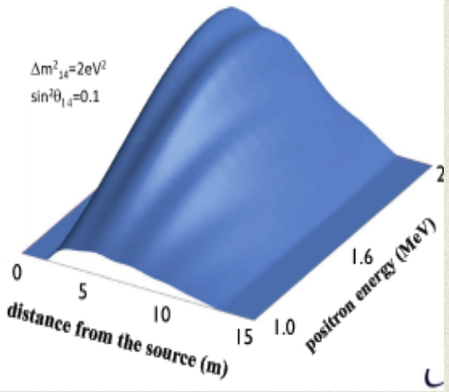
- **SOX-A**
  - ^{51}Cr neutrino source (external)
  - Tentative schedule: 2015/2016
- **SOX-B**
  - ^{144}Ce anti-neutrino source (external)
  - Tentative schedule: 2015-2016 (TBD)
- **SOX-C**
  - ^{144}Ce anti-neutrino source (internal)
  - No schedule (>2016)



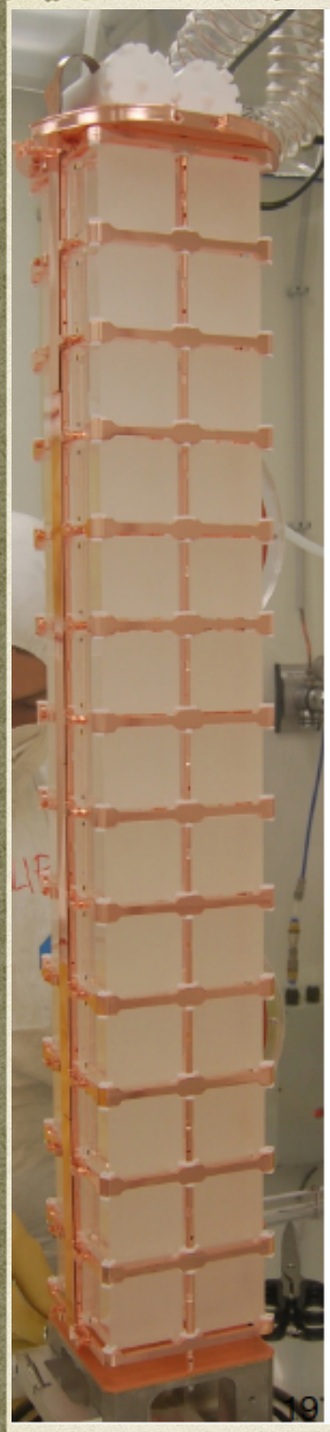
SOX-A

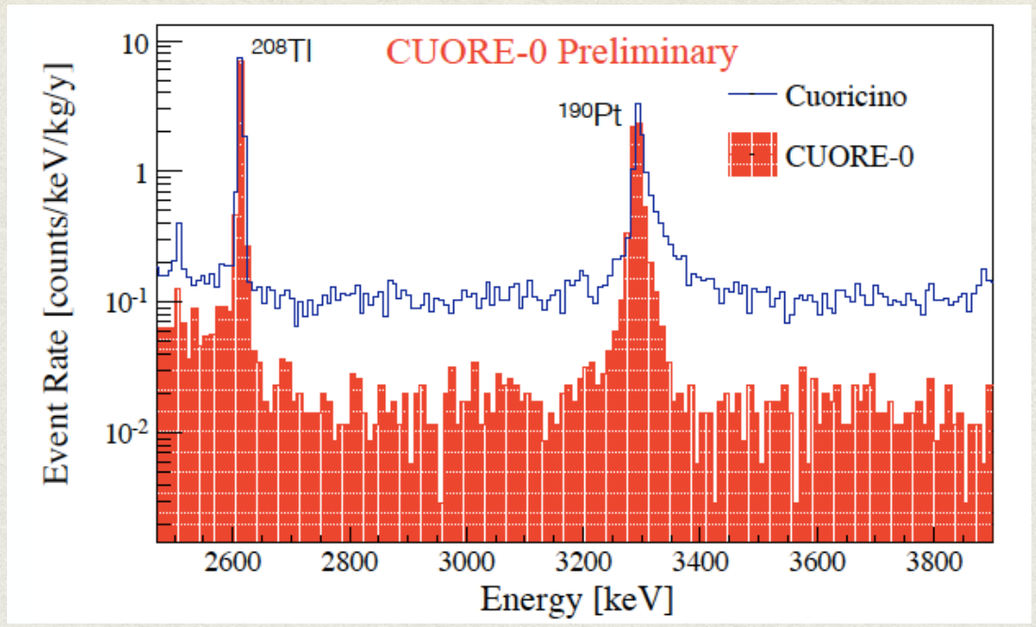


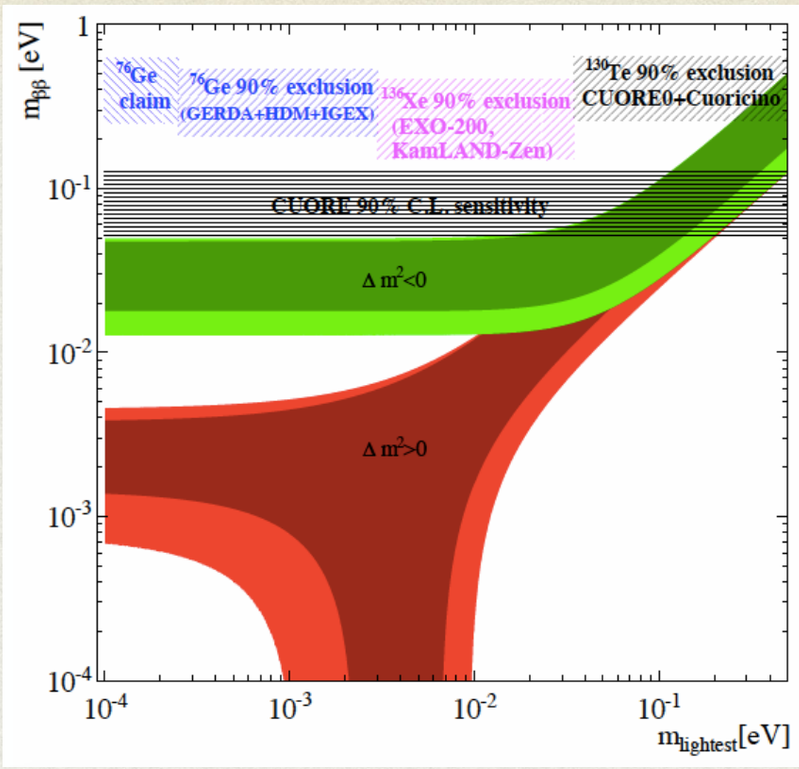
SOX-C

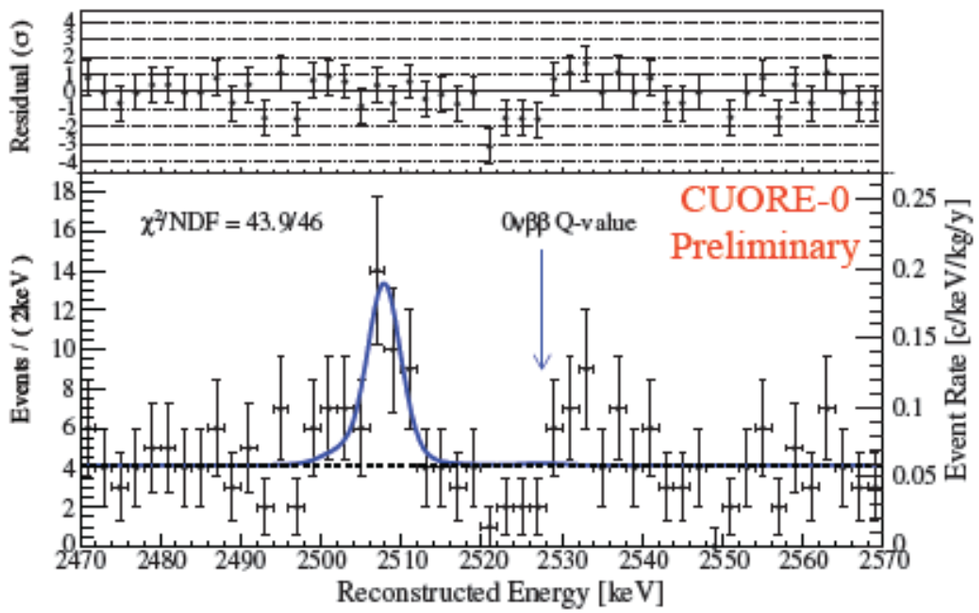


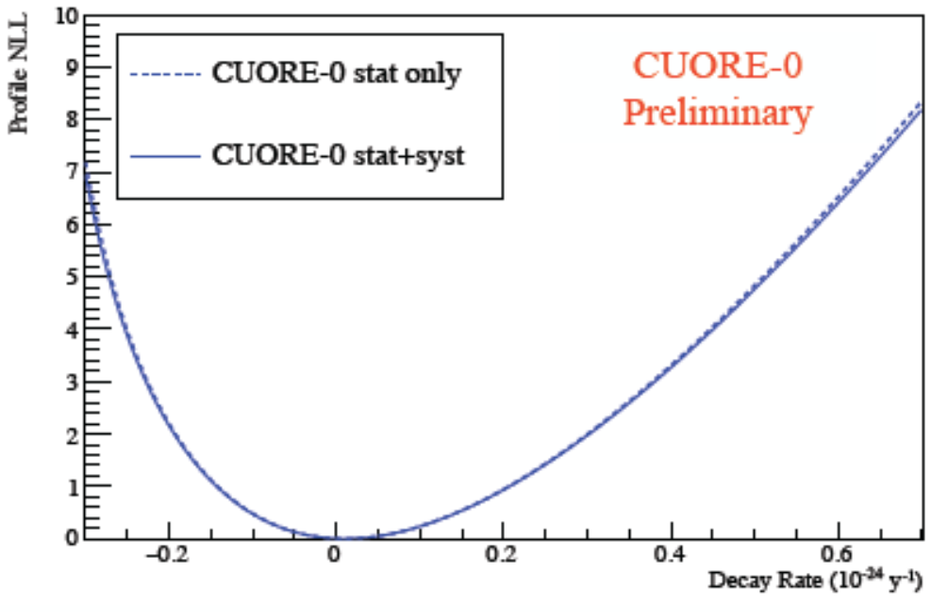
CUORE-0 ON THE WAY TO CUORE



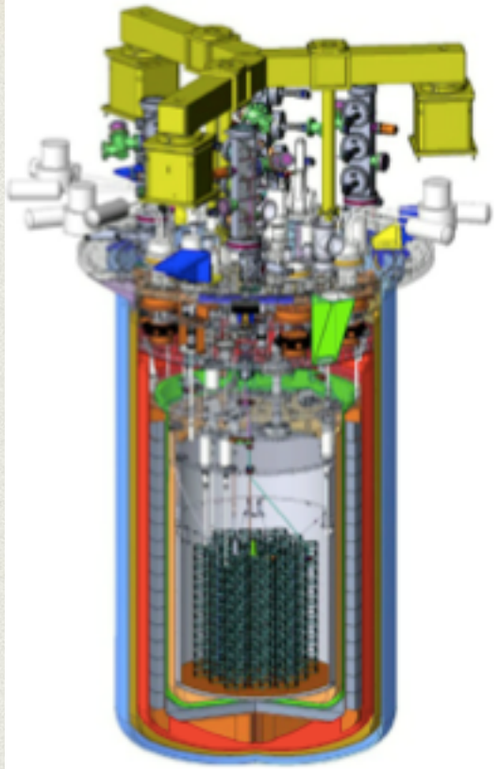








CUORE

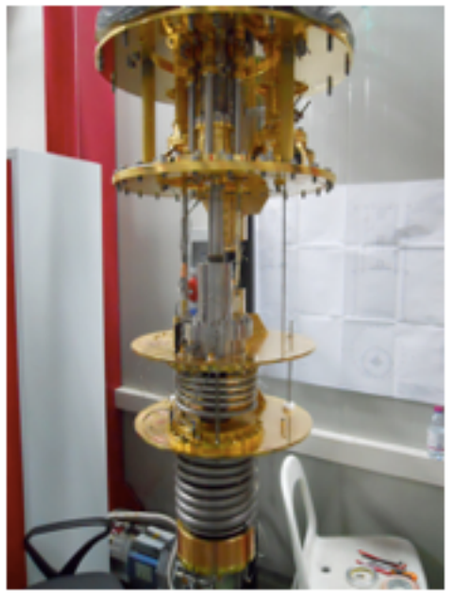


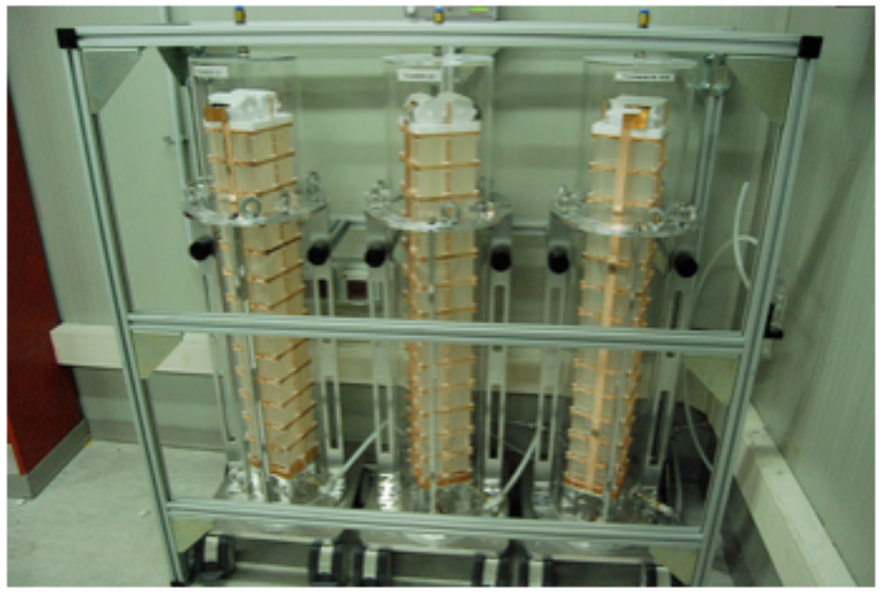
The CUORE experiment

- 10/19 towers assembled
- cryostat in commissioning phase

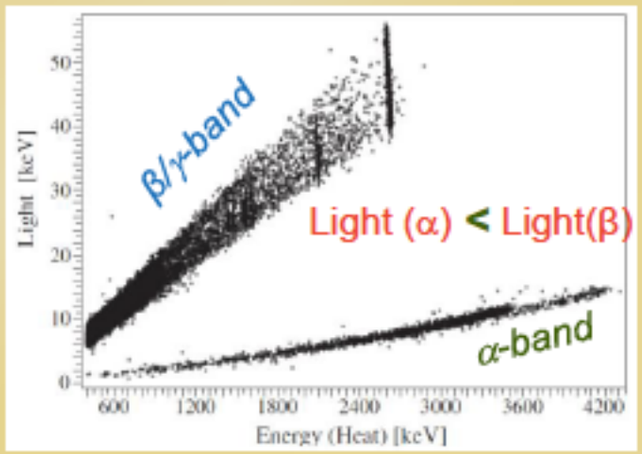
Data Taking 2015

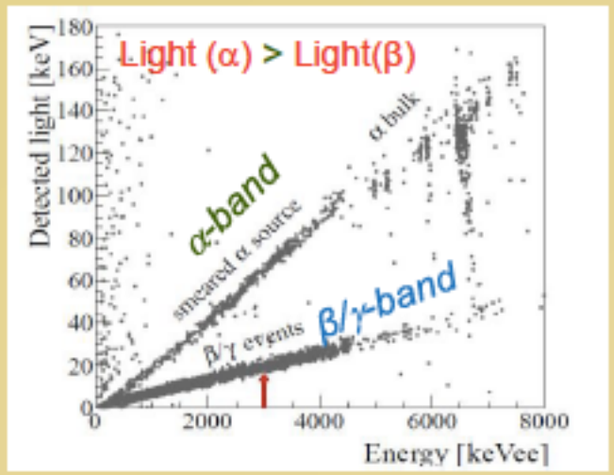
- Technological challenge: the operation of 3 ton of crystals and copper at 10 mK and ~20 tons of several materials at different temperature stages has never been done before
- The success of CUORE is fundamental for future bolometric experiments

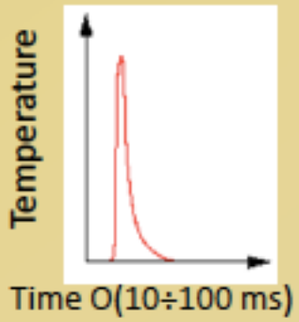


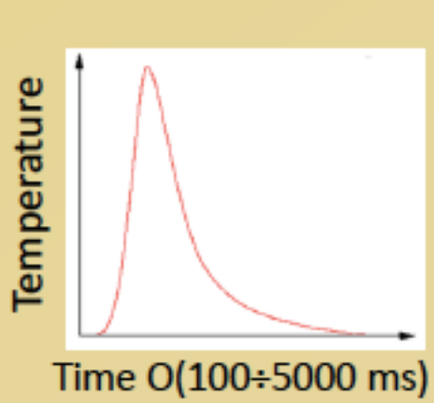


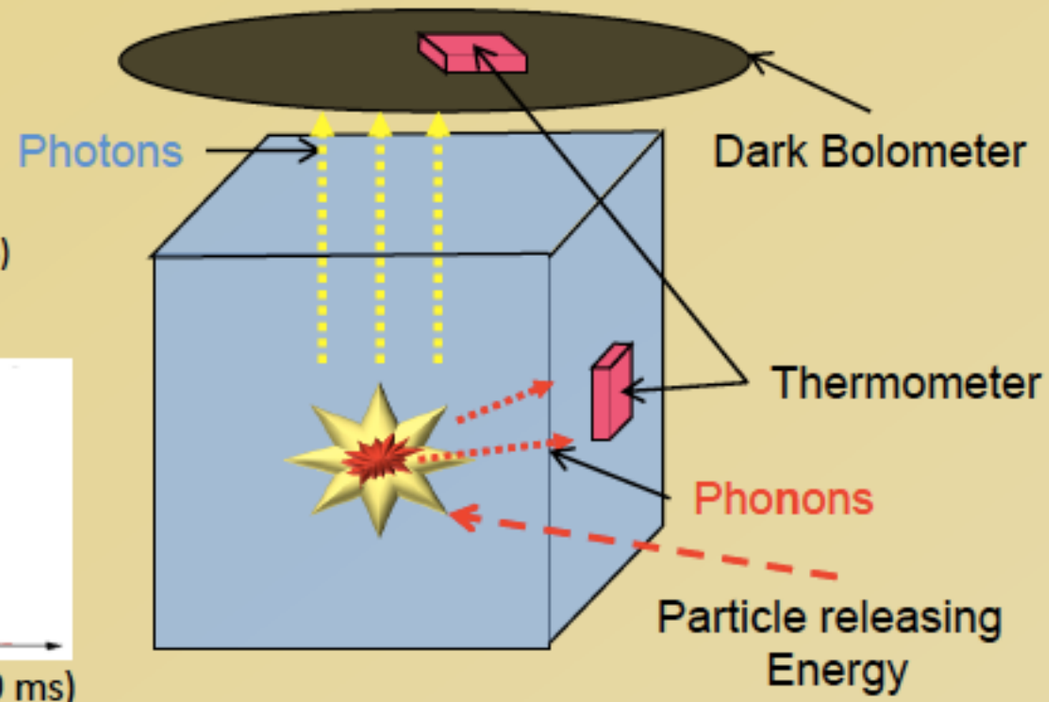
A SCINTILLATING FUTURE
(IN THE QUEST FOR ZERO BACKGROUND)

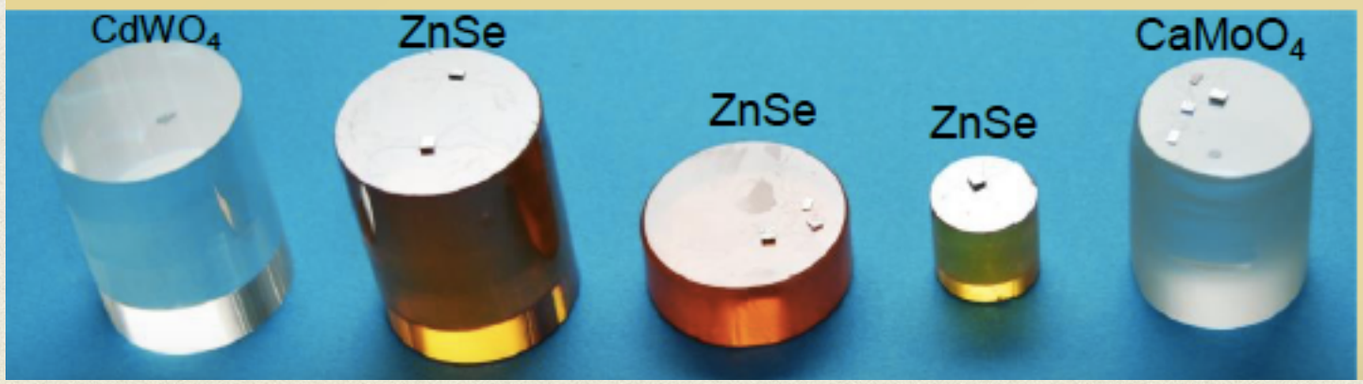


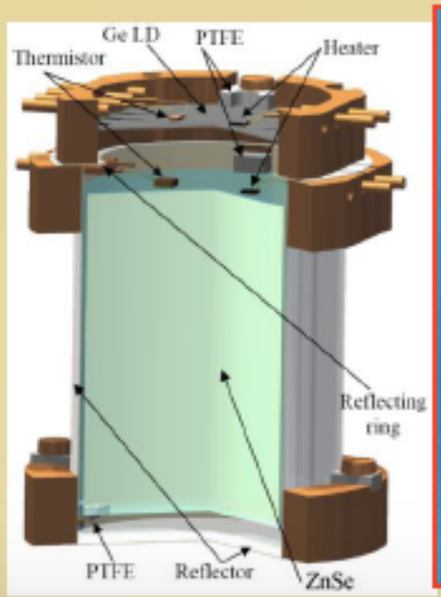


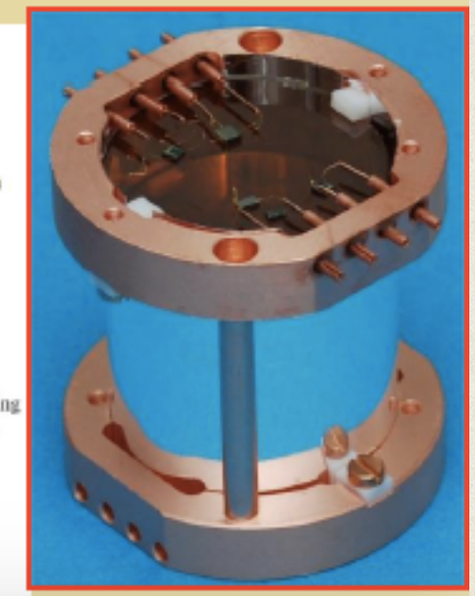












INDEED INFN LOVES NEUTRINOS

"The name neutrino was coined by Enrico Fermi as a word play on neutrone, the Italian name of the neutron."

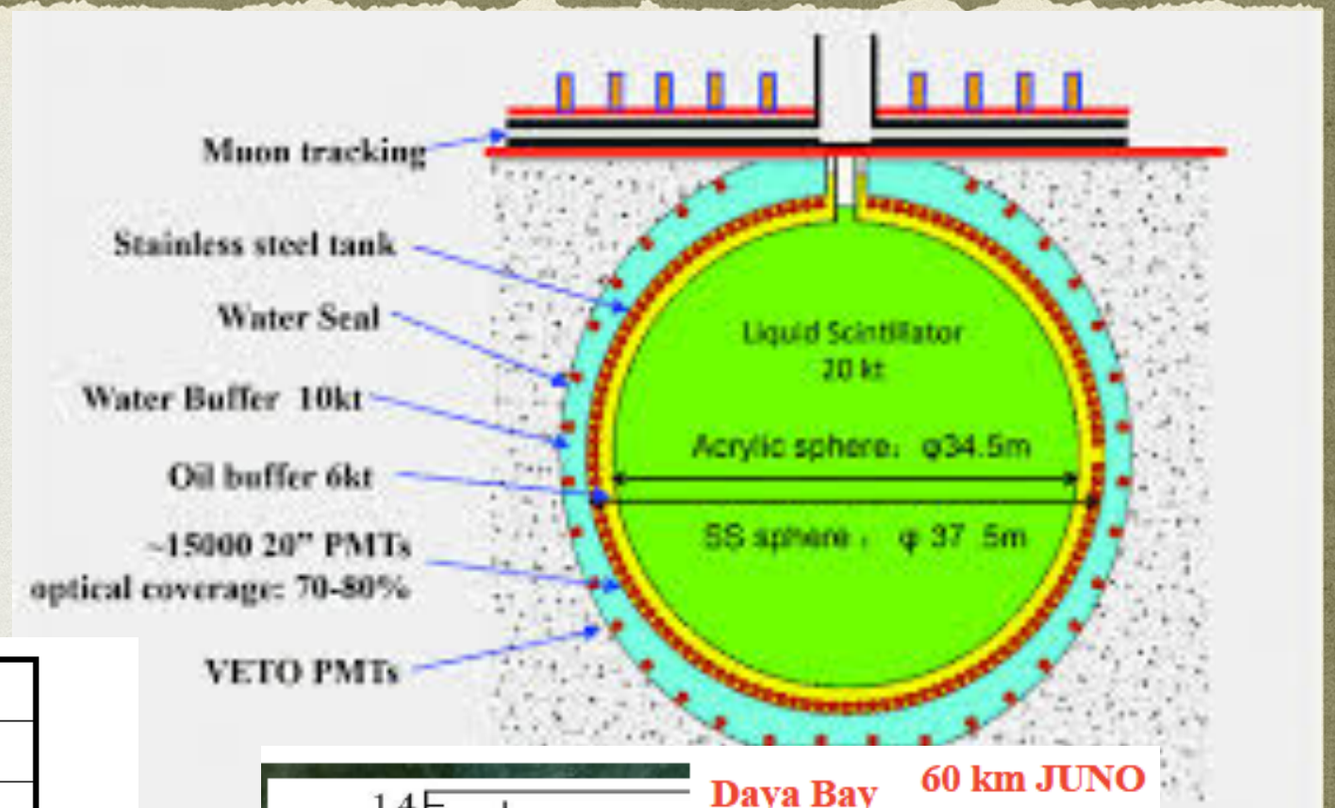
A Majorana fermion, also referred to as a Majorana particle, is a fermion that is its own antiparticle. They were hypothesised by Ettore Majorana in 1937.

Neutrino is the only particle known to us that could be a Majorana fermion.

AN ENDLESS RESEARCH FIELD

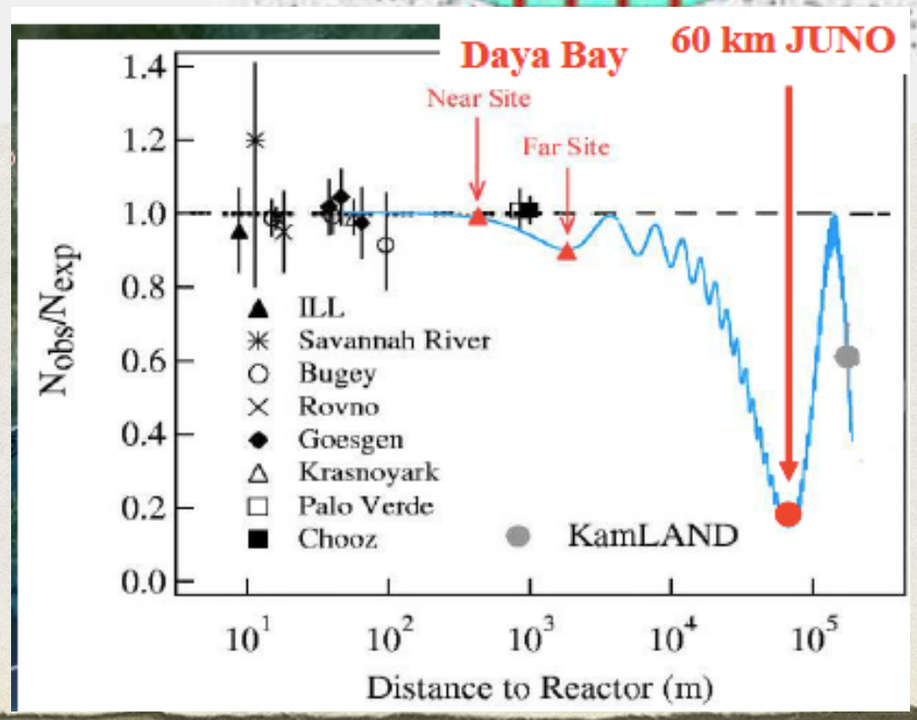
- How much does a neutrino weigh ?
- What is the mass ordering (hierarchy)
- Is neutrino a Majorana or Dirac particle
- Do more (sterile) neutrinos exist ?
- Do neutrinos violate CP ?
- Can we observe the CNB (a picture of a universe 1 second old)

JUNO: THE REACTOR OPTION



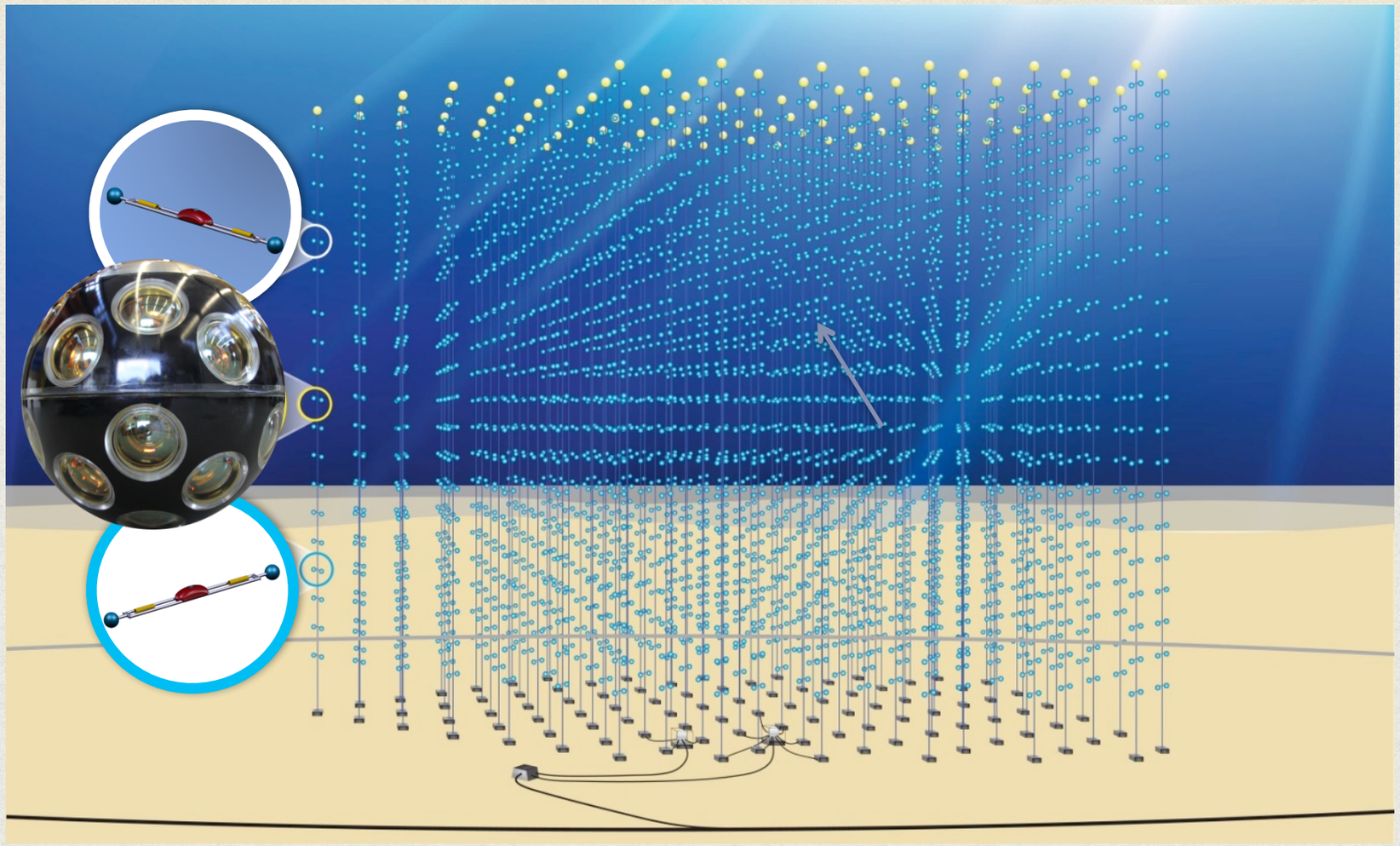
	Current	Daya Bay II
Δm^2_{12}	3%	0.6%
Δm^2_{23}	5%	0.6%
$\sin^2\theta_{12}$	6%	0.7%
$\sin^2\theta_{23}$	20%	N/A
$\sin^2\theta_{13}$	14%➔ 4%	~ 15%

Will be more precise than CKM matrix elements !



Bring in expertise in purification of liquid scintillator from Borexino

AND EVEN NEUTRINOS UNDERWATER



Very high energy neutrinos from sources in cosmo

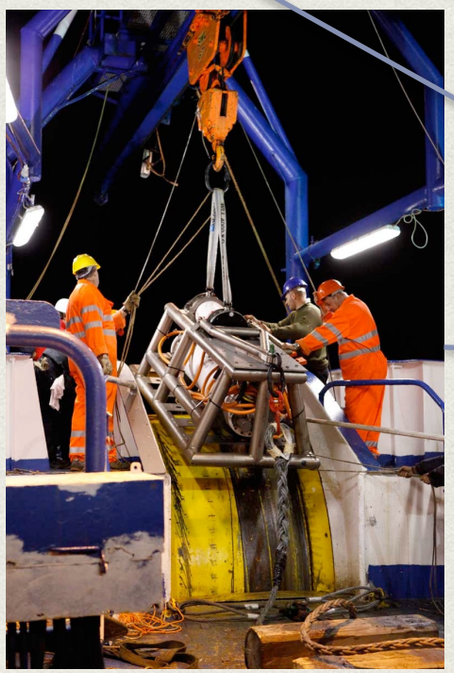
Part of the multi messenger program

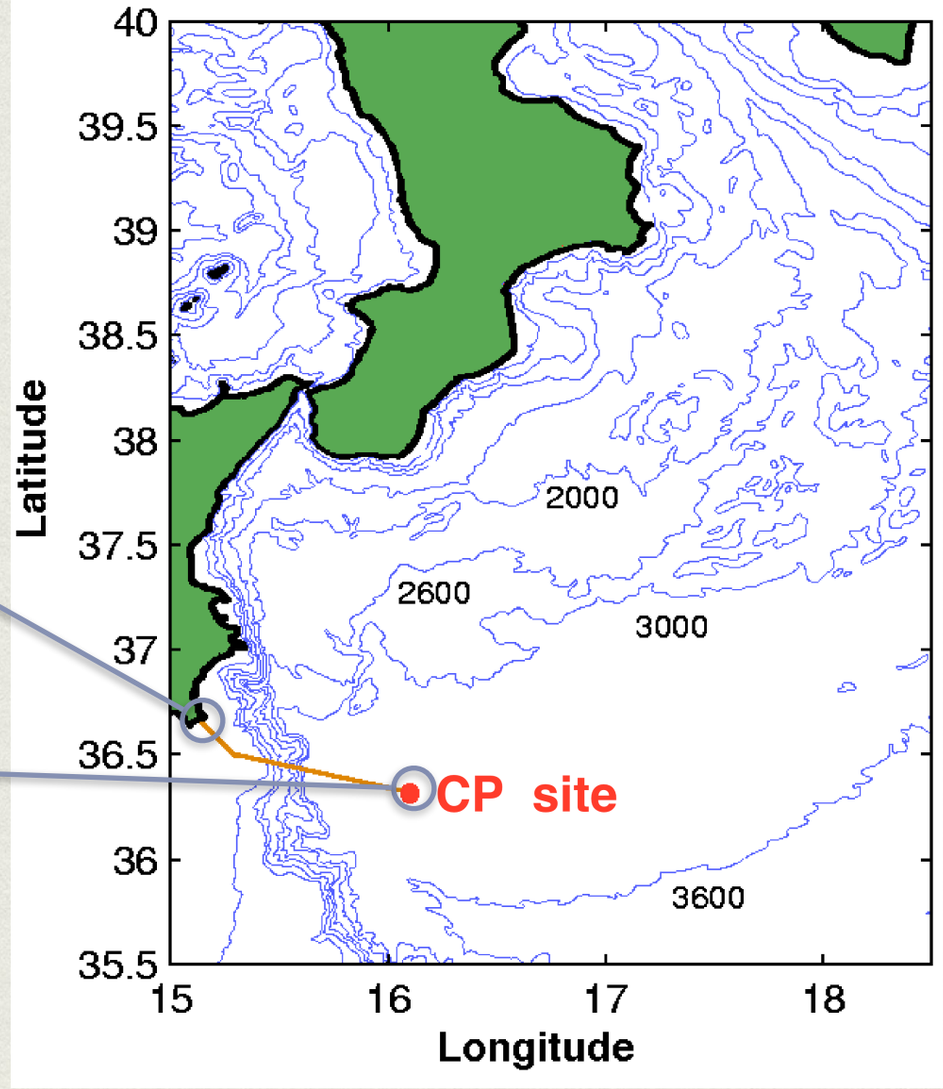
THE CAPO PASSERO SITE

Capo Passero is one of the candidate sites for the installation of KM3NeT
Deep sea site studied and fully characterized in the past 12 years
Already existing infrastructure with to be upgraded for KM3NeT-Italia

Present infrastrucures

- Deep-sea 10 kW DC/DC converter
- Main 100 km electro-optical cable
- Power feeding system
- Shore station
- High bandwidth (1 Gbps) connection to LNS



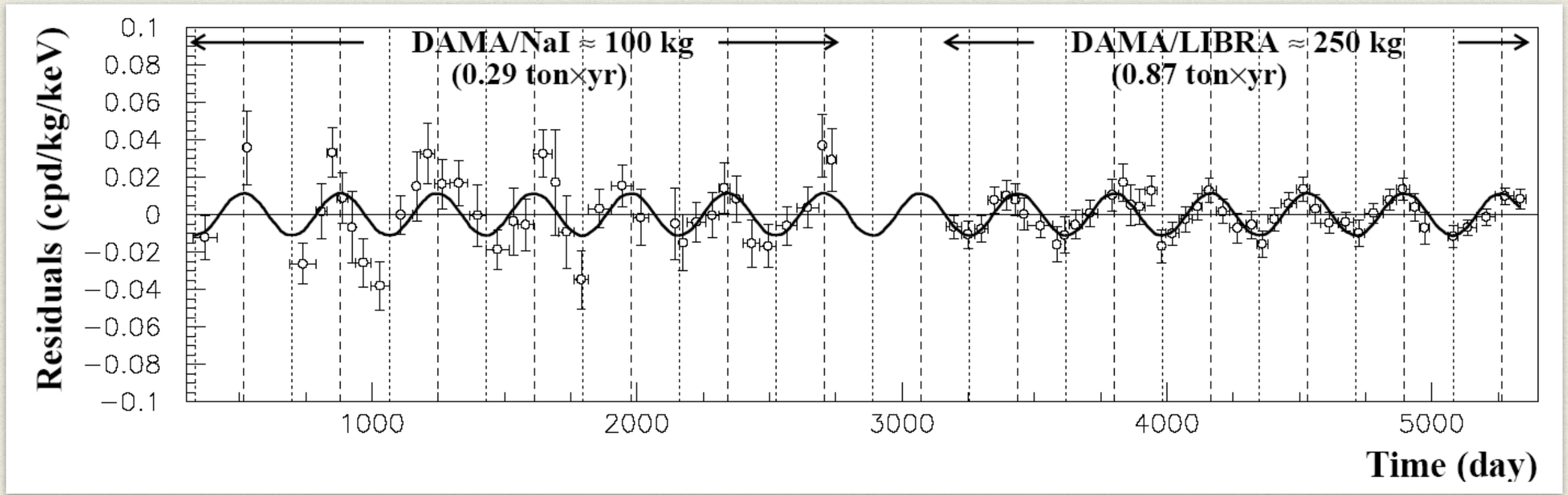


DARK MATTER

- The intriguing result of DAMA/LIBRA
- The competition XENON-LUX
- The bet on Dark Side

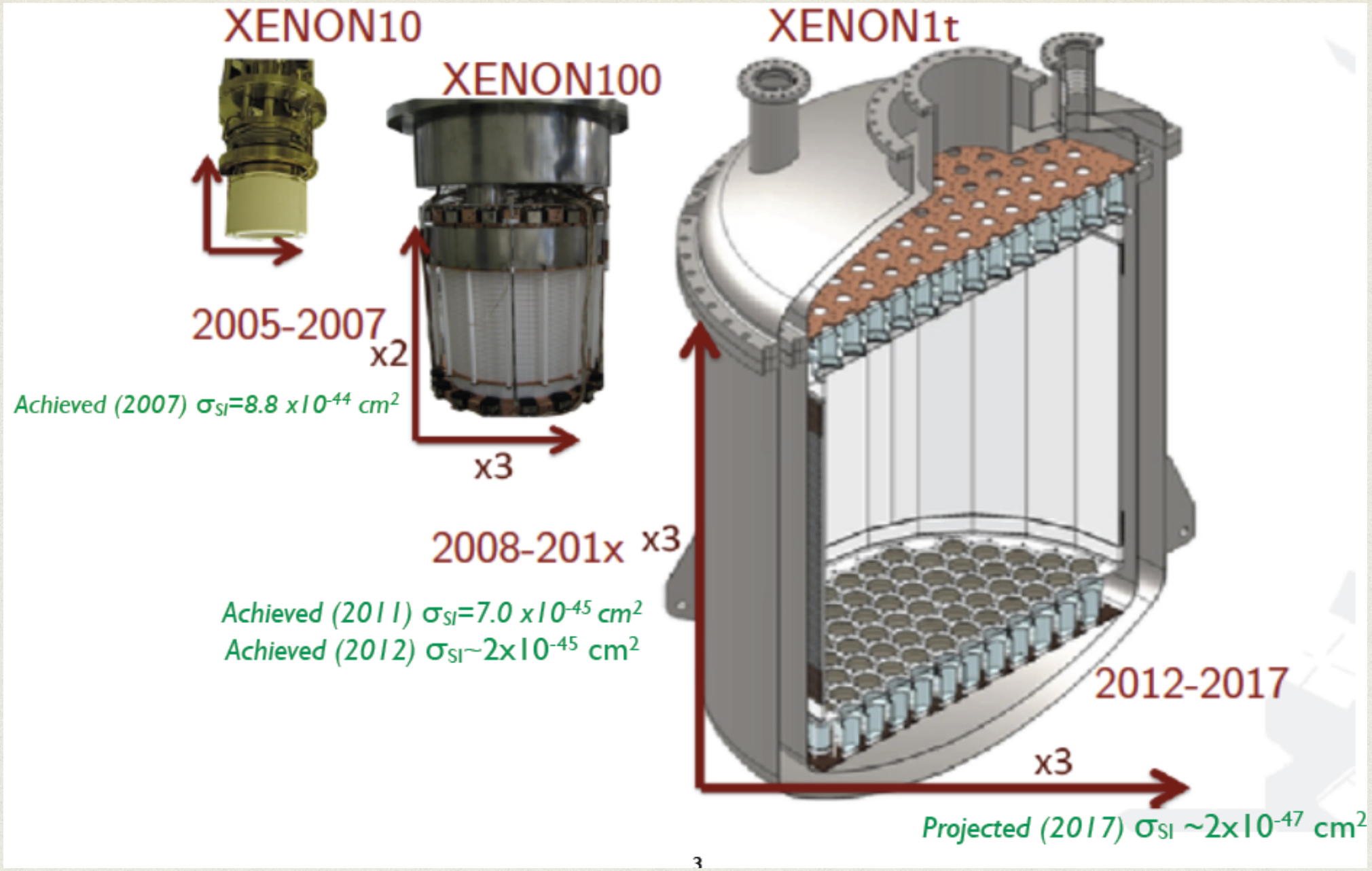
DAMA/LIBRA

The most intriguing result on dark matter searches

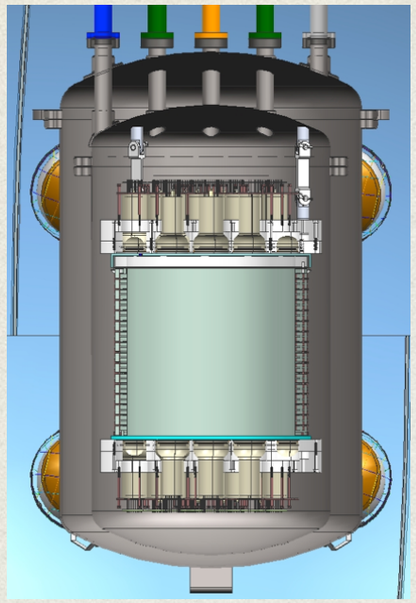


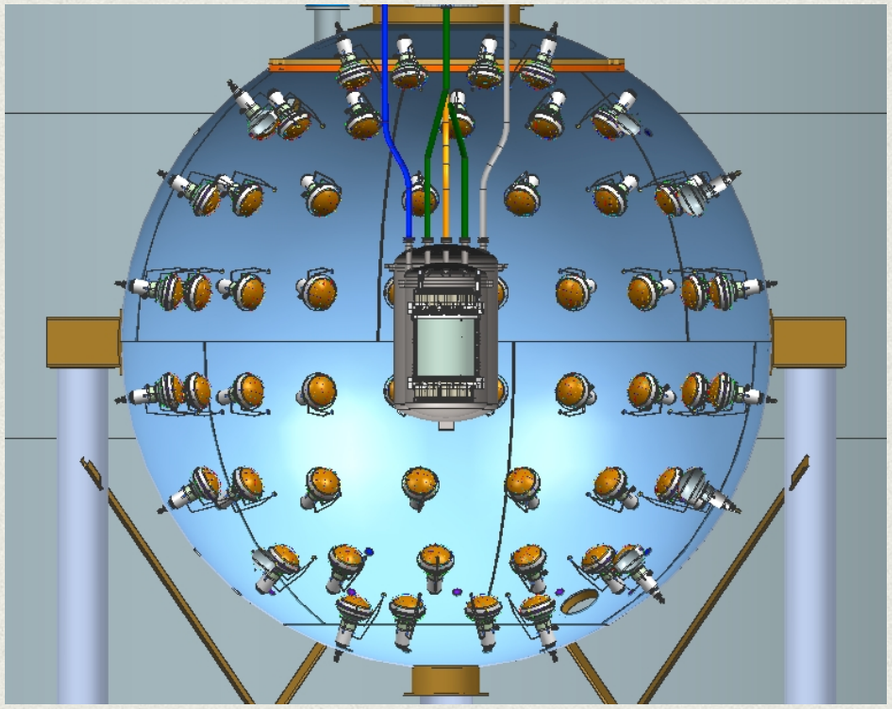
desperately seeking for a confirmation

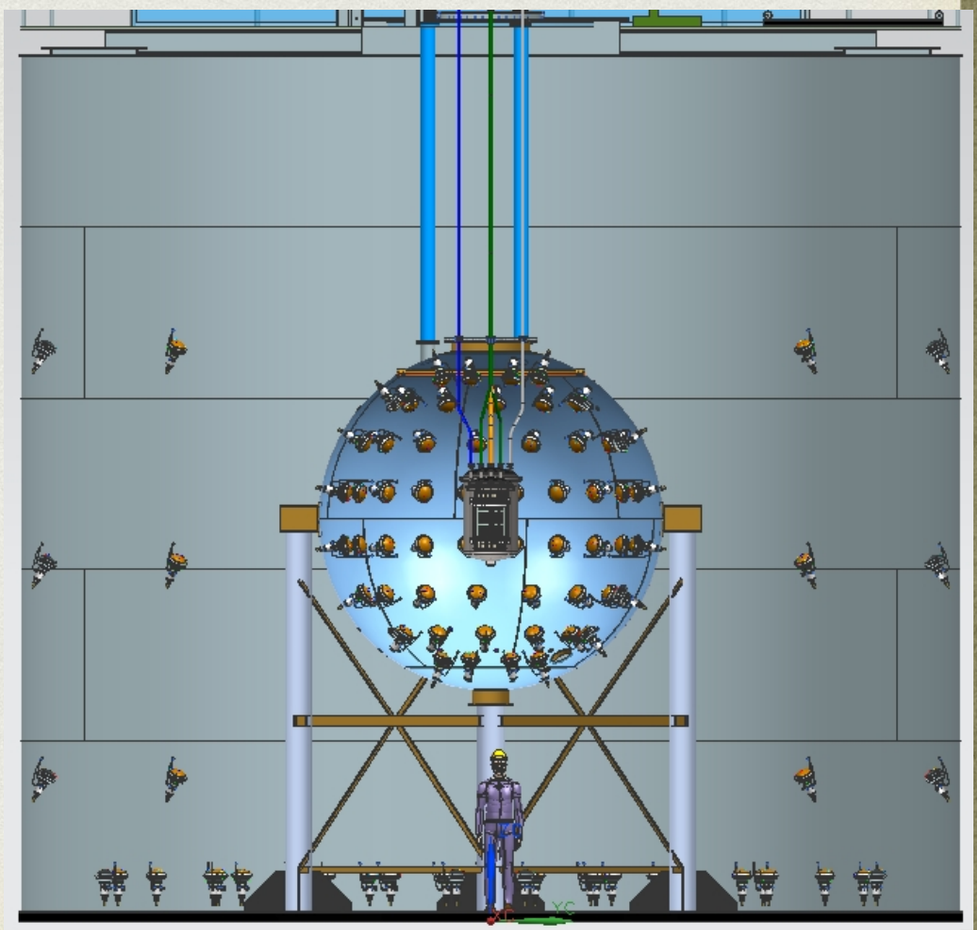
THE XENON FAMILY



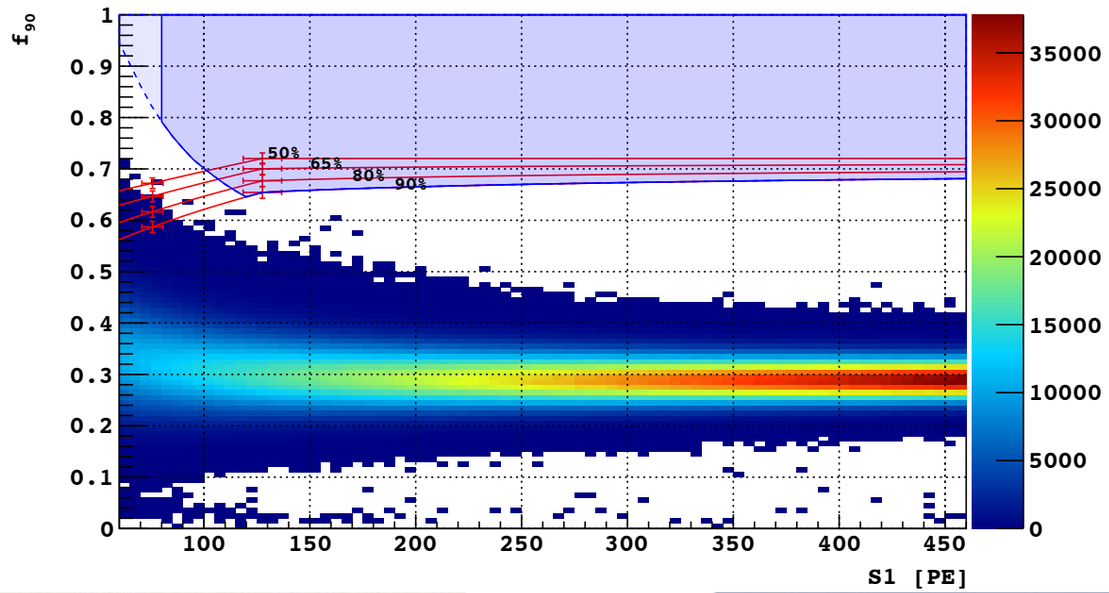
DARK SIDE: QUEST FOR ZERO BACKGROUND

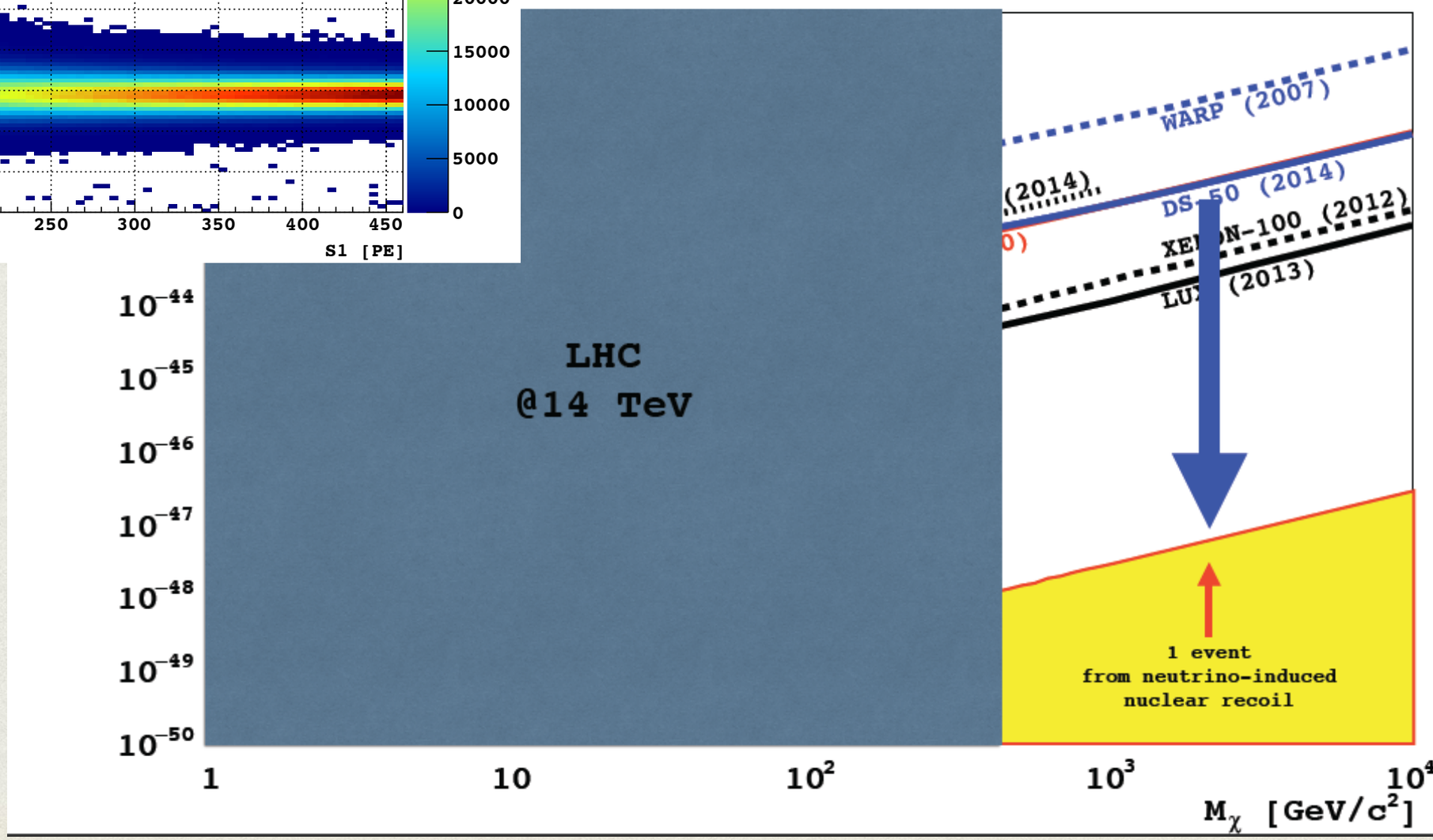




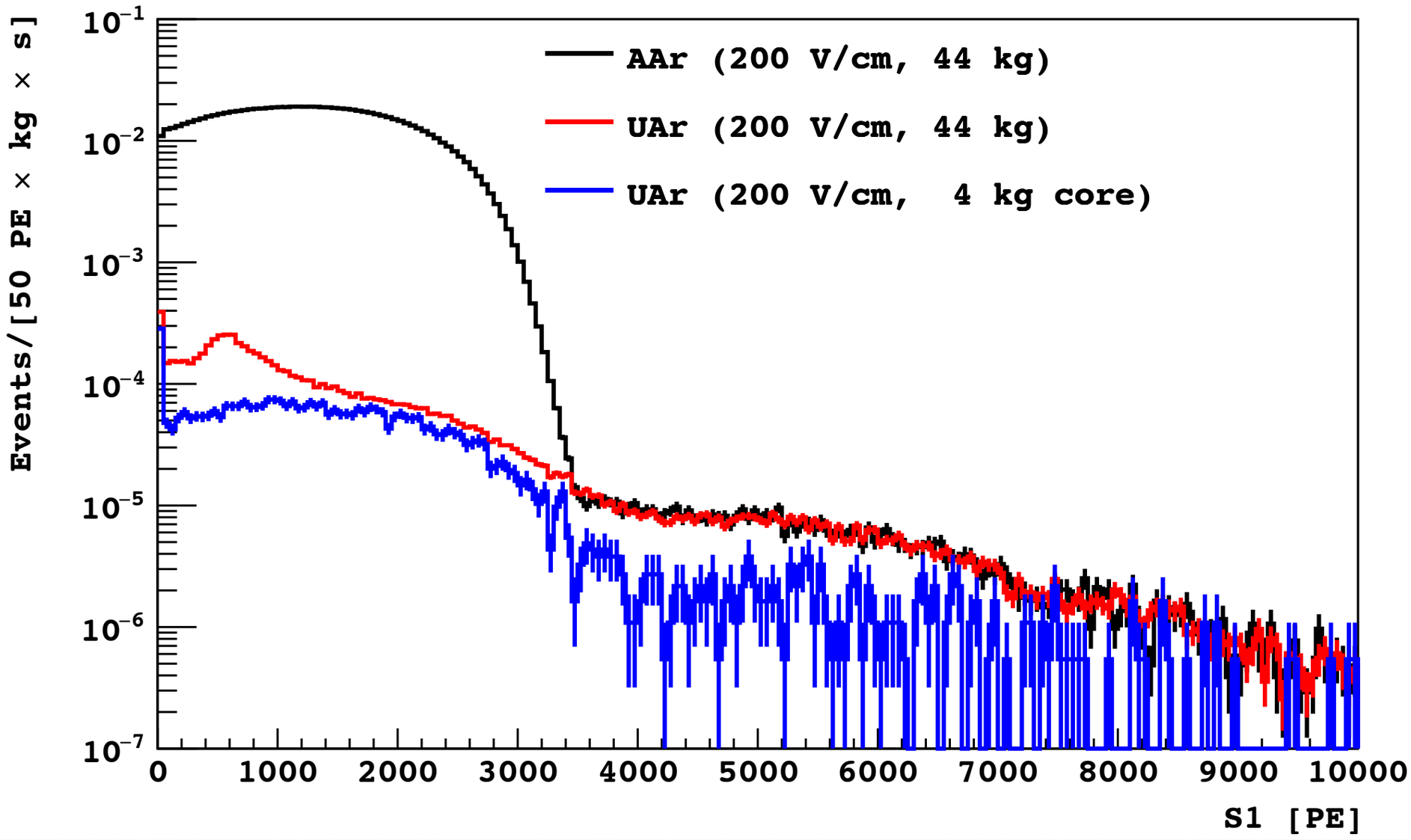


TEST WITH DS-50 VERY ENCOURAGING





IF AND ONLY IF



A TWO STEP PROCESS

1) URANIA in Colorado

- Made possible by generosity of Kinder Morgan
- 150 kg of underground argon collected and filled in DarkSide-50
- Depletion of $^{39}Ar > 300$
- Funding from INFN to build a plant to collect ~100 kg/day of underground argon
- Generosity of Kinder Morgan was rewarded with helium study and will be rewarded with DarkSide engagement in critical R&D studies for carbon sequestration, in cooperation with Carbosulcis S.p.A.

2) ARIA in Sardinia

- Made possible by Protocollo di Intesa between INFN and Regione Autonoma della Sardegna

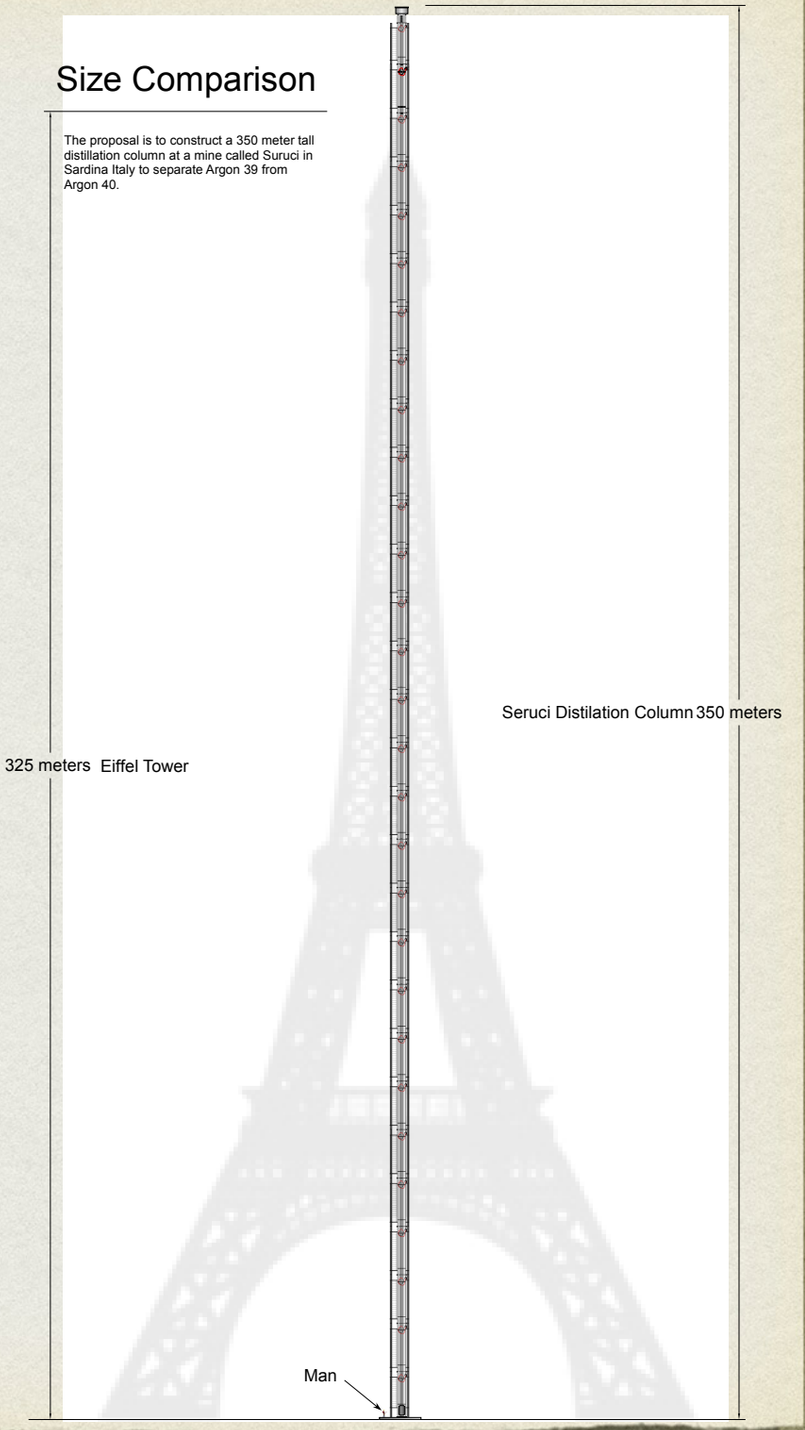
- First contribution for design study from NSF

- Will help deliver ^{40}Ar for DarkSide-20k by purifying argon from Cortez, CO, and depleting it further from ^{39}Ar

- Will improve availability and affordability of ^{13}C, ^{15}N, and ^{18}O, crucial for advanced screening against cancer and neurological diseases

NOT ONLY PHYSICS : AN EXAMPLE OF INDUSTRIAL COOPERATION AND SOCIAL BENEFIT

Cryogenic distillation plant



BTW: MOUNTAIN AND SEA (COME AND JOIN US !)

GW AT EGO

EGO-VIRGO

Consortium of

cnrs

INFN

dépasser les frontières

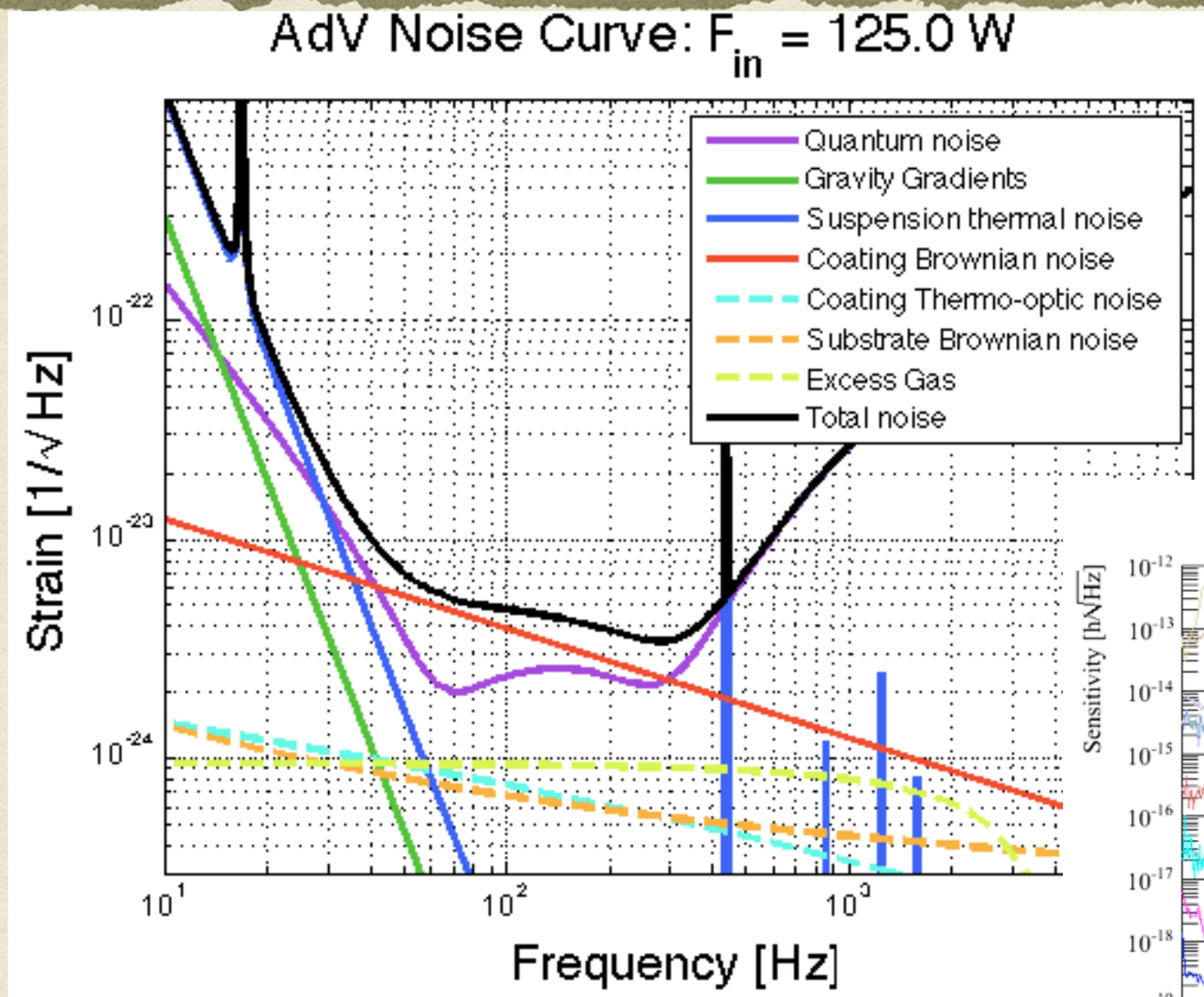
The

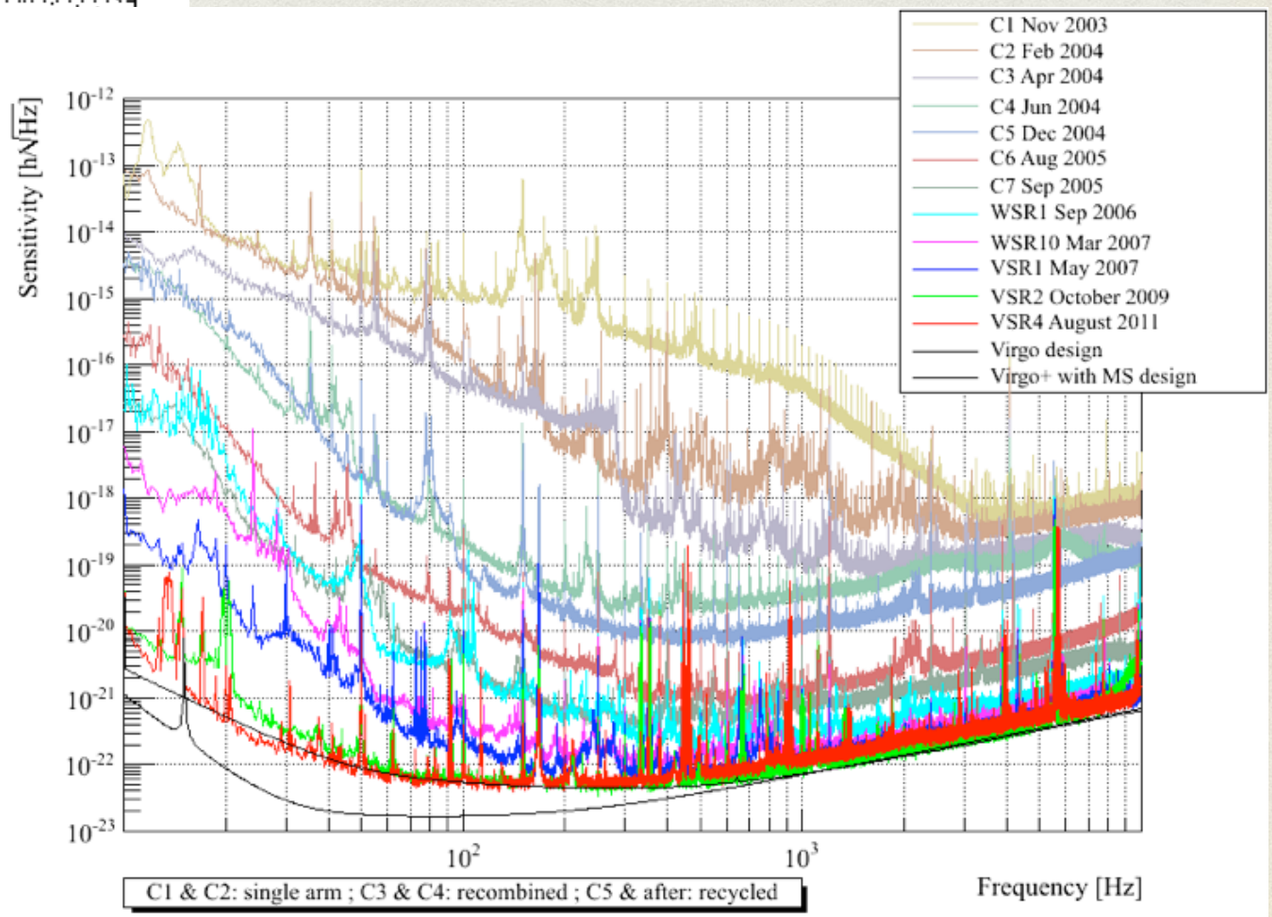
Gravitational

Waves

quest

ADVANCED VIRGO: 2016



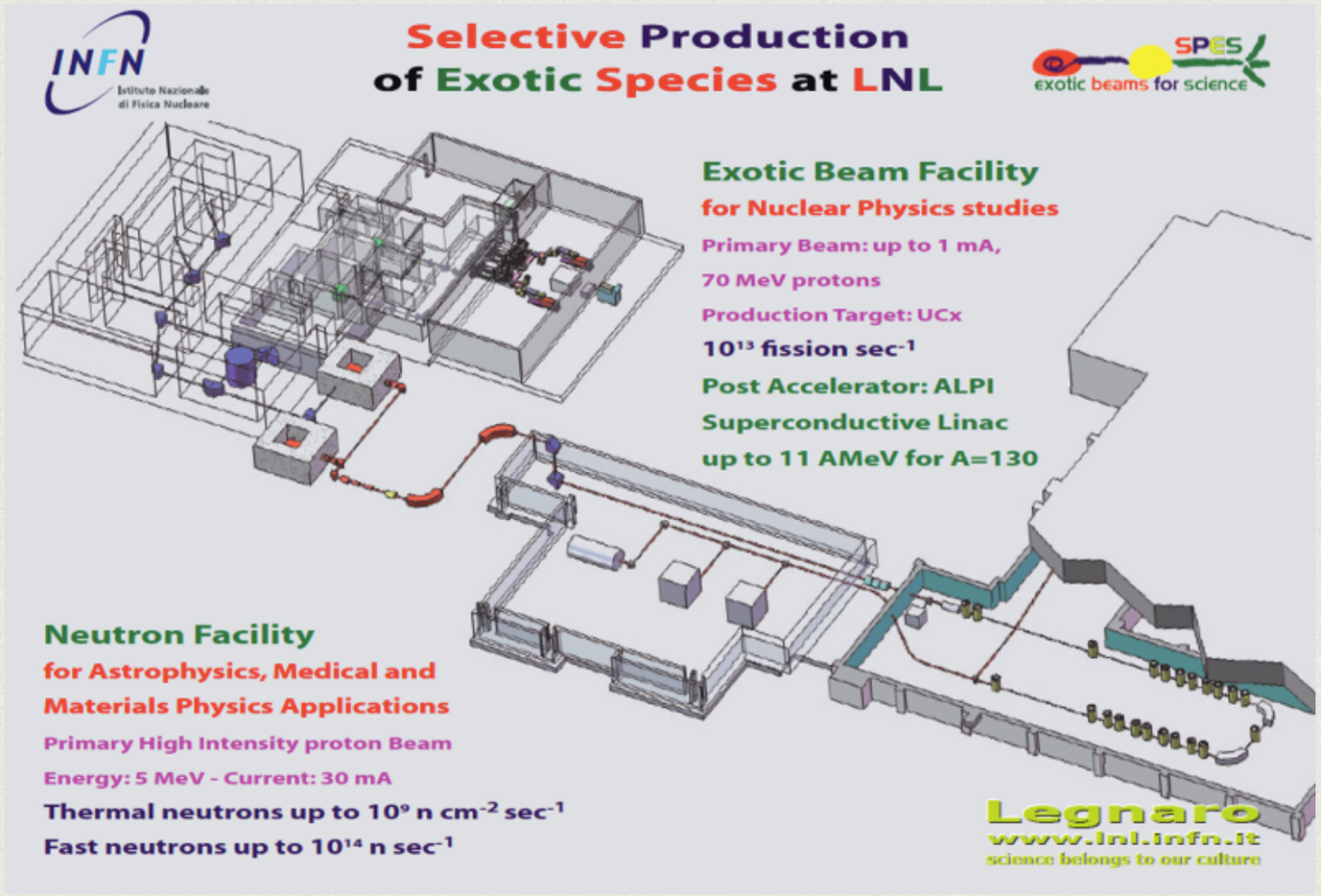


ACCELERATOR STUDIES

LNL

1. Radioactive Ion Beams are produced by proton induced fission on a UCx direct target at a rate of 10^{13} fission/s.
2. Neutron rich re-accelerated beams will be available at energies up to 13 MeV/u in the mass region A=130.
3. Re-acceleration will be performed by the superconducting linear accelerator complex (PIAVE-ALPI) of the Laboratori Nazionali di Legnaro.
4. The facility for applied physics is based on proton and neutron beams from a two exit port cyclotron (70 MeV, 500 microA) and the high intensity RFQ TRASCO (5 MeV, 30 mA).

Working out an agreement with a private company for radioisotopes production

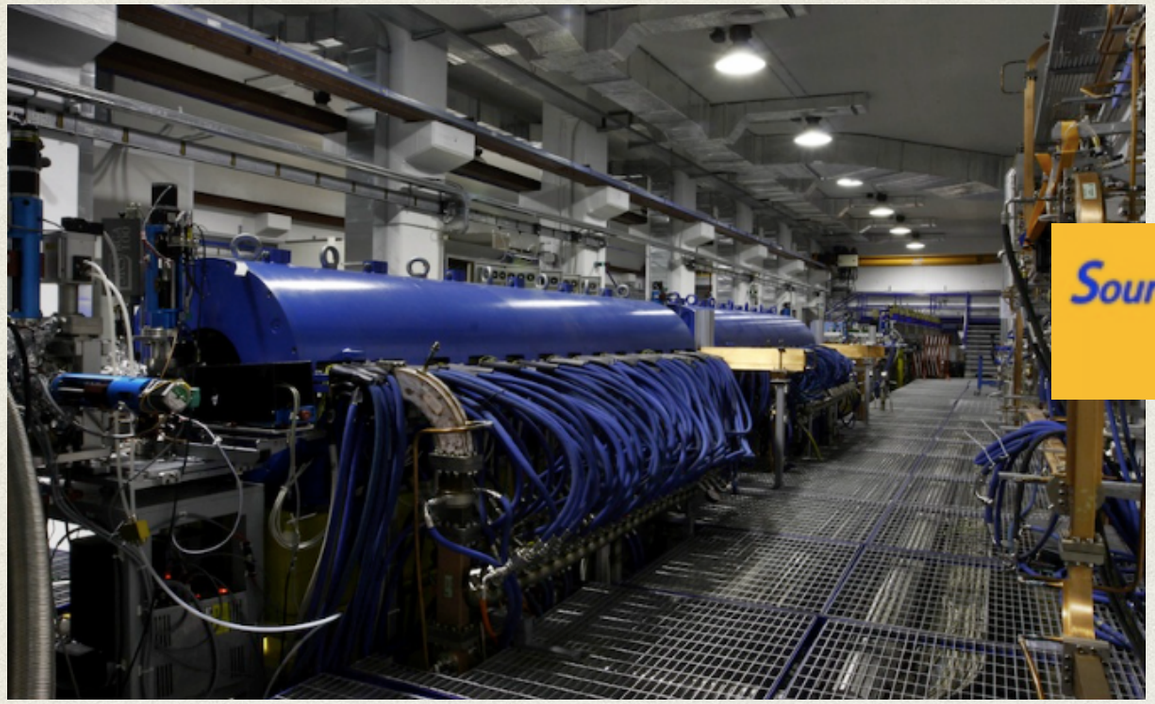


JUST ARRIVED ....

Radioisotopes by 2016

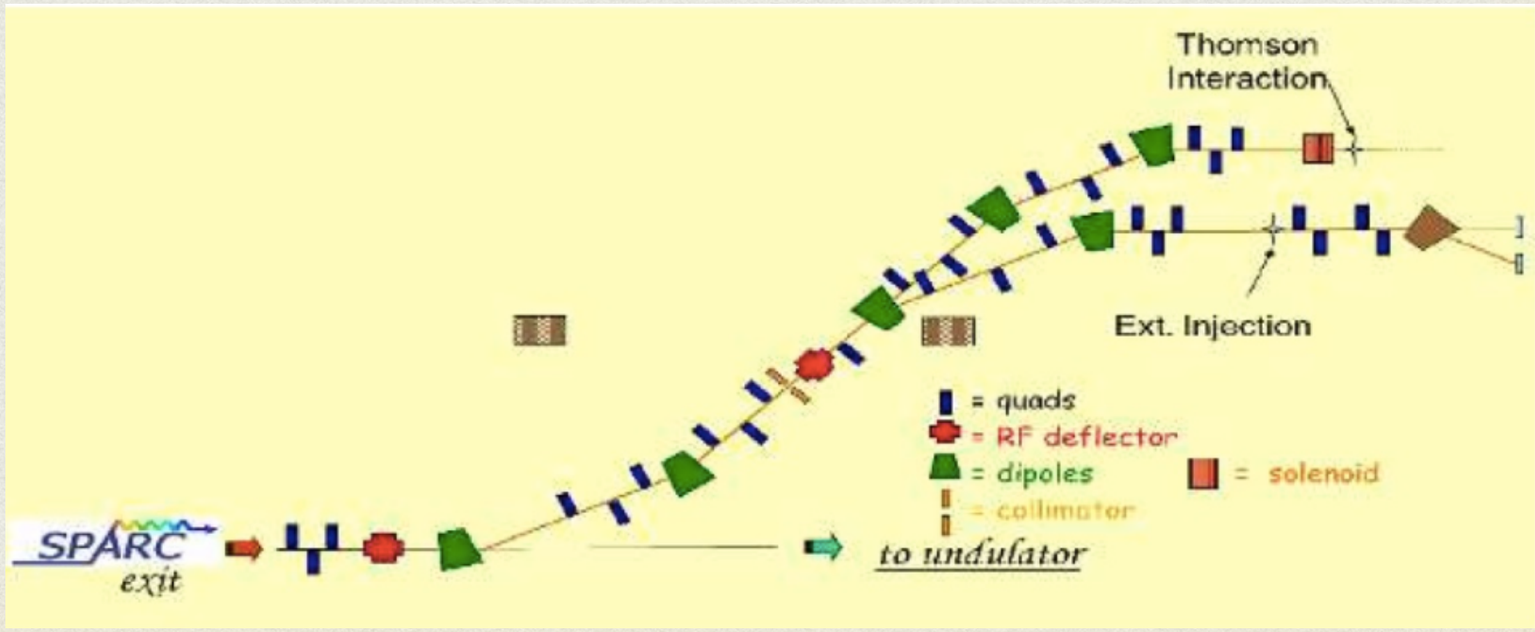
NP by 2018

LNF: SPARC



Sources for Plasma Accelerators and Radiation Compton with Lasers And Beams

Main focus: PWA either with a Laser (300TW) generated plasma or electron driven plasma



A LOT OF ACCELERATOR PHYSICISTS AND EXPERTS

- the road to build larger machine than the one we have is unlikely to be open (lack of money at a level of a couple of hundred MEuro in, say, 5 years)

- look outside, there are several sites in Europe (and perhaps elsewhere) where our contribution can be substantial

- find the right balance between maintaining the expertise, have new people to train , offer in-kind contribution made at home , send people to help (and possibly get them back !)

WHERE DO WE GO ?

- ELI-NP at Magurele (Romania)
- ESRF at Grenoble (France)
- ESS at Lund (Sweden)
- X-FEL at Hamburg (Germany)
- SESAME at Allan (Jordan)
- CERN is too obvious to discuss….

DISCUSSING THE FUTURE

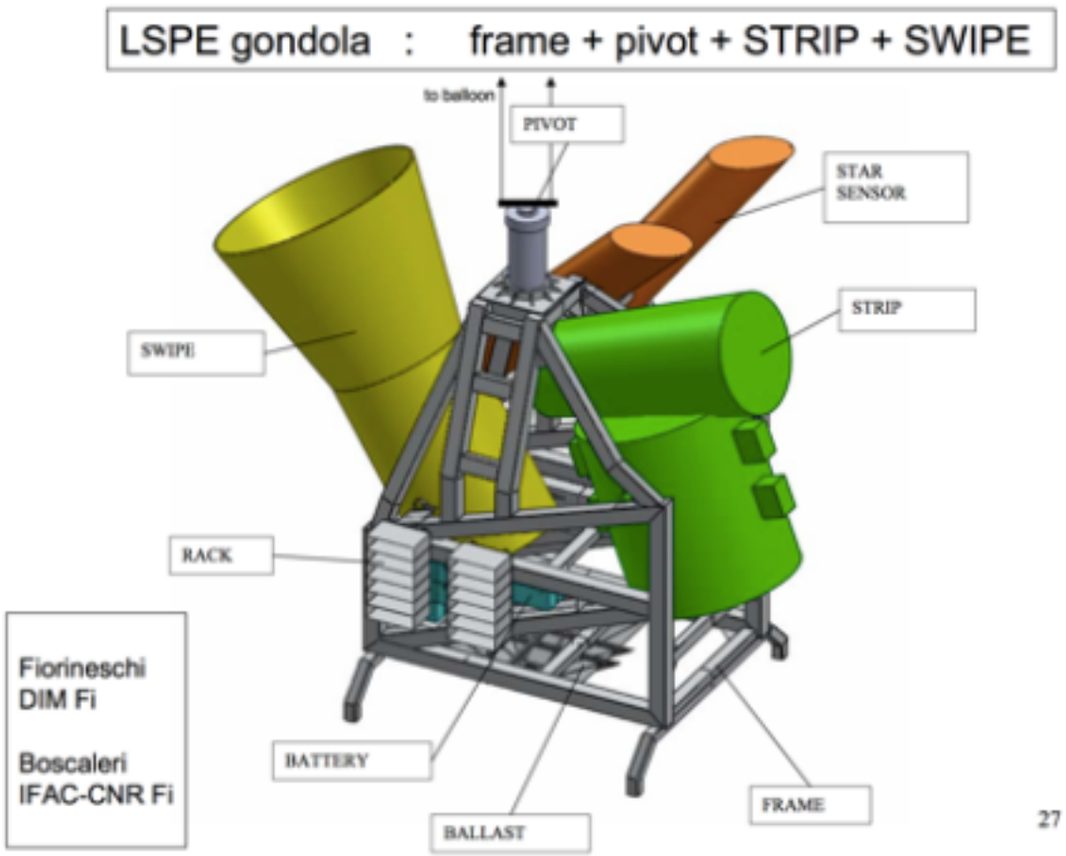
700+ people

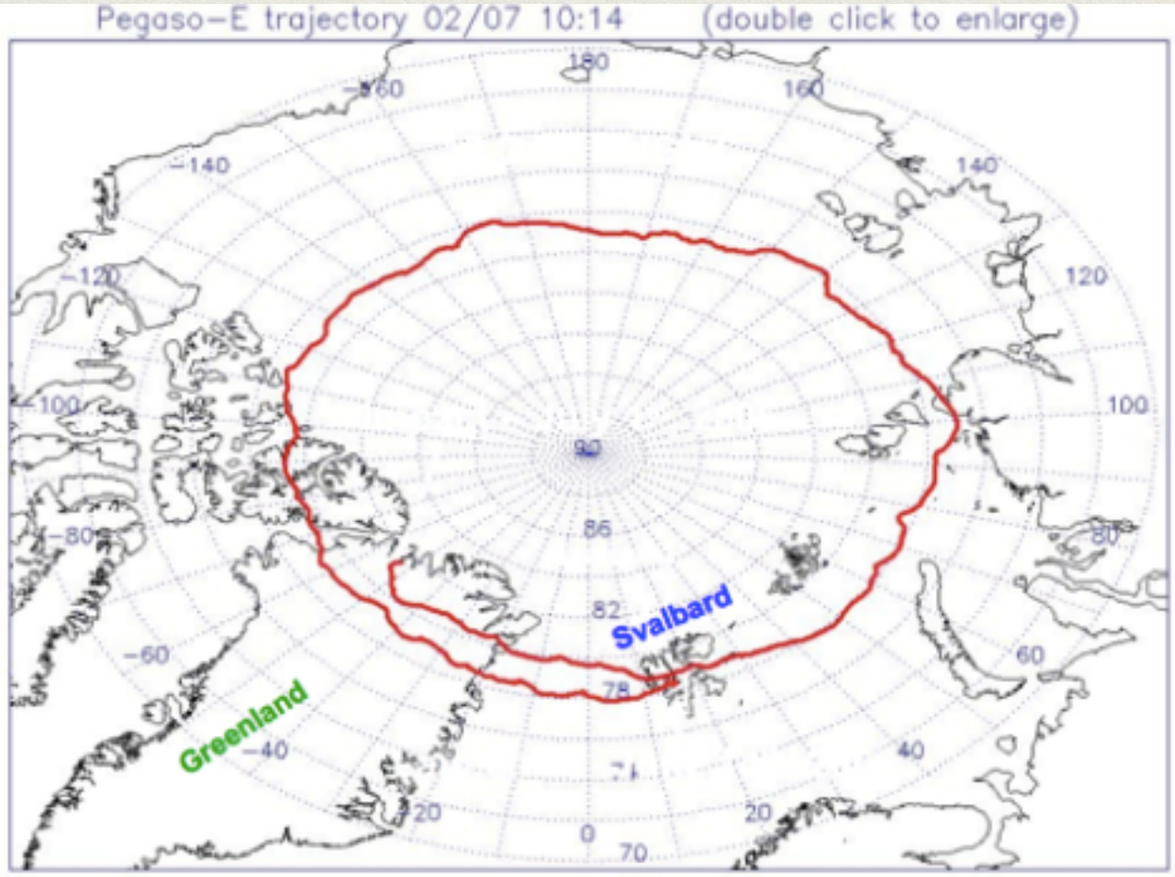
No WiFi

conclude the process by February 2016

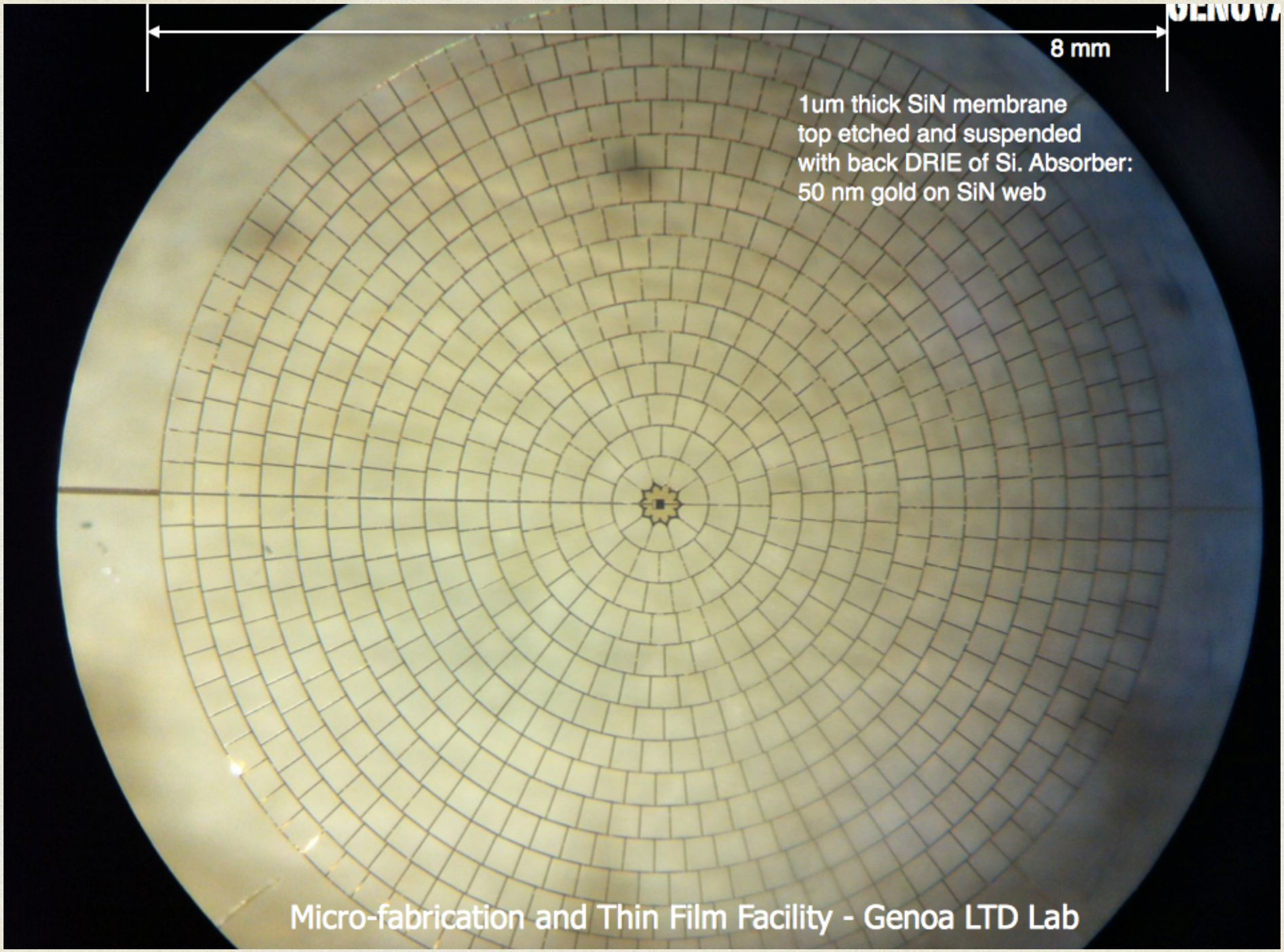
JUST ONE EXAMPLE OF A NEW BORN ACTIVITY

A BALLOON FLYING AROUND NORTH POLE





WITH THIS NICE BOLOMETER



CONCLUSION

- we have a lot to do now
- we know what to do next without thinking (ballistic projects)
- in spite of this we decided to think for an even more rich and diversified future