

# *WA104: R&D on new large LAr detector*

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*ICARUS-LBNE Collaboration*

*ICFA Meeting at Paris Diderot University  
January 10th, 2013*

# The need for a continuing neutrino programme

- The recent, major success of ICARUS-CNGS2 experiment has conclusively demonstrated that LAr-TPC is *a leading technology for future short/long baseline accelerator driven neutrino physics.*
- With a total LAr volume of 720 ton, the ICARUS detector has a unique role since it is presently the largest operational LAr-TPC and it will remain so for several years to come. It represents the status of the art and it marks a milestone in the practical realization of any future larger scale LAr detector.
- INFN has just concluded an important cooperation agreement toward a joint experiment with US-LBNE collaboration, involving the long term realization of a large mass, LAr-TPC detector.
- *The direct and continued access to a neutrino beam either at CERN or alternatively at FNAL is necessary* to maintain the appropriate levels in R&D and participation in physics developments *within a "learning" process based on real events and cross sections.*

## Next neutrino activities

- In view of the relative novelty of LAr-TPC technology, a vast “LAr programme” must be continued, studying real  $\nu$  and anti- $\nu$  low energy events.
- ICARUS will be moved to CERN early 2014 for an overhauling and complemented with a new smaller T150 module “clone” of 1/4 of T600. Vigorous technology developments *while maintaining the already achieved basic features of T600* will introduce important new features and improvements such as:
  - Introduction of an analyzing magnetic field in LAr;
  - Improvement of LAr purification;
  - Better, completely passive, thermal insulation;
  - New design for ultra-pure LAr containment;
  - Linearization of calorimetric response by compensation of recombination effects;
  - Modification on T600 and new electronics for T150;
  - Improved light collection system.

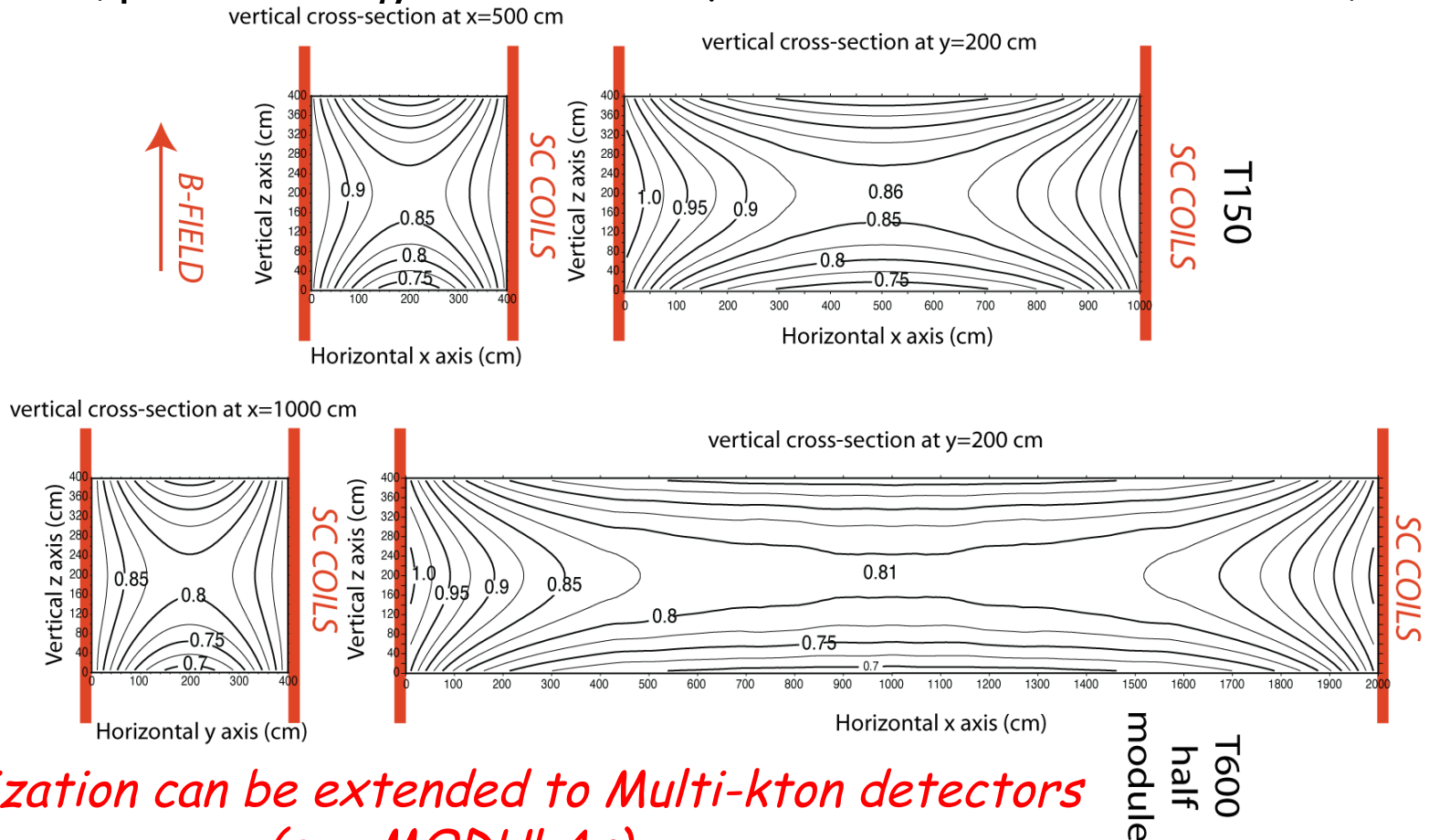
# A multi-faceted programme

- ICARUS will then be operated (*either at CERN, if a beam will be made available on a reasonable time schedule, or else at FNAL, provided it will be approved*) collecting a large event sample ( $\geq 10^6$ ) on short baseline with appropriate energy for the future LBNE exp.
- In addition to a *definitive clarification of sterile neutrino*, the R&D programme in LAr will pave the way to ultimate realization of the LNBE detector with the above mentioned important technological developments and with essential studies like, for instance:
  - The accurate determination of cross sections in Argon;
  - The experimental study of all individual CC and NC channels;
  - The realization of sophisticated algorithms capable of the most effective identification of the events.



# R&D-1: Magnetising LAr

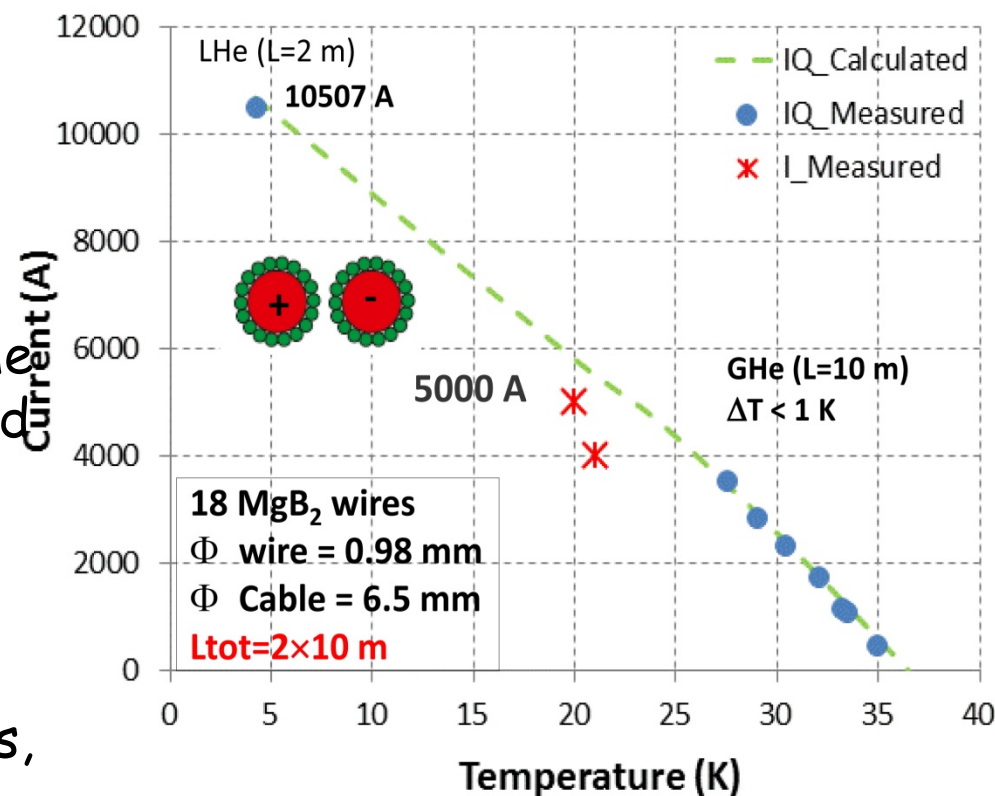
- The addition of an appropriate magnetic field to the LAr-TPC detector has been already described in the first ICARUS.
- The presence of the magnetic field nicely complements the calorimetric tracking of the events, introducing with the charge and curvature of the tracks a complete analogy to the one of the traditional bubble chamber.



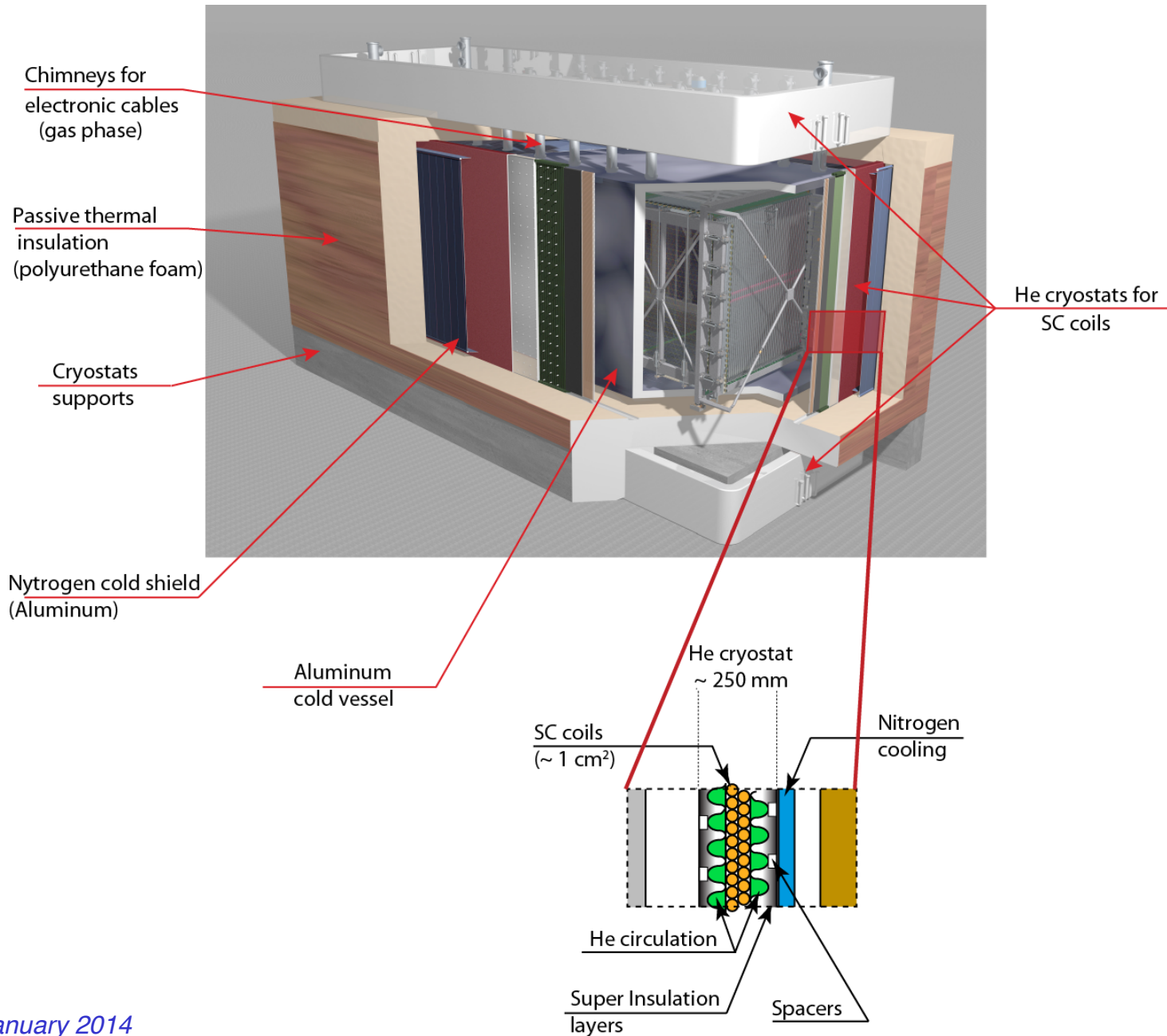
*Magnetization can be extended to Multi-kton detectors  
(e.g. MODULAR)*

# Possible solutions

- Although “hot” superconductors may also be possible, a more conventional approach seems to be more suitable to our needs, based on recently developed technologies.
- The standard Niobium-Titanium superconducting cable would depend on a rather sophisticated cryogenic system that uses liquid Helium at 4.2 K - 1.9 K.
- ✧ We consider new SC wires based on Magnesium Diboride ( $\text{MgB}_2$ ) that offers the major advantage to remain functional at up to 25 K. This superconductor, developed at CERN with IASS [11] in collaboration with the Italian company Columbus can be cooled using Helium gas (as opposed to liquid Helium), greatly simplifying the demands on the cryogenic system. In addition,  $\text{MgB}_2$  can work with a temperature margin of several degrees, a great advantage from the operation point of view.

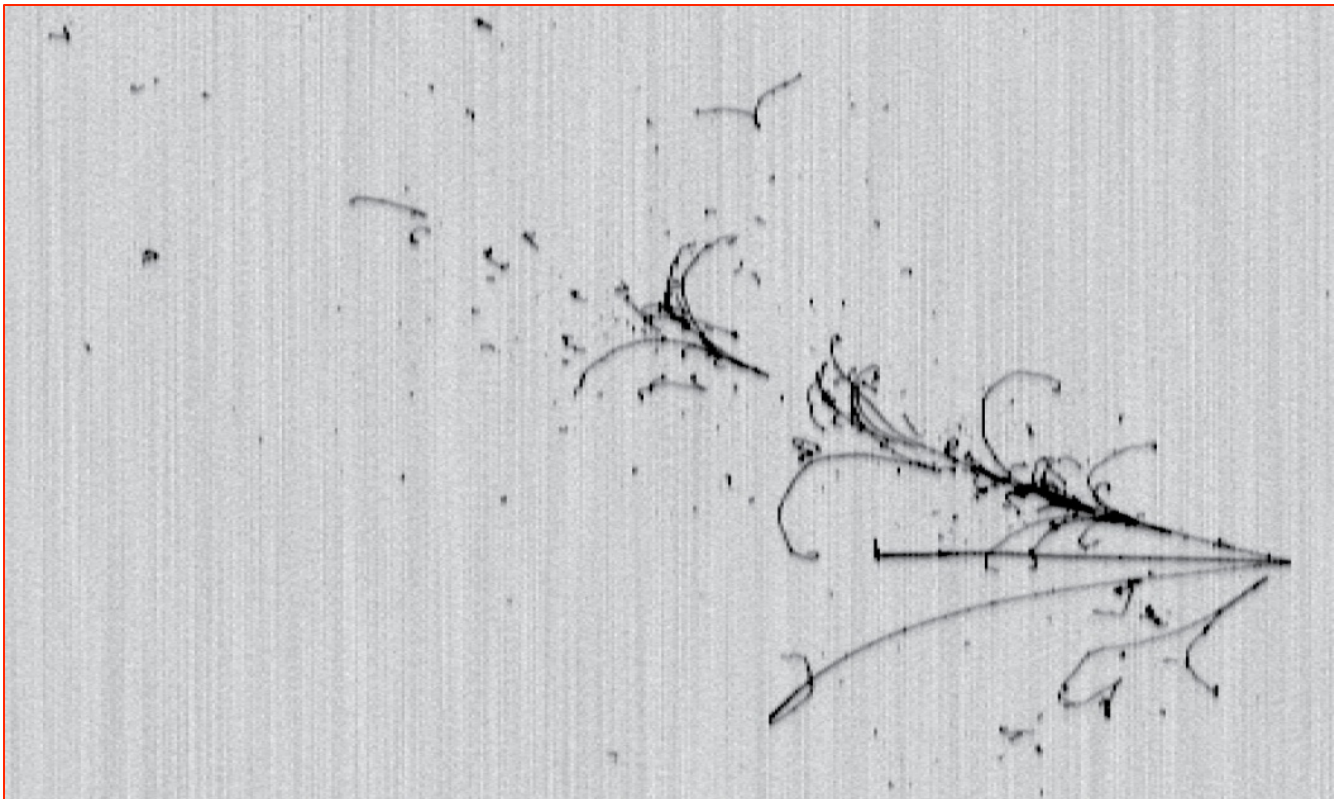


# T150 Configuration with magnetization



# Benefits

- The introduction of an appropriate magnetic field to the LAr-TPC permits to further contribute to the progress of LAr technology, allowing the unambiguous determination of the sign and momentum of the secondary charged particles and a greatly improved visibility of the e.m. showers.
- It provides an even closer visual similarity to the one of a "Gargamelle like" bubble chamber, with the added advantage of an accurate calorimetry and  $dE/dx$  identification of the tracks.

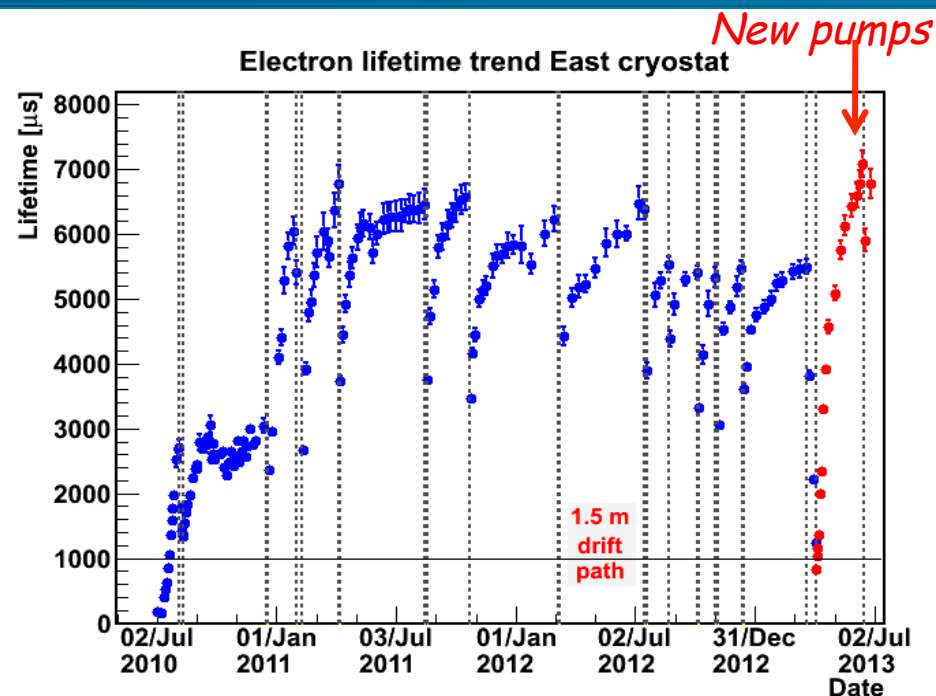


*Example of a 4 GeV  
e-neutrino event,  
with a negative  
electron,  $\pi^0$ ,  $\pi^+$  and  
proton in the final  
state*

# R&D-2: LAr purification

- The dual cryogenic system at T600 requires  $> 10$  liquefiers with a total electric consumption of  $\sim 400$  kW and a “brute force” approach.
- The present system is therefore very delicate and requires a very sophisticated technology, namely:

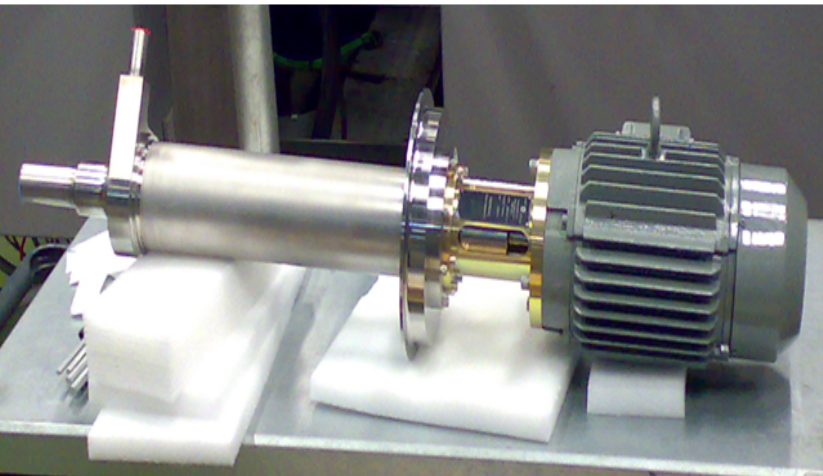
- Purification ( $100 \text{ Nm}^3/\text{h}$ ) of gas phase ( $\sim 40 \text{ Nm}^3$ ) to block impurity diffusion from hot parts of the detector and from micro-leaks on the opening
- Purification ( $4 \text{ m}^3/\text{h}$ ) of the bulk liquid volume ( $\sim 550 \text{ m}^3$ ) to efficiently reduce the initial impurities concentration
- As soon as the purification stops purity decreases within days.



*A more efficient purification system is required*



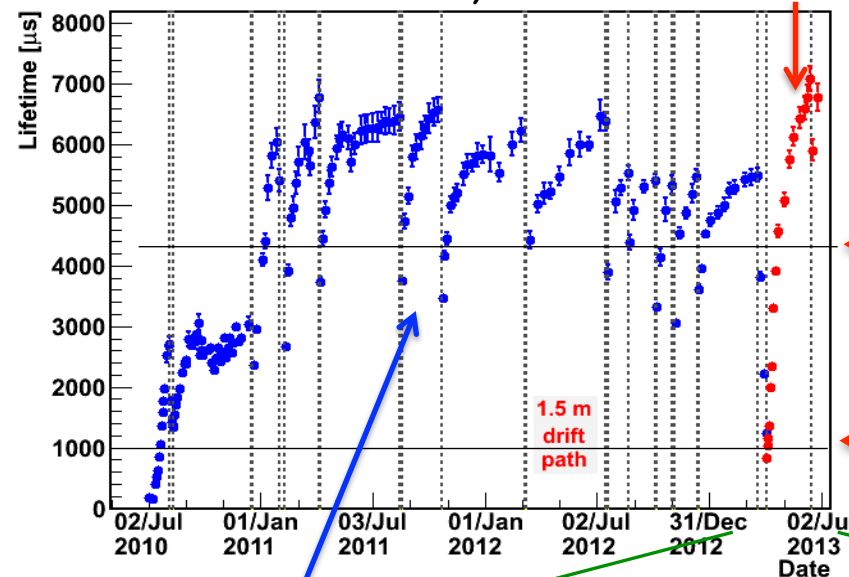
# LAr purification -2



*ACD LAr pump faults*

- New Barber Nichols pump with non immersed motor (BNHEP-23-000) successfully tested (Apr - June 2013) allowing to exceed  $\tau_{ele} > 7\text{ms}$
- $\tau_{ele} > 5\text{ms}$  (~60 ppt  $[\text{O}_2]_{eq}$ ): maximum charge attenuation of 17% at 1.5 m

*East Cryostat*

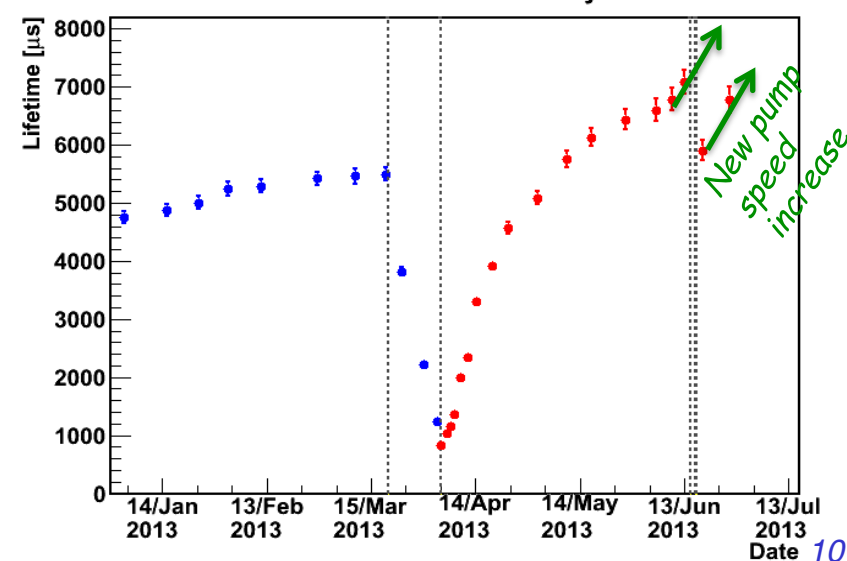


*New pump*

*60 ppt  $[\text{O}_2]_{eq}$*

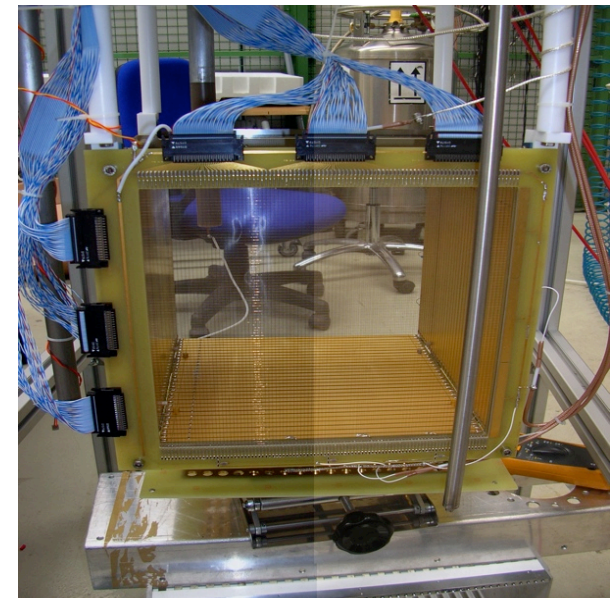
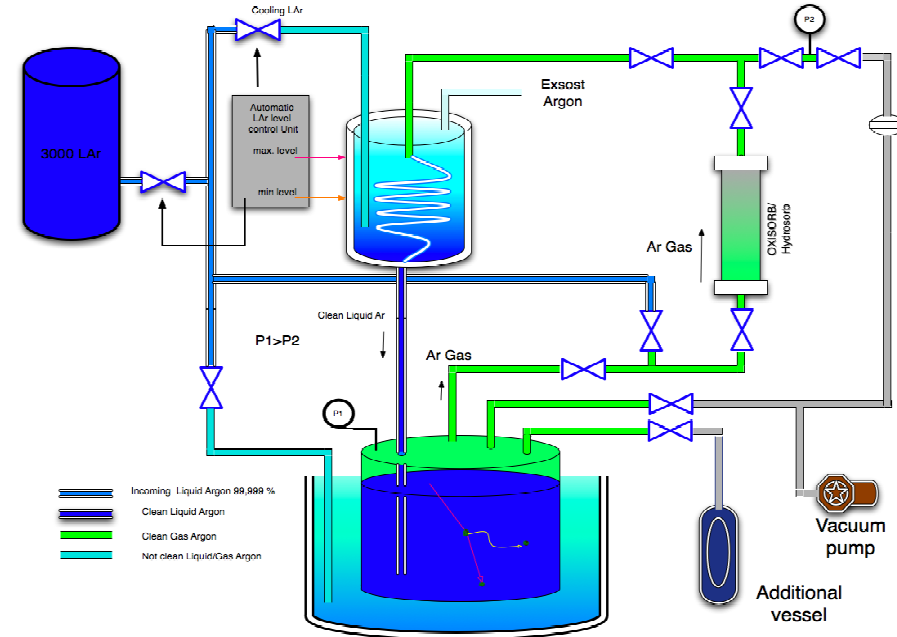
*max drift*

*Electron lifetime trend East cryostat*

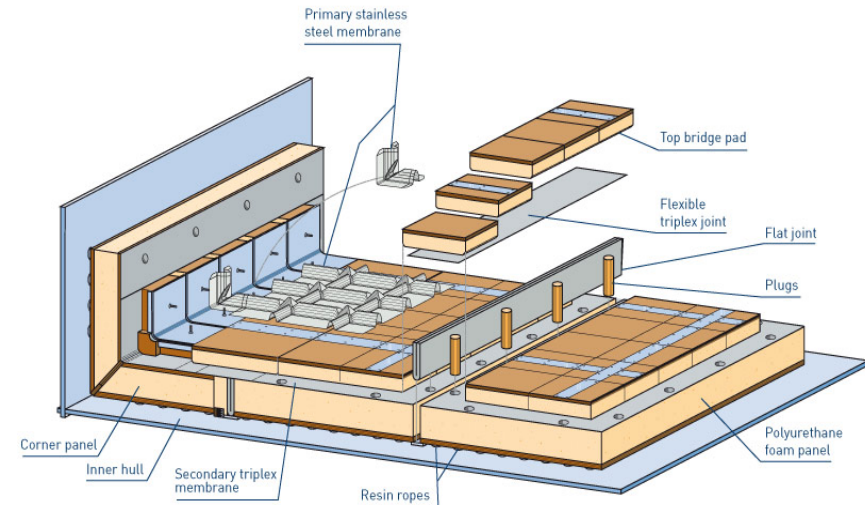
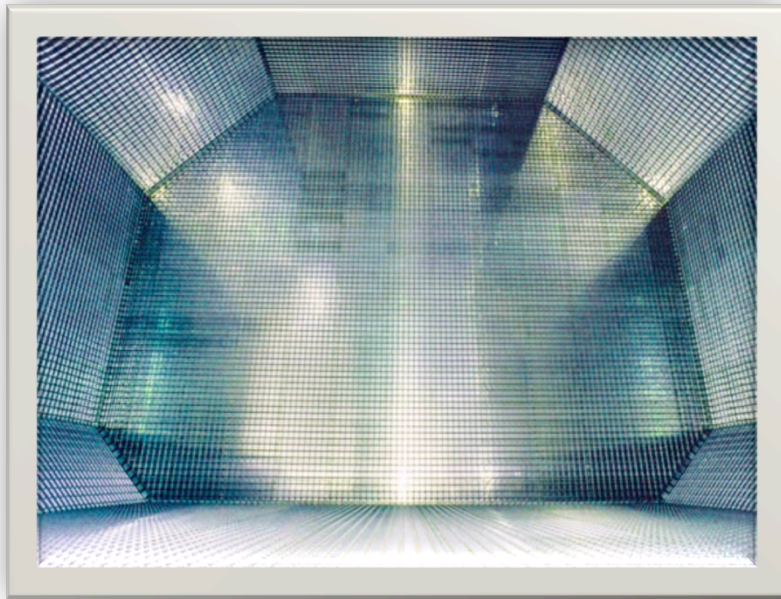


# New purity achievements

- LBNE requires:  $\tau_{ele} > 12$  ms and  $E_{drift} = 0.5 \text{ kV/cm}$  for 15% attenuation at 3.0 m,
- Extremely high  $\tau_{ele}$  have been already obtained with cosmic  $\mu$ 's and the ICARINO programme
- The short path length used (30 cm) is compensated by the accuracy in the observation of the specific ionization
- The result reported is  $\tau_{ele} \approx 21$  ms corresponding to  $\approx 15$  ppt, namely a  $\approx 10^{-11}$  molecular Oxygen eq. impurities.
- These activities were initiated in view of "Modular" Project.



# R&D-3: New Thermal Insulation



Purely passive insulation chosen for the new T600/T150 installation, coupled to our standard cooling shield with boiling Nitrogen.

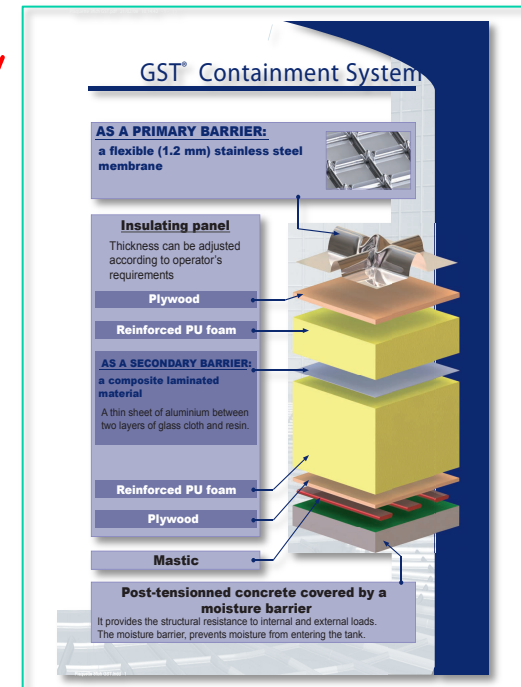
Technique developed for 50 years and widely used for large industrial storage vessels and ships for liquefied natural gas.

Expected heat loss through the insulation:

T600  $\approx$  6.6 kW ; T150  $\approx$  3.5 kW

Preliminary design appointed to GTT in Jan 2013

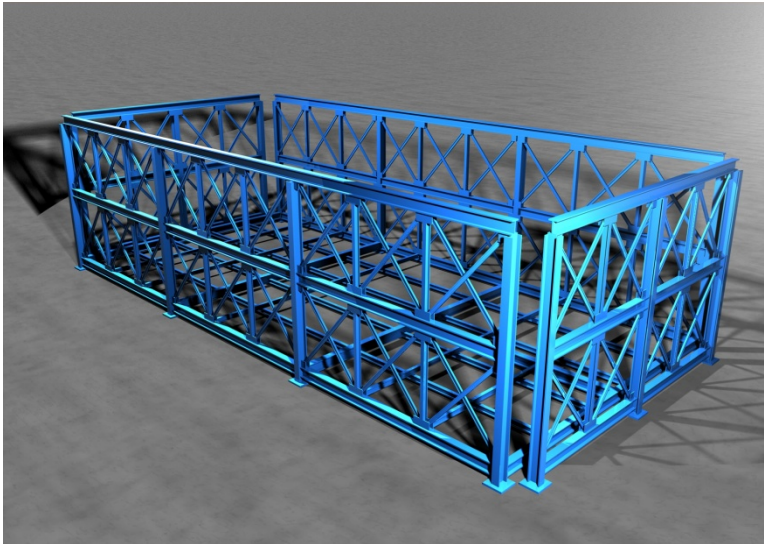
No internal membrane is required for our case



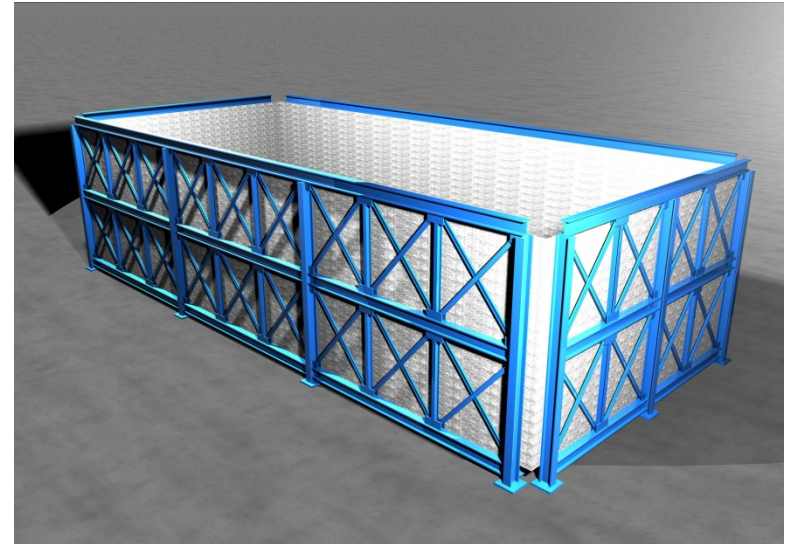


# New T600/T150 layout

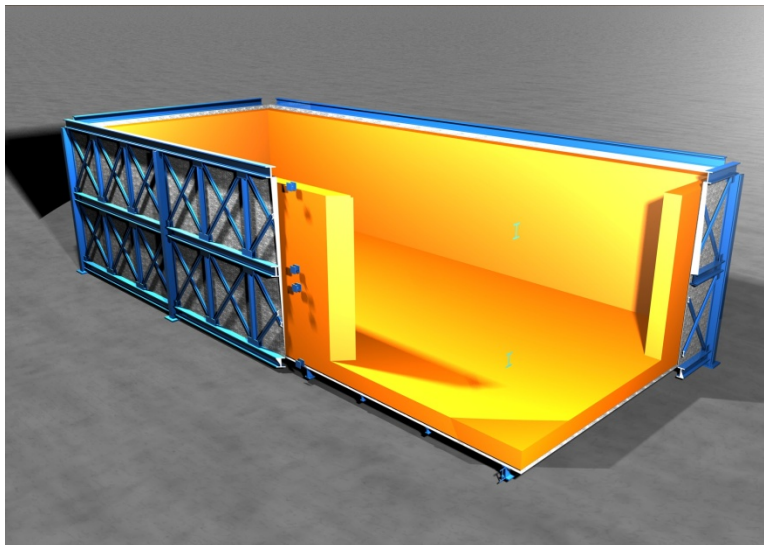
*Warm vessel cage*



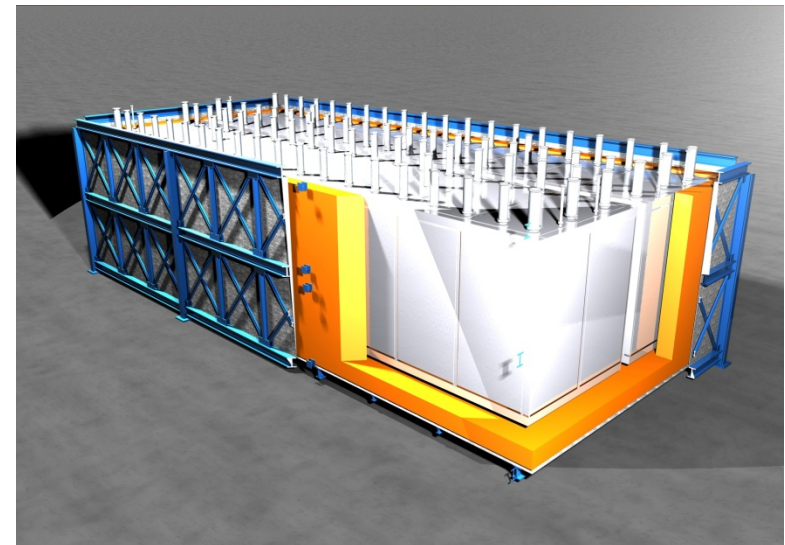
*External skin*



*Insulation panels*

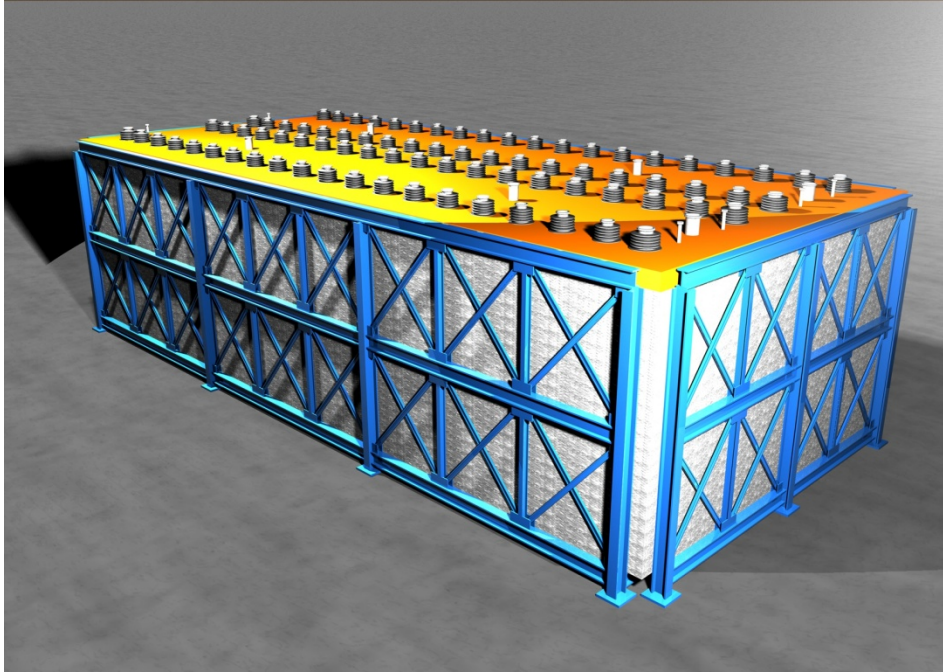


*T600 modules*

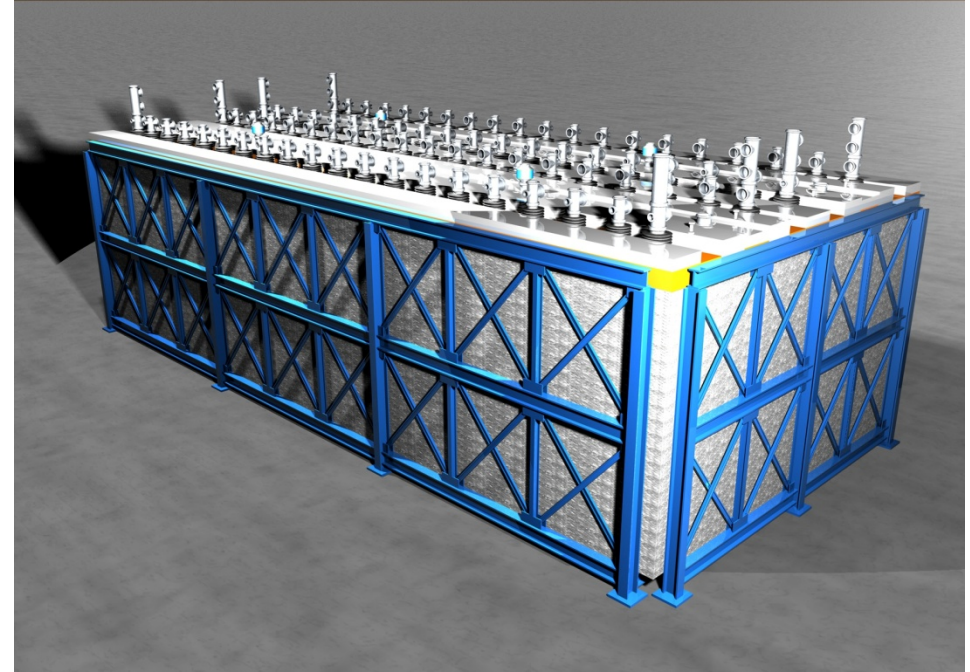


# New T600/T150 layout

*Insulation top*



*Top flanges (final layout)*





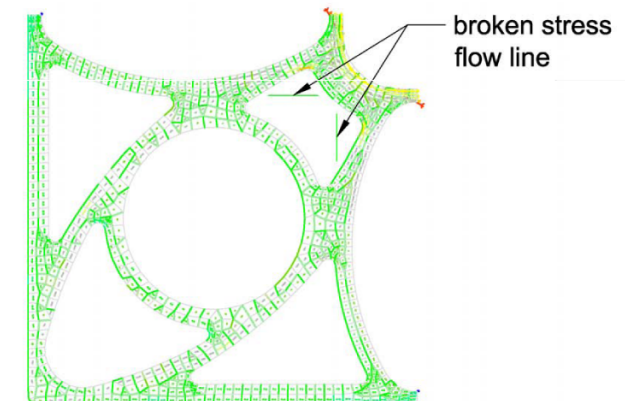
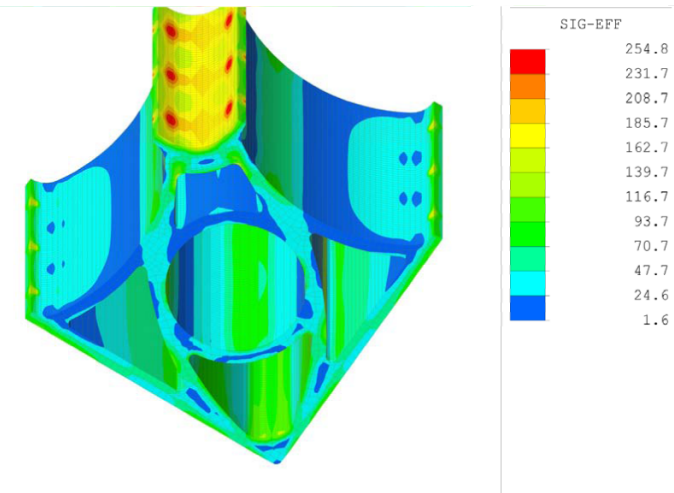
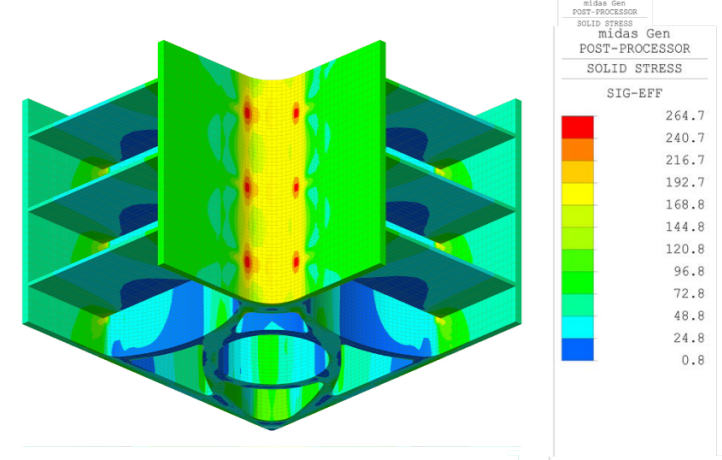
# R&D-4: New cold bodies design

The new cold bodies design appointed to a mechanical engineering company connected to the Milano Politecnico (Finzi e Associati).

Work is progressing:

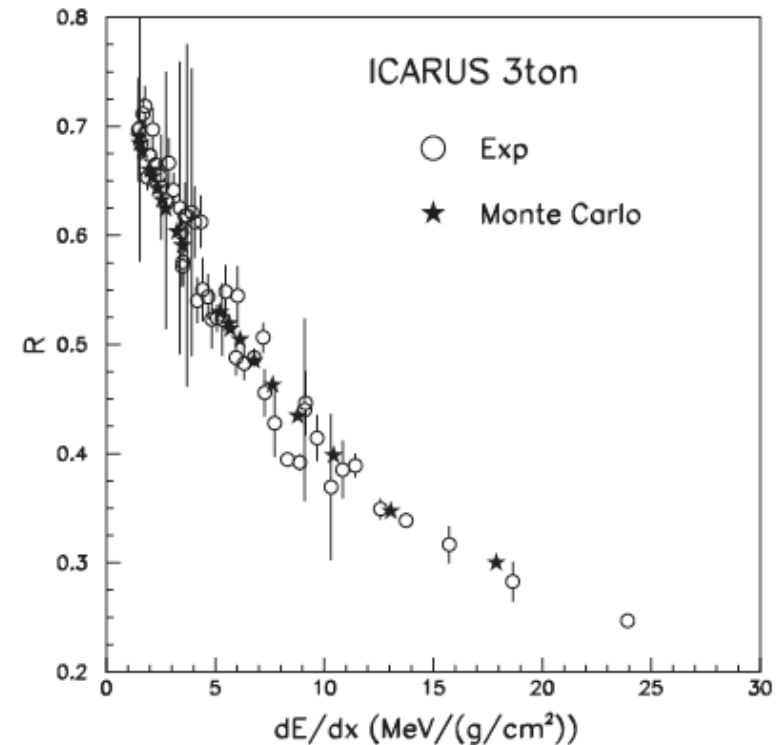
- Detailed modelling of the aluminium profiles (done).
- Compute behaviour under the several loading conditions (done)
- Optimization of the aluminium profiles (done)
- Define assembly and welding procedures (in progress)
- Verify time scale and construction cost (done)

This solution could represent a valid alternative to membrane (as originally foreseen for MODULAR) for LAr containment.



## R&D-5: Compensating recombination effects

- None of the electron recombination theories developed so far is fully successful in describing all the experimental data in liquid argon. Nevertheless, they provide the basis for its understanding and for all phenomenological approaches.
- The recombination effect has been already carefully studied by us and it is a very important process which needs to be further studied.
- There are several minor additives to the LAr which modify this effect, transforming some of the produced light into additional ionization which could be useful also for the future LBNE programme.

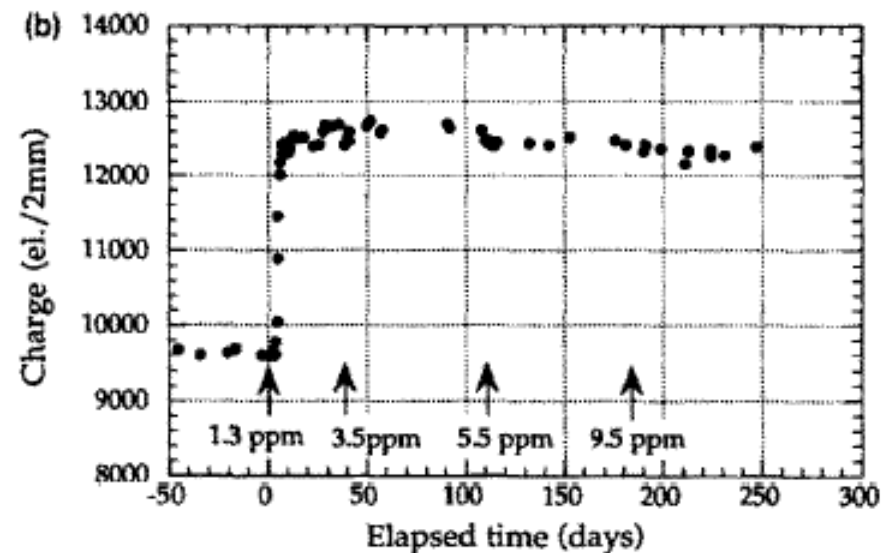
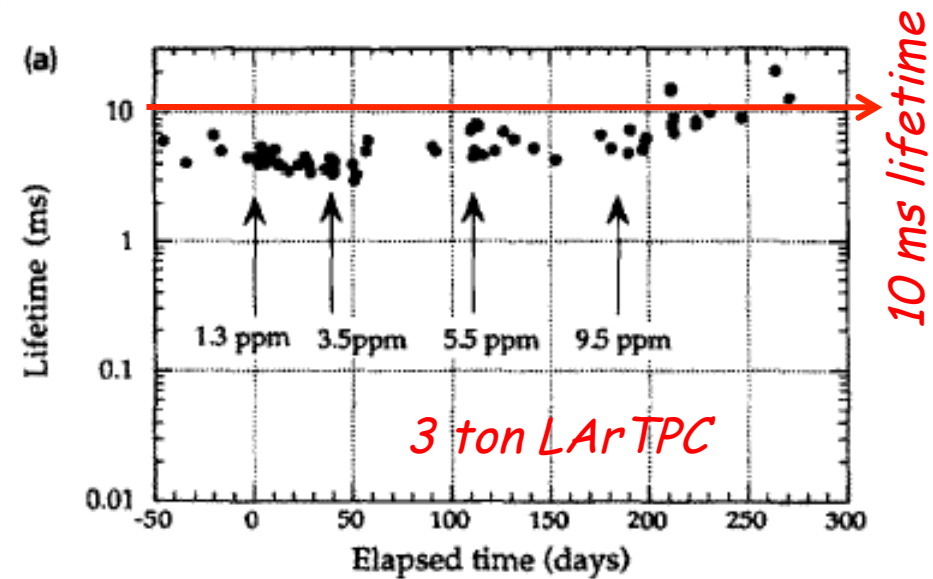
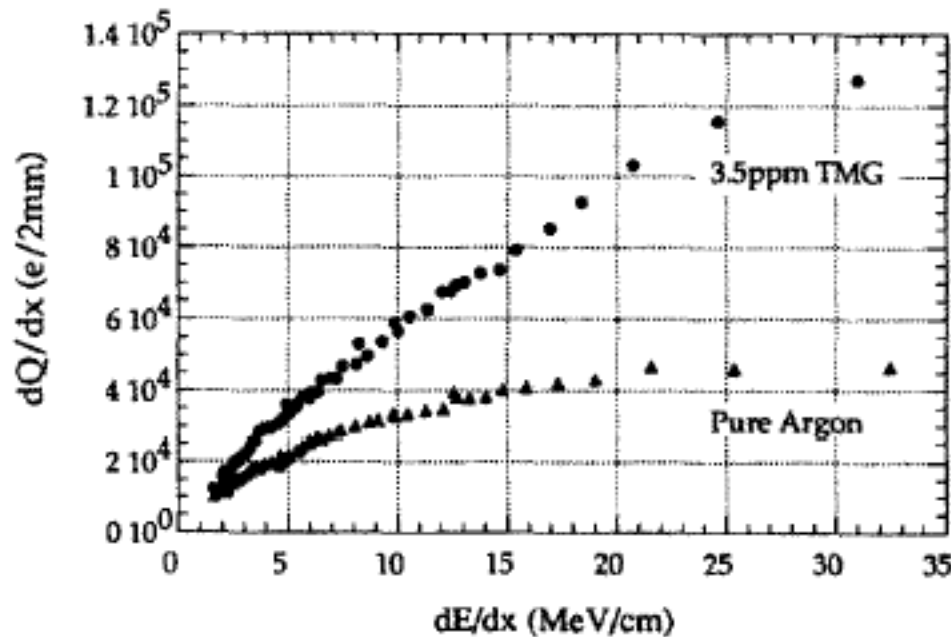


# Doping with tetra-methyl-germanium (TMG)

- The nonlinear detector response may degrade the particle identification capability of the LAr-TPC.
- A possible solution to improve the linearity of the detector response is to introduce photo-sensitive dopants able to convert part of the scintillation light into additional free electron-ion pairs, thus enhancing the linearity as a function of the deposited energy density and electric field.
- We have chosen TMG as photo-sensitive dopant since:
  - TMG is not absorbed in the recirculation system.
  - pure TMG can be easily purified to an electron lifetime better than  $10\ \mu\text{s}$ .
  - TMG has a large photo-absorption cross section of 62 Mbarn and has an acceptable quantum efficiency.
  - See: P. Cennini, et al. (ICARUS Coll.), NIM A355 (1995) 660-662
- The performance of the detector is greatly improved and is remarkably stable in time.
- A signal increase of +25% to +220% was found from 1.6 to 32 MeV/cm.

# Doping with tetra-methyl-germanium (TMG)

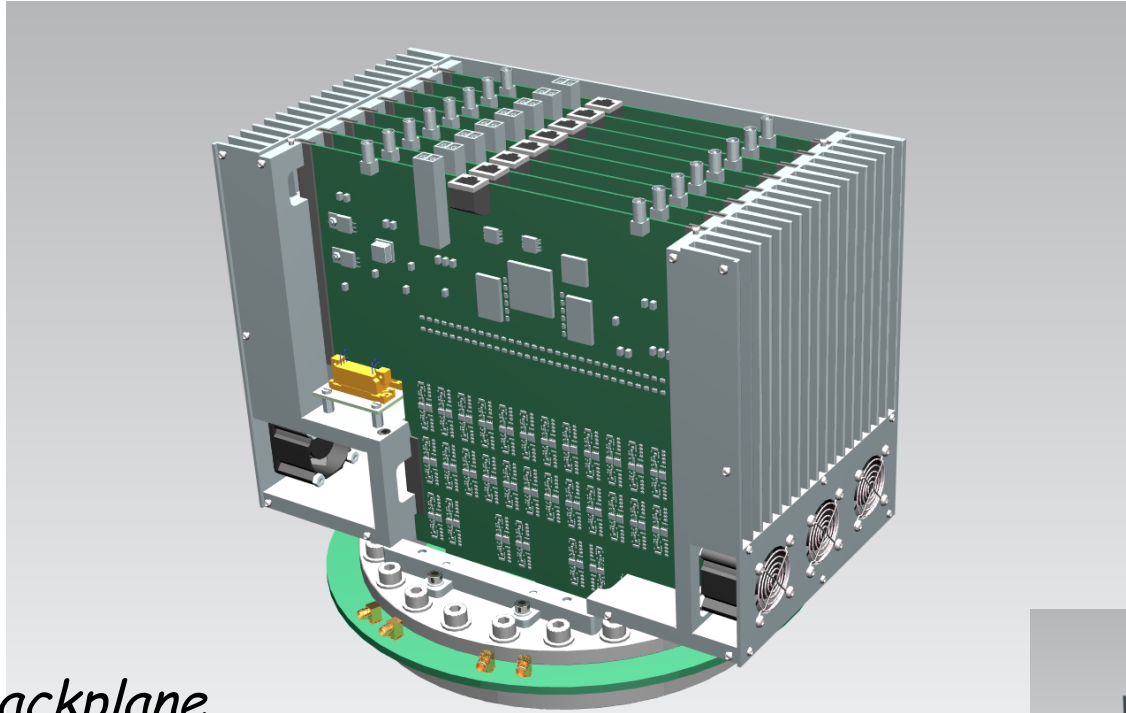
- Collected charge and deposited energy at an electric field of 200 V/cm and TMG concentration of 1.3 ppm and 3.5 ppm from stopping muon and proton events.
- Time evolution at 300 V/cm during the LAr doping with TMG.



## R&D-6: Modifications on the T600 and new Electronics for the T150

- The T600 electronics, by now 15 years old, requires substantial refurbishing and consequent upgrades.
- One evident limitation in the DAQ was due to the adoption of the VME standard (8-10 MB/s).
- The T600 system is being re-designed to overcome these limitations, for instance adopting a modern switched I/O and the parallelization of data flows.
- An R&D upgrading programme has been initiated, in order to realize:
  - A more compact electronics both for analogue and digital
  - Improvements of the signal to noise ratio shortening cables
  - Integrating electronics onto the flanges with lower power
  - Adopting serial switched I/O for data flow

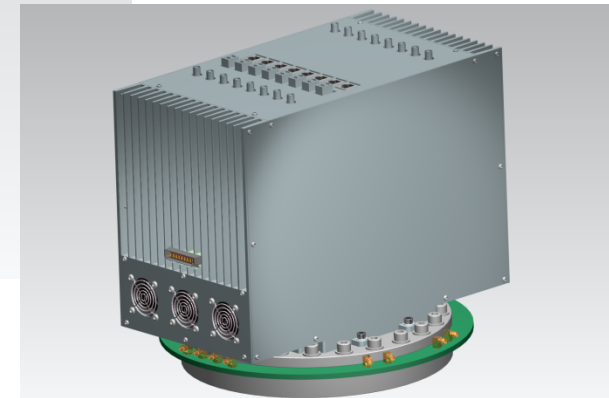
# Electronics on the flange



*Backplane  
integrated on  
the flange*

*Power distribution on the  
auxiliary connectors on  
side bus*

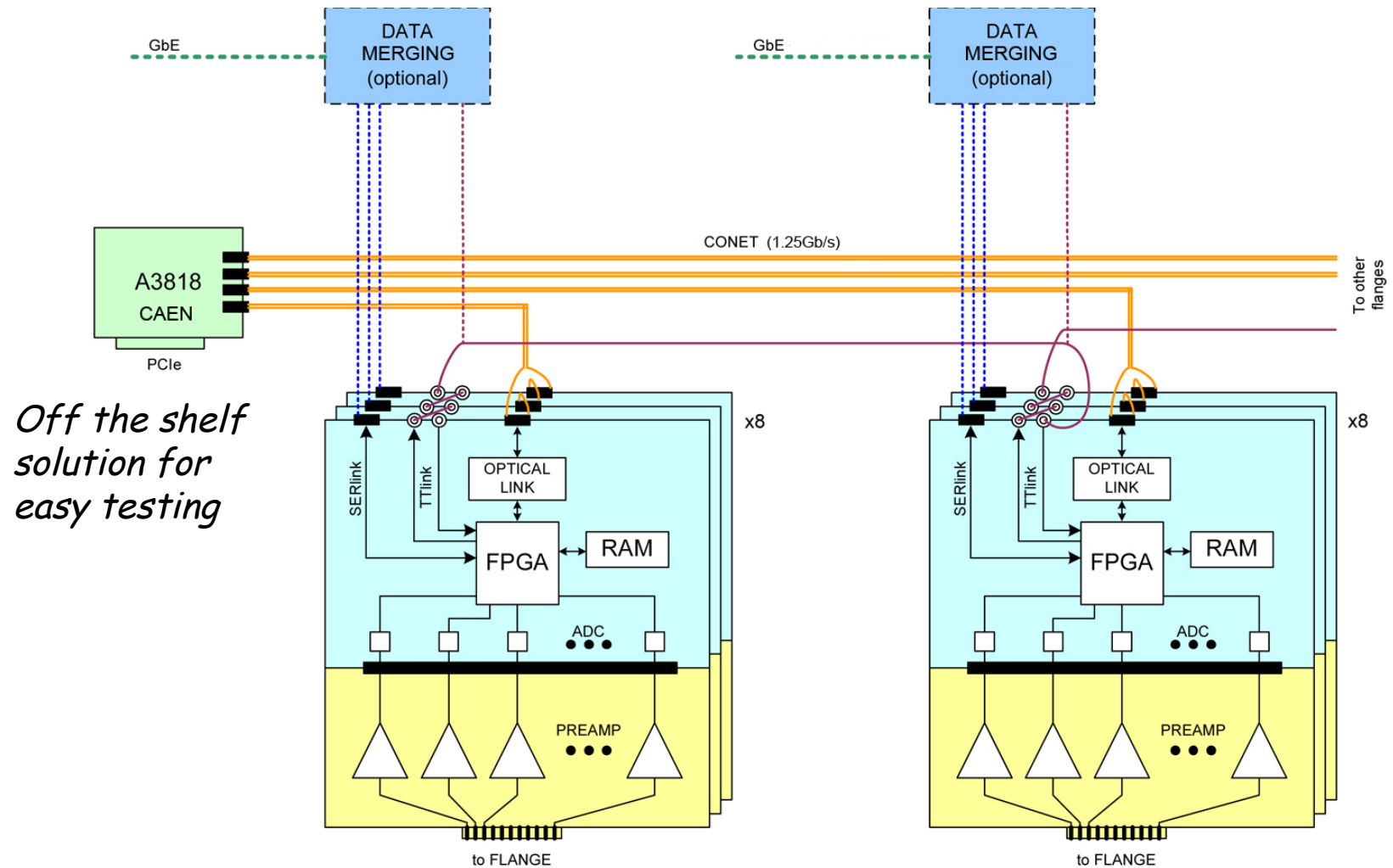
*Optical connectors  
Lemo connectors  
Ethernet connector*



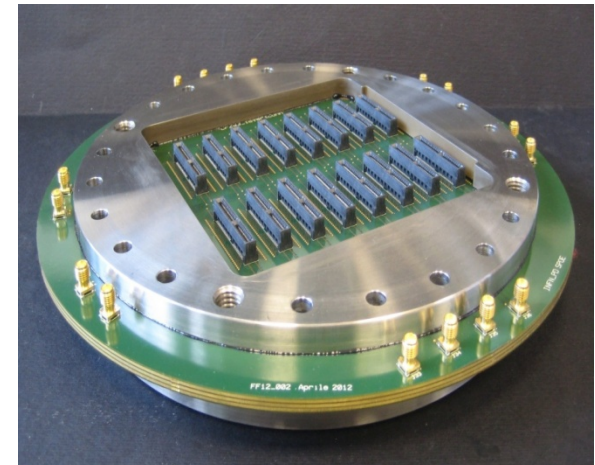
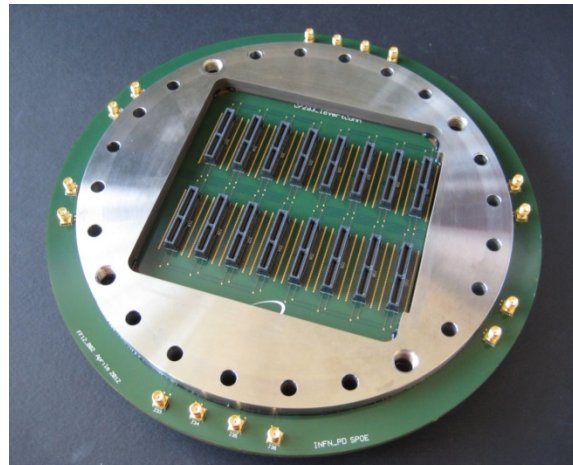
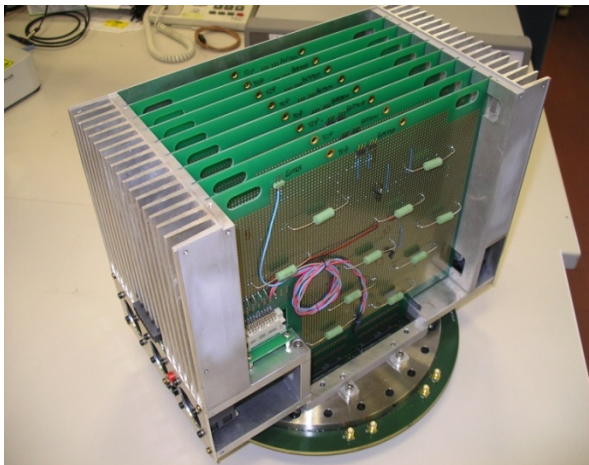
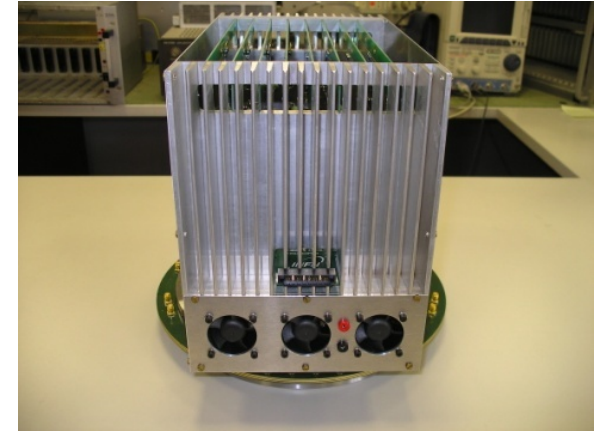
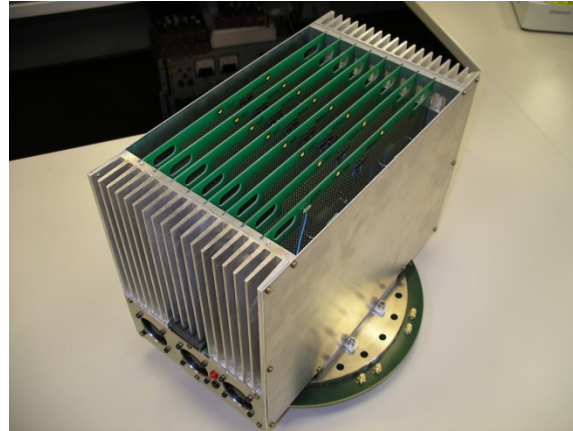
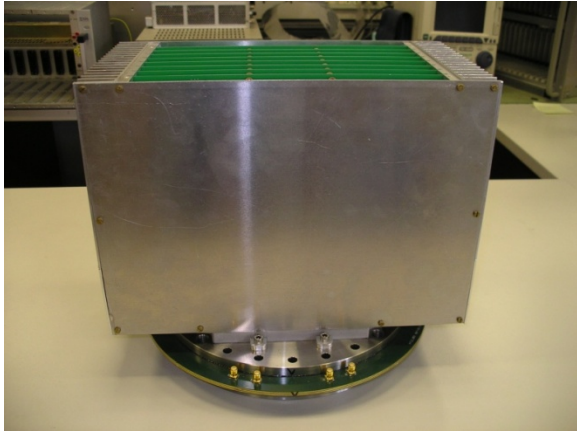
***This layout is also suitable for housing front-end amplifiers in LAr in order to improve S/N achieved in T600.***



# Architecture



# Prototype of flange under test



## R&D-7: New light collection system

- As alternative solution to the traditional PMs for the detection of the scintillation light, solid-state photo-detectors, such as Silicon Photomultipliers (SiPM) can be envisaged for the light detection inside a magnetic field.
- New light collection systems (wave-shifting waveguides/reflectors) can be implemented to increase the light collection efficiency.
- Effects of dopants (e.g. Xenon) will be studied to verify the possibility to collect a fraction of the scintillation light also using TMG to compensate for recombination effects.

# Conclusions

- ICARUS has now successfully completed the CNGS-2 experiment.
- As recommended by the CERN/DG and the CERN Research Board ICARUS-NESSIE is now the approved experiment WA104 (T600 overhauling, T150 construction and R&D programme only, at present).
- T600 will be transported at CERN where it will be overhauled. A **new T150 detector will be constructed using the same technology of the T600 for the TPCs** and new solutions for LAr purification, electronics, light collection and **complemented with a magnetic field**.
- CERN will be a crucial asset for the future development of neutrino physics in Europe, providing support with expertise and infrastructures
- ICARUS is the only operational, physical scale LAr detector and it shall be so for several years to come. We intend to:
  - contribute to the clarification of the "sterile neutrino" story;
  - collaborate with LBNE during the preparation phase with a vigorous R&D programme and with a large amount of neutrino/anti-neutrino events at the appropriate energy;
  - use our detector as a "near detector" for LBNE.





***Thank you !***