CERN-WA104:
R&D on new large LAr detector

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The future ICARUS physics program

- In the next 2 years ICARUS will be considerably improved at CERN with an extensive R&D program, in a close collaboration with LBNE experiment. In analogy with traditional bubble chambers a SC magnetic field of ~1 T will be applied to the LAr-TPC's.
- During 2016/17 it is proposed to move the T600 to FNAL short base line neutrino beams for sterile neutrino search. The presence of ICARUS at FNAL is an important addition to MicroBooNE since, in the absence of "anomalies", the ν spectra in several detectors at different distances should be a precise copy of each other.
- A definitive clarification of the LSND anti-neutrino anomaly requires also the exploration of the anti-ν signal, with the adequate mass of the T600 and *the necessary inclusion of a magnetic field.*
- The T600 may also record on the same time a large number of ve events from the off-axis NUMI k-e3 beam to prepare for the LBNE long baseline program.
- Intended primarily in the framework of the preparatory work for the LBNE collaboration, the ICARUS team is interested in extending the participation to other short baseline neutrino activities, collaborating with the already existing FNAL groups.

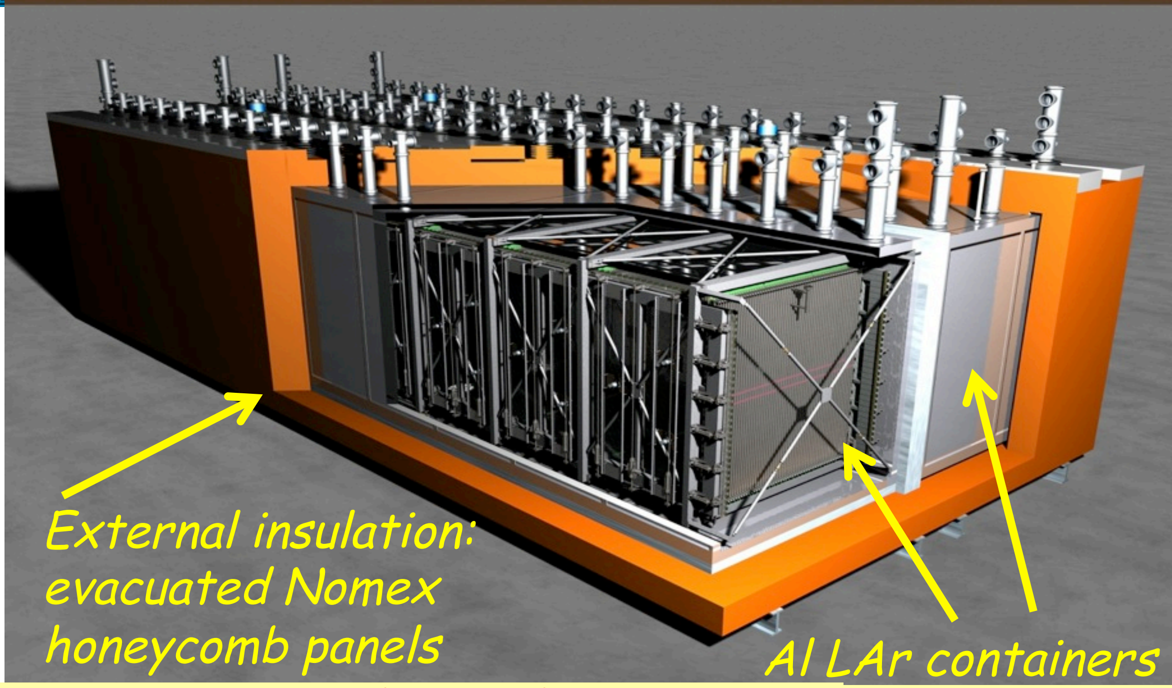
Improvement and Development LAr Program

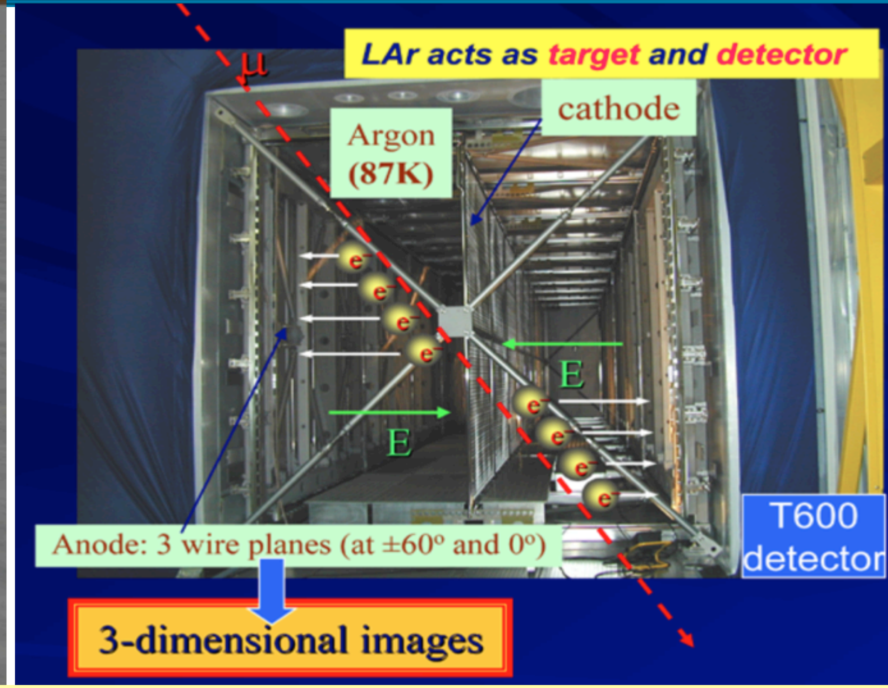
- New thermal insulation
- New cold bodies design
- Enlargement of the maximum drift
- Magnetizing LAr
- Recombination effects
- Overhauling of T600 electronics
- New light collection system

Work Schedule and Project Milestones

- First T600 TPC transport to CERN: September 2014
- Second T600 TPC transport to CERN: October 2014
- First T600 aluminum vessel transport to CERN: December 2015
- Second T600 vessel transport to CERN: April 2016
- First T600 TPC ready for insertion in the new vessel: Dec. 2015
- Second T600 TPC ready for insertion in vessel: April 2016

ICARUS detector, single-phase, T600 LAr-TPC

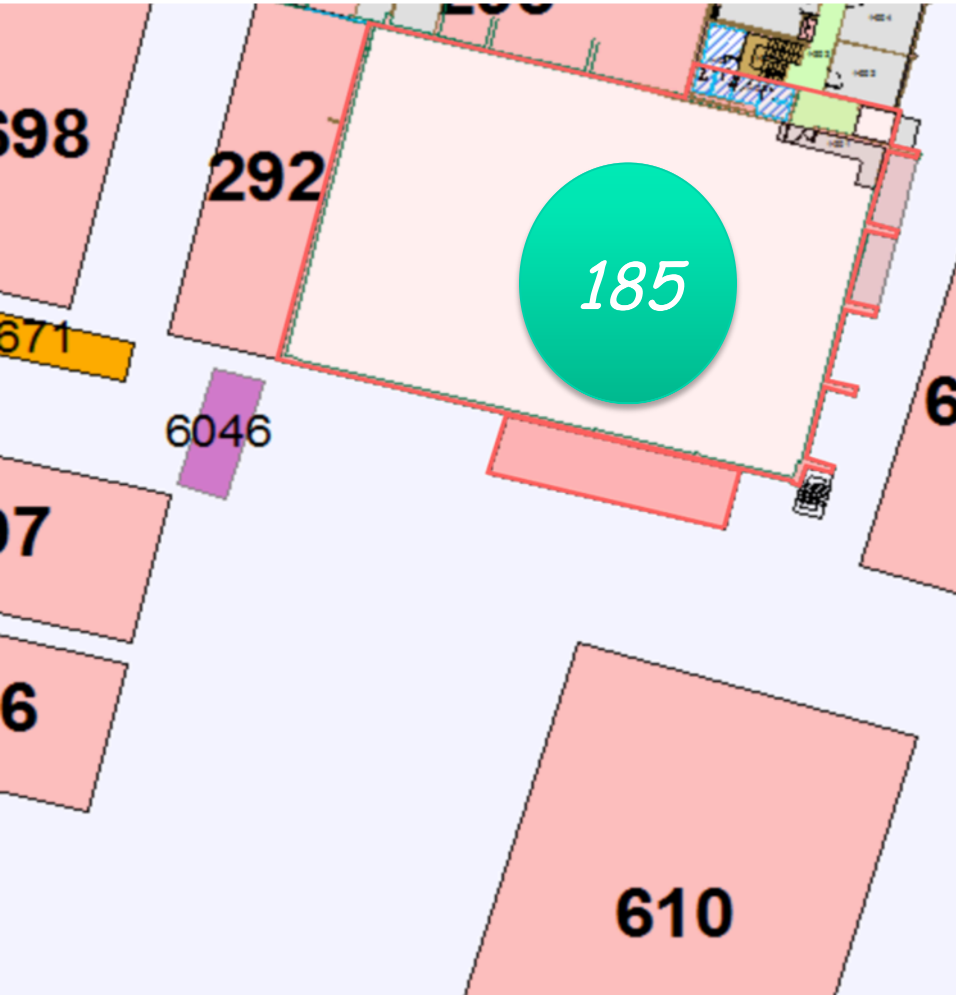


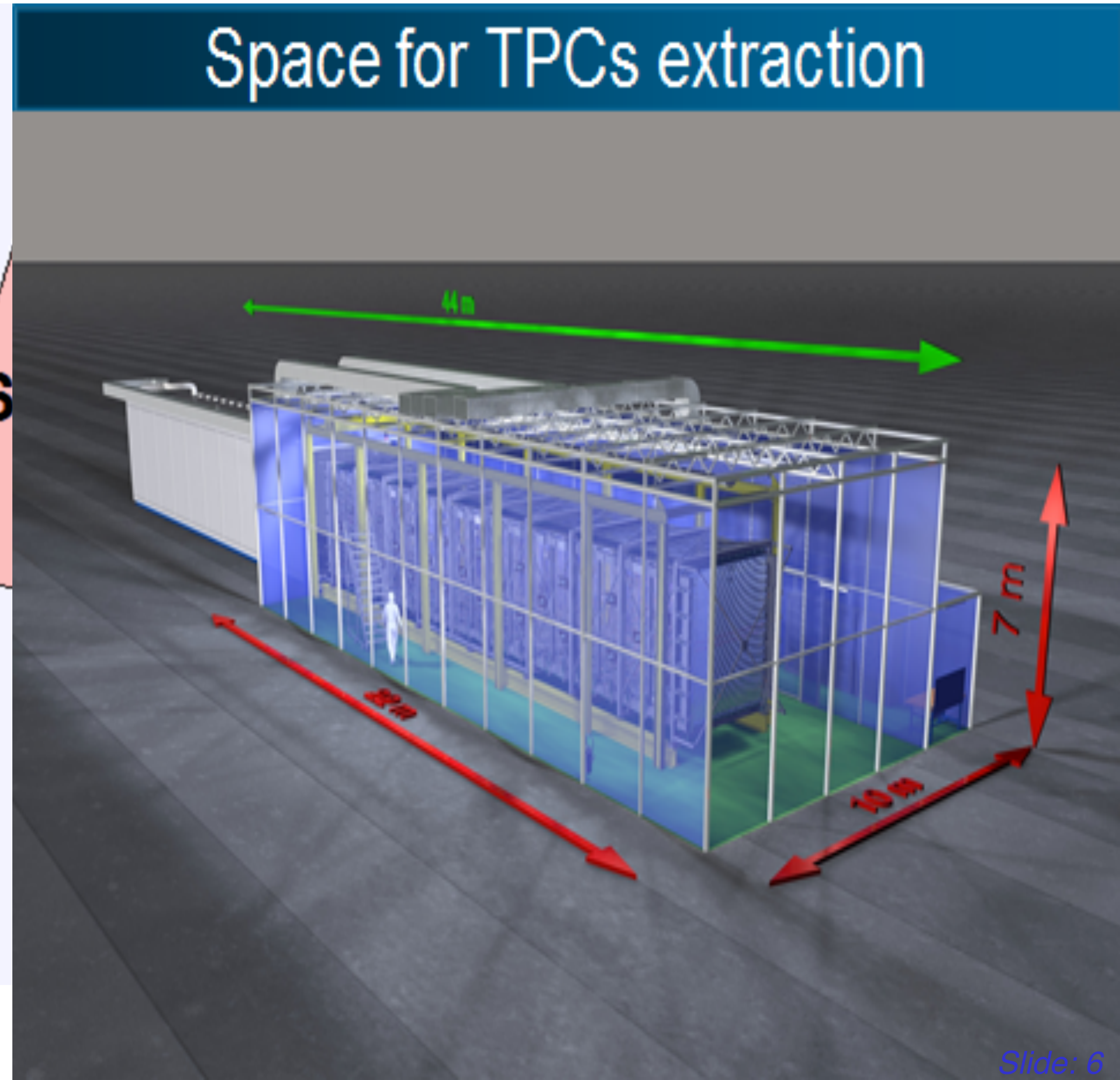


- *Two identical modules*
  - *3.6x3.9x19.6 ≈ 275 m³ each*
  - *Liquid Ar active mass: ≈476 t*
  - *Drift length = 1.5 m (1 ms)*
  - *HV = -75 kV; E = 0.5 kV/cm*
  - *v-drift = 1.55 mm/μs*
  - *Sampling time 0.4μs (sub-mm resolution in drift direction)*
- *4 wire chambers:*
  - *2 chambers per module*
  - *3 "non-distructive" readout wire planes per chamber wires at 0,±60° (up to 9 m long)*
  - *Charge measurement on collection plane*
  - *≈ 54000 wires, 3 mm pitch and plane spacing*
- *20+54 8" PMTs for scintillation light detection*
  - *VUV sensitive (128nm) with TPB wave shifter*

Location of T600 at CERN

A bldg. (185) will be adapted and dedicated to assemble the TPCs into the cold vessels.

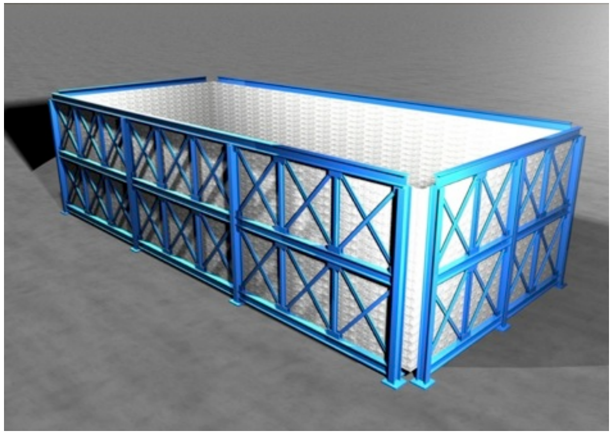




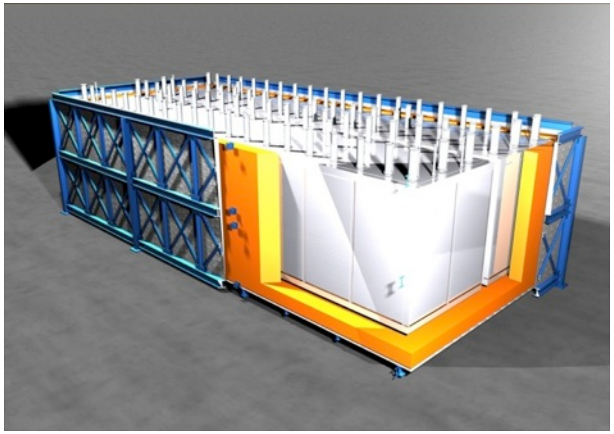
T600 new Thermal insulation

- Purely passive insulation chosen for T600 installation, coupled to ICARUS standard cooling shield with boiling N_2
- GTT 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 ≈ 6.6 kW ;
  T150 ≈ 3.5 kW

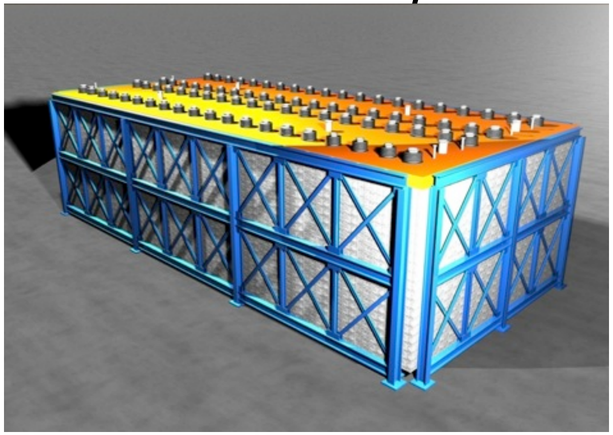
Warm cage + ext. skin



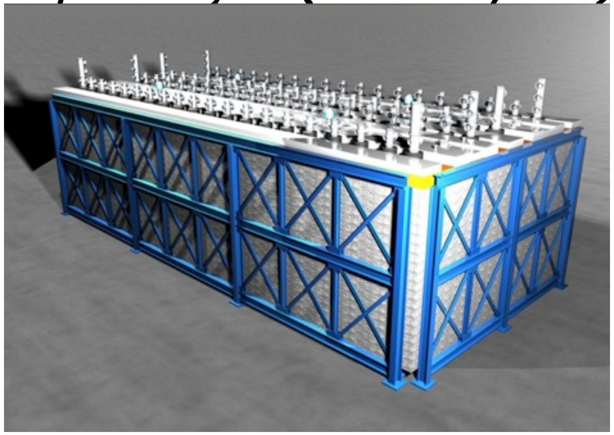
Insulation +T600 modules



Insulation top



Top flanges (final layout)



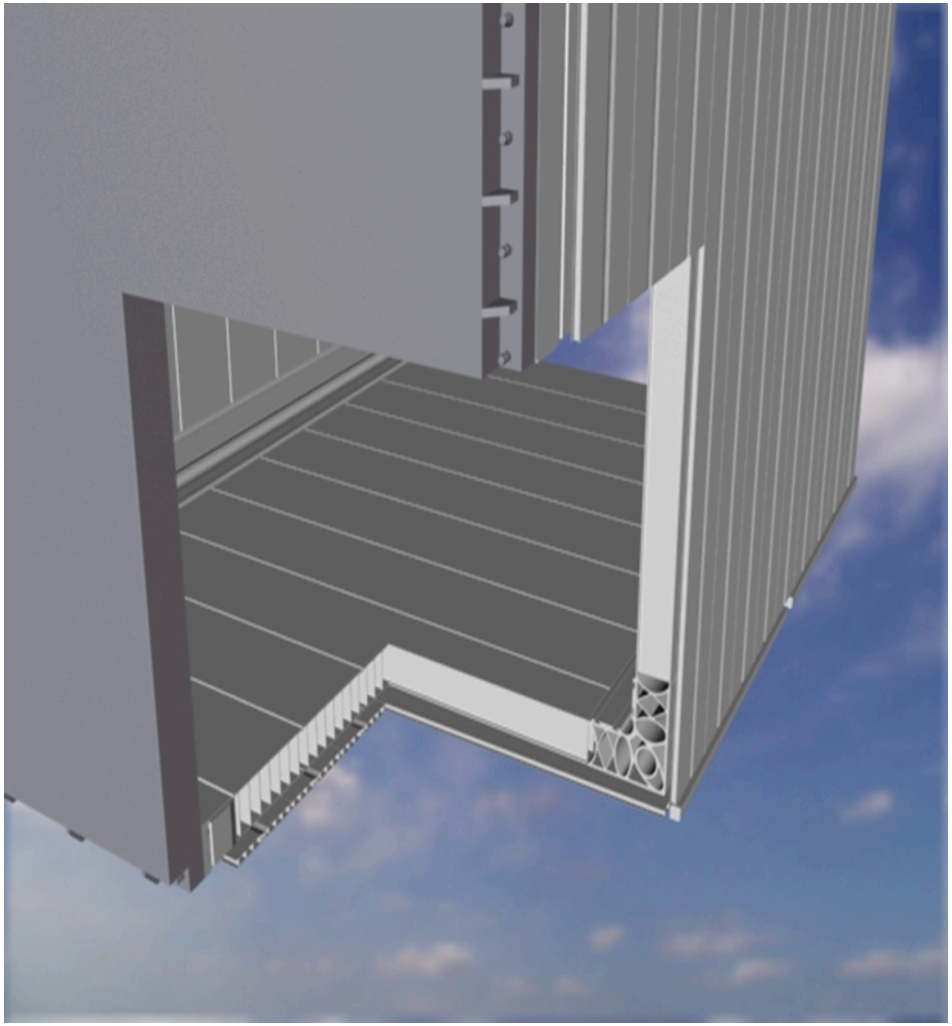
The new Cold Vessels

Aluminum vessels of welded extruded profiles, designed in collaboration with Industries and Milano Politecnico to be super clean, vacuum-tight and to stand 1.5 bar max operating internal overpressure.

Work has addressed:

- Detailed modelling of the aluminium profiles.
- Computation of behaviour under the several loading conditions.
- Optimization of the aluminium profiles.
- Assembly and welding procedures.
- Time scale and construction cost.

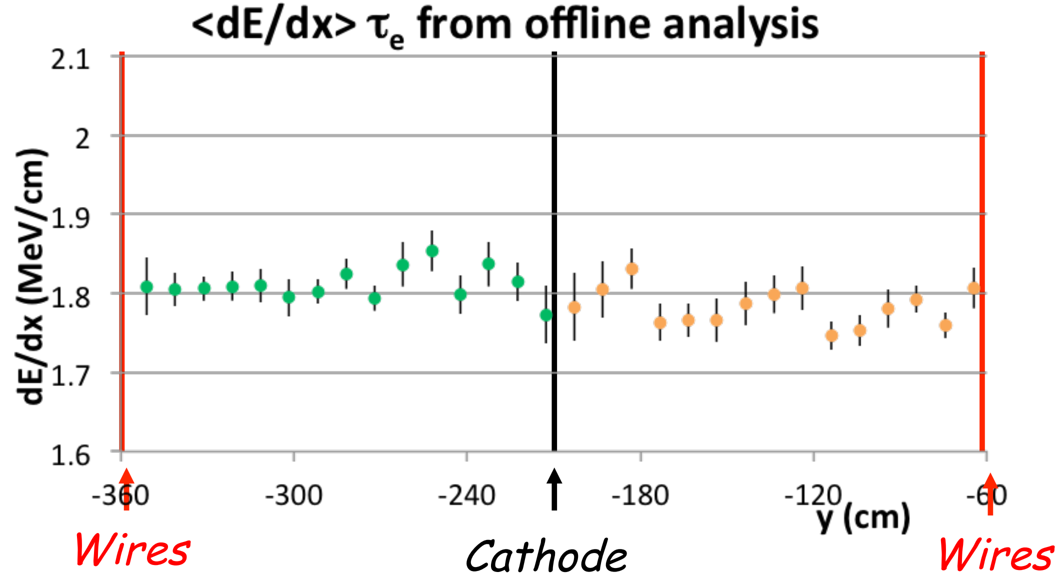
This solution could represent a valid alternative to membrane (as originally foreseen for MODULAr) for LAr containment.



Cryogenics and LAr purification

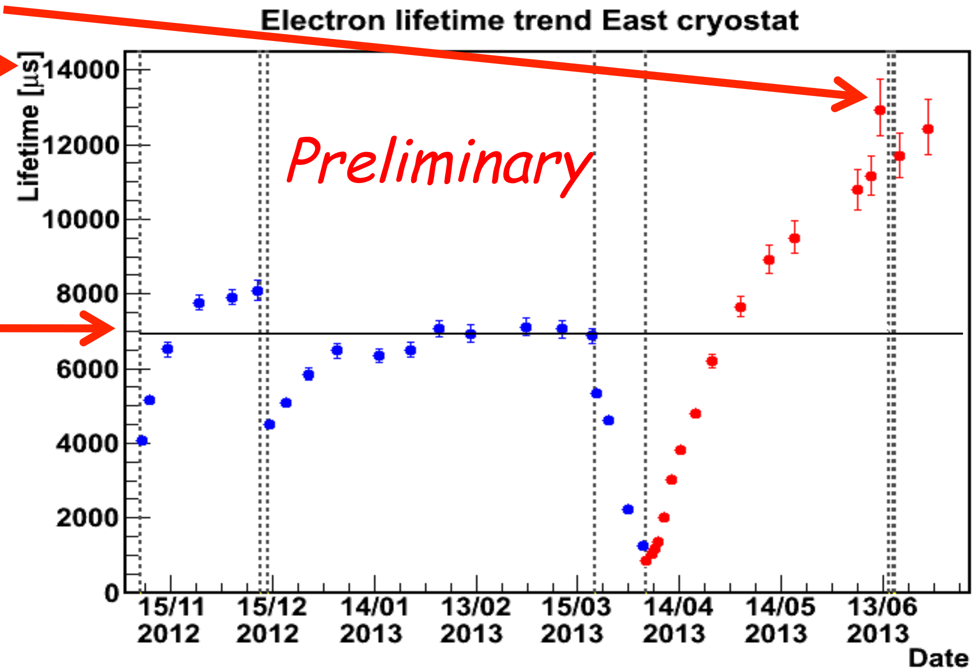
- The cryogenic system of T600 requires > 10 liquefiers with a total electric consumption of ~400 kW and a "brute force" approach.
- The present system is therefore very delicate and requires a very sophisticated technology, namely.
- The new passive insulation scheme addresses this issue
- Purification (100 Nm^3/h) of *gas* phase (~40 Nm^3) to block impurity diffusion from warm parts and micro-leaks
- Purification (4 m^3/h) of the bulk liquid volume (~550 m^3) to efficiently reduce the initial impurities concentration
- *As soon as the purification stops purity decreases within days:* improvements concern pump reliability and recirculation speed.

- The electron lifetime τ_{ele} is a crucial parameter since LAr TPC performance strongly depends on the LAr purity.
- A detailed offline analysis with a robust algorithm and large μ statistics has been performed to measure very small signal attenuation along the drift:
  - Accurate identification/removal of δ and e.m. activity associated to μ;
  - A 10% truncated mean is applied to signals of single tracks to remove under/over fluctuations;
  - $1/\tau_{ele}$ is used as estimation of the signal attenuation.
- Cross check with muons from CNGS ν interacting in the upstream rock: <dE/dx> is correctly reconstructed constant along the drift coordinate



ICARUS T600 LAr purity offline analysis: new results

- ICARUS has operated with τ_{ele} > 7 ms (~40 p.p. trillion $[O_2]_{eq}$) corresponding to a 12% maximum charge attenuation at longest drift distance!
- New pump has been installed on East cryostat since April 4th, 2013: *τ_{ele} exceeding 12 ms and still rising!*
- A remarkable purity has been achieved on ~1 kt scale detector, to be compared with ≈ 1ms longest electron drift time, approaching the LAr lifetime of τ_{ele} ≈ 21 ms previously observed with a ~100 litres prototype

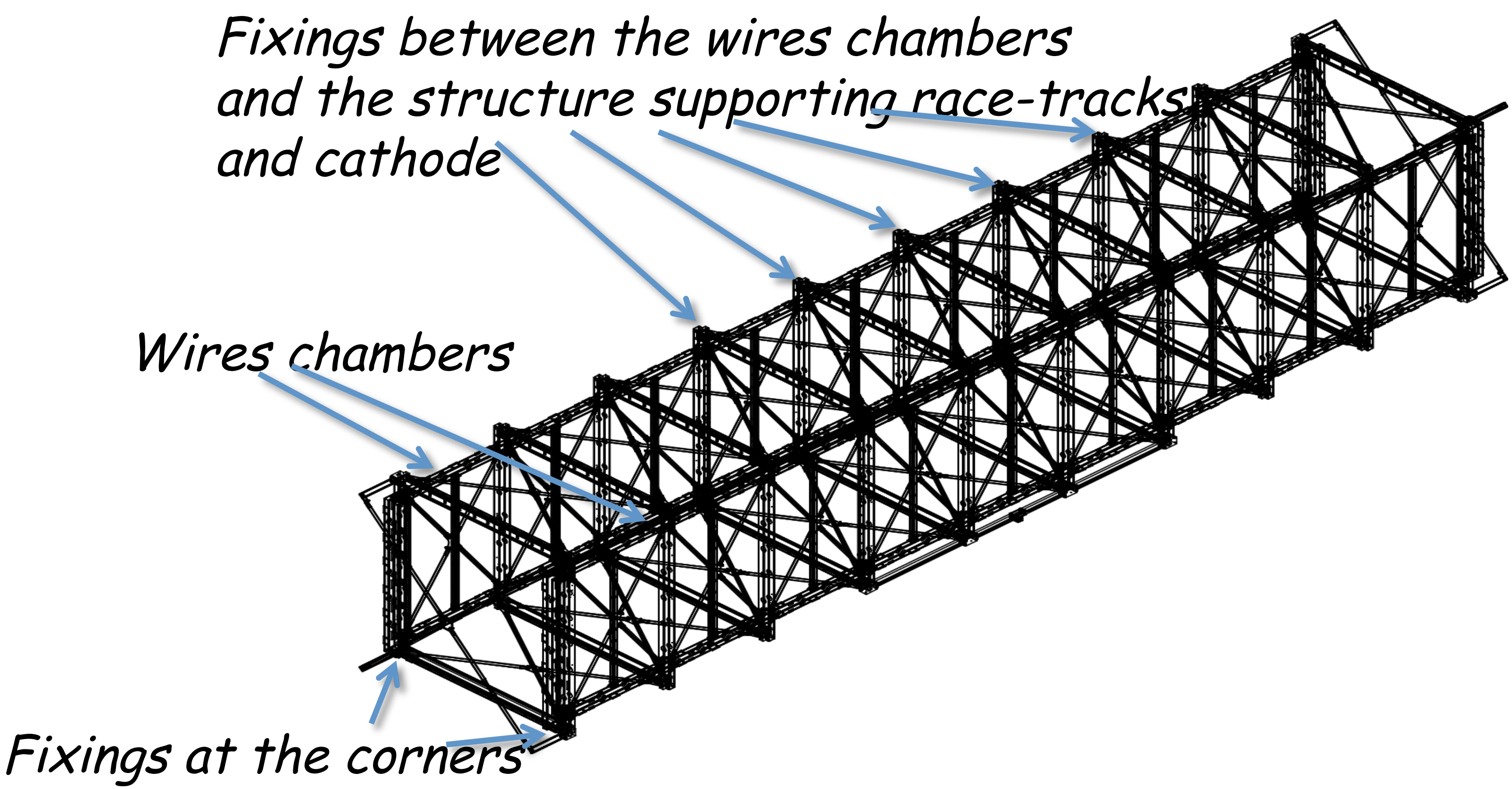


ICARUS has demonstrated the effectiveness of the single phase LAr-TPC technique, paving the way to huge detectors/~5 m drift as required for LBNE project

Increase of the T600 maximum drift

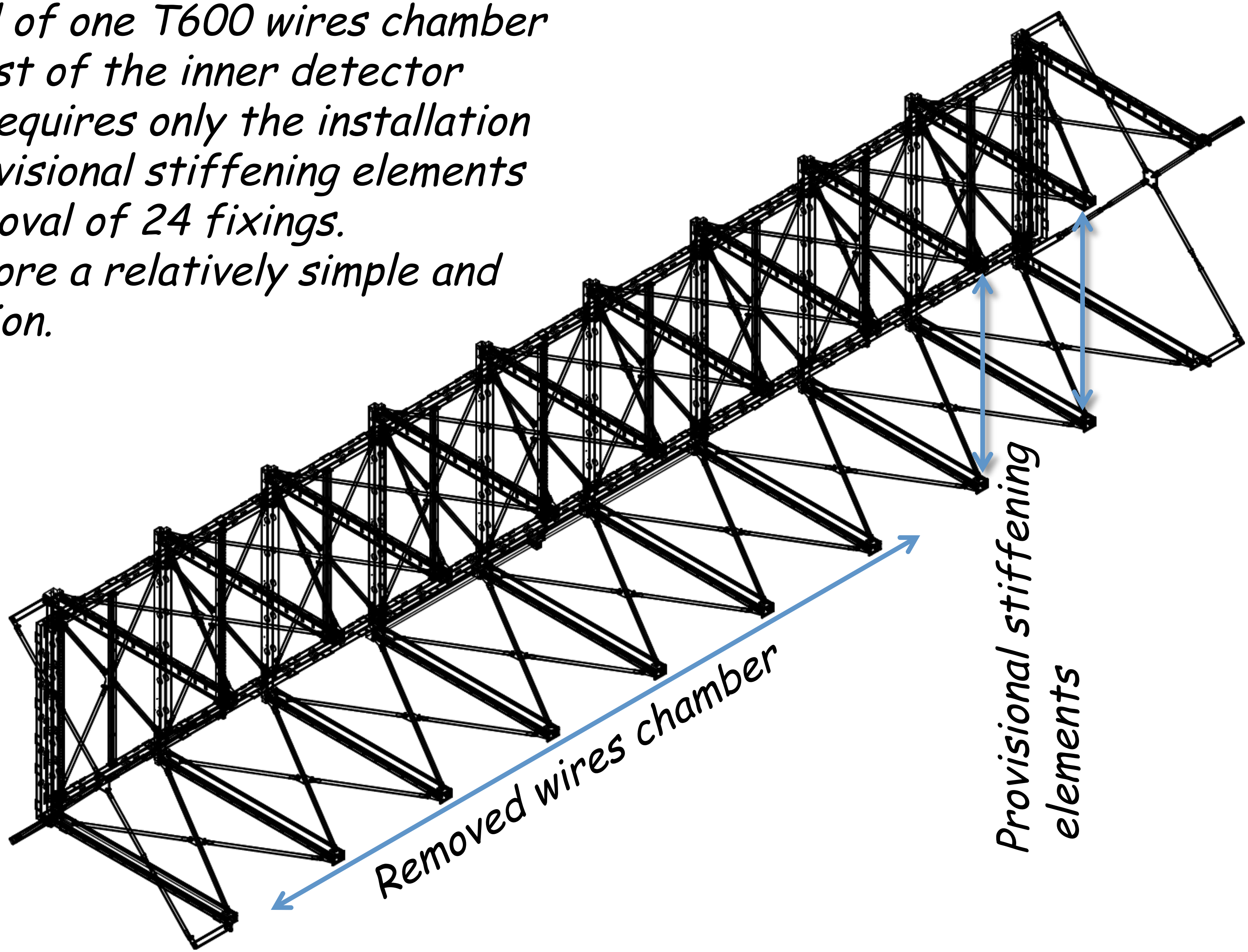
- In view of an increase of sensitive mass for the experiment at FNAL, and considering the extremely high LAr purity achieved with the T600 at LNGS, we are evaluating the possibility to increase the actual maximum drift distance of the T600.

Present structure of one T600 module



Removal of the wires chamber

The removal of one T600 wires chamber from the rest of the inner detector structure requires only the installation of some provisional stiffening elements and the removal of 24 fixings.
It is therefore a relatively simple and safe operation.



Increasing the T600 maximum drift

- Several options can be considered to increase the T600 drift volume; as an example we consider the following (T600++):

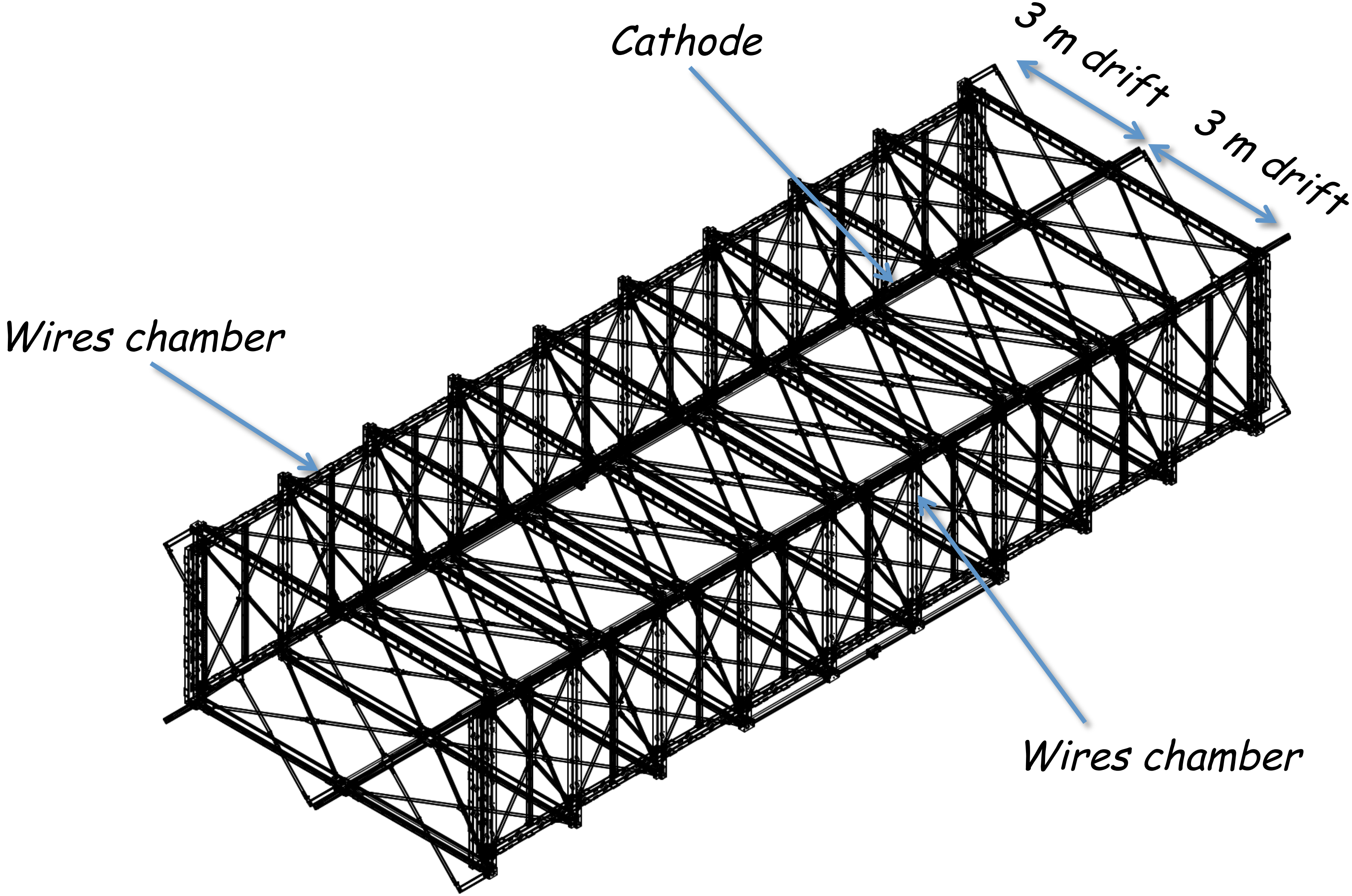
  - the two T300 chambers, with one of the wires chambers being removed, are placed face to face and connected with simple elements.

  - a cathode is placed in the middle, reproducing the present T300 layout with ≈ 3.2 m drift. Distance of the cathode from the metallic structure is identical as the one at present.

  - Features: minor new design for the connecting elements; the LAr containers have to be re-designed; no need to re-design insulation and cryogenics; assembly schemes and logistics have to be re-considered.

  - The removed chambers, equipped with an identical cathode + race-tracks system, will constitute the internal detector of a second T600 module, thus bringing the total active mass to about 1200 ton.

Option 2: (T600++)



Aluminum vessels with increased (≈ 7.5m) width

- A preliminary evaluation for an aluminum vessel with a width adequate to host a T600++ module (central cathode, two chambers with ≈ 3 m drift) has been performed by the structural engineers that made the design of the new containers for the present T600.
- The preliminary evaluation shows that the present solution with the same extruded aluminum profiles could also be applied for the larger containers. An additional set of "annular" reinforcements have to be implemented together with a longitudinal reinforcement and a set of central supports on the basement to hold the weight of the LAr. The reinforcements are of the same type as those already designed for the "standard" containers to be used in correspondence of the "feet" of the wires chambers structure.

Aluminum containers with increased (≈7.5 m) width

Extracted for the structural engineers reports

"Annular" reinforcements

Longitudinal reinforcement and addition set of supports

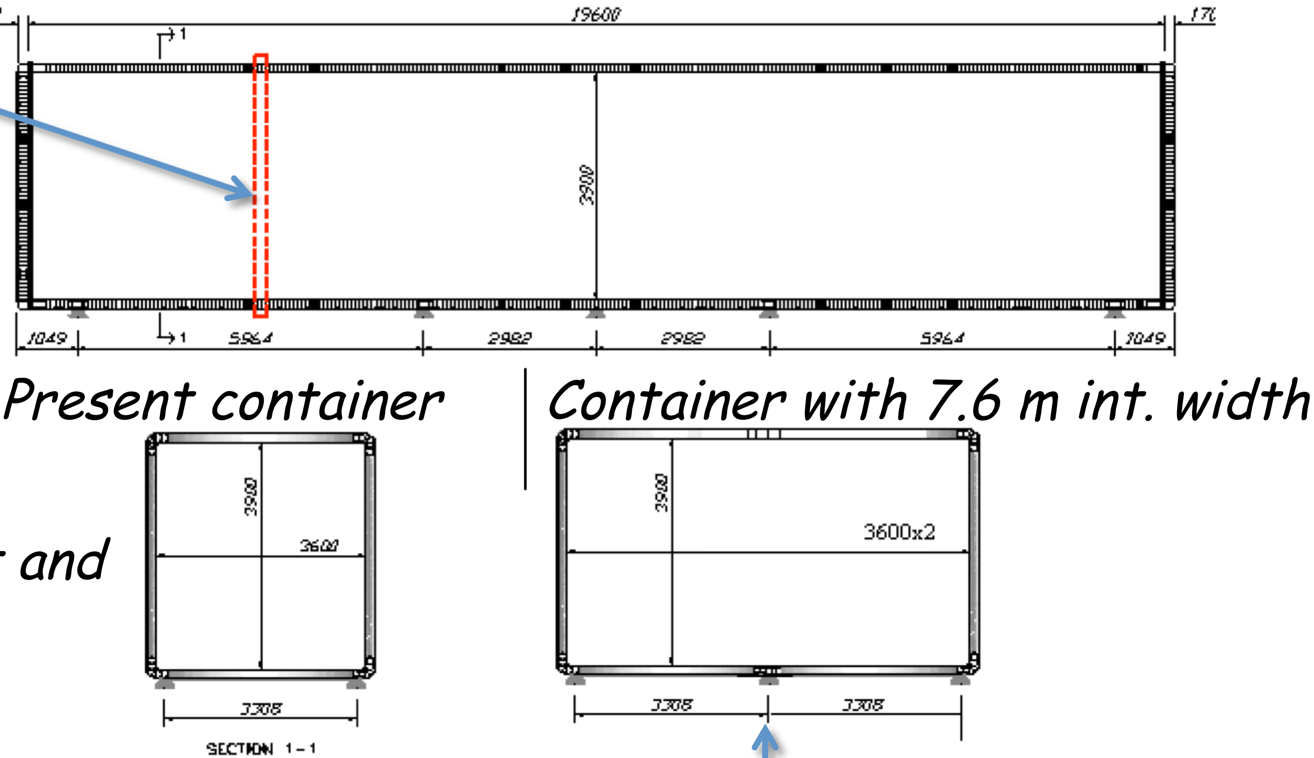


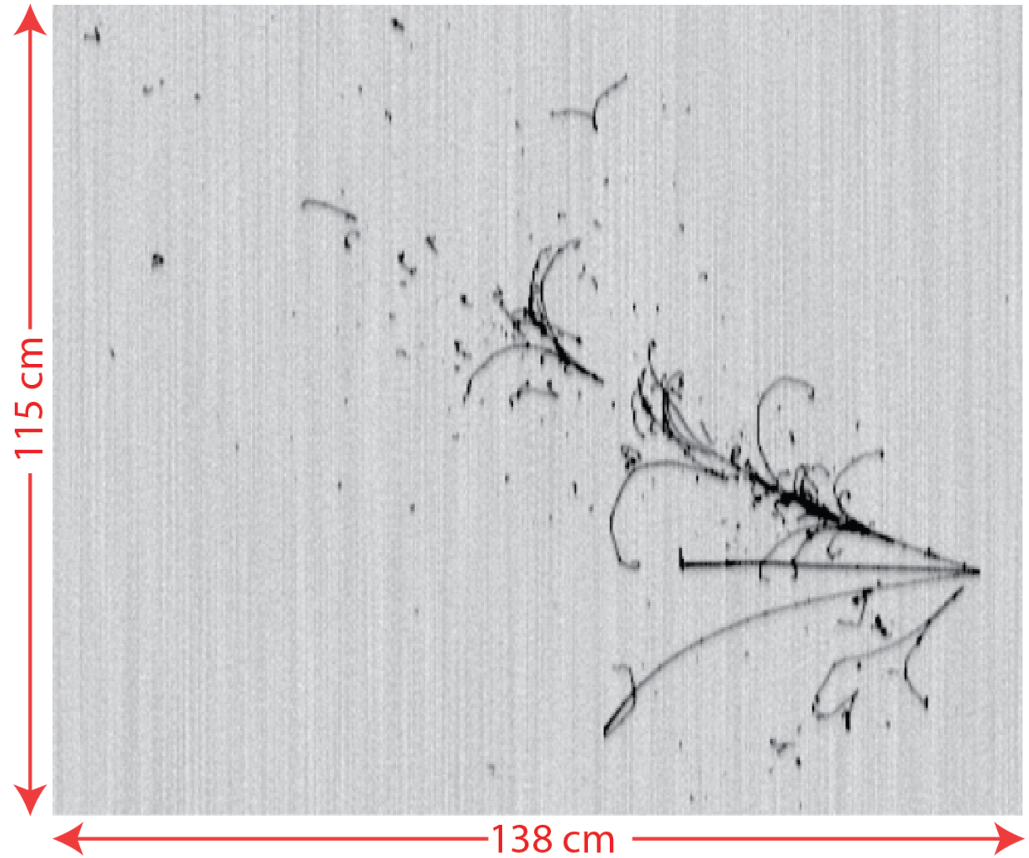
Figure 1 - vessel longitudinal section in a vertical plane (above) and transversal section, (below). Left side, the actual cross section, right side that presently discussed.

The discussion is based on the assumption of a third line of supports, linked together by a longitudinal beam, as fig. 1 shows. Similarly, the plate at the top of the vessel should be reinforced by a longitudinal center-line beam. Next section shows that without this intermediate support line, the elements thickness (presently 7 mm) will increase to a thickness at the limit of the extrusion capability. The increase of the external dimension of the wall, presently 170 mm, shall be examined. The presence of the longitudinal beams is thus taken for granted.

Magnetizing LAr

- The addition of magnetic field to the LAr-TPC detector has been already described in the first ICARUS proposals (1985).
- 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.

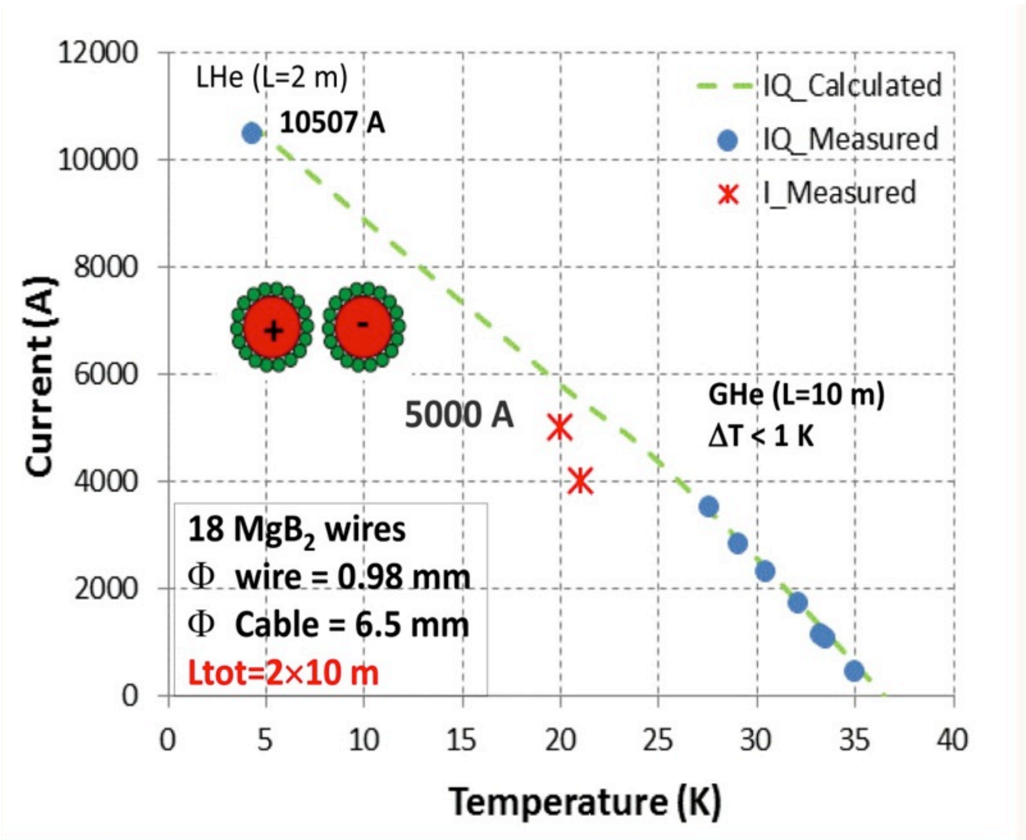
Example of a 4 GeV e-neutrino event in LAr-TPC with 1 Tesla magnetic field.



A negative electron, π^0, π^+ and proton are recognized in the final state

Possible solutions

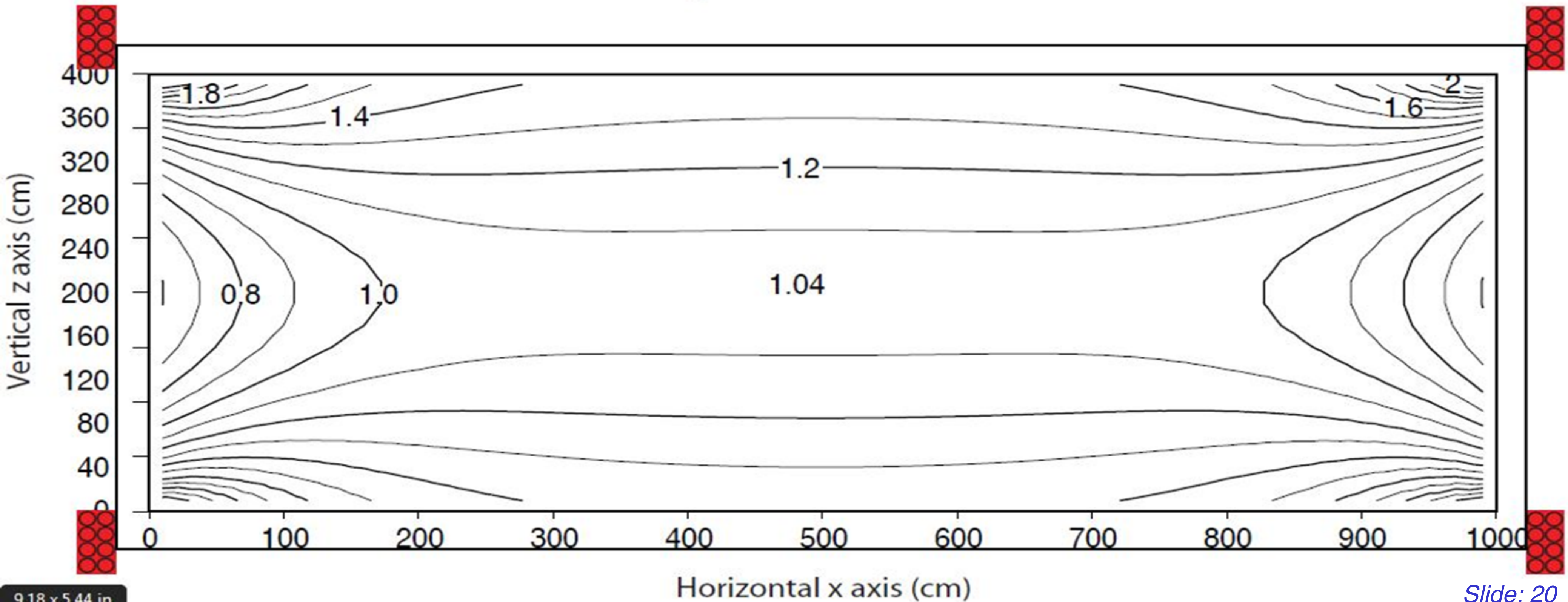
- Although "hot" superconductors may be used, a more conventional approach seems to be suitable, based on recently developed technologies.
- The standard Niobium-Titanium superconducting cable would depend on a cryogenic system that uses liquid Helium at 4.2 K - 1.9 K.
- We consider as an alternative new SC wires based on Magnesium Diboride (MgB_2) that offers the advantage to remain functional at up to 25 K.
- This superconductor, developed at CERN with IASS in collaboration with industry, can be cooled using Helium gas (as opposed to liquid Helium), simplifying the demands on the cryogenic system.
- In addition, MgB_2 can work with a temperature margin of several degrees, a great advantage from the operation point of view.



Helmholtz Configuration

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.

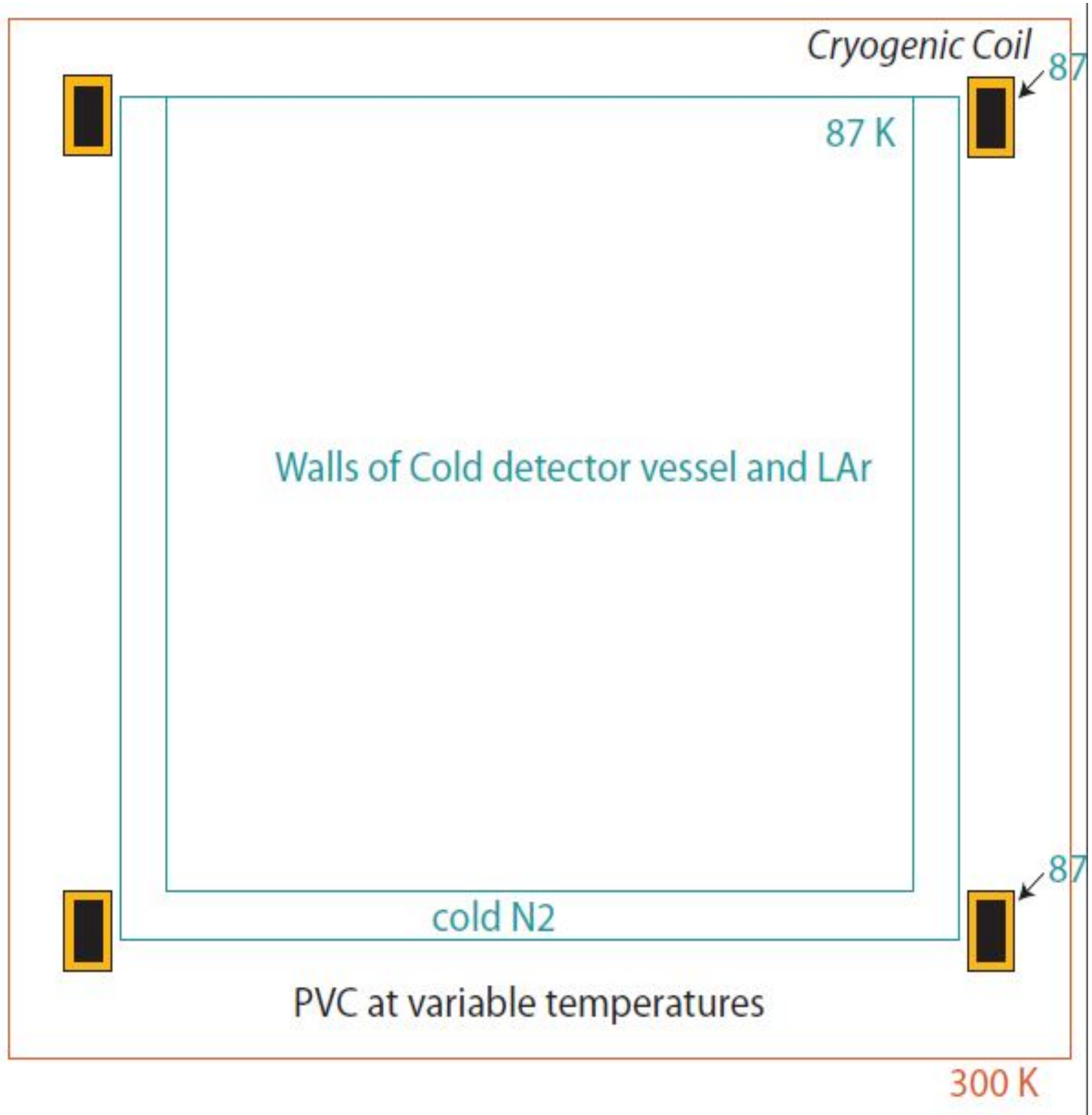
Two orizontal coils, at top and bottom of the cold vessel.
Current =20 kA – 300 turns for each coil
Field oriented along vertical axis.



9,18 x 5,44 in

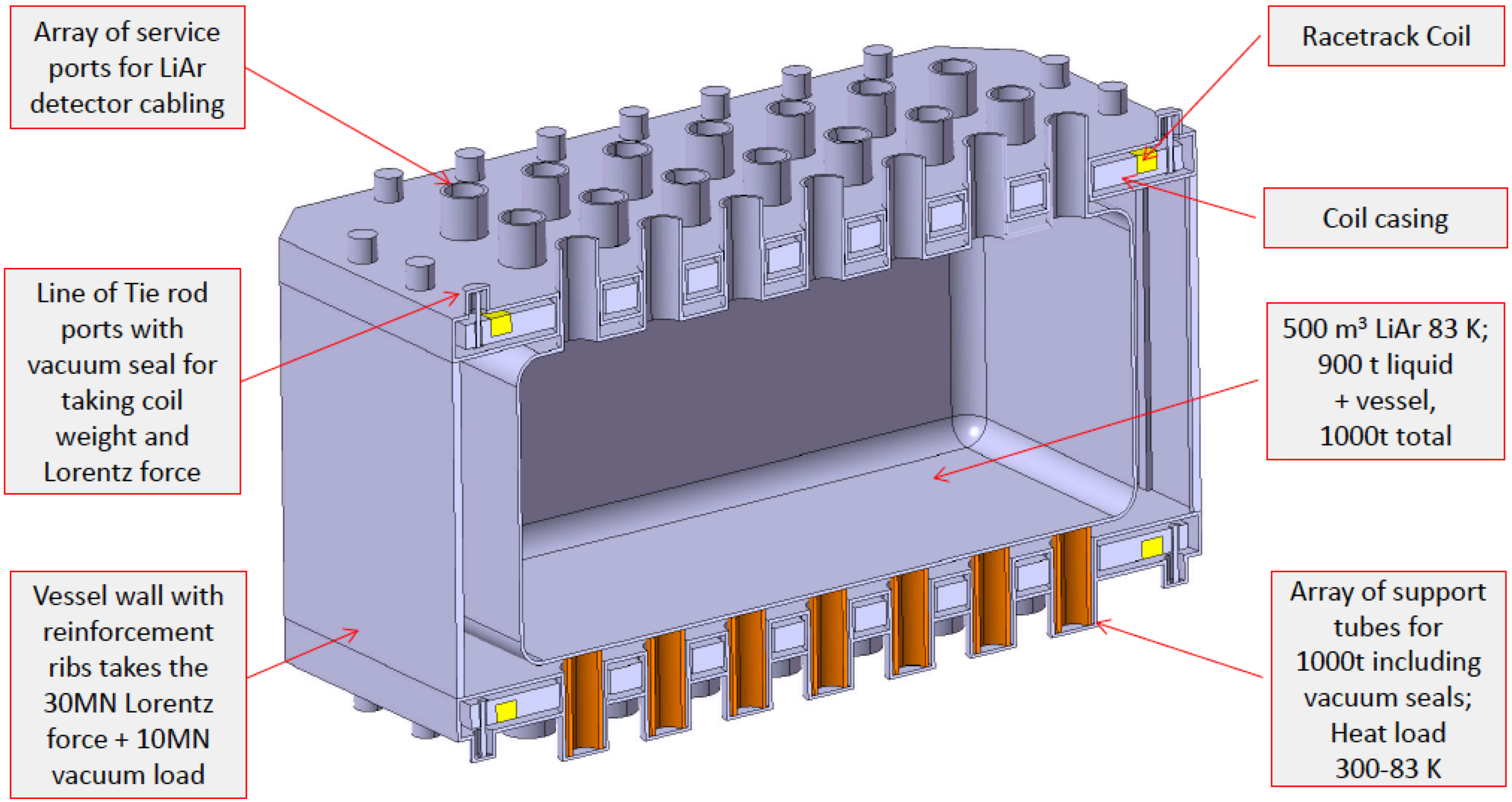
- The Superconductive cable, surrounded by vacuum and Mylar superinsulation, is inserted in the passive insulation of the Lar-TPC cryostat at a temperature close to 90 K.

- *Magnetization scheme could be extended to Multi-kton detectors (e.g. MODULAr)*



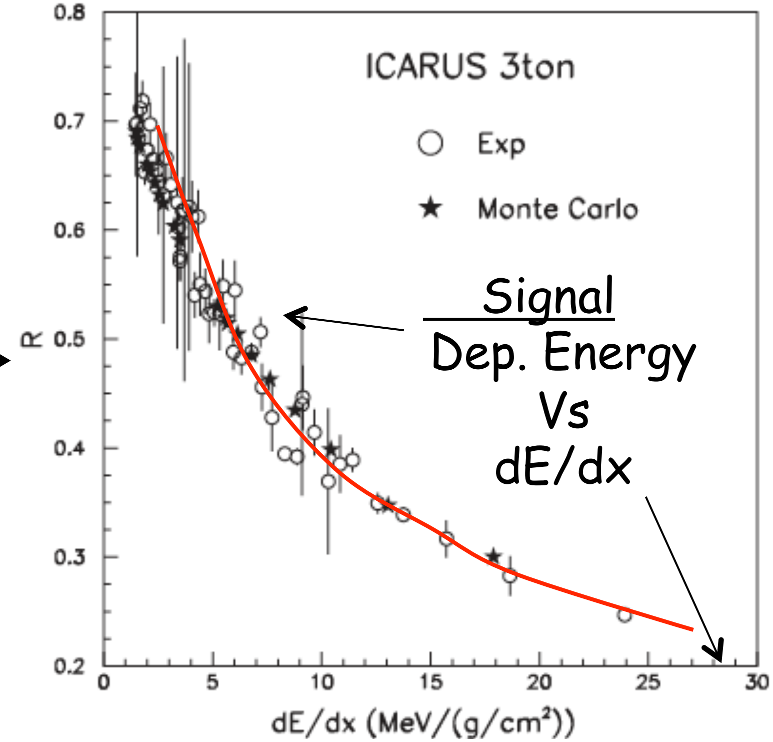
A possible implementation of the magnet coils under study

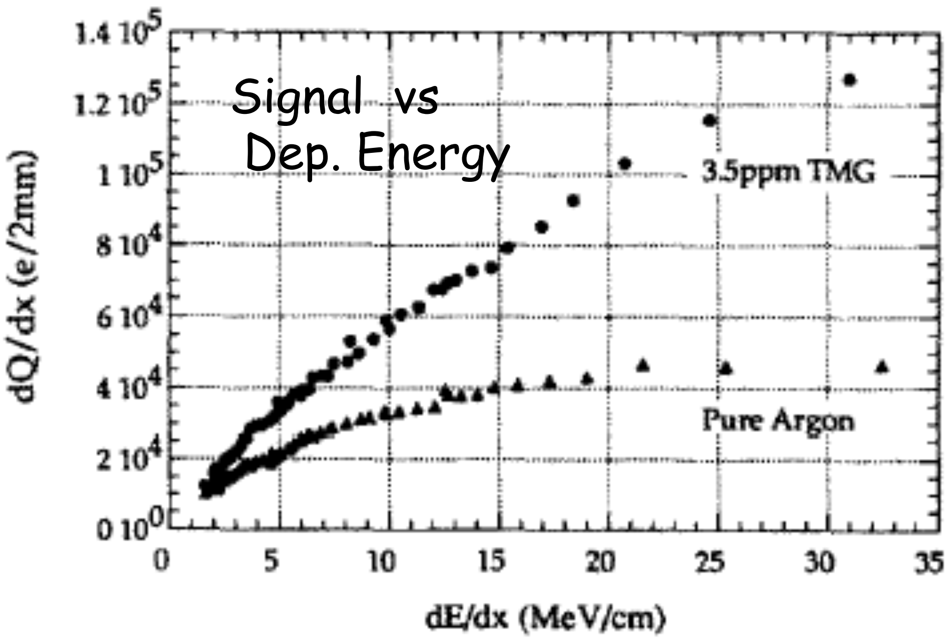
- *A concept design has been elaborated for the T600 at CERN (exploiting also the experience on the similar ATLAS toroidal magnet coils arrangement).*



Recombination effects

- Charge recombination, increasing with ionization density, induces non-linear detector response:
- No full theoretical description
- Phenomenological approaches allow to reproduce the data
- Substantial software corrections needed



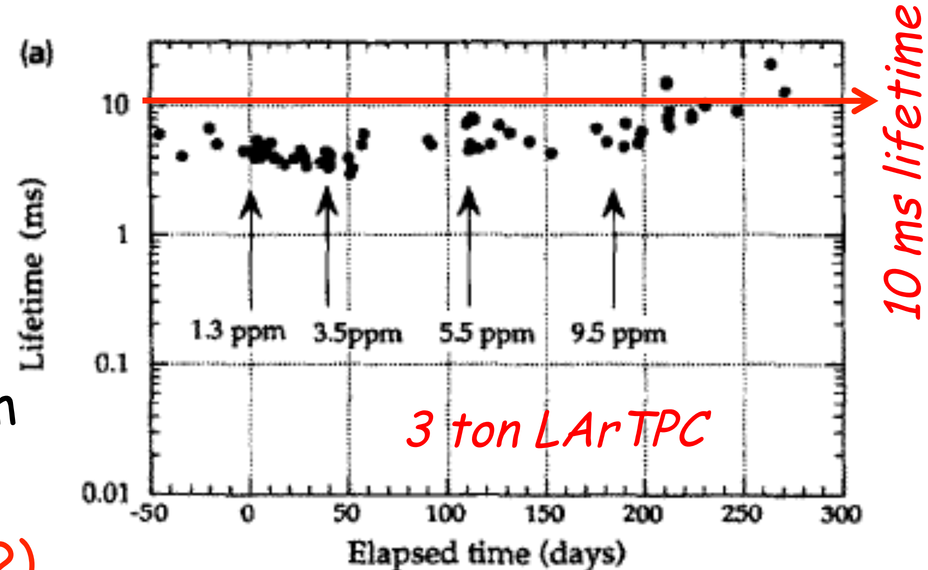


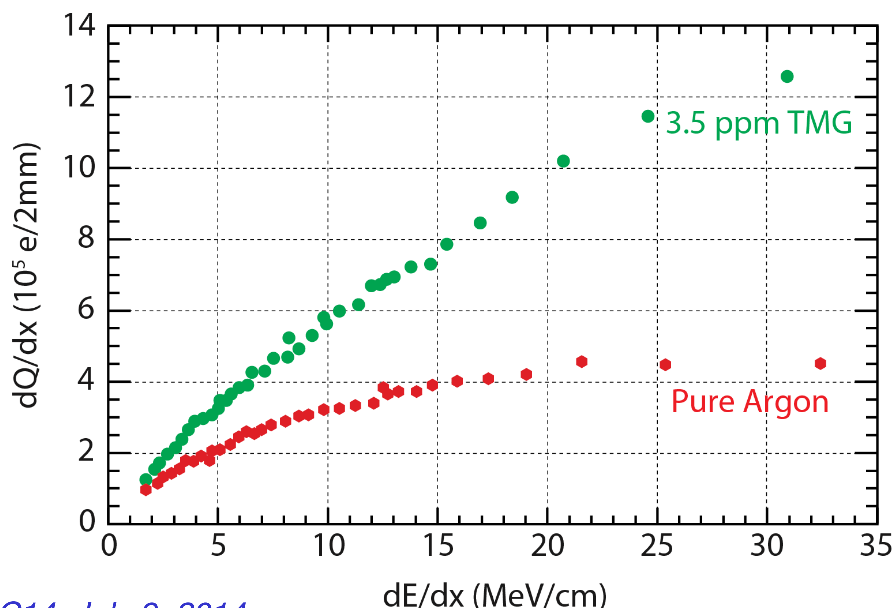
- Add dopants to convert part of the scintillation light into electron-ion pairs
- Few PPM tetra-methyl-germanium
- Observed signal increase : +25% to +220%
- Purity and resolution not affected

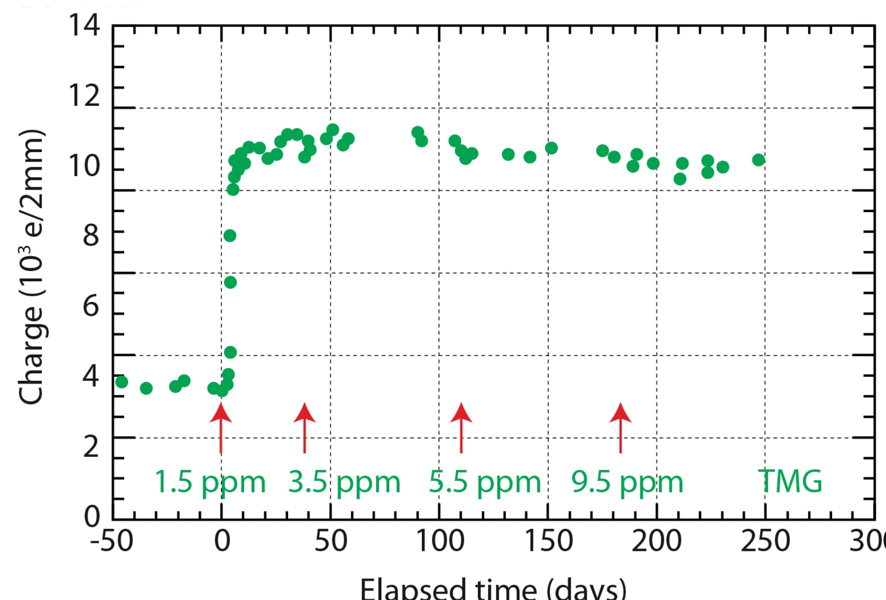
Doping with tetra-methyl-germanium (TMG)

P. Cennini et al. (ICARUS Coll.), NIM A355 (1995) 660-662

- TMG is not absorbed in the recirculation system.
- pure TMG can be easily purified to an electron lifetime better than 10 μs.
- TMG has a large photo-absorption cross section of 62 Mbarn and has high quantum efficiency (close to 100%).
- Drawback: no more VUV light (IR instead?)

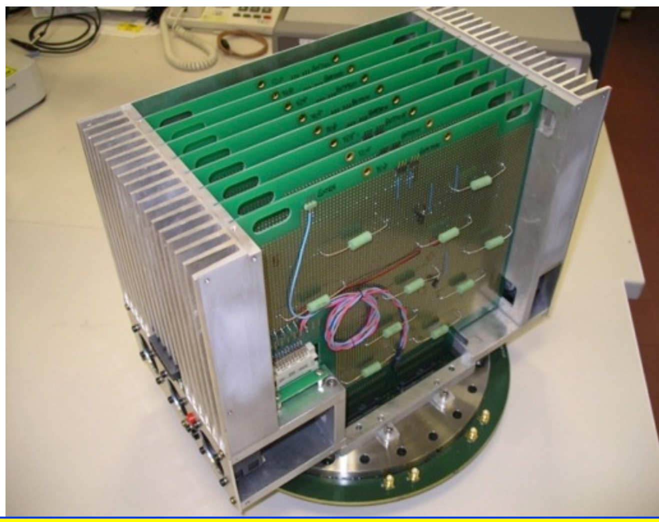


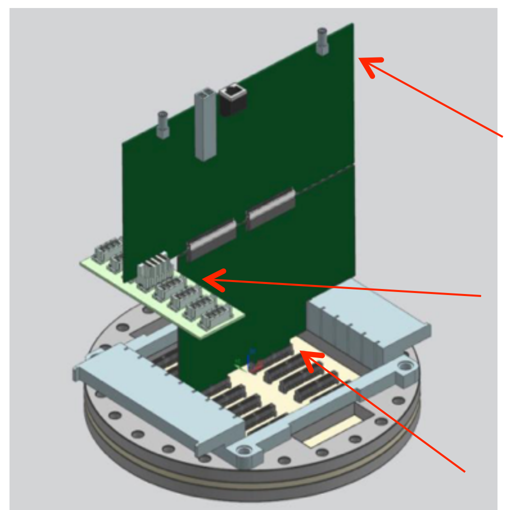




Modifications on the ICARUS Electronics

- The T600 system is being re-designed adopting a modern switched I/O and parallelization of data flow, with an upgrading program concerning:
  - 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 + optical link (for Gb/s transmission rate).





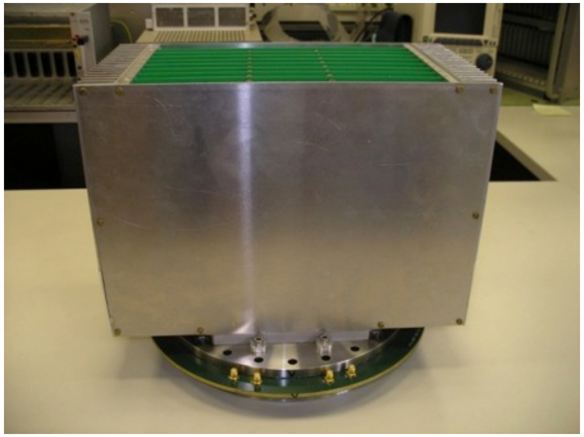
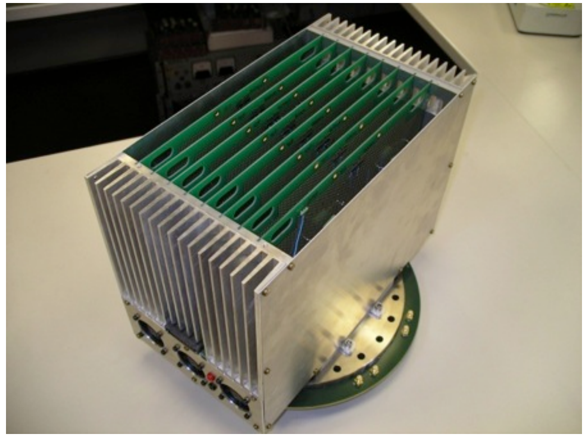
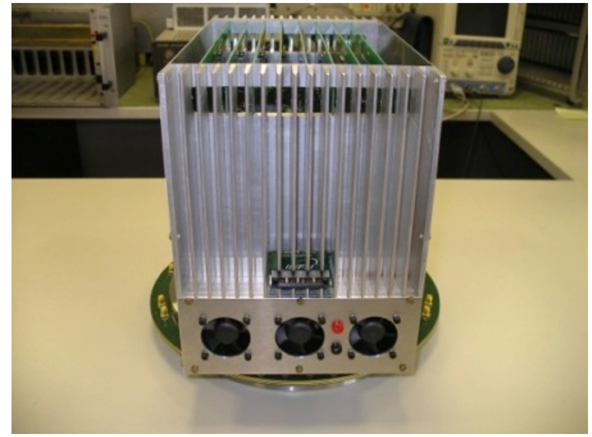
I/O connectors (Optical, Lemo, Ethernet)

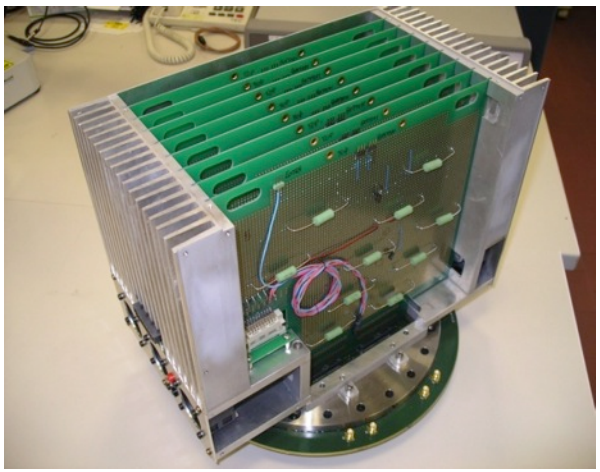
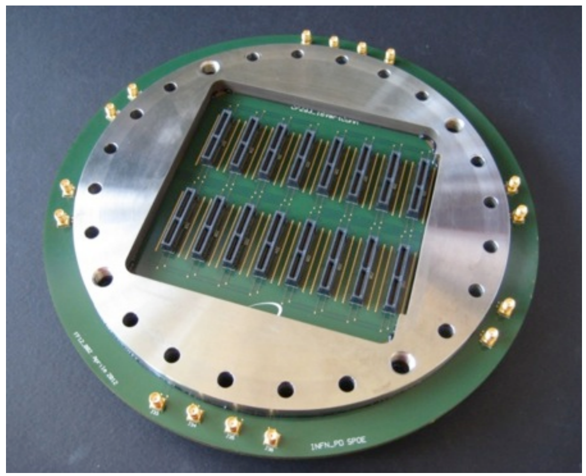
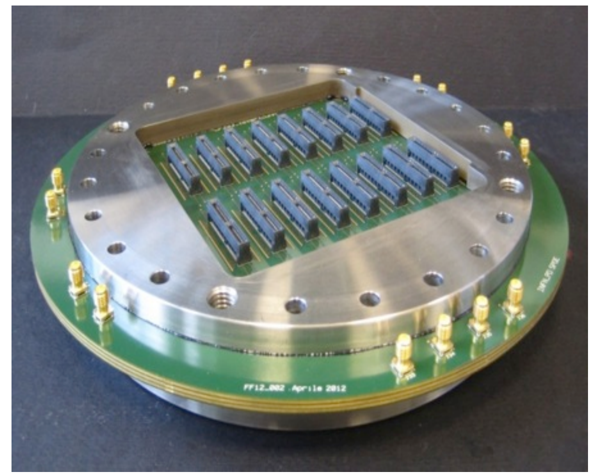
Power distribution on auxiliary connectors on side bus

Backplane integrated on flange

This layout is also suitable for front-end amplifiers in LAr in order to improve S/N: tests are in preparation with cold front-end and warm digital processing

Prototype of crate/flange under test

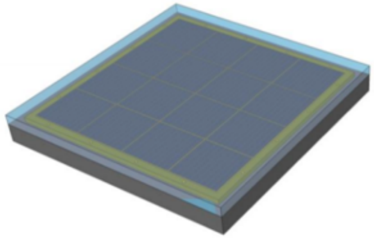




- Total of 200W distributed on eight boards (512 chs)
- The temperature inside the crate increases less than 20 degrees with respect to the ambient

R&D on scintillation light detection system

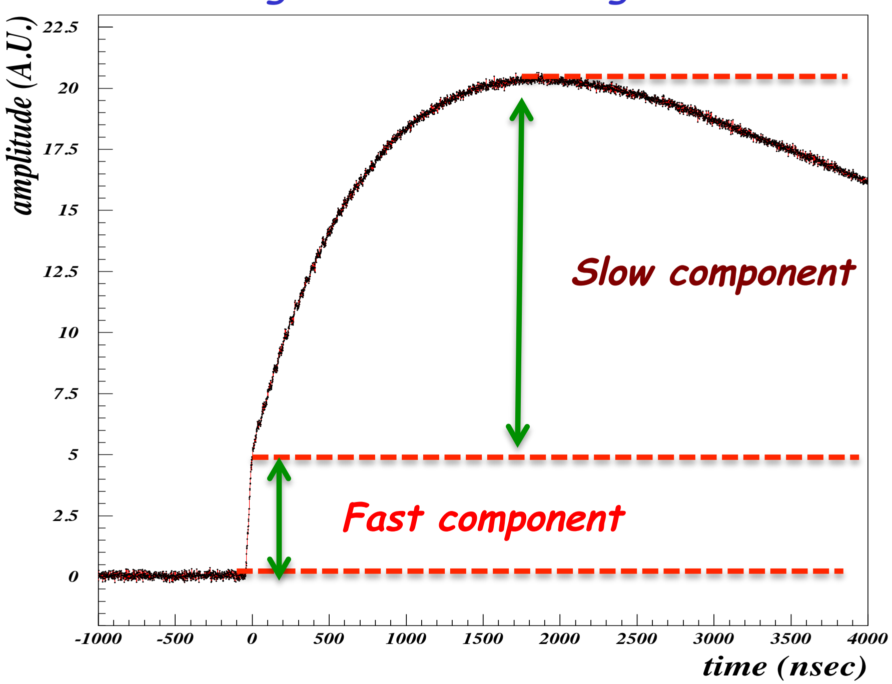
- For the next phase of the T600 operation we plan to use an improved set of PMTs with large area coverage and specific sensitivity also to Cerenkov light.

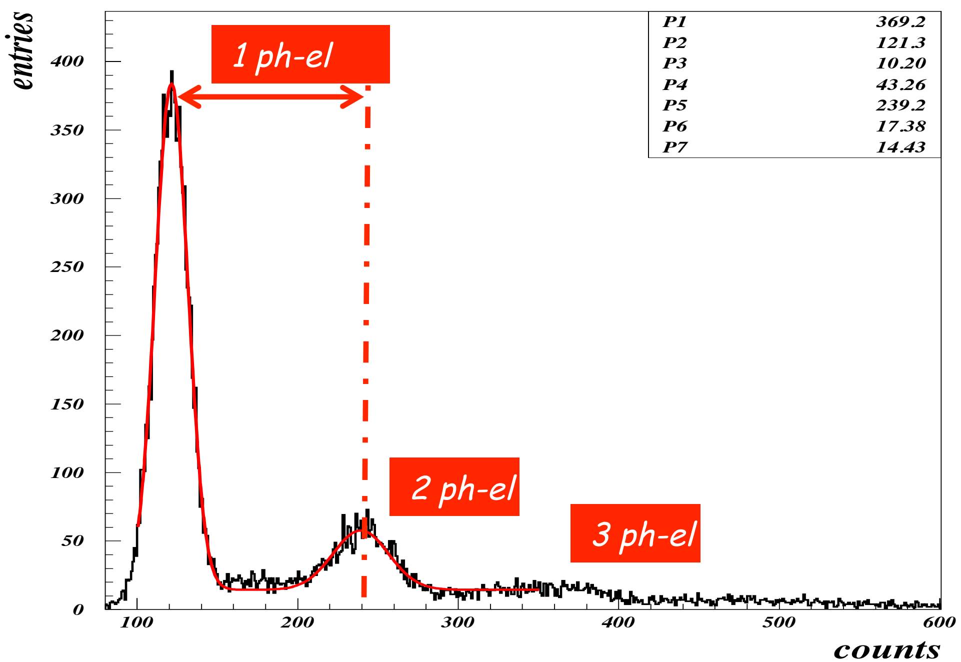


- For second phase operation of the T600, with magnetic field, we have setup an intense R&D programme for alternative solutions to PMTs:
  - Silicon Photomultipliers (SiPM);
  - Scintillation light slabs.
- SiPMs have been proven to work under very high magnetic field, but their functioning has to be better characterized at cryogenic temperature.
- SiPMs have to be coupled to light slabs or scintillation optical fibers.
- Investigations on materials and doping are necessary.

- Large area SiPMs (Hamamatsu S11828-3344M) have been successfully operated immersed in LAr.
- The SiPM device is able to detect VUV LAr scintillation light when coupled to a standard wavelength shifter (TPB) with high quantum efficiency (~ 40% - higher than that of the best PMTs), without requiring high voltage and any amplification.

SiPM average waveform for gammas in LAr





Conclusions

- ICARUS is the largest operational, physical scale LAr detector and it shall be so for several years to come.
- As recommended by the CERN/DG and the CERN Research Board, in the framework of the approved R&D program WA104, T600 will be transported at CERN where it will be overhauled.
- As part of the T600 overhauling several new solutions will be implemented while additional R&D activities will be carried for a second phase of the experiment.
- CERN will be a crucial asset for the future development of neutrino physics, providing support with expertise and infrastructures.
- We intend to:
  - contribute to the clarification of the "sterile neutrino" story;
  - collaborate with LBNE with a vigorous R&D program during and beyond the preparation phase
  - collect a large amount of neutrino/anti-neutrino events at the appropriate energy also from the off-axis kaon-neutrino NUMI beam ;
  - The convenience of ICARUS as one of "near detectors" for LBNE.

Thank you !