7^{th} Symposium on Large TPCs for low energy rare events detection

The WA104 experiment at CERN

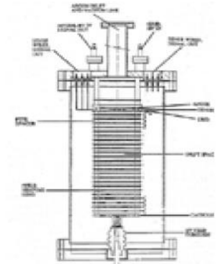
M. Bonesini

Sezione INFN Milano Bicocca,
Dipartimento di Fisica G. Occhialini,
Universita' Milano Bicocca

(for the WA104 Collaboration)

The Icarus path to massive liquid Argon detectors

1



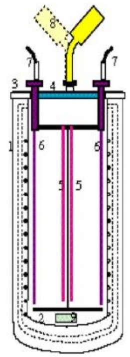
CERN

24 cm drift wires chamber

1987: First LAr TPC. Proof of principle. Measurements of TPC performances.

2

3 ton prototype



1991-1995: First demonstration of the LAr TPC on large masses. Measurement of the TPC performances. TMG doping.

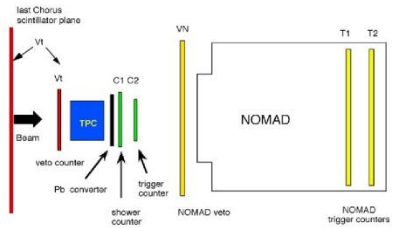
CERN

Laboratory work

3

CERN

50 litres prototype 1.4 m drift chamber



1997-1999: Neutrino beam events measurements. Readout electronics optimization. MLPB development and study. 1.4 m drift test.

4

10 m^3 industrial prototype

1999-2000: Test of final industrial solutions for the wire chamber mechanics and readout electronics.

Pavia

T600 detector

2001: First T600 module

5

Cooperation with industry and several companies

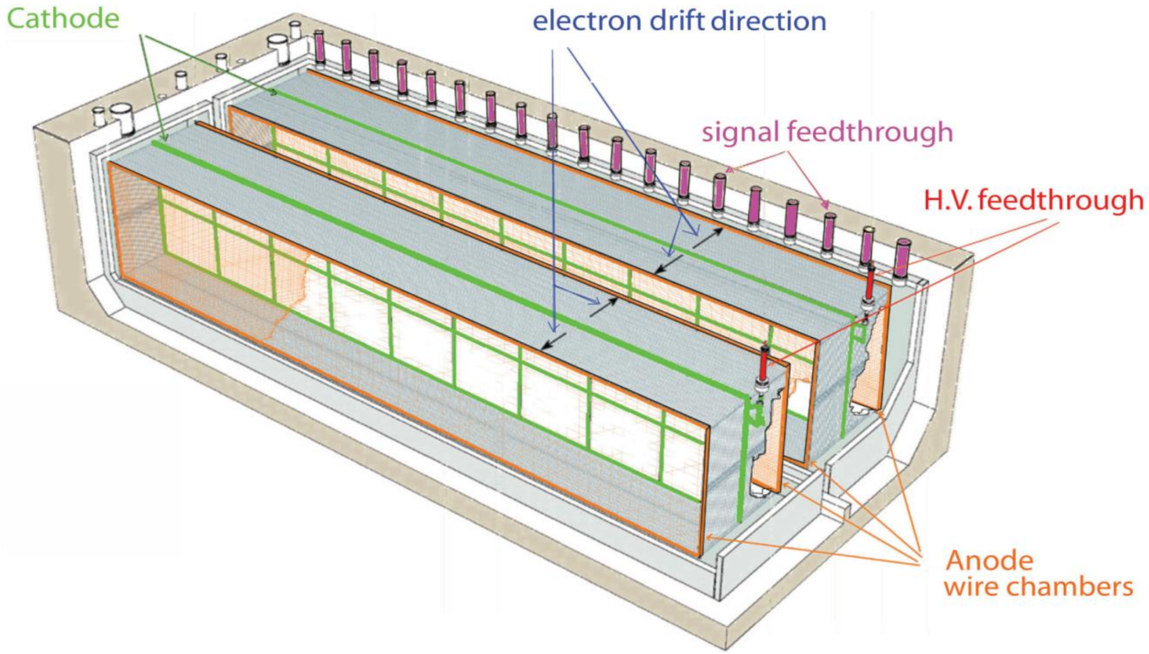
ICARUS T600 experiment

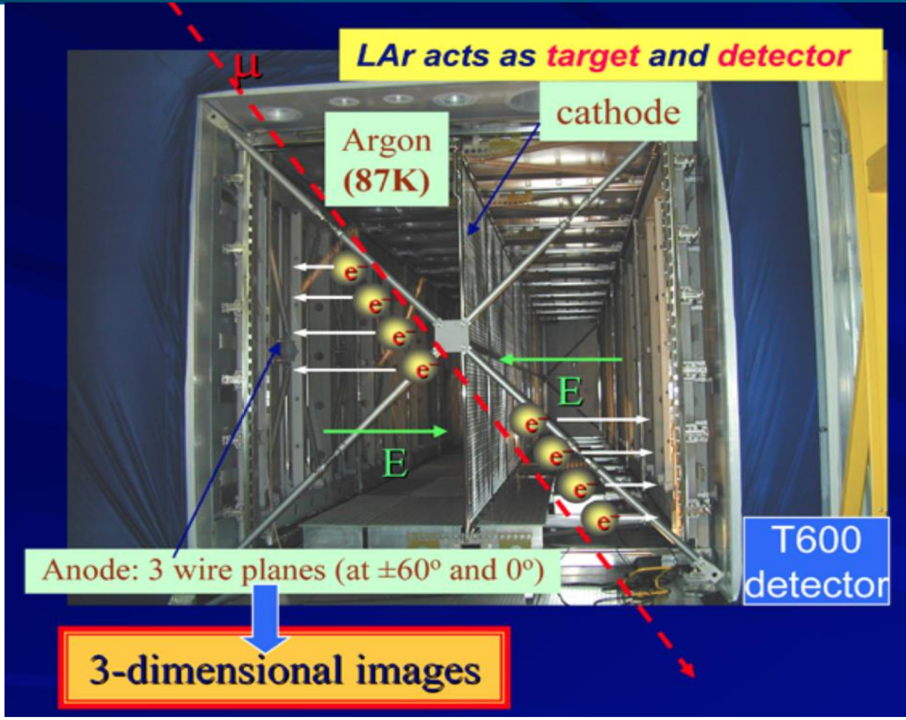
2010 - 2013 : Data taking with CNGS beam

6

LNGS Hall-B

The ICARUS T600 detector

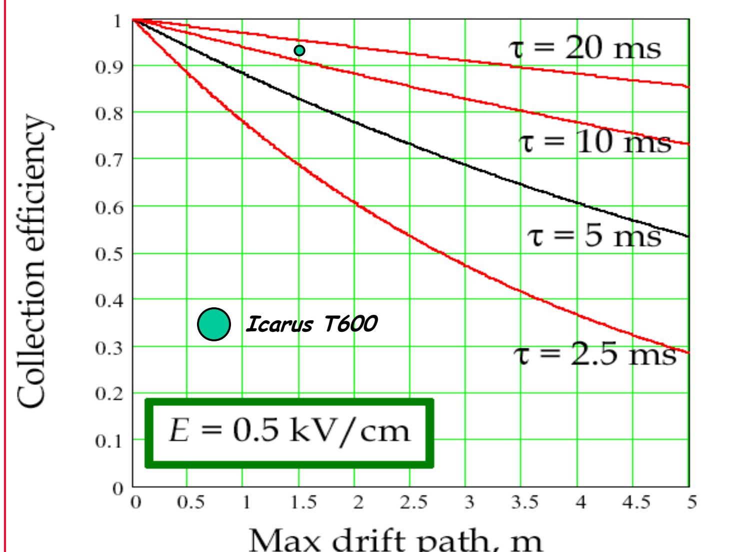




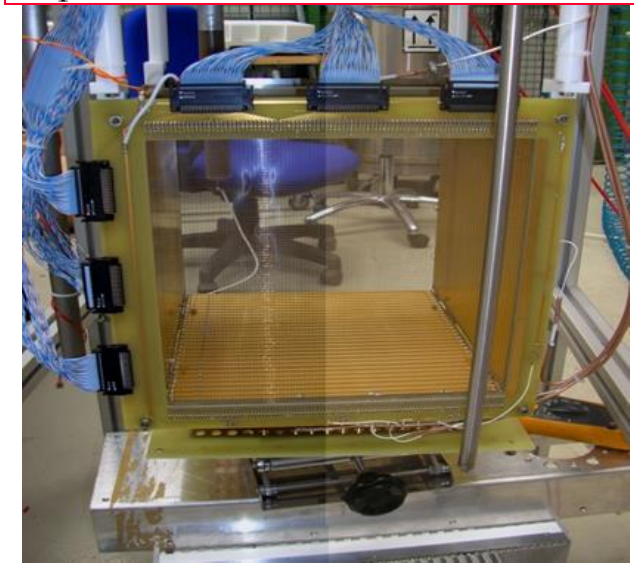
- Two identical modules
  - 3.6 x 3.9 x 19.6 ≈ 275 m^3 each
  - Liquid Ar active mass: ≈ 476 t
  - Drift length = 1.5 m (1 ms)
  - HV = -75 kV   E = 0.5 kV/cm
  - v-drift = 1.55 mm/μs
- 4 wire chambers:
  - 2 chambers per module
  - 3 readout wire planes per chamber, wires at 0,±60°
  - ≈ 54000 wires, 3 mm pitch, 3 mm plane spacing
- 20+54 PMTs , 8” Ø, for scintillation light:
  - VUV sensitive (128nm) with wave shifter (TPB)

The key features of LAr imaging: very long e-mobility

- The main technological challenge of the development of the cryogenic LAr TPC is the capability of ensuring a sufficiently long lifetime of drifting electrons.
- 2001 technical run in Pavia, τ_{el} = 1.8 ms
- New industrial purification methods developed at an exceptional level: remnants of electronegative impurities (O_2) have to be initially and continuously purified.
- Extremely high τ_{el} ≈21 ms (≈15 ppt molecular impurities) measured with cosmic μ's in the 120 litres ICARINO LAr-TPC at INFN LNL.
- Electron signal attenuation of ~10 % for a longest drift of 5 meters, opening the way to exceptionally long drift distances.

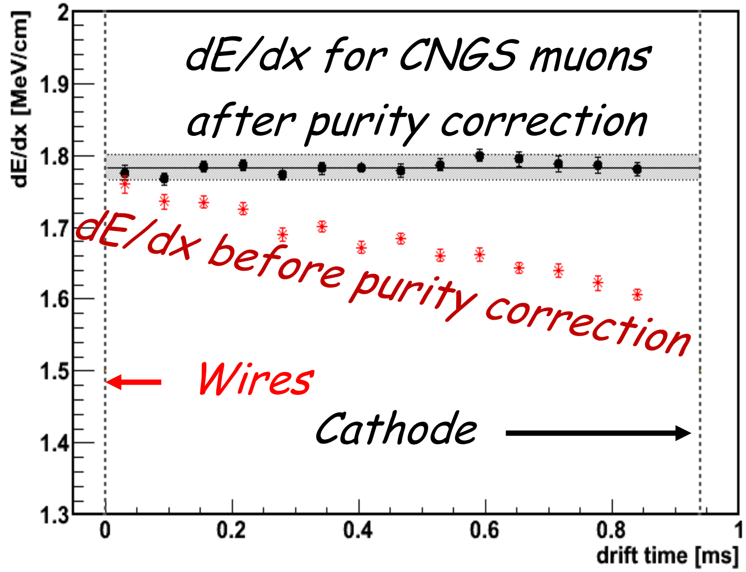


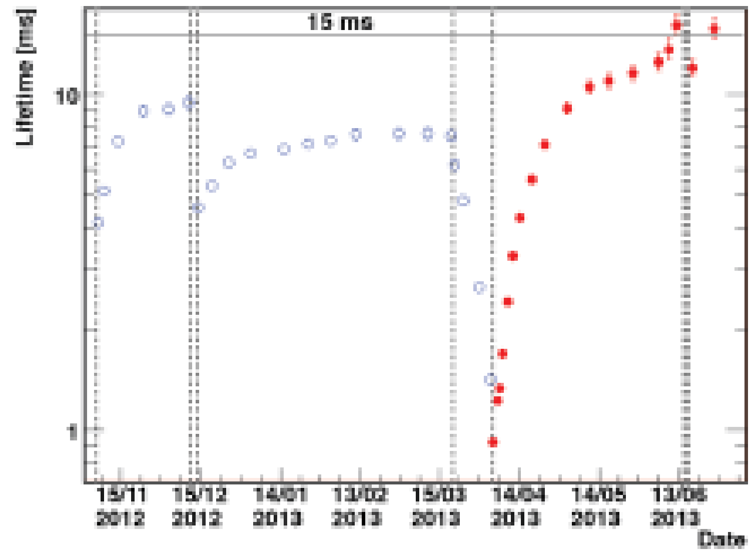
Drifting charge attenuation versus drift path at different electron lifetimes



ICARUS T600 LAr purity

- Electron lifetime measured during the ICARUS run at LNGS studying the charge signal attenuation on traversing cosmic-ray muons: τ_{el} > 7 ms (~40 p.p. trillion $[O_2]_{eq}$) →12% maximum charge attenuation
- Cross check with muons from CNGS ν interacting in the upstream rock: dE/dx signal correctly reconstructed constant along the drift coordinate
- τ_{el} uniform along the longitudinal direction
- New pump installed on East cryostat since April 4th, 2013: τ_{ele} > 15 ms !





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

published on JINST

WA104 Project at CERN: refurbishing of the T600

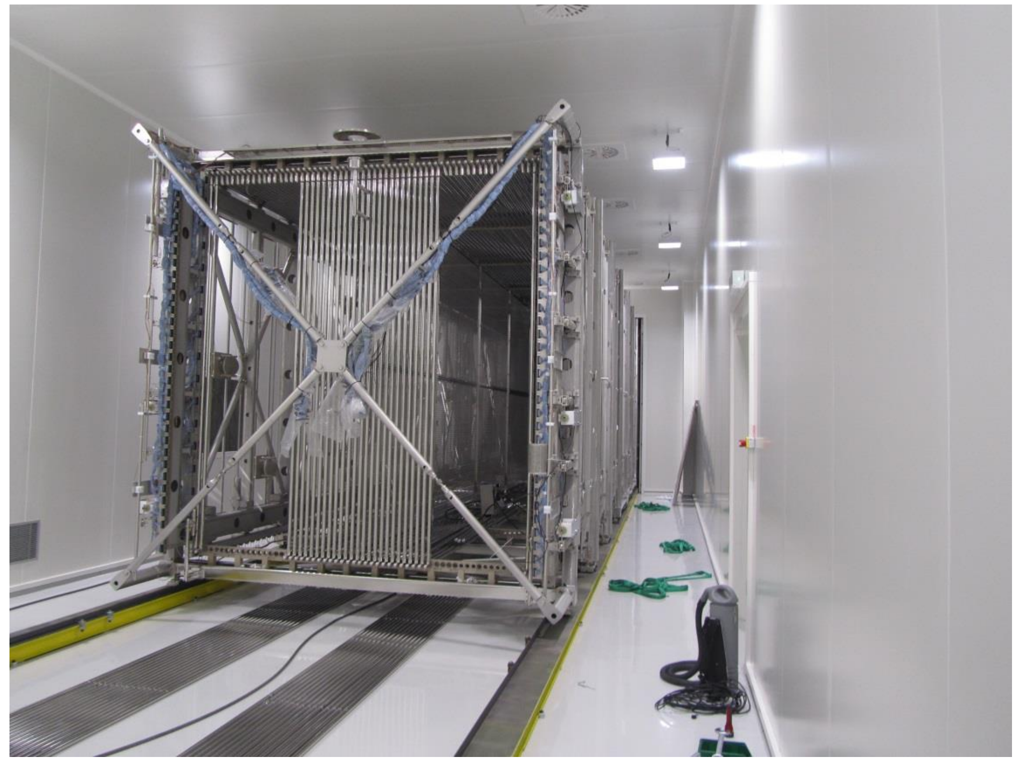
- WA104 program at CERN: two-years to prepare the ICARUS detector for the forthcoming search of sterile neutrinos within the FNAL Short Baseline neutrino program.
- First TPC in clean room at CERN. Transport of the 2nd TPC on December 2014.

- At CERN, the following main operations will be carried out on the TPCs:
  - Cathode deformation mapping, new design with better planarity;
  - New cold vessels, new purely passive insulation and corresponding new supporting structure (warm vessel);
  - Upgrade of the light collection system;
  - New faster, higher-performance read-out electronics solution.

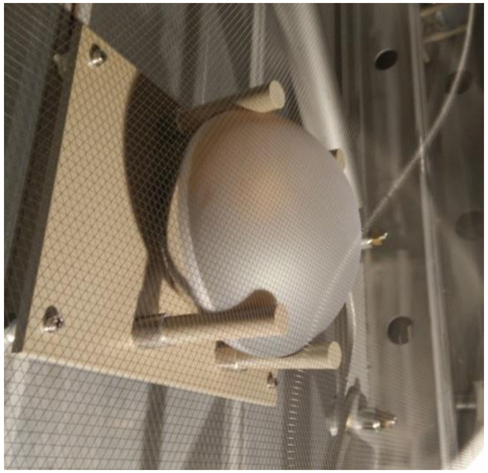
Some additional images

inside the clean room at CERN bldg 185

on the highway to CERN



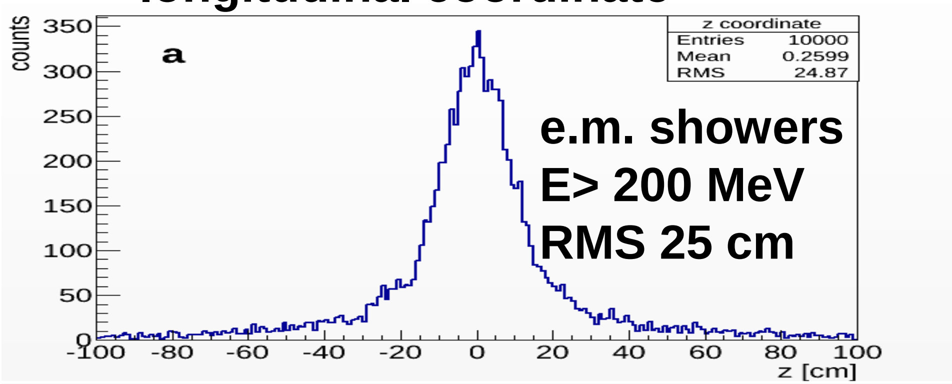
Upgraded light collection system (Photomultipliers)

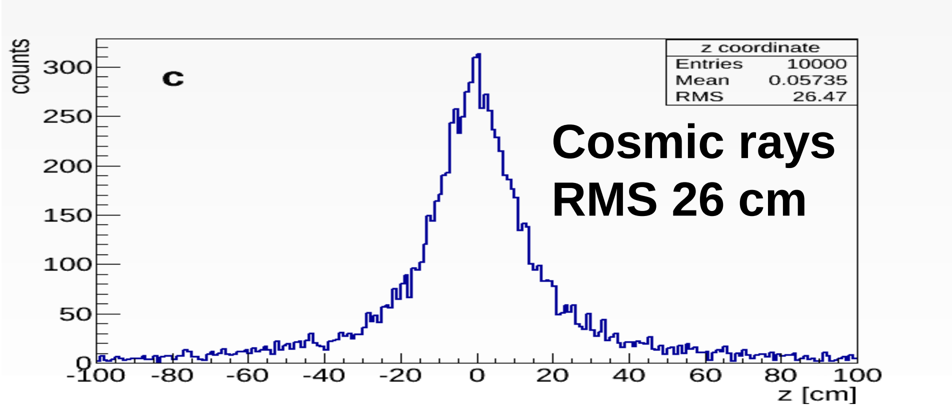


Upgrade of the light collection system:

- ~100 PMT ("8) per TPC, large surface, higher QE
- Implementation of electrostatic shields, to prevent inducted spurious signals on wire planes.
- Read-out electronics: ~ ns resolution with GHz digitizer.

longitudinal coordinate



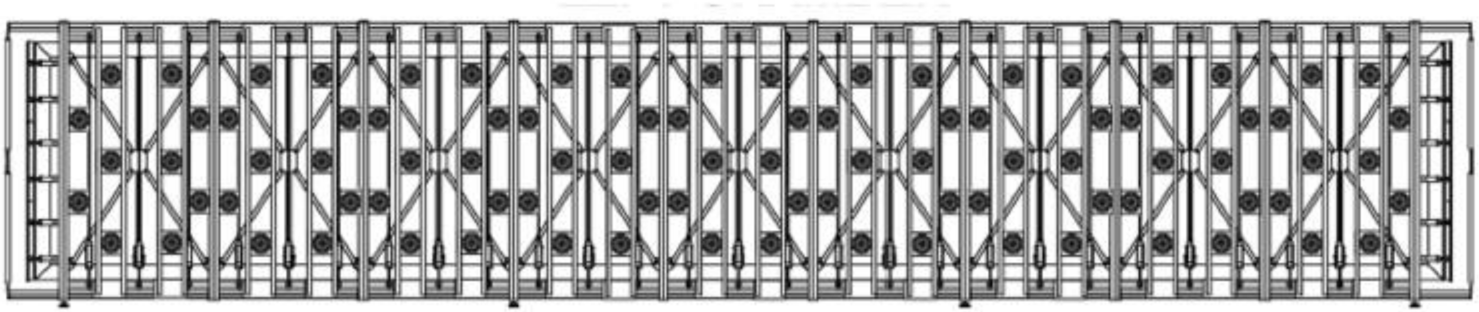


Ongoing activities

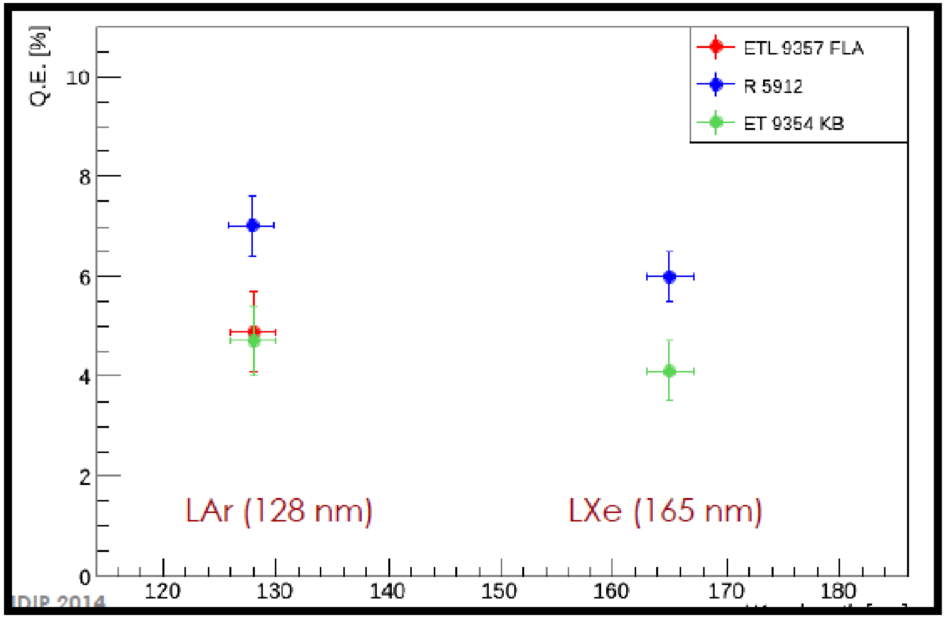
- Evaluation of tracks localization based on light signal intensities, as a function of the PMT number/ arrangement: space resolution better than 0.5 m;
- Characterization of different new PMTs looking for the best solution in the overhauled TPCs.

Proposed PMTs deployment

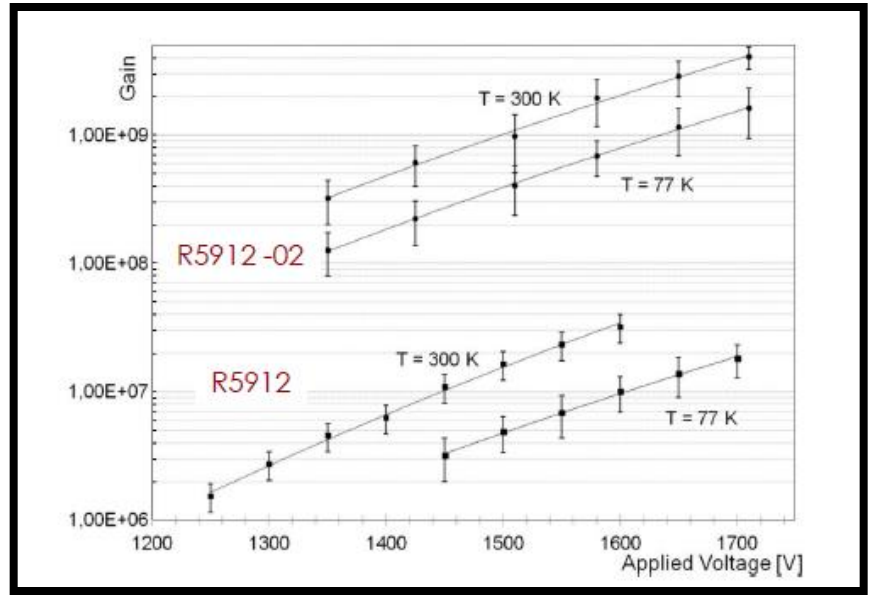
- *Given the present TPC mechanical structure, a possible layout foresees 90 PMTs behind each chamber (for a total of 360 PMTs)*
- *5% photocathode coverage*
- *Choice between Hamamatsu 8" R5912 PMTs and ETL 9357 KFLB PMTs under study*



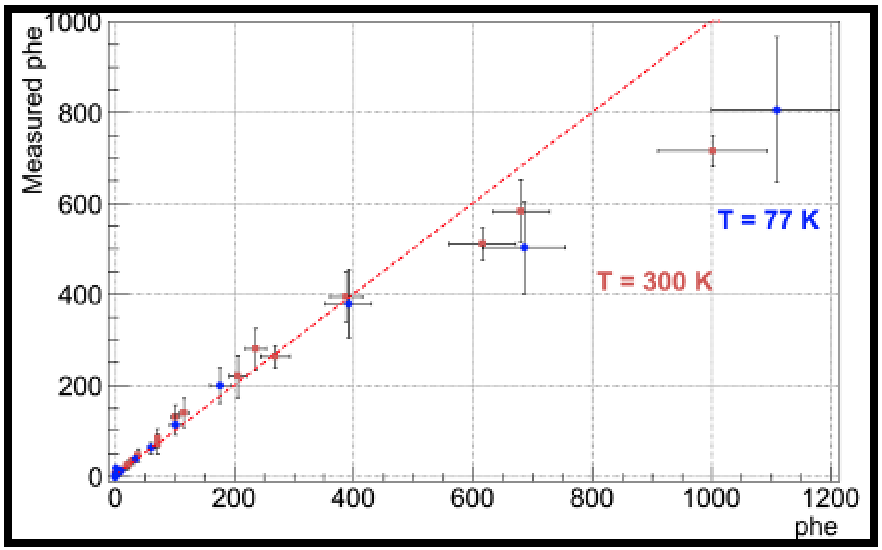
Results on 8” PMT tests



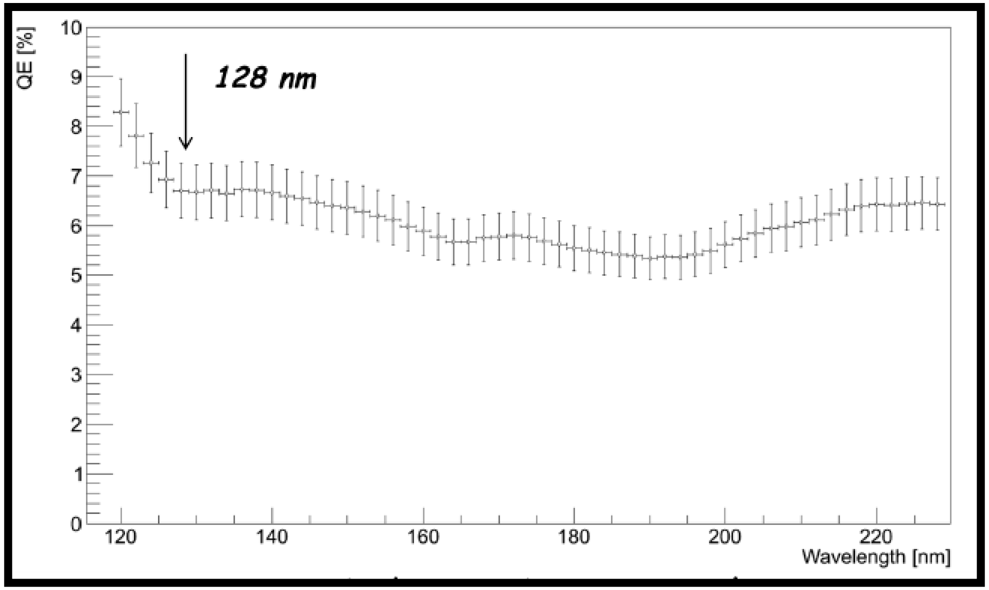
Q.E. with TPB coating



Gain at cryogenic temperature



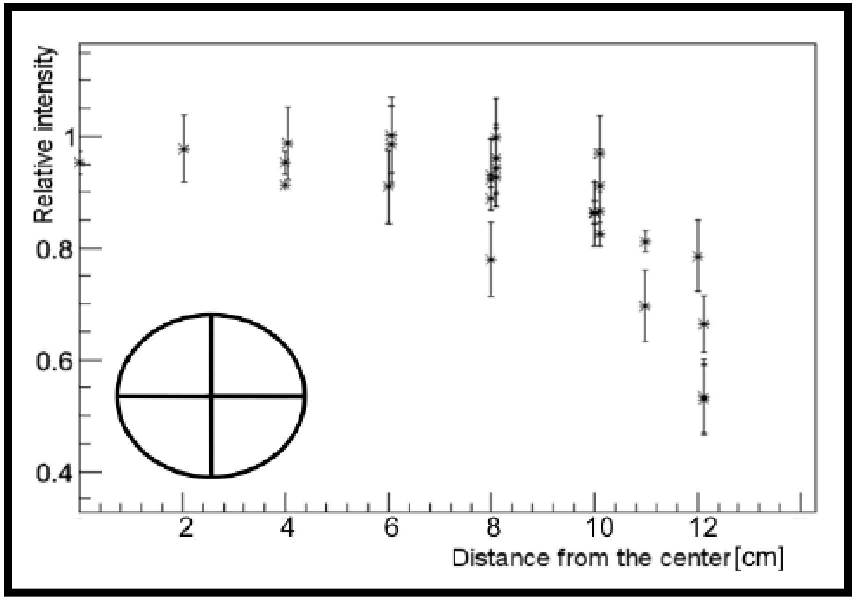
R5912 Linearity at cryogenic temperatures



Q.E. with TPB coating for Hamamatsu R5912 PMTs

Response uniformity for Hamamatsu R5912 PMTs

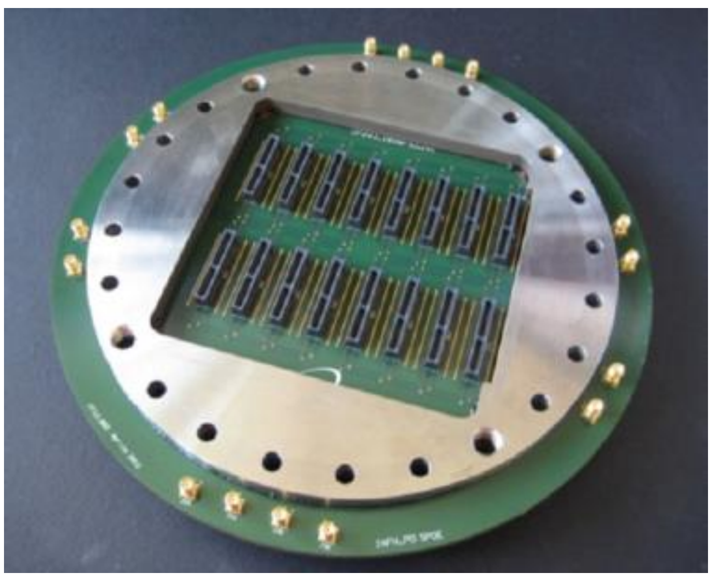
Distances on PMT surface

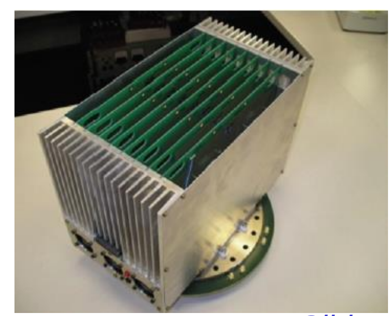


New electronics

New design developed for the electronics chain, featuring:

- more compact electronics for both analogue and digital, flange integrated (CF250 – INFN Proprietary design, figures below);
- serial ADCs (1/chan) instead of multiplexed ones used in LNGS run (-> synchronous sampling time, 400 ns);
- modern serial switched I/O for data flow + optical link (for Gb/s transmission rate).
- First prototype of new boards (analogue and digital) under test in LNL.

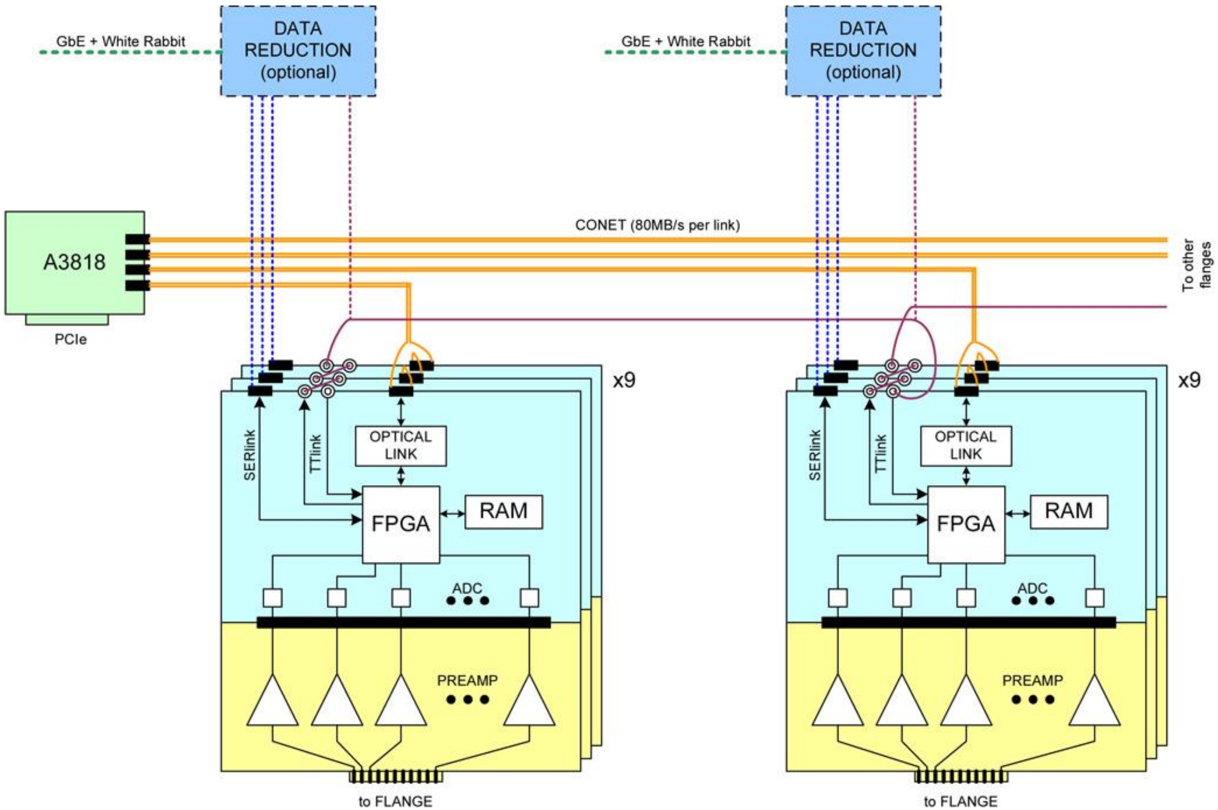




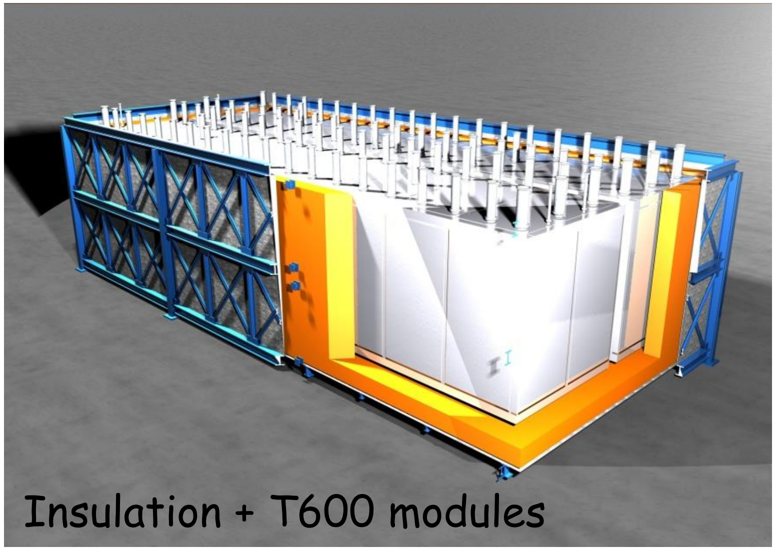
Some details

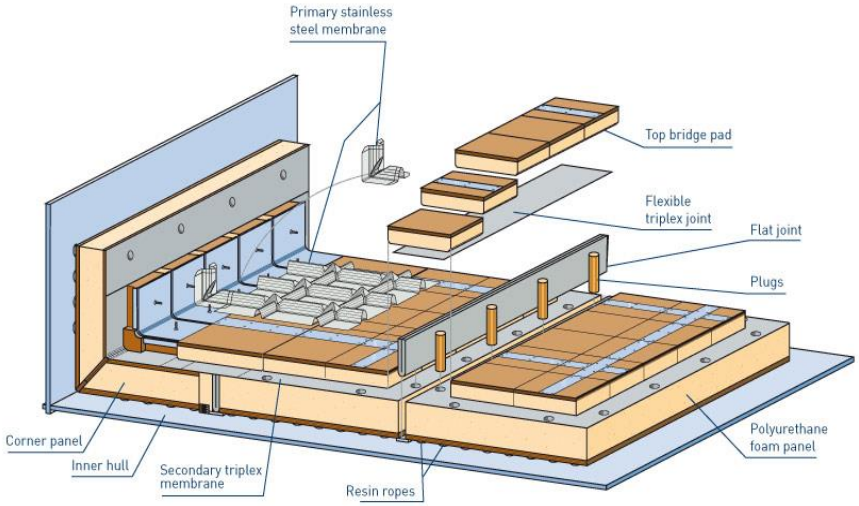
Performance, in terms of throughput of the read-out system, will be improved replacing the VME (8 - 10 MB/s) and the sequential order single board access mode inherent to the shared bus architecture, with a modern switched I/O. Such I/O transaction can be carried over low cost optical Gigabit/s serial links.

A prototype is under development, based on CONET (by CAEN) transfer protocol and one A3818 controller for up to 4768 channels

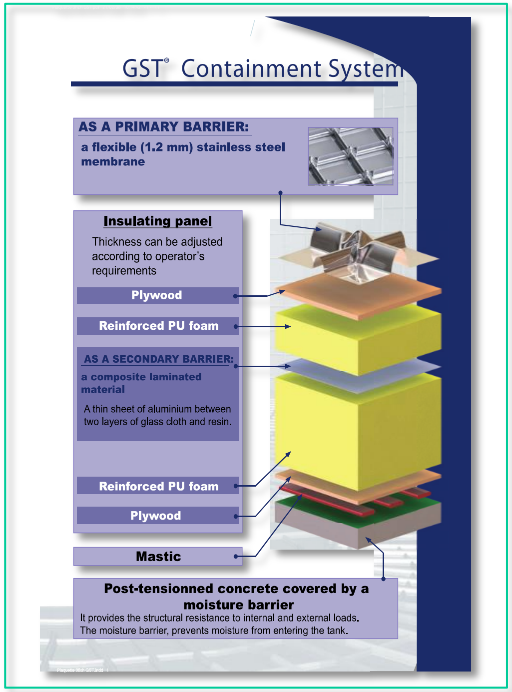


New thermal insulation


Insulation + T600 modules

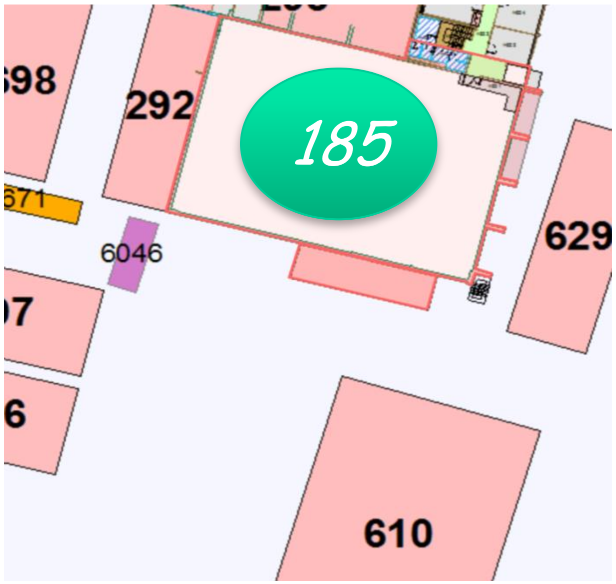


- Purely passive insulation chosen for the new T600 installation, coupled to our standard cooling shield with boiling Nitrogen.
- Technique developed for 50 years and widely used for large industrial storage vessels and ships for liquefied natural gas.
- Expected heat loss through the insulation: T600 ≈ 6.6 kW.
- Preliminary design appointed to GTT in Jan 2013.
- No internal membrane is required for our case.



WA104 facility at CERN, building 185

- Activities will be carried on at existing CERN building 185. A dedicated clean room, to house the TPCs during operations, is ready



- Design and construction of a new, 4π 'Cosmic Rays Tagging System' (CRTS) around the LAr sensitive volume, to tag cosmic rays and associated e.m. activity crossing the active volume in the SBN sterile neutrino search at FNAL (surface detector location).
- Further R&D activities will be carried on in parallel (including some specifically related to future LBNF program):
  - LAr magnetization;
  - Consequent replacement of PMTs with different light detectors (SiPM)
  - LAr doping, Argon purification.

What's next: sterile neutrino puzzle

- Sterile neutrinos were first hypothesized by B. Pontecorvo in 1957, as particles not interacting via any SM interaction but gravity. Nonetheless they could mix with standard neutrinos via a mass term.
- *Recently experimental ν anomalies started to build up, which could be explained with the oscillation into sterile neutrinos:*
  - Anomalous anti-ν_e production from anti-ν_μ beam at short distances detected by LSND experiment and later confirmed by MiniBooNE with ν_μ/amti-ν_μ beams $\rightarrow \Delta m^2_{new} \approx 10^{-2} \div 1$ eV^2 .
  - Anti-ν_e disappearance from reactors
  - ν_e disappearance from very intense e-conversion ν sources in Gallium experiments (designed to detect solar ν_e) $\rightarrow \Delta m^2_{new} \gg 1$ eV^2.
- *The CNGS facility delivered an almost pure ν_μ beam in 10-30 GeV E_ν range (beam associated ν_e ~1%) at a distance L=732 km from target.*
- Unique detection properties of LAr-TPC technique allow to identify unambiguously individual e-events with high efficiency

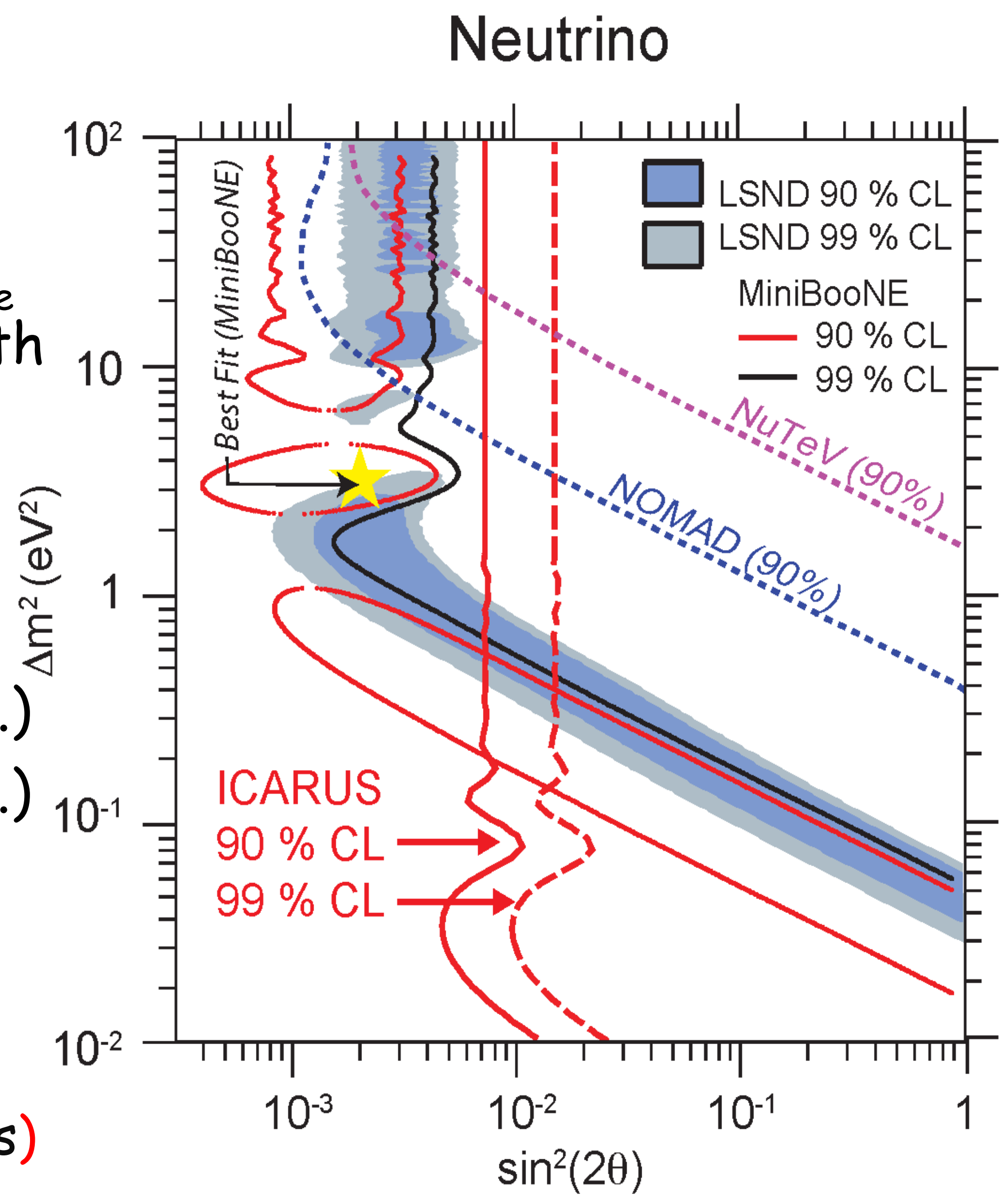
→ *Search for ν–e events excess*

ICARUS result on the search of the LSND-anomaly

- Analysis on 2450 ν events (7.23×10^{19} pot out of the full statistics of 8.6×10^{19} pot): 6 ν_e events observed in agreement with expectations due to conventional sources (7.9 ± 1.0).
- These provide the limits on the oscillation probability:
  - $P(\nu_\mu \to \nu_e) \leq 3.85 \times 10^{-3}$ (90 % C.L.)
  - $P(\nu_\mu \to \nu_e) \leq 7.60 \times 10^{-3}$ (99 % C.L.)

Eur.Phys.J.C (2013) 73:2345
Eur.Phys.J.C (2013) 73:2599

(see J. Kisiel talk for more details)



Results confirmed by OPERA

Future steps: clarifying the anomalies

- ICARUS experiment has conclusively demonstrated that LAr-TPC is *a leading technology for future short/long baseline accelerator driven n physics*. The detector is a "bubble chamber like" sampling, homogeneous calorimeter with excellent accuracies and the total energy reconstruction of the event from charge integration.
- A new experiment, capable to clarify all the ν anomalies at the appropriate > 5 sigma level is therefore highly desirable.
- Such an experiment is based on two main, innovative concepts and a low energy ν and anti-ν beam.
  - The first concept is the comparison for spectral differences of two (or more) identical detectors located at two different distances

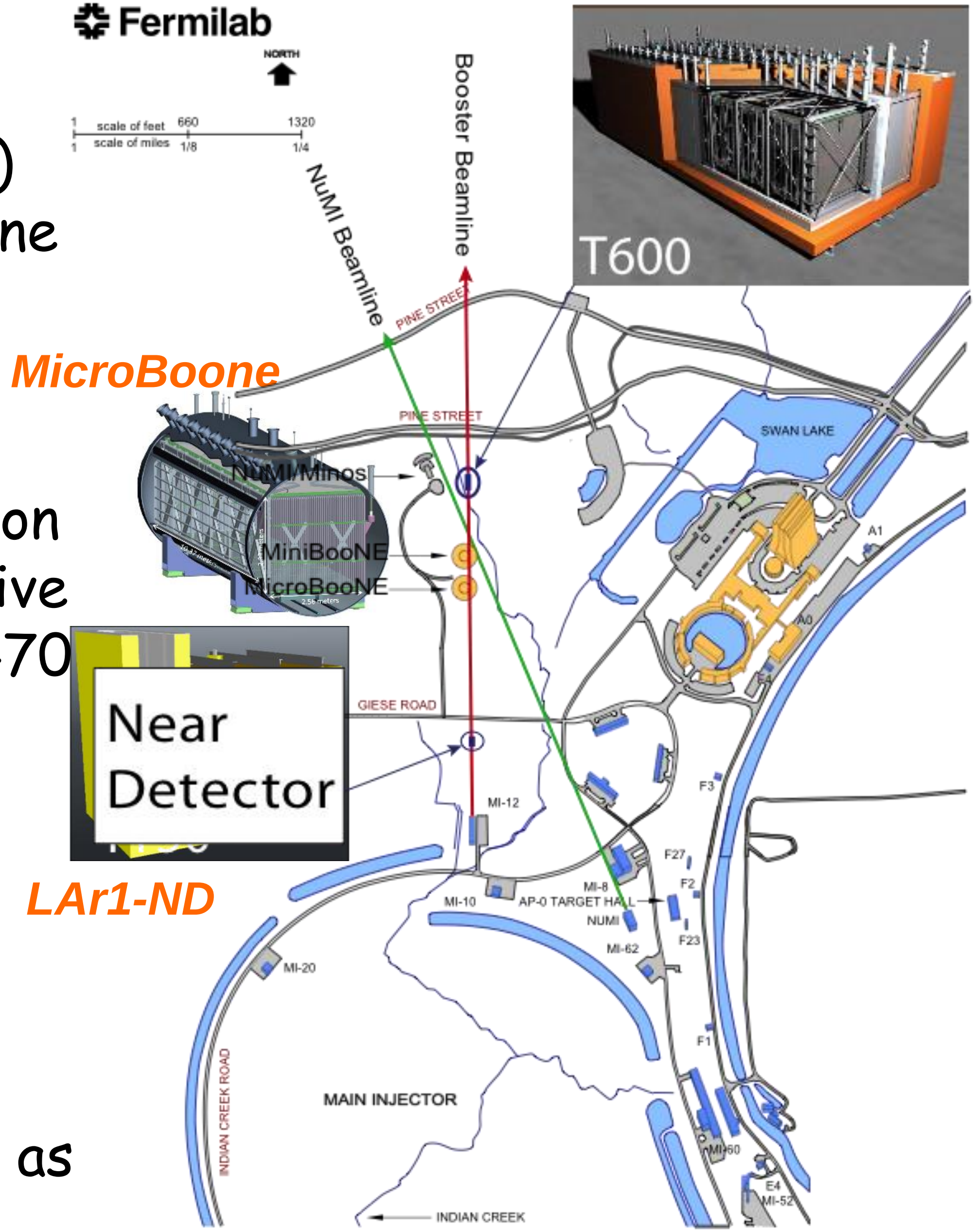
    (concept pioneered by the I216 proposal at CERN)
  - The second concept is the now fully operational large mass Liquid LAr-TPC detectors.

Basic features of the proposed experiment

- The experiment, initially proposed for CERN and now under consideration at FNAL, may be able to give a likely definitive answer to the following:
  - The LSND+MiniBooNe both antineutrino and neutrino $\nu_\mu \rightarrow \nu_e$ oscillation anomalies;
  - The Gallex+Reactor oscillatory disappearance of the initial ν-e signal, both for neutrino and antineutrinos
  - an oscillatory disapp maybe present in the ν-μ signal, so far unknown.
  - Accurate comparison between neutrino and antineutrino related oscillatory anomalies, maybe due to CPT violation.
- In addition, the proposed experiment ensures the bulk of the preparatory phase of the LBNE Coll., accumulating ν events *for test and analysis purposes as a running premise to LBNE*, providing:
  - An accurate determination of cross sections in Argon;
  - The experimental study of all individual CC and NC channels;
  - The realization of sophisticated algorithms and automatized procedures for the most effective identification of events.

Experiment layout at the FNAL neutrino beam lines

- ICARUS T600 detector may be located at shallow depth (3m deep) along the Booster Neutrino Beamline (<Eν> ~0.8 GeV) at ~600 m from target (proposal to PAC ready).
- Two LAr-TPCs with a smaller sensitive mass will be also located on axis: LAr1-ND at 110m with an active mass of 82 t and MicroBooNE at 470 m with an active mass of 89 t.
- T600 at FNAL will also provide additional information in the framework of LBNE with ν's from the off-axis kaon-neutrino NUMI beam peaked at ~2 GeV and an enriched flux of ν_e events as large as ~ 5%.

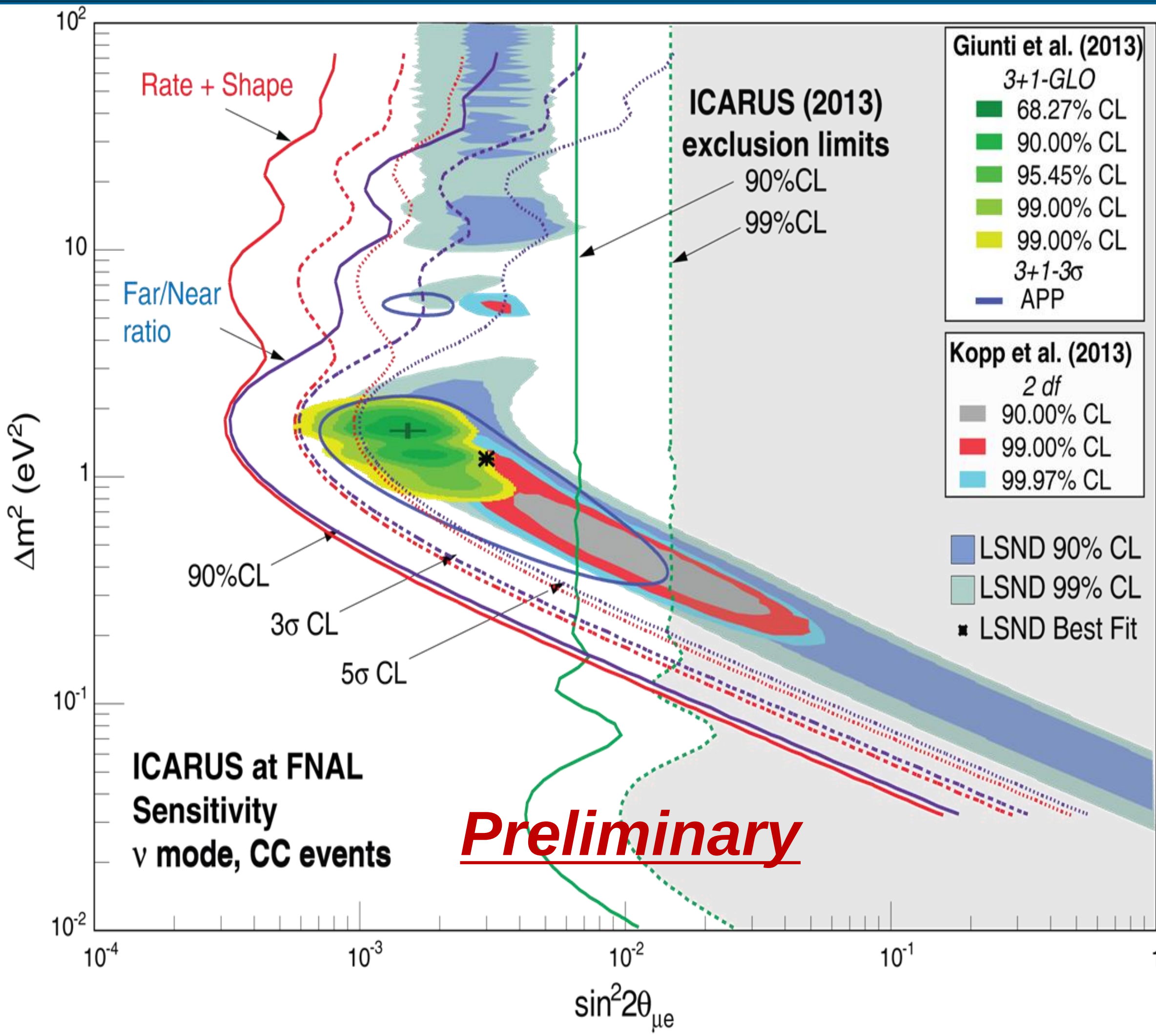


Ongoing study activities

- A joint INFN, FNAL and CERN effort to finalize the exp design :
  - Residual flux uncertainties in predicting near to far ν flux;
  - Background induced from cosmic rays and mitigation strategies;
  - Cryogenic infrastructures needed at FNAL to integrate the LAr-TPC's.
- In the low energy Booster beam, γ cosmogenic background could affect significantly the experimental $\nu_\mu \rightarrow \nu_e$ sensitivity :
  - Compton /Pair prod. signals from μ's may lead to an ionizing electron;
  - ≈ 11 cosmic μ's expected in T600 at shallow depth in the 1 ms drift time
  - ✓ The new 'Cosmic Rays Tagging System,' around the LAr sensitive volume, will reduce cosmic bckg from position/time of μs entering the detector;
  - ✓ A further background reduction in the 1.6 μs proton spill is expected by exploiting the bunched structure of the proton beam spill.
- ν_eCC identification efficiency under study

A definitive assessment of the LSND anomaly

- Expected LSND like sensitivity with Lar1-ND and T600 to ν_μ -> ν_e oscillations *after 3 years - 6.6 10^{20} pot BNB positive focusing at the present FNAL beam rates*
- Signal is computed as difference between Far and Near detectors with a small correction for the expected Near to Far beam shape differences
- *The predicted signal regions are well covered within 5σ.*

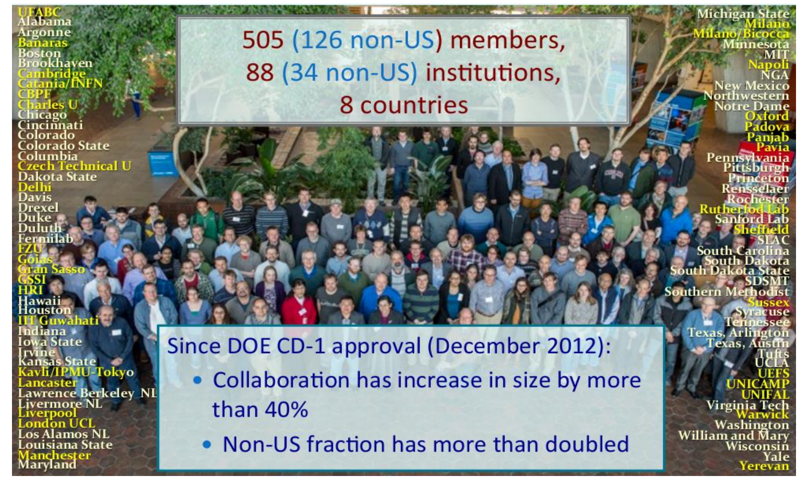


Exposure: 6.6 10^{20} pot – 3 years

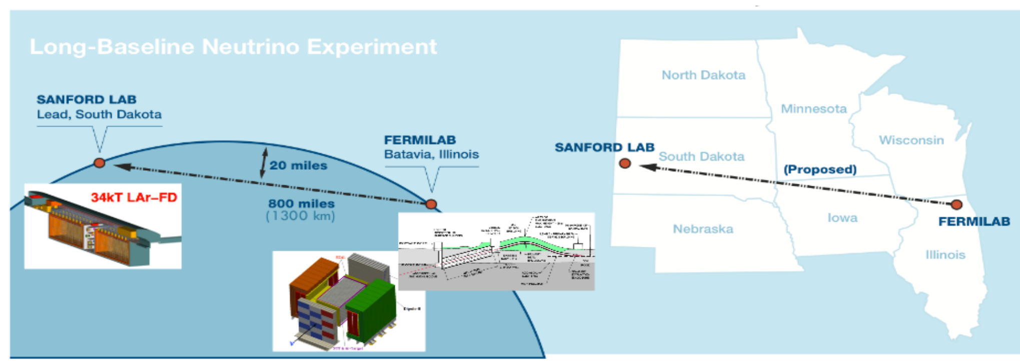
T600: 430 t fiducial mass at 600 m
LAr1-ND : 50 t fiducial mass at 150 m

Long Term ? The Long-Baseline Neutrino Experiment

- FAR detector: LBNE single phase LAr TPC based on the ICARUS/ Modular design & technology; GOAL: 34 kton fiducial mass;
- Neutrino beam from FNAL to SURF: 1300 km baseline
  - Protons 60-120 GeV, 1.2→2.3 MW, from upgraded Main Injector , 10 s pulses every 1.0 to 1.33 s
  - Neutrinos: sign selected, horn focused, energy range 0.5-5 GeV;
- Baseline and ν energy chosen to maximize sensitivity to CP violation.



ν_e CC events collected by ICARUS with the NUMI Off-Axis beam will be a fundamental asset for the LBNE project



Conclusions

- *After the completion of the ICARUS programme, with the CNGS neutrino beam, at the LNGS underground laboratory, the ICARUS T600 detector will located at CERN for overhauling and R&D within the approved WA104 project.*
- *The ICARUS technology and experience constitutes a crucial asset for the future development of neutrino physics in Europe; CERN is expected to provide the needed technical support and capabilities for the programme realization.*
- *On the experimental side, ICARUS is expected to clarify the "sterile neutrino" puzzle with the next short baseline experiment and to participate to the LBNE project during the preparation phase with a vigorous R&D programme and a large amount of neutrino/anti-neutrino events at the appropriate energy. The use of T600 detector as a "near detector" for LBNE is under study.*


Thank you !