WA104/ICARUS

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on behalf of
WA104/ICARUS Collaboration

117th Meeting of the SPSC – April 14, 2015

WA104/ICARUS Collaboration

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Foreword

- In 2013 ICARUS concluded a very successful, long duration run with the T600 detector at the LNGS underground laboratory taking data both with the CNGS neutrino beam and with cosmic rays. Several relevant physics and technical results were achieved.
- It is mainly thanks to the continuing efforts of the ICARUS Collaboration and to the support of INFN, that the LAr TPC technology has been taken to full maturity. The T600, with about 500 ton of sensitive mass, is the largest LAr TPC ever constructed.
- A highly sensitive search for $\nu_\mu - \nu_e$ oscillation in the appearance mode was proposed already in 2009 by the ICARUS Coll. to test at CERN the LSND claim (arXiv:0909.0355, SPSC-P-345, SPSC-P-347)
- The proposed dual detector experiment allows to separately identify the Δm^2 and $\sin^2(2\theta)$ by the (simultaneous) observation at different distances of neutrino interaction with:
  - appropriate L/E oscillation path lengths to ensure appropriate matching to the Δm^2 window for the expected anomalies;

Foreword

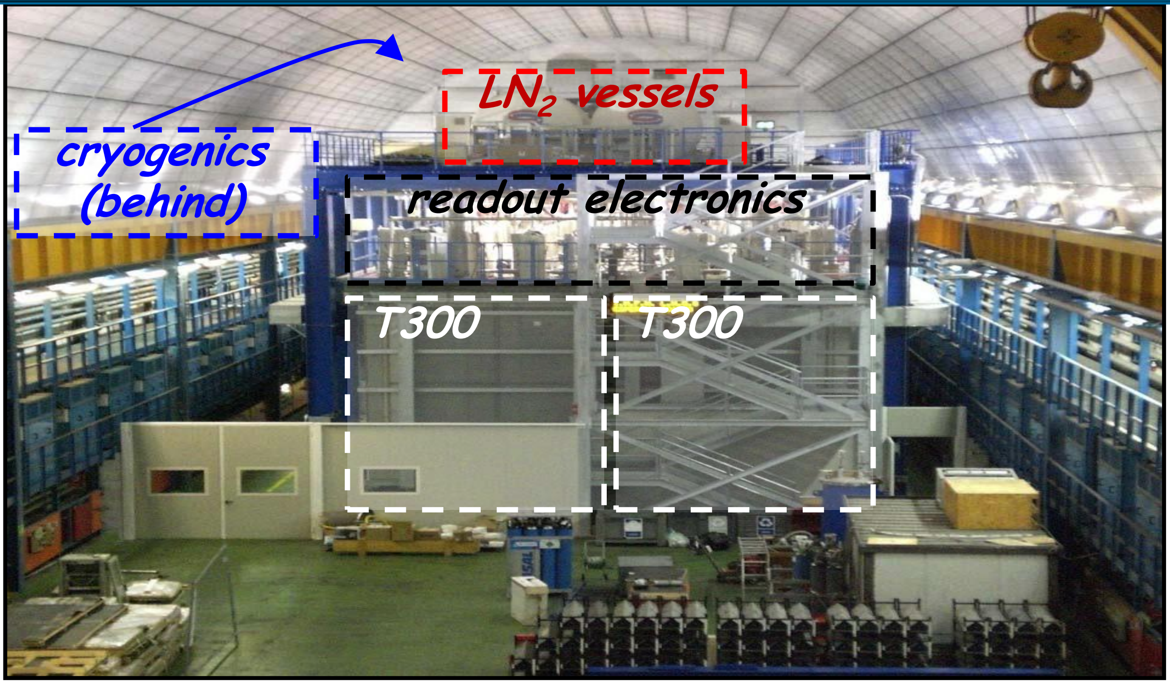
- Imaging" detector capable to identify unambiguously <u>all</u> reaction channels with a LAr-TPC;
- Very high rates due to large masses, in order to record relevant effects at the % level (>10^6 ν_μ, ≈10^4 ν_e events);
- Both initial ν_e and ν_μ components cleanly identified;

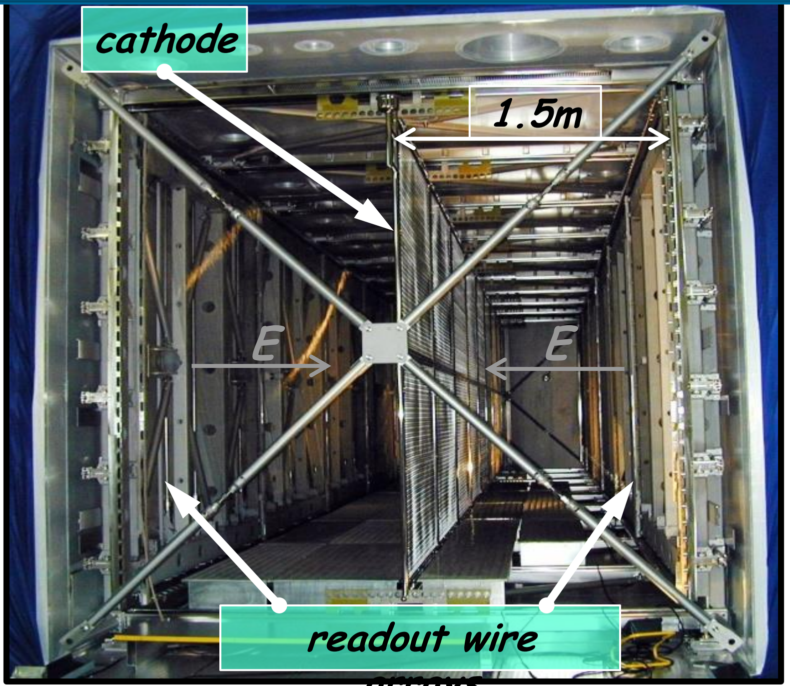
- After clarification of the CERN strategy on neutrino physics (2014-18 MTP) a similar dual detector experiment was proposed at the FNAL Booster beam (ICARUS at FNAL, Dec.2013). Two new proposals were then submitted to FNAL-PAC about one year ago.
- A joint ICARUS/LAr1-ND/MicroBooNE effort is taking place to develop a collaborative, international program at FNAL's BNB (and NuMI off-axis) with three detectors at different baselines by 2018 (near: Lar1-ND, mid: MicroBooNE, far: ICARUS);
- A common Conceptual Design Report has been submitted to the FNAL PAC in January 2015:
  - **The Proposal got level 1 approval.**

Foreword

- Expressions of interest for participating to the WA104/ICARUS program came from US groups. Discussions among these groups and WA104/ICARUS representatives took place from January 2015 and should be soon concluded with a formal application for entering the Collaboration.
- A second phase of the experiment is also under consideration with a fourth detector at a longer distance (≥1500 m) to extend the sterile neutrino search to lower Δm^2 as indicated by cosmology (ν_μ disappearance).
- This presentation will be focused on main physics motivations for the Short Baseline experiment at FNAL with the T600 as Far Detector and on the onset of the WA104 activities at CERN for detector overhauling.

ICARUS-T600 detector





- *Two identical modules (T300)*
  - 3.6x3.9x19.6 = 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
  - drift velocity = 1.55 mm/μs
  - Sampling time 0.4 μs (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° (ind1, ind2, coll view)
  - ~ 54000 wires, 3 mm pitch and plane spacing
  - Charge measurement on collection plane
- *20+54 8” PMTs for scintillation light detection*
  - VUV sensitive (128nm) with TPB wave shifter

Persisting anomalies in the neutrino sector

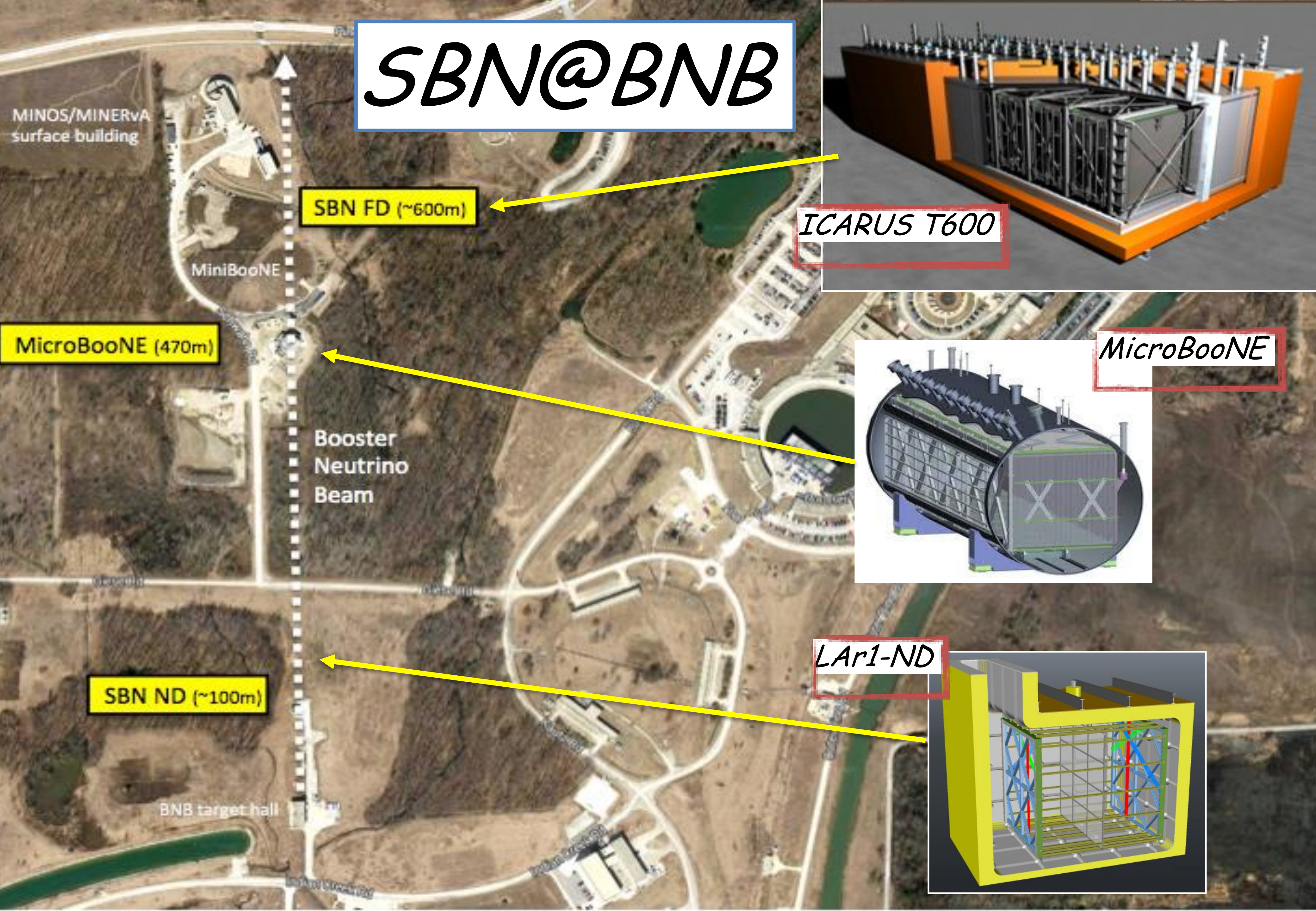
- Three main classes of anomalies have been reported, namely the apparent disappearance signal in the anti-ν_e events
  - (1) detected from near-by nuclear reactors, where the observed to predicted event rate is $R = 0.938 \pm 0.023$ and
  - (2) from Mega-Curie k-capture calibration sources in the experiments to detect solar ν_e with $R = 0.86 \pm 0.05$, and, in addition,
  - (3) observation of excess signals of ν_e electrons from muon neutrinos from particle accelerators (the LSND effect: 3.8 σ evidence for oscillations).
- These three independent signals may all point out to the possible existence of at least a fourth non standard and heavier "sterile" neutrino state driving oscillations at a small distances, with Δm^2_{new} of the order of ≈ 1 eV^2 and relatively small $\sin^2(2\theta_{new})$ mixing angles.
- According to Planck measurement and Big Bang cosmology, at most one sterile ν is expected, with m< 0.4 eV.

Sterile neutrino search at the FNAL Booster { beamline

- An ultimate experiment with multiple LAr-TPCs exposed to FNAL Booster ~ 0.8 GeV neutrino beam has been proposed as definitive answer to the "sterile neutrino puzzle".
- The Conceptual Design Report, a joint ICARUS/LAr1-ND/MicroBooNE effort presented to FNAL PAC (Jan 15th , 2015), will exploit three LAr-TPC detectors at different distances from target: *LAr1-ND (82 t active mass), MicroBooNE (89 t) and ICARUS T600 (476 t) at 150, 470 and 600 m.*
- The experiment will likely clarify both LSND/MiniBooNE and Gallex/reactor anomalies by precisely and independently measuring both $\{_e$ appearance and $\{_\mu$ disappearance, mutually related through the relation

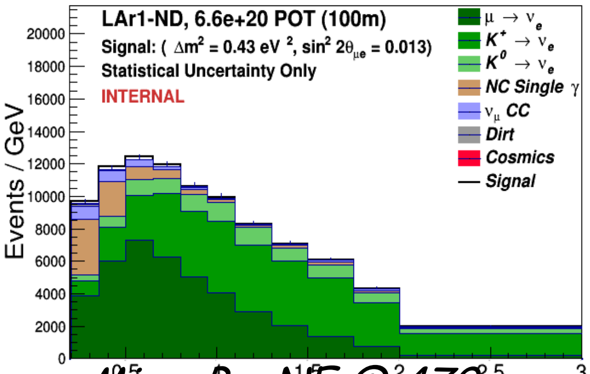
$$\sin^2\left(2J_{me}\right) £ \frac{1}{4}\sin^2\left(2J_{mx}\right)\sin^2\left(2J_{ex}\right)$$

- In absence of "anomalies", the three detector signals should be a closer copy of each other for all experimental signatures. However, the intrinsic $\{_e$ events with a disappearance signal (if f.i. confirmed by reactors) may result in the reduction of a superimposed LSND $\{_e$ signal. These two effects can be disentangled by changing the intrinsic $\{_e$ beam contamination with different beamline optics (horn and decay tunnel length).

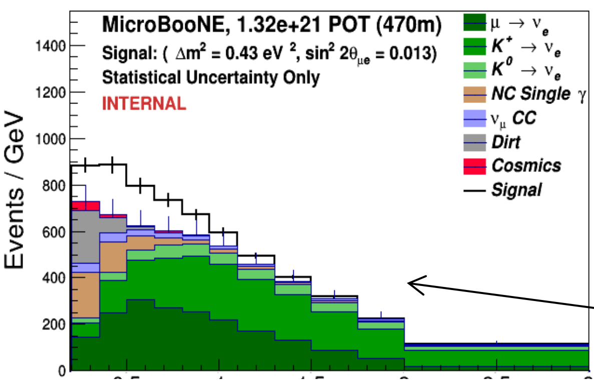

SBN@BNB
MINOS/MINERvA surface building
SBN FD (~600m)
ICARUS T600
MiniBooNE
MicroBooNE (470m)
MicroBooNE
Booster Neutrino Beam
LAr1-ND
SBN ND (~100m)
BNB target hall

$\nu_\mu \rightarrow \nu_e$ appearance sensitivity

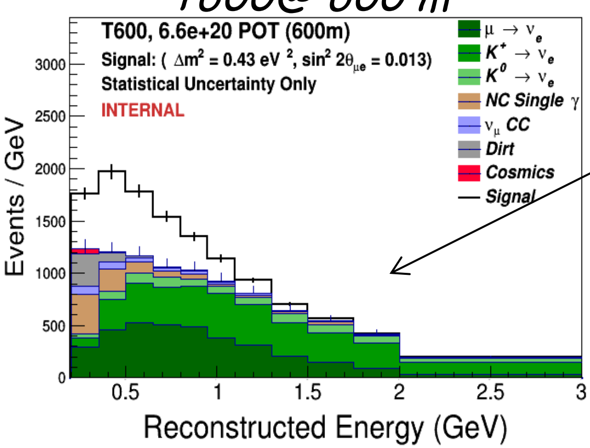
LAr1ND @ 100 m



MicroBooNE @ 470 m



T600@ 600 m

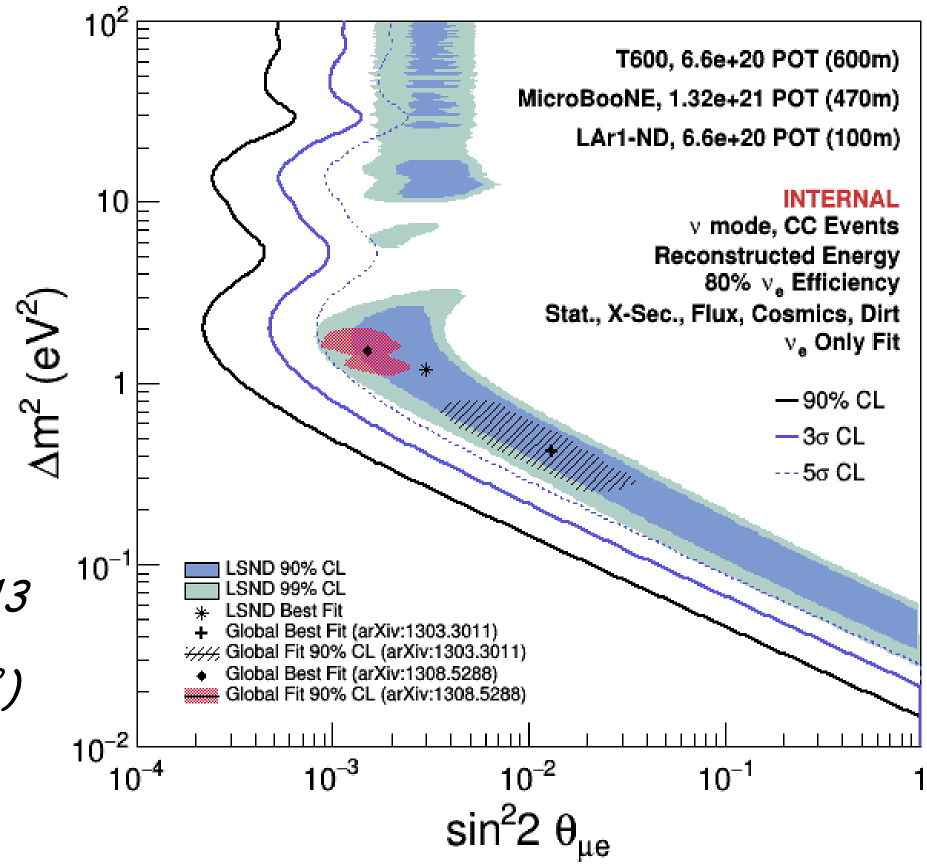


Example for

($sin^2(2\theta)=0.013$

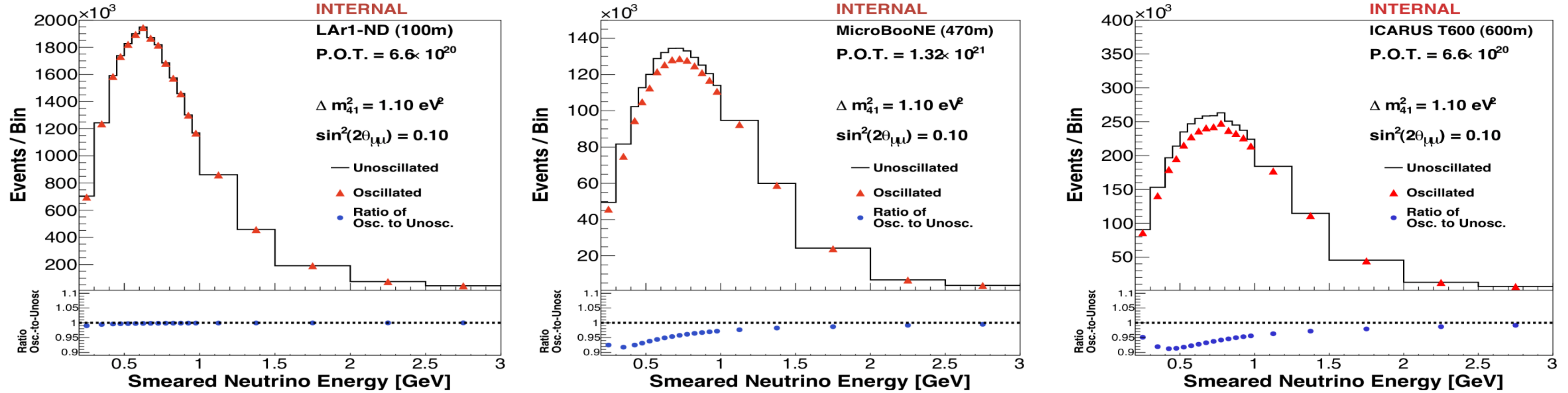
$\Delta m^2=0.43\ eV^2$)

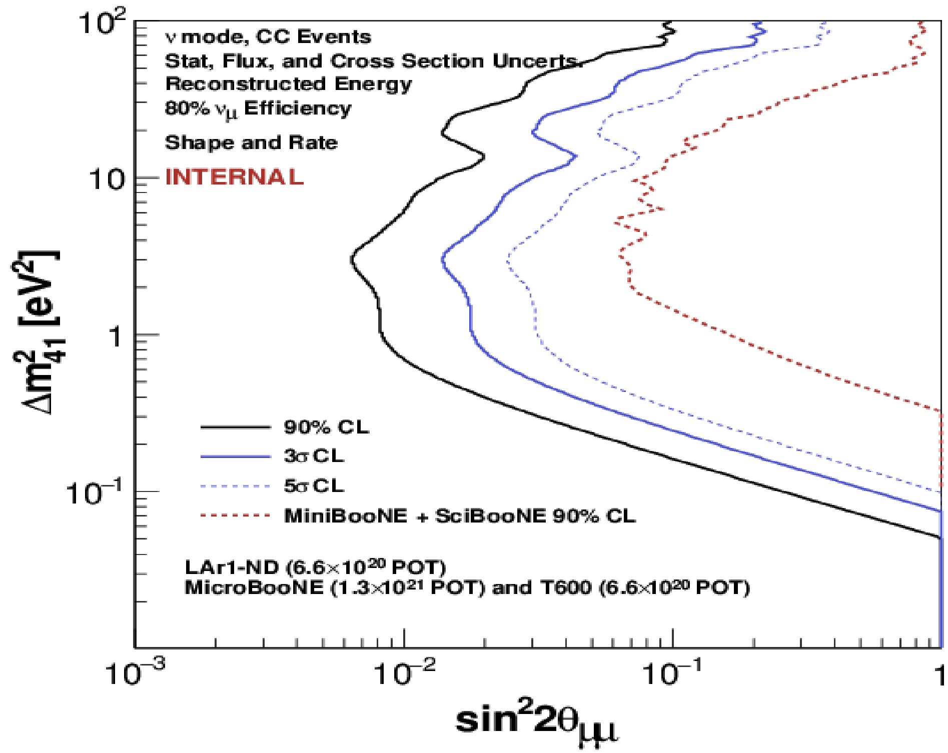
- Expected exposure sensitivity of $\nu\mu \rightarrow \nu e$ oscillations for 3 years - 6.6 10^{20} pot BNB positive focusing (6 years for MicroBooNE).



The LSND 99%CL region is covered at the ~5σ level

νμ disappearance sensitivity

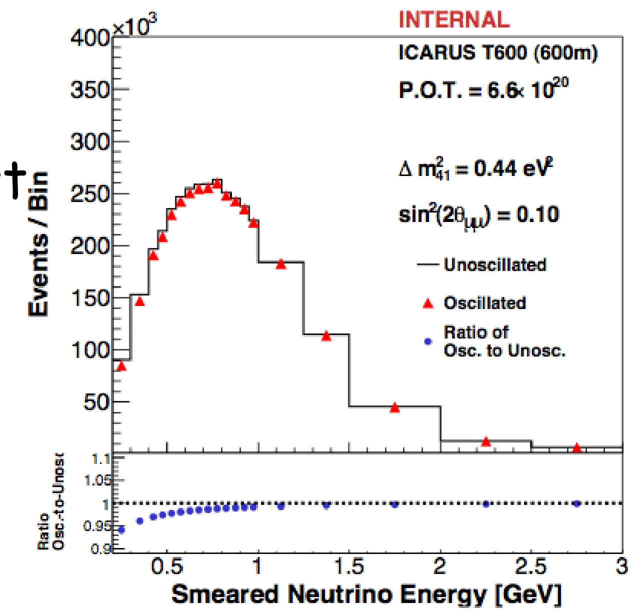


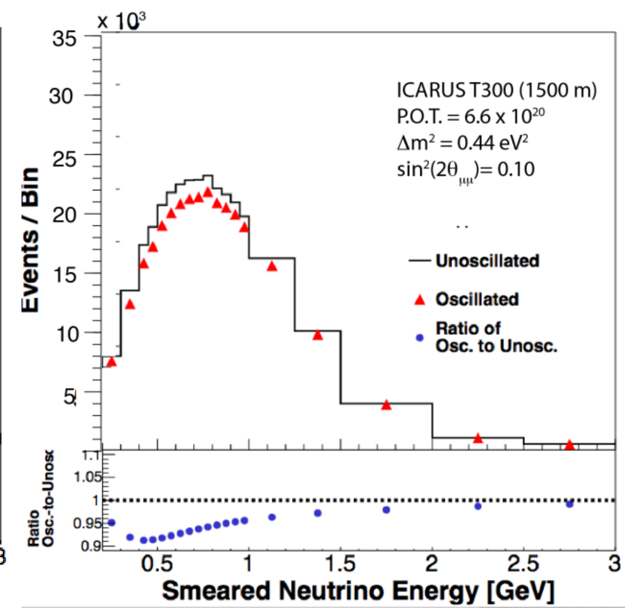


- Disappearance analysis can profit from high rates and correlations between the three LAr-TPC detectors
- SBN can extend sensitivity by 1 order of magnitude beyond SciBooNE+MiniBooNE

A second stage

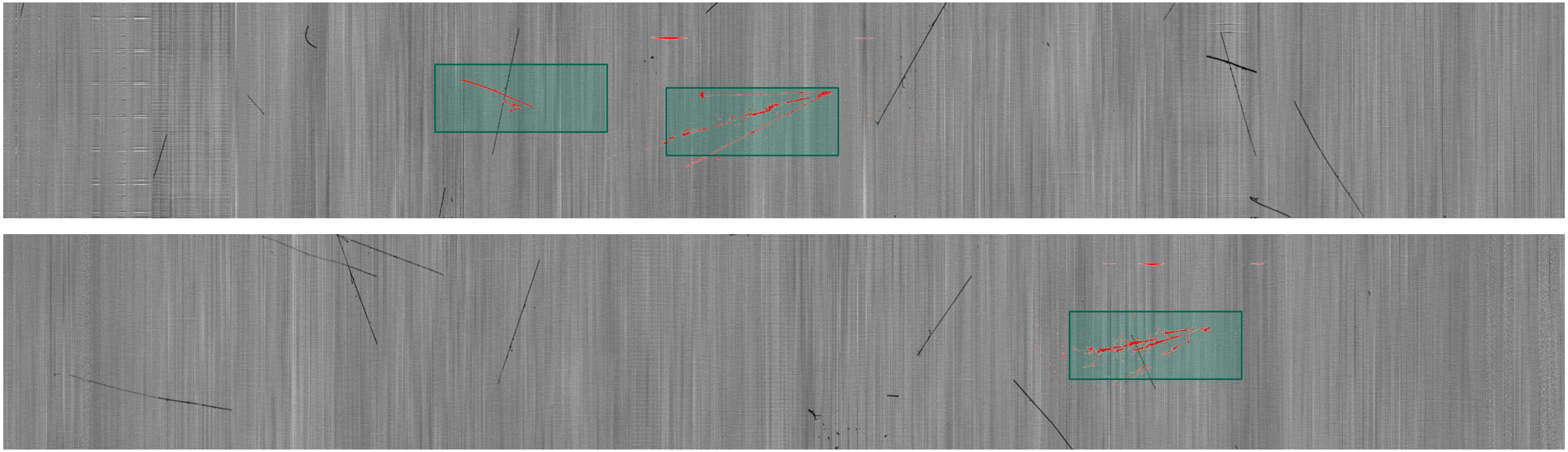
- Within 3+1 model, the most relevant and solid result is LSND, where $sin^2 2\nabla_{e\mu}$= $4|U_{e4}|^2|U_{\mu 4}|^2$ ≈ 1.5 10^{-3}. If LSND is confirmed, both $ν_e$ and $ν_\mu$ disappearance are present, since $sin^2 2\nabla_{ee}= 4|U_{e4}|^2 (1-|U_{e4}|^2)$ and $sin^2 2\nabla_{\mu\mu}= 4|U_{\mu 4}|^2 (1-|U_{\mu 4}|^2)$
- Reactor experiments presently claim $sin^2 2\nabla_{ee}$≈0.12, $|U_{e4}|^2$= 0.03.
- From LSND and assuming naively muon-electron universality, we expect at FNAL $sin^2 2\vartheta_{ee}= sin^2 2\vartheta_{\mu\mu}$≈0.08, about ½ of the present reactor data and Mega-sources much smaller than claimed.
- For $\otimes m^2$< 0.5 eV^2 the $ν_\mu$ disappearance effect at 600 m will be limited at the lowest $ν$ energy bins 0.2-0.4 GeV.
- In order to amplify the effect, we install at a later stage an additional detector to 1500 m distance.





Facing a new situation: the LAr-TPC near the surface

- At shallow depths several uncorrelated cosmic rays will occur in T600 during the 1 ms drift window readout at each triggering event: ~ 12 muon tracks per drift in each ICARUS half module were measured on surface (Pavia 2001).
- This represents a new problem compared to underground operation at LNGS since, in order to reconstruct the true position of each track, it is necessary to associate precisely the related timing of each element of the TPC image with respect to the trigger time.



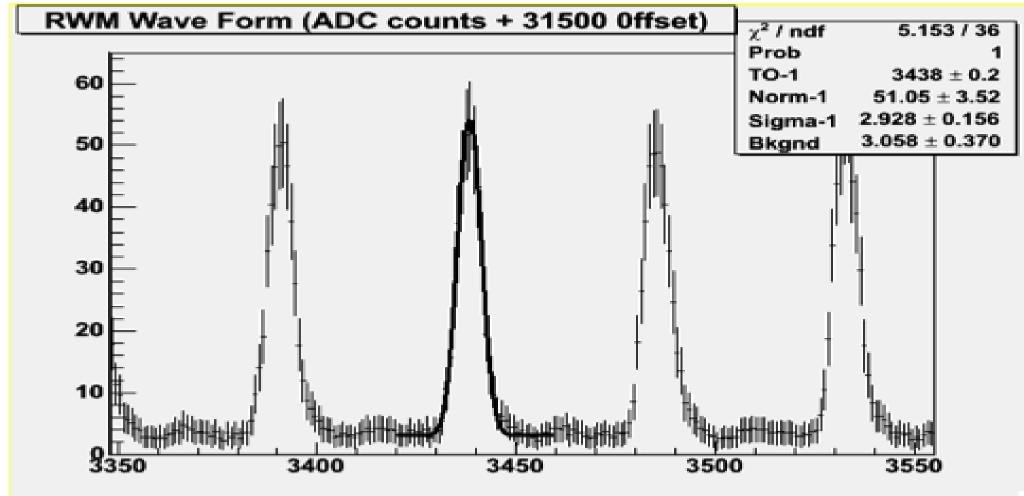
Cosmic rays (PV) + low energy CNGS beam events

Cosmogenic background mitigation

- Photons associated with cosmic μ represent a serious background for the ν_e appearance search, since electrons generated in LAr via Compton scattering / pair production can mimic a ν_eCC signal.
- In order to strongly mitigate the cosmogenic background, all the c-ray particles entering the detector must be unambiguously identified. This can be achieved by implementing a Cosmic Rays Tagging around the LAr active volume that provides an external timing of each track to be combined with the TPC reconstructed image. This system could consist either of external RPCs or plastic scintillation counters or internal readout plates detecting ionization signals.
- The adoption of a muon tagging system with 95% detection efficiency of single muon hit could ensure 99% efficiency in c-rays identification in T600, relying on double crossing of muons (only 15% are expected to stop in LAr).

Further mitigation of cosmogenic background

- Further rejection capabilities will come from precise timing information from internal scintillation light detectors. A ~ 1 ns accuracy will enable exploiting the bunched structure of the Booster p beam within spill (2 ns wide bunches every 19 ns).

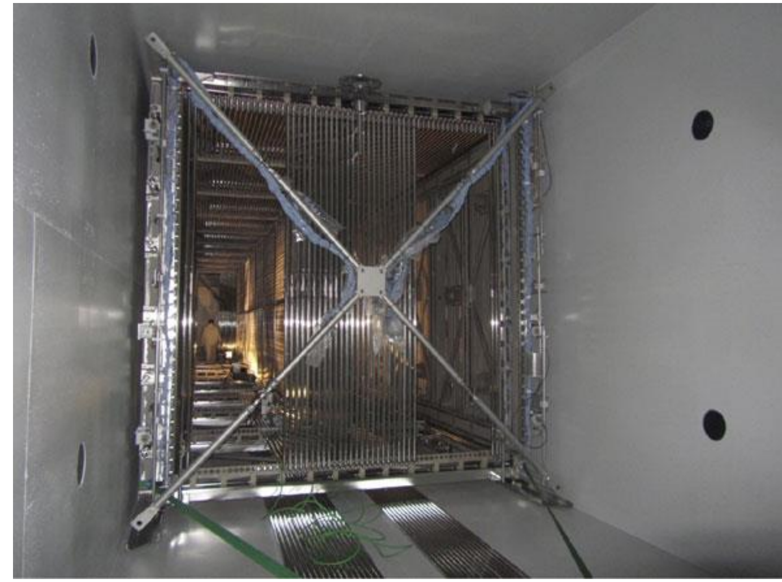


- Additional background mitigation strategies, exploiting the topological capability of the LAr-TPC, will be also applied to identify photons inside LAr active volume associated with cosmic muons.
- This requires the development of automatic tools to efficiently select, identify and reconstruct the neutrino interactions among the millions events triggered by cosmics (to be compared with the ~ 3000 ν events collected by ICARUS during CNGS run at LNGS!).

A continuing neutrino program

- The recent success of ICARUS-CNGS2 experiment has conclusively demonstrated that LAr-TPC is *the leading technology for future short/long baseline accelerator driven neutrino physics.*
- INFN has signed a Memorandum of Understanding for **WA104 project at CERN** and just concluded an important cooperation agreement for a short baseline experiment in the framework of the US-LBNF collaboration, involving the long term realization of a truly large mass, LAr-TPC detector.
- During its operation in the Short Baseline Neutrino Oscillation Program **SBN at Fermilab**, ICARUS will collect also ν_eCC events with the NUMI Off-Axis beam peaked at ~ 2 GeV, which will be an asset for the LBNF project.
- These activities represent as well an opportunity to further develop the LAr-TPC technique in view of the ultimate realization of the LBNF detector, with:
  - accurate determination of cross sections in liquid Argon;
  - experimental study of all individual CC and NC channels;
  - realization of sophisticated algorithms to improve the automatic identification of neutrino interactions.

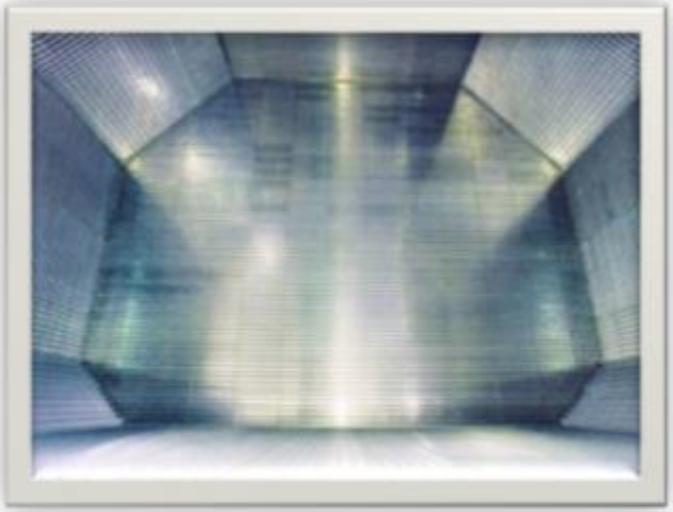
WA104 Project at CERN: overhauling of the T600

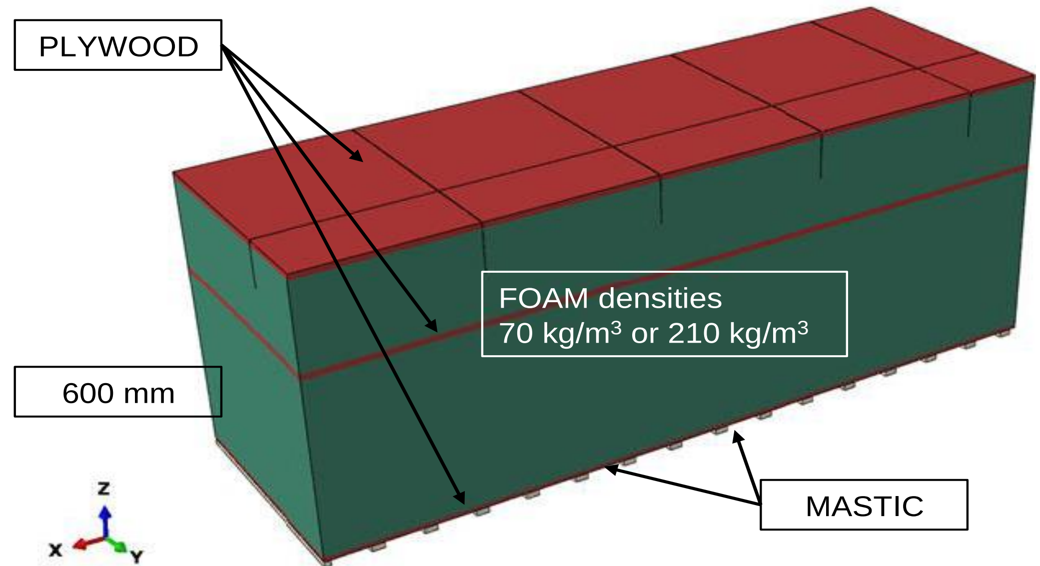


- The T600, already moved to CERN, is being upgraded introducing technology developments while maintaining the already achieved performance:
  - new cold vessels and new purely passive insulation;
  - refurbishing of the cryogenic and purification equipment;
  - new cathode with better planarity;
  - upgrade of the light collection system;
  - new faster, higher-performance read-out electronics.
- In parallel, the muon tagging system will be designed and constructed.
- Fully automatic tools for event reconstruction have to be developed.
- The detector is expected be transferred to FNAL before end of 2016 for installation, commissioning and start of data taking with ν beam.

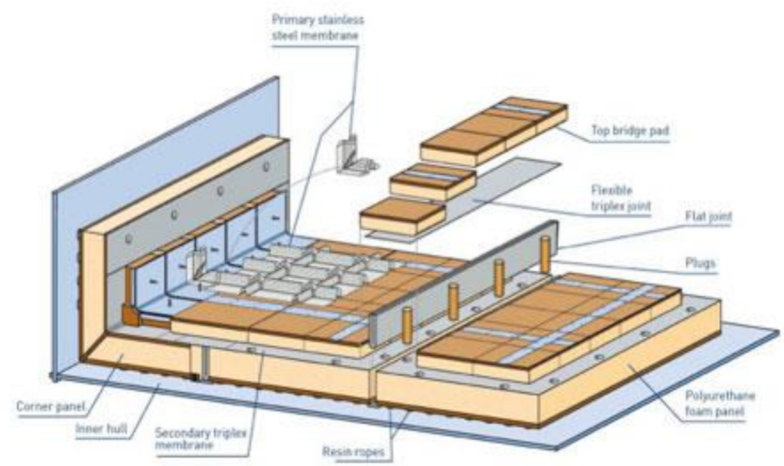
Transfer of ICARUS-T600 from LNGS to CERN

New Thermal Insulation



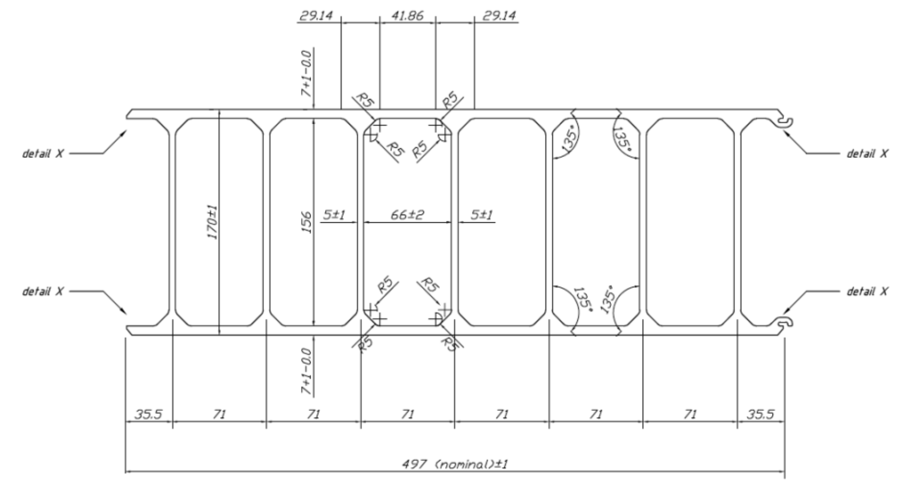


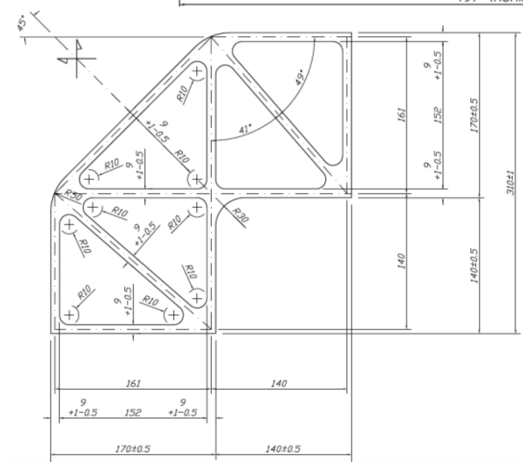
- Purely passive insulation chosen for the installation at CERN, coupled to standard cooling shield with boiling Nitrogen;
- Technique developed for 50 years and widely used for large industrial storage vessels and ships for liquefied natural gas.
- Expected heat loss through the insulation: T600 ≈ 6.6 kW
- No internal membrane is required

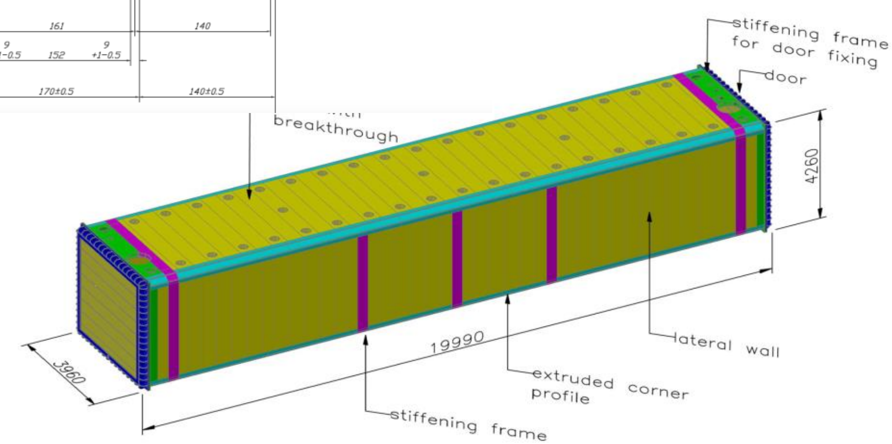


New Cold Vessels

- *A major activity is the construction of the new main LAr containers.*
- *Cold vessels will be made by extruded aluminum profiles welded together to form a vacuum tight double walled container of parallelepiped shape.*
- *Tender for the production of the extrusion matrices and of the extruded profiles has been awarded at the beginning of April 2015. Production will start by May 2015 and to be completed by July.*
- *Pre-assembly of panels will be done by ext. companies.*
- *Final assembly will be done at CERN, in building 185.*
- *The first cold vessel will be completed by end of 2015; the second one will be ready ~6 months later.*

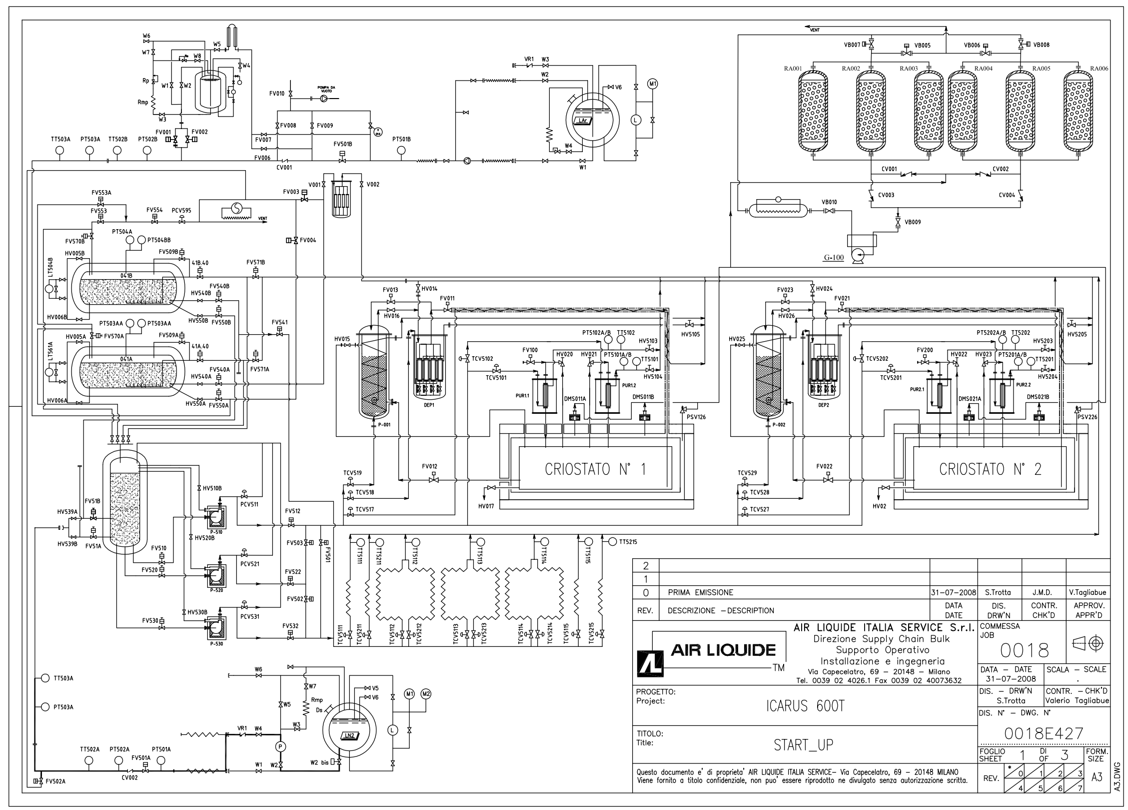






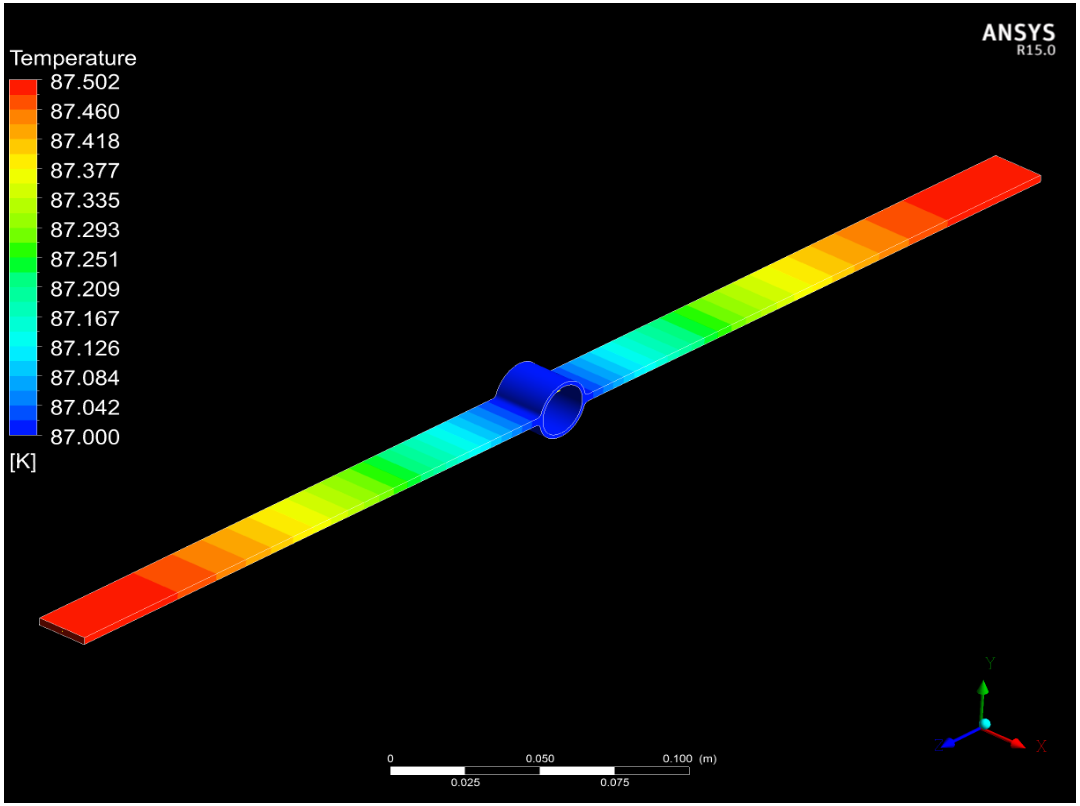
Overhauling of cryogenics and purification systems

- *Overhauling and partial reconstruction of the T600 cryogenics and purification systems is under the main responsibility of CERN. All the cryogenic equipment that could be recovered from the T600 plant in LNGS has been transported to CERN and is presently hosted inside dedicated containers and in dedicated areas (the most delicate components). The original layout of the T600 plant is presently being revised: it will be re-organized into self-consistent sub-units (skids) to be built and fully tested prior to delivery to FNAL.*



New cold shields

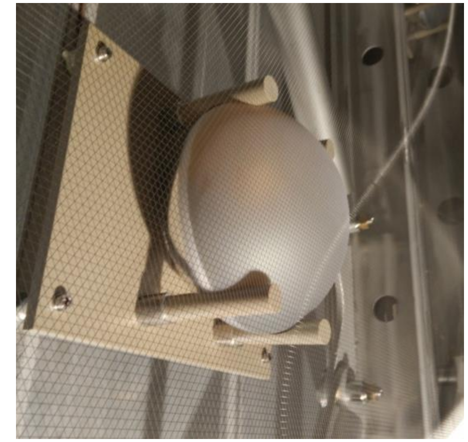
- *The cold shield, that surrounds completely the two cold vessels and into which Nitrogen is circulated in bi-phasic conditions to ensure temperature uniformity, has to be completely rebuilt. A preliminary design has been done, based on thin aluminum panels. A test will be performed in CERN's cryolab to validate the computing model. The engineering design will be finalized before Fall 2015. Production will take place by end 2015.*

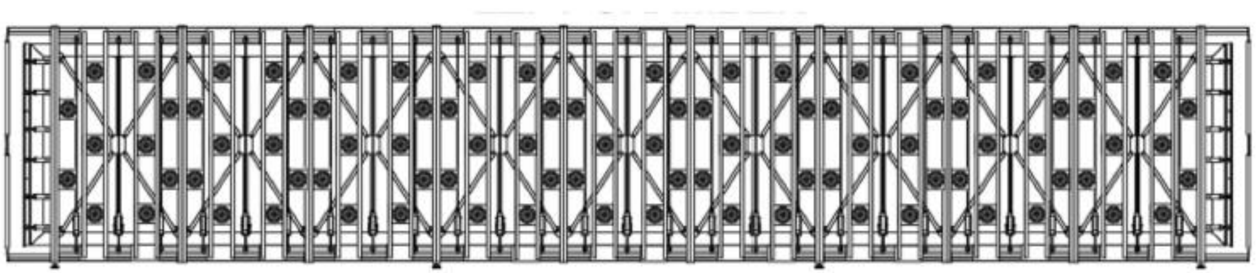


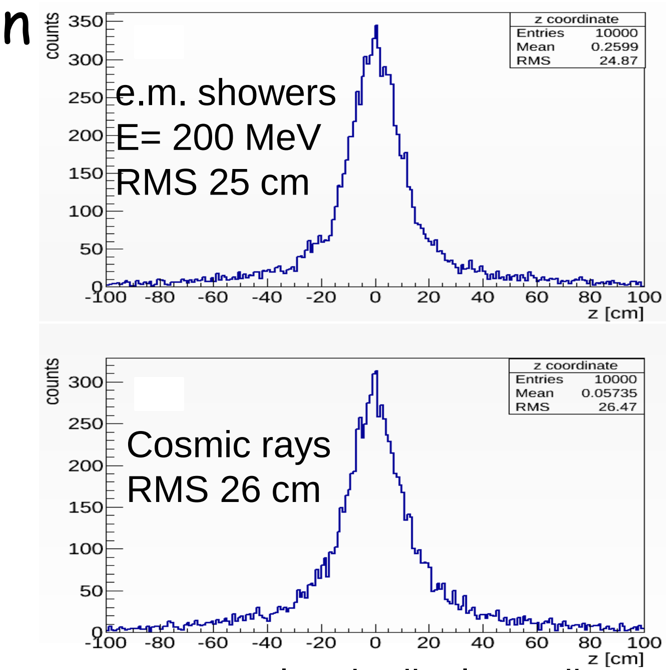
Upgrade of the light collection system

Large surface 8" PMTs will be adopted as in T600, but major improvements in space/time event localization capabilities are required to reject cosmogenic bckg:

- higher quantum efficiency (QE);
- improved photocathode coverage > 5%. F.i. a 90 PMTs per TPC layout, compatible with present mechanical structure, allows to obtain longitudinal resolution < 0.5 m (MC simulation with 5% effective QE).







longitudinal coordinate

- new PMT voltage divider, to prevent induced spurious signals on TPC wire planes;
- better performance readout electronics, with ~ ns resolution, to exploit the bunched beam structure.

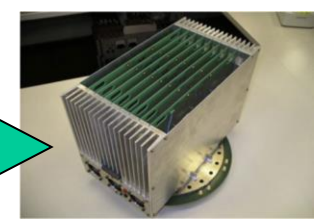
The need for an upgraded electronics

- Architecture of ICARUS-T600 electronics is based on analogue low noise "warm" front-end amplifier, a multiplexed 10-bit 2.5 MHz AD converter and a digital VME module for local storage, data compression & trigger information.
- A signal to noise ratio better than 10 and a ~ 0.7 mm single point resolution were obtained during the LNGS run, resulting in precise spatial reconstruction of events and allowing to measure muon momentum by multiple scattering (MS) with $\otimes p/p$ ~14% in the 0.4-4 GeV/c range.
- Even though well suited for larger size LAr-TPC, ICARUS-T600 electronics is affected by some limitations, like the asynchronous sampling of all channels within 400 ns sampling time, which slightly affects the muon momentum measurement with multiple scattering, and data throughput mainly due to the choice of VME standard (8-10 MB/s).
- Some conceivable improvements concern:
  - adoption of high frequency serial ADCs with synchronous sampling;
  - housing and integration of electronics onto detector;
  - adoption of a modern serial bus architecture with optical links for faster transmission rate (Gbit/s).

New simplified/compact design (warm electronics)

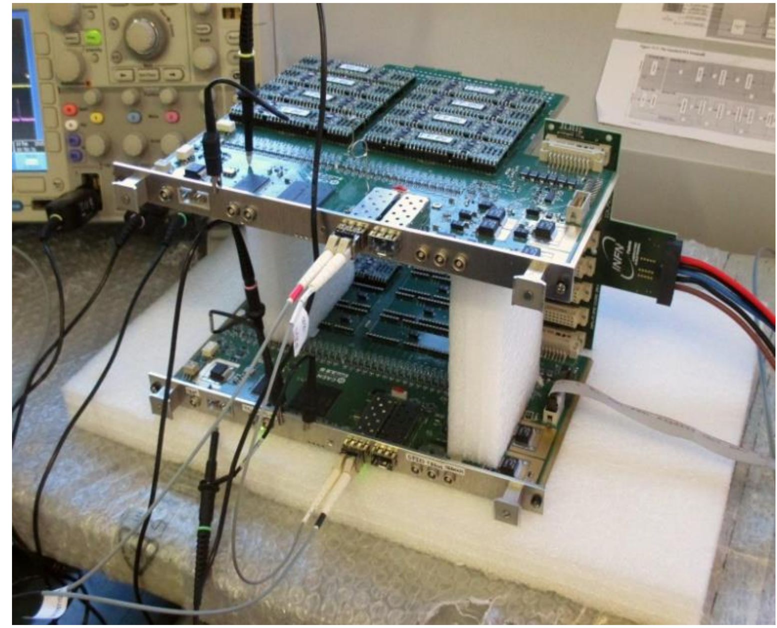
- A relevant change concerns the adoption of serial ADCs (10-12 bits, one per channel) in place of the multiplexed ones used in T600 al LNGS.
- The advantage of *synchronous* sampling of all channels (at 400 ns sampling time) of the whole detector, is relevant the improvement of the muon momentum measurement resolution.
- The digital part is fully contained in a single high performance FPGA per board, that handles signal filtering and organizes the information provided by the serial ADCs.
- A new, compact design, has been conceived to host both analogue and digital electronics directly on the ad-hoc flanges.
- Prototype boards are under test at Padova INFN-LNL.

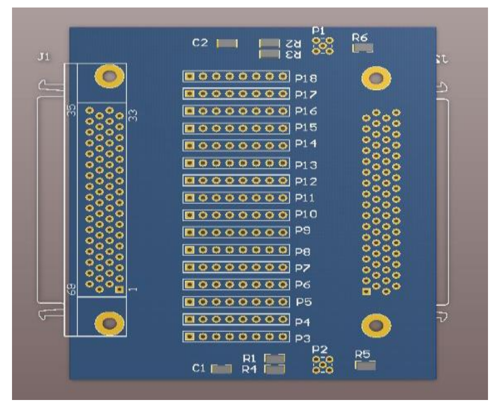
From 595 to 10 liters

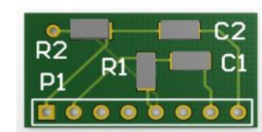


Tests of warm Analogue Electronics

- Each board serves 64 channels and has serial optical link. One flange uses daisy chained single fiber for read-out and slow control. Each channel has a 128kbyte memory buffer.
- First results with test pulses on new front-end with 1.5 us peaking-time show a noise level compatible with expectations (<700 el., Cd = 0).
- T600 TPCs re-cabling will be redone with some improvements aiming at el. noise reduction
  - Decoupling capacitor and biasing resistors will be placed on the TPC frame in LAr avoiding the biasing voltage on the signal cables and feed-throughs (special adapter is under development with 32 decoupling capacitors and biasing resistors);
  - New dedicated coaxial biasing cable.







General layout of adapter board

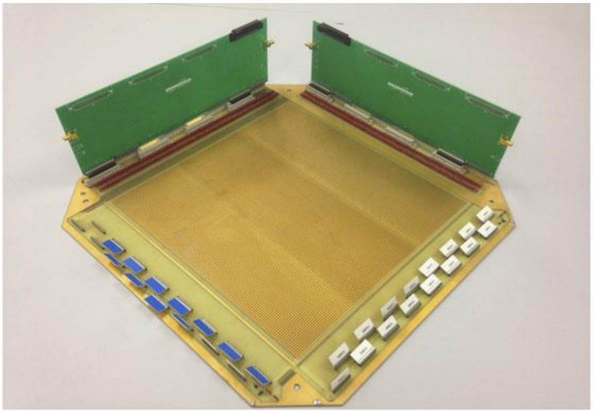
- test on electronic component (capacitors, resistors) reliability in LAr as well as on the HV cable leakage in LAr are presently underway.

Tests of Cold Analogue Electronics

- *Due to the short cables inside T600 (C_{cable}= 95pF compared to C_{wires}= ~75pF) the use of electronics in LAr close to the wires, should not be a major improvement in term of noise.*

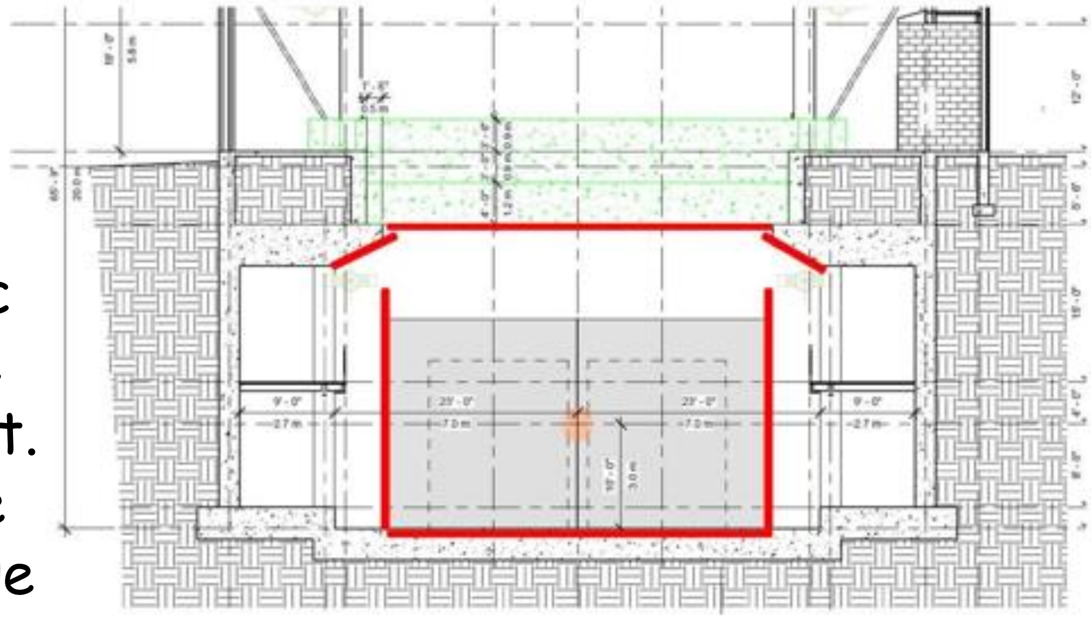
- However, A new version of the analogue readout electronics working at LAr temperature is presently being tested in collaboration with BNL, at CERN, on a 50 liters chamber:
  - Front-end preamps located on the wire frame in LAr
  - For compatibility with the new ICARUS DAQ design, on the ICARUS boards the cold front-end receiver will replace the warm front-end.

- Preliminary results, at room temperature, on 30 cm long wires, exhibit noise performance in line with expectations.



Cosmic Rays Tagging System

- A detector to identify and tag comic rays entering the LAr active volume is being studied in details. A minimum efficiency of 95% is required to reject cosmic rays induced backgrounds to the levels needed for the experiment. A common solution for the three detectors (LAr1-ND, MicroBooNe and T600) is needed, most likely based on plastic scintillators.
- The technical implementation of the Cosmic Rays Tagging System is under discussion. A significant contribution from US-based groups on this subject is expected and warmly welcome.



Far Detector Building

- A final review of the (new) experimental hall to host the T600 at FNAL was done the 8th of April 2015.
- The building design is almost finalized, with latest details being included.
- Ground breaking is expected by May 2015.
- Beneficial occupancy is expected by November 2016.

Conclusions

- Exposed in the underground Hall B of the Gran Sasso Laboratory at 730 km to the neutrino beam from CERN, the ICARUS T600 neutrino experiment made of 770 ton of highly purified LAr has successfully completed a three years physics program at CNGS.
- The T600 detector has now been moved to CERN for a significant overhauling in view of a short baseline neutrino experiment on the FNAL Booster and NUMI beams based on three detectors at different baselines (near: Lar1-ND, mid: MicroBooNE, far: ICARUS).
  The experiment is expected to start data taking by end 2017.
- Aim of the experiment is the definitive clarification of the LSND signal in terms of neutrino oscillations (ν_e appearance). The experiment will also provide a significant amount of data in the energy range of interest for future Long Baseline experiments.
- A second phase of the experiment is also under consideration with a fourth detector at a longer distance (≥1500 m) to extend the sterile neutrino search to lower Δm^2 as indicated by cosmology (ν_μ disappearance).


Thank you !

Considerations about the opportunity of burying front-end

- Cable length inside T600, for collection and induction 1, is 2,2 meters with cable that has C=43pf/m capacitance, that means C_{cable}= 95pf:
  - Detector itself has a wire capacitance that is ~75pf;
  - Cold electronics means avoiding a capacitance of ~95pf;
  - Noise measured (~1500e) during LNGS run indicated an "equivalent" capacitance ≥400pf, much more than the cable plus detector (unavoidable) capacitance.
- This indicates that the major problem is NOT the cable capacitance but the correct grounding of the signal generator (detector itself).
- Even with cold electronics the grounding problem may remain the main issue.