Consuntivi Scientifici
Esperimenti di Gruppo 2

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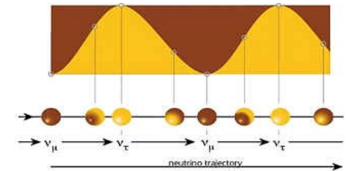
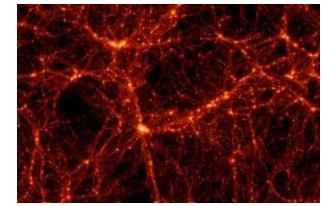
CdS INFN Pavia
10 maggio 2015

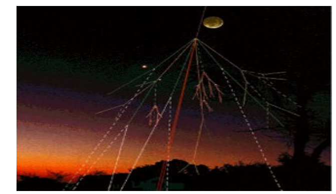
Attività: 4 settori di ricerca

Le attività sono state raggruppate in quattro settori (rispetto ai sei dello scorso anno):

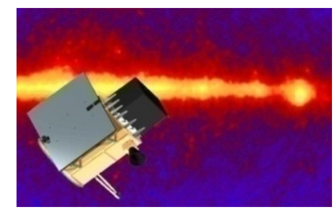




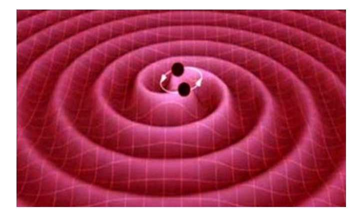
Linea 1: Fisica del neutrino.
Oscillazioni di neutrino, decadimento doppio beta.



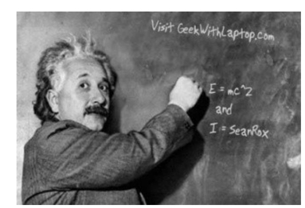
Linea 2: Radiazione dall'Universo
Raggi cosmici, raggi gamma, neutrini cosmici, antimateria.



Linea 3: L'Universo Oscuro
Materia Oscura, Energia Oscura, Assioni.



Linea 4: Onde gravitazionali, fisica generale e quantistica.
Onde gravitazionali, misure di g, effetti relativistici, proprietà quantistiche del vuoto.



Risorse 2016

Distribuzione delle risorse per linea di ricerca.

Linea (* = nuova sigla)	N. esp.	Budget 2016
1-Fisica del neutrino. BOREXINO, CUORE, CUPID*, GERDA, HOLMES (DTZ), ICARUS, JUNO, T2K	8	32.7%
2-Radiazione dall'Universo AMS2, AUGER, CTA-RD, DAMPE, FERMI, ***GAMMA400,*** JEM-EUSO, KM3, LHAASO*, LSPE, LVD, MAGIC, NIRFE (DTZ), WIZARD	14	36.8%
3-L'Universo Oscuro COSMO_WNEXT, CRESST, DAMA, DARKSIDE, KWISP (DTZ), MOSCAB (DTZ), NEWS*, QUAX, SABRE*, XENON	10	13.2%
4-Onde gravitazionali, fisica generale e quantistica FISH, G-GRANSASSO-RD, HUMOR, LARASE, LIMADOU_CSN2, LISA-PF, MAGIA-ADV, MOONLIGHT-2, PVLAS, SUPREMO, VIRGO	11	17.3%
Totale **FTE** **Persone** **Istituzioni**	**43**	**12150 k€** **715** **1048** **29**

SIGLE CHIUSE: AURIGA, ROG, NESSIE-RD, OPERA, LUCIFER-RD **+ GAMMA400**

Confronto 2012-2016

	2012	2013	2014	2015	2016
Budget (k€)	**12259**	**11368**	**11483**	**12875**	**12150**
FTE	**586**	**550**	**605**	**660**	**715**
Persone	**845**	**856**	**865**	**931**	**1048**

CSN2 è la commissione che è cresciuta di più in termini di FTE/persone nel quinquennio 2012-2016:

- FTE cresciuti del 22% dal 2012;
- Numero persone cresciuto del 24% dal 2012;
- Stesso budget 2012...

Gruppo 2 a Pavia

Distribuzione dei ricercatori e delle risorse per linea di ricerca.

Linea	Esperimento	FTE/persona
1. F. Boffelli, T. Cervi, A. Menegolli, C. Montanari*, A. Rappoldi, G.L. Raselli, M. Rossella, A. Scaramelli, M. Spanu, M. Torti. **In congedo al CERN (0 FTE)*	ICARUS	6.3/10
***2.** P.W. Cattaneo, A. Rappoldi*	*GAMMA400*	*0.6/2*
3.		
4.		
Totale	**2**	**6.9/12**

Gamma-400

P.W. Cattaneo, A. Rappoldi

- Esperimento cancellato a fine 2015 dopo la riconfigurazione del rivelatore da parte dell'agenzia spaziale russa ROSCOSMOS.

- Attività del gruppo pavese svolta attraverso la sigla di CSN5 CaloCube (spin off di GAMMA400).

- Si rimanda la relazione sulle attività di GAMMA400 ai consuntivi di Gruppo V.

- Per quanto riguarda il futuro, il gruppo sta seguendo l'evoluzione della fisica dei raggi cosmici dell'ente, e manifesta un interessa per gli esperimenti GAPS (misura di antideuterio su pallone) e HERD (raggi cosmici e raggi gamma di alta energia sulla stazione spaziale cinese).

GAMMA400 PV: anagrafica

Nome	Qualifica	FTE	Note
Paolo Walter Cattaneo	Primo Ricercatore	0.3	Responsabile locale
Andrea Rappoldi	Primo Tecnologo	0.3	
TOTALE		0.6	

ICARUS/WA104

F. Boffelli, T. Cervi, A. Menegolli, C. Montanari, A. Rappoldi,
G.L. Raselli, M. Rossella, A. Scaramelli, M. Spanu, M. Torti.

ICARUS/WA104

- Nel 2013 ICARUS ha concluso le attività presso i LNGS, dopo aver raccolto dati con il rivelatore T600 sia dal fascio CNGS sia con raggi cosmici.
- Il T600, con circa 500 tonnellate di massa attiva, è tuttora la più grande TPC ad Argon liquido mai costruita.
- Una ricerca di oscillazione $\nu_\mu - \nu_e$ in appearance mode, per verificare l'eccesso di eventi LSND (evidenza di neutrini sterili?) era stata già proposta nel 2009 dalla Collaborazione ICARUS (arXiv:0909.0355, SPSC-P-345, SPSC-P-347).
- L'esperimento si basava su due rivelatori "gemelli" per indentificare Δm^2 e $\sin^2(2\theta)$ osservando a differenti distanze le interazioni di neutrino.
- Un esperimento simile, ma da collocarsi al BNB del FNAL era stato riproposto nel 2013.
- Il proposal finale (approvato a livello 1 dal PAC 2015) prevede tre rivelatori LAr TPC (LAr1ND, MicroBOONE e ICARUS) per la ricerca di neutrini sterili al BNB del FNAL.

Anomalie nel settore dei neutrini

- Tre classi principali di anomalie:
  il segnale disappearance negli eventi anti-ν_e:

  (1) rivelati da esperimenti su reattore short-baseline, dove il rapporto osservato/predetto è $R = 0.938 \pm 0.023$;

  (2) da esperimenti sui neutrini solari che hanno usato sorgenti di calibrazione dell'ordine del Mega Curie, con $R = 0.86 \pm 0.05$;

  inoltre:

  (3) osservazione di un eccesso di interazioni ν_e da fasci artificiali di neutrini m (LSND: evidenza di oscillazioni a 3.8 σ).

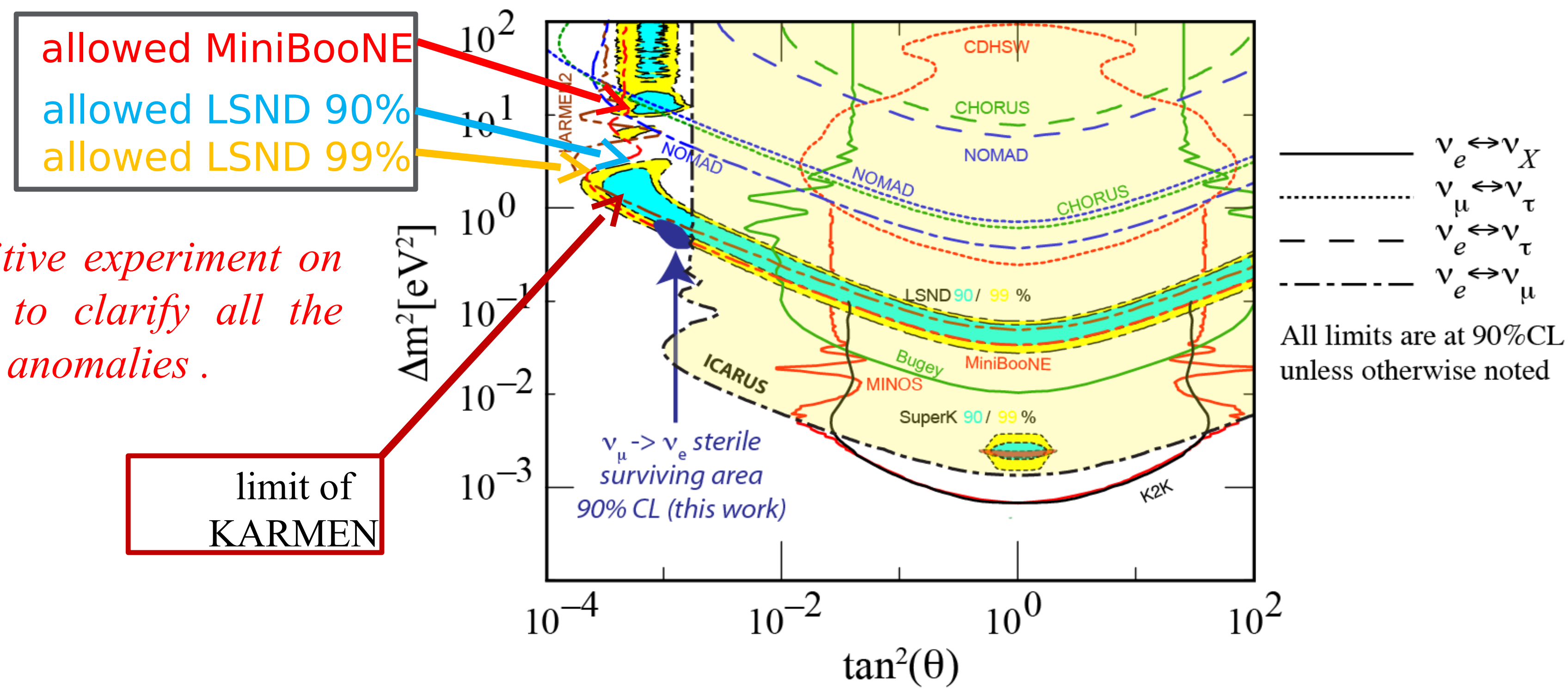
- Questi segnali indipendenti suggeriscono la possibile esistenza di almeno un quarto neutrino "sterile" che piloti le oscillazioni a piccole distanze, con Δm^2_{new} dell'ordine di $\approx 1\ eV^2$ e angoli di mixing $\sin^2(2\theta_{new})$ relativamente piccoli.

- I risultati del satellite Planck e la cosmologia del Big Bang indicano che possa esistere al più uno stato sterile, con massa $m < 0.4$ eV.

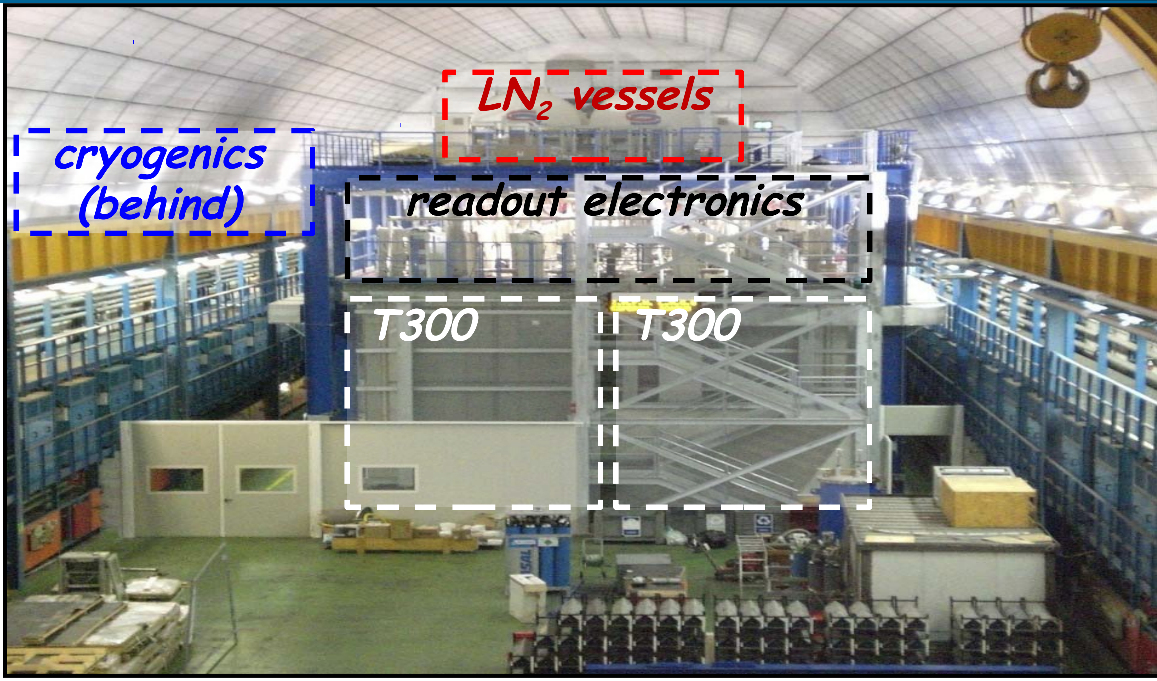
Search for LSND-like anomaly by ICARUS at LNGS

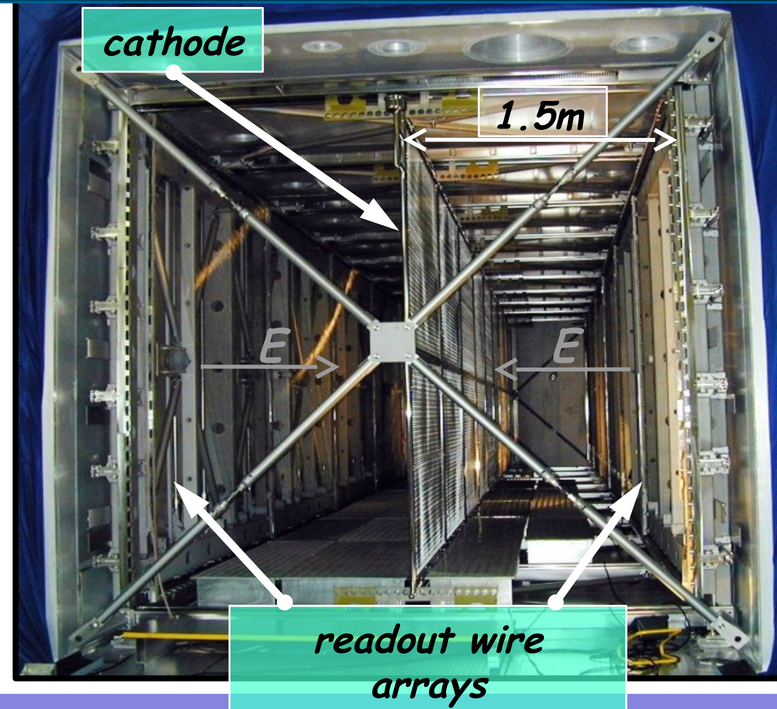
- ICARUS searched for νe excess related to LSND-like anomaly on the CNGS ν beam (~1% intrinsic νe contamination, L/Eν ~36.5 m/MeV). No excess was observed: number of νe events as expected in absence of LSND signal.
- Analysis on 7.23 x 10^{19} pot event sample provided the limit on the oscillation probability $P(\nu\mu \rightarrow \nu e) \leq 3.85\ (7.60) \times 10^{-3}$ at 90 (99) % C.L.
- ICARUS result indicates a very narrow region (Δm^2~0.5 eV^2, $\sin^2 2\theta$~0.005) where all experimental results can be accommodated at 90% CL.

Need for a definitive experiment on sterile neutrinos to clarify all the reported neutrino anomalies .

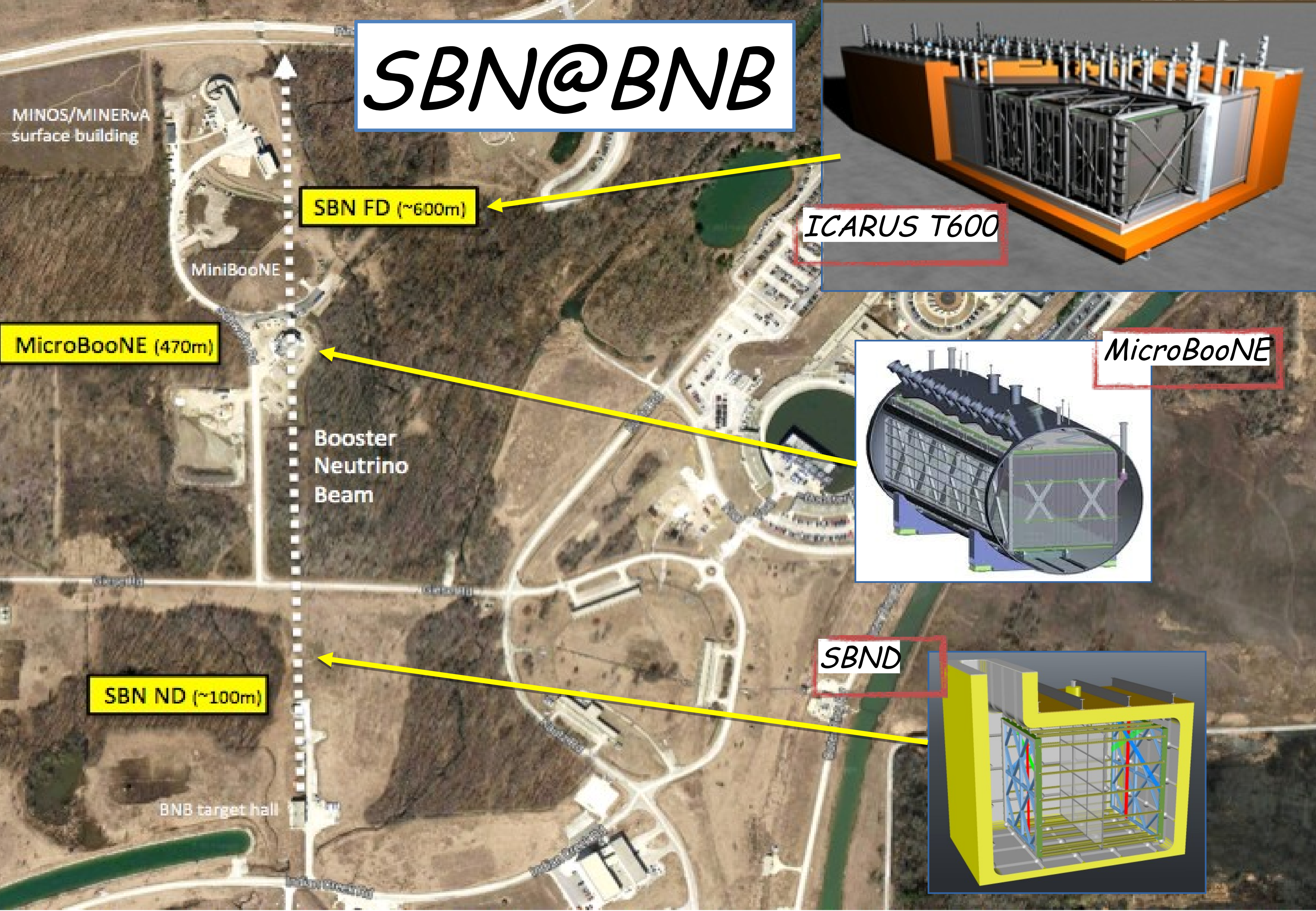


Rivelatore ICARUS T600



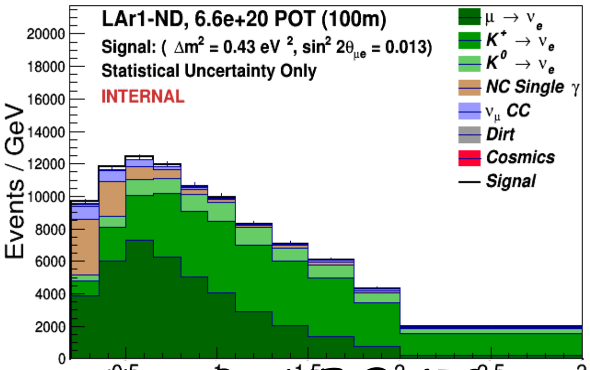


- *Two identical modules (T300)*
  - 3.6x3.9x19.6 = 275 m^3 each
  - Liquid Ar active mass: ~476 t
  - Drift length = 1.5 m (1 ms)
  - HV = -75 kV; E = 0.5 kV/cm
  - drift velocity = 1.55 mm/µs
  - Sampling time 0.4 µs (sub-mm resolution in drift direction)
- *4 wire chambers*
  - 2 chambers per module
  - 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

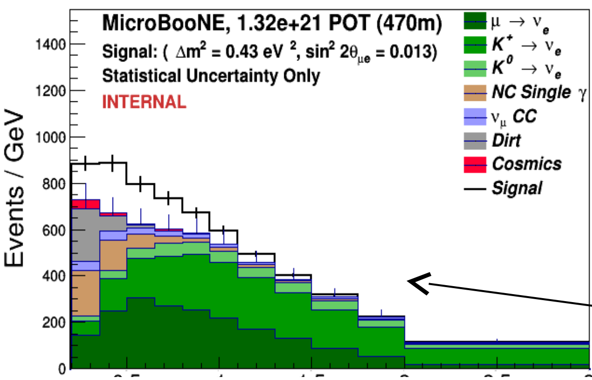

SBN@BNB
MINOS/MINERvA surface building
SBN FD (~600m)
ICARUS T600
MiniBooNE
MicroBooNE (470m)
MicroBooNE
Booster Neutrino Beam
SBND
SBN ND (~100m)
BNB target hall

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

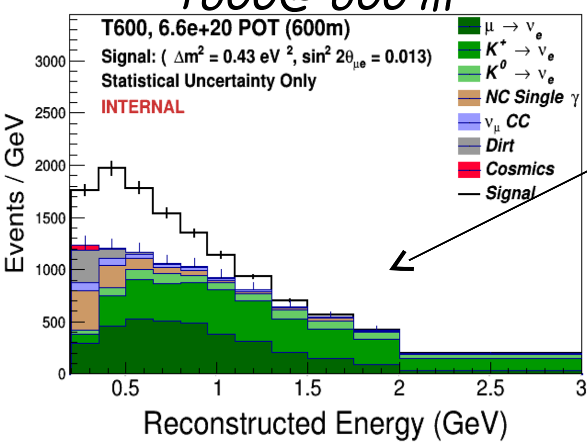
LAr1ND @ 100 m



MicroBooNE @ 470 m



T600@ 600 m

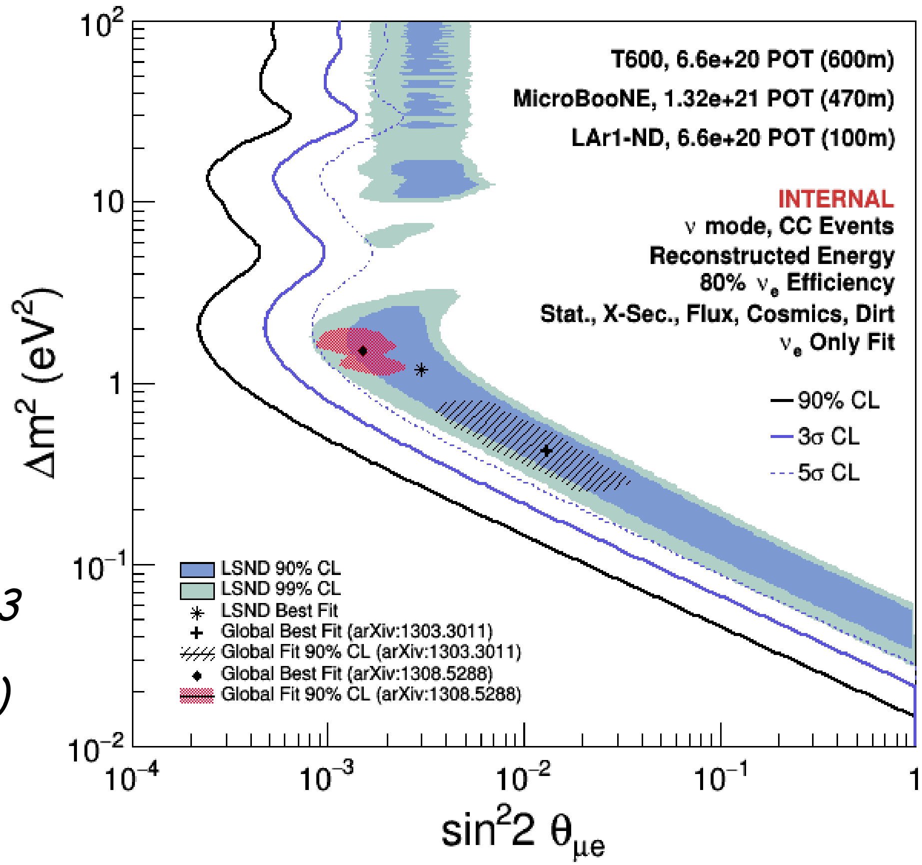


Expected exposure sensitivity of $\nu_\mu \rightarrow \nu_e$ oscillations for 3 years - 6.6 10^{20} pot BNB positive focusing (6 years for MicroBooNE).

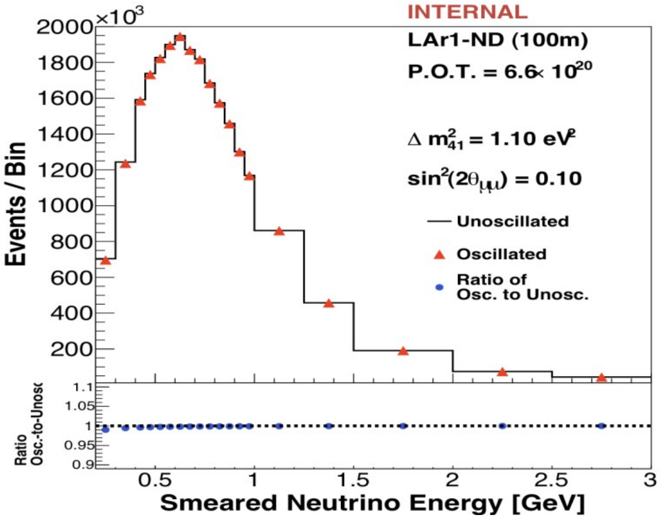
Example for

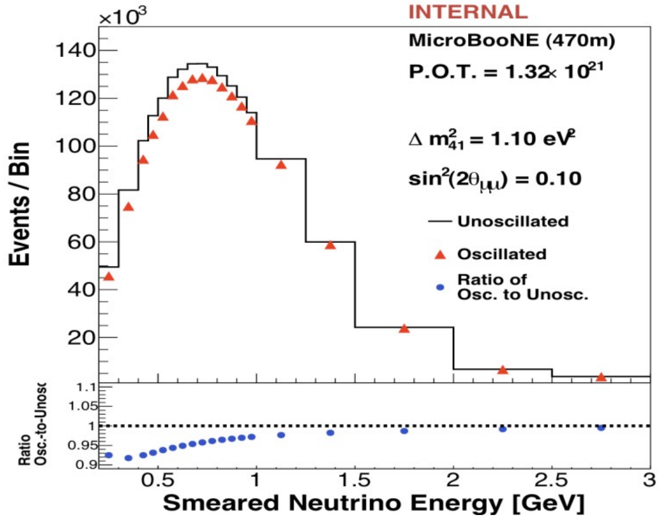
($\sin^2(2\theta)$=0.013

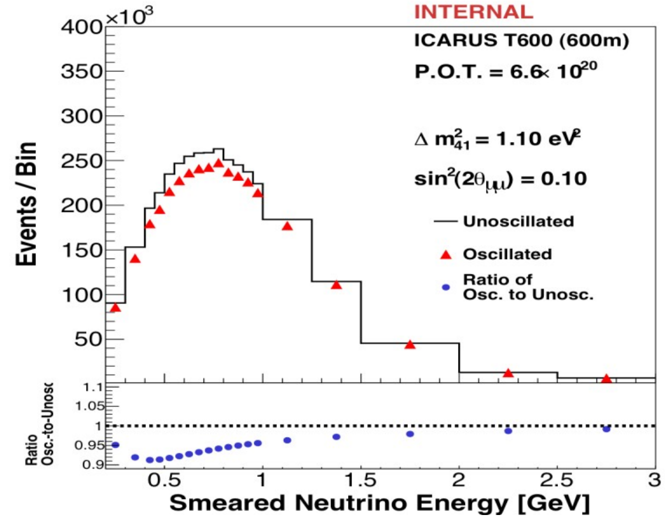
Δm^2=0.43 eV^2)



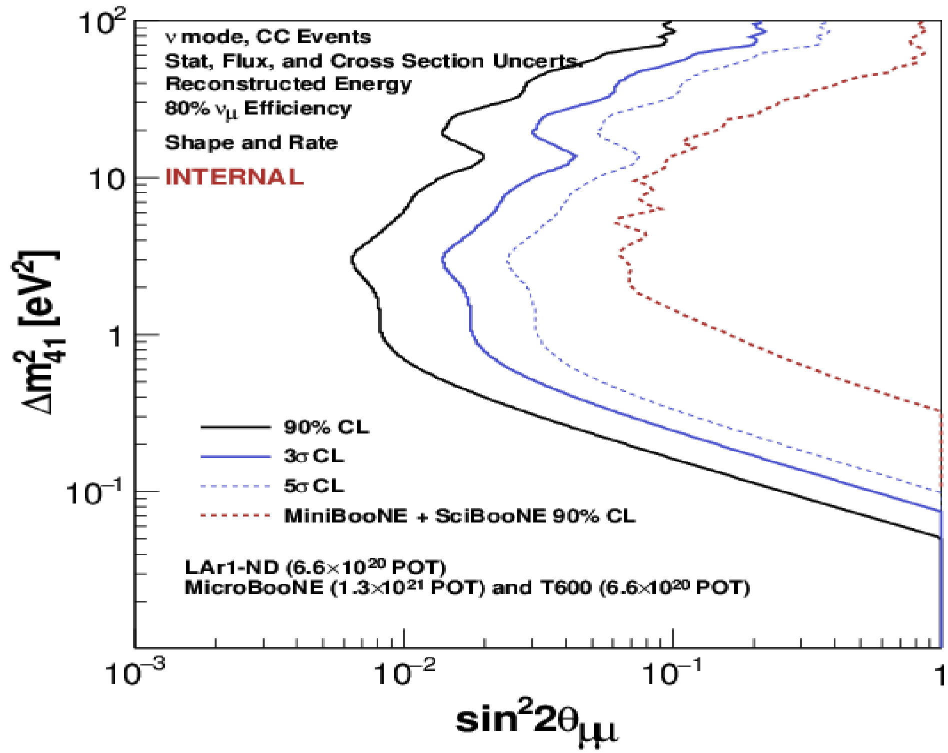
The LSND 99%CL region is covered at the ~5σ level





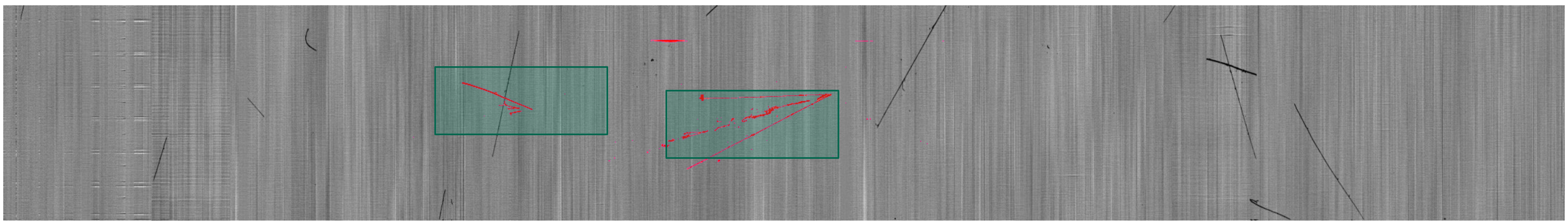


- Disappearance analysis can profit from high rates and correlations between the three LAr-TPC detectors
- SBN can extend sensitivity by 1 order of magnitude beyond SciBooNE+MiniBooNE



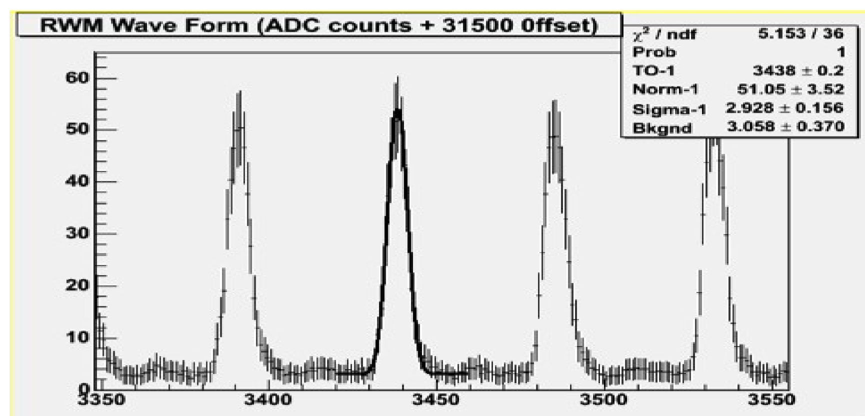
LAr TPC in superficie

- Circa 12 tracce per drift di 1 ms sono previste per ciascun modulo del T600
- Per ricostruire la posizione di ciascuna traccia è necessario conoscere il timing di ciascun deposito di carica sui fili rispetto al tempo di trigger dato dal gate aperto in corrispondenza del fascio BNB.
- Si prevede di implementare un tagger per muoni cosmici esterno al volume attivo.



Cosmic rays (PV) + low energy CNGS beam events

Ulteriore reiezione si otterrà dal timing fornito dal sistema di PMT interno per la rivelazione della luce di scintillazione (utilizzo della struttura a bunch del fascio BNB).



Progetto WA104 al CERN

L'INFN ha firmato un MoU per il progetto **WA104 al CERN** e ha concluso un accordo di cooperazione nel contesto della collaborazione DUNE (oscillazioni long baseline con detector ≈ 40 kton LAr TPC).

- Il T600, spostato al CERN a fine 2014, è in corso di upgrade:
  - Nuovi corpi freddi e isolamento puramente passivo.
  - Rinnovamento degli impianti criogenico e di purificazione.
  - Nuovo catodo con miglior planarità.
  - Nuovo sistema di raccolta della luce di scintillazione.
  - Nuova elettronica di read-out.

- Il rivelatore sarà trasferito al FNAL all'inizio del 2017 per l'installazione, il commissioning e la presa dati con il fascio BNB.

ICARUS T600 building at FNAL

- Engineering design of the infrastructures (Far Detector building and services) to host the T600 plant at FNAL was completed in July 2015. Groundbreaking started in August 2015.

ICARUS T600 building at FNAL

- According to schedule, the two T300 modules will be ready for shipment by the end of 2016, which is compatible with the foreseen beneficial occupancy of the Far Detector building in beginning 2017.

Ground level walls under construction and preparatory work for the loading dock (front) April 7, 2016

Cryogenics and purification systems

- Maintenance of cryogenic pumps and valves from the Gran Sasso installation was started in 2015. Selection of parts to be recovered for operations at FNAL is underway, with the help of CERN Cryolab group.

- Tests of the new, dual-phase N2 cold shield have been done in 2015. Lab. measurements confirm the numerical model, and technical drawings now are being prepared.

- New purifiers for LAr are being tested at CERN, to substitute Oxysorb/Hydrosorb filters used in the previous ICARUS experience. Such filters allowed reaching extremely high purity results (electron lifetime $\tau_e > 16$ ms), but their content of hexavalent chromium has raised safety issues for use in US laboratories.

- A search for chemical residuals of chromium was performed at CERN on the T600 detector in 2015, yielding no positive results. A similar analysis will be done on detectors at FNAL employing the copper filters, to ensure that no Cu dust is found anywhere in the active volume. Also on this depends the final choice, still under discussion, between the Oxysorb commercial solution, widely used in Europe (ICARUS, ATLAS), and the copper purifiers.

Characterization of copper filters

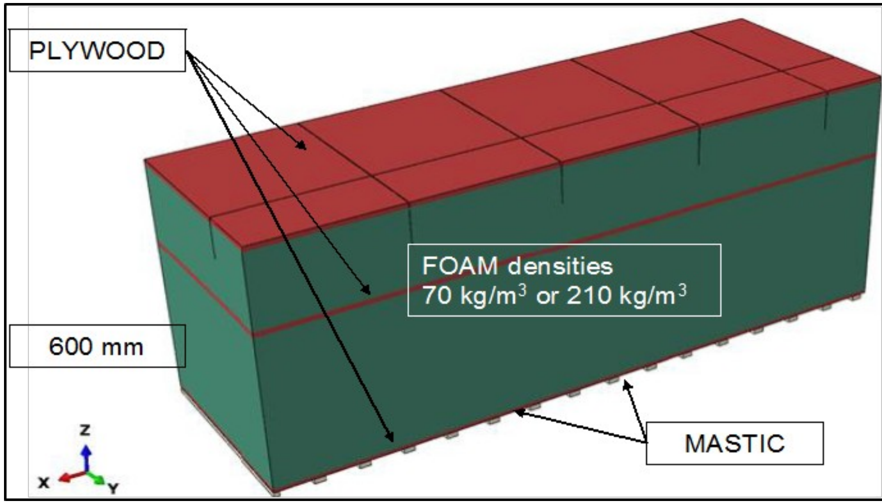
- New filters, based on copper, were proposed by FNAL laboratory. Such purifiers were developed by the lab. personnel, who has the know-how to carry out regeneration in house. The filters are made of alumina pellets with copper deposited on them (10% mass of Cu). Copper surface is rough, in order to increase active adsorption area.

- A small, 50 liters TPC at CERN is used to characterize the copper filters:
  - to verify that their performance is compatible with ICARUS requests;
  - to size new cartridges to be used for detector filling at FNAL.

- Results with gas circulation show that purification capability is compatible with ICARUS needs: easily reached $\tau_e > 10$ ms, above the sensitivity of the 50 l chamber. Measured adsorption capacity in gas is of 5 g of O_2 per kg of filtering material. Further tests for purification in liquid phase are being prepared. According to experience from US colleagues, a factor 5-10 decrease in adsorption capacity is expected.

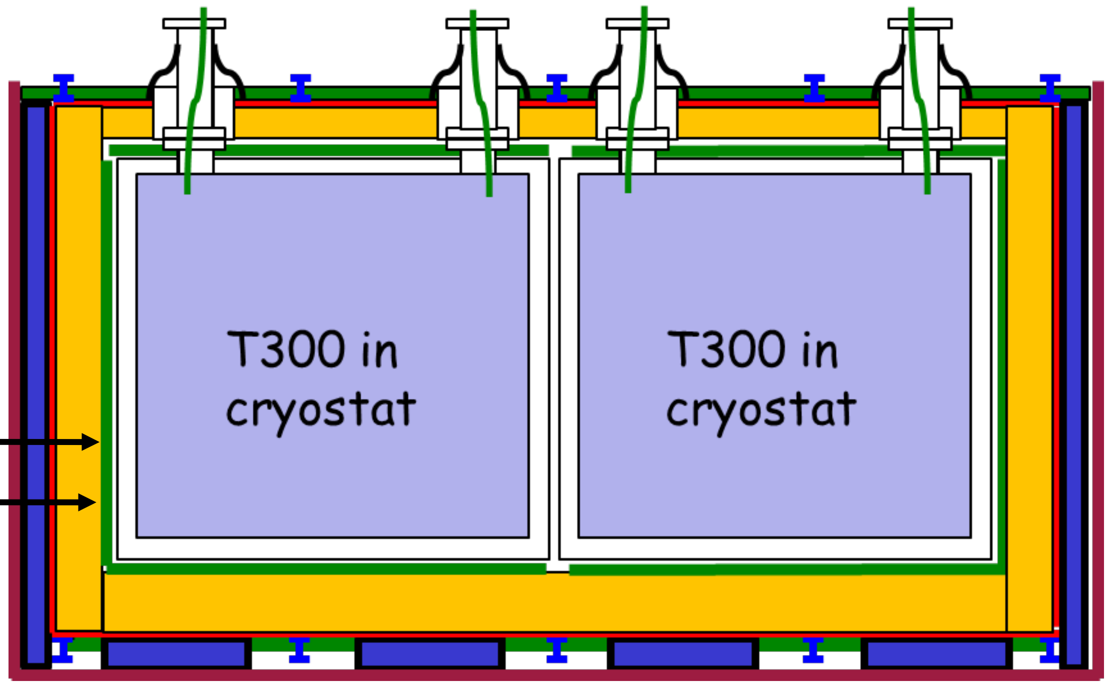
Thermal Insulation

- Purely passive insulation (right), coupled to two-phase N2 cooling shield.
- Insulation technique developed with membrane for LNG transport ships. Expected heat loss through insulation: ≈ 6.6 kW (10-15 W/m2).
- No internal membrane is required here.
- Preliminary design of the insulation 2 years ago by GTT: to be refined and integrated in the next two months.



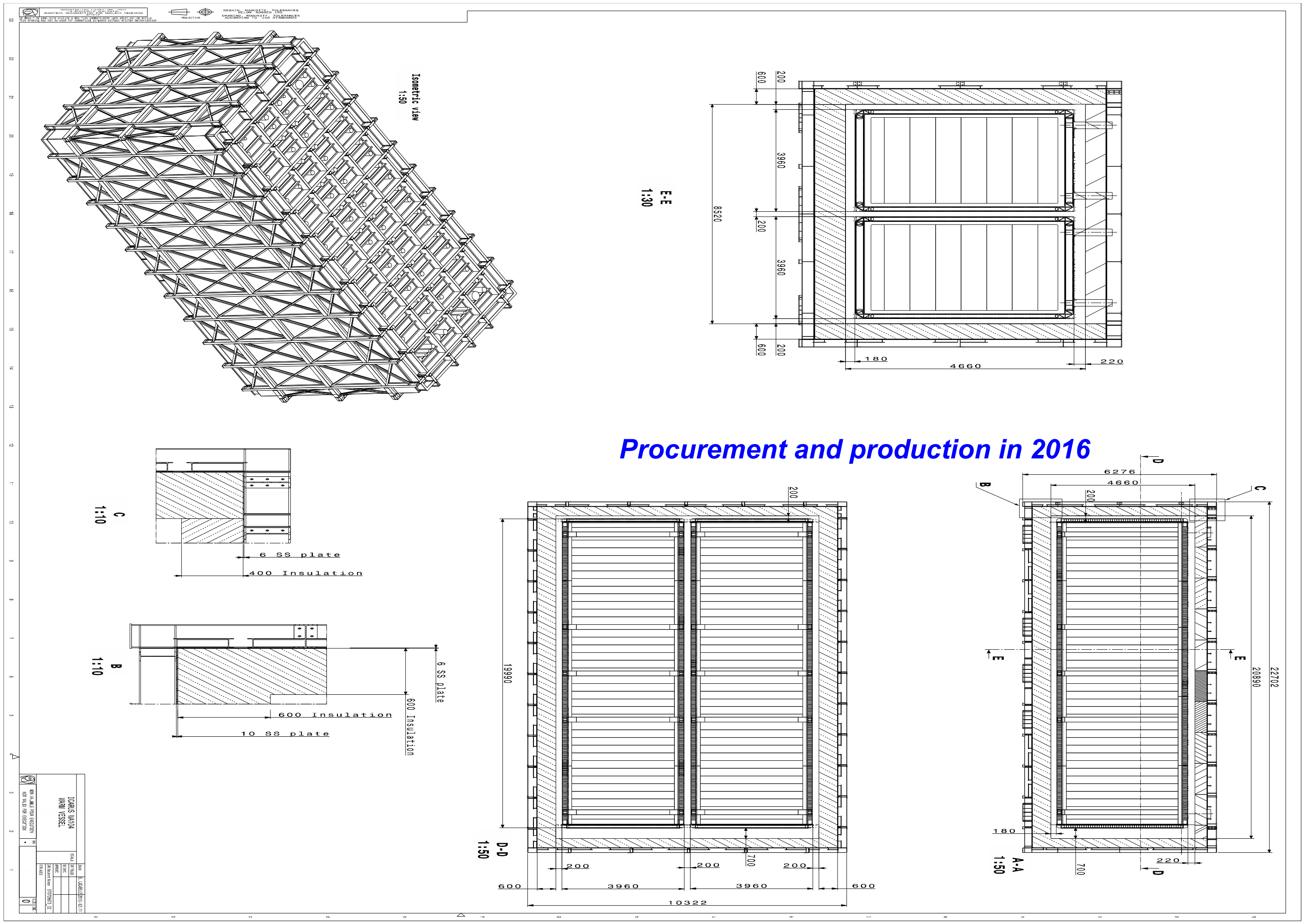
Simplified front view of the installed ICARUS detector:

- N2 cooling shield;
- thermal insulation;
- external warm vessel (see next slide).



T600 warm vessel

- Design, under CERN responsibility, is almost complete and ready for tender.
  - Close collaboration with the FNAL Integration and Installation team, to prepare the warm vessel installation procedure on site.



Procurement and production in 2016

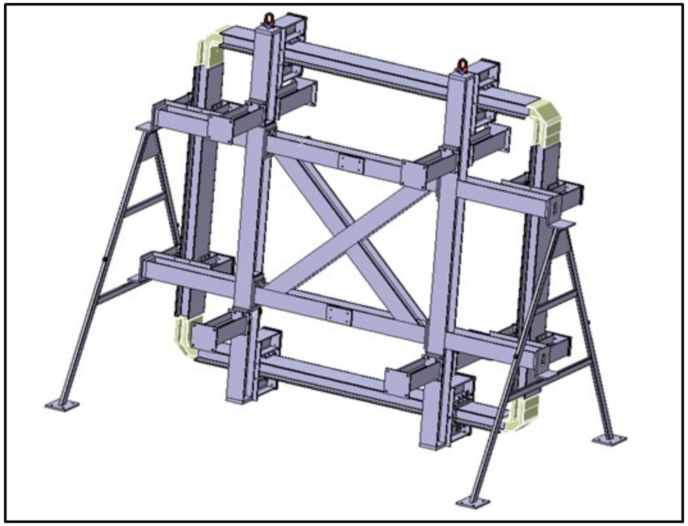
New cold vessel construction

- The new cold vessels are being assembled at CERN, under supervision of Main Workshop personnel. Production and delivery of the pre-assembled aluminum profiles (orders sent out in 2015) is on schedule.
- CERN Main Workshop is also proceeding with the assembly of the stiffening frames, special profiles that will stand the LAr mass. All the pieces of the stiffening frames (angular and "I" profiles) have been delivered at CERN.
- CERN Main Workshop performed intensive tests on various kinds of welds to be performed on the cold vessel. Welding procedures have been defined in order to achieve maximum quality.
- The 1st module is being assembled in bdg. 156 and will be completed in June.
- The 2nd will be ready in October: it will be built in bdg. 185, to allow for partially operating in parallel.

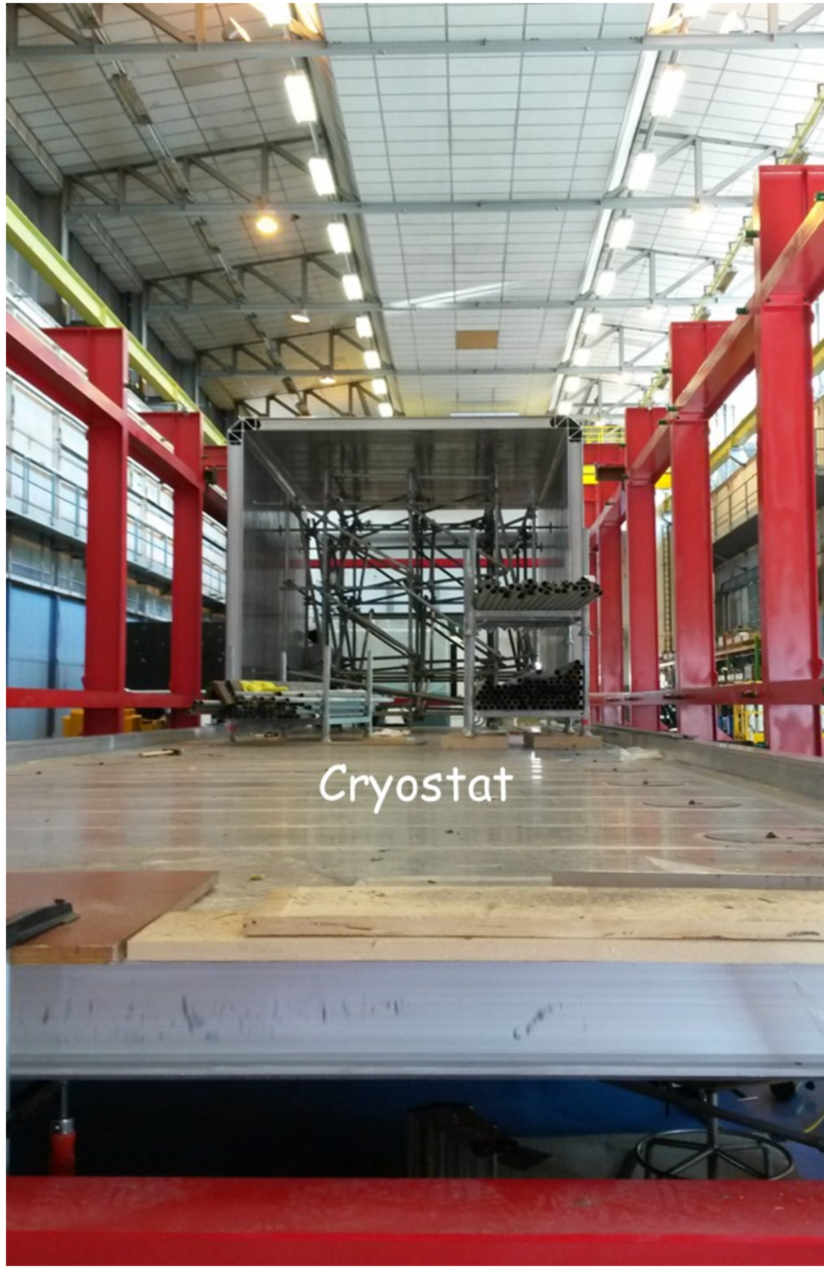
Roof pre-assembly

New cold vessels

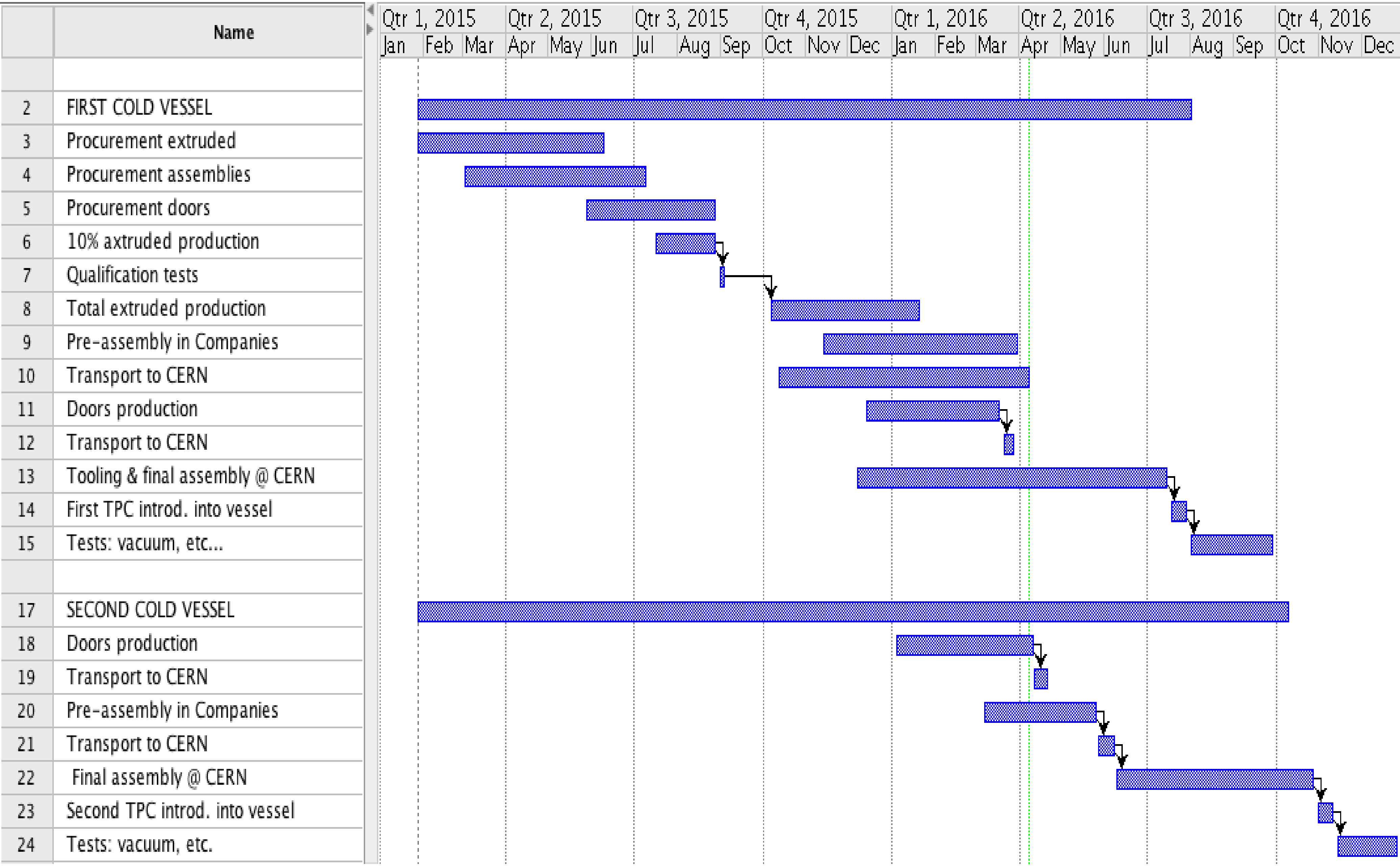
- A dedicated tool was built for the assembly of stiffening frames at CERN.



Main assembly structure

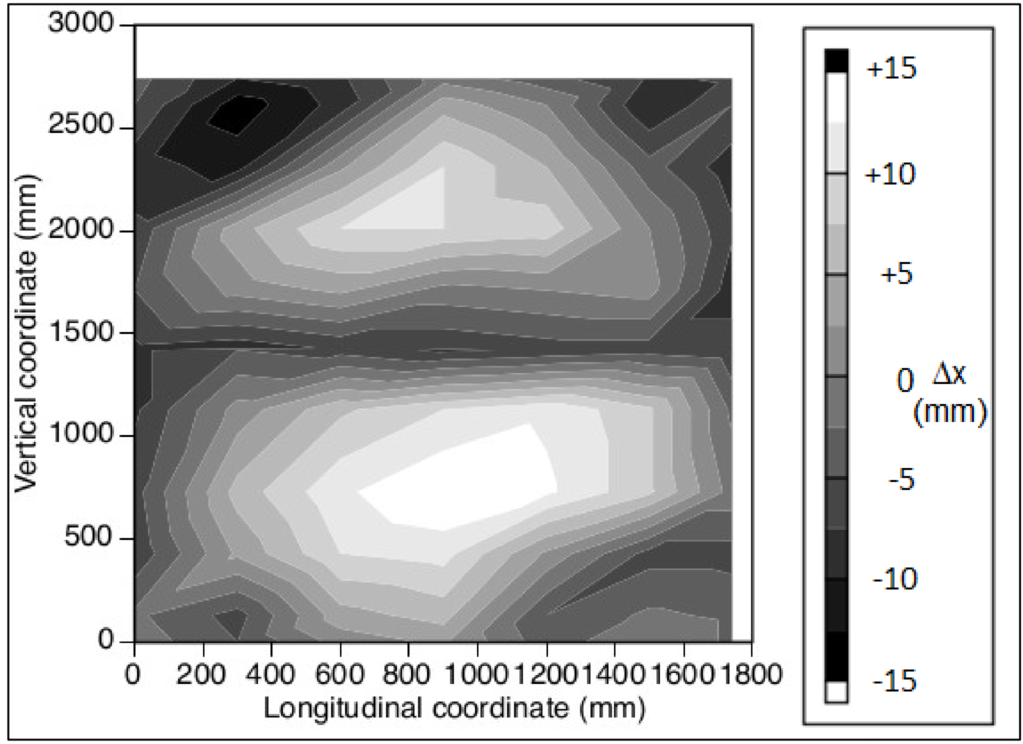


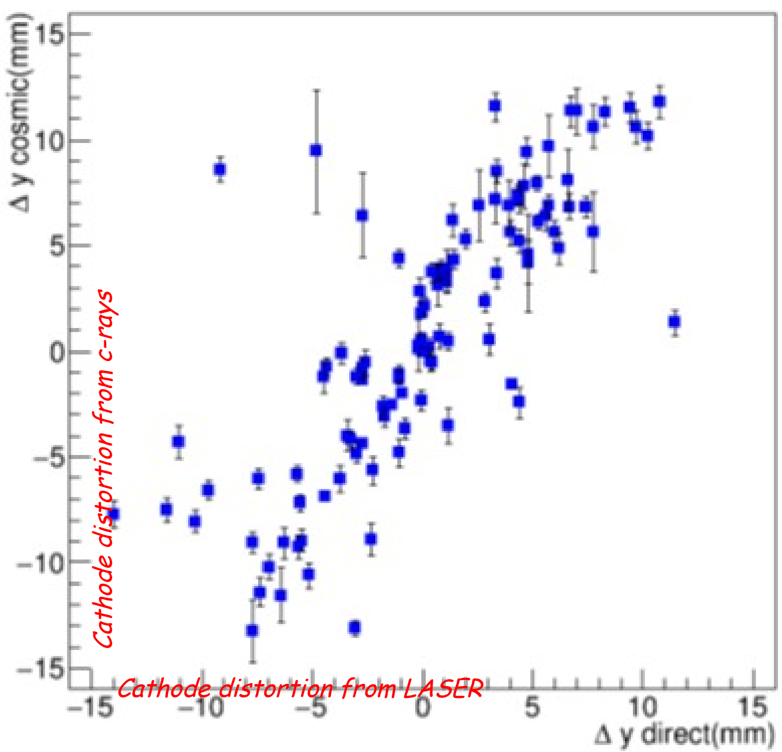
Cold Vessels Time Schedule



Cathode distortion recovery

- Cathode planarity was measured at CERN with a laser-meter: distortions up to $\Delta x = \pm 15$ mm, with respect to a fixed reference distance, are found. In the figure on the right an example is shown of a non-planarity map referring to one single panel.





- Left: correlation between cathode distortion from direct measurements with LASER (at room temperature) and independent measurements exploiting cosmic muon tracks crossing the cathode in LNGS run (LAr temperature). The correlation confirms that the distortions are not due to cool-down.

Cathode flattening intervention

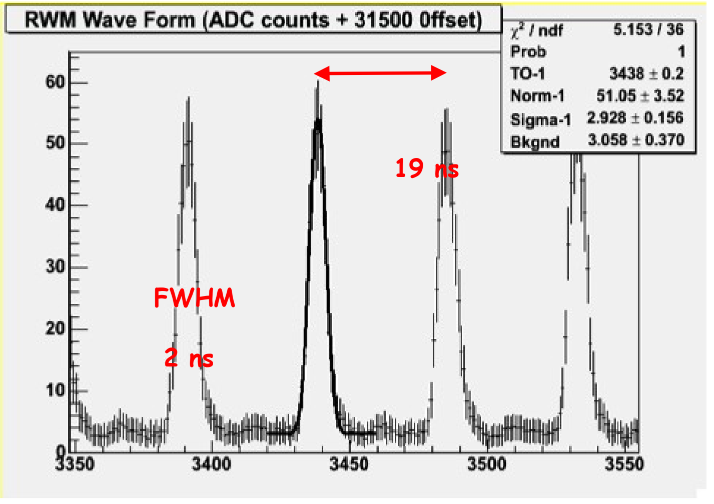
- The panels of the first module underwent in September 2015 a thermal treatment, including local heating and pressing. The intervention, performed by CERN Main Workshop, was successful in reducing the non-planarity to within few mm;
- Panels were reinstalled in the detector after cleaning and electro-polishing.
- The 2nd TPC cathode will be treated in the summer.

The carried out studies and interventions will improve the event imaging and track reconstruction in ICARUS T600 extending the muon momentum measurement by MCS well above the range required by the next short/long base-line neutrino experiments.

Upgrade of the light collection system (Pavia group lead)

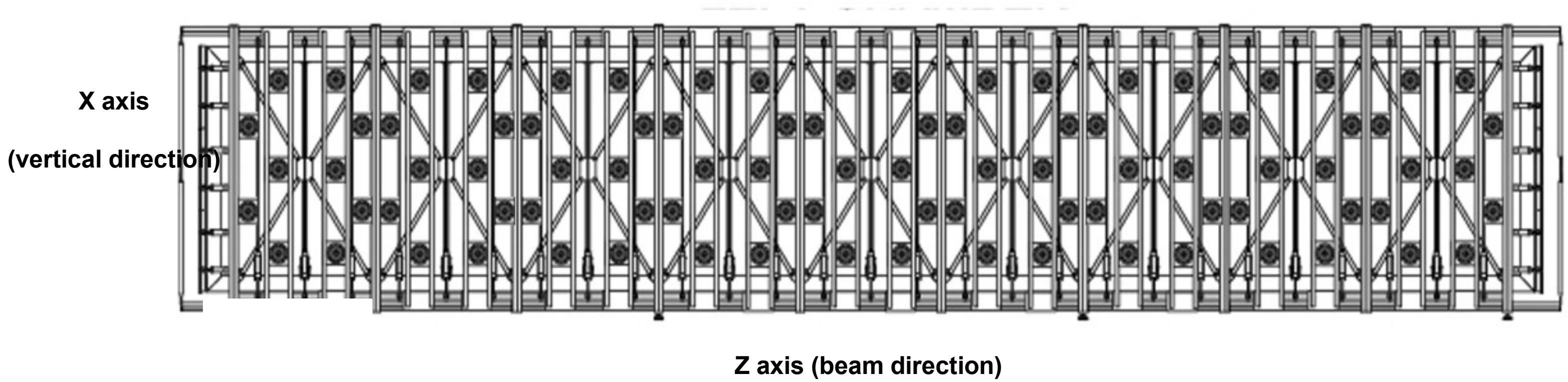
- *The improved light detection system is devoted to:*
  - The generation of a light based trigger signal;
  - The identification of the time of occurrence (t0) of each interaction with high temporal precision;
  - The initial identification of event topology for fast event selection purposes.

- *Main requirements for the light detection system are:*
  - High detection coverage, to be sensitive to low 100 MeV En deposition in LAr;
  - High detection granularity, to localize events/unambiguously associate the collected light to deposited charge;
  - Fast response - high time resolution, to be sensitive to time and evolution of each event in the T600 drift time window (~ 1 ms);
    1 ns precision is required to exploit the available 2ns/19ns bunched beam structure.



New T600 light collection system

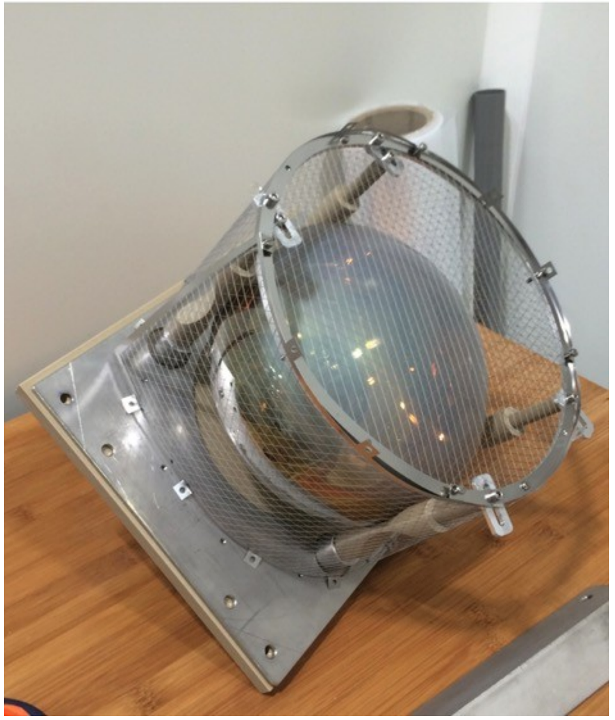
- The new light collection system consists of 90 PMTs 8" HAMAMATSU R5912-MOD for TPC, installed behind each wire chamber (360 PMTs in the whole T600). About 200 mg/cm^2 of wavelength shifter is deposited on each PMT window. The photo-cathode coverage corresponds to 5% of the wire plane area.
- The number of photo-electrons collected per MeV of deposited energy in a single TPC is ~ 15 phe/MeV (9 phe/MeV for events close to the cathode) allowing the possibility to trigger low energy (100 MeV) events with fairly high threshold and multiplicity.



- An event localization better than 0.5 m and an initial classification of different topologies (cosmic ms, e.m. showers, $\nu\mu$ CC) can be obtained exploiting the arrival time of prompt photons and the collected light signal intensity.

PMT procurement status

- A total of 400 R5912-MOD PMTs, which include 10% of spare samples, were produced by Hamamatsu and delivered to CERN.
- Each PMT is equipped with a customized cryogenic base. The biasing of dynodes is obtained through a passive resistive voltage divider, directly mounted on the PMT flying-leads. Divider components were selected for operation at cryogenic temperature.
- New mechanical supports for the PMT installation were designed. Each device is set inside a wire shielding cage which prevents the induction of PMT pulses on the facing collection planes. All the necessary components were delivered to CERN.
- A test installation of one basic unit was carried out to check mechanical interferences and to perfect the assembly sequence.



PMT test at CERN

- All the PMTs have been tested and characterized at room temperature.
- Tests were carried out using a pulsed LASER source (405 nm) illuminating each PMT by means of an optical fiber.
- A sample of 60 PMTs was also tested at cryogenic temperature (all PMTs are mechanically tested in LN2 by Hamamatsu).
- Present results on all 400 PMTs are consistent with the nominal values given by the manufacturer and are compliant with the technical specifications (IT-4126/DG-DI/WA104 Tender Form).
- Tests on all PMTs are concluded.
- All the PMTs are being coated by evaporation with ~200 mg/cm2 of Tetra-Phenyl-Butadiene (TPB) which acts as a wavelength-shifter from VUV to visible light.
- About 5 PMTs are coated per day; the whole production for the first T600 half-module is concluded; the production for the second half-module is underway.

Activities at CERN

Activities on the PMTs are organized at CERN in three different areas:

Room temperature tests
IdeaSquare building 3179

Tests carried out in consecutive bunches of 16 samples.

Cold tests
building 182

A cryogenic facility allows the simultaneous measurement of 10 PMTs in a LAr bath.

TPB deposition
TE-Laboratory hall (B169)

The facility allows the production of ~5 coatings per day.

PMT electronics and calibration system (PV+MiB)

- Studies are ongoing also to choose the electronics for PMT signal acquisition: the input dynamics must allow for recording the fast component of the scintillation light and, at the same time, for recording the single photons arriving from the slow component.

- The ADC sampling frequency should be sufficiently high, in order to allow a time resolution of 1 ns, with a buffer size long enough to collect all the events occurring during the 1 ms acquisition windows. Possible acquisition boards will be tested in the next months.

- To obtain a proper 1 ns timing resolution, a PMT timing calibration system is necessary to compensate individual channel delays and transit-time drifts. The equalization of all the channels will be performed by splitting the signal from a fast LASER to all the PMTs.

- The system will be made by fused fiber splitters, optical switches and optical patch-cords. The fibers to be inserted in the detector were selected for LAr temperature endurance and were commissioned. Each element of the system will be tested for proper installation and functionality.

ICARUS PV: anagrafica

Nome	Qualifica	FTE	Note
Fabrizio Boffelli	Docente Univ. a contratto	-	
Tommaso Cervi	Dottorando	1	
Alessandro Menegolli	Ricercatore Universitario	0.6	
Claudio Montanari	Primo Ricercatore	-	Mobilità al CERN
Pio Picchi	Associato Senior	-	
Andrea Rappoldi	Primo Tecnologo	0.4	
Gian Luca Raselli	Ricercatore	1	Responsabile locale
Massimo Rossella	Primo Tecnologo	0.3	
Alberto Scaramelli	Associato Senior	1	
Maura Spanu	Dottorando	1	
Marta Torti	Dottorando	1	
TOTALE		6.3	

ICARUS PV: attività 2015/2016

- Collaborazione per disegno nuovi criostati e isolamento termico.

- Ripristino della planarità dei catodi.

- Test a caldo e a freddo dei nuovi PMT per la rivelazione di luce di scintillazione in LAr. Deposizione di w.l.s. sulle finestre dei PMT per la conversione della luce VUV in visibile.

- Analisi dati LNGS e sviluppo software per analisi dati FNAL.

- R&D nuovi tipi di foto-rivelatori a temperature criogeniche (SiPM).

ICARUS PV: pubblicazioni 2015

- M. Antonello et al. "*Operation and performance of the ICARUS T600 cryogenic plant at Gran Sasso underground Laboratory*", JINST, vol. 10, p. P12004 (2015)

- A. Falcone et al., "*Comparison between large area photo-multiplier tubes at cryogenic temperature for neutrino and rare event physics experiments*", Nucl. Instr. Meth. A787, 55-58 (2015).

- A. Falcone et al., "*Vacuum ultra-violet and ultra-violet scintillation light detection by means of silicon photomultipliers at cryogenic temperature*", Nucl. Instr. Meth. A787, 216-219 (2015).

ICARUS PV: conferenze 2015

- C. Montanari, "*ICARUS*", 16th International Workshop on Neutrino Telescopes (Venice)

- T. Cervi, "*Characterization of SiPM for cryogenic application*", Frontier Detectors for Frontier Physics (La Biodola, Isola d'Elba, Livorno)

- A. Falcone, "*Performance of large area PMTs at cryogenic temperatures for neutrino and rare event physics experiments*", 4th International Conference on New Photo-Detectors (Moscow)

- M. Torti, "*Search for space charge effects in the ICARUS t600 LAr-TPC*" , 4th International Conference on New Frontiers in Physics (Kolymbari).

- M. Spanu, "*Evaporation test for the ICARUS-T600 new light collection system*", VI International Pontecorvo Neutrino Physics School (Horný Smokovec).

- A. Falcone, "*Icarus T600 for Short Baseline (SBN) at Fermilab* ", 101th Congresso Nazionale SIF (Roma).

- A. Menegolli, "*ICARUS T600:status and perspectives for sterile neutrino searches at FNAL*", International Workshop for the Next Generation Nucleon Decay and Neutrino Detector (NNN15) and Unification Day 2 (UD2) (Stony Brook, NY)

ICARUS PV: tesi 2015

- **T. Cervi**: "*Caratterizzazione di SiPM a temperature criogeniche, in vista dello svilppo di un rivelatore di luce di scintillazione in TPC a liquido di gas nobile*", **Tesi di Laurea Magistrale**, a.a. 2013/14.