Consuntivi Scientifici
Esperimenti di Gruppo 2

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CdS INFN Pavia
5 giugno 2016

Attività: 4 settori di ricerca

Le attività di CSN2 sono raggruppate in quattro settori:

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.

Bilancio 2016

Distribuzione delle risorse per linea di ricerca.

	N. esp.	Budget 2016
1-Fisica del neutrino. BOREX, CUORE, CUPID, GERDA, HOLMES_2 (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, WIZARD	13	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**	**42**	**12143.5 k€** **717** **1052**

***GAMMA400 chiusa in corso d'anno.**

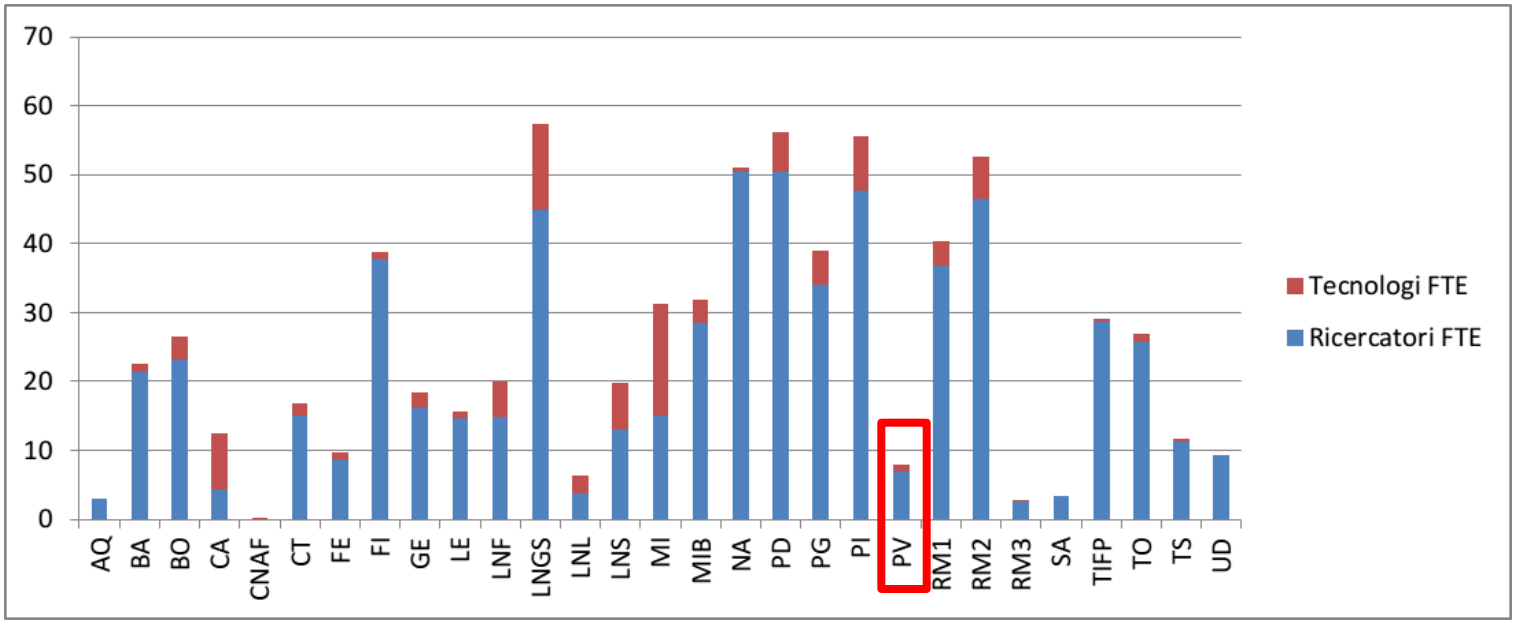
Bilancio: 2012-2016

	2012	2013	2014	2015	2016
Budget (k€)	**12259**	**11367.5**	**11482.5**	**12875**	**12143.5**
FTE	**586**	**550**	**605**	**660**	**717**
Persone	**845**	**856**	**865**	**931**	**1052**

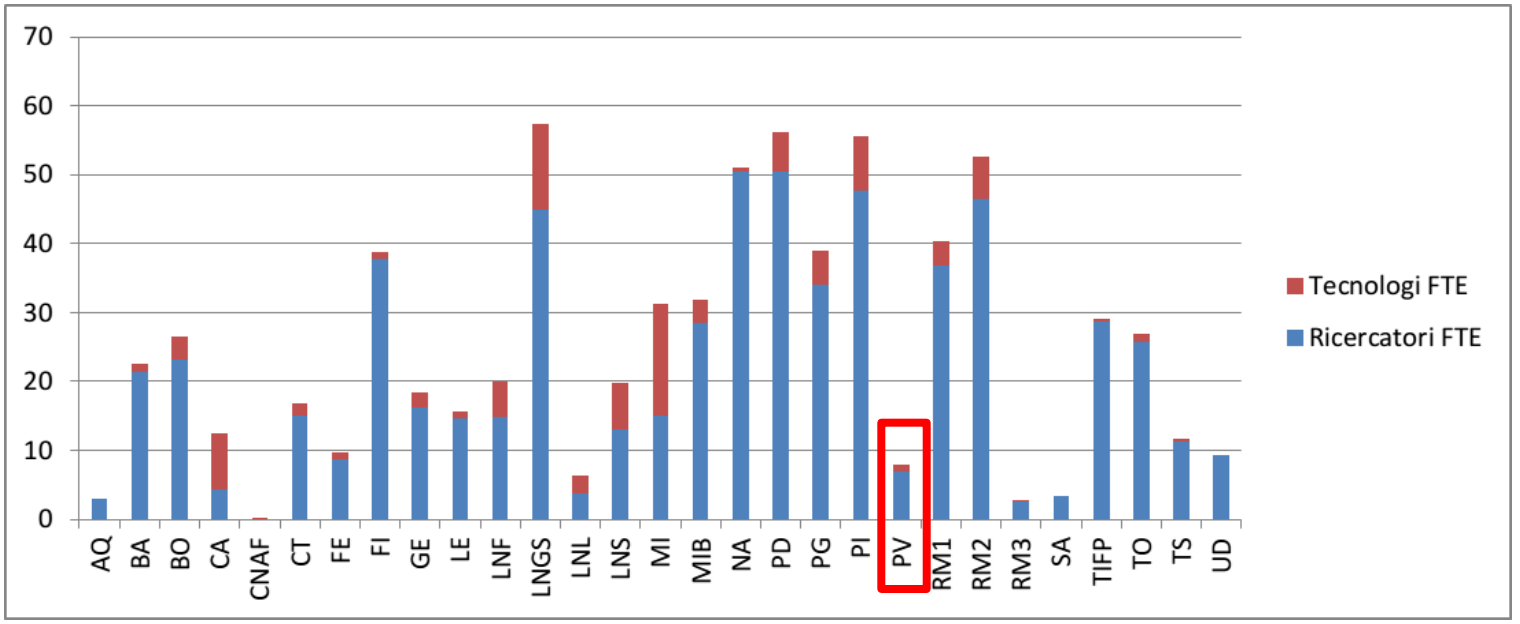
CSN2 è la commissione che è cresciuta di più in termini di FTE/persone nel quinquennio 2012-2016:

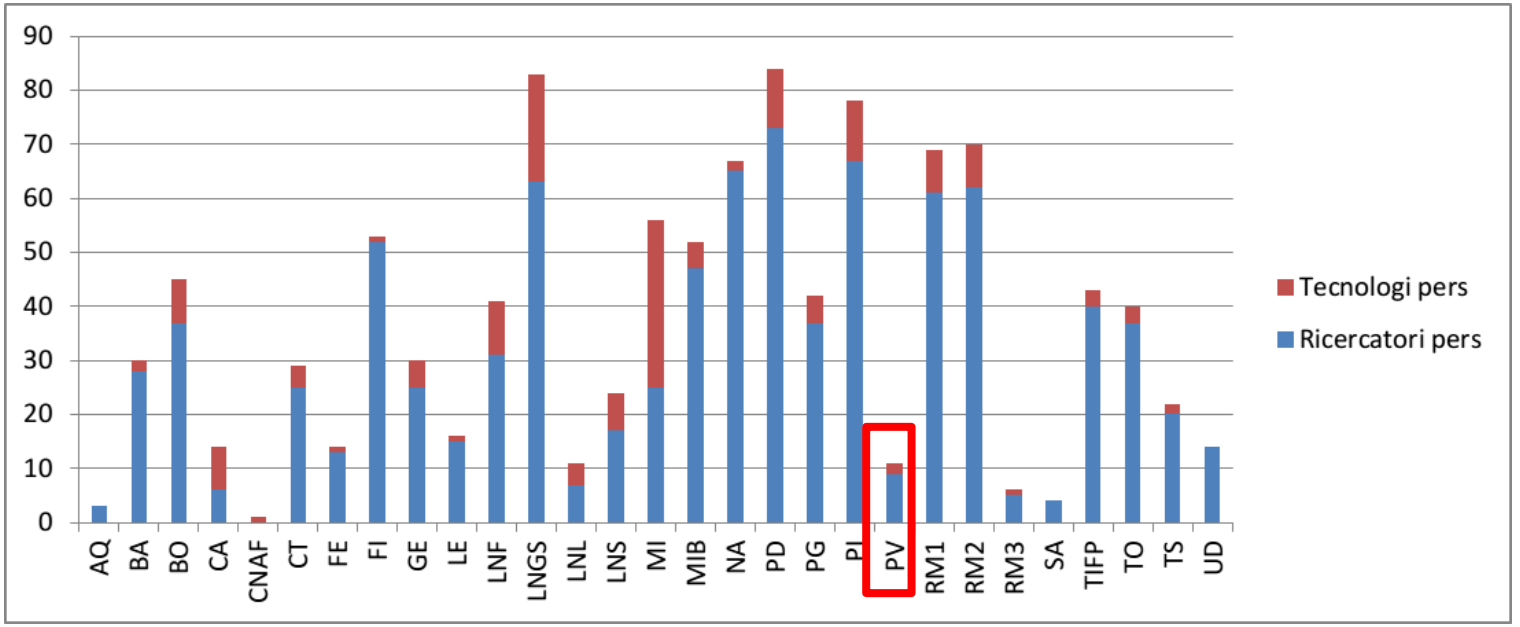
- FTE cresciuti del 22% dal 2012;
- Numero persone cresciuto del 24% dal 2012;
- Sigle in leggera diminuzione.

Anagrafica 2016

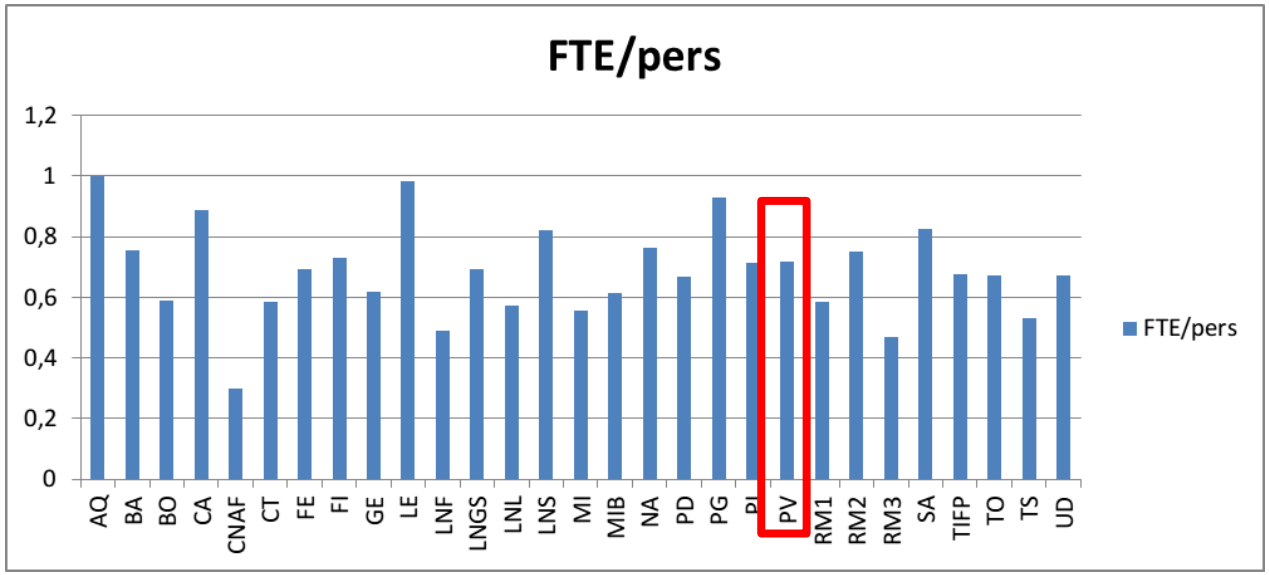


Anagrafica 2016



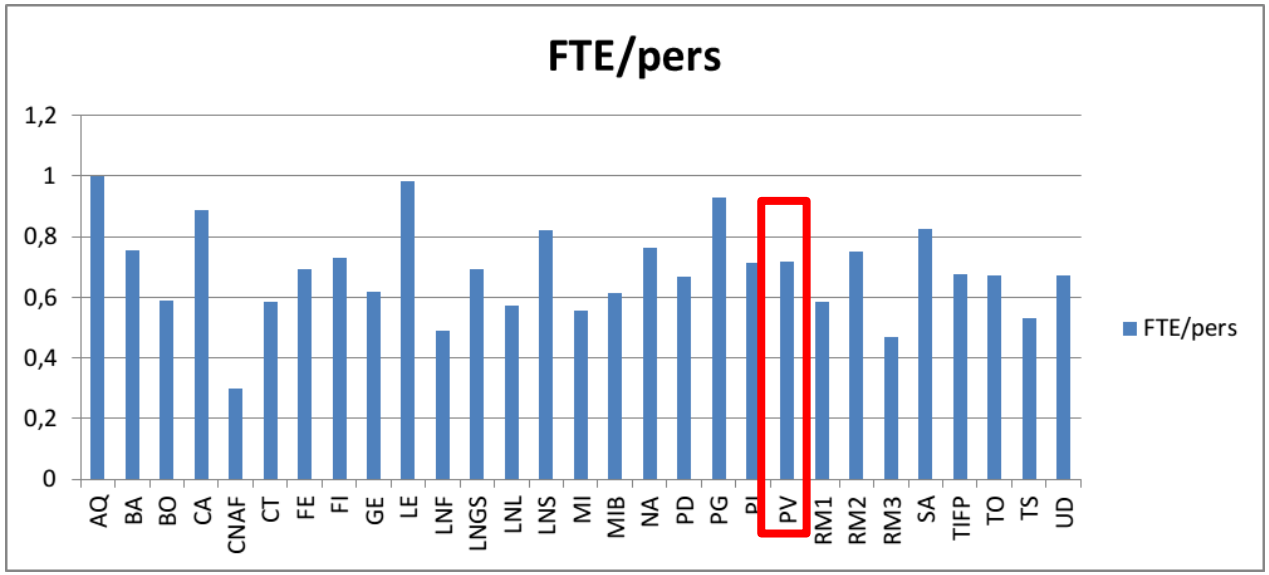


Anagrafica 2016



Pavia: 0.718 (Media: 0.685)

Anagrafica 2016



Pavia: 0.718 (Media: 0.685)

Linea	Esperimento	FTE/persona
1. A. Falcone, A. Menegolli, C. Montanari*, A. Rappoldi, G.L. Raselli, M. Rossella, A. Scaramelli, M. Spanu, M. Torti, A. Zani **In congedo al CERN (0 FTE)*	ICARUS	7.3/10
2. *P.W. Cattaneo, A. Rappoldi*	*GAMMA400*	*0.6/2*
3.		
4.		
Totale	**2**	**7.9/11**

ICARUS/WA104

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).

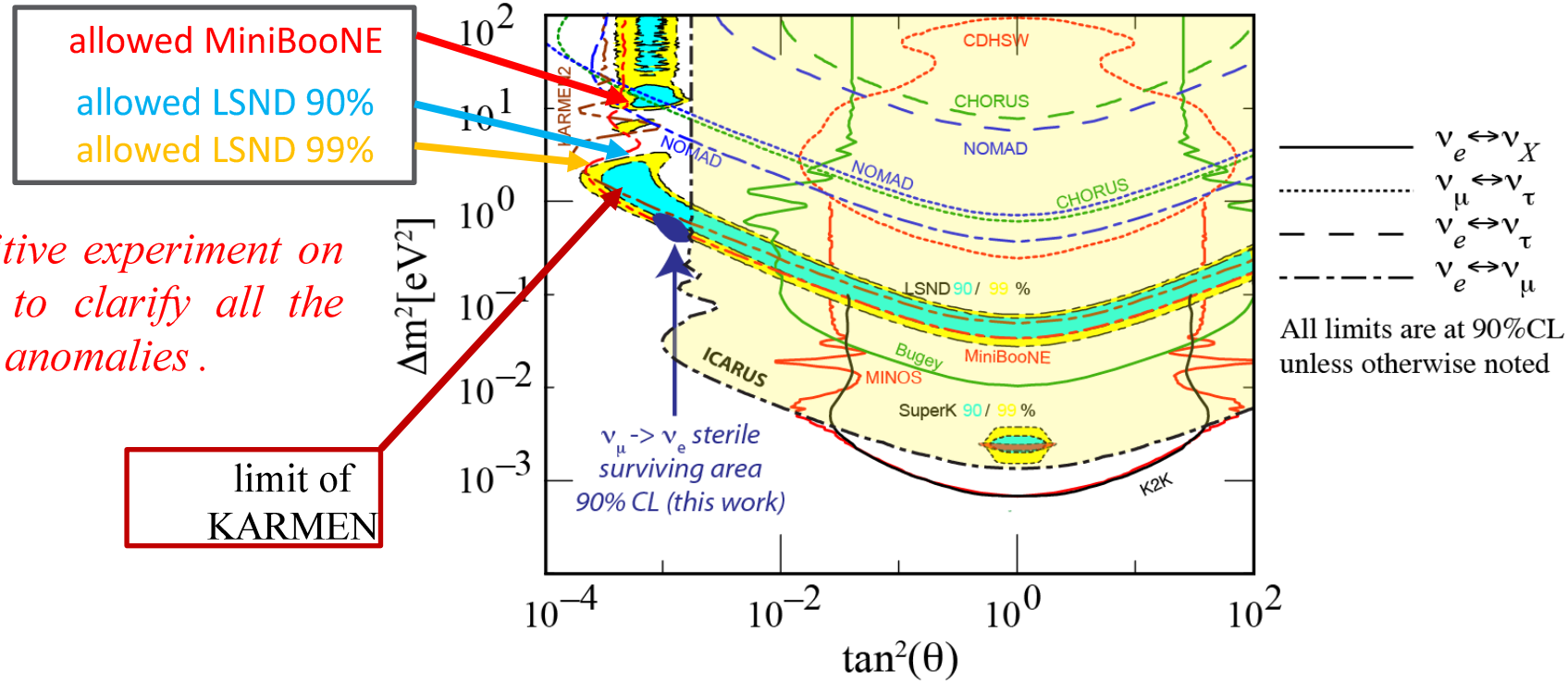
- Questi segnali indipendenti suggeriscono la possibile esistenza di almeno un quarto neutrino "sterile" che piloti le oscillazioni a piccole distanze, con Δm^2_{new} dell'ordine di ≈ 1 eV^2 e angoli di mixing $\sin^2(2\theta_{new})$ relativamente piccoli.

- 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.

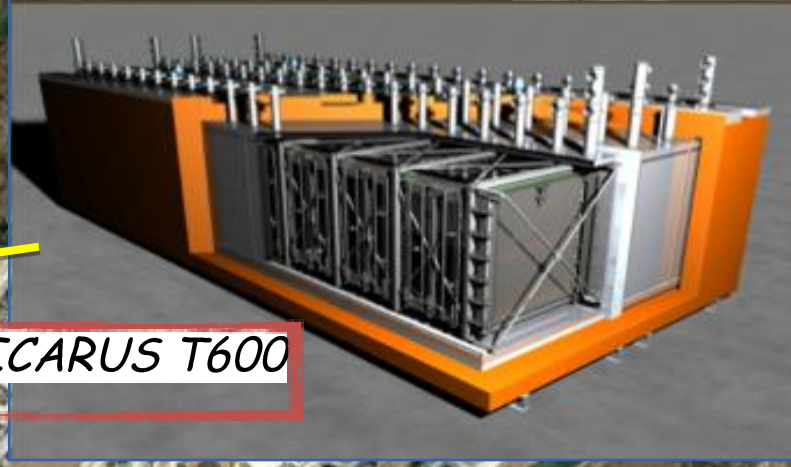
Search for LSND-like anomaly by ICARUS at LNGS

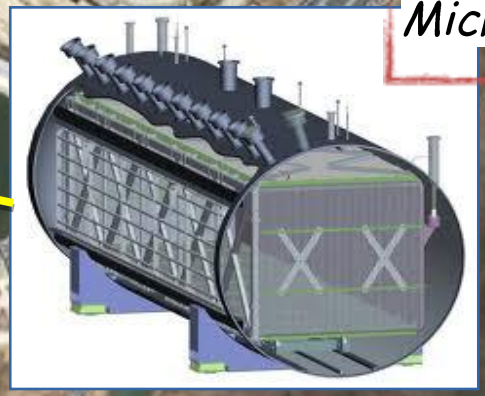
- ICARUS searched for νe excess related to LSND-like anomaly on the CNGS ν beam (~1% intrinsic νe contamination, L/Eν ~36.5 m/MeV). No excess was observed: number of νe events as expected in absence of LSND signal.
- Analysis on 7.23 x 10^{19} pot event sample provided the limit on the oscillation probability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

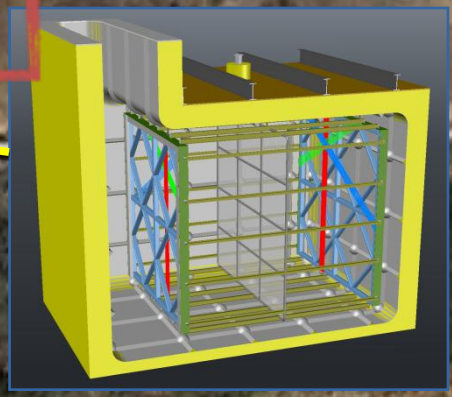
Need for a definitive experiment on sterile neutrinos to clarify all the reported neutrino anomalies .



SBN@BNB







MINOS/MINERvA surface building

SBN FD (~600m)

MiniBooNE

MicroBooNE (470m)

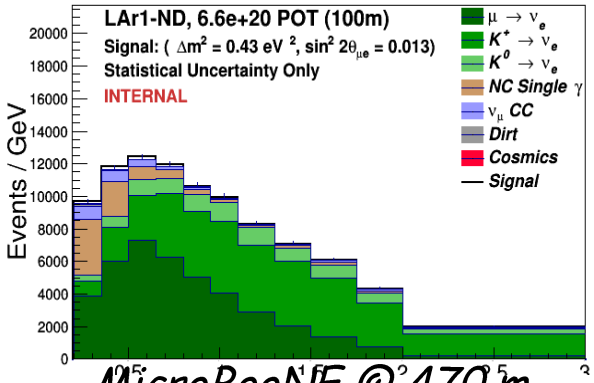
Booster Neutrino Beam

SBN ND (~100m)

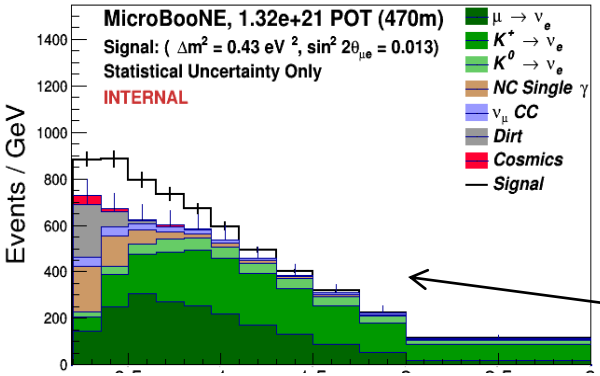
BNB target hall

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

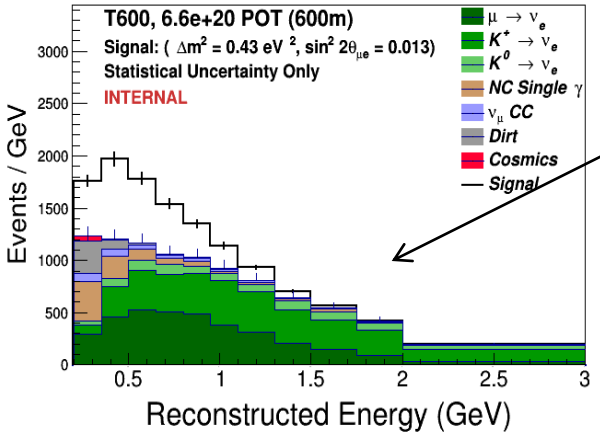
LAr1ND @ 100 m



MicroBooNE @ 470 m



T600@ 600 m

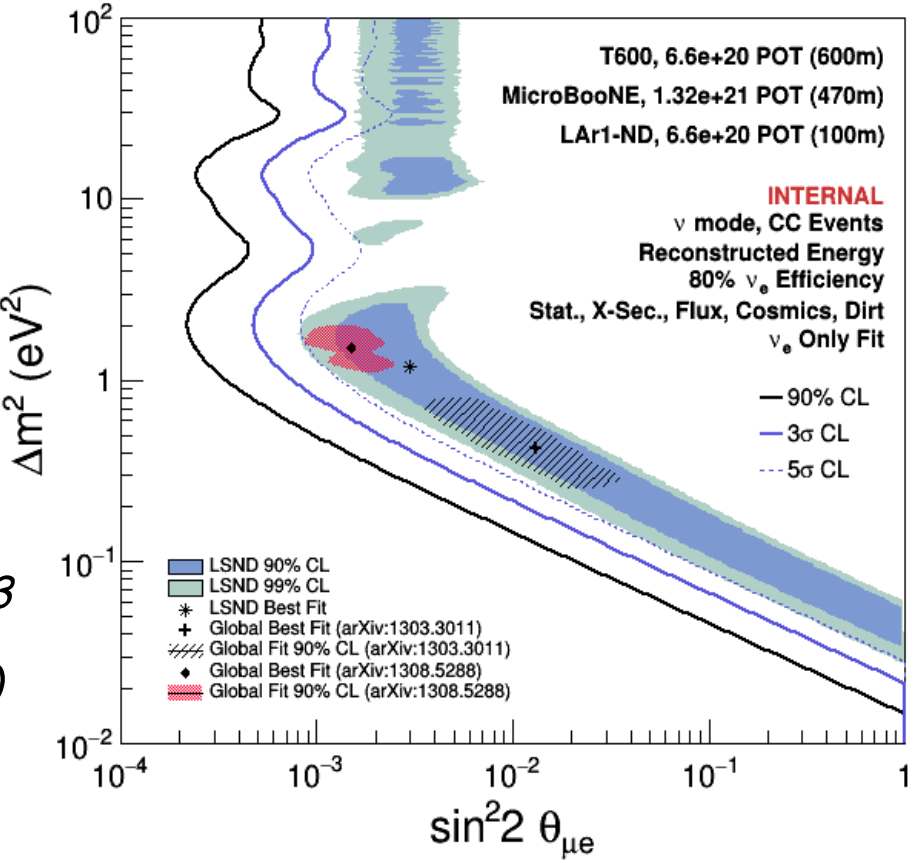


Example for

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

Δm^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).



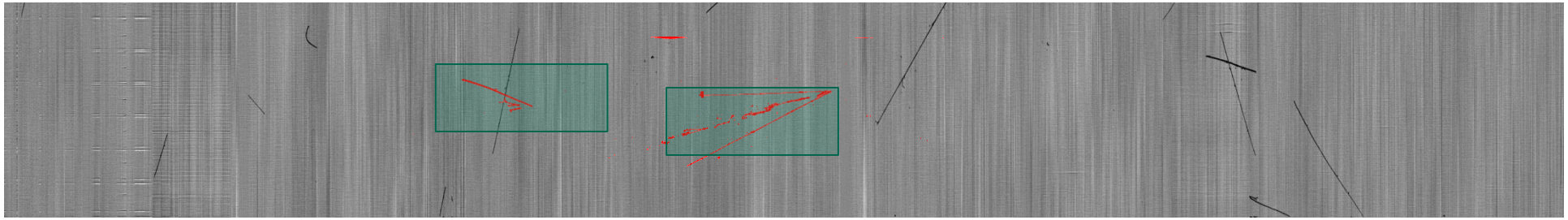
The LSND 99%CL region is covered at the ~5σ level

LAr TPC in superficie

- Circa 12 tracce per drift di 1 ms sono previste per ciascun modulo del T600

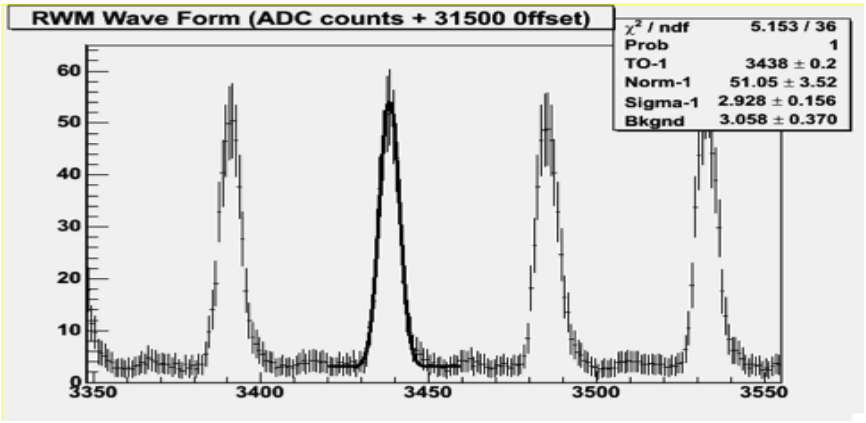
- Per ricostruire la posizione di ciascuna traccia è necessario conoscere il timing di ciascun deposito di carica sui fili rispetto al tempo di trigger dato dal gate aperto in corrispondenza del fascio BNB.

- 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 stato oggetto 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 è pronto per essere trasferito a FNAL (giugno 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.

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

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Cryogenics upgrades:

- Maintenance of cryogenic pumps and valves from the Gran
- Tests of the new, dual-phase N2 cold shield.
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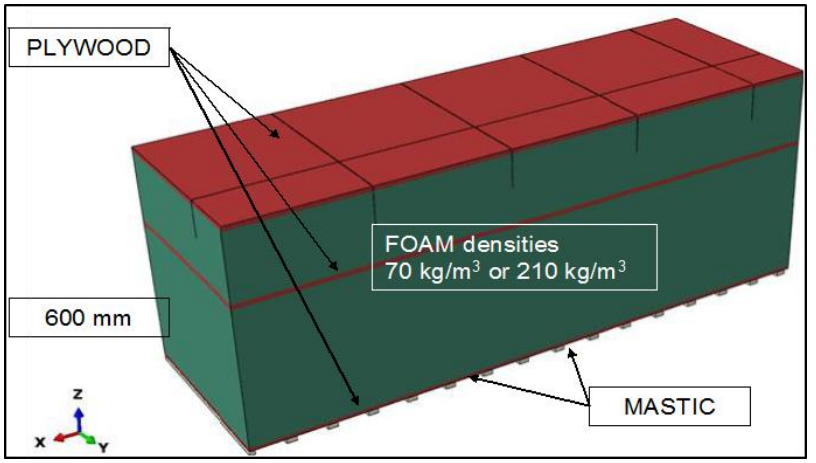

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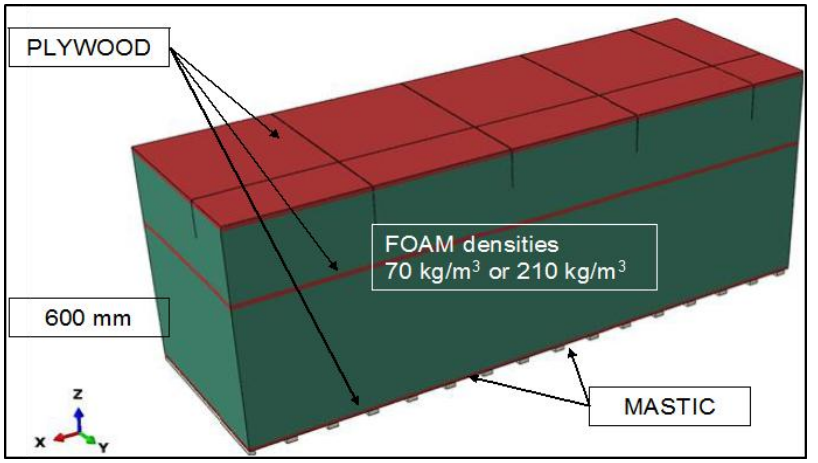

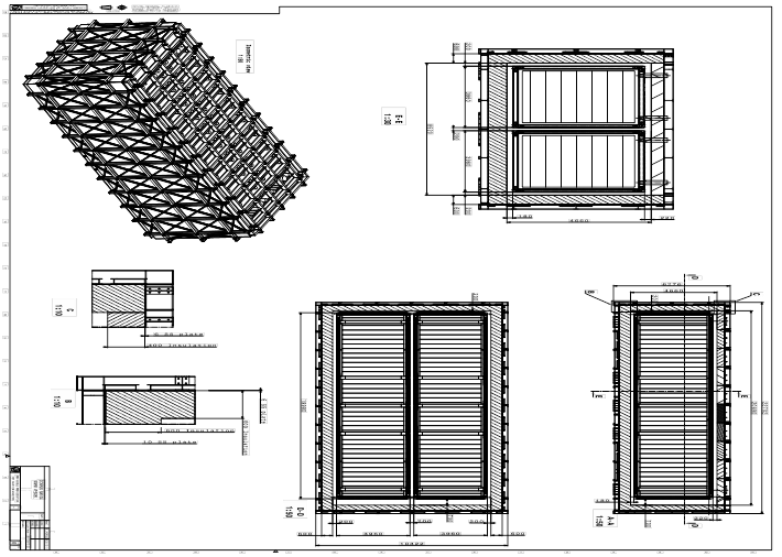

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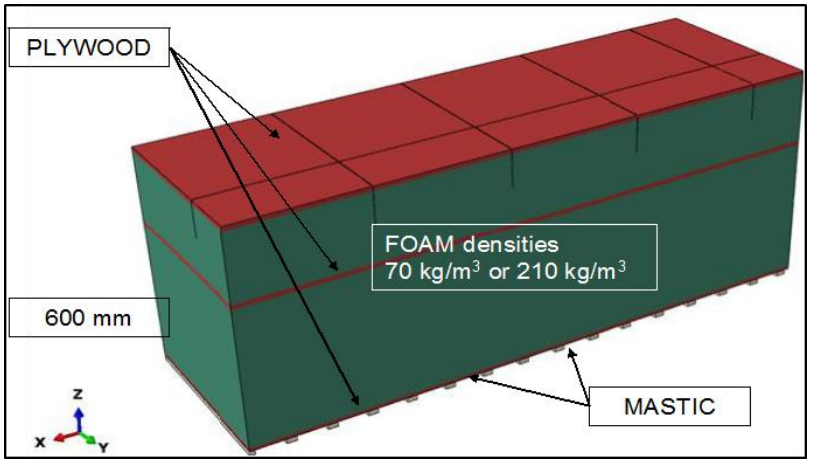
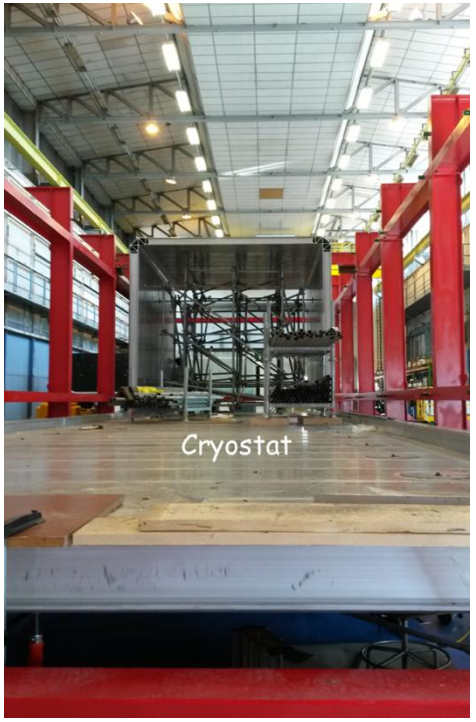


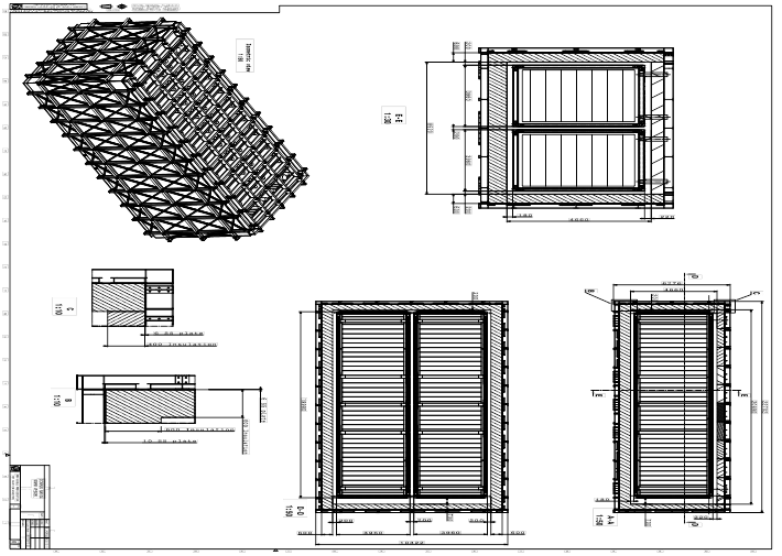
- Thermal insulation studies.

- New warm vessel studies and procurement.

- New cold vessels construction.

Roof pre-assembly





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;

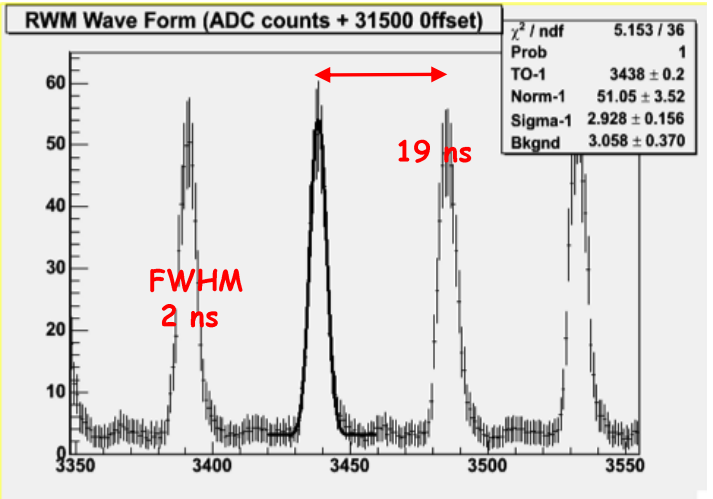
- Panels were reinstalled in both detectors after cleaning and electro-polishing. .

These 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)

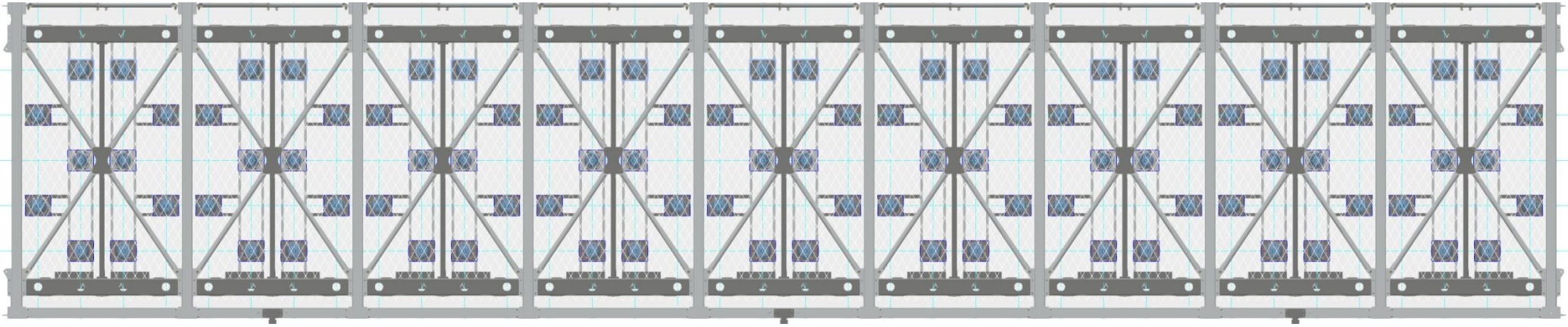
- *The improved light detection system is devoted to:*
  - The generation of a light based trigger signal;
  - The identification of the time of occurrence (t0) of each interaction with high temporal precision;
  - The initial identification of event topology for fast event selection purposes.

- *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 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 muons, e.m. showers, ν_μCC) can be obtained exploiting the arrival time of prompt photons and the collected light signal intensity.

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 have been coated by evaporation with ~200 mg/cm2 of Tetra-Phenyl-Butadiene (TPB) which acts as a wavelength-shifter from VUV to visible light.

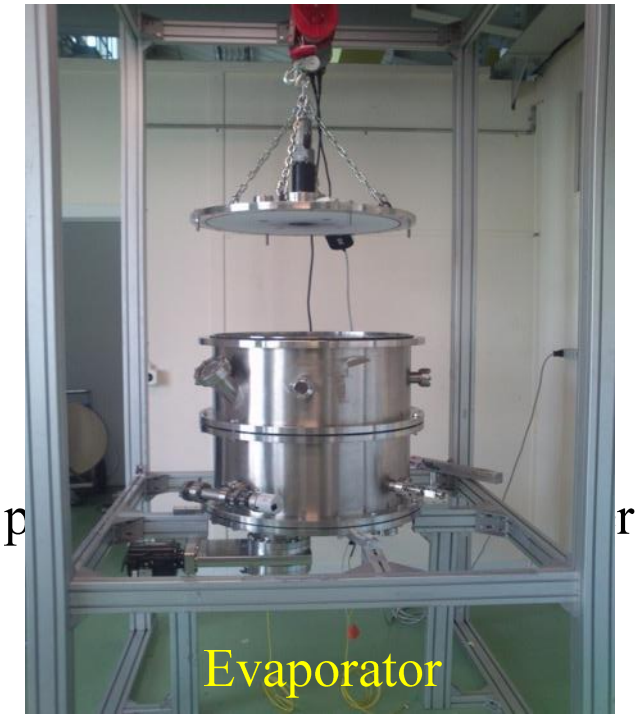
Activities at CERN

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

Room temperature tests
IdeaSquare building 3179

Cold tests
building 182

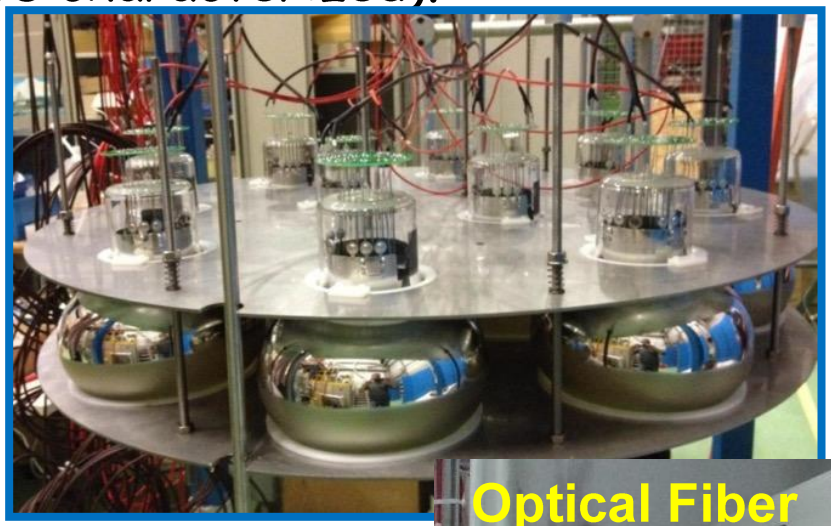
TPB deposition
TE-Laboratory hall (B169)



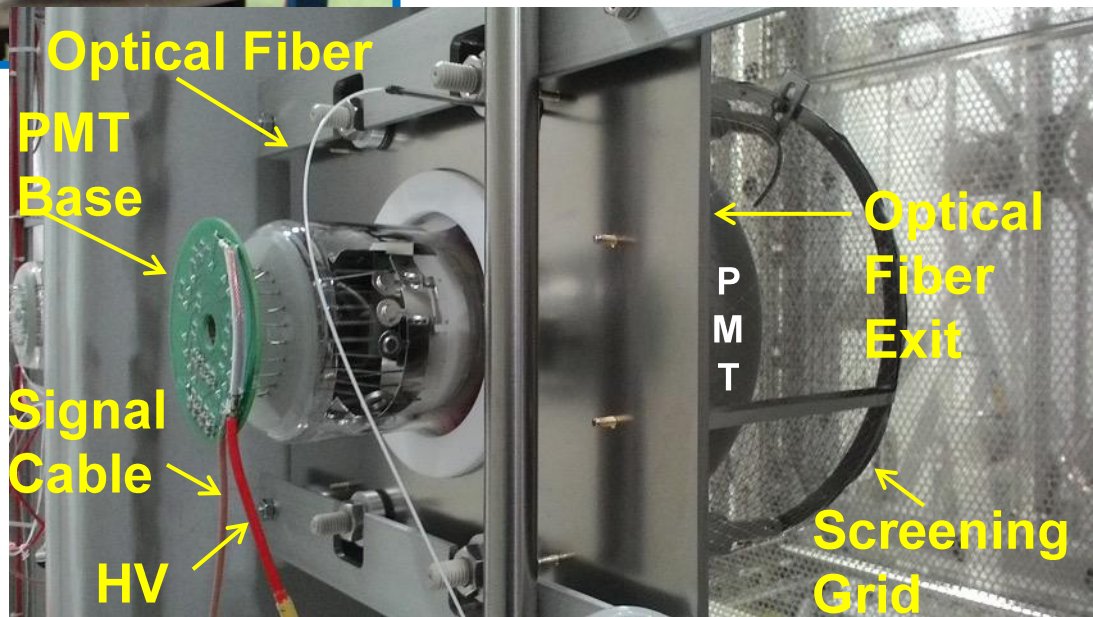
PMT tests and installation

- All PMTs have been characterized at room temperature, gain set to 10^7 e^-/phe with ~1500 V.
- Average gain loss in LAr ~ 50%, recovered by raising HV of ~ 150 V (60 PMTs characterized).

Set-up for LAr test: gain, linearity and dark counts

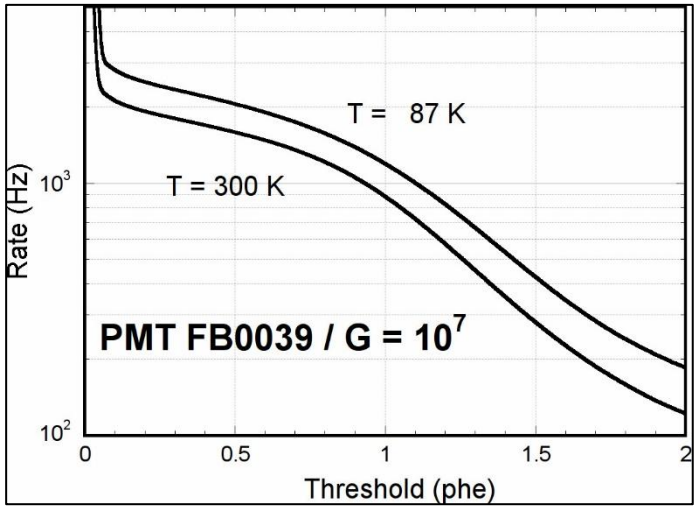


- 200 μg/cm² TPB layer evaporated on tubes, for VUV light shifting to visible spectrum;
- Calibration system with optical fibers and laser.

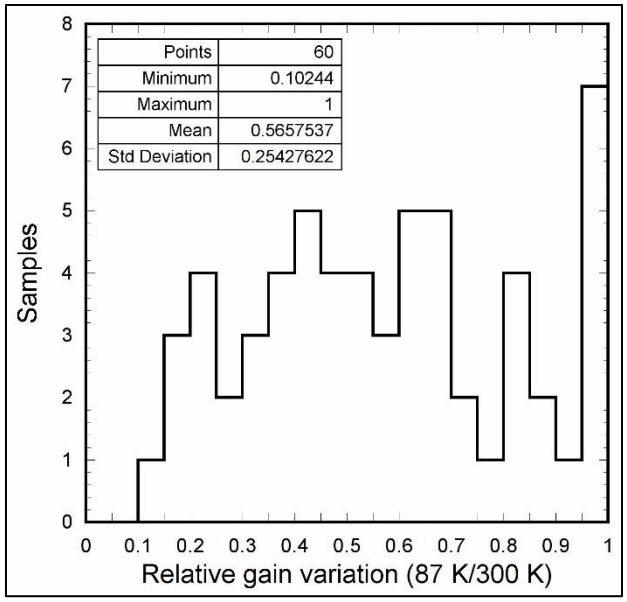


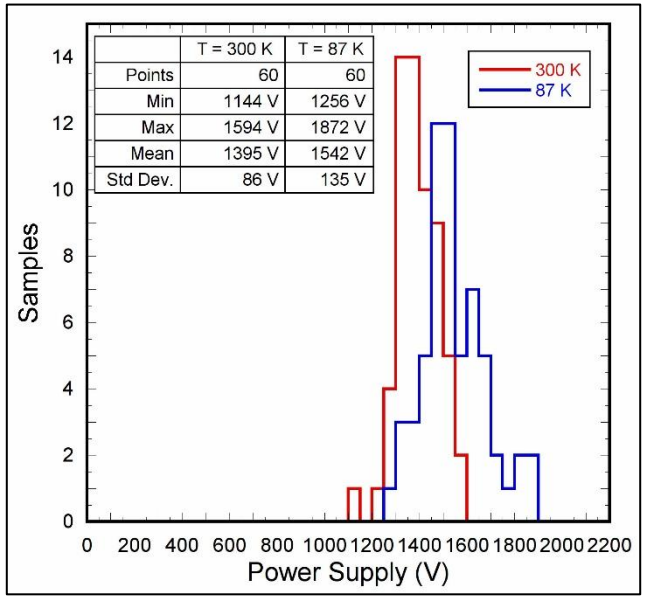
PMT test results

Test results on the PMT sample characterized both at room and Liquid Argon temperature.



Gain variation of the PMT Gain and voltage difference at room and LAr temperature, in order to have $G = 10^7$.





Dark count rate at room and LAr temp on a sample PMT, at gain $G = 10^7$.

All PMT installed!

PMT electronics and calibration system (PV+MiB)

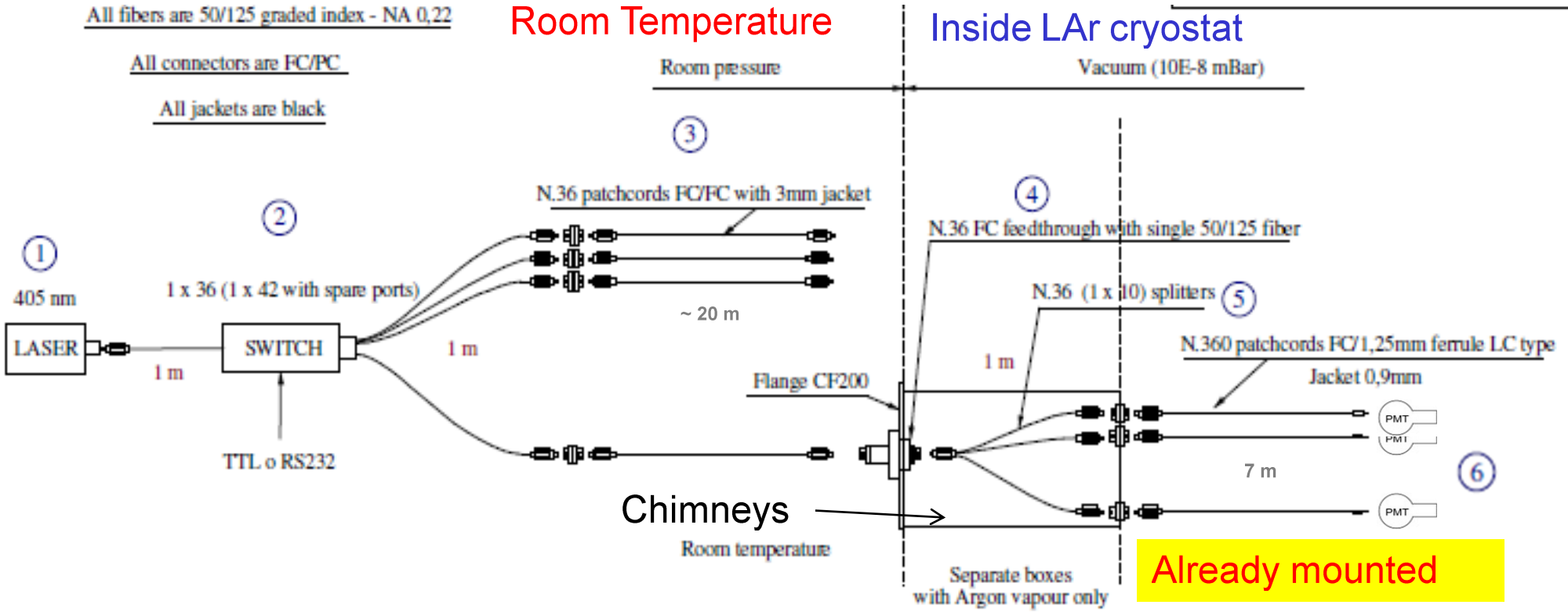
- Studies are ongoing also to choose the electronics for PMT signal acquisition: the input dynamics must allow for recording the fast component of the scintillation light and, at the same time, for recording the single photons arriving from the slow component.

- 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.

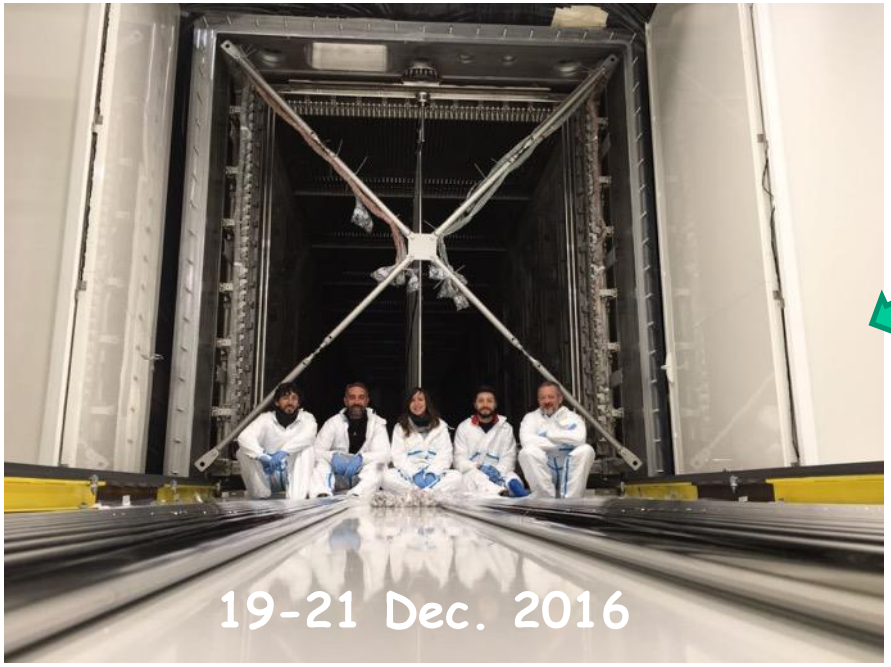
- The system will be made by fused fiber splitters, optical switches and optical patch-cords. The fibers to be inserted in the detector were selected for LAr temperature endurance and were commissioned. Each element of the system will be tested for proper installation and functionality.

Layout of the laser calibration system



1. 405 nm Laser [1]
2. 1x42 optical switch [1]
3. ~20 m armed FC/FC patchcords [36]
4. FC/FC UHV feedtrough [36]
5. 1x10 fused fiber splitters [36]
6. 7m FC/ferrule injection patch fiber [360]

First module moved into cold vessel



Un’anticipazione del 2017…

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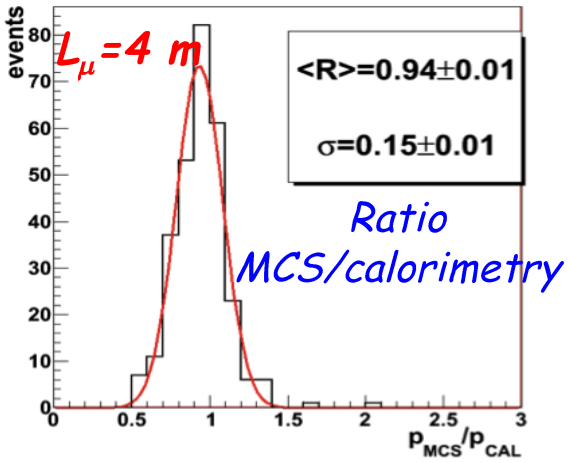
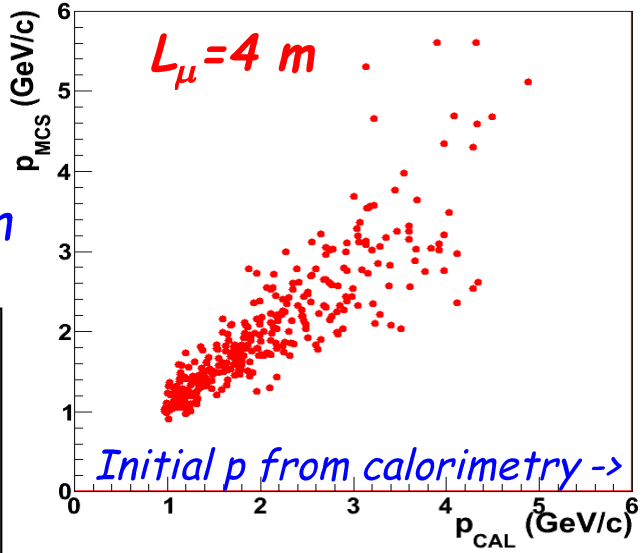
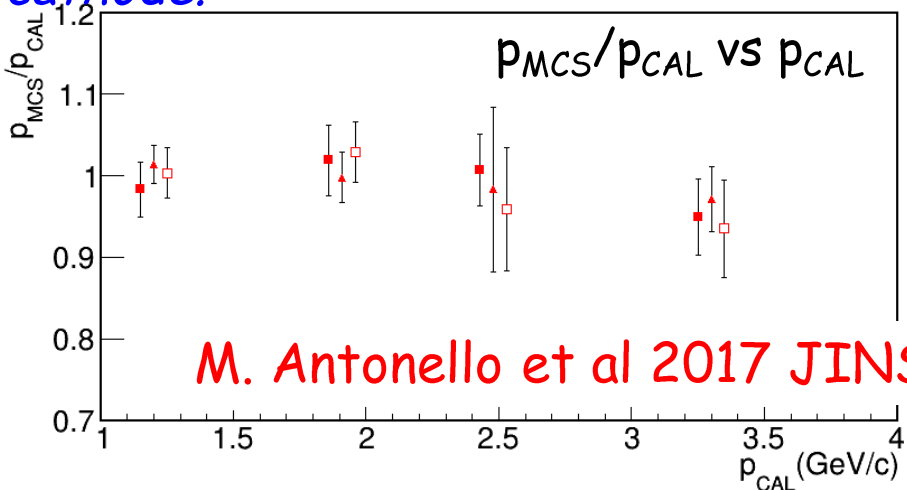
Muon momentum measurement via multiple Coulomb scattering

- Muon momentum measurement by *Multiple Coulomb Scatt.* has been validated comparing p_{MCS} with corresponding calorimetric measurement p_{CAL} for ~500 *stopping* μ*s* produced by CNGS ν_μ interactions in upstream rock;
- *p_{MCS} is well correlated with p_{CAL}.* Unexpected p_{MCS} under-estimation is detected at p >3 GeV/c for μs travelling close to TPC cathode, due to its $\Delta x \sim \pm 15$ mm non-perfect planarity which affect electron drift velocity (*percent E_D distortions)*
- *These effects have been accounted for applying the actual computed electric field to MC events to extract average corrections to p_{MCS} as a function of μ momentum and distance from cathode.*



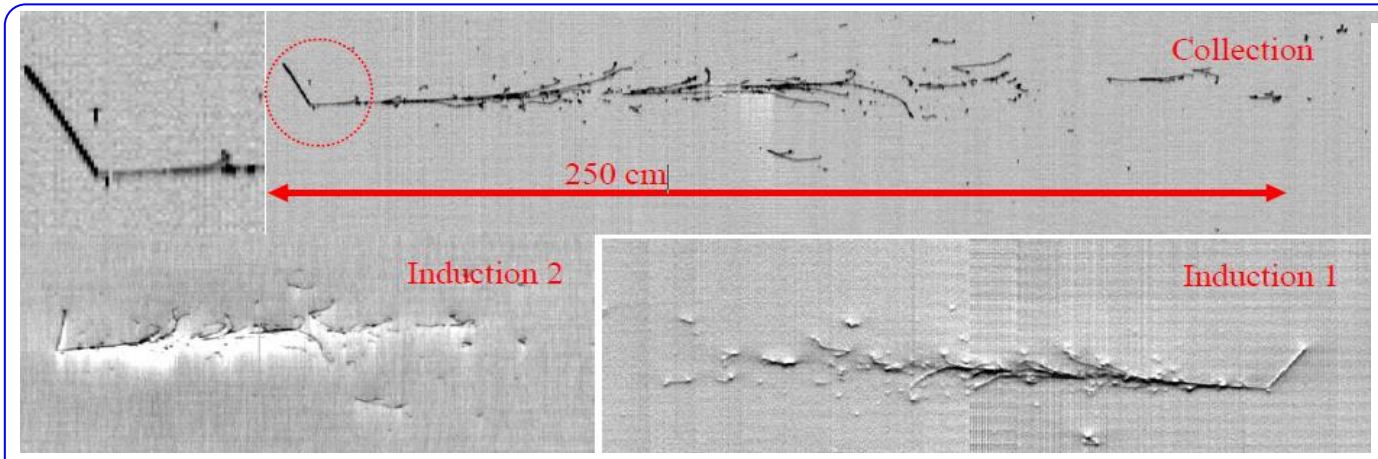


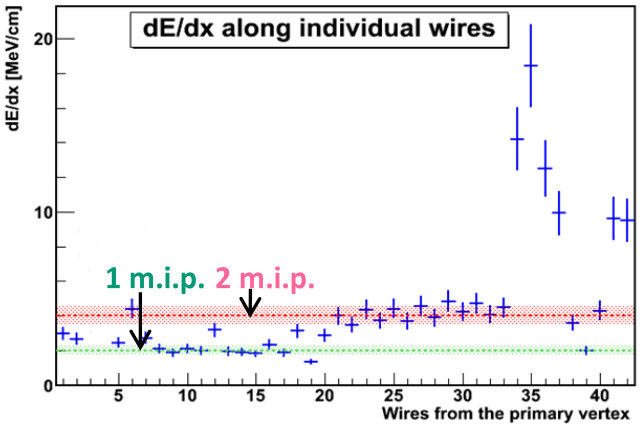
$p_{MCS} \sim p_{CAL}$ data within ~5%.



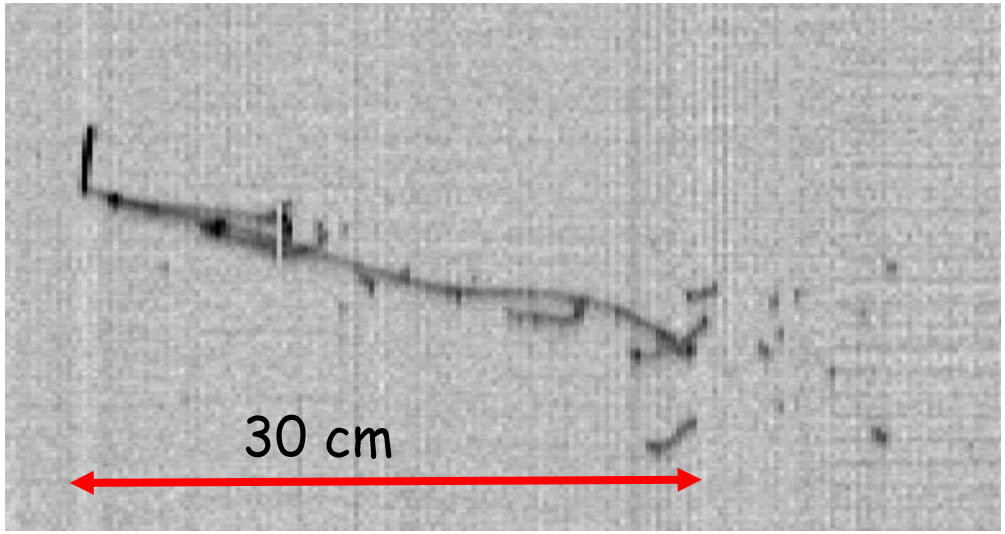
M. Antonello et al 2017 JINST 12 P04010

First atmospheric ν_e CC events observed in LAr TPC





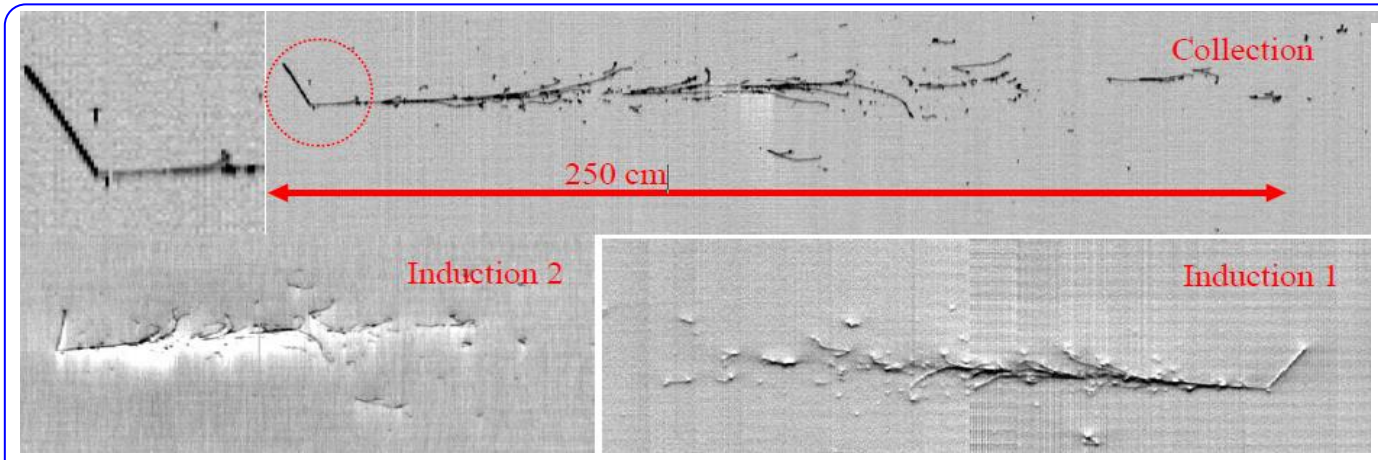
- Quasi-elastic ν_eCC with E_{Dep}=2.12 GeV
- Clear primary electron initiated (single m.i.p.) shower (2 GeV);
- 115 MeV proton identified by dE/dx

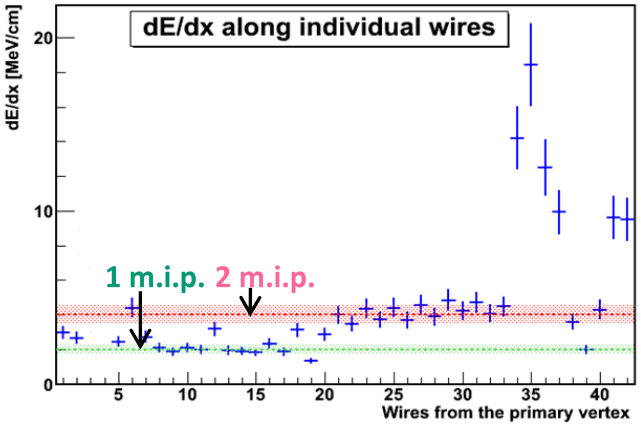


Downward-going, quasi elastic event: deposited energy: 240 MeV!

- dE/dx measured on first wires (2.1 MeV/cm) corresponds to a m.i.p.
- One short proton track recognized.

First atmospheric ν_e CC events observed in LAr TPC





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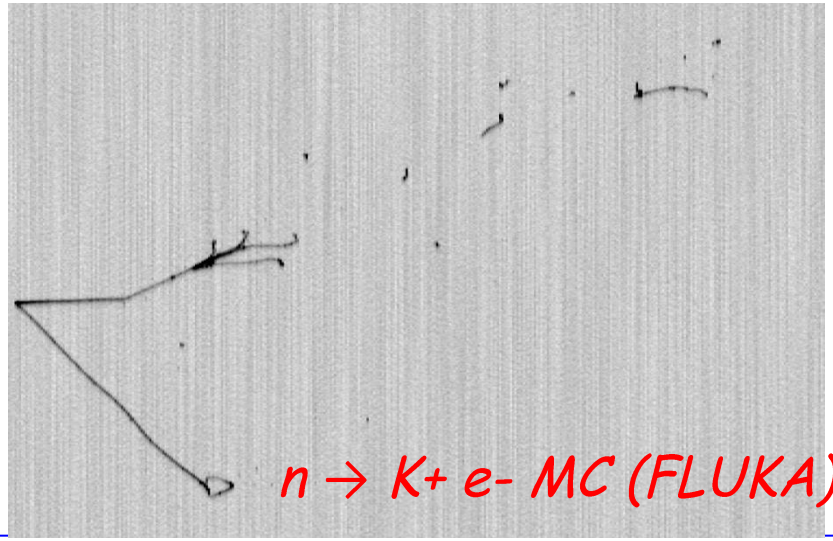
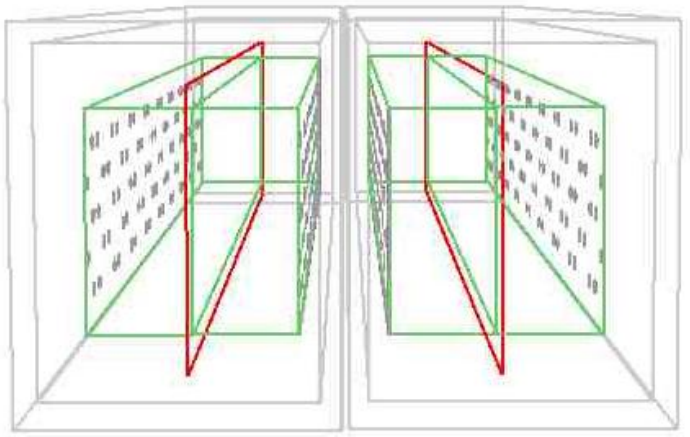
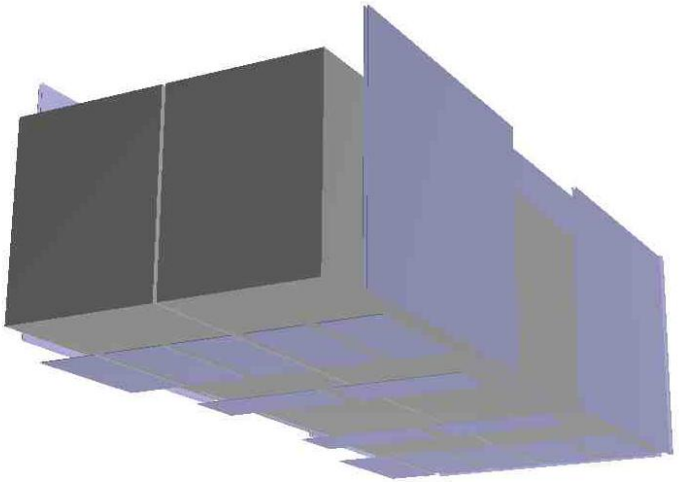


- Analysis useful for nucleon decay searches in the channel: n → K+ e-

- ICARUS T600 competitive with PDG limits!

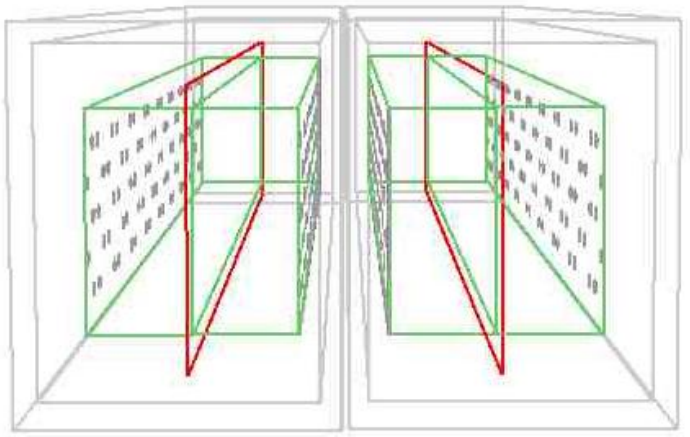
Sviluppo software e simulazione ICARUS-SBN

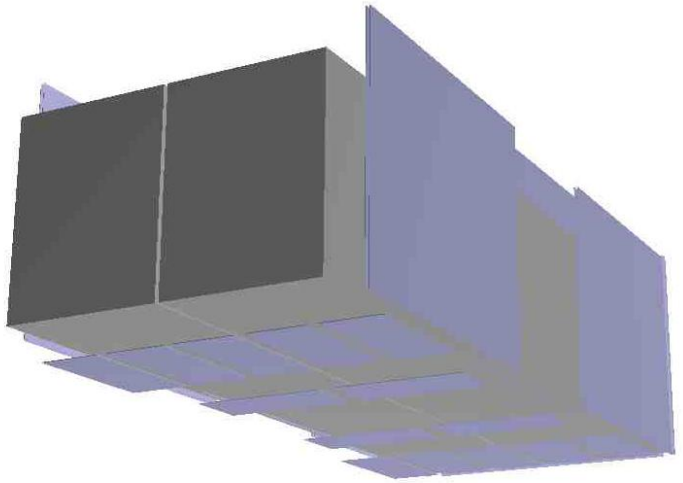




Nuova geometria ICARUS + PMT + CRT per ambiente LArsoft (G4-like)

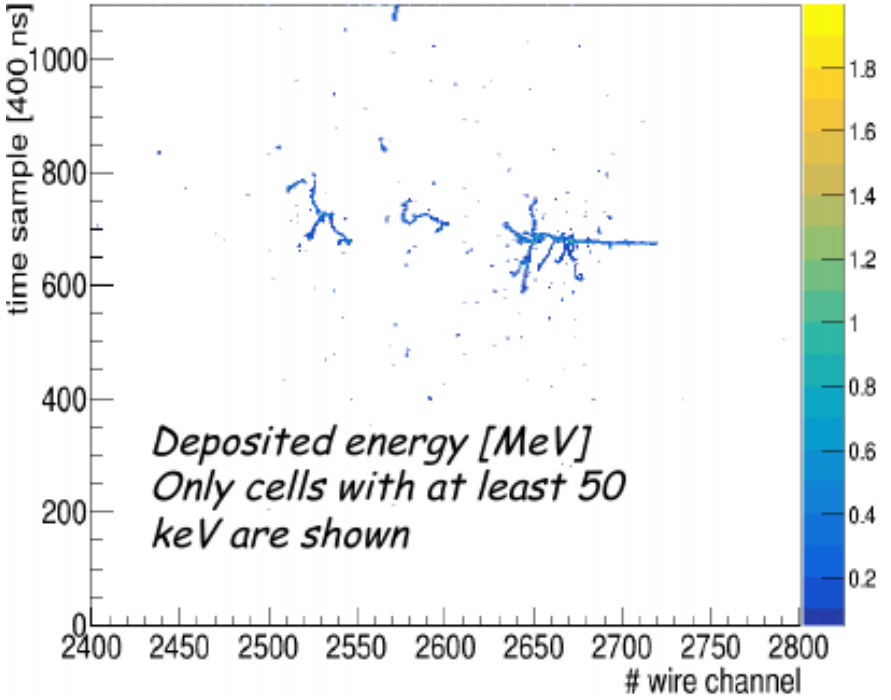
Sviluppo software e simulazione ICARUS-SBN





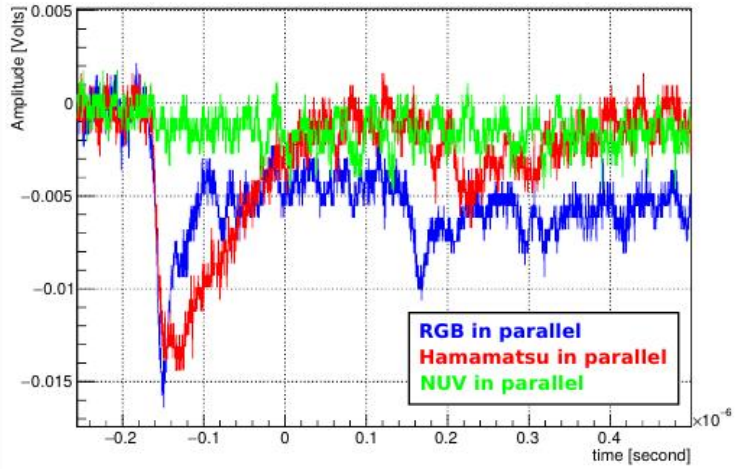
Nuova geometria ICARUS + PMT + CRT per ambiente LArsoft (G4-like)

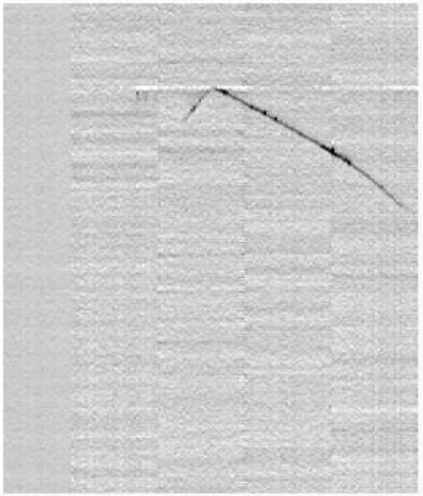
Esempio di simulazione di un elettrone da 600 MeV in ICARUS, ambiente LArsoft



R&D photo-detectors: SiPM arrays

50 liters LAr-TPC at CERN





A muon that cross the TPC and the signals recorded with all the models in parallel.

ICARUS PV: 2016

- Collaborazione per disegno nuovi criostati e isolamento termico.

- Ripristino della planarità dei catodi e refurbishing del T600.

- 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. Installazione dei PMTs nel primo T300 (primi mesi 2017: installazione PMT nel secondo T300).

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

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

ICARUS PV: pubblicazioni e tesi 2016

- Cervi T., Bonesini M., Falcone A., Menegolli A., Raselli G.L., Rossella M., Simonetta M., Torti M., *«Characterization of SiPM for cryogenic applications»,* Nucl. Instr. Meth. A824 824, p. 89-91 (2016).

- Menegolli A. on behalf of ICARUS Collaboration, "*Some recent results from the ICARUS experiment",* Nucl. Part. Phys. Proc. vol. 273-275, p. 1891-1896 (2016).

- Torti M. on behalf of ICARUS Collaboration, "*Search for space charge effects in the ICARUS T600 LAr-TPC",* EPJ WEB CONF, 126-, 05013 (2016).

- Zani A. on behalf of ICARUS Collaboration, *"ICARUS T600: physics results and future activities"*, EPJ WEB CONF, 126-, 04056 (2016).

- M. Antonello et. al., *"Muon momentum measurement in ICARUS-T600 LAr-TPC via multiple scattering in few-GeV range",* arXiv:1612.07715 (published on JINST in 2017).

- **A. Falcone**: "*Studies and tests for the new light collection system of the ICARUS T600 detector*", **Tesi di Dottorato**

ICARUS PV: conferenze 2016

- C. Montanari, "*ICARUS Operations Experience*", Workshop on Cryogenic Operations (Fermilab, USA)

- T. Cervi, "*Study of SiPM custom arrays for scintillation light detection in liquid argon Time Projection Chambers*", Topical Seminar on Innovative Particle and Radiation Detectors (IPRD2016), Siena (Italy).

- A. Falcone, "*Performance study of the new light collection system for the ICARUS T600 detector*", XXVII International Conference on Neutrino Physics and Astrophysics, London (UK)

- M. Torti, "*Electron diffusion measurements in the ICARUS T600 detector*", XXVII International Conference on Neutrino Physics and Astrophysics, London (UK)

- M. Spanu, "*TPB thickness and Quantum Efficiency measurements for the new Icarus T600 light detection system in the SBN project*", XXVII International Conference on Neutrino Physics and Astrophysics, London (UK)

- A. Menegolli, "*Sterile neutrino searches with ICARUS T600*", Sixth Workshop on Theory, Phenomenology and Experiments in Flavour Physics - FPCapri2016 (Capri, Italy).

- G.L. Raselli, "*Sterile searches with Liquid Argon at FNAL*", Neutrino Oscillation Workshop (NOW 2016), Otranto (Italy)

- G.L. Raselli, "*Test and Characterization of 20 Pre-Series Hamamatsu R5916-MOD Photomultiplier Tubes for the ICARUS T600 Detector*", IEEE Nuclear Science Symposium and Medical Imaging Conference 2016, Strasbourg (France).

- T. Cervi, "*Characterization of AdvanSiD and Hamamatsu SiPMs for Novel Design Cryogenic Detectors*", IEEE Nuclear Science Symposium and Medical Imaging Conference 2016, Strasbourg (France).