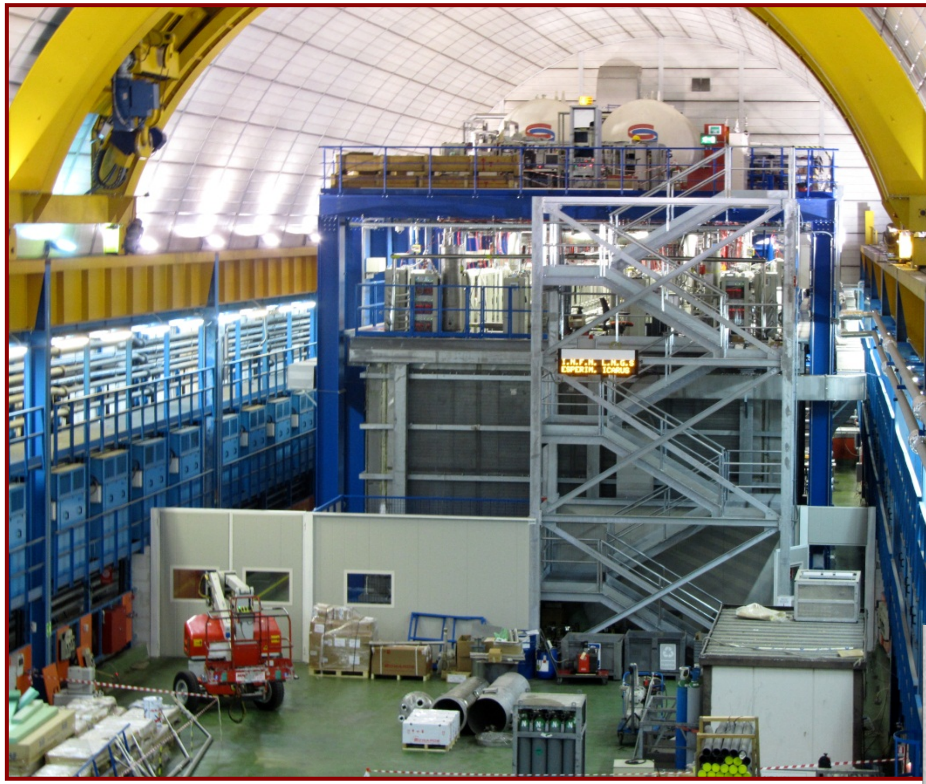
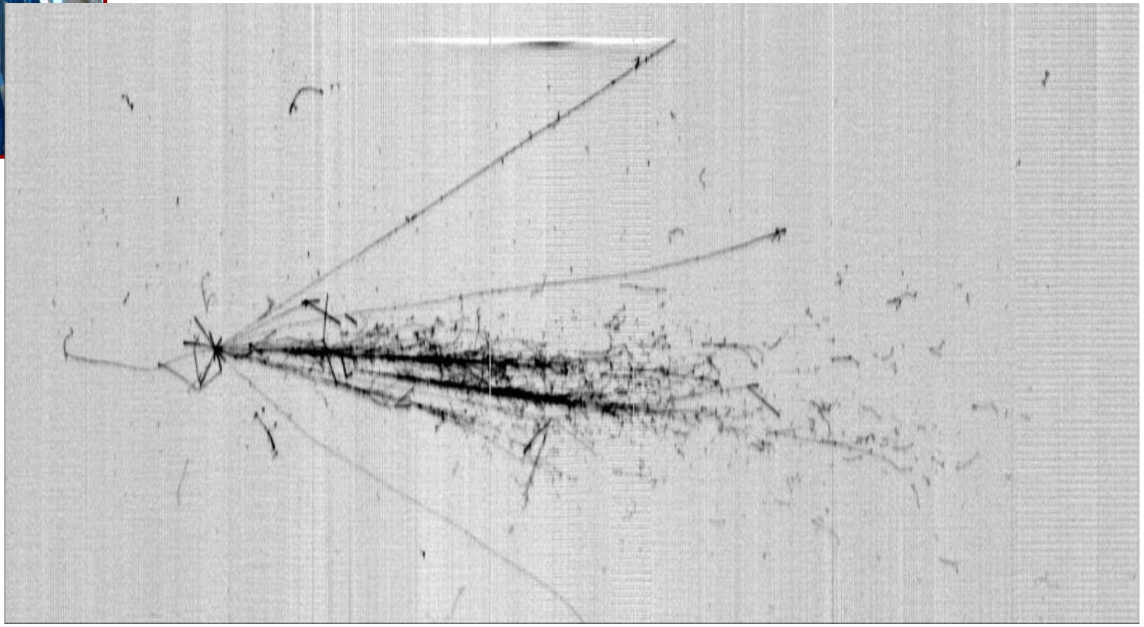
The ICARUS T600 LAr TPC and its scalability to multi kton detectors





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for the ICARUS Collaboration

LAr TPC R&D Workshop
FNAL, 21 March 2013

Outline

- The ICARUS T600 Time Projection Chamber
- Performance of the ICARUS T600 detector at LNGS
- A modular approach towards multi kton LAr TPC
- Conclusions

ICARUS T600: the state of the art of LAr TPC detectors

- ICARUS T600 detector was conceived in the late '90s after an extensive R&D programme following the first design concept by C. Rubbia (1977).
- The first 300 ton half-module (T300) was successfully brought to operation and tested already in 2001 with a surface run held in Pavia (Italy).
- The two T300 were finally installed in the LNGS underground laboratories where they are collecting data since 2010, taking data on the CNGS neutrino beam with an extremely high Argon purity, time stability, detector efficiency with negligible dead time.
- No anomalous behaviour despite evacuation and cooling (the first T300 two times!). Also, the transportation of the two T300 to LNGS from Pavia site to LNGS did not cause any stress on the inner detector mechanics.
- The successful operation of the ICARUS T600 detector demonstrates the enormous potential of this detection technique and represents a major milestone for the deployment of multi-kton size detectors.

Basic requirements

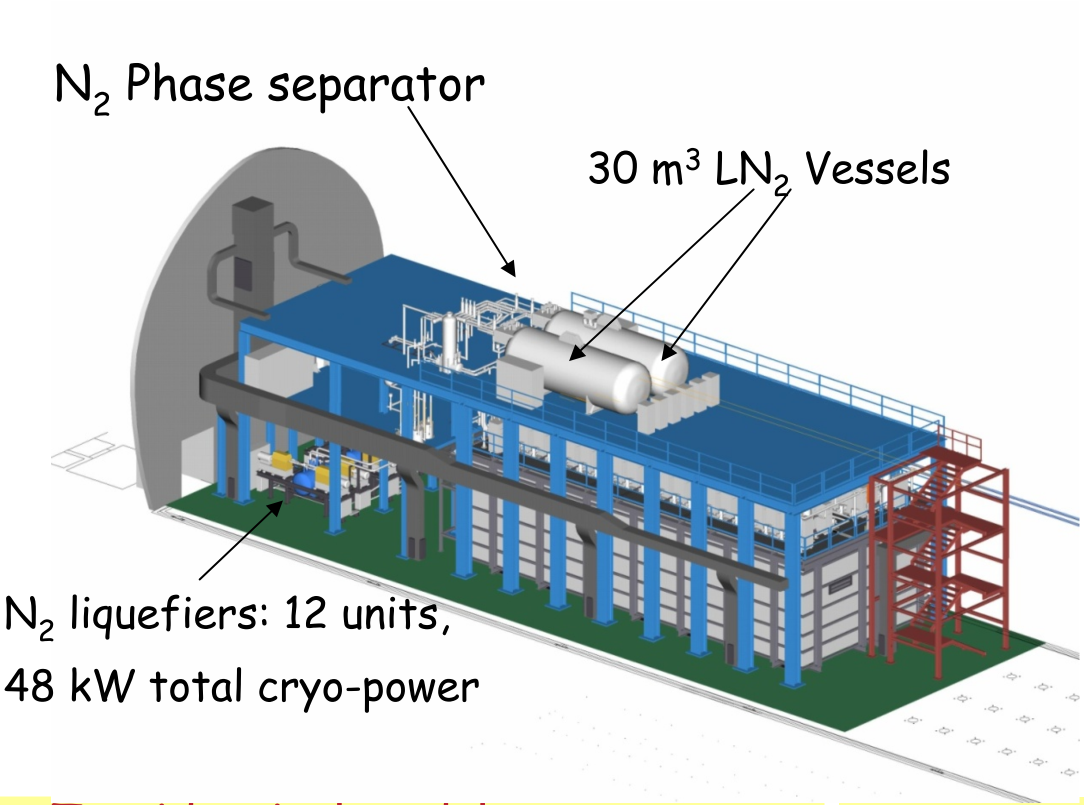
- *Argon purification*:

  - Ultra-pure LAr, even in the presence of a large number of feed-throughs (signals, HV) with wire chambers and cables in the clean volume;
  - contamination of electronegative impurities must be as low as 0.1 ppb to allow long electron drifts (~ meters).

- *Wire chambers*:

  - non-destructive read-out with several planes with a few millimeters pitch;
  - stand the thermal stress for cooling down from room to LAr temperature;
  - high precision and reliability of the mechanics;
  - high uniformity of the electric field in the detector.

The ICARUS T600 detector



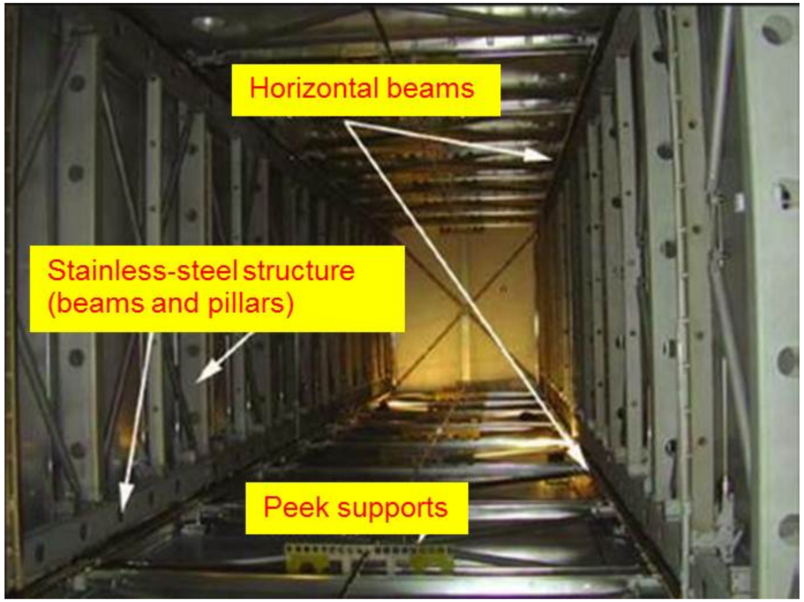
Hall B @ LNGS

- 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 detection:
  - VUV sensitive (128nm) with wave shifter (TPB)

The T600 inner detector

- Each of the two T300 half-modules hosts a stainless-steel mechanical structure that sustains the different inner detector subsystems.
- All materials of the mechanical structure chosen and treated to guarantee the LAr purity and the minimum radioactive contamination.
- Main components (beams and pillars): AISI 304L stainless-steel (pickling+passivation). Other parts (supports, spacers): PEEK.
- All components washed in ultrasound bath with de-mineralized water, dried in a vacuum oven and packed in dry air atmosphere



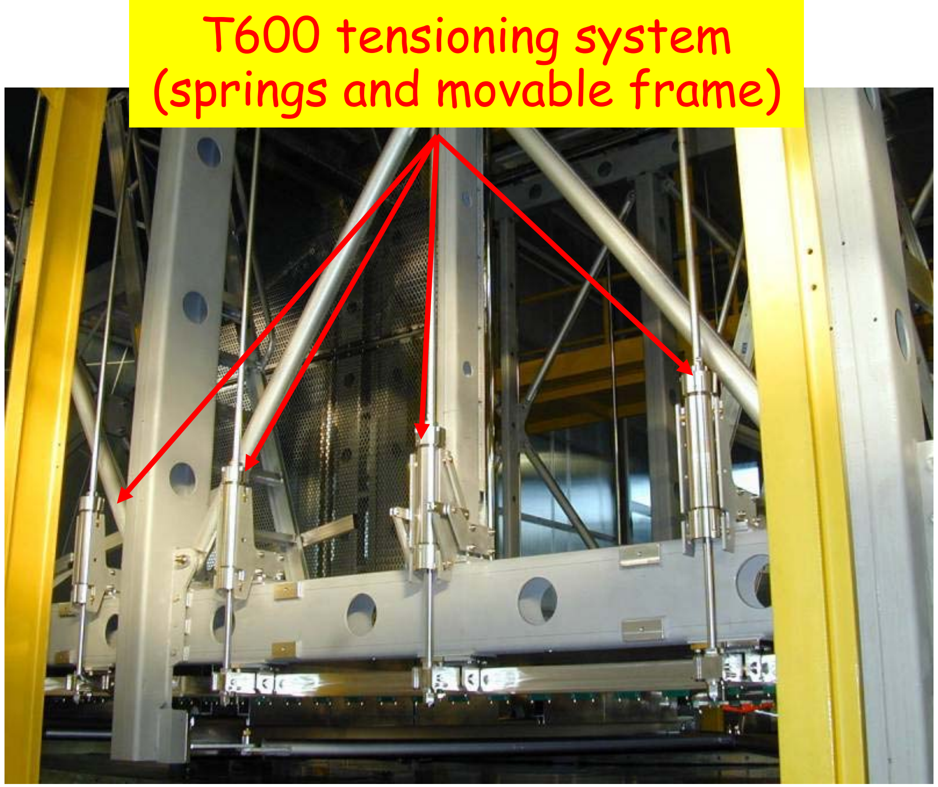
Mechanical precision achieved for all the inner detector parts ~100 μm

No distortion by misalignment of wire planes.

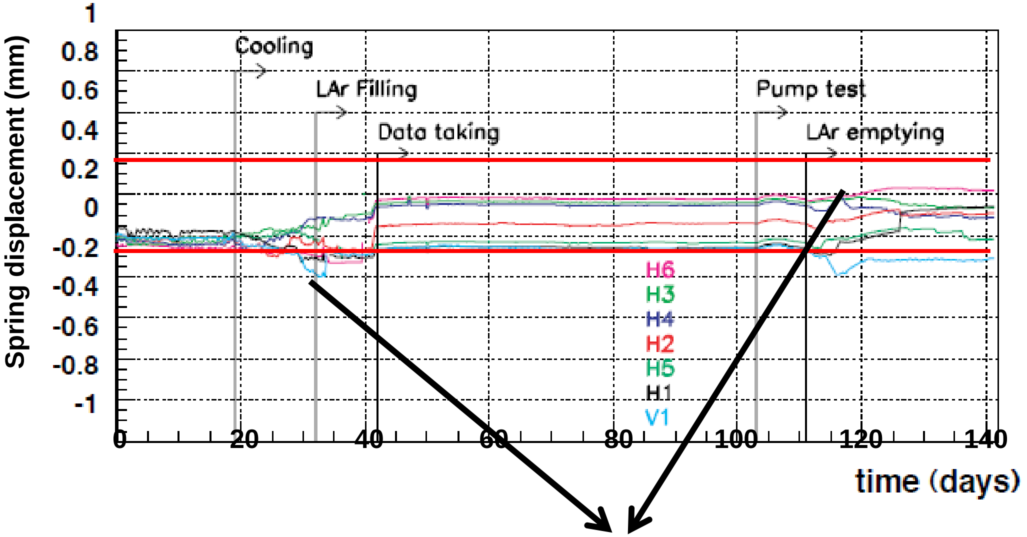
The T600 inner detector (cont.)

The ICARUS T600 wire frame design is based on the concept of the *variable geometry design*: beams of the wire frames are movable.

Frame beams (both horizontal and vertical ones) are connected by a set of calibrated springs compensating for tension increase on wires possibly occurring during cooling and filling phases.


T600 tensioning system (springs and movable frame)

Wire movement (Pavia 2001 test run)



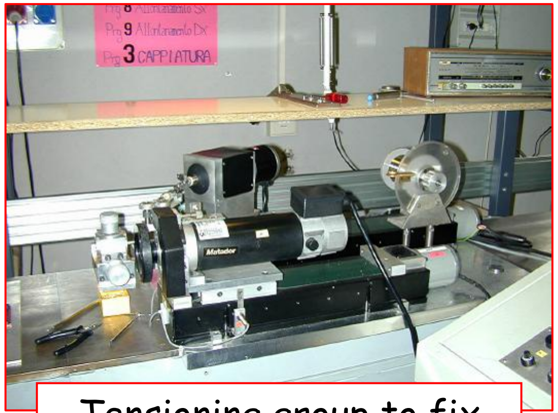
Max elongation observed ~200 μm.

➡ No significant wire tension variations during cooling and filling.

➡ *Simplification of TPC frame geometry without springs in future detectors?*

Wiring devices

Wiring table



Tensioning group to fix and tension the wires

Wire module rolling around a PVC spool

PVC spools after washing and during drying

Wire production speed for T600 wires:
<u>1 hour</u> for the assembly of a 32 wires module

- <u>Over 50,000 wires</u> with lengths up to 9.42 m produced and tested for ICARUS T600.
- After two commissionings and a transport, <u>NO WIRES</u> got broken!
- The same wiring table can be easily extended to wire lengths of tens of meters.

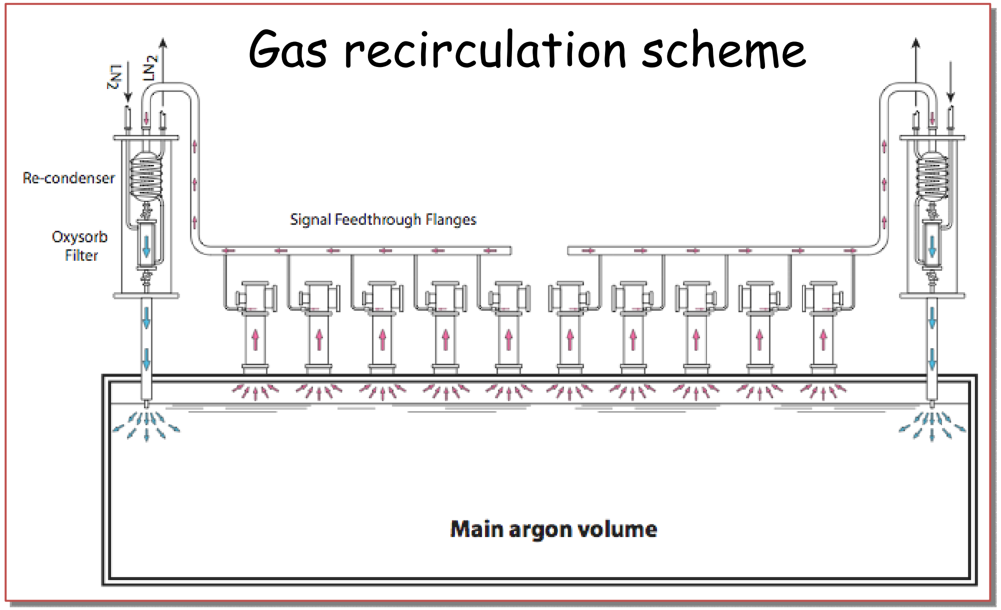
ICARUS T600 timeline at LNGS and beyond

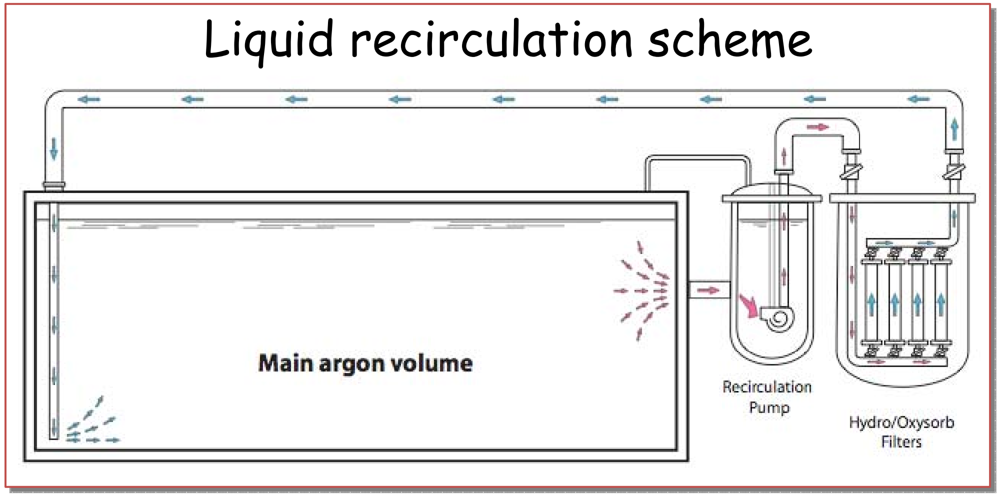
- 2010: Successful assembly and commissioning of ICARUS T600
  - January-March: vacuum phase (10^{-5} mbar)
  - April-May: cooling with LN2 and filling
  - May 28th : first CNGS neutrino
  - June-September: commissioning of DAQ/trigger
  - October: start of physics runs
- 2011 -> Dec 3rd, 2012:T600 runs with CNGS beam and cosmic rays
  - Nov. 2011 & March 2012: two run periods with bunched beam for ν velocity measurement
  - Nov. 2011-Feb. 2012: upgrade of PMT DAQ and timing
- Dec. 2012 - June 2013: data taking with cosmic rays
- 2013: Decommissioning
- 2014 and beyond: reinstallation for Sterile Neutrino searches

LAr purification in T600

Highly efficient filters based on Oxysorb/Hydrosorb for removal of electro-negative impurities (O_2, H_2O, CO_2)

- UHV standards for detector components design, construction, cleaning, assembly.
- Evacuation and out-gassing to molecular vacuum level ($< 10^{-3}$ mbar).
- Fast cooling (to minimize out-gassing) and filling with ultra-purified LAr.
- Recirculation/purification (100 Nm^3/h) of GAr (~40 Nm^3) to block the diffusion of impurities from hot parts of detector and from micro-leaks into liquid bulk.
- Recirculation/purification (4 m^3/h) of liquid bulk (~550 m^3) to efficiently reduce initial impurities.

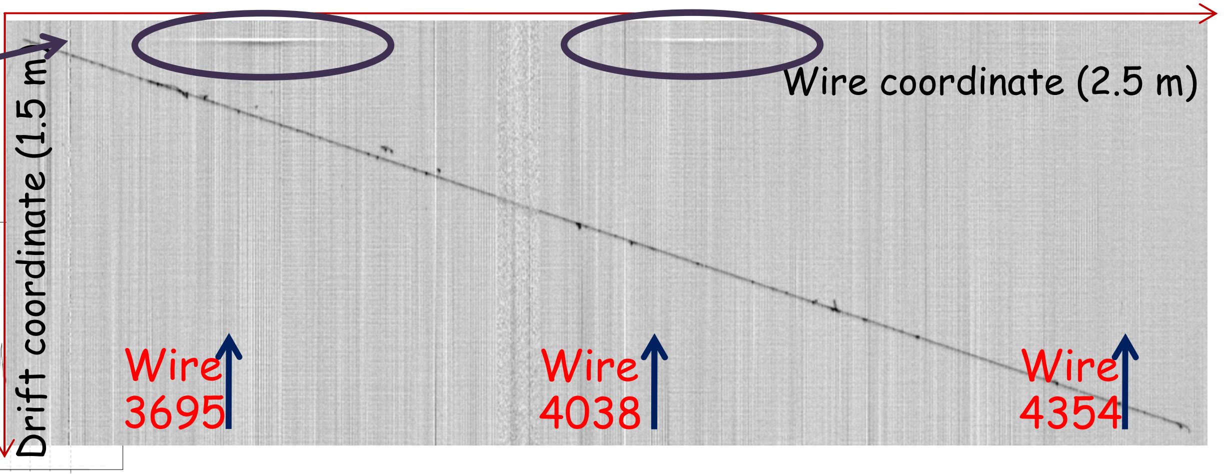

Gas recirculation scheme


Liquid recirculation scheme

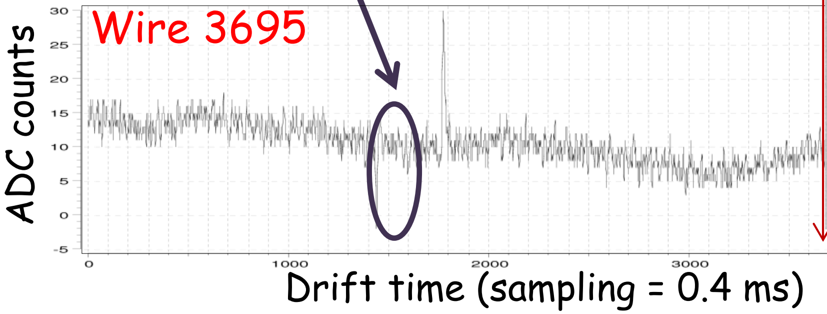
LAr purity monitoring

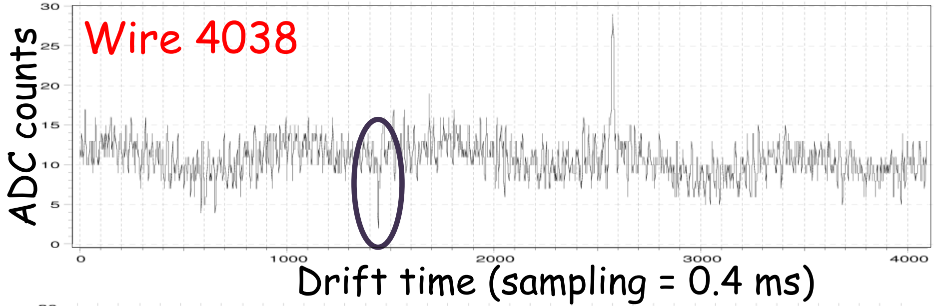
Charge attenuation along track allows event-by-event measurement of LAr purity.

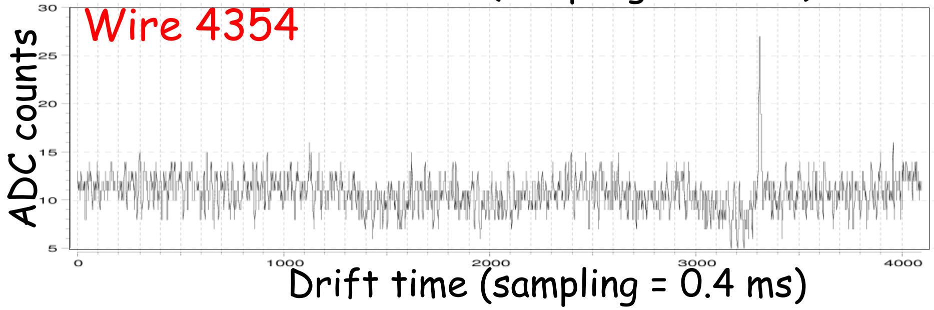
T = 0 estimated by induction of PMT signal on Collection view.



Run 10139 Event 8961 Collection view





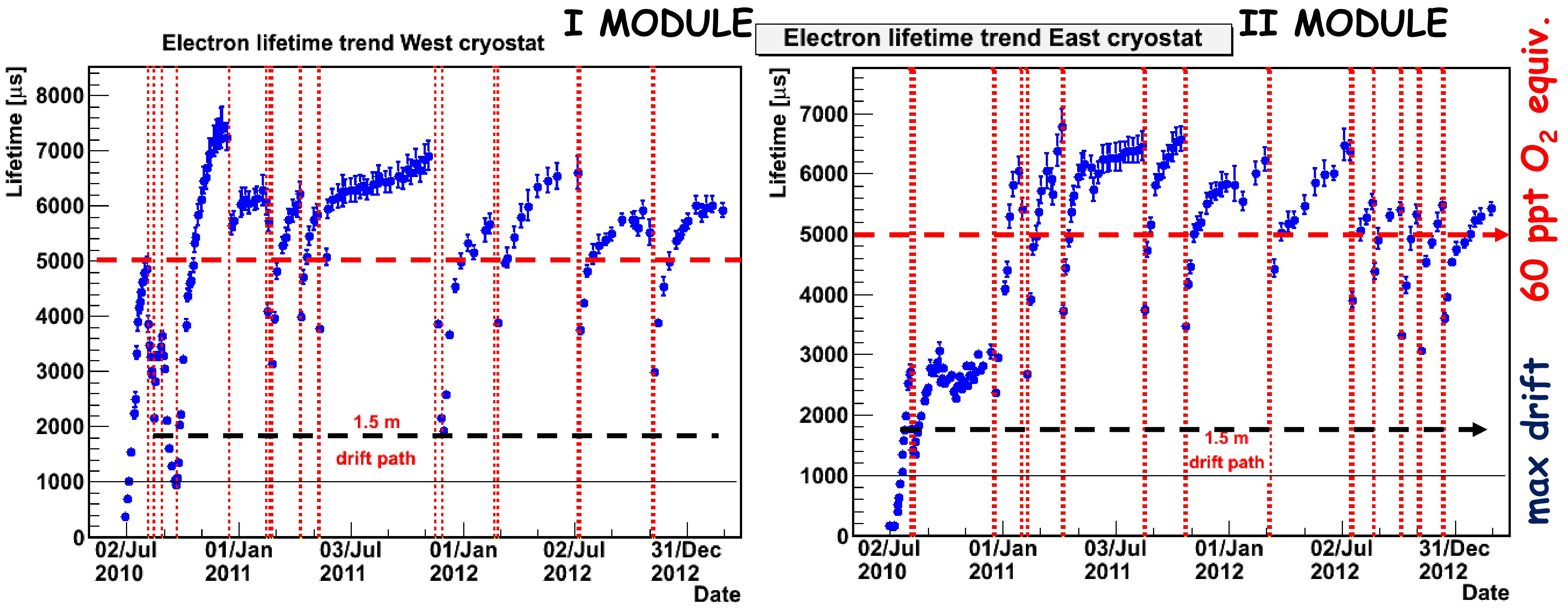


Pulse height for 3 mm m.i.p.
~ 15 ADC # (15000 electrons)

Noise r.m.s.
~ 1.5 ADC # (1500 electrons)

Continuous monitoring of charge attenuation with cosmic muon tracks

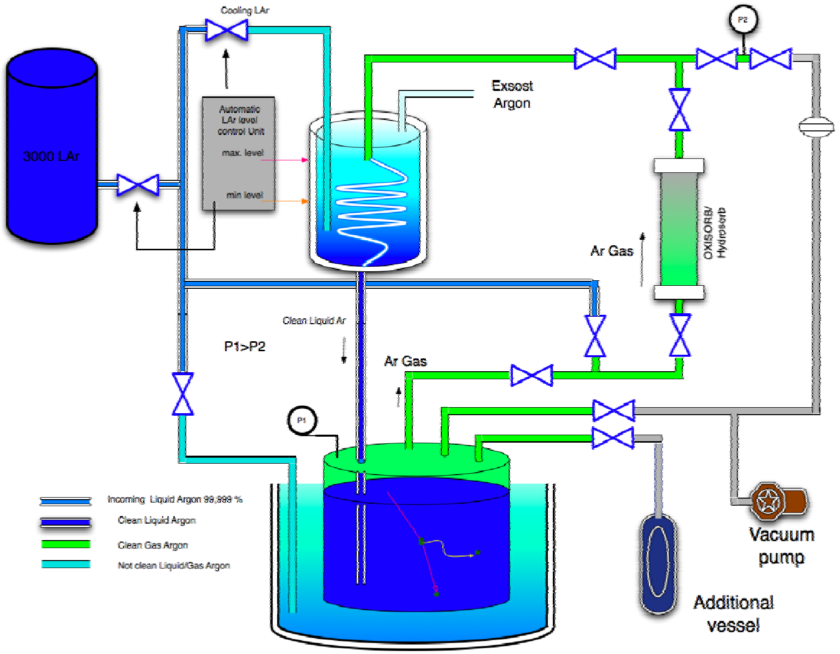
LAr purity achievements: T600

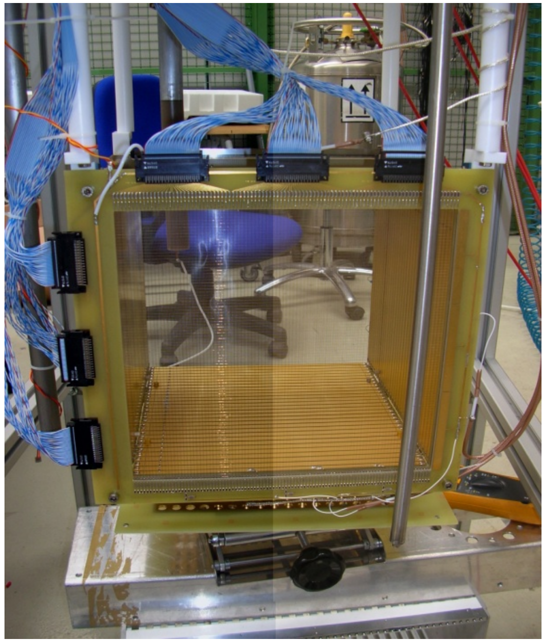


- ➢ During data taking: τ_e > 5 ms ≈ 60 ppt O_2 equivalent impurities ⇔ max. 17% signal attenuation after 1.5 m for the longest e^- drift distance, E_{drift} = 0.5 kV/cm.
- ➢ System is highly performing thanks to frequent maintenance of recirculation pumps.

Recent progress in experimental purity achievements

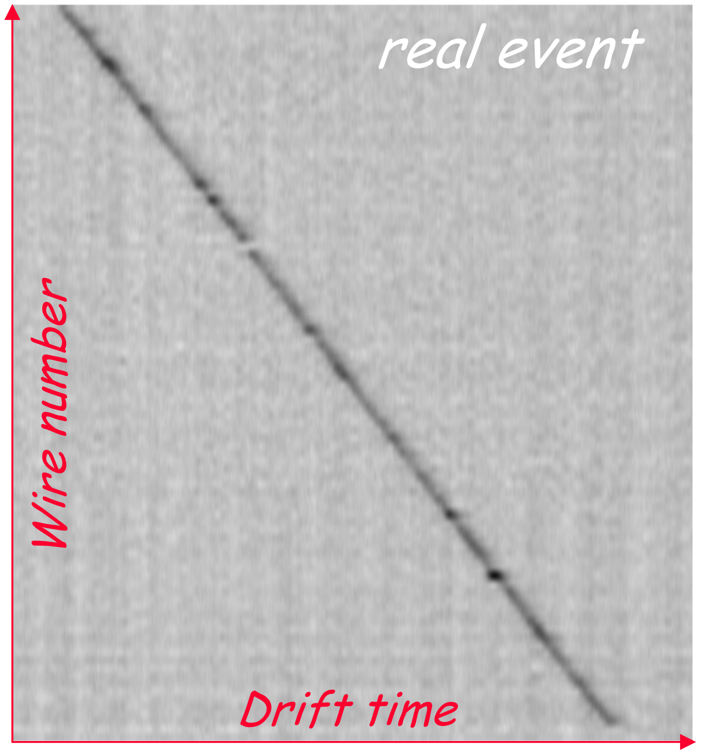
- New industrial purification methods have been developed at an exceptional level, especially remnants of O_2 which have to be initially and continuously purified.
- Extremely high τ_e have been determined with cosmic μ's in a small 50 litres LAr-TPC.
- The short path length used (30 cm) is compensated by the high accuracy in observation of the specific ionization
- The result here reported is $\tau_{ele} \approx 21$ ms corresponding to ≈15 ppt, namely a $\approx 10^{-11}$ molecular impurities in Ar

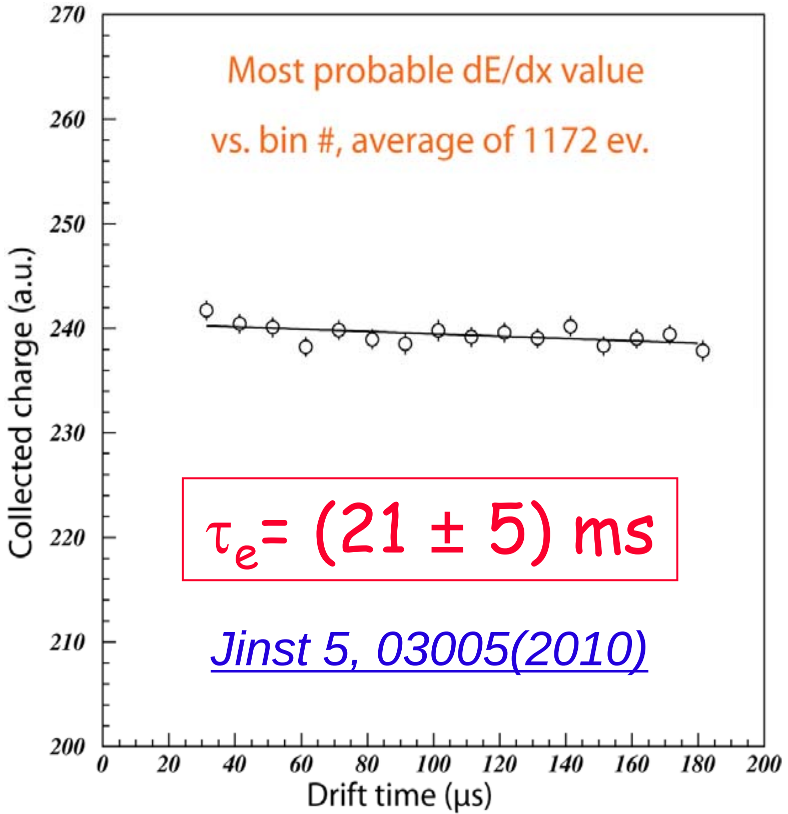




ICARINO-Legnaro

- The measured value to the experimental τ_e corresponds to an attenuation of about 10 % for a longest drift of 5 meters, opening the way to exceptionally long drift distances.

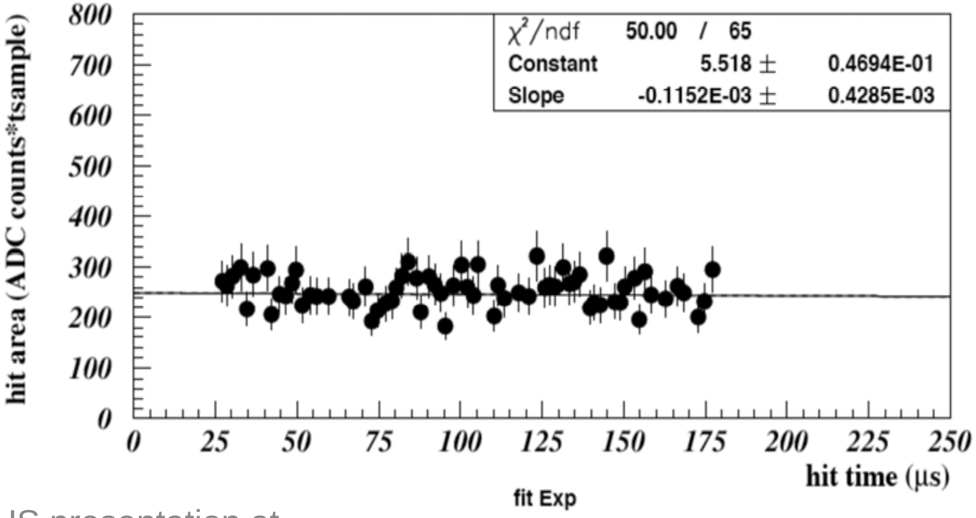




Most probable dE/dx value vs. bin #, average of 1172 ev.

τ_e= (21 ± 5) ms

Jinst 5, 03005(2010)



CNGS neutrino runs - summary

CNGS data taking (Oct. 2010 – Dec. 2012)

- large sample of ν interactions
- superluminal ν searches

  Cherenkov-like e^+e^- emission: P. L. B711 (2012) 270

  timing measurement: P. L. B713 (2012), 17

  Precision measurement: JHEP 11 (2012) 049
- ν oscillations

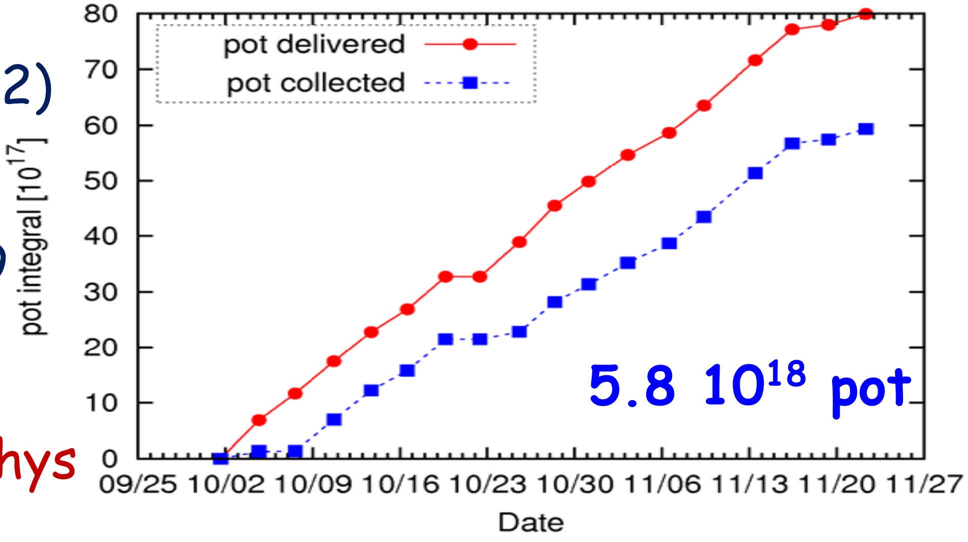
  $\nu_\mu \rightarrow \nu_\tau$ $\tau^- \rightarrow e^- \nu_e \nu_\tau$

  $\nu_\mu \rightarrow \nu_e$ "LSND/MiniBooNE" anomaly Eur. Phys J. C 73:2345, ArXiv:1209.0122

detector live-time > 93%

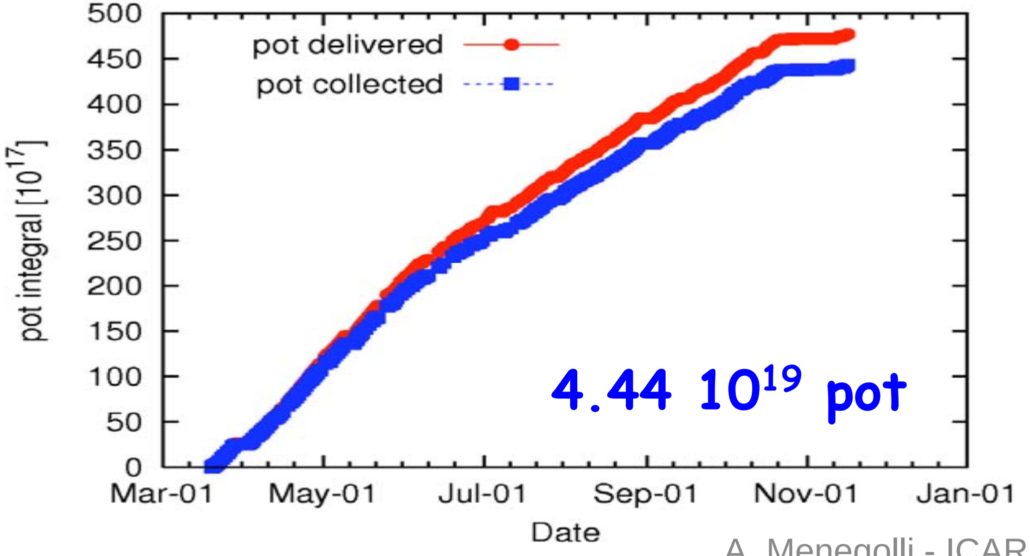
total 8.6 x 10^{19} pot collected

2010: Oct. 1st ÷ Nov. 22nd



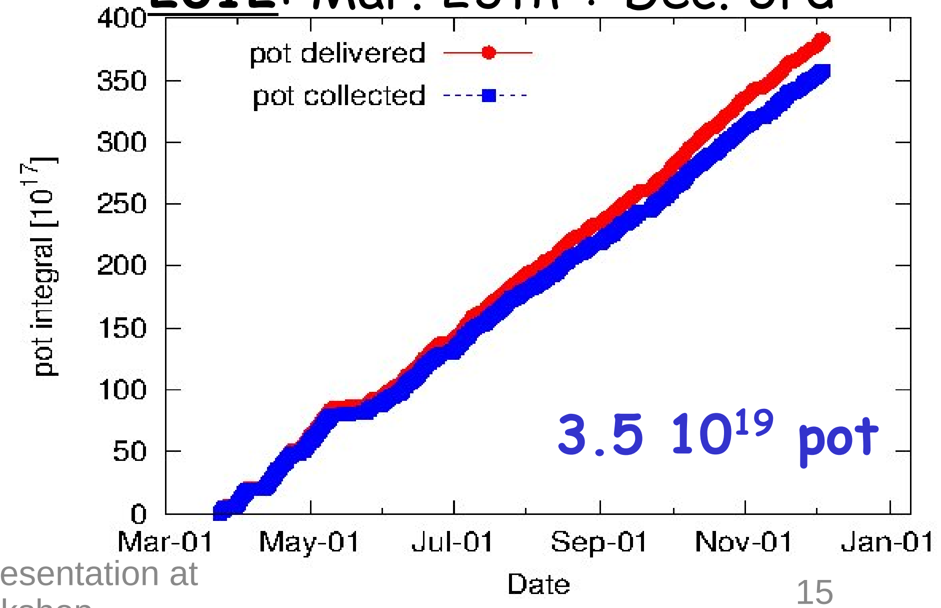
5.8 10^{18} pot

2011: Mar. 19th ÷ Nov. 14th



4.44 10^{19} pot

2012: Mar. 23th ÷ Dec. 3rd

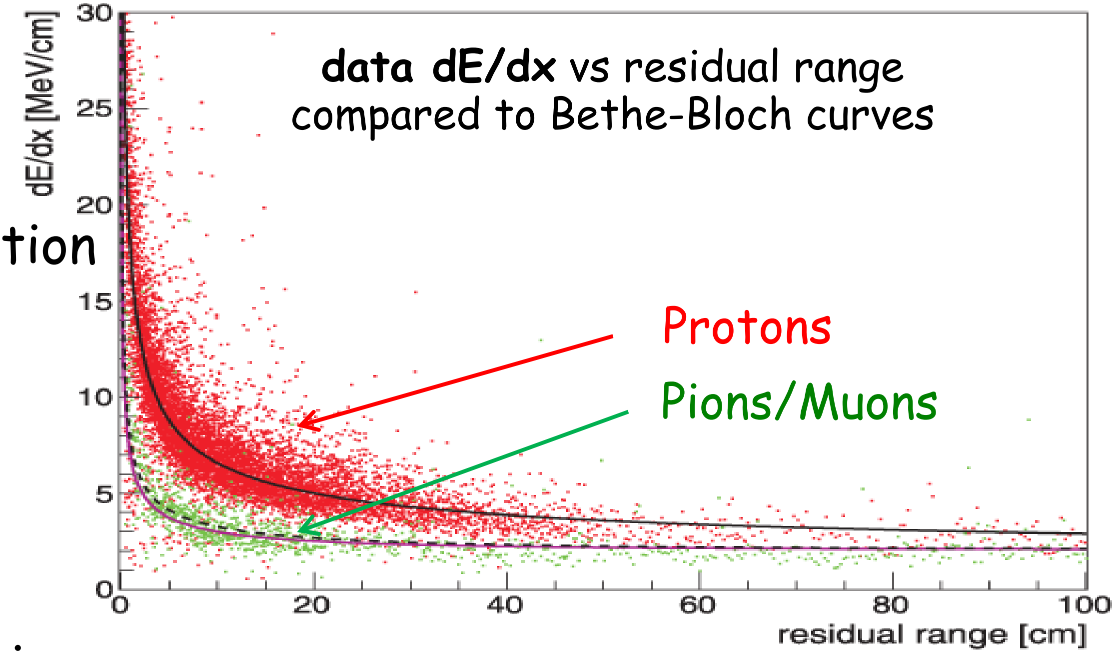


3.5 10^{19} pot

The LAr TPC performance

1) <u>PID</u>: dE/dx vs. residual range relation (REAL tracks in CNGS data):

- dE/dx from calorimetry (quenching included)
- dx from 3D reconstruction



data dE/dx vs residual range compared to Bethe-Bloch curves

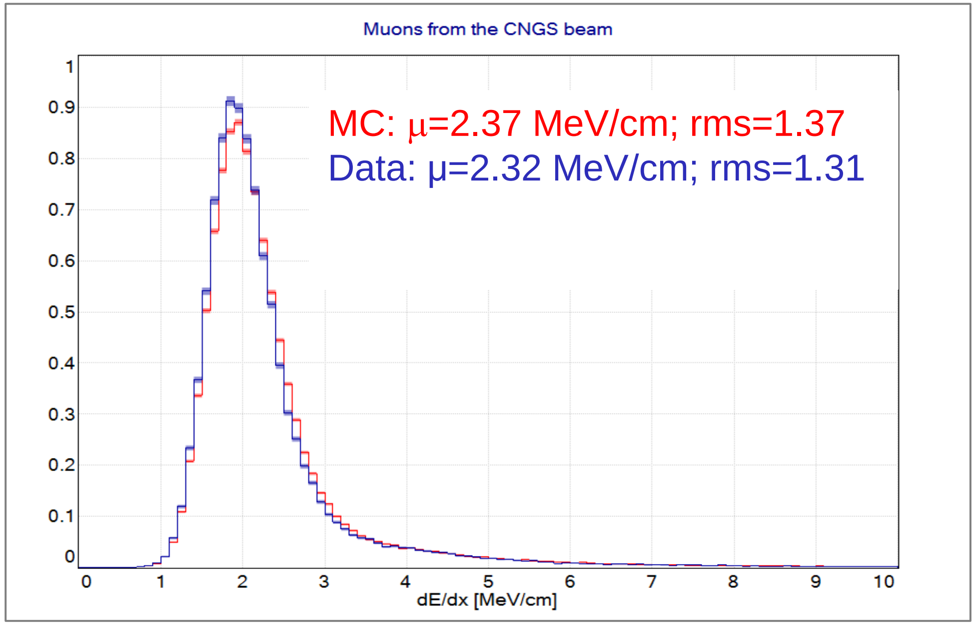
Protons

Pions/Muons

2) <u>Measurement of dE/dx</u>: distribution for hundreds of muon tracks in CNGS ν_μCC compared to Monte Carlo.

Absolute single channel energy calibration with high precision.

Matching uniformity and precision requirements on wire spacing, signal calibration and drift field.

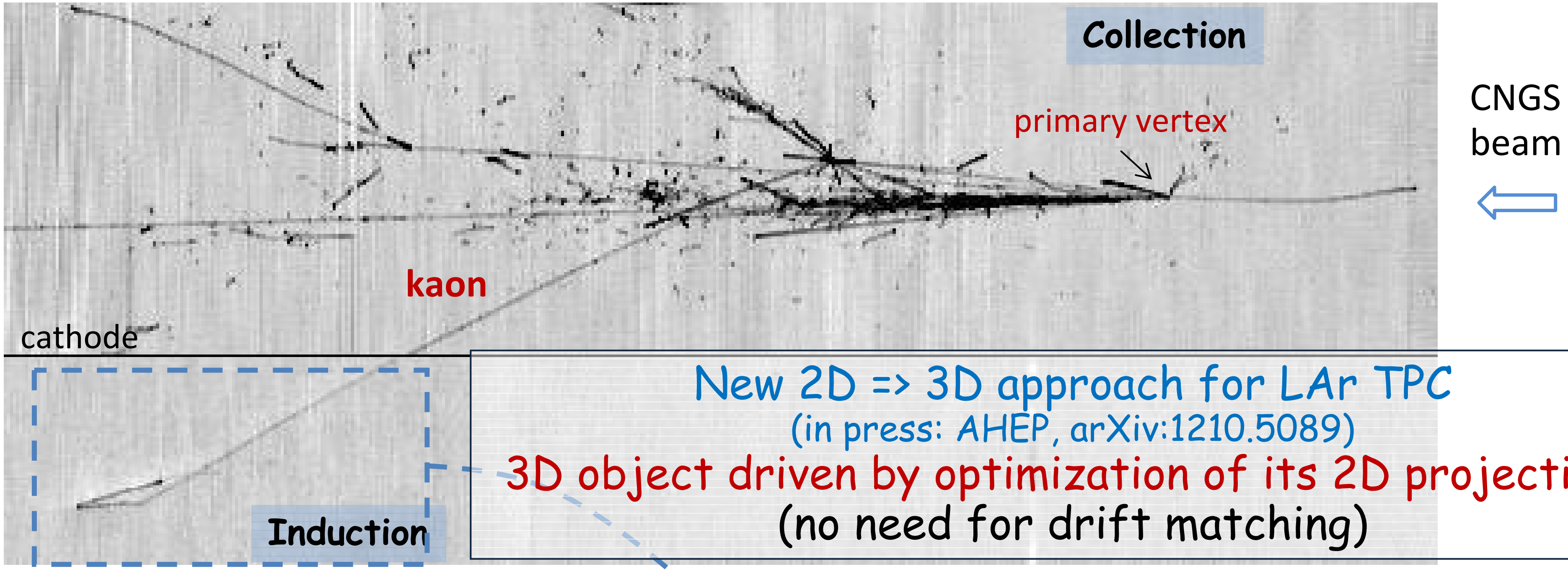


Muons from the CNGS beam

MC: μ=2.37 MeV/cm; rms=1.37

Data: μ=2.32 MeV/cm; rms=1.31

3D reconstruction example on CNGS data

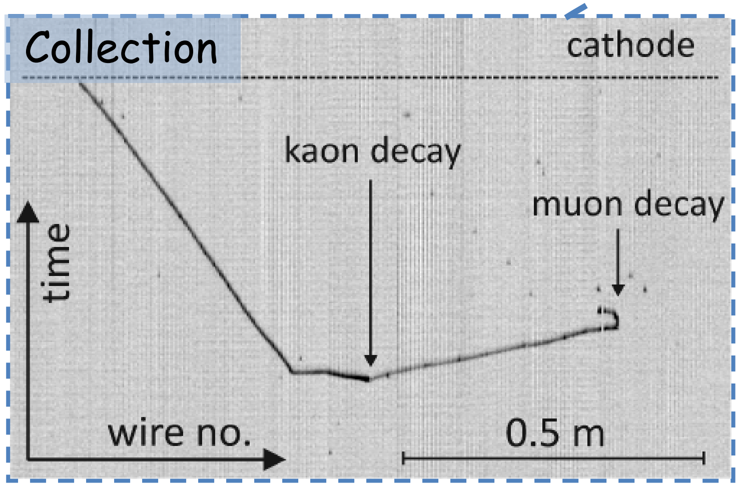


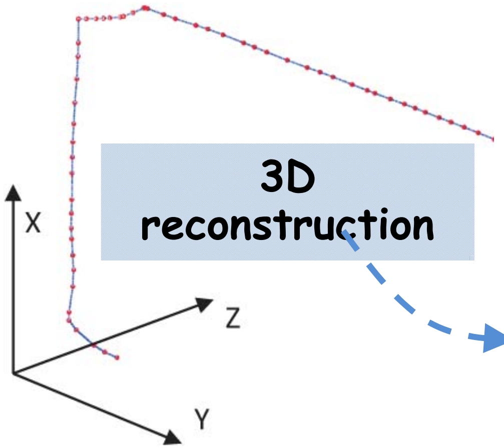
New 2D => 3D approach for LAr TPC

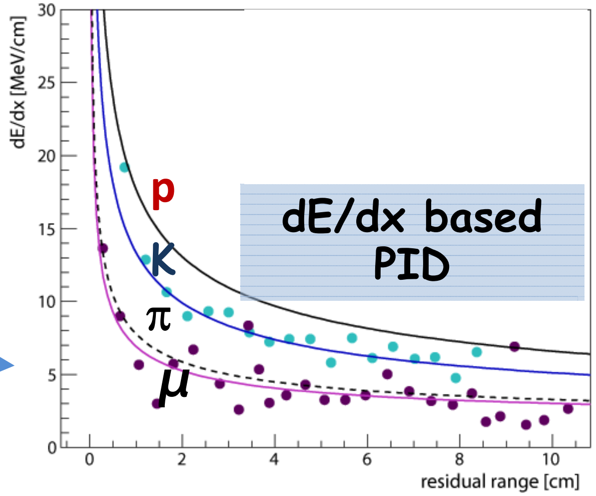
(in press: AHEP, arXiv:1210.5089)

3D object driven by optimization of its 2D projections

(no need for drift matching)





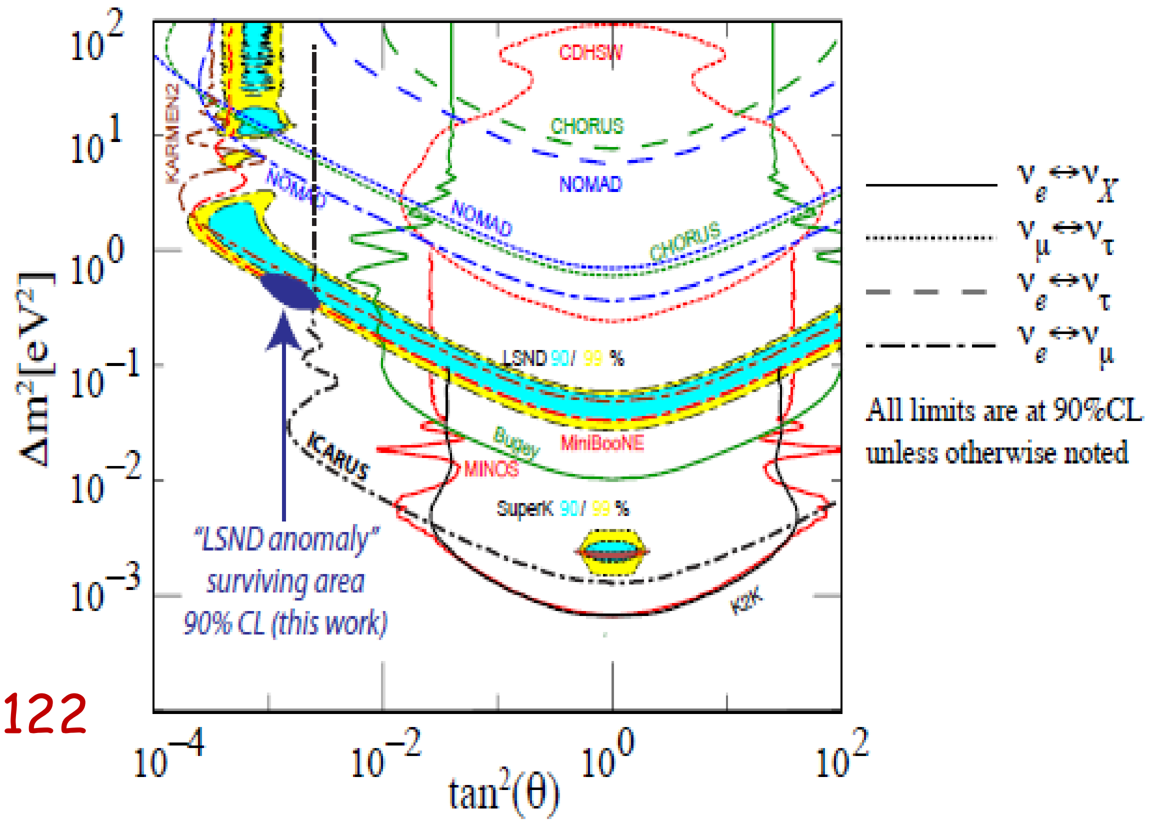


Search for LSND-like effect in ICARUS at LNGS

- CNGS beam is peaked in the 10-30 GeV range: LSND oscillations can be studied by looking for ν_e appearance in the ν_μ beam (intrinsic ν_e ~ 1%).
- ν_e signature observed visually (efficiency ~74%, estimated from MC).
- Present sample: 1091 neutrino events from 2010 and 2011.
- Expected background for ν_e appearance: 3.7 ± 0.6 events

- The ICARUS experiment is presently compatible with the absence of a LSND anomaly.
- LSND/MiniBooNE signal are strongly constrained by ICARUS: a small region around $\Delta m^2 \approx 0.5$ eV^2, $\sin^2(2\theta) \approx 0.005$ survives

Eur. Phys. J. C 73:2345, arXiv:1209.0122



"LSND anomaly" surviving area 90% CL (this work)

All limits are at 90%CL unless otherwise noted

A modular approach for multi kton LAr TPCs

- Already in 2007 the ICARUS Collaboration proposed a graded program for proton decay and neutrino oscillation studies, based on the subsequent deployment multi kton Liquid Argon TPC units (MODULAr program, arXiv:0704.1422v1 [hep-ph] 11 Apr 2007).
- The design of the basic module (5 to 10 kton LAr mass) was vastly based on the T600 design with some significant differences:
  - The LAr volume is not evacuated before filling; air has to be removed by pure argon gas flushing;
  - The wires pitch is increased, to preserve the nominal signal to noise ration of 10:1;
  - Pure passive thermal insulation is used with the walls of the cavern acting as the external walls of the LAr cryostats.
- The MODULAr approach offers the several advantages (flexibility, cost reduction, safety) that have been also recognized by LBNE.

Conclusions

- ICARUS T600 experience at LNGS marked a major milestone for the LAr TPC technology.
- Its safe and stable operation for three year in underground environment with high performance demonstrates that the LAr TPC is a sound option for neutrino physics.
- A number of physics results have been already obtained and new ones will come soon, both with CNGS neutrinos and with cosmic rays.
- The approach of a modular design seems the best option for a direct scalability of the T600 design towards multi kton LAr TPCs.
- With some R&D the experience of ICARUS T600 can be extended to the MODULAr/LBNE concept of blocks of 5/10 kton each.

Thank you!