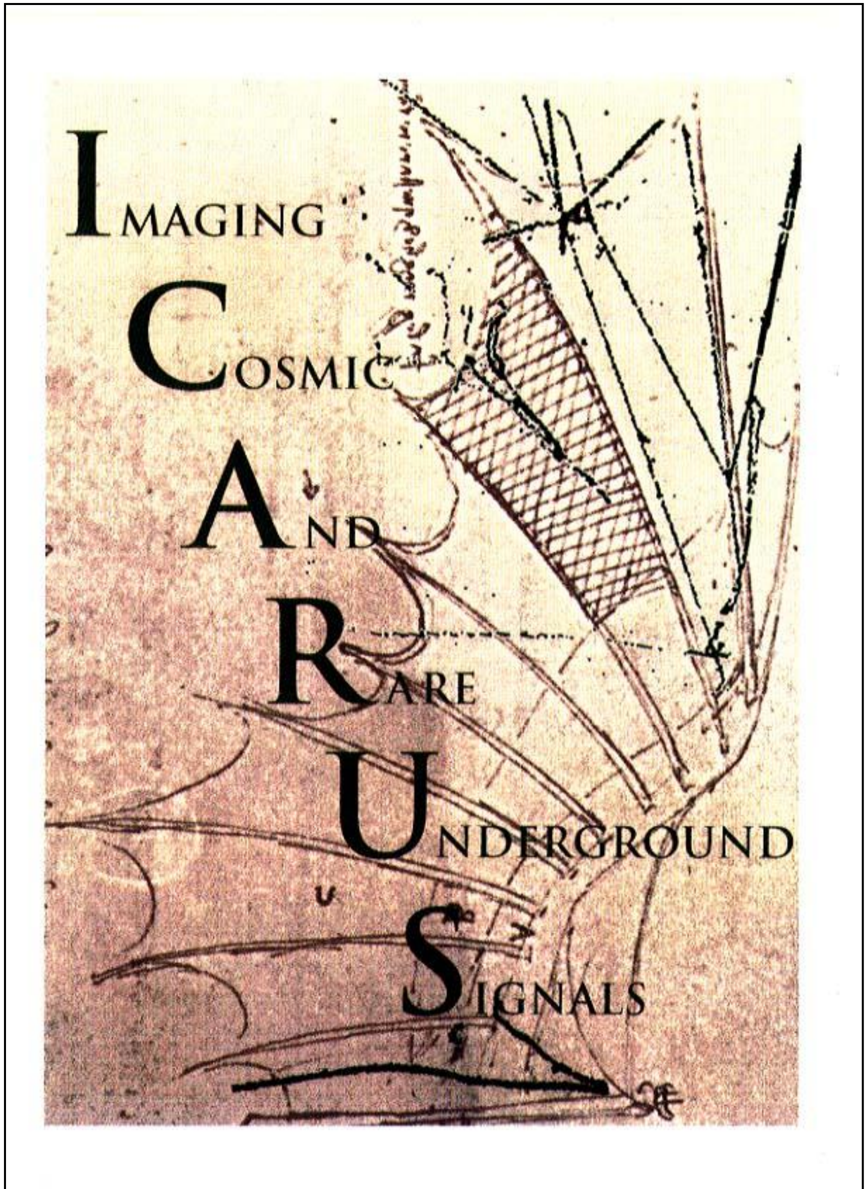
Status of ICARUS T600

P. Sala for the ICARUS collaboration

Now2010 , September 2010



The ICARUS collaboration

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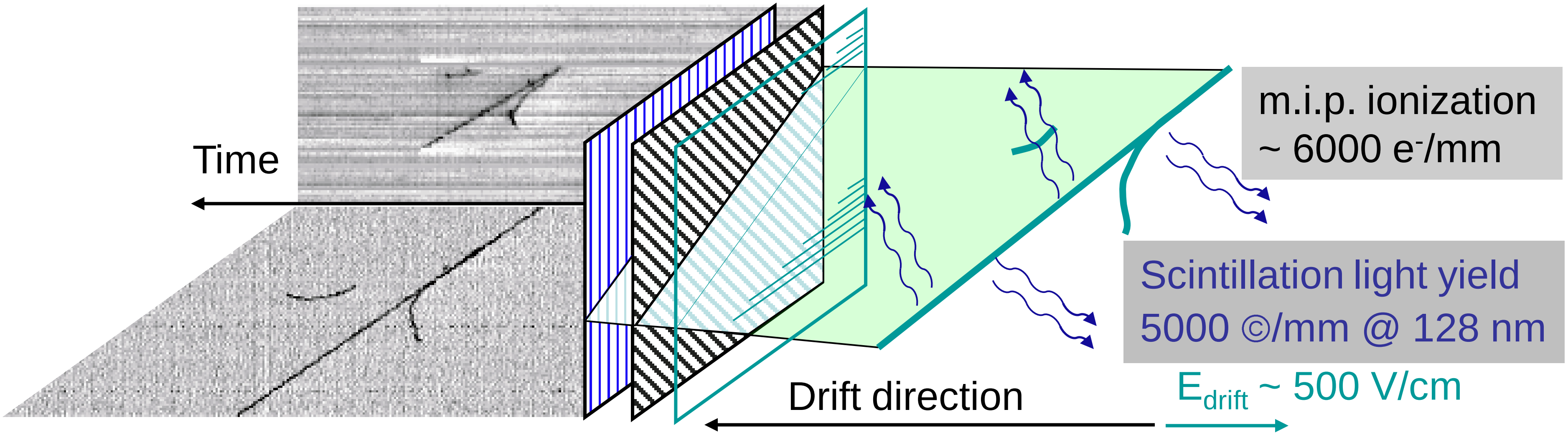
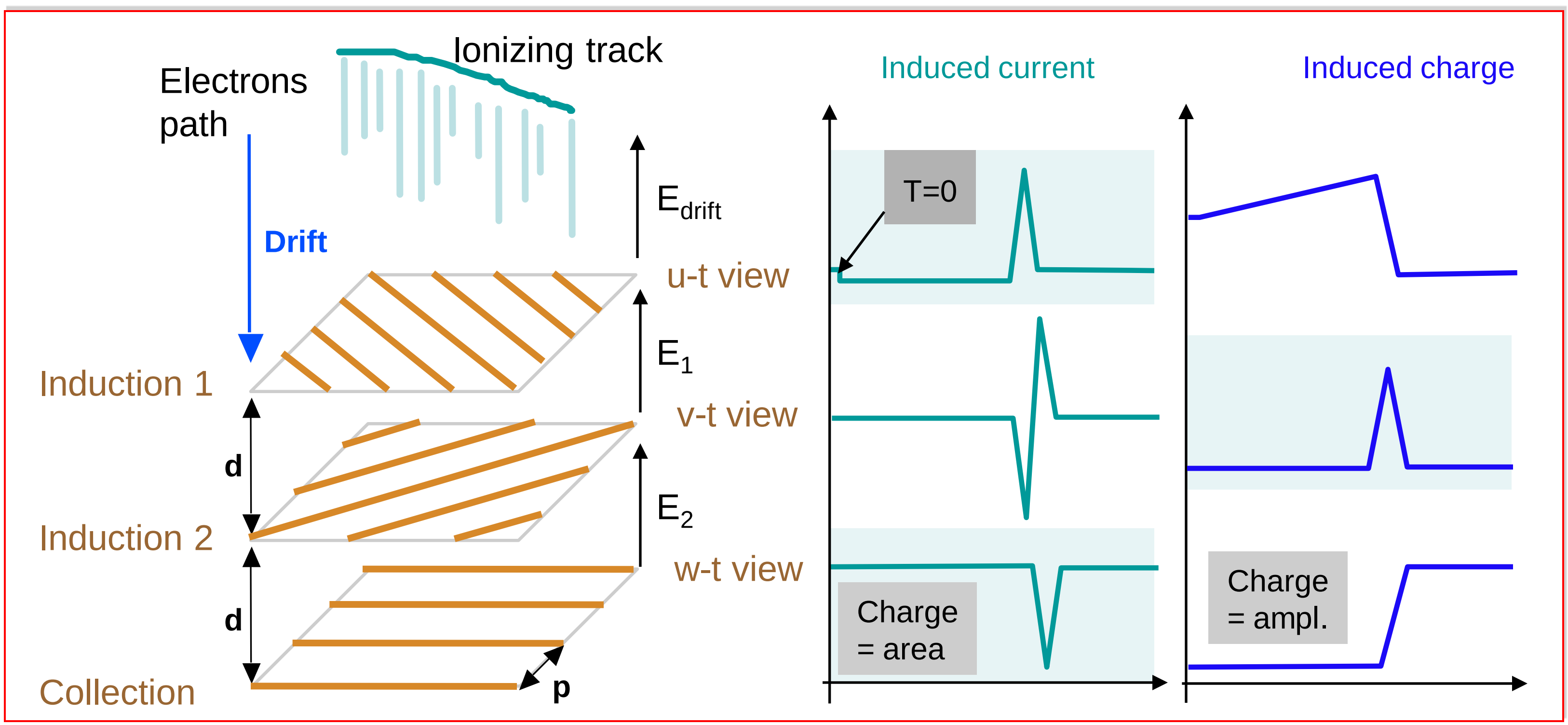
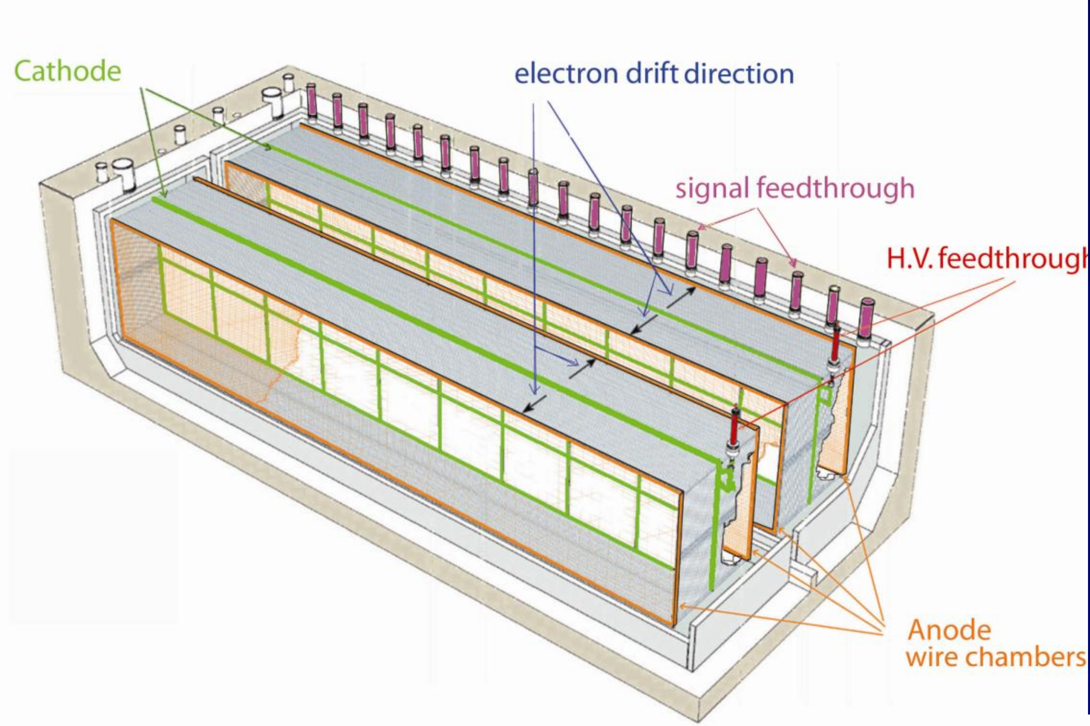
- The T600 detector is the first large-mass application of a powerful detection technique:
  - the Liquid Argon Time Projection Chamber
    - [C. Rubbia: CERN-EP/77-08 (1977)]
  - first proposed to INFN in 1985
    - [ICARUS: Imaging Cosmics And Rare Underground Signals: INFN/AE-85/7]
- A long road..in many aspects

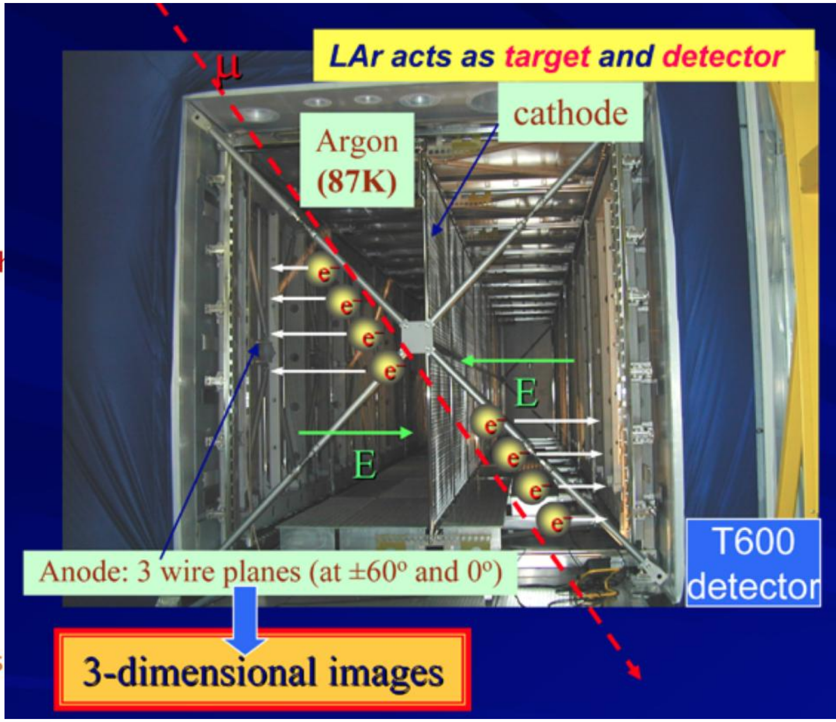
The ICARUS read-out principle





The ICARUS T600 detector





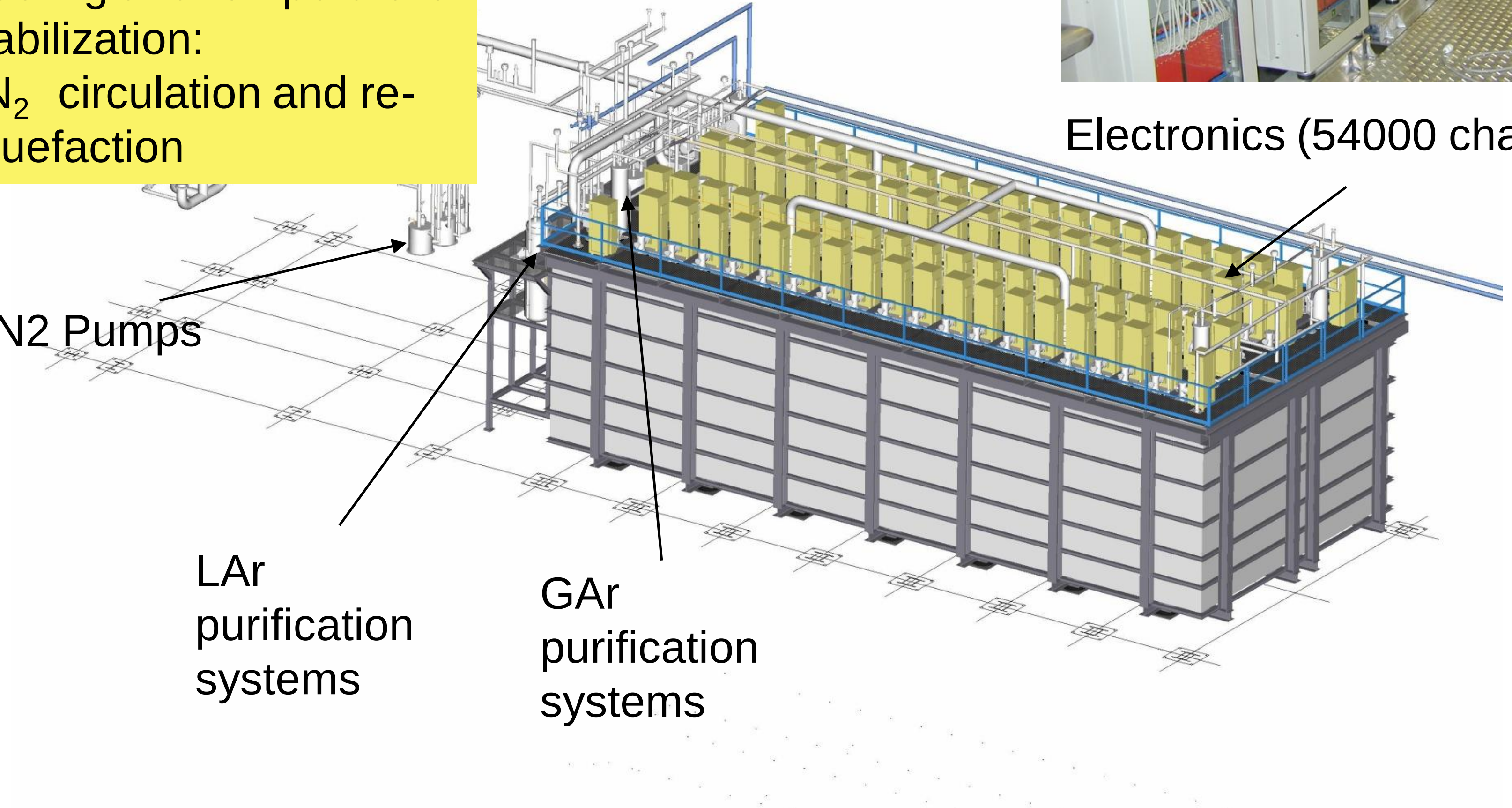
- Two identical modules
  - 3.6 x 3.9 x 19.6 ≈ 275 m^3 each
  - Liquid Ar active mass: ≈ 476 t
  - Drift length = 1.5 m
  - HV = -75 kV E= 0.5 kV/cm

- 4 wire chambers:
  - 2 chambers / module
  - 3 readout planes / chamber: at 0°, +60°, -60°
  - **3 mm wire** spacing
  - 400 ns t sampling **-> 0.6 mm granularity**
  - ≈ 54000 wires
- PMT for scintillation light:
  - (20+54) PMTs, 8" Ø
  - VUV sensitive (128nm) with wave shifter (TPB)

T600 cryostats layout in LNGS Hall B

Extra-pure argon needed to avoid charge recombination : less than 1ppb O_2 equiv.
=> Purification systems

Cooling and temperature stabilization:
LN_2 circulation and re-liquefaction

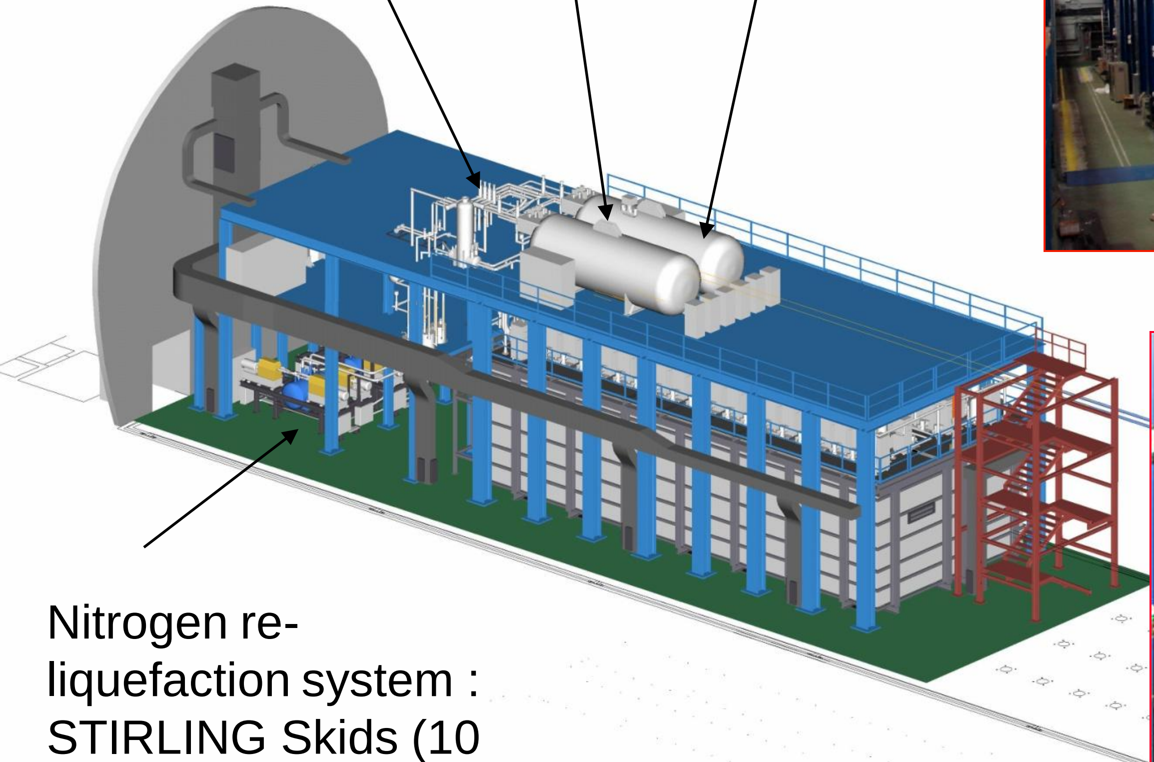


T600 cryogenic plant at LNGS

30 m^3 LAr Vessel

30 m^3 LN_2 Vessel

N_2 Phase separator

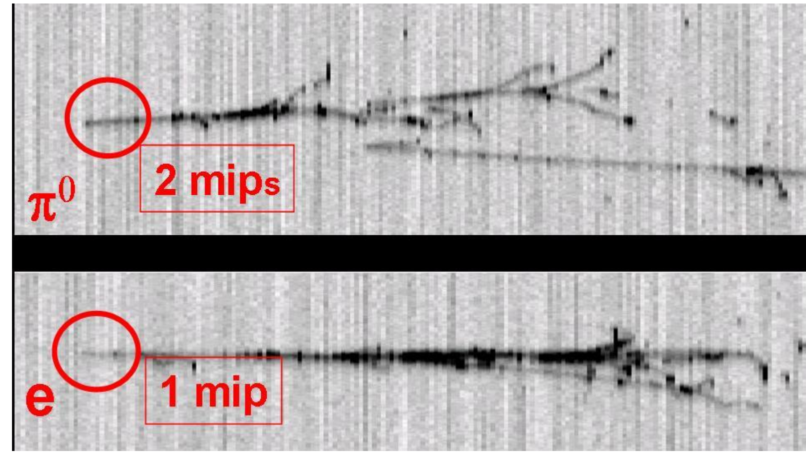


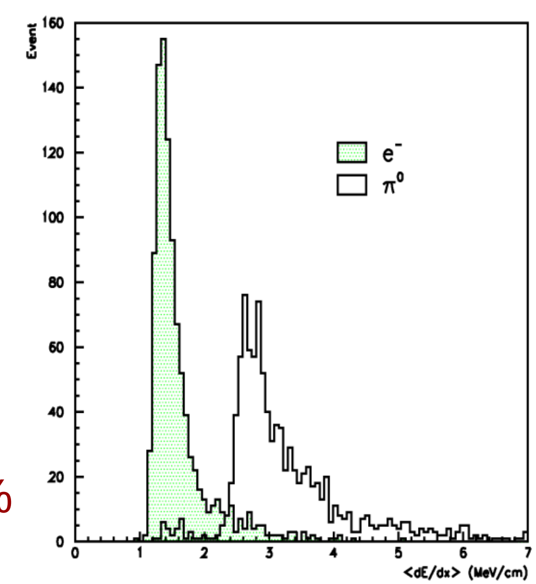
Nitrogen re-liquefaction system : STIRLING Skids (10 units)

LAr-TPC performance

- Tracking device
  - Precise event topology
  - Muon momentum via multiple scattering
- Measurement of local energy deposition dE/dx
  - e/γ separation (2% X_0 sampling)
  - Particle ID by means of dE/dx vs range
  - e/π^0 discrimination at 10^{-3}, 90 % electron ident. eff. by γ convertion from vertex, π^0 mass measurement and dE/dx.
- Total energy reconstruction of the events from charge integration
  - Full sampling, homogeneous calorimeter with excellent accuracy for contained events

Fundamental for $\nu_\mu - \nu_e$ oscillation search!





RESOLUTIONS

Low energy electrons: $\sigma(E)/E = 11\% / \sqrt{E(MeV)} + 2\%$

Electromagn. showers: $\sigma(E)/E = 3\% / \sqrt{E(GeV)}$

Hadron shower (pure LAr): $\sigma(E)/E \approx 30\% / \sqrt{E(GeV)}$

Physics potentials of ICARUS T600

- T600 is a major milestone towards the realization of a much more massive multikton LAr detector, but it offers also some interesting physics in itself. The unique imaging capability of ICARUS, its spatial/calorimetric resolutions, and e/π^0 separation allow "to see" events in a new way, w.r.t. previous/current experiments.

- The detector is collecting "bubble chamber like" CNGS events:
  - CC event rate ≈ 1200 ev/year
  - NC event rate ≈ 400 ev/year
  - Muons from GS rock ≈ 3700 ev/year
  - If lucky : $\nu_\mu \Rightarrow \nu_\tau$ detecting τ decay with kinematical criteria.
  - Search for sterile neutrinos in LSND parameter space, with e-like CC events excess at E>10GeV.

- The T600 is also collecting simultaneously "self triggered" events:
  - ≈ 100 ev/year of atmospheric ν CC interactions
  - ≈ 300 solar neutrino electron interactions > 8 MeV.
  - Supernova neutrino detection (≈ 200 evts from 10kpc)
  - A zero backgr. proton decay with $3\ 10^{32}$ nucleons

ICARUS T600 road map

Detector assembly completed by December 2009

Cryogenic plant completed by March 2010

- **Vacuum phase**: the cryostats evacuation started on January 9th, 2010. Reached 6.6 10^{-5} mbar in both cryostats
- **Cooling phase**: the vacuum was broken on April 14th and the volume was filled with ultra-pure Argon gas; the LN_2 cool-down of the ICARUS walls started on April 16th, reaching the LAr temperature (90K) on April 23rd.
- **Filling phase**: with ultra-pure LAr started immediately after (April 29th) at a rate of ~2 m^3/hour. On May 18th both modules were completely full.
- On May 26th liquid recirculation started (~2 m^3/h per cryostat).
- 8 Stirling machines out of 10 are operating (32 KWatt) smoothly.
- **T600 commissioning**: On May 27th HV and wire biasing and PMT's were turned on the West Cryostat. At 12.24 the first muon crossing track was recorded.
- On May 28th at 19.54 the first CNGS neutrino interaction was observed.
- On June 1st the East cryostat was also turned on without problems.
- Muon tracks are presently used to evaluate electron lifetime in real time.
- Electronics for PMTs' signal discrimination and trigger logic under optimization.

Trigger system commissioning

- ICARUS-T600: continuously active and self-triggering detector.
- Flexible trigger is required to acquire wide range of event topologies and rate (CNGS, atmospheric, solar, SuperNovae neutrinos, p-decay etc..)
- Total effective rate dominated by crossing cosmic muons

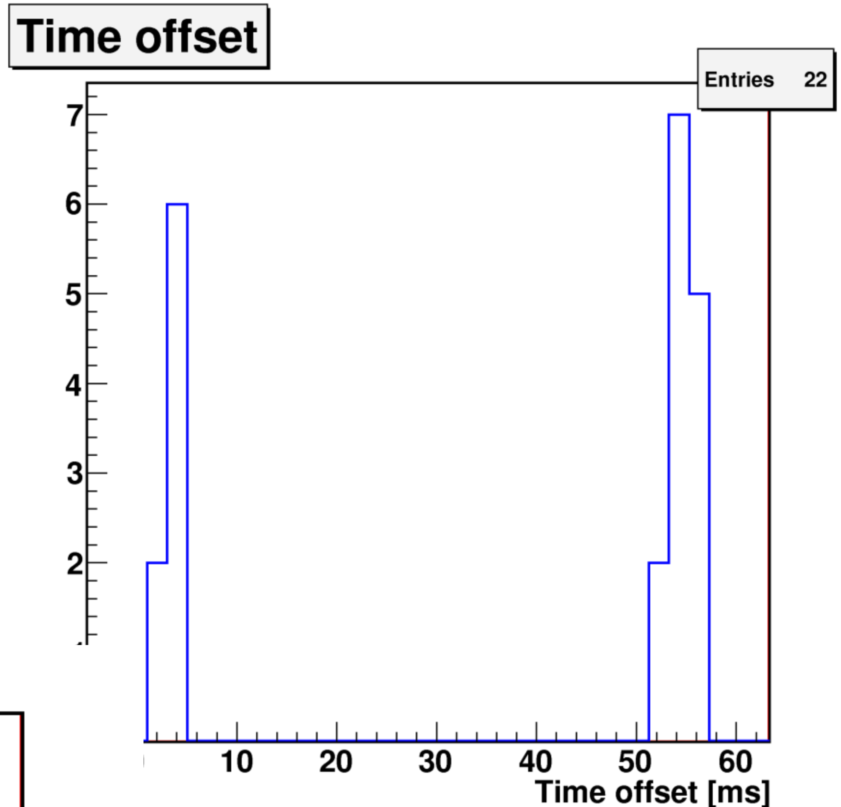
Available signals:

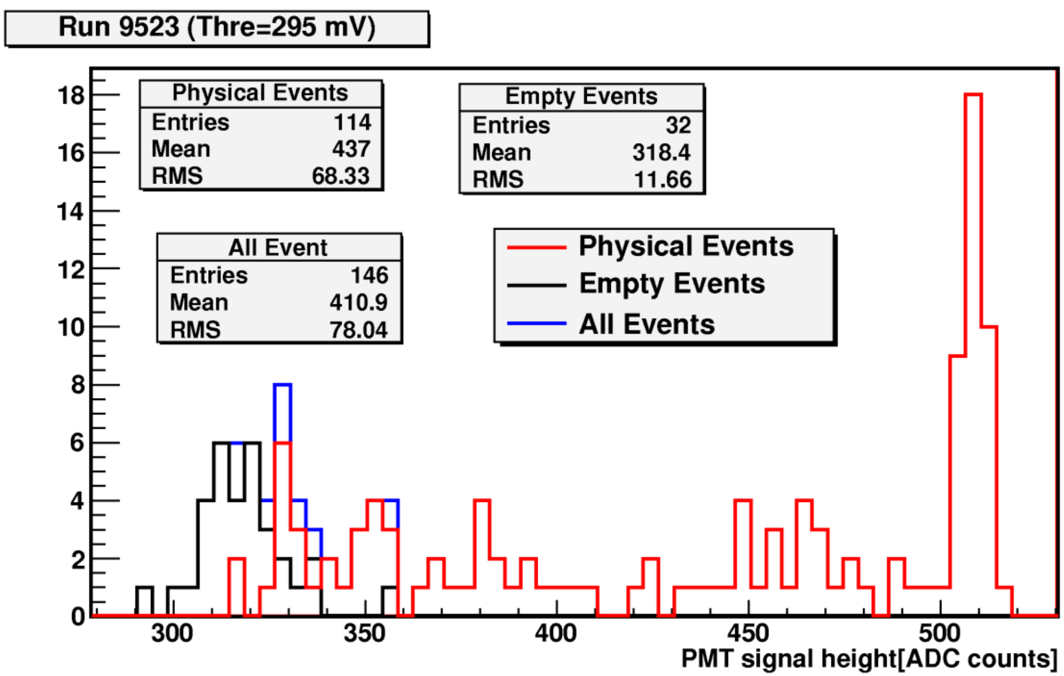
- Prompt global scintillation light from internal PMT arrays (< 2 μs). Optimization ongoing
  - PMT signal majority (three-fold coincidence)
  - PMT signal sum
  - Used also for T=0 determination
- Early warning CNGS extraction signal.
  - Sent 80 ms before extraction. Implementation of synchronization on going.

On board hit finding algorithm: studies on going on LAr-TPC prototype at LNL for RoI detemination (second level trigger / data reduction)

Work in progress on trigger

Preliminary: CNGS event tagging.
More precise timing is being set up

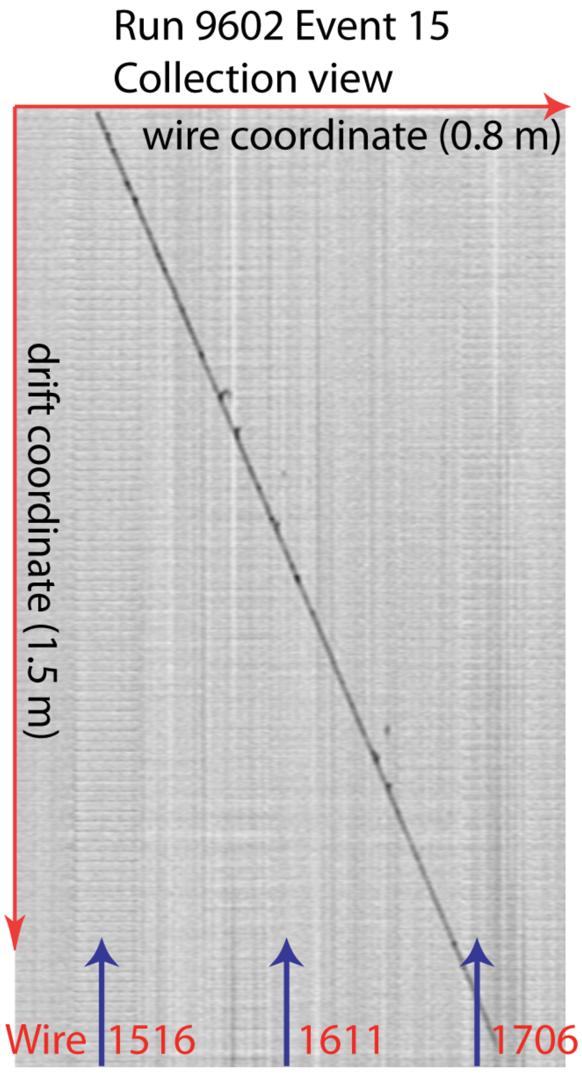


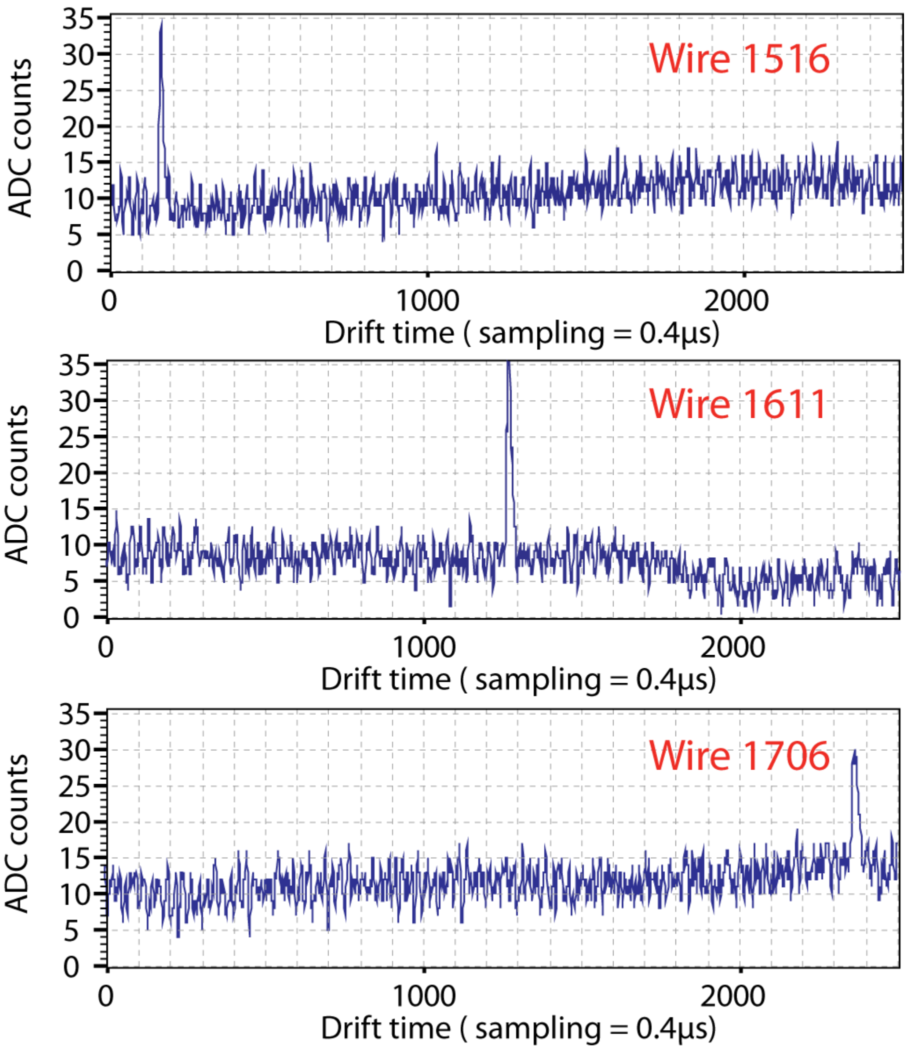


Preliminary : threshold setting on PMT summed signal

Example of muon crossing track

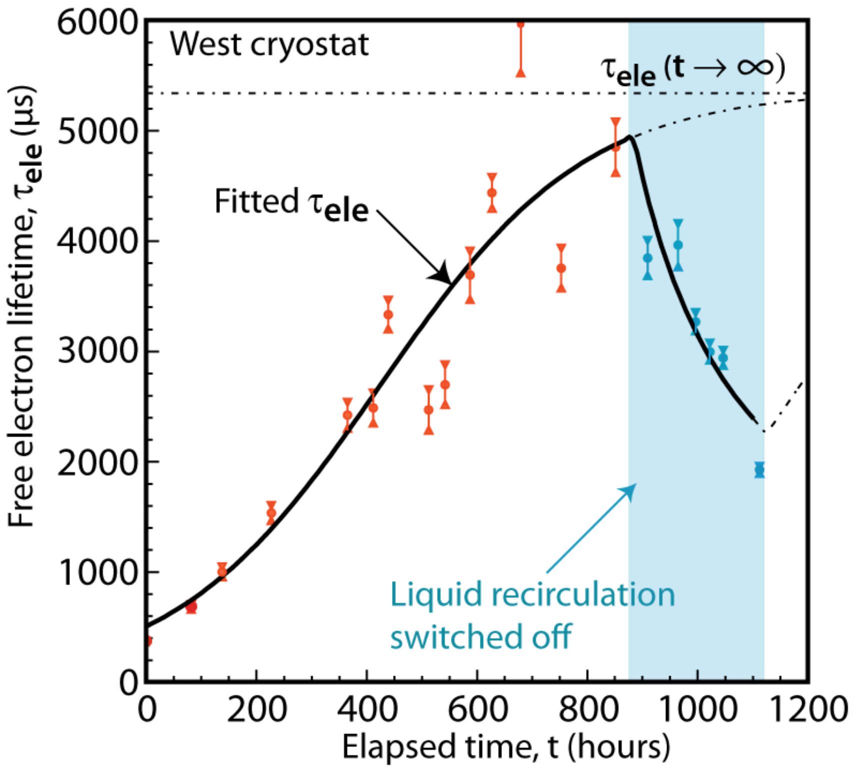
150 wires
1024 t-samples

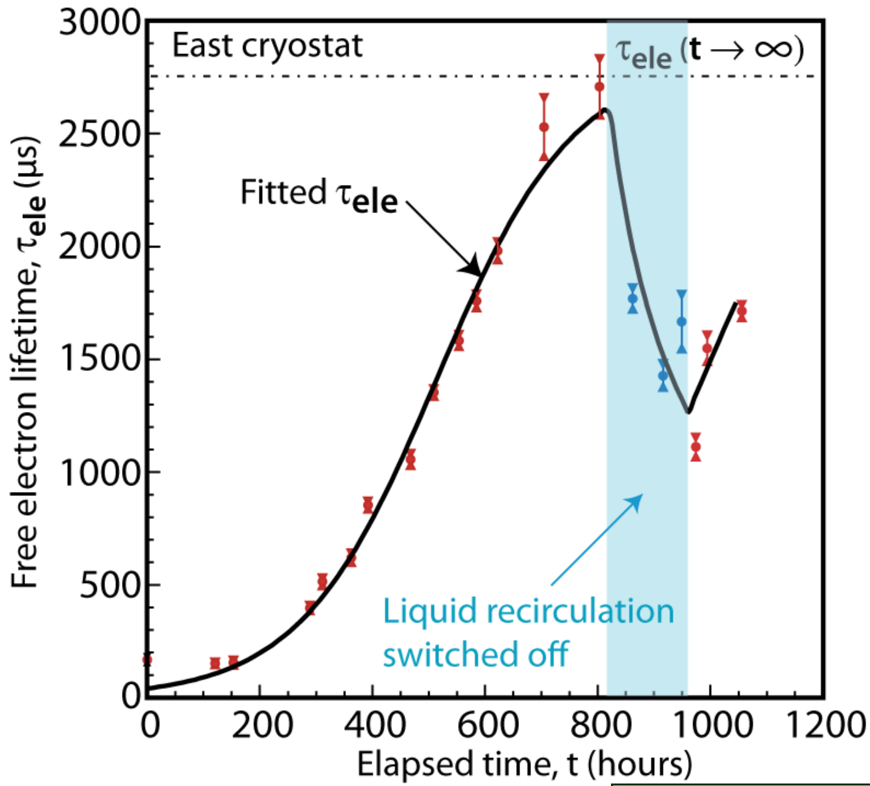




r.m.s noise is 1.5 ADC counts (1500 electrons equivalent);
Typical pulse height for a 3 mm m.i.p. is about 12 ADC counts (12000 electrons).
T=0 comes from induction of PMT signal on collection.
Charge attenuation along the track allows event-by-event measurement of LAr purity

Evolution of purity





Level of impurities $N(t) = k\tau_o + [N(t=0) - k\tau_o]\exp(-t/\tau_o)$

$$N[ppb] = \frac{300}{\tau_{ele}[\mu s]}$$

Equilibrium free electron lifetime $\tau_{ele}(\infty)$: 5.39 ms and 2.73 ms.

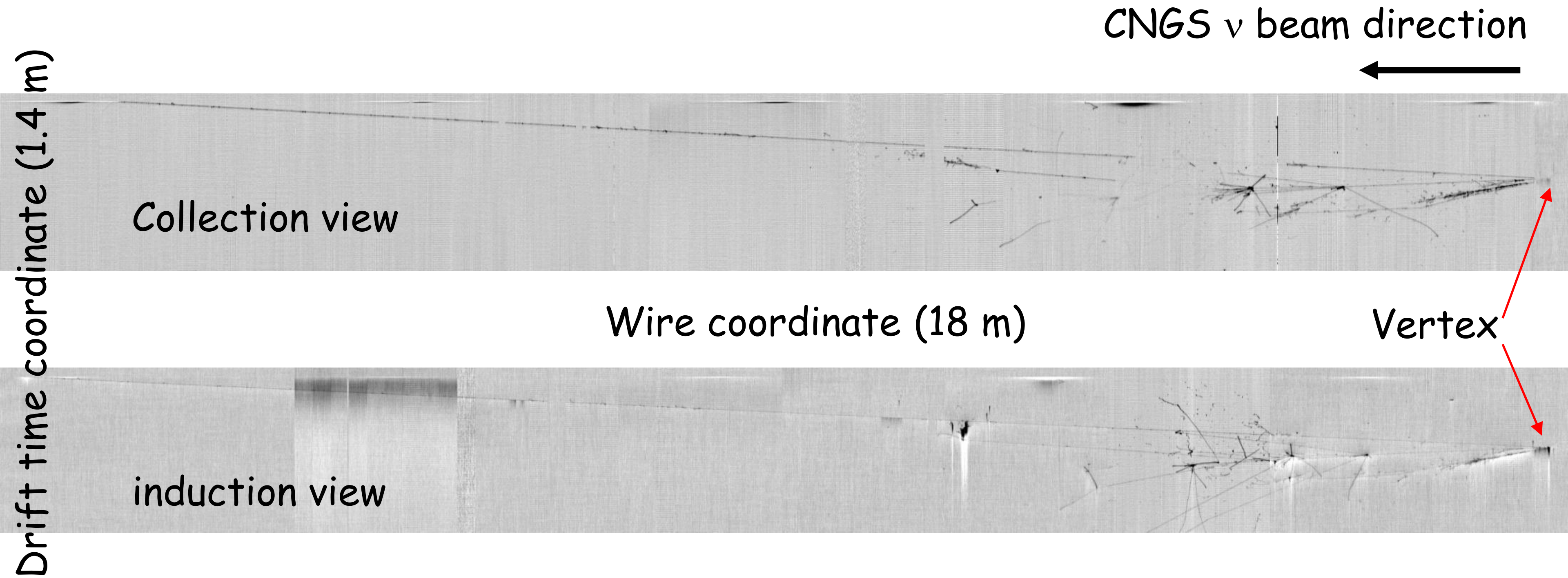
free electron charge attenuations for 1.5 m == 17% and 31% respectively.

Recirculation time τ_0 6.7 and 5.5 days

in agreement with the known pump-driven recirculation ==280 m^3 at $2m^3/h$.

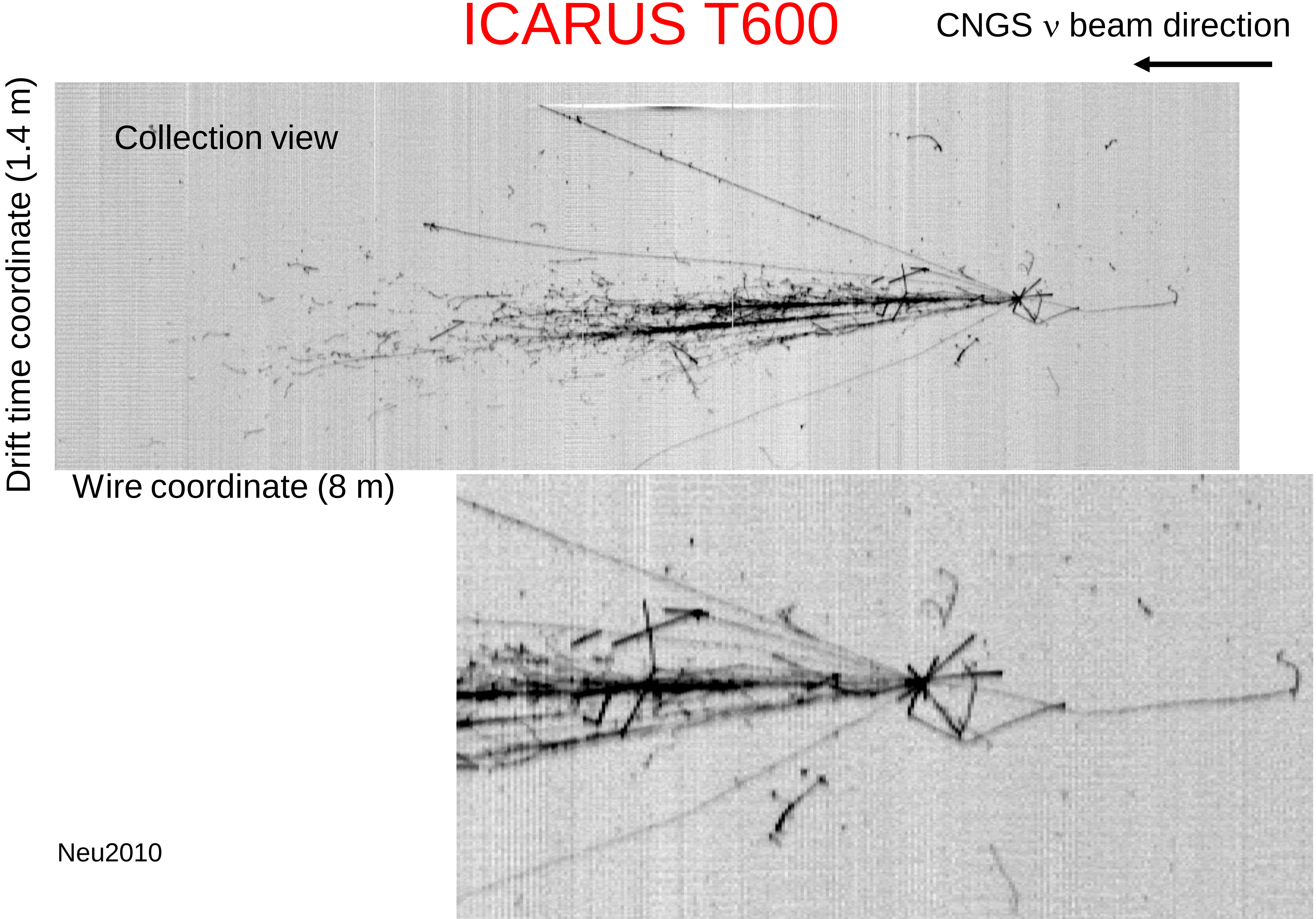
Impurities continuously generated inside the cryostats, k : 7.2 and 20 ppt/day (part per trillion, O_2 equiv.) ==2.2 x 10^{-3} and 6.0 x 10^{-3} gram/day of O_2 equiv.

The first CNGS neutrino interaction in ICARUS T600



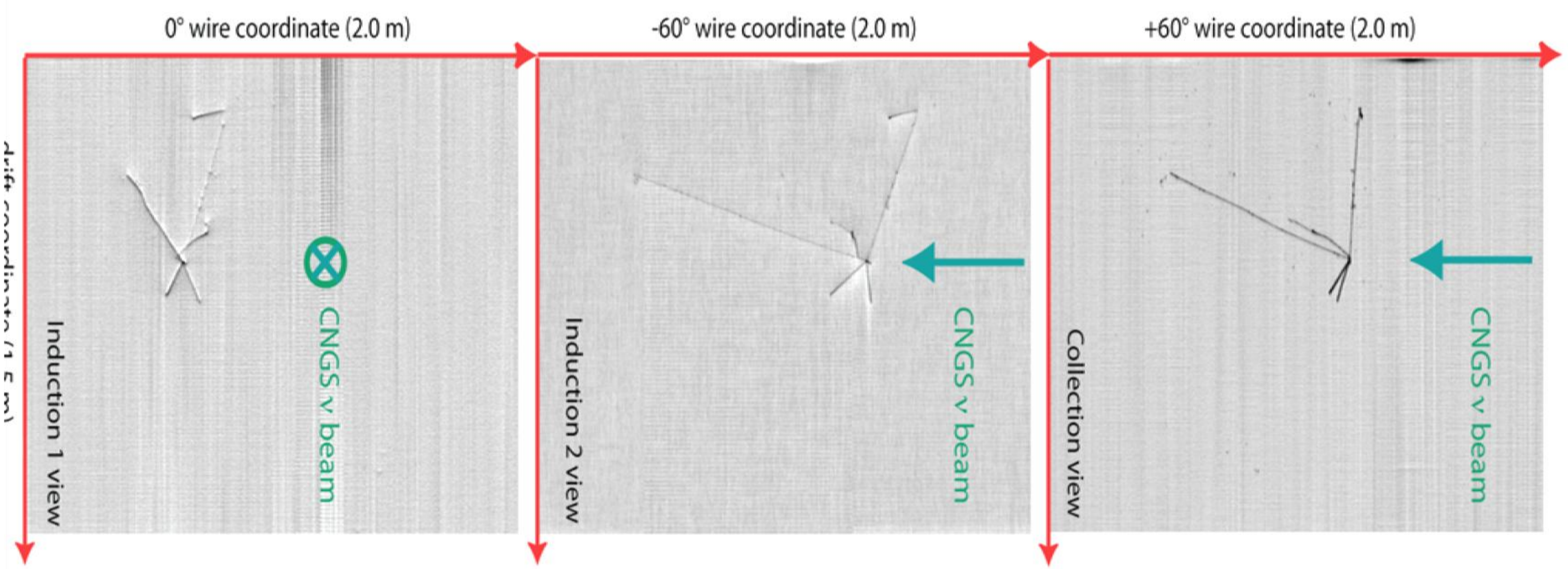
- Leading muon (crossing horizontally the whole cryostat)
- Two charged particle tracks undergoing hadronic interactions
- Two γ converting at 14 and 16 cm from vertex (π^0?)
- Vertex not fully visible in collection view, due to locally wrong wire biasing

The second CNGS neutrino interaction in ICARUS T600

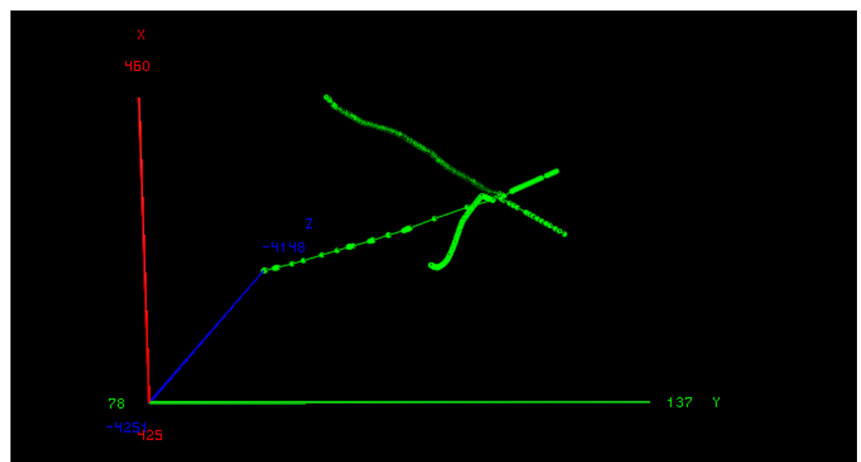


Neu2010

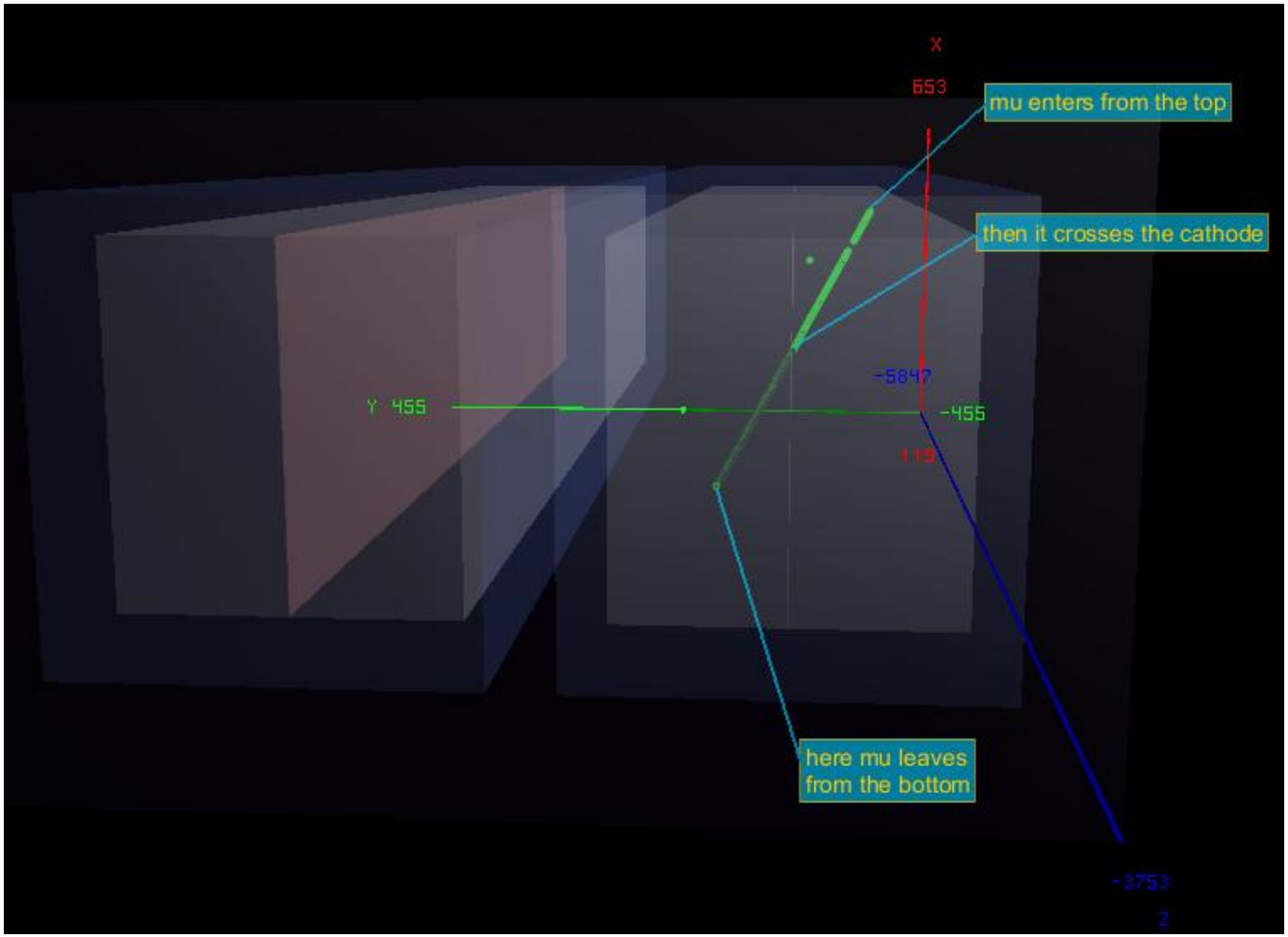
Another Neutrino interaction



Total visible energy: 770 MeV (including quenching and electron lifetime correction)



Crossing muon



Estimated Drift Velocity: ≈1.589 mm/μs

Conclusions

- The successful assembly and operation of the ICARUS-T600 LAr-TPC demonstrate that the technology is mature.
- The T600 is presently taking data, smoothly reaching optimal working conditions. Neutrino interactions have been observed.
- The ICARUS experiment at the Gran Sasso Laboratory is so far the most important milestone for this technology and acts as a full-scale test-bed located in a difficult underground environment.

For a possible second life of T600 see

A New search for anomalous neutrino oscillations at the CERN-PS.

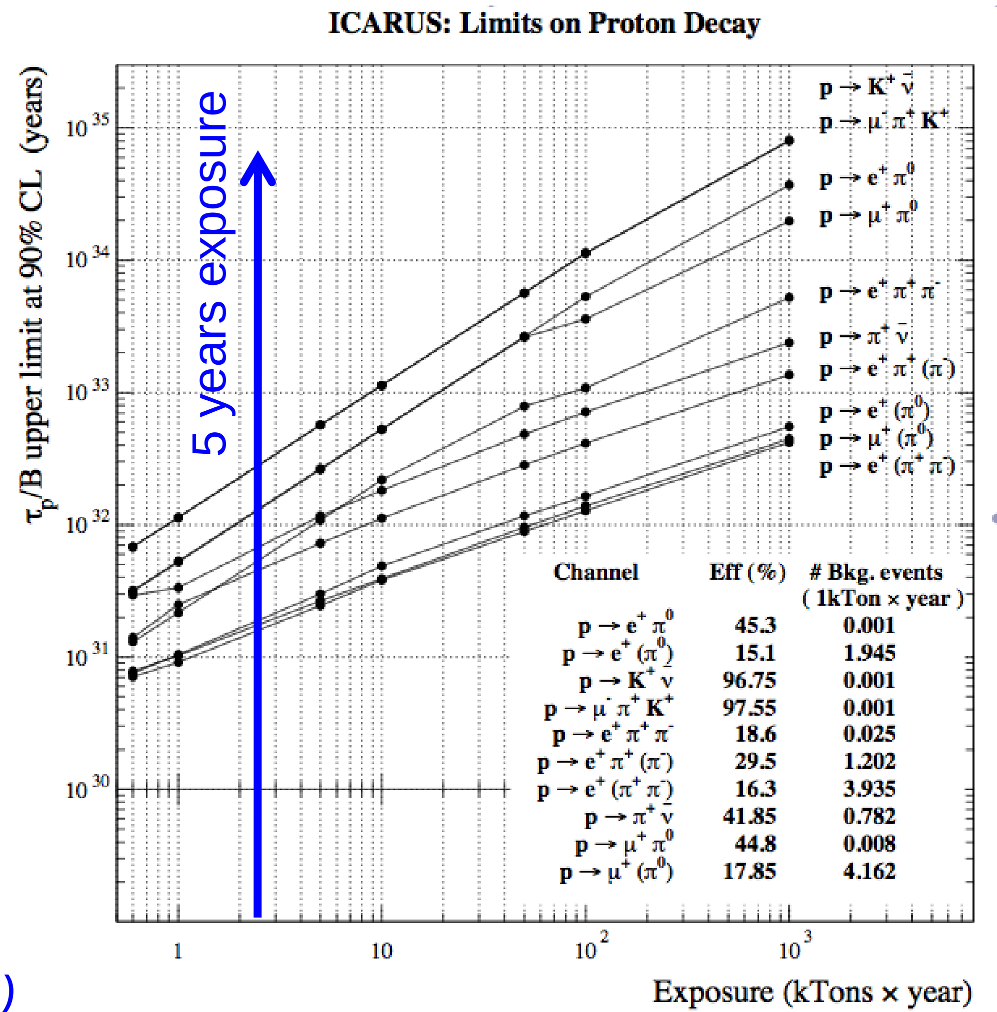
e-Print: **arXiv:0909.0355** [hep-ex]

Update coming soon

THANK YOU !

Nucleon decay : single event capability

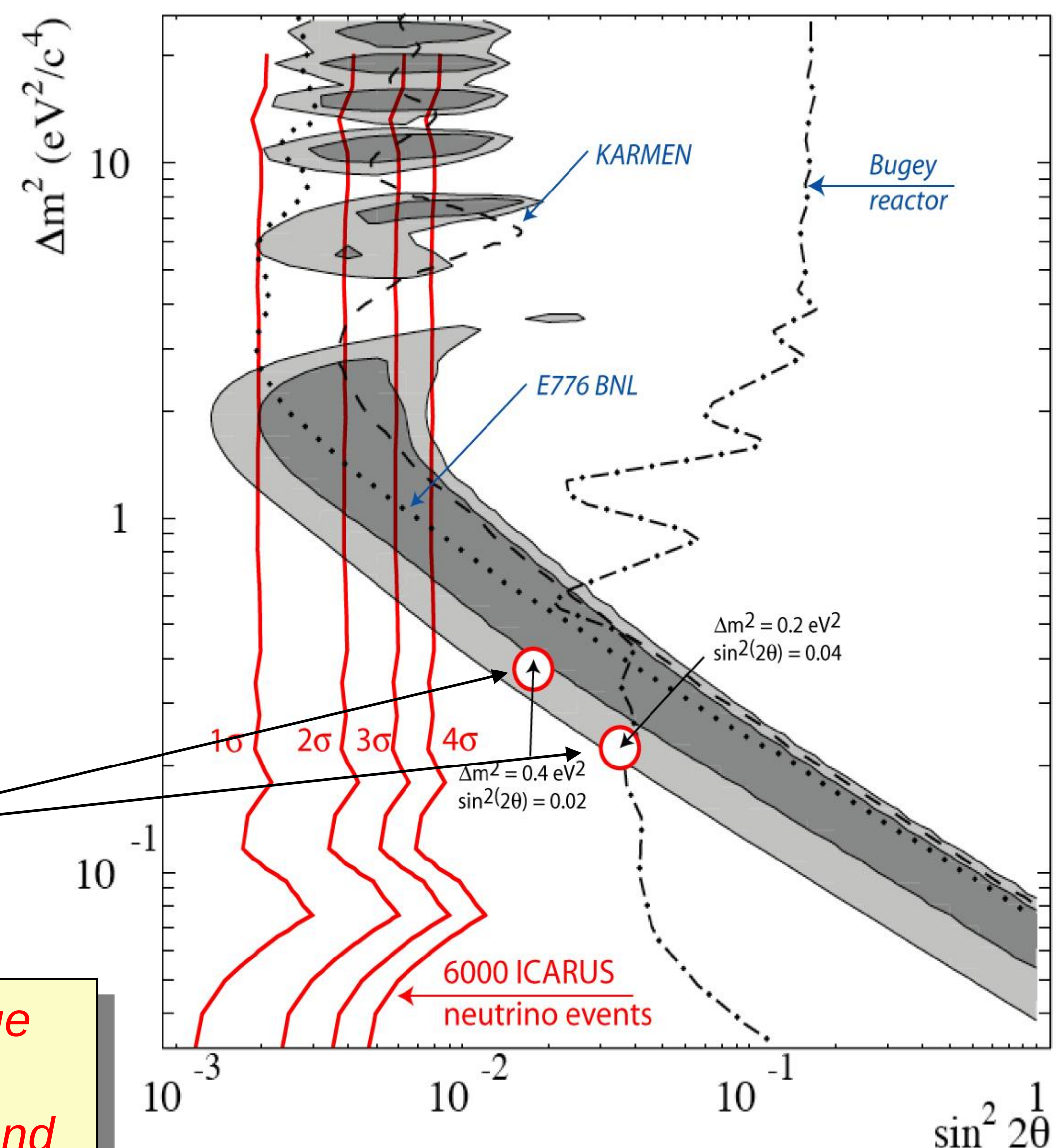
- LAr-TPC provides a much more powerful bkg rejection w.r.t. other techniques. It can perform a large variety of exclusive decay modes measurements in bkg free mode.
- In particular the T600 (*3 10^{32} nucleons*) is well suited for channels not accessible to Č detectors due to the complicated event topology, or because the emitted particles are below the Č threshold (e.g. $K^{\pm}$).
- *In few years exposure the T600 can improve limits on some "super-symmetric favored" exotic channels:*



Channel	90%CL-5y	(pdg 90%CL)
$p \to \nu\ \pi^+$	1.1 10^{32}	(2.5 10^{31})
$p \to \mu^-\ \pi^+ K^+$	2.7 10^{32}	(2.5 10^{32})
$n \to e^- K^+$	3.2 10^{32}	(3.2 10^{31})
$n \to \mu^+\ \pi^-$	1.5 10^{32}	(1.0 10^{32})
$n \to \nu\ \pi^0$	1.1 10^{32}	(1.1 10^{32})

Limits at T600 with 6000 events.

- Sensitivity region, in terms of Standard Deviations σ, for 6000 raw CNGS neutrino events. The potential signal is above the background generated by the intrinsic νe beam contamination, in the deep inelastic interval 10-30 GeV.
- The Δm^2 distribution extends widely beyond the LNSD and MiniBoone regions.
- Two indicated points are reference values of MiniBoone proposal and of



T600 at the CNGS offers an unique possibility of searching for sterile neutrinos, largely complementary and comparable to the Fermilab programme.

C. Rubbia, SPSC ct. 2006

Table 1: CC event rates for 5 years T600 at 4.510^{19} pot/y. 90% acceptance

	Background					$\nu_\mu \rightarrow \nu_e$ θ_{13}	$\nu_m u \rightarrow \nu_e$ Signal	
	ν_e	τ	NC	$\bar{\nu}_e$	TOTAL	CHOOZ lim.	LSND1	LSND2
$0 < E_{vis} < 30$	27	5	1	1.5	35	10	50	101
$10 < E_{vis} < 30$	22	2	0.3	1	25	5	41	85

ICARUS Vacuum phase

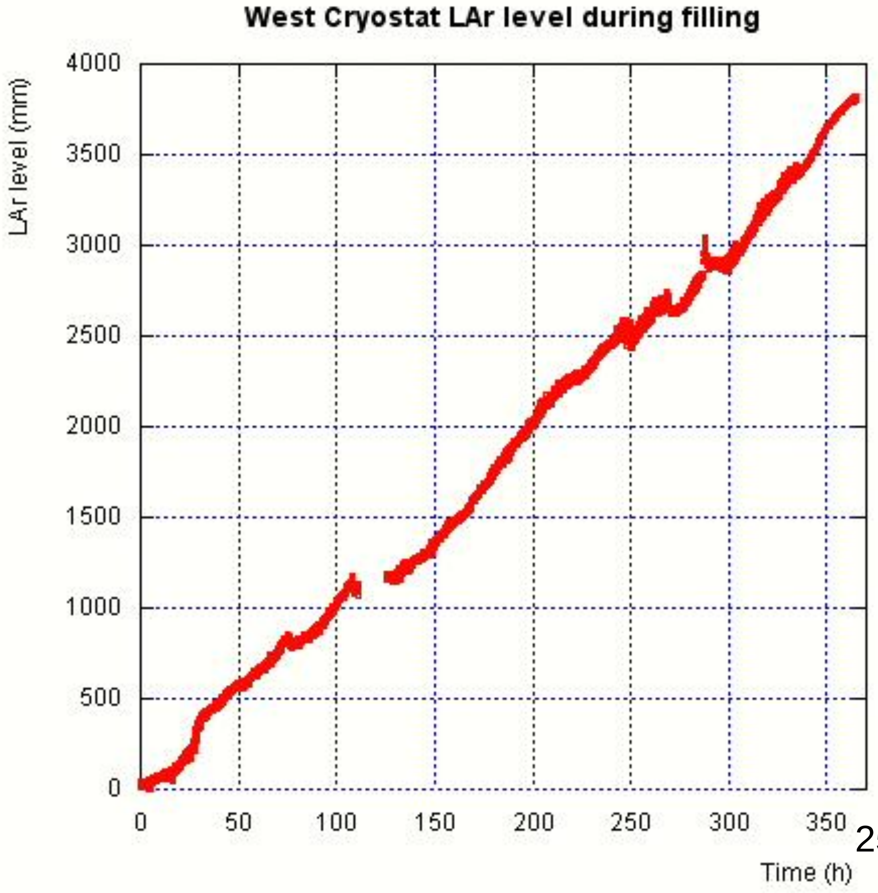
- December 2009: over pressure tests with Argon
- January, 9th 2010: start of cryostats evacuation phase
- During the whole vacuum phase: monitoring of the mechanical deformations of the inner walls
- March 2010 : 6.6 10^{-5} mbar in both cryo

ICARUS Cooling phase

- On April 14th: the vacuum phase ended and ultra pure Argon gas was loaded at +100 mbar pressure.
- On the 16th of April the cooling of cryostats started
- On the 23th of April the LAr temperature (90 K) was reached at a average rate of about 1 K/hour, to minimize mechanical stresses.
- A measure of the heat losses was performed resulting in 24 kWatts (6 Stirling units)

ICARUS Filling phase

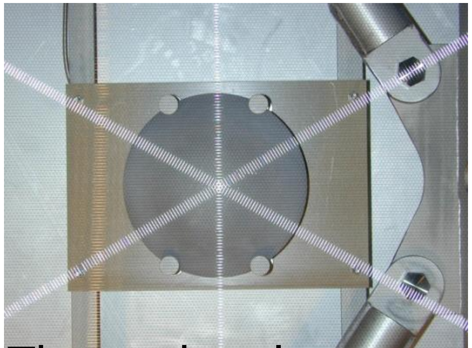
- From April 29th the four gaseous re-circulations are operating at maximum speed of >20 Nm^3/h each (>24 l/h of LAr, ~2 kWatt).
- Cryostats filling was performed with 47 trucks during 2 weeks, for a total amount of 610511 Argon liters. The filling rate was more than 1 m^3/hour/cryostat during the whole period.
- On May 18th LAr filling ended. The liquid level reached in both cryostats is 3825 mm, i.e. 65 mm from internal top, enough to completely cover HV electrodes.
- On May 26th liquid recirculation started (~2 m^3/h per cryostat).
- 8 Stirling machines out of 10 are operating (32 KWatt) smoothly.



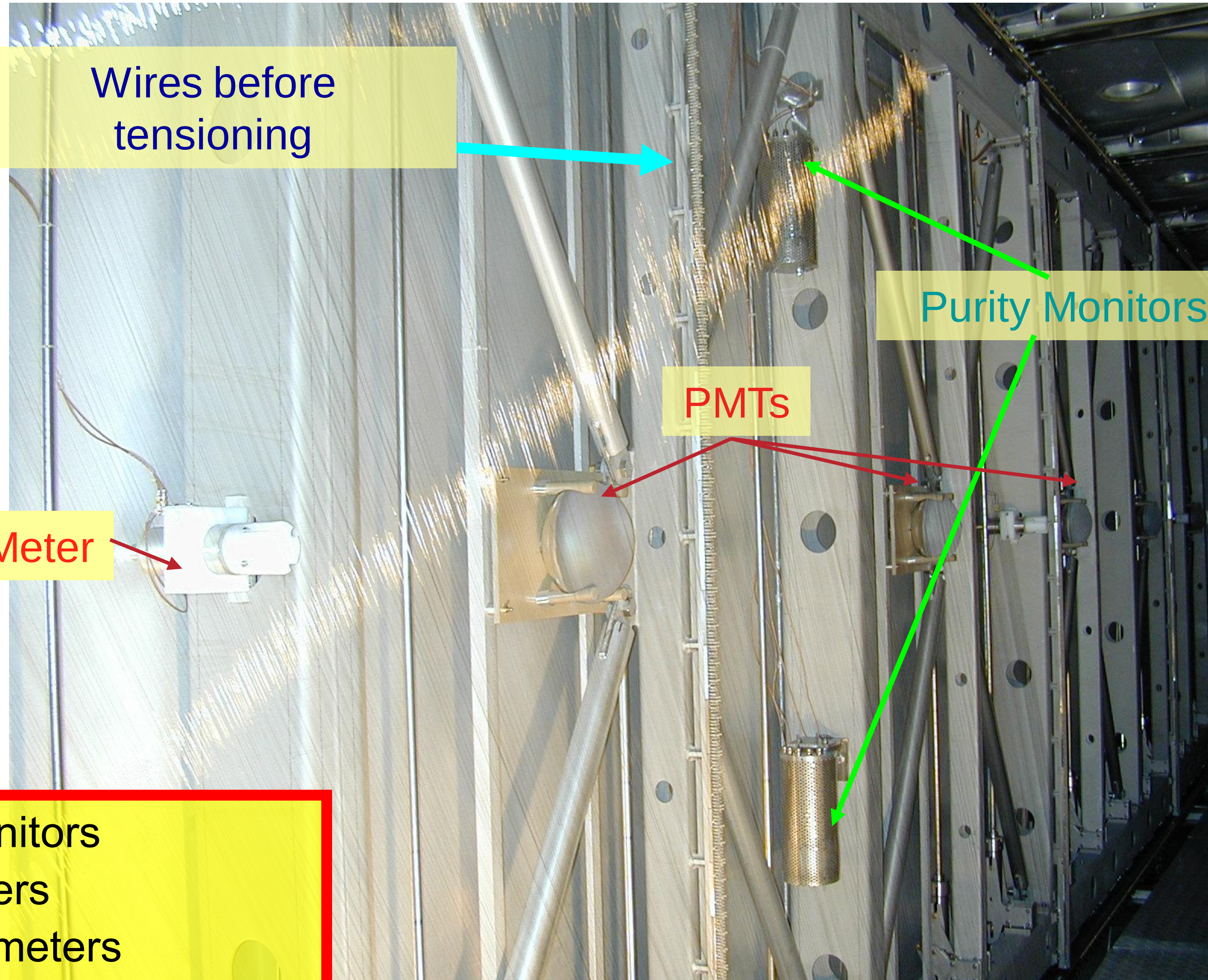
ICARUS detector commissioning

- On May 18th, electronic racks were mechanically connected to feed-throughs, and Faraday cages closed in order to shield the electronics from external noise.
- On May 20th, start activation of West cryostat.
  - cathode HV suppliers were turned on without problems: the -75 kV nominal power was reached, showing a stable current.
  - PMTs: good signal from 19 over 21 internal photomultipliers (the remaining two are under investigation).
  - On May 27th, nominal values applied to wire biasing at (-220, 0, +280 V) without any problem (low and stable current).
  - At 12.24 the first ionization track was recorded and visualized by DAQ; during the night the firsts horizontal muons crossing the cryostat West and pointing back to CERN were recorded (nu int. in upstream rock).
  - On May 28th at ~19.54 the first CNGS neutrino interaction was observed.
- On June 1st the East cryostat was also turned on without problems.
- Muon track are presently used to evaluate electron lifetime in real time.
- Electronics for PMTs' signal discrimination and trigger logic is under optimization.

Charge and light read-out



Three wire planes and a PMT



6	LAr purity monitors
16	LAr level meters
7	wire position meters
8	wall position meters
30	temperature probes