The 600 Ton ICARUS detector at the LNGS

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Topics

1. R & D on ICARUS technology detector method
2. Installation of the T600 at the LNGS
3. Physics program: (a) high energy neutrons from CERN, (b) Search for exotic proton decay
4. Possible future plans to search for sterile neutrinos
5. As a prototype for multi-kiloton detector around the world

Summary

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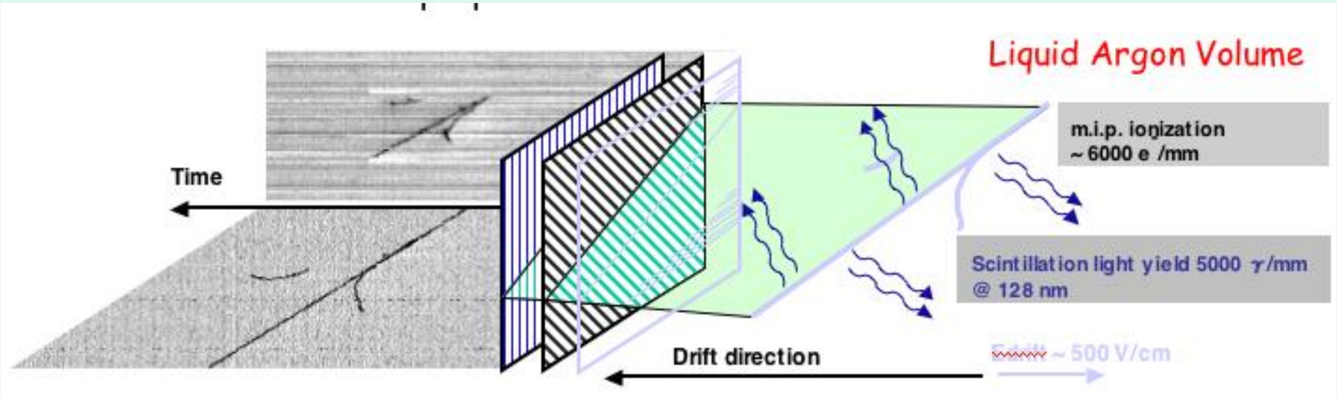
A powerful detection technique

The Liquid Argon Time Projection Chamber [C. Rubbia: CERN-EP/77-08 (1977)] first proposed to INFN in 1985 [ICARUS: INFN/AE-85/7] capable of providing a 3D imaging of any ionizing event (''electronic bubble chamber'') with in addition:

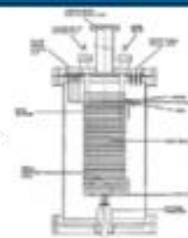
- continuously sensitive, self triggering
- high granularity (~ 1 mm)
- excellent calorimetric properties



Electrons from ionizing track are drifted in LAr by E_{drift}. They traverse transparent wire arrays oriented in different directions where induction signals are recorded. Finally electron charge is collected by collection plane.

- Key feature: LAr purity form electro-negative molecules (O_2, H_2O,$C0_2$).
- Target: 0.1 ppb O_2 equivalent= 3 ms lifetime (4.5 m drift @ E_{drift} = 500 V/cm).

The path to larger LAr detectors



CERN

24 cm drift wires chamber

1

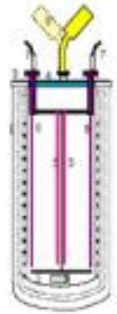
1987: First LAr TPC. Proof of principle. Measurements of TPC performances.

2

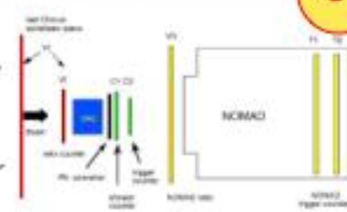
3 ton prototype

1991-1995: First demonstration of the LAr TPC on large masses. Measurement of the TPC performances. TMG doping.

CERN



Laboratory work



3

CERN

50 litres prototype
1.4 m drift chamber

1997-1999: Neutrino beam events measurements. Readout electronics optimization. MLPB development and study. 1.4 m drift test.

4

Icarus T600 experiment

2010-... : Data taking with CNGS beam

10 m3 industrial prototype

1999-2000: Test of final industrial solutions for the wire chamber mechanics and readout electronics.

Pavia

T600 detector

2001: First T600 module

Cooperation with industry
AirLiquide, Breme, Cinel, CAEN

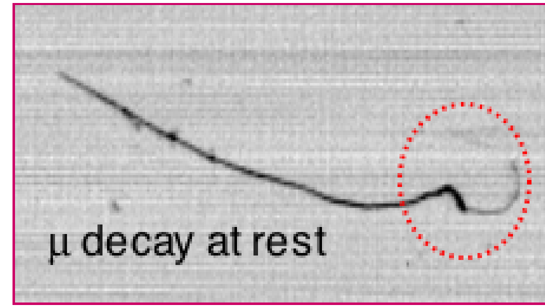
5

6

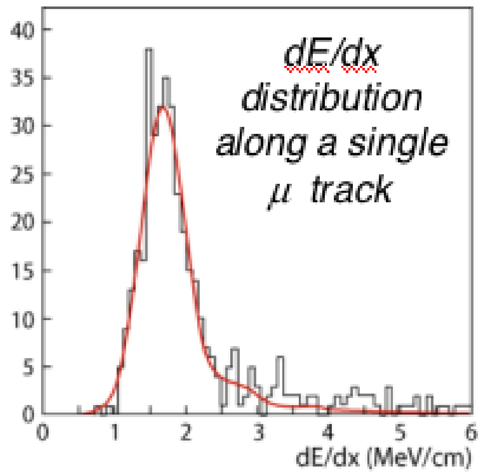
LNGS Hall-B

LAr-TPC performance

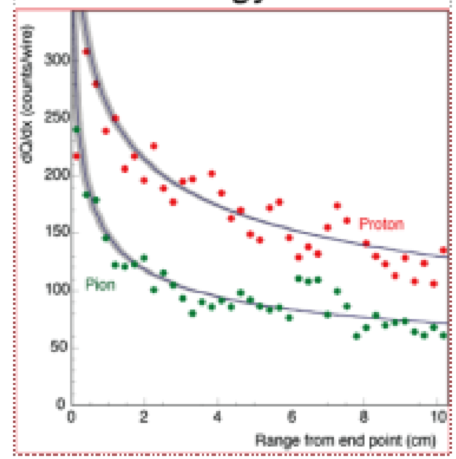
- Tracking device:
  - precise event topology ($s_{x,y}$ ~ 1mm, s_z ~ 0.4mm)
  - μ momentum measurement via multiple scattering: _p/p ~10-15% depending on track length and p



- Measurement of local energy deposition dE/dx:
  - e/≥ separation (2% X_0 sampling);
  - particle ID by means of dE/dx vs range



dE/dx energy losses



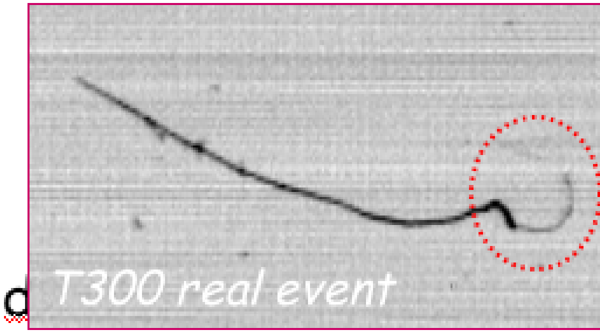
- Total energy reconstruction by charge integration:
  - full sampling, homogeneous calorimeter with excellent accuracy for contained events

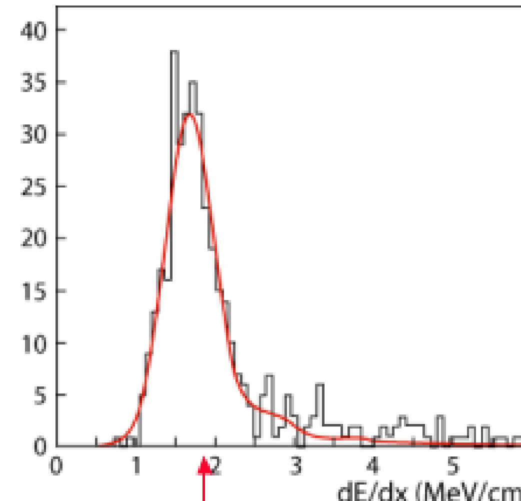
RESOLUTIONS

Low energy electrons:	_(E)/E = 11% / √ E(MeV)+2%
Electromagnetic showers:	_(E)/E = 3% / √ E(GeV)
Hadron shower (pure LAr):	_(E)/E ≈ 30% / √ E(GeV)

Summary of LAr TPC performances

- Tracking device
  - Precise event topology
  - Momentum via multiple scattering
- Measurement of local energy deposition a
  - e / γ separation (2%X_0 sampling)
  - Particle ID by means of dE/dx vs range
- Total energy reconstruction of the events from charge integration
  - Full sampling, homogeneous calorimeter with excellent accuracy for contained events





dE/dx distribution along a single muon track

RESOLUTIONS

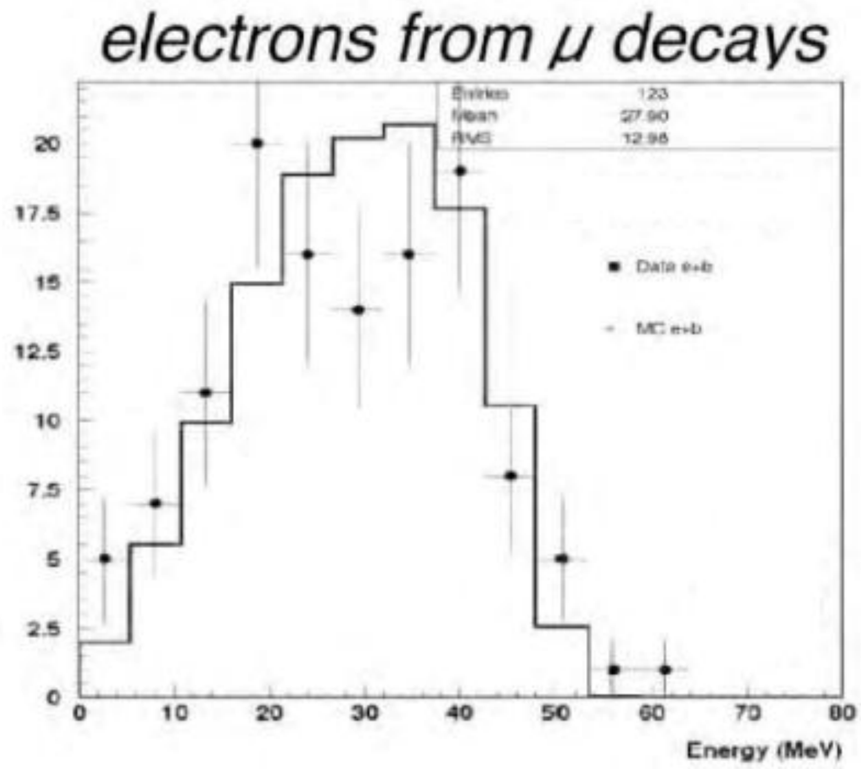
Low energy electrons: $\sigma(E)/E = 11\% / \sqrt{E(MeV)} + 2\%$

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

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

Electrons from muon decay

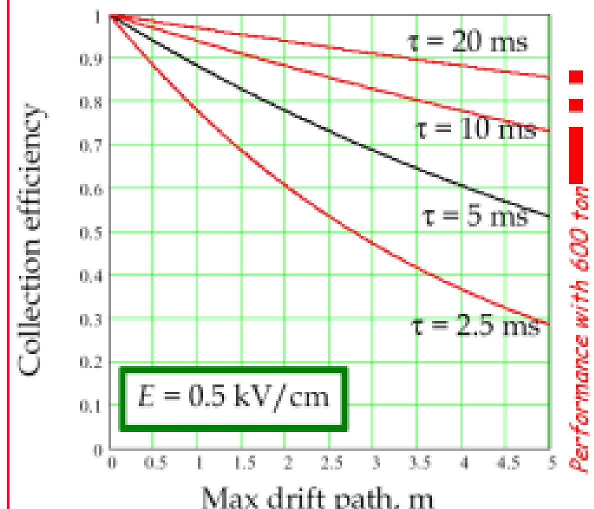
- Excellent resolution obtained from the measured decay electron spectrum (Michel parameter) from muon decays



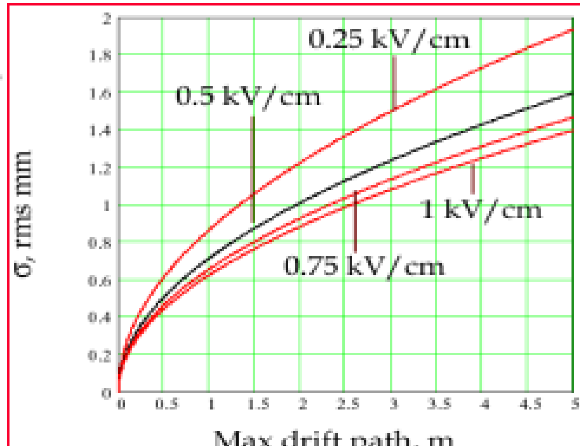
The key feature of LAr imaging: very long e-mobility

- The main technological challenge of the development of the cryogenic liquid Ar chamber is the capability of ensuring a sufficiently long free electron lifetime.
- Indeed the free electron path in a liquid is ≈ 600 times shorter than in a gas. For instance 10 ms lifetime corresponds to a 30 ppt (t=trillion !) of Oxygen equivalent.
- At 500v/cm, a 5m drift length corresponds to a drift time of 3.1 ms (1.6 m/ms).
- The intrinsic bubble size (rms diffusion) is given by
- The values for 5m drift are $\langle\sigma_D\rangle \approx 1.1$ mm and $\sigma_{max} \approx 1.6$ mm , tiny with respect to the wire pitch (≥ 2mm).

$$\sigma_D[mm] = 0.9\sqrt{T_D[ms]}$$

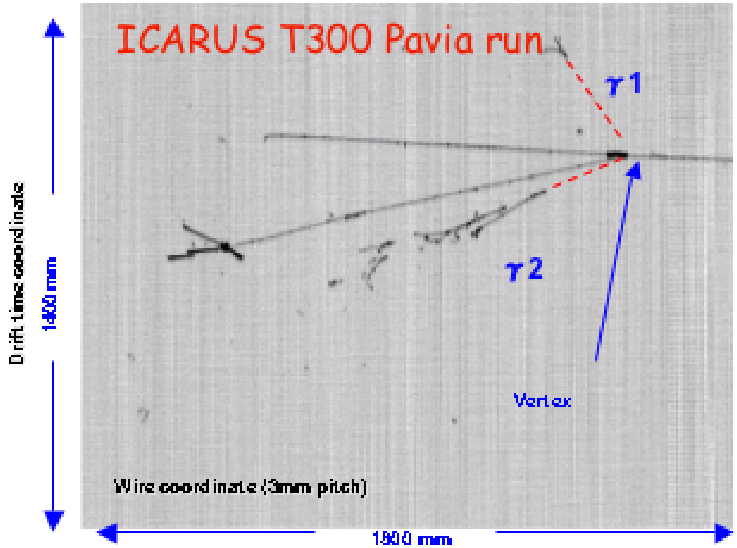


Drifting charge attenuation versus drift path at different electron lifetimes

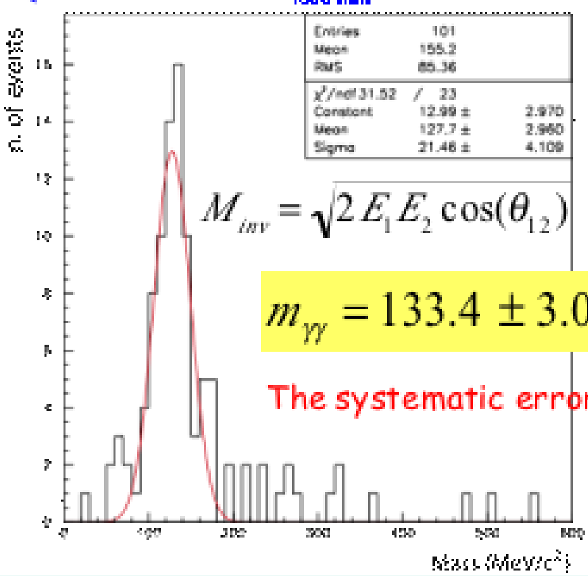


electron - π^0 identification

Reconstruction of π^0-showers



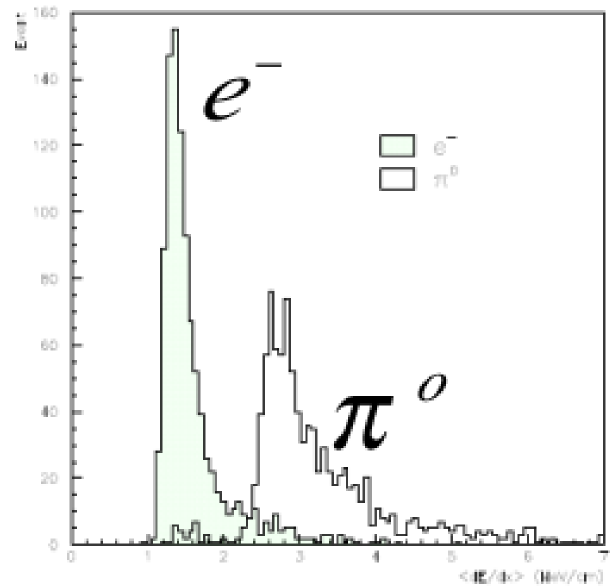
Electron shower events are extremely well identified experimentally, because of the ionization behaviour in the first cells after the vertex.



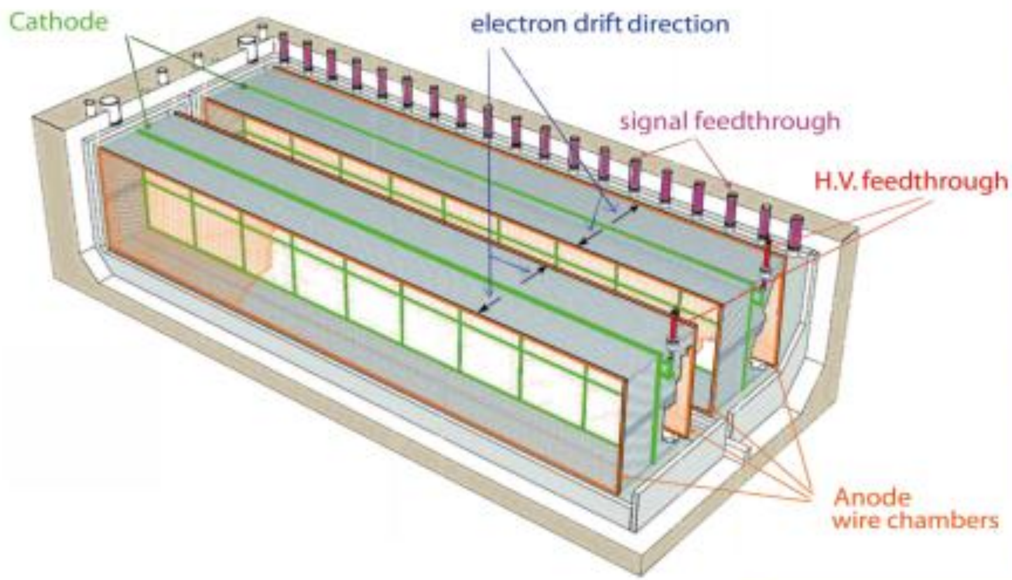
$$M_{inv} = \sqrt{2E_1E_2\cos(\theta_{12})}$$

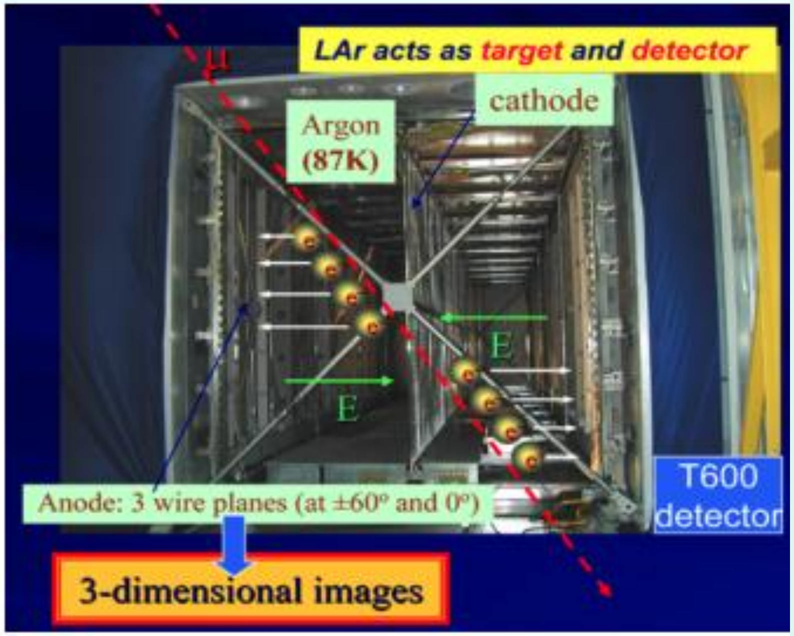
$$m_{\gamma\gamma} = 133.4 \pm 3.0(stat) \pm 4.0(sys)\,\mathrm{MeV/c^2}$$

The systematic error mostly due to the calibration



The ICARUS T600 detector

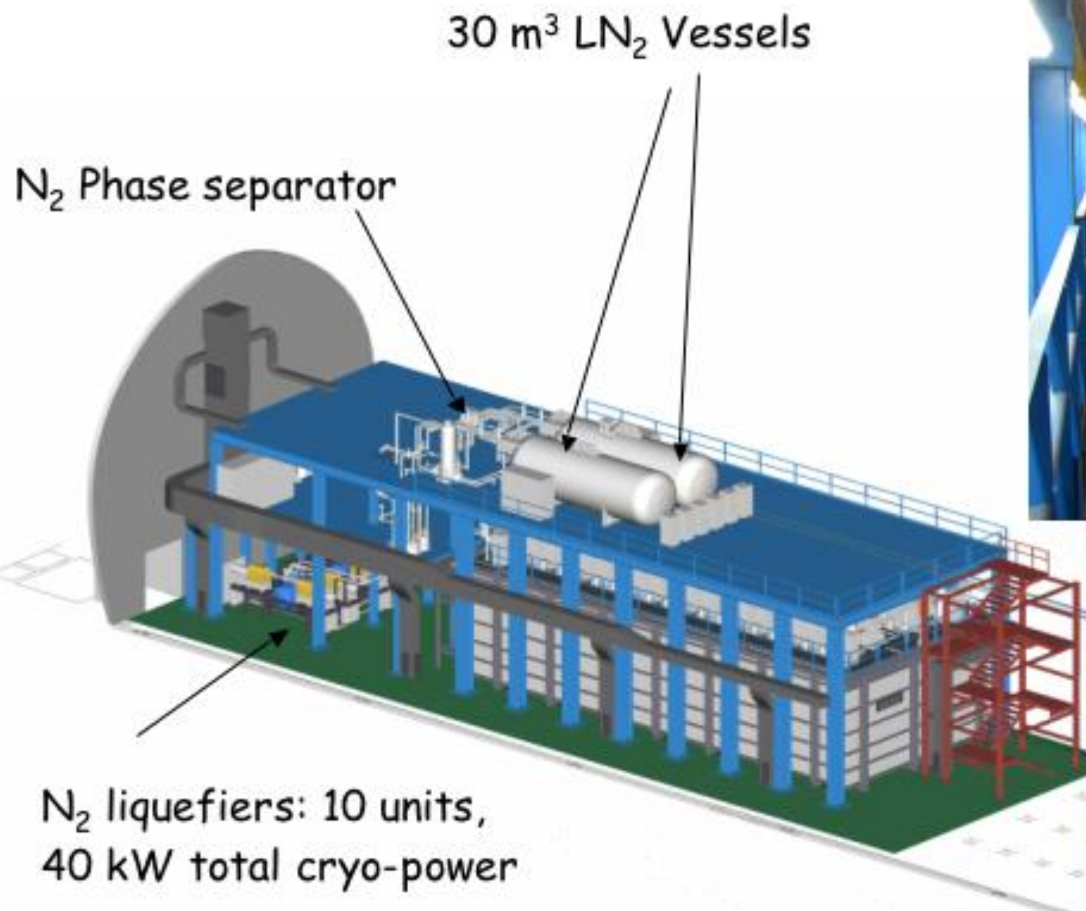




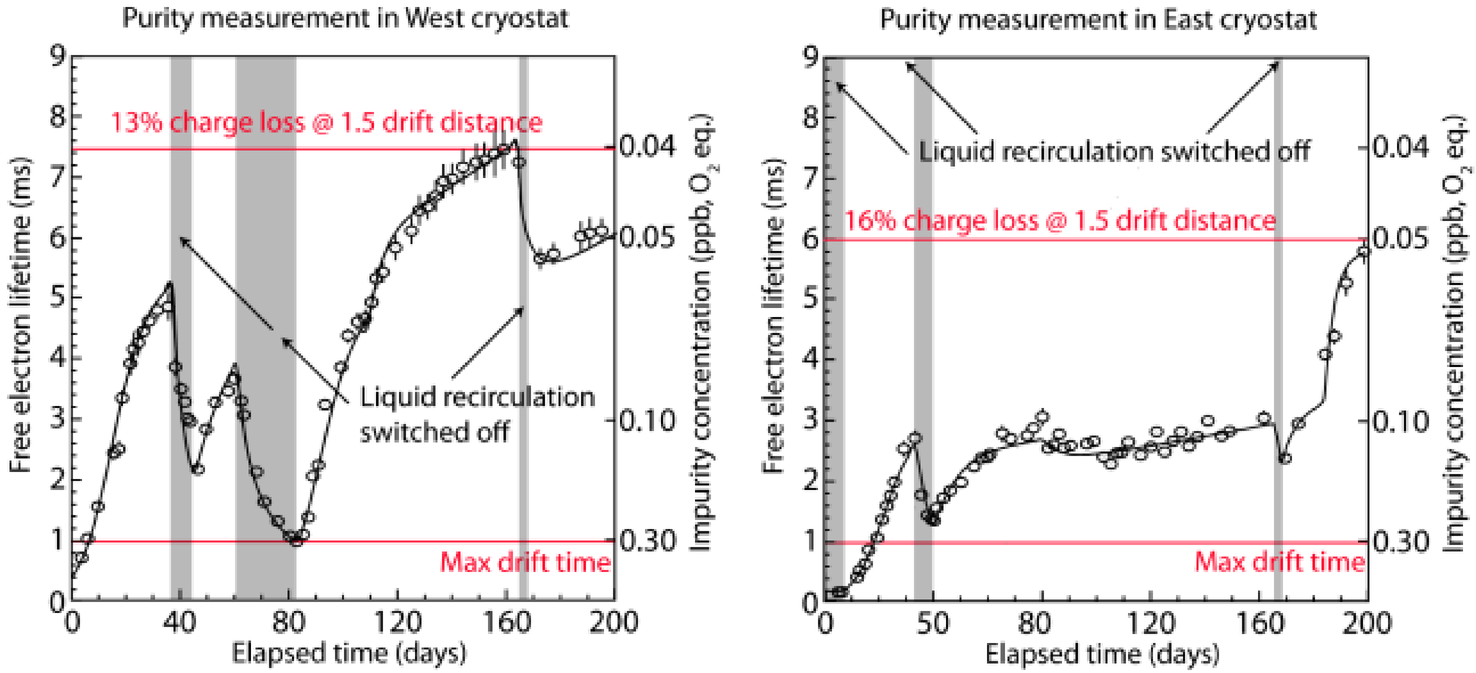
- Two identical modules
  - 3.6 x 3.9 x 19.6 ≈ 275 m^3 each
  - Liquid Ar active mass: ≈ 476 t
  - Drift length = 1.5 m
  - HV = -75 kV E = 0.5 kV/cm
  - vdrift = 1.55 mm/μs

- 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
- PMT for scintillation light:
  - (20+54) PMTs, 8" Ø
  - VUV sensitive (128nm) with wave shifter (TPB)

ICARUS T600 in LNGS Hall B



LAr purity time evolution



Simple model: uniform distribution of the impurities, including internal degassing, decreasing in time, constant external leak and liquid purification by recirculation.

$$dN/dt = -N/\tau_R + k + k_I \exp(-t/\tau_I)$$

τ_{ele} [ms] = 0.3 / N[ppb O_2 equivalent]

τ_R: recirculation time for a full detector volume

k_I and τ_I : related to the total degassing internal rate

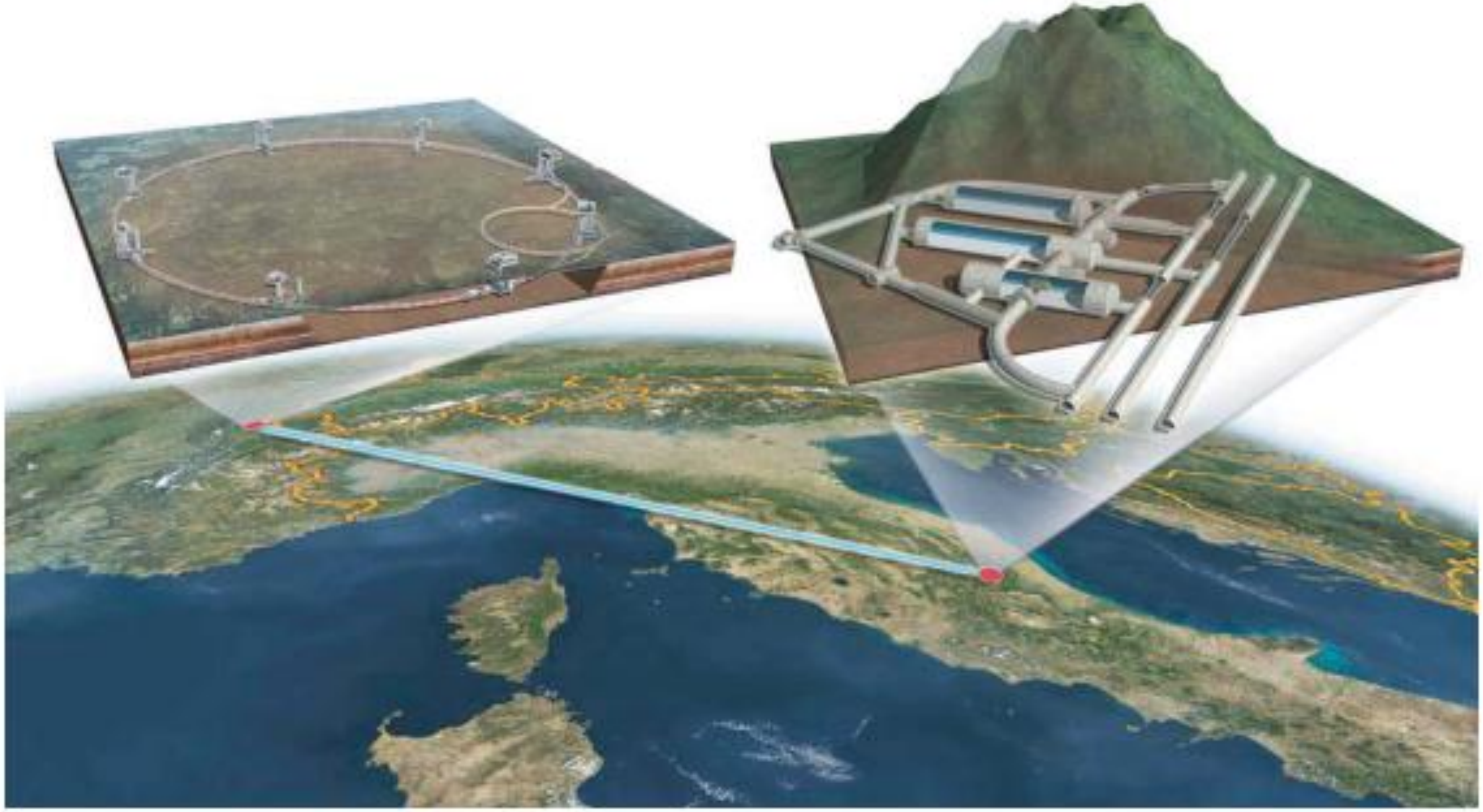
τ_R: 2 m^3/h corresponding to ≈ 6 day cycle time

k : related to the external leaks

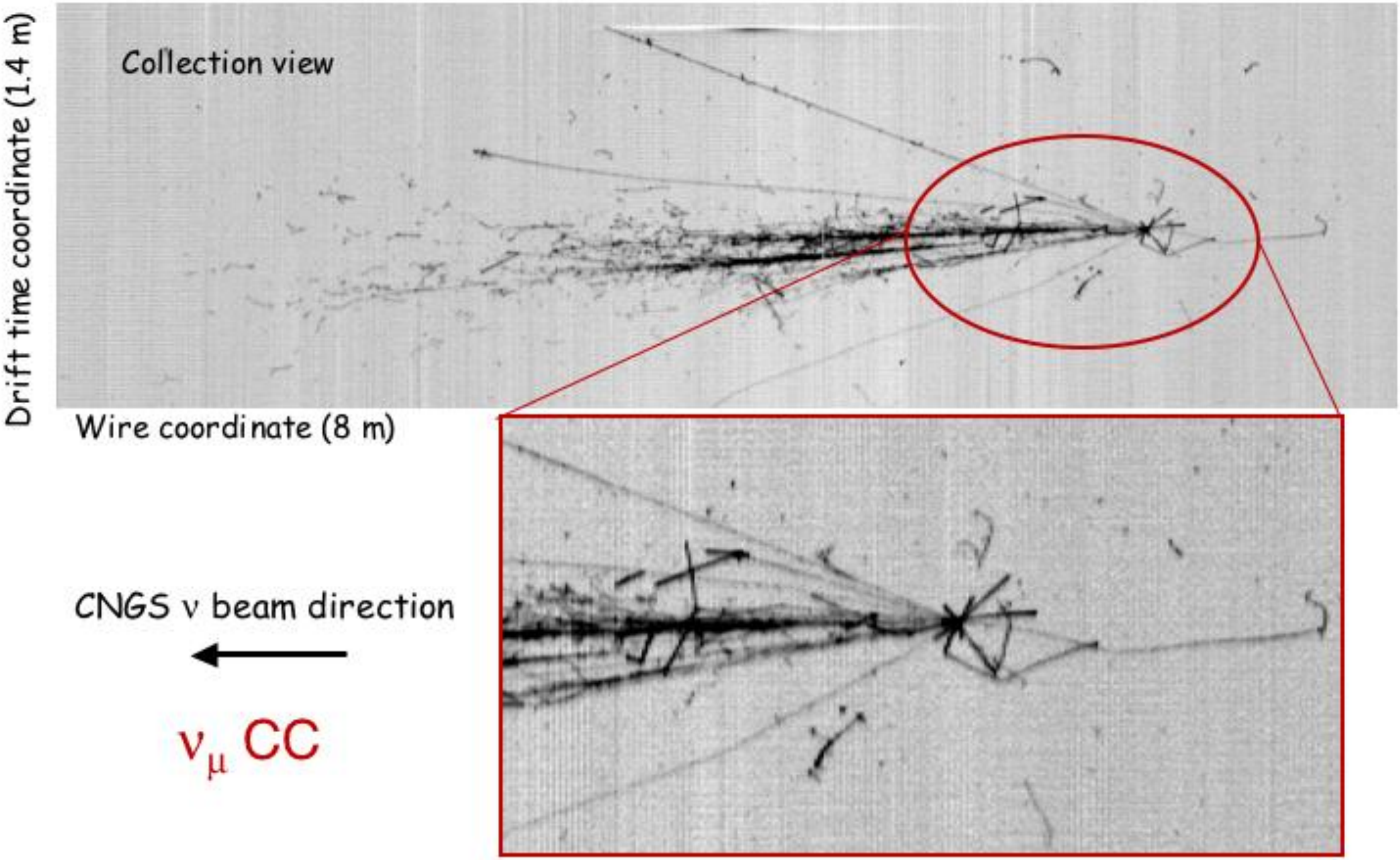
ICARUS T600 physics potential

- ICARUS T600: **major milestone** towards realization of large scale LAr detector. Interesting physics in itself: unique imaging capability, spatial/calorimetric resolutions and e/π^0 separation $\rightarrow$ **events "seen in a new Bubble chamber like" way**.
- CNGS ν events collection (beam intensity 4.5 10^{19} pot/year, $E_\nu \sim 17.4$ GeV):
  - 1200 ν_μ *CC* event/year;
  - ~ 8 ν_e *CC* event/year;
  - observation of ν_τ events in the electron channel, using kinematical criteria;
  - search for sterile ν in LSND parameter space (deep inelastic ν_e *CC* events excess).
- "Self triggered" events collection:
  - ~ 80 events/y of unbiased atmospheric ν *CC*;
  - zero background proton decay with 3 x 10^{32} nucleons for "exotic" channels.

ICARUS and Status of Liquid Argon Technology

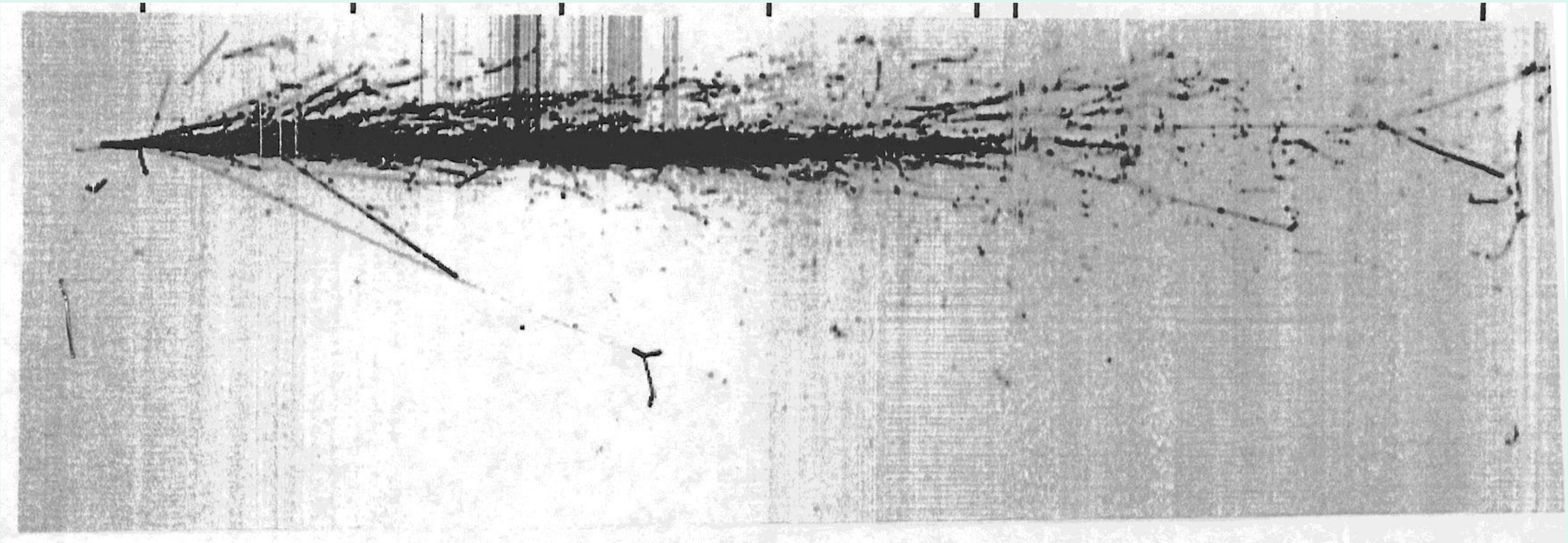


CNGS neutrino interactions in ICARUS T600



ICARUS 9839/1274

CERN beam→



Candidate for a ν_e interaction

Preliminary results of first CNGS 2010 run

- Analyzed sample: 1494 CNGS triggers, i.e. $4.54 \cdot 10^{18}$ pot = 78 % out of whole sample. Classified by visual scanning into fiducial volume of 434 t.

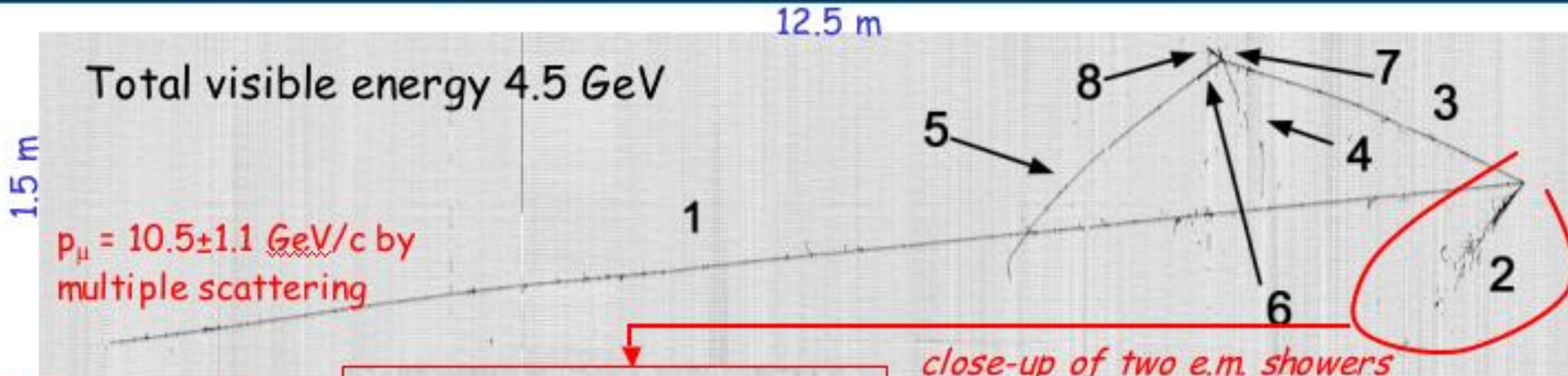
- Number of collected interactions compared with number of interactions predicted ((2.6 CC + 0.86 NC) 10^{-17}/pot), in the whole energy range up to 100 GeV, corrected by fiducial volume and DAQ dead-time.

Event type	Collected	Expected
CC	94	98
NC	32	31
XC *	6	-
Total	132	129

* Events at edges, with μ track too short to be visually recognized: further analysis needed.

On overall statistics in agreement with expectations.

LAr-TPC: powerful technique. Run 9927 Event 572

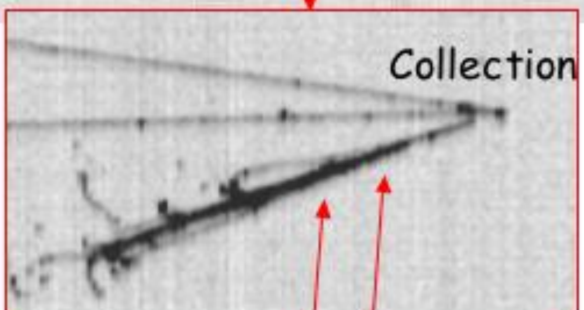


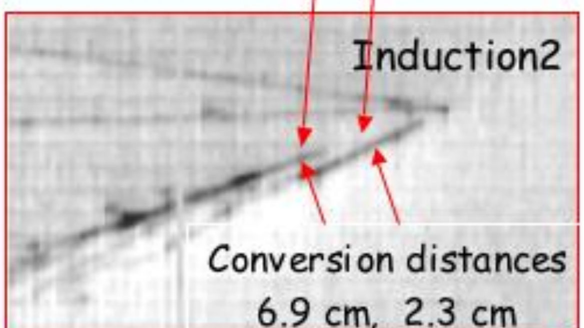
Primary vertex (A)

very long μ (1), e.m. cascade(2), pion (3).

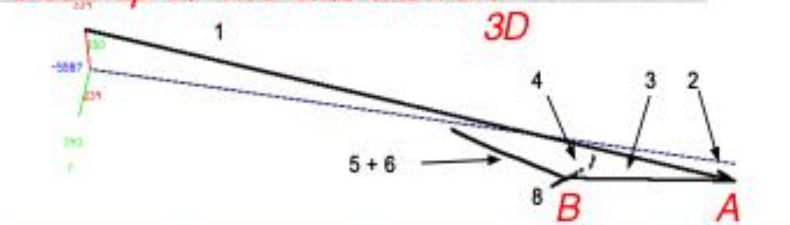
Secondary vertex (B)

The longest track (5) is a μ coming from stopping k (6). - μ decay is observed.



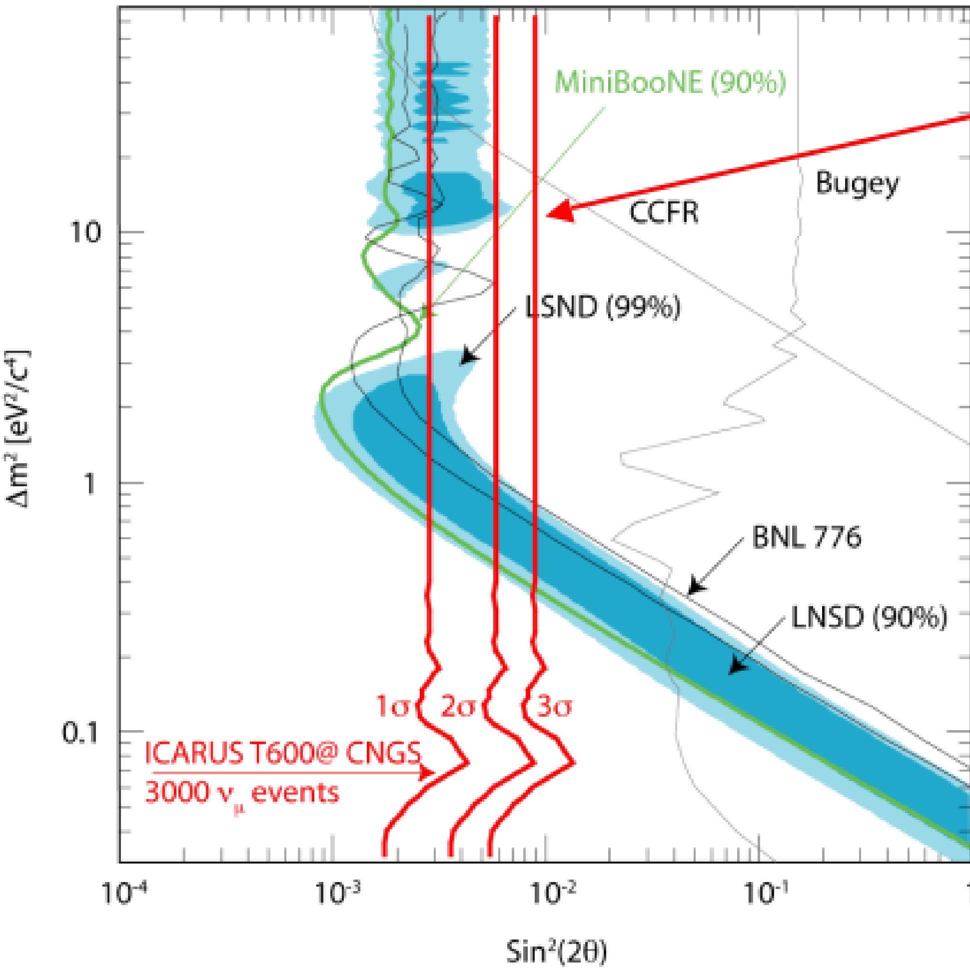


$M^*_{\gamma\gamma}$ = 125±15 MeV/c²



Track	E_{dep}[MeV]	cosx	cosy	cosz
1 (μ)	2701.97	0.069	-0.040	-0.997
2 (π^0)	520.82	0.054	-0.420	-0.906
3 (π)	514.04	-0.001	0.137	-0.991
Sec.vtx.	797.			
4	76.99	0.009	-0.649	0.761
5 (μ)	313.9			
6 (K)	86.98	0.000	-0.239	-0.971
7	35.87	0.414	0.793	-0.446
8	283.28	-0.613	0.150	-0.776

Sterile neutrino search with ICARUS T600

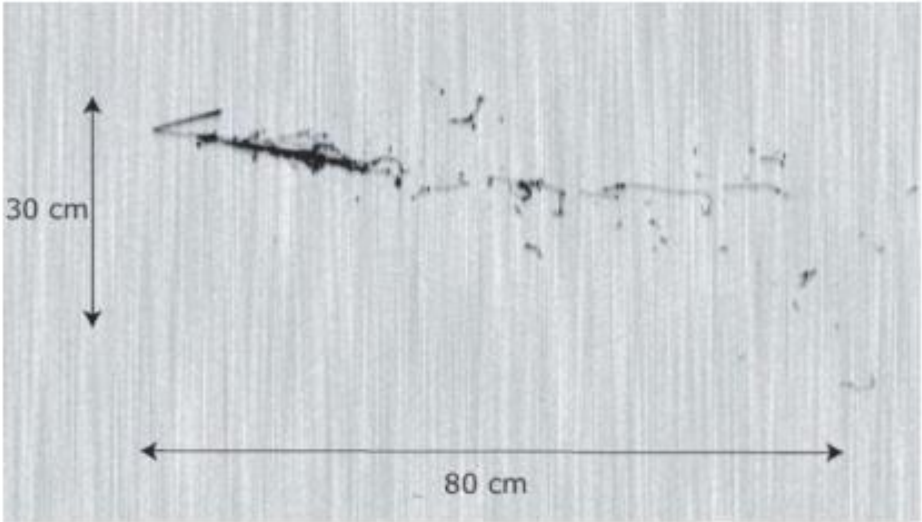


$\nu_\mu \rightarrow \nu_e$ appearance search in T600 in LNSD parameter space

- Sensitivity region, in terms of standard deviations, for 3000 raw CNGS muon neutrino events.
- The potential signal is above the background generated by the intrinsic ν_e beam contamination, in the deep inelastic interval 10-30 GeV.
- Largely complementary to the Fermi-lab program in terms of energy and baseline.

ν_e CC interaction at ~ 1.5 GeV

- At these energies, electron identification and energy reconstruction of ν_e interactions is ensured with ~5 X_0 (X_0=14cm) longitudinal cut and ~2 X_0 side cut of the sensitive volume are performed, corresponding to a fiducial volume of ~ 80 % of the active one.



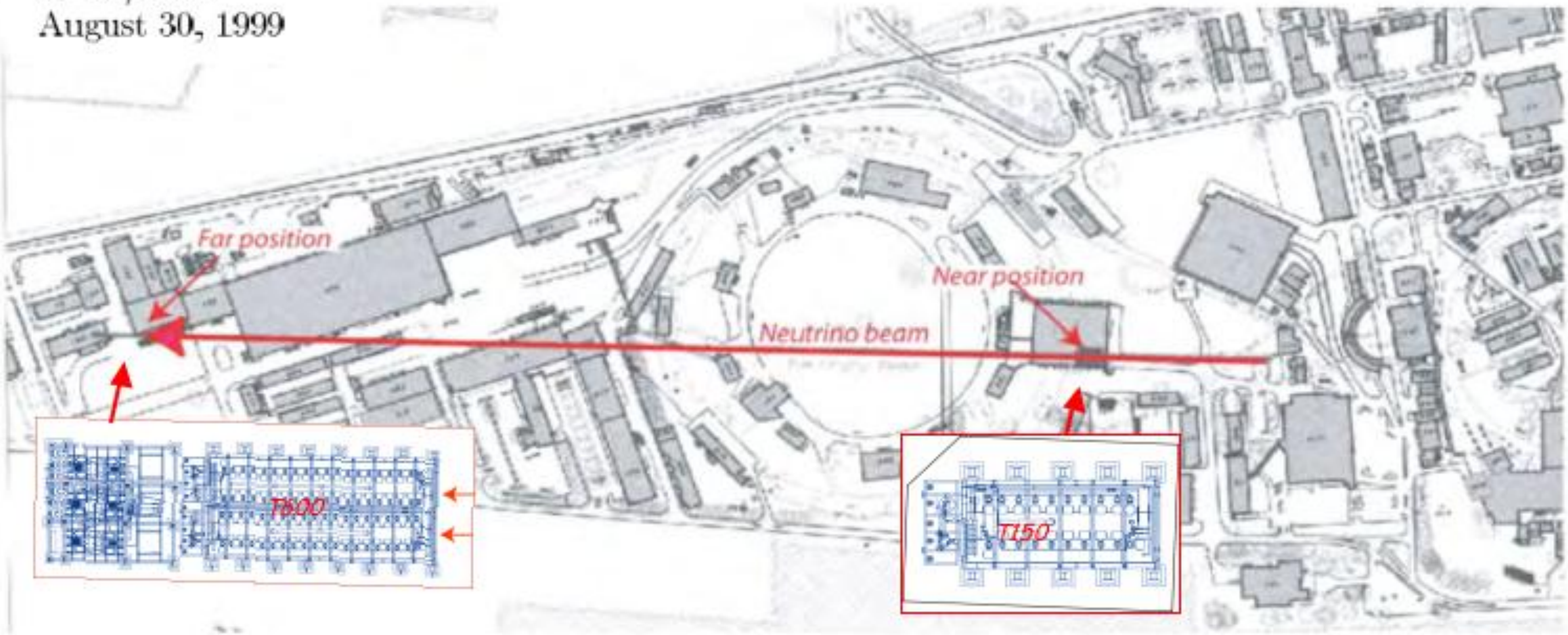
π^0 from NC are rejected by photon vertex identification, invariant mass reconstruction and dE/dx measurement: the expected π^0 mis-interpretation probability is 0.1 %, with ν_e detection efficiency of 90 % within the fiducial volume.

With these fiducial cuts, the expected ν_e energy resolution is around 14 %

Two LAr-TPC detectors at the CERN-PS neutrino beam

CERN-SPSC/99-26
SPSC/P311
August 30, 1999

SEARCH FOR $\nu_\mu \rightarrow \nu_e$ OSCILLATION AT THE CERN PS

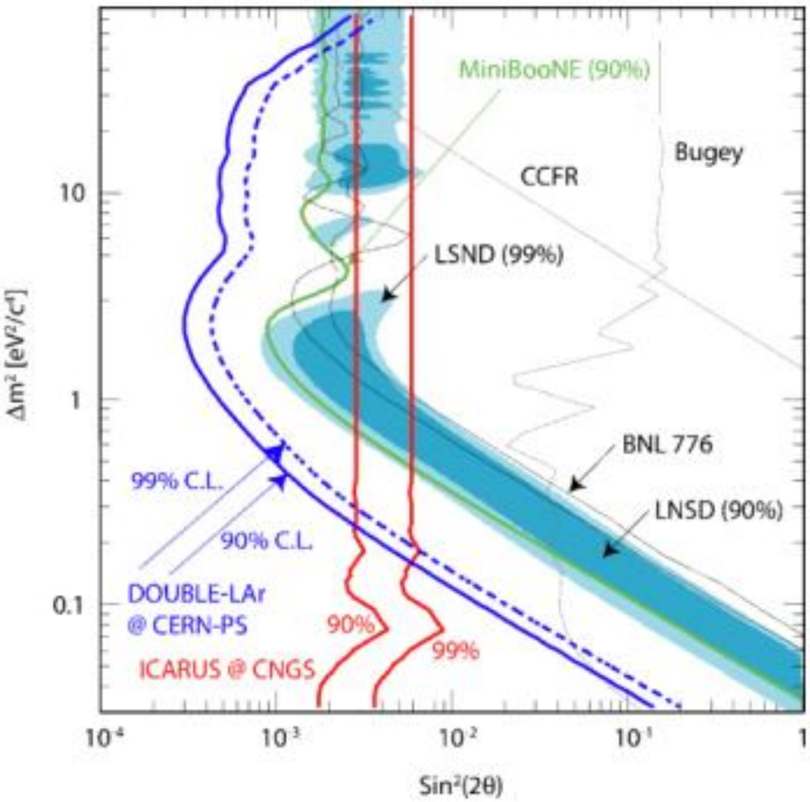


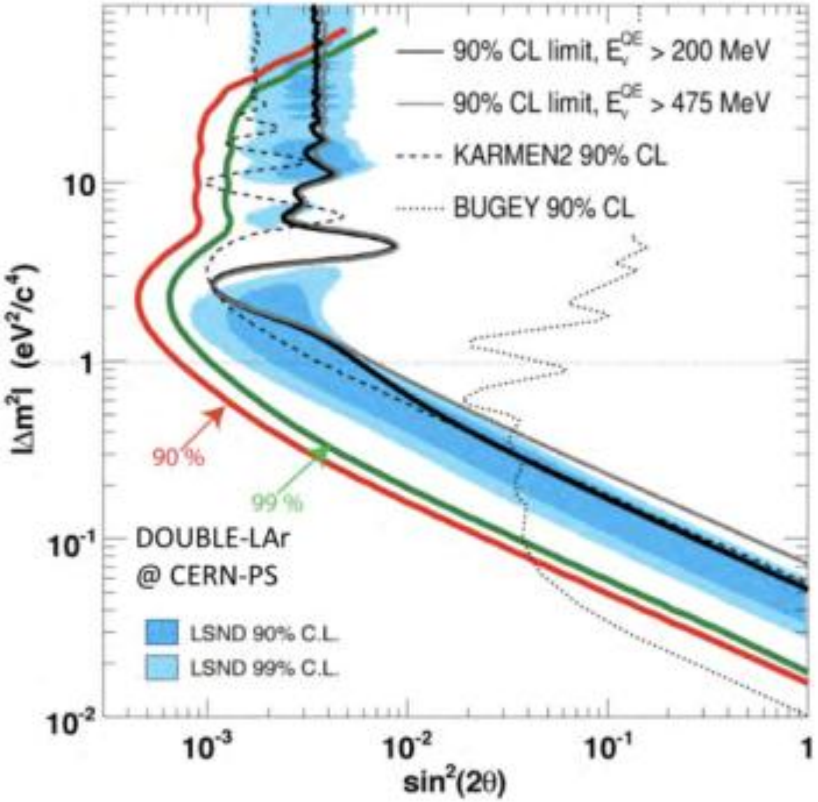
Two positions are foreseen for the detection of the neutrinos

The far (ICARUS-T600) location at 850 m from the target: L/E ~ 1 km/GeV;

The additional detector and new location at a distance of 127 m from the target: L/E 0.15 km/GeV

Comparing LSND sensitivities *(arXiv:0909.0355)*



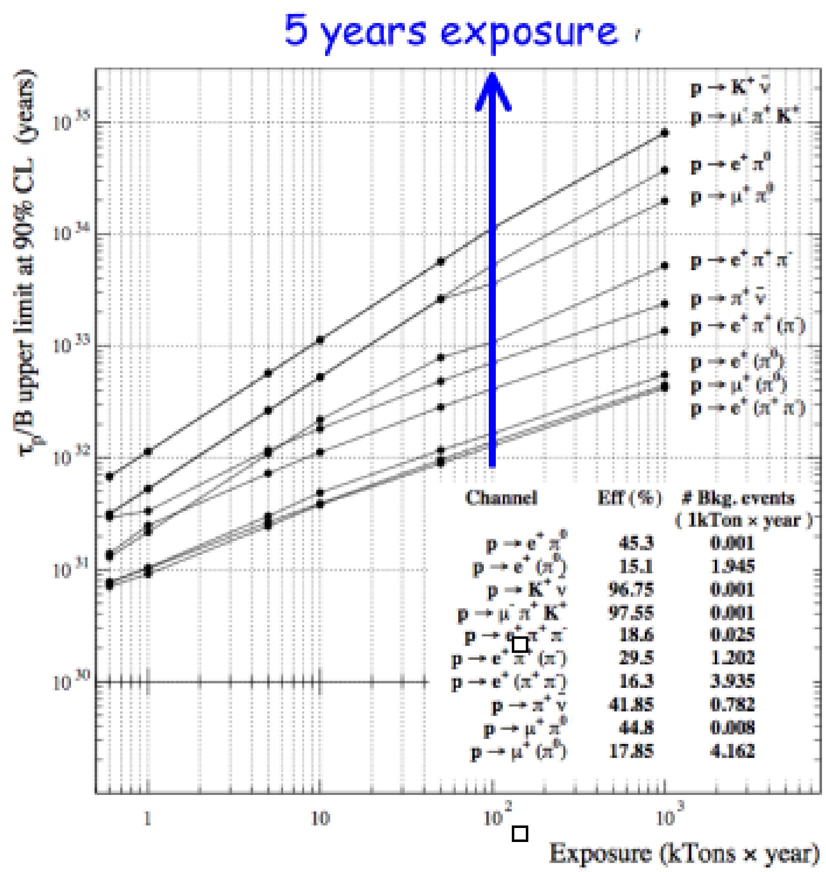


Expected sensitivity for the proposed experiment exposed at the CERN-PS neutrino beam (left) for 2.5 10^{20} pot (30 kW basic option) and twice as much for anti-neutrino (right). The LSND allowed region is fully explored both for neutrinos and anti-neutrinos. The T600 expectations from one year at LNGS are also shown.

Nucleon decay expectations

- 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.
- With *1.2 10^{34} nucleons*, MODULAr is well suited for channels not accessible to _ detectors due to the complicated event topology, or if the emitted particles are below the _ threshold (e.g. *K^+*)

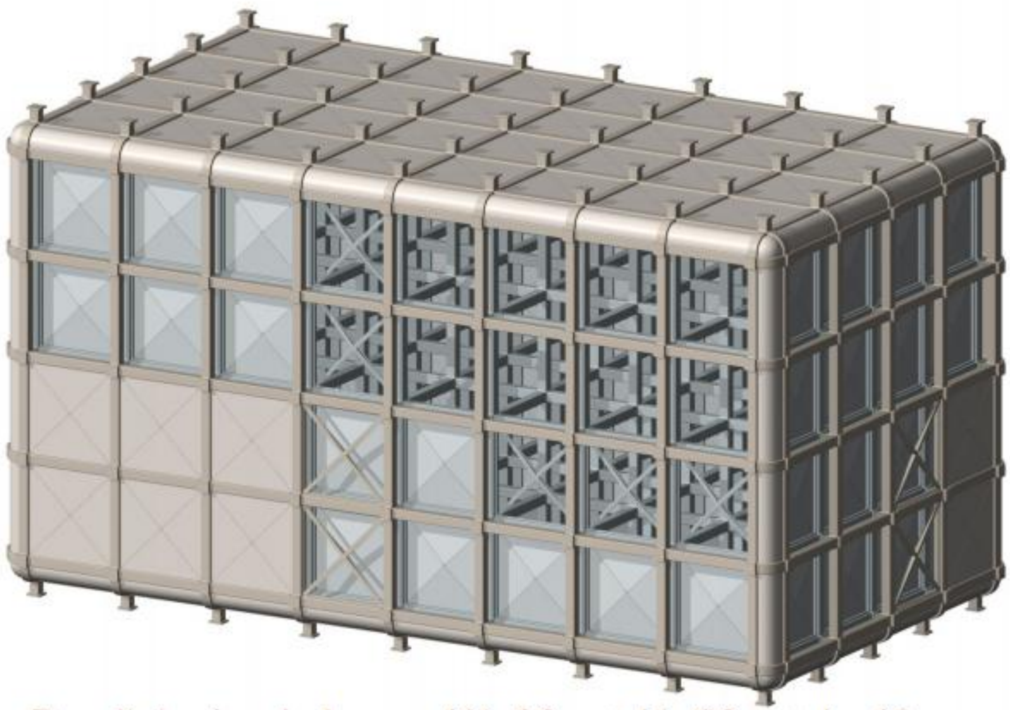
Channel	*90%CL-5y*	*(pdg 90%CL)*
$p \to \nu\, \pi^+$	$4.4\ 10^{33}$	$(2.5\ 10^{31})$
$p \to \mu^-\, \pi^+ K^+$	$1.1\ 10^{34}$	$(2.5\ 10^{32})$
$n \to e^- K^+$	$1.3\ 10^{34}$	$(3.2\ 10^{31})$
$n \to \mu^+\, \pi^-$	$6.0\ 10^{33}$	$(1.0\ 10^{32})$
$n \to \nu\, \pi^0$	$4.4\ 10^{33}$	$(1.1\ 10^{32})$



Vacuum Insulated Modular Detector for LBNE: Design Guidelines

Detector configuration based on one or two double-wall, vacuum-insulated cryostats with the possibility of inside vacuum before filling by LAr.

In order to resist to the outer pressure and vacuum insulation loads the cryostat(s) are built as a 3D array of cubic cells (5m side) without inner common walls to get a continuous LAr active volume across the inner array structure.



Parallelepiped shape ~W=20m × H=20m × L=40m

Outer vessel linked to the inner one trough thermal bridges (transversally sliding and longitudinally elastic to follow the inner vessel shrinkage).

To get temperature uniformity and minimize updrafts in the active LAr the inner array structure is made by hollow square (or round) beams with inside circulation of LN_2 (or dirty LAr) kept liquid by cryogenerators on the top.