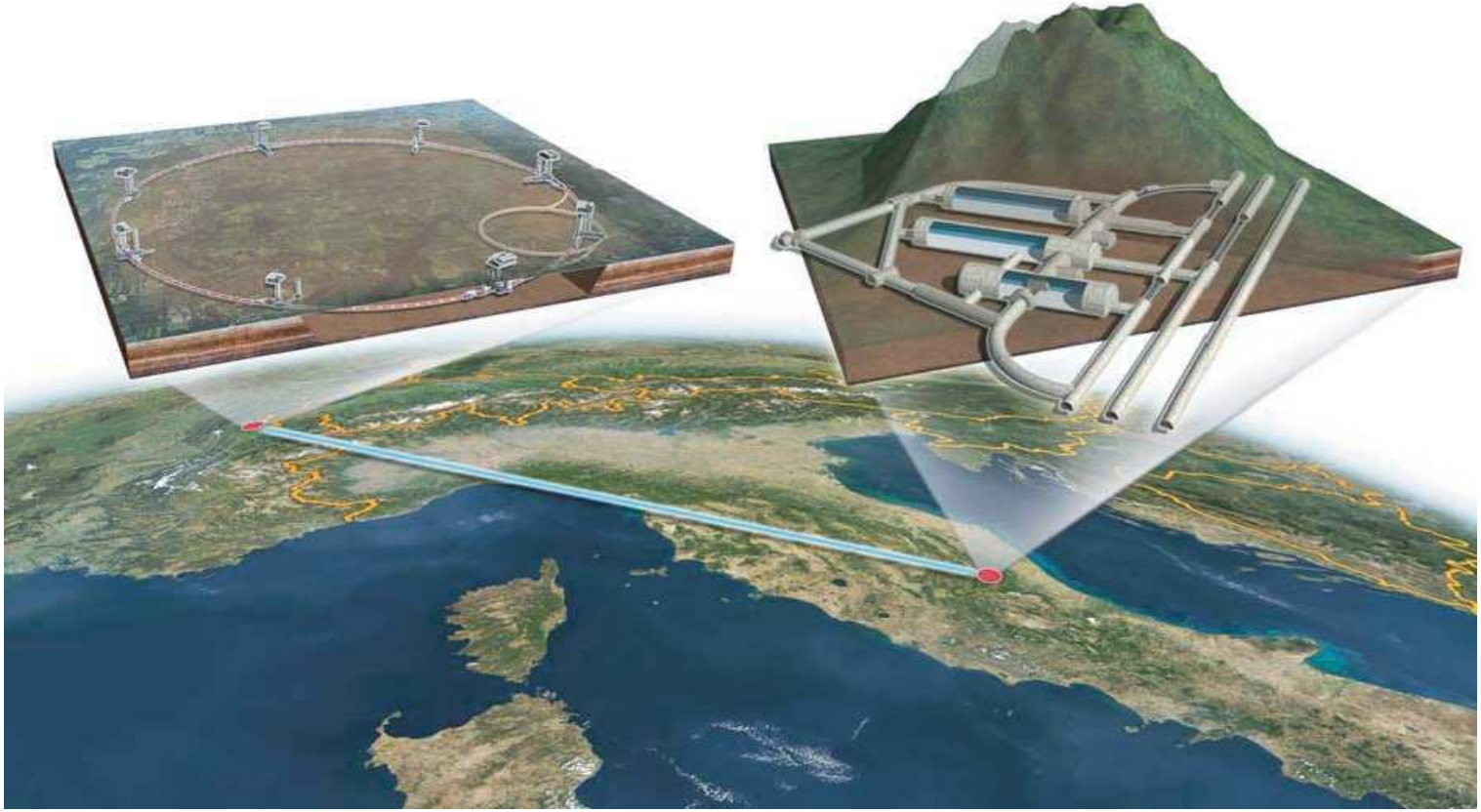
ICARUS and Status of Liquid Argon Technology



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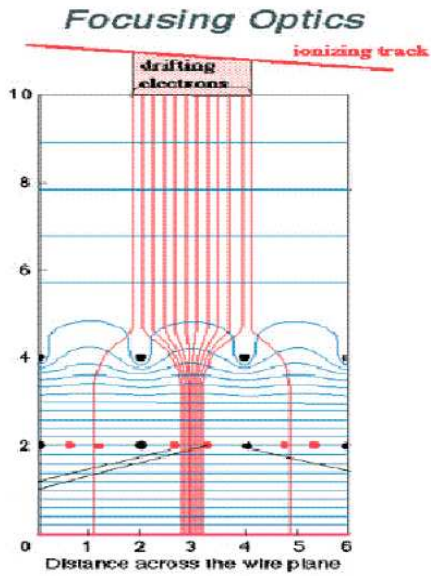
A powerful detection technique

The Liquid Argon Time Projection Chamber [C. Rubbia: CERN-EP/77-08 (1977)]

- 3D imaging of any ionizing event ("electronic bubble like")
- continuously sensitive
- high granularity (~ 1 mm)
- excellent calorimetric properties
- particle id (dE/dx vs range)
- self triggering

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.

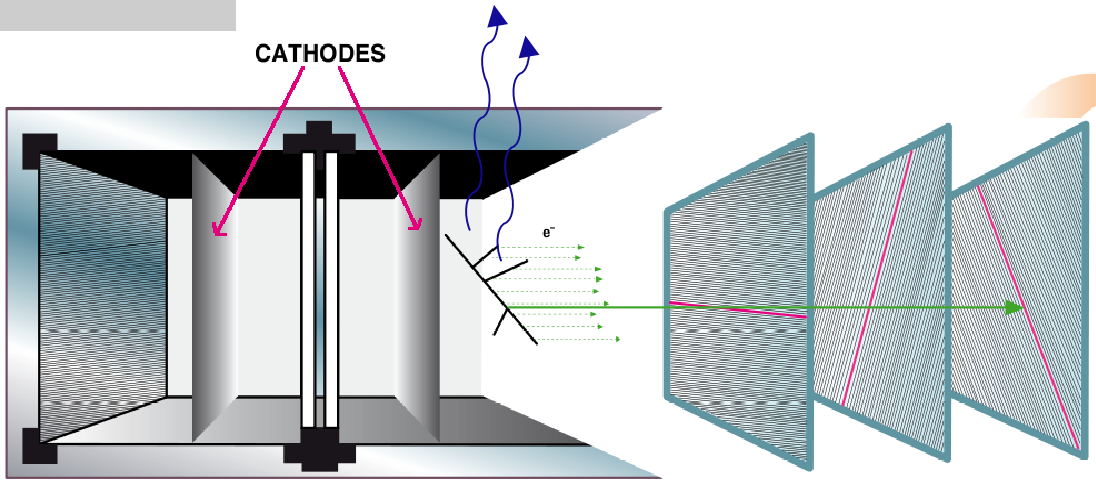


m.i.p. ionization

~ 6000 e^-/mm

~ 42000 e^-/MeV

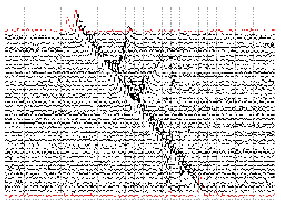
Scintillation light yield
5000 γ/mm @ 128 nm



FRONT VIEW OF THE DETECTOR

E_{drift} ~ 500 V/cm

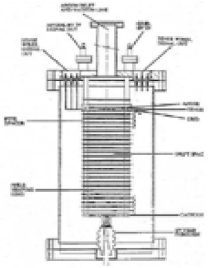
WIRE PLANES
ANODE



WIRE SIGNAL

GEOMETRICAL RECONSTRUCTION
ON A PLANE

The path to larger LAr detectors



CERN

24 cm drift wires chamber

1

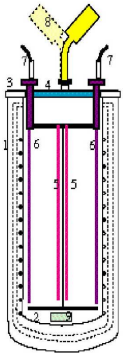
1987: First LAr TPC. Proof of principle. Measurements of TPC performances.

2

3 ton prototype

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

CERN

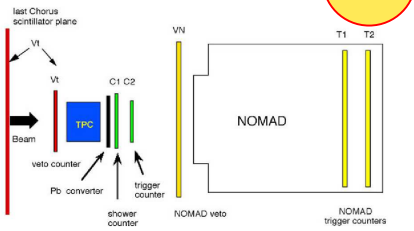


Laboratory work

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.

Icarus T600 experiment

2010 - … : Data taking with CNGS beam

4

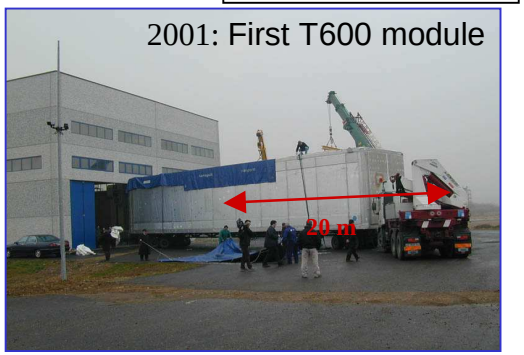
10 m^3 industrial prototype

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

Pavia

T600 detector

Cooperation with industry
AirLiquide, Breme, Cinel, CAEN



5

6

LNGS Hall-B

LAr purification

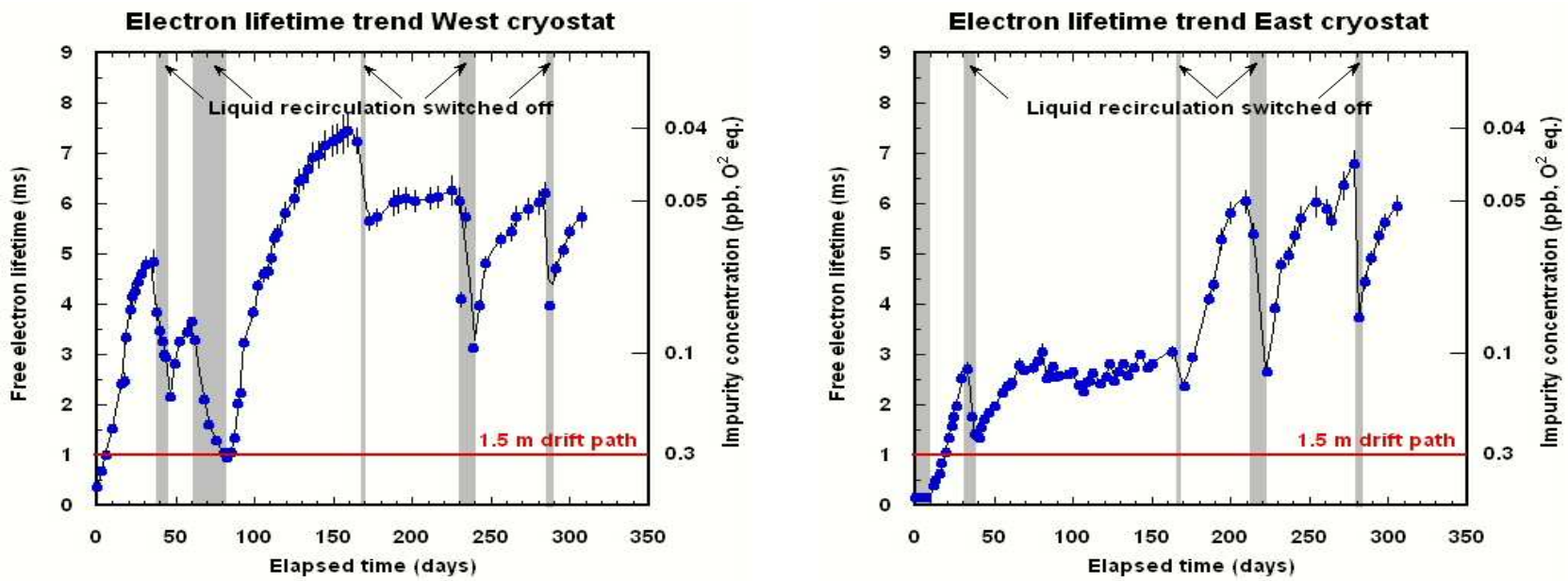
LAr purity (from electro-negative molecules as O_2, H_2O, CO_2) is a key issue of the LAr technology, especially to prove its scalability:

event energy underestimation due to charge signal attenuation by electron trapping

$Q = Q_0 \exp(-t/\tau_{e^-})$ $\quad\quad$ τ_{e^-} [ms] ~ 0.3 / N [ppb O_2 equivalent]

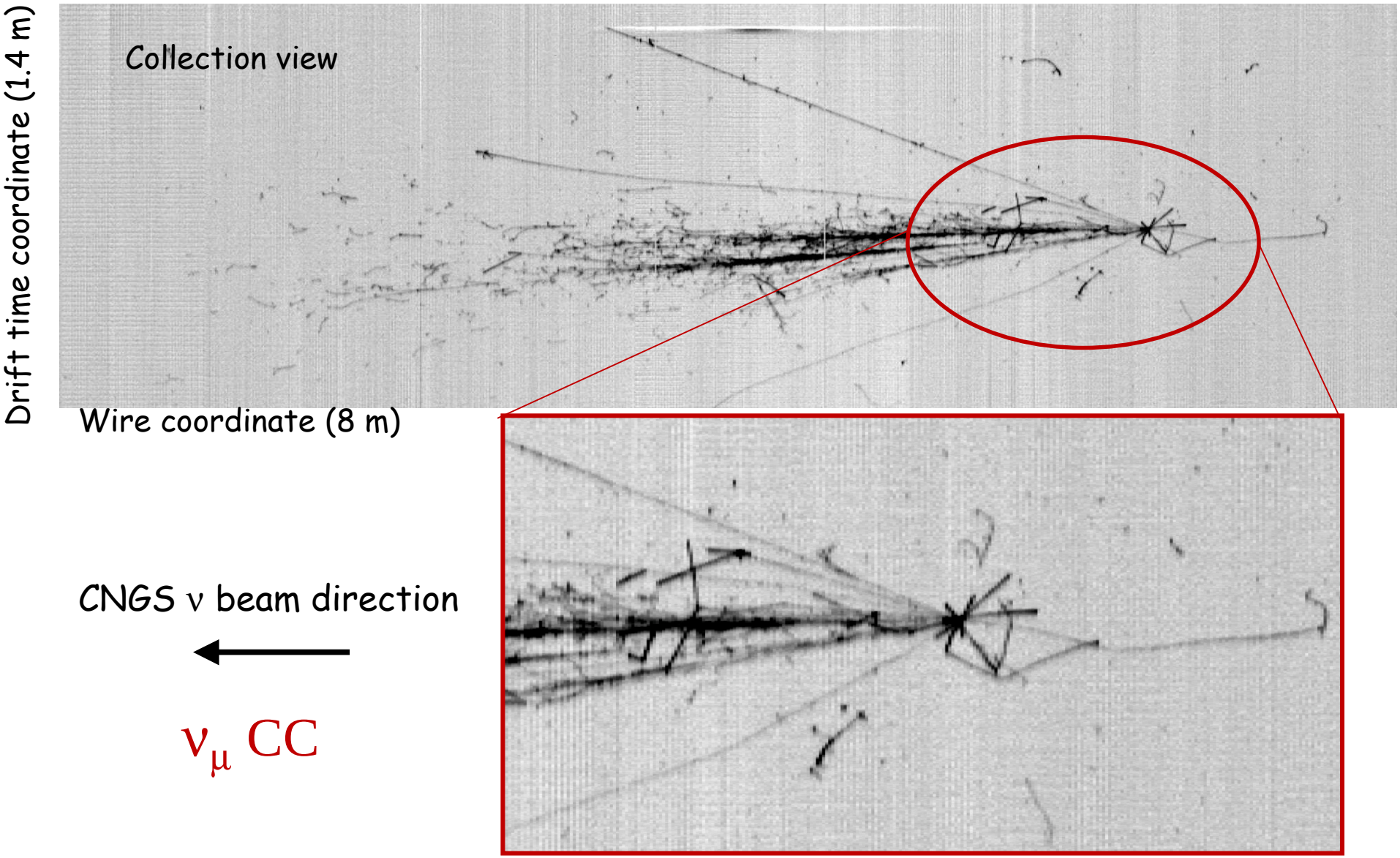
=> ultra high vacuum before filling (10^{-5} mbar)

=> online continuous gas & liquid argon recirculation/purification



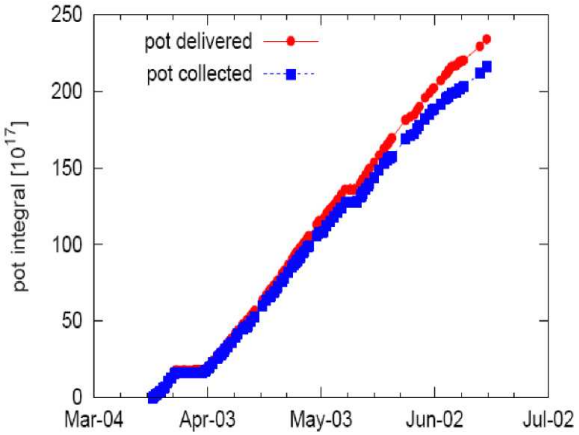
- **6 ms electron lifetime** (w.r.t. 1 ms drift time) corresponds to **≈ 50 ppt (10^{12}) O_2 eq!**
  => enough for 3 m drift detectors (<30% attenuation)
- Dedicated measure in a 50 l LAr-TPC @ LNL-> 15.8 ms @ 90% C.L. => allows 5 m drift!

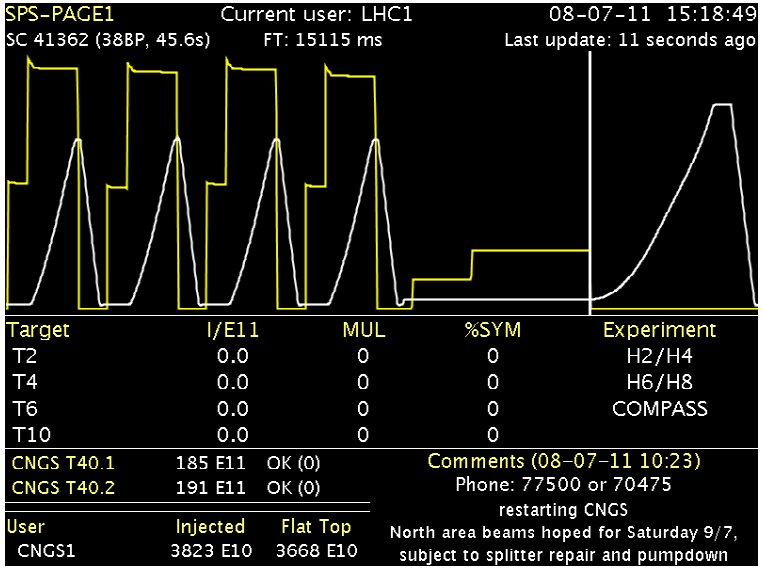
The first CNGS neutrino interaction in ICARUS T600



Data Taking

ICARUS T600 detector, activated on 27th May 2010, is fully operational in stable conditions since 1st Oct 2010



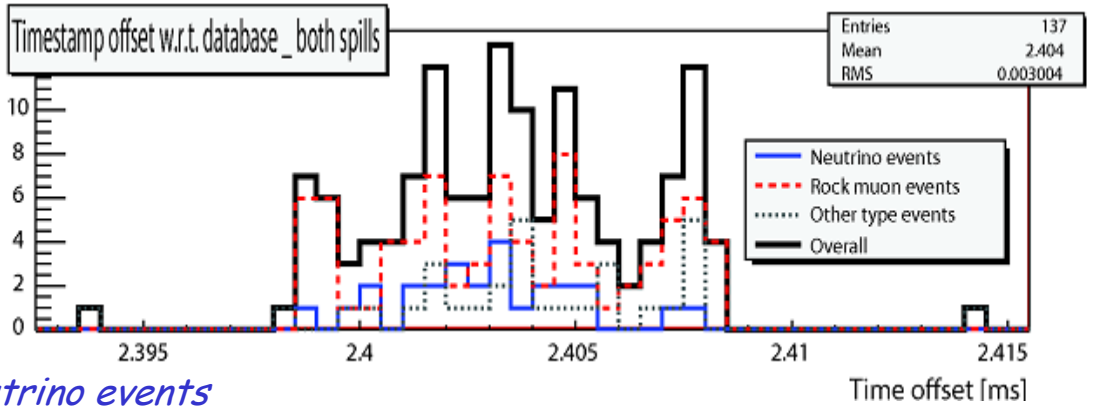


Detector livetime ≈ 93%

- trigger+DAQ optimized in 2010
- $2.2 \cdot 10^{19}$ pot collected up to June 10th

Trigger sources:

- internal PMTs
- "Early Warning" of the CNGS proton extraction time 80 ms before the spill => trigger gate of 60μs (LNGS atomic clock syncronization)
- Wires charge with FPGA => local trig. (under test)



Trigger logics:

- CNGS + Low Threshold PMT (~100phe) *-> CNGS neutrino events*
- CNGS only -> online Software Trigger
- Low Threshold PMT coincidence of 2 adjacent cryostat *-> Mainly "cosmic" events*

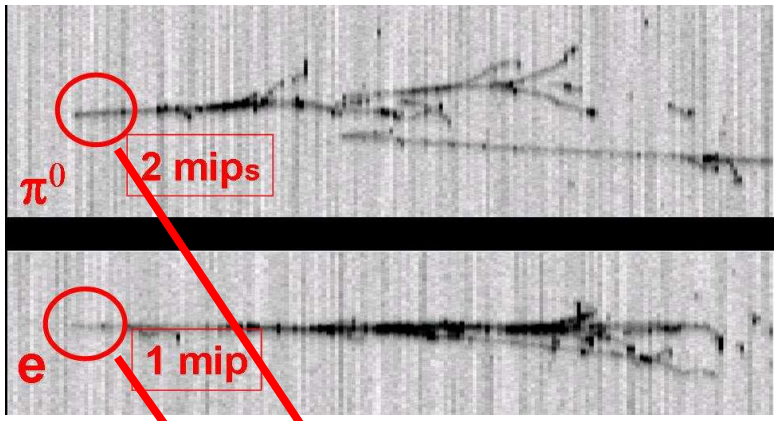
Trigger rates: 50 mHz (1 mHz CNGS + 49 mHz cosmic) => 4500 ev/day (100 MB/ev)

LAr-TPC performance

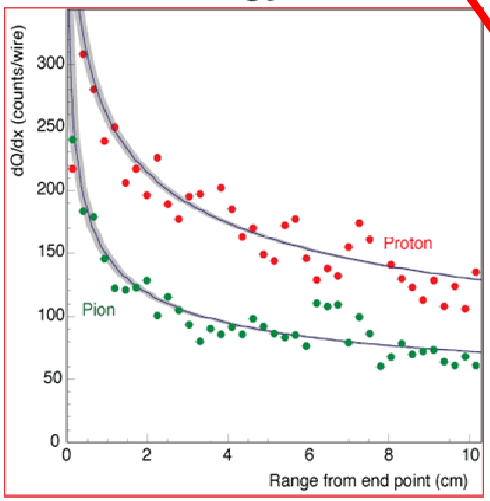
- Tracking device:
  - precise event topology ($s_{x,y}$ ~ 1mm, s_z ~ 0.4mm)
  - μ momentum measurement via multiple scattering: Δp/p ~10-15% depending on track length and p
  - Total energy reconstruction by charge integration

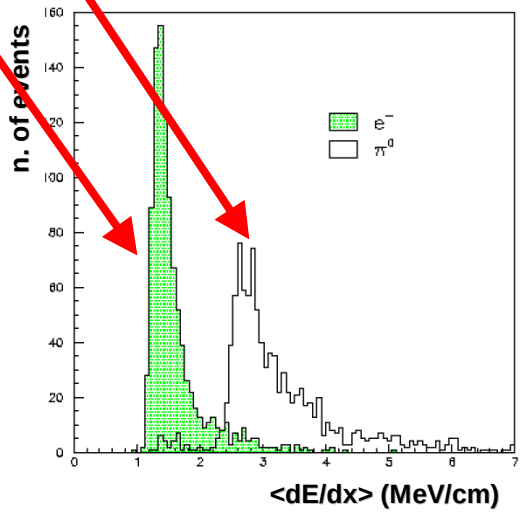
- Measurement of local energy deposition dE/dx:
  - e/μ separation (2% X_0 sampling);
  - particle ID by means of dE/dx vs range

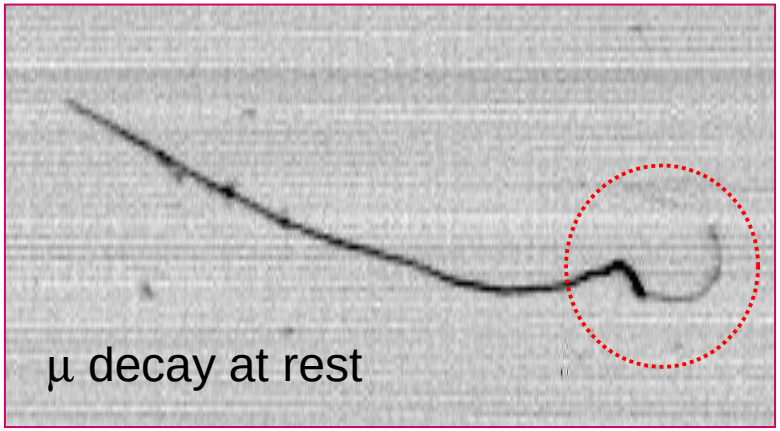
- Good e/π^0 separation (10^{-3}) by means of dE/dx in the first part of the track after the vertex



dE/dx energy losses







RESOLUTIONS:

Low energy electrons	σ(E)/E = 11% / √E(MeV)+2%
Electromagnetic showers	σ(E)/E = 3% / √E(GeV)+1%
Hadron shower (pure LAr)	σ(E)/E ~ 30% / √E(GeV)

Data analysis

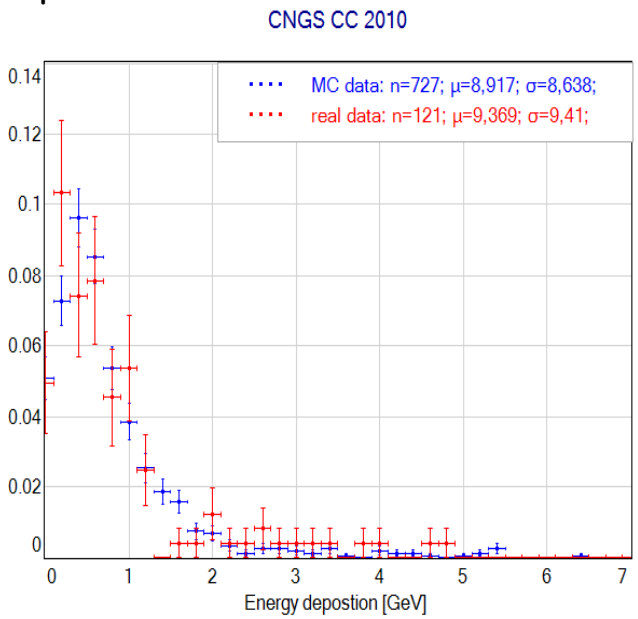
❑ Visual scanning analysis

- 2010 data sample fully classified (5.8 · 10^{18} collected pot)
  - ✓ overall statistics in agreement with expectations

Event type	Collected	Expected
ν_μ CC	115	129
ν NC	46	42
ν_e CC	1	1
ν XC *	7	-
Total	169	172

❑ Calorimetric reconstruction of the global deposited energy

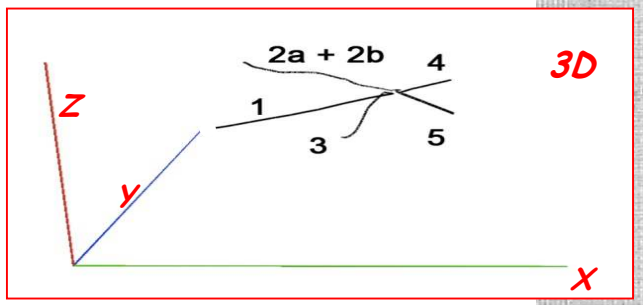
- Correction for electron lifetime charge reduction effects (hit by hit) and quenching

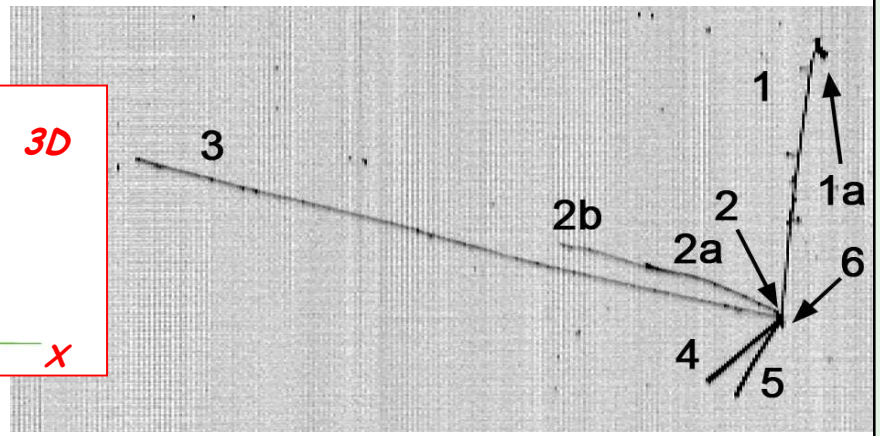


❑ 3D reconstruction => PID

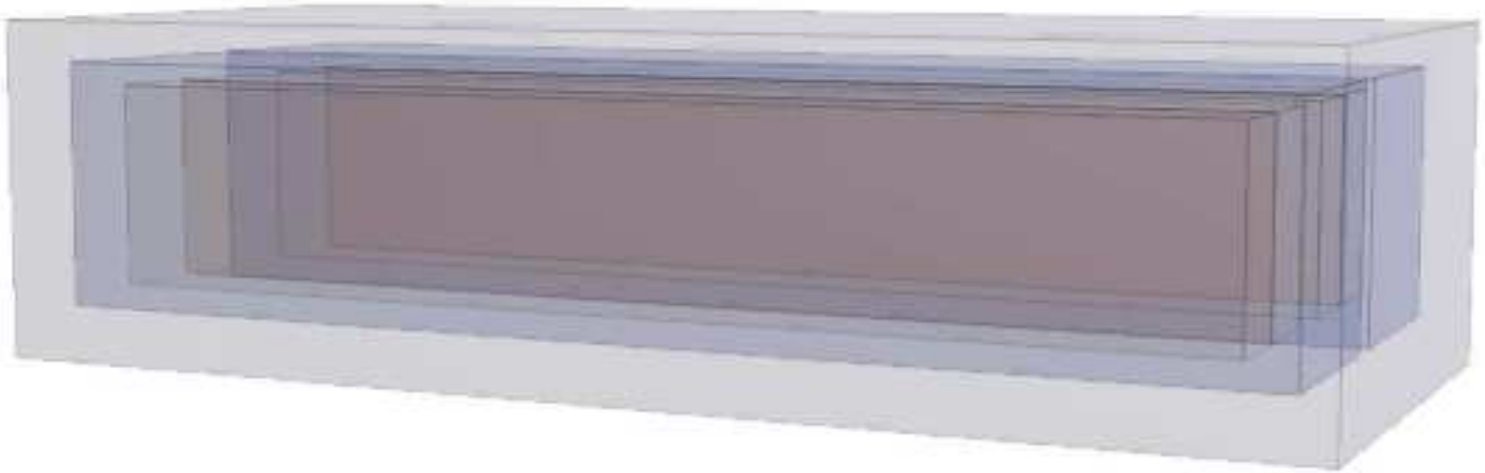
- Distance between 2 nearby hits (dx)
- Calorimetric reconstruction (hit by hit)

⇒ Particle ID using dE/dx vs range (work in progress)





Track	E_k [MeV]	Range [cm]
1 (prob. π, decays in flight)	136.1	55.77
2 (π)	26	3.3
2a (μ)	79.1	17.8
2b (e)	24.1	10.4
3 (μ)	231.6	99.1
4 (p)	168	19.2
5 (p)	152	16.3
6 (?) (merged with vertex)		2.9



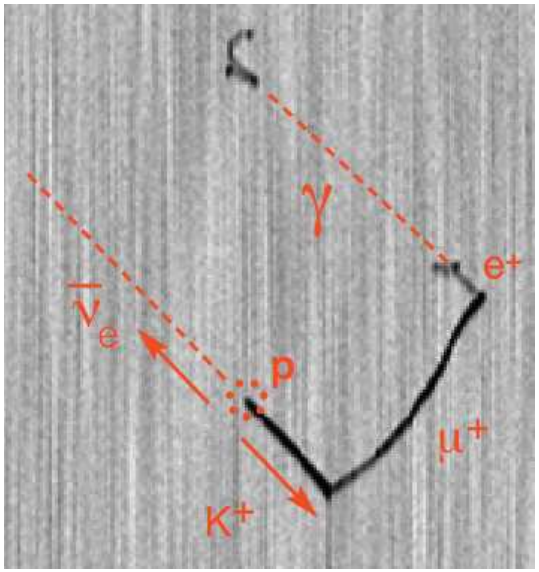
ICARUS T600 physics potential

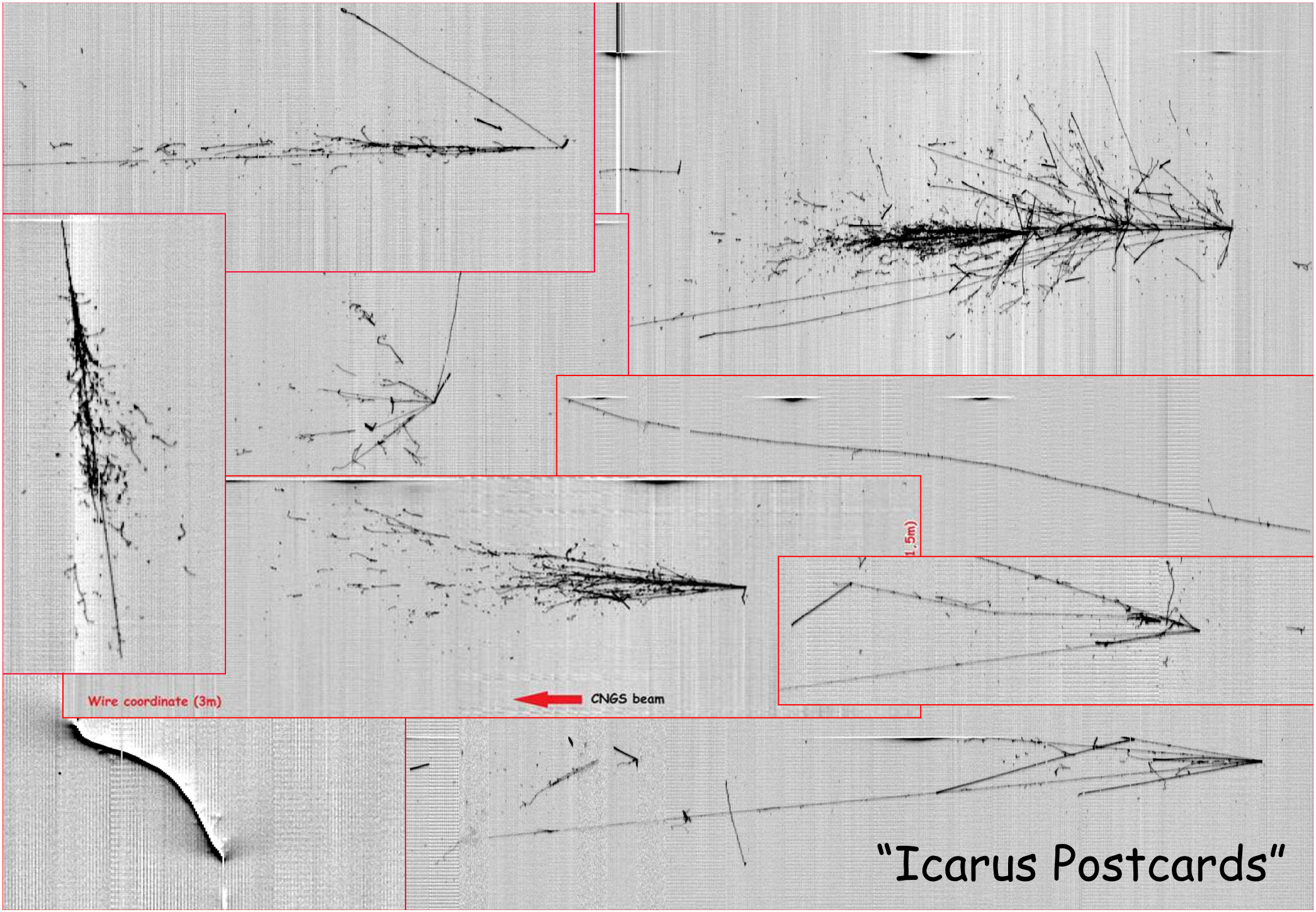
ICARUS T600 is the major milestone towards realization of large scale LAr detector (tens of kton for the ModuLAr project)

- Interesting physics in itself: unique imaging capability (events "seen in a new Bubble chamber like" way)

- CNGS ν events collection (beam intensity 4.5 10^{19} pot/year, E_ν~17.4 GeV):
  - 1200 ν_μ CC event/year
  - ~ 8 ν_e CC event/year
  - observation of ν_τ events in the $\tau \rightarrow e\nu\nu$ channel (using kinematical criteria)
  - search for sterile ν in LSND parameter space from deep inelastic ν_e CC events excess (CERN-PS proposal)

- "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 Postcards"