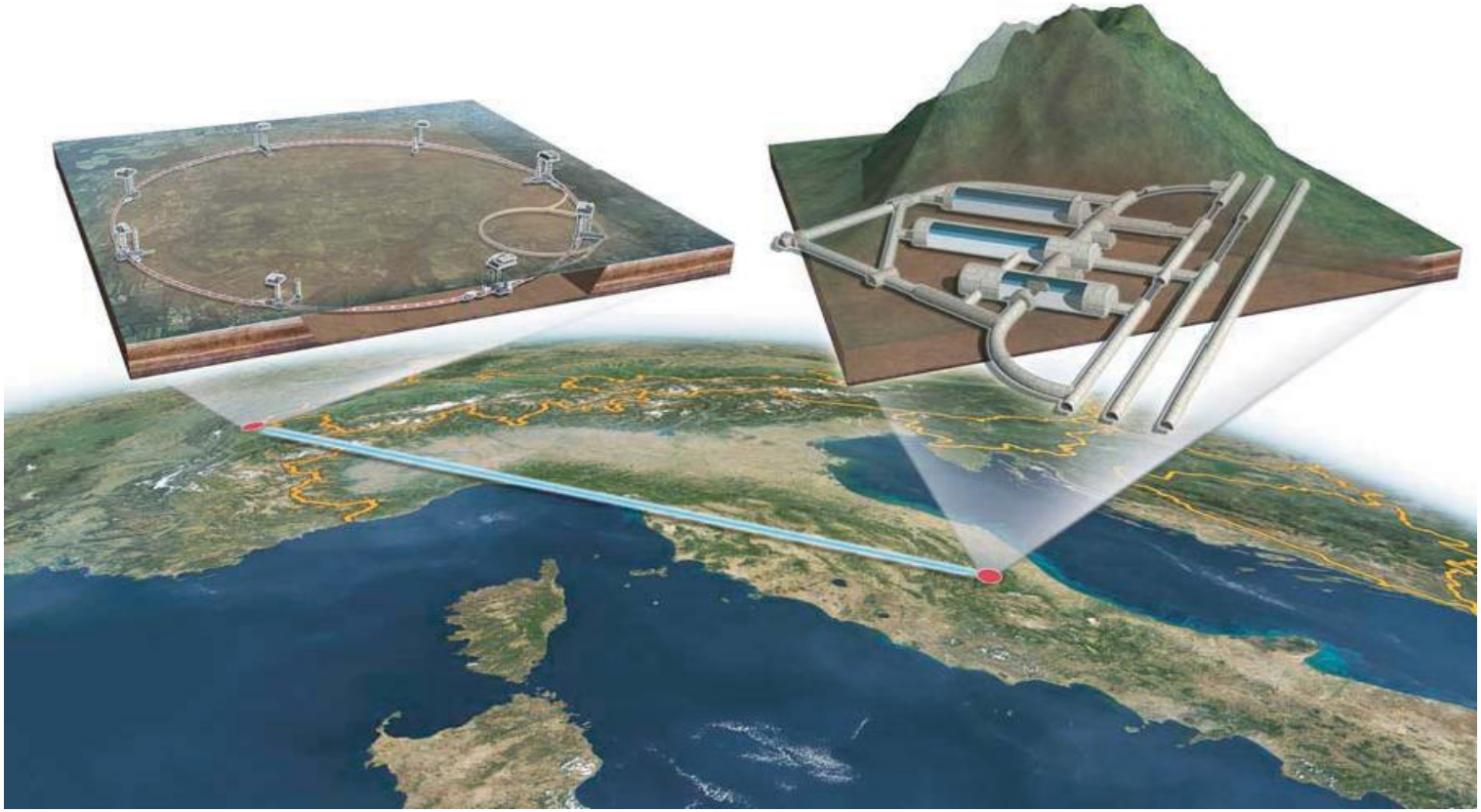
ICARUS-T600: A Liquid Argon Imaging Chamber



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ICARUS-T600: A Liquid Argon Imaging Chamber

Cryogenic noble liquids and Argon "in primis" have recently regained a strong interest in the scientific community.

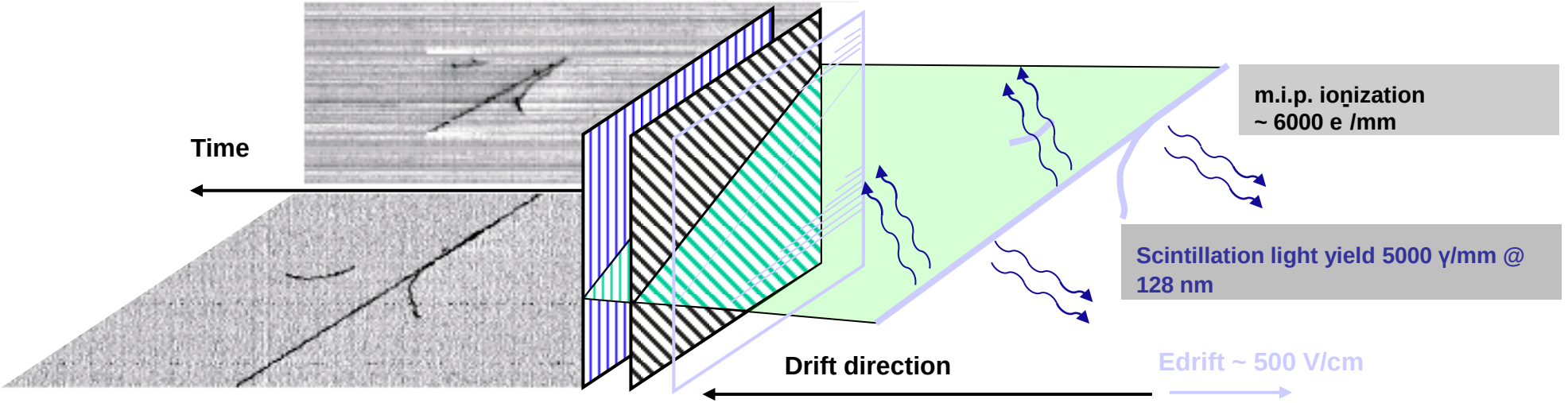
The ICARUS experiment at the Gran Sasso Laboratory is so far the most important milestone for this technology and acts as a full-scale test-bed located in a difficult underground environment.

- The successful assembly and operation of the ICARUS-T600 LAr-TPC demonstrate that the technology is mature.
- The wide physics potentials offered by high granularity imaging and extremely high resolution will be addressed already with the T600 detector:
  - Underground physics (proton decay, solar, supernova, …)
  - Long-baseline, high precision neutrino physics
- The T600 is presently taking data, smoothly reaching optimal working conditions. Neutrino interactions have been observed. Data analysis already on-going.

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
- particle identification (through dE/dx vs range)



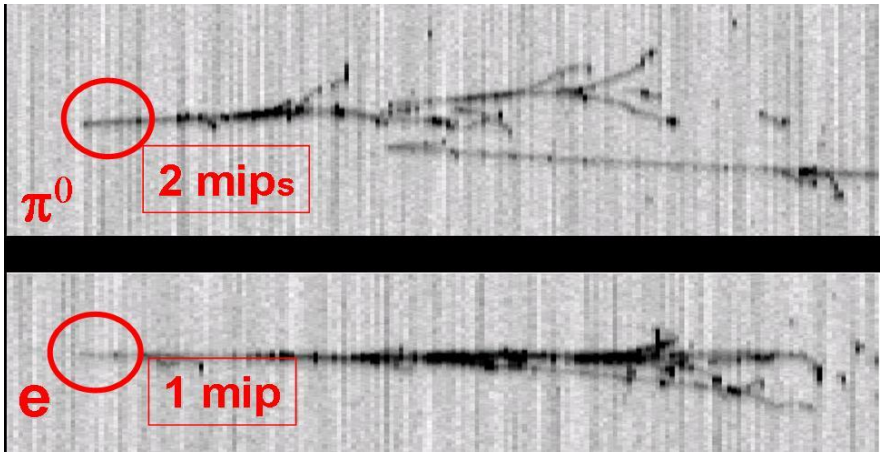
Electrons from ionizing track are drifted in LAr by E_{drift}. They traverse transparent wires arrays oriented in different directions where induction signals are recorded. Finally electron charge is collected by collection plane.

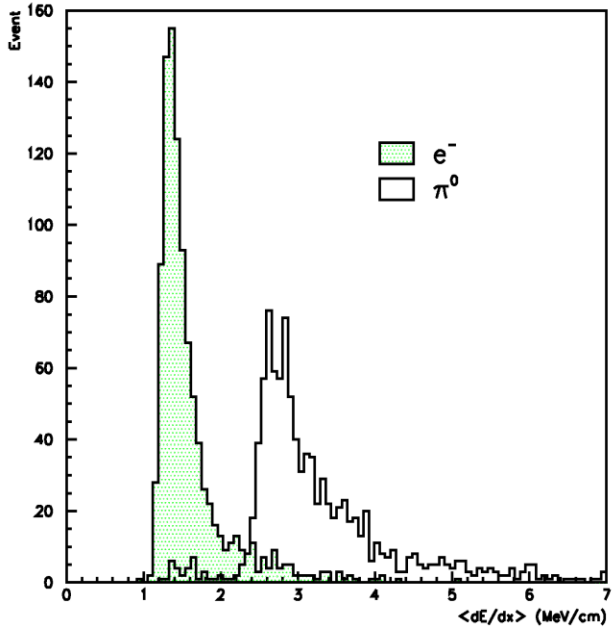
Key feature: LAr purity form electro-negative molecules (O_2, H_2O,CO_2).
Target: 0.1 ppb O_2 equivalent= 3 ms lifetime (4.5 m drift @ E_{drift} = 500 V/cm).

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 νμ–νe oscillation search!





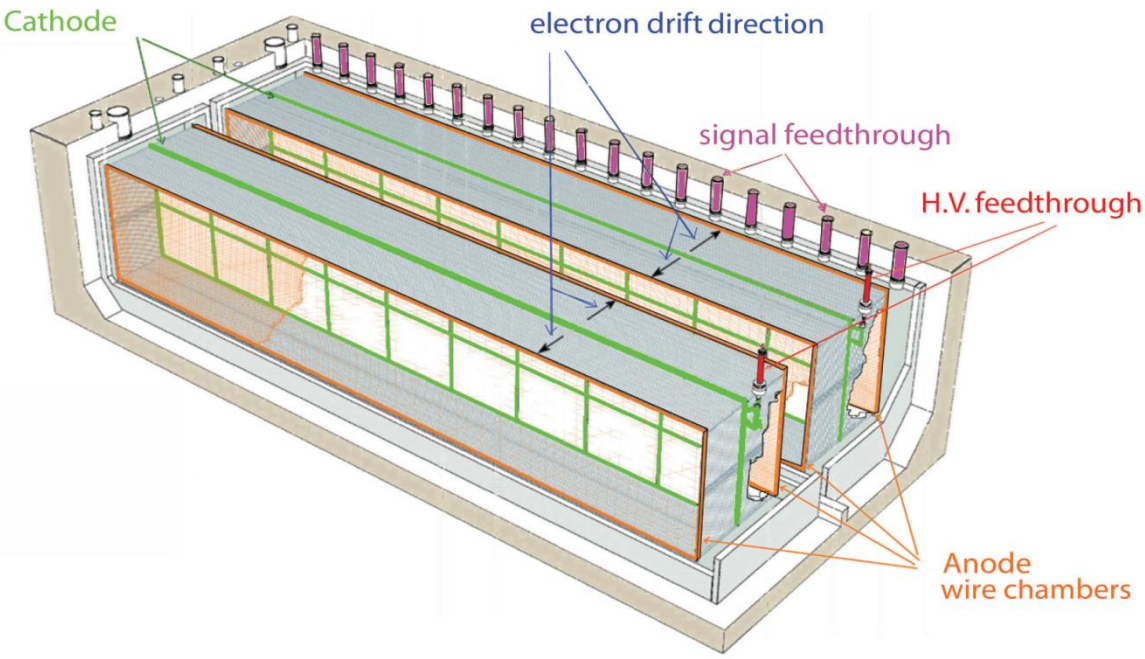
RESOLUTIONS

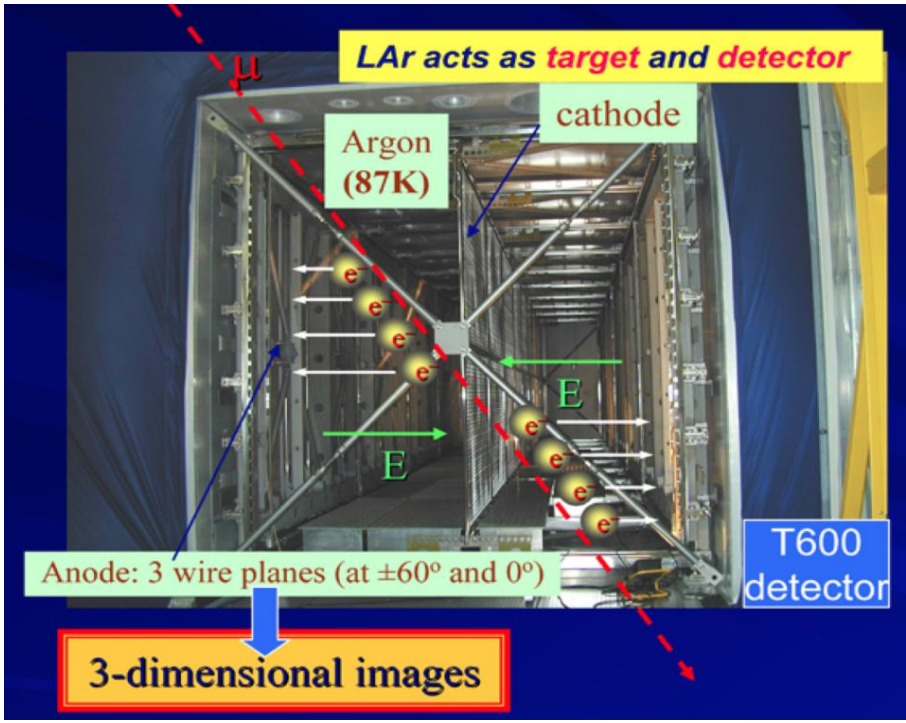
Low energy electrons: σ(E)/E = 11% / √ E(MeV)+2%

Electromagn. showers: σ(E)/E = 3% / √ E(GeV)

Hadron shower (pure LAr): σ(E)/E ≈ 30% / √ E(GeV)

The ICARUS T600 detector

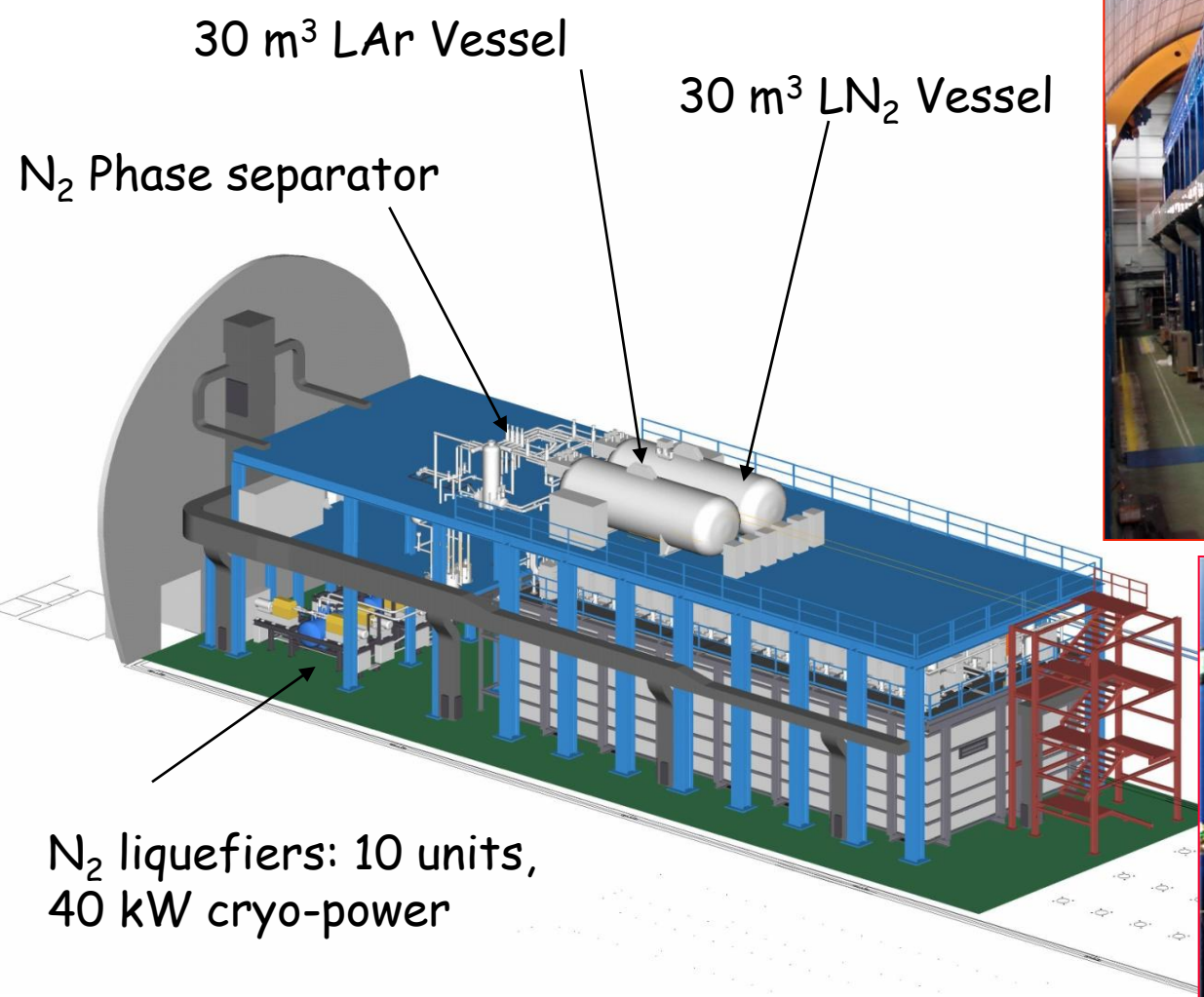




- Two identical modules
  - 3.6 x 3.9 x 19.6 ≈ 275 m^3 each
  - Liquid Ar active mass: ≈ 476 t
  - Drift length = 1.5 m
  - HV = -75 kV E = 0.5 kV/cm
  - vdrift = 1.55 mm/μs

- 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



T600 cryostats layout

Electronics (54000 channels)

Pipe from safety magnetic disks

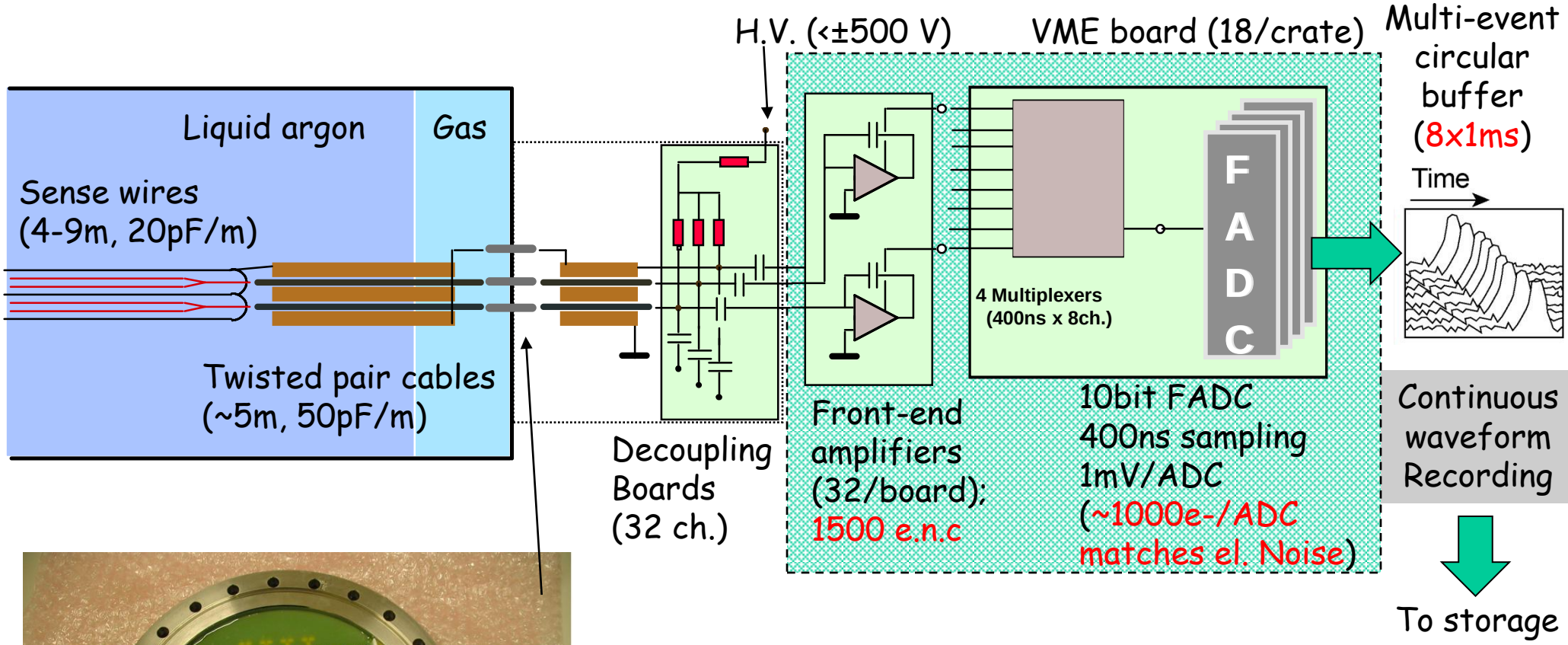
Passive heaters

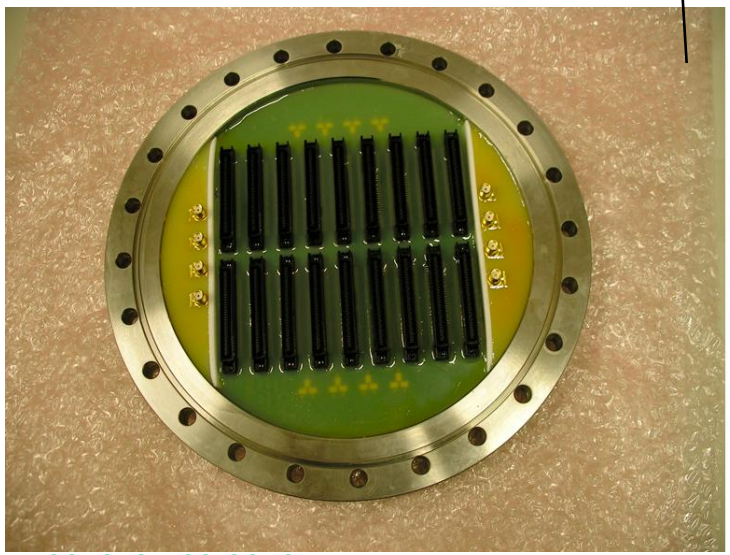
LN_2 Pumps

LAr purification systems

GAr purification systems

ICARUS front-end Electronics

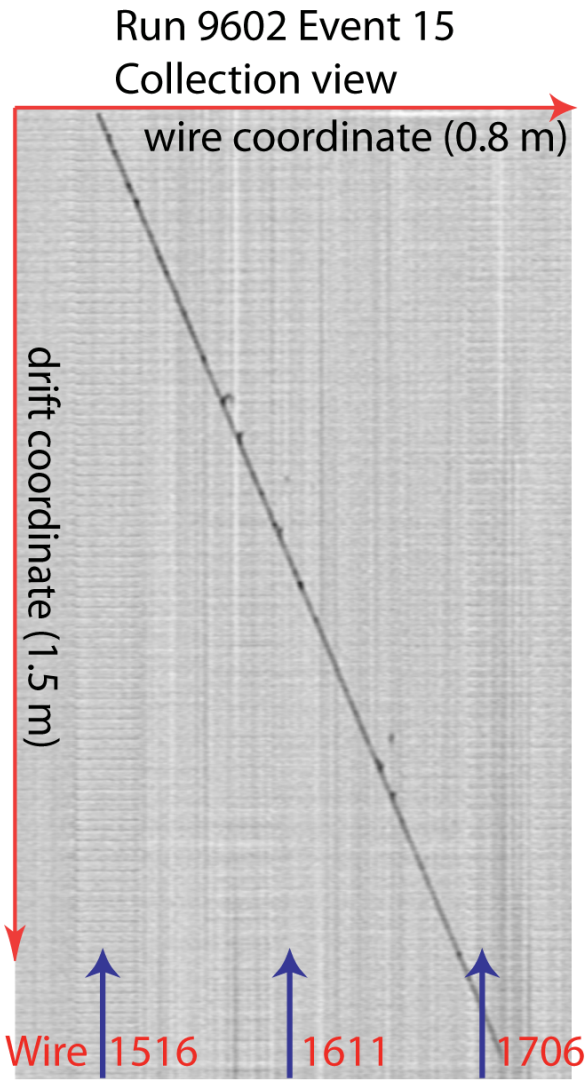


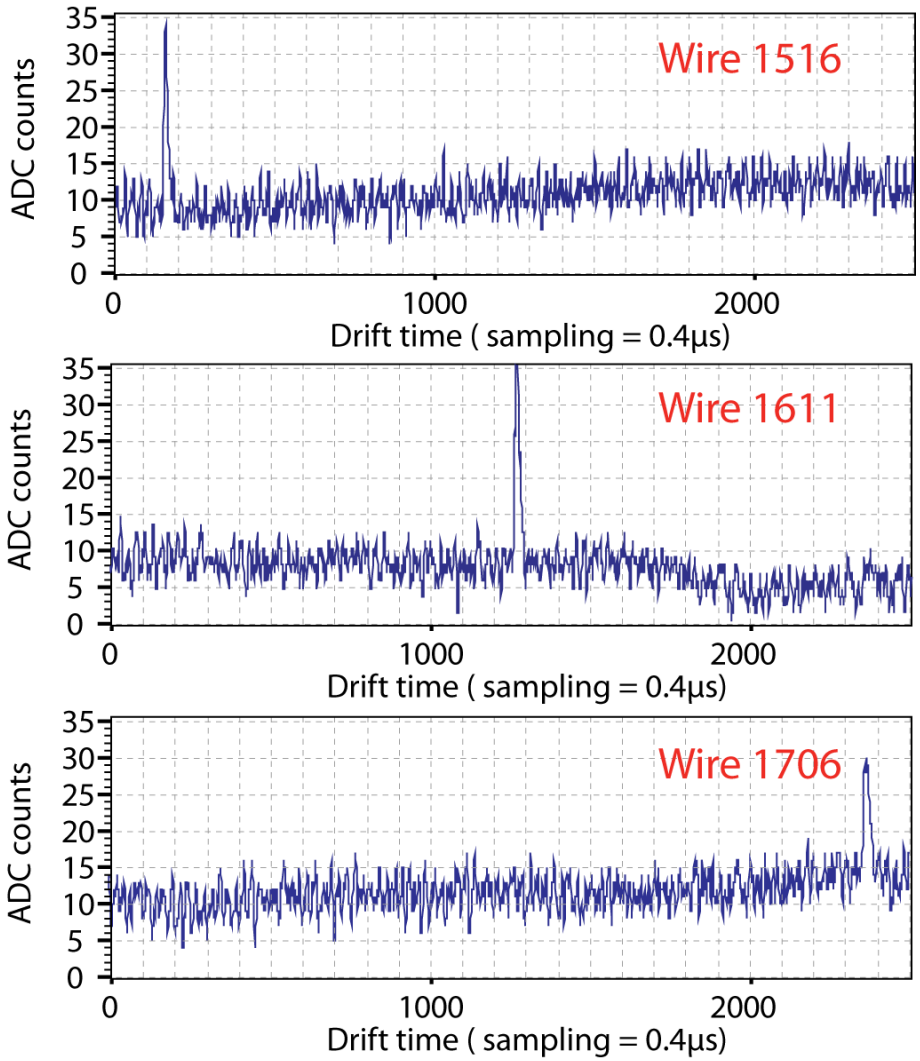


100 UHV feed-throughs: 576 channels
(18 connectors x 32 + HV wire biasing)

New Design based on multi-layer PCB with blind holes:
- electrical continuity
- ultra high vacuum tightness

Example of muon crossing track





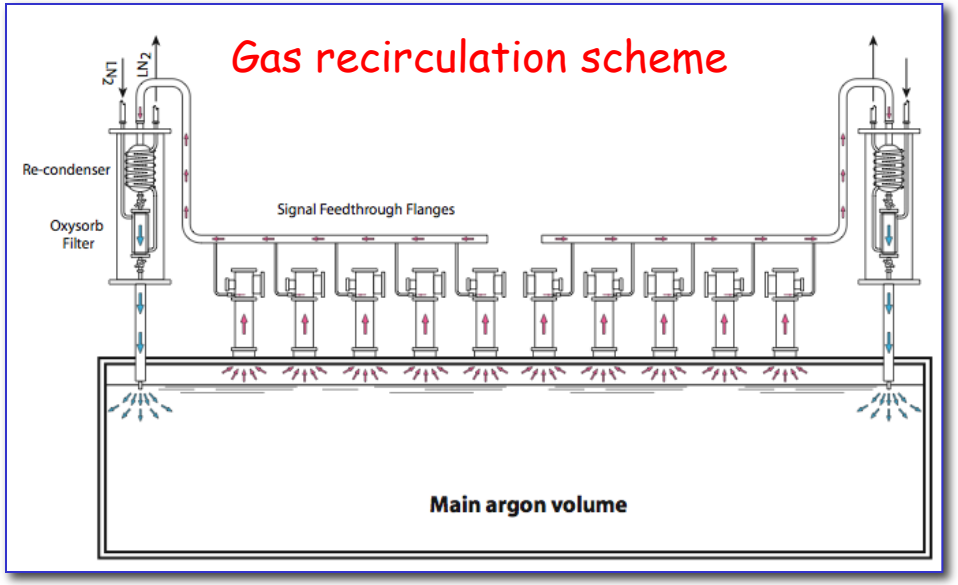
Typical pulse height for a 3 mm m.i.p. ~12 ADC # (12000 electrons).

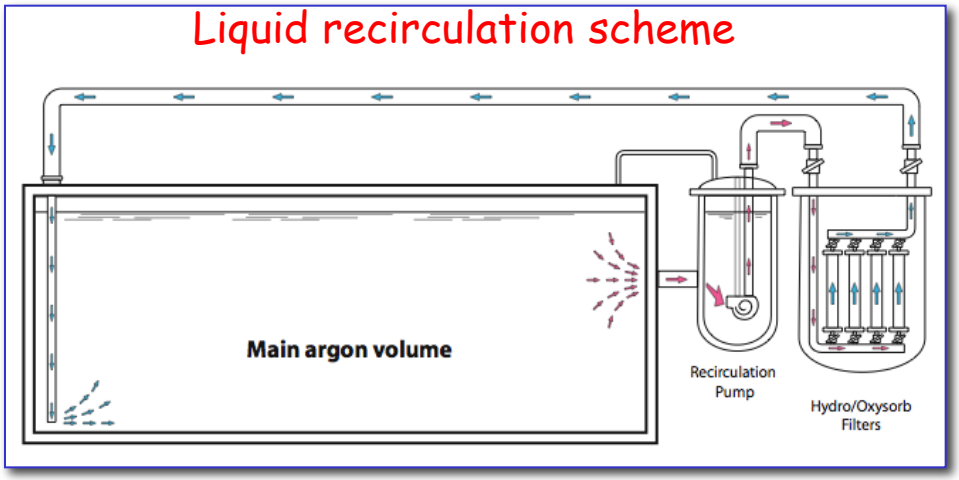
r.m.s noise ~ 1.5 ADC # (1500 electrons eq.)

T=0 comes from induction of PMT signal on collection.
Charge attenuation along the track allows event-by-event measurement of LAr purity

LAr Purification in T600

- The presence of electron trapping polar impurities attenuates the electron signal as $\exp(-t_D/\tau_{ele})$
- τ_{ele} ~ 300 μs / ppb (O_2 equivalent).
- Because of temperature (87 K) most of the contaminants freeze out spontaneously. Main residuals: O_2, H_2O, CO_2.
- Recirculation/purification (100 Nm^3/h) of the gas phase (~40 Nm^3) to block the diffusion of the impurities from the hot parts of the detector and from micro-leaks on the openings (typically located on the top of the device) into the bulk liquid.
- Recirculation/purification (4 m^3/h) of the bulk liquid volume (~550 m^3) to efficiently reduce the initial impurities concentration (can be switched on/off).





LAr purity measurement

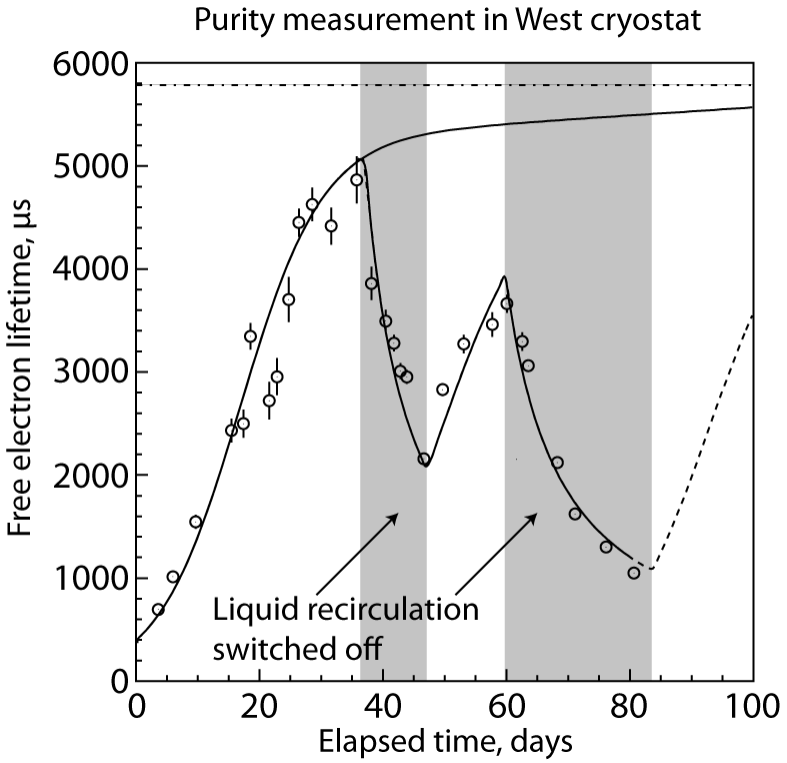
- On-line measurement with charge attenuation along single muon crossing tracks:

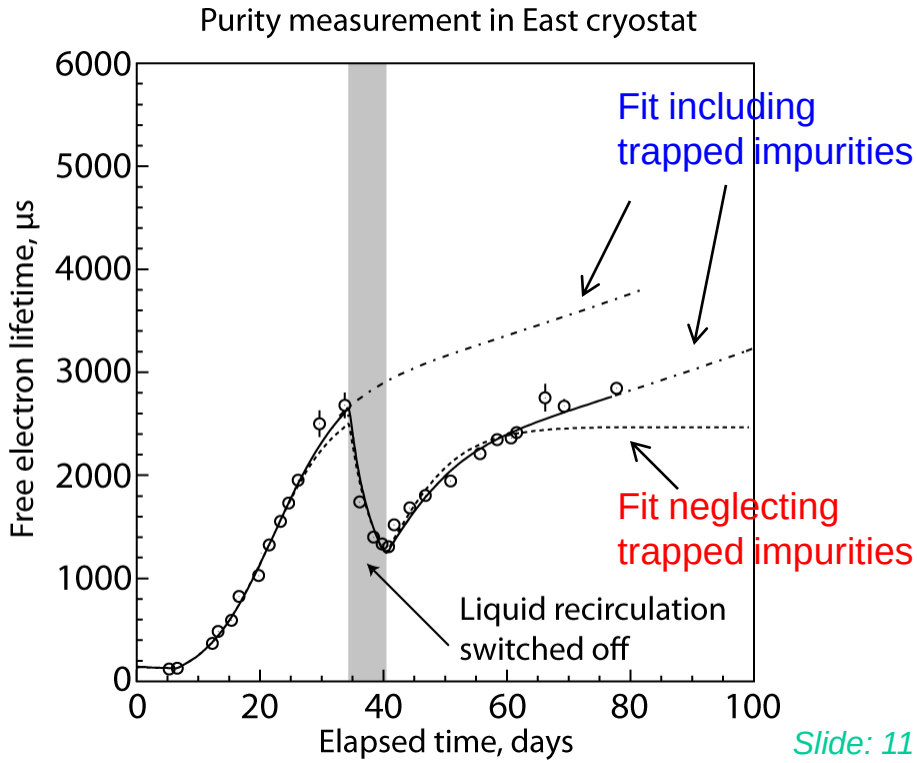
  Recirculation time ~ 6 days, in agreement with the known pump-driven recirculation of ~ 280 m^3 at 2 m^3/h.

  Estimated residual leaks in LAr: < 10 ppt/day O_2 equivalent (~ 3×10^{-3} g/day of O_2)

  Probably some impurities trapped in East cryostat are gradually released and purified.

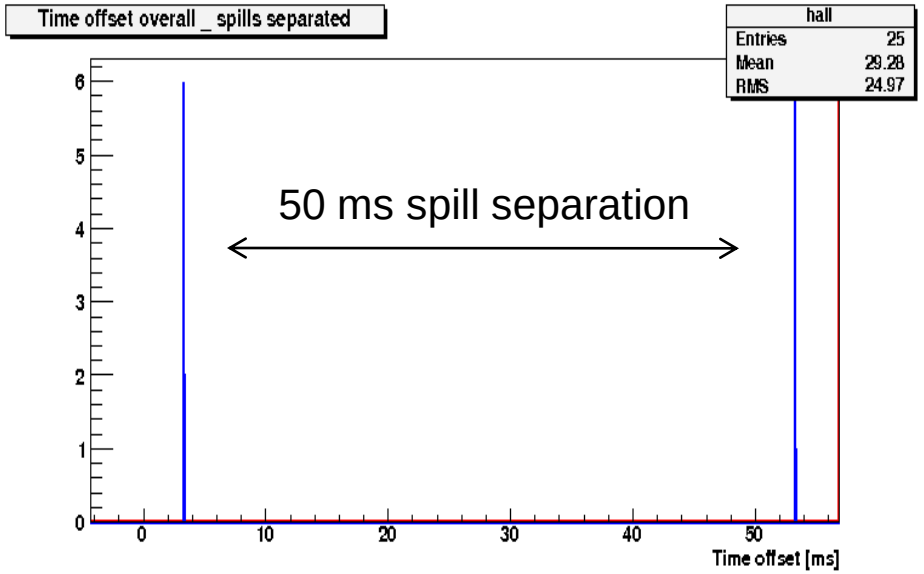
  Estimated equilibrium free electron lifetime higher that 5 ms. Free electron charge attenuations for 1.5 m less then 17%.

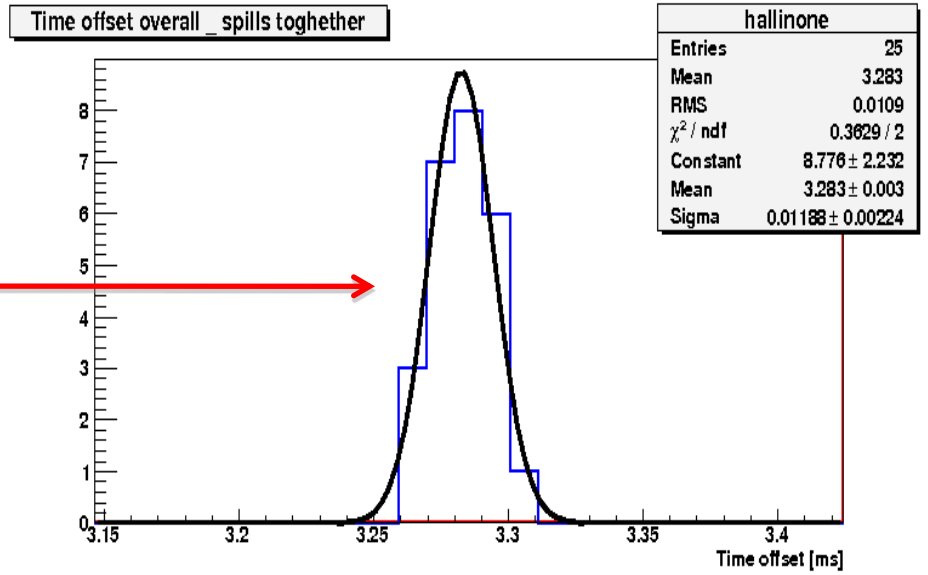




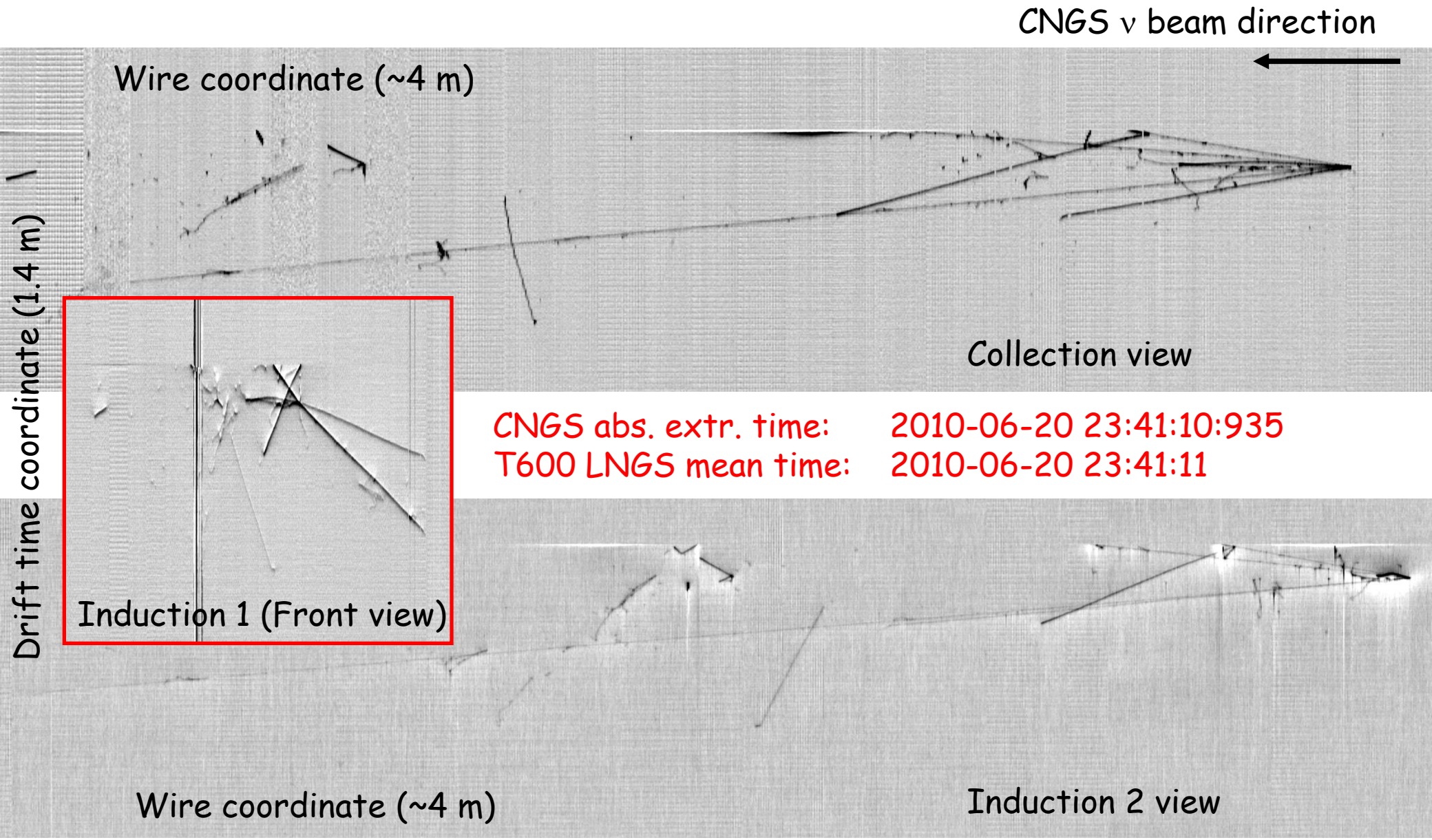
CNGS Gate

- Trigger based on prompt scintillation light in LAr, collected by internal PMT's arrays.
- Absolute time from the LNGS atomic watch included in the trigger system for DAQ synchronization.
- Early warning signal from CNGS correctly decoded and DAQ properly synchronized.
- Events from CNGS tagged with a resolution of 12 μs and synchronization offset measured.
- CNGS gate implementation for specific "CNGS trigger"



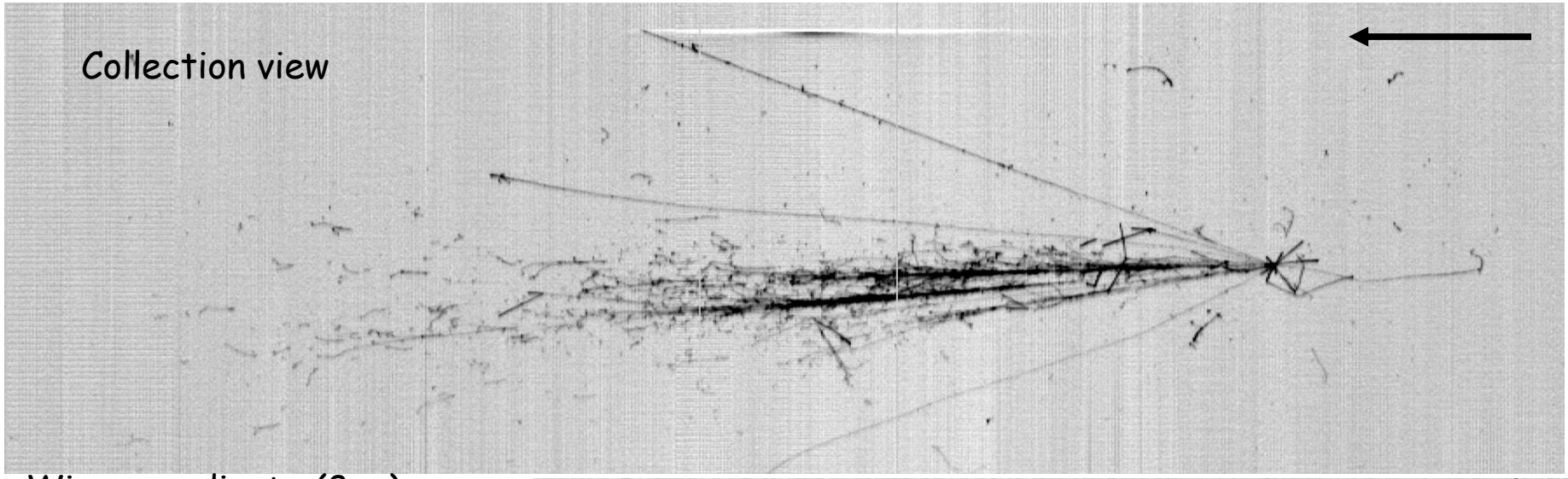


A CNGS neutrino interaction with time coincidence



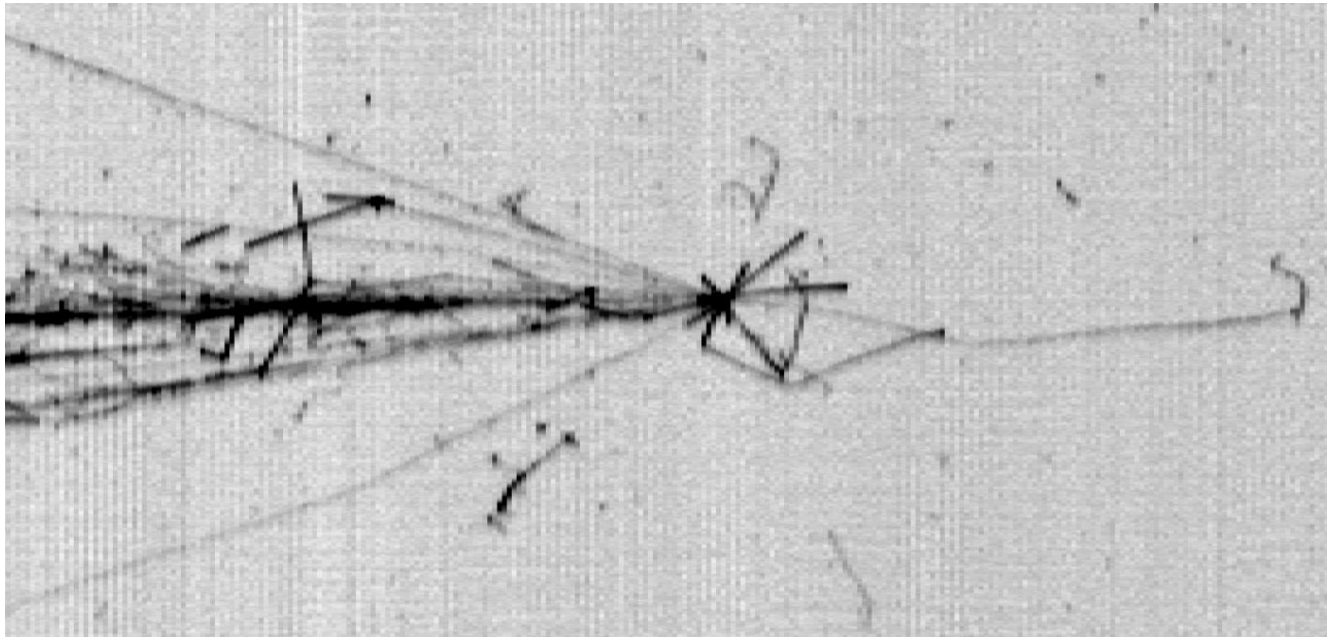
CNGS neutrino interactions in ICARUS T600

CNGS ν beam direction

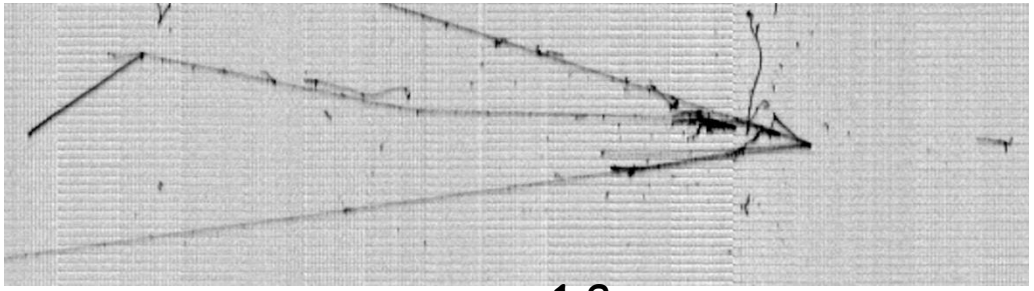


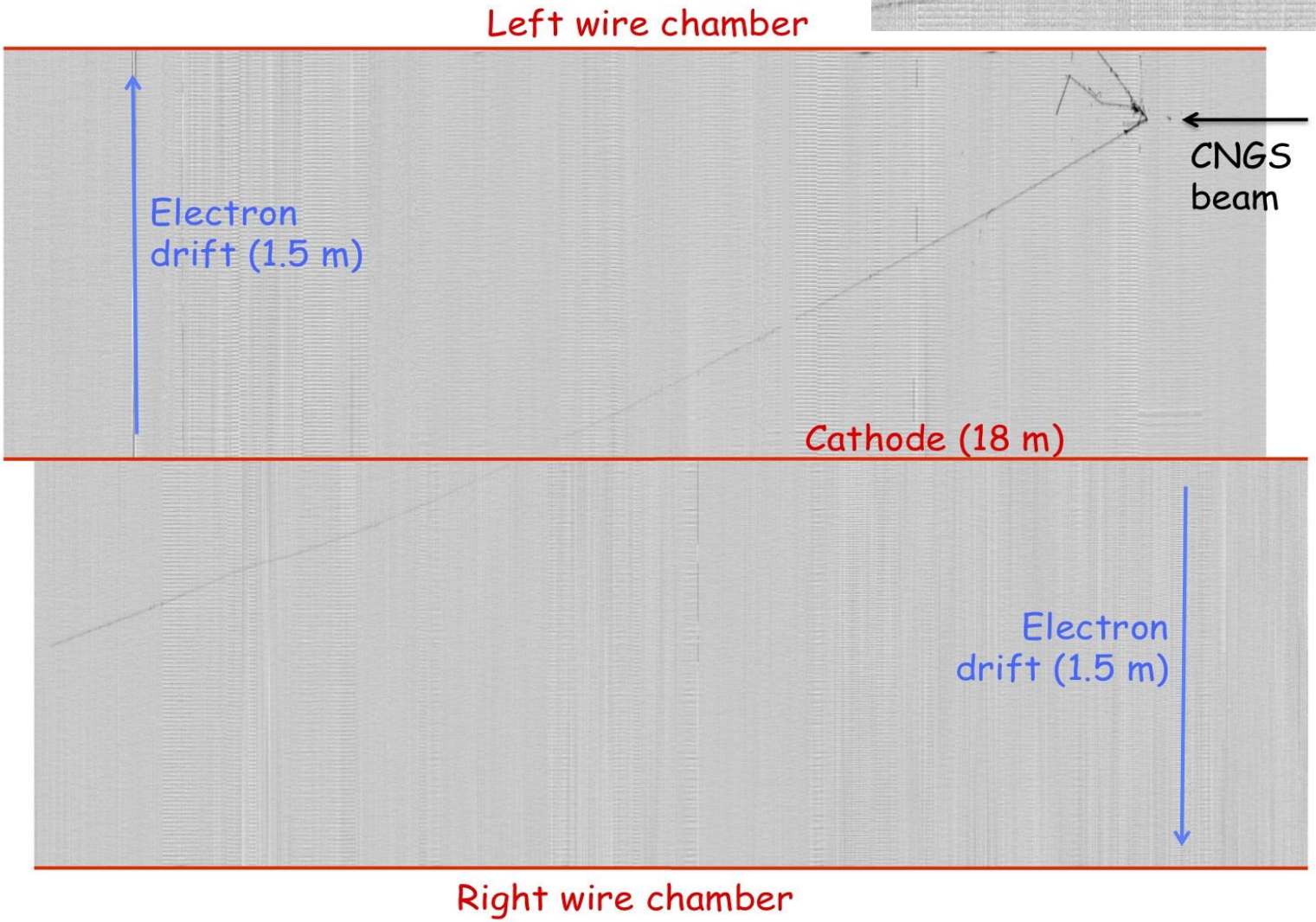
Drift time coordinate (1.4 m)

Wire coordinate (8 m)



Low energy CNGS neutrino interaction

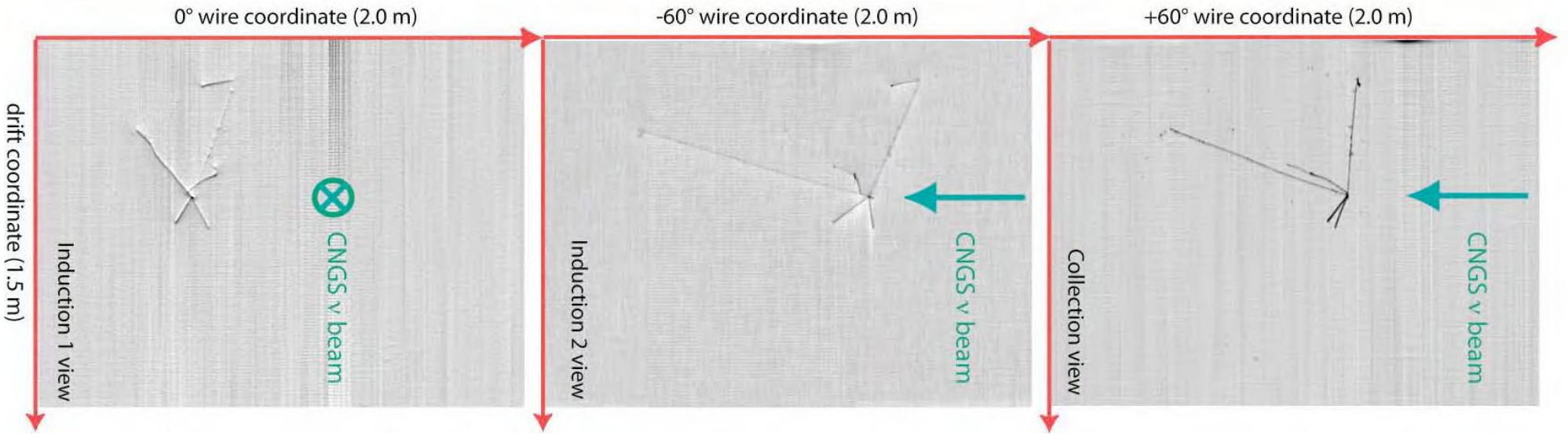




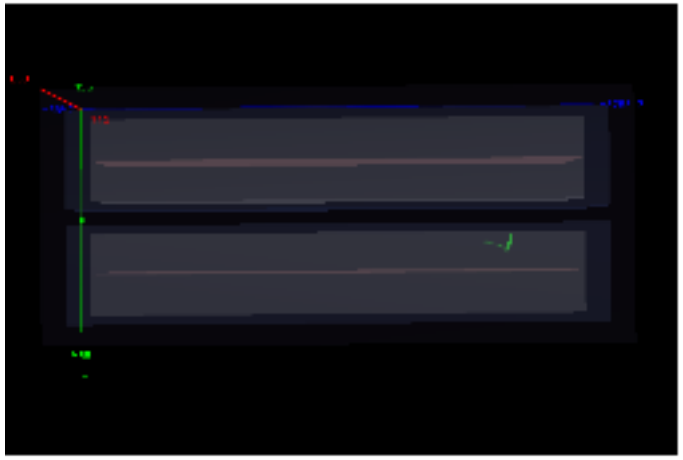
Evis ~ 9 GeV
Electron lifetime
and quenching
accounted for

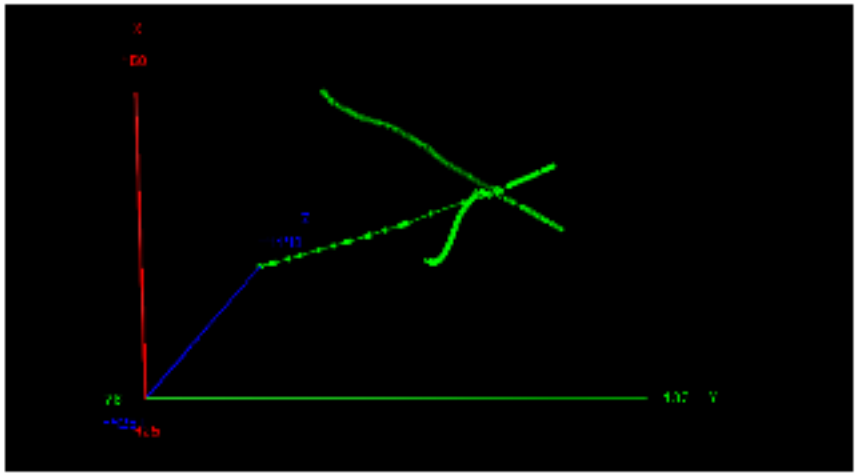
Collection views
(not to scale!)

Very low energy CNGS neutrino interaction



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





ICARUS T600 @ LNGS: Physics potential

- 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:
  - a beam related rate ≈ 1200 ev/year with 90 % efficiency of collection inside raw fiducial volume ≈ 480 t corresponding to ≈ 5000 beam related neutrino events for 18 10^{19} pot.
  - Search for ■ decay with kinematical criteria.
  - Search for sterile neutrinos with deep e-like inelastic CC events in LSND parameter space with equivalent L/E.
- The T600 is also collecting simultaneously "self triggered" events:
  - ≈ 100 ev/year of individually recorded atmospheric CC cosmic rays.
  - Solar neutrino electron rates > 8 MeV.
  - A zero backgr. proton decay with 3 10^{32} nucleons for "exotic" channels.

Thank you !