The ICARUS programme

(a very short overview)

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Restricted ECFA Meeting

1. March 2002

The ICARUS project

- The ICARUS (Imaging Cosmic And Rare Underground Signal) experiment is an international project that takes place at the European Underground Gran Sasso Laboratory
- It consists of the novel liquid argon time projection chamber of a very large (kton) scale used as a particle detector.
- 21 Institutes, ≈100 members
- Supported by Italy (INFN, Major contributor), Switzerland (SNF + ETHZ), USA (DOE), China, Poland and Spain (after 1.4.2002)
- Neither a CERN-approved experiment, nor a CERN-recognized experiment, i.e. *CERN-parasitic experiment*

The ICARUS Collaboration

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Cracow University of Technology, Krakow - Poland

Warsaw University, Warszawa - Poland

UCLA, Los Angeles - USA

IHEP, Academia Sinica, Beijeing - China

Politecnico di Milano - Italy

University of Mining and Metallurgy, Krakow - Poland

Jagellonian University, Krakow - Poland

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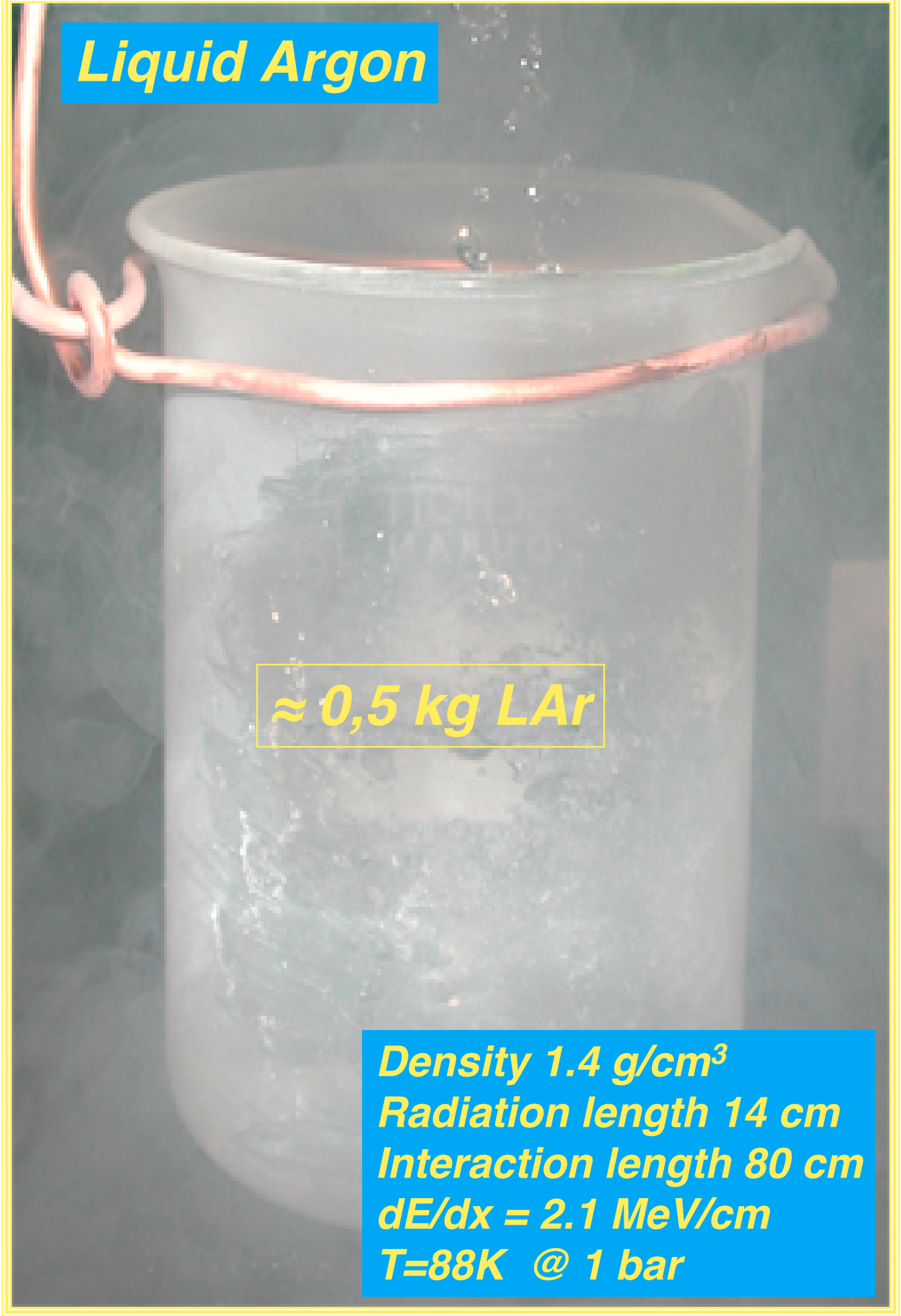
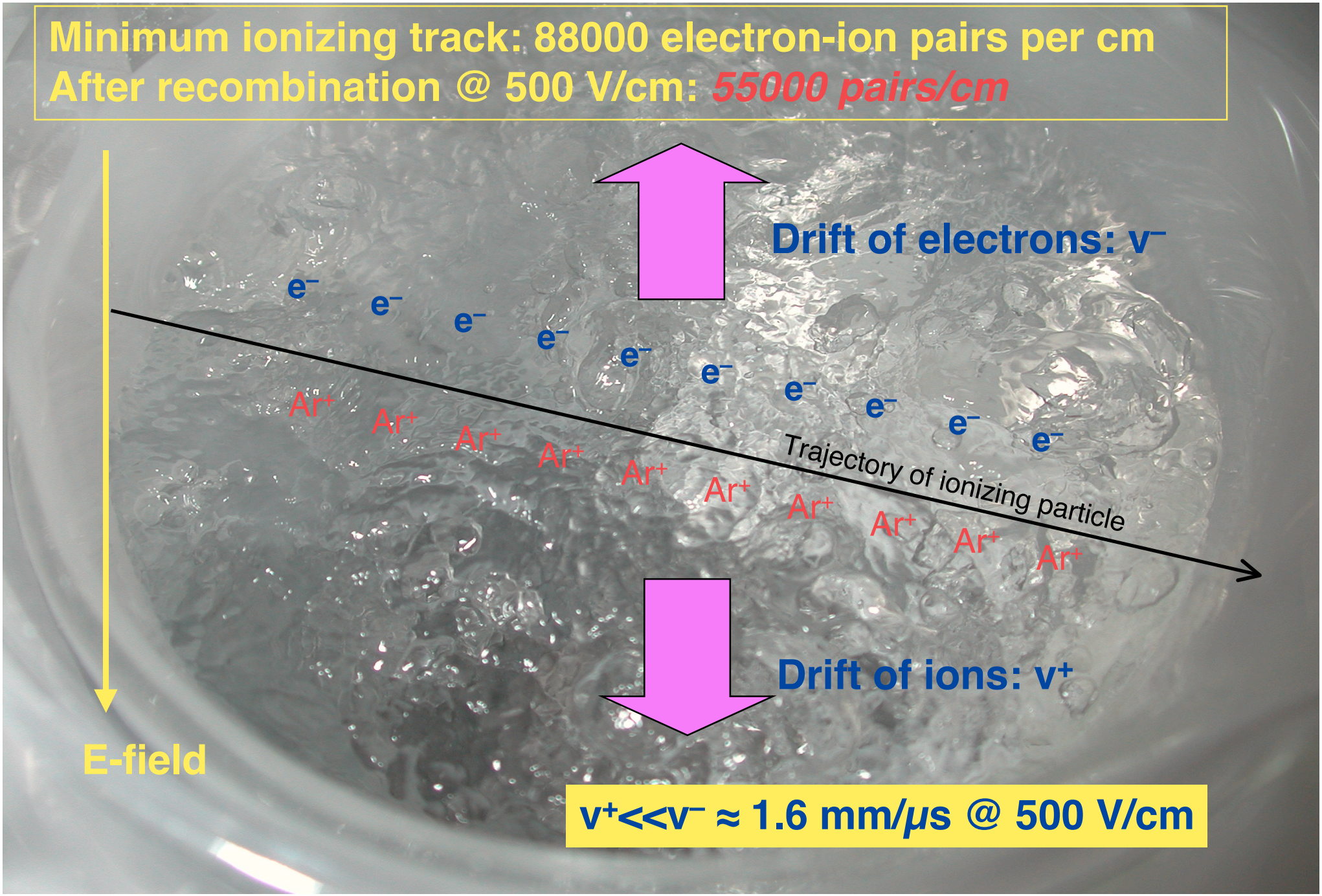
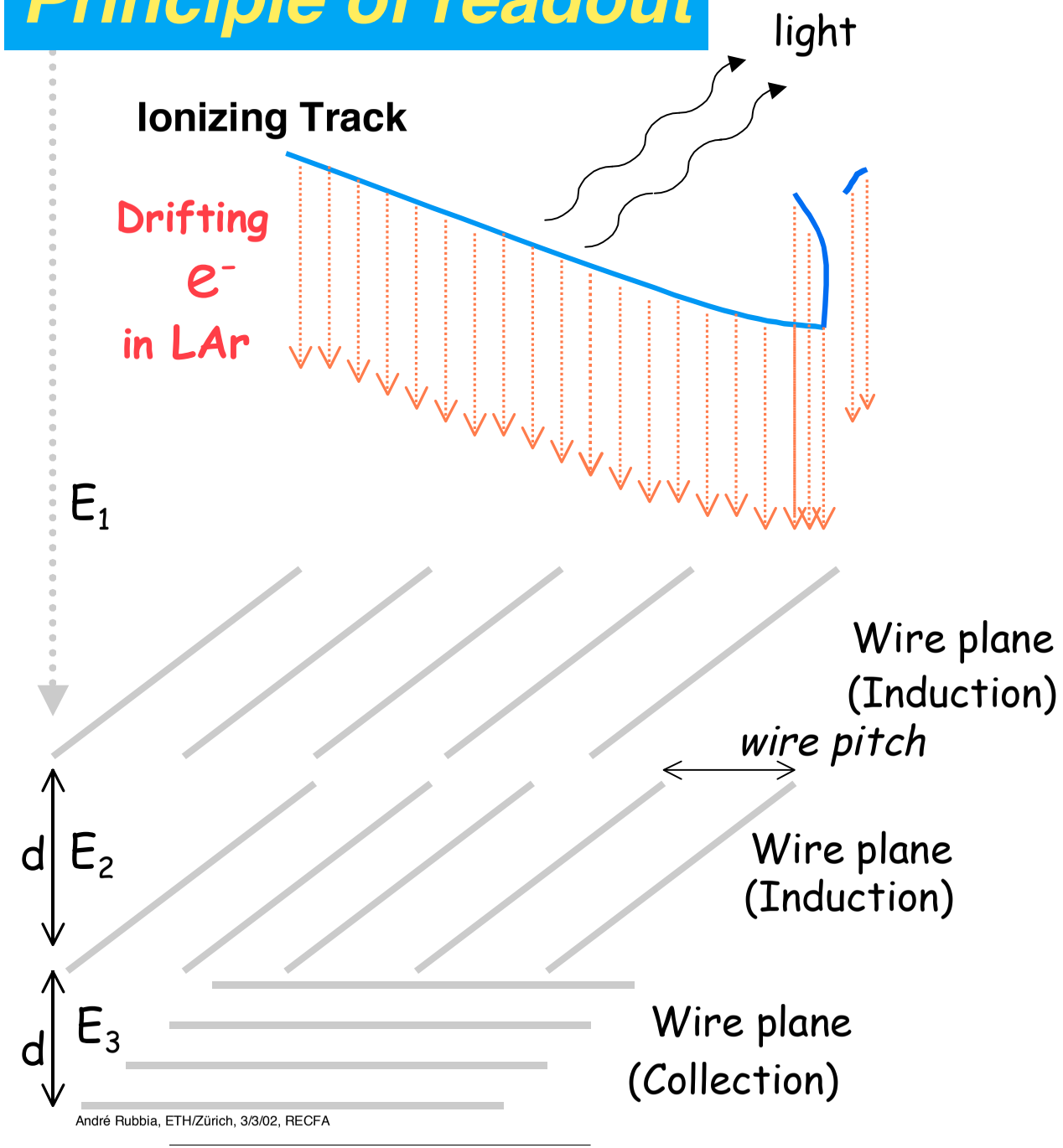
Wroclaw University, Wroclaw - Poland



André Rubbia, ETH/Zürich, 3/3/02, RECFA


Minimum ionizing track: 88000 electron-ion pairs per cm
After recombination @ 500 V/cm: 55000 pairs/cm
Drift of electrons: v⁻
e⁻
Ar⁺
Trajectory of ionizing particle
Drift of ions: v⁺
E-field
v⁺<<v⁻ ≈ 1.6 mm/μs @ 500 V/cm

Principle of readout



✓When charges drift, they induce a signal on the wires

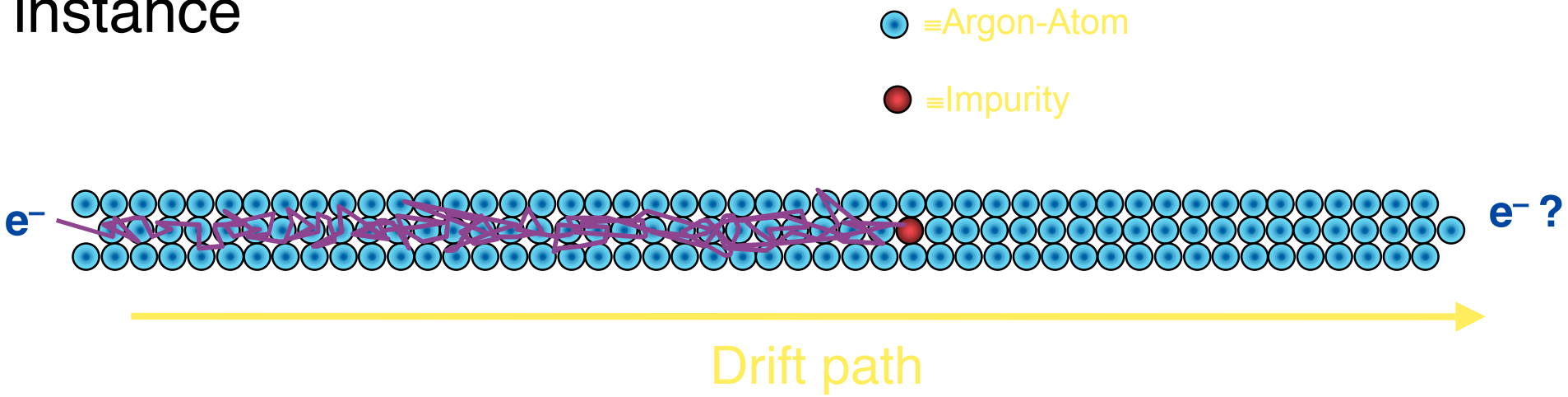
✓Since the mobility of electrons is much higher than that of ions, only electrons contribute to the observed signal.

✓Electrons can drift over macroscopic distances if argon very pure
(e.g. ≈ meter drift requires purity of <1 in 10^{10} atoms)

✓Multiple non-destructing readout wire planes can be assembled for multi-views

Argon purity

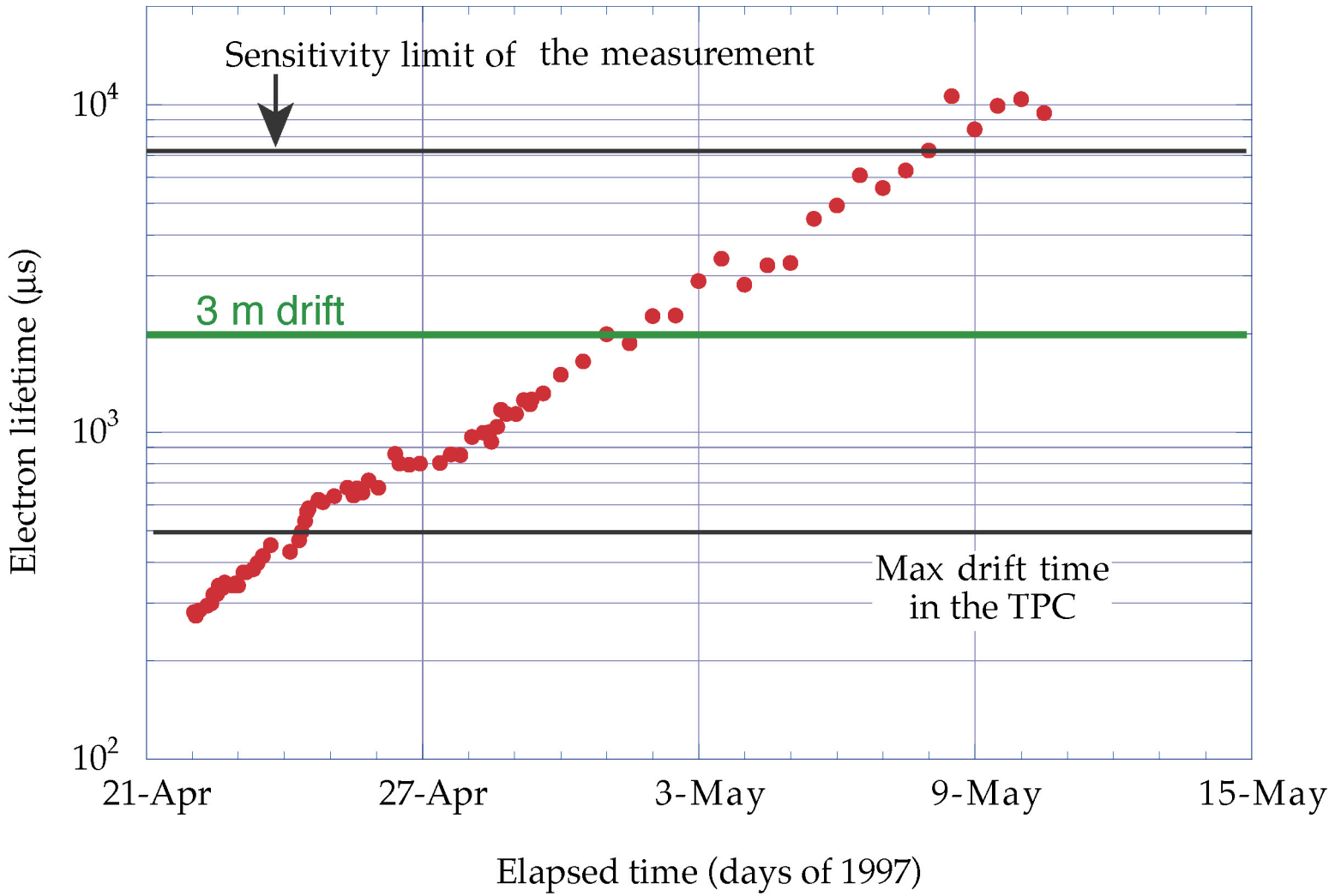
- To drift over long distances, the liquid argon must be very pure.
- Free electrons can attach to impurities like Oxygen for instance



Along its drift the electron must not encounter any impurity...

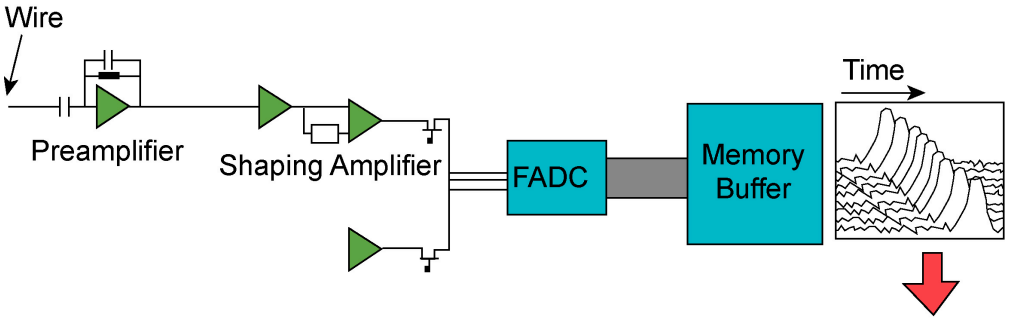
Radius of Atom: ≈2 Angström and driftpath d=2 meters
Electron meets ≈ 10^{10} Atoms ⇒ **<0.1 ppb Oxygen-equivalent**

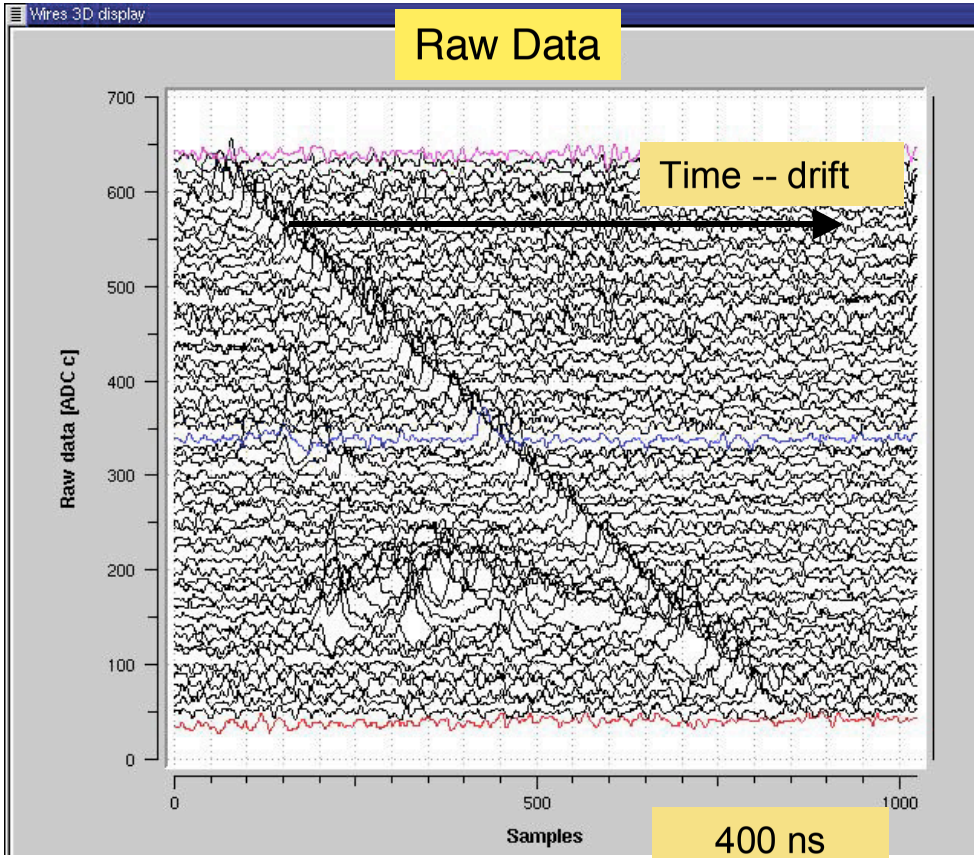
Electrons Lifetime in a 50 litre Prototype

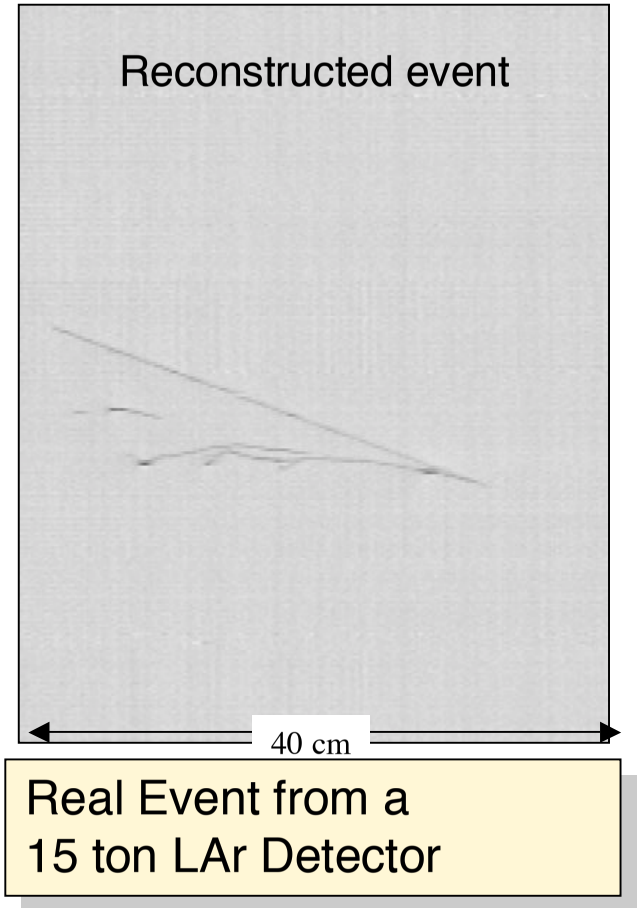


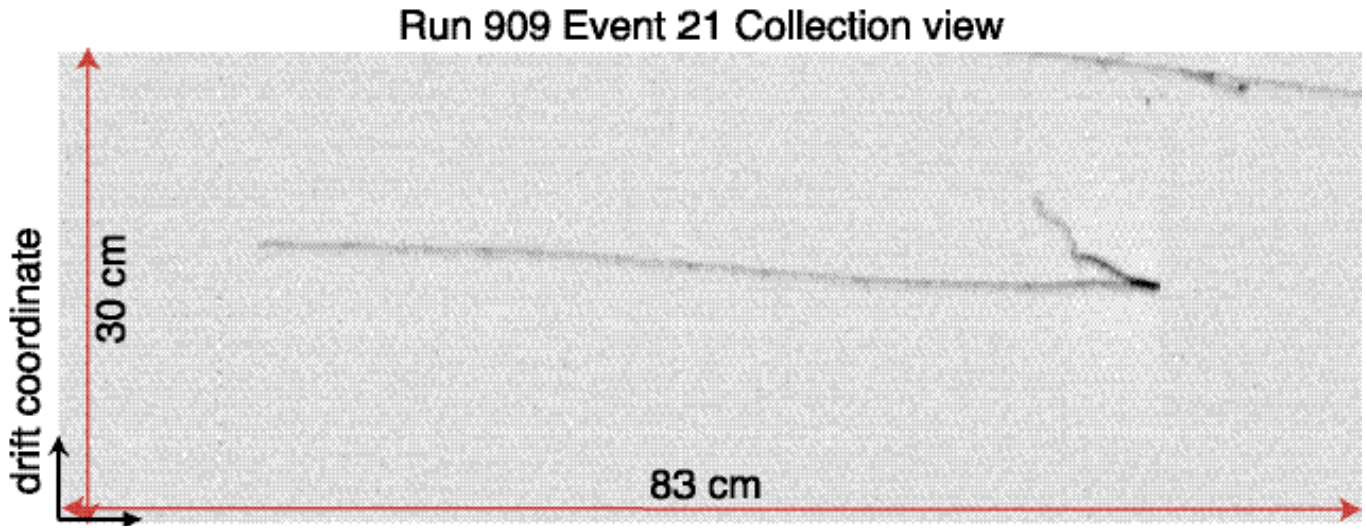
Principle of signal recording

55000 e⁻/cm and no amplification near wires (liquid)
⇒ low-noise electronics
typ. 1000 e⁻ RMS



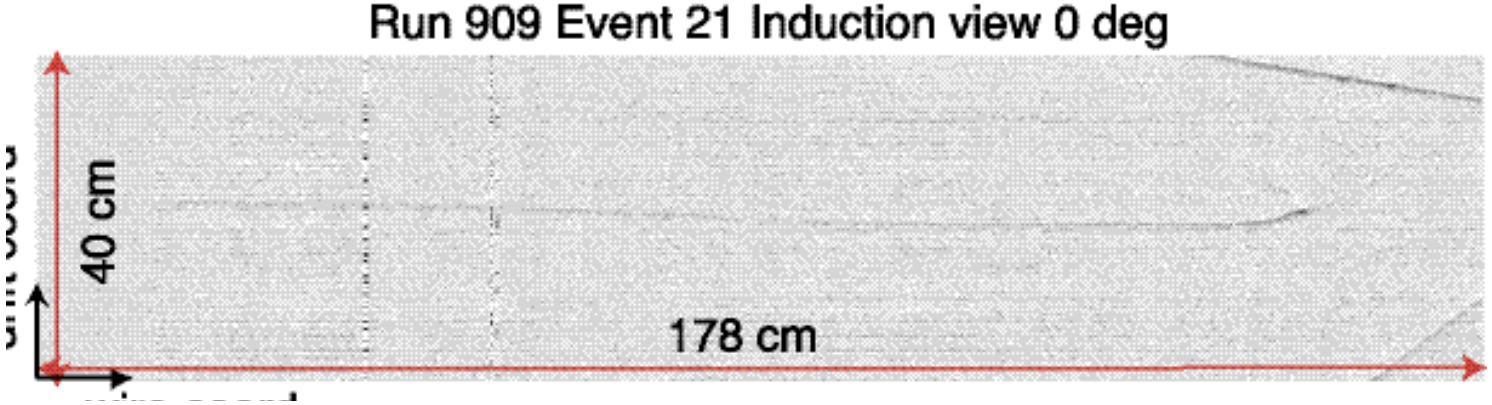




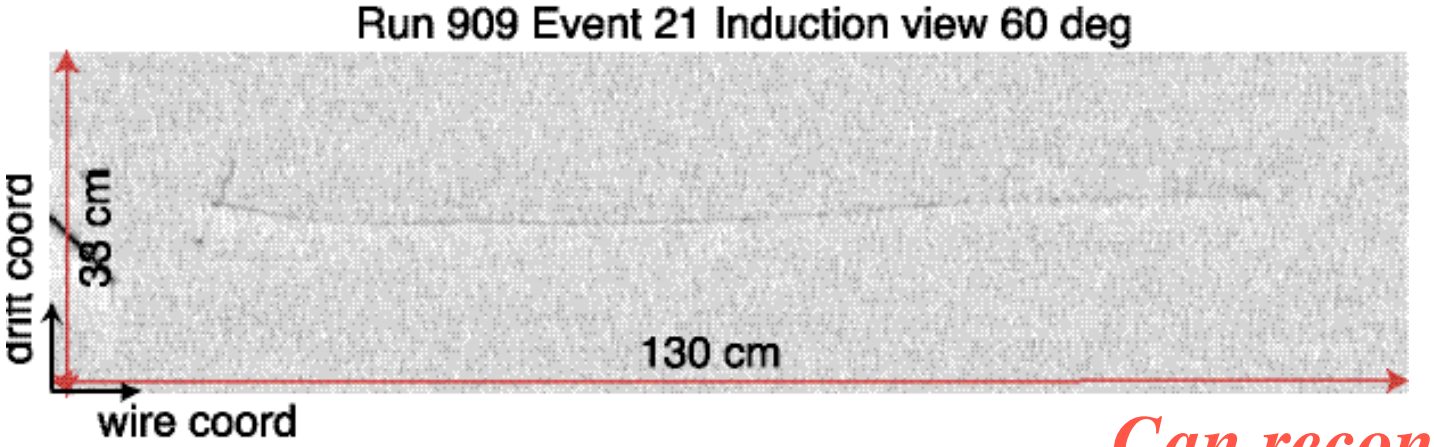


Multiple plane readout

collection



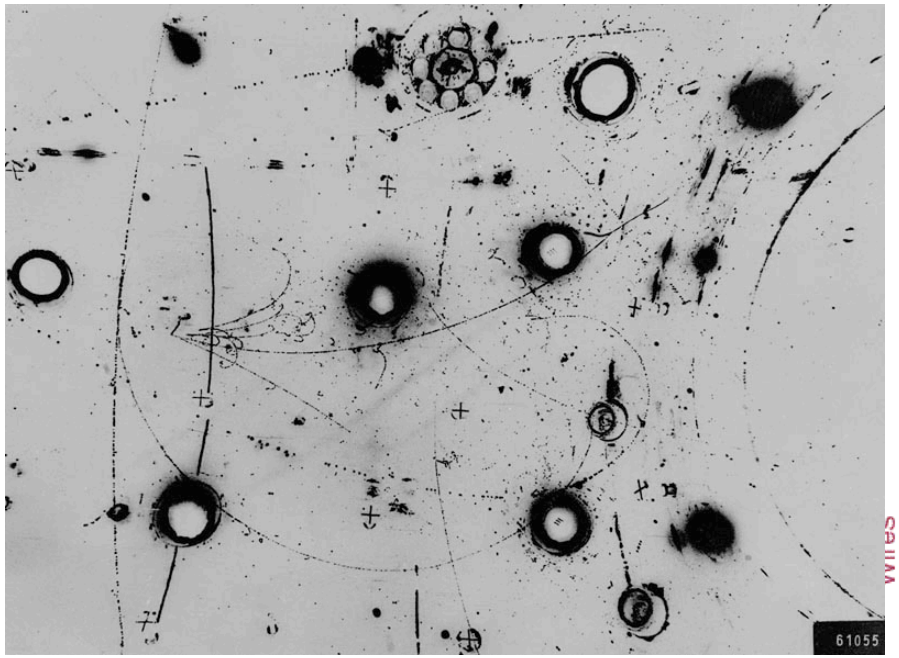
Induction 1



Induction 2

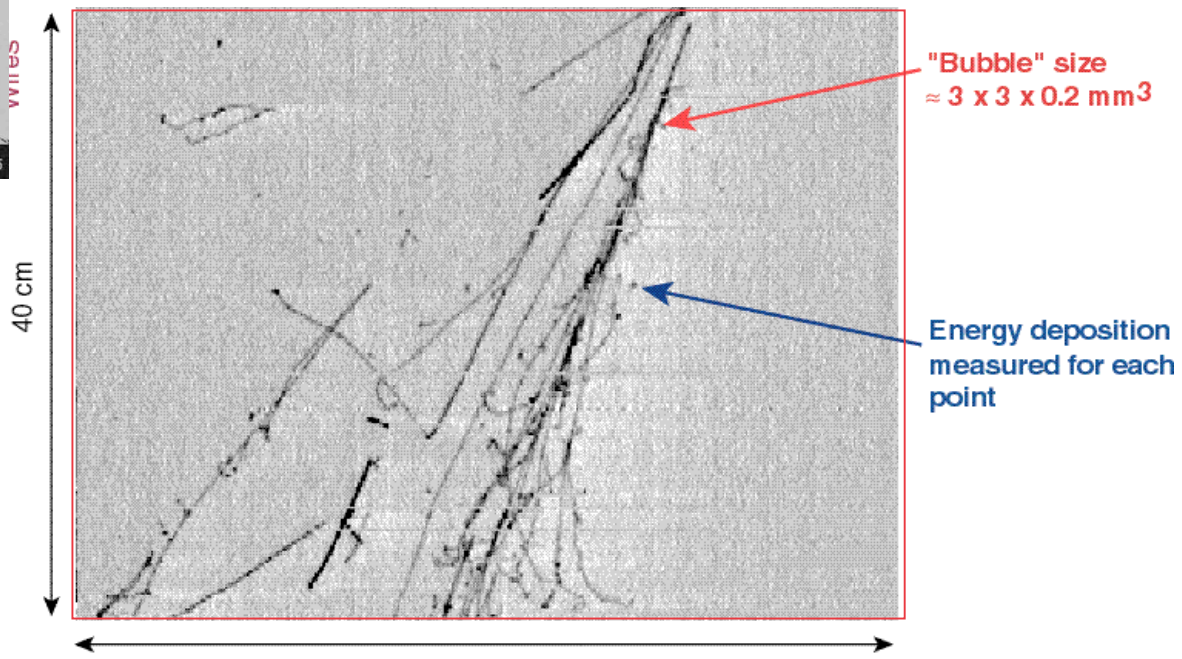
Can reconstruct 3D images !

Electronic bubble chamber



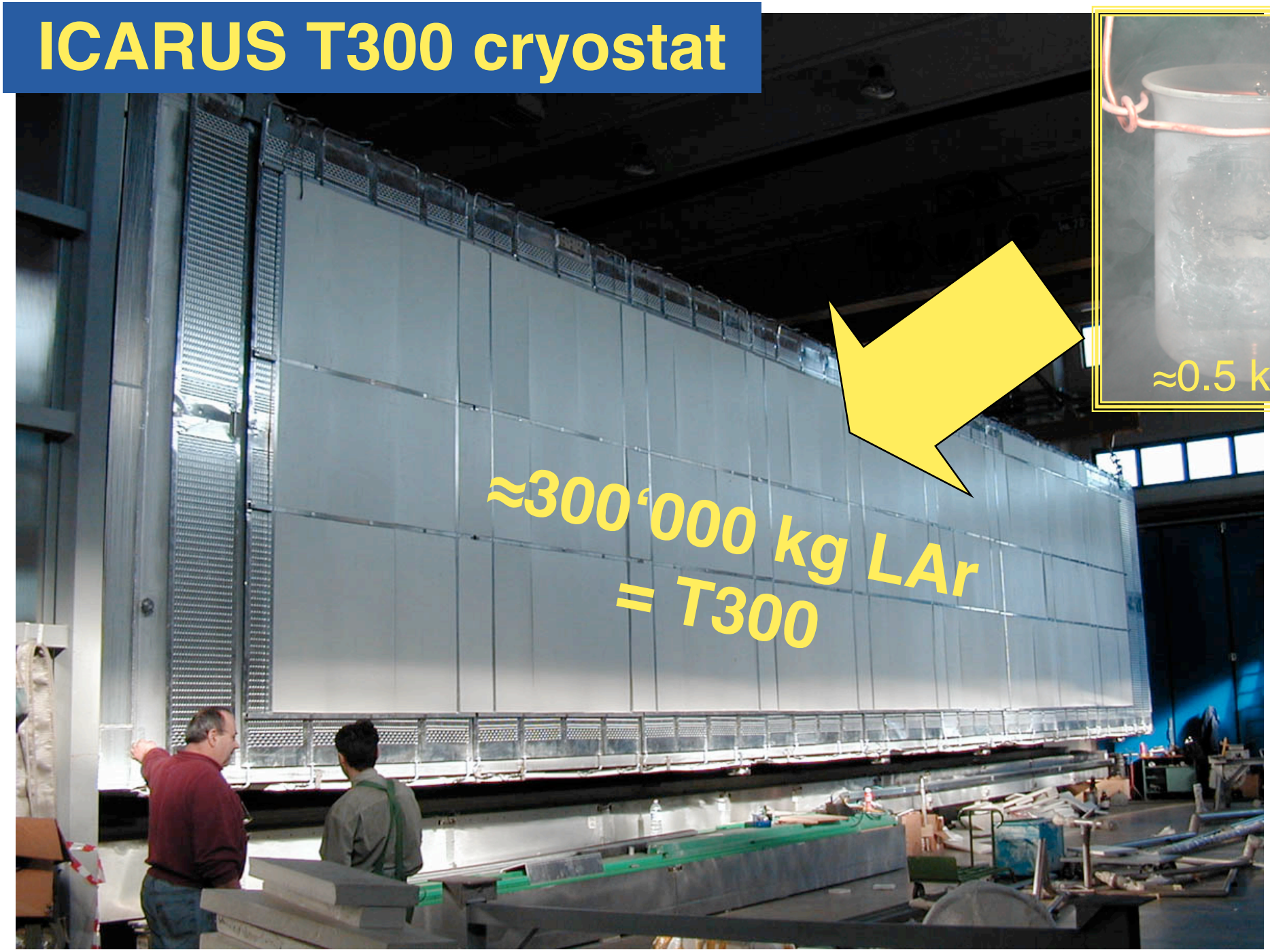
Bubble chamber

Liquid Argon Imaging TPC

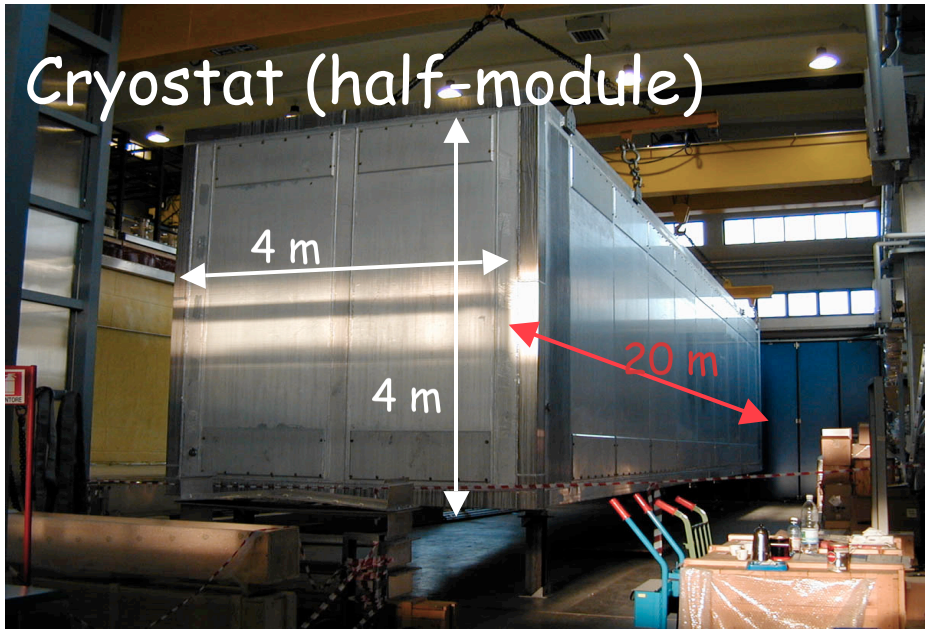


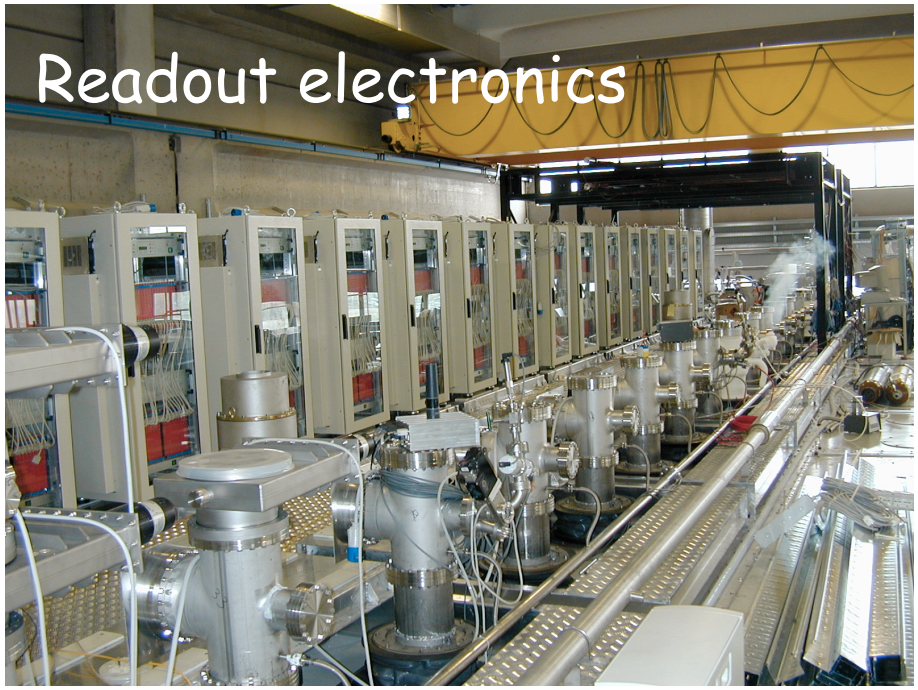
In both cases, medium is used as „target“ and as „detector“

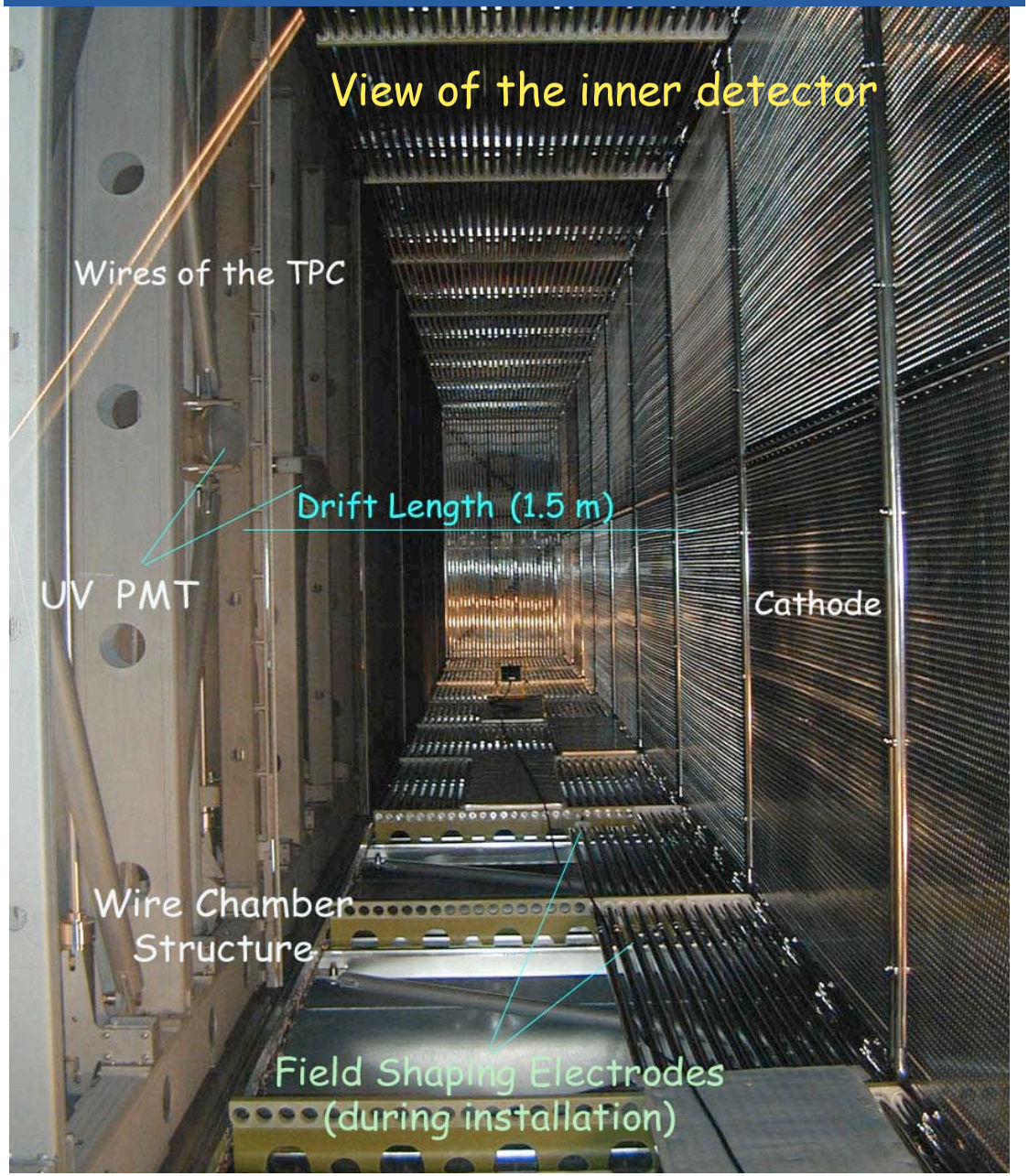
ICARUS T300 cryostat



ICARUS T300 prototype





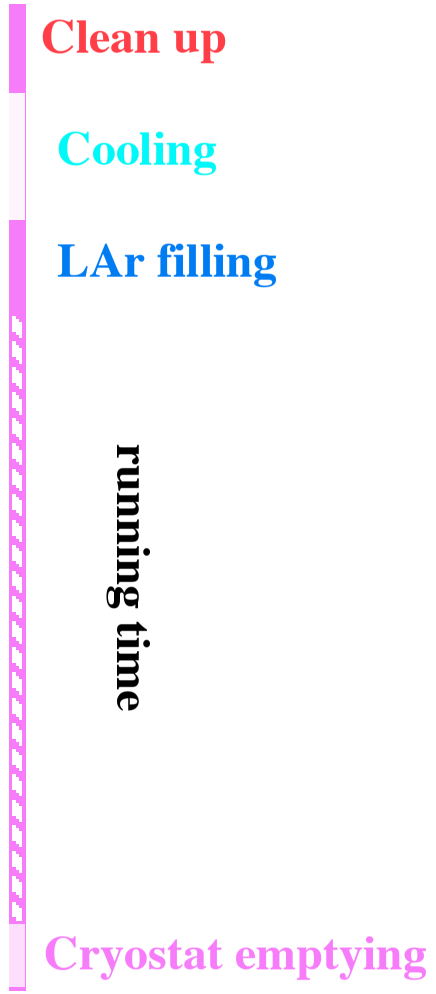


The ICARUS project: summary

- **1985**: first proposal
- **1994**: updated proposal after long R&D
- **1997**: concept of “modularity” ⇒ ***Approval and financing of the first 600 ton detector***
- **Summer 2001**: ***first technical run of 300 ton in Pavia***
- **November 2001**: Proposal to “clone” 1200 ton modules (T1200) to extend liquid argon to reach design mass (2005-2006 ⇒ 3000 tons)
- **March 2002**: ***Allocation of entire LNGS Hall B for ICARUS***
- **2002**: Continue planning for installation of 600 ton to LNGS (installation plan, safety aspects, power consumption, etc…) includes pre-project for successive T1200 modules.

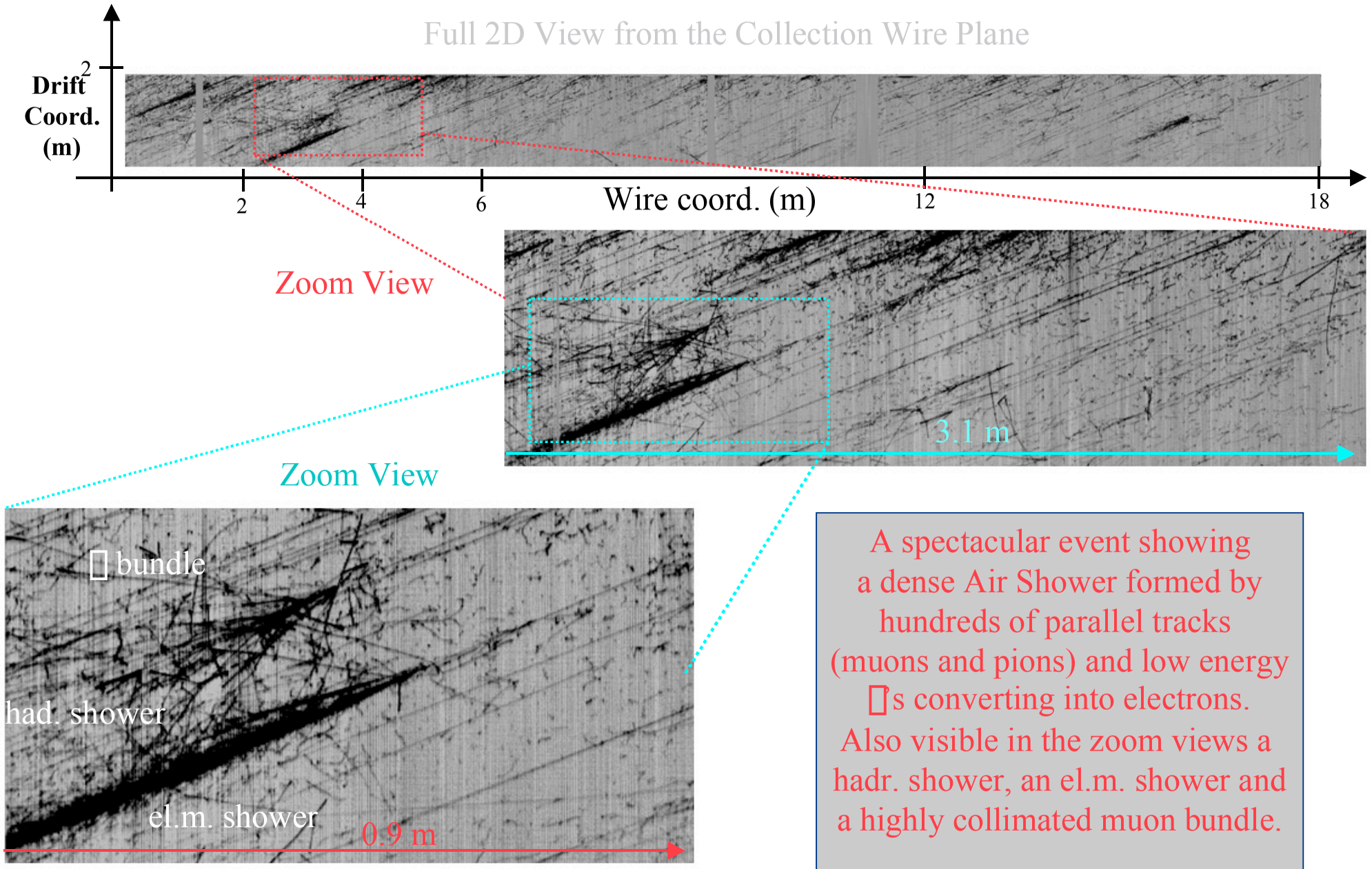
T600 half-module technical run (2001)

- Clean up (vacuum): 10 days
  - 7 days to find and recover the leaks
  - 3 days to reach 10^{-4} mbar
- Cooling: 14 days
  - 11 days for pre-cooling (down to -50 °C)
  - 3 days to reach -178 °C
- LAr filling: 10 days
- True running time: 68 days
- Cryostat emptying: 7 days



Tot. 109 days

Detector has been carefully monitored during all phases of running and demonstrated to behave as expected !



A spectacular event showing a dense Air Shower formed by hundreds of parallel tracks (muons and pions) and low energy s converting into electrons. Also visible in the zoom views a hadr. shower, an el.m. shower and a highly collimated muon bundle.

T600 test @ Pv: Run 308 - Evt 4 (July 2nd, 2001)

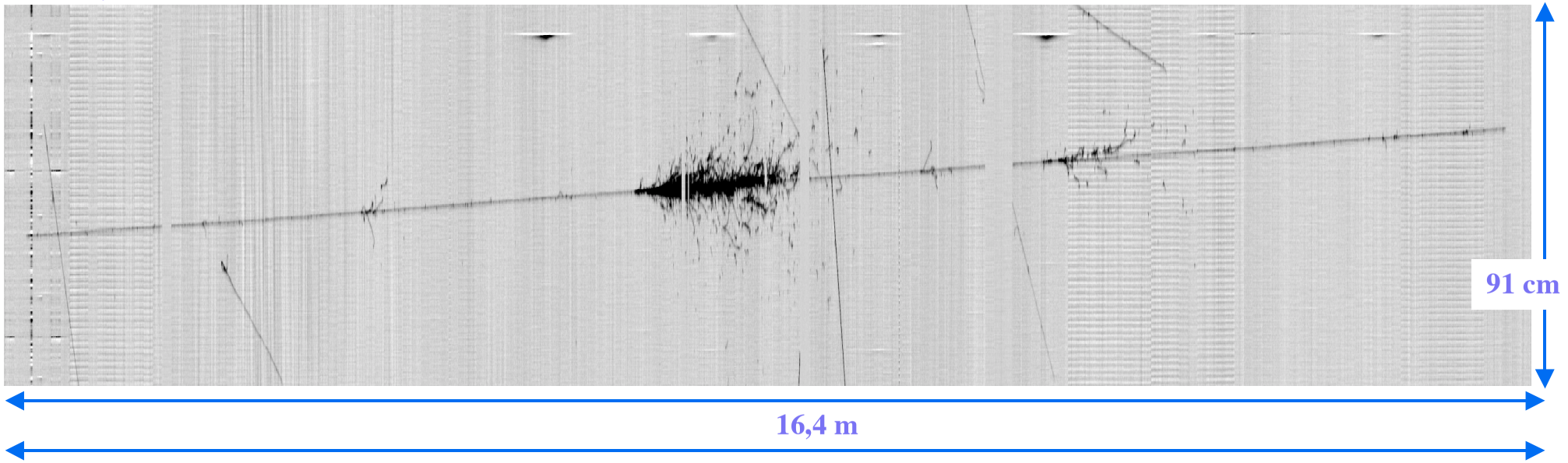
Event scanning

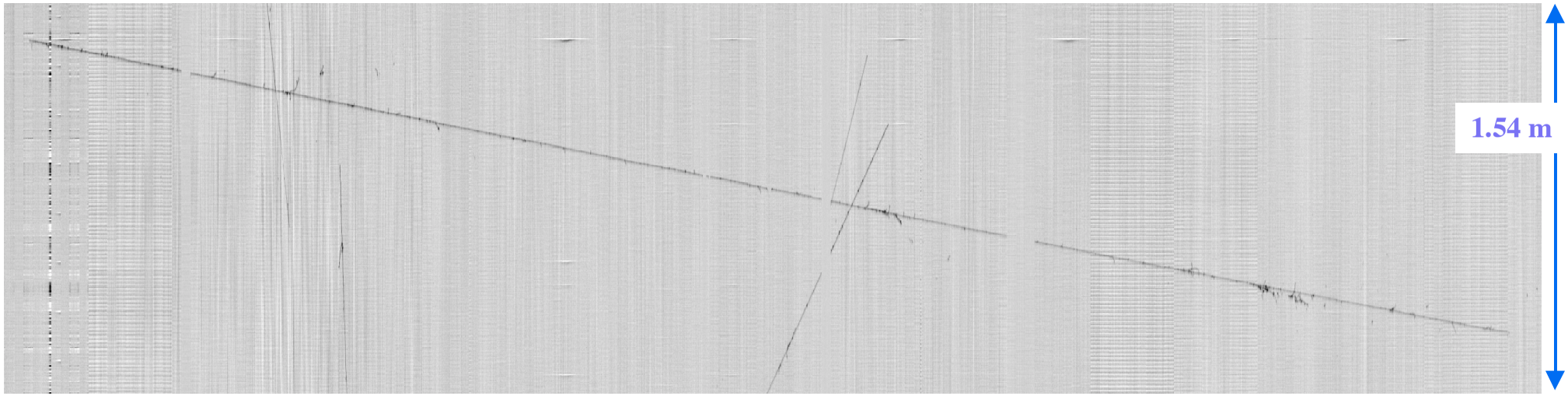
So far 38 Runs, ≈1700 events out of ≈28000 triggers

Visual scanning results (20/Feb)	
Shower	512
Muon decay/stopping	865
Hadron interaction	411
V_0	27
Long track	174
Muon bremstrahlung	656
Multiple showers	367
Multiple muons	33

Long tracks + bremsstrahlung

Run 975, Event 93 Collection Left

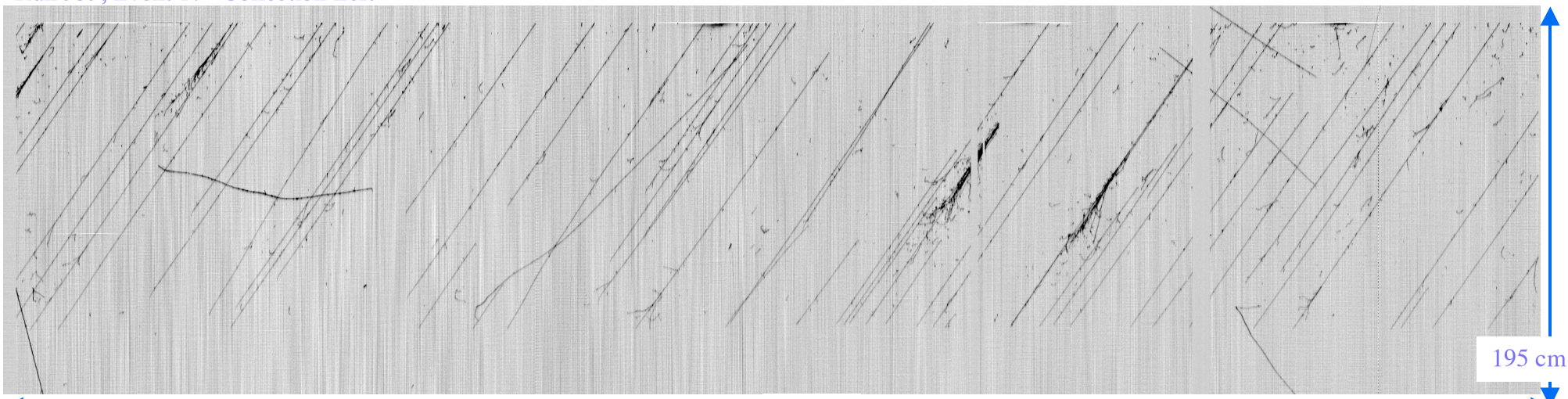




Run 975, Event 140 Collection Left

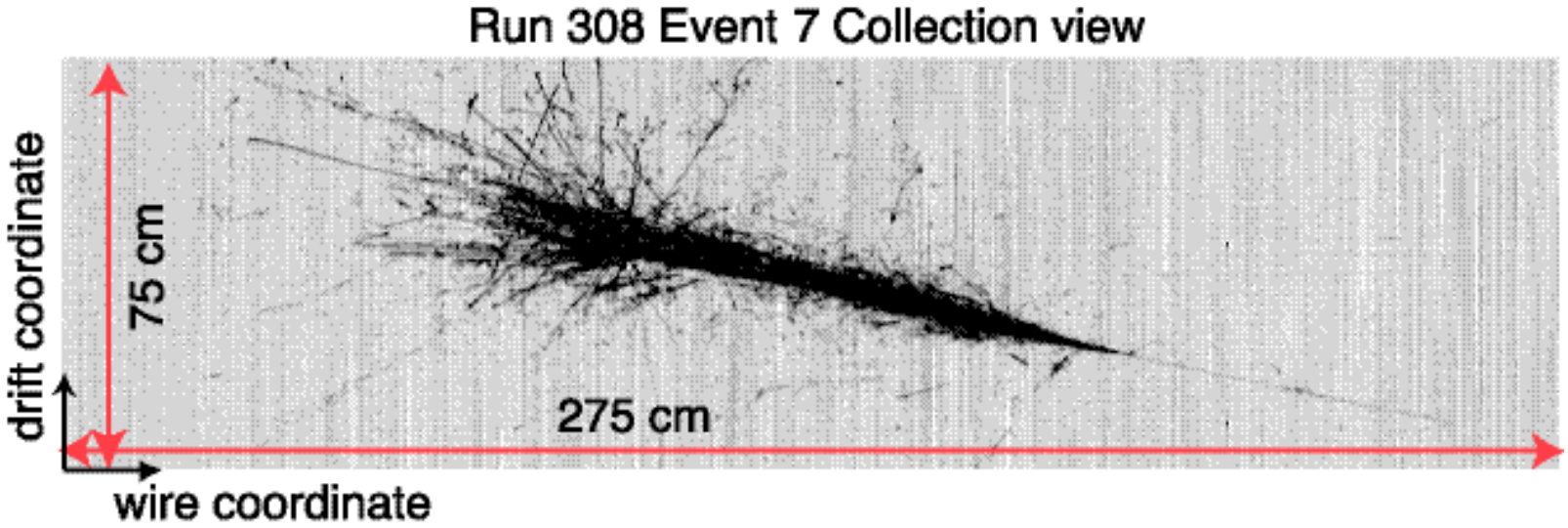
Parallel muon + bremsstrahlung. Long track + bremsstrahlung

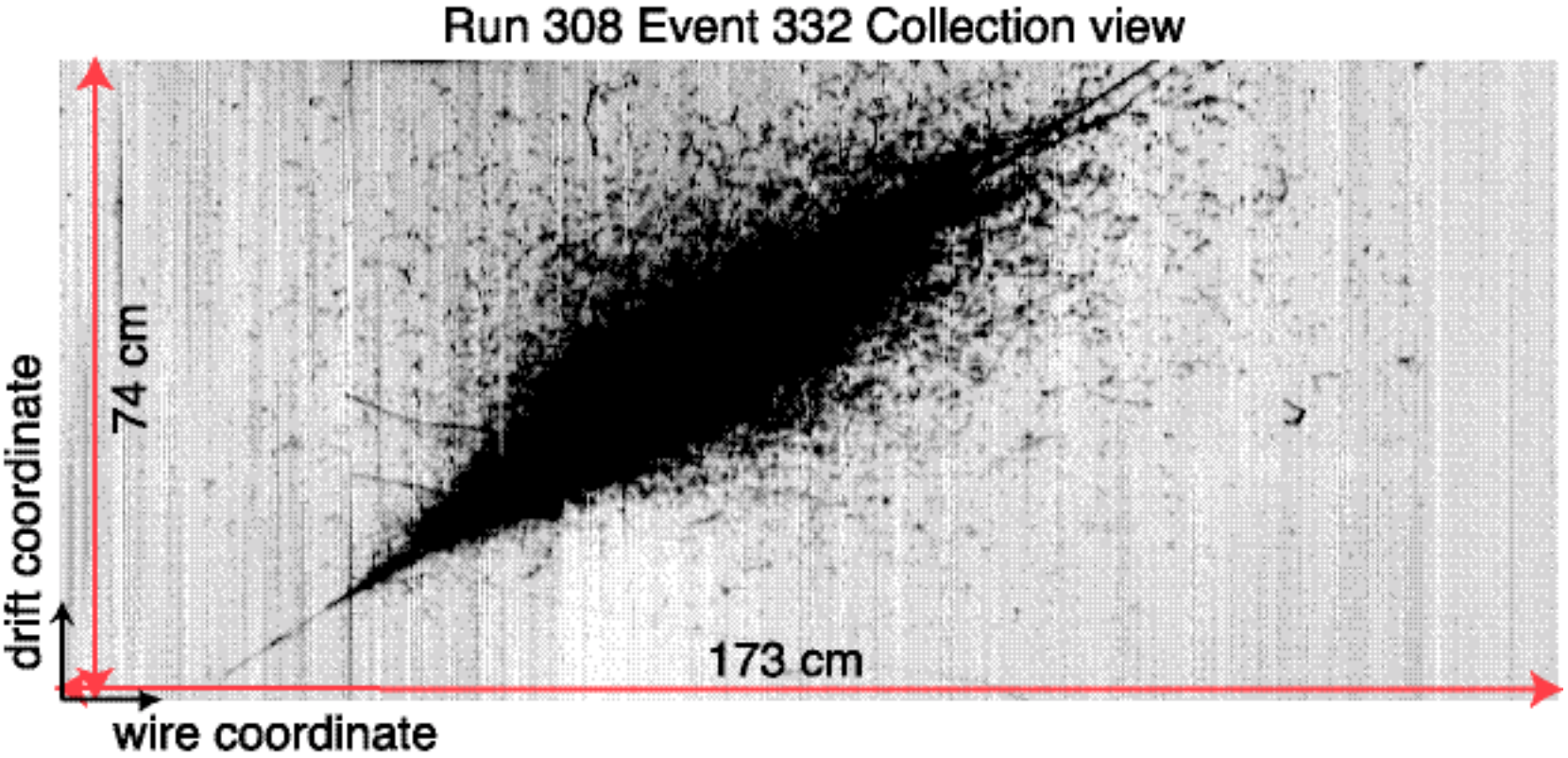
Run 959, Event 17 Collection Left



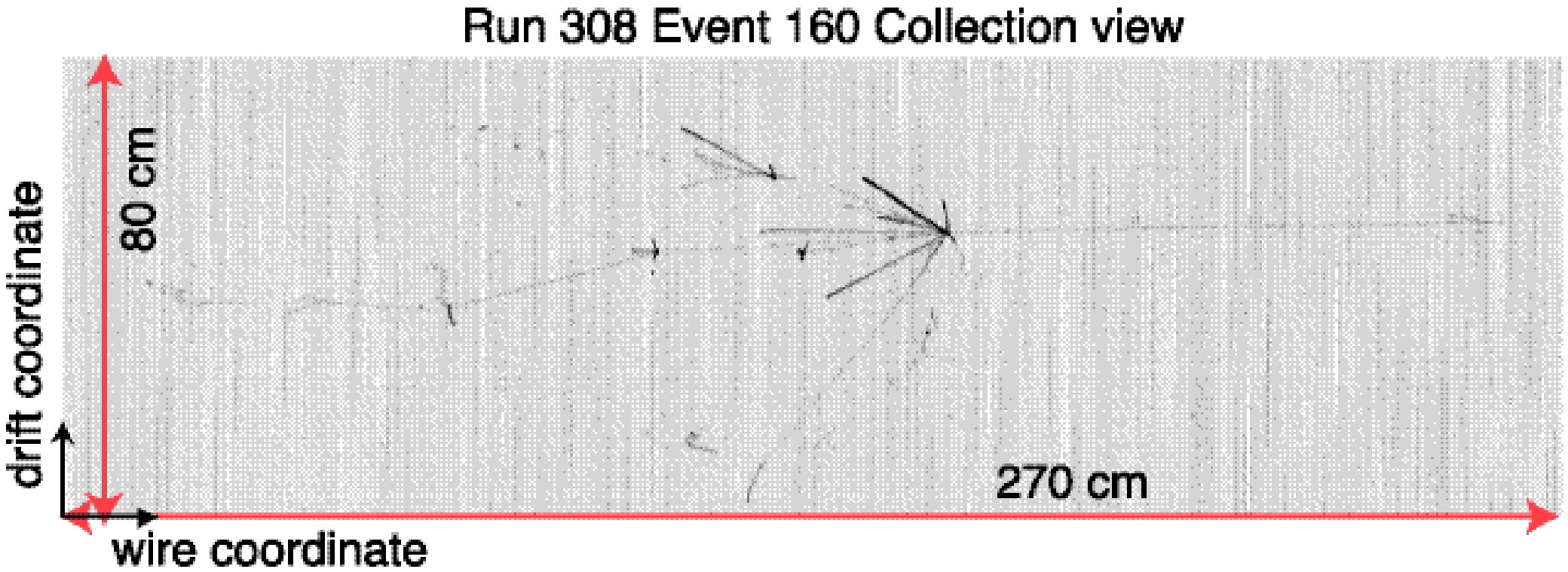
Run 975, Event 61 Collection Left

Showers

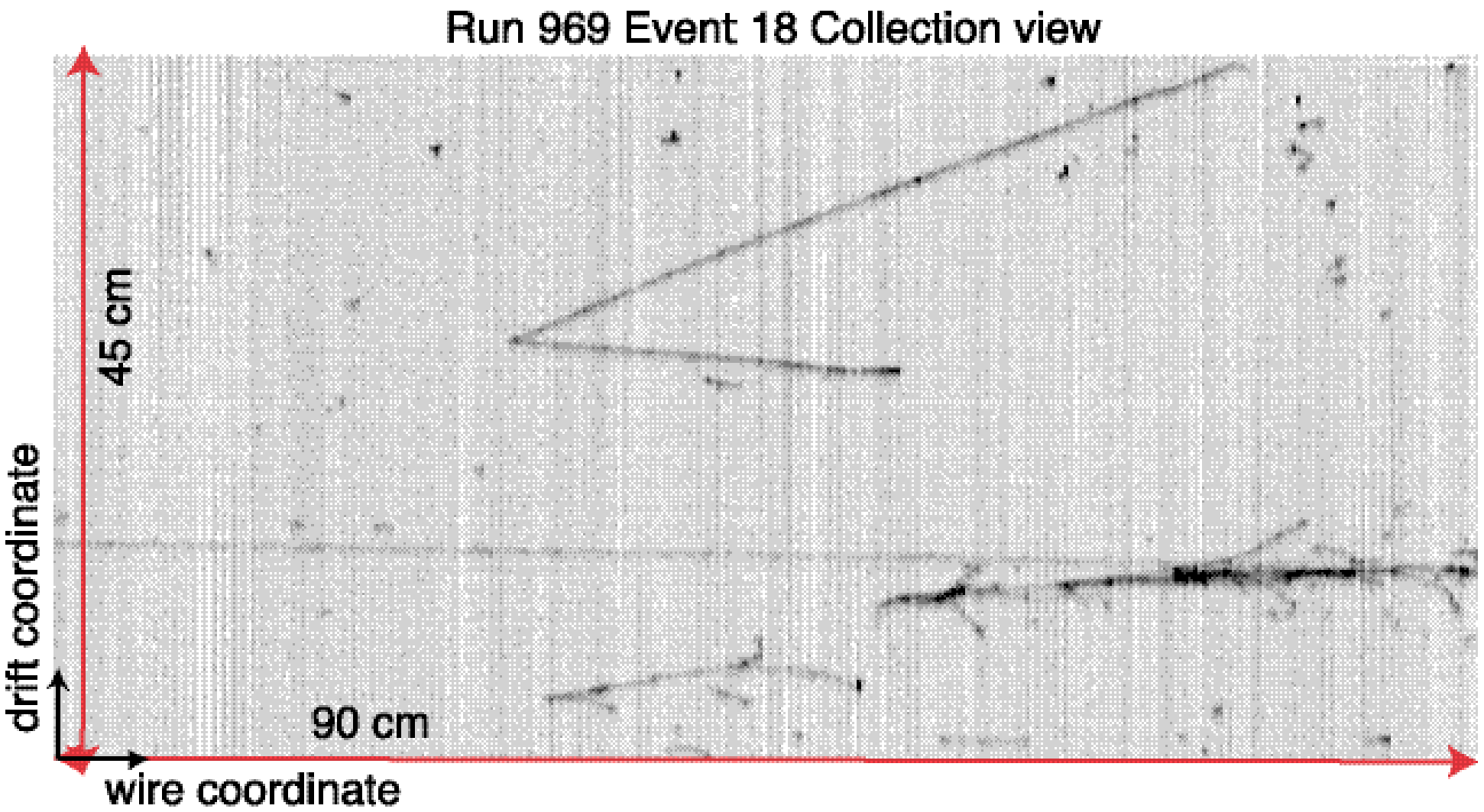

Run 308 Event 7 Collection view
drift coordinate
75 cm
275 cm
wire coordinate


Run 308 Event 332 Collection view
drift coordinate
74 cm
173 cm
wire coordinate

Hadron interaction



V0 candidate



ICARUS T600 prototype

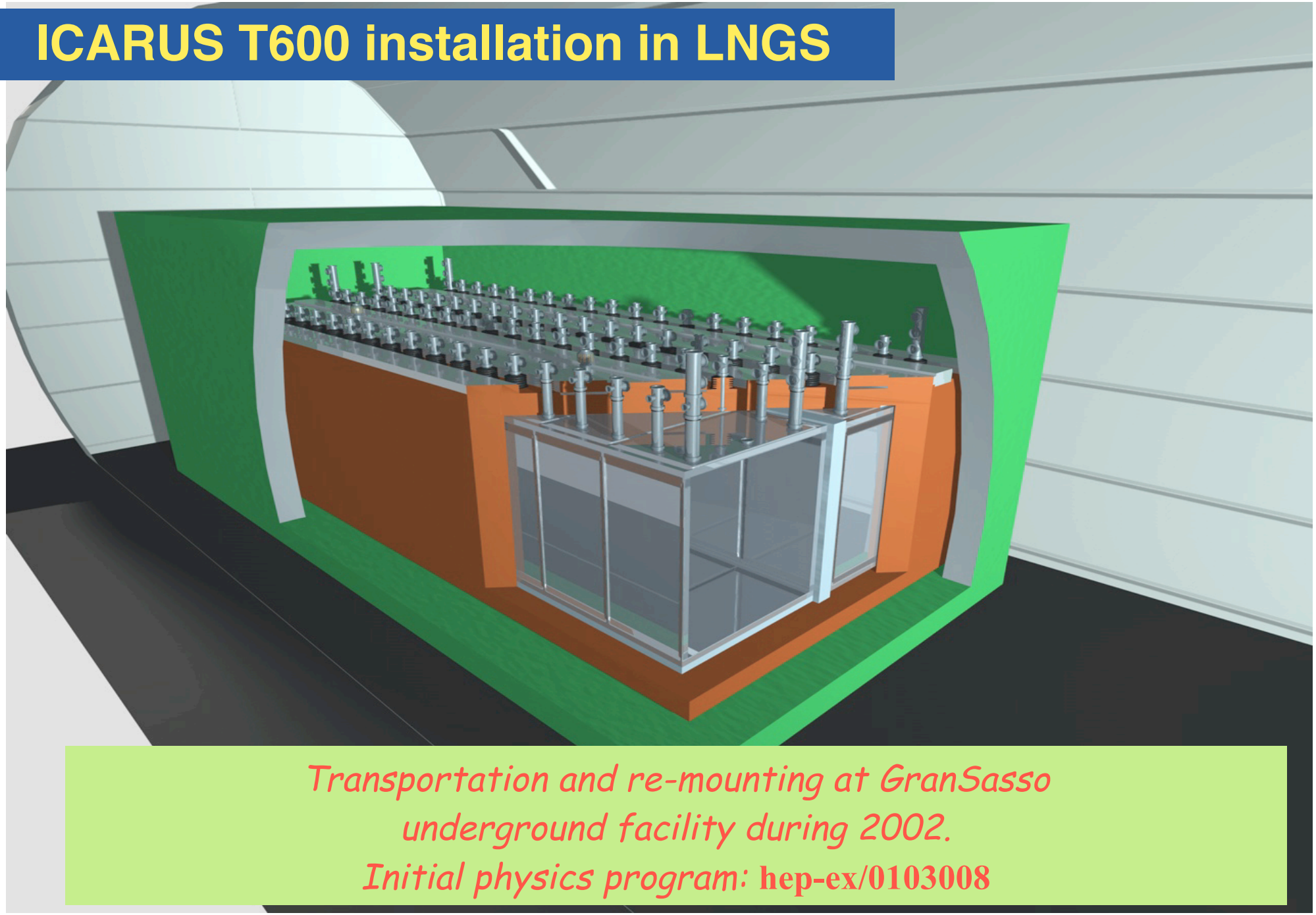
The developed technology allows (relatively) easy transportability

The *ICARUS T600* module (cryostat & internal detector) can be fully assembled and then shipped to the defined experimental beam site

Ext. insulation, Electronic & DAQ installation

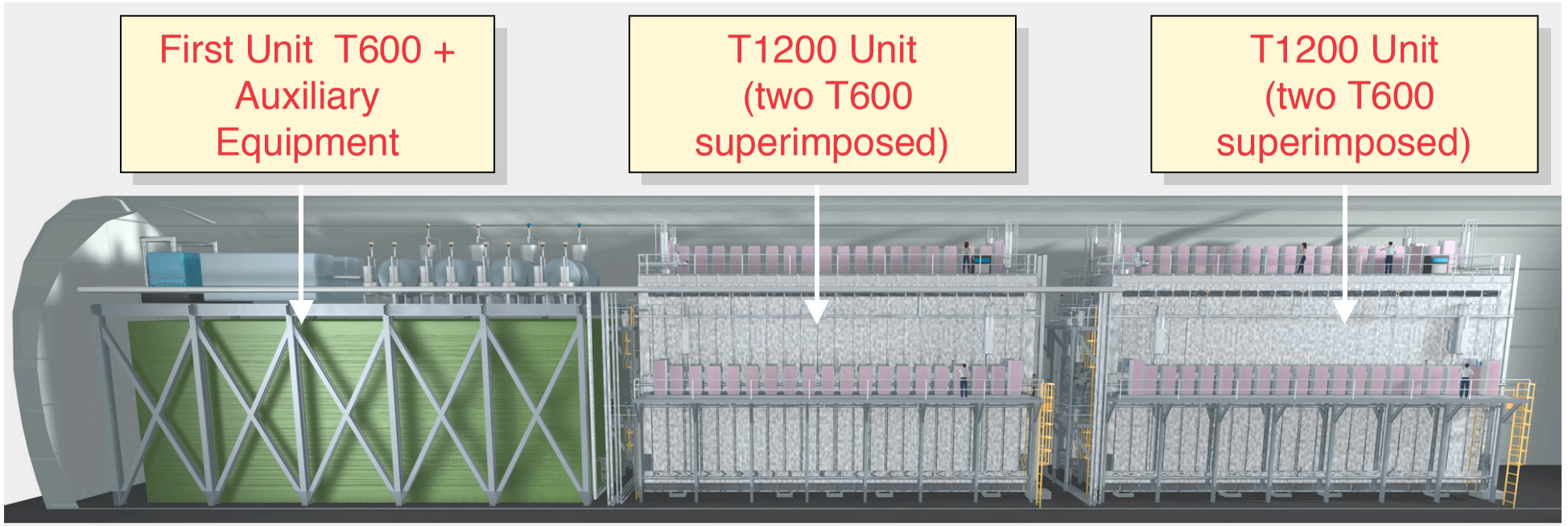
LAr filling, RUN

ICARUS T600 installation in LNGS



Transportation and re-mounting at GranSasso underground facility during 2002.
Initial physics program: **hep-ex/0103008**

T3000 Detector in Hall B of LNGS (cloning of T600)



T600: installed in LNGS early 2003

T3000: operational by summer 2005

The ICARUS physics

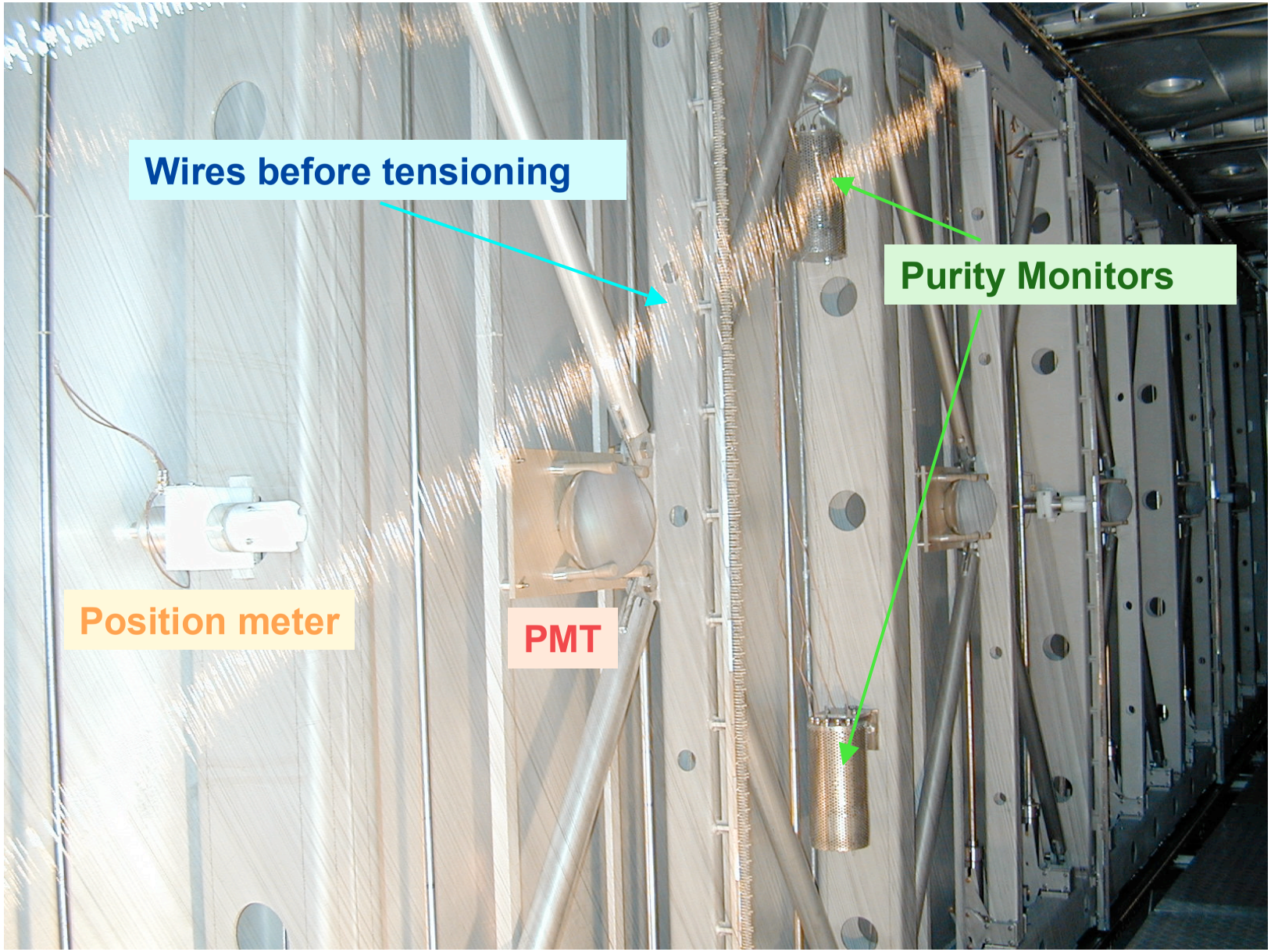
- The physics program addresses fundamental issues of **elementary particle and astro-particle physics** such as:
  1. The observation of **solar neutrinos**
  2. The detection of **atmospheric neutrinos**
  3. The nature of neutrinos: **neutrino mass and oscillations**
  4. The stability of matter (**nucleon decay searches**)
  5. The search for neutrino signals from **exploding supernovae** or **relic neutrinos from past supernovae**
- In addition, ICARUS will detect the neutrinos from the CERN-NGS neutrino beam to directly **directly prove** the flavor oscillation (to tau and electron) transition over a long-baseline.

The physics potentialities of ICARUS have been discussed in many occasions and they can be found in the various proposals

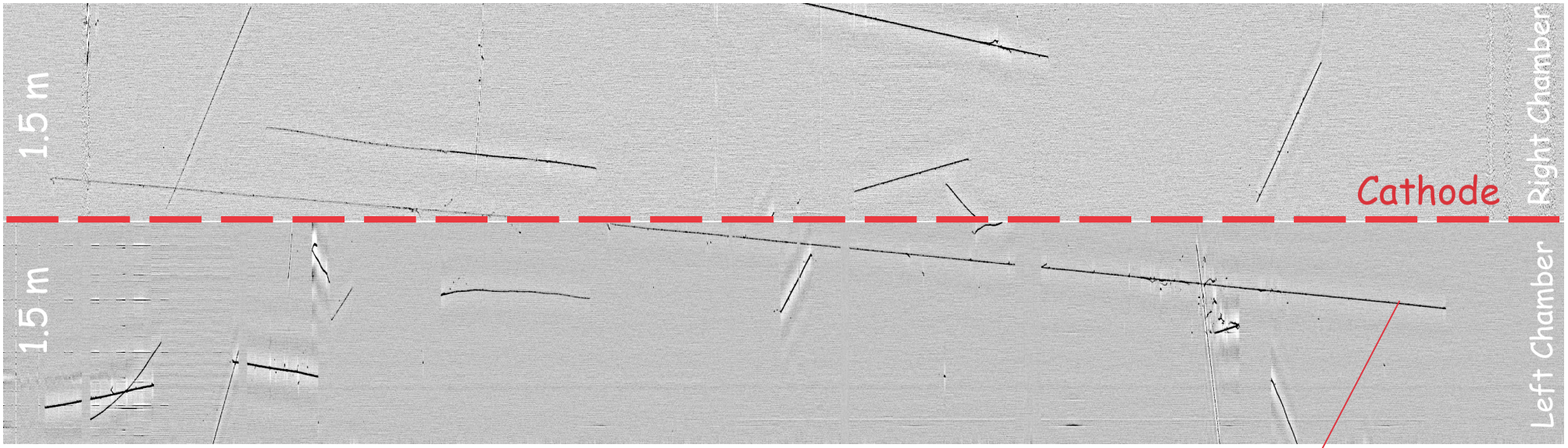
Switzerland in ICARUS T600

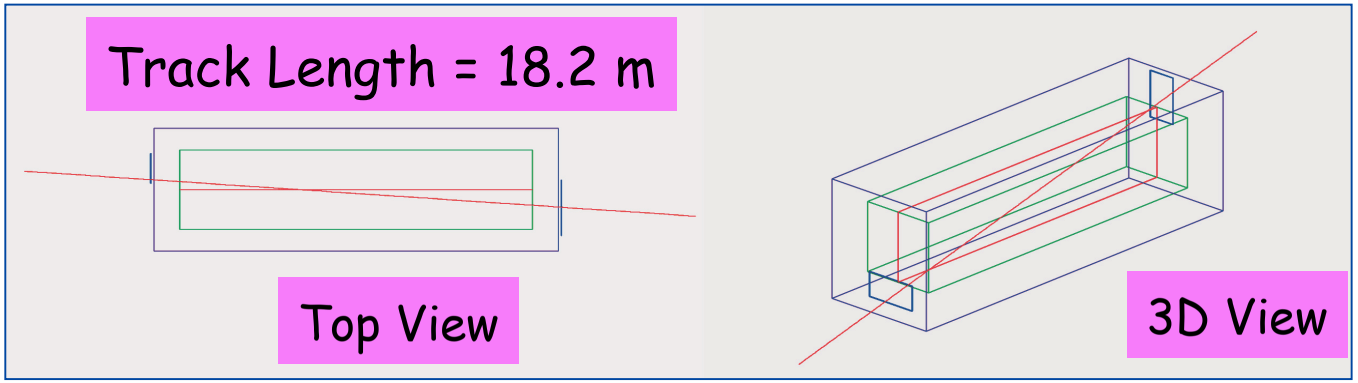
- ETHZ joined ICARUS in January 1998
  - Basic design of ICARUS T600 had already essentially been accomplished and financed by INFN
  - Most of the strength of the ETHZ group come earlier experience in neutrino physics (e.g. NOMAD experiment at CERN)
  - Responsible for physics studies and simulations, for writing proposals
  - In charge of software for generation, simulation, reconstruction and analysis of events : *see next slides for examples of reconstruction of T600 data*
- However, the purpose of an experimental group is to be involved in hardware.
  - Took full responsibility in slow control system
  - Control non-trivial cryogenic and mechanical behavior of the detector, most important during transition phases (see next slides).
  - Involvement during the intense assembly phase in Spring 2001 (where presence of physics is required and help from our mechanical technician)

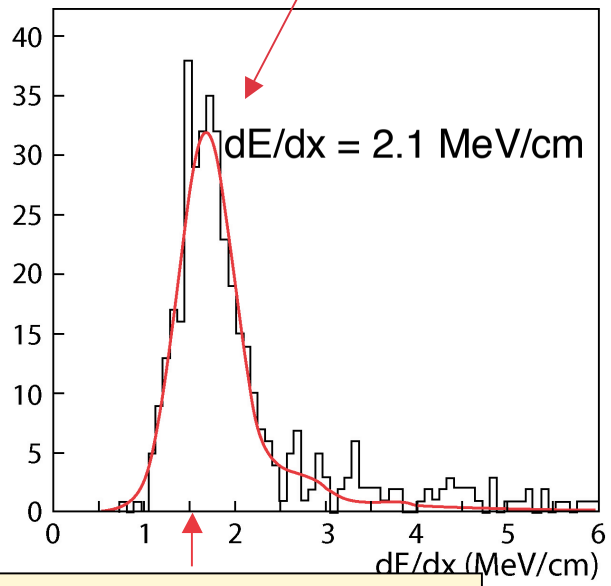
Slow control sensor (behind wire planes)



Longitudinal muon track crossing two gaps





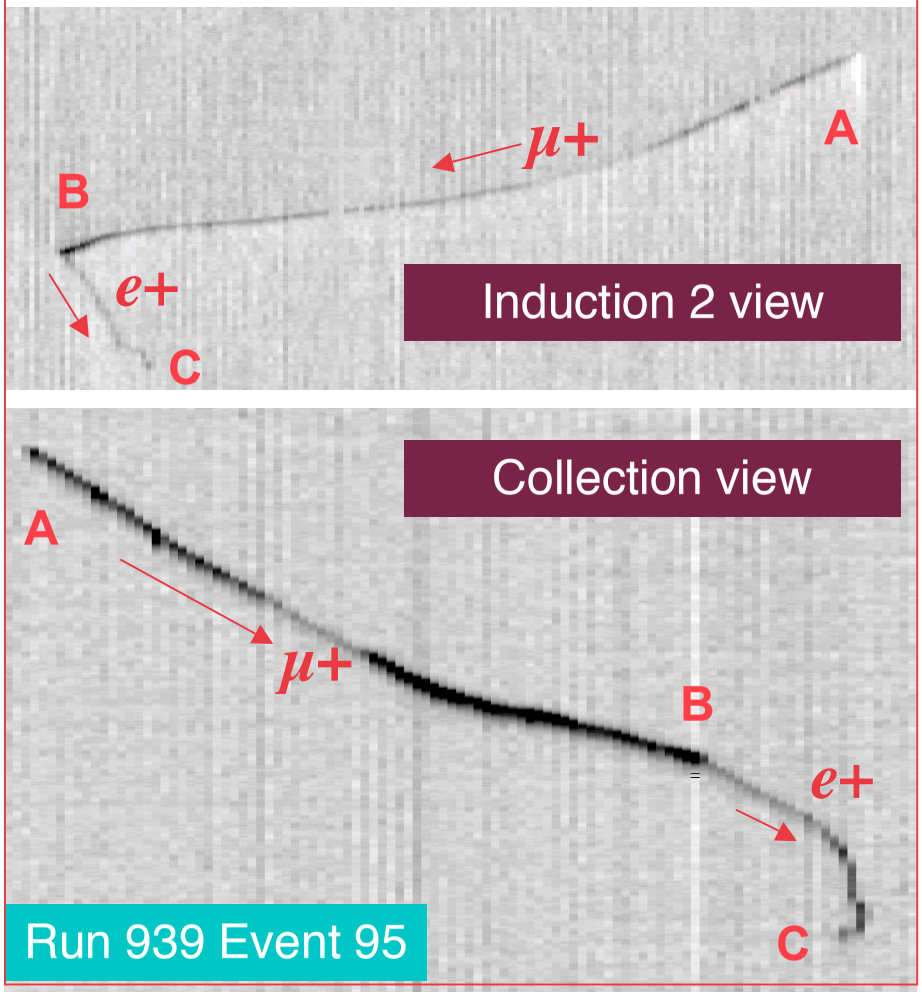


3-D reconstruction of the long track

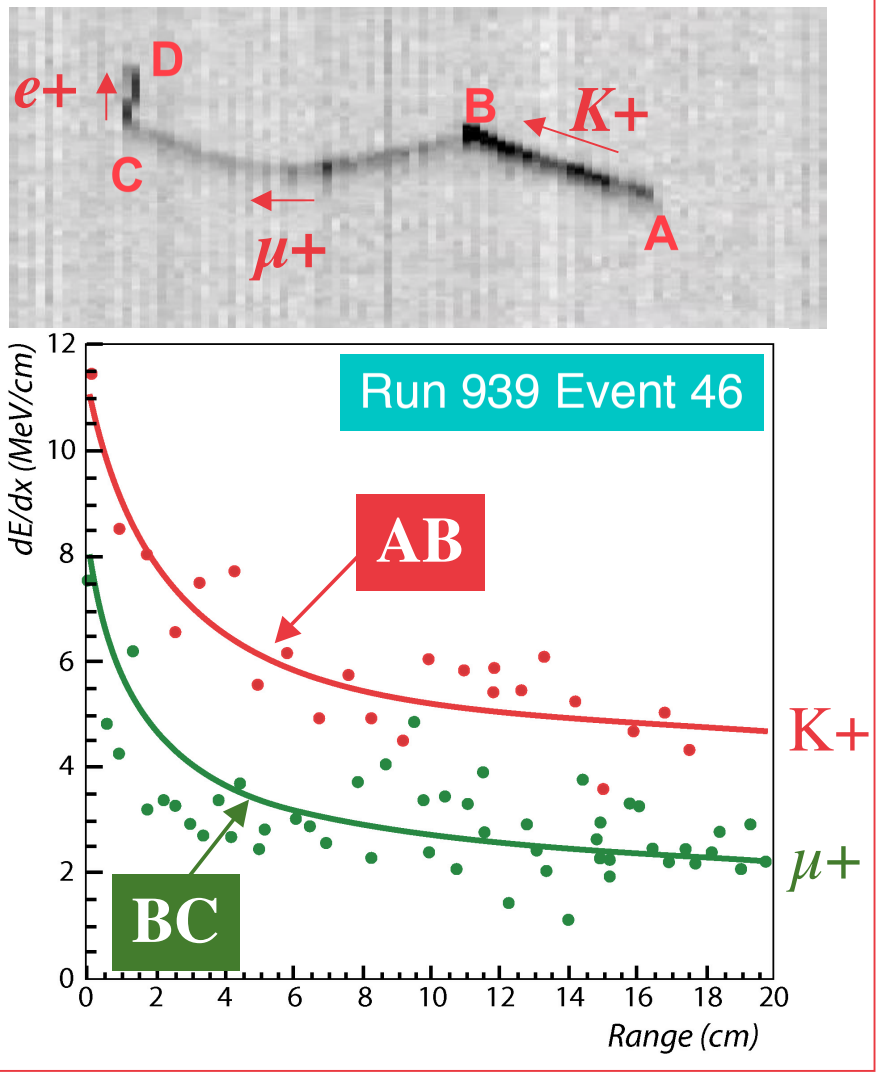
dE/dx distribution along the single track !

Particle identification

$\pi^+[AB] \rightarrow \mu^+[BC]$

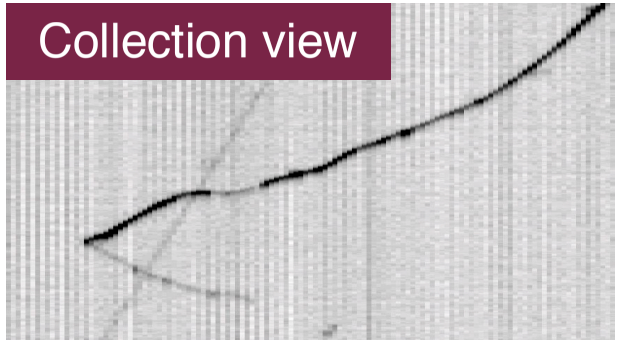


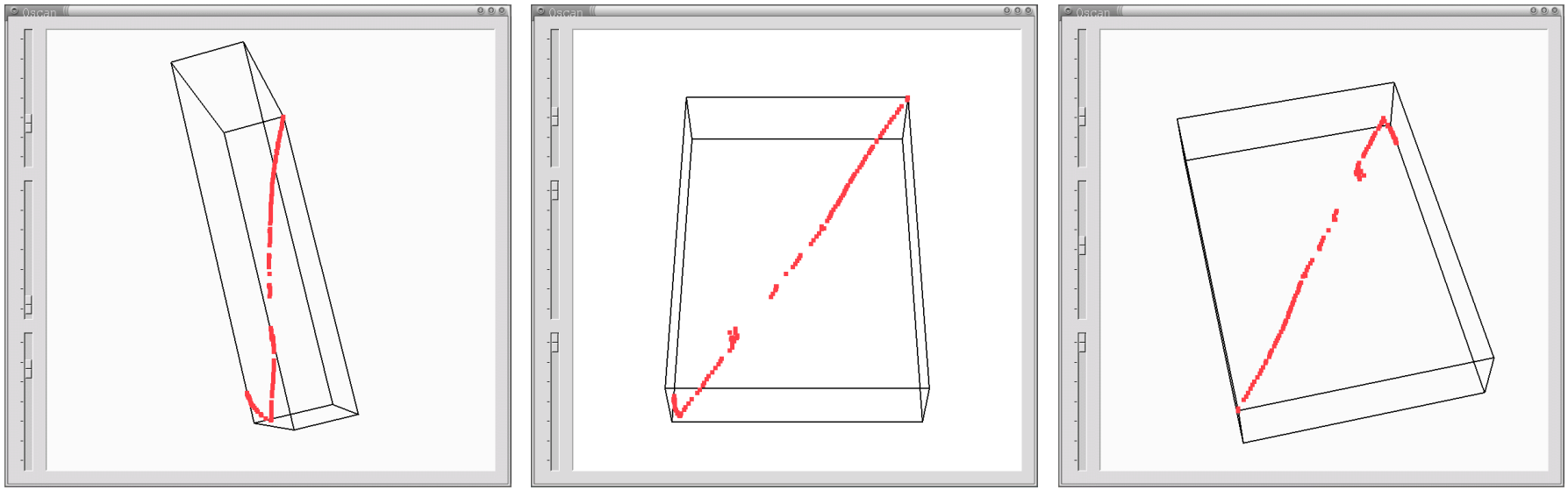
$K^+[AB] \rightarrow \pi^+[BC] \rightarrow e^+[CD]$



Reconstruction in 3-D

- Since the detector has three views 60° apart, it is possible to reconstruct the events in space, using the redundancy of



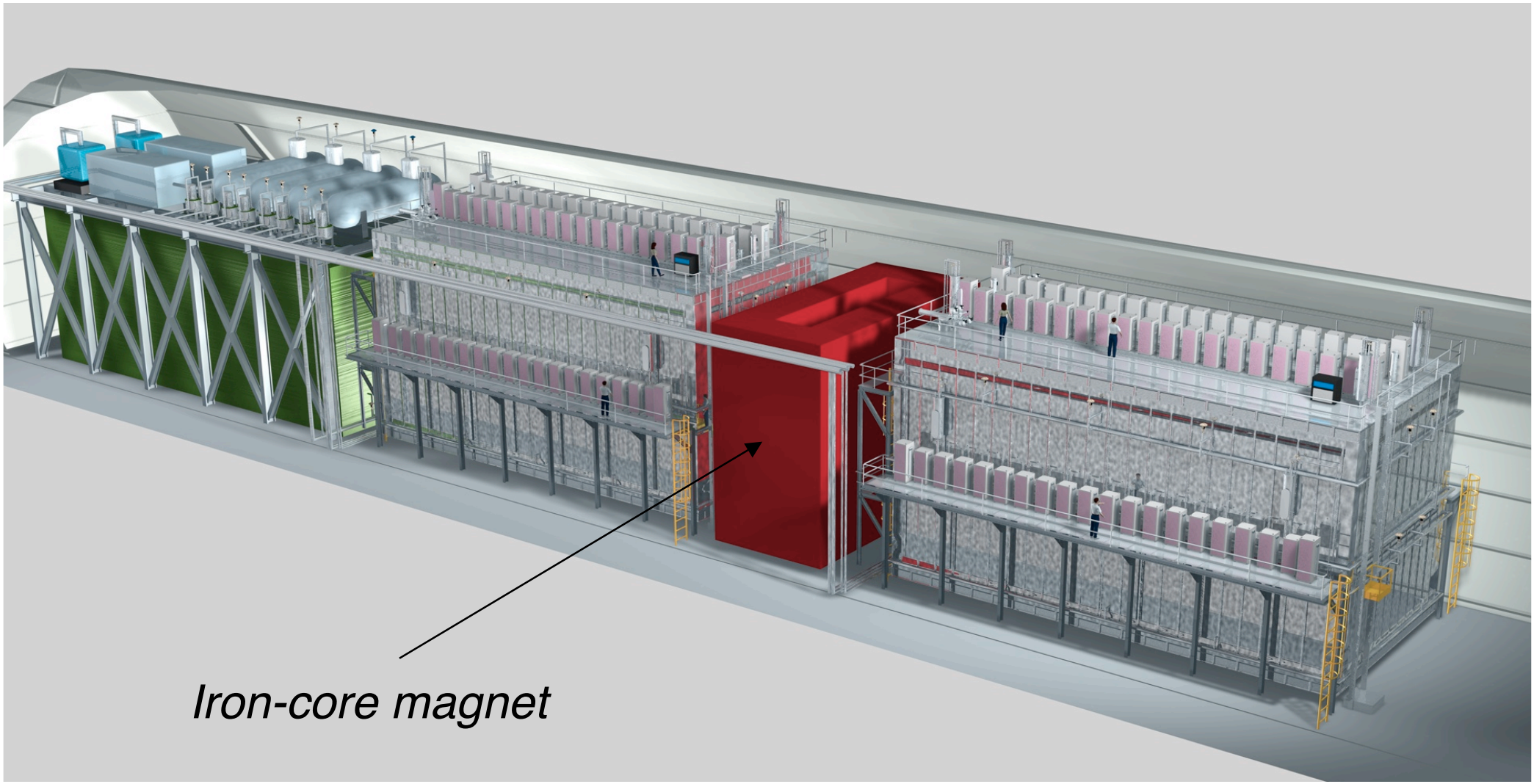


Run 939 Event 51

Switzerland in ICARUS T1200 and beyond

- **Well-defined hardware activities:**
  - ➥Slow control
  - ➥Development of a new-kind of purity monitor
    - – 1.5 years R&D, 3 diploma theses, and 0.3 doctoral thesis
  - ➥Pad readout electrodes (new)
  - ➥Design of muon spectrometer
  - ➥Test of liquid argon in magnetic field
- **Well-defined software activities:**
  - ➥Official software for generation, simulation, reconstruction and analysis of events
- **Present in all analysis activities:**
  - ➥Physics analyses of solar, atmospheric, proton decay and eventually CNGS neutrinos.

ICARUS T3000 + muon spectrometer



ICARUS and education

- A project
  - ➥which forms “real” experimental physicists
  - ➥whose timescale is matched to doctoral thesis
- Require involvement in hardware and software
- Access to real data
- Experiment involves about 100 physicists:
  - ➥a human scale where young talents can blossom
- Swiss statistics (ETHZ students):
  - ➥4 PhD students currently working (due date: 1 in 2002, 2 in 2003 and 1 in 2004)
  - ➥5 Diploma students so far (2x 2000, 2x 2001, 1x 2002)
  - ➥An additional PhD requested (to start in 2002)
  - ➥2 off-semester “Praktikum-Arbeit”s

ICARUS time scale

- **Phase I: (starts in 2003)**
  - ➥600 ton ICARUS detector
  - ➥Observation of solar and atmospheric neutrinos
- **Phase II: (starts ca. 2005)**
  - ➥3000 ton ICARUS detector
  - ➥Continue observation of solar und atmospheric neutrinos with larger statistics
  - ➥Investigation of stability of matter (proton-decay)
  - ➥Detection of artificial neutrino beam from CERN
- **Phase III (??? >2010)**
  - ➥>3000 ton ICARUS
  - ➥Investigation of new neutrino beams with very high intensity (i.e.. “Superbeams“ or “neutrino-factory“)
  - ➥Improved sensitivity for proton-decay

Concluding remarks

- Neutrino physics and proton decay continue to be experimentally driven and surprises are not unexpected.
- Europe with ICARUS is very well positioned since
  - **We directly compete with Japan but with a much better technology than water; USA does not manage to play a significant role**
  - **T600 should start data-taking in 2003 for solar, atm and p-decay**
  - **CNGS+T3000 should come around 2005 for direct proof of flavor mixing**
- Europe must define its future beyond CNGS program
  - How to best compete with the JHF+SK program ? i.e. **discover θ_{13} and CP** ?
  - Liquid Argon technology is the "European" technology, took decade to develop, far more advanced than Water, anybody who wants to use large Water detectors should go to Japan
  - ICARUS should reach multikton mass: it's feasible
  - **LNGS**: a "European" Underground facility; an existing infrastructure that took decades to build: **the only realistic choice (i.e. no Frejus, no islands, …)**
  - Anybody interested in the future should be involved in LNGS+CNGS
- We must build a European post-CNGS program keeping LNGS and LAr in mind.