ICARUS T600

Imaging Cosmic And Rare Underground Signals

Sandro Centro

ICARUS Collaboration

Paris NNN08 - September 2008

The ICARUS collaboration

A. Ankowski[1], M. Antonello[2], P. Aprili[3], F. Arneodo[3], B. Baibussinov[4], M. Baldo Ceolin[4], G. Battistoni[5], P. Benetti[6], A. Borio[6], E. Calligarich[6], M. Cambiaghi[6], F. Carbonara[7], F. Cavanna[2], S. Centro[4], A. Cesana[5], K. Cieslik[8], D. B. Cline[17], A. G. Cocco[7], A. Dabrowska[8], R.Dolfini[6], C. Farnese[4], A. Fava[4], A. Ferrari[5], G. Fiorillo[7], S. Galli[2], D. Gibin[4], A. Gigli Berzolari[6], A.Giuliano[9],K.Graczyk[1],S. Gninenko[10], A. Guglielmi[4],C. Juszczak[1], J. Holeczek[11], D. Kielczewska[12], M. Kirsanov[10], J. Kisiel[11], T. Kozlowski[13], N. Krasnikov[10],M. Lantz[5], G. Mannocchi[9], M. Markiewicz[8], Ch. Matthey[17], V. Matveev[10], F. Mauri[†], A. Menegolli[6], G. Meng[4],C. Montanari[6], S. Muraro[5], J. Nowak[1], S. Otwinowski[17], O. Palamara[3], L. Periale[9], G. PianoMortari[2], A. Piazzoli[6], P. Picchi[9], F. Pietropaolo[4], W. Polchlopek[14], M. Posiadala[12], M. Prata[6], P. Przewlocki[13], A. Rappoldi[6],.G. L. Raselli[6], E. Rondio[13], M. Rossella[6], C. Rubbia[3], P. Sala[5], L. Satta[9], D. Scannicchio[6], Y. Seo[17], E. Segreto[3],F. Sergiampietri[15], J. Sobczyk[1], D. Stefan[8], J, Stepaniak[13], R. Sulej[16], M. Szarska[8], M. Terrani[5], G. Trinchero[9], F. Varanini[4], S. Ventura[4], C. Vignoli[6], T. Wachala[8], A. Zalewska[8], K. Zaremba[16] B. Lisowski[17], H. Wang[17], X. Yang[17]

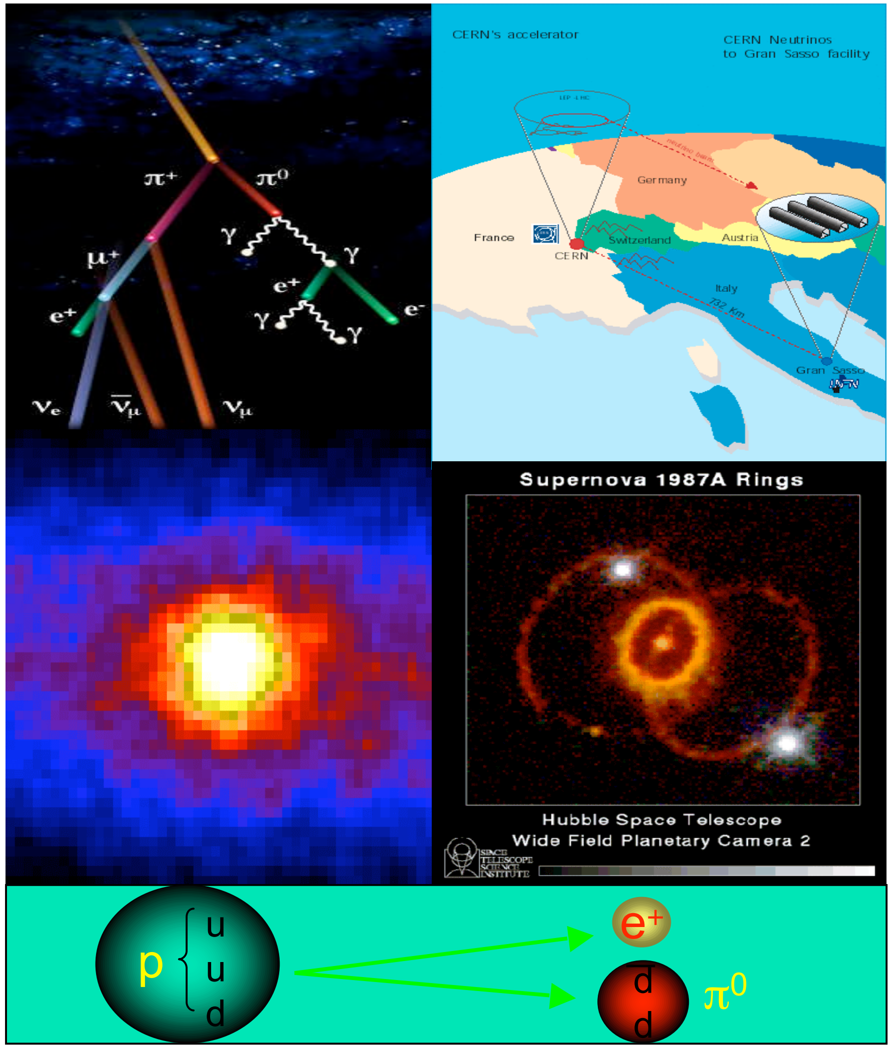
[1] Wroclaw University of Technology, Wroclaw, Poland
[2] Dipartimento di Fisica e INFN, Università di L'Aquila, Via Vetoio, I-67100
[3] Laboratori Nazionali del Gran Sasso dell'INFN, Assergi (AQ), Italy
[4] Dipartimento di Fisica e INFN, Università di Padova, Via Marzolo 8, I-35131
[5] Dipartimento di Fisica e INFN, Università di Milano, Via Caloria 2, I-20123
[6] Dipartimento di Fisica Nucleare, Teorica e INFN, Università di Pavia, Via Bassi 6, I-27100
[7] Dipartimento di Scienza Fisiche, INFN e Università Federico II, Napoli, Italy
[8] H. Niewodniczanski Institute of Nuclear Physics, Krakow, Poland
[9] Laboratori Nazionali di Frascati (INFN), Via Fermi 40, I-00044
[10] INR RAS, prospekt 60-letiya Oktyabrya 7a, Moscow 117312, Russia
[11] University of Silesia, 12 Bankowa st., 40-007 Katowice, Poland
[12] Warsaw Univeristy, Krakowskie Przedmiescie 26/28, 00-927 Warszawa, Poland
[13] A. Soltan Institute for Nuclear Studies, 05-400 Swierk/Otwock, Poland
[14] AGH University of Science and Technology, Al. Mickiewicza 30, 30-059 Krakow, Poland
[15] Dipartimento di Fisica, Università di Pisa, Largo Bruno Pontecorvo 3, I-56127
[16] Univeristy of Technology, Pl. Politechniki 1, 00-661 Warsaw, Poland
[17] Department of Physics and Astronomy, University of California, Los Angeles, USA
† Deceased

Outline

- Physics program hints
- Icarus T600 architecture
- Dewar and inner detector
- Read-out electronics
  - Architecture
  - Performance
- First run in Pavia
- Installation and commissioning in LNGS
- Present Status

The Physics Program with T600

- Atmospheric neutrinos
- Long Baseline Neutrino Experiment
- Solar neutrinos
- Cosmic neutrinos:
  - SN, γ-ray bursts, neutron star collapse
- Nucleon Decay (exotic channels)

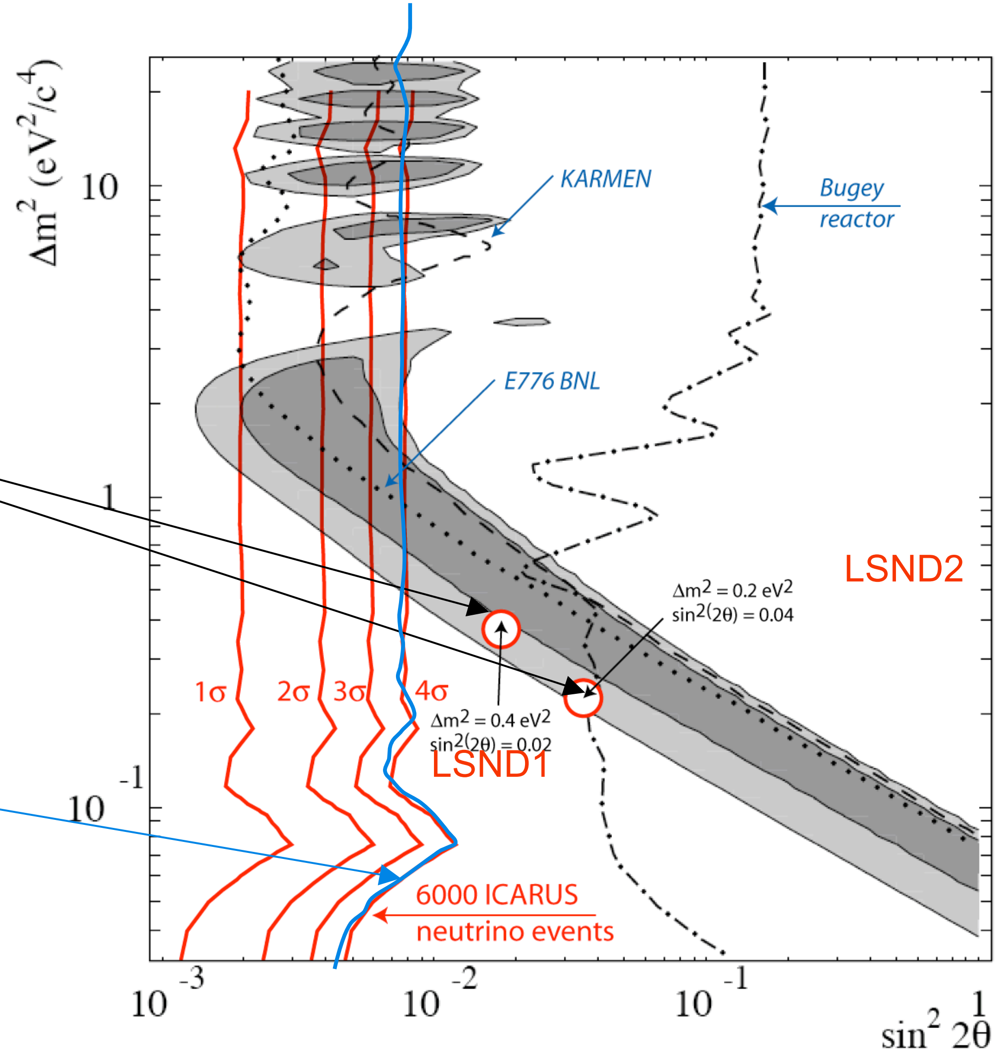


Physics issues

- The ICARUS T600 detector is a necessary intermediate technical step towards a much more massive LAr detector (multikton LAr-TPC are now being actively studied), but it offers also some interesting physics in itself.
- The T600 at LNGS will collect simultaneously “self triggered” events of different nature. This in particular represents:
  - ≈ 100 ev/year of individually recorded atmospheric CC neutrinos.
  - Solar electron neutrinos >5 MeV.
  - Supernovae neutrinos.
  - A zero background proton decay with 3 x 10^{32} nucleons for ”exotic” channels.
  - CNGS beam related neutrino events:
    - The T600 raw fiducial mass ≈ 480 t will collect up to 1200 ν_μ CC ev/y and 7-8 ν_e CC ev/year.
    - ≈ 84 $\nu_\mu \rightarrow \nu_\tau$ raw events (Δm^2_{23} = 2.5 10^{-3} eV^2) : 7 $\pm$ 2.6 $\tau \rightarrow e$ events out of bckg.
    - Search for sterile neutrinos in the LSND (Liquid Scintillator Neutrino Detector - Los Alamos) parameter region.

Physics reach

- The $\sin^2(2\theta)$-Δm^2 explored region covers most of LNSD allowed areas and extends to lower value of Δm^2
- Two indicated points are reference values of MiniBooNE proposal and of previous slides
- One year of data taking will be enough to exclude $\sin^2(2\theta)$ values larger than 10^{-2} at 90% CL.

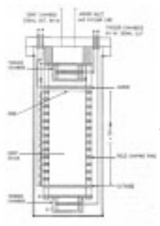


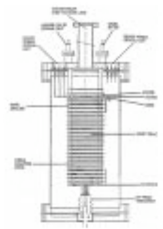
ICARUS genealogy since 30 years

1987

First purity monitor chamber

Lifetime measured >10ms





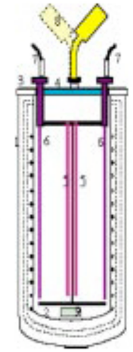
1987

24 cm drift wires chamber

Proof of LAr TPC operation

1991-1995

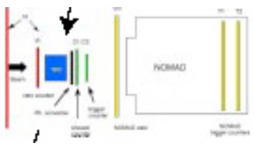
3 ton prototype



First “large mass” LAr TPC operation

1997-1999

Neutrino beam events measurements. Readout electronics optimization. 1.4 m drift test.



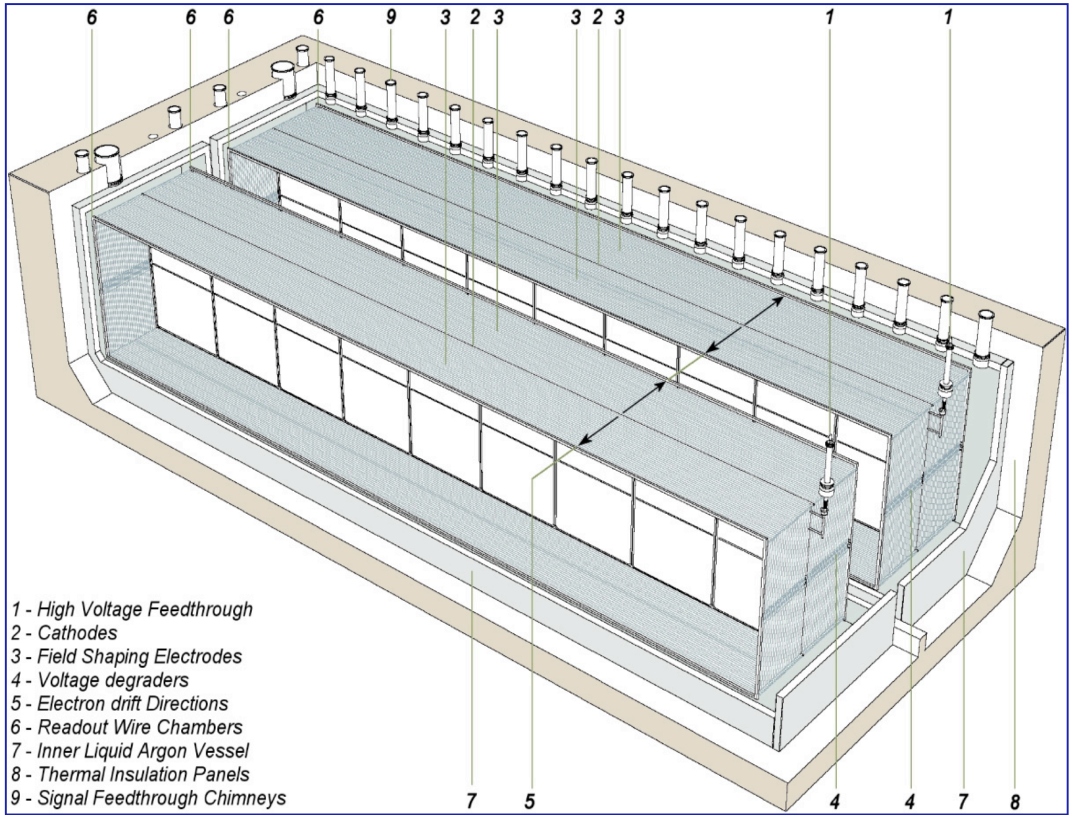
50 litres prototype 1.4 m drift chamber

1998-1999

10 m3 industrial prototype

Ultra-pure LAr technique industrialization.
Forced LAr recirculation.

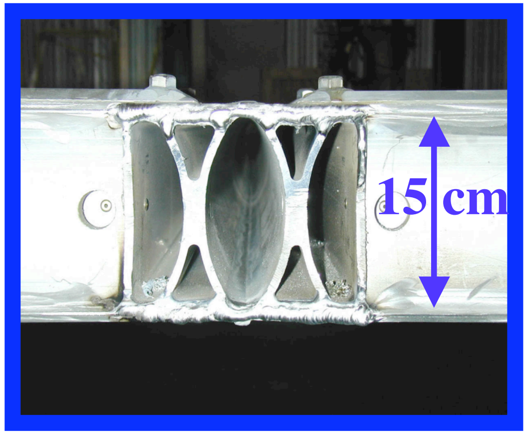
The T600

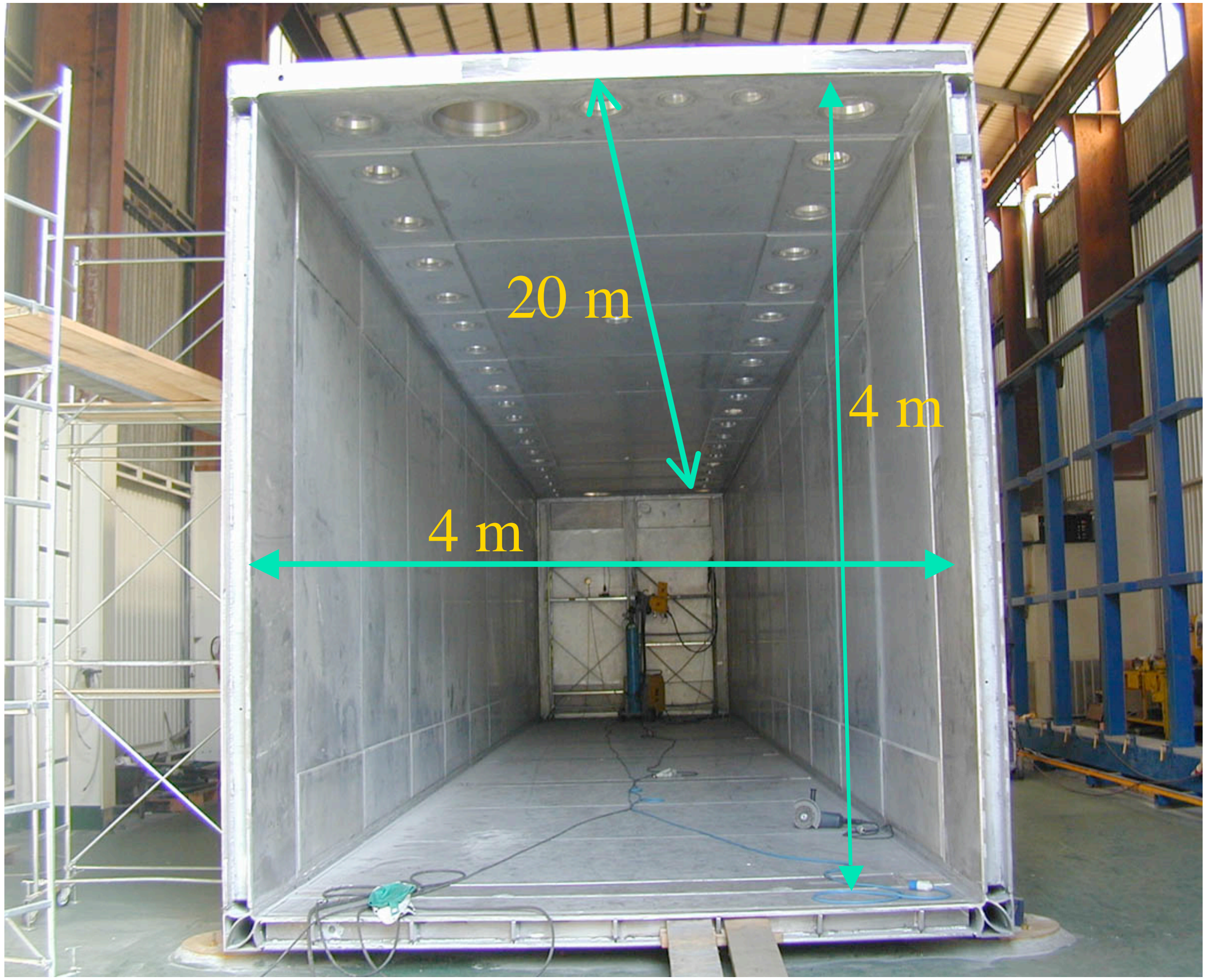


- Two identical modules
  - 3.6 x 3.9 x 19.6 ≈ 275 m^3 each
  - Liquid Ar fiducial mass: ≈ 476 t
  - Drift length = 1.5 m
  - HV = -75 kV E= 0.5 kV/cm
- 4 wire chambers:
  - 2 chambers / module
  - 3 readout planes / chamber: at 0°, +60°, -60°
  - ≈ 54000 wires
- PMT for scintillation light:
  - (20+54) PMTs, 8" Ø
  - VUV sensitive, λ=128nm

The first module empty

Panels junction





Aluminum honeycomb panels,
$2x4\ m^2$. and
Aluminum extruded beams,
4 m.

Elastic suspension of chamber frame

The wire chamber

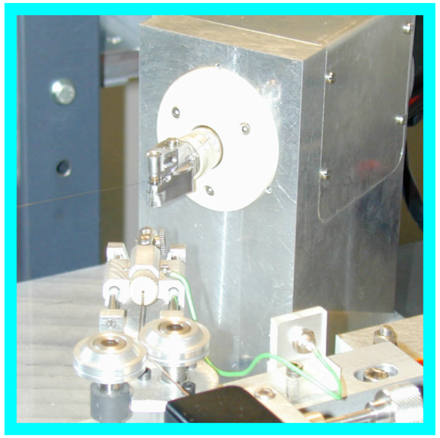
Each chamber has three wire planes (3mm pitch), oriented at 0° (9.42 m x2), +60°(0.49 - 3.77 m), and -60 °(0.49 - 3.77 m).

The planes distance is 3 mm.

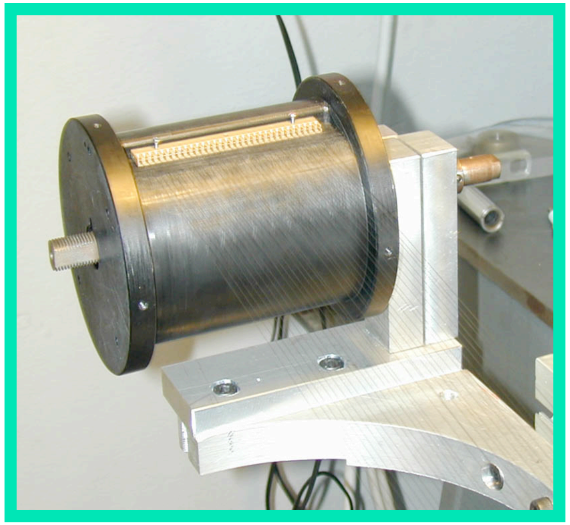
- Stainless steel wires, Ø 150 μm.
- A twisted loop holds the wire to a sleeve.
- Wires are produced and pre-assembled in sets of 32.
- The sleeves are hooked to the pins of a connector: 32 wires on each connector.

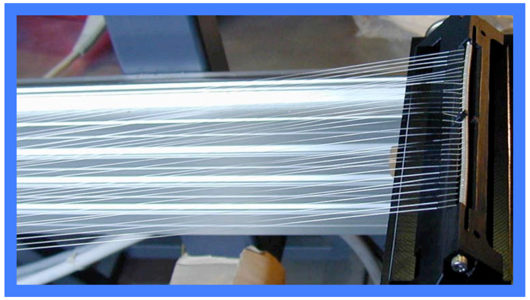
The wire factory

Twisting mandrel

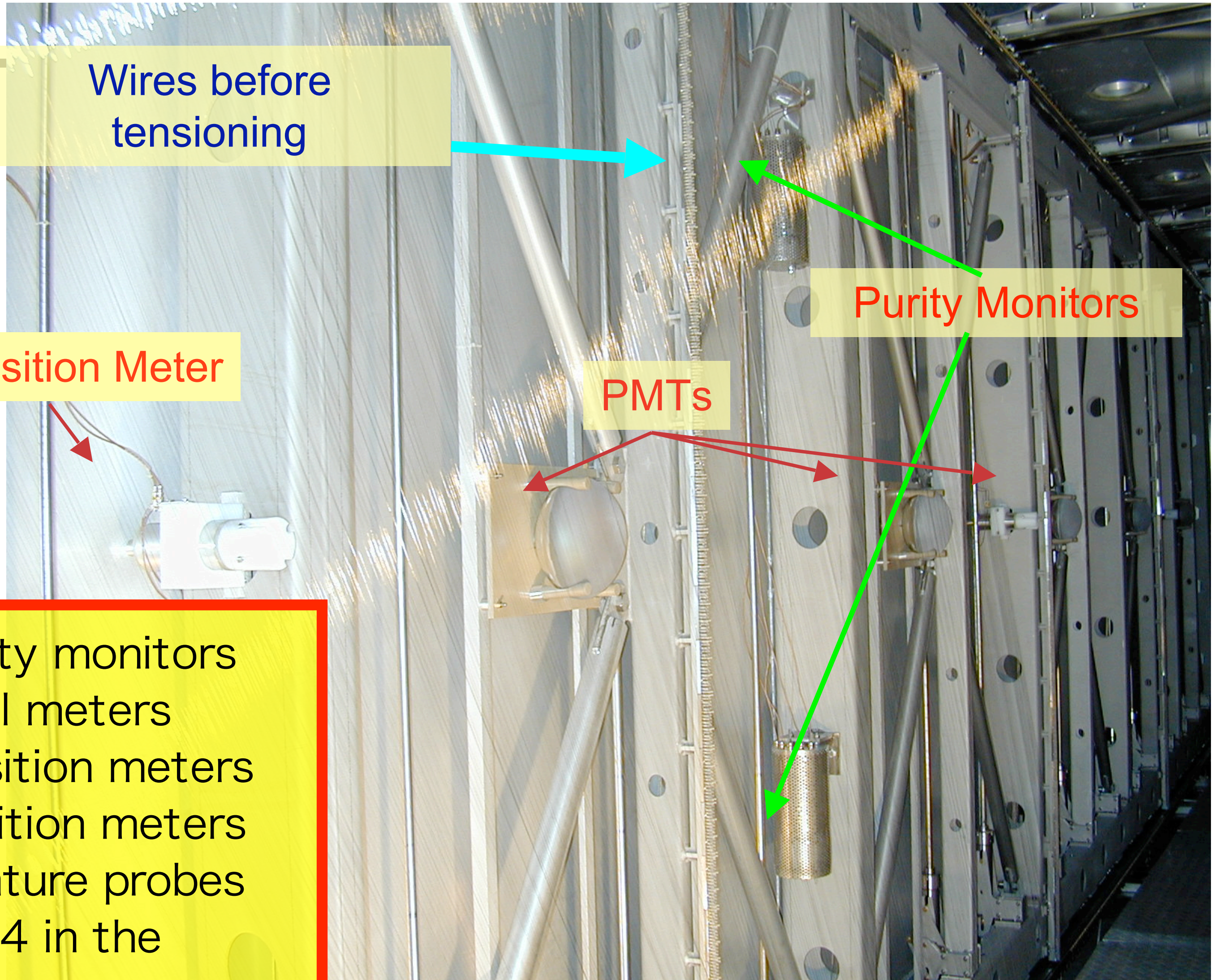


Storage coil



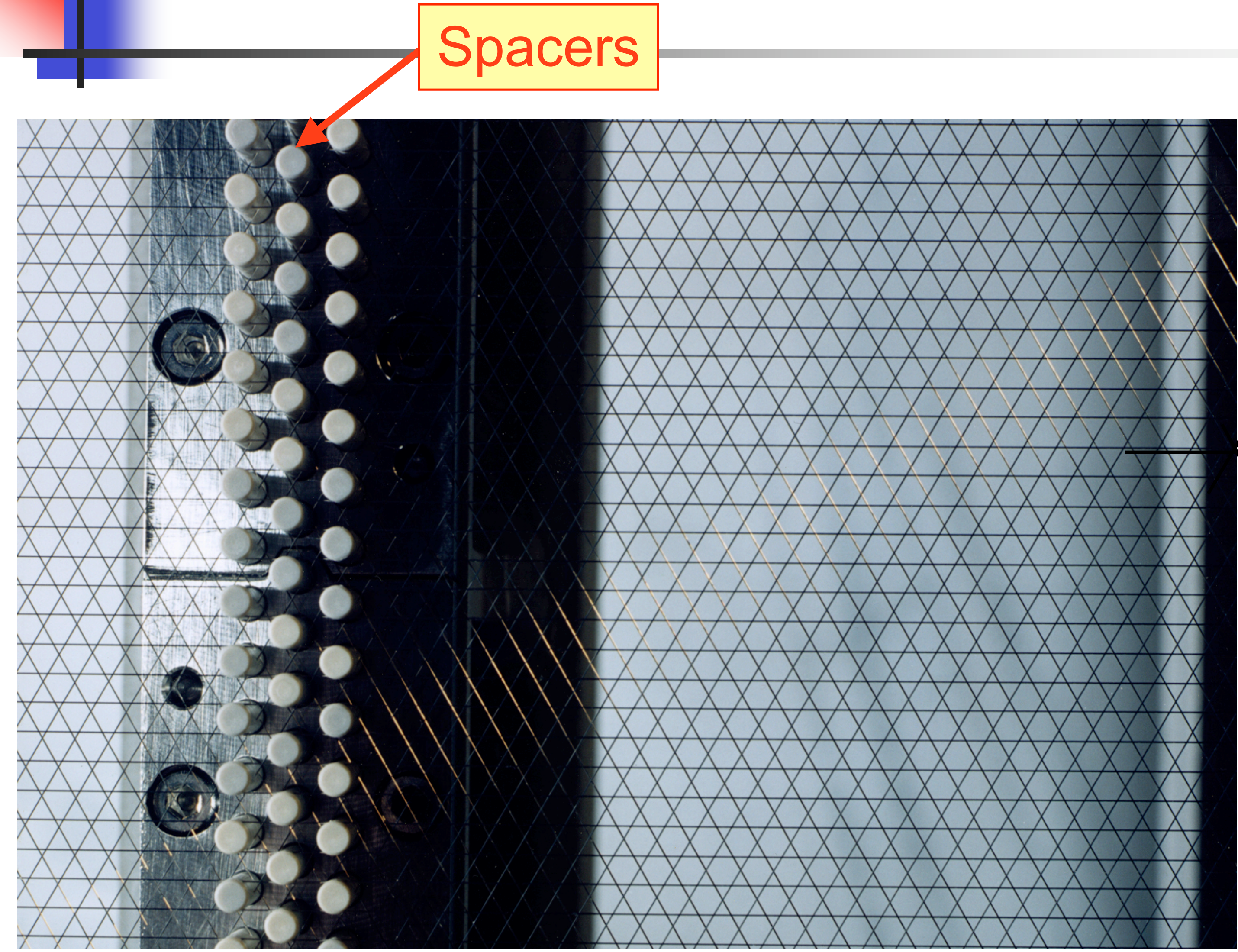


The detector instrumented

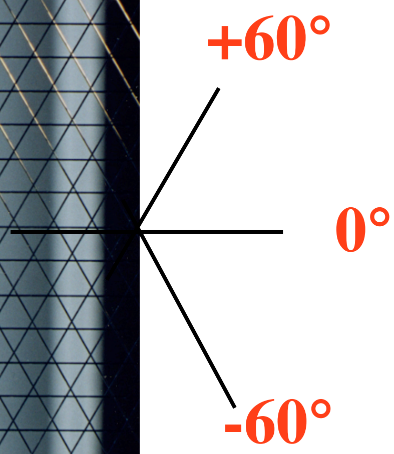


- 6 LAr purity monitors
- 16 LAr level meters
- 7 wire position meters
- 8 wall position meters
- 30 temperature probes
- 20 PMTs (54 in the second)

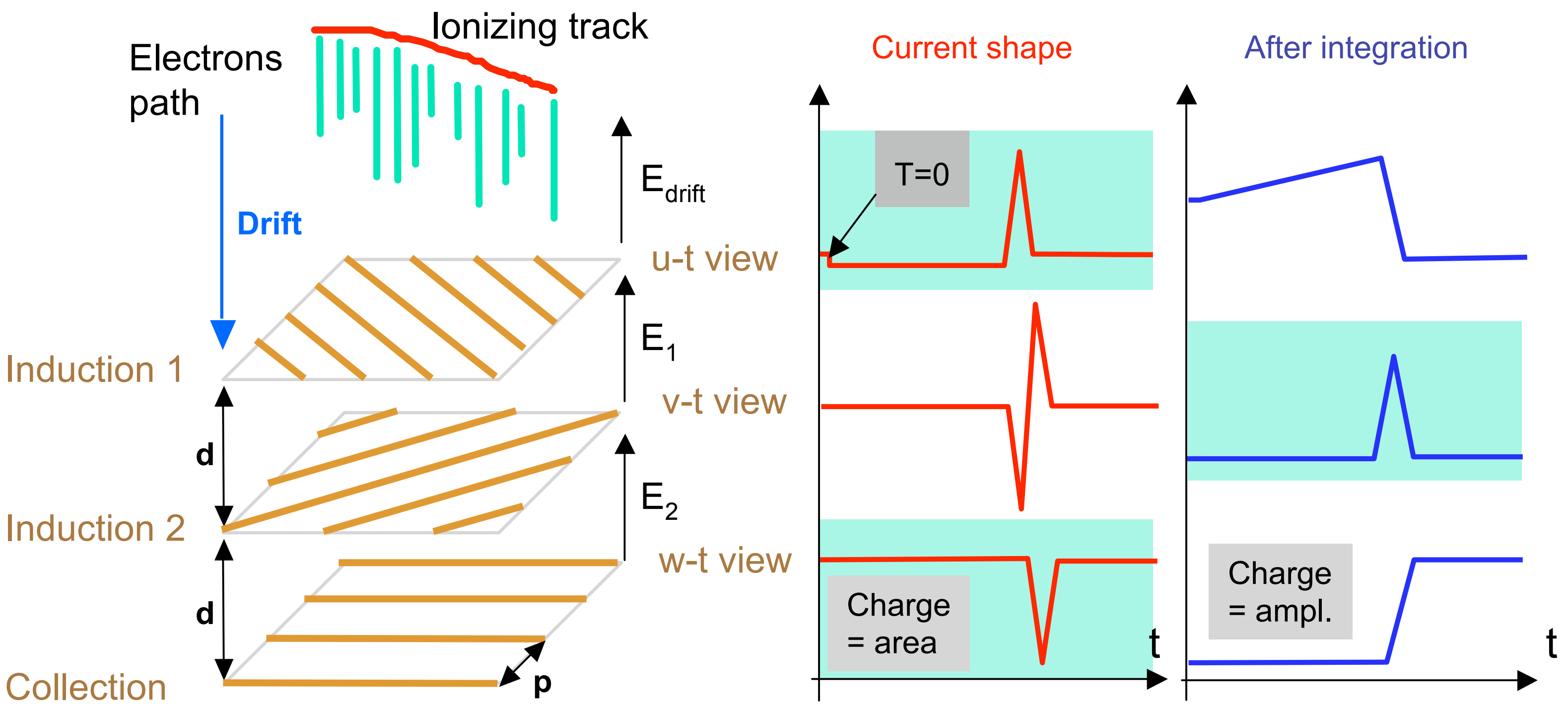
Chamber detail



Three wire planes 3mm pitch



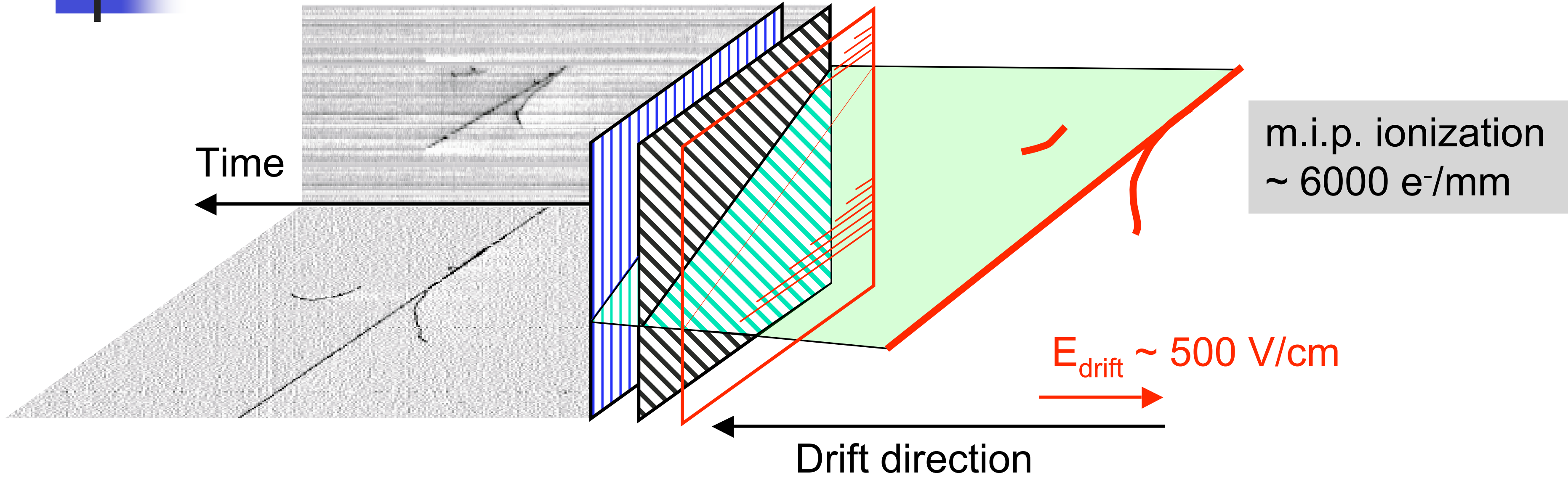
Induction and Collection signals

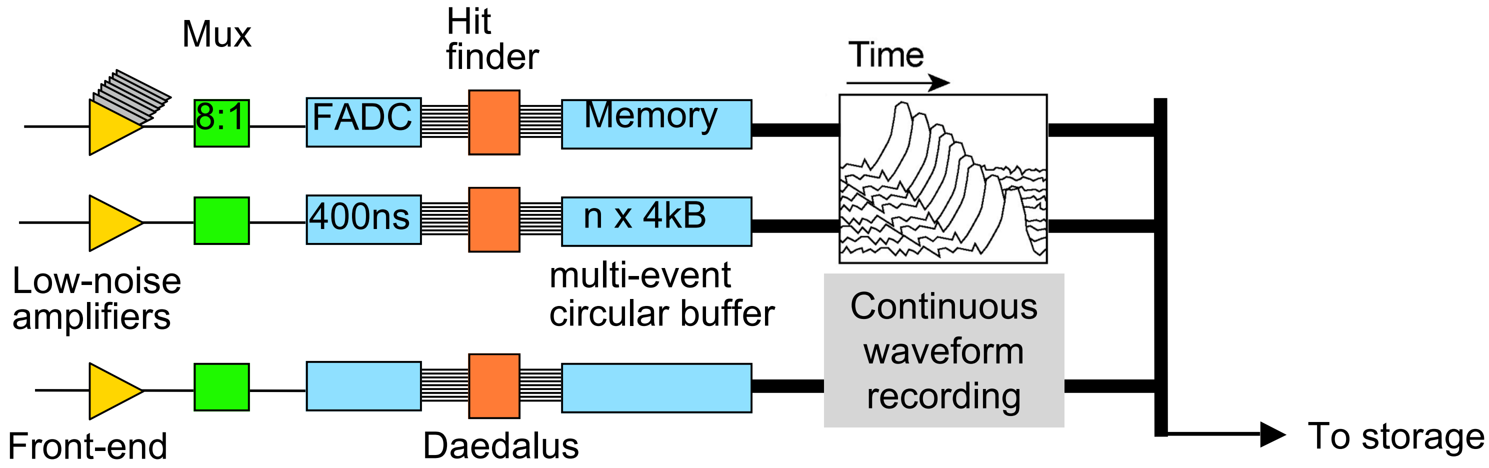


- ICARUS T600: three wire planes (pitch 3mm, separation 3mm)
- Active volume 170,2m^3 , VOXEL = 5,4mm^3 -> total n. of VOXELs = 31,5 10^9

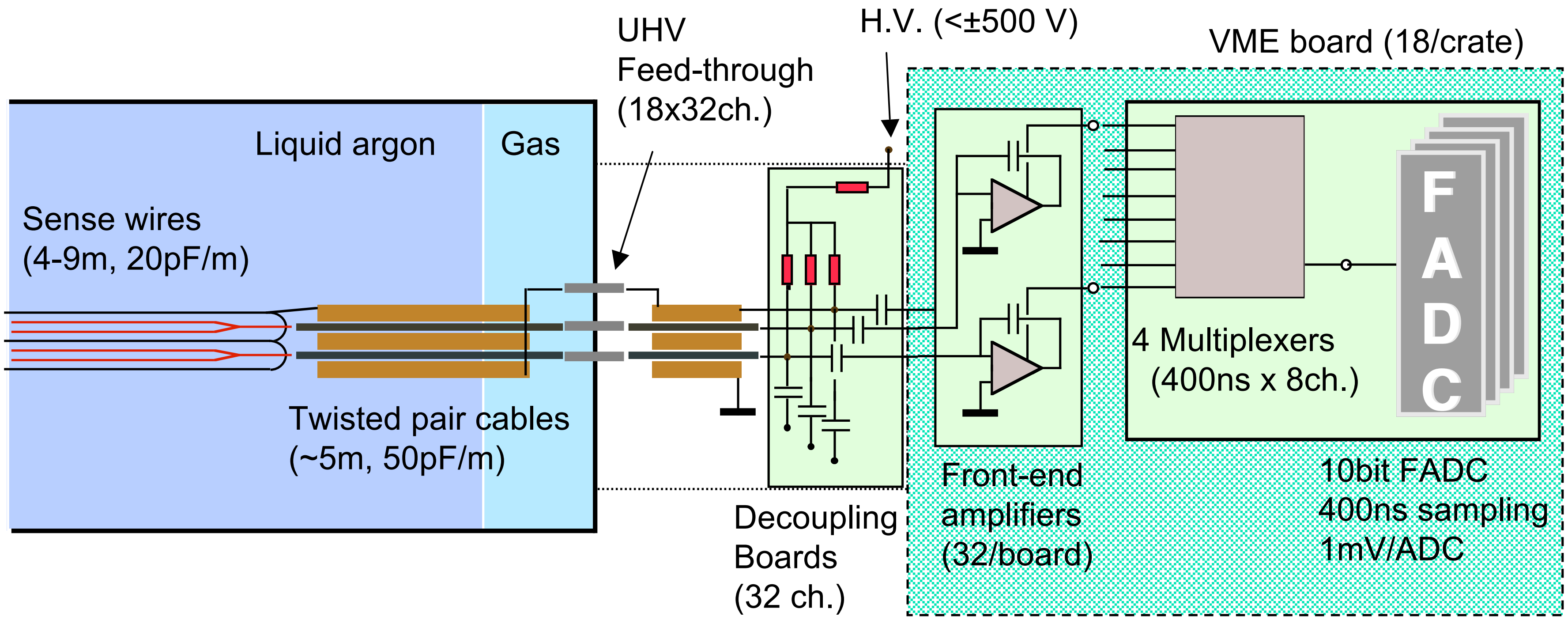
E_{drift} = 500 V/cm
Mip signal ~ 12000 e$^-$ (inc. recombinantion)
Electron drift velocity ~ 1.5 mm/μs
Typical grid transit time ~ 2-3 μs

The ICARUS read-out





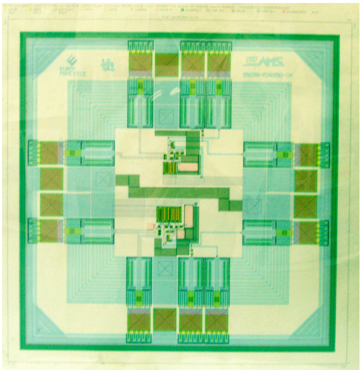
Layout of front-end electronics



ICARUS T600: ~ 54000 channels — 1720 boards — 96 crates
Cost of the full electronic chain: ~ 65 € / channel (*today*)

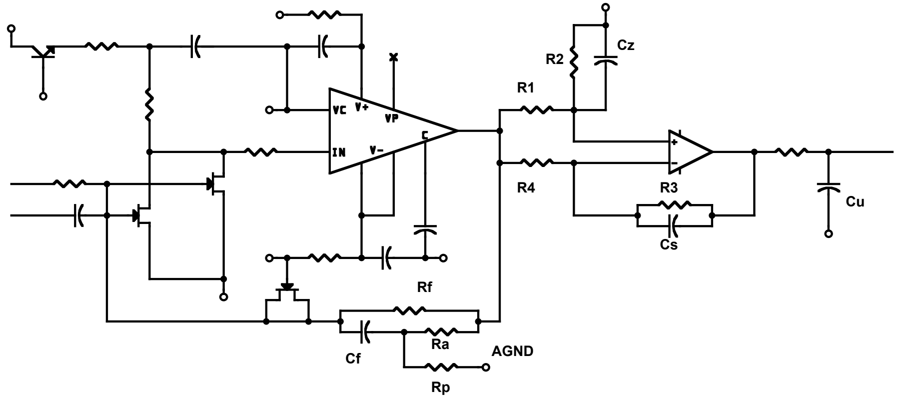
The ICARUS T600 preamplifier

- Custom IC in BiCMOS technology
  - Unfolded Radeka integrator
  - External input stage jFET's, g_{mtot} =50-60 mS
  - External feed-back network
  - External baseline restorer circuit
- Only two channels per IC: fully symmetrical layout guarantees identical electrical behavior



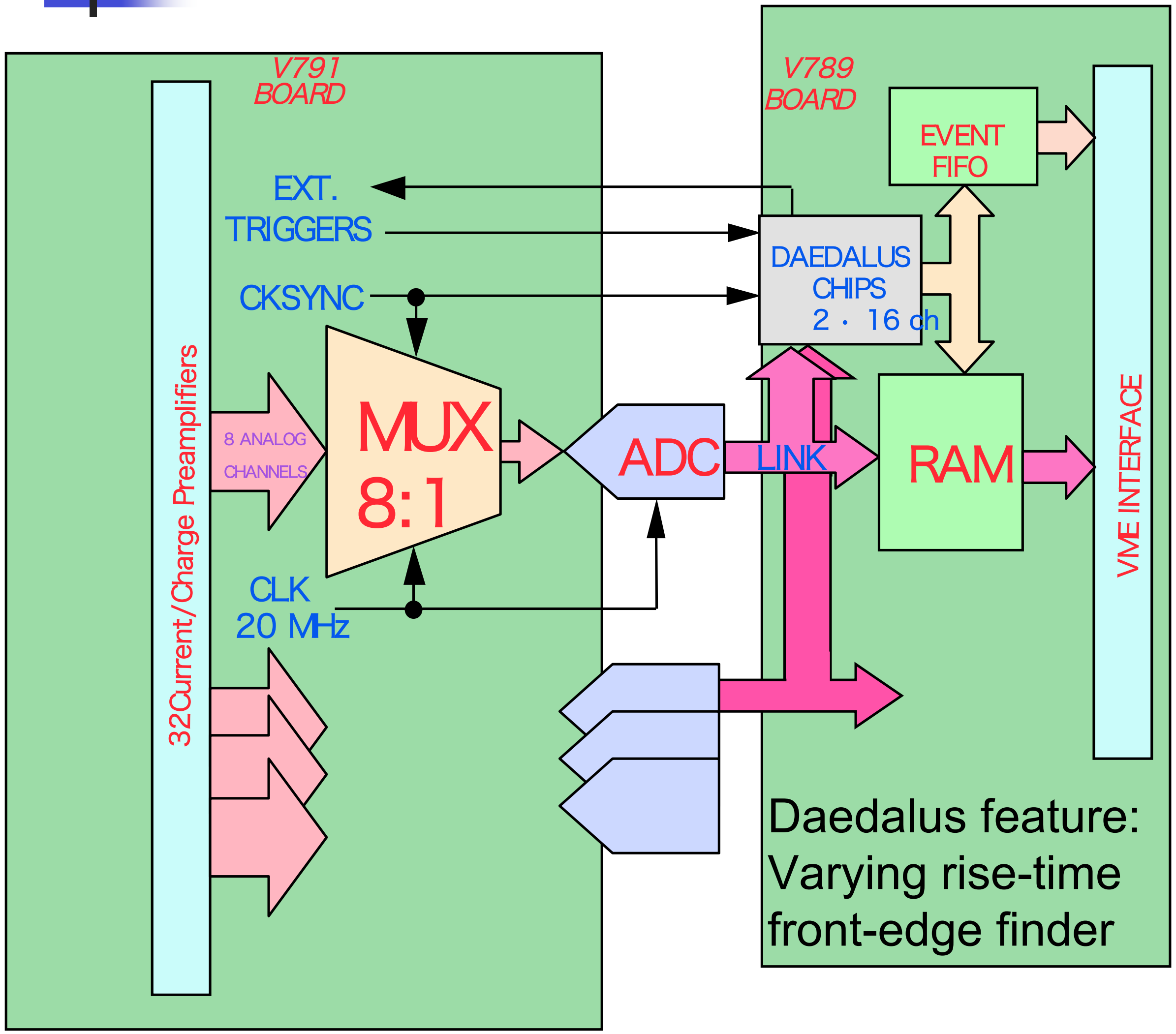
BiCMOS die

Two versions:
"quasi-current" mode: $R_fC_f \approx 1.6\mu s$ (collection + first induction)
"quasi-charge" mode: $R_fC_f \approx 30\mu s$ (mid induction)

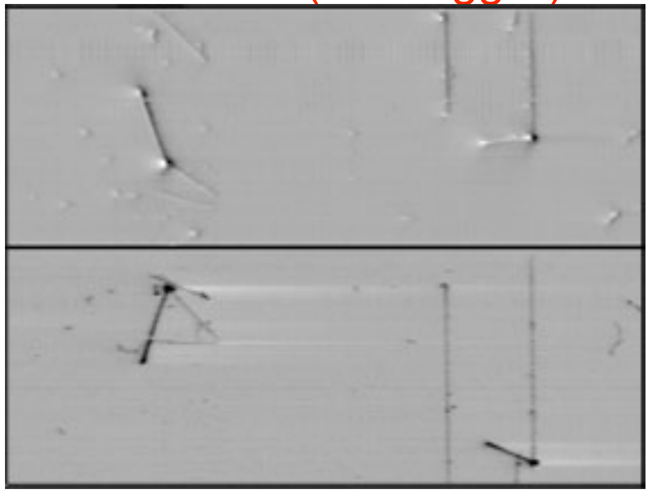


Sensitivity ≈ 6 mV/fC
Dynamic range > 200 fC
Linearity < 0.5% @ full scale
Gain uniformity < 3%
E.N.C. ≈ (350 + 2.5 x C_D) el ≈ 1200 el. @ 350pF
Power consumption ≈ 40 mW

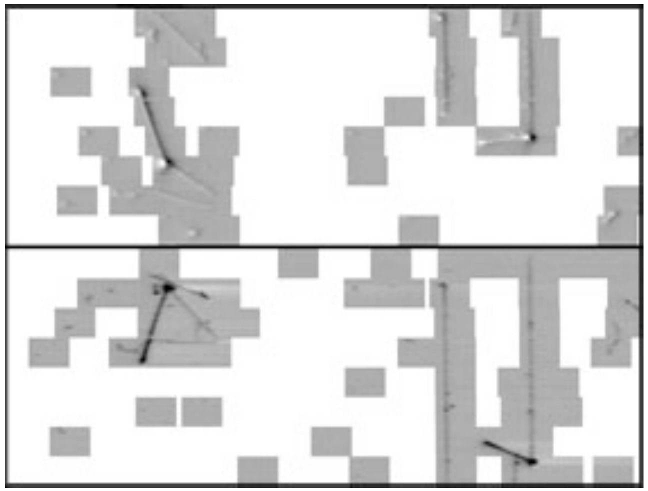
DAEDALUS: a custom VLSI for Feature extraction



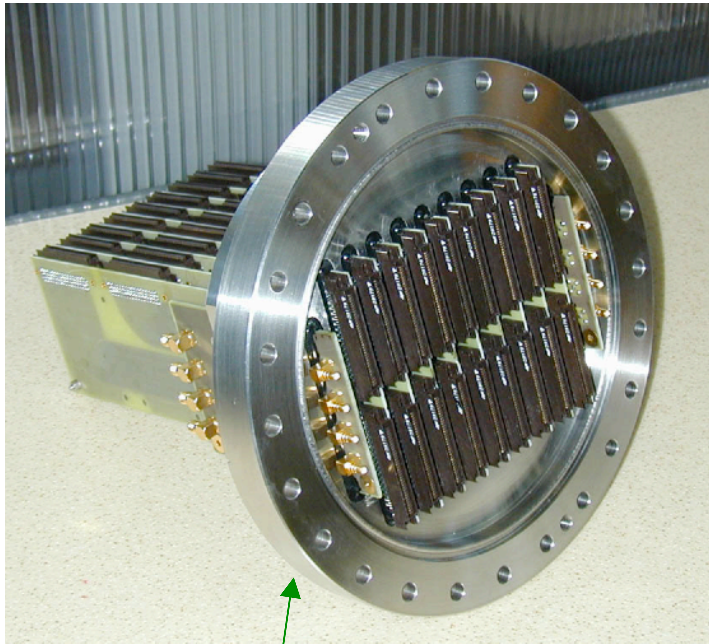
Raw data (ext. trigger)



Reduced data

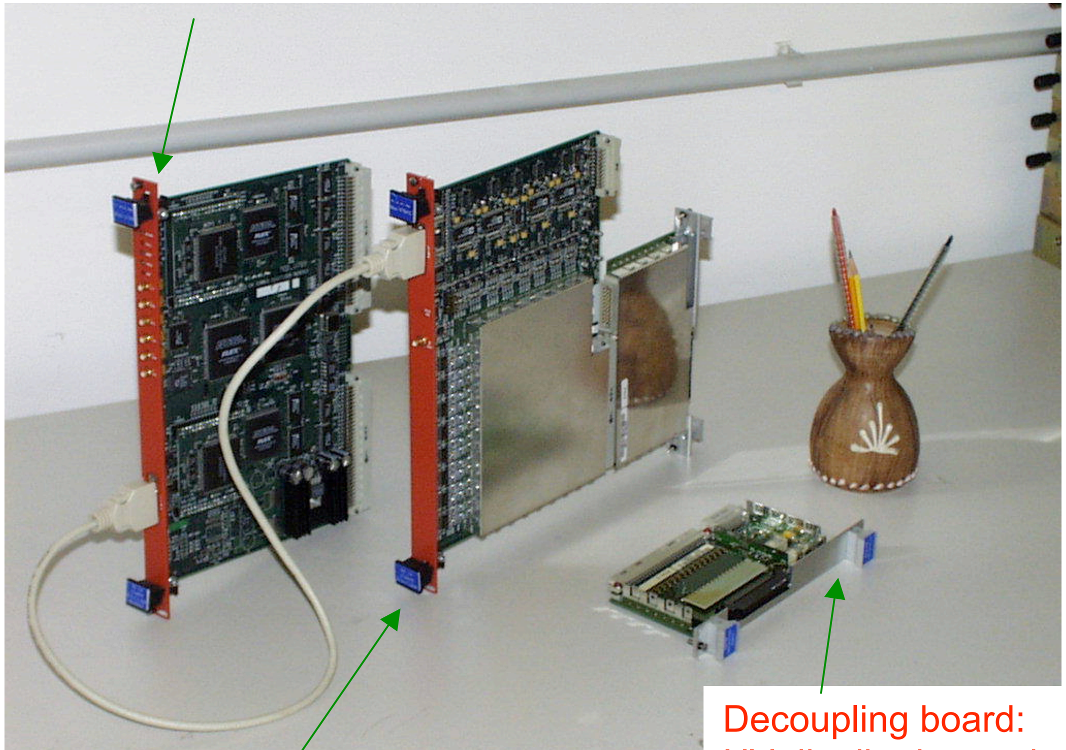


The ICARUS T600 read-out chain



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

CAEN-V789 board: 2 Daedalus VLSI * 16 input channels (local self-trigger & zero suppression) + memory buffers + data out on VME bus

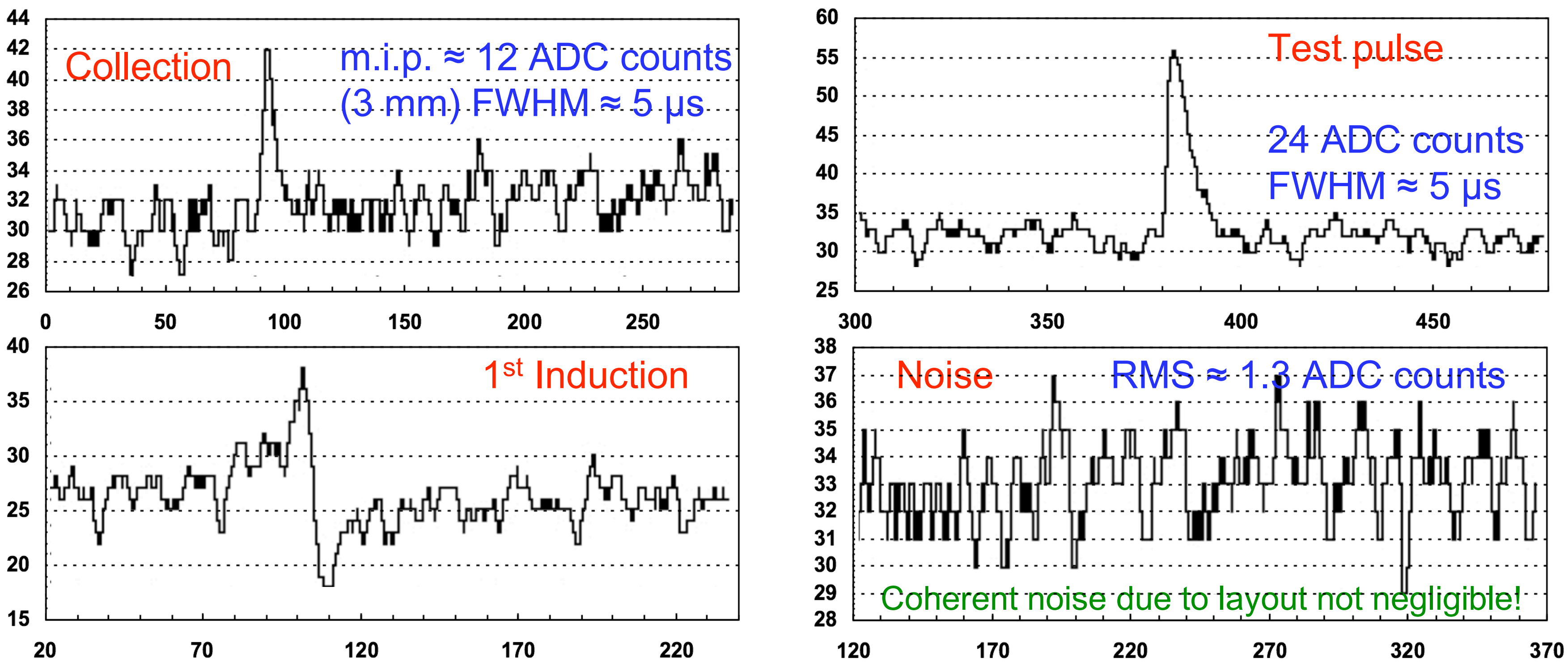


CAEN-V791 board: 32 pre-amplifiers +
4 multiplexers (8:1) + 4 FADC's (10 bits - 20 MHz)

Decoupling board:
HV distribution and
signal input

Signals from Collection and First induction planes

- Single wire waveforms (horiz. axis unit = 400 ns)



Summer 2001 - Pavia run

Bake out and vacuum: 10days

-7 for leak test

-3 days to reach 10^{-4} mbar.

Cooling 14 days

-11 days for pre-cooling to -50 ºC

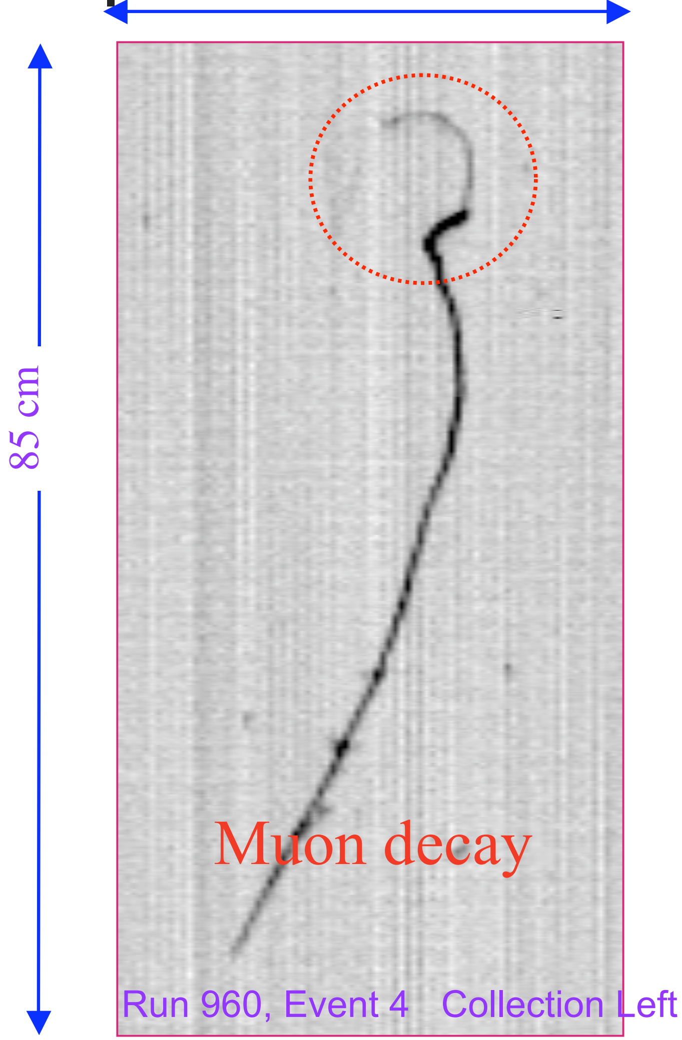
- 3 days to reach -178 ºC

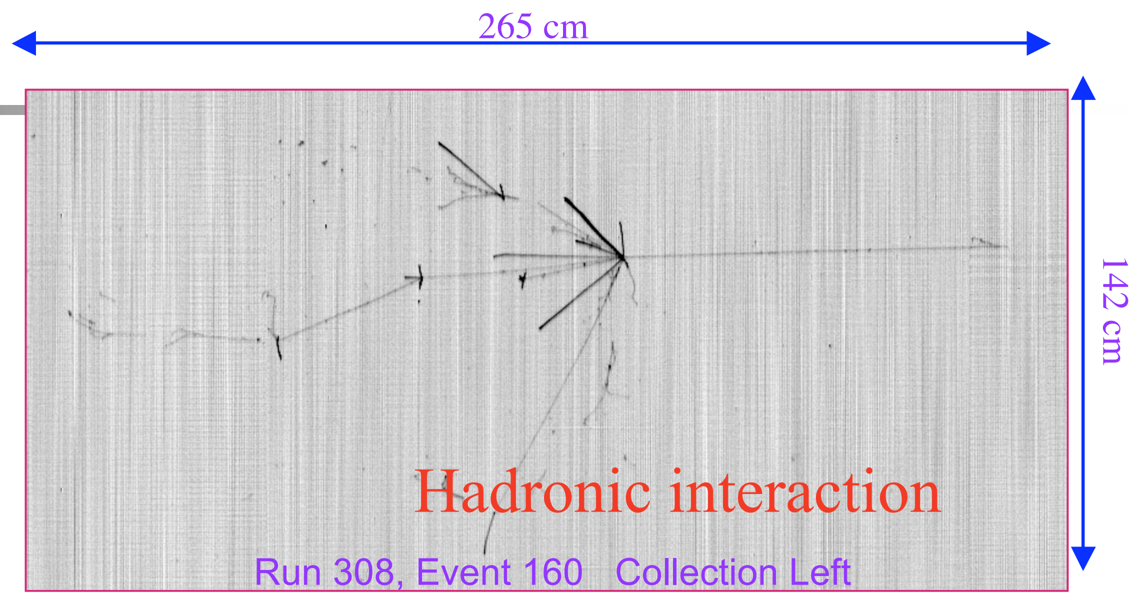
Liquid Ar filling 10 days

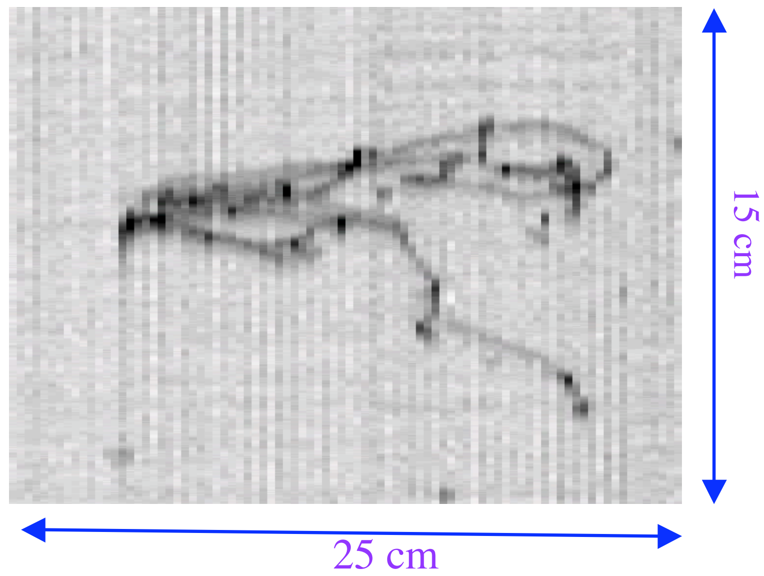
Data taking 68 days (life time >2ms)

Liquid Ar recuperation 3 days

An electronic bubble chamber







Events with leading electron signature

- The CNGS ν_μ spectrum has a most probable energy of about 25 GeV.

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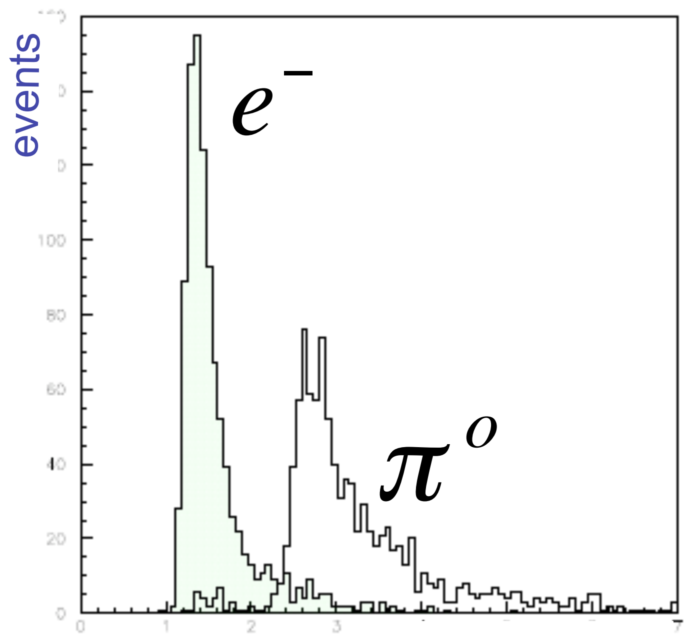
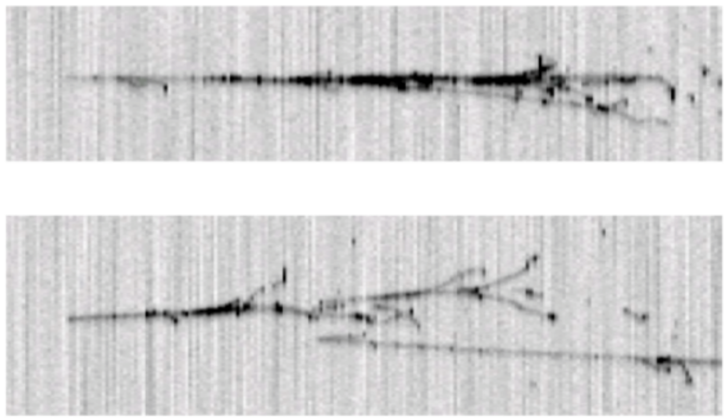
- Electron shower events are extremely well identified experimentally, because of the ionization behaviour in the first cells after the vertex.

Neural Currents background rejected thanks to:

•Vertex reconstruction
•Pion mass reconstruction
•dE/dx analysis of electron/photon tracks

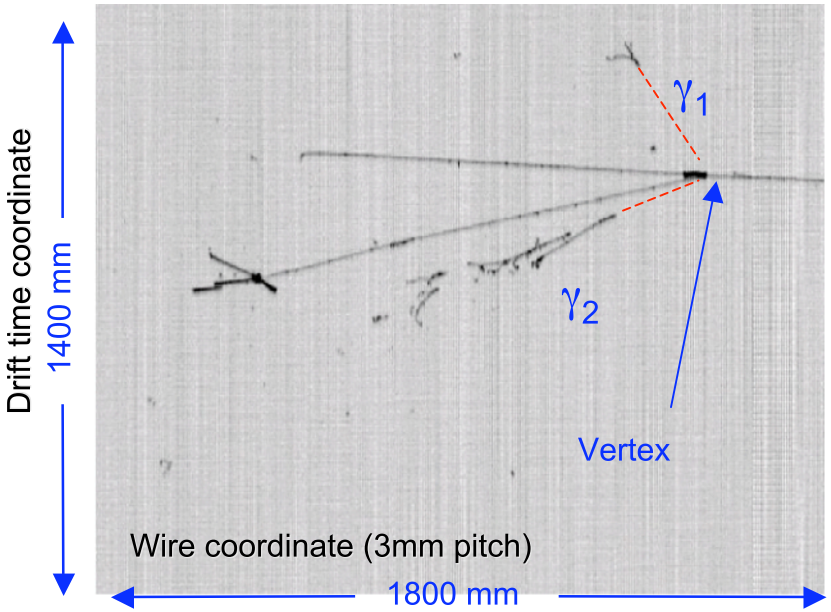


electron (top) and π^0 (bottom) in T600



π^0 reconstruction

230 hadronic interactions with $\pi^0 \rightarrow \gamma\gamma$ candidates have been selected from ICARUS T300 Pavia run



The average (γ,γ) invariant mass is in agreement with the π^0 mass hypothesis ($m_{\pi 0}$ = 135 MeV/c^2);

$$m_{\gamma\gamma} = 127.7 \pm 3.0(stat) \pm 4.0(sys)\mathrm{MeV/c^2}$$

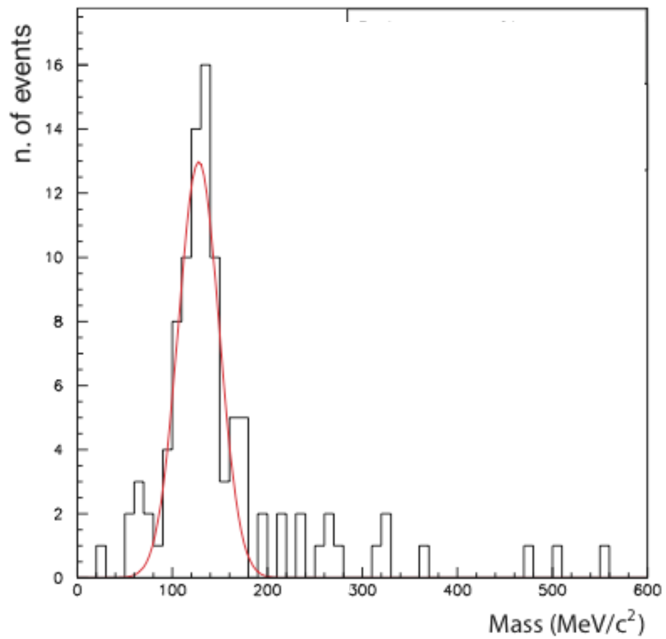
The systematic error is mostly due to the calibration

The measured photon radiation length is

$$X_{\gamma,meas} = (17.4 \pm 0.8)\mathrm{cm}$$

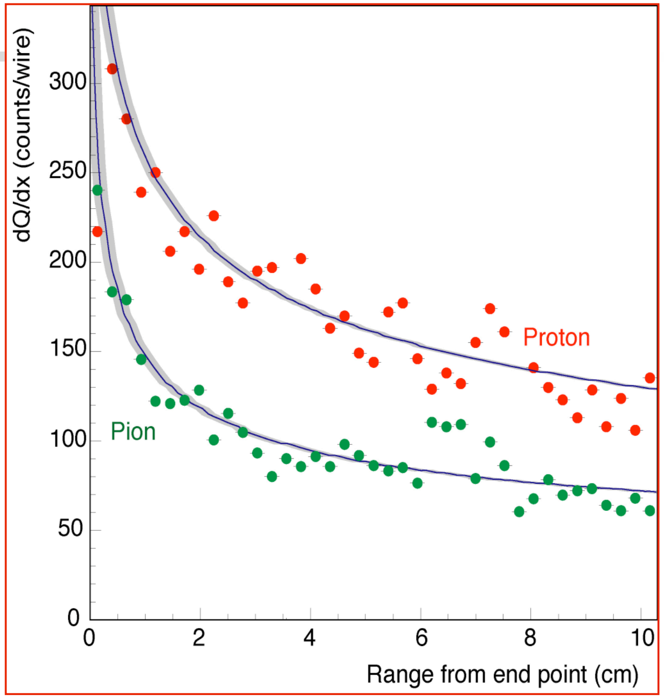
in agreement with expectation:

$$X_{\gamma,\exp} = \frac{9}{7} \cdot 14\mathrm{cm} = 18\mathrm{cm}$$



Detector performance

- Measurement of local energy deposition:
  - Electron / gamma separation (3mm)
  - Particle ID by means of dE/dx vs range measurement



- Total energy reconstruction of the events from charge integration ➔ **excellent calorimeter** with high accuracy for contained events

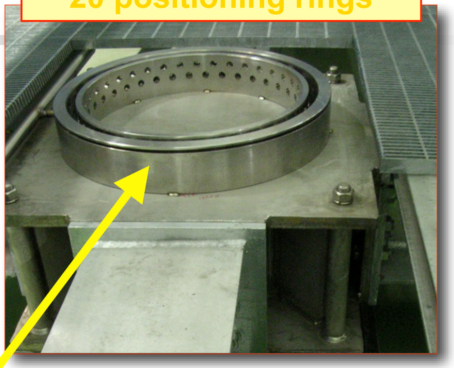
RESOLUTIONS

Low energy electrons:	$\sigma(E)/E = 7\% / \sqrt{E(MeV)}$
Electromagn. showers:	$\sigma(E)/E = 3\% / \sqrt{E(GeV)}$
Hadronic showers (pure LAr):	$\sigma(E)/E = 16\% / \sqrt{E(GeV)} + 1\%$
Hadronic showers (+TMG):	$\sigma(E)/E = 12\% / \sqrt{E(GeV)} + 0.2\%$

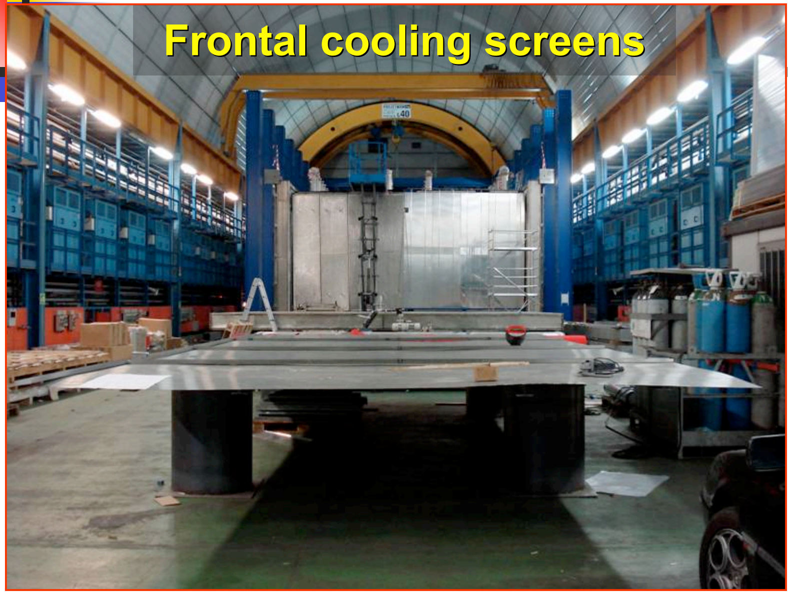
Supporting structure

- **Insulation acts as a containment box in case of cryogenic liquid spillages and stands 100 mbar overpressure**

20 positioning rings



Insulation closure



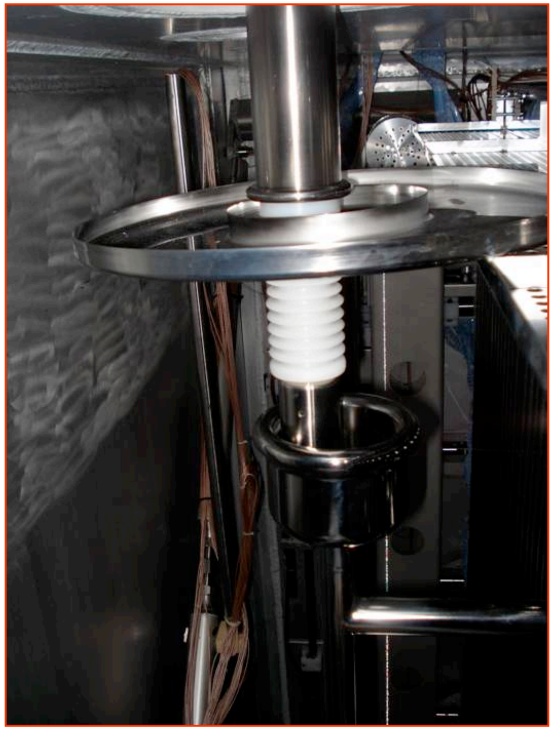
External structure

Internal checks

- Cathode and racetrack holding mechanics
- Field shape resistors check
- Electrical continuity check
- HV feed-through mounting

✓ HV system is in perfect conditions

  ➔ No effects due to transportation

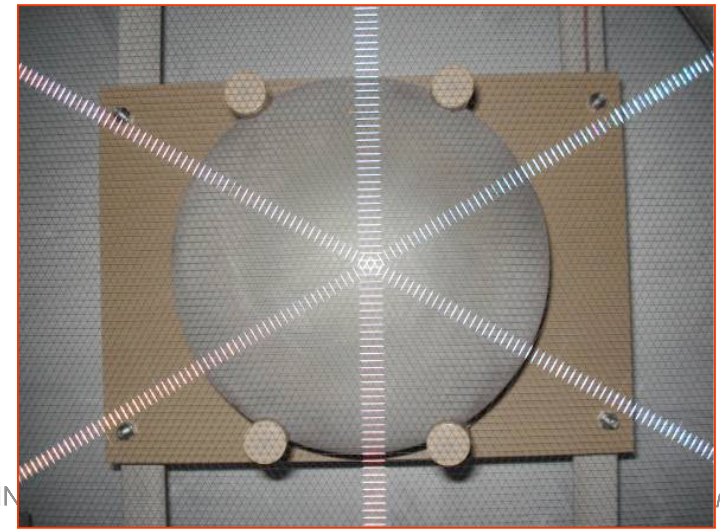


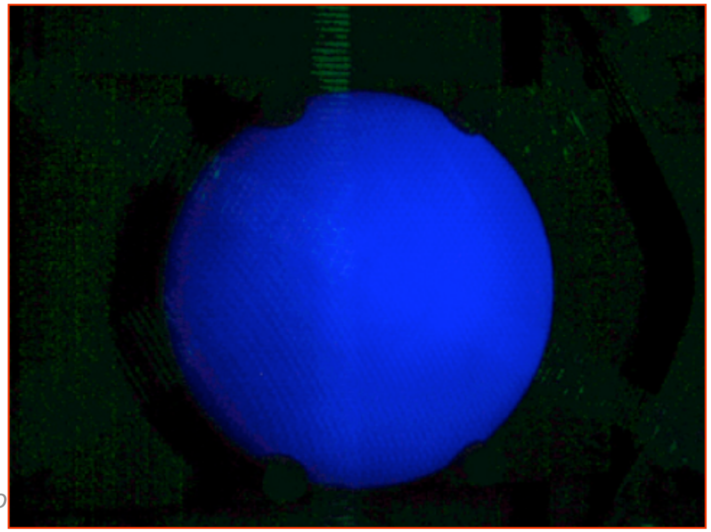
PMTs

- Survey of the PM integrity
- Check of the TPB coatings on the PM surfaces by means of an UV lamp
  - No visible aging effect,
  - No difference between the 2 T300
  - Stability & adherence of the shifter coating

✓the PM system was found in good conditions

➔No effects due to transportation, aging (7 years), cooling and LAr immersion

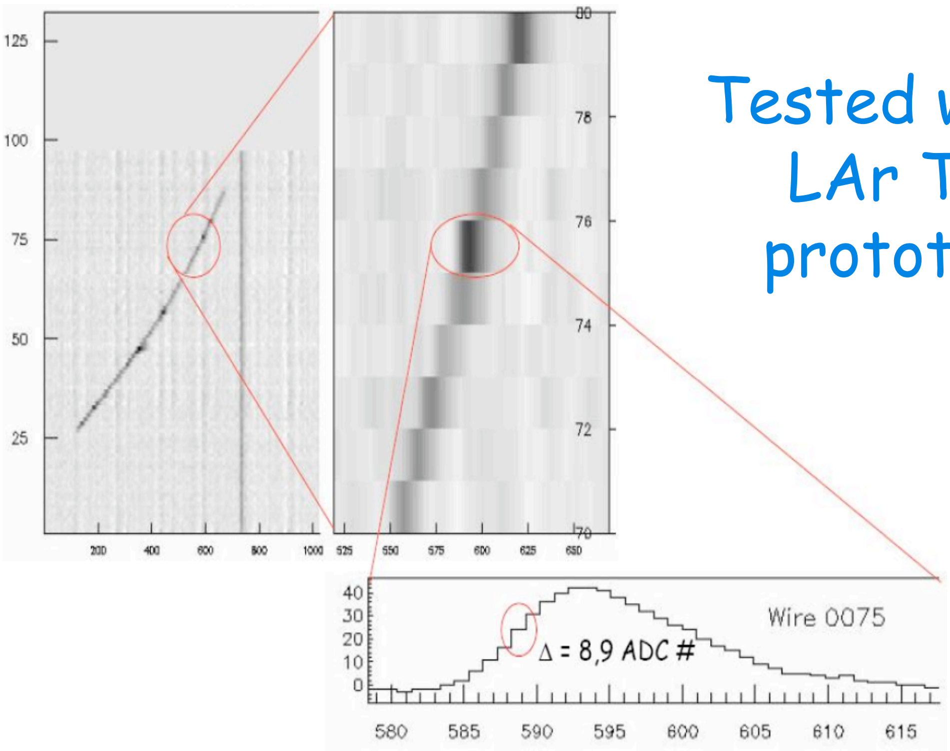




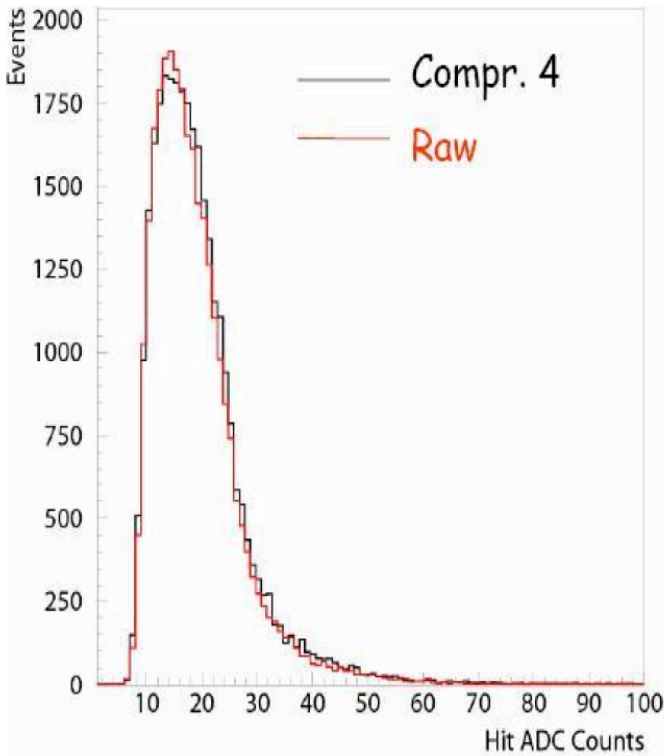
New digital data compression

New firmware implements loss-less factor-4 data compression.

- It stores **difference** between consecutive samples (4 bit -> ±7 ADC counts) instead of **absolute values** (10bit).
- It handles overflows in case of differences more than ±7 ADC counts (see picture)

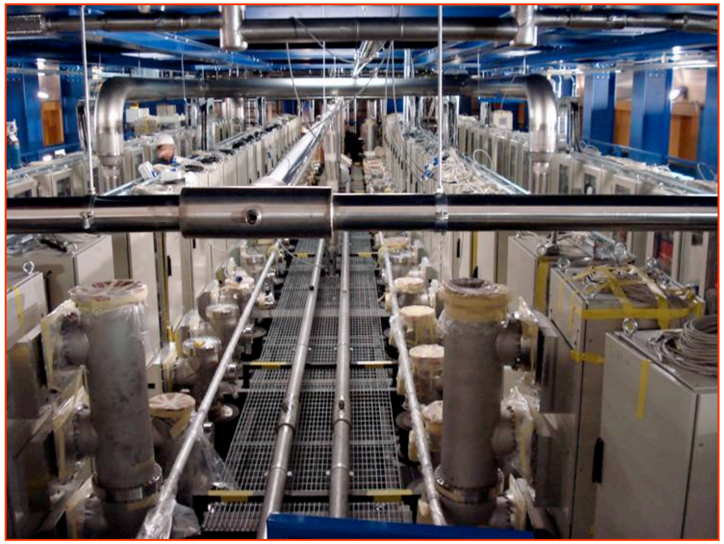


Tested with a LAr TPC prototype



Present status

- 88 front-end electronic racks (fully instrumented and off-line tested) in their final position on the T600 top.
- 6 trigger /DAQ control racks + 2 cabinets for detector power supply placed on the top of the service structure.
- The overall rack connection is ongoing.
- **Noise test ongoing on the connected racks.**



Conclusions

- T600 installation in an underground laboratory with all required infrastructures and safety requirements has been more complex and slower than expected.
- However impressive progress in the T600 installation have been achieved in the last months. Detector and data acquisition are ready.
- The filling of the T600 operation now is mainly depending on the ongoing commissioning of the re-liquefier and crygenics interconnections.
- The filling of the nearly 700 ton of liquid Argon cannot start before middle of October and it should last 2-3 weeks.
- The detector is expected to operate both with cosmic neutrinos and accelerator beam. T600 will not be ready before the end of 2008 beam, but important cosmic data will be recorded before the end of 2008.