R&D Plan towards 100 kton LAr Detector

A. Marchionni, ETH Zurich
NNN08, Paris, Sept. 2008

- GLACIER: a concept for a scalable LAr detector up to ~ 100 kton
  - a precision detector for
    - proton decay searches
    - neutrino oscillation measurements
    - low energy neutrino astronomy
    - same technique suitable for dark matter searches
- Necessary R&D and plans
  - dewar design, safety, underground operation
  - novel readout techniques, electronics (performance, reliability, cost reduction,…)
- LAr LEM-TPC: a novel scalable detector for cryogenic operation
  - first operation of a 0.1 x 0.1 m^2 test setup
  - low-noise preamplifiers and DAQ developments
- ArDM: a ton-scale LAr detector with a 1 x 1 m^2 LEM readout
  - status of the inner detector
  - cryogenics and first cool down
- Conclusions

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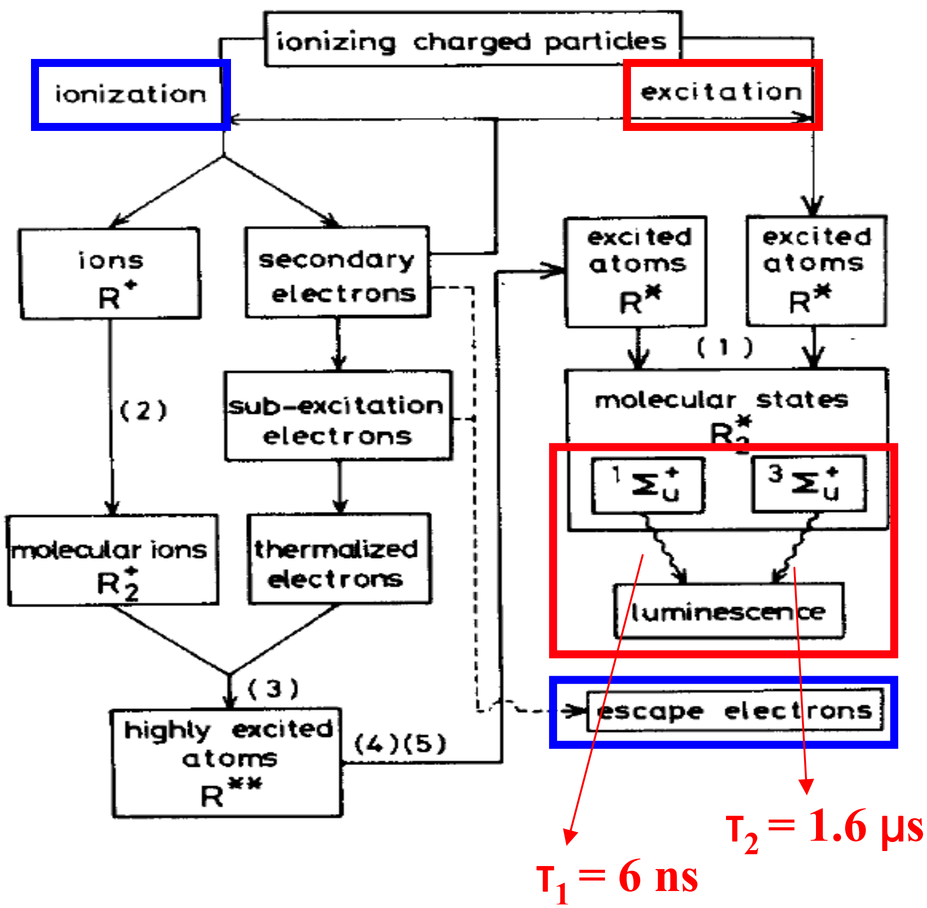
Processes induced by charged particles in liquid argon



M. Suzuki et al., NIM 192 (1982) 565

When a charged particle traverses medium:

- **Ionization** process
- **Scintillation** (luminescence)
  - UV spectrum (λ=128 nm)
  - Not energetic enough to further ionize, hence, argon is transparent
  - Rayleigh-scattering
- **Cerenkov light** (if fast particle)

→ *UV light*

→ *Charge*

→ *Cerenkov light (if $\beta > 1/n$)*

Comparison Water - liquid Argon

Particle	Cerenkov Threshold in H_2O (MeV/c)	Corresponding Range in LAr (cm)
e	0.6	0.07
μ	120	12
π	159	16
K	568	59
p	1070	105

- LAr allows lower thresholds than Water Cerenkov for most particles
- Comparable performance for low energy electrons

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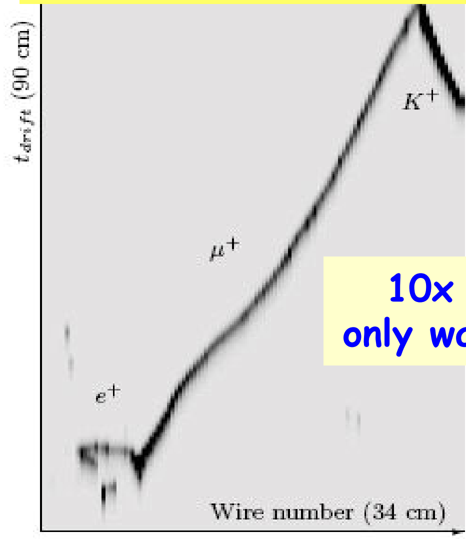
LAr TPC as proton decay and neutrino detector

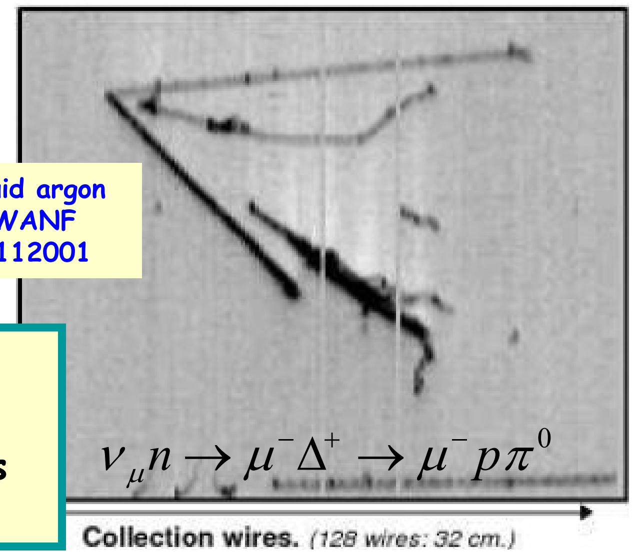
LAr MC: $p \to K^+ \bar{\nu}$



A. Bueno et al. "Nucleon decay searches with large liquid Argon TPC detectors at shallow depths: atmospheric neutrinos and cosmogenic background", JHEP04 (2007) 041

10x efficiency than WC
only way to reach 10^{35} years

F. Arneodo et al., "Performance of a liquid argon time projection chamber exposed to the WANF neutrino beam", Phys. Rev. D 74 (2006) 112001



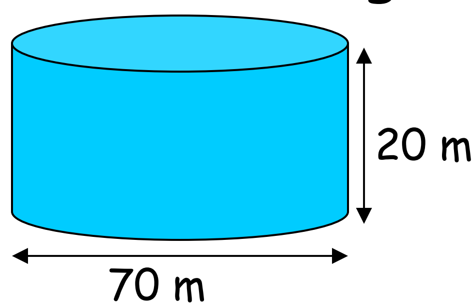
A LAr TPC is the best detector for $\nu_\mu \to \nu_e$ oscillation searches:

- provides high efficiency for ν_e charged current interactions
- adequate rejection against ν_μ NC and CC backgrounds

- A.Meregaglia, A. Rubbia, "Neutrino oscillation physics at an upgraded CNGS with large next generation liquid argon TPC detectors", JHEP 0611:032, 2006
- V. Barger et al., "Report of the US long baseline neutrino experiment study", arXiv:0705.4396, May 2007
- A. Badertscher et al., "A possible future long baseline neutrino and nucleon decay experiment with a 100 kton Liquid Argon TPC at Okinoshima using the J-PARC neutrino facility", arXiv:0804.2111, March 2008
  - see also T. Hasegawa, "J-PARC neutrino beam", talk at this Workshop

A LAr detector …

- must be **BIG** to be competitive with other technologies
  - 50 ÷ 100 kton range



⇨ 100 kton

- drift lengths of at least a few meters are necessary

Shopping list for a large LAr detector:

- Dewar (underground construction and operation)
- Argon procurement and purification system
- High Voltage system
- Readout device → **R&D on novel readout techniques, other than wires, possibly with amplification of the ionization signals**
- Electronics → **R&D on warm/cold solutions**
- Detector engineering
- Prototypes and "Test" beams

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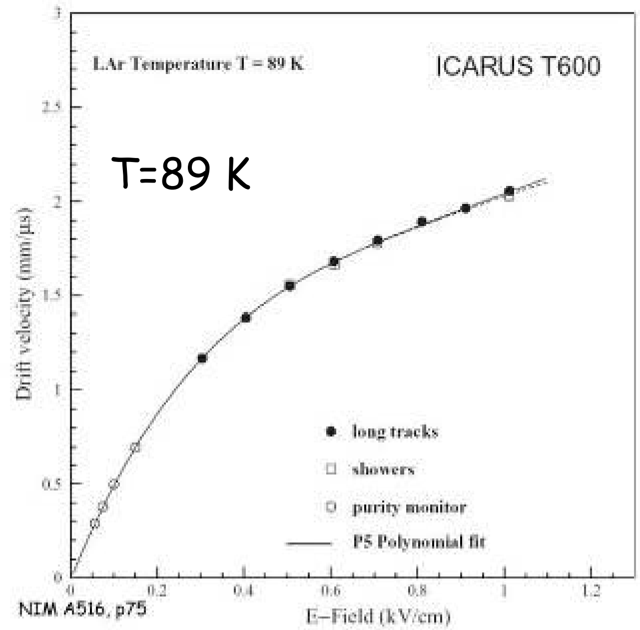
Can we drift over over long distances?

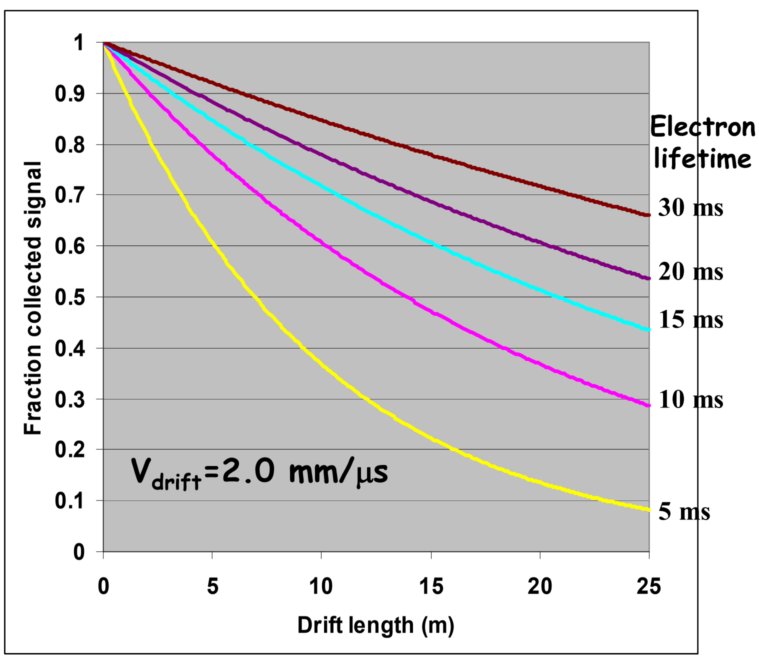
- HV feedthrough tested by ICARUS up to 150 kV (E=1kV/cm in T600)
- v_{drift}= 2 mm/μs @ 1kV/cm
- Diffusion of electrons:

$$\sigma_d = \sqrt{2 \times D \times t}, D = 4.8 \pm 0.2\ cm^2 s^{-1}$$

σ_d=1.4 mm for t=2 ms (4 m @ 1 kV/cm)

σ_d=3.1 mm for t=10 ms (20 m @ 1 kV/cm)





- to drift over macroscopic distances, LAr must be very pure
  - a concentration of 0.1 ppb Oxygen equivalent gives an electron lifetime of 3 ms
- for a 20 m drift and >30% collected signal, an electron lifetime of at least 10 ms is needed

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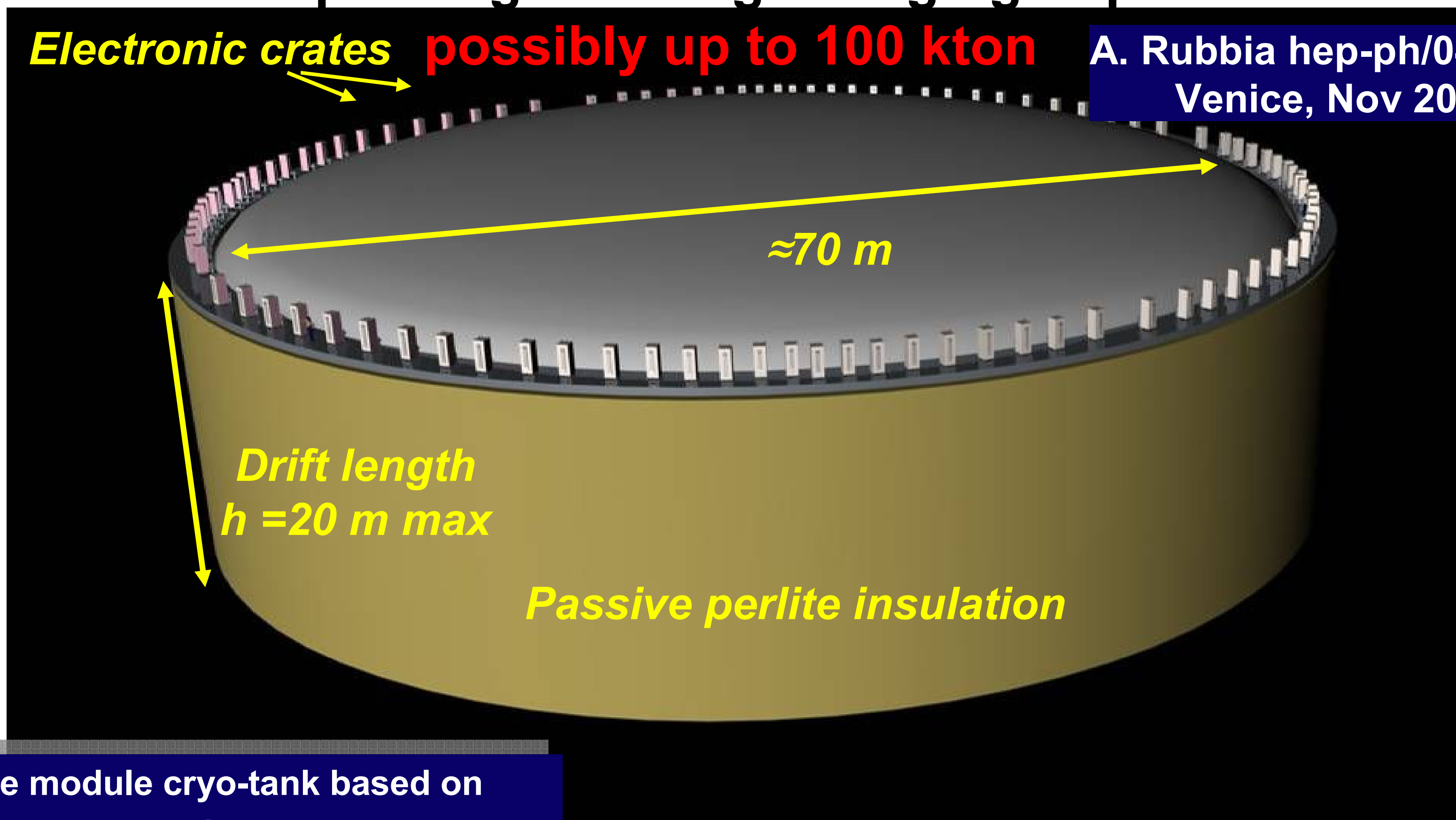
GLACIER

A scalable detector with a non-evacuable dewar and ionization charge detection with amplification

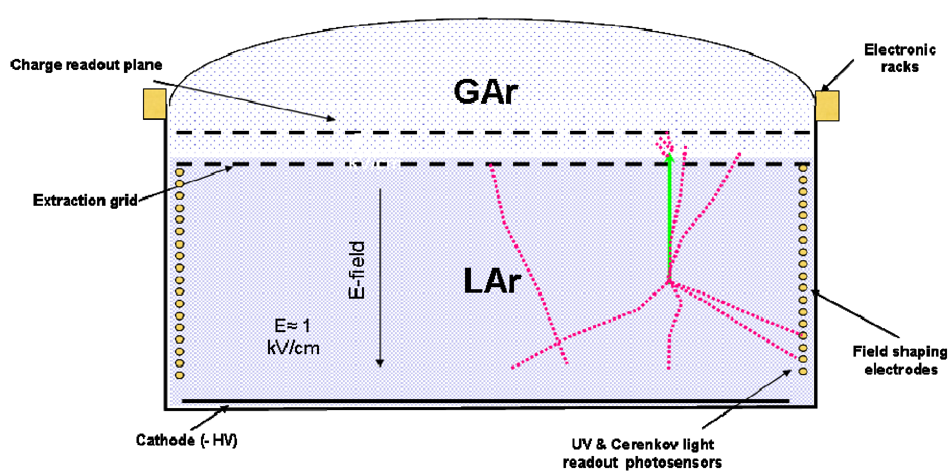
Giant Liquid Argon Charge Imaging ExpeRiment



Single module cryo-tank based on industrial LNG technology

GLACIER concepts for a scalable design

- **LAr storage based on LNG tank technology**
  - Certified LNG tank with standard aspect ratio
  - Smaller than largest existing tanks for methane, but underground
  - **Vertical electron drift** for full active volume
- A new method of readout (**Double-phase with LEM**)
  - to allow for very long drift paths and cheaper electronics
  - to allow for low detection threshold (≈50 keV)
  - to avoid use of readout wires
  - A path towards pixelized readout for 3D images
- **Cockroft-Walton (Greinacher) Voltage Multiplier** to extend drift distance
  - High drift field of 1 kV/cm by increasing number of stages, w/o VHV feed-through
- **Very long drift path**
  - Minimize channels by increasing active volume with longer drift path
- **Light readout** on surface of tank
- Possibly immersed superconducting solenoid for B-field



Scalable detector

Size (kton)	Diameter (m)	Height (m)
100	70	20
10	30	10
1	10	10

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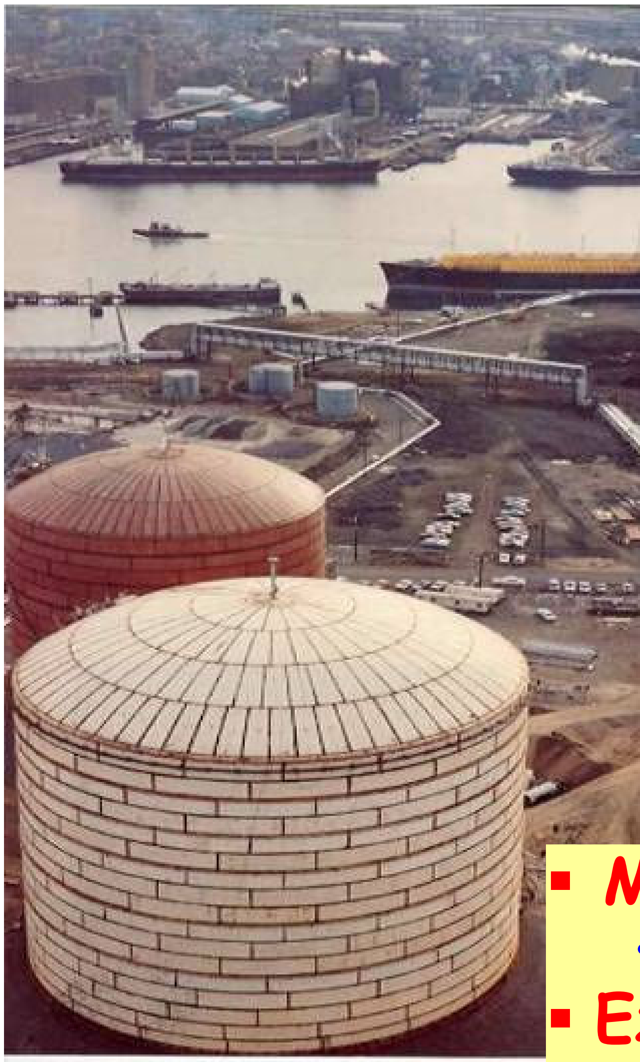
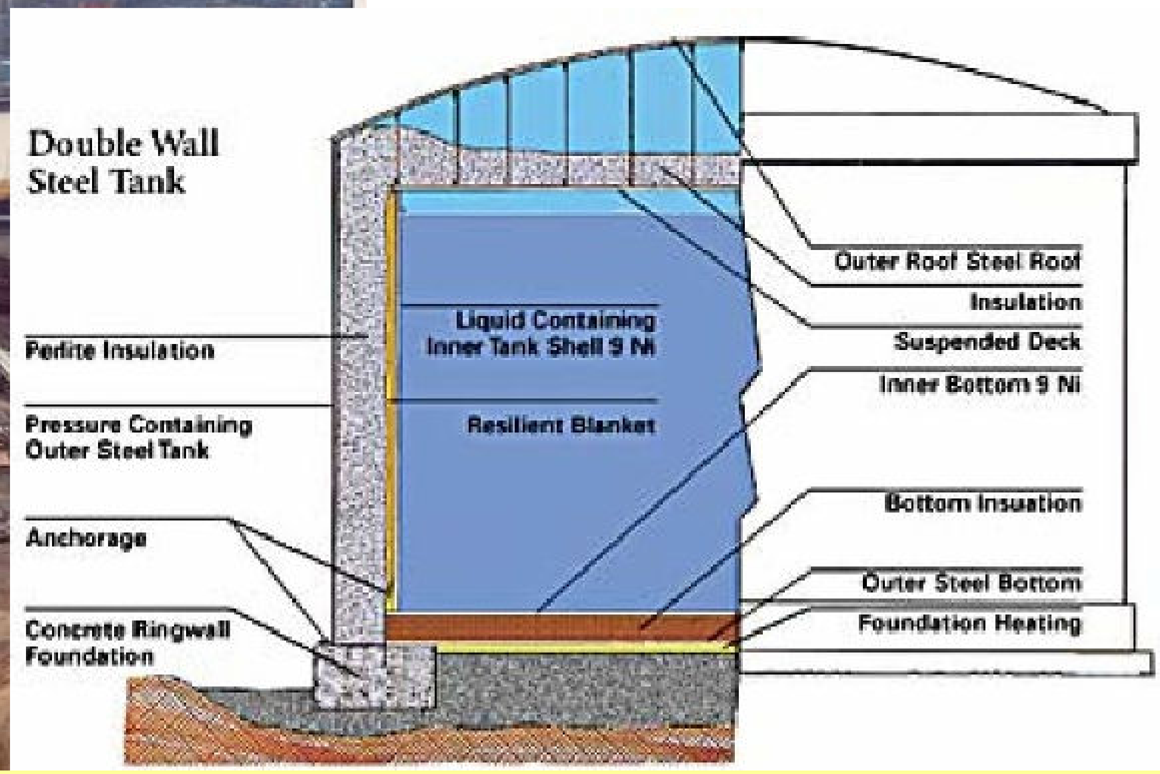
Cryogenic storage tanks for LNG





- **Many large LNG tanks in service**
  - Vessel volumes up to 200000 m^3
- **Excellent safety record**
  - Last serious accident in 1944, Cleveland, Ohio, due to tank with low nickel content (3.5%)

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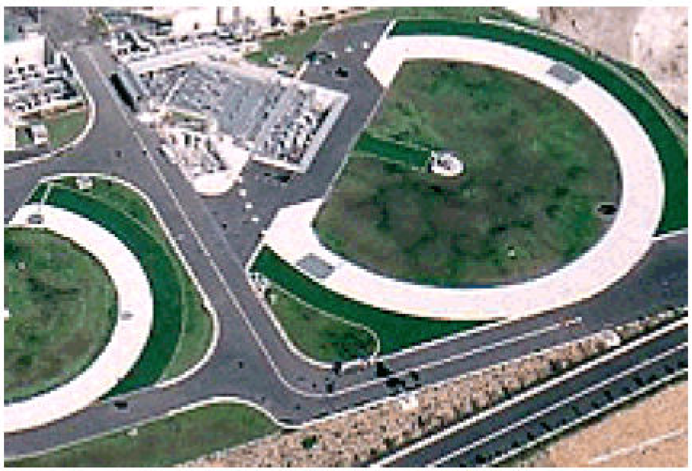
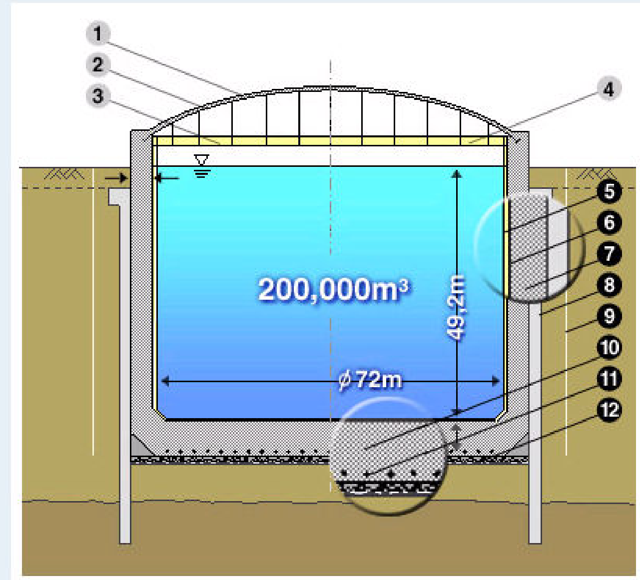
More on LNG storage tanks

Bird's-eye view of in-ground storage tanks



Bird's-eye view of underground storage tanks

In-ground and underground storage tanks from Tokyo Gas

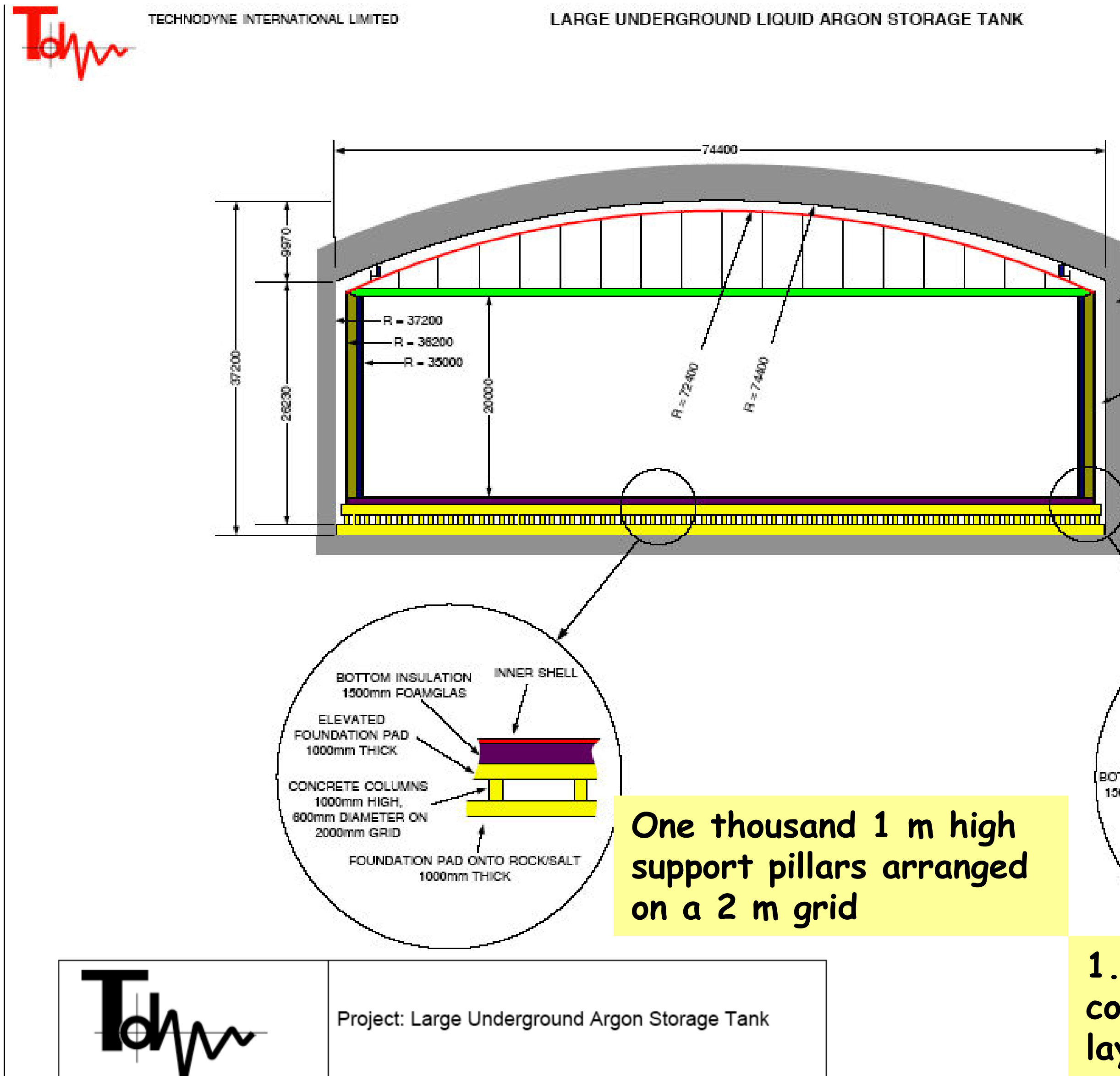


Tokyo Gas

LAr vs LNG (≥ 95% Methane)

- **Boiling points of LAr and CH_4 are 87.3 and 111.6 °K**
- **Latent heat of vaporization per unit volume is the same for both liquids within 5%**
- **Main differences:**
  - **LNG flammable when present in air within 5 – 15% by volume, LAr not flammable**
  - **$\rho_{LAr} = 3.3\ \rho_{CH4}$, tank needs to withstand 3.3 times higher hydrostatic pressure**

A first study of an underground LAr storage tank



Full containment tank consisting of an inner and an outer tank made from stainless steel

Tanks construction:
6 mm thick at the base, sides ranging from 48 mm thick at the bottom to 8 mm thick at the top

One thousand 1 m high support pillars arranged on a 2 m grid

1.2 m thick side insulation consisting of a resilient layer and perlite fill

A feasibility study mandated to Technodyne Ltd (UK): Feb-Dec 2004

Estimated boil-off 0.04%/day

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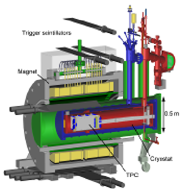
Dewar Considerations

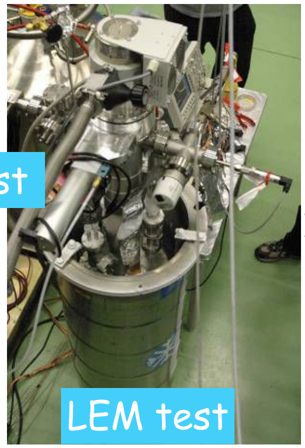
- **The dewar technology is a crucial choice for huge LAr detectors**
  - **A modular approach is unfeasible for ~100 kton LAr mass (cost, complications, …)**
  - **Huge evacuable dewars (~40x40x40 m^3) have quite a complicated mechanical structure and might present safety problems during evacuation**
  - **Huge non-evacuable dewars are currently built as LNG containers , also as underground installation**
    - heat input and argon consumption have to be carefully evaluated (⇨ running costs)
    - purification of such large volumes starting from air at atmospheric pressure should not be a problem (but R&D on powerful clean cryogenic pumping system is essential)
    - a harder problem is how to check for leaks, which might limit the achievable argon purity, if it is not possible to evacuate the dewar. Will have to rely on careful checks of all welding joints …
  - ***Case studies of specific European sites by Technodyne in the framework of the LAGUNA project by 2010***

Steps towards GLACIER

Small prototypes ➠ ton-scale detectors ➠ 1 kton ➠ ?

B-field test





LEM test

proof of principle double-phase LAr LEM-TPC on $0.1 \times 0.1\ m^2$ scale

➠

LEM readout on $1 \times 1\ m^2$ scale
UHV, cryogenic system at ton scale, cryogenic pump for recirculation, PMT operation in cold, light reflector and collection, very high-voltage systems, feed-throughs, industrial readout electronics, safety (in Collab. with CERN)

ArDM ton-scale

we are here

➠ **direct proof of long drift path up to 5 m**

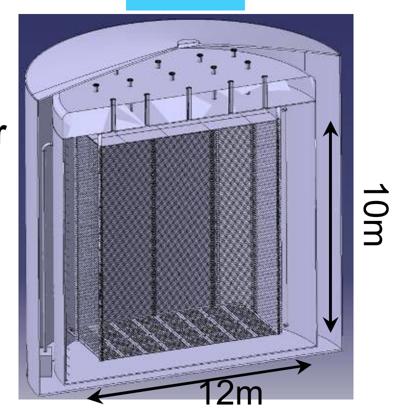
ArgonTube: long drift, ton-scale

➠ **Application of LAr LEM TPC to neutrino physics**: particle identification (200-1000 MeV electrons), optimization of readout and electronics, cold ASIC electronics, possibility of neutrino beam exposure

Test beam
1 to 10 ton-scale

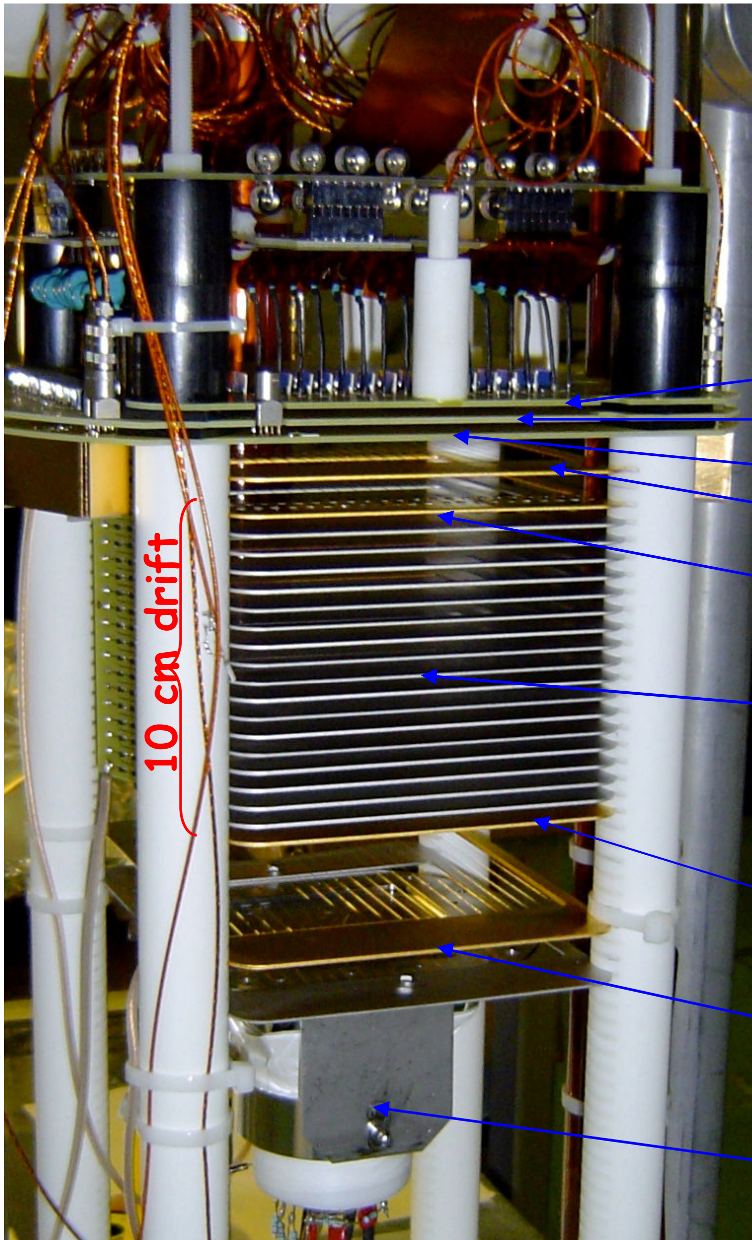
➠ **full engineering demonstrator for larger detectors**, acting as near detector for neutrino fluxes and cross-sections measurements, …

1 kton

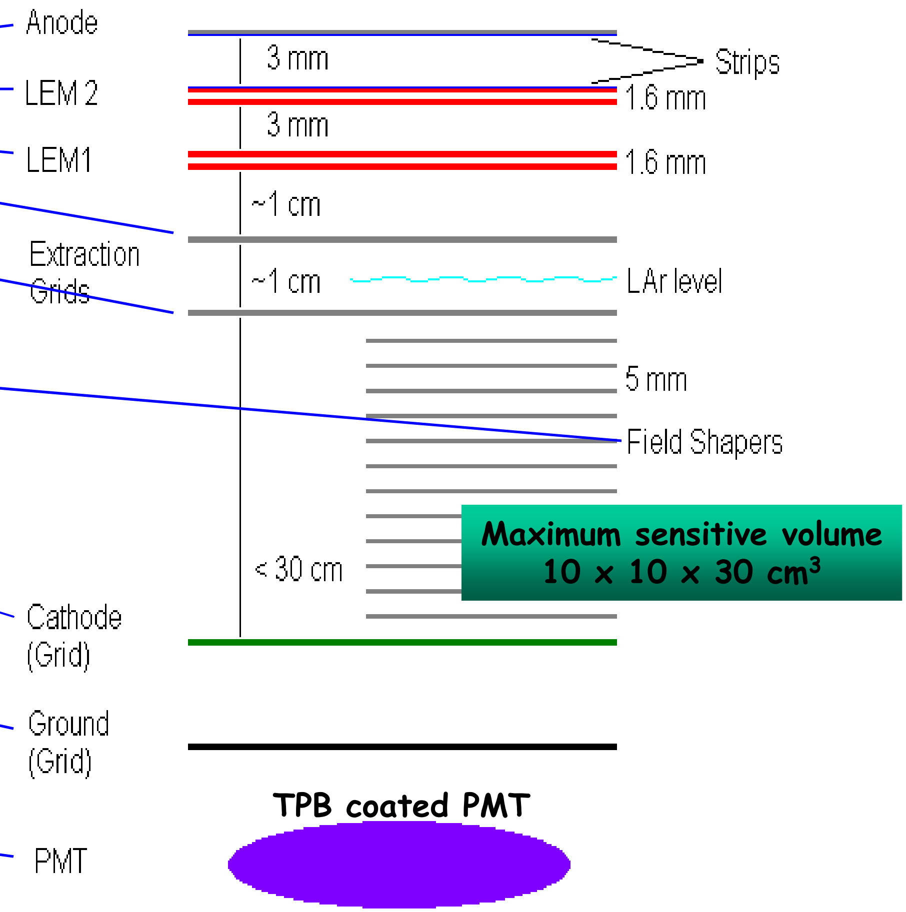


LAr LEM-TPC

A novel kind of LAr TPC based on a Large Electron Multiplier (LEM)

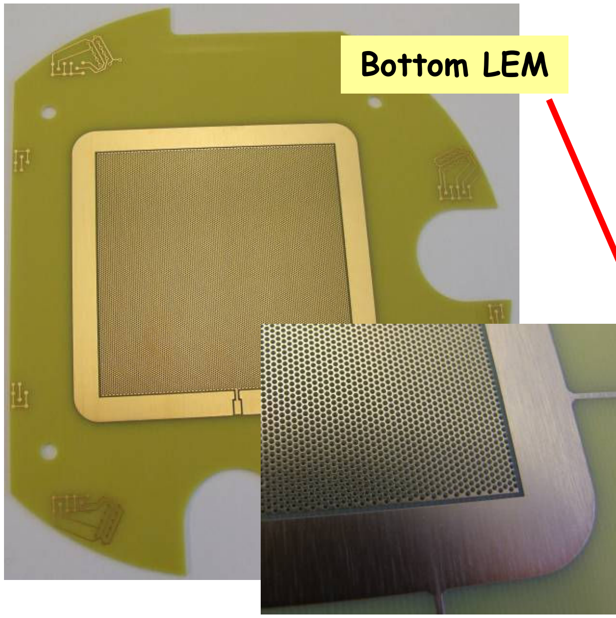


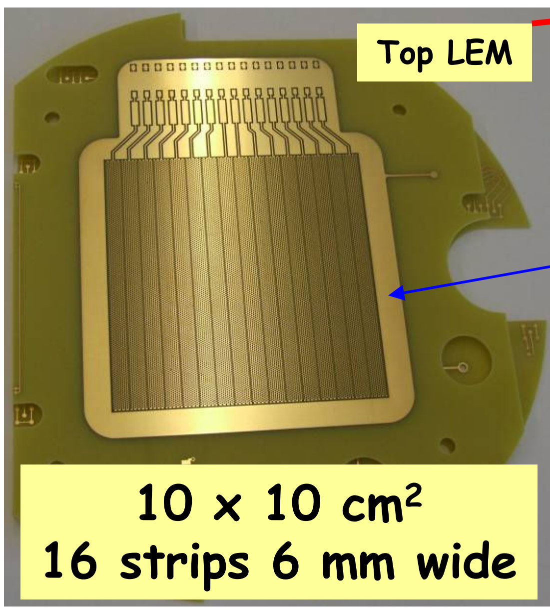
A. Badertscher et al., 'Construction and operation of a double phase LAr Large Electron Multiplier TPC', accepted contribution at the 2008 IEEE Nucler Science Symposium, Dresden, Germany

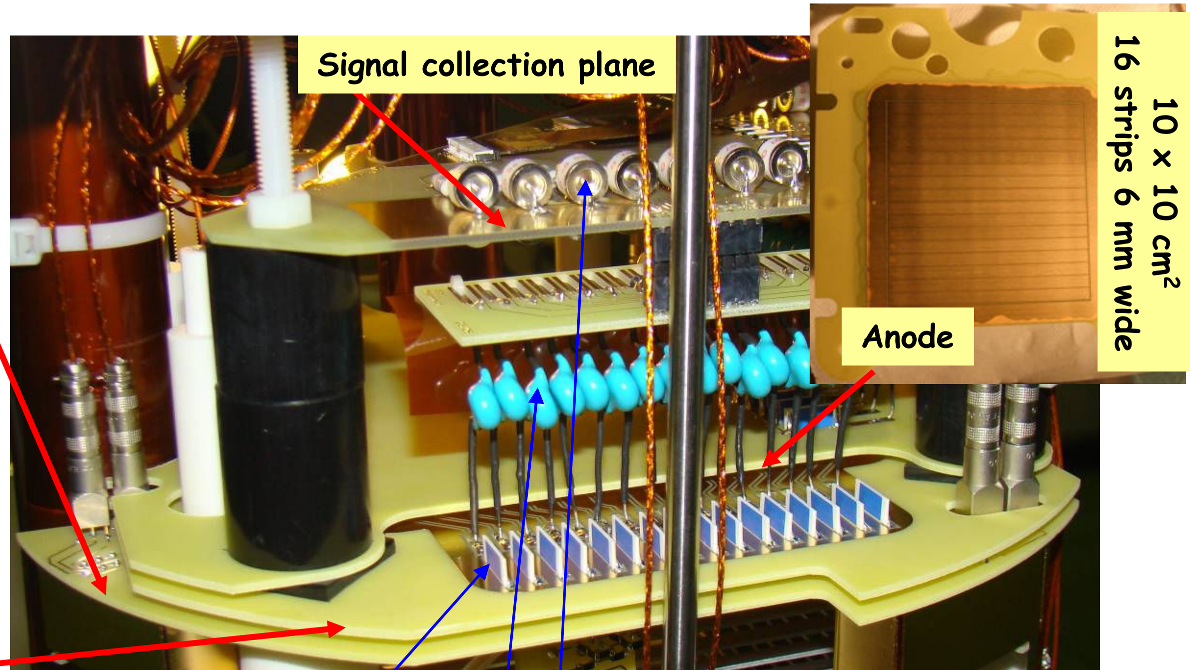


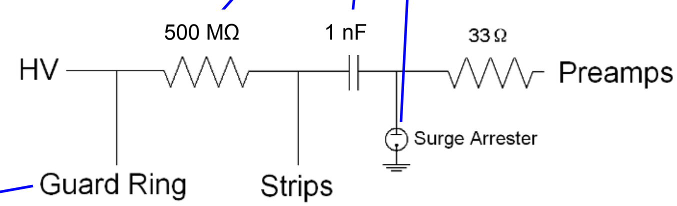
Operated in double phase: liquid-vapor

Double stage LEM with Anode readout



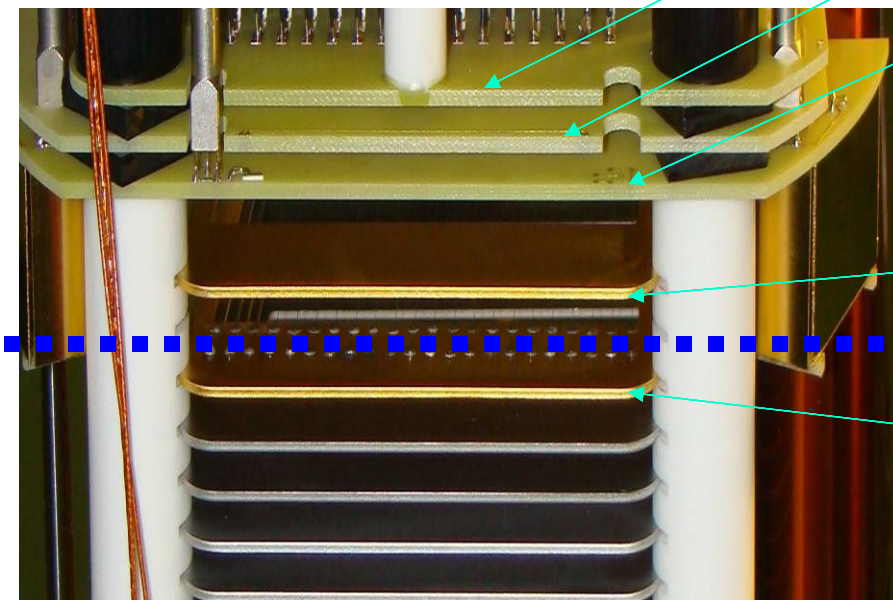


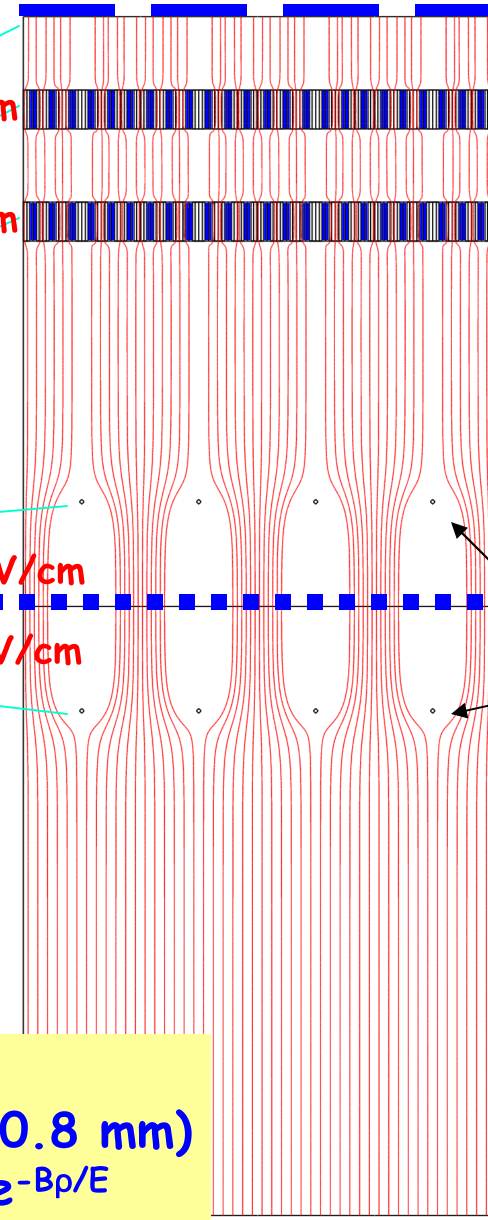




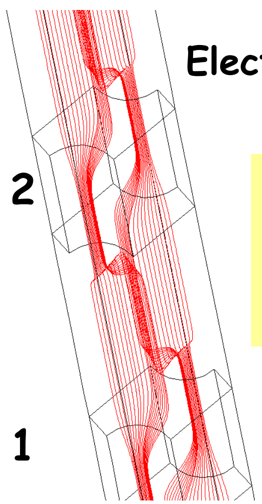
- Produced by standard Printed Circuit Board methods
- Double-sided copper-clad (18 μm layer) FR4 plates
- Precision holes by drilling
- Gold deposition on Cu (<~ 1 μm layer) to avoid oxidization
- Single LEM Thickness: 1.55 mm
- Amplification hole diameter = 500 μm
- Distance between centers of neighboring holes = 800 μm

LAr LEM-TPC: principle of operation





Typical Electric Fields for double-phase operation



Electric field in the LEM region up to 30 kV/cm

$Gain = G_{LEM1} \cdot G_{LEM2} = G^2 = e^{2\alpha x}$

x: effective LEM hole length (~0.8 mm)

α: 1st Townsend coefficient $\approx A\rho e^{-B\rho/E}$

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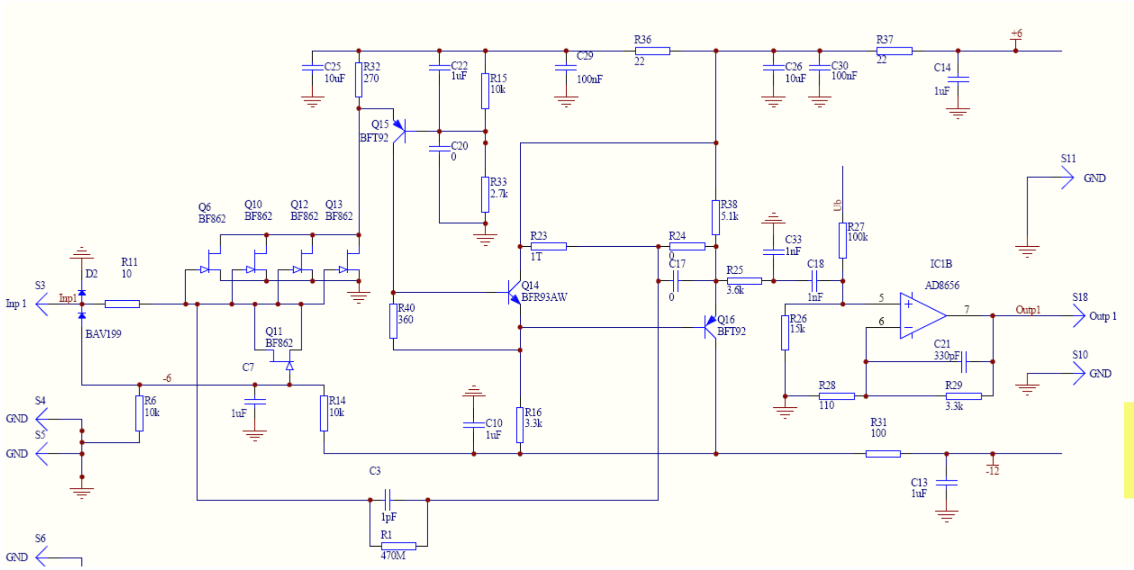
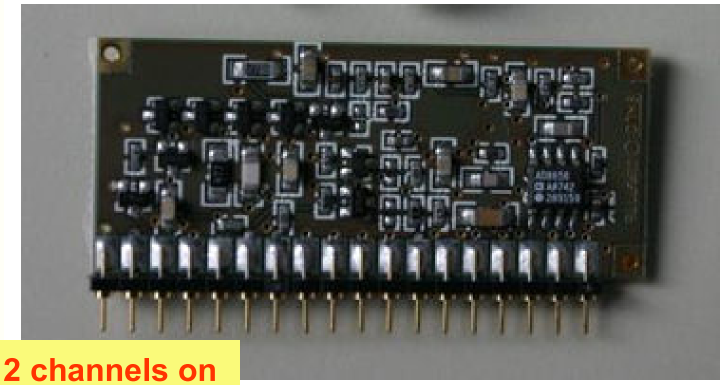
Preamplifier development



Inspired from C. Boiano et al.
IEEE Trans. Nucl. Sci. 52(2004)1931



2 channels on one hybrid

Custom-made front-end charge preamp + shaper

4 different shaping constants — **Measured values**

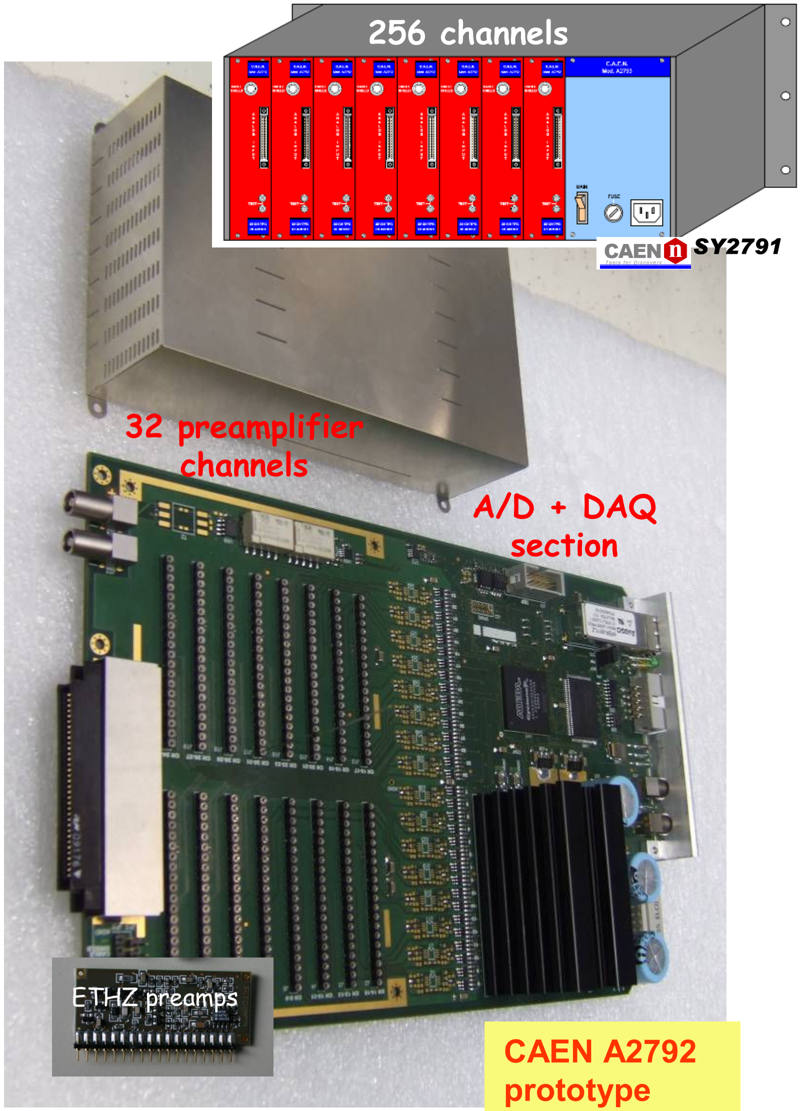
Version	FET integrator decay time constant (μs)	Shaper integration time constant (μs)	Shaper differentiation time constant (μs)	Sensitivity (mV/fC)	Noise (e^-) C_i= 200 pF	S/N @ 1 fC C_i= 200 pF
V1	470	3.6	13	12.5	395	15
V2	470	3.6	1.3	11.9	485	13
V3	470	0.15	0.5	(10)		(6)
V4	470	0.6	2	11.6	620	10

ICARUS electronics (τ_f=1.6 μs)

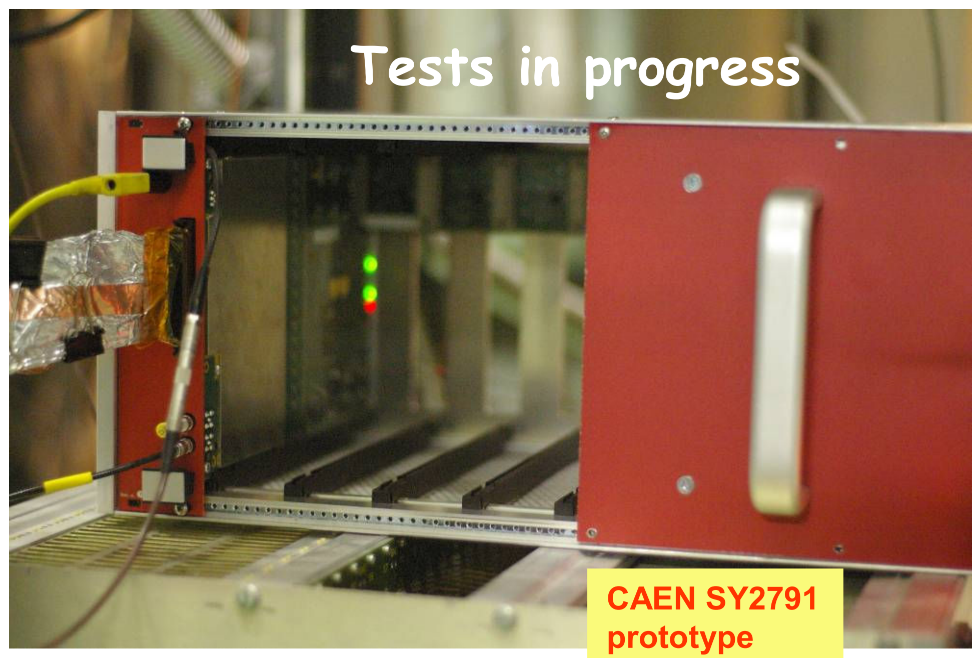
- S/N=10 @ 2 fC, C_i=350 pF
- equivalent to S/N=7 @ 1 fC, C_i=200 pF

Data Acquisition System development

- In collaboration with CAEN, developed A/D conversion and DAQ system



❑ 12 bit 2.5 MS/s flash ADCs + programmable FPGA with trigger logic
❑ Global trigger and channel-by-channel trigger,switch to 'low threshold' when a 'trigger alert' is present
❑ 1 MB circular buffer, zero suppression capability, 80 MB/s chainable optical link to PC



LEM-TPC operation in pure GAr at 300K

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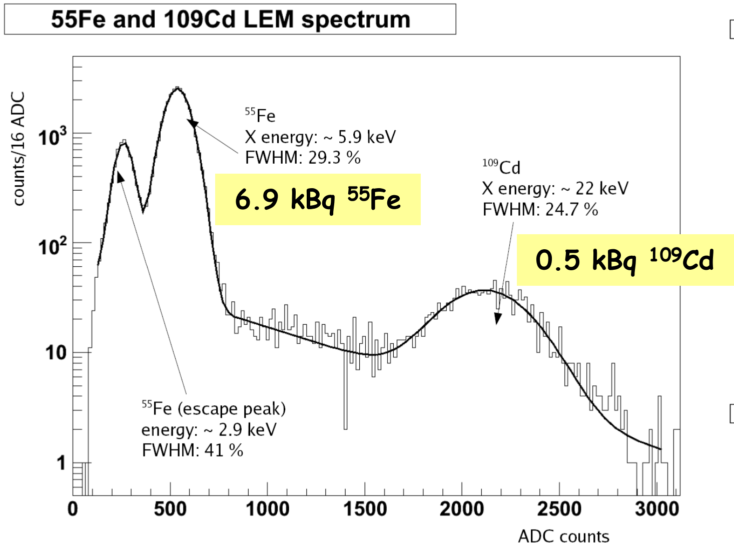
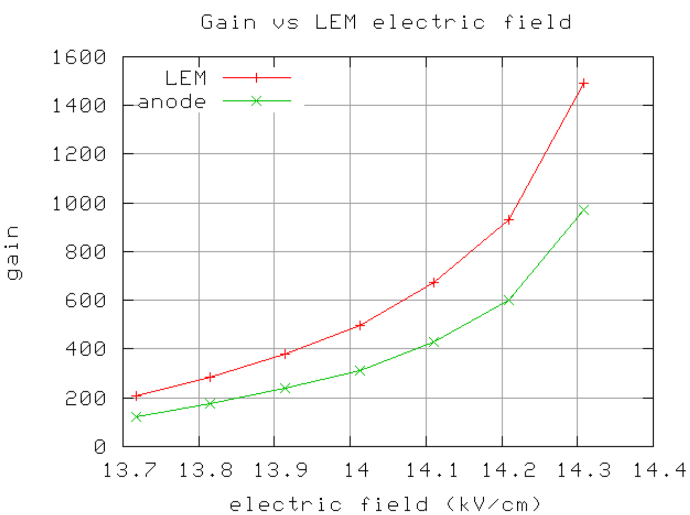
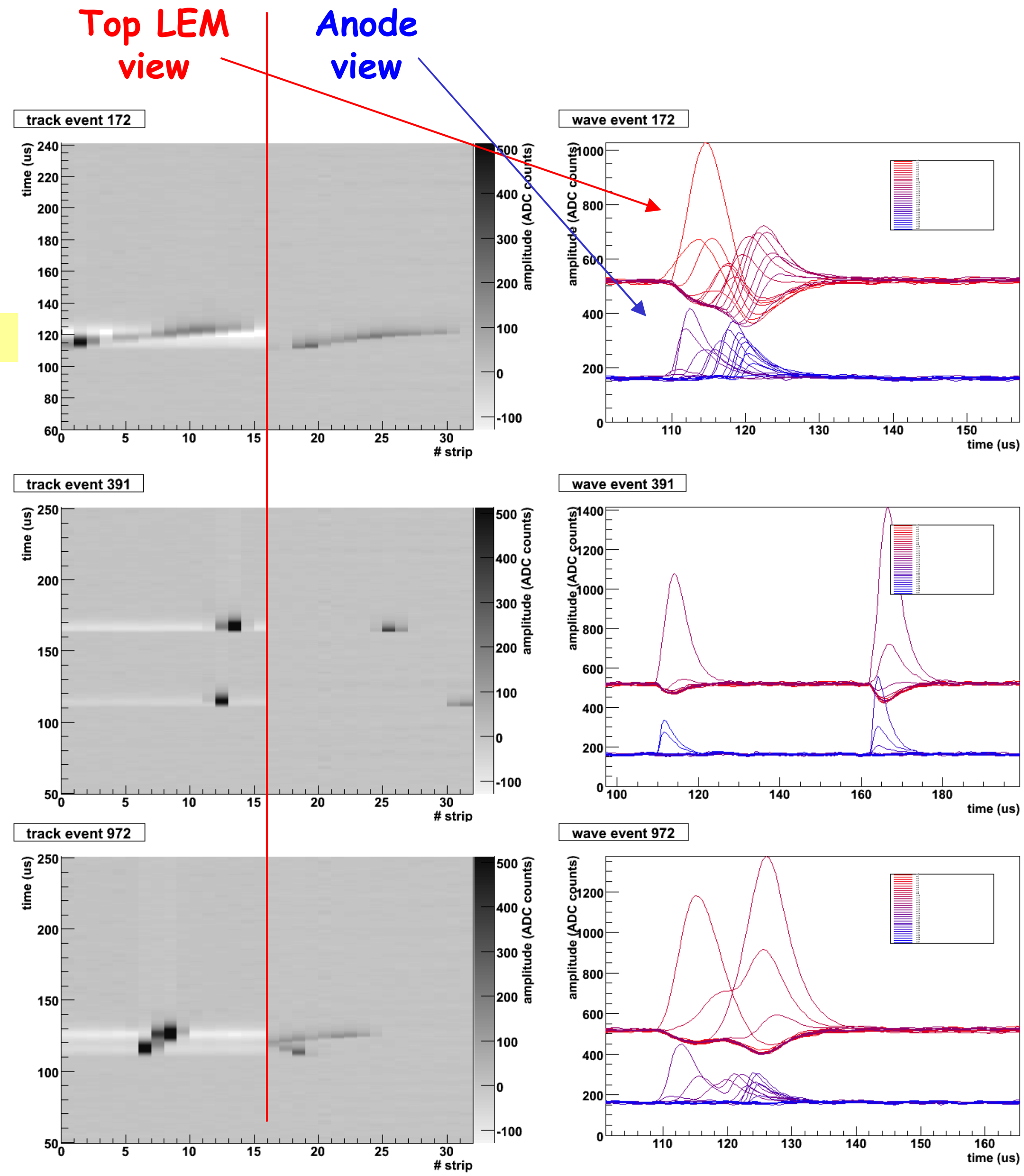
Radioactive sources







Typical cosmic ray events

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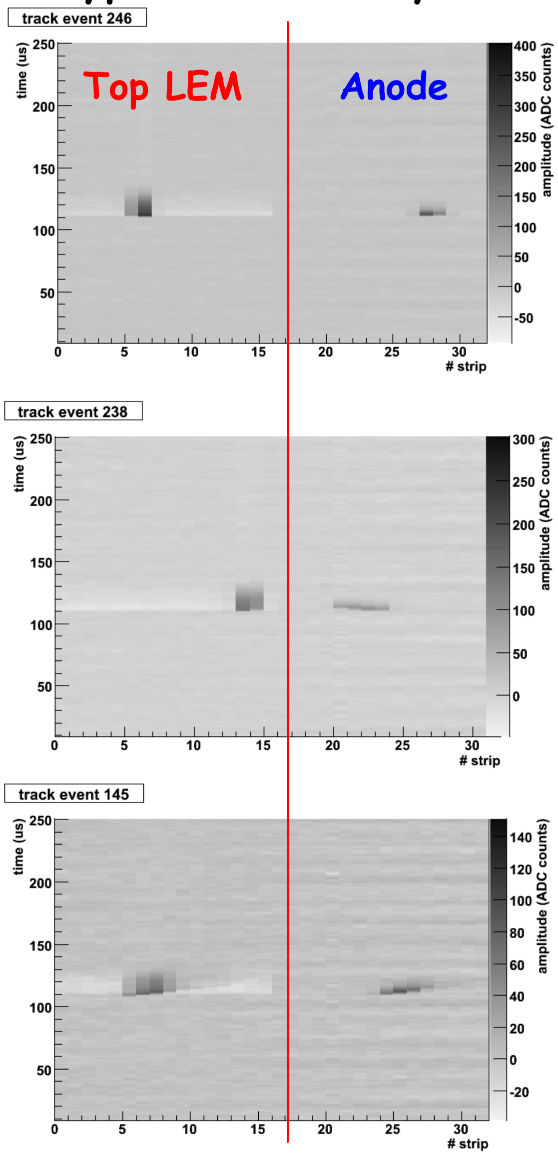
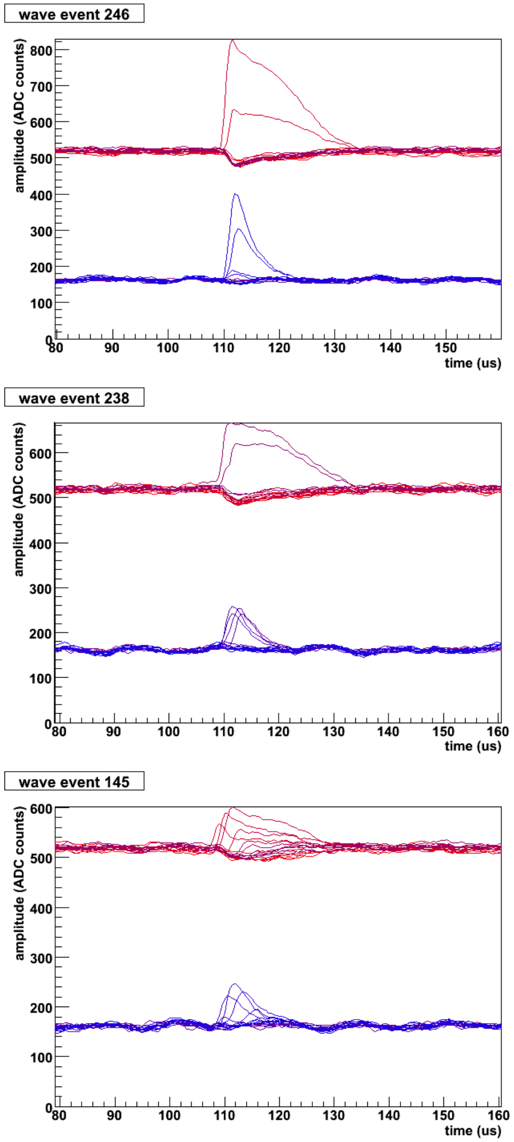
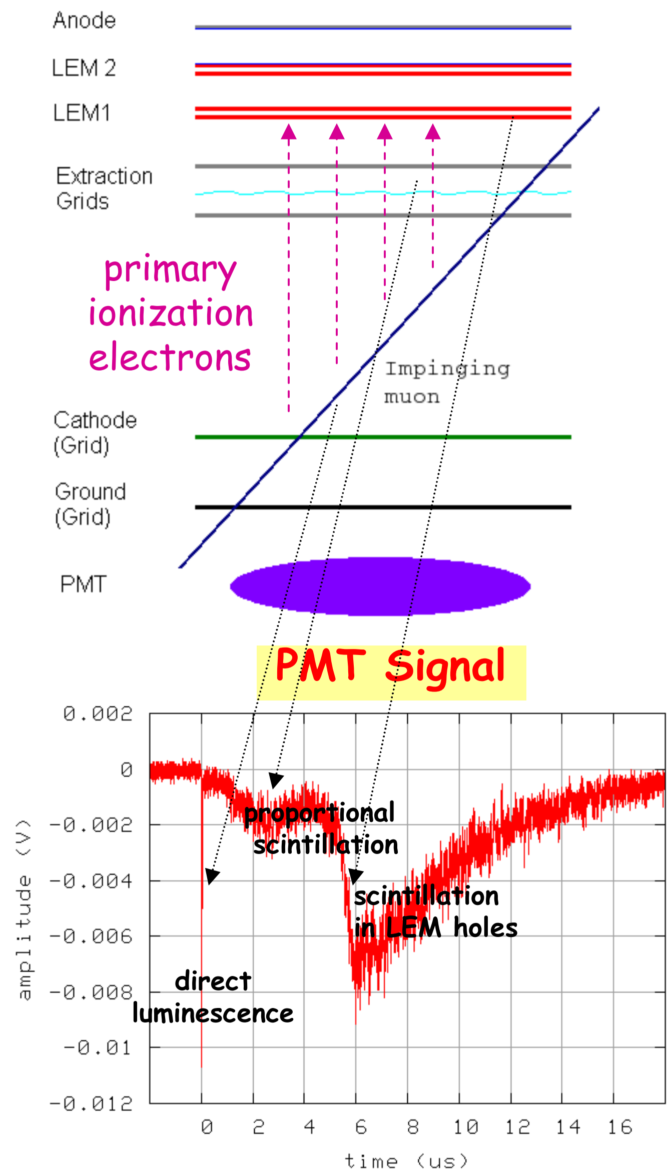
LEM-TPC operation in double phase Ar

Proof of principle of a LAr LEM-TPC

Typical cosmic ray events







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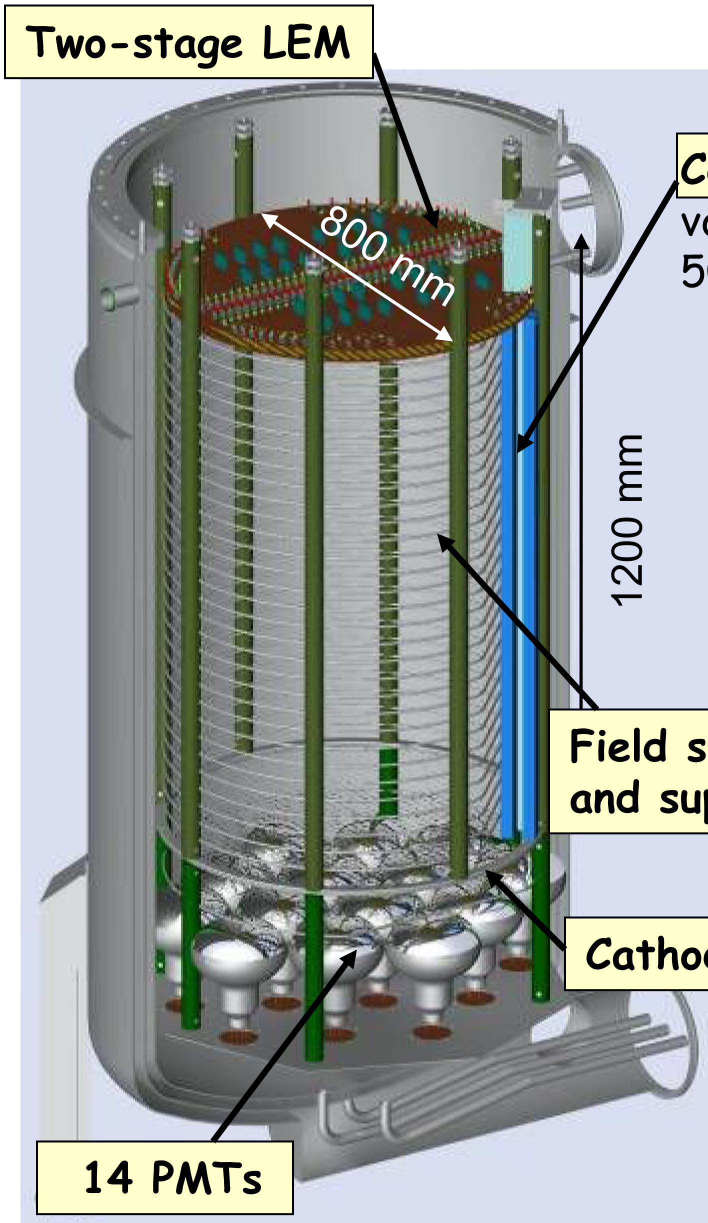
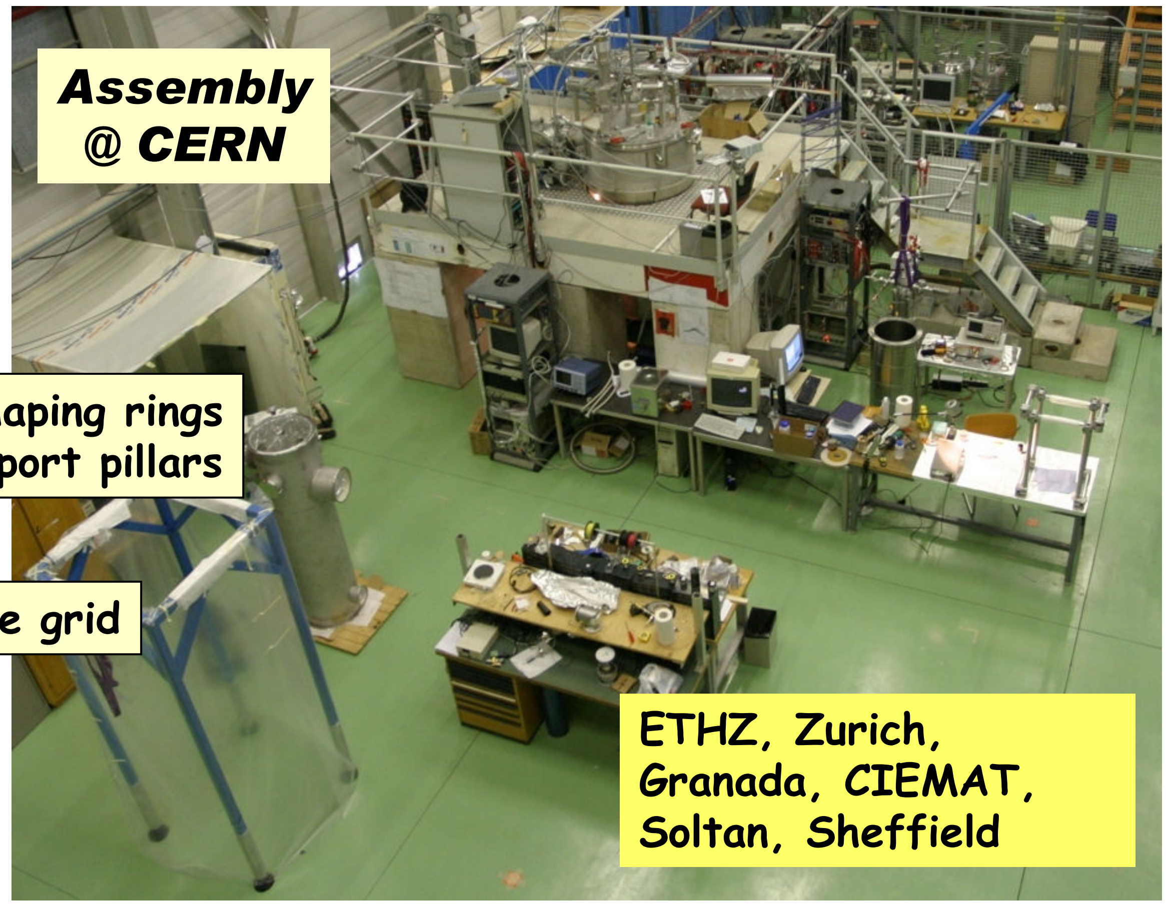
ArDM: a ton-scale LAr detector with a 1 x 1 m^2 LEM readout

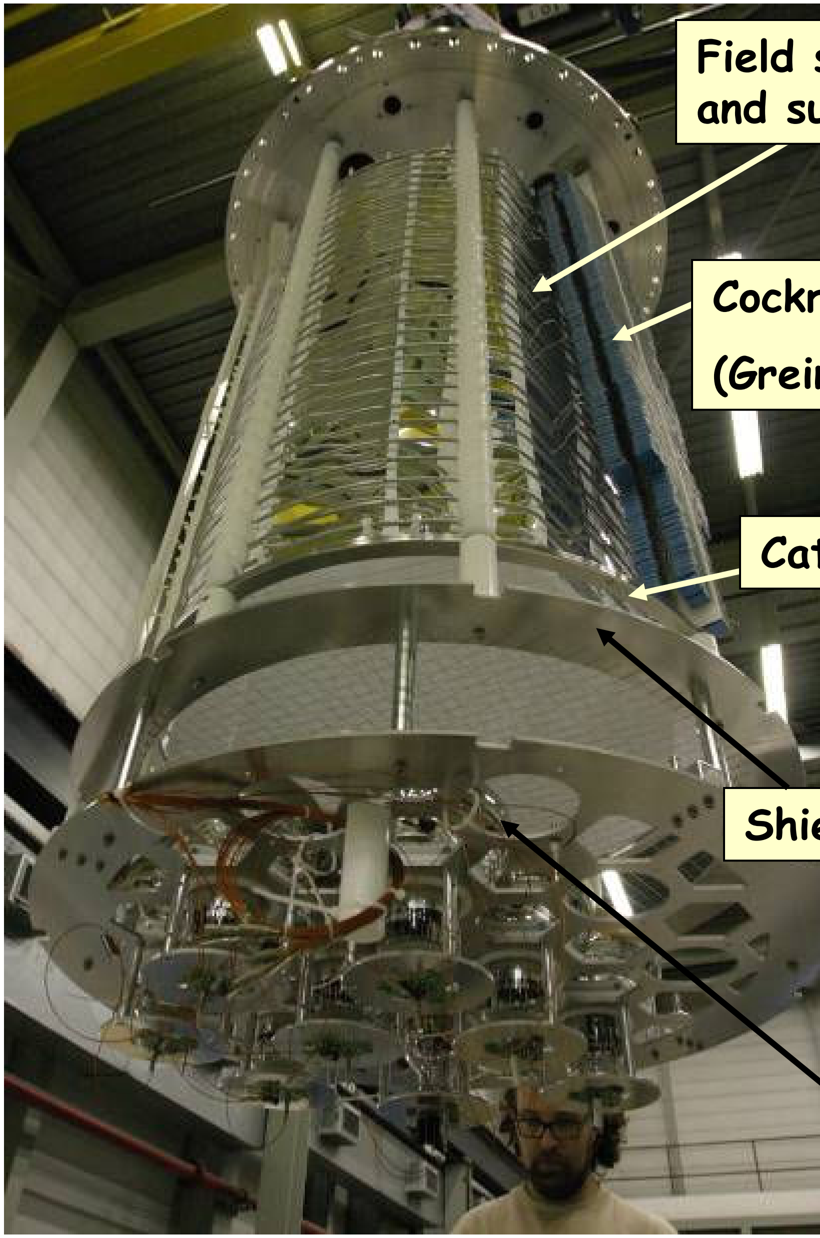
A. Rubbia, "ArDM: a Ton-scale liquid Argon experiment for direct detection of dark matter in the universe", J. Phys. Conf. Ser. 39 (2006) 129

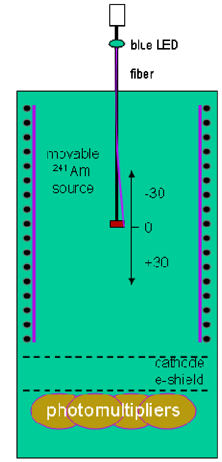


Cockroft-Walton (Greinacher) chain: supplies the right voltages to the field shaper rings and the cathode up to 500 kV (E=1-4kV/cm)



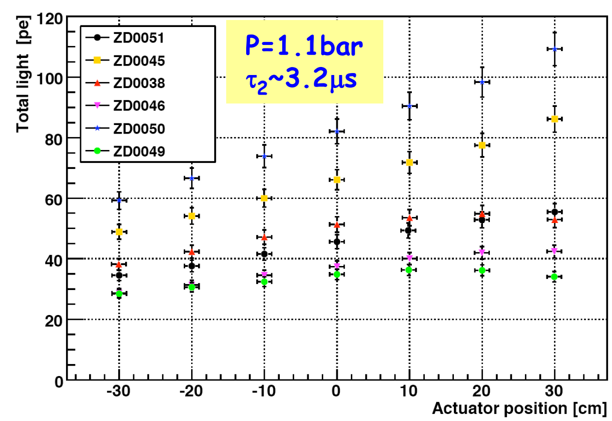
ArDM Inner Detector

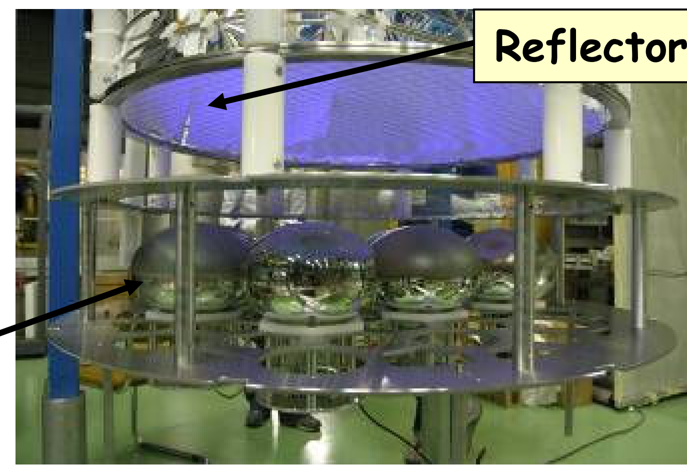




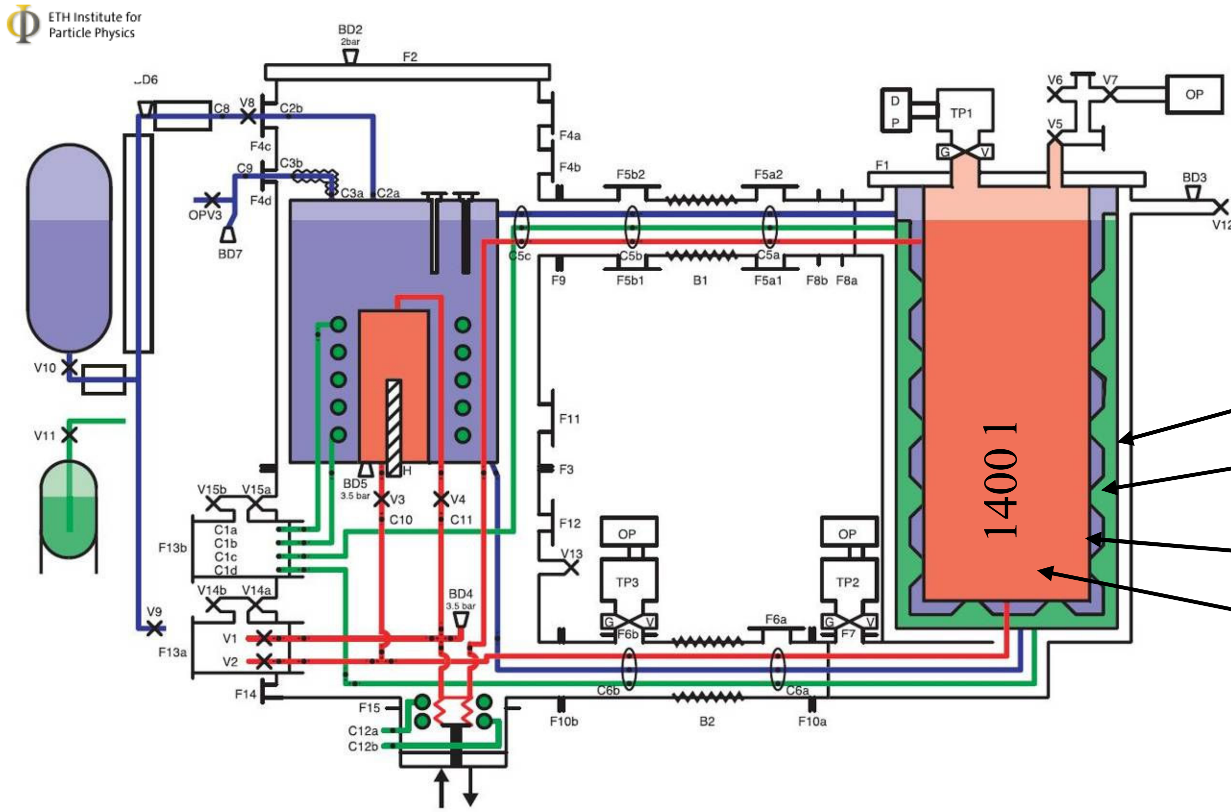
Light measurements vs. position of ^{241}Am source

GAr @ 88K





ArDM Cryogenics and LAr purification



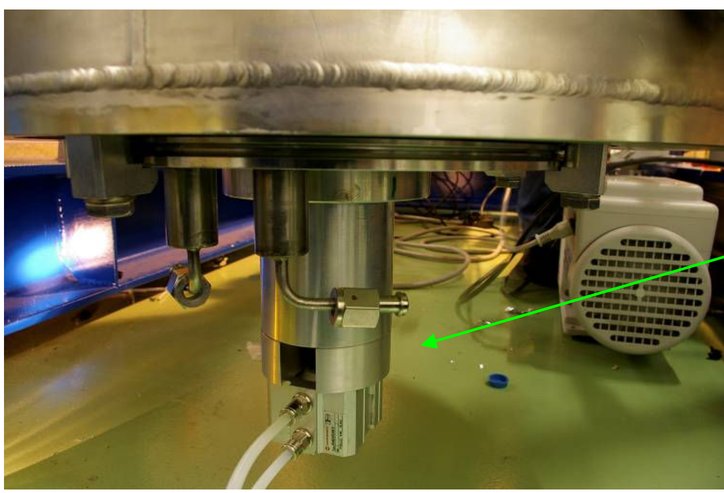
vacuum insulation

LN2 cooling jacket

'dirty' LAr cooling bath

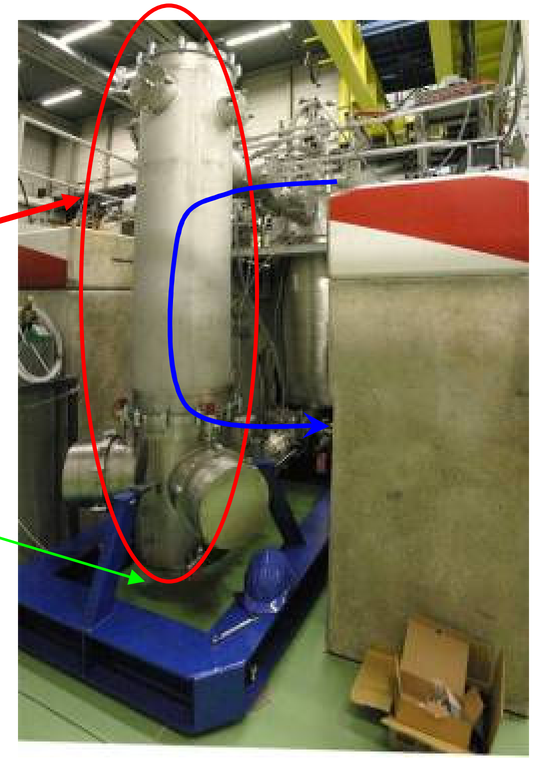
pure LAr closed circuit

In collaboration with BIERI engineering Winterthur, Switzerland

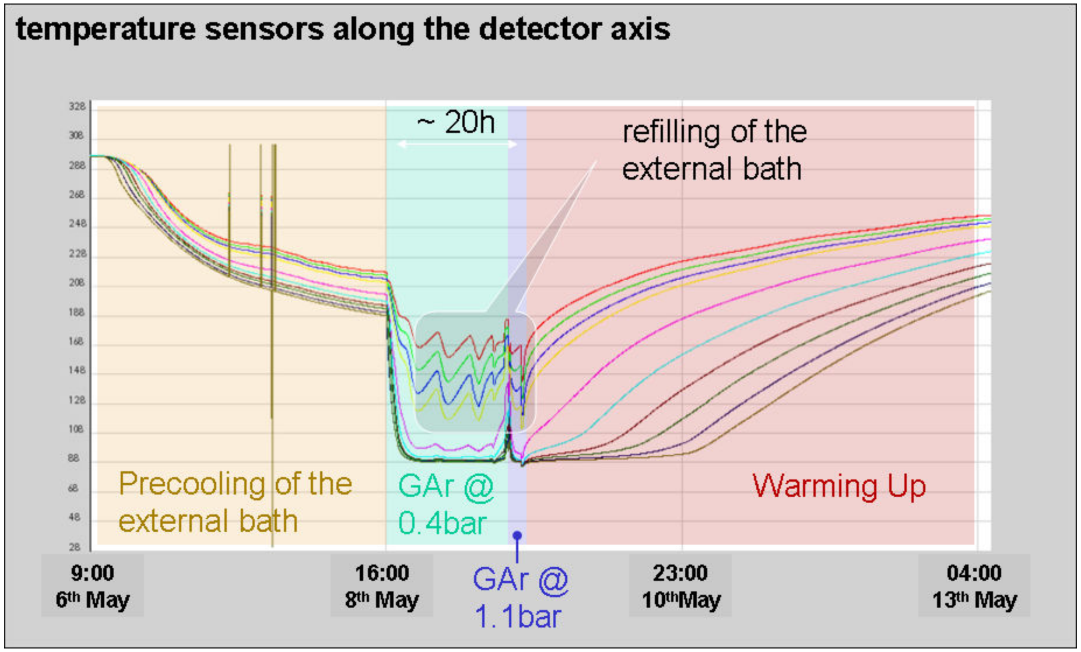


Recirculation and CuO purification cartridge

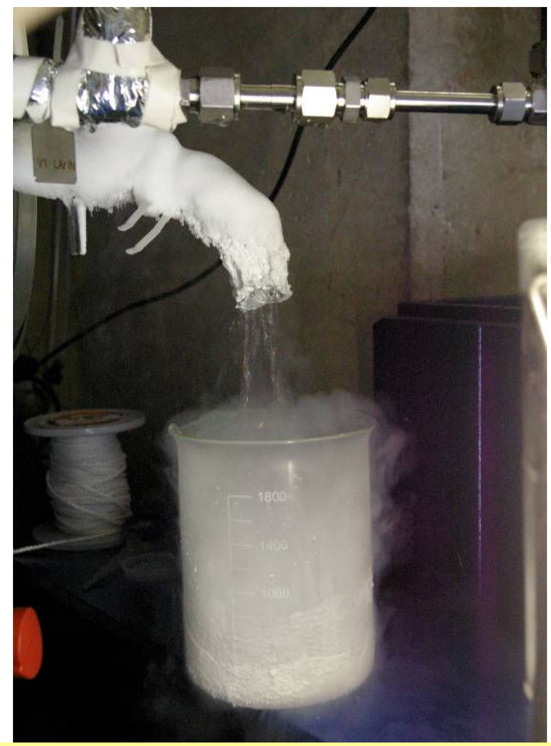
Bellow pump



Cryogenic Tests

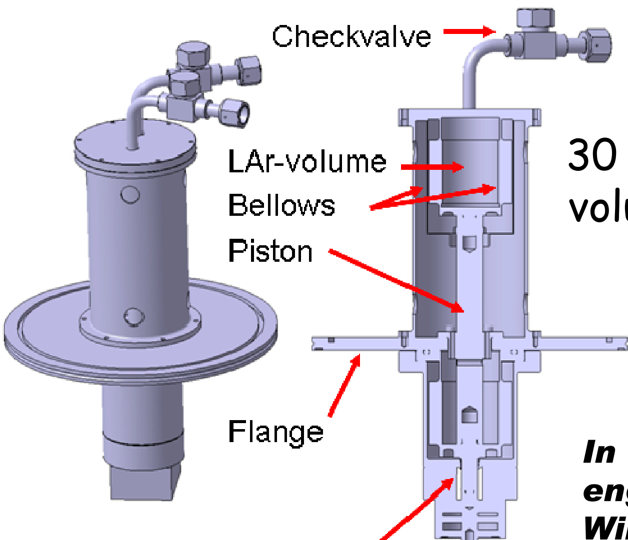


First ArDM cooldown with automatic refill of LAr cooling bath



Measured LAr flux ~ 20 l/hr

LAr Pump test



In collaboration with BIERI engineering Winterthur, Switzerland

ETH Institute for Particle Physics

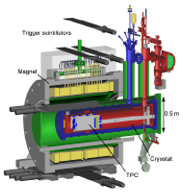
The next short-term steps …

- Engineering design of an underground 100 kton LAr tank
  - Part of LAGUNA package by Technodyne
- Small LAr LEM-TPC
  - implementation of a recirculation system for LAr purification
  - test of cold electronics
  - investigation of efficiency, stability and energy resolution of the LEM readout system
- Filling of ArDM inner detector with LAr
  - address safety issues of ArDM: handling of one ton of LAr, in situ-regeneration of the LAr purification cartridge
  - operation of the LAr pump and purification cartridge
  - tests of light readout in LAr
  - test of the HV system
  - stability of cryogenic operation of the device: installation of a cryocooler
- Design and construction of a 1 x 1 m^2 LEM readout system for ArDM

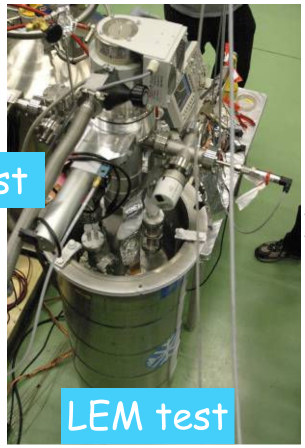
ETH Institute for Particle Physics

Steps towards GLACIER

Small prototypes ➠ ton-scale detectors ➠ 1 kton ➠ ?



B-field test



LEM test

proof of principle double-phase LAr LEM-TPC on 0.1x0.1 m² scale

➠ **LEM readout on 1x1 m² scale**
UHV, cryogenic system at ton scale, cryogenic pump for recirculation, PMT operation in cold, light reflector and collection, very high-voltage systems, feed-throughs, industrial readout electronics, safety (in Collab. with CERN)

ArDM ton-scale

we are here

➠ **direct proof of long drift path up to 5 m**

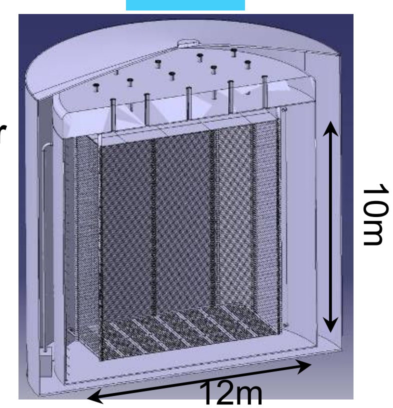
ArgonTube: long drift, ton-scale

➠ **Application of LAr LEM TPC to neutrino physics**: particle identification (200-1000 MeV electrons), optimization of readout and electronics, cold ASIC electronics, possibility of neutrino beam exposure

Test beam
1 to 10 ton-scale

➠ **full engineering demonstrator for larger detectors**, acting as near detector for neutrino fluxes and cross-sections measurements, …

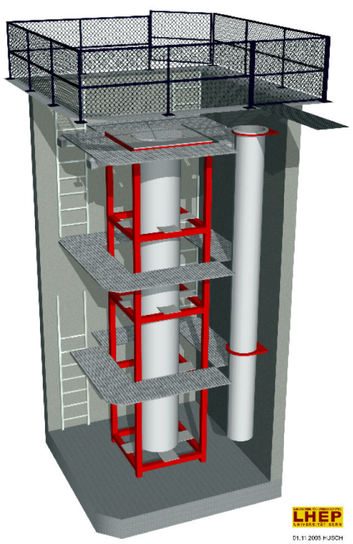
1 kton

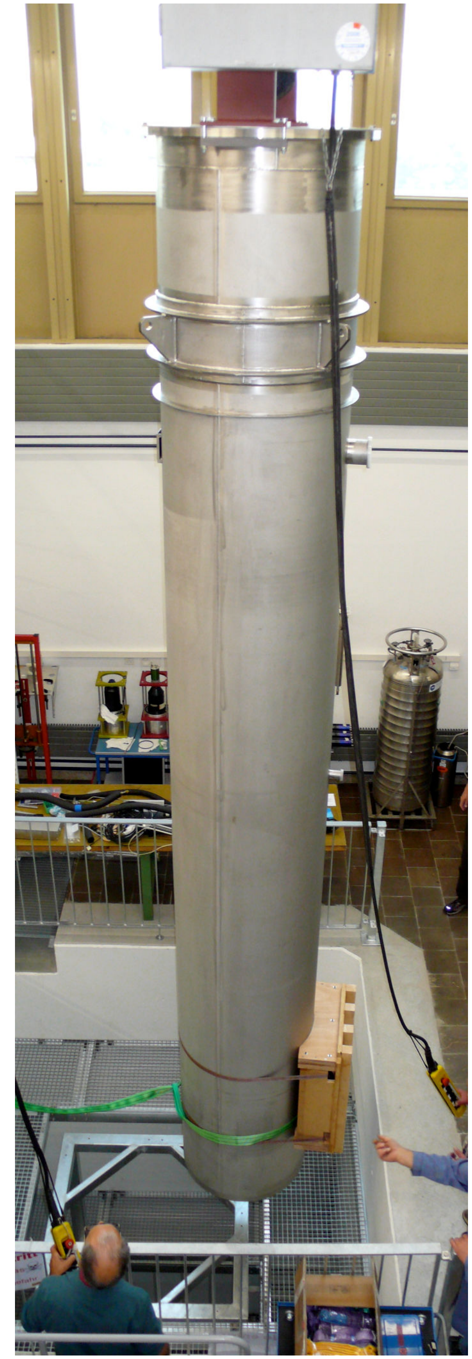


ARGONTUBE

Bern, ETHZ, Granada

- Full scale measurement of long drift (5 m), signal attenuation and multiplication, effect of charge diffusion
- Simulate 'very long' drift (10-20 m) by reduced E field & LAr purity
- High voltage test (up to 500 kV)
- Measurement Rayleigh scatt. length and attenuation length vs purity
- **Infrastructure ready**
- **External dewar delivered**
- **Detector vessel, inner detector, readout system, … in design/procurement phase**



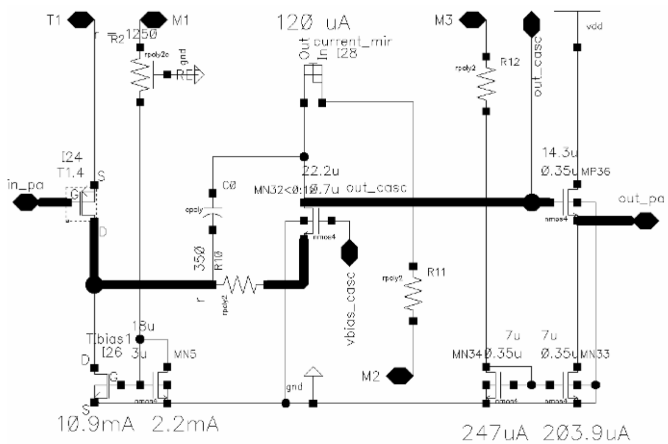


R&D on electronics integrated on the detector

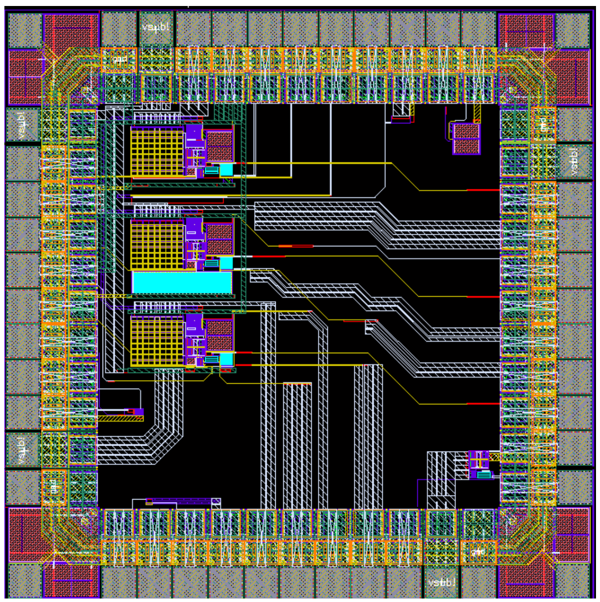
IPNL Lyon in collaboration with ETHZ

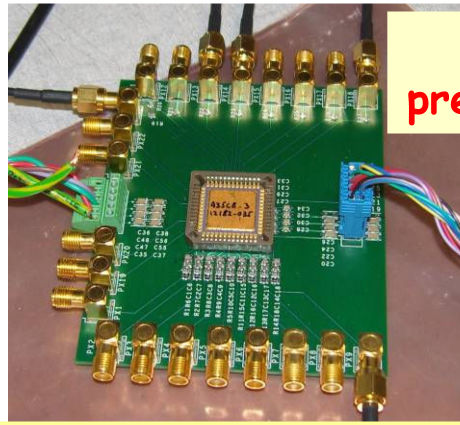
- **R&D on an analog ASIC preamplifier working at cryogenic temperature**
  - very large scale integration
  - low cost
  - reduction of cable capacitances
- **R&D on a Gigabit Ethernet readout chain + network time distribution system PTP**
  - further development of the OPERA DAQ, with larger integration, gigabit ethernet, reduced costs
  - implementation in just one inexpensive FPGA of the capabilities provided by the OPERA 'mezzanine' card
  - continuous and auto-triggerable readout
  - synchronization and event time stamp on each sensor with an accuracy of 1 ns

0.35μm CMOS charge amplifier

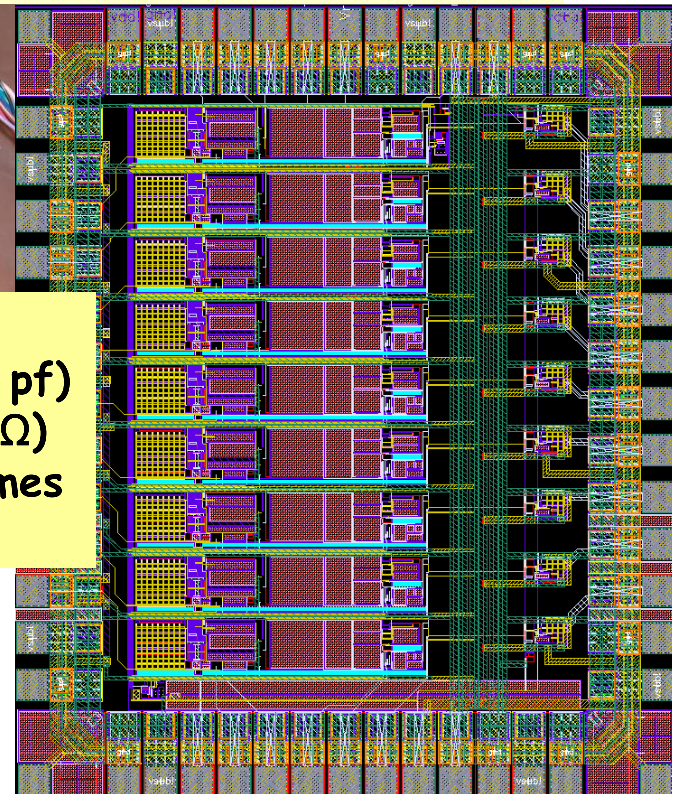


First test (characterization of the components,…) received in October 2007





delivered on July 2008
presently under test in Lyon



- selectable feedback capacitance (500 fF-1 pf) and resistor (2 – 10 MΩ)
- selectable shaping times (0.5 – 4 μs range)

E. Bechetoille , H. Mathez, IPNL Lyon
Proceedings of Wolte-08, June 2008

to be tested on the LEM-TPC setup integrated with IPNL DAQ

Conclusions

- The synergy between precise detectors for long neutrino baseline experiments and proton decay (and astrophysical neutrinos) detectors is essential for a realistic proposal of a 100 kton LAr detector
  - discovery physics, not only precision measurements
- GLACIER is a concept for a scalable LAr detector up to 100 kton demanding concrete R&D
- ArDM is a real 1-ton prototype of the GLACIER concepts
- ArgonTube will be a dedicated measurement of long drifts (5m)
- Aggressive R&D on readout electronics ongoing (warm/cold options, detector integration…)
- After a successful completion of this R&D (ArDM, test beams, …) we want to proceed to a proposal for a 100 kton scale underground device
  - discussion of a 1 kton full engineering prototype