R&D on LAr TPCs for neutrino, proton decay and DM experiments

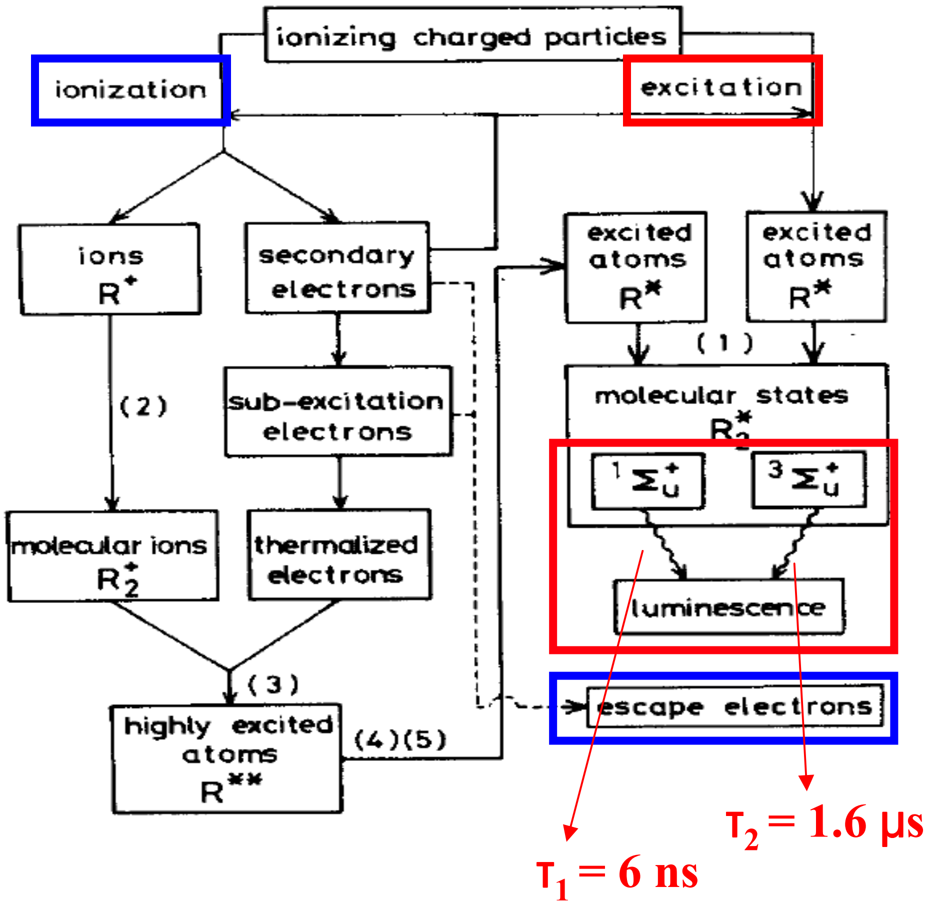
Presented by A. Marchionni, ETH Zurich

CHIPP Annual Plenary Meeting, Sept. 2008

- GLACIER: a concept for a scalable LAr detector up to ~ 100 kton
  - a precision detector for proton decay searches & neutrino oscillation measurements
- 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
  - $0.1 \times 0.1\ m^2$ test setup
  - low-noise preamplifiers and DAQ developments
- ArDM: a ton-scale LAr detector with a $1 \times 1\ m^2$ LEM readout
  - status of the inner detector
  - cryogenics and first cool down
- Conclusions

ETH Institute for Particle Physics

Processes induced by charged particles in liquid argon



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

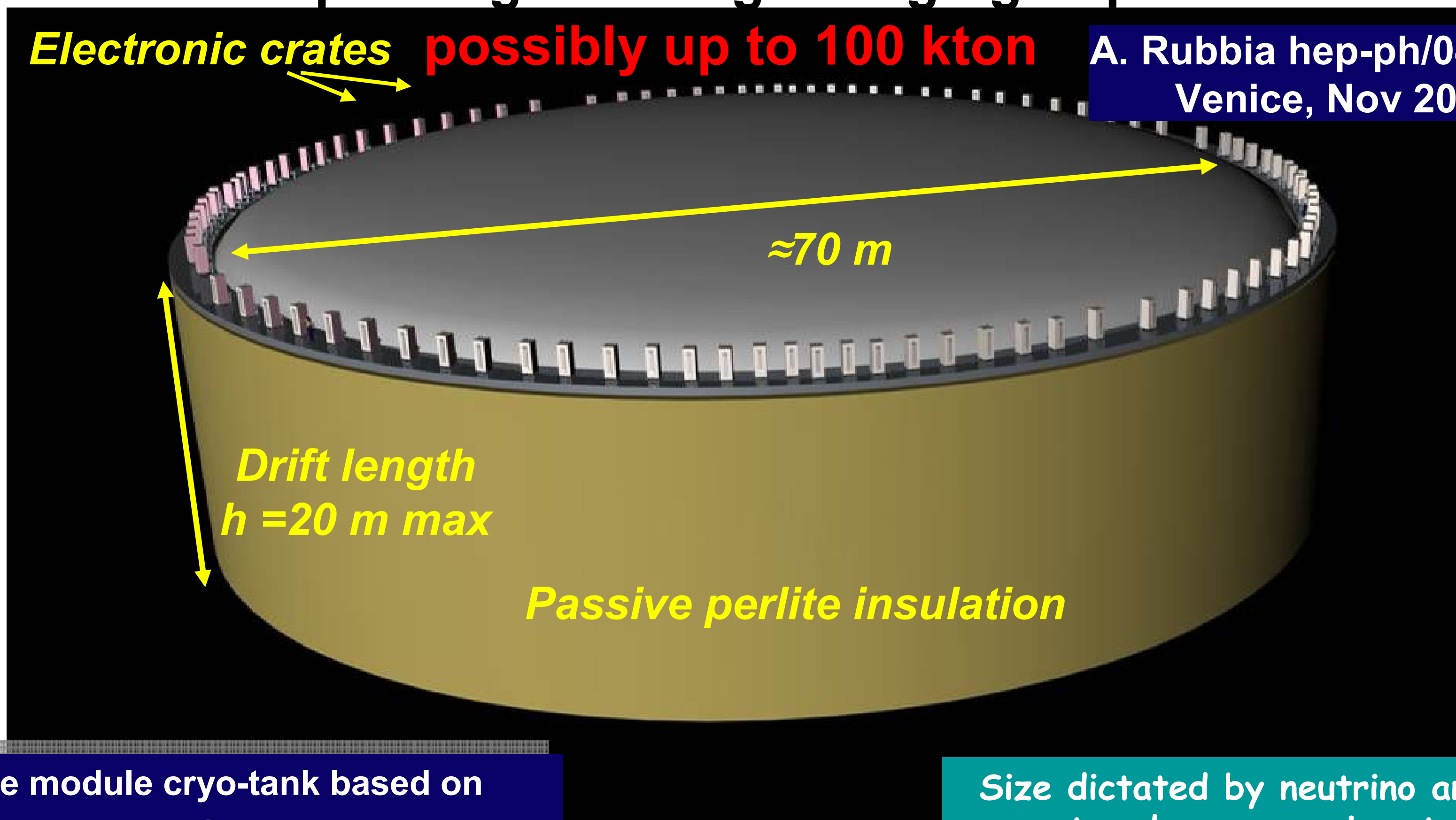
When a charged particle traverses medium:

- **Ionization** process → *UV light*
- **Scintillation** (luminescence) → *Charge*
  - UV spectrum (λ=128 nm)
  - Not energetic enough to further ionize, hence, argon is transparent
  - Rayleigh-scattering
- **Cerenkov light** (if fast particle) → *Cerenkov light (if β>1/n)*

GLACIER

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

Giant Liquid Argon Charge Imaging ExpeRiment

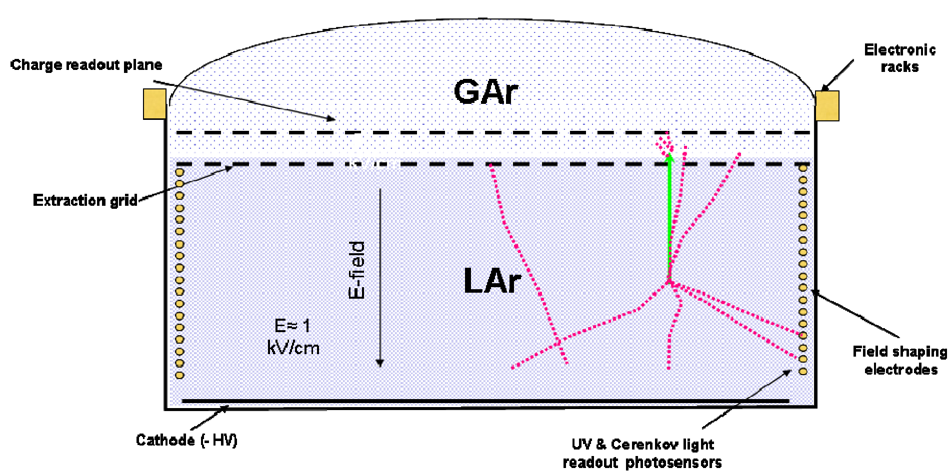


Single module cryo-tank based on industrial LNG technology

Size dictated by neutrino and proton decay experiments

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

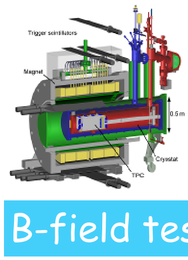


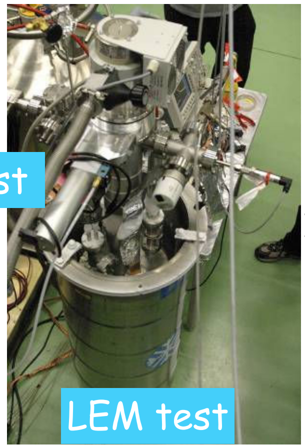
Scalable detector

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

Steps towards GLACIER

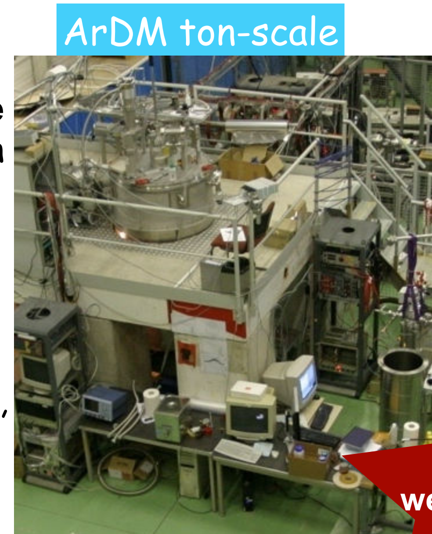
Small prototypes ➠ ton-scale detectors ➠ 1 kton ➠ ?



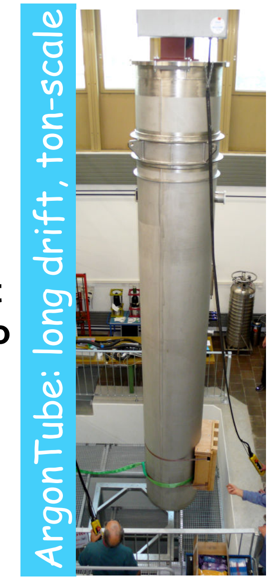


proof of principle double-phase LAr LEM-TPC on 0.1x0.1 m^2 scale

➠ **LEM readout on 1x1 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)

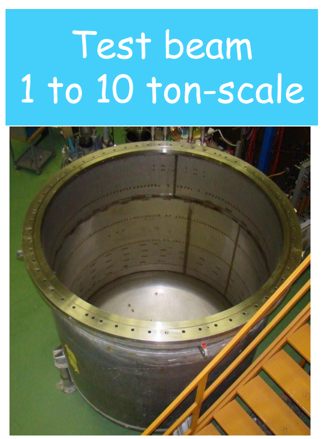


➠ **direct proof of long drift path up to 5 m**

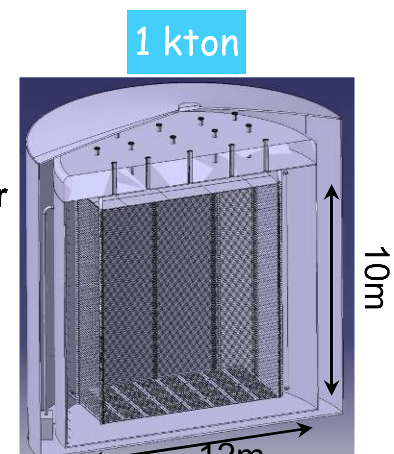


we are here

➠ **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



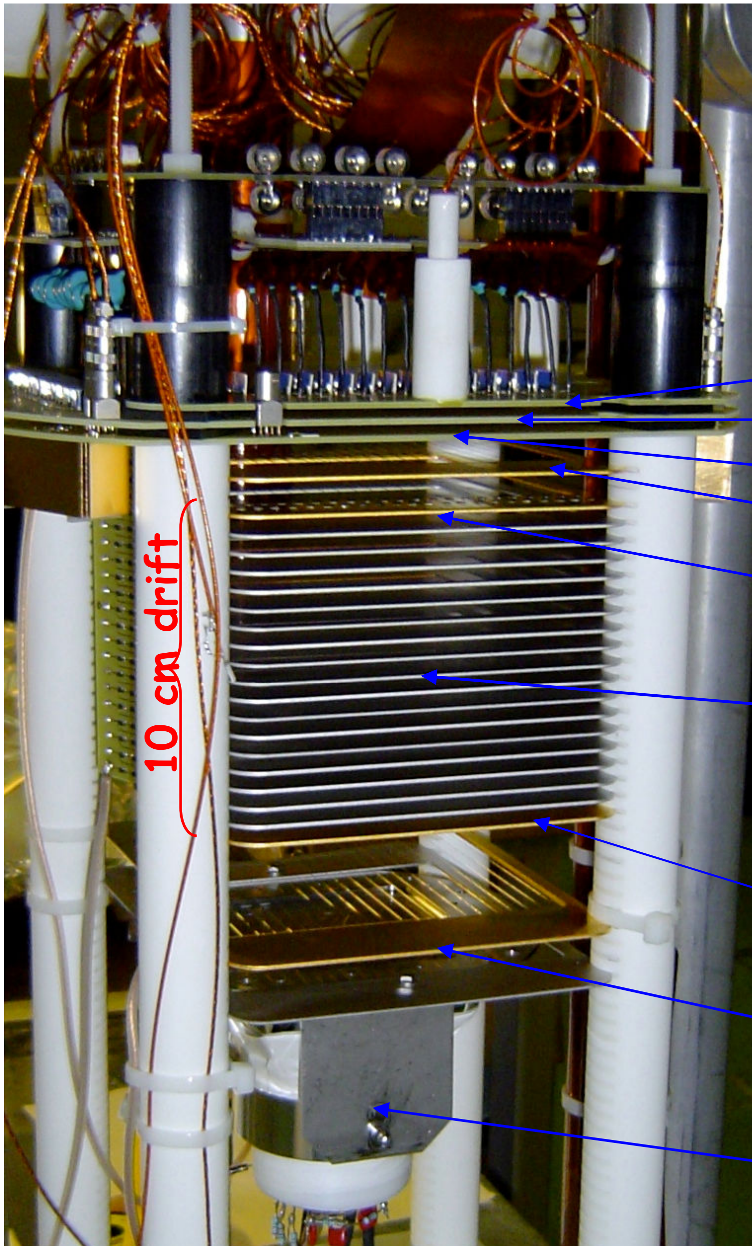
➠ **full engineering demonstrator for larger detectors**, acting as near detector for neutrino fluxes and cross-sections measurements, …



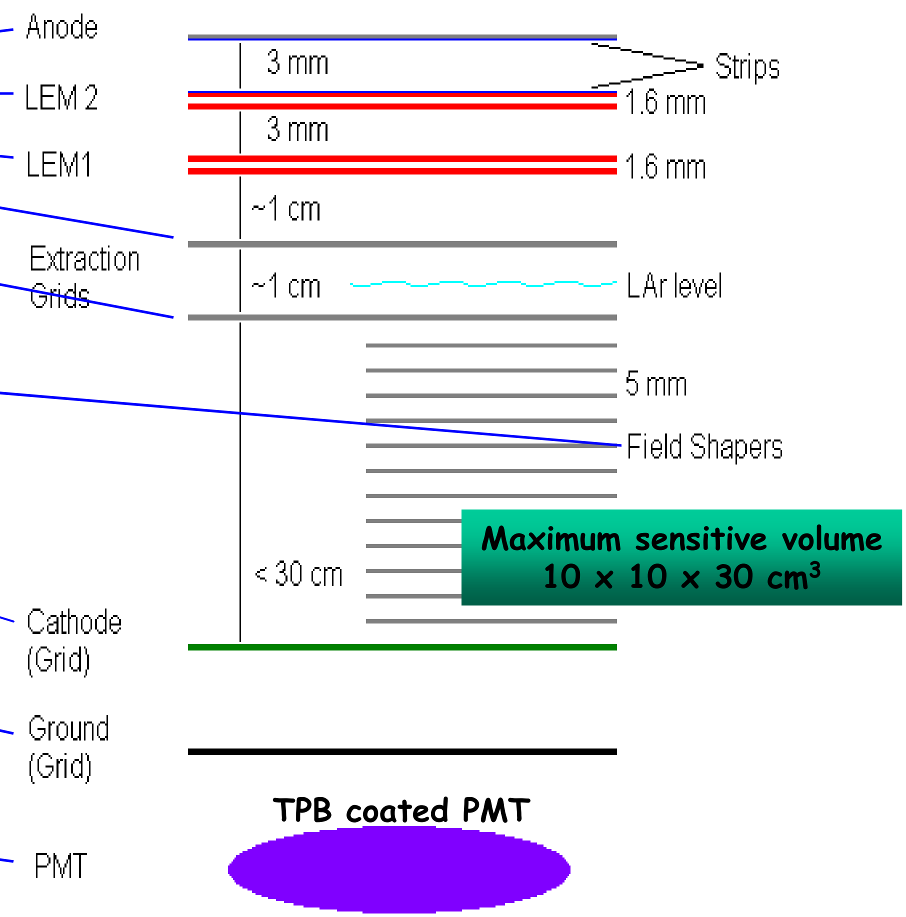
LAr LEM-TPC

ETH Institute for Particle Physics

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

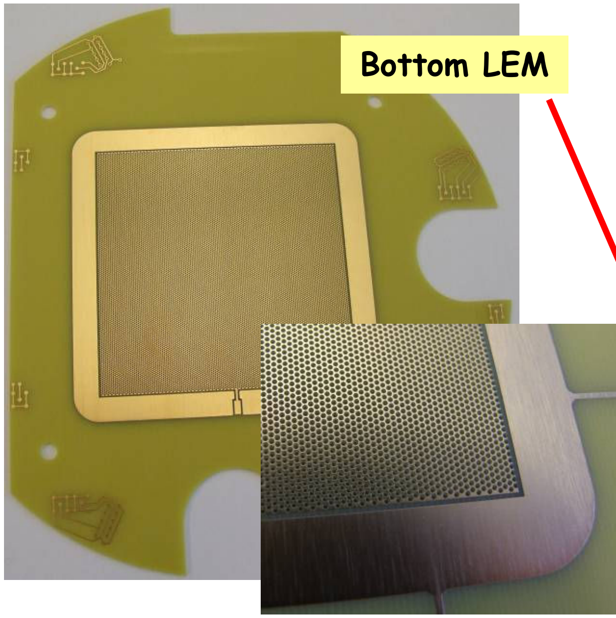


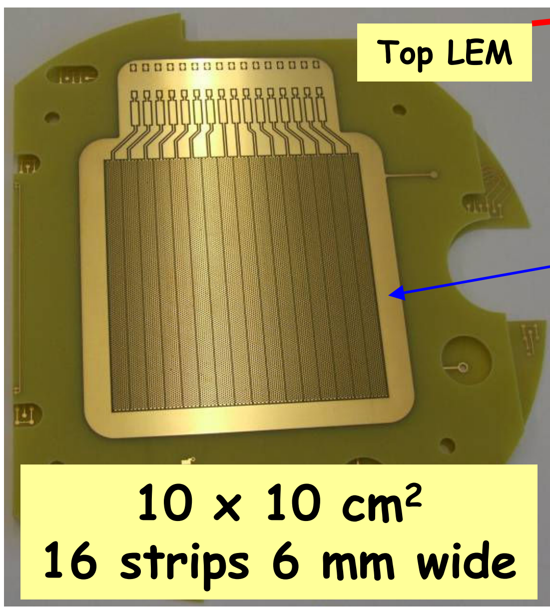
A. Badertscher et al., 'Construction and operation of a double phase LAr Large Electron Multiplier TPC', accepted contribution at the 2008 IEEE Nucler Science Symposium, Dresden, Germany

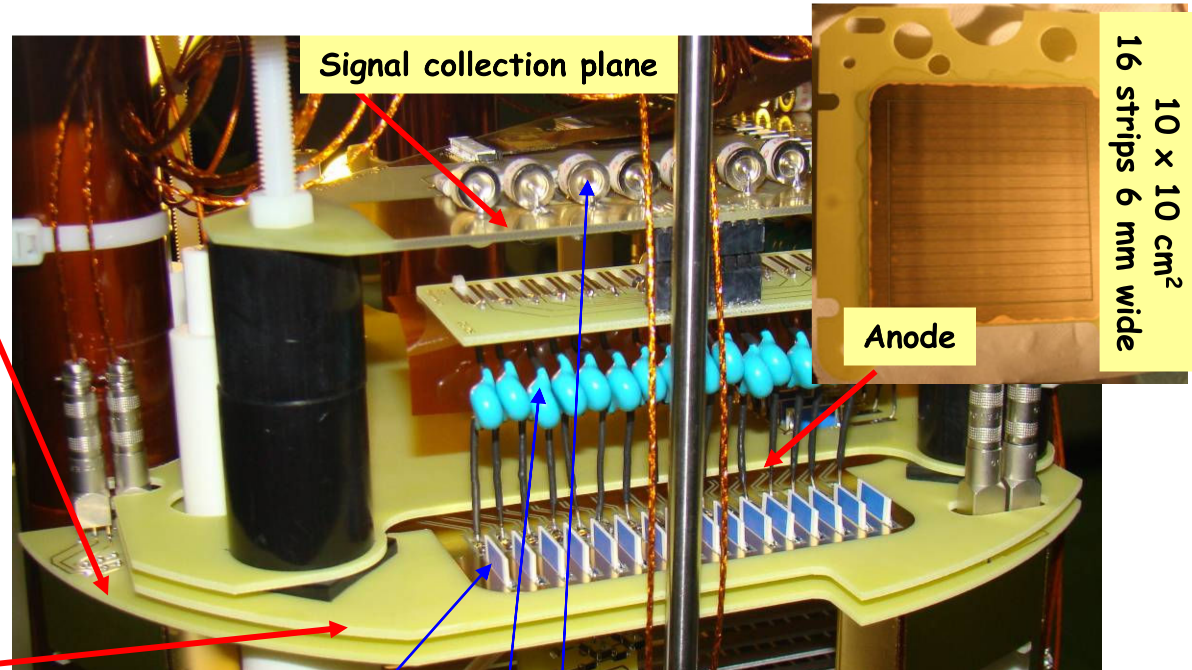


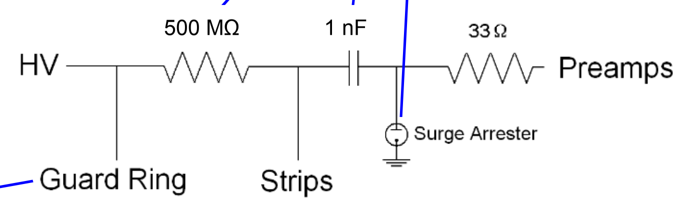
Operated in double phase: liquid-vapor

Double stage LEM with Anode readout



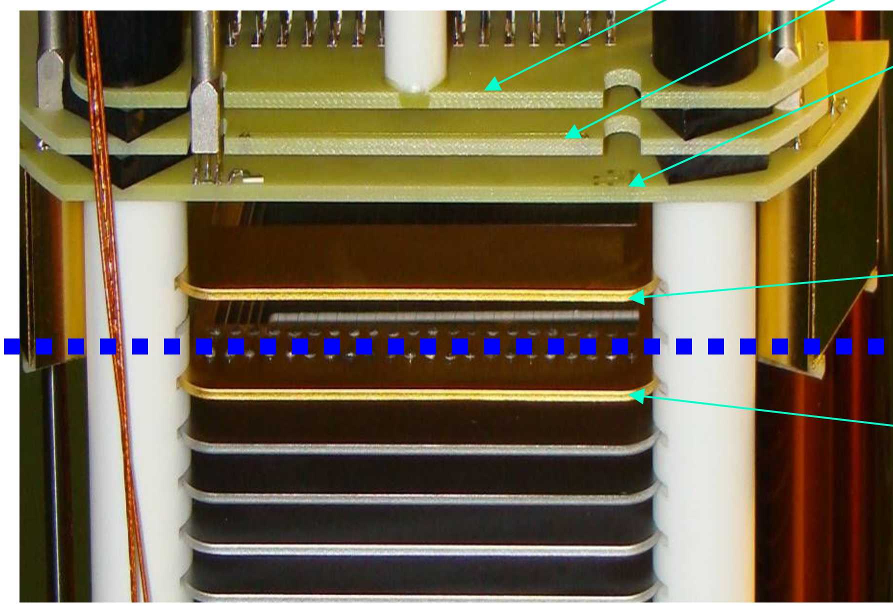


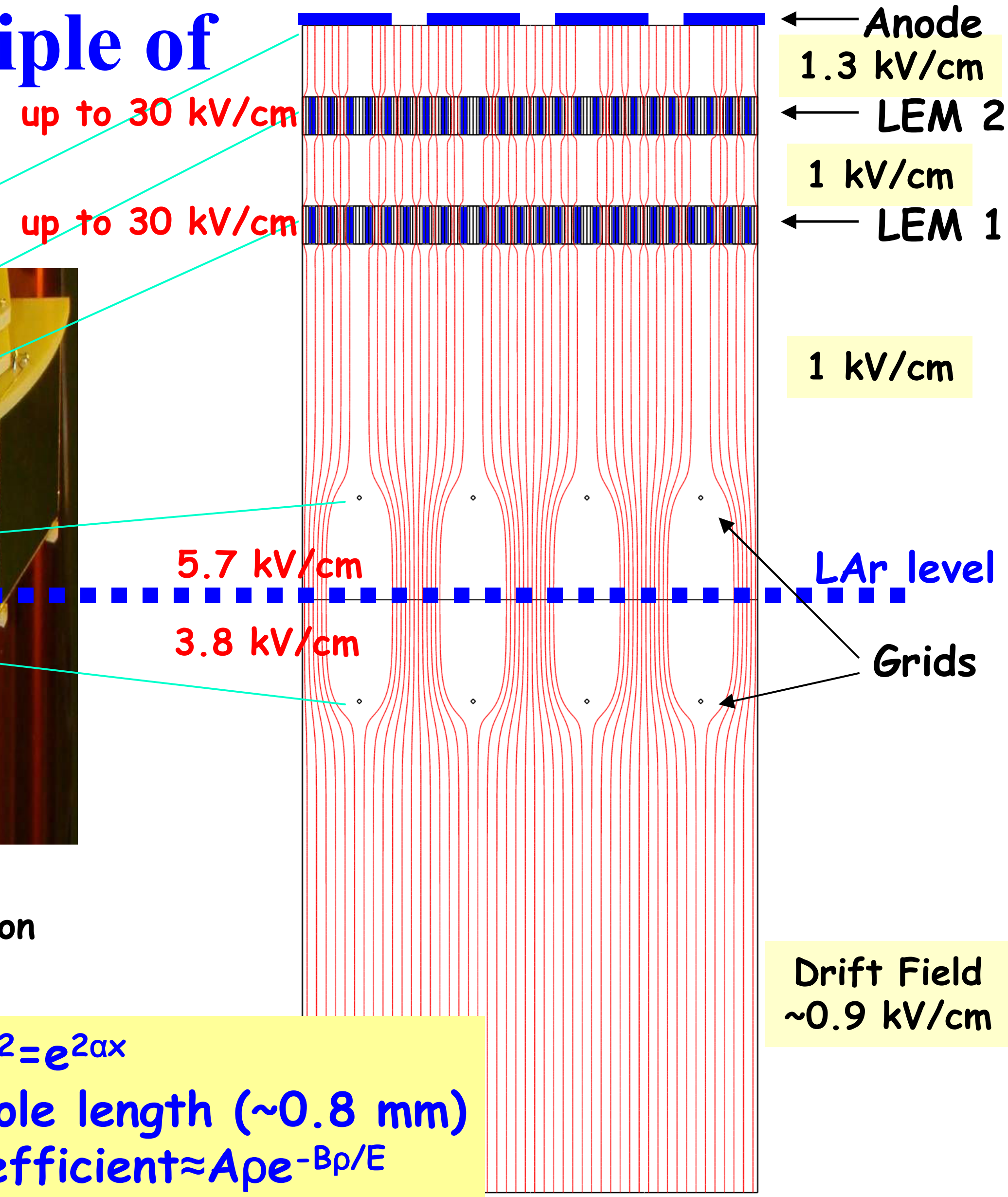




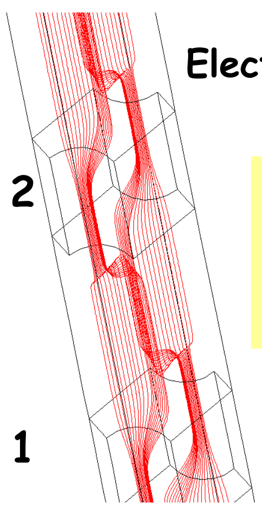
- **Produced by standard Printed Circuit Board methods**
- Double-sided copper-clad (18 μm layer) FR4 plates
- Precision holes by drilling
- Gold deposition on Cu (<~ 1 μm layer) to avoid oxidization
- Single LEM Thickness: 1.55 mm
- Amplification hole diameter = 500 μm
- Distance between centers of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

LAr LEM-TPC: principle of operation





Typical Electric Fields for double-phase operation

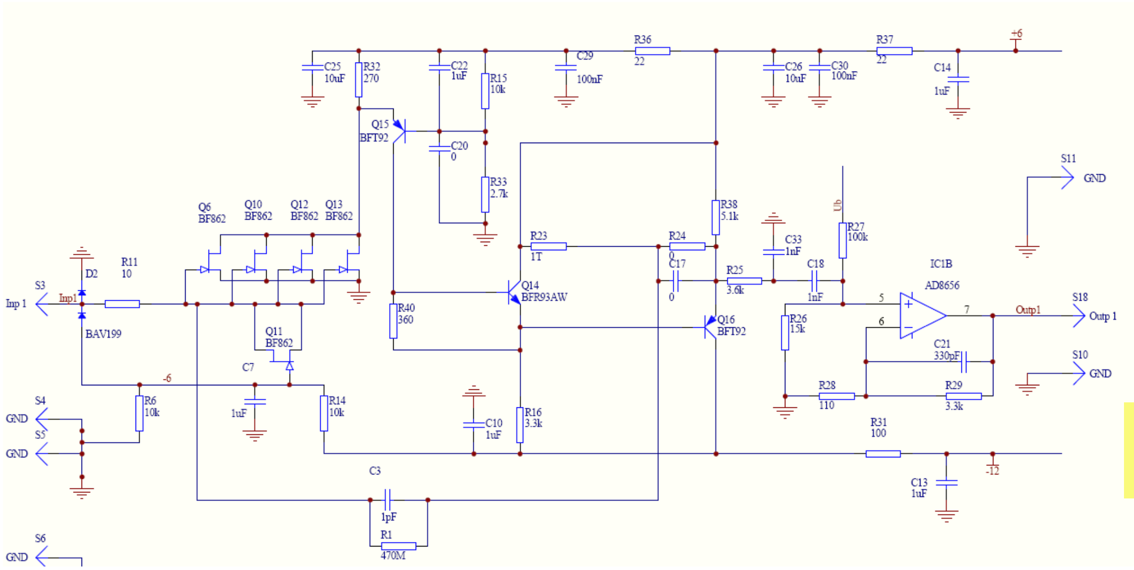


Electric field in the LEM region
~ 25 kV/cm

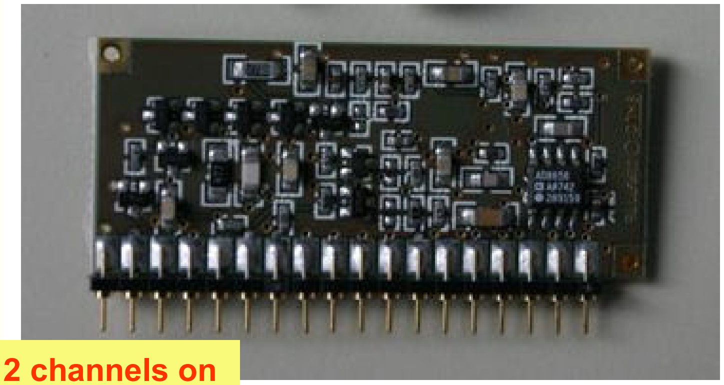
Gain=$G_{LEM1} \cdot G_{LEM2} = G^2 = e^{2\alpha x}$
x: effective LEM hole length (~0.8 mm)
α: 1st Townsend coefficient≈$A\rho e^{-B\rho/E}$

ETH Institute for Particle Physics

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**

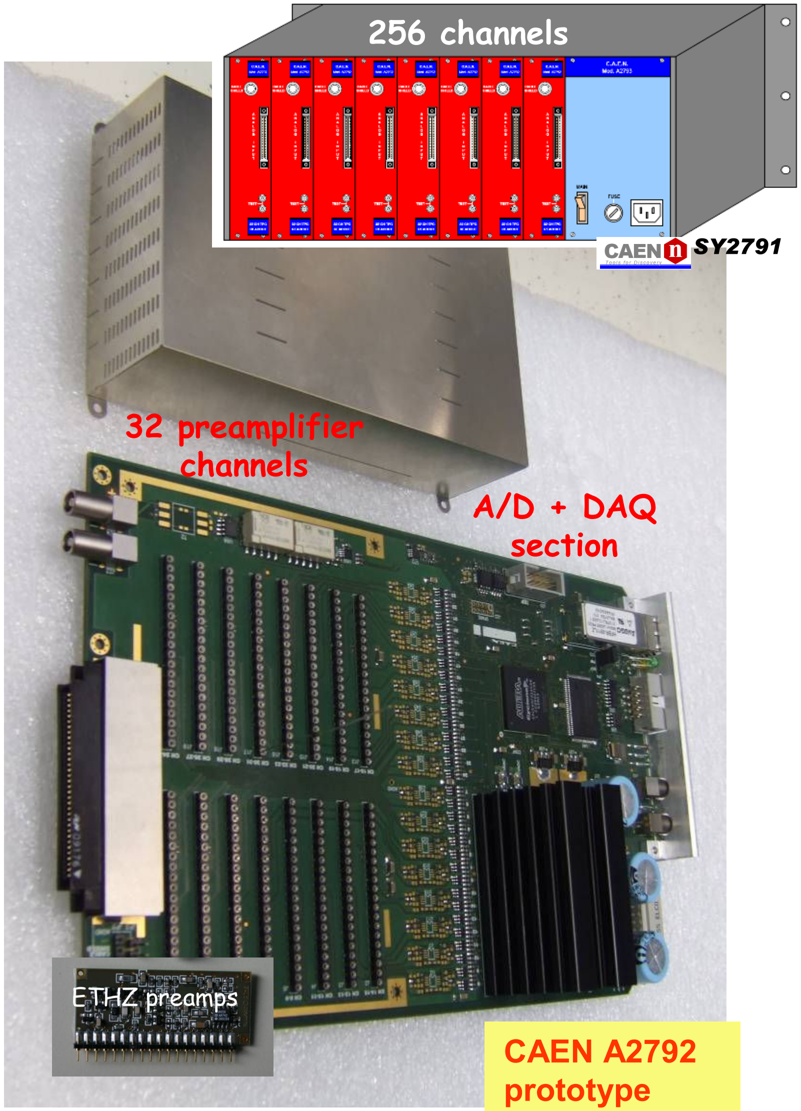
Version	FET integrator decay time constant (µs)	Shaper integration time constant (µs)	Shaper differentiation time constant (µs)	Sensitivity (mV/fC)	Noise (e^-) C_i= 200 pF	S/N @ 1 fC C_i= 200 pF
V1	470	3.6	13	12.5	395	15
V2	470	3.6	1.3	11.9	485	13
V3	470	0.15	0.5	(10)		(6)
V4	470	0.6	2	11.6	620	10

ICARUS electronics (τ_f=1.6 µs)

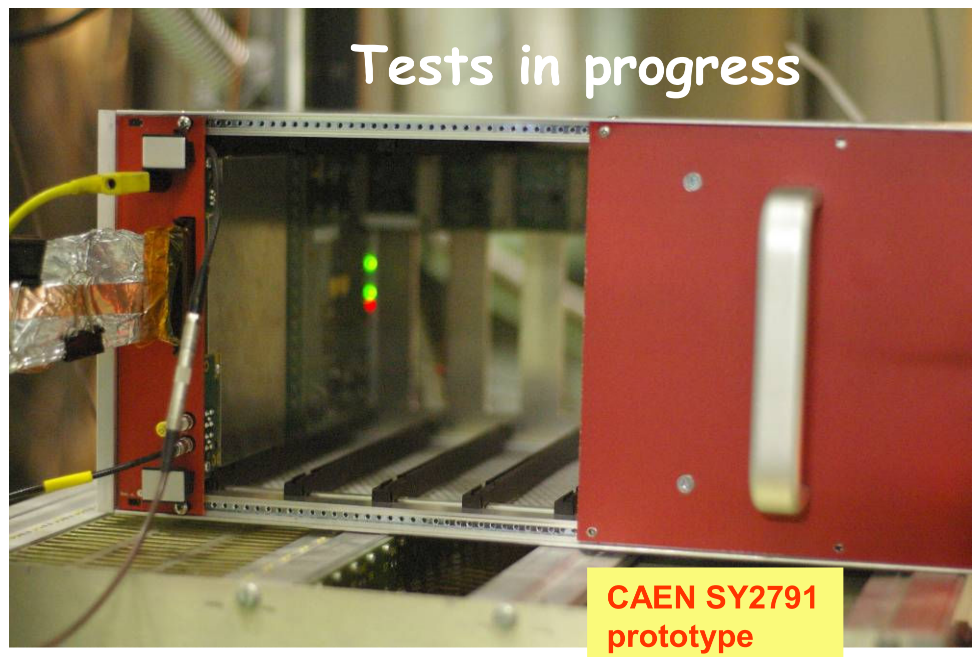
- S/N=10 @ 2 fC, C_i=350 pF
- equivalent to S/N=7 @ 1 fC, C_i=200 pF

Data Acquisition System development

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



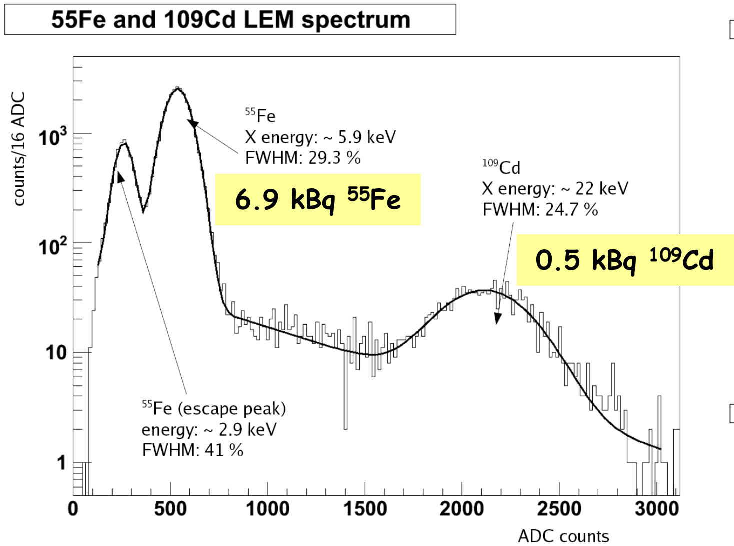
- ❑ 12 bit 2.5 MS/s flash ADCs + programmable FPGA with trigger logic
- ❑ Global trigger and channel-by-channel trigger,switch to 'low threshold' when a 'trigger alert' is present
- ❑ 1 MB circular buffer, zero suppression capability, 80 MB/s chainable optical link to PC

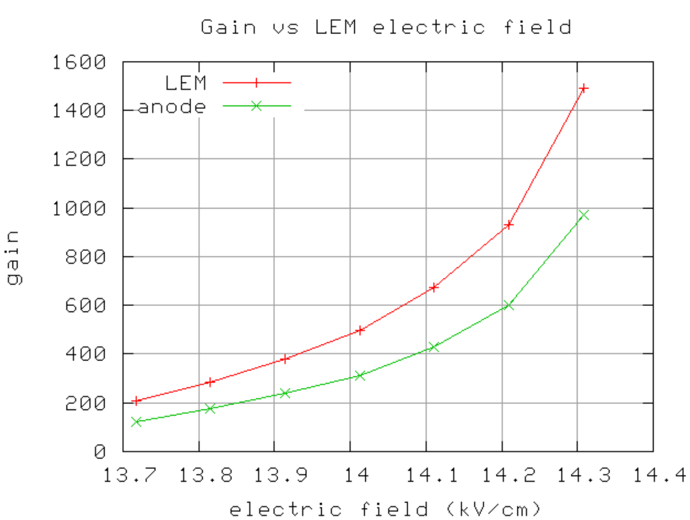


LEM-TPC operation in pure GAr at 300K

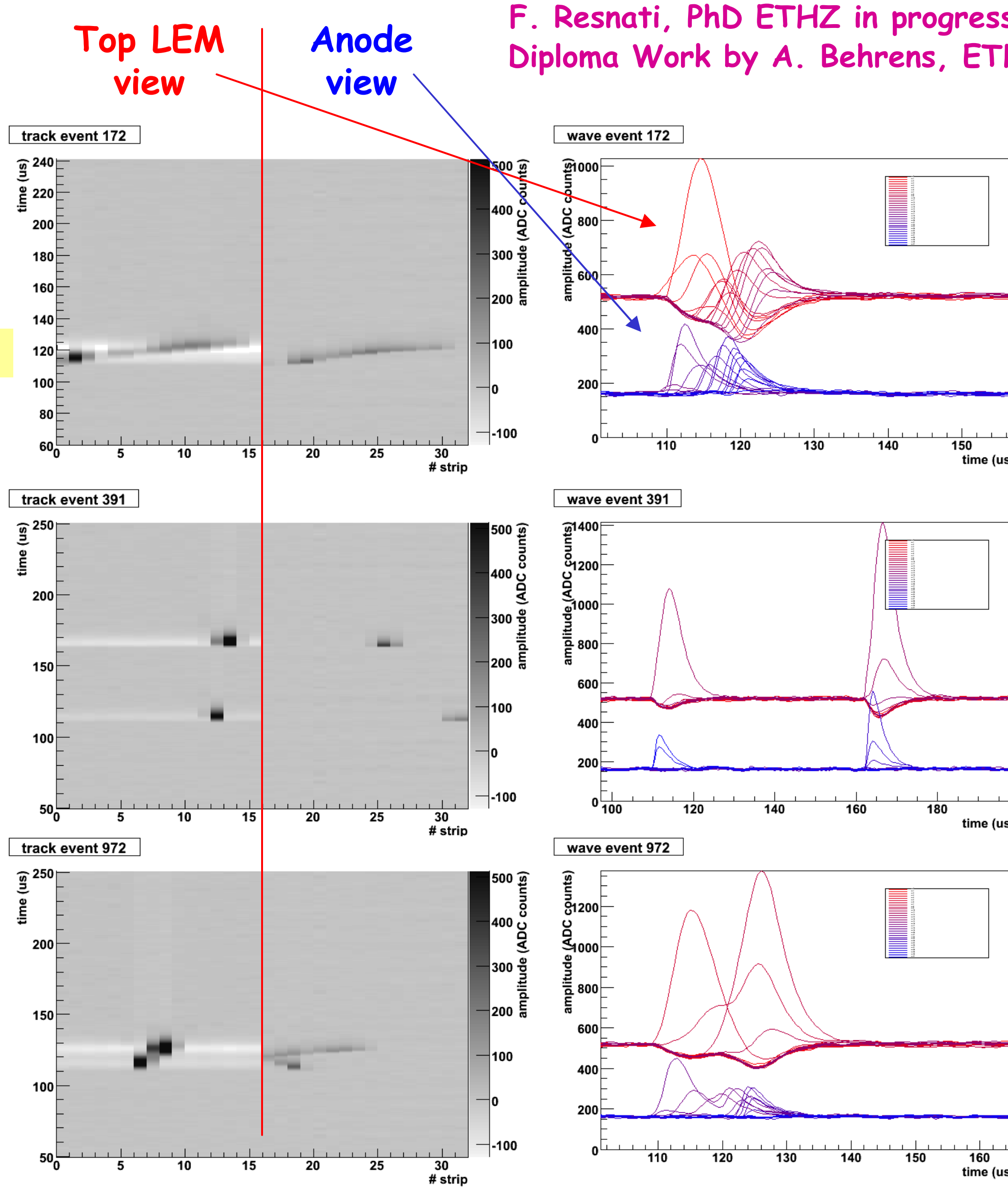
F. Resnati, PhD ETHZ in progress
Diploma Work by A. Behrens, ETHZ

Radioactive sources





Typical cosmic ray events

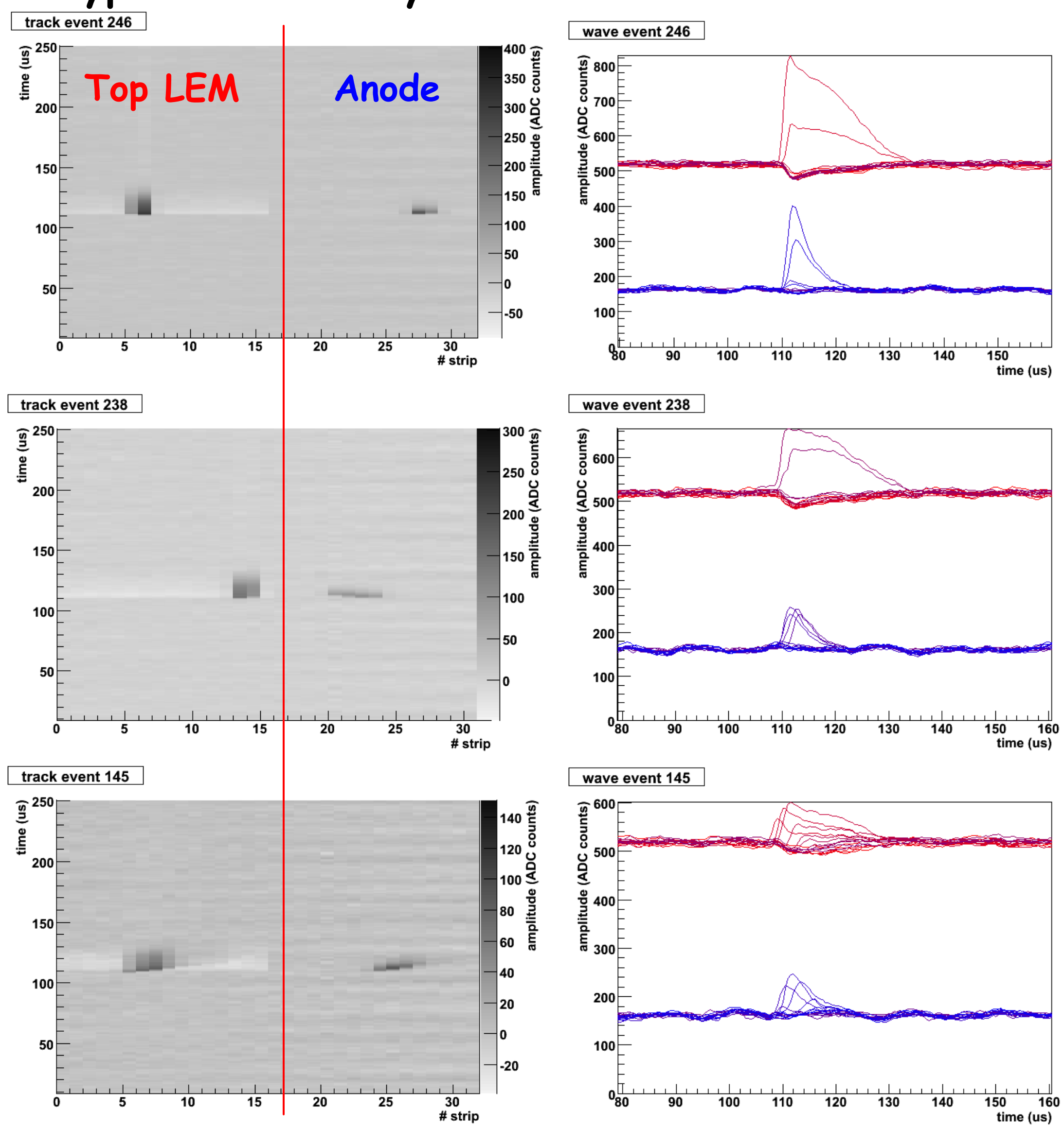


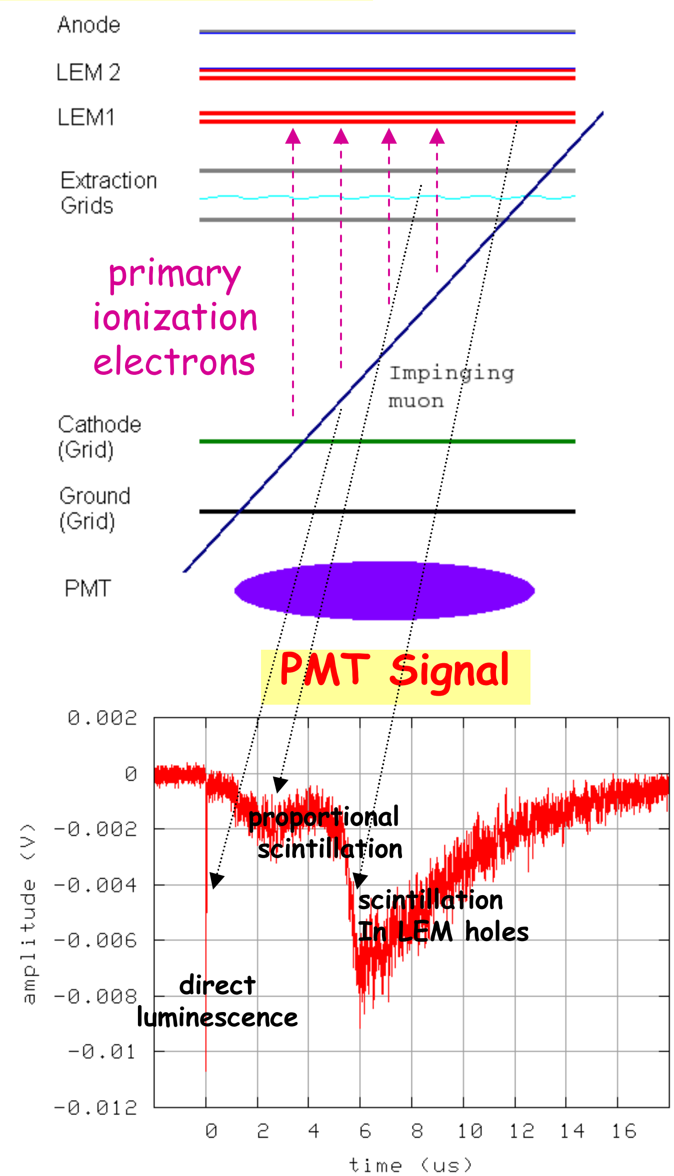
LEM-TPC operation in double phase Ar

F. Resnati, PhD ETHZ in progress

Proof of principle of a LAr LEM-TPC

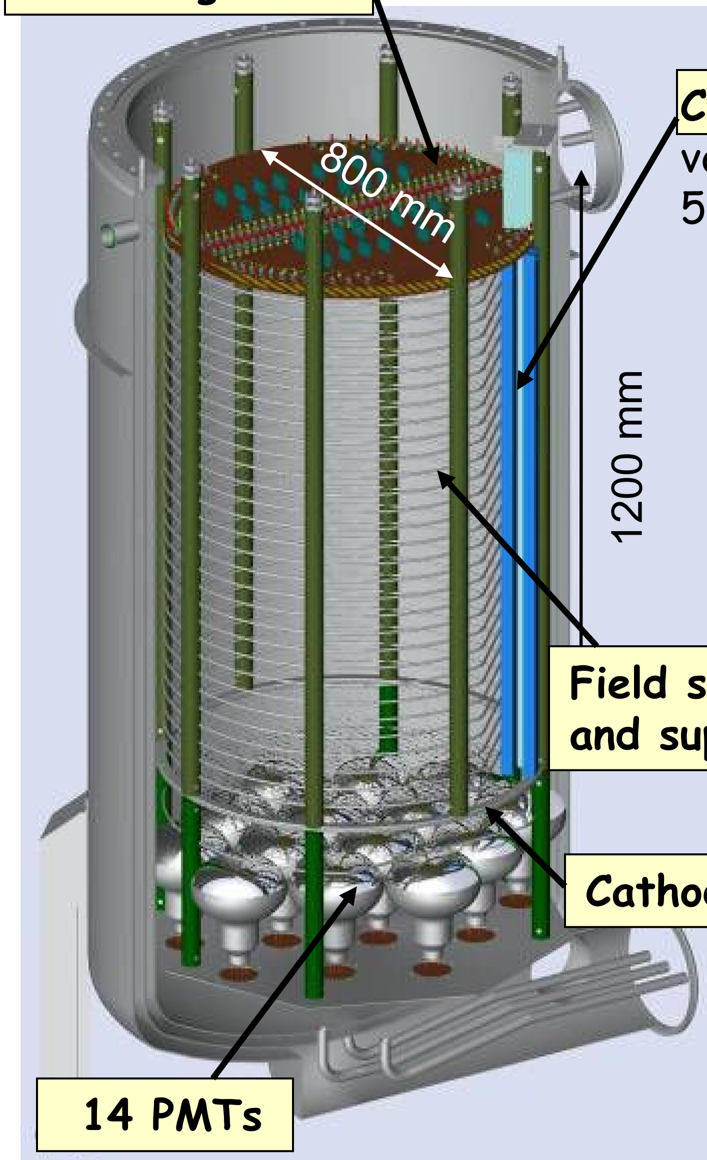
Typical cosmic ray events



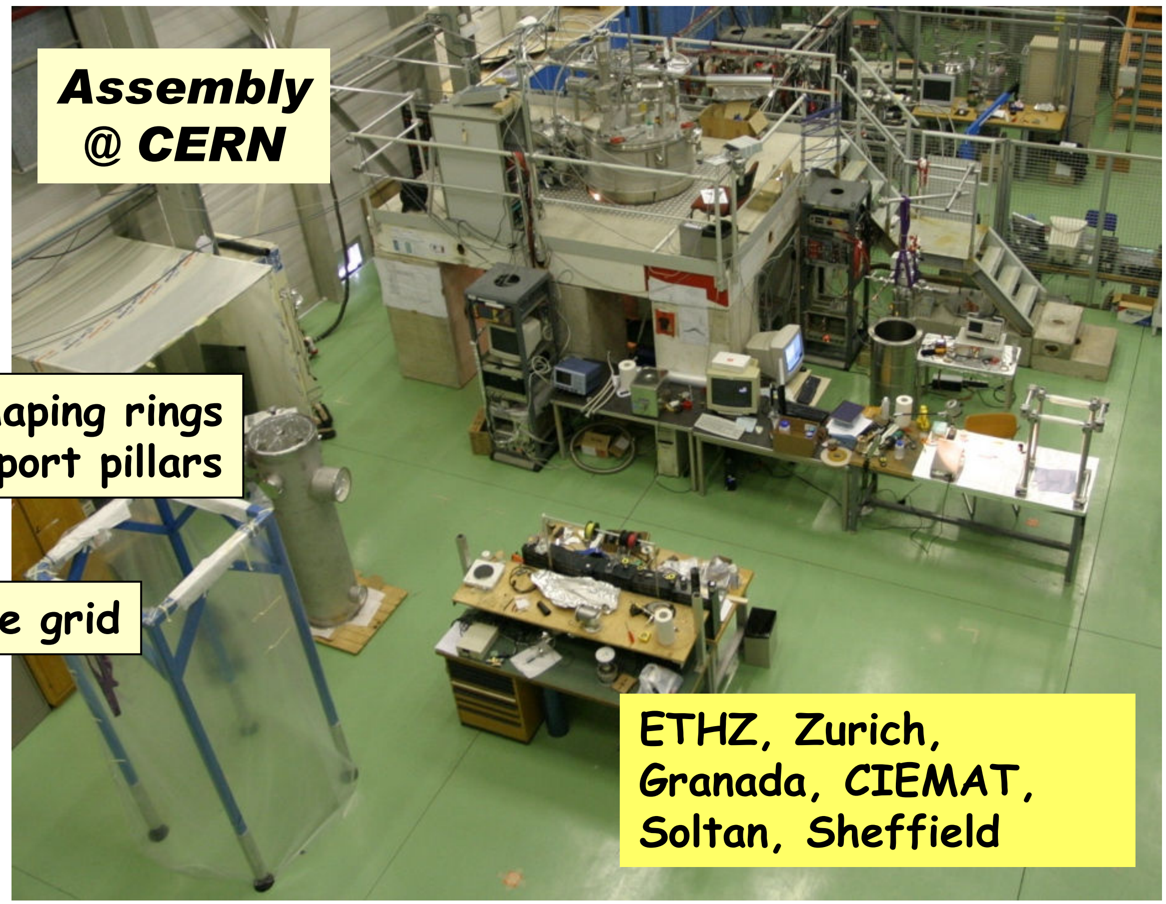


ArDM: a ton-scale LAr detector with a 1 x 1 m² LEM readout

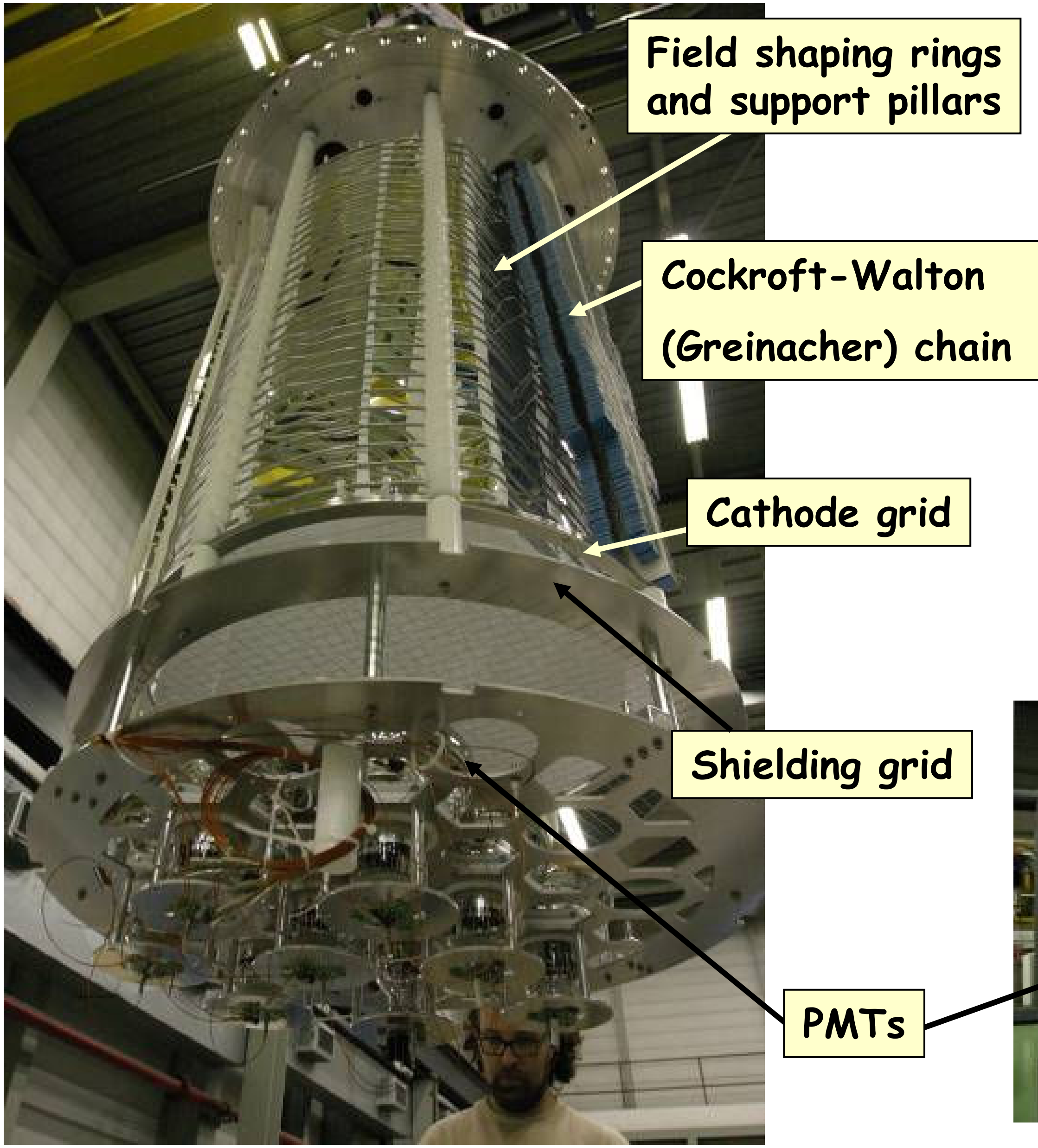
A. Rubbia, "ArDM: a Ton-scale liquid Argon experiment for direct detection of dark matter in the universe", J. Phys. Conf. Ser. 39 (2006) 129

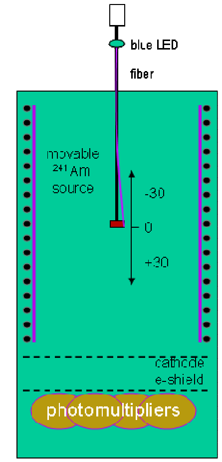


Cockroft-Walton (Greinacher) chain: supplies the right voltages to the field shaper rings and the cathode up to 500 kV (E=1-4kV/cm)



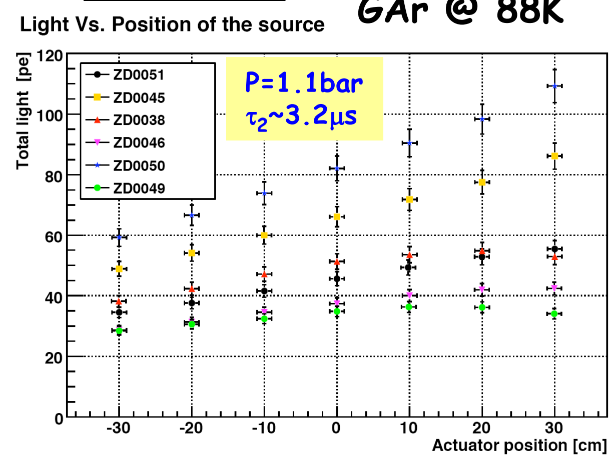
ArDM Inner Detector

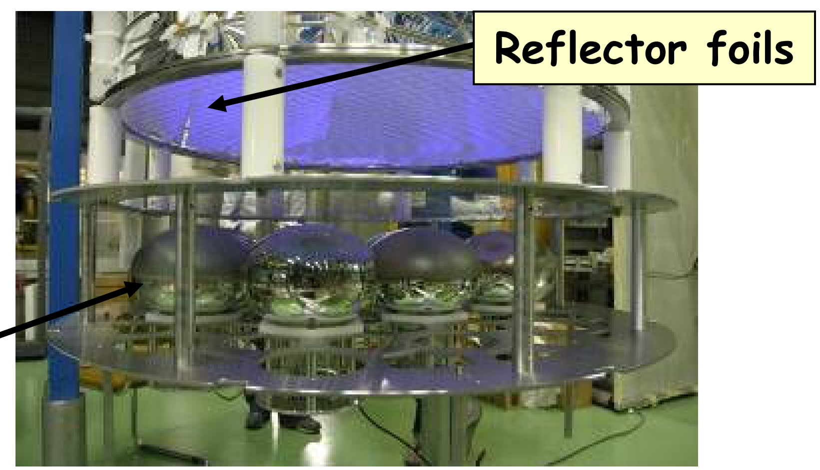




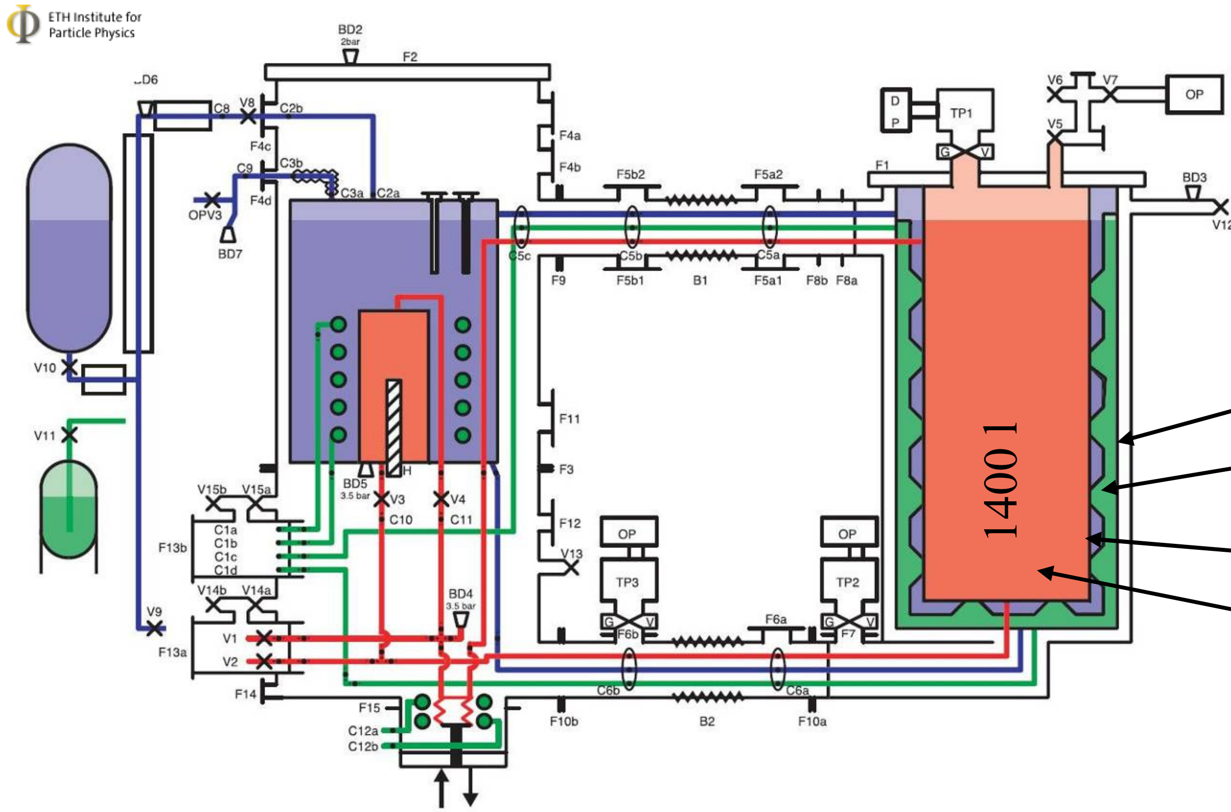
Light measurements vs. position of ^{241}Am source

GAr @ 88K





ArDM Cryogenics and LAr purification



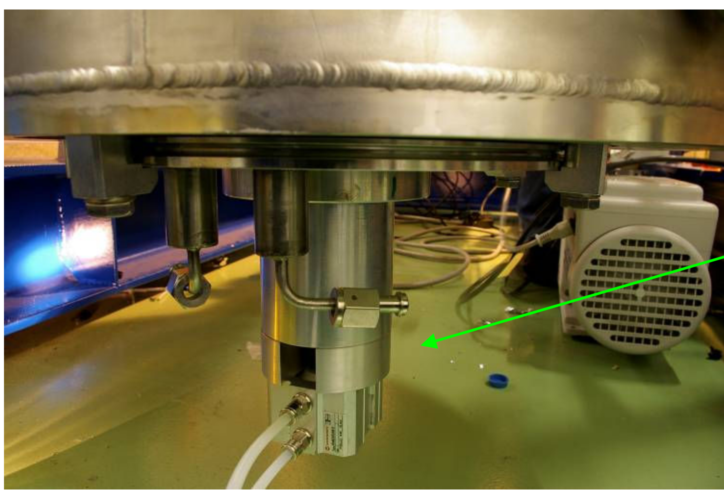
vacuum insulation

LN2 cooling jacket

'dirty' LAr cooling bath

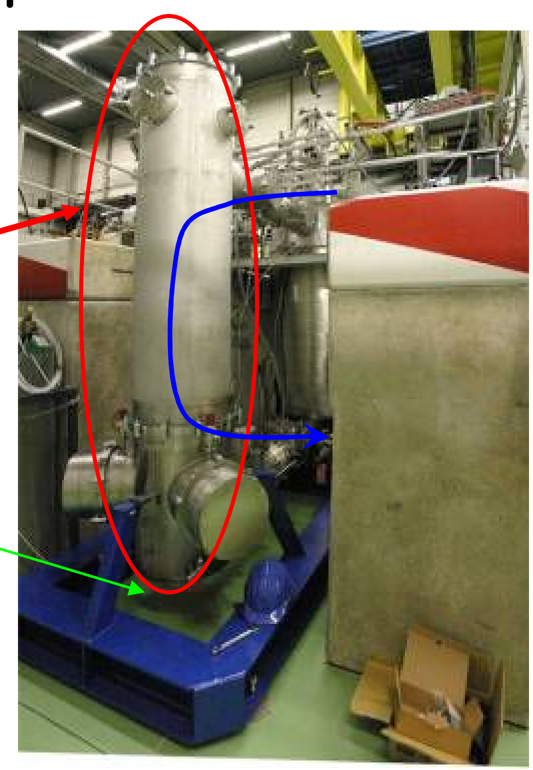
pure LAr closed circuit

In collaboration with BIERI engineering Winterthur, Switzerland



Recirculation and CuO purification cartridge

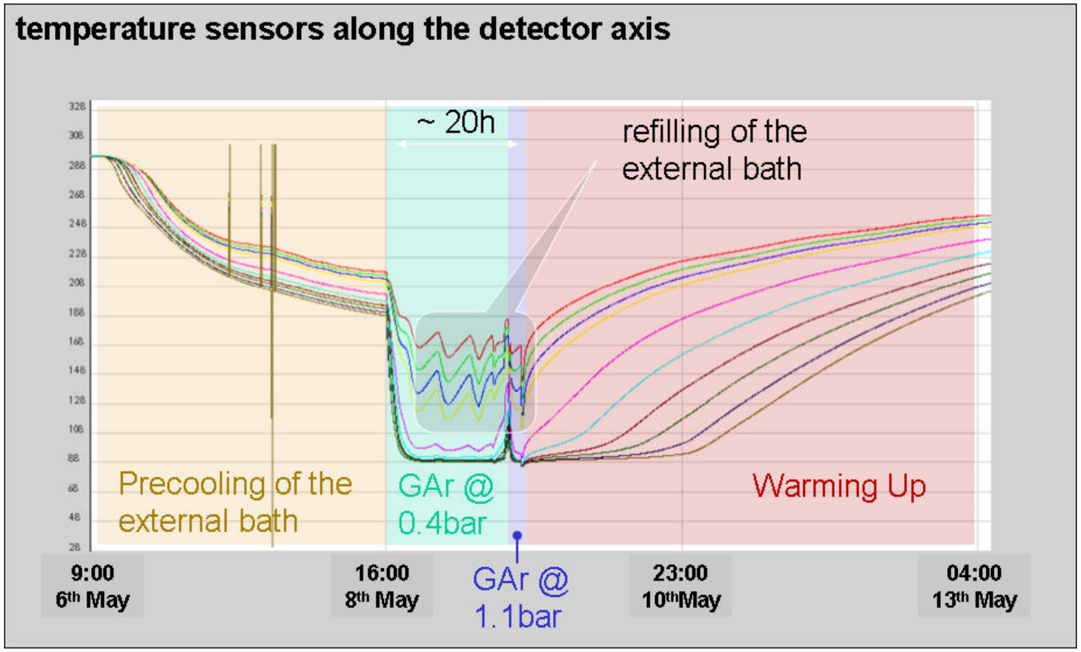
Bellow pump

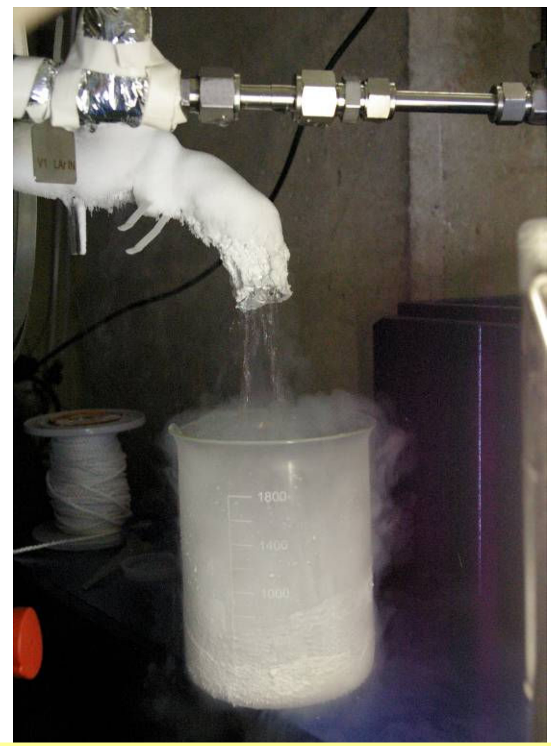


Cryogenic Tests

Diploma Work by U. Degunda, ETHZ

First ArDM cooldown with automatic refill of LAr cooling bath

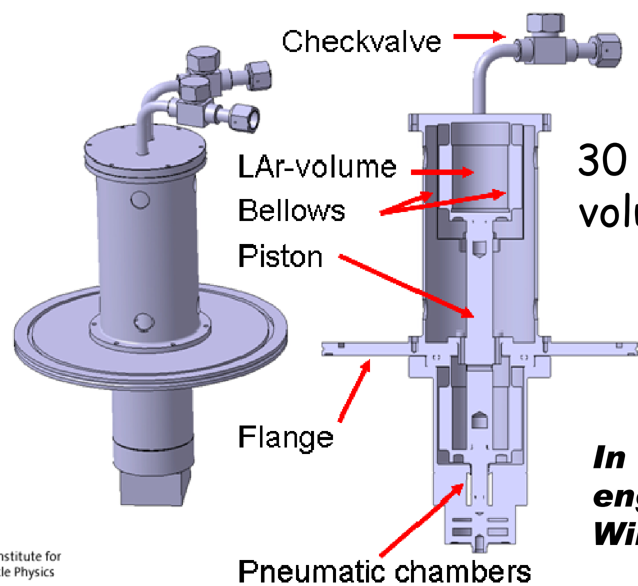




Measured LAr flux ~ 20 l/hr

LAr Pump test

Diploma Work by L. Epprecht, ETHZ



30 cm^3 volume

In collaboration with BIERI engineering Winterthur, Switzerland

ETH Institute for Particle Physics

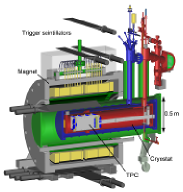
The next short-term steps …

- **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**

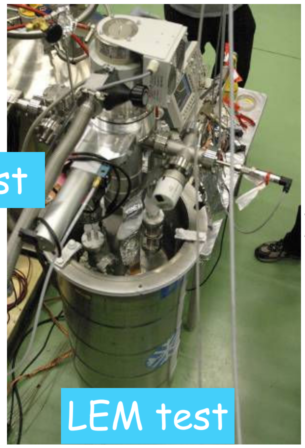
ETH Institute for Particle Physics

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 m^2 scale

➠ **LEM readout on 1x1 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

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

we are here

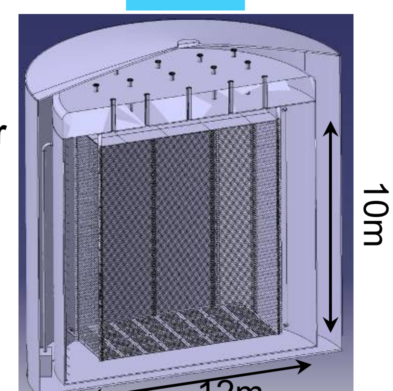
ArgonTube: long drift, ton-scale

➠ **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

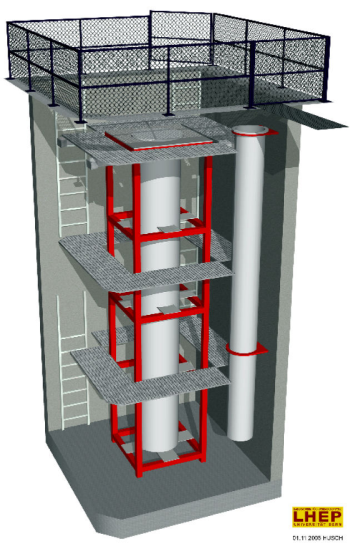


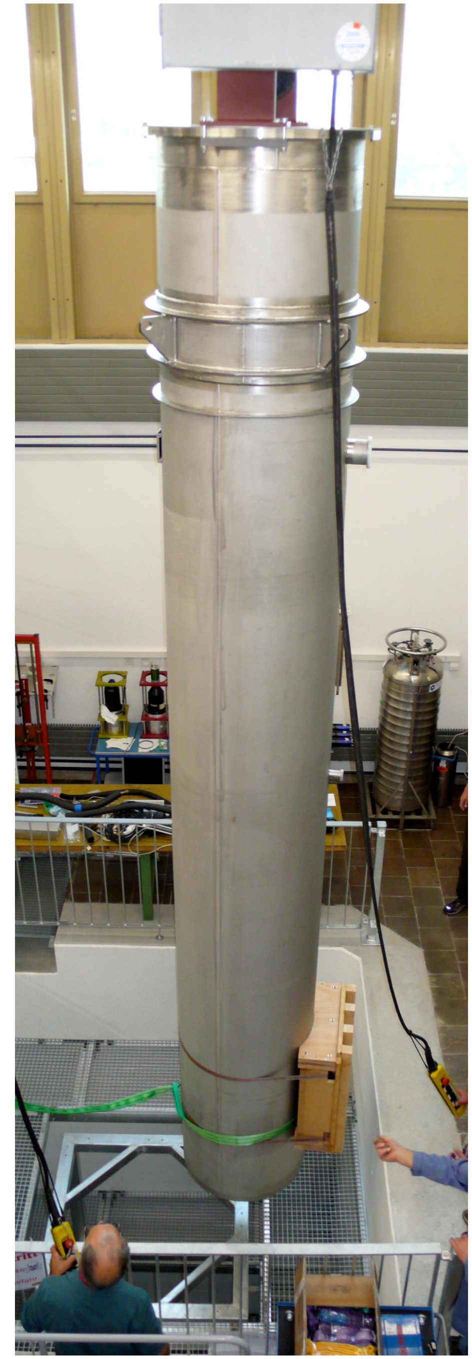
ETH Institute for Particle Physics

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**

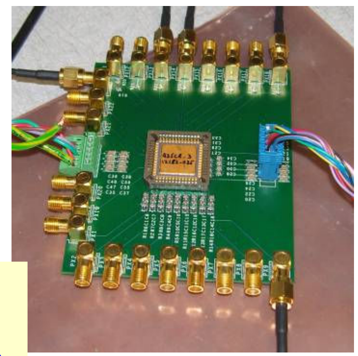




R&D on electronics integrated on the detector

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



0.35μm CMOS charge amplifier delivered on July 2008, presently under test in Lyon

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

- **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

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

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

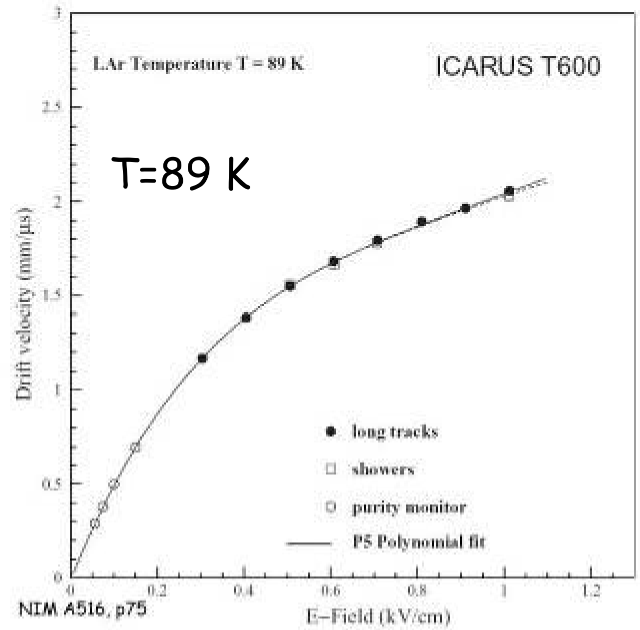
Can we drift over over long distances?

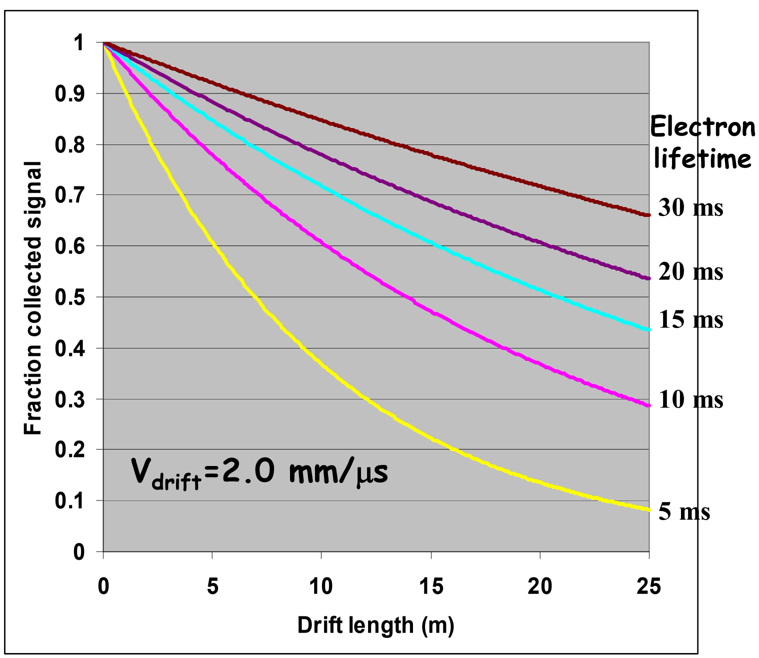
- HV feedthrough tested by ICARUS up to 150 kV (E=1kV/cm in T600)
- v_{drift}= 2 mm/μs @ 1kV/cm
- Diffusion of electrons:

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

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)

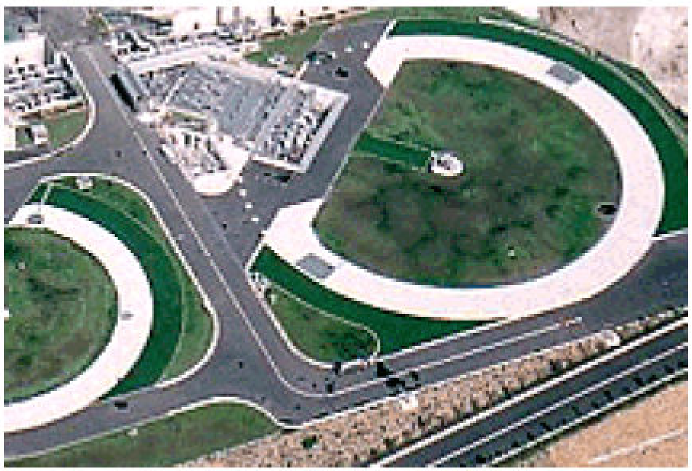




- to drift over macroscopic distances, LAr must be very pure
  - a concentration of 0.1 ppb Oxygen equivalent gives an electron lifetime of 3 ms
- for a 20 m drift and >30% collected signal, an electron lifetime of at least 10 ms is needed

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

- 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%)

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