

# GLACIER

## Giant Liquid Argon Charge Imaging Experiment

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on behalf of the GLACIER Collaboration



ASPERA Technology Forum  
Photosensors and auxiliary electronics  
21–22 October 2010

Carl Friedrich von Siemens Stiftung, Nymphenburg Castle, Munich



Eidgenössische Technische Hochschule Zürich  
Swiss Federal Institute of Technology Zurich



ETH Institute for  
Particle Physics

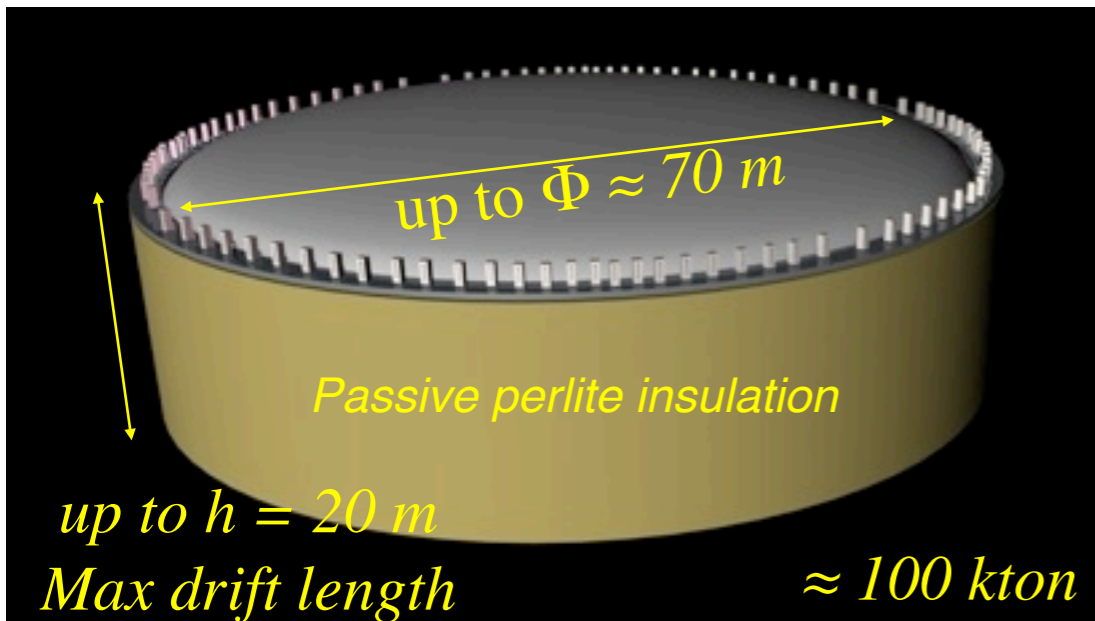
# Outline

of this talk

- GLACIER – Giant Liquid Argon Charge Imaging Experiment
- Next generation neutrino observatory
- In the framework of FP7 LAGUNA design study of Europe
- Detector design – towards a giant scale LAr TPC
- R&D in staged approach – ArDM-It at CERN
- High-QE cryogenic PMT
- Conclusions

# GLACIER

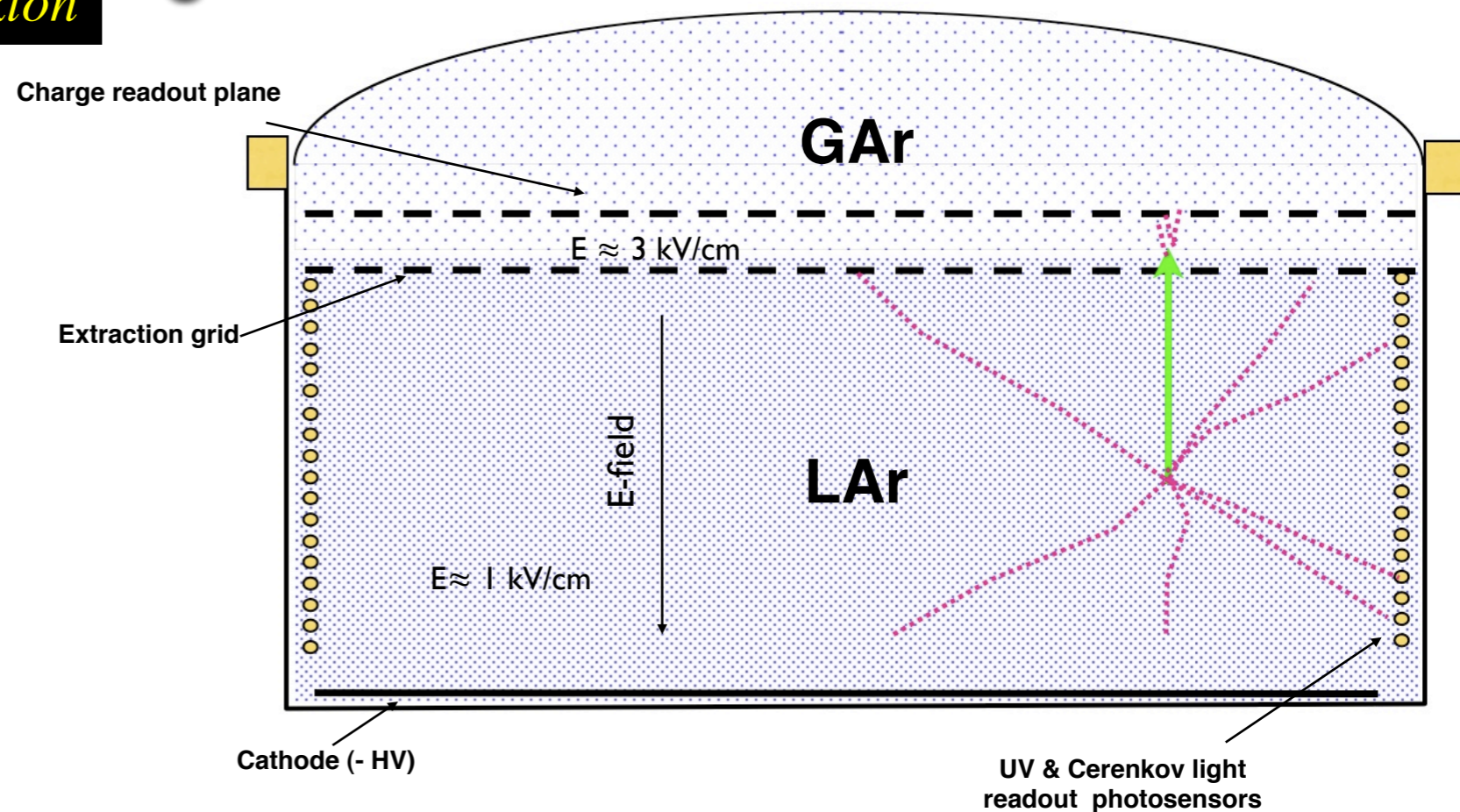
## Giant Liquid Argon Charge Imaging Experiment



Density (g/cm <sup>3</sup> )	1.4
Radiation length (cm)	14.0
Interaction length (cm)	83.6
dE/dx mip (MeV/cm)	2.1
We (eV) @ E=∞	23.6
Wγ (eV) @ E=0	20
Refractive index (visible)	1.24
Cerenkov angle	36°
Cerenkov d <sup>2</sup> N/dEdx (β=1)	≈ 130 eV <sup>-1</sup> cm <sup>-1</sup>
Muon Cerenkov threshold	140 MeV/c
Boiling point @ 1 bar	87 K

Giant scale LAr TPC combining charge, scintillation and possibly Cerenkov light readout

- Ar composes 1% of air, giant scale conceivable
- undistorted “bubble chamber” track image can be transported to ~20 m (in ultra pure LAr)
- excellent scintillation characteristics
- Cerenkov radiation similar to water



Next-generation large underground neutrino observatory

# Physics goals of a U observatory

to go beyond present experiment(s)

- ★ Proton decay
- ★ Long baseline neutrino oscillations and CP violation in the leptonic sector (with super beam, possibly beta beam or neutrino factory)
- ★ Atmospheric neutrinos
- ★ Diffuse Supernova Neutrino Background
- ★ Galactic Supernova Burst
- ★ Solar Neutrinos
- ★ Dark Matter indirect search
- ★ Look for the unexpected

**Giant LAr TPC  $\Rightarrow$  Next generation underground neutrino detector – a new way to look at rare events – to go beyond present experiment(s)**

## Large Apparatus for Grand Unification and Neutrino Astrophysics

- Objective: defining and realizing this research programme in Europe
- Participation (open): very interdisciplinary - most European physicists interested in massive detectors; geo-technical experts, geo-physicists; structural engineers; tank and mining engineers
- EC contribution: 1.7 M€ (PI A. Rubbia) to be mainly devoted to the sites infrastructure studies (FP7 “Design Studies” Research Infrastructures LAGUNA GA No. 212343)  
21 beneficiaries in 9 countries: 9 higher education entities, 8 research organizations, 4 private companies (+4 additional universities)

Discuss and assess:

- rock engineering → feasibility
- needed infrastructure
- cost of excavation
- assembly of underground tank
- physics programme

*Detector R&D to be funded at national level*



**WP2: Underground infrastructures and Engineering**

**WP3: Safety, environmental and socio-economic issues**

**WP4: Science Impact and Outreach**

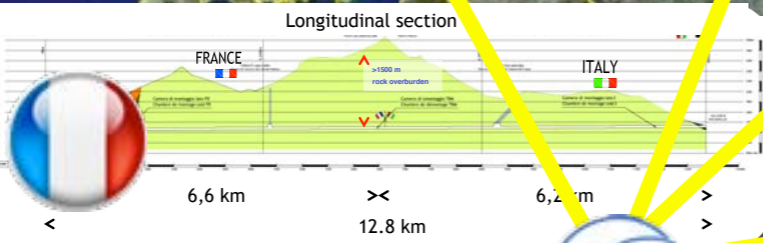
# 7 potential sites



1. Boulby



3. Fréjus



2. Canfranc



4. Pyhäsalmi



5. Sieroszowice



6. Slanic



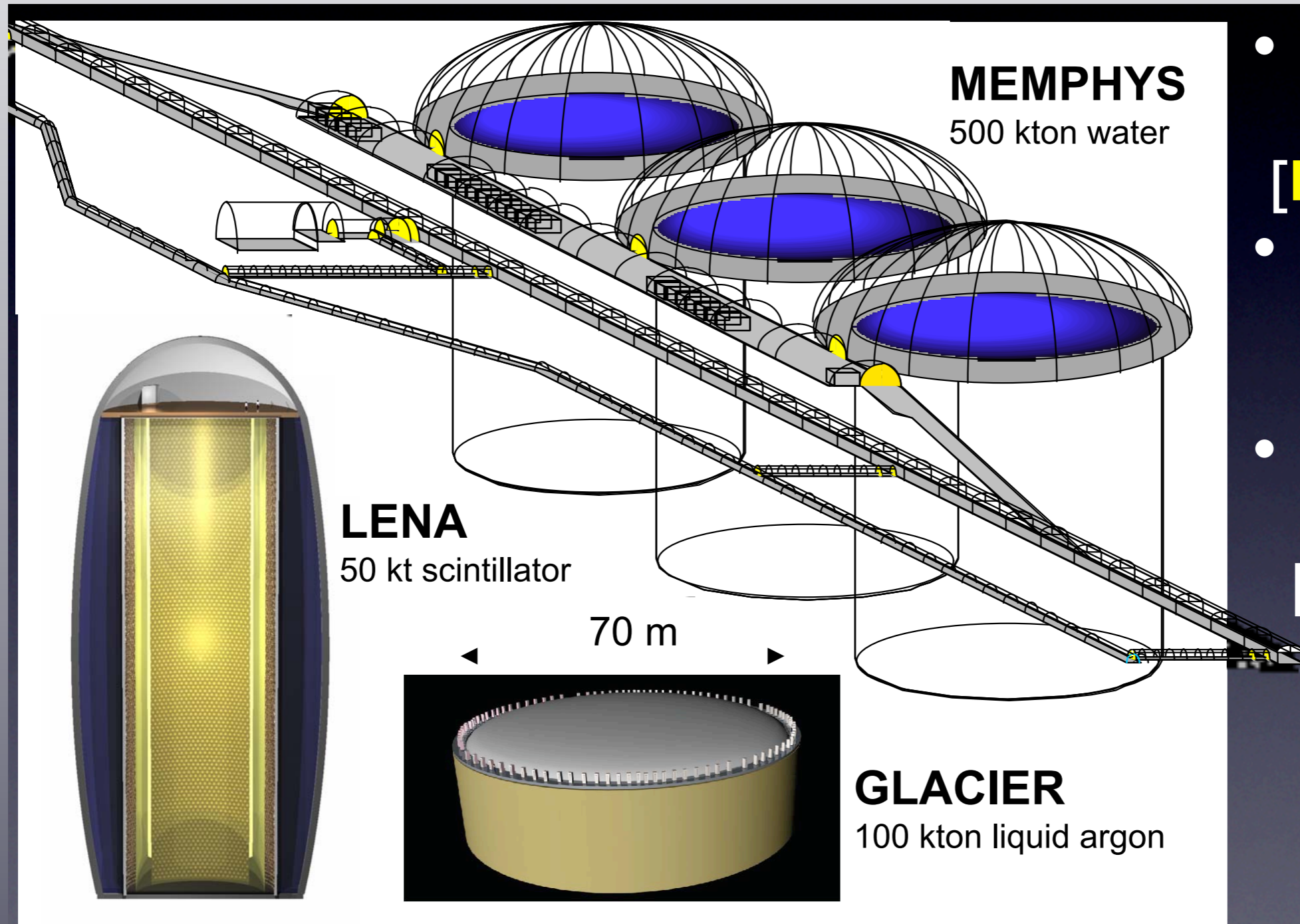
7. Umbria



# LAGUNA detector options



- Three options considered (MEMPHYS, LENA, GLACIER) with total mass in the range 50-500 kton

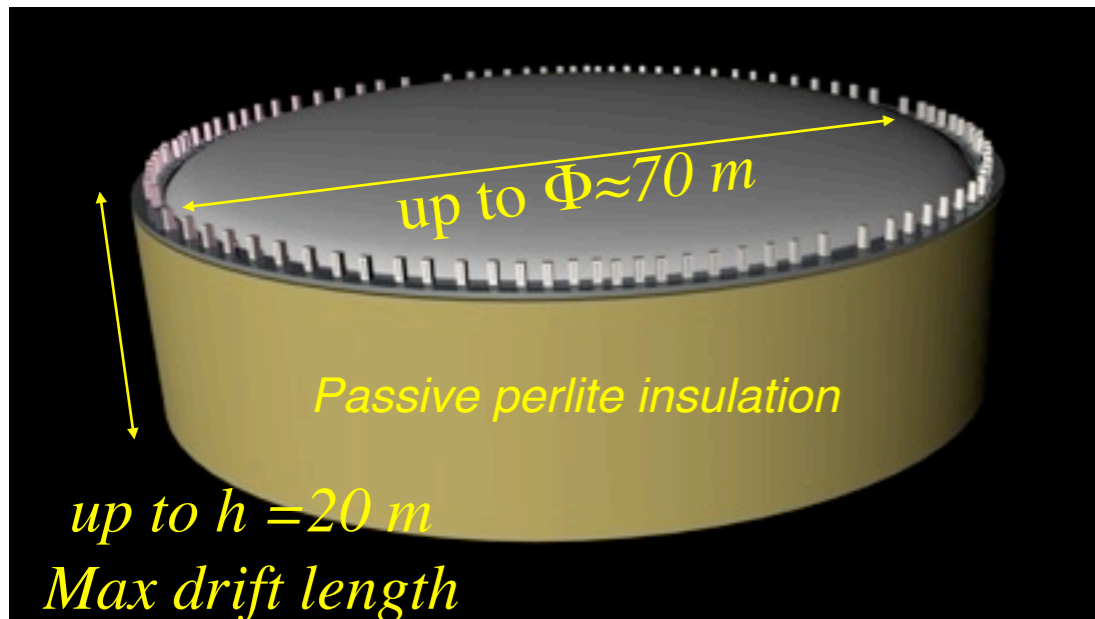


- Water Cerenkov  
[**MEMPHYS**]
- Liquid scintillator  
[**LENA**]
- Liquid Argon TPC  
[**GLACIER**]

# GLACIER design study

Simple and scalable design possibly up to 100 kton

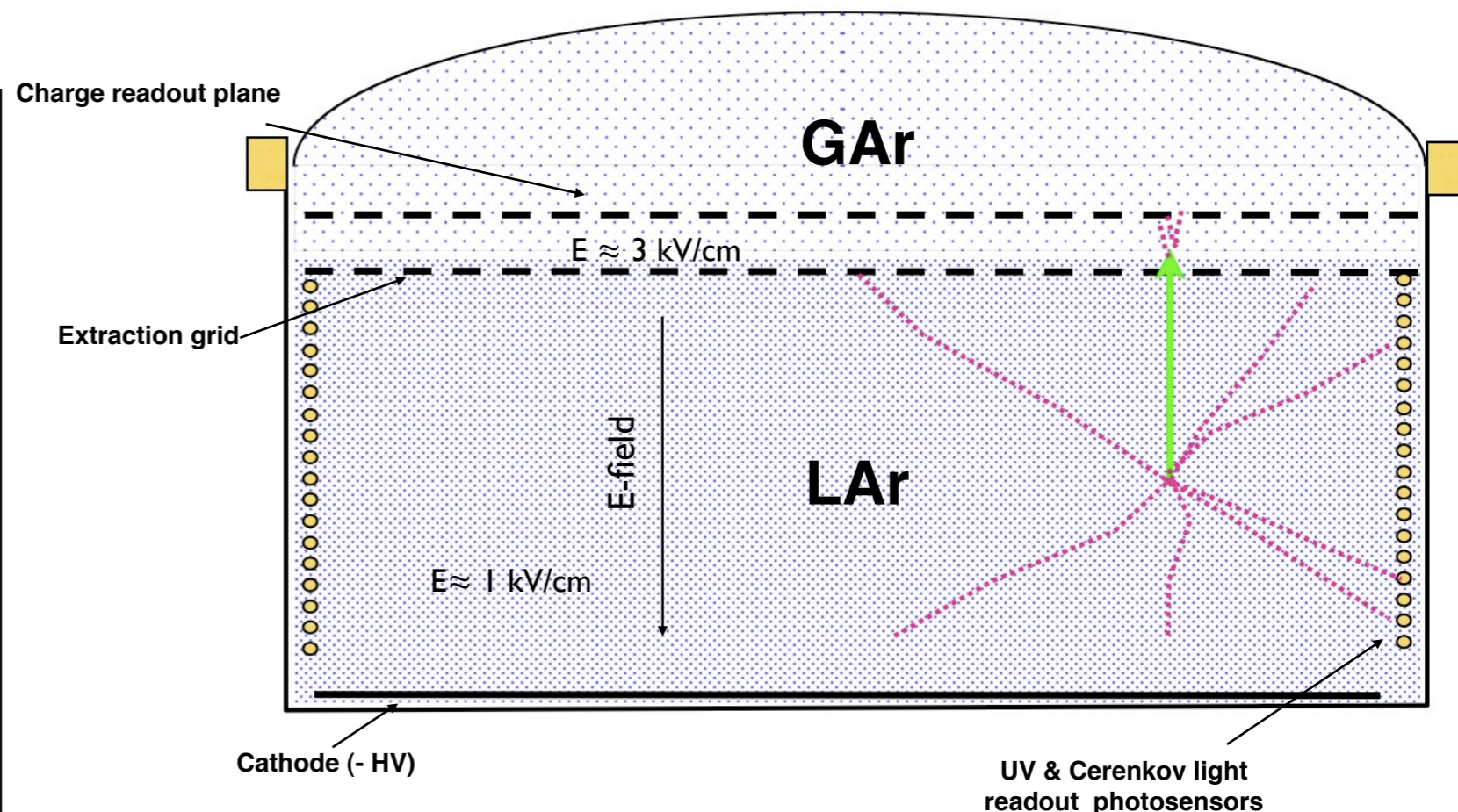
A.Rubbia, hep-ph/0402110, Venice 2003



- Single module non-evacuatable cryo-tank based on industrial LNG technology
- Cylindrical shape with excellent surface / volume ratio
- Simple, scalable detector design, possibly up to 100 kton
- Single very long vertical drift with full active mass
- A very large area LAr LEM-TPC for long drift paths
- Possibly immersed visible light readout for Cerenkov imaging
- Possibly immersed (high  $T_c$ ) superconducting solenoid to obtain magnetized detector
- Reasonable excavation requirements ( $< 250'000\text{ m}^3$ )

## Design technical issues:

- Tank with passive insulation heat loss  $\approx 80\text{ kW@LAr}$
- Very large area ( $\approx 3500\text{ m}^2$ ) LEM/THGEM + anode with 3-mm readout pitch, modular readout, strip length modifiable,  $\geq 2.5 \times 10^6$  channels
- Purification to  $< 10\text{ ppt}$  ( $\text{O}_2$  equiv.) in large non-evacuatable vessel
- Immersed HV Cockcroft-Walton for drift field ( $1\text{ kV/cm}$ ) up to  $2\text{ MV}$
- Readout electronics (F/E; DAQ; network data flow & time stamp distribution)
- WLS-coated  $1000 \times 8''$  PMT and reflectors for DUV light detection



# GLACIER design study

Simple and scalable design – parameters for 100 kton

## Light readout

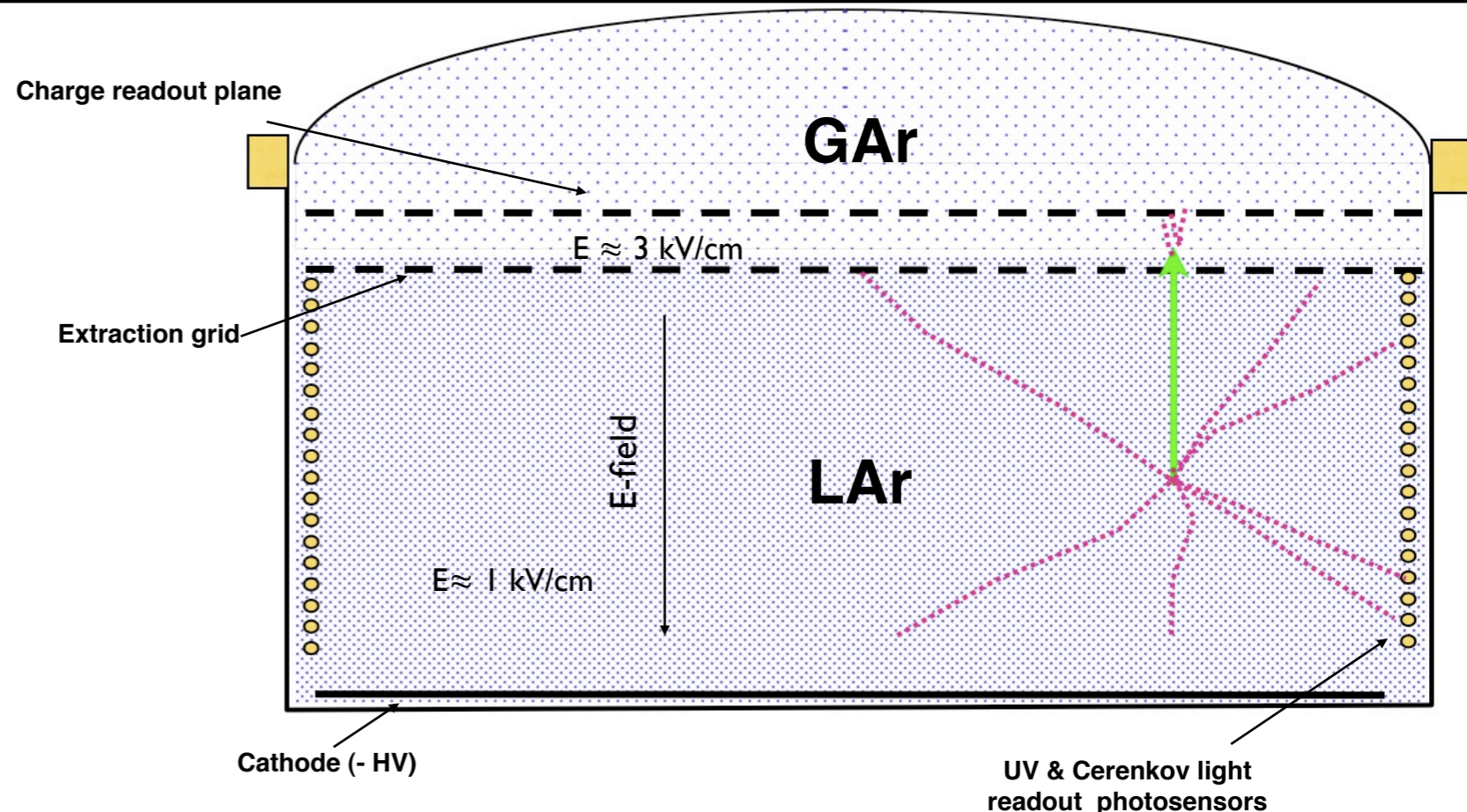
### Scintillation

- a line at 128 nm
- 1000 immersed 8" cryogenic PMTs coated with wave shifting TPB
- additional calorimetric information + trigger

### Cerenkov

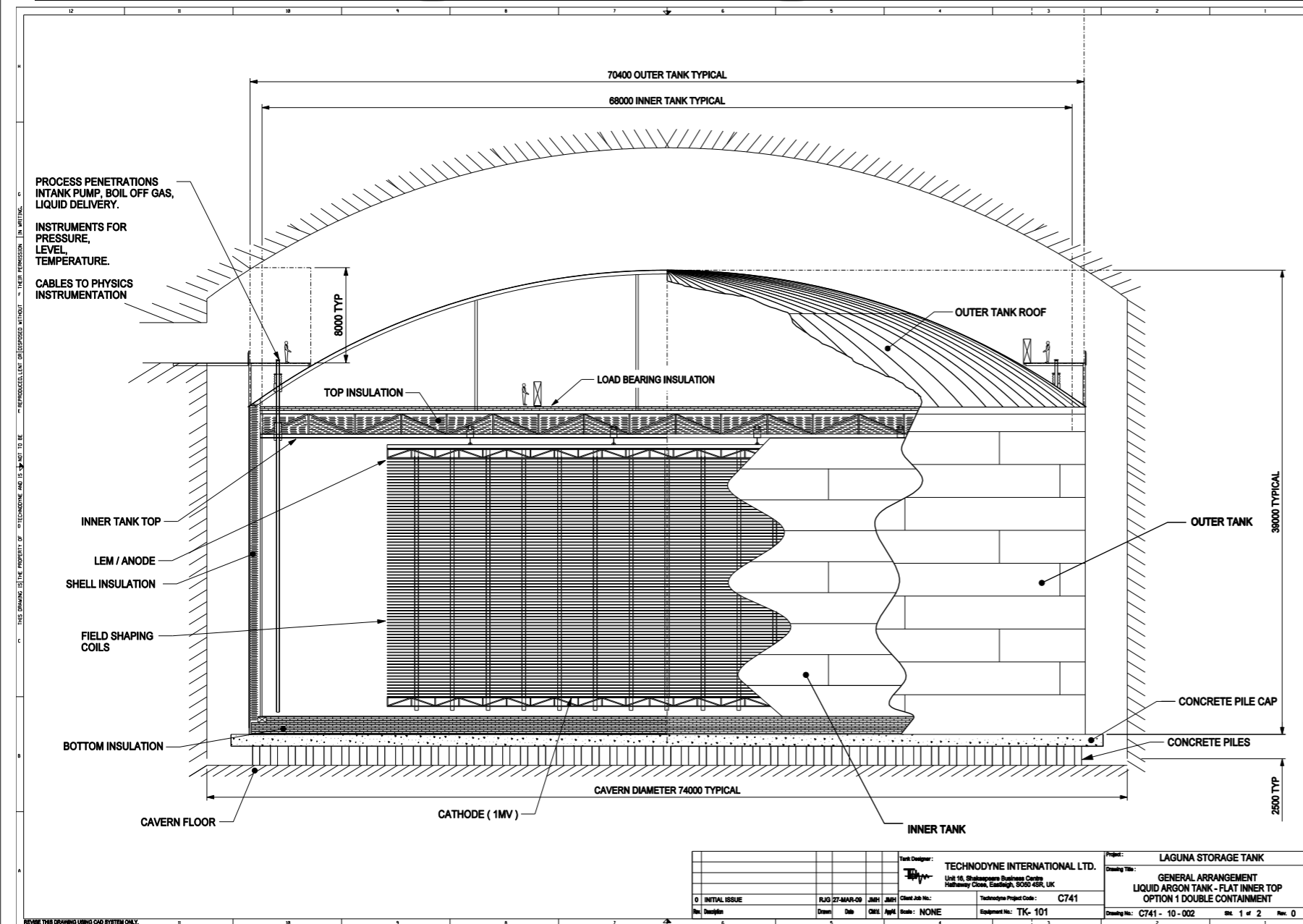
- 27000 immersed uncoated 8" cryogenic PMTs for 20% coverage
- Cerenkov imaging, improved PID

Dewar	$\varphi \approx 70$ m, height $\approx 20$ m, perlite insulated, heat input $\approx 5$ W/m <sup>2</sup>
Argon storage	Boiling Argon, low pressure (<100 mbar overpressure)
Argon total volume	73000 m <sup>3</sup> , ratio area/volume $\approx 15\%$
Argon total mass	102000 tons
Hydrostatic pressure at bottom	3 atmospheres
Inner detector dimensions	Disc $\varphi \approx 70$ m located in gas phase above liquid phase
Charge readout electronics	2500000 channels
Scintillation light readout	Yes (also for triggering), 1000 immersed 8" PMTs with WLS
Visible light readout	Yes (Cerenkov light), 27000 immersed 8" PMTs of 20% coverage, single $\gamma$ counting capability



# Engineering of tank & detector

*LNG technology feasibility  
& safety already proven at  
the required scale*

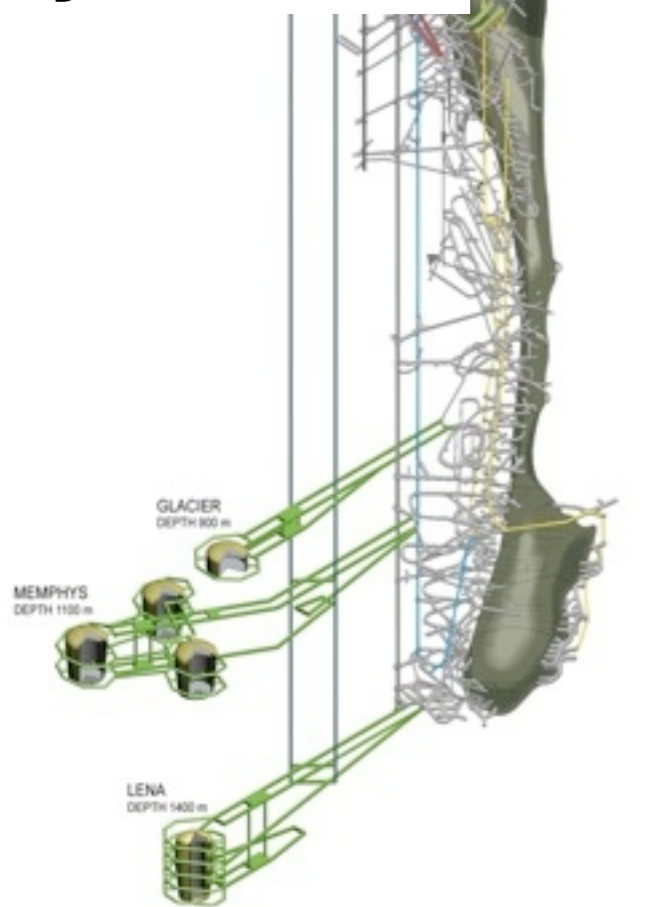


- Study started in 2004 with Technodyne International Ltd
- Recent progress within the EU FP7 LAGUNA DS
- Study covers conceptual design including detector support, tank construction sequence, and tank costing (for high&low seismic region)
- Considers incremental cost (multiplicative) for underground construction

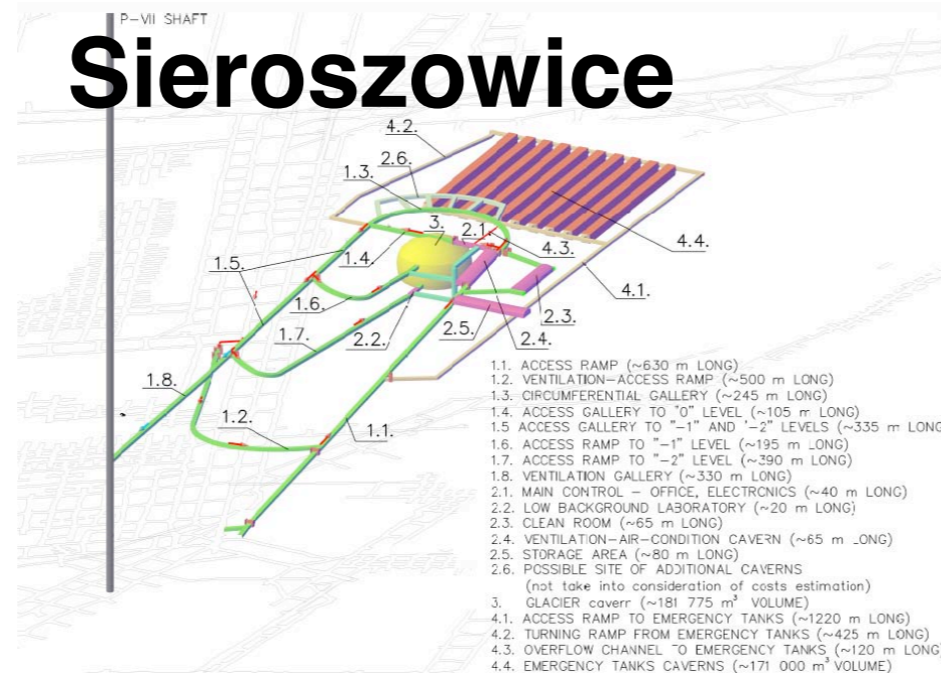
# Underground Layouts

Details of layout including MDC, auxiliary caverns, access, escape routes, etc...  
at various sites being considered within LAGUNA DS and for Okinoshima, Japan

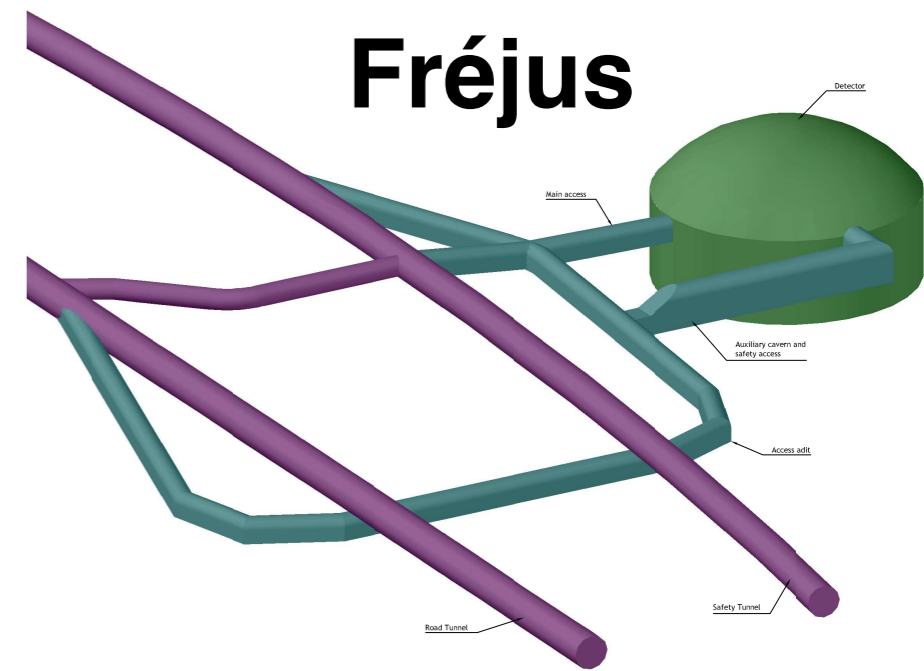
## Pyhäsalmi



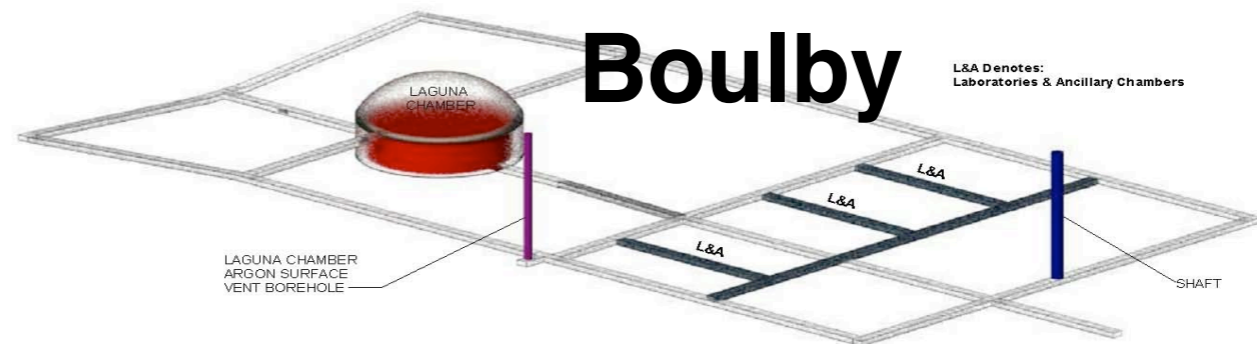
## Sieroszowice



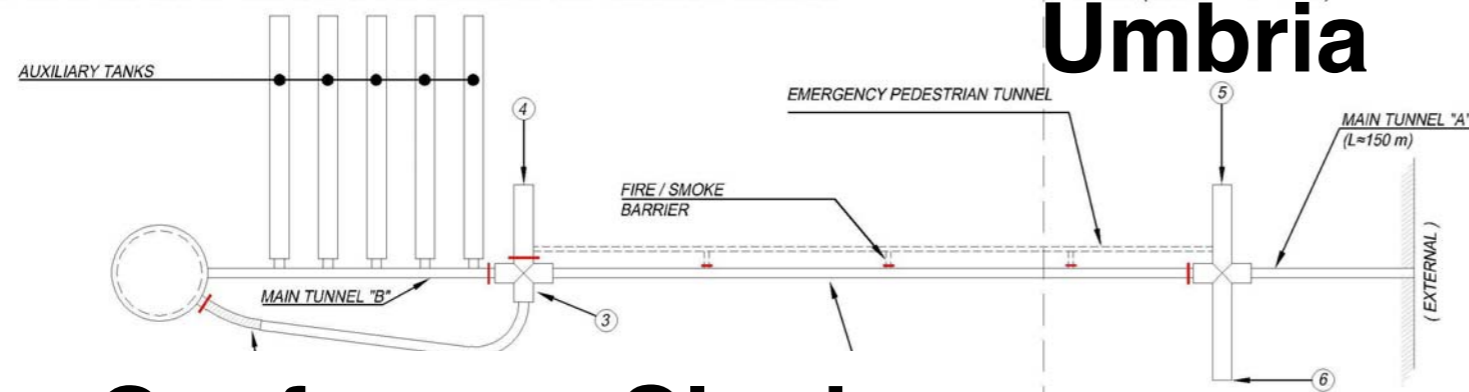
## Fréjus



## Boulby



PROPOSED LAY-OUT OF UNDERGROUND SERVICES AND AUXILIARY CAVERNS

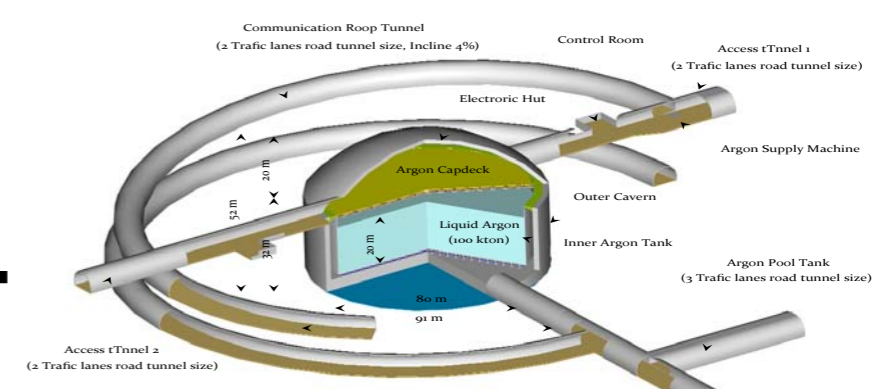


+ Canfranc + Slanic

TYPE A (SITE: 1 - 3 - 4 - 5)

## Umbria

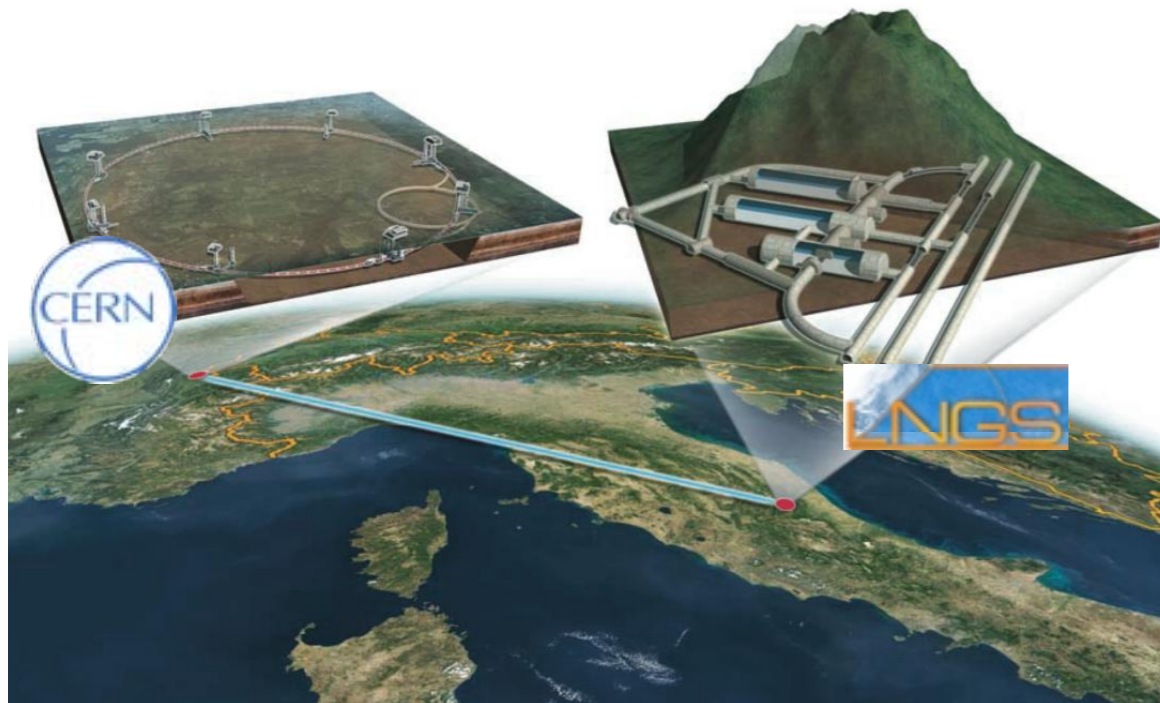
+



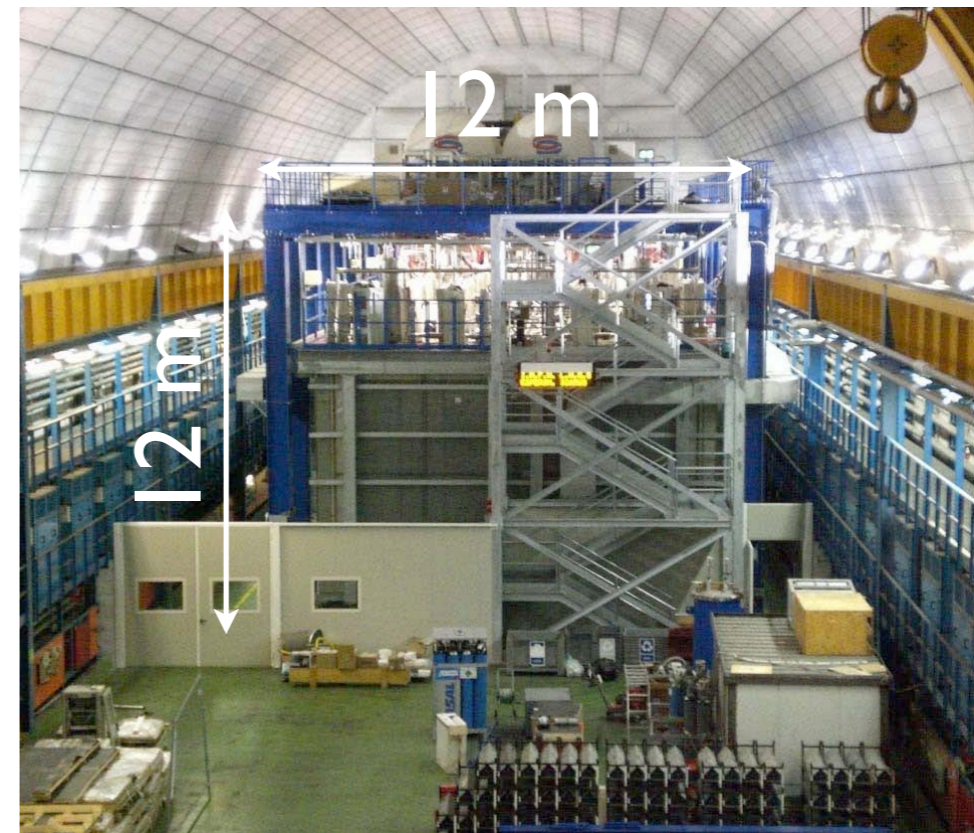
Okinoshima, Japan

# ICARUS-T600@LNGS

LAr TPC of  $\sim 0.5$  kton is already operating underground !!



ICARUS T600 built between years 1997 and 2002  
(including prototyping, industrialization and testing):  
Completely assembled in a surface assembly hall in Pavia.  
Full scale demonstration on surface with first T300 in 2001  
T600 second half-module terminated in 2002



T600 modules moved to LNGS: December 2004  
Installation at LNGS completed including electronics  
and DAQ: December 2009

Vacuum phase: started on January 9th, 2010

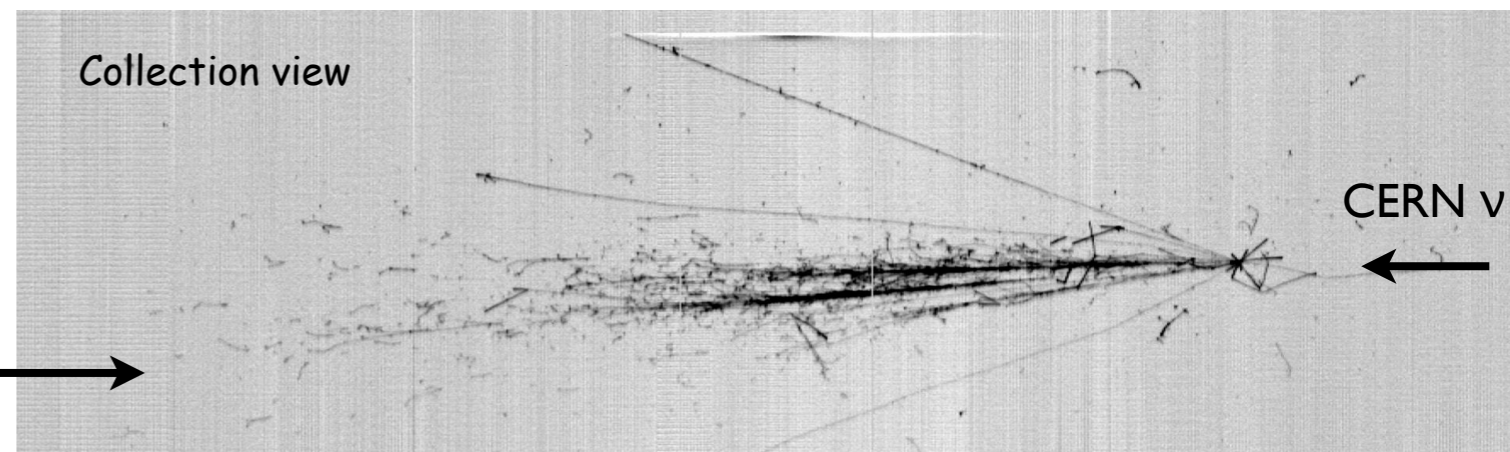
Cryogenic plant completed: March 2010

Cooling phase: LN<sub>2</sub> cool-down started on April 16th.  
Filling phase: on April 29th ultra-pure LAr was injected  
at a rate of  $\sim 2$  m<sup>3</sup>/hour.

On May 18th both modules were completely full

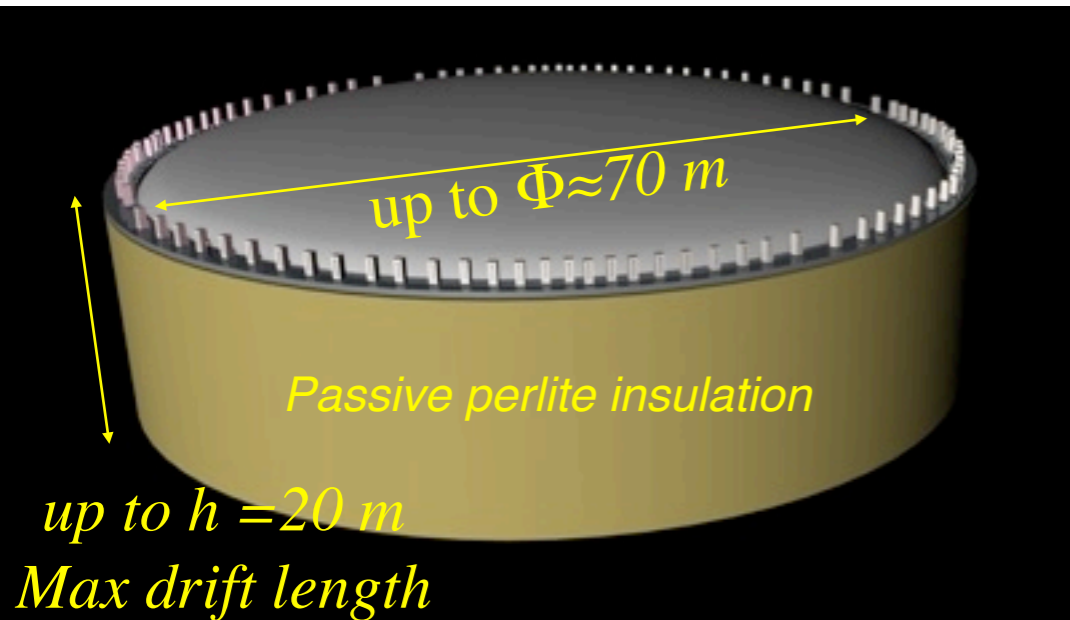
**On May 28th at 19.54 the first CNGS  
neutrino interaction was observed**

**The second CNGS  
neutrino interaction**



# Concepts for Giant LAr detectors

*Consider dedicated caverns and underground construction*

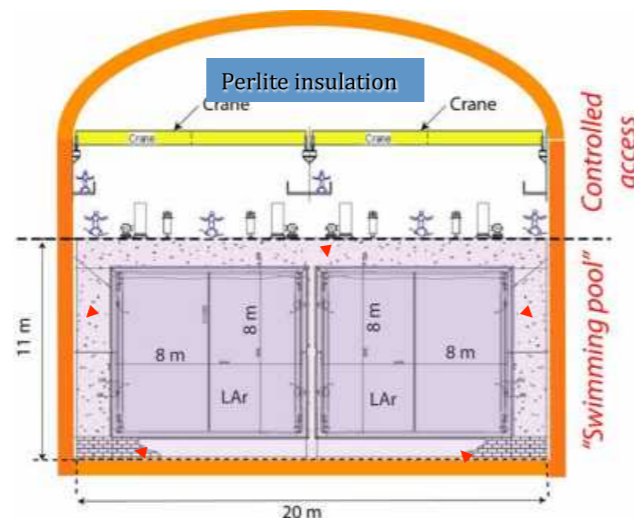


**GLACIER (2003)**

**LNG-tank**

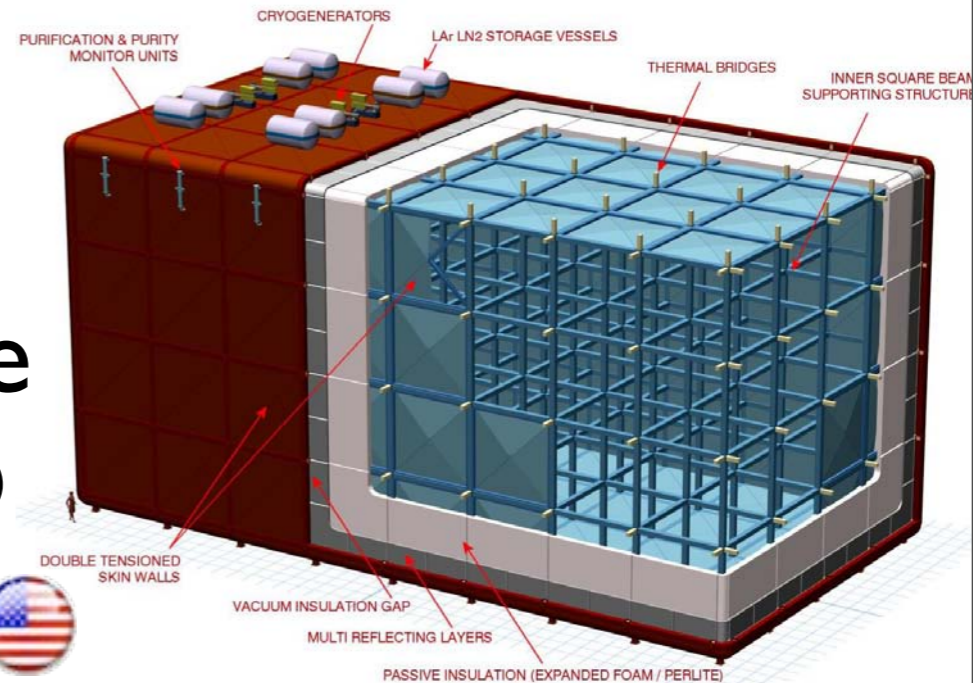
**up to 100 kton**

**MODULAR  
(2008)  
10 kton**

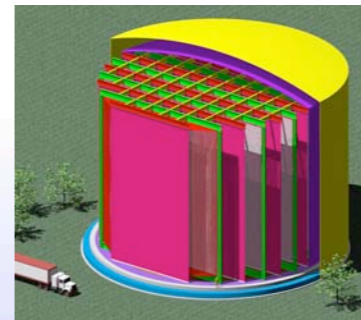


Low conductivity foam glass light bricks for the bottom support layer

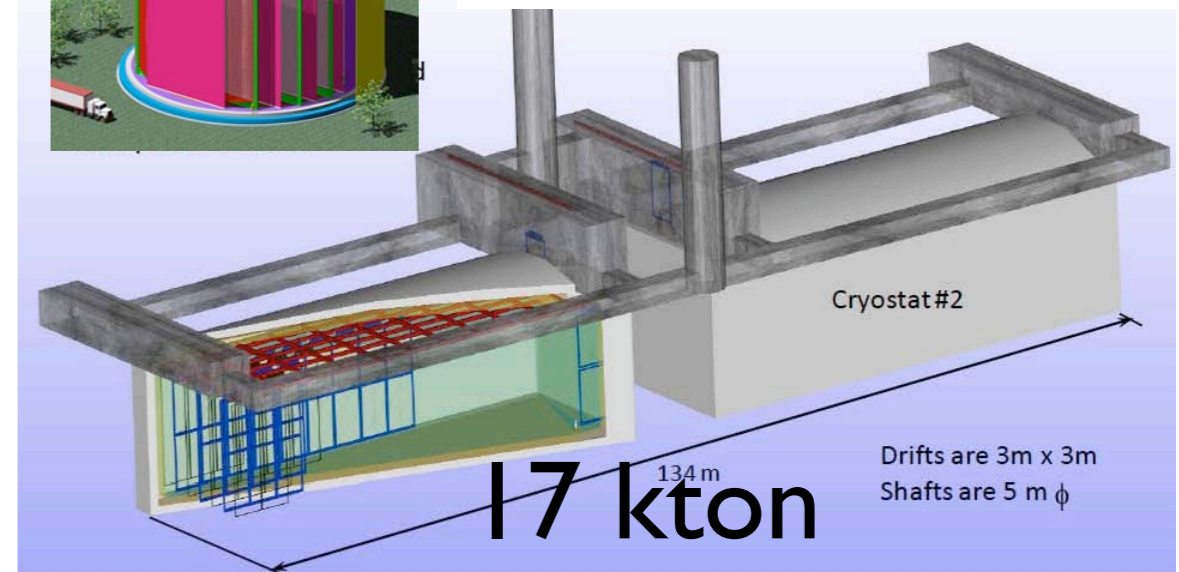
**50 kton  
evacuatable  
LANND  
(2006)**



FLARE detector (2005)



**LAr20@DUSEL  
(2009)**



# GLA2010

28–31 March 2010 at KEK in Japan

<http://neutrino.kek.jp/GLA2010/>

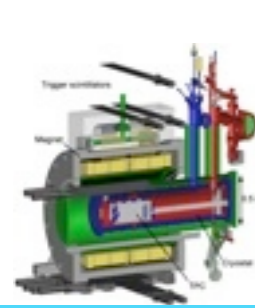


Next meeting in Europe in 2011

A strong worldwide momentum  
towards the giant scale LAr TPC !!

# GLACIER roadmap

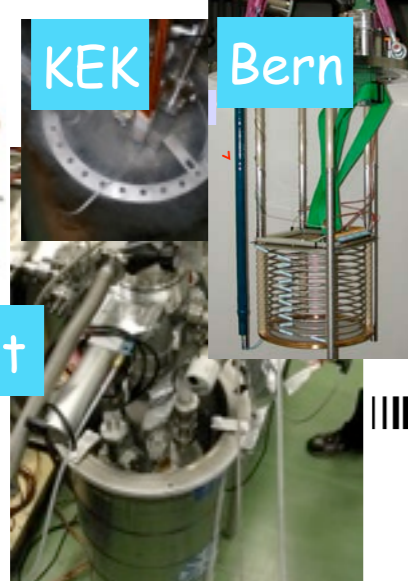
see J.Phys.Conf.Ser.171:012020  
(2009)



KEK

Bern

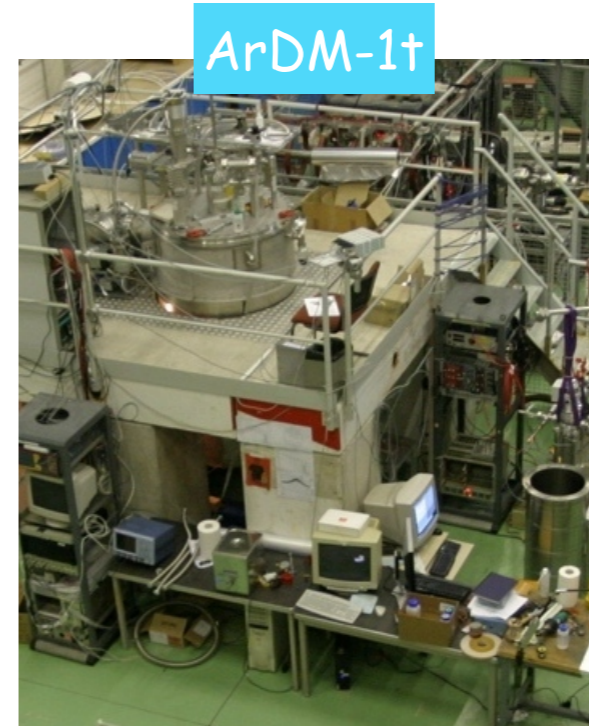
B-field test



LEM-TPC ETHZ

**proof of principle  
double-phase LAr LEM-  
TPC on 0.1x0.1 m<sup>2</sup>  
scale**

**LEM readout on 1x1 m<sup>2</sup>  
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-1t

Now operating at CERN



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

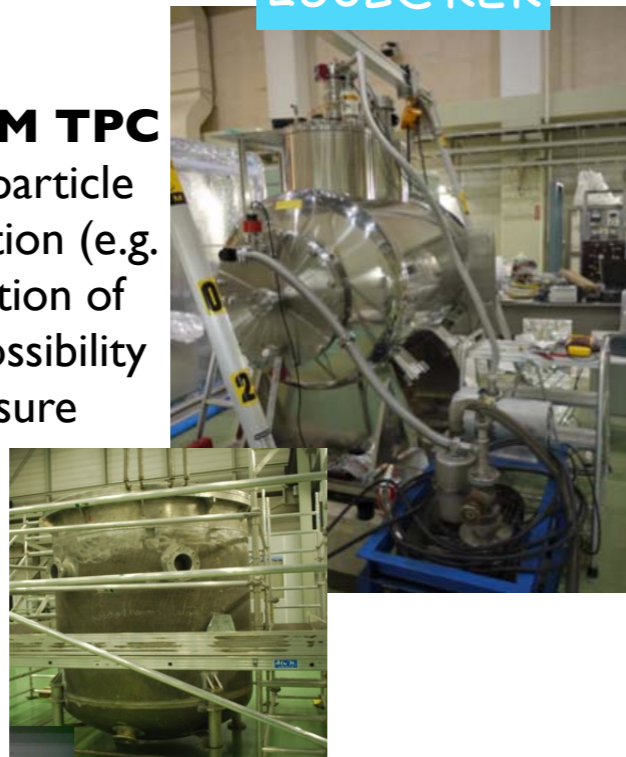
ArgonTube: long drift, ton-scale



250L@KEK

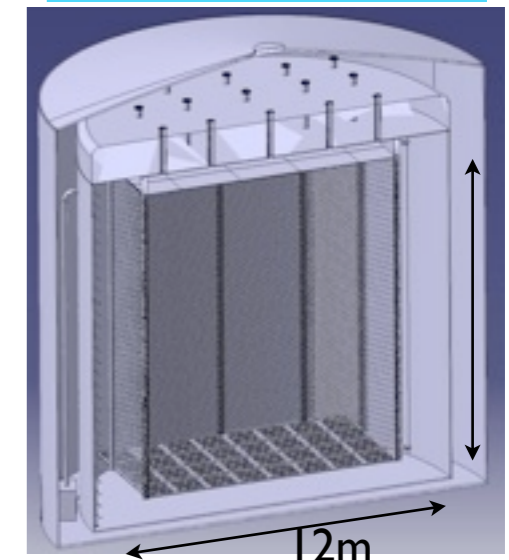
**Application of LAr LEM TPC  
to neutrino physics:** particle  
reconstruction & identification (e.g.  
1 GeV e/ $\mu$ / $\pi$ /K), optimization of  
readout and electronics, possibility  
of neutrino beam exposure

6m<sup>3</sup> @ CERN  
→ NA ?



**full engineering  
demonstrator for larger  
detectors**, acting as near  
detector for neutrino fluxes and  
cross-sections measurements, or  
with a stand-alone short baseline  
physics programme

1 kton → CERN ?

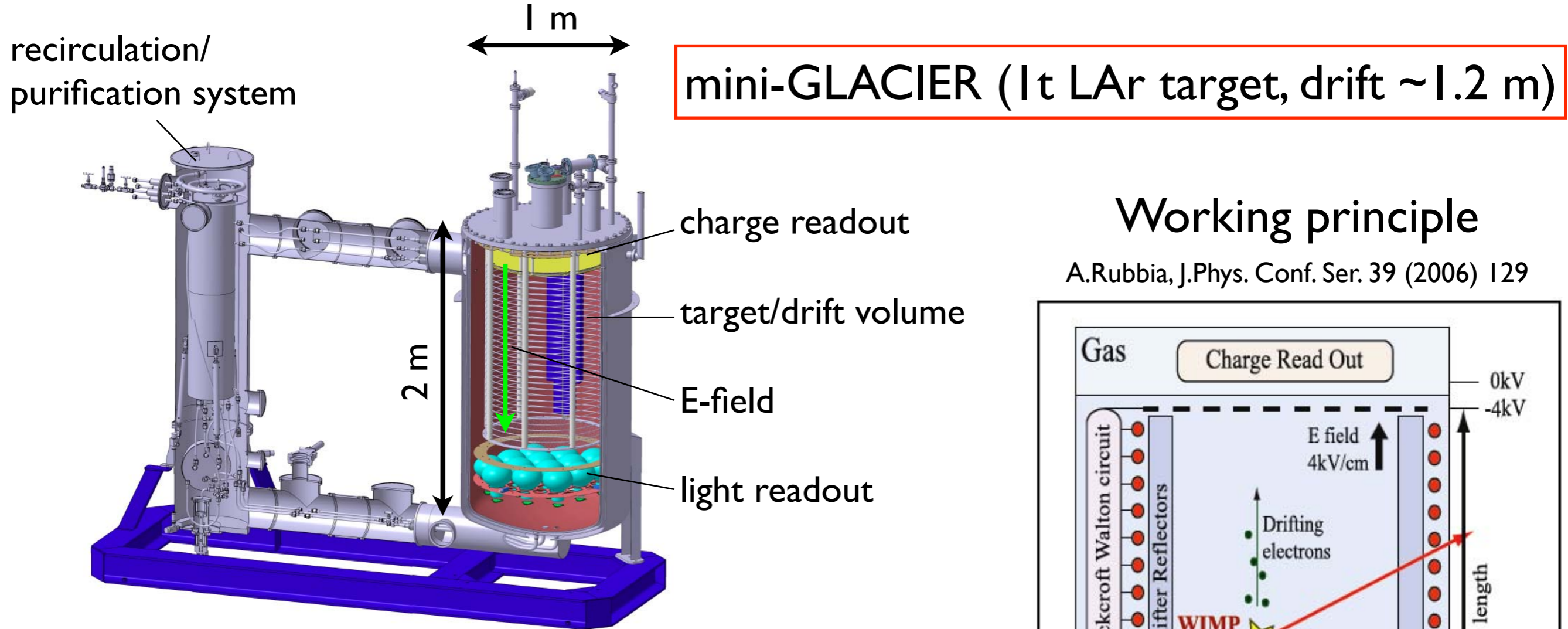


10m

12m

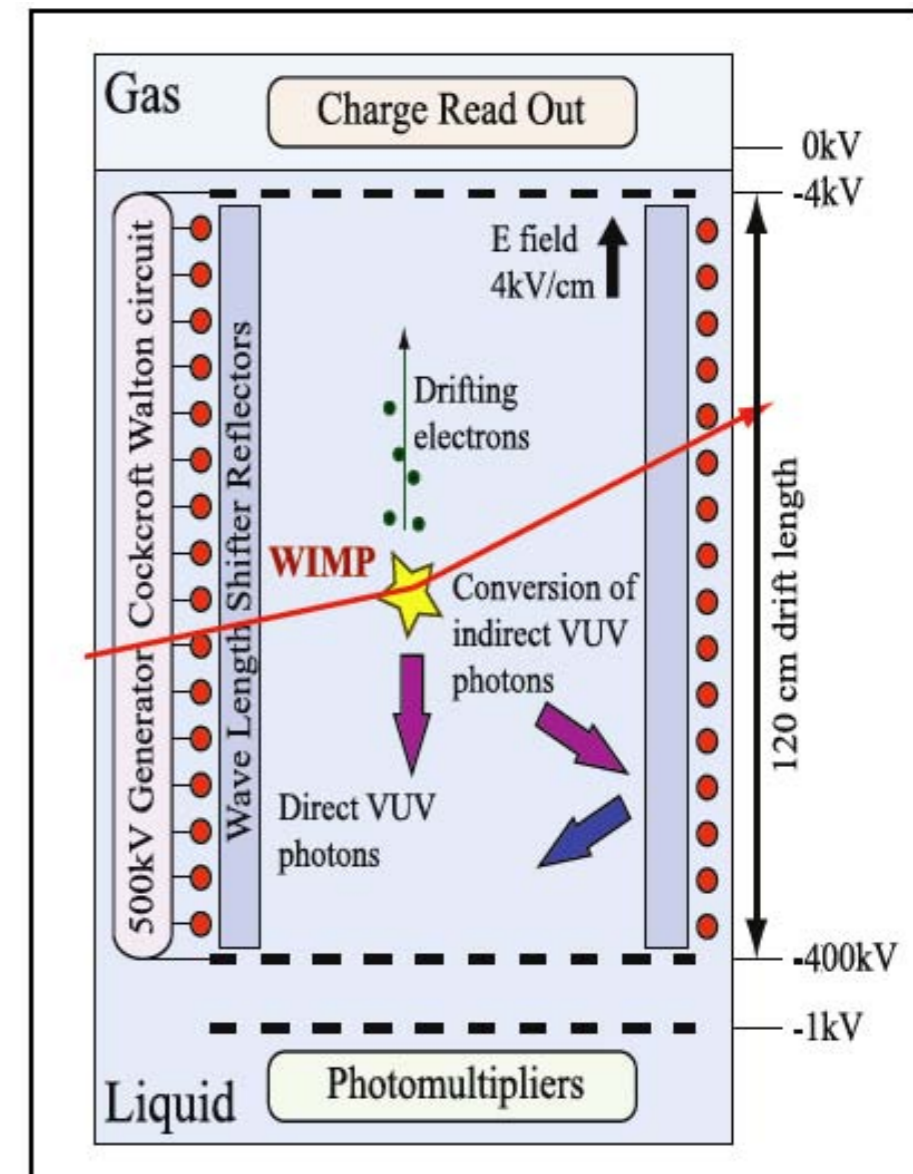
# ArDM-It

## It-LAr LEM-TPC for direct detection of WIMPs



## Working principle

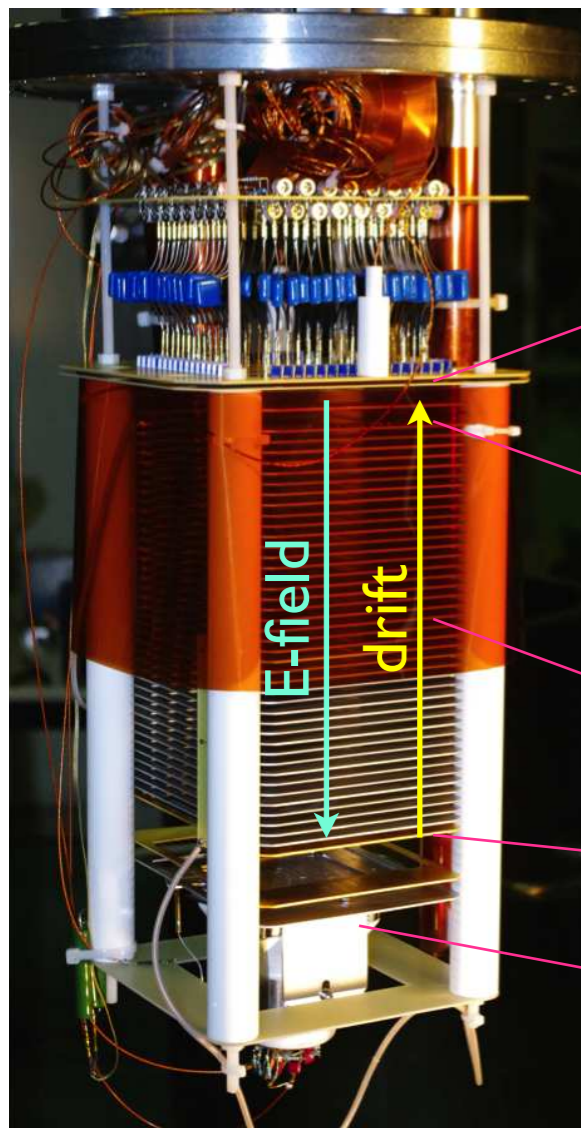
A. Rubbia, J. Phys. Conf. Ser. 39 (2006) 129



- detection of nuclear recoils (above 30 keVr) induced by WIMPs
- independent readout of the scintillation light and the ionization charge
- currently operating on surface at CERN
- to be moved to underground in 2011 (Canfranc)

# ArDM-It – Charge readout

State-of-the-art double-phase LAr LEM-TPC



3-It setup at CERN  
“mini-ArDM”

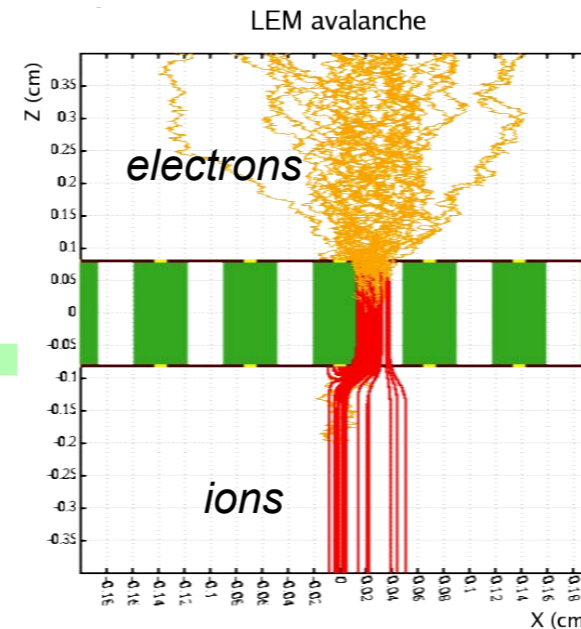
charge readout (2D)  
with amplification (LEM)

charge extraction  
across the liquid surface

target/drift volume  
with E-field

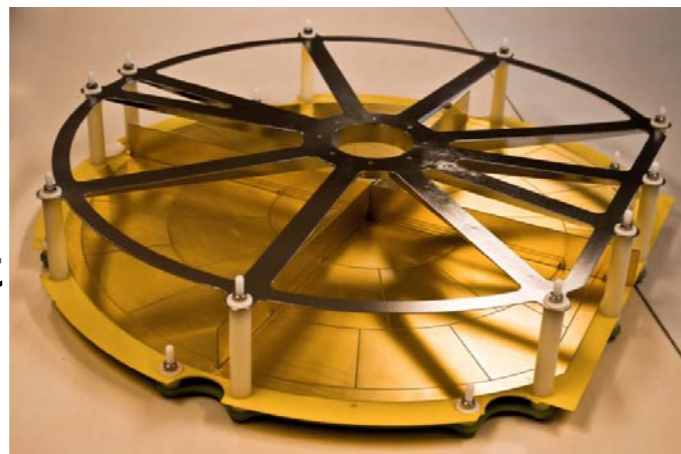
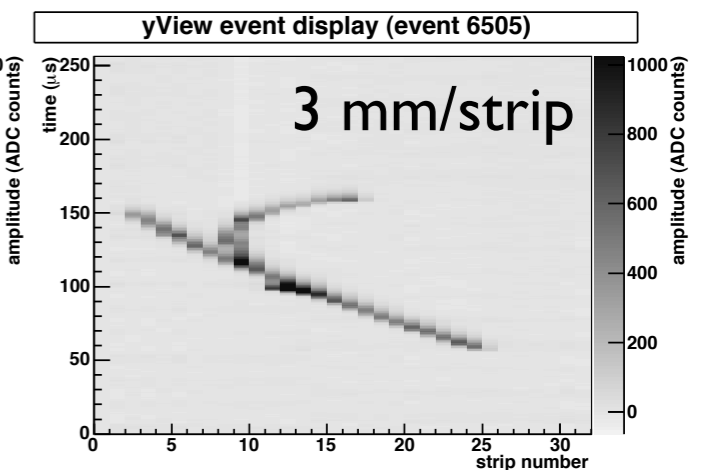
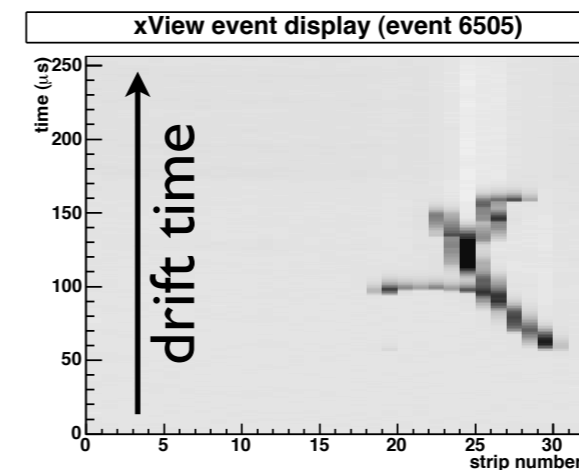
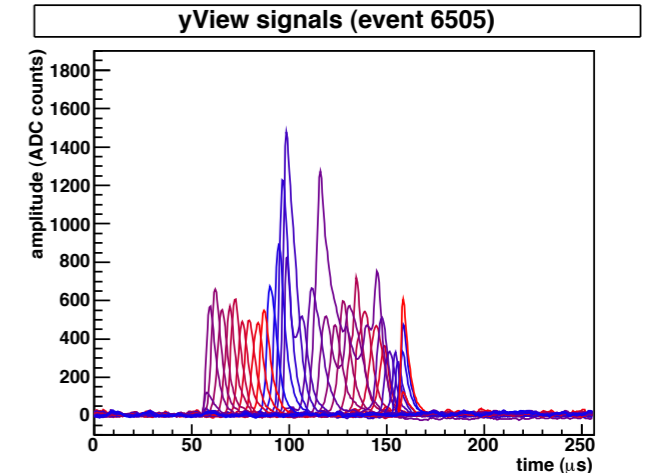
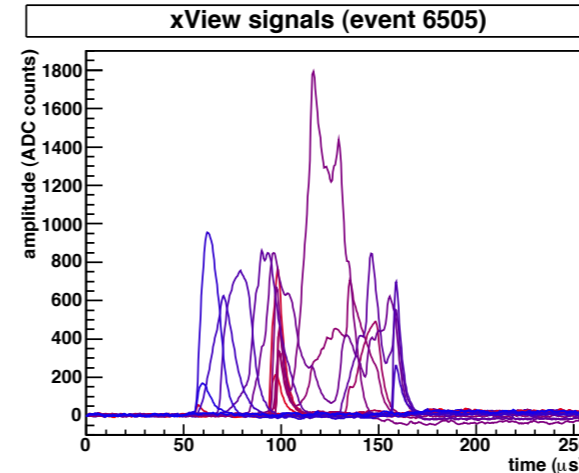
cathode

PMT



A. Badertscher et al.,  
arXiv:1010.2482 [physics.ins-det]

1-mm-thick LEM  
+ 2D anode  
CR with  $\delta$ -rays



Present “temporary”  
ArDM charge readout  
with extraction and  
32-pad anode

# ArDM-It – Light readout

14 immersed cryogenic 8" PMTs + wavelength shifting TPB

- LAr scintillation light, a line at 128 nm
- 14 cryogenic 8" PMTs  
Hamamatsu R5912-02MOD (QE ~ 20%)  
coated with TPB by evaporation

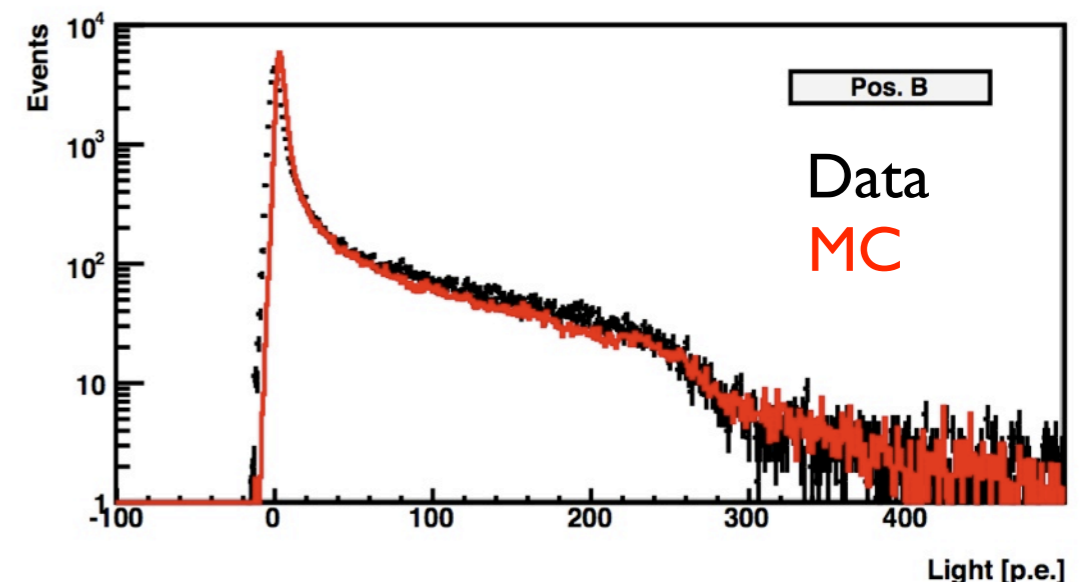


- The drift volume  
lined with diffusive  
reflector foils coated  
with TPB by  
evaporation

V. Boccone et al.,  
JINST 4:P06001,2009.  
arXiv:0904.0246 [physics.ins-det]

- The response to the  
LAr scintillation light  
very well understood

C. Amsler et al.,  
arXiv:1009.3641 [physics.ins-det]

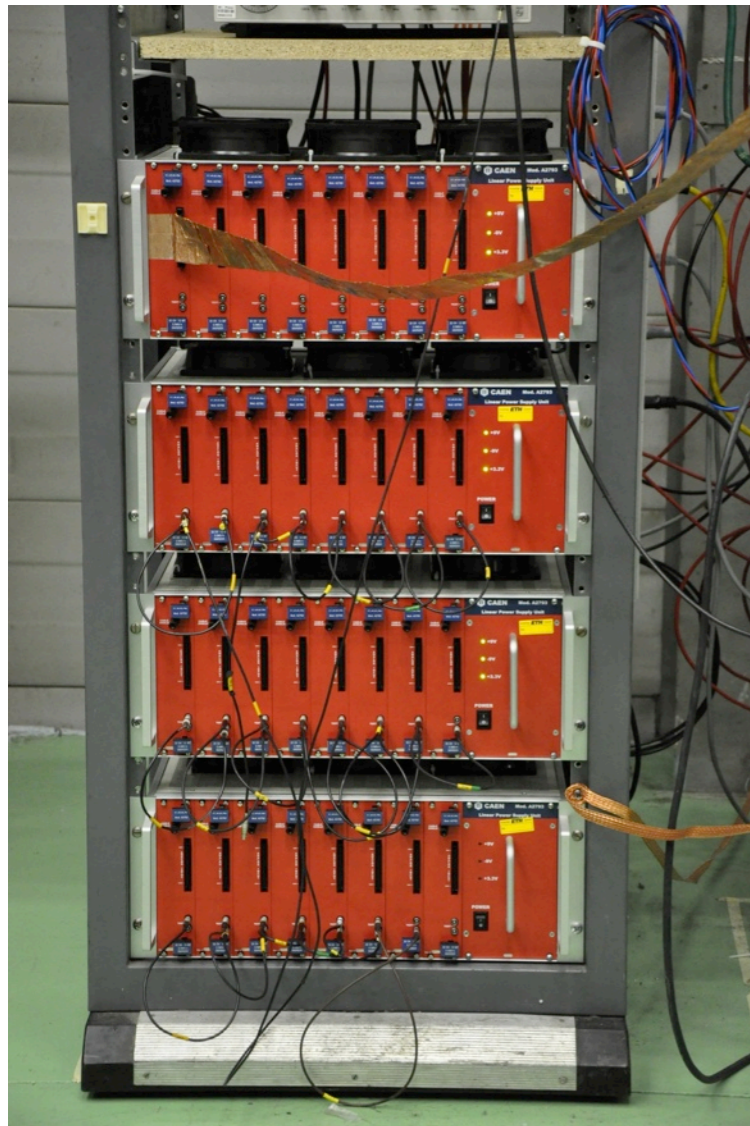


$^{22}\text{Na}$  source externally triggered  
(7 PMTs)

# ArDM-It – Readout electronics

Flash-ADC-based DAQ system by CAEN

## Charge Readout



4 crates - 1024 channels

CAEN SY2791

CAEN, in collaboration with ETHZ, developed A/D and DAQ system: 12 bit 2.5 MS/s flash ADCs + FPGA. Successfully tested and fully operational on small scale setups. 1000 readout channels available

## Light Readout



- CAEN V1720 used in the most recent test of ArDM-It – VME based, 250MS/s 12bit 1.25MS/Ch (up to 10MS/Ch available)
- good overall performance
- data taking at kHz rate
- scalable, easy to modify firmware, already integrated to the existing DAQ for charge readout, reasonable cost

# ArDM-1t – Slow control

## PLC-based system for a safe and consistent operation

Safe and consistent operation in an underground location of the detector system containing a large amount of cryogenic liquid is a very important and crucial issue particularly for the realization of a giant scale detector

- A PLC based control of the vacuum and cryogenic systems has been installed in 2010 and now fully tested
- PMT HV and DAQ being included

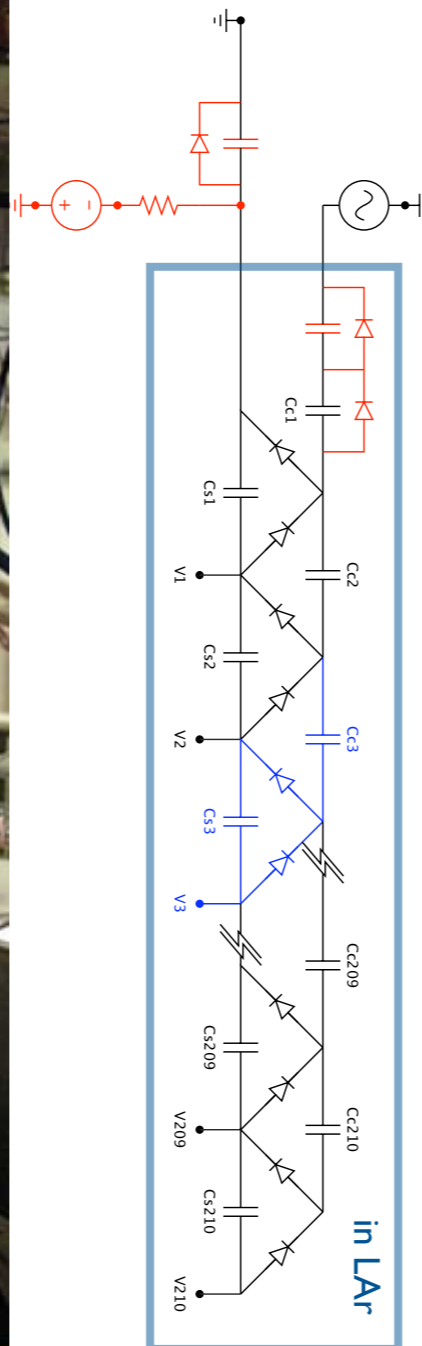
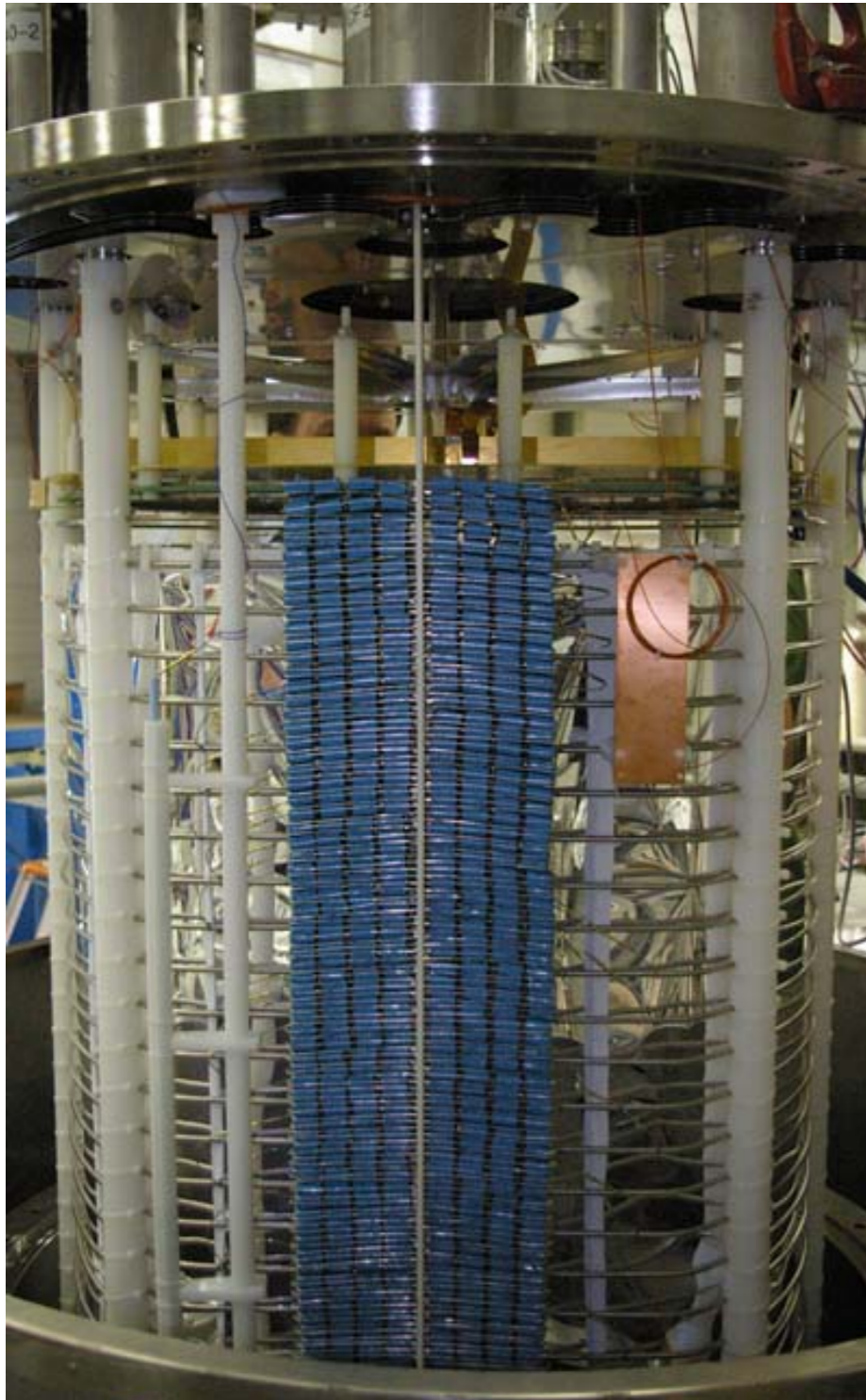
The PLC (programmable logic controller) approach gives a consistent way of handling the operation of ArDM-1t, good for safety but also in reducing the requirements in terms of manpower



# ArDM-It – Very HV system

## 210-stage immersed Greinacher (Cockcroft-Walton) HV multiplier

Novel method to generate the drift “very” HV

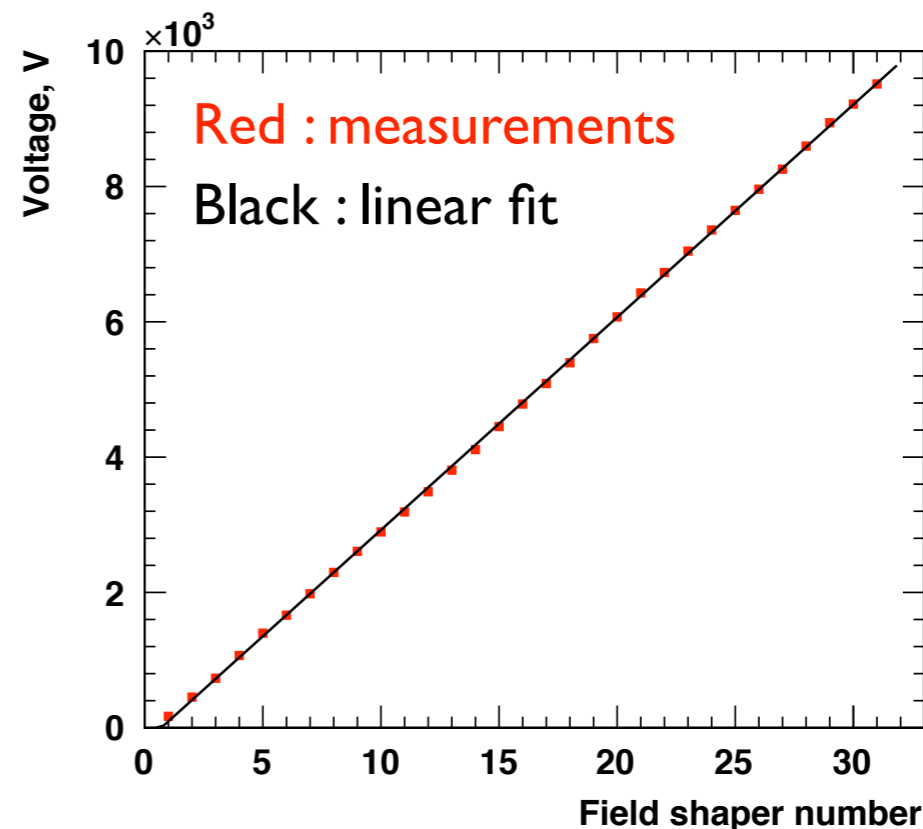


- 210-stage ArDM Greinacher circuit
- 1520 polypropylene capacitors  
St.1–170 :  $4 \times 82 \text{ nF}$  ; St.171–210 :  $2 \times 82 \text{ nF}$

1260 avalanche diodes  
3 diodes in series at each symbol

- Designed for 400 kV (operated up to 70 kV)
- Extrapolation to ~MV possible

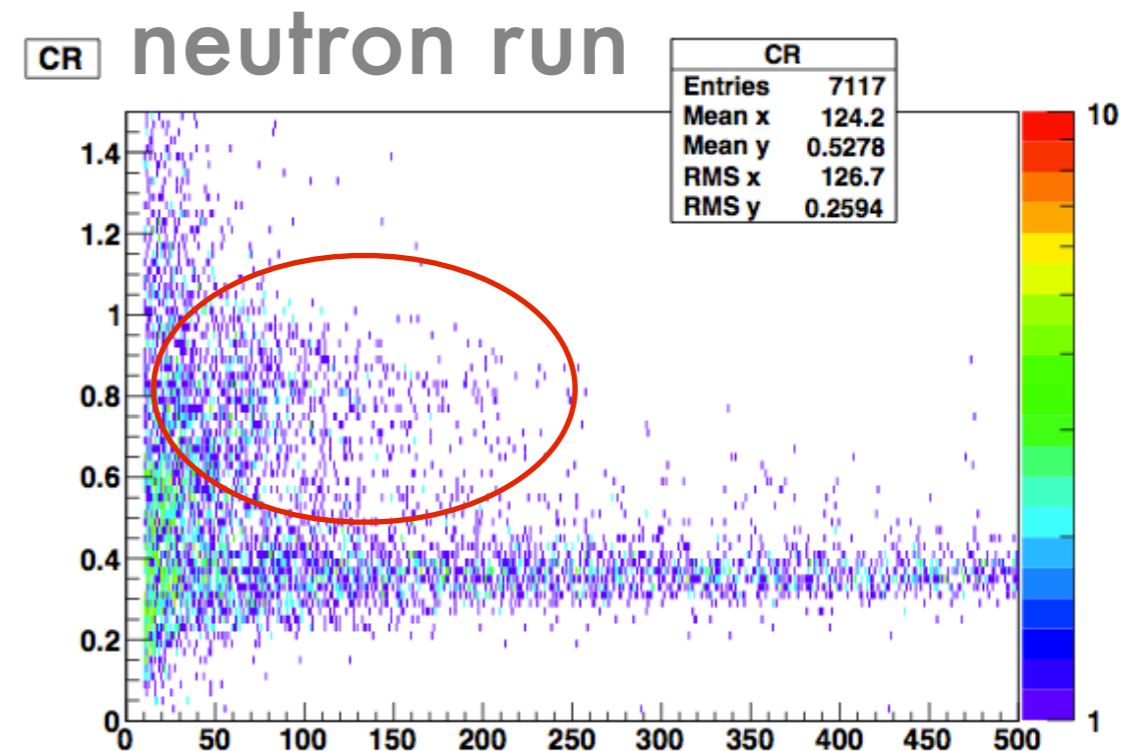
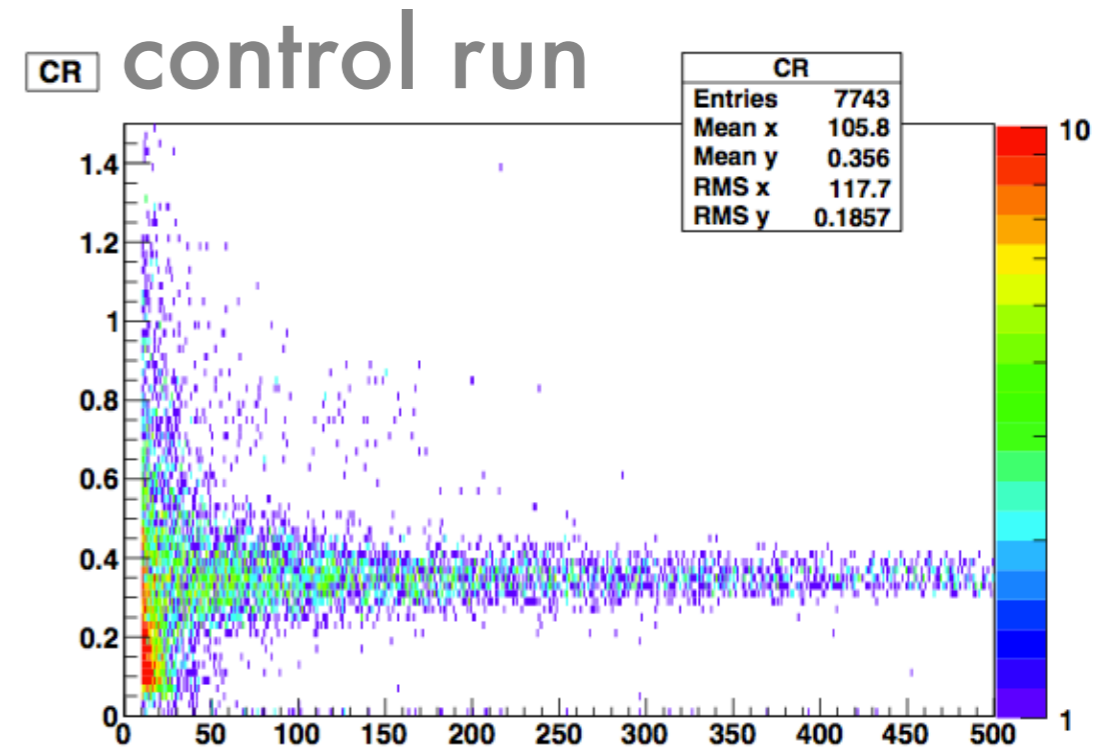
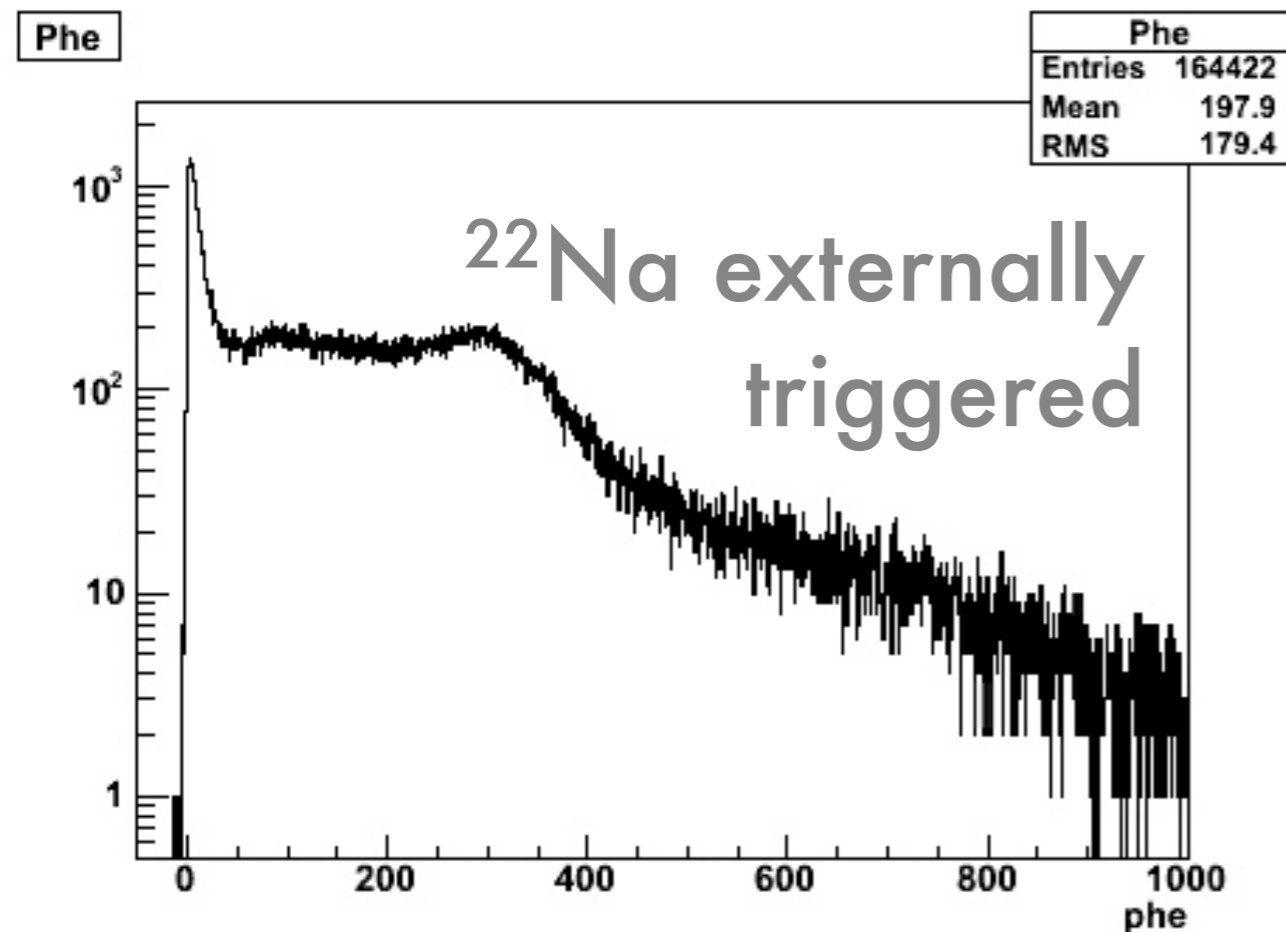
S. Horikawa et al., arXiv:1009.4908 [physics.ins-det]



# ArDM-It – Very preliminary results

Engineering run at CERN in September 2010

- Full light readout system with 14 x 8" PMTs
- Improved light yield verified !!
- Also with ... (results will come soon)
- temporary 32-pad charge readout
- drift HV system equipped (operated up to 70 kV)



# High-QE cryogenic PMT

The technology is developing rapidly

- An example : **Hamamatsu R11065 (3")**
  - High-QE, low background PMT specifically designed for LAr Dark Matter experiments
  - ~30% QE at 420 nm in cold
  - 12 dynode stages, gain  $4 \times 10^6$  (typ.)
- 4 such PMTs have been procured for tests in view of the upgrade of the ArDM system

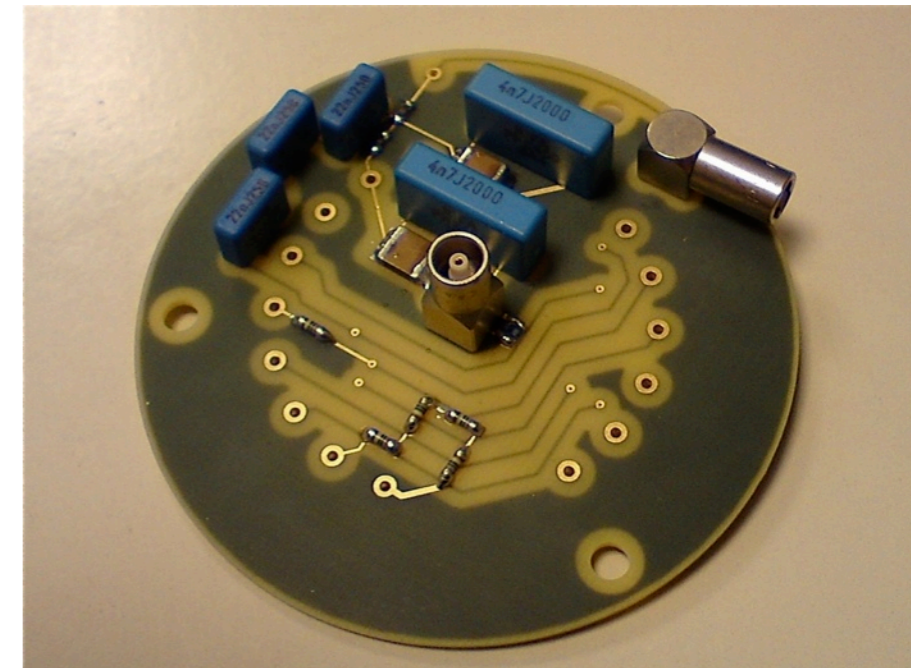


For **GLACIER ??**

- High-QE large area (e.g. 8") cryogenic PMTs currently are not available but in development

Collaboration with manufacturers very desirable !!

PCB with the PMT base



# Conclusions

- GLACIER is a **next generation** large underground observatory for neutrino astrophysics based on a **giant ( $\approx 100$  kton) scale liquid argon time projection chamber**, with which proton decay and CP violation in lepton sector can also be explored.
- Combining charge, scintillation and possibly Cerenkov light readout it provides an ideal detector with a precise “bubble-chamber” track imaging, excellent calorimetric measurements and particle identification.
- Engineering of the underground giant LAr tank is being studied under the FP7 LAGUNA design study of Europe.
- The detector design is highly scalable allowing a staged approach in the R&D, which is ongoing world wide very actively.
- The ArDM-1t Dark Matter experiment is currently operating on surface at CERN, which is a good demonstrator of the design and the working principle of GLACIER.
- Techniques for detecting the LAr scintillation light (128 nm) using the cryogenic PMTs and the wave shifting TPB is well established. The GLACIER design study thus far is based on the 8” cryogenic PMTs currently available on the market. High-QE large area PMTs are highly desirable for the project.