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1854-3

Workshop on Grand Unification and Proton Decay

22 - 26 July 2007

Towards large LAr detectors

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Towards large LAr detectors

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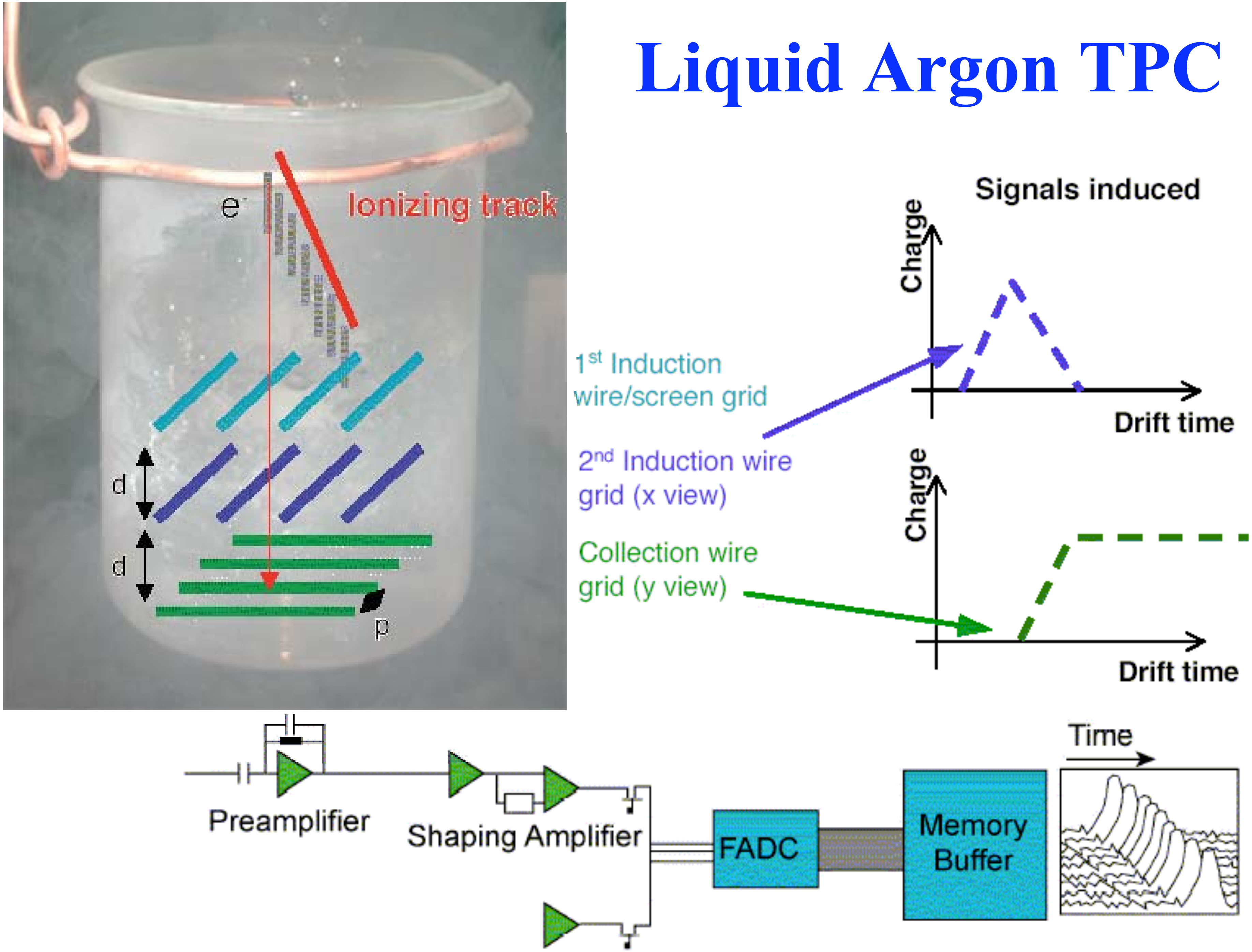
Workshop on Grand Unification and Proton Decay, ICTP, July 2007

- LAr TPC working principle and present achievements
  - detection of ionization and light
  - ICARUS prototypes and the T600 module
- Physics with a large LAr detector
- R&D steps and physics proposals for a multi-kton LAr TPC
  - a world wide effort
    - ICARUS, LANND, GLACIER, LArTPC, MODULAR
  - dewars
  - Argon purification
  - High Voltage systems
  - readout devices and electronics
  - "test" beams
- Reach of a 100 kton LAr TPC for proton decay searches
- Conclusions

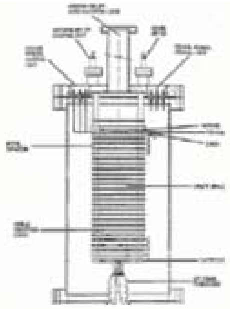
Liquid Argon TPC



Use of LAr as detector medium

- **L.W. Alvarez** (late 60'): noble liquids for position sensitive detectors
- **W.J. Willis & V. Radeka** (70'): large LAr calorimeters for HEP experiments
- **H.H. Chen, P.E. Condon, B.C. Barish, F.J. Sciulli** "A neutrino detector sensitive to rare processes. A study of neutrino electron reactions", Fermilab Proposal P-0496, May 1976
    - 'A highly segmented, independently sampled, totally live target consisting of roughly a thousand planes (1 cm thick) of liquid argon'
- **H.H. Chen & J.F. Lathrop** "Observation of ionization electrons drifiting large distances in liquid Argon", NIM 150 (1978) 585
    - achieved 7.5 cm drifts
- **C. Rubbia** "The Liquid-Argon Time Projection Chamber: a new concept for neutrino detectors", CERN Report 77-8, May 1977
    - 'It appears possible to realize … a drift length as long as 30 cm'
- **E. Aprile, K.L. Giboni and C. Rubbia** "A study of ionization electrons drifting large distances in liquid and solid Argon", NIM A241 (1985) 62
    - 'The longest observed drift times in the 10 cm chamber are of the order of 1.8 ms at 10 V/cm. … an attenuation length of about 7.5 m is expected for a field of 1 kV/cm.'
- **ICARUS Coll.** "ICARUS: a proposal for the Gran Sasso Laboratory", INFN/AE-85/7, Frascati 1985

The ICARUS steps

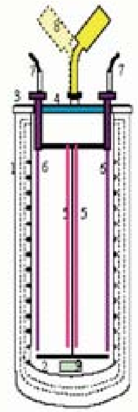


24 cm drift wires chamber

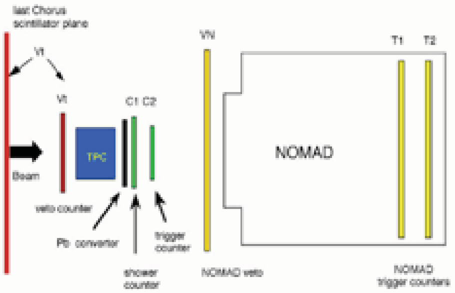
1987: First LAr TPC. Proof of principle. Measurements of TPC performances.

3 ton prototype

1991-1995: First demonstration of the LAr TPC on large masses. Measurement of the TPC performances. TMG doping.



50 litres prototype
1.4 m drift chamber



1997-1999: Neutrino beam events measurements. Readout electronics optimization. MLPB development and study. 1.4 m drift test.

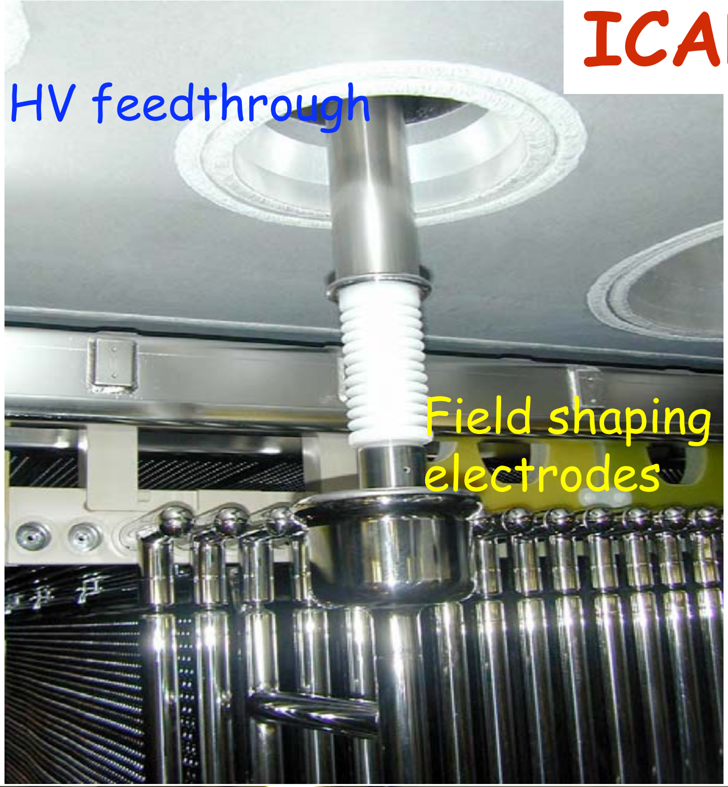
10 m³ industrial prototype

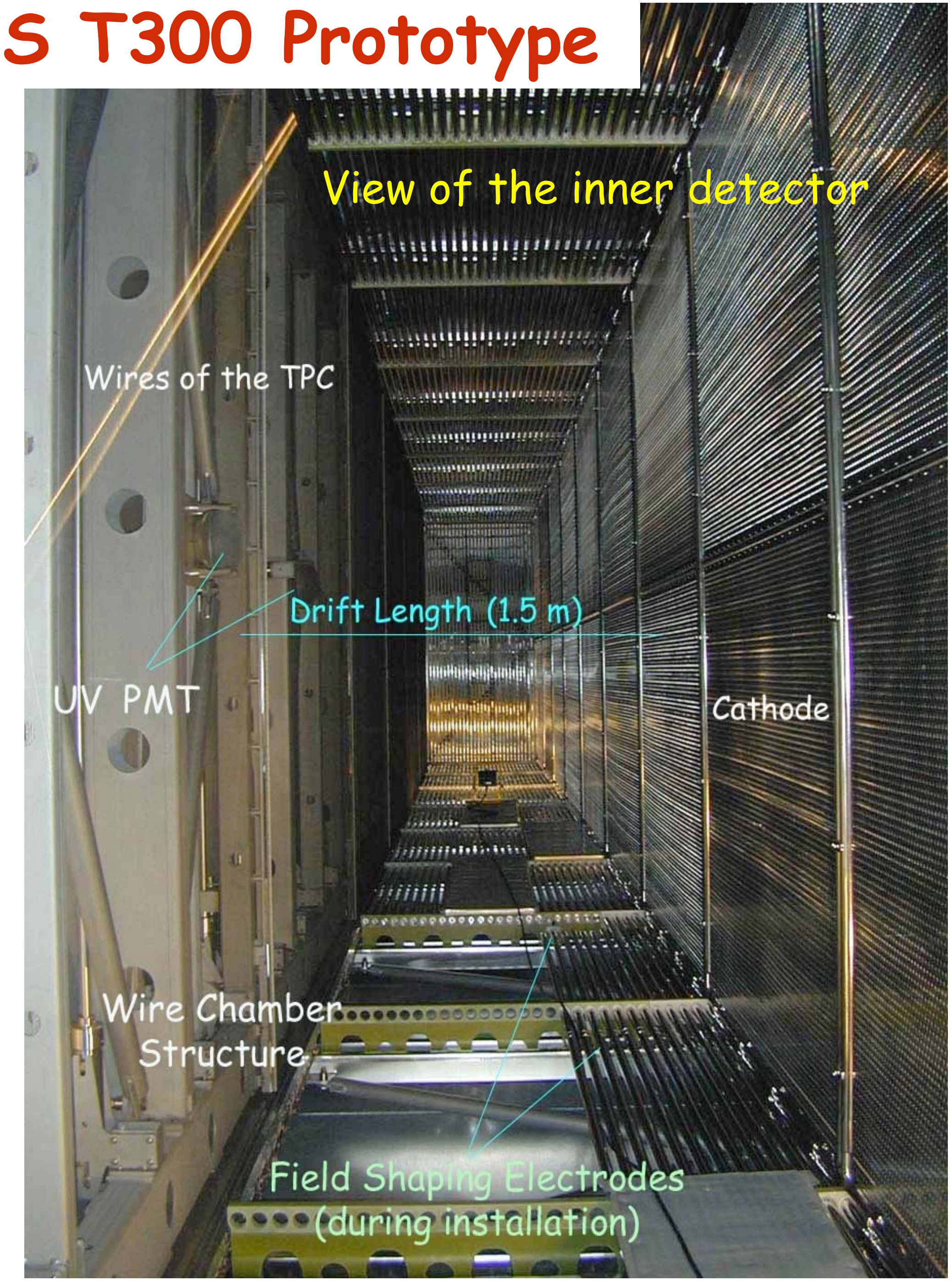
1999-2000: Test of final industrial solutions for the wire chamber mechanics and readout electronics.

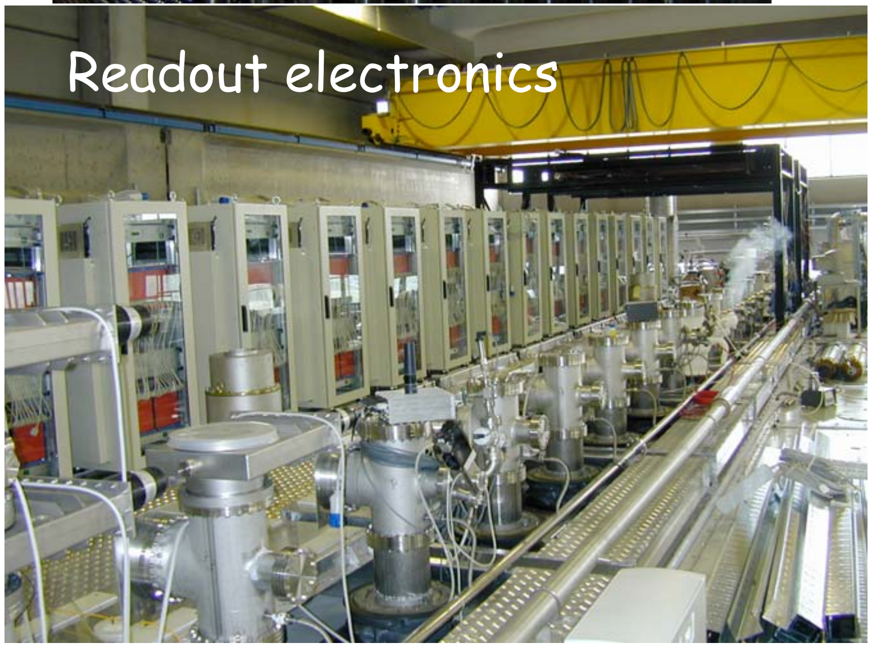
600 ton detector

2001- present: 300 ton detector tested on surface in Pavia. 600 ton detector being presently assembled at LNGS.

ICARUS T300 Prototype

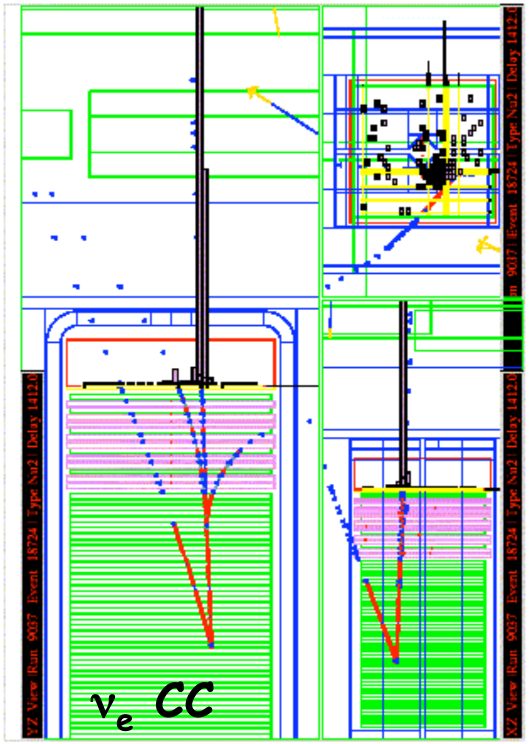






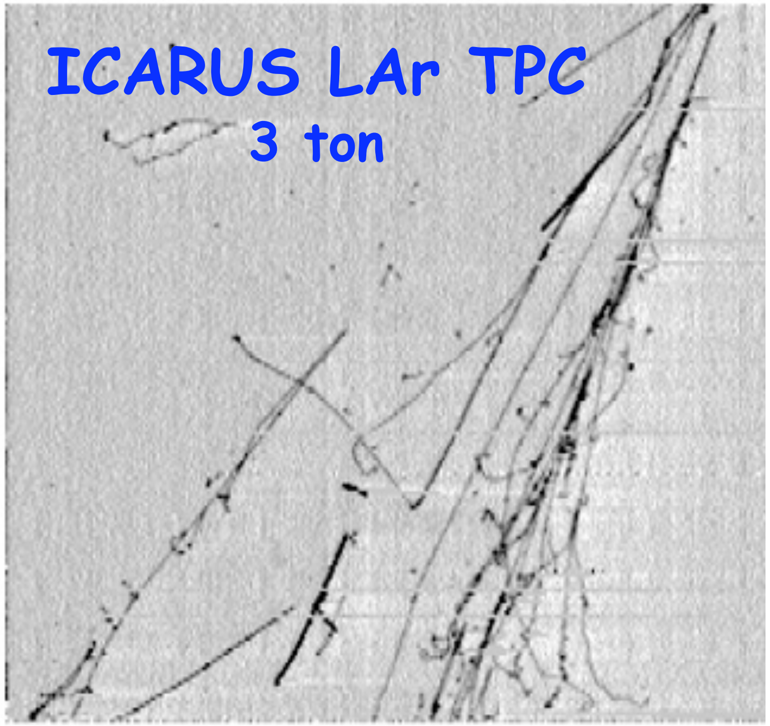
Bubble ∅ (mm)	3
Density (g/cm^3)	1.5
X_0 (cm)	11.0
λ_T (cm)	49.5
dE/dx (MeV/cm)	2.3

NOMAD



2.7 tons drift chambers target
Density (g/cm^3) 0.1
2% X_0/chamber
0.4 T magnetic field

TRD detector
Lead glass calorimeter



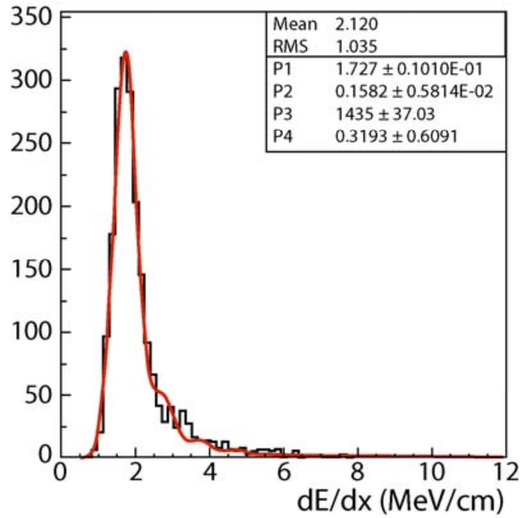
Resolution (mm^3)	2×2×0.2
Density (g/cm^3)	1.4
X_0 (cm)	14.0
λ_T (cm)	54.8
dE/dx (MeV/cm)	2.1

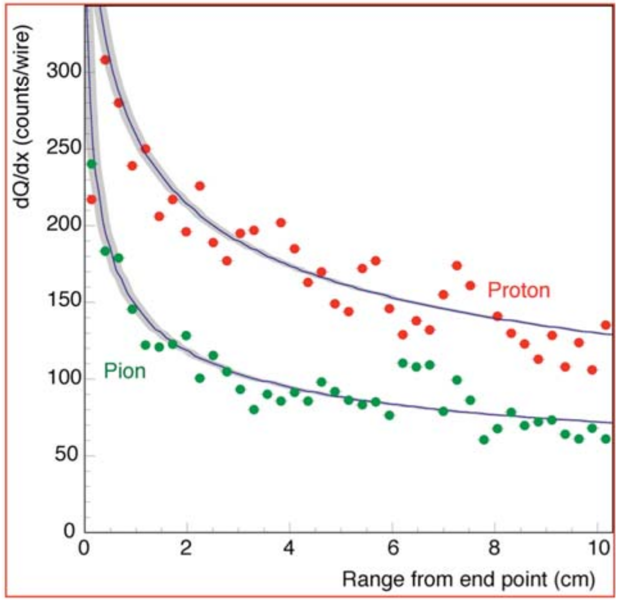
A tracking calorimeter

➢ **High granularity**: readout pitch ≈3 mm, local energy deposition measurement, particle type identification

$$T_{kin} = \int \frac{dE}{dx} dx$$

$$\frac{\sigma_{T_{kin}}}{T_{kin}} \approx 4\%$$

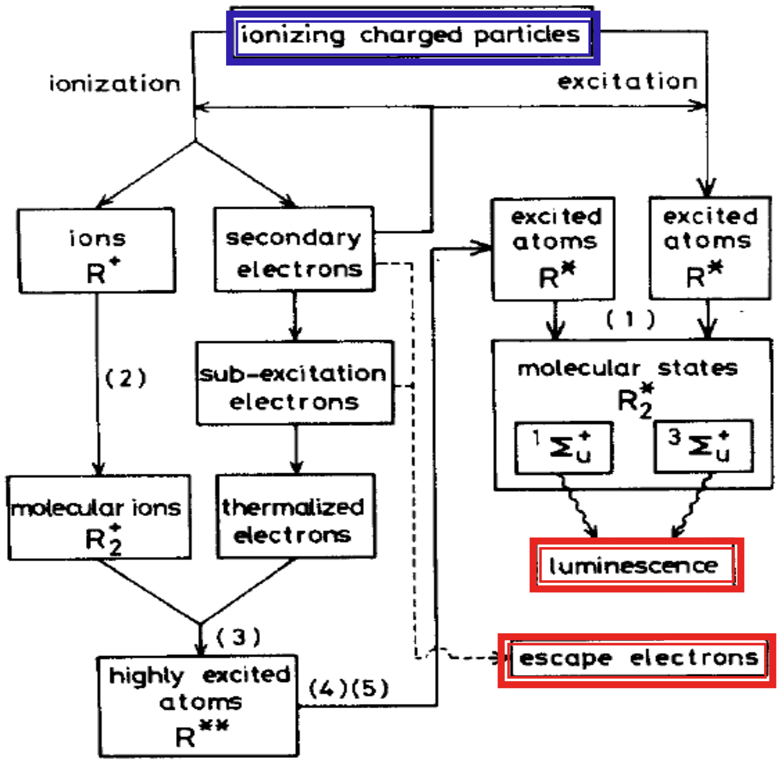




➢ **Fully homogenous, full sampling calorimeter**

- Low energy electrons: $\frac{\sigma(E_e)}{E_e} = \frac{11\%}{\sqrt{E_e(MeV)}} \oplus 2.5\%$
- Electromagnetic shower: $\frac{\sigma(E_{em})}{E_{em}} = \frac{3\%}{\sqrt{E_{em}(GeV)}} \oplus 1.5\%$
- Hadronic shower: $\frac{\sigma(E_{had})}{E_{had}} \simeq \frac{30\%}{\sqrt{E_{had}(GeV)}} \oplus 10\%$

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 β>1/n)*

Comparison Water - liquid Argon

	Water	Liquid Argon
Density (g/cm^3)	1	1.4
Radiation length (cm)	36.1	14.0
Interaction length (cm)	83.6	83.6
dE/dx (MeV/cm)	1.9	2.1
Refractive index (visible)	1.33	1.24
Cerenkov angle	42°	36°
Cerenkov $d^2N/dEdx$ (β =1)	$\approx 160\ eV^{-1}\ cm^{-1}$	$\approx 130\ eV^{-1}\ cm^{-1}$
Muon Cerenkov threshold (p in MeV/c)	120	140
Scintillation	No	Yes (≈50000 γ/MeV @ λ=128nm)
Cost	1 CHF/liter (Evian)	≈1 CHF/liter

Comparison Water - liquid Argon

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

➡ *A "new way" to look at rare events…*

LAr TPC as proton decay detector

Observation of a mass of M kton (~ 6×10^{32} nucleons/kton) for T years would provide a limit on the proton lifetime of:

$$\tau_p/B > M(\mathrm{kton})\times\varepsilon\times T\times6\times10^{32}\ \mathrm{years}$$

branching fraction — efficiency

To reach 10^{35} years a mass in the range 50÷100 kton with 10 years of observation is required.

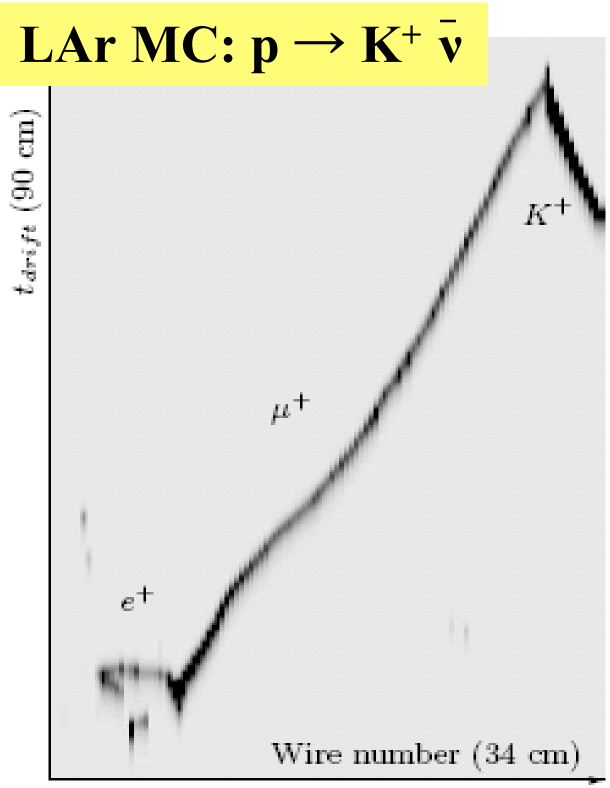
Proton decay signals are characterized by:

- **their topology, with a lepton (electron, muon, neutrino) in the final state and few other particles**
- **total energy of the event should be close to the nucleon mass and the total momentum should be balanced, apart from nuclear effects**

A LAr TPC provides:

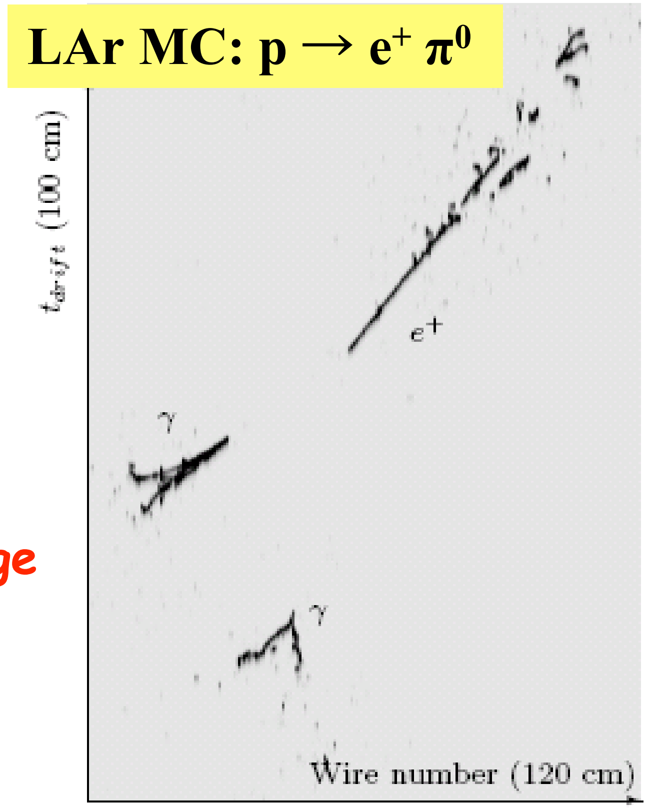
- **excellent tracking and calorimetric resolution to constrain the final state kinematics and suppress atmospheric neutrino background**
  - particularly suited to the 100÷1000 MeV/c range
- **particle identification (in particular kaon tagging) for branching mode identification**
- **possibility to instrument large masses of LAr**

LAr TPC as proton decay detector



K.L. Giboni "A two kiloton liquid Argon detector for solar neutrinos and proton decay", NIM 225 (1984) 579

ICARUS Coll. "ICARUS II. A second generation proton decay experiment and neutrino observatory at the Gran Sasso Laboratory", Sept. 1993

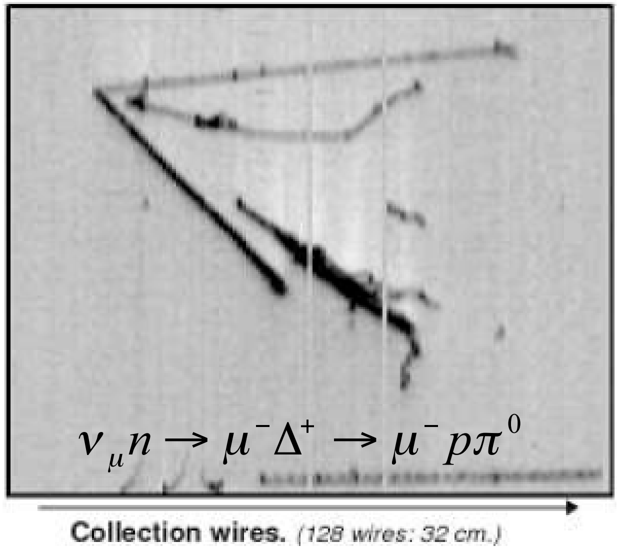


A. Bueno, M. Campanelli, A. Ferrari, A. Rubbia "Nucleon decay studies in a large liquid Argon detector", AIP Conf. proc. 533 (2000) 12

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

LAr TPC as neutrino detector

- **provides high efficiency for ν_e charged current interactions**
- **adequate rejection against ν_μ NC and CC backgrounds**
  - **e/π^0 separation**
    - fine longitudinal segmentation (few % X_0)
    - fine transverse segmentation, finer than the typical spatial separation of the 2 γ's from π^0 decay
  - **e/μ,h separation**
- **embedded in a magnetic field provides the possibility to measure both wrong sign muons and wrong sign electrons samples in a neutrino factory beam**



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

Data collected in 1997

Search for QE events

86 "golden events with an identified proton of kinetic energy larger than 40 MeV and one muon matching NOMAD reconstruction

LAr TPC as neutrino detector

- ICARUS Coll., "The ICARUS Experiment: a second-generation Proton decay experiment and Neutrino Observatory at Gran Sasso Observatory - Initial Physics Program", LNGS-P28/2001, March, 2001
- F. Sergiampietri, "On the possibility to extrapolate liquid argon technology to a super massive detector for a future neutrino factory", NUFACT01, Tsukuba, 2001
- A. Rubbia, "Experiments for CP violation: a giant liquid Argon scintillation, Cerenkov and charge imaging experiment?", hep-ph/0402110, Workshop on Neutrinos in Venice, 2003
- L. Bartoszek et al.,"FLARE, Fermilab liquid argon experiments: Letter of intent", hep-ex/0408121, Aug. 2004
- A. Meregaglia and A. Rubbia, "Contribution of a liquid argon TPC to T2K neutrino experiment", Acta Phys. Polon. B37 (2006) 2387, 20th Max Born Symposium, Wroclaw, Poland, Dec 2005
- D. Finley et al."A large liquid argon time projection chamber for long baseline, off-axis neutrino oscillation physics with the NuMI beam", FERMILAB-FN-0776-E, Sept. 2005
- A.Meregaglia, A. Rubbia, "Neutrino oscillation physics at an upgraded CNGS with large next generation liquid argon TPC detectors", JHEP 0611:032, 2006
- B. Baibussinov et al., "A new, very massive modular Liquid Argon Imaging Chamber to detect low energy off-axis neutrinos from the CNGS beam. (Project MODULAr)", arXiv:0704.1422 [hep-ph]
- V. Barger et al., "Report of the US long baseline neutrino experiment study", arXiv:0705.4396, May 2007

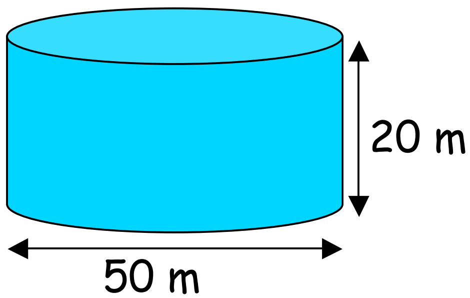
Physics synergies

A neutrino detector optimized for proton decay searches is also well matched to detect neutrinos of <~ 1 GeV

- **Japan**: Super -K (50 kton) → Hyper-K (1 Mton) (T2K phase II)
- **US**: Report of the US long baseline neutrino experiment study "A well instrumented very large detector, in addition to its accelerator based neutrino program, could be sensitive to proton decay which is one of the top priorities in fundamental science… Indeed, there is such a natural marriage between the requirements to discover leptonic CP violation and see proton decay that it could be hard to imagine undertaking either effort without being able to do the other"
- **Europe**: ApPEC recommendation "We recommend that a new large European infrastructure is put forward as a future international multi-purpose facility on the 100 – 1000 ktons scale for improved studies of proton decay and of low-energy neutrinos from astrophysical origin. The detection techniques … should be evaluated in the context of a common design study, which should also address the underground infrastructure and the possibility of an eventual detection of future accelerator neutrino beams"

A LAr detector …

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



⇨ 55 kton

- drift lengths of at least a few meters are necessary

Shopping list for a large LAr detector:

- Dewar
- Argon and purification system
- High Voltage system
- Readout device
- Electronics
- "Test" beams

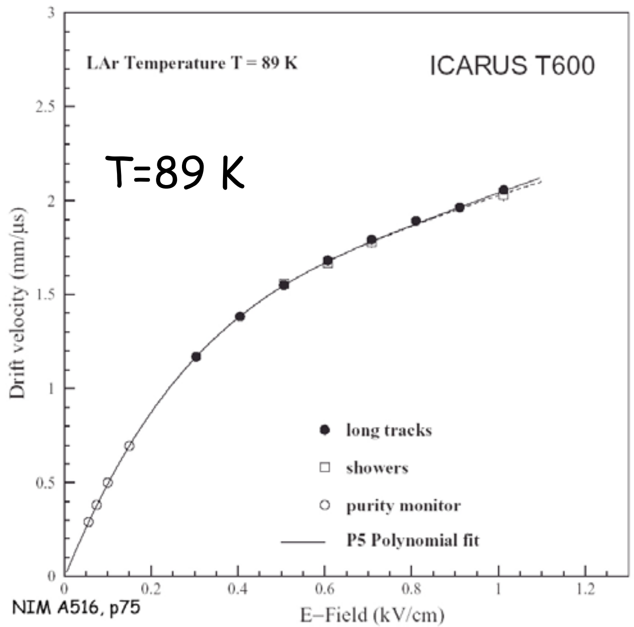
Can we drift over over long distances?

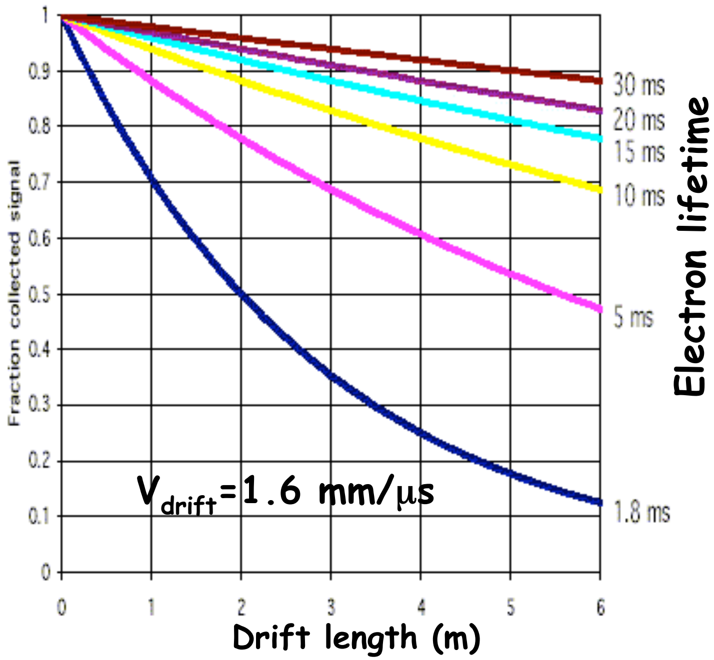
- HV feedthrough tested by ICARUS up to 150 kV (E=1kV/cm in T600)
- v_{drift}= (1.55±0.02) mm/μs @ 500 V/cm
- Diffusion of electrons:

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

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)



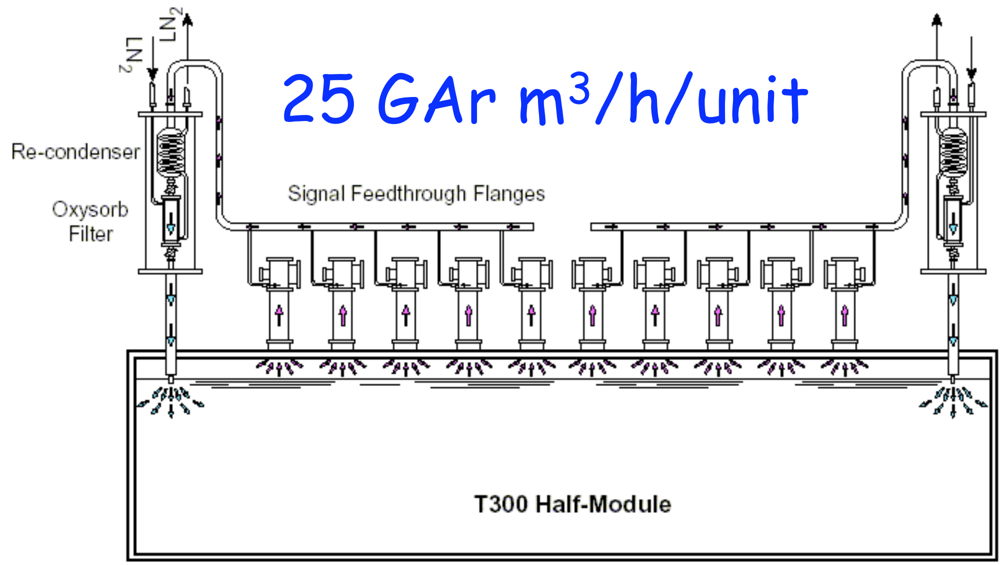


❖ to drift over macroscopic distances, LAr must be very pure

➢ a concentration of 0.1 ppb Oxygen equivalent gives an electron lifetime of 3 ms

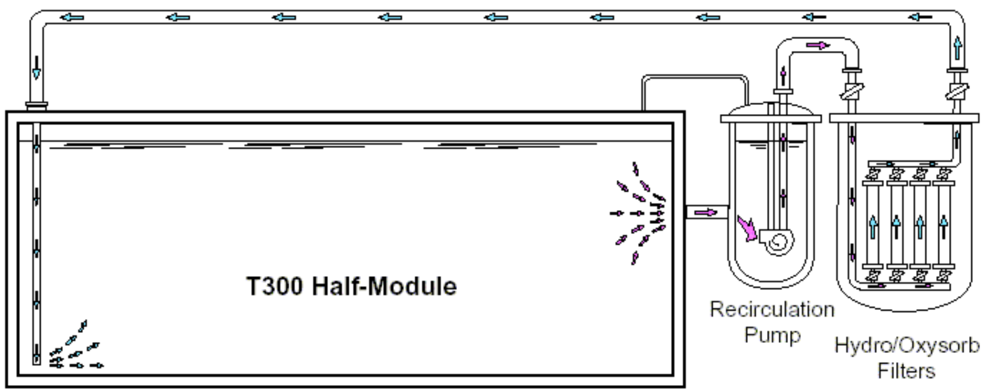
❖ for a 5 m drift and <30% signal loss we need an electron lifetime of 10 ms

Argon purification in ICARUS



25 GAr m³/h/unit

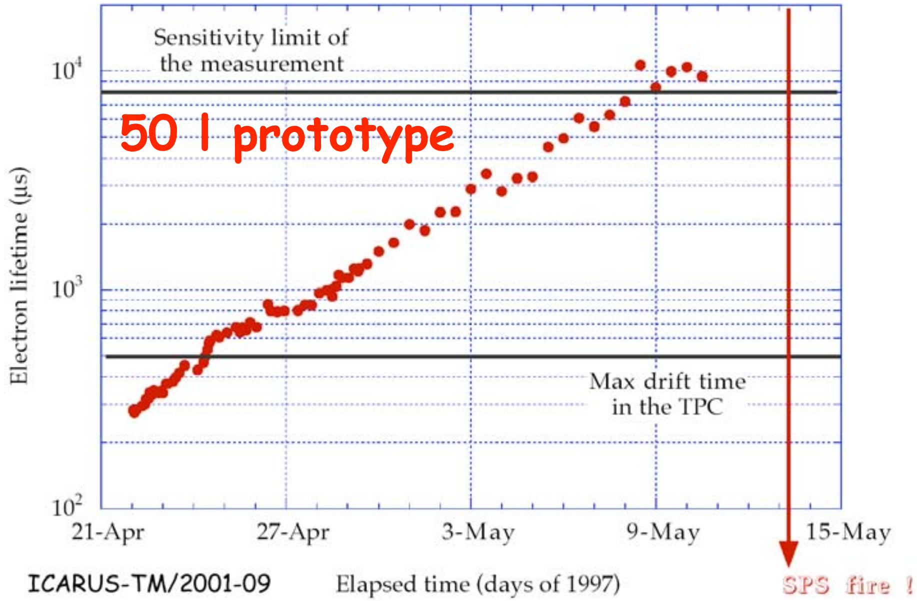
Recirculate gaseous and liquid Argon through standard Oxysorb/Hydrosorb filters



2.5 LAr m³/h

It was verified that LAr recirculation system does not induce any microphonic noise to the wires, so it can be active during the operation of the detector

Argon purity, electron lifetime in ICARUS



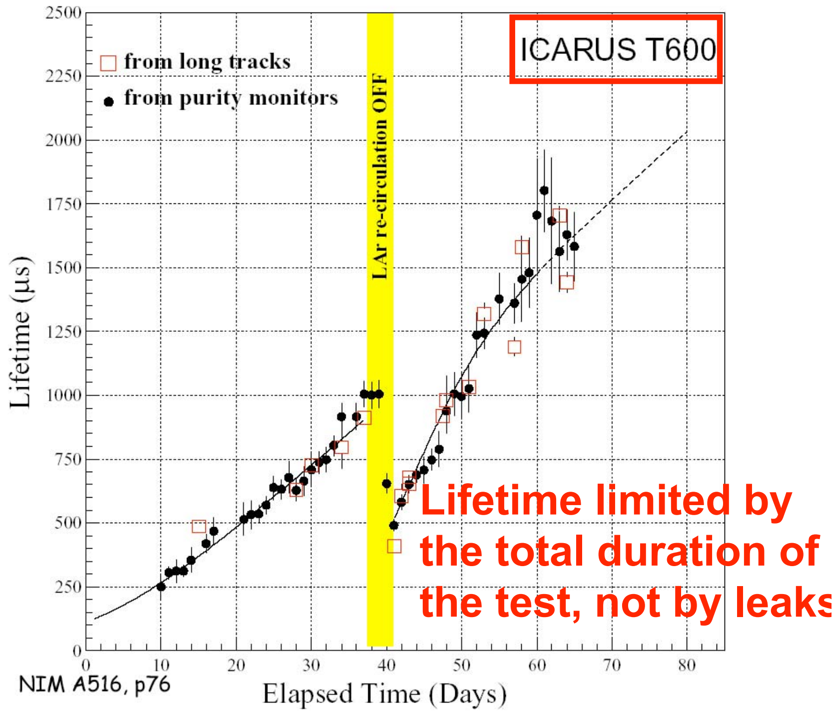
The concentration of impurities, N, is determined by

- constant input rate of impurities (leaks) Φ_{in}^0
- outgassing of material A, B
- purification time τ_c

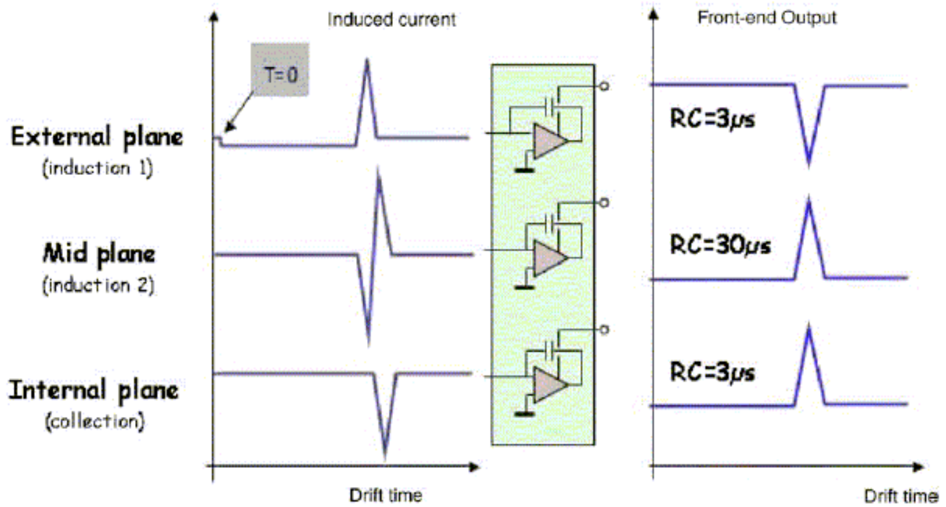
[redacted]

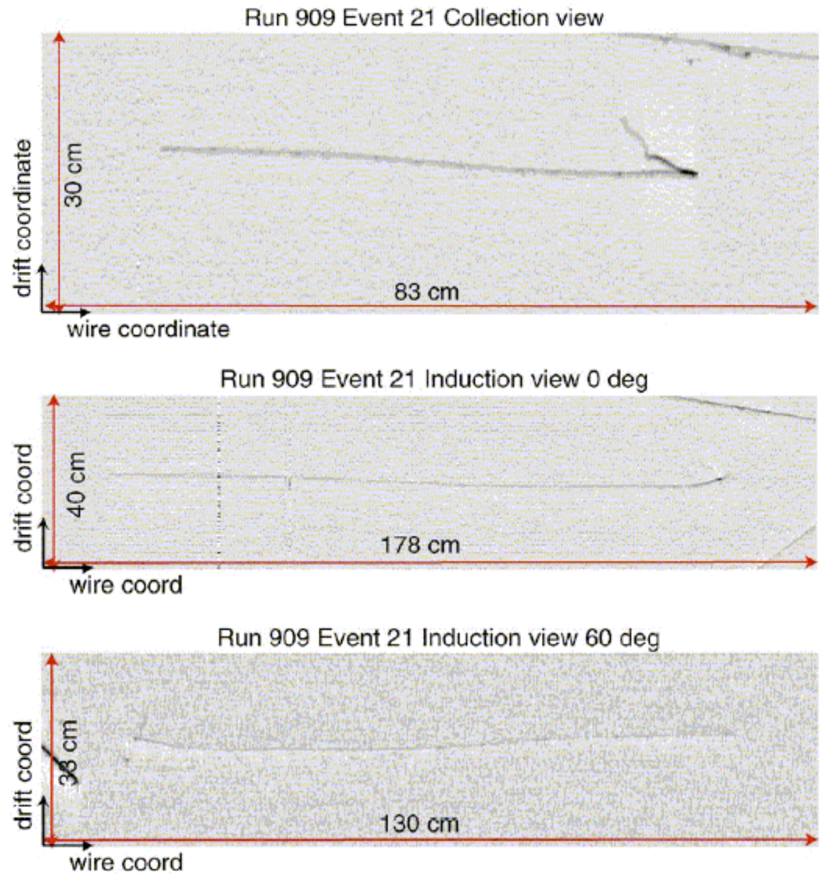
[redacted] τ_c [redacted] Φ_{in}^0 [redacted] A [redacted] B

Φ_{in}^0= (5±5)×10^{-3} ppb/day oxygen
A=0.33±0.07 ppb/day
B=1.39±0.05



Signals and event reconstruction from T300





- 3 wire planes (0°, ±60°), 3 mm wire pitch, 3 mm distance between wire planes
- 0° wires: 9.4 m long, ±60° wires: 3.8 m
- input capacitance (wire+cable)
  0° wires: ~400 pF, ±60° wires: ~200 pF

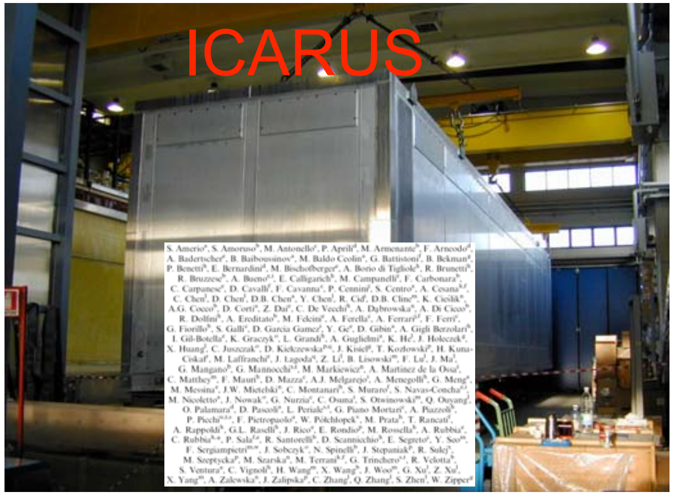
- ionization signal: 5500 e/mm @ 500 V/cm (before attenuation due to drift)
- Equivalent Noise Charge Q_{noise}=(500+2.5×C_{input} [pF]) electrons
- Signal/Noise ratio: ~ 10: is this enough?
- each wire digitized at 2.5 MHz by a 10 bit Flash ADC

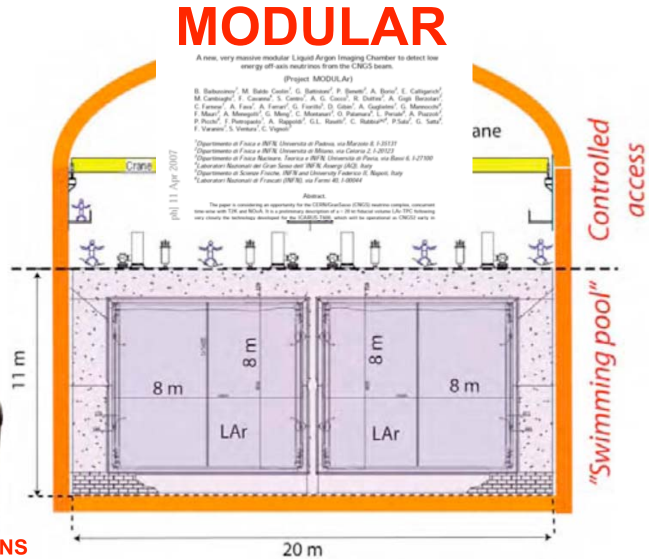
A world wide effort towards large LAr TPCs

- ICARUS 1985
- LANND 2001
- GLACIER 2003
- LArTPC 2005
- MODULAR 2007

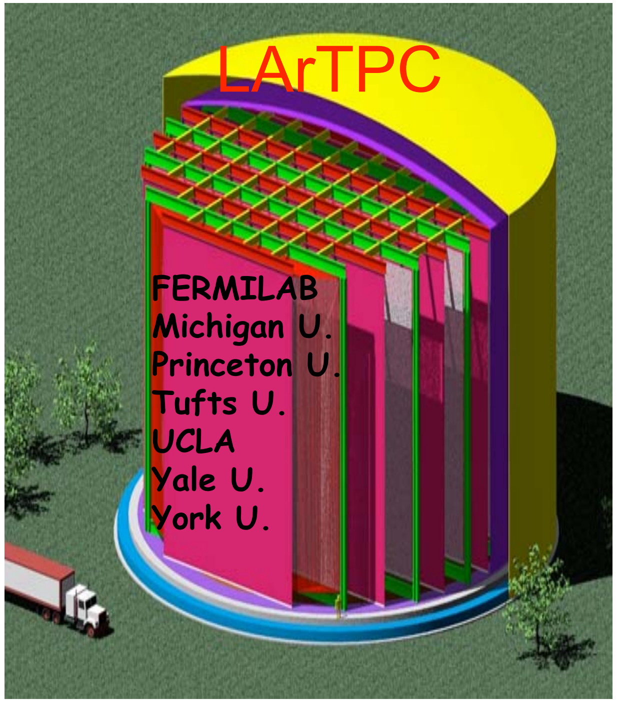
...with different approaches:

- a **modular** or a **scalable** detector for a total LAr mass of 50-100 kton
- **evacuable** or **non-evacuable** dewar
- detect ionization charge in LAr **without amplification** or with **amplification**


ICARUS


MODULAR
A new, very massive modular Liquid Argon Imaging Chamber to detect low energy off-axis neutrinos from the CNGS beam.
(Project MODULAr)
Crane
ane
Controlled access
"Swimming pool"
11 m
8 m
8 m
8 m
8 m
LAr
LAr
20 m


LANND
A LINE OF LIQUID ARGON TPC DETECTORS
SCALABLE IN MASS FROM 200 TONS TO 100 KTONS
David B. Cline [1], Fabrizio Raffaelli [2] and Franco Sergiampietri [1,2]
[1] Astrophysics Division, Department of Physics & Astronomy,
University of California, Los Angeles, CA 90095 USA
[2] INFN-Sezione di Pisa, Largo B. Pontecorvo 3, 56127 Pisa,
ITALY

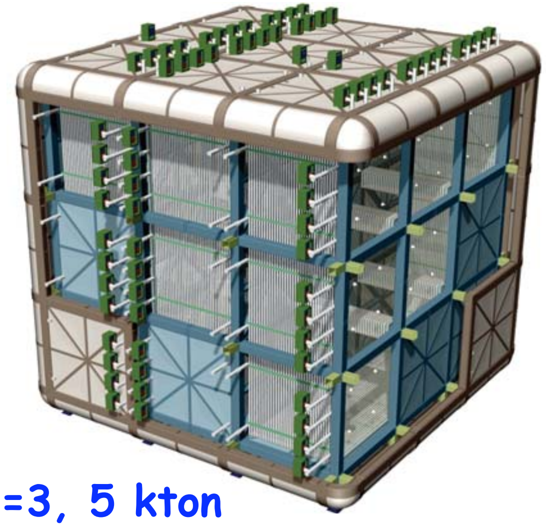

LArTPC
FERMILAB
Michigan U.
Princeton U.
Tufts U.
UCLA
Yale U.
York U.


GLACIER
ETHZ, Bern U., Granada U., INP Krakow, INR
Moscow, IPN Lyon, Sheffield U., Southampton U.,
US Katowice, UPS Warszawa, UW Warszawa, UW
Wroclaw

LANND

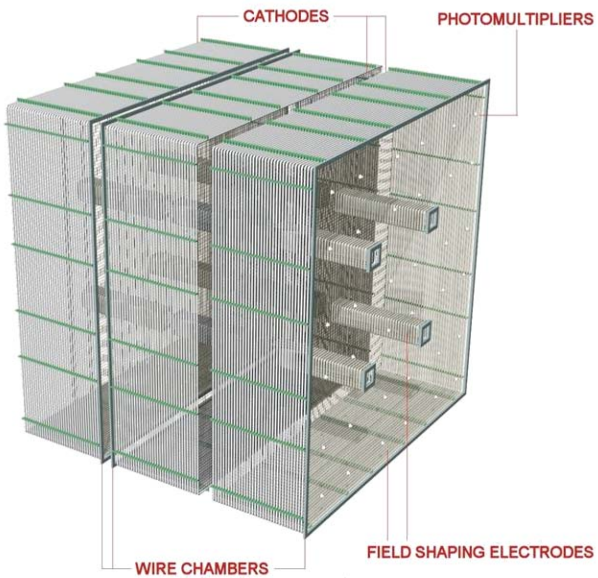
A scalable detector with an evacuable dewar and ionization charge detection without amplification

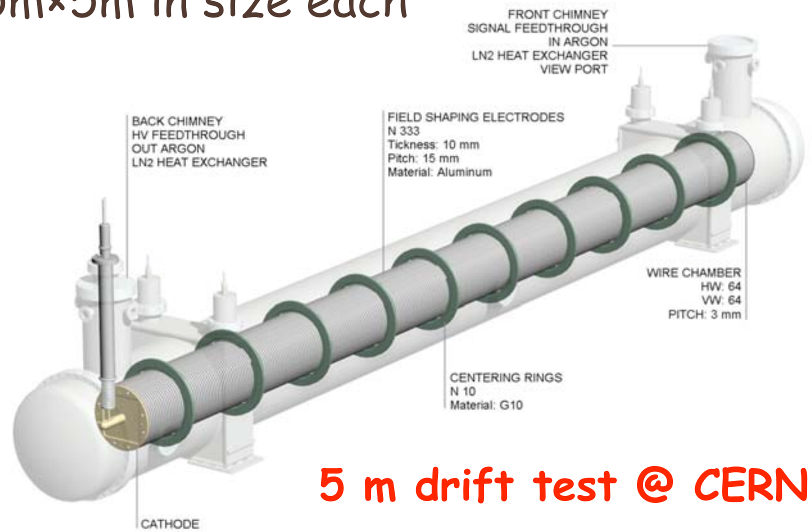
D.B. Cline, F. Raffaelli, F. Sergiampietri,
Homestake Lab Workshop, Feb. 2006



n=3, 5 kton

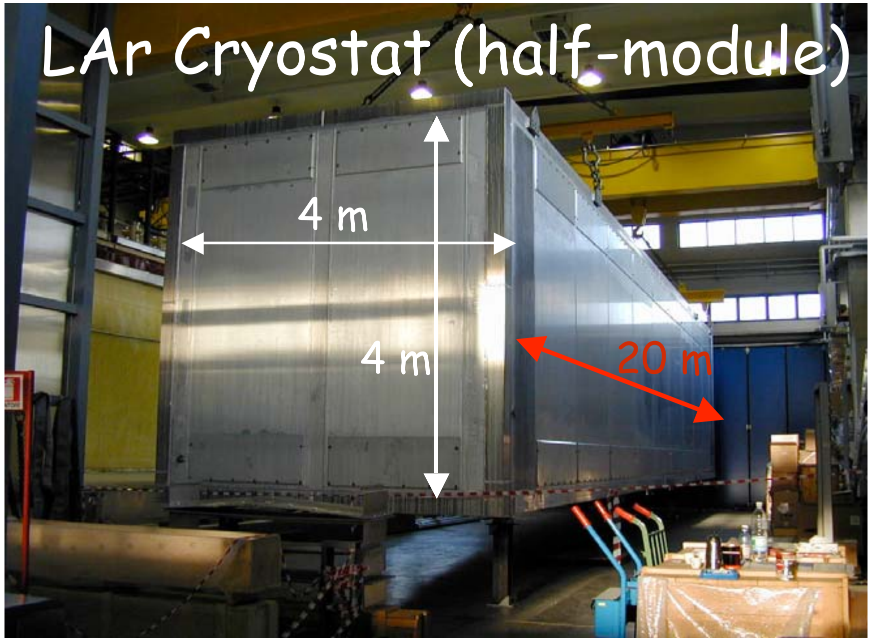
- Drift paths up to 5 m
- Evacuable dewar and UHV standards for any device in contact with the argon
- A continuous (not segmented) active LAr volume (high fiducial volume) contained in a cryostat based in a multi-cell mechanical structure
- This solution allows a cubic shape composed by n^3 cells, 5m×5m×5m in size each





5 m drift test @ CERN

T300 cryostat



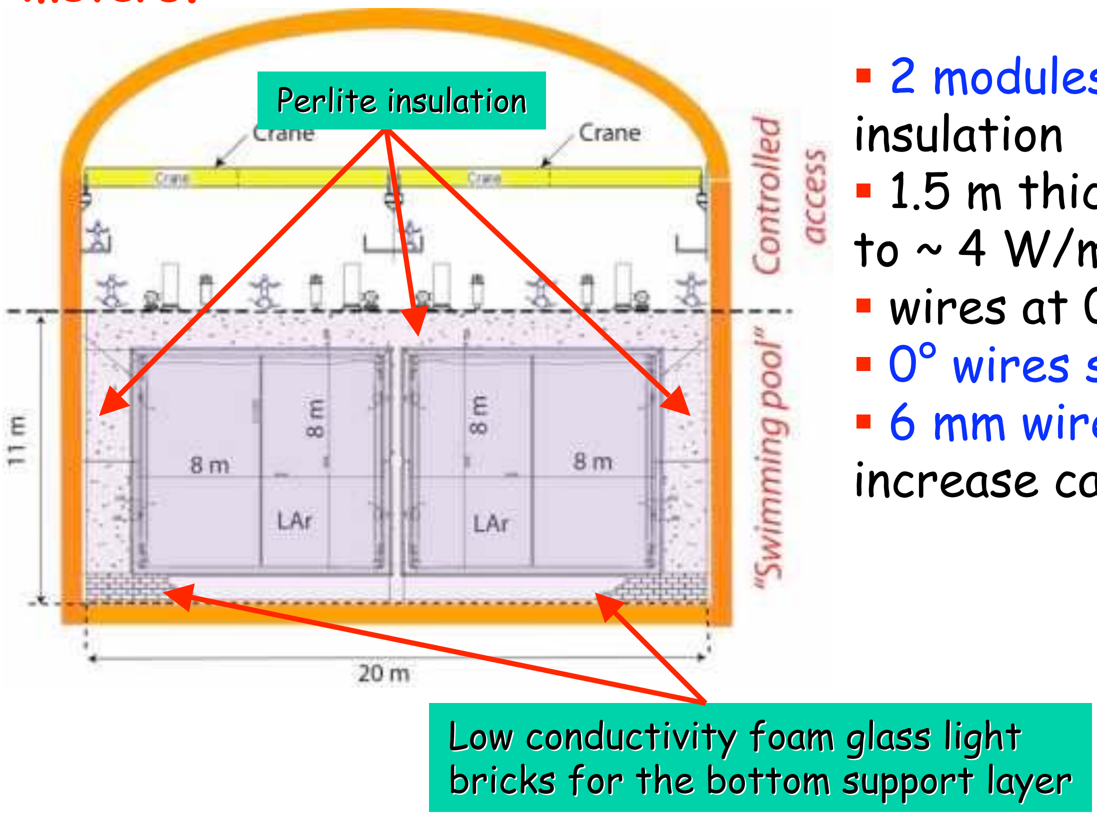
- T300 is a half-module of the T600
- cryostat constructed out of 15 cm thick panels, made of aluminum honeycomb sandwiched between aluminum skins
- thermal insulation panels, 0.5 m thick, made of Nomex (pre-impregnated paper) honeycomb
- cooling performed by circulating LN_2 inside cooling circuits placed immediately outside of the cryostat
- possibility to evacuate the cryostat down to 10^{-4} mbar
- … but relatively large thermal losses, up to 22 W/m^2

MODULAR

A modular detector with a non-evacuable dewar and ionization charge detection without amplification

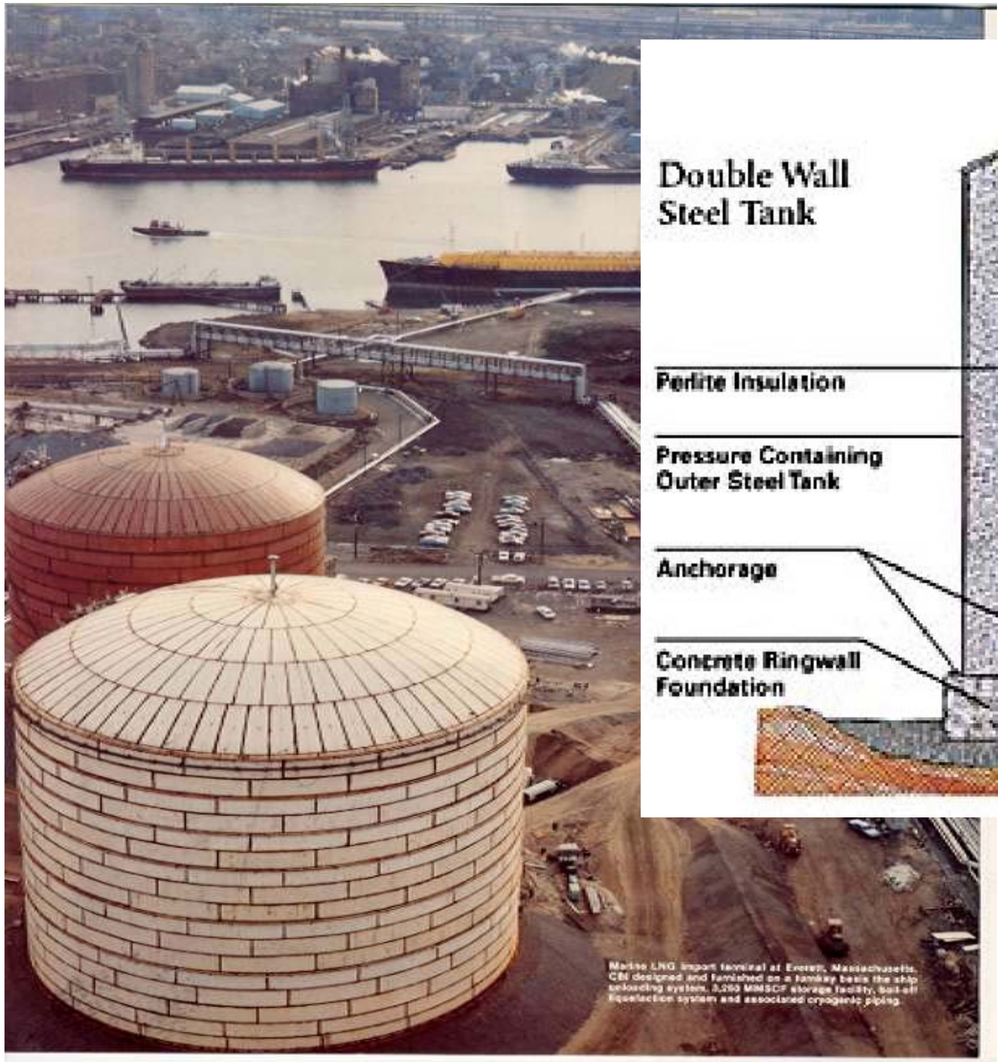
B. Baibussinov et al., arXiv:0704.1422 [hep-ph]

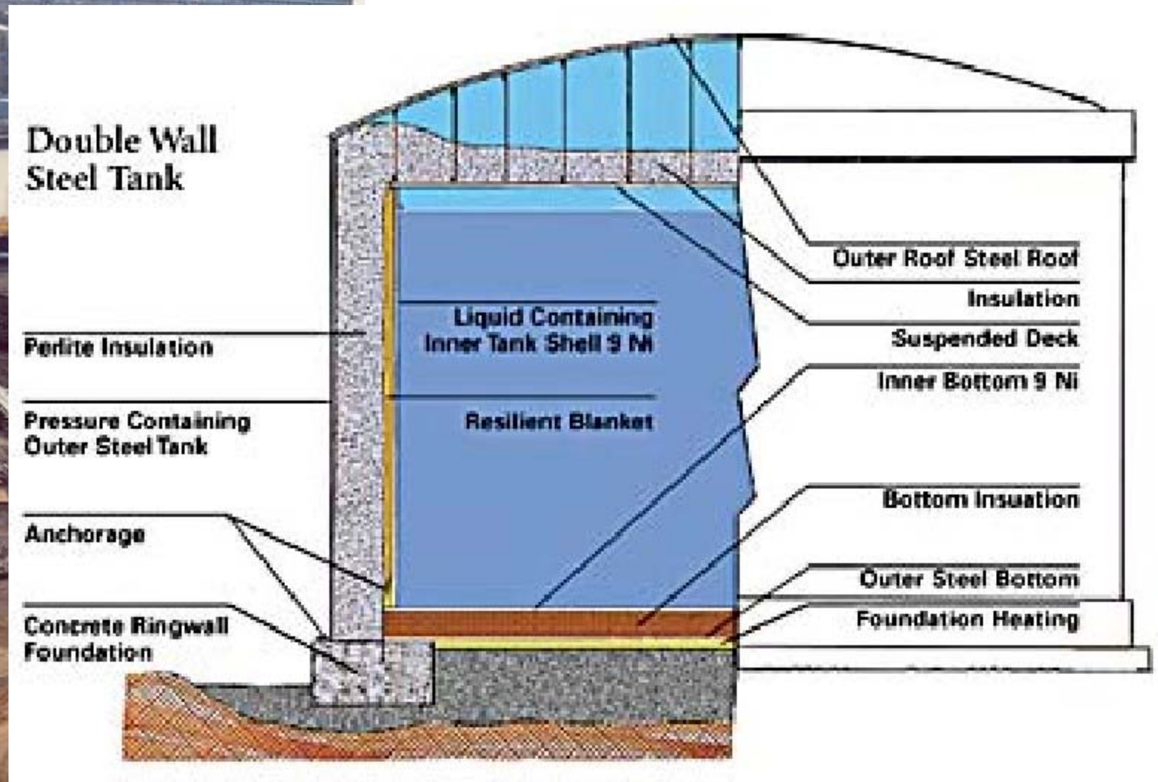
Geometry of an ICARUS-T600 half-module (T300) "cloned" into a larger detector scaled by a factor **8/3 = 2.66**: the cross sectional area of the planes is **8 x 8 m²** rather than 3 x 3 m². The length of such a detector is **50 meters.**



- 2 modules of 5 kton each with common insulation
- 1.5 m thickness of perlite, corresponding to ~ 4 W/m² thermal loss
- wires at 0°, ±60°
- 0° wires split in two, 25 m long, sections
- 6 mm wire pitch, to compensate for the increase capacitance of the longer wires

Cryogenic storage tanks for LNG





Many large LNG tanks in service. excellent safety record

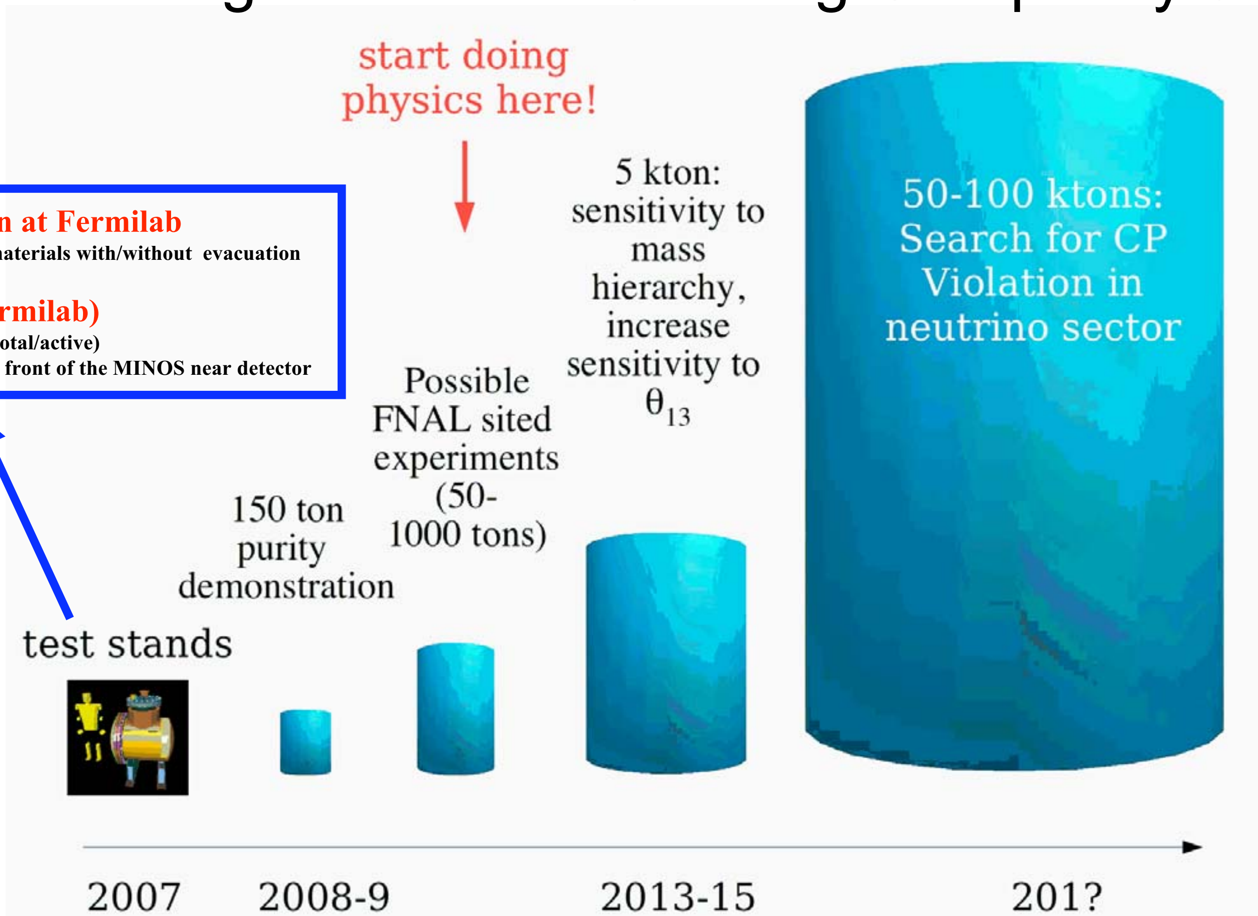
Concept for Mid-Term R&D Path @ Fermilab (LArTPC)

http://www-lartpc.fnal.gov/

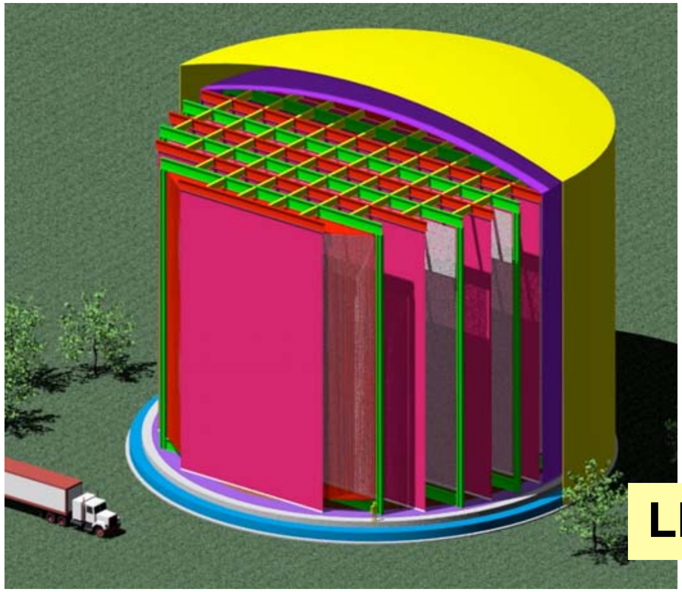
From B. Fleming to Fermilab Steering Group May 31, 2007

Materials Test Station at Fermilab
Qualify / disqualify materials with/without evacuation

T962 (Yale, MSU, Fermilab)
~0.7/~0.35 ton TPC (total/active)
Proposed to be put in front of the MINOS near detector



http://www.fnal.gov/directorate/Longrange/Steering_Public/documents.html



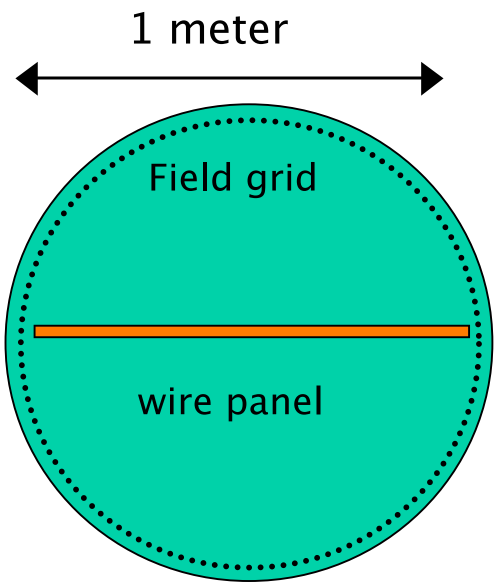
LArTPC @ Fermilab

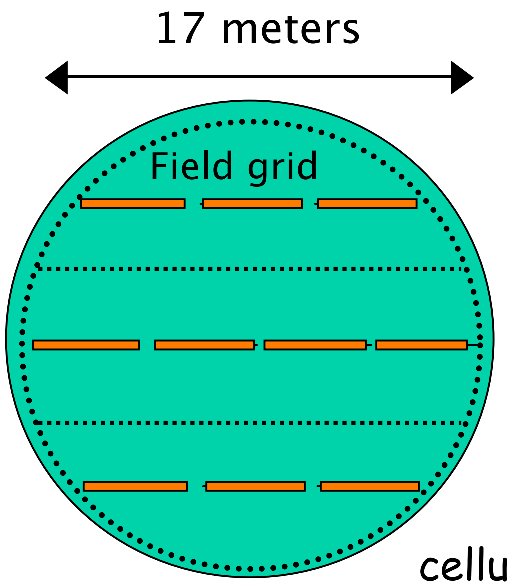
A scalable detector with a non-evacuable dewar and ionization charge detection without amplification

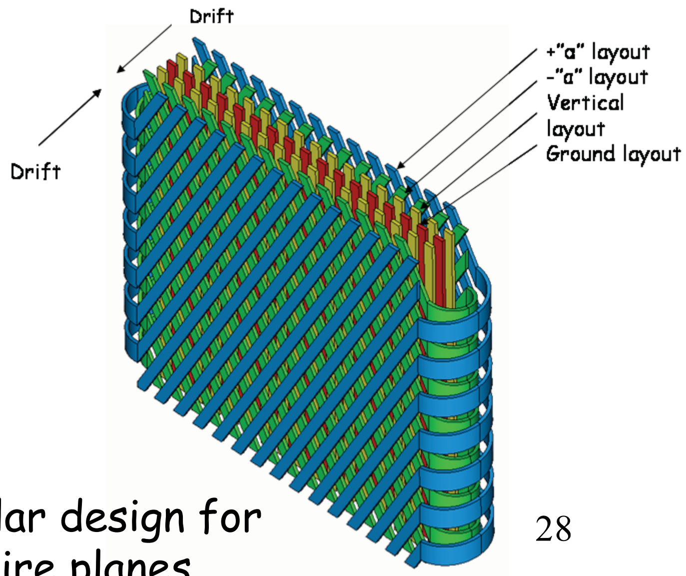
LNG style tank

A 5 ton detector is a cylinder 5 meters high with diameter 1 meter.

A 5 kton detector is a cylinder 17 meters high with diameter 17 me







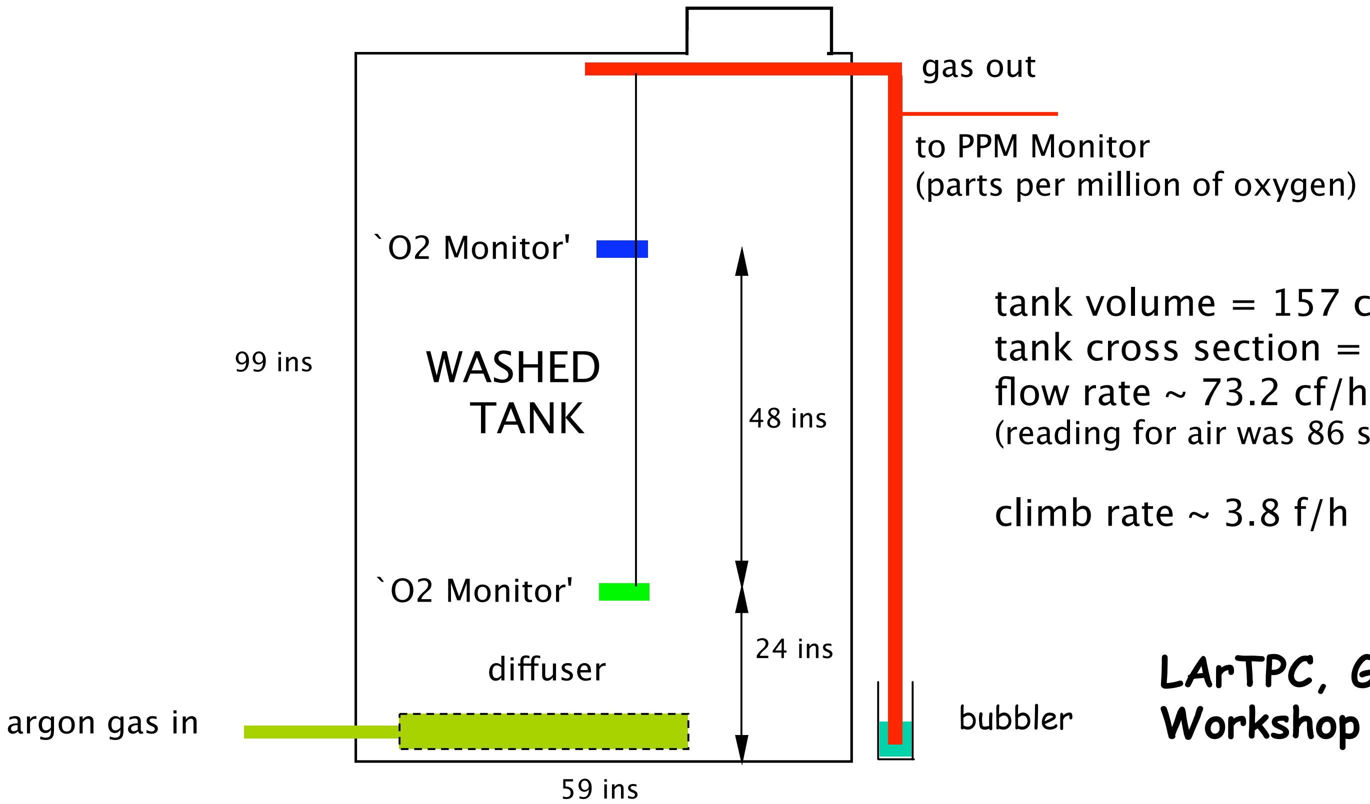
cellular design for wire planes

Purification starting from air in the Tank

Warm argon gas used as a piston
- purge oxygen to 50ppm or less
- vertical velocity chosen to control diffusion

Recirculation to purify warm argon gas
- remove water and oxygen, goal is 500ppb oxygen
- i. e., achieve purity similar to that achieved by ICARUS with evacuation

Liquid purification
- Final purity expected to be determined by contaminants from tank walls, TPC materials, flow restrictions due to presence of TPC, leaks, etc.

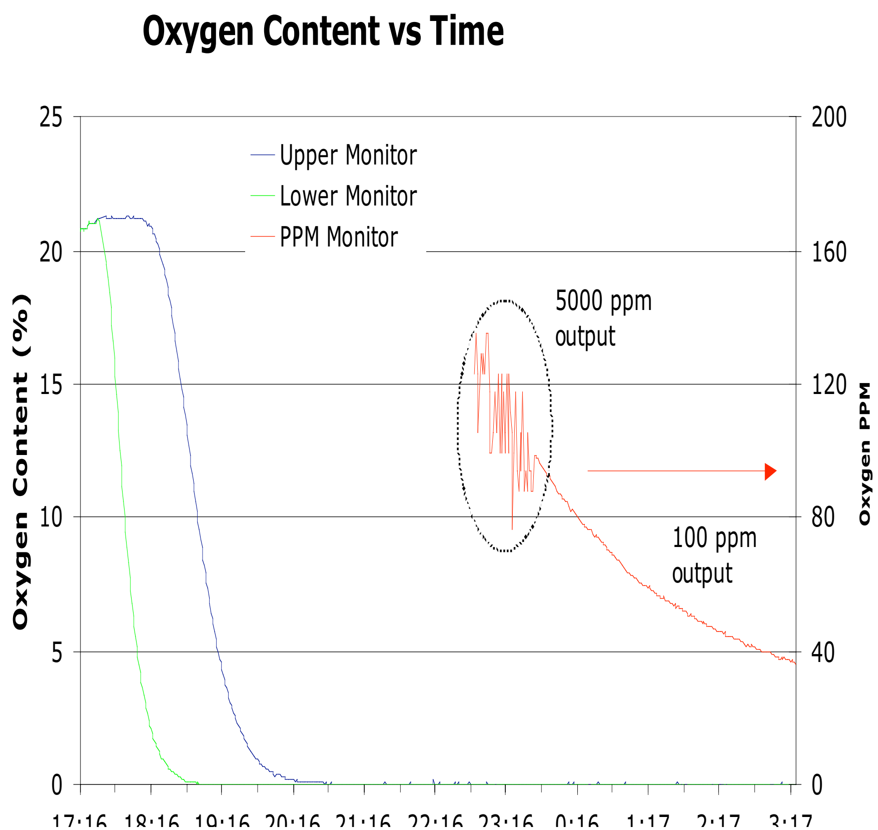


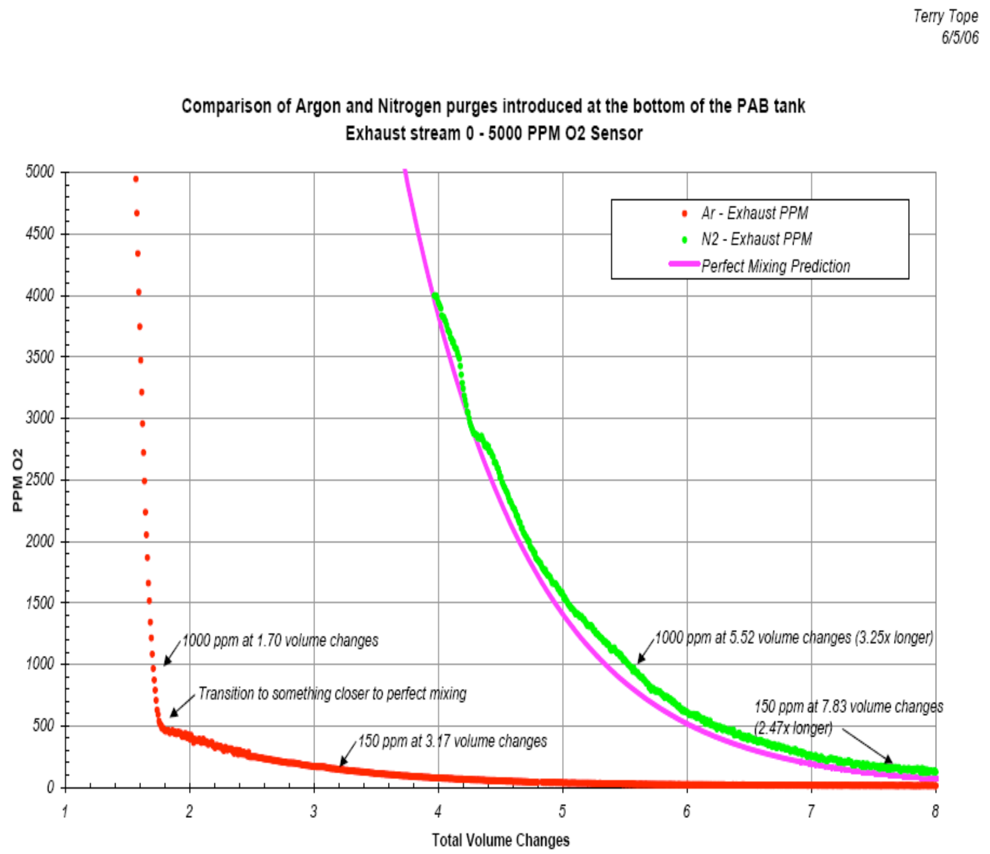
tank volume = 157 cf
tank cross section = 19 sf
flow rate ~ 73.2 cf/h
(reading for air was 86 scfh)

climb rate ~ 3.8 f/h

LArTPC, Gran Sasso Cryodet1 Workshop March 2006

Measurements using an "Argon Piston" to Purge oxygen





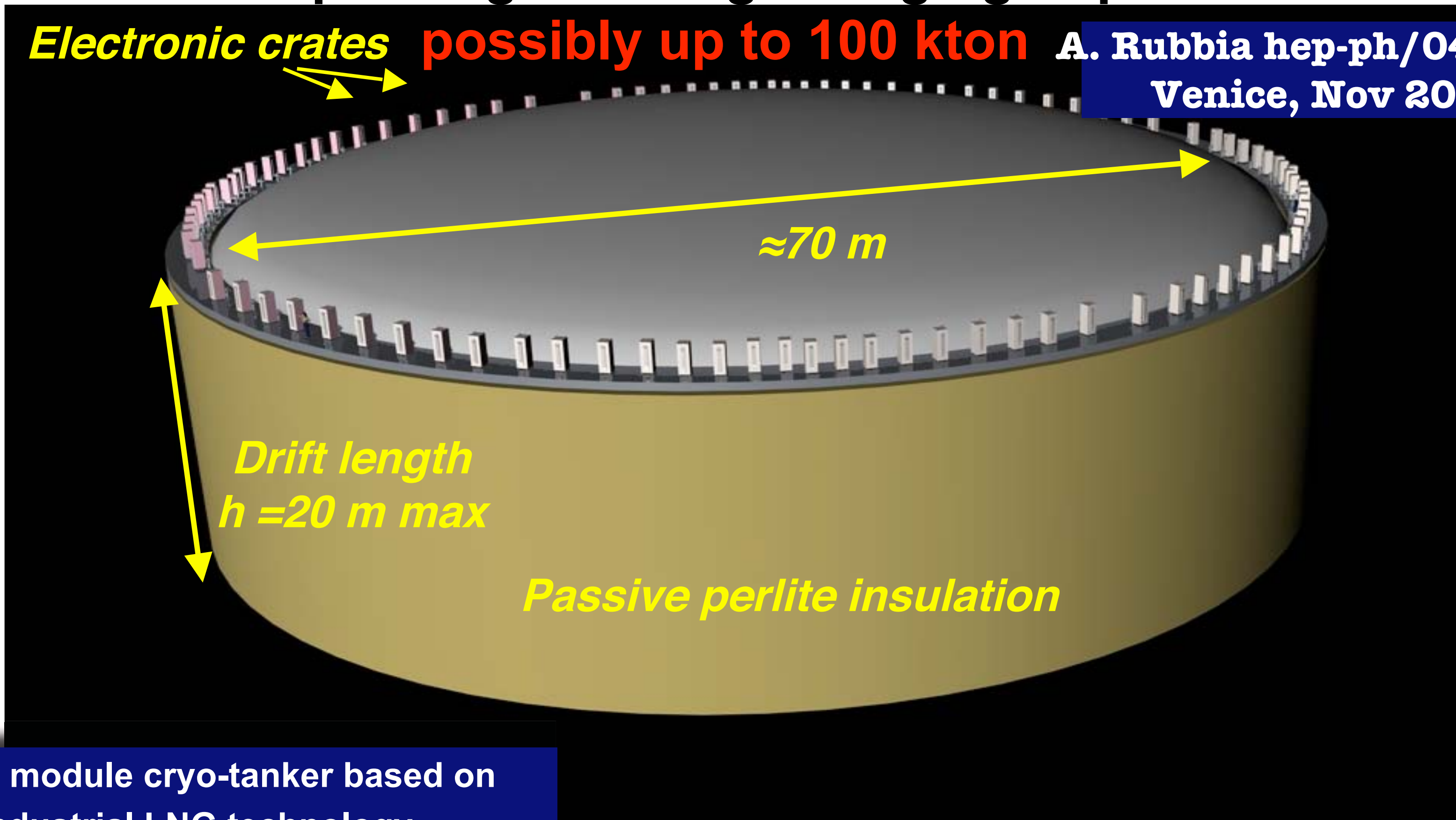
to 100 ppm (reduction of 2,000) takes 6 hrs = 2.6 volume changes
(cf simple mixing, which predicts ln(2000) = 7.6 volume changes)

LArTPC, Gran Sasso Cryodet1 Workshop March 2006

GLACIER

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

Giant Liquid Argon Charge Imaging ExpeRiment



A. Rubbia hep-ph/040211
Venice, Nov 2003

Single module cryo-tanker based on industrial LNG technology

GLACIER concepts for a scalable design

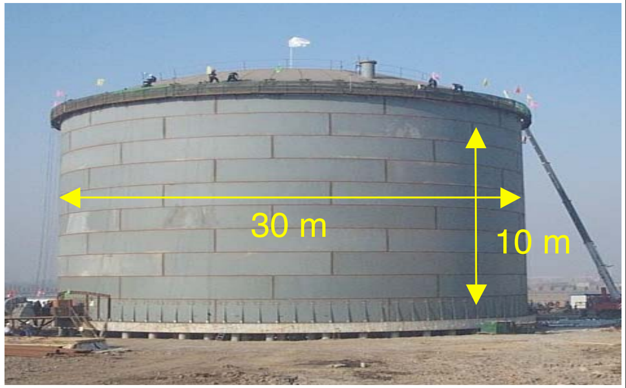
- LNG tank, as developed for many years by petrochemical industry
  - Certified LNG tank with standard aspect ratio
  - Smaller than largest existing tanks for methane, but underground
  - Vertical electron drift for full active volume
- A new method of readout (Double-phase with LEM)
  - to allow for 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

Scaling parameters

100 kton:

Dewar	Ø ≈ 70 m, height ≈ 20 m, perlite insulated, heat input ≈ 5 W/m^2
Argon storage	Boiling Argon, low pressure (<100 mbar overpressure)
Argon total volume	73000 m^3, ratio area/volume ≈ 15%
Argon total mass	102000 tons
Hydrostatic pressure at bottom	3 atmospheres
Inner detector dimensions	Disc Ø ≈70 m located in gas phase above liquid phase
Charge readout electronics	100000 channels, 100 racks on top of the dewar
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 photon counting capability

10 kton:

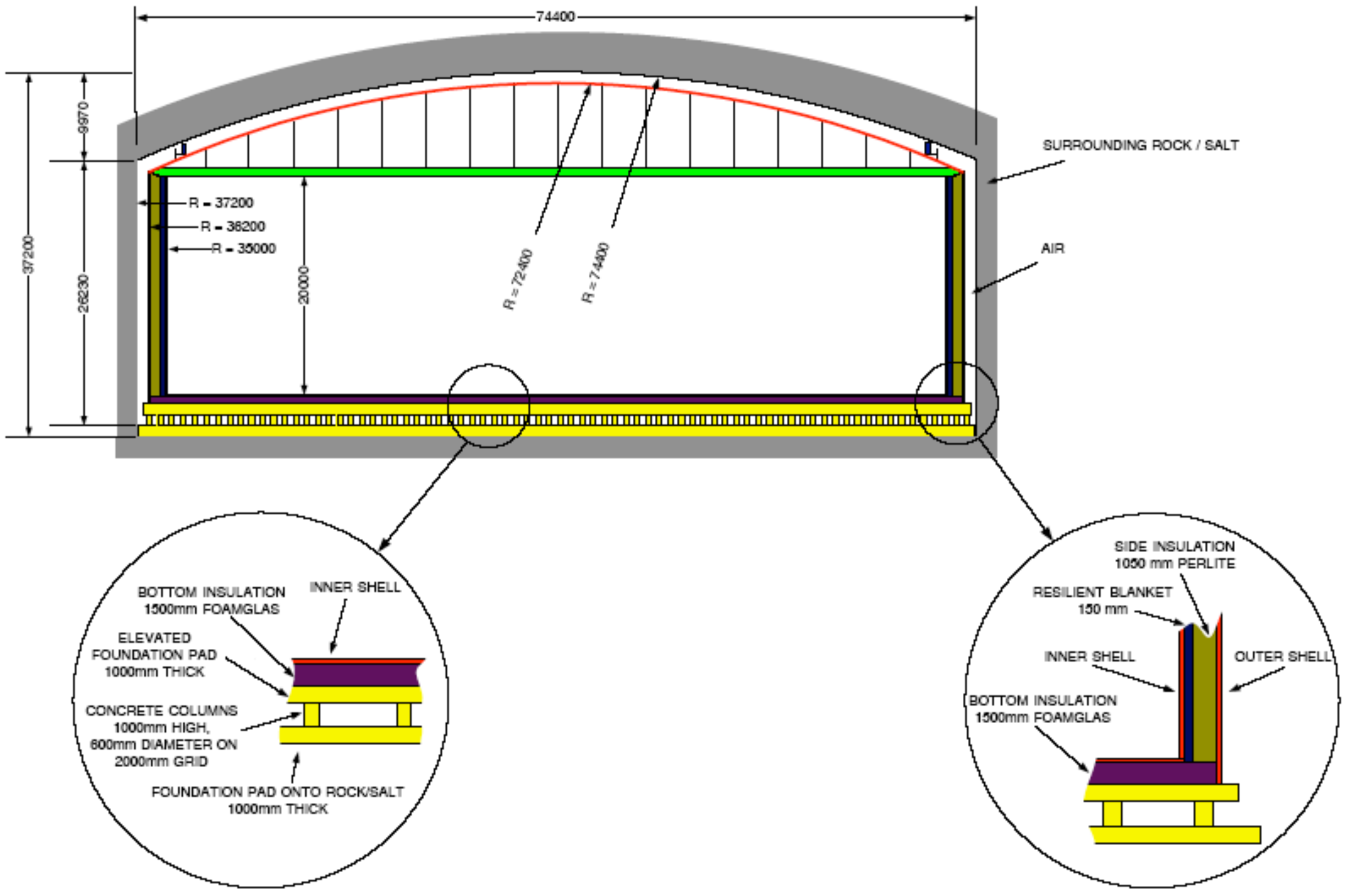


Dewar	Ø ≈ 30 m, height ≈10 m, perlite insulated, heat input ≈ 5 W/m^2
Argon storage	Boiling Argon, low pressure (<100 mbar overpressure)
Argon total volume	7000 m^3, ratio area/volume ≈ 33%
Argon total mass	9900 tons
Hydrostatic pressure at bottom	1.5 atmospheres
Inner detector dimensions	Disc Ø ≈30 m located in gas phase above liquid phase
Charge readout electronics	30000 channels, 30 racks on top of the dewar
Scintillation light readout	Yes (also for triggering), 300 immersed 8“ PMTs with WLS

1 kton: **1% prototype: engineering detector, Ø ≈ 10m, h ≈ 10m, shallow depth?**

TECHNODYNE INTERNATIONAL LIMITED

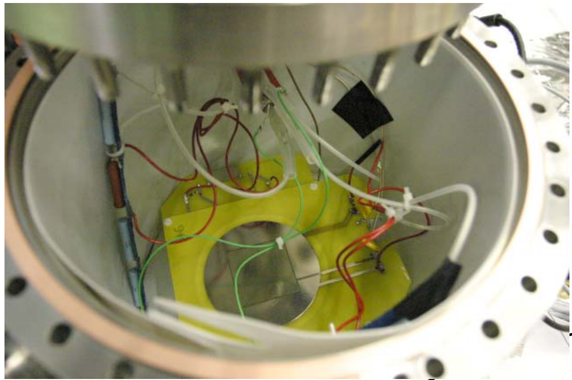
Large underground LAr storage tank



Project: Large Underground Argon Storage Tank

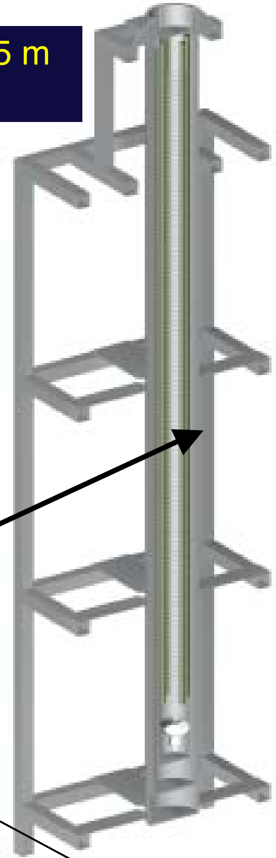
A feasibility study mandated to Technodyne Ltd (UK): Feb-Dec 2004

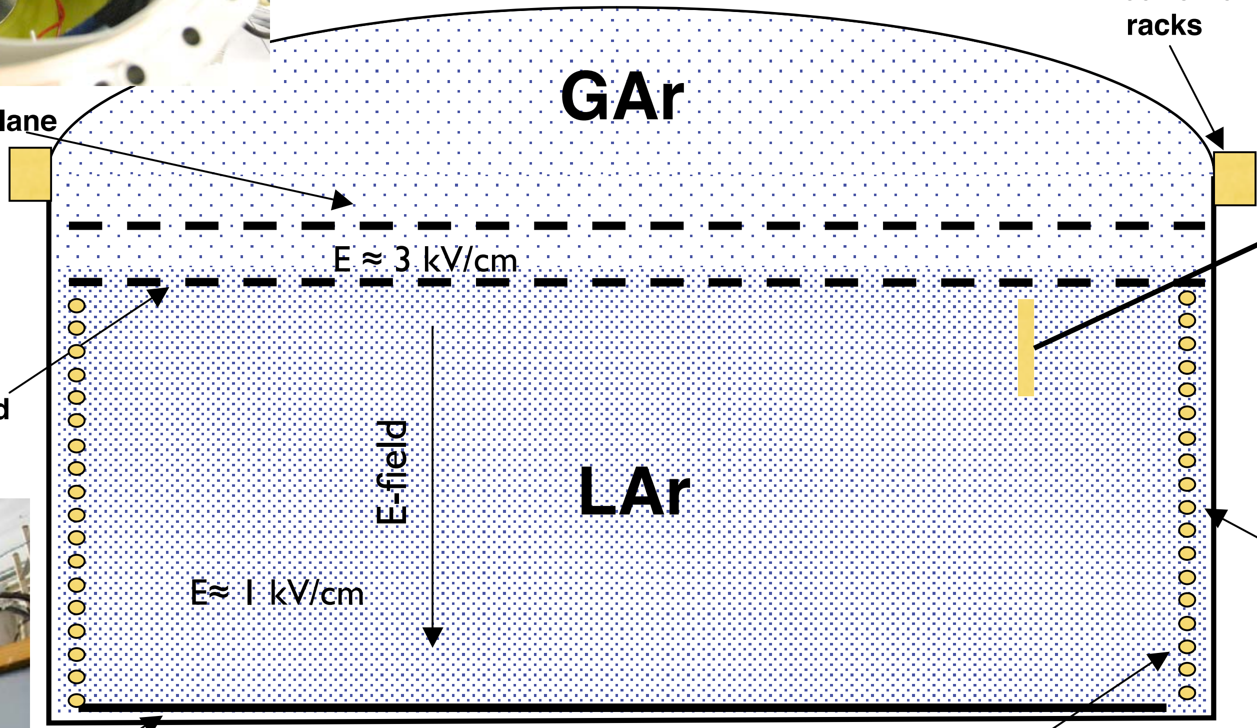
GLACIER R&D



Charge readout with extraction from liquid phase & amplification in gas phase for long drifts

ArgonTube: 5 m drift test



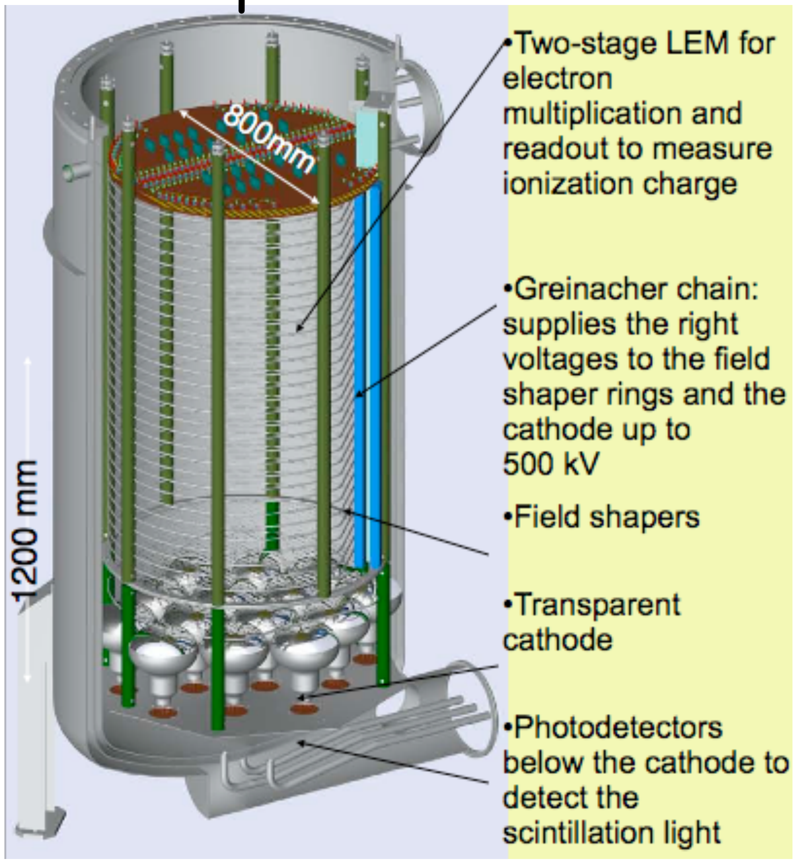


Greinacher voltage multiplier up to MV

Large area DUV sensitive photosensors

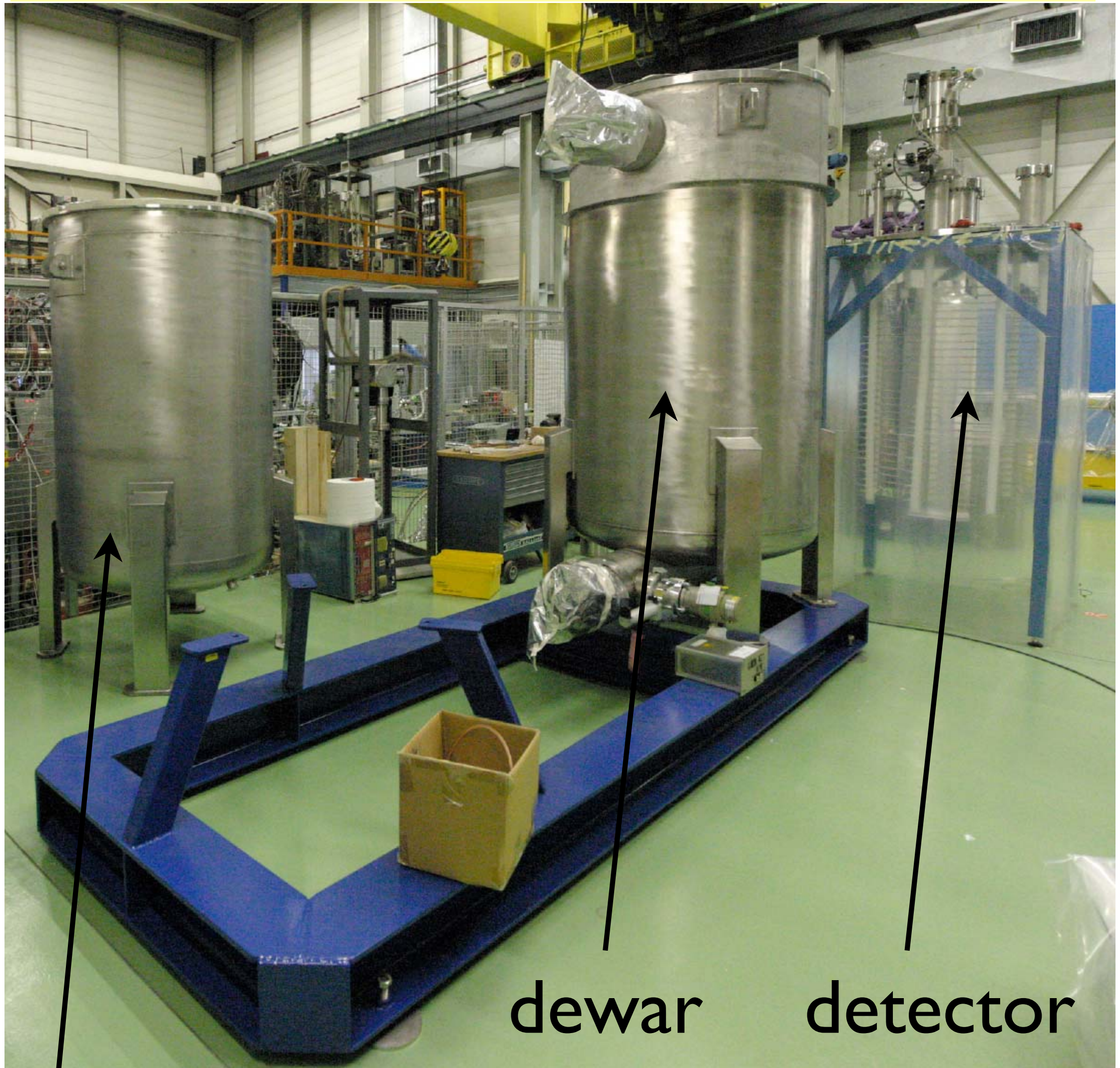
ArDM assembly @ CERN

Argon Dark Matter experiment



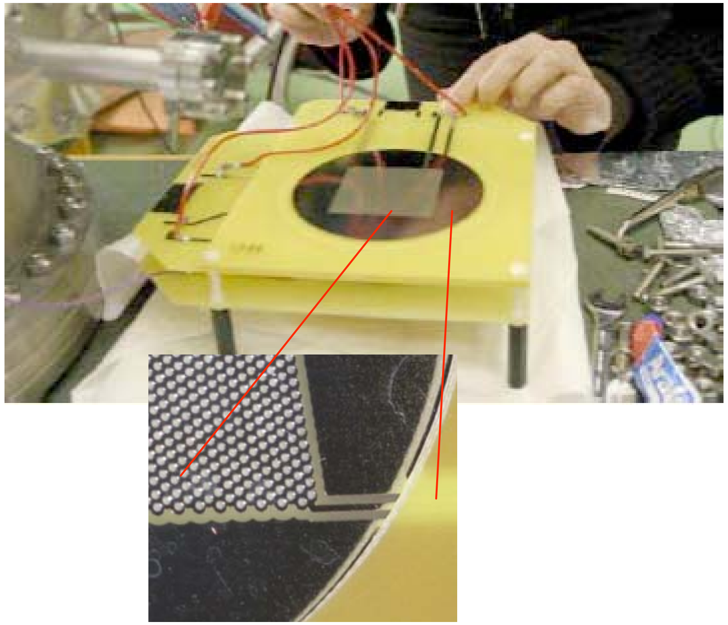
Start tests in 2007

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



(backup dewar)

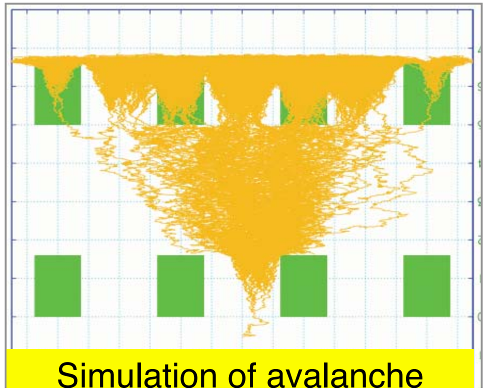
Charge readout: Thick Large Electron Multiplier (LEM)

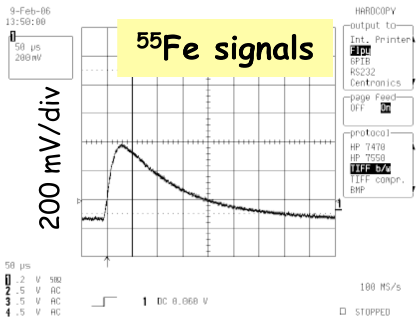


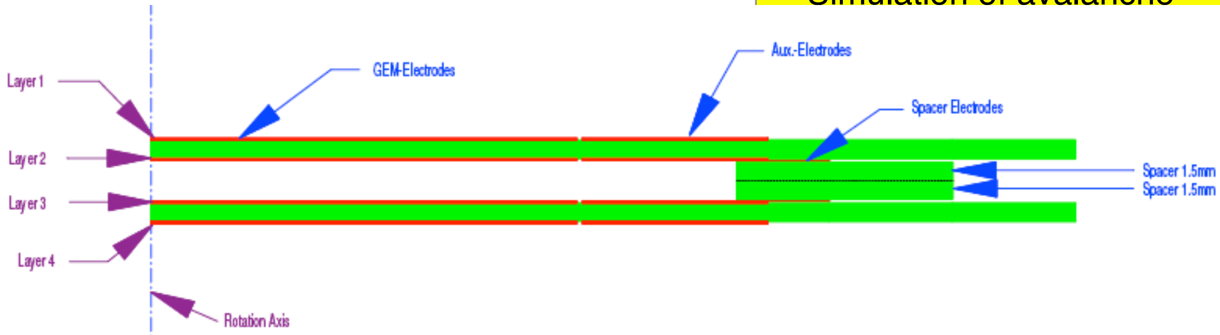
Thick-LEM: Vetronite with holes, coated with copper

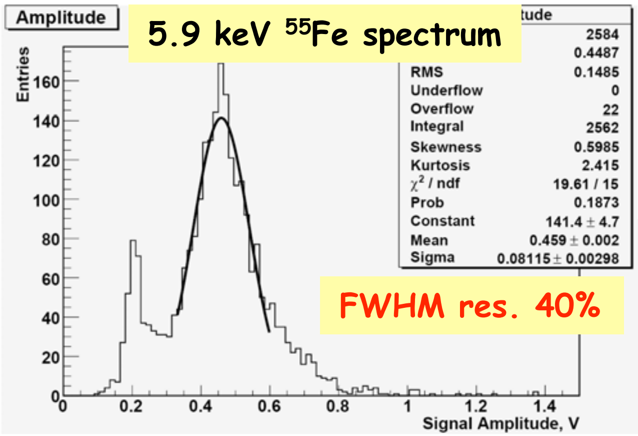
➡ **macroscopic GEM**

➡ **easier to operate at cryogenic temperatures**



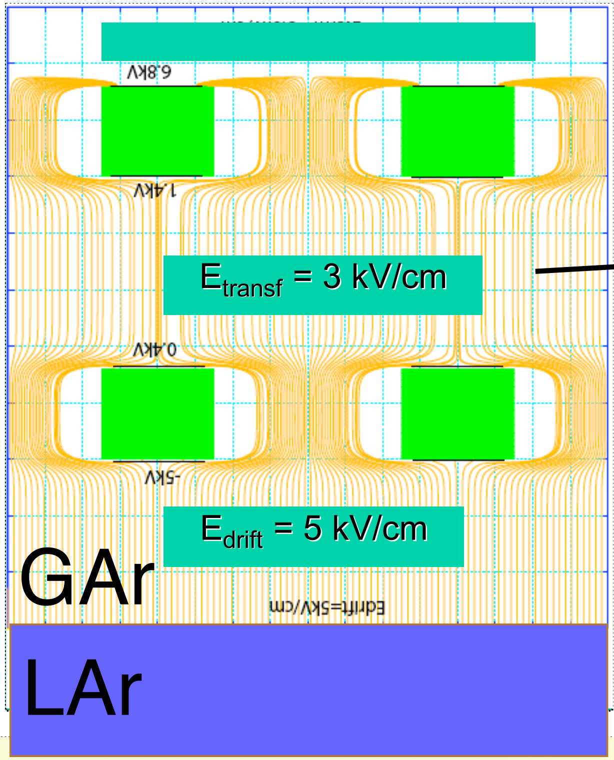


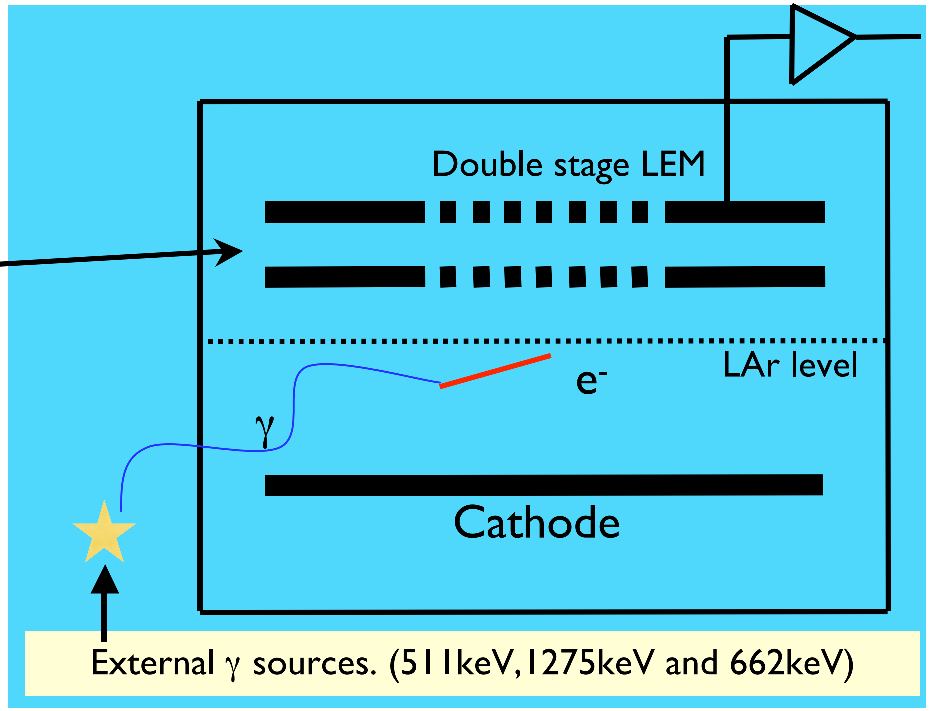


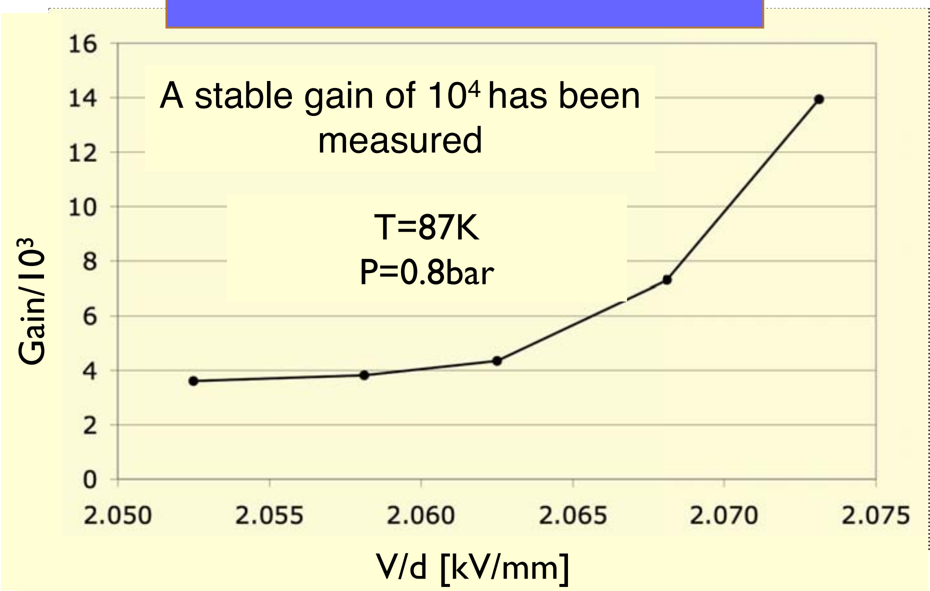


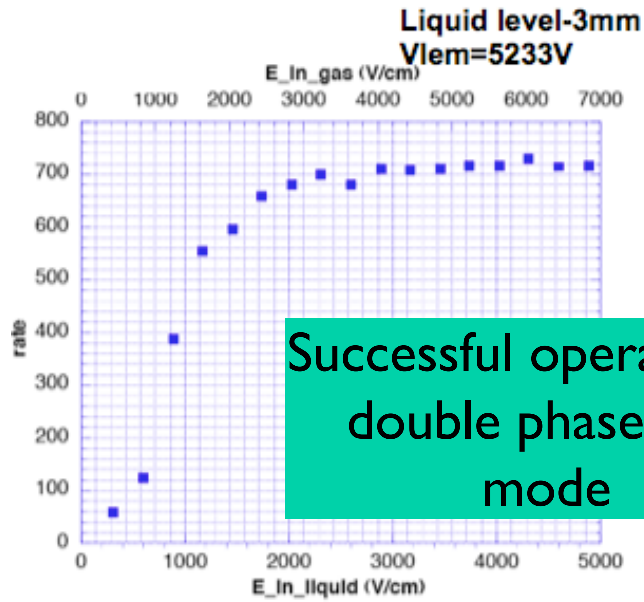
- Single LEM Thickness: 1.5 mm
- Amplification hole diameter = 500 μm
- Distance between centers of neighboring holes = 800 μm
- Distance between stages: 3 mm
- Avalanche spreads into several holes at second stage
- Reached gains of $10^3 \div 10^4$, with good stability

Double phase operation with two stages LEM





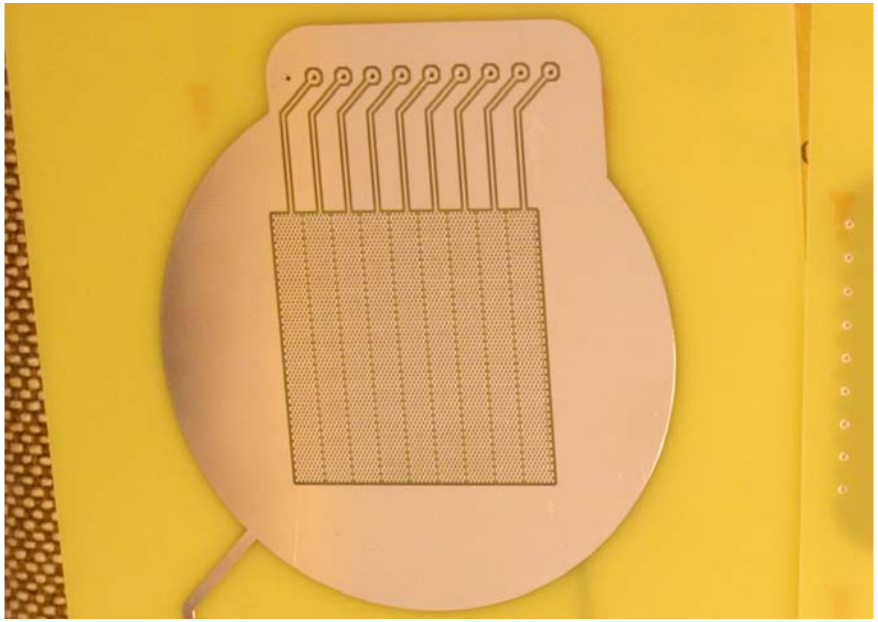


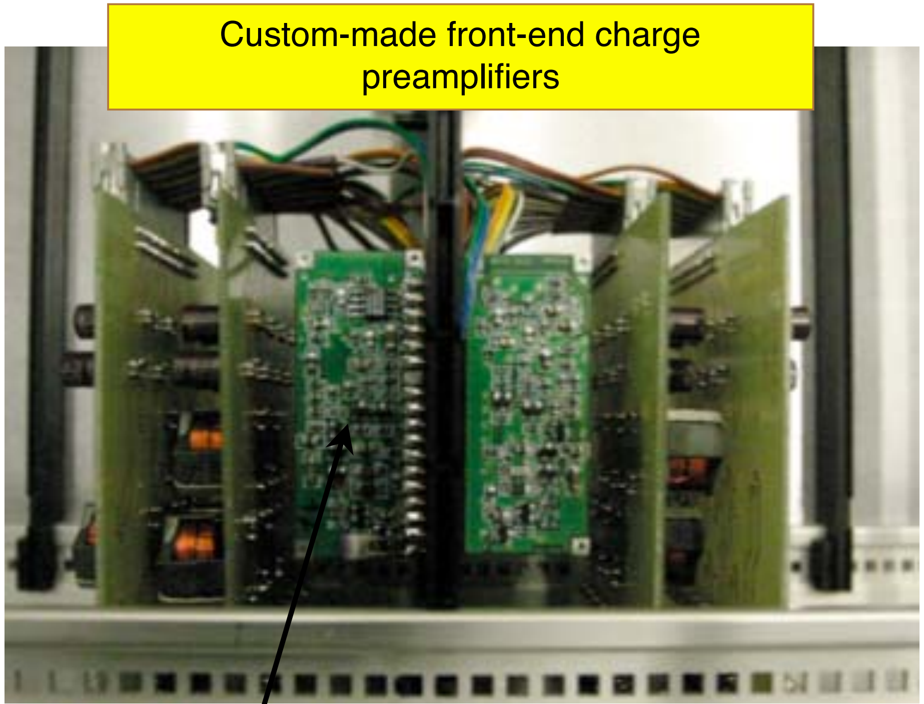


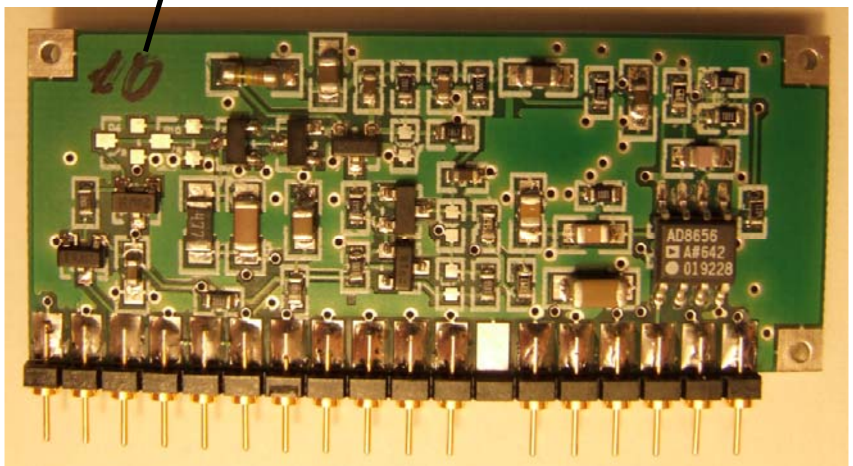
Successful operation in double phase LAr mode

Segmented double stage LEM

9 independent strips



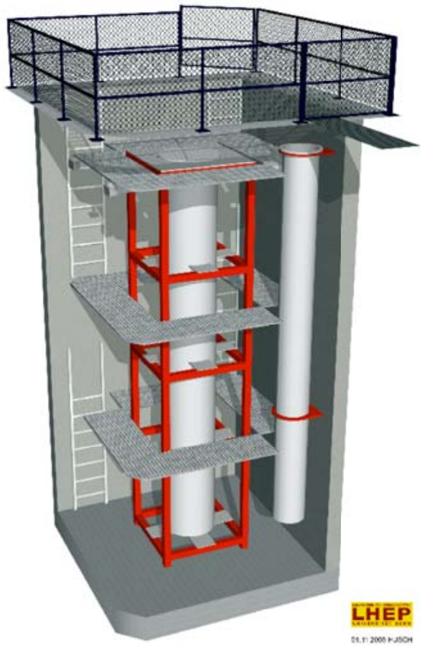




- Development F/E preamplifers **(also cold operation with IPN Lyon)** + MHz serial ADCs + DAQ
- Industrial version with CAEN (new module)

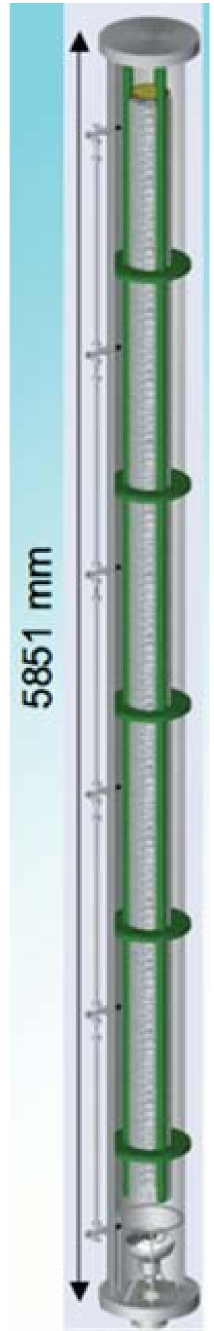
ARGONTUBE

Bern, ETHZ, Granada



First tests foreseen in 2008

- 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, detector container, inner detector, readout system, … in design/procurement phase

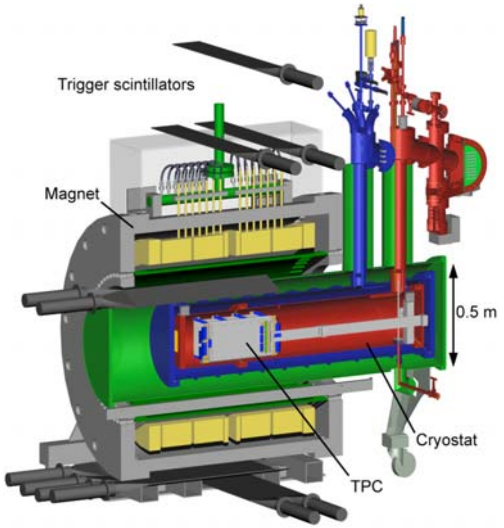


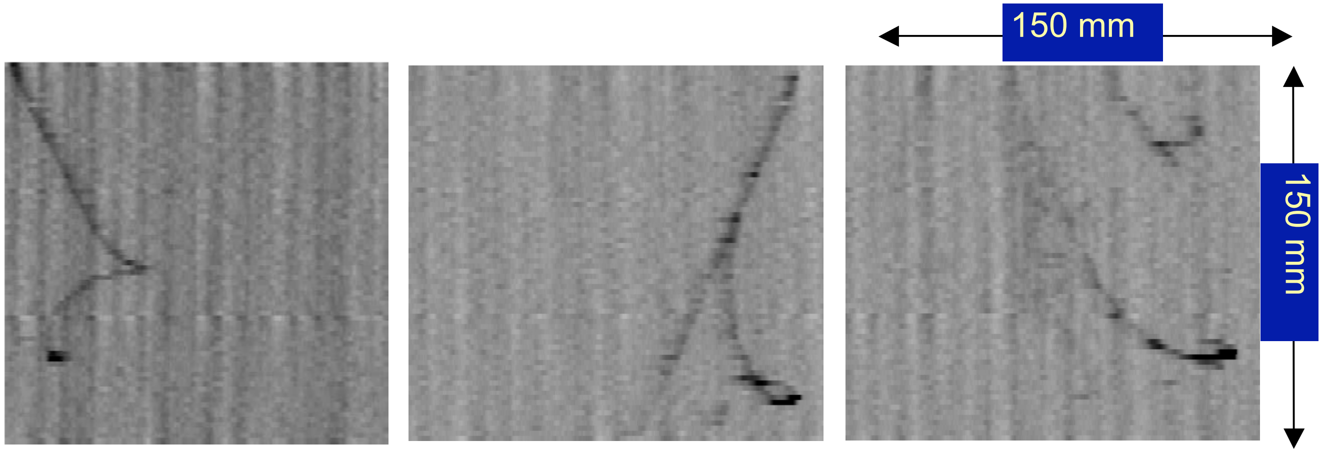
Ø = 35 cm

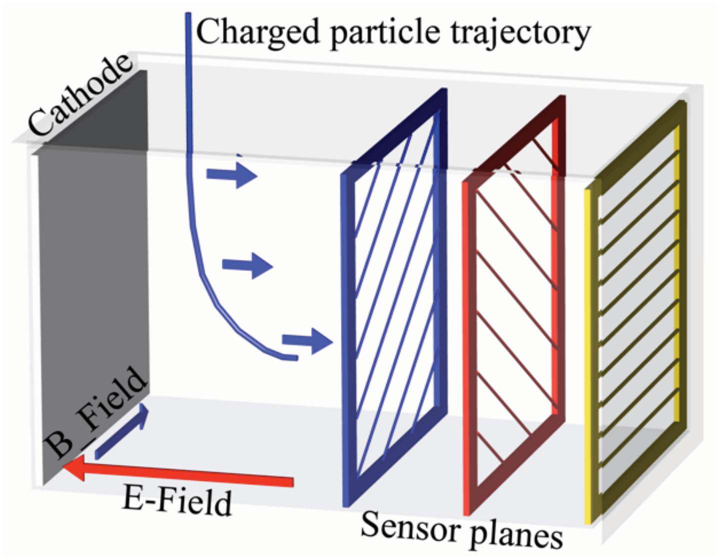
First operation of a LAr TPC embedded in a B-field

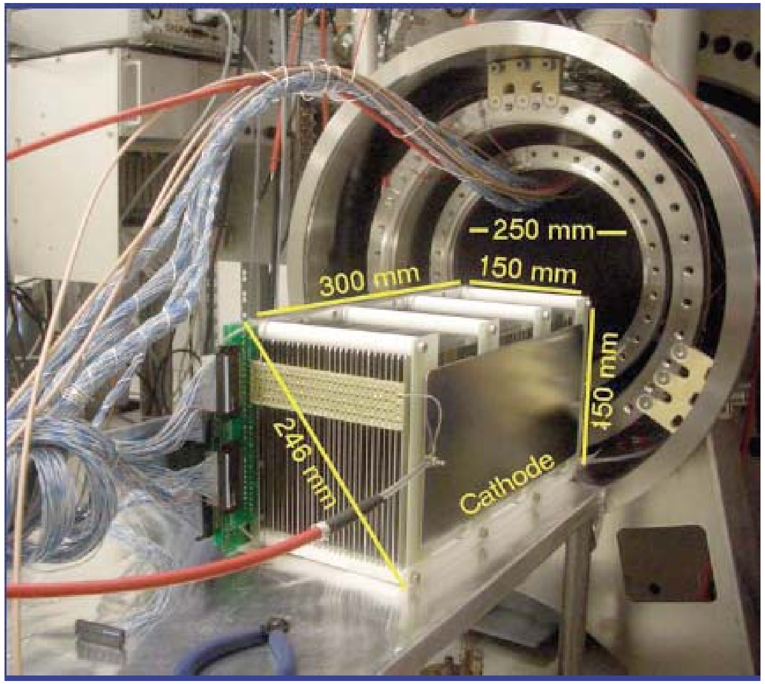
First real events in B-field (B=0.55T):

New J. Phys. 7 (2005) 63
NIM A 555 (2005) 294



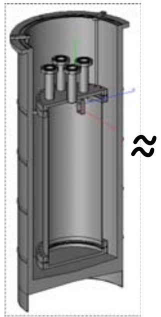






GLACIER steps

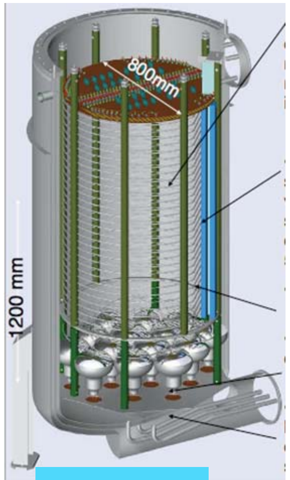
Test stands



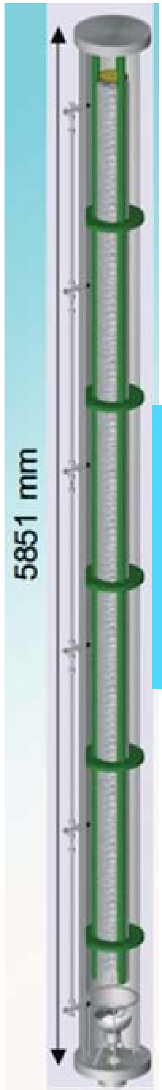
≈ 5 lt

LEM test stand

≈ 0.8 ton



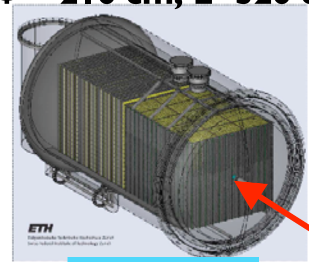
ArDM



ArgonTube

"Small" size detectors

Φ = 210 cm, L=320 cm



≈ 15 ton

$e^-, \pi^-, \ldots$

EPiLAr

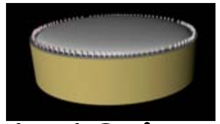
$\pi^- + p \rightarrow \pi^0 + n$

Electron/π^0 separation

T2K-2km

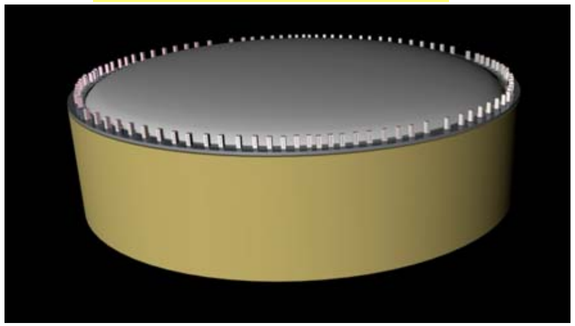
1 kton WC + 150 ton LAr
~ 200000 ν interactions/year

Medium size detector



1÷10 kton
shallow depth location (?)

Large size detector



50÷100 kton

GLACIER rough cost estimate

Item	100 kton	10 kton	1 kton
LNG tank (see notes 1-2)	50÷100	20÷30	8
Inner detector mechanics	10	3	1
Charge readout detectors	15	5	1
Light readout	60 (with Č)	2 (w/o Č)	1
F/E & DAQ electronics	10	5	1
Miscellanea	10	5	1
Detector total	**155 ÷ 205**	**40 ÷ 50**	**13**
Refilling plant	25	10	2
Purification system	10	2	1
Civil engineering + excavation	30	5	2
Forced air ventilation	10	5	1
Safety	10	5	1
Merchant cost of LAr (see note 3)	100	10	1
Grand total	**340 ÷ 390**	**77 ÷ 87**	**21**

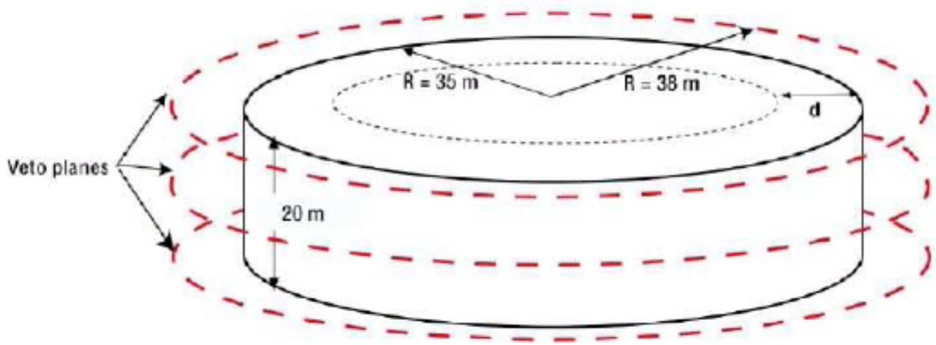
M€

Notes:
(1) Range in cost of tank comes from site-dependence and current uncertainty in underground construction
(2) Cost of tank already includes necessary features for LAr TPC (surface electropolishing, hard roof for instrumentation, feed-throughs,…)
(3) LAr Merchant cost ≠ production cost. Fraction will be furnished from external companies and other fraction will be produced locally (by the refilling plant)

GLACIER location

A. Bueno et al., JHEP04 (2007) 041

❖ At which depth should we position the detector?
  ➢ 2 background components
    ▪ **atmospheric ν background** (~ 250000 events for an exposure of 1000 kton-year)
    ▪ **cosmic muon induced background**
      • assume that events in which the parent μ enters the active LAr volume can be discarded thanks to a veto based on the LAr imaging (restrict backgrd. sources to neutrons, neutral kaons, lambdas)
      • exclude events produces at a distance smaller than 'd' from the walls
      • consider annular planes of active muon detectors to detect muons that pass within 3 m from the active LAr volume



A LAr TPC does not necessarily require very deep underground laboratories (self-shielding and with 3-D imaging properties)

GLACIER (100 kton) proton decay summary

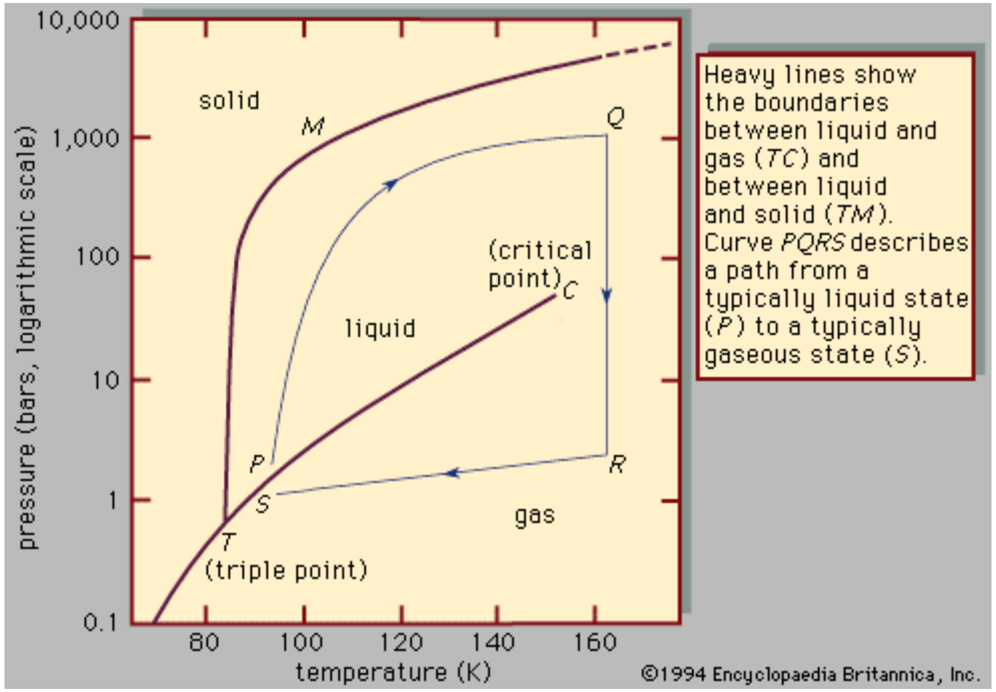
A. Bueno et al.,
JHEP04 (2007) 041

Channel	Cut efficiency (%)	Total background per year in fiducial volume	τ/B limit (years) 1 year exposure	τ/B limit (years) 10 years exposure
(p1) $p \to e^+ \pi^0$	45.3	0.1	0.5×10^{34}	0.4×10^{35}
(p2) $p \to \pi^+ \bar{\nu}$	41.9	82 (3 km w.e.)	0.7×10^{33}	0.3×10^{34}
		151 (1 km w.e.)	0.5×10^{33}	0.2×10^{34}
		148 (0.5 km w.e.)	0.5×10^{33}	0.2×10^{34}
		143 (Under the hill)	0.4×10^{33}	0.2×10^{34}
		149 (Under the hill+2 veto planes)	0.5×10^{33}	0.2×10^{34}
		152 (Under the hill+3 veto planes)	0.5×10^{33}	0.2×10^{34}
(p3) $p \to K^+ \bar{\nu}$	96.8	0.2 (3 km w.e.)	1.0×10^{34}	0.6×10^{35}
		0.2 (1 km w.e.)	0.8×10^{34}	0.6×10^{35}
		0.2 (0.5 km w.e.)	0.8×10^{34}	0.4×10^{35}
		0.2 (Under the hill)	$(0.8–0.7) \times 10^{34}$	$(0.5–0.4) \times 10^{35}$
		0.2 (Under the hill+ 2 veto planes)	$(0.9–0.8) \times 10^{34}$	$(0.5–0.5) \times 10^{35}$
		0.2 (Under the hill+ 3 veto planes)	$(1.0–0.8) \times 10^{34}$	$(0.6–0.5) \times 10^{35}$
(p4) $p \to \mu^+ \pi^0$	44.8	0.8	0.4×10^{34}	0.2×10^{35}
(p5) $p \to \mu^+ K^0$	46.7	< 0.2	0.5×10^{34}	0.5×10^{35}
(p6) $p \to e^+ K^0$	47.0	< 0.2	0.5×10^{34}	0.5×10^{35}
(p7) $p \to e^+ \gamma$	98.0	< 0.2	1.1×10^{34}	1.1×10^{35}
(p8) $p \to \mu^+ \gamma$	98.0	< 0.2	1.1×10^{34}	1.1×10^{35}
(p9) $p \to \mu^- \pi^+ K^+$	97.6	0.1	1.1×10^{34}	0.8×10^{35}
(p10) $p \to e^+ \pi^+ \pi^-$	18.6	2.5	0.1×10^{34}	0.5×10^{34}
(n1) $n \to \pi^0 \bar{\nu}$	45.1	50 (3 km w.e.)	0.1×10^{34}	0.5×10^{34}
		92 (1 km w.e.)	0.1×10^{34}	0.4×10^{34}
		89 (0.5 km w.e.)	0.1×10^{34}	0.4×10^{34}
		86 (Under the hill)	0.1×10^{34}	0.3×10^{34}
		90 (Under the hill+ 2 veto planes)	0.1×10^{34}	0.4×10^{34}
		91 (Under the hill+ 3 veto planes)	0.1×10^{34}	0.4×10^{34}
(n2) $n \to e^- K^+$	96.0	< 0.2	1.4×10^{34}	1.4×10^{35}
(n3) $n \to e^+ \pi^-$	44.4	0.8	0.4×10^{34}	0.2×10^{35}
(n4) $n \to \mu^- \pi^+$	44.8	2.6	0.4×10^{34}	0.2×10^{35}

Conclusions

- The successful operation of the ICARUS T300 module has wakened new interest in LAr TPC detectors for neutrino oscillation measurements and proton decay searches
  - … but the ultimate physics goals require detectors at least 50 times bigger
  - exposure of 100 ton – 1 kton detectors to neutrino beams in "near" locations would provide a wealth of information
- A world-wide effort is undergoing to design a multi-kton LAr TPC detector
  - modular/scalable design
  - evacuable/non-evacuable dewar and Argon purification
  - readout devices (wires, LEM,…) and analog and digital electronics
  - high voltage systems
- A 50-100 kton LAr detector would allow to explore proton decay modes with $\tau/B \sim 10^{34} \div 10^{35}$ years
- The synergy between precise detectors for long neutrino baseline experiments and proton decay (and astrophysical neutrinos) apparatus is essential for a realistic proposal for a 50-100 kton LAr detector

LAr thermodynamical properties



	P (bar)	T (K)	Density (g/cm^3)
Solid phase		83.0	1.625
Liquid phase	1.00	87.2	1.396
Boiling point	1.013	87.3	1.395
Triple point	0.689	83.8	
Critical point	48.63	150.7	0.553

At the boiling point:

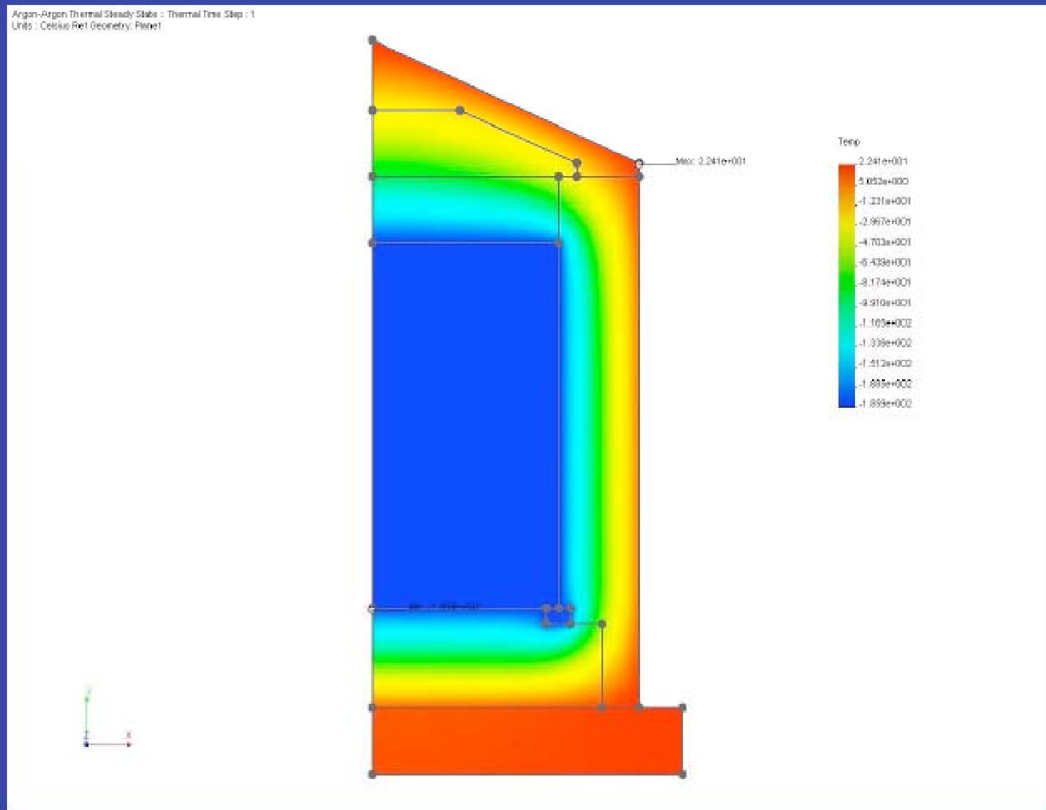
- Heat capacity (C_p) 0.2670 cal/g K
- Thermal conductivity 3.00×10^{-4} cal/s cm K
- Latent heat of vaporization 38.4 cal/g

Technodyne baseline design

- The tank consists of the following principal components:
  1. A 1m thick reinforced concrete base platform
  2. Approximately one thousand 600mm diameter 1m high support pillars arranged on a 2m grid. Also included in the support pillar would be a seismic / thermal break.
  3. A 1m thick reinforced concrete tank support sub-base.
  4. An outer tank made from stainless steel, diameter 72.4m. The base of which would be approximately 6mm thick. The sides would range from 48mm thick at the bottom to 8mm thick at the top.
  5. 1500mm of base insulation made from layers of felt and foamglas blocks.
  6. A reinforced concrete ring beam to spread the load of the inner tank walls.
  7. An inner tank made from stainless steel, diameter 70m. The base of which would be approximately 6mm thick and the sides would range from 48mm thick at the bottom to 8mm thick at the top.
  8. A domed roof with a construction radius of 72.4m attached to the outer tank
  9. A suspended deck over the inner tank to support the top-level instrumentation and insulation. This suspended deck will be slightly stronger than the standard designs to accommodate the physics instrumentation. This in turn will apply greater loads to the roof, which may have to be strengthened, however this is mitigated to some extent by the absence of wind loading that would be experienced in the above ground case.
  10. Side insulation consisting of a resilient layer and perlite fill, total thickness 1.2m.
  11. Top insulation consisting of layers of fibreglass to a thickness of approximately 1.2m.

Insulation considerations

- Based upon current industry LNG tank technology, Technodyne have designed the tank with 1.5 m thick load bearing Foamglas under the bottom of the tank, 1.2 m thick perlite/resilient blanket on the sides and 1.2m thick fibreglass on the suspended deck. Assuming that the air space is supplied with forced air at 35 degrees centigrade then the boil off would be in the order of 29m³ LAr per day. This corresponds to 0.039% of total volume per day.



Tank budgetary costing

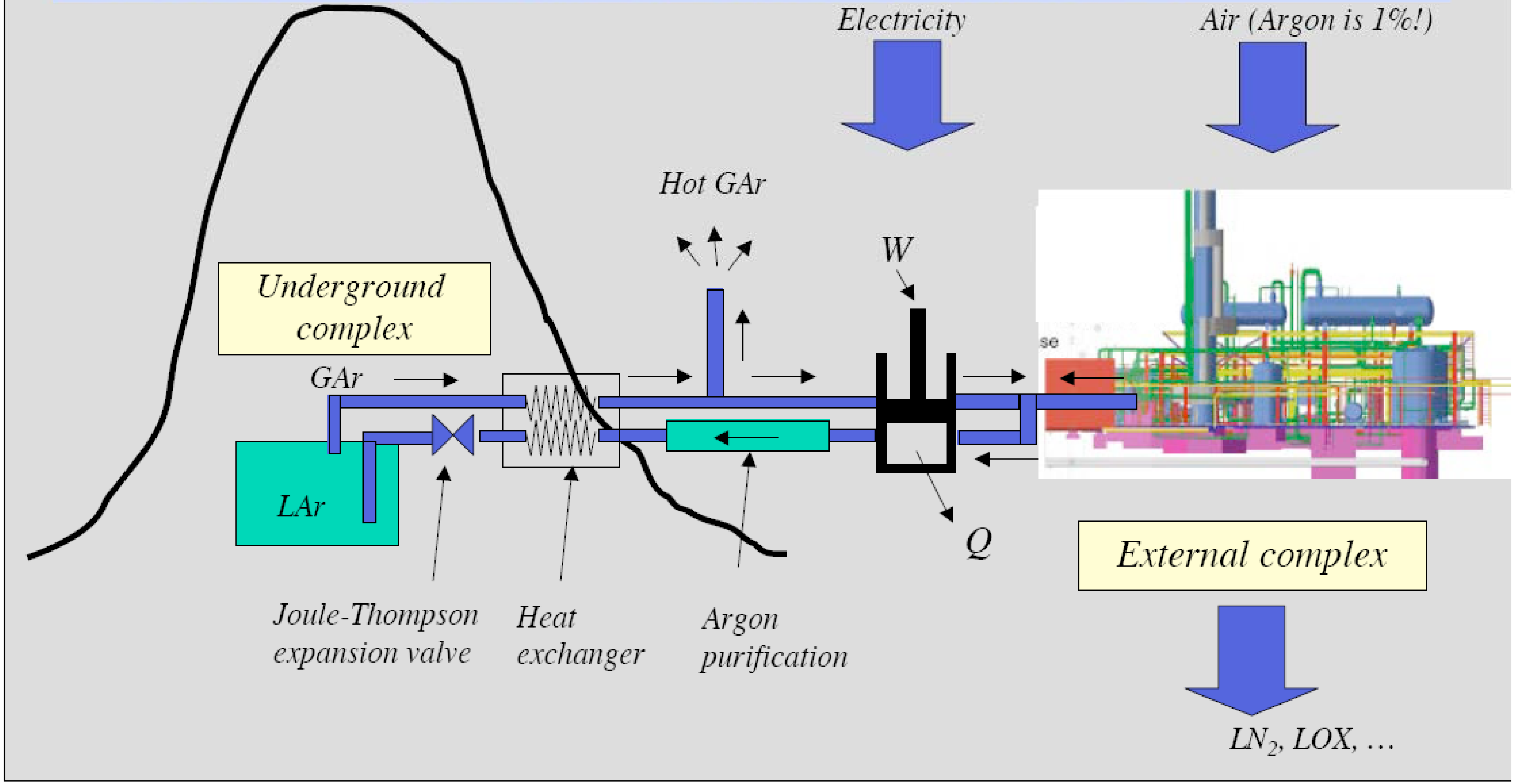
- The estimated costs tabulated below are for an inner tank of radius 35m and height 20m, an outer tank of radius 36.2m and height 22.5m. The product height is assumed to be 19m giving a product mass of 101.8 k tonnes.

Item	Description	Size	Million Euros
1	Steel	3400 tonnes	11.6 (*)
2	Insulation	16200 m^3	2.6
3	Concrete	9000 m^3	2.7
4	Electro-polishing	38000 m^2 Plate 20.5 km weld	8.2
5	Construction design / labour		18.8
6	Site equipment / infrastructure		9.8
	Total		**53.7**
6	Underground factor		2.0 ← Estimate based on existing data for mine operations
	Underground tank cost		107.4

(*) includes the recent increase of steel cost (was 6.2 MEuro in 03/2004)

Process system & equipment

- Filling speed (100 kton): 150 ton/day → 2 years to fill
- Initial LAr filling: decide most convenient approach: transport LAr and/or in situ cryogenic plant
- Tanker 5 W/m^2 heat input, continuous re-circulation (purity)
- Boiling-off volume at regime: ≈45 ton/day (≈10 years to evaporate entire volume)



Process considerations

- There are three major items required for generating and maintaining the Liquid Argon needed in the tank. These are:
  - Filling the tank with the initial Liquid Argon bulk
  - Re- liquefaction of the gaseous Argon boil-off.
  - Continuous purification of the Liquid Argon.
- *1.1 Initial fill*
  - The requirements for the initial fill are large, corresponding to 150 tonnes of Liquid Argon per day over two years. Argon is a by product of the air separation plant which is usually aimed at a certain amount of oxygen production per day. The amount required is a significant proportion of the current European capacity. Hence new investment will be required by the industry to meet the project requirement. This could either be a specific plant located for the project or increases in capacity to several plants in the area. British Oxygen's largest air separation plant in Poland has the capability to produce 50 Tonnes of Liquid Argon per day. However, this is nearly all supplied to industry and therefore the available excess for a project of this size would be relatively small.
  - A typical air separation plant producing 2000 tonnes per day of Oxygen would produce 90 tonnes per day of Liquid Argon. This facility would have a 50-60 metre high column, would need approximately 30m x 40m of real-estate, would need 30-35MW of power and cost 45 million euros. Energy to fill would cost ≈25MEuro.
  - Purchasing LAr costs would be in the region of 500 euros per tonne. Transportation costs are mainly dependant upon the cost of fuel and the number of kilometres between supply and site. To fill the tank would require 4500 trips of 25 tons trucks and would cost ≈30 million euros for transport.

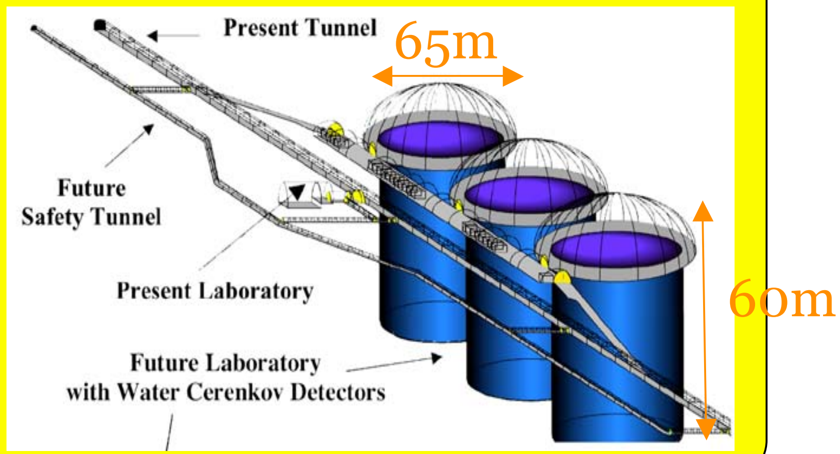
Process considerations

- *1.2 Cooldown*
  - Assuming a start temperature of 35 degrees C and using Liquid Argon to perform the cool-down then the amount of liquid Argon required for the cool-down process would be ≈1000 tonnes LAr. Assuming that the liquefaction plant can produce 150 tonnes / day of liquid argon then the cool-down process would take 7 days.
- *1.3 Re-Liquefaction of the boil-off*
  - The Technodyne design of the tank assumes that an adequate supply of air is circulated around the tank to prevent the local rock / salt from freezing, thereby reducing the risk of rock movement or fracture. For an air temperature of 35 degrees (constant throughout a 24 hour period) the boil off of Liquid argon would be in the region of 29000 litres per day. This would require ≈10 MW of power.
  - Alternatively a compression system can take the boil off gas and re-compress, filter and then re-supply to the tank. The power is likely to be a similar order of magnitude of 8 MW.
- *1.4 Purification of the Liquid Argon*
  - The Liquid Argon should be as pure as possible, the required target impurities being less than 0.1 ppb. To achieve this argon must be re-circulated through a filter system to remove impurities. The requirement is to re-circulate all the LAr in a period of 3 months. This equates to $33m^3$ / hour. The use of Messer- Griesheim filters suggests that a flow of 500 l / hour is possible through a standard hydrosorb / oxysorb filter. This would equate to a requirement for a minimum of 67 filters to achieve the required flow rate.

LAGUNA: a proposal for a "Design of a pan-european infrastructure for large apparatus studying Grand Unification and Neutrino Astrophysics"

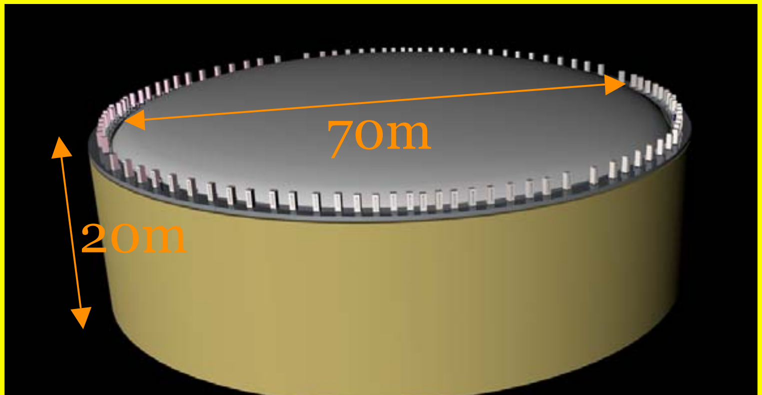
3 detection techniques under considerations

MEMPHYS-like



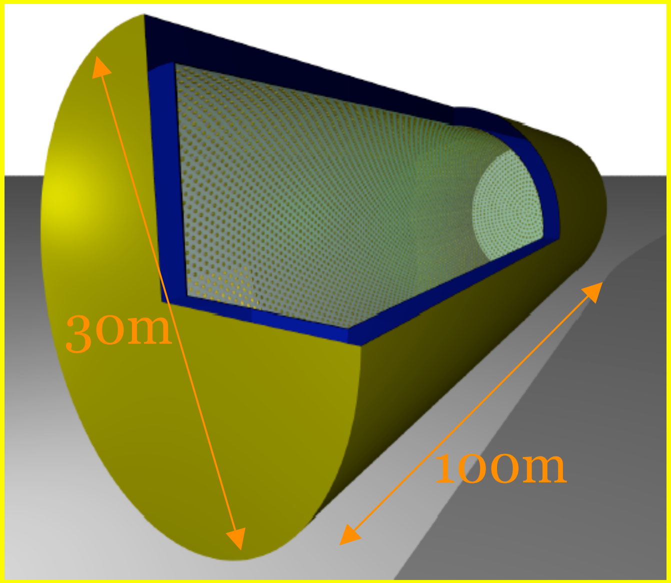
Water Cherenkov (≈0.5 → 1 Mton)

GLACIER-like

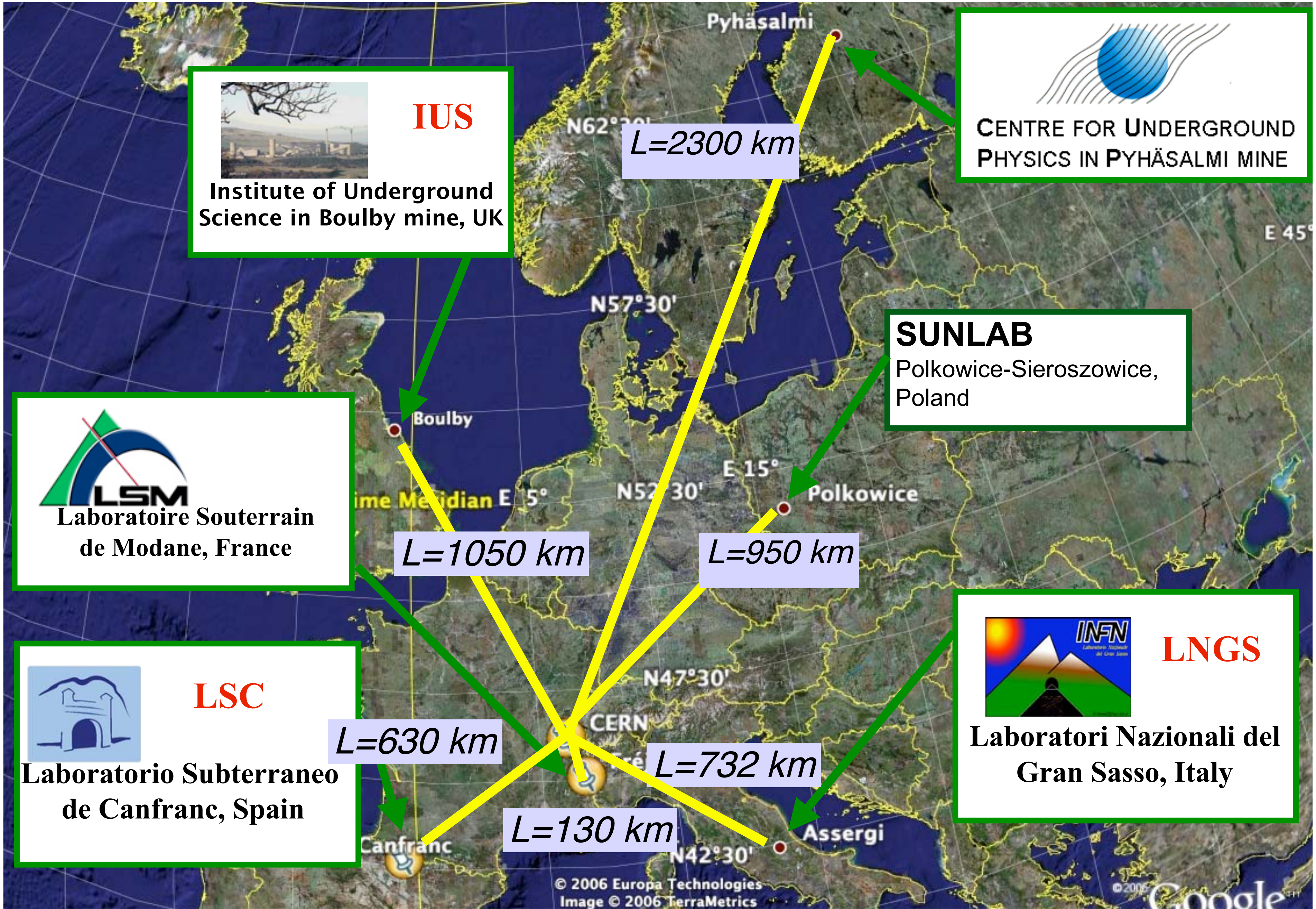


Liquid Argon (≈10→100 kton)

LENA-like



Liquid Scintillator (→ 50 kton)



The existing or emerging six national underground science laboratories

Muon rates

Depth		Code	All muons		$E_\mu > 1$ GeV		Effective mass
Water equiv.	Standard rock		Particles/s	Particles/10 ms	Particles/s	Particles/10 ms	
Surface detector		FLUKA	1700000	17000	1300000	13000	–
$\simeq$ 0.13 km w.e.	50 m	FLUKA	11000	110	10000	100	50 kton
$\simeq$ 0.5 km w.e.	188 m	FLUKA	330	3.3	320	3.2	98 kton
	200 m	GEANT4	–	–	420	4.2	98 kton
$\simeq$ 1 km w.e.	377 m	FLUKA	66	0.66	65	0.65	100 kton
$\simeq$ 2 km w.e.	755 m	FLUKA	6.2	0.062	6.2	0.062	100 kton
$\simeq$ 3 km w.e.	1.13 km	FLUKA	0.96	0.01	0.96	0.01	100 kton
Under the hill (see Figure 8)		GEANT4	–	–	960	9.6	96 kton

Cosmogenic bacground

Depth	Channel	Background source N_b^o (particles/year)			Cosmogenic background reduction		
		Neutron	K^o	Λ	Distance cut d (m)	Fiducial mass (kton)	Background N_b (events/year)
$\simeq$0.5 km w.e.	$p \to \pi^+\bar{\nu}$	570	–	–	1.5	92	76
(188 m rock)	$n \to \pi^o\bar{\nu}$	450	–	8	1.7	91	46
FLUKA	$p \to K^+\bar{\nu}$	–	135	–	6.6	66	0.1
$\simeq$ 1 km w.e.	$p \to \pi^+\bar{\nu}$	200	–	–	0.7	96	77
(377 m rock)	$n \to \pi^o\bar{\nu}$	130	–	2.3	0.75	96	47
FLUKA	$p \to K^+\bar{\nu}$	–	39	–	5.45	71	0.1
$\simeq$ 3 km w.e.	$p \to \pi^+\bar{\nu}$	4.0	–	–	0	100	4.0
(1.13 km rock)	$n \to \pi^o\bar{\nu}$	2.6	–	–	0	100	2.6
FLUKA	$p \to K^+\bar{\nu}$	–	0.74	–	1.8	90	0.1
Under the hill	$p \to \pi^+\bar{\nu}$	2900	–	–	2.7	85	76
(see Figure 8)	$n \to \pi^o\bar{\nu}$	2300	–	–	2.9	84	46
GEANT4	$p \to K^+\bar{\nu}$	–	36–360	–	5.4–7.5	72–62	0.1
Under the hill	$p \to \pi^+\bar{\nu}$	430	–	–	1.3	93	76
+ two veto planes	$n \to \pi^o\bar{\nu}$	340	–	–	1.5	92	46
GEANT4	$p \to K^+\bar{\nu}$	–	5–54	–	3.65–5.75	80–70	0.1
Under the hill	$p \to \pi^+\bar{\nu}$	170	–	–	0.6	97	77
+ three veto planes	$n \to \pi^o\bar{\nu}$	140	–	–	0.8	95	46
GEANT4	$p \to K^+\bar{\nu}$	–	2–20	–	2.8–5	85–74	0.1