R&D for future 100 kton scale LAr Detectors

A. Marchionni, ETHZ, Zurich

European Strategy for Future Neutrino Physics, CERN, Oct. 2009

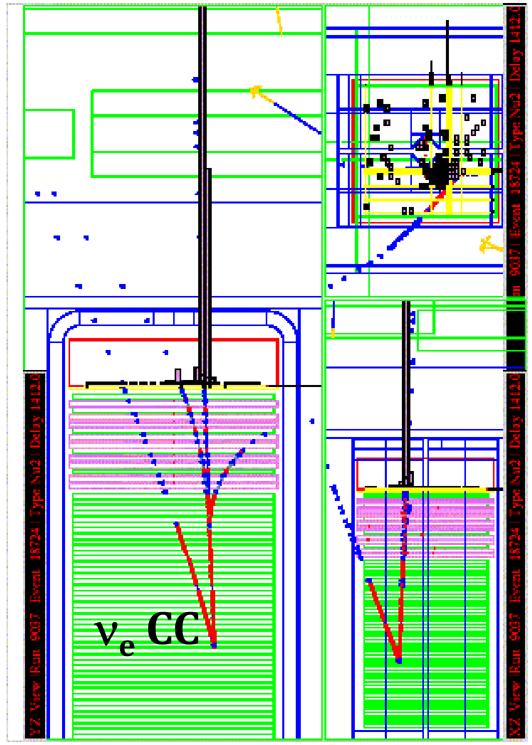
- **Physics reasons for a large LAr TPC detector**
- **R&D items towards large LAr TPC**
  - **Readout devices and electronics**
  - **Cryostats**
  - **Argon purity**
  - **High voltage systems**

  ⇒ **Long Drifts**
  Physics Performance
- **Review of the existing main design concepts**
- **How to get there? The R&D path**
- **Physics capabilities**
- **Conclusions**

3 detectors

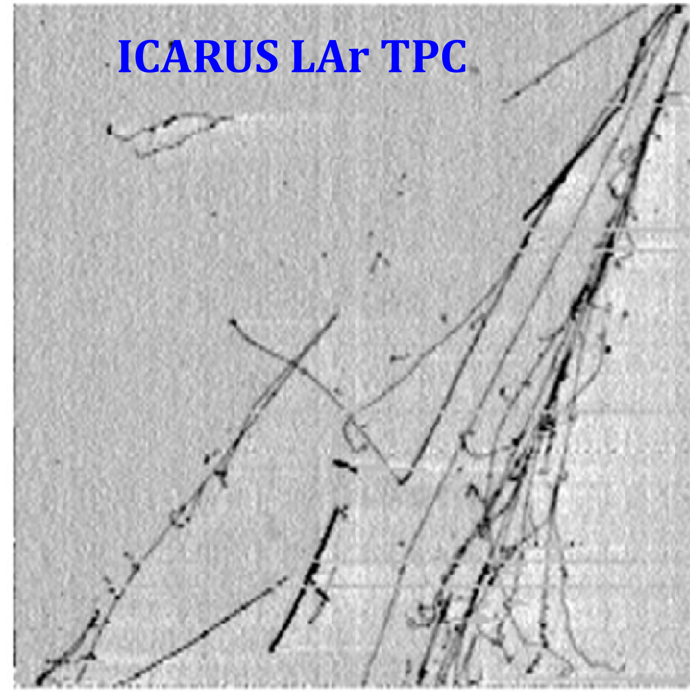
Bubble ∅ (mm)	3
Density (g/cm^3)	1.5
X_0 (cm)	11.0
λ_T (cm)	49.5
dE/dx (MeV/cm)	2.3

NOMAD



2.7 tons drift chambers target
Density (g/cm3) 0.1
2% X_0/chamber
0.4 T magnetic field

TRD detector
Lead glass calorimeter



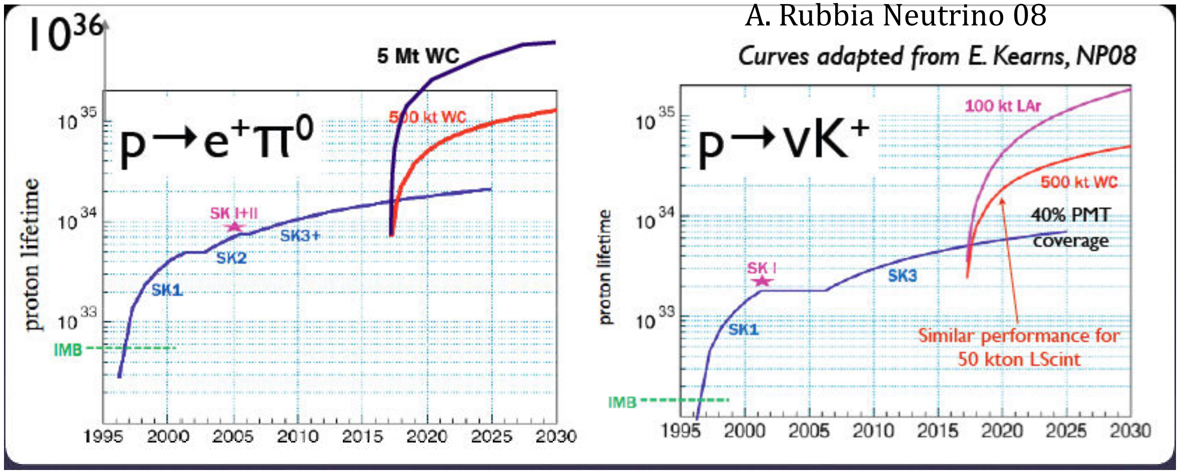
Resolution (mm^3)	3×3×0.2
Density (g/cm^3)	1.4
X_0 (cm)	14.0
λ_T (cm)	54.8
dE/dx (MeV/cm)	2.1

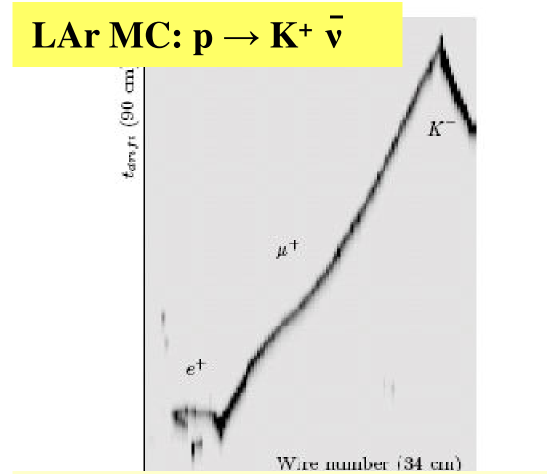
C. Rubbia,
CERN Report 77-8,
May 1977

Why a 100 kton scale LAr detector?

- **Proton decay searches**

2 possible channels

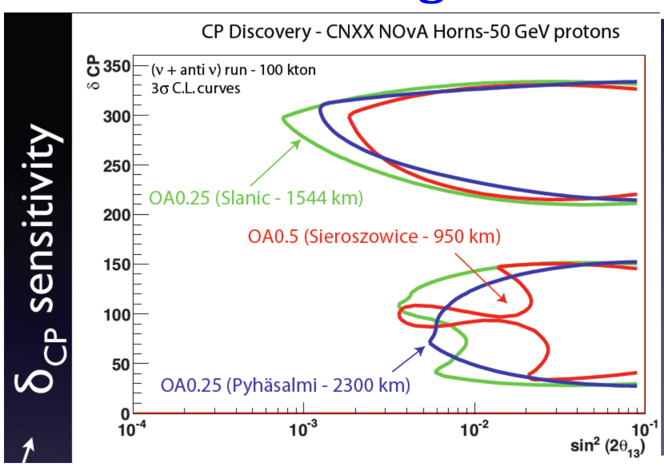


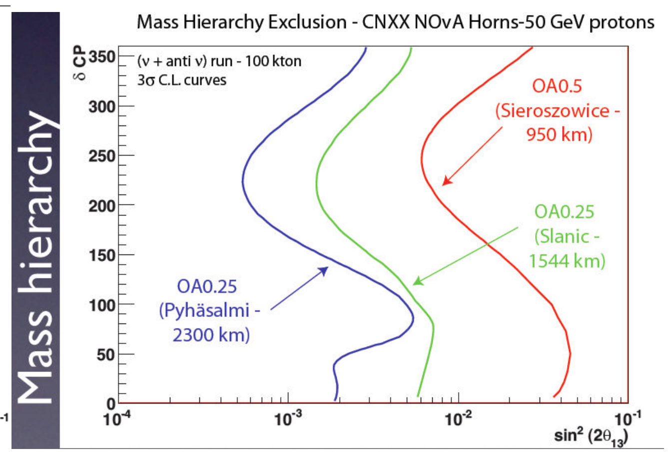


10x efficiency than WC
only way to reach 10^{35} years

- **Long baseline neutrino oscillation**

A. Rubbia WIN09

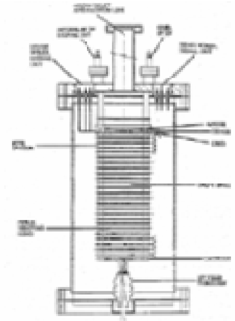




δ_{CP} and mass hierarchy sensitivities for different baselines in Europe

- **1.6 MW WBB from CERN**
- **100 kton LAr detector**

The ICARUS steps

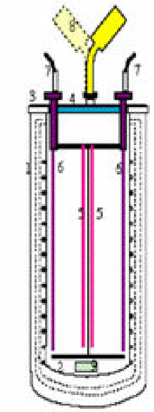


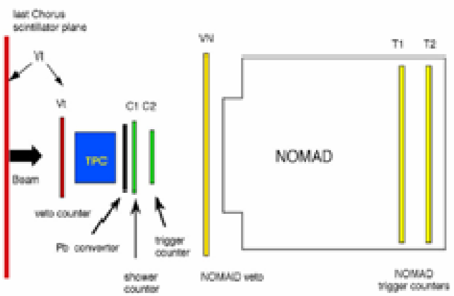
24 cm drift wires chamber

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 m^3 industrial prototype

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

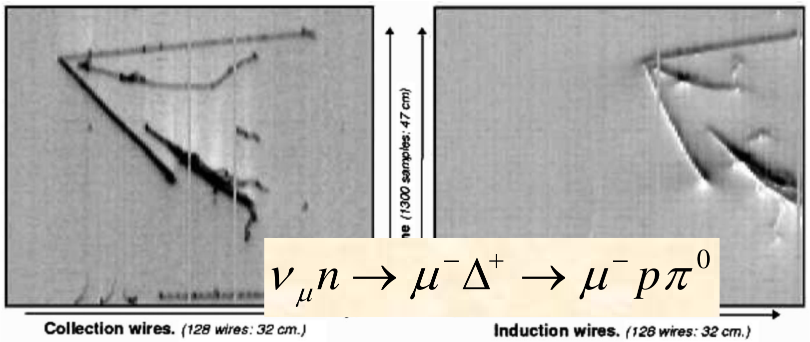
600 ton detector

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

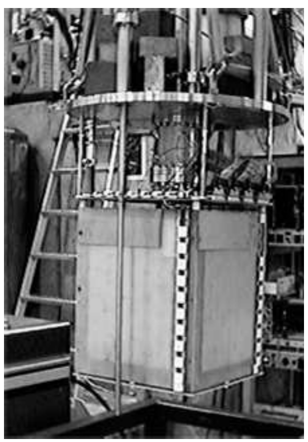
NIM A 527 (2004) 329

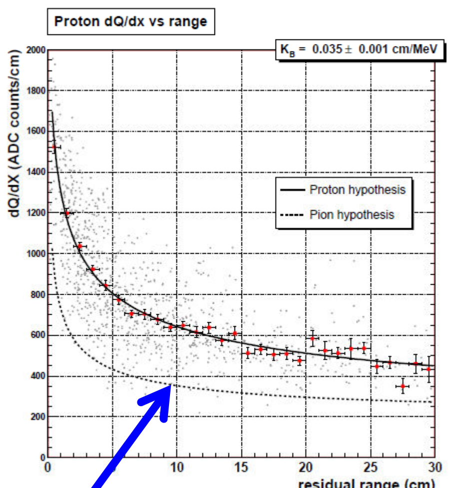
Observation of ν interactions in a LArTPC

ICARUS 50 lt @ CERN



$$\nu_\mu n \to \mu^- \Delta^+ \to \mu^- p \pi^0$$

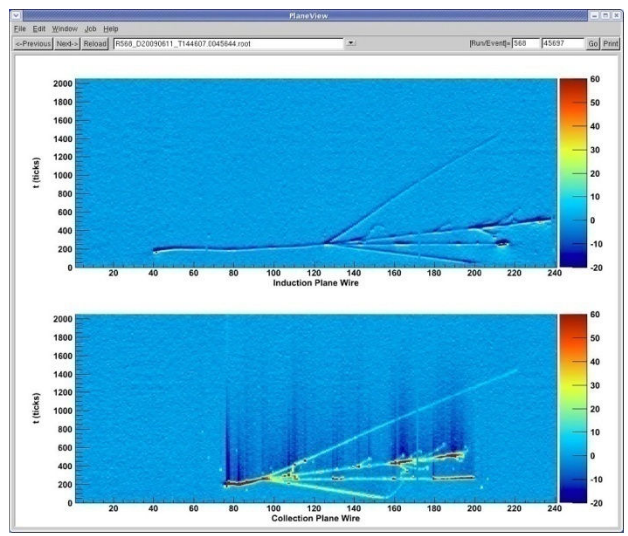




proton identification in ν interactions

ArgoNeut@ FNAL

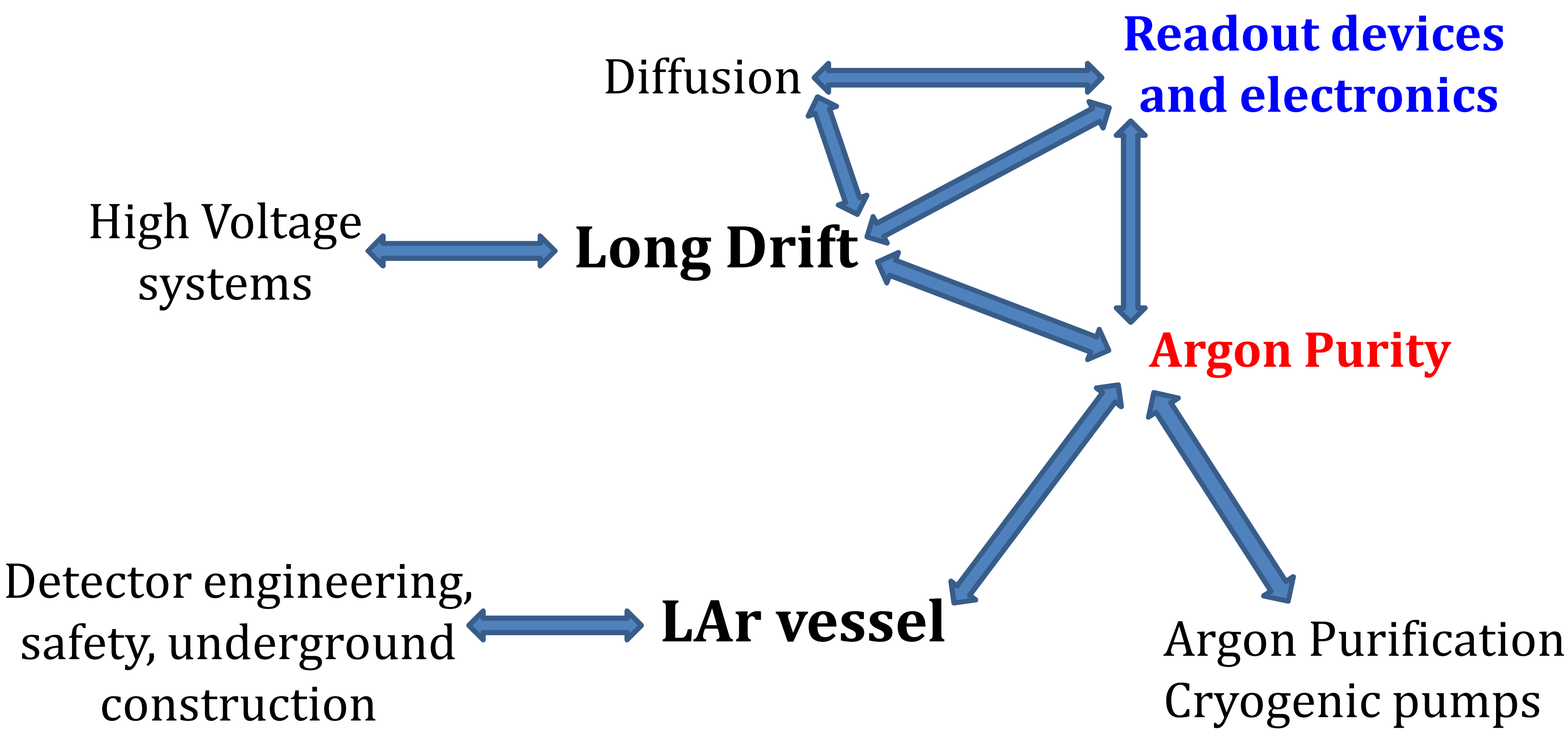
~175 lt on NuMI ν beam



250 lt @ KEK

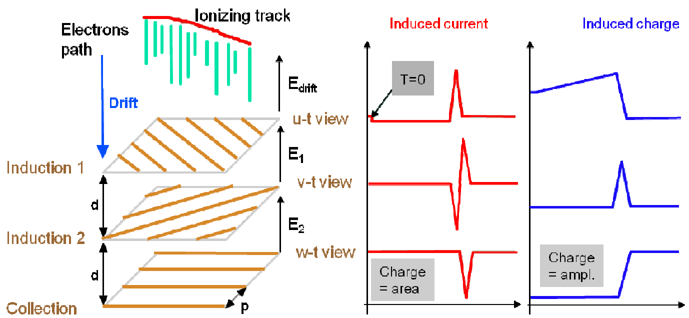
cosmic rays in 2010
ν beam @ J-PARC

Technical issues for large LAr TPCs



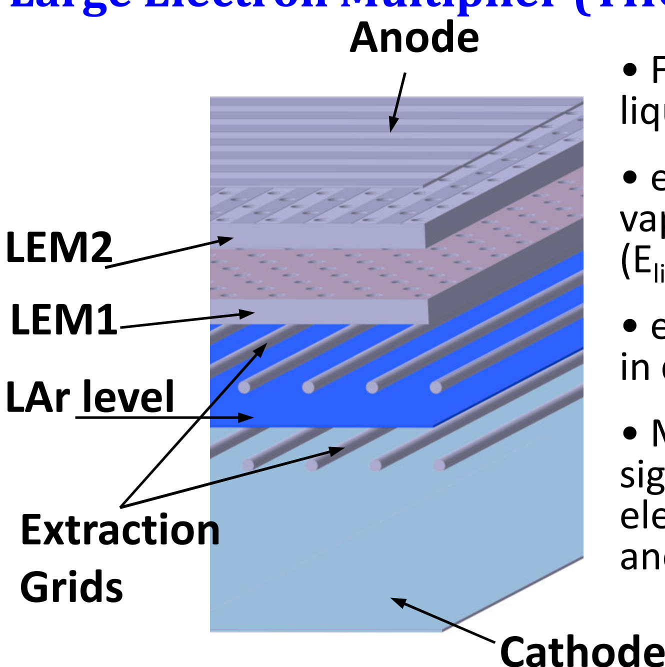
Ionization charge readout techniques in LAr

single LAr phase, wire planes



C. Rubbia, CERN Report 77-8, May 1977

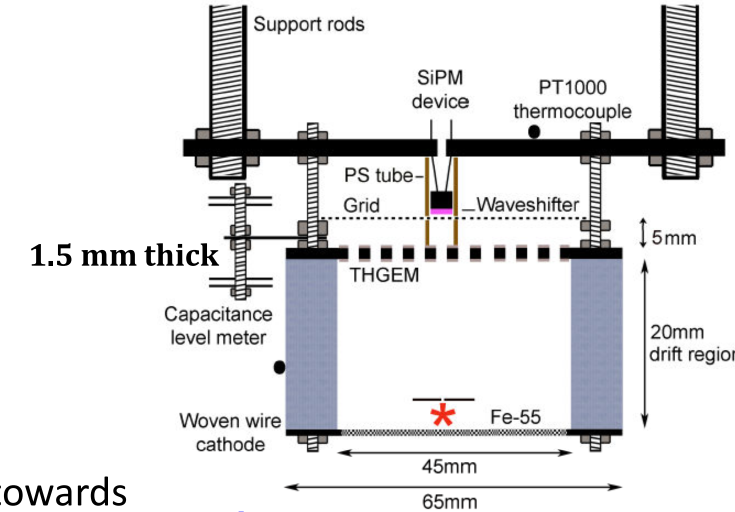
double phase Ar
Large Electron Multiplier (THGEM)



- Free e^- drift in LAr towards liquid-vapour interface.
- e^- are extracted to the vapour via extraction grids (E_{liq} > 2.5 kV/cm).
- e^- undergo multiplication in double stage LEM.
- Multiplied charge induces signals on the segmented electrodes of top LEM and anode.

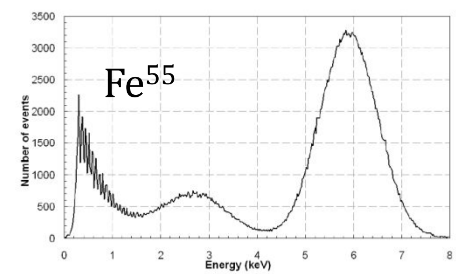
A. Badertscher et al., arXiv:0811.3384

secondary scintillation from THGEM



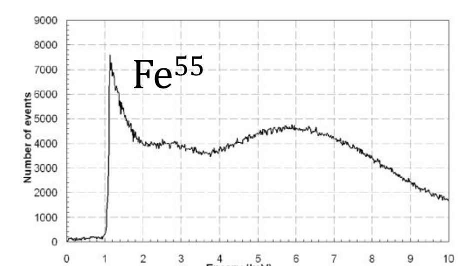
P.K. Lightfoot et al., JINST 4 (2009) P04002

double phase Ar



V_{THGEM}=2.2 kV

single phase LAr



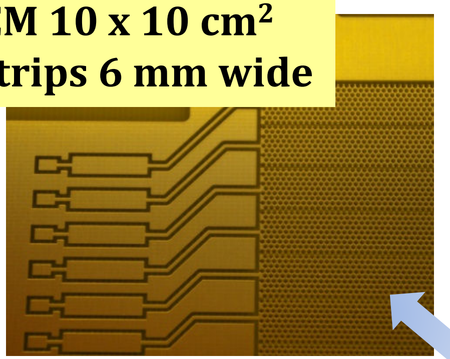
V_{THGEM}=10.2 kV

ETH Institute for Particle Physics

A Large Electron Multiplier LAr TPC

ETHZ

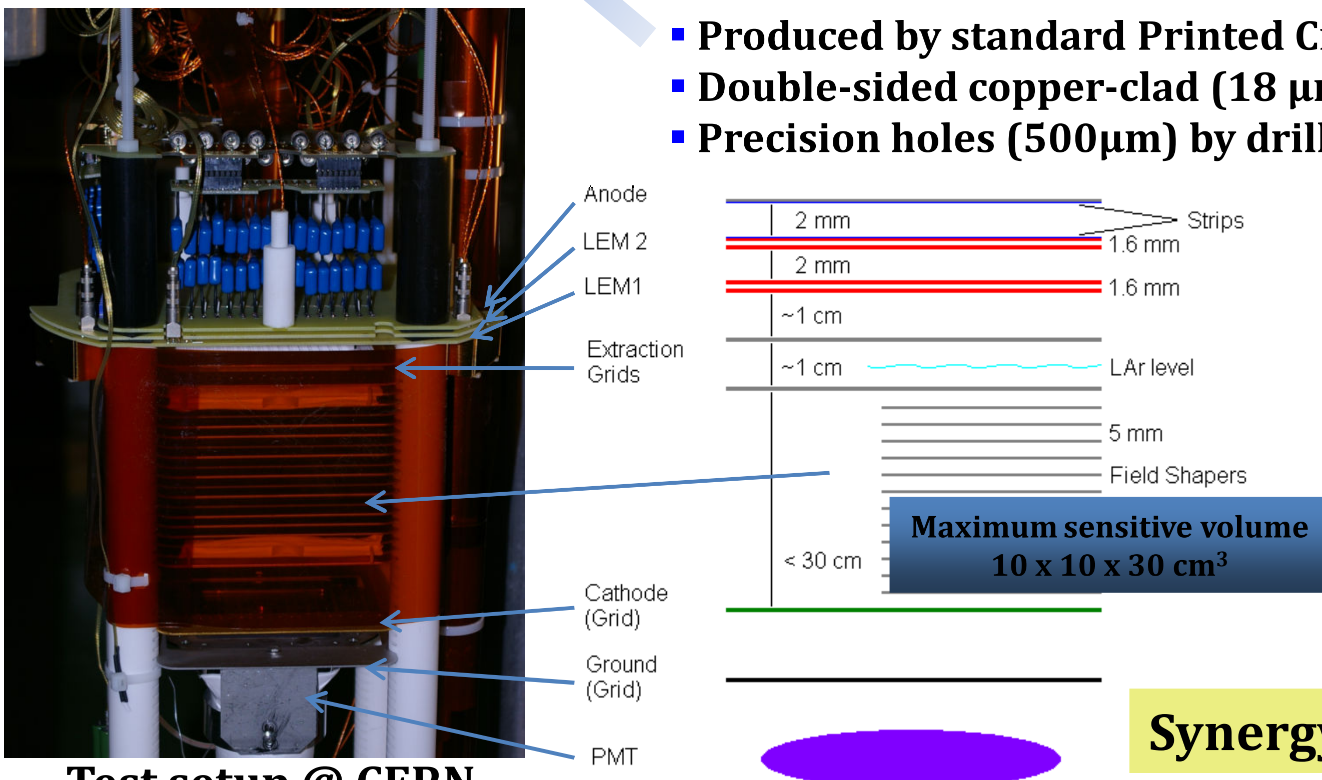
LEM 10 x 10 cm^2
16 strips 6 mm wide



A novel kind of LAr TPC based on

- operation in double phase Argon
- amplification in pure GAr by 1 or more stages of Large Electron Multipliers (LEM)
- extrapolated from GEM technology

- Produced by standard Printed Circuit Board methods
- Double-sided copper-clad (18 μm layer) FR4 plates
- Precision holes (500μm) by drilling



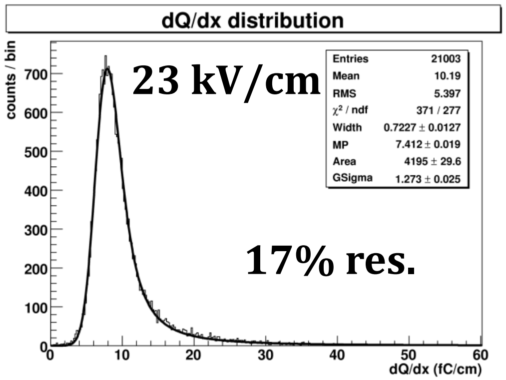
Test setup @ CERN

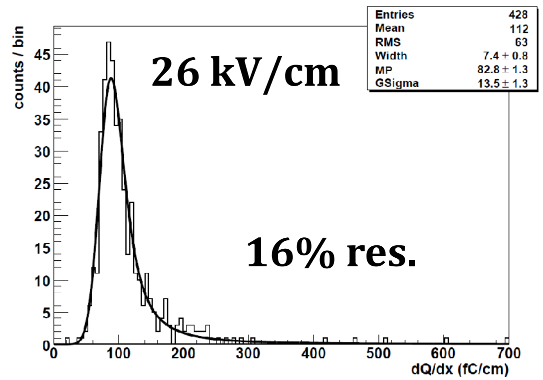
A. Badertscher et al., arXiv:0907.2944

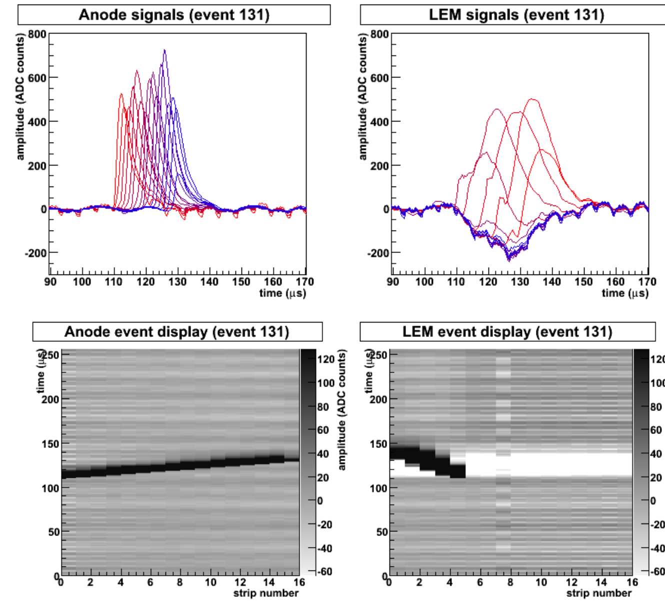
Synergy with RD51 @ CERN

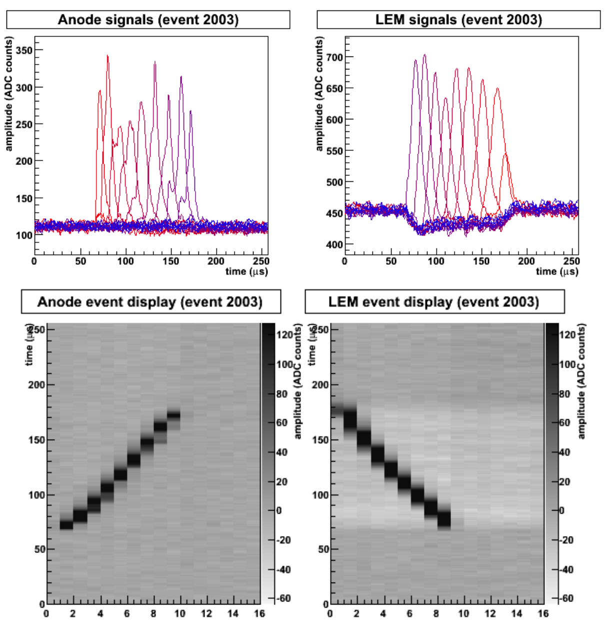
Performance of a double-phase LEM LAr TPC

Double stage 1.6 mm LEM

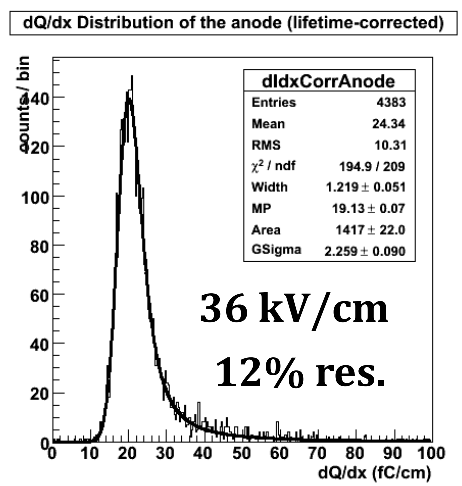


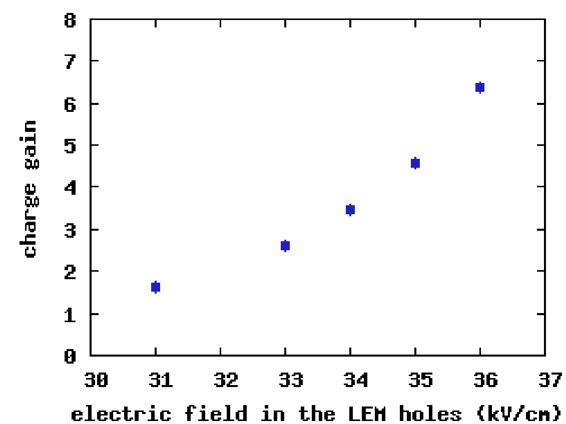






Single stage 1.0 mm LEM

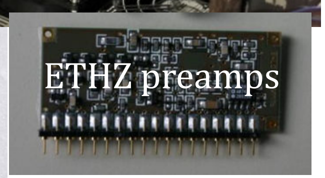




Development and R&D on readout electronics

❑ Development of LAr TPC electronics for small scale devices

- CAEN, in collaboration with ETHZ, developed A/D and DAQ system
- 12 bit 2.5 MS/s flash ADCs + FPGA

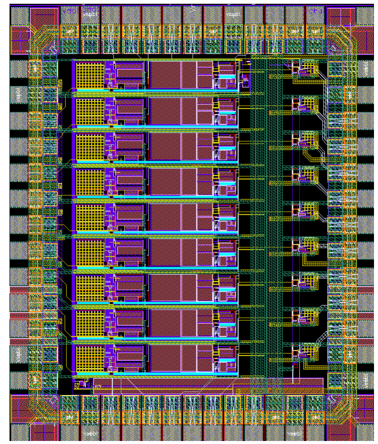


~11 mV/fC
S/N =10
@ 1 fC, C_i=200 pF

MIP ~10 fC/cm

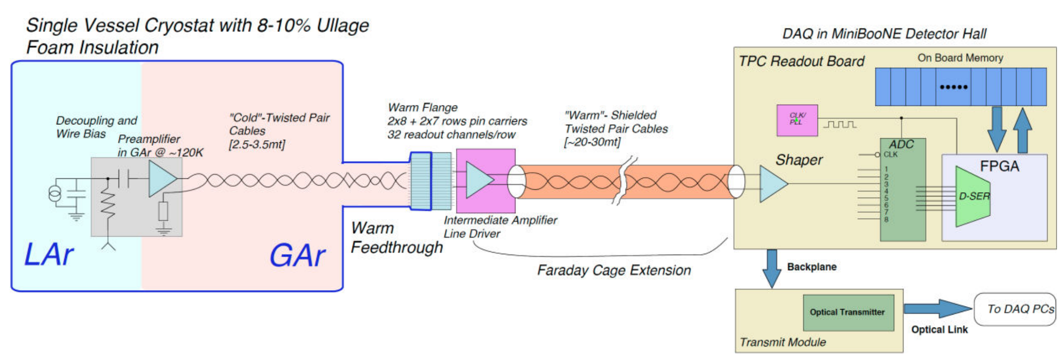
❑ R&D on electronics integrated on the detector

C. Girerd et al., poster at this workshop



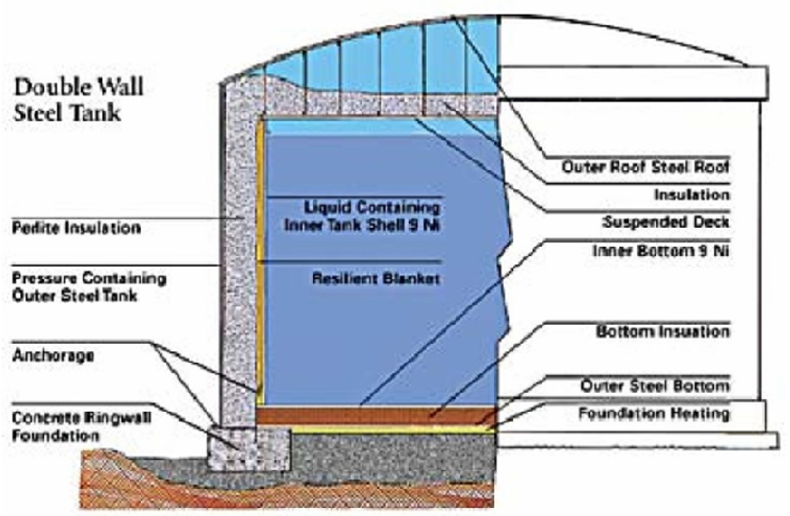
- IPNL Lyon - 0.35μm CMOS charge amplifier working at cryogenic temperature
- 1st version bench-tested in 2008
- new version with shaper optimization under development
- to be tested on a LEM TPC setup

MicroBoone electronics

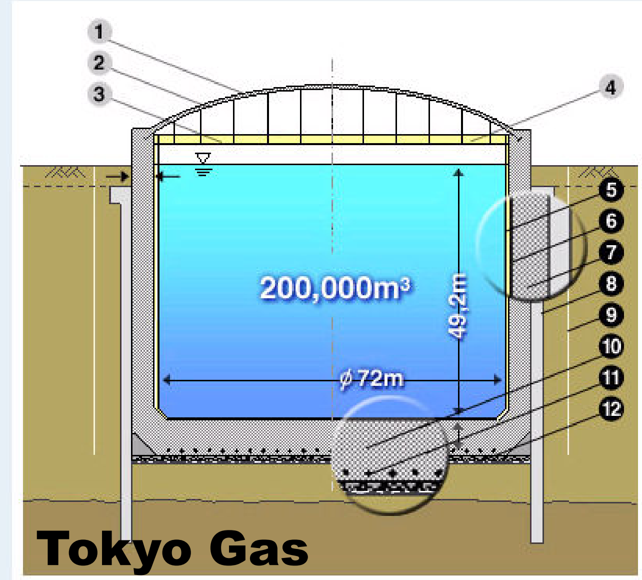


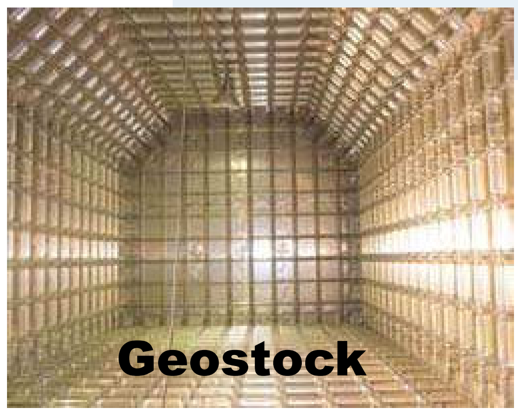
- 10^4 electronic channels : JFET in cold Gar
- V. Radeka group @ BNL working on 87K CMOS ASIC

LNG storage tanks



1. Reinforced concrete tank cover
2. Steel roof
3. Suspended deck
4. Glass wool insulation
5. Non-CFC rigid polyurethane form (PUF) insulation
6. 18Cr-8Ni stainless steel membrane
7. Reinforced concrete side wall
8. Reinforced concrete cut-off wall
9. Side heater
10. Reinforced concrete bottom slab
11. Bottom heater
12. Gravel layer





- Underground storage of LNG
- containment with a corrugated stainless steel / invar membrane

LAr vs LNG (≥ 95% Methane)

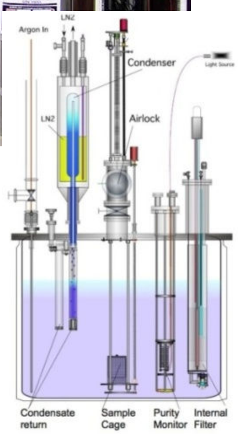
- Boiling points of LAr and CH_4 are 87.3 and 111.6 K
- Latent heat of vaporization per unit volume is the same for both liquids within 5%

Vessel volumes up to 200000 m^3

ETH Institute for Particle Physics

R&D on Argon Purity

Materials Test Stand @ FNAL



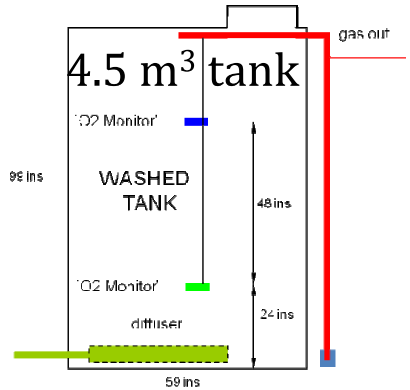
to qualify materials for use in a large LAr TPC

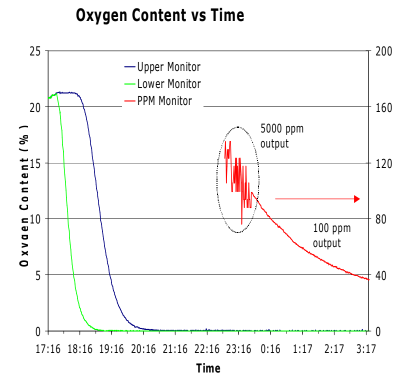
- no contamination in cold
- only contaminant is H_2O
- NIM A 608 (2009) 251

- achieved lifetimes > 10 ms with a non-proprietary regenerable filter
- NIM A 605 (2009) 306

Purification starting from air in the tank

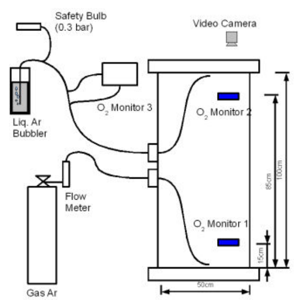
@ FNAL: warm Argon gas used as a piston

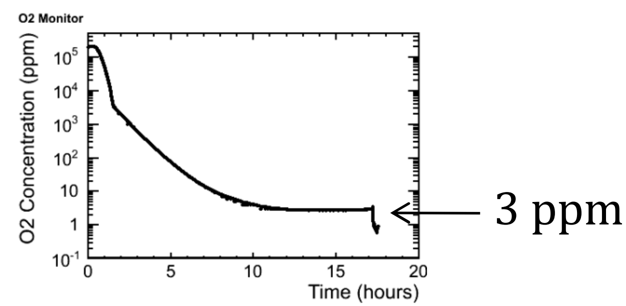




2.6 volume changes to reach 100 ppm O_2

@ KEK, Ar purging in 0.2 m³ tank



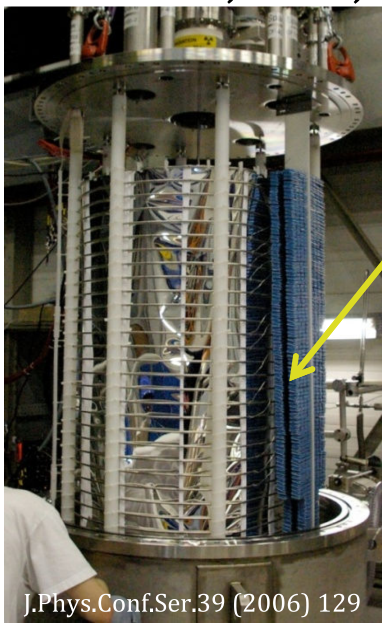


ETHZ@ CERN, starting Ar purging tests with a 6 m³ tank

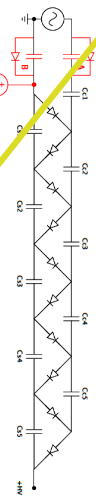
Synergy with Dark Matter experiments

ArDM (RE18): a ton-scale LAr detector with a 1 x 1 m^2 LEM readout

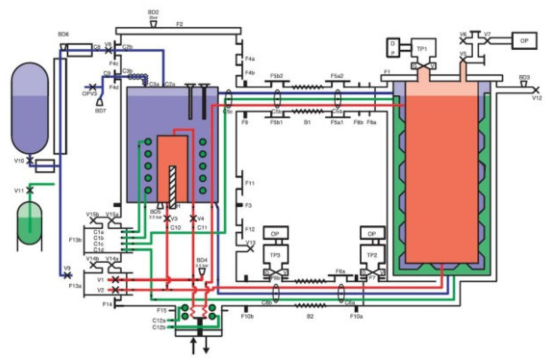
U. Zurich, ETHZ, CIEMAT, Sheffield, Soltan Inst.



J.Phys.Conf.Ser.39 (2006) 129



- Cockcroft-Walton voltage multiplier immersed in LAr
- 210 stages
- max. voltage/stage 2kV



- cryogenics
- purification system
- safety

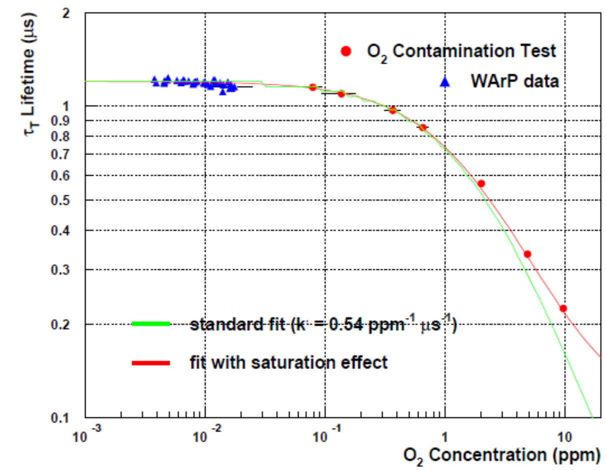
Light collection

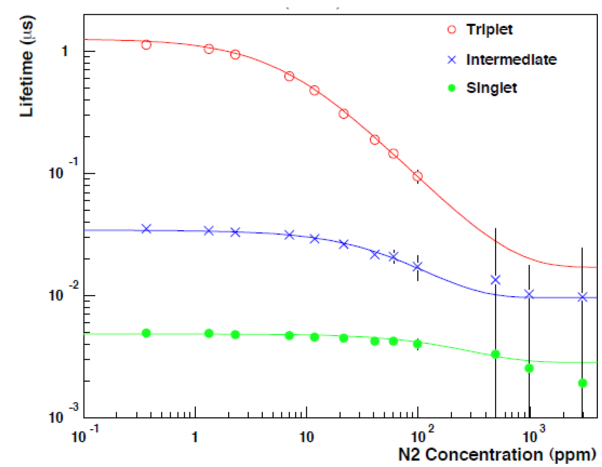
JINST 4 (2009) P06001

WLS-coated PMTs in LAr

WArP @ LNGS

Reduction of Ar scintillation as a function of Oxygen/Nitrogen contaminants



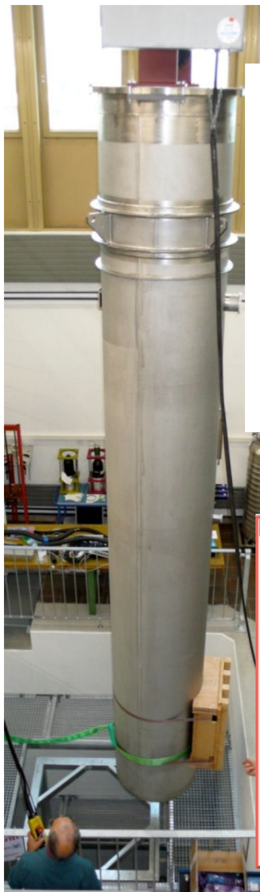


arXiv:0804.1222, arXiv:0804.1217

R&D on Long Drifts

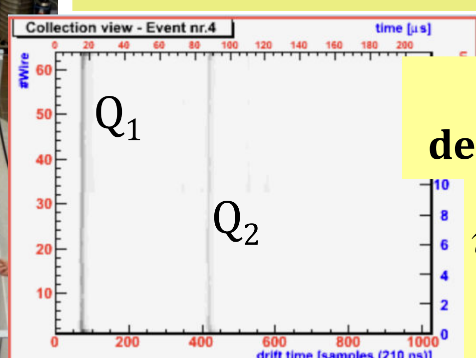
- Full scale measurement of long drift, signal attenuation, effect of charge diffusion
- High voltage test

ArgonTube @ Bern University



- 5 m drift
- Infrastructure ready
- External dewar delivered
- Detector vessel, inner detector in procurement phase

UV laser ionization in LAr

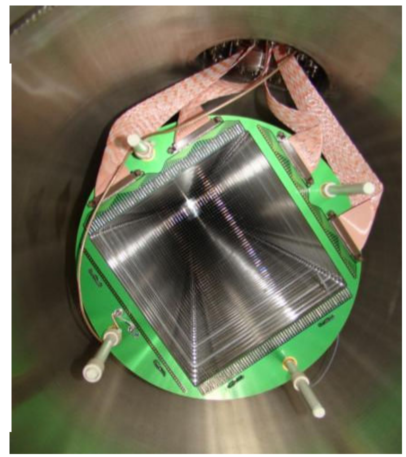


Lifetime determination

$$\tau = \frac{\Delta t}{\ln \frac{Q_1}{Q_2}}$$

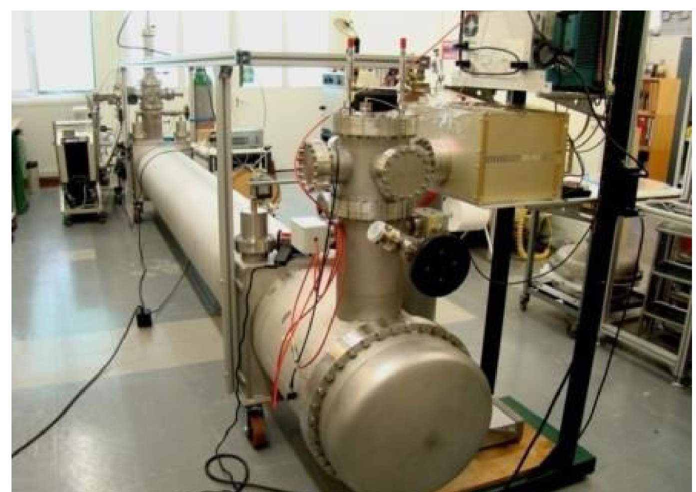
JINST 4 (2009) P07011

LANDD – 5 m drift test @ CERN

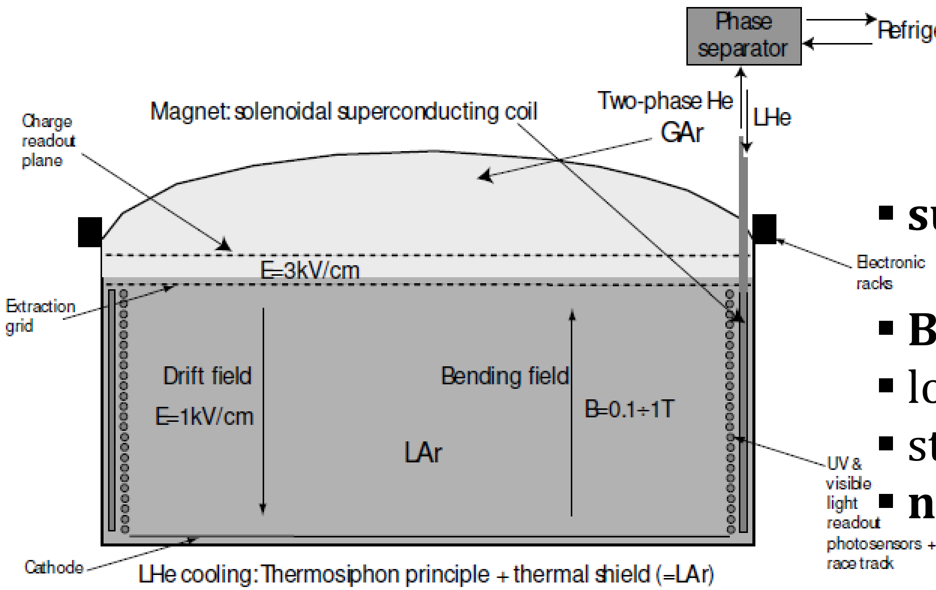


F. Sergiampietri, D.B. Cline

- detector fully assembled
- vacuum debugging
- readout electronics in preparation



R&D on a magnetized LAr



A. Ereditato, and A. Rubbia, Nucl Phys B (Proc Suppl) 155 (2006) 233

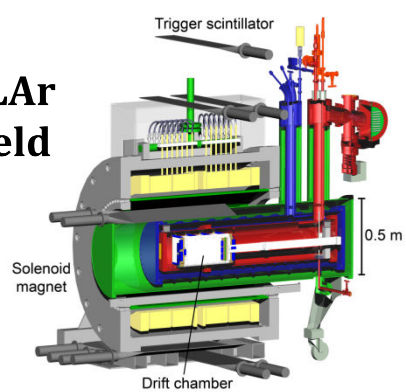
- **superconducting solenoid immersed in LAr**
  - **LHe or HTS superconductor?**
- **B** parallel to **E**
- low field (B=0.1 T) to measure μ charge
- strong field (B=1 T) to to measure 'e' charge
- **need to monitor market of HTS cables**

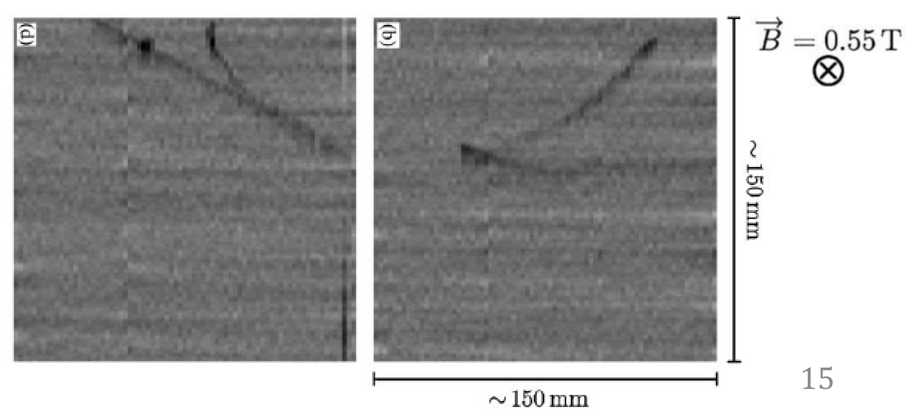
Comparison of superconducting solenoidal magnets. ATLAS column corresponds to the solenoid.

	10 kton LAr	100 kton LAr	ATLAS	CMS
Magnetic induction (T)	0.1/0.4/1.0	0.1/0.4/1.0	2.0	4.0
Solenoid diameter (m)	30	70	2.4	6
Solenoid length (m)	10	20	5.3	12.5
Magnetic volume (m^3)	7700	77000	21	400
Stored magnetic energy (GJ)	0.03/0.5/3	0.3/5/30	0.04	2.7
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

First operation of a LAr TPC in a magnetic field @ ETHZ

NIM A 555 (2005) 294



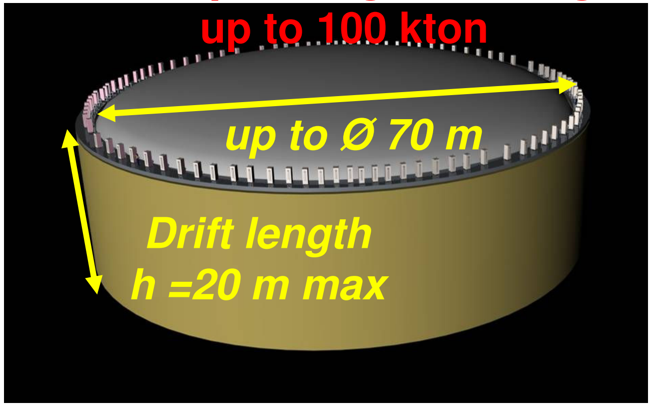


ETH Institute for Particle Physics

Main Design concepts I

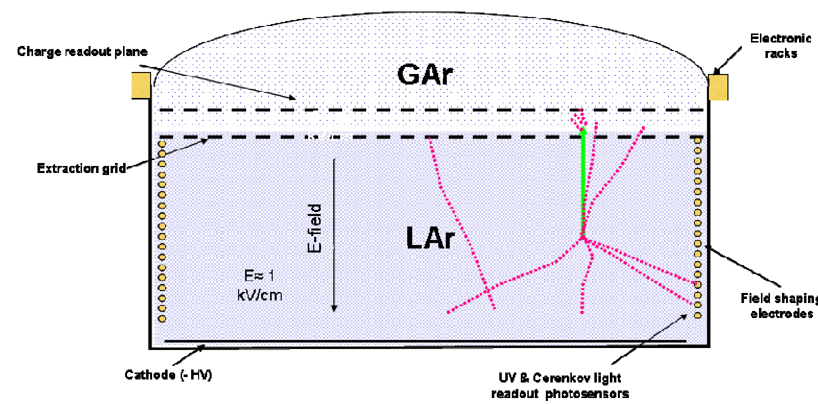
A. Rubbia hep-ph/0402110
Venice, Nov 2003

Giant Liquid Argon Charge Imaging ExpeRiment



- **Single module cryo-tank based on industrial LNG technology**
- **Scalable detector with similar aspect ratio to standard LNG tanks**
- 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 light readout for Cerenkov imaging
- Possibly immersed (high Tc) superconducting solenoid to obtain magnetized detector
- Reasonable excavation requirements (<250000 m^3)

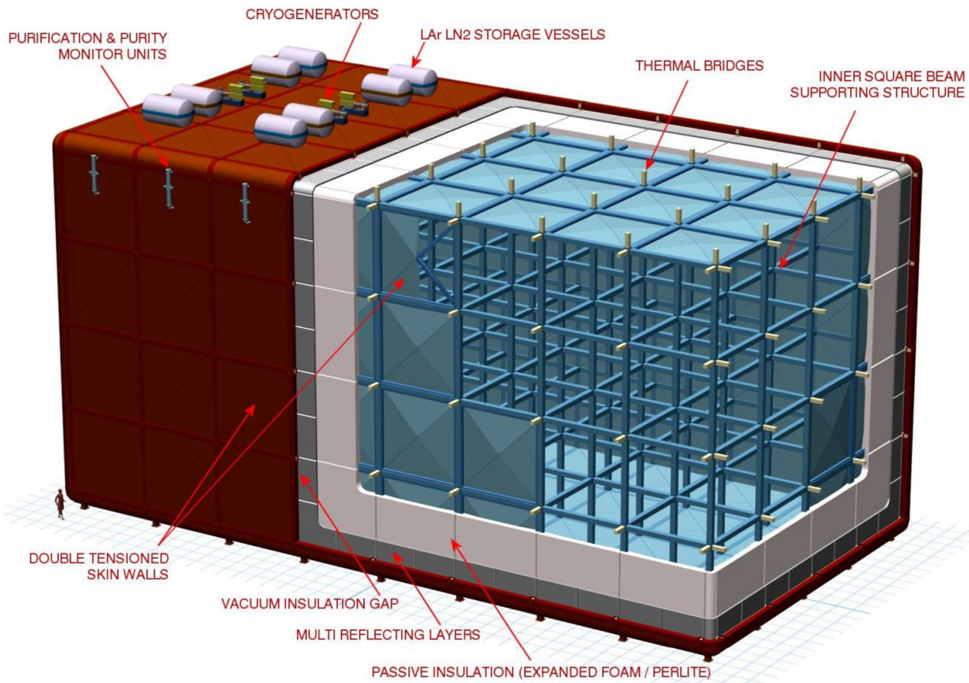
- **Passive insulation heat loss ≈ 80kW@LAr**
- **LEM+anode readout with 3mm readout pitch, modular readout, strip length modulable, 2.5×10^6 channels**
- **Purity < 0.1 ppb (O2 equiv.) in nonevacuable vessel**
- **Immersed HV Cockcroft-Walton for drift field (1 kV/cm)**
- **Readout electronics (digital F/E with CAEN; cold preamp R&D ongoing; network data flow & time stamp distrib.)**
- **WLS-coated 1000x 8" PMT and reflectors for DUV light detection**



European underground sites and tank issues under study in LAGUNA (FP7)
Report in Summer 2010

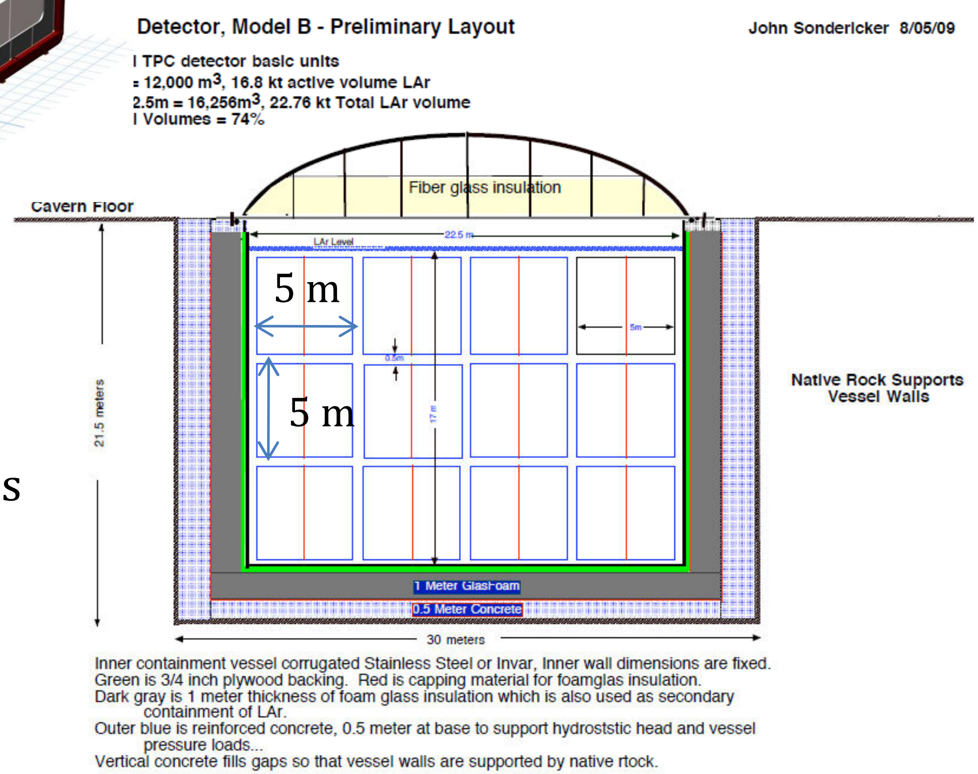
Main design concepts II

LAr at DUSEL



- LANDD Concept
- Double wall cryostat, vacuum insulated, internally supported
- Evacuation possible

D.B. Cline, F. Raffaelli, F. Sergiampietri
JINST 1 T09001 2006



- Inner containment vessel: corrugated stainless steel or Invar
- Externally supported by cavern walls
- Not evacuable
- ~20 kton LAr module
- Max drift length 2.5 m
- Readout with wire planes

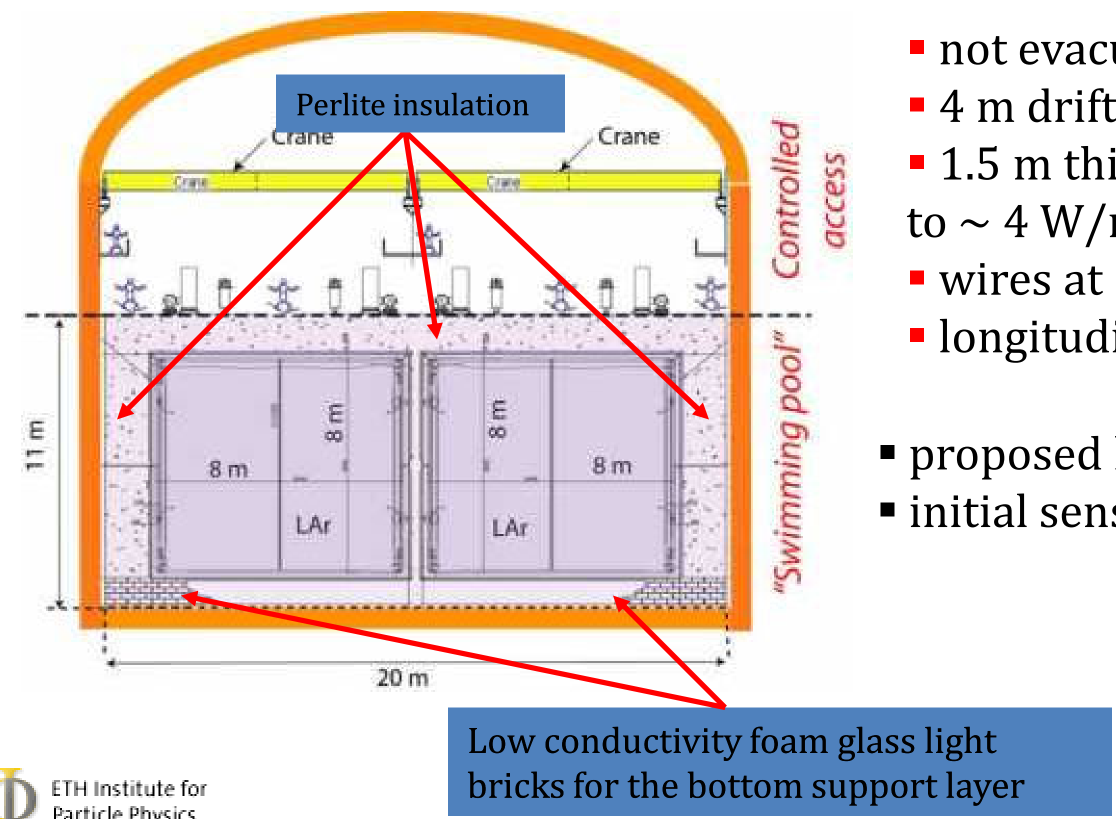
Main design concept III

MODULAR

B. Baibussinov et al., Astr. Phys. 29 (2008) 174
D. Angeli et al., JINST 4 (2009) P02003

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 **~60 meters.**

10 kton

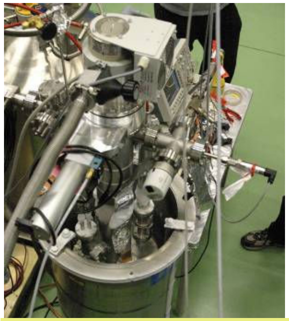


- not evacuable
- 4 m drift length
- 1.5 m thickness of perlite, corresponding to ~ 4 W/m² thermal loss
- wires at 0°, ±60°, with ~6 mm pitch
- longitudinal wires ~30 m long

- proposed location: 10 km off-axis from LNGS
- initial sensitive volume of at least 20 kton

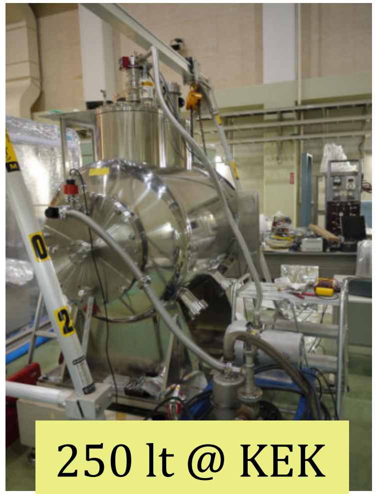
ETH Institute for Particle Physics

GLACIER Roadmap



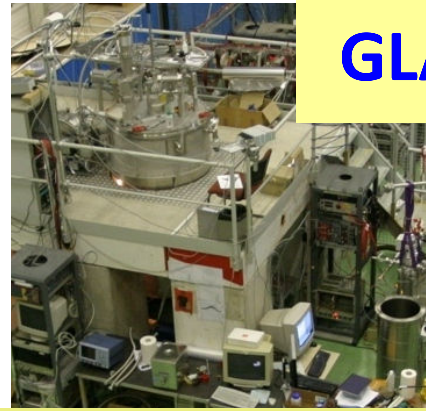
3 lt @ CERN,
10 lt @ KEK

small test setups for readout devices, electronics



250 lt @ KEK

detector construction 2009
e/γ test beam
ν beam @ JPARC

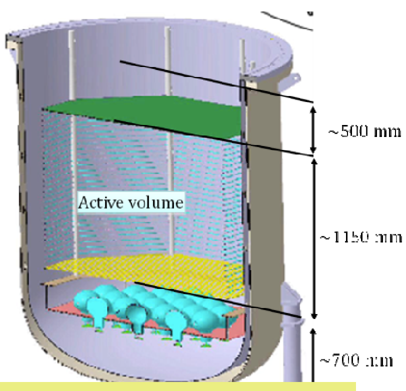


ArDM (RE18) @ CERN

1 ton LAr, Cockroft-Walton, LAr recirculation and purification, industrial electronics, safety, optimized for dark matter searches, in operation

ArgonTube@ Bern

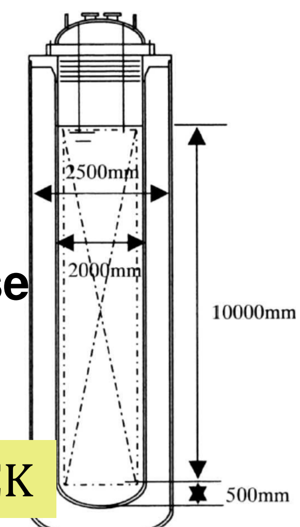
5 m drift under procurement



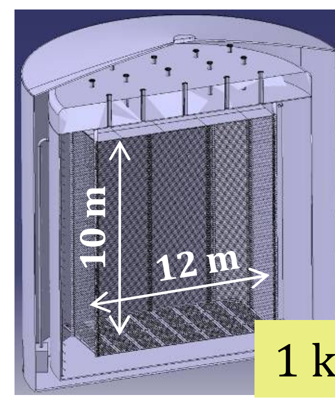
6 m^3 @ CERN (?)

to be proposed in 2010 for test beams in NA

10 m long drift test in design phase



30 m^3 @ KEK



1 kton

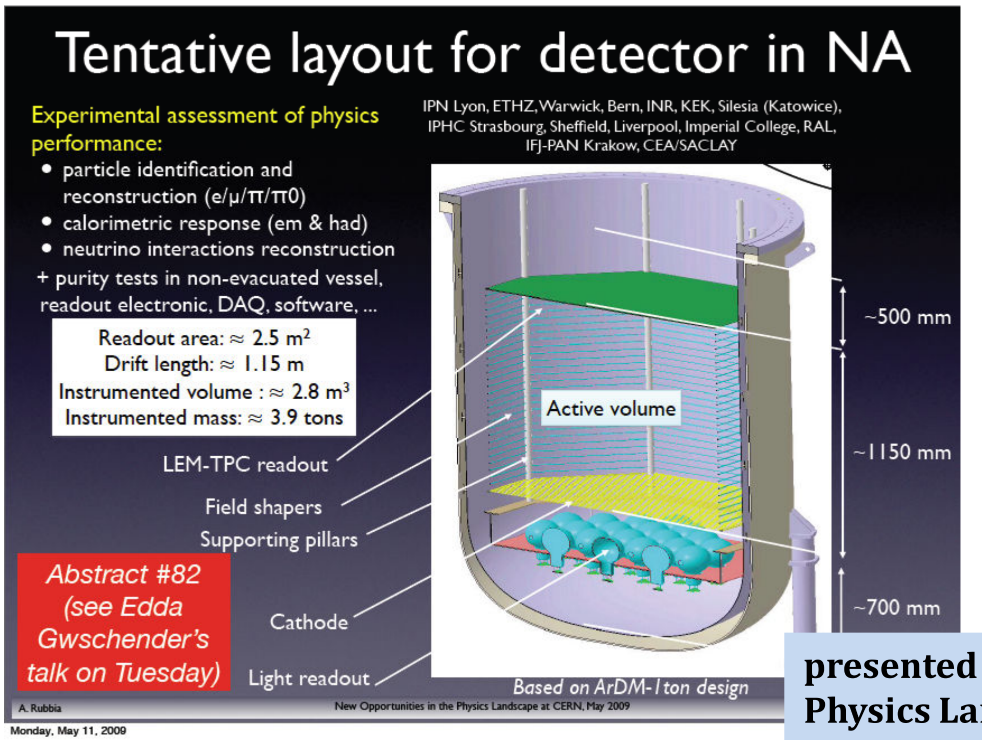
full engineering demonstrator for larger detectors + physics construction 2012-2016

Test beam exposure of a Liquid Argon TPC Detector at the CERN SPS North Area

Abstract #82

D.Autiero[a], A. Badertscher[b], G. Barker[c], Y. Declais[a], A. Ereditato[d], S.Gninenko[e], T. Hasegawa[f], S. Horikawa[b], J. Kisiel[g], T. Kobayashi[f], A.Marchionni[b], T. Maruyama[f], V. Matveev[e], A. Meregaglia[h], J.Marteau[a], K. Nishikawa[f], A. Rubbia[b], N. Spooner[i], M. Tanaka[f], C.Touramanis[j], D. Wark[k,l], A. Zalewska[m], M. Zito[n]

(a) IPN Lyon (b) ETH Zurich (c) University of Warwick (d) Bern University (e) INR, Moscow (f) KEK/IPNS (g) University of Silesia (Katowice) (h) IPHC Strasbourg (i) University of Sheffield (j) University of Liverpool (k) Imperial College (l) RAL (m) IFJ-PAN, Krakow (n) CEA/SACLAY



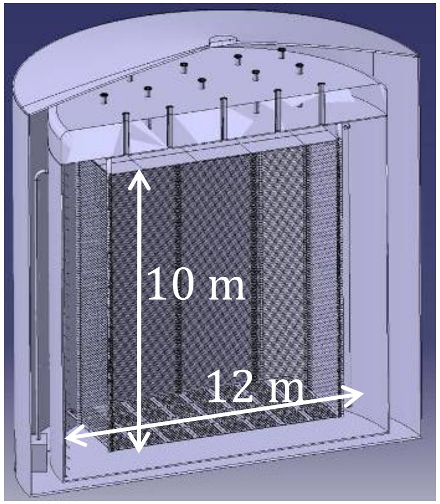
- **Electron, neutral pion, charged pion, muon reconstruction**
- **Electron/π^0 separation**
- **Calorimetry**
- **Hadronic secondary interactions**
- **[+ purity tests in non-evacuated vessel, cold readout electronics, DAQ development, ...]**

to be proposed in 2010

presented by A. Rubbia at New Opportunities in the Physics Landscape at CERN, May 2009

Why a 1 kton intermediate step?

A 1 kton-scale device is the appropriate choice for a full engineering prototype of a 100 kton detector



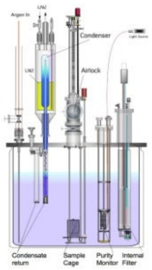
- the largest possible detector as to minimize the extrapolation to 100 kton
- the smallest detector to minimize construction timescale and costs
- all **tank** and **LAr purification** issues addressed
- only a **factor 2** extrapolation in **drift length**
- volume scaling by increasing the diameter not critical
- if built underground would address installation/safety issues

If fully instrumented plenty of physics output

- at a near location on a neutrino beam: precision cross section measurements (M_A,…), e/π^0 separation
- as a near detector of a long baseline neutrino oscillation experiment
- in an underground location study of backgrounds for proton decay/astrophysical neutrinos

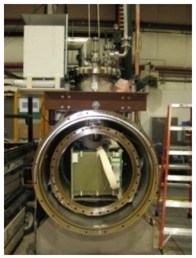
A. Rubbia, J.Phys.Conf.Ser.171:012020,2009

LAr ν Roadmap



Materials Test Stand, Cosmic Ray Test Stand

R&D — Purity, electronics development



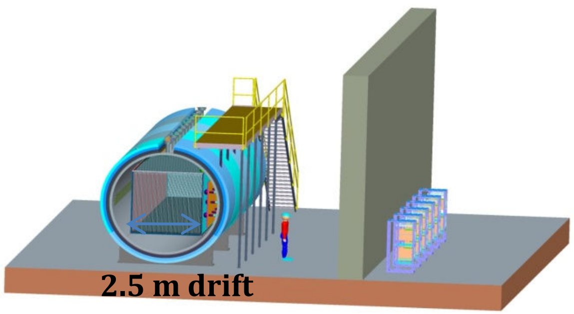
ArgoNeut (0.2t)

R&D | Physics — Underground safety, TPC operation, reconstruction

Liquid Argon Purity Demonstration

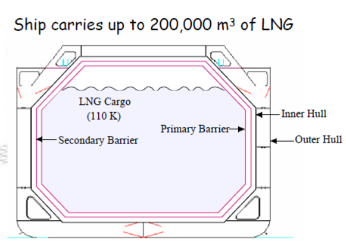
R&D — Large tank purity, insulation

20 ton LAr
no TPC



MicroBooNE (70t fiducial)

R&D | Physics — 120°K electronics, large tank purity, insulation



LAr at DUSEL (16.7kt + 2 x 16.7kt fiducial)

Physics

Conclusions

- **The synergy between precise detectors for long neutrino baseline experiments, proton decay and astrophysical neutrinos detectors is essential for a realistic proposal of a 100 kton LAr detector**
  - **discovery physics, not only precision measurements**
  - **this detector could use a new neutrino beam from CERN (large choice of underground facilities at different baselines, being studied by LAGUNA)**
- **Concrete R&D for a ~100 kton LAr detector is ongoing**
- **Many R&D initiatives on LAr throughout the world, following somewhat different concepts for the final detector design, but with many common basic R&D issues**
- **R&D on LAr pioneered at CERN (ICARUS)**
- **Nowadays LAr R&D well alive at CERN: ArDM (RE18), 5m drift and more initiatives in preparation envisioning the use of test beams**
- **Synergy with other activities present at CERN (RD51, cryogenic, electronic and technical expertise at CERN,…)**
- **Within the GLACIER program, the aim is to propose a 1 kton detector within 2012**

ETH Institute for Particle Physics

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