Detectors for superbeam beta beam experiments and neutrino astrophysics

André Rubbia (ETH-Zürich)

Neutrino Horizons in the 21st Century
Cosener's House (UK)
April 18th, 2008

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Detectors for superbeam (beta beam) experiments and neutrino astrophysics, and proton decay searches

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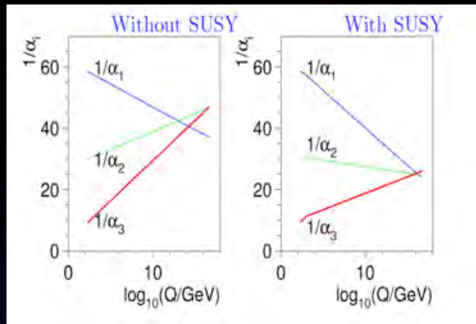
Broad and rich physics programme

- Direct evidence for Grand Unification (Proton decay)
- Low energy neutrino astronomy (SN, solar, geo, atm)
- Long baseline neutrino beam (CP̸)

Combine accelerator & non-accelerator physics
Probably the only viable strategy

Fundamental questions

(1) Grand Unification - proton decay



•In 4D SUSY SU(5), SO(10) dimension 6 operators "Msusy independent" depend essentially on unification mass

generically predict $\tau_p = 10^{34}\text{-}10^{36}$y

•In 4D SUSY SU(5), SO(10) dimension 5 operators depend on sparticle spectrum (Msusy), family structure, triplet higgs mass

generically predict $\tau_p = 3\times10^{33}\text{-}\ 3\times10^{34}$y

(3) Long baseline neutrino oscillations

θ_{13}, δ, sgn(ΔM^2)

$\nu_\mu \rightarrow \nu_e$

High intensity low energy conventional neutrino sources

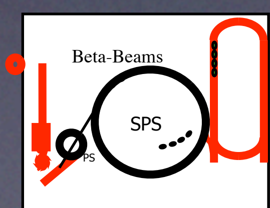
"superbeams" ?
MW power >2016

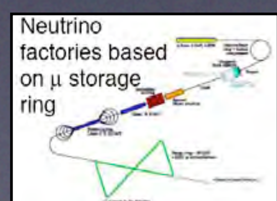
2/4 GeV p ? 50 GeV p ?
400 GeV ?

$\nu_e \rightarrow \nu_\mu$

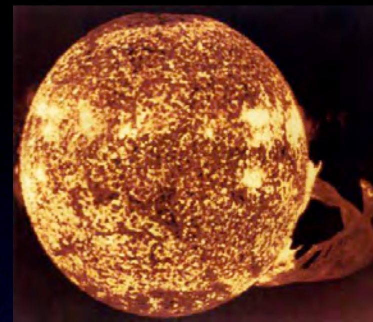
New neutrino production technology

>2020 ?

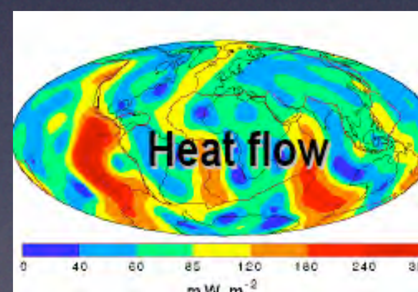




(2) MeV-GeV neutrino "astronomy"



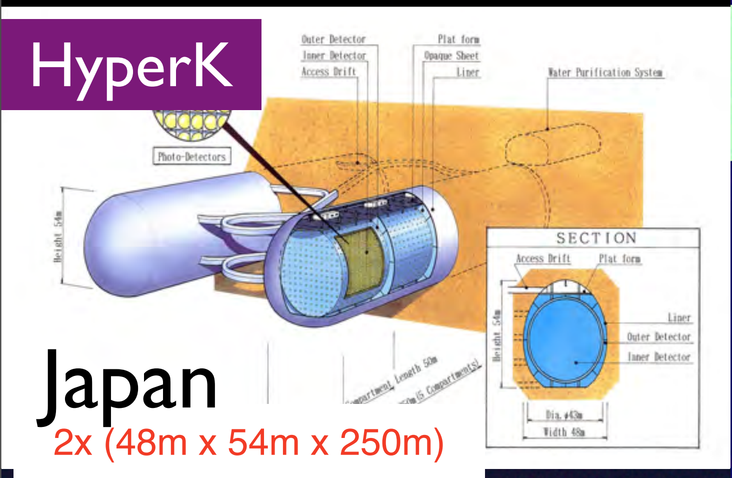
- Astrophysical origin:
  - ★ Sun's interior (day&night)
  - ★ Supernova core collapse
  - ★ Diffuse supernova relic neutrinos
  - ★ Dark Matter annihilation
- Terrestrial origin:
  - ★ Atmospheric neutrinos
  - ★ Geo-neutrinos (Earth natural radioactivity)
  - ★ Nuclear reactor cores

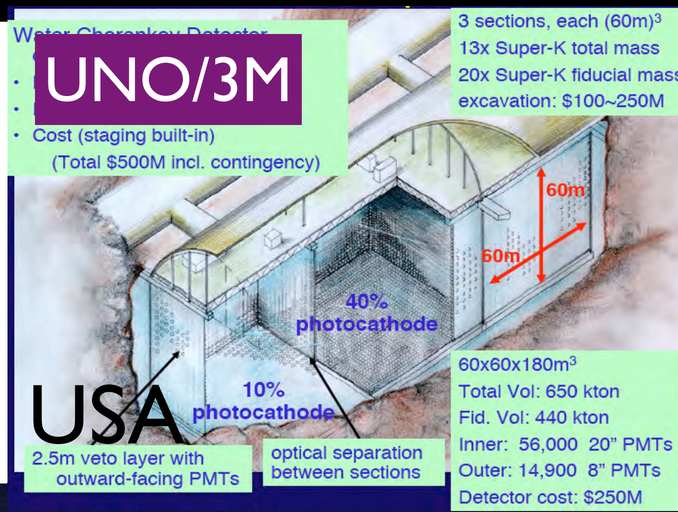


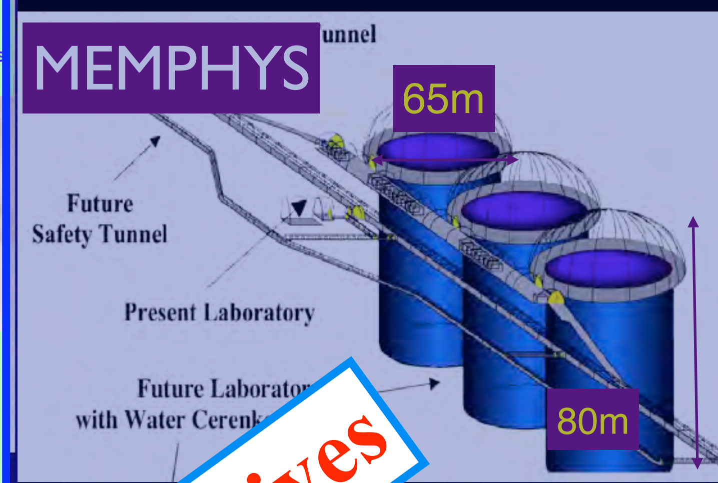
Some detectors presented at NNN Workshops

Stony Brook 1999, ..., Aussois 05, Seattle 06, Hamamatsu Oct 07, Paris 08

Water Čerenkov 500kt→1Mt

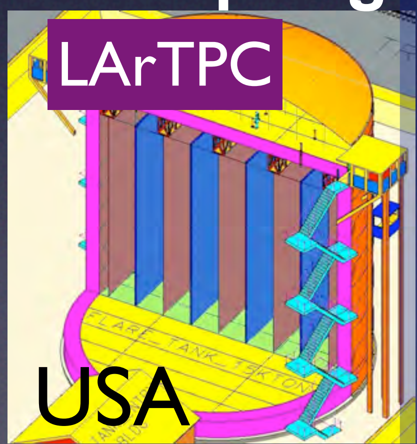


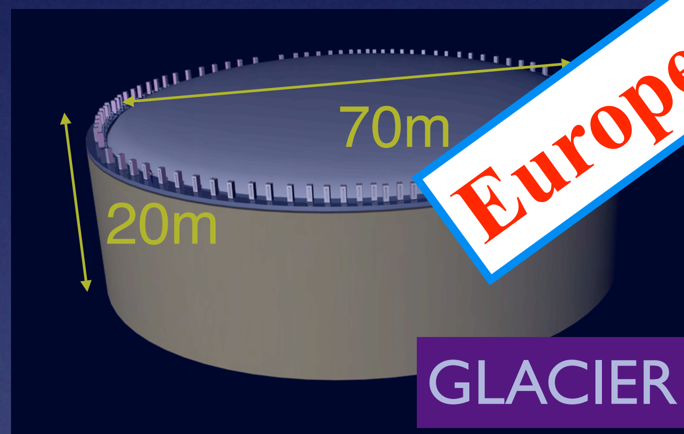


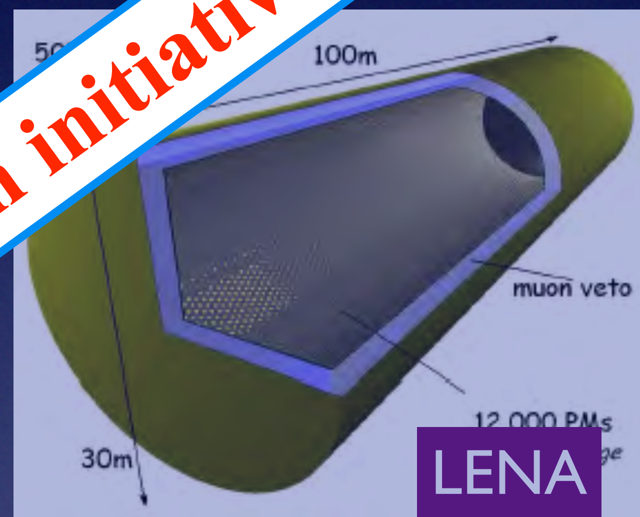


European initiatives

Liq. Argon→100kt







Liq. Scintillator→50kt

Large Apparatus for Grand Unification and Neutrino Astrophysics : LAGUNA

Astroparticle Physics Coordination in Europe (ApPEC)

Roadmap, January 2007

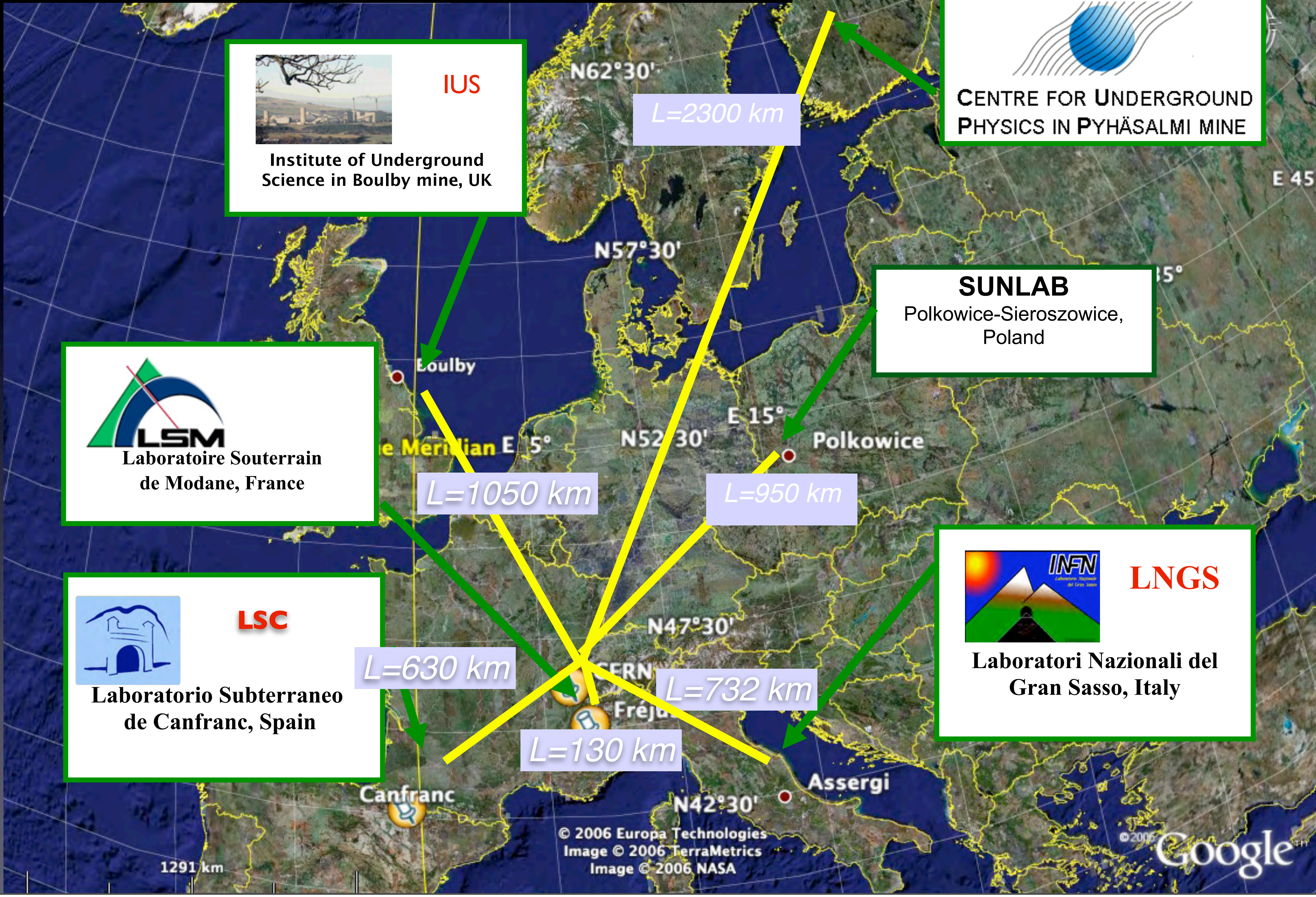
Proton decay and low energy neutrino astrophysics

Field/ Experiments	Cost scale (M€)	Desirable start of construction	Remarks
Dark Matter Search: Low background experiments with 1-ton mass	60-100 M€	2011-2013	2 experiments (different nuclei, different techniques), e.g. 1 bolometric, 1 noble liquid; more than 2 worldwide.
Proton decay and low energy neutrino astronomy: Large infrastructure for p-decay and ν astronomy on the 100kt-1Mton scale	400-800 M€	2011-2013	- multi-purpose - 3 different techniques; large synergy between them. - needs huge new excavation - expenditures likely also after 2015 - worldwide sharing - possibly also accelerator neutrinos in long baseline experiments
The high energy universe: *Gamma rays:* Cherenkov Telescope Array CTA *Charged Cosmic Rays:* Auger North *Neutrinos:* KM3NeT	100 M€ (South) 50 M€ (North) 85 M€ 300 M€	first site in 2010	Physics potential well defined by rich physics from
Gravitational Waves: Third generation interferometer	250-300 M€	Civil engineering 2012	Conceived as underground

Next ASPERA Roadmap Workshop : September 29th&30th 2008 Brussels

Submission to ESFRI ?

LAGUNA: Design of a Pan-European Infrastructure for Large Apparatus studying Grand Unification and Neutrino Astrophysics
Approved as FP7 Research Infrastructures Design Study
EC FUNDING 1.7 M€



List of Beneficiaries

Beneficiary no.	Beneficiary name	Beneficiary short name	Country	Date enter project	Date exit project
1. (coordinator)	Swiss Federal Institute of Technology Zurich	**ETH Zurich**	Switzerland	1	24
2.	University of Bern	**U-Bern**	Switzerland	1	24
3.	University of Jyväskylä	**U-Jyväskylä**	Finland	1	24
4.	University of Oulu	**U-Oulu**	Finland	1	24
5.	Kalliosuunnittelu Oy Rockplan Ltd	**Rockplan**	Finland	1	24
6.	Commissariat à l'Energie Atomique / Direction des Sciences de la Matière	**CEA**	France	1	24
7.	Institut National de Physique Nucléaire et de Physique des Particules (CNRS/IN2P3)	**IN2P3**	France	1	24
8.	Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V.	**MPG**	Germany	1	24
9.	Technische Universität München	**TUM**	Germany	1	24
10.	H.Niewodniczanski Institute of Nuclear Physics of the Polish Academy of Sciences, Krakow	**IFJ PAN**	Poland	1	24
11.	KGHM CUPRUM Ltd Research and Development Centre	**KGHM CUPRUM**	Poland	1	24
12.	Mineral and Energy Economy Research Institute of the Polish Academy of Sciences	**IGSMiE PAN**	Poland	1	24
13.	Laboratorio Subterraneo de Canfranc	**LSC**	Spain	1	24
14.	Universidad Autonoma, Madrid	**UAM**	Spain	1	24
15.	University of Granada	**UGR**	Spain	1	24
16.	University of Durham	**UDUR**	United Kingdom	1	24
17.	The University of Sheffield	**U-Sheffield**	United Kingdom	1	24
18.	Technodyne International Ltd	**Technodyne**	United Kingdom	1	24
19.	University of Aarhus	**U-Aarhus**	Denmark	1	24
20.	AGT Ingegneria Srl, Perugia	**AGT**	Italy	1	24
21.	Institute of Physics and Nuclear Engineering, Bucharest	**IFIN-HH**	Romania	1	24
22.	Lombardi Engineering Limited	**Lombardi**	Switzerland	1	24

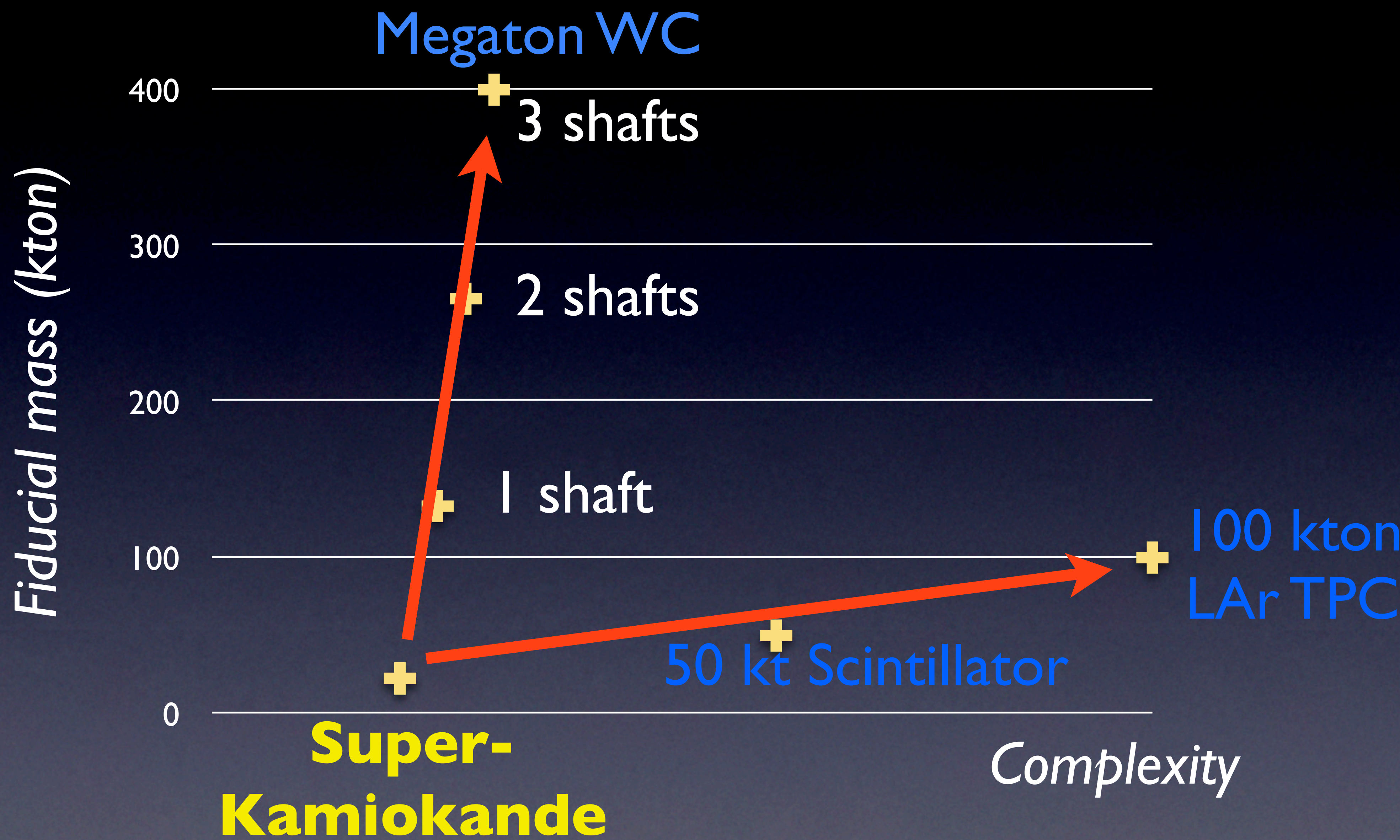
LAGUNA beneficiaries

The main “deliverable” of LAGUNA

- The LAGUNA DS will lead to a “conceptual design report” for a new infrastructure, to allow policy makers and their advisors to prepare the relevant strategic decisions for the development of a new research infrastructure in Europe.

- The deliverables contain the elaboration of “decision factors” like
  (i) technical feasibility (cavern, access, safety, liquid procurement, ...)
  (ii) cost optimization of infrastructure (digging, safety, ...)
  (iii) physics performance (e.g. depth, baseline, ...)
  (iv) ...

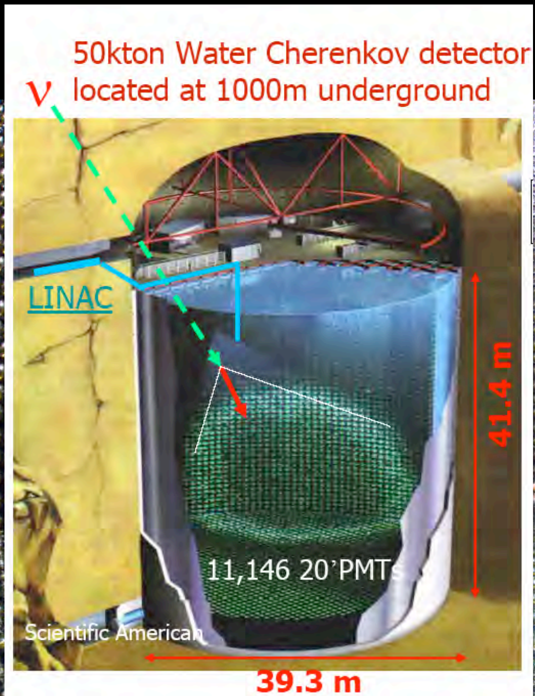
Next generation detectors

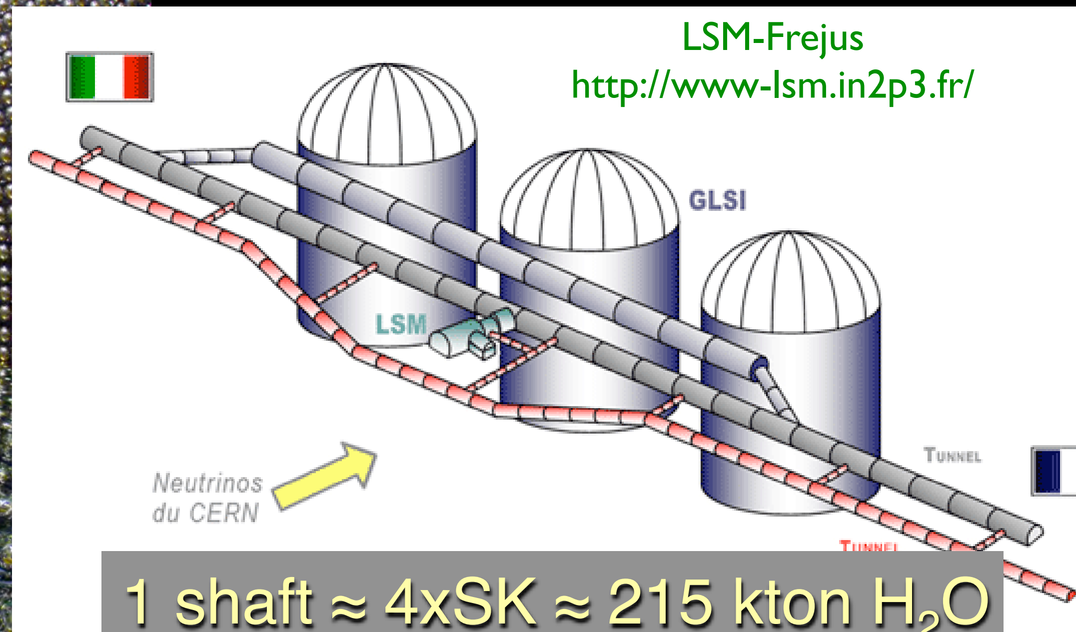


Size of unit (=shaft) typically limited by size of underground cavity

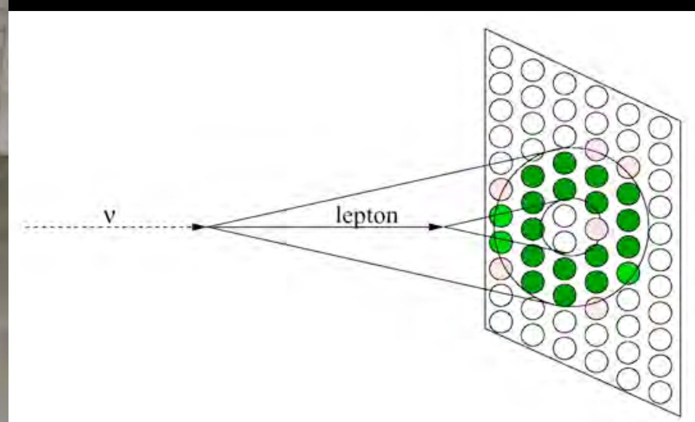
Megaton Water Cerenkov detectors

Up to 400 kton fiducial mass





1 shaft ≈ 4xSK ≈ 215 kton H_2O



MEMPHYS

About 170 γ/cm in 350 < λ < 500 nm
With 40% PMT coverage, Q.E.≈20%
Relativistic particle produces
⇒≈14 photoelectrons / cm
⇒≈7 p.e. per MeV

R&D for Water Cherenkov

from T.Abe (Univ. of Tokyo) at NP08

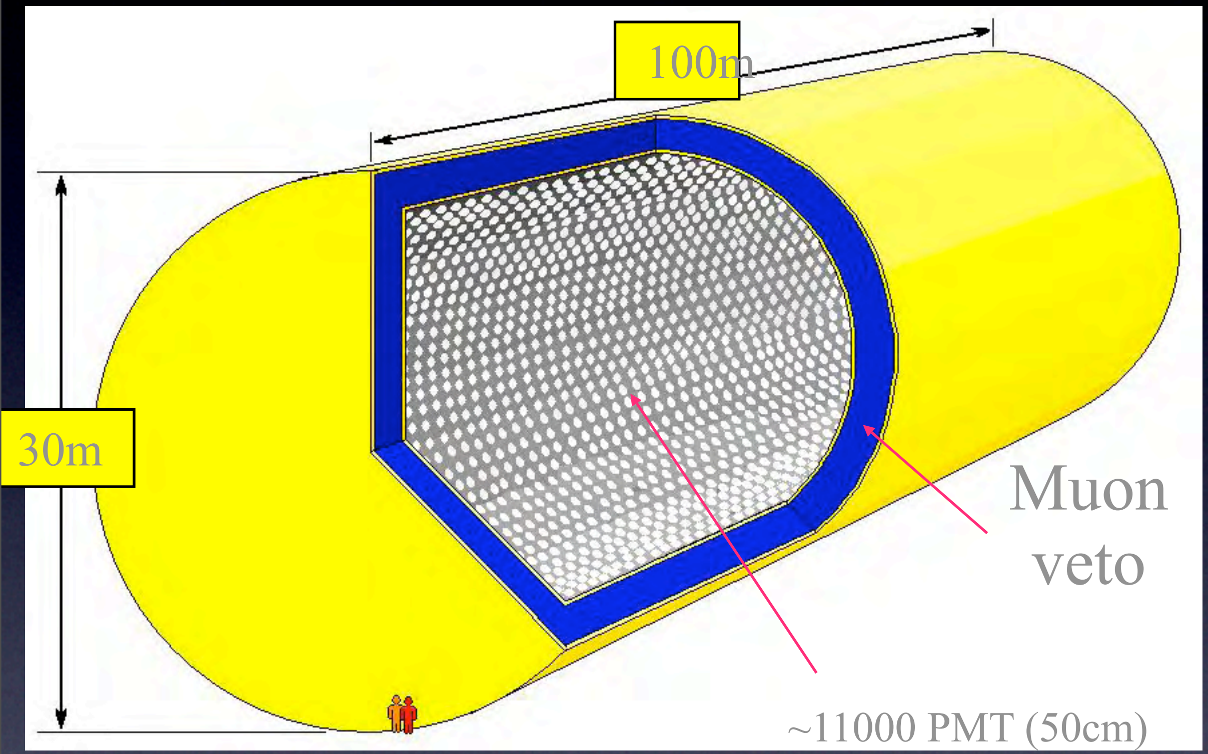
Photo sensor solution

- Photo sensor gives a sizable portion in the total cost of the experiments.
- There are two propositions to give the solution

1. PMT with small size (conservative approach)
   by French team (PMm^2) with PHOTONIS
2. New photo sensor (aggressive approach)
   by Japanese team with Hamamatsu

Low Energy Neutrino Astrophysics (LENA)

Design for a large (~50 kton) liquid scintillator underground detector

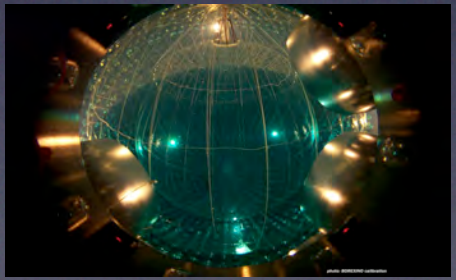


Based on technique of BOREXINO, KAMLAND, SNO+,...

Scintillator solvent: PXE ($C_{16}H_{18}$), ultrapure.
Assumed attenuation length ≈ 12 m @430 nm

Estimated light yield ~ 110 pe / MeV

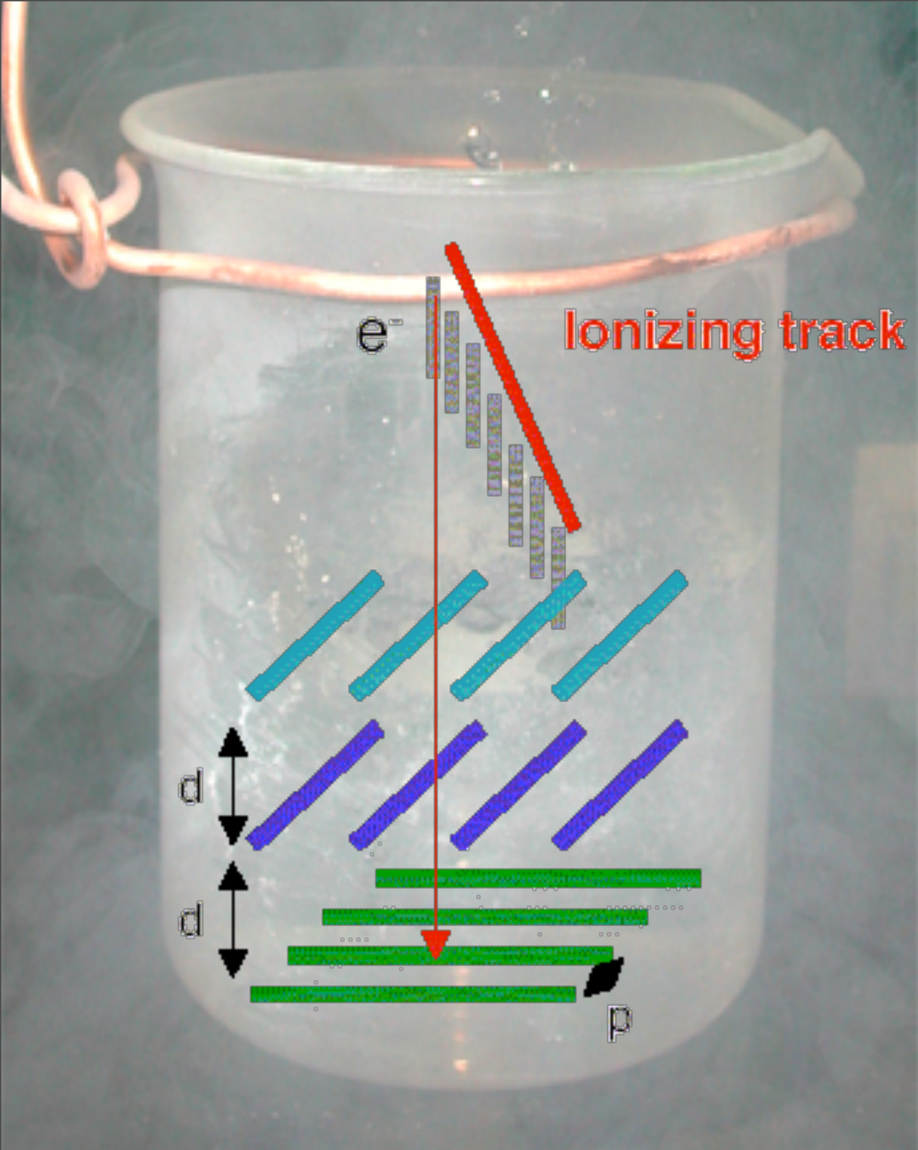
Total number of photomultiplier ~ 11000 (30% coverage)



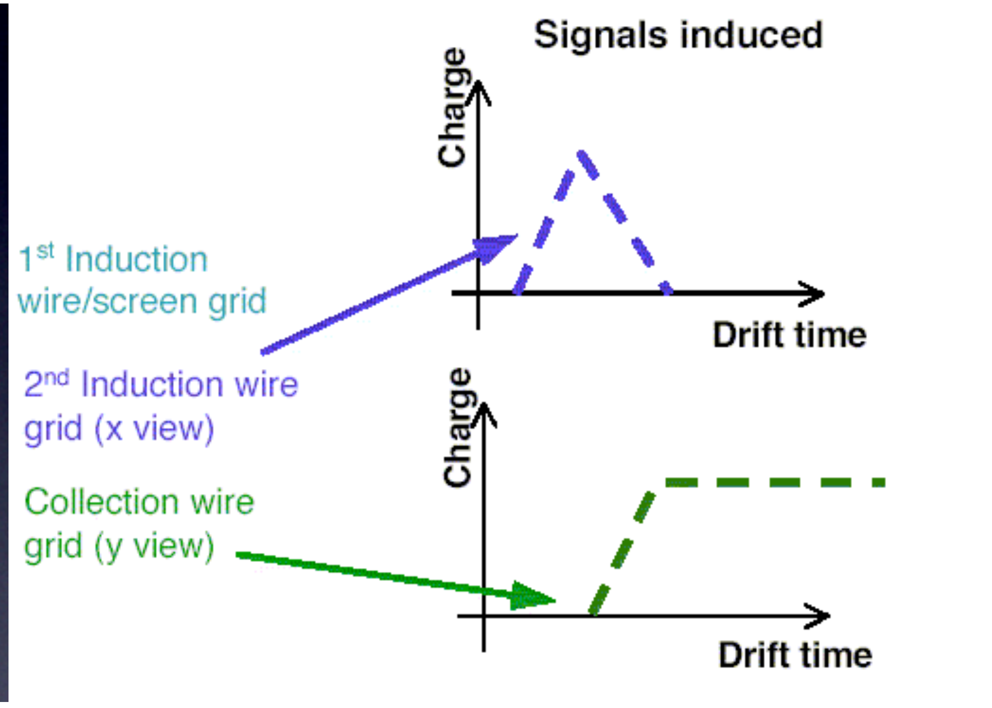
Borexino

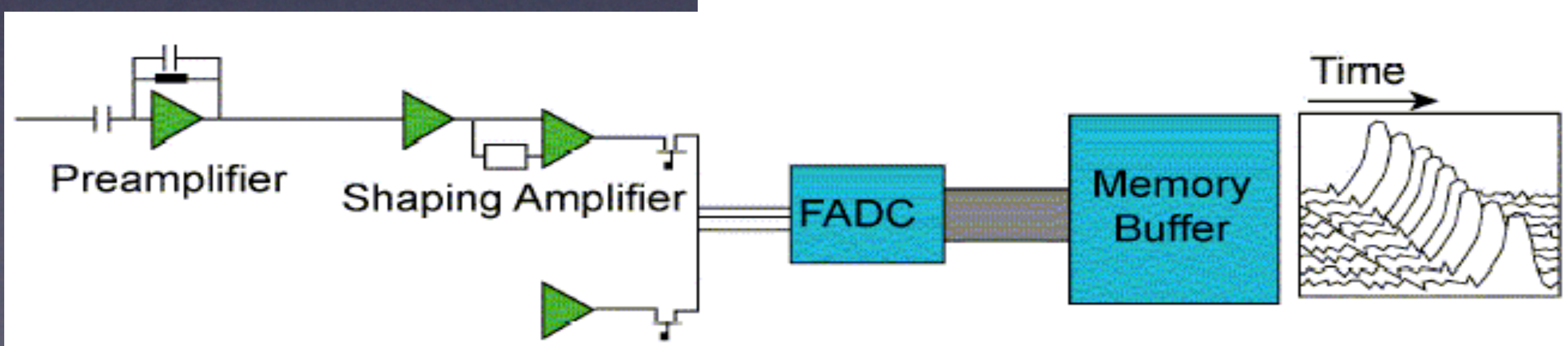
- non hazardous, flashpoint 145° C ➠ easy handling
- density 0.99 ➠ high self shielding
- high light yield ➠ low energy events
- low background level U, Th ➠ solar ν, geo ν, srn ν

Liquid Argon TPC

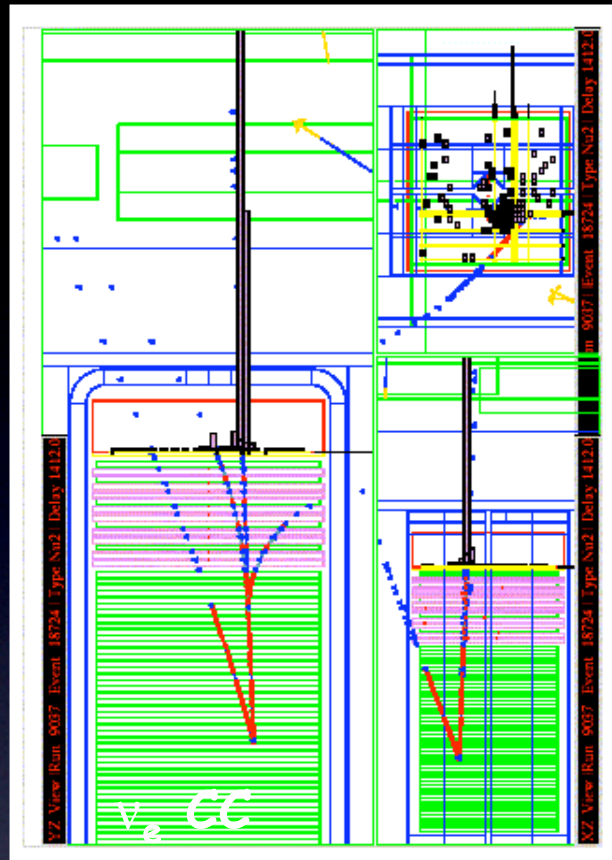


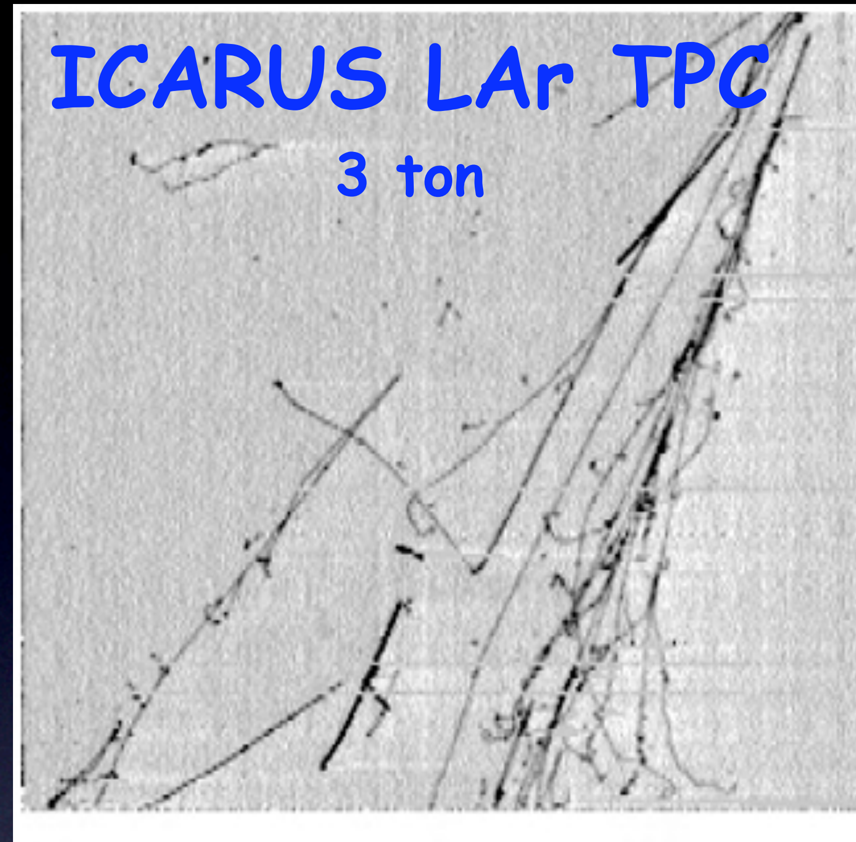
- **C. Rubbia** "The Liquid-Argon Time Projection Chamber: a new concept for neutrino detectors", CERN Report 77-8, May 1977
- **H.H. Chen & J.F. Lathrop** "Observation of ionization electrons drifiting large distances in liquid Argon", NIM 150 (1978) 585
- **E. Aprile, K.L. Giboni and C. Rubbia** "A study of ionization electrons drifting large distances in liquid and solid Argon", NIM A241 (1985) 62





NOMAD

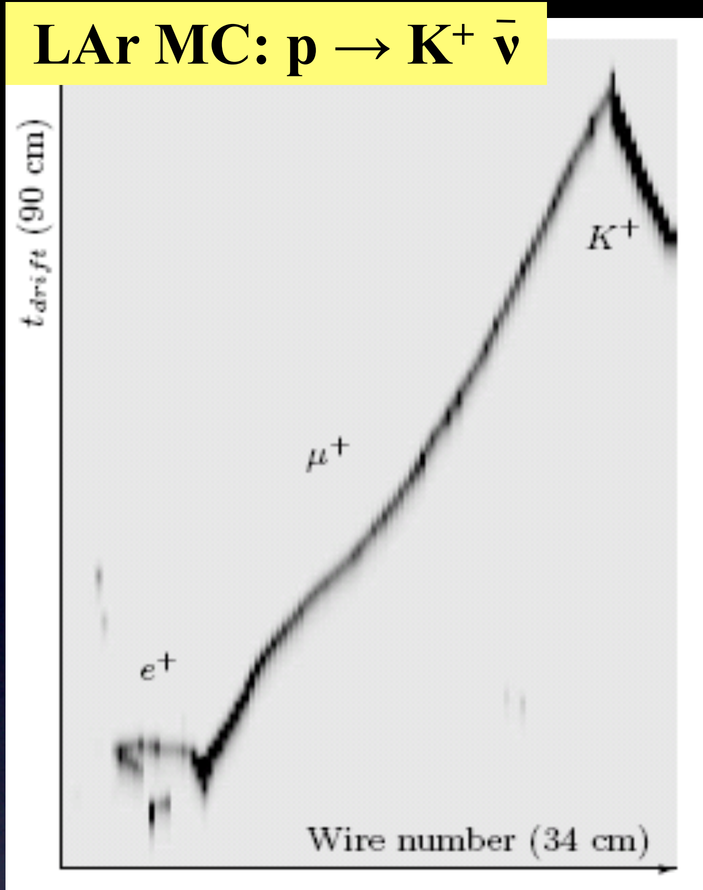




Bubble ∅ (mm)	3
Density (g/cm^3)	1.5
X_0 (cm)	11.0
λ_T (cm)	49.5
dE/dx (MeV/cm)	2.3

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

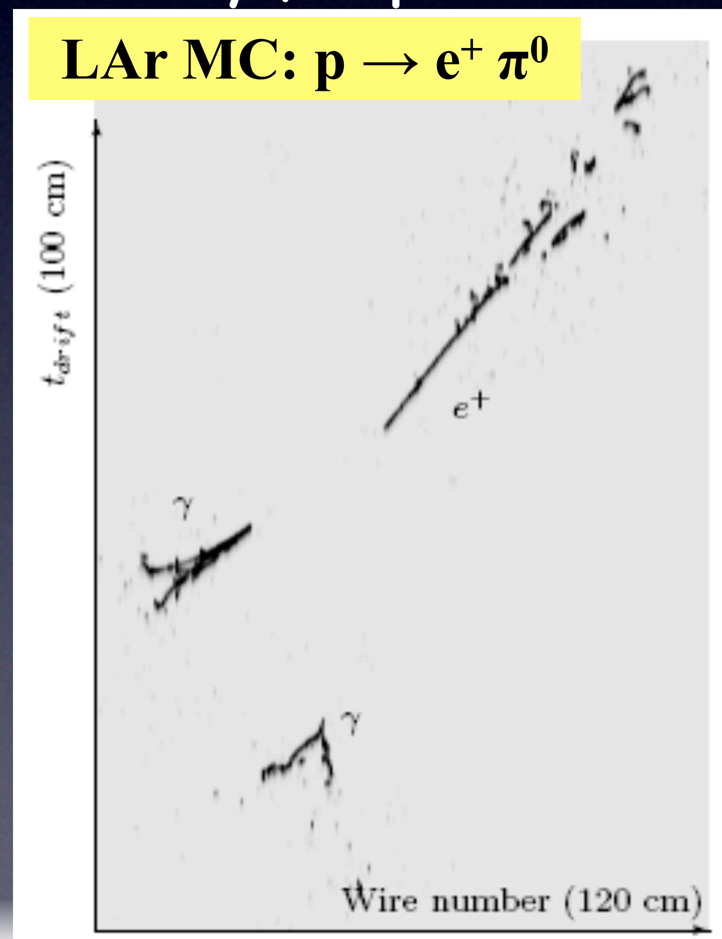
Resolution (mm^3)	2×2×0.2
Density (g/cm^3)	1.4
X_0 (cm)	14.0
λ_T (cm)	54.8
dE/dx (MeV/cm)	2.1



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 proton decay detector

To reach 10^{35} years sensitivity in lifetime a detector mass of ≈100 kton and 10 years of observation are 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

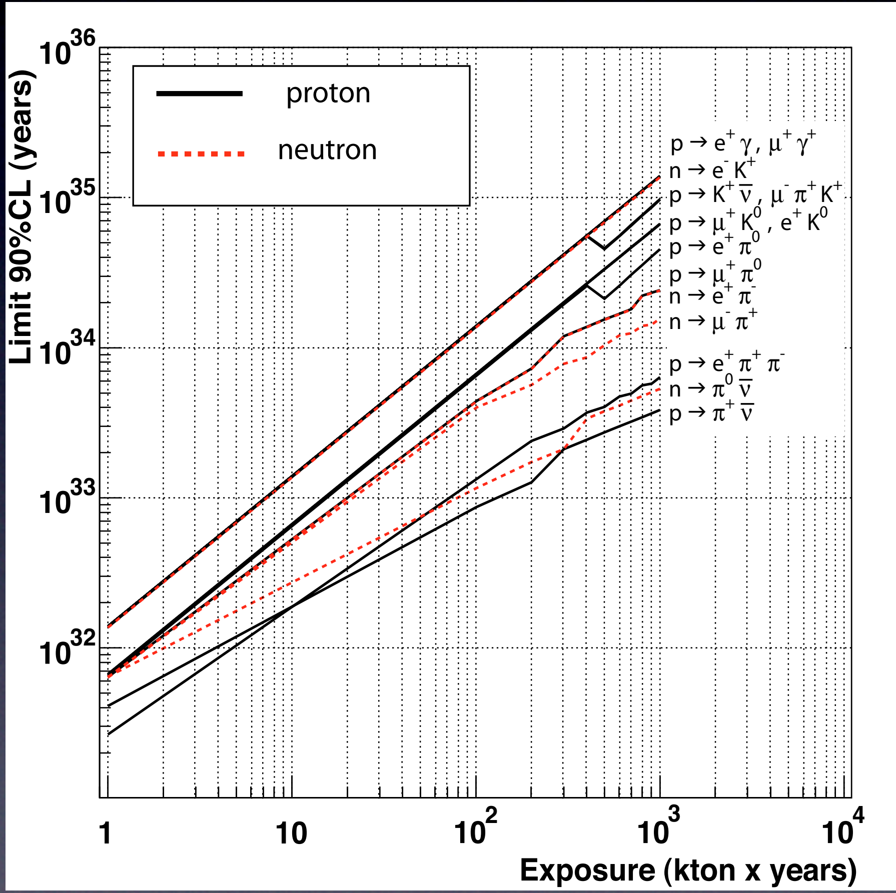
A LAr TPC provides:

★ 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

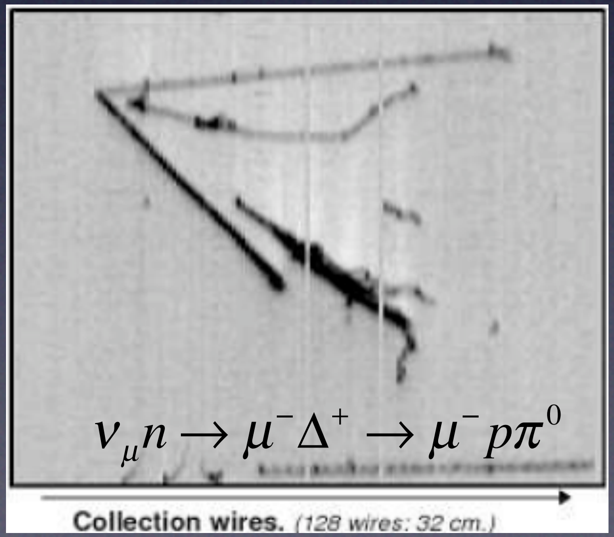
★ access to many possible decay modes (since particle detection threshold essentially negligible)



JHEP04 (2007) 041

LAr TPC as high E neutrino detector

- provides high efficiency for ν_e charged current interactions
- high rejection against ν_μ NC and CC backgrounds also in MultiGeV region
  - e/π^o separation
    fine longitudinal segmentation (few % X_o) – to be optimized !
    fine transverse segmentation, finer than the typical spatial separation of the 2 γ's from π^o decay
  - e, μ/π, K, p 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
- unlike WC detectors, detection and reconstruction efficiency does *not* depend on volume of detector ➔ direct near / far detector comparison (apart from flux extrapolation)



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 beam 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
- A. Meregaglia, A. Rubbia, “Neutrino Oscillations With A Next Generation LAr TPC Detector in Kamioka or Korea Along The J-PARC Neutrino Beam “, arXiv:0801.4035
- A. Badertscher et al., “A Possible Future Long Baseline Neutrino and Nucleon Decay Experiment with a 100 kton Liquid Argon TPC at Okinoshima using the J-PARC Neutrino Facility “, arXiv:0804.2111

arXiv:0804.2111

April 14, 2008

A Possible Future Long Baseline Neutrino and Nucleon Decay Experiment with a 100 kton Liquid Argon TPC at Okinoshima using the J-PARC Neutrino Facility

A.Badertscher[1], T.Hasegawa[2], T.Kobayashi[2], A.Marchionni[1], A.Meregaglia[1*], T.Maruyama[2,3], K.Nishikawa[2], and A.Rubbia[1]
(1) ETH Zürich, (2) KEK IPNS, (3) University of Tsukuba

Abstract

In this paper, we consider the physics performance of a single far detector composed of a 100 kton next generation Liquid Argon Time Projection Chamber (LAr TPC) possibly located at shallow depth, coupled to the J-PARC neutrino beam facility with a realistic 1.66 MW operation of the Main Ring. The new far detector could be located in the region of Okinoshima islands (baseline $L \sim 658$ km). Our emphasis is based on the measurement of the θ_{13} and δ_{CP} parameters, possibly following indications for a non-vanishing θ_{13} in T2K, and relies on the opportunity offered by the LAr TPC to reconstruct the incoming neutrino energy with high precision compared to other

Possible MR Power Improvement Scenario KEK ROADMAP

	Day1 (up to Jul.2010)	Next Step	KEK ROADMAP	Ultimate
Power(MW)	0.1	0.45	1.66	?
Energy(GeV)	30	30	30	
Rep Cycle(sec)	3	3-2	1.92	
No. of Bunch	6	8	8	
Particle/Bunch	1.2×10^{13}	$<4.1\times10^{13}$	8.3×10^{13}	
Particle/Ring	7.2×10^{13}	$<3.3\times10^{14}$	6.7×10^{14}	
LINAC(MeV)	181	181	400	
RCS	h=2	h=2 or 1	h=1	

After 2010, plan depends on financial situation

Future Investment for the "Discovery" in ν Physics
Look for opportunities to find new physics
Not much Interested in Upper Bound Physics

If ν_e oscillation Signal found (in T2K...)→

Proceed Immediately to CP Violation Discovery

MUST: Improve ν Beam Intensity

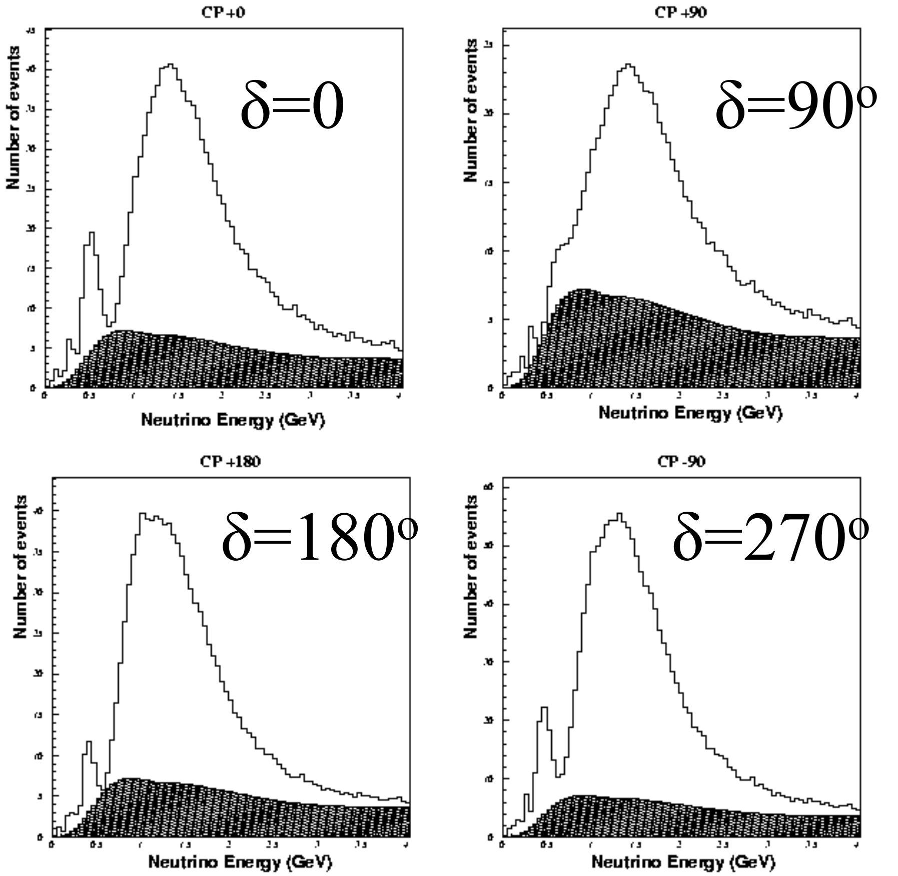
MUST: Improve the Main(Far) Detector Quality

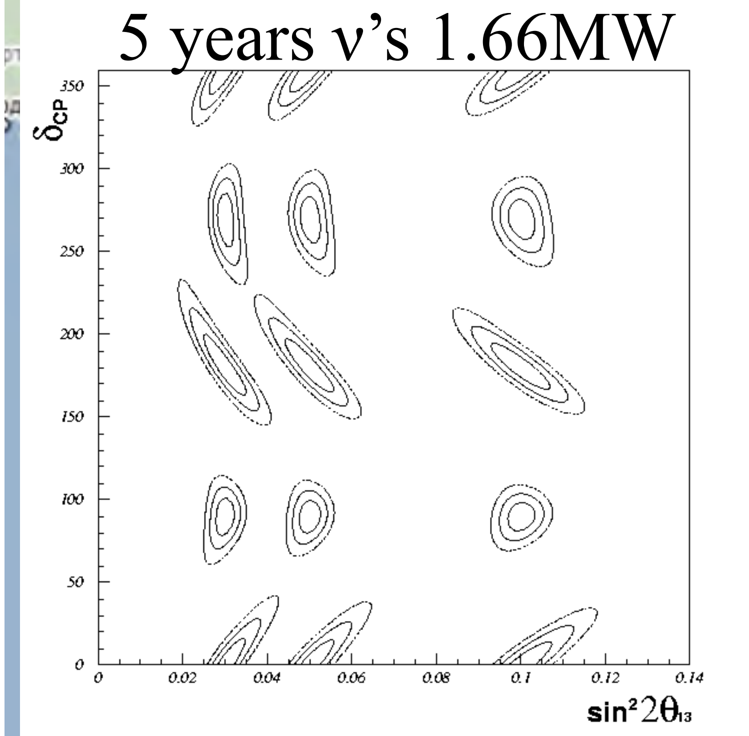
In terms of

Detector Technology, Volume and Baseline+Angle

Probably: improve Near Detector (whatever it is)

T. Hasegawa, summary NP08 workshop





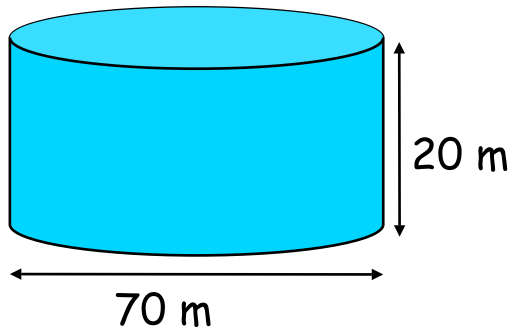
- Realistic upgrade of J-PARC MR at 1.66 MW
- Neutrino run only
- 100 kton LAr detector
- Exploit excellent energy resolution
- Good e/π^0 separation

arXiv:0804.2111

A LAr TPC detector …

- must be BIG to be competitive
  - ➠ 50 ÷ 100 kton range
  - ➠ drift lengths of at least a few meters are necessary

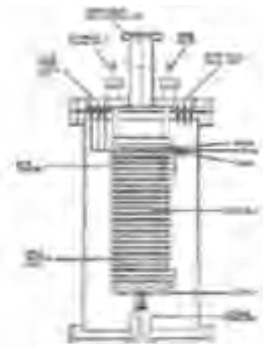
e.g.:



⇨ 100 kton

- Shopping list for a large LAr detector:
  - ★ Dewar
  - ★ Argon procurement and purification system
  - ★ High Voltage system
  - ★ Readout device
  - ★ Electronics
  - ★ “Test” beams
  - ★ Underground construction and operation

The pioneering efforts: ICARUS

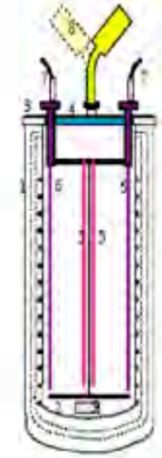


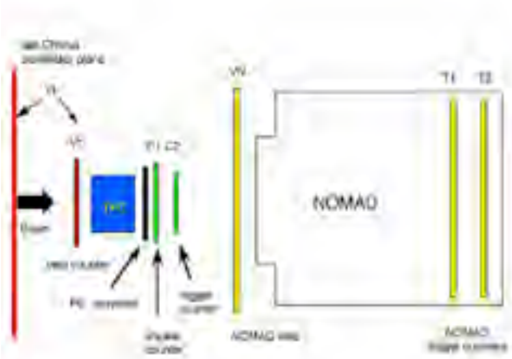
24 cm drift wires chamber

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

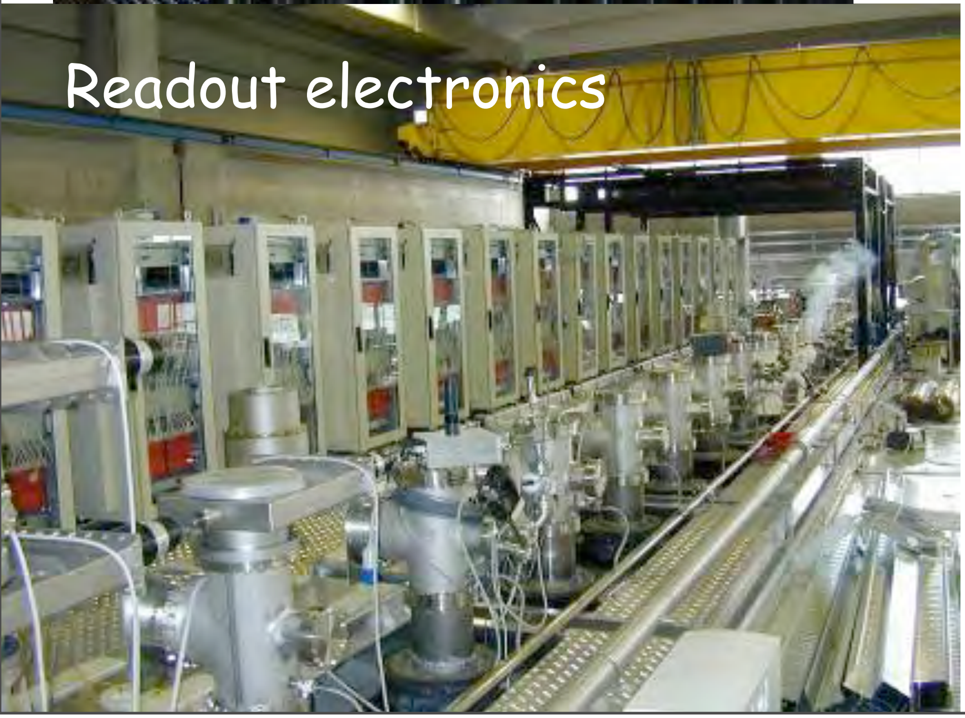
1999-2000: Test of final industrial solutions for the wire chamber mechanics and readout electronics.

600 ton detector

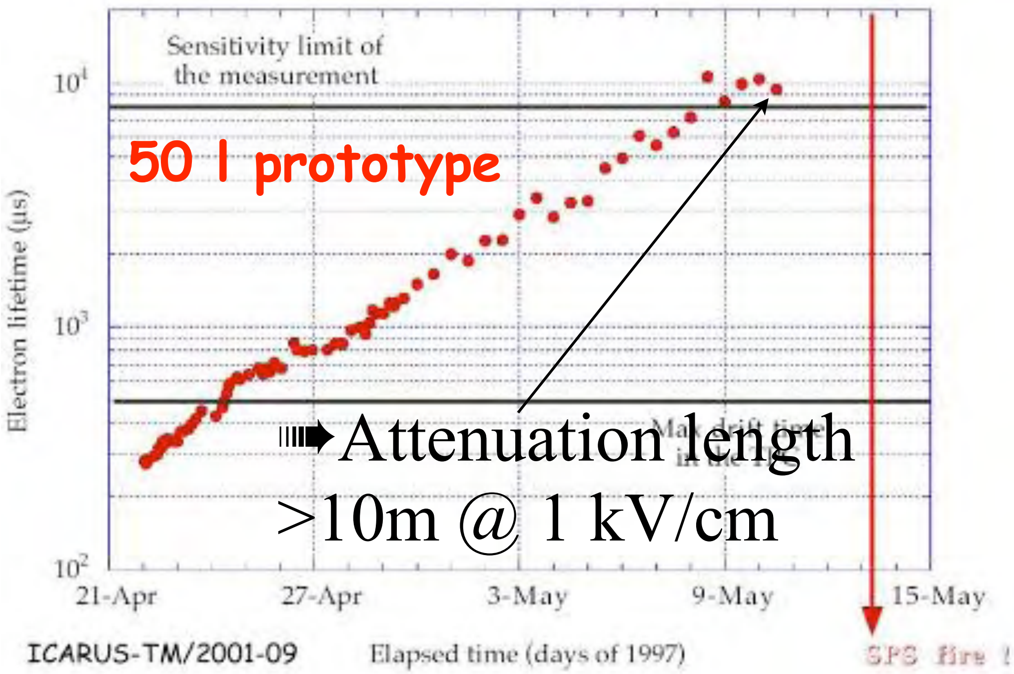
2001- present: 300 ton detector tested on surface in Pavia. 600 ton detector being presently assembled at LNGS.

20 years later...

ICARUS T300 Prototype



Argon purity, electron lifetime in ICARUS



The concentration of impurities, N, is determined by

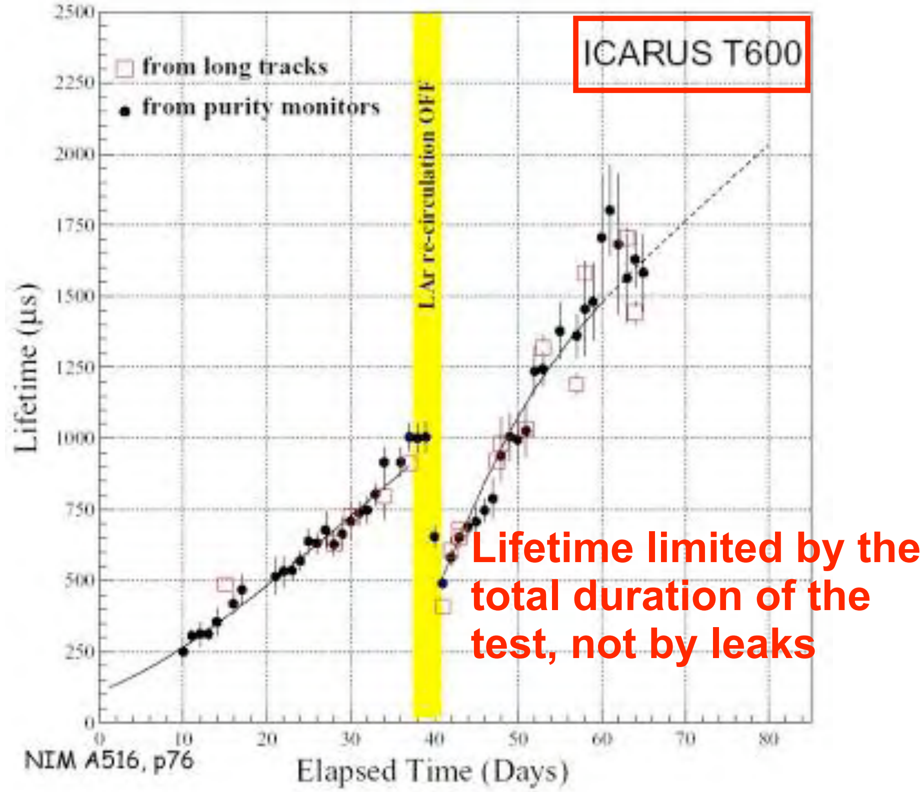
- constant input rate of impurities (leaks) Φ_{in}^{0}
- outgassing of material A, B
- purification time τ_c

$$\frac{dN}{dt} = -\Phi_{out}(t) + \Phi_{in}(t) = -\frac{N(t)}{\tau_c} + \Phi_{in}^{0} + \frac{A}{(1+t/t_0)^B}$$

Φ_{in}^{0}= (5±5)×10^{-3} ppb/day oxygen

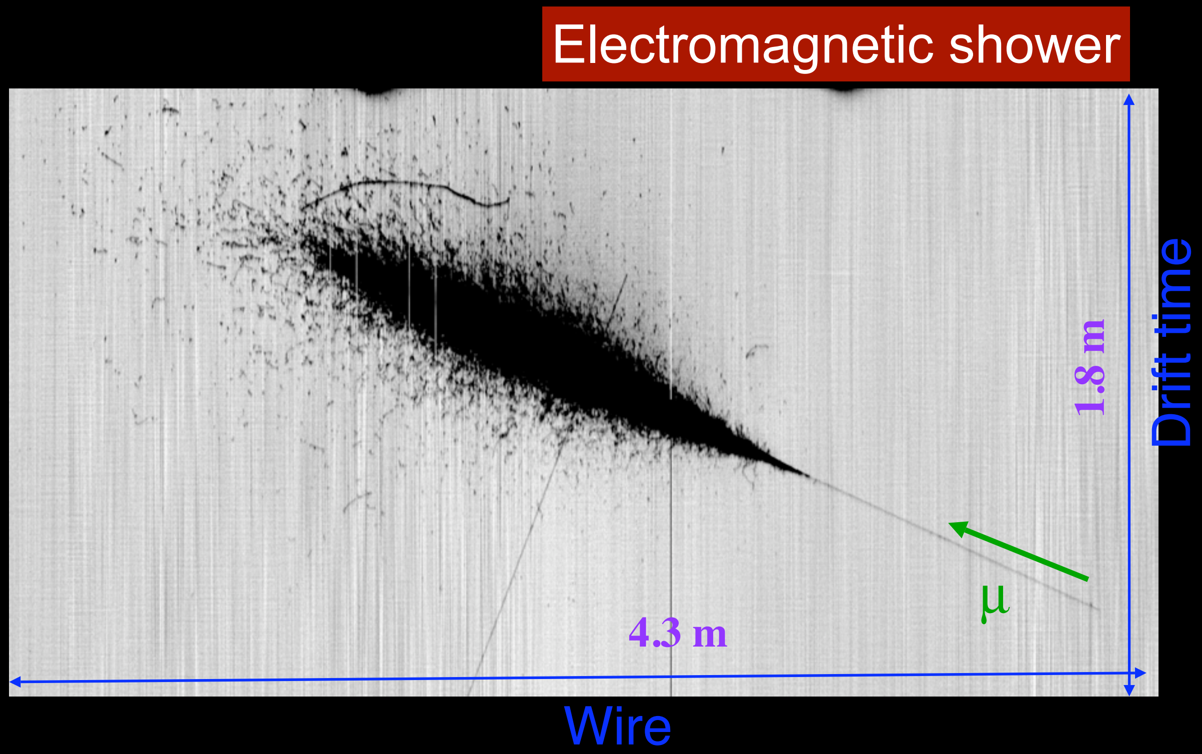
A=0.33±0.07 ppb/day

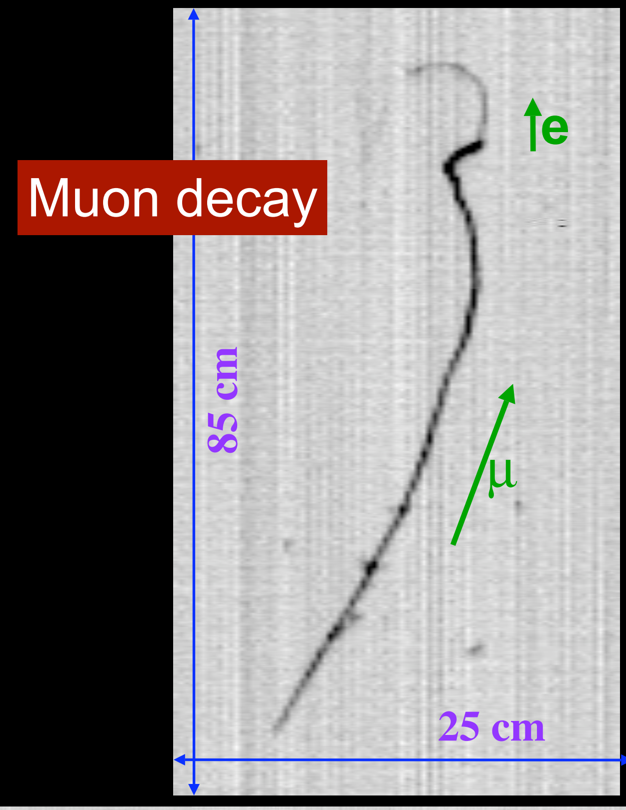
B=1.39±0.05

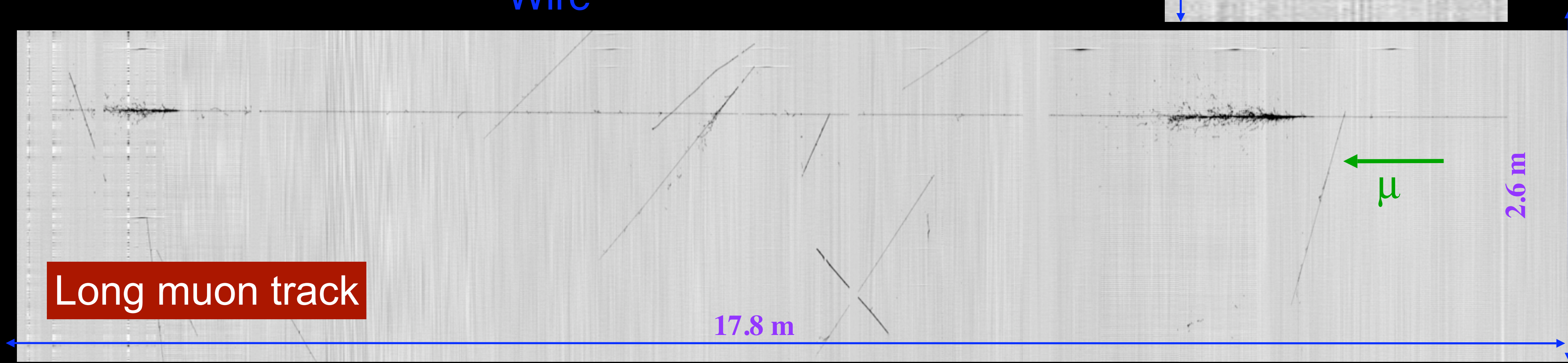


ICARUS T300 test on surface (2001)

Data from test run: 27000 triggers from cosmic ray interactions







Towards very large LAr TPCs

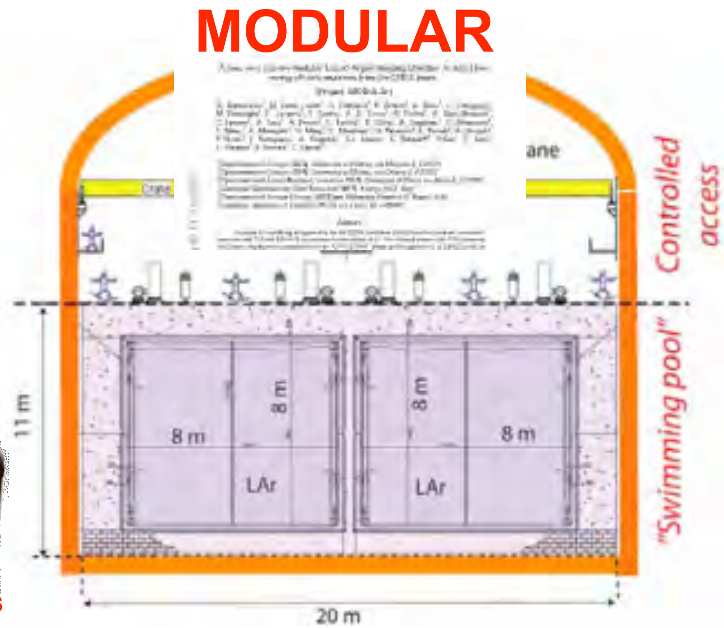
Starting from ICARUS (1985), several proposals towards large LAr TPCs:

- ✦ LANNDD 2001
- ✦ GLACIER 2003
- ✦ FLARE 2004
- ✦ MODULAR 2007

...with different approaches:

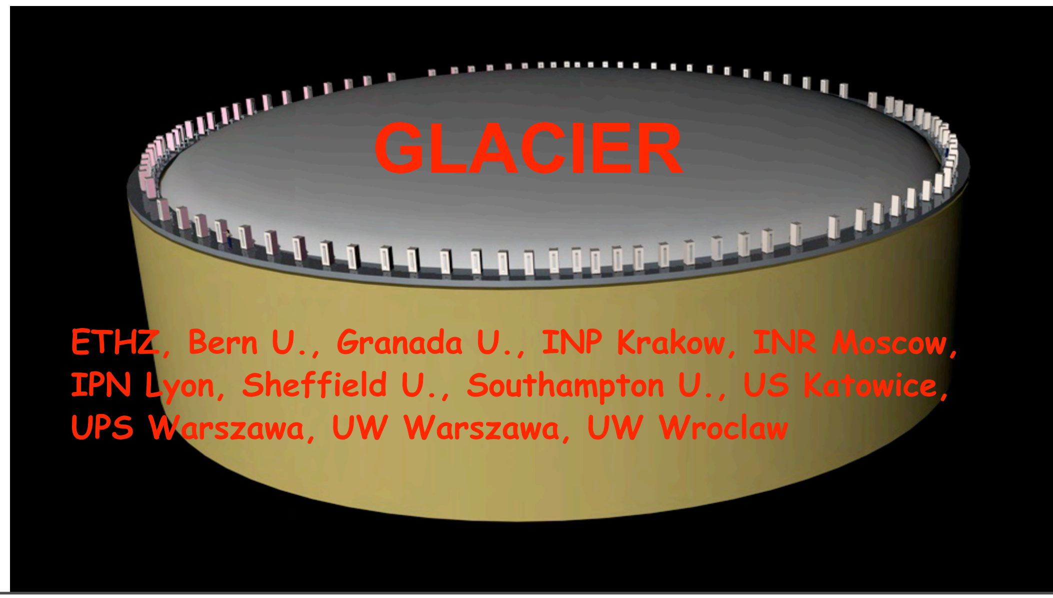
- a **modular** or a **scalable** detector for a total LAr mass of 50-100 kton
- **evacuable** or **non-evacuable** dewar
- detect ionization charge in LAr **without amplification** or with **amplification**


ICARUS


MODULAR
11 m
8 m
8 m
8 m
8 m
LAr
LAr
20 m
"Swimming pool"
Controlled access


LANNDD
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 UCLA
2 Pisa,


FLARE
Bartoszek Eng. - Duke - Indiana - Fermilab -
LSU - MSU -Osaka - Pisa - Pittsburgh - Princeton -
Silesia - South Carolina - Texas A&M -
Tufts - UCLA - Warsaw University -
INS Warsaw - Washington - York-Toronto


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

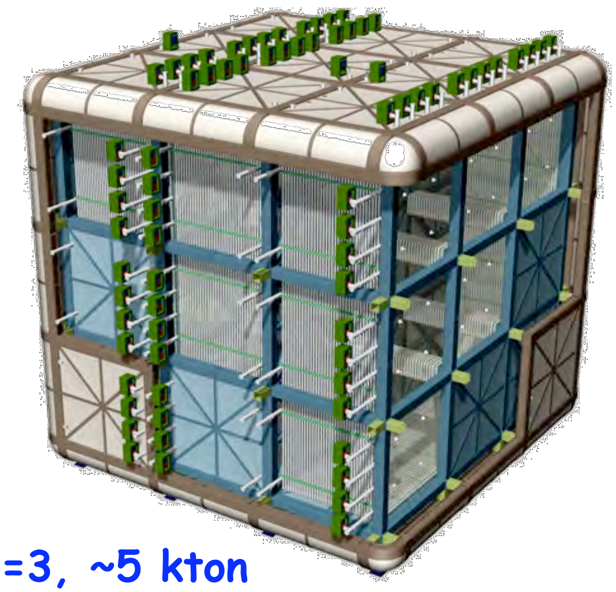
Considerations on large detectors

- **The dewar technology is the crucial choice for huge LAr detectors**
  - ➡ **A modular 5-kton/unit approach is unrealistic for ~100 kton LAr mass (cost, complications, ...)**
  - ➡ **Huge evacuable dewars (~40x40x40 m^3) have quite a complicated mechanical structure and might present safety problems during evacuation**
  - ➡ **Huge non-evacuable dewars are currently built as LNG containers, also as underground installation**
    - ★ heat input and argon consumption have to be carefully evaluated (running costs)
    - ★ purification of such large volumes starting from air at atmospheric pressure should not be a problem (but R&D on powerful clean cryogenic pumping system is essential)
    - ★ a harder problem is how to check for leaks, which might limit the achievable argon purity, if it is not possible to evacuate the dewar. Will have to rely on careful checks of all welding joints ... a Q&A problem!
- **Novel readout techniques, other than wires, possibly with amplification of the ionization signals, are an essential R&D item**
  - ➡ amplification allows longer drift paths
  - ➡ how to handle, electrically and mechanically, wire lengths ≥ 20 m?

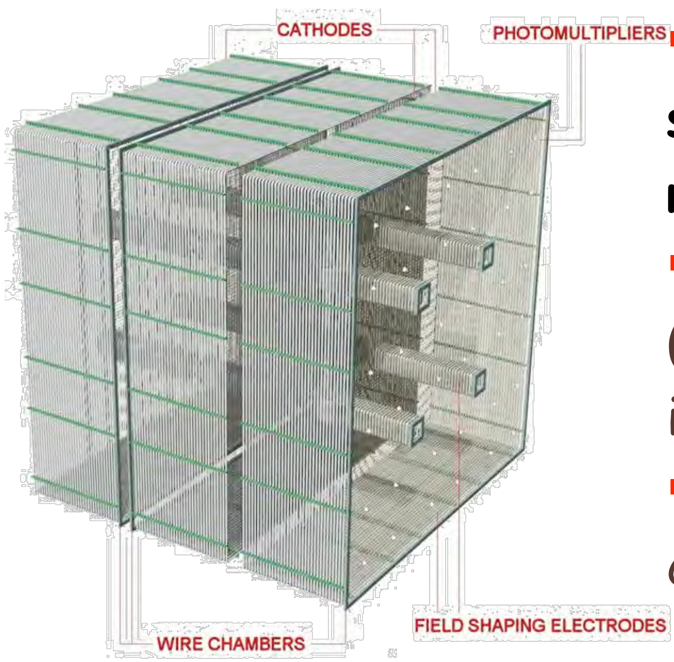
LANNDD

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

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



n=3, ~5 kton



- Drift paths up to 5 m
- Evacuable dewar with the possibility of checking its tightness
- Use of stainless steel for the inner vessel and for cathodes, wire chamber frames and shaping electrodes
- UHV standards for any device in contact with the argon
- Vacuum insulation, together with the use of superinsulation jacket around the cold vessel, to reduce running costs
- 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

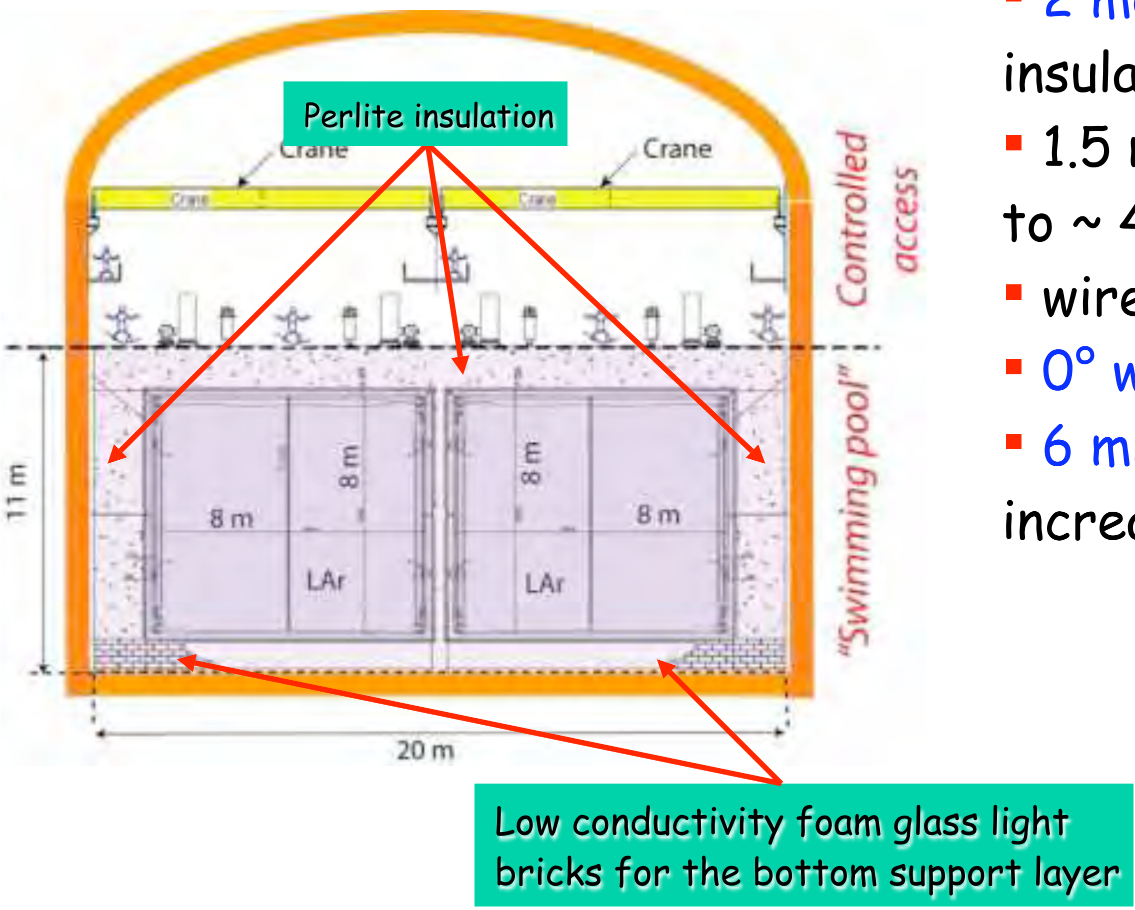
▸ ***implications of evacuated dewar?***

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 m^2** rather than 3 x 3 m^2. The length of such a detector is **50 meters.**

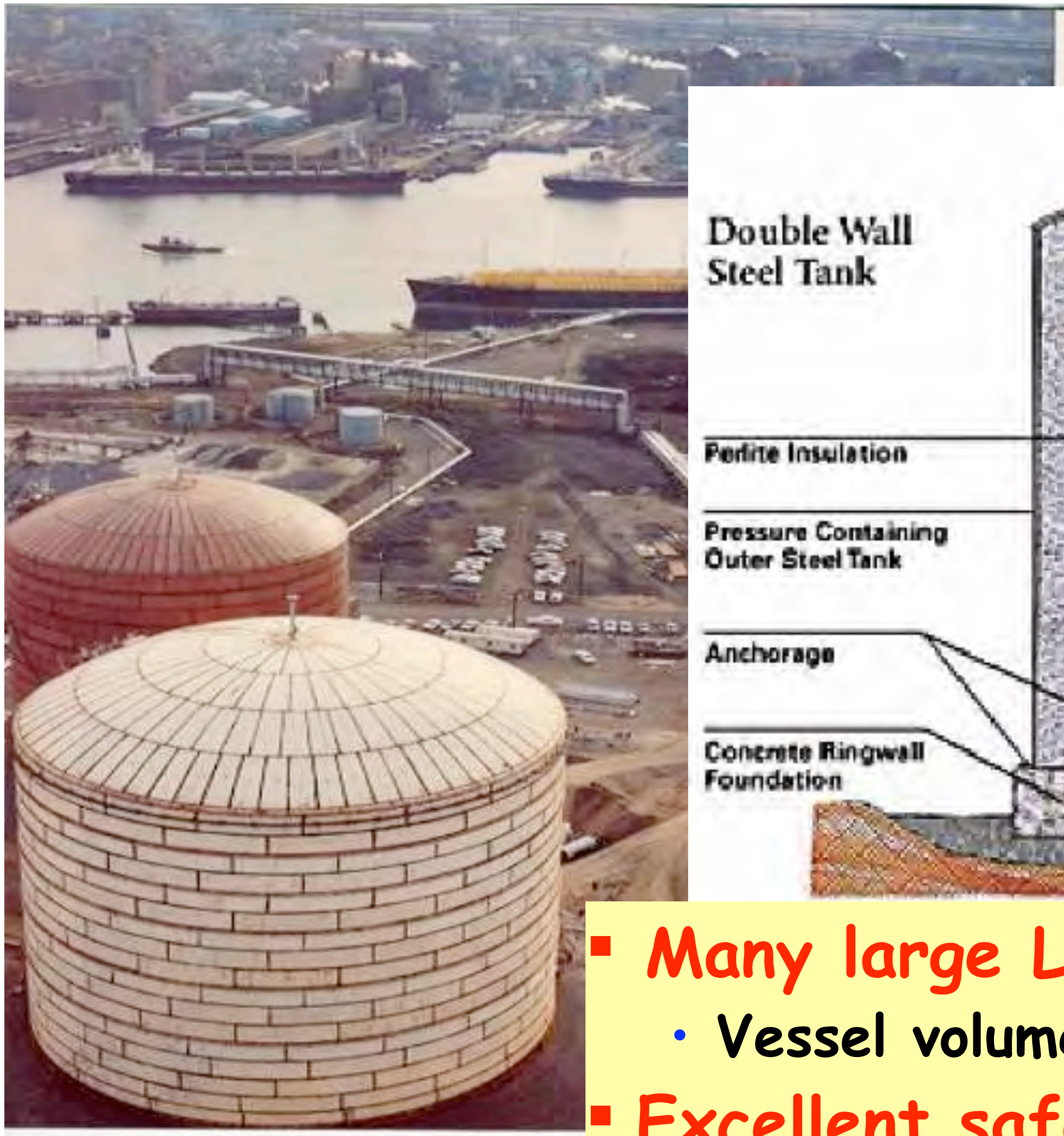


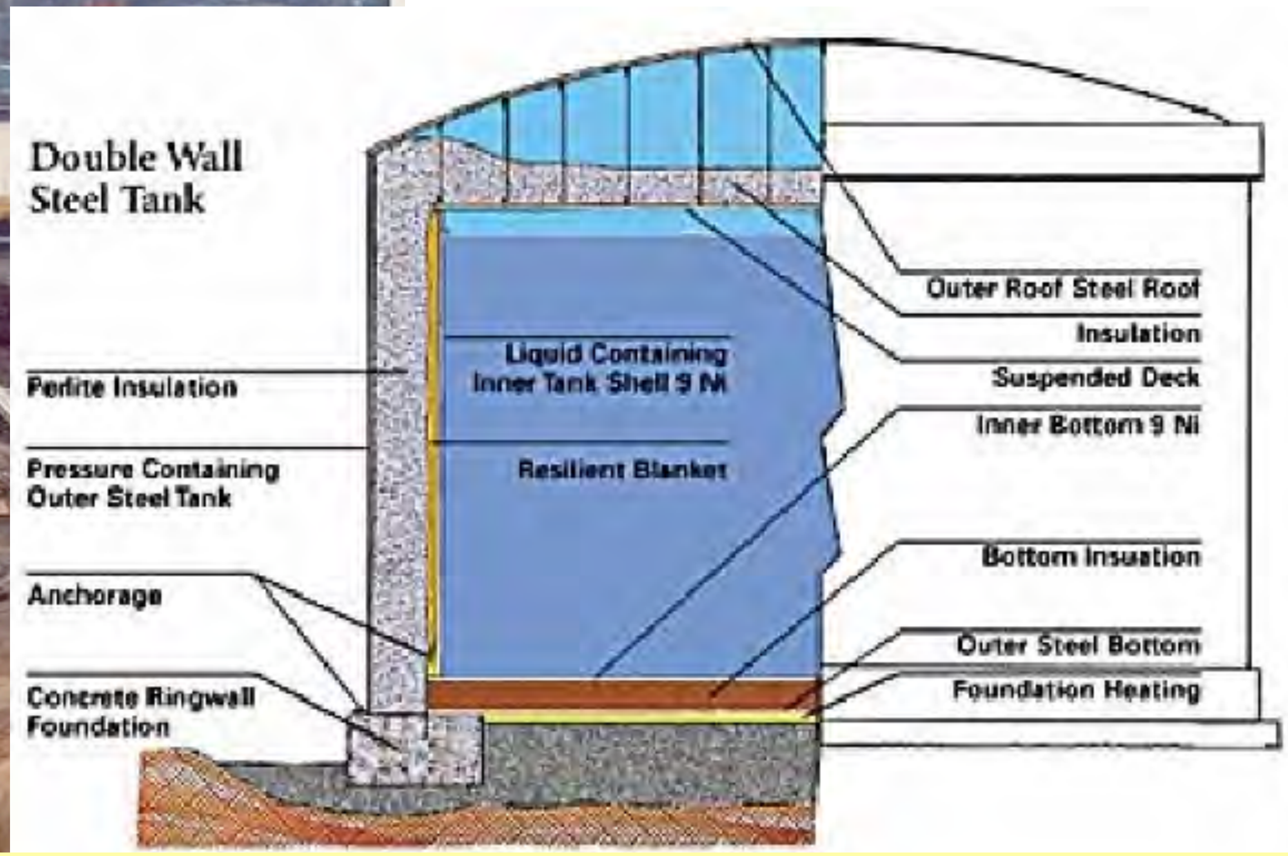
- 2 modules of 5 kton each with common insulation
- 1.5 m thickness of perlite, corresponding to ~ 4 W/m^2 thermal loss
- wires at 0°, ±60°
- 0° wires split in two, 25 m long, sections
- 6 mm wire pitch, to compensate for the increase capacitance of the longer wires

▸***can one reach 100 kton scale with 20 modules??***

▸***loss of physics performance! (pitch, fiducial volume, ...)***

Cryogenic storage tanks for LNG



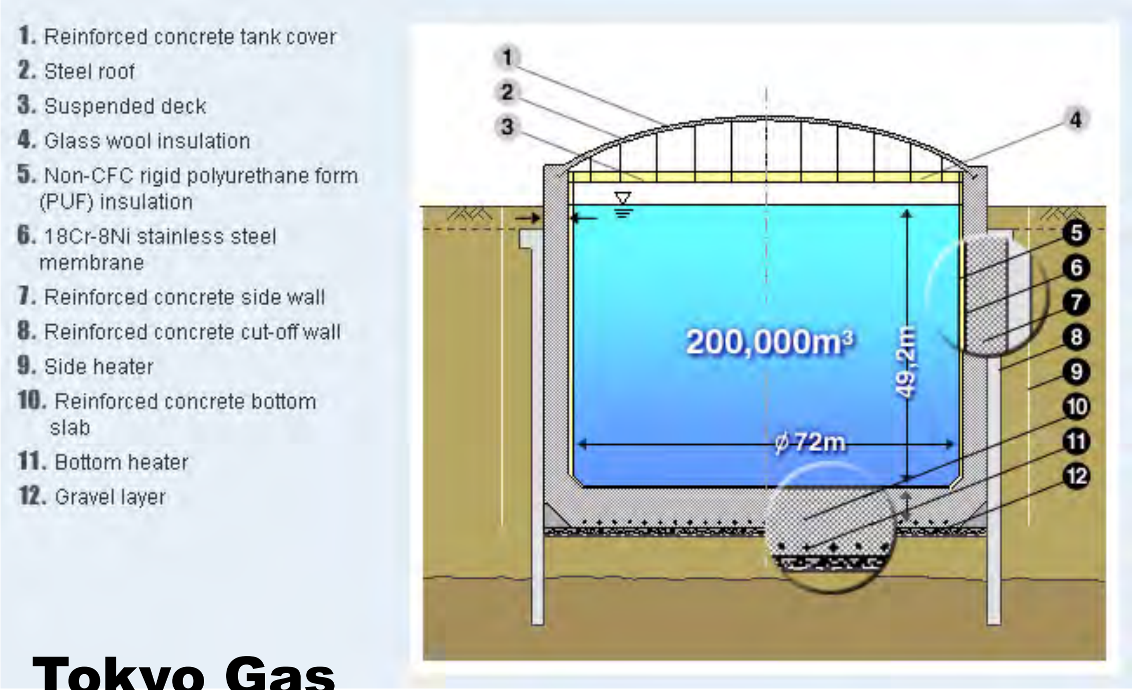


- **Many large LNG tanks in service**
  - Vessel volumes up to 200000 m^3
- **Excellent safety record**
  - Last serious accident in 1944, Cleveland, Ohio, due to tank with low nickel content (3.5%)

More on LNG storage tanks

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

Bird's-eye view of underground storage tanks



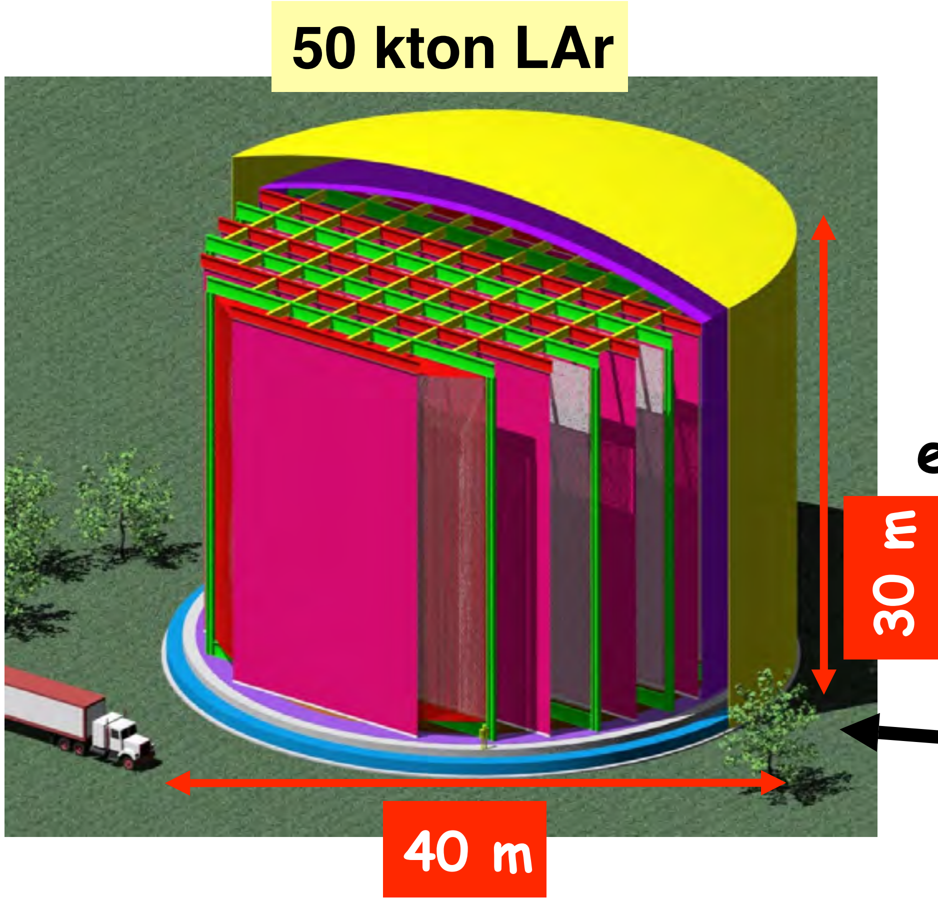
Tokyo Gas

In-ground and underground storage tanks from Tokyo Gas

LAr vs LNG (≥ 95% Methane)

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

FLARE



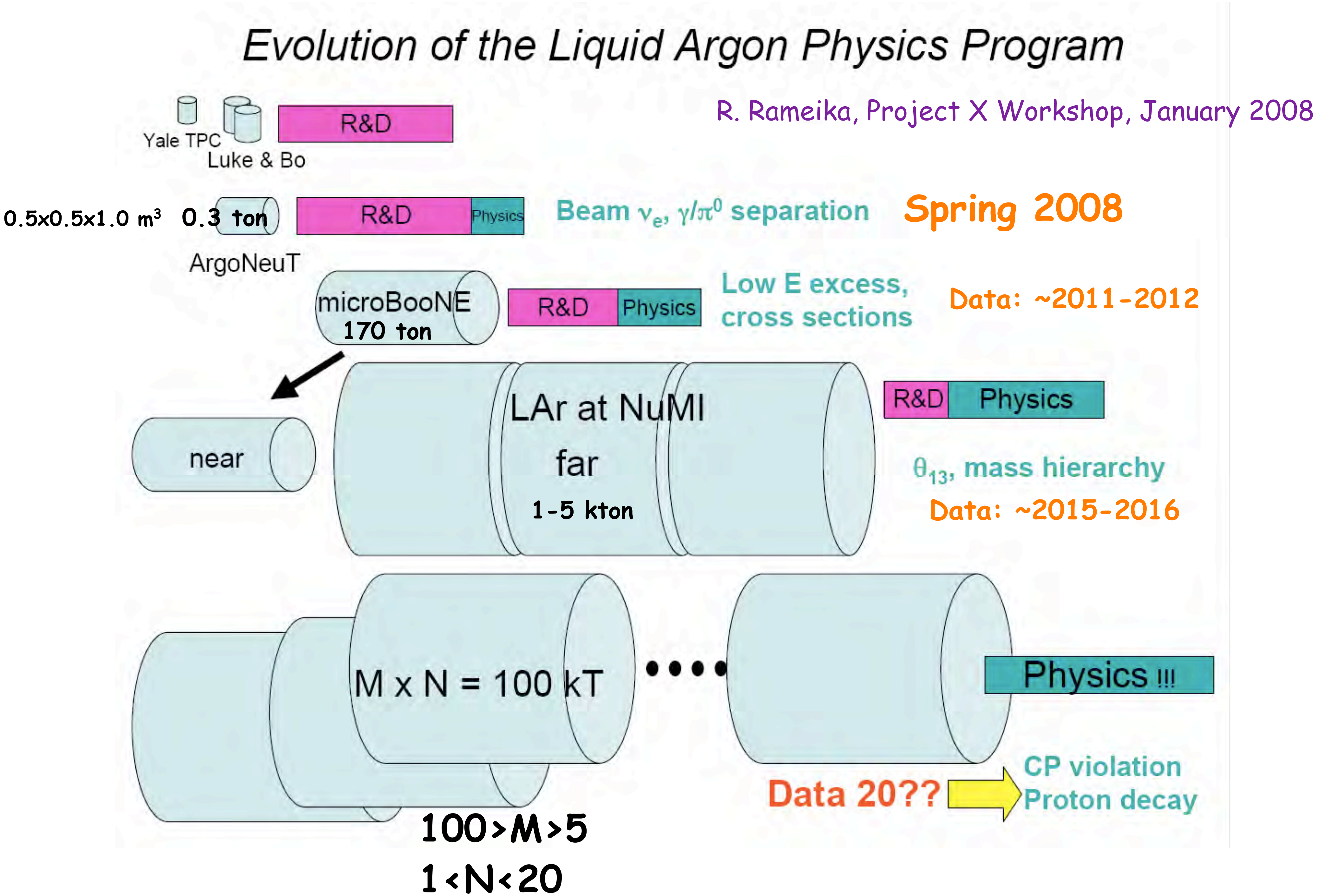
Fermilab-Proposal-0942, Aug. 2004
hep-ex/0408121

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

LNG style tank: CB&I standard design for double wall and double roof vessel

- Thermal insulation
  - 1.2 m thick layer of perlite
  - boil-off rate of 0.05%/day (25 ton/day)
  - a cryogenic system is necessary in order to re-liquefy this gas mass
- Wire planes
  - 3 m drift distance, 5 mm wire spacing
  - large wire planes, with the largest of 30x40 m^2

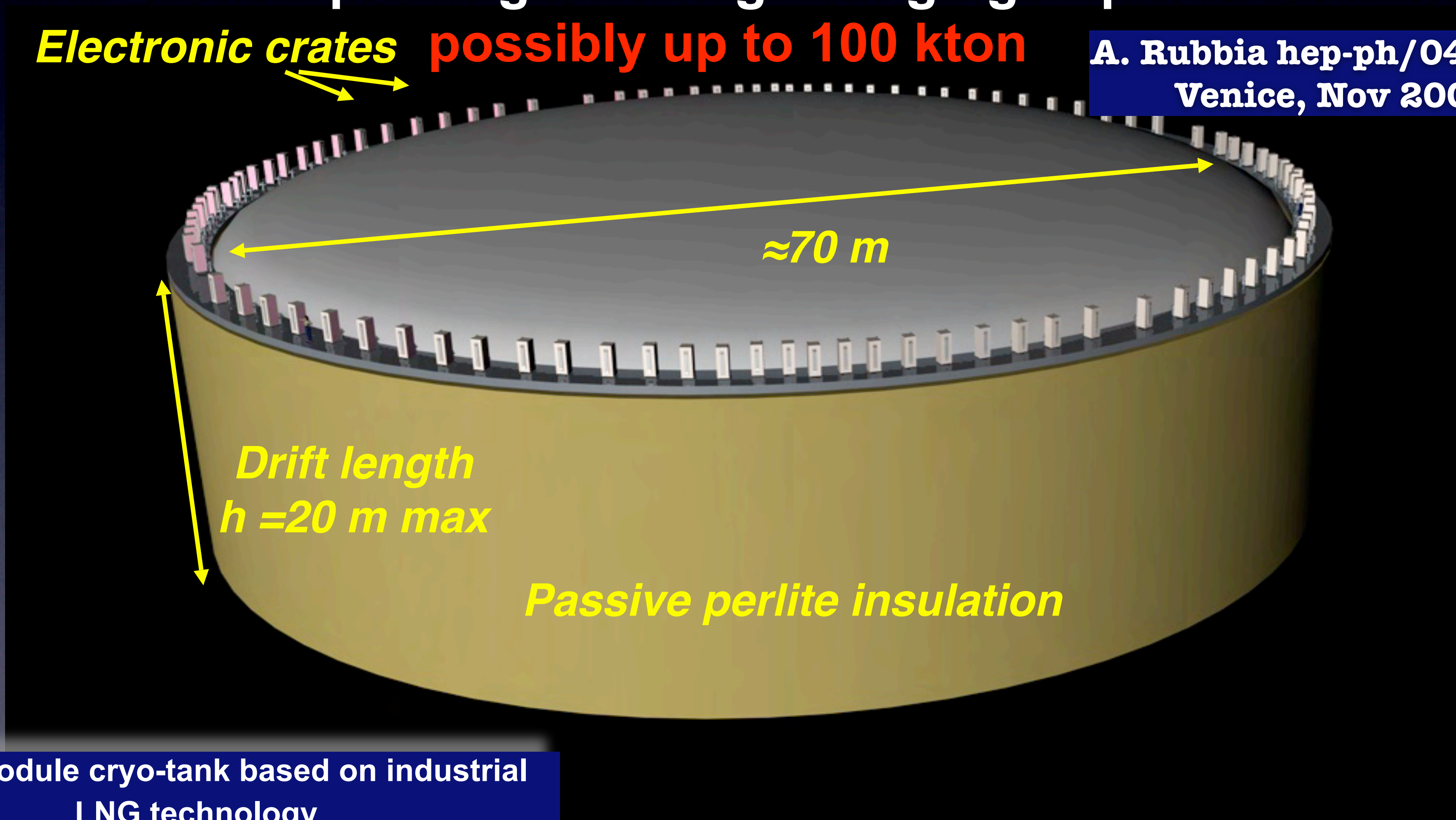
Recently Proposed Strategy @ Fermilab



GLACIER

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

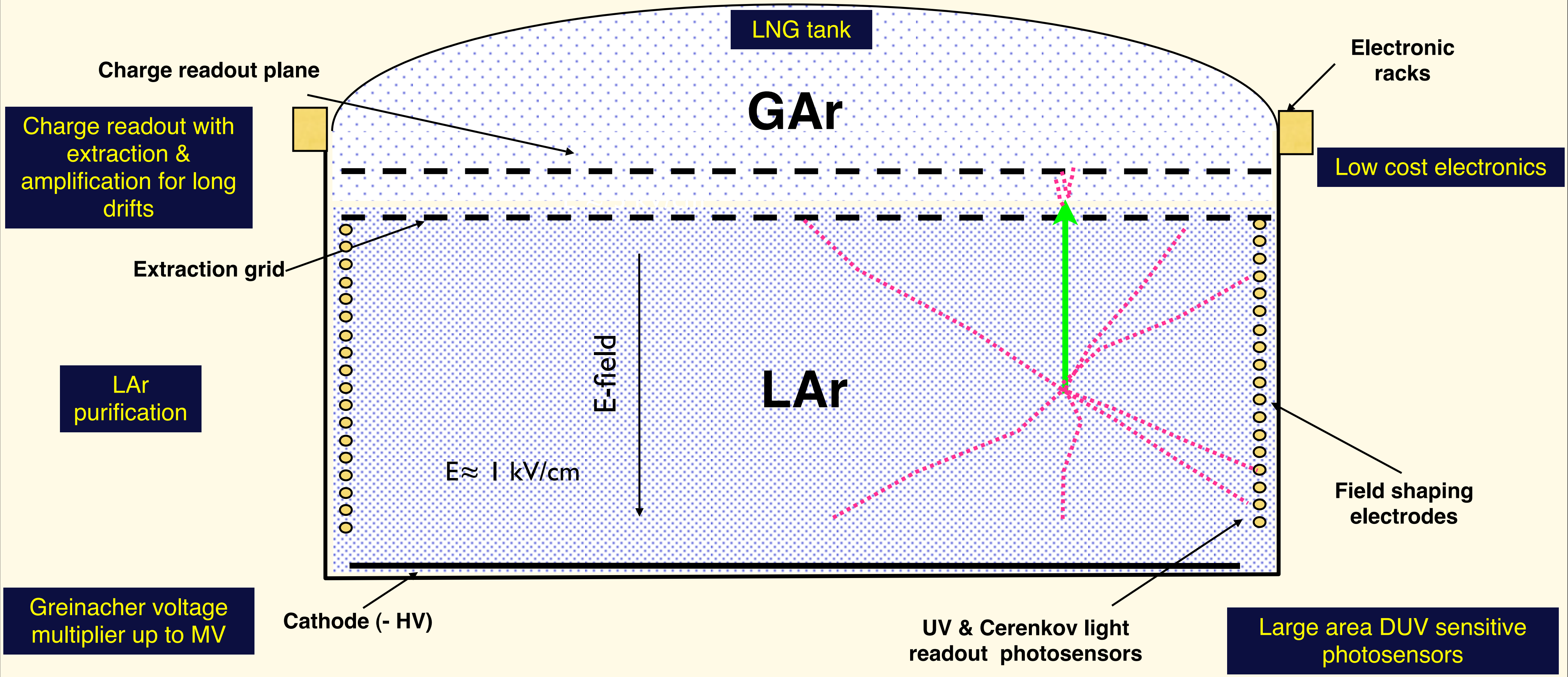
Giant Liquid Argon Charge Imaging ExpeRiment



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

Single module cryo-tank based on industrial LNG technology

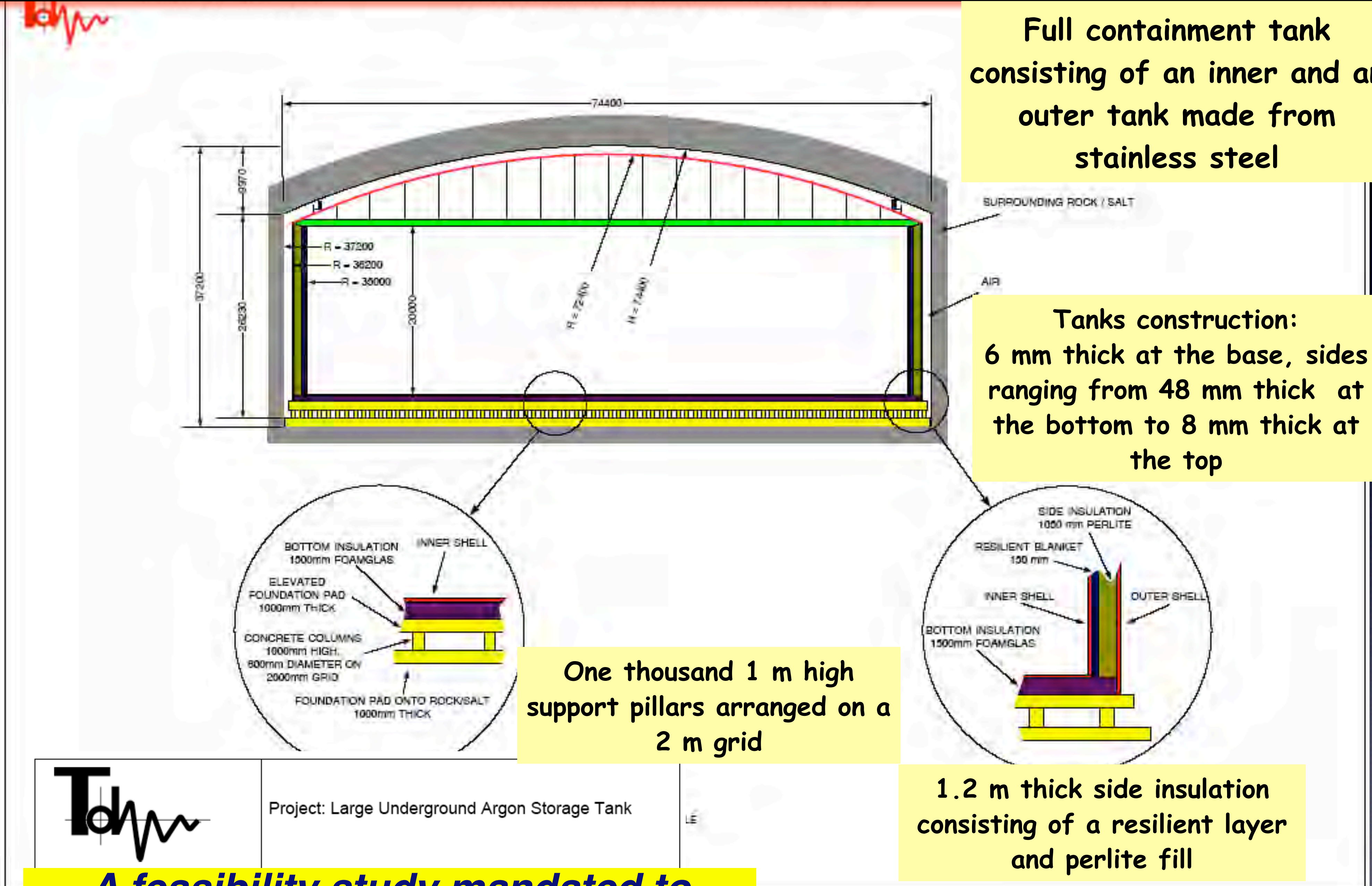
GLACIER novel concept for inner detector



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
- Immersed DUV sensitive light readout on surface of tank for T_0
- Possibly immersed superconducting solenoid for B-field

Large underground LAr storage tank



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

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

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

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

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

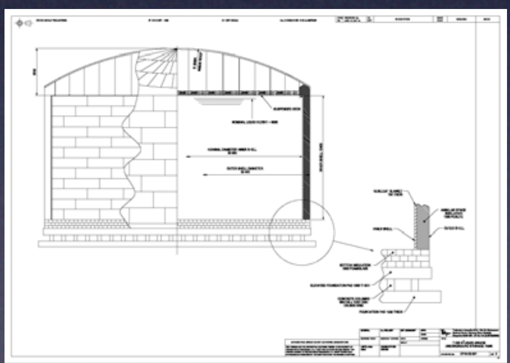
Estimated boil-off 0.04%/day

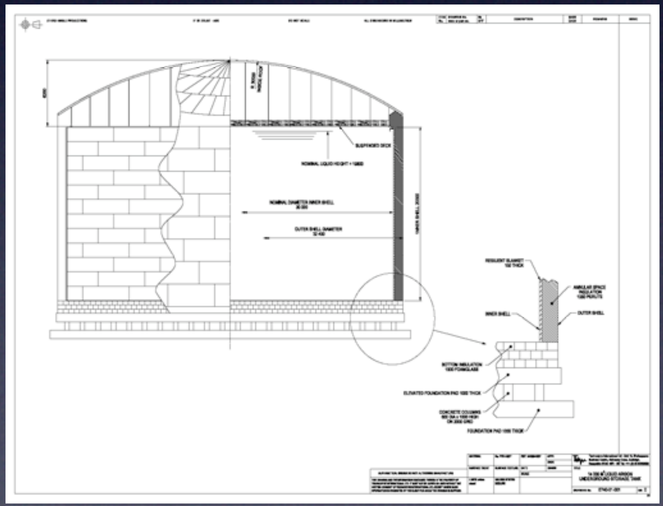
Large LNG scaling parameters

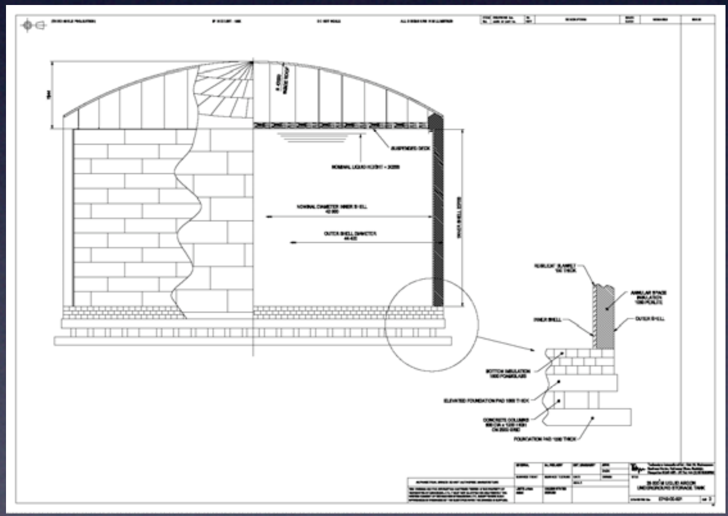
100 kton:
$\phi \approx 70$m,
$h \approx 20$m

Dewar	$\phi \approx 70$ 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 $\approx 15\%$
Argon total mass	102000 tons
Hydrostatic pressure at bottom	3 atmospheres
Inner detector dimensions	Disc $\phi \approx 70$ 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 γ counting capability

10 kton → 20 kton → 40 kton



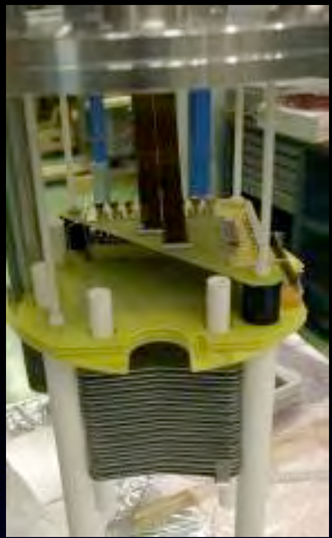




Φ=30 m, h=10 m → Φ=30 m, h=20 m → Φ=40 m, h=20 m

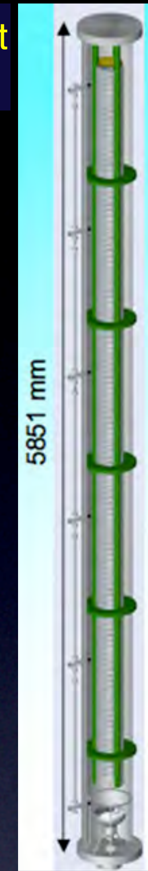
1 kton: near ν’s source, engineering detector, $\phi \approx 12$m, $h \approx 10$m, near surface

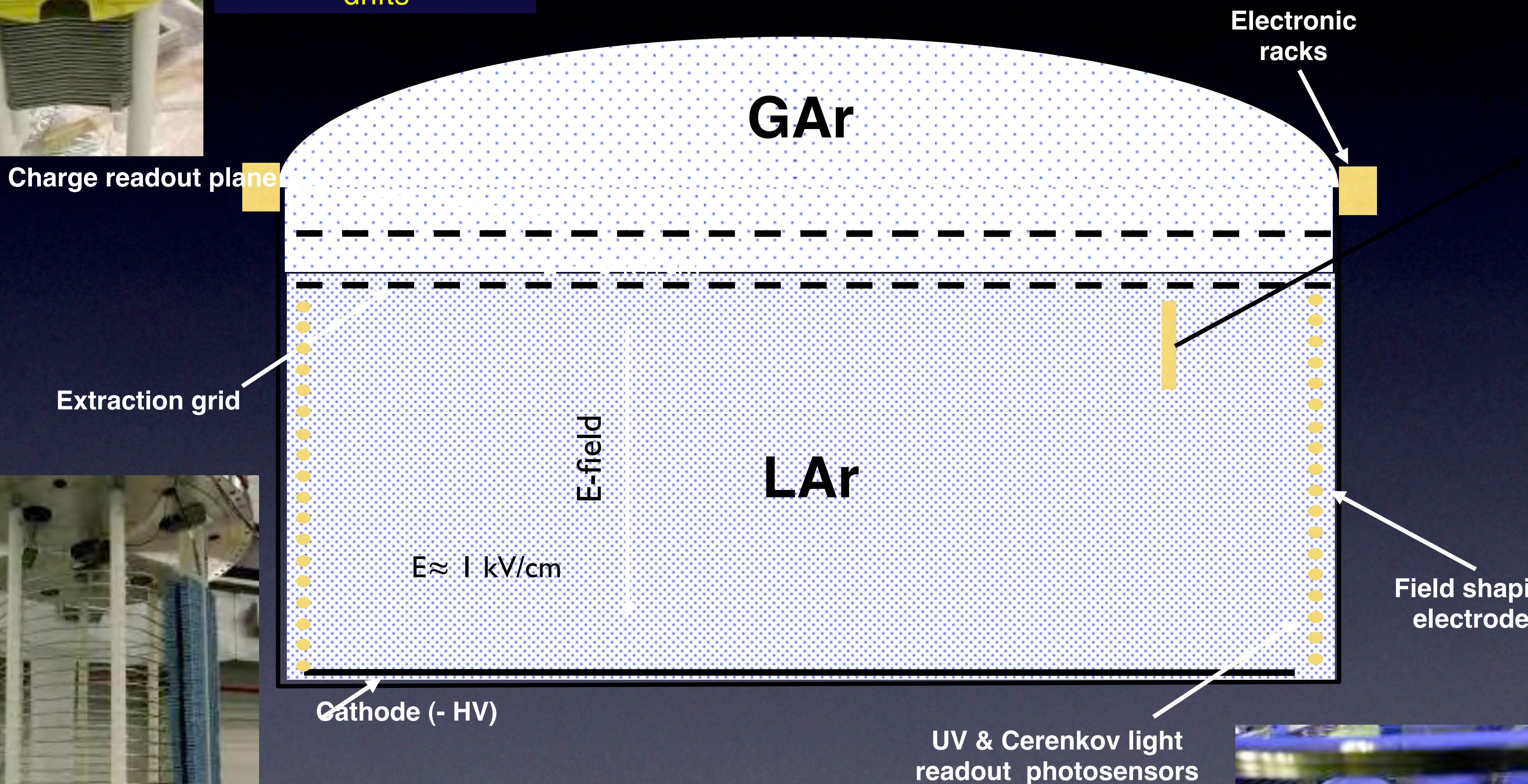
R&D on scalability of liquid Argon detectors (GLACIER)

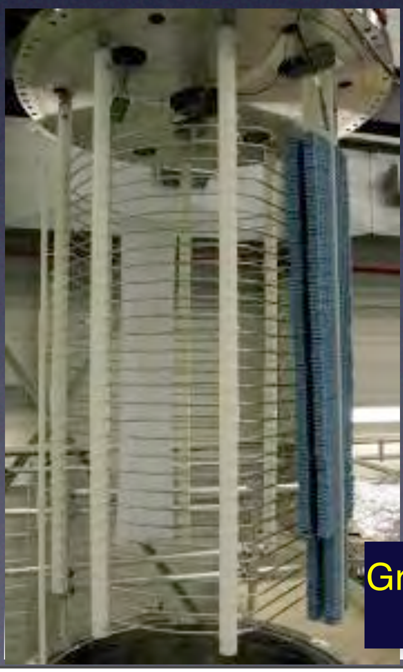


Charge readout with extraction from liquid phase & amplification in gas phase for long drifts

ArgonTube: 5 m drift test

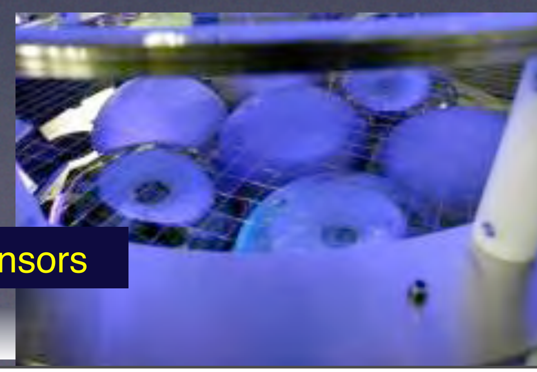






Greinacher voltage multiplier up to MV

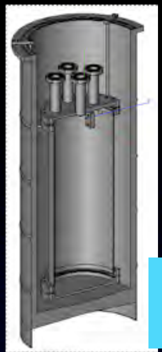
Large area DUV sensitive photosensors

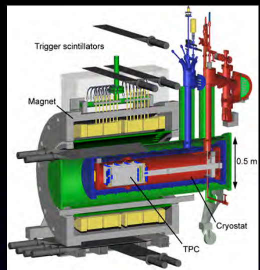


GLACIER steps

Present tests

≈ 5 lt

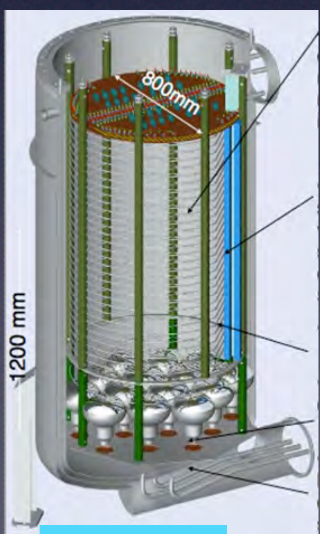




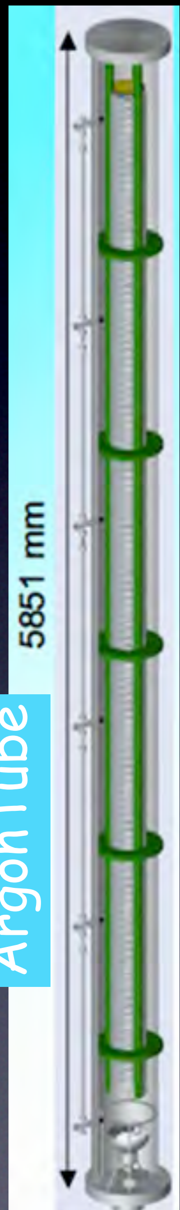
B-field test

LEM test stand

≈ 0.8 ton



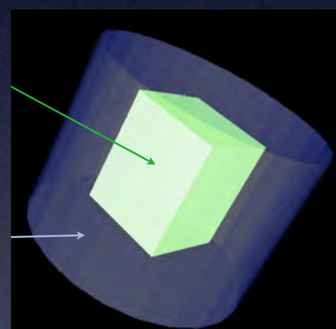
ArDM 2008



ArgonTube

2009

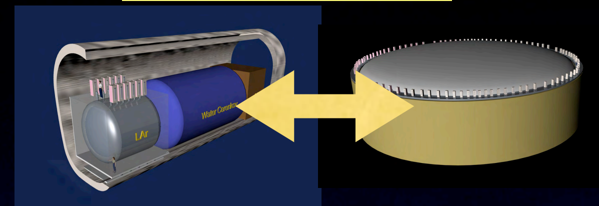
"Small" size detectors



≈ 1-10 ton

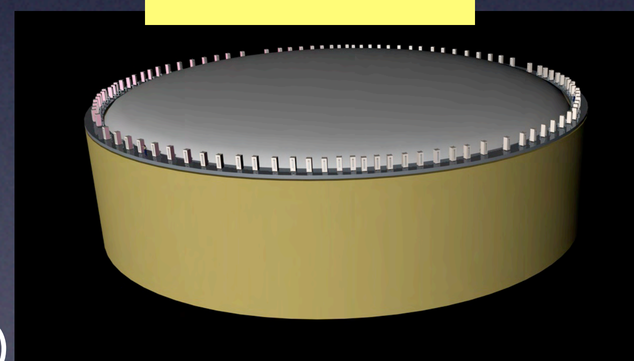
Electron/π^0 separation
Neutrino beam (vtx detector)
Test beam
2010 ?

Near detector



0.1÷1 kton
near location
2012 ?

Far detector

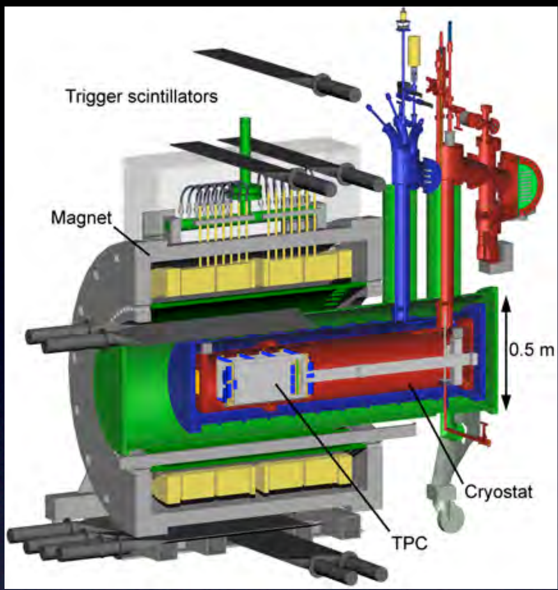


100 kton total mass
Proposal 2014 ?

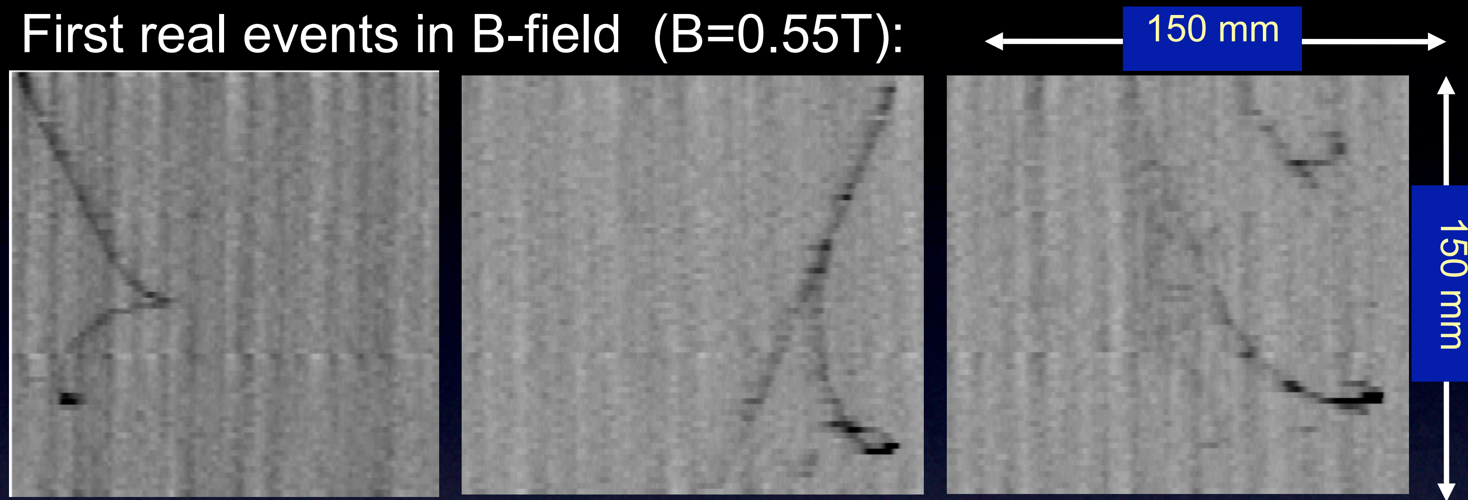
First operation of a LAr TPC embedded in a B-field

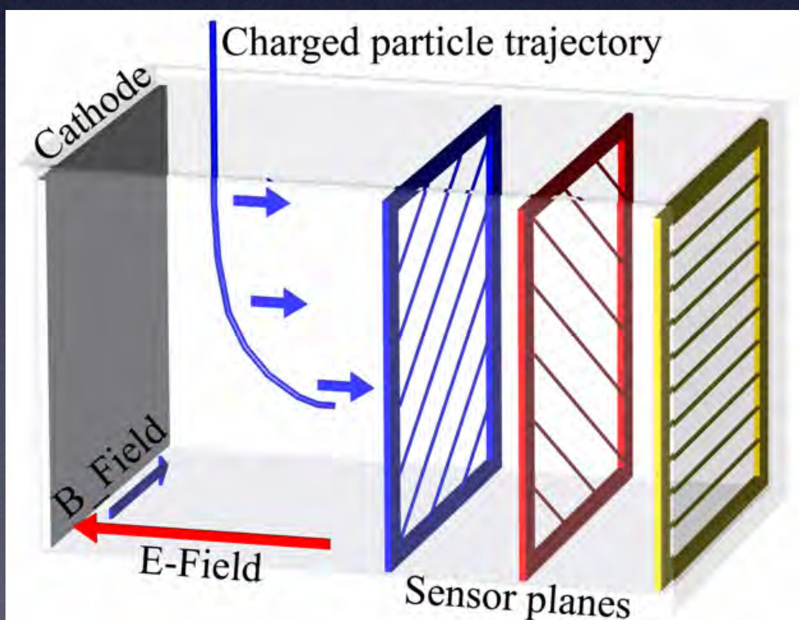
➠ *Also for the NF...*

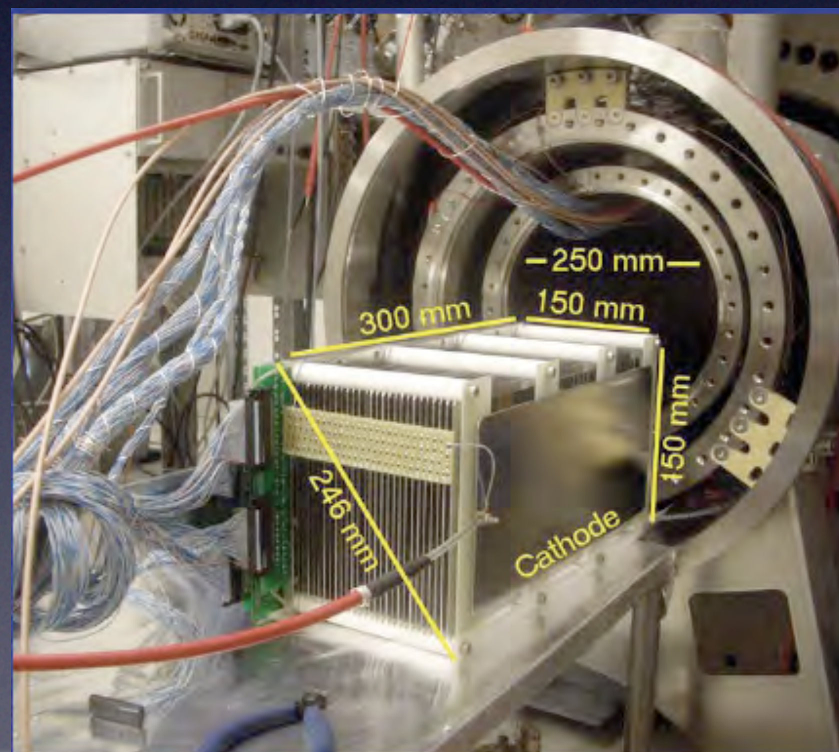
New J. Phys. 7 (2005) 63
NIM A 555 (2005) 294



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

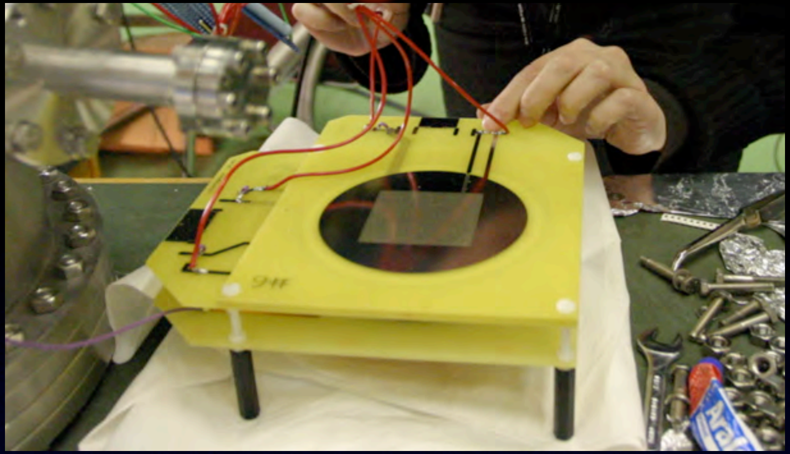




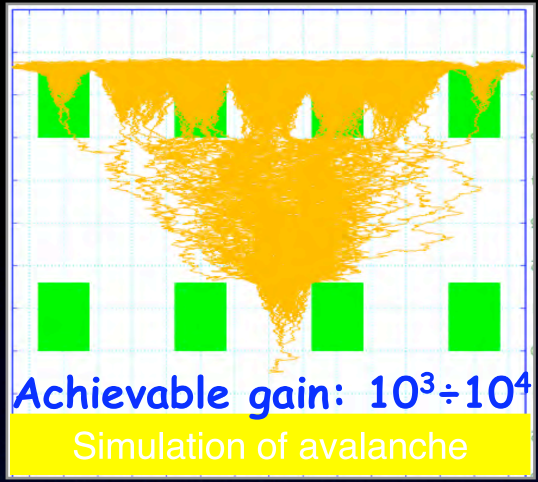


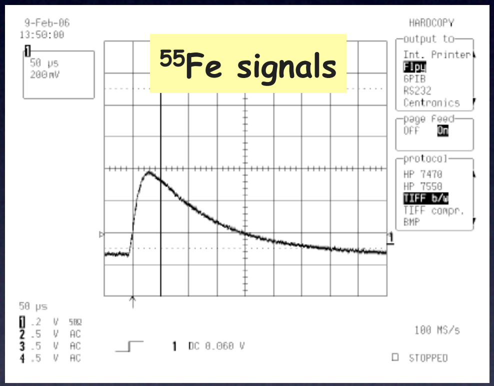
Thick Large Electron Multiplier (LEM)

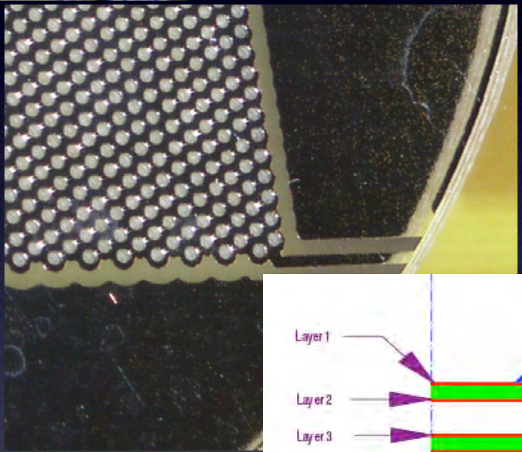
GEM: F. Sauli, NIM A386 (1997) 531
Optimized GEM: V. Peskov et al., NIM A433 (1999) 492
THGEM: R. Chechik et al., NIM A535 (2004) 303
P. Otiougova (for ArDM Coll.), Proc. TAUP '07



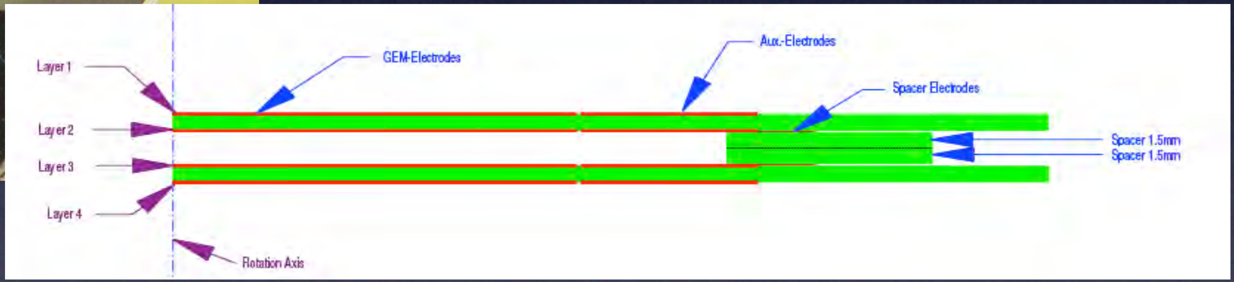
- Double-sided copper-clad (35 µm layer) G-10 plates
- Precision holes by drilling
- Palladium deposition on Cu (<~ 1 µm layer) to avoid oxidization
- Two stages

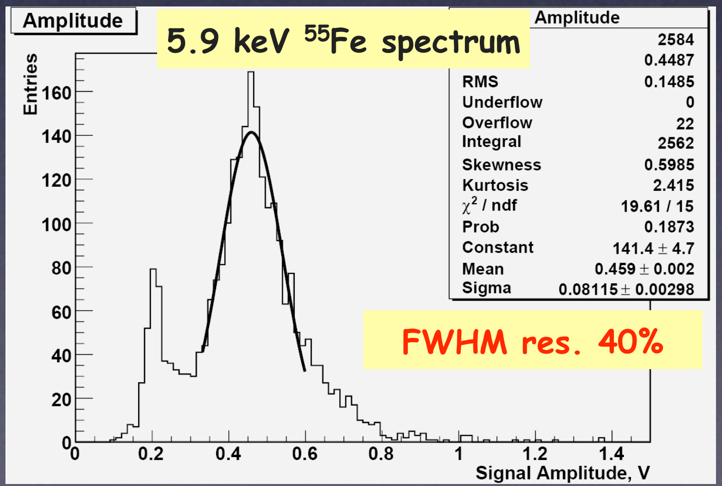






Produced by standard Printed Circuit Board methods

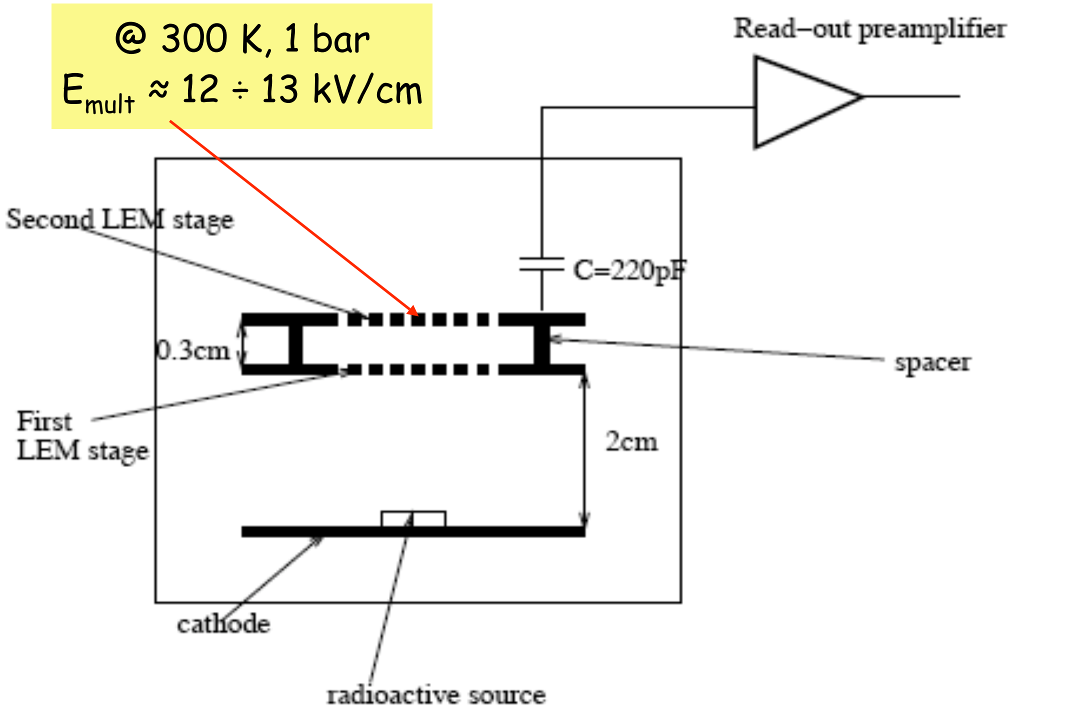


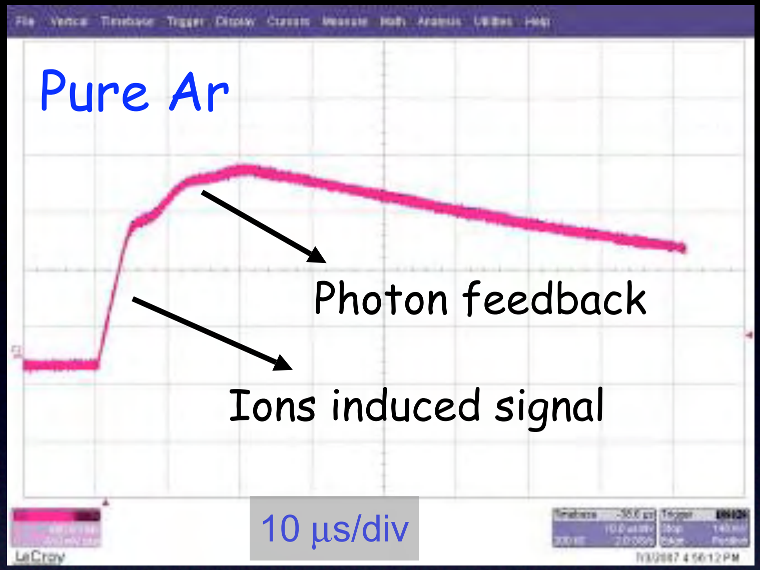


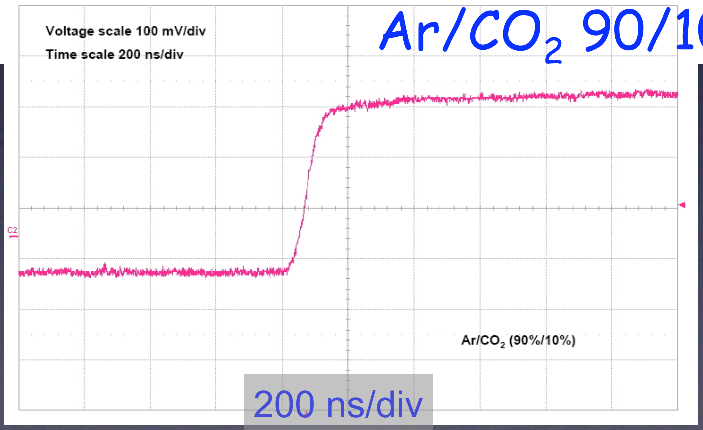
- Single LEM Thickness: 1.5 mm
- Amplification hole diameter = 500 μm
- Distance between centers of neighboring holes = 800 μm
- Distance between stages: 3 mm
- Avalanche spreads into several holes at second stage
- Good stability

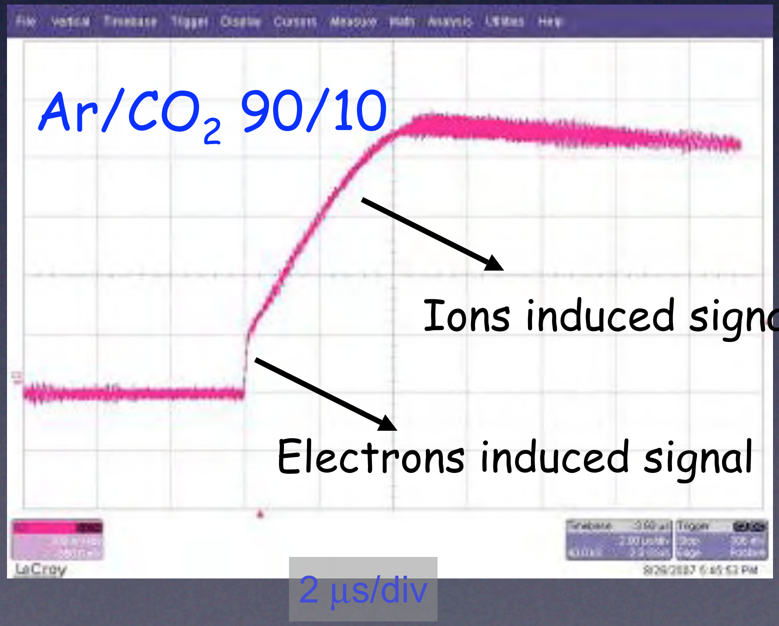
LEM operation at room temperature

@ 300 K, 1 bar
$E_{mult} \approx 12 \div 13$ kV/cm



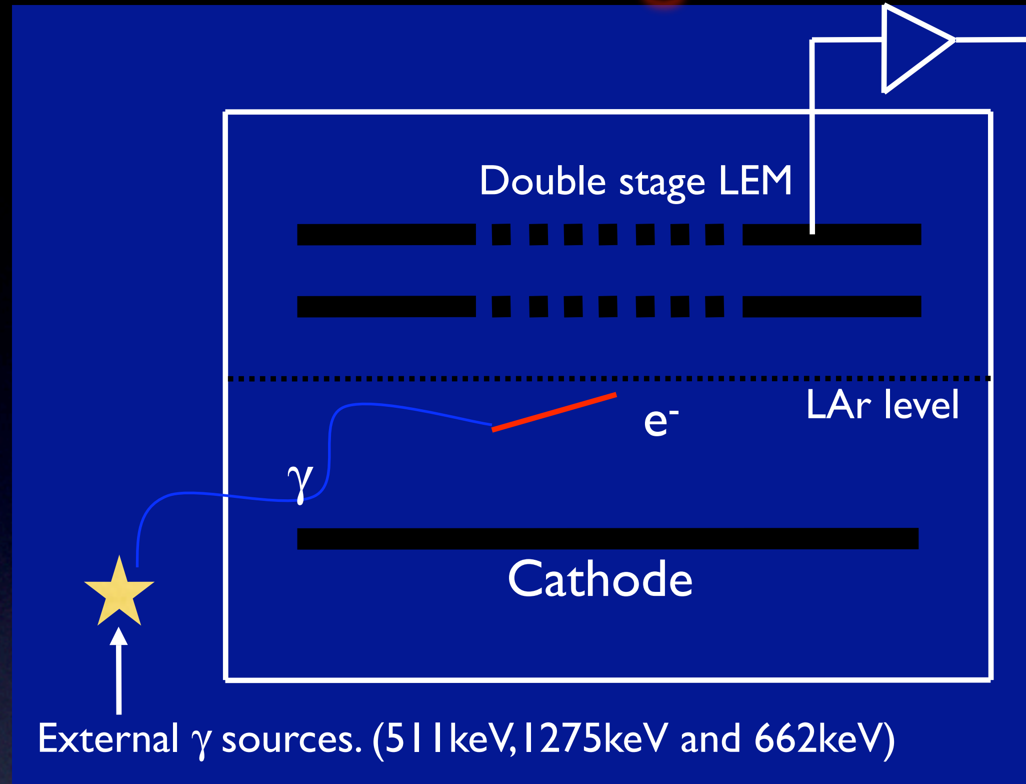


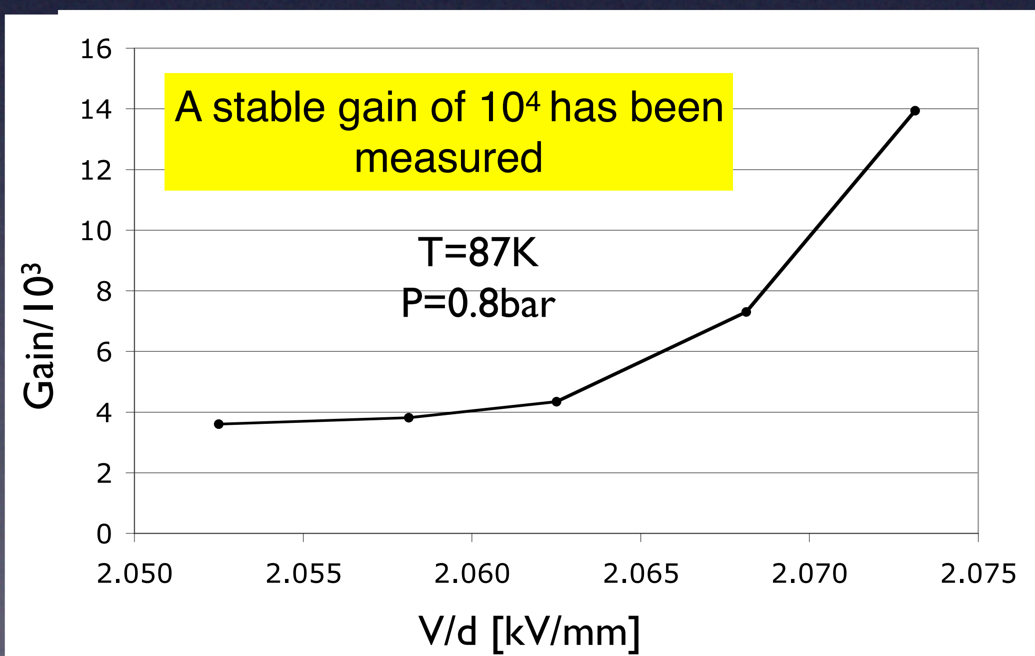


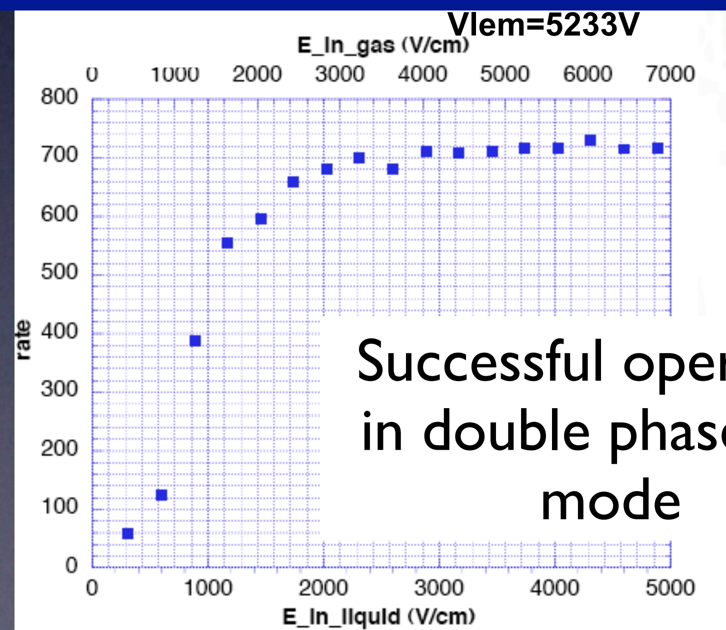


Faster signal achieved by drifting electrons to an anode and so enhancing the electron component signal

Liquid-vapor phase operation with two stages LEM

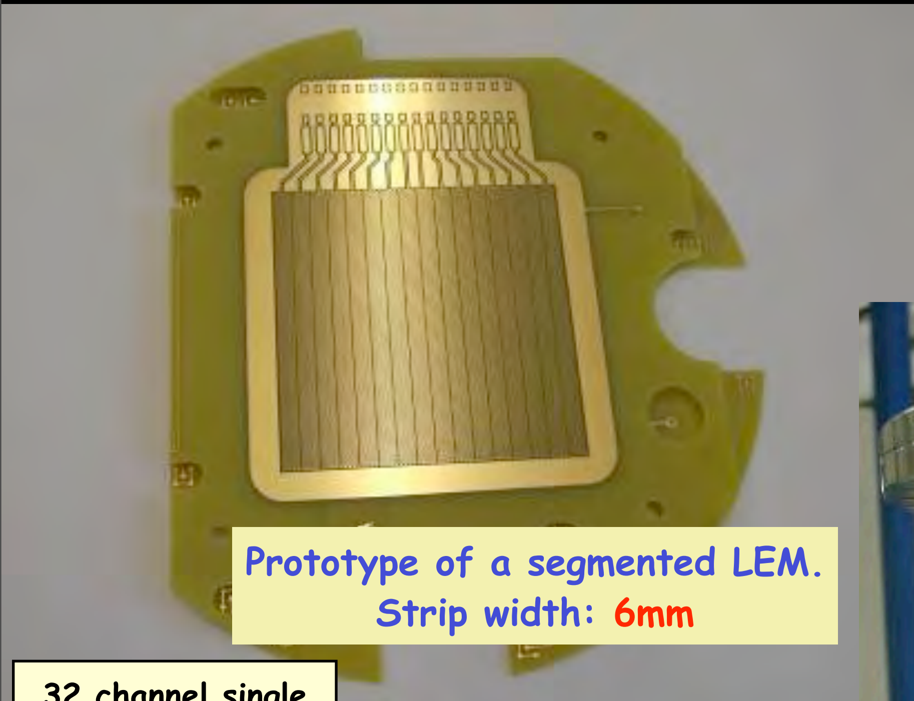






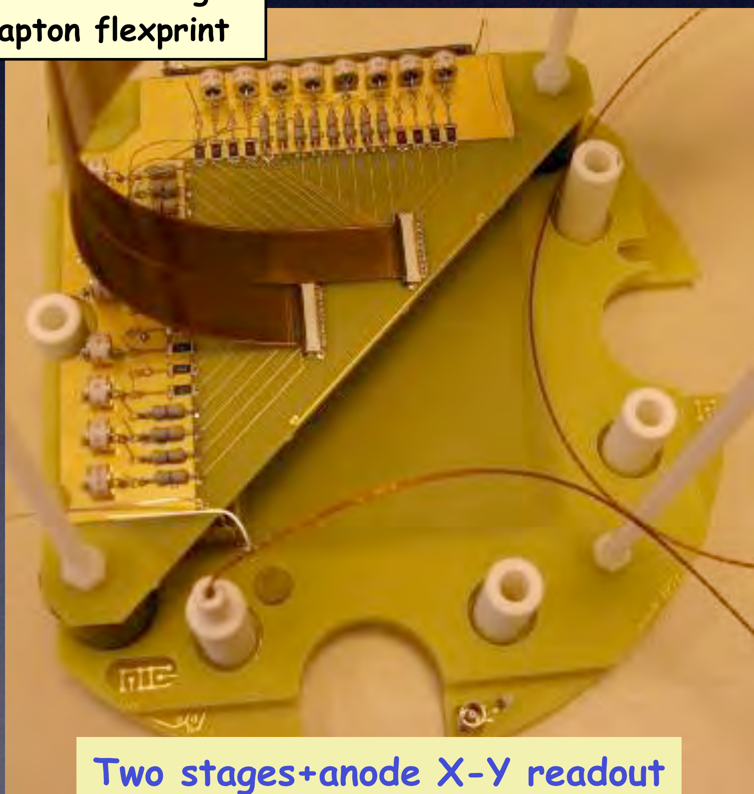
Successful operation in double phase LAr mode

Prototype segmented LEM-TPC readout

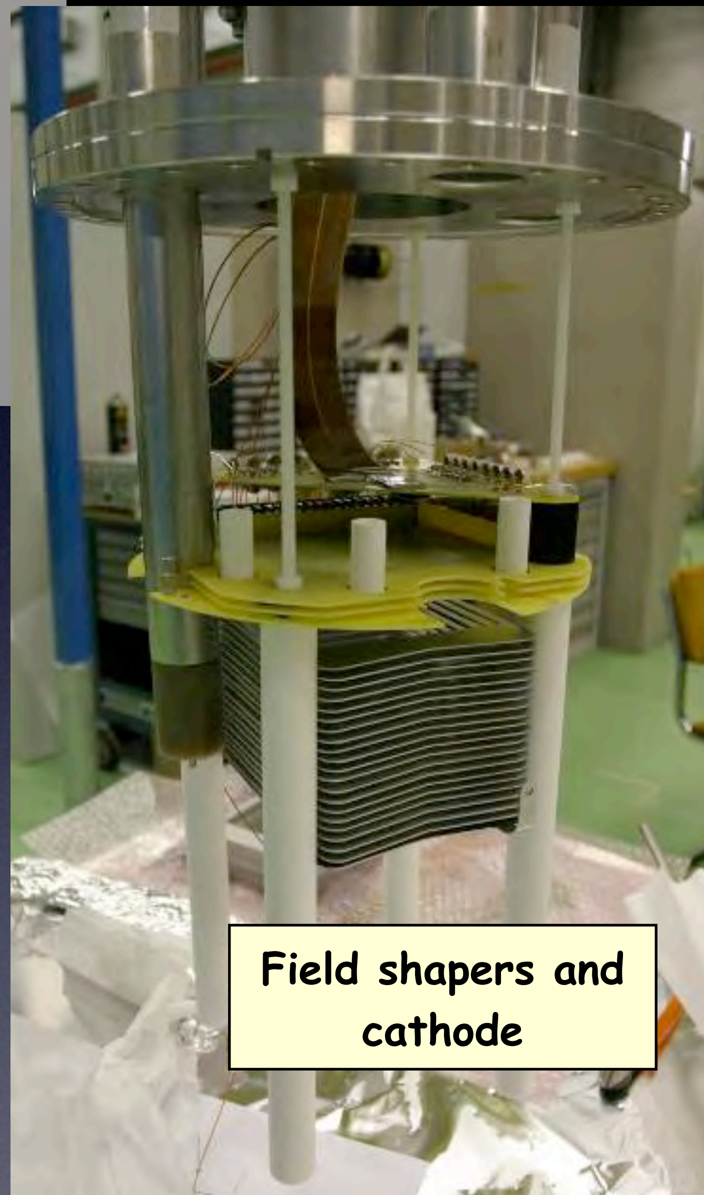


Prototype of a segmented LEM. Strip width: 6mm

32 channel single kapton flexprint

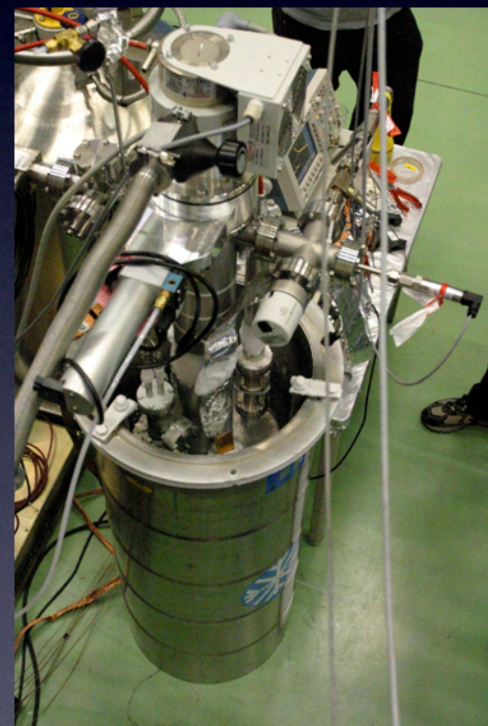


Two stages+anode X-Y readout



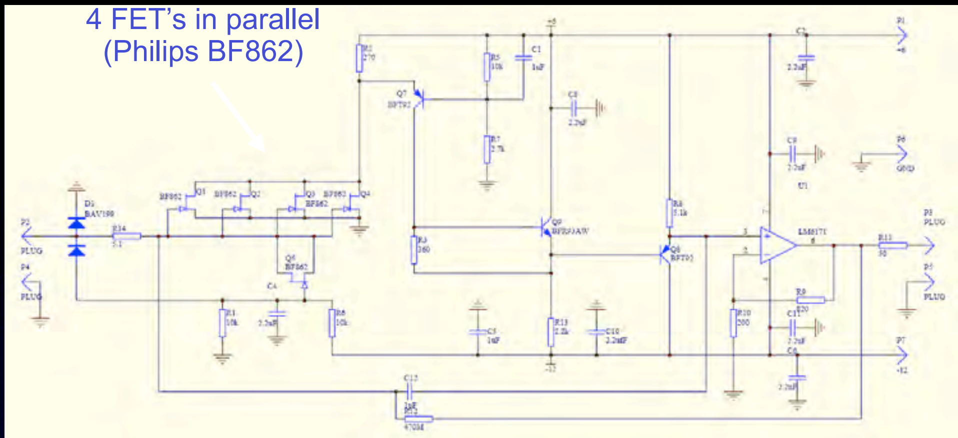
Field shapers and cathode

Cryogenic setup



LEM-TPC Readout Electronics

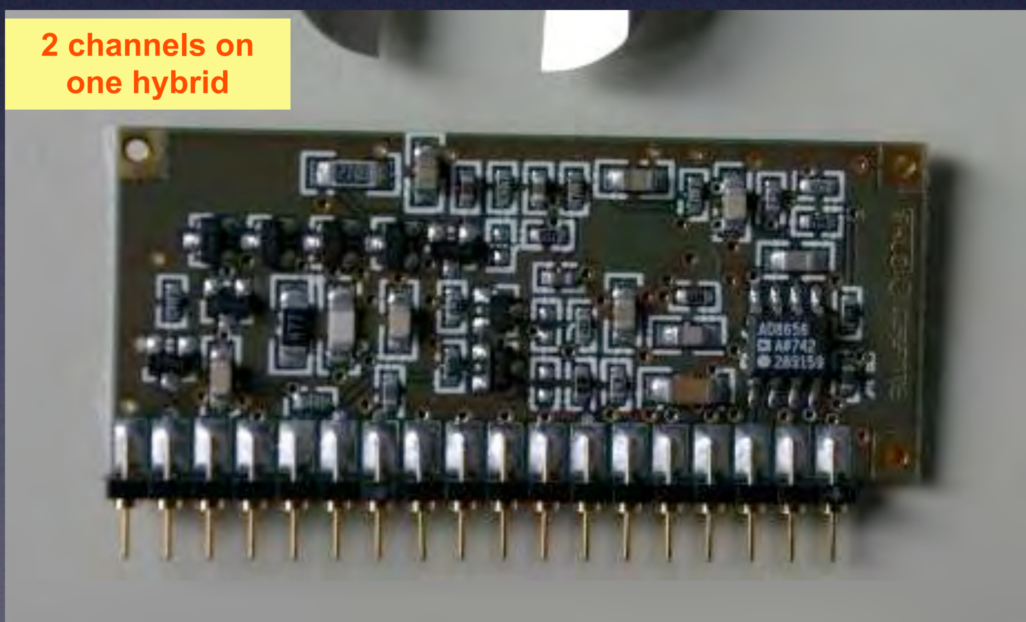
Low noise charge preamp inspired from
C. Boiano et al. IEEE Trans. Nucl. Sci. 52(2004)1931

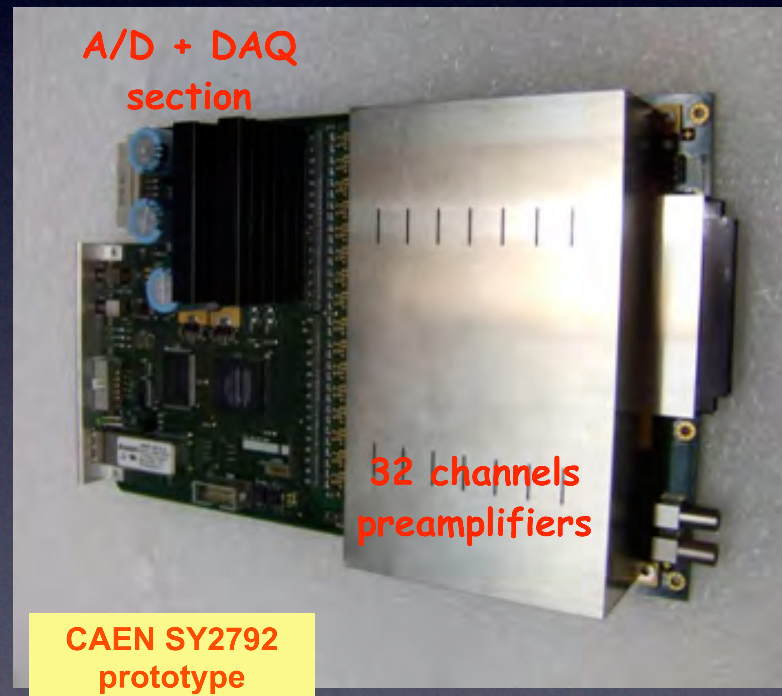


CAEN, in collaboration with ETHZ, developed A/D conversion and DAQ system:

2.5 MHz serial ADC + FPGA + dual memory buffer + CAEN optical link

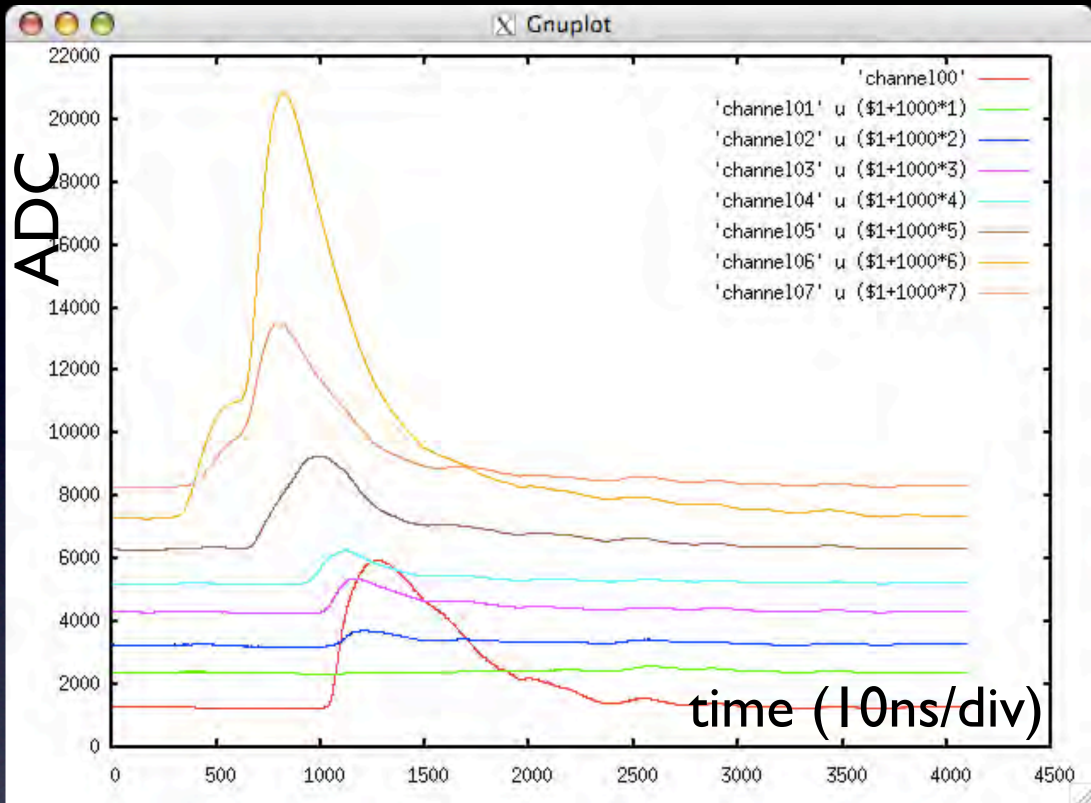
ETHZ design front-end charge preamp + shaper
G ~15mV/fC, S/N ~10 @ 1fC for C_i=200 pF

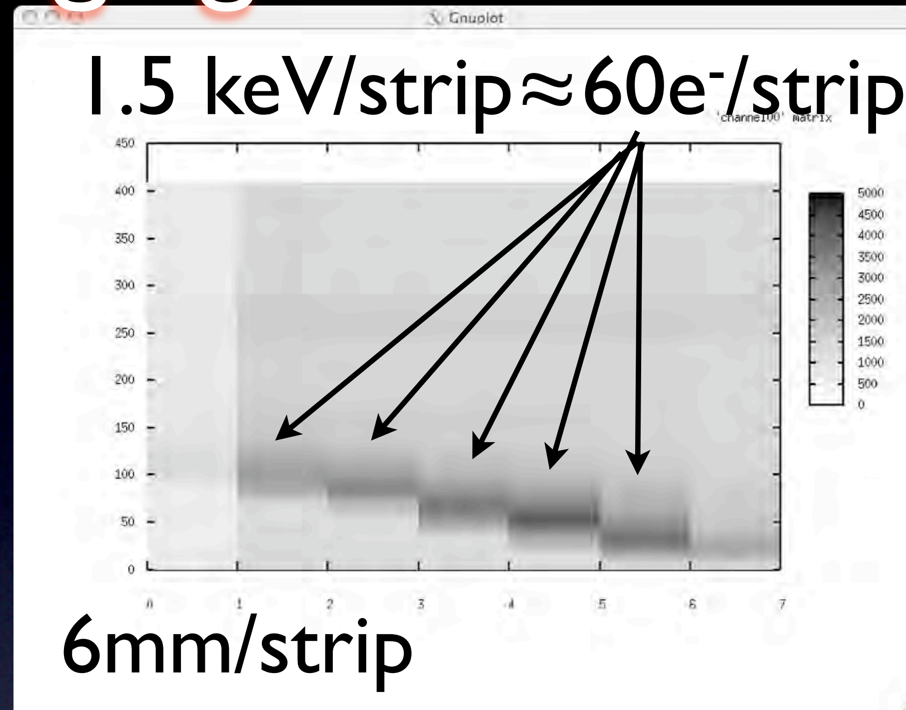


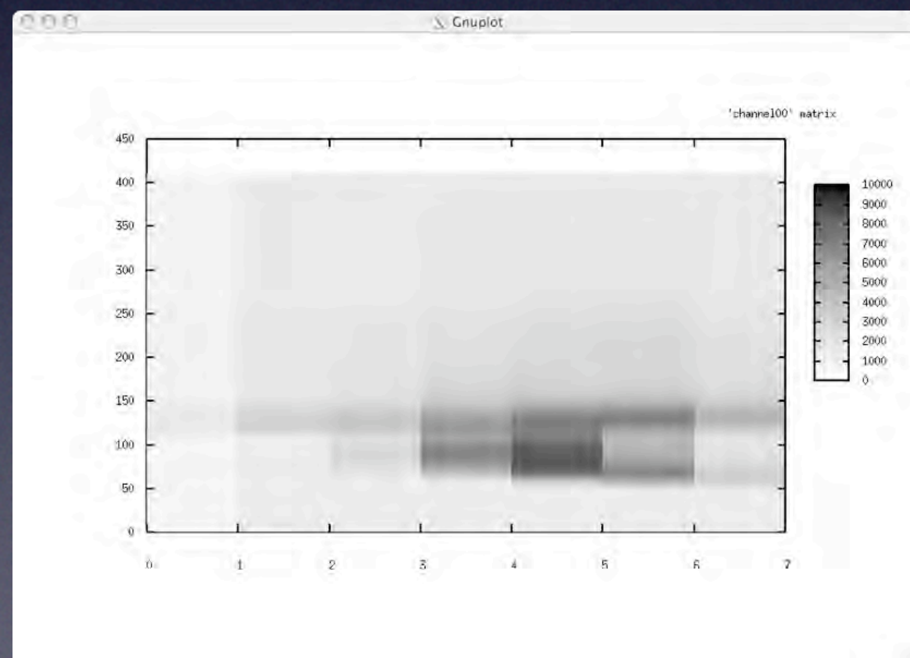


Development of F/E preamp in cold operation with IPN Lyon

LEM-TPC as imaging device







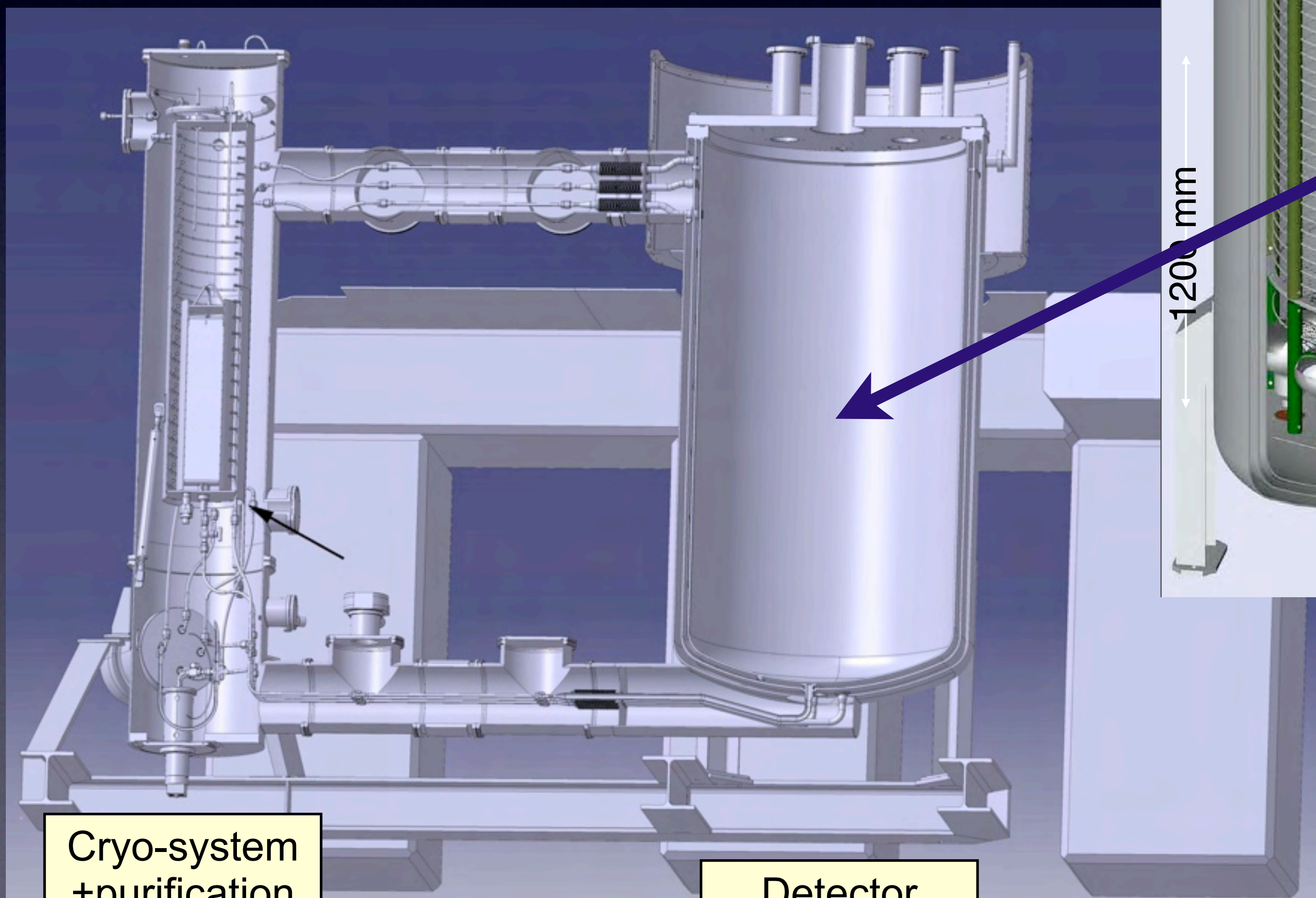
- Tracks observed in gas
- Cryogenic operation presently being tested

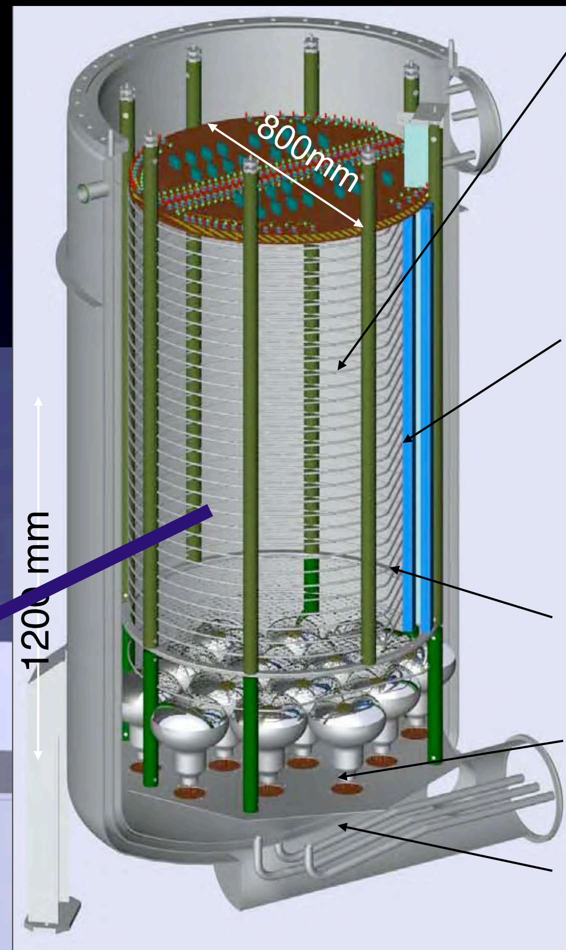
ArDM experiment

ETHZ, Zurich, Granada, CIEMAT, Soltan, Sheffield

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

Ton-scale double phase LAr LEM-TPC for nuclear recoil detection

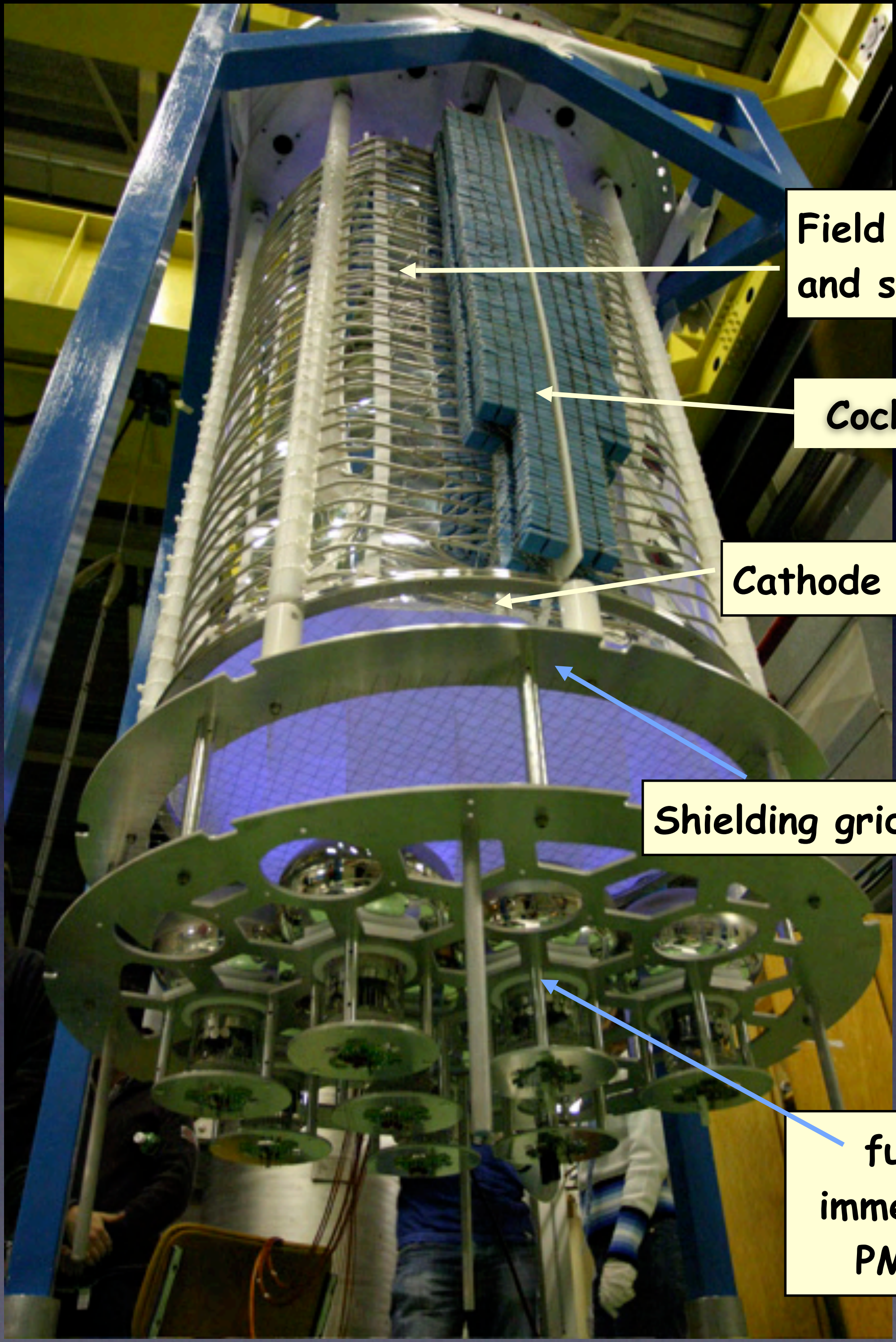




- Two-stage LEM for electron multiplication and readout to measure ionization charge
- Greinacher chain: supplies the right voltages to the field shaper rings and the cathode up to 500 kV
- Field shapers
- Transparent cathode
- Photodetectors below the cathode to detect the scintillation light

14 PMTs

ArDM inner detector



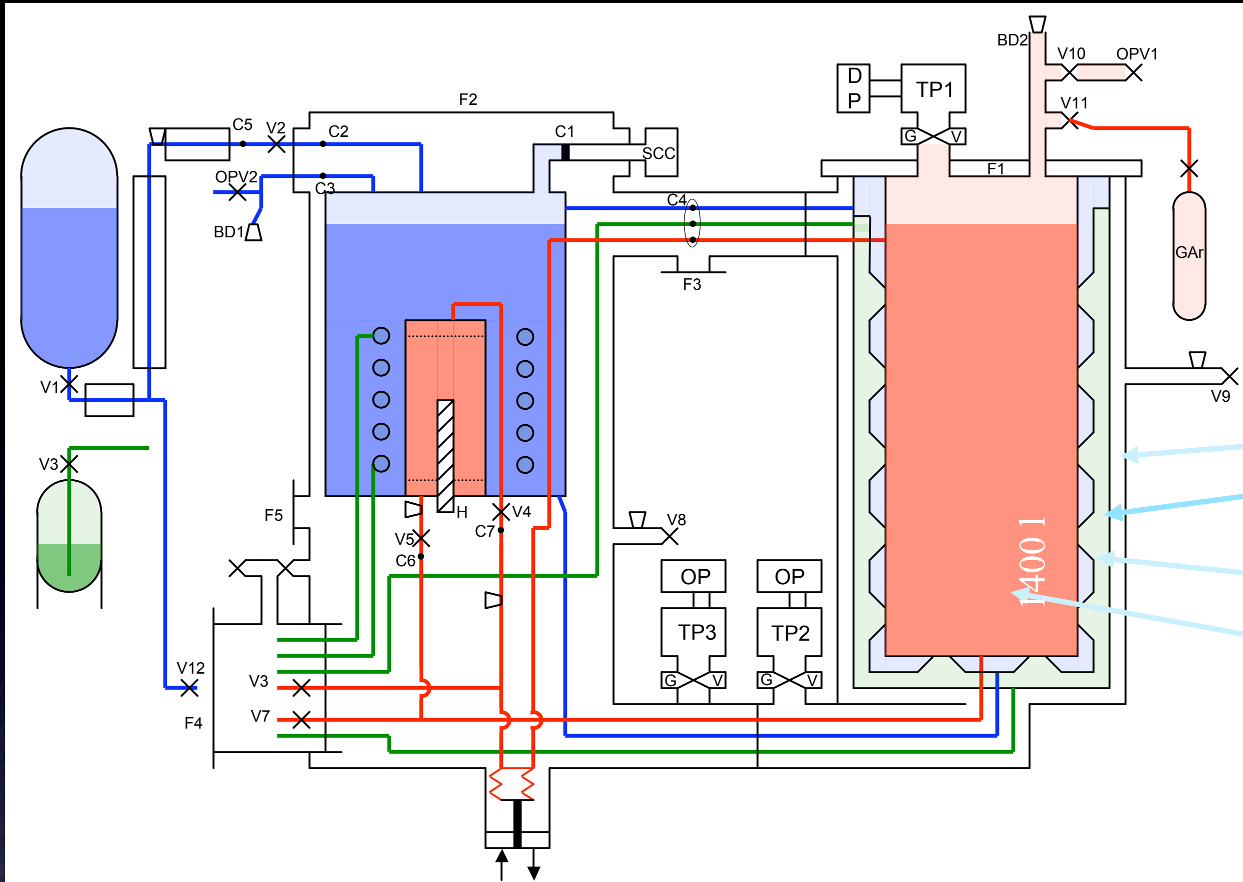
Detector illuminated with UV lamp

ArDM surface test @ CERN

- ✓ *Assembly finished*
- ✓ *Vacuum fully commissioned*
- ✓ *Cryo system OK*
- ✓ *HV system OK*
- ✓ *Safety aspects reviewed*
- ✓ *Light collection & detection in gas OK*

First fill with LAr in the coming weeks

Cryogenics and LAr purification

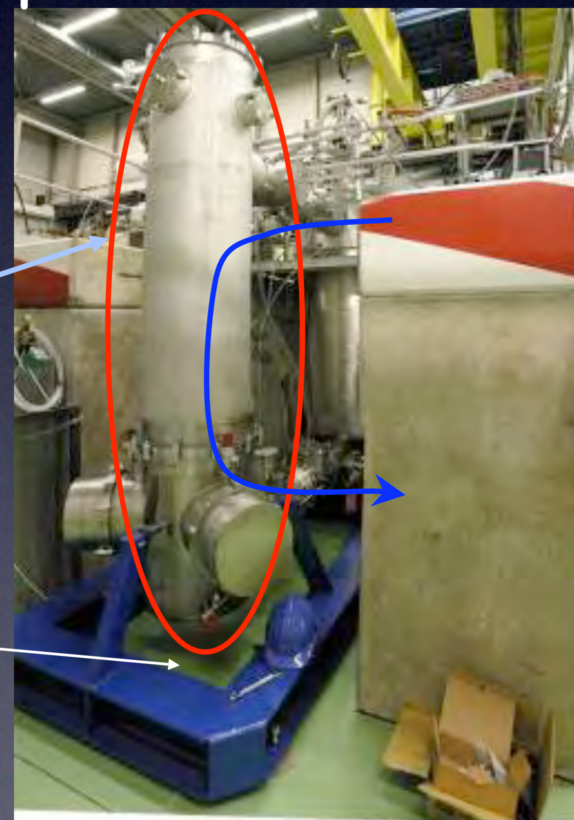


vacuum insulation

LN2 cooling jacket

'dirty' LAr cooling bath

pure LAr closed circuit



Recirculation and CuO purification cartridge (ETHZ design)

BIERI engineering Winterthur, Switzerland

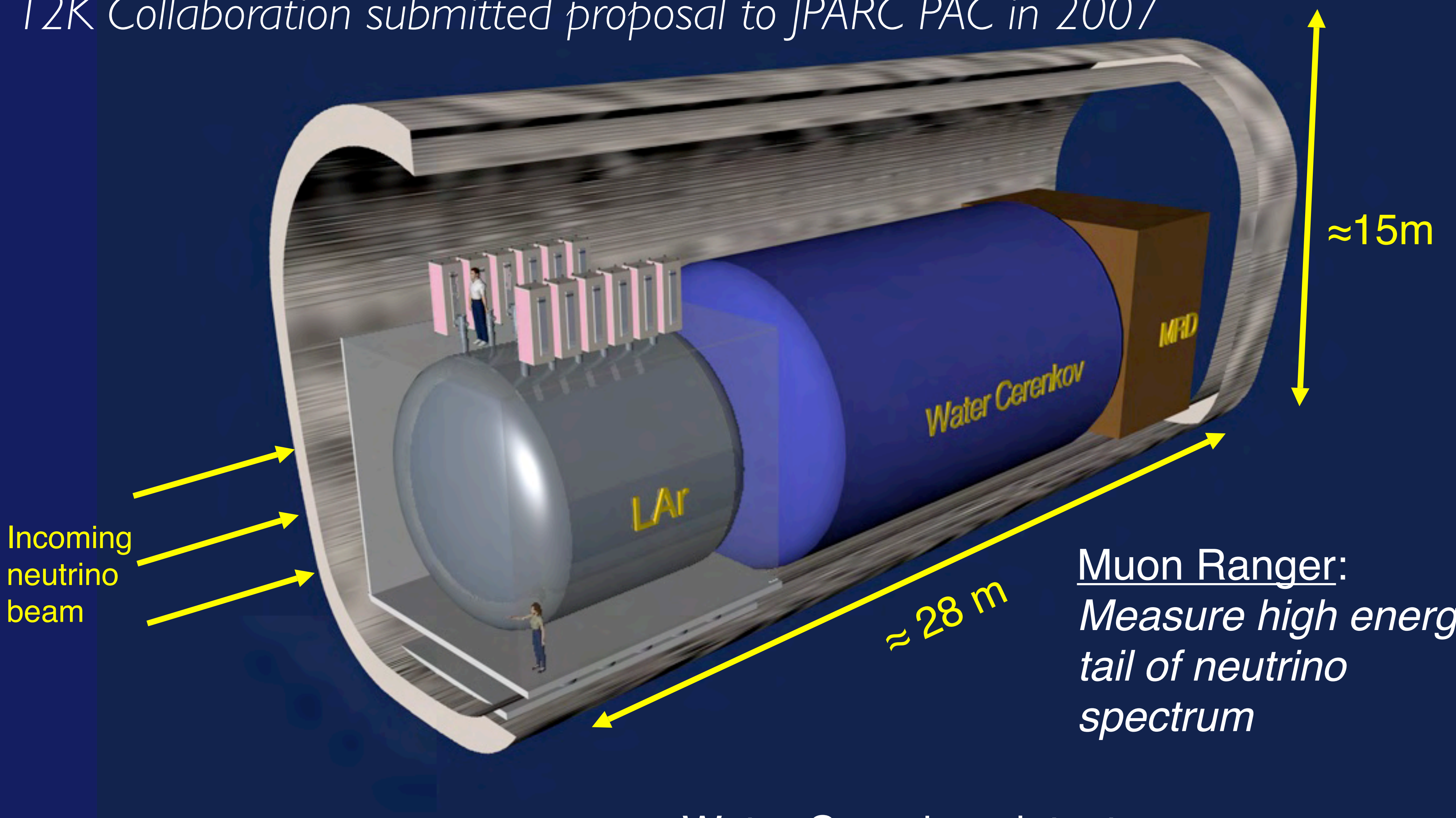
Bellow pump (Bieri design) up to 30 l/h

Further steps on LAr TPC...

- The construction and operation of a 100 kton liquid Argon TPC certainly represents a technological challenge at the present state of knowledge of the technique.
- For it to become a realistic option, further R&D and dedicated experimental measurement campaigns are required.
- At this stage, we intend to pursue our investigations on a ton-scale prototype based on the novel double-phase readout imaging method.
- Options to operate small devices in a neutrino beam are being assessed in parallel.
- In addition, we have started to address the possibility of an "intermediate" prototype

Potential new 2km site at JPARC

T2K Collaboration submitted proposal to JPARC PAC in 2007



Muon Ranger:
Measure high energy tail of neutrino spectrum

Liquid Argon detector:
Exclusive final states
Frozen water target

Water Cerenkov detector:
Same detector technology as SK
≈1 interaction/spill/kton

or a O(1 kton) near detector ??

- Address the possibility of an "intermediate" prototype of 100 kton.
  ➡ **1 kton near surface, near detector**
- ≈2x ICARUS T600
- Tank and detector design and engineering, and construction would based on a similar but scaled down techniques of the potential 100 kton detector.
  - ➡ rely on industrial techniques
  - ➡ actual proof of concepts, ready to be scaled up
- Physics goals, e.g.:
  - ➡ High statistics neutrino interactions
  - ➡ Neutrino energy resolution
  - ➡ Neutrino electron signal background suppression (e/π0)
  - ➡ Direct cross-check with other near detectors in same beam
  - ➡ ...
- Timescale ≈ 2012 ?

Conclusion

- Key questions in particle and neutrino astroparticle physics can be answered only by construction of new giant underground observatories to search for rare events and to study sources of terrestrial and extra-terrestrial neutrinos.
- R&D and prototyping should proceed until proposals for next generation underground detectors will presumably be made around 2014.
- A potential European siting of next generation large underground detectors will be addressed with the LAGUNA DS.
- European and world-wide coordination is the only winning strategy to address projects of this scale. In addition, "accelerator-based" and "astrophysics" should be coordinated and considered as part of a single programme.

Thank you.