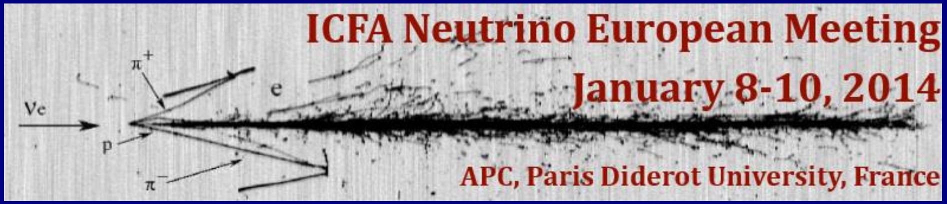


LBNO-Proto (WA105)

Double-phase liquid argon TPC prototyping efforts at CERN

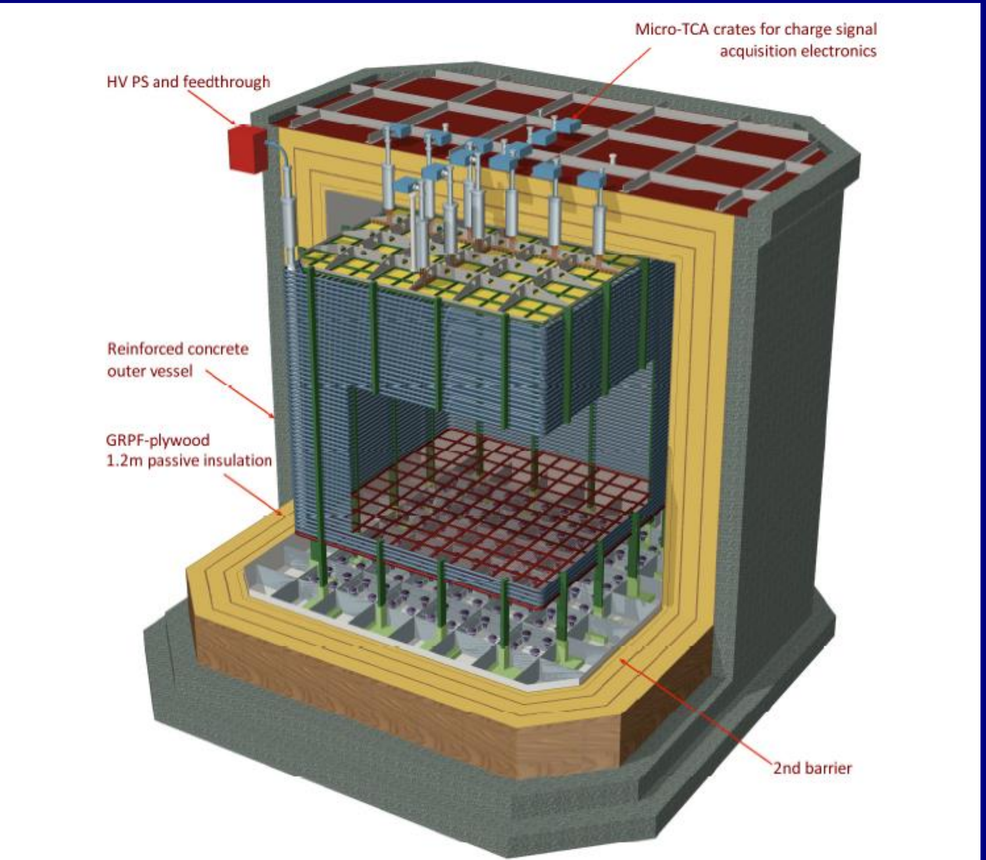
ICFA Neutrino European Meeting

Paris, January 10th 2014

D. Autiero (IPNL Lyon)

On behalf of the

WA105 proto–collaboration



The Liquid Argon Time Projection Chamber (C. Rubbia 1977)

- Homogeneous massive target and ionization detector → electronic bubble chamber

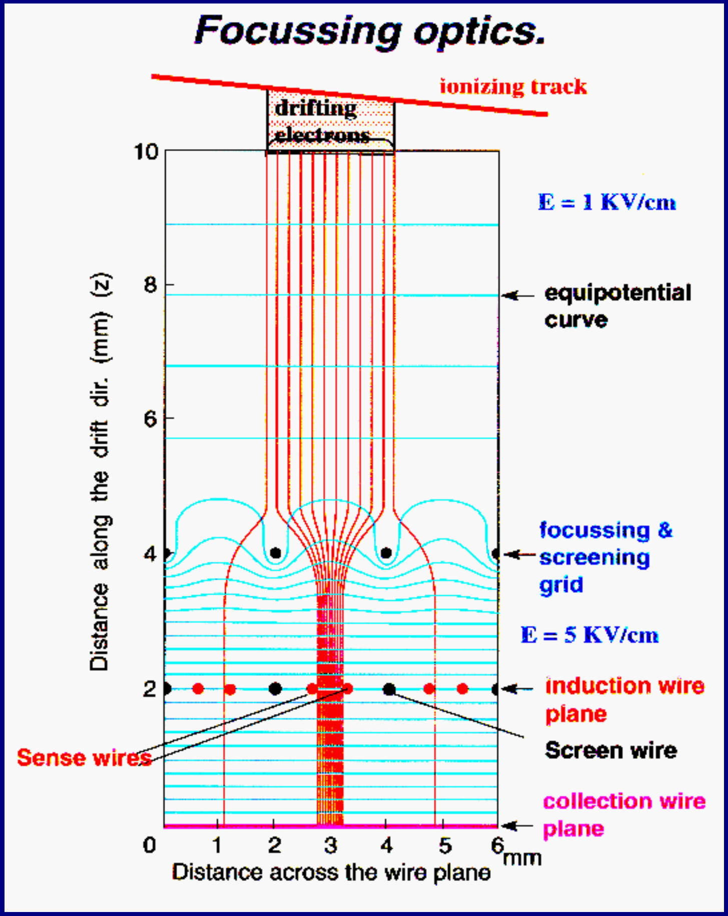
- 3D event reconstruction with ~1 mm resolution, Surface readout of instrumented volume

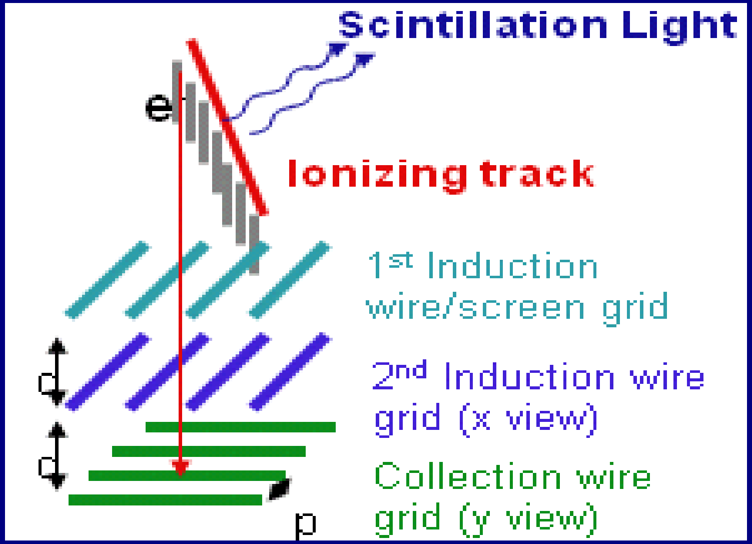
- High resolution calorimetry (electromagnetic and hadronic showers)

- Primary ionization in LAr: 1 m.i.p ~ 20000 e- on 3 mm

- Detection of UV scintillation light in LAr (5000 photons/mm at 128 nm) to provide t = 0 signal of the event

Ideal detector for neutrino oscillations, supernovae neutrinos and proton decay





X,Y
Non-destructive multiple readout with induction planes

Z = drift time

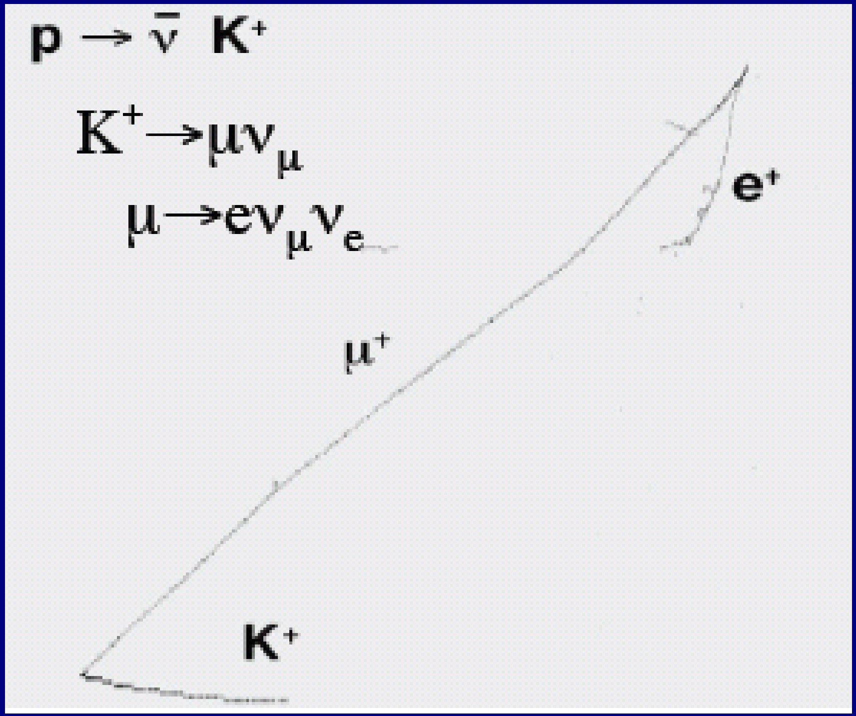
Drift Field: 0.5-1 kV/cm
Drift time:
2 m/ms @1 kV/cm

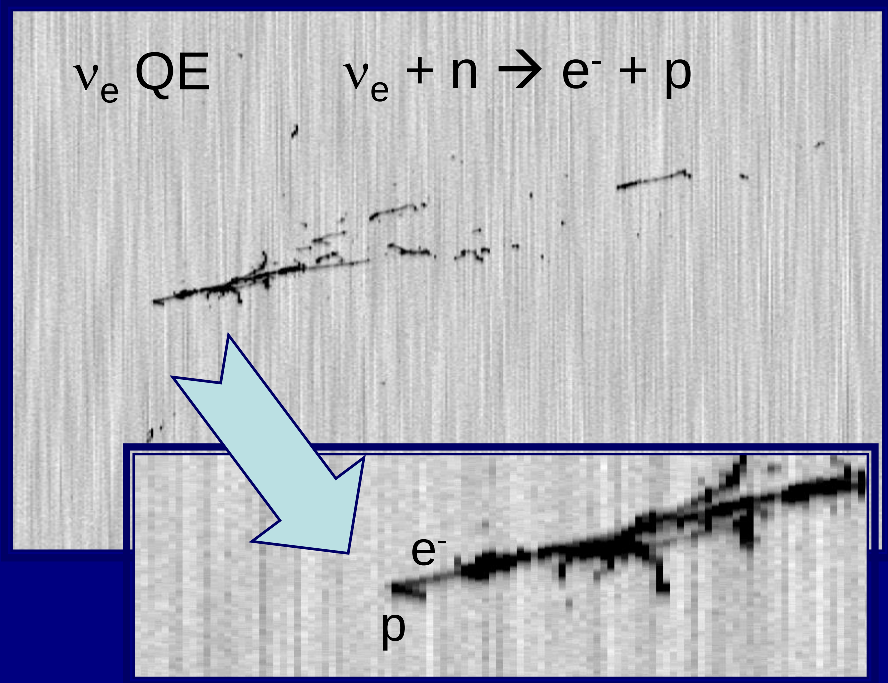
→ **drift requiring < 0.1 ppb O_2 equiv. impurities**

The LAr TPC as an electronic bubble chamber

- Large mass, homogeneous detector, low thresholds, exclusive final states
- Tracking + calorimetry (0.02 X0 sampling)
- **Electron** identification, π^0 rejection, particles **identification with dE/dx**

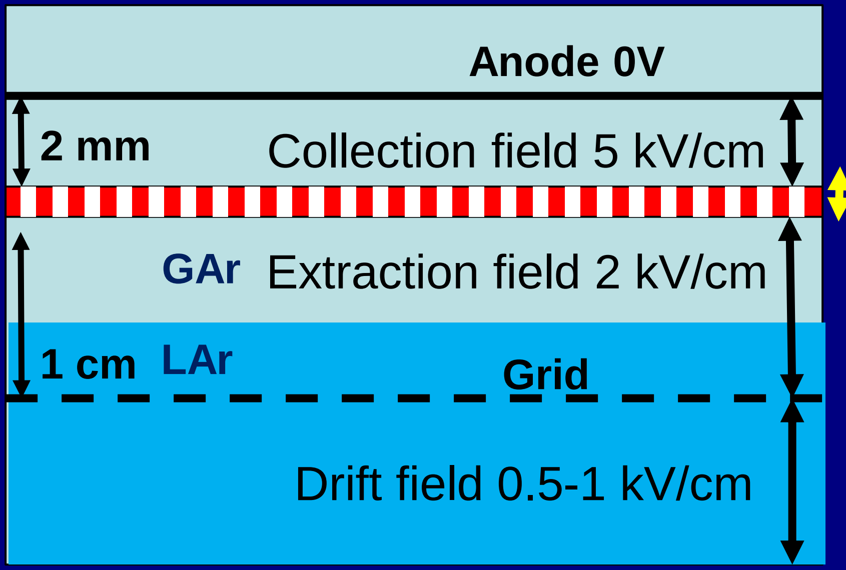
→ Neutrino physics (electron identification, reconstruction of event kinematics, identification of exclusive states, excellent energy resolution from sub GeV to multi GeV)
→ Supernovae neutrinos
→ Proton decay search (large mass, particles id.)

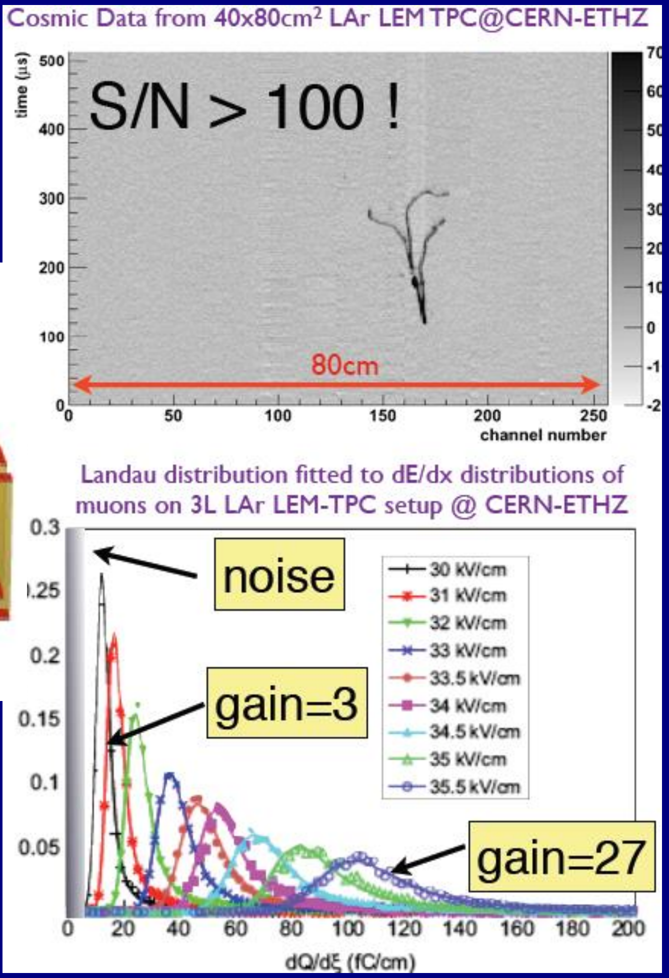


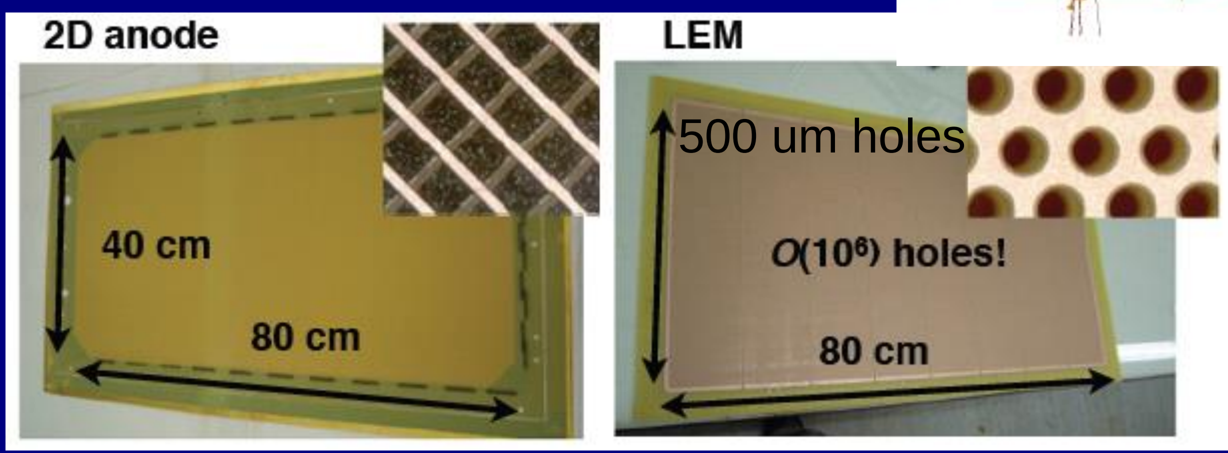


Double-phase readout:

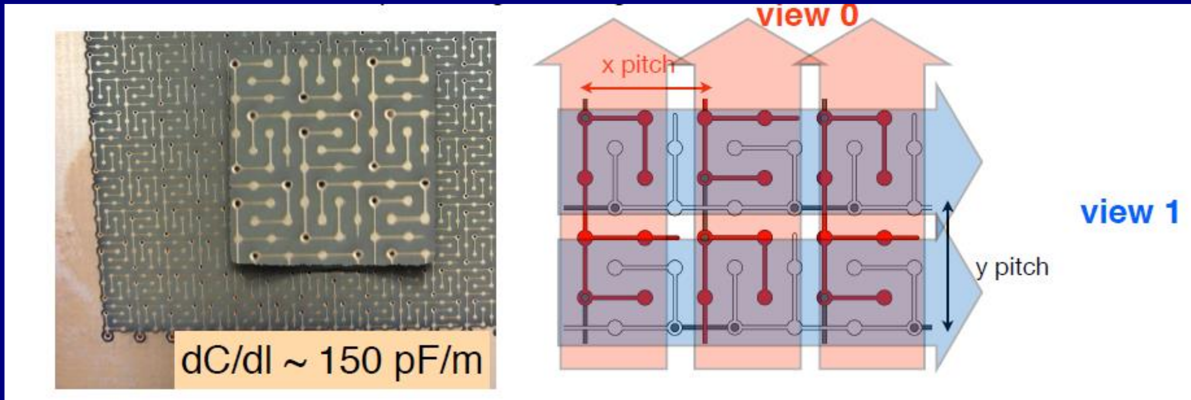
Compensate for long drift: extraction of electrons from the liquid and multiplication with avalanches in pure argon with detectors like LEM (Large Electron Multipliers) or 100 um bulk Micromegas.
Low gain (~20), coupling to cold electronics in integrated modules



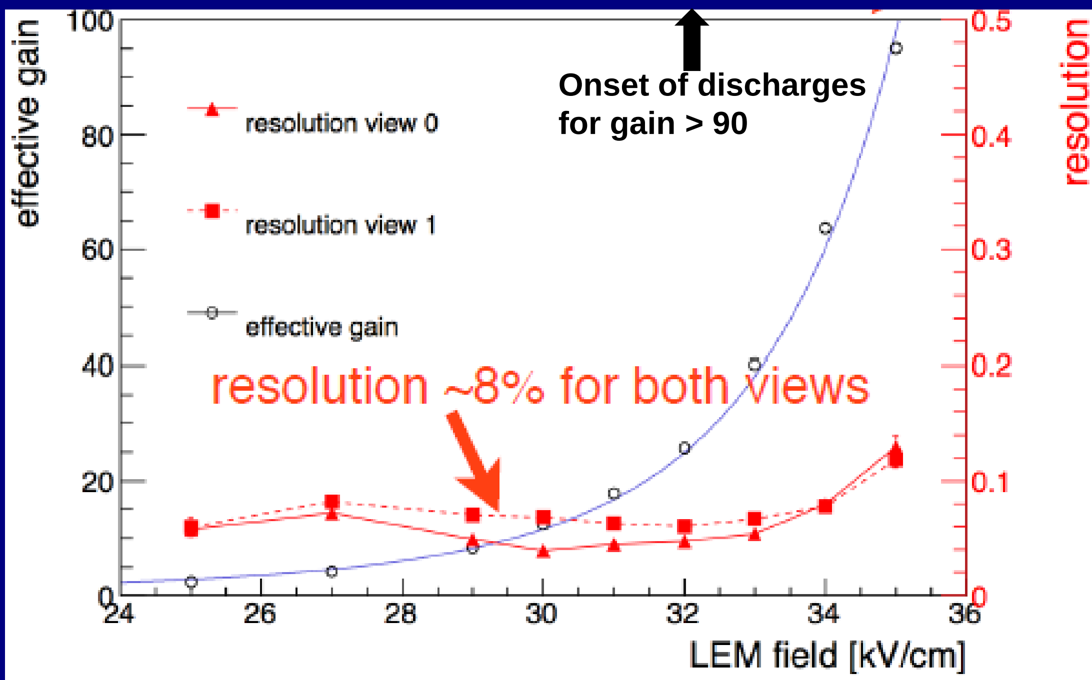


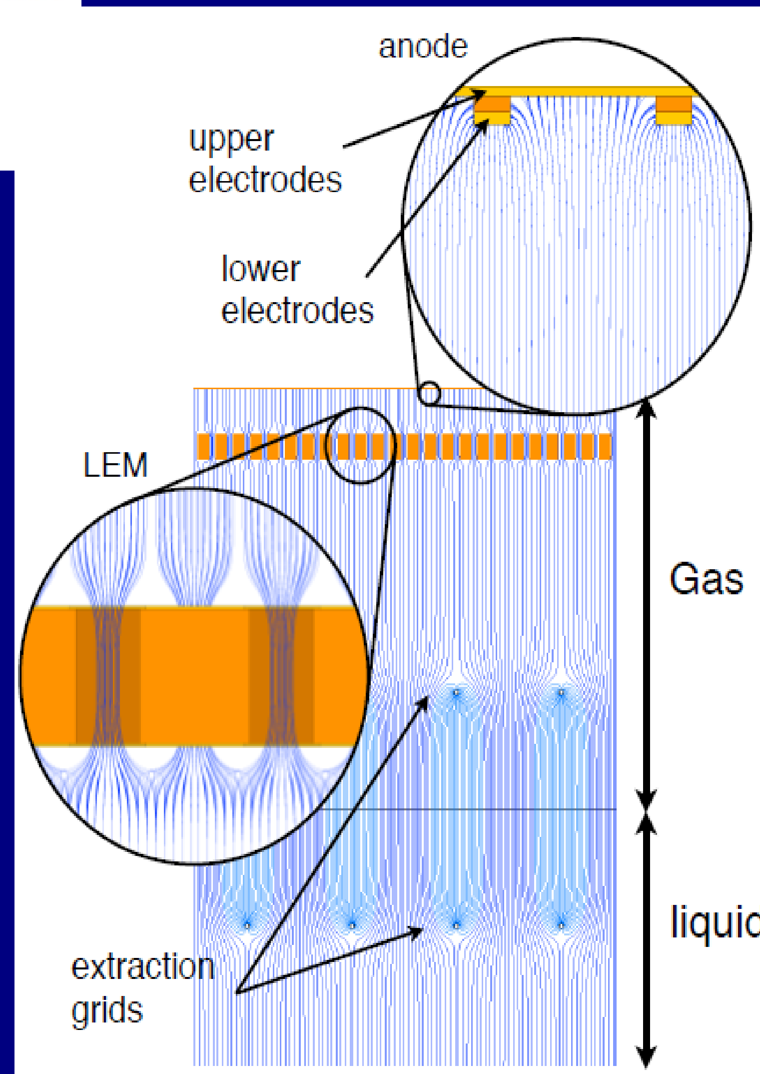


LEM charge readout: R&D results from long-standing prototyping tests



Multi-layer PCB anode with symmetric x-y charge sharing



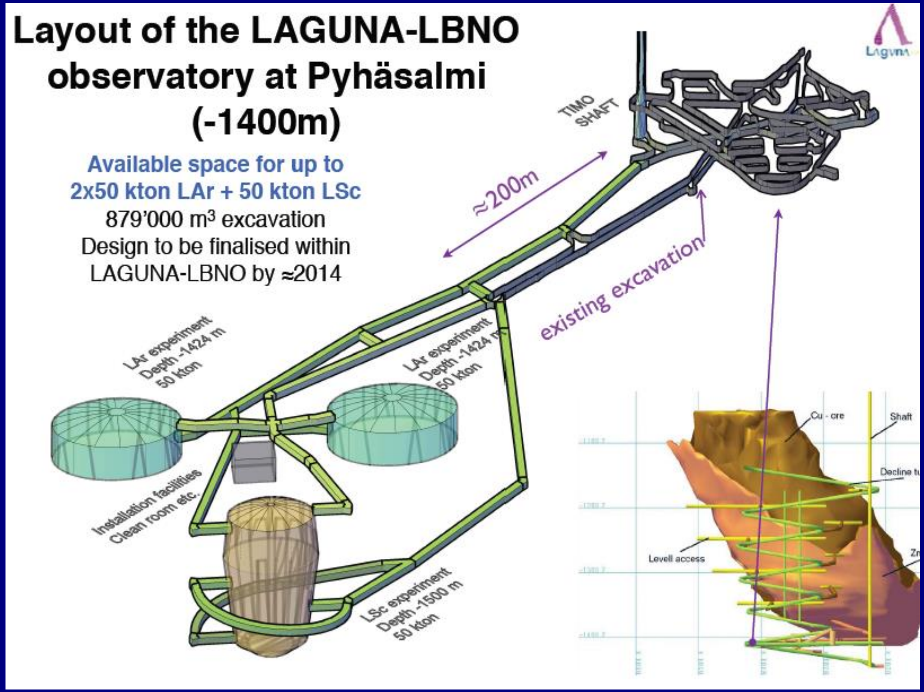


Gain and resolution for different LEM fields

Gain stability reproduced over several weeks
arXiv:1312.6487

LAGUNA-LBNO:

A very long baseline neutrino experiment
2 EU programs: 2008-2011/2011-2014
14 Meur (7 Meur from EU)
CERN EOI June 2012
http://cdsweb.cern.ch/record/1457543
224 physicists, 52 institutions

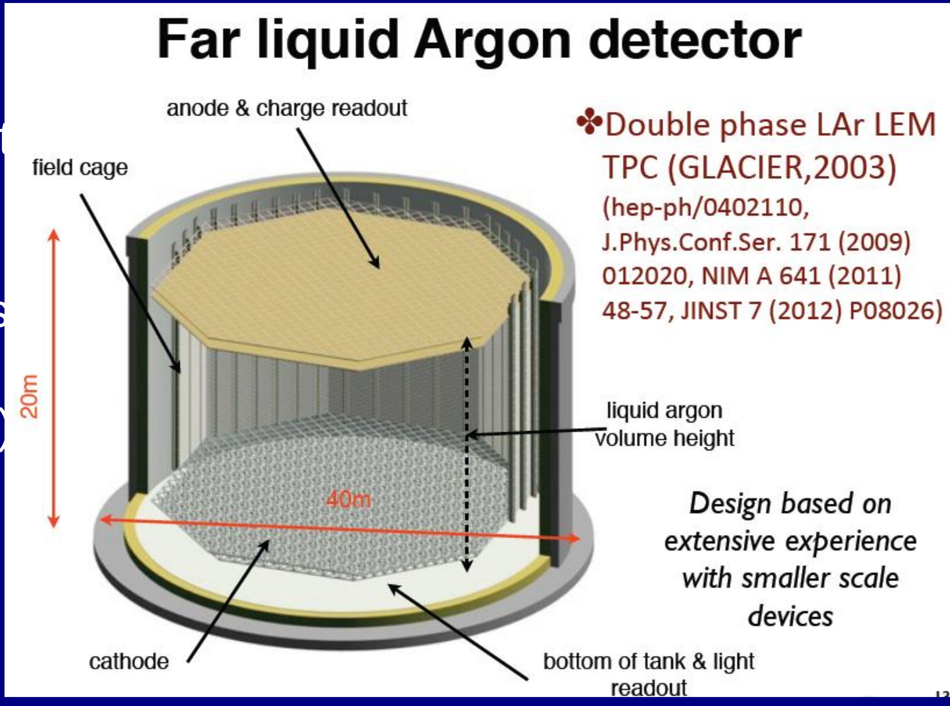


Physics program 2023-…

- Determination of neutrino mass hierarchy
- Search for CP violation
- Proton decay
- Atmospheric and supernovae neutrinos

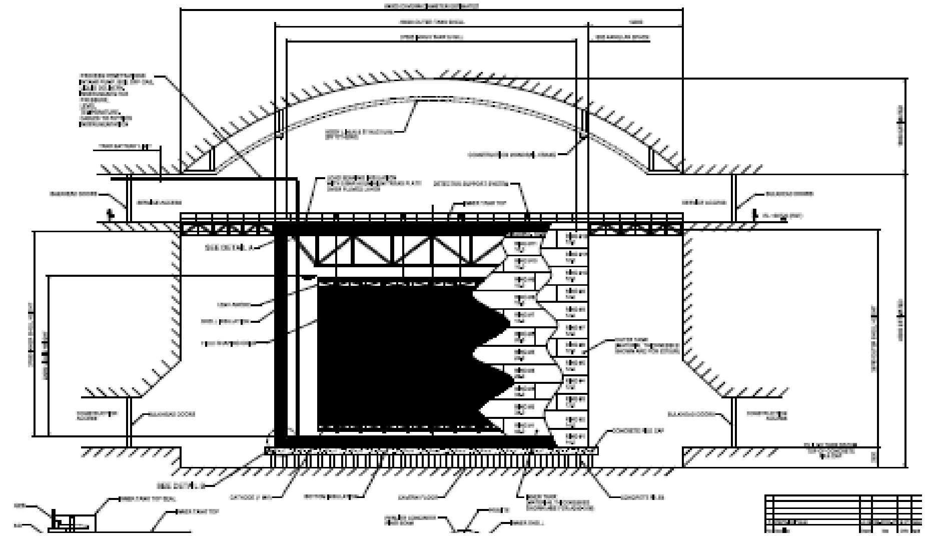
LBNO Phase I:
the only experiment capable of guaranteeing unambiguous mass hierarchy determination (>5σ)

20 kton double phase LAr TPC

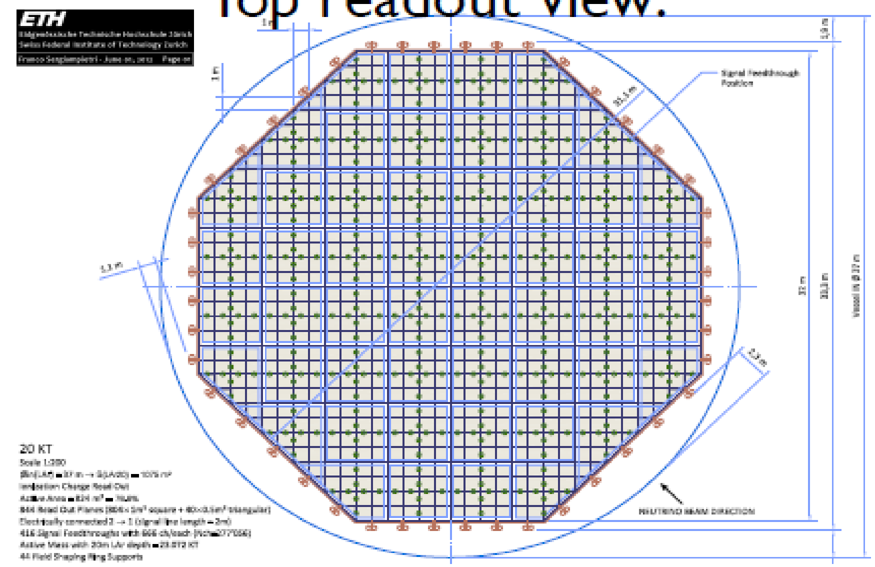


GLACIER detector design

- ★ Concept unchanged since 2003: Simple, scalable detector design, from one up to 100 kton (hep-ph/0402110)
- ★ Single module non-evacuable cryo-tank based on industrial LNG technology
  - industrial conceptual design (Technodyne, AAE, Ryhal engineering, TGE, GTT)
  - two tank options: 9% Ni-steel or membrane (detailed comparison up to costing of assembly in underground cavern)
  - three volumes: 20, 50 and 100 kton
- ★ Liquid filling, purification, and boiloff recondensation
  - industrial conceptual design for liquid argon process (Sofregaz), 70kW total cooling power @ 87 K
  - purity < 10 ppt O_2 equivalent
- ★ Charge readout (e.g. 20 kton fid.)
  - 23'072 kton active, 824 m^2 active area
  - 844 readout planes, 277'056 channels total
  - 20 m drift
- ★ Light readout (trigger)
  - 804 8" PMT (e.g. Hamamatsu R5912-02MOD) WLS coated placed below cathode
- ★ The concept and the designs are reaching the required level of maturity for submission to SPSC.



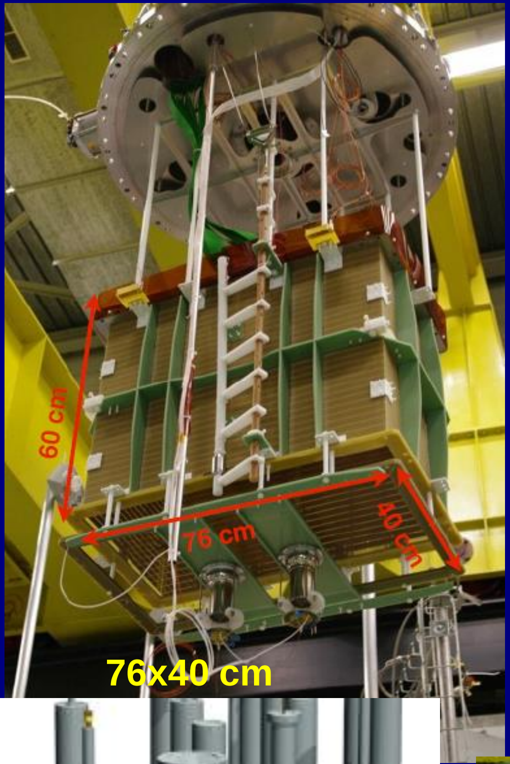
Top readout view:



Technical aspects being finalized in the LAGUNA/LBNO study as deliverables (June 2014) including detailed costing

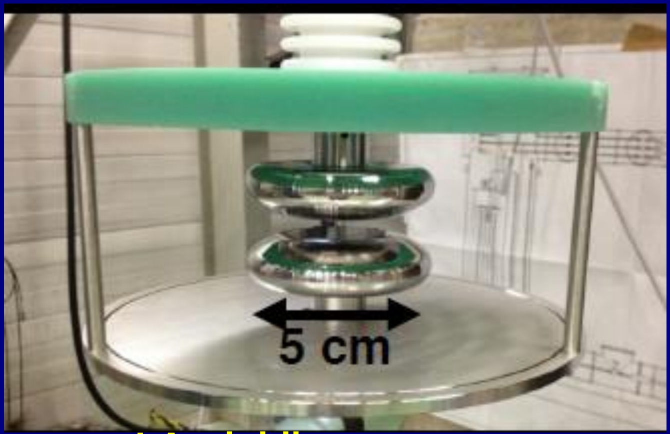
(See also talk by M. Zito)

Parallel ongoing technical R&D activities:

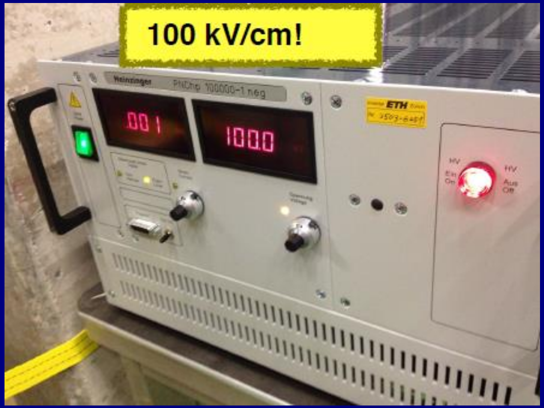


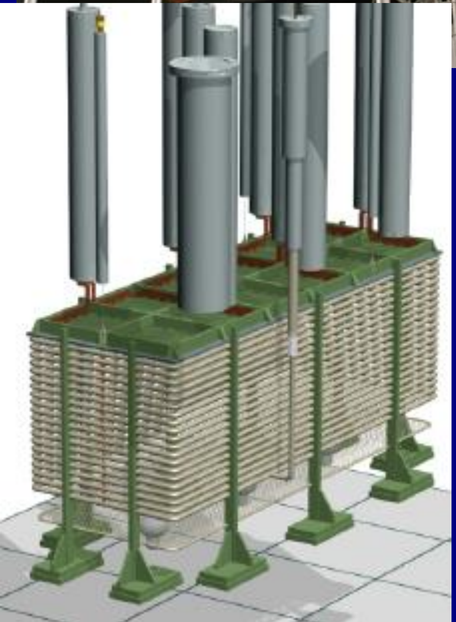
76x40 cm

10x10x20 cm
LEM-anode fast test setup

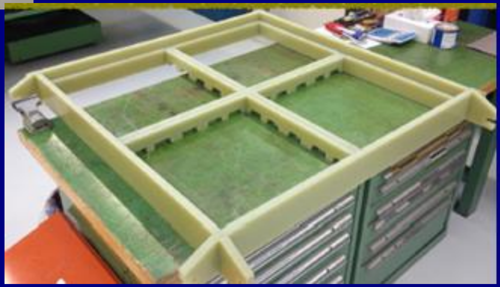


LAr rigidity test setup





3x1x1 m mockup
(3 CRP)



CRP mockup

Readout test setup in Lyon

LBNO

Expression of Interest for a very long baseline neutrino oscillation experiment

CERN-SPSC-2012-021 ; SPSC-EOI-007

An incremental approach, based on the findings of LAGUNA

Submitted in June 2012

June 2012: Expression of Interest for the LBNO experiment submitted to the SPSC and the European Strategy Group.

http://cdsweb.cern.ch/record/1457543

150 pages proposal

Germany, Finland, France, Italy, Switzerland, Poland, Russia, UK

~230 authors, 51 institutions

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Erice 25 January 2013,
CERN Council 7 May 2013:

Update of the European Strategy for Particle Physics

f) Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector. *CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.*

LBNO LAr demonstrator at CERN (LBNO-Proto/WA105)

Configuration: $6 \times 6 \times 6\,m^3$ active volume LAr TPC detector with double phase + charge amplification + 2-D collection readout PCB anode. Exposure to charged hadrons beam (1-20 GeV/c)

Purpose:

1) Full-scale demonstrator of the R&D on all the technologies studied in LAGUNA-LBNO **for the construction of a large and affordable underground LBNO far detector:**

- **LNG tank construction technique (with non evacuated detector)**
- **Purification system**
- **Long drift**
- **HV system 300-600 KV**
- **Double-phase readout**
- **Readout electronics**

2) **Assess the TPC performance in reconstructing hadronic showers** (the most demanding task in reconstructing neutrino interactions):

- Measurements in hadronic and electromagnetic calorimetry and PID performance
- Full-scale software development, simulation and reconstruction to be validated and improved

→ Fundamental step for the construction of the final LBNO detector

- The most advanced full proof prototyping program which has no equivalent in the world
- Experience with this demonstrator scalable to future LBNO detectors, putting the European groups in a very advanced and strong position for the participation to a world-wide joint program

WA105 as an international project:

- **Ongoing contacts with US (LBNE) for LBNX and Japan (via KEK participation)**

LBNE-LBNO agreement (also presented at P5):

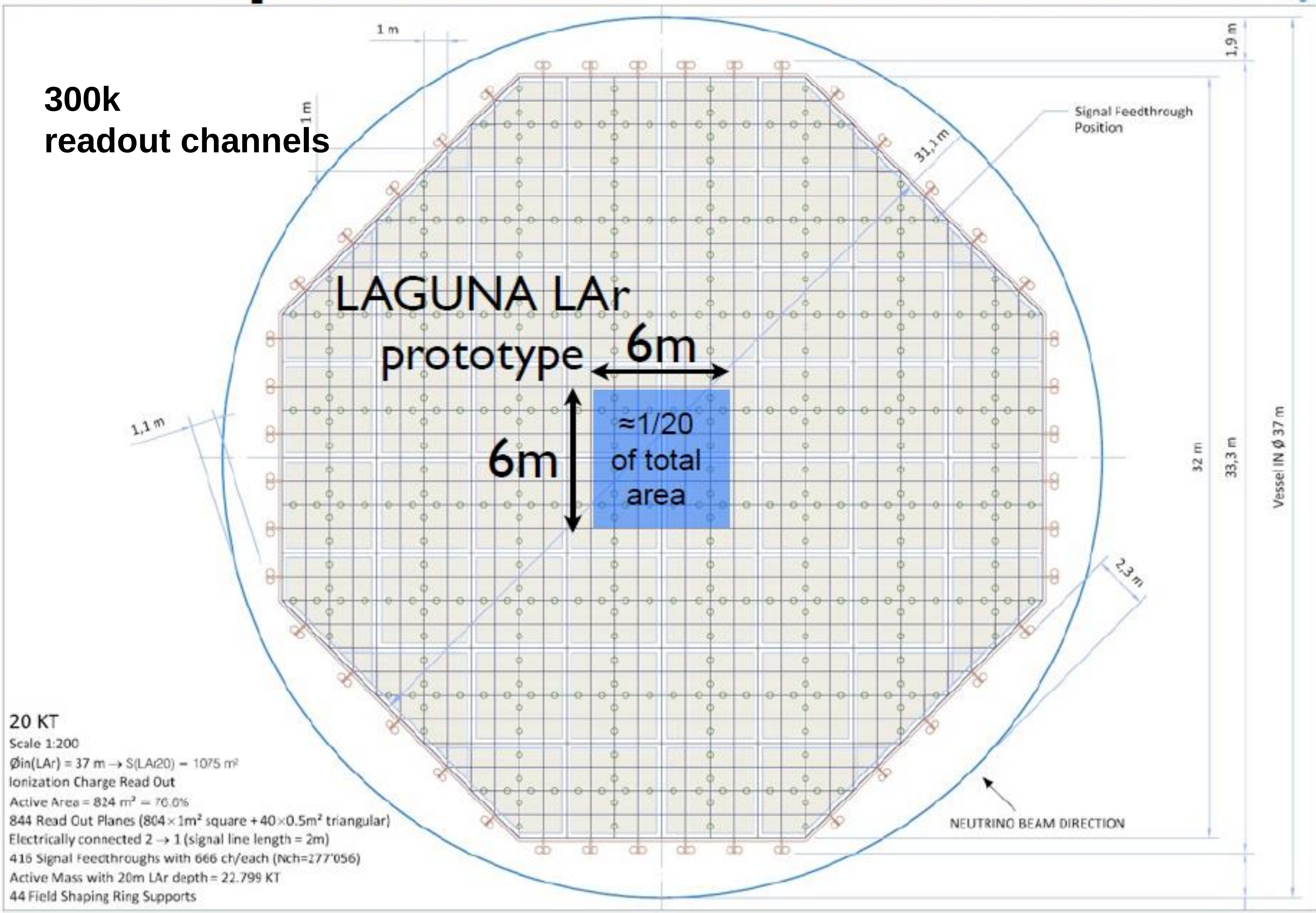
Europe/LBNO

- This section addresses the LAGUNA/LBNO collaboration, which has more than 200 members and includes institutions from nine CERN member states (Bulgaria, Finland, France, Germany, Greece, Italy, Poland, Spain, Switzerland, and the UK), as well as one candidate for accession to CERN (Romania) and two CERN observers (Russia, Turkey)
- The LBNO collaboration is nearing completion of an EU-funded design study, and the detailed engineering and full costing of LBNO Pilot, Phase 1(20kton LAr) and Phase 2 (70kton) at Pyhäsalmi will be delivered in June 2014.

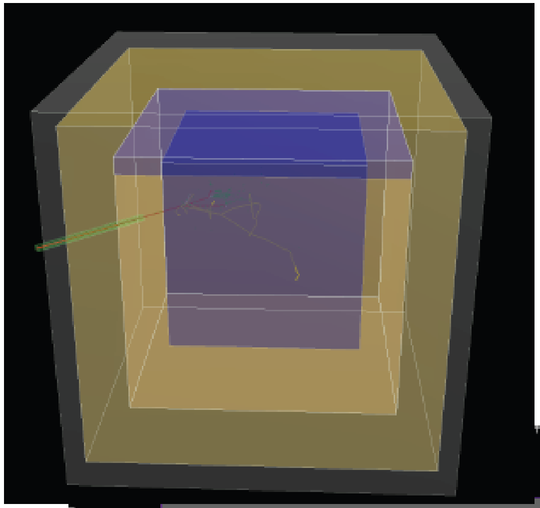
Status of discussions of "merger" between LBNE and LBNO

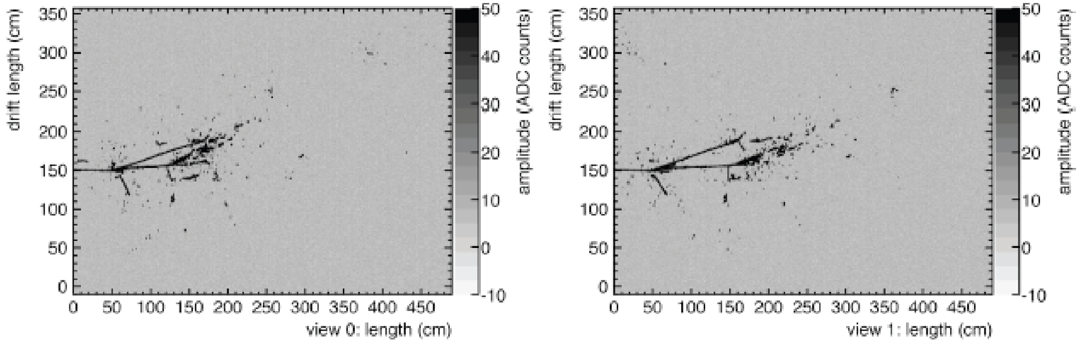
- The scientific goals and chosen detector technology of LBNE and LBNO are very similar. Leadership of both LBNE and LBNO have agreed that working together towards our common goals would be mutually beneficial.
- A task force to investigate joining forces between LBNE and LBNO, which has 5 members from each Executive Committee, meets every ~2 weeks.
- A Joint Physics Task Force is carrying out a careful comparison of analyses and developing a common understanding of science strategy.
- LBNO plans a program of development of their far detector, in particular the two-phase readout technology, including a $(6\ \mathrm{m})^3$ prototype in a $(8\ \mathrm{m})^3$ cryostat that would be a proof of principle that a large scale detector can be built. This will be carried out at CERN under the newly approved WA105 project and is expected to be completed around 2017.
- LBNE and LBNO are discussing initial collaboration that would be centered on detector development under WA105, including common LAr technology, comparison of single- and double-phase readout, and use of the large cryostat for prototyping LBNE as well as LBNO detectors.

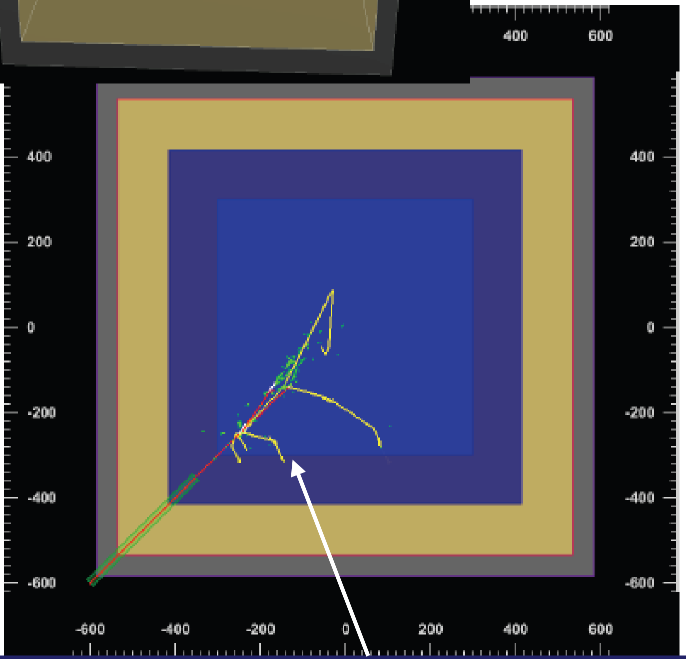
Compared to GLACIER 20 kton

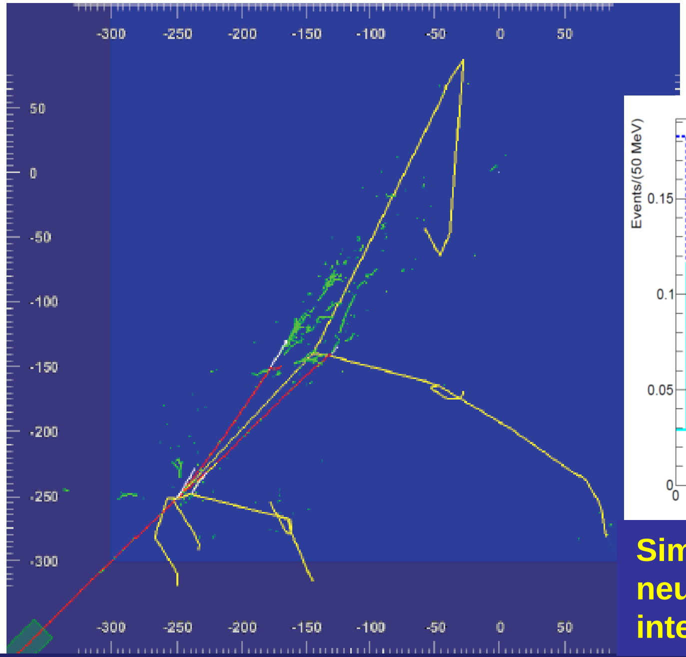


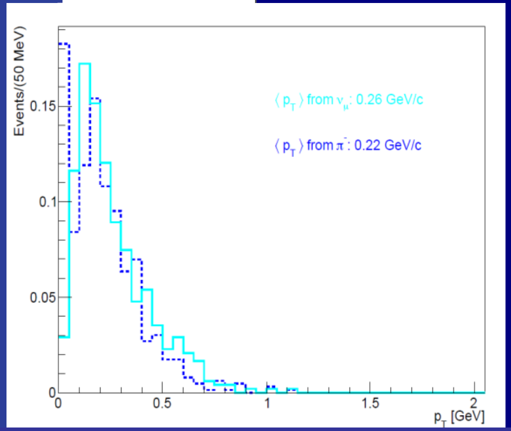
5 GeV π^+ simulation in 6x6x6m^3











Similar Pt spectra for pions in neutrino and hadronic interactions

Hadronic showers fully contained in the 4x4 m2 Glacier readout unit

Technical challenges for the construction and operation of a large and affordable LAr TPC with long drift length to be assessed with the WA105 demonstrator

• **Very high purity:** Drift of electrons over 20 m distance requiring very clean environment, with impurities ~100 ppt O2 (electron lifetime of 3-10 ms). Achieved so far on small prototypes. This will be the first test with a large scale non-evacuable prototype and the same tank construction technique foreseen for the far detector.

• **Large field cage:** This is a large structure with demanding requirements on its mechanical precision and capable of sustaining a large potential difference (up to 500 kV).

• **Very high voltage generation:** Very low noise and stable power supply able to reach 600 kV to generate an uniform drift field of 1 kV/cm (300 kV power supplies within specifications are commercially available).

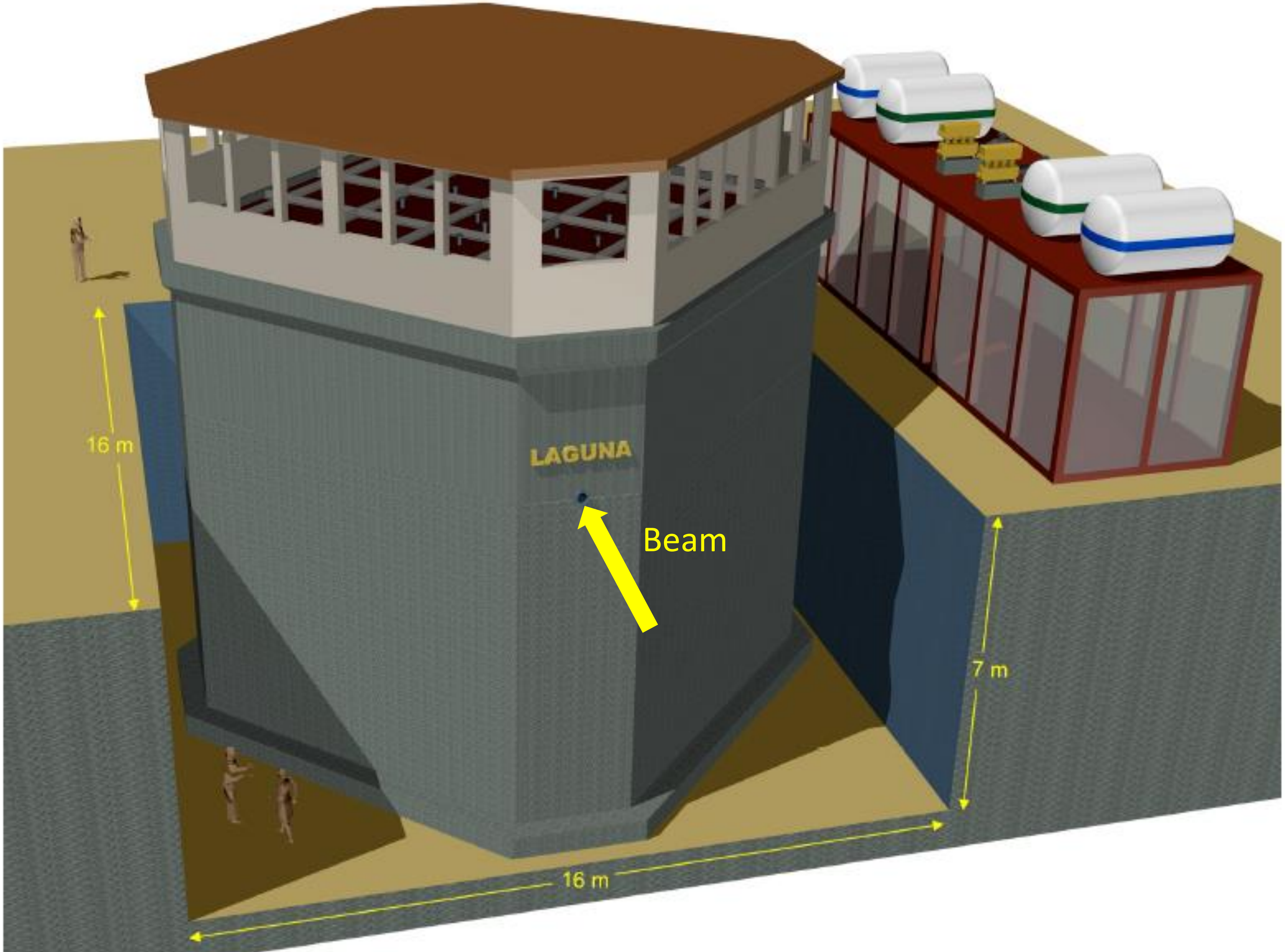
• **Large area micro-pattern charge readout:** A 36 m^2 surface will be instrumented with a charge sensitive device providing gas amplification in ultra pure argon vapors.

• **Cold front-end charge read-out electronics:** Good S/N is crucial to reach the required physics performances, especially for the low energy neutrino physics. Innovative solution with preampliers located as close as possible to the charge-sensitive anode, but yet accessible without opening the inner vessel, will be tested..

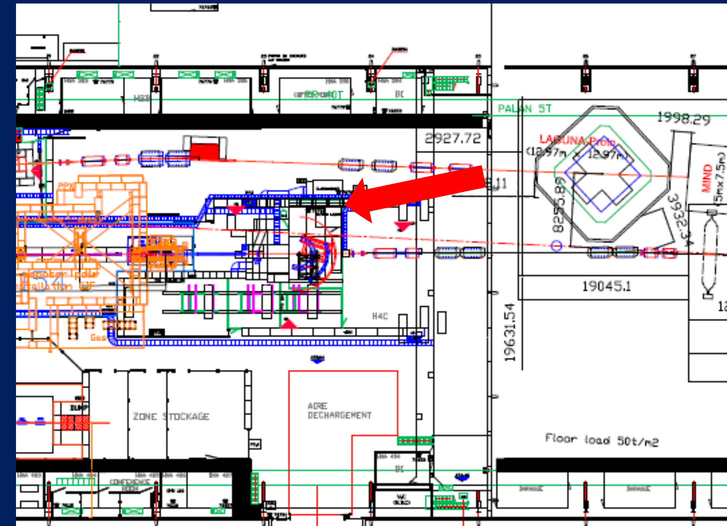
• **Long term WLS coating:** A method based on WLS deposition with very long stability (> 10 years) will be implemented and tested.

• **Integrated light readout electronics:** New integrated devices will be developed for the digitization of argon scintillation light, scalable to very large detectors.

General Overview



WA105 in the CERN North Area EHN1 extension

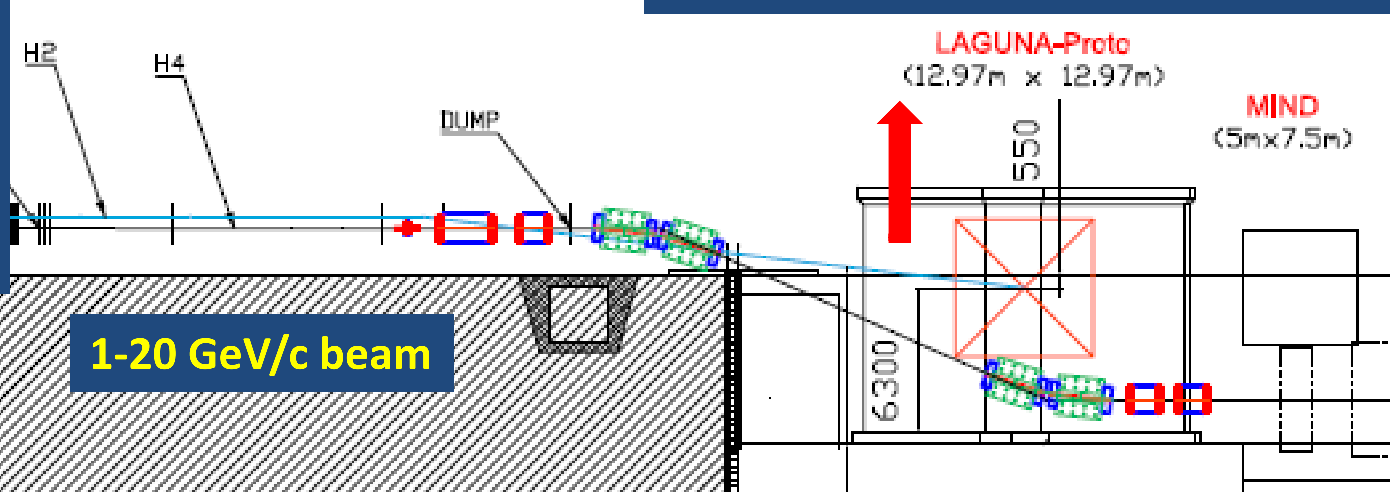


Requirements:
20x30 m^2, 2m deep pool

→ Fitting in half of the EHN1 extension or in existing EHN1 hall (as backup solution if extension not built in timely fashion)

EHN1 Extension foreseen by CERN

Civil engineering activities started



Status:

WA105 experiment approved by the CERN RB (August 2013) conditional to the TDR writing.

- Participation of CERN, French (IN2P3/CEA), KEK and Swiss groups already approved.
- Russians and Spanish groups submitted funds requests.
- Participation of Finnish, Italian, UK and USA groups under discussion.

MOU status as of January 6th with agreed contributions for the LAr demonstrator

MIND detector under discussion

7.9 MCHF total cost, of which ~3.7 MCHF from CERN support

LBNO 6x6x6 m3 LAr prototype in EHN1-X

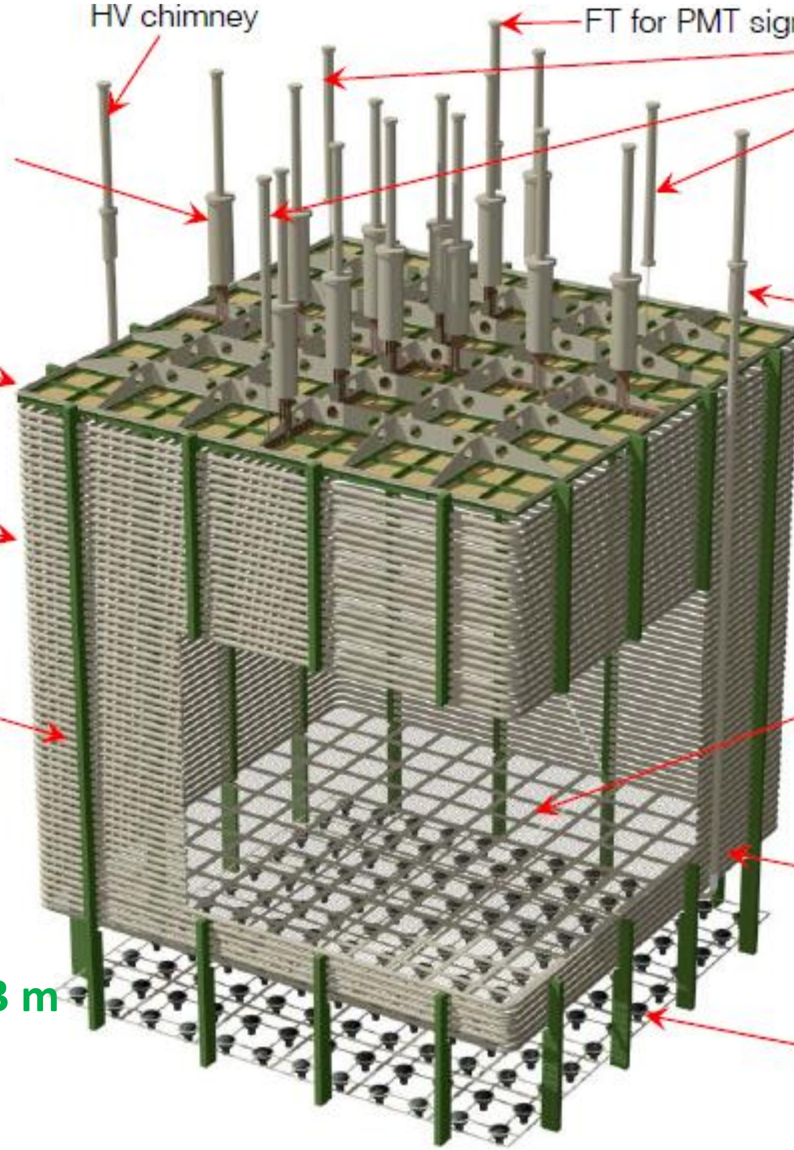
#	item	Contributing institute
1	Supporting concrete structure	CERN
2	Anode charge readout	CEA, ETHZ
3	Hanging anode frame + movement	LAPP
4	Drift cage	CEA, ETHZ
5	Light readout	APC, LAPP, Barcelona, CIEMAT, KEK
6	Power supplies	ETHZ
7	600 kV supply + feed-through	LPNHE, ETHZ
8	F/E electronics	IPNL
9	DAQ	IPNL
10	Cryogenic vessel	CERN, ETHZ
11	Cryogenic plant	CERN, ETHZ
12	Detector DCS	CERN, ETHZ
13	Clean room	CERN, ETHZ
14	Logistics and integration	CERN, ETHZ

Table 1 Sub-units of the LBNO LAr prototype.

Time-scale as defined in MOU:

- March 2014 submission of the LBNO-Proto TDR to the SPSC (120 pages detailed technical document already written) and finalization of the MOU
- Beneficial occupancy EHN1: September 2015
- Vessel constructed: March 2016 (9 months vessel construction , then vessel used as clean-room for inner-detector assembly)
- Inner-detector constructed: Jan 2017
- Detector start commissioning: Mar 2017
- Beginning test-beam data-taking: Spring 2017

WA105 LAr demonstrator: inner instrumentation



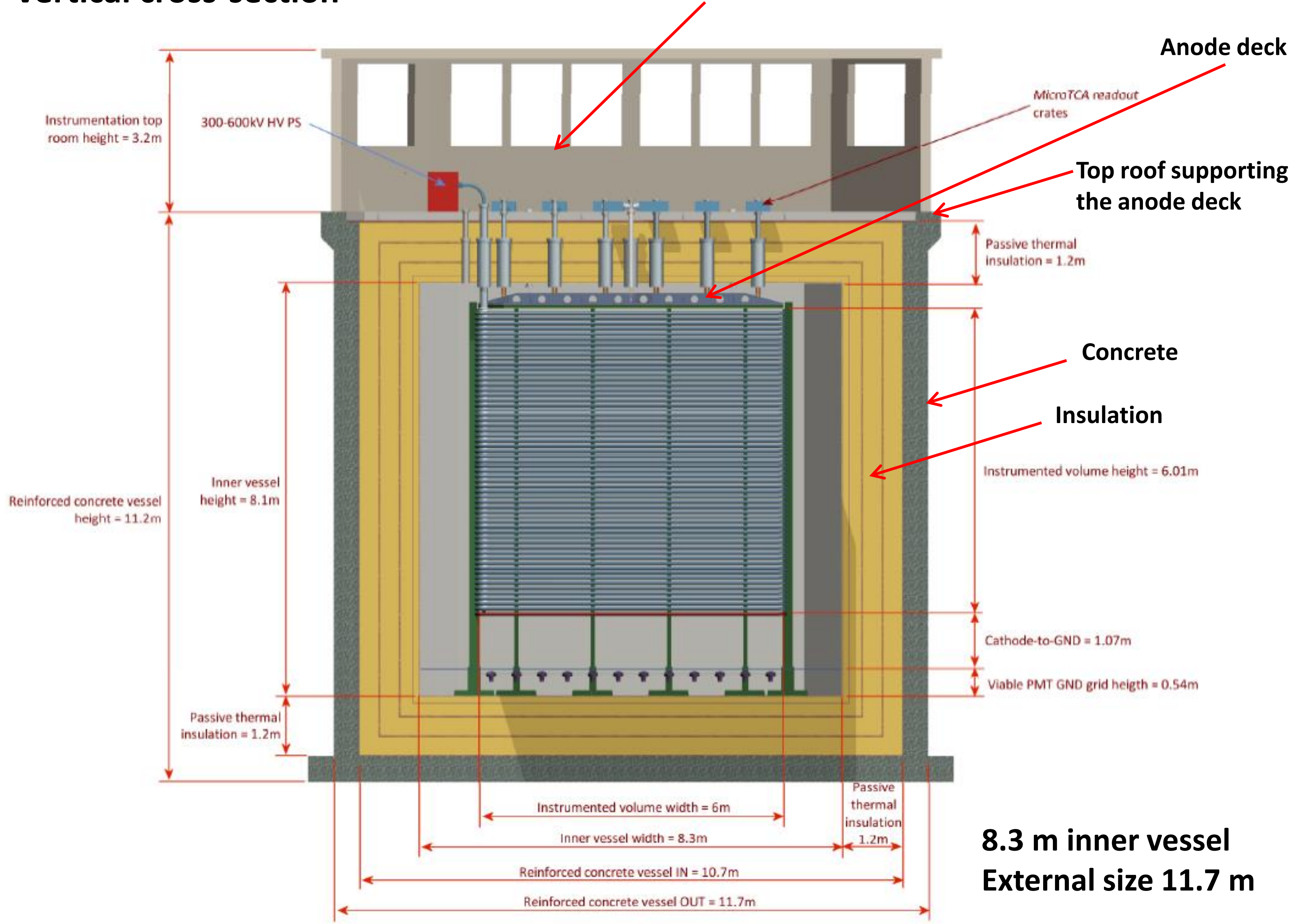
- **Total LAr volume size 8.3 m**
- **Active size 6 m**

7680 readout channels, ICARUS T600 for a similar fiducial mass had 27000 channels

Overview of parameters

Liquid argon density at 1.2 bar	[T/m^3]	1.38346
Liquid argon volume height	[m]	7.6
Active liquid argon height	[m]	5.992
Pressure on the bottom due to LAr	[T/m^2]	1.05 (≡ 0.1 MPa ≡ 1.031 bar)
Inner vessel size (W x L x H)	[m x m x m]	8.288 x 8.288 x 8.108
Inner vessel base surface	[m^2]	67.6
Total liquid argon volume	[m^3]	509.6
Total liquid argon mass	[T]	705.0
Active LAr area (percentage)	[m^2]	36 (53.3%)
Active (instrumented) mass	[T]	298.2
Charge readout square panels (0.5m×0.5m)		144
Number of signal feedthroughs (640 channels/FT)		12
Number of readout channels		7680
Number of PMT (area for 1 PMT)		144 (0.5m×0.5m)

Vertical cross-section



8.3 m inner vessel
External size 11.7 m

Inner vessel thermal insulation

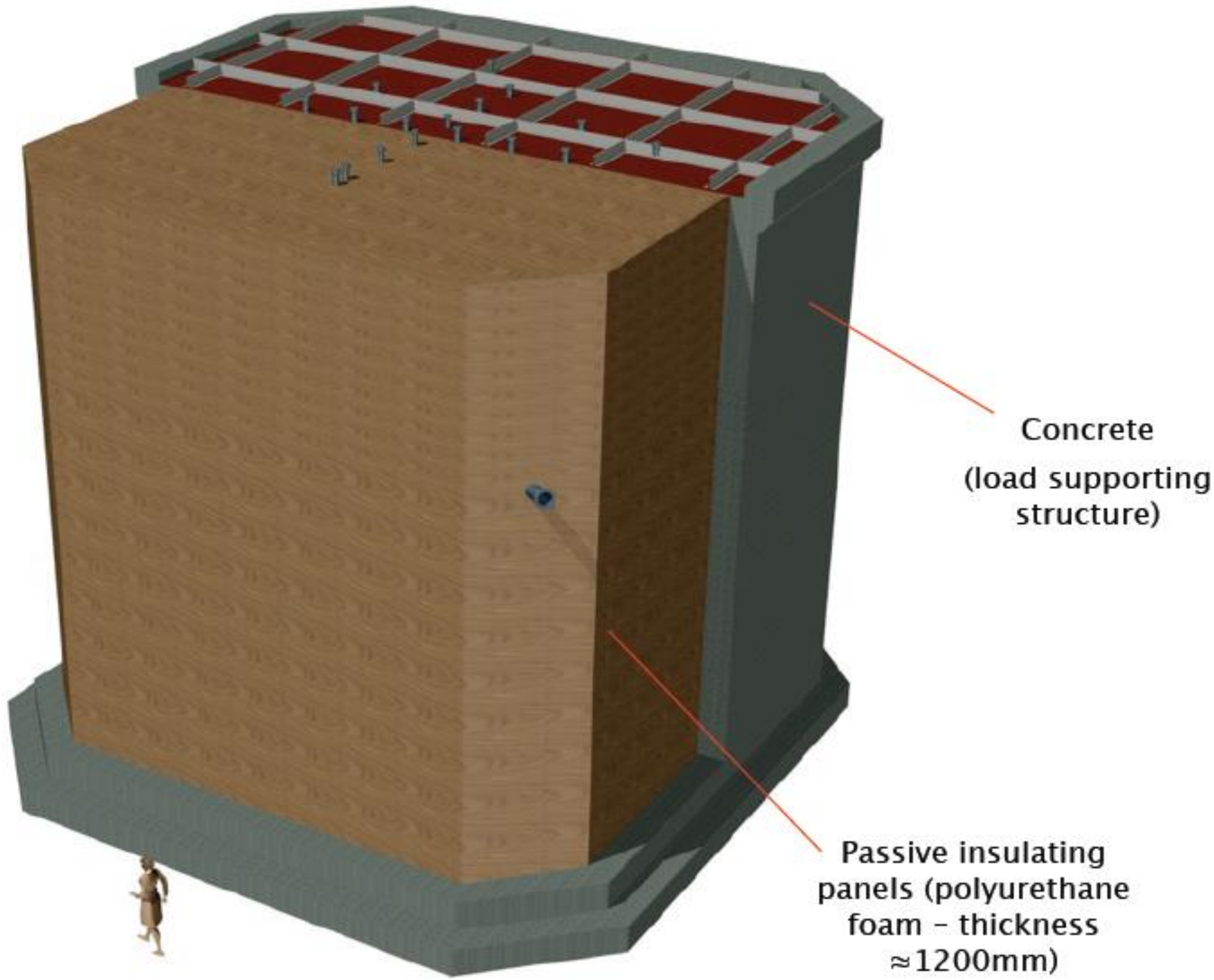
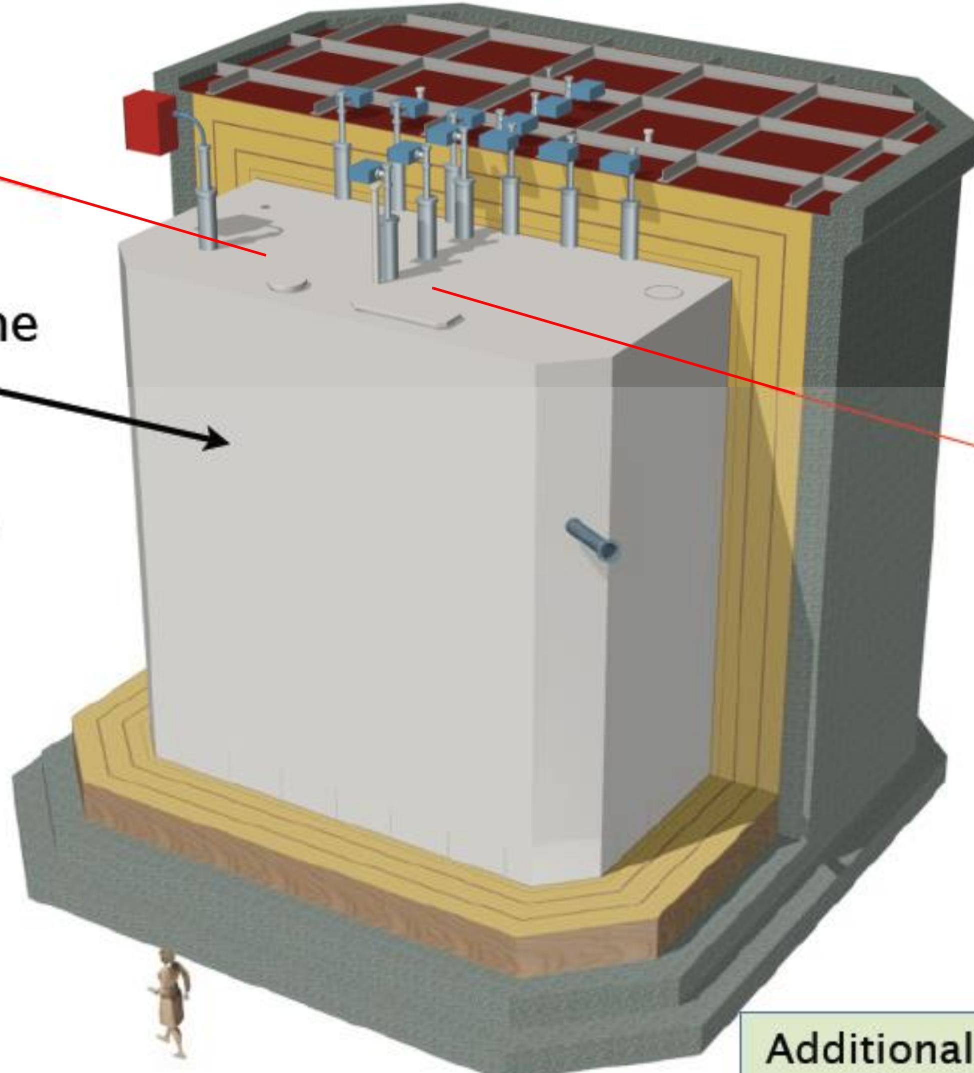
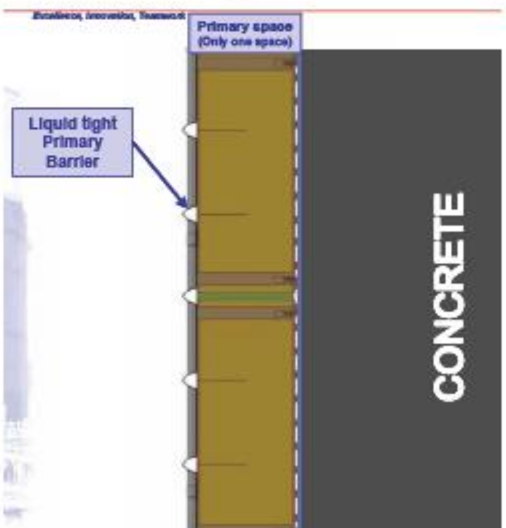


Illustration of inner SS membrane

304L SS membrane



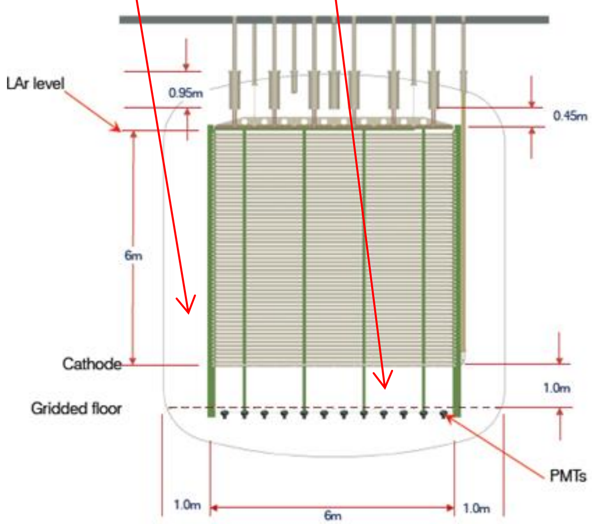
Design in partnership with GTT



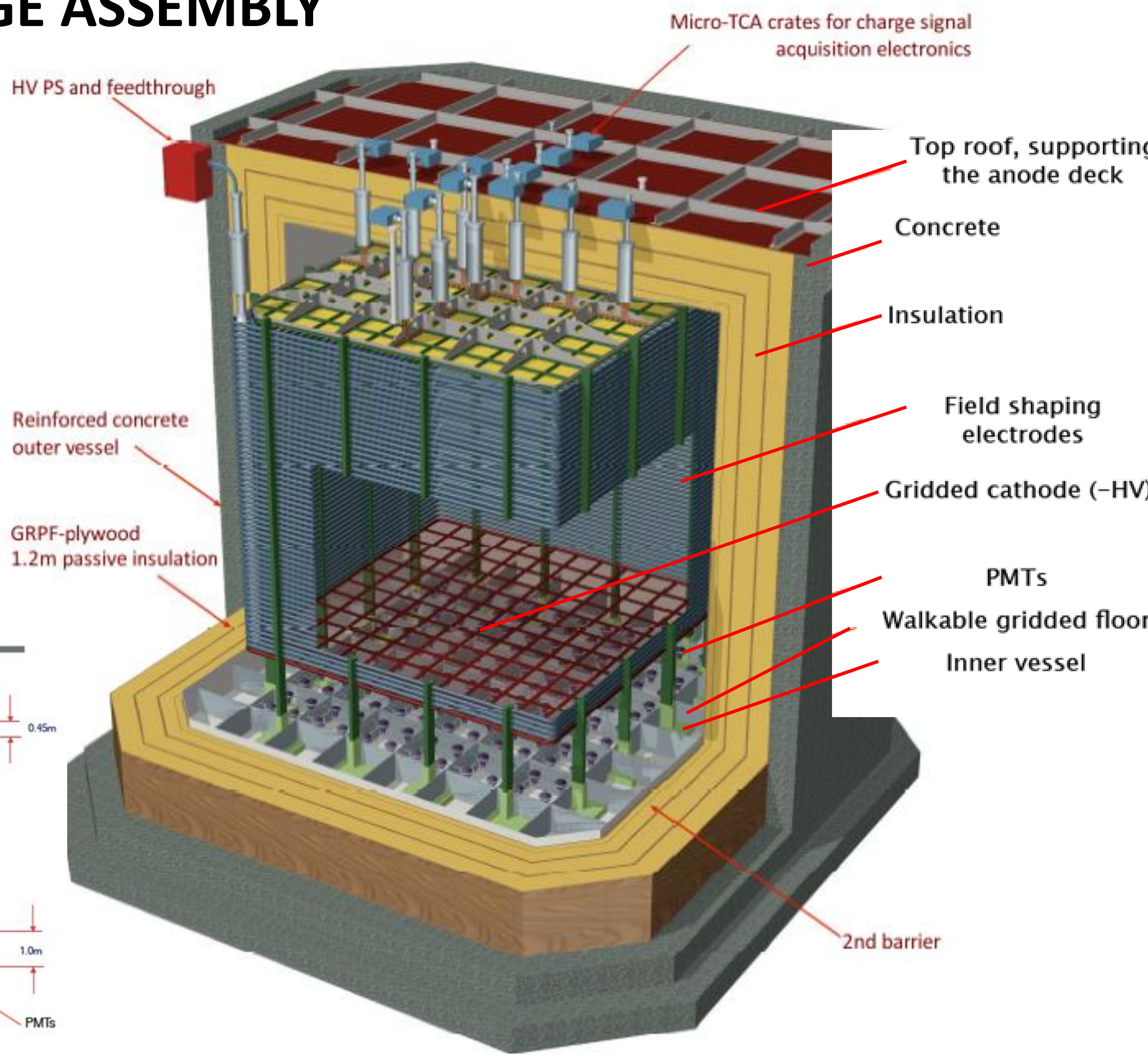
Additional services for gas and liquid handling to be added

FINAL FIELD CAGE ASSEMBLY

- **1 m distance field cage - walls**
  - **1 m distance cathode-PMTs**

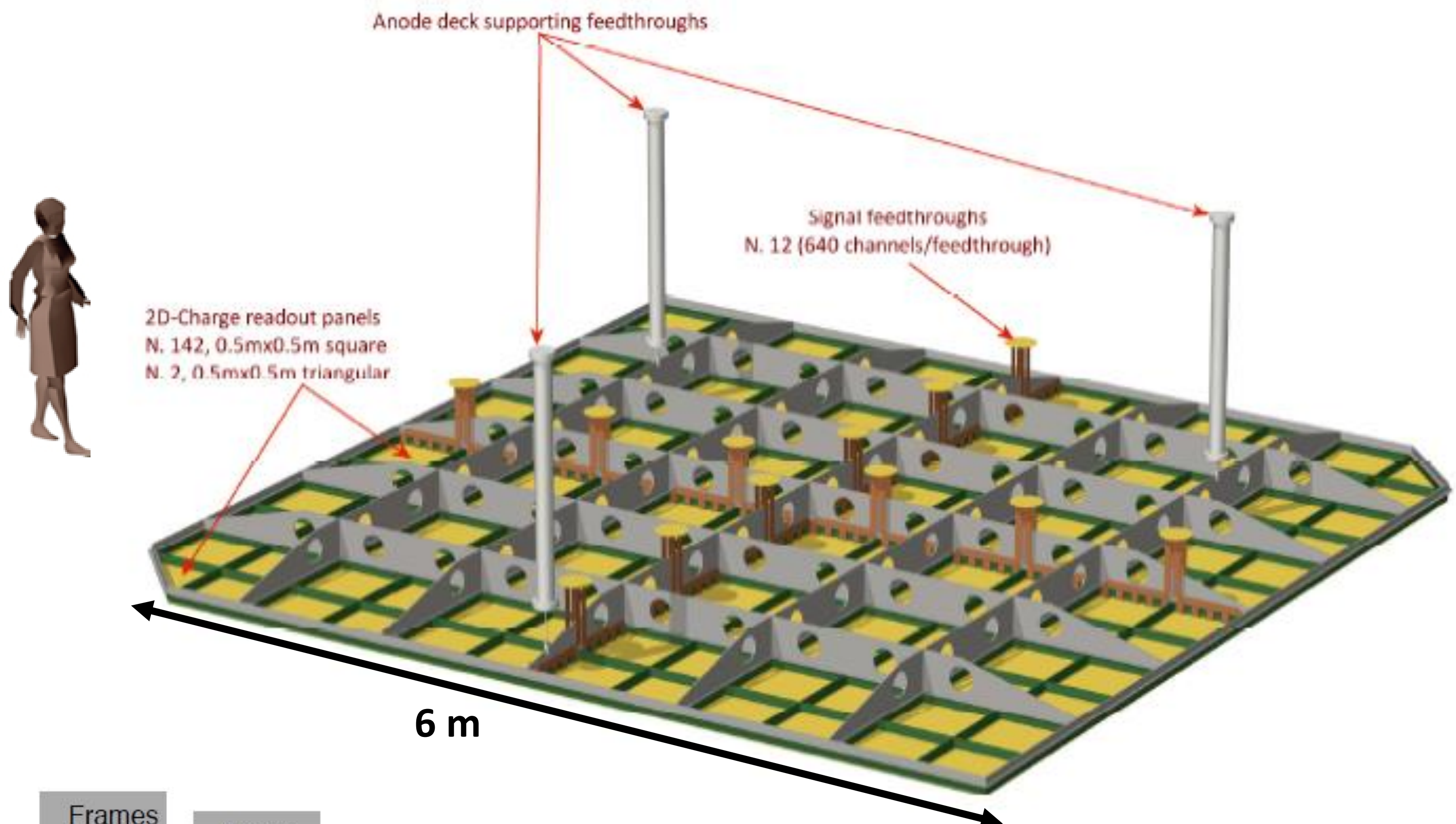


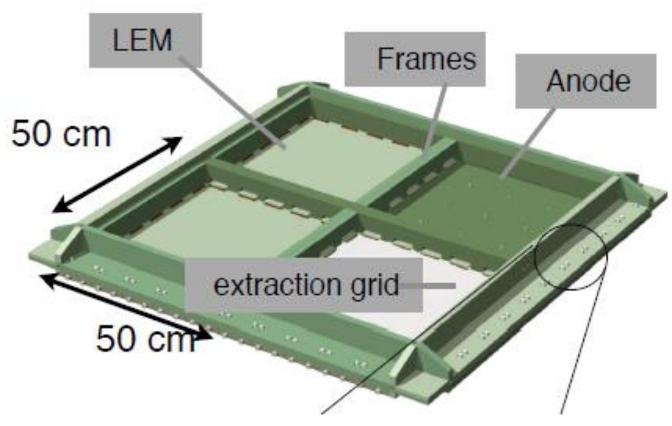
side view



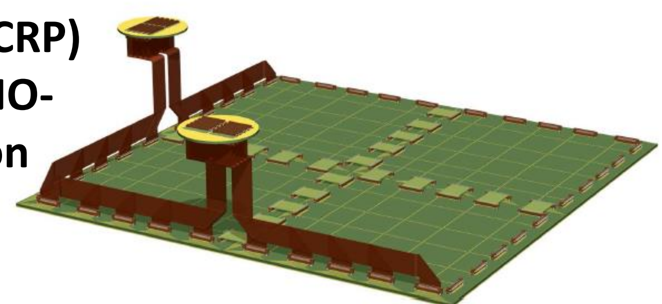
Charge readout anode deck

144 Readout Modules 0.5x0.5 m2
Two anode coordinates, 3 mm pitch

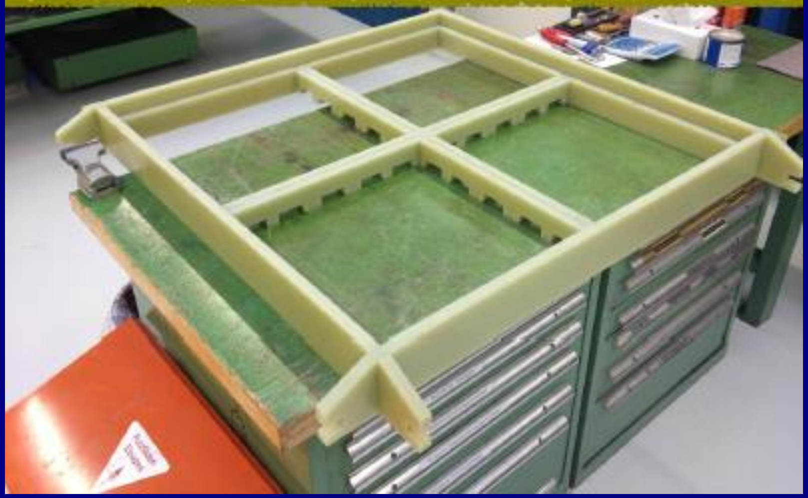


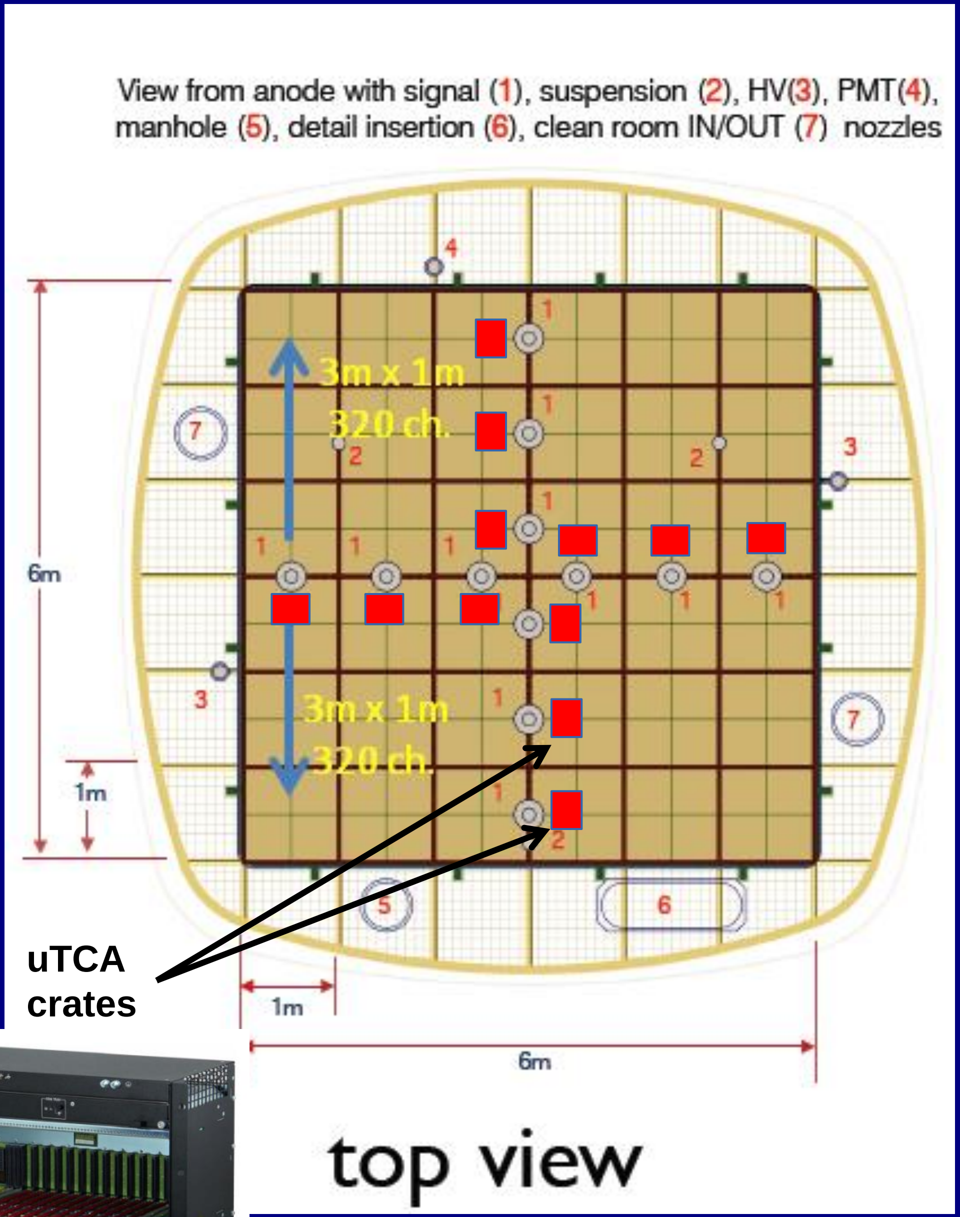


4 Readout Modules assembled in a Charge Readout Plane (CRP) unit 1x1 m2 common to LBNO-proto and Glacier 20/50 kton



1x1m² mechanical mockup in construction

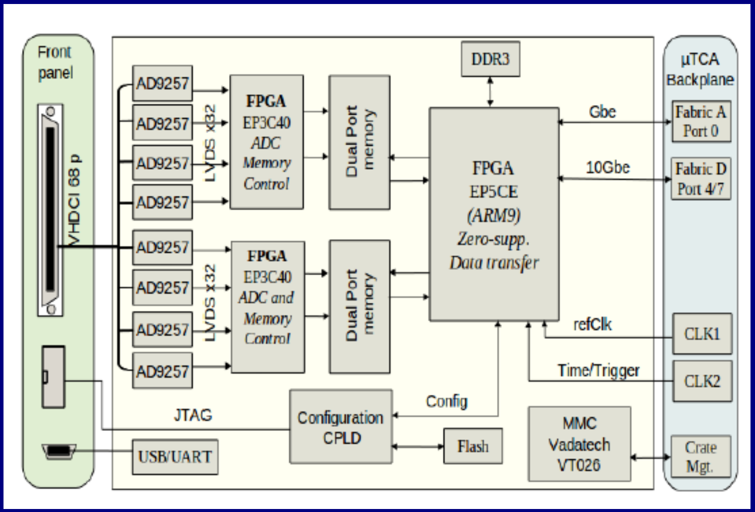




Readout in groups of 640 channels per chimney

uTCA crates

64 channels AMC card



Cost effective cold front-end electronics and DAQ R&D

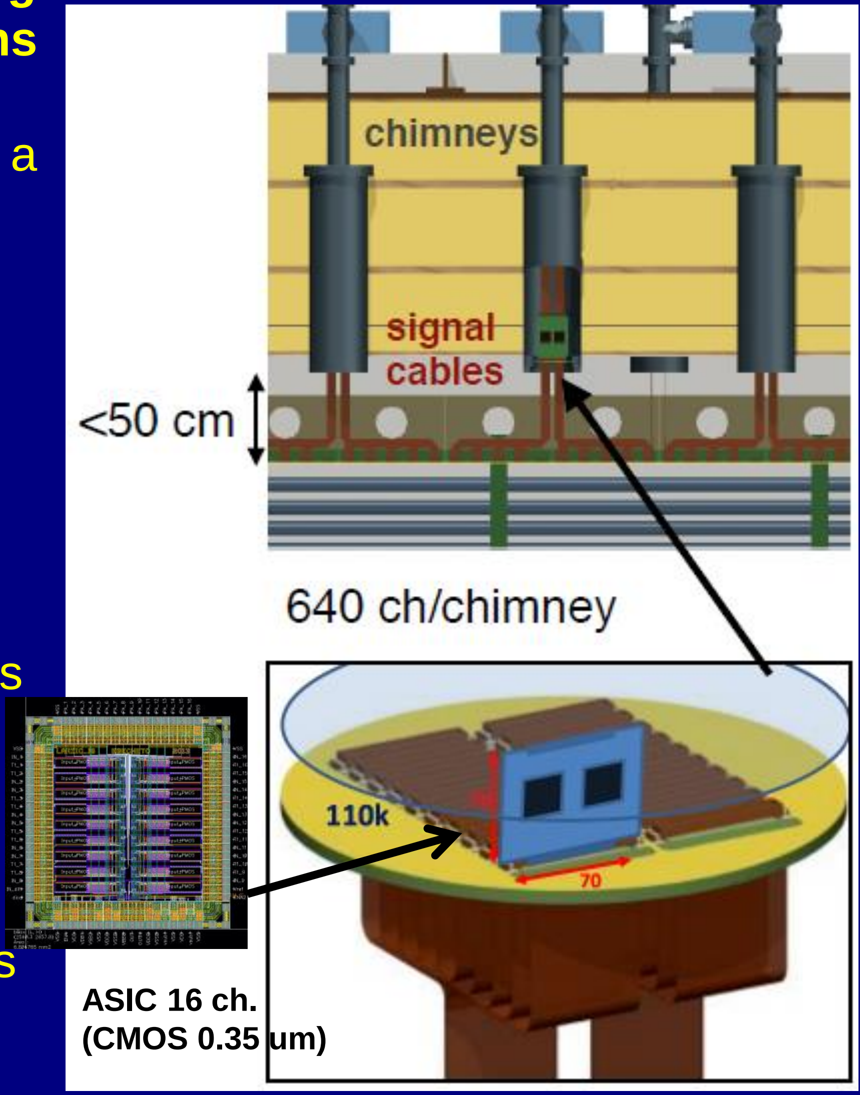
Remove long cables and their capacitance, exploit intrinsic noise reduction at low T

ASIC (CMOS 0.35 um) 16 ch amplifiers working ~110 K to profit from minimal noise conditions

- FE electronics inside chimneys, cards fixed to a plug accessible from outside
- Distance cards-CRP<50 cm
- Dynamic range 40 mips
- Power consumption 18 mW/ch

DAQ in warm zone on the tank deck

- architecture based on uTCA standard
- local processors replaced by virtual processors emulated in low cost FPGAs (NIOS)
- integration of the time distribution chain (improved PTP)
- Bittware S5-PCIe-HQ 10 Gbe backend with OPENCL and high computing power in FPGAs



→ Large scalability (300k channels for 20kton) at low costs

Conclusions:

- LBNO foresees a breakthrough R&D activity at CERN: test of a full scale (6x6x6m^3) demonstrator, exposed to charged hadrons beam in the North Area.

- The demonstrator will be constructed with all the techniques developed in LAGUNA-LBNO and needed for the affordable implementation of the far underground detector.
  It will represent a milestone for future long-baseline programs.

- It will also test and calibrate the response to hadronic showers and the reconstruction and, as physics byproduct, it will improve in general the modeling of hadronic showers

- With this operation CERN will strengthen the European groups which have already an advanced expertise in the field acquired with LAGUNA/LAGUNA-LBNO (as recommended by the ESG)

A task force (D.Autiero, A. Blondel, I. Gil-Botella, T.Hasegawa, Y.Kudenko, E.Noah, T.Patzak, A.Rubbia, F.Sanchez, P.Soler, A.Tonazzo, M.Zito) has been set up in order to finalize the TDR and the MOU with the goal of delivering it to the LAGUNA-LBNO collaboration for the next general meeting

Signatures and interests for WA105 will be finalized at the LBNO general meeting in February

LNG Carrier Containment Systems

NO96 System

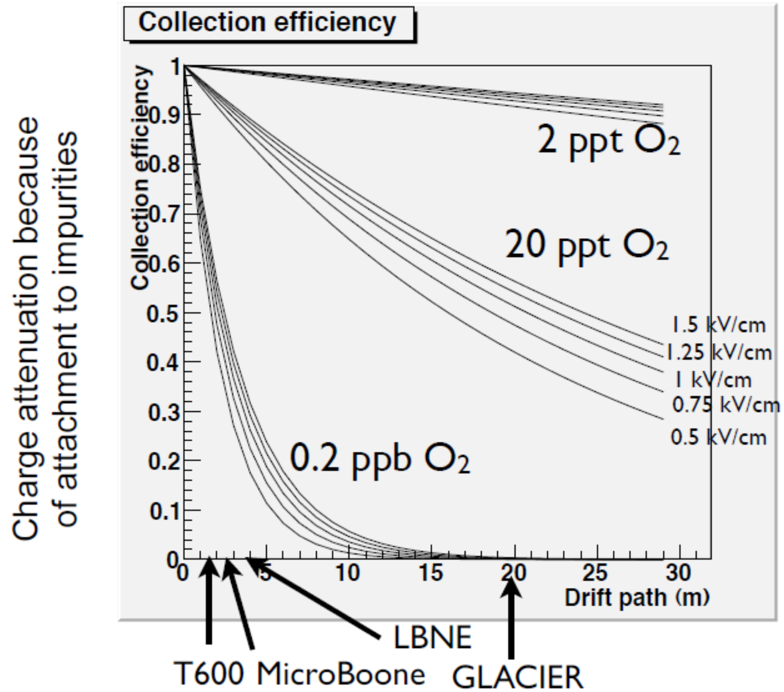
NO 96 Membrane System
is a cryogenic liner directly supported by the ship's inner hull.
This liner includes two identical metallic membranes and two independent insulation layers:

Primary & secondary Invar membranes

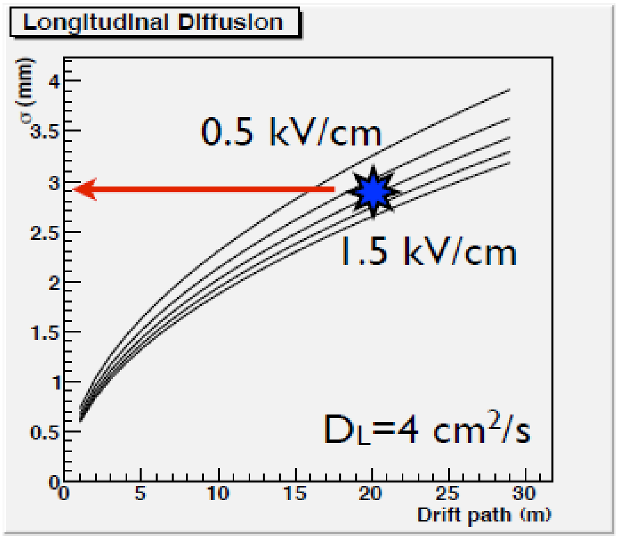
The primary and secondary membranes are made of Invar, a 36% nickel-steel alloy, 0,7 mm thick. The primary membrane contains the LNG cargo, while the secondary membrane, identical to the primary, ensures a 100 % redundancy in case of leakage. Each of the 500 mm wide invar strakes is continuously spread along the tank walls and is evenly supported by the primary and the secondary insulation layers.

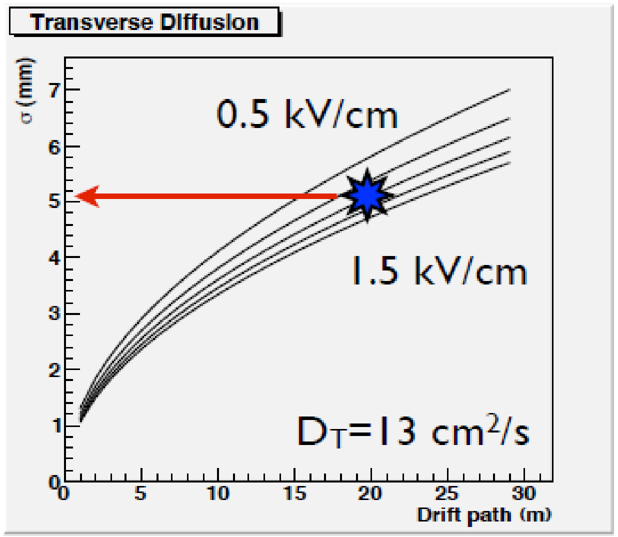
Primary & secondary thermal insulation

The primary and secondary insulation layers consist in a load bearing system made of prefabricated plywood boxes filled with expanded perlite. The standard size of the boxes is 1m x 1.2m. The thickness of the primary layer is adjustable from 170mm to 250mm, to fulfill any B.O.R. requirements ; the typical thickness of the secondary layer is 300 mm. The primary layer is secured by means of the primary couplers, themselves fixed to the secondary coupler assembly. The secondary layer is laid and evenly supported by the inner hull through load-bearing resin ropes, and fixed by means of the secondary couplers anchored to the inner hull.



Drift fields E=0.5,0.75,1,1.25,1.5 kV/cm





CRYOGENIC VESSEL AND THERMAL INSULATION

- The inner vessel has a cubic shape with inner dimensions ~8.3x8.3x8.3m3.
- This volume ensures enough space surrounding the drift cage, acting as electric insulation (~1 m of LAr), for safe operation at HV with up to 300 kV at the cathode.
- This volume shall also be used for access and movement inside the vessel during the construction phase. A manhole and a detail-introduction hole are located at the top face of the vessel.
- During the inner detector assembly, additional chimneys are used to install a controlled air circulation. These additional chimneys are available for the implementation of the liquid argon process during normal operation.
- The cryogenic vessel is built using technologies developed by the petro-chemical industry. This topic has been the subject of several developments between LAGUNA and industry over many years (since 2004). The so-called corrugate membrane panels technique (licensed by GTT/France), has been envisaged as an attractive solution for the LAGUNA LAr prototype.
- The thermal insulation is passive, based on GRPF (glass reinforced polyurethane foam) layers, interspersed with pressure distributing layers of plywood. Its thickness and composition is such to reach a residual heat input of 5 W/m2 in cold operation.
- The total heat input (including the input from the roof and the cables) in cold operation at LAr temperature is ~2 kW.

GLACIER + MIND

- **20 kton double phase LAr LEM TPC (GLACIER): best detector for electron appearance measurements with excellent energy resolution and small systematic errors**
  - Very fine grain tracking-calorimeter
  - Exclusive final states, low energy threshold on all particles
  - Excellent ν energy resolution and reconstruction ability from sub GeV to a few GeV, from single prong to high multiplicity
  - Suitable for spectrum measurement with needed wide energy coverage
  - Excellent π^0/electron discrimination
  - Best detector for baselines > 300km
- **35 kton magnetized Muon Detector (MIND): conventional and well-proven detector for muon CC, and NC**
  - muon momentum & charge determination, inclusive total neutrino energy
  - rsμ/wsμ with Neutrino Factory
  - 3cm Fe plates, 1cm scintillator bars, B=1.5-2.5 T