Progress report on LBNO-DEMO/WA105 (2015)

The WA105 Collaboration

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1 Introduction

The initial design of the $6 \times 6 \times 6$ m$^3$ detector (DLAr) has been discussed in details in the TDR submitted one year ago [1]. During this year there has been a lot of progress in WA105 in formalizing the collaboration structure, creating a technical board and science board organization, starting the software developments and finalizing the DLAr design by speeding up the production aspects and technical implementation of several elements on a $3 \times 1 \times 1$ m$^3$ (LAr-Proto) setup which has the minimal size of a readout unit in the DLAr (see Figure 1). This prototype has allowed to anticipate several practical and technical problems proper to the final construction phase and to put the collaboration in a very good position to gain time on the construction of the WA105 demonstrator in the EHN1 hall.

WA105 6x6x6 m$^3$ (DLAr)

WA105 3x1x1 m$^3$ (LAr-Proto)

FIG. 1: Illustration of the DLAr (top) and LAr-Proto (bottom) showing the overall layout and a detailed drawing of the detector.
In parallel the infrastructure works of EHN1 and the beam design have been advancing. The collaboration has also been finalizing the Memorandum of Understanding.

2 Progress on the DLAr design and construction

2.1 Technical board organization and detector progress

A technical coordination structure has been set up since the beginning of 2015. The Technical Board (TB) supervises all the aspects related to the detector developments, procurement, construction and installation in the ENH1 hall. The TB is chaired by Dario Autiero (IPNL) and it includes three Coordinators respectively for: the DLAr detector (S. Murphy, ETHZ), the MIND activities (E. Noah, Geneva) and the infrastructure (I. Efthymiopoulos, CERN). A Run and Beam coordinator, as limited duration task turning among different people, is also foreseen during the commissioning and running periods of the experiment. A detailed Work Breakdown Structure (WBS) has been defined, including the construction responsibilities of all the detector systems and about 25 persons have been assigned responsibilities of supervising various technical tasks. The TB has regular biweekly meetings which are focused on specific design and construction aspects of the detector.

Since the submission of the TDR, the completion of the design of the DLAr and the preparation of its construction have been progressing very quickly during the last year. Many technical aspects of the design have largely benefited of the possibility of performing a pre-production and direct practical implementation on a $3 \times 1 \times 1$ m$^3$ (LAr-Proto) setup which has the minimal size of a readout unit in the DLAr. This allowed to have a first overview of the complete system integration; to produce a fully engineered prototype version of many detector parts including all their installation details and ancillary services; to set up full Quality Assessment (QA), construction, installation and commissioning chains and to anticipate legal and practical aspects related to the procurement of the different components. There has been a lot activity in the last months focused on the technical work which could be already implemented at the level of the $3 \times 1 \times 1$ m$^3$ (LAr-Proto) setup. This activity is regularly discussed and monitored in weekly specific meetings in addition to the general TB meetings.

The LAr-Proto represents a technical playground and integration exercise to speed up the design, procurement, QA and commissioning activities needed for the DLAr detector. However, given its very limited dimensions, the LAr-Proto cannot provide any of the physics and technological answers which will come from the commissioning and data-taking of the DLAr demonstrator in the North Area and from its exposure to a well controlled particles beam.

In the following we will describe in details all the progress on the DLAr detector for each subsystem and mention how the practical work on the LAr-Proto allowed to advance more effectively
2.1 Technical board organization and detector progress

and to anticipate the production work and mitigate possible problems. A complete description of the LAr-Proto setup will be provided as well at the end of this section.

2.2 Infrastructure

The activities related to the DLAr have required the construction of a new clean room located in the building 182 for the assembly and test of the detector components. The clean room was built around the fall of 2014 and is now fully operational and being exploited for the LAr-Proto construction.

Its dimensions are about $10(l) \times 6.4(w) \times 3(h)$ m$^3$. It contains one changing room, one main assembly room and one soldering area with fume extractors. A plan of the clean room as well as a few pictures are shown in Figure 2.

The ventilation produces a horizontal laminar air flow and maintains the inside at a slight over-pressure of typically $\sim 20$ Pa with respect to that of building 182. The ventilation is capable of recirculating about 10 total volumes per hour. The amount of dust particles per cubic meter have been measured and results indicate that the clean room reaches the ISO-7 class without any people inside. With 3-4 people working it should therefore match the construction goal of an ISO-8 class. The clean room overpressure as well as the temperature and humidity are constantly monitored. All the documentation on the structural components, ventilation, electricity, etc., can be found on the WA105 EDMS webpage [2].

2.3 Vessel design and procurement

According to the conclusions of the LAGUNA and LAGUNA-LBNO EU FP7 design studies, it is technically feasible to build a very large (20-50-100 kt) underground tank based on the LNG industrial technology that satisfies the requirement of long-term storage of ultra-pure liquid argon, and that can fully accommodate a double phase detector with the necessary cold-warm interfaces. From the two main solutions employed by the LNG industry (9% Ni-steel and membrane), the design studies also preferred the choice of the corrugated membrane technology licensed by GTT/France$^1$, which offered several advantages in the deep underground environment and for liquid argon storage (as opposed to their industrial use for LNG). In a LNG membrane tank, the three main functions of structural support, thermal insulation and liquid containment are all realised by separate elements: (a) the outer supporting structure, (b) the specially designed thermal insulating panels with plywood and expanded foam and (c) the thin layer of steel membrane. The welded membrane provides the primary

$^1$ GTT (Gaztransport & Technigaz), www.gtt.fr
The above findings are very promising for the cost-effective realization of a very large deep underground liquid argon detectors, however several aspects need to be verified. According to this graded strategy, we have been proposing to build two consecutive cryogenic vessels of increasing volumes: the cryostat for the $3 \times 1 \times 1 \text{m}^3$ active TPC prototype followed by the cryostat for the $6 \times 6 \times 6 \text{m}^3$ active TPC demonstrator. See Table I.

The inner vessel required for the $6 \times 6 \times 6 \text{m}^3$ demonstrator is a cubic shape with inner dimensions...
### 2.3 Vessel design and procurement

<table>
<thead>
<tr>
<th></th>
<th>$6 \times 6 \times 6 \text{ m}^3$</th>
<th>$3 \times 1 \times 1 \text{ m}^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner vessel size (WxLxH)</td>
<td>$8.3 \times 8.3 \times 8.1$ m$^3$</td>
<td>$2.4 \times 4.8 \times 3$ m$^3$</td>
</tr>
<tr>
<td>Inner vessel base surface</td>
<td>67.6 m$^2$</td>
<td>11.5 m$^2$</td>
</tr>
<tr>
<td>Total liquid argon volume</td>
<td>509.6 m$^3$</td>
<td>17 m$^3$</td>
</tr>
<tr>
<td>Total liquid argon mass</td>
<td>705 t</td>
<td>24 t</td>
</tr>
<tr>
<td>Active LAr area</td>
<td>36 m$^2$</td>
<td>3 m$^2$</td>
</tr>
<tr>
<td>Charge readout module (0.5 x0.5 m$^2$)</td>
<td>36</td>
<td>12</td>
</tr>
<tr>
<td>N of signal feedthrough</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>N of readout channels</td>
<td>7680</td>
<td>1920</td>
</tr>
<tr>
<td>N of PMT</td>
<td>36</td>
<td>5</td>
</tr>
</tbody>
</table>

**TABLE I**: Some parameters of the $6 \times 6 \times 6 \text{ m}^3$ demonstrator compared to $3 \times 1 \times 1 \text{ m}^3$ prototype.

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 (and possibly up to 600 kV, to be tested as part of the demonstrator). This volume shall also be used for access and movement inside the vessel during the construction phase. A manhole and possibly a smaller material 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.

In 2014 ETHZ in Collaboration with CERN started to consider the design and procurement of the smaller membrane vessel for the $3 \times 1 \times 1 \text{ m}^3$ prototype. A preliminary engineering study has been performed in Collaboration with GTT in spring 2014. It led to the conceptual design of the vessel of 17 m$^3$ of liquid argon (see Figure 3). The tank is designed to store LAr at a temperature between 86.7

![FIG. 3: Conceptual design of the first membrane cryostat to be built at CERN (left) iso-view without top-cap (right) with top-cap.](image-url)
K and 87.7 K and to operate at a pressure differential of $\pm 50 \text{ mbar}$ with respect to the atmospheric pressure. The membrane is made from 1.2 mm thick stainless steel. 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/m$^2$ in cold operation. The adopted design has the shape of an open cup with a thermally insulated top-cap. This design allows to use standard membrane panels all the way to the top and avoids complications at the level of the roof. The top-cap is assembled externally and shipped to CERN in a single piece. It is weldable on the top of the membrane vessel. The top-cap has several vertical nozzles, through which the services and interfaces are passing into the main vessel.

After the GTT conceptual design phase, the procedure of tendering for executive design, procurement and assembly was launched in April 2014. The invitation to tender was sent to a list of European firms that are licensed to construct GTT membrane tanks. Attempts to sign a contract with a first firm failed and a fall-back solution had to be implemented. CERN took responsibility for the construction of the outer-structure, based on a solution composed of a regular carbon-steel I-beams welded into frames. The frames are made by independent pieces made by parts welded by an external company and of size allowing for easy transportation by road. The independent pieces were then bolted in-situ in order to assemble the complete outer-structure. The outer-structure has a mechanical supporting role, and has to sustain the forces of the over-pressure in the inner vessel as defined in the operating pressure specification listed above. The executive engineering of the membrane cryostat was contracted to GTT which honored their contract. For installation of the panels and the welding of the membrane, an “outfitter” company – a Spanish firm licensed by GTT to execute repair of membrane ships – was selected. The procurement of the panels has been launched in January 2015 and will be delivered in the coming weeks. As the membrane technology is licensed, this solution allows for a significant cost reduction. However, it required the development of an agreement between CERN and GTT for our specific application. GTT has accepted that the same agreement will be used also for the design, procurement and assembly of the larger membrane tank for the $6 \times 6 \times 6 \text{ m}^3$ demonstrator (and for all other tanks that might be constructed in the context of the CERN neutrino platform). The construction of the $3 \times 1 \times 1 \text{ m}^3$ cryostat has therefore opened the path for future applications of the membrane technology for liquid argon detectors.

2.4 Cryogenics

The task of the cryogenic system for the DLAr is to safely compensate for the boiling-off gas and simultaneously purify both the gas and liquid argon to a level below 0.1 ppb (parts per billion) of
oxygen equivalent, needed in order to achieve an electron lifetime better than 3 ms.

In previous applications for LAr TPC cryostats, the boiling-off gas is taken by a gas pump and then sent to the condenser where it turns into liquid and returns back to the vessel. In this case the warming-up of the cold gas before reaching the gas pump adds to the cooling power requirements. Though well functioning in small or medium size cryostats, this method is not scalable to big tanks as the 20 and 50 kton far detectors described in the LAGUNA-LBNO design study.

For the DLAr, an evaporation rate of $\sim 450$ l GAr/min is foreseen. This is difficult to handle with a single pump. Thus, an alternative approach to condense the cold boiling-off gas is proposed. This design has a first concrete realization with the system under construction for the $3 \times 1 \times 1$ m$^3$ prototype. Given the fact that the membrane cryostat cannot be evacuated and the fact that there is no surrounding cooling vessel, we have designed special systems for purging, cooling and for gas and liquid argon recirculation. These systems satisfy both the purity and rating pressure requirements.

A step-by-step operation sequence has been then defined to safely operate the cryogenic system as described below:

- First, the tank is purged with argon gas coming from an evaporator connected to the liquid argon storage tank. The purging stage lasts for at least 10 volume changes and will stop when the monitored oxygen contamination in the argon gas falls below 10 ppm (parts per million).

- Immediately after the purging stage, a closed gas recirculation and purification system will further reduce the impurity level down to 1 ppm, which corresponds to less than 1 ppb impurities to the liquid after the gas re-condensation.

- After the gas recirculation and purification step, the cooling of the tank will start. The tank is cooled by taking the warm gas, passing it via a to the condenser and re-injecting back the cooled gas inside. During this cooling-down phase, the gas is continuously purified by both the gas purifier and the custom-made activated copper cartridge after the condenser.

- When the temperature of the tank is within 50 Kelvin above the liquid argon temperature, the tank will be filled with liquid argon passing through a custom-made activated copper cartridge.

- Once the LAr level will have reached the required level in the tank, normal operation will start. During normal operation, the LAr is recirculated by a submersed centrifugal pump, the boiling-off gas is re-condensed by the condenser and purified by the custom-made activated copper cartridge after the condenser.
This cryogenic system concept has now been implemented on a smaller scale for the the LAr-Proto prototype, as shown in Figure 4. According to different functionalities, the system is separated into three blocks: the purge and gas purification (PGP) system, the boiling off compensation and purification (BOCP) system and the liquid argon filling, recirculation, purification (LFRP) system.

The PGP system consists of an evaporator, a gas recirculation and purification system and an impurity trace analysis system. The evaporator is a commercial product. We have chosen the one from Criotec with a 8 m finned tube. For the gas argon recirculation, a double diaphragm pump (KNF 0150.1.2 AN.12 E) takes the gas from the vessel at a speed of 200 l/min, then the gas argon passes through a commercial gas purifier (SAES MicroTorr MC4500) where impurities including H₂O, O₂, CO, CO₂, H₂, etc are removed. The 200 l GAr / min gas recirculation flow is limited by the specification of the purification cartridge. At this recirculation speed, the gas volume changes every 2 hours. During this purge and gas recirculation stage, the gas impurities are continuously monitored with three trace analyzers: the AMI 2001R for oxygen, the Gow-mac 1402 for water and Gow-mac 1200 for nitrogen. The sample gas to the trace analyzers is taken from a double diaphragm pump (KNF
N 86 AN.12DC-B) with a capacity of 4.5 l/min. The gas purification has been designed as shown in Figure 5. Currently, the instruments are being ordered. The construction of the PGP system will be completed before this summer.

The BOCP system consists of a condenser, a LAr bellow pump and a copper and molecular sieve cartridge. The boiling-off gas is directly sent to the condenser driven by the differential pressure between the tank and the condenser. This principle is scalable and saves additional cooling power to warm up the gas first if we use a gas pump for the boiling-off gas. The LAr bellow pump runs at a speed of 0.2 l/min to push the LAr after the condenser through the activated copper cartridge and molecular sieve back to the tank.

The submersed centrifugal pump for LAr recirculation is shown in Figure 6 left. It is a new product with the model type TC34.2 from the company called ACD. ACD provided the submersed centrifugal pump AC32 for both the ICARUS experiment and the Fermilab LBNE 35ton prototype. These AC32 pumps ran successfully for both experiments and achieved the required LAr purity.

Compared with AC32, the TC34.2 has several advantages. Compared to AC32 with a single stage impeller, the 3 impeller stages make TC34.2 better performing in the differential pressure head, it shows a better efficiency and a lower net positive suction head (NPHR). The higher efficiency reduces the cooling power by 100 W. The bearing lifetimes of TC34.2 is also higher than AC32. Figure 6 (right) shows the pump performance curves.

For the 3 × 1 × 1 m³ prototype, the LAr pump will run at a speed around 23 l/min meaning 2 volume changes per day. For the DLaR with much larger LAr volume, increasing the pump capacity and implementing multiple pumps in parallel is needed. Multiple pumps in parallel also reduce the
risk due to potential bearing failures.

The $3 \times 1 \times 1$ m$^3$ prototype allowed for a first concrete implementation of the cryogenic/purification scheme designed for very large tanks and to be demonstrated in the WA105 DLAr detector. This implementation can be considered as a building block in order to scale up to the requirements for the final DLAr detector cryogenic system.

![Prototype Image]

**FIG. 6**: Left: the submersed TC34.2 centrifugal LAr pump; right: the pump performance curves.

### 2.5 Design and assembly of Charge Readout Plane

In the double phase LAr-TPC concept the ionization charge is extracted to the Argon gas phase where it is amplified by a Large Electron Multiplier (LEM) which triggers Townsend multiplication in the high electric field regions in the LEM holes [3]. The electrons are efficiently extracted from the liquid with an electric field of around 2 kV/cm and amplified with a field of about 30 kV/cm applied across both electrodes of the LEM. The amplified charge is then collected and recorded on a two-dimensional segmented anode. The anode consists of a set of strips (views) that provide the $x$ and $y$ coordinate of the event with a 3 mm pitch. A sketch with the typical electric fields and the distances between each stage is shown in Figure 7.

In the design concept of the DLAr, all those stages (extraction grid, LEM and anode) are assembled.

![Charge Readout Plane Diagram]
in a single Charge Readout Plane (CRP). The CRP therefore consists of the 2D anode, the LEMs and the extraction grid assembled as a multi-layered “sandwich” unit with precisely defined inter-stage distances and inter-alignment.

The CRP is made from independent LEM and anode units of 50 × 50 cm$^2$. The adjacent anodes can be bridged together to form readout strips of the required lengths and the signals are brought to the front end electronics embedded inside dedicated signal feed-through chimneys. The length of the strips foreseen for the DLAr is 3 m.

This scheme has been fully implemented in the CRP of the LAr-Proto detector which has the minimal size of a 3 × 1 m$^2$ independent readout unit of the DLAr.

Drawings of both CRPs are shown in Figure 8 and some of their characteristics are summarized in Table II.

<table>
<thead>
<tr>
<th>Component</th>
<th>50 × 50 cm$^2$ Anode panels</th>
<th>50 × 50 cm$^2$ LEM panels</th>
<th>Signal feedthrough</th>
<th>Suspension feedthrough</th>
<th>readout strip length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DLAr</td>
<td>144</td>
<td>144</td>
<td>12</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>LAr-Proto</td>
<td>12</td>
<td>12</td>
<td>6</td>
<td>3</td>
<td>1 or 3</td>
</tr>
</tbody>
</table>

**TABLE II: Components of the CRPs.**

We now have received the CRP for the LAr-Proto detector which is currently being assembled inside the building 182 clean room. It is made from twelve 50 × 50 cm$^2$ anode and LEM modules. An exploded view is shown in Figure 9.

The anode and LEM panels are screwed to 3 identical 1 × 1 m$^2$ G10 frames, which are fixed to the 3 × 1 m$^2$ stainless steel structure. Each G10 frame hosts 4 LEM/anode modules. The LEM and anodes are fixed together with 24 M2 peek screws each containing a precisely machined 2 mm thick pillar
in order to guarantee a constant interstage distance between the entire $50 \times 50$ LEM/anode modules. As can also be seen in Figure 9 the entire area of the LEM and anode is active and each adjacent module has an inter-space of only 0.5 mm. It is therefore important to note that, although composed of independent LEM/anode modules, the entire $3 \times 1 \text{m}^2$ area is fully active within our 3 mm readout.
2.5 Design and assembly of Charge Readout Plane

The extraction grid consists of 100 µm diameter stainless steel wires tensed in both x and y directions. They are soldered by group of 32 on independent wire tensioning pads spaced on the side of the frame. Each wire tensioning pad consists of a PCB precisely fixed on a mechanical wire holder. The PCB hosts the high voltage connection and has 32 soldering pads with 200 µm grooves to precisely position the wires. During the wire soldering process each wire is tensioned by 150 g lead weights and precisely positioned inside the grooves. With this method the precision on the wire pitch, measured under the microscope, was better than 50 microns. The PCB is then fixed on the wire-holder and the whole system can provide precise tension to the group of 32 wires by pushing the holder against the CRP FR4 frame with two stainless steel screws (see Figure 10).

The full design of the CRP including the extraction grid tensioning system was tested on a 1m² mechanical mockup which is described in the TDR [1]. Pictures of the assembly are shown in Figure 11.

The stainless steel frame was measured to have a planarity of ± 1 mm over the entire 3m². We have also measured the interstage distance between a LEM and anode sandwich at the CERN metrology laboratory in many points. The results are shown in Figure 12 and are described in [4]. They indicate that the planarity is within our tolerance of 2 mm ±100µm .

The design of the CRP for the DLAr and its hanging system are currently being finalized. The DLAr CRP will integrate similar structures as the one constructed for the LAr-Proto . We furthermore foresee an immersion test of the 3×1 m² CRP in LN₂ instrumented with temperature probes and strain gauges to precisely monitor its thermal deformations. In addition to test the behavior of the structure in cold before operation it will provide important feedback data for the design of the 6×6 m² CRP. In parallel we have been defining a mounting sequence of the different elements of the CRP (LEM-anode
sandwiches, extraction grid wires) by using the DLAr cryostat as clean room and accessing the top of the detector with a scaffolding. This situation has to take into account several constraints such as the maximal dimensions of the parts to be introduced inside the cryostat from the clean room by using
the Temporary Construction Opening (TCO) lateral access, the cabling to the chimneys and the use of the scaffolding. Mounting tests have been defined in order to mimic these working conditions on the assembly of $50 \times 50 \text{ cm}^2$ panels in the $3 \times 1$ structure.

2.6 Test of anode/LEM

A lot of effort has recently been invested in developing the systematic procedure for cleaning, testing and assembling a large number of $50 \times 50 \text{ cm}^2$ LEMs and anodes. This work includes as well the investigation of all the procurement issues with the industry of the various components of the LEM-anode sandwich, their processing at CERN and the related quality assessment and the detector elements commissioning.

The procedure which has been fully developed for the LAr-Proto prototype will be scaled up to match the much larger numbers required for the DLAr detector. A picture of the LEMs and anodes along with a zoom on their structure is shown in Figure 13.

![Figure 13: Top: pictures of the LEM and anode along with microscope views. Bottom: close up of the LEM HV connectors and back view of the anode with the 20 soldered connectors.](www.eltos.it)

They are all produced at a PCB manufacturing company called ELTOS\textsuperscript{2}. Their designs are the outcome of intensive R&D effort of the last years, aimed at getting the largest signal-to-noise ratio ($S/N$) for the large area readouts foreseen in the WA105 detectors and future giant double phase liquid
argon TPCs.

We briefly summarize below the results:

- the anode is manufactured from a single multilayer printed circuit board (PCB) whereby its 3.125 mm readout strips for both views consist of interconnected gold plated copper tracks. The design is such that both x and y views collect the same amount of charge independently of the angle at which the drifting electrons cross the readout strips. Various layouts of the readout views have been tested and optimized as described in [5]. Thanks to this innovative design the electrical capacitance of its electrodes is reduced to only 150 pF/m which translates into an electronic noise of about ∼ 1000 electrons for a two meter readout.

- the LEMs consist of copper cladded epoxy plates, with a thickness of one millimeter and mechanically drilled holes of 500 µm diameter surrounded by a 40 µm dielectric rim around. The holes are arranged in a honeycomb pattern with a pitch of 800 µm yielding about 200 holes per cm² and o(500’000) holes over the entire 50x50 cm² area. The amplification of the drifting charges in pure argon vapor at 87 K with LEMs has been demonstrated many times on a chamber with 10×10 cm² area readouts (see e.g Refs. [6, 7] ) but also on a larger device consisting of a 40×80 cm² readout and 60 cm drift [8]. Both setups were successfully operated in a stable condition at constant gains of about 15 corresponding to S/N ≈ 60 for MIPs. In one of our latest publications [9] we also studied the impact of the rim size, insulator thickness, hole diameter and hole layout on 10×10 cm² area LEMs. We compared their response in terms of maximal reachable gain and influence on the collected charge uniformity as well as the long-term stability of the gain.

Although twelve of each are needed to cover the active area of the LAr-Proto detector, we have however ordered 20 LEMs and 15 anodes in case of defects or to keep the extra ones as spares. They will anyhow be needed for the DLAr . The procedure for purchasing, cleaning, quality assurance (QA) and assembly of the LEM-anode sandwiches is summarized in Figure 14 and described below.

**a) 50 × 50 cm² anode QA.**

One of the main advantages of the anode design is that it can be manufactured with standard PCB techniques at a relatively low cost by many companies. We have chosen ELTOS since they also produce the LEMs. Before delivery to us all the strips on the anode undergo a test of electrical signal continuity as well as an optical scan. Once received we solder the 20 connectors³ at the CERN SMT workshop. Each connector is connected to 32 strips of the anode. Since the anode has 160 strips

³ KEL 8925E-068-179-F connectors
b) $50 \times 50 \text{ cm}^2$ LEM QA.

The entire procedure from the production of the LEM until its acceptance has been carefully planned according to our experience in handling and operating these devices. First, after exploring multiple PCB manufacturing companies, ELTOS was the only one that we found can guarantee satisfactory products at the scale we require. The procedure summarized in Figure 15 is decomposed in two main parts: the production which is in the hands of ELTOS and the cleaning/testing phase which is performed by us mainly at the CERN PCB laboratory.

Once cleaned the LEM should be baked once for 4 hours at a temperature of 180°C which is just above the glass transition of the FR4. This process is called polymerization, it is known (and confirmed by our measurements) to significantly improve the maximum reachable field across the LEM. This procedure is done only once even if the LEM has to undergo multiple cleanings. Since, by design, the entire area of the LEM is active their handling during the cleaning procedure requires great care. Furthermore once cleaned exposure to dust and direct touching should be kept to a minimum. For this reason each LEM has its own handling Aluminum plate as shown in Figure 16. Both the HV testing and storage boxes are designed to accommodate the LEM with its handling plate so that the LEM is never touched until installation on the detector.
With the required infrastructure in place, the cleaning process itself is rather fast (typically 20 mins) and straightforward. Some steps are illustrated in Figure 16.

After being cleaned the LEM is powered in air inside a dedicated high voltage testing box with a transparent window. The test is performed in a clean room where the atmospheric conditions are stable. The LEM is considered as satisfactory if we reach within a few minutes 3.5 kV over its electrodes (or an equivalent electric field of 35 kV/cm) with a negligible leakage current of typically a few nA. Above this value the observed discharges should be randomly distributed. If this condition is not respected then the cleaning process is repeated.

It should be noted that when powered for longer timescales of typically a few hours the cleaned
LEM can reach stable voltages around 3.5-4 kV in air. This long term powering is important to train the LEM and is done at a later stage. We are developing a test-bench with a Labview controllable power supply to monitor the evolution of the voltage and current over long periods. First results comparing the same LEM before and after cleaning are shown in Figure 17. The high voltage test boxes are currently being upgraded with better insulation and pressure monitor to also perform those tests in pure Ar or N\textsubscript{2} gases.

![Graph](image1.png)

FIG. 17: First results of LEM high voltage test in air. The high voltage and monitored current across the LEM are shown as a function of time and the spikes indicate that a discharge occurred. Although this first test was done at a low electric field (27.5 kV/cm) a clear improvement is seen after cleaning.

A more sophisticated setup (see Figure 18) allows for a complete characterization of the LEM gain uniformity over the entire surface. This setup is built out of a sealed gas chamber filled with a Ar-isobutane mixture, the chamber integrates a XY scanning system with a radioactive source of \textsuperscript{55}Fe.

![Graph](image2.png)

FIG. 18: (Left) Gas chamber with an integrated scanning system for the LEM gain uniformity measurements. (Right) some measurements of the gain as a function of the LEM voltage are shown in the plot.

The work performed on the LAr-Proto has represented an invaluable opportunity for setting up in real conditions all the procurement, assembly and testing chain of the anode and LEM, all the related infrastructure and tools, like the clean room installation, and to define precisely the processing and commissioning procedures. This complete exercise provided a net anticipation of all the technical issues
for the construction of the DLAr which can now exploit all the design, procedures and tools worked out during the last year and rely on scaling up the production of the LEM/anode sandwiches.

2.7 Feedthroughs and chimneys

The components of the feedthroughs and chimneys have been fully designed and prototyped for the DLAr. All these feedthroughs have been implemented, in some cases in a reduced size, in the LAr-Proto. This full implementation can be appreciated in the design top-cap of the LAr-Proto vessel. This top-cap is crossed by several chimneys, as described in Figure 19. Chimneys labeled as Type 2, Type 3, Type 7 and Type 4 are described in the following sub-sections.

![FIG. 19: Top cap of the LAr-Proto detector with chimney position. 1: manhole, 2: Signal FT chimney, 3: Slow control chimney, 4: HV feedthrough chimney, 5: Cryogenics chimney, 6: gas recirculation chimneys, 7: Anode deck suspension chimneys.](image)

2.7.1 Signal feedthrough chimneys.

The Signal-feedthrough chimneys (SFTC, number 6 in Figure 19) are designed for the connection of the anode charge collection strips to the cold electronics front-end cards, hosted in the bottom of each chimney. To allow for eventual repair/replacement of a front-end electronic card, each chimney is built as a hermetic vertical pipe with, at the bottom, a cold signal feedthrough (CSFT) with connectors on the bottom to connect to the anode panels and connectors on the top for hosting the “cold” amplifier cards (see Figure 20).

The output of the front-end electronics is sent, via twisted pair ribbon cables, to a warm signal feedthrough (WSFT) on the top/side of the chimney. The chimney is filled with $N_2$ gas and equipped
2.7 Feedthroughs and chimneys

with a heat exchanger at the level of the “cold electronics” to stabilize the temperature at \(\sim 110\text{K}\) (optimum for the S/N ratio of the charge preamplifiers). The heat exchanger, a Cu tubular coil with circulation of liquid argon, will compensate the heat dissipation of the 320 electronic channels (\(\sim 5\text{W}\)) and the conduction heat through the twisted pairs ribbon cables to the warm WSFT (\(\sim 2.7\text{W}\)).

FIG. 20: Signal feedthrough chimney.

FIG. 21: Picture of the first signal feedthrough chimney.
The first of the six SFTCs under construction is shown in Figure 21, Figure 22 and Figure 23. A "N₂ flushing ring" is inserted at the bottom of the chimney to flush N₂ in case of emergency opening of the top of the chimney for the repair or replacement of a faulty electronic card. The cards are hanged to FR4 vertical blades with handles on the top for their insertion/extraction. Each chimney hosts 320 channels for the LAr-Proto and 640 for the DLAr where the number of chimneys is 12.

### 2.7.2 Slow control feedthrough chimneys.

Figure 24 shows the layout of the three Slow control feedthrough chimneys (SCFTC) through the insulator. A detailed view of the flanges with weldable connectors is provided in Figure 25.

The slow control chimneys are used to provide the connection interface for all the following items:

a. One calibration feedthrough with 60 channels to inject calibration signals on the charge collection
2.7 Feedthroughs and chimneys

FIG. 24: Slow control feedthrough chimneys crossing pipe in top cap insulation.

FIG. 25: SCFT flanges of type 1,3 (left) and 2 (right) with weldable connectors.

strips of the anode panels: one signal per group of 32 channels. This will allow the control of the correct connection, the estimate of cross-talk between near channels and calibration of the preamplifier response. Four of such calibration feedthroughs will be required for the LAr-Proto, with the same configuration. The calibration of the preamplifiers gain will also be possible with a charge injection signal via the signal feedthroughs.

b. 30 SHV-6kV weldable feedthroughs for biasing the top (12) and the bottom (12) of the LEM panels and to power the PMTs (5).
2.7.3 Suspension feedthrough chimneys.

The suspension of the CRP deck for the LAr-Proto is obtained by hanging it in 3 points by 2 mm (5mm for the DLAr) diameter stainless steel ropes. The hanging positions are chosen to equally distribute the anode deck weigh and centering its center of mass. The ideal positions calculated for 3×1m², for 4×4m² (for the 20-50kTon detector) and for the 6×6m² anodes, are shown in Figure 26. They are obtained by splitting the rectangular and square anodes into 3 equal area sectors. The sectors are defined by the condition that the center of mass of the centers of masses of the 3 sectors is positioned in the geometrical center of the CRP. The compromise configuration shows the hanging points shifted on the nearest CRP frame support (every 0.5m).

The suspension mechanism has already been designed and all the parts have been ordered as part of the LAr-Proto activities. A drawing is presented in Figure 27. The device allows a 40 mm full range displacement with a 0.1 mm position accuracy. This precision is required in order to precisely position the LEM half a millimeter above the LAr level. The system reads the LAr level thanks to the eight capacitive level meters connected to the CRP (see Section 2.9) and automatically adjusts the frame at the required height. It has its own SIEMENS PLC that is connected to the global slow control system.
2.7 Feedthroughs and chimneys

FIG. 26: Hanging positions for the $3 \times 1 \, m^2$, $4 \times 4 \, m^2$ and $6 \times 6 \, m^2$ CRP. Ideal positions are shown in the top and compromise positions on the bottom.

FIG. 27: Drawings of the suspension feedthrough mechanism and view of the integration on the LAr-Proto
2.7.4 High voltage feedthrough.

The DLAr requires a negative 300 kV potential at the cathode in order to provide the 500 V/cm drift field over the entire length of detector. We have already purchased a 300 kV power supply and are in the process of designing the corresponding high voltage feedthrough (HVFT). Both will be equipped on the LAr-Proto in order to assess their performance. Although the LAr-Proto, which has a one meter drift, only requires 50 kV at the cathode, we will nevertheless take the opportunity to test the HVFT up to the maximum voltage of 300 kV. A schematic of the 300 kV HVFT that will be installed on the LAr-Proto is shown in Figure 28. It is ~2.6m long and is scaled up from a design that was successfully tested at 100 kV [10]. The feedthrough is configured as a coaxial “female-female” connector, with the top connection designed for the 300kV cable and the bottom connection (“cold”) to a tubular elbow welded to the cathode. The cold connection is made via metallic springs that will compensate the thermal shrinkage of the cathode and of the HVFT itself.

![Figure 28: The High voltage feedthrough with its connection to the elbow contact to the cathode plane. In the middle its position is shown with respect to the SCFT chimneys. The left picture shows the Heinzinger 300 kV power supply currently in building 182.](image)

2.8 Readout electronics and DAQ

The developments for of the front-end electronics and the digitization electronics for the DLAr charge readout have been progressing since the TDR with the goal of starting the production of the ASIC amplifiers and of the microTCA digitization boards, for the 7680 channels foreseen in the DLAr

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4 PnChp 300 kV, 0.5 mA, 100 ppm ripple from Heinzinger electronic GmbH, Rosenheim(D)
A first version of the cryogenic ASIC amplifier adapted to the LEM signals dynamics (1200 fC) was already produced in 2014. In the fall of 2014 a new version was submitted characterized by a double-slope gain with a larger gain in the region 0-10 MIP, in order to enhance the resolution in the dE/dx measurements and a gain reduced by a factor 3 in the region 10-40 MIP, which is characterized by the signals from the electromagnetic showers. This concept and the supporting arguments from the simulations were already described in the TDR, the new ASIC version was delivered in January 2015 and is current under test (see Figure 29).

The implementation of the double-slope gain regime is obtained by replacing the feedback capacitor of the OPAMP with a MOS capacitance which changes its value above a certain threshold voltage. This effect is also present during the discharge and it can be corrected with the inclusion in the feedback also of branch with a diode and a resistor which keep the RC value constant. This branch can be selected/deselected with an internal switch for all the channels in the ASIC (see Figure 30).

Both ASIC versions compatible with the LEM signals dynamics are realized in the CMOS 0.35 microns technology, have 16 channels, 18mW/channel or less thermal dissipation, about 1300 electrons ENC at 250pF input detector capacitance and operate with this best S/N ratio figure around a temperature of 100 K inside ad hoc designed signal chimneys. The front-end cards in the chimney host each one two ASIC chips plus a few discrete components. Particular care has been taken in testing several options (GDT, MOV, Diodes) for the surge arrestor components which has to protect the ASICs from
occasional sparks which may be generated in the CRP in order to maximize their protection efficiency, test the components durability for a very high number of sparks and minimize the input capacitance. A special setup has been build for the automatic stress tests of these components by generating calibrated discharges and their characterization (see Figure 31).

The design of the digitization cards (microTCA AMCs, 64 input channels, 14 bits, 2.5 to 25 Msps, data transmission via 10GbE, local buffer 12228 samples/channel, see Figure 32) for the charge readout
has been proceeding with the realization of a demonstrator based on a commercial programmable AMC evaluation card from Bittware (microTCA AMC S4AM) providing a very flexible development environment coupled to the FMC mezzanine board including the final 64 channels ADC circuitry (see Figure 33).

![AMC card design: block diagram](image)

**FIG. 32: Schematics of the charge readout 64 channels AMC digitization card**

This demonstrator allowed to fully test the analog part of the circuit and the ADCs implementation as well as all the firmware for the NIOS operation and the data acquisition on a FPGA Stratix IV GX. The demonstrator has been successfully taking and transmitting data on the 10GbE and it has validated the firmware development and the dimensioning of the FPGA for the design of the final AMC card which is currently being completed.

The DAQ developments included as well the definition of the global architecture for the back-end, event building and time and trigger distribution. A general scheme is presented below (see Figure 34):

The charge readout system is organized in 12 microTCA crates hosting each 10 digitization AMCs cards with 64 channels per card. Each microTCA crate is connected to the back-end card (Bittware S5PHQ-8) via a 10GbE optical link for data transmission. Each back-end card can handle up to 8 10GbE links and it is characterized by high local data processing power for the event building. The AMCs digitize the signal on a common time base provided by the time distribution system based on the White Rabbit (WR) protocol. The WR can distribute to all the slave nodes a common clock source
FIG. 33: Photo of the DAQ demonstrator card: 64 ADC ch. AMC mezzanine + S4AM development board

FIG. 34: General architecture of the DAQ and time and trigger distribution systems

(provided by a GPS disciplined oscillator) and the related synchronization signals in order to obtain sub-ns synchronization accuracy. These signals are received by a slave node implemented as mezzanine on the microTCA MCH and distributed to the AMCs via the backplane of the microTCA crate. The WR is a data network which can also distribute the beam trigger time stamps which are produced with about 100Hz frequency on a WR slave node on a PC. The bandwidth for the trigger distribution is very low and it does not interfere with the exchange of the WR synchronization data. The time distribution
WR architecture is based on commercial components (the WR switch, the WR slave clock nodes and the WR time tagging PC card), the only development occurring in WA105 concerns interfacing the WR slave clock card to the MCH, the distribution of the clock and sync. signals on the microTCA backplane and their decoding by the AMCs. The AMCs have thus a knowledge of the beam trigger time stamp in order to organize the proper treatment of the data belonging to the drift time window of a given beam event. The charge readout DAQ is designed also to take data without zero skipping with a maximal rate of 100 Hz and lossless data compression methods, as the Huffman compression are under implementation in order to reduce the data volume. A microTCA crate hosting the light readout digitization cards, acquiring a total of 36 photomultipliers, is naturally integrated in this architecture by taking into account the common time distribution and data transmission systems. During the data taking outside the beam spills it is foreseen to take data on the basis of a trigger with an external hodoscope of scintillators designed to select horizontal cosmics (large area trigger counter) and with a trigger which can be generated by the light readout microTCA crate and its time-stamp can be transmitted over the WR network similarly to the beam trigger.

A prototype of the light readout AMC is also being realized by still using the Bittware development card S4AM and a mezzanine card including the ADC and the trigger circuit (see Figure 35).

![Block diagram of the light readout AMC demonstrator card](image)

The light trigger trigger is obtained from the PARISROC2 ASIC while the signal digitization is provided by a AD9249 ADC chip. This AMC card demonstrator will be tested during the summer 2015.
2.9 Slow control

The slow control system for the DLAr is part of a continued progressive prototyping effort aiming at developing a control system dedicated to multi-ton liquid argon double phase detectors. It has been designed following the successful example and the expertise developed in the context of the ArDM experiment [11] which is currently operating 1 ton of liquid argon in an underground laboratory (LSC, Spain).

Differently from ArDM the acquisition of the physical quantities of interest is done thanks to versatile and compact National Instruments compact RIO, as partially already experienced in NA62 experiment at CERN; National Instruments offers a vast choice of different modules each designed for a specific family of sensor. The solution proposed using those modules guarantees scalability and reduced need of cabling, keeping costs reasonably low if compared to a PLC based solution.

As for the other sub-systems of the DLAr detector the LAr-Proto offered the playground to perform a full implementation of the slow control system then scalable to the full detector.

The slow control system of the DLAr and LAr-Proto detectors is built to monitor:

- temperature
- pressure
- liquid argon level
- deformation of materials

mainly inside the tank; moreover it provides the hardware infrastructures needed to monitor traces of impurity in the tank, high and low voltage power supplies, heaters, lighting system, vision system and will interfaces with the cryogenic system and with the motorized system to control the positioning of the CRP. As mentioned a new DAQ system based on National Instruments modules is proposed for the slow control scheme of the WA105 detectors. To assess their performances a reduced number of modules has been purchased and assembled in a small rack by the PH-DT department at CERN as shown in Figure 36.

The entire control system will be monitored through a single LabView interface which will implement together with the required sensor calibration, control of the actuators and the platform for vision system inside and outside the tank. The overlying supervisory level will be implemented in UNICOS and will provide an interface to the operator for monitoring of all the quantities and handling of alarms, as commonly done in all CERN experiments.
FIG. 36: The rack is a prototype of the entire Control System; it embeds modules for resistive temperature sensors, pressure sensors, strain gauges, liquid argon level meters, control for heaters. On the upper part a redundant 24 V power supply provides fault tolerant power to the National Instrument controller and modules. Calibration of modules and sensors is ongoing.

Given the nature of LAr-Proto detector as a prototype towards the DLAr, its instrumentation is abundant in terms of number of sensors; the uniqueness of the large area CRP suggested us to place a significant number of temperature sensors which will guarantee a fine monitoring of the temperature distribution. The location of the sensors on the LAr-Proto CRP is shown in Figure 37.

FIG. 37: Representation of the distribution of sensors on the Charge Readout Plane.
We also propose to monitor the behavior of materials in cold thanks to strain gauges which will be tested extensively beforehand in a open bath test in April 2015. Considering we aim to obtain a 100 μm precision on the CRP vertical position with respect to the LAr level over its entire 3m², we opted for a redundancy in the number of parallel plate capacitors dedicated to this measure. We instrumented then the drift cage with a set of three parallel plate level-meters to assess finely the absolute level of the liquid in the tank in addition to a coarse measure with the 2 long coaxial level-meters all along the drift length. A picture of both types of level meter is presented in Figure 38. They have been abundantly tested on the ArDM experiment.

![FIG. 38: Parallel plate and coaxial capacitor level meters](image)

An intense calibration activity is ongoing in parallel to the design of the cryogenic system addressed to the monitoring of contaminants inside the tank; for this purpose oxygen, nitrogen and moisture trace analyzers have been purchased and tested to prove their resolution and stability.

To survey the status of the tank, of the detector and the conditions of liquid argon during maintenance period, a cryo-vision system has been proposed, based on the use of USB cameras and LEDs lighting system. The solution has been tested and currently is being improved in the existing 3 liters test setup in Blg. 182. The CMOS sensor is proved to be not working at liquid argon temperature so we glued a 20 W heater and a temperature sensor on the PCB of the camera so that we can set the temperature of the device into its working range thanks to an ON-OFF control of the heater (see Figure 39).
A complete list of the sensors which are been foreseen for both the DLAr and LAr-Proto detectors is provided in Table IV. The numbers presented for the DLAr are an extrapolation from the sensors we are installing in the LAr-Proto and they are not yet final.

Overall the entire slow control system can be seen as an ensemble of three sub-systems:

- Process Control System (PCS), responsible for monitoring of temperatures, pressure and liquid Argon level, survey of the tank (temperatures and pressures of the insulating space) and monitoring of the cryogenic system

- Detector Control System (DCS), monitoring of low and high voltages power supplies and temperatures inside the rack

- Detector Safety System (DSS), monitoring of all the quantities considered critical, handling of alarms, interlocks on instrumentation.

This distinction is needed to address the correct redundancy and wiring for instrumentation to accomplish the required level of safety which all the system has to comply with.

### 2.10 Online processing and data storage

During the last months the requirements in terms of local storage and online data processing have been studied and a general architecture designed. This infrastructure includes:

- The DAQ servers hosting the Bittware back-end cards, data dispatching and the DAS local storage

- The local network
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TABLE IV: List of the slow control sensors for the LAr-Proto and DLAr detectors.
• The temporary local storage to buffer the data for online analysis and in case of limited bandwidth to the data transfer to the IT department

• The local cluster of machines which should perform the online analysis (purity and gain measurement, events monitoring, data filtering etc)

• The link to the IT department in order to copy data for permanent storage

In absence of zero skipping and data compression, by running with a beam trigger at 100 Hz, the WA105 DAQ system, given the event size of about 150 MB, can generate a data flow up to 15GB/s. This number is one order of magnitude larger than a typical LHC experiment. A guiding principle for defining the architecture of this system is that the local storage should be able to buffer the DAQ data flow under these conditions for about one day, which translates to a storage capacity at the Petabyte level. The system is then dimensioned in order to ensure the data transfer with a bandwidth of 20 GB/s and concurrent access from the online reconstruction and monitoring tasks. A cluster a few hundreds processors will perform the online reconstruction of the events with a high degree of parallelism in order to ensure the analysis of the cosmic rays overlapped to the drift windows of the beam triggers, the purity analysis with a point every 10 minutes and the monitoring of the gains of the detectors. The online processing will thus ensure a constant assessment of the data quality and of the detector performance. Thanks to the technological evolution on High Throughput the data transfer and storage industrial components to set up a system with these requirements are available on the market. Storage solutions providing a capacity at the Petabyte level with a bandwidth of 20 GB/s and concurrent access from the DAQ and the online processing exist at reasonable costs, well within the budget foreseen in the WA105 MOU for this item, as for instance the High Throughput LUSTRE Data System by Hitachi. The design of the architecture of the system is being finalized in collaboration with industrial partners.

2.11 Large area trigger counters.

Some large area trigger counters are foreseen in order to select nearly horizontal cosmic rays for the data taking. By using the same detector technology foreseen for MIND (3 consecutive strips of 3 m length and cross section of $12 \times 1 \text{ cm}^2$, with WLS fibers readout at both ends by SiPMs and same electronics as MIND) it is possible to build scintillator biplanes of $9 \times 9 \text{ m}^2$, each view will include 270 scintillator bars. The counters can be arranged to cover two opposite faces of the detector at a distance of about 12 m (see Figure 40). This detector will provide a cosmic ray trigger outside the beam spills. Nearly horizontal cosmics at various heights are interesting for the detector characterization.
studies (purity, diffusion, space charge effects etc ...). In addition this application will provide a good opportunity for a large surface application of the detection technologies developed for MIND and it is intended to use exactly the same components as for the scintillator planes embedded in the iron sandwich structure.

![Diagram of large area trigger counters layout](image)

**FIG. 40: Large area trigger counters layout**

The large area trigger counters have been fully costed and included in the MoU as the other DLAr components. A full simulation of the cosmic ray flux in undergoing in order to take into account the effect on the cosmic rays flux the structure of the pit hosting the detector and of the liquid argon and the passive material constituting the cryostat and its supporting structure.

### 2.12 Progress on the EHN1 extension, beam infrastructure and instrumentation

The civil engineering works for the extension of the EHN1 hall in the North Area are progressing well and are on schedule. Digging is in progress for the foundations of the building and the creation of the pit which will host WA105 (see Figure 41).

In parallel the design of the building infrastructure and services is being finalized, considering the integration of the experiment for what concerns the cryogenic system, the ventilation system, the access infrastructure to the top platform, the counting rooms, the external clean room and TCO for the access to the cryostat, which will be used as internal clean room for the detector assembly, the top-cap mounting area and the electrical power and network needs. A general 3D view of what will be hosted inside the ENH1 hall extension including the beam line reaching WA105 can be seen in
2.12 Progress on the EHN1 extension, beam infrastructure and instrumentation

The beam requirements for WA105 are described in details in the TDR document. It is foreseen to have a hadron beam as well as a pure electron beam with fluxes ranging from sub-GeV/c to about 20 GeV/c, a momentum bite of about 5% for hadrons (and less than 1% for electrons) and a trigger rate of a few 100 Hz. The refurbishing and extension works of the previously existing H2-VLE tertiary beam are in progress. The area occupied by CMS on the H2-VLE beam is going to be cleaned up, the

FIG. 41: Civil engineering works for the extension of the EHN1 hall in the North Area

Figure 42.

FIG. 42: General layout of the of EHN1 extension including the H2-VLE tertiary beam line and the WA105 cryostat
north wall of EHN1 is going to be removed and a new version of the secondary target station is going to be installed in an upstream position at the end of the already existing EHN1 hall, from this position the new tertiary beam will be transported down to WA105, as much as possible in vacuum pipes, with new dipole and quadrupole beam elements for a total length of about 50 m (see Figure 43).

![FIG. 43: Layout of the beam elements used for the extension of the H2-VLE beam line down to the WA105 cryostat](image)

The beam optics of the tertiary beam is being optimized. The beam line will also integrate the beam instrumentation. It is foreseen to have trigger counters and a scintillating fibers tracker for the beam profile. In order to perform the tagging of hadrons it is foreseen to install three Cerenkov gas counters complemented by Time of Flight measurement from the scintillator counters. The simulation of the beam fluxes is being performed in order to optimize also the beam line instrumentation.

The beam will reach the cryostat with a slope of 5.3 degrees at a height corresponding to about the middle of the active volume. The impinging direction of charged particles is will be at around 45 degrees with respect to the two perpendicular readout views on the anode in order to maximize without degeneracies the imaging information of each view on the reconstruction of the showers and to exploit the diagonal of the detector for full containment. A beam pipe is foreseen in order not to spoil the momenta of the incoming particles and minimize interactions upstream the active volume, this aspect is particularly important in case the incoming particle is an electron. This pipe will have the shape of a vertical slit of about two meters height in order to provide the possibility of sending particles at various vertical depths and slopes inside the detector, testing so the effects related to different drift paths. The pipe will cross the external reinforced concrete structure, the insulation layers, the cryostat membrane, the liquid argon outside the fiducial volume and the field cage rings, so that interactions will occur directly in the liquid argon fiducial volume. In order to minimize the heat flow inside the cryostat, the inner part of the pipe and its output window in contact with the liquid argon will be made of insulating material (polyethylene) and the inner volume of the pipe will be evacuated. This
polyethylene pipe will be supported by a thin metallic pipe welded to the cryostat membrane and hermetically sealed at the level of its interface to the metallic pipe.

2.13 Overview and time schedule of the LAr-Proto detector

Significant progress has been made in the last months in the construction of the LAr-Proto detector. As already mentioned the ongoing work on the LAr-Proto has already helped us to anticipate a lot of the tasks related to the DLAr integration and construction.

A drawing of the detector has been shown in Figure 1 and an overview of the entire structure is given in Figure 44.

![Figure 44: Overview of the LAr-Proto with the cryostat.](image)

The detector encompasses a $3 \times 1 \text{m}^2$ charge readout plane (CRP), 20 field shapers placed every 50 mm and a metallic grid cathode. The charge readout plane is hung from a top cap by means of three cables inserted in dedicated suspension feedthroughs (see Section 2.7.3) and the field shapers are fixed to eight FR4 bars which are also attached to the top cap. The LAr-Proto is positioned on the second floor of building 182 as shown in the layout of (see Figure 45).

The assembly of the cryostat outer structure started in December last year. The steel I-beams were transported in parts and bolted on site. From January onwards the $60 \times 60 \text{cm}^2$ stainless steel plates
were welded from the inside. Temporary stairs and a protection barrier were subsequently installed. The outer structure construction is now complete and the inside as well as the outside have been surveyed. Some pictures of the outer structure assembly are shown in Figure 46 and Figure 47.

A drawing of the field cage is shown in Figure 48, it contains 19 identical field shaping rings placed at a constant spacing of 50 mm. The first and last field shaper (cathode) is connected to the HV feedthroughs which bring the HV from an external power supply. A uniform drift field of 1 kV/cm is provided by a resistor divider chain situated between the first and last field shaper (cathode). This requires a voltage of -100 kV at the cathode. A metallic grid with the same potential as the PMT photo cathode is added to protect the PMTs from this -100 kV voltage. The field shapers are fixed to
2.13 Overview and time schedule of the LAr-Proto detector

FIG. 47: Pictures of the outer structure as of March 2015. A panoramic view of the inside is shown on the bottom.

8 FR4 bars which are then hung from the top cap.

FIG. 48: View of the drift cage hanging from the top cap and zoom on a photomultiplier tube with the TPB coated acrylic window.

The light readout is provided by five Hamamatsu 8” R5912 photomultiplier tubes (PMTs). Three of them will be directly coated with the TPB wavelength shifter and the other two will have a coated acrylic window instead. Those two PMTs will also have the high voltage and response signal traveling through the same cable. This configuration is foreseen for all 36 PMTs of the DLAr. Laboratory tests of the electronic bases to provide this feature are currently ongoing and their installation in the LAr-Proto will therefore serve as operating proof of principle. The coating and Quantum efficiency measurements of all five PMTs (+ spares) are planned to take place in April at the CERN thin film
We have a well defined schedule and plan to finalize the detector installation inside the tank before the end of the year. This would also include in December a first trial of the argon gas purge and purification system described in Section 2.4. All the tasks are clearly decomposed in dedicated work packages as shown in Figure 49. We also have a week by week work breakdown structure (WBS) that runs until the end of 2015. The WBS is checked on a weekly basis at our regular meetings and as of today we are on schedule.

![Summary tree of different work packages related to the installation of the LAr-Proto](image)

**FIG. 49:** Summary tree of the different work packages related to the installation of the LAr-Proto.

### 3 Software and analysis developments

The Science Board (SB) coordinates the preparation and the follow up of the physics measurements to be performed with WA105. The tasks of the SB include the preparation of the simulation and reconstruction software and the extraction of results needed for the validation of the physics sensitivity of future large underground liquid argon TPC detectors based on the double phase technology. The science board is chaired by Takuya Hasegawa of KEK. The science board structure includes as well a "Software and Simulation Coordinator" (S. Di Luise, ETHZ) and a "Physics Analysis Coordinator" (S. Galymov, IPNL) who have been appointed in January 2015.

The software coordination is organized in WA105 in order to allow all collaborators to join efficiently the software development and analysis activities of WA105. A Software Manager (E. Pennacchio, IPNL)
has been as well specifically appointed in order to coordinate the definition, test and distribution of
the software releases for the production and the definition and use of the production resources. The
computer center of IN2P3 (CCIN2P3) in Lyon, under the coordination of the Software Manager,
provides a common environment platform for the development of the simulation and reconstruction
software, for the conduction of massive productions of simulated data and for their storage as well as
of the relevant databases.

One of the main goals of WA105 is the experimental validation of the physics sensitivity of huge
double-phase liquid Ar TPCs at deep underground. The primary interest of this detector is focused on
accelerator based long-baseline neutrino experiments investigating CP violation in the neutrino sector
and determining neutrino mass hierarchy. These experiments will as well perform proton and neutron
decay searches and measure supernova neutrinos.

Prior to the WA105 demonstrator data taking, simulation studies are in progress in the collaboration
in order to characterize the impact on the physics sensitivity of this class of future experiments, related
to all the advantages of the double-phase liquid argon TPC technology:

• exploitation of the high signal to noise ratio achieved by the multiplication of the charge ioniza-
tion signal by the LEM in the gas phase

• equal quality charge sharing obtained in the two collection views of the anode avoiding the use
of the problematic induction views

• long drift distance, providing a better containment of the events

The study of long-baseline neutrino oscillations requires:

• good energy resolution and high measurement efficiency over the energy range of wide band
neutrino beams. These are both affected by the reconstruction capability of secondary tracks of
electromagnetic and hadronic showers

• excellent particle identification capabilities, especially for the separation of electrons (and
positrons) from $\gamma$ conversions (and $\pi^0$).

These two aspects, which are going to be intensively studied in WA105, are key elements to achieve
the extremely stringent requirement of 1% systematic uncertainty on the normalization of the signal
related to the appearance of electron neutrinos.

The WA105 physics studies aim also at investigating the detector performance aspects related to
the specific requirements for the search for proton and neutron decays:
• good particle identification capabilities for the nucleon decay product, especially for kaons

• understanding of the behavior of kaon, $\pi$ and $\mu^-$ (for its capture) inside liquid Ar medium

Given its high signal to noise ratio, the advantage of double phase liquid Ar TPC for the measurements of low energy phenomena, such as supernovae neutrinos ($< 50$ MeV) should be prominent. The way to demonstrate this, for instance by showing the detector performance in the reconstruction of Michel electrons, is under investigation.

Given the fact that the WA105 detector is operated on surface, being exposed to large flux of cosmic rays, it is possible to use the cosmic muons as a calibration tool to continuously monitor, for instance, the purity and its uniformity of liquid Ar, the uniformity of the drift electric field, the uniformity of the LEM gain, and the gain of the photomultipliers for the light readout. In order to establish the data processing strategy for these calibration tasks, realistic cosmic ray simulations, reproducing the flux, spectra, angular distribution and particle species information are being set up with CRY.

The software package Qscan, benefits of a decade of developments in the R&D preceding WA105 with many prototypes. It fully simulates the ionization charge signal in the dual phase liquid argon TPC and it provides all the basic reconstruction functionalities. It can be used with both simulated and real data and it is ready for use. Qscan is based on the ROOT framework and on GEANT. It gives access to the information on the particles simulated at the Monte Carlo level and to the basic reconstructed quantities. This package includes the event display functionalities, as well.

A simulation software for the scintillation light signal in liquid argon is being intensively developed. It emulated the experimentally measured scintillation light properties such as the emission spectrum, time structure, quenching, scattering and absorption inside the liquid Ar medium. A first global software release, based on the simulation and reconstruction Qscan software, the light simulation software and the cosmic rays generator, has been installed in an integrated development and production environment at the CCIN2P3 in Lyon.

The operation of WA105 on surface is a particular environment with the presence of a large cosmic rays flux. In order to to understand and optimize the test beam event reconstruction in presence of the cosmic rays, a software package which fully simulates the cosmic ray overlaps on both charge and light signals is being finalized. Figure 50 shows, for a simulated event, the typical arrival time distribution of the cosmic ray overlaps in a window going from $-4$ ms to $+4$ ms with respect to the test beam trigger ($4$ ms corresponds to maximum drift time of charge in liquid Ar TPC with a drift field of 500 V/cm). Figure 51 shows the corresponding simulated cosmic rays overlapping track segments. Thanks to high granularity of the detector, the disentangling of cosmic rays can be well kept under control. The tagging with the light readout system of the prompt component of the light generated
by the cosmic rays allows reconstructing the correct drift coordinate in the window defined by the external beam trigger so that these tracks can be exploited for the purity analysis.

![Time distribution, with respect to the beam trigger, of the cosmic ray tracks overlapping to a DLAr simulated event.](image)

**FIG. 50:** Time distribution, with respect to the beam trigger, of the cosmic ray tracks overlapping to a DLAr simulated event.

## 4 General organization of the Collaboration and Memorandum of Understanding

The WA105 collaboration finalized during the last months its organization structure with the formalization of the Institution Board (IB), including 21 institutions, and the adoption of the collaboration bylaws. All the coordination roles foreseen in top-level governance of the the experiment have been covered with the elections of the following persons in charge:

- Chairman of the Technical Board: Dario Autiero, IPNL, France
- Chairman of the Science Board: Takuya Hasegawa, KEK, Japan
- Chairman of the Dissemination Board: Jukka Maalampi, University of Jyväskylä, Finland
- Spokesperson: André Rubbia, ETHZ, Switzerland
• Chairman of the Institution Board: Thomas Patzak, APC, France

The Deputy Spokesperson: Marco Zito (CEA/IRFU France) was then appointed. The Dissemination Board and the Executive Board, including ex-officio the persons in charge listed above, were formed with the nomination of additional members.

Non ex-officio members of the Dissemination Board:

• Ines Gil Botella, CIEMAT, Spain

• Dominique Duchesneau, CNRS/IN2P3/LAPP, France

• Yuri Kudenko, INR, Russia

Non ex-officio members of the Executive Board:

• Alain Blondel, University of Geneva, Switzerland

• Ines Gil Botella, CIEMAT, Spain

• Yuri Kudenko, INR, Russia

• Marzio Nessi, CERN, Switzerland
The GLIMOS: Sebastien Murphy (ETHZ, Switzerland) was also appointed.

Several coordination roles, as described in the respective sections of this document, were assigned within the Technical Board and the Science Board. The WA105 collaboration is organizing general meetings every four months. Working meetings are regularly occurring every week, organized by the Technical Board and the Science Board.

The WA105 collaboration finalized its Memorandum of Understanding. The contributions of the institutions belonging to WA105 have been defined in details. The overall funding situation is in balance with the needs of the experiment. The MoU is actually under signature.

5 Conclusions

Since the last SPSC annual review in 2014, corresponding to the submission of the WA105 TDR, there was large progress in the formalization of the WA105 collaboration organization. A detailed collaboration structure has been defined with all the coordination roles covered by elected or appointed persons. All the needed resources for the construction of the detector have been identified and covered in a Memorandum of Understanding which is now under signature. The Technical Board and the Science Board are regularly following the technical and software developments for the preparation of the WA105 DLAr detector in the North Area. In particular all the hardware activities benefited largely of the possibility of performing an immediate implementation of the components designed for the DLAr detector on a smaller LAr-Proto prototype being completed in the Building 182. This activity on the LAr-Proto, as described in this document, allowed to anticipate several aspects related to the procurement and the setting up of the quality assessment of the components needed for the DLAr detector and to make sure that its installation in the North Area could happen following the expected schedule. The LAr-Proto will become operative by the end of 2015. The experiment schedule foresees that the DLAr detector should be ready for data-taking in 2018, in order to take beam data before the LHC LS2 (see Figure 52).
CONCLUSIONS

FIG. 52: Installation schedule of the WA105 DLaR detector in the North Area.


