Towards GLACIER, an underground giant liquid argon neutrino detector

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Abstract. GLACIER is a proposed giant liquid argon multi-purpose next-generation underground neutrino observatory, possibly scalable to an active mass of 100 kton, optimal for ultimate long baseline neutrino oscillation studies, nucleon decay searches and for the detection of known or unknown astrophysical neutrinos. It is one of the three detector options considered in the European FP7 design studies LAGUNA and LAGUNA-LBNO.

1. Motivation
A very massive (giant) underground neutrino observatory GLACIER (Giant Liquid Argon Charge Imaging ExpeRiment) is proposed [1, 2] to address the unification of elementary forces with next-generation searches for nucleon decays [3], and to advance the field of the multi-messenger astronomy with the detection of astrophysical sources (e.g. supernovae [4, 5], atmospheric neutrinos [6], Dark Matter signals [7]). Neutrino flavor oscillations can be addressed in an ultimate way by coupling this observatory to intense neutrino beams [8], for example from CERN, in order to determine the neutrino mass hierarchy, and precisely measure the mixing parameters, including the CP-violating phase $\delta$. The underground localization of the experiment is being investigated along the JPARC neutrino beam [9] and in Europe within the LAGUNA/LAGUNA-LBNO design study [10] [11].

2. Why a next generation liquid Argon TPC?
A liquid Argon Time Projection Chamber [12] provides a totally homogeneous and 4$\pi$ full-sampling calorimeter-tracker. The reconstruction of tracks produced by ionizing particles is possible in three-dimensional space and with millimeter-scale space resolution [13]. A very low detection energy threshold and a very high signal-to-noise ratio at the hit level is achievable in a configuration with charge amplification [14] [15]. In this case, energy deposits smaller than 100 keV can be imaged with high efficiency and low fake rate. Because of the full sampling calorimetric nature of the detector, the energy resolution is excellent. The $dE/dx$ measurements, with very high sampling rates of 2% of a radiation length $X_0$, yield superb particle identification and accurate kinetic energy reconstruction [16]. The separation between electrons and neutral pions is also very efficient, thanks to the imaging of the photon conversion vertices and the double ionization of converted pairs [17]. The combination of $dE/dx$ with range information provides muon, pion, kaon and proton identification and separation, down to kinetic energies as low as few tens of MeVs. The large quantity of precise information obtained for each triggered event
can be combined to reconstruct unbiased and exclusive final state event topologies. The event timing and thereby the position along the drift coordinate can be extracted by correlating the prompt scintillation light with the retarded ionization measurements. The technology is known to be applicable to a very wide range of energies (from 10’s keV to 10’s GeV). And finally, the technology appears scalable to large masses. The detector is expected to provide the highest efficiency for $\nu_e$ charged current interactions (“signal” events), with high rejection power against $\nu_\mu$ neutral and charged currents backgrounds in the GeV and multi-GeV region. Embedded in a magnetic field, a LAr TPC gives the possibility to measure both wrong sign muons and wrong sign electrons samples in a neutrino factory beam [18][19].

3. The GLACIER detector concept
The proposed design for GLACIER [1] relies on the novel LAr LEM-TPC concept, which operates the detector in double phase with charge extraction and adjustable amplification in the vapor phase [14][15]. See Figure 1. A strong vertically-oriented electric field drifts the ionization charges to the surface of the liquid, at the interface between the liquid and the vapor. The electrons are extracted by a set of grids into the gas phase and driven into the holes of one or more LEMs, where charge amplification occurs. A LEM is a effectively thick macroscopic hole multiplier, which can be manufactured with standard PCB techniques. A two-dimensional projective anode collects the charge along two independent views with a common time coordinate. The two independent views are used to reconstruct a three-dimensional view of the ionizing event. The cryostat is based on a cylindrical module, derived from the liquefied natural gas (LNG) industry. The design is highly scalable, possibly up to a total mass of 100 kton. One key technical challenge is to drift free electrons in liquid argon over a length as large as 20 meters. This requires special care to achieve and maintain high purity in the liquid argon bulk [20] and the high voltage necessary to generate the drift field [21]. The detector is presently being engineered and costed as part of the LAGUNA/LAGUNA-LBNO design efforts [22]. Figure 2 shows for example the present concept of the tank with the integrated detector, supported by the roof (“space-frame”). The excavation of the underground cavern is particularly modest, requiring about 250’000 m$^3$ and possibly relatively shallow depths.

4. Recent progress in prototyping
A ton-scale LAr LEM-TPC detector has been constructed and operated at CERN within the CERN RE18 experiment (ArDM, focused on direct Dark Matter searches [23]). It is presently being transported at the Canfranc Laboratory in the French-Spanish Pyrenees to be operated
underground. Concerning the charge readout, a small prototype of a 10x10 cm² area with a drift length up to 30 cm was intensively tested and a stable gain of ~30 has been reached [15]. As a next step towards an almost m² size charge readout a LAr TPC chamber with a 1 mm thick LEM of ~ 800 x 400 mm² has been constructed. The charge readout is segmented in 8 parts with a pitch of 1.5 mm between the segments and is read out with a 2D anode of 512 channels. Its drift distance is 600 mm whereas the high voltage of ~ 1 kV/cm is provided by a Cockcroft-Walter voltage multiplier circuit [21]. The readout was implemented as a compact, robust and scalable readout cassette called ”sandwich” (See Figure 3). The LEM was produced by an Italian company called ELTOS and the 2D projective anode at CERN by the TS/DEM group. Some details of the assembly can be found in the attached pictures. The chamber was successfully operated on surface at CERN and collected magnificent cosmic ray tracks. For example, a crossing muon with delta-rays is shown in Figure 4. The performance achieved on the large 40x80 cm² LAr LEM-TPC equaled those obtained on the small 10x10 cm² prototype.

5. Outlook

Beyond these efforts, additional dedicated test beam campaigns are being considered for a detector with a mass of about 10 tons [24], to test and optimize the readout methods and to assess the calorimetric performance of such detectors. A 1 kton-scale device could be an appropriate choice for a full engineering prototype of GLACIER. The choice of the size for the prototype is the result of two a priori contradictory constraints: (1) having the largest possible detector as to minimize the extrapolation to 100 kton (2) having the smallest possible detector to minimize the cost and time requirement to build it. A 1 kton GLACIER full prototype can be built with a diameter of 12 m and a vertical drift of 10 m [2]. Hence, the prototype will be the practical demonstration for the long drift of free electrons in realistic conditions. At the same time, the rest of the volume scaling from the 1 kton to the 100 kton can be achieved by increasing the diameter to about 70 m, and is relatively straightforward noting that (a) large LNG tanks with similar diameters and aspect ratios already exist (b) the LAr LEM-TPC readout above the liquid will be scaled from an area of 80 m² (1 kton) to 3800 m² (100 kton). The LAr LEM-TPC is fully modular, and this will not require a fundamental extrapolation of the principle, but rather only poses technical challenges of production, which can be solved in collaboration with...
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80cm drift 60cm

Figure 4. Cosmic ray events as seen in the 40×80 cm² LAr LEM-TPC at CERN. The two pictures correspond to two perpendicular independent views of the event (labelled View 0 and 1). The vertical axes correspond to the drift time and the horizontal axes to the channel number.

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