2 The ARGONTUBE detector

The next generation of LArTPCs with sensitive masses of the order of 10 kt to 100 kt introduce a number of new challenges. A major one is the long drift distance of 10 m to 20 m needed to reduce the number of read-out channels, and thus the cost, and allowing to build a detector with a large monolithic sensitive volume. An electric field strength of about 0.5 kV/cm to 1 kV/cm was found to be a good compromise to limit the amount of electron-ion recombination, to obtain a high drift velocity and to keep diffusion at a low level. On distance scales of 10 m to 20 m, this results in voltages of up to 2 MV between anode and cathode. It is a difficult task to construct a leak-tight feedthrough that holds these voltages without dielectric breakdowns. An alternative way is to generate the voltage directly inside the cryostat [6–8]. A consequence of high voltages are strong electric fields between the TPC field cage and the cryostat walls. The dielectric strength of liquid argon was measured at distance scales of 100 μm and less, and voltages of the order of 10 kV [57, 58]. Depending on the argon purity, breakdown field strengths reaching from 0.85 MV/cm to 1.7 MV/cm were measured. Reports from currently running LArTPCs and dedicated measurements indicate that these limits are not valid at larger distance scales of several mm or more [59–61].

Apart from the difficulties related to high voltages, larger drift distances imply longer drift times and the level of impurities in the medium becomes more relevant. The attenuation of the detector output signals by contaminant molecules grows exponentially with the drift time. Control and continuous removal of impurities coming from outgassing of detector parts and from residual gas leaks is necessary. By using the latest cryogenic preamplifier technologies, one can partly compensate the signal attenuation and significantly improve the signal-to-noise ratio [56, 62–64].

M. Schenk, *Studies with a Liquid Argon Time Projection Chamber,* BestMasters,
DOI 10.1007/978-3-658-09430-0_2, © Springer Fachmedien Wiesbaden 2015

To study the feasibility of long drift distances of the order of several meters along with the necessary technologies, the ARGONTUBE project has been initiated at the AEC-LHEP of the University of Bern. It is a LArTPC with a drift distance of nearly 5 m, the longest reached to date [6–8]. Apart from the cryostat vessels the detector was designed and constructed in Bern and firstly operated in 2011. It is installed in the 'Grosslabor' in a 7 m deep pit to allow for convenient maintenance and upgrading of the device (see Figure 2.1, left). This chapter gives an overview on the ARGONTUBE cryostat design, the TPC, high voltage generation, liquid argon purification methods, the installed UV laser system, read-out, data-acquisition (DAQ) and triggering systems as well as the routine operation of the detector. It closes with a gallery of events recorded during the latest ARGONTUBE runs.

2.1 Cryostat design

The ARGONTUBE cryostat is realized as a bath cryostat, meaning that it is composed of two stainless steel cylinders, an inner (main) and an outer vessel. The latter is permanently installed in the 7 m deep pit (see Fig. 2.1, left), has a diameter of about 80 cm and a length of roughly 6 m. During detector operation, it serves as a cold reservoir for the inner vessel and is continuously refilled with liquid argon. To minimize the heat input, it features a vacuum insulated wall containing 50 layers of superinsulation film. The inner vessel has a diameter of 50 cm and a length of 5.6 m and contains the TPC. Both, TPC and inner vessel can be completely extracted from their containers for maintenance and upgrades of the detector. During operation, the inner vessel is hermetically sealed. The feedthroughs needed for instrumentation of the device are located on the top flange and are, wherever possible, made with conflat (CF) flanges and copper gaskets which provide a metal-to-metal seal suited for cryogenic temperatures. Top and bottom flanges are sealed by means of indium wire. The outer volume is not hermetically sealed as there is no exchange with the inner volume and thus no need for highly pure liquid argon. The

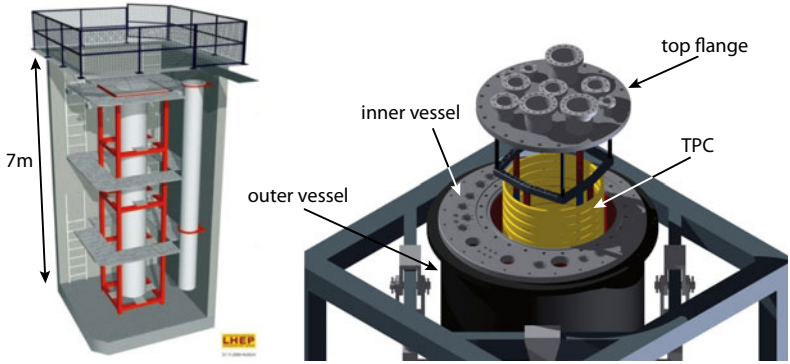


Figure 2.1: *Left:* CAD model of the 7 m deep pit where the detector is installed. *Right:* CAD drawing of the bath cryostat with the outer and the inner vessels as well as the partly extracted TPC field cage attached to the top flange [8].

right hand side of Figure 2.1 shows a drawing of the outer vessel, the inner vessel and the partly extracted TPC field cage attached to the top flange. Two photographs of the real device, during the maintenance phase (left) and during operation (right), are given in Figure 2.2.

2.2 Field cage design and high voltage generation

The TPC field cage has a cylindric geometry of diameter 40 cm and of a length of up to 4.96 m. It is an array of 125 field-shaping ring electrodes (see Fig. 2.3). The simulation software COMSOL was used to optimize the field cage geometry for field uniformity, active detector volume and mass [7]. At the same time, the electric field strength between the cryostat wall and the field cage was minimized to reduce the risk of dielectric breakdowns. Ring electrodes with a racetrack-shaped cross section arranged with a pitch of 4 cm and a gap of 5 mm were found to fulfill the requirements. To achieve a smooth and inert surface, they are made of gold-plated and polished solid aluminum. Given that the electrodes are at their design electric potentials, the

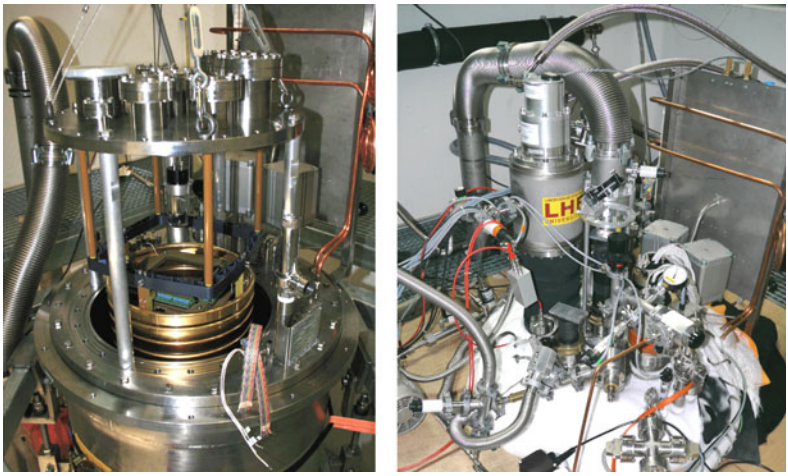


Figure 2.2: *Left:* The ARGONTUBE during the maintenance and preparation phase for the following run. The TPC is attached to the top flange and partly extracted from the inner vessel. *Right:* The ARGONTUBE fully instrumented and in operation.

simulation indicates field strength variations smaller than 0.5 % within the detector sensitive volume [7]. Torlon PAI (polyamide-imide)[1] pieces are used to combine five rings to one module and to assemble the field cage as illustrated in Figure 2.3 on the bottom right. PAI is a high-tech polymer with exceptional mechanical and thermal properties, chemical resistance and a low outgassing rate. The field cage structure which weighs nearly 250 kg is attached to the top flange of the inner vessel by four PAI pillars (see Fig. 2.2, left).

ARGONTUBE was designed for an electric field strength of 1 kV/cm. Given the drift distance, this requires a potential difference between cathode and anode of nearly −500 kV. The construction of a leak-tight feedthrough suited for such a high voltage (HV) is a very challenging task and a different approach was chosen. Instead of generating the voltage outside, a Greinacher/Cockcroft-Walton HV multiplier,

[1] `www.solvayplastics.com`

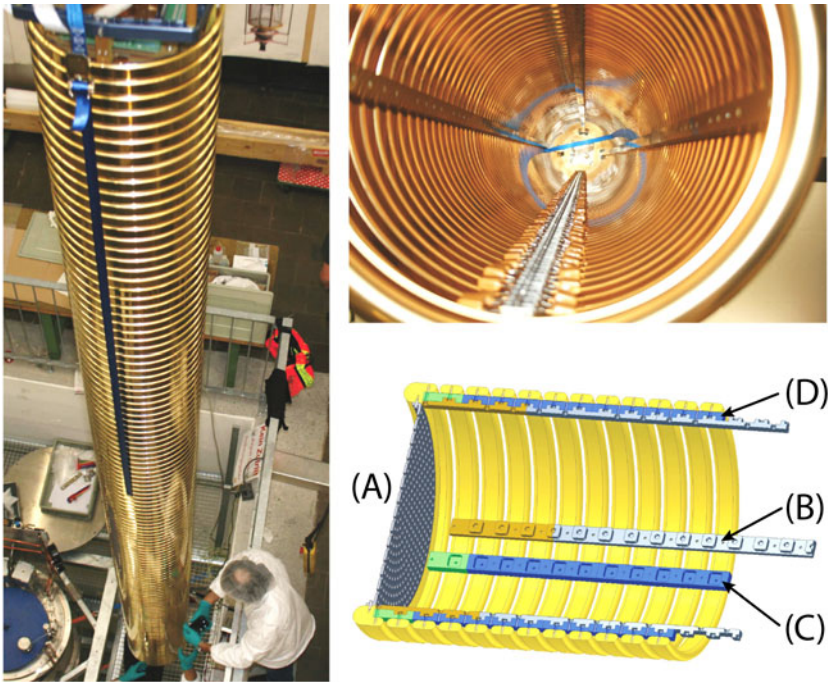


Figure 2.3: *Left:* The fully assembled field cage with 125 ring electrodes. *Top right:* View on the inside of the field cage. Four PAI columns hold the structure together. The Greinacher voltage multiplier is installed on one of the columns. *Bottom right:* CAD drawing showing a cutaway view of the lowermost part of the field cage and the cathode (A). The principle of the assembly is illustrated. PAI pieces (C) hold together the five rings of one module. Their counterparts (B) are plugged into them across two consecutive modules (D).

immersed in liquid argon, produces the HV directly in place. This allows the use of low supply input voltages of the order of a few kV for which commercial feedthroughs are available. A diagram of the first two stages of the Greinacher circuit used for the ARGONTUBE is shown in Figure 2.4. It consists of diodes, capacitors and resistors. The latter are added to limit the discharge current to protect the

diodes and capacitors in case of a dielectric breakdown. The circuit is driven by an AC input voltage (VAC) with an amplitude $U_{\mathrm{in}}^{\mathrm{AC}}$. The theoretical DC voltage at the final stage, given a number N of stages, amounts to $U_{\mathrm{N}}^{\mathrm{DC}} = -2NU_{\mathrm{in}}^{\mathrm{AC}}$ with respect to the reference point denoted by *Ref* in the figure. In theory, an arbitrarily high voltage can be generated by adding more and more stages to the cascade. To operate the Greinacher HV multiplier successfully at cryogenic temperatures, the electronic components must be chosen carefully [8]. In ARGONTUBE, the current configuration uses 4.7 kΩ film type resistors with a tolerance of 5 % and a rating of 0.5 W, diodes of type M160UFG manufactured by Voltage Multipliers Inc[2] with a threshold voltage of 15 V and a breakdown voltage of 16 kV, and capacitors of type PHE450 made by Evox Rifa[3] with a capacitance of 47 nF (at room and at liquid argon temperatures) and a voltage rating of 2 kV. The originally used capacitors with a rating of 4 kV and a capacitance of 158 nF (at liquid argon temperature) had to be replaced for reasons of robustness at cryogenic temperatures. With the new type, only half (−250 kV) of the ARGONTUBE design potential can be reached in theory. The actual limiting factor, however, are dielectric breakdowns in liquid argon occurring already much below this value.

Thanks to the cascade structure of the HV multiplier, it was possible to design the field cage such that there is exactly one Greinacher stage in between two ring electrodes. Given the 125 electrodes, a bias voltage of 2 kV between any two rings leads to a maximum negative potential of −250 kV on the cathode. Consequently, an AC voltage of up to 2 kV peak-to-peak has to be fed in. The Greinacher multiplier with its sharp edges and tiny structures is installed on the inside of the field cage (see Fig. 2.3, top right) to avoid high electric field strengths between the circuit and the cryostat wall and thus to reduce the risk of dielectric breakdowns. The drawback are local distortions of the electric field in the detector sensitive volume.

[2] `www.voltagemultipliers.com`
[3] `www.kemet.com`

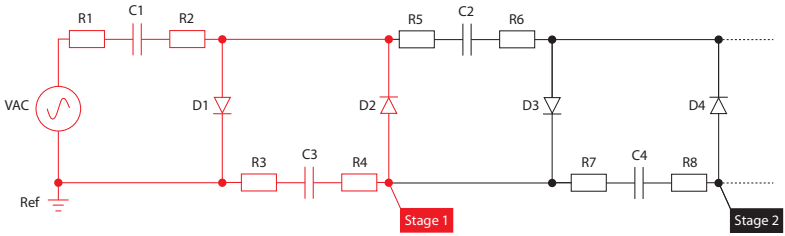


Figure 2.4: The first two stages of the Greinacher voltage multiplier used for the ARGONTUBE to generate the HV. It produces negative DC voltages with respect to the reference point *Ref*.

Compared to using an external power supply to generate the HV, the Greinacher multiplier has the disadvantage of taking a relatively large amount of time to be charged. The characteristic charging time is dependent on the capacitance, the protective resistors and on the charging frequency. Due to a continuous leakage current or occasional dielectric breakdowns in ARGONTUBE, the Greinacher multiplier must be recharged periodically during detector operation. The data taking is vetoed during these periods as there would be a strong pickup noise induced on the sensing wires of the read-out plane. To increase the Greinacher charging speed by a factor of four, the frequency of the AC input has recently been changed from 50 Hz to 500 Hz. At 500 Hz, the characteristic charging time of the circuit was measured to be $\tau = 78 \pm 4\,\mathrm{s}$.

2.3 Liquid argon purification

For drift distances as long as those in ARGONTUBE, an electron 'charge lifetime' of several ms must be achieved. Following the rule of thumb given in Equation 1.26, this translates into $\rho_{O_2} \approx 0.1\,\mathrm{ppb}$ of oxygen equivalent impurities in the sensitive detector volume. To reach these values, it is necessary to correctly design the system by using standard and well-established vacuum technique [65]. This

includes a careful choice of materials[4] with thorough cleaning and baking out before installation to minimize the outgassing rate from their surfaces. Cryogenic temperatures, mechanical stability, dielectric strength and other required properties limit the spectrum of materials that can be used. In terms of vacuum suitability, metals like stainless steel or aluminum are good choices. When metals may not be used for certain reasons, high-tech plastics like PAI, PEEK (polyether ether katone) or materials from the Teflon family should be used. Any material with a high affinity to water, such as nylon, should be avoided. Apart from the material choice, the structures which are located inside the vacuum chamber must be designed such that they do not have any enclosed volumes (virtual leaks) which continuously release contained air at small rates. Moreover, the external leak rate must be held as low as possible and careful leak tests with a sensitive device (helium leak detector) are indispensable. Despite the careful choice of materials, there always is residual outgassing. At cryogenic temperatures, the process is slowed down and the rate of outgassing is considered negligible for detector parts situated in liquid argon. In the argon gas phase at the top of the detector sensitive volume, however, significant outgassing takes place and constantly supplies the argon with impurities. Besides, tiny external leaks are unavoidable (permeation).

To reach a high level of argon purity in ARGONTUBE, the inner vessel is evacuated by a vacuum pump system for at least one week before filling and operation to remove air and moisture from the volume. Commercially available liquid argon contains only about order of ppm oxygen and water contaminants [66]. To reach sub-ppb levels of impurities, however, additional in situ purification of the detector medium is necessary. The first stage of liquid argon purification is done upon filling of the inner vessel when the argon passes through an oxygen and water filter[5]. The working principle of the purifiers

[4] `outgassing.nasa.gov`

[5] Criotec Impianti S.r.l, Via Francesco Parigi 4 – zona industriale Chind, 10034 Chivasso (To), Italy.

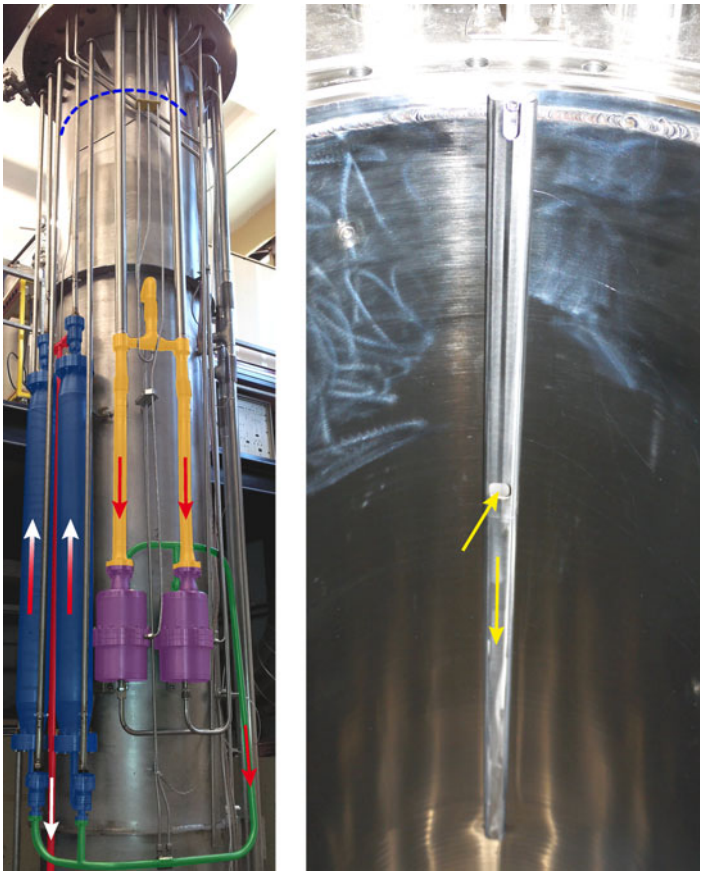


Figure 2.5: *Left:* Liquid argon is taken in from the top of the vessel by two bellow pumps (purple) through the inlet pipe (yellow). It is pushed through the filters (blue) and is brought back to the main volume through the line (red) which reaches to the very bottom of the vessel. The dashed line in the upper part of the image indicates the approximate level of the wireplane. Colors are available online. *Right:* Photograph of the additional pipe that was installed to shift the inlet to the height of the wireplane (cut out window). It is held by a screw on top and stuck into the original inlet at the lower end.

is explained in Chapter 3. During detector operation, the liquid is continuously recirculated through two filter cartridges of the same type, since one-time filtering is not enough to reach the necessary purity levels and the permanent contamination by outgassing and residual gas leaks must be compensated for.

The ARGONTUBE recirculation system was manufactured by Criotec Impianti and is shown in Figure 2.5 on the left. The direction of flux is indicated by the arrows. The liquid argon flux is maintained by two bellow pumps, driven by pressurized nitrogen gas. They take in the liquid and push it through the two filter cartridges. The argon is injected back to the main volume through the pipe reaching to the very bottom of the inner vessel. Bellow pumps were chosen for their high throughput, simplicity and purity, low heat input and low noise induction on the detector read-out. The latter was the major reason as the recirculation has to run non-stop during detector operation to guarantee the necessary level of argon purity. A flux of about 300 l/h is achieved corresponding to a full inner volume change every four to six hours.

The pump inlet is situated well below the inner filling level which is indicated by the dashed line shown in the upper part of Figure 2.5 on the left. Hence, an additional pipe (see Fig. 2.5, right) has been installed on the inside of the inner vessel to shift the inlet up to the level of the wireplanes where most of the contaminants are expected to come from (gas phase). Since there is a gap of only about 5 cm between the TPC field cage and the cryostat wall, a pipe with a flat cross section was chosen and care was taken to manufacture the bending at the lower end as smooth as possible to minimize the electric field strength between the field cage and the pipe. At the level of the newly installed pipe, the absolute electric potentials on the field cage rings are relatively small (< 50 kV) and no additional negative impact on the stability of the HV during detector operation was found as a consequence of this modification.

http://www.springer.com/978-3-658-09429-4

Studies with a Liquid Argon Time Projection Chamber
Addressing Technological Challenges of Large-Scale
Detectors

Schenk, M.

2015, XI, 152 p. 59 illus., Softcover
ISBN: 978-3-658-09429-4