DEAR Technical Note IR-37

Cryogenic setup for Kaonic Nitrogen

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Achieving, in the last DEAR runs, the best "expected signal" / "measured background" ratio with the NTP setup, in the actual machine conditions, suggested, as next step, the use of the cryogenic setup also for measuring kaonic nitrogen. This because, despite the positive performance, the ratio was still dramatically far from a realistic possibility to measure a kaonic nitrogen line.

The installation of the cryo setup, already in this phase of the scientific programme of DEAR, will allow an enhancement both of the signal and of the shielding factor. This is due to a bigger detector solid angle and intrinsic efficiency, to an increased rate of kaonic atoms formation for the higher density and to a better compactness of the cryogenic setup, allowing a more efficient shielding. This Note is intended to give a technical description of the cryogenic setup installed to measure kaonic nitrogen.

1. Introduction

A Monte Carlo study has shown [1] that with the cryogenic setup equipped with 8 CCD-22 and 4 CCD-05, filled with nitrogen at 5 equivalent bars at room temperature, it is possible to identify the 7.6 keV line of kaonic nitrogen with only few thousands nb^{-1} of integrated luminosity, if the signal / background ratio is at least of the order of 1 / 20, by applying a suitable background subtraction technique.

After the last period of DEAR runs, which took advantage of a fully shielded NTP setup (what practically saturated any further possibility of shielding this setup), the background measured at the position of the 7.6 keV line of the kaonic nitrogen spectrum turned out about 2.6 X / nb^{-1} [2], for an expected signal of about 0.05 X / nb^{-1}, which means a ratio still far from the above threshold. It was therefore decided to install the cryogenic setup - foreseen for the hydrogen measurement - already for the nitrogen measurement, with an additional special shielding, based on what learned - and positively applied - on the NTP setup. The expected increasing of the signal - due to the increased number of detectors, 4 CCD-05 and 8 CDD-22, the latter with larger area and higher depletion layer, as well as due to the increased density (about x 5 with respect to ρ_{NTP}) should allow, in principle, to reach a signal / background ratio such to allow to measure a kaonic nitrogen transition.

A description of the installed cryogenic setup, with special emphasis on the applied shielding, both external and internal to the setup, is given in this Note. In Section 2, the nitrogen cryogenic setup is described. Section 3 describes the shielding performed externally to the setup, while Section 4 describes the internal shielding. Section 5 deals with CCDs positioning and readout systems. In Section 6 the choice of the degrader is given. Section 7 contains a description of the slow controls and monitoring system.

2. The nitrogen cryogenic target

The octagonal target cell shown in Fig. 1 is made of specially selected aluminum alloy for the cell body (AlMgSiO.5). For the window frames pure aluminum Al (99.98 %) was used to avoid interference from x-ray lines coming from components such as Fe or Mn present in most common aluminum alloys. The cell has a side length of 55 mm and a height of 140 mm. On each of the eight side-walls are two thin hostaphan windows (50 μm) facing the CCD surfaces. The absorption in the window material is less than 5 % for 5 keV X rays. The kaon entrance window has a diameter of 100 mm and is also made of hostaphan with a thickness of

100 μm. The distance from the target cell entrance window to the center of the beam pipe is 122 mm.

The target cell is placed in the center of the vacuum chamber (Fig. 1), whose entrance window is a pure aluminum foil, 100 μm thickness. The insulation vacuum - unique for target and CCDs - is maintained to 10^{-6} mbar using two wide range turbomolecular pumps (VARIAN 300 HT).

The density of the target was optimized in order to reach a compromise between yield and absorption of the lines. The optimum yield for the 7.6 keV line of kaonic nitrogen ($6 \rightarrow 5$ transition) is obtained at the equivalent pressure at room temperature of about 5 bars, which can be reached with a relatively low pressure in the target (about 2 bars) by cooling nitrogen gas down to about 120 K.

Three cooling systems consisting of two-stage closed-cycle PT-16 refrigerators (APD Cryo-Tiger) were installed: one for the target cell, one for the CCD-05 and the last for the CCD-22. The cooling system initially foreseen for the target cell filled with hydrogen planned to use a helium refrigerator APD HC4, which has a power of 10 watts at 25 K. This cooling power is too high to keep nitrogen in gaseous state, so it was preferred to connect a Cryo-Tiger cooling head to the target. The temperature reached are: 177 K for CCD-22, 166 K for CCD-05 and 118 K for the target cell, which, for the pressure of 2 bars, corresponds to a density about 5 x ρ_{NTP}.

3. External shielding

The external shielding of the setup is made out of three parts:

3.1 Lead walls to shield the DEAR interaction region

Two lead walls were installed on the beam pipe between the first and the second quadrupole, on both electron and positron sides. Each wall surface is 1200x1200 mm^2 with a thickness of 200 mm, and is supported by columns in stainless steel. The walls are made with 220 lead pigs, 200 x 100 x 50 mm^3. The central zone is made by lead pieces with special shape in order to stay very close (few mm) to the beam pipe. The same kind of shielding was installed also for the NTP setup, but the new walls have a double thickness and are better shaped to surround the pipe, leaving less free space for escaping to background particles.

The design of the lead walls is reported in Fig.2.

3.2 Lead-reinforced platform for the setup

The “below (setup) shielding”, previously placed between the aluminum platform and the target cell, is now constituted by the platform itself, so allowing less reduction in solid angle.

The platform is a composite made by a lattice with rectangular cells 100 x 25 mm^2, of stainless steel plates, 2-mm thick, and by a pure lead cast in the central zone of the platform. The shape is “butterfly-like”, with the central “body” incapsulated between the two flanges of the 69 cm DEAR beam pipe. The thickness of the platform is 34 mm. Its weight is about 250 Kg and the deflection in the center, with an extra load of 350 Kg, is about 1.5 mm.

The platform is placed, by four stainless steel legs, on a special support, which stays, through four stainless steel columns, on the concrete girder on which the elements of the machine are located. The support has the degree of freedom of vertical movement. The actual distance between the platform and the pipe is 7 mm, which means 52 mm from the machine axis. The design of the platform is reported in Fig. 3. A photograph of the platform is shown in Fig. 4.

3.3 Shielding around the setup

The cylindrical vacuum chamber is fully shielded by four lead cylindrical layers surrounding completely the setup, and shaped so to match perfectly the vacuum chamber, starting from the platform plane up to the CCDs highest border. The lead cylindrical crown has a depth of 100 mm around the setup and a global height of 150 mm, as shown in Fig. 1. This kind of full-covering shielding was impossible on the NTP setup, due to the presence of the CCDs canisters and of the readout boxes supports, situated on the platform itself. The NTP shielding was indeed affected by large holes, which could be hardly closed using bags filled with small lead balls.

4. Internal shielding

We intend for “internal shielding” the shielding of all those parts of the setup which fall within the solid angle seen by the CCDs. Typically, we distinguish three regions:

a) the cylindrical path through the platform up to the entrance window of the target vacuum chamber and then up to the bottom of the chamber itself;

b) the bottom of the vacuum chamber;

c) the aluminum frames of the target cell windows and of the CCDs.

"Golden rule" for internal shielding – whose application allowed to obtain the best performance on the NTP setup [3] – is the use of sandwich-type structures, made by initial high Z / high density materials to finish with low Z materials. Typically, the sequence of layers is lead–aluminum–polyethylene.

Below, the description of the shielding of the three above region is given and shown in Fig. 5.

4.1 Cylindrical path through the platform

The platform has a central hole, 150 mm diameter. Within the hole, through the platform, an annular lead ring is inserted, 148 mm external diameter, 98 mm internal diameter, 23 mm high, from the lower border of the platform up to the 100 μm aluminum target vacuum entrance window, which is fixed on it. Inside the lead ring, an aluminum cylinder, 2 mm thick, is placed. Finally, a polyethylene cylinder, 9.5 mm thick, is installed in the remaining aperture. Its role, together with that of aluminum, is to absorb the low – energy X rays created eventually in the lead hole by large angle Bremsstrahlung of high energy electrons and positrons escaping from the beam pipe in the interaction point.

The cylindrical path from the entrance window of the vacuum chamber up to the bottom of the chamber was as well analogously shielded with a polyethylene cylinder, 25 mm high, 4 mm thick.

4.2 Bottom of the vacuum chamber

On the bottom of the vacuum chamber the shielding is made by a 10 mm layer of lead ring shaped around the target cell. The lead is coated with a 300 μm layer of aluminum, on which is placed an annular ring of polyethylene, 2 mm thick.

4.3 Frames of target cell windows and of CCDs

All the aluminum frames of the target cell windows, directly facing the CCDs, were coated with a 100 μm thick layer of hostaphan (not shown in Fig. 5), in order to absorb the low-energy Bremsstrahlung X rays created by high energy electrons and positrons scattered from the beam pipe through the central hole of the platform. Moreover, on the CCD frames a 12 μm thick hostaphan foil was glued in order to stop low-energy (less than 20 keV) electrons, coming from the surrounding aluminum pieces, and able to give single-pixel hits.

5. CCD configuration and readout systems

Two types of CCD were mounted inside the setup:

- 8 CCD-22, each with an active surface of 5.76 cm^2, 361200 pixels and a depletion layer of 40 μm;

- 4 CCD-05-20, each with an active surface of 4.57 cm^2, 866400 pixels and a depletion layer of 30 μm.

Two sockets, placed in front of 4 windows of the target cell, remained empty. One CCD-22, following the “tradition”, died during the installation, so the setup actually consists of 7 CCD-22 plus 4 CCD-05. The layout is shown in Fig. 6.

The readout is done with the Jumbo-2 and the Jumbo-3 systems. The four CCD0-05 are split (as usually) in two halves and seen as eight independent devices by Jumbo 2. The reason for this is the number of pixels, the readout time and the charge transfer efficiency. Each CCD-22 is entirely read on a single Jumbo 3 channel, so eight images are recorded. In order not to waste disk space and analysis time and to reduce crash probability, the acquisition of the CCD-22 image corresponding to the broken detector (H) is disabled.

The acquisition runs on two independent PCs. The PC corresponding to the CCD-05 runs under Windows 95®, while the PC corresponding to the CCD-22 group runs under Win 3.11®. Two versions of the DAQ program are used: JumbCtrl for the CCD-05 and JumbCtrl2 for the CCD-22. The “.ini” files for the acquisition and pre-analysis programs have been set with the parameters corresponding to each DAQ system and CCD configuration. JVM addresses and counting modes, as well as Command Box line and pixel boards are also set to the correct values. Different types of readout boxes are used for each system.

6. Degrader

The optimization of the degrader has the goal to center the kaons stopping points distribution in a region with maximized solid angle and minimized absorption with respect to the CCDs positions.

The calculation was carried out using the DEAR Monte-Carlo program. The program took into account the present geometry of the setup, the beam pipe structure, the installed kaon entrance windows (100 μm Al, 100 μm hostaphan foils) and the 15 μm zirconium foil for the energy calibration, placed on the vacuum chamber entrance window.

The resulting degrader is made of a layer of plexiglass ($\rho \cong 1.20$ g / cm^3) of 2 mm thickness and two layers of mylar ($\rho \cong 1.36$ g / cm^3), 125 μm thickness each, optimized for a density of nitrogen which corresponds to the equivalent pressure of 5 bars at room temperature.

7. Slow controls and monitoring

The DEAR slow controls and monitoring system consists in a SCXI crate connected to a control box, a temperature controller and a computer, which remotely drives both items.

The system is able to:

- read the target temperature and adjust it using a temperature controller;
- read the CCD temperatures;
- read the target and vacuum pressures;
- read and change the position of the safety valve and of the calibration source (in-out);
- switch on and off all the consumers in the pit (cryogenics, pumps, readout electronics).

The SCXI crate is equipped with ADC modules, I/O ports and a signal-conditioning module. The communication with the computer is done via RS485 serial interface. One analog and one digital cable connect the SCXI modules to the control box.

The control box has the task to convert TTL states of the output ports into power switch commands, to convert status switch voltages into TTL levels, to be read by the input ports, and also to ensure a reliable connection of all the analog cables to the SCXI crate. It is equipped with power and BNC connections, power transistors and relé.

The temperature controller has a GPIB interface connected to a GPIB-RS485 adapter and from here to the computer.

The computer is equipped with a two port RS485 National Instruments serial interface: one port ensures the communication with the SCXI crate and the other connects the target temperature controller.

The SCXI modules are seen as two remote devices by the computer, which uses N.I.-DAQ® 6.8 software as driver.

The slow controls and monitoring software is written mainly in LabView®, with some C-routines (CINs); it runs under WinNT ® ver.4.0 SP.6 on PCDEARA.

In the present phase of the experiment, we don't need to adjust the target temperature, neither to read nor control the safety valve and the calibration source (not installed). For simplicity, a reduced version of the system without these features was installed. The corresponding program to be used with is called “Slow Monitor Light”.

A schematic representation of the slow controls and monitoring system is shown in Fig. 7.

References

[1] C. Petrascu, **Kaonic nitrogen X rays detection by background subtraction** , DEAR Note-IR-33, November 7, 2000.

[2] M. Bragadireanu, M. Cargnelli, C. Curceanu (Petrascu), J. -P. Egger, C. Guaraldo, M. Iliescu, T. Ishiwatari, V. Lucherini, L. Ludhova, D. Soare, J. Zmeskal, **Report on the runs period December 2000 with collisions in DEAR IP**, DEAR Note-IR-35, February 5, 2001.

[3]) M. Bragadireanu, C. Curceanu (Petrascu), B. Gartner, C. Guaraldo, M. Iliescu, B. Lauss, V. Lucherini, L. Ludhova, D. Soare, **"En attendant Godot": background reduction obtained in the NTP setup in the period 16 October - 5 December 2000**, DEAR Note-IR-34, January 9, 2001.

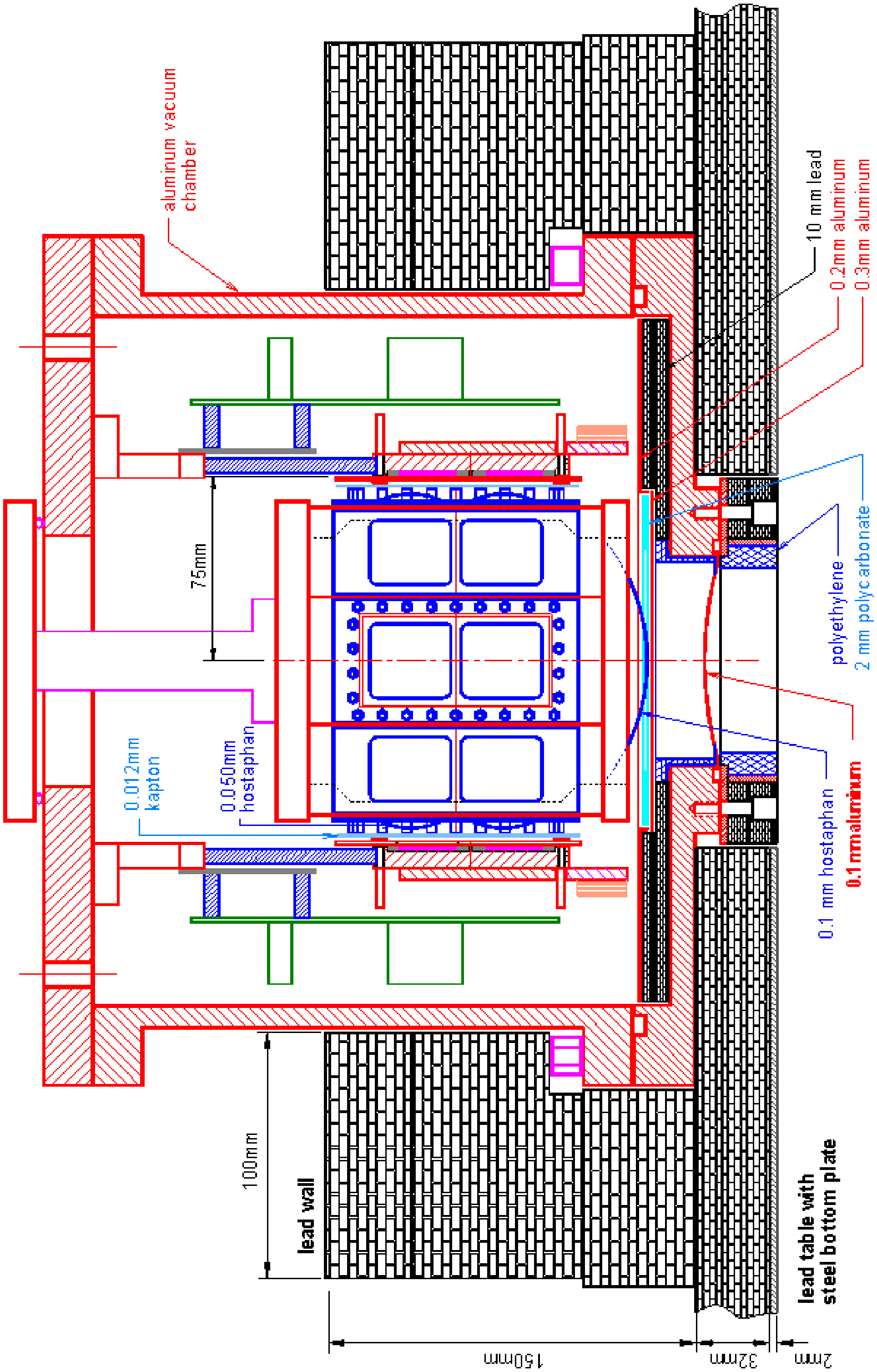

Figure 1: The cryogenic setup for kaonic nitrogen.

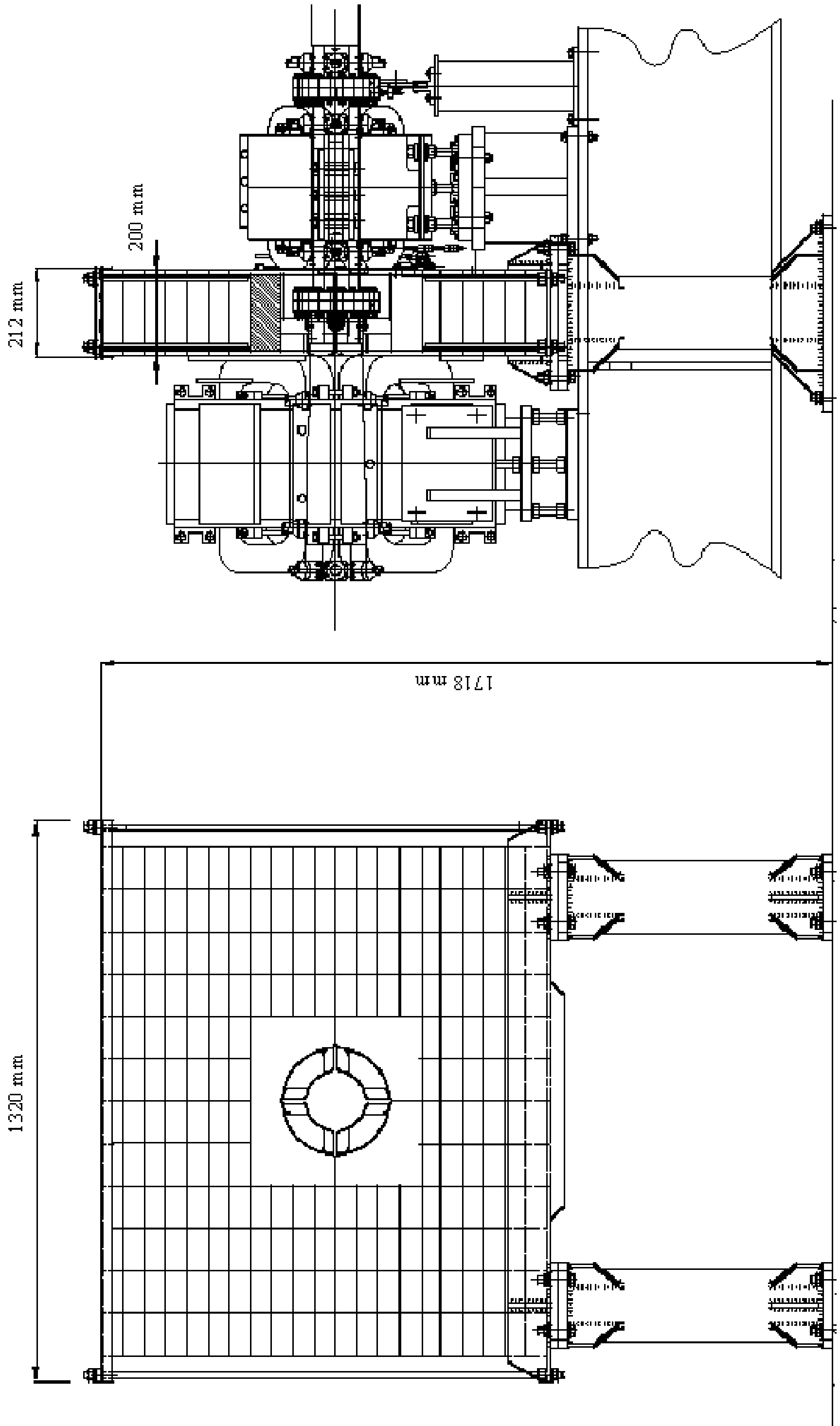

Figure 2: The lead walls shielding the DEAR interaction region.

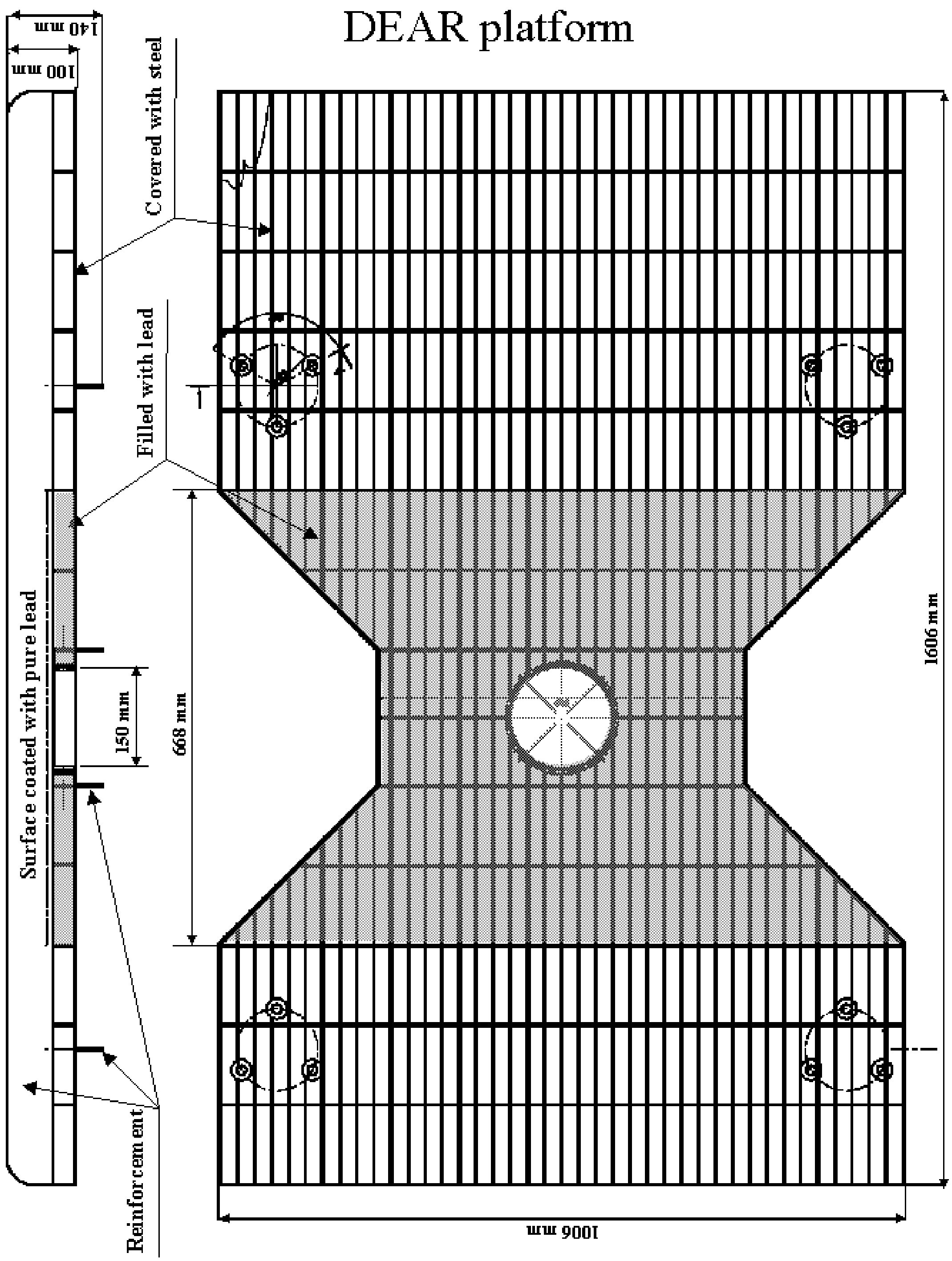

Figure 3: Design of the setup platform with the lead central zone.

Figure 4. The new reinforced setup platform.

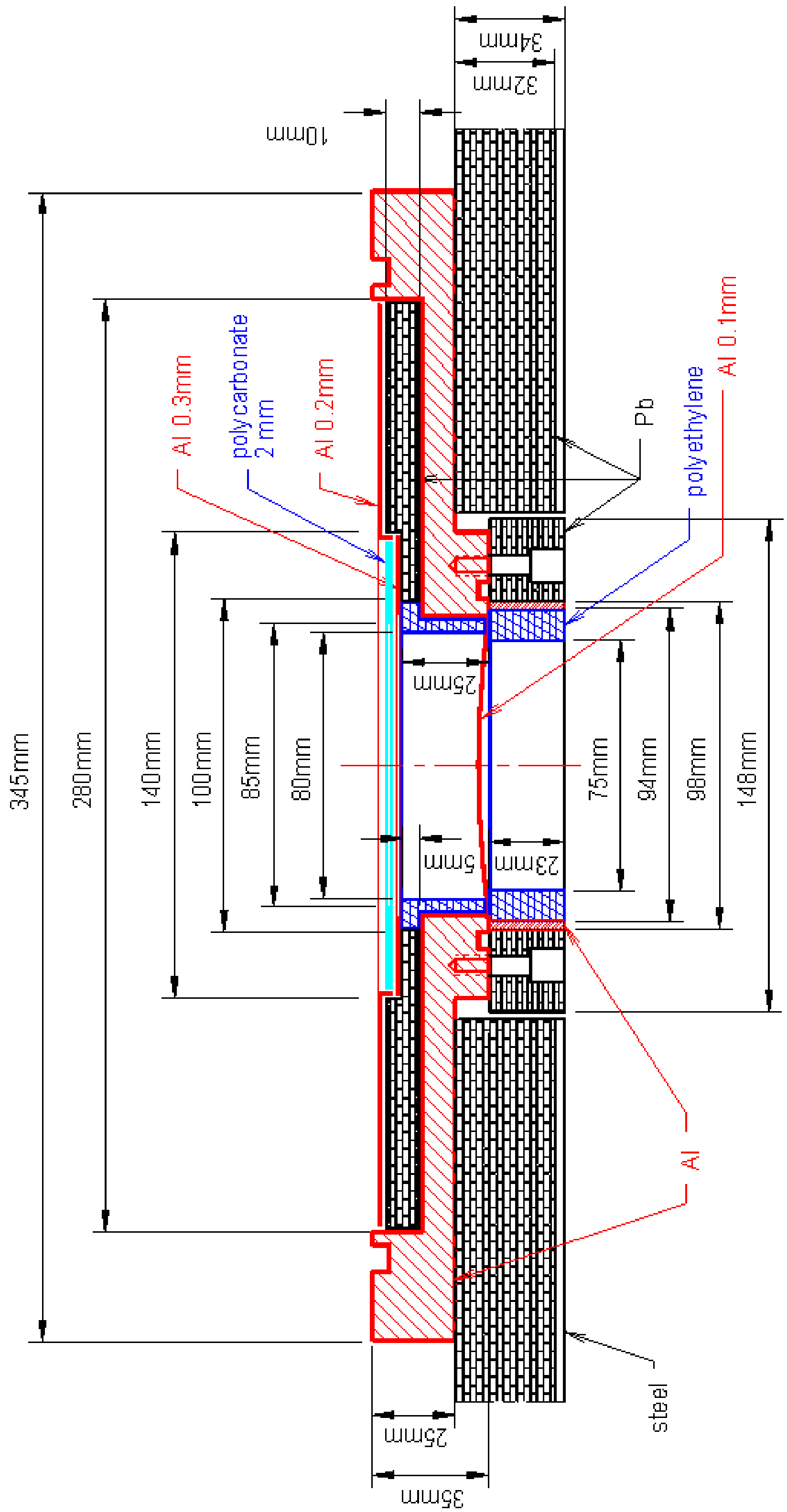

Figure 5: Internal shielding of the setup.

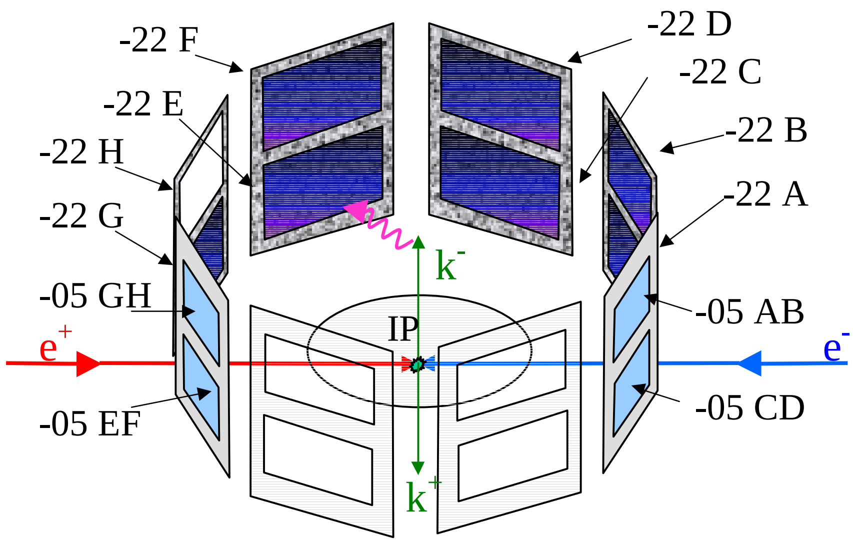

Figure 6: CCDs positioning and labelling.

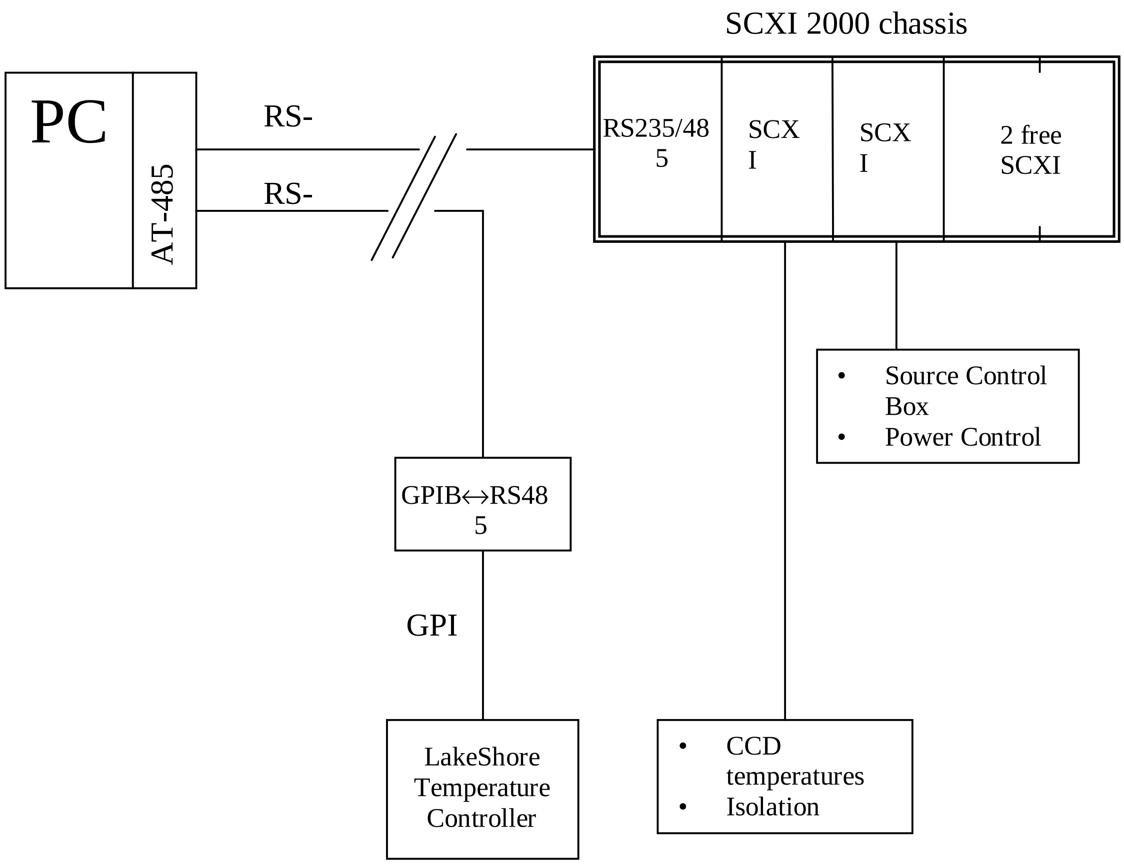

Figure 7: Slow controls and monitoring system block-scheme.