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Design of the scattering chamber of the NUMEN experiment

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Summary. — In the NUMEN experiment campaigns, the integration of the scattering chamber with all the components around represents an important engineering challenge. The target of the experiment consists of a thin isotope layer deposited on a graphite layer. That is supported by a suited target holder, which clamps it and hold it in position above a cold finger of a cryo-cooler. Since the radiation level expected will be non-negligible, an automatic system is designed for the manipulation of the target, together with the target holder, to manage the target replacement. The main geometry of the chamber must take into account not only its rotation around the target, but also the presence of the systems for the diagnostic of the beam and the presence of gamma detectors. This work focuses on the design of the scattering chamber, starting with an analysis of its experimental constraints, then briefly describing all the systems integrated around this structure and concluding with some considerations about its shapes which leads to possible future designs.

1. – Introduction: the NUMEN experiment

The NUMEN project aims to study Double Charge Exchange (DCE) nuclear reactions, in order to use their similarities with Neutrinoless Double Beta decay to investigate about the neutrino particle nature [1,2]. Some preliminary data have been taken at *Laboratori Nazionali del Sud*, using the MAGNEX magnetic spectrometer [3]. Since high statistic is required to get good precision measurement, an upgraded superconducting cyclotron has been designed, within POTLNS project supported by a national program in the frame of the European Strategy Forum for Research Infrastructure (ESFRI), in order to give more intense beams [4]. This upgrade will be conducted together with an upgrade of the whole spectrometer.

The new experimental setup (in fig. 1) consists of a new beam line (a), a high-intensity beam (10^{13} pps), pointing toward the target but positioned with an angle of 70° counterclockwise from the existing one (b) (with a lower intensity, 10^{11} pps). The two lines converge to the position of the target (c), which is clamped into a target holder and contained into the scattering chamber. The MAGNEX spectrometer is composed by a

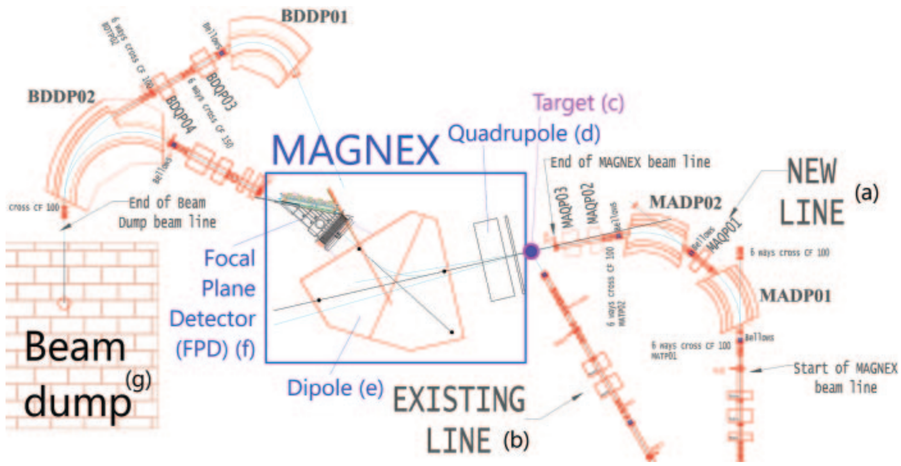

Fig. 1. – Plan view of the principal structure of the new design of MAGNEX experimental room (figure from a private communication by L. Calabretta from LNS).

quadrupole (d), a dipole (e) and a Focal Plane Detector (FPD) (f); they are positioned on a single rotating platform, which rotates around the target in order to allow data taking from all the physical channels requested by experimental conditions. The beam then is transported to the beam dump (g) by the beam dump magnets [3].

This work is about the new design of the Scattering Chamber (SC) and the integration of all the systems connected. It starts considering the actual shape and structure of the chamber by adding all the new elements fundamental to the new working conditions.

2. – Constraints to the new design

SC is supposed to be mounted on the rotating platform, as the actual setup of MAGNEX. The new design must allow the alternative connection to the two different beam lines, permitting also the relative rotation of these (beam lines are fixed to the ground, SC rotates). During the experimental operations the SC will be in high vacuum (10^{-6} mbar).

The target also must be upgraded to a new design in order to adapt it to the new experimental conditions (higher-intensity beam line); this aspect will be described later. Due to the high level of radiation generated by the use of a higher-intensity ion beam (expected to be up to 2×10^6 Gy during a month of operation), it is necessary to design a new system to handle the target and to manage automated target replacements.

It is also necessary to define the interaction product emission cone by the help of a slits system, taking into account the acceptance of MAGNEX ($\pm 7.5°$ in vertical direction and $\pm 6.5°$ in horizontal direction). The SC new design is constrained by the positioning around it of gamma detectors and also all the instruments useful to diagnostic and calibration of the beam (*e.g.*, thermal camera, pepperpot, Faraday cup).

3. – The target and manipulation system

The target of the experiment consists of a film of isotope deposited on a very thin substrate of graphite featuring high thermal conductivity (Highly Oriented Pyrolytic Graphite, HOPG) [5]. The system is clamped in a frame called Target Holder (TH, built

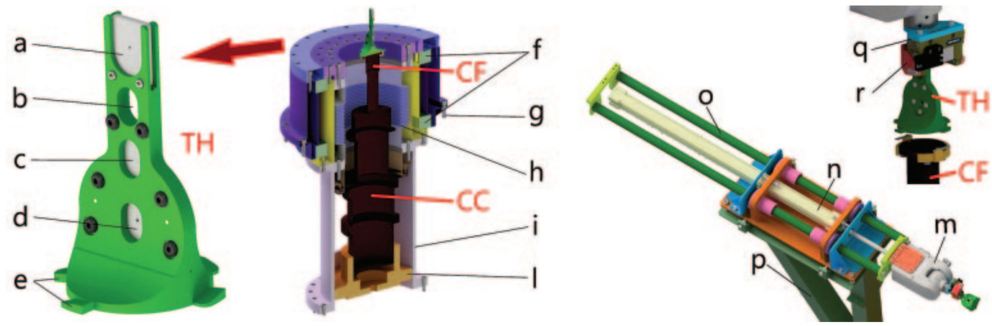

Fig. 2. – Representation of the TH on the left. On the right the assembly of TH + CC, here we can find: bearings for rotation (f), flanges for connection with chamber body (g), bellows for vacuum retaining around CC (h), vertical guide (i) and joining element to vertical movement system (l) [7]. In the right part of the figure there are two representations of the manipulator: in the upper part the grip of the TH, in the lower the main structure of this system. All these four figures are not in the same scale.

in copper and around 100 mm high) positioned on top of a Cold Finger (CF) of a Cryo-Cooler (CC) which helps cooling of the target (down to about 40 K) [6].

TH (fig. 2 on the left) also contains other slots in order to include elements useful for the beam; starting from the top they are: an alumina plate for definition of the beam (a), an empty hole to center the beam and check interferences with the holder (b), a layer of graphite for reference measurements (c) and last the main target (d). In the lowest part we can find the interface surface to the CF, which presents the joining elements (e) for automatic coupling (bayonet coupling) managed by an automatic system [7].

The assembly (TH + CC) is completed by a system which allows its vertical movement with 100 mm stroke (fig. 2 in the center) to align all the slots to the beam.

As mentioned before the TH must be replaced automatically, so an automatic system is designed to handle the target [7]. On the right part of fig. 2 there are two representations of this, in the lower part an overview of the main structure, in the upperpart an internal view of the gripper during operation (when the TH is already disconnected from CF). It is composed by an electromechanical wrist with two degrees of freedom (m), a main pneumatic actuator (n) with stroke of 800 mm which brings the wrist inside and outside from the SC and two different lateral supports to this movement (o). This system is supported by a steel frame to the rotating platform (p) and completed with an automatic storage system that can storage up to six different TH. Inside the chamber the manipulator uses a pneumatic gripper (q) with two fingers (r) to handle the TH.

4. – Scattering chamber design with cylindrical shape

The design of SC proposed as a result of these requests has a semi-cylindrical shape with two lateral truncations, one on the right part of the beam, one on the bottom part. The main structure is made by stainless steel, with 20 mm thickness.

Figure 3 represents all main features of this design: a gate valve to gain access to the manipulator system (a), a sliding seal (b) to connect alternatively to both beam lines with the possibility to rotate around it ($-5°/+25°$), thermal camera flange to get the temperature map of the irradiated target (c), structural support with connection to the platform (d), flanges to vacuum pumping system (e), slits system in tantalum to select

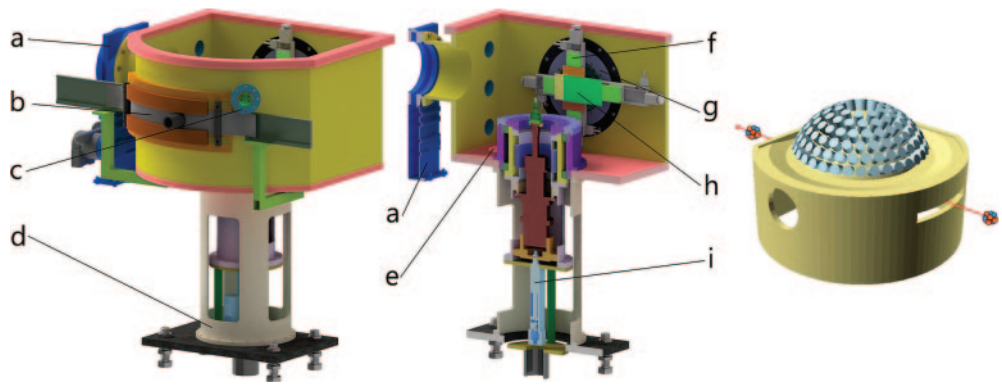

Fig. 3. – On the left, representation of the SC with cylindrical shape. In the center, section of this solution. On the right, hypothetical positioning of gamma detectors with this solution [6].

ions beyond target (f), connection flanges to quadrupole (g), pepperpot (h) to geometrically define the ion beam envelope to be transported downstream to the FPD (composed by a tantalum screen with a particular matrix of holes), actuator for vertical movement of the TH (i).

This design allows the positioning of the Gamma Detectors (GD, based on $LaBr_3$ sensors) only over the superior covering of the SC, suitably thinned in material, radially toward the target (fig. 3 on the right) [8]. The geometrical correlation between gamma rays emitted in the events of interest and ions entering and detecting in the FPD suggests to better position GD around 45° and 135° of incidence from the beam line, so further studies are needed to improve this aspect.

5. – Conclusion

This overview about the design of the SC for NUMEN experiment shows various aspects of this engineering process. Obviously, further considerations must be done in order to better integrate this structure and to improve the overall efficiency of this apparatus. An important idea to work on could be the reshaping of the SC with a spherical design, that could be much more performing for GD positioning. A spherical design requires a higher level of integration of the structure around, this aspect could lead to a modularization of all the system with the possibility to increase the level of automation of all the parts, increasing radiation safety.

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