TOWARDS THE INTEGRATION OF THE NUMEN EXPERIMENT

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The physics case

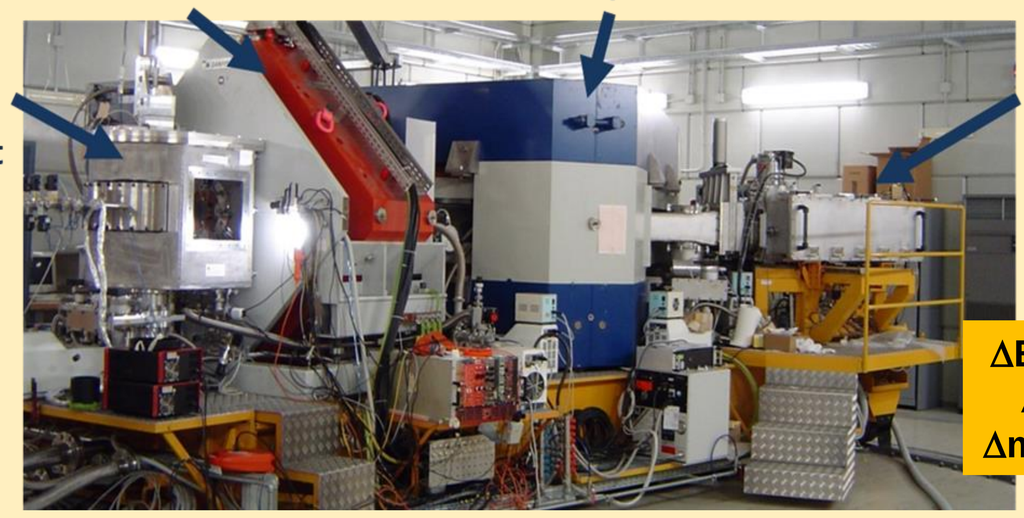
What is the nature of neutrino ?

Is the total lepton number conserved ?

The most promising probe to establish the Majorana or Dirac nature of the neutrino is the Neutrinoless Double Beta Decay ($0\nu\beta\beta$).
If the $0\nu\beta\beta$ decay is detected, the effective neutrino mass would be evaluated by the knowledge of the corresponding Nuclear Matrix Elements (NME).
Information on these NME can be obtained using Heavy-Ion Double Charge Exchange (DCE) reactions, because they present many similarities even if they are mediated by different interactions. One similarity is that initial and final nuclear states are the same.

NUMEN proposes to measure the absolute cross section of DCE of nuclei of interest for the $0\nu\beta\beta$ decay and investigate an overlap for the NME of two processes.
In particular, two sets of measurements will be performed, corresponding to $\beta^-\beta^-$ and $\beta^+\beta^+$ decays that feature the two directions of isospin lowering and raising operators, respectively.
The first set exploits the (^{20}Ne, ^{20}O) DCE reaction, the second set the (^{18}O, ^{18}Ne) reaction.
Competing channels to each of this reactions will be measured too.
Examples of candidate isotopes of interest are ^{48}Ti, ^{76}Se, ^{116}Sn with (^{18}O, ^{18}Ne) reaction, and ^{116}Cd, ^{130}Te, ^{76}Ge using (^{20}Ne, ^{20}O) reaction.

The existing, large acceptance, magnetic spectrometer MAGNEX



It has been used for pilot runs with some nuclei of interest for $0\nu\beta\beta$ and the ion beams (up to 10^{10} pps) provided from the existing cyclotron at INFN-LNS. However, to get significative values in the measurements of tiny DCE cross sections and to speed up a systematic study of the large number of nuclei of interest for $0\nu\beta\beta$, a new configuration is needed and for that:

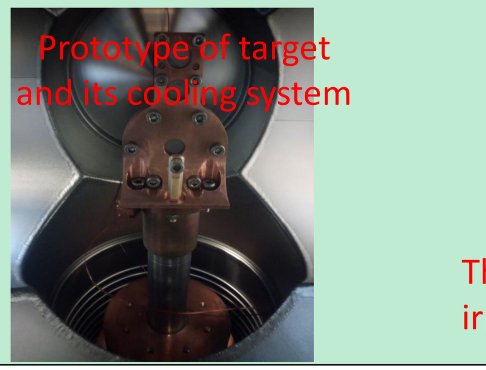
- The upgrade of MAGNEX spectrometer is ongoing
- A new superconducting cyclotron will be installed in LNS laboratory and new ion beam lines as well. Highlights of this new accelerator are:
  - 15 ÷ 70 MeV/u
  - up to 10^{13} pps

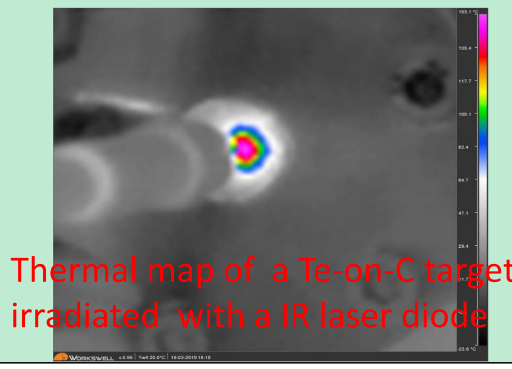
The new target system

Requirements:

- a lot of heat, produced by beam-target interaction, must be quickly removed
- target must be thin to allow a good energy resolution.
- due to high radiation level, the target has to be handled using an automatic manipulator

The custom solution foresees a deposition of isotope of interest (some hundreds of nm) on Higly Oriented Pyrolitic Graphite (HOPG) few μm thin film featuring high thermal conductivity. The graphite sheet is pinched by a copper target-holder tightened to a cryo-cooler. The deposition must be homogeneous and uniform.

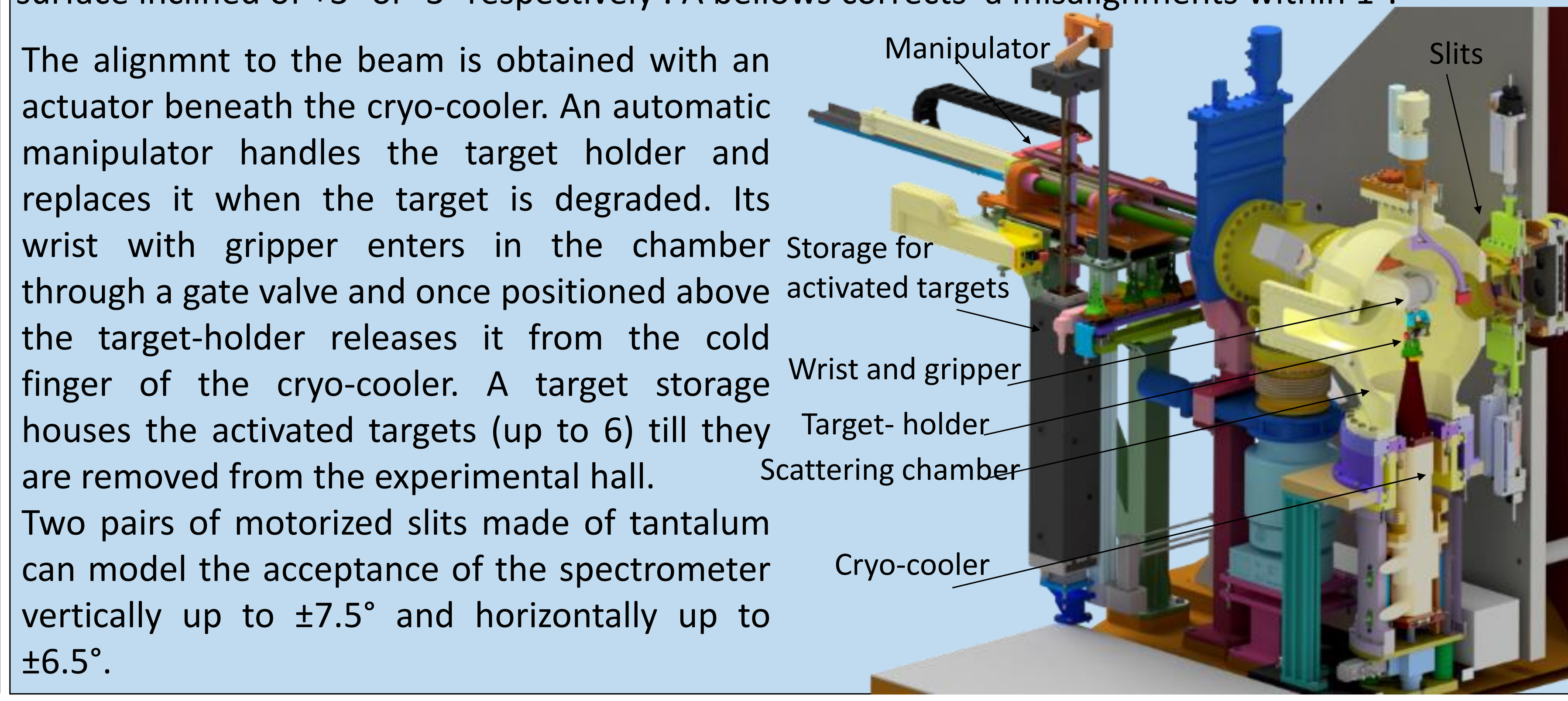




New scattering chamber and target

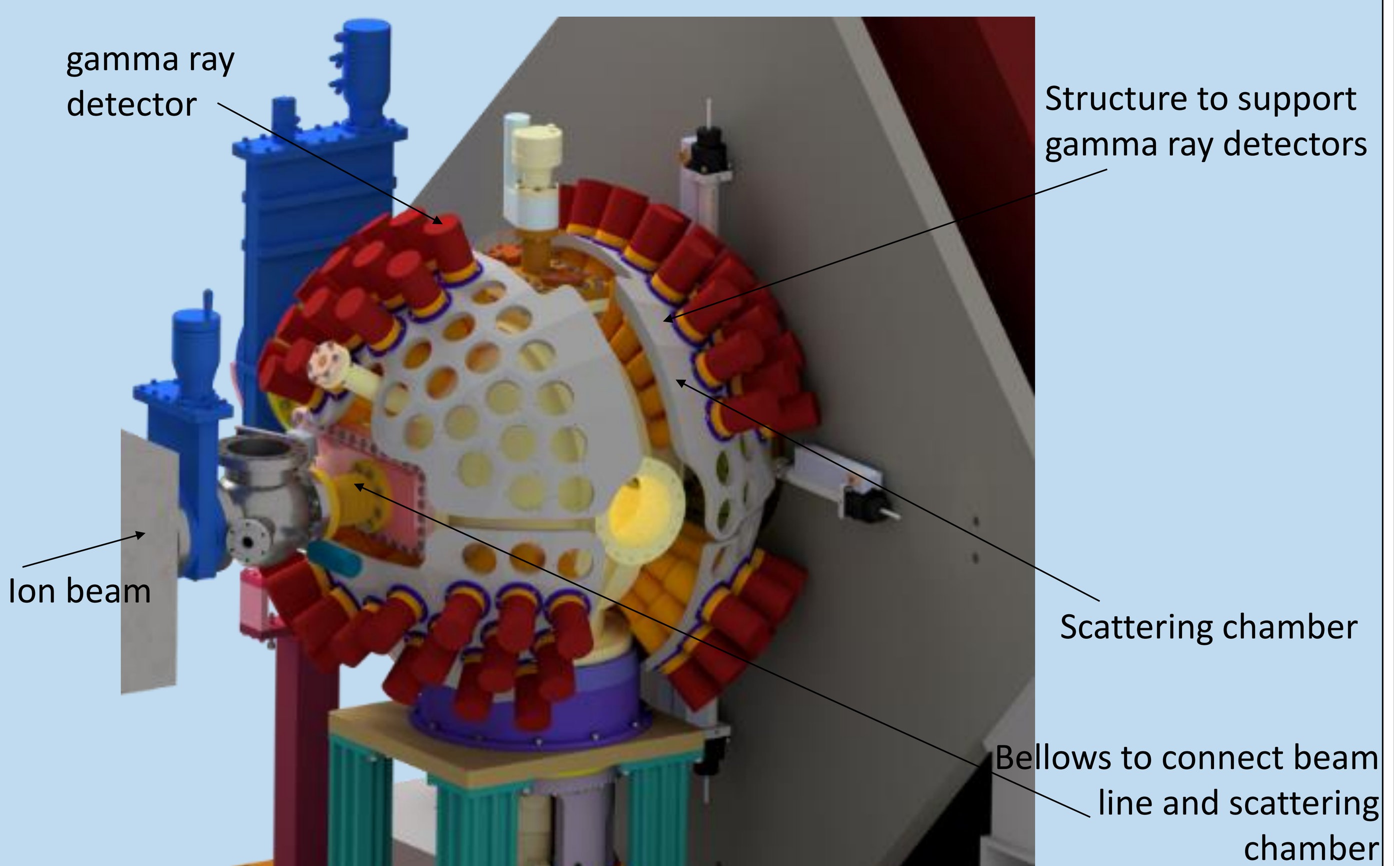
The target is inside a spherical like shape scattering chamber (460 mm of diameter) supported with a complex cylindrical structure that wraps its cooling system based on a cryo-cooler. The target is the rotation fulcrum of the entire spectrometer therefore always offering its surface orthogonally to the incident ion beam. In fact, the spectrometer angular position has to be optimized according to the O or Ne beams using a connection plate, upstream chamber, with a surface inclined of +3° or -3° respectively . A bellows corrects a misalignments within 1°.

The alignmnt to the beam is obtained with an actuator beneath the cryo-cooler. An automatic manipulator handles the target holder and replaces it when the target is degraded. Its wrist with gripper enters in the chamber through a gate valve and once positioned above the target-holder releases it from the cold finger of the cryo-cooler. A target storage houses the activated targets (up to 6) till they are removed from the experimental hall.
Two pairs of motorized slits made of tantalum can model the acceptance of the spectrometer vertically up to ±7.5° and horizontally up to ±6.5°.



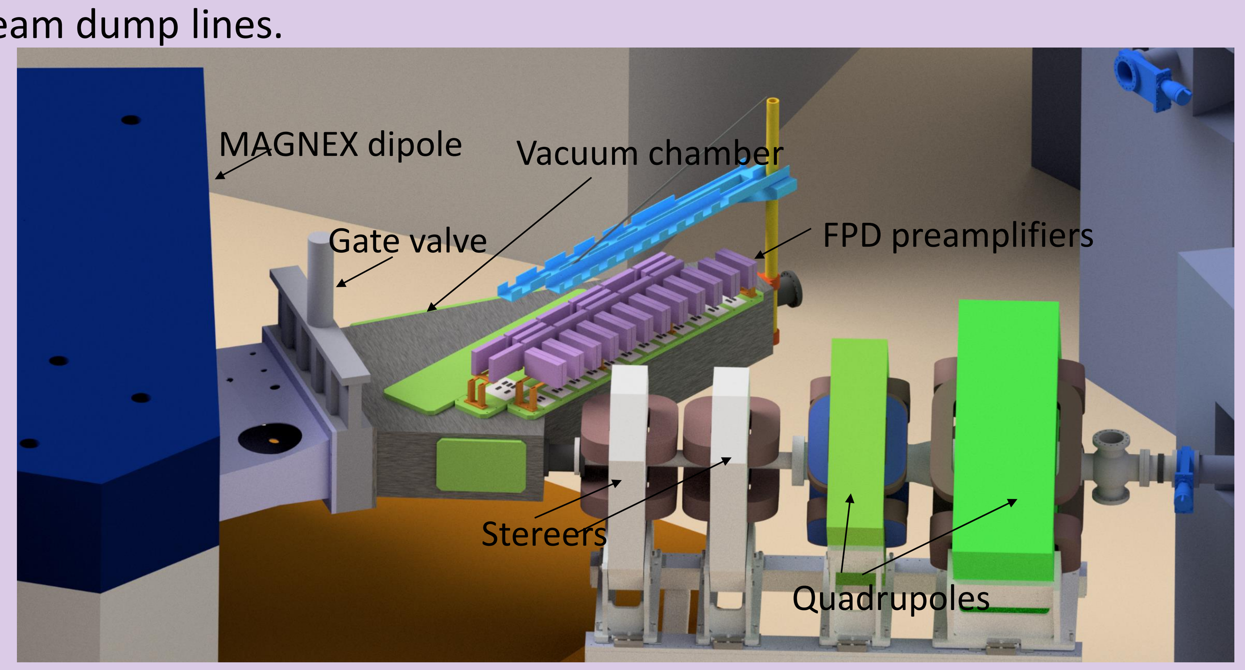
New scattering chamber and gamma detectors

In specific cases such as deformed target nuclei or beam energies ≥ 30 MeV/u, the MAGNEX energy resolution does not allow sufficient separation of the low lying DCE states of the projectile-like fragment and target-like fragment. To reach this task, an additional gamma-ray spectrometer composed of about 110 $LaBr_3$ (Ce) scintillator detectors, each with its photomultiplier (with a total length of ≈ 22 cm) will be installed around the scattering chamber.
The 3 mm thickness of the chamber wall is the compromise between the high vacuum (~10^{-5}-10^{-6} mbar) inside the chamber, most obtained with static sealing, and the request to minimize the material in front of the gamma detectors. Ribs aid the mechanical stability.
The detectors cover the 20% of the total solid angle and feature a total photo-peak efficiency near 4% and energy resolution of ≈ 3%, at 1.3 MeV gamma-ray energy. A time resolution better than 1 ns guarantees the capability to separate events of interest from the high background, up to 10^5 cps.
Since the expected radiation level around the target region is high and this part of experiment is highly crowded with mechanical components and instrumentation, it is very difficult for a person operates on the detectors.
For this reason is under study a spherical like shape support split in some parts to facilitate their handling.

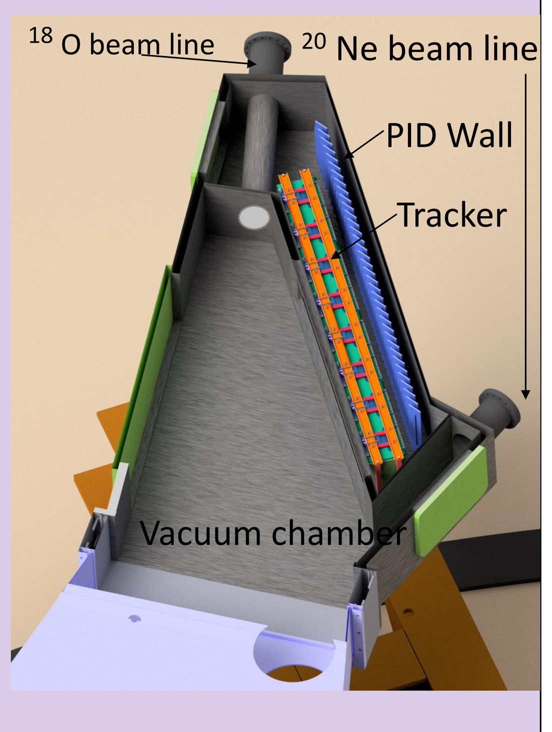


Upgrade of the magnetic elements and new Focal Plane Detector

The transport of high energy ions requires to have a higher magnetic rigidity of the quadrupole and dipole, then their magnetic fields will be increased of 20% compared to the present values, up to 1.139 T and 1.380 T respectively.
A new chamber is connected to the dipole vacuum chamber with a large rectangular valve and it houses the gas tracker and the PID wall, they form the Focal Plane Detectors (FPD). A fine focusing of the ejectiles is obtained with the upgraded dipole surface α-coil.
The new chamber features 230 mm height and its width increases, starting from the 800 mm of width of the gate valve, with a angular divergence of about 6° to allow the transport in vacuum of the unreacted ion beams up to the beam dump lines.



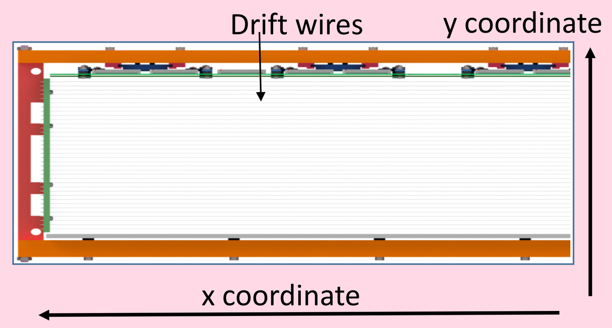
The FPD, tilted with an angle of 59° with respect the gate valve shutter, is positioned in the middle and filled with isobutane (absolute pressure of ≈ 20 mbar). It offers a few μm thin mylar window (920 mm x 150 mm) to the entry of ions coming from the vacuum part of the chamber.
The gas tracker and the PID wall are suspended to independent stainless steel rectangular flanges sealed to the chamber top to facilitate their insertion/extraction with a specific lifting system.
The flanges houses intermediate PCBs equipped with connectors, short cables wire the detectors, inside the chamber, and the preamplifiers positioned on the chamber top.



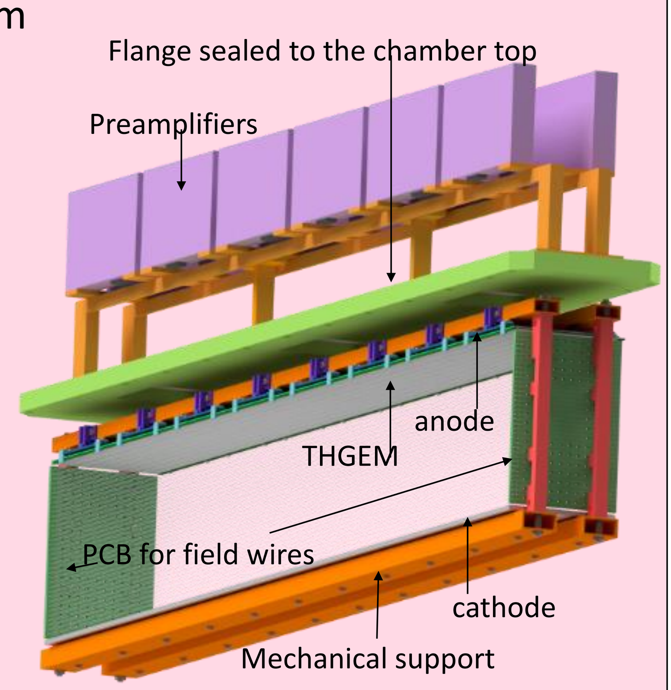
Gas tracker

Requirements:

- Measurements of the track parameters of the ejectiles crossing the focal plane with resolutions < 600 μm for x and y coordinates and < 500 μrad for horizontal and vertical angles. Time resolution of about 1 ns.
- To withstand a rate of about 50 kHz/cm along the horizontal direction.



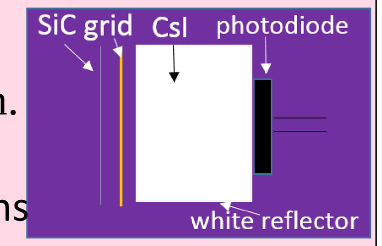
The implemented solution is a gas tracker based on 3 THGEM layers able to withstand the expected rate. The sensitive volume is of 1200 x 116 x 108 mm^3. 1200 pads are arranged in 5 rows and spaced each other to guarantee the sampling of the ion tracks.
Since isobutane gas fills the tracker and a 50 V/m electric field is kept, the measured drift velocity is ≈ 5 cm/μs.



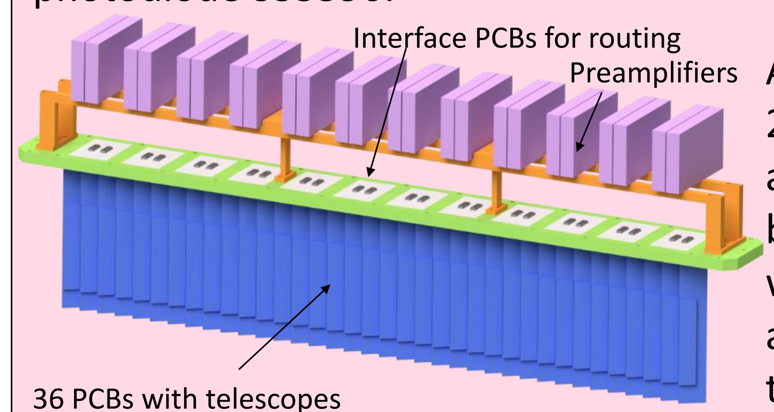
PID Wall

Requirements:

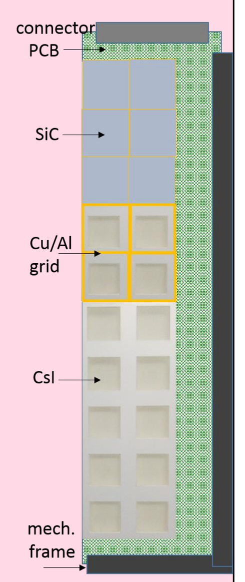
- Measurements of the energy loss of ions and of
- the residual energy. Request of ≈ 2% energy resolution.
- Good radiation hardness
- Horizontal coordinate of hit and time resolution of ≈ 1 ns



The implemented solution is a telescope composed of 100 μm thin SiC sensor (15 mm x 15 mm), to measure the ion energy loss, glued to a Cu/Al grid on the top of a 5 mm thick CsI (Tl) (to measure the ion residual energy) read with a Hamamatsu photodiode S35590.

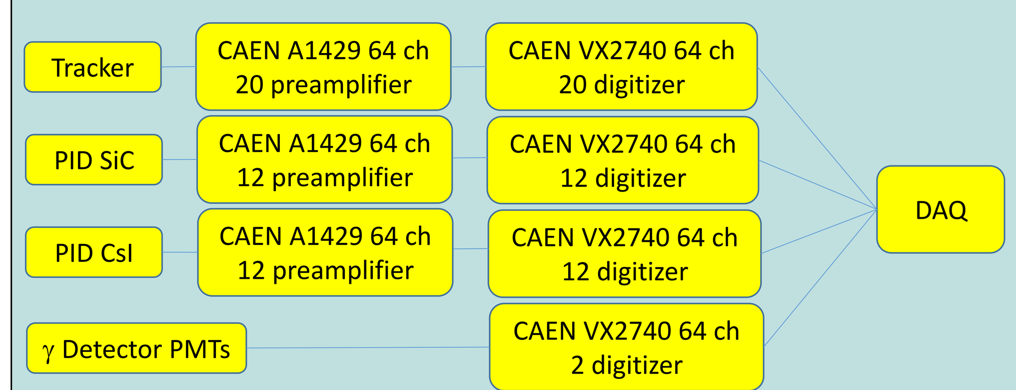


A custom PCB houses 20 telescopes, 10 row and two columns 36 boards build the PID wall, each tilted of 35° angle with respect the tracker



Electronics and DAQ

The readout architecture foresees to amplify the tracker and PID Wall signals with the CAEN A1429 charge-sensitive preamplifier circuit, its output feed the CAEN VX2740 digitizer. The PMTS signals of the gamma-ray detectors do not need to be amplified and then feed directly the digitizer.
The VX2740 digitizer features a 125 MHz sampling rate. A good timing resolution is reached with a 8-ps steps, and a very good energy resolution is obtained using a 16-bit conversion. With dedicated algorithms, signals from both sensors of the PID telescope can be correlated, the on-board FPGA can discard uncorrelated signals and select those belonging to the same ion that crosses the telescope.



This architecture will manage a maximum rate of:

- less than one hundred kHz each pad of the tracker
- few kHz each telescope of the PID Wall.
- few MHz for PM of the gamma ray detector.

Due to the very high rate expected from the gamma-ray detectors, they will be used in coincidence with the FPD only at lower beam intensity (≈ 10^{12} pps).
This procedure will guarantees a max data rate of the order of 50-60 Mbytes/s, each hit information is stored with a 9 byte data format. All the digitizers sent their data to concentrators with 10 Gbit/s Ethernet links, then a dedicated system stores the data. The DAQ works in free-running mode.