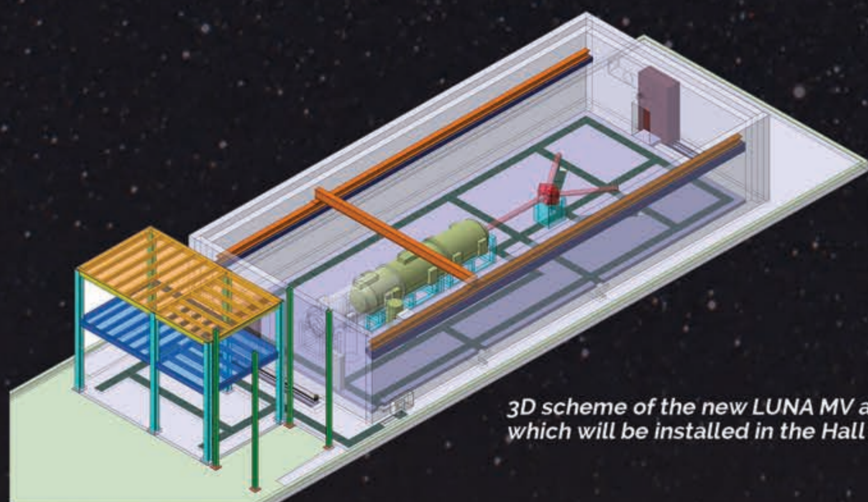
Looking forward: LUNA MV

After the successful results obtained in more than 15 years with the LUNA 50kV and LUNA 400 kV accelerators, in 2007 the LUNA collaboration proposes the installation at LNGS of a new machine able to deliver higher energy beams compared to the previous accelerators. The new LUNA MV accelerator, with a maximum terminal voltage of 3.5 MV, would allow to study reactions happening in stars at temperatures between 500 millions and 1 billion degrees, i.e. at energies higher than those investigated with previous accelerators.

In the successive years, the LUNA MV project is defined more precisely and a real feasibility study starts. Thanks to the financing obtained by the Italian Research Ministry (MIUR), which recognizes the potentiality of the project to consolidate the capabilities of LNGS, the purchase of the accelerator and the construction of the infrastructure to host it can become true.



3D scheme of the new LUNA MV accelerator which will be installed in the Hall B of LNGS

The installation of the new accelerator in the Hall B of LNGS is foreseen for the second half of 2018. The machine will be able to deliver intense beams of protons, alpha particles and Carbon ions to two different beam lines, one equipped with solid targets and the other with gaseous targets. The machine and beam lines will be hosted in a concrete infrastructure, 80 cm thick, able to provide a complete shielding of the accelerator compared to the rest of the LNGS Laboratory.
In this way, even the very low neutron flux expected from the reactions under investigation will not interfere with the measurements of other experiments running at LNGS.

The scientific program of LUNA MV is very ambitious and extended over time. The main aims are to study the key reactions of Helium and Carbon burning, and the so-called neutron-source reactions, which produce the neutron flux necessary for the formation of most of the elements heavier than Iron.
The experiments at LUNA MV will start in 2019.

LUNA is an international collaboration consisting of about 40 researchers belonging to different Institutions all over Europe: the Helmholtz-Zentrum Dresden-Rossendorf in Germany, the MTA-ATOMKI in Hungary, the School of Physics and Astronomy of Edinburgh University in the United Kingdom, the Gran Sasso National Laboratory of INFN, INFN Sections and Universities of Bari, Genoa, Milan, Naples, Padua, Rome (La Sapienza), Turin and the Osservatorio Astronomico di Teramo of INAF in Italy.

INFN LNGS

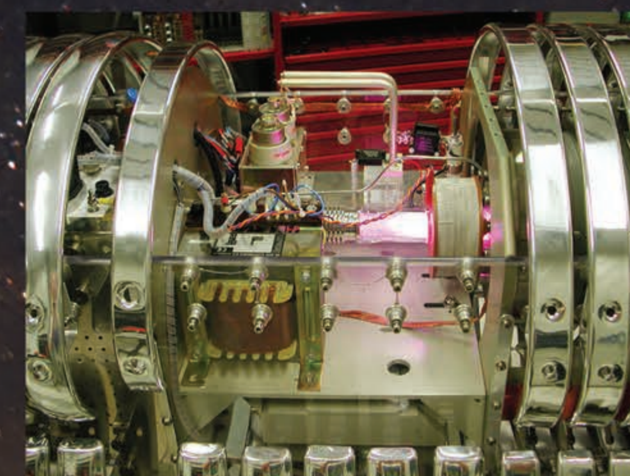
LUNA

Laboratory for Underground Nuclear Astrophysics

LUNA experiment, located in the heart of Gran Sasso, investigates the nuclear fusion reactions which are essential for the life of stars as well as for the evolution of the whole Universe.
Indeed, such reactions are the main source of the energy irradiated by stars and created all of the elements around us.
The whole life of a star can be described as a series of phases in which heavier and heavier elements are burned in the stellar core by means of nuclear fusion reactions, a process consisting in the interaction of two or more atoms with emission of energy.

Such series of reactions starts with the fusion of hydrogen, the most abundant element in the Universe and main component of the mass of a star, into helium. In the second phase, in very massive stars, helium nuclei are burned to form carbon. The nuclear fusion cycles can proceed until the production of iron. If the star dies in an explosive event (e.g. novae or supernovae), all of the elements synthesized in the inner regions are ejected into the interstellar medium and form a cloud. Such cloud can subsequently give birth to new stars or planets.
Being aware of the probability of nuclear reactions occurring in the stars is therefore essential to understand both their evolution and the abundance of all the elements in the Universe. In particular, in the case of our Sun, such knowledge is fundamental also to quantify the flux of solar neutrinos constantly crossing our Earth, which constitutes a unique probe to investigate the interior of the Sun.

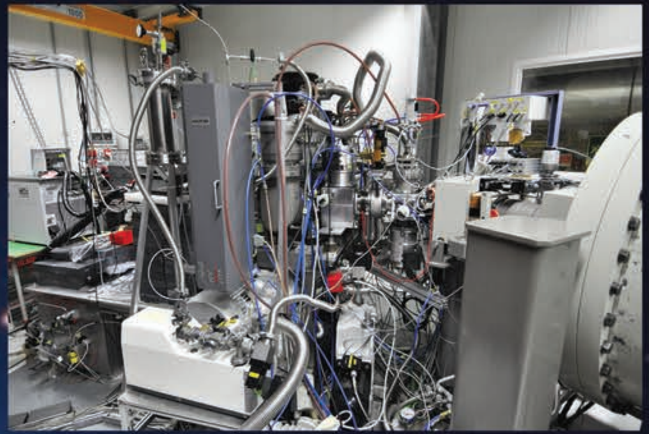
Given the huge luminosity of stars, one may think that the nuclear processes powering them are very intense. On the contrary, the probability for two nuclei to fuse is very small.



Being positively charged, nuclei tend to repel each other thus producing a "repulsive barrier" that can only be overcome thanks to a very weak quantum process called the "Tunneling Effect".
About 600 million tons of hydrogen need to be burned every second to power the Sun.
Obviously, the high densities and temperatures of the stellar core cannot be reached in a laboratory. However, it is possible to reproduce nuclear reactions occurring in the stars at the same energies (tens of keV), which are from 100 to 1000 times smaller than the energies normally investigated in nuclear physics laboratories.
The fusion events occurring in the experimental apparatus are so rare that it is quite impossible to observe them in the presence of background radiation due to cosmic rays.
Therefore, in order to study nuclear reactions at energies relevant to astrophysics, every source of background in the laboratory should be minimized.
Since 1991, the LUNA experiment reproduces what happens in the core of the stars exploiting the very low cosmic background of Gran Sasso National Laboratory (LNGS).

From the accelerator to the "nuclear furnace"

The LUNA 400 kV accelerator is installed in the underground laboratory of Gran Sasso since the year 2000. It is a single stage "Cockcroft-Walton" accelerator able to provide intense beams of protons and helium with a very good stability over time and an excellent energy resolution. The beam of LUNA 400 kV can reach two different beam lines, one equipped with a solid target and the other with a gaseous target.



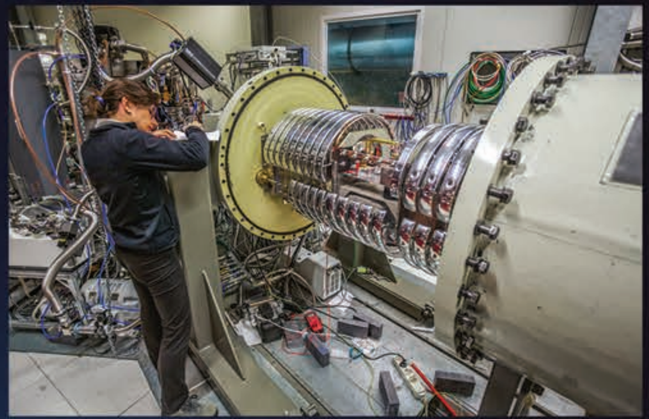
LUNA 50 KV: THE BEGINNING

The first accelerator, LUNA 50 kV, was installed at LNGS in 1991 and operated until 2002. The accelerator, providing very intense protons and alpha particles beams, allowed to measure the fundamental reactions of the hydrogen burning cycle (proton-proton chain reactions) and to study the phenomenon according to which electrons gravitating around the nucleus increase the reaction probability (electron screening).

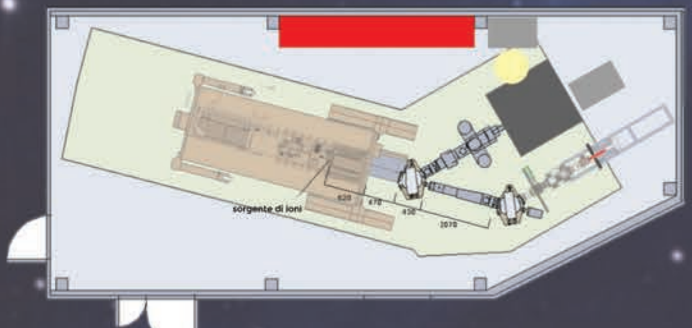
The solid target consists of a support on which atoms of the element supposed to be "fused" with the beam ions are deposited. It is generally cooled with water in order to dissipate the heat produced by the beam. The target is mounted next to a copper tube cooled with liquid Nitrogen able to reduce the buildup of impurities on the target surface.

The gaseous target is contained in a cylinder with a small hole (collimator) to let the beam pass through. Although they would be necessary to contain the gas in the volume of the interaction, in the target there are no windows to separate the different areas because they would degrade the energy of beam particles. For this reason, between the target and the accelerator, a system of pumps and collimators operate in order to reach the pressure conditions necessary for the measurements.

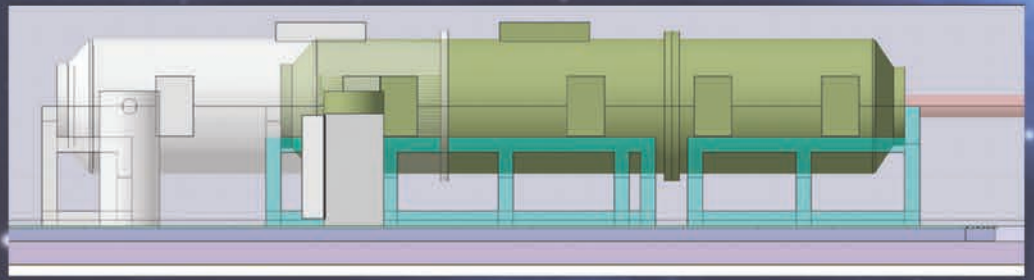
Nuclear reactions occurring in the interaction of beam and target can emit gamma rays or charged particles. Gamma rays are generally detected by high purity Germanium detectors (HPGe) or BGO scintillators; charged particles are instead detected with Silicon detectors.



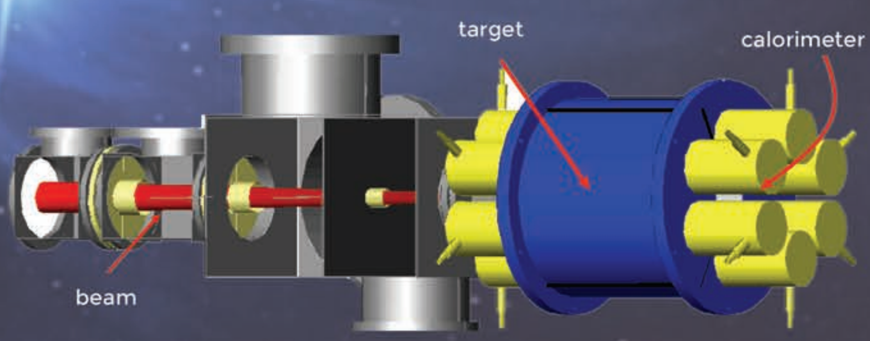
A passive shielding of Lead and/or Copper can be used to reduce the environmental background. Eventually, a "radon box" can enclose the shielding thus allowing, by replacing normal air containing Radon with Nitrogen inside the box, to further decrease the environmental background. The combination of cosmic background reduction offered by the underground laboratory and passive shielding, makes the LUNA experiment worldwide unique for measurements of nuclear reaction cross sections of astrophysical interest.



In the picture the accelerator Luna 400kV and the two different beam lines are visible



Graphic representation of the accelerator



3D reconstruction of the gaseous target