A Megavolt Accelerator for Underground Nuclear Astrophysics

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The experimental program put forward by the community interested in Underground Nuclear Astrophysics demands for the construction of an underground accelerator, able to produce ion beams with energies of several MeV for signally charged particles. The experience gained at LUNA in successfully running accelerators in the underground laboratory of the Laboratori Nazionali del Gran Sasso (LNGS) can be used as a starting point for the implementation of such a machine.

Not only the specific conditions in an underground laboratory but the scientific program envisaged poses some important conditions in choosing the accelerator. The physics cases with the highest priority involve reactions with alpha beams with an energy between 3.5 MeV and 350 keV. The new machine must allow easy modification of the beam energy needed for the study of non resonant processes, resonance profiles and broad resonances. Due to the low cross sections involved the beams must be intense and stable in energy and in time, operating contentiously over several weeks without the permanent presence of an operator on site. These conditions strongly disfavor tandem accelerators which deliver only poor alpha beams.

Underground locations normally pose strict limitations concerning available surface and volume as well as on the accessibility of the experimental site itself. Moreover particular infrastructural and environmental conditions must be taken under consideration. This applies to availability of electricity, ventilation and safety in particular when accelerators involving pressure vessels or explosive gases are considered. At the same time a well protected and reliable remote control of specific parameters of the machine and of the experimental equipment must be provided by any hosting laboratory.

Running and maintaining such an accelerator and the related scientific program requires a lot of technical and scientific skills. In particular the availability of mechanical and electronic workshops as well as dedicated technical and scientific staff personnel in the hosting laboratory is mandatory for efficient operation. The presence and accessibility of a low level counting laboratory, a chemistry lab and a vivid scientific community are desirable.

Beam induced background is a problem of major importance in experiments which involve low reaction cross sections. Part of this problem are particles (e.g. ^{13}C) carried with the beam while passing through the accelerator beam lines. These particles are deposited on the target or the beam stop and can build up to self targets jeopardizing the target purity needed by the experiment. This effect can be mitigated by using oil-free pumping systems and beam lines with metal sealing.

The presence of other experiments exploiting the low background environment of an underground laboratory requires that the experimental activities involving a MeV-machine do not alter the background conditions outside its dedicated experimental area in all its operational conditions. While the production of X-rays is not a problem any more with modern MeV-machines, the production of neutrons cannot be excluded. This is a basic difference to the LUNA 400kV accelerator where the available beam energies are well below the thresholds of most of the relevant (p,n) and (p,α) reactions. The few remaining cases like ^{13}C(p,n) have been treated individually in the operating license of the accelerator.

On the contrary in the case of the MeV-machine the neutron production must be evaluated in detail and dedicated shielding are needed. This shielding can have a strong impact on the available place and the accessibility of the experimental site. They also interfere e.g. with the ventilation. Finally the cost of such an installation must be considered. An optimization of the shielding by Monte Carlo Simulation is needed. A good knowledge of the underground neutron flux as a function of energy is another important ingredient for optimizing the neutron shield to the effective needs.

The natural neutron background of an underground laboratory is so low that a real time measurement of the reference flux is not possible. To overcome the problem a detailed simulation of the shielding can also be used to identify the upper limits for neutron flux inside the shiedling which in turn can be checked experimentally with standard equipment.

In the course of the experiments performed at LUNA it has turned out that the location in an underground laboratory and the need for high availability and reliability of the accelerator poses operative constrains to activities involving accelerator development. The machine is supposed to be reliable and easy to maintain the way that the experimental actives can be focused as much as possible on the those aspects which are related to the underground location itself. It is advisable to bring machine innovation and accelerator related R&D in laboratories above ground until the new technology has proven to be sufficiently reliable.

The setups for experiments in Underground Nuclear Astrophysics often involve detector setups with heavy lead shielding and complex pumping systems which are difficult to modify. On the other hand experience at LUNA has shown that it is advantageous to have one experiment in the construction or evaluation phase while another initiative is taking data. This approach helps to optimize the use the accelerator itself and the related scientific output. An accelerator system with at least 2 beam lines is highly desirable.

Picture 1: Example of the layout of 3.5MV accelerator at LNGS

As an example of a possible design for a MV-machine in an underground laboratory the basic outline of the proposed LUNA-MV machine at the Laboratori Nazionali del Gran Sasso (LNGS) is presented in Picture 1. It is based on a commercial single ended 3.5 MV Singletron equipped with an RF source. The accessible energy range links this accelerator to the already operating LUNA 400 kV machine which can be used to extend the energy range below 350 keV. The proposed ion source has proven to deliver alpha beams of at least 200µA with a duty cycle of four weeks. Possibly more performing source concepts are not put forward as they still do not reach the needed reliability or are even incompatible with the available place. All other components are commercially available, too. The machine is equipped with two beam lines. Heavy neutron shielding designed on the basis on a detailed Monte Carlo simulation is located at the exits of the experimental area. Control and service rooms are placed outside the shielded area. On site 100 kW of electrical power, telephone lines, LAN, ventilation, compressed air and water cooling are available. Safety plants include oxygen and hydrogen monitors, a fire detection and extinguishing system and accelerator access control. The site is connected to the control room of the underground labs of LNGS supervision. Automatic alarming of the responsible researcher in case of unexpected problems will be performed by e-mail and SMS.