PROCEEDINGS OF SCIENCE

Towards a study of ^{22}Ne(p,γ)^{23}Na at LUNA in Gran Sasso

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The ^{22}Ne(p,γ)^{23}Na is a reaction of the NeNa cycle of stellar hydrogen burning. This cycle is active in the Red Giant Branch and Asymptotic Giant Branch stars, as well as in novae explosions. In particular, it rules the abundance of the elements between ^{20}Ne and ^{27}Al. Furthermore, the proton capture on ^{22}Ne may have an impact on the production of ^{23}Na in type Ia supernovae, with a possible link to the ^{56}Ni yield. The amount of ^{56}Ni determines the light curve of these supernovae, used as standard candles in cosmology.
The ^{22}Ne(p,γ)^{23}Na reaction rate is highly uncertain because of a large number of yet unobserved resonances in the energy region of the Gamow peak.
A study of the ^{22}Ne(p,γ)^{23}Na is on-going at LUNA in Gran Sasso. The results of a feasibility test, as well as the measurement strategy and the setup for the first experimental campaign are discussed.

XV Workshop on Neutrino Telescopes,
11-15 March 2013
Venice, Italy

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PoS(Neutel 2013)068

1. Introduction

Thermonuclear reactions are the main source of the energy irradiated by stars, and are responsible for the synthesis of the elements heavier than primordial hydrogen, helium and lithium.
At typical stellar temperatures, the kinetic energy of nuclei is much lower then the Coulomb repulsive potential. Therefore, nuclear reactions can only occur *via* quantum mechanical tunnelling, which leads to very small cross sections.
Because of the small signal to noise ratio, direct measurements of fusion cross sections at stellar energies are often impossible in laboratories on the Earth surface.
The Laboratory for Underground Nuclear Astrophysics (LUNA) is located at Gran Sasso National Laboratories (Italy) [1] [2]. The laboratory is shielded against cosmic radiation by 1400 m of rocks, reducing the cosmic muon and neutron flux by six and three orders of magnitude, respectively.
A measurement of the ^{22}Ne(p,γ)^{23}Na cross section is currently underway at LUNA.
The ^{22}Ne(p,γ)^{23}Na reaction takes part in the neon - sodium cycle of hydrogen burning (fig. 1). This cycle is active in red giant stars [3], as well as in classical novae [4] and type Ia supernovae explosions [5]. In these scenarios, the NeNa cycle is particularly important for the synthesis of the elements between ^{20}Ne and ^{27}Al.

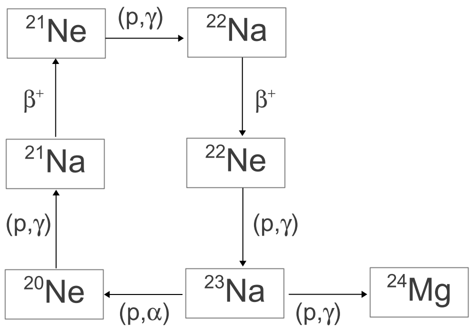

Figure 1: Schematic view of the neon - sodium cycle.

Among the reactions of the NeNa cycle, the ^{22}Ne(p,γ)^{23}Na has the most uncertain reaction rate.
In the energy range relevant for astrophysics, the reaction cross section is dominated by the contribution of a large number of resonances (fig. 2). So far, none of the resonances between 50 and 400 keV has been directly observed, and only upper limits exist for the resonance strengths [6].

Because of this lack of information, the reaction rate uncertainty is as high as a factor of 2000.

2. The LUNA experiment

The LUNA setup is composed of a 400 kV electrostatic accelerator providing an high intensity ($\sim$200 μA) proton or alpha beam. The beam can be delivered to a solid or gas target system. Different gamma-ray or particle detectors can be used, depending on the characteristics of the nuclear reaction to be studied.
For the ^{22}Ne(p,γ)^{23}Na cross section measurement, a proton beam will be delivered to a windowless

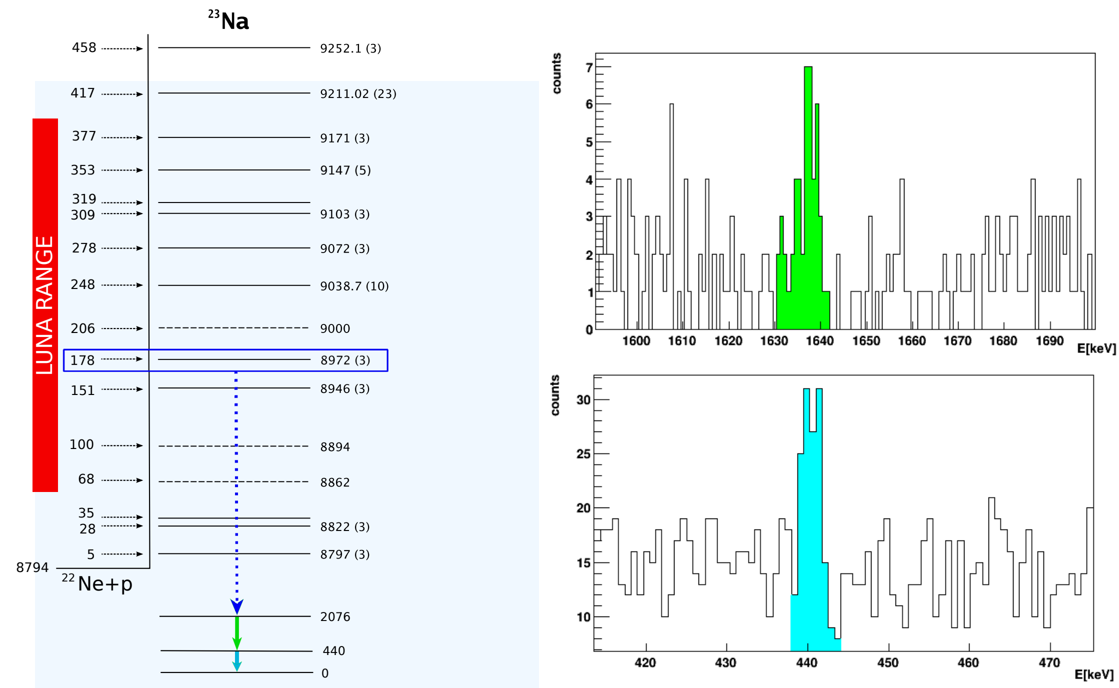

Figure 2: Left: partial level scheme of ^{23}Na. For each excited state, the corresponding resonance energy is reported. Right: 178 keV resonance peaks observed in the gamma - ray spectrum. The peaks correspond to the decay of the first (bottom) and second (top) excited states of ^{23}Na.

gas target filled with 99.9% enriched ^{22}Ne.
The gamma-rays emitted in the de-excitation of ^{23}Na will be detected by two HPGe detectors placed at 45° and 90° angle with respect to the beam direction.
In order to reduce the environmental background, the two detectors will be surrounded with a 25 cm thick lead and copper shielding (fig. 3). GEANT 4 simulations of the setup indicate that this shielding will ensure about four orders of magnitude background reduction for γ - ray energies below 3 MeV.

3. Measurement plan

As a first step, a feasibility test was performed using the setup of the previous ^{2}H(α,γ)^{6}Li experiment [7].
For this test, neon gas with natural isotopic composition was used (90.48% ^{20}Ne, 0.27% ^{21}Ne and 9.25% ^{22}Ne). The aim of the test was to study the possible sources of beam induced background, and to have some hints on the sensitivity to the ^{22}Ne+p resonant cross section.
During the test, runs on the ^{22}Ne(p,γ)^{23}Na resonances at 100, 151, 178 and 248 keV have been performed. Despite the use of non enriched gas (only 9.25% ^{22}Ne) and a setup which was not optimized for this measurement, gamma-rays from the 178 keV resonance have been observed in a 12 h run (fig. 2). This resonance was never observed in previous experiments, and the literature upper limit for the resonance strength is $\omega\gamma < 2.6 \cdot 10^{-6}$ eV.
Following the feasibility test, the characterization of the setup for the first experimental campaign

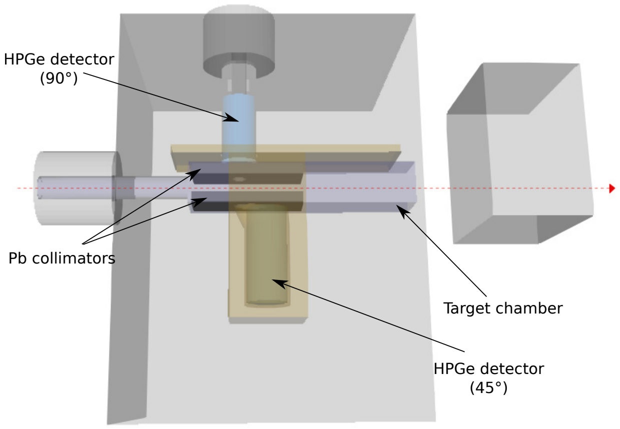

Figure 3: GEANT 4 simulation of the setup for the ^{22}Ne(p,γ)^{23}Na measurement.

on the ^{22}Ne(p,γ)^{23}Na resonances was started.
In particular, the pressure and temperature profile of the gas inside the target chamber have been studied using a dedicated setup. Then the beam heating effect in natural neon gas has been measured with the resonance scan technique, using the intense ^{21}Ne(p,γ)^{22}Na resonance at 271 keV beam energy.
The preparation of the final setup is currently on-going, and the data taking is planned to start in winter 2013.

4. Conclusions

An direct measurement of the ^{22}Ne(p,γ)^{23}Na cross section is needed to understand the synthesis of the elements with mass number around 20 in many astrophysical scenarios.
A new measurement of the ^{22}Ne(p,γ)^{23}Na cross section is now starting at LUNA.
The first test run demonstrated that the sensitivity to the weak resonances lying in the Gamow window can be significantly improved thanks to the low background. This will allow to observe some resonances for the first time, or significantly lower the existing upper limits on the resonance strengths.

References

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