STUDY OF BIG BANG NUCLEOSYNTHESIS DEEP UNDERGROUND

C. GUSTAVINO (for the LUNA collaboration)

Department of Physics, University of Rome "Sapienza", P.le A. Moro 2, Rome, Italy

The good accuracy of elemental abundances inferred from astronomical observations and the high precision of the baryon density measured by CMB experiments suggest a renewed study of several nuclear reactions of the BBN chain, to improve constraints on cosmology and particle physics. It will be shown that the ongoing study of the $D(p,\gamma)^3He$ reaction at BBN energies with the underground LUNA accelerator is of primary importance to improve the constraints on the existence of "dark radiation" and to measure the baryon density with accuracy comparable to the one derived from CMB data.

1 BBN and nuclear astrophysics at LUNA

In the standard scenario, the primordial abundance of elements created during the Big Bang Nucleosynthesis (BBN) only depends on the baryon density Ω_b, on the dynamics of particle physics and on nuclear astrophysics, i.e. cross sections of nuclear reactions of BBN chain. Presently the uncertainty of BBN predictions mainly depends on the knowledge of cross sections of BBN nuclear processes, because particle physics is known with extraordinary accuracy and recent CMB data provide the value of Ω_b at percent level [1]. Therefore, in the present precision era of cosmology, it is highly desirable to improve the knowledge BBN nuclear processes, in order to constrain cosmology and particle physics through the comparison of elemental abundances inferred from astronomical observations with the ones calculated with BBN theory. At BBN energies the cross sections are very low because of the coulomb barrier between interacting charged nuclei. Therefore it is convenient, if not essential, to perform measurements deep underground to reduce the background induced by cosmic rays. LUNA (Laboratory for Underground Nuclear Astrophysics) at LNGS ("Laboratori Nazionali del Gran Sasso", Italy) is the workd's only underground accelerator of ion devoted to nuclear astrophysics measurements. The Gran Sasso mountain provides a huge reduction of background induced by cosmic rays, making possible measurements of nuclear cross sections at energies well below the Coulomb barrier. The key reactions $d(p,\gamma)^3He$ and $d(^3He,p)^4He$ has been studied with the previous 50 kV accelerator [3,4], while the cross sections of $^3He(^4He,\gamma)^7Be$ and $D(^4He,\gamma)^6Li$ processes have been measured by means the present LUNA400 facility [5,6]. This four reactions are particularly important to calculate the abundance of deuterium, ^3He, ^7Li and ^6Li respectively. As an Example, LUNA has measured for the first time the cross section of the $D(^4He,\gamma)^6Li$ reaction at BBN energy, making the calculation of ^6Li abundance much more reliable because no more based on extrapolations of data taken at higher energies [6].

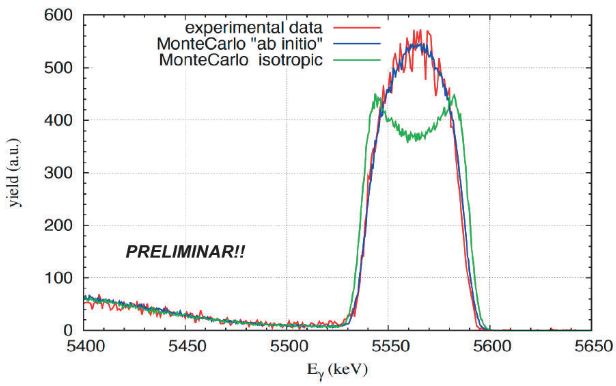

Figure 1 – Simulated spectra of the $D(p,\gamma)^3He$ reaction, assuming isotropic (green) and "ab initio" (blue) angular distribution at $E_{cm} = 112.5$ keV. The LUNA experimental data (red) are also shown. Data have been normalized to remark the close agreement with the "ab initio" angular distribution of emitted photons.

2 The $d(p,\gamma)^3He$ at LUNA

Presently the primordial deuterium abundance extracted from direct observations $(D/H)_{obs}$ [2] is more accurate with respect the calculated value $(D/H)_{BBN}$. The uncertainty of $(D/H)_{BBN}$ is mainly due to the paucity of data at BBN energies of the deuterium-burning reaction $d(p,\gamma)^3He$[7]. In fact, in the BBN energy region, the measurements have a large error (about 9%) and differs from the theoretical "ab initio" calculation of about 20%. Therefore a renewed measurement is necessary to improve the BBN calculation accuracy. The goal of the ongoing LUNA measurement is to measure the cross section at $40 < E_{cm} < 266$ with 3% accuracy. Such a measurement allows to measure Ω_b with a precision comparable to the one obtained by the PLANCK collaboration [1]. As the deuterium abundance relative to hydrogen also depends on the expansion rate of universe, the comparison of $(D/H)_{BBN}$ with $(D/H)_{obs}$ allows to constrain the existence of "dark radiation", i.e. the existence of extra relativistic particles (only photons and 3 neutrino families account for the early universe expansion in the ΛCDM model) [7]. Finally, the total and differential cross section measurements allows the comparison of data with theoretical "ab initio" nuclear calculations. A preliminary comparison of data with "ab initio" angular distribution and the isotropic one is shown is shown in fig.1. Data taking will last about 8 months from now.

References

1. PLANCK collaboration: arXiv:1502.01589v2 [astro-ph.CO] 6 Feb 2015.
2. R. Cooke *et al*, ApJ. **781**, 31, (2014).
3. C. Casella *et al*, Nuclear Physics A **706** 203-216. (2002).
4. H. Costantini *et al*, Phys. Lett. B **482** 430-49 (2000).
5. F. Confortola *et al*, Phys. Rev. C **75**, 065803 (2007).
6. M. Anders *et al*, PRL **113**, 042501 (2014).
7. E. Di Valentino *et al.*, Phys. Rev. D **90**, 023543 (2014).