***<u>Ph.D student</u>*: LUCIA ANNA DAMONE**

# First year Ph.D. research activity report

During the first year of my Ph.D I worked essentially on two topics. The main topic of my Ph.D is the *$^{7}$Be (n,p) cross section measurement for the Cosmological Lithium Problem in the second experimental area of the n_TOF (neutron time of flight) facility at CERN*. The second topic regards the measurement of *the $^{235}$U(n,f) cross section from 200 MeV to 1 GeV at n_TOF*. This activity will be mainly carried out during the second year, that I will spend at CERN as an INFN Associate ("simil-fellow"). Here below, the activity carried out so far and the activity envisaged for the second year of my PhD are briefly described.

## *Measurement of the $^{7}$Be (n,α) and $^{7}$Be (n,p) cross section for the Cosmological Lithium Problem at n_TOF-EAR2*

Theoretical models of the Big Bang Nucleosynthesis (BBN), i.e. the production of light elements in the first few minutes of the life of the Universe, correctly predicts the abundance of all primordial elements except for $^{7}$Li that is overestimated by a factor of 3-5. This significant discrepancy between observation and predictions of BBN is known as the **cosmological lithium problem (CLiP)**. It's known that 95% of the primordial $^{7}$Li is produced by the electron capture decay of $^{7}$Be. This information allows us to guess that a higher destruction rate of $^{7}$Be can solve or at least partially explain the CLiP. In this scenario, reactions induced by neutrons on $^{7}$Be, in particular the $^{7}$Be(n,α)$^{4}$He and the $^{7}$Be(n,p)$^{7}$Li reactions, could play an important role in explaining this discrepancy. However, there are essentially no data available on these reactions. The lack of experimental data is essentially due to the intrinsic difficulty of the measurement, related to the low cross section and to the extremely high specific activity of $^{7}$Be. The recent construction of a second experimental area (EAR2) at n_TOF (neutron time of flight) offered the unique opportunity to perform a first time-of-flight measurement of $^{7}$Be(n,p)$^{7}$Li and $^{7}$Be(n,α)$^{4}$He cross sections over a wide energy range, covering the one of interest for the Big Bang Nucleosynthesis, with a very high instantaneous neutron flux ($10^{8}$ n/cm$^{2}$/pulse)**,** a good energy resolution and a low repetition rate.
The setup for this measurement consisted of two Si-$^{7}$Be-Si sandwiches placed directly in the neutron beam (see Fig.1). Before the measurement, a test was performed at n_TOF on Silicon detectors, in order to study the behavior of the detectors in the neutron beam. With the chosen configuration there were two problems to be investigated:

• the background due to the high neutron flux impinging on the Silicon detector;

• the potential damage from radiation and the consequent degradation in the performance of the detectors with increasing absorbed dose.

The analysis of this test was part of the activity at the beginning of my PhD thesis. The results have been extremely encouraging. Despite being subjected to an intense neutron flux, the energy resolution of the detectors did not degrade significantly. Also the reverse current of the two Silicon detectors was monitored and, as expected, increased proportionally to the absorbed dose, with a rate of a few nA/h. This current did not affect the performance of the detectors and, as expected from these tests, at the end of the measure the current didn't reach a value that would have compromised the performance of the detectors.

During the first year of my PhD I participated to the data analysis for the extraction of the $^{7}$Be(n,α)$^{4}$He cross section, performed with two Si-$^{7}$Be-Si sandwiches in the beam. The samples were prepared by the PSI, one by electrodeposition on a 5 µm thick Al foil and one by droplet deposition on a 0.6 µm thick polyethylene foil. The activity of the two samples was respectively 19 GBq and 20 GBq. Coincidences of two α particles coming from $^{7}$Be(n,α)$^{4}$He reaction have been observed above 0.025 eV and the energy-dependent $^{7}$Be(n,α)$^{4}$He cross section has been measured for the first time over a wide neutron energy range (from 10 meV to 10 keV). The results have been published in Physical Review Letters, and the article selected as "PRL Editors' Suggestion". Because of the importance of the results, communications have been posted on the INFN and CERN web site, as well as on that of ASI, INAF and Le Scienze. The measurement has also been cited on Rai Tv program "Unomattina".

In the second part of the year, the activity regarded the measurement and analysis of the $^{7}$Be(n,p)$^{7}$Li reaction performed in EAR2@n_TOF. The measurement was performed in May 2016, and I am currently analysing the data. To this regards, I have also performed simulations with Geant4 to estimate the efficiency of the experimental set up.

For this measurement a telescope made of two Silicon strip detectors placed outside the neutron beam were used (see Fig.2). The system was calibrated by means of the well known $^{6}$Li(n,α)$^{3}$H reaction, whose cross section is standard from thermal up to 1 MeV.

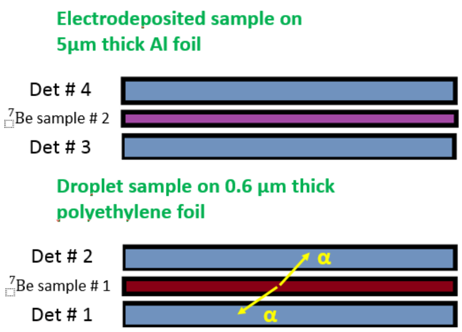


**Figure 1**: Schematic view of two Si-$^{7}$Be-Si sandwiches.

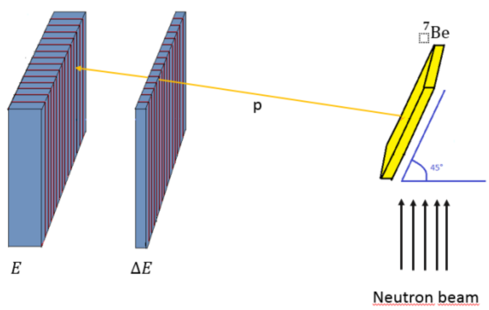


**Figure 2**: Schematic view of the Silicon Telescope. In yellow the slab of $^{7}$Be. The Silicon strip detectors are in blue.

The $^7$Be sample was prepared thanks to a collaboration of PSI and ISOLDE. The sample was produced by implantation of a beam of $^7$Be from ISOLDE, on an Aluminum backing. The mass of the sample was 90 ng, corresponding to 1 GBq activity. I spent a few weeks at CERN for the preparation and data taking of this measurement. Soon afterwards, I started the data analysis. I extracted coincidence of protons between the strips of the two array of Silicon detectors, one acting as a $\Delta$E detector, the other a stop (or E) detector (Fig. 3).

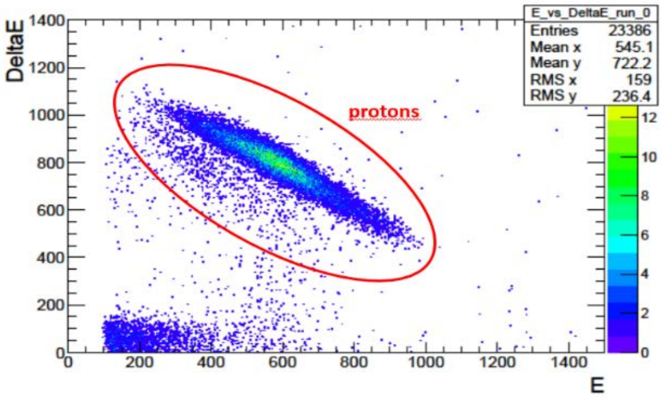


**Figure 3**: Coincidence of protons between the strips of the two array of Silicon detectors.

.

To check the procedure I analysed tritons coming from the $^6$Li(n,α)$^3$H reaction whose cross section is standard. In particular I extracted the cross section for the reference reaction. The agreement between the measured $^6$Li(n,α)$^3$H cross section and the one evaluated by ENDF is very good, thus confirming that the analysis is proceeding in the right direction. I will now concentrate on extracting the cross section of the $^7$Be(n,p) reaction and analyse its implications on the Cosmological Lithium Problem .

## *Geant4 simulation of a Proton Recoil Telescope for the measurement of the $^{235}$U(n,f) cross section from 200 MeV to 1 GeV.*

The second activity I have been carrying out in the first year of my PhD is on simulations of a Proton Recoil Telescope for the measurement of the $^{235}$U cross section.
The $^{235}$U(n,f) cross section is one of the most important cross-section standards for measurements of neutron-induced reaction cross-sections, or for the measurement of neutron flux for various applications. The cross section of $^{235}$U(n,f) is adopted as a standard at thermal neutron energy and between 0.15 MeV and 200 MeV.
At energies above 200 MeV, the $^{235}$U(n,f) cross section plays an important role for several applications, as well as for fundamental nuclear physics.
Despite the importance of the high-energy region, at present no data exist above 200 MeV, and one has to rely on highly uncertain theoretical estimates.
Thanks to its very wide neutron energy spectrum, which extends from thermal

energies up to more than 1 GeV, the n_TOF facility offers the unique opportunity to perform these measurements with a good accuracy. The measurement of the neutron-induced fission cross section of $^{235}$U at high energy can only be performed relative to the well known n-p elastic scattering.

The n_TOF data would improve the knowledge of this cross section all the way to 1 GeV, discriminating between various theoretical models on high-energy neutron-induced fission reactions, and establishing a reliable reference cross section above 200 MeV.

Our measurement of the $^{235}$U(n,f) cross section will rely on the best known and generally accepted primary reference reaction that is the elastic neutron–proton scattering (n–p scattering). This reaction is widely used for fluence determination and as reference for other reaction cross sections. The prerequisite for this measurement is the availability of a Proton Recoil Telescope (PRT). The PRT will consists of a target made of hydrogenous material and an arrangement for detection and identification of the recoil protons from the n–p reaction in a well-defined geometry.

During the first year of my Ph.D, I simulated with Geant4 several telescope configurations and I found out that the best choice consists in a configuration with few Silicon detectors, followed by fast plastic scintillators of different thickness. Each element, or a combination of elements, acts either as $\Delta$E or E (stopping) detector. In this way it is possible to identify protons and discriminate between them and other particles produced in the reaction (see Fig.4).

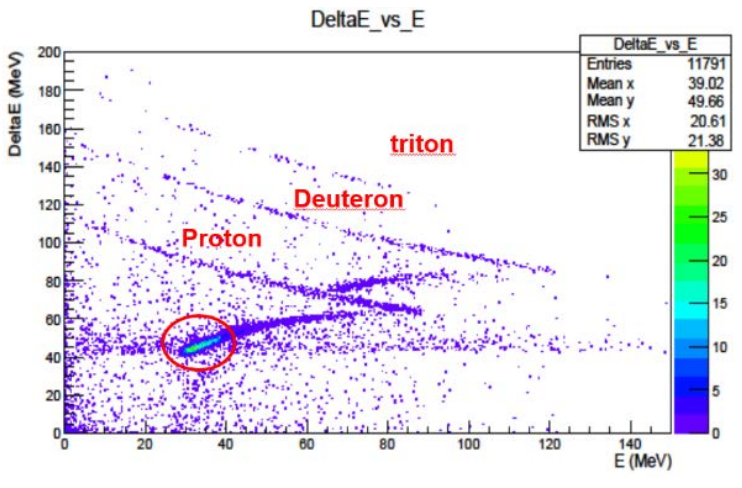


**Figure4**: Simulation of a 2D DeltaE vs E plot obtained by sending 250 MeV neutron beam impinging on a polyethylene radiator.

The best geometrical configuration is with trapezoidal detectors; in this way the solid angle is well defined. In Fig. 5 the simulated configuration is reported. It consists of four Silicon and four plastic scintillators all read-out independently, to discriminate recoil protons from other light charged particles, in particular deuterons and tritons.

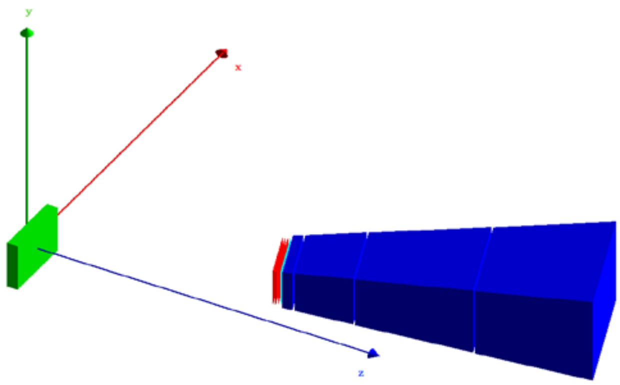

**Figure 5**: Schematic view of the PRT. In green the slab of Polyethylene. The Silicons are in red except for the last that is thinner and in light blue. The four scintillators are in blue. The PRT is shifted by 22° respect to the z axis.

One of the main aim of the simulations was to study the background due to the interactions between neutrons and carbon in the Polyethilene target and in the scintillators, as well as the background due to those protons that do not cross in a straight way the Telescope because of scattering in the detectors. These protons are considered also a background source because we do not manage to reconstruct their energy. The PRT efficiency depends on the number of these protons. With the simulations I have also studied the dependence of the efficiency as a function of the energy of the neutrons impinging on the target.
Following these simulations, a test has been made at CERN in the last month under the n_TOF neutron beam. The data of the test are still being analysed. If, as expected, no problem shows up, we will perform the measurement next year.

## *Pubblications*

- L. Cosentino et al., "*Experimental setup and procedure for the measurement of the $^{7}$Be(n,α)α reaction at n_TOF", NIM A 830 (2016) 197-205*
- M. Barbagallo et al.,*The $^{7}$Be(n,α)$^{4}$He reaction and the Cosmological Lithium Problem: measurement of the cross section in a wide energy range at n TOF (CERN)*. Physical Review Letters 117, 152701 (2016). Article "Selected as PRL Editors' Suggestion".

## *Participation to meetings, and National and International Conferences*

- n_TOF collaboration meeting (CERN, 30 November - 4 December 2015);
- Russbach Nuclear Astrophysics School ( 6-12 March 2016);
- Shift (CERN, 20-26 March 2016);
- Data taken (CERN, 6-13 April);
- n_TOF collaboration meeting (Catania, 17-22 May 2016);
- XXVIII seminario nazionale di Fisica nucleare e subnucleare “Francesco Romano” (Otranto, 3-10 June 2016); where I presented a talk on: "Simulazioni con Geant4 di un proton recoil Telescope per la misura ad n_TOF del flusso di neutroni tra 100 MeV e 1 GeV";
- Data taken and shift (CERN, 4-11 July 2016);
- The XII Torino workshop and IV CSFK Astromineralogy workshop (Budapest, 31 July-5 August 2016); where I presented a talk on: "$^{7}$Be(n,α) and $^{7}$Be(n,p) cross section measurement for the Cosmological Lithium Problem at n_TOF-EAR2"
- 102° Congresso della Società Italiana di Fisica (Padova, 26-30 September 2016); where I presented a talk on: "Geant4 simulations of a Proton Recoil Telescope for the measurement of the n_TOF neutron flux between 100 MeV and 1 GeV"
- Meeting n_TOF Italia (Legnaro, 19-21 October 2016);
- Terzo Incontro Nazionale di Fisica Nucleare INFN 2016 (14-16 November 2016); where I presented a poster on: " Geant4 simulation of a Proton Recoil Telescope for the measurement of the $^{235}$U(n,f) cross section up to 1 GeV at n_TOF ";
- n_TOF collaboration meeting (CERN, 21-24 November 2016)

***Exams***

The table below lists the first year exams of my Ph.D.

| ESAME E DOCENTE | ESITO |
|---|---|
| “Inglese”, C. White | SUPERATO |
| “Progetto Europeo”, A. D’orazio | SUPERATO |
| “Introduction to C++ programming”, F. Cafagna | SUPERATO |
| “Advanced C++ programming”, F. Cafagna | SUPERATO |
| “Rivelatori al Silicio”, D. Creanza | SUPERATO |
| “Analisi dati sperimentali”, A. Pompili | CONSEGNATO |
| “Rivelatori a gas e scintillatori”, V. Peskov | 15-December |
| “Astrofisica Nucleare”, G. Tagliente | SUPERATO |

***Goals for the second year of Ph.D.***

In the course of the second year of my PhD I will complete the analysis of the $^{7}$Be(n,p) reaction, and I will be responsible for the measurement of the $^{235}$U(n,f) cross section relative to the n-p scattering, with the Proton Recoil Telescope. For this last subject, I have been appointed a fellowship as "CERN Associate" (also called "simil fellow"), which will allow me to spend the whole year (2017) at CERN. During this period I will also participate in all other measurements that will be performed at n_TOF, helping with the experimental apparatus, the data taking and analysis. In 2017 I plan to attend a few conferences where to present my results, and a school in Nuclear Astrophysics.