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Laser-driven neutrons for time-of-flight experiments?

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Abstract. Neutron beams, both pulsed and continuous, are a powerful tool in a wide variety of research fields and applications. Nowadays, pulsed neutron beams are produced in conventional accelerator facilities in which the time-of-fight technique is used to determine the kinetic energy of the neutrons inducing the reactions of interest.

In the last decades, the development of ultra-short (femtosecond) and ultra-high power ($> 10^{18}$ W/cm^2) lasers has opened the door to a vast number of new applications, including the production and acceleration of pulsed ion beams. These have been recently used to produce pulsed neutron beams, reaching fluxes per pulse similar and even higher than those of conventional neutron beams, hence becoming an alternative for the pulsed neutron beam users community. Nevertheless, these laser-driven neutrons have not been exploited in nuclear physics experiments so far.

Our main goal is to produce and characterize laser-driven neutrons but optimizing the analysis, diagnostic and detection techniques currently used in conventional neutron sources to implement them in this new environment. As a result, we would lay down the viability of carrying out nuclear physics experiments using this kind of sources by identifying the advantages and limitations of this production method.

To achieve this purpose, we plan to perform experiments in both medium (50TW@L2A2, in Santiago de Compostela) and high (1PW@APOLLON, in Paris) power laser facilities.

1 Introduction

Pulsed neutron beams entail a powerful probe in nuclear physics with applications in a wide variety of fields like astrophysics, image diagnostics, medical applications, material analysis, fission and fusion research, irradiation of electronics, etc. In those applications where the energy of the neutron is relevant, it is necessary to work with pulsed neutron beams using the time-of-flight technique to determine the energy which produces a certain reaction or event of interest. The temporal resolution, the intensity of the pulses and the repetition rate between pulses are critical parameters to successfully exploit time-of-flight measurements.

Nowadays, the major neutron facilities worldwide are based on huge and complex accelerators, limiting the applications of neutrons. In 2004, the IAEA called about the need of developing small scale and compact neutron sources [1] to fully exploit all the possibilities of these techniques.

> *"There is a general belief in the life sciences community that neutron methods are an emerging technique and not exploited to their full capacity. This is partly due to the fact that useful neutron beams can only be generated at advanced research reactors and/or high energy neutron spallation sources."*

In this context, the development of ultra-short (femtosecond) and ultra-high power ($> 10^{18}$ W/cm^2) lasers can be revolutionary, allowing us to reach shorter and more intense neutron pulses in more compact and cheaper facilities.

2 Lasers as accelerators

The development of ultra-short and ultra-high power lasers has opened the door to a vast number of new applications, such as the production and acceleration of ions [2].

There are several methods to accelerate particles using a laser. The most used method is the Target Normal Sheath Acceleration (TNSA) [3] (Figure 1), although not the most prolific. The broad use of this method is due to the fact that the conditions over the laser parameters and the target

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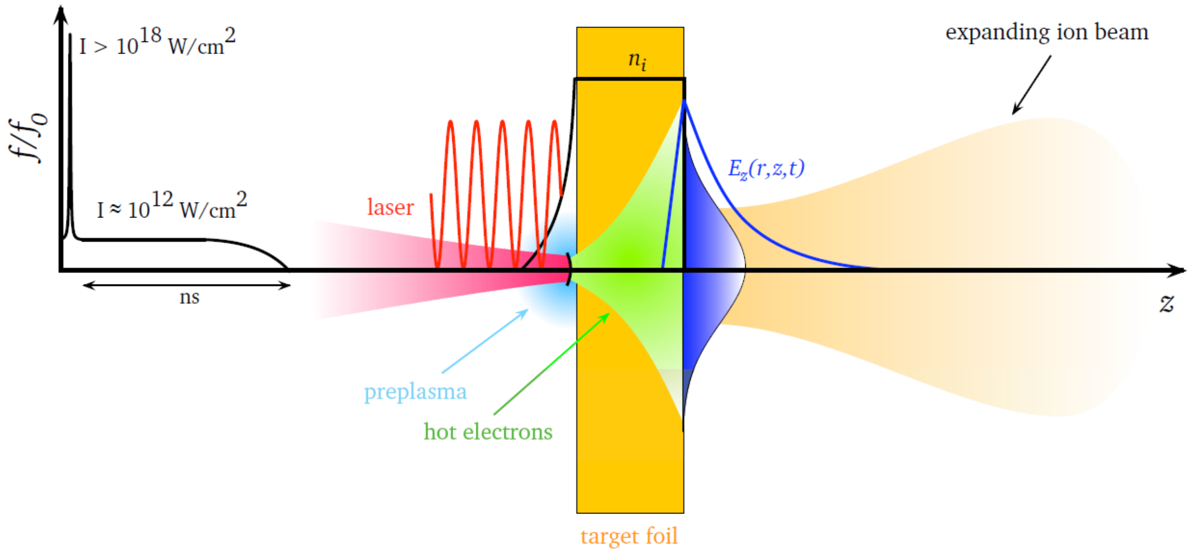

Figure 1. Target normal sheath acceleration graphic representation. Extracted from [3].

choice are less demanding, so it is more reproducible than other methods.

The mechanism consists in taking advantage of the laser “prepulse”, the spontaneous emission of energy before the main pulse, to produce a plasma in the front surface of a thick production target. At the arrival of the main pulse, the electromagnetic field couples with the electrons in the plasma. This electrons leave the target by the rear surface producing a charge separation equivalent to TV/m electric field. This field is strong enough to ionize and accelerate light elements from the rear surface of the target, usually hydrogen impurities, obtaining an exponential continuous beam up to tens of MeV in the case of protons (Figure 2) [4]. This pulsed ion beam can then be used to produce neutrons by means of nuclear reactions.

3 Laser-driven neutrons

There are multiple methods to produce a neutron beam based on a primary ion or electron beam and different nuclear reactions which have neutrons as final product. Each kind of reaction determines the final features of the beam. The main reactions used in conventional neutron sources for this purpose are photofission induced by an electron beam on a heavy element target (e.g. GELINA, in Belgium, with a 100 MeV electron beam colliding on a uranium target), spallation reactions (e.g. n_TOF, in Switzerland, with 20 GeV protons from CERN’s PS accelerator producing spallation on a lead target), D-D and D-T fusion reactions, and other nuclear reactions like ^{7}Li(p,n), ^{9}Be(p,n),^{9}Be(d,n) (FRANZ, LiLiT, Frascati, HiSPANoS, etc.).

Using high power lasers and the TNSA mechanism, we can obtain high intensity and a very short duration (ps) pulses of ions (mostly protons and deuterons) with a wide dispersion of energies. These are precisely the necessary characteristics of a particle beam for its use in neutron production for time-of-flight experiments. The usual setup that is used for this purpose is a pitcher-catcher double target configuration (Figure 4). The laser is focused over a first target to produce an electron or ion beam with the TNSA mechanism. The resulting beam collides with a second target designed to produce a nuclear reaction with neutrons as final product. Using these ion beams for neutron production made possible to reach fluxes per pulse which are competitive with more conventional neutron sources.

Until now, the record in laser-driven neutron production was set by the work of Roth *et al* [5] in 2013 in the 90 J and 200 TW TRIDENT laser of Los Alamos (USA). Based on those results, Guerrero *et al* [6] made a comparative study between a potential laser neutron facility (with and without moderation) and the conventional but state-of-the-art facilities n_TOF at CERN, GELINA and FRANZ. This analysis is shown in Figure 3, where a 10 Hz repetition rate is supposed for the record pulse obtained in TRIDENT as a benchmark of the capability of a laser system as a neutron source. The instantaneous intensity of the beam produced by laser is higher in the region of MeV neutrons, and much higher also in the epithermal region (keV) than the ones at EAR1@n_TOF and GELINA facilities.

The main advantages of these new sources are the compact size and economical price of the facilities. In addition, with the femtosecond technology in laser systems, we can produce shorter neutron pulses to improve the resolution in time-of-flight measurements. Besides, the most relevant advantage is that the laser technology is now developing fast, so the main disadvantages nowadays -such as the slow repetition rate or target refreshing- are expected to be overcome in the next years.

On the other hand, there are yet some issues to be taken care of. Until now, we only can work in “single shot” mode, meaning that the laser has to be (re)tuned between consecutive pulses and the target (pitcher) refreshed. At

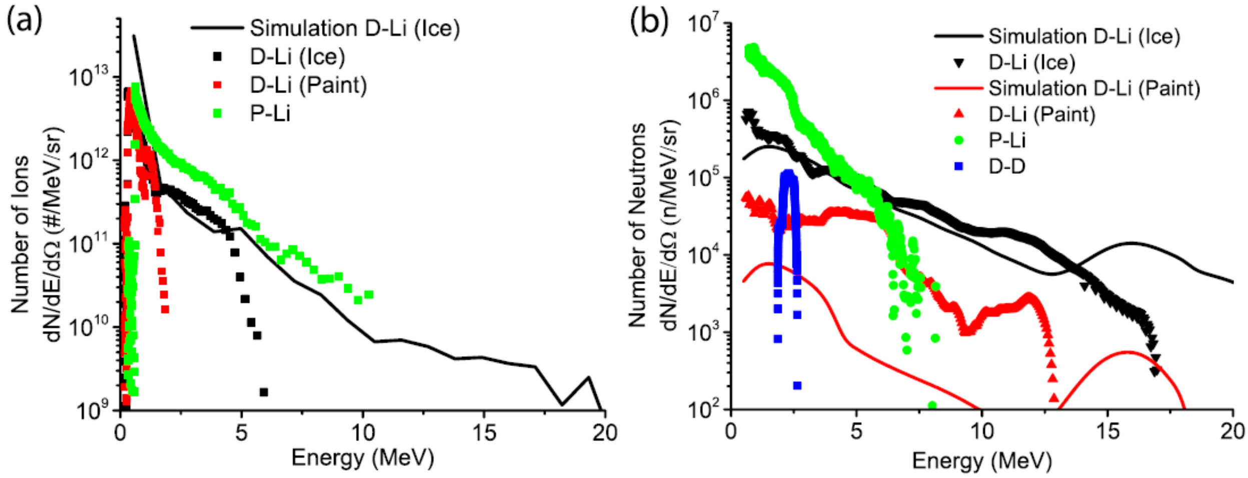

Figure 2. Experimental and simulated ion (a) and neutron (b) spectra along the target normal direction obtained by Zulick *et al.* in the 1,1 J and 300 TW HERCULES laser facility [4].

this moment, the best repetition rate in a medium power laser facility is given by the 50 TW laser L2A2 in Santiago de Compostela [7], where proton beams have been produced at a frequency of 10 Hz. In PW laser facilities the maximum repetition rate available is 1 Hz or lower [8].

The relativistic pulsed background in these setups is not yet characterized and the optical devices need more frequent maintenance than common accelerators (specially because the blow off of the target gets the optical surfaces dirty). For all these factors, the reproducibility between the pulses is questioned nowadays in this type or sources.

Although there are several and recent works about neutron production by laser, these are focused on the optimization of the laser parameters or the target configuration in terms of the neutron yield or the repetition rate, but none has yet studied these kinds of sources in terms of the applications in nuclear physics or time-of-flight experiments. That is precisely the aim of our research team.

4 Multiple detectors experiment

In our experiments with laser-driven neutron beams we plan to take measurements to produce and characterize them but optimizing the analysis, diagnosis and detection techniques currently used in conventional neutron sources to implement them in this new environment.

One of the first objectives is to measure and characterize the background conditions in this kind of sources in terms of the gamma flash or the relativistic electrons, taking into consideration that each type of detector will have a different response to these.

We also want to compare the neutron flux and background conditions resulting from the different ion acceleration mechanisms in order to identify which one is more adecuate for time-of-flight experiments.

To achieve these goals, we propose a setup that we can test both in a conventional neutron source, such as HiSPANoS in Sevilla, and in laser facilities (in principle L2A2 and APOLLON).

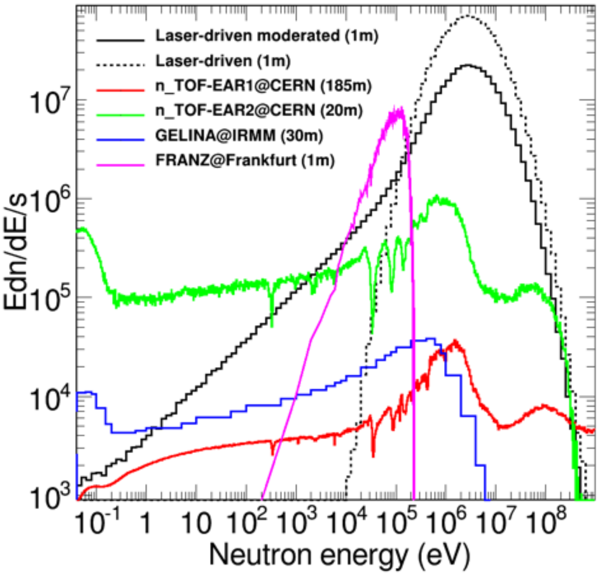

Figure 3. Neutron flux based in M. Roth, et al. results from 2013 experiments at TRIDENT PW Laser System [5]. Extracted from [6].

The ideal configuration should have different detectors that are currently used in nuclear physics experiments with neutron beams (Figure 4): lithium detectors for thermal and epithermal neutron detection, organic liquid detectors for fast neutrons, fast (LaBr3) γ-ray detectors for measuring neutron capture reactions, fission detectors, diamond or silicon detectors for charged particles and a neutron camera to study the neutron transmission and the possibilities of neutron imaging.

The first experiments would be carried out from this summer onward at the medium energy laser system L2A2

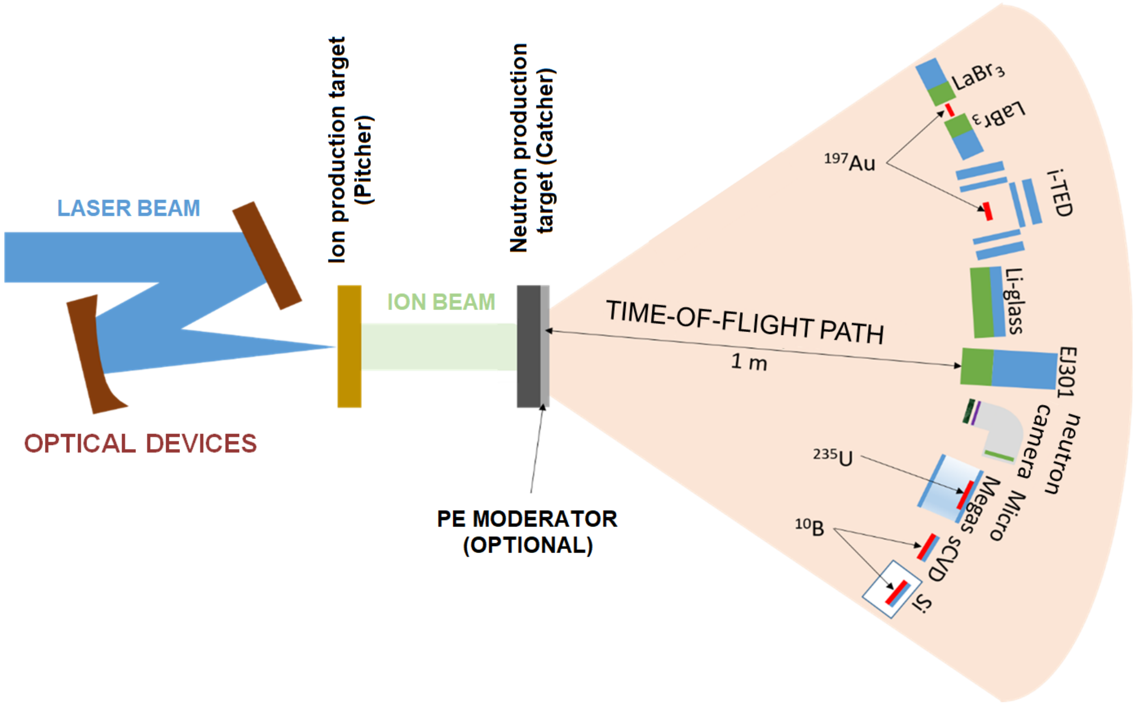

Figure 4. Pitcher-Catcher setup in the multiple detectors experiment

	L2A2 @USC
Facility	50 TW 1,2 J Laser System
Pulse Duration	~ps
Repetition Rate	10 Hz
Proton/pulse	$1,5{\cdot}10^{9}$

	HiSPANoS @CNA
Facility	3 MV Tandem Accelerator System
Pulse Duration	1-2 ns
Repetition Rate	1 MHz
Proton/pulse	$1,2{\cdot}10^{6}$

	APOLLON @LULI
Facility	10 PW 150 J Laser System
Pulse Duration	~ps
Repetition Rate	1 shot/minute
Proton/pulse	$>10^{13}$ expected

Table 1. Summary of the characteristics of the facilities for the first stage of the experiment.

in Santiago de Compostela, where the neutron beam should be comparable to the HiSPANoS facility (Table 1).

This stage would allow us to characterize and optimize the analysis, diagnosis and detection techniques. We would be able to identify the candidates for the first cross-section measurement in a laser-based neutron source based on the results of this first test.

In a second phase the experiments would be performed at the high power laser APOLLON (1-10 PW) in Paris [9]. In these laser systems we can reach fluxes competitive with sources like GELINA or n_TOF to study the viability of carrying out the first cross-section measurement in a high power laser-based neutron source.

References

[1] IAEA, Report of a technical meeting, IAEA-TECDOC-1439, Vienna, 18-21 May 2004.

[2] M. Borghesi, Nucl. Instrum. Methods Phys. R. A, **740**, 6-9 (2014)

[3] M. Roth, M. Schollmeier, CERN yellow reports, [s.l.], **1**, 231 (2016).

[4] C. Zulick, et al., Appl. Phys. Lett. 102, 124101 (2013).

[5] M. Roth, et al., Phys. Rev. Lett, **110**, 044802 (2013).

[6] C. Guerrero et al., Eur. Phys. J. A, **53**:87 (2017).

[7] J. Benlliure, et al. Nucl. Instrum. Methods Phys. R. A, **916**,158-168 (2019)

[8] L. Roso, EPJ Web Conf., **167**, 01001 (2018).

[9] B. Le Garrec, et al. Proc. SPIE 10238, 102380Q (2017).