Polarized targets for laser-plasma applications

M. Büscher[1,2], A. Hützen[1,2], J. Böker[3], R.W. Engels[3], R. Gebel[3], A. Lehrach[3,4], P. Gibbon[5], A. Pukhov[6], R.W. Aßmann[7], T.P. Rakitzis[8,9], L. Ji[10,11], T. Schenkel[12], X. Wei[13]

[1] Peter Grünberg Institut (PGI-6), Forschungszentrum Jülich, 52425 Jülich, Germany
[2] Institut für Laser- und Plasmaphysik, Heinrich-Heine-Universität Düsseldorf, 40225 Düsseldorf, Germany
[3] Institut für Kernphysik, Forschungszentrum Jülich, 52425 Jülich, Germany
[4] JARA-FAME Forschungszentrum Jülich and RWTH Aachen University, 52056 Aachen, Germany
[5] Institute for Advanced Simulation, Jülich Supercomputing Centre, Forschungszentrum Jülich, 52425 Jülich, Germany
[6] Institut für Theoretische Physik I, Heinrich-Heine-Universität Düsseldorf, 40225 Düsseldorf, Germany
[7] DESY, Notkestraße 85, 22607, Hamburg, Germany
[8] Department of Physics, University of Crete, 71003 Heraklion-Crete, Greece
[9] Institute of Electronic Structure and Laser, Foundation for Research and Technology-Hellas, 71110 Heraklion-Crete, Greece
[10] State Key Laboratory of High Field Laser Physics, Shanghai Institute of Optics and Fine Mechanics, Shanghai 201800, China
[11] CAS Center for Excellence in Ultra-intense Laser Science, Shanghai 201800, China
[12] Accelerator Technology and Applied Physics Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA
[13] Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA

Abstract

Spin-polarized particle beams are of crucial importance for nuclear and particle physics. This LoI outlines strategies that could lead to the generation of polarized electron, proton and ion beams in next generation accelerator facilities based on ultra-intense lasers. Recently rapid progress has been made in the development of numerical tools to describe the effect of the huge laser-plasma magnetic fields on the particle spins. In parallel, first polarized targets, tailored for laser applications, are now in the commissioning phase. The development of laser-plasma accelerated polarized beams relies on several key competences: beam and spin simulation with PIC codes, production and handling of polarized sources and targets and experience with experiments at conventional storage rings (beam transport and polarimetry) as well as the expertise to operate ultra-intense laser systems. For an in-depth description of this research area, we refer to our recent Review Paper [1].

1 Current Status

Laser-driven generation of polarized proton and ^{3}He-ion beams in combination with the development of advanced target technologies is being pursued by our group in the framework of the *Ju*SPARC facility [2], the ATHENA consortium („Accelerator Technology HElmholtz iNfrAstructure") and EUPRAXIA [3]. These novel target technologies will be tested at different laser facilities, *e.g.* at the 10 Petawatt laser system SULF at SIOM/Shanghai (China) and the PHELIX Petawatt Laser Facility in Darmstadt (Germany) in the near future. After demonstration of laser-accelerated polarized hadron beams, our targets will be modified such that they can also serve as sources of polarized electrons [4]. These could be used also at laser facilities in the U.S., like BELLA (USA).

1.1 The need for polarized targets

In a series of theoretical papers (see e.g. [1,5] and references therein) we have demonstrated that a crucial prerequisite for producing polarized relativistic particle beams is the availability of targets containing high-density pre-polarized nuclei. In order to predict the degree of beam polarization from a laser-driven plasma accelerator, particle-in-cell (PIC) simulations including spin effects have been carried out. For this purpose, the Thomas-BMT equation, describing the spin precession in electromagnetic fields, has been implemented into PIC codes (VLPL and EPOCH).

We have then initiated the development of several polarized targets:

- A polarized HCl gas-jet target is under commissioning at Forschungszentrum Jülich, Germany [6]. The necessary densities, for laser-ion acceleration of polarized particles, of at least 10^{19} cm^{-3} have been demonstrated recently, from the photodissociation of DI molecules [7]. The experiments with nuclear polarized H atoms from HCl jet at SULF will start in 2021. Beam energies of a few 10 MeV at high degrees of polarization (up tp 82%) are expected from our PIC simulations.

- In parallel to the experiments at high-power laser facilities we will also carry out proof-of-principle studies at the COSY/Jülich accelerator facility also aiming acceleration of polarized protons/deuterons from molecular targets.
- We have built a hyperpolarized ^{3}He gas–jet target for experiments for the PHELIX Petawatt Laser Facility at GSI in Darmstadt for measuring the spin-polarization degree of laser-accelerated $^3He^{2+}$ ions. The particular advantage of ^{3}He gas is that it can be polarized, stored and transported at room temperature and can preserve high degrees of polarization over many hours.
- On a long-term scale, it is foreseen to freeze out polarized molecules from an atomic beam source on a cold surface below 10 K to collect the D_2 or HD gas as polarized ice. This ice can be transported and used as targets for laser-acceleration experiments to produce polarized proton/deuteron beams or for laser-induced nuclear fusion with polarized fuel.
- In a collaboration with the Budker Institute for Nuclear Physics (Russia) financed by a joined DFG/RSF grant, another method for the production of polarized H_2 and D_2 molecules is on the way. The existing superconducting ABS for the polarized target at the VEPP 3 accelerator was modified by the Russian partners to separate different hyperfine states of the molecules by the Stern-Gerlach method.

1.2 Preparatory experiments at laser facilities

The only experiment measuring the polarization of laser-accelerated protons has been performed by our group at the 100 TW ARCturus laser facility at HHU Düsseldorf (Germany) [8]. During these measurements (with an unpolarized foil target) we developed a polarimeter for MeV protons that is the basis for our future studies with polarized targets *e.g.* at SULF and Phelix.

A proof-of-principle experiment at PHELIX showed that (yet unpolarized) ^{3}He ions can be accelerated to energies of a few MeV out of a ^{3}He gas-jet target [9]. The measurements with polarized gas will continue in 2021.

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