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# POLARIZED DEUTERON NEGATIVE ION SOURCE FOR NUCLEAR PHYSICS APPLICATIONS

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## *Abstract*

The proposed U.S. Electron-Ion Collider (EIC) provides a unique tool to explore the next frontier in Quantum Chromodynamics, the dependence of hadron structure on the dynamics of gluons and sea quarks. Polarized beams are essential to these studies; understanding of the hadron structure cannot be achieved without knowledge of the spin. The existing EIC concepts utilize both polarized electrons and polarized protons/light ion species to probe the sea quark and gluon distributions. Polarized deuterons provide an especially unique system for study by essentially providing a combination of quark and nuclear physics. This polarized deuteron source can serve as a polarized deuteron injector for a future EIC.


## INTRODUCTION

Highly polarized ion sources are essential to the development of the next generation high-luminosity high-polarization colliders. Maximum beam polarization at collision is crucial to reduce systematic and statistical errors in measurements of spin-dependent effects. Maximum polarization of the neutral atoms before ionization is also desired for polarimeter applications where the polarized atoms serve as a polarized target for recoil measurements [1].

## TECHNICAL APPROACH

### *Background Information*

The proposed U.S. Electron-Ion Collider envisions providing polarized light ion species, $H^-$, $D^-$, $^3He$, $^6Li$, as probes for understanding hadron structure. While polarized $H^-$ beams are readily available at RHIC [2] and active development of polarized $^3He$ beams is ongoing [3], there are currently no operational polarized deuteron sources in the United States. Existing polarized deuteron sources are typically atomic beam polarized ion sources (ABPIS) [4,5,6] that have seen incremental upgrades over their multi-decade lifetimes, but still retain legacy components that have not been optimized using modern techniques or materials. Currently operational ABPIS sources have not met the beam pulse structure/intensity requirements that have been put forth by the EIC design teams. As an example, for the Jefferson Lab Electron-Ion Collider (JLEIC) concept, 2 mA/0.5 ms polarized deuteron beams with ~90% vector nuclear polarization are desired [7]. These parameters have not been demonstrated in existing sources and, to the best of our knowledge, active development is not being pursued for polarized $D^-$ from ABPIS sources.

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### *Laser Photolysis Generation of Polarized Deuterons*

A novel method of polarized deuteron generation [8] has recently been demonstrated that provides polarized deuteron beam pulses with production rates that are ~$10^4$-$10^6$ times higher than the rates achievable in a conventional ABPIS. This method involves the UV photodissociation of deuterium iodide (DI) gas. The measured nuclear polarization of the polarized deuteron pulse is ~60%. We plan to explore this method of polarized deuterium atom generation by combining it with novel ionizer components of a ABPIS source, creating a novel hybrid ABPIS for high intensity, highly polarized deuterium ions.

UV photodissociation methods for production of polarized deuterium ions have gained interest in the nuclear fusion community as a means to test the properties of polarized fusion [8]. The method produces short bunches (~ns scale) of polarized deuterium ions with densities on the order of $10^{18}$ cm$^{-3}$, several orders of magnitude larger than the densities that have been produced in ABPIS sources (~$10^{12}$ cm$^{-3}$).

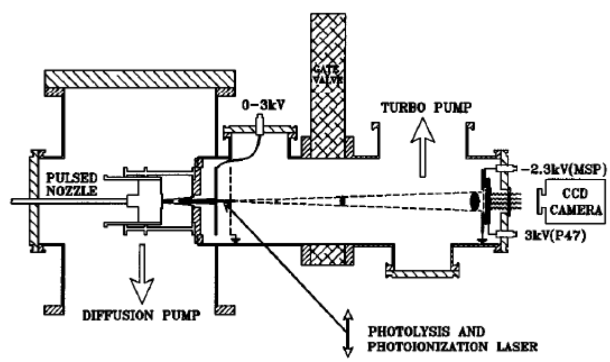


Figure 1: Experimental apparatus for laser photolysis generation of polarized deuterium ions.

The experimental setup used to demonstrate this method is shown in Fig. 1 [9]. The laser photolysis method for polarized deuterium ion production uses one laser pulse to first dissociate deuterium iodide (DI) molecules. The laser photodissociation results in D and I photofragments that are initially electronically polarized; the polarization oscillates between the electron and nuclear spins due to the hyperfine interaction, as seen in Fig. 2 [8]. This oscillation is terminated by ionizing the photofragments with a second laser pulse; proper timing of the second laser pulse allows one to terminate the polarization exchange when the nuclear polarization is at a maximum.

An advantage of this method is the ability to produce intense pulses of polarized deuterons; one photon in the photodissociation pulse produces one polarized deuteron, and thus kilowatt-class UV lasers can achieve polarized

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deuteron production rates on the order of $10^{21}$ $s^{-1}$, several orders of magnitude larger than is currently achieved in atomic beam source methods [1]. The current method produces short bunches of polarized deuterium ions with a maximum measured polarization of 60%. These parameters are not compatible with the desired parameters for a polarized deuteron injector for a high luminosity collider. We propose to evaluate this method for production of polarized deuterium atoms only, combining it with aspects of an ABPIS device for resonant charge-exchange ionization to achieve the ionization process. Because this method can generate higher densities of polarized deuterium atoms, it has the potential to produce more intense pulses of polarized deuterium ions than are available from conventional ABPIS devices.

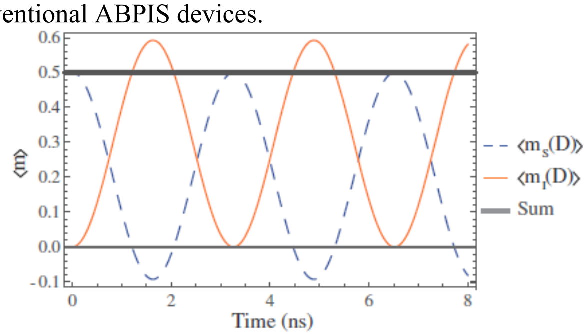


Figure 2: Electronic (dashed blue line) and nuclear (orange solid line) polarization vectors for the polarized deuterium ion generated by laser photolysis.

We will study alternative methods for termination of the electronic-nuclear polarization oscillation, since the hybrid ABPIS envisions utilizing the resonant charge-exchange ionization process.

*ABPIS Components*

ABPIS devices have been used for many years as sources of polarized $H^-$ and $D^-$ ions. The source comprises two major components: an atomic beam source that produces atomic particles and polarizes them, and an ionizer that facilitates the resonant charge-exchange reaction between the polarized atoms and unpolarized ions. The ionizer itself comprises a plasma source for the generation of the relevant ion species, and a charge-exchange cell. A schematic of such a source is shown in Fig 3 [10]. For the ABPIS production of polarized $D^-$, the charge-exchange reaction is:

$$D^0\uparrow + H^- \Rightarrow D^-\uparrow + H^0$$

In this case, deuterium atoms are generated in the atomic beam source through dissociation of the molecular gas via RF discharge

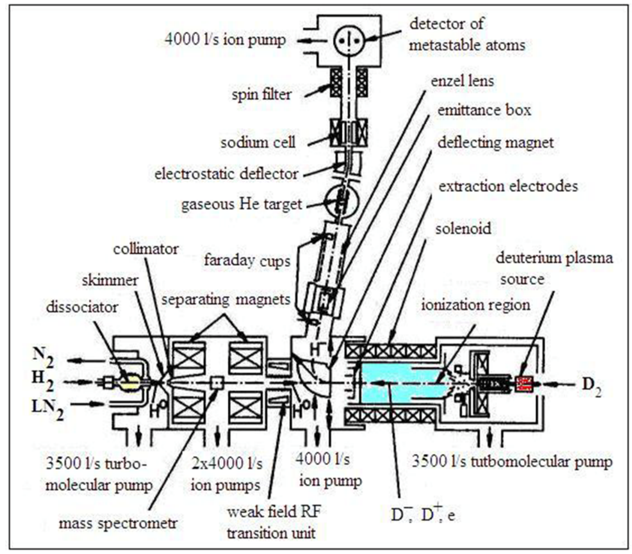


Figure 3: Schematic diagram of an ABPIS with resonant charge-exchange ionization. The atomic beam source components are to the left, and the ionizer components are to the right.

The atoms are then cryogenically cooled and polarized through a series of RF transition units before injection into one end of the charge-exchange cell. Hydrogen ions are injected into the opposite end of the charge-exchange cell from the plasma source. The polarized Deuterium atoms and unpolarized Hydrogen ions are confined within the charge-exchange cell by a solenoid field on the order of 1 kG. The cross-section for this reaction is $10^{-14}$ $cm^2$ at Hydrogen ion energies ~10 eV [10]. For this process, the efficiency of the conversion from polarized atom to polarized $D^-$ is estimated to be on the order of 12% [6]. Each major component of an ABPIS device facilitates complex physics processes and has several avenues for optimization.

A previous ABPIS for polarized deuteron production [5] used an arc-discharge plasma source and cesiated converter stages to enhance the production of unpolarized $H^-$ ions. We propose to optimize the plasma source design by incorporating multi-spherical focusing of the negative ions produced by the plasma. We believe that the negative ion flux can be enhanced using this method, and the overall intensity of the polarized $D^-$ beams can be improved in this hybrid ABPIS.

Plasma sources for intense negative ion production rely on the efficient conversion of positive plasma ions to negative ion species on surfaces with reduced work functions [11,12]. The emission is enhanced by using cesium to lower the work function of the emission surface, a well-known and often-used technique. Shaping of the emission surface into concave spherical surfaces, known as geometrical focusing or self-extraction [13, 12], results in a natural focusing of the negative ions that increases the negative ion current density. This has demonstrated an increase in negative ion emission even on cesiated surfaces [14]. The concept is illustrated in Fig. 4.

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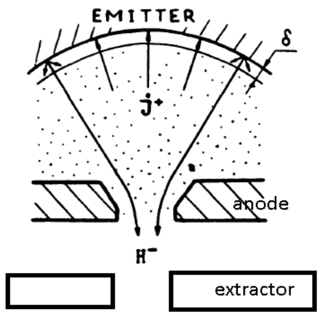


Figure 4: Cylindrical or spherical shaping of the emitter surface geometrically focuses the emitted negative ions.

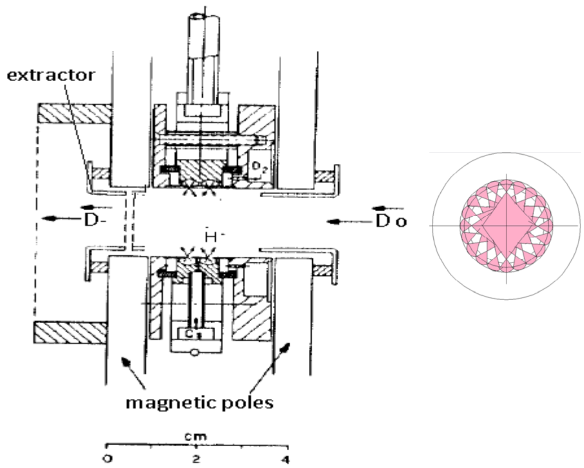


Figure 5: Surface plasma source-based ionizer for resonant charge-exchange ionization of polarized atomic hydrogen will extract the polarized D-.

The concave spherical emitter electrodes in the surface plasma source can be arranged such that the generated negative hydrogen ions are focused onto apertures leading away from the discharge, into a charge exchange area.

We will design and simulate aspects of a surface plasma source-based ionizer with multi-spherical focusing of negative H- ions. The ionizer combines the surface plasma source with a short charge-exchange region into which the unpolarized $H^-$ ions are injected radially. The polarized atomic deuteron beam will be injected into this charge-exchange region on axis from one end of the region, and an extraction grid at the opposite end. The concept is illustrated in Fig. 5.

## REFERENCES

[1] A. Zelenski *et al.,* "Polarized $H^-$ Jet Polarimeter for Absolute Proton Polarization Measurements in RHIC", in *Proc. AIP Conference*, 675, p. 954, 2003.

[2] A. Zelenski *et al.,* "The RHIC polarized $H^-$ ion source", Rev. Sci. Instrum. 87, paper 02B705, 2016.

[3] A. Zelenski *et al.,* "The RHIC polarized $H^-$ ion source", Rev. Sci. Instrum. 87, paper 02B705 2016.

[4] V.P. Derenchuk and A.S. Belov, "A multi-milliampere polarized and unpolarized negative ion source for IUCF", Conf.Proc. C0106181, 2001, pp. 2093-2095.

[5] V.P. Derenchuk and A.S. Belov, "Polarized D- Operation and Development of the IUCF Ion Source CIPIOS", in *Proc AIP.* 675, p. 887, 2003.

[6] .S. Belov *et al.,* "Intensity improvements of pulsed source of polarized negative hydrogen ions", Rev. Sci. Instrum. 77, paper. 03A522, 2006.

[7] V. Dudnikov *et al.,* Perspective for development of a universal source of highly polarized ions", PoS (PSTP2013)050, `http://pos.sissa.it/archive/conferences/182/050/PSTP2013_050.pdf`

[8] D. Sofikitis *et al.,* "Highly Nuclear-Spin-Polarized Deuterium Atoms from the UV Photodissociation of Deuterium Iodide", PRL 118, 233401, 2017.

[9] P.C. Samartzis *et al,* "Photofragmentation study of Cl2 using ion imaging", J. Chem. Phys. 107, 43 1997.

[10] A.S. Belov *et al.,* "High-intensity source of polarized negative hydrogen ions with a resonant charge-exchange plasma ionizer", Rev. Sci. Instrum. 67, 1293 1996.

[11] V. Dudnikov, «Method of negative ion production", Author Sertificat Кл.H 01 J 3/0,4, 411542, filed 10/III,1972. `http://www.findpatent.ru/patent/41/411542.html`

[12] Yu.I. Belchenko, G. Dimov and V. Dudnikov., "A powerful injector of neutrals with a surface-plasma source of negative ions", Nucl. Fusion 14 113 1974.

[13] V. Dudnikov, Yu. Belchenko, Journal de Physique, v. 40, p. 477, 1979.

[14] Yu.I. Belchenko *et al.,* "Ion sources at the Novosibirsk Institute of Nuclear Physics", Rev. Sci. Instrum. 61, p. 378 1990.

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