PROCEEDINGS OF SCIENCE

# Storage Cell Tests for the Polarized Target at LHCb

**R. Engels,**[a,b,*] **O. Bilen**[a,c] **and K. Grigoryev**[a,b] **for the LHCspin Collaboration**

[a] *Institute for Nuclear Physics, Research Center Jülich,*
*Wilhelm-Johnen-Str. 1, 52425 Jülich, Germany*

[b] *GSI Helmholtzzentrum für Schwerionenforschung GmbH,*
*Planckstraße 1, 64291 Darmstadt, Germany*

[c] *Heinrich-Heine-Universität Düsseldorf,*
*Universitätsstr. 1, 40225 Düsseldorf, Germany*

*E-mail:* r.w.engels@fz-juelich.de

T-shape cells fed with polarized hydrogen or deuterium atoms have been implemented in several storage rings like COSY, DESY or IUCF as polarized internal targets. To inhibit polarization losses of the stored atoms, e.g. by recombination into molecules, different solutions have been adopted for the surface materials. For example, aluminum with its ceramic monolayer of aluminum oxide on top, Teflon or a water ice surface are successfully used. These surface materials are not allowed for the coming polarized storage cell target at LHCb as not compatible with the vacuum system or because of beam interactions. The only allowed material is amorphous carbon coating, but exists so far no experience about possible depolarization effects. For this reason experiments to investigate the recombination rate of polarized hydrogen atoms and the polarization preservation are under way at the research center in Jülich.

*19th Workshop on Polarized Sources, Targets and Polarimetry (PSTP2022),*
*26-30 September, 2022*
*Mainz, Germany*

*Speaker





PoS(PSTP2022)036

## 1. Introduction

The LHCSpin project [1] aims to install an internal polarized gas target in front of the LHCb detector [2], bringing polarized physics to the LHC for the first time. An important part of the target for the LHC Run 4 will be an openable T-shaped storage cell, based on the SMOG2 design [3]. The cell will be fed with polarized hydrogen or deuterium atoms produced by an atomic beam source (ABS).
To inhibit polarization losses of the injected atoms in the cell, a coating of the cell wall is foreseen. At LHC the usual coatings like water ice, aluminum or teflon are not allowed due to compatibiity with vacuum protocols or their high secondary electron yield (SEY). A possible material for the coating could be amorphous carbon, which should ensure a low SEY to preserve the beam lifetime. However, a carbon coated storage cell has never been experimentally investigated.
At the Institute for Nuclear Physics at the Research Center Jülich a setup exists dedicated to study polarization losses in storage cells as a function of surface materials, temperature, magnetic holding fields, and recombination. Using this setup, the recombination of hydrogen and deuterium on various metal coated storage cells has already been conducted [4], showing that recombined molecules only hold 50% of the initial atomic polarization. Also, a Fomblin oil coated storage cell has been investigated where the recombined molecules, $H_2$, $D_2$ and HD [5] preserved nearly the full atomic polarization. After some preliminiary tests with a self-made carbon coating in 2022 it is foreseen to investigate storage cells coated with 200 nm amorphous carbon.
In addition, due to a modification of the ABS used in Jülich, it will be also possible to investigate the influence of Lyman-$\alpha$ photons from the dissociator of the ABS on the recombination process. Such measurements could give new insights to improve the construction of future polarized storage-cell targets. Furthermore, the recombination of hydrogen atoms on carbon surfaces is thought to play an important role in the formation of molecular hydrogen clouds in the interstellar medium (ISM) [6].

## 2. The apparatus

A beam of polarized hydrogen or deuterium atoms is produced by an ABS, formerly used as part of the ANKE experiment at COSY/Jülich [7]. This ABS is able to produce every possible combination of nuclear and electron spin orientations. The ABS is fed by molecular gas dissociated in an RF-induced plasma, a process which creates a high number of Lyman-$\alpha$ photons. The beam is injected into the storage cell located inside a liquid-helium-cooled superconducting magnet. The solenoid provides magnetic holding fields up to a field strength of 1 T. The wall temperature of the storage cell can be set between 45 K and 120 K using the cooling and a heater at the center of the cell. Inside the storage cell, the injected atoms and the molecules formed by recombination on the walls are ionized by an electron gun mounted on the left side of the interaction chamber. The ionized particles are accelerated out of the storage cell by a positive potential of about +1 kV. Afterwards, the ions enter a Lamb-shift polarimeter (LSP). The LSP [8] is able to measure the polarization of the ionized particles, i.e. protons, deuterons, $H_2^+$-, $D_2^+$- and $HD^+$-ions leaving the storage cell. A Wien filter installed between LSP and storage cell separates ions due to their different masses. For a more detailed description of the setup and how the polarization is measured, look at [9, 10]. A detailed scheme of the whole setup is shown in Fig. 1.

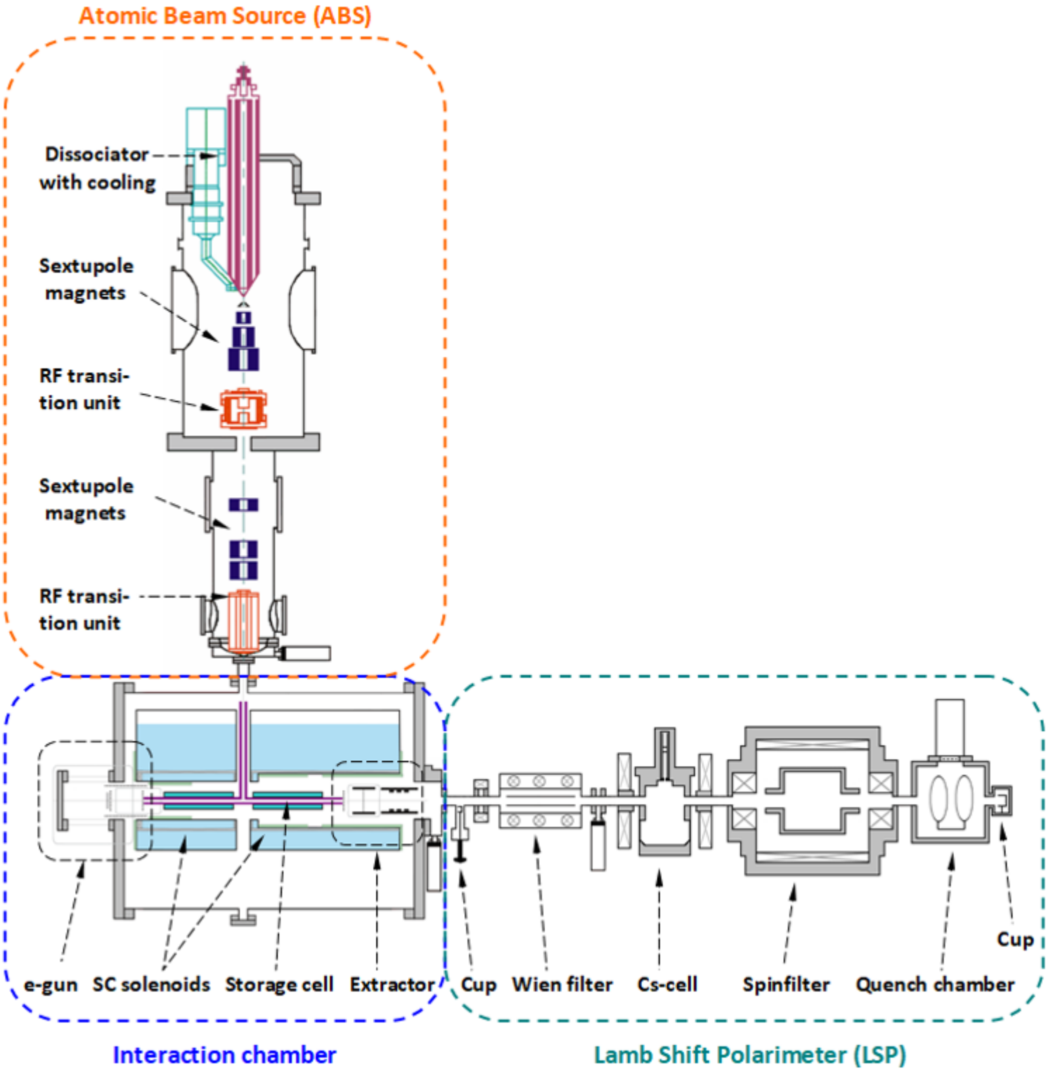


**Figure 1:** The experimental setup: An ABS is feeding an exchangeable storage cell inside a superconducting magnet with polarized hydrogen and/or deuterium atoms. The atoms and the recombined molecules are ionized with an electron beam and the produced ions are accelerated into the LSP to determine the nuclear polarization.

The carbon coating of the cell has been produced by adding a few drops of ethanol into the cell and by heating the cell with a hydrogen flame to more than 2000 K. At this temperature the chemical bonds of the ethanol are broken and the hydrogen and oxygen leave the cell as gases, but the carbon is condensed on the inner surface of the glass cell. By choosing the temperature it is even possible to control the carbon surface either to get an amorphous or a more crystalline surface.

## 3. The Results

When the ABS injected a polarized hydrogen beam into the storage cell, the amount of protons in the cup at the end of the Lamb-shift polarimeter (see Fig. 1) was much larger than the $H_2^+$ ion current. Thus, the first observation indicated a very low recombination rate. This was expected, because during the cooling down of the superconducting solenoid the residual water in the chamber condenses on the cooled surfaces and water is well known to inhibit the recombination [11]. After a short heating procedure of the cell the water is vaporized and the measurement on the carbon surface is possible. The measured recombination rate was between 80 and 90 %.
To provide a possible explanation of the measurement the setup was modified like shown in Fig. 2.

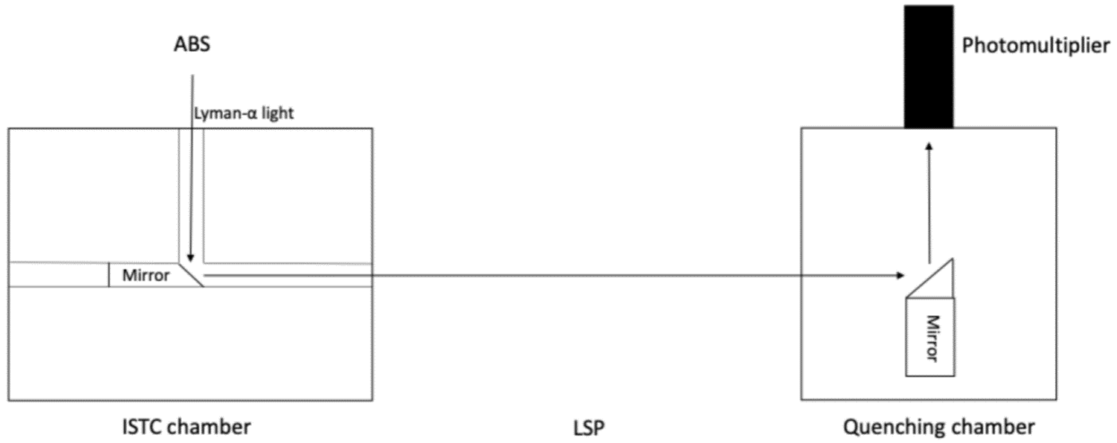


**Figure 2:** Observation of Lyman-$\alpha$ photons coming from the ABS: An aluminum mirror inside the T-shaped storage cell deflects the photons on the beam axis into the LSP. Another mirror in the quenching chamber guides them to the photomultiplier that is sensitive only for wave length between 110 and 135 nm.

Aim of the measurement was to proove that a large amount of Lyman-$\alpha$ photons (10.2 eV), produced in the dissociation plasma of the ABS, enters the cell with the atomic beam. By implementing a special beam stopper in the ABS beam line about 85% of the photons could be stopped together with only 40% of the hydrogen atoms. Even in this case the recombination rate was rather large.
A polarization measurement during this time was not possible, because the corresponding spinfilter of the LSP did not work reliably due to a shortcut of the coils inside.

## 4. Conclusion and Outlook

In astrophysics recombination of hydrogen atoms on carbon surfaces is considered one of the few options to form the molecular hydrogen clouds in the Universe [6]. Experiments showed that the Langmuir-Hinshelwood and the Eley-Rideal mechanisms, the most probable recombination mechanisms, are not effective on a carbon surface. Only a photon-induced destruction of the C-H bond (4.3 eV) allows the recombination with another atom on the surface into a molecule. The experiments on recombination of polarized hydrogen atoms inside a carbon-coated storage cell showed a large recombination rate that might possibly be explained by the Lyman-$\alpha$ photons that

are induced in parallel. A reduction of the photon flux with a small beam stopper on the axis by nearly one order did not decrease the recombination rate.
According to this interpretation the presence of the Lyman-$\alpha$ photons within the polarized atomic beam of an ABS might explain the development of storage cells in the last decades. Like carbon, several materials showed a large recombination rate, even when chemistry predicted no recombination. The materials, i.e. aluminum, titanium, Teflon and water ice, that are used today for the surface coating to avoid recombination and polarization losses are either reflecting these photons or allow some transmission at least.
As next a measurement with a storage cell coated with 200 nm of amorphous carbon is foreseen. Meanwhile, the Los Alamos spinfilter is repaired and can be used to investigate the nuclear polarization of the atoms and molecules inside the storage cell.
The presence of the Lyman-$\alpha$ photons in the ABS beam is an important detail that, if proven, might play an important role in the design of coming polarized internal storage-cell targets. A beam stopper on axis reduces the amount of these photons, but at the same time, reduces also the intensity of the ABS. Therefore, a re-design of an ABS might be helpful. For example, the first set of sextupoles might be replaced by a 25 cm long classical dipole magnet that is separating the atoms due to their electron spin. In this case the atomic beam will be deflected by about $4^\circ$ and its axis wil be separated from the photon beam. If the RF-transition units are installed afterwards large polarization values are possible. By proper focusing of the dipole magnet in one plane higher intensities might theoretically be reached. In addition, the intra-beam scattering is suppressed due to the spatial separation of atoms with different velocities and the open sides of this dipole magnet allow better pumping that might lead to an increase in beam intensity too.

## References

[1] C. A. Aidala *et al.*, The LHCSpin Project (2019).

[2] A. A. Alves, Jr. *et al.*, The LHCb Detector at the LHC, JINST **3**, S08005 (2008).

[3] LHCb Collaboration, LHCb SMOG Upgrade, Tech. rep., CERN, Geneva (2019).

[4] R. Engels *et al.*, Phys. Rev. Lett. **115**, 113007 (2015).

[5] R. Engels *et al.*, Phys. Rev. Lett. **124** 113003 (2020).

[6] D. Hollenbach and E. E. Salpeter, Astrophys. J. **163**, 155 (1971).

[7] M. Mikirtytchiants *et al.*, Nucl. Instrum. Meth. **721**, 83 (2013).

[8] R. Engels *et al.*, Rev. Sci. Instr. **74**, 4607 (2003).

[9] R. Engels *et al.*, PoS (PSTP2017) 033.

[10] R. Engles *et al.*, Rev. Sci. Instr. **85**, 103505 (2014).

[11] C. Baumgarten *et al.*, Nucl. Instrum. Meth. **496**, 263 (2003).



PoS(PSTP2022)036