PROCEEDINGS OF SCIENCE

Polarization measurement of a pulsed H^-/D^- ion beam with a Lamb-shift Polarimeter

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At the FZ Jülich a polarized ion source produces a pulsed beam of nuclear spin polarized H^- or D^- ions for stripping injection into the storage ring COSY. Before injection, the nuclear polarization needs to be determined and optimized. Until now, this is done with a device called Low Energy Polarimeter (LEP), which is based on the polarization dependent elastic scattering of protons on a carbon foil. This procedure requires a pre-accelerated beam of 45 MeV from the cyclotron JULIC and is also time consuming. To make this measurement faster and more energy efficient (cheaper), the idea was to measure the polarization directly behind the source with a Lamb-shift Polarimeter (LSP). Typically, LSP measurements are performed with protons but in this experiment it was shown that a polarization measurement is possible by using H^- or D^- ions directly. First results of the polarization measurements for this pulsed negative ion beam are presented as well as further ideas, e.g. for the automatization of the process, are discussed.

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1. Introduction

In past experiments polarization measurements with a Lamb-shift Polarimeter (LSP) were typically performed with protons or deuterons. In more recent projects it was shown that the polarization measurement of H_2^+, D_2^+ and HD^+ molecular ions is possible as well [1, 2]. Furthermore, there exists a debate about the possibility to measure the polarization of H^- ions directly with a LSP. Being able to measure the nuclear spin polarization of H^- ion beams is an advantage for COSY[1]. The injection into the ring is done by sending the negative ions through a thin carbon foil exactly in the right place to strip off the electrons. The generated protons continue moving on the right orbit inside the storage ring. To conduct experiments with polarized beams at COSY, the beam polarization needs to be determined and optimized. Measuring the nuclear spin polarization of an ion beam can be done by making use of the spin-dependent scattering properties of the particles by using the LEP[2]. Since this method requires a pre-accelerated beam of 45 MeV and is very time consuming, the experiments presented in this proceeding aim at replacing the current method by measuring with an LSP directly behind the source. The use of the LSP also has advantages with respect to the use of the accelerator for experiments with unpolarized particles, because the beamline is not blocked. After measuring polarization spectra by hand, the data acquisition was planned to be automized.

2. Experimental setup

2.1 Polarized beam source

For this experiment the beam source produces a pulsed 2 keV nuclear spin polarized H^- ion beam from unpolarized molecules. The general functioning of the source is given by the interaction of two beams. Like shown in figure 1, a polarized hydrogen beam coming from the right and a neutral cesium beam coming from the left.
The hydrogen part starts with a dissociator in which H_2 molecules are dissociated into atoms with the energy delivered by inducing a radio-frequency (RF). Next, the hydrogen atoms move through a cooled nozzle into the transition zone. It consists of sextupol magnets which separate the states depending on their electron spins (Stern-Gerlach effect) and transition units which induce transitions between single hyperfine substates by injecting a RF field inside magnetic field gradients. Behind the transition zone, single hyperfine substates with defined nuclear spin and electron spin enter the charge exchange area.

[1]COSY: Cooler Synchrotron
[2]Low energy polarimeter

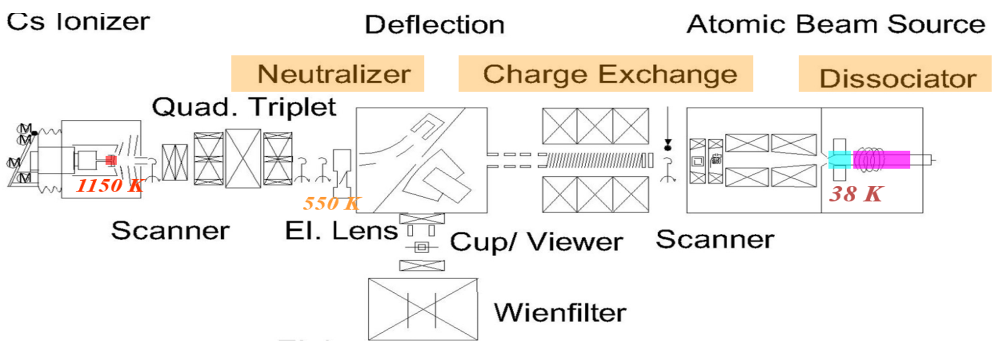

Figure 1: Setup of the atomic beam source [3].

The cesium beam, coming from the left side, has the task to ionize the polarized hydrogen atoms to produce H^- ions. Since negativ ions are needed, cesium is well suited for this purpose because as an element from the alkaline group it can be ionized very easily to get noble gas configuration. The beamline starts with a heatable tungsten button in which the cesium is filled in. Due to the high thermal energy, the cesium diffuses through the button and releases the outer eletron. A strong electric field accelerates the Cs^+ ions along focusing magnets into a neutralization cell. Here, the positive cesium ions are neutralized by charge-exchange with cesium vapor again and move through the device into the charge exchange area. There the reaction $Cs + H \longrightarrow H^- + Cs^+$ takes place. Now, H^- ions are created and accelerated due to a negative potential and than directed towards the LSP by magnetic and electrostatic deflectors. As can be seen in figure 2, the beamline is quiet complex since the LSP was installed on the ground floor of the building and the source is located in the basement. As illustrated in figure 2 the unpolarized source (AEA Source) is placed next to the polarized source in direction of the cyclotron which pre-accelerates the ions before injection into the storage ring. Since the LEP also requires pre-accelerated ions for polarization measurements, the beamline is blocked for unpolarized injection into COSY while working with the LEP. Thus, in addition to saving energy and time, the usage of the LSP to optimize the beam polarization would also have the advantage of being able to conduct experiments at COSY with unpolarized beams at the same time.

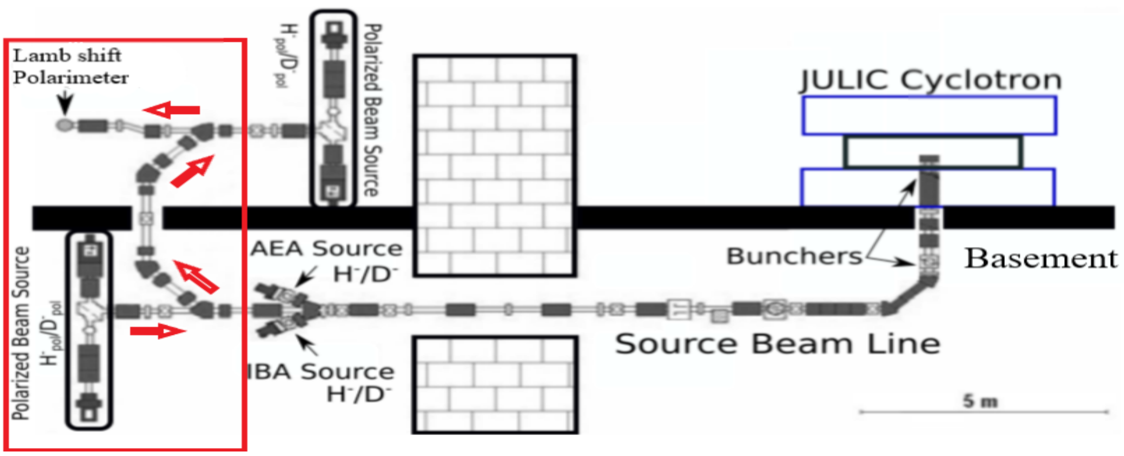

Figure 2: Beam line of the COSY source.

2.2 Lamb-shift Polarimeter

A Lamb-shift Polarimeter consists of three main devices [4]. A cesium cell in which incoming H^- ions interact with the heated cesium vapor and undergo a charge exchange process to produce metastable hydrogen atoms ($H^- + Cs \longrightarrow H_{2S_{1/2}} + Cs + e^-$). A longitudinal magnetic field preserves the nuclear spin during this reaction. In the following spinfilter, all atoms are quenched into the ground state. Only by setting certain conditions of a longitudinal magnetic field, a static electric field and a radio frequency of 1.60975 GHz it is possible to transmit certain hyperfine substates. The important parameter here is the longitudinal magnetic field that is ramped in order to decide between two substates with a different nuclear spin. In the following quenching chamber the residual metastable atoms are quenched into the ground state and the produced Lyman-α photons are detected with a photomultiplier. The spectrum in figure 3 shows the photomultiplier intensity as a function of the B-field in the spinfilter. The relative difference in the peakheights of the two possible substates visible in the spectrum is a measure of the beam polarization.

3. Results

When the source is running and all steerers and deflectors are set, the ion beam moves through the beamline into the LSP. At the end of the beamline a cup is mounted to monitor the beam intensity. With intensities of several nA it is possible to make polarization measurements. The magnetic field of the spinfilter is scanned at fixed intervals and the photomultiplier signal is measured with an oscilloscope. The source is pulsed at a frequency of 0.5 Hz, which means that a measurement can only be taken every 2 seconds. If it is necessary to measure several signals for one magnetic field value to improve the uncertainty, the measurement will take some time. Figure 3 shows two spectra measured with this procedure. In the left figure, the peak height for both hyperfine substates is almost equal for the incoming unpolarized ions. The still visible difference in peak heights can be explained with a magnetic field dependent ion background and intensity fluctuations of the source during the data taking.

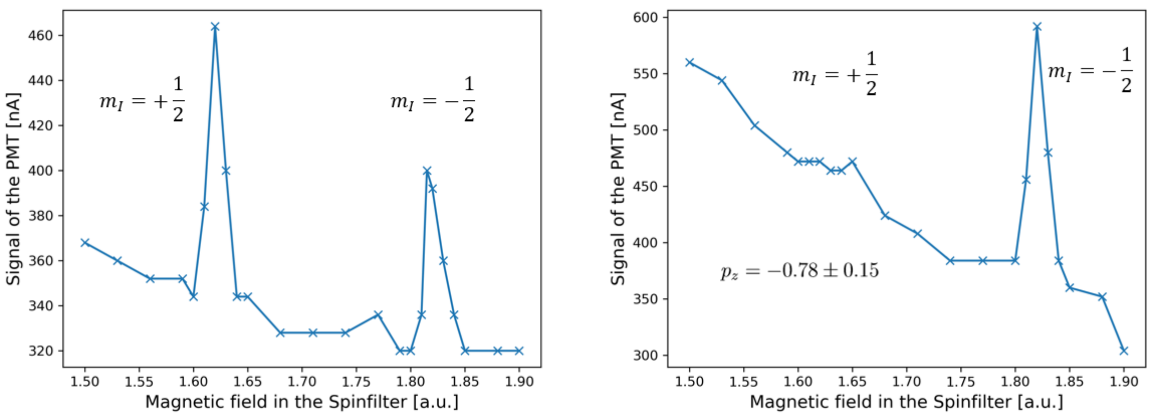

Figure 3: Hand measured spectra of polarized H^- ions. The left figure shows a spectrum of a unpolarized beam and the right figure shows the spectrum of an ion beam with negative polarization.

When a negative polarization was switched on at the source, the right spectrum was measured. It is clearly visible that more atoms with the antiparallel orientation of the proton spin are part of the beam. Due to the relation of the peak heights the polarization would be $p_z = -0.78 \pm 0.15$. The background mainly consists of residual ions. Nevertheless, the uncertainty is still very large due to small statistics, there are many options for improvements.

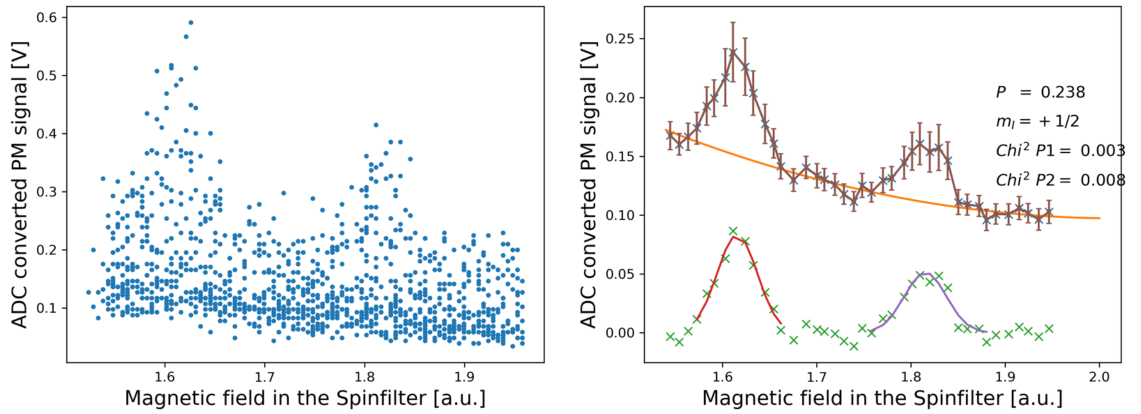

Figure 4: Automatically measured Lyman-α spectrum for positive polarization. The left plot shows the raw data whereas the right plot shows the analyzed data. Also, the gaussian fit results for the two peaks are shown.

For the spectra shown in figure 4, a new data taking method was used. The setup for this data acquisition consists of an additional computer with a software which runs a loop for the data taking and also stores the data. First, the start and end values of the magnetic field were manually specified, and with a certain step size, the software automatically ramps the magnetic field while recording multiple data points at each individual step (in this case 30 data points per step). This allows for better reproducibility and better statistics of the measurement. The left plot in figure 4 shows the raw data. After averaging the intensity values for each magnetic field, the right plot evolves. Here, the background could be fitted and substracted, which leads to the data points in the bottom part of the right plot. With a fit of a gaussian curve to the peaks, a polarization of approx. $p_z = 0.238$ was calculated. In the raw data, a broad band of measured points close to zero is visible. The reason was the limited time resolution of the ADC that was used to take the data. In further tests it was found that the ADC misses about 50 % of the signals if they are shorter than 100 ms. This explains the accumulation of data points close to zero. Since the pulsed source delivers a pulse in the order of about 50 ms, some pulses are simply missed after triggering the measurement device. For future

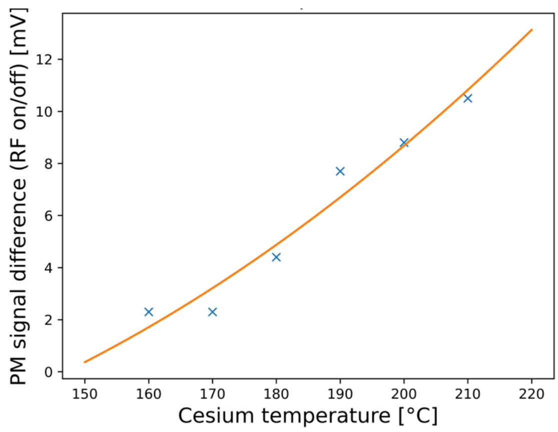

Figure 5: Cesium temperature scan.

measurements a faster ADC should be installed to record the signals more reliably.
Figure 5 shows an important graph referring to the charge exchange process in the cesium cell. Usually, the cesium cell is used for proton/deuteron beams only, thus, a helium gas storage cell was implemented in front of the LSP to strip the electrons of the negative ions. The intensity losses due to the additional device in the beamline made the measurement very difficult since only 1 nA of protons reached the LSP. Alternatively, the helium gas storage cell was removed and the negative ions directly move into the cesium cell to produce metastable atoms. The efficiency of producing metastable hydrogen atoms is very important for polarization measurements since only atoms in this excited substate live long enough to reach the quenching area for producing signals detected by the photomultiplier. Therefore, a measurement was conducted to investigate the intensity of metastable atoms in dependence of the temperature in the cesium cell. In the temperature scan in figure 5 can be seen that increasing the temperature leads to an increase of the production of the metastable atoms. Even at 210 °C there is no saturation of the intensity visible. The spectra shown in figure 4 were measured at a temperature of 160 °C as this is the optimum temperature for protons to undergo this transition. The temperature scan now provides further room for improvements in future measurements.

4. Conclusion

With this setup it is now possible to measure the polarization of pulsed H^-/D^- ion beams with an LSP. In addition, the data acquisition was automized and tested. Since the sample rate of the ADC is too small to measure the signal reliably and accurately, it should be replaced by a more useful device. One problem that was found out in the temperature scan of the cesium cell was that the temperature was not optimal. For possible future measurements, the signal height could be increased by a factor of 10 with higher temperatures.
Another physically interesting measurement would be the polarization conservation of the beam as a function of the strength of the magnetic field applied in the cesium cell. The required field strength to maintain the polarization could provide information about the charge exchange process to the metastable state itself. Naively, it is possible that during this process an outer electron is stripped off and the residual groundstate atom is excited in another collision. Maybe it could also strip one electron and in the same process excite the other one to reach the metastable state directly. Due to the different main quantum number of the $1S$ and $2S$ states, the average distances between electron and proton and thus also their interaction differ significantly. This leads to different necessary field strengths of the holding field in the cesium cell to preserve the beam polarization.

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