PROCEEDINGS OF SCIENCE

Tests of a polarimeter for laser-driven proton beams at the 45-MeV cyclotron JULIC

Chuan Zheng,[a,b,*] **Ralf Engels,**[c] **Chrysovalantis Kannis,**[c] **Olaf Felden,**[c] **Andreas Lehrach**[c] **and Markus Büscher**[a,f]

[a] *Peter Grünberg Institut (PGI-6), Forschungszentrum Jülich, D-52425 Jülich, Germany*
[b] *ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung, D-64291 Darmstadt, Germany*
[c] *Institut für Kernphysik, Forschungszentrum Jülich, D-52425 Jülich, Germany*
[f] *Institut für Laser- und Plasmaphysik, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany*

E-mail: c.zheng@fz-juelich.de, r.w.engels@fz-juelich.de

A novel method of laser-plasma acceleration employing dynamically polarized gas-jet targets (HCl/HBr gas) has been proposed to generate 100-MeV polarized proton beams. To achieve the beam polarization measurement in laser-plasma experiments at multi-Petawatt lasers, we have developed a polarimeter based on p-Carbon scattering, detected with the help of Solid-State Nuclear Track Detectors (SSNTDs), and tested it with 45 MeV polarized proton beam at JULIC. The most demanding part of the data analysis is to identify protons and carbon ions on top of large background of secondary particles. In this paper we compare the performance of the proton polarimeter based on SSNTDs to a low energy polarimeter (LEP) at JULIC, giving a first calibration of the analyzing power for the new polarimeter at 45 MeV. The polarimeter based on SSNTDs has been extended to ^{3}He ion beams and applied successfully at the PHELIX laser facility, GSI-Darmstadt.

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

*Speaker

PoS(PSTP2022)031

1. Introduction

Our group aims at the generation of laser-driven polarized particle beams from pre-polarized gas-jet targets [1]. A very first experiment, focusing on the polarization measurement of laser-accelerated protons from a yet unpolarized foil target, was carried out at the ARCturus laser facility (100 TW) of Heinrich-Heine University Düsseldorf. A polarimeter based on secondary-target scattering of the laser-accelerated few-MeV protons, detected with the help of Solid-State Nuclear Track Detectors (SSNTDs), has been used [2].

This polarimeter needs to be modified for laser-driven proton beams at PW-class lasers, e.g., the 10 PW SULF facility in Shanghai. According to PIC simulations [3], the proton energy is about 50 MeV at a laser power of 1.34 PW and 100 MeV at 5.37 PW, respectively. Assuming a 100% initial polarization of the gas-jet target, the remaining proton beam polarization is 82% and 65% at these laser powers. The beam polarization can be measured with elastic proton-carbon scattering in a thin CH_2 foil with two setups for the detection of carbon ions or protons, depicted in Figure 1.

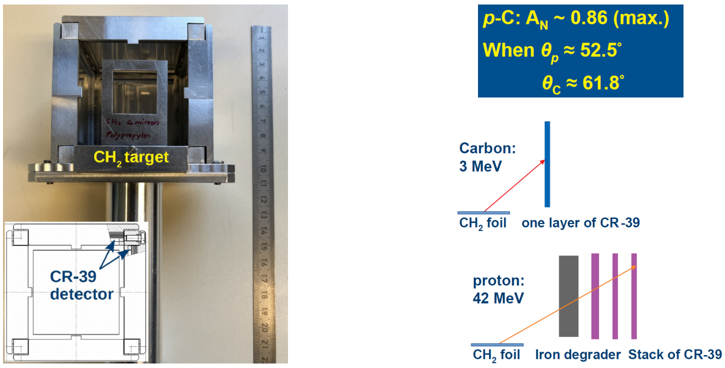

Figure 1: Polarimeter setup. (left) The polarimeter includes a CH_2 foil target and stacks of CR-39 plastic plates (Columbia Resin No. 39, a kind of plastic SSNTDs) on each side. (right) Two setups for the detection of carbon ions and protons, respectively.

2. Experimental results

The polarimeter with the two detector configurations, one for protons and the other for carbon ions, was tested in a combined set-up to make efficient use of the one-week beam time with 45 MeV polarized proton beam at JULIC. After data analysis, it is found that the proton tracks are hardly distinguishable from a large neutron-induced background. However, the carbon ions can be easily identified, leading to reasonable experimental asymmetry and consequently accurate polarization determination.

2.1 Particle detection and identification

A Geant4 simulation shows that 42-MeV protons at the polar angle of 53° can be stopped by a stack of CR-39 plates behind an iron degrader, as depicted in Figure 2 (left). Their tracks are observed on the last layer in the stack on top of a large background induced by neutrons, see Figure 2 (right). These neutrons, mostly of a few-MeV energy, are caused by the 45-MeV proton beam interacting with a 3-mm diameter aluminum aperture in front of the polarimeter. The neutrons have less effects on the very first CR-39 layer in the stack, because their tracks are actually induced by the hydrogen atoms in the CR-39 material after collisions with neutrons.

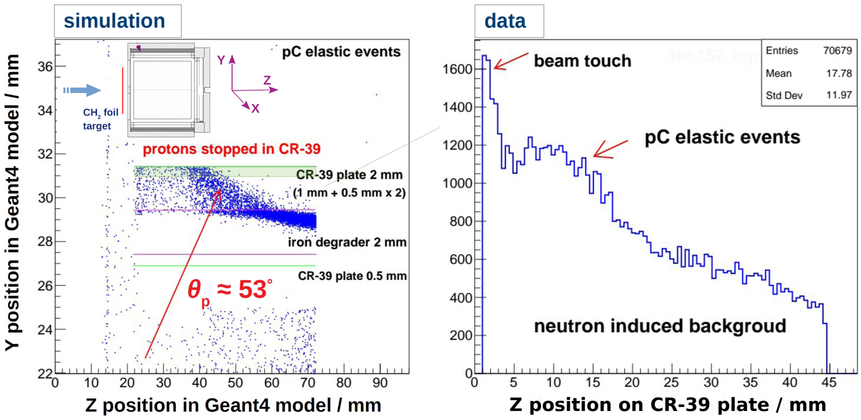

Figure 2: Detection of proton tracks with SSNTDs. (left) Geant4 simulation of the penetration depth of proton tracks in the CR-39 stack. (right) Data analysis reveals *p*-C elastic events on top of a large background induced by neutrons.

Therefore, the carbon-ion tracks can clearly be distinguished from the background using the first layer (see Figure 3), since the heavier ions with higher charge states have larger ionizing powers, which normally leads to larger track areas after etching compared to protons. Due to the small penetration depths of few-MeV carbon ions, the etching time should be reduced according to the etching rate of bulk material, and the ion tracks are scanned with a larger amplification of the microscope.

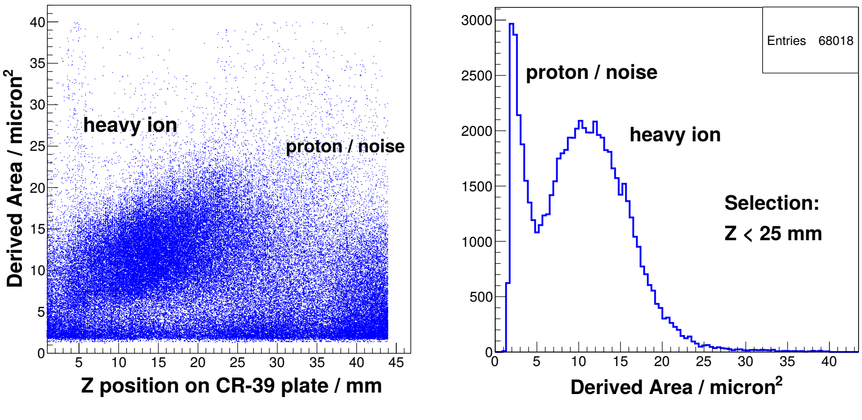

Figure 3: Particle identification of carbon ions and α particles (denoted as heavy ions). (left) 2D distribution of the measured areas of etched tracks *versus* their positions on the CR-39 plate along the Z axis. (right) 1D histogram of the areas with a selection of Z positions for background suppression.

2.2 Comparison of SSNTDs polarimeter with LEP at JULIC

When the carbon-ion tracks are selected, the polar-angle distributions of ion tracks after scattering are obtained from the track positions on the CR-39 plates and the geometry of the polarimeter setup. The deduced angular distributions (red histograms in Figure 4) show a left-right asymmetry after a measurement of 6 hours with 45-MeV polarized proton beam with an average current of 2.5 nA on the target. They are compared with a reference measurement of 6 hours (blue histograms) using unpolarized proton beams with an average current of 5 nA on the target. The experimental asymmetry, i.e., $(N_L - N_R)/(N_L + N_R)$ is calculated in the polar angle range 50–55° for carbon ions, corresponding to proton-scattering angles of 76–65°. After normalization to the reference measurement, the experimental asymmetry is determined as -0.17 ± 0.01. Here, only the statistical errors are included.

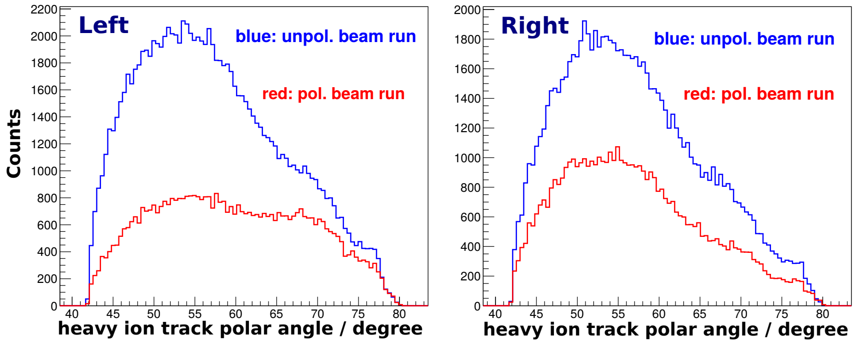

Figure 4: Angular distributions of heavy-ion tracks obtained by the polarimeter based on SSNTDs from a polarized beam run (red histograms) and an unpolarized beam run (blue histograms), respectively.

The proton-beam polarization was also measured with the low energy polarimeter at JULIC during our beam time [4]. The experimental asymmetry is obtained from *p*-C elastic-scattering events after fitting the energy spectra of protons, shown in Figure 5. The left-right asymmetry of $+0.53 \pm 0.02$ gives a beam polarization of $(62 \pm 2)\%$. The inelastic-scattering channels generate carbon ions and α particles emitted from ^{12}C excited states (see Table 1), which reduces the left-right asymmetry measured by the polarimeter based on SSNTDs.

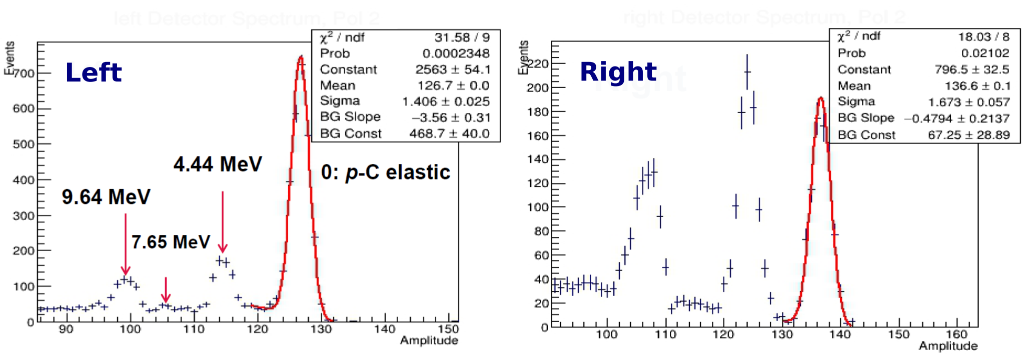

Figure 5: Proton energy spectra measured with the LEP at JULIC from a polarized beam run with the same polarization. Both elastic and inelastic *p*-C scattering are marked in the spectra.

3. Conclusion

A polarimeter based on SSNTDs for laser-accelerated protons has been tested with polarized proton beam accelerated to 45 MeV with the cyclotron JULIC. The analyzing power of the po-

Table 1: Excited states of ^{12}C from p-C inelastic scattering [5].

E_{level} (MeV)	J^P	Γ (eV)	Decay
0	0^+	stable	no
4.44	2^+	10.8×10^{-3}	$^{12}C^* \rightarrow ^{12}C + \gamma$ (% IT = 100)
7.65	0^+	9.3	$^{12}C^* \rightarrow 3\alpha$ (% $\alpha \approx 100$)
9.64	3^-	46×10^3	$^{12}C^* \rightarrow 3\alpha$ (% $\alpha \approx 100$)
			Q(3α) = -7.367 MeV

larimeter is calibrated at a beam polarization of 60% by comparison with the LEP at JULIC. The signs of the analyzing powers of the two polarimeters are opposite, since the SSNTDs polarimeter measures the asymmetry with carbon-ion tracks, whereas the LEP at JULIC uses proton spectra. The value for the analyzing power for the SSNTDs polarimeter is about one third of the latter one, which measures at the maximum value of the analyzing power (86%). If the polarimeter based on SSNTDs can be optimized to identify carbon ions from α particles, i.e., to distinguish p-C elastic scattering from inelastic scattering, the analyzing power of the polarimeter should be improved further in the future.

Our conclusion from the operation of the polarimeter based on SSNTDs is to put emphasis on the identification of ions instead of protons. This knowledge has already been applied to a polarimeter for ^{3}He ion beams from laser-plasma interactions at the PHELIX laser facility, GSI-Darmstadt [6].

Acknowledgments

We gratefully acknowledge the strong support by the COSY accelerator staff at IKP, FZJ.

References

[1] M. Büscher *et al.*, *Polarized proton beams from a laser-plasma accelerator*, Int. J. Mod. Phys. A **34**, 1942028 (2019).

[2] N. Raab *et al.*, *Polarization measurement of laser-accelerated protons*, Phys. Plasmas **21**, 023104 (2014).

[3] L. Jin *et al.*, *Spin-polarized proton beam generation from gas-jet targets by intense laser pulses*, Phys. Rev. E **102**, 011201(R) (2020).

[4] O. Felden, R. Gebel, and R. Maier, *The COSY/Jülich polarized H^- and D^- ion source*, Contribution to: **PSTP 2009**, 23-30, doi.org/10.1142/9789814324922_0003 (2011).

[5] National Nuclear Data Center, https://www.nndc.bnl.gov

[6] C. Zheng *et al.*, *Polarimetry for ^{3}He ion beams from laser-plasma interactions*, Instruments **6**, 61 (2022).