P371 Status Report

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Abstract

The P371 experiment aims to investigate whether antiprotons produced in a high-energy proton beam collision with an unpolarized solid target via the reaction are initially polarized. The polarization can be determined by measuring the asymmetry of elastic $\bar{p}p$-scattering with a known analyzing power in the Coulomb-Nuclear Interference region. The experiment was carried out in July and August 2025 using the T11 beam line in the East Area. Data analysis is currently ongoing.

1 Introduction

The preparation of a polarized antiproton beam, useful for experiments exploring new physics topics remains a significant challenge. No efficient polarization method has yet been established for long-term measurement campaigns. A simple and attractive possibility would be if the antiproton production process itself yields a significant degree of polarization.

To test this hypothesis, a dedicated polarization measurement of the antiproton beam is proposed. Assuming an analyzing power of approximately 4.5% which is expected at the CNI (Coulomb Nuclear Interference) region of the antiproton-proton elastic scattering, the polarization can be detected by measuring the left-right asymmetry of the elastic events at scattering angle around 10 mrad using a 3.5 GeV/c antiproton beam. The concept of the measurement is to use a liquid hydrogen target as an analyzer with incident and scattered particle tracks reconstructed using tracking detectors upstream and downstream of the target. Scattered antiprotons can then be identified and distinguished from background (mainly charged pions) by a DIRC system for offline particle identification.

A first proposal for the investigation of possible polarization effects in the production process of antiprotons was submitted to the SPSC in 2014 [1]. Initial measurements were performed but the collected statistics was far too low to extract any information. With an improved detector setup and extended beam time can now be achieved to determine whether antiproton polarization exists at production to a measurable degree.

A new beam time request has been submitted to the SPSC in October 2024. This status report will briefly summarize the main activities in the past year, such as the preparation of the beam time, conduction of the beam time as well as the data analysis.

2 Experiment Setup

A sketch of the detector arrangement is shown in Figure 1. The setup includes scintillators for trigger generation, a threshold Cherenkov detector for online pion suppression, scintillating fiber detectors, a liquid hydgrogen analyzer target, straw-tube trackers and a DIRC detector for offline particle identification.
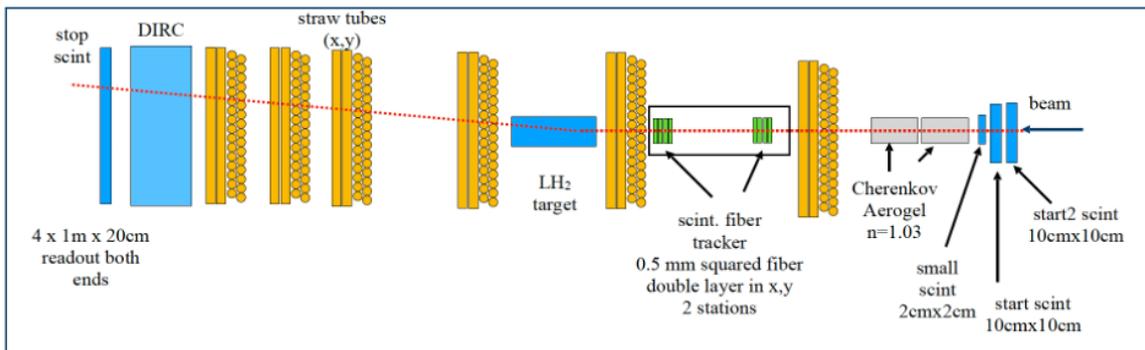

Figure 1: Sketch of the P371 detection system for the beam time.

The analyzer target is a 12 cm long liquid hydrogen cell with a diameter of 6.5 cm placed inside a vacuum chamber and cooled by a cryogenic cold head to 20 K. Kapton foils are used for the target cell and vacuum chamber windows. The entire system operates in air. Multiple scattering in materials between the beamline exit window and the first tracking detector, as well as in air and detector components, contribute less than 1 mrad to angular straggling. The angular resolution of the scintillating fiber system is 1 mrad, while the straw-tube trackers achieve a track resolution of below 0.5 mrad.

Each scintillating fiber station consists of two closely spaced layers (0.4m apart) with 0.5 mm thick squared fibers, shifted by half a fiber diameter to eliminate dead zones. The straw tubes (10 mm

diameter) are operated with an Ar(90%)/CO2(10%) mixture at 1 bar overpressure, yielding a position resolution of 100 - 150 μm via drift-time measurement.

A threshold aerogel Cherenkov detector (n $\sim$ 1.03) strongly suppresses the dominant pion background by generating a veto signal for the trigger. At 3.5 GeV/c, antiprotons have a velocity of β(p(3.5 GeV/c)) = 0.966 , i.e. the threshold for Cherenkov light emission is at n = 1.035. For pions, the velocity is close to c ($\beta(\pi$(3.5 GeV/c)) = 0.9992) with a threshold refractive index of n = 1.0008. Therefore, pions produce Cherenkov light, while antiprotons do not, enabling efficient online vetoing.

The DIRC detector with a Plexiglas radiator [3] is used for offline particle identification. Cherenkov arcs from pions and antiprotons are detected by a PMT matrix. Behind the DIRC a scintillator wall with four 20 cm wide paddles, readout on both ends has been placed to trigger on single track events.

A new data acquisition system, DOGMA [4], was used for the first time in this experiment. The DOGMA is a modularized DAQ board, which offers 32 channels input and consists of an integrated amplifier with a maximum gain of 30, discriminator and TDC. The board has optical fiber control and data transfer, eliminating potential grounding problems which often occurs for DAQ system. Despite still under development, lab tests confirmed its suitability for the beam time.

3   Activities in 2025

In addition to constructing new detectors and upgrading the DIRC readout, a verification test for the new aerogel Cherenkov detectors was performed from 27-30 May in the T10 area.

The full experiment integration and production beam time took place from early July to the end of August 2025 in the T11 area of the PS East Hall.

3.1   Cherenkov Detector Test at T10

In order to achieve a reasonable reduction of the trigger rate for the beam test, two new Cherenkov detectors with an aerogel with a refractive index of n=1.03 have been designed, built and tested with cosmic rays at the lab in Forschungszentrum Juelich. As the Cherenkov detector has shown good efficiency on cosmic rays, their pion veto performance was validated using time-of-flight (ToF) measurements in the T10 beamline in May 2025.

Figure 2: Cherenkov detector test at T10.

Benefiting from the low n-index of 1.03, the threshold of the Cherenkov light for a passing proton or antiproton is about 3.8 GeV/c, while the threshold of the Cherenkov light for pions or muons are 565 MeV/c and 428 MeV/c, respectively. The beam particles contain pions, muons, electrons/positrons,

protons or antiprotons, depending on the setting of the beam line either for positively or negatively charged particles.

The Figure 2, shows the two Cherenkov detectors located on the movable detector platform. The start timing detector was the scintillator detector in the T10 beam line, while the stop timing detector was a fast plastic scintillator bar detector located at the end of the beam path in the T10 area. The flight distance was roughly 18.5 m between the two timing detectors.

With a 2 GeV/c positive beam, protons were clearly separated from lighter particles (ΔTOF $\approx$ 6 ns). The two Cherenkov detectors reduced the trigger rate by a factor of about 100 as depicted in Figure 3a and b.
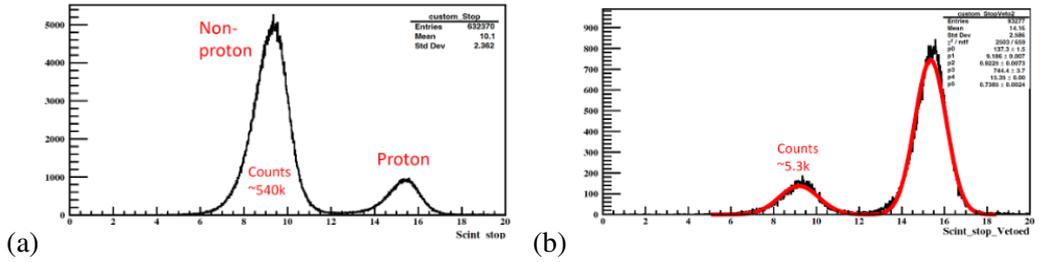

Figure 3: TOF spectra of the beam particles at 2 GeV/c without (a) and with (b) Cherenkov veto.

For a 3.5 GeV/c negative beam the ΔTOF of antiprotons and non-antiprotons is about 2 ns. Due to the low fraction of antiprotons in the beam as well as the small ΔTOF value the antiprotons peak is partially mixed with other particles as indicated in Figure 4a. The separation between antiprotons and non-antiprotons is not feasible. After having implemented the offline veto by two Cherenkov detectors, a shoulder-like peak emerged at the right side of the TOF spectrum while a reduction factor of 70 has been achieved. After subtraction of the non-antiprotons content in the TOF spectra, the antiprotons peaks can be separated from the residuals of the non-antiproton particles as shown in the Figure 5a. By integrating the antiprotons in the time window presented in Figure 5b, the fraction of the antiprotons in the beam particles at 3.5 GeV/c is 0.25%, which is lower than the previous measurement with a fraction of 0.85% for the antiprotons at 4 GeV/c [2].
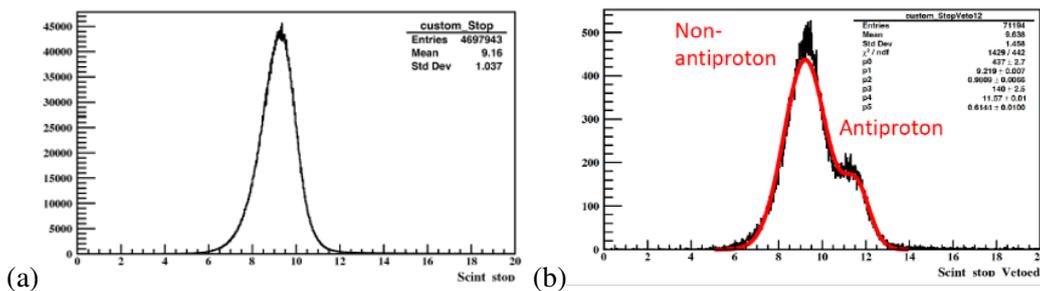

Figure 4: TOF spectra of the negative charged beam particles at 3.5 GeV/c without (a) and with (b) Cherenkov veto.

The convincing results confirmed the effectiveness of the Cherenkov veto system for the upcoming beam time at T11.

3.2 Experiment Setup Integration and Production Beam Time at T11

The main objective was to transport the pre-assembled detector system to the T11 area and complete the measurement on schedule. There were two phases of the beam time campaign, i.e., experiment setup integration and production beam time.
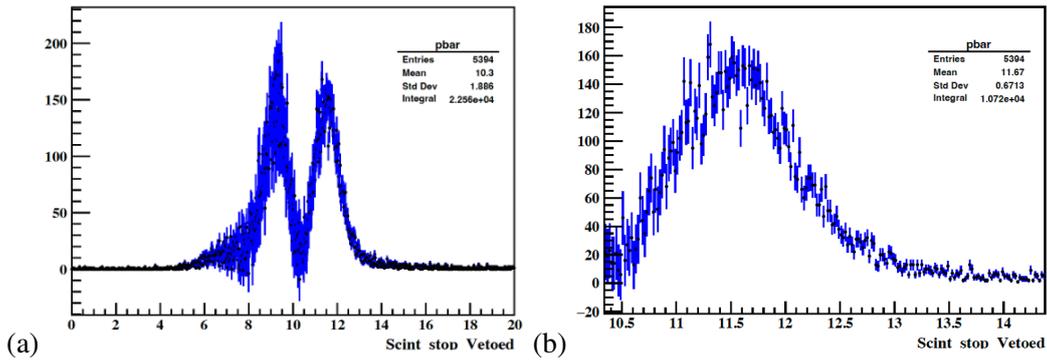
Figure 5: TOF spectra after subtraction of non-antiprotons (a) and the antiprotons peak (b).

3.2.1 Experiment Setup Integration

The experiment setup integration started at T11 with few days behind the schedule due to a delay in the transportation of the equipment. As seen in the Figure 6, all sub-detectors are modularized and preinstalled on an Aluminum platform.
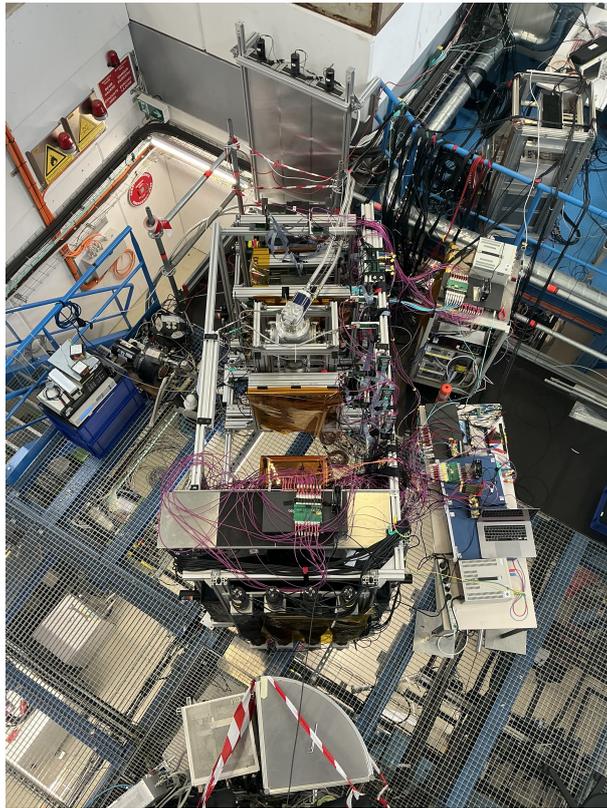

Figure 6: A picture taken from the top of the CLOUD chamber is shown. The detectors frame with the visible cold head of the target, as well as the supporting elements, like the target control and pump (on the left), the DAQ switches and power supply (on the table to the right) and the rack for the high voltage system and trigger logic (on the blue platform) is visible.

The integration work consisted of not only cabling all the signal channels or high voltage supplies but also the detector readout to data acquisition system. One major challenge of the integration was to tune each detector together with DOGMA system since it was the first time to use it for such an

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experiment. Despite the first-time integration challenges, such as wrong cabling, detector noise, missing channels and so on, commissioning took several days and proceeded smoothly. The platform was aligned to the beam axis with an electrical motor for height adjustment while the move in horizontal direction was done manually. The alignment work has been done together with the commissioning of the tracking detectors.

The liquid hydrogen target was generated right after the experiment setup alignment. The complete process of target generation including the pumping time of the target chamber, cool down the target cell as well as liquefying the hydrogen gas was about 10 hours. The whole process is under local as well as remote control, the filling process is being monitored via optical tools. As estimated the target cell was filled by 90% of its volume. The Figure 7 shows the filling level of the target cell during the generation period at half of the filling time.

Figure 7: A picture of the target cell during the filling process is shown. The level of the the liquid hydrogen is clearly visible at half the cell height as well as bubbles rising from the bottom.

3.2.2   Detector Performance

• Straw tracker

The straw tracker detector has been put before and behind the lH$_2$ target to provide either the primary tracking of the beam particles or the tracking of particles passing through the liquid hydrogen target. Each station of the straw tracker consists of 32 straws in X and Y coordinates and provides the beam profile directly. Figure8 presents the beam profiles on three sequential straw stations, which has a gap of 20 cm between two adjacent stations.
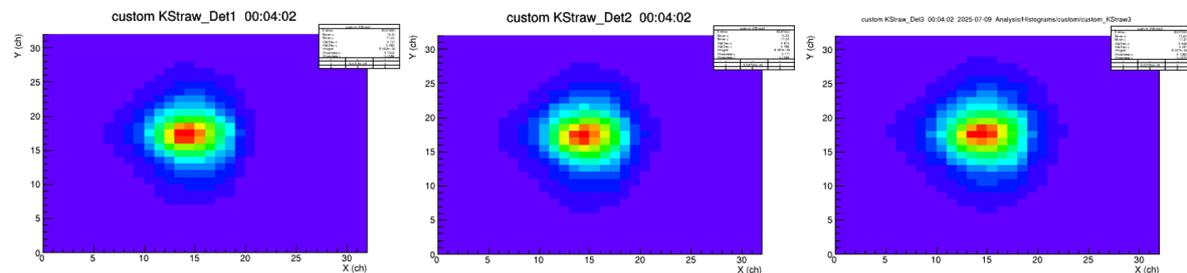

Figure 8: Beam profile on 3 straw stations.

The beam direction is from the left to the right of three beam profiles. As expected the beam profile is also slightly getting bigger due to the beam emittance as well as the beam particle scattered with target or other material.

• Fiber detector

The fiber tracker was newly built. The squared scintillating fibers are 0.5 mm thick and are arranged in horizontal and vertical direction. Each direction of the fiber station employed two layers of scintillating fibers with a half size (0.25 mm) shift with each other, in order to have no dead area for the direction. A 64-fold pixel PMT has been used to readout one of the layers of scintillating fiber, which contains 64 fibers and covers 32 mm effectively in X or Y direction. Two fiber trackers have been installed in front of the liquid hydrogen target to measure the track of the primary beam particles. Figure 9a and b show the beam profiles on two fiber tracker stations respectively.
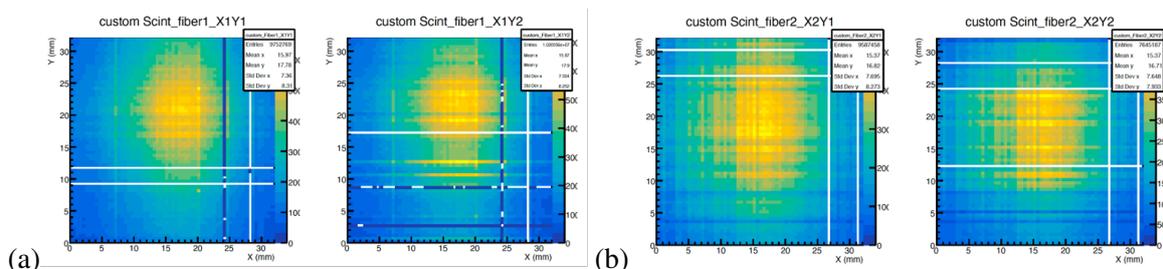

Figure 9: Beam profile on Fiber 1 and Fiber 2.

• DIRC

The role of DIRC detector in the setup is to identify different incident particles, here mainly antiprotons and charged pions. The working principle of the DIRC is that the antiprotons and charged pions with the same beam momentum will produce different Cherenkov arcs that will be observed by the PMTs at different position on the readout window. The Figure 10 shows an arc distribution of all of the readout pixels from left to right in beam direction. Constrained by the big beam spot, the arc contributed by antiprotons and charged pions can't be separated directly. It is noticed that the tracking information is required to determine the entry position of the particle, producing the Cherenkov light in order to separate different incident particles.
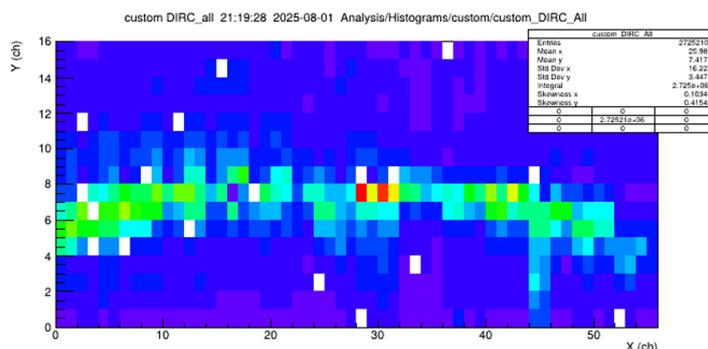

Figure 10: Hit distribution of the DIRC PMT-matix for an event sample.

The achievable $\pi^-/\bar{p}$ separation can be seen in Fig.11 generated from data of a former measurement performed in 2015 with a better focused beam.

• Scintillators

Plastic scintillators with different dimensions have been employed for the beam time. For instance, a 2x2 cm small scintillator serves as the start detector for trigger while big scintillator paddles (100x20 cm) are the stop detector. Cooperating with the scintillator detector in the beam line, a TOF measurement with
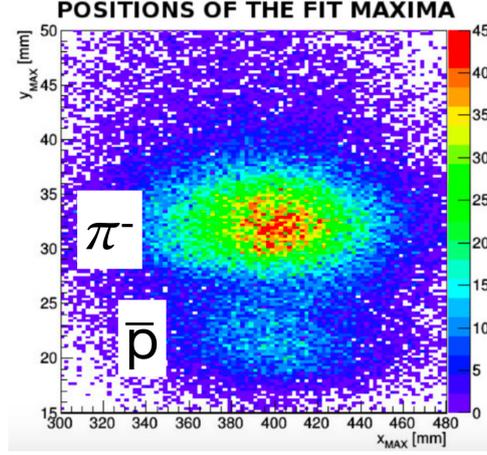
Figure 11: Distribution of Cherenkov arc maxima from data taken in a measurement in 2015.

8.6 m flight distance can be performed for the beam particles. To check the beam condition and the setup one TOF measurement has been done with beam momentum at 1 GeV/c for positive beam. Figure 12 shows the TOF spectra of the beam particles. The proton peak located at the right of the plot is clearly separated with non-proton particles with a ΔTOF of ≈ 10 ns.
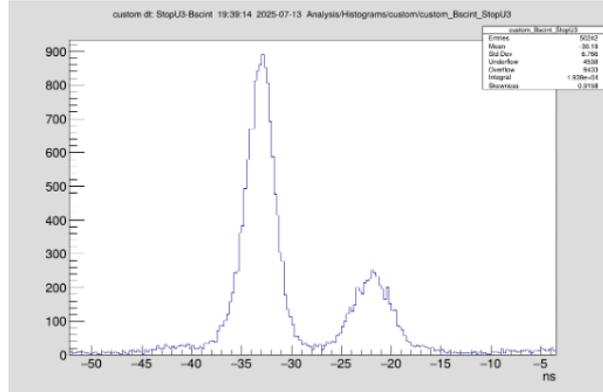

Figure 12: TOF spectrum at 1 GeV/c with flight distance of ≈ 8.6 m.

3.2.3 Measurements and Statistics

The beam time was completed successfully as scheduled. The liquid hydrogen target remained stable during the entire beam time. Due to the condensation on the Kapton window of the target cell, the target was regenerated once by heating up to room temperature to empty the target cell and evaporate the condensate at the Kapton foils and refill after cooling to 20 K. The particle rate measured with the scintillator in the beam line was at about $1.2 \cdot 10^6$ particles/spill with a spill length of about 400 ms and our trigger rate without Cherenkov veto was about $1.1 \cdot 10^6$ particles/spill. It means that the detection system was quite well adjusted that nearly all beam particles pass through the system. With the online Cherenkov veto, the trigger rate was roughly 10 to 15 kHz. Approximately 30 TB of data with -3.5 GeV/c beam were recorded. Figure 13a demonstrates the beam spills versus the day of the beam time while the Figure 13b shows the integrated beam spills which reached about 75% of the proposed spills for the beam time. In the proposal of the P371 experiment the estimated number of spills required to achieve the aimed statistics amounts to 225000. This corresponds to a number of about $1.6 \cdot 10^6$ scattering events in the angular range relevant for the polarization determination which is based on the assumed number of 8000

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antiprotons/spill. According to GEANT4 simulation studies, with this number of events a polarization of 12% can be measured with a confidence level of 5σ and aiming for a confidence level of 3σ a polarization of 7% is measurable. If the event number is reduced by a factor 2 the measurable level of polarization is reduced by a factor $\sqrt{2}$. For a required confidence level of 3σ a reduction of the statistics by a factor 2 will reduce the measurable polarization from 7% to 10% and for a reduction of the statistics by a factor 4 the measurable polarization is reduced to 14%.

During the measurement the detector components were monitored by online spectra of hit distributions. For further checks of the performance of the detection system some data have been taken for various momenta between 1.0 and 3.0 GeV/c with steps of 0.5 GeV/c for positively and negatively charged particles. At the end of the beam time an empty target measurement was performed for about 10 hours.
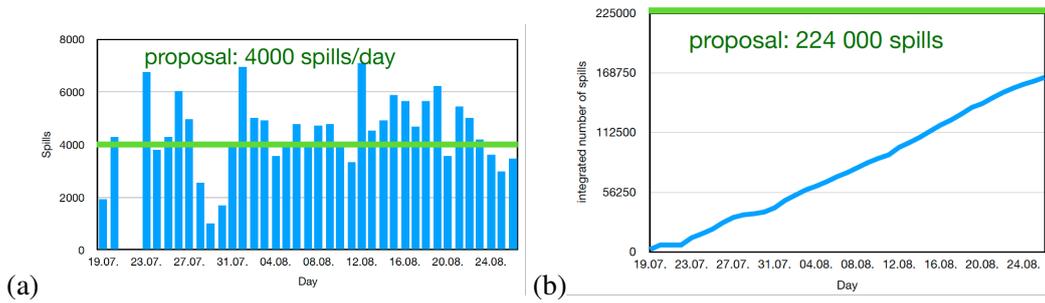

Figure 13: Spills received during the beam time with a) spills per day, b) total number of spills over time. Days without or with few spills might be due to down time of the PS, reference measurement with different momentum, access to the area etc.

4 Status and Outlook

The data analysis for the obtained data is still ongoing, however no estimate about the number of antiprotons can be given so far. One main challenge is robust particle identification using the DIRC, which is complicated by the large beam spot and small angular separation between pion and antiproton Cherenkov rings. A simple global fit is insufficient, therefore event-by-event reconstruction incorporating tracking information is being implemented.

Once reliable particle identification is achieved, the total antiproton statistics can be estimated. Given that only 75% of the proposed spills were received and the antiproton rate per spill seems to be approximately four times lower than anticipated (based on T10 measurements), additonal beam time in 2026 may be required in order to reach the statistics needed for a conclusive polarization measurement.

In preparation for a potential additional beam time in 2026, several upgrades and optimizations are foreseen to increase the efficiency, improve particle identification, and achieve the required statistical precision:

– **Improved beam monitoring and particle identification**
   The existing beam line scintillators showed limited time resolution. It is proposed to install a new, fast scintillator in the T11 beamline to provide accurate starting time, enabling reliable time-of-flight (TOF) measurement, which might enable PID potential.

– **Replacement of the straw-tube trackers**
   Some straw tubes in the present system suffered from missing or inefficient channels. This was not a problem during the beam time because due to the large area of the straw tube package the units could be moved to a region with working straw tubes. These not working straw tubes will be exchanged.

– **Investigation of high DIRC hit multiplicity**
The DIRC detector exhibited high hit occupancy during the 2025 run. Detailed studies are ongoing to determine whether this is an intrinsic feature of the secondary beam (e.g., halo, δ-ray) or originates from detector noise or cross talk. Appropriate shielding, readout adjustments, or electronics upgrades will be implemented as needed.

– **New scintillator system for trigger generation**
Replacement and upgrade of the trigger scintillators, several of which were damaged during transport back to Jülich with new scintillator detectors is planned.

– **Enhanced platform mechanics for faster alignment**
The current detector platform has motorized vertical movement and manual horizontal adjustment. The support structure might be upgraded with motorized actuators in both transverse directions or employing extra base under the bottom of the current frame, which will reduce the alignment time and allow rapid optimization of the setup with respect to the beam axis.

Acknowledgements

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