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Direct detection of antiprotons with the Timepix3 in a new electrostatic selection beamline

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A B S T R A C T

We present here the first results obtained employing the Timepix3 for the detection and tagging of annihilations of low energy antiprotons. The Timepix3 is a recently developed hybrid pixel detector with advanced Time-of-Arrival and Time-over-Threshold capabilities and has the potential of allowing precise kinetic energy measurements of low energy charged particles from their time of flight. The tagging of the characteristic antiproton annihilation signature, already studied by our group, is enabled by the high spatial and energy resolution of this detector. In this study we have used a new, dedicated, energy selection beamline (GRACE). The line is symbiotic to the AEgIS experiment at the CERN Antiproton Decelerator and is dedicated to detector tests and possibly antiproton physics experiments. We show how the high resolution of the Timepix3 on the Time-of-Arrival and Time-over-Threshold information allows for a precise 3D reconstruction of the annihilation prongs. The presented results point at the potential use of the Timepix3 in antimatter-research experiments where a precise and unambiguous tagging of antiproton annihilations is required.

1. Introduction

Antimatter experiments often make use of annihilation detectors, i.e. detectors dedicated to spatially and temporally resolve an annihilation event by the detection of annihilation products.

To date, tracking detectors have always been employed to detect remote annihilations, i.e. annihilations happening at a distance from the detector planes. This allows to have the antimatter interactions happening in a separate environment from where the detector is located, thus relaxing the constraints on environmental parameters (mainly pressure and temperature) for the detector operation.

In the AEgIS experiment [1,2] at the CERN Antiproton Decelerator (AD) [3], a silicon strip detector will be used for the first time as a direct annihilation detector. The detector will provide preliminary position information along with Time-of-Arrival (ToA) of a collimated antihydrogen beam, annihilating on the detector surface. Submicron-resolution will be then provided by a downstream emulsion detector, that will tag and reconstruct the single annihilation vertices, to be matched with single hits measured on the strip detector. The position information will be used to measure the small deflection from a straight path of a free-falling antihydrogen beam. This deflection is expected to be in the order of 20 μm.

Along with the development of the strip detector, in its final stages, we are currently investigating ToA-capable thick pixel detectors, which could provide a stand-alone solution for antimatter detection and tagging in scenarios with more relaxed position resolution requirements.

In the following sections we will present the results obtained using the Timepix3 readout ASIC (Application Specific Integrated Circuit) and a relatively thick silicon pixel sensor. The tests were aimed at validating for the first time a new slow antiproton extraction line (GRACE), that will be dedicated to detector test and interferometry study. The beamline employs electrostatic optics and is able to select antiprotons of ~keV energy. We further demonstrate the potential shown by the Timepix3 in its use as a direct-annihilation detector. These results complement previous works published by our group, employing different sensor technologies [4–6].

2. Antiproton annihilation physics

When antiprotons come to rest in $Z>1$ materials, they annihilate with a proton or a neutron of the atoms composing the material. The direct products of this annihilation are mesons (pions and kaons), resulting from a rearrangement of the quarks composing the antiproton and the proton or neutron. As some of these pions cross through the now destabilized nucleus, nuclear fragmentation may occur with the further production of heavy charged particles. The total energy available in an annihilation event (to be distributed between the pions' mass and the kinetic energies of the annihilation products) is given by the mass-to-energy equivalence of the antiproton and proton (or neutron) taking part in the annihilation (~2 GeV). Hence the energy of the products is usually in the order of few $\cdot 10^2$ MeV. A more detailed description of the process, together with estimated multiplicities of the different annihilation products in silicon, is provided in [4].

3. Experimental setup

3.1. The Timepix3

The Timepix3 is a data-driven hybrid pixel readout ASIC developed in the context of the Medipix3 collaboration [7]. The ASIC provides a readout matrix of 256×256 pixels, spaced by a pitch of 55 μm. A dynamic range of at least 4–500 keV per pixel can be achieved. Each pixel is equipped with its own preamplifier with a peaking time which is tuneable around a default value of 25 ns. The ASIC is able to measure simultaneously the Time-over-Threshold (ToT) and Time-of-Arrival (ToA) for pulses of charge detected at each pixel. The accuracy on the ToA is 1.58 ns.

We present here the results obtained using a 675 μm thick sensor. The sensor, manufactured with p-readout, n-bulk technology was produced and bump-bonded by ADVACAM (Finland) [8]. The depletion voltage for the sensor was 200 V. We operated the sensor at a voltage of 350 V throughout the measurements presented here. A photo of the Timepix3, as implemented in our setup, is provided in Fig. 1.

3.2. The GRACE beamline

The purpose of the GRACE beamline is to provide slow antiprotons of known energies, while minimizing the background produced by the annihilations of faster antiprotons. The AD delivers antiprotons in bunches of $3\cdot 10^7$ particles at an energy of 5.3 MeV. The bunches are delivered with a slightly variable repetition rate in the order of ~100 s. In order to slow the antiprotons down to energies of a few keV thin foil moderators are used. In our case, the AD beamline is terminated with a 50 μm thick titanium vacuum separation foil. The GRACE entrance window is located downstream of the AD window, after a ~40 mm air grap. The entrance window is made of 25 μm thick Ti foil. Taking into account the attenuation power of the air gap, a further 46 μm