Nuclear Instruments and Methods in Physics Research A 765 (2014) 161–166

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Investigation of silicon sensors for their use as antiproton annihilation detectors

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ARTICLE INFO

Available online 19 June 2014

Keywords:
Silicon
Antiprotons
Detector

ABSTRACT

We present here a new application of silicon sensors aimed at the direct detection of antinucleons annihilations taking place inside the sensor's volume. Such detectors are interesting particularly for the measurement of antimatter properties and will be used as part of the gravity measurement module in the AEg̅IS experiment at the CERN Antiproton Decelerator. One of the goals of the AEg̅IS experiment is to measure the gravitational acceleration of antihydrogen with 1% precision. Three different silicon sensor

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http://dx.doi.org/10.1016/j.nima.2014.06.036

AEgIS
Strip
Pixel

geometries have been tested with an antiproton beam to investigate their properties as annihilation detection devices: strip planar, 3D pixels and monolithic pixel planar. In all cases we were successfully detecting annihilations taking place in the sensor and we were able to make a first characterization of the clusters and tracks.

1. Introduction

The goal of the AEḡIS experiment [1] located at the CERN Antiproton Decelerator (AD) [2] is to make the first measurement of the acceleration of antimatter in the Earth's gravitational field. AEḡIS will also be the first experiment to use a segmented silicon sensor as part of a hybrid position sensitive detector, the *Gravity Module*, to directly detect the annihilation position of cold antihydrogen atoms. After the production and acceleration of a pulsed beam of antihydrogen atoms upstream in the apparatus (100 mK), the antihydrogen atoms pass through a moiré deflectometer [3] producing a fringe pattern on the annihilation plane: the segmented silicon detector (see Fig. 1) provides TOF information and a first position resolution of ~7–8 μm. The annihilation products will travel on and leave tracks in the emulsion detector [4] that will provide high resolution (1–2 μm) position reconstruction. A scintillating fiber tracker located behind the emulsion detector (not shown in Fig. 1) will also provide 3D online information on the antihydrogen annihilation vertex and on the TOF. Together this hybrid position detector will achieve a resolution of 1% on the gravitational acceleration of antihydrogen with 600 events [4].

This is the first adaptation of a silicon detector for direct measurement of antimatter annihilation. Previous works [5] report the use of silicon as an active annihilation target, but no position resolution was provided in that case. We present new results on the annihilation detection capabilities of three different types of silicon detectors:

- planar strip;
- 3D pixels;
- monolithic planar pixel.

The analysis and the comparison of the results obtained with the different geometries will be presented in Section 4.

2. Silicon as an annihilation detector

When antihydrogen approaches matter, the positron annihilates with an electron, generating 2 × 511 keV photons – towards which silicon tracking sensors have no sensitivity. For this reason, once ensured , the annihilation of antiprotons can be deemed to be equivalent to annihilation of antihydrogen atoms. The distinction between antihydrogen and antiprotons has to be ensured independently (in our case through discrimination of the flight times).

When an antiproton annihilates with a nucleon from a silicon atom, the primary products of annihilation are the charged and neutral pions. Charged pions are emitted with an average multiplicity of 1.53 ± 0.03 pions per charge sign [6]. One of the pions can interact with the nucleus, fragmenting it. Fragments are then emitted with kinetic energies in the order of tens to hundreds of MeV [6]. Detection of primary charged pions and of charged fragments can be used as a signature of an annihilation event. Detectable annihilation products can be emitted within a wide range of multiplicities and kinetic energies [6]. The upper limit for the kinetic energy of annihilation products is set by the total energy released by the annihilation of a nucleon and an antinucleon (~1880 MeV). Some of the products (protons, pions) can have a travel range in excess of several millimeters, resulting in the production of charge clusters which can spread as well over several millimeters. A proper understanding of the annihilation signature is thus necessary in order to identify the real annihilation point.

We performed Geant4 simulations on single annihilation events in silicon, using the Fritjof-Precompound physics list as included in Geant4 (version 4.9.5) [7]. Fig. 2 shows the simulated distribution of the most important annihilation products in silicon. Among the charged products, keeping in mind the maximum total energy released in an annihilation event, one can predict (for example using a tool like SRIM [8]) that heavy nuclear fragments will be responsible for high and localized energy depositions. Lighter fragments and pions, with longer stopping ranges, are able

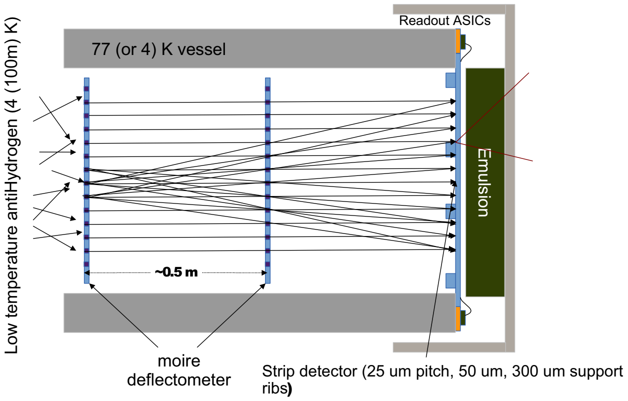

Fig. 1. The gravitational measurement with the *Gravity Module*, as proposed in AEḡIS: A moiré deflectometer produces a fringe pattern on the silicon detector where the antihydrogen atoms annihilate. Behind there is a high resolution emulsion detector for reconstruction of the annihilation products.

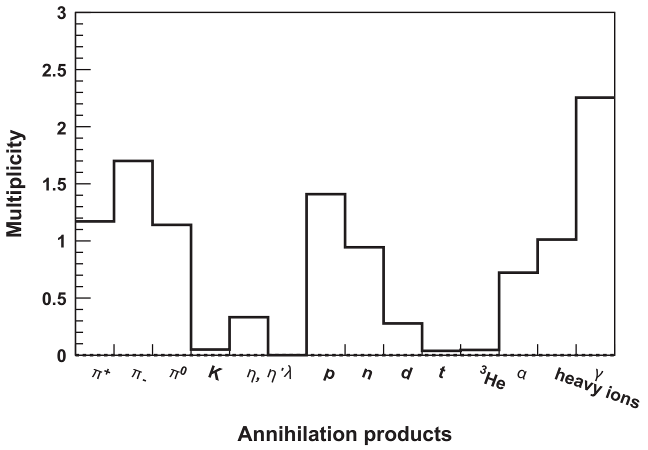

Fig. 2. Average multiplicity of the different products for the annihilation of a single antiproton on a silicon atom as simulated in Geant4 with the Fritjof-Precompound physics list.