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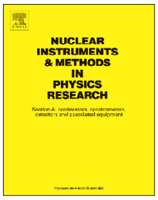

Silicon vertex detector upgrade in the ALPHA experiment

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ABSTRACT

The Silicon Vertex Detector (SVD) is the main diagnostic tool in the ALPHA-experiment. It provides precise spatial and timing information of antiproton (antihydrogen) annihilation events (vertices), and most importantly, the SVD is capable of directly identifying and analysing single annihilation events, thereby forming the basis of ALPHA's analysis. This paper describes the ALPHA SVD and its upgrade, installed in the ALPHA's new neutral atom trap.

1. Introduction

The ALPHA experiment is dedicated for studying antihydrogen. ALPHA routinely traps cold antihydrogen in a neutral atom trap [1], achieving trapping times up to 1000 s [2,3]. More recently the ability to perform spectroscopic measurements on antihydrogen was demonstrated [4]. The ultimate goal of the experiment is to perform precise laser spectroscopy on antihydrogen. A Silicon Vertex Detector (SVD) is placed around the neutral trap of the ALPHA experiment. The detector is sensitive to the annihilation products of antihydrogen, namely pions from antiproton annihilation. The pions escape the trap and their tracks can be traced back to their point of origin. The detector enables spatial annihilation vertex track reconstruction, essential for the ALPHA physics programme [5]. The apparatus has recently been upgraded to facilitate the capability for improved trapping and innovative techniques of spectroscopy including lasers. This paper discusses the performance and role of the SVD. Upgrades made to the SVD are described.

2. Module survey

During the maintenance cycle the detector has been transported from its operational location at CERN to the University of

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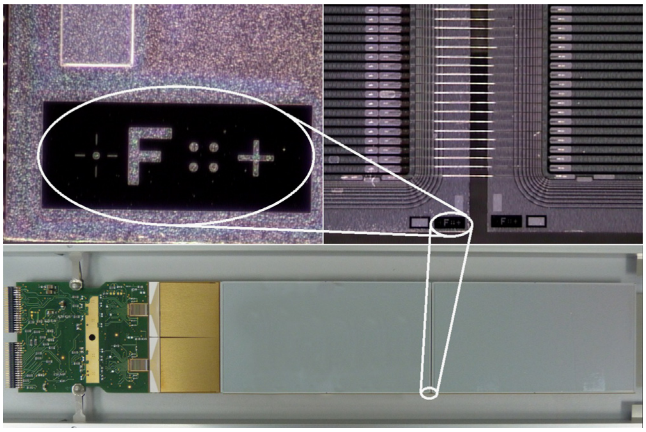

Fig. 1. The ALPHA hybrid as seen from the silicon p-side, which faces the centre of a neutral trap (bottom). The two sensors are wire bonded to connect the p-side strips (upper right). Example: marker used to determine the silicon sensor alignment (upper left).

Liverpool Semiconductor Centre for maintenance. A new procedure to measure the alignment and position of the silicon sensors on the hybrid module was implemented. Using a precise 3D optical microscope, the positions of the three mount points of the hybrid module and the six alignment points for the individual silicon modules were found and recorded for each module (Fig. 1). The measurement precision was found to be 2.5 μm. The vertical and horizontal silicon sensor mechanical alignment accuracy was identified to be 15 and 32 μm respectively, due to the sensor assembly process.

This displacement of the silicon sensor from the specified design is very small and within tolerance. Given that the strip width along the horizontal and vertical axes are 875 μm and 227 μm respectively, the corrections are small proportion of the strip width. This data will be used to modify reconstruction methods of the detector for greater vertex accuracy. This is not expected to be a major correction and the exact effect on the upgraded detector has not been deduced due to lack of experimental annihilation data.

3. Upgrade to new detector geometry

3.1. *Original and upgraded detector design overview*

The original and upgraded detectors have identical roles in the ALPHA experiment, to identify and analyse the single annihilation events during the experimental procedure. Tight geometrical constrains meant a design which had to fit into a compact space. The ALPHA neutral atom trap, around which the SVD is installed, limits the inner radius, and a solenoid magnet used for the Penning trap limits the outer radius. The original SVD was constructed of 3 barrel layers in two halves, consisting of 8, 10, and 12 independent hybrid modules in the inner, middle and outer layers respectively. The upgraded geometry has been constrained further by new hardware introduced to the ALPHA apparatus upgrade. The inner bore radius has increased with a new neutral atom trap, and the outer bore has also increased with the introduction of a new Penning trap magnet. A comparison of the module layout for the detector is shown in Fig. 2 with the layer radii summarized in Table 1. Given the geometrical constrains, the upgraded detector resembles the design of the original, again consisting of 3 barrel layers in two halves, but now with 10, 12 and 14 independent hybrid modules on the inner, middle and outer layers respectively. The hybrid modules are arranged around the beam pipe, with each layer staggered, improving solid angle coverage for particles travelling from the trapping region of the experiment. The upgrade covers a solid angle of 77% at the very centre of the trap for track candidates travelling in a straight line interacting at least once with the active area of each layer. (72% for the original design). The improvement is due to the staggering of the layers.

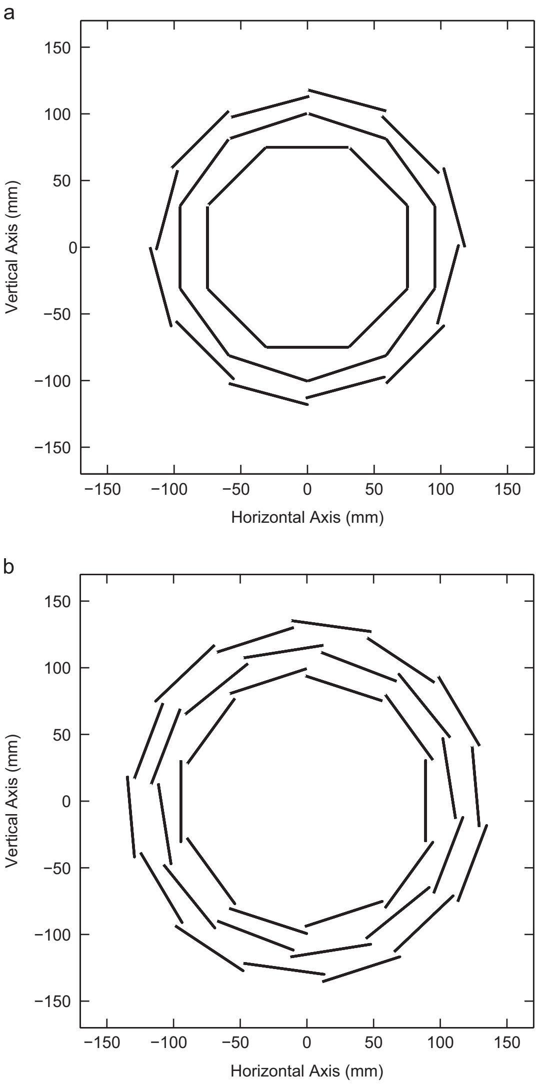

Fig. 2. The original module configuration (upper diagram) versus the upgraded detector (lower diagram). The number of modules was increased from 60 to 72 and the radii changed as indicated in Table 1. The upgraded geometry allowed module staggering, yielding the effective solid angle gain of 6% relative to full solid angle.

3.2. *Construction*

Mounting of hybrid modules on to the new mechanical mount was carried out methodically, installing one layer at a time and then testing the performance of each module. Once a layer had passed quality assurance the subsequent layer was installed. This next layer underwent the same testing procedure and layer directly underneath it was re-tested to ensure there has been no accidental damage.

3.3. *Operational environment*

The detector is operated at atmospheric pressure with the same cooling equipment as in the original design [6]. Two vortex tubes supplied with pressurised, filtered and dried air cool the detector.

Table 1
The layer radii of the original and upgraded detector.

Vertex detector layer	Original SVD (mm)	Upgraded SVD (mm)
Inner	75	89
		94.5
Middle	95.5	108
		113.5
Outer	108	127
	114	132.5

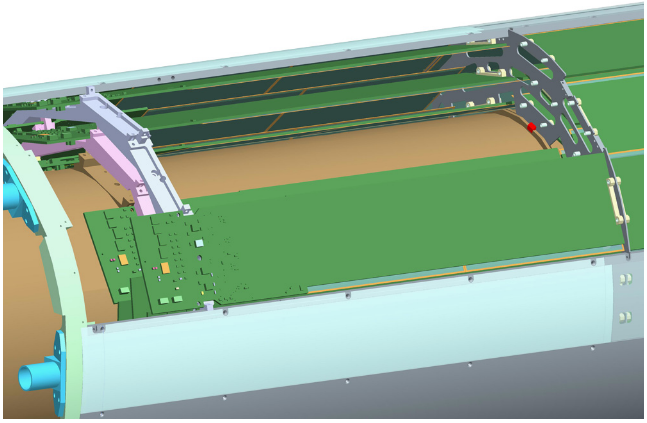

Fig. 3. Cutaway drawing of the ALPHA module mechanical arrangement, showing the "left" section partially cut away and the vortex inlet tubes in blue and the "right" cut away showing only the outer layer. (For interpretation of the references to colour in this figure caption, the reader is referred to the web version of this article.)

With the new detector geometry, airflow is less constricted leading to more effective cooling. Fully powered, the detector runs at a stable temperature below 20 °C and relative humidity of 10%.

3.4. *Readout*

The detector analogue readout is logically organized in two parts ("left" and "right", separated symmetrically around the trap; see Fig. 3), while the trigger readout is organized per layer. Each set of 128 strips is read out by a VA1TA chip [7] that provides a trigger signal when the charge from any strip exceeds a specified limit, typically set to correspond to 4800 generated electron–hole pairs. A multiplexed analogue output is then amplified by a Front-end Repeater Card (FRC). The signal-to-noise for the two sides of the silicon is typically 15 and 33 on the n and p sides respectively [6].

The trigger signals are then passed to two Timing and Trigger Control (TTC) units responsible for evaluating a set of multiplicity criteria for each layer and coordinating the readout of the analogue strip signals. A general purpose VME FPGA board (IO32) takes the layer-based criteria from the TTCs as input and performs the final decision to trigger the readout of the silicon strips. When the readout is started, a hold signal is broadcast to the VA1TAs via the FRCs. The TTCs then supervise the time multiplexed readout of the analogue strip signals, and the analogue signals are digitalised by means of eight 48-channel pulse shape digitisers (VF48s) [8]. The IO32 board also provides a common 20 MHz reference clock for the TTCs and VF48s. A multiplexer clock frequency of 3.33 MHz, limited by the VA1TA chip specifications and cable impedances, and a VF48 sampling clock of 60 MHz are used, with the VF48s sampling every 18th clock cycle. The digitised analogue data and trigger patterns are read out by a GE Fanuc V7805 VME controller and transmitted via Gigabit Ethernet to a standard desktop for storage. The readout system is integrated into the MIDAS data acquisition system [9]. The readout rate is currently limited to 250 Hz by the throughput for writing the data to the MIDAS shared-memory buffer. This can be increased by introducing zero suppression algorithms.

4. Reconstruction methodology

An antiproton annihilation event results in an average of two to four tracks in the SVD [10]. The hit patterns recorded by the SVD are weighted by averaging the pulse height distribution in order to find the exact spatial interaction points. This information is further analysed for identifying track candidates and locating the annihilation vertex. The procedure is comprehensively described in Ref. [10]. It is noteworthy that the annihilation takes place on the gold coated Penning-trap electrodes or with the vacuum residual gas. A variety of reaction by-products follows from the antiproton annihilation, but due to the large amount of material associated with the neutral trap configuration, only the energetic pions emitted within the annihilation process survive through the SVD. This means that the recorded events are typically exclusively high energy pions and the only contribution to the background is from cosmic muons mimicking an annihilation event. The fingerprints generated by the cosmic events, however, differ significantly from the annihilation events and they are rejected to contribute only a 3 mHz background rate. The spatial reconstruction resolution for the SVD is 6 mm by experimental annihilation hot spot analysis. The upgraded detector is expected to have a reconstruction resolution of 8.5 mm from Monte Carlo simulation, though this awaits verification.

5. Summary

The ALPHA SVD has proven its value as the main analysis tool in the experiment, providing spatial and timing information of single antiproton/antihydrogen annihilation events. It has recently been upgraded to surround the new ALPHA neutral trap geometry in a larger radius. The tentative experimental results indicate that the upgraded detector performs similar to its predecessor, with a better solid angle coverage. Simulation gives it a slightly worse position resolution, though there are, as yet, no experimental data available to confirm. The SVD is, and will remain, an extremely important diagnostic tool within the experiment, making it possible to meet the challenging restrictions associated with rare event physics.

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References

[1] G.B. Andresen, et al., Antihydrogen Formation Dynamics In A Multipolar Neutral Anti-Atom Trap, Physics Letters B 685 (2010) 141.
[2] G.B. Andresen, et al., Nature 468 (2010) 673.
[3] G.B. Andresen, et al., Nature Physics 7 (2011) 558.
[4] C. Amole, et al., Nature 483 (2012) 439.
[5] C. Amole, et al., New Journal of Physics 14 (2012) 105010.
[6] G.B. Andresen, et al., Journal of Instrumentation 7 (2012) C01051.
[7] VA1TA Manual, Ideas ASA, Hovik, Norway.
[8] J.-P. Martin, P.-A. Amaudruz, A 48 channel pulse shape digitizer it DSP, in: Proceedings of 14th IEEE-NPSS Real Time Conference, 2005, pp. 362–366.
[9] S. Ritt, P.-A. Amaudruz, The MIDAS data acquisition system, in: Proceedings of 10th IEEE Real Time Conference, 1997, pp. 309–212. Midas online: ⟨https://midas.psi.ch⟩.
[10] G.B. Andresen, et al., Antihydrogen annihilation reconstruction with the ALPHA silicon detector, Nuclear Instruments and Methods in Physics Research Section A 684 (2012) 73.