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Alternative method for reconstruction of antihydrogen annihilation vertices

C. Amole · M. D. Ashkezari · G. B. Andresen · M. Baquero-Ruiz · W. Bertsche · P. D. Bowe · E. Butler · C. L. Cesar · S. Chapman · M. Charlton · A. Deller · S. Eriksson · J. Fajans · T. Friesen · M. C. Fujiwara · D. R. Gill · A. Gutierrez · J. S. Hangst · W. N. Hardy · R. S. Hayano · M. E. Hayden · A. J. Humphries · R. Hydomako · S. Jonsell · L. Kurchaninov · N. Madsen · S. Menary · P. Nolan · K. Olchanski · A. Olin · A. Povilus · P. Pusa · F. Robicheaux · E. Sarid · D. M. Silveira · C. So · J. W. Storey · R. I. Thompson · D. P. van der Werf · J. S. Wurtele · Y. Yamazaki · ALPHA Collaboration

Abstract The ALPHA experiment, located at CERN, aims to compare the properties of antihydrogen atoms with those of hydrogen atoms. The neutral antihydrogen atoms are trapped using an octupole magnetic trap. The trap region is surrounded by a three layered silicon detector used to reconstruct the antiproton annihilation vertices. This paper describes a method we have devised that can be used for reconstructing annihilation vertices with a good resolution and is more efficient than the standard method currently used for the same purpose.

Keywords Antihydrogen · Vertexing · Vertex reconstruction · Track reconstruction · Silicon detector · Helix trajectory

C. Amole (✉) · S. Menary
Department of Physics and Astronomy, York University, Toronto, ON, M3J 1P3, Canada
e-mail: chanpreet.amole@cern.ch

M. D. Ashkezari · M. E. Hayden
Department of Physics, Simon Fraser University, Burnaby, BC, V5A 1S6, Canada

G. B. Andresen · P. D. Bowe · J. S. Hangst
Department of Physics and Astronomy, Aarhus University, 8000 Aarhus C, Denmark

M. Baquero-Ruiz · S. Chapman · J. Fajans · A. Povilus · C. So · J. S. Wurtele
Department of Physics, University of California, Berkeley, CA 94720-7300, USA

W. Bertsche · M. Charlton · A. Deller · S. Eriksson · A. J. Humphries · N. Madsen · D. P. van der Werf
Department of Physics, Swansea University, Swansea, SA2 8PP, UK

E. Butler
Physics Department, CERN, 1211, Geneva 23, Switzerland

C. L. Cesar
Instituto de Física, Universidade Federal do Rio de Janeiro, Rio de Janeiro, 21941-972, Brazil

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1 Introduction

The ALPHA antihydrogen trapping experiment uses a three-layer double-sided silicon detector (Fig. 1) to reconstruct the trajectories (tracks) of charged particles created when the antiproton in an antihydrogen atom annihilates on the inner wall of the trap electrodes. To reconstruct a track, three hits are needed, each of which requires signals on both the p-side and n-side strips of each silicon layer as seen in Fig. 2.

The standard method [1] for reconstructing a vertex from two or more tracks is to determine the point of closest approach among the given tracks and use the mean distance among them as the vertex position. Hence, this standard way of reconstructing vertices requires a minimum of two tracks. The alternate method was proposed due to the unique geometry of our experiment. Other than the rare annihilation with the residual gas, all the annihilations occur on the electrodes (radius of 2.2275 cm) which is the first material antihydrogen encounters once the trap is released. This alternate method exploits this experimental constraint. Along with improved vertex reconstruction resolution, one can further use this method to reconstruct vertices in events where only one track was found and additional tracks were not reconstructable due to missing hits. This paper describes the method (dubbed the 'projection method') and discusses its advantages over the standard method.

T. Friesen · M. C. Fujiwara · R. Hydomako · R. I. Thompson
Department of Physics and Astronomy, University of Calgary, Calgary, AB, T2N 1N4, Canada

M. C. Fujiwara · D. R. Gill · L. Kurchaninov · K. Olchanski · A. Olin · J. W. Storey
TRIUMF, 4004 Wesbrook Mall, Vancouver, BC, V6T 2A3, Canada

A. Gutierrez · W. N. Hardy
Department of Physics and Astronomy, University of British Columbia,
Vancouver, BC, V6T 1Z4, Canada

R. S. Hayano
Department of Physics, University of Tokyo, Tokyo, 113-0033, Japan

S. Jonsell
Fysikum, Stockholm University, 10609, Stockholm, Sweden

P. Nolan · P. Pusa
Department of Physics, University of Liverpool, Liverpool, L69 7ZE, UK

F. Robicheaux
Department of Physics, Auburn University, Auburn, AL 36849-5311, USA

E. Sarid
Department of Physics, NRCN-Nuclear Research Center Negev, Beer Sheva, 84190, Israel

D. M. Silveira · Y. Yamazaki
Atomic Physics Laboratory, RIKEN Advanced Science Institute,
Wako, Saitama, 351-0198, Japan

D. M. Silveira · Y. Yamazaki
Graduate School of Arts and Sciences, University of Tokyo, Tokyo, 153-8902, Japan

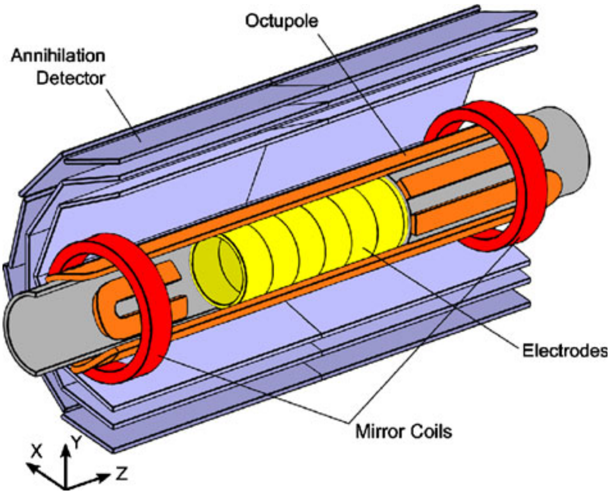

Fig. 1 Overview of ALPHA apparatus immersed in a 1 tesla solenoidal field (not to scale)

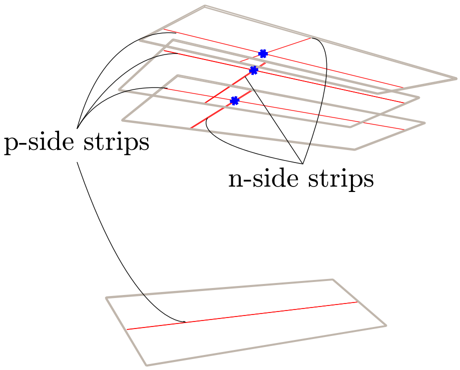

Fig. 2 Silicon modules, with signals on both p-side and n-side strips forming hits (*top*) and a module with only a p signal (*bottom*) and hence, unable to record a hit position

2 Projection method

When extrapolating the helical trajectory of the charged particles, each reconstructed track provides two intersection points as it passes through the cylindrical electrodes as shown in Fig. 3.

The intersection points clustered together indicate the point of annihilation. The annihilation vertex position is taken as the mean of the intersection points on the surface of the cylinder with a radius of 2.2275 cm. Often tracks come close to, but do not intersect the cylinder. For these tracks, we calculate the point of distance of closest approach (DCA) and use it as an intersection point (Fig. 4). Using Monte Carlo simulation, the various cuts (maximum DCA and maximum distance between intersection points) are optimized to maximize the efficiency and resolution.

Other implications of using the projection method to reconstruct vertices are discussed in the following sections.

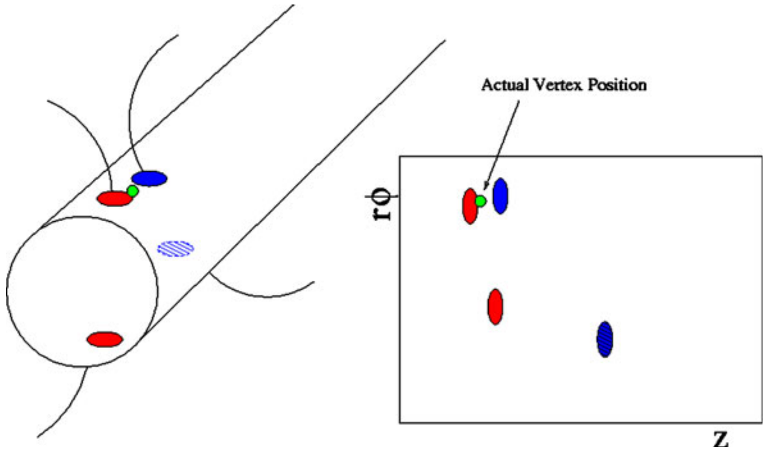

Fig. 3 Intersection points of the constructed tracks projected on the cylindrical plane

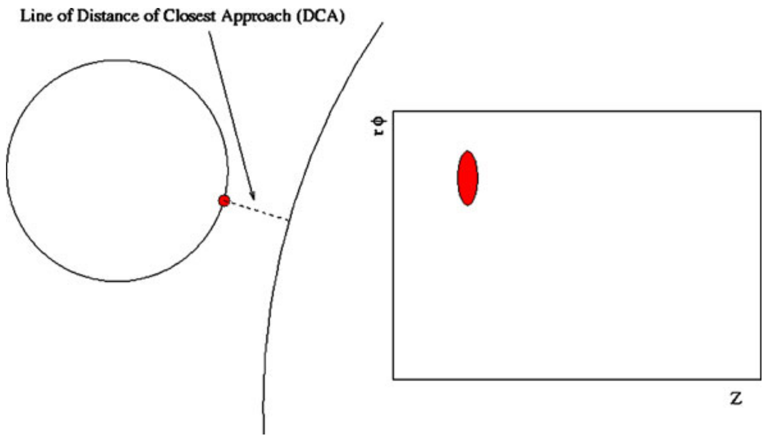

Fig. 4 Example of a DCA track and its projection

2.1 Recovering single track events

A minimum of three hits are required to reconstruct a track. An example of this can be seen in Fig. 5. Occasionally, a charged particle track can not be reconstructed due to a missing hit in one of the three layers. This can happen if the track passes through a gap between detector modules, or passes through a module but does not deposit enough energy in either or both of the orthogonal strips (p-side and n-side) of the module. Using the intersection point from the one reconstructed track as a hit along with the two other unused hits, a new track is reconstructed. This new track is accepted if the track passes through a gap (between the edges of consecutive modules) in the layer where there was a missing hit. Another acceptance criterion is if the track passes through one of the modules of the layer with the missing hit, and instead of leaving a hit signature (which requires both p-side and n-side signals), it

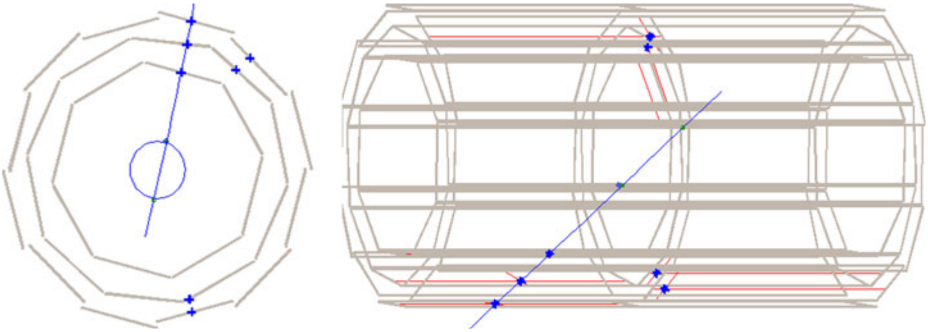

Fig. 5 A single track event with two other track candidates which were not reconstructed due to missed hits

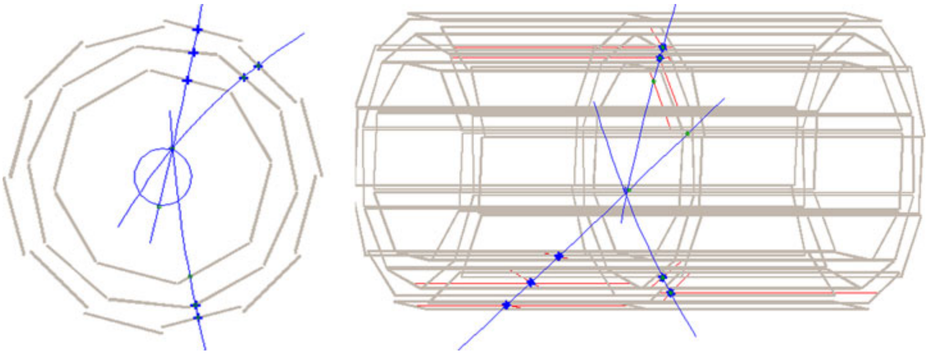

Fig. 6 Two new tracks reconstructed using the single track recovery method, one passing through a gap and the other leaving an incomplete signal in a module

only leaves a signal on p-side or n-side strip. A Monte Carlo event is shown in Fig. 6 with two new tracks constructed, one with an incomplete hit signal and the other one passing through a gap in one of the layers.

2.2 Recovering more tracks

The track recovery method is useful in all events, but especially in those with two tracks since the cosmic rejection criteria are much tighter for them. Most of the cosmic background events that return a vertex are two track events and hence the data set is divided into two categories, $N_{tracks} = 2$ and $N_{tracks} > 2$. An example of the potential of the method can be seen in Fig. 7. After applying this method, a third track is reconstructed (Fig. 8). Even though this does not guarantee that it will be validated as an annihilation event, it does give us a better chance to identify it correctly. In two track events, the reconstructed vertex (using the original two tracks) is used to replace the missing hit to reconstruct the additional tracks.

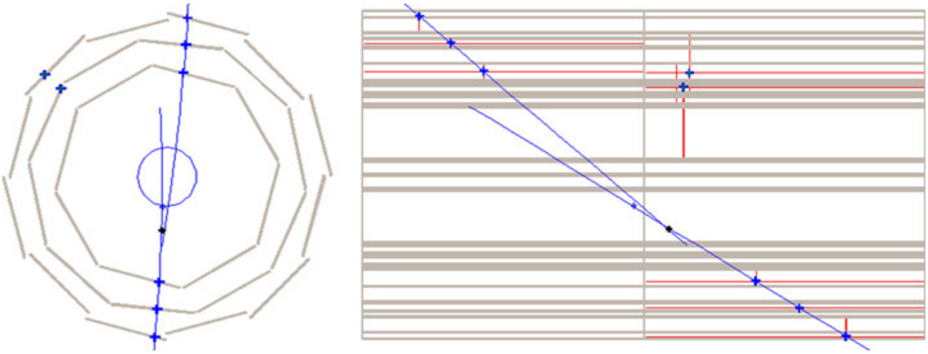

Fig. 7 Example of a Monte Carlo event which would be treated as a two track event and misidentified as a cosmic event

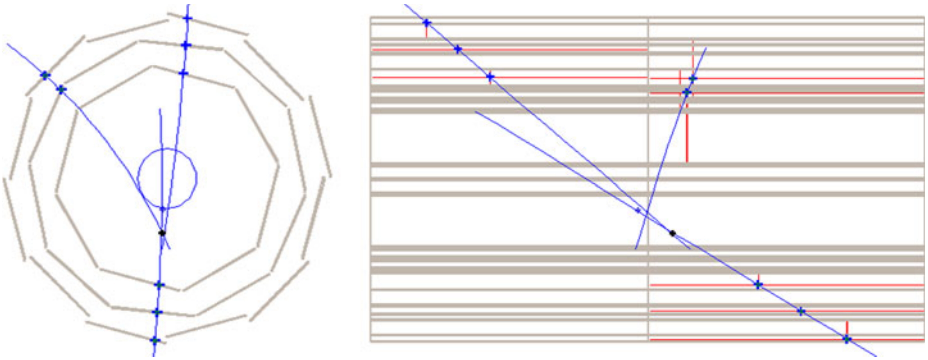

Fig. 8 With a third track reconstructed, it is re-evaluated as a three track event and possibly as a signal event

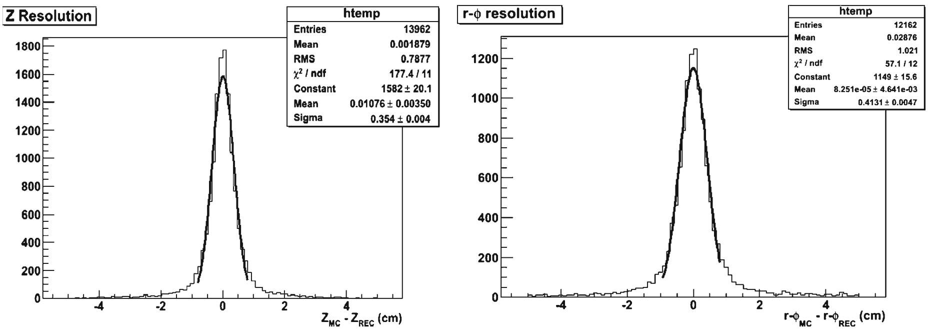

Fig. 9 Overall, the projection method reconstructs vertices with a z resolution of 0.35 cm (*left*) and $r - \phi$ resolution 0.41 cm (*right*)

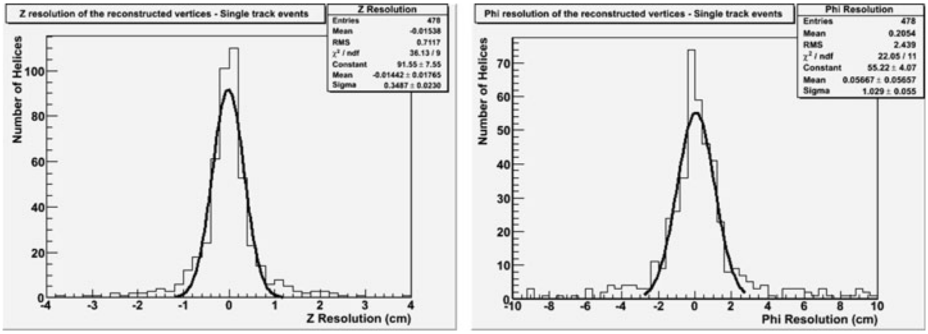

Fig. 10 For the single track events, the reconstructed vertices had a z resolution of 0.35 cm (*left*) and $r - \phi$ resolution of 1.00 cm (*right*)

3 Preliminary results

The vertex resolution of the projection method can be checked by comparing the reconstructed vertex position with the actual known simulated annihilation position. The overall resolution of this method is shown in Fig. 9.

Next, we study the efficiency and accuracy of the track recovery method by using a simulated data set of 10,000 events. In addition to the vertices produced in $N_{track} > 1$ events, a total of 478 new vertices were reconstructed from single track ($N_{track} = 1$) events. The resolutions of these additional events are shown in Fig. 10.

Finally, a new track was reconstructed in 420 two track events, which were then switched to $N_{track} > 2$. Detailed comparison with the standard method is in progress.

4 Conclusion

Having established that this method gives the same if not better resolution, we can be confident in the reconstruction of vertices. On top of that, its ability to reconstruct vertices for many single track events make it an attractive alternative. The projection method also allows us to better identify annihilation events, which might have previously considered ‘cosmic ray events’. In conclusion, the current results suggest that this alternative method is a successful candidate to perform the vertex reconstruction analysis for the ALPHA experiment and further comparison with the original method is needed.

Reference

1. Andresen, G.B., et al. (ALPHA Collaboration): Search for trapped antihydrogen. Phys. Lett. B **695**, 95–104 (2011)