Experimental Search for Lorentz Violation in Antihydrogen

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Data on locations of antihydrogen annihilations in the ALPHA trap is retrospectively analyzed for temporal variation due to violations of Lorentz Invariance as the Earth rotates and orbits the sun. To be continued...
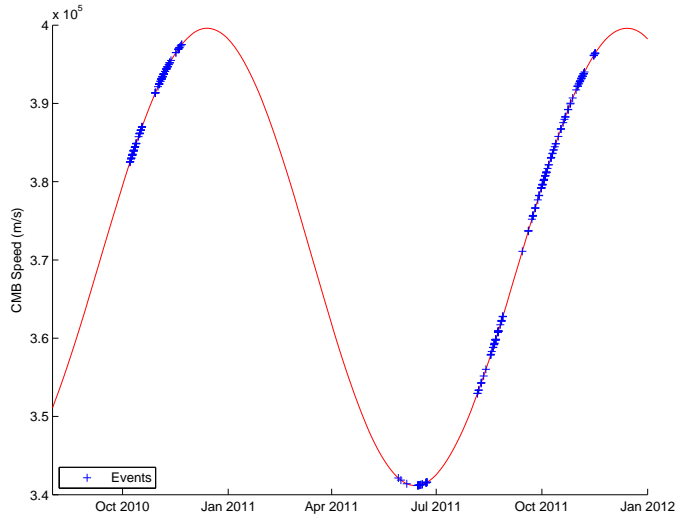
FIG. 1. The CMB speed of the Earth over the period of time during which ALPHA was running. Times of the $\bar{H}$ annihilation events are marked.

I. INTRODUCTION

General relativity purports that a particle's charge is independent of the observer's reference frame. Although the theoretical underpinnings of this prediction are strong, experimental verification of fundamental predictions of physics are critical to assessing the axioms necessary to develop such theory. In this spirit, we have performed a retrospective analysis on the data collected during the ALPHA experiment's runs in 2010 and 2011 to examine it for indications of Lorentz violation in the antimatter sector.

Proposed violations are expected to be correlated with the velocity and/or orientation of the trap relative to a preferred frame. As is common in searches for Lorentz violation, speed is measured relative to the rest frame of the CMB. The Earth's CMB speed varies by ∼15% as it orbits the sun (see Fig 1).

Over 386 antihydrogens in 320 experimental runs passed all detection criteria, hereafter referred to as cuts[1]. Only the antihydrogens that passed the cuts are included in the analysis. The times of these events were distributed over 405 days and over all hours of the day, (see Fig.2), which covers both annual and daily cycles.
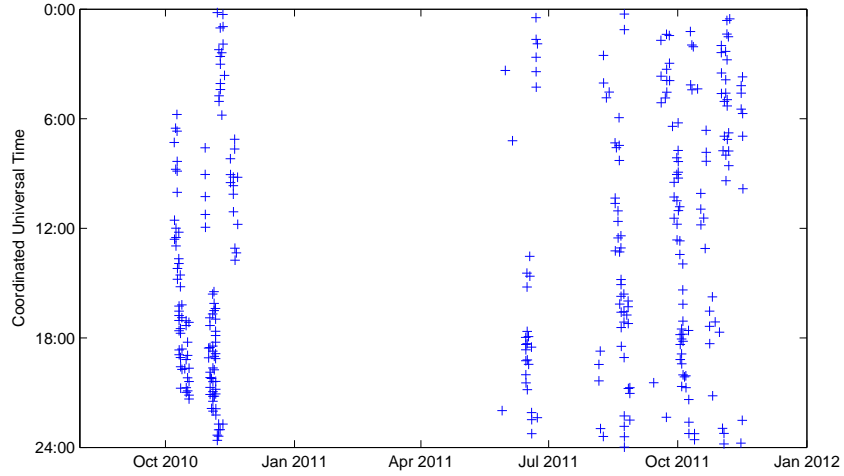
FIG. 2. The hour when antihydrogen events detected over the period of time during which ALPHA was running in Coordinated Universal Time.

II.   METHODS SUMMARY

A bound on the temporal variation of the antihydrogen charge is performed by comparison of a test statistic S, constructed to approximate the magnitude of a Fourier coefficient, of the collected data to simulated distributions of this statistic. A statistically significant nonzero value of S would indicate a violation of Lorentz Invariance.

The full data set consists of the annihilation times and z-values (position along trap axis) from ALPHA's trapping attempts. Define $f(t)$ to be a function that maps times of $\bar{H}$ annihilations to the z position of those annihilations. To be continued ...

Time Selection

The annihilation time of events for simulation was randomly selected from the time span when we were able to operate trapping trials, which were chosen based on the statistical data analysis of ~ 1900 trapping trials operated in 2010 and 2011.

The trial time spans were assumed to be from when the first trial trap started to when the last one started within the fixed $4 \sim 17$ hours of time shift when we can access to Antiproton Decelerator. The first and last trial trap time were predicted by Poisson process since the former time relative to when the shift starts, and the latter time relative to when the shift ends show exponential distribution. The distributions of these two kinds of simulated time are shown in Fig.3
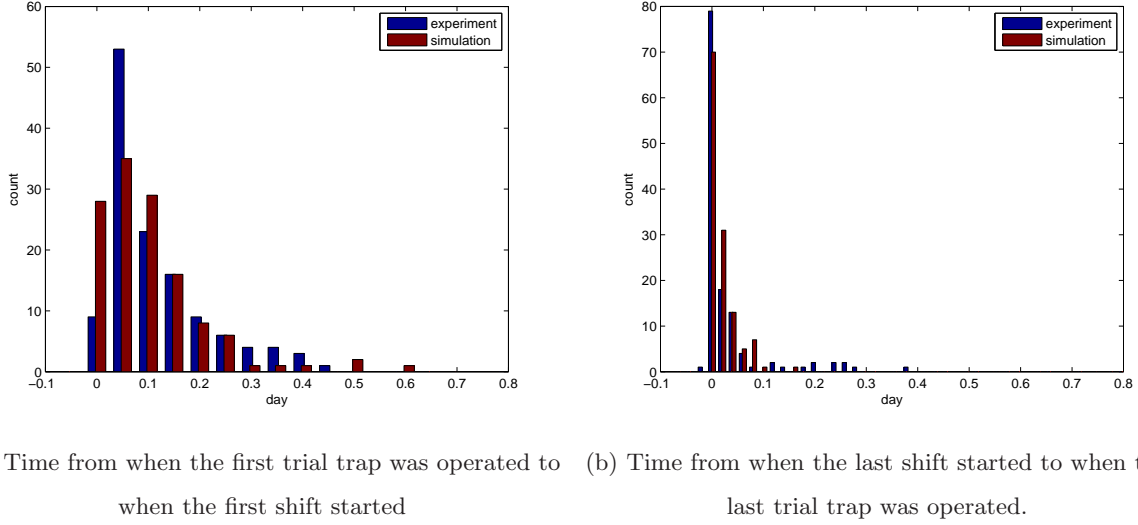
(a) Time from when the first trial trap was operated to when the first shift started

(b) Time from when the last shift started to when the last trial trap was operated.

FIG. 3. Distributions of simulated time spans overlaid with the experimental data.

with experimental data overlaid. Then the operation time of 320 ± 18 trapping trials succeeded in trapping $\bar{H}$ annihilation(s) were randomly selected within the time span. The time duration of the trapping trial was fixed to 10.00 minutes based on the experiment. The number of annihilation events for each successful trapping trial were chosen from the fact that the probability of getting one event per a trapping trial predicted by Poisson statistics was $\lambda = 0.387532$. Note that mili seconds of time difference between more than one $\bar{H}$ annihilations in a same trapping trial were ignored since we have time information of annihilation events in order of a second. The example of time selection with this method is shown in Fig.4.

Position Selection

Creation of pseudo-data sets requires an algorithm capable of generating z positions of $\bar{H}$ annihilations for arbitrary charge values. This is achieved by randomly sampling an approximated inverse CDF of the annihilation locations along the trap axis for the given charge.

Using the symplectic integrator discussed in Ref. 1, a list of annihilation z coordinates is created for both quip directions for several different charges $\{q_i\}$, indexed in order of increasing charge. These lists are then adjusted to account for effects from detector smearing and missed detections due to cosmic ray filtering criteria, also discussed in Ref. 1. For each charge q_i, let $D_{q_i}(z)$ denote the linear interpolation of the distribution's normalized CDF for a given direction (either left or right). Two $D_{q_i}(z)$ are depicted in Fig. 5 (blue solid lines). Furthermore, let $D_{q_i}^{-1}(r)$ denote the inverse of $D_{q_i}(z)$. For any one of the q_i, a random annihilation position z_0 is chosen by selecting a
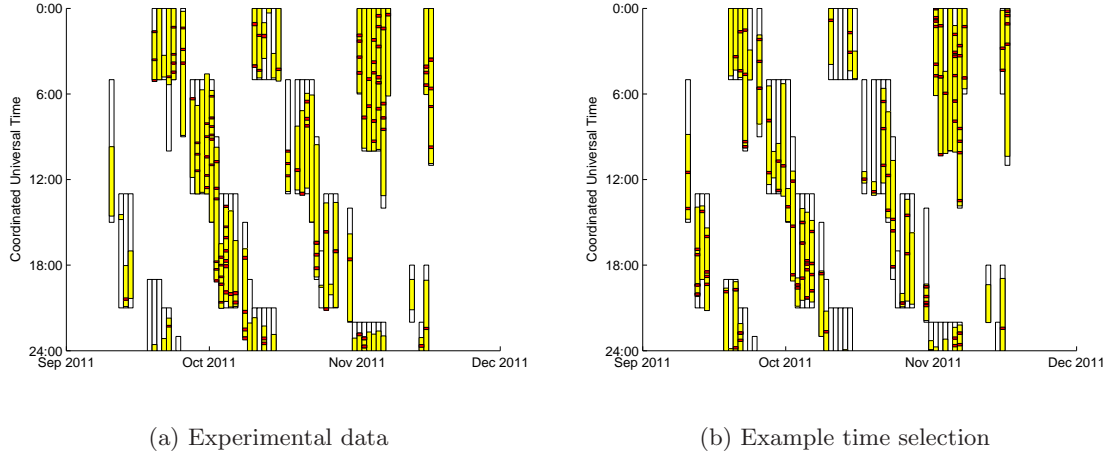
(a) Experimental data

(b) Example time selection

FIG. 4. The time table of (a) the experimental data and (b) example time selection in Coordinated Universal Time against day. The time span when we were able to run trapping trials (yellow boxes) was chosen within each assigned shift schedule (white boxes). Then within the trial time span, the time of 320 ± 18 successful trapping trials (red boxes) were randomly chosen. We detected at least one annihilation event at the end of successful trapping trials (the bottom of red boxes).

random value r_0 in the interval $(0, 1)$, then setting $z_0 = D_{q_i}^{-1}(r_0)$.

For a charge q between the discrete q_i, let q_k denote the q_i with the largest value less than q. Then q_{k+1} will be the q_i with the least value greater than q. A random annihilation position for this q is chosen by first selecting a random value r_0 in the interval $(0, 1)$ as before, then calculating z_0 from Eqn. 1. The weights $(q_{k+1} - q)$ and $(q - q_k)$ are chosen to provide a linear interpolation between the two inverse CDFs. The process is summarized in Fig. 5.

$$z_0 = \frac{D_{q_k}^{-1}(r_0) * (q_{k+1} - q) + D_{q_{k+1}}^{-1}(r_0) * (q - q_k)}{q_{k+1} - q_k} \tag{1}$$

ACKNOWLEDGMENTS

To be continued. . .

III.   NOTES

The graphs right now are created in Matlab. In the future they will be made in Origin and should look prettier.

Cite aephem

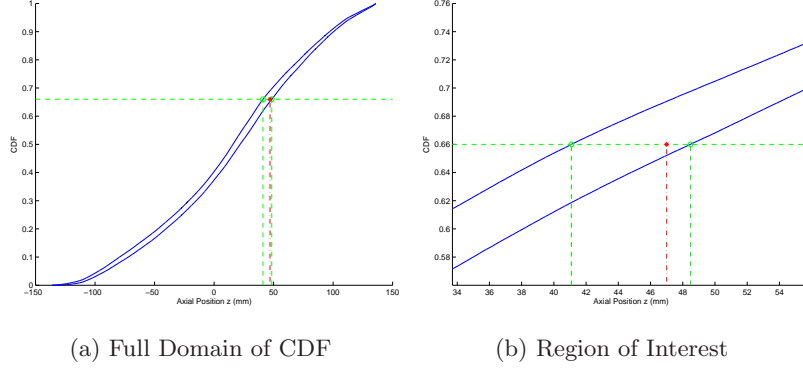(a) Full Domain of CDF   (b) Region of Interest

FIG. 5. Graphical depiction of the annihilation z value selection algorithm. Empirical CDFs are generated for several different charges q_i and then linearly interpolated to give $D_{q_i}(z)$. Two such $D_{q_i}(z)$ are shown (blue solid curves). When a z position is desired for a given charge q, a random value r_0, here shown as 0.66, is picked and the values of the inverse CDFs $D_{q_i}^{-1}(r_0)$, which can be read off of the x-axis here, are determined (green dashed lines). The weighted average is then taken to give the sampled z value for q (red dash-dot line). Here q is closer in value to q_{k+1} than q_k.

Look for other papers on charge invariance

Mention this method can be done better in the future

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[1]   C. Amole, et al. Experimental limit on the charge of antihydrogen. 2014. in press at Nat. Commun.