USING MACHINE LEARNING TO DETECT ANTIHYDROGEN IN FREE FALL

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INTRODUCTION & OBJECTIVES

- The properties of the hydrogen atom have played a central role in fundamental physics for the past 200 years.
- The CPT theorem, a cornerstone of the standard model, requires that hydrogen and antihydrogen ($\bar{H}$) have the same properties.
- The ALPHA experiment attempts to test this theory by measuring the fundamental properties of antihydrogen; and has recently measured the effect of gravity on antimatter[1].
- The ALPHA experiment makes use of several particle detector technologies, one of the key challenges for these detector systems is to distinguish between antihydrogen annihilations and cosmic rays, a classification problem well-suited for machine learning.
- Here we describe how the ALPHA collaboration uses these classification models to aide in the study of antimatter.

MATERIALS & METHODS

- Neutral antihydrogen is formed by mixing antiprotons delivered from CERNs ELENA, with positrons emitted from an Na-22 radioactive source.
- The coldest(<100mK) few (∼20 per cycle) atoms are trapped in the 1T magnetic well surrounding the mixing region.
- By lowering the well with a certain relative bias we are able to simulate the effect of gravity on the atoms, allowing us to see if they fall up or down.
- Annihilations are detected with a 3m long TPC and read out for reconstruction and classification.

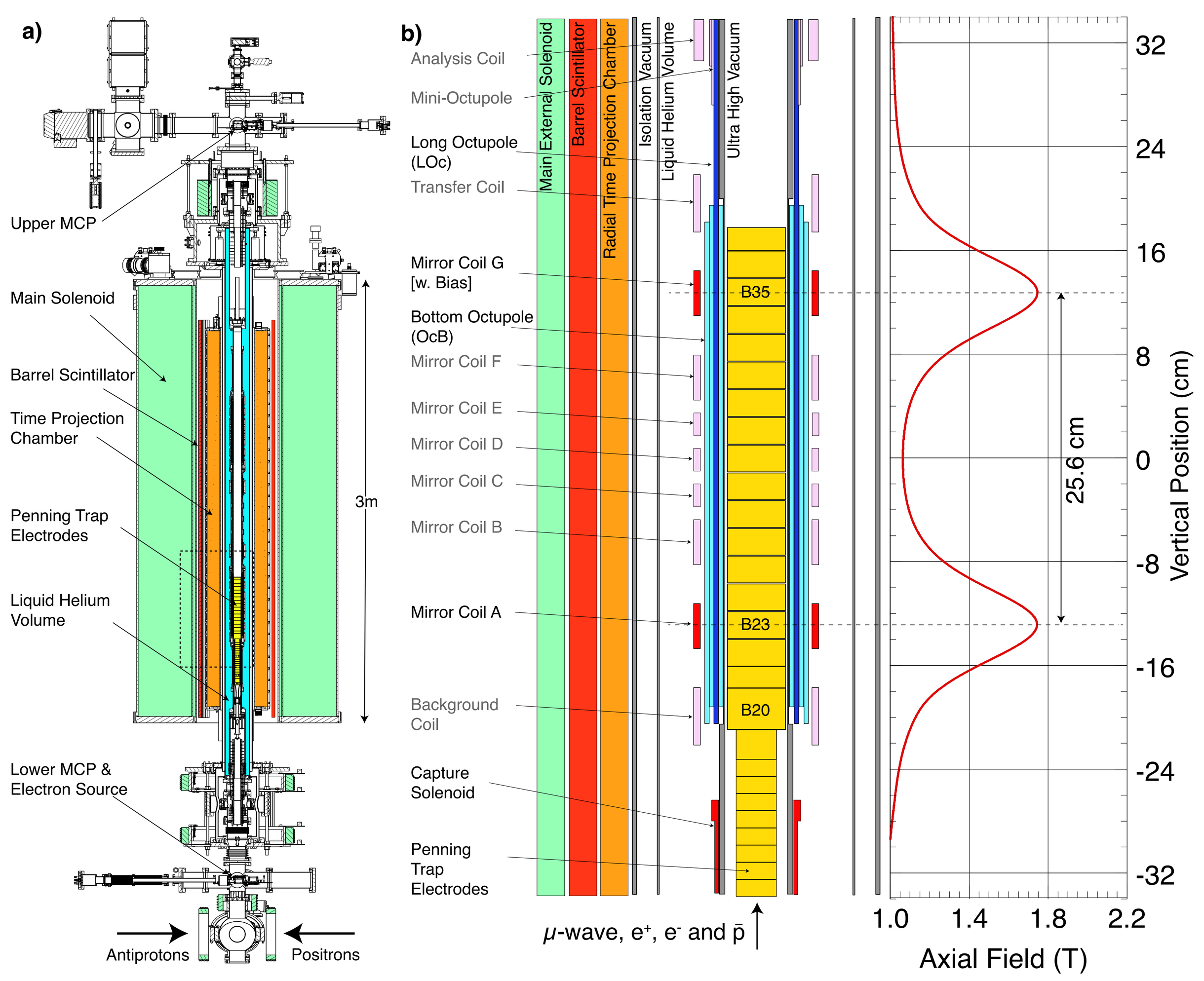

Figure 3: Experimental setup of ALPHA-g

RESULTS

- Performing the experiment outlined in the Methods section gives us the following histograms of anihilation positions for each bias. (Only events passing the event classification cut are displayed here, suppressing the cosmic background rate of 70Hz).
- It can be seen by the $10g$, and $-10g$ trials respectively that we are able to push the atoms in either direction with a force equivalent to $10g$.
- It can further be seen that the distribution of annihilations in the up/down direction are roughly 50/50 at $-1g$, showing consistency with the effect of gravity on normal matter.

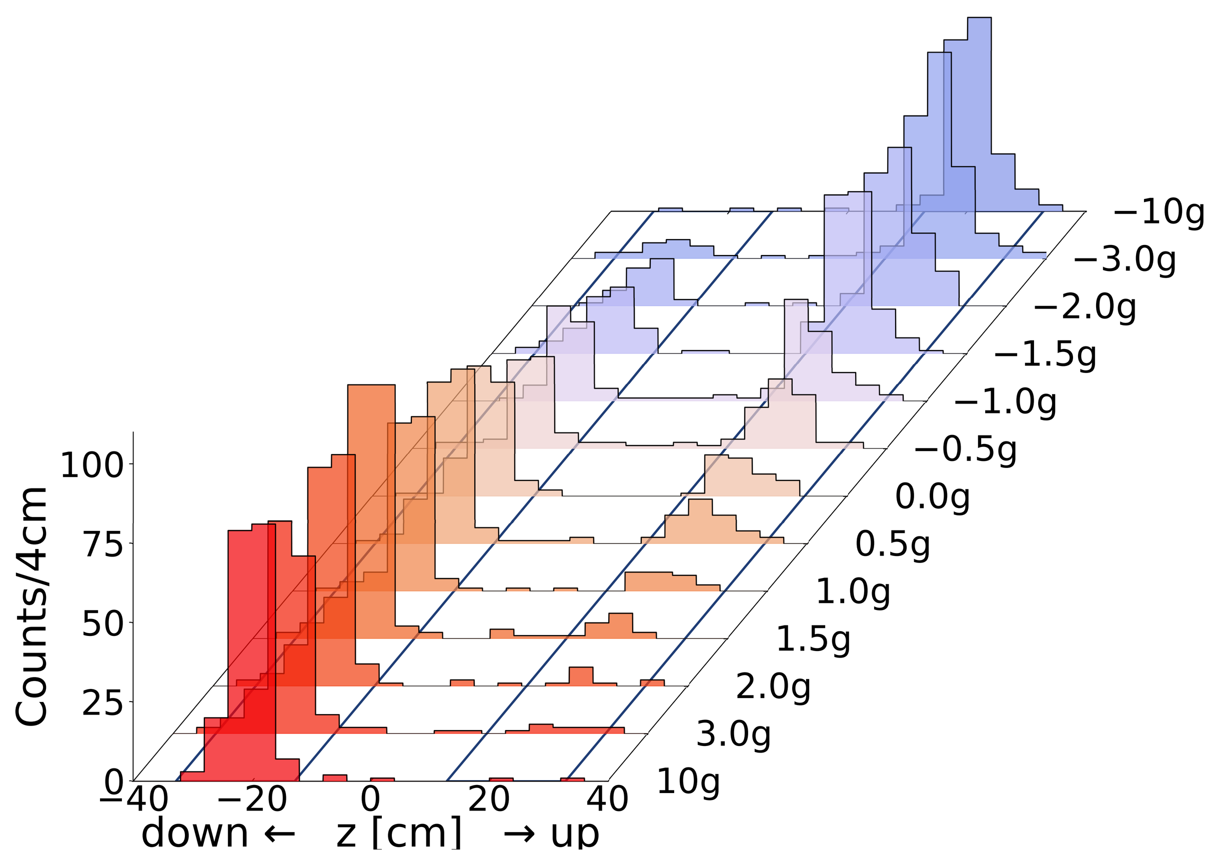

Figure 4: The binned z position of detected vertices for each bias (7 trials).

EVENT CLASSIFICATION

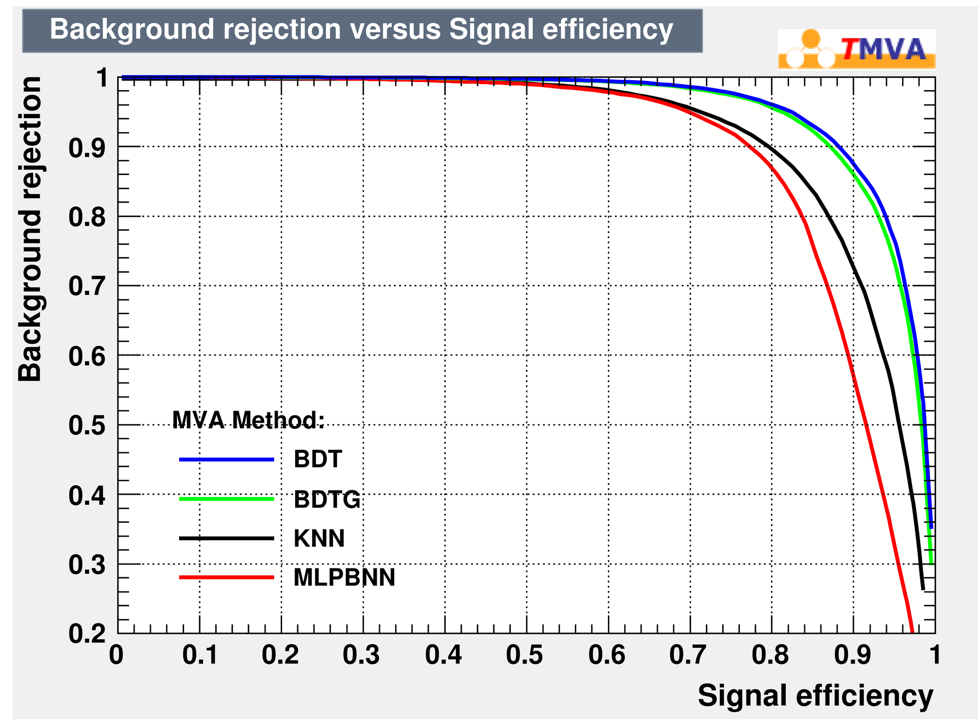

Figure 1: ROC plot for various models trained and tested.

- Cosmic rays are the dominant source of background.
- The cosmic event rate of 70 Hz is suppressed by a factor of approximately 350 by off-line machine-learning (ML) analysis.
- Twenty selection variables that are sensitive to the topological differences between annihilation and background events are used as inputs to a Boosted Decision Tree classifier.
- The ML classifier is trained using experimental data sets of signal and background events. The signal sample (371,362 events) was obtained from antihydrogen produced during antiproton and positron mixing near z=0, filtered to only include periods of high event rates to minimize cosmic contamination.
- The background sample (610,942 events) was collected when there were no antiprotons in the apparatus.
- None of the ML variables in the training samples showed significant correlation with the vertical axis (z).
- A forest of 850 decision trees was trained with a max depth of three, a minimum node size of 2.5%, GINI index for separation, and Ada boost.
- The resulting BDT response and ROC curve are shown in Figure 2 and Figure 1 respectively.

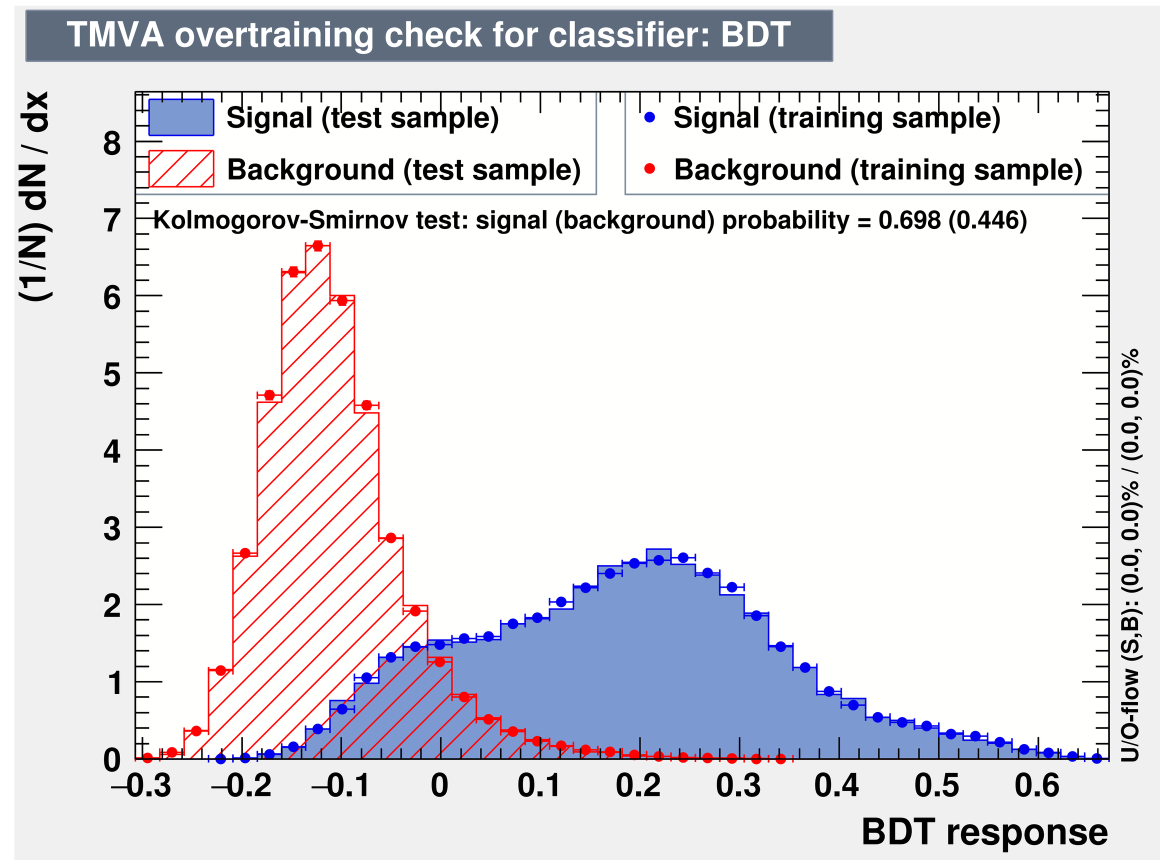

Figure 2: Histogram of the BDT response, separated by signal and background.

CONCLUSION

- Without the ML classifier the result becomes lost in noise, each trial took place over a 20s window, was repeated multiple times, and has a 70Hz cosmic rate. This gives ∼7000 events per bias that need to be filtered.
- Using the ML to increase the significance of the result we are able to quote the value of gravity with respect to antimatter $\bar{g} = 0.75 \pm 0.13$ (statistical + systematic) ± 0.16 (simulation)g where $g = 9.81ms^{-2}$

REFERENCES

[1] The ALPHA Collaboration. Observation of the effect of gravity on the motion of antimatter. *Nature*.

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