



Hyperfine Structure of Antihydrogen

ERC Advanced Grant

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AdG HBAR-HFS no. 291242

Antihydrogen Detection for Measuring the Ground State Hyperfine Splitting of Antihydrogen

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Outline

Overview of experiment

Antihydrogen detector
Tracking detector

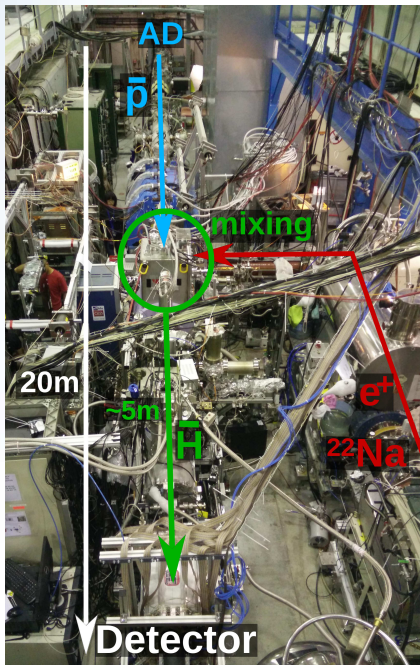
Analysis

Summary and outlook

Overview of \bar{H} HFS experiment

- ▶ **slow antiprotons** from CERN's Antiproton Decelerator and **Positrons** from ^{22}Na source form cold \bar{H} within CUSP trap in a **mixing process**
- ▶ neutral antiatoms will escape trap, enter **spectroscopy beam line**: cavity (spin flips), sextupole (analyses spin)

- ▶ **detector**: monitors count rate of arriving \bar{H}



Detector: counting antihydrogen atoms

low \bar{H} production rate \rightarrow **requirements**: efficiently detect annihilation, background suppression

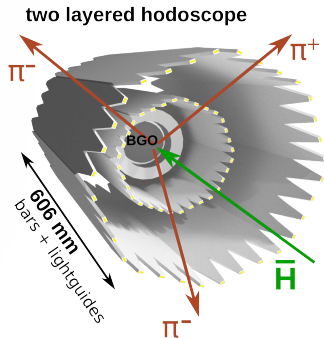
central calorimeter:

- ▶ detect antiproton annihilations
- ▶ BGO disc (\varnothing 9cm, 5mm thickness)
- ▶ read out by 4 Multi Anode Photomultiplier \rightarrow **energy and position information**

2-layered hodoscope for tracking:

- ▶ 32 plastic scintillating bars per layer
- ▶ **tracking** secondary particles from antiproton annihilation, cosmic particles etc.

C. Sauerzopf et al. NIMA A845 (2017) 579-582

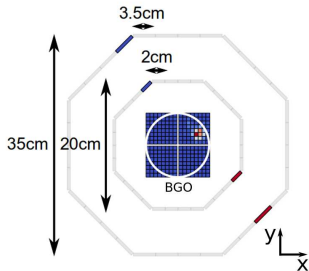
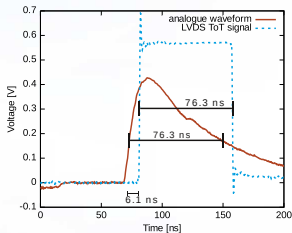
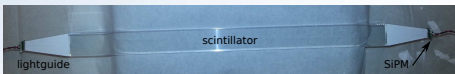
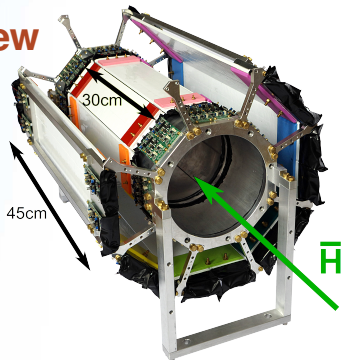


hodos: greek for 'path'

skopos: greek for 'an observer'

Tracking detector – overview

- ▶ scintillating light detection with **silicon photomultipliers** (SiPMs) on both ends of bars
- ▶ SiPMs are read out and powered by preamplifier electronics: analogue and digital signal



Tracking detector – characteristics

measurements in the lab with cosmics:

- ▶ **timing**: diameter of outer hodoscope 35 cm \rightarrow ToF possible with resolution < 600 ps, discriminate: particles from outside or inside detector!

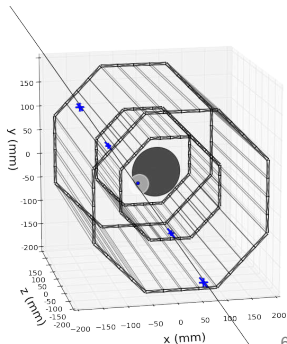
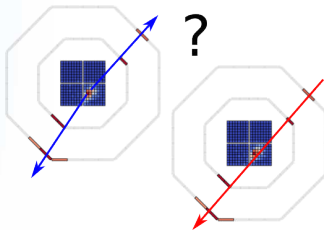
outer: 551 ± 5 ps (FWHM)
inner: 497 ± 3 ps

- ▶ **hit position in beam direction**: from time information of up and downstream SiPM signals

outer: 7.3 ± 0.3 cm (FWHM)
inner: 5.9 ± 0.4 cm



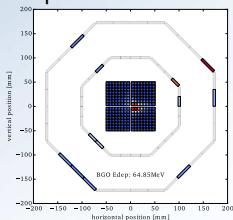
length of bars: inner: 30 cm,
outer: 45 cm



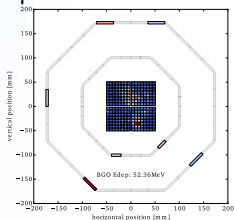
What do signal and background look like?

- ▶ **signal:** annihilation of antiproton, secondary particles (mostly pions)
- ▶ **background:** dominated by cosmic particles (can be measured during beam off periods), annihilations on beam pipe in front of detector

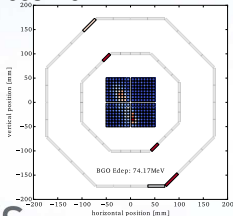
antiproton:



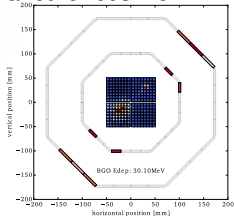
upstream annihil.:



cosmic:



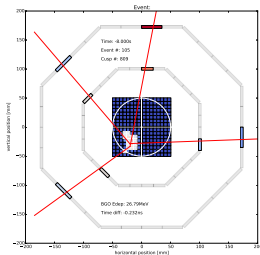
another cosmic:



\bar{H} identification – overview

Event features:

- ▶ **BGO**: energy deposit, hit pattern in BGO
- ▶ **hodoscope**: tracks (at the moment use mainly 2D tracking), time of flight, angles between tracks
- ▶ → supervised **machine learning** for identification!

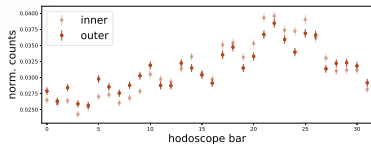
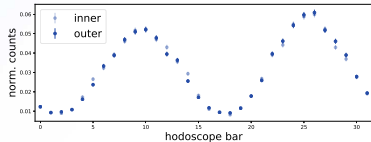
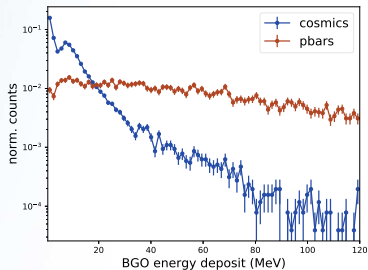
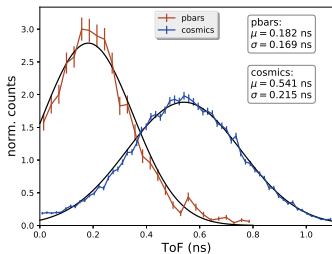
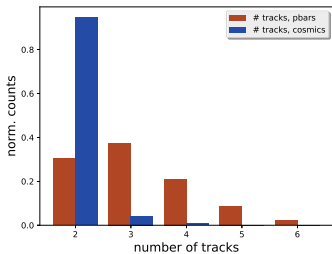


- ▶ use **real data** for training: recorded background (beam off periods) and antiproton extractions to the detector
- ▶ selection of training data: careful **pre-cuts to reduce background** in antiproton data (e.g. arrival time at detector, number of tracks)

	training sample	test sample (1/3 total events)
pbar	2882	1428
cosmics	28620	14089

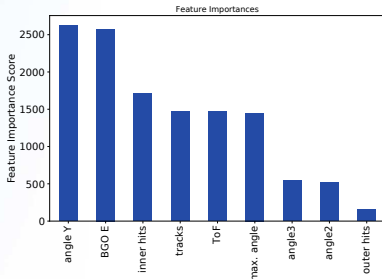
- ▶ estimated cosmics still in signal training data: 4
- ▶ imbalanced data – oversampling

\bar{p} vs cosmics: preliminary results, beam time 2016



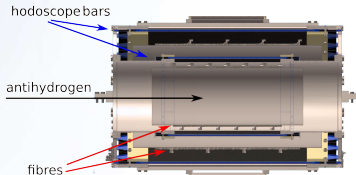
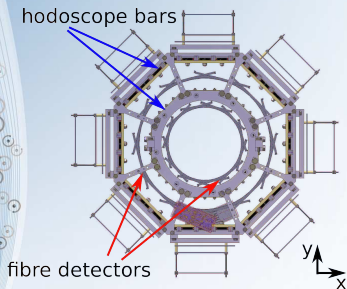
data-driven machine learning – preliminary results

- ▶ **boosted gradient decision trees (XGBoost)**
- ▶ **choose input parameters (event features)**
- ▶ **feature importance score**



- ▶ use trained model to predict class (cosmic or \bar{p}) of test sample:
 - ▶ **cosmic rejection: 99.76 %**
 - ▶ **false positive rate: 0.0038 /s**
 - ▶ **pbar efficiency: 82 %**
- ▶ → use model to identify antihydrogen candidates (see V. Mäckel's talk)

Hodoscope upgrade using scintillating fibres



4mm x 4mm

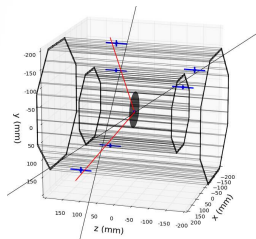
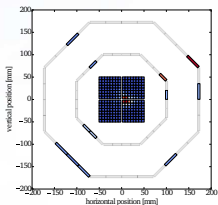
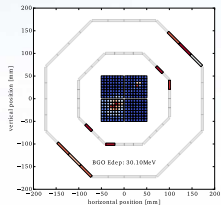


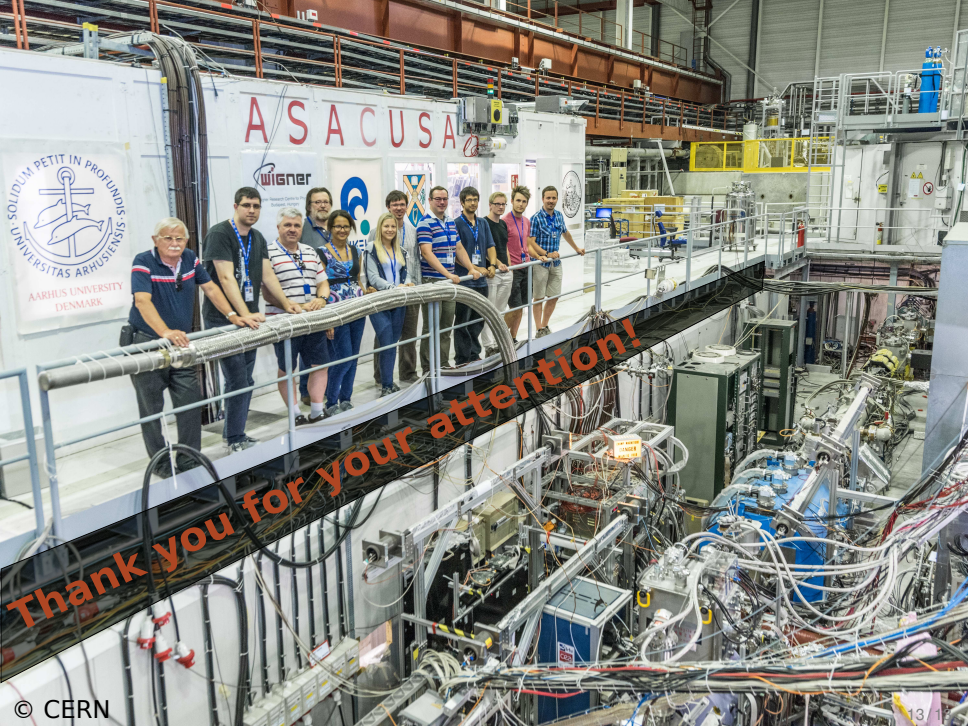
- ▶ increase position resolution in beam direction
- ▶ **enables 3D tracking**: discriminate between straight tracks created by cosmics and tracks with a kink due to antiproton annihilations
- ▶ **precise vertex reconstruction**: helps to reject upstream annihilations

Poster by Markus Fleck: A compact scintillating fibre detector add-on for ASACUSAs hodoscope

Summary and outlook

- ▶ low antihydrogen count rate → essential to learn about the signal, **antiproton extractions** during beam time 2016
- ▶ data-driven machine learning algorithm for signal and background identification
- ▶ **fibre upgrade** enables 3D tracking for analysis: distinguish upstream annihil. from events on BGO
- ▶ for 2017: antiproton extractions with upgraded detector and annihilations on **different materials**





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Thank you for your attention!