



# Antihydrogen Detection for Measuring the Ground State Hyperfine Splitting of Antihydrogen

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# Outline

Overview of experiment

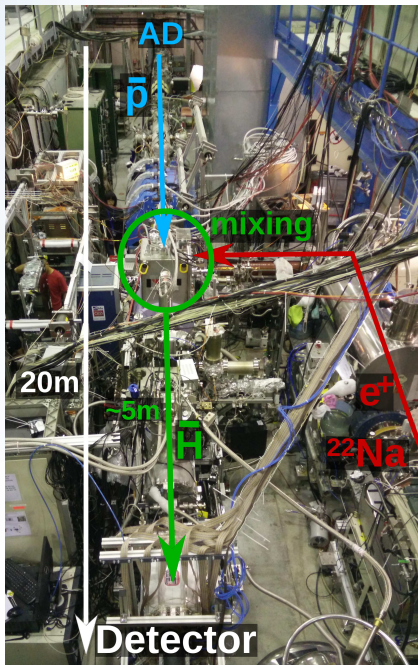
Antihydrogen detector  
Tracking detector

Machine learning analysis

Summary and outlook

## Overview of $\bar{H}$ HFS experiment

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

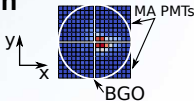


## Detector: counting antihydrogen atoms

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

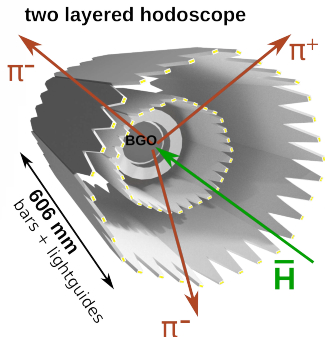
### central calorimeter for detecting $\bar{\text{p}}$ annihilations:

- ▶ 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.



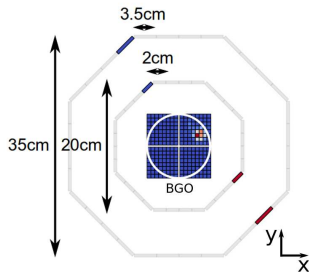
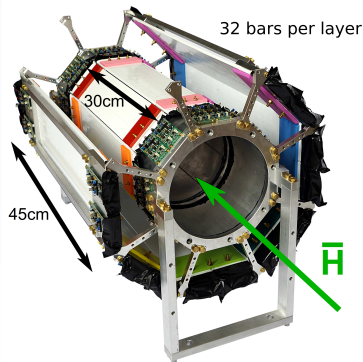
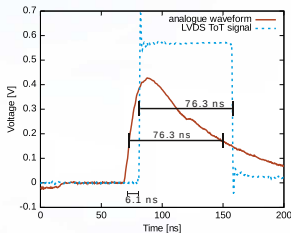
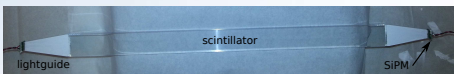
hodos: greek for 'path'

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

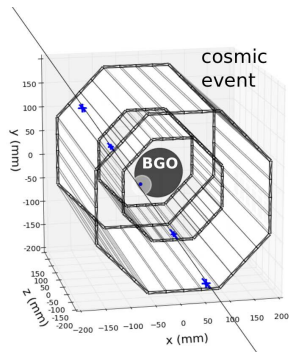
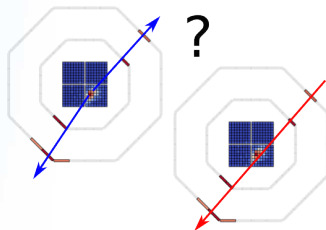
- ▶ **ToF**: diameter of outer hodoscope 35 cm  $\rightarrow$  ToF possible with resolution  $< 600$  ps, discriminate: particles from outside or inside detector!

outer:  $551 \pm 5$  ps (FWHM)  
inner:  $497 \pm 3$  ps

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

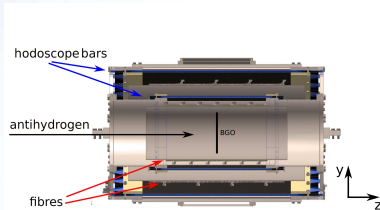
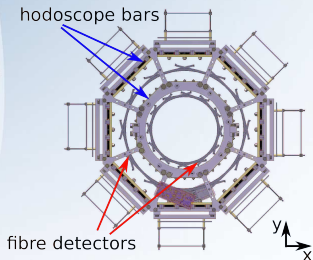
outer:  $7.3 \pm 0.3$  cm (FWHM)  
inner:  $5.9 \pm 0.4$  cm

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



# Tracking detector – upgrade using scintillating fibres I

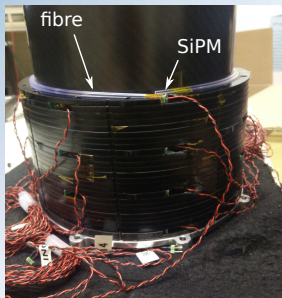
- increase position resolution in beam direction



4mm x 4mm

- 2 add. layers out of fibres perpendicular to bars
- $2 \times 2$  mm fibres, bundled into  $4 \times 4$  mm bunches
- 1 turn around per bunch, read out by SiPM on one end
- outer: 100 ch, inner: 63 ch

## Tracking detector – upgrade using scintillating fibres II



- ▶ **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
- ▶ ready for this years beam time!

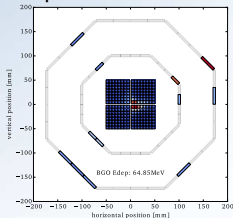


Poster by Markus Fleck: A compact scintillating fibre detector add-on for ASACUSAs hodoscope

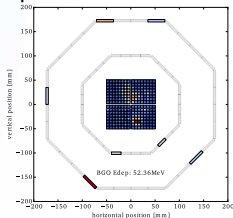
# What do signal and background look like?

- ▶ **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

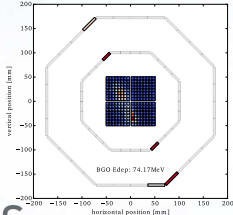
antiproton:



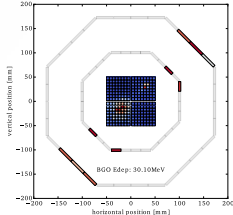
upstream annihil.:



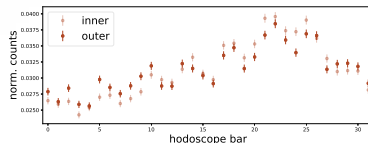
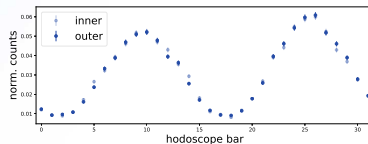
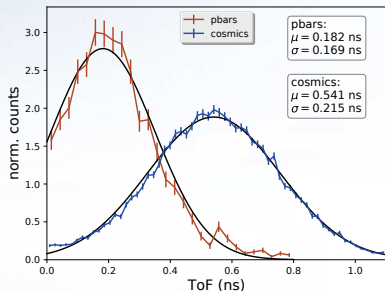
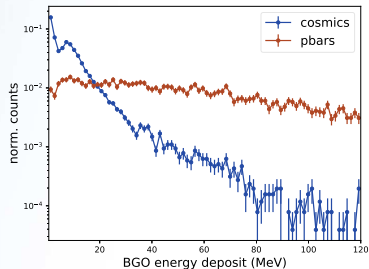
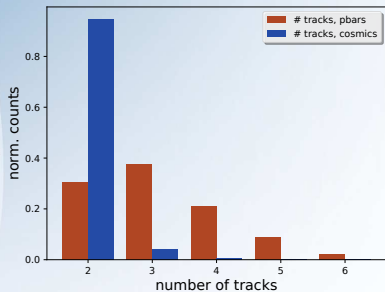
cosmic:



another cosmic:



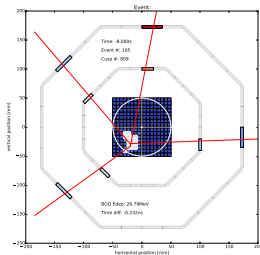
# $\bar{p}$ vs cosmics: preliminary results, beam time 2016



# $\bar{H}$ identification – overview

## Event features:

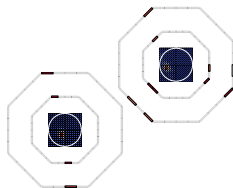
- ▶ **BGO**: energy deposit, hit pattern in BGO
- ▶ **hodoscope**: tracks (at the moment use mainly 2D tracking), time of flight, angles between tracks
- ▶ → supervised **machine learning** for identification!
- ▶ use **real data** for training: recorded background (beam off periods) and antiproton extractions to the detector
- ▶ trigger condition: hit on the BGO
- ▶ background rate (beam off periods):  $\approx 1.57$  Hz



## $\bar{H}$ identification – selection of data for machine learning

- ▶ careful **pre-cuts to reduce background** in antiproton data (e.g. arrival time at detector, number of tracks)

antiprotons	number of events
cosmics	3883
estimated cosmics left in $\bar{p}$ data	31957
	10

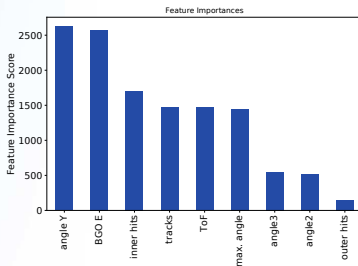


- ▶ random selection of events into **training (2/3) and test (1/3) sample**
- ▶ **imbalanced data** – oversampling
- ▶ test sample stays untouched!
- ▶ **small size of data sample** causes fluctuations in training and test data → also in the results predicted by algorithm!



# data-driven machine learning – preliminary results

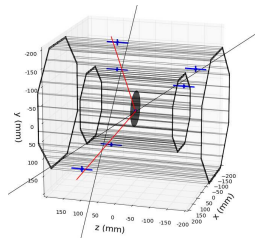
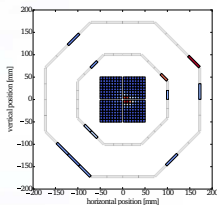
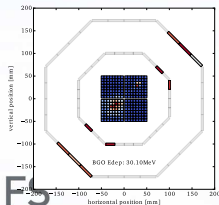
- ▶ **boosted gradient decision trees** (tree ensemble)
- ▶ feature importance score
- ▶ several rounds of training and testing each with randomly selected training/test sample

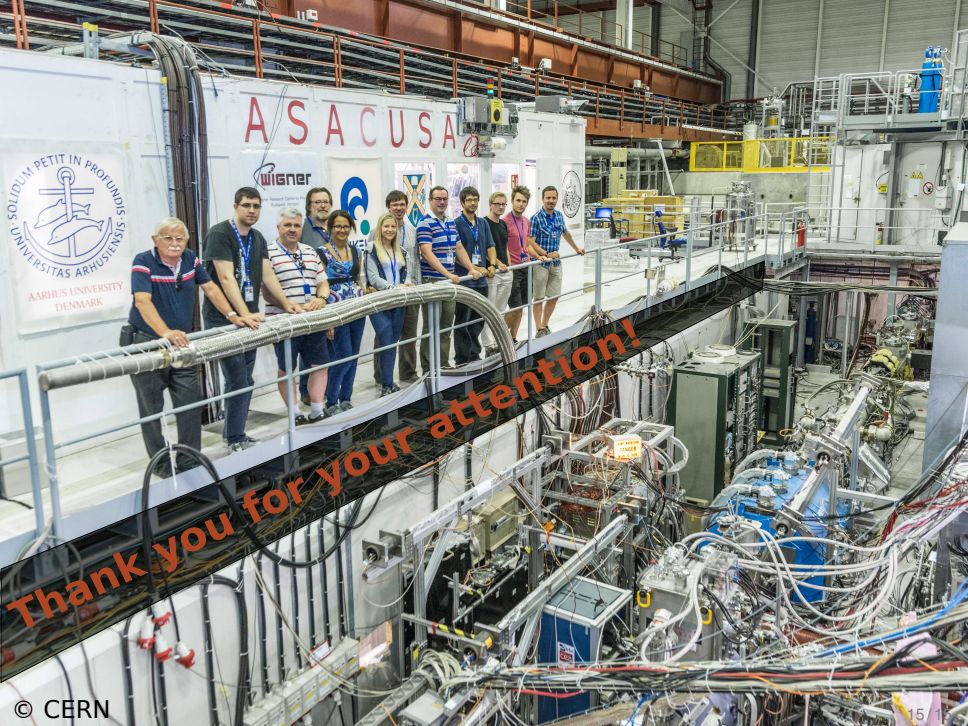


- ▶ use trained algorithms to predict class (cosmic or  $\bar{p}$ ) of test samples:
  - ▶ **cosmic rejection:**  $(99.755 \pm 0.015) \%$
  - ▶ **false positive rate:**  $(0.00391 \pm 0.00025) / s$
  - ▶ **pbar efficiency:**  $(79.58 \pm 0.79) \%$
- ▶ predict antihydrogen candidates → get probability by number of occurrences of events

# Summary and outlook

- ▶ detector for antihydrogen detection and its upgrade has been presented
- ▶ 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!