ERC Advanced Grant
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AdG HBAR-HFS no. 291242

Antihydrogen Detection

for Measuring the Ground State Hyperfine Splitting of Antihydrogen

B. Kolbinger on behalf of the ASACUSA collaboration

LEAP Conference, March 2018

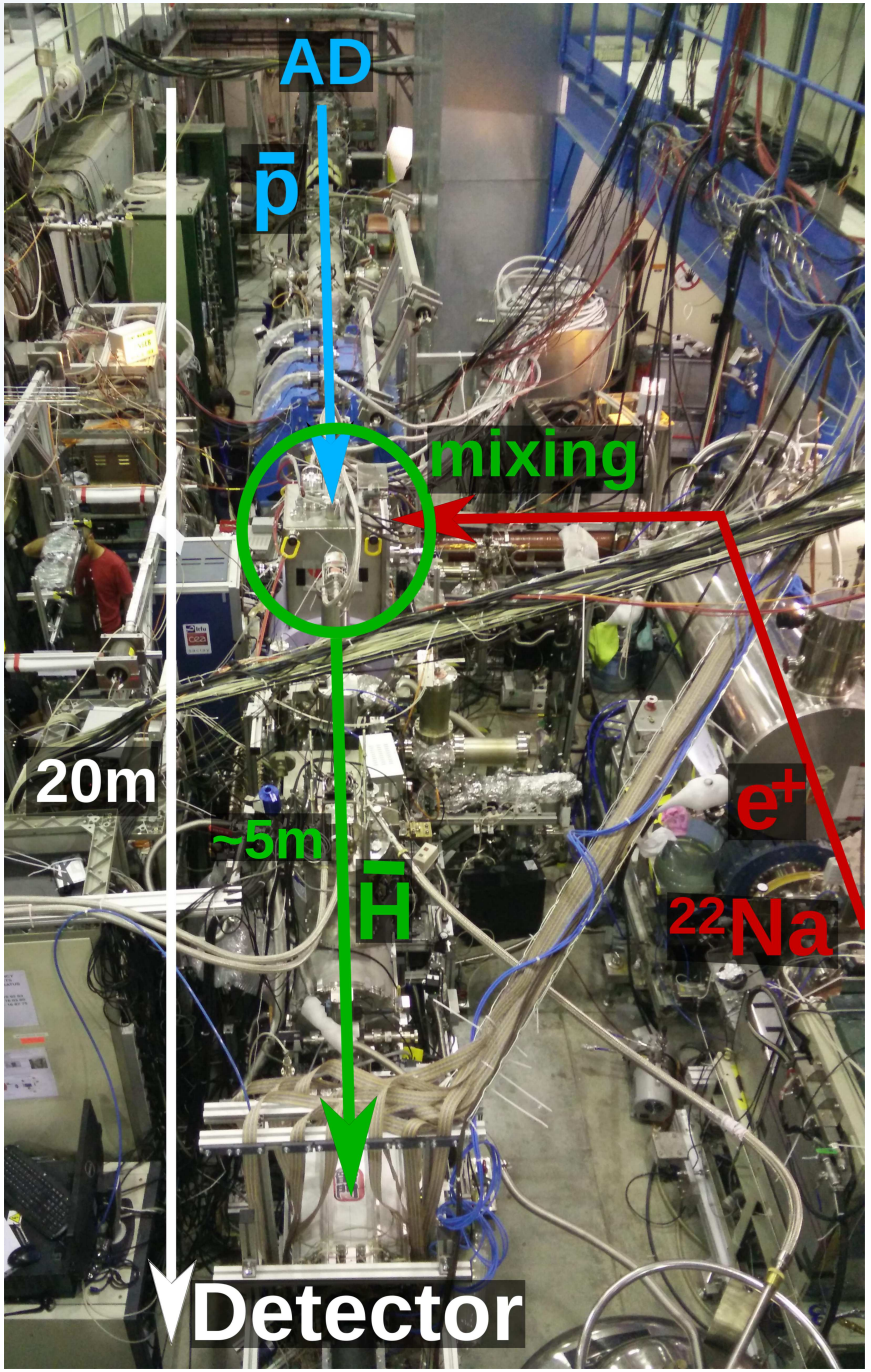
Outline

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

- **slow antiprotons** (CERN's AD) and **Positrons** (^{22}Na) form cold $\bar{H}$ within CUSP trap in a **mixing process**

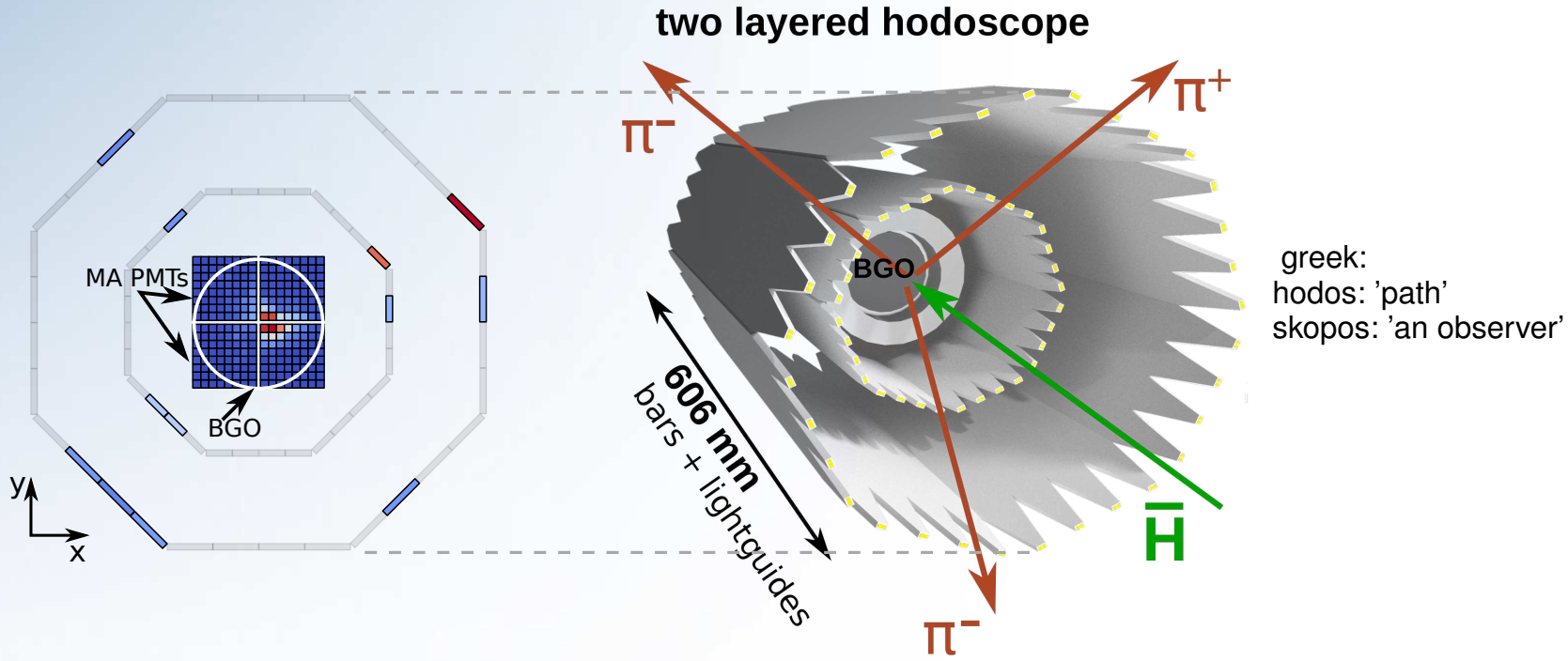
- antiatoms will escape trap, **beam** enters **spectroscopy beam line**: cavity (spin flips), sextupole (analyses spin)

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



Detector: counting antihydrogen atoms

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



greek:
hodos: 'path'
skopos: 'an observer'

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

- BGO disc (⊘ 9cm, 5mm thickness)
- read out by 4 Multi Anode Photomultiplier $\rightarrow$ **energy and position information**

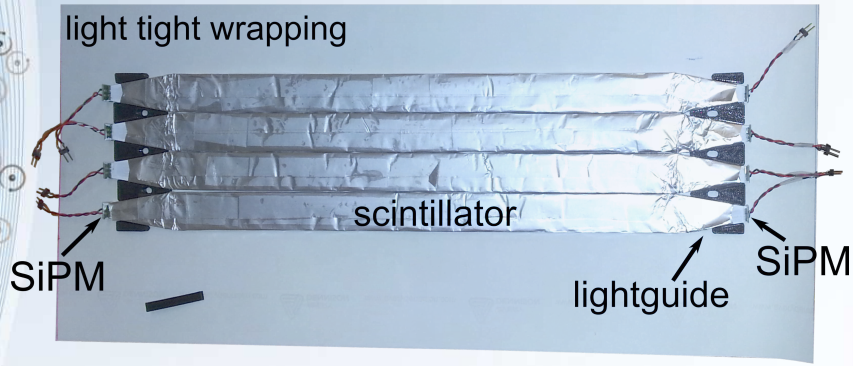
2-layered hodoscope for tracking:

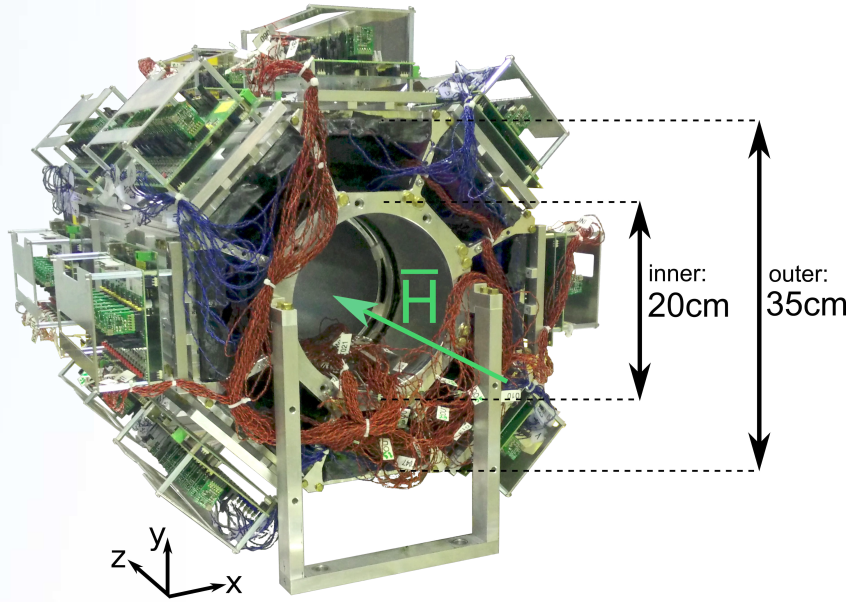
- 32 plastic scintillating bars per layer
- **tracking** secondary particles from antiproton annihilation, cosmic particles etc.

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

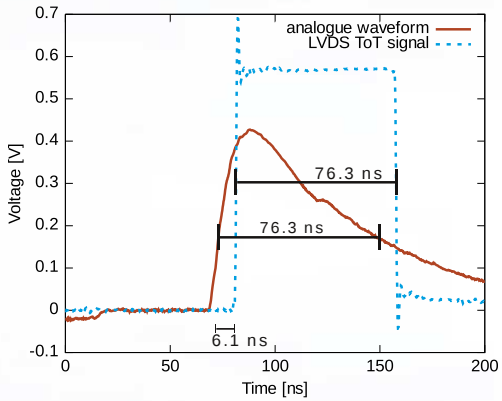
Tracking detector I

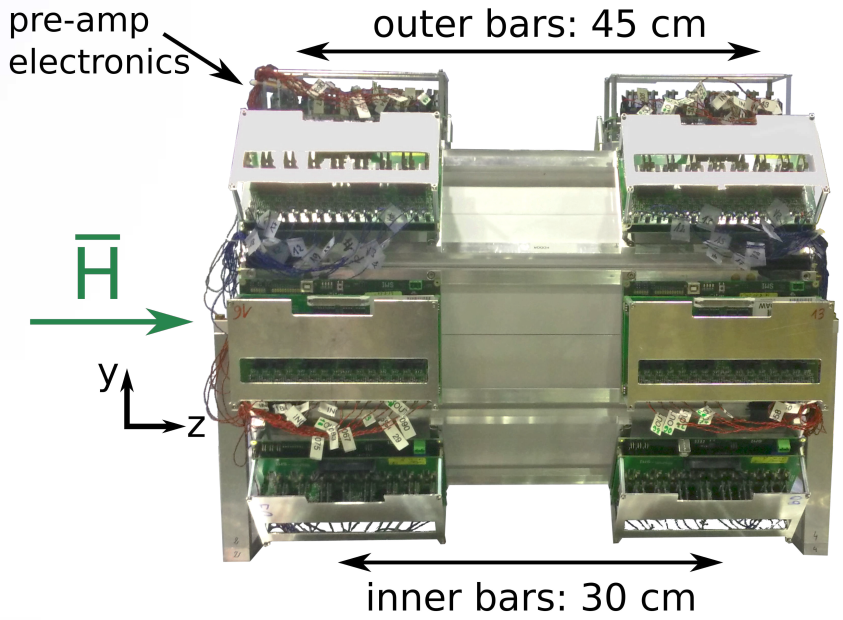
- scintillating light detection with **silicon photomultipliers** (SiPMs) on both ends of bars





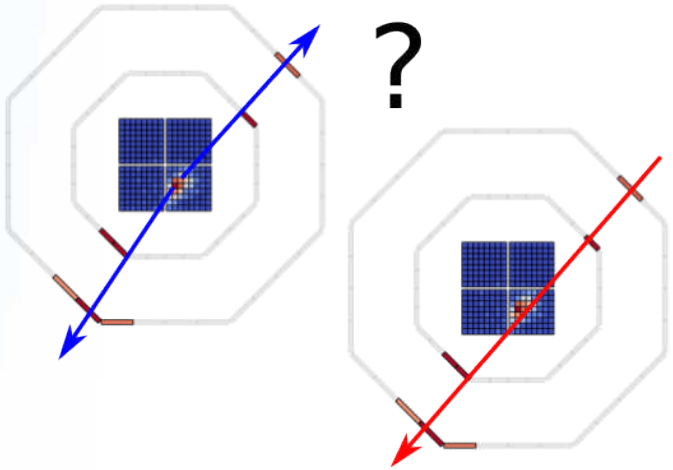
- SiPMs are read out and powered by preamplifier electronics
- record signals with waveform digitisers





Tracking detector II

- **time of flight**: diameter of outer hodoscope 35 cm → ToF possible with resolution < 600 ps, discriminate: particles from outside or inside detector! measured resolution:

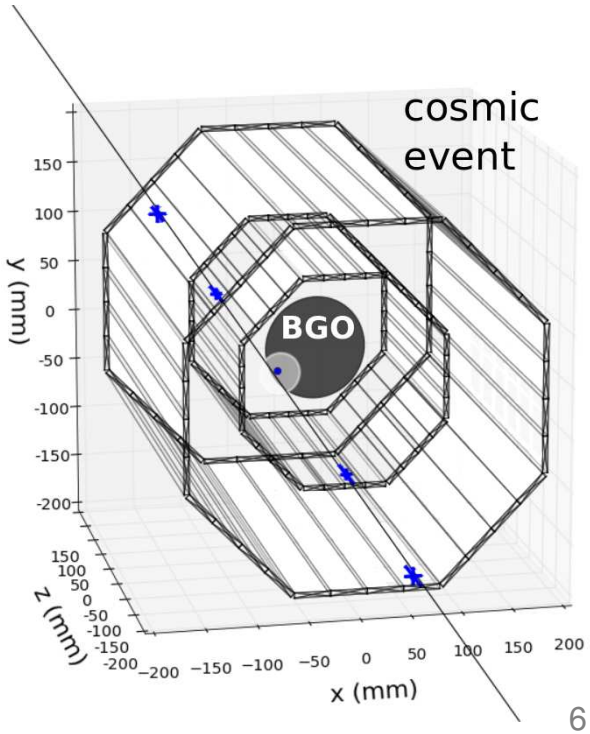


outer: 551 ± 5 ps (FWHM)
inner: 497 ± 3 ps

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

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

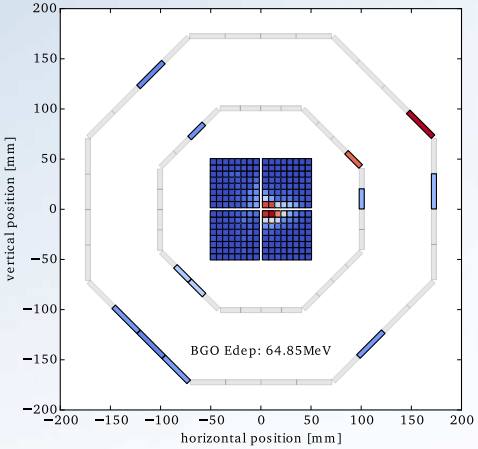
length of bars: inner: 30 cm, outer: 45 cm



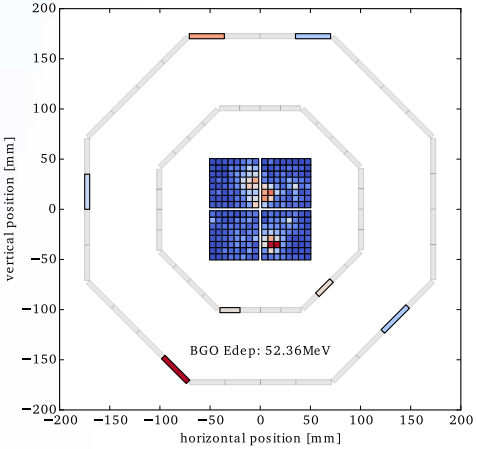
What do signal and background look like?

- **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

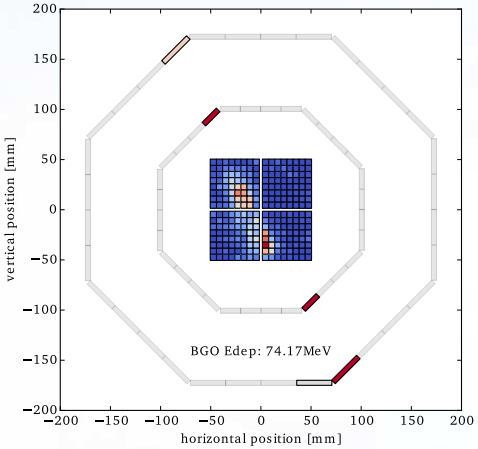
antiproton:



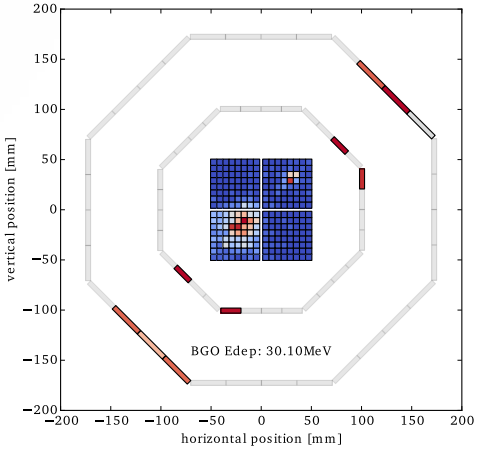
upstream annihil.:



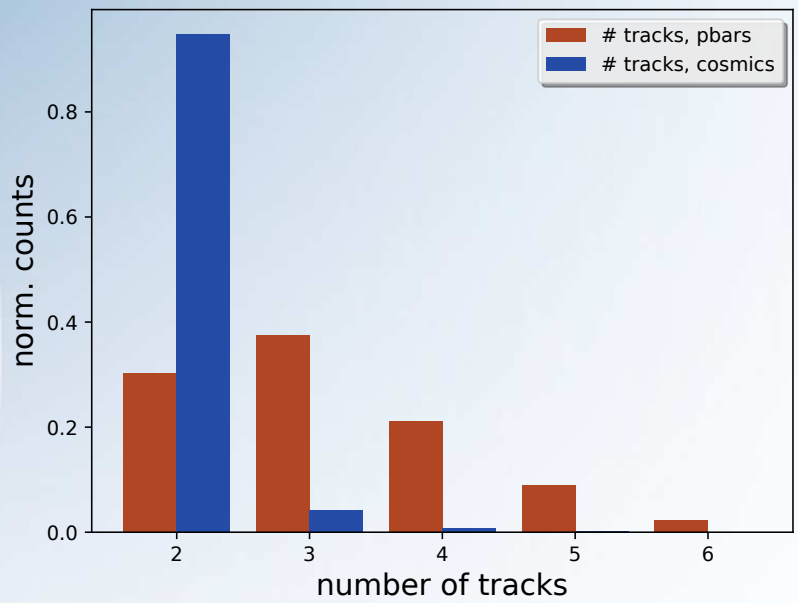
cosmic:

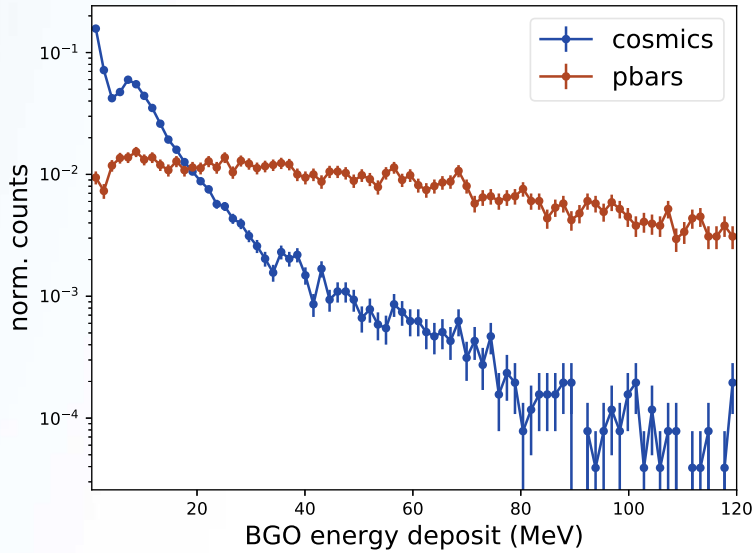


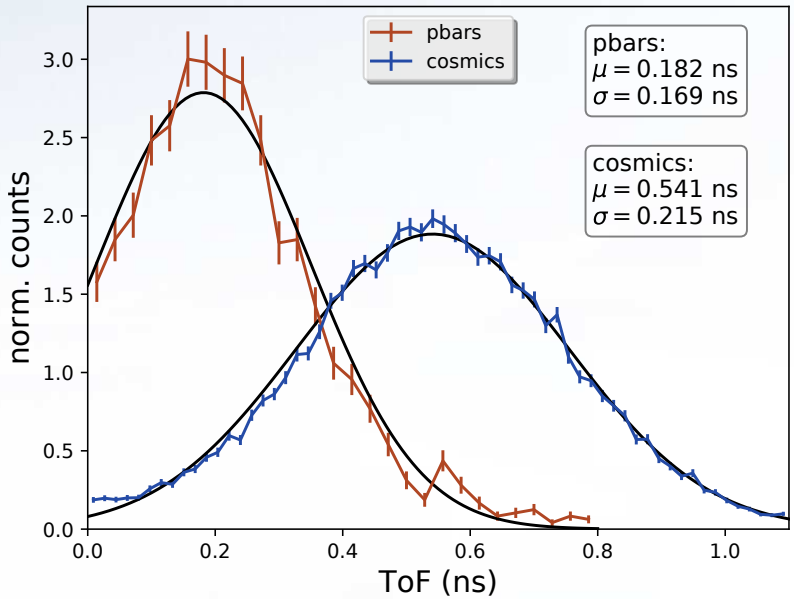
another cosmic:

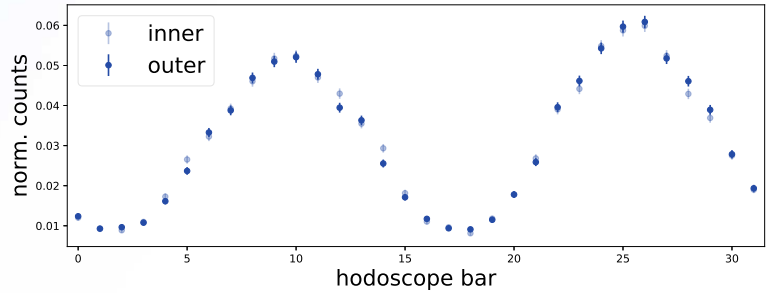


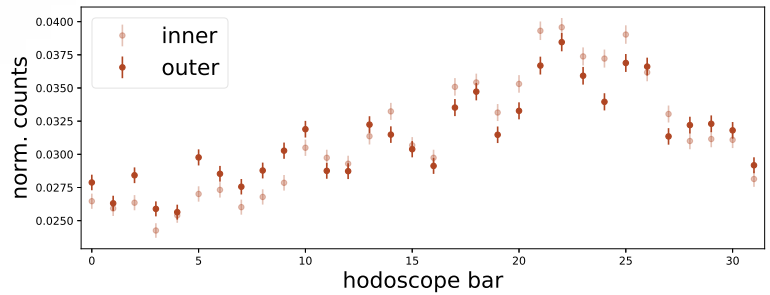
recorded $\bar{p}$ vs cosmics





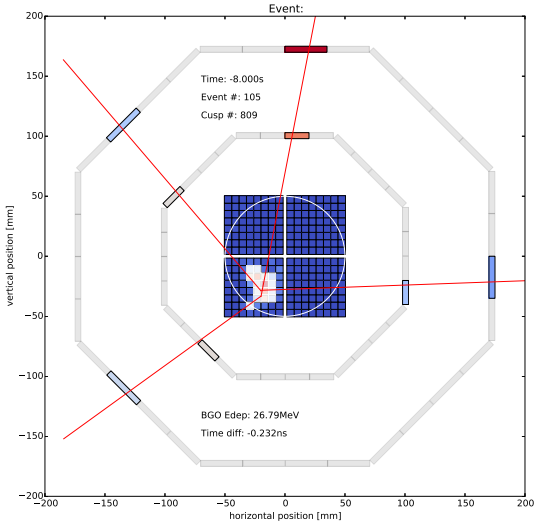






$\bar{H}$ identification

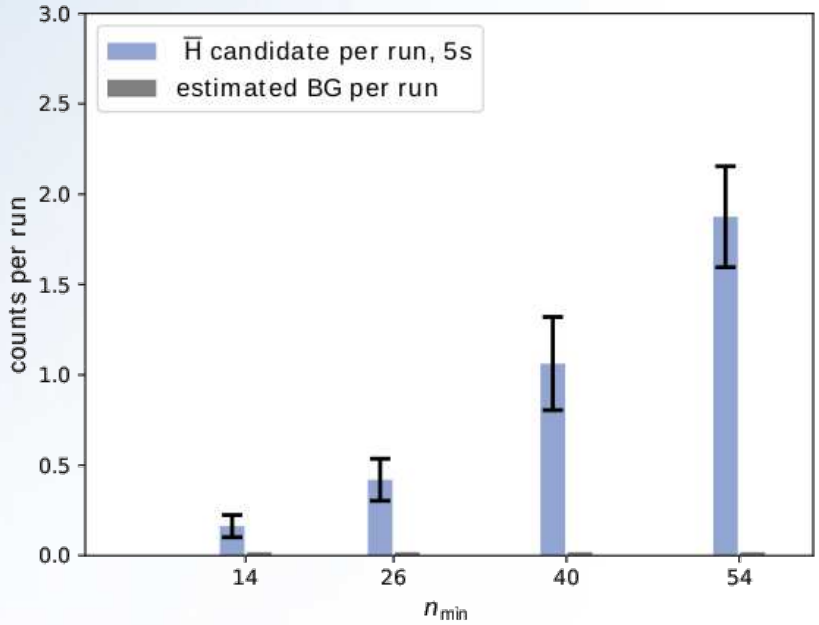
- $\rightarrow$ supervised **machine learning**: boosted gradient decision trees
- use **measured data** for training and testing
- $\approx$ 4000 $\bar{p}$ events, $\approx$ 30000 cosmic events
- careful **cuts to reduce background** in antiproton data $\rightarrow$ estimated cosmics left: 0.3% of signal data



- split into 2/3 training and 1/3 testing sample, several rounds of training and testing
- from the class predictions of the algorithm for the test sets:
  - **cosmic rejection**: (99.755 ± 0.015) %
  - **false positive rate**: $(0.00391 \pm 0.00025)\ /s$
  - **pbar efficiency**: (79.58 ± 0.79) %
- **identify antihydrogen events in mixing runs**

Identifying $\bar{H}$ candidates using machine learning (2016)

- quantum state distribution of $\bar{H}$ candidates

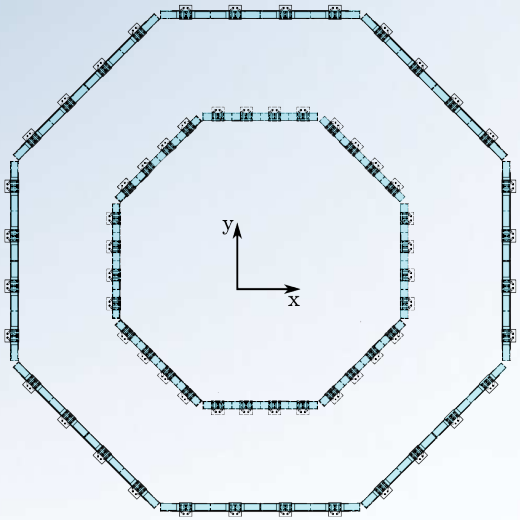


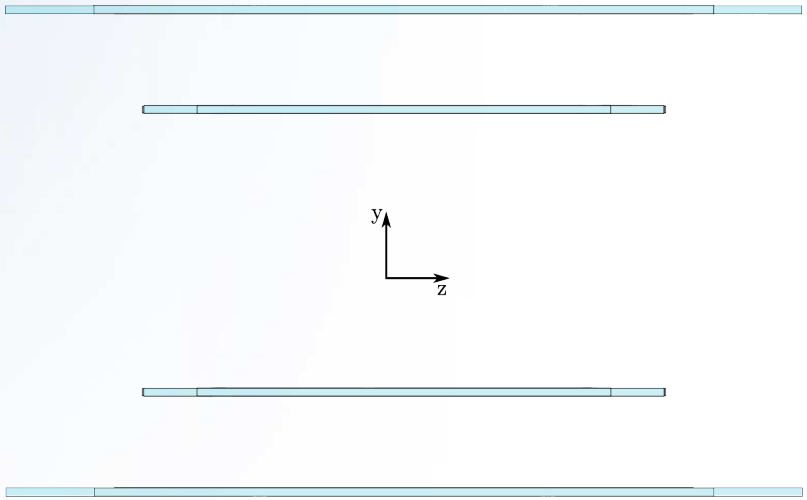
- field ioniser after mixing trap
- ionise atoms above principal quantum number n_{min}
- 0.16 counts per run for $n < 14$ (4.5σ)

Malbrunot, C. et al., Phil. Trans. R. Soc. A **376**, 20170273 (2018)

Tracking detector – upgrade using scintillating fibres I

- purpose: **increase position resolution in beam direction**



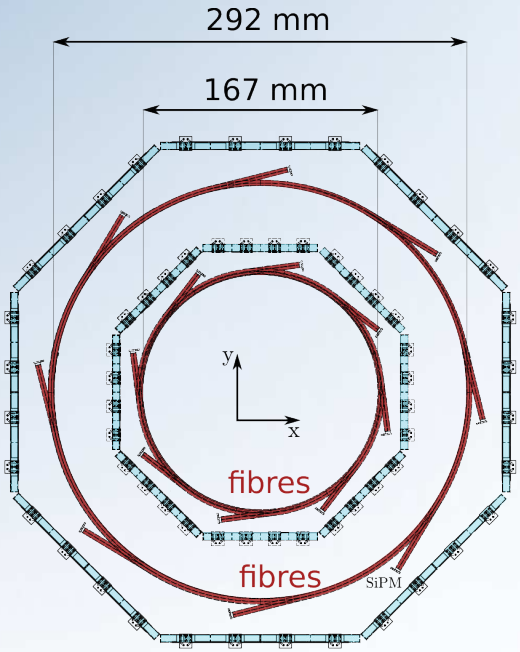


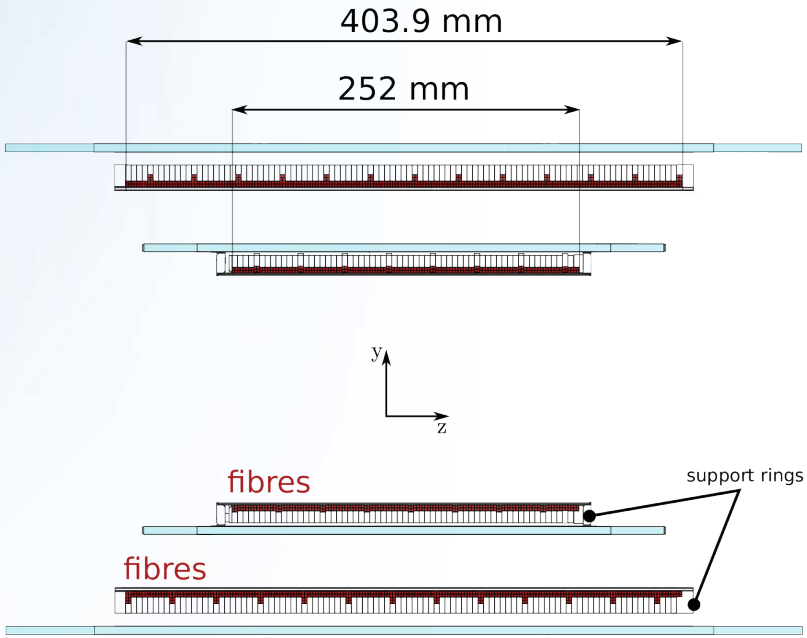
reminder:

- z resolution of bar hodoscope: $\approx$ 6 cm to 7 cm (FWHM)
- length inner bars: 30 cm, length outer bars: 45 cm

Tracking detector – upgrade using scintillating fibres I

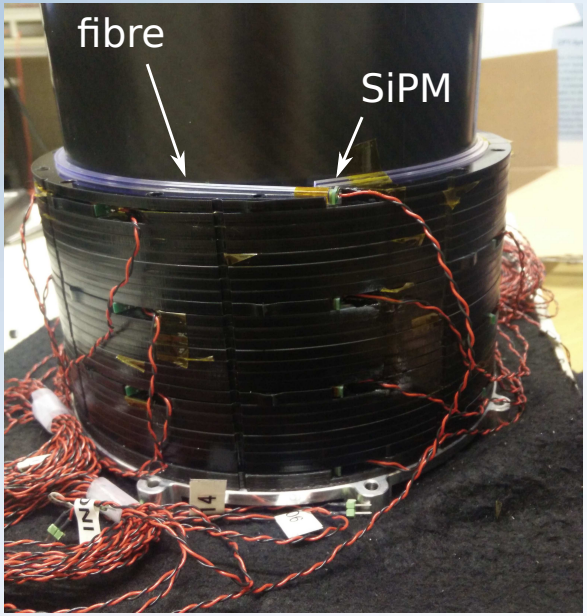
- purpose: **increase position resolution in beam direction**

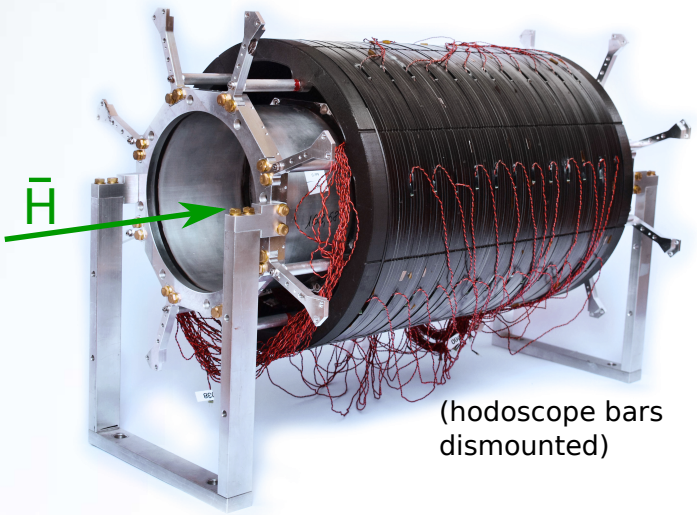




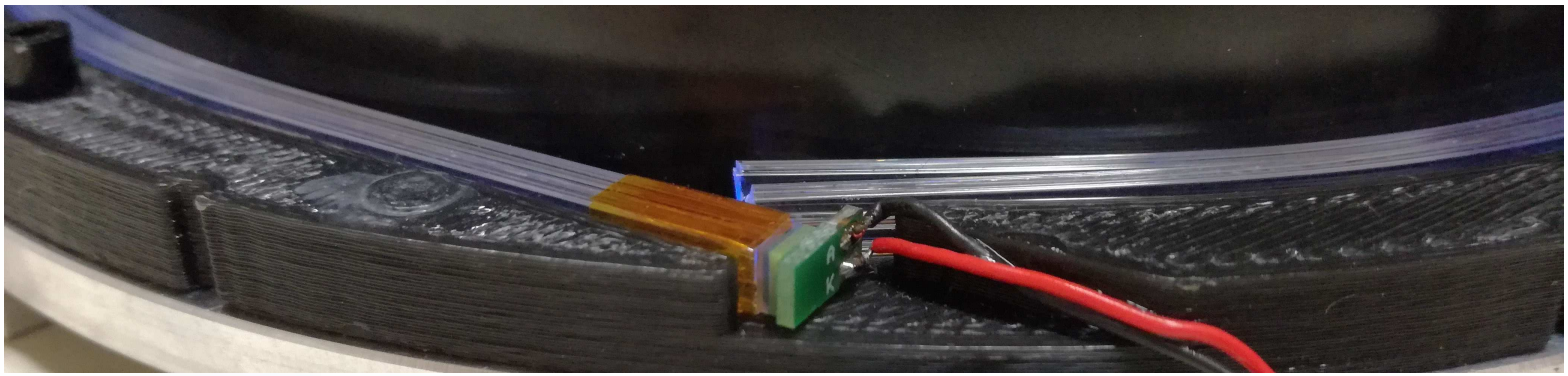
- 2 add. layers out of **fibres perpendicular to bars**
- 2×2 mm fibres, bundled into 4×4 mm bunches
- 1 turn around per bunch, read out by **SiPM on one end**
- outer: 100 ch, inner: 63 ch
- digital leading edge signal fed into **TDCs**, record timestamp and time-over-threshold

Tracking detector – upgrade using scintillating fibres II



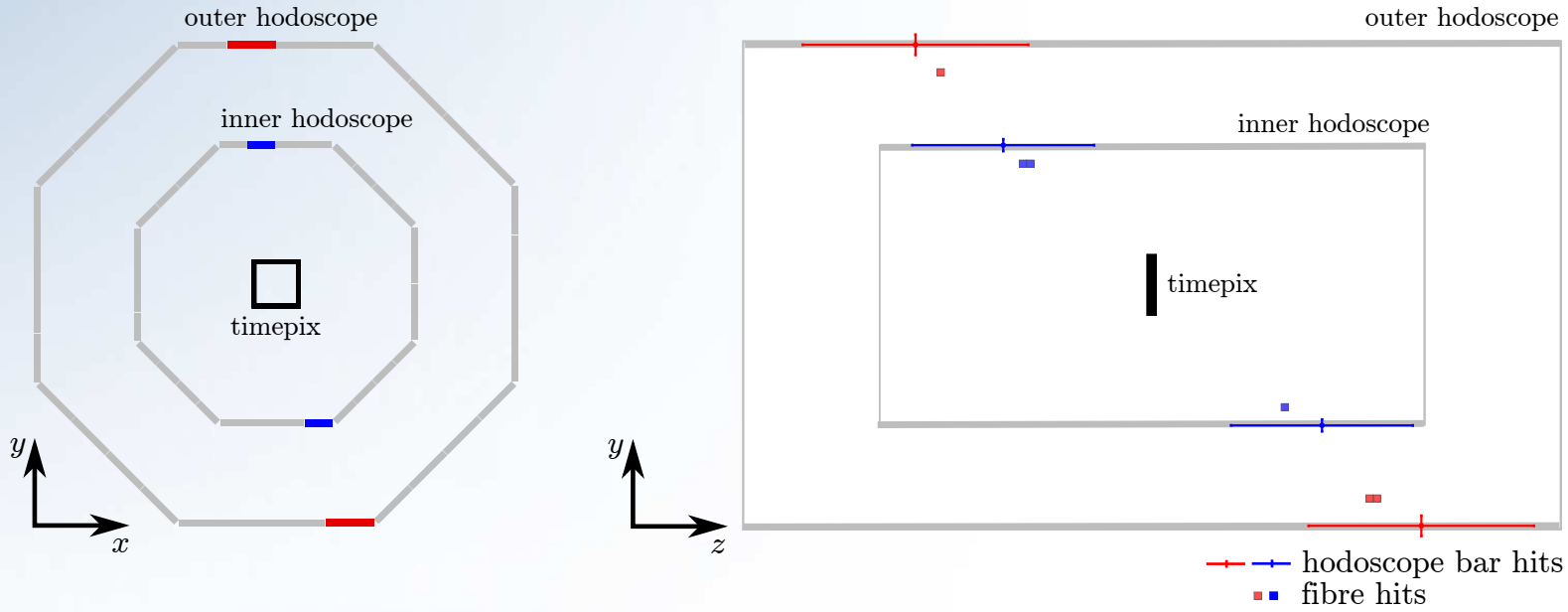


- **enables 3D tracking**: discriminate between straight tracks created by cosmics and tracks with a kink due to antiproton annihilations
- **precise vertex reconstruction**: helps to reject upstream annihilations, defocused high field seekers



Events in 3D – example cosmic event

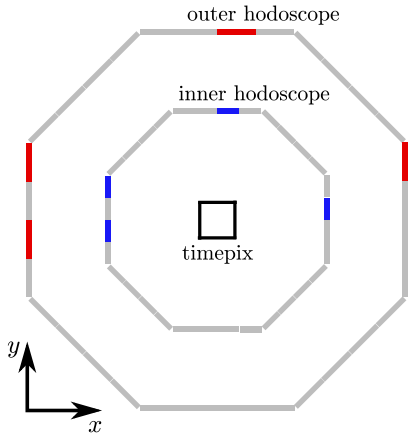
- 3D tracking on-going



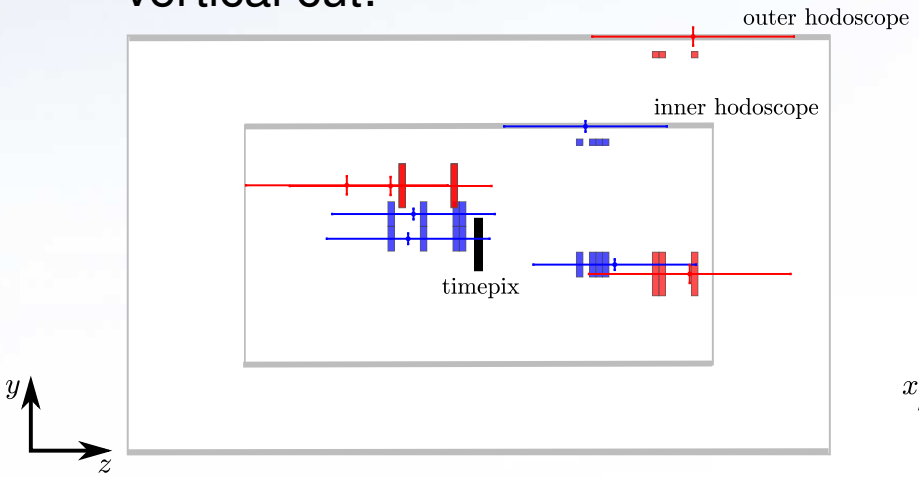
- inner layers: blue, outer layers: red
- crosses: bar hodoscope, width: z-resolution (2σ)
- squares: fibres with a hit
- consistency of sub-detectors and increased position resolution

Events in 3D – example $\bar{p}$ event

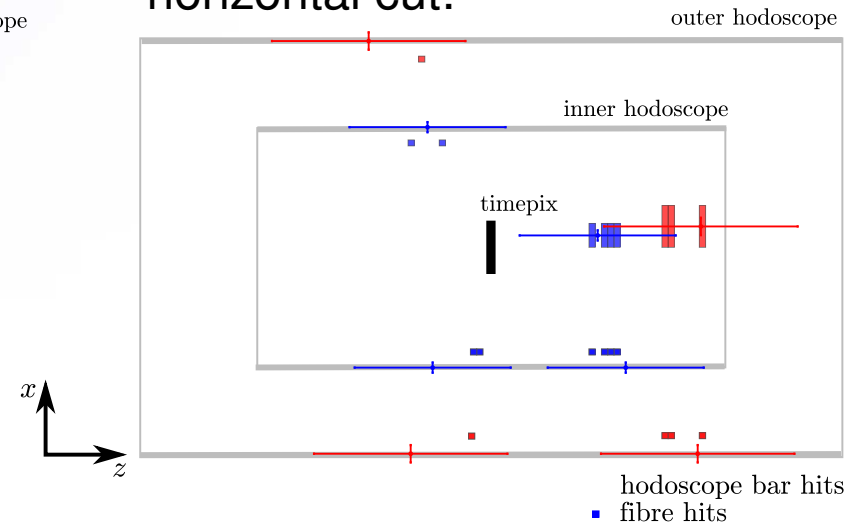
- preliminary matching of fibre with bar hits (no ϕ resolution of fibre detector)
- crosses: bar hodoscope, width: z-resolution (2σ)
- squares: fibres with a hit
- tracks drawn to guide eye



vertical cut:



horizontal cut:



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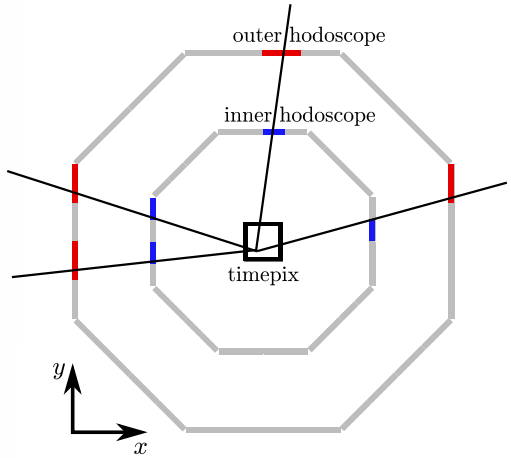

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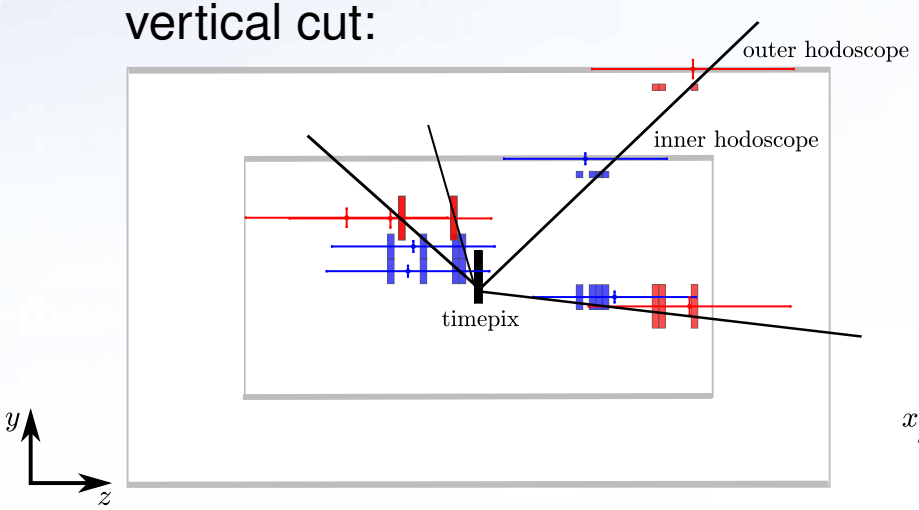

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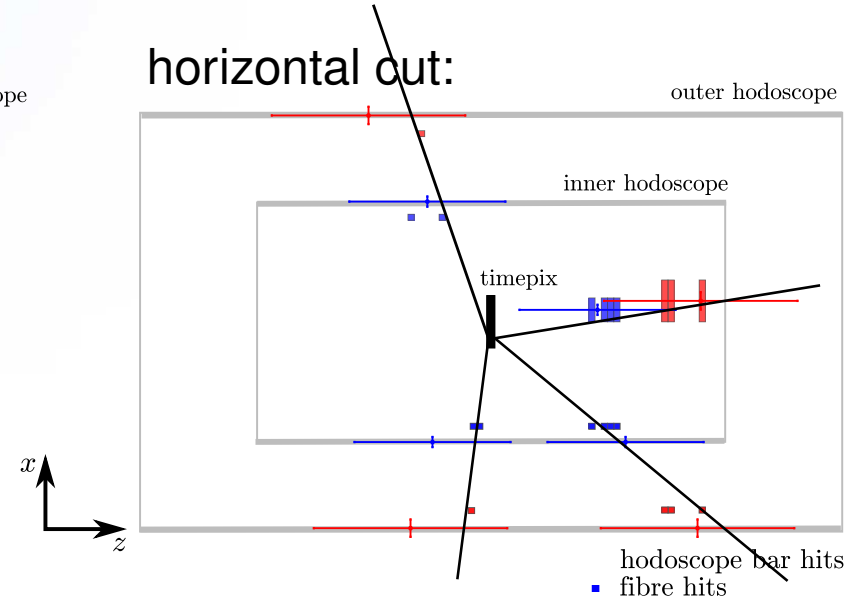

Summary

- ASACUSA detector for antihydrogen detection and its upgrade has been presented
- **data-driven machine learning** algorithm for signal and background identification
  - result: quantum state distribution
- **fibre upgrade** first time integrated into the experimental setup in 2017
  - enables 3D tracking for analysis (on-going)
  - discriminate against additional background sources (upstream annihil.)