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Development of nuclear emulsions with 1 μm spatial resolution for the AEgIS experiment

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ABSTRACT

The main goal of the AEgIS experiment at CERN is to test the weak equivalence principle for antimatter. We will measure the Earth's gravitational acceleration $\overline{g}$ with antihydrogen atoms being launched in a horizontal vacuum tube and traversing a moiré deflectometer. We intend to use a position sensitive device made of nuclear emulsions (combined with a time-of-flight detector such as silicon μ−strips) to

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CERN-AD
Photographic emulsions
AEgIS

measure precisely their annihilation points at the end of the tube. The goal is to determine $\bar{g}$ with a 1% relative accuracy. In 2012 we tested emulsion films in vacuum and at room temperature with low energy antiprotons from the CERN antiproton decelerator. First results on the expected performance for AEgIS are presented.

1. The AEgIS experiment

The main goal of the AEgIS experiment (CERN/AD6) is to test the weak equivalence principle (WEP) using antihydrogen ($\overline{H}$). This principle of the universality of free fall has been tested with tremendous precision for matter, but not with antimatter particles, due to major technical difficulties related to stray electric and magnetic fields. In contrast, the electrically neutral $\overline{H}$ atom is an ideal probe to test the WEP and the antiproton decelerator at CERN is a worldwide unique antihydrogen factory. In AEgIS the gravitational deflection of $\overline{H}$ atoms launched horizontally and traversing a moiré deflectometer will be measured with a precision of 1% on $|\Delta g|/g$, using a position sensitive annihilation detector [1]. The required position resolution should be a few μm to achieve the 1% goal.

As we discuss in this paper, the antihydrogen annihilation point can be determined in a novel application of emulsion films [2] using the techniques applied to the OPERA experiment [3]. This is the first time that nuclear emulsions will be used in vacuum. The vertical precision on the measured annihilation point will be about 1 μm, an order of magnitude better than proposed originally with silicon μ−strip detectors [1]. Fig. 1 shows the principle of the experiment and the estimated number of annihilations needed to reach a given precision on $\bar{g}$, as a function of position resolution.

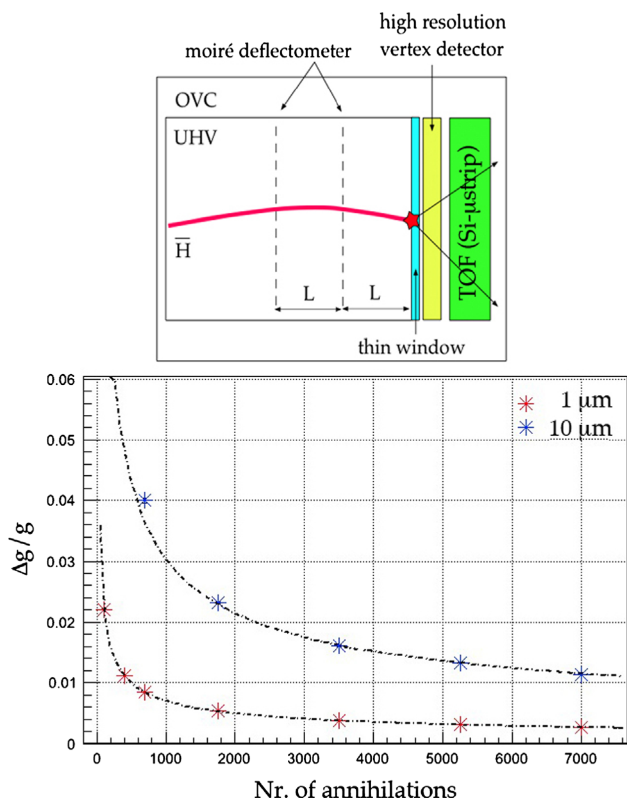

Fig. 1. Top: Schematics of the AEgIS detectors. The vertex detector is made of nuclear emulsions. The time-of-flight detector (TOF) is needed to measure the velocities of the $\overline{H}$ atoms. The thin window limits the position resolution (due to multiple scattering), but is needed to separate the ultra-high vacuum (UHV) part from the outer vacuum region (OVC) containing the emulsion films. Bottom: $\Delta g/g$ vs. number of particles for a vertex resolution of 1 μm (red) and 10 μm (blue). (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

2. Nuclear emulsions

Nuclear emulsions [4] are photographic films with extremely high spatial resolution, better than 1 μm. A track produced by a charged particle is detected as a sequence of silver grains (Fig. 2), where about 36Ag grains per 100 μm are created by a minimum ionizing particle. The intrinsic spatial resolution is about 50 nm. In recent experiments such as OPERA [3], large area nuclear emulsions were used thanks to the impressive developments in automated scanning systems.

For AEgIS, we developed nuclear emulsions which can be used in ordinary vacuum (OVC, 10^{-5}–10^{-7} mbar). This opens new applications in antimatter physics research. We performed exposures with stopping antiprotons in June and December 2012. A sketch of the experimental setup is shown in Fig. 3. The emulsion detector consisted of five sandwiches made of emulsion films deposited on both sides of (200 μm thick) plastic substrates ($68 \times 68 \times 0.3$ mm^3).

A thin foil will be needed in the gravity measurement as a window to separate the $\overline{H}$ beam line at UHV pressure from the

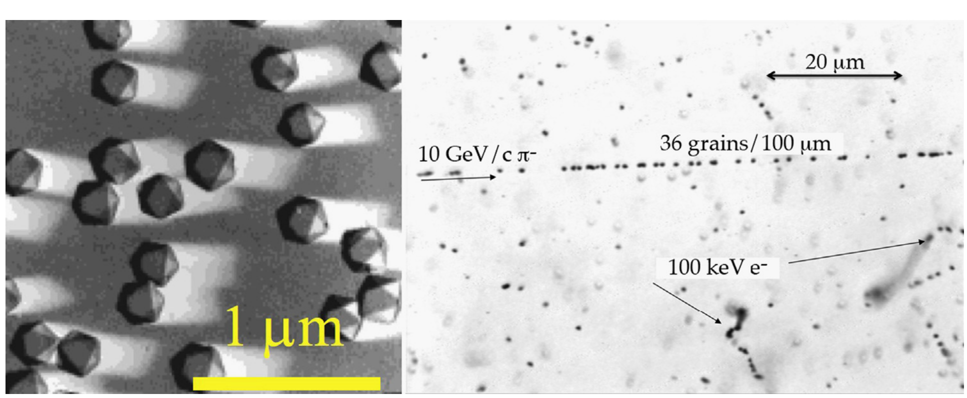

Fig. 2. Left: AgBr crystals in emulsion layers observed with a scanning microscope. Right: A minimum ionizing track from a 10 GeV/c pion.