Development of nuclear emulsions with 1 µm spatial resolution for the AE*g*IS experiment

M. Kimura on behalf of the AE*g*IS collaboration.

Albert Einstein Center for Fundamental Physics, Laboratory for High Energy Physics, University of Bern
Contact e-mail: mitsuhiro.kimura@lhep.unibe.ch

The AE*g*IS experiment

The goal of the AE*g*IS experiment (CERN AD6) is to test the Weak Equivalence Principle (WEP) using antihydrogen ($\bar{H}$). The gravitational sag of a $\bar{H}$ beam will be measured with a precision of 1% on $\Delta g/g$ by means of a moiré deflectometer and a position sensitive annihilation detector. The required position resolution should be a few µm to achieve the 1% goal.

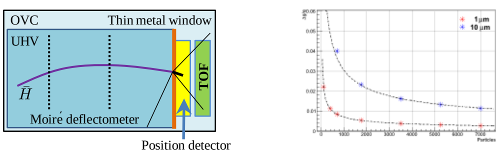

Fig.1 *Left*: Schematic view of the AE*g*IS detectors. *Right*: $\Delta g/g$ vs. number of particles for a position sensitive detector resolution of 1 µm (red) and 10 µm (blue).

Nuclear emulsions

Nuclear emulsions are photographic film with extremely high spatial resolution, better than 1 µm. In recent experiments such as OPERA, large area nuclear emulsions were used thanks to the impressive developments in automated scanning systems. For AE*g*IS, we developed nuclear emulsions which can be used in ordinary vacuum (OVC, $10^{-5\sim-7}$ mbar). This opens new applications in antimatter physics research.

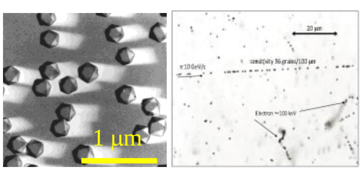

Fig. 2. *Left*: AgBr crystals in emulsion layers observed by SEM. *Right*: A minimum ionizing track (MIP) of a 10 GeV/*c* pion.

Exposure of nuclear emulsions to stopping antiprotons

We performed exposures with stopping antiprotons in June and December, 2012. The emulsion detector consisted of sandwiches each made out with 10 films on five double sided plastic substrates (68 x 68 x 0.3 mm^3) .

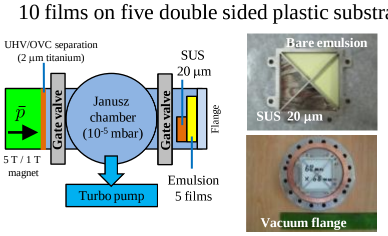

Fig. 5. *Left*: Schematic view of the detector setup. *Upper right*: Emulsion holder. *Lower right*: Emulsion detector attached to the vacuum flange by a crossed bar frame.

The 3D tracking and annihilation vertex reconstruction were performed at the University of Bern. Annihilation stars were observed together with tracks from nuclear fragments, protons, and pions. From the measured impact parameters a spatial resolution of ~1 µm on the vertical position of the annihilation vertex can be achieved.

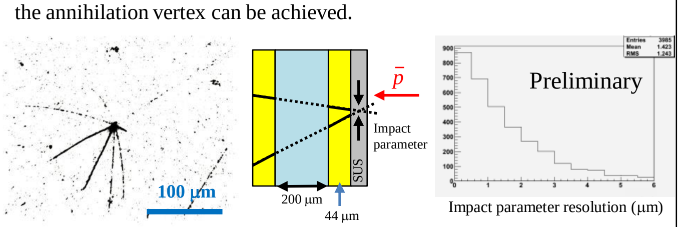

Fig.6. *Left*: A typical antiproton annihilation vertex in the emulsion layer.
Middle: Definition of the impact parameter.
Right: Impact parameter resolution with a window of 20 µm stainless steel (SUS).

Reference

C. Amsler *et al.*, 'A new application of emulsions to measure the gravitational force on antihydrogen'., JINST (in press), arXiv:1211.1370.

Emulsion in high vacuum

Experiments with emulsions under high vacuum have not been performed so far. We therefore tested their behavior in respect to such conditions. Water loss in the gelatine can produce cracks in the emulsion layer compromising the mechanical stability (µm level needed). Therefore we developed glycerine treatment to avoid this effect. Glycerine can efficiently prevent the elasticity loss in the emulsion (see fig. 3).

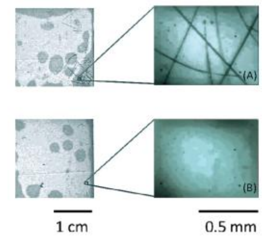

Fig. 3. Emulsion films after 3.5 days in the vacuum chamber without glycerine treatment (A) and with treatment (B).

Emulsion properties after glycerine treatment

Since the glycerine treatment changed the composition of the emulsion layer, we investigated :

- The detection efficiency per AgBr crystal with 6 GeV/*c* pions
- The background in terms of the *fog density* (the number of noise grains per 10^3 µm^3)

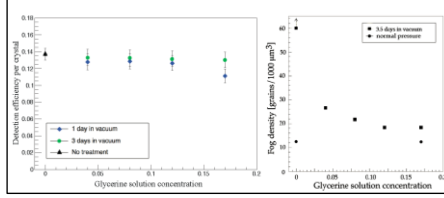

Fig. 4. *Left*: Crystal sensitivity vs. glycerine concentration. *Right*: Fog density vs. glycerine content for films kept in vacuum for 3.5 days (square), compared to atmospheric pressure(dots).

Proof of principle using a miniature moiré deflectometer

We irradiated emulsion films with antiprotons passing through a small moiré deflectometer. The simulation below shows as an example the expected interference pattern at the emulsion layer, generated by a pair of gratings (12 µm slit, 40 µm pitch, separated by 25 mm). The antiproton data is being analyzed and preliminary results are encouraging.

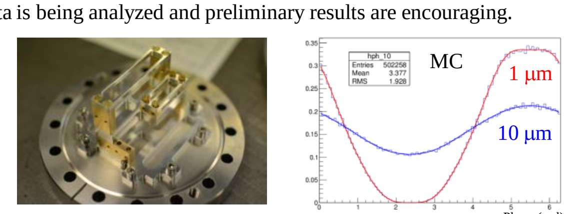

Fig. 7. *Left*: Holder of the miniature moiré deflectometer. *Right*: **Simulated** intensity distribution of reconstructed vertices with position resolutions of 1 µm (red) and 10 µm (blue).

Glass-based films with highly sensitive emulsions

Annihilation products from annihilating $\bar{H}$ will be isotropically distributed. Since MIP tracks at large incident angles reduce the track finding efficiency in our automatic scanning system, we are presently investigating new emulsions with increased sensitivity. They were developed at Nagoya University (Japan) and then coated onto glass substrates in Bern. Glass is well suited for highest position resolutions thanks to its superior environmental stability (temperature and humidity), as compared to plastic.

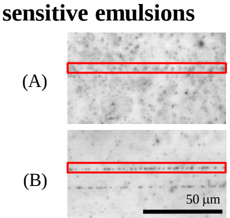

Fig.8. A 10 GeV/*c* pion track in the reference film (A) and in a highly sensitive one (B).

Gel type	Development time [min]	Grain density [grains/100 µm]	Fog density [grains/µm^3]
OPERA	25	30.3 ± 1.6	10.1 ± 0.7
Nagoya	20	47.7 ± 2.0	1.9 ± 0.2
Nagoya	25	55.1 ± 2.6	3.0 ± 0.3

Tab.1. Comparison between the reference films (OPERA) and the new emulsions (Nagoya University).