Test of Weak Equivalence Principle on Antimatter in AEgIS

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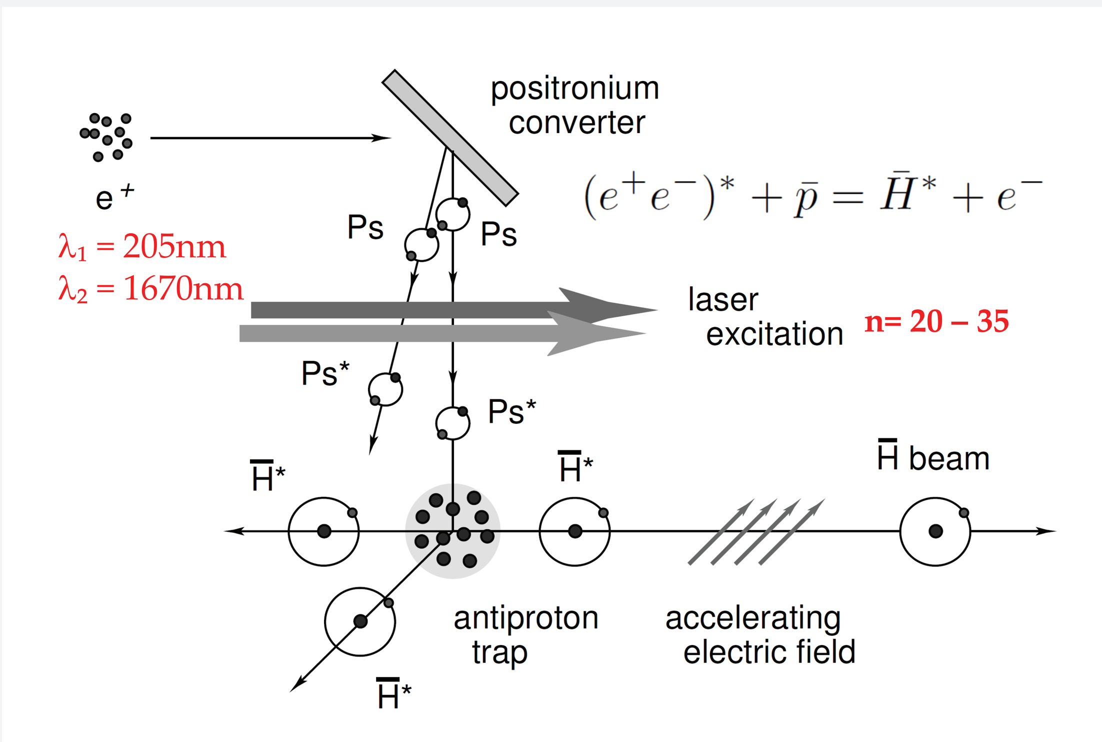
Introduction

Antimatter Experiment: Gravity, Interferometry and Spectroscopy (AEGIS) is an experiment located at the Antiproton Decelerator ring at CERN, Geneva. The goal of the first phase of the experiment is to measure within a 1% precision the local gravitational acceleration g on antihydrogen in the gravitational field of the Earth and testing in a direct way the weak equivalence principle on antimatter [2,3].

AEgIS will make use of pulsed production of antihydrogen using the charge-exchange reaction of antiprotons with laser-excited Rydberg positronium, created by an impact of positrons on a converter target. Using the Stark acceleration of antihydrogen we will create a neutral antimatter beam [4] and observe the shift of this beam due to the gravity on a position sensitive detector.

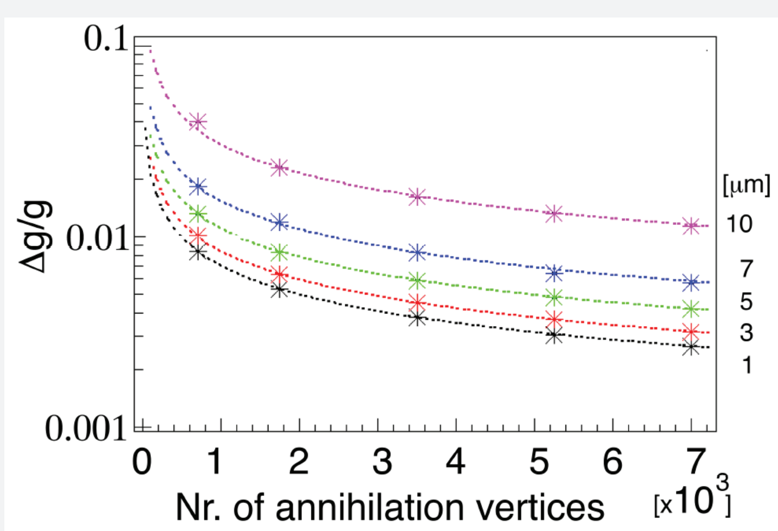


Schematic of pulsed beam formation: Antihydrogen is produced via charge exchange reaction between antiprotons and excited ortho-positronium. Immediately after, an electric field gradient is switched on to accelerate the cold antihydrogen in the direction of the gravity detector.

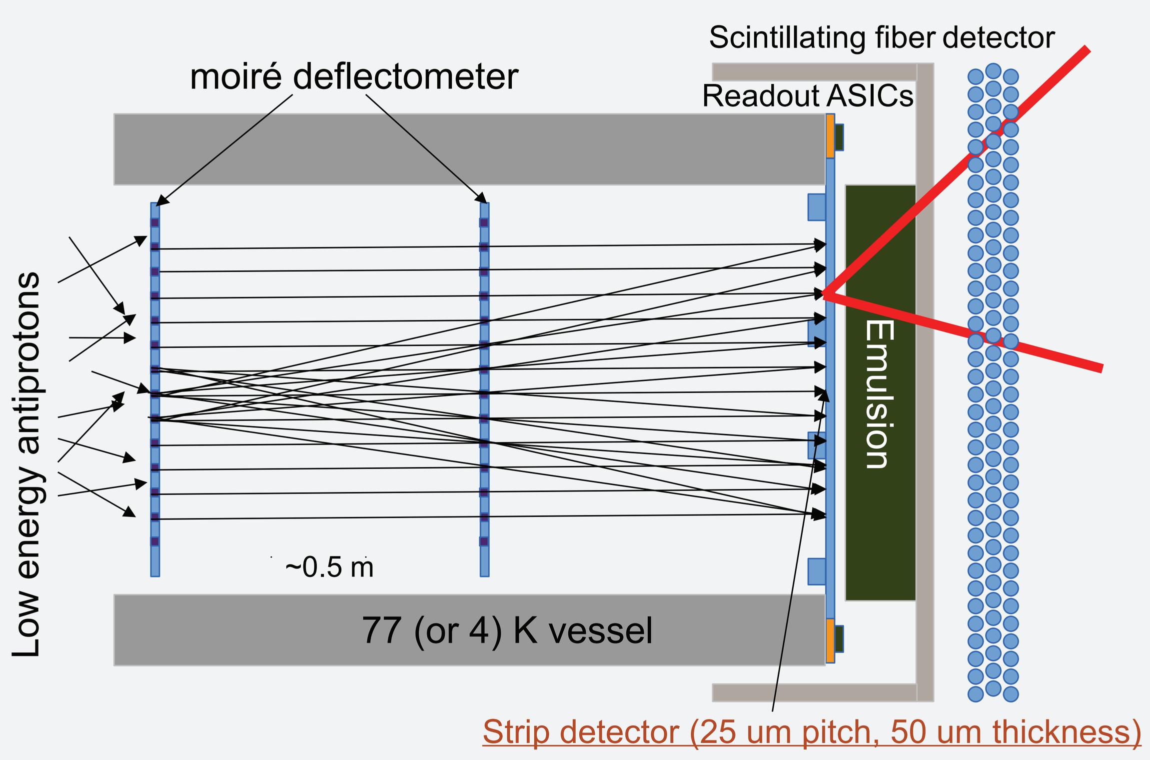
Moiré deflectometer and gravity measurement

Atom interferometeric measurement for antihydrogen is currently unachievable since it would require a highly collimated anti-atomic beam (T in the µK range). AEgIS will use a classical counterpart to the atomic interferometer the *moiré deflectometer*, where two identical gratings with 40 µm pitch create a shadow image of the particle beam. This device does not need a point-like, monochromatic and neither collimated beam. Measurement of g with a deflectometer and Ar atoms has reached precision better than 1% [5]. In AEgIS instead of a third grating that is used in matter research a position sensitive hybrid detector (with a resolution better than 10 µm) will be used to directly detect the annihilations on its surface.

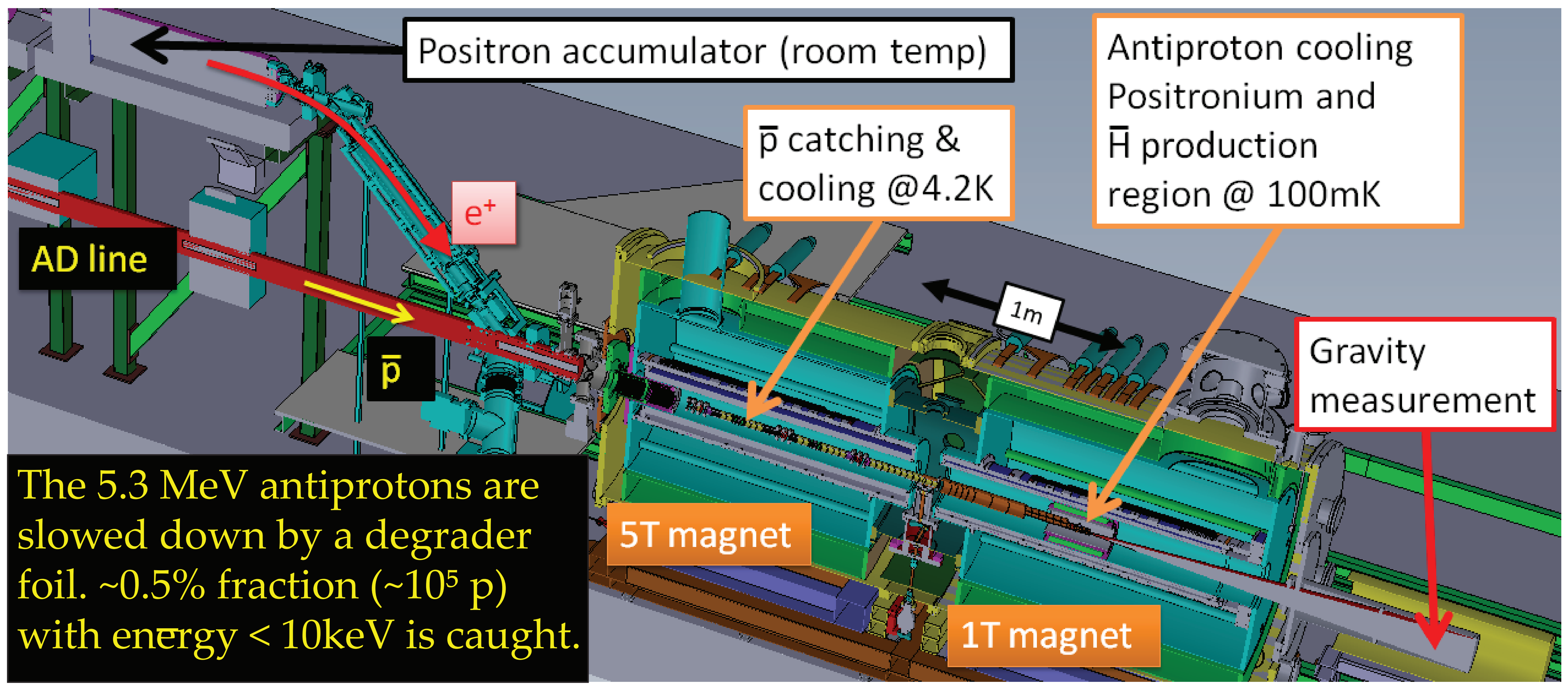
Using the time-of-flight (from the Stark acceleration start time and the hit time on the detector) and the vertical shift of antihydrogen Δy, we can measure g of antihydrogen. To achieve 1% relative precision it will be necessary to record at least ~10^3 antihydrogen atoms at the gravity detector if its vertex resolution is 3µm.



Simulation of precision on g vs. number of detected antihydrogen annihil. vertices [6]



AEgIS gravity module: moire' deflectometer and a position sensitive hybrid detector composed of thin Si-strip detector, a nuclear emulsion and a scintillating fiber tracker. [7] Moiré deflectometer creates a "shadow" pattern whose shift due to the gravity is measured precisely with an emulsion. Si and fiber trackers serve to record the time and a rough position of each annihlation and also increase the overall reconstruction efficiency.



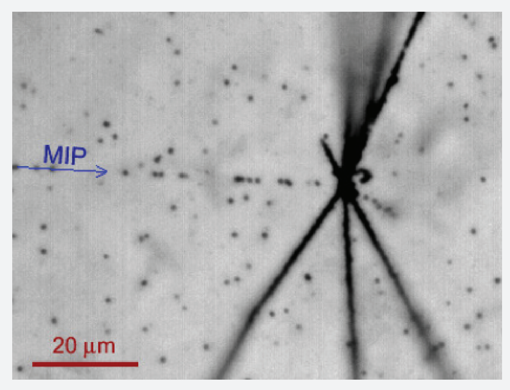
Nuclear emulsions in vacuum

The emulsion detection technology with modern readout techniques offers unprecedented antiproton annihilation vertex resolution and thus is being investigated by the AEgIS collaboration. Due to the stringent requirement on the XHV vacuum of the cryogenic AEgIS antiproton trap system the nuclear emulsion of the hybrid position sensitive detector has to be separated from the antihydrogen beam by a thin foil. We have measured [6] that if the emulsion is covered even with a 20 µm stainless steel foil, the vertex recnstruction precision is of the order of 1 µm.

	Si		Ti	
Gap [µm]	σ [µm]	ε [%]	σ [µm]	ε [%]
0	1.0	53	0.8	45
100	1.4	49	1.3	44
250	2.2	46	1.9	41
500	2.9	41	2.8	37
1000	4.2	37	4.2	33
0	1.1	46	0.8	41
100	1.5	44	1.2	39
250	2.1	41	1.6	35
500	2.5	37	2.2	33
1000	3.7	34	2.9	30

Table of simulated vertex resolution σ and reconstruction efficiency ε of emulsion detector for 50µm Si or 5µm Ti window of AEgIS hybrid detector. (Gap is the distance of the emulsion from the vacuum sep. window)

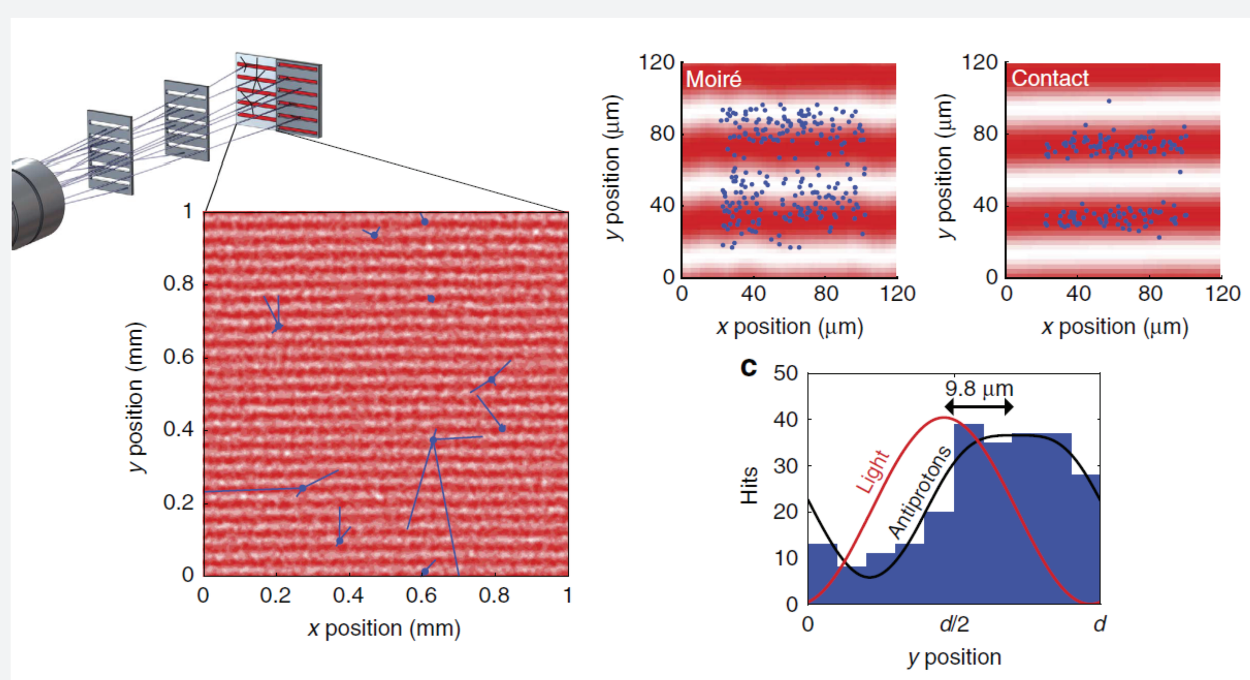
Antiproton annihilation in a newly developed nuclear emulsion for in-vacuum use



Proof-of-principle measurement

During the 2012 beam-time a miniature version of the moiré deflectometer was tested on slow (100 keV) antiproton beam in AEgIS [8]. Gratings with 40 µm pitch and 25mm spaced apart were used. Part of the antiproton beam passed through the deflectometer and its moiré pattern was detected by a nuclear emulsion and a part of the beam passed directly onto part of the emulsion covered with a contact grating of the same pitch. By shining a light through the deflectometer it was possible to identify a shift of the antiproton pattern due to a Lorentz force of the order of 500aN. Even though this force is orders of magnitude higher than what is necessary for a gravity measurement, the absolute value of the shift measured (Δy = 9.8 µm) is sufficient for an antihydrogen gravity measurement.

In addition, new techniques like light referencing has been developed, which allows for significant systematic error reduction.



References

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[7] S. Aghion et al. (AEgIS Collaboration), JINST 9 P06020 (2014)
[8] S. Aghion et al. (AEgIS Collaboration), Nature Communications 5 (July 2014)

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