DOES ANTIMATTER FALL LIKE MATTER? : THE GBAR EXPERIMENT (CERN)

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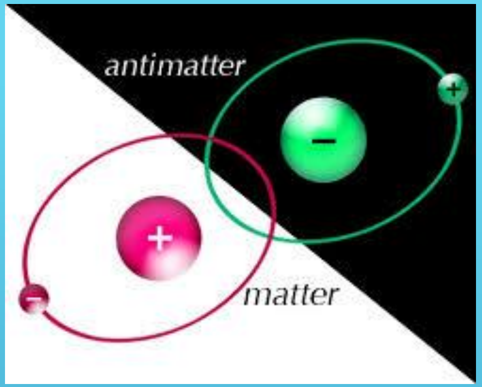
Antimatter and gravity

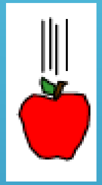


In 1928, Paul Dirac predicted the existence of antiparticles with the same mass as particles and an opposite charge .

$$i\hbar\gamma^\mu \partial_\mu \psi - mc\psi = 0$$

One of the main questions of fundamental physics is the asymmetry between matter and antimatter observed in the universe, and the action of gravity on antimatter.

« Does antimatter fall like matter ? »



Arguments in favor of gravity:

- Antigravity violates conservation of energy and vacuum is unstable (*Morrison, 1958*).
- Positive energy theorem in GR (*Witten, 1981*).
- Other arguments in (*Nieto, 1991* and *Adelberger, 1991)*.

Arguments in favor of antigravity:

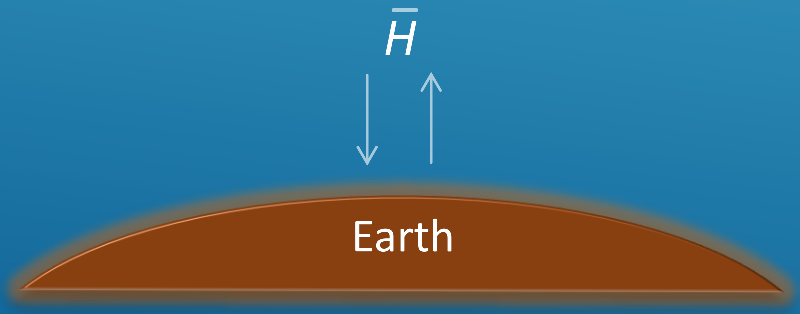
- We can build negative mass solutions that respect the equivalence principle (*Bondi, 1957*).
- Is compatible with GR and would indicate that antimatter has a negative gravitational mass <0.
- Could explain the asymmetry matter/antimatter in the universe (*G. Chardin, 1997*).
- Bimetric theories (*Hossenfelder, 2008*).

GBAR experiment: principle and motivations

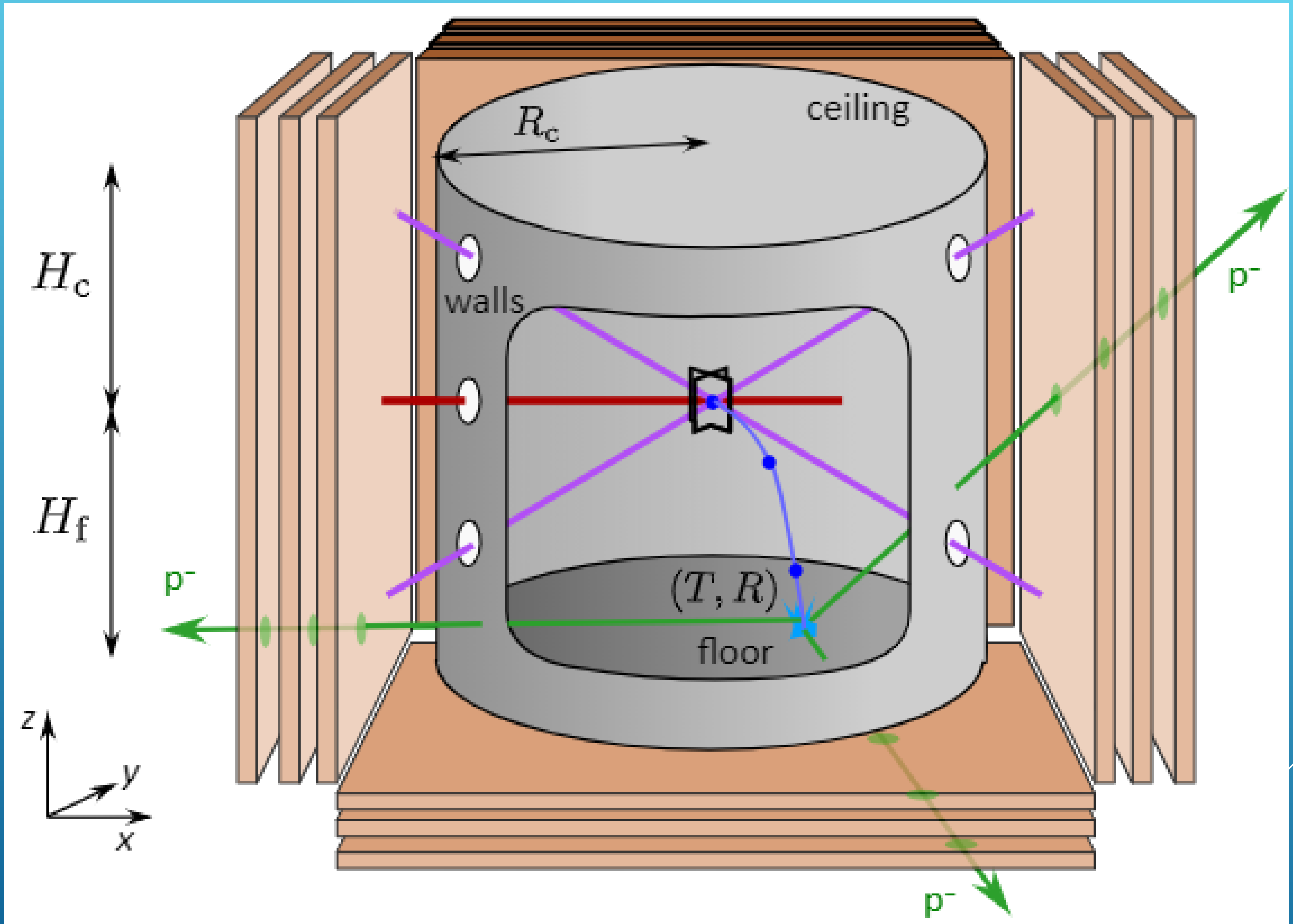
Sign of gravity acceleration not yet known experimentally, with bound: $-65 \leq \bar{g}/g \leq 110$

(*Alpha Collaboration, 2013*)

GBAR collaboration: *Gravitational Behaviour of Antihydrogen at Rest*
(LKB, ETHZ, ILL Grenoble and other labs)
Goal: measuring the acceleration $\bar{g}$ of ultracold antihydrogen atoms during a free fall in Earth's gravitational field, with 1% precision.
https://gbar.web.cern.ch/public/



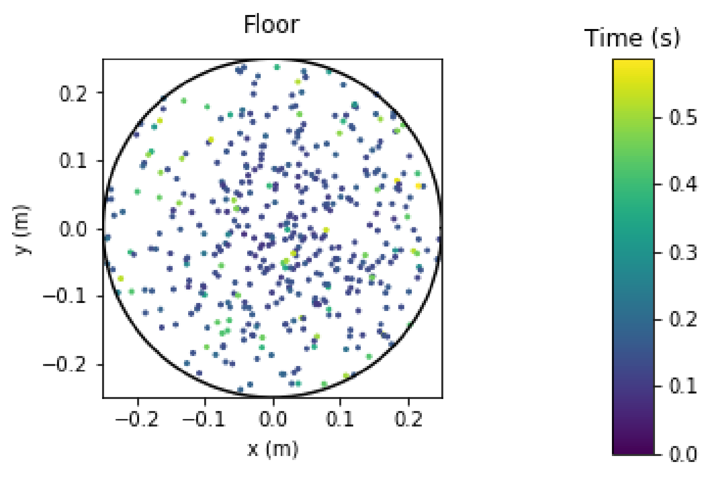
GBAR free fall chamber (initial geometry)



The free fall acceleration $\overline{g}$ is deduced from a statistical analysis of annihilated events.

Monte-Carlo analysis (same scheme as an experimentalist)

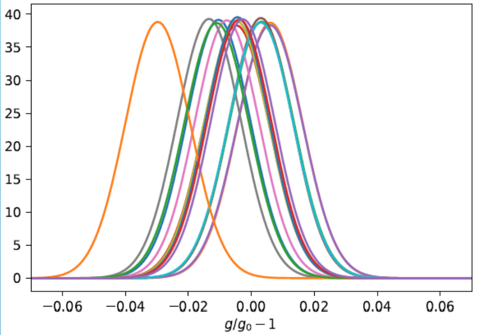
N=1000 antiatoms



Generation of *N* events (with $g_0 = 9.81$ m/s²)

Likelihood

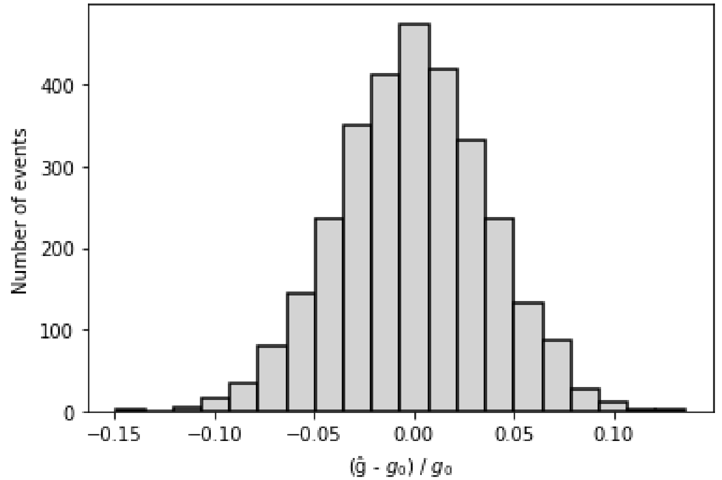
$$\mathcal{L}(g) = \prod_{i=1}^{N} J_g(x_i, y_i, z_i, t_i).$$



$$\hat{g} = \frac{\int g\mathcal{L}(g)dg}{\int \mathcal{L}(g)dg}.$$

Mean likelihood estimator

Repeated *M* times



Distribution of $\hat{g}$

Average: μ_g

Relative uncertainty: σ_g / g_0

Not biased: $\mu_g - g_0 < \sigma_g$

Effects of design parameters

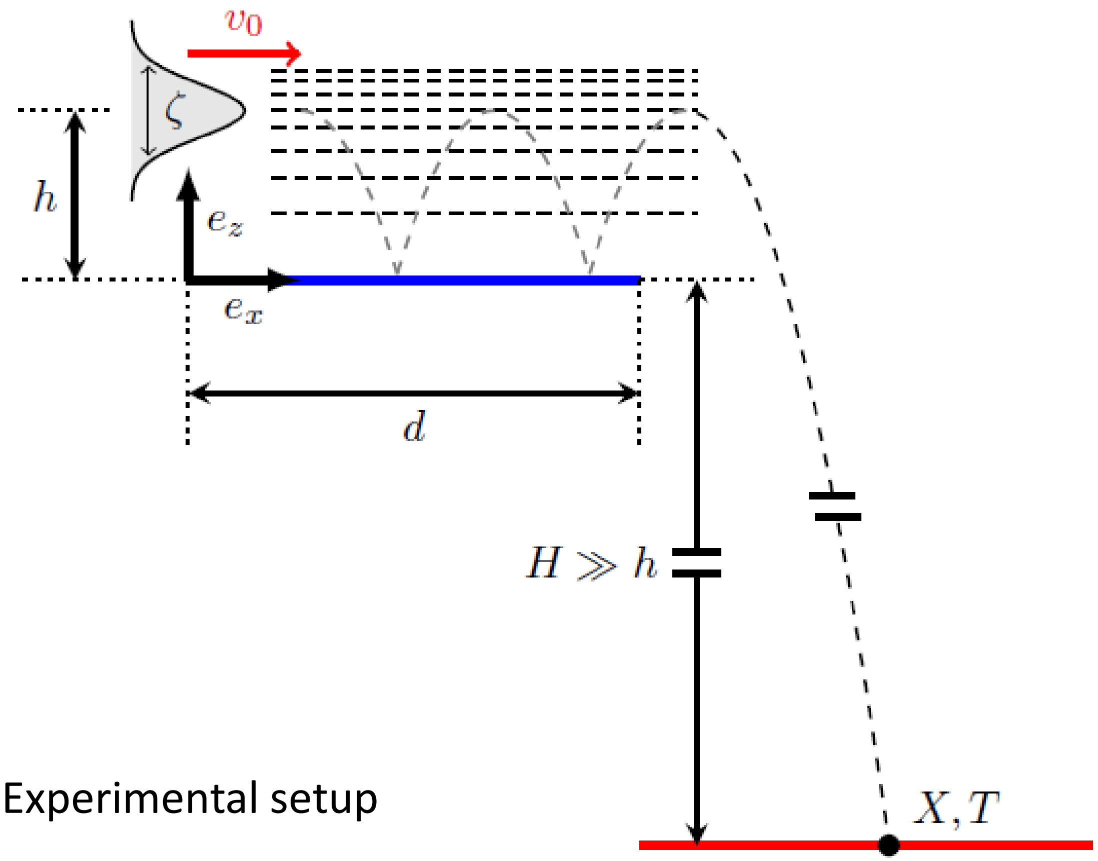
Which parameters affect the accuracy of the measurement?

- Geometry of the free-fall chamber
- Number of atoms N
- *Radius of the chamber* R_c
- Wavepacket velocity dispersion Δv

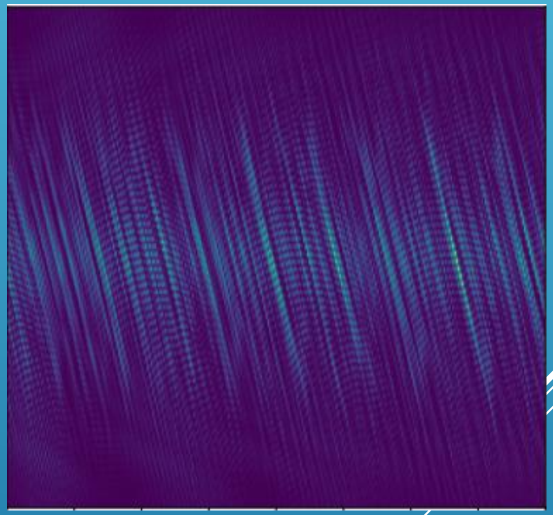
Horizontal polarization $\Delta v = 0,44 m/s$, $v_e = 1,77 m/s$:
$\sigma_g / g \approx 0,93\%$
→ confirmation of the goal of uncertainty < 1%.

Quantum interference measurement

Implementation of a mirror some *μm* below the trap.
Atoms bounce several times above the mirror (quantum reflection on Casimir-Polder potential). Quantum paths corresponding to different GQS (*Gravitational Quantum States*) interfere. After free fall, the quantum interference pattern on the detector.



Experimental setup



interference pattern on the detector

$\sigma_g / g \approx 10^{-6}$

Thank you for your attention !

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