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Does antimatter fall like matter ?: *focus on GBAR experiment (CERN)*

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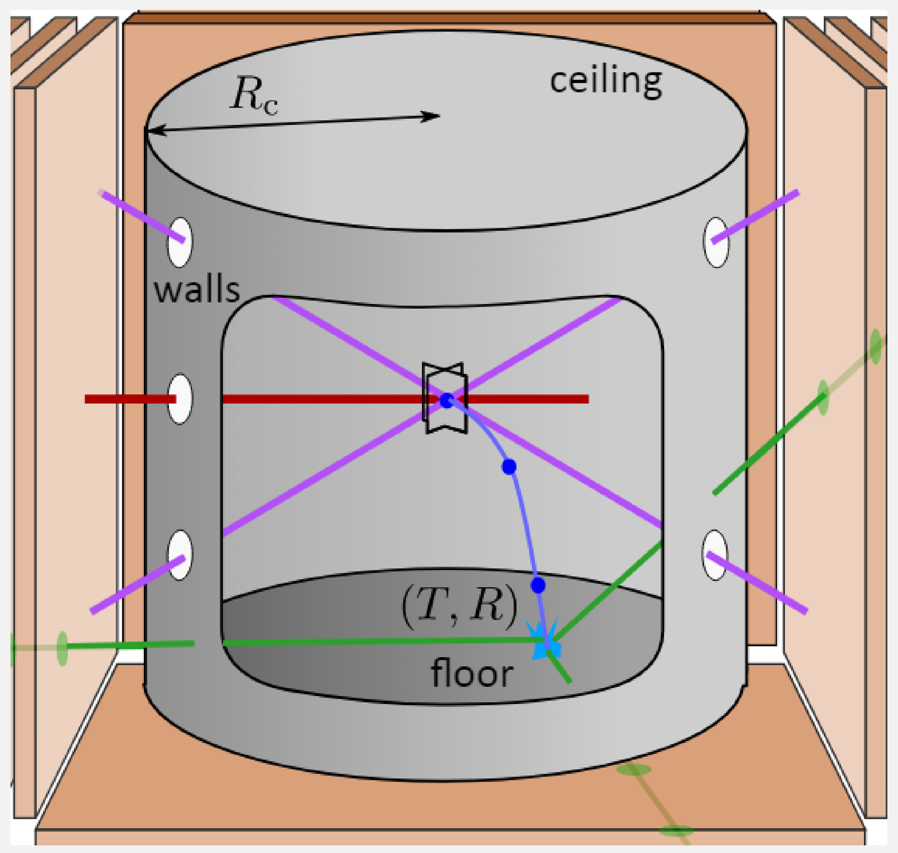
1. Presentation of GBAR (*Gravitational Behaviour of Antihydrogen at Rest*)

One of the main questions of fundamental physics is the action of gravity on antimatter.
Current experimental bound: $-65 \leq \bar{g} / g \leq 110$.
(*Alpha Collaboration, 2013*)

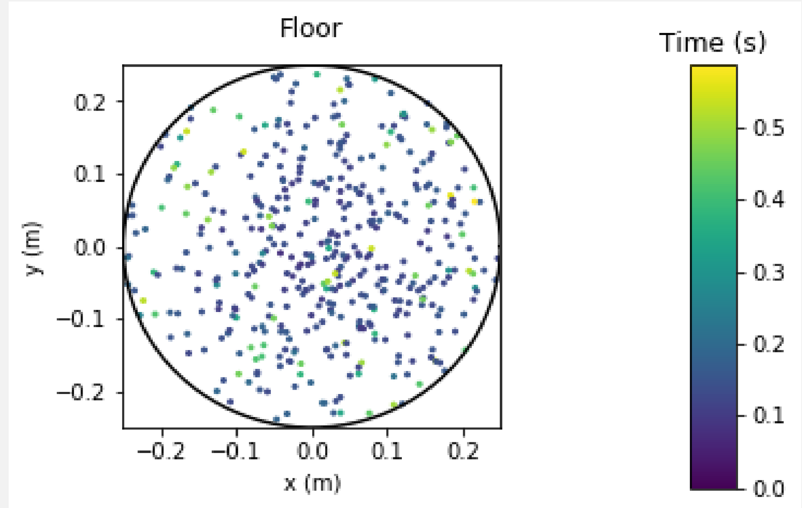
Experiment GBAR (https://gbar.web.cern.ch/): aims at measuring free fall acceleration $\bar{g}$ of cold antihydrogen atoms in the gravitational field of Earth, with an accuracy of 1%. Initially, ion $\bar{H}^+$ is trapped at very low temperature.
Start time t_0: the excess e^+ of $\bar{H}^+$ is photodetached -> neutral $\bar{H}$ anti-atom released;
Stop T: annihilation of $\bar{H}$ on the surface of the detector after free fall (of height 30 cm).
The statistical analysis of annihilation events allows to deduce the free-fall acceleration $\bar{g}$.



2. Monte-Carlo simulation and analysis of the classical timing measurement

$(V_{x,0}, V_{y,0}, V_{z,0})$ —> (X, Y, Z, T)
Initial velocity — Impact

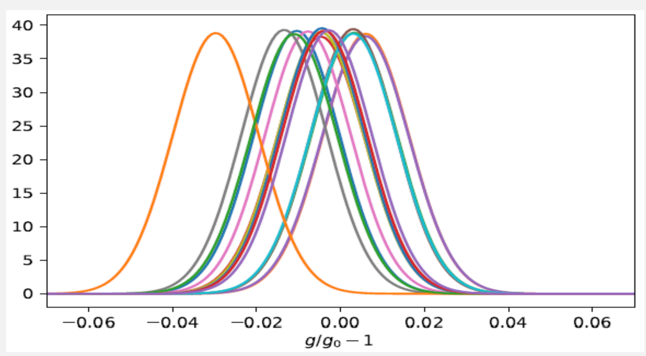
$$V_x = \frac{X}{T} \quad , \quad V_y = \frac{Y}{T} \quad , \quad V_{z,0} = \frac{Z}{T} + \frac{gT}{2}$$



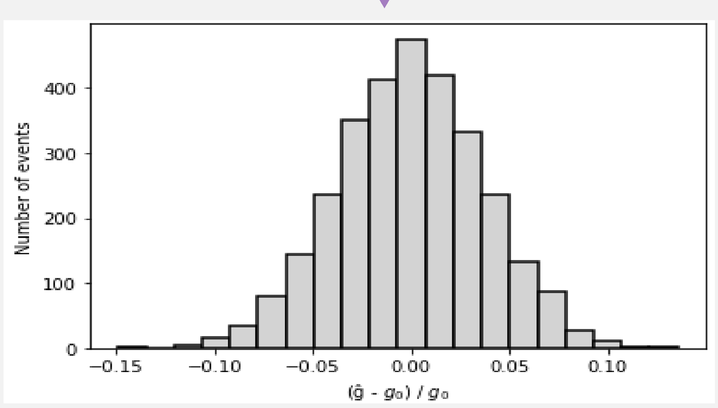
Generation of *N=1000* events
(with g_0=9.81 m/s²)

$$\mathcal{L}(g) = \prod_{i=1}^{N} J_g(X_i, Y_i, Z_i, T_i) \longrightarrow \hat{g} = \frac{\int g\mathcal{L}(g)dg}{\int \mathcal{L}(g)dg}$$

Likelihood estimator



Process repeated *M* times



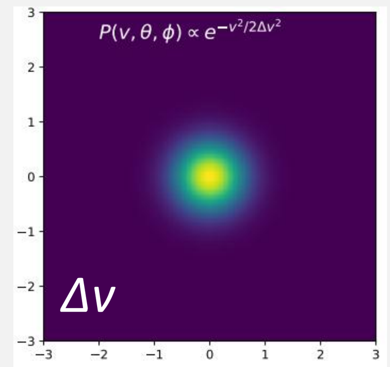
Histogram of the distribution of $\hat{g}$

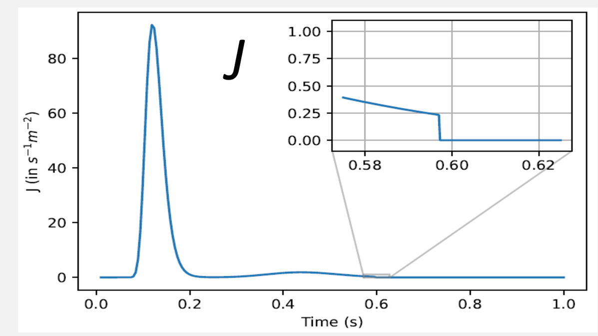
Average: $\mu_g \approx g_0$ (no bias) Relative uncertainty: σ_g / g_0

3. Effects of design parameters

Which parameters affect the accuracy of the measurement ?

- Geometry of the free-fall chamber;
- Number of atoms *N;*
- Wavepacket velocity dispersion *Δv;*
- Photodetachement atom recoil v_e;
- Polarization of the laser ϑ_n;
- Cuts in the probability current density *J;*
- Spatial resolution *Δz* on detection.





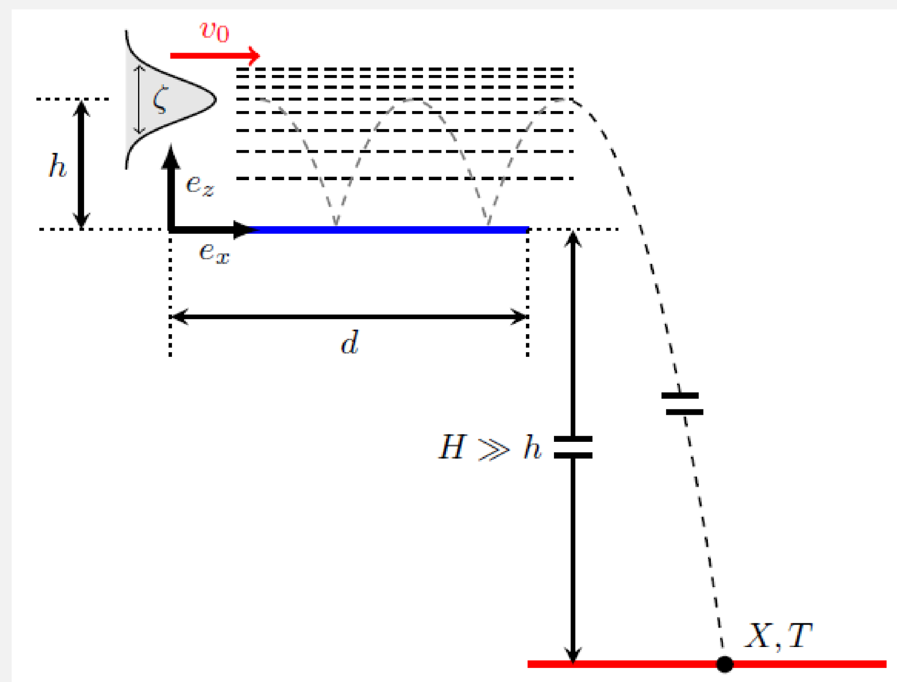
For *Δv=0,44 m/s*, v_e*=1,77 m/s*, horizontal polarization of the laser and current geometry of the design (*O. Rousselle et al., to be published*):

$\sigma_g / g \approx 0{,}91\%$

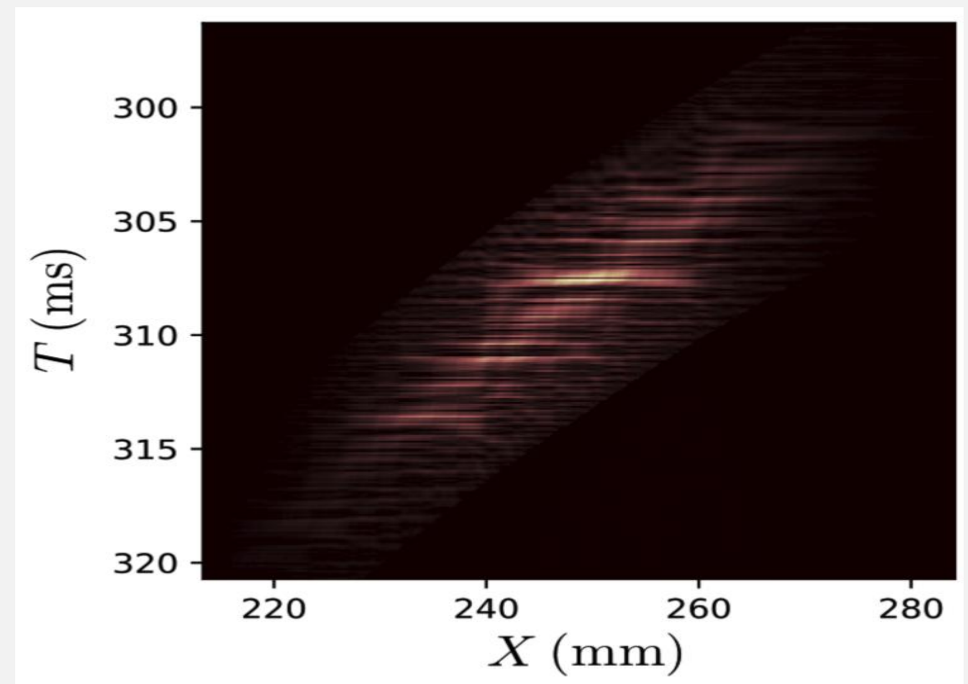
—> confirmation of the goal of uncertainty < 1%.

4. Quantum interference measurement

Addition of a mirror some *µm* below the trap (*P.P. Crépin et al., 2019*).
Atoms bounce several times above the mirror (quantum reflection on Casimir-Polder potential), and the quantum paths corresponding to different GQS (Gravitational Quantum States) interfere.



2D representation of the quantum experimental setup



Current|J(X,T)| on the detection plate

After free fall, the quantum interference pattern on the detector reveals much more information than the classical one -> better uncertainty: $\sigma_g / g \approx 10^{-6}$.

References

GBAR Collaboration, *The GBAR project, or how does antimatter fall?*, Hyperfine Interactions 228, 2014
P.-P. Crépin et al., *Quantum interference test of the equivalence principle on antihydrogen*, Phys. Rev. A 99, 2019