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Simulation of GBAR experiment at CERN:

does antimatter fall or is there antigravity?

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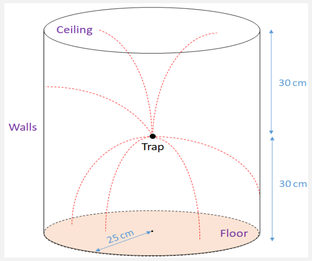
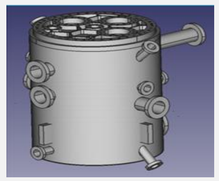
$\overline{H}$

1. Presentation of GBAR experiment (CERN)

One of the main questions of fundamental physics is the action of gravity on antimatter.
Current experimental bound: $\boxed{-65 \leq \bar{g}/g \leq 110}$
(*Alpha Collaboration, 2013*).
Experiment GBAR: start in 2022; Goal: measuring $\bar{g}$ with an accuracy of the order of 1%.
We present in this poster the simulation of the last part of the experiment GBAR, i.e. the measurement of the free fall acceleration $\bar{g}$ of cold antihydrogen atoms in the gravitational field of Earth.
Classical measurement: the $\overline{H}$ atom freely falls from a height *H=30 cm* on a detector.



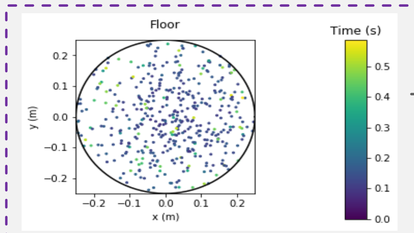
Inside view of the chamber


Outside view

2. Monte-Carlo simulation and data analysis

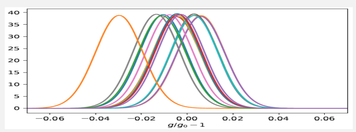
$(V_x, V_y, V_{z,0}) \longrightarrow (X, Y, Z, T)$
Initial velocity Impact

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

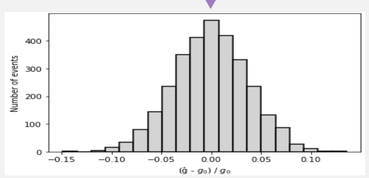


Generation of *N=1000* events
(with g_0=9.81 m/s²)

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


Likelihood estimator

Process repeated *M* times



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

Average: $\mu_g \approx g_0$ (no bias)

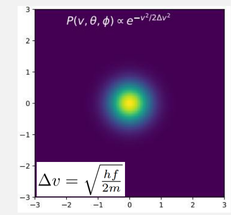
Relative uncertainty: σ_g/g_0

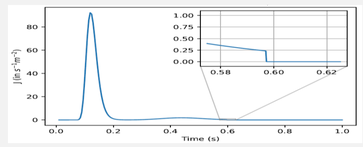
Other method: calculation of Fisher information: $I(g) = \int dSdT \frac{(\partial_g J_g)^2}{J_g}. \quad \sigma_{g_{CR}} = \frac{1}{\sqrt{N.I(g)}}$

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;*
- Polarization of the laser ϑ_n;
- Cuts in the probability current density *J;*



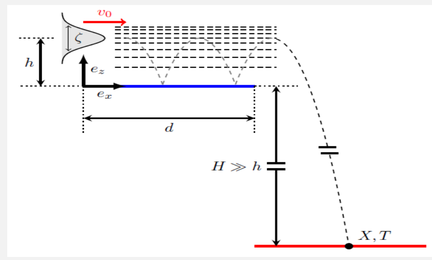


- Spatial resolution *Δz.*

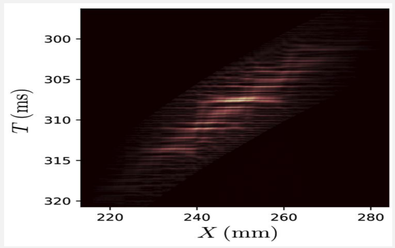
For the current geometry of the design: $\sigma_g/g_0 \approx 8.10^{-2}$ (*O. Rousselle et al., to be published*).

4. Quantum interference measurement

Implementation 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 Schematic representation of the quantum experimental setup;
Mirror in blue and detector in red



Probability current density $|J(X,T)|$ on the detection plate, with interference pattern

After free fall, the quantum interference pattern on the detector reveals much more information than the classical one -> better uncertainty (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
P.-P. Crépin, *Quantum reflection of a cold antihydrogen wave packet*, thesis Sorbonne Université, 2019