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

INTERNATIONAL CONFERENCE ON EXOTIC ATOMS AND RELATED TOPICS (EXA 2021)

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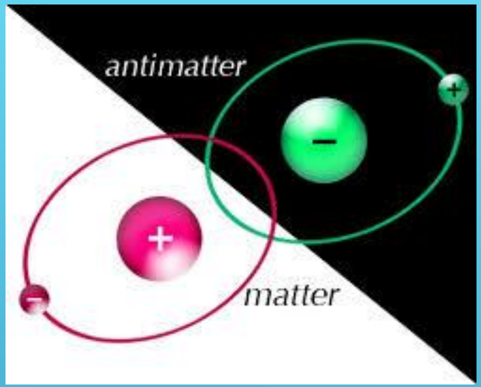
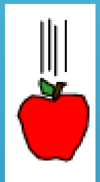
Antimatter and gravity



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.

« How does antimatter fall? »

Antigravity:
- is compatible with GR and would indicate that antimatter has a gravitational mass <0 ;
- could explain the asymmetry matter/antimatter in the universe (*G. Chardin*).

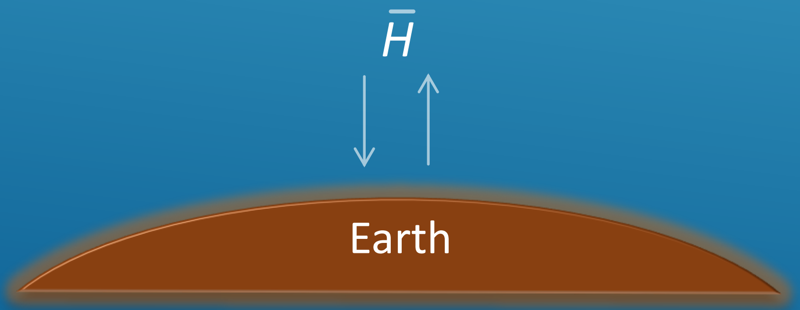
Sign of gravity acceleration not yet known experimentally, with bound: $-65 \leq \bar{g}/g \leq 110$

(*Alpha Collaboration, 2013*)

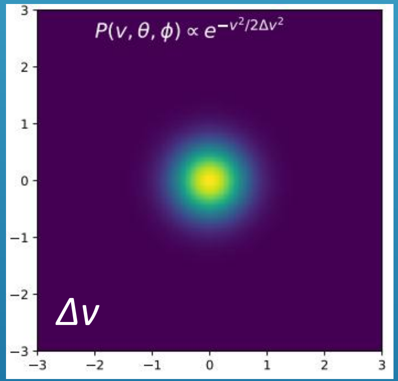
GBAR experiment: principle and motivations

GBAR collaboration (LKB, ETHZ, ILL Grenoble and other labs)
https://gbar.web.cern.ch/public/

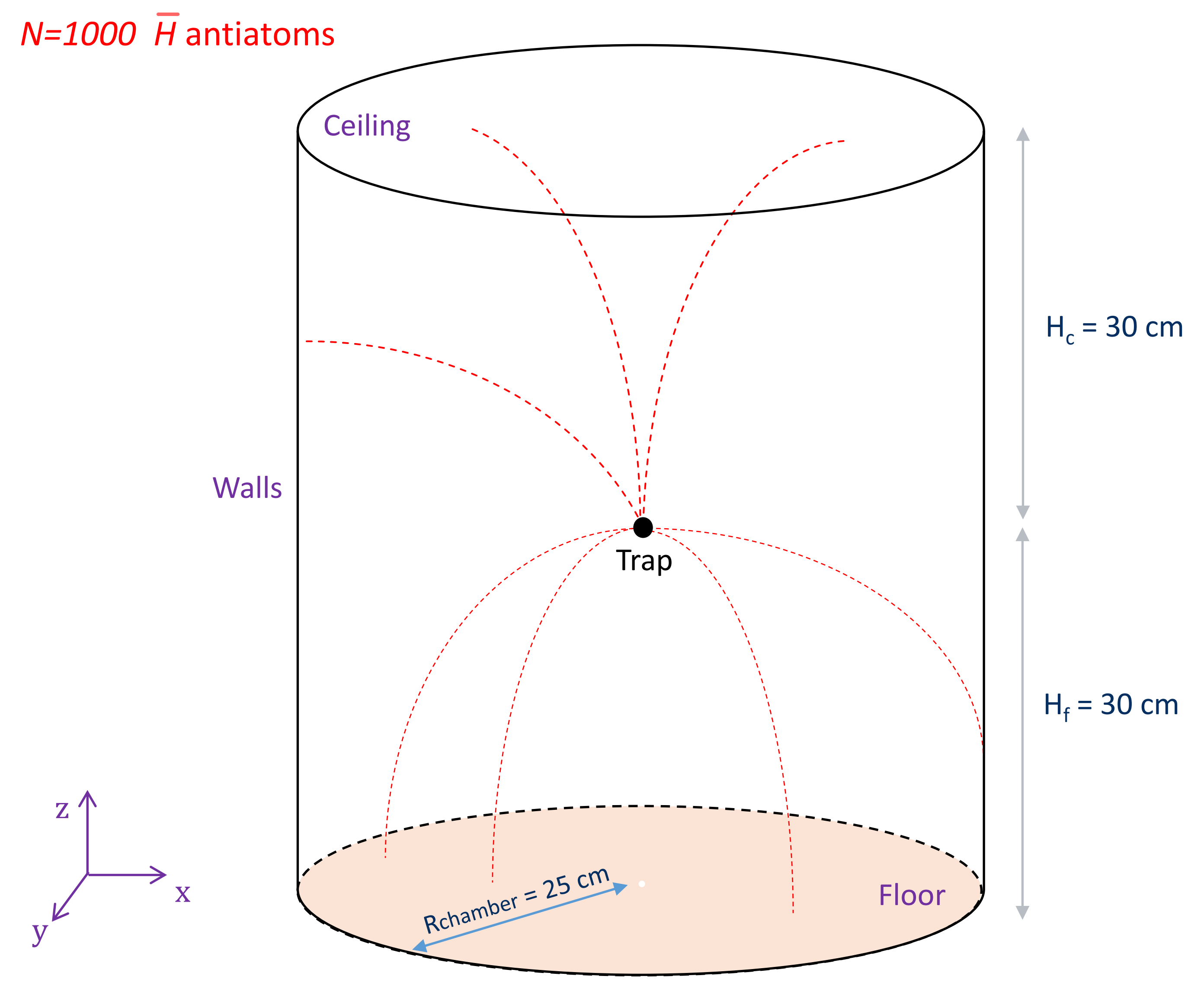
Gravitational Behaviour of Antihydrogen at Rest
Goal: measuring the acceleration $\bar{g}$ of ultracold antihydrogen atoms during a free fall in Earth’s gravitational field, with 1% precision.

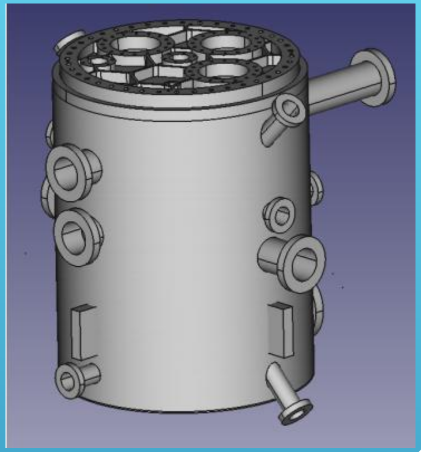


GBAR free fall chamber (initial geometry)

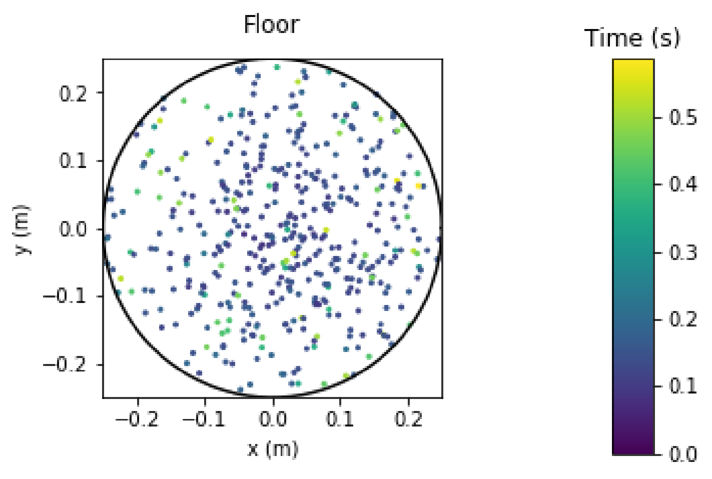


Ground state of the harmonic trap





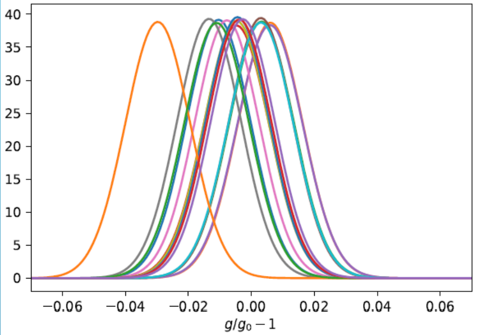
Monte-Carlo analysis (same scheme as an experimentalist)



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

Likelihood

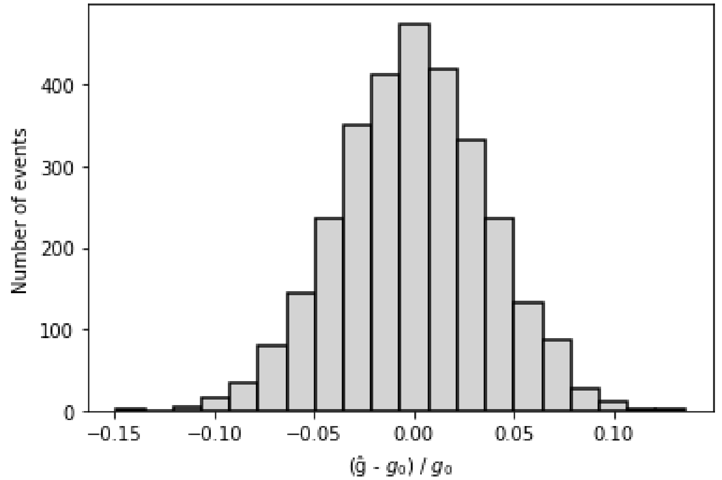
$$\mathcal{L}(g) = \prod_{i=1}^{N} J_g(x_i, y_i, z_i, t_i).$$



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

Mean likelihood estimator

Repeated M times



Distribution of $\hat{g}$

Average: μ_g

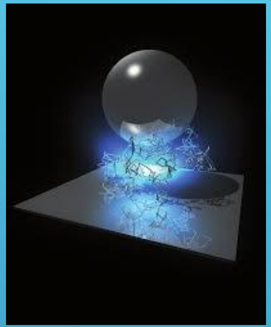
Relative uncertainty: σ_g / g_0

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

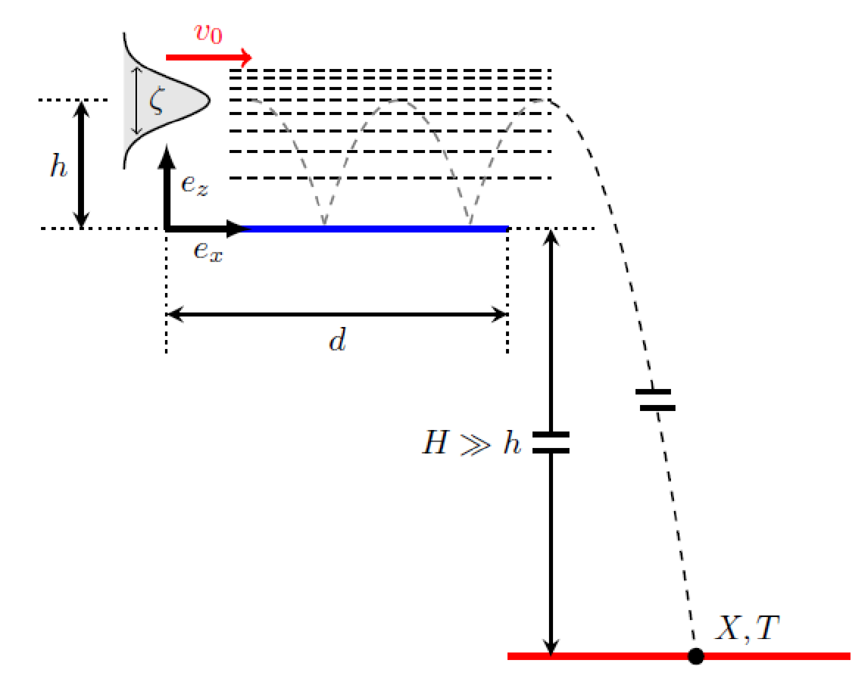
Quantum interference measurement

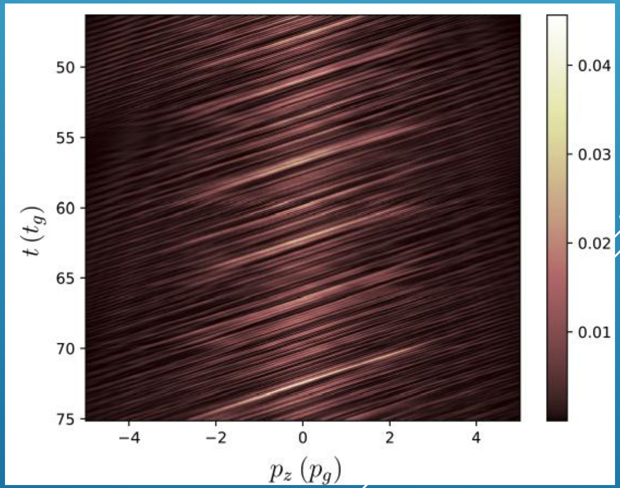
Goal: use quantum reflection to produce an interference pattern on the detector. The information extracted from the interference figure will lead to an improved uncertainty.

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.



ζ=0.5 μm, h=10μm, d=5 cm, H=30cm

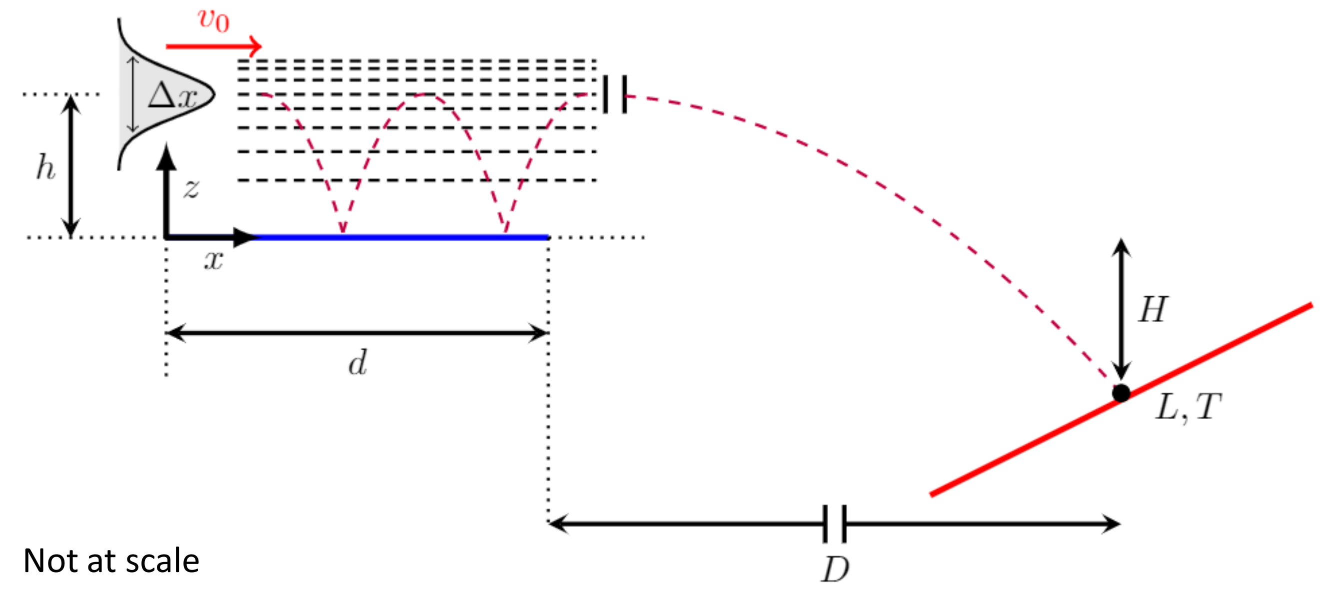


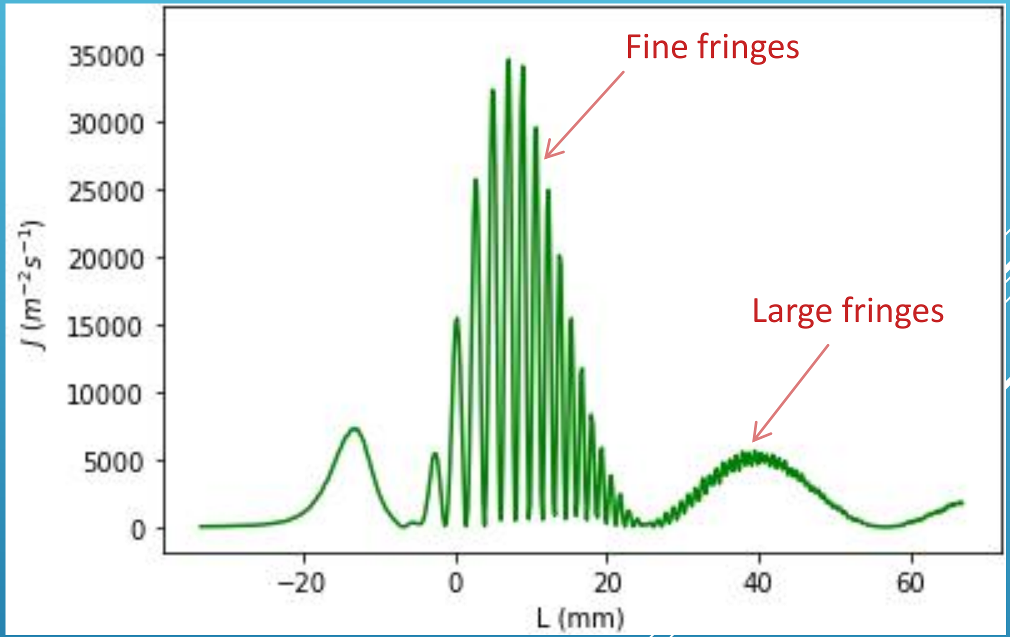


$\sigma_g / g \approx 10^{-6}$

Quantum interferences of hydrogen atoms

GRASIAN experiment: https://grasian.eu/
Goal: 1st highlighting of gravitational quantum states on atoms.





l_L (interfringe) ≈ 1.75 mm

Parameters: v_0 = 40 m/s, $\Delta v_x = \Delta v_z$ = 0.08 m/s, h = 5 µm, d = 20 cm, D ≈ 2 m (H~mm), ϑ = 5° and n=1000 states.
Inclined plan -> sufficient spatial resolution

Thank you for your attention !

References:

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