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

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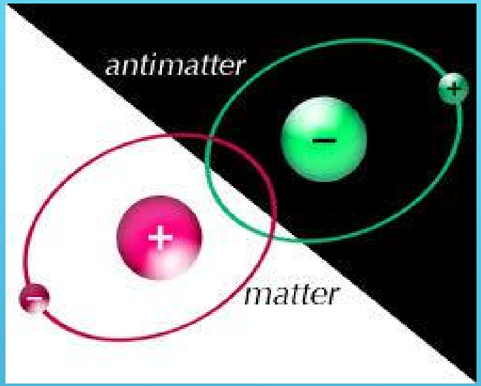
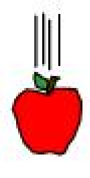
Antimatter and gravity



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.

« 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*)

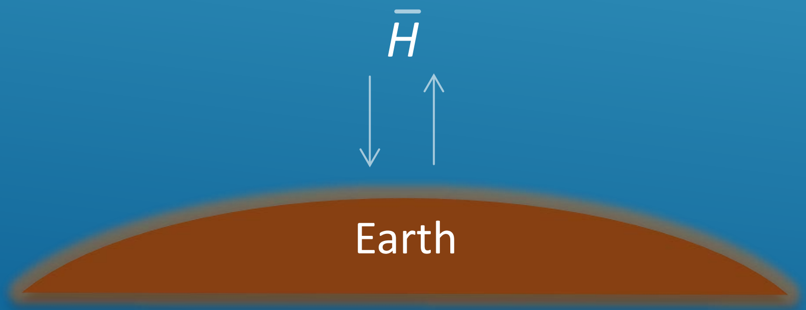
GBAR experiment: principle and motivations

GBAR collaboration (LKB, ETHZ, ILL Grenoble and other labs)

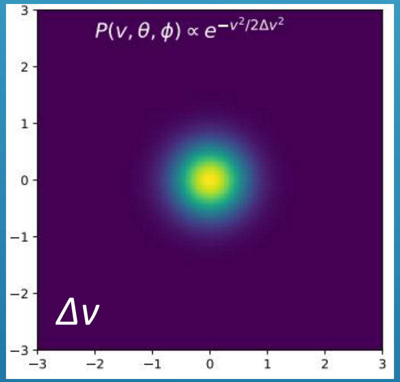
https://gbar.web.cern.ch/public/

Gravitational Behaviour of Antihydrogen at Rest

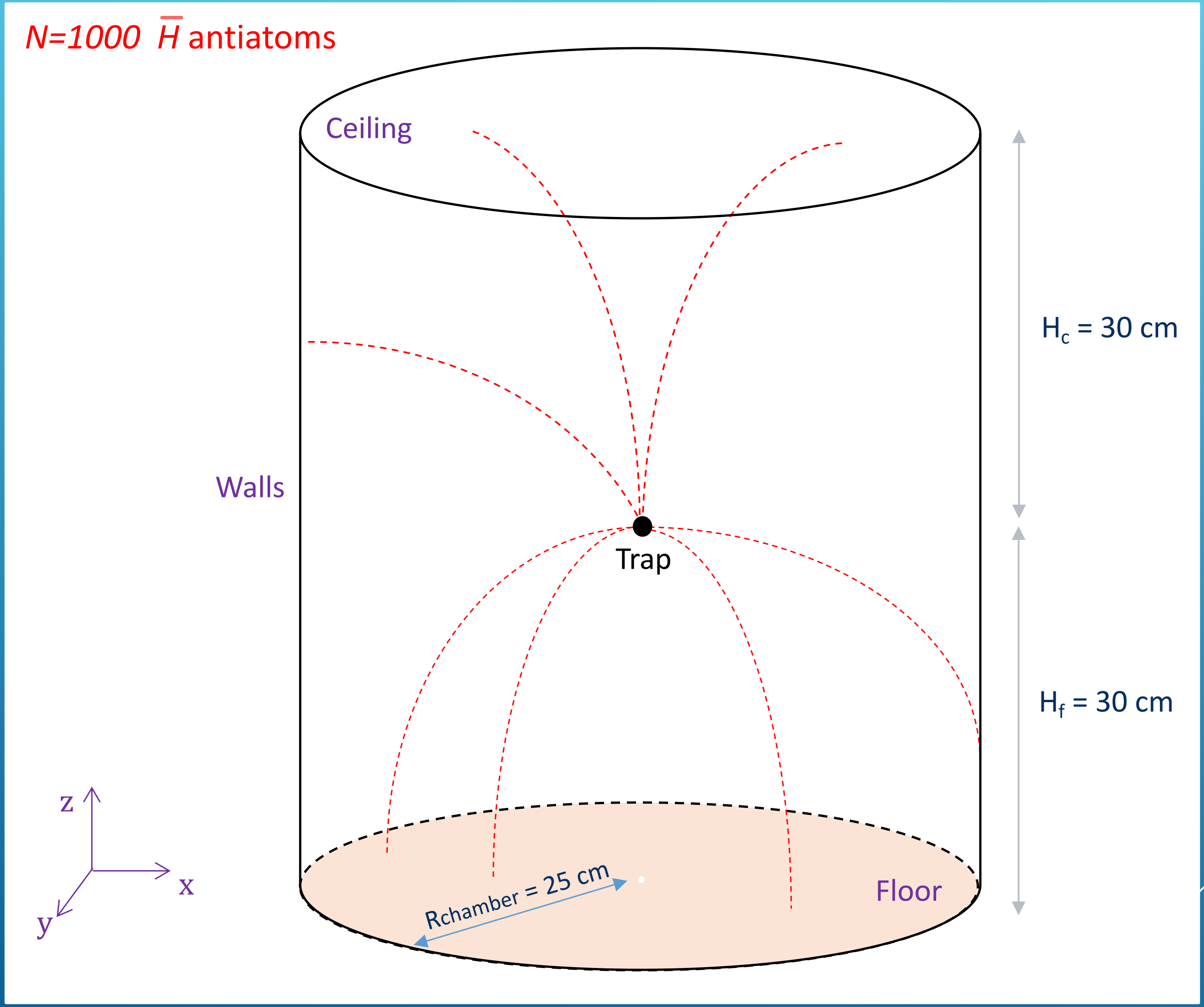
Goal: measuring the acceleration $\bar{g}$ of ultracold antihydrogen atoms during a free fall in Earth's gravitational field, with 1% precision.

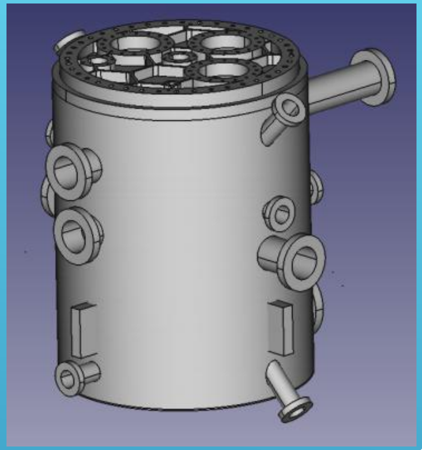


GBAR free fall chamber (initial geometry)



Ground state of the harmonic trap

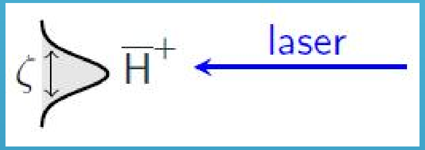




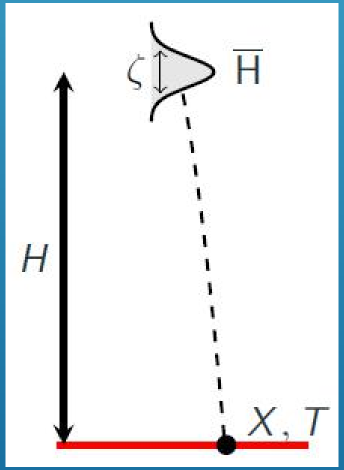
Free fall timing

Initially, ion $\overline{H}^+$ is trapped at very low temperature (*10 μK*)

Start t_0 : The extra e^+ of $\overline{H}^+$ is photodetached -> neutral H anti-atom released

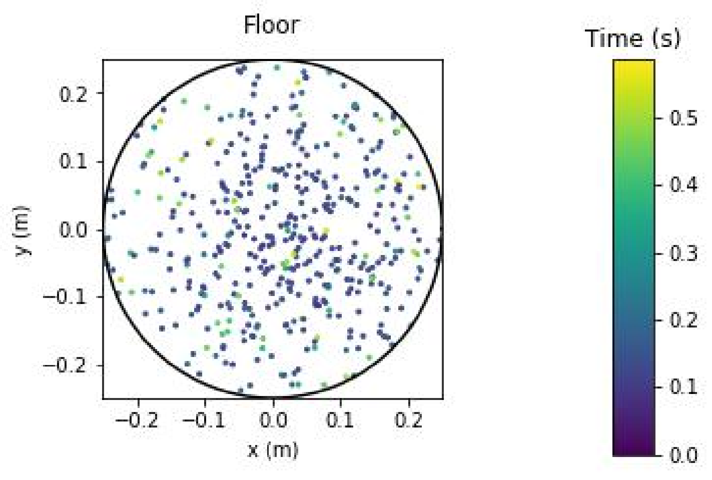


Stop T : annihilation of $\overline{H}$ on the surface of the detector after free fall



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

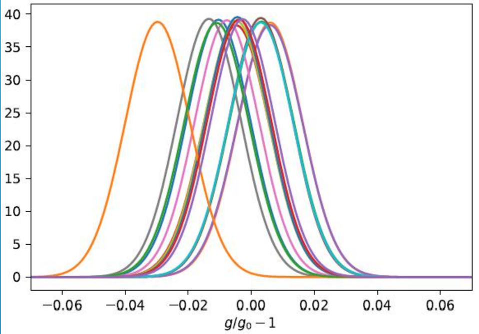
Monte-Carlo analysis (same scheme as an experimentalist)



Generation of N events (with $g_0=9.81\ m/s^2$)

Likelihood

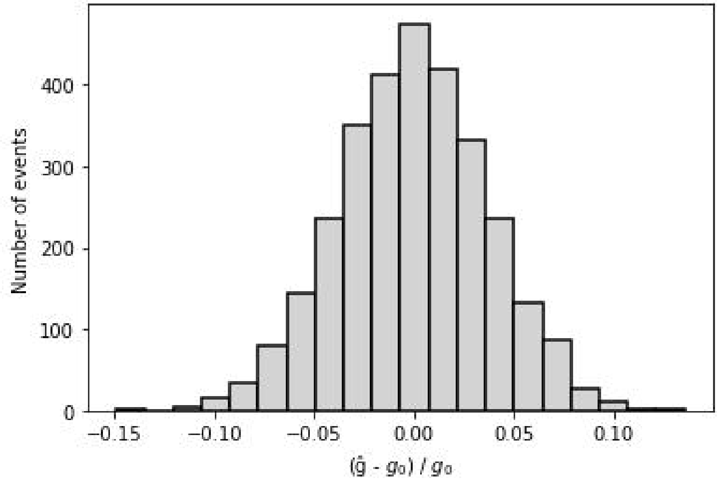
$$\mathcal{L}(g) = \prod_{i=1}^{N} J_g(x_i, y_i, z_i, t_i).$$



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

Mean likelihood estimator

Repeated M times



Distribution of $\hat{g}$

Average: μ_g

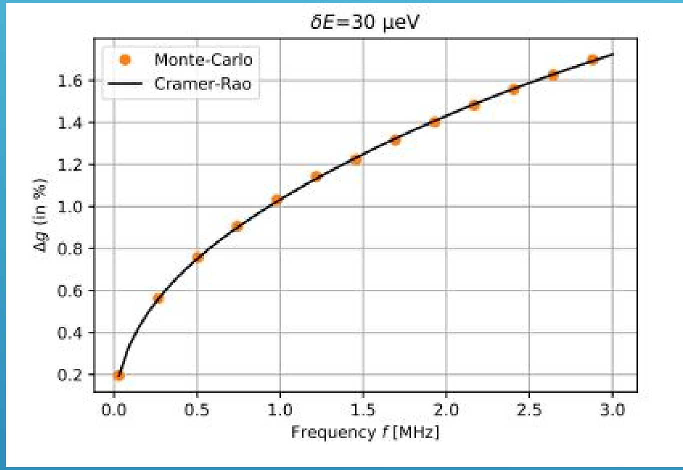
Relative uncertainty: σ_g/g_0

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

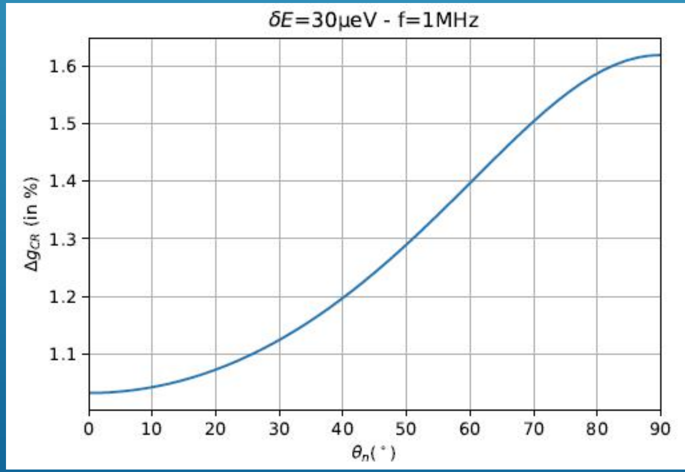
Effects of design parameters

Which parameters affect the accuracy of the measurement?

- Geometry of the free-fall chamber
- Number of atoms *N*
- Photodetachement atom recoil v_e
- Wavepacket velocity dispersion Δv



- Polarisation of the laser ϑ_n

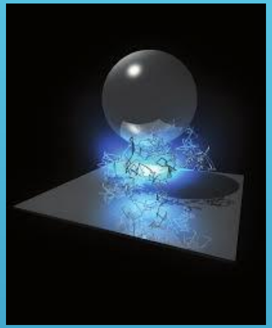


Horizontal polarization
$\Delta v=0{,}44m/s$, $v_e=1{,}77m/s$:
$\sigma_g/g \approx 0{,}91\%$
→ confirmation of the goal of uncertainty < 1%.

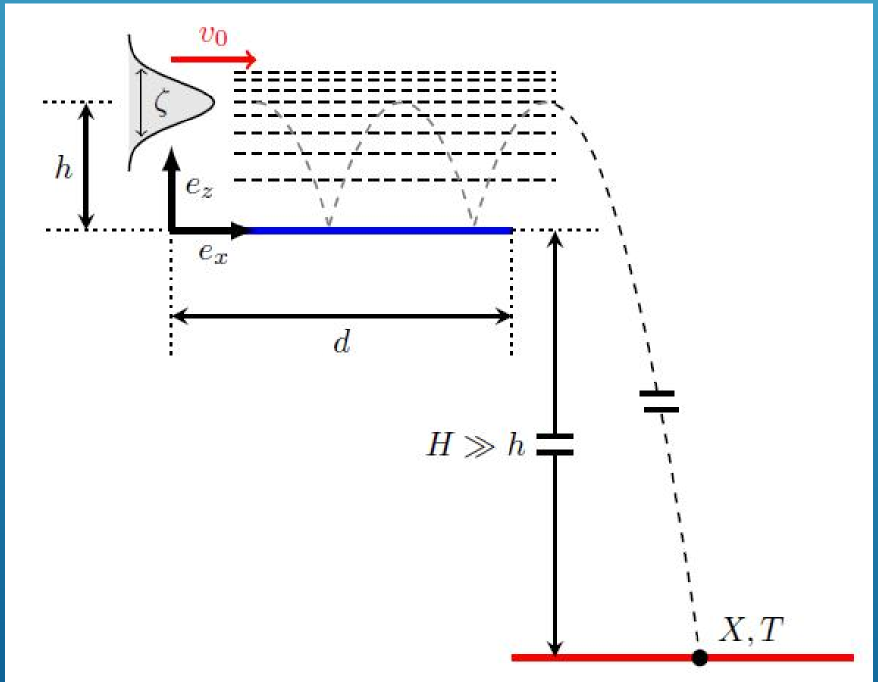
Quantum interference measurement

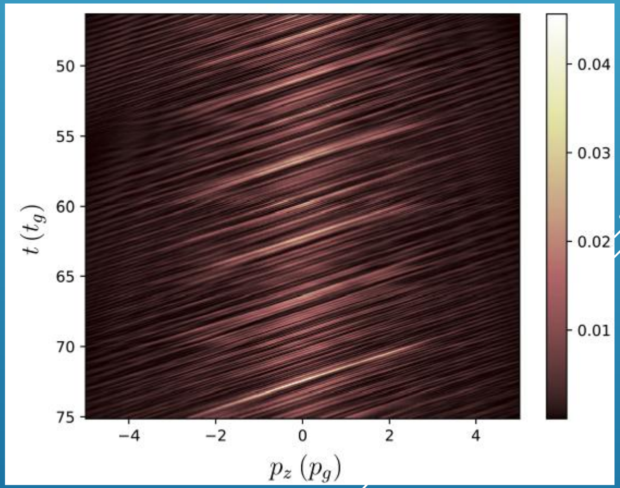
Goal: use quantum reflection to produce an interference pattern on the detector. The information extracted from the interference figure will lead to an improved uncertainty.

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.

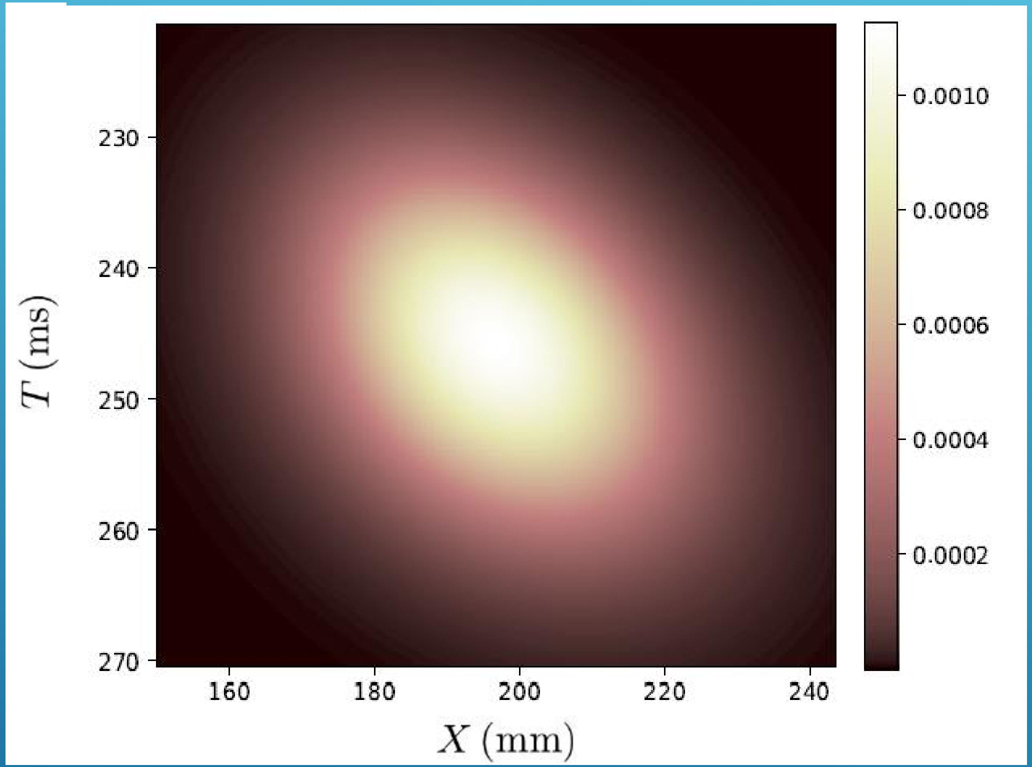


ζ=0.5 μm, h=10μm, d=5 cm, H=30cm

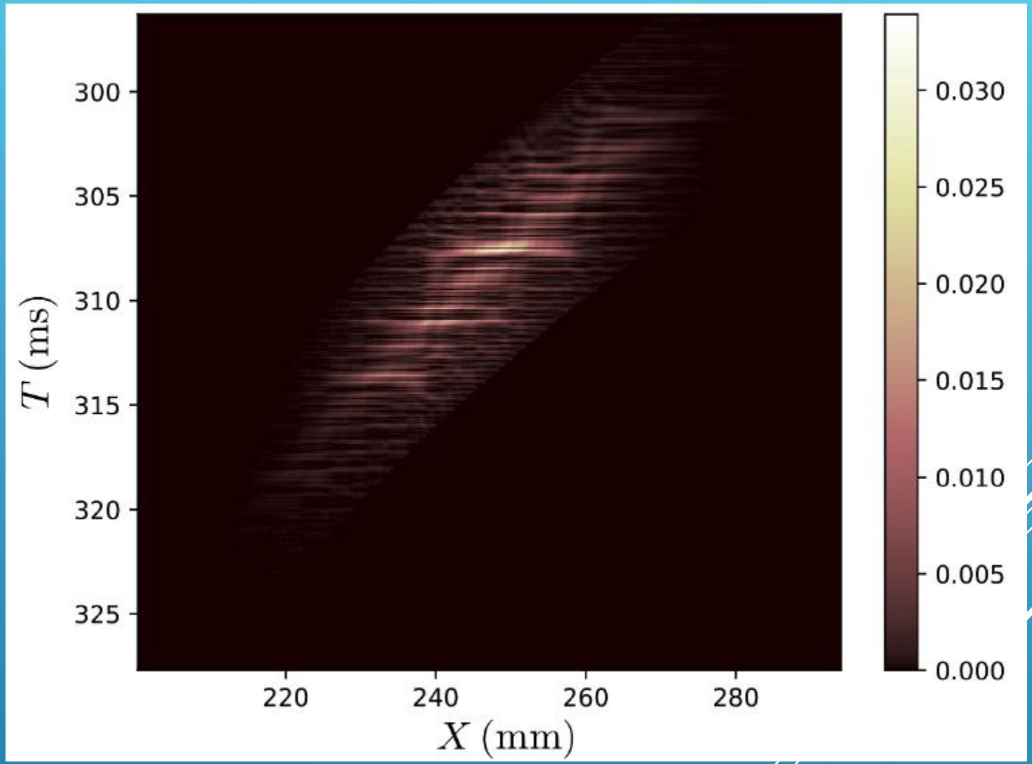




Detection pattern: comparison classical / quantum cases



$\sigma_g / g \approx 10^{-2}$



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

The quantum interference pattern on the detector reveals much more information than the classical one.

Thank you for your attention !

References:

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