Measuring antimatter gravity with antihydrogen

Antihydrogen is regarded to be an excellent test body to study antimatter gravity

Testing the WEP for antimatter and theoretical descriptions of gravity

Gravitational acceleration of antimatter never directly measured

Measure free propagation of antihydrogen atoms in the earth gravitational field by spatial and temporal recording of the atom impact points

Need cold antihydrogen atoms (<100mK)

Theoretical predictions

The unification of quantum mechanics and gravity was not successful so far. Remarkably, the most realistic theories today all predict new types of gravitational interactions that might indeed cause an antiparticle to fall to the ground differently from an ordinary particle. Any of these do violate the Equivalence Principle.

	Spin	Similar Chrg.	Opposite Chrg.	Example
Scalar	0	attractive	attractive	Graviscalar
Vector	1	repulsive	attractive	Graviphoton
Tensor	**2**	**attractive**	**attractive**	**Graviton**

From the $1/r^2$ law for matter

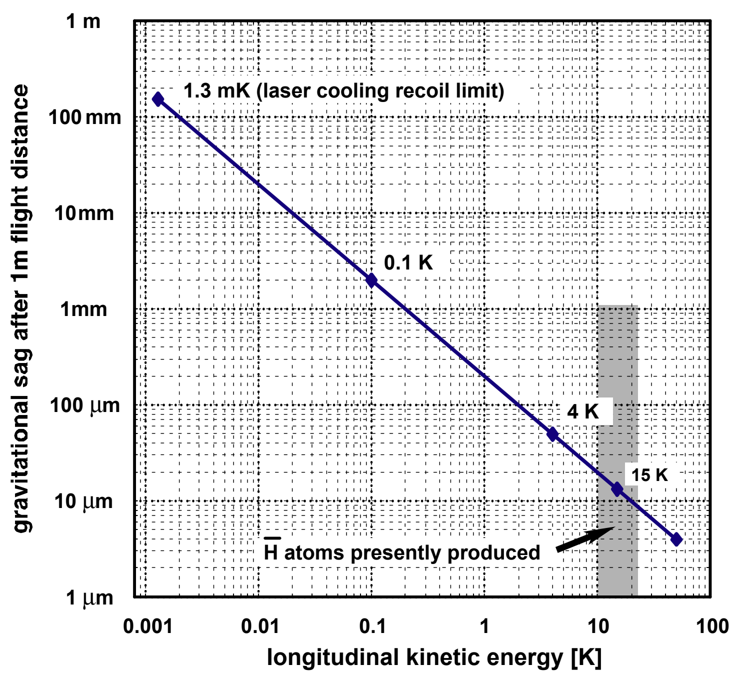
$$\text{Scale}: \ (g - \bar{g})/g = \ldots 10^{-6} \ldots$$

Nieto, Goldmann, Phys. Rep. 205/5 (1991) 221
Adelberger et al. PRL 66 (1991) 850
L.I. Schiff PRL 1 254 (1958), Proc. Natl Acad. Sci. 45 (1959) 69

Measurement basis: cold antihydrogen atoms + Si-μ-strip

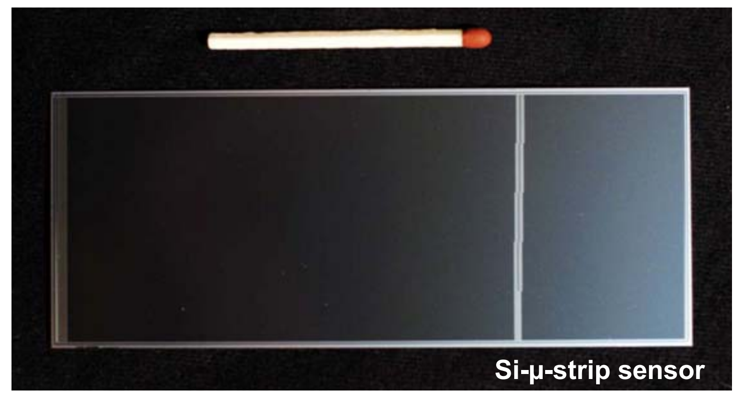
Sag in the earth gravitational field

$$h = \frac{g}{2} \bullet \left(\frac{L}{v_{long.}}\right)^2$$



Measure the annihilation pions

Antihydrogen, easy to detect !
Annihilation position + time (of flight) with Si-μ-strip detectors. Precision ~5μm, 20ns.

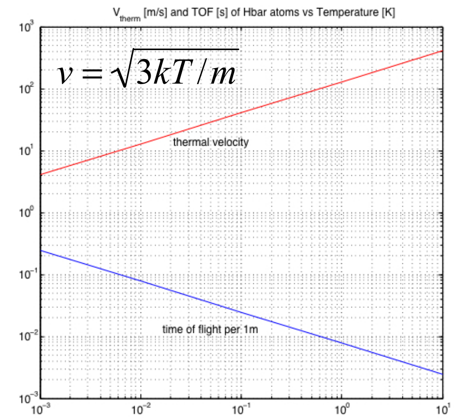


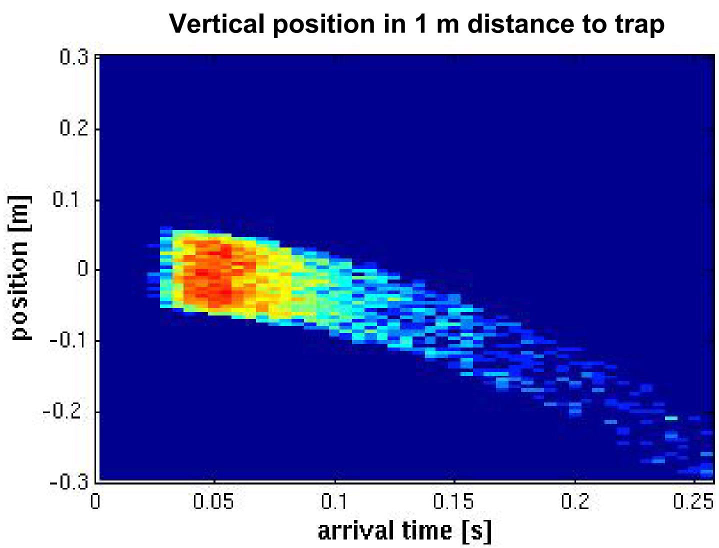
High efficiency!

Inefficiency basically determined by
p̄N -> all-neutral annihilations (~4%)

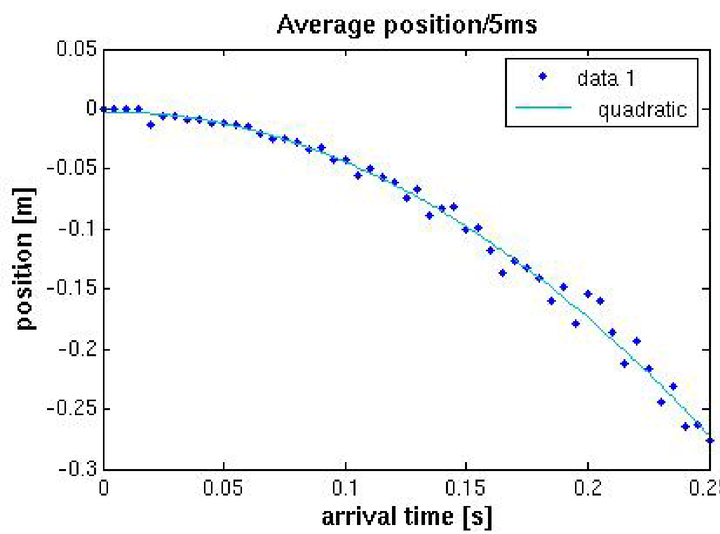
Horizontally released antihydrogen atoms

- 100000 atoms (10mK) emitted by opening the magnetic bottle
- Maxwellian and isotropically distributed
- Initial transversal position precision 1mm
- Slit (10mm) after 10cm distance to trap (~4000 atoms survive)





Not regarded:
Release time error (<1ms)
Fringe field effects
Magnetic and electric stray fields
and more …



Similar experiment possible with vertically released atoms (Fairbanks-type, measuring cut-off time)

Precision ~ 10^{-3}

"Switch off" gravity by dropping the detector?

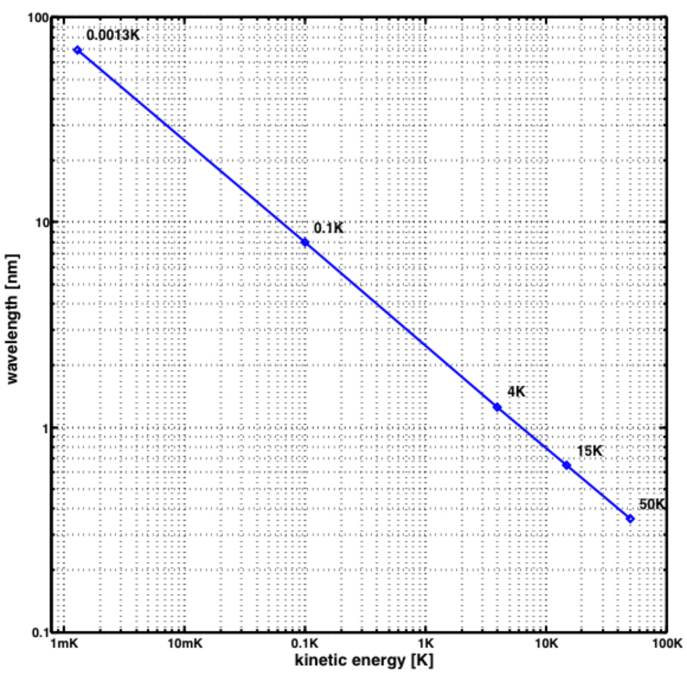
Higher precision - interferometric measurements

Idea: create a handle on the sag (h) by a interference pattern

T.J. Phillips (Hypf.Int. 109 (1997) 357) Antimatter gravity studies with interferometry

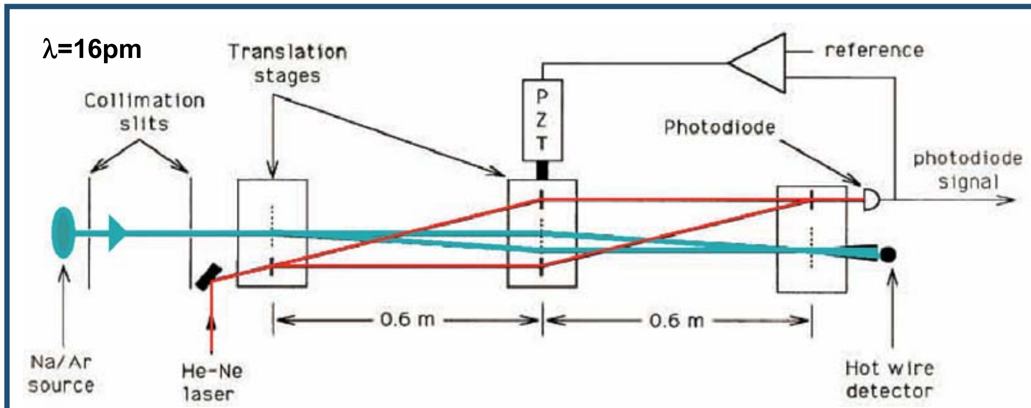
$\bar{H}$ wavelength: $\lambda = h/p$

$\lambda \approx$ 1-100 nm (4K-1mK)



Matter-wave interference (done on neutrons, atoms)

interference pattern “falls” during traversing time



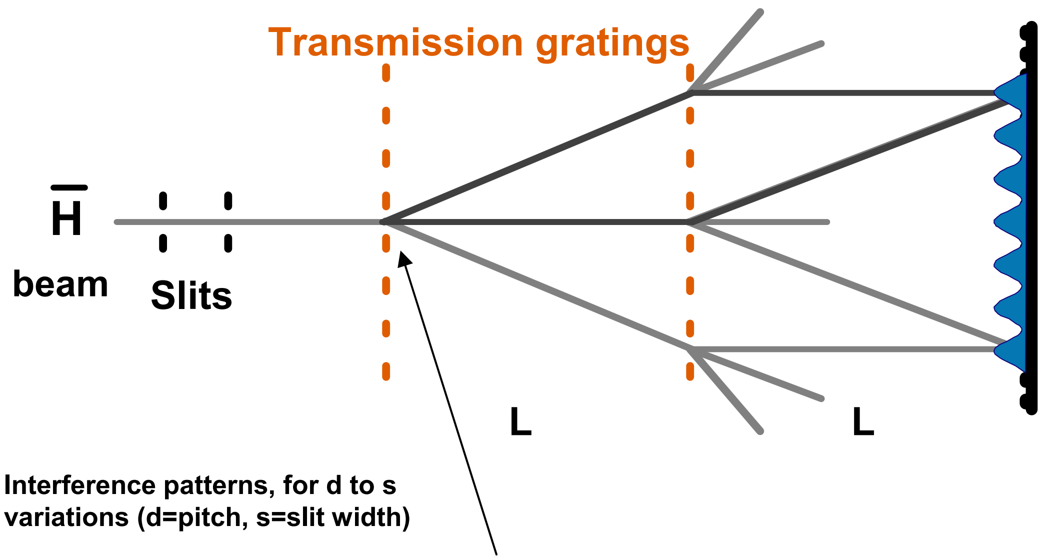
D. Keith, D. Pritchard et al. PRL 66/21 (1991) 2693

With λ=10nm neutrons: M.Gruber, Zeilinger et al.
Phys.Lett. A 140 (1989) 363

With laser cooled Na atoms (30µK) $\Delta g/g = 10^{-8}$ was achieved (< 10^{-10} planned). M. Kasevich, S.Chu: Appl. Phys.B 54 (1992) 321

Mach-Zehnder Interferometer

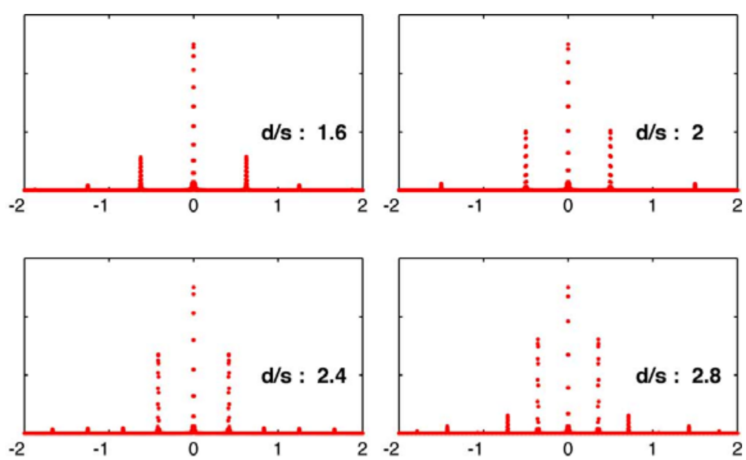
Interference pattern intrinsically independent on wavelength and spatial coherence
(not in the case of gravitational acceleration, sag depends on time of flight)

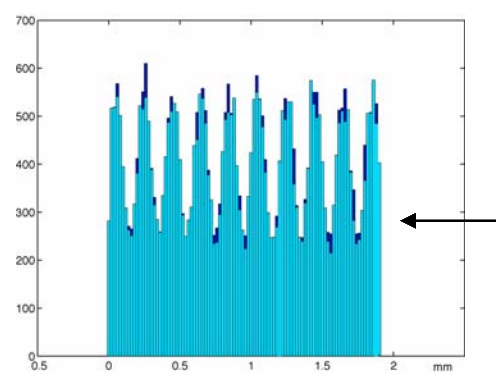


- **Fixed mounted detector.**
- **Turning around axis switches gravity off.**
- **Interference pattern from thermally distributed atoms can be combined offline**

Phase shift: $$\Delta\phi = g \bullet \frac{\pi}{d} \bullet \left(\frac{2L}{v_{long.}}\right)^2$$

Interference patterns, for d to s variations (d=pitch, s=slit width)





Typical interference pattern (simulation with two gratings 200µm grid spacing 1m apart, 15K atoms, isotrope emission) 100000 atoms emitted ~25000 detected

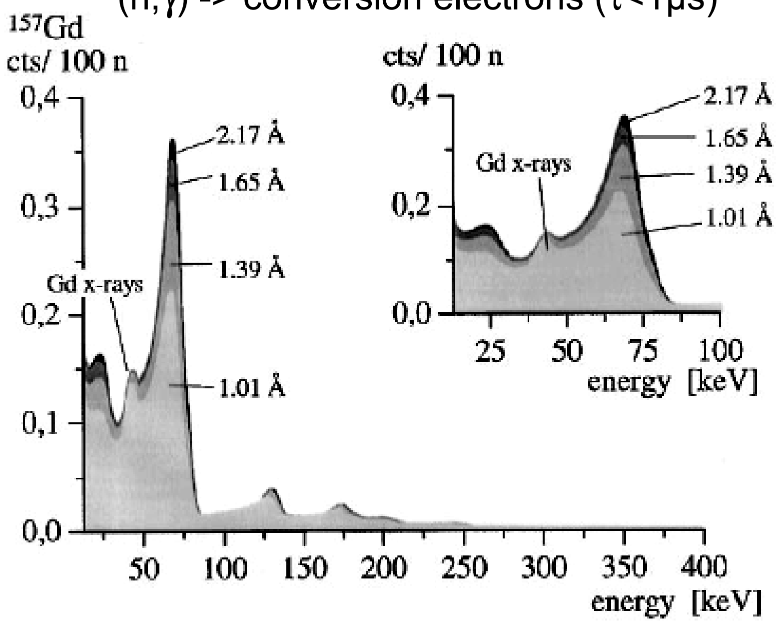
Position on the detector with (light) and without gravity(dark)

Gadolinium on silicon: emulating impinging antihydrogen with neutrons

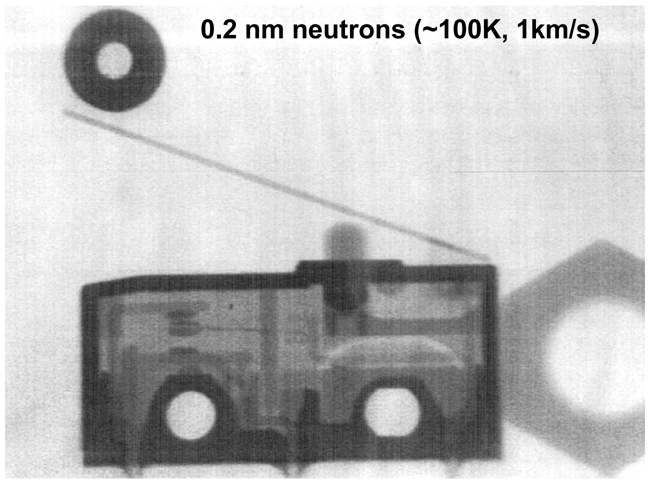
Gd: Highest known thermal neutron absorption cross section (1/v law)

~60000 Barns per Atom (natural Gd)
~250000 Barns per Atom (^{157}Gd)

(n,γ) -> conversion electrons (τ<1μs)



Neutron transmission image as seen by a double-sided si-strip detector (size 23.4 x 30 mm^2)

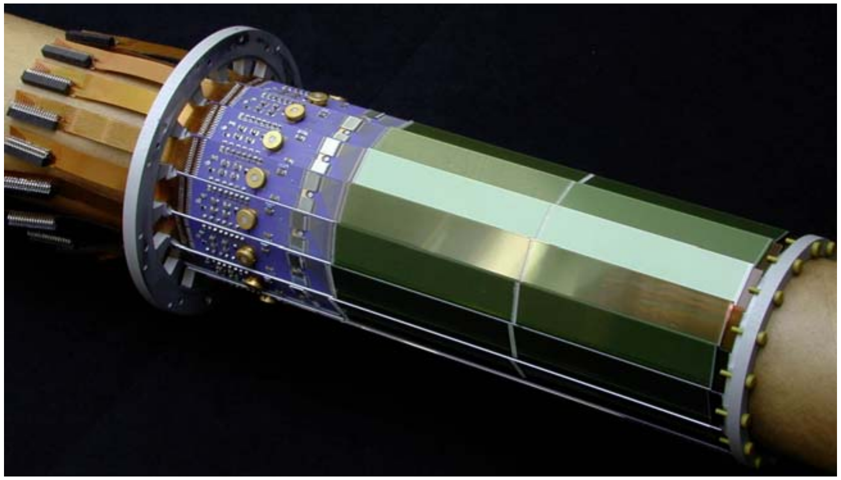


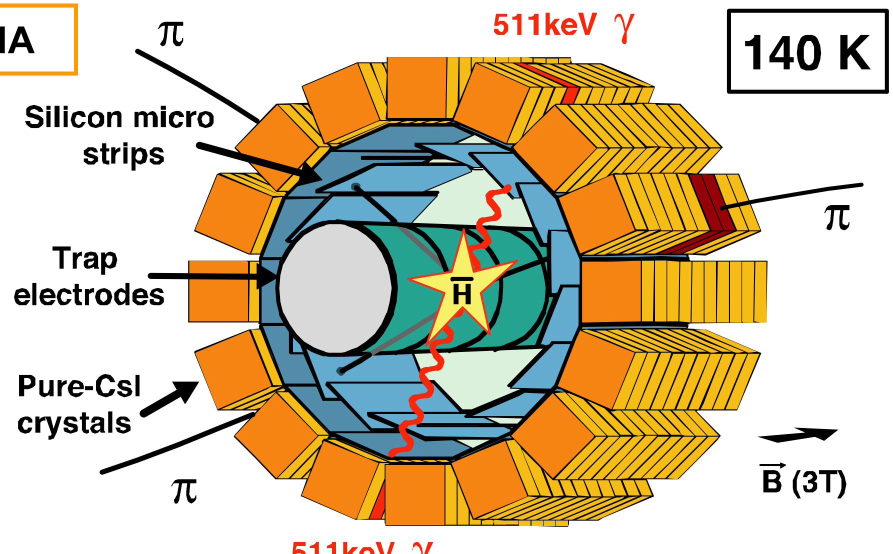
Bruckner, Czermak, Rauch, Weilhammer NIM A 424 (1999) 183

Setup can be tested and developed at slow/uc neutron source at the SINQ /PSI

University of Zürich group, detector expertise

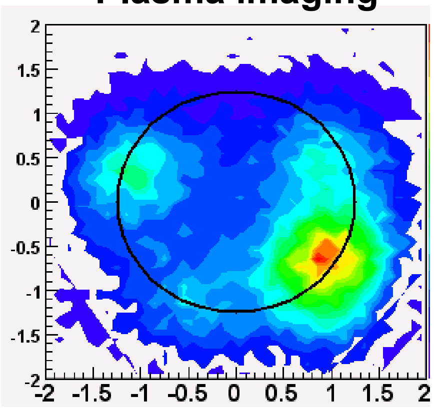
Cryogenic Si-μ-strip and pure CsI detector for ATHENA



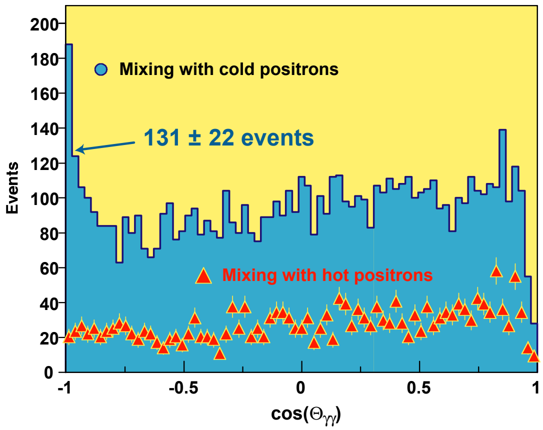


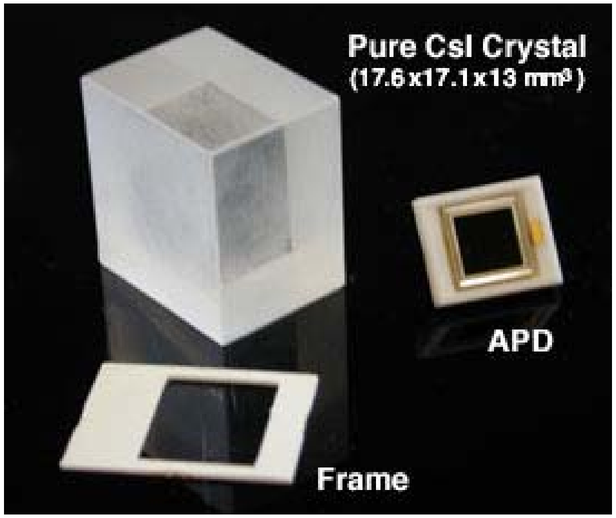
C. Regenfus, NIM A 501, 65 (2003)

Plasma imaging



Hbar signal





3 years R&D, resources ca. 350 kCHF