Neutrons test Gravity, Dark Matter and Dark Energy

Snapshots of a Quantum Bouncing Ball & Gravity Resonance Spectroscopy

EPS-HEP

23.07.2015

Gunther Cronenberg

Neutrons & new forces

energy

distance

LHC
TeV

25
orders

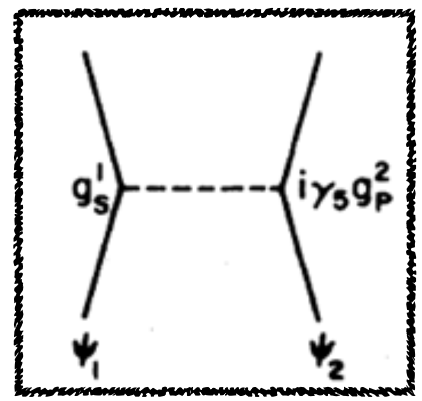
qBounce
pico eV

$$V = -\widetilde{G}\frac{mM}{r^{1+n}}$$

torsion
effects

n

spin-mass
coupling



curvature

$$V(z) = mgz + \beta\frac{m}{M_{\mathrm{Pl}}}\Lambda\hbar c\left(\frac{2+n}{\sqrt{2}}z\Lambda\right)^{\frac{2}{2+n}}$$

cosmological

small

Neutrons & Gravity

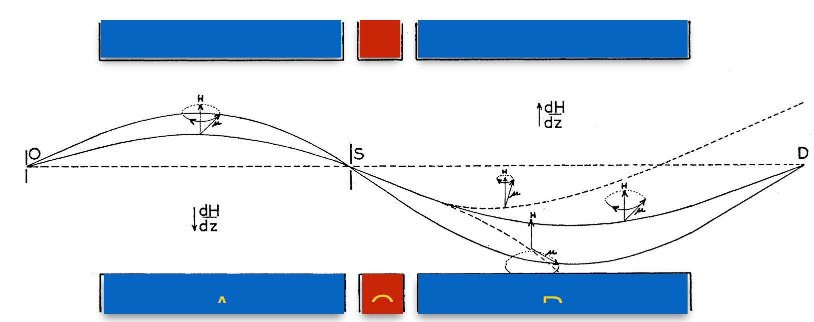
Combine unique system with well-performed method to ensure high precision

The neutron

no charge
low polarizability $(11.6 \pm 1.5) \cdot 10^{-4} \mathrm{fm}^3 \propto 10^{-19} \alpha_{\mathrm{atom}}$
magnetic moment
nEDM $|d_n| < 2.9 \times 10^{-26} e\mathrm{cm}$

The method

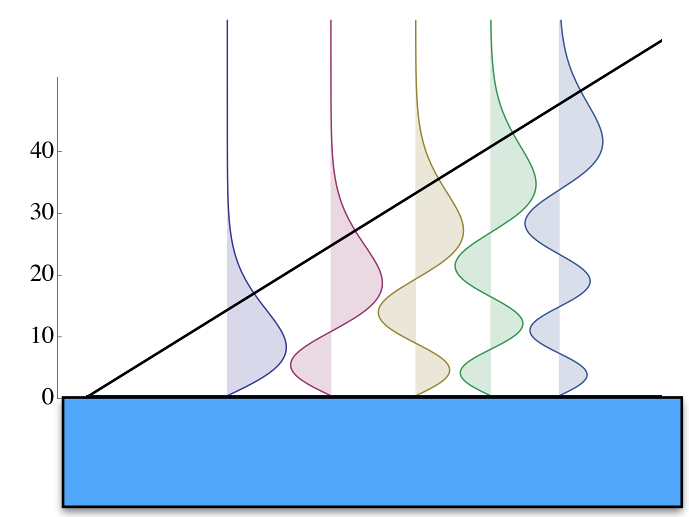
Resonance Spectroscopy: $\boxed{E = h\nu}$



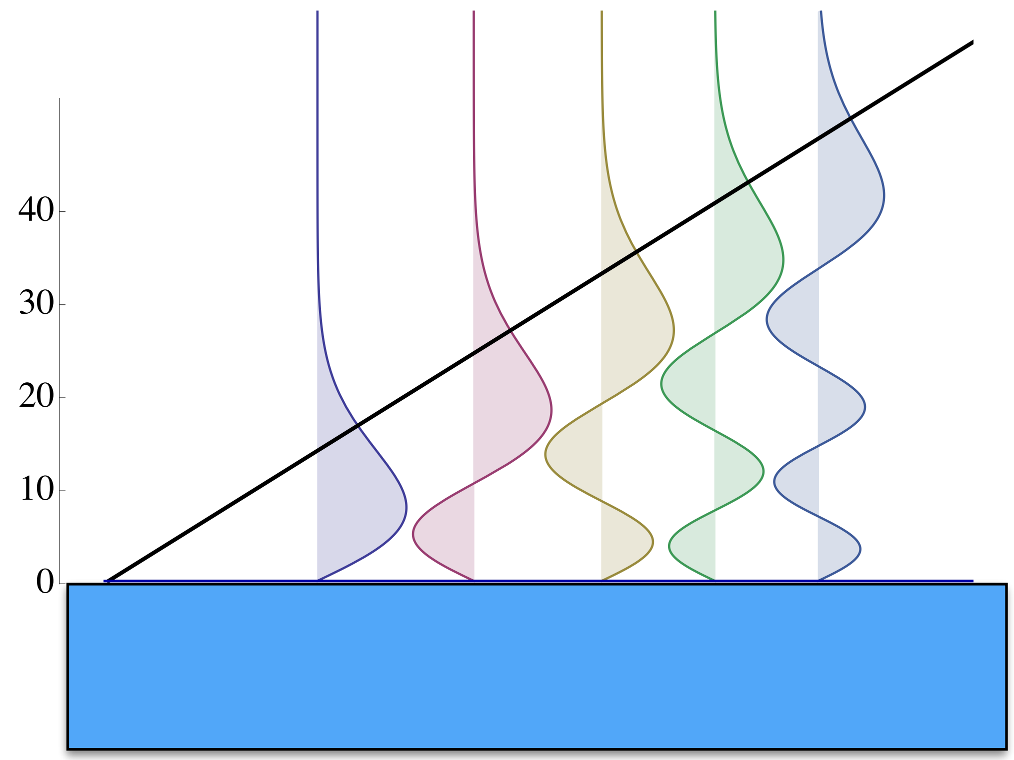
The system

Ultra-cold neutron above a mirror

- no electromagnetic interaction
- low energy
- Energy resolution: $\Delta E = 10^{-21} \mathrm{eV}$

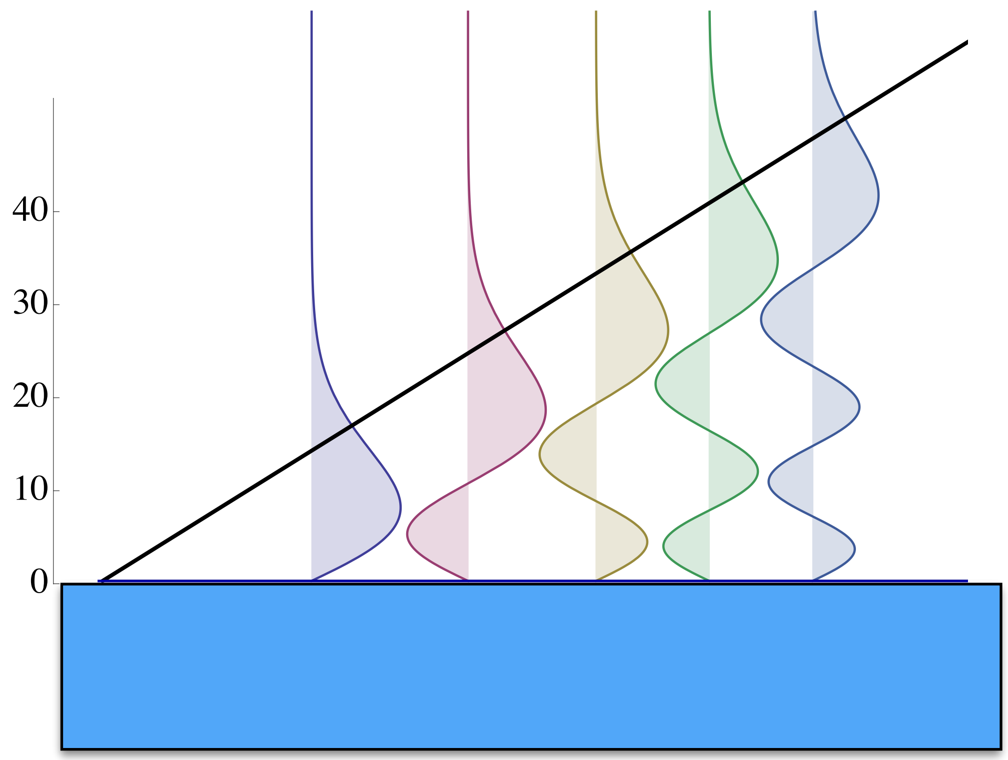


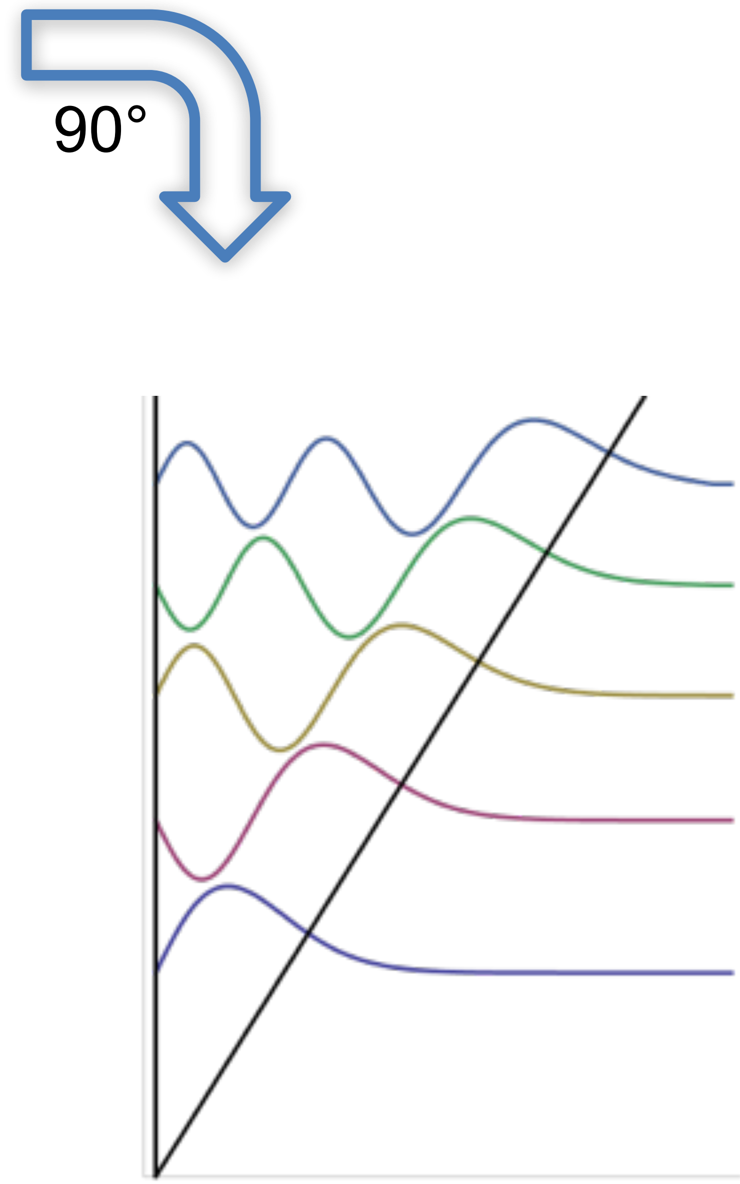
UCNs in the gravity field



V.I. Luschikov and A.I. Frank, JETP Lett. 28 559 (1978)
V. Nesvizhevsky et al., Nature, 415 297 (2002)

UCNs in the gravity field





high sensitivity to
modification of potential

V.I. Luschikov and A.I. Frank, JETP Lett. 28 559 (1978)
V. Nesvizhevsky et al., Nature, 415 297 (2002)

UCNs in the gravity field

- Schrödinger eq. with linearized gravity potential

$$\left(-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial z^2} + mgz\right)\varphi_n(z) = E_n\varphi_n(z)$$

bc: $\varphi_n(0) = 0$

$$\varphi_n(z) = a_n Ai\left(\frac{z}{z_0} - \frac{E_n}{E_0}\right)$$

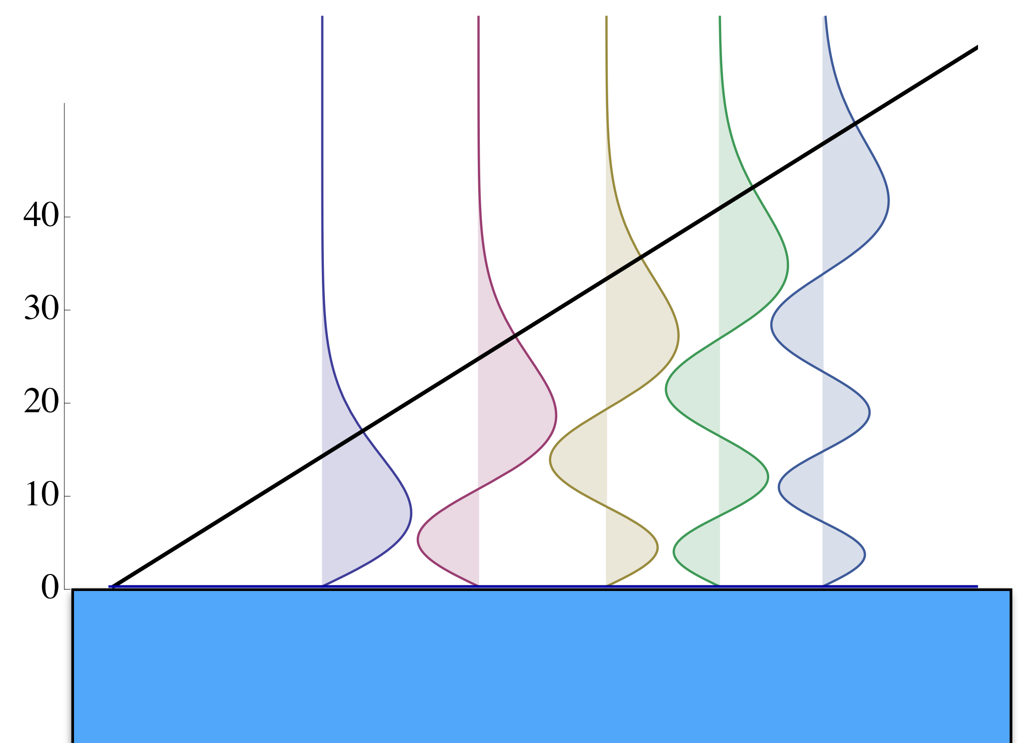
- bound, discrete states
- Non-equidistant energy levels

state	energy
1	1.41 peV
2	2.46 peV
3	3.32 peV

$$E_0 = \sqrt[3]{\frac{\hbar^2 m g^2}{2}} = 0.6\text{peV}$$

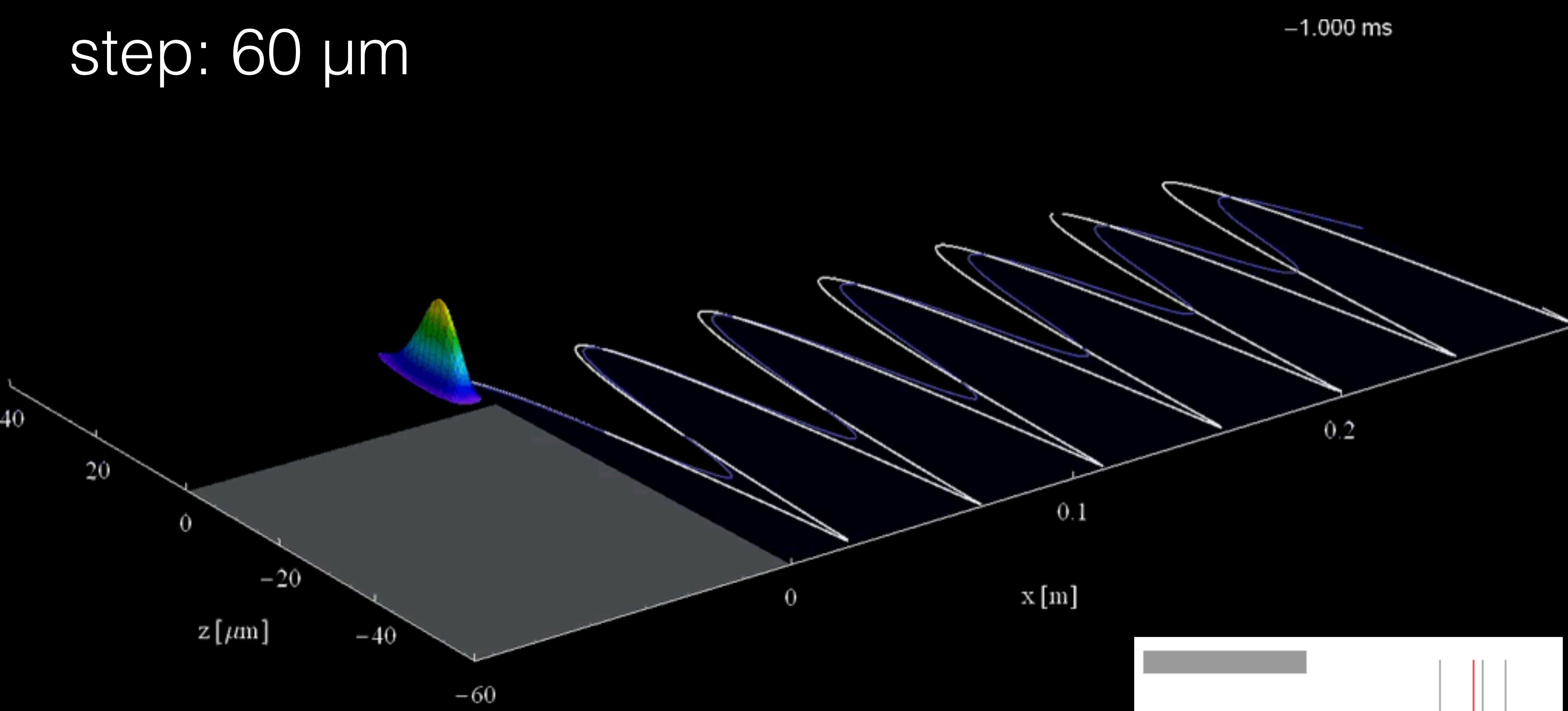
$$z_0 = \sqrt[3]{\frac{\hbar^2}{2m^2 g}} = 5.9\mu\text{m}$$

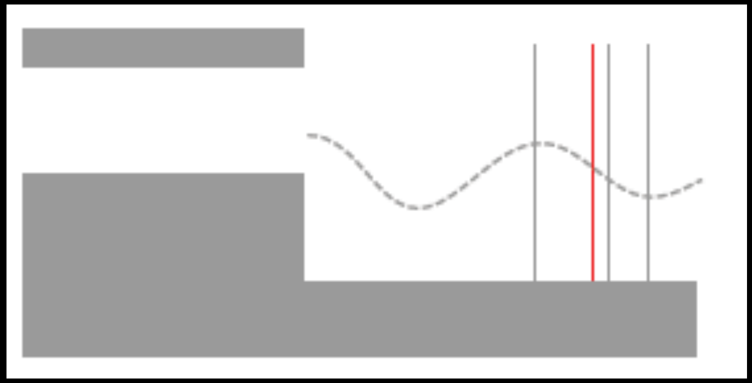
$$t_0 = \sqrt[3]{\frac{2\hbar}{m g^2}} = 1.1\text{ms}$$



Quantum Bouncer

step: 60 μm



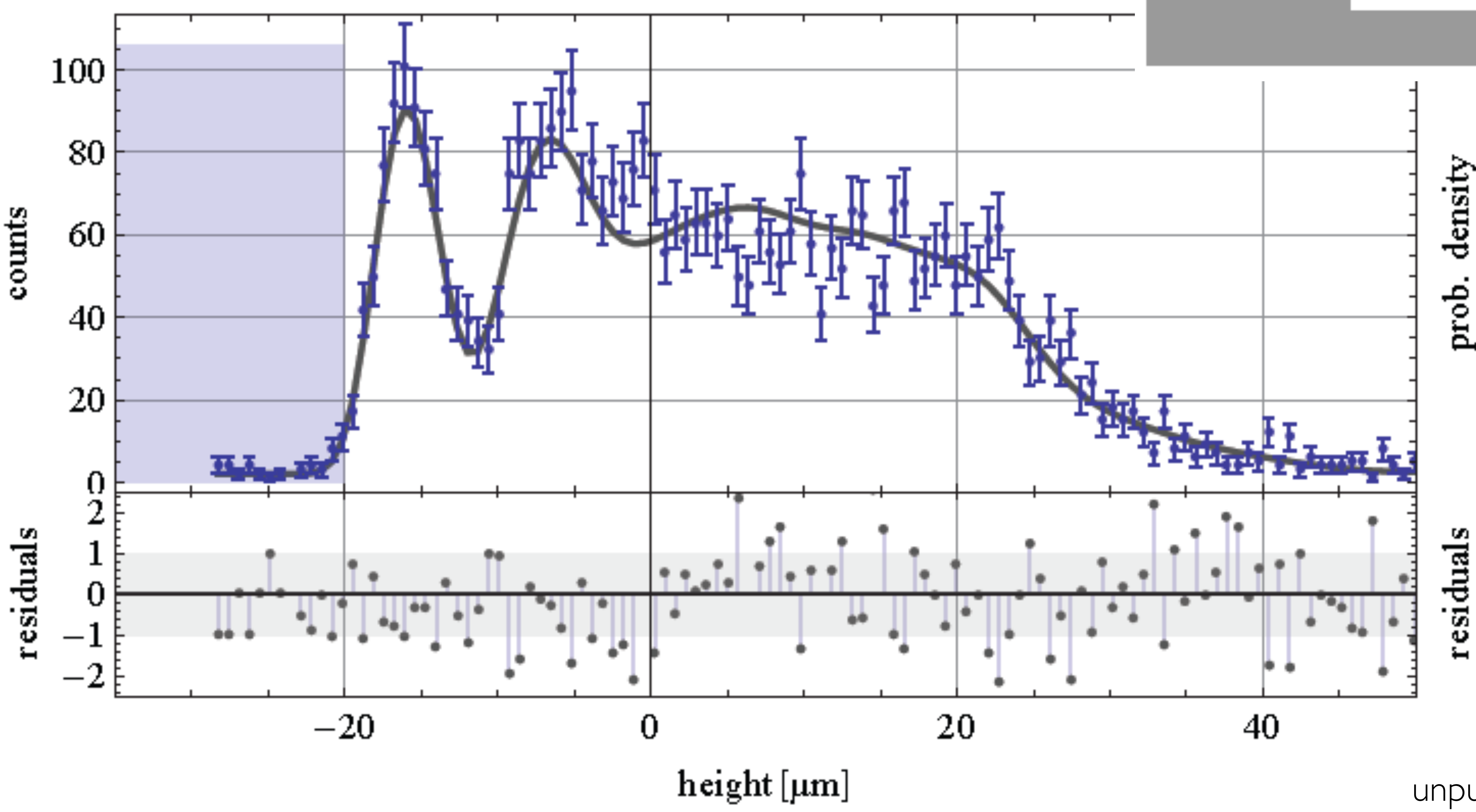


qBounce

measurements at different positions

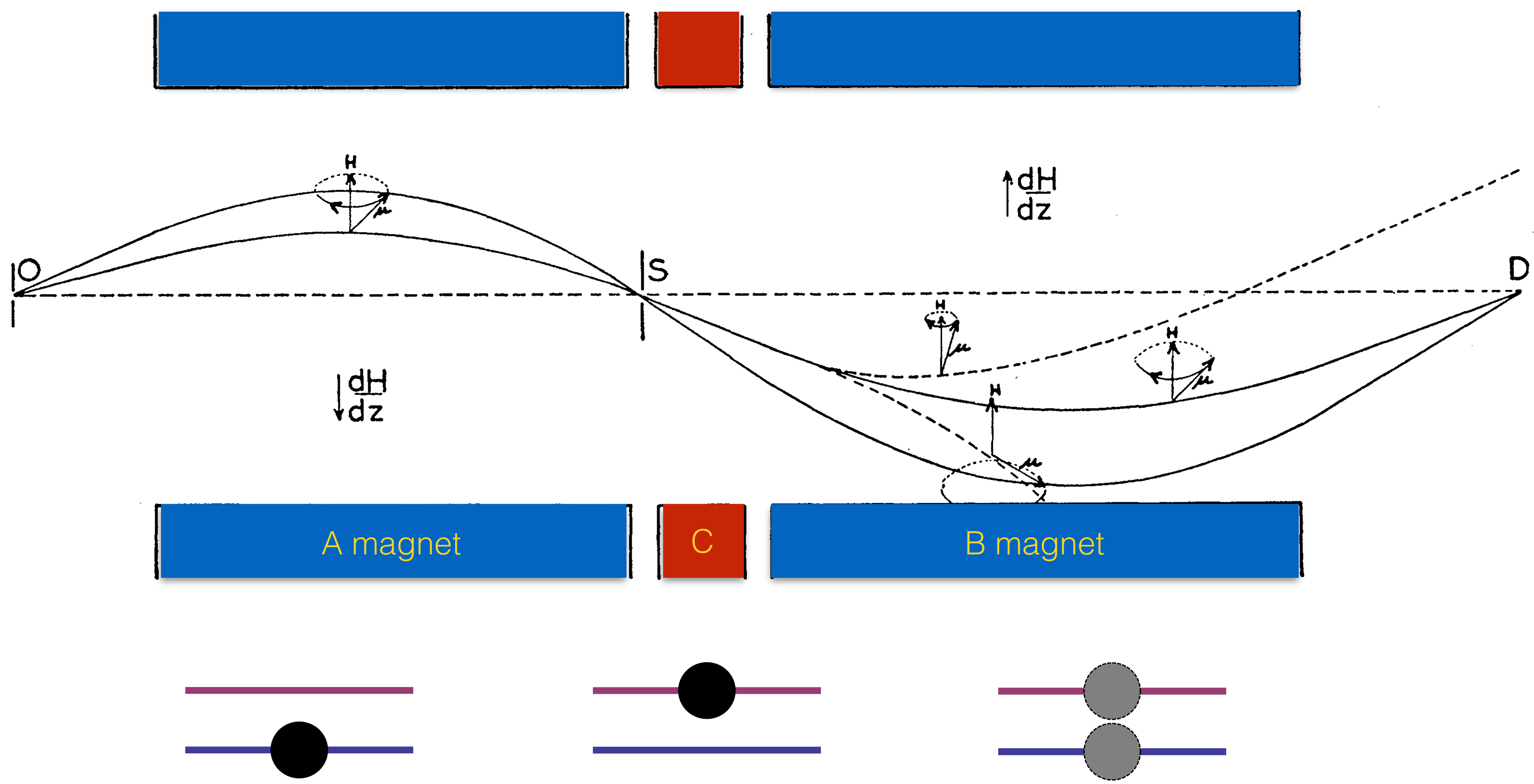
explicit quantum behaviour

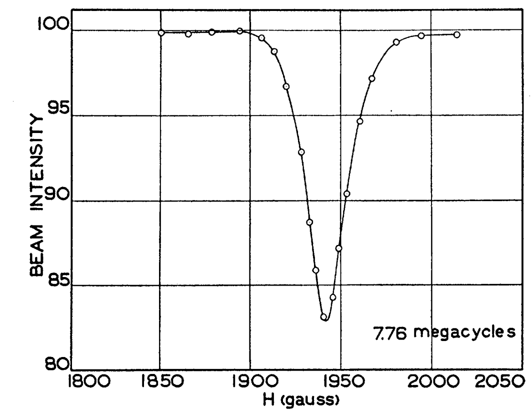
51mm behind 20μm step



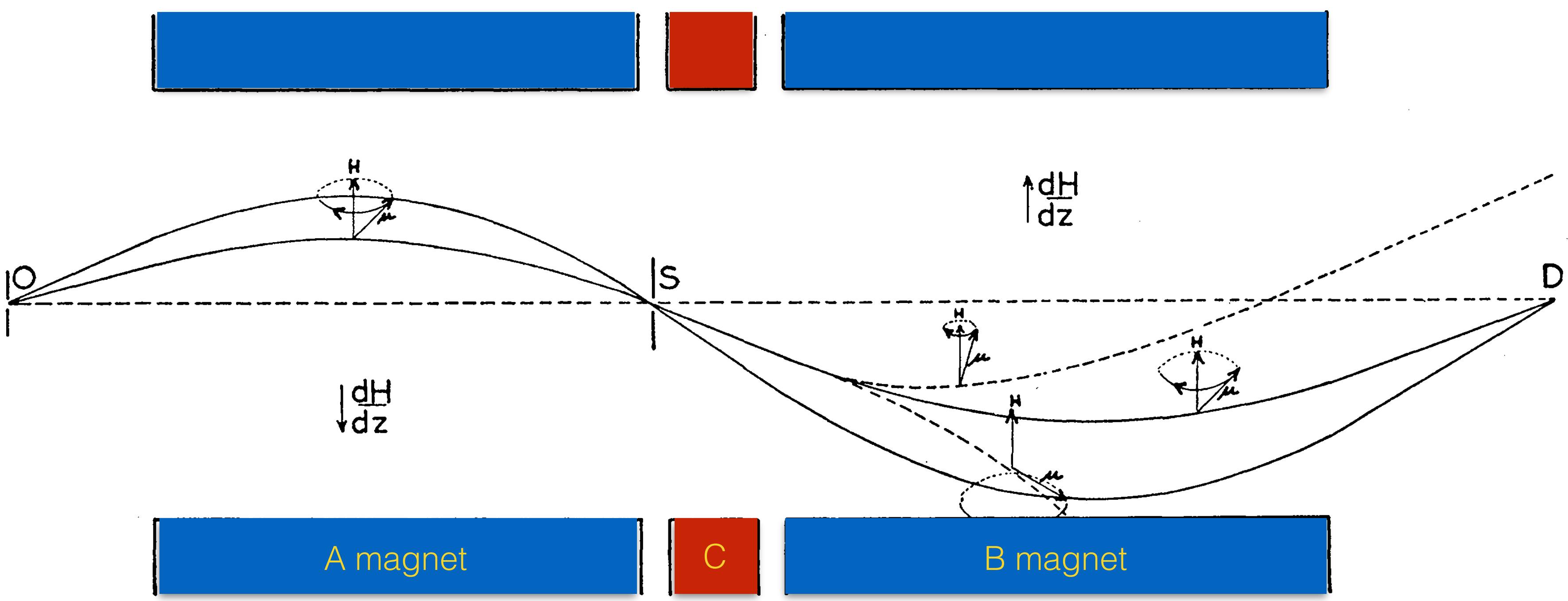
unpublished

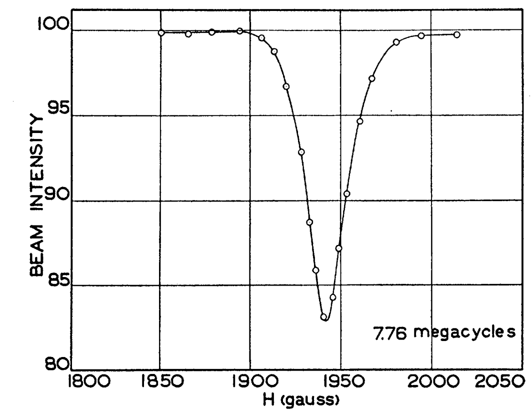
Rabis method

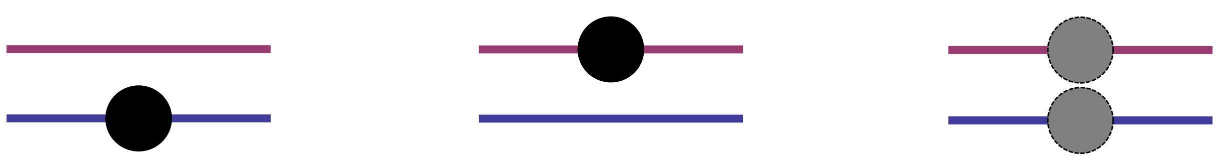


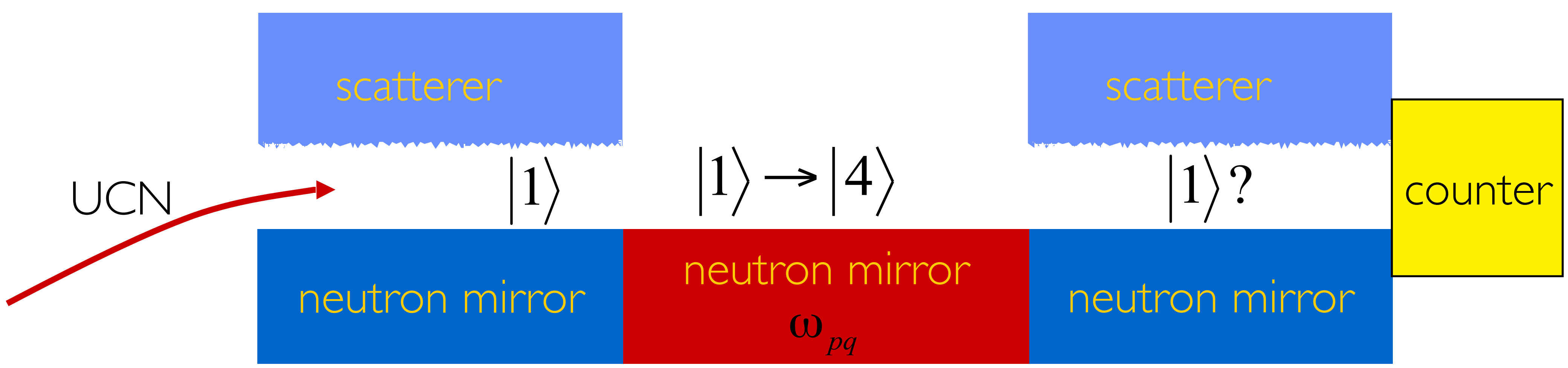


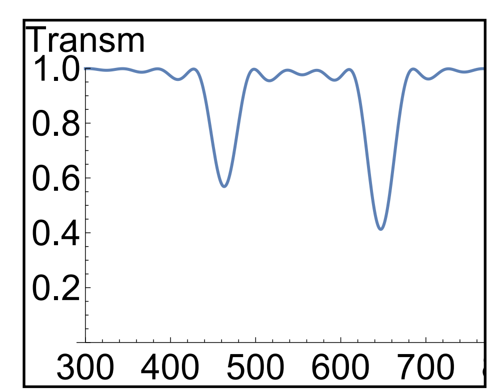
Rabis method





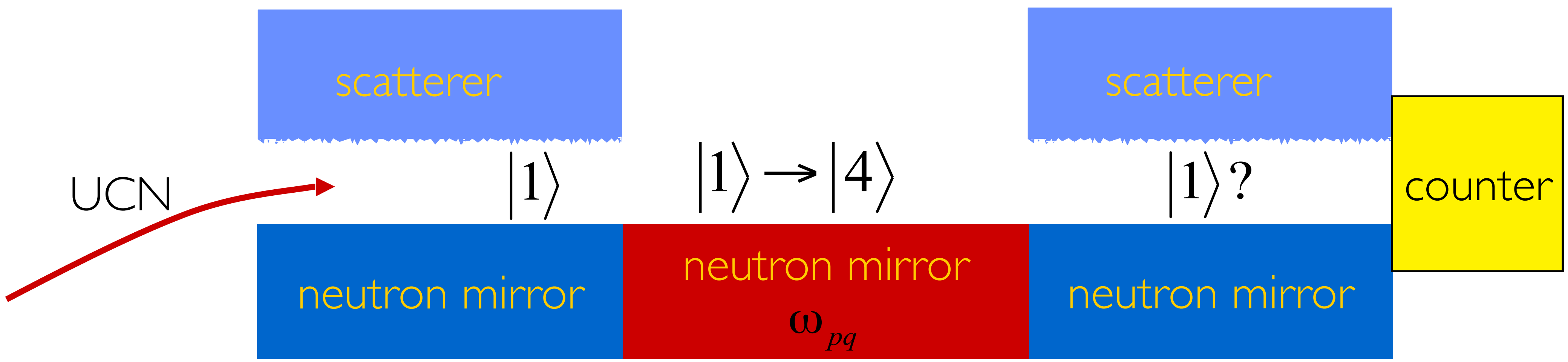




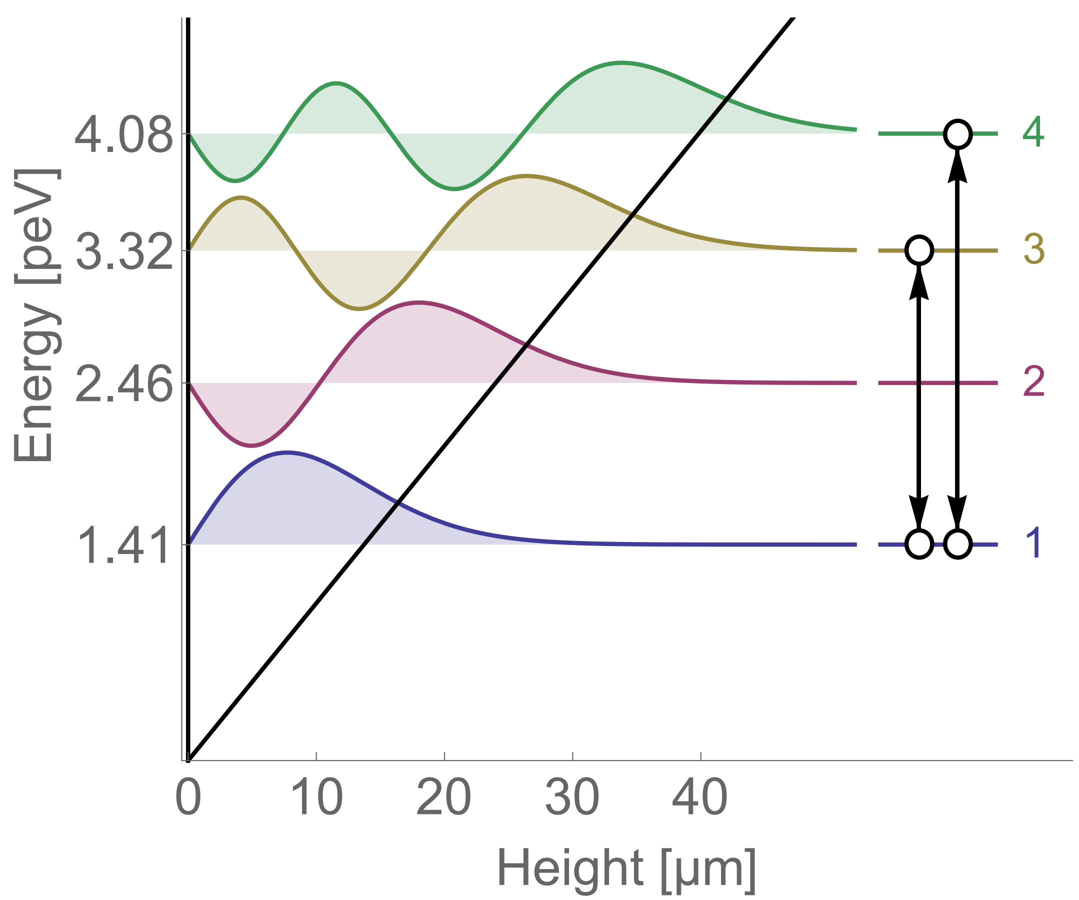


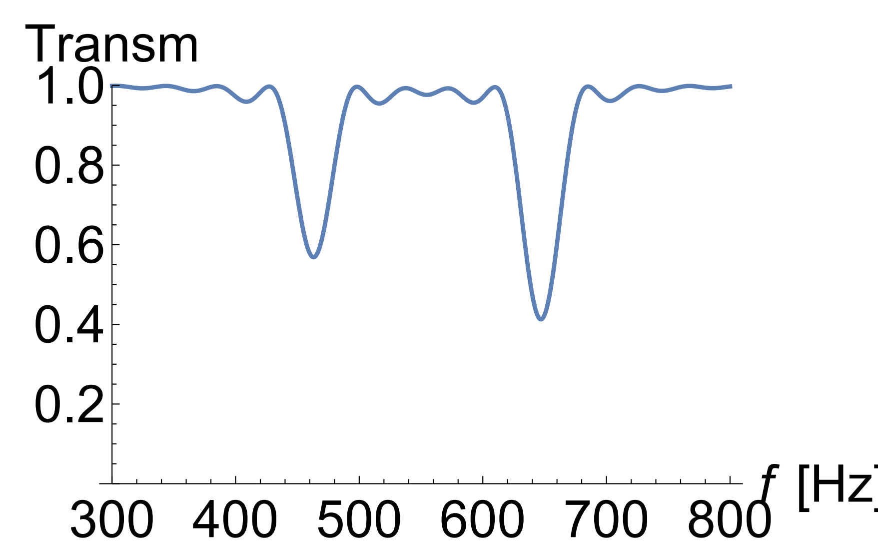
Gravity Resonance Spectroscopy

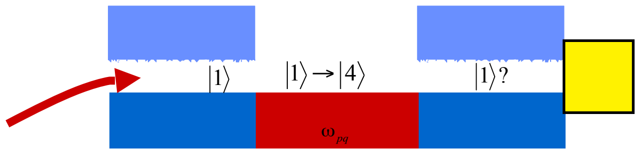
Rabi



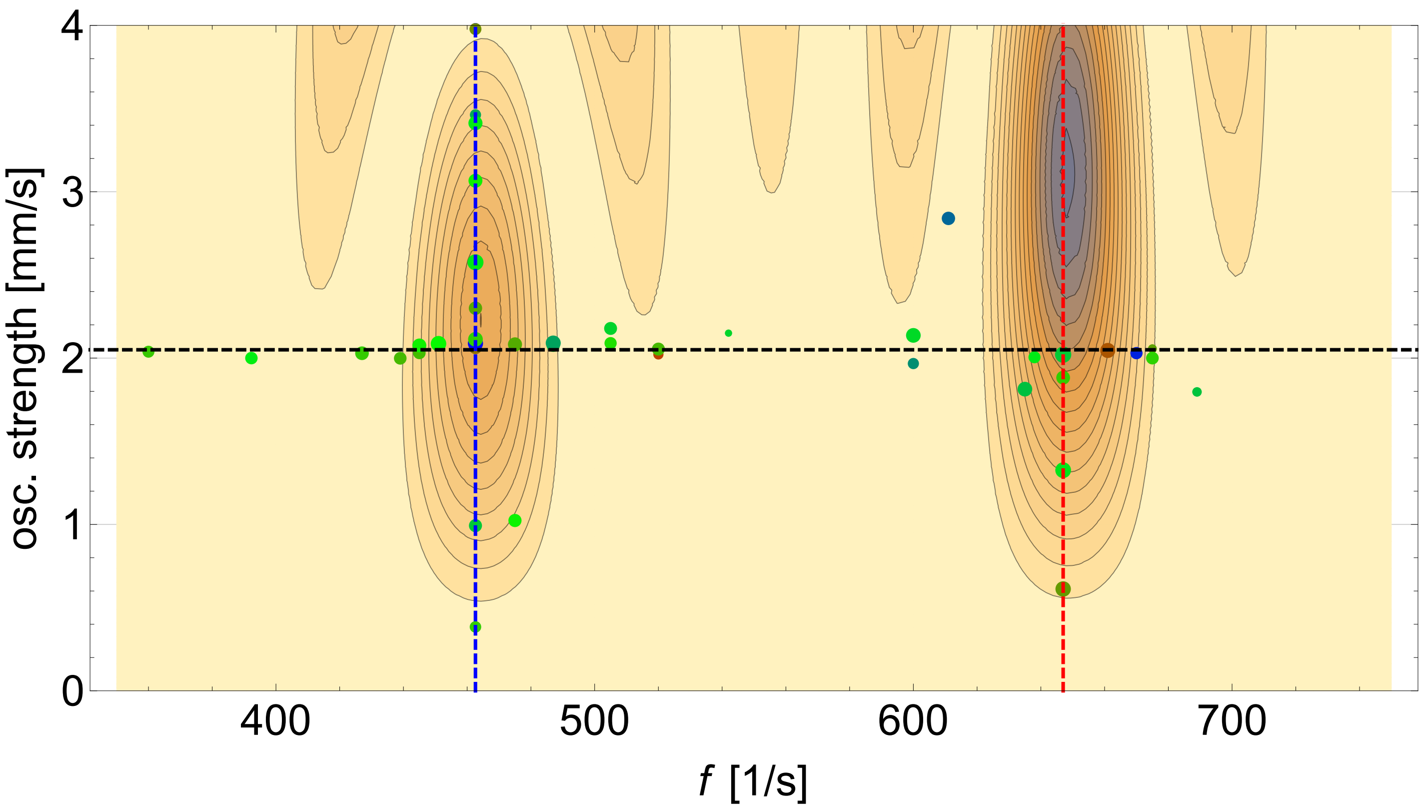
$$\boxed{E = h\nu}$$

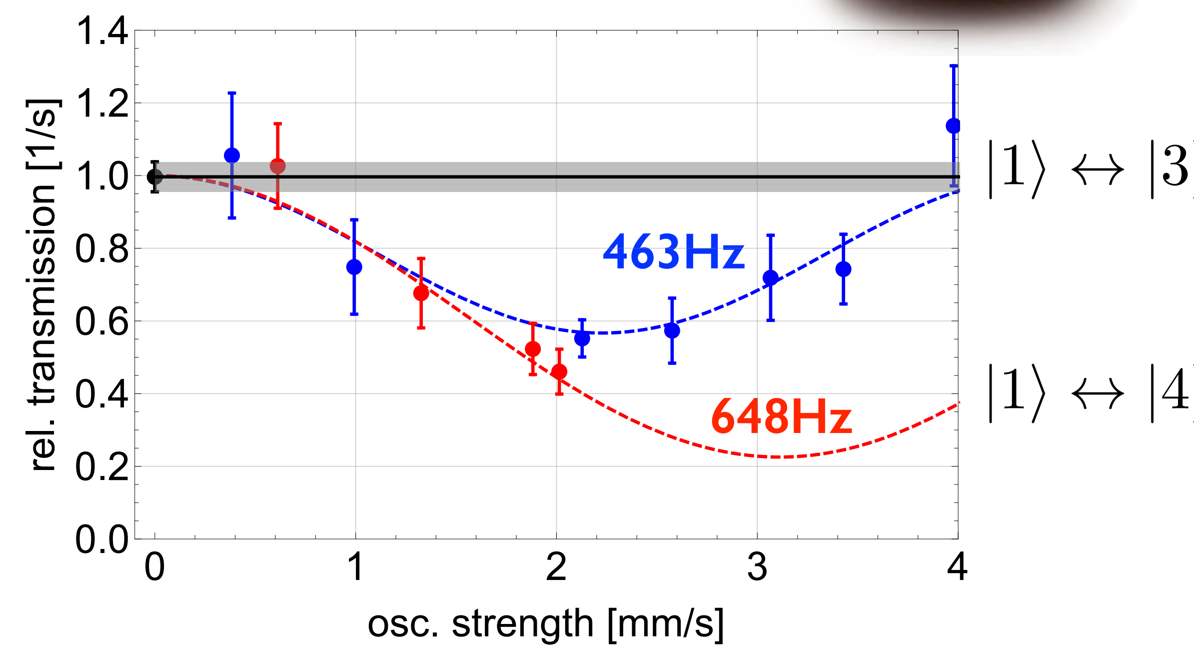




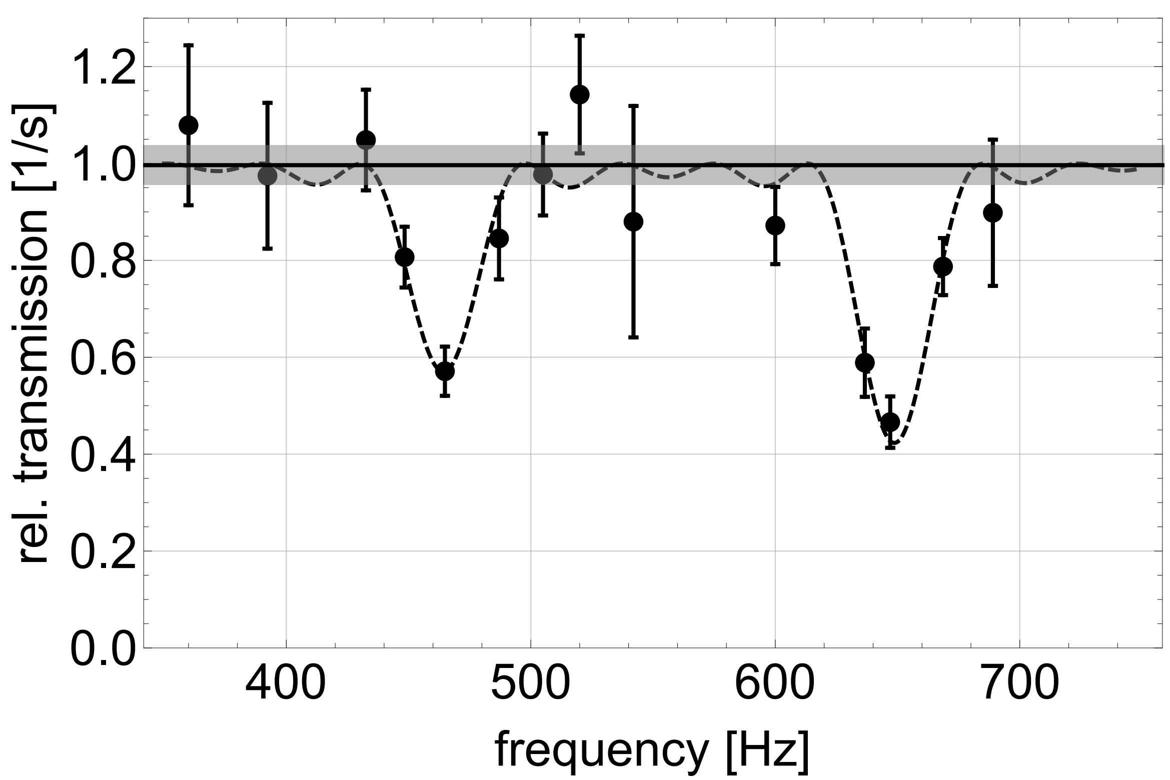


GRS





$$P(t) = \left(\frac{\Omega_R}{\Omega'_R}\right)^2 \sin^2\left(\frac{\Omega'_R}{2}t\right)$$



$$\Omega'_R = \sqrt{\Omega_R^2 + (\omega_{pq} - \omega)^2} = \sqrt{\Omega_R^2 + \delta^2}$$

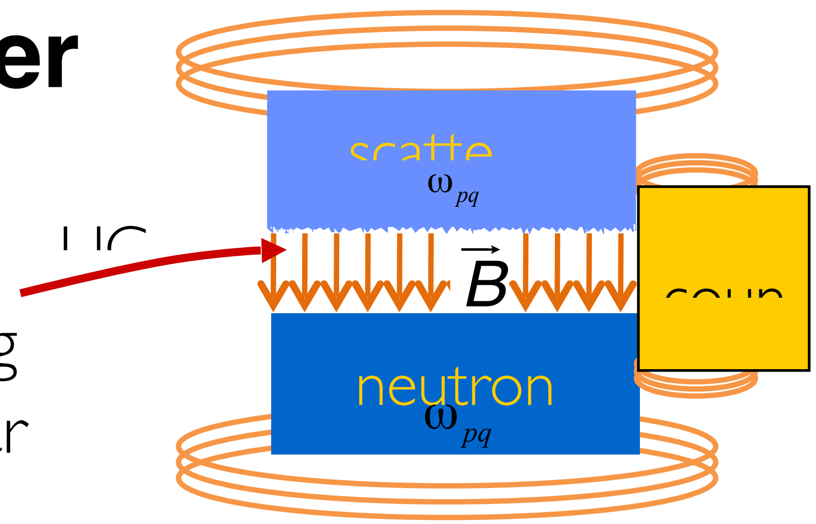
$$\nu_{13} = 463.74^{+1.05}_{-1.10}\text{Hz}$$

$$\nu_{14} = 648.24^{+1.46}_{-1.53}\text{Hz}$$

no decoherence observed!

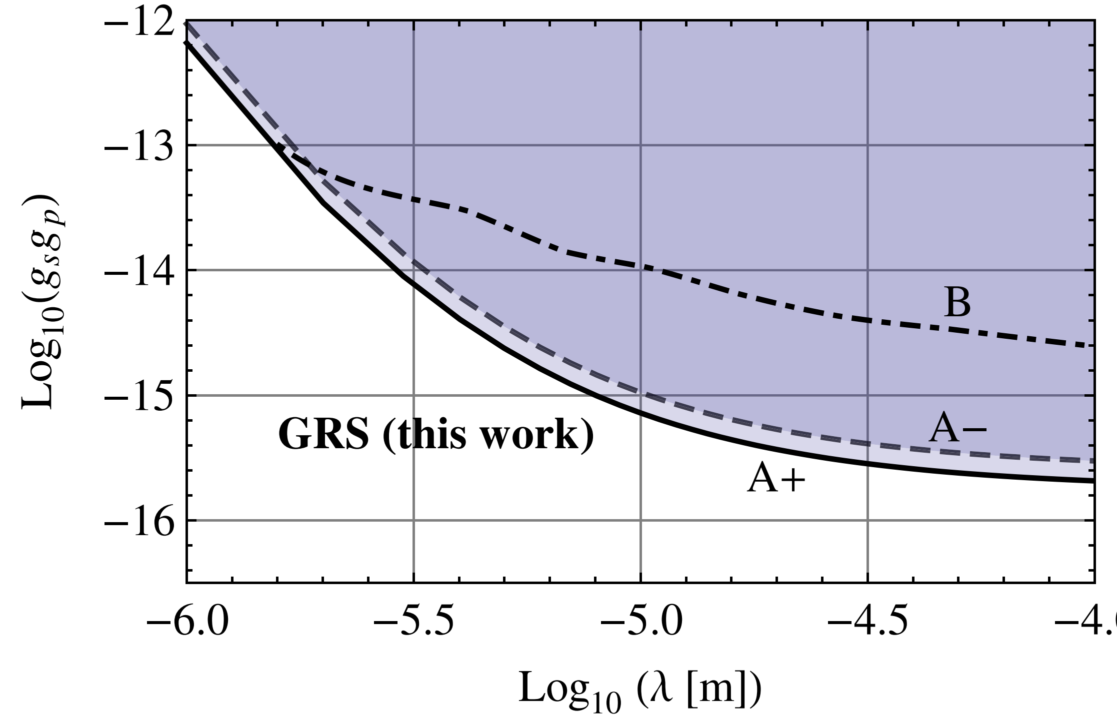
Dark universe

Dark Matter



Axions

- spin-mass coupling
- scalar-pseudoscalar coupling

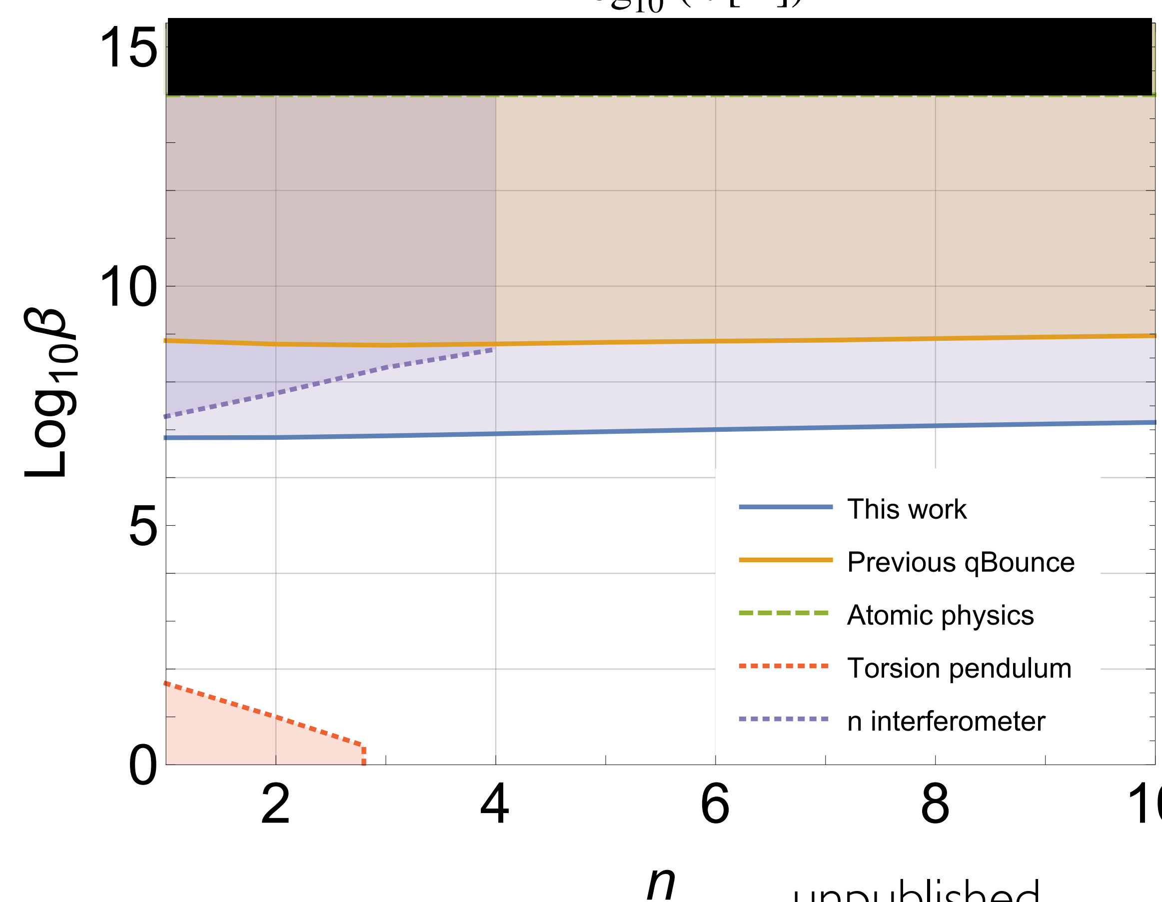


Dark Energy

Chameleons

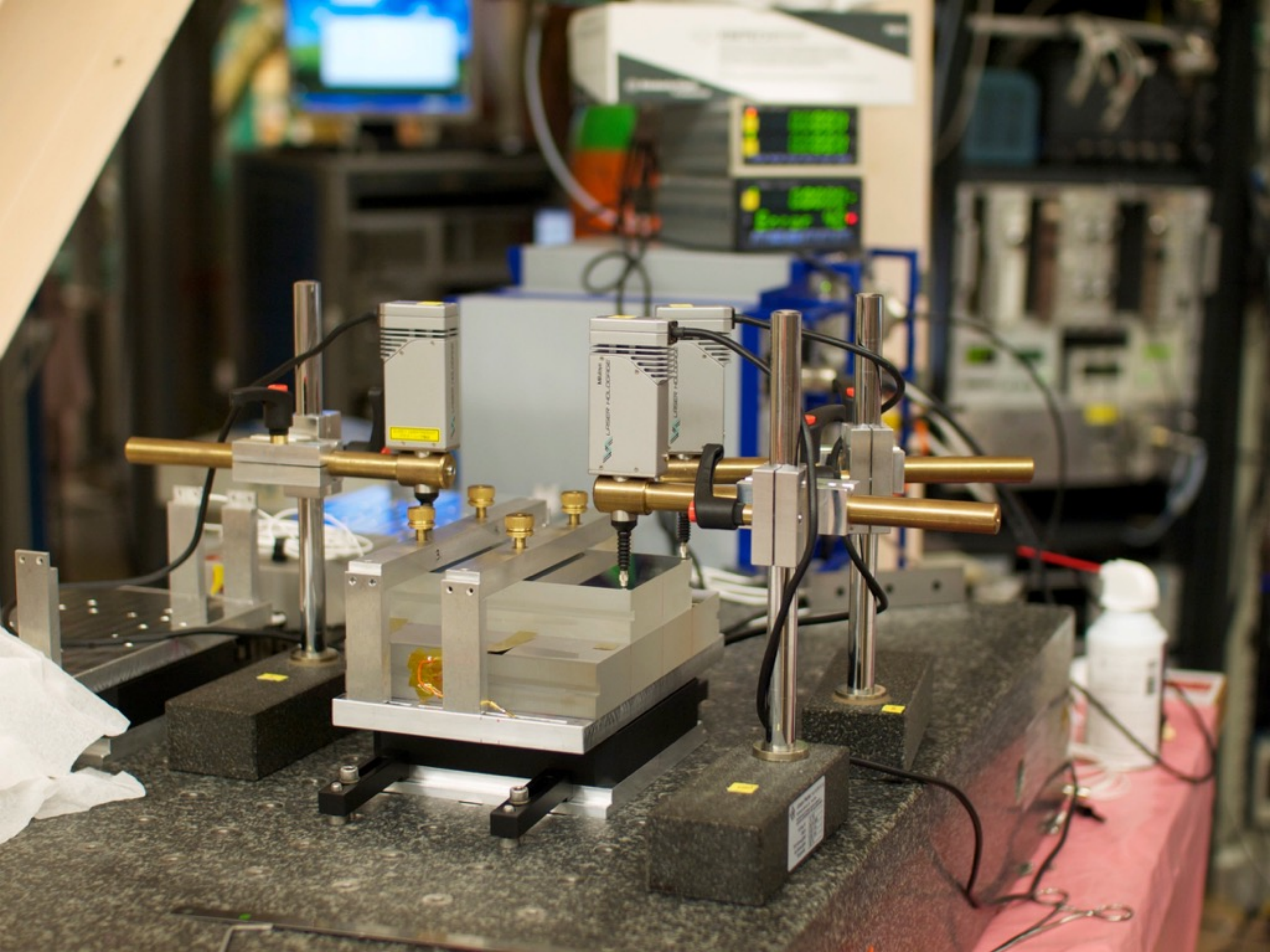
- mechanism suppresses in vicinity of masses
- have screening mechanism

Torsion, vacuum energy



unpublished

Jenke, T., Cronenberg, G., et al. Phys. Rev. Lett., 112, 151105. (2014)



NEUTRONS FOR SCIENCE®

TU WIEN

Kevin Mitsch

Jason Jung

Martin Thalhammer

G. C.

Peter Geltenbort

Hanno Filter

Tobias Jenke

Hartmut Abele