Slow neutrons and their role to test gravity

Testing Gravity 2015

16.01.2015

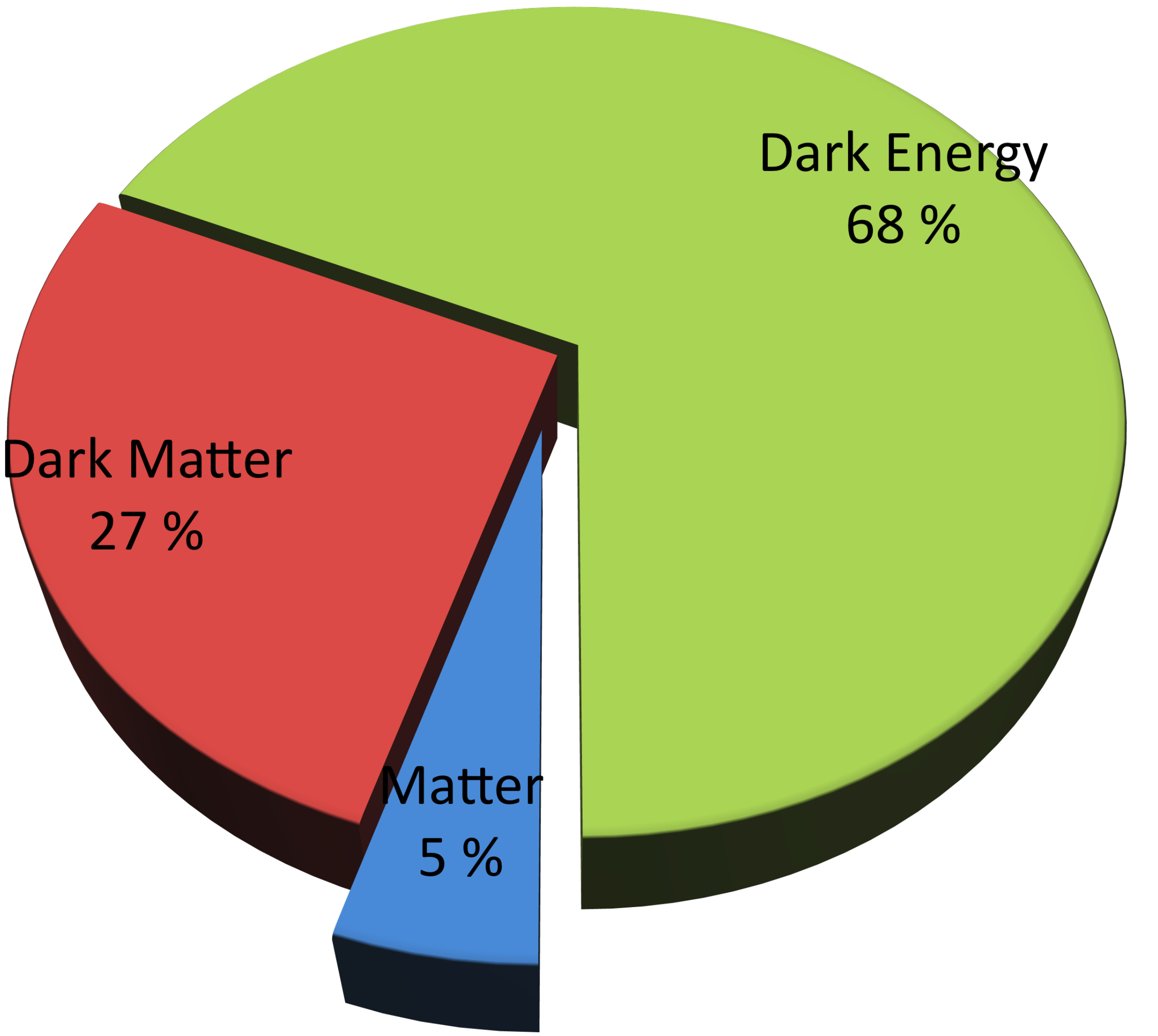
Gunther Cronenberg

Dark Matter & Dark Energy Search

- galaxy rotation problem
- Supernova Ia
- cosmic microwave background (CMB)

experimental evidence for Dark Matter (DM) and Dark Energy (DE)

After Planck



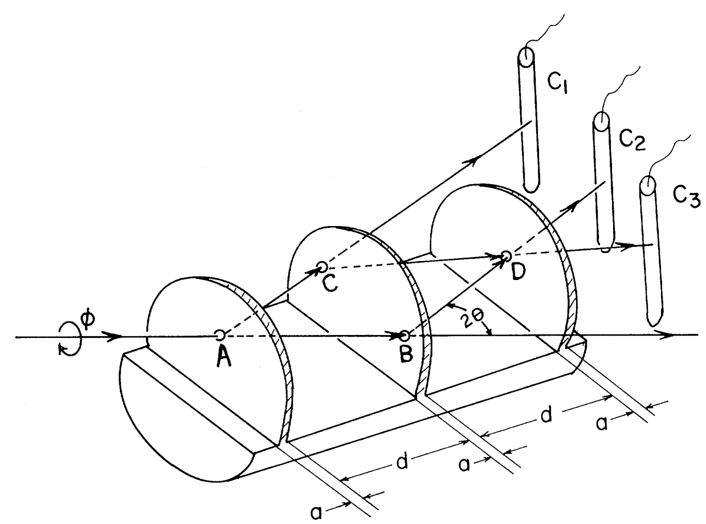
Planck 2013 results, arXiv:1303.5076

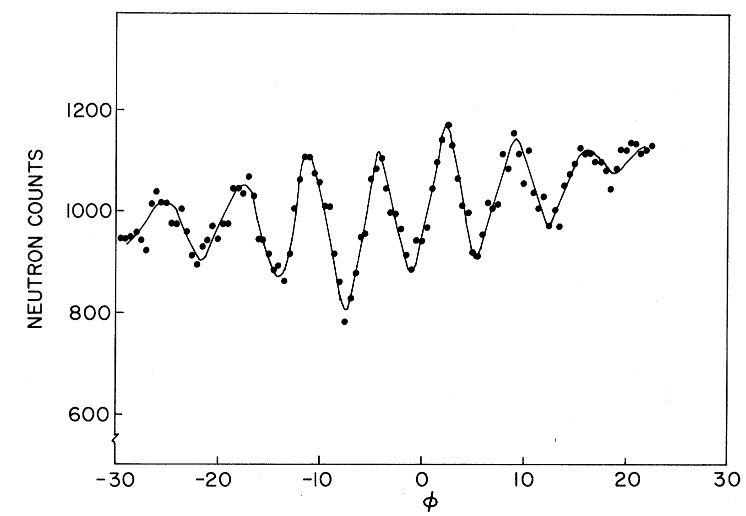
Neutrons & Gravity

First experiments:

- COW (1975):

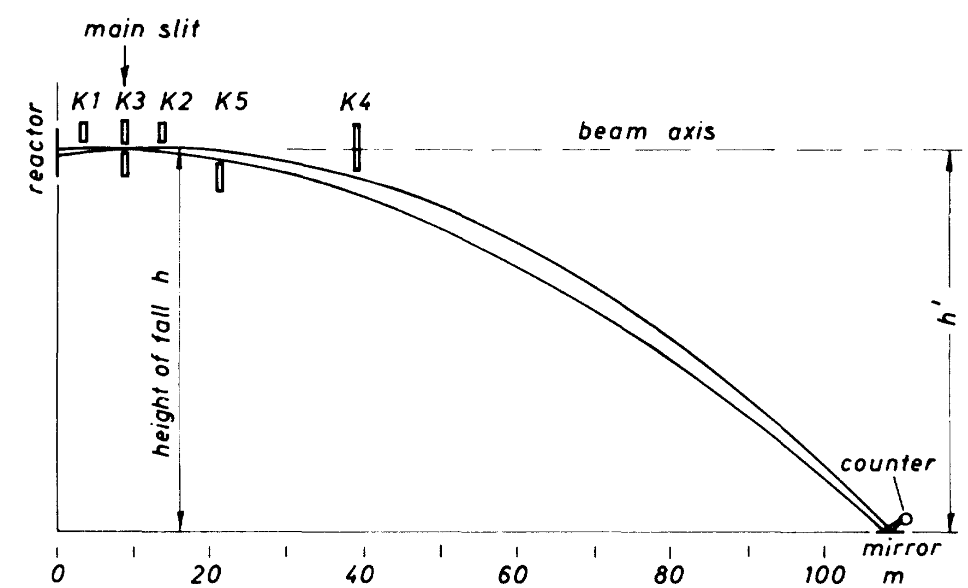
  first observation of
  gravitational shift
  for neutrons





- Köster (1976):

  test equality of inertial and
  gravitational mass
  by scattering length measurements



Colella, R., Overhauser, A., & Werner, S. (1975). Physical Review Letters, 34(23), 1472
Koester, L. (1976).Physical Review D, 14(4),

Ultra/Very Cold Neutrons

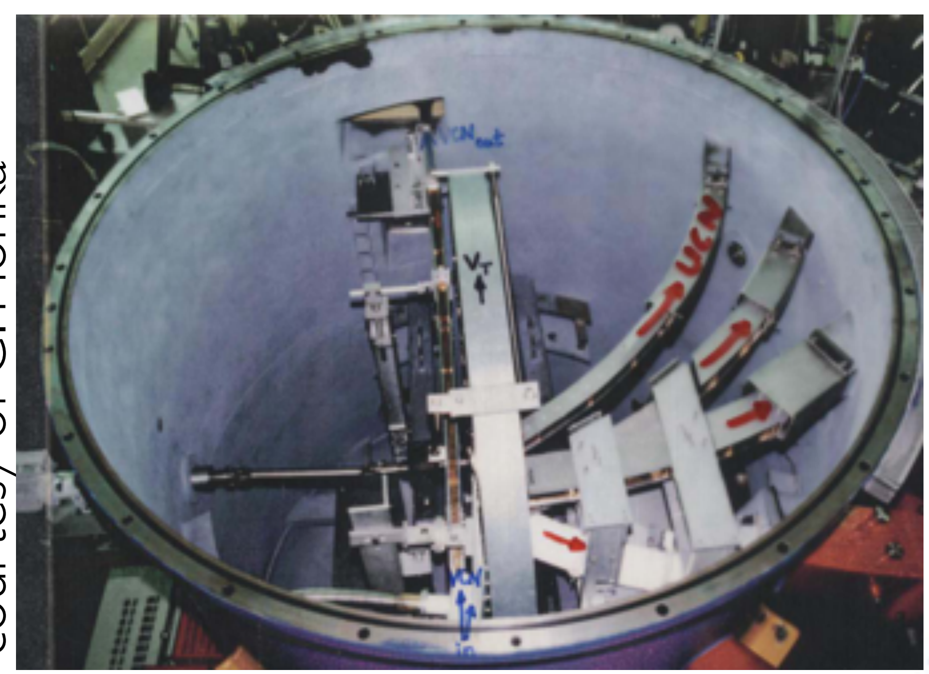
UCN $\lambda \approx 1.5\text{nm} - 15\text{nm}$

VCN $\lambda \sim 50\text{nm} \quad E_{\text{kin}} \approx (50 - 300)\text{neV}$

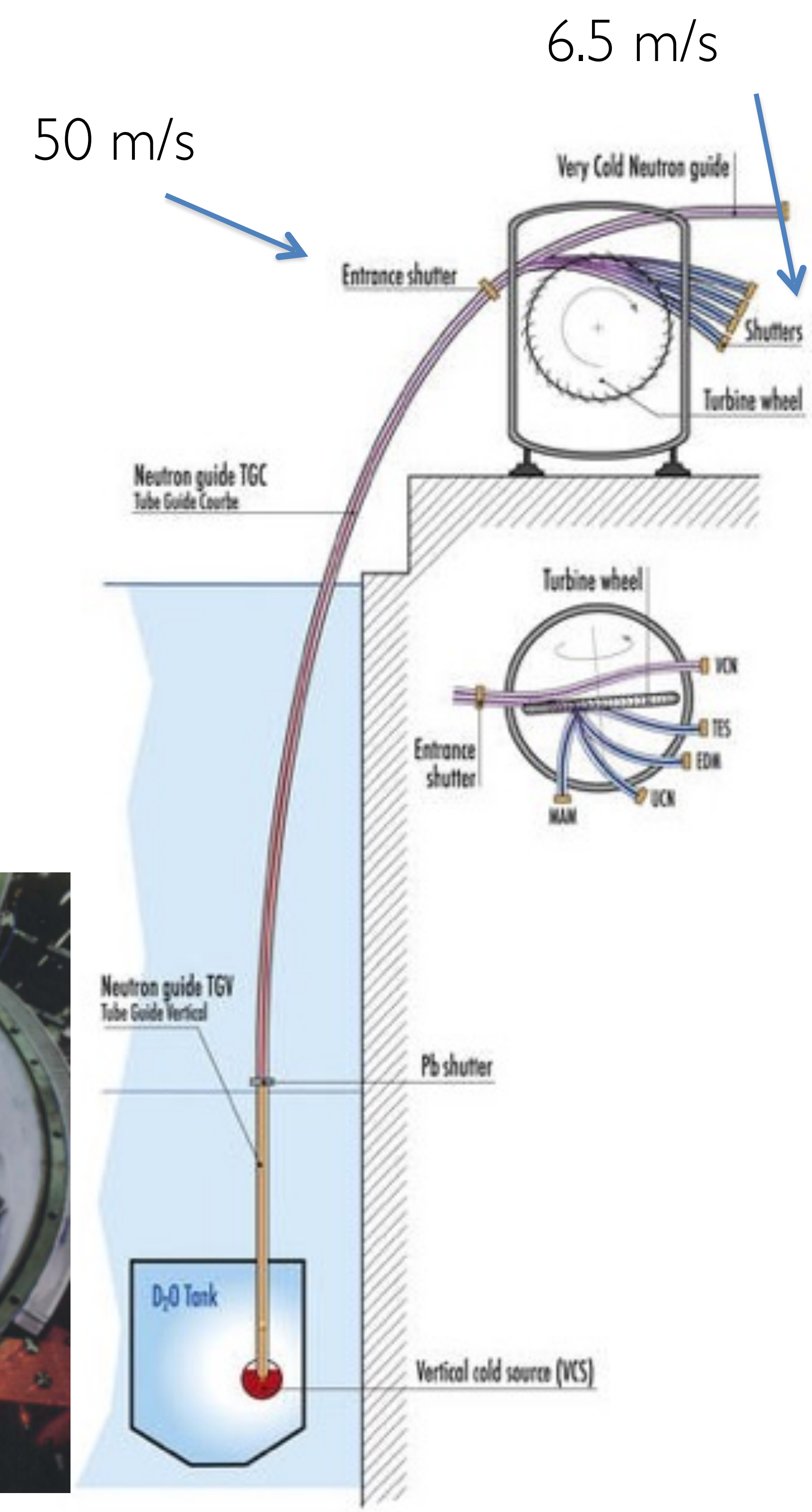
Neutron:

- no electric charge
- small polarisability $(11.6 \pm 1.5) \cdot 10^{-4}\,\text{fm}^3 \propto 10^{-19} \alpha_{\text{atom}}$
- nEDM $|d_n| < 2.9 \times 10^{-26} e\text{cm}$
- total reflection for even big angles (VCN < 1°)
- absorption !

UCN/VCN source:
PF2 at ILL

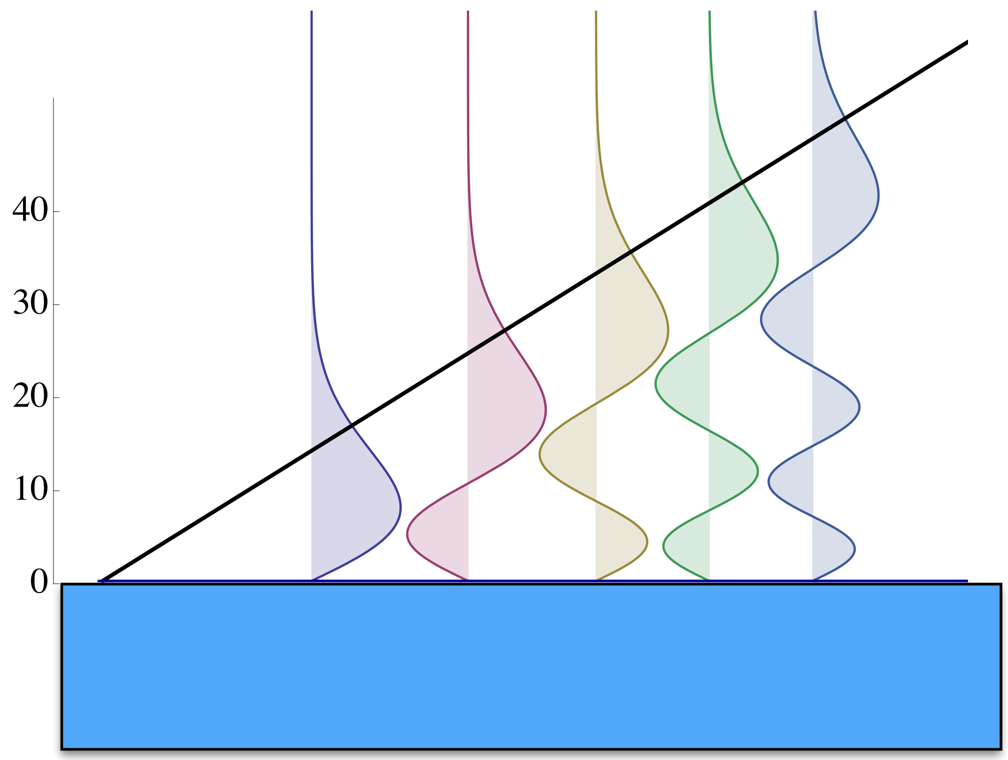


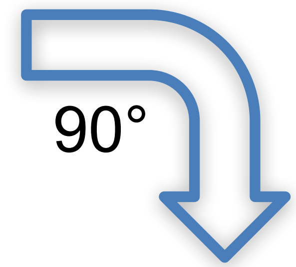
courtesy of C. Plonka

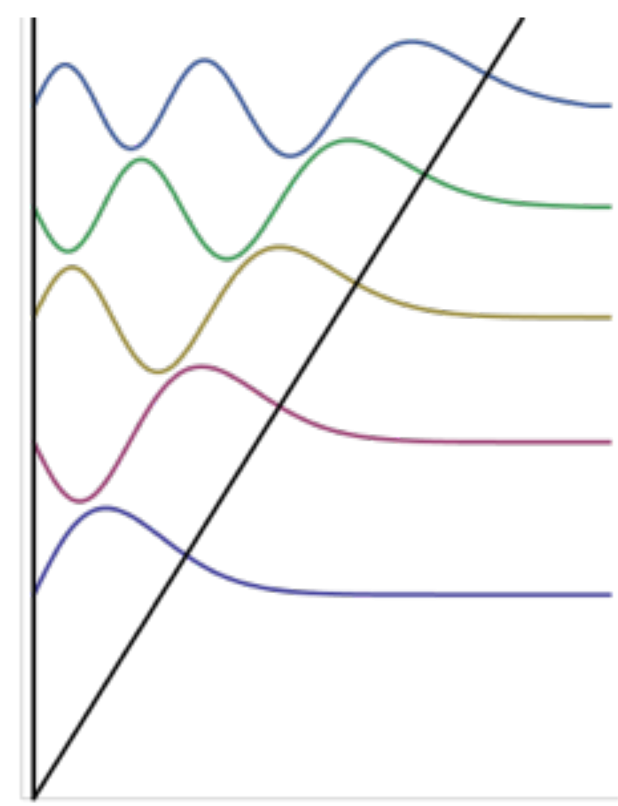


Baker, C. A., et al. (2006), Physical Review Letters, 97(13)

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

- Schrödinger eq. with linearized gravity potential

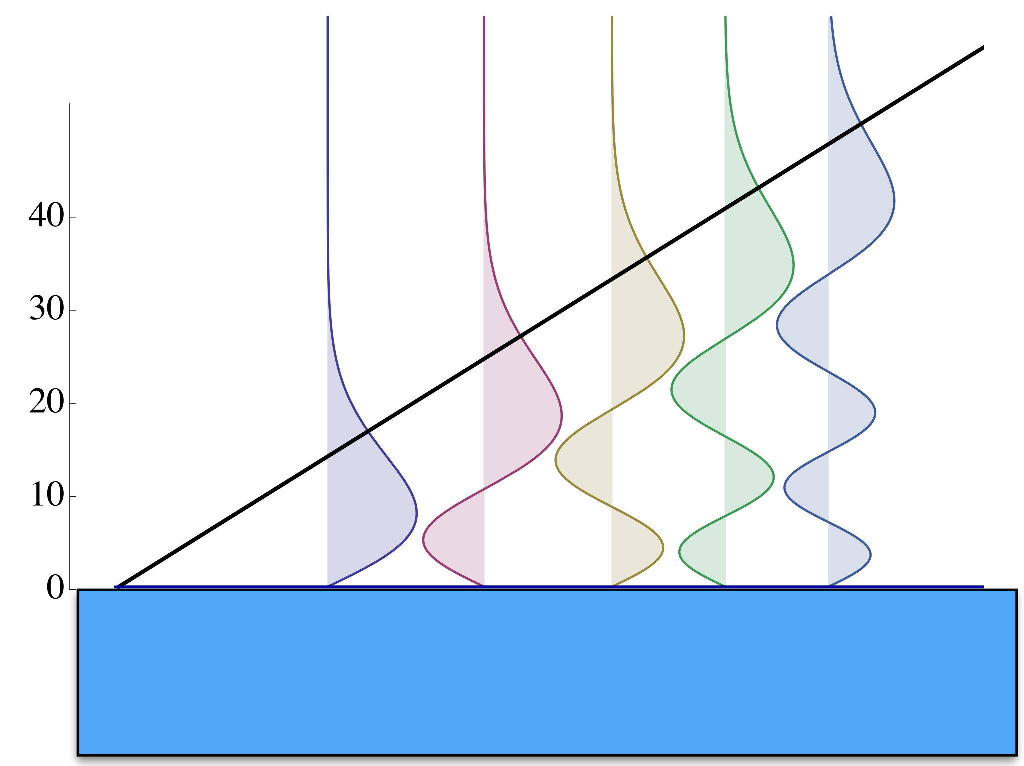
$$\left(-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial z^2}+mgz\right)\varphi_n(z)=E_n\varphi_n(z)$$

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



Quantum Bouncer

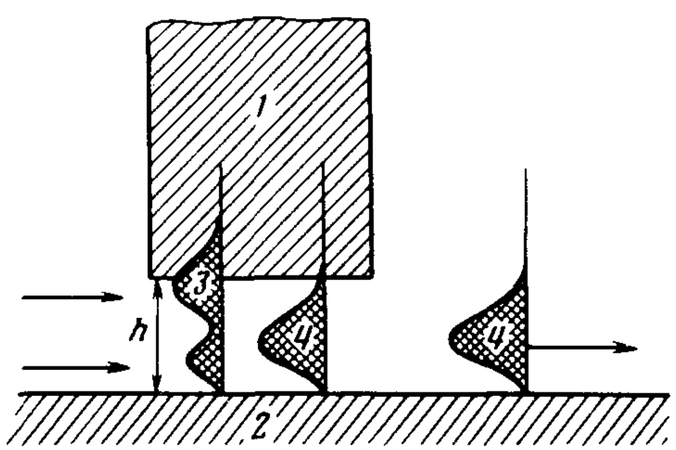
1971, 1974
Langhoff, Gibbs
The Quantum Bouncer

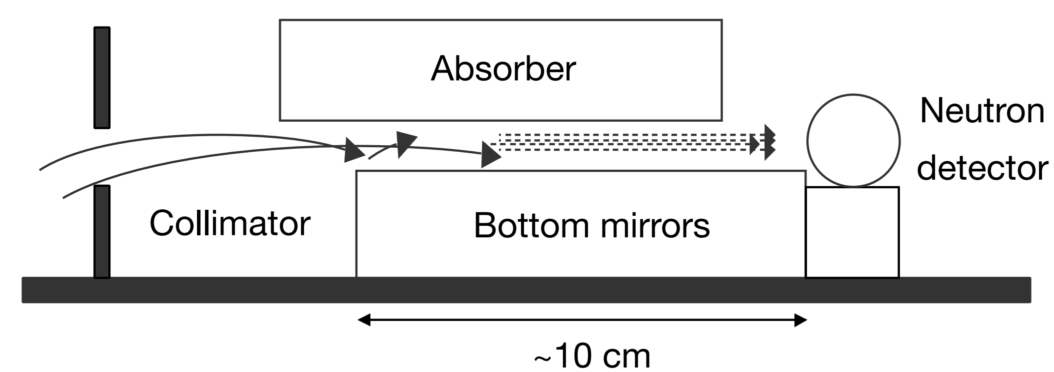
1978
Lushchikov, Frank
Quantum Bouncer with UCN

1992
Wallis et al.
Trapping Atoms in a Gravitational Cavity

2002
Nesvizhevsky, Abele et al.
Demonstation of UCN gravity states

2009
Della Valle et al.
Photon Bouncing Ball





P.W. Langhoff, Am. J. Phys. 39, 954 (1971)
R. Gibbs, American Journ. o. Phys. 43 25 (1975)
V.I. Luschikov and A.I. Frank, JETP Lett. 28 559 (1978)

H. Wallis et al., Appl. Phys. B, 54 407 (1992)
V. Nesvizhevsky et al., Nature, 415 297 (2002)
G. Della Valle et al., PRL, 102 (2009)

qBounce: Timeline

2009
Jenke et al.
First Gravity Resonance Spectroscopy

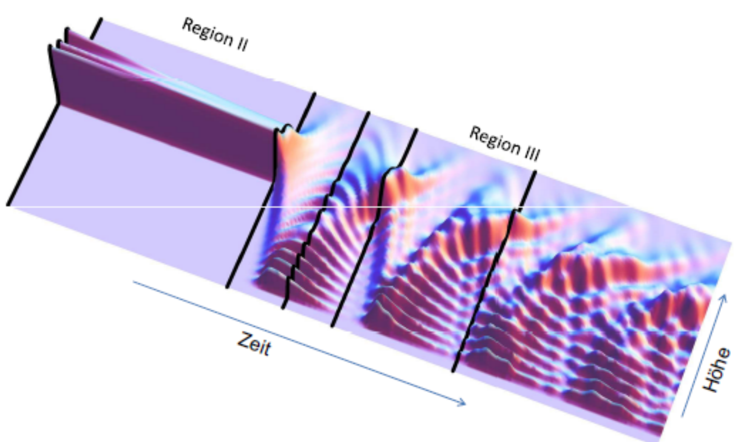
2012
Cronenberg, TJ, HF, MT et al.
Full 3-part Rabi like setup

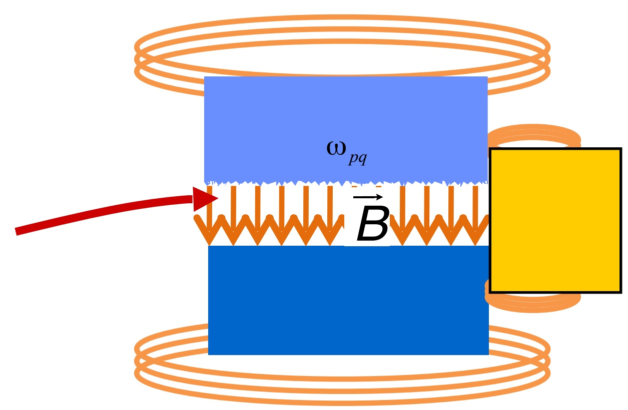
2014
Thalhammer, TJ, TR et al.
qBouncer

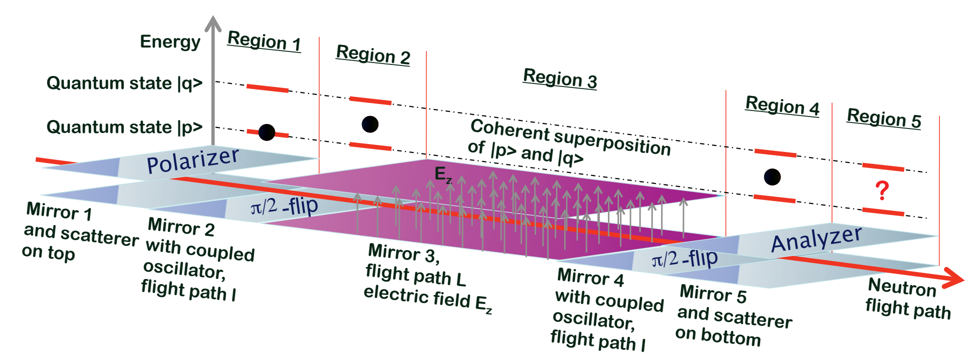
2007-2009
Jenke et al.
qBouncer

2010, 2011
Jenke, GC et al.
Axion, Chameleon measurements

H. Filter
Neutron charge



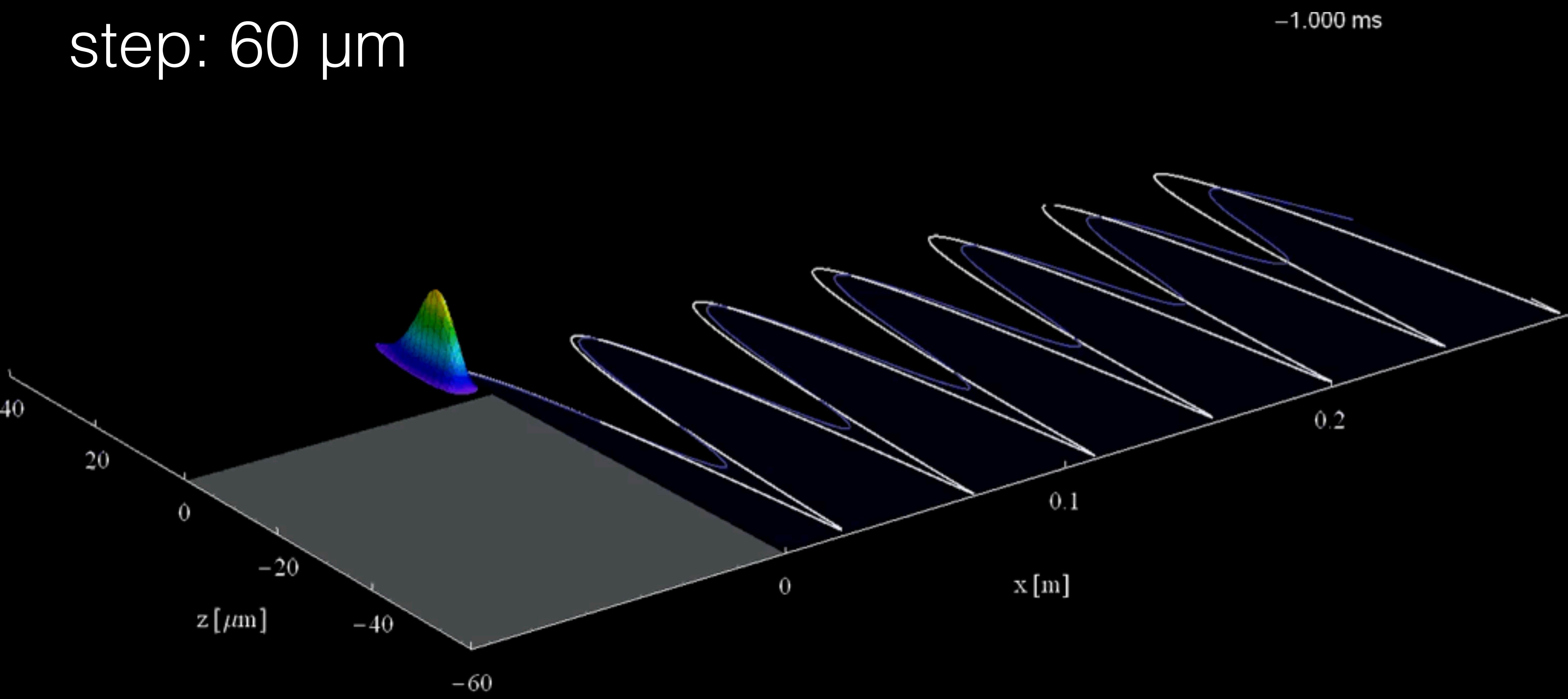




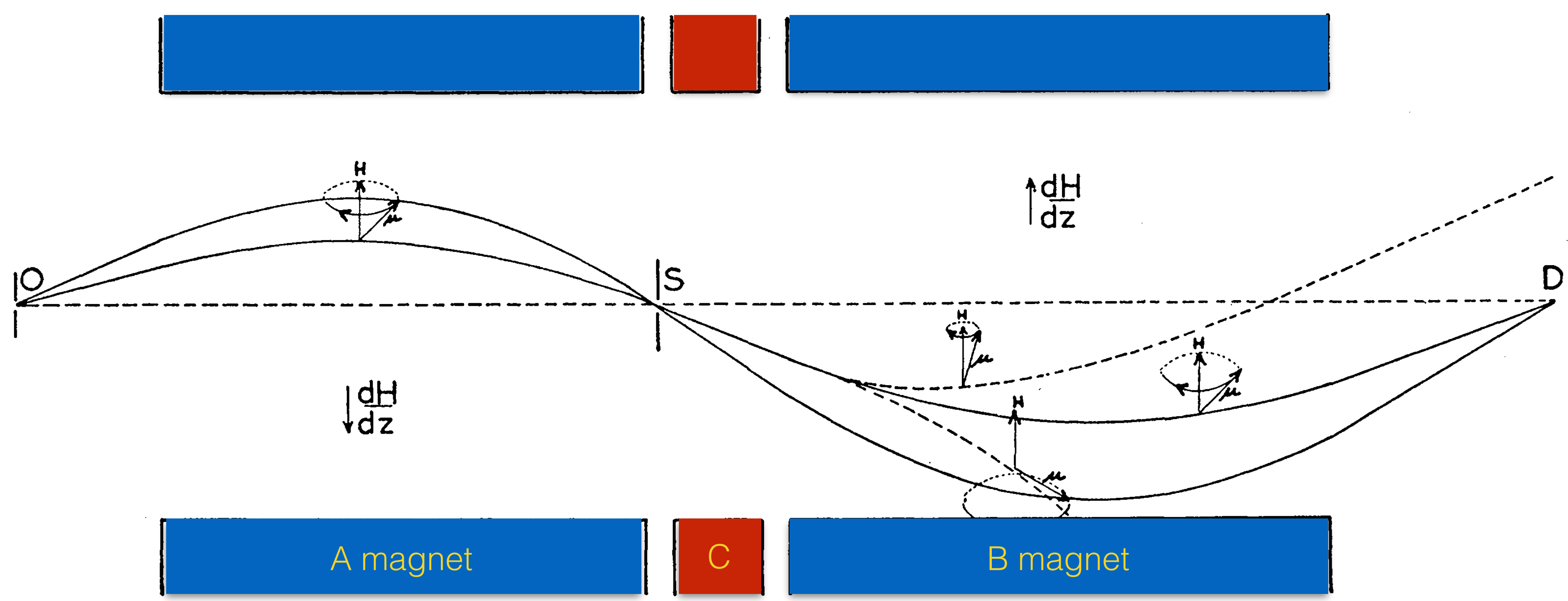
T. Jenke et al., NIM A 611 318 (2009)
H. Abele et. al., Nucl. Phys A827, 593c (2009)
V.I. Luschikov and A.I. Frank, JETP Lett. 28 559 (1978)

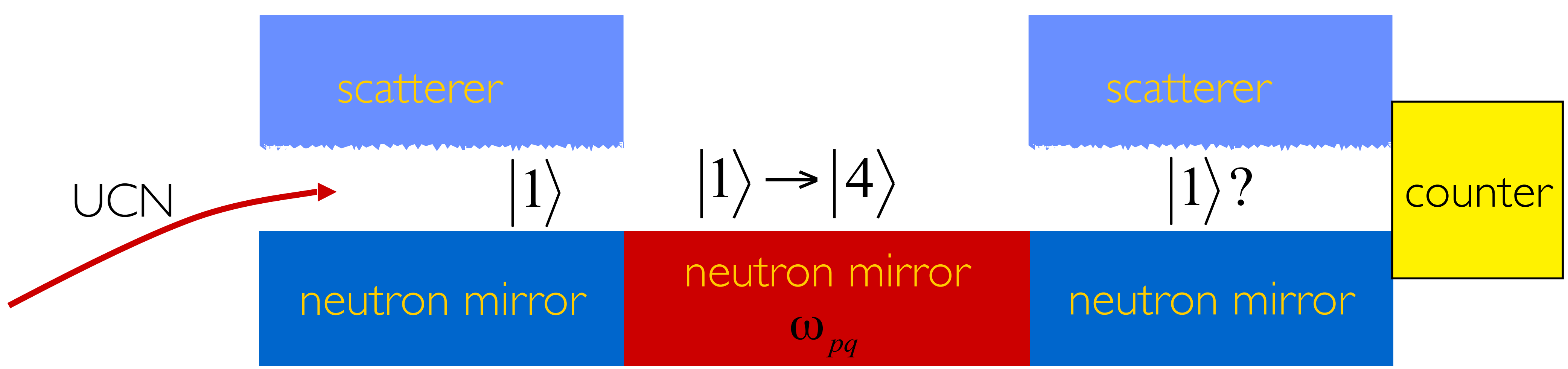
Quantum Bouncer

step: 60 μm



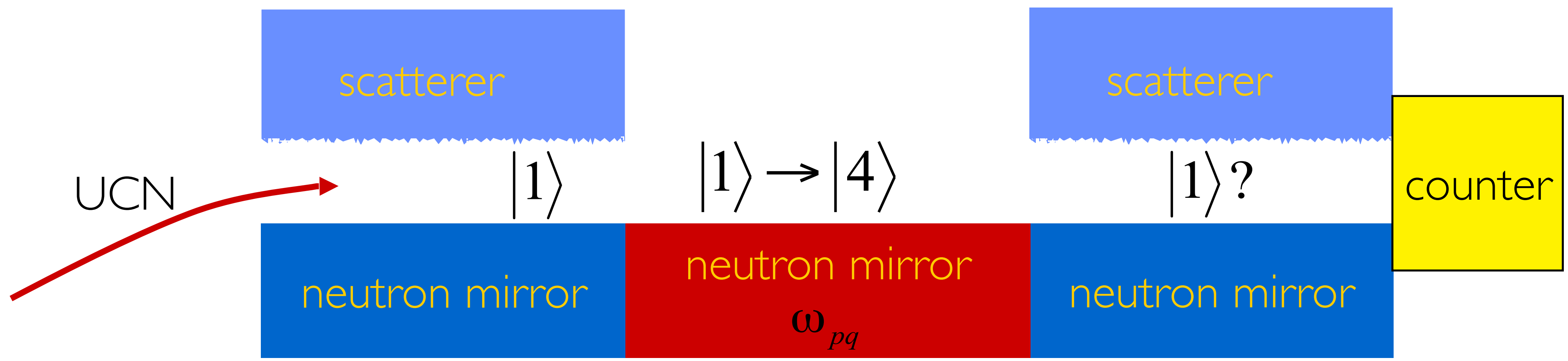
Rabis method





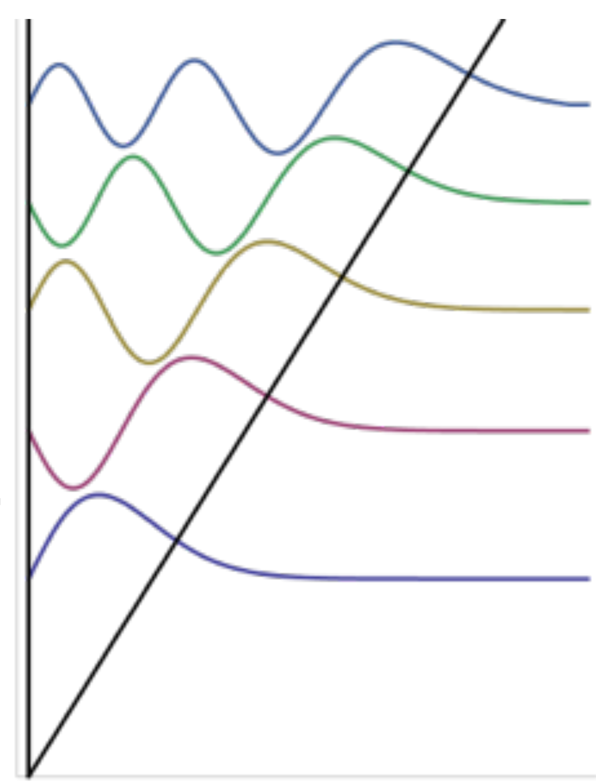
Gravity Resonance Spectroscopy

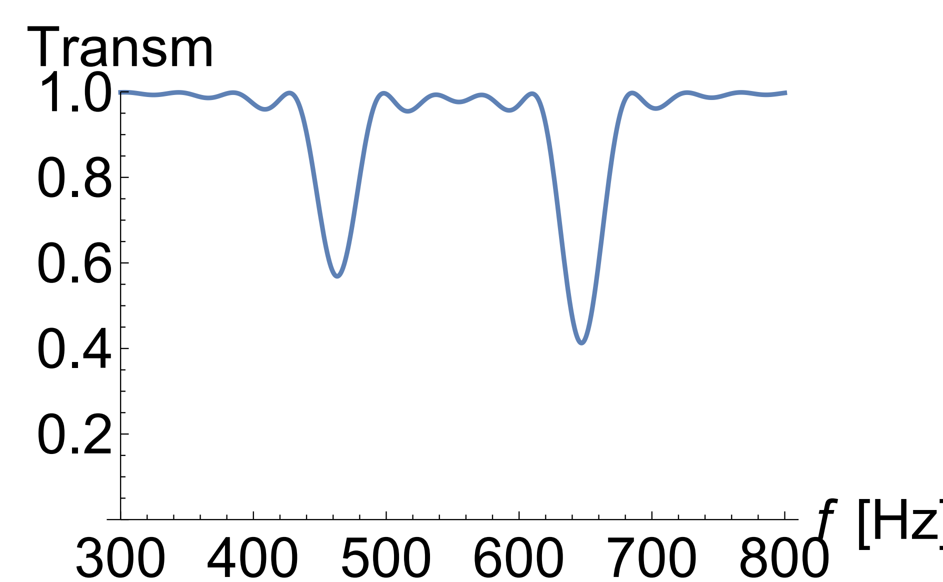
- Rabi



$$E = h\nu$$

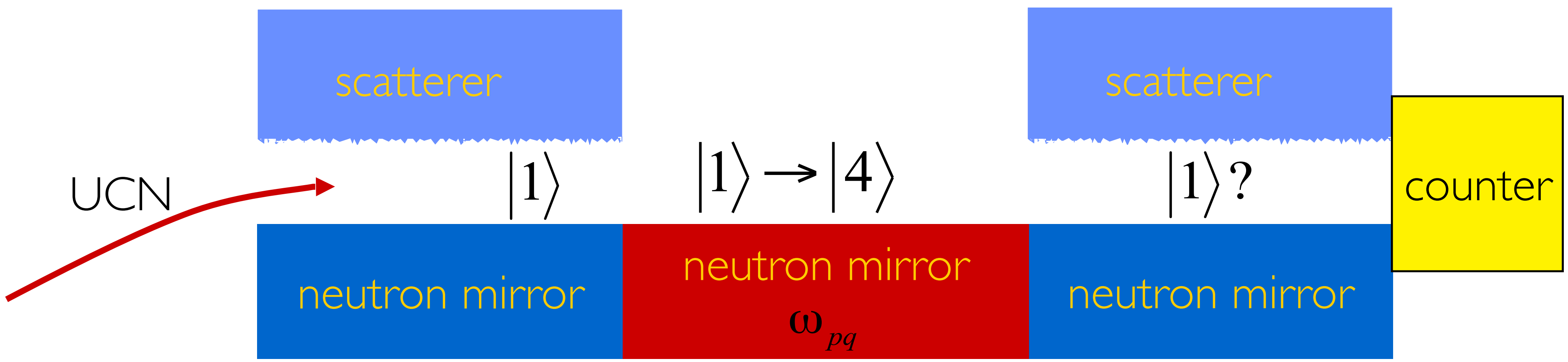
transitions induced by **mechanical oscillations** or magnetic fields



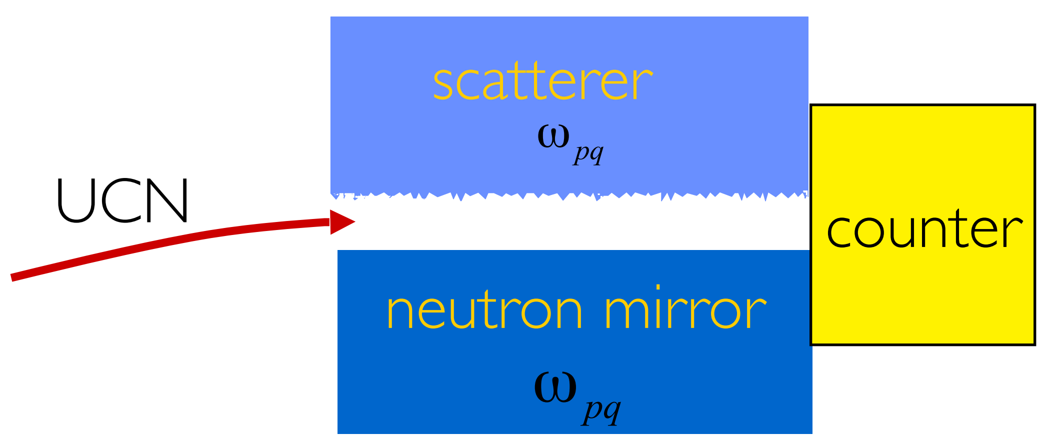


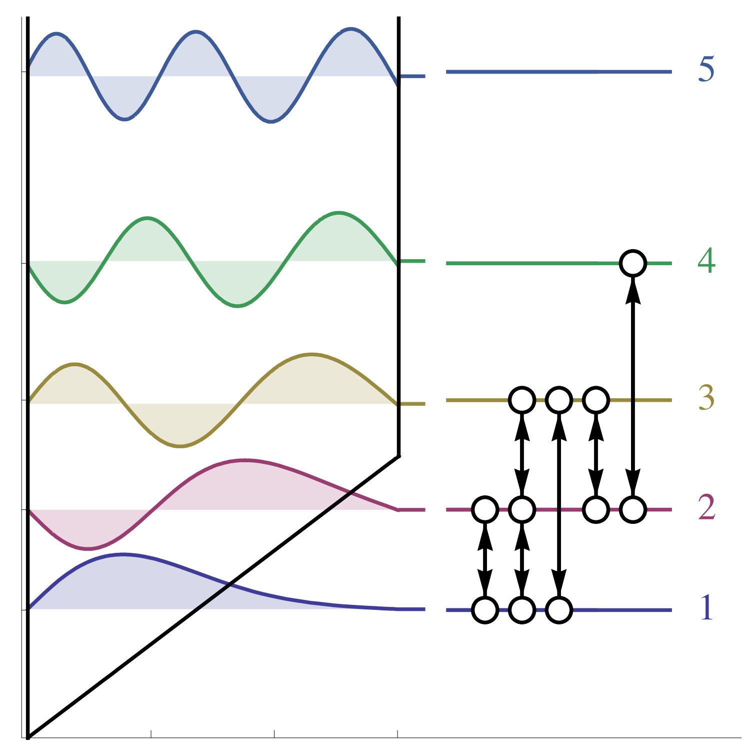
Gravity Resonance Spectroscopy

- Rabi (2012)



- First realisation (2009, 2010)

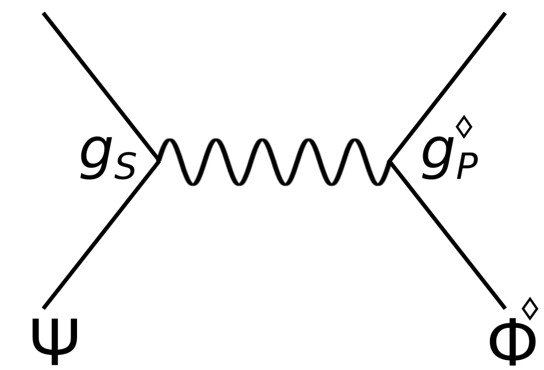




T. Jenke et al.: "Realization of a gravity-resonance-spectroscopy technique" Nature Physics 7, 468–472 (2011)

Axions

- spin-mass coupling
- scalar-pseudoscalar coupling



Introduced to solve problem on CP-violation in strong interactions

Candidates for dark matter

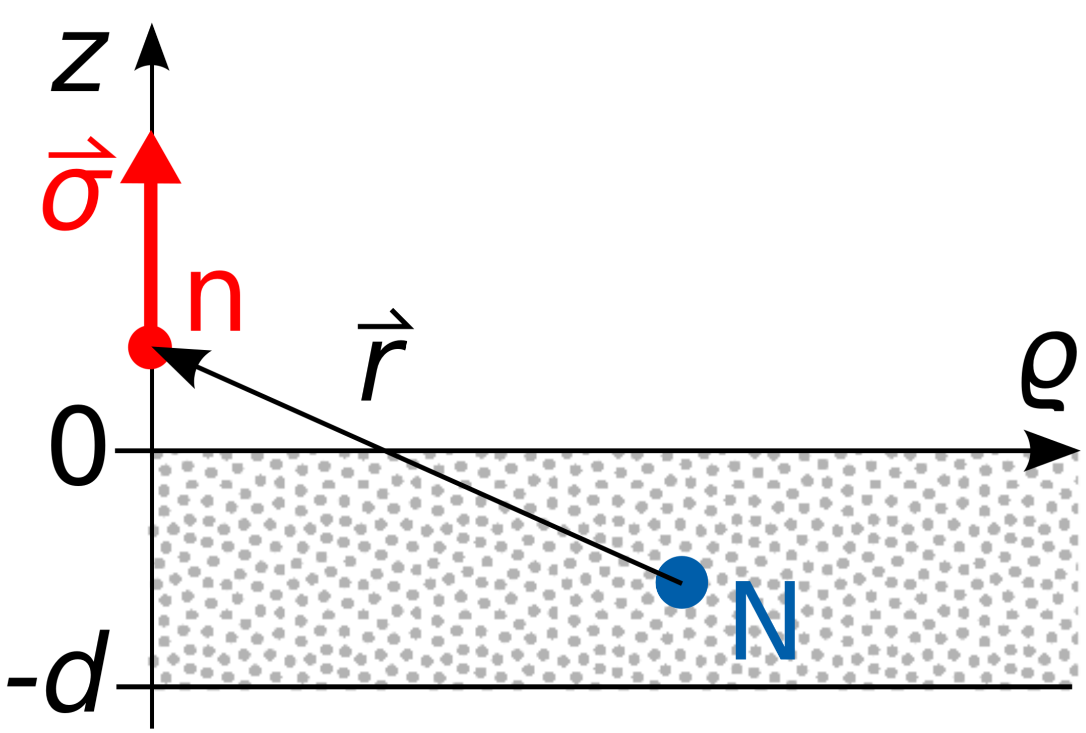
$$V(\overrightarrow{r}) = \hbar g_s g_p \frac{\overrightarrow{\sigma} \cdot \overrightarrow{n}}{8\pi mc} \left(\frac{1}{\lambda r} + \frac{1}{r^2} \right) e^{-r/\lambda}$$

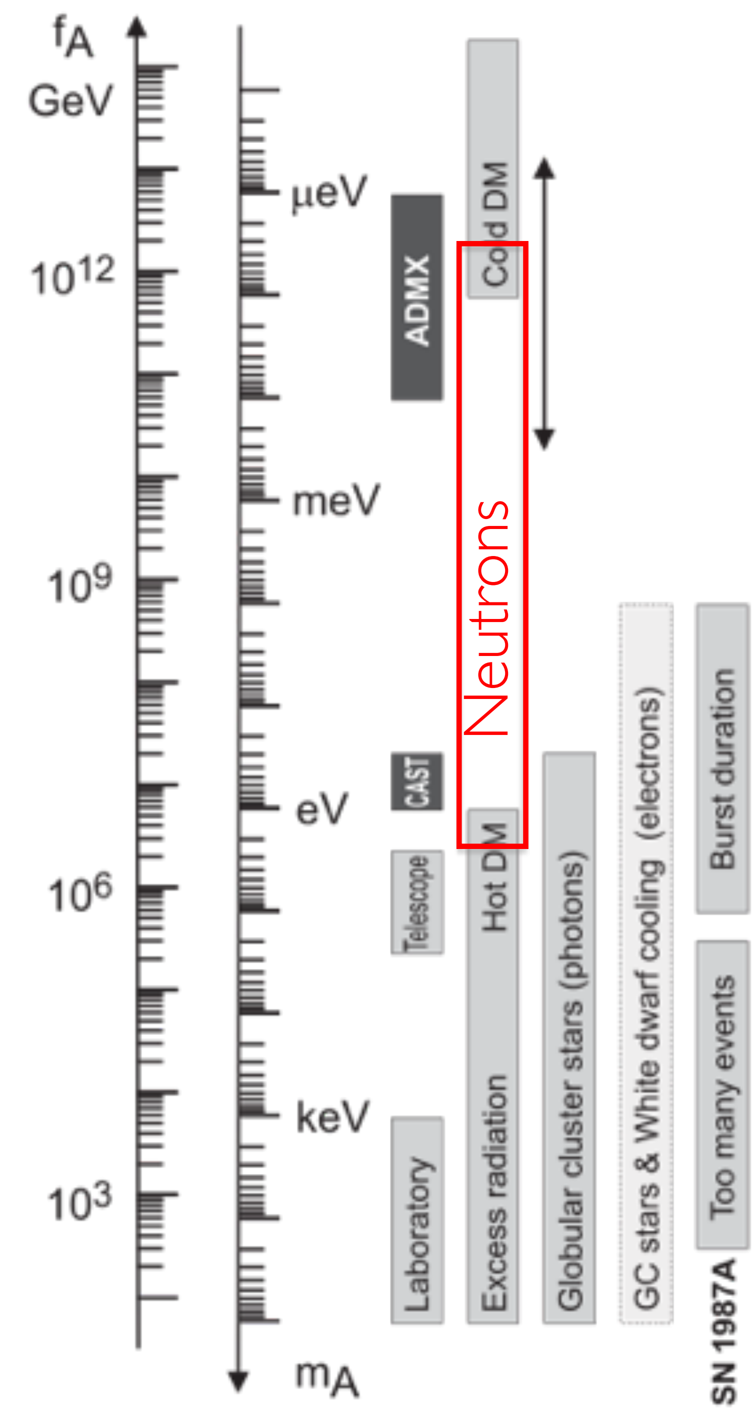
Also search for Axion-like particles (ALPs)

Search for Axions

Setup is sensitive to axions for

$$0.2\mu\text{m} \leq \lambda \leq 2\text{cm} \quad (10\mu\text{eV}..1\text{eV})$$



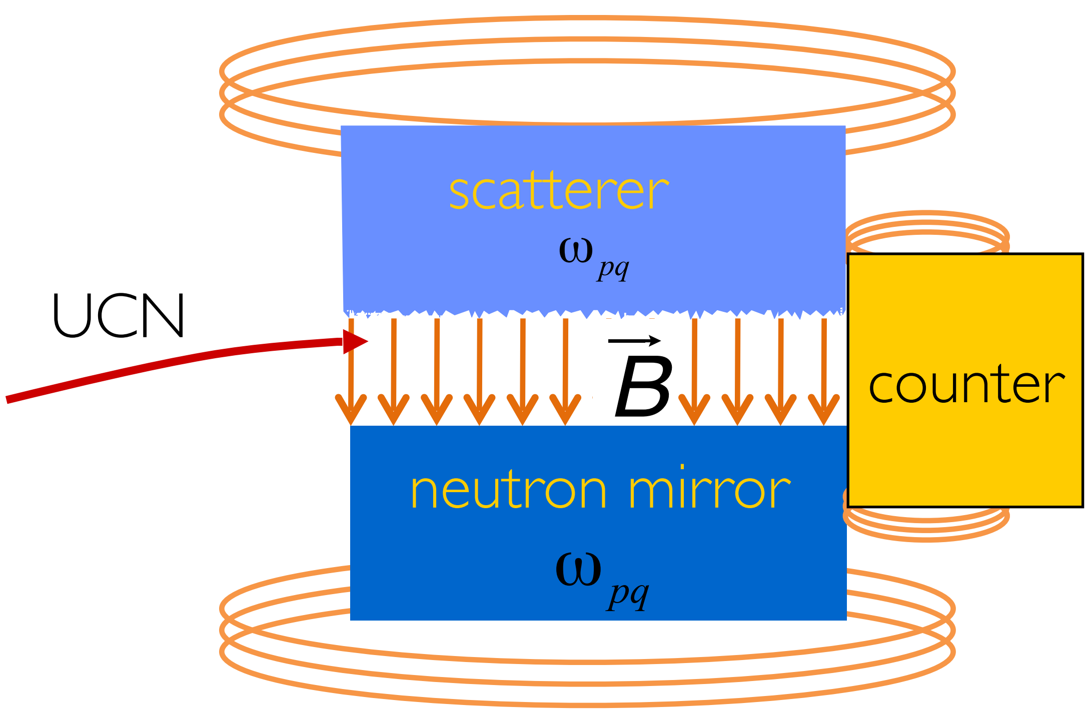


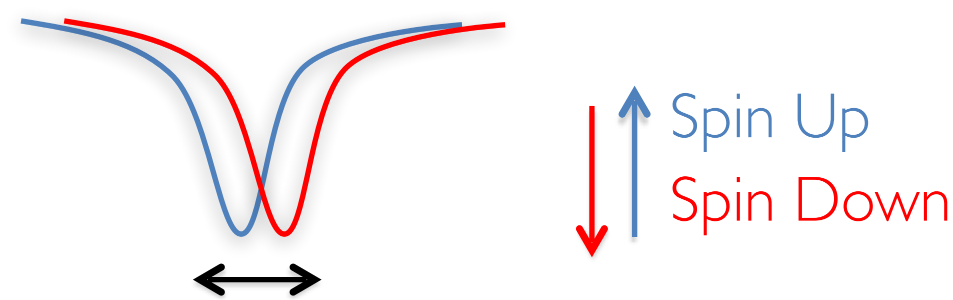
Afach, S., et al. (2014). arxiv:1412.3679

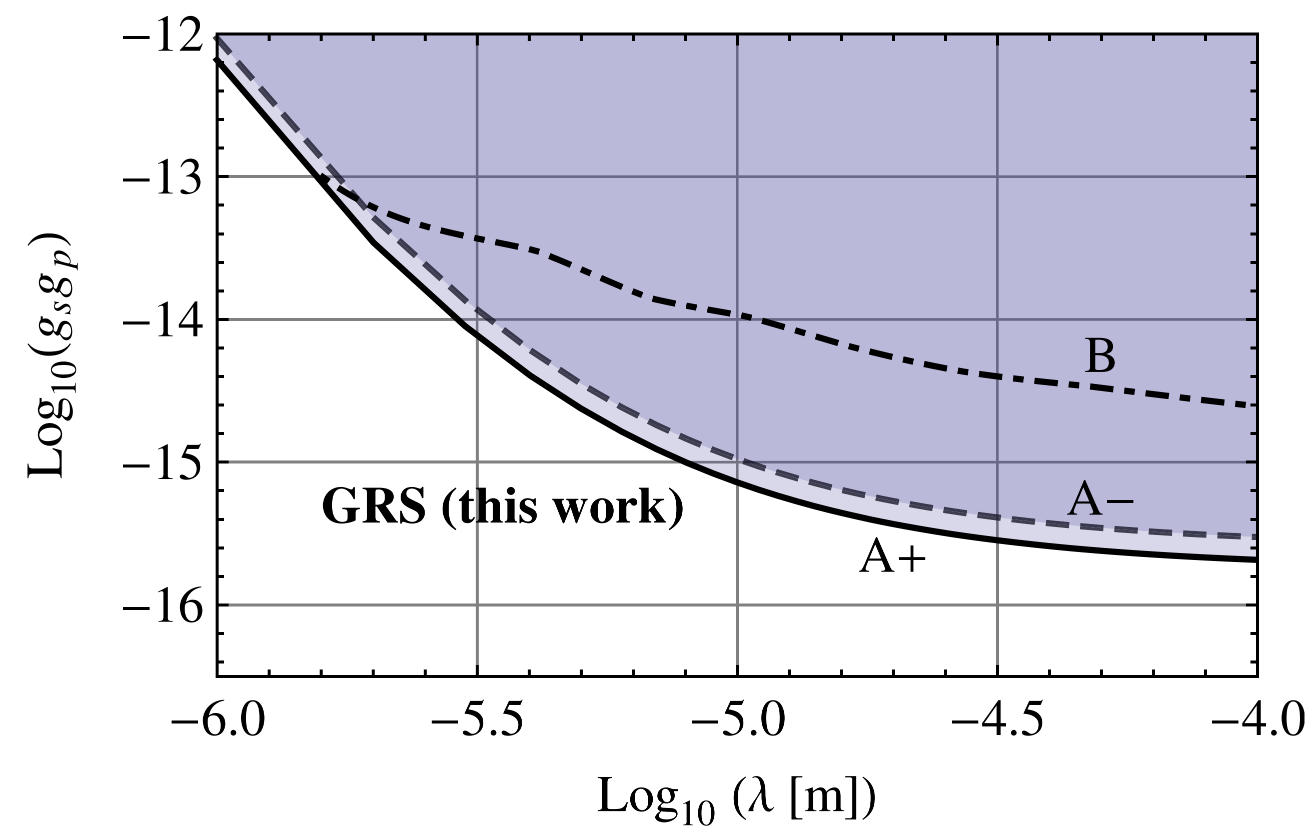
K. Nakamura et al. (Particle Data Group), JPG 37, 075021

Search for Axions & ALPs

- Applying magnetic field
- Measuring effect for each spin





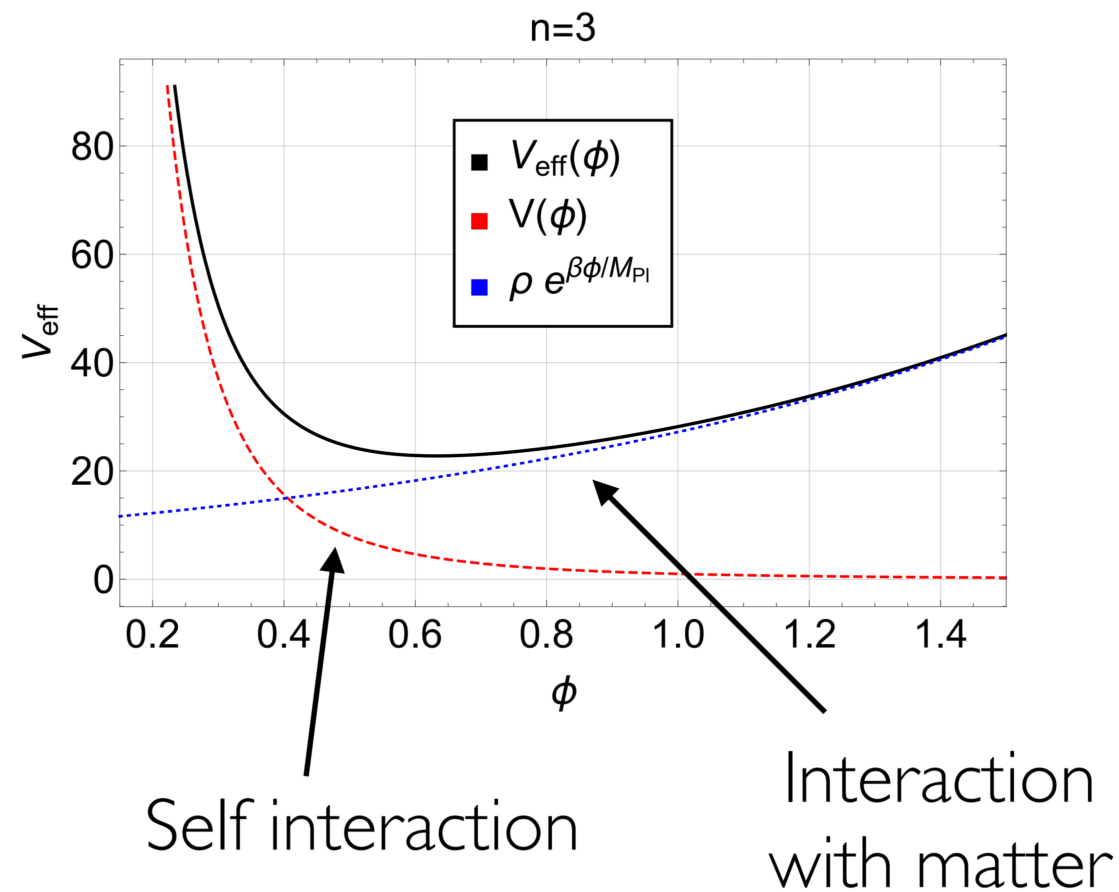


Jenke, T., Cronenberg, G., et al. Phys. Rev. Lett., 112, 151105. (2014)

L. Filter

Chameleons

- Dark energy candidate
- mechanism suppresses in vicinity of masses



massless scalar field, hidden at laboratory scales

$$V_{\text{eff}}(\varphi) = V(\phi) + \frac{\beta}{M_{\text{Pl}}}\varphi\rho$$

Ratra-Peebles model (n > 0):

$$V(\varphi) = \Lambda^4 + \frac{\Lambda^{4+n}}{\varphi^n}$$

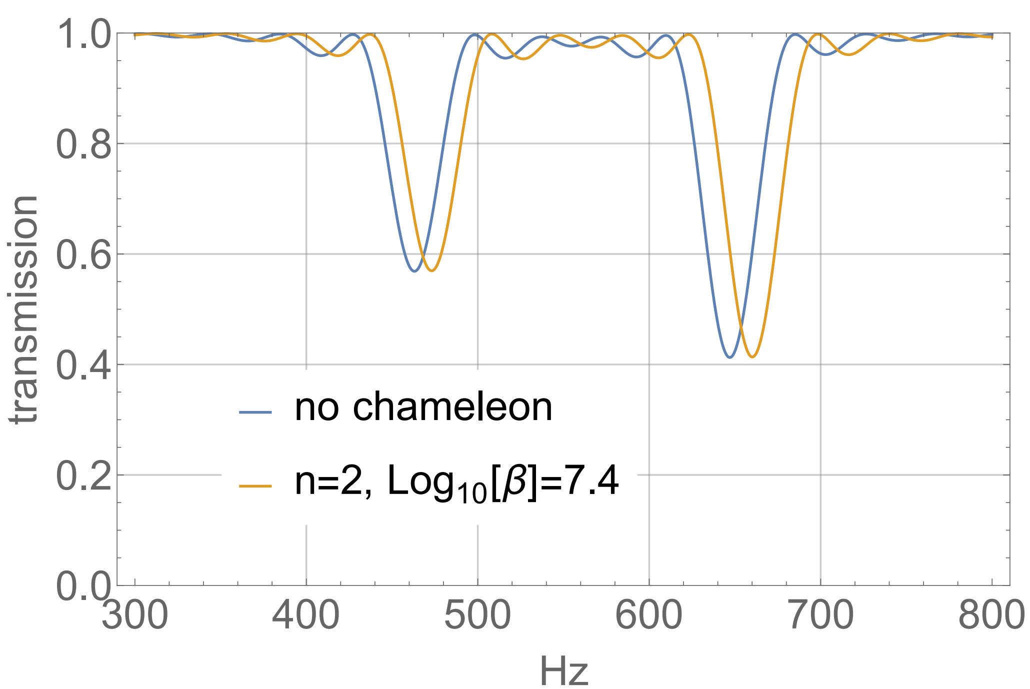
leads to screening effects

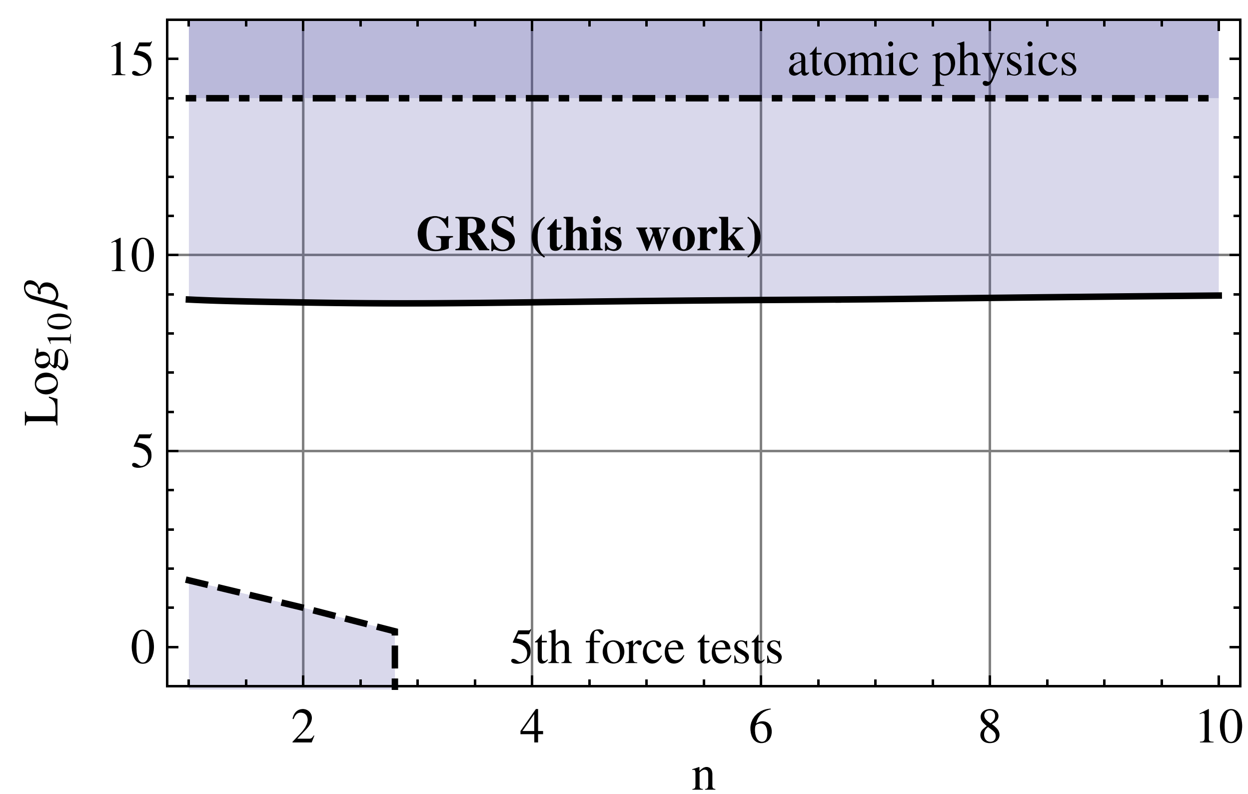
Khoury, J., & Weltman, A. (2004). Chameleon cosmology. Physical Review D, 69(4)
P. Brax, G. Pignol, Phys. Rev. Lett. 107, 111301 (2011)

Chameleon fields

Chameleon shifts energy of state: $$\delta E_n = \langle \psi_n | (z\Lambda)^{\frac{2}{2+n}} | \psi_n \rangle$$

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





P. Brax, G. Pignol, Phys. Rev. Lett. 107, 111301 (2011)
A.N. Ivanov et al., (2013). Physical Review D, 87(10), 105013.
Jenke, T., Cronenberg, G., et al. Phys. Rev. Lett., 112, 151105. (2014)

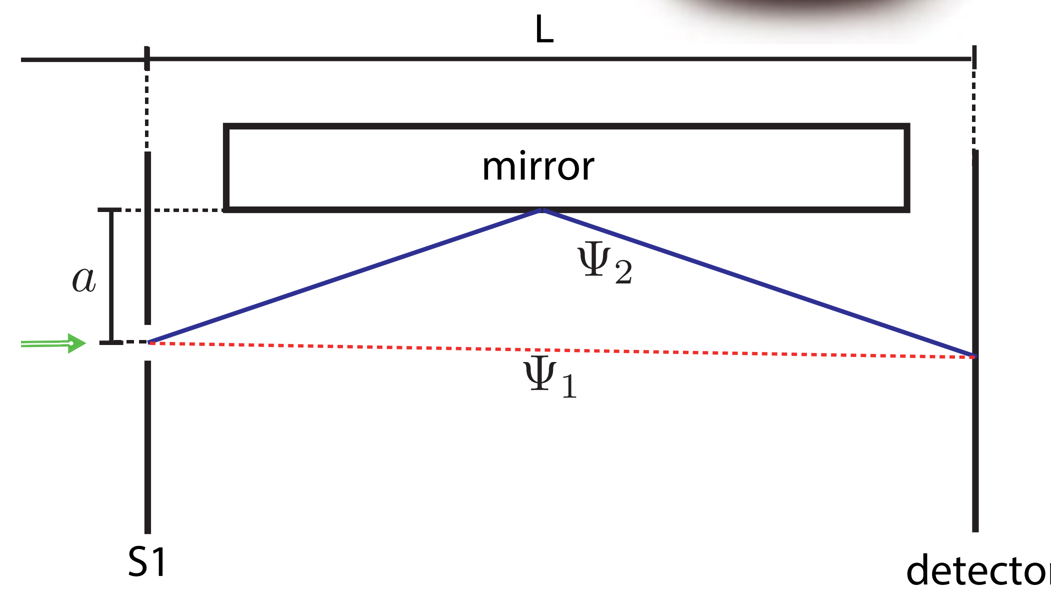
Lloyd interferometer

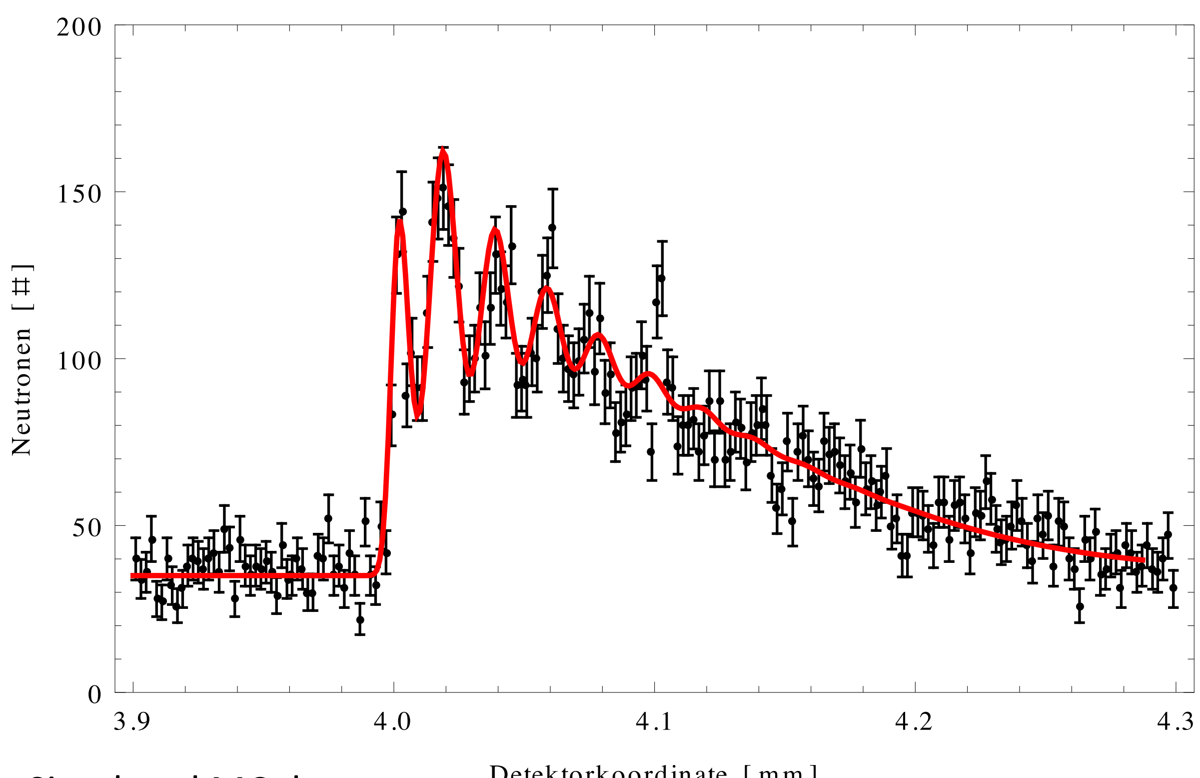
very cold neutrons 10 nm, 40 m/s

in realization by Filter, Masahiro, Oda et al.

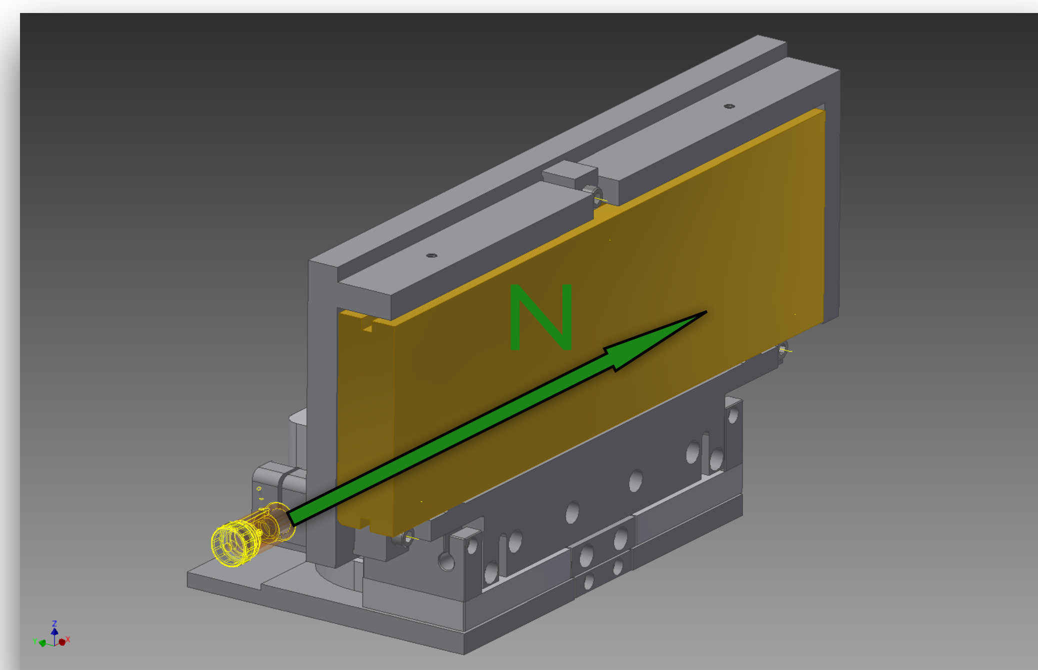
$$\lambda_{\text{Lloyd}} = \frac{L}{2a}\lambda_{\text{neutron}}$$

$$\Phi_{\text{Gesamt}} = \Phi_{\text{Geo}} + \Phi_{\text{Refl}} + \Phi_{\text{Grav}} + \Phi_{\text{Corr}} + \Phi_{?}(y)$$





Simulated MC data



Roman Gergen

Pokotilovski, Y. N. (2011). JETP Letters, 94(6), 413–417

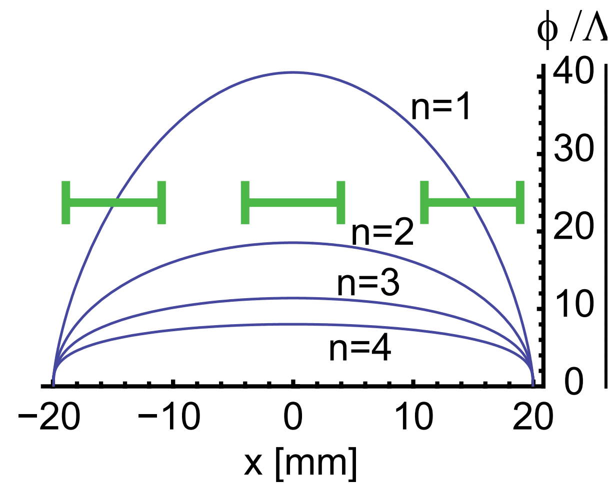
Slow neutrons

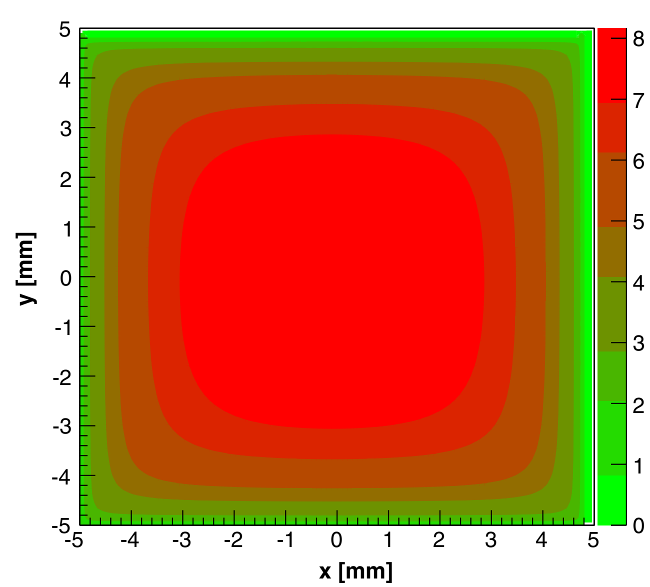
interferometric setup
S18 at ILL
realized by Th. Potocar /
T. Jenke & collaborators

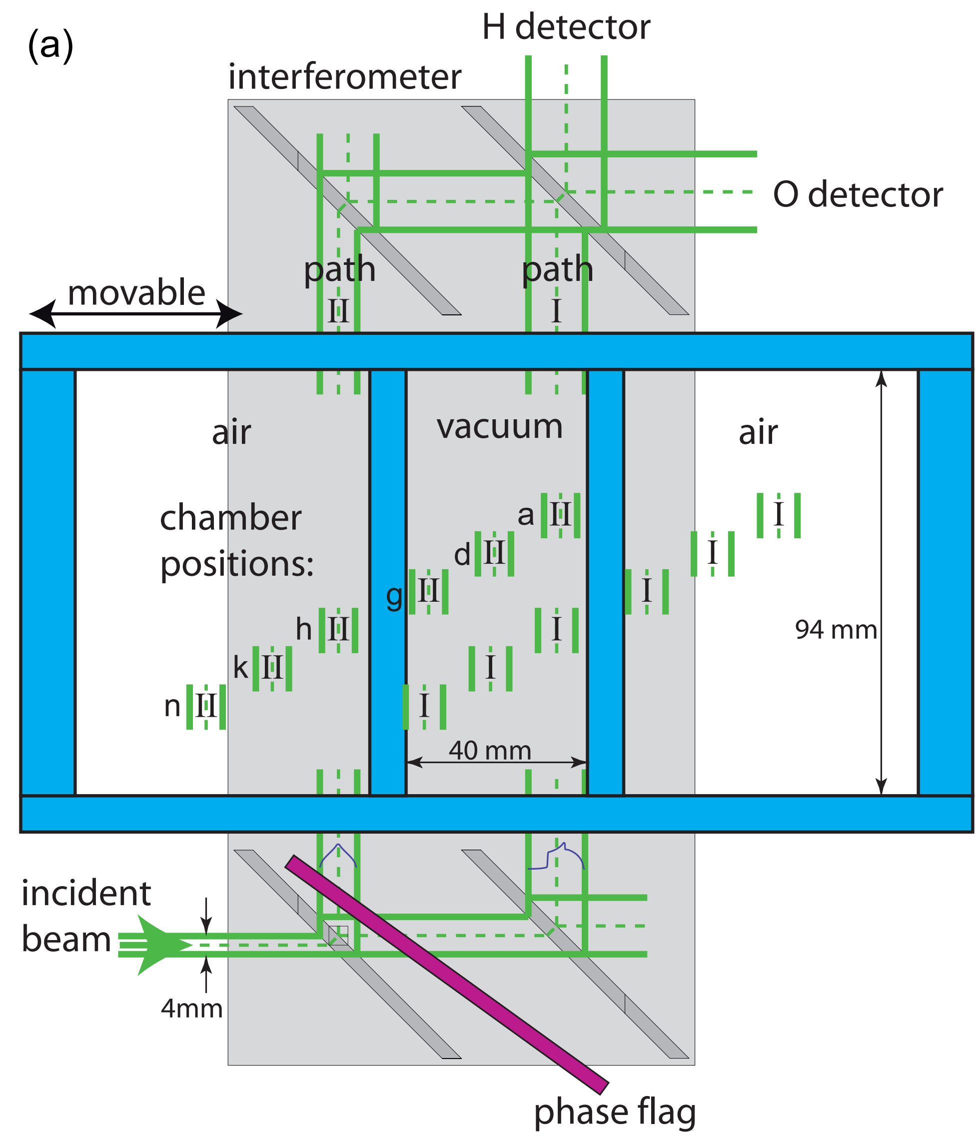
neutrons wavelength

$$\lambda \approx 3\mathring{A}$$

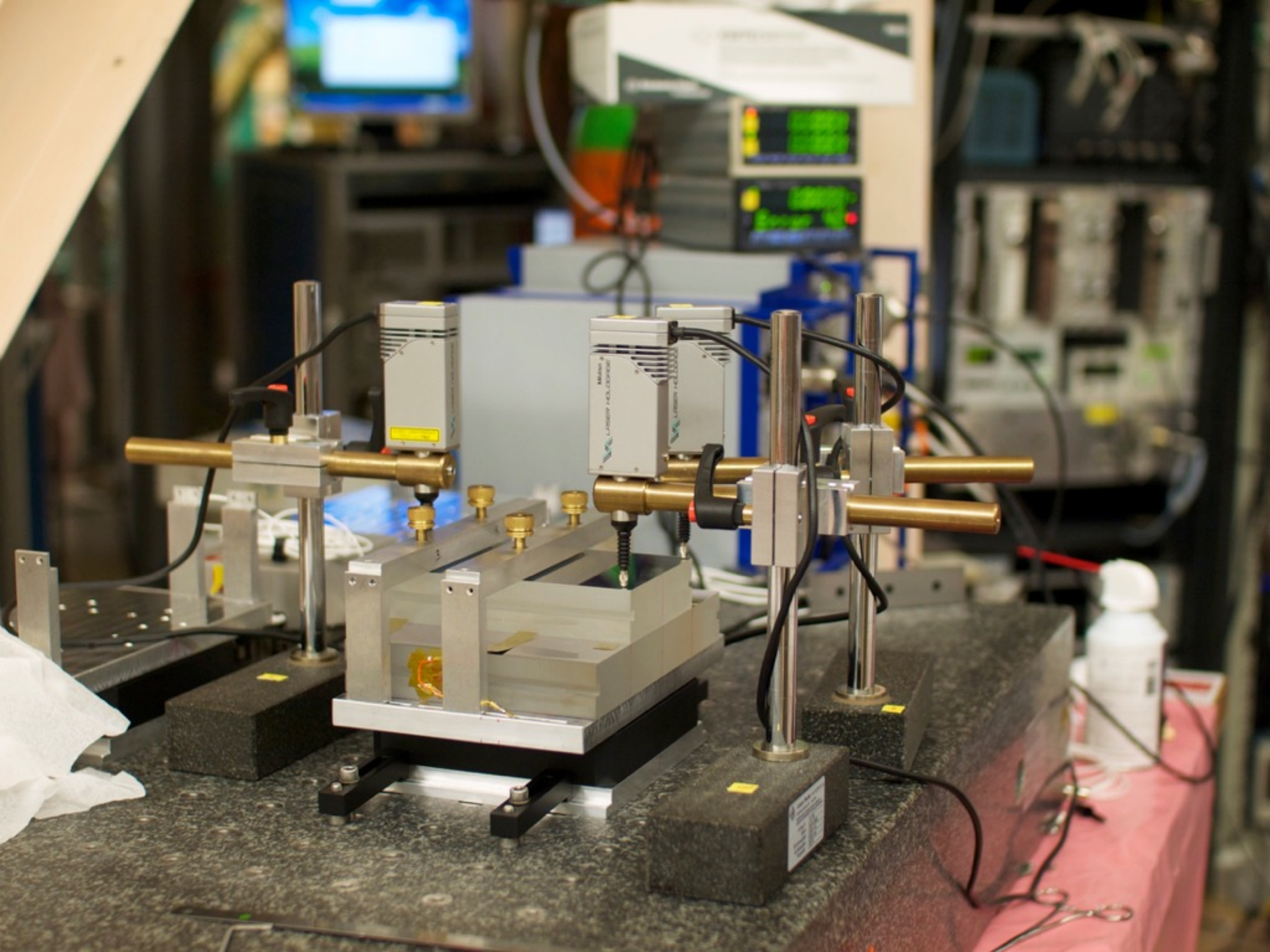
- spacial profile measured
- density dependence





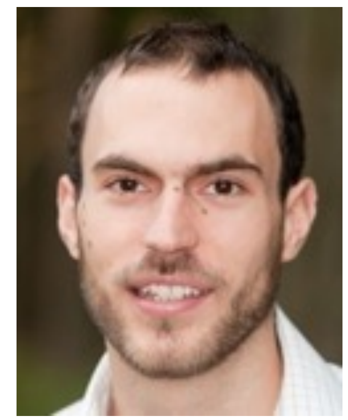


Brax, P., Pignol, G., & Roulier, D. (2013). Physical Review D, 88(8), 083004



NEUTRONS FOR SCIENCE®

TU WIEN



Kevin Mitsch

Jason Jung

Martin Thalhammer

G. C.

Peter Geltenbort

Hanno Filter

Tobias Jenke

Hartmut Abele