The GRANIT project: Status and perspectives

EPS-HEP 2011

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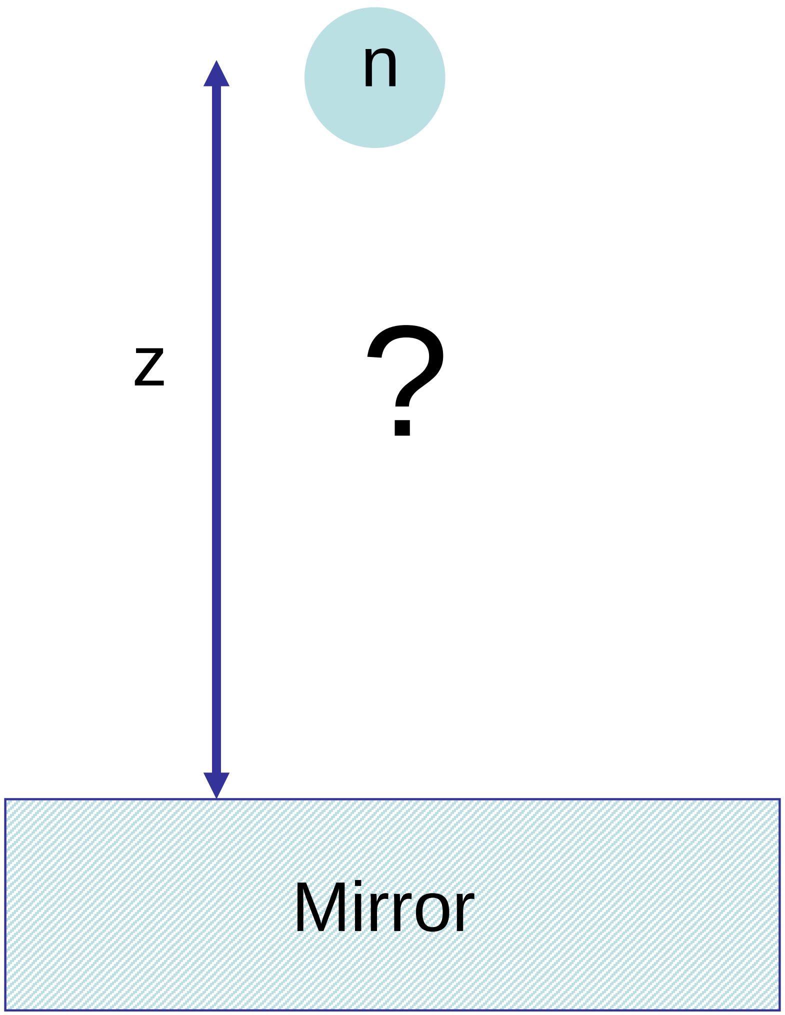
Outline

- The quantum phenomenon
- First observations
- GRANIT
- Constraint on Chameleon models

Will neutrons bounce off the mirror ?



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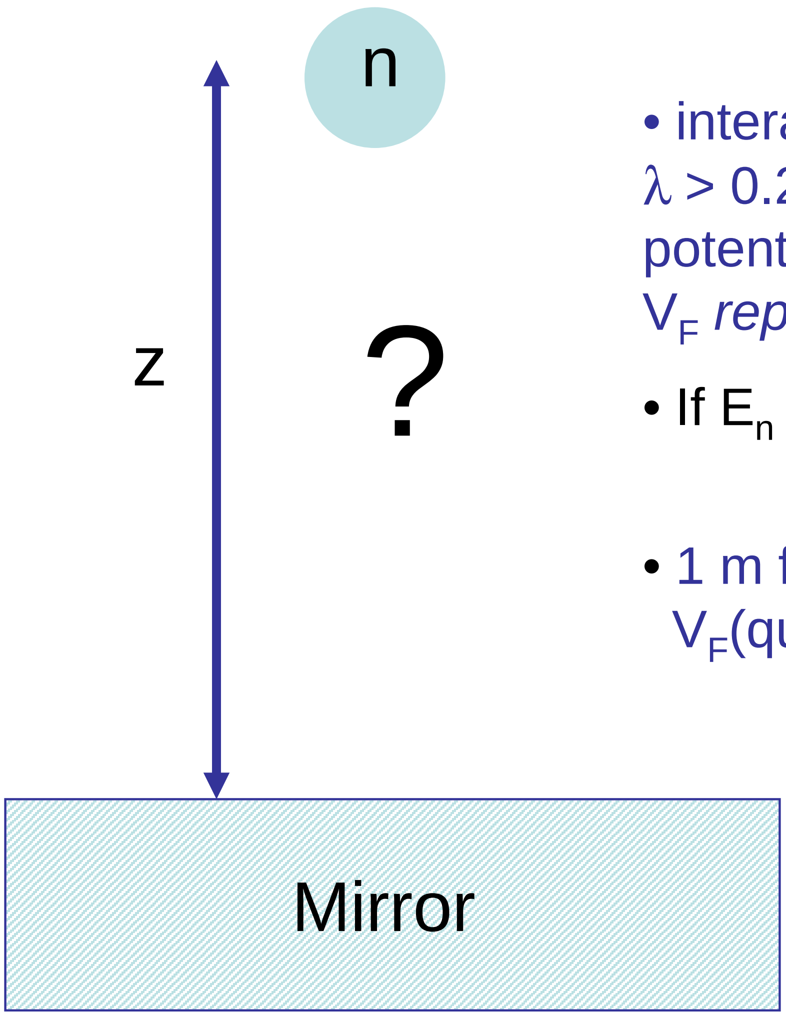

- interaction between low energy neutrons (E_n < 25 meV, λ > 0.2 nm) and matter described by an effective potential V_F (Fermi potential).
V_F *repulsive* for most usual materials (V_F~50-300 neV).
- If $E_n < V_F$ → reflexion at any incidence angle
≡ Ultra Cold Neutrons (UCN)
- 1 m free fall = 100 neV (5 m/s)
V_F(quartz) = 90 neV

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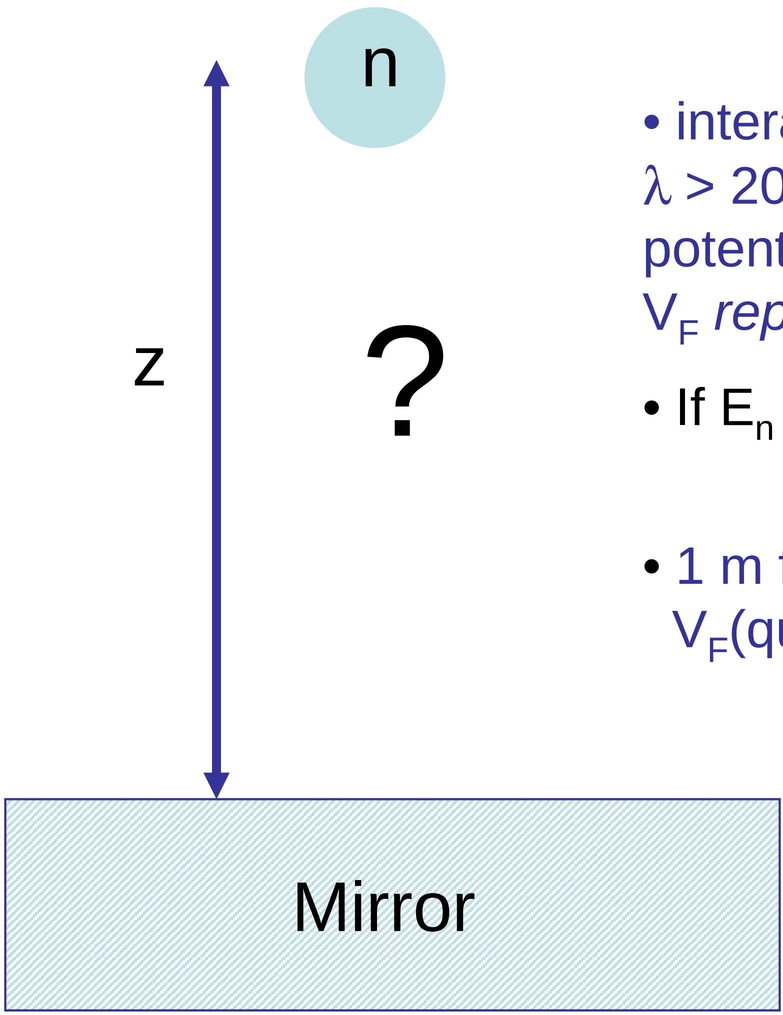
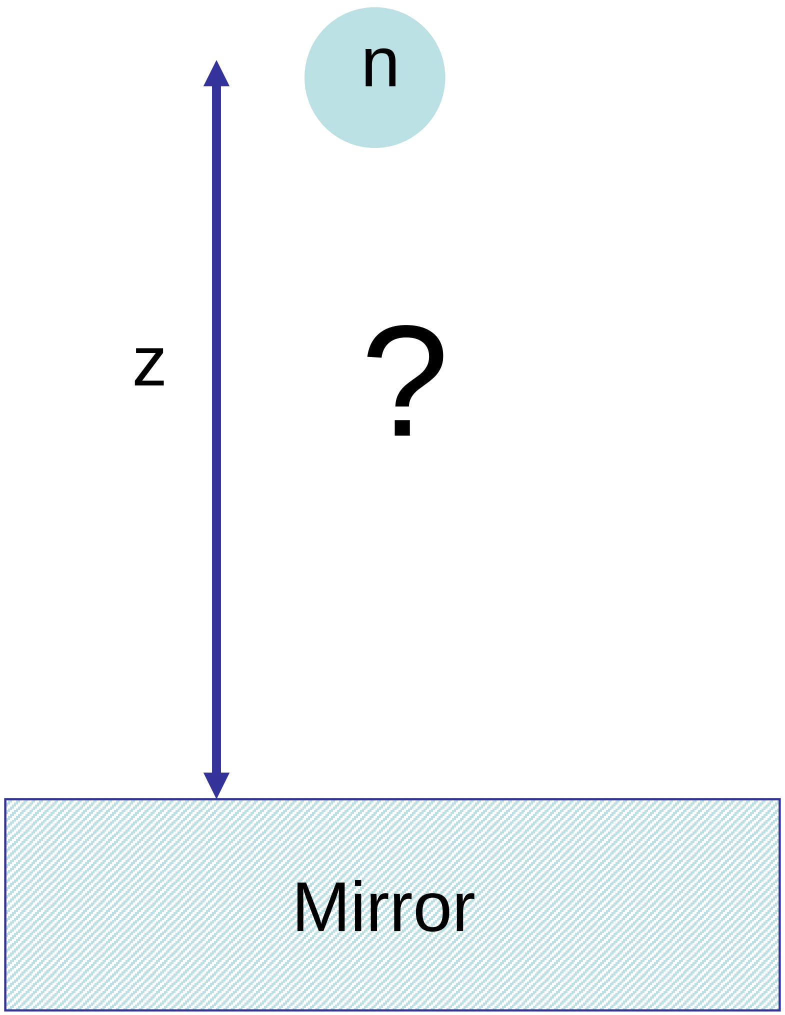


- interaction between low energy neutrons (E_n < 25 meV, λ > 20 nm) and matter described by an effective potential V_F (Fermi potential).
  V_F *repulsive* for most usual materials (V_F~50-300 neV).
- If $E_n < V_F$ → reflexion at any incidence angle
  ≡ Ultra Cold Neutrons (UCN)
- 1 m free fall = 100 neV (5 m/s)
  V_F(quartz) = 90 neV

Neutrons will rebound at the same height for z < 90 cm.

The quantum regime



Action of system: $\mathcal{L} = (8)^{1/2}\, m\, g^{1/2}\, z^{3/2}$

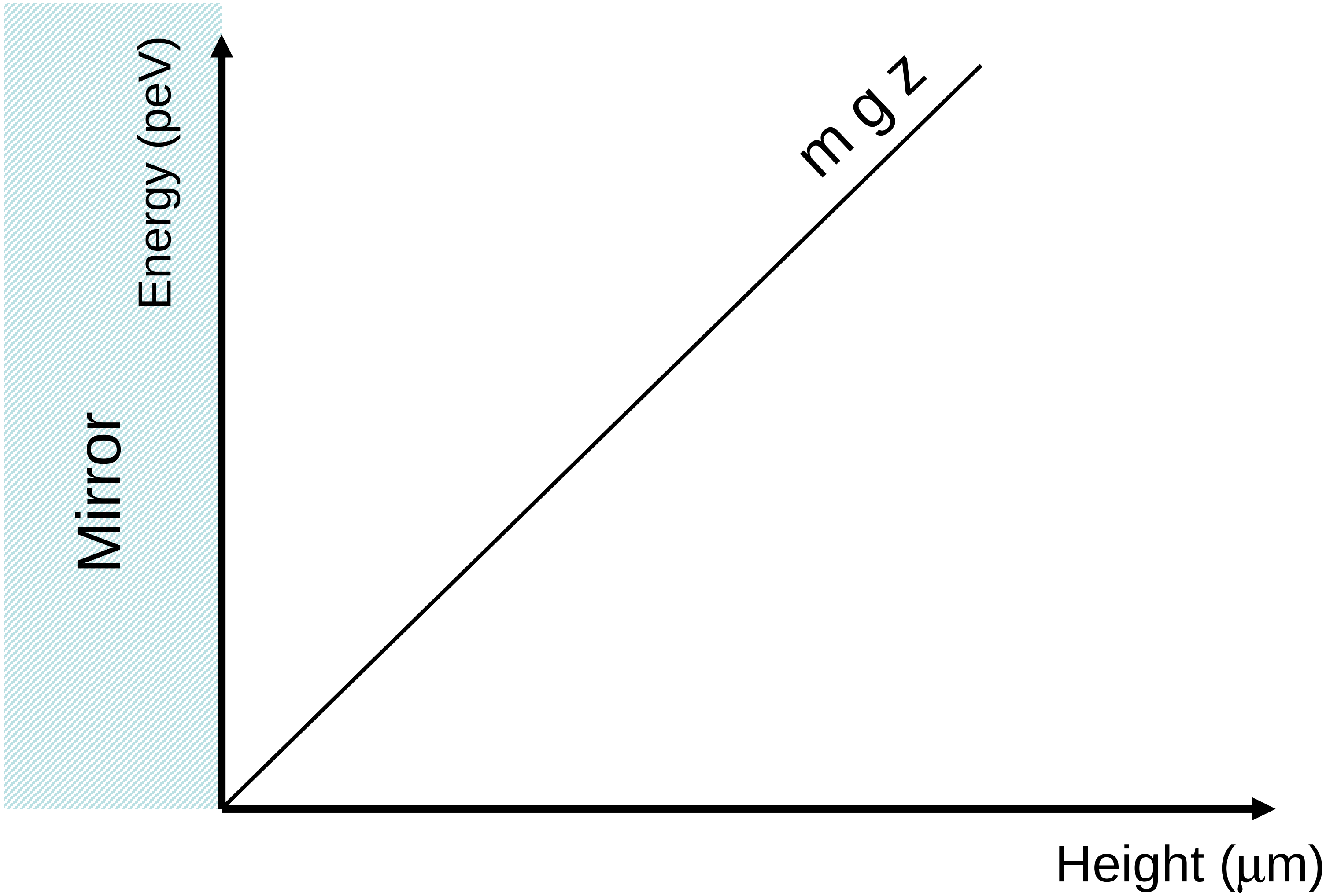
For $\mathcal{L} = \hbar$:

→ $z \approx 3\ \mu m$

→ $E \approx 0.3$ peV (7 cm/s)

→ $f \approx 100$ Hz

A potential well problem



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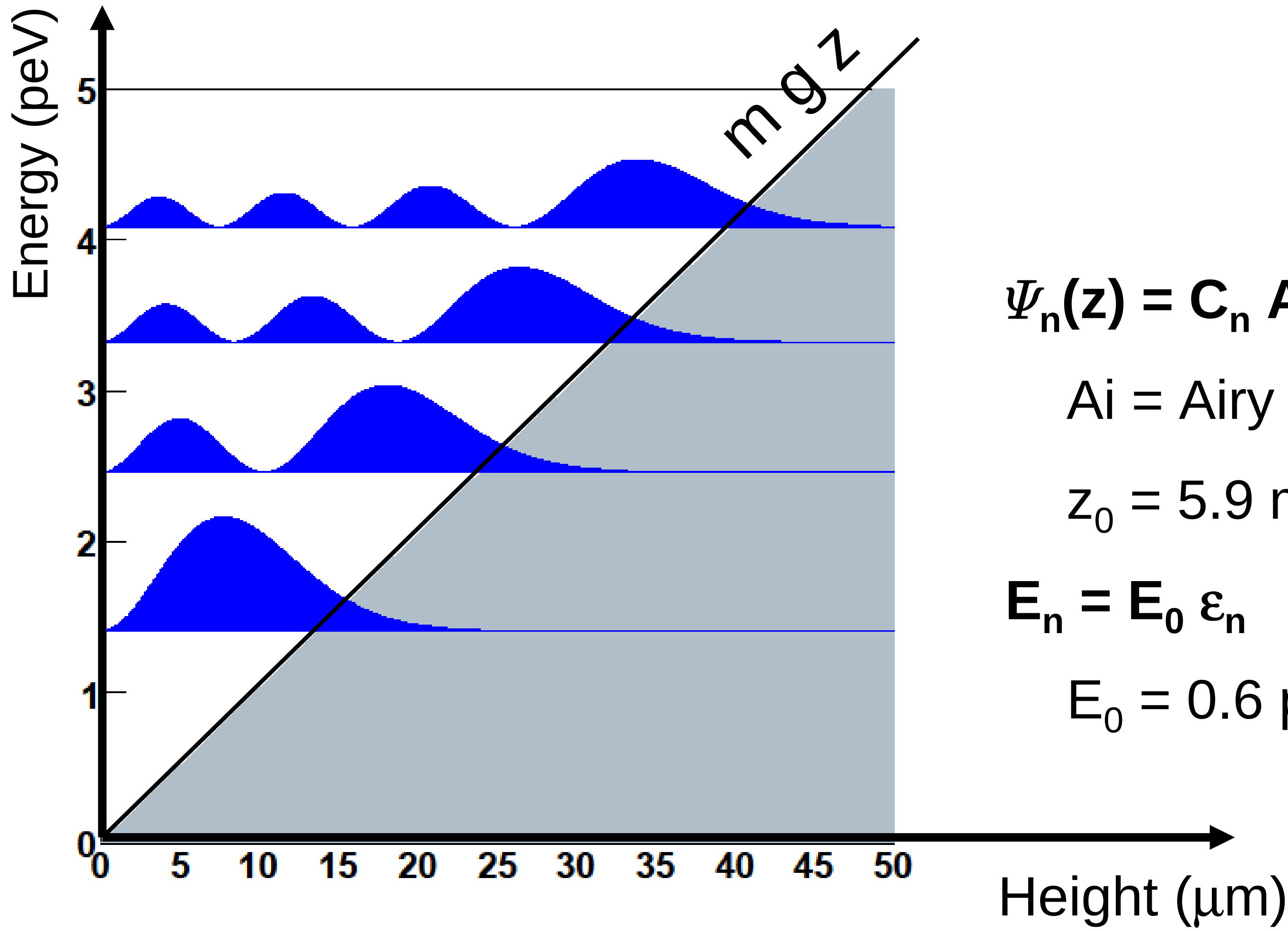


$\Psi_n(z) = C_n\, A_i(z/z_0 - \varepsilon_n)$

Ai = Airy functions

z_0 = 5.9 mm

$E_n = E_0\, \varepsilon_n$

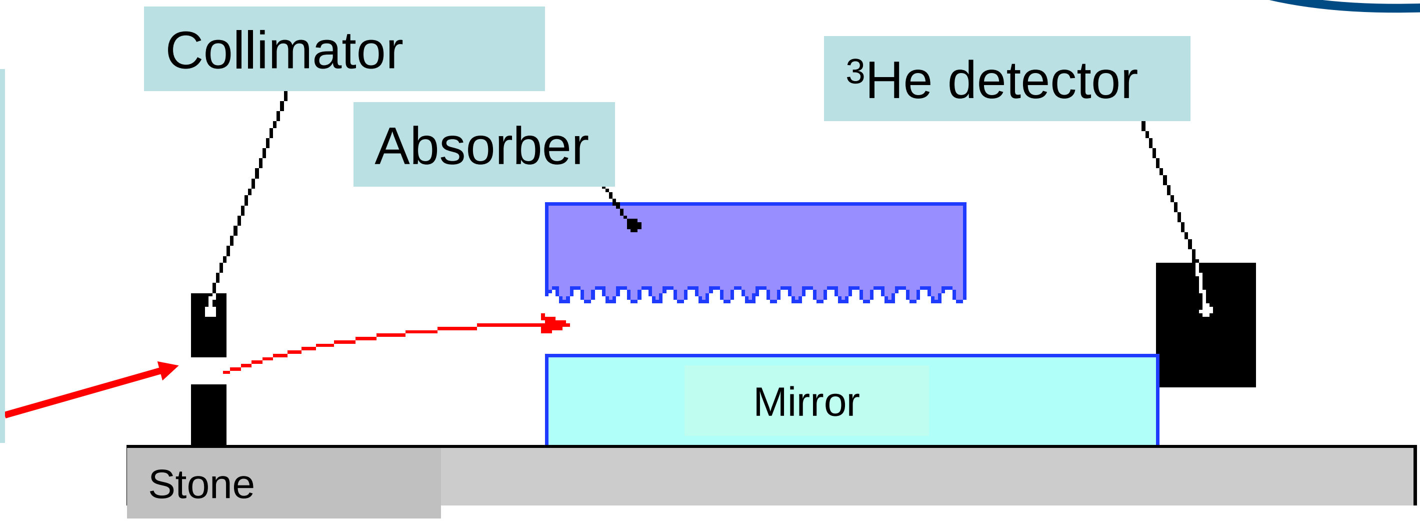
E_0 = 0.6 peV

$$-\frac{\hbar^2}{2m}\frac{d^2\Psi}{dz^2} + mgz\,\Psi = E\,\Psi$$

The first observations (ILL, 2000) (Integral mode)

UCN source
(PF2 at ILL)

- V_{UCN} ~ 5 m/s
- E_{UCN} ~ 100 neV



The first observations (ILL, 2000) (Integral mode)

UCN source
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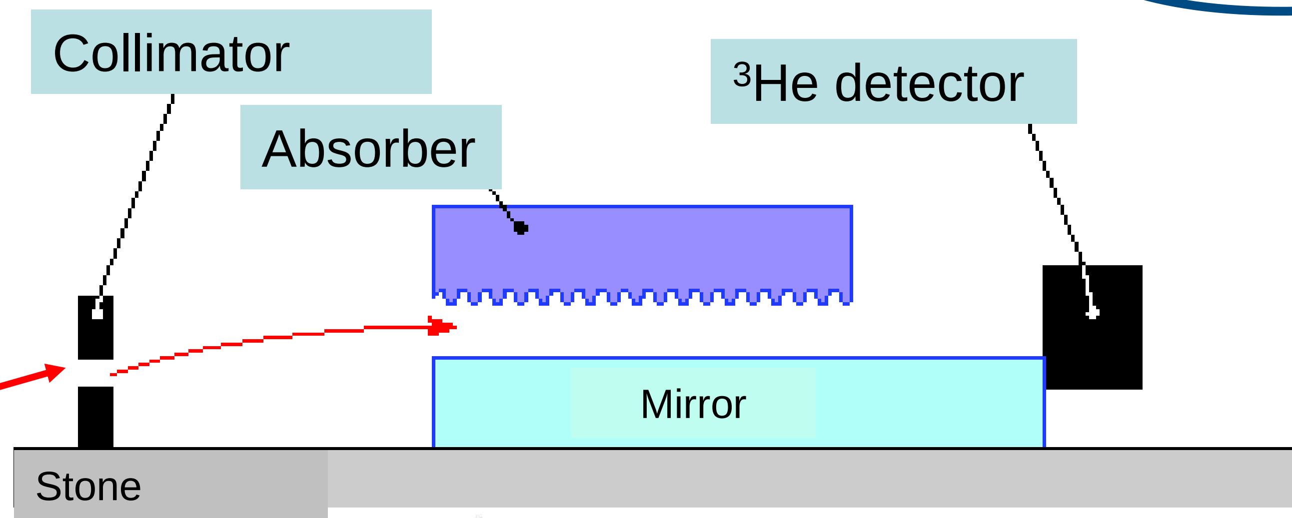
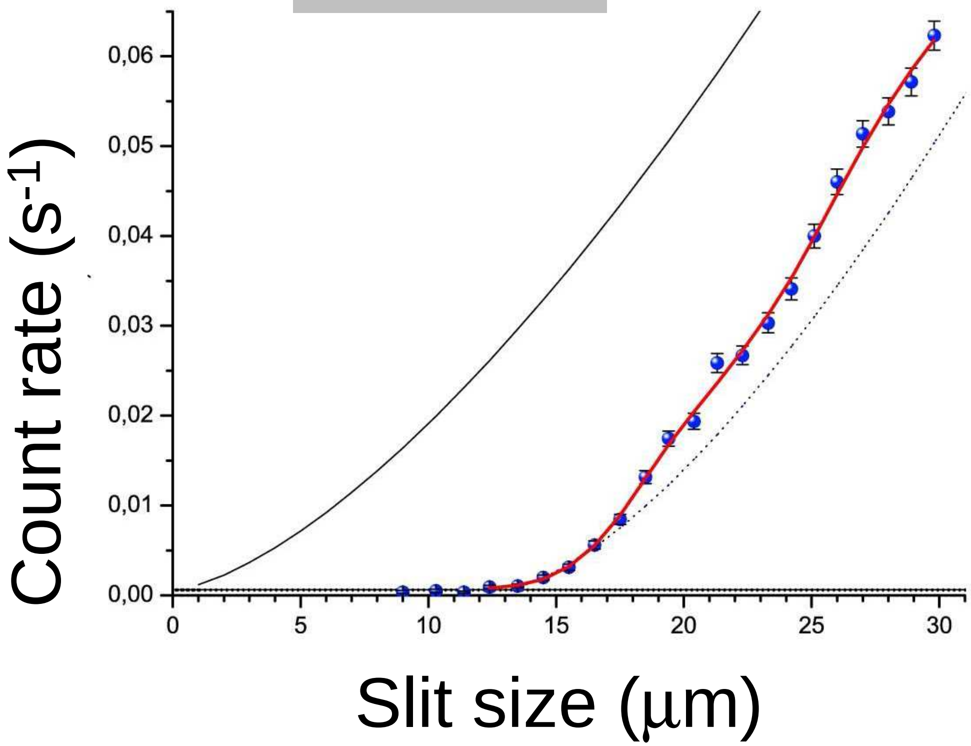
- $V_{UCN} \sim 5$ m/s
- $E_{UCN} \sim 100$ neV



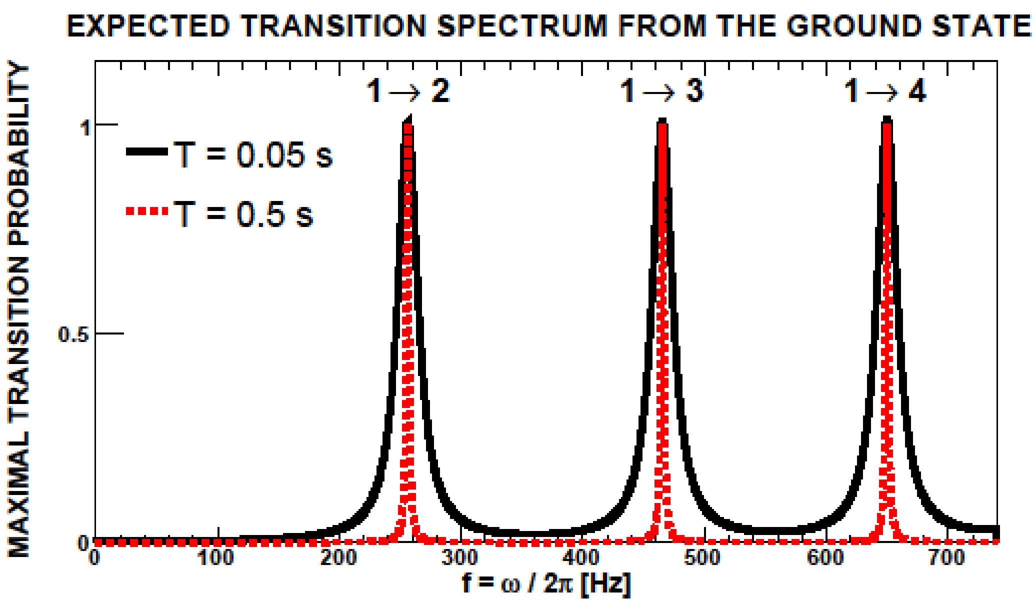


V. Nesvizhevsky et al., Nature 2002

The future: spectroscopy measurements

Goal: induce resonant transitions to measure energy of quantum levels via frequency measurements.

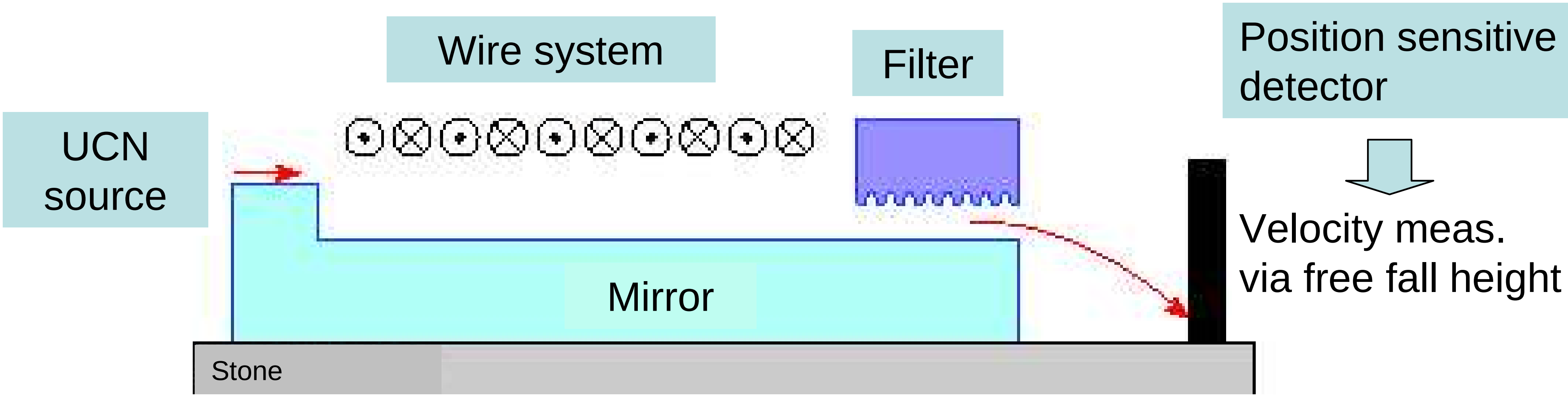
Method: use of an oscillating perturbation (Rabi resonance).



Perturbation:

- Vibration of the mirror (Jenke et al, Nature Phys. 2011)
- Magnetic field gradients → GRANIT

Transitions induced by magnetic field gradients (Flow through mode)



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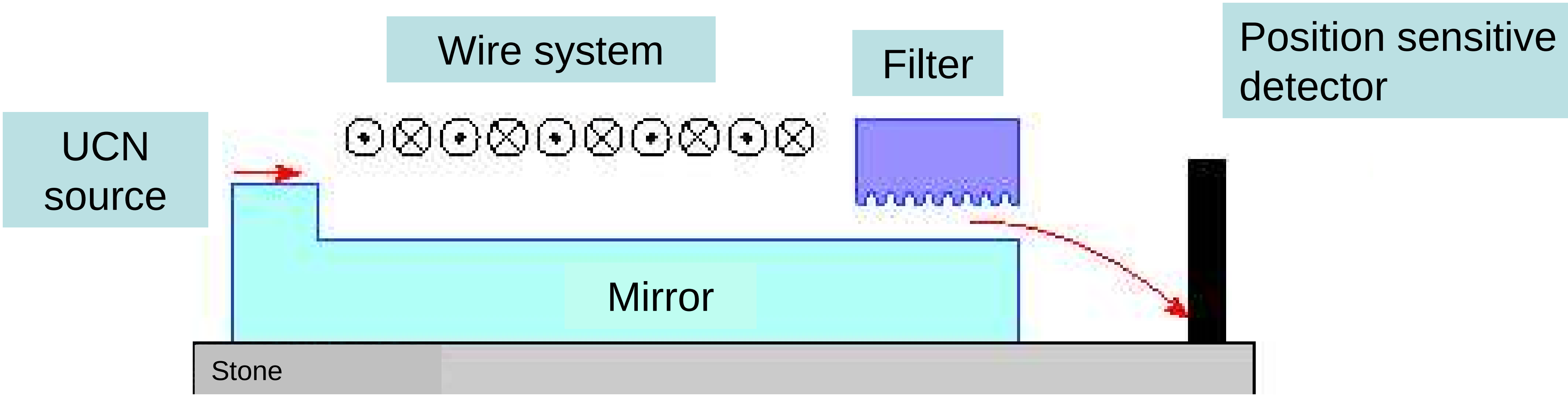
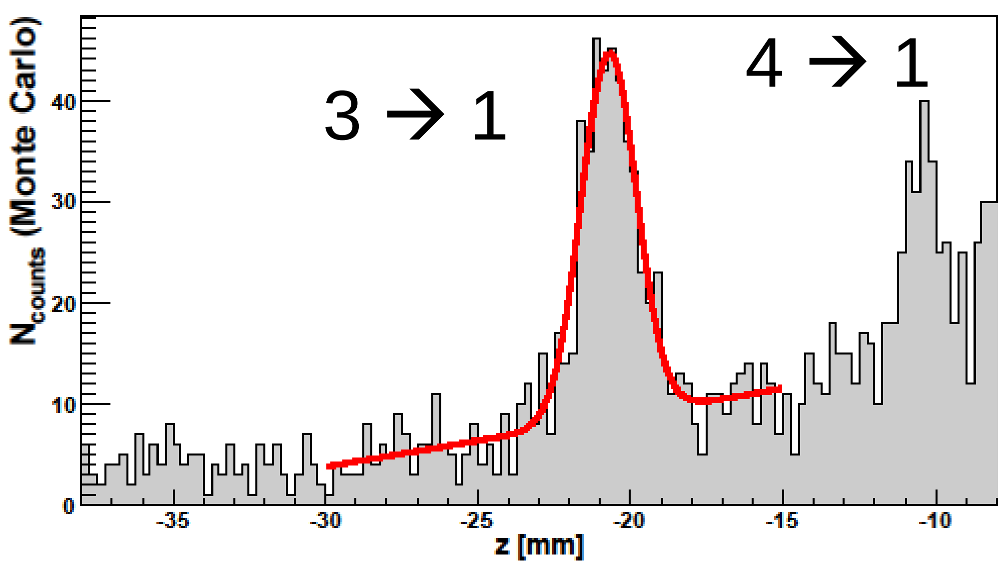
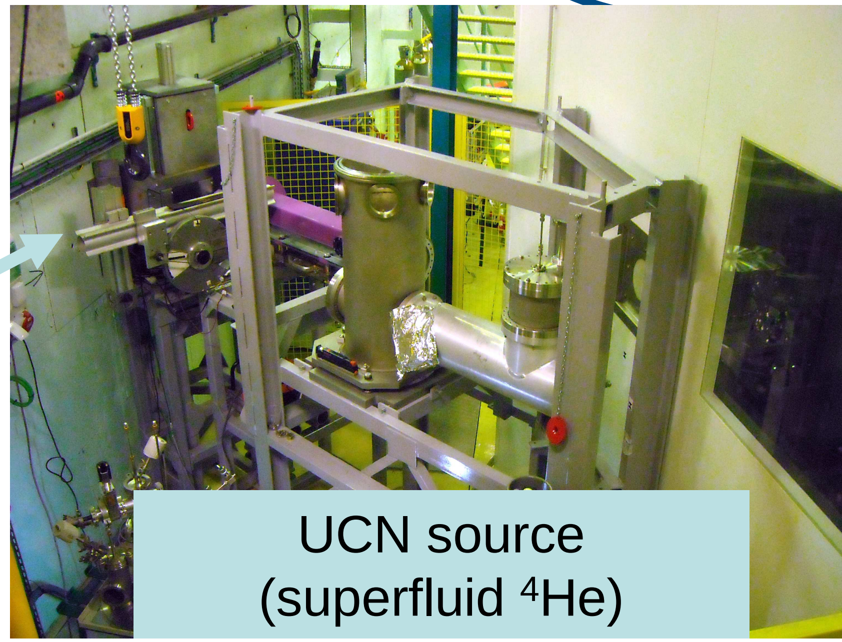
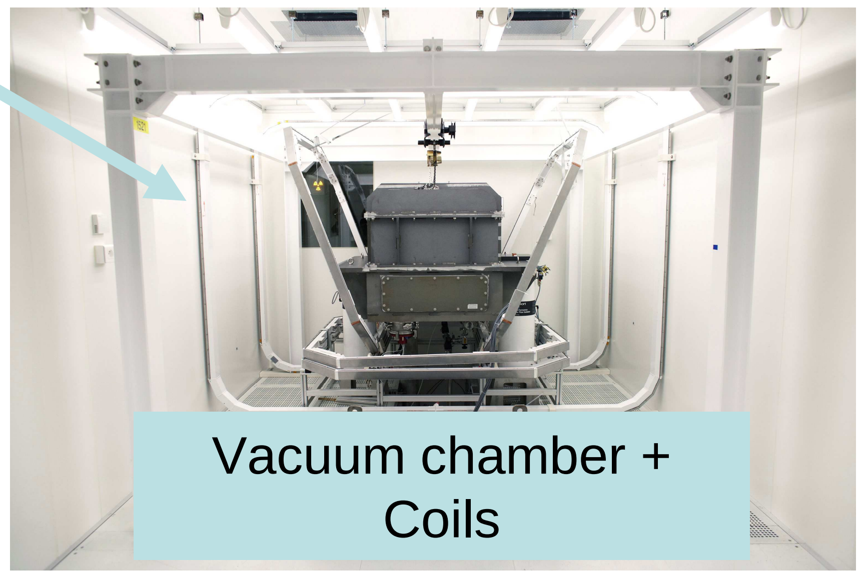




Height ⟺ UCN velocity ⟺ Frequency

The GRANIT spectrometer





Limits on a fifth force

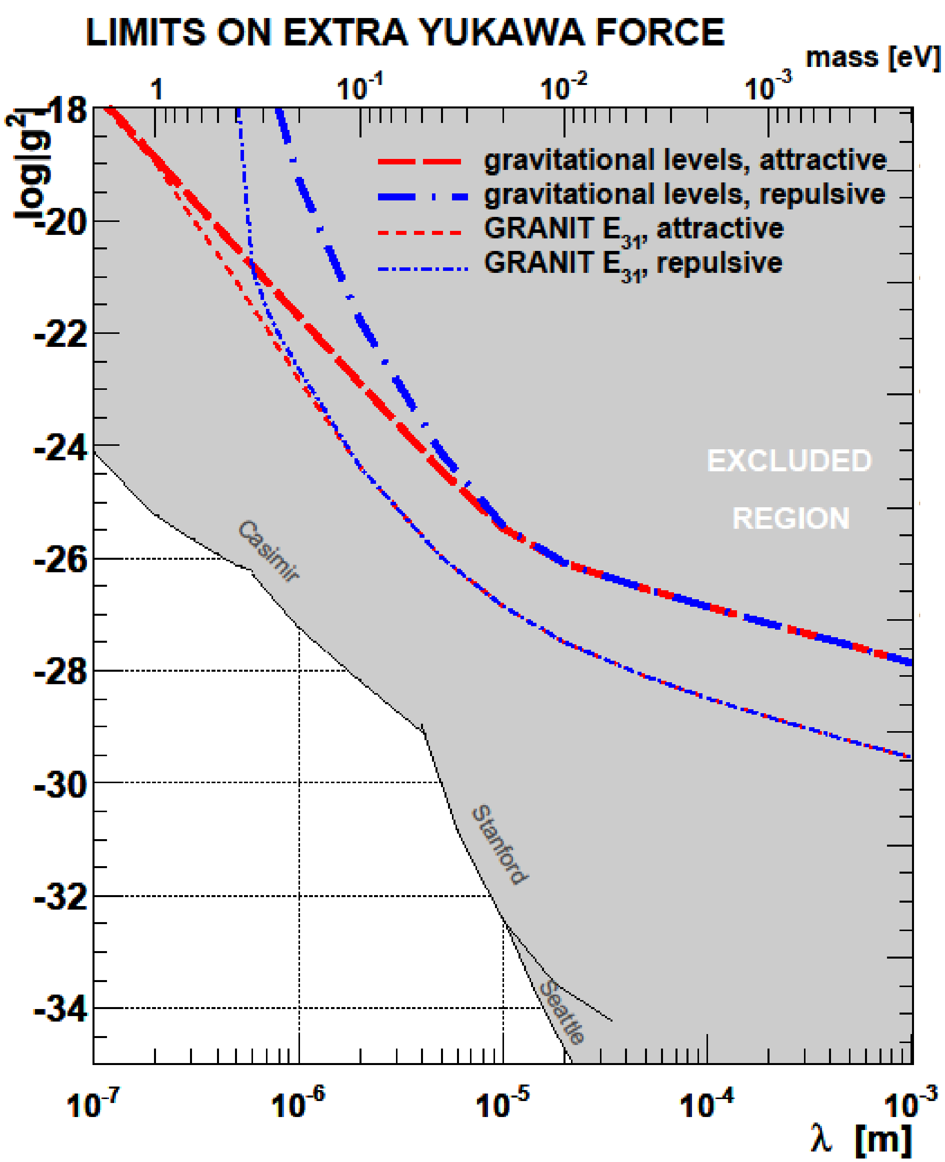
Yukawa interaction between neutron and mirror:

$$V(z) = \frac{g^2 \rho}{2 m_n} \hbar \, c \, \lambda^2 \, e^{-z/\lambda}$$

g = coupling constant

λ = range

ρ = 2.5 g.cm^{-3} (quartz density)



G. Pignol, UJF PhD thesis, 2009

Chameleon models

- Cosmological model to explain the dark energy problem.
- Scalar field *coupled* to matter.
- Chameleon mechanism: only thin shell at the surface of a body contributes to the field
  - → Could evade lab limits with macroscopic bodies even for strong coupling
  - → Modification of the gravity law close to the surface of a body

$$\Phi(z) = m_n\, g\, z + \beta\, \frac{m_n}{M_{Pl}}\, \phi_{Ch}(z)$$

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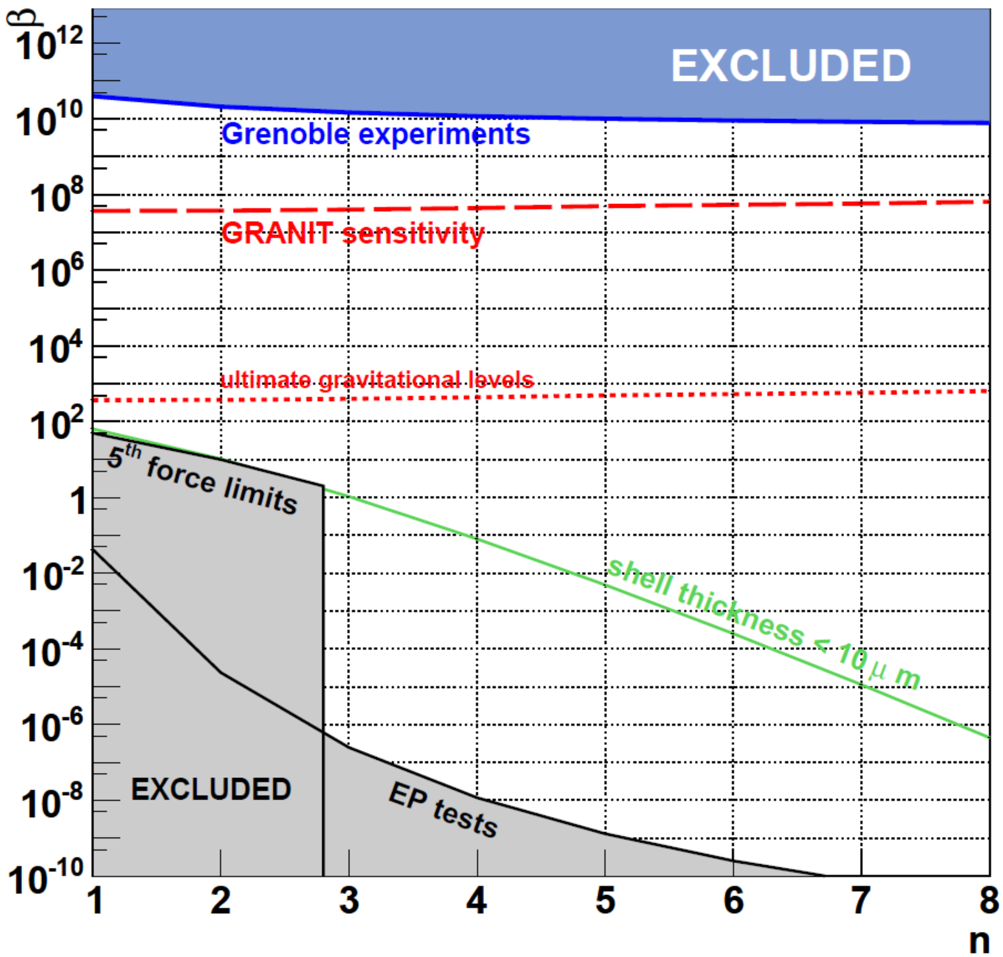
Calculation for GRANIT (Brax & Pignol, arXiv:1105.3420v1):

$$\phi_{Ch}(z) = \frac{\hbar\, c}{d_{DE}} \left(\frac{z}{d_{DE}} \right)^{2/2+n}$$

n= 1, 2, 3…

where d_{DE} = 82 μm is the characteristic distance associated to the dark energy ($\hbar$ c / d_{DE}^4 = dark energy density).

Chameleon exclusion plot

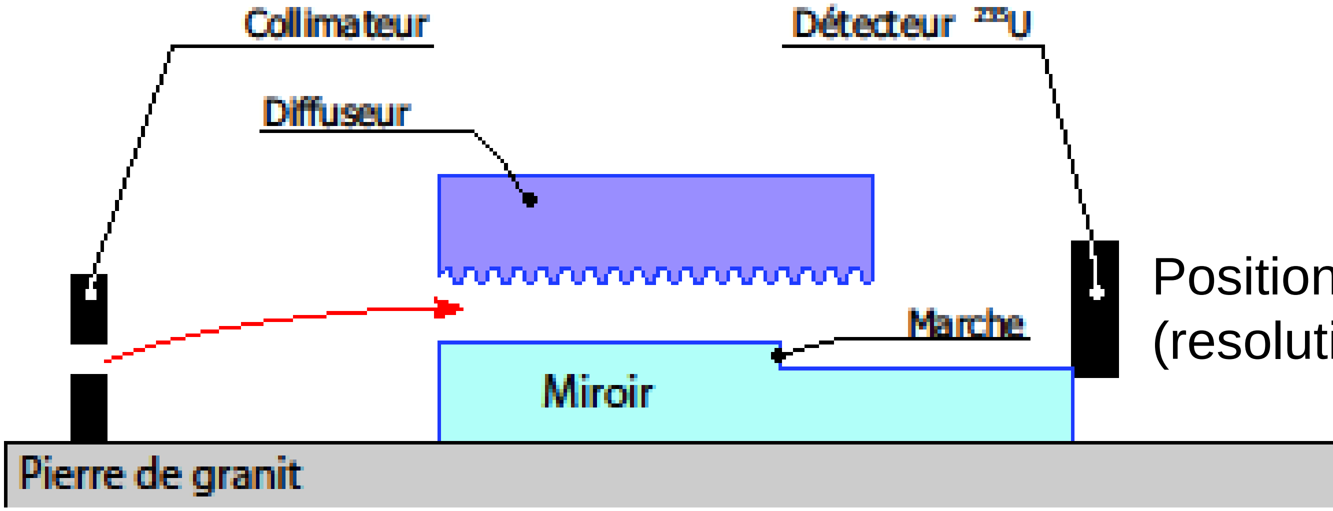


⇔ Additional bound state

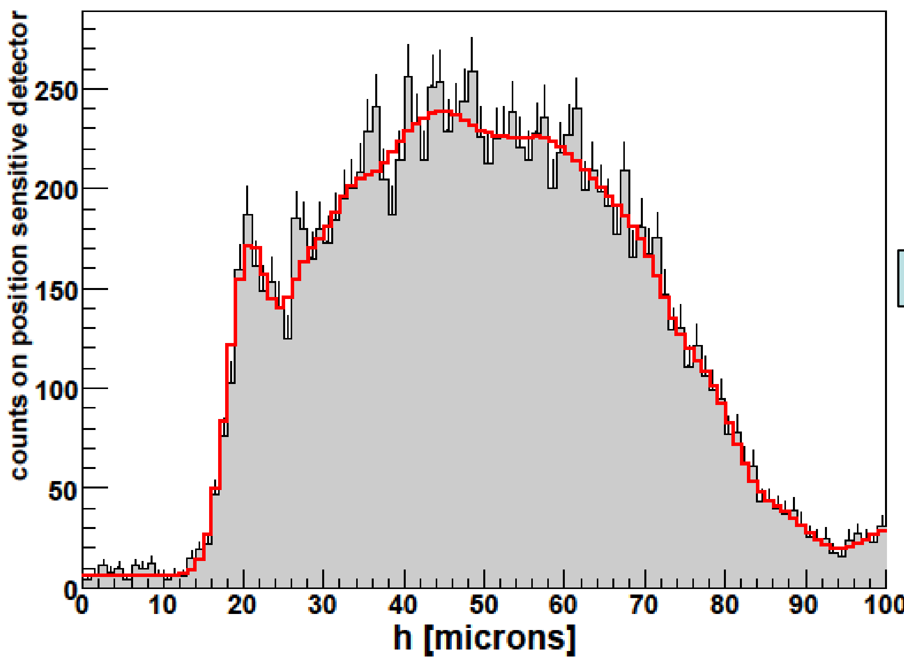
→ Competitive limit for strongly coupled chameleons

Thank you for your attention.

Observations in differential mode



Position sensitive detector (resolution = 2 μm)



Measurement of z_0 with a precision ≈ 3 %