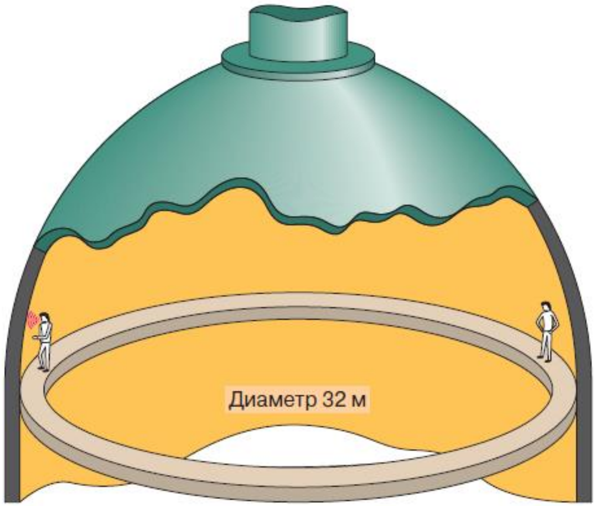
Neutron whispering gallery resonator

ISINN- 23 Dubna 2015



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Important references

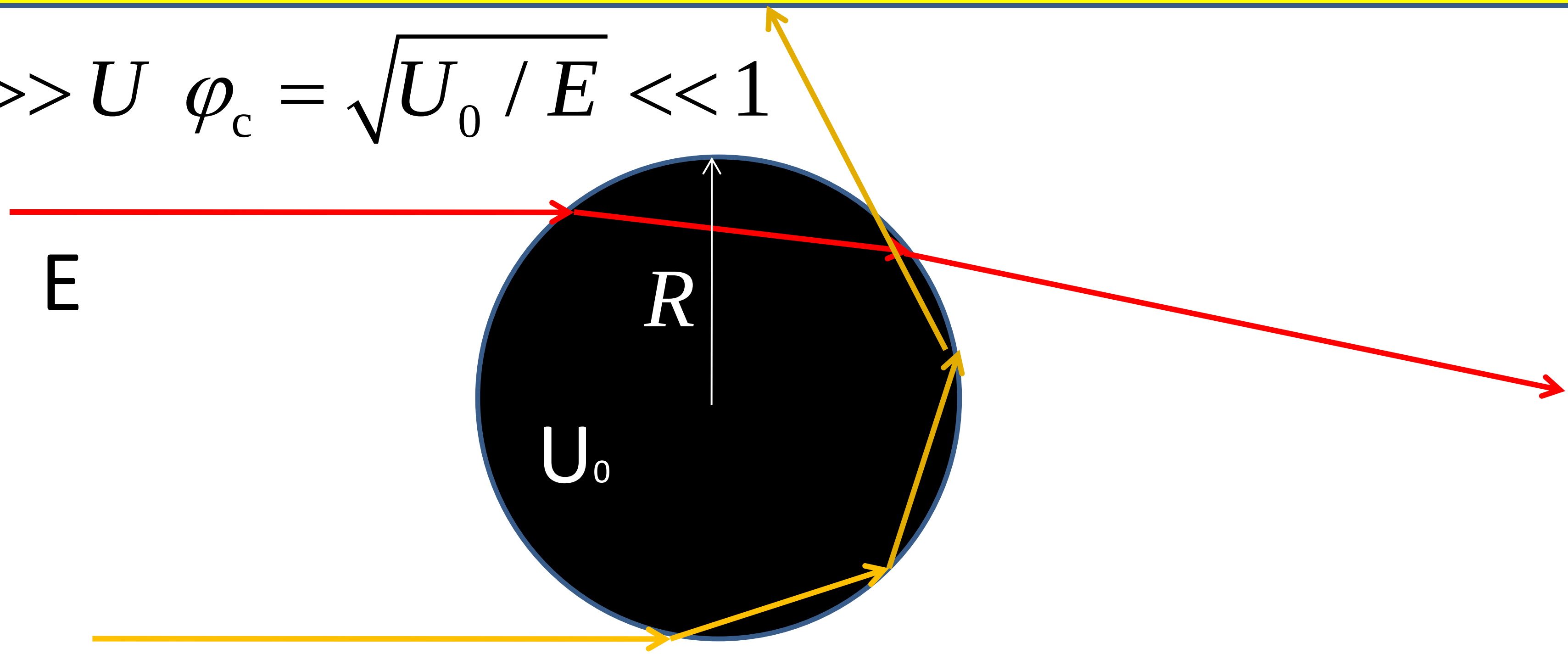
- V.V. Nesvizhevsky, A. Voronin, R.Cubitt and K.V. Protasov (2010) "**Neutron whispering gallery**"
  Nature Physics 6:114-117
- R. Cubitt, V.V. Nesvizhevsky, A.K. Petukhov, A.Yu. Voronin, G. Pignol, K.V. Protasov, and P. Gurshijants **(2009).** ***"Methods of observation of the centrifugal quantum states of neutrons."*** **NIM A 611: 322-325**
- V. V. Nesvizhevsky, A. K. Petukhov, K. V. Protasov, and A. Yu. Voronin "**Centrifugal quantum states of neutrons**" **Phys. Rev. A 78, 033616 (2008)**
- K. V. Protasov and A. Y. Voronin
  "**Regge Poles in Neutron Scattering by a Cylinder**"
  Adv. High En. Physics 124592, (2014)

Plan of the talk

- Whispering gallery effect in neutron scattering on cylinder
- Neutron whispering gallery resonator and trap
- Short-range forces and gravitational effect

Neutron scattering on a cylinder

$$E >> U \quad \varphi_c = \sqrt{U_0 / E} << 1$$

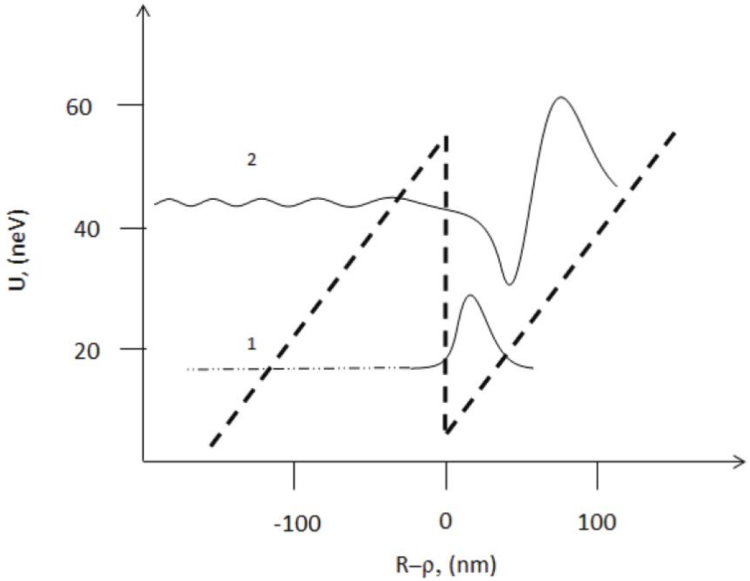


$$\varphi >> \varphi_c \quad \frac{mv_{\perp}^2}{2} \approx U_0 \quad mvR / \hbar \gg 1$$

Whispering gallery states

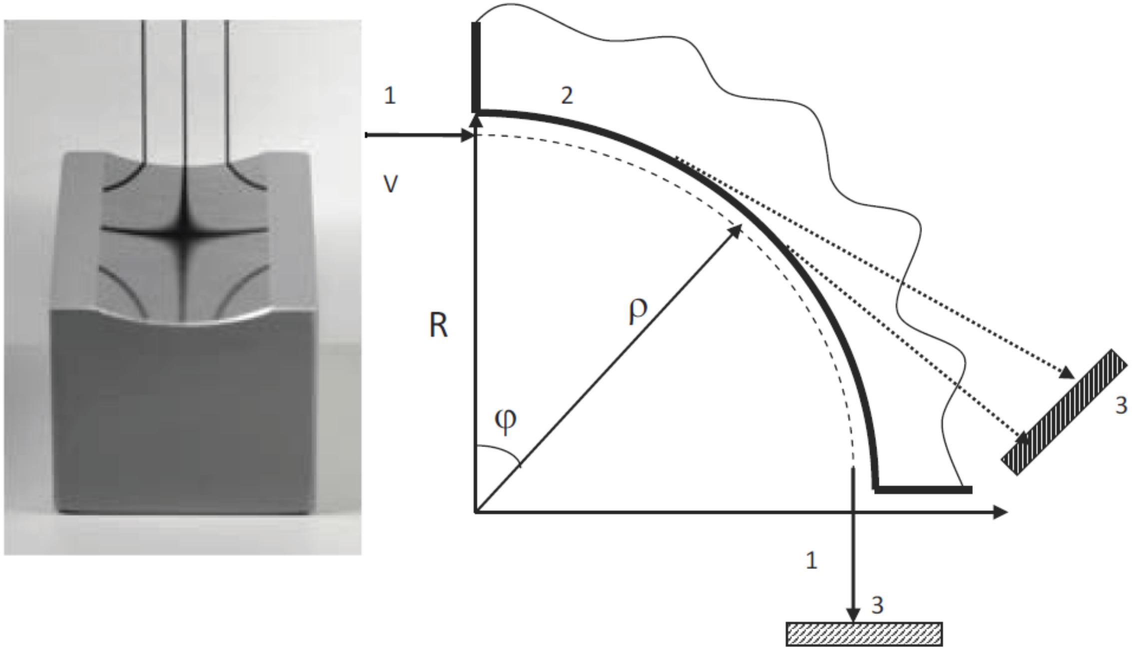
$$\left[-\frac{1}{2M}\frac{\partial^2}{\partial z^2} - U_0\Theta(z) - \frac{Mv^2}{R}z - \varepsilon_\mu\right]\chi_\mu(z) = 0$$

$$\varepsilon_\mu = E - \frac{(\mu^2 - 1/4)}{MR^2}$$



$$l_0 = \left(\frac{\hbar^2 R}{2M^2 v^2}\right)^{1/3} \approx 40\ \text{nm} \quad \varepsilon_0 = \left(\frac{\hbar^2 M v^4}{2R^2}\right)^{1/3} \approx 15\text{neV} \quad g_{eff} = \frac{v^2}{R} \sim 10^7 g$$

First observation of neutron WG effect



1- neutron classical trajectories, 2- cylindrical mirror, 3-detector

V.V. Nesvizhevsky, A. Voronin, R.Cubitt and K.V. Protasov (2010) "**Neutron whispering gallery**" **Nature Physics** 6:114-117

Neutron rainbow

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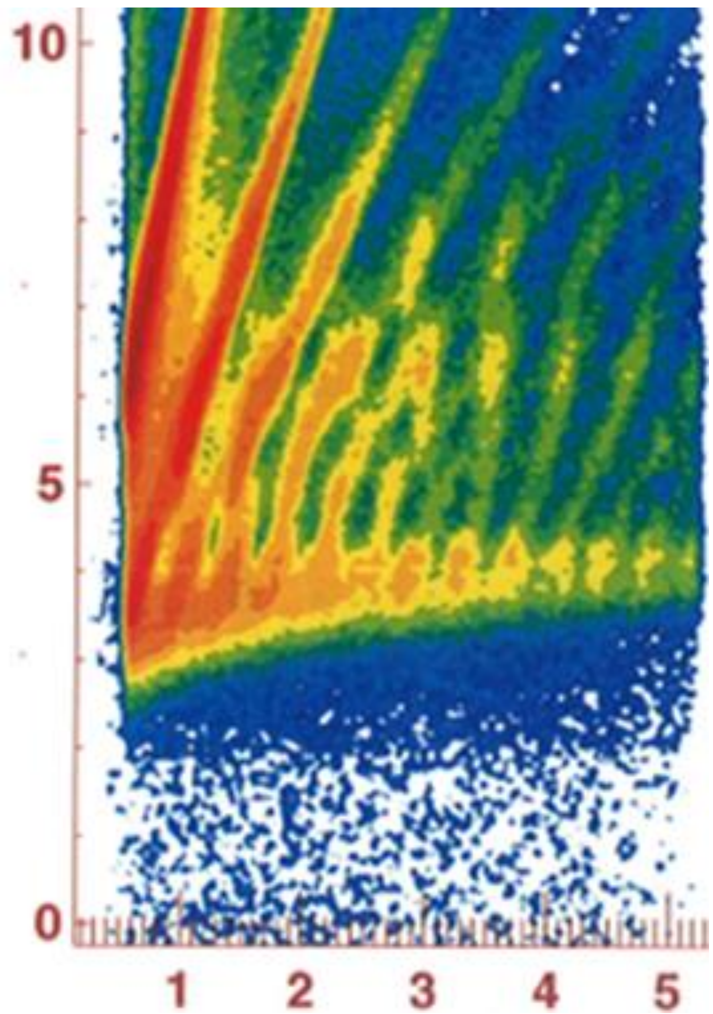
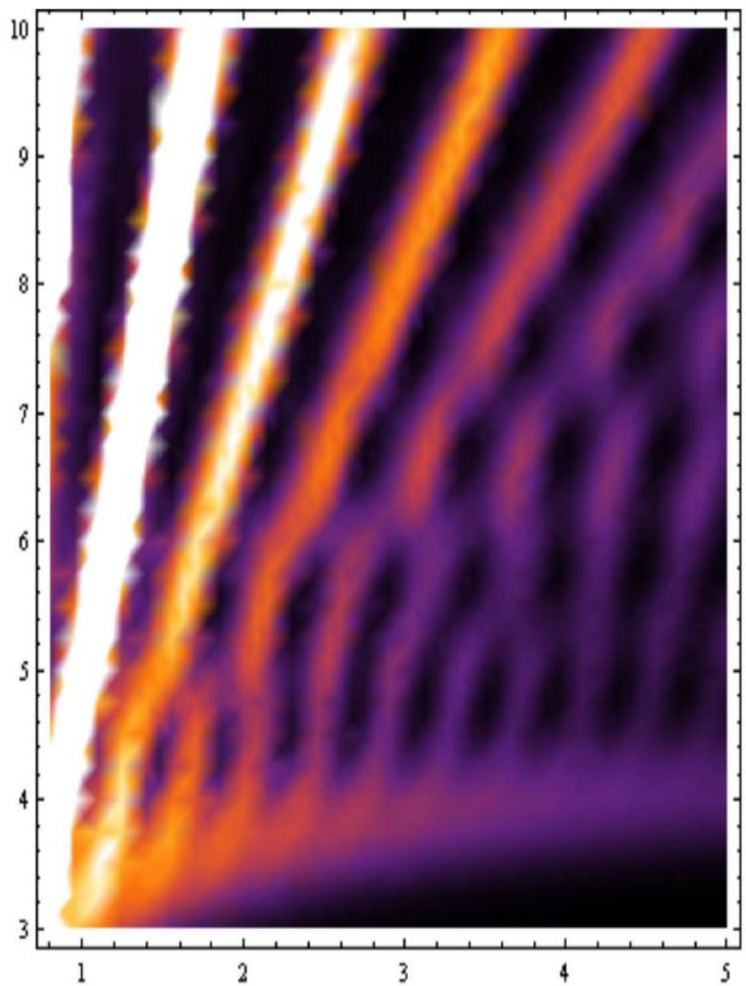
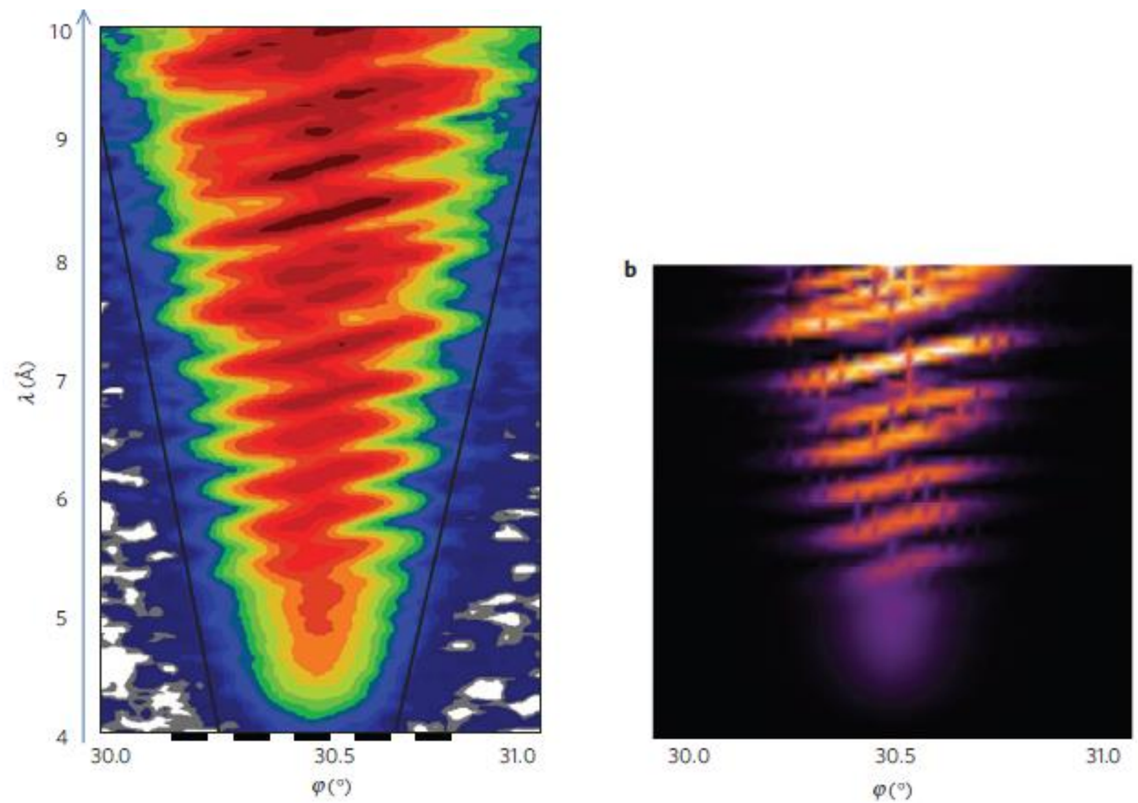




Experiment φ **Theory**

Interference of deep WG states

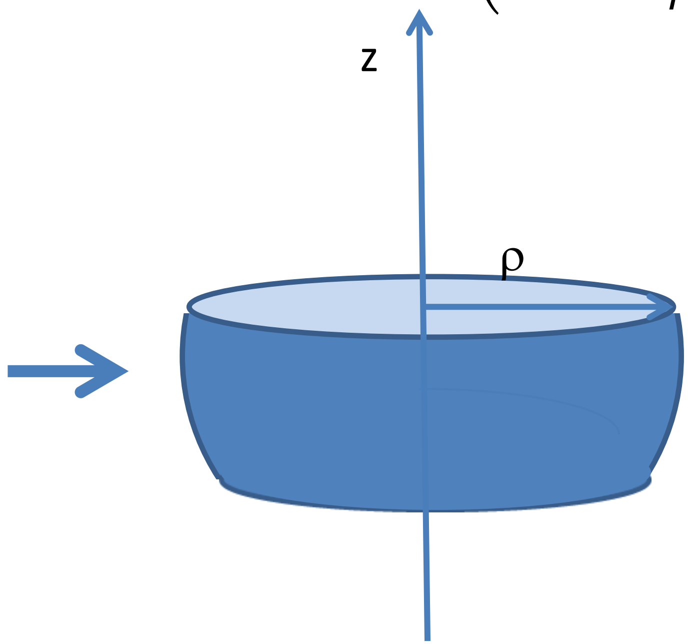


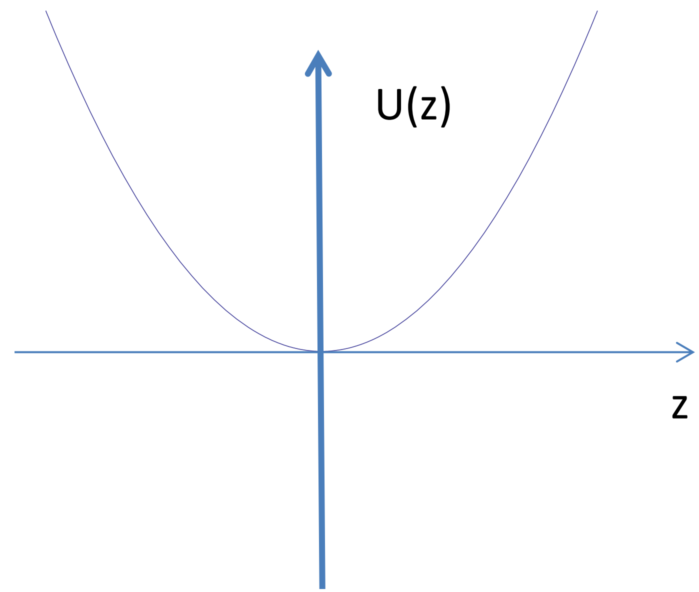
High sensitivity of interference pattern on details of neutron-surface interaction

WG resonator

$$\rho(z^2) = \sqrt{R^2 - z^2}$$

$$\left(\widehat{T}_z + \frac{\hbar^2}{2m\rho(z)^2}\left(\mu^2 - \frac{1}{4}\right) + \varepsilon_n(z) - E\right)\mathrm{f}(z) = 0$$





A 3D neutron trap is produced by superposition of centrifugal and optical potential

Spherical WG resonator

$$\left[\hat{T}_\rho + \hat{T}_\theta + \hat{T}_\varphi - E\right]\chi(\rho)Y_{l\mu}(\theta)\exp(i\mu\varphi) = 0;$$

$$\left[-\frac{\hbar^2 d^2}{2mdx^2} - \frac{\hbar^2 l(l+1)}{mR^3}x - \varepsilon_n\right]\chi(x) = 0;$$

radial

$$x = R - \rho;\ \ \varepsilon_n = \frac{\hbar^2 l^{4/3}}{2^{1/3} mR^2}\lambda_n;\ Ai(-\lambda_n) = 0;$$

$$\left[-\frac{\hbar^2 d^2}{2mdz^2} - \frac{\hbar^2 \mu^2}{2mR^4}z^2 - \hbar\omega(n + 1/2)\right]\psi(z) = 0;$$

vertical

$$z = R\sin(\theta);\ \ |\theta - \pi/2| \ll 1; \omega = \frac{\hbar\mu}{mR^2} \approx \frac{v_\tau}{R}$$

Spherical WG energies

$$\Psi(x,z,\varphi) = Ai(x-\lambda_n)H_k(z)\exp(i\mu\varphi);$$

$$E_{n,k,\mu} = \frac{\hbar^2\mu^2}{2mR^2} + \frac{\hbar^2\mu(k+1/2)}{mR^2} + \frac{\hbar^2(\mu+k)^{4/3}}{2^{1/3}mR^2}\lambda_n$$

$\mu \gg 1$ – WG modes

$k \sim 1; n \sim 1$ – full quantum regime

$k \gg 1; n \sim 1$ – radial quantum reqime

$k \sim 1; n \gg 1$ – vertical quantum regime

Short-range forces and gravity effects

Gravity

$\Delta z_0 = gR^2 / v_\tau^2 -$ shift of zero level (of order of mm for UCN)

$\Delta\omega(g) -$ account of z^4 terms

Short-range forces

$\Delta\varepsilon_n -$ account of hypothetical Yukawa-type terms $\exp(-\lambda x) / x$

Observation- interference of WG states

Conclusions

- WG states- quantum tool for studding fundamental neutron-matter interactions
- WG effect- long time localization in quantum state near material surface
- WG resonator- “both-sided” open 3D neutron trap for extra-long keeping in WG quantum state
- Promising tool for studding short-range forces and gravity