Analysis of storage times of UCN in gravitational quantum states

Les Houches, Febuary 15 2009

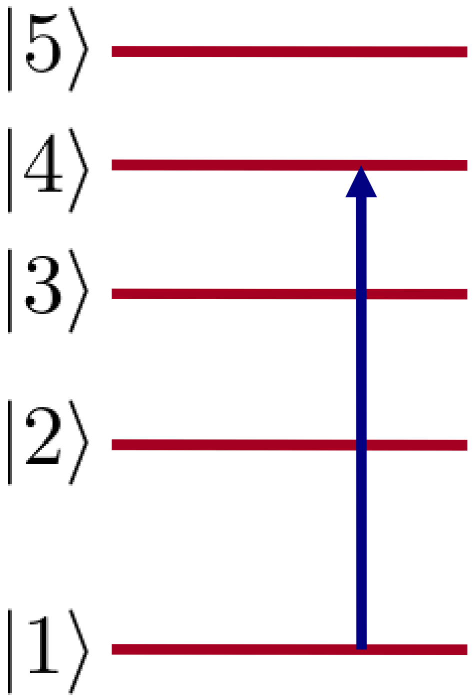
Outline

1 Lifetimes of quantum states

2 Losses of quantum states
Verticality of the walls
Holes in the corners
Mirror's waviness
Vibrations
Earth rotation

Conclusion

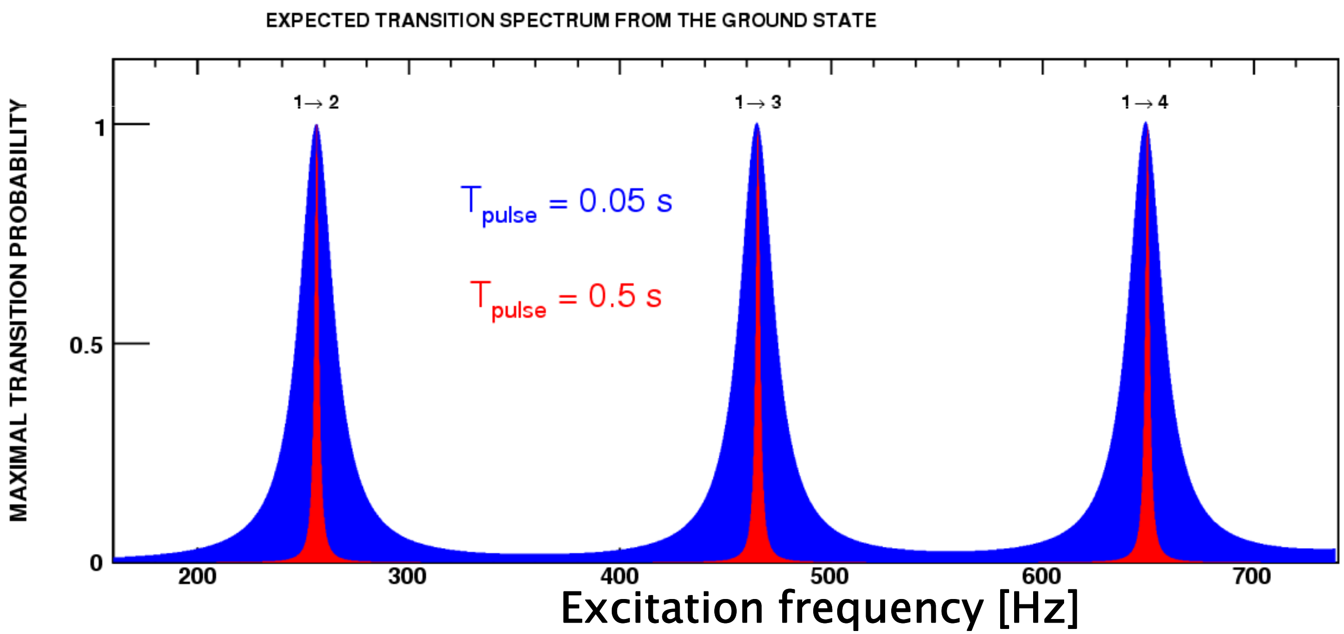
Resonant transitions



One applies harmonic excitation V(t)
at frequency ω during time t

$$P_{N\to n}(t) = \frac{\sin^2\left(\sqrt{(\omega-\omega_{Nn})^2+\Omega_{Nn}^2}\ \frac{t}{2}\right)}{1+\left(\frac{\omega-\omega_{Nn}}{\Omega_{Nn}}\right)^2} \qquad \Omega_{Nn} = \frac{2}{\hbar}\langle n|\, V(z)\, |N\rangle$$

$$f_{Nn} = \frac{E_N - E_n}{h}$$



One observes resonances

One measures differences c

Lifetimes of quantum states are important

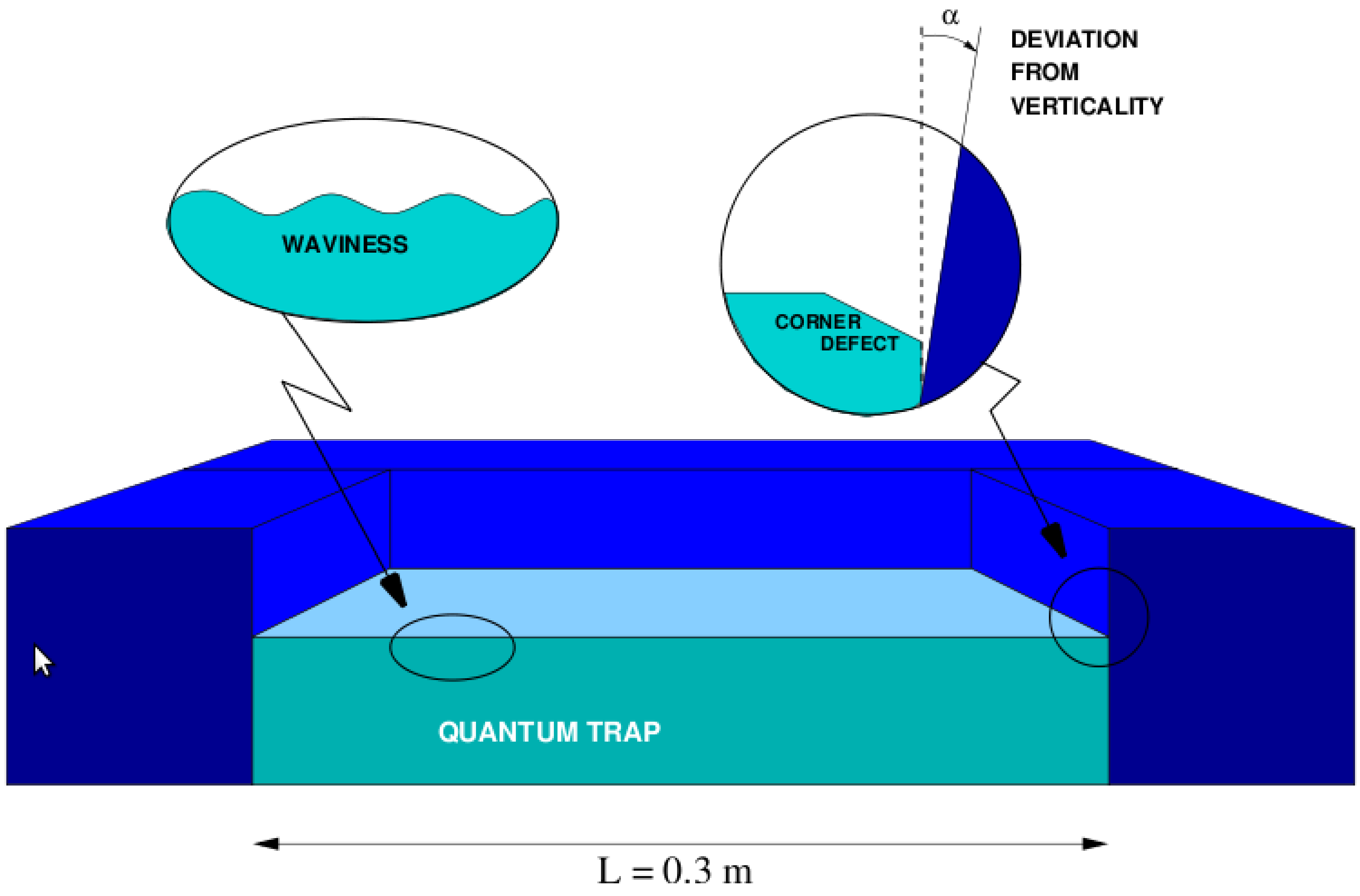
Width of the resonances

$$\Delta E \cdot T_{\mathrm{pulse}} = h$$

- Pulse time needed to resolve neighbouring states: 10 ms
- Flow through mode $T \approx \frac{0.3\ \mathrm{m}}{5\ \mathrm{m/s}} \approx 50$ ms

We want the lifetimes of quantum states to be larger than 50 ms and eventually larger than the beta decay lifetime

Outline


α
DEVIATION
FROM
VERTICALITY
WAVINESS
CORNER
DEFECT
QUANTUM TRAP
L = 0.3 m

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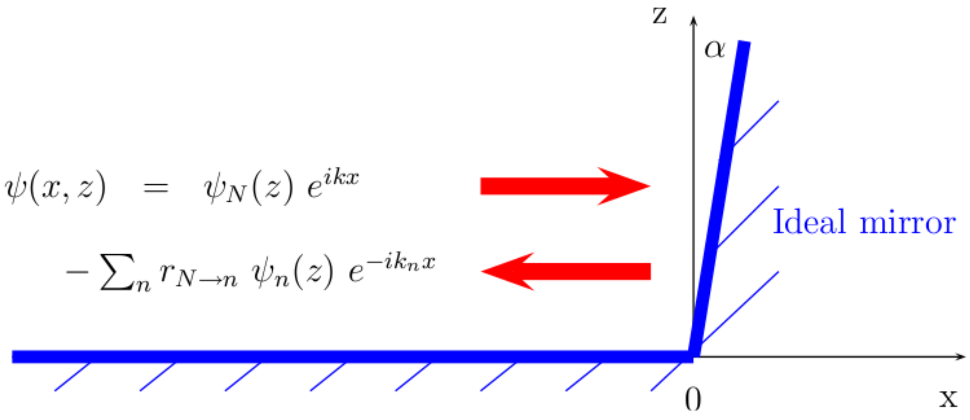
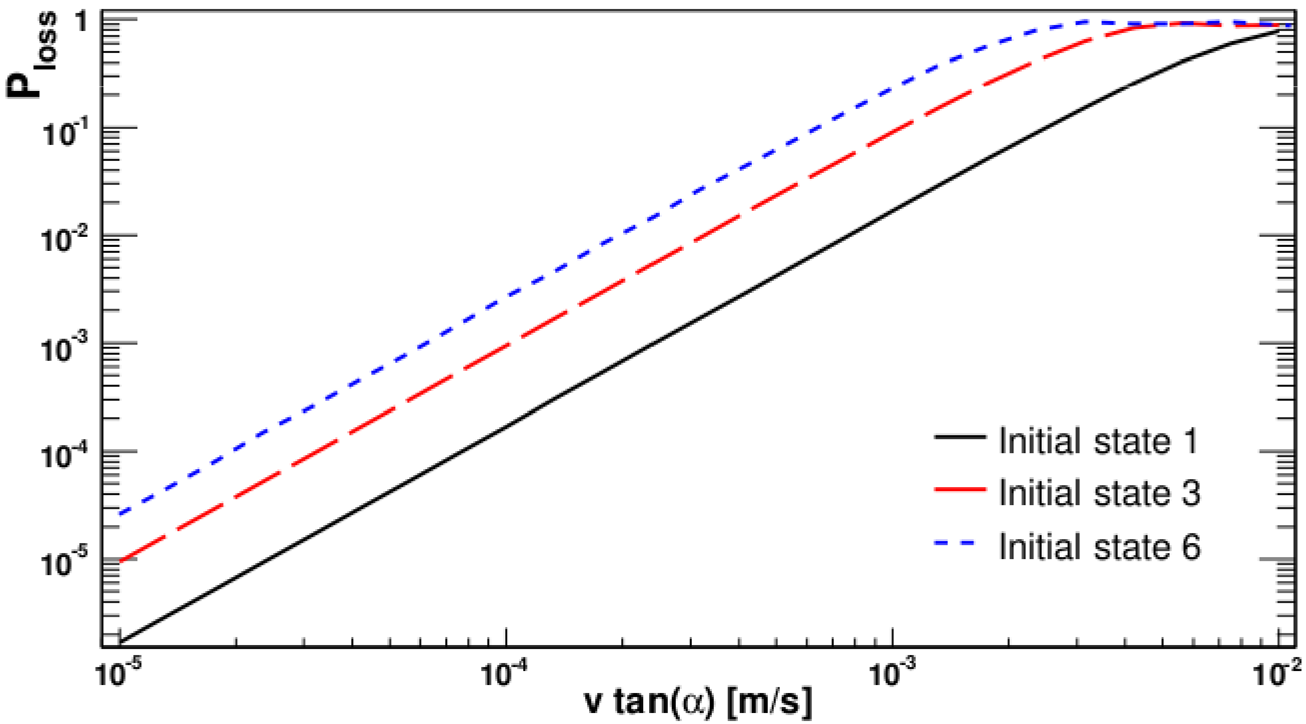
Verticality of the walls

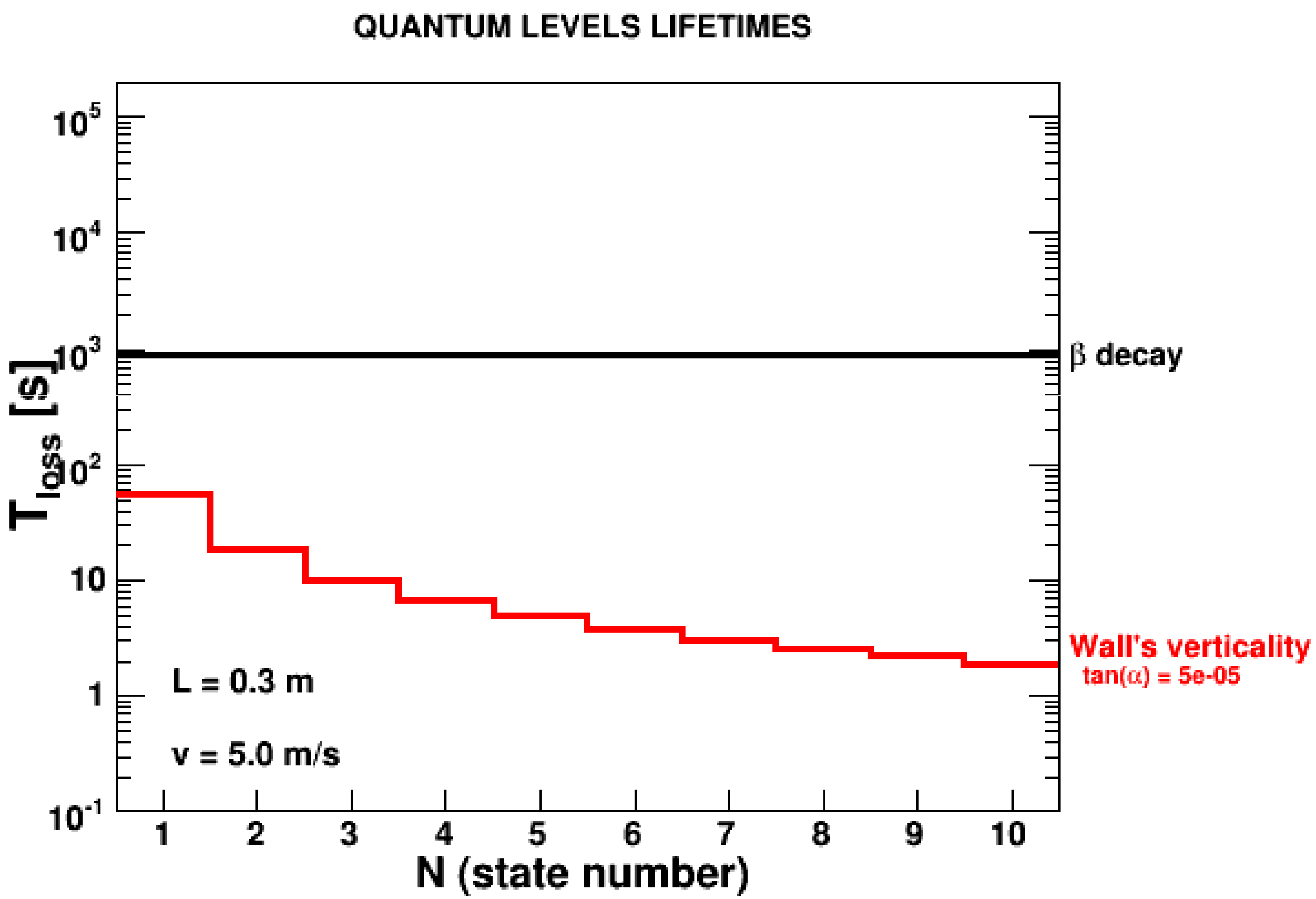


Imposing $\psi(\tan(\alpha)z, z) = 0$ we get:

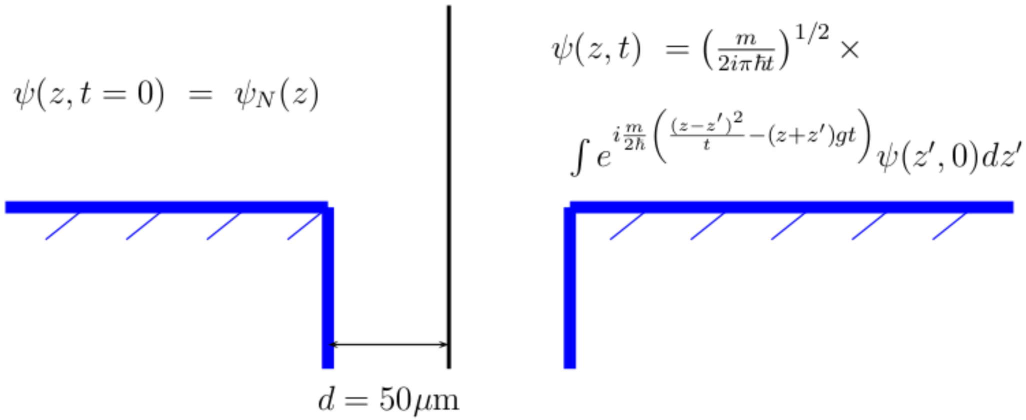
$$
\begin{aligned}
P_N &= 1 - |r_{N\to N}|^2 \\
&= 1 - |<N|e^{2ik\tan(\alpha)\hat{z}}|N>|^2
\end{aligned}
$$

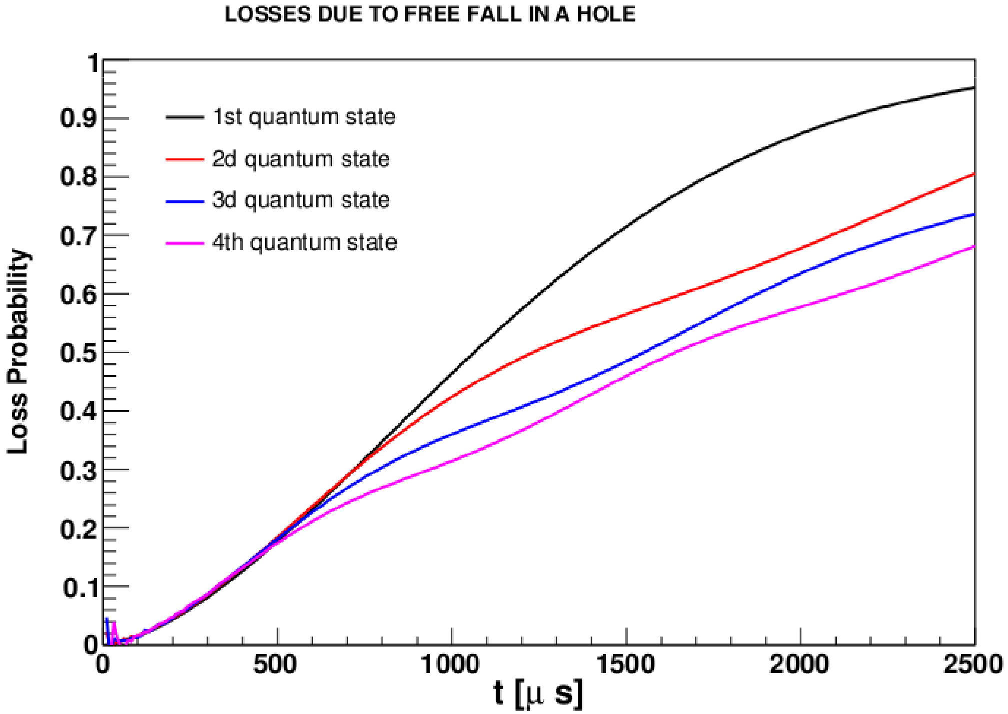


Verticality of the walls

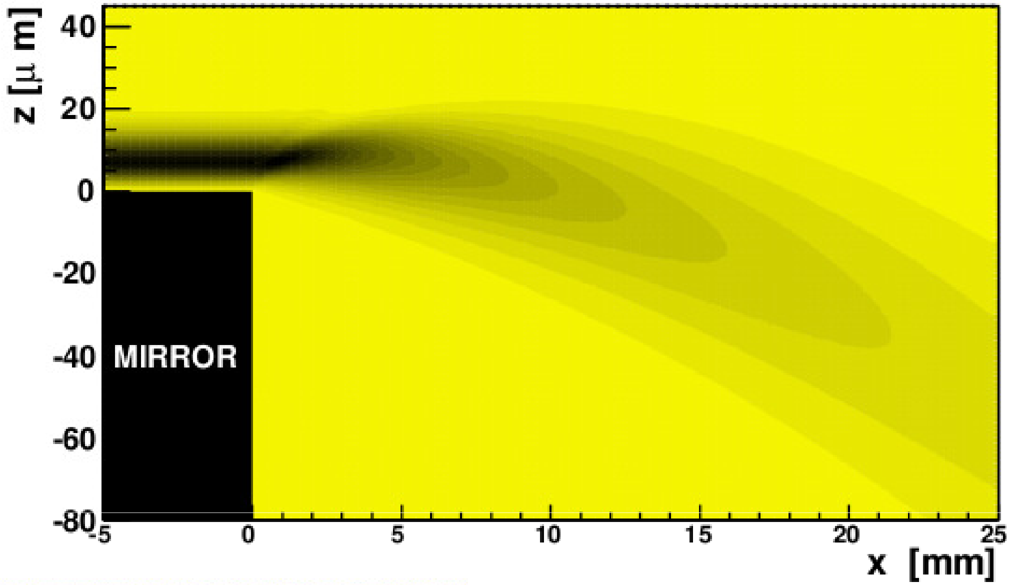


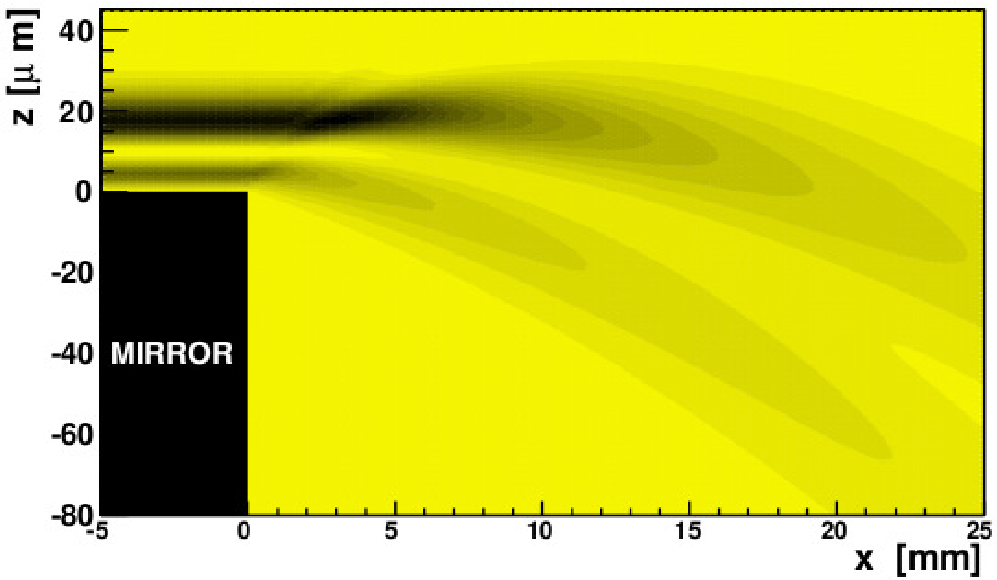
Holes in the corner





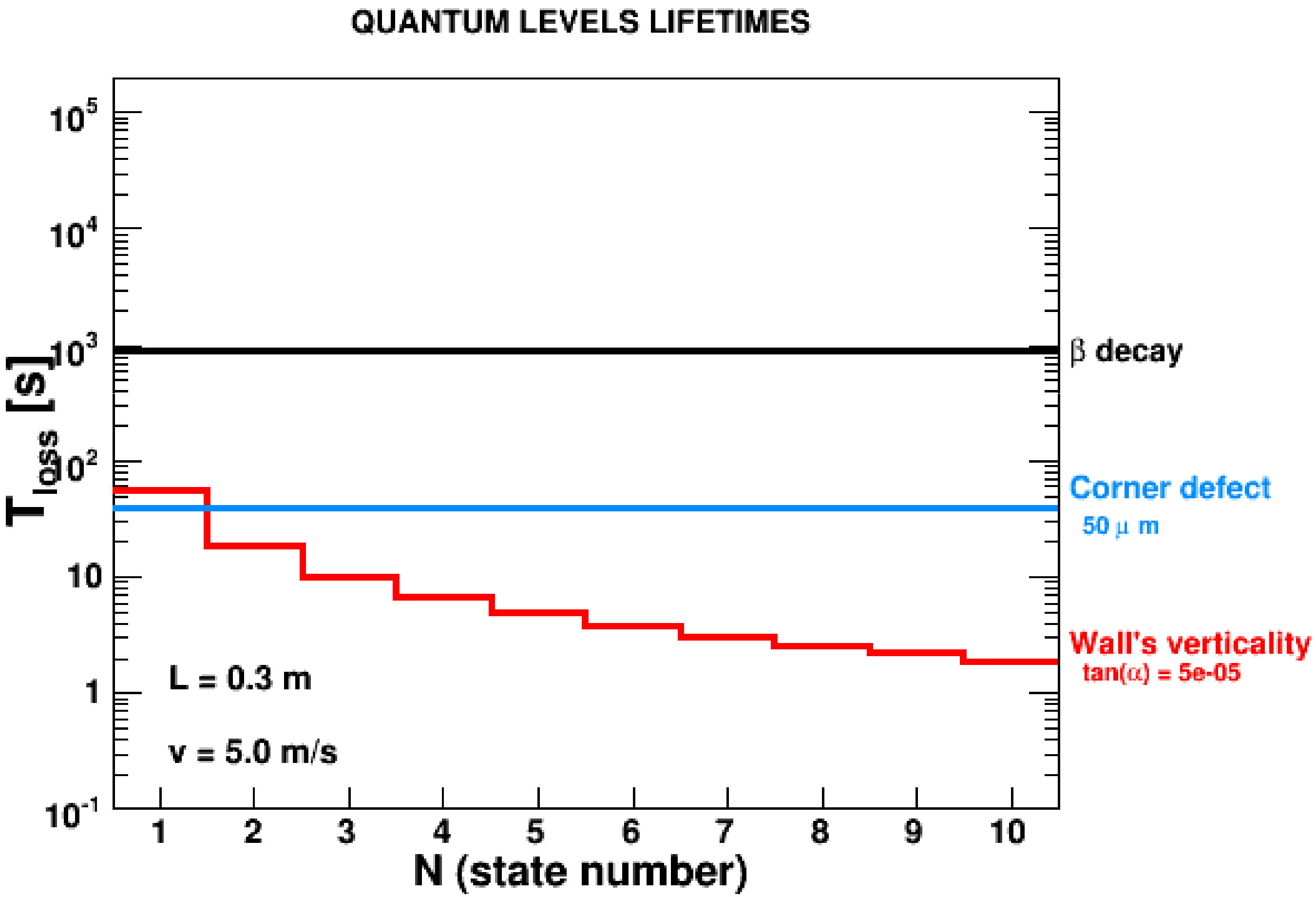
A nice picture





The free fall of quantum states 1 and 2

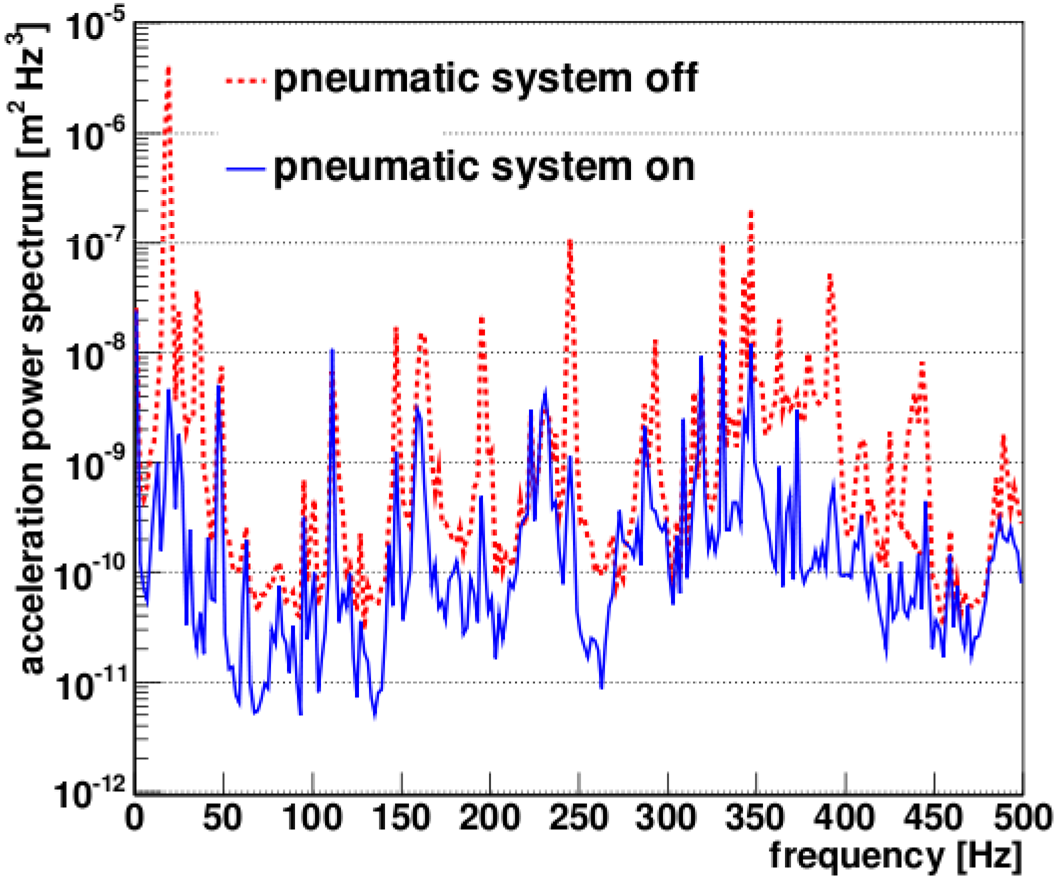
Holes in the corner



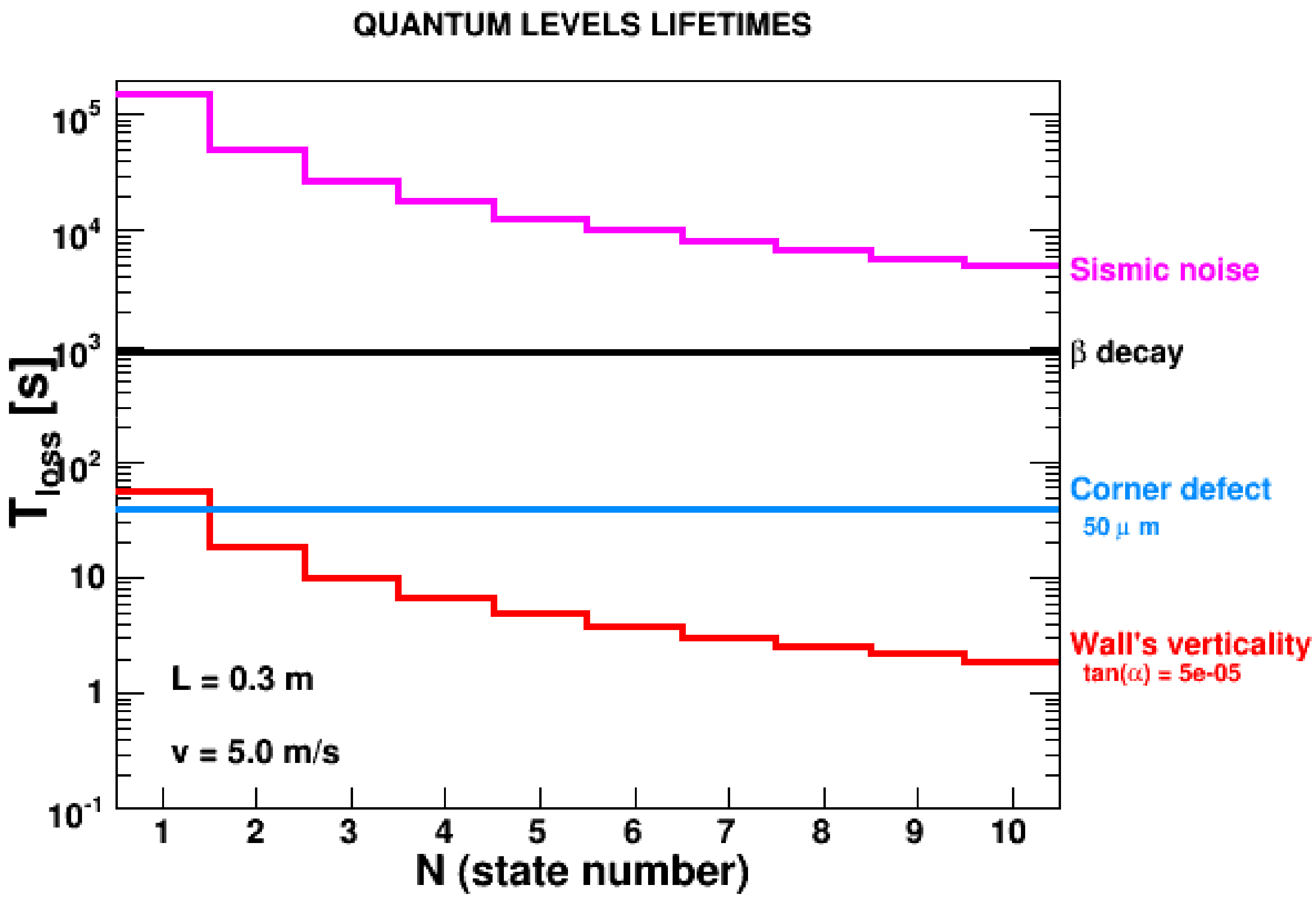
Losses due to vibrations

$$S_a(f) = \frac{1}{T}\left|\int_0^T a(t)e^{2i\pi f}\,dt\right|^2$$

$$\frac{1}{T_{N\to n}} = \left(\frac{\hbar}{mg}\right)^2 \frac{(2\pi f_{Nn})^4}{S_a(f_{Nn})}$$



Losses due to vibrations



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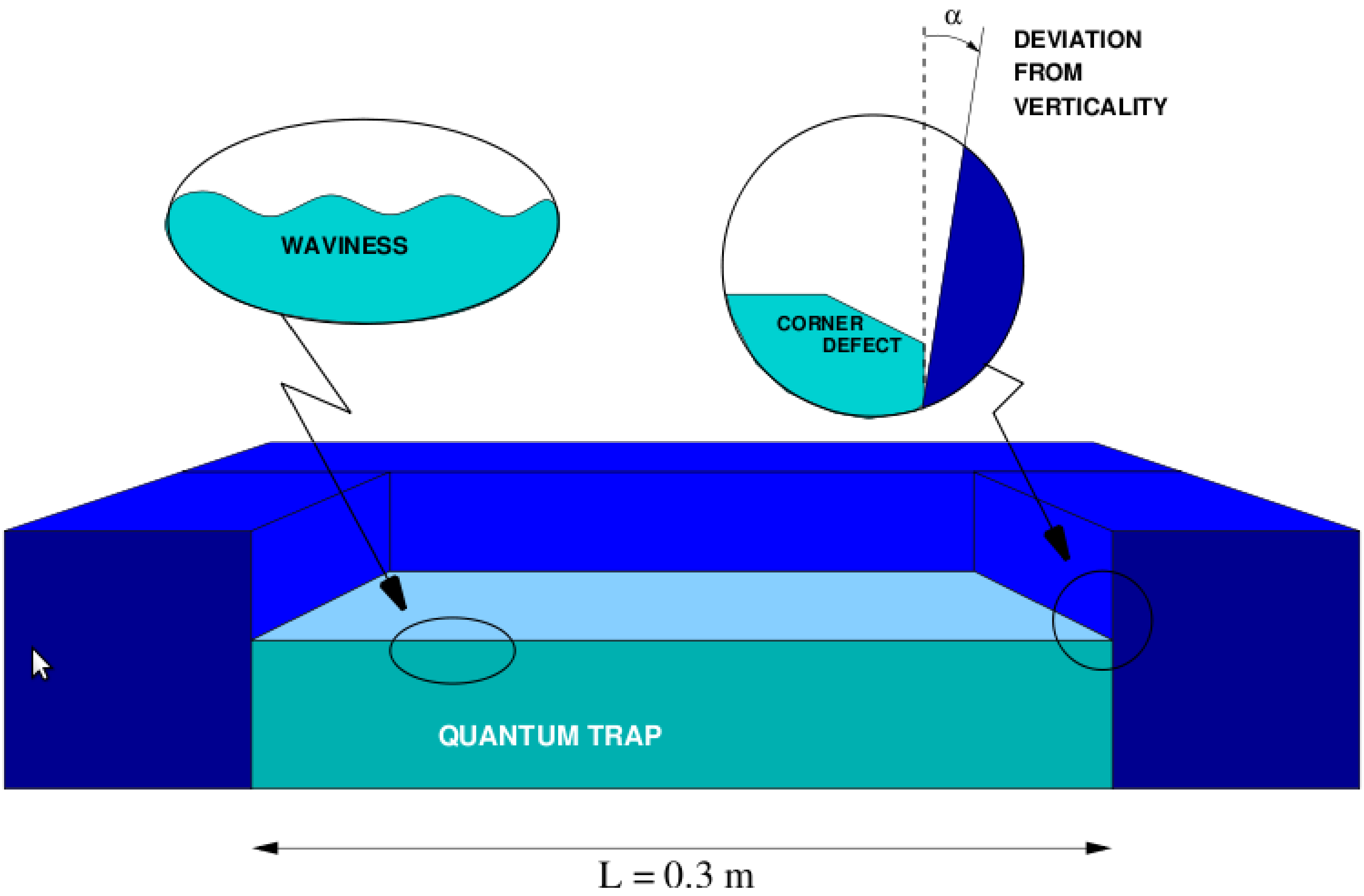

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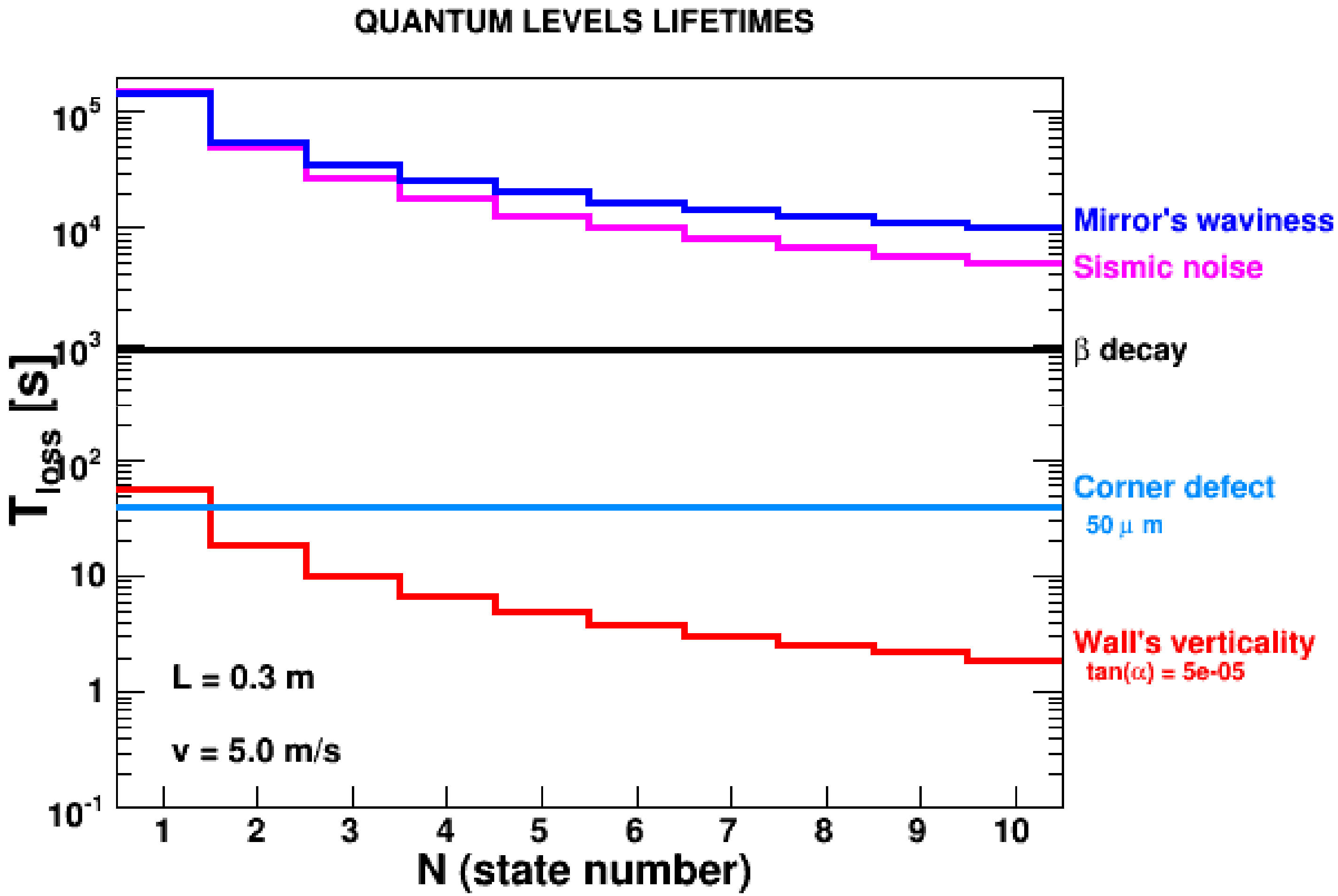
Losses due to mirrors waviness



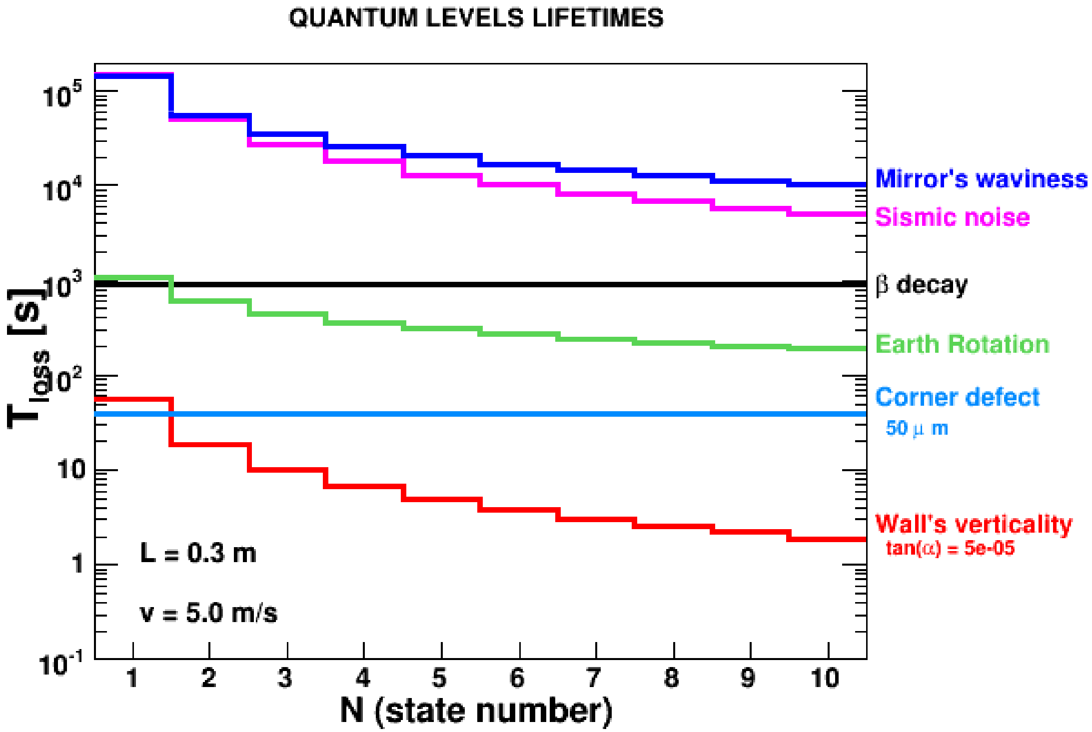
Limitations du to Earth rotation

The Coriolis force $\vec{F}_c = 2m\vec{v} \times \vec{\Omega}$

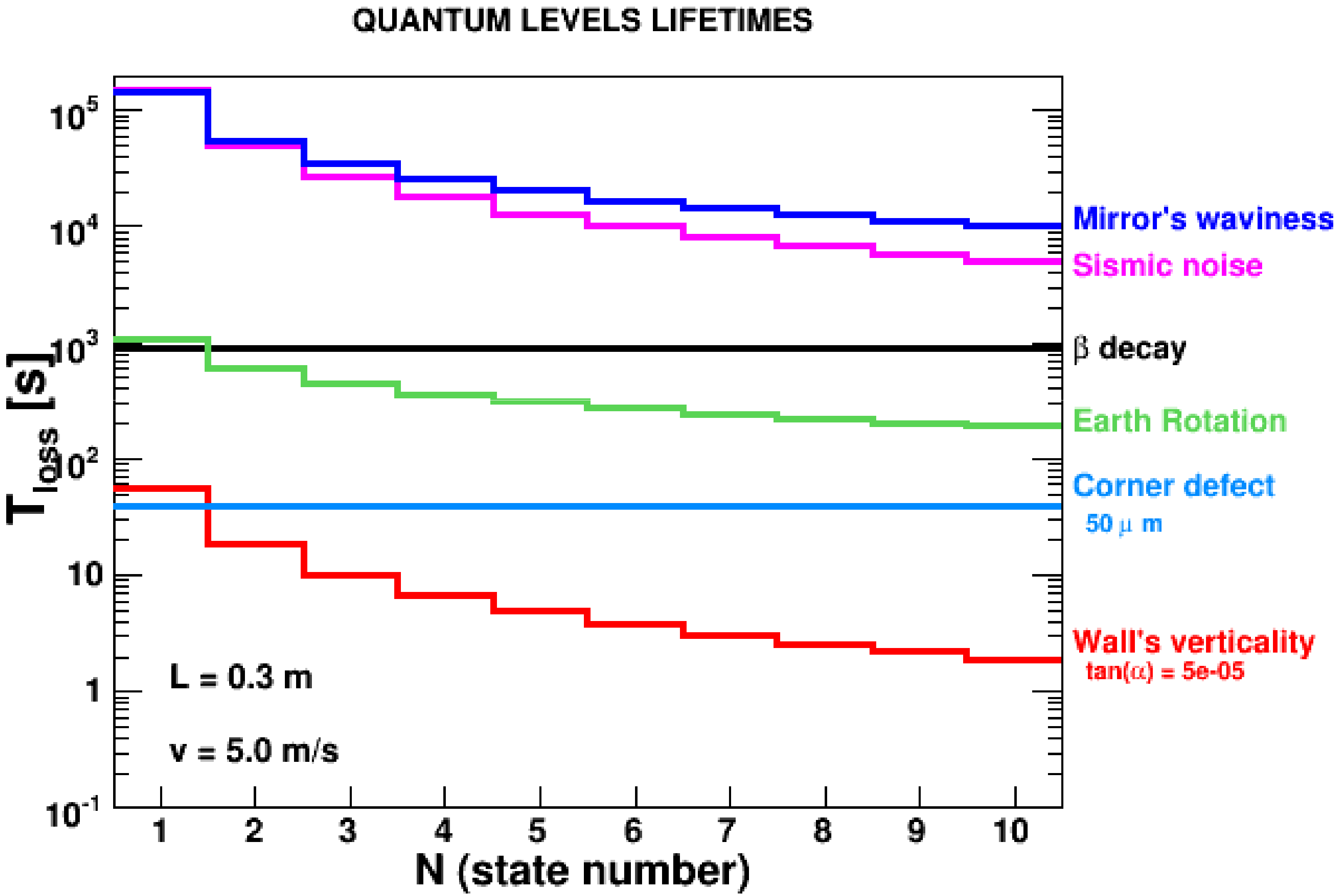
Modifies effectively the gravitational acceleration

$$\vec{F}_c \cdot \vec{e}_z = 2mv\Omega\cos\lambda \qquad g_{\text{eff}} = g - 2v\Omega\cos\lambda$$

Leading to Coriolis widening of the resonances



The hole picture



One last academic remark

Spontaneous decay of quantum states through graviton emission?

A semiclassical estimate
Pignol Protassov Nesvizhevsky Class Quant Grav 24 (2007)

$$T_{decay} \simeq 10^{77} \text{ s}$$

Conclusions

Requirements in flow through mode T > 1 s

1) Mirrors verticality has to be better than 10^{-4} rad
2) Holes have to be smaller than 0.5 mm
3) Vibrations have been tested to be ok
4) Mirror's waviness should be ok

In latter stages

Beta decay and Coriolis force are the fundamental limitations

Wall's verticality has to be better than 10^{-5} rad

Holes have to be smaller than 50 μm

Vibrations have been tested to be ok

Mirror's waviness should be ok