Searching for Short Distance Forces with the Mossbauer Effect

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The Johns Hopkins University

With David E. Kaplan and Giorgio Gratta,
arXiv:2010.03588

Short Distance Forces

Light bosonic particles motivated by BSM Physics
(e.g. radions, moduli, relaxions)

$$\mathcal{L} \supset y_q \phi \bar{q} q + \frac{\phi}{f_\gamma} F_{\mu\nu}^2 + \frac{\phi}{f_g} G_{\mu\nu}^2 + \frac{\tilde{h}_{\mu\nu}}{f_T} F^{\mu}{}_{\sigma} F^{\nu\sigma} + g \phi h^2 + \frac{m_\phi^2}{2} \phi^2$$

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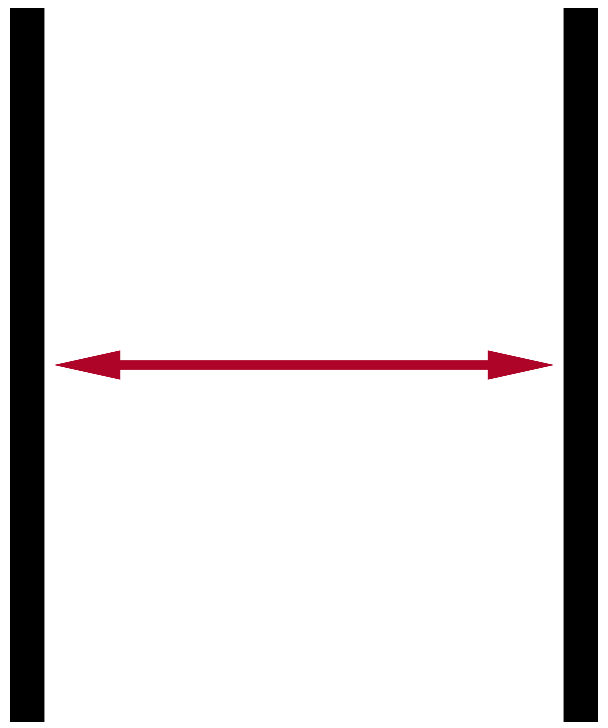

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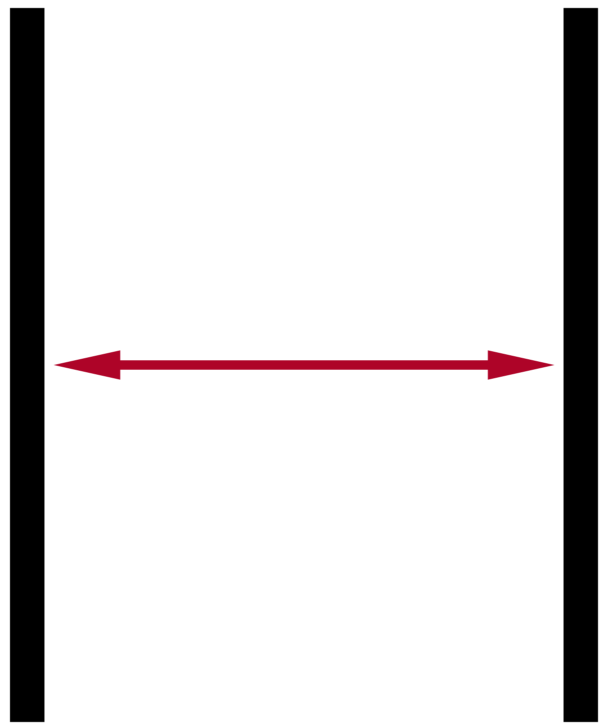

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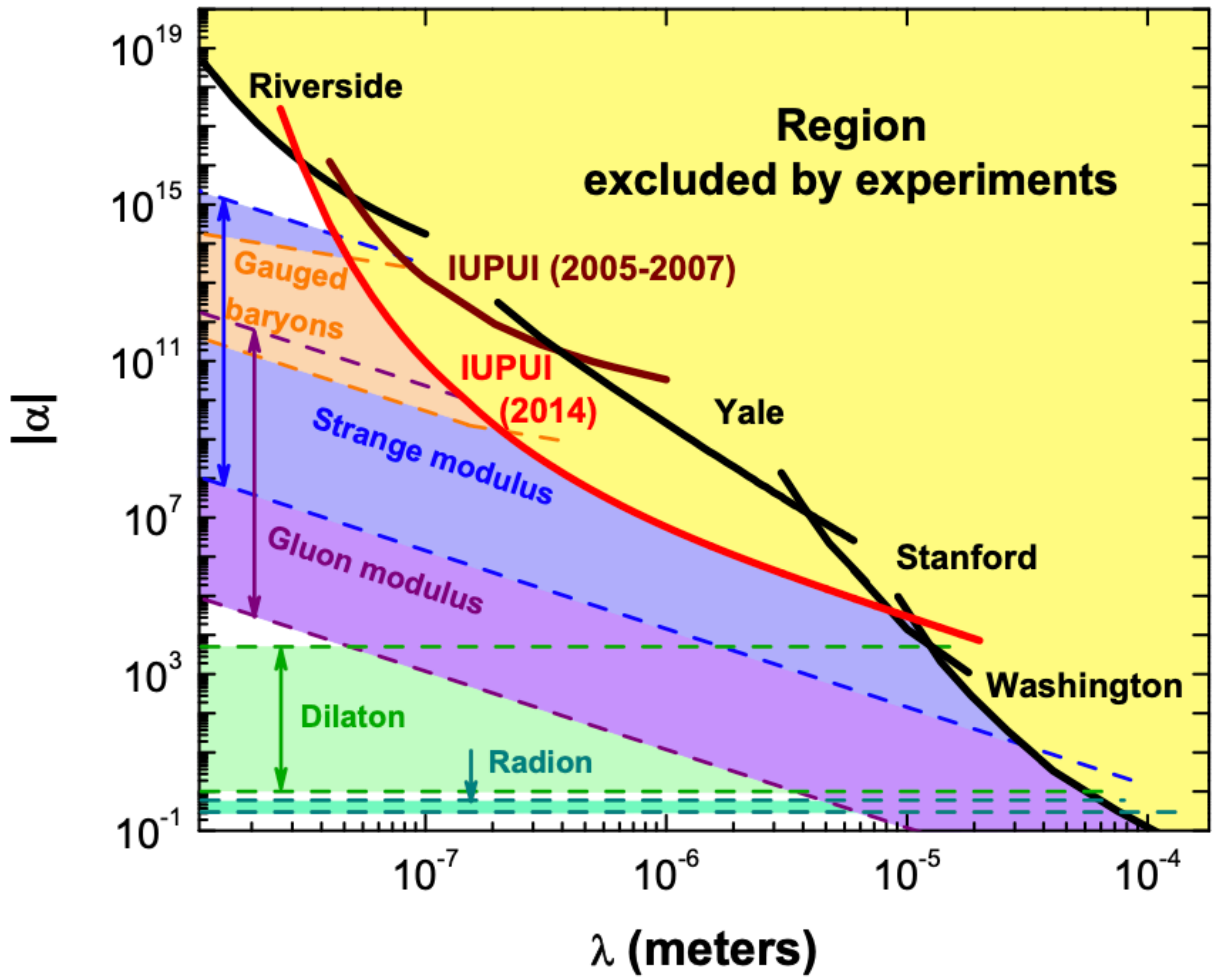
Measure Relative Acceleration

Where are we?



Very strong constraints at long (> μm) distances

Sensitivity rapidly drops at short (< μm) distances

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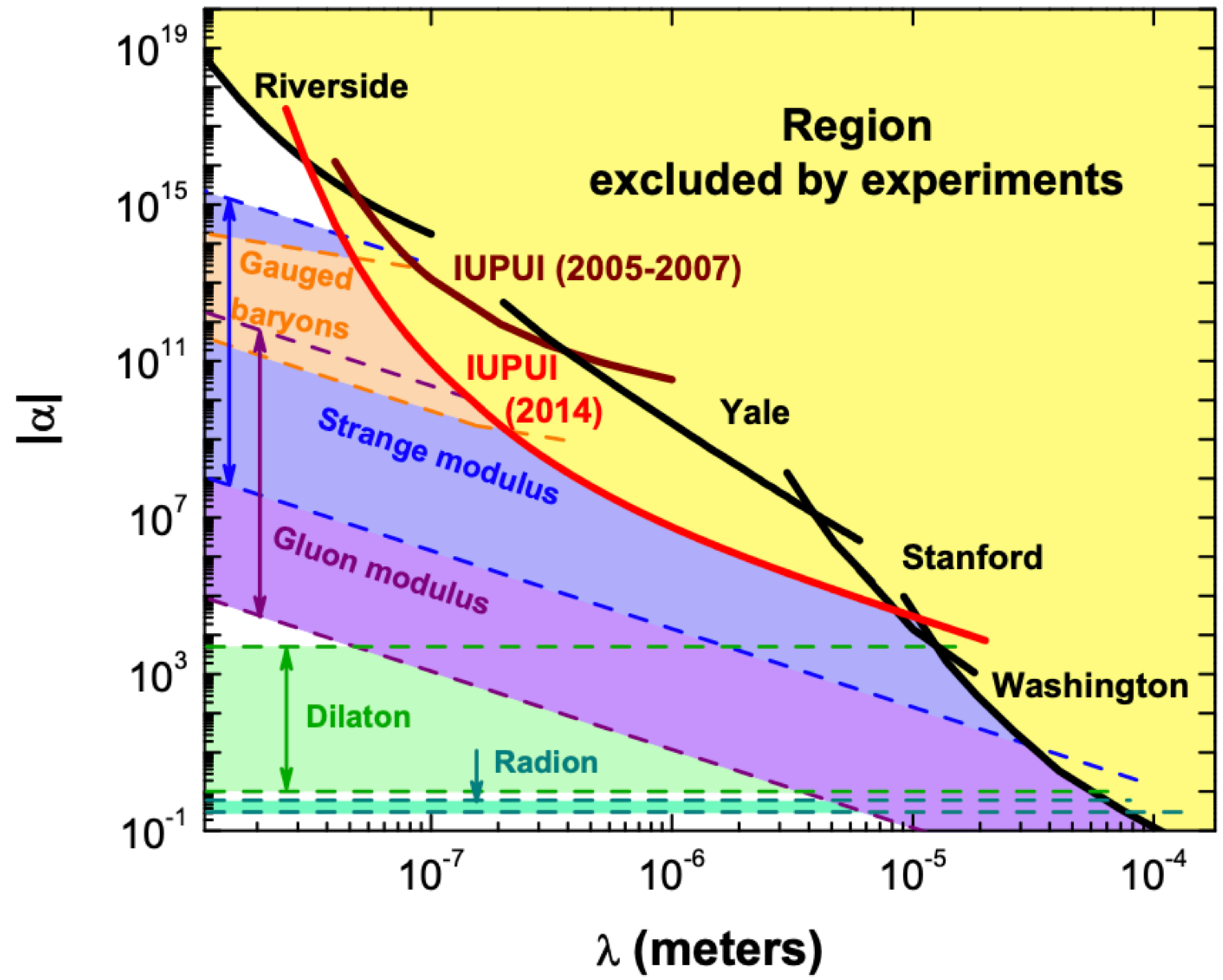

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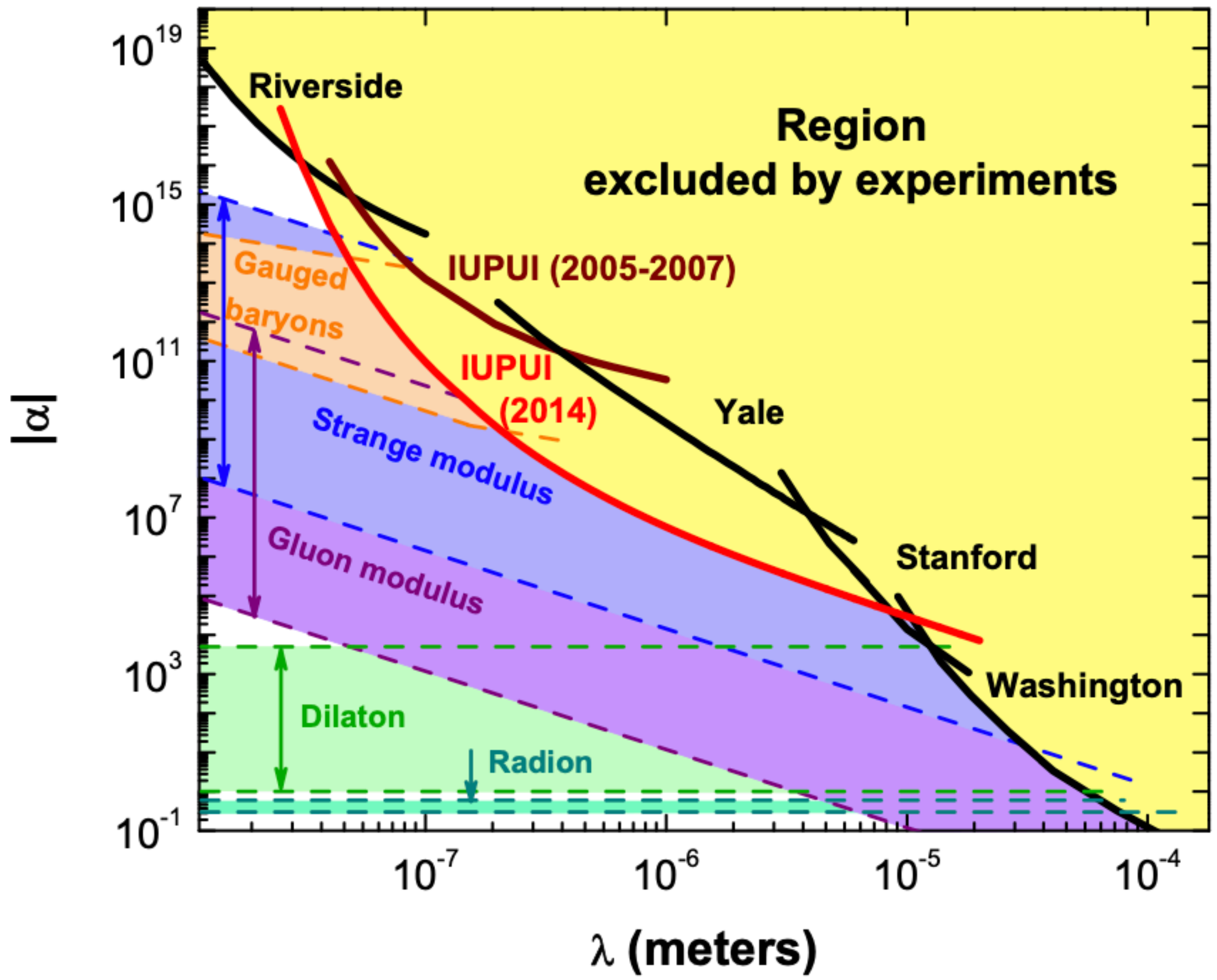

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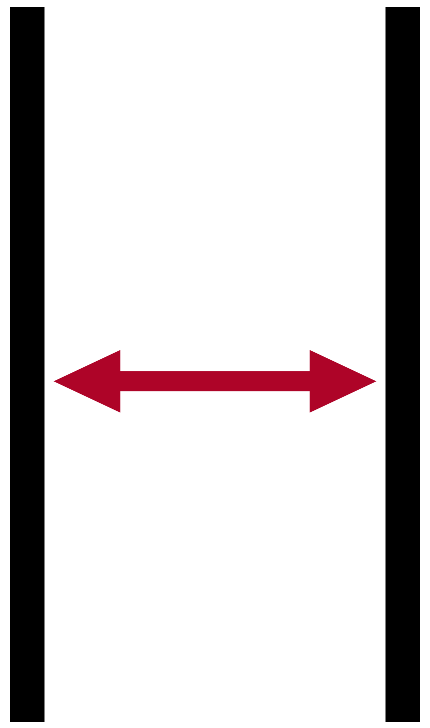

Short Range => Objects need to be close

Electromagnetism >> New Physics

Short Range => Only material within λ affected

Need to deal with thin objects with high precision

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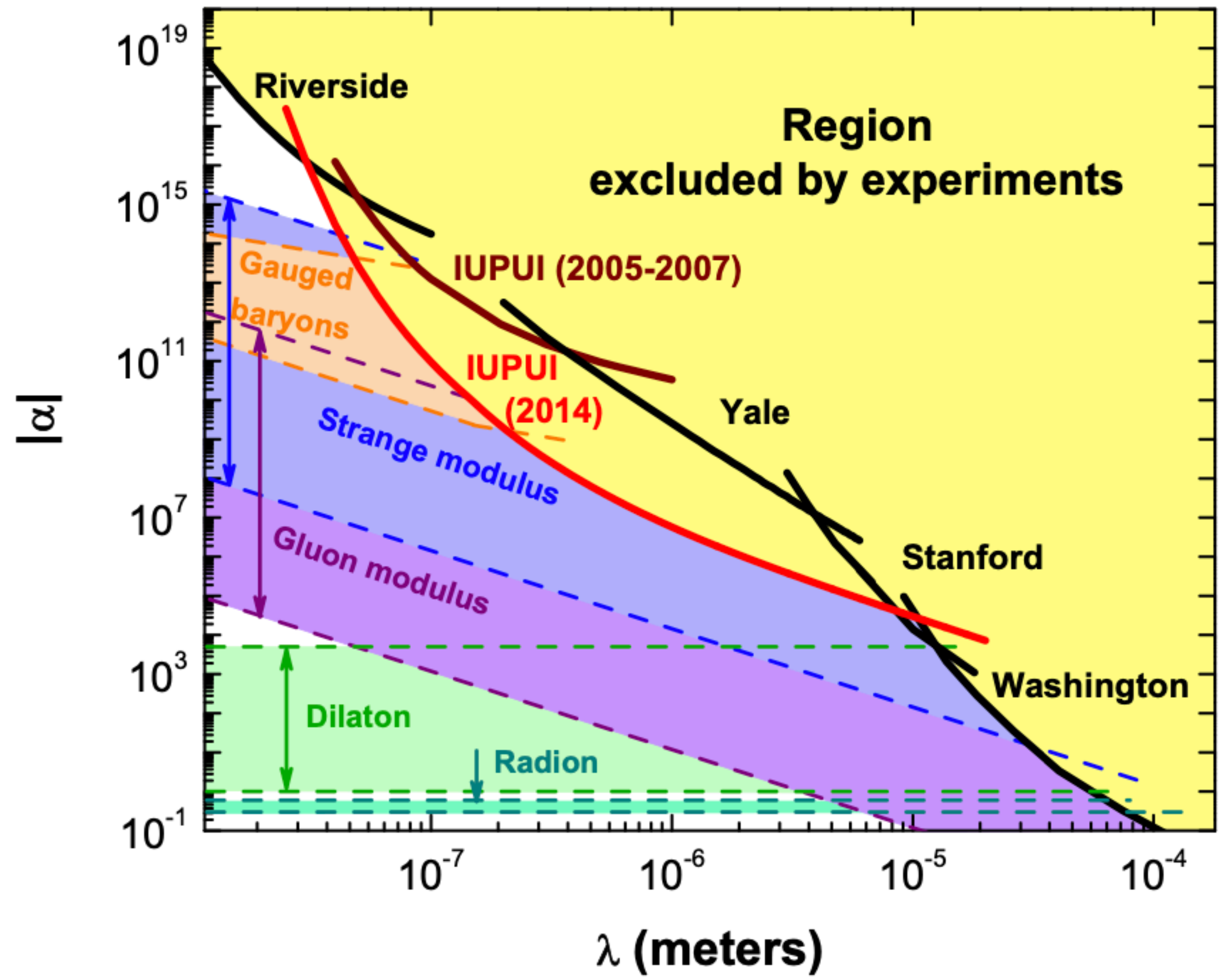

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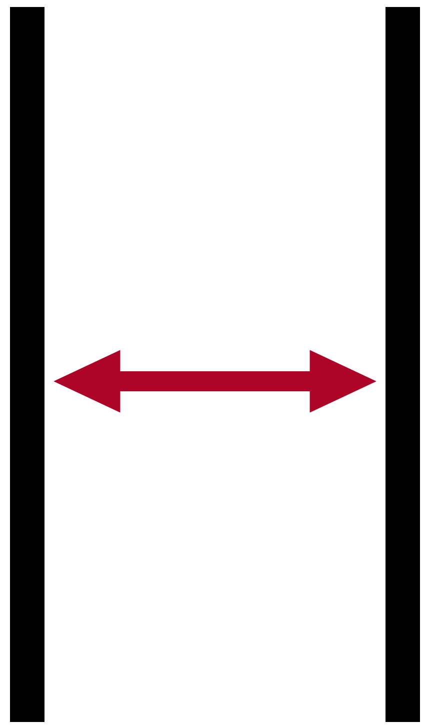

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Progress?

Outline

1. Mossbauer Effect

2. Setup

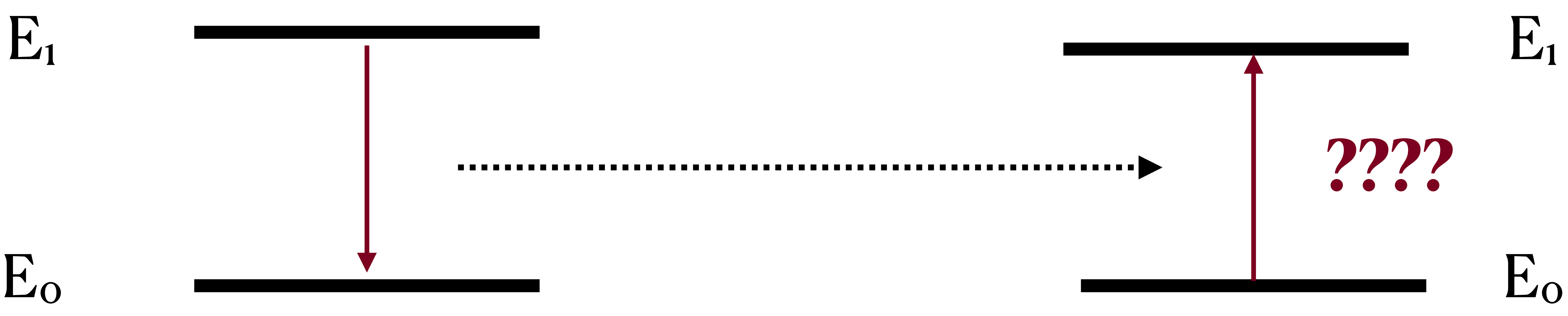
3. Backgrounds

4. Sensitivity

5. Synchrotron Light Sources?

6. Conclusions

Mossbauer Effect



Excited nuclear state decays via γ emission

Can the γ be reabsorbed?

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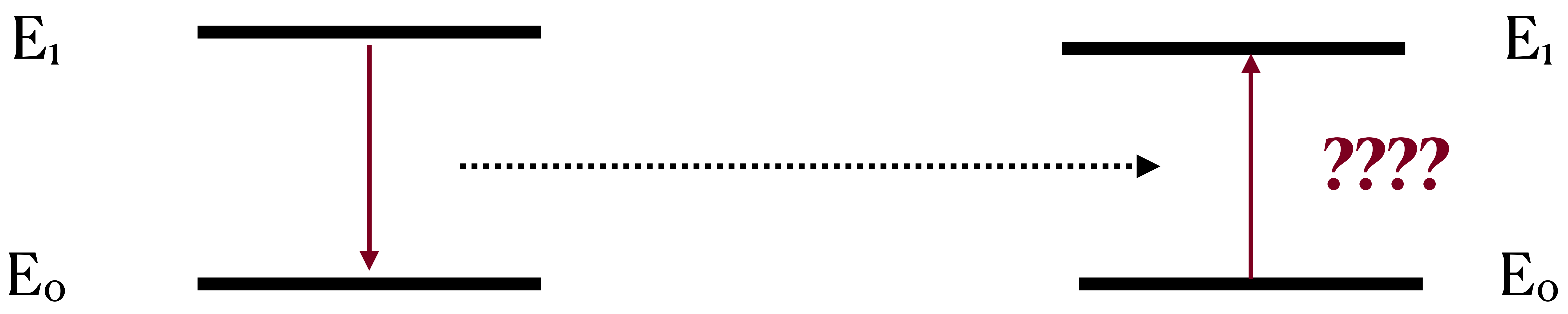

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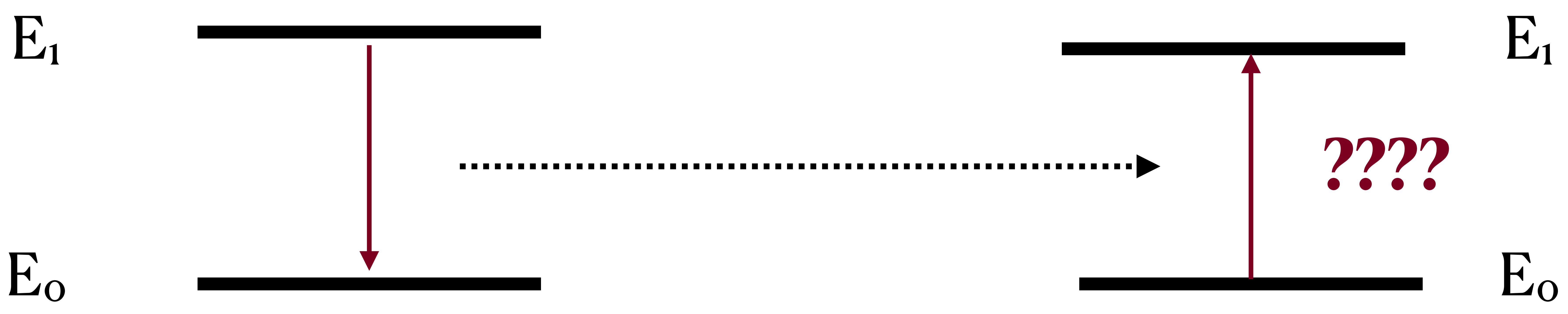

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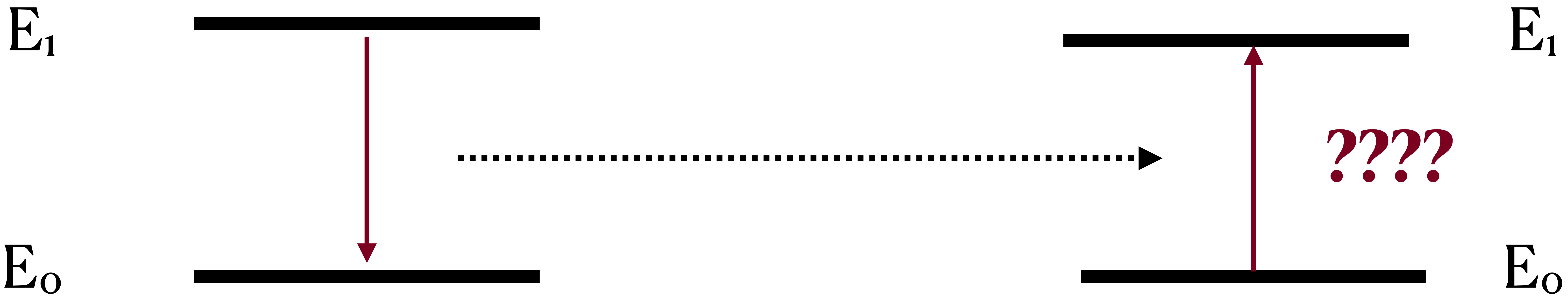
No : Recoiling nucleus takes energy, γ outside narrow width

Mossbauer Effect



Small enough E_γ, entire lattice recoils!
Negligible lattice kinetic energy - monochromatic E_γ

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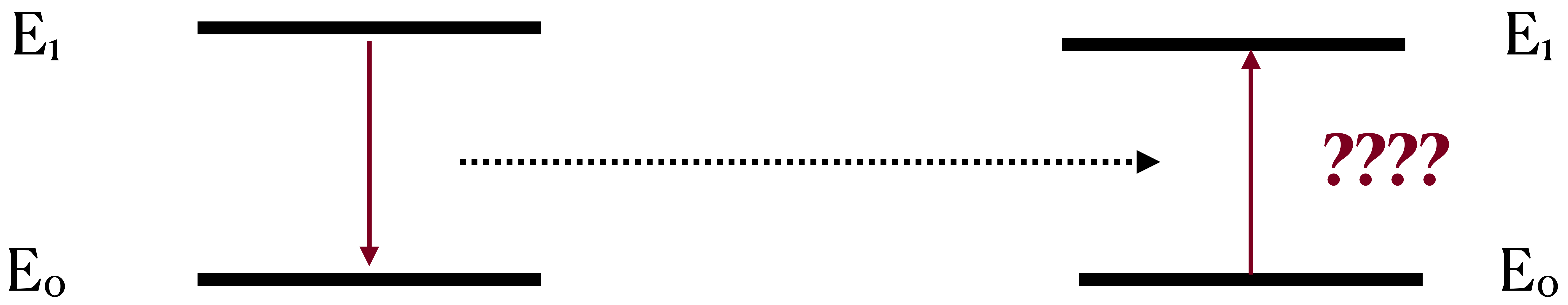

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Narrow Nuclear Lines => High Sensitivity to energy shifts

Setup

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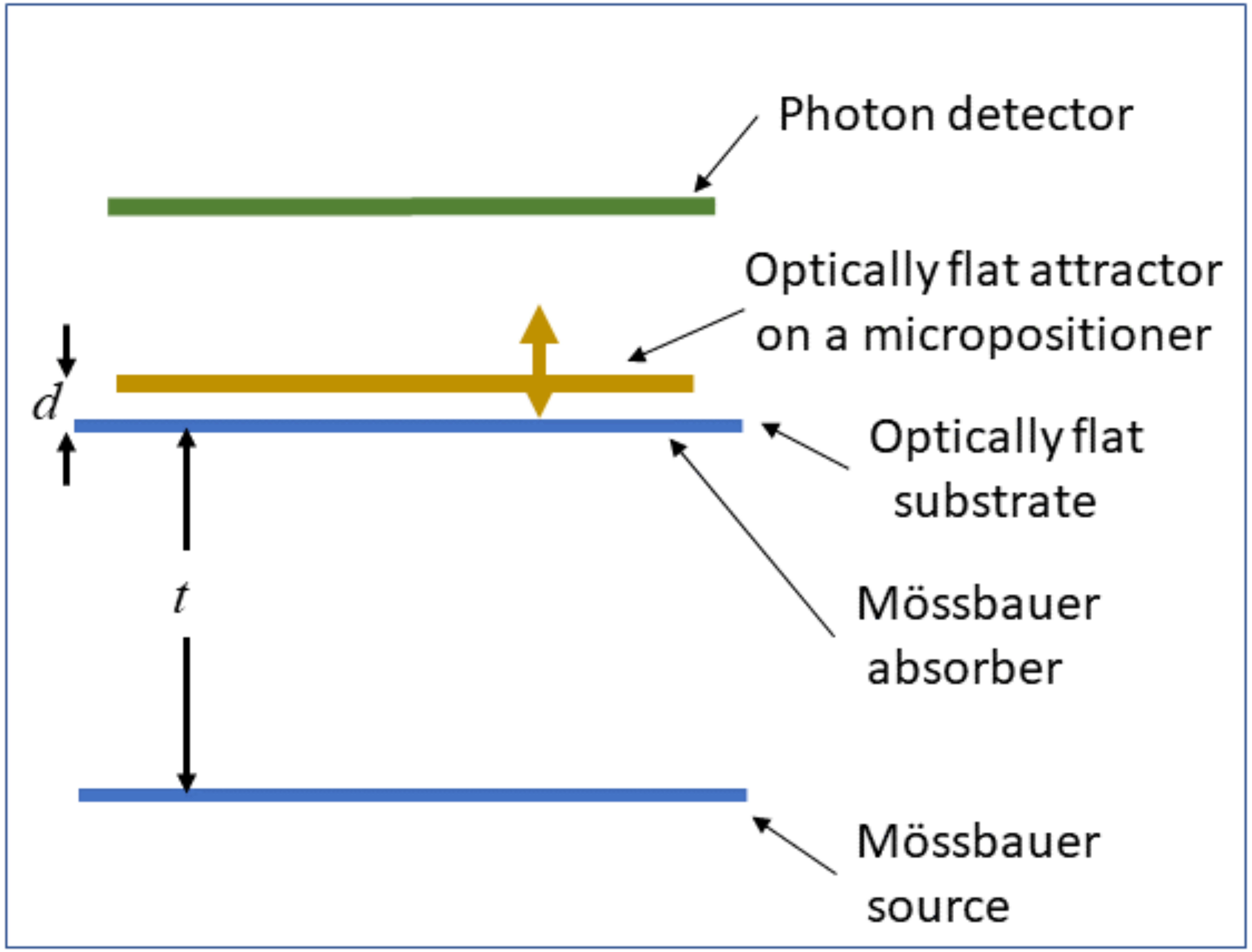
New interaction shifts nuclear energy



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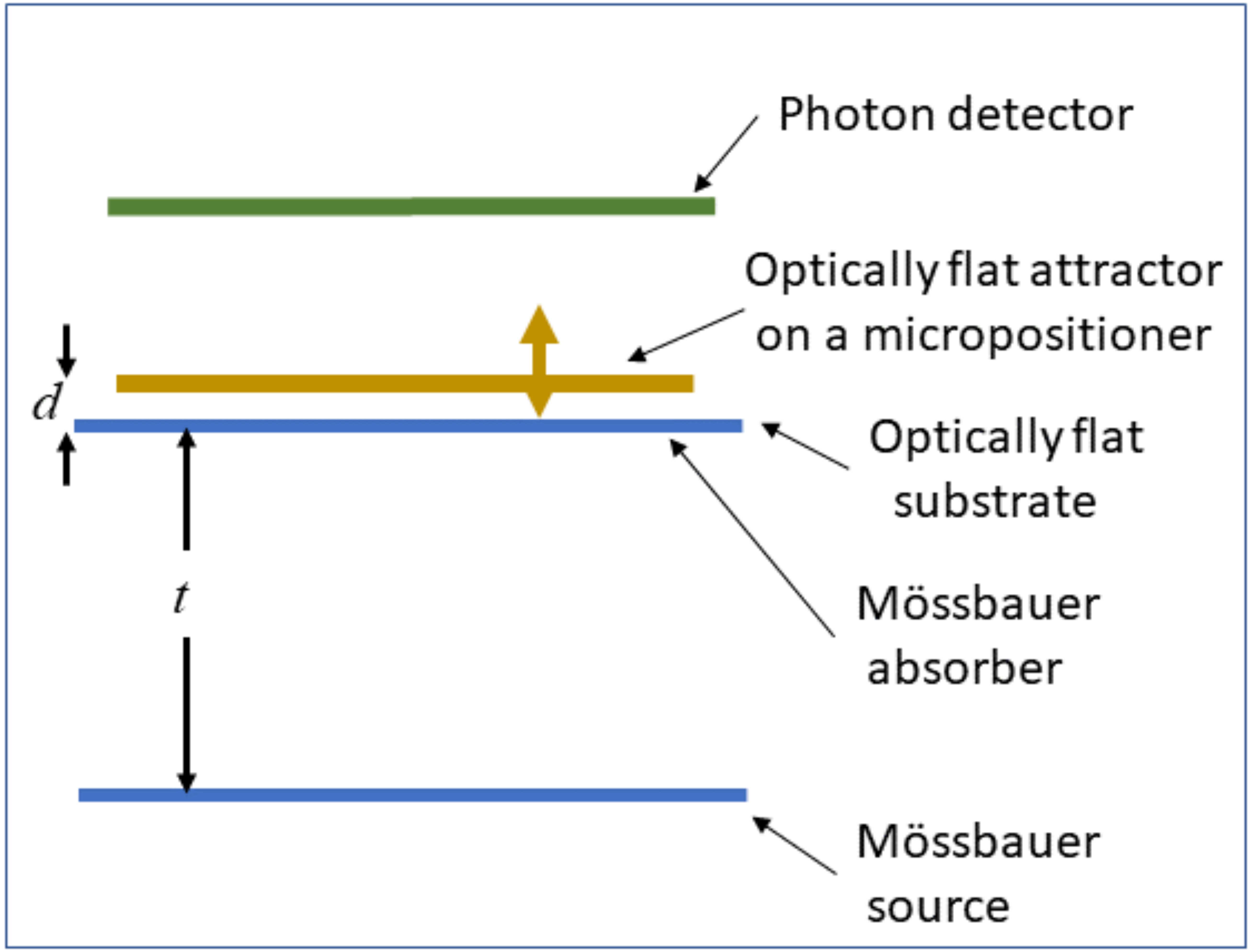

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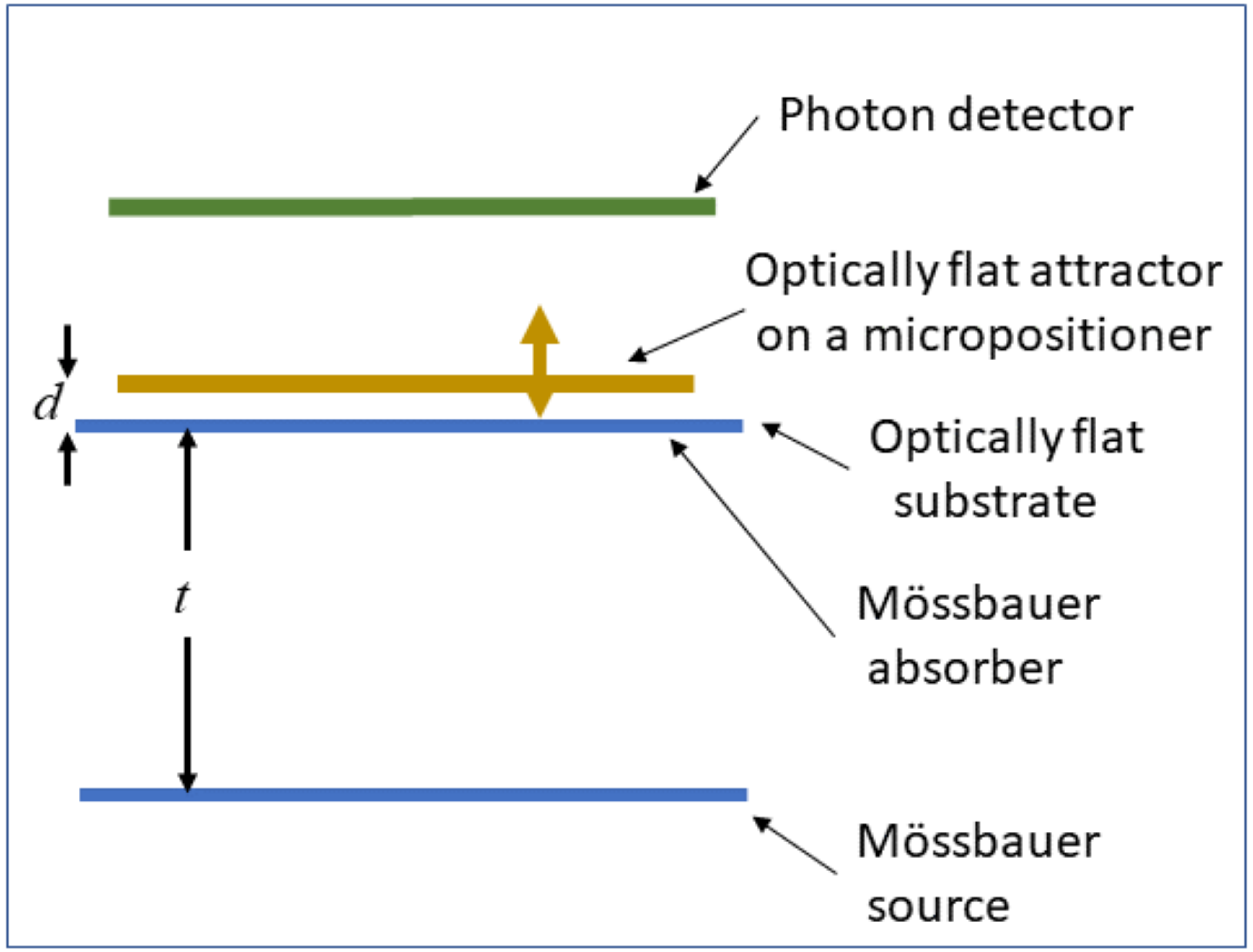
Electromagnetism?

Needs to change nuclear transition energies

Suppressed by small nuclear moments, electron shielding



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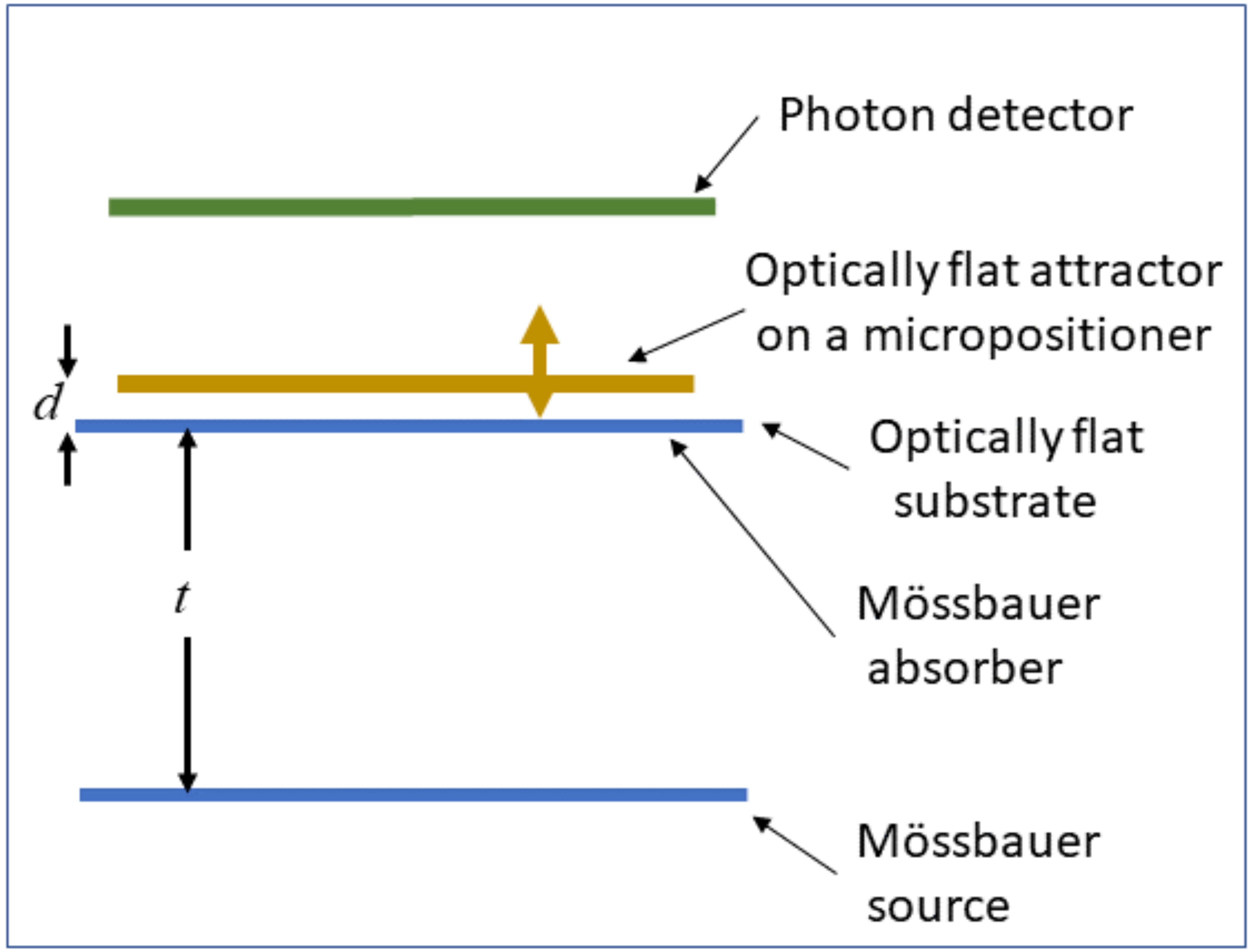

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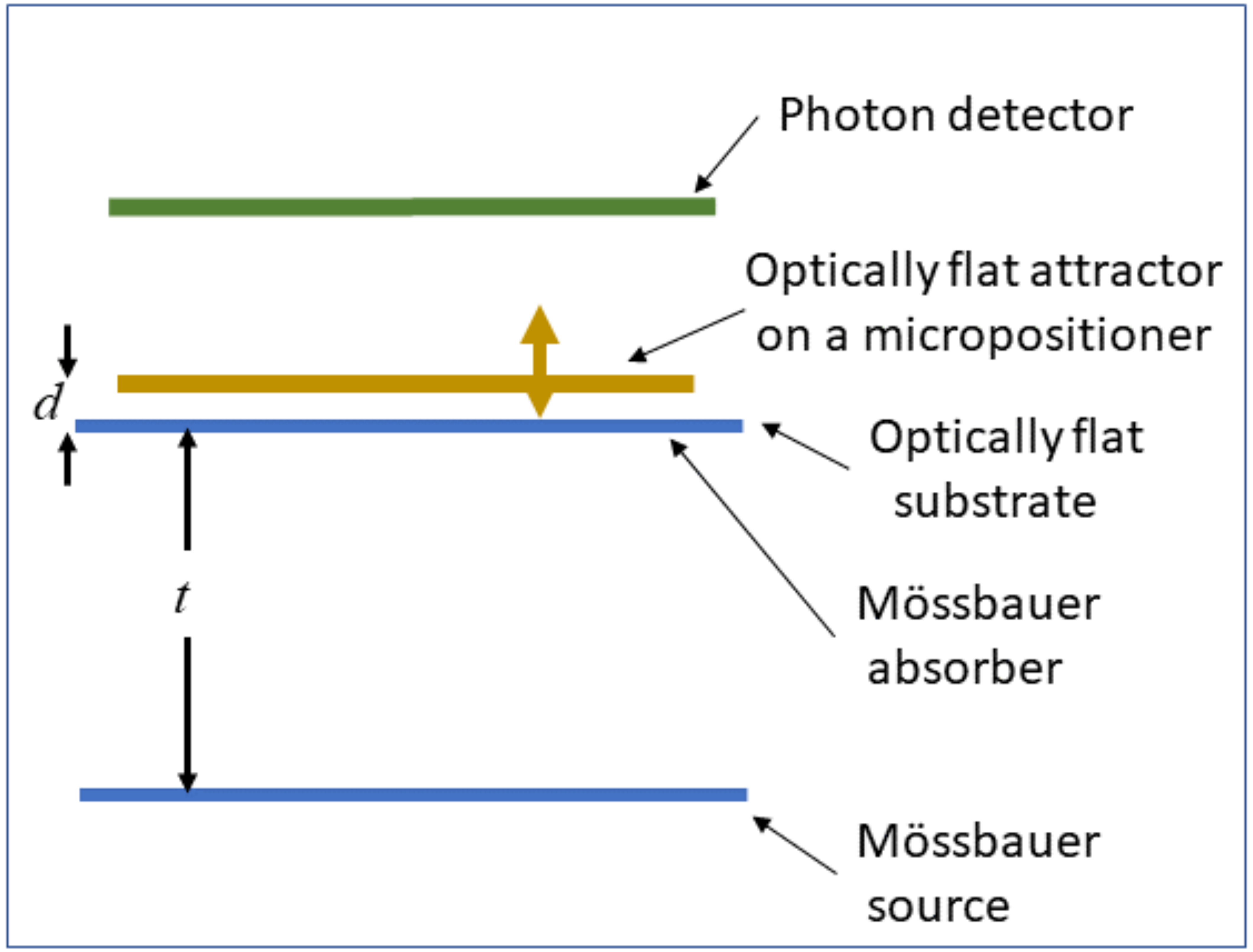

First order effects irrelevant

Leading Background: Chemical Shift from Casimir

Sensitivity

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$^{57}\mathrm{Fe}$ **ΔE = 10^{-15} eV**

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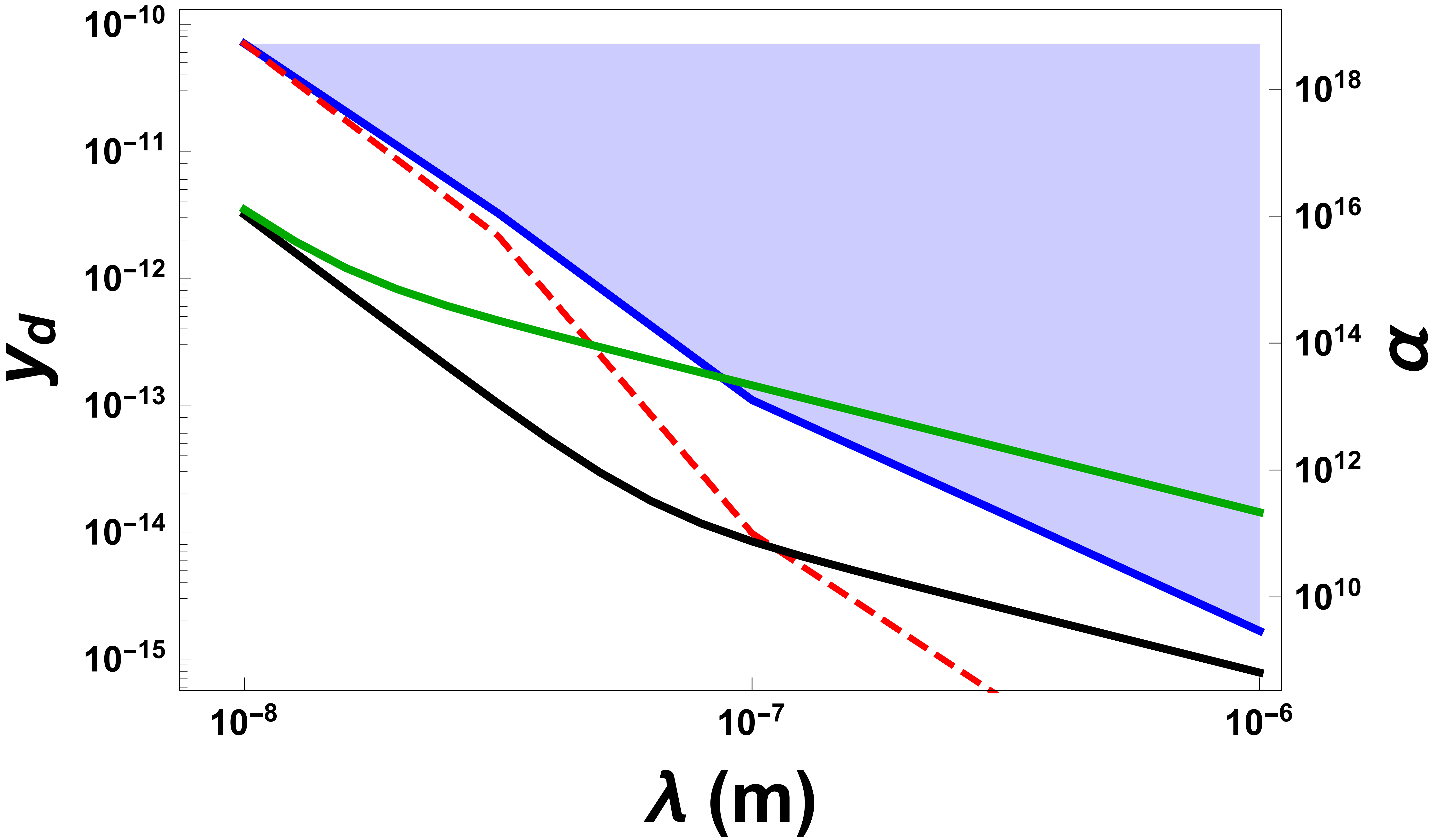
$$N_\gamma = 3 \times 10^{14}$$



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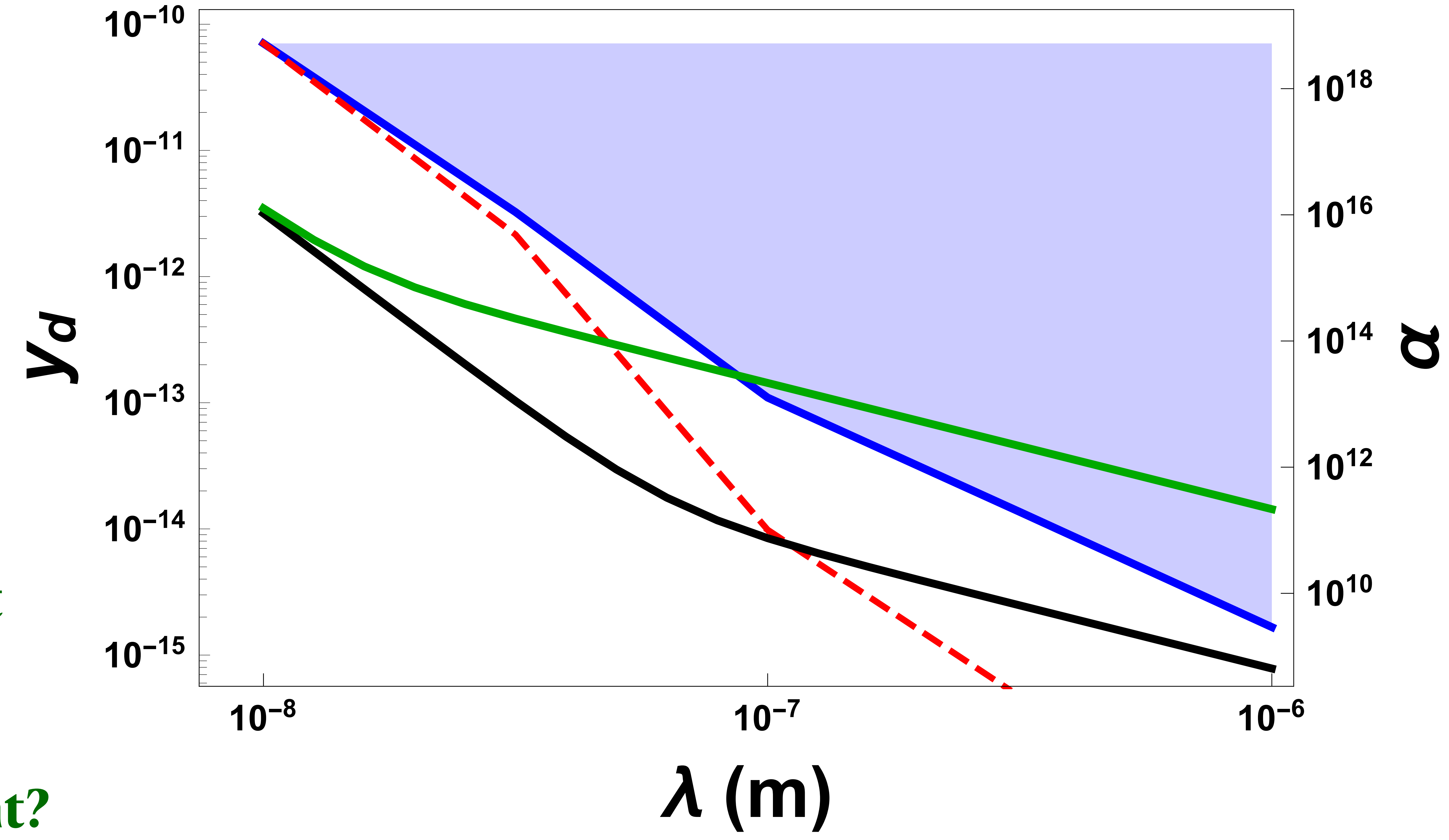
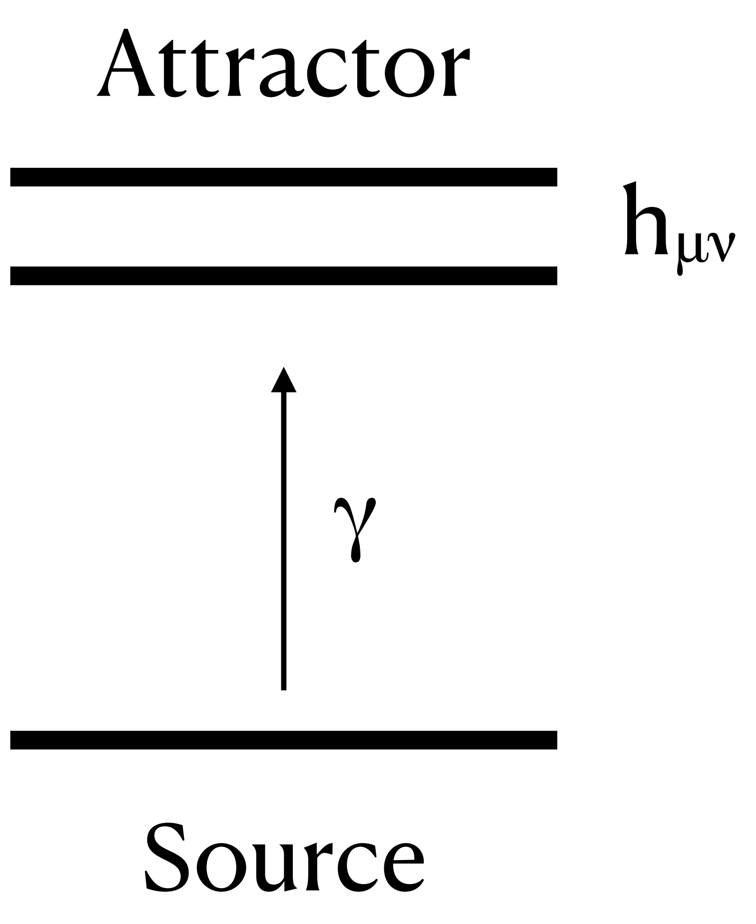
Second Order Casimir Background at shortest distances



Mitigate using differential measurement?

Sensitivity

$$\mathcal{L} \supset \frac{\tilde{h}_{\mu\nu}}{f_T} F^{\mu}{}_{\sigma} F^{\nu\sigma}$$



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Electromagnetic Contribution to the Mass of a nucleus of charge Z - assuming this is a uniform ball of charge Z

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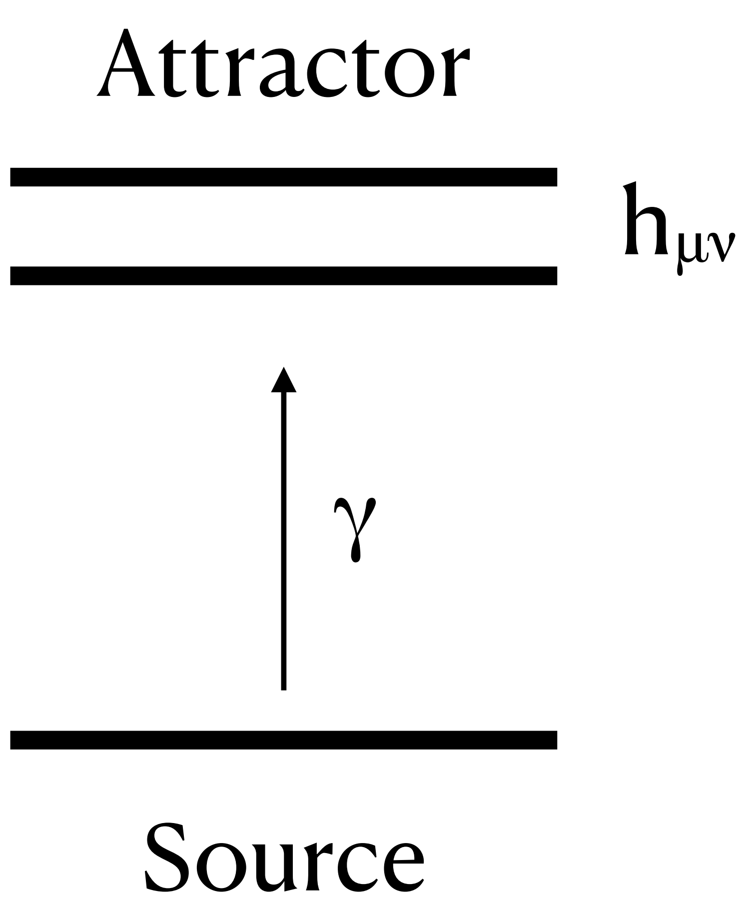

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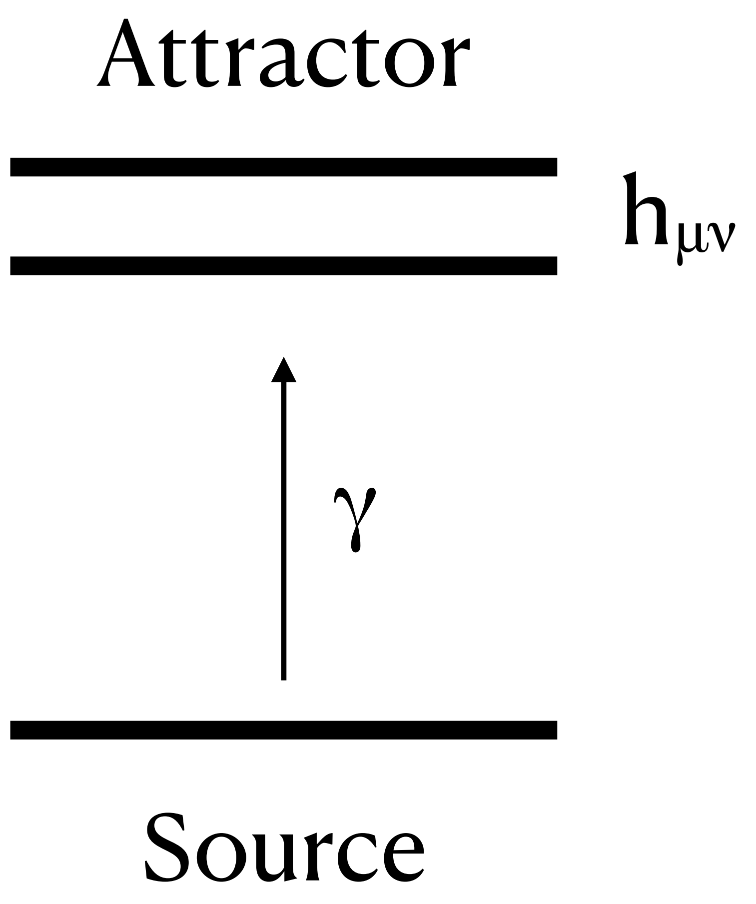

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From this, find the effective contribution per proton/nucleon

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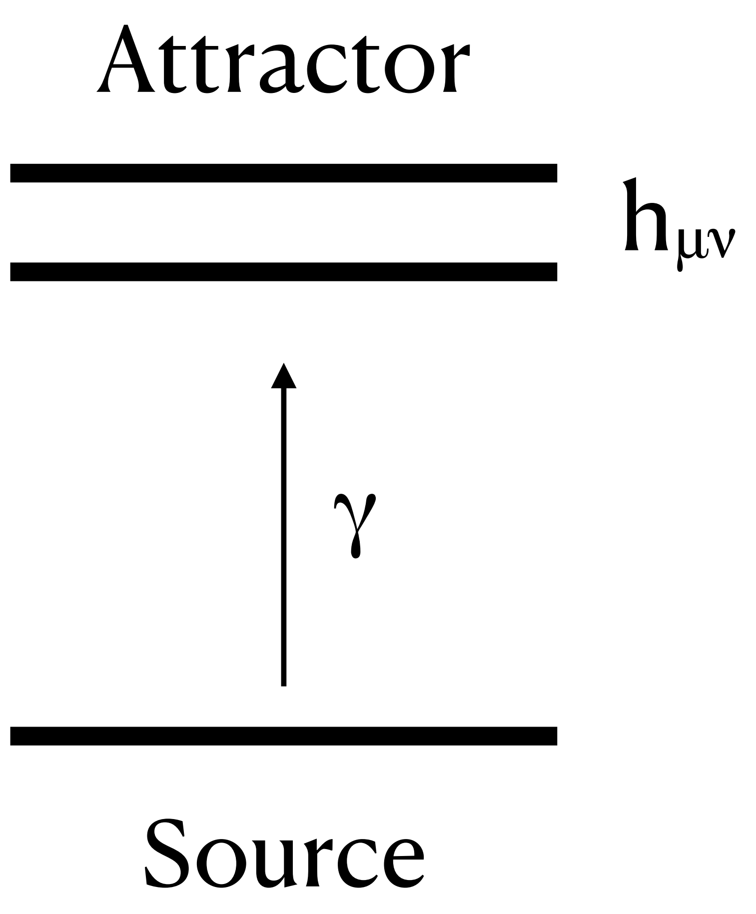

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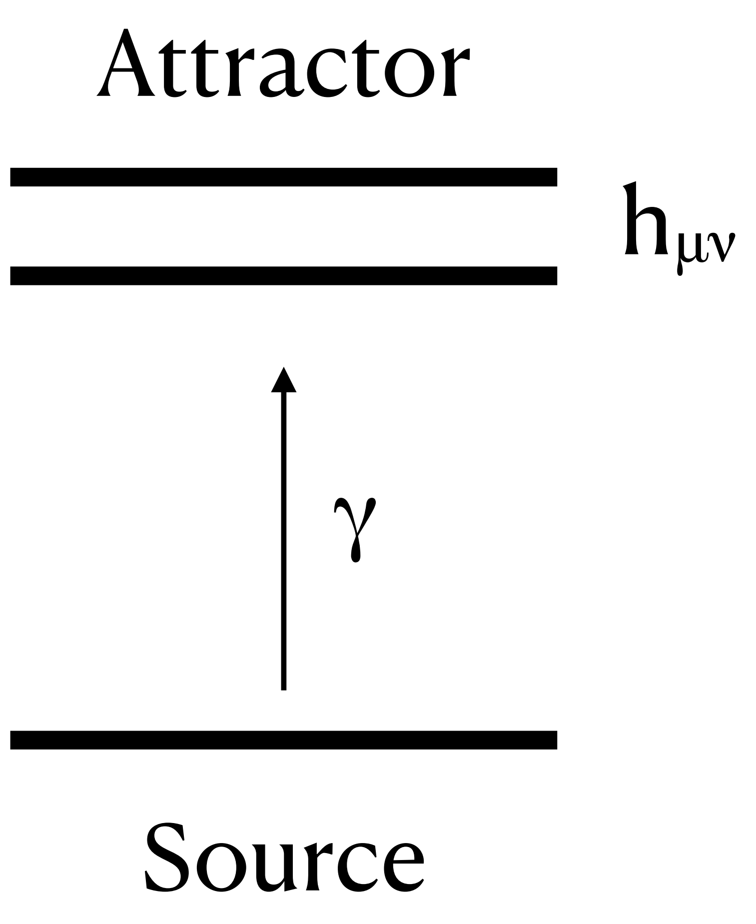

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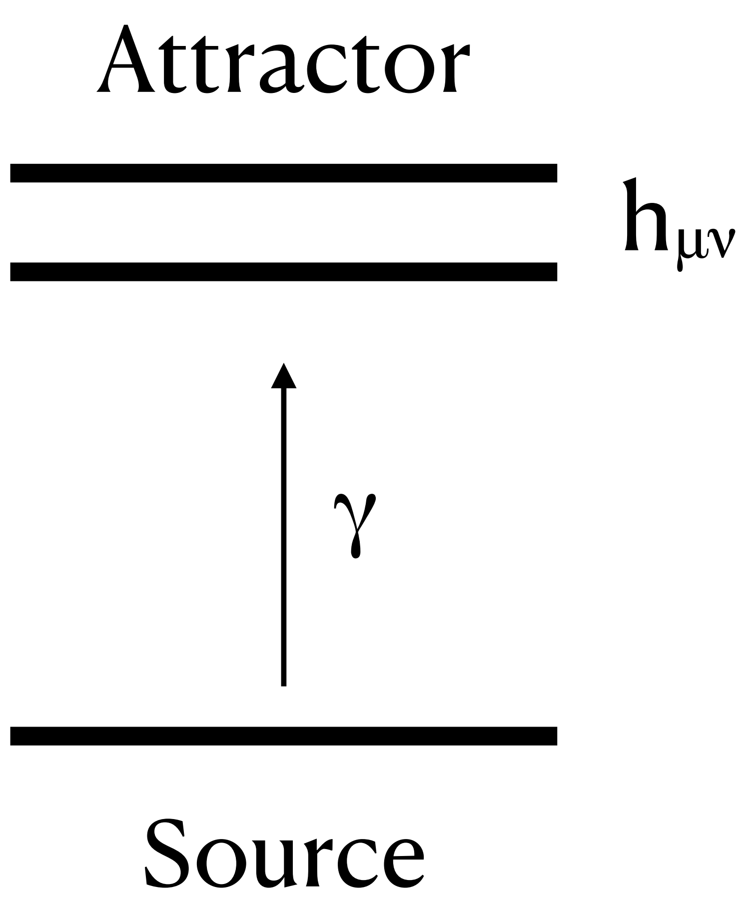

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Frequency Shift

$$\delta\omega = \omega \frac{h}{f_T}$$

Sensitivity

$$\delta\omega = \delta E$$

$$\implies f_T = \frac{1}{3}\frac{\sqrt{n_0}Z\sqrt{\alpha}\lambda\sqrt{\omega}}{A^{\frac{2}{3}}\sqrt{r_p}\sqrt{\delta E}}$$

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Numbers - take Gold attractor

$$n_0 = \frac{10 \times 10^{24}}{\mathrm{cm}^3} \quad Z = 79,\ A = 197$$

$$\alpha = \frac{1}{137},\ r_p = 1\,\mathrm{fm} \quad \lambda = 10^{-7}\ \mathrm{m}, \delta E = 10^{-15}\ \mathrm{eV}$$

$$\implies \frac{1}{f_T} \sim \frac{2 \times 10^{-9}}{\mathrm{GeV}}$$

Sensitivity

Conversion to the alpha - lambda plot

$$g = \frac{m_p^{em}}{f_T}$$

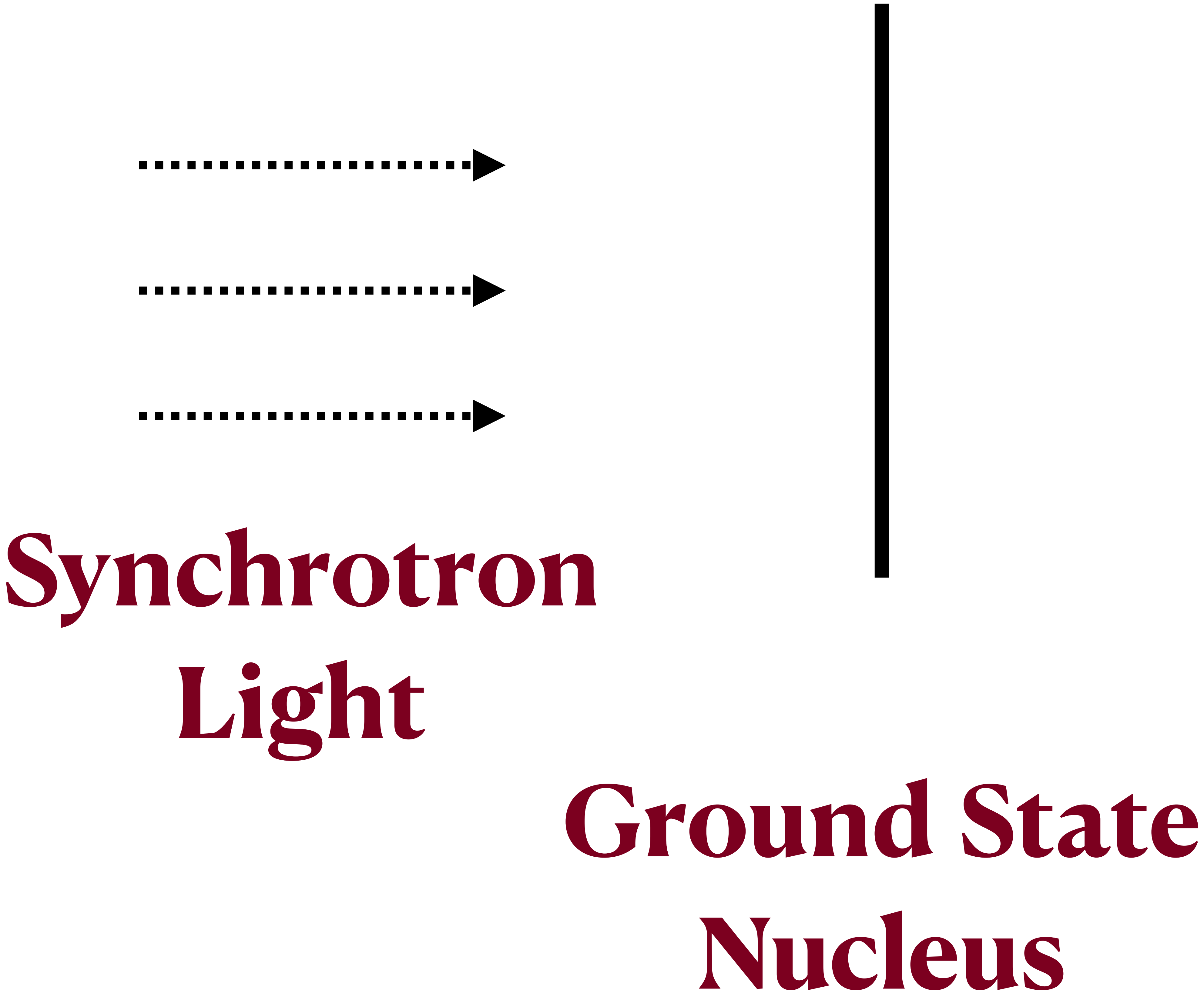
$$F_\lambda = \frac{\text{GeV}}{g}$$

$$\alpha_\lambda = \frac{\left(1.2 \times 10^{19}\ \text{GeV}\right)^2}{4\pi F_\lambda^2}$$

Plugging in with the values for Gold and f_T we found in the previous slide, we get

$$\alpha_\lambda \sim 2 \times 10^{15} \text{ at } 100 \text{ nm}$$

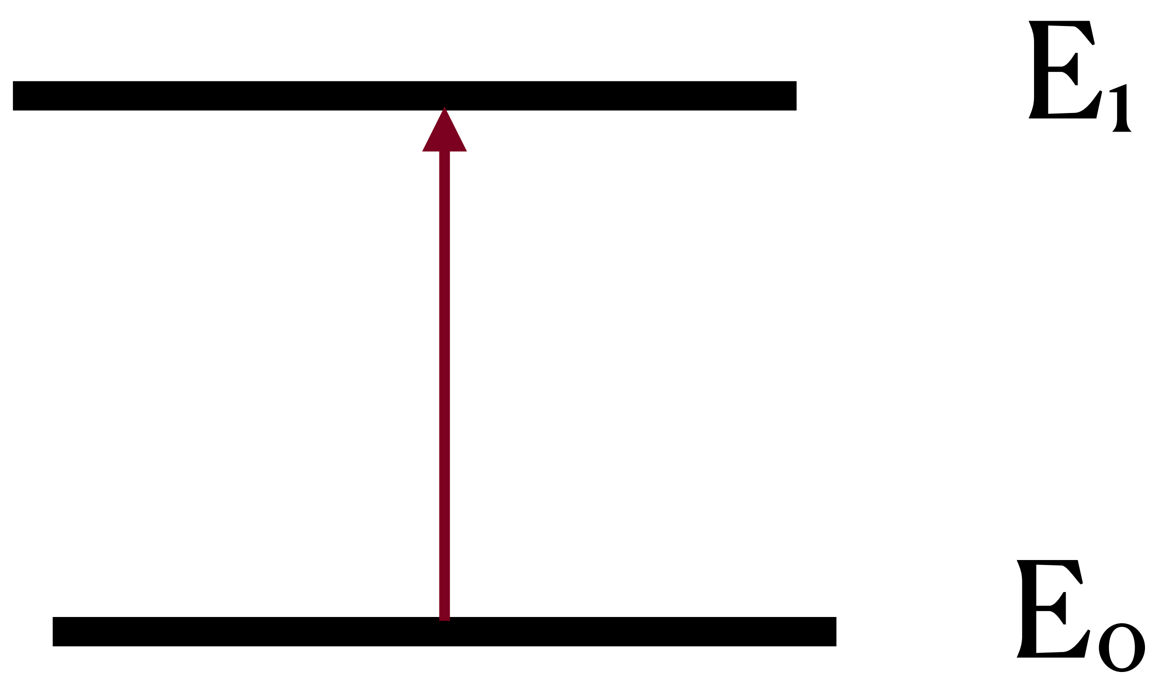
Mossbauer at Synchrotron Source



Mossbauer at Synchrotron Source

Synchrotron Light

Ground State Nucleus



All the nuclei are coherently driven to excited state

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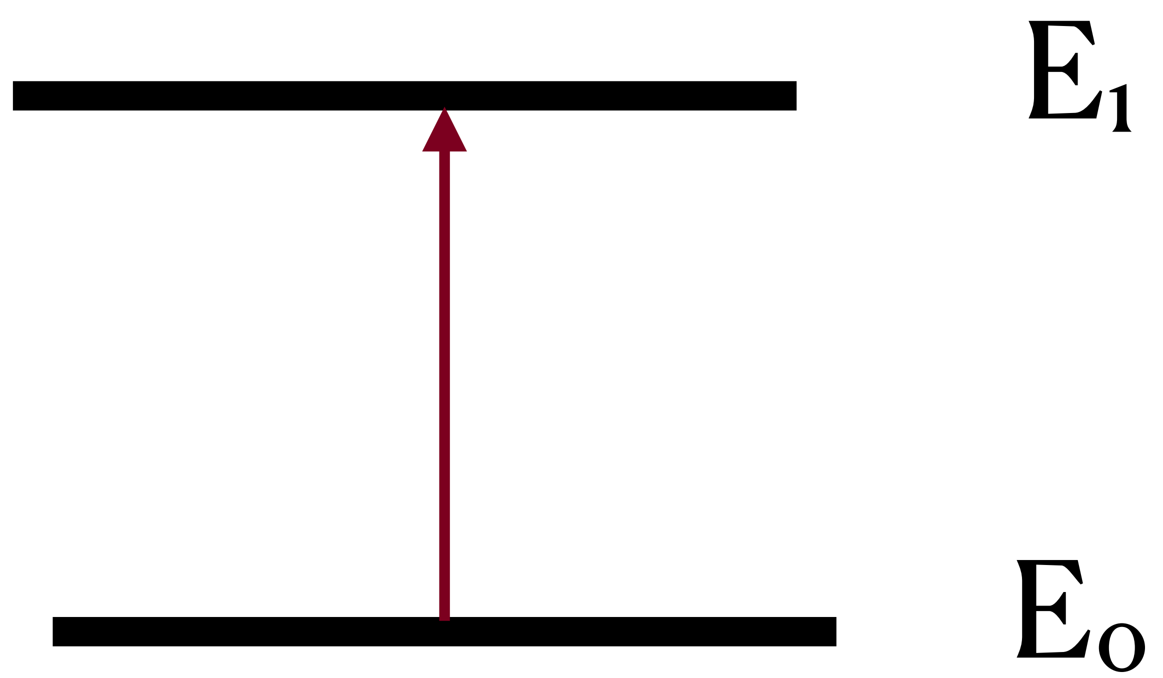

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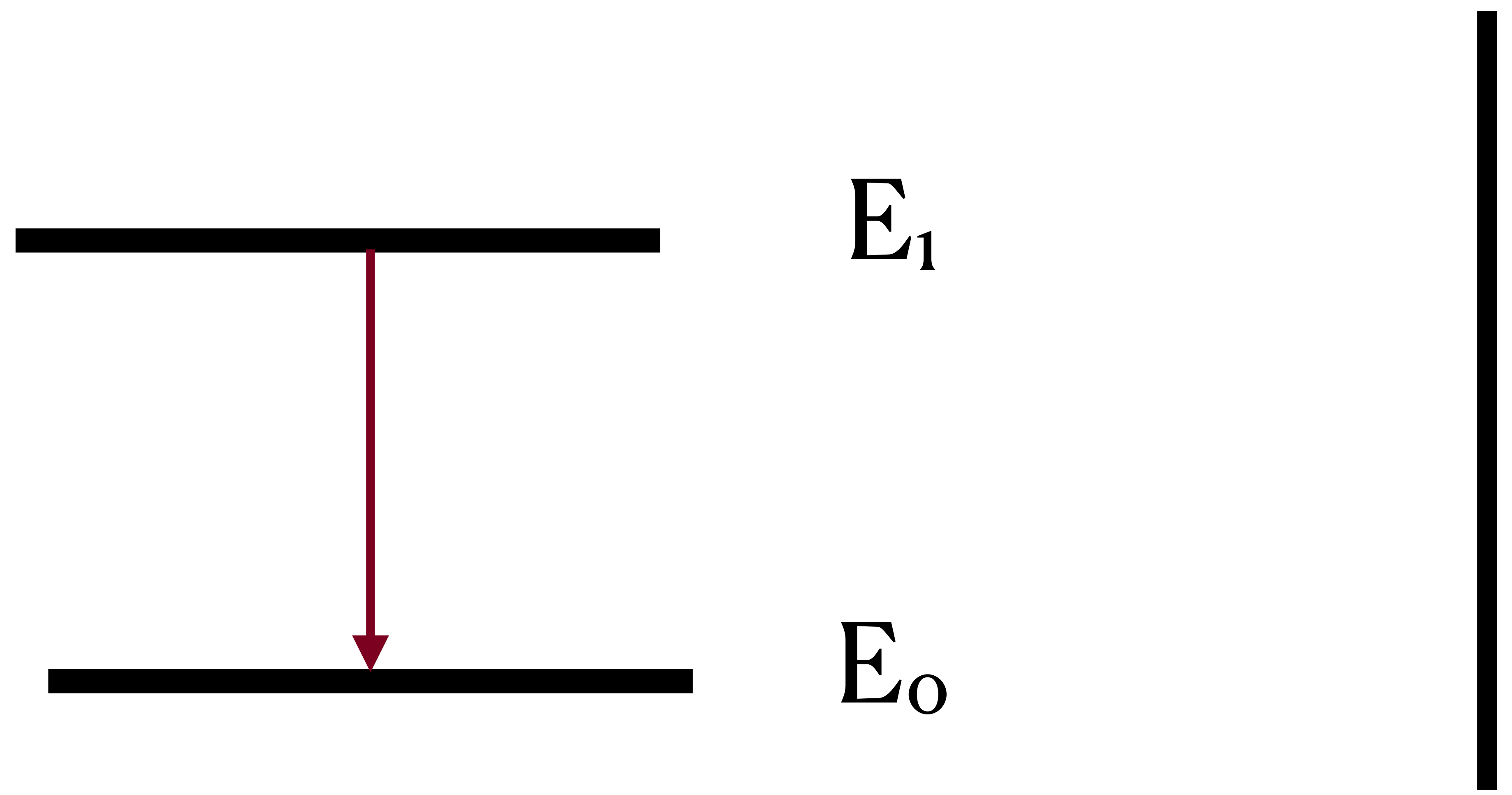
Short Pulse << Lifetime of State

Mossbauer at Synchrotron Source

Well after pulse, state starts to decay
Coherent initial excitation => decays in phase

Decay along forward direction amplified by in phase addition



In phase decay

Excited State

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Send Synchrotron Pulse

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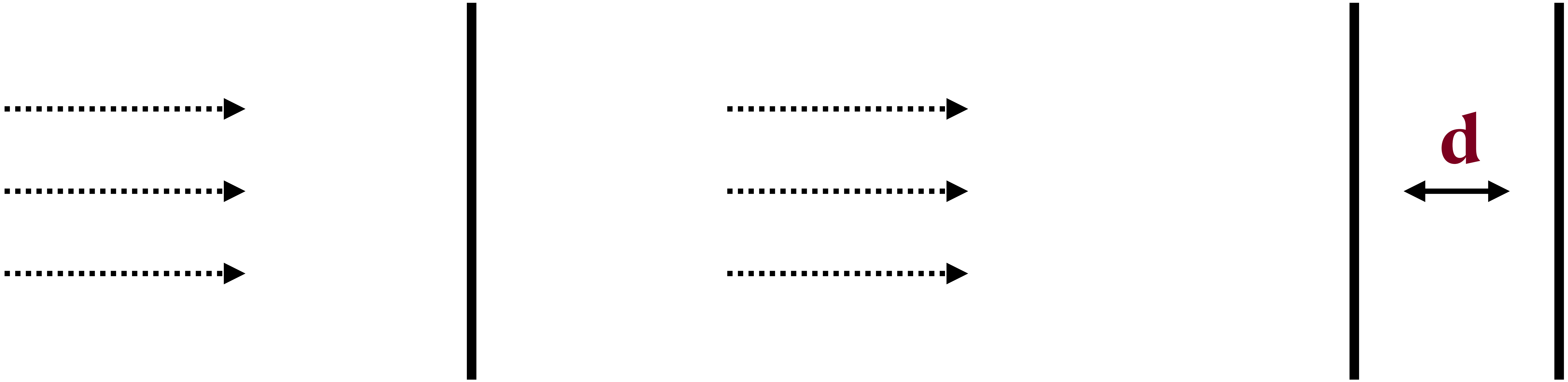

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Well after pulse, collimated emission

Measure resonant reabsorption as a function of d

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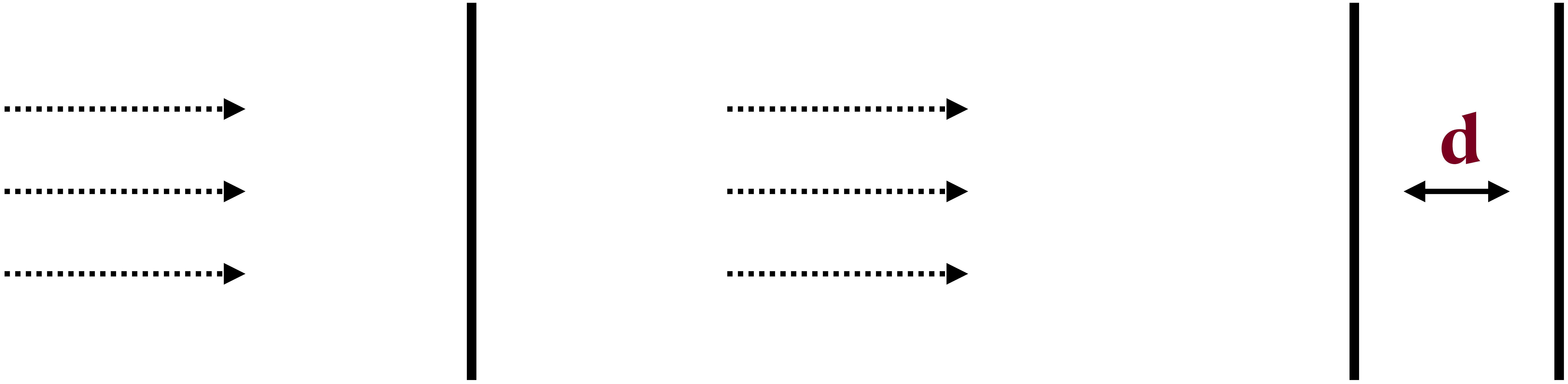

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Why?

Clean excitation unlike radioactive decay

May enable new class of ultra narrow Mossbauer

Conclusions

1. Mossbauer Effect seems well suited to probe short distance forces

2. Natural electromagnetic background suppression

3. Ideal for scalar and tensor forces

4. Synchrotron light sources may enable new Mossbauer sources