Electron Trap as a meV Axion and Dark-Photon Dark Matter Detector

Yawen Xiao

May 13, 2024

Pheno 2024

2208.06519 & 2405.xxxxx: Xing Fan, Gerald Gabrielse, Peter W. Graham, Roni Harnik, Thomas G. Myers, Harikrishnan Ramani, Benedict A. D. Sukra, Samuel S. Y. Wong, and Yawen Xiao

Stanford

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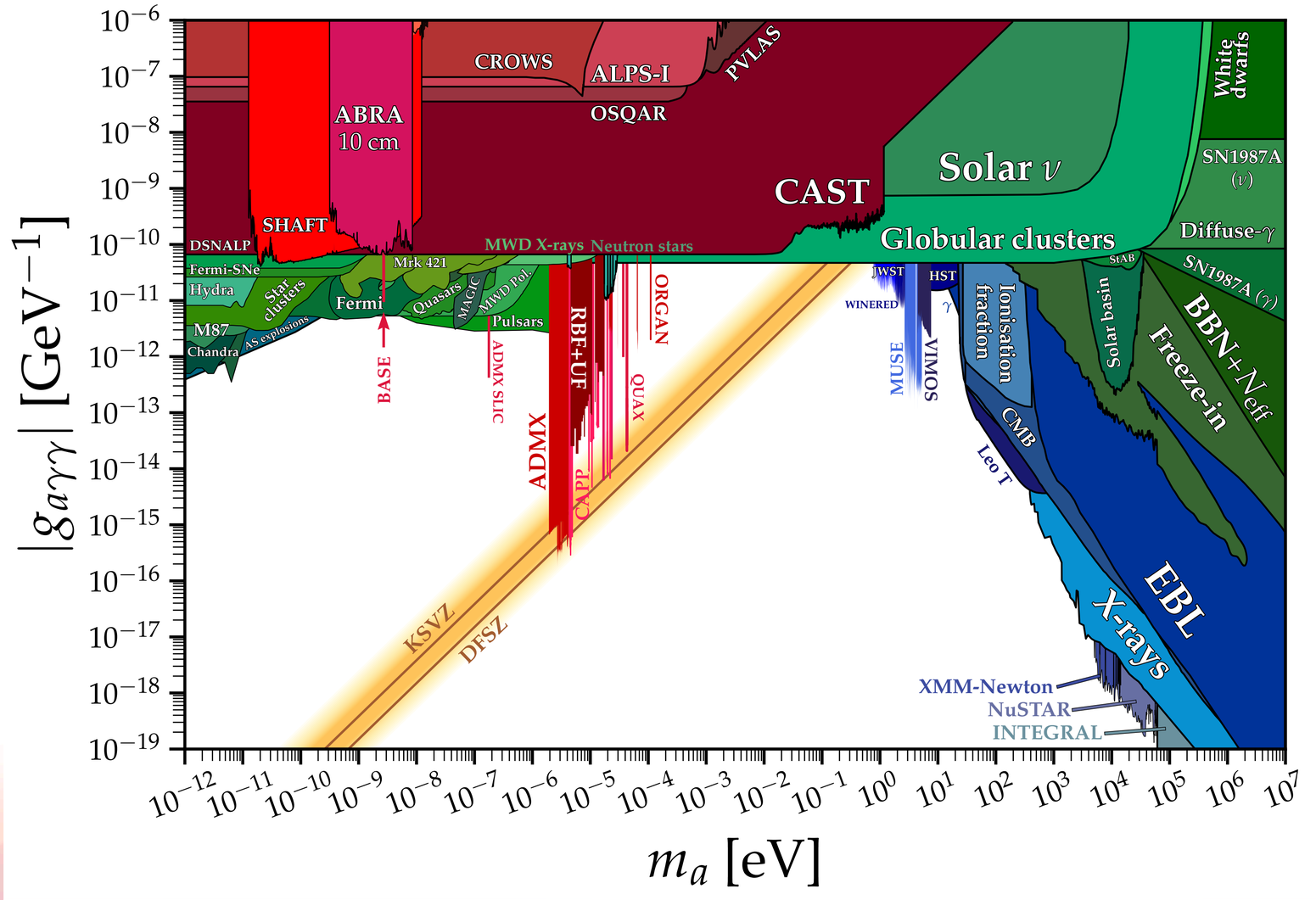
Axions

$$\mathcal{L} \supset -\frac{g_{a\gamma\gamma}}{4} a F_{\mu\nu}\tilde{F}^{\mu\nu} + \frac{1}{2} m_a a^2$$
$$= g_{a\gamma\gamma} a \mathbf{E}\cdot\mathbf{B} + \frac{1}{2} m_a a^2$$

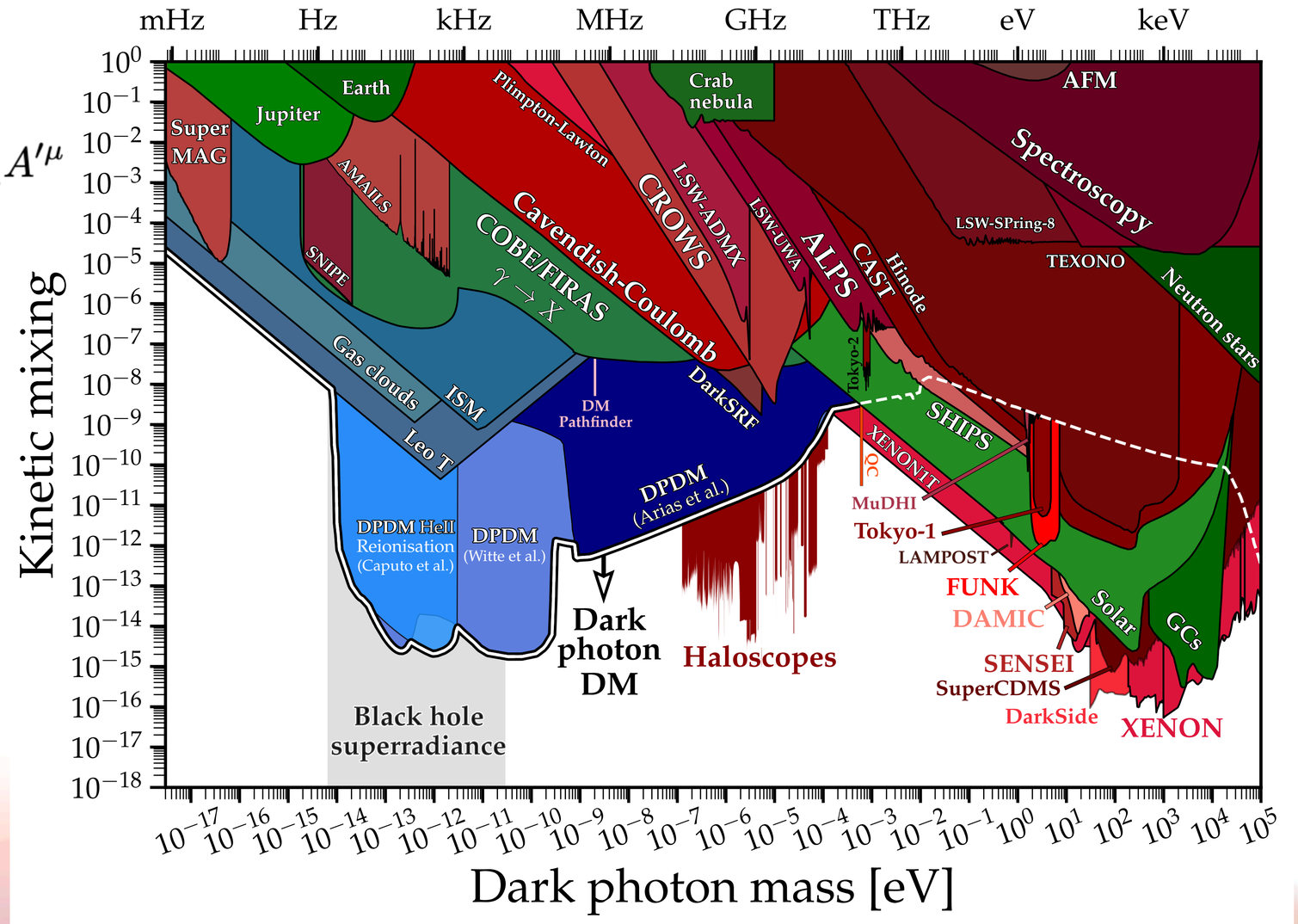
- Pseudo scalar
- Strong CP problem: QCD Axion
- Dark Matter Candidate



Dark Photon Dark Matter (DPDM)

$$\mathcal{L} \supset -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{\epsilon}{2}F^{\mu\nu}F'_{\mu\nu} + \frac{1}{2}m^2_{A'}A'_\mu A'^\mu$$

- Dark U(1)
- Massive vector



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- Dark U(1)
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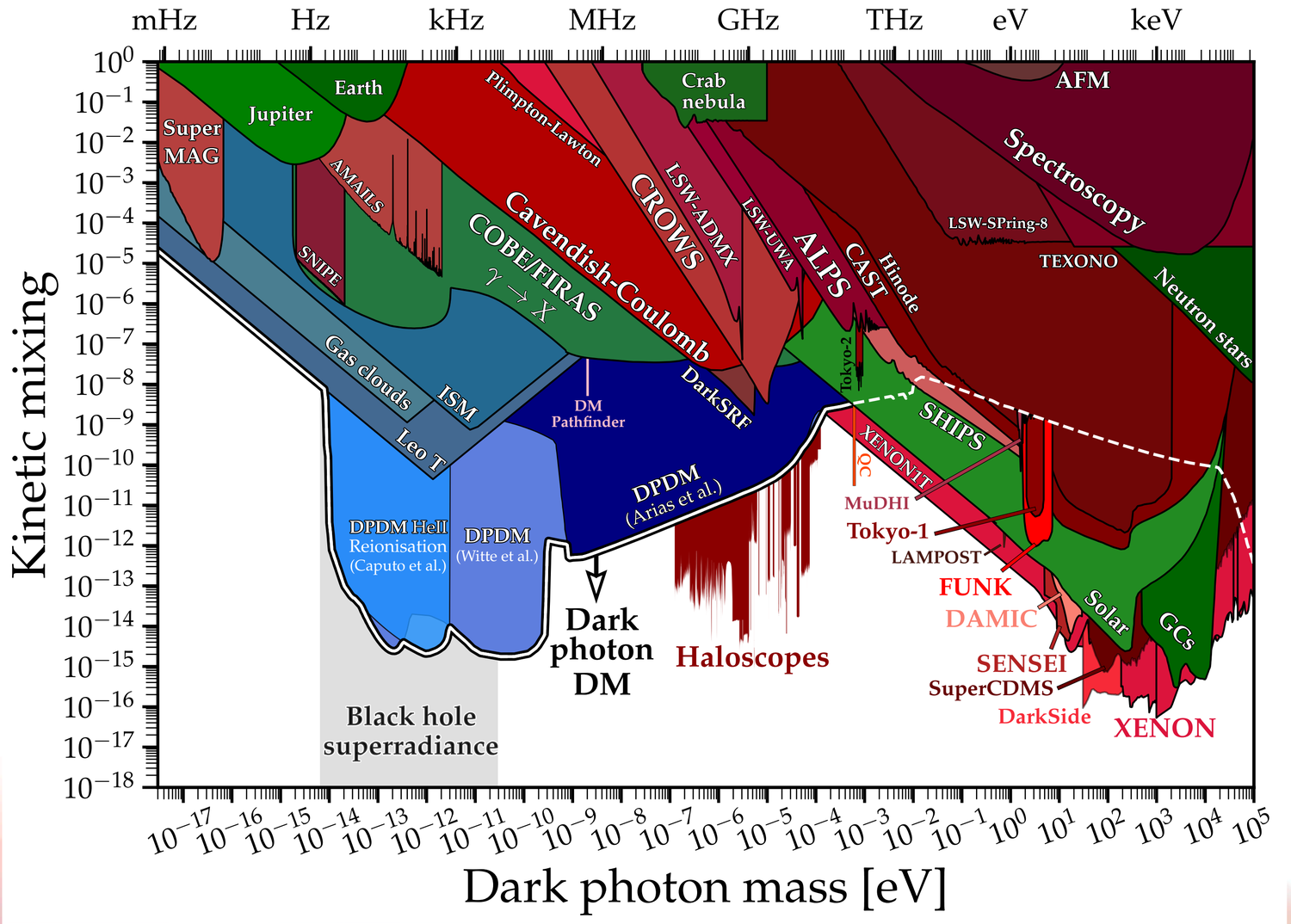
- Kinetic mixing
- Dark Photon Dark Matter



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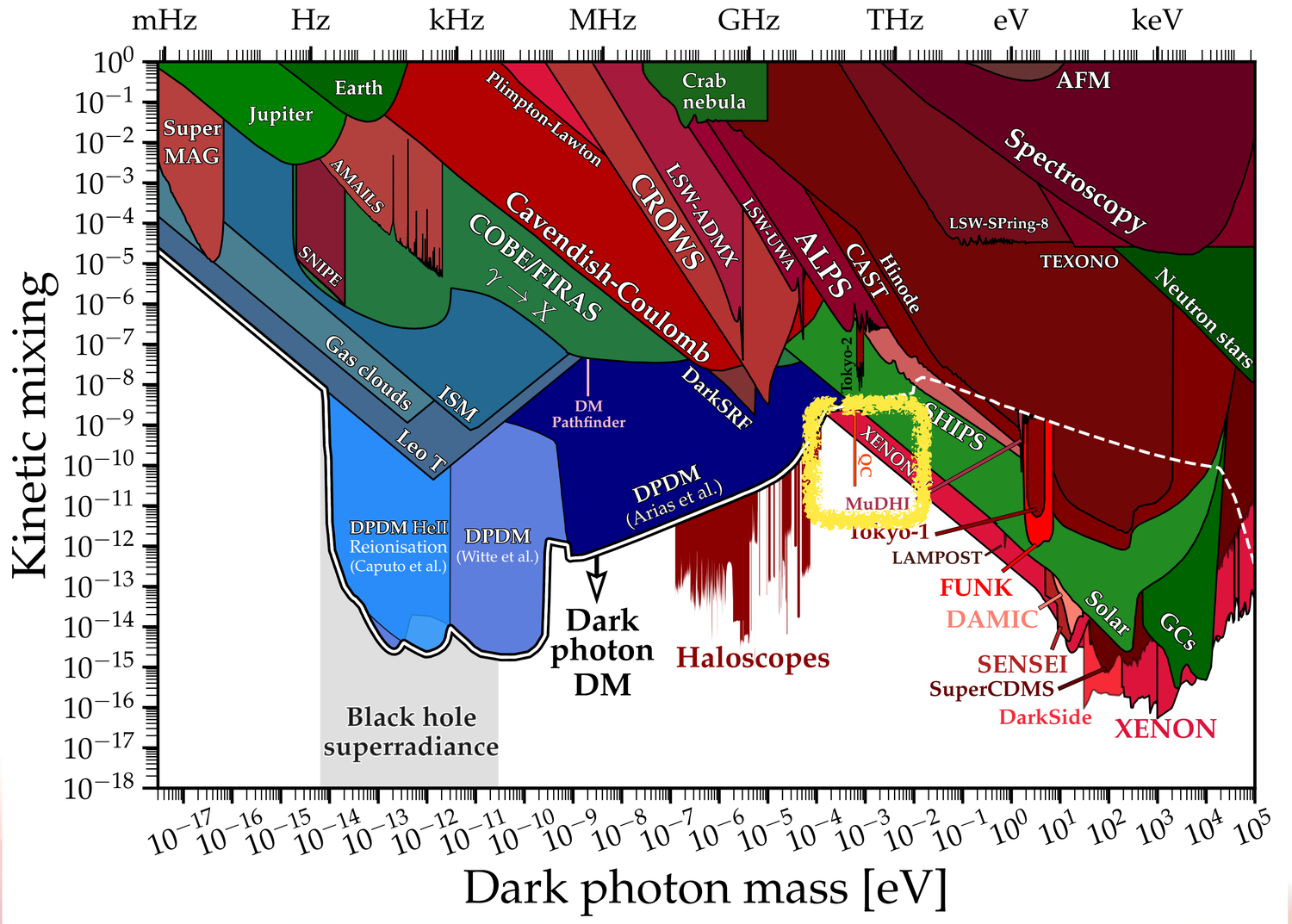

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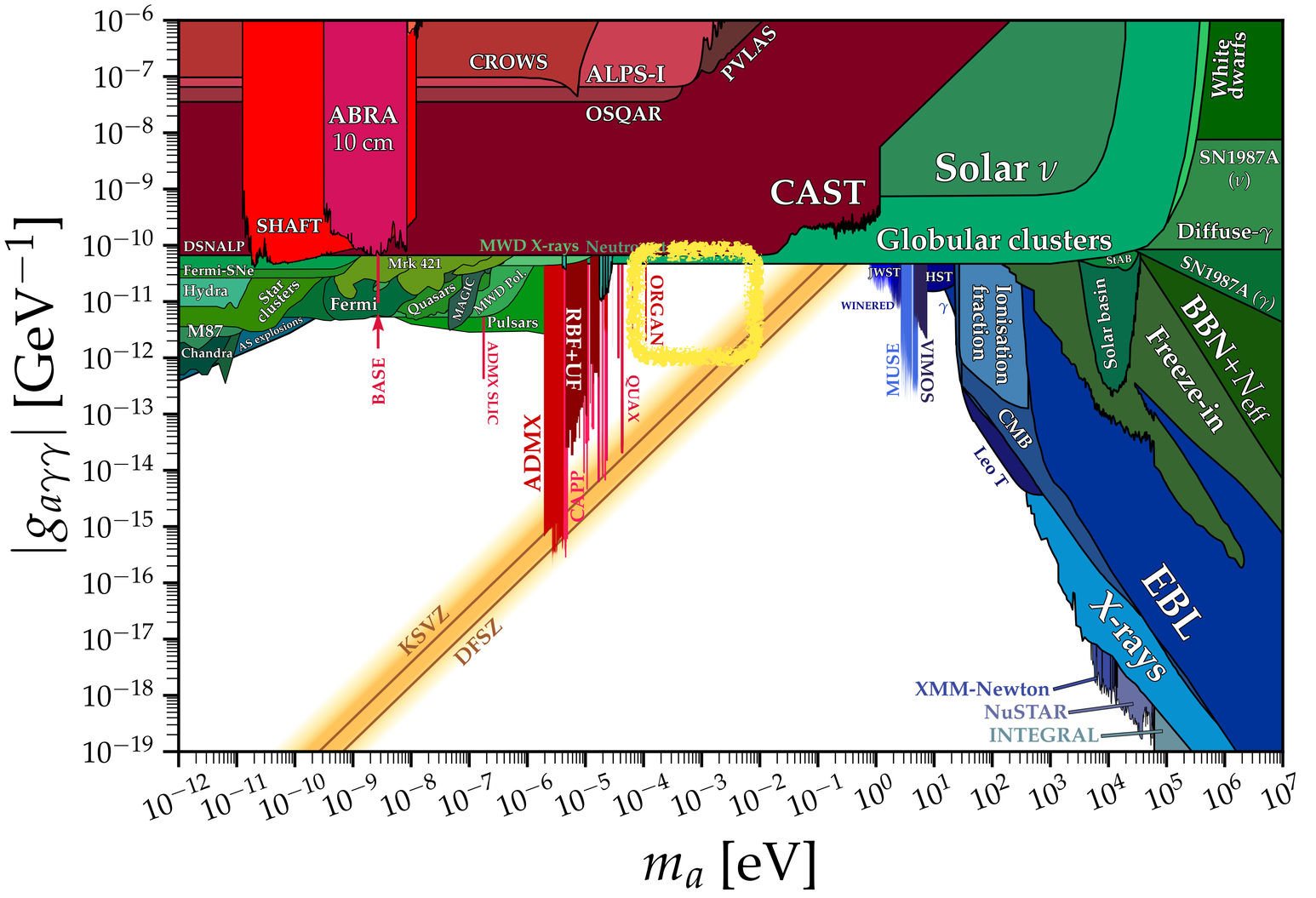
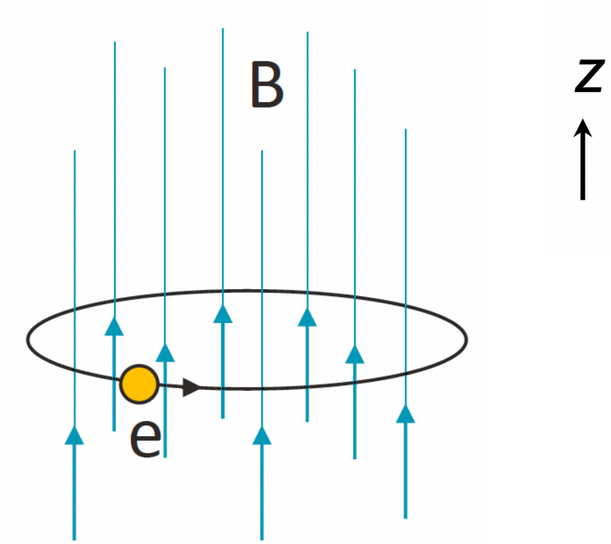
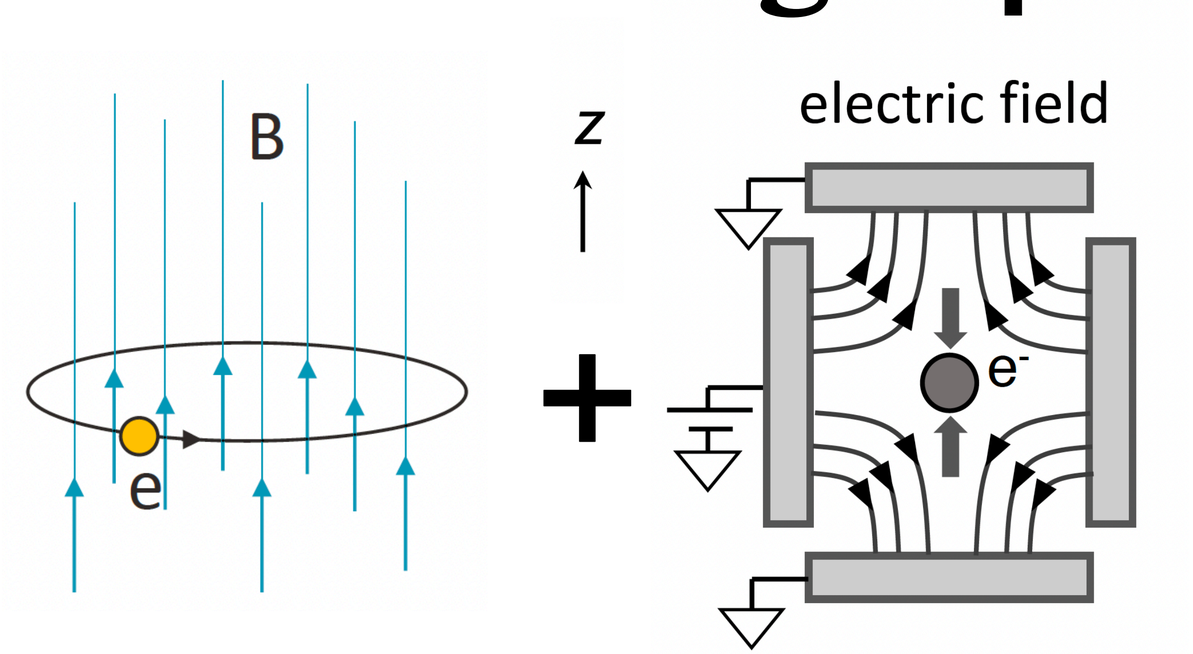


Electron Penning trap



z

Electron Penning trap



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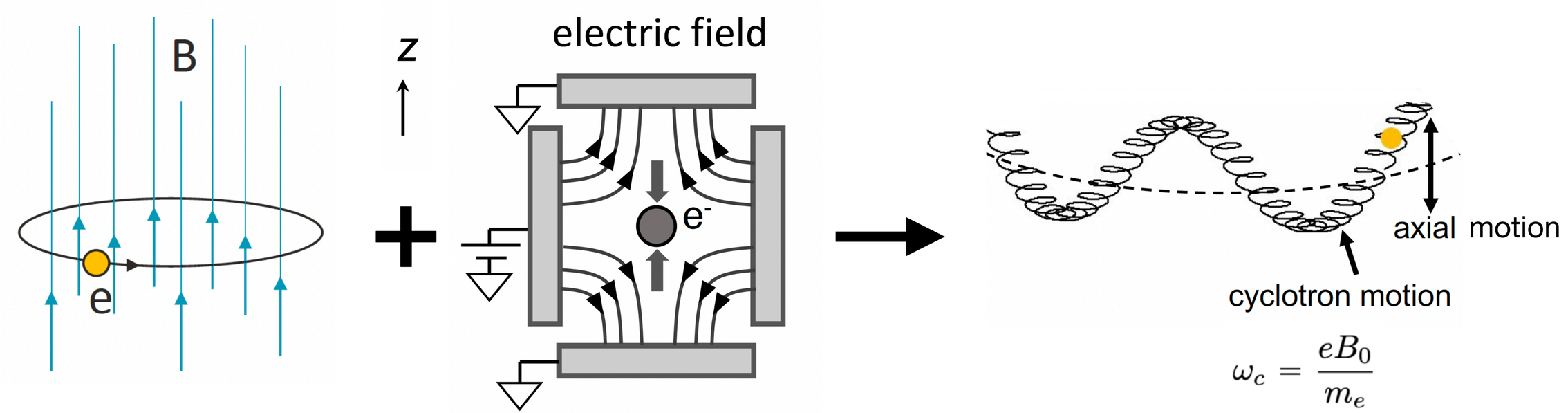
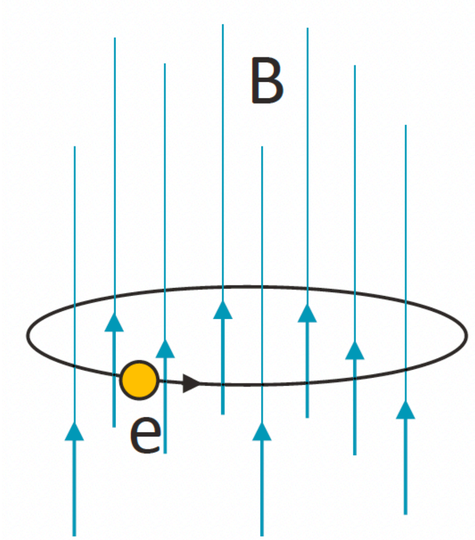
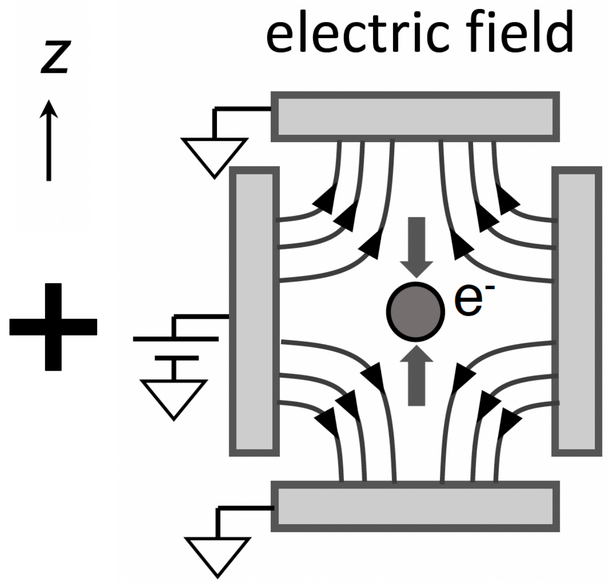
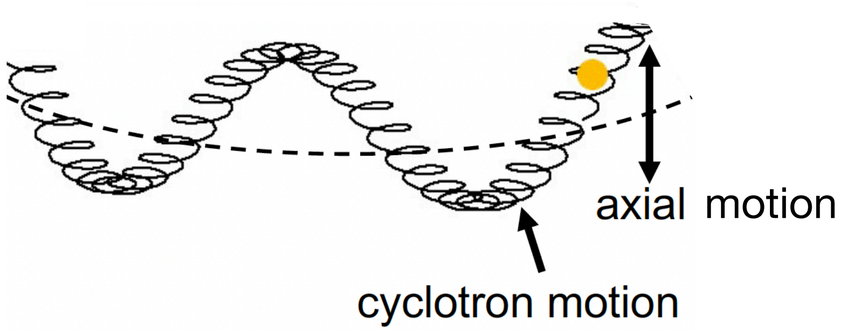


$$\omega_c = \frac{eB_0}{m_e}$$

Electron Penning trap







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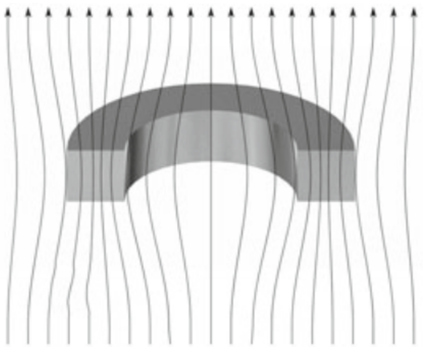
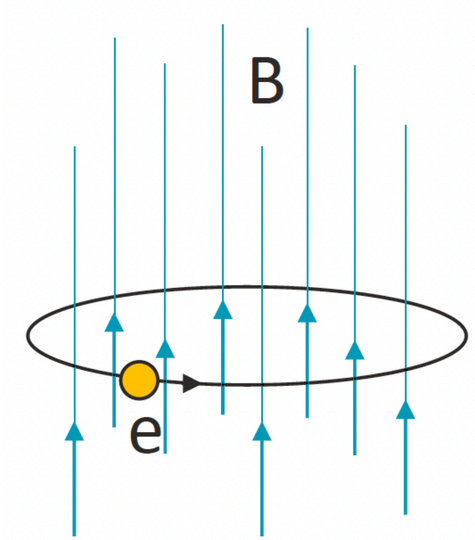
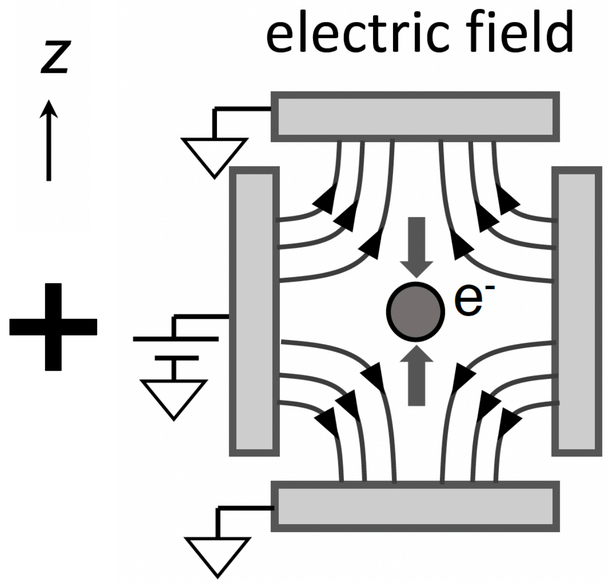


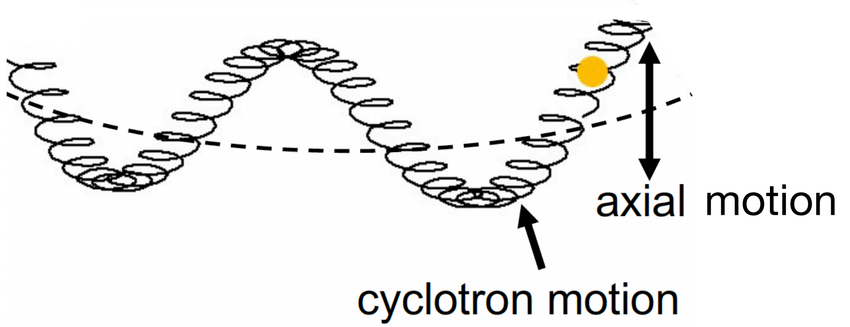
$$\Delta B \propto z^2$$

monitor the cyclotron state by quantizing axial shift

Electron Penning trap







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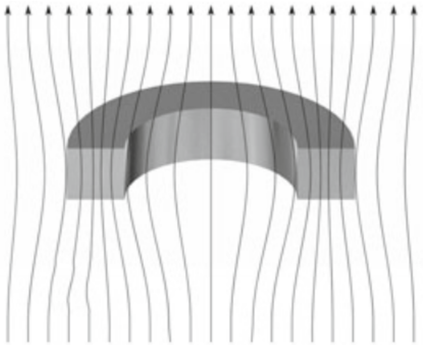
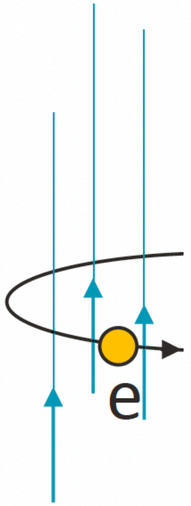


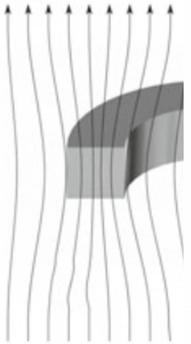
$$\Delta B \propto z^2$$

monitor the cyclotron state by quantizing axial shift

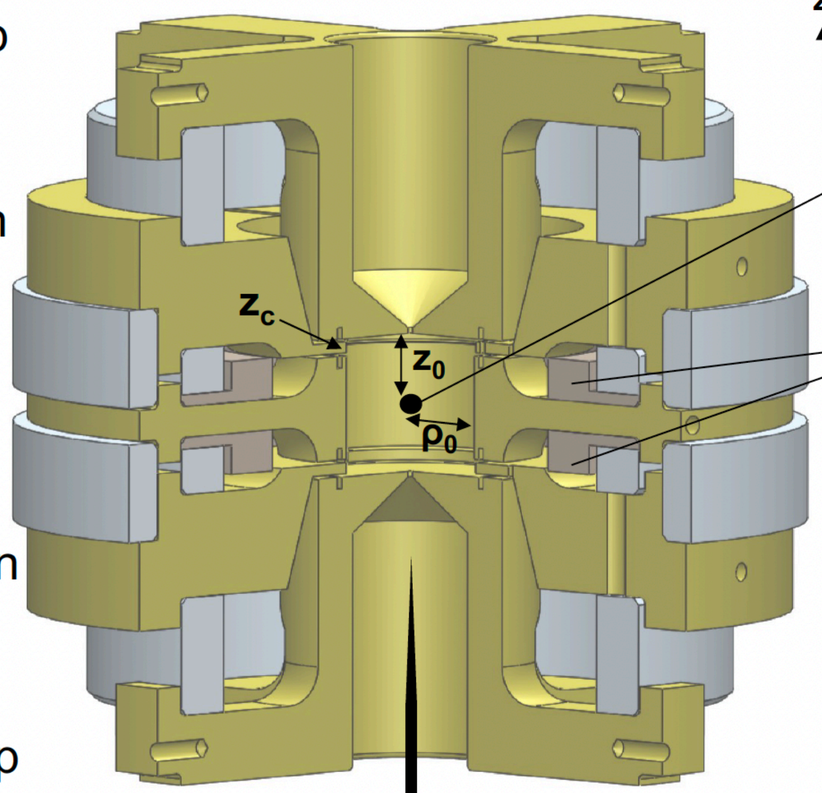
jump in cyclotron mode $\Rightarrow \omega_z$ shift $\Rightarrow \dot{z} \Rightarrow$ classical current signal

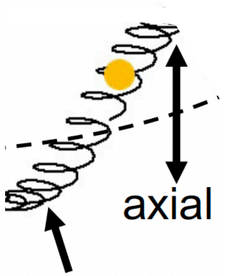
Electron Penning trap





ΔE

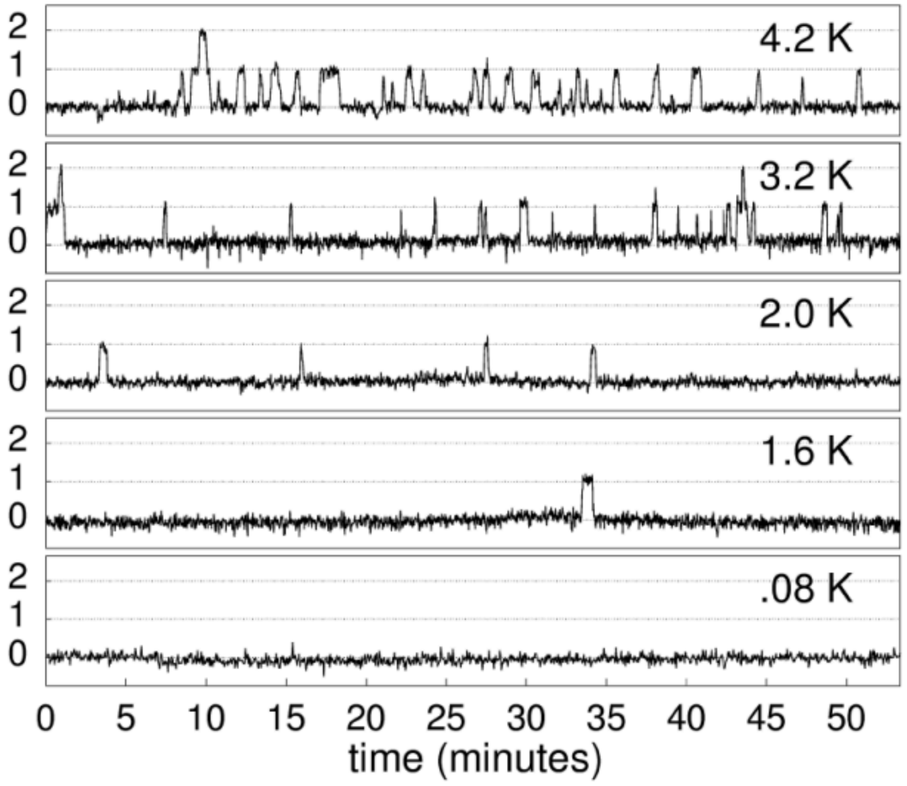




$$\frac{eB_0}{m_e}$$

sical current signal

Background-free detection

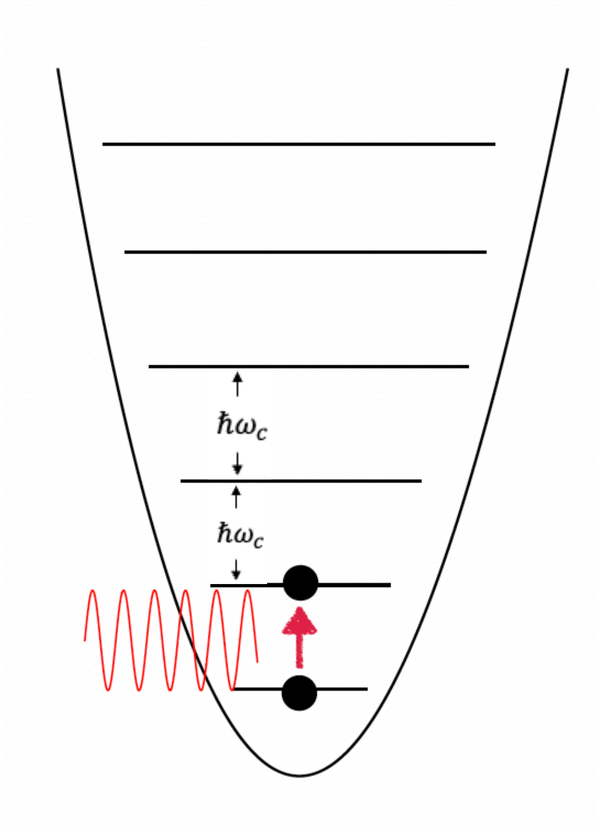


[S. Peiland G. Gabrielse, *Phys.Rev.Lett.*83(1999)7]

- Quantization of states
- One single jump is detectable
- Noise reduced at low T

Proof-of-principle experiment: Background-free over 7.4 days!

Resonance & Selection Rule



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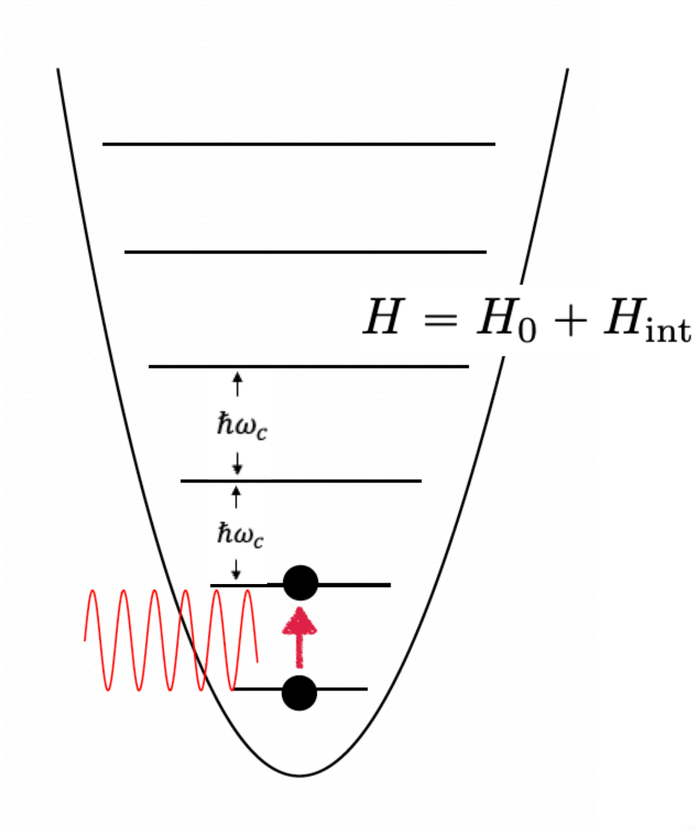
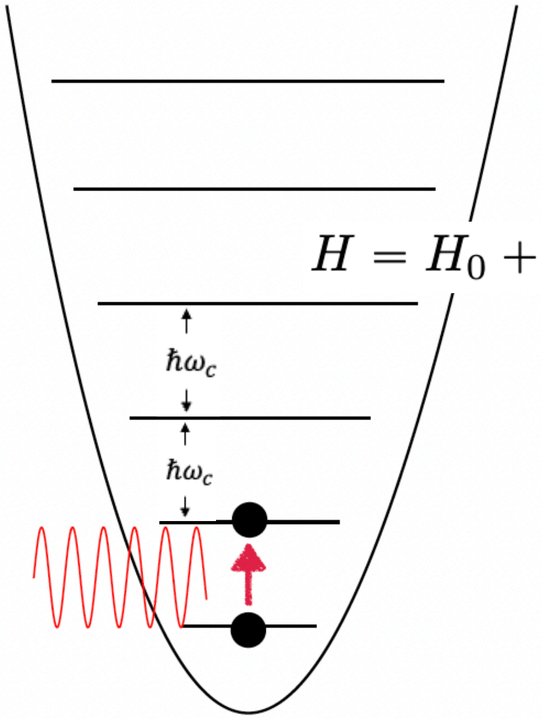


Selection Rule: only one jump at a time.

Due to the small coupling with dark matter

First-order perturbation theory applied

Resonance & Selection Rule



$$H = H_0 + H_{\text{int}} \Rightarrow \begin{cases} \text{Axions: } \Gamma_{c,\text{free}} \propto g_{a\gamma\gamma}^2 B_{\text{ext}}^2 \dfrac{\rho_{\text{DM}}}{\Delta\omega_a} \\ \text{DPDM: } \Gamma_{c,\text{free}} \propto \epsilon^2 \dfrac{\rho_{\text{DM}}}{\Delta\omega_{A'}} \end{cases}$$

The transition rate is enhanced by the dark matter width $\Delta\omega_{A'} \approx \frac{1}{2} m_{A'} v^2$

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Focusing–Effect of Cavity

$$\Gamma_{c,\mathrm{cavity}} = \kappa^2 \Gamma_{c,\mathrm{free}}$$

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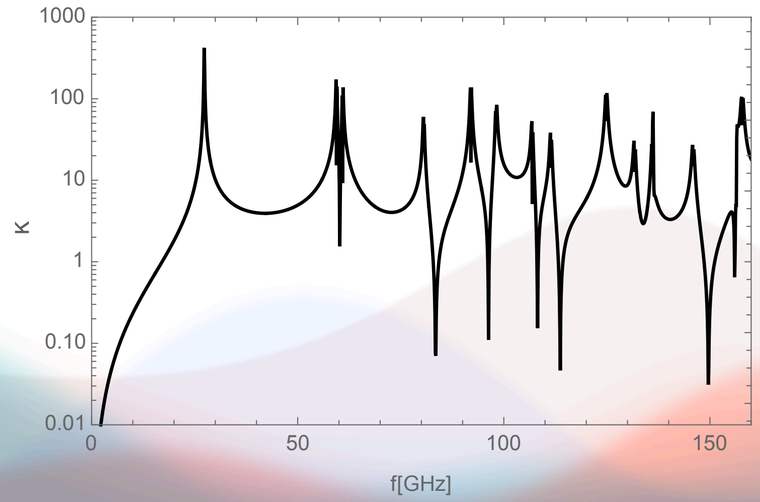

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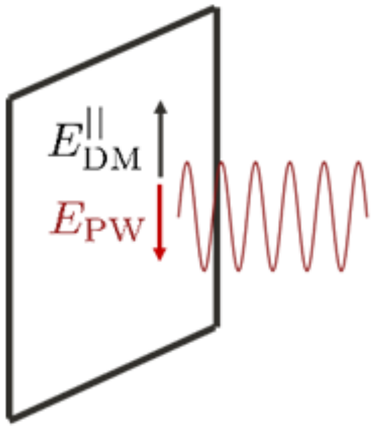

[Horns et al., 1212.2970]

$$E^{\mathrm{Dark}}_{||} = \epsilon\sqrt{2\rho_{\mathrm{DM}}}\cos\omega t$$

$$E^{\mathrm{pw}}_{||} = -\epsilon\sqrt{2\rho_{\mathrm{DM}}}\cos\left(\omega t \pm kx\right)$$

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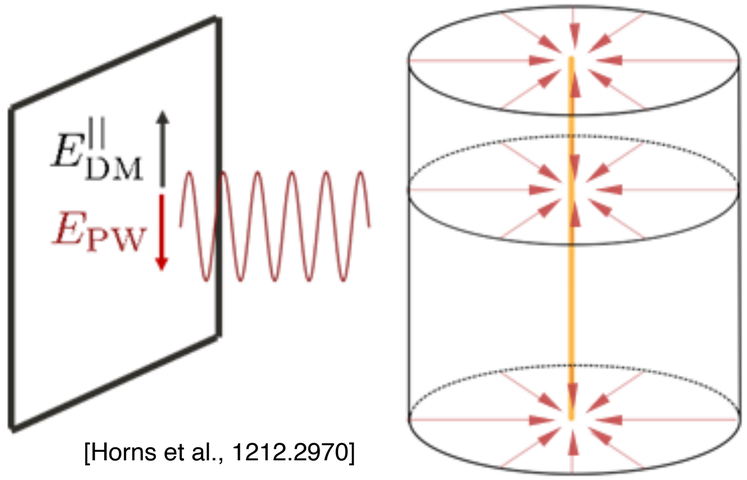

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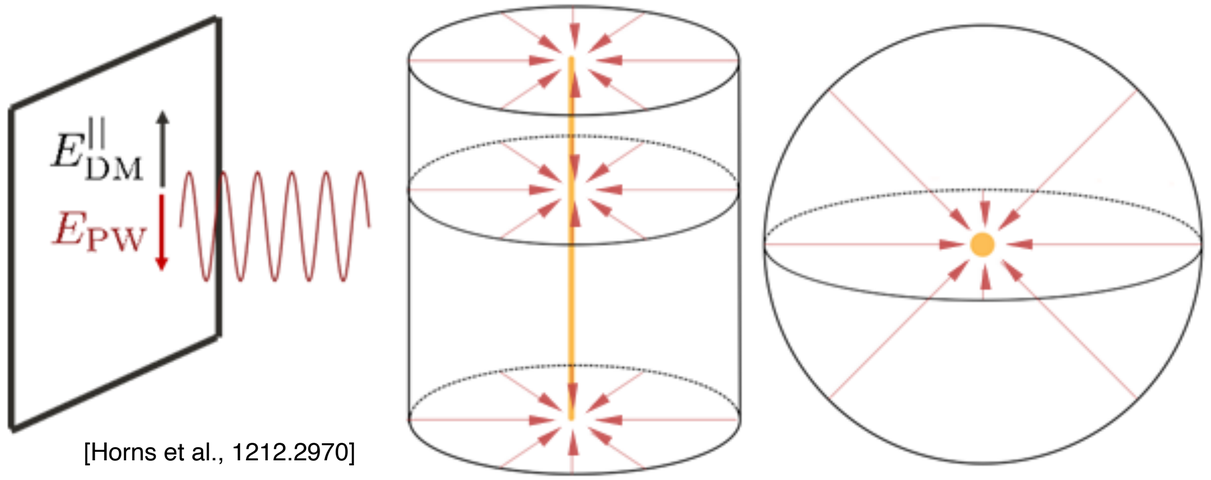

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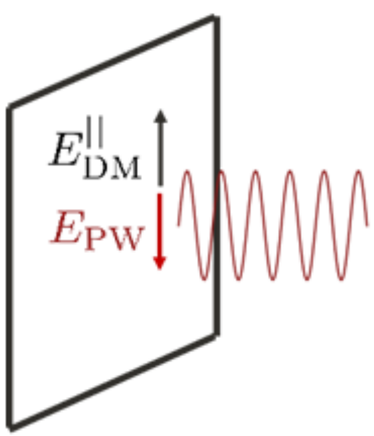

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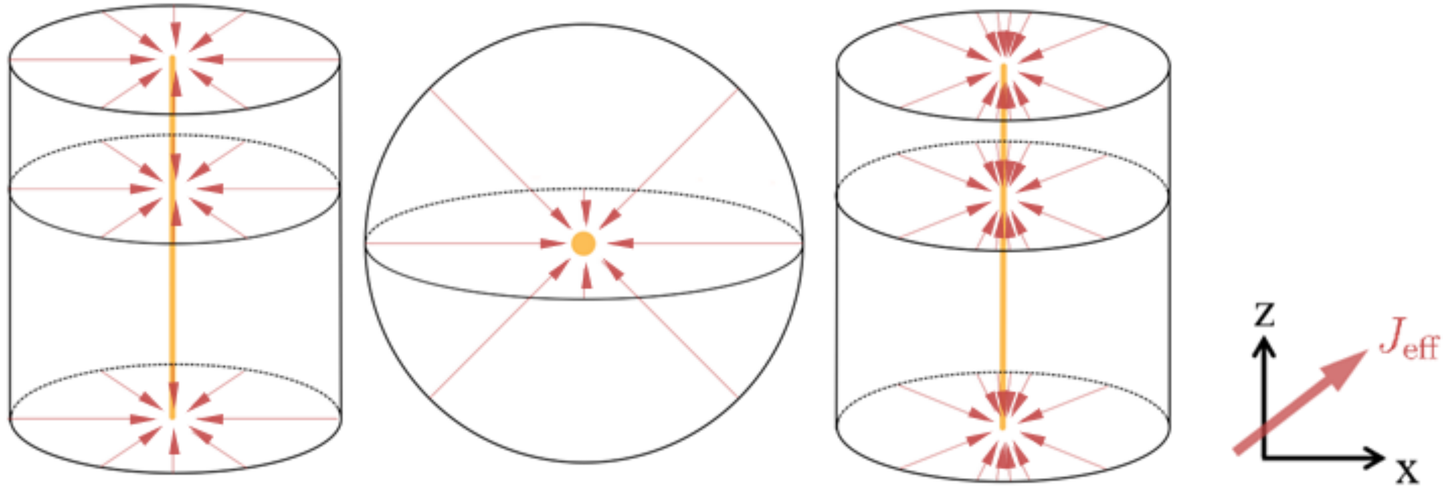

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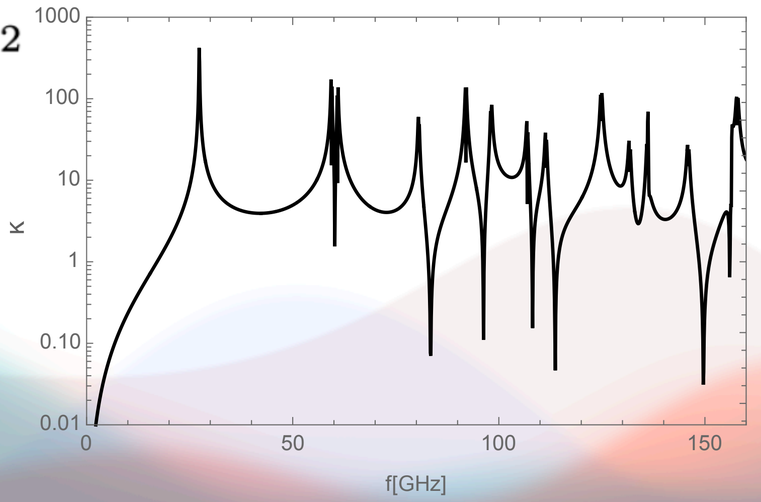
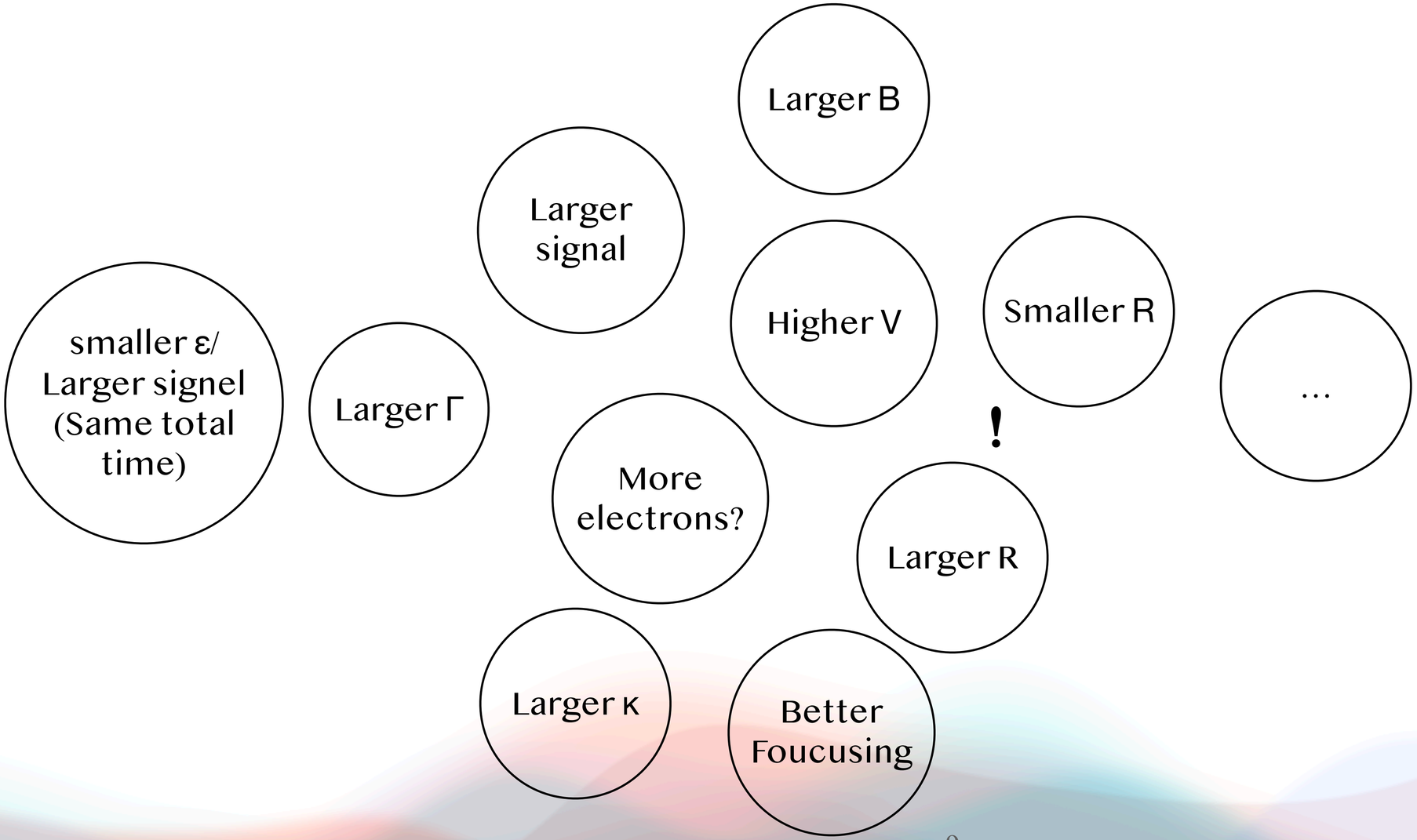
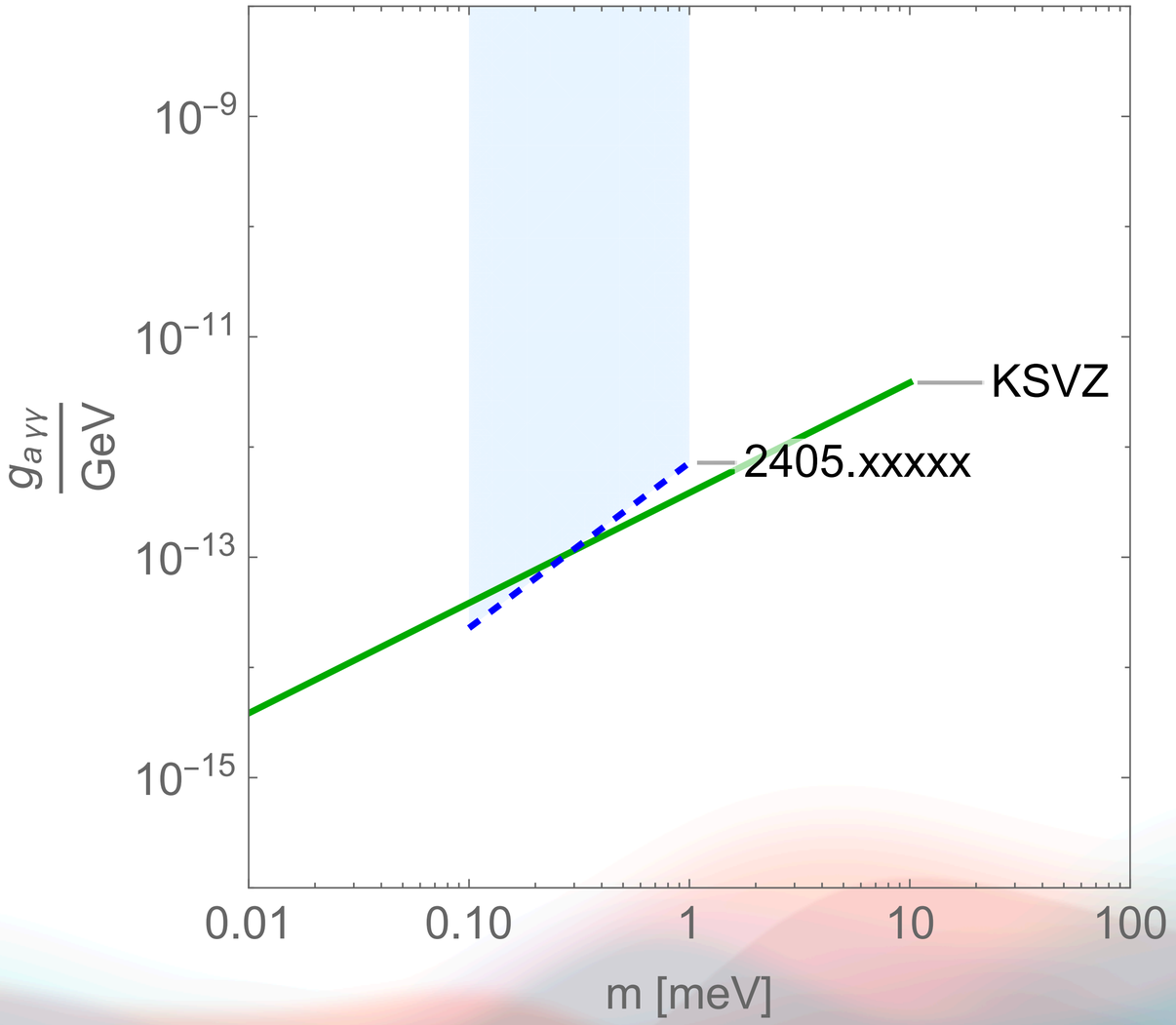
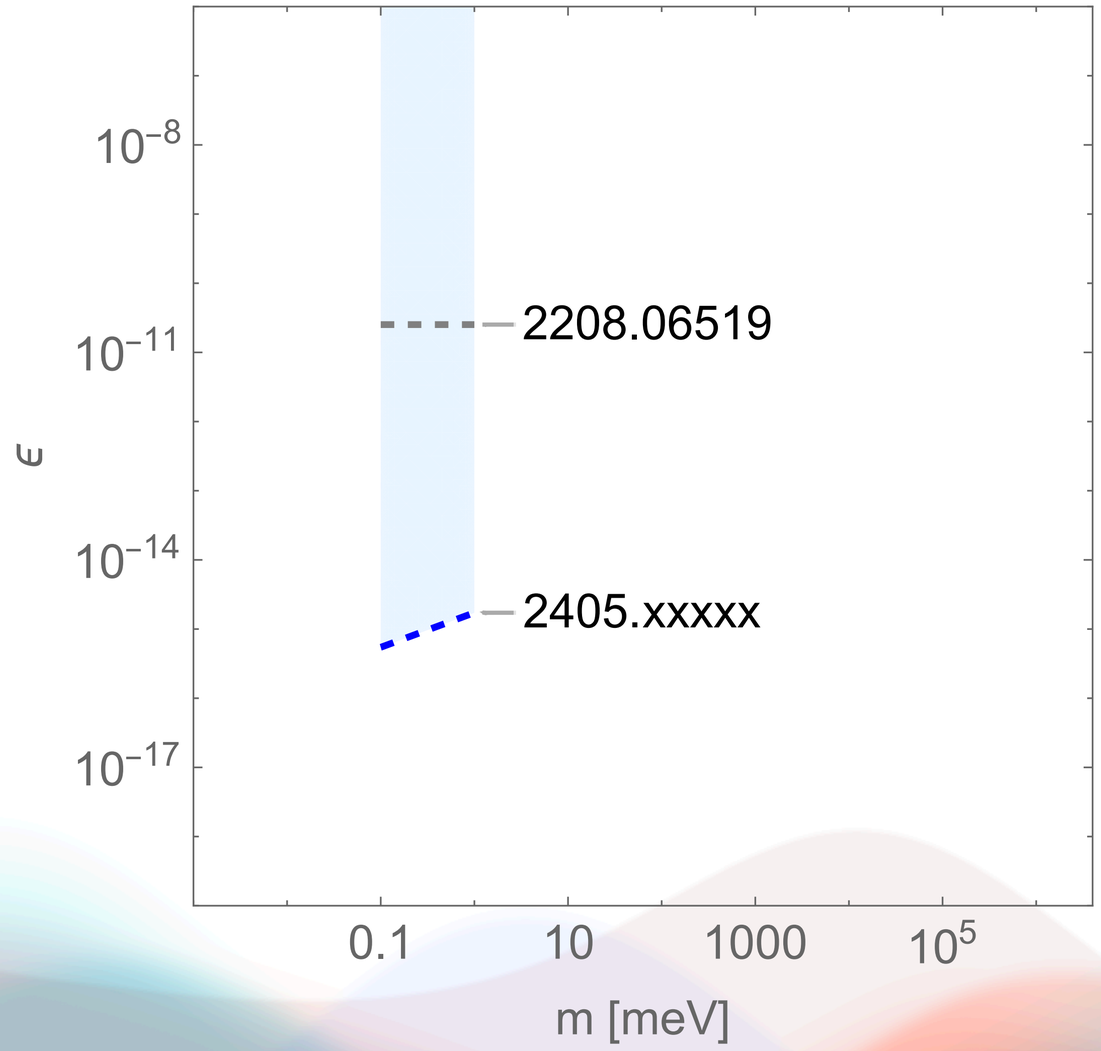


Global Optimization



“Preliminary”





Conclusion

- Try to Detect meV Dark Matter
- Using Electron Trap as a Detector
- Background-free Over 7.4 Days
- Results Enhanced by Focusing
- Increase the Result by Optimizing Some Parameters

Thank You

Questions?