Non-perturbative superradiant interactions in the eikonal regime

Marios Galanis

Stanford University

Based on arXiv:2608.xxxxx
with Asimina Arvanitaki (PI), Savas Dimopoulos (Stanford & PI), Derek Li (Stanford)

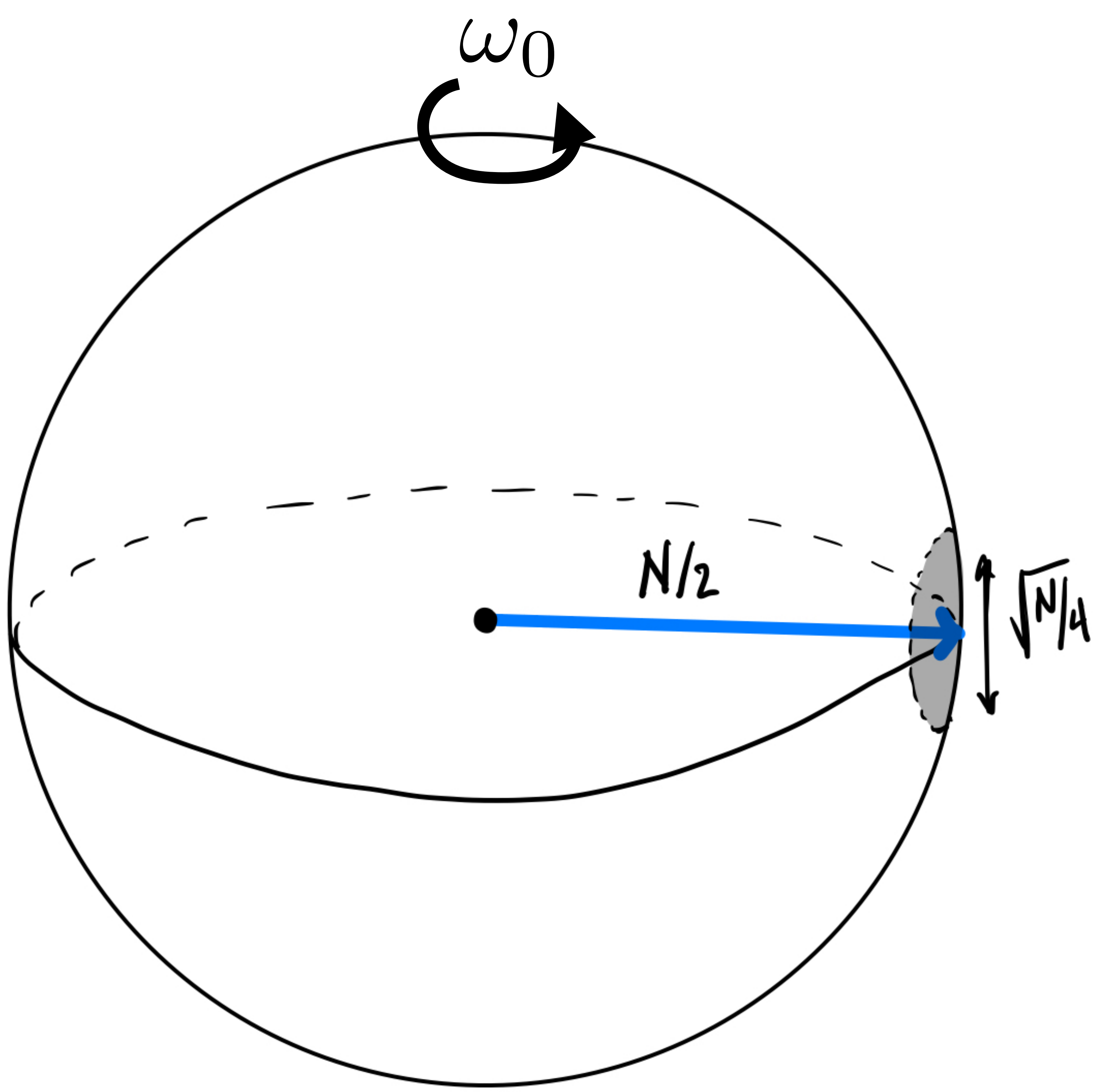
Continuation of: on Phys. Rev. D 111, 055015, 2025/arXiv:2408.04021,
Phys. Rev. A 113, 063714, 2026/arXiv:2508.20520

Light Dark World 2026 - July 29, 2026

Superradiant Interactions

Length ~ N

Variance in energy ~ N



$$\frac{1}{2^{N/2}}\prod_{i=1}^{N}(|g\rangle + |e\rangle)$$

[A.Arvanitaki, S. Dimopoulos, **MG**, arXiv:2408.04021]

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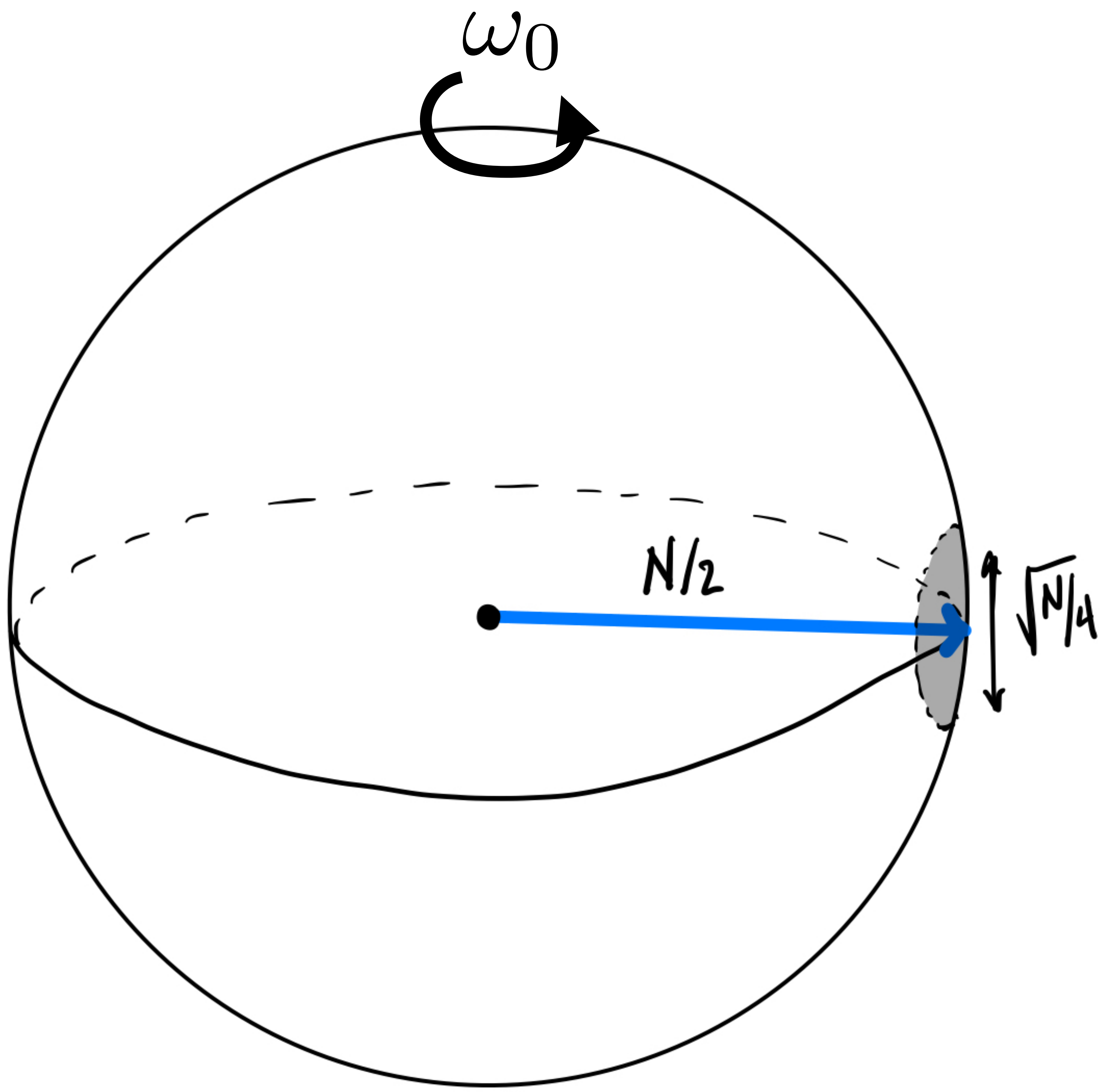

$$\prod_{i=1}^{N} \frac{1}{\sqrt{2}} \left(e^{-i\frac{\omega_0}{2}t} \left|g\right\rangle + e^{i\frac{\omega_0}{2}t} \left|e\right\rangle \right)$$

[A.Arvanitaki, S. Dimopoulos, **MG**, arXiv:2408.04021]

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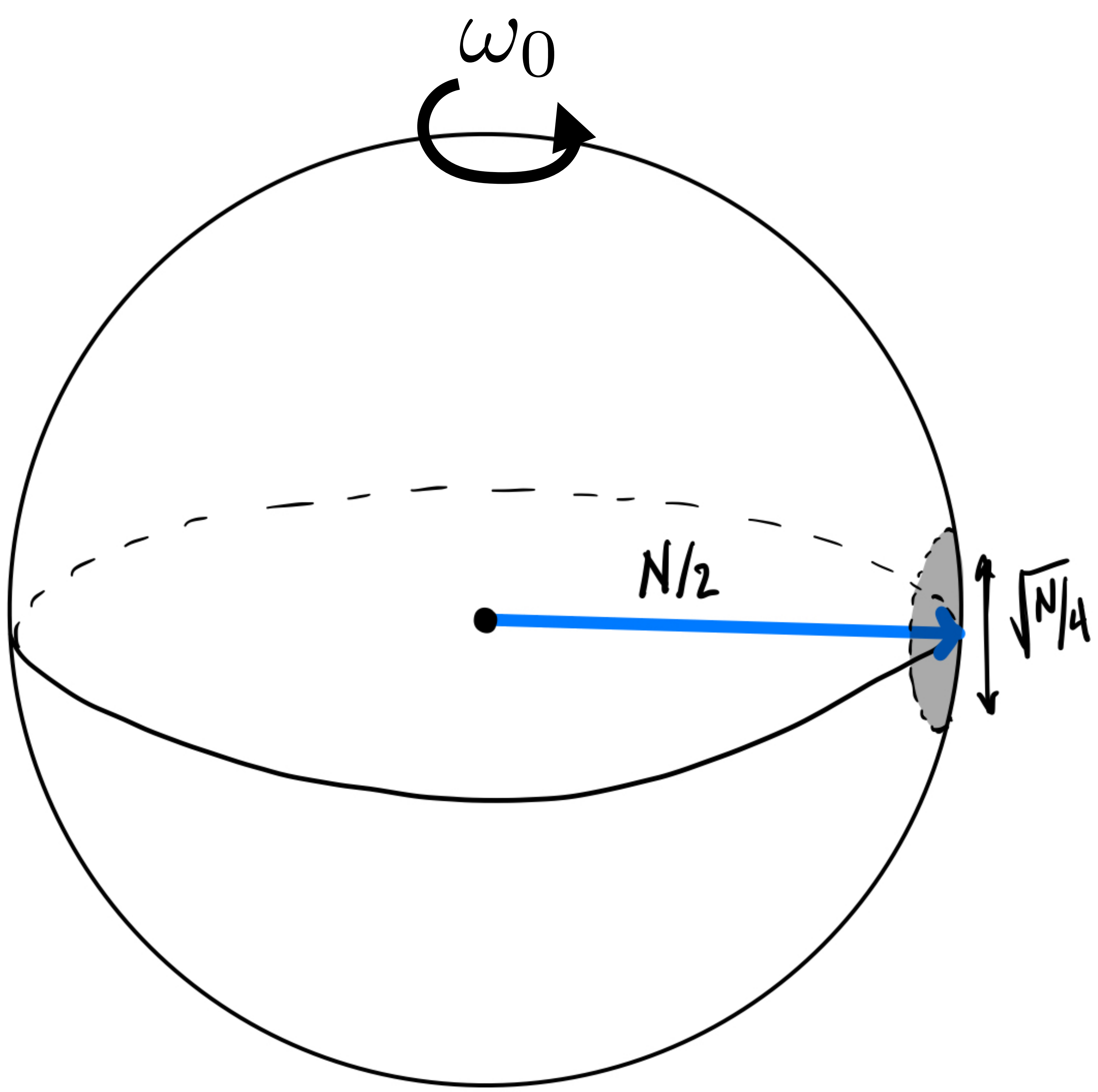
Very large rotating dipole: $\boldsymbol{\mu}_N \sim \frac{N}{2}\boldsymbol{\sigma}\cos\omega_0 t$



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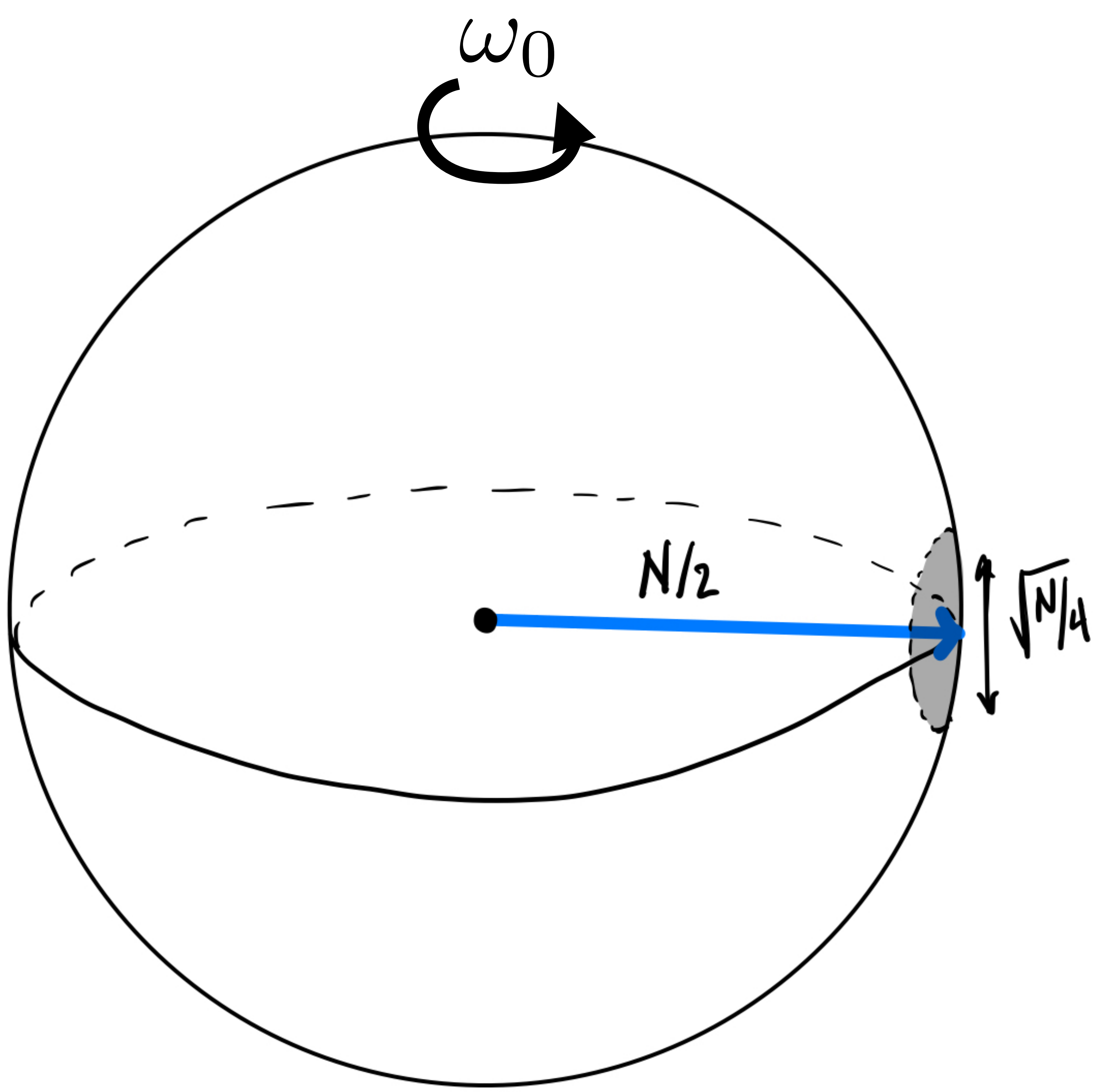

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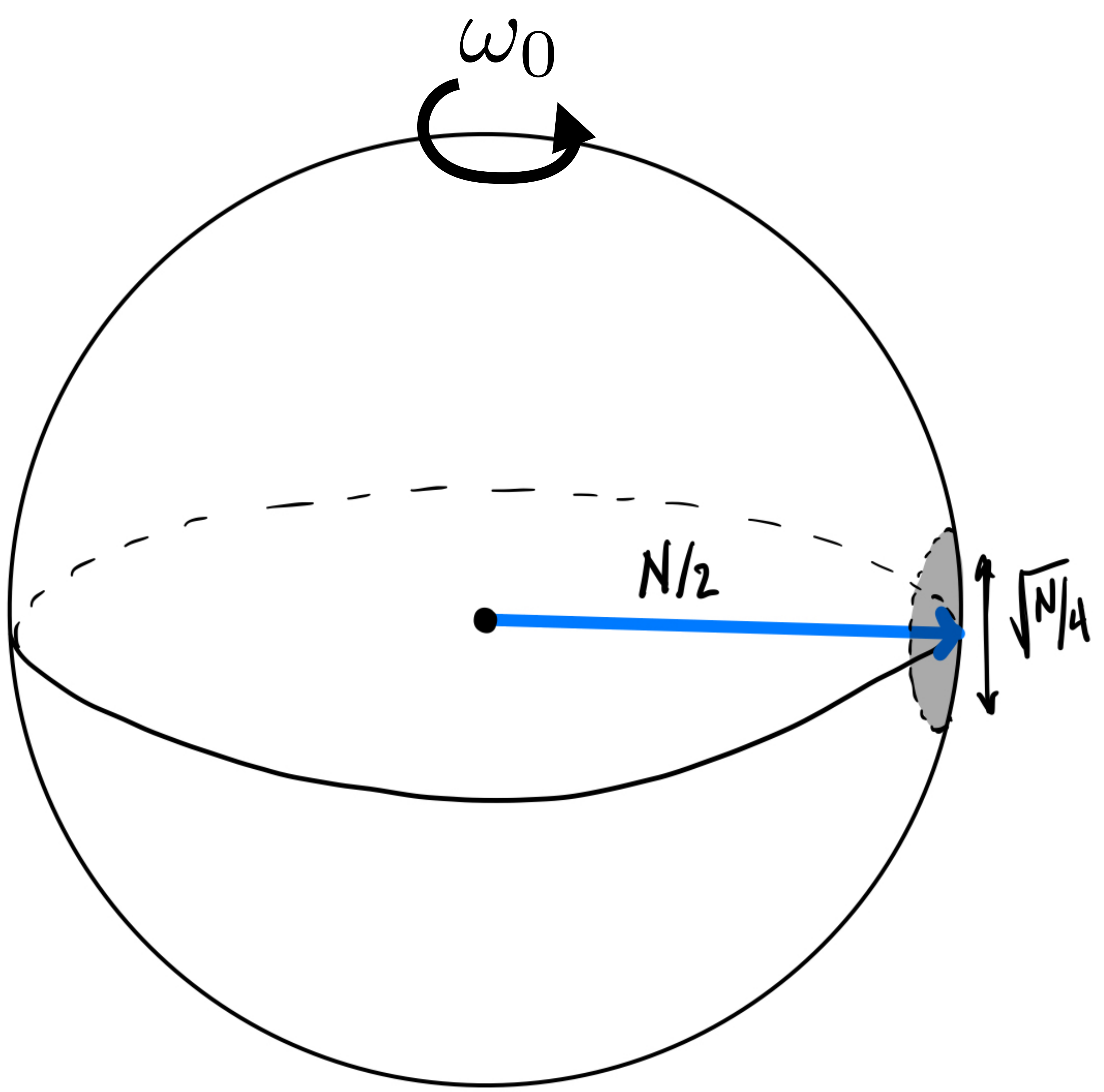

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CvB: $V_0 \simeq \frac{g_A G_\mathrm{F}}{\sqrt{2}} \delta^{(3)}(\mathbf{x}_\mathrm{s} - \mathbf{x}_\nu)$ $\quad \boldsymbol{\mathcal{O}}_p = \boldsymbol{\sigma}_\nu$

Axion: $V_0 \simeq \frac{v\sqrt{\rho_\mathrm{DM}}}{m_a f_a}$ $\quad \boldsymbol{\mathcal{O}}_p = \hat{\mathbf{v}}$

Millicharge: $V_0 \simeq \frac{q_\chi \mu_N v}{r^2}$ $\quad \boldsymbol{\mathcal{O}}_p = \hat{\mathbf{v}}$

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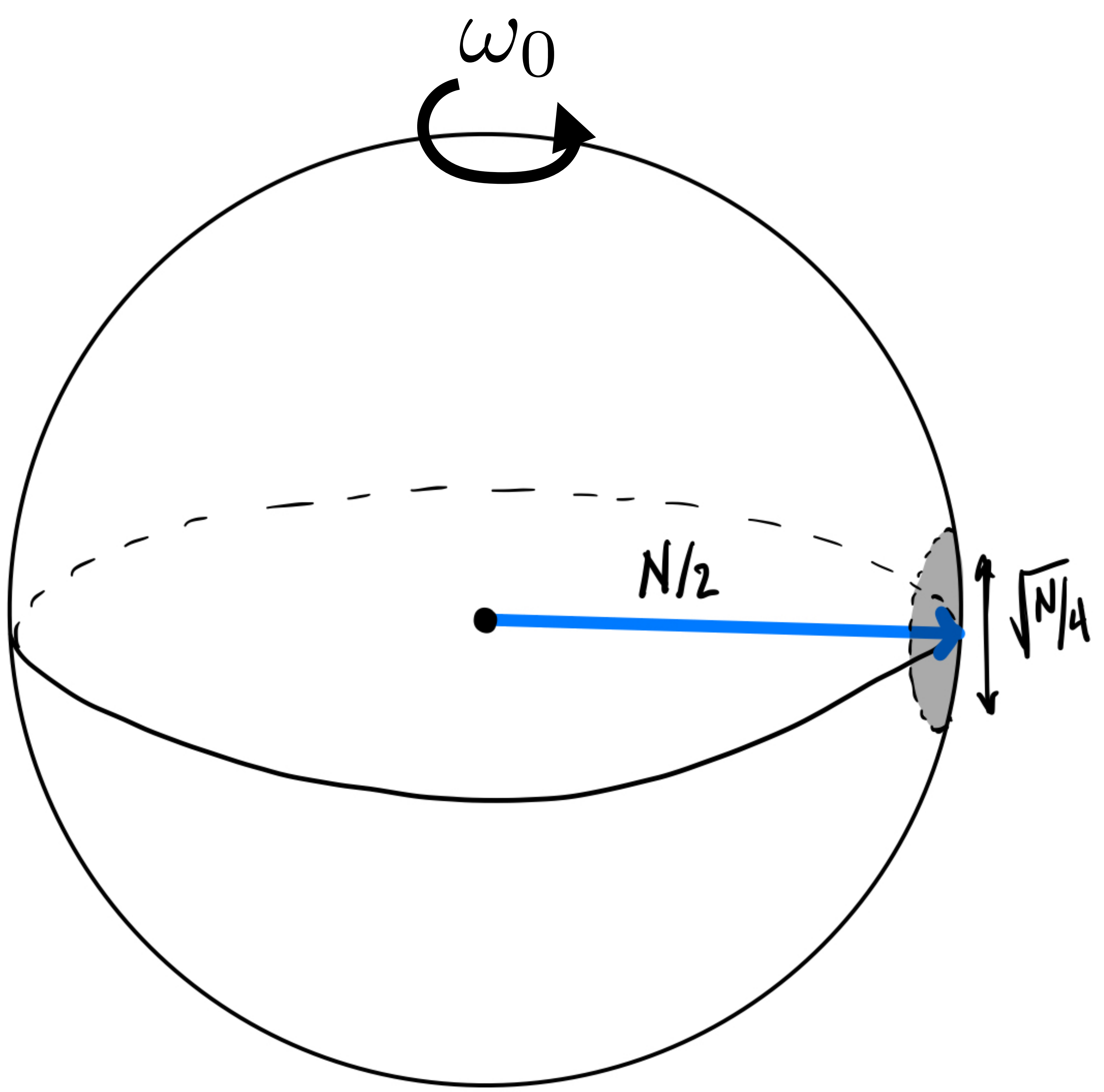

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Rate: $\Gamma \propto V^2 \propto N^2/4$

[A.Arvanitaki, S. Dimopoulos, **MG**, arXiv:2408.04021]

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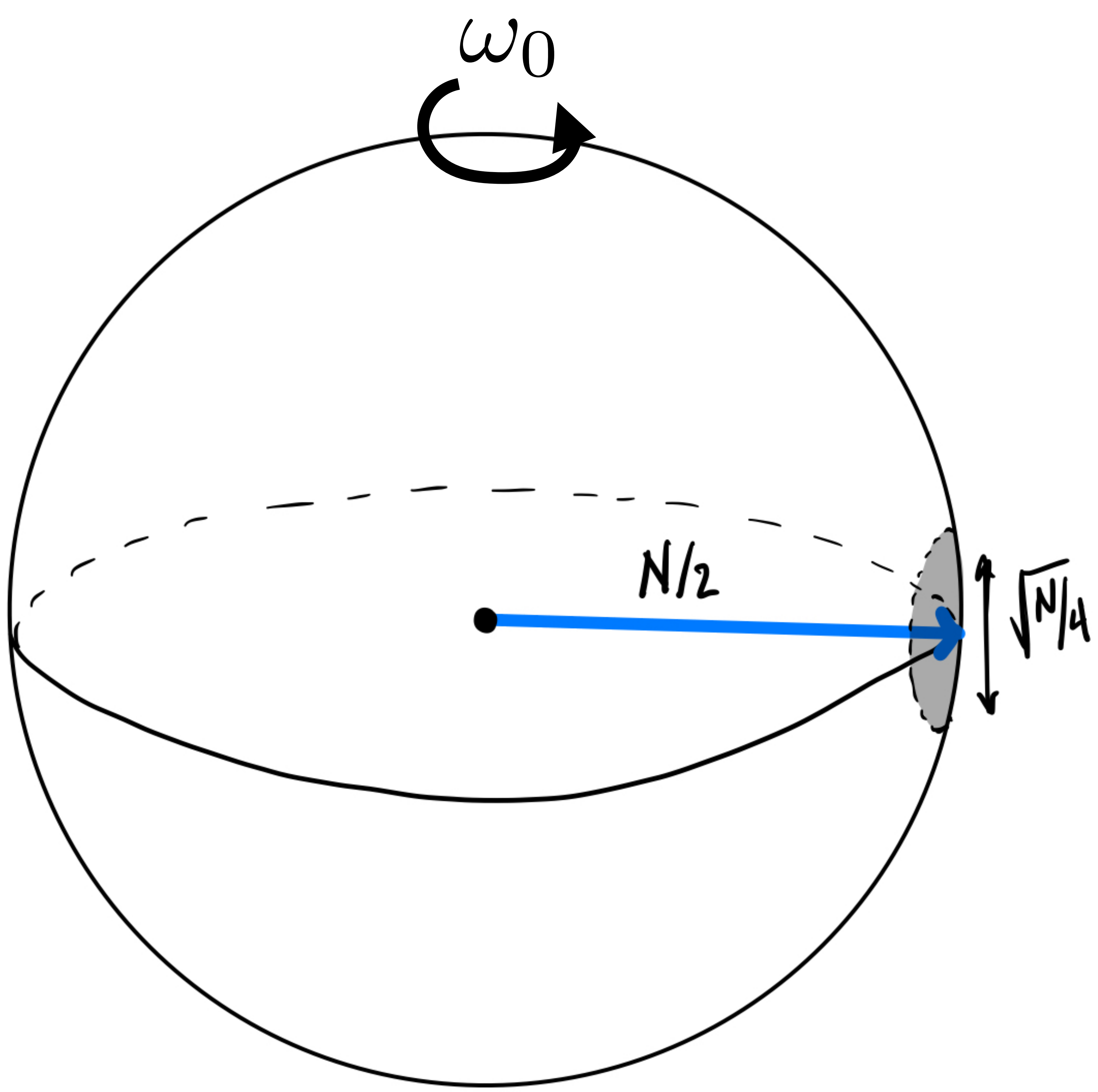

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$\boxed{\omega_0 t_{\mathrm{tr}} \lesssim 1 \text{ or } \frac{\omega_0 R}{v} \lesssim 1}$

[A.Arvanitaki, S. Dimopoulos, **MG**, arXiv:2408.04021]

Observables

Scattering particle sees a classical potential $V \propto N \cos \omega_0 t$

[A.Arvanitaki, S. Dimopoulos, **MG**, D. Li arXiv:2608.xxxxx]

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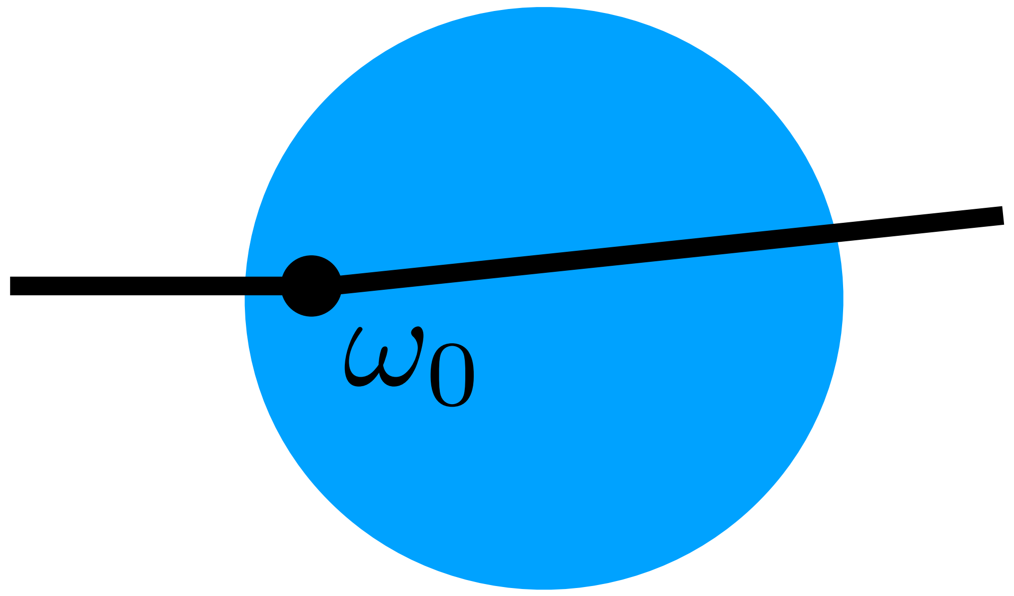

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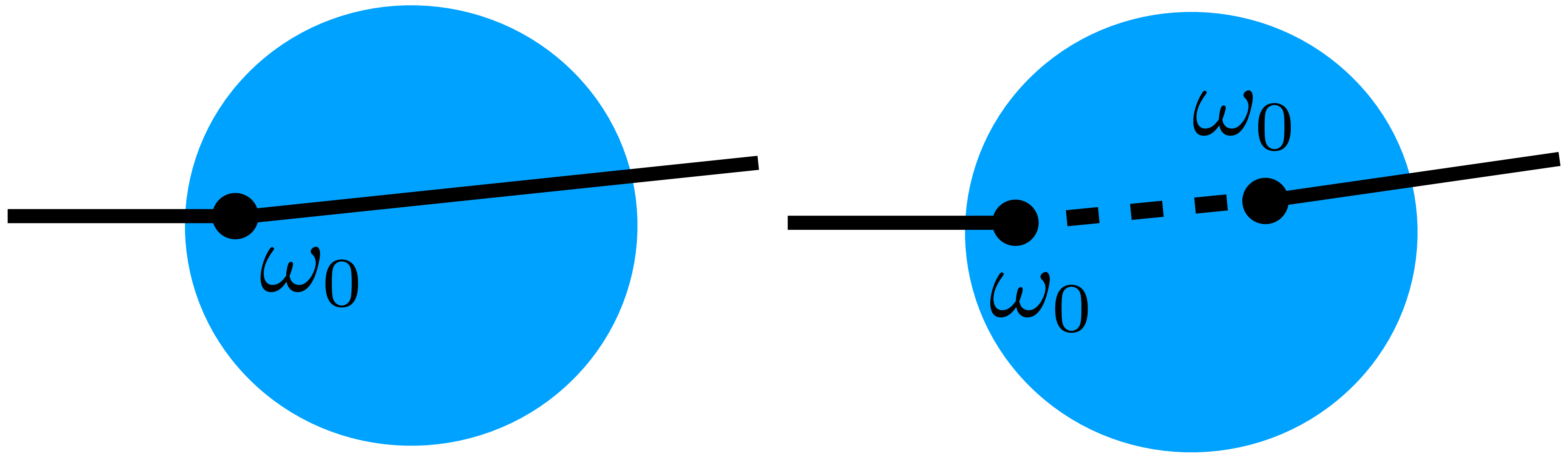

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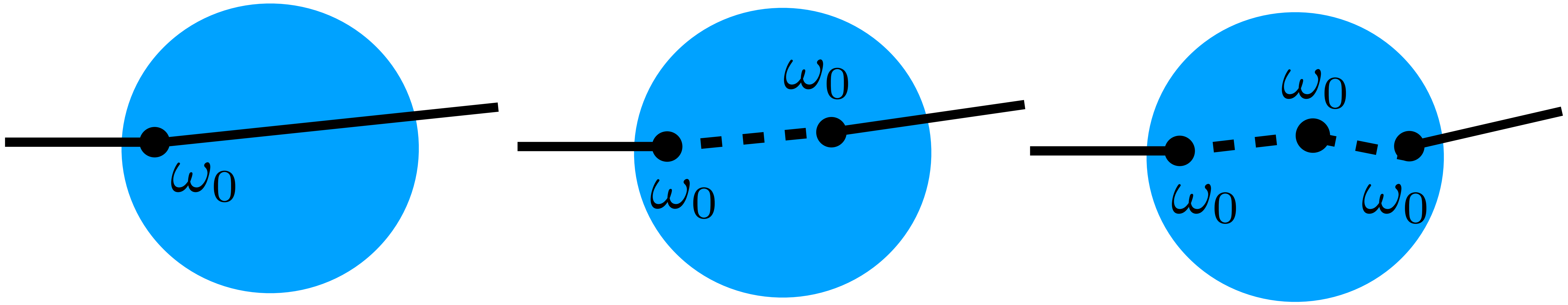

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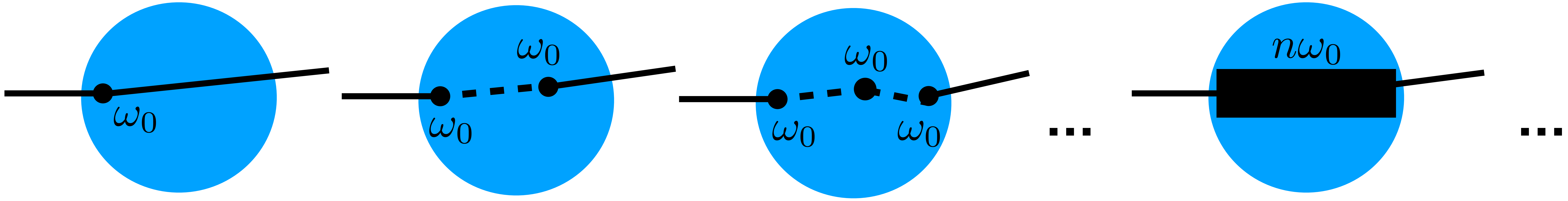

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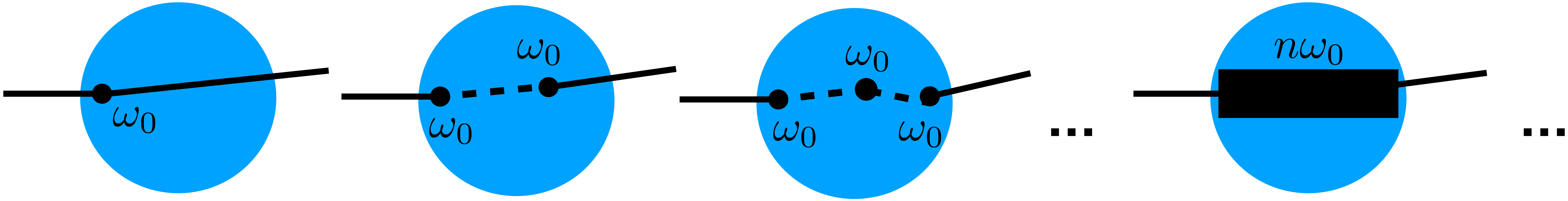

Rate to exchance n quanta $\Gamma_n \approx n_\chi \sigma_n v$

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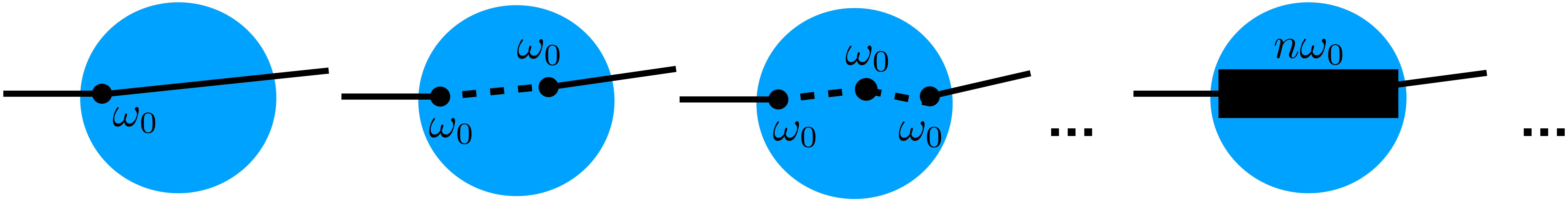

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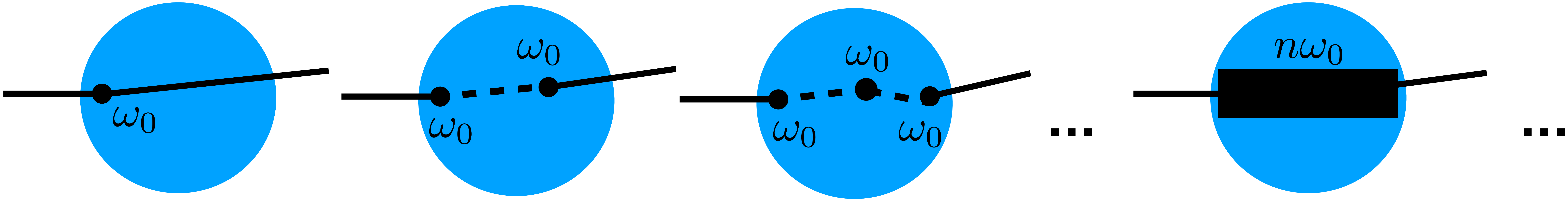

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Energy transfer from and to the *scattering* particles

$$\frac{\mathrm{d}\langle E\rangle}{\mathrm{d}t} = \sum_n \Delta E_n (n_\chi \sigma_n v), \qquad \Delta E_n = n\omega_0$$

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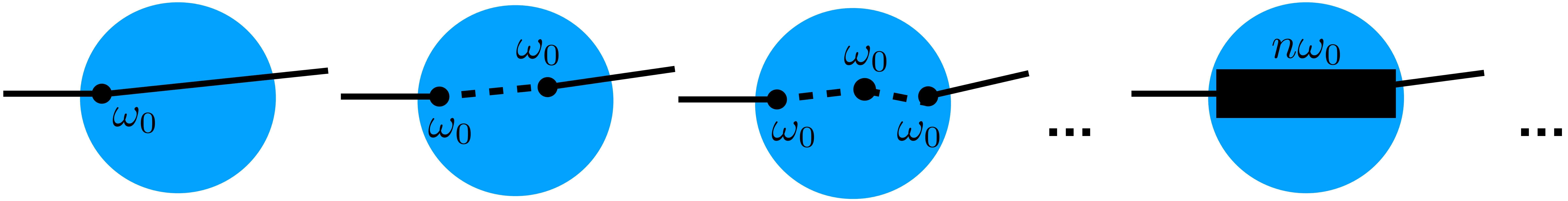

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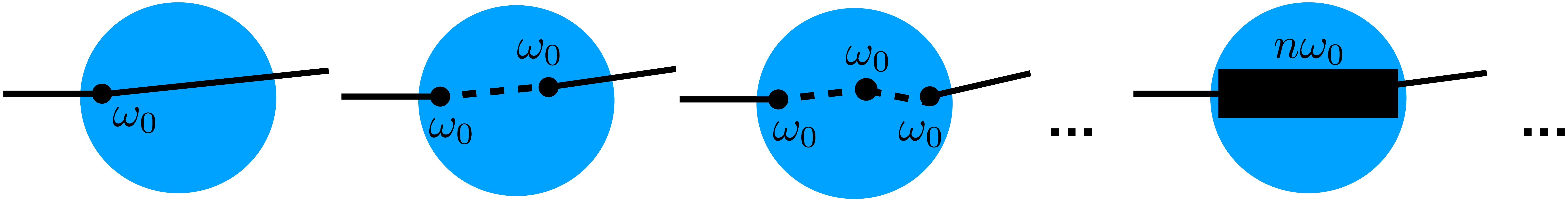

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[A.Arvanitaki, S. Dimopoulos, **MG**, D. Li arXiv:2608.xxxxx]

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The eikonal regime

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$$i\frac{\partial\psi}{\partial t} = -\frac{\nabla^2}{2m}\psi + \left[V_0 \left\langle J \right\rangle \cos\omega_0 t\right]\psi$$

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Cross-section capped by unitarity

[A.Arvanitaki, S. Dimopoulos, **MG**, D. Li arXiv:2608.xxxxx]

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$\sum_n J_n^2 = 1$ Cross-section capped by unitarity

$\sum_n n^2 J_n^2(\chi_0) = \chi_0^2$ Decoherence is not capped, gets a $\chi_0^2 \gg 1$ enhancement

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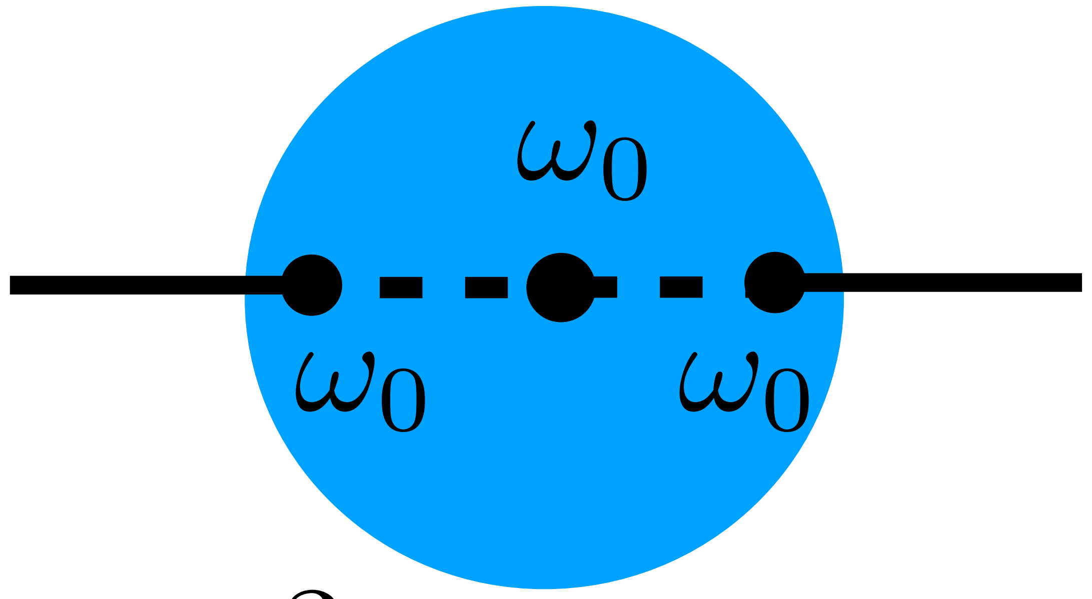

$$i\frac{\partial\psi}{\partial t} = -\frac{\nabla^2}{2m}\psi + \left[V_0\left\langle J\right\rangle \cos\omega_0 t\right]\psi$$

$\chi_0 \sim 3$

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Example: Accumulating millicharges from cosmic rays

[A. Berlin et al., *Phys.Rev.D* 114 (2026) 1, 015016, arXiv:2510.25834]

See Zach's talk later today: *Cavendish Searches for Millicharged Particles*

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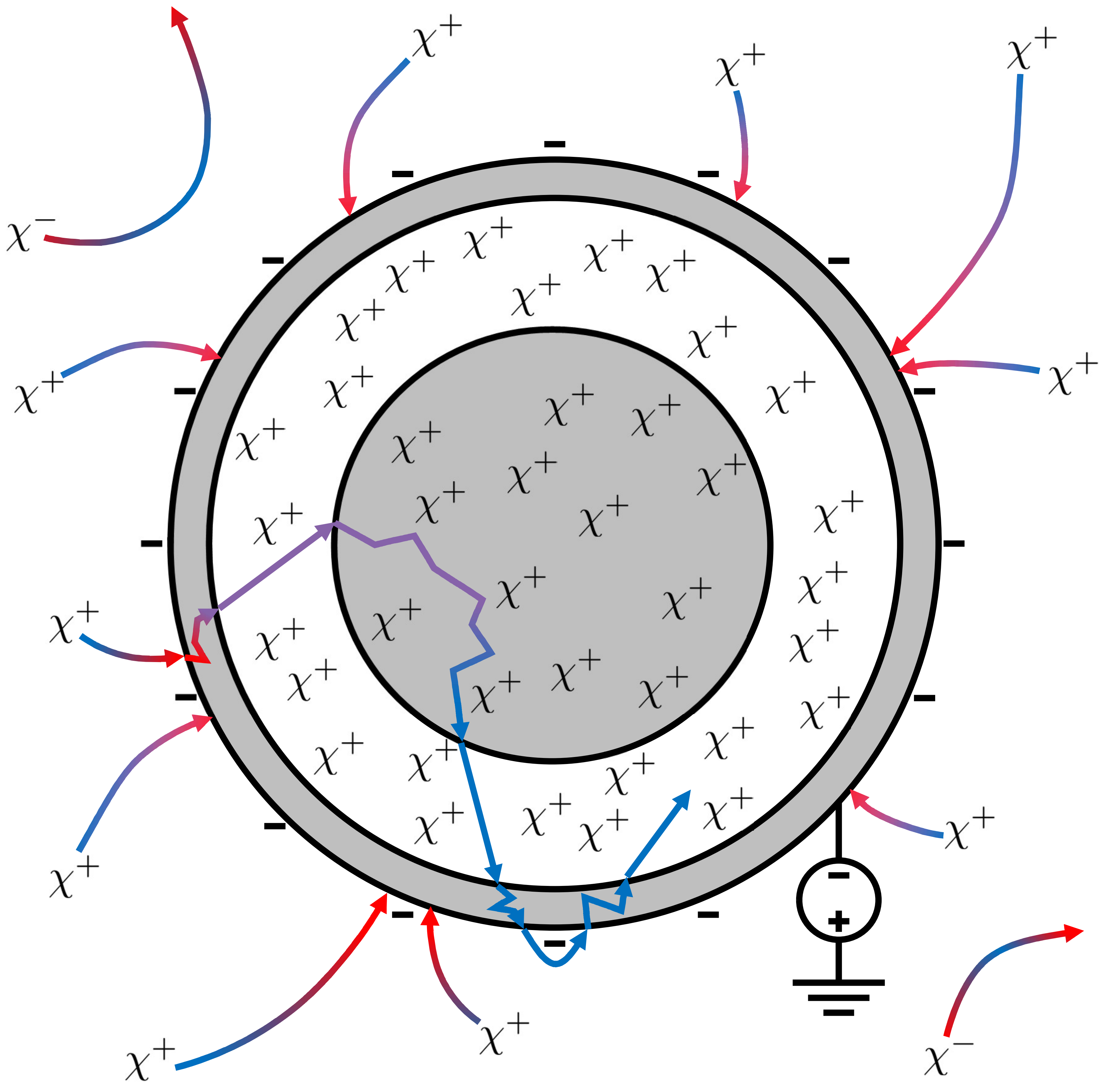

All figures here are from [Berlin et. al]

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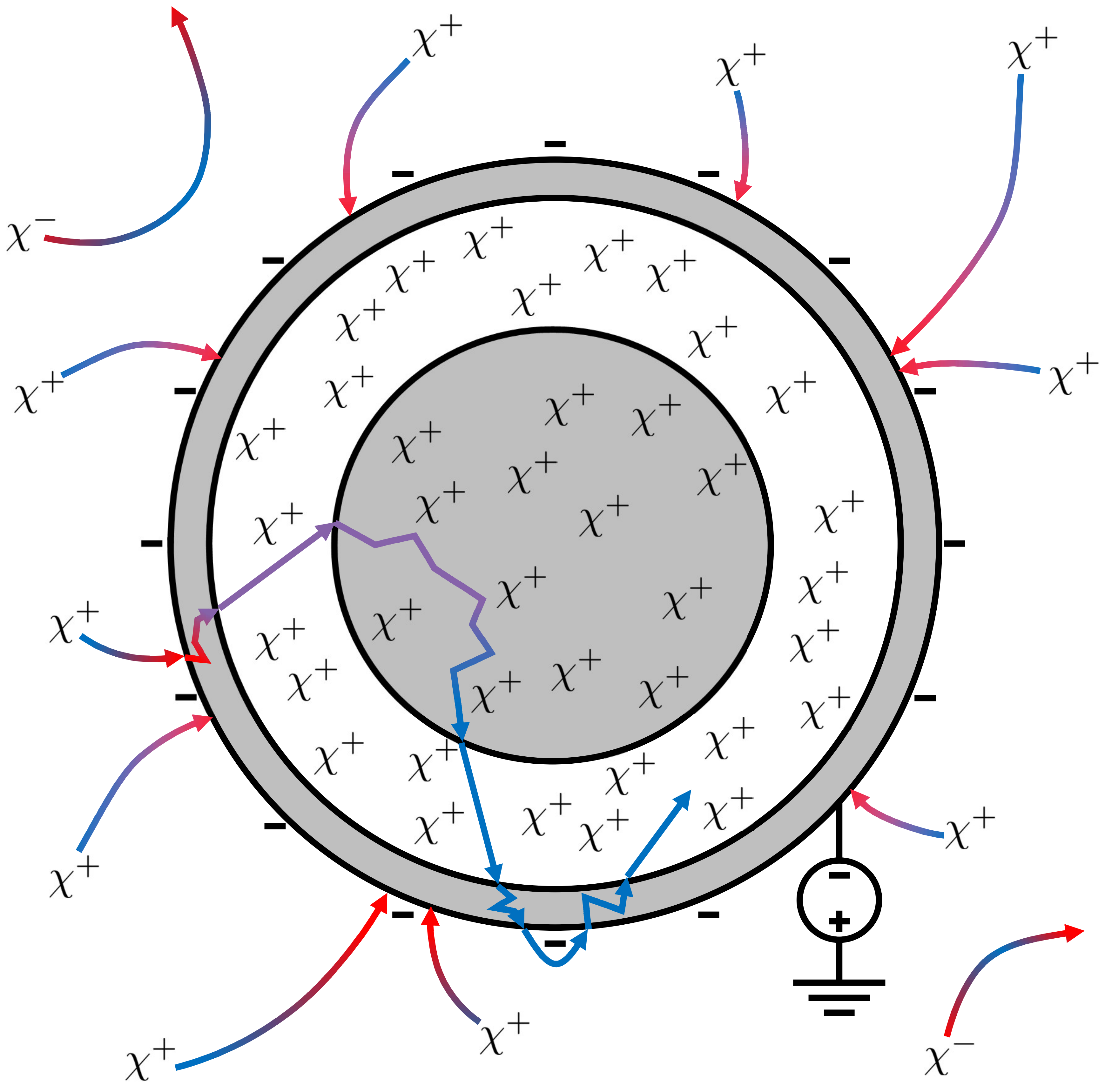

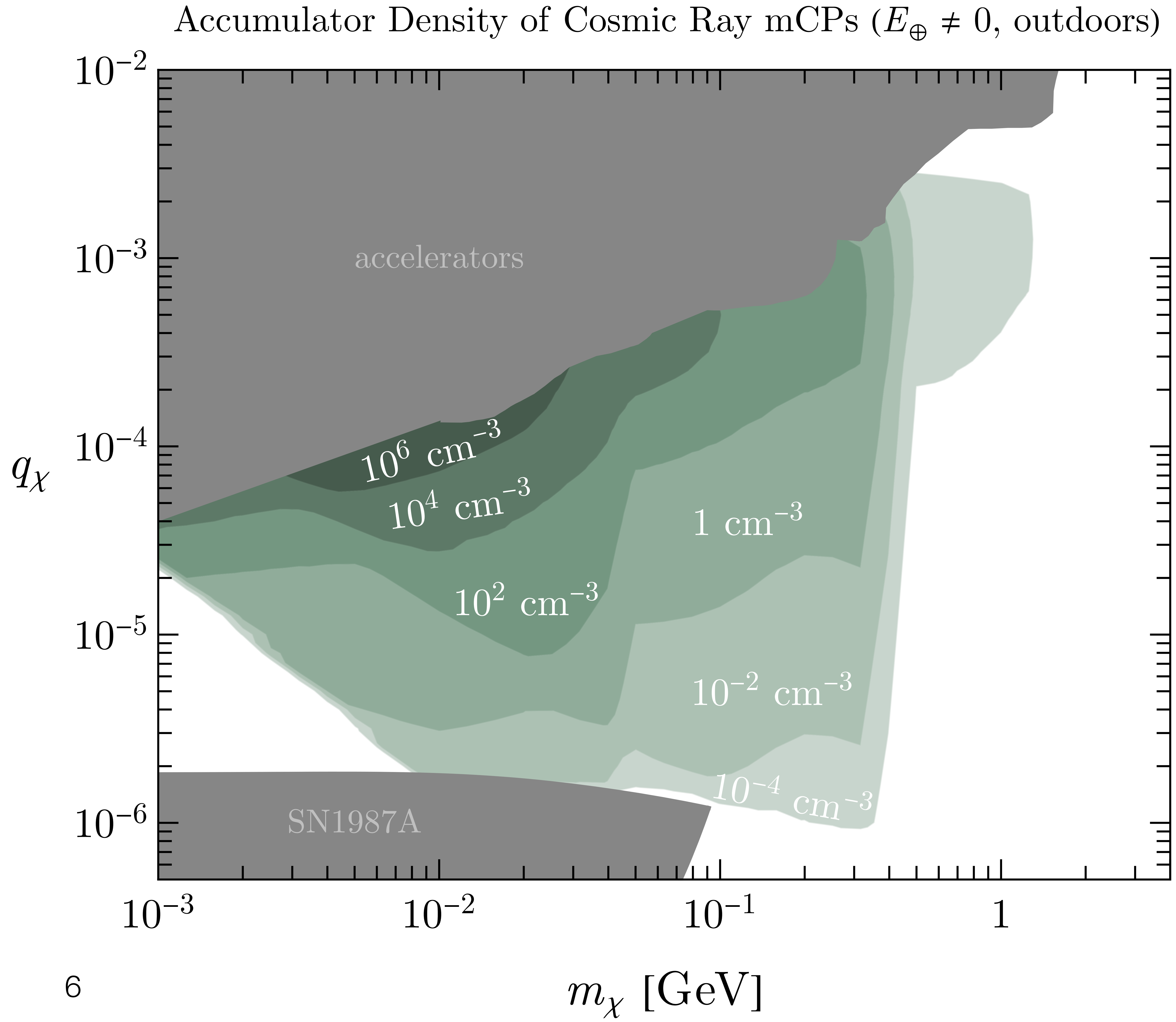

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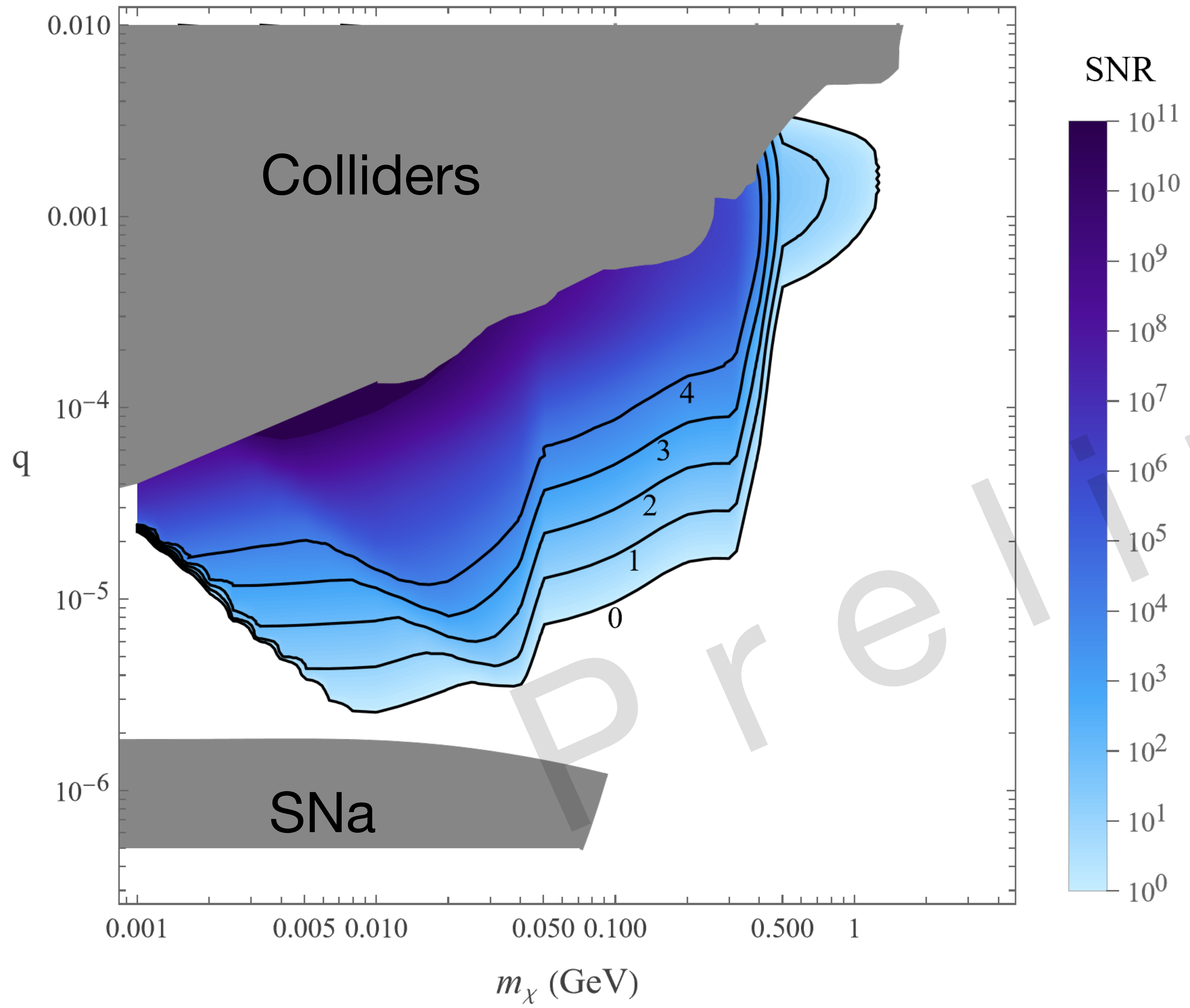
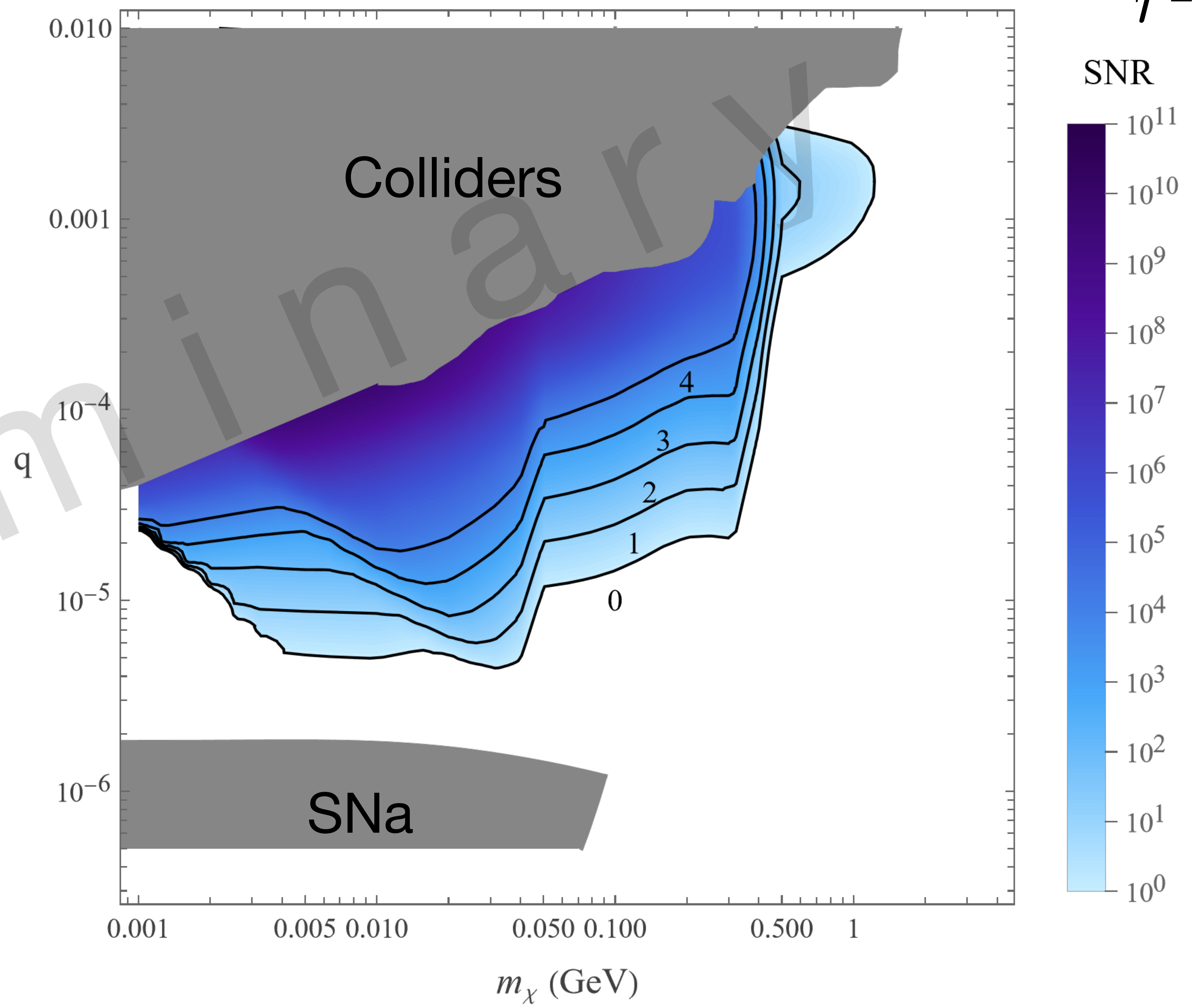
Energy transfer



Decoherence

$$V \sim \frac{q_\chi \mu_N v}{r^2}$$



Assuming the nuclear spin quantum protocol of [**MG** et al., Phys. Rev. A 113, 063714, 2026/arXiv:2508.20520]
MC densities from [Berlin et al. *Phys.Rev.D* 114 (2026) 1, 015016, arXiv:2510.25834]

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Conclusions

Superradiant interactions are a new class of **coherent inelastic effects**

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Non-perturbative regime → **Eikonal approximation**

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Establishes nuclear spin systems as
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