In collaboration with Riccardo Catena, Timon Emken, Nicola Spaldin, Marek Matas

General Dark Matter Electron Interactions in Detector Materials

With a focus on Graphene and Carbon Nanotubes, Materials of Novel Experiments

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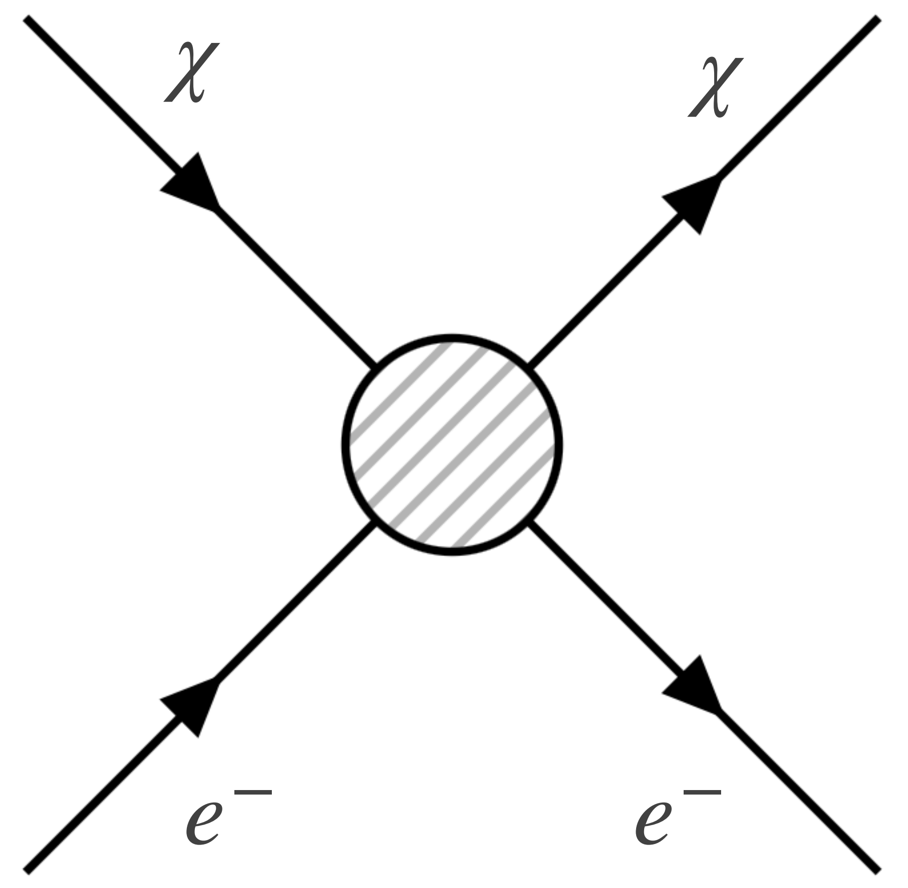

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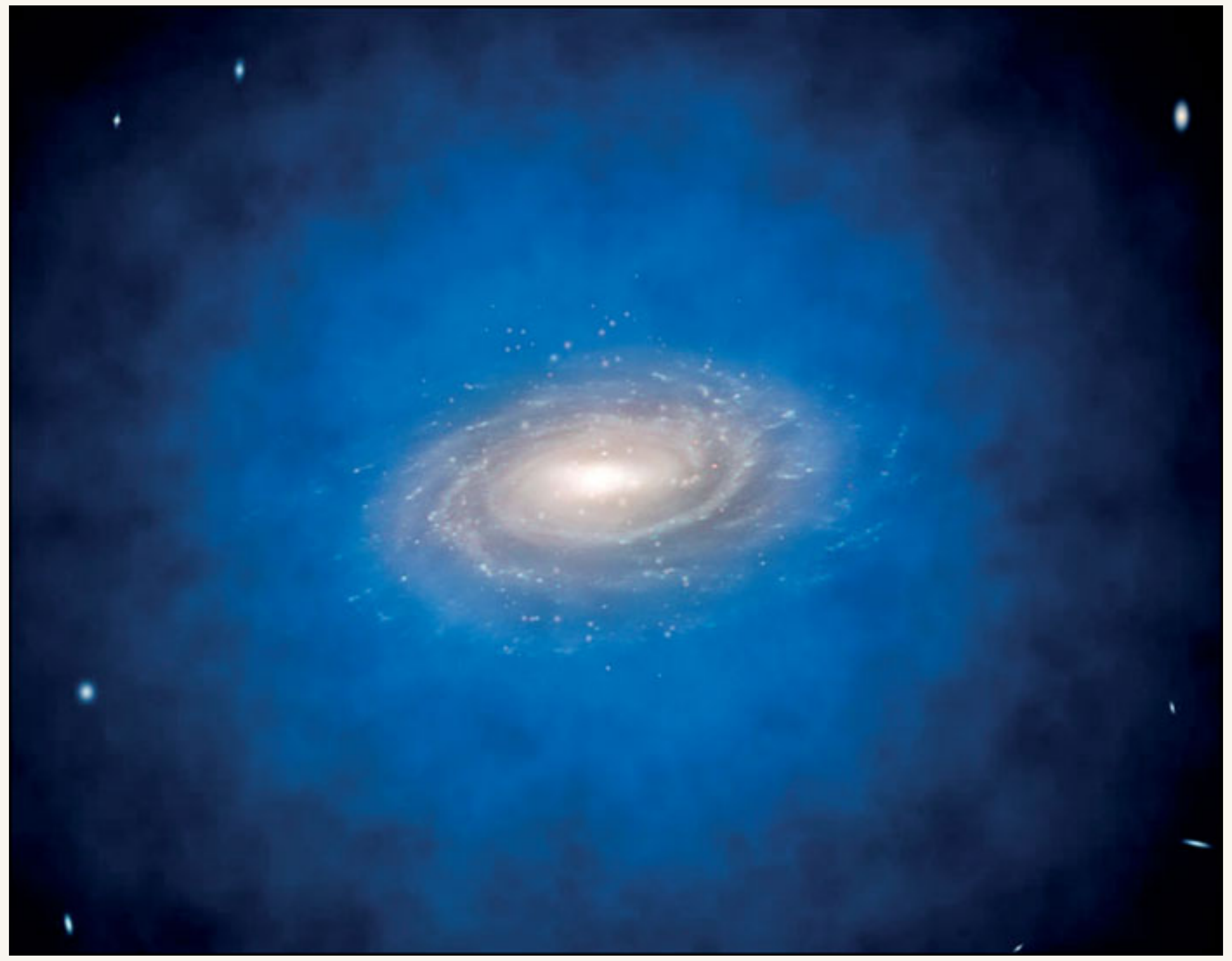
Outline

- Direct detection of Dark Matter (DM)
- Directional Detection of DM
- DM induced electron ejections in graphene and carbon nanotubes

Dark Matter (DM) distribution in our galaxy

- DM density $\rho_\chi \approx 0.4\,\mathrm{GeV/cm^3}$
- DM velocity is Boltzmann distributed, $\mathbf{v} \sim e^{\frac{-\mathbf{v}^2}{v_0^2}}$
- Motion of Sun shifts the velocity by $\mathbf{v}_\oplus$, $\mathbf{v} \sim e^{\frac{-(\mathbf{v}+\mathbf{v}_\oplus)^2}{v_0^2}}$
- $v_0 \approx 220\,\mathrm{km/s}$ and $v_\oplus \approx 244\,\mathrm{km/s}$, so $v \ll c$



Credits: ESO/L Calçada

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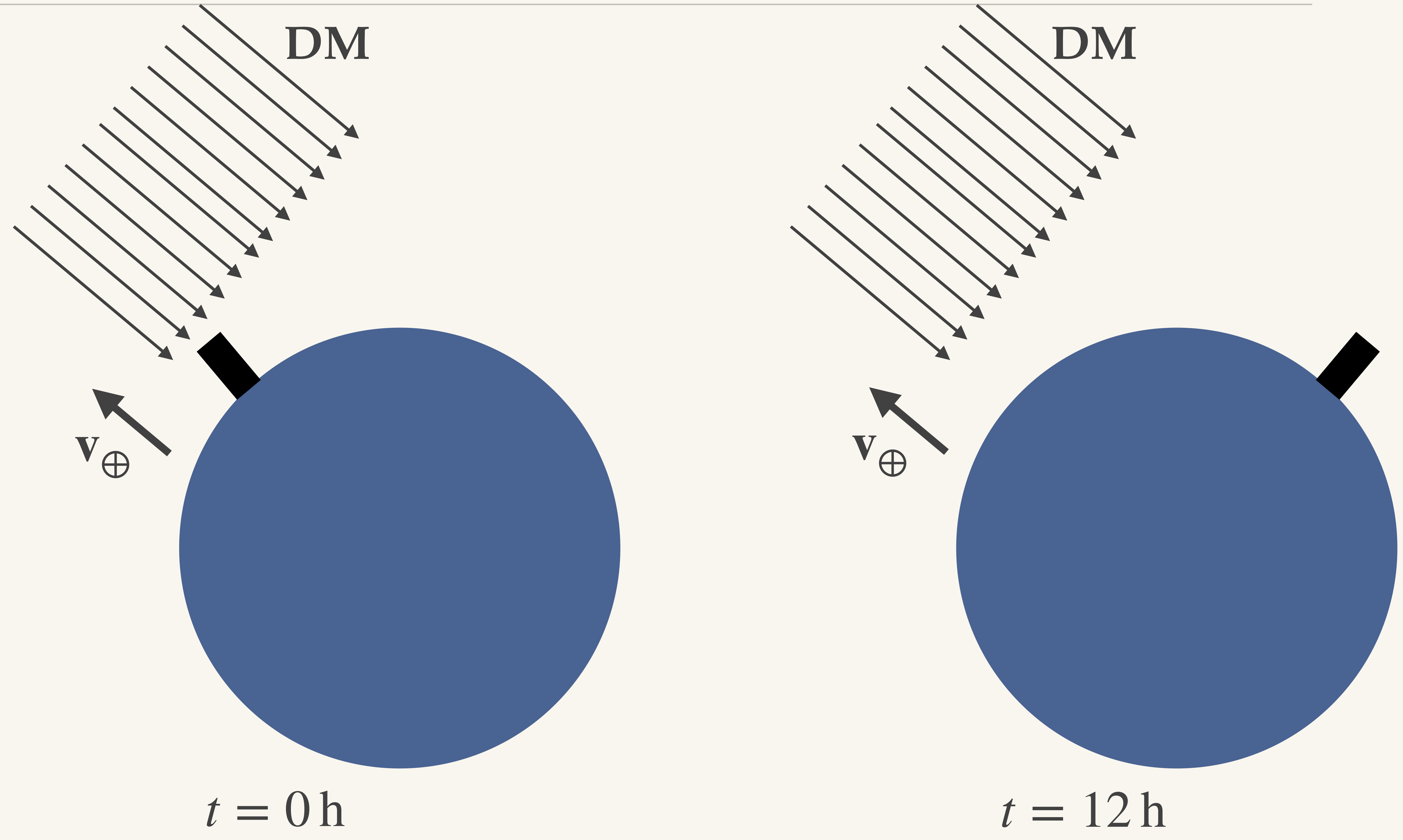
Directional Detection of DM

- Direction of DM wind changes throughout the day
- Experiments sensitive to directionality can discriminate signal from background



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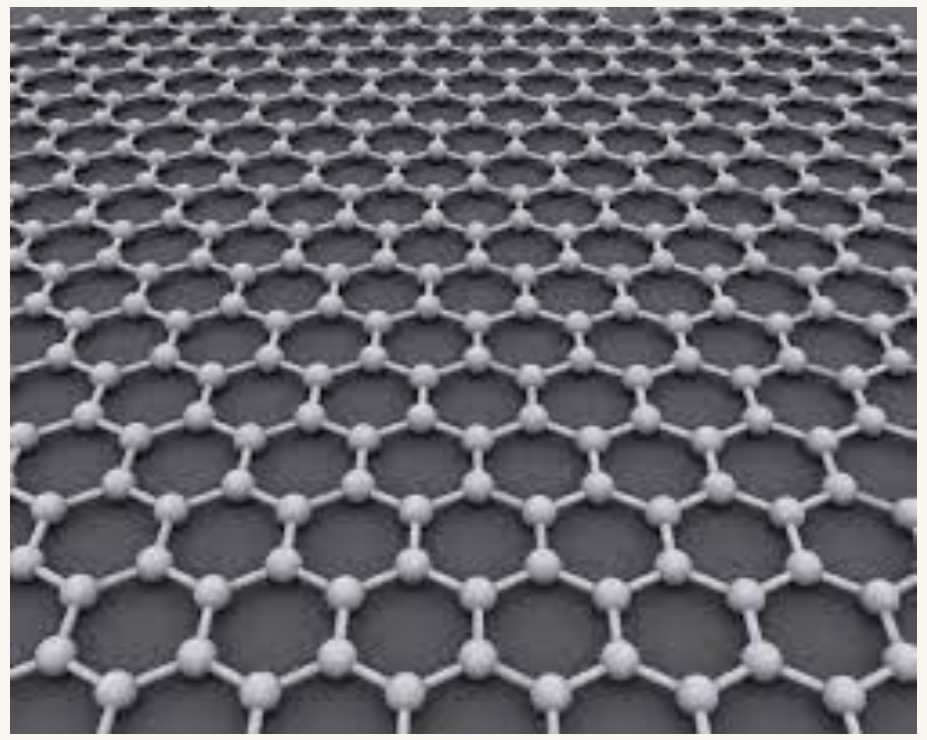
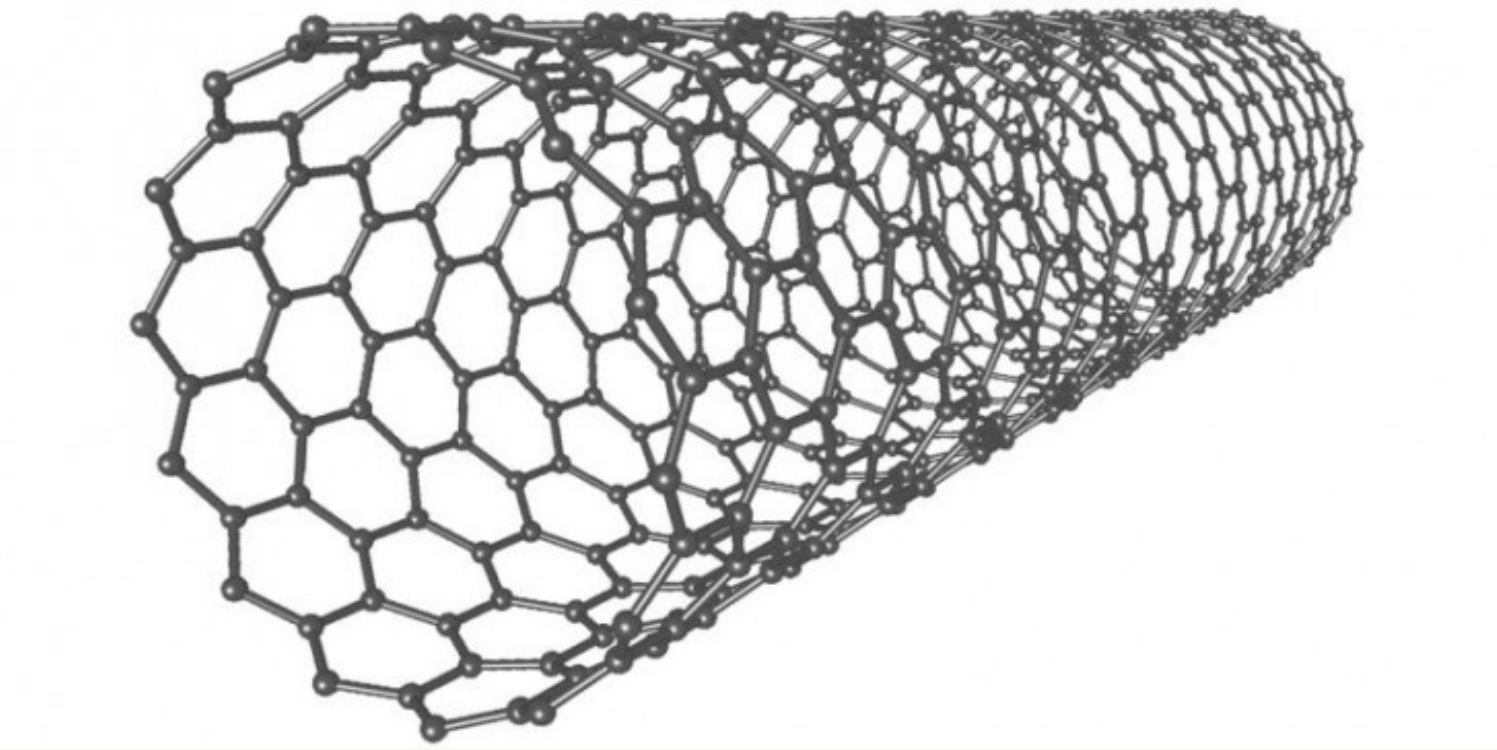
DM induced electron ejections from graphene and nanotubes

- The materials have asymmetric electron momentum distributions
- Electron scatterings are sensitive to DM masses down to a couple MeV
- Using NR-EFT to model arbitrary DM electron interactions, we find

$$\overline{\left|\mathcal{M}_{1\to 2}\right|^2} = \underbrace{\overline{\left|\mathcal{M}'\right|^2}}_{\text{DM particle physics}} \times \frac{1}{V} \underbrace{\left|\widetilde{\psi}_1(\mathbf{k}'-\mathbf{q})\right|^2}_{\text{target properties}}$$

Catena, Emken, Matas, Spaldin, Urdshals: Work in progress





$$\mathcal{O}_1 = \mathbb{1}_{\chi e}$$
$$\mathcal{O}_3 = i\mathbf{S}_e \cdot \left(\frac{\mathbf{q}}{m_e} \times \mathbf{v}_{\rm el}^{\perp}\right)$$
$$\mathcal{O}_4 = \mathbf{S}_\chi \cdot \mathbf{S}_e$$
$$\mathcal{O}_5 = i\mathbf{S}_\chi \cdot \left(\frac{\mathbf{q}}{m_e} \times \mathbf{v}_{\rm el}^{\perp}\right)$$
$$\mathcal{O}_6 = \left(\mathbf{S}_\chi \cdot \frac{\mathbf{q}}{m_e}\right)\left(\mathbf{S}_e \cdot \frac{\mathbf{q}}{m_e}\right)$$
$$\mathcal{O}_7 = \mathbf{S}_e \cdot \mathbf{v}_{\rm el}^{\perp}$$
$$\mathcal{O}_8 = \mathbf{S}_\chi \cdot \mathbf{v}_{\rm el}^{\perp}$$
$$\mathcal{O}_9 = i\mathbf{S}_\chi \cdot \left(\mathbf{S}_e \times \frac{\mathbf{q}}{m_e}\right)$$
$$\mathcal{O}_{10} = i\mathbf{S}_e \cdot \frac{\mathbf{q}}{m_e}$$
$$\mathcal{O}_{11} = i\mathbf{S}_\chi \cdot \frac{\mathbf{q}}{m_e}$$
$$\mathcal{O}_{12} = \mathbf{S}_\chi \cdot \left(\mathbf{S}_e \times \mathbf{v}_{\rm el}^{\perp}\right)$$
$$\mathcal{O}_{13} = i\left(\mathbf{S}_\chi \cdot \mathbf{v}_{\rm el}^{\perp}\right)\left(\mathbf{S}_e \cdot \frac{\mathbf{q}}{m_e}\right)$$
$$\mathcal{O}_{14} = i\left(\mathbf{S}_\chi \cdot \frac{\mathbf{q}}{m_e}\right)\left(\mathbf{S}_e \cdot \mathbf{v}_{\rm el}^{\perp}\right)$$
$$\mathcal{O}_{15} = i\mathcal{O}_{11}\left[\left(\mathbf{S}_e \times \mathbf{v}_{\rm el}^{\perp}\right) \cdot \frac{\mathbf{q}}{m_e}\right]$$

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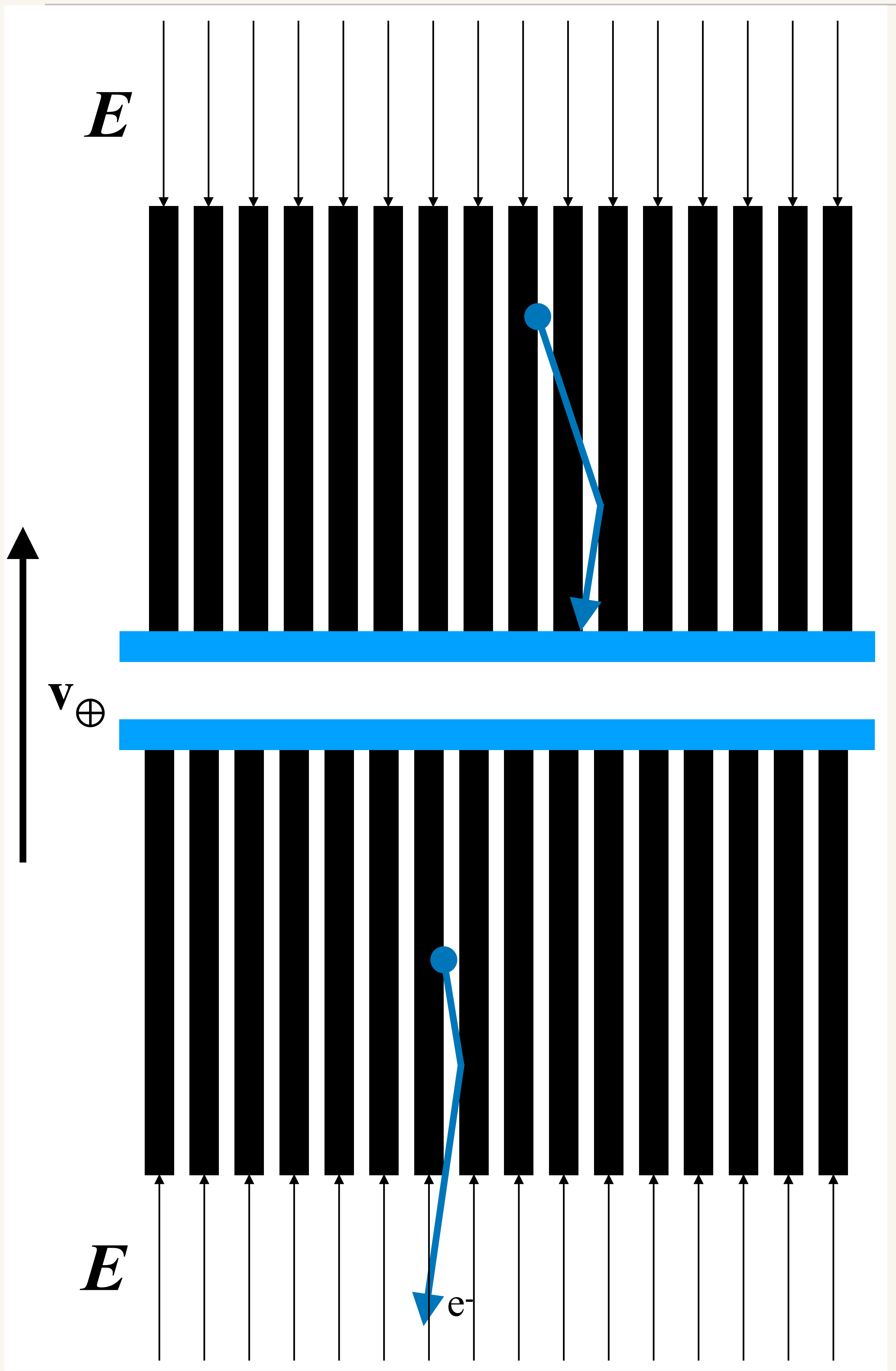
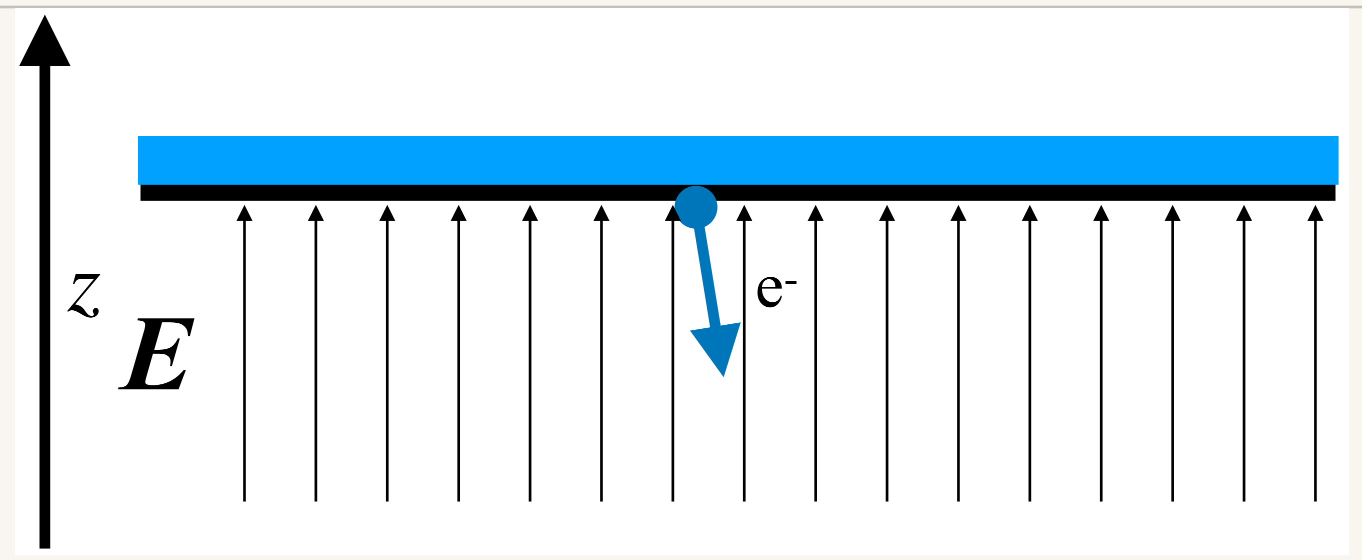
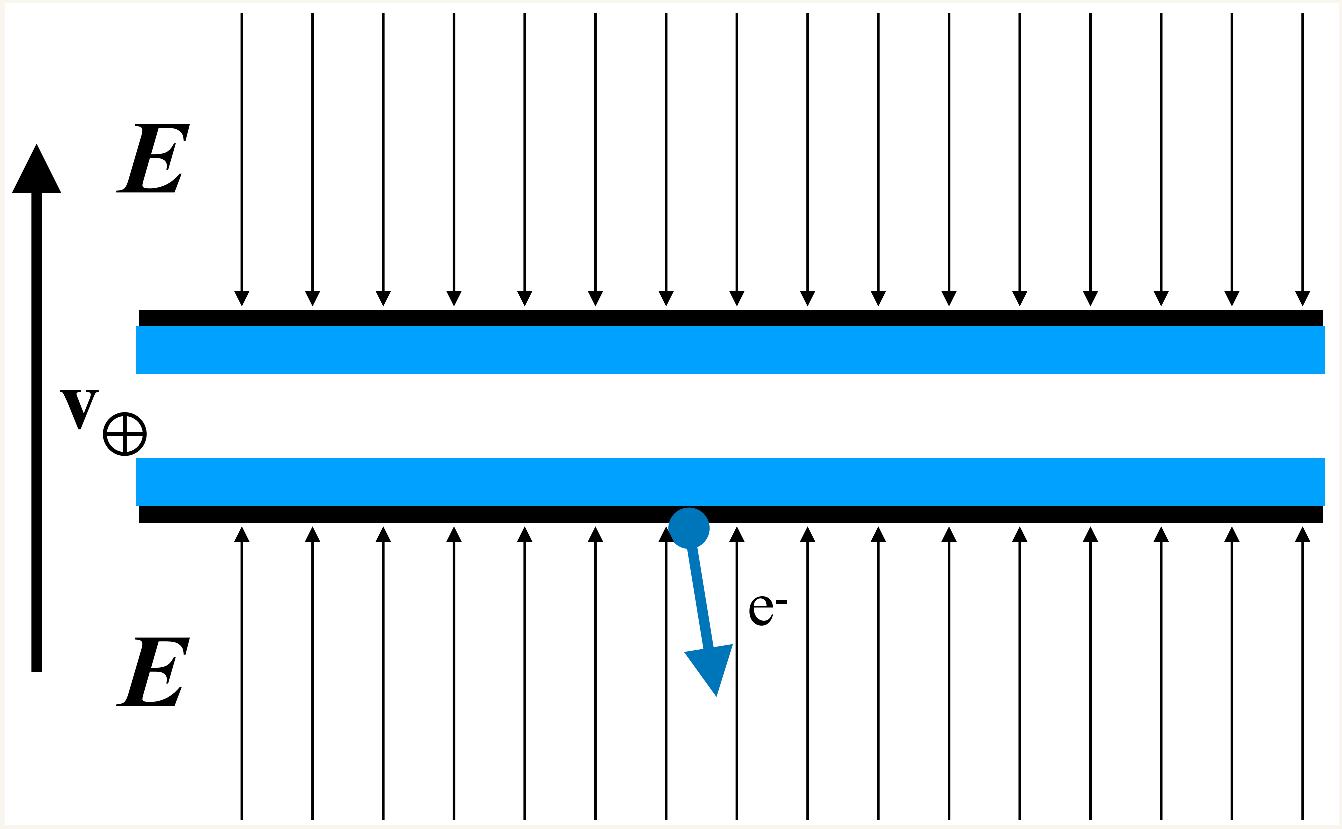
Experimental setups



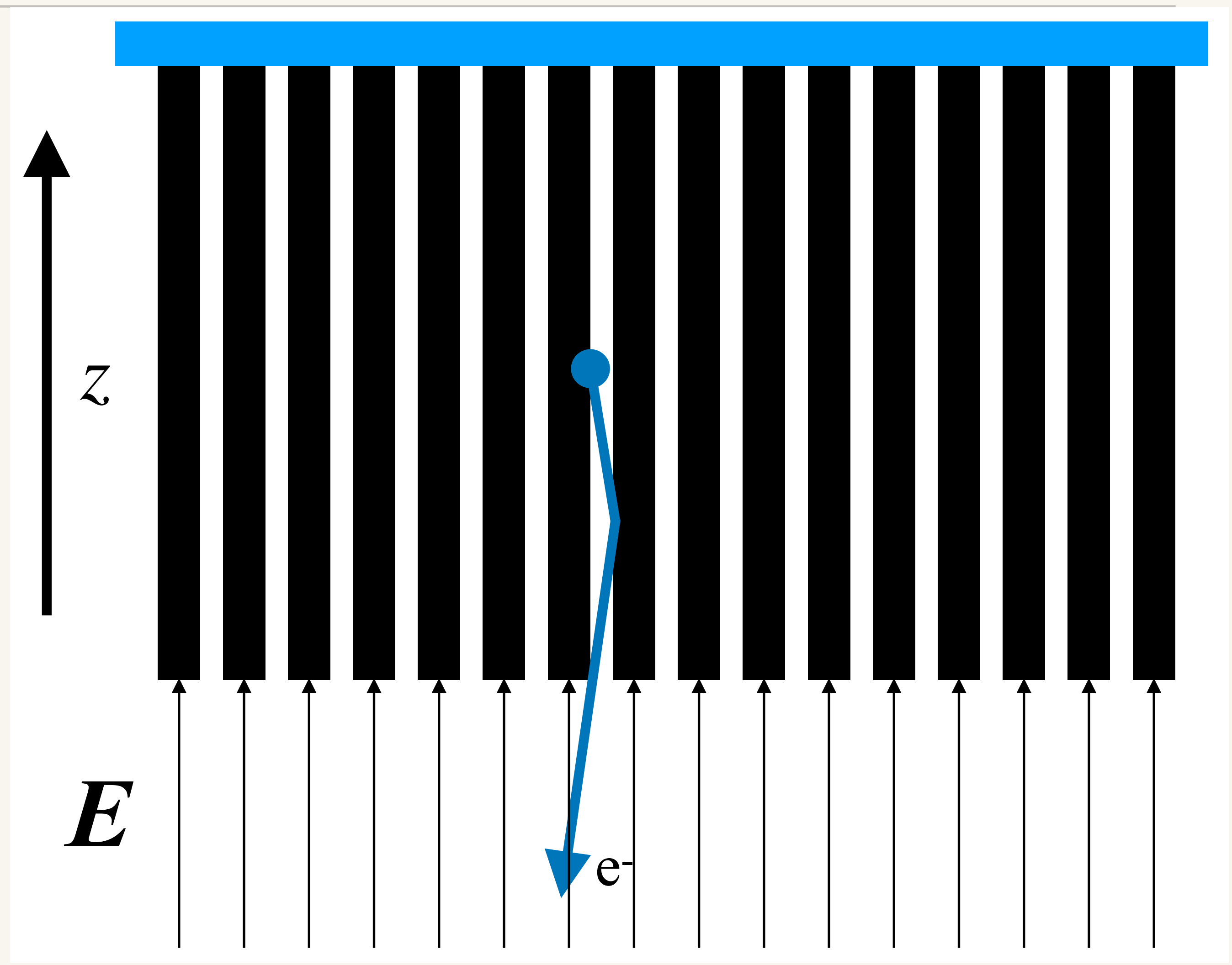
Moving Tubes (To be built by PTOLEMY CNT)



Fixed Sheets



Moving Sheets



Fixed Tubes

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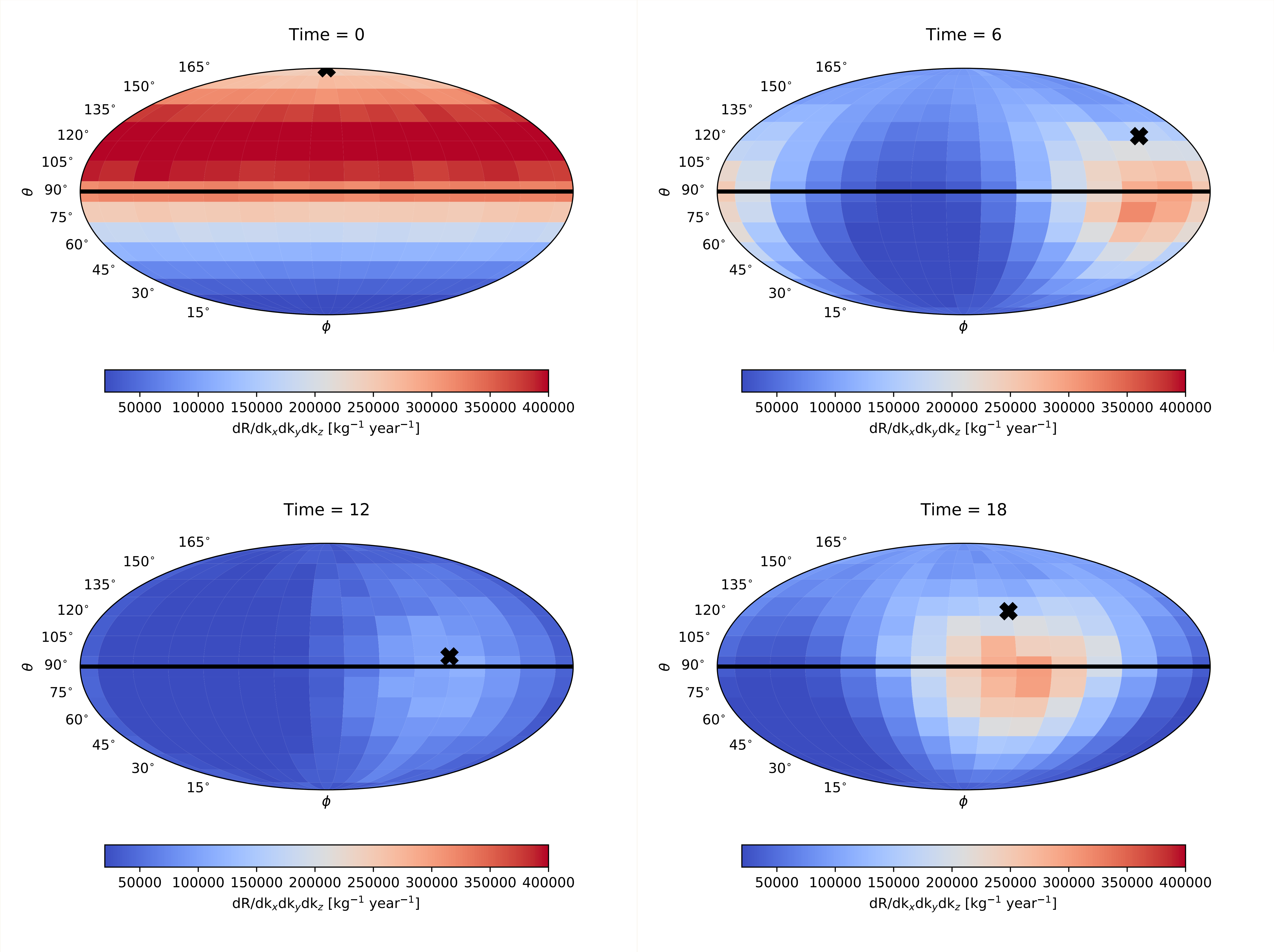
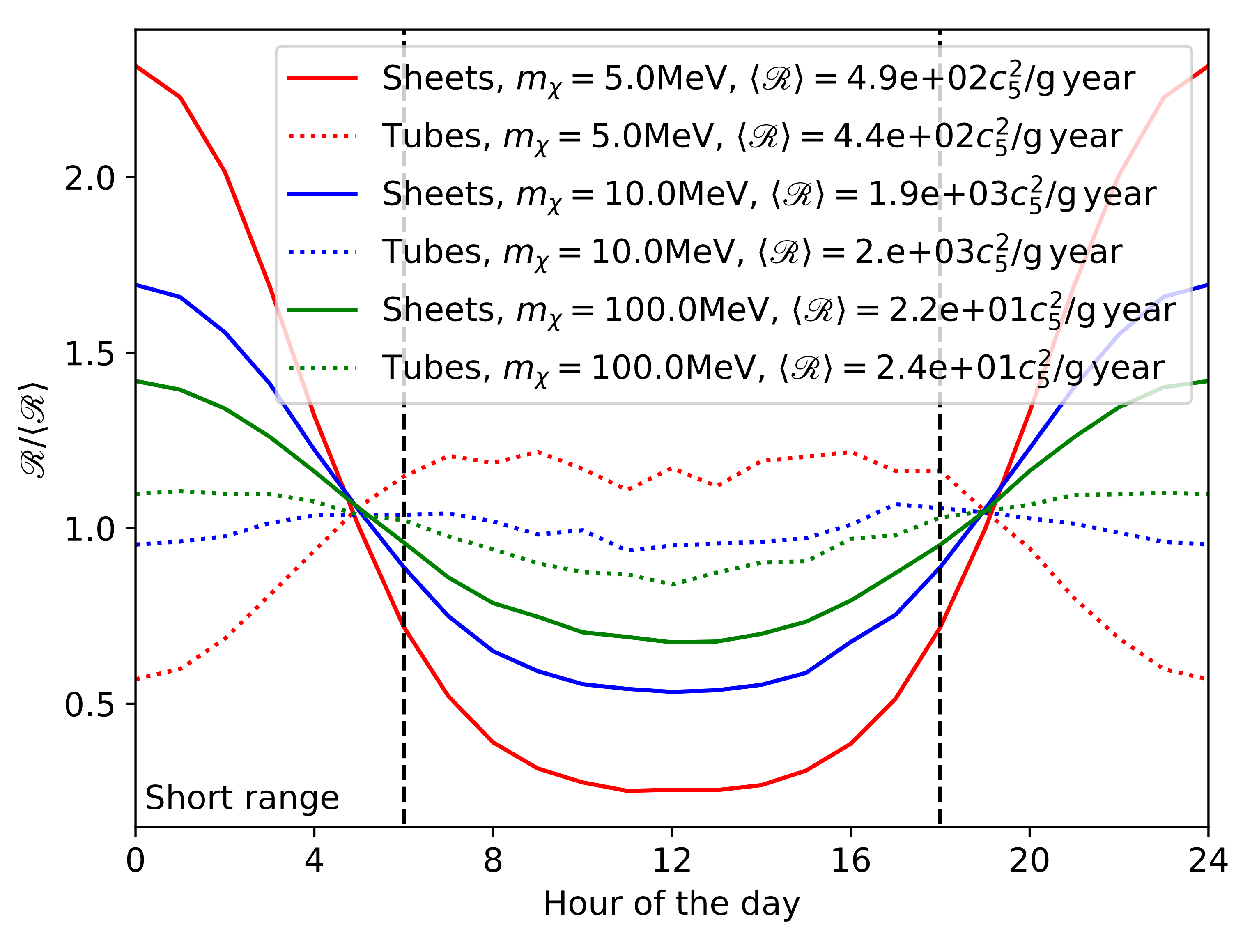
Daily Modulation in Fixed Experiments

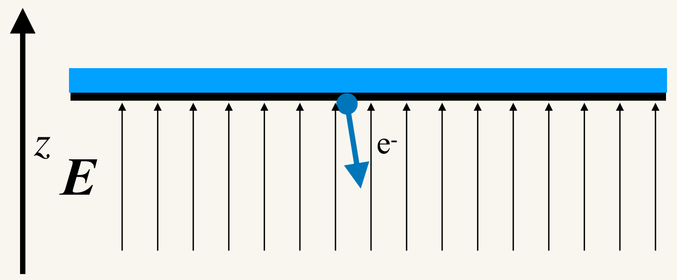


Catena, Emken, Matas, Spaldin, Urdshals: Work in progress

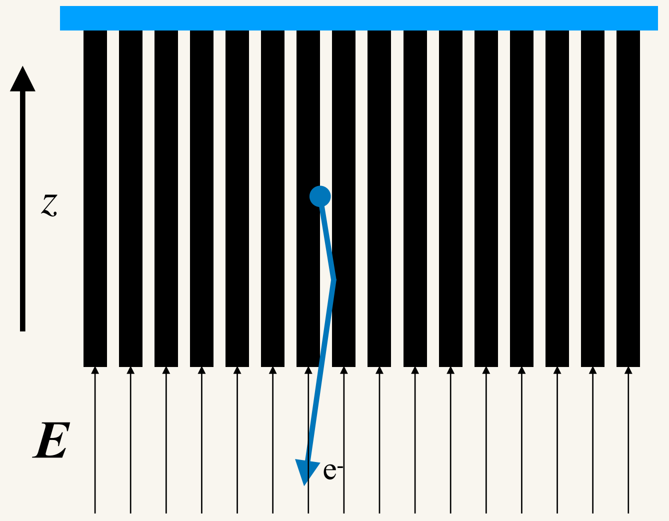
$$\mathcal{O}_5 = i\mathbf{S}_\chi \cdot \left(\frac{\mathbf{q}}{m_e} \times \mathbf{v}\right)$$



Catena, Emken, Matas, Spaldin, Urdshals: Work in progress



Fixed Sheets



Fixed Tubes

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Expected Sensitivity at 90% Confidence level

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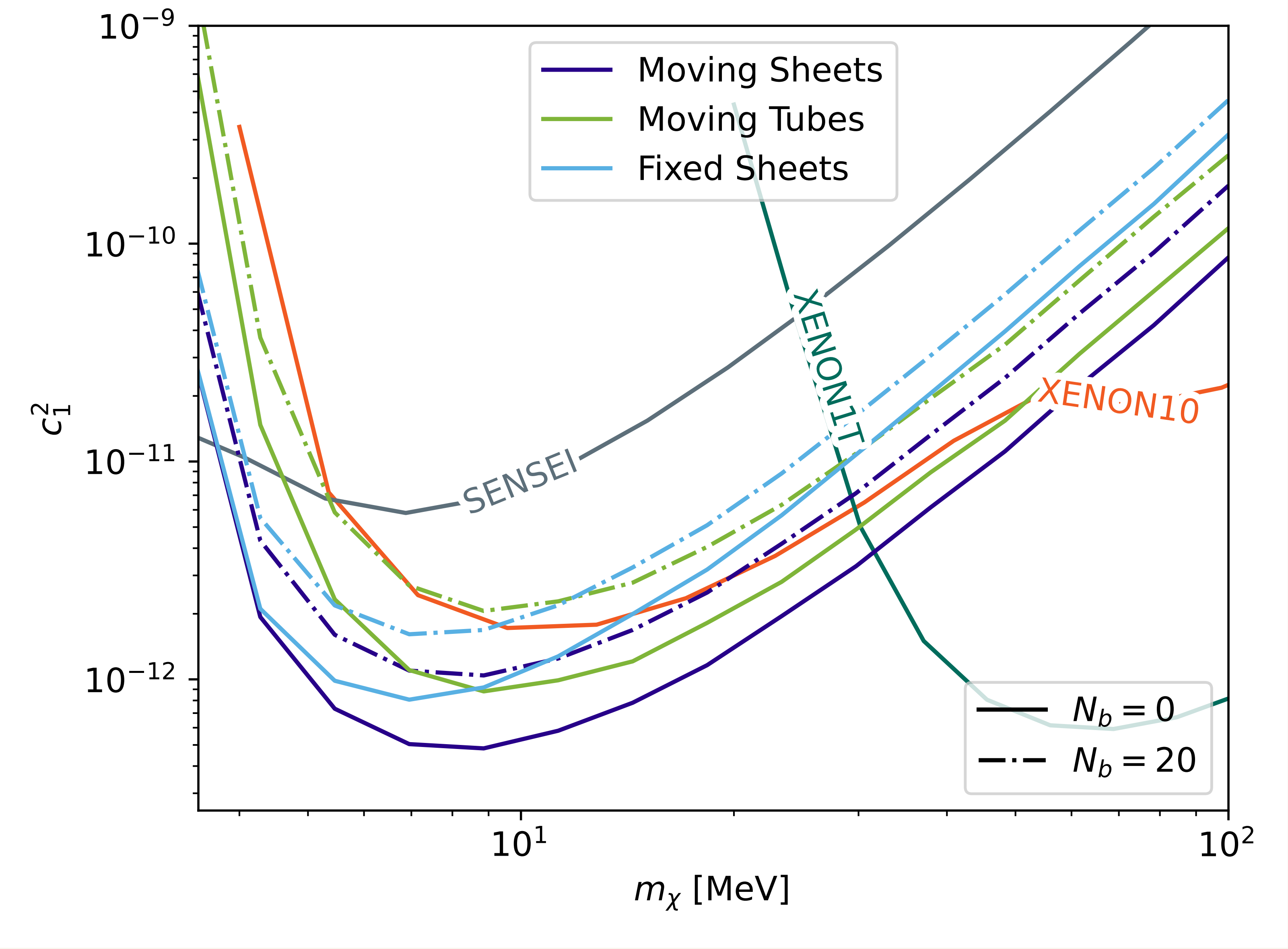
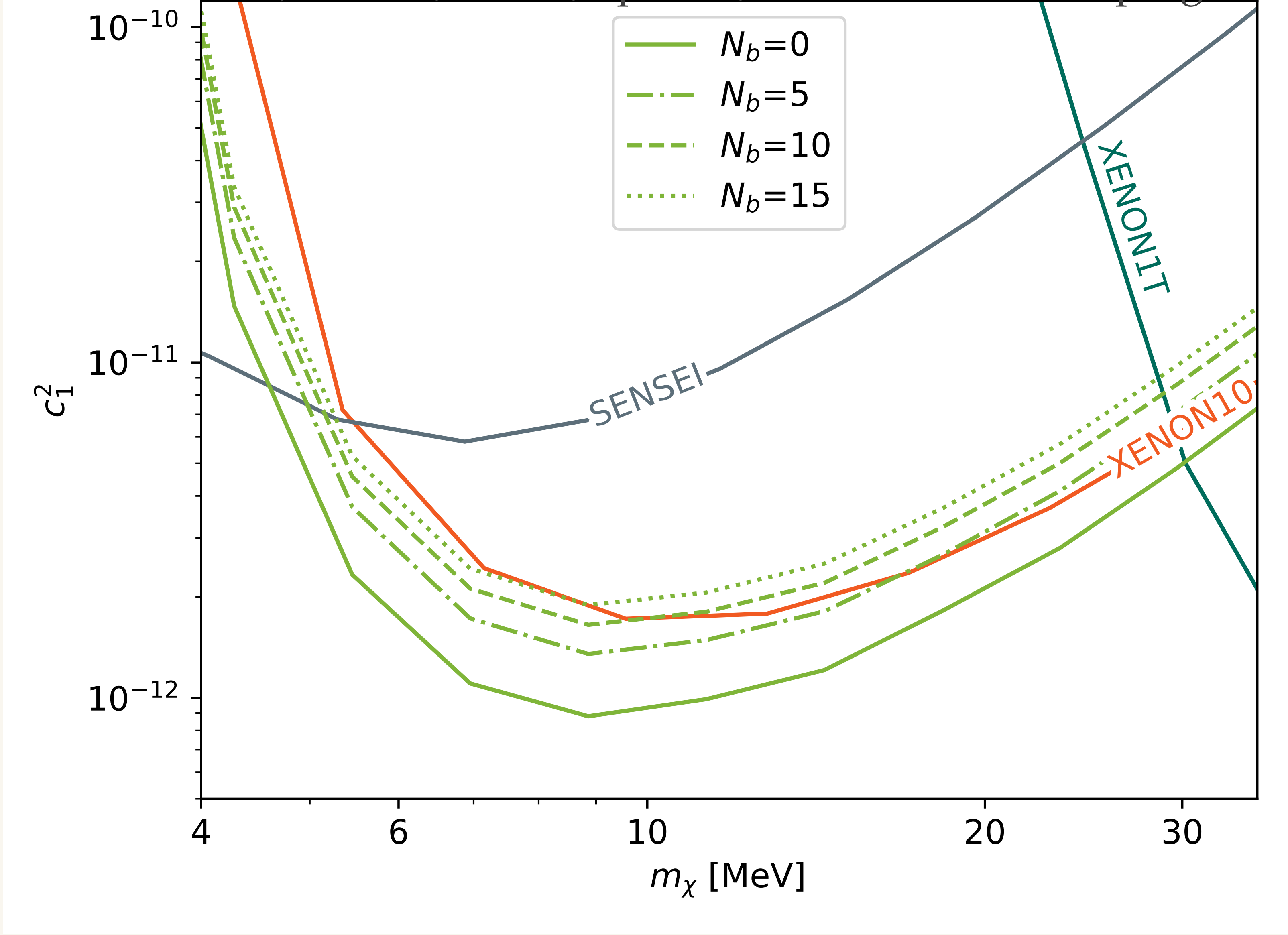
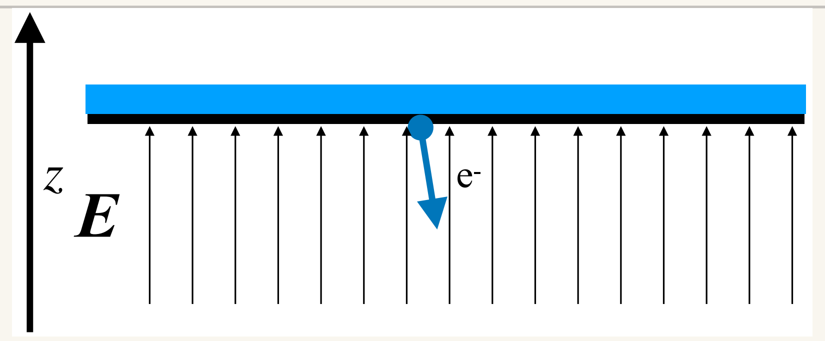
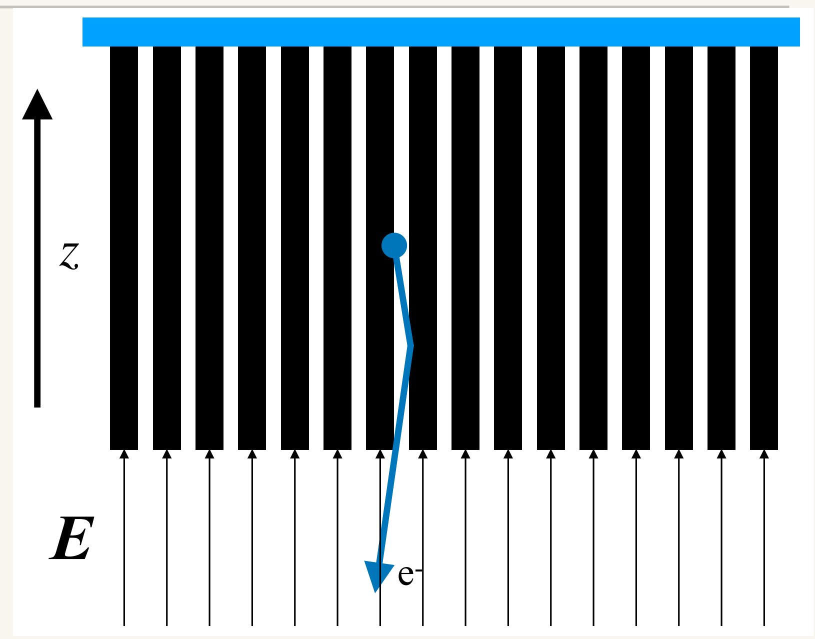




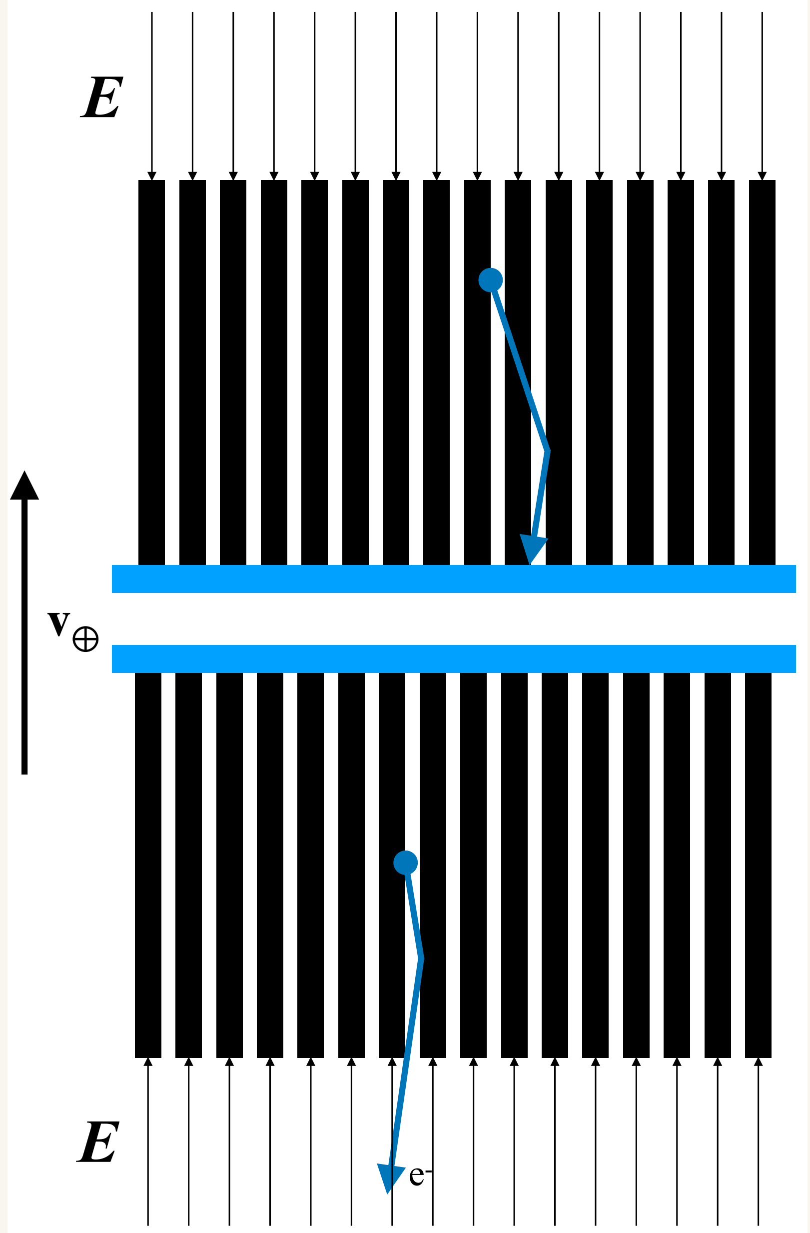
Assuming graphene/carbon nanotube exposure of 10g year



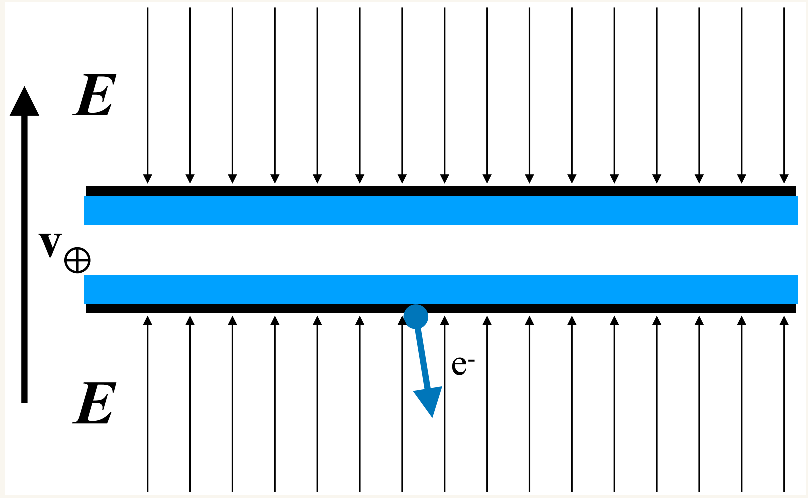
Fixed Sheets



Fixed Tubes



Moving Tubes



Moving Sheets

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Take Home Message

- Graphene and carbon nanotubes can be used to detect a smoking gun signals from DM.
- For the same exposure, graphene sheets are better suited for DM detection than carbon nanotubes (but nanotubes are easier to grow to larger detector mass)
- If DarkPMT manage an exposure of 10g year, they can detect DM if they manage less than ~20 background events.

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