

Cavendish Tests to Search for Millicharged Particles

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Based on hep-ph/2510.25825 and hep-ph/2510.25834
with Asher Berlin, Peter Graham, and Hari Ramani
and ongoing work with the above and Kent Irwin

Outline

1. Earth-Bound Millicharged Dark Matter Models
2. New Constraints from Old Experiments
3. Projected Reach of a Dedicated Experiment

Earth-Bound Millicharged Dark Matter Models

Dark matter can have a small electric charge

- “True” millicharges can carry a very small hypercharge
- Low energies: usually only the small resulting EM charge matters

$$\mathcal{L} \supseteq -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \bar{\psi}(i\not{D} - \mu)\psi - q\bar{\psi}\gamma^\mu\psi A_\mu$$

Millicharged particle of mass μ and charge $q \ll e$

SM photon

For simplicity, this is the case I'll assume in most of this talk

MCPs can also arise from kinetic mixing

- DM particles could instead be coupled to a dark photon
- Kinetic mixing with the SM photon gives an “effective” millicharge

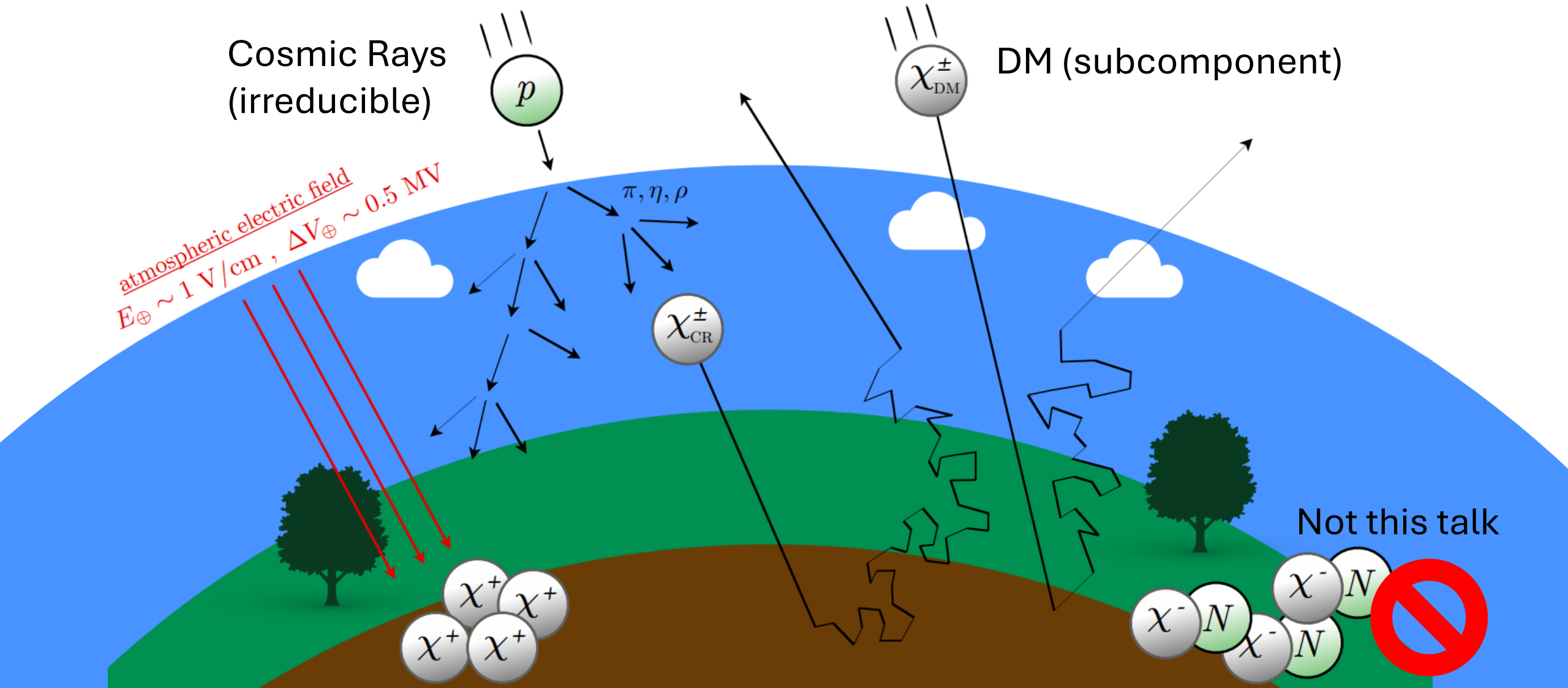
$$\mathcal{L} \supseteq -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{1}{2}\epsilon F_{\mu\nu}F'^{\mu\nu} + \frac{1}{2}m_{A'}^2 A_\mu A^\mu + g A'_\mu J_{\text{DM}}^\mu$$

Dark photon of mass $m_{A'}$

Kinetic mixing

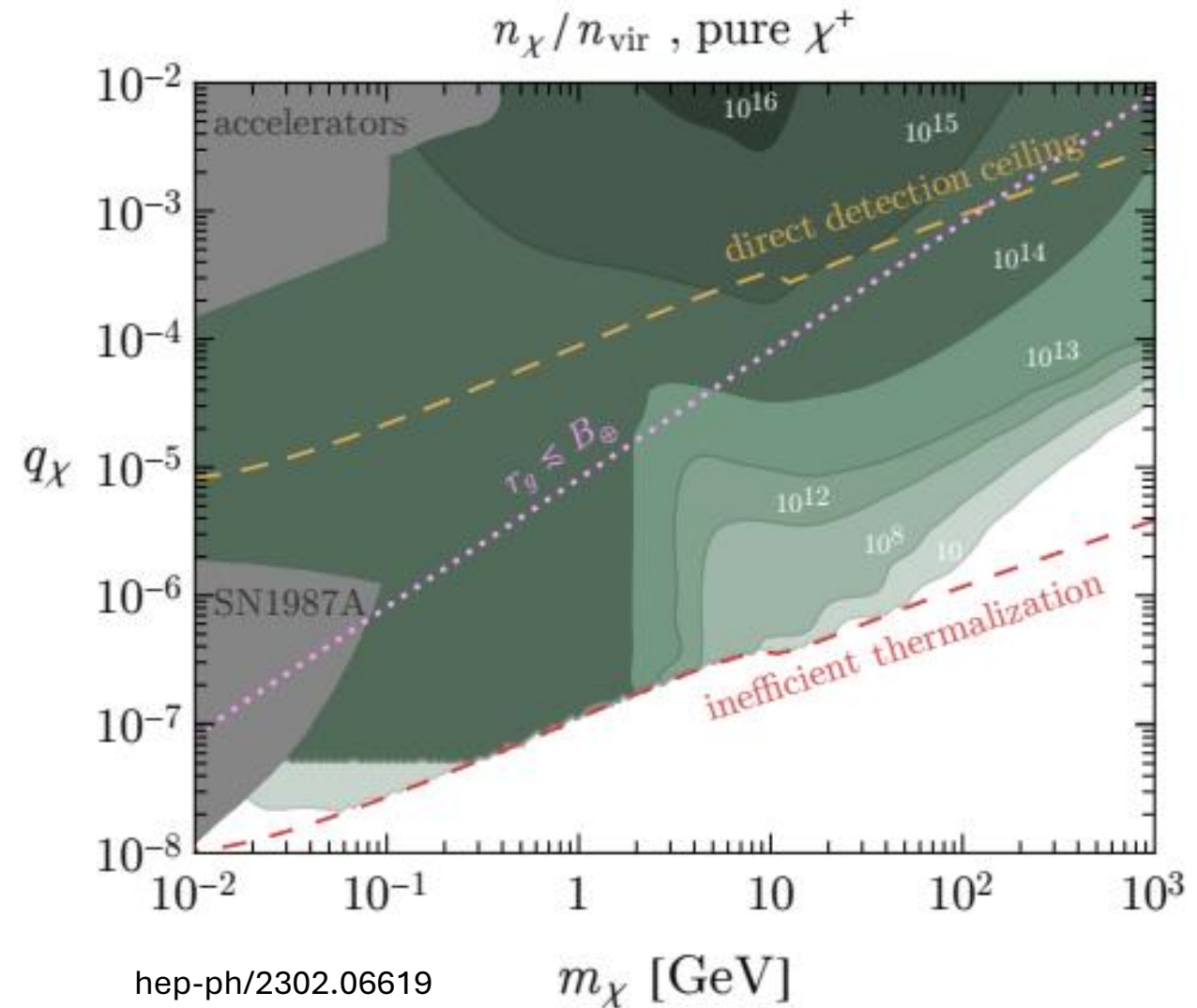
On length scales $\ll m_{A'}^{-1}$, DM picks up an effective charge of $q_{\text{eff}} = \epsilon g$

MCPs can accumulate on Earth



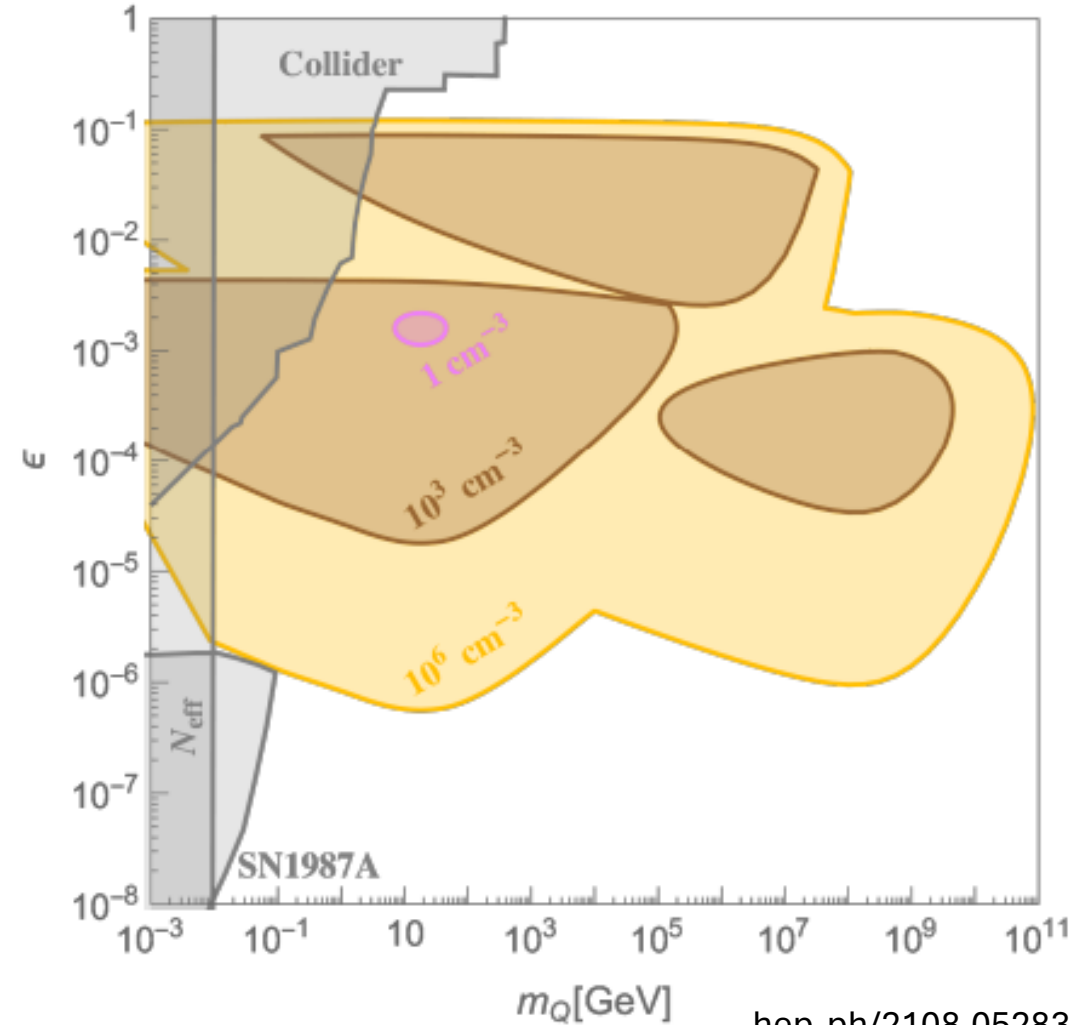
Millicharged DM can reach huge overdensities

Rapid thermalization
+
Atmospheric trapping
+
Slow diffusion
↓
High terrestrial density
Low energy

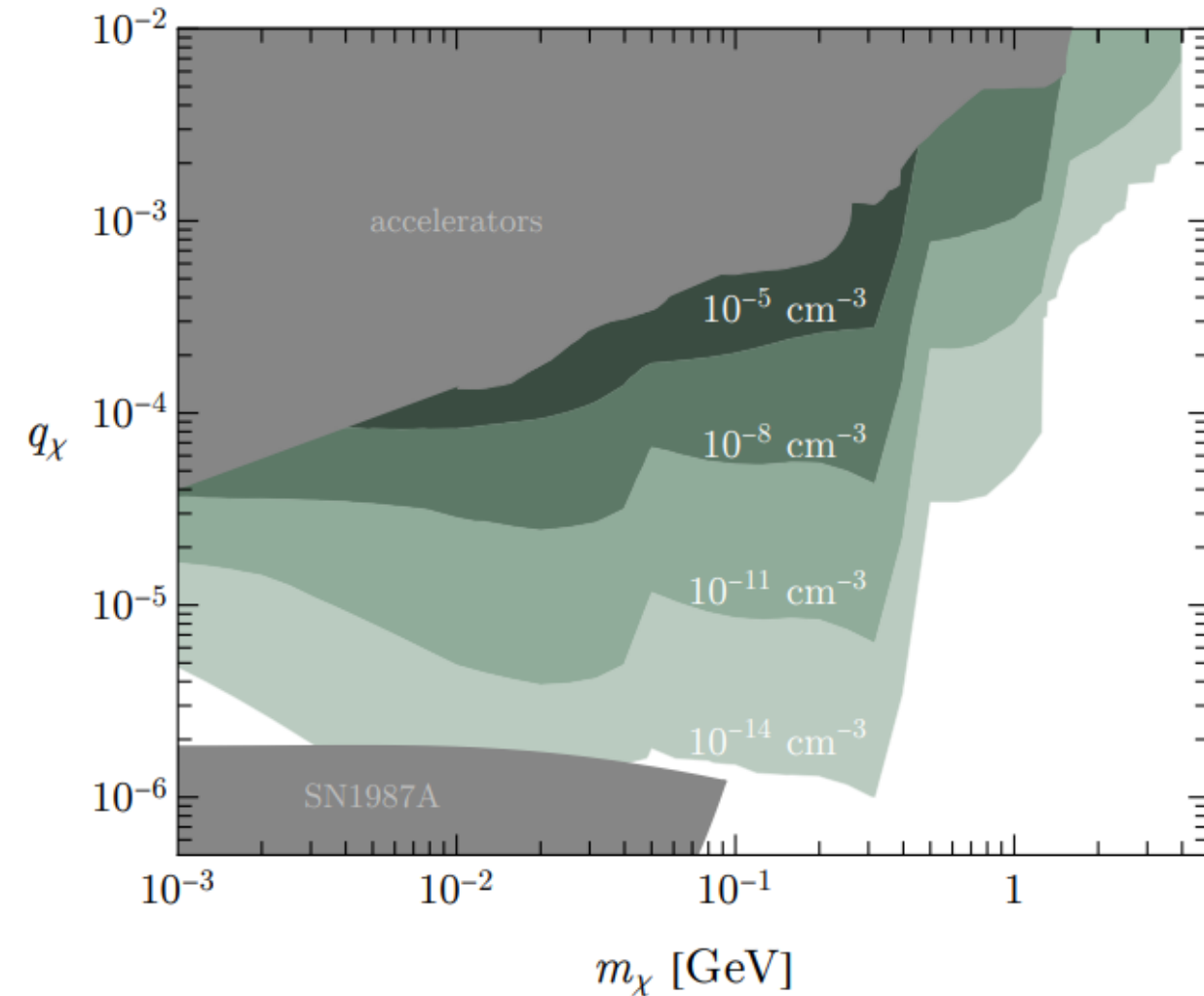


Millicharge parameter space – Earth-bound

- In the case of Earth-bound millicharges, we have an additional degree of freedom: the terrestrial density
- Difficult to predict from f_{DM} so we will work directly in terms of this terrestrial density



Millicharge parameter space – cosmic rays



- Millicharges can also be created by meson decays in Earth's atmosphere from cosmic ray interactions
- This leads to a terrestrial millicharge density even if the millicharges aren't DM

New Constraints from Old Experiments

A test of Coulomb's law: P&L, 1936

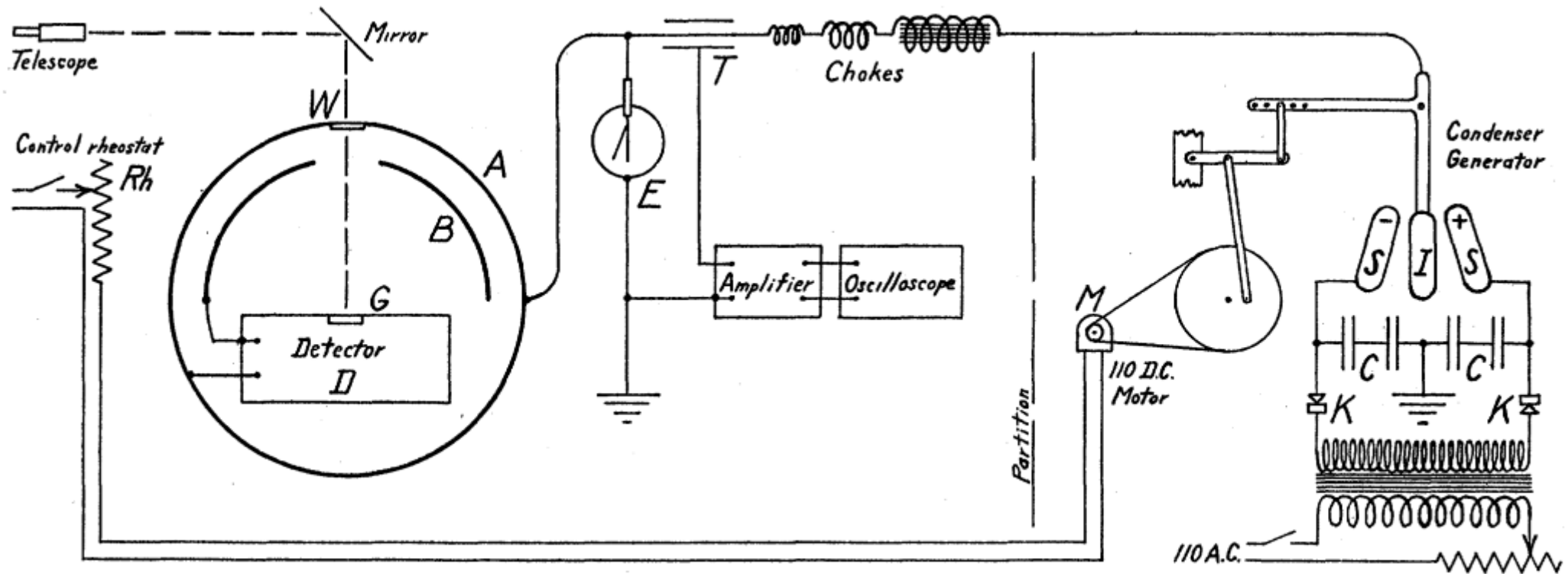
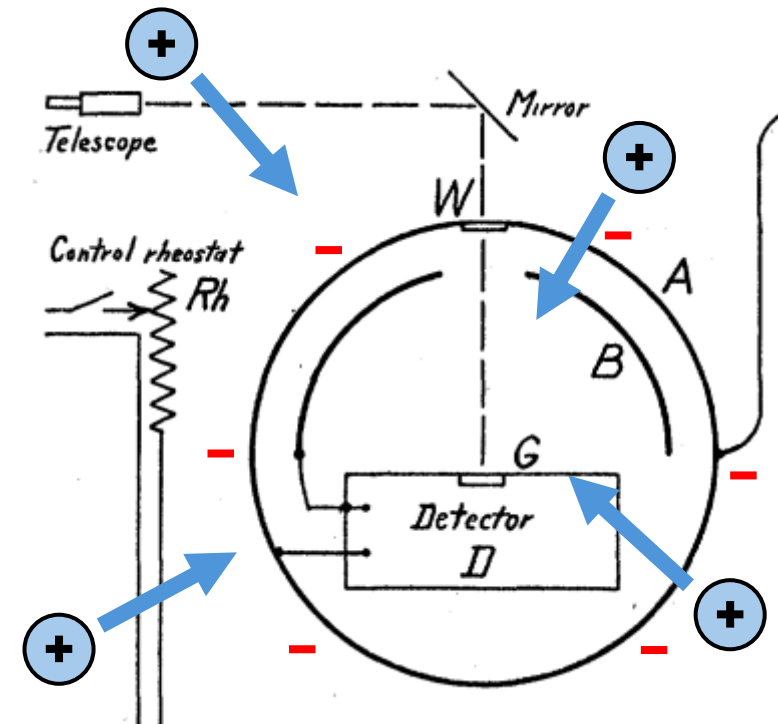


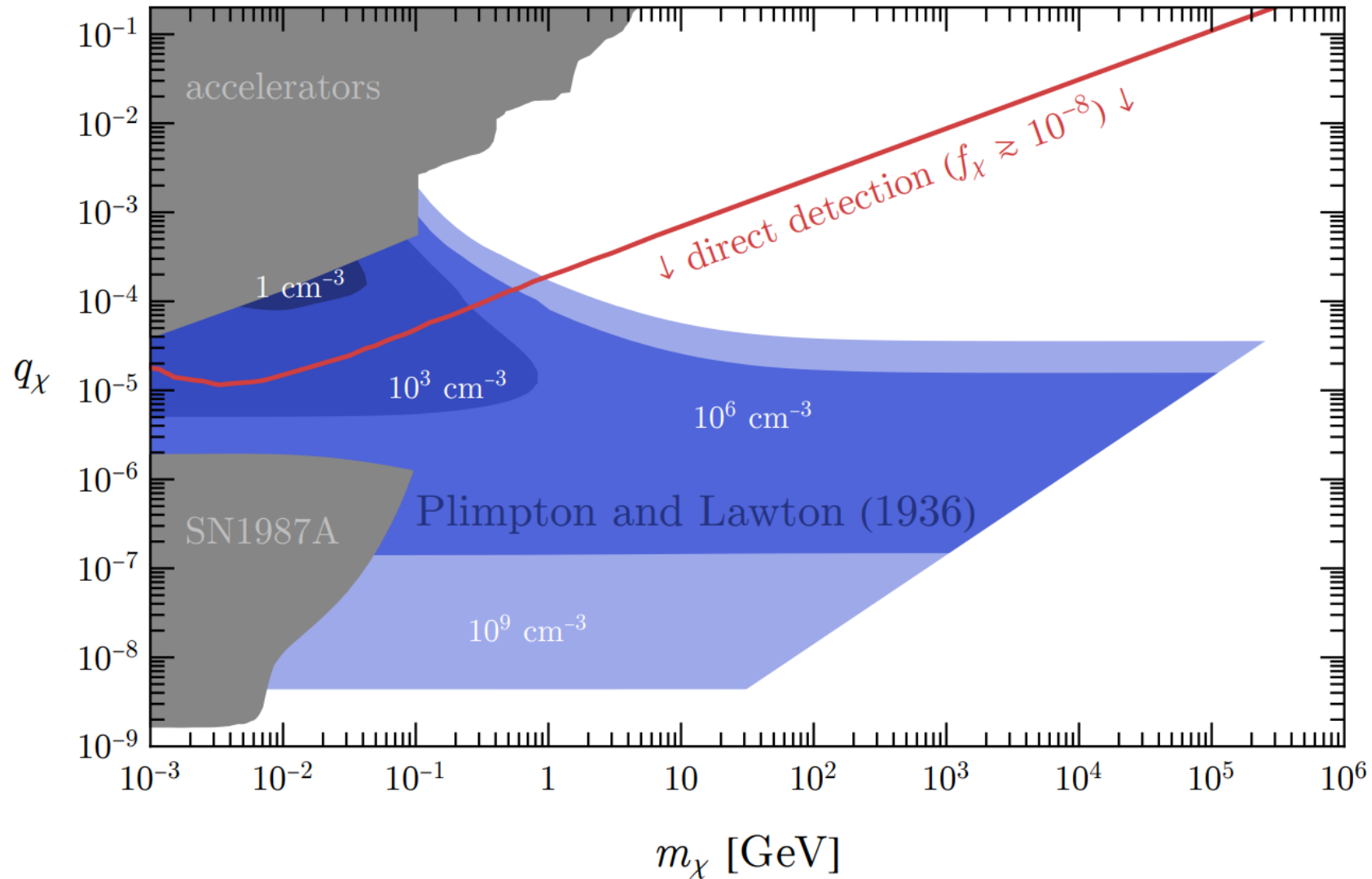
FIG. 1. Apparatus for testing the inverse square law of force between charges.

P&L, 1936 could also detect millicharges

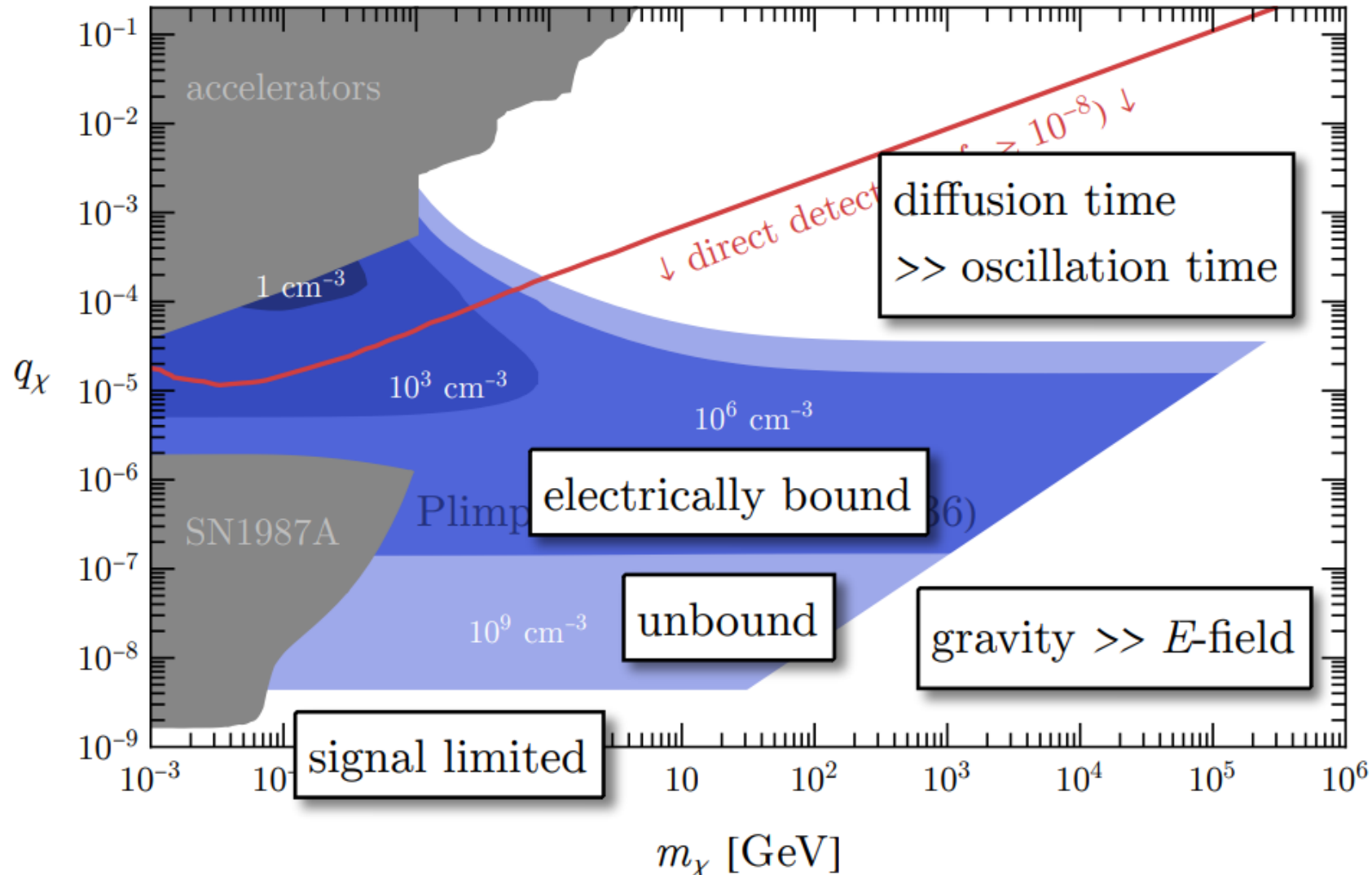
- The potential of the outer shell will pull in opposite-sign millicharges
- These pass through the conductor and create a potential on the inner shell
- Negligible field inside, so millicharges don't get pushed back out



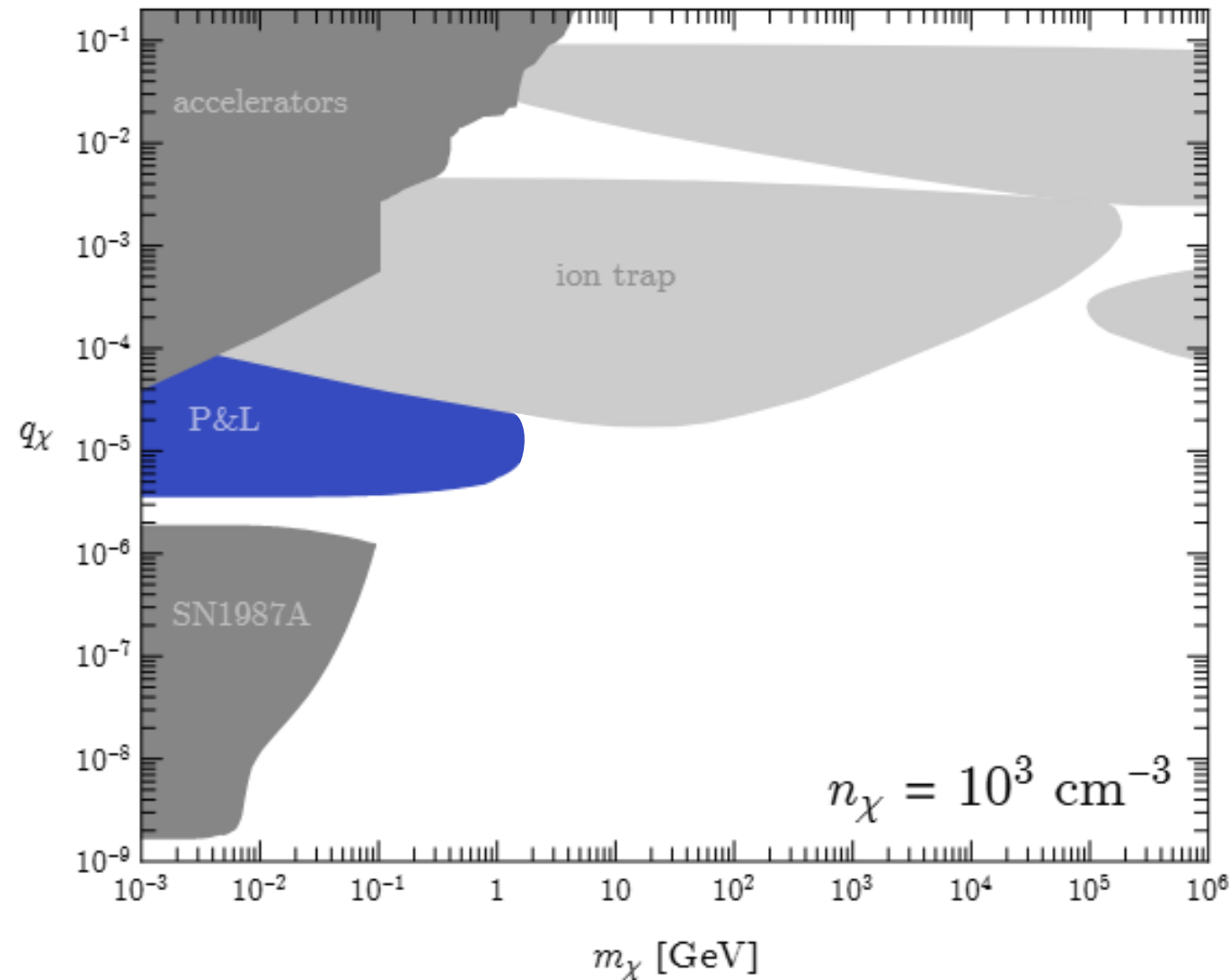
P&L, 1936 sets new limits on millicharged DM



P&L, 1936 sets new limits on millicharged DM

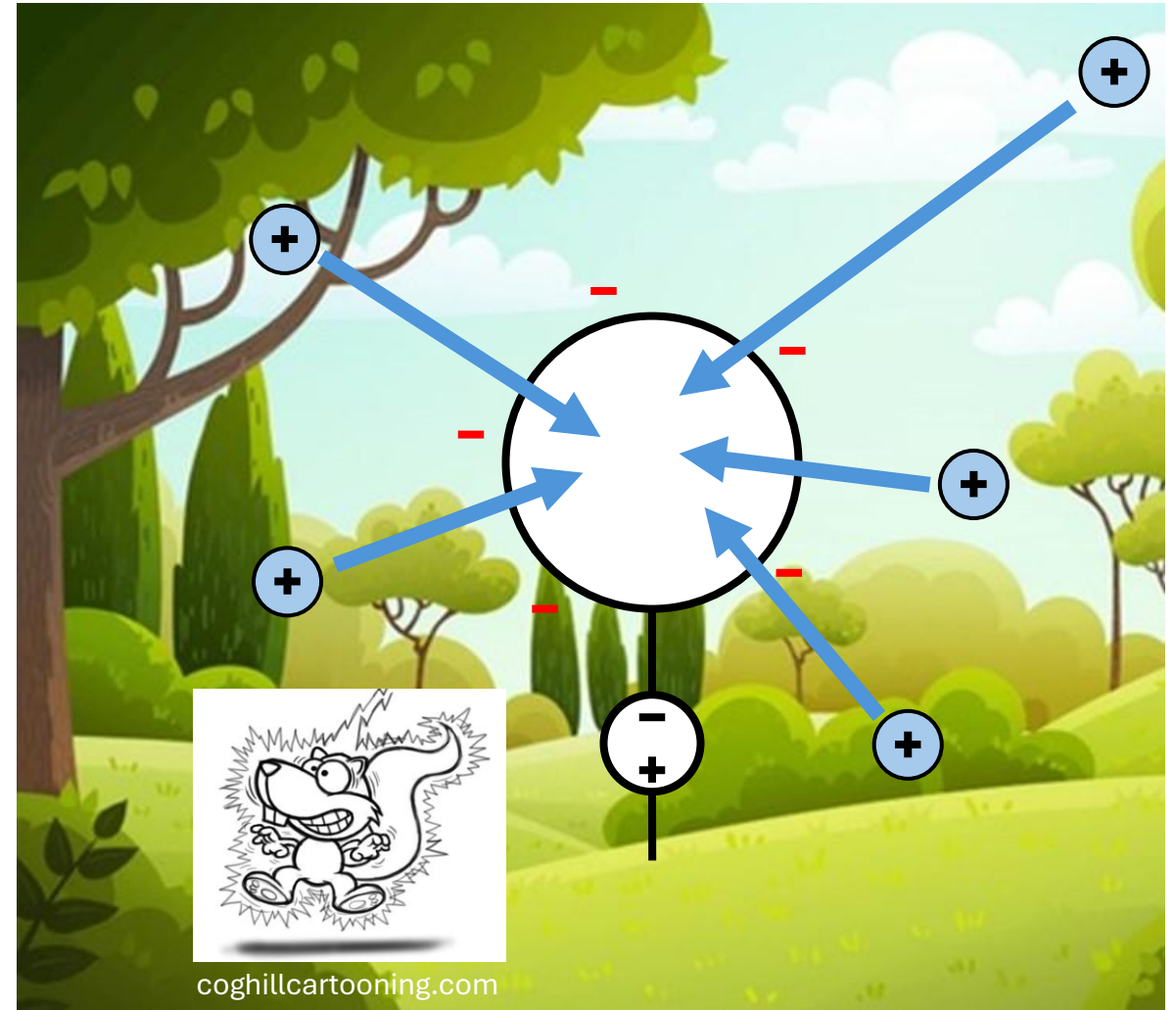
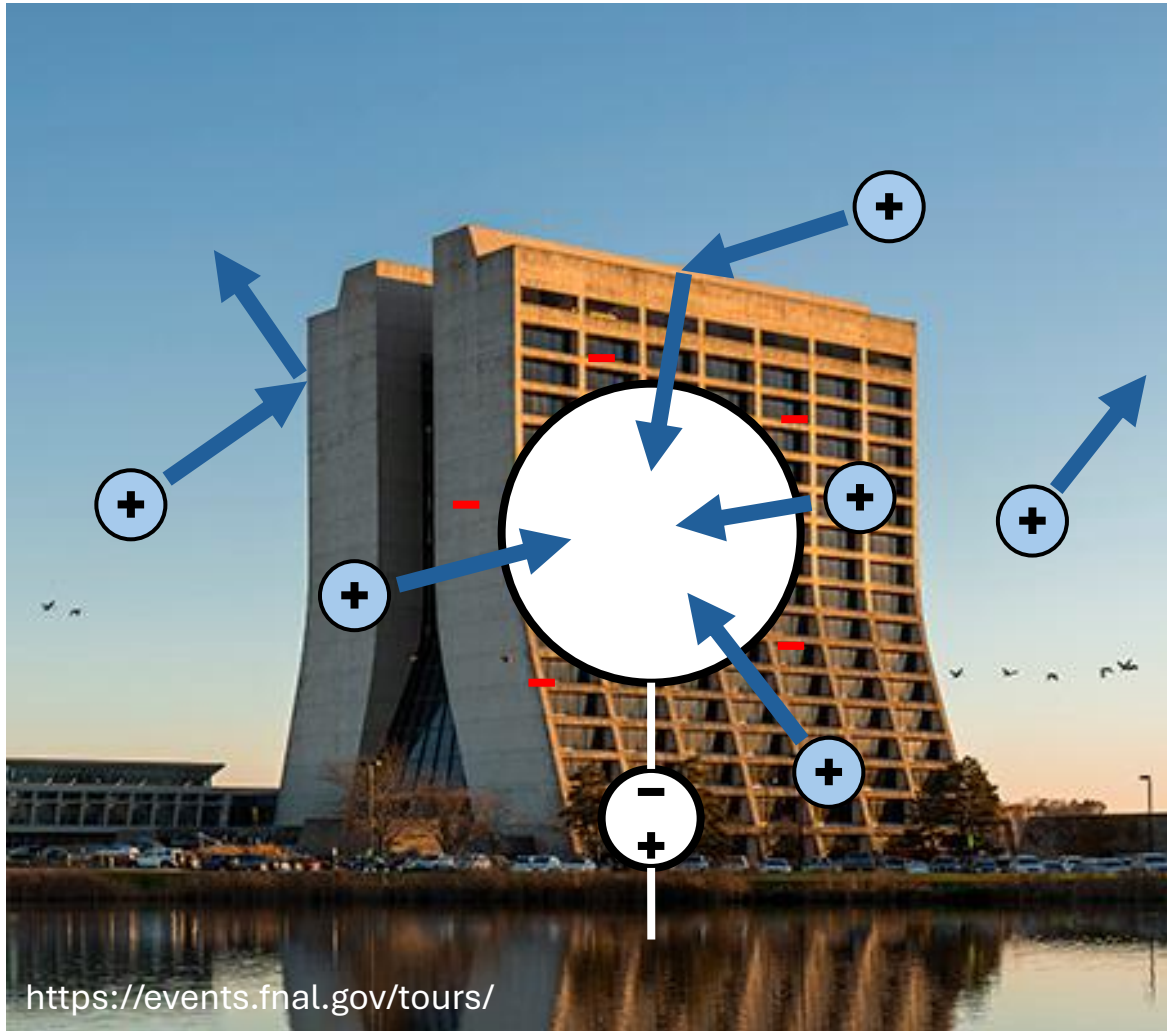


P&L, 1936 sets new limits on millicharged DM

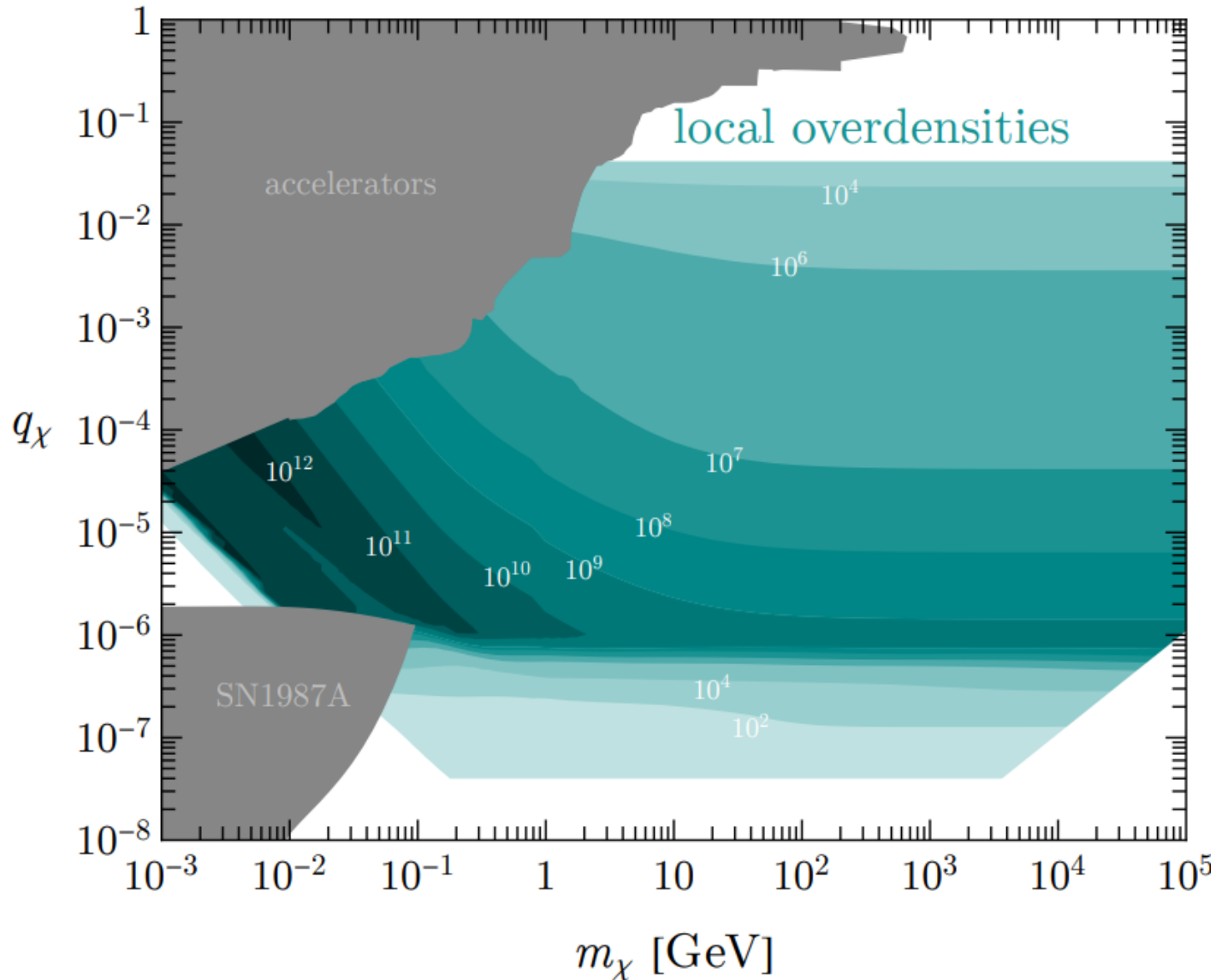


Projected Reach of a Dedicated Experiment

A fixed potential will vacuum up millicharges

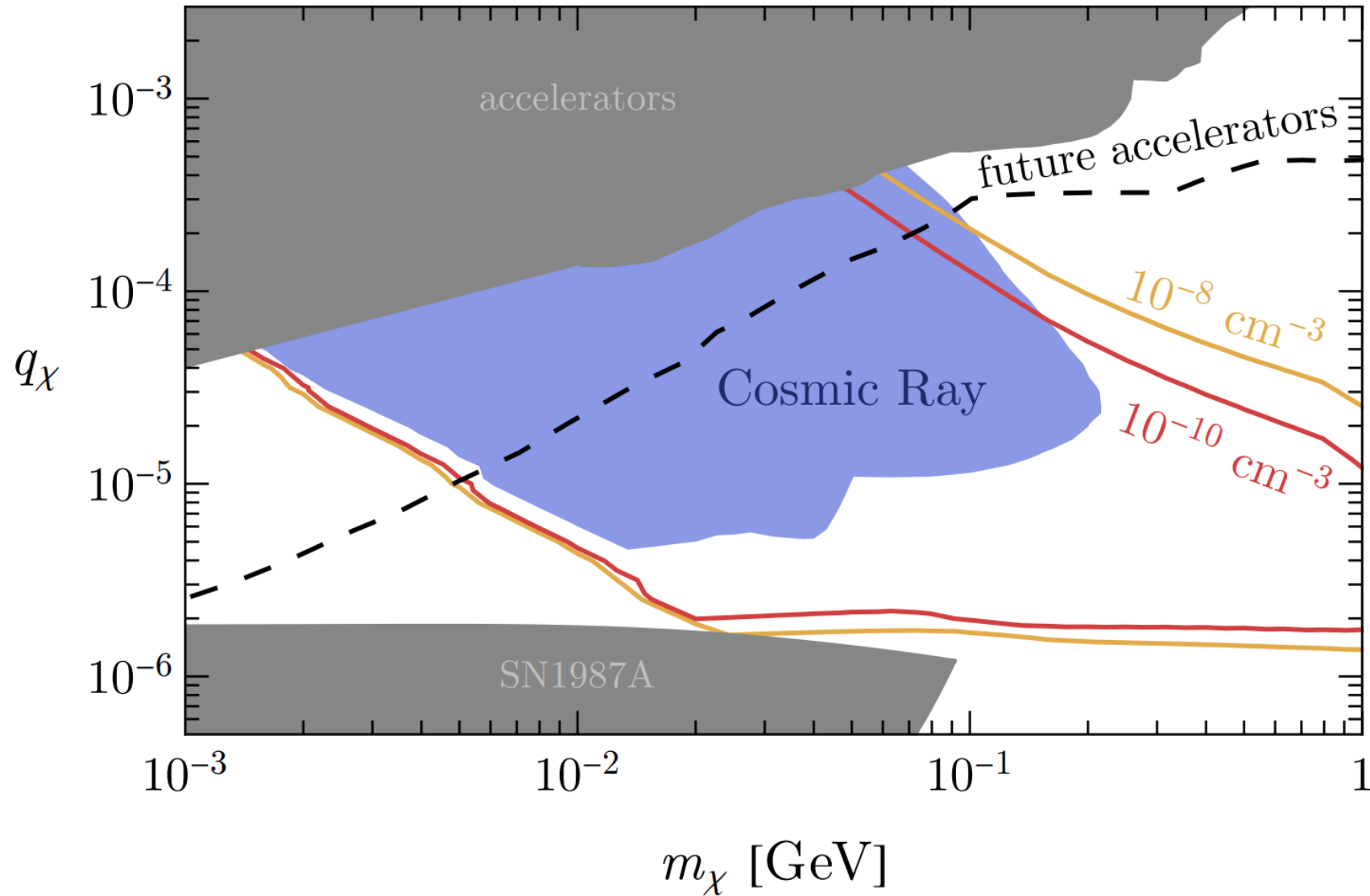


Fixed potentials can give large overdensities

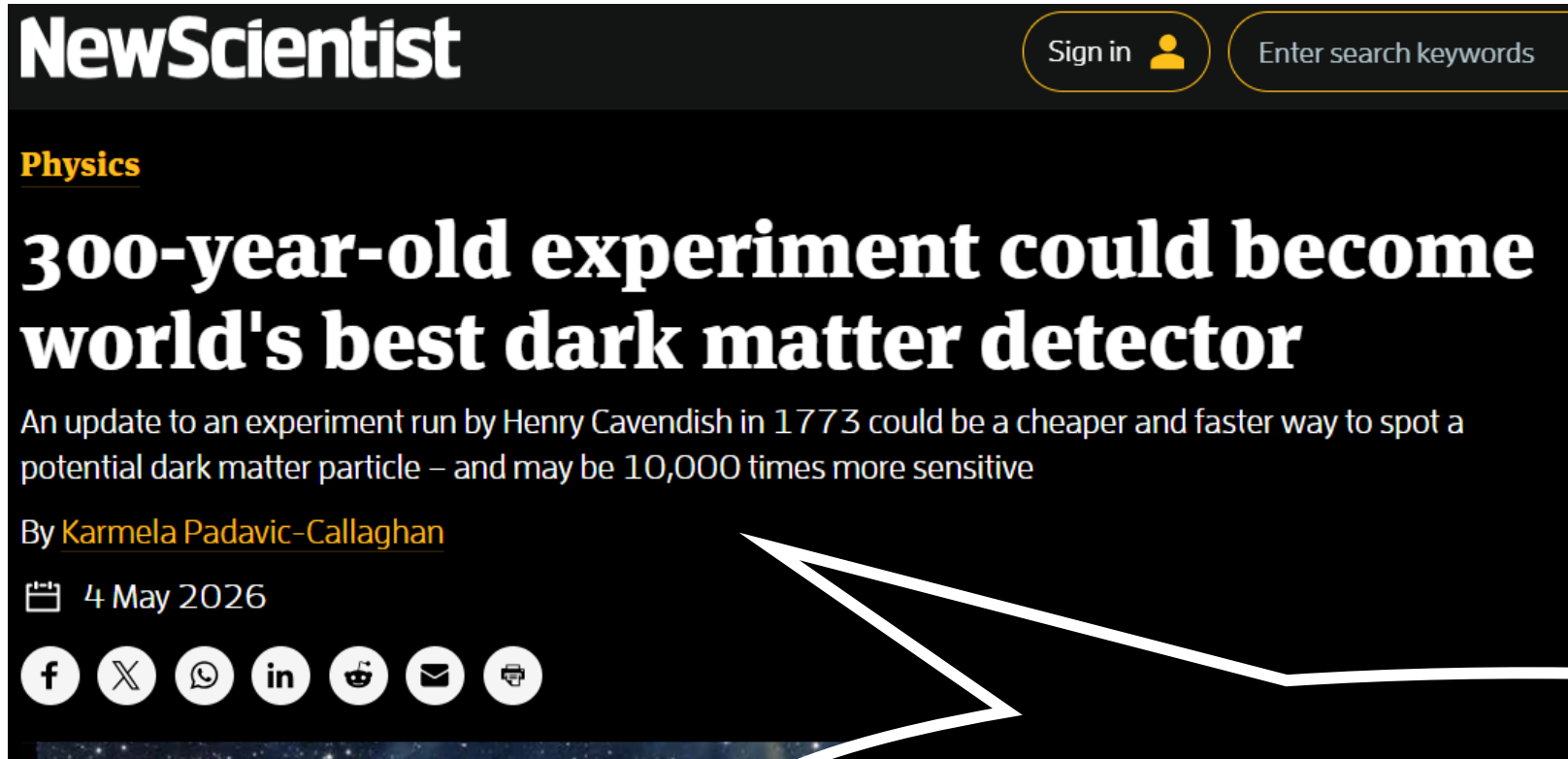


This is the outdoor case for simplicity; indoors depends on many more parameters but can still be very large

Modified P&L, 1936 – sensitivity



Summary



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Physics

300-year-old experiment could become world's best dark matter detector

An update to an experiment run by Henry Cavendish in 1773 could be a cheaper and faster way to spot a potential dark matter particle – and may be 10,000 times more sensitive

By Karmela Padavic-Callaghan

 4 May 2026

A white speech bubble originates from the author's name 'Karmela Padavic-Callaghan' and points towards a large black oval containing a quote.

“You could store and gift people millicharged particles,”

Questions?