Cavendish Tests to Search for Millicharged Particles

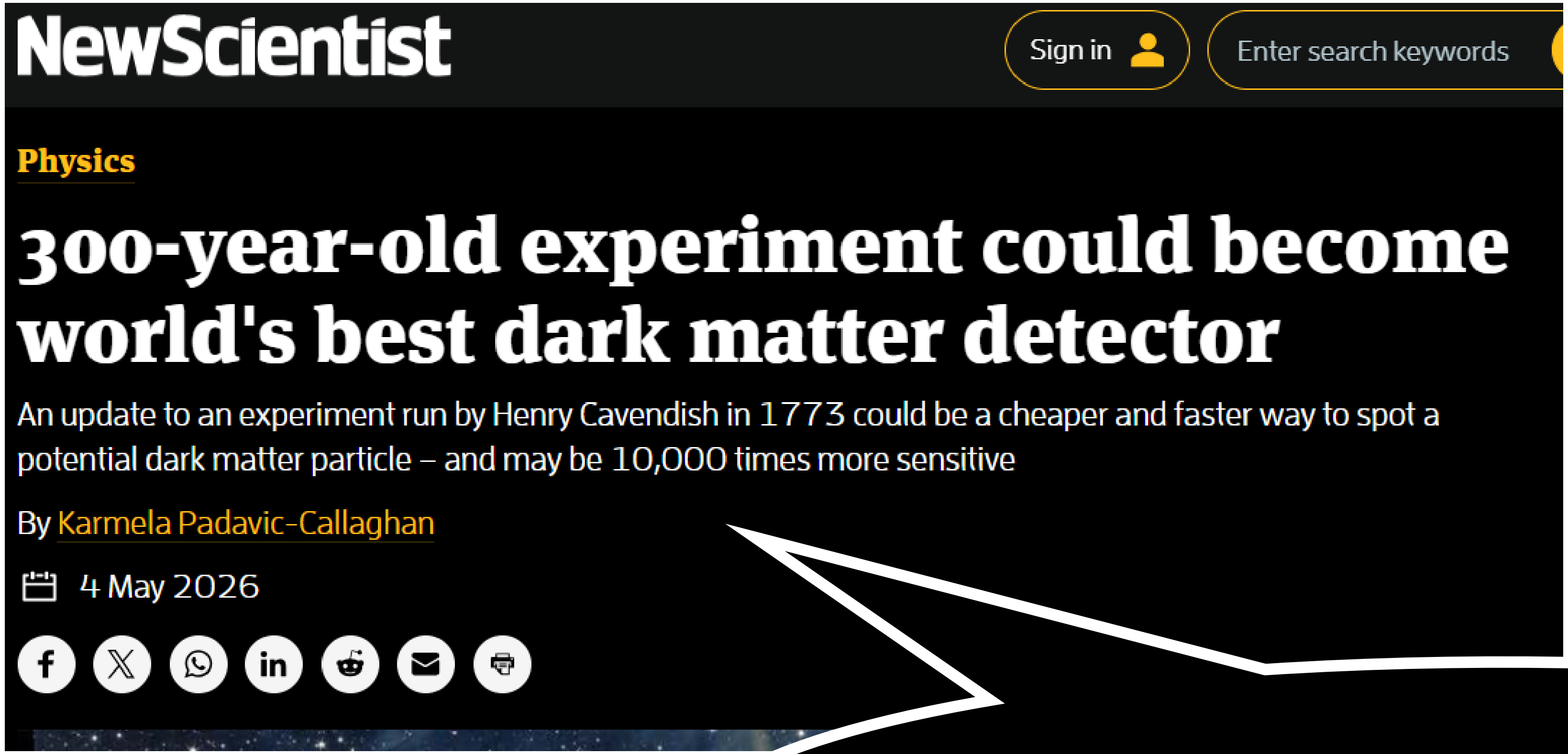
Zach Bogorad (Fermilab)

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

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

"You could store and gift people millicharged particles,"

https://www.newscientist.com/article/2524958-300-year-old-experiment-could-become-worlds-best-dark-matter-detector/

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

$$\mathcal{L} \supseteq -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \bar{\psi}(i\partial\!\!\!/ - \mu)\psi - q\bar{\psi}\gamma^{\mu}\psi A_{\mu}$$

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 be coupled to a "dark photon"

- Kinetic mixing with the SM photon gives an "effective" millicharge

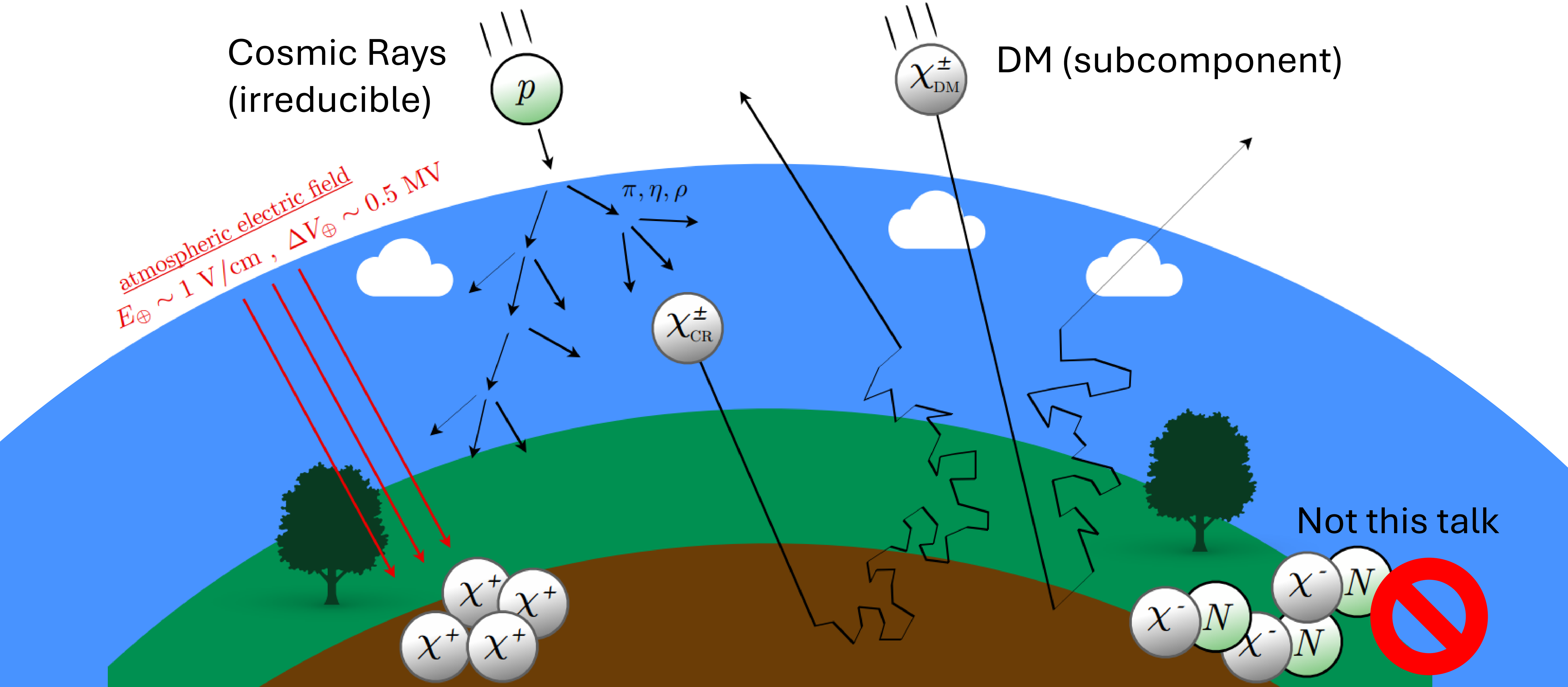
$$\mathcal{L} \supseteq -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{1}{2}\epsilon F_{\mu\nu}F'^{\mu\nu} + \frac{1}{2}m_{A'}^2 A_\mu A^\mu + gA'_\mu J^\mu_{\mathrm{DM}}$$

Dark photon of mass $m_{A'}$

Kinetic mixing

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

MCPs can accumulate on Earth



Millicharged DM can reach huge overdensities

Rapid thermalization

+

Atmospheric trapping

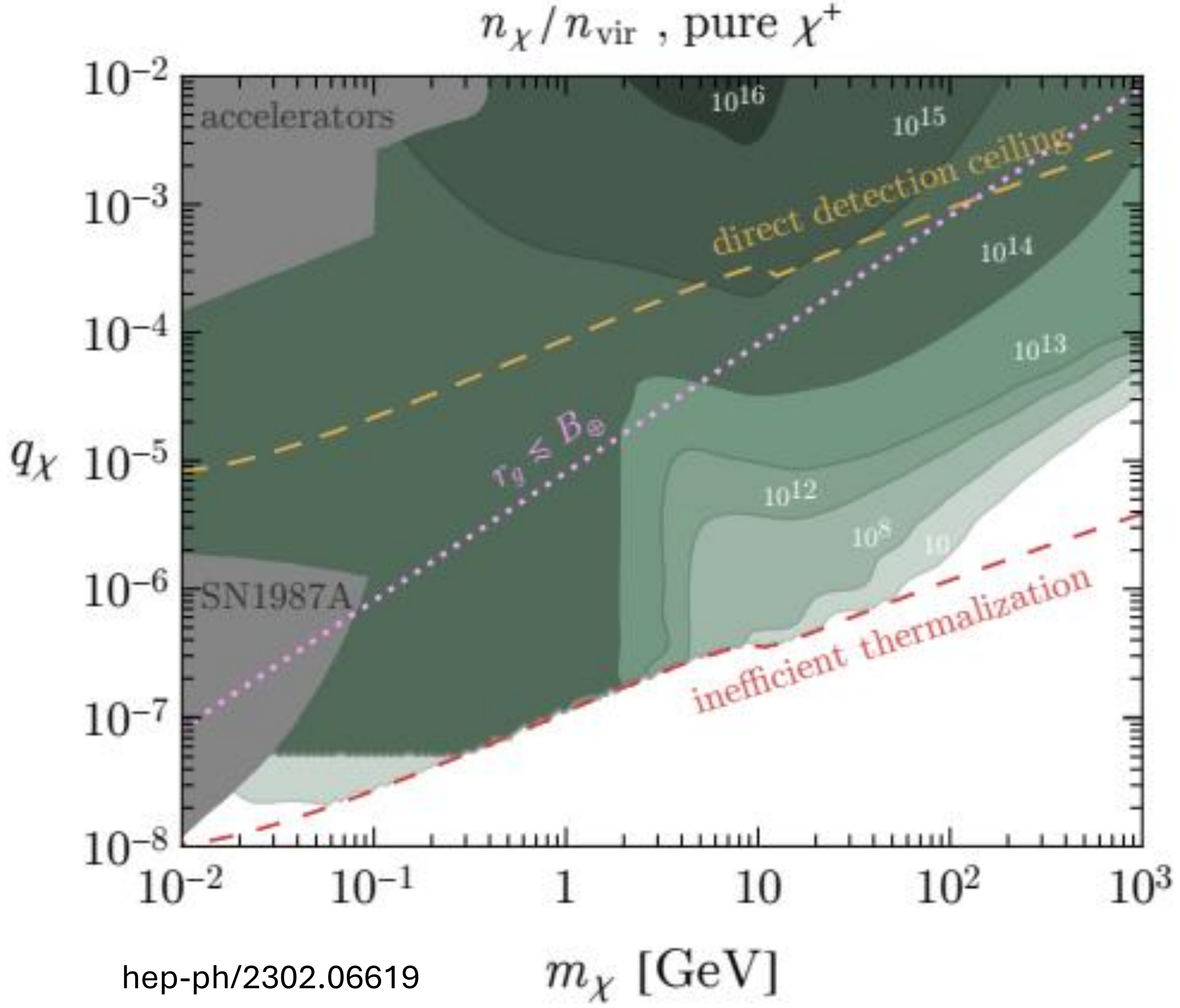
+

Slow diffusion

⇩

High terrestrial density

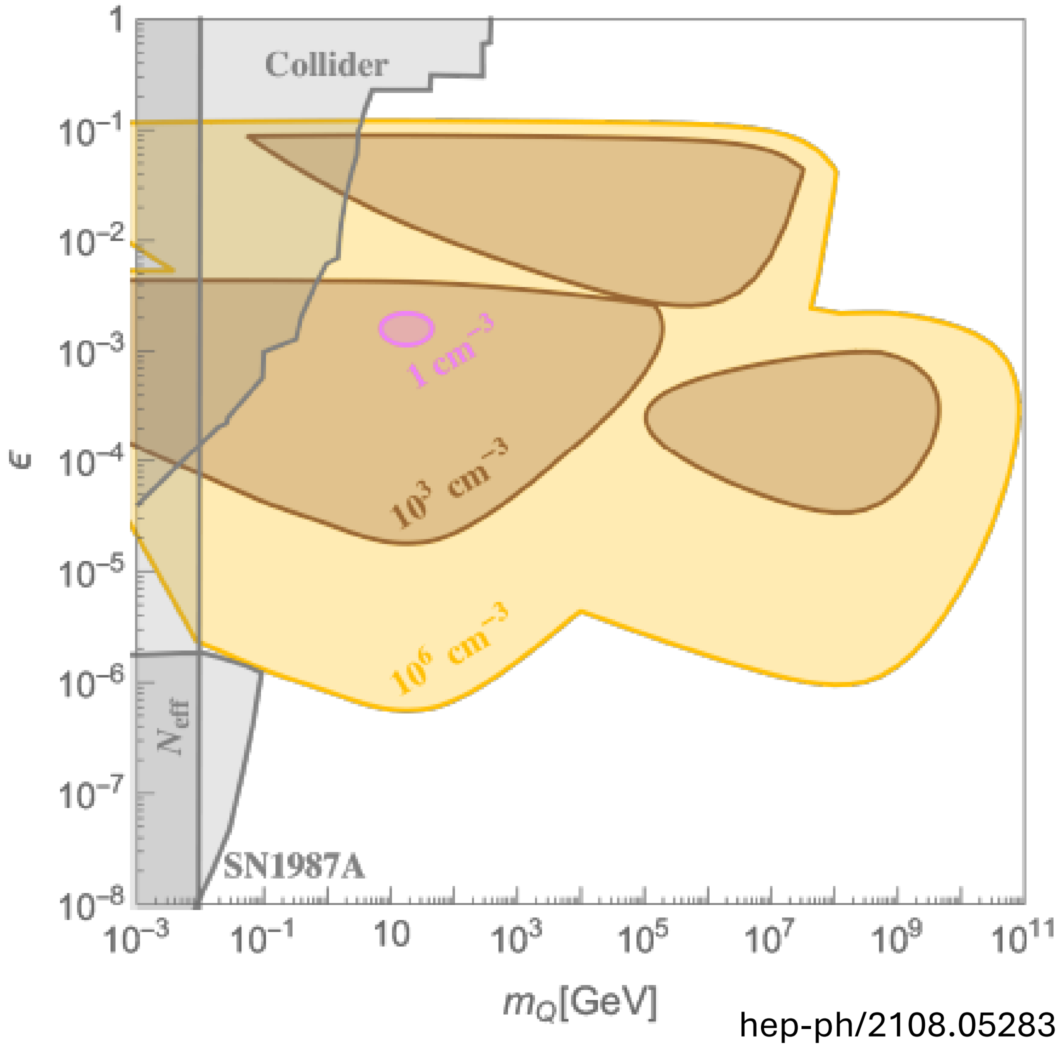
Low energy



hep-ph/2302.06619

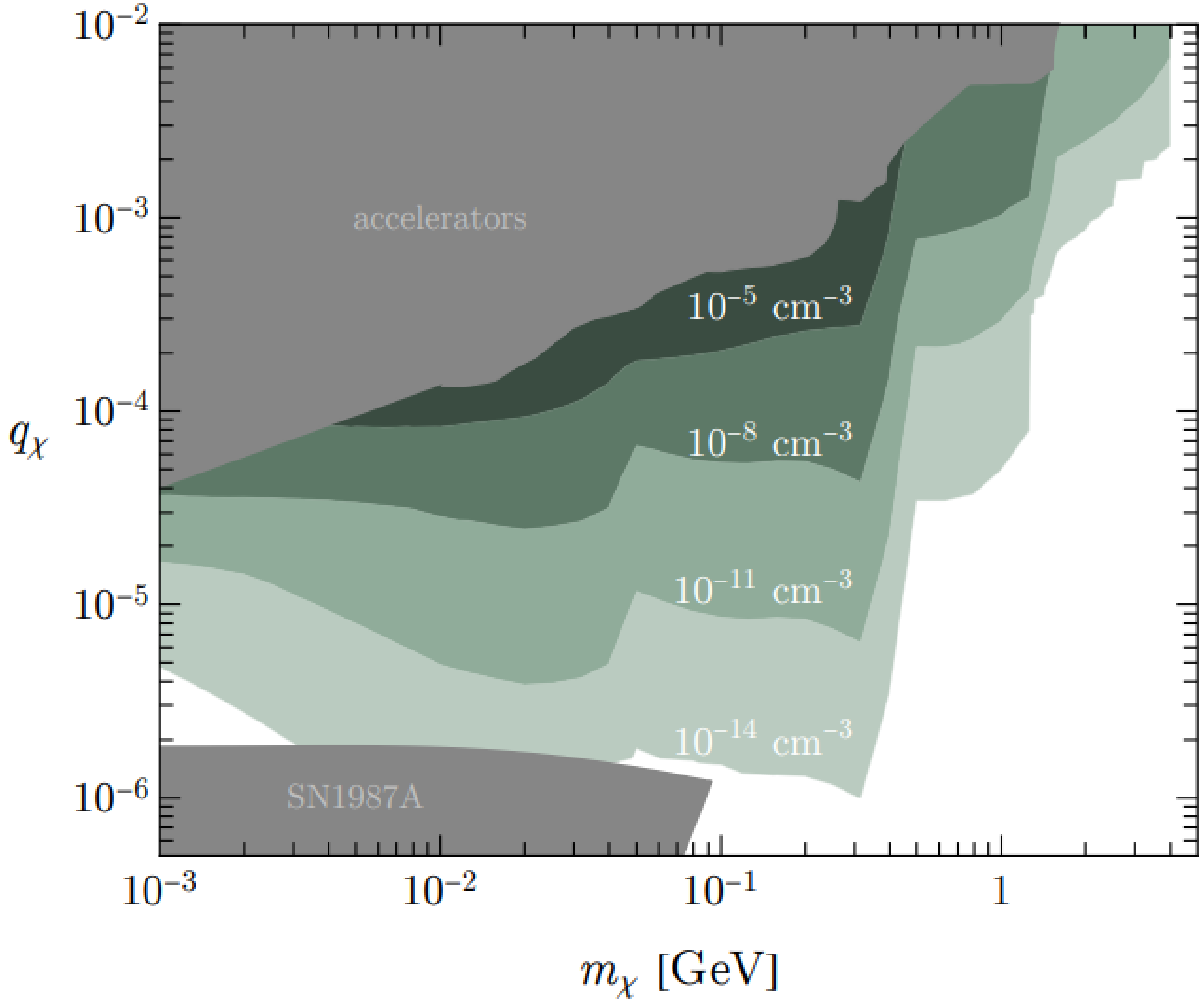
Millicharge parameter space – Earth-bound

- In the case of Earth-bound millicharges, we have an additional degree of freedom: the terrestrial density
- Parameter space / constraints therefore look very different



hep-ph/2108.05283

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

Tests of Coulomb's law – P&L, 1936

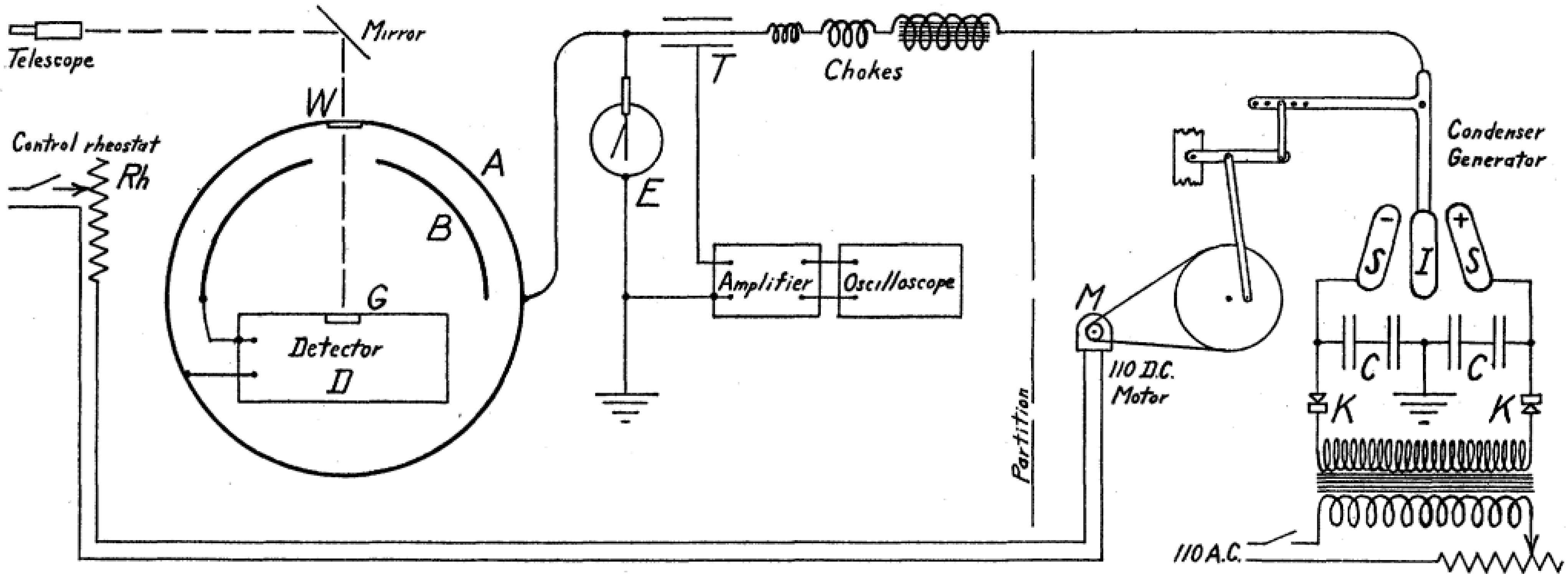
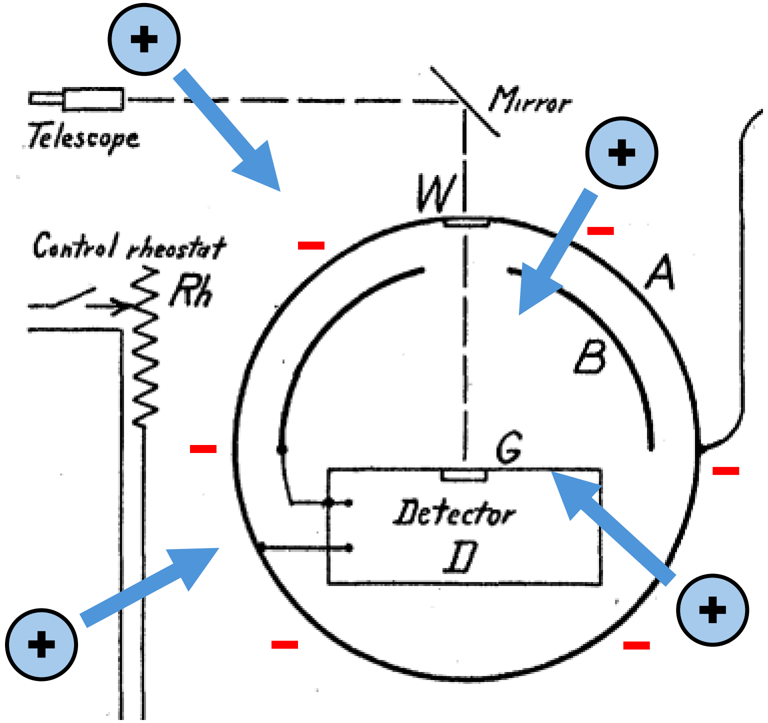


FIG. 1. Apparatus for testing the inverse square law of force between charges.

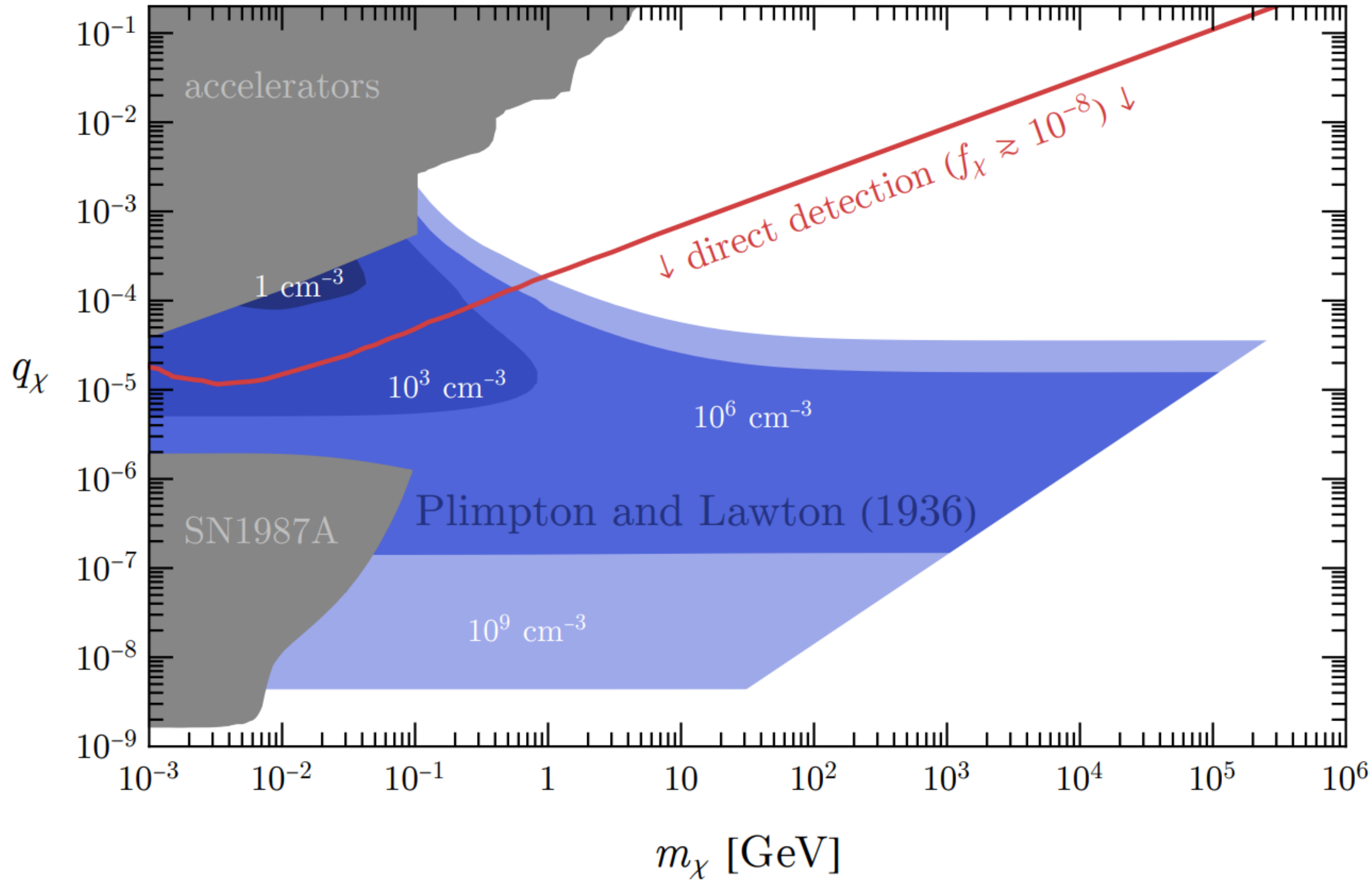
Pimpton and Lawton (1936)

P&L, 1936 – effects of millicharges

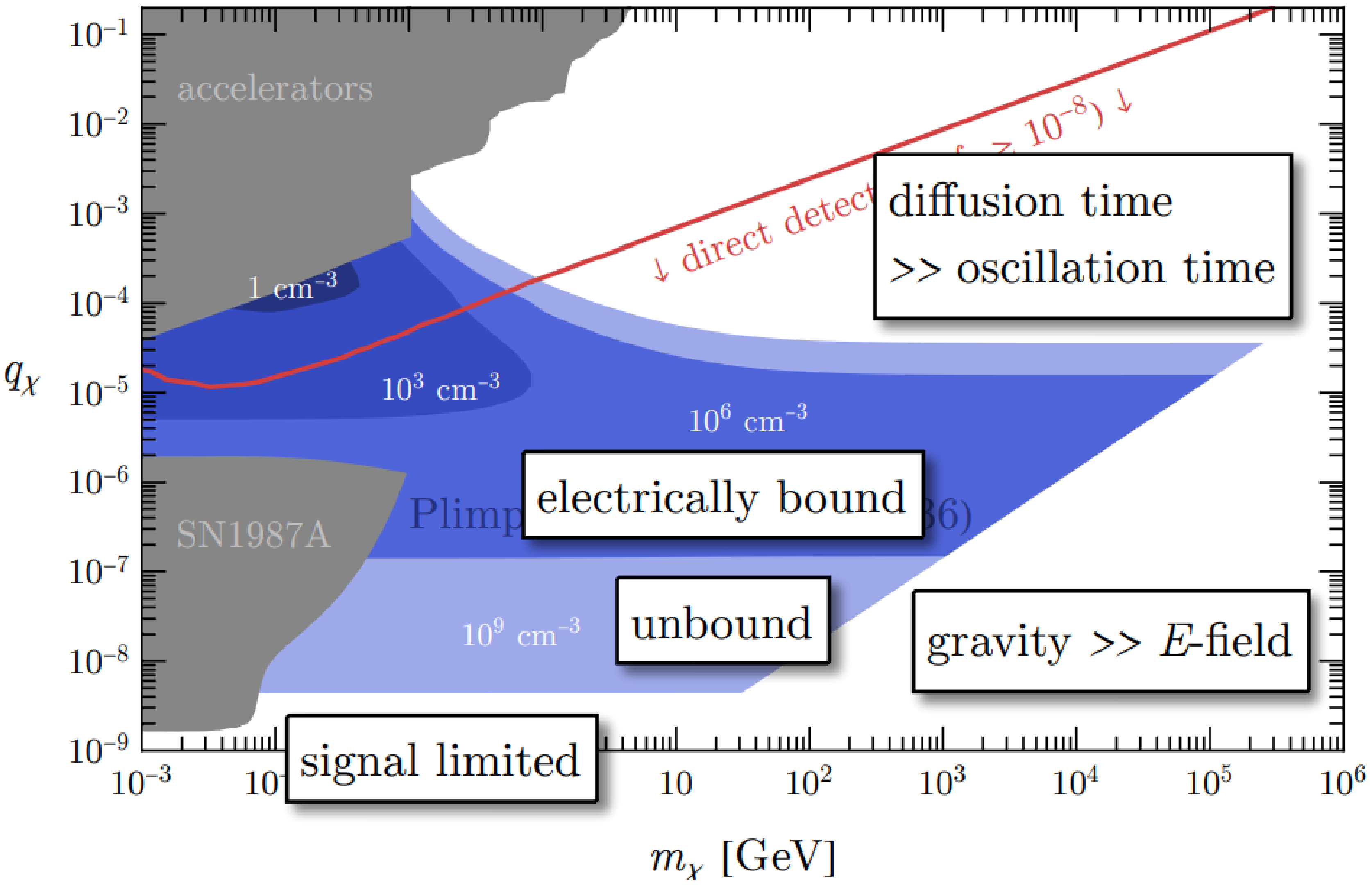
- The potential of the outer shell will pull in opposite-sign millicharges
- These pass through the conductor and create a potential on the inner shell
- No field inside, so millicharges don't get pushed back out



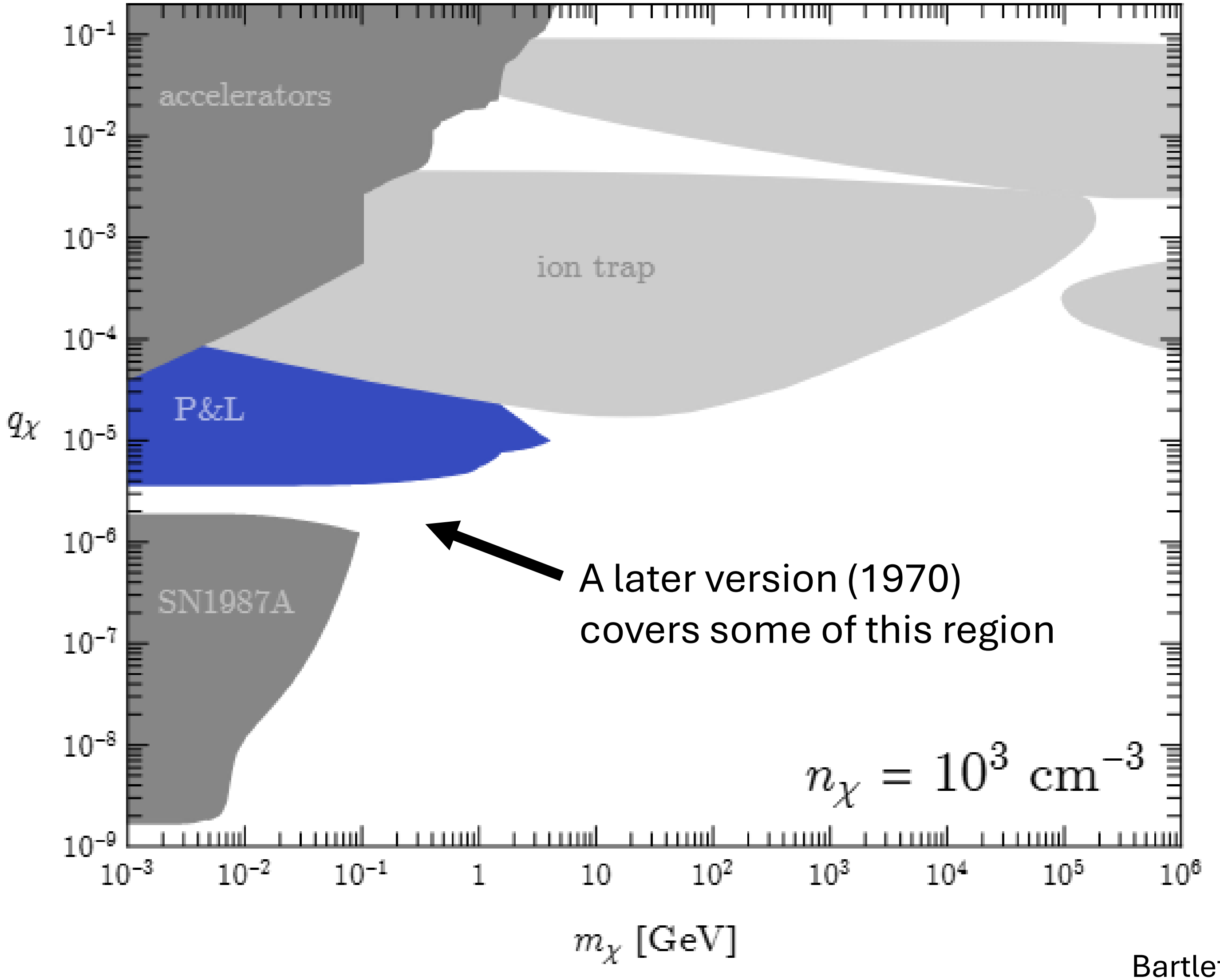
P&L, 1936 sets new limits on millicharged DM



P&L, 1936 sets new limits on millicharged DM



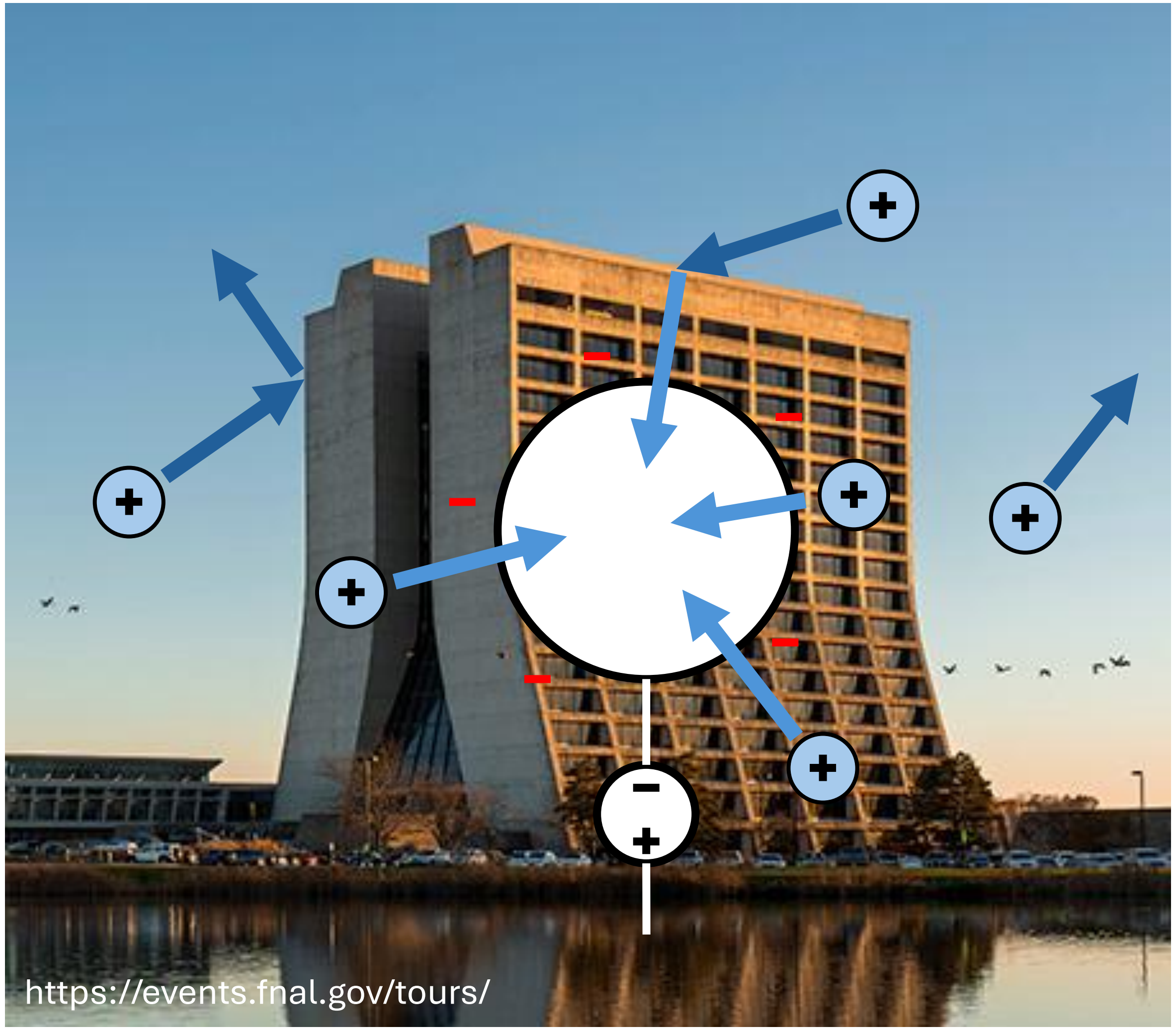
P&L, 1936 sets new limits on millicharged DM

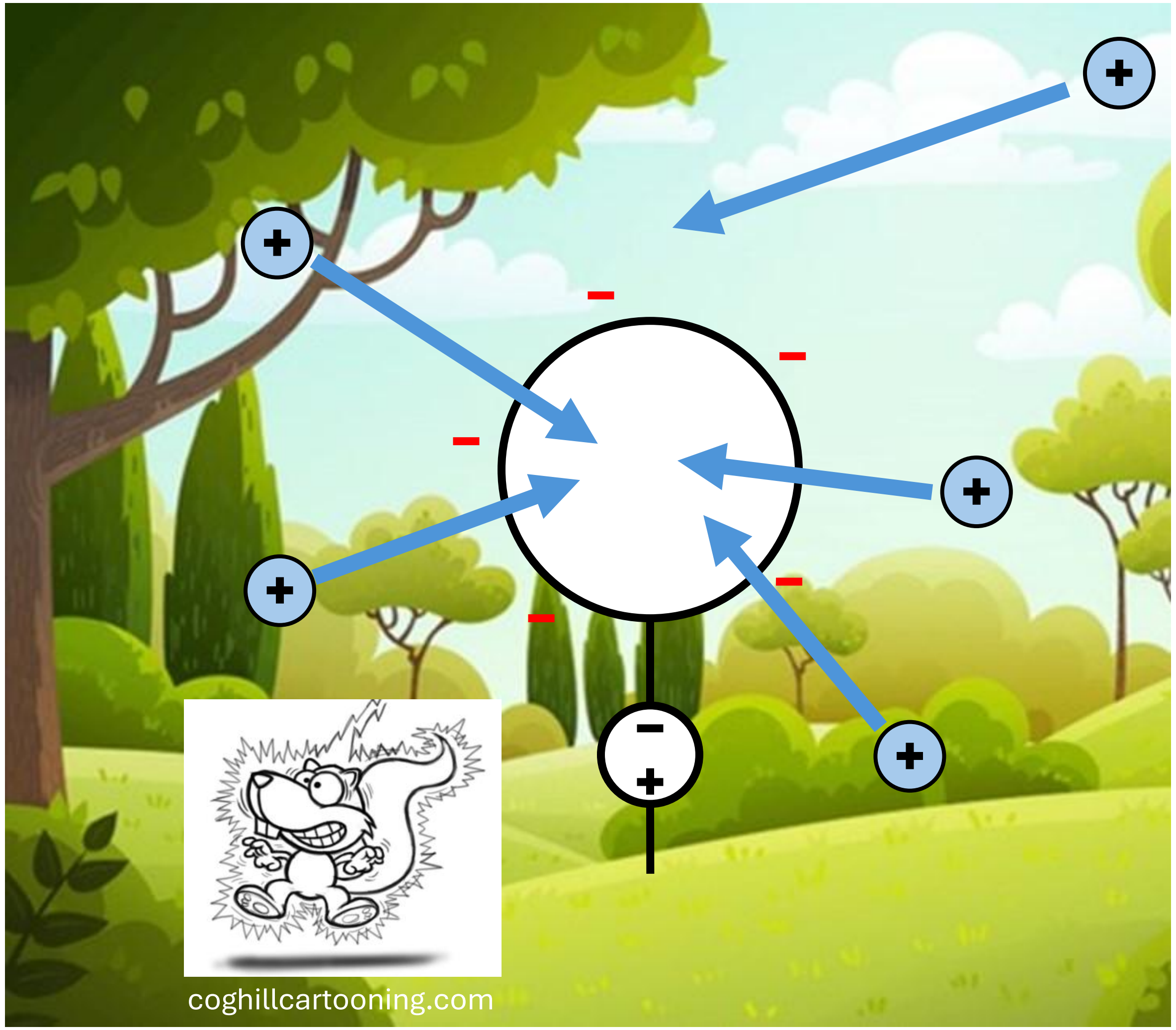


Bartlett, Goldhagen and Phillips (1970)

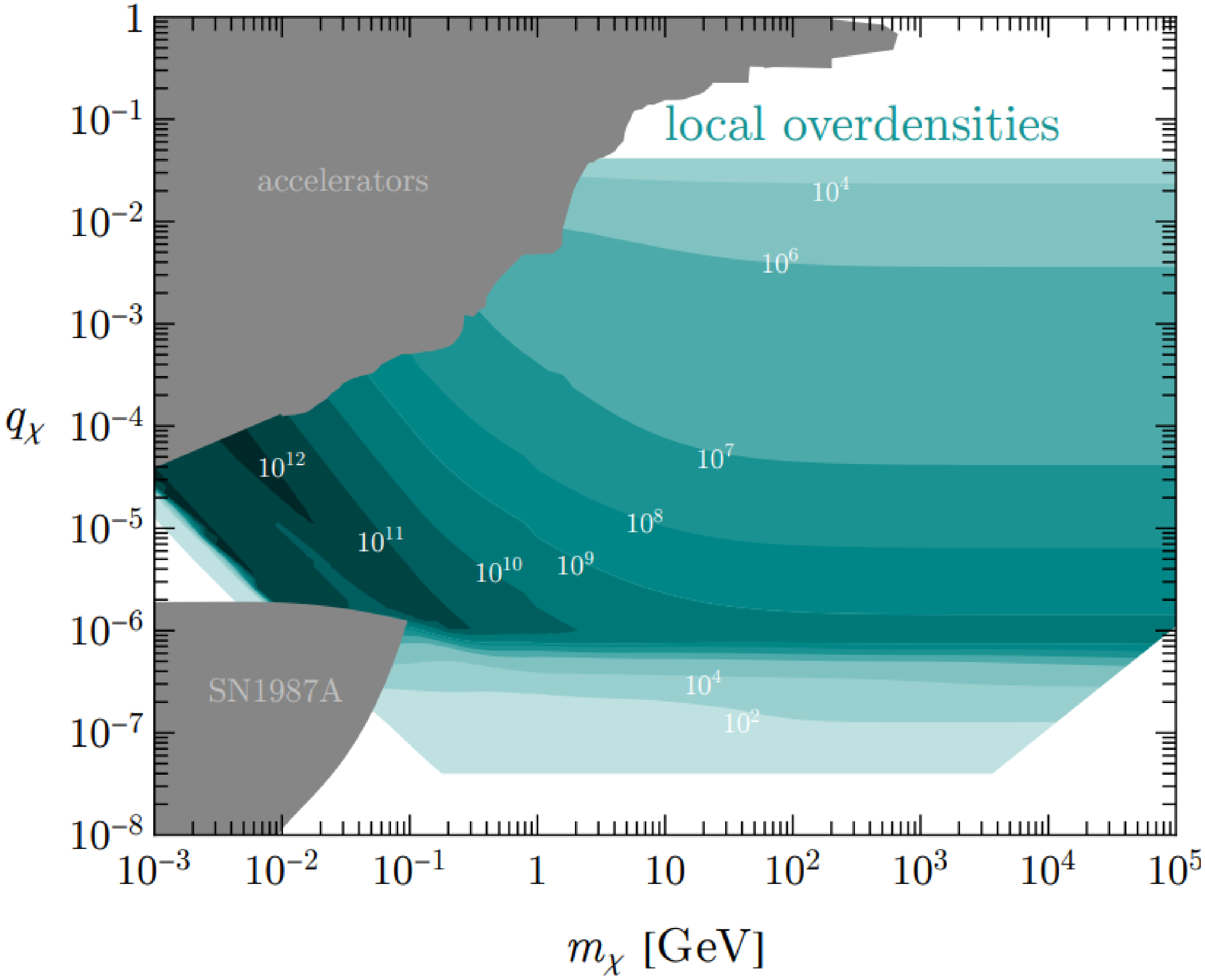
Projected Reach of a Dedicated Experiment

A fixed potential will vacuum up millicharges



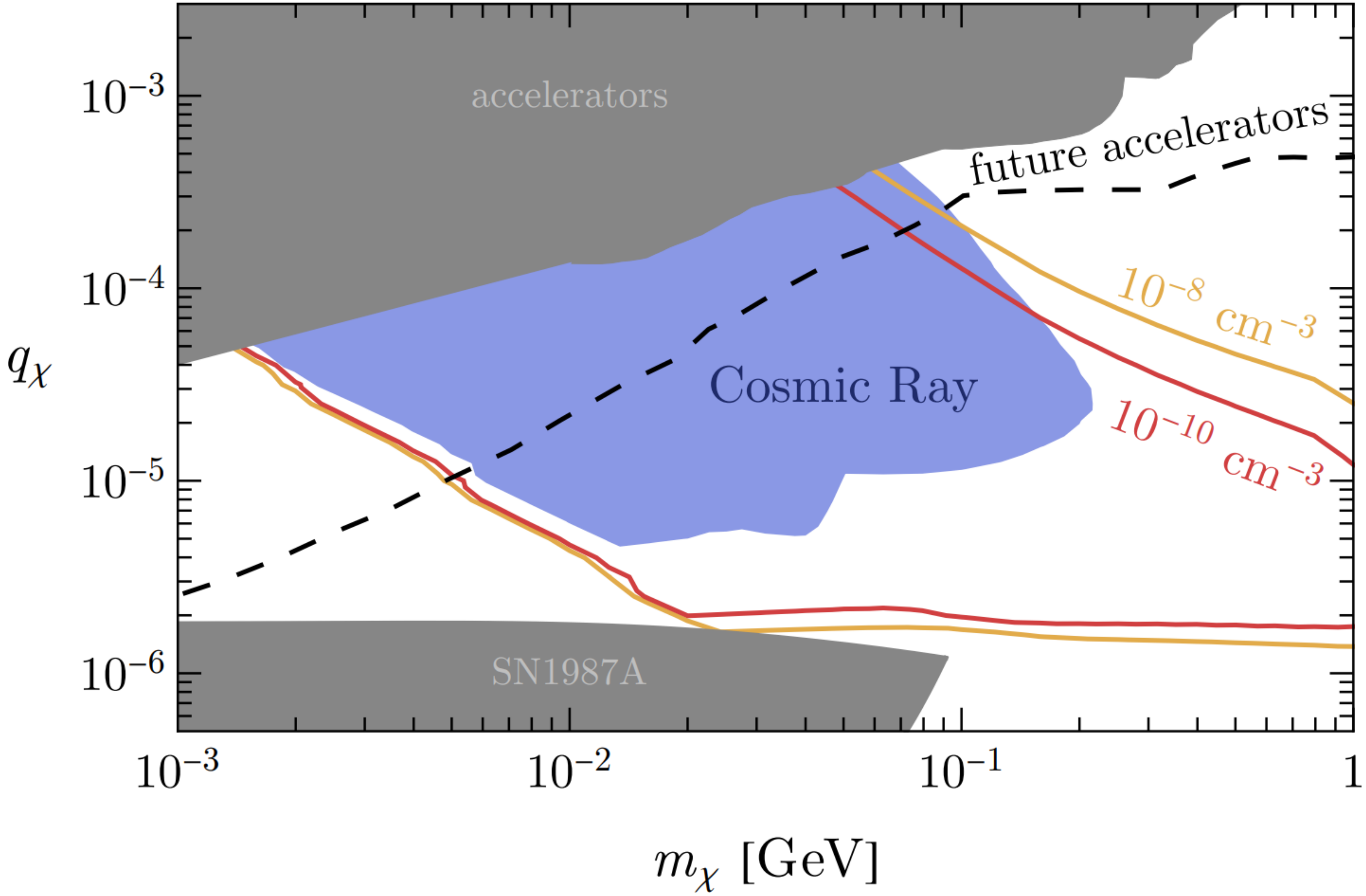


Fixed potentials can give large overdensities



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

Modified P&L, 1936 – sensitivity



Questions?