Millicharged Particles from the Heavens

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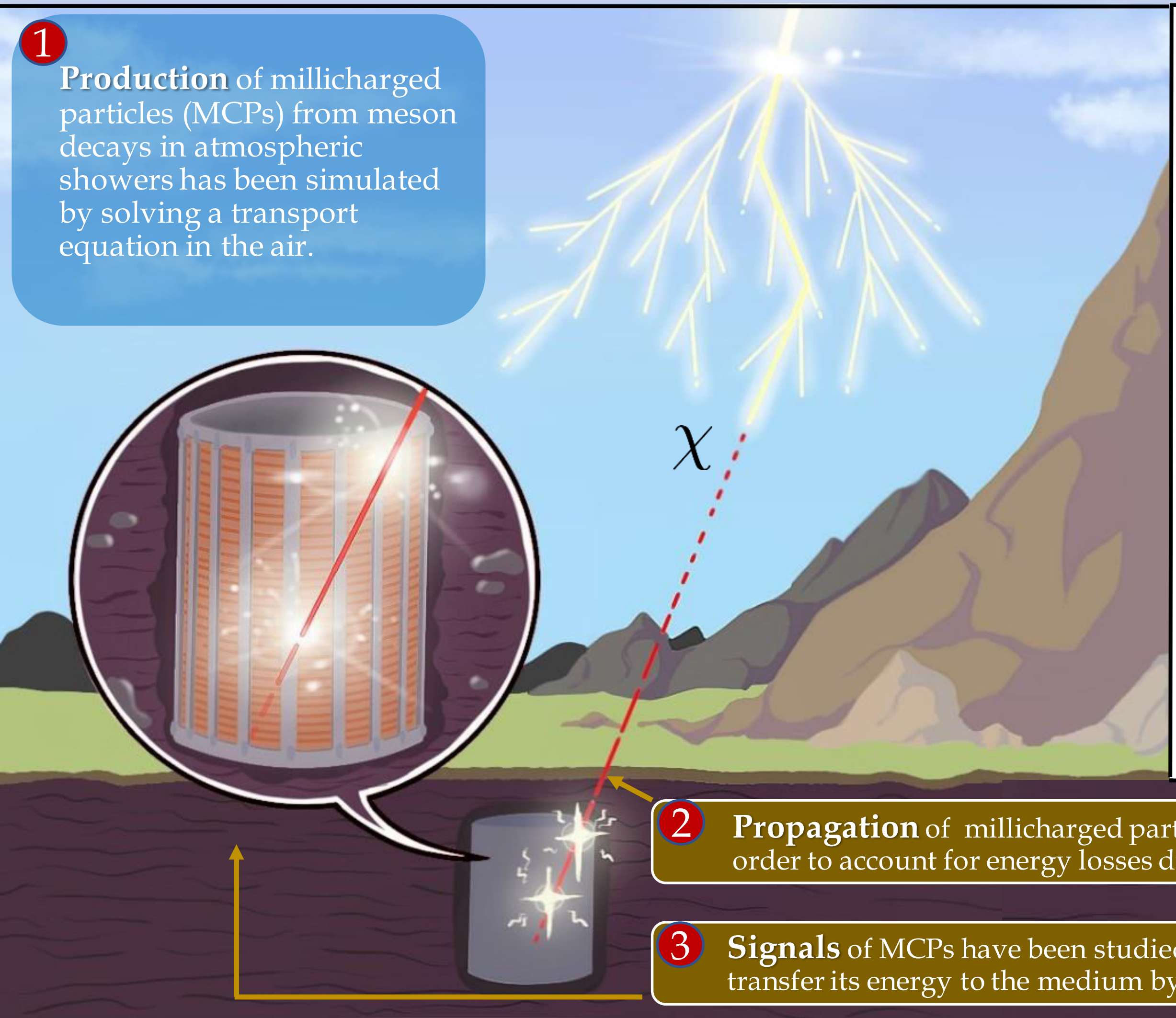
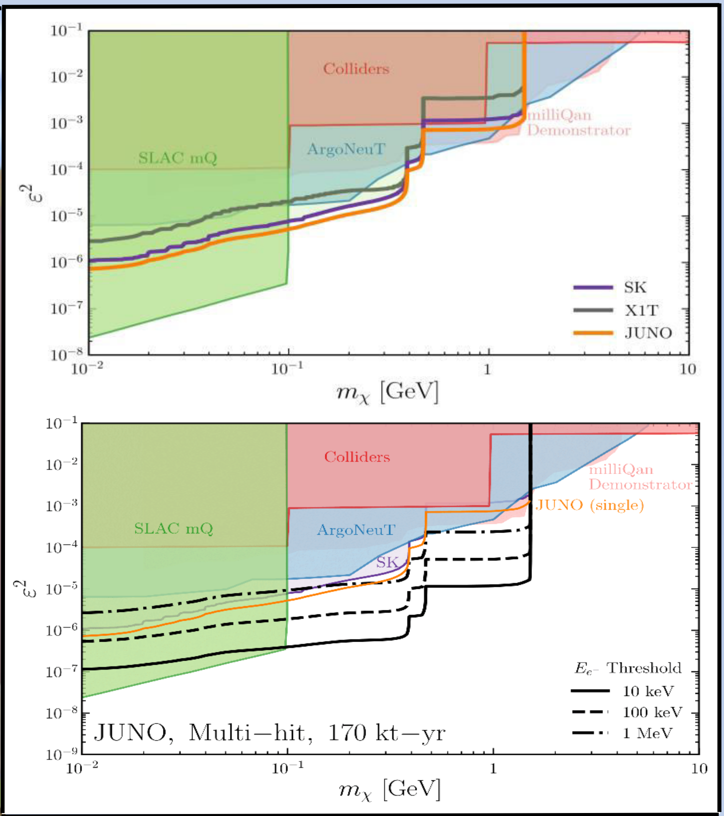
A millicharged particle is a hypothetical elementary particle with a small electric charge $Q = \varepsilon\, e$. This particle can be produced in cosmic ray air showers, being able to reach the surface of the earth, propagate, and be detected in underground experiments of dark matter and neutrinos.



1 **Production** of millicharged particles (MCPs) from meson decays in atmospheric showers has been simulated by solving a transport equation in the air.

2 **Propagation** of millicharged particles through the earth has been modeled in order to account for energy losses due to ionization and interactions with nuclei.

3 **Signals** of MCPs have been studied in underground detectors where the particle can transfer its energy to the medium by scattering off electrons.



Electron recoil signals at underground experiments can be used to set stringent constraints in the charge fraction ε, for a given MCP mass. We used data from Xenon1T, and Super-Kamiokande experiments to derive updated constraints in the sub-GeV mass range. We have also performed a sensitivity study for the future JUNO experiment.

A millicharged particle can deposit its energy in the detector multiple times along its path. A signal with multiple-scattering events within a short time window can be very difficult to mimic, implying a significant reduction of the background. A large detector with a low energy threshold such as JUNO, is an ideal experiment to search for this kind of signal. The projections derived in our study show a significant improvement for MCP searches.

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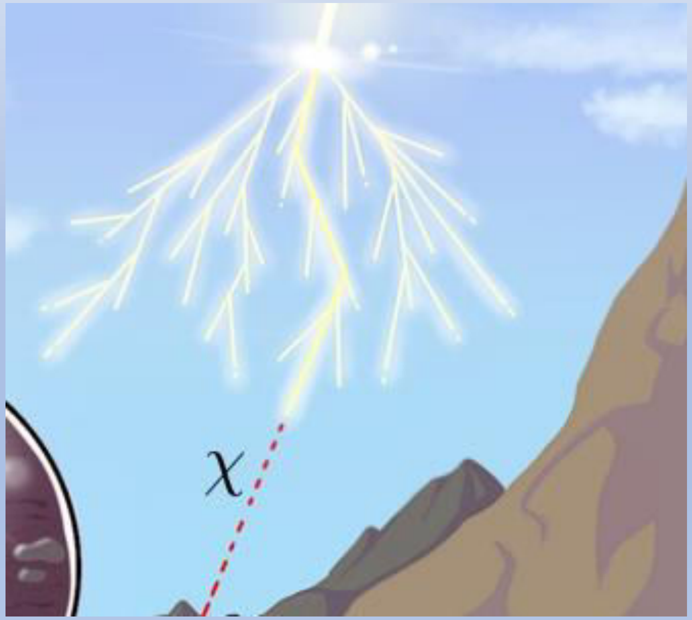
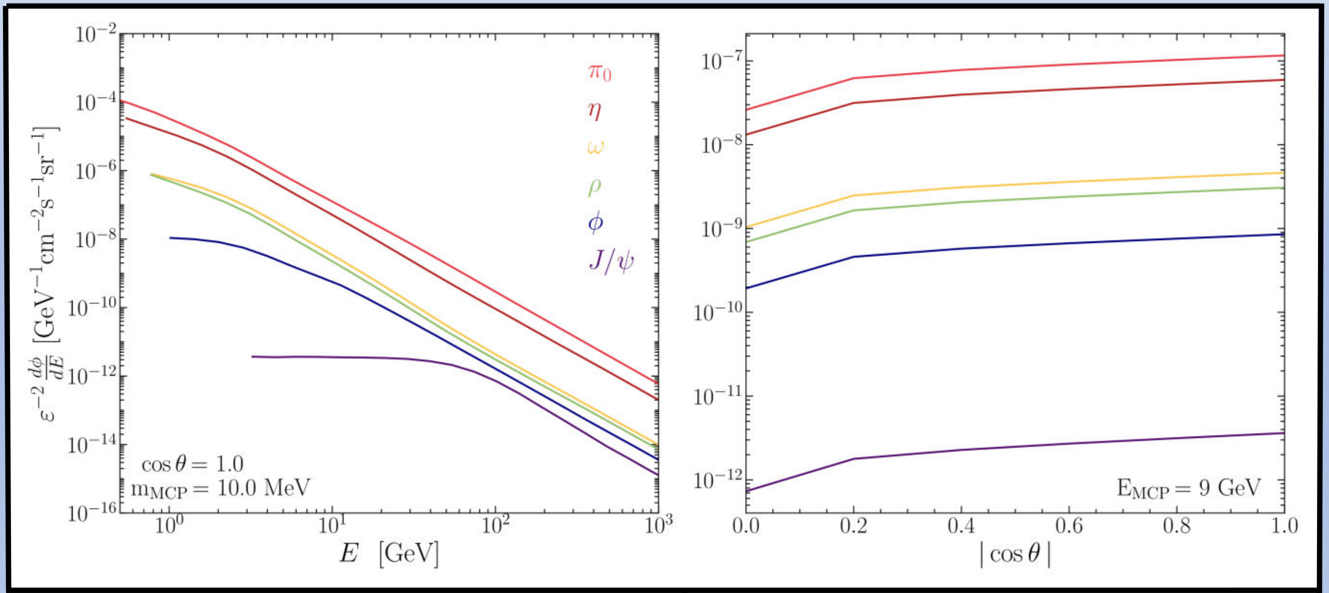
Production of MCPs

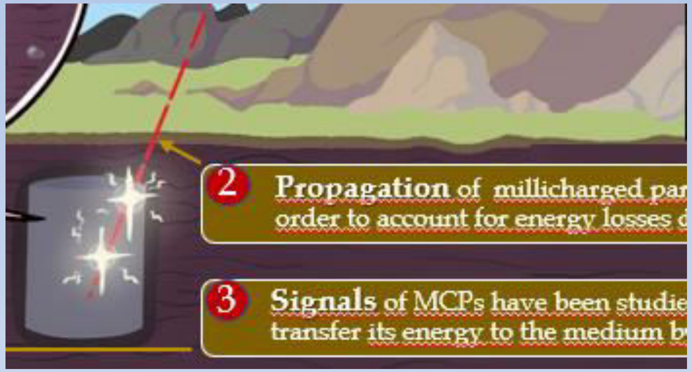
$$\frac{d\Phi_\chi}{dE\, d\cos\theta\, dX} = \int dE_M \frac{1}{\rho(X)\lambda_M(E_M)} \frac{d\Phi_M}{dE_M\, d\cos\theta} \frac{dn}{dE}(M \to \chi)$$

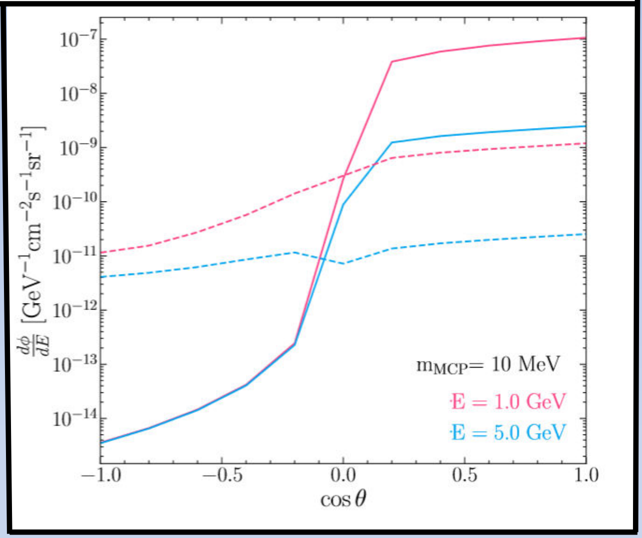




Flux attenuation after propagation

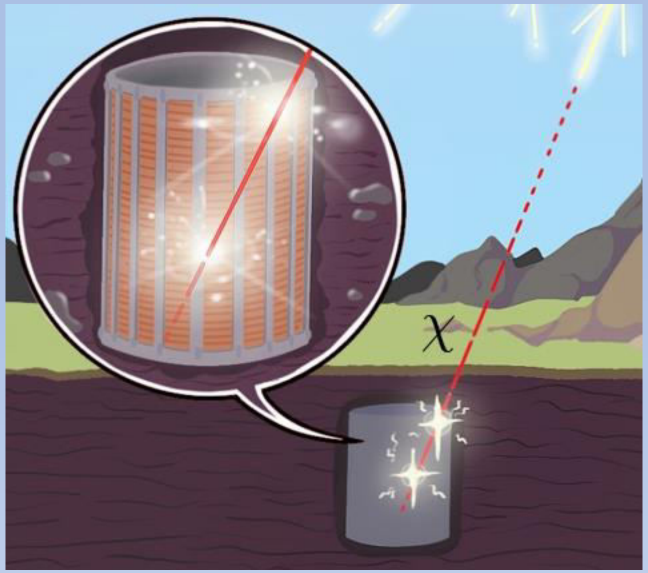
$$-\frac{dE}{dX} \approx \epsilon^2(a + bE)$$

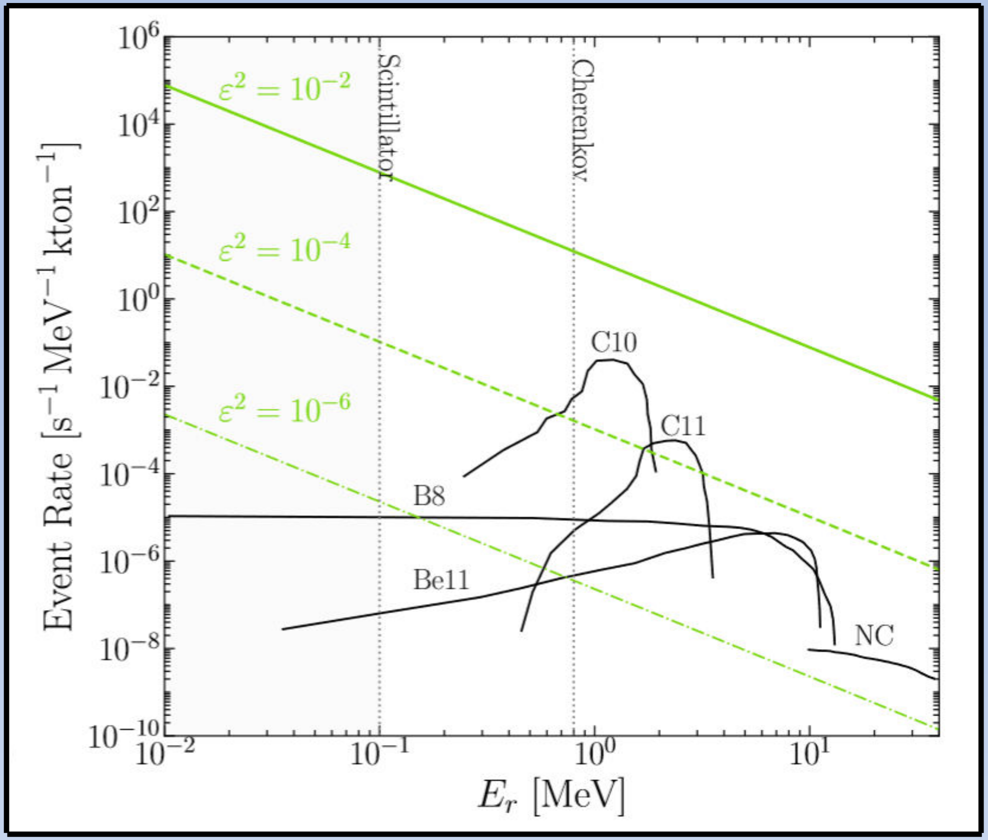


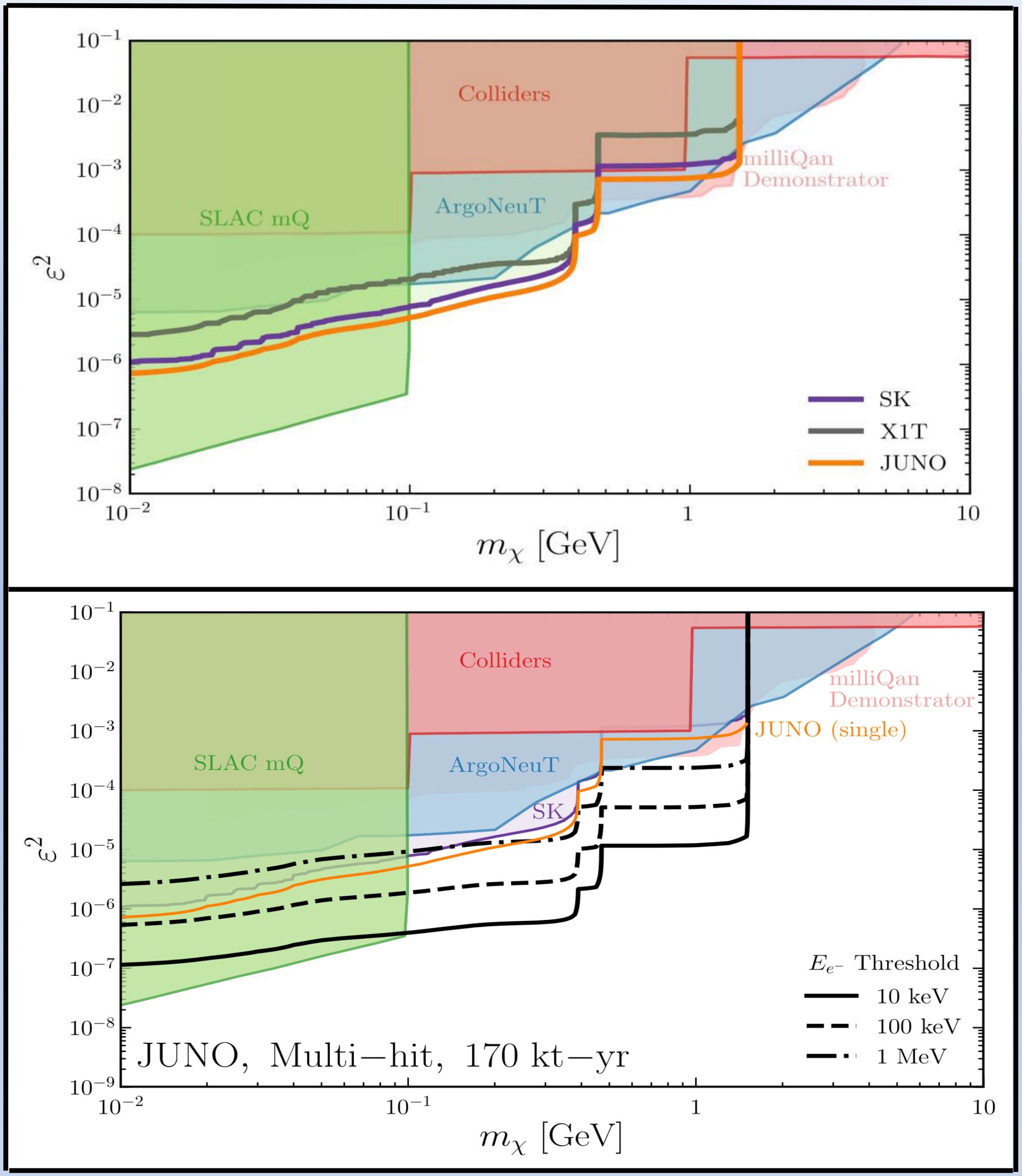


Event Rate

$$\frac{dN}{dE_r\, d\cos\theta} = n_e \epsilon(E_r) \int dE_\chi \, \frac{d\phi}{dE_\chi\, d\cos\theta} \frac{d\sigma}{dE_r}$$







Single-Hit searches at X1T, JUNO and Super-Kamiokande

Multiple-Hit searches at JUNO

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