Improved Limits on Millicharged Particles Using the ArgoNeuT Experiment at Fermilab

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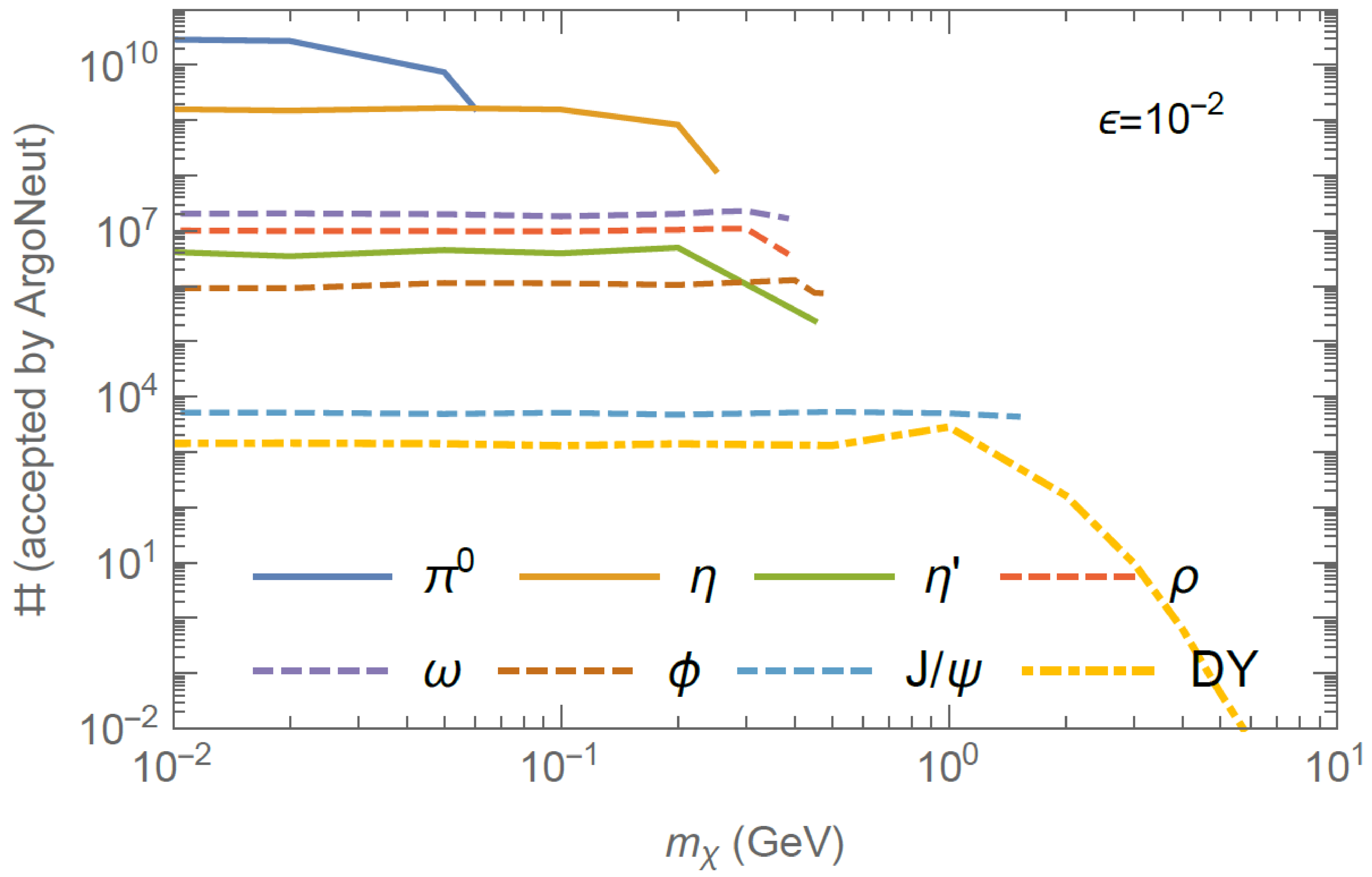
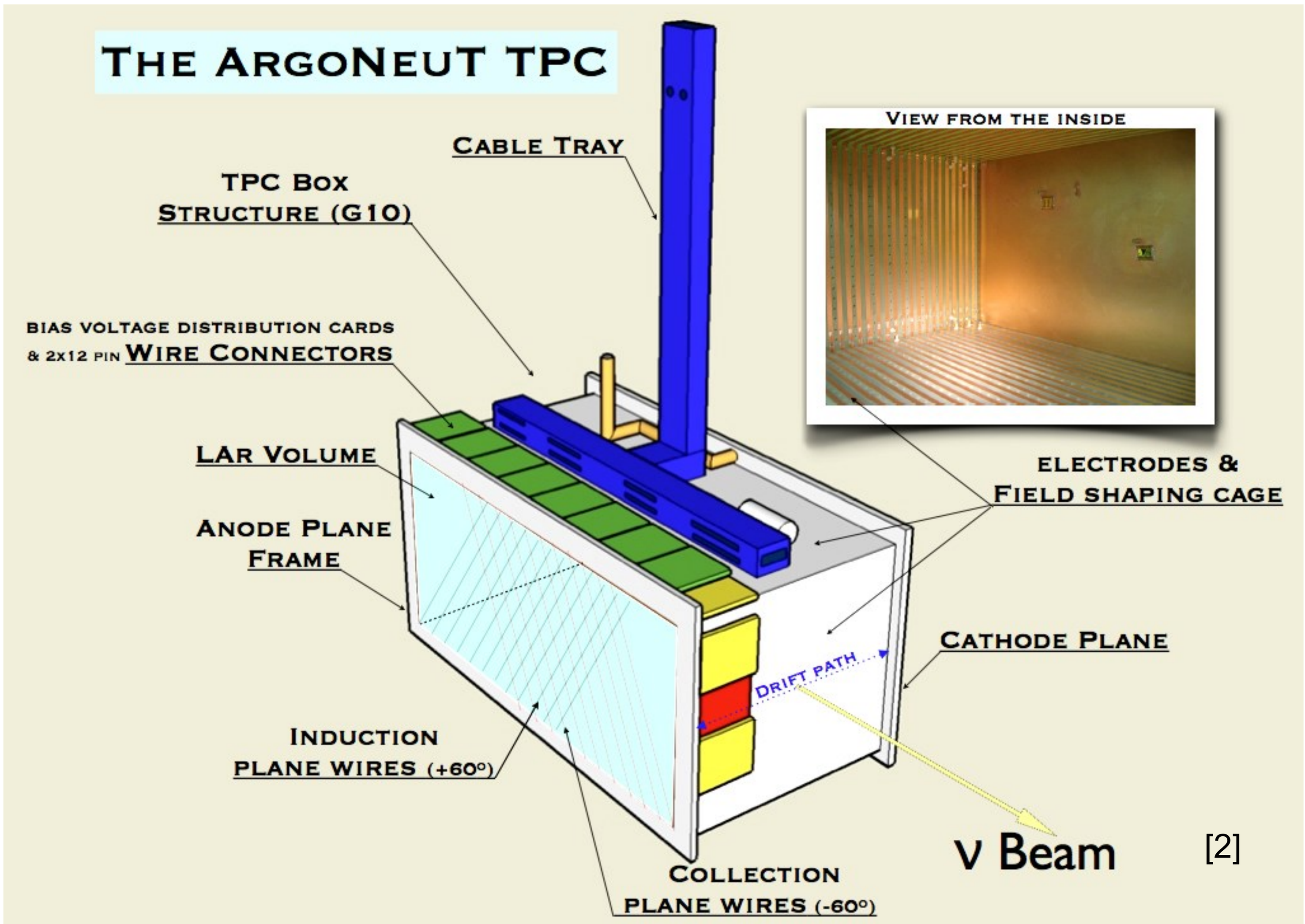
Millicharged Particles

- Particles with fractional charge ε
- Arise from dark sectors with U(1)′ gauge symmetries with kinetic mixing
- Produced in proton interactions via neutral meson decay and Drell-Yan
- Can be produced in neutrino beams

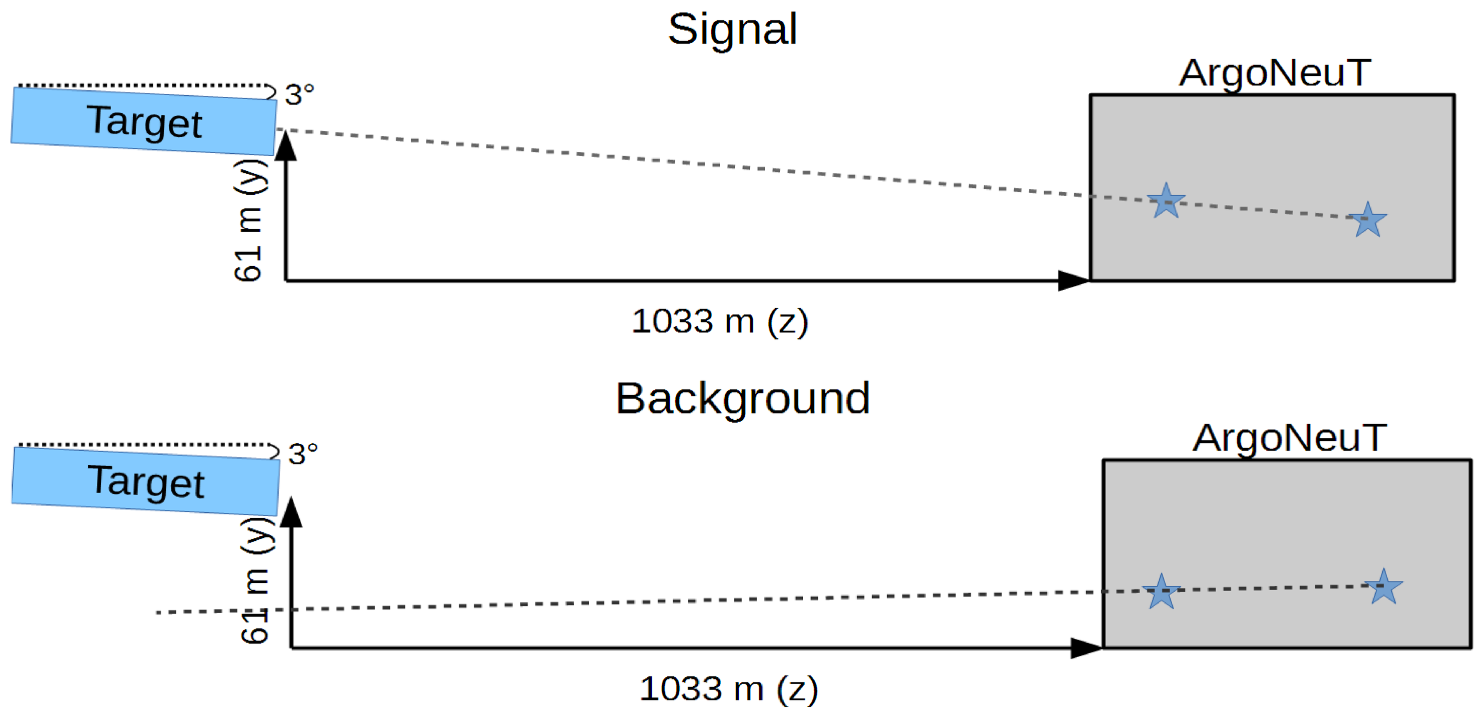


Number of millicharged particles with charge 1/100th of an electron produced by the NuMI beam at Fermilab and entering the detector used in this study. The horizontal axis indicates the mass of the millicharged particle. The lines indicate which neutral meson decay or process produced the particle. From [1].

ArgoNeuT



Signal Description



Schematic (not to scale) of the ArgoNeuT detector location relative to the upstream target. Signal is double-hit event with the line that is defined by the two hits pointing to the target (top). A background double-hit event generically will not point to the target (bottom). Figure adapted from Ref. [1].

- Millicharged particles interact by electron scattering, at a reduced rate.
- Deflection of millicharged particles is small: travel in a straight line.
- Cross section depends on detection threshold.
- Signal: sub-MeV range isolated hits pointing back to the target

Signal Selection

- We use reconstruction methods described in [3].
- Look for energy depositions (“clusters”) above threshold (~300 keV)
- Keep only events with 2+ clusters
- Obtain 3D positions of these clusters
- Create lines using these clusters as points on the line

[1] J. High Energy Phys. 07 (2019) 170

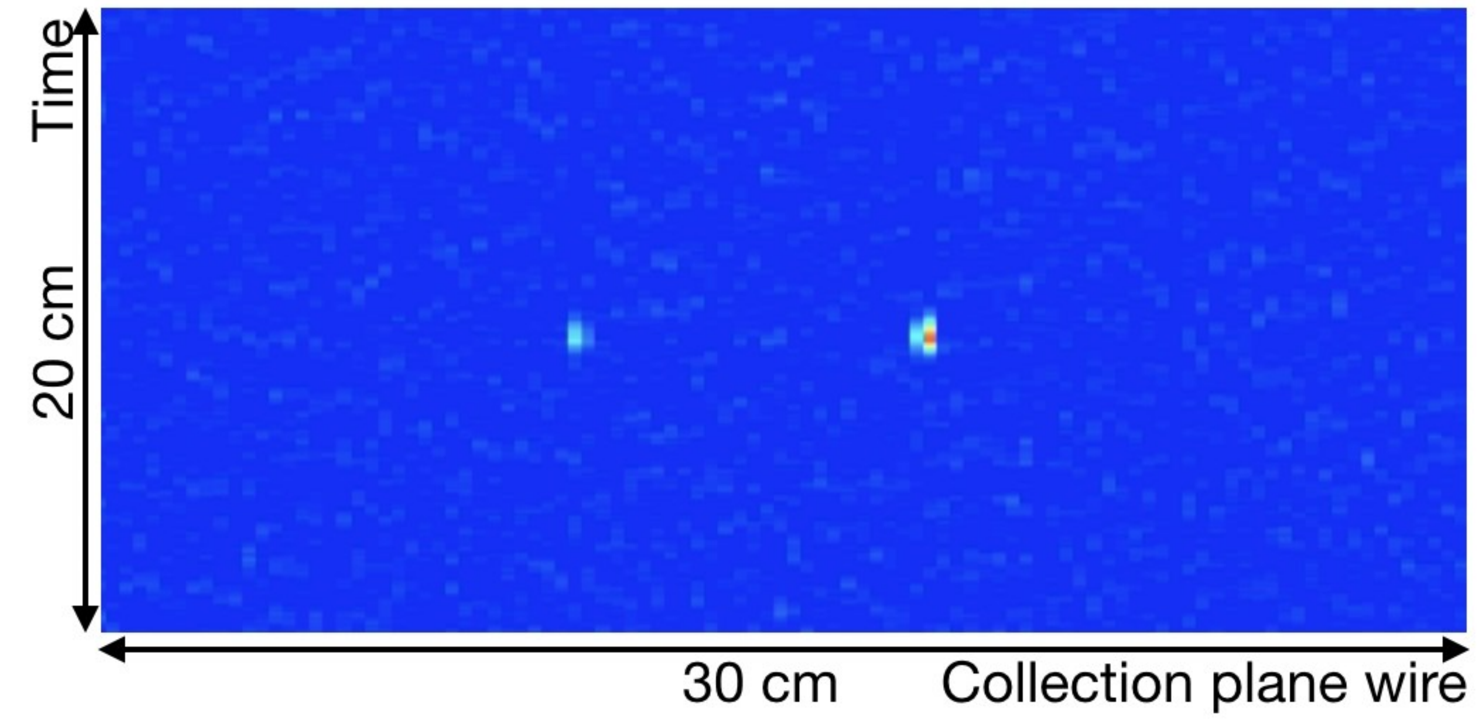
[2] J. Instrum. 7, P10019 (2012)

[3] Phys. Rev. D **99** 012002 (2019)

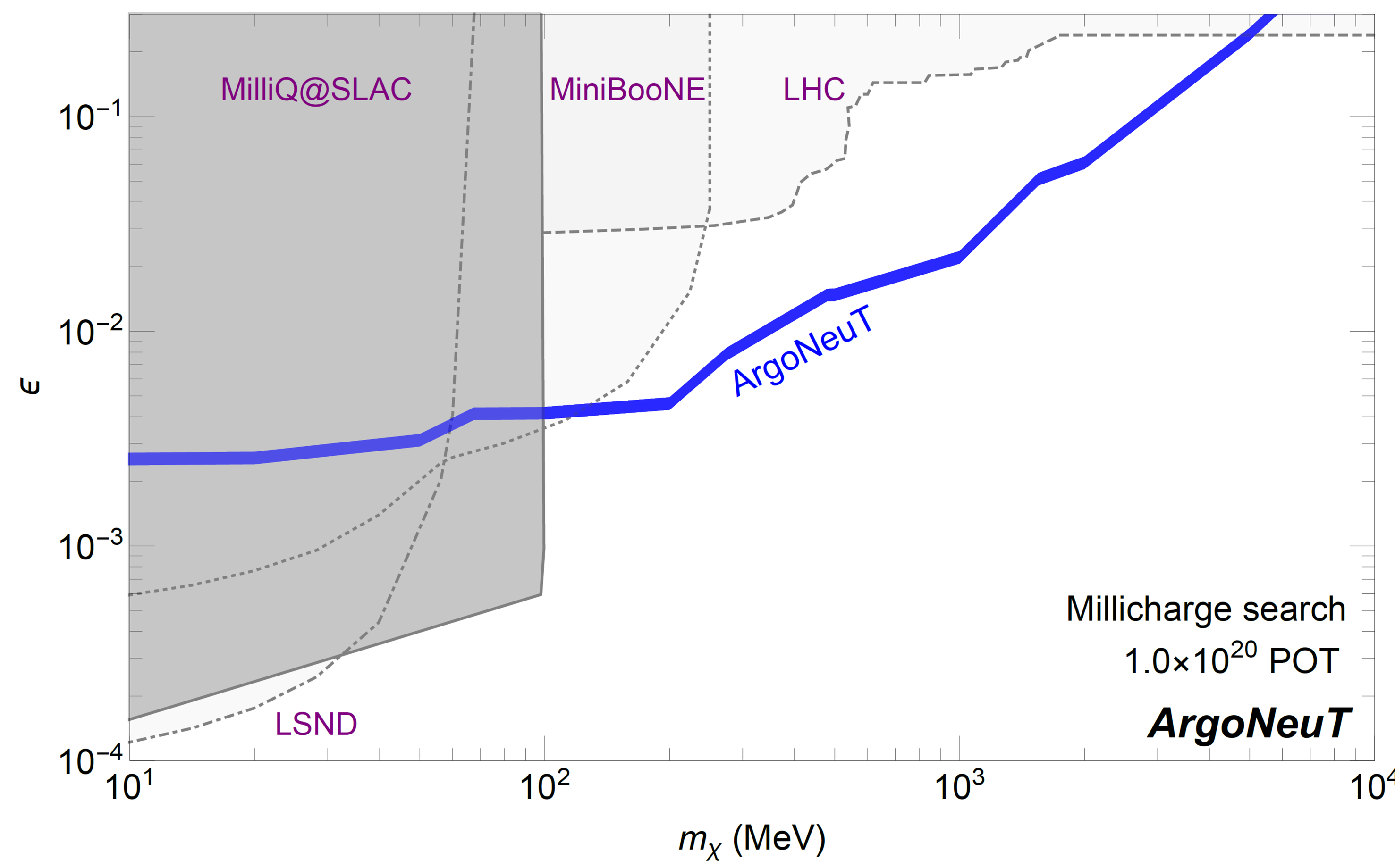
[4] Phys. Rev. Lett. **124**, 131801 (2020)

Results

- Check to see if lines point back to the target
  - Lines produced by millicharged particles will point back to the target.
- We find one candidate event, compatible with the expected background, allowing us to set leading limits.



The candidate signal event. Enlarged image from the collection wire plane. Two isolated clusters are visible in the event. Color in the image indicates the amount of charge collected. The horizontal axis is perpendicular to the collection plane wires. The vertical axis is parallel to the drift direction.



ArgoNeuT limits (blue) in the $m_\chi-\epsilon$ plane for millicharged particles at 95% C.L., where $\epsilon = Q_\chi/e$. The limit is drawn where mCPs are unlikely to produce more than the observed number of events. The thickness of the blue band accounts for the systematic uncertainty in detector placement. Existing experimental limits from SLAC MilliQ are shown in dark gray within a solid line. Other limits using results from the LSND and MiniBooNE neutrino experiments and collider experiments are shown in light gray within broken lines. See [4] for more information and citations.