BEYOND 0νββ : LEGEND-200's sensitivity to fractionally charged particles

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1) INTRODUCTION

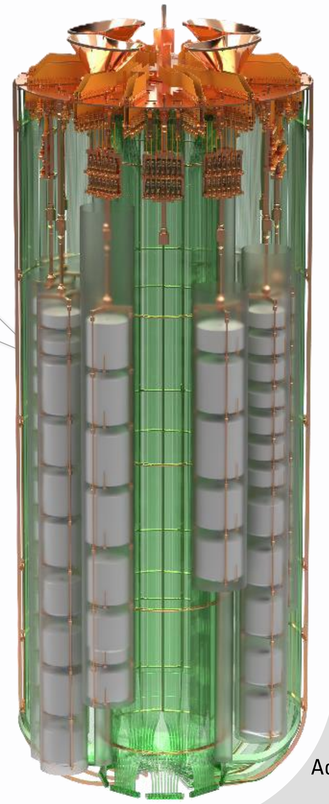
LEGEND-200: **Low Backgrounds** and **Large Ge Detectors**
Excellent observatory for Beyond Standard Model (BSM) Physics.
Primary physics goal: 0νββ, first limits published in [1].

March 2023 to Feb 2024 (PRL dataset)
- Ge detectors arranged in 10 strings
- 74 kg-yr stable energy dataset

Summer 2025 to Present
- Larger Ge detectors
- Coax detectors removed
- Detectors arranged in 9 strings
- 29 kg-yr stable energy dataset

IC Ge detector

- Point contact
- Low noise
- Large size
- O(keV) intrinsic threshold

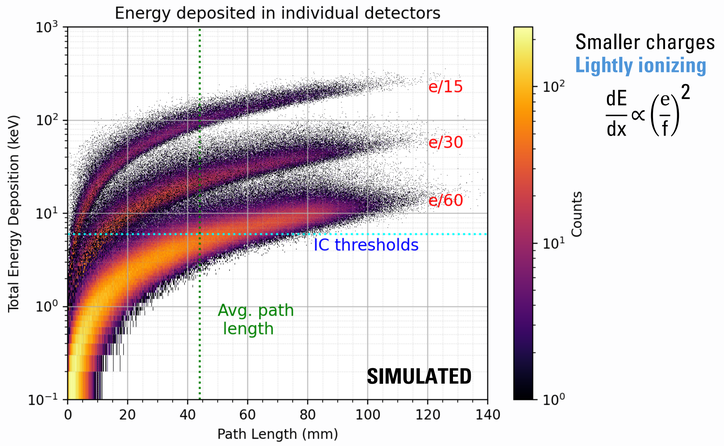


2) FRACTIONALLY CHARGED PARTICLES (FCPs)

Free charges occur in **integral multiples of e**
No known physics laws constrain charge quantization

- Observation of FCP → non-quantization of charge.
- Quarks fractionally charged but confined.
- **4D String theory** generally predicts existence of FCPs [2].
- **BSM Dark Sector** could motivate FCPs in charge range e/100 to e/10 [3].
- Alternately, existence of magnetic monopoles →charge quantization but have not yet been observed [4].

Can free FCPs exist?



Smaller charges
Lightly ionizing

$$\frac{dE}{dx} \propto \left(\frac{e}{f}\right)^2$$

Direct search for fractionally charged muon-like particles (**Minimum ionizing** nature) produced in atmosphere.

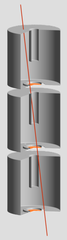
Previous underground searches

- MAJORANA DEMONSTRATOR (MJD) [5]
- CUORE [6]
- CDMS II [7]
- CDMSlite [8]

3) SIGNAL…

High Multiplicity

Straight Track, low energy deposition

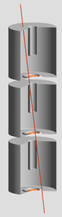


…& BACKGROUNDS

Muon tracks

Energy Cut

Muons deposit higher energy across the array



Coincidence

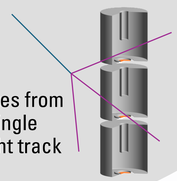
Multiplicity Cut

Accidental M3 Rate
< 3x10^{-12} Hz
across the full array

Muon showers

MJD Tracking **Max Multiplicity Cut**

Deviates from a single straight track



Showers hit > 1 string

This sensitivity study uses only the **Ge detectors** for **signal identification** and **background (bkg) rejection**

(No LAr, water Cherenkov)

4) THRESHOLDS

- **Hardware threshold (HWT)**: If a channel has energy deposited ≥ 40 keV , all channels are read out.
- **Multiplicity threshold** : At least 2 other Ge channels should have a hit above 6 keV (10 keV if Coax).
- For the new detector configuration, no Coax detectors but multiplicity threshold is conservatively loosened to 7 keV, due to increased noise.

5) METHODS

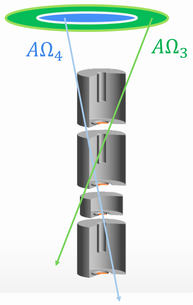
remage for germanium experiment simulations [9], extended using Geant4-based package to simulate FCPs [10].

$$\phi(f) = \frac{n}{\sum_i \sum_m (\varepsilon_{det} A\Omega)_{m,i} \varepsilon_{cut} t_i}$$

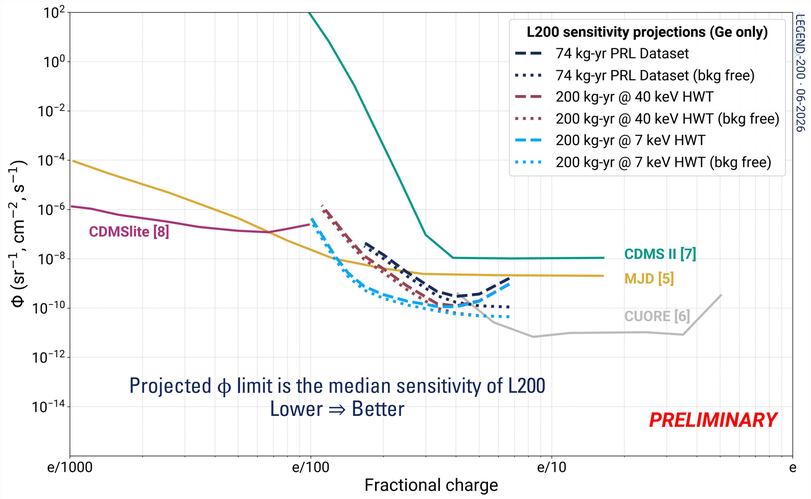
From Simulations

ϕ	flux of FCPs incident on detector	m	multiplicity reconstructed
n	Observed/Limit on candidate events set by one-sided Feldman Cousins	$A\Omega$	Detector acceptance [11]
i	run index	ε_{det}	Hardware threshold efficiency
t_i	Livetime for run i	ε_{cut}	Optimized cut efficiency

Joint optimization of the background rejection **cuts** based on muon background simulations.



6) SENSITIVITY PROJECTIONS



LEGEND-200 has leading sensitivity for charge ranges from…

e/40 to e/24 using the **PRL dataset**

e/43 to e/22 for **future 200 kg-yr** dataset, with unchanged HWT

Lowering HWT to 7 keV extends region down to **e/77**

7) FUTURE PLANS

- Will continue to acquire data in the latest configuration.
- Explore methods to lower hardware thresholds, improving sensitivity to smaller charges.
- L1000 will be well suited to search for FCPs due to its larger exposure, lower O(keV) hardware thresholds; sensitivity studies to come.

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References

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