# Search for fractionally charged particles with CDMSlite

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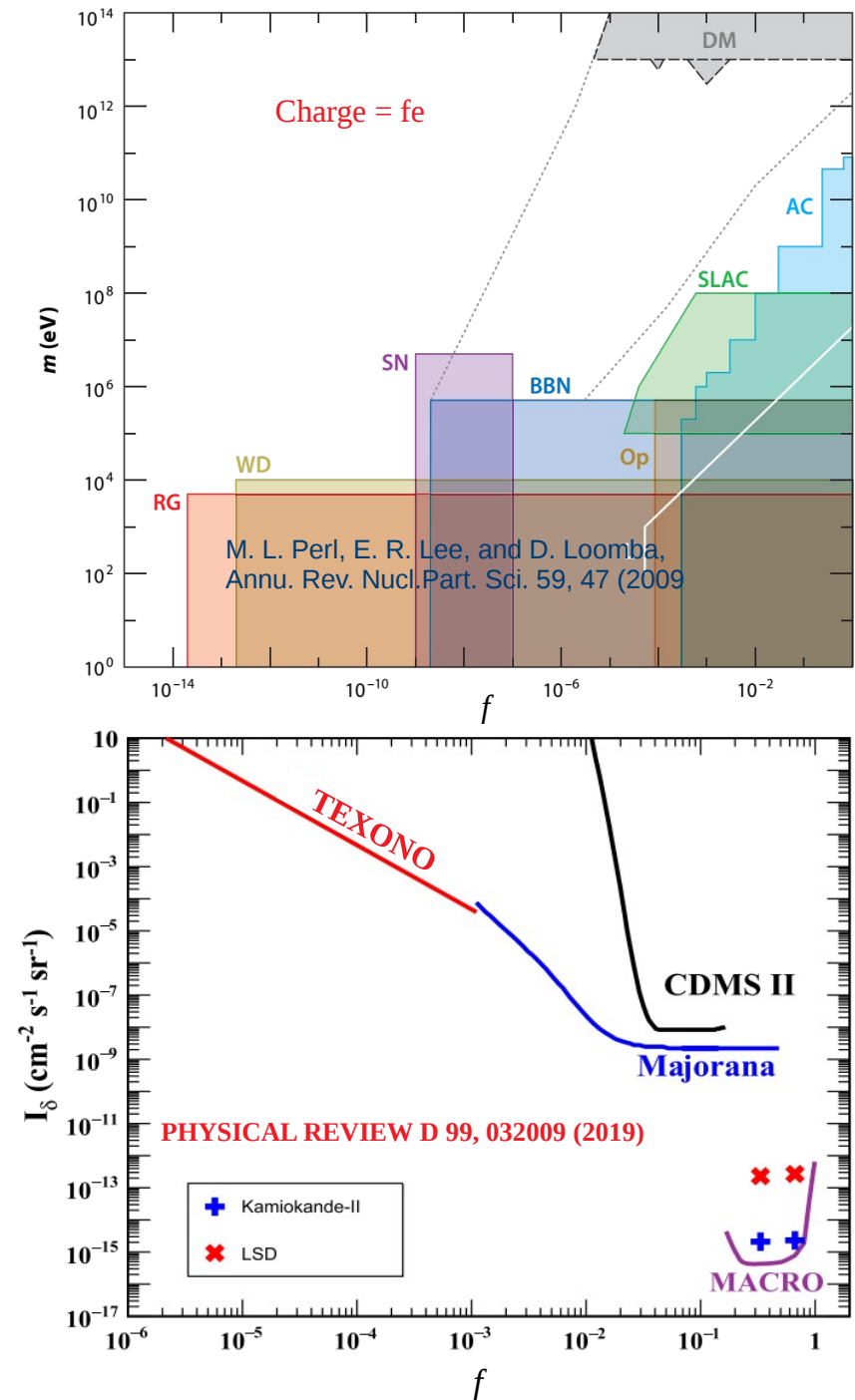NISER, HBNI, India

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Outline

➢ Motivation

➢ SuperCDMS Soudan and CDMSlite

➢ FCP search analysis

➢ Intensity limit projections

➢ Summary

# Motivation for FCP search

- ➢ Experimentally found all free charged particles have charges integer multiples of charge of an electron

- ➢ No strong theoretical motivation for quantization of particle charges

- ➢ Charge quantization explained only by assuming existence of magnetic monopoles*

  - ➢ Monopoles yet to be discovered which opens the possibility of finding fractionally charged particles (FCPs)

- ➢ Several experiments have looked for FCPs, exploring wide range of masses and charges

- ➢ There is a lot of parameter space yet to cover

- ➢ SuperCDMS sensitive to probe charges as small as $e/10^8$, mass: 5 MeV/c$^2$ – 100 TeV/c$^2$ , $\beta\gamma$: 0.1 - $10^6$
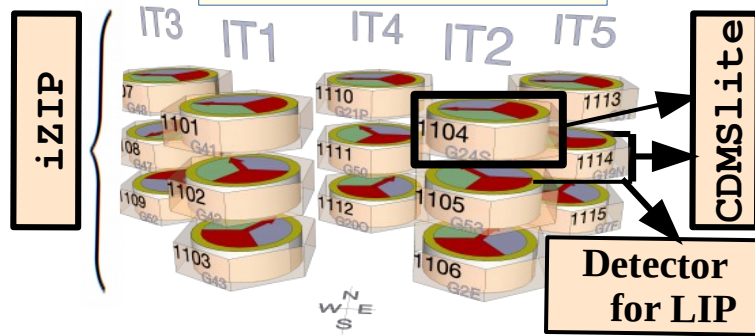
*P. A. M. Dirac, Proceeding of Royal Society London A133, 60 (1931), doi:10.1098/rspa.1931.0130.



M. L. Perl, E. R. Lee, and D. Loomba, Annu. Rev. Nucl.Part. Sci. 59, 47 (2009

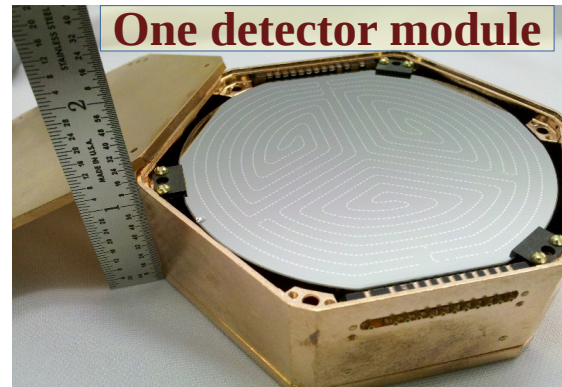PHYSICAL REVIEW D 99, 032009 (2019)

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# SuperCDMS Soudan and CDMSlite

- Super Cryogenic Dark Matter Search: direct-detection dark matter search experiment at Soudan mine (2100 m.w.e.), Minnesota, USA

- Deployed germanium detectors to primarily search for WIMPs

- Measure very small amount of energy depositions* as particles interact with the detector material
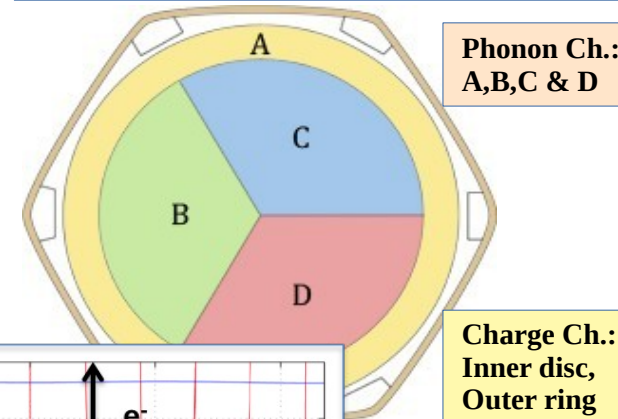
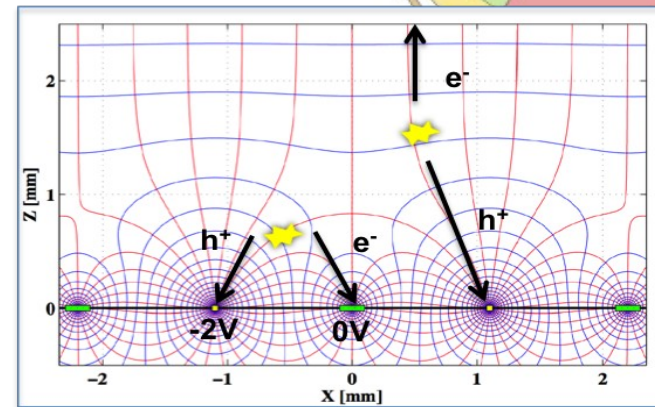- Sensitive to detect fractionally charged particles



**Soudan detectors**

iZIP

IT3 IT1 IT4 IT2 IT5

CDMSlite

Detector for LIP



**One detector module**



**Phonon & charge channels**

Phonon Ch.: A,B,C & D

Charge Ch.: Inner disc, Outer ring

- Five towers of detectors

- Detector material: Ge

- Mass: 0.6 kg each

- Temperature : 50 mK

- Detects ionization and phonon signal

- 4 phonon channels, 2 charge channels at each side

- Phonon channels are grounded, charge channels are biased at ~4V or ~70V

- In high bias-voltage mode, detectors sensitive to very small energy depositions: CDMS low ionization threshold experiment

*as small as 56 eVee energy deposition is measured in CDMSlite Run 2
PHYSICAL REVIEW D 97, 022002 (2018)



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# CDMSlite FCP search

- Energy depositions above 100 eV are considered

  - Provides sensitivity to FCPs with very small fractional charge

- First direct search to put intensity limits for charges smaller than $e/(3 \times 10^5)$*

  - Charges explored: $e/100$ to $e/10^8$

- Wide range of mass is explored

  - Mass: $5$ MeV/$c^2$ to $100$ TeV/$c^2$

- First search for non-relativistic FCPs

  - $\beta\gamma$ explored: $0.1$ to $10^6$

Tower 5

iZIP1

iZIP2

iZIP3
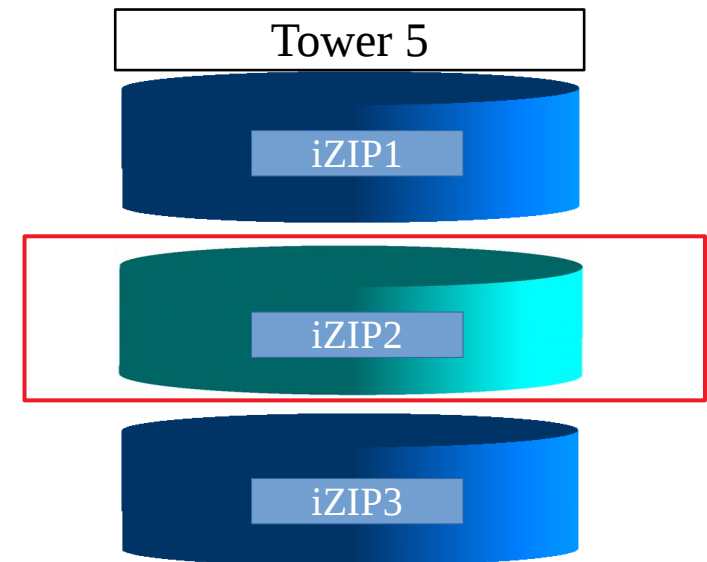
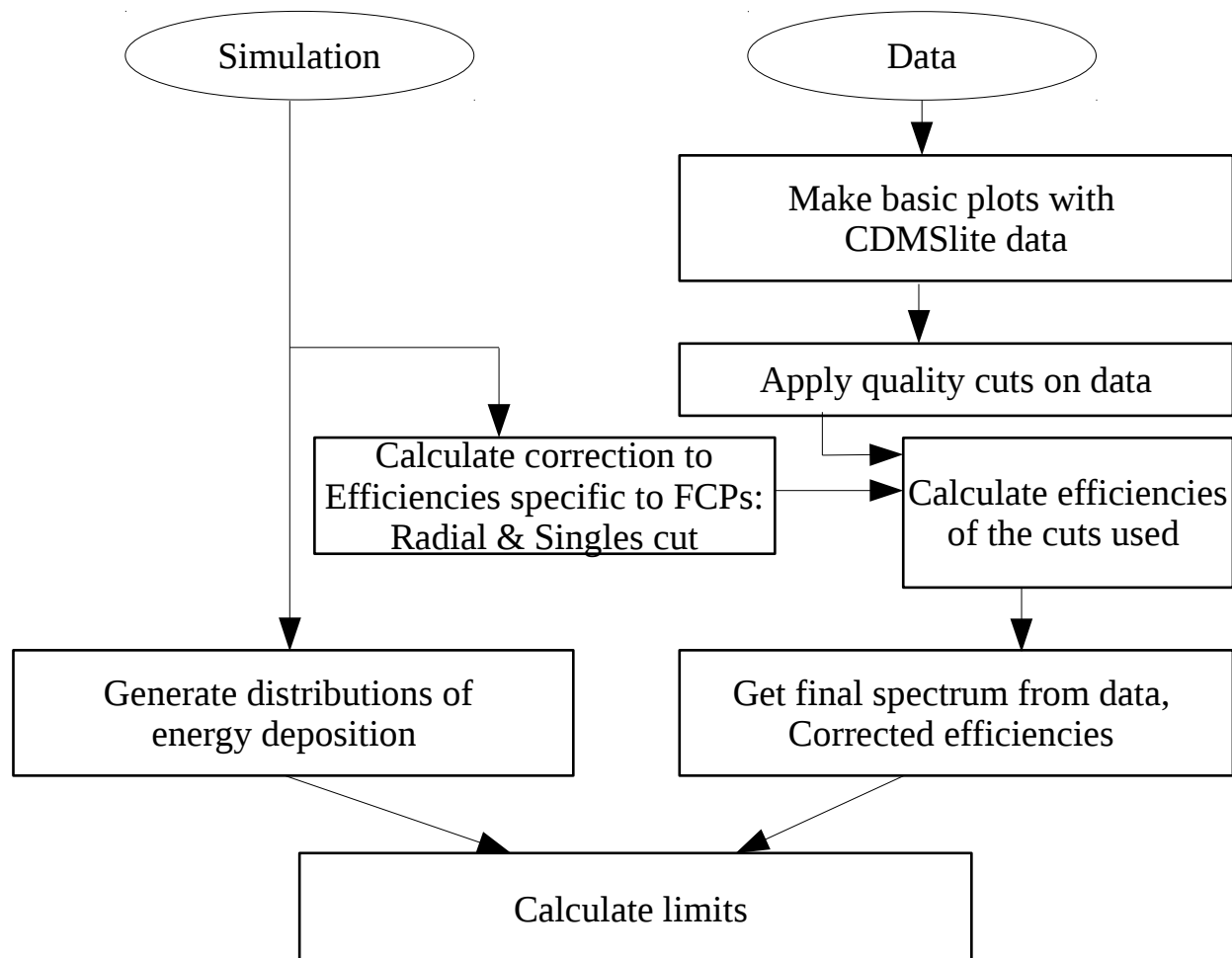- ✓ iZIP2 was run in CDMSlite mode

- ✓ Energy deposition spectrum measured in iZIP2 is used to search for FCP in this analysis

*Limits from TEXONO excluded charges between $e/10^3$ and $e/(3 \times 10^5)$:
**PHYSICAL REVIEW D 99, 032009 (2019)**
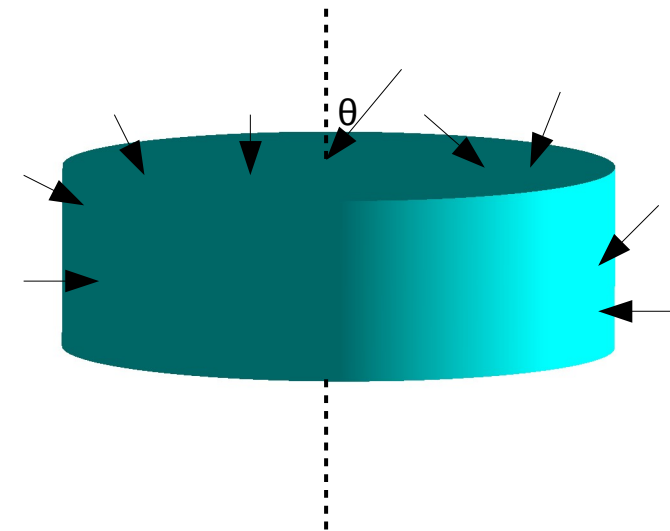
# FCP search analysis flow

$$I_v^{90}(f) = \frac{N^{90}(f)}{\tau \times \int_{100 \text{ eV}}^{2000 \text{ eV}} \int \underbrace{(\epsilon(E) \times \text{PDF}(f, E, \theta))}_{\text{detection efficiency}} dE \times \underbrace{2\pi A(\theta) \sin\theta}_{\text{geometric factor}} d\theta}$$

$N^{90}(f)$: Upper limit on # of FCP-events

Four major components for limits:

1) Data spectrum of energy deposition

2) Efficiency ($\epsilon(E)$) of all cuts used to select the data

3) Livetime of the detector

4) Signal model: Probability distribution functions (PDFs) of energy deposition

```
              Simulation                          Data
                  |                                 |
                  |                                 v
                  |                    ┌──────────────────────────┐
                  |                    │  Make basic plots with   │
                  |                    │      CDMSlite data        │
                  |                    └──────────────────────────┘
                  |                                 |
                  |                                 v
                  |                    ┌──────────────────────────┐
                  |                    │  Apply quality cuts on data│
                  |                    └──────────────────────────┘
                  v                                 |
  ┌──────────────────────────┐                      v
  │  Calculate correction to │        ┌──────────────────────────┐
  │Efficiencies specific to  │───────▶│  Calculate efficiencies   │
  │FCPs: Radial & Singles cut│        │     of the cuts used      │
  └──────────────────────────┘        └──────────────────────────┘
                  |                                 |
                  v                                 v
  ┌──────────────────────────┐        ┌──────────────────────────┐
  │  Generate distributions  │        │  Get final spectrum from  │
  │   of energy deposition   │        │  data, Corrected efficiencies│
  └──────────────────────────┘        └──────────────────────────┘
                   \                            /
                    \                          /
                     v                        v
                  ┌──────────────────────────┐
                  │     Calculate limits      │
                  └──────────────────────────┘
```



$\theta$

➢ Isotropic and $\cos^2\theta$ angular distributions are assumed for incident FCPs

# Energy deposition distributions: minimum ionizing FCPs
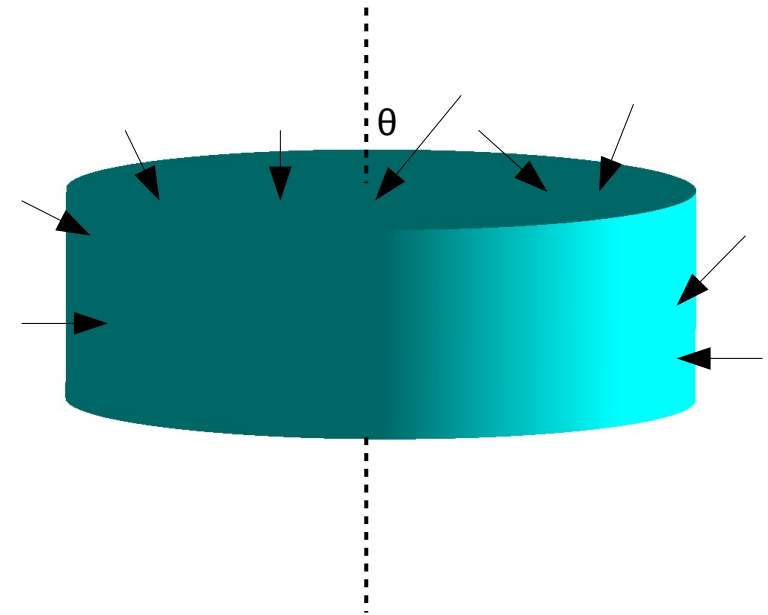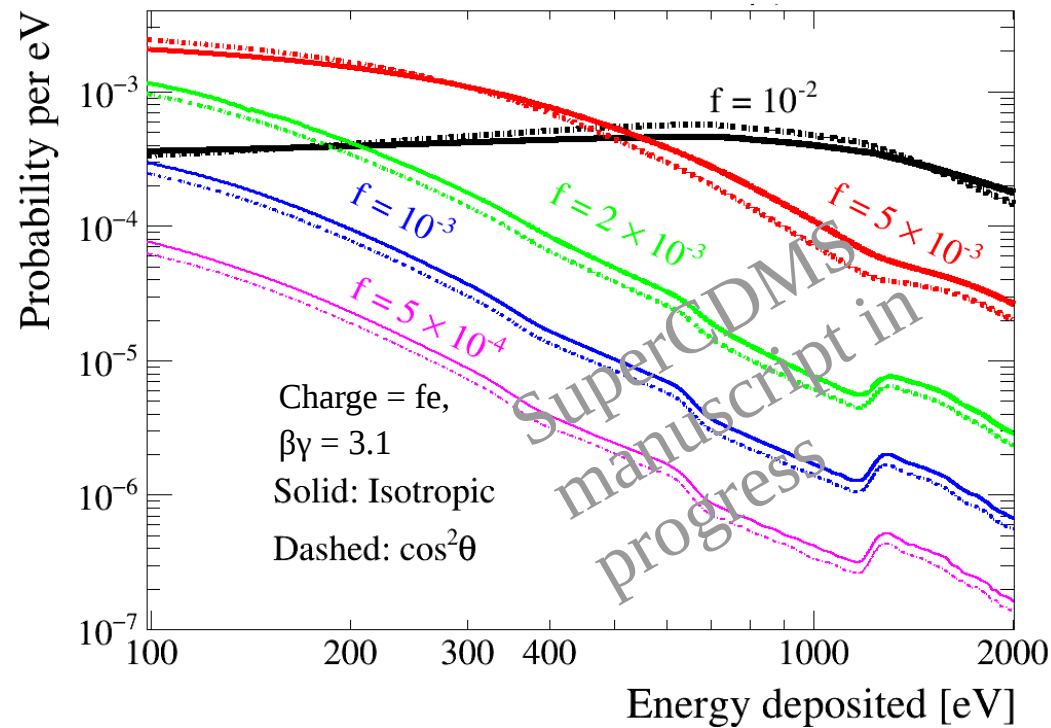


- ➤ For large charge ( $\geq e/100$ ), higher energy depositions are more probable
- ➤ As charge is decreased, probability of energy deposition also reduces
- ➤ For very small fractional charge, the shape of the distributions does not change, only amplitude reduces by a relative charge-squared factor
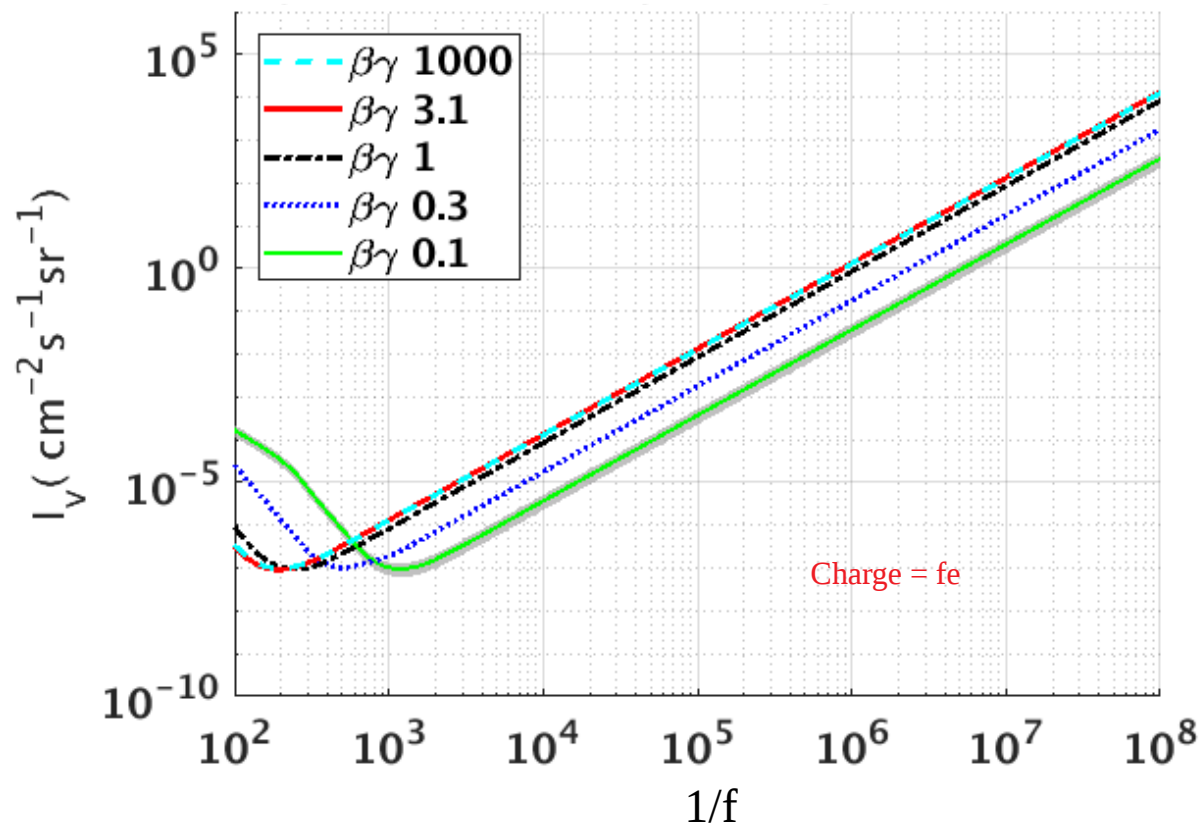- ➤ The distributions are independent of mass
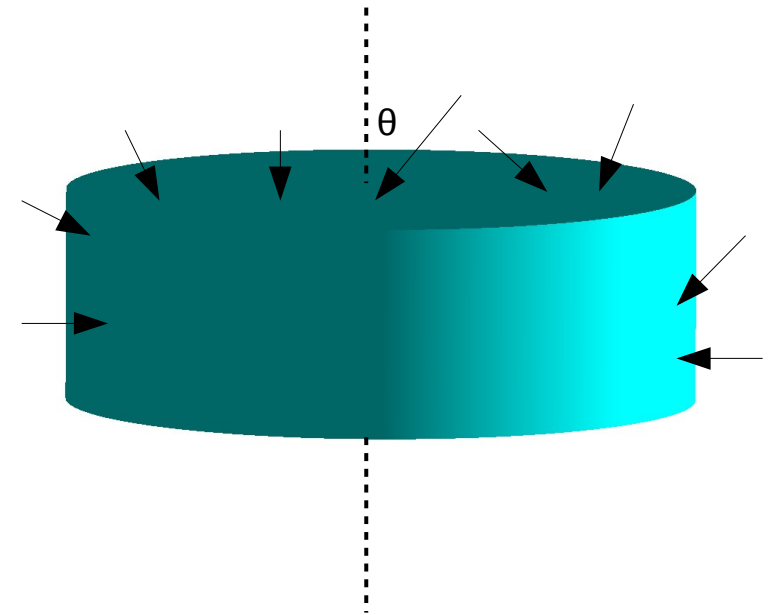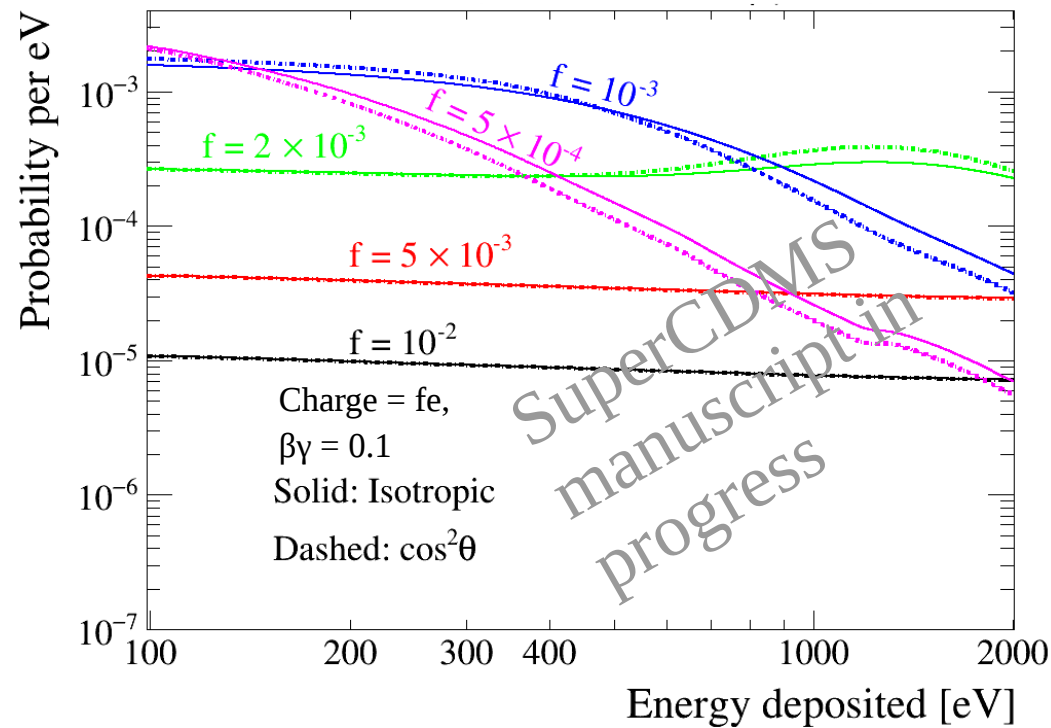
- ➢ At small velocities, interactions inside the detector occur more often

  - ➢ Larger energy depositions are more probable

- ➢ As charge is decreased, probability of energy deposition also reduces

- ➢ The distributions are independent of mass

# FCP search efficiency



Accept

Reject



CDMSlite Run 2 Period 1



Isotropic angular distribution
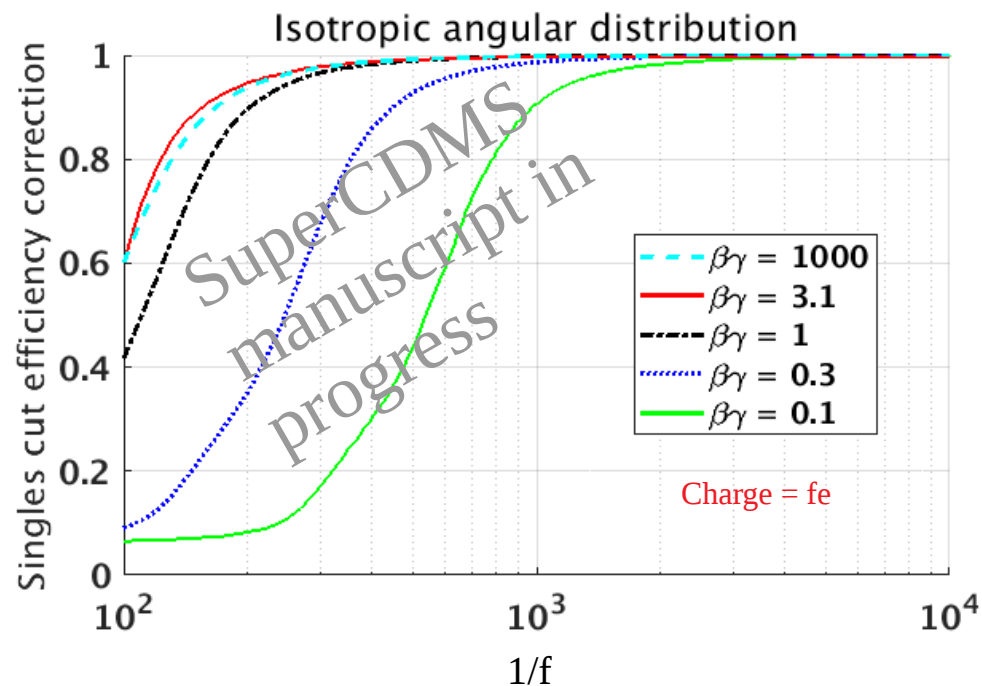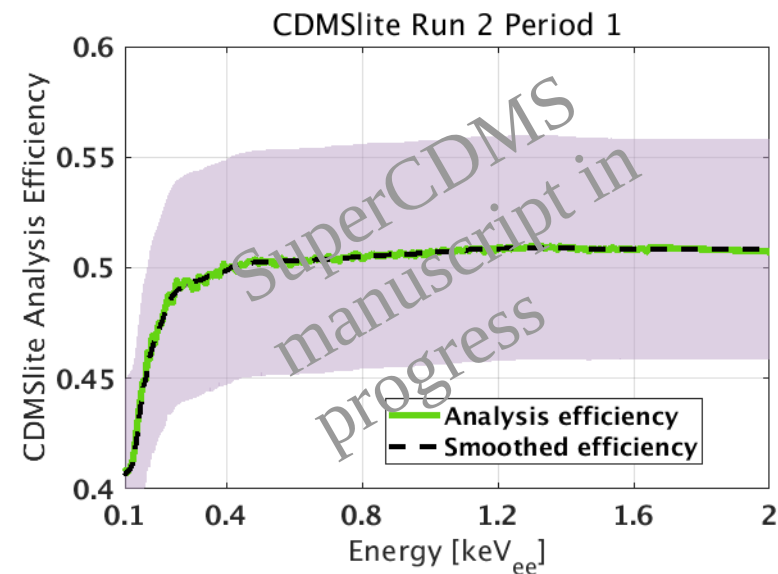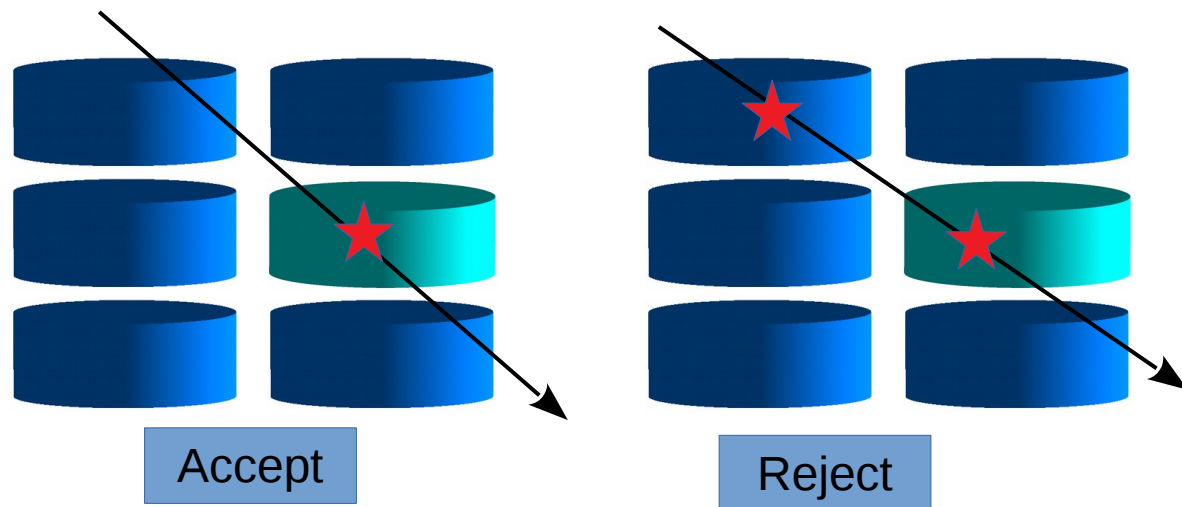
Charge = fe

- ➢ CDMSlite WIMP-search selection criteria and efficiencies are used in FCP search analysis
- ➢ WIMP does not multiple scatter, FCP with large charge does
  - ➢ Correction to efficiency is calculated using simulation
  - ➢ Correction tends to unity for very small charge of FCPs

# Intensity limit projection



- ➢ Intensity limit projections are calculated for various fractional charges, masses and βγ

- ➢ The lowest sensitivity is achieved at charge e/120 for minimum ionizing (βγ=3.1) FCPs

- ➢ As energy deposition distributions are independent of mass, the limits are applicable for all masses between 5 MeV/c$^2$ to 100 TeV/c$^2$

# Summary

➢ CDMSlite, having a very small energy threshold in the detector, is sensitive to FCPs with very small fractional charge

➢ Plans to set limit for FCPs with charges smaller than e/100 and up to $e/10^8$

➢ First to probe non-relativistic FCPs; a wide range of velocities are explored

➢ Final results will be published soon

# Thank You

# Back up

# Stopping power Vs. momentum