

DOE Grant Number:
DE-SC0015657

Grant Recipient:
University of South Dakota

Title:
Direct Detection of Dark Matter at the University of South Dakota

Principle Investigator: Prof. Joel Sander
Reporting Period: 05/01/2016 to 05/31/2024

Date of Report: 10/10/2024

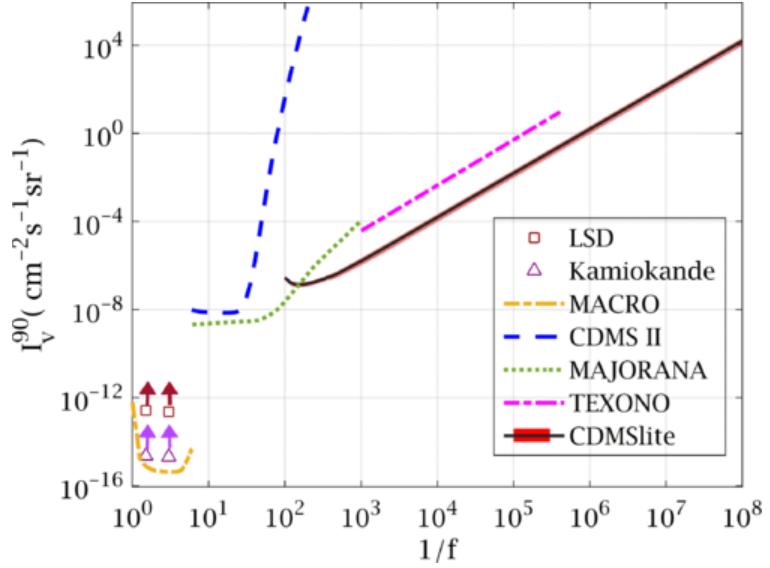
Final Technical Report for DE-SC0015657

1. Abstract

The grant supports experimental research to address one of the pressing questions of our time is the nature and composition of the dark matter. Direct detection of dark matter is possible because the rotation curves of galaxies suggest the presence of a sufficiently-large weakly interacting massive particle (WIMP) density. However, the absence of any confirmed dark matter detection indicates the need for more sensitive experiments. SuperCDMS SNOLAB is a generation-2 dark matter search experiment that is designed to have vastly improved sensitivity to low-mass WIMPs. SuperCDMS SNOLAB unique capabilities also enable sensitivity to a broader range of science beyond WIMPs. The SuperCDMS SNOLAB experiment is being installed and integrated at SNOLAB, near Sudbury, Ontario in Canada. The University of South Dakota (USD) group is deeply invested in the installation, integration and planning for commissioning and operations of the SuperCDMS SNOLAB experiment.

2. Technical Description

This final report on the research at the University of South Dakota is supported by a grant for the DOE High Energy Physics Cosmic Frontier office. Group members made a number of science contributions. Graduate student Soudip Poudel co-led the *Constraints on Lightly Ionizing Particles from CDMSlite* science result with Sander serving as the PI guiding and supporting the requisite simulation and analysis. This result (submitted in 2020) is the first to directly probe for particles with micro electric charge, or electric charge a million times smaller than that of the electron. Sander served or chaired multiple SuperCDMS paper review committees. The figure (right) shows the resulting exclusion region of new parameter space in vertical intensity vs inverse fractional electric charge.



Sander also serves as the Ombudsperson where he founded the Ombuds/Safe People group and led writing of the SuperCDMS DEI statement. The Ombuds role has a non-standard definition focused on supporting collaboration members: *"The SuperCDMS Ombudsperson serves as a confidential point of contact for informal exploration of complaints and possible*

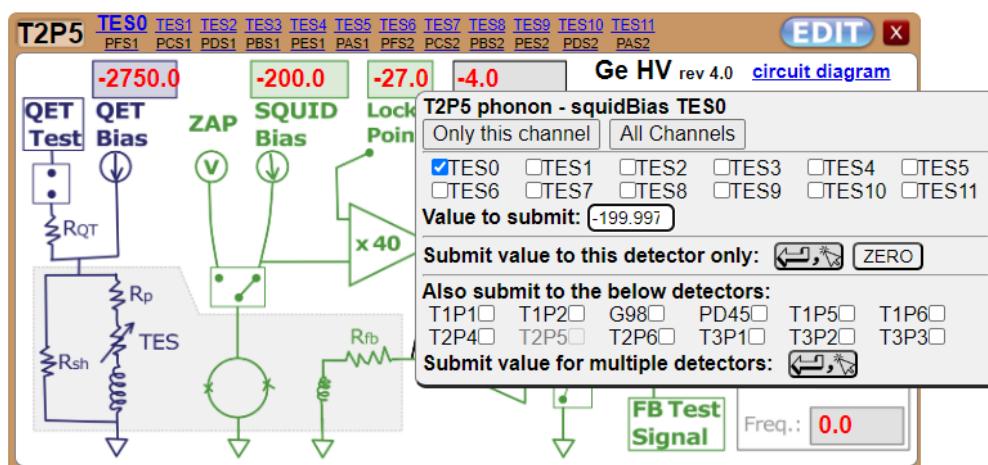
unofficial resolution of any issues. They foster discussions of whether an allegation is warranted or not, or whether an individual wants to bring forward an allegation. In addition, they provide confidential support for individuals, and help everyone in the collaboration understand the boundaries in difficult situations. They will maintain a website with helpful information and a list of additional individuals who can be contacted confidentially about issues.” In addition to fulfilling this role, as Ombudsperson Sander also conducts annual SuperCDMS environmental surveys and initiates change where member and survey information indicate the need for systemic improvement.

Sander supports a well-functioning collaboration in multiple other roles. Sander is the chair of the Records Committee and is a member of the Policy and Outreach Committees. Sander founded and chaired the Working Group Task Force to assess how WGs interact with all collaboration members and recommend ways in which WGs can better serve and empower all members. In 2022, the Task Force made a number of recommendations that were impactful to WG Chairs, the Spokesperson, and the Council Chair.

SuperCDMS Project

The largest technical effort during the first four years of the reporting period was supporting the Project of building the SuperCDMS experiment at SNOLAB specifically in the areas of data acquisition (DAQ) and data quality monitoring (DQM). Accomplishments include:

- Supported the SuperCDMS-SNOLAB Project by developing the DAQ’s detector configuration system (WBS 1.6.3).
- Supported the SuperCDMS-SNOLAB Project by developing the DQM system (WBS 1.6.4) in collaboration with Dave Toback’s group at Texas A&M University.
- Sander and Roberts wrote the detector configuration, data quality monitoring and SuperCDMS SNOLAB projected sensitivity to lightly ionizing particles for the Project’s Technical Design Report.
- Roberts performed analyses designed to understand the impact of radon in the air volume near the SuperCDMS-Soudan detectors in order to inform SuperCDMS-SNOLAB radon-mitigation design efforts.
- Podviianiuk traveled to SLAC to assist in detector tower installation.



The image above shows a snapshot of one part of the user interface for which USD continues to provide support.

SuperCDMS Installation & Integration and Operations

Under SuperCDMS Operations, Sander served as the Operations Level 3 Technical Coordinator for DAQ/Trigger support through July 2022 when he was elected and transitioned to a Level 1 advisory role as Operations Scientist. In early 2024, Sander was re-elected Operations Scientist. Postdoctoral Scholar Ruslan Podviianiuk is the only person from a US-institution to relocate to Sudbury enabling a highly-integrated, cost-effect outsized impact on installation and integration of the experiment. Podviianiuk has had an impactful role in numerous installation and integration activities at SNOLAB, including cryogenics, copper etching and passivation, and detector tower handling. Sander and Podviianiuk are responsible for development and support of the DAQ user interface. Podviianiuk is responsible for development and support of the back-end run control which takes user run settings and translates them into MIDAS sequencer commands. Podviianiuk also played a leadership role in defining the instrumentation package for the dedicated cold test at SNOLAB to validate the cryogenic system. Graduate student Lekhraj Pandey is the deputy Level 3 Data Quality Monitoring Manager, and graduate student Joseph Mammo is in training to become the deputy Level 3 Data Processing and Data Handling Manager. Pandey, Mammo and Sander have taken multiple on-site shifts in support of SuperCDMS including Sander spending about two months of his fall 2022 sabbatical on site. Pandey and Mammo took on-shifts supporting shield installation. SuperCDMS Operations operated a single production detector tower in the CUTE test facility to exercise experiment commissioning activities and to answer a number of commissioning questions including identifying detector operational parameters, determining the method of detector neutralization, and validating detector calibration plans. Mammo took on-site shifts and all group members took off-site data quality shifts in support of the ~4 month operation of a detector tower in the CUTE facility. In 2024, the need for chilled water backup was identified. Sander led consensus building and is responsible for procurement of the primary chilled water backup equipment using non-DOE-provided funds. Graduate Student Sedonah Franzen is responsible for development of software for monitoring UPS performance and initiating a safe shutdown in the event of a significant power outage. Franzen also has DAQ responsibilities for the SuperCDMS Operations effort at the NEXUS test facility to measure a characteristic SuperCDMS detector's (1) ionization response down to recoil energies below those previously measured and (2) fiducial volume. These NEXUS measurements address the primary systematic uncertainties that would otherwise limit the SuperCDMS SNOLAB science results.

3. Presentations and Venues

Sander and other USD group members have made numerous presentations primarily at conferences, universities, and collaboration meetings. Nearly all presentations were given within the US, but two international presentations were given for the Saha Institute of Nuclear Physics and NISER both in India. Junior group members also gave regular presentations with national, local and USD scope.

4. Personnel Involvement

Research Associates: none

Postdocs:

- Dr. Amy Roberts (2014-2017, now faculty at CU Denver)
- Dr. Ruslan Podviianiuk (2018-present)

Graduate Students:

- Manish Jha (current)
- Sedonah Franzen (current)
- Joseph Mammo (current)
- Lekhraj Pandey (current)
- Garrett Terry (MS, Dec. 2023)
- Sudip Poudel (PhD, May 2021)
- Thomas Binder (MS, July 2018)

Undergraduate Students:

- Oleksandra Lukina (Honors BS with high distinction, May 2024)
- Sedona Franzen (Honors BS with distinction, May 2023)
- Thomas Binder (Honors BS, May 2016)

5. Unexpended Funds

There are no unexpended funds.

6. Products

- First Measurement of the Nuclear-Recoil Ionization Yield in Silicon at 100 eV, <https://www.osti.gov/servlets/purl/2280762>
- Search for low-mass dark matter via bremsstrahlung radiation and the Migdal effect in SuperCDMS, <https://www.osti.gov/pages/biblio/1987928>
- The level-1 trigger for the SuperCDMS experiment at SNOLAB, <https://www.osti.gov/servlets/purl/1867681>
- Investigating the sources of low-energy events in a SuperCDMS-HVeV detector, <https://www.osti.gov/pages/biblio/1873591-investigating-sources-low-energy-events-supercdms-hvev-detector>
- Ionization yield measurement in a germanium CDMSlite detector using photo-neutron sources, <https://www.osti.gov/pages/biblio/1880245>
- Constraints on Lightly Ionizing Particles from CDMSlite, <https://www.osti.gov/biblio/1821884>
- Light Dark Matter Search with a High-Resolution Athermal Phonon Detector Operated above Ground, <https://www.osti.gov/biblio/1821463>
- Constraints on low-mass, relic dark matter candidates from a surface-operated SuperCDMS single-charge sensitive detector, <https://www.osti.gov/biblio/1712825>

- Constraints on dark photons and axionlike particles from the SuperCDMS Soudan experiment, <https://www.osti.gov/biblio/1631320>
- Search for low-mass dark matter with CDMSlite using a profile likelihood fit, <https://www.osti.gov/biblio/1550884>
- Production rate measurement of Tritium and other cosmogenic isotopes in Germanium with CDMSlite, <https://www.osti.gov/biblio/1468413>
- Nuclear-recoil energy scale in CDMS II silicon dark-matter detectors, <https://www.osti.gov/biblio/1437301>
- Energy loss due to defect formation from 206Pb recoils in SuperCDMS germanium detectors, <https://www.osti.gov/servlets/purl/1475487>
- First Dark Matter Constraints from a SuperCDMS Single-Charge Sensitive Detector, <https://www.osti.gov/pages/biblio/1462788/cite/>
- Results from the Super Cryogenic Dark Matter Search Experiment at Soudan, <https://www.osti.gov/pages/biblio/1420014>
- Projected sensitivity of the SuperCDMS SNOLAB experiment, <https://www.osti.gov/biblio/1390406>