The SPICE and HeRALD Experiments for Sub-GeV Dark Matter Detection

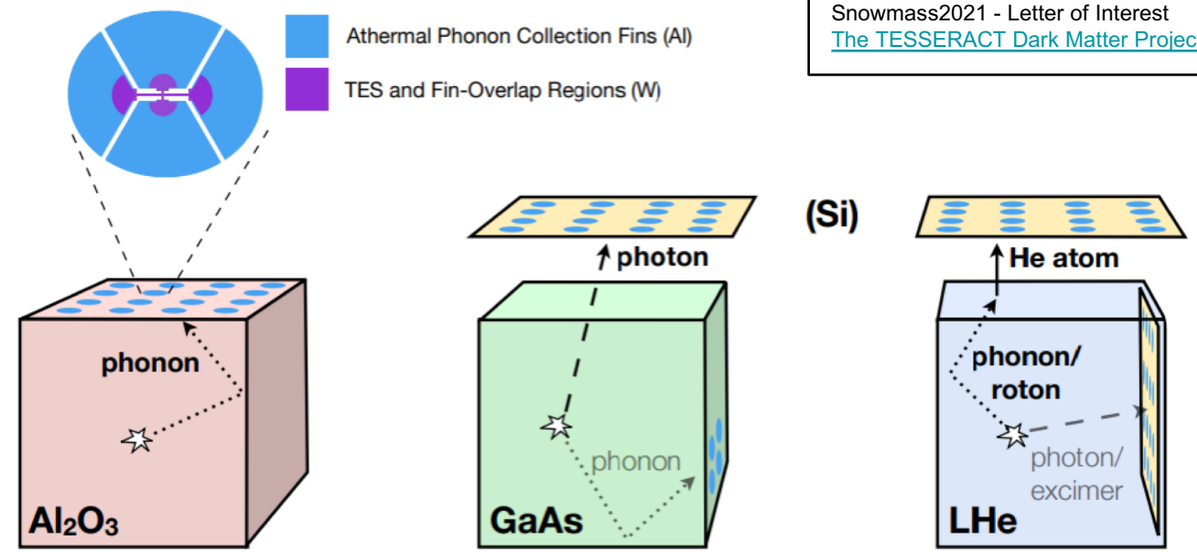
Dan McKinsey
TESSERACT Project Director
LBNL/UC Berkeley

SNOLAB Workshop, May 10-12, 2021

Snowmass2021 - Letter of Interest
The TESSERACT Dark Matter Project

TESSERACT project

- Managed by LBNL for DOE-HEP
- Different targets with complementary DM sensitivity
- All using TES readout
- ~40 people from 8 institutes
- Includes SPICE (polar crystals) and HeRALD (superfluid helium) experiments



- **Science goal:**
  - Direct detection of particle-like sub-GeV dark matter
  - Sensitive to a wide variety of dark matter interaction modes
    - dark photon-phonon interactions
    - electron scattering
    - nuclear scattering / absorption

- **Technology: Transition Edge Sensors (TESs)**
  - Athermal phonon readout for fast signals, decreased noise
  - Shared engineering on shielding design, vibrational isolation, electromagnetic interference, TES readout electronics
  - Multiple targets, each under zero electric field. Sapphire, Silica, Gallium arsenide, Superfluid helium

- **R&D:** Couple TES to different targets, test detector signal and background, calibrate target material response.

- **Schedule: Project planning stage:** 5 years, FY20-FY24
  - Project planning stage: 2020-2024
  - Fabrication: 24 months beginning 2025-2026
  - Operations: Beginning 2027

SPICE and HeRALD - projected sensitivity

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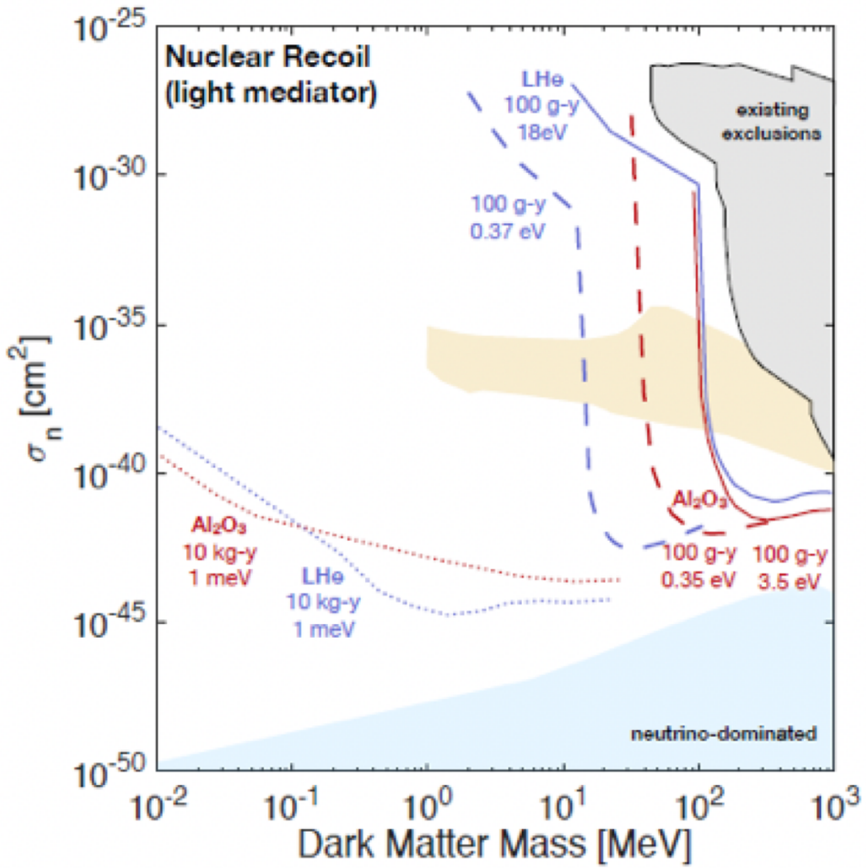

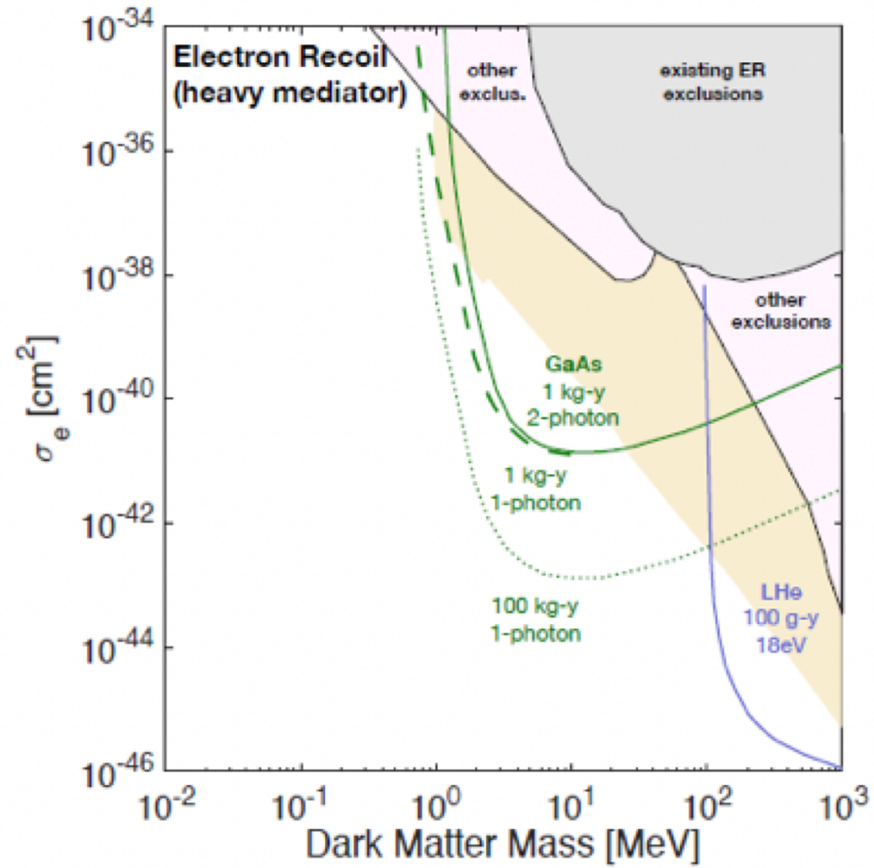

SPICE and HeRALD - projected sensitivity

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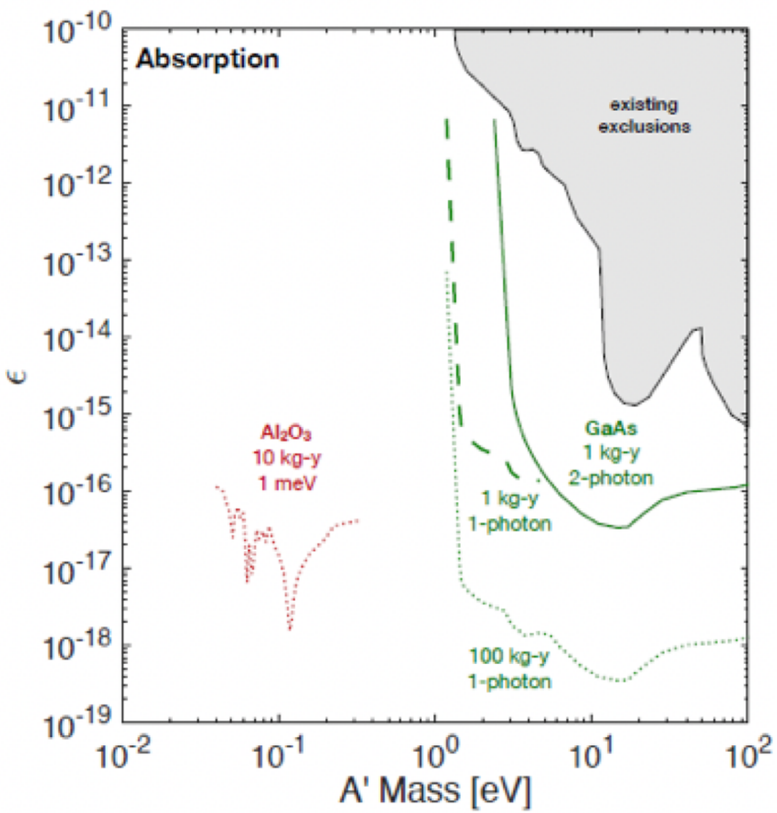
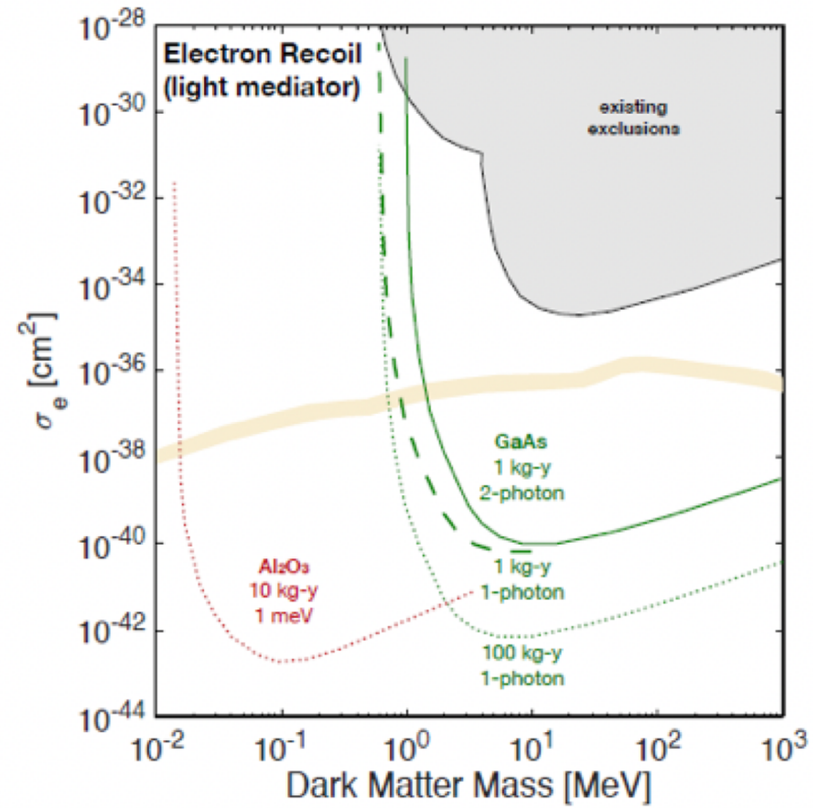
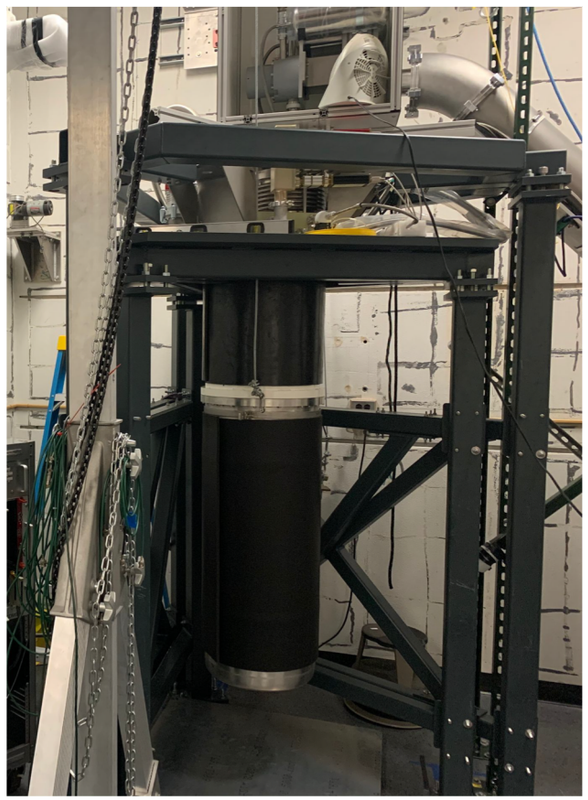




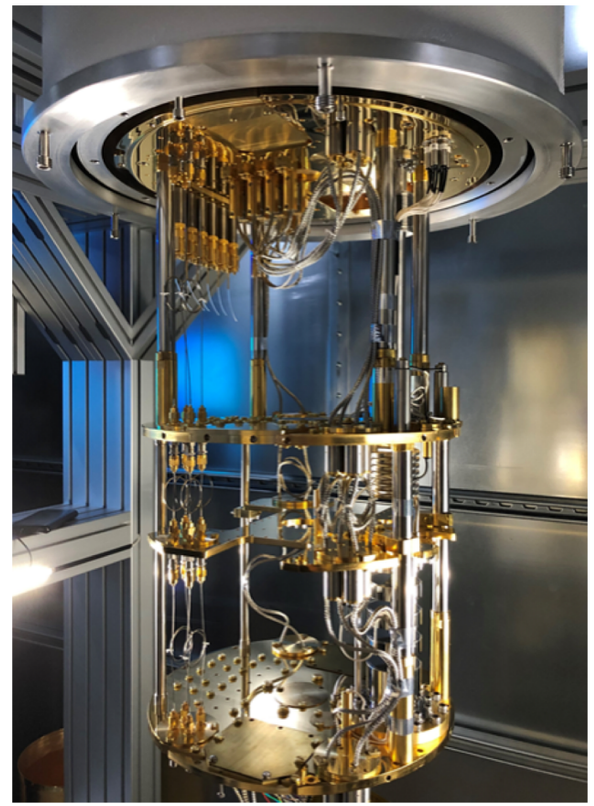
SPICE/HeRALD testbeds

Leiden MNK126-500
McKinsey Group @ UCB

CryoConcept UQT-B 200
Pyle Group @ UCB



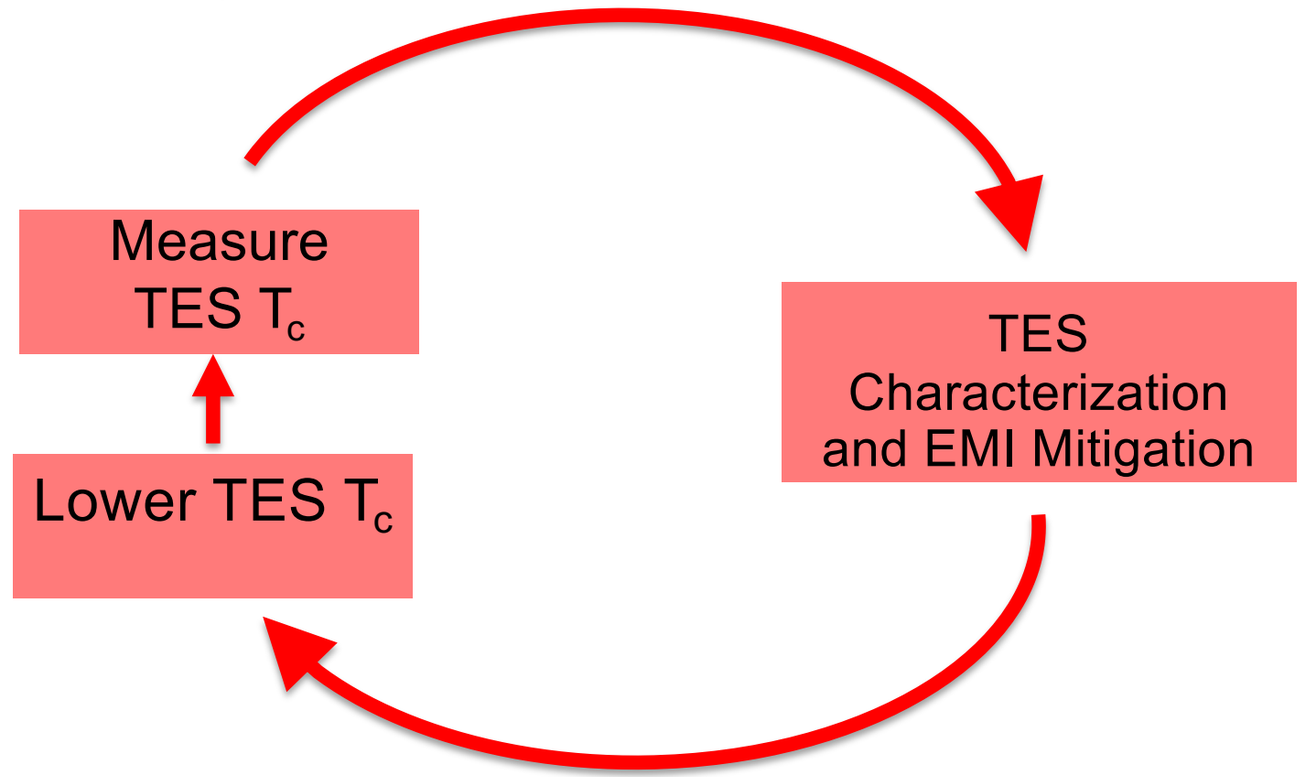
BlueFors LD-400
Suzuki Group @ LBNL



CryoConcept HEXADRY UQT-B 400
Hertel Group @ UMass

Major R&D goal: Develop ultra sensitive TES

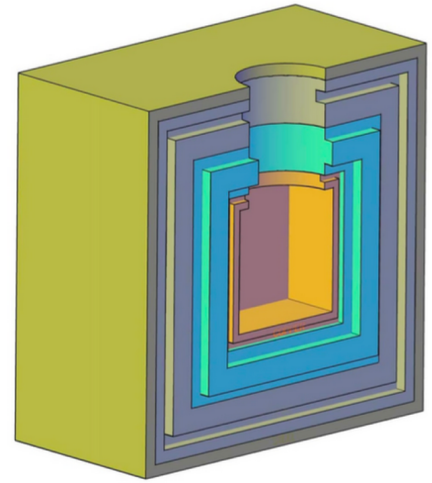
Work ongoing on fabrication (TAMU and ANL) and testing (UC Berkeley, LBNL, UMass)

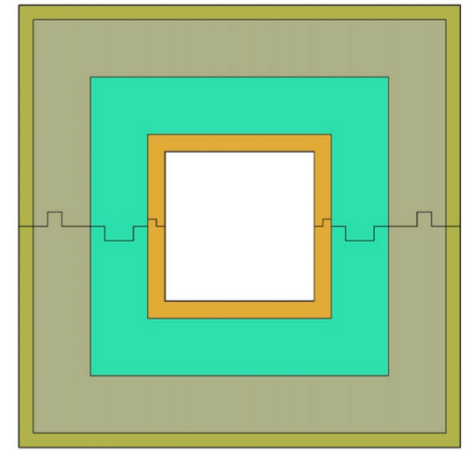


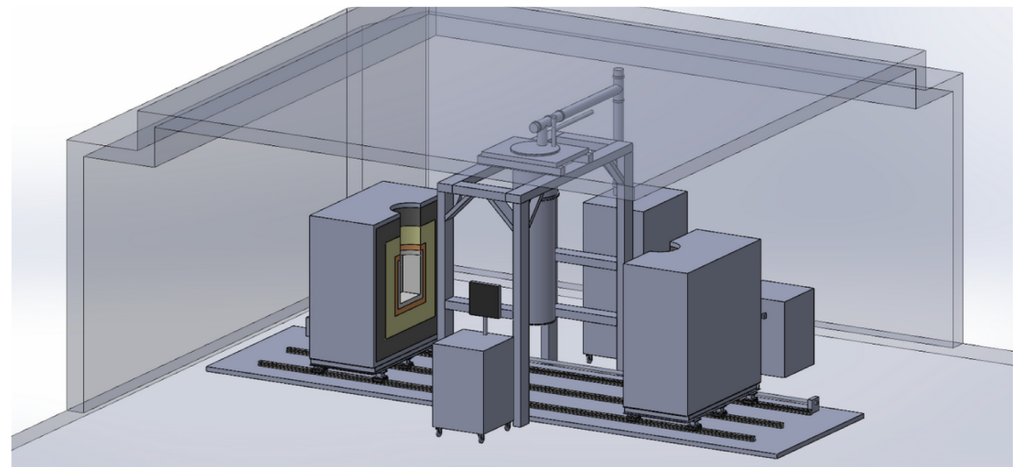
The experiments will be operated in an underground laboratory. Discussions are just beginning.

The shielding design has converged on a compact lead/polyethylene approach. Shielding will come off on rails so as to enable quick and straightforward access to the cryostat. There could be two copies of the setup.

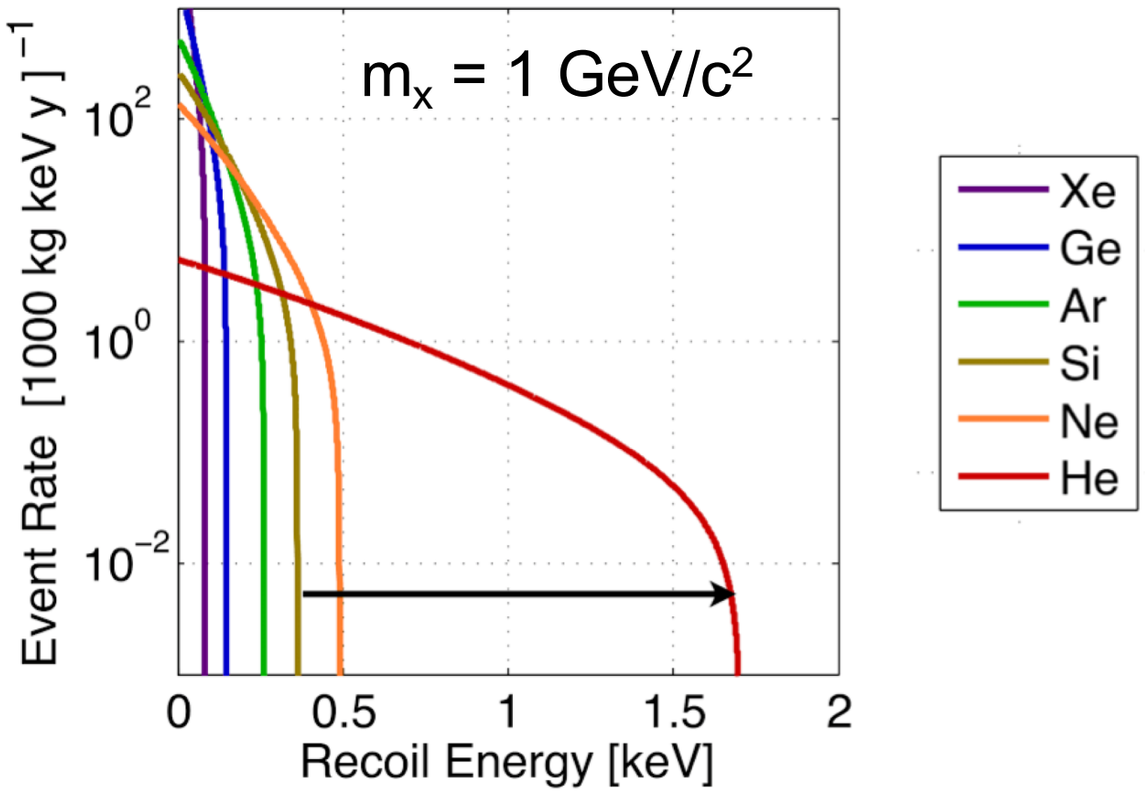
Significant emphasis on vibrational and EM noise suppression. Substantial R&D effort is being devoted to reducing these instrumental backgrounds.

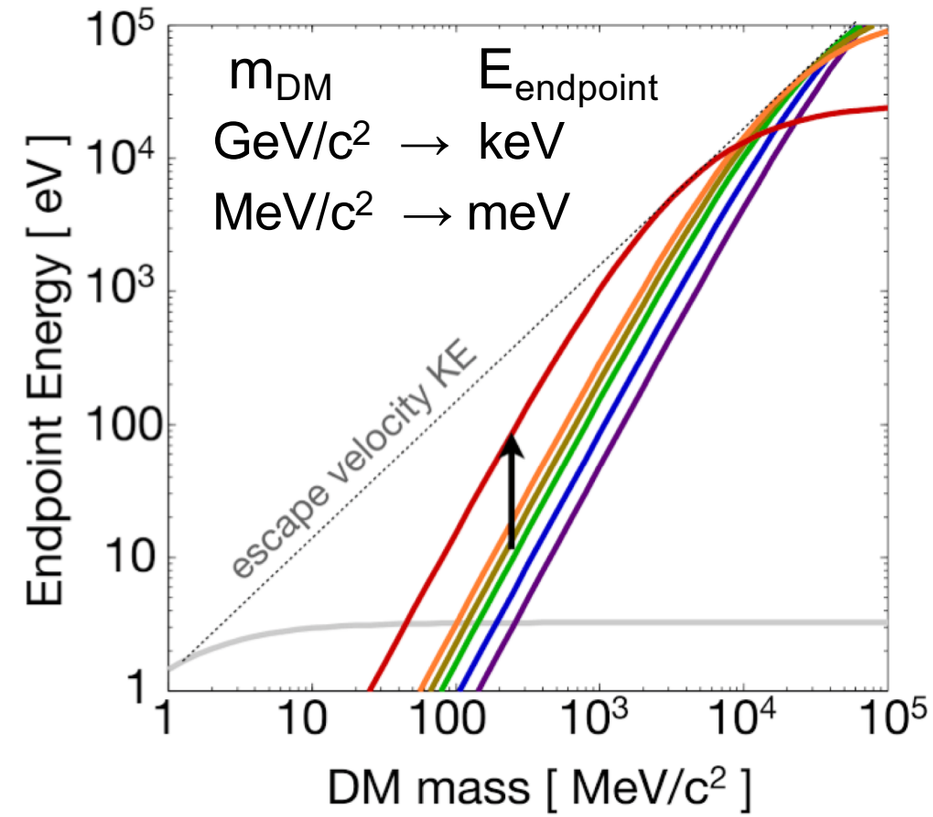






Helium as a light baryonic target

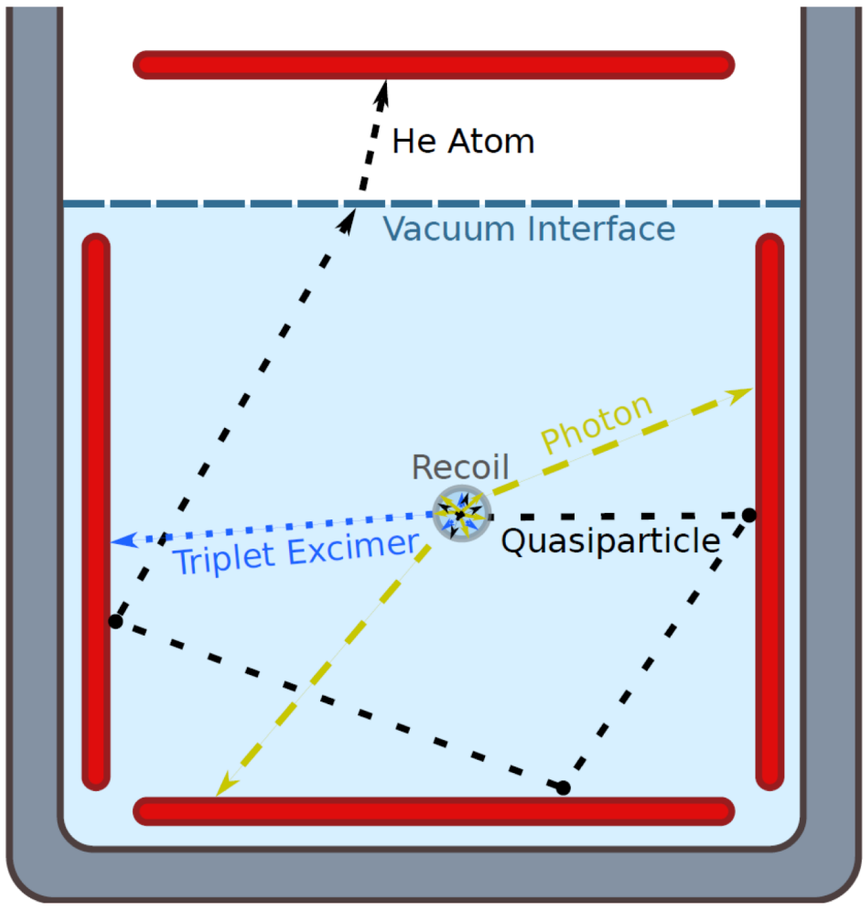




- Practical benefits of He-4:
  - Relatively cheap (~$100k/ton)
  - Extremely good intrinsic radioactivity
  - Monolithic detector - scalability
  - Remain liquid at mK - calorimetry

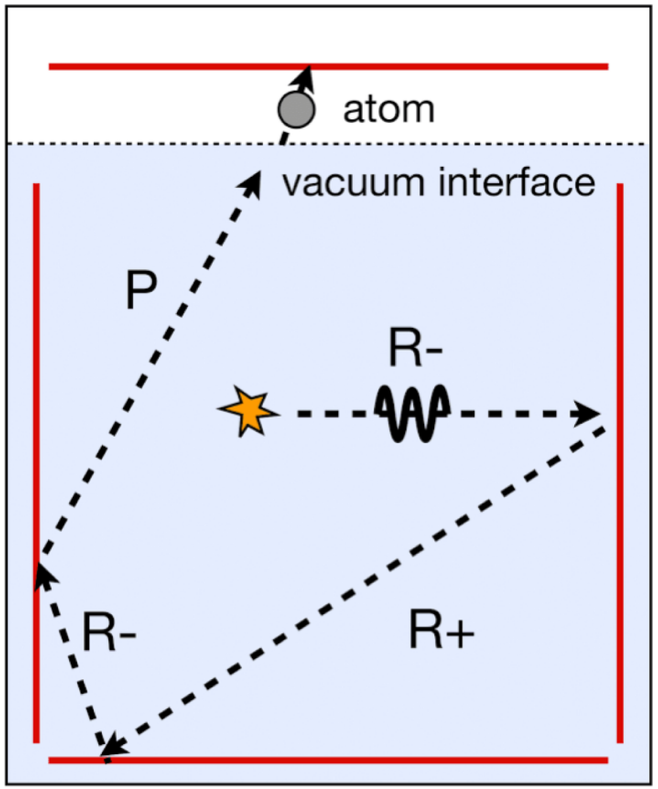
HeRALD concept and sensitivity paper
PhysRevD.100.092007

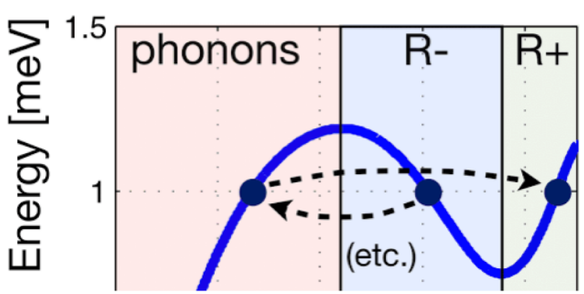
Helium **R**oton **A**pparatus for **L**ight **D**ark matter (HeRALD)

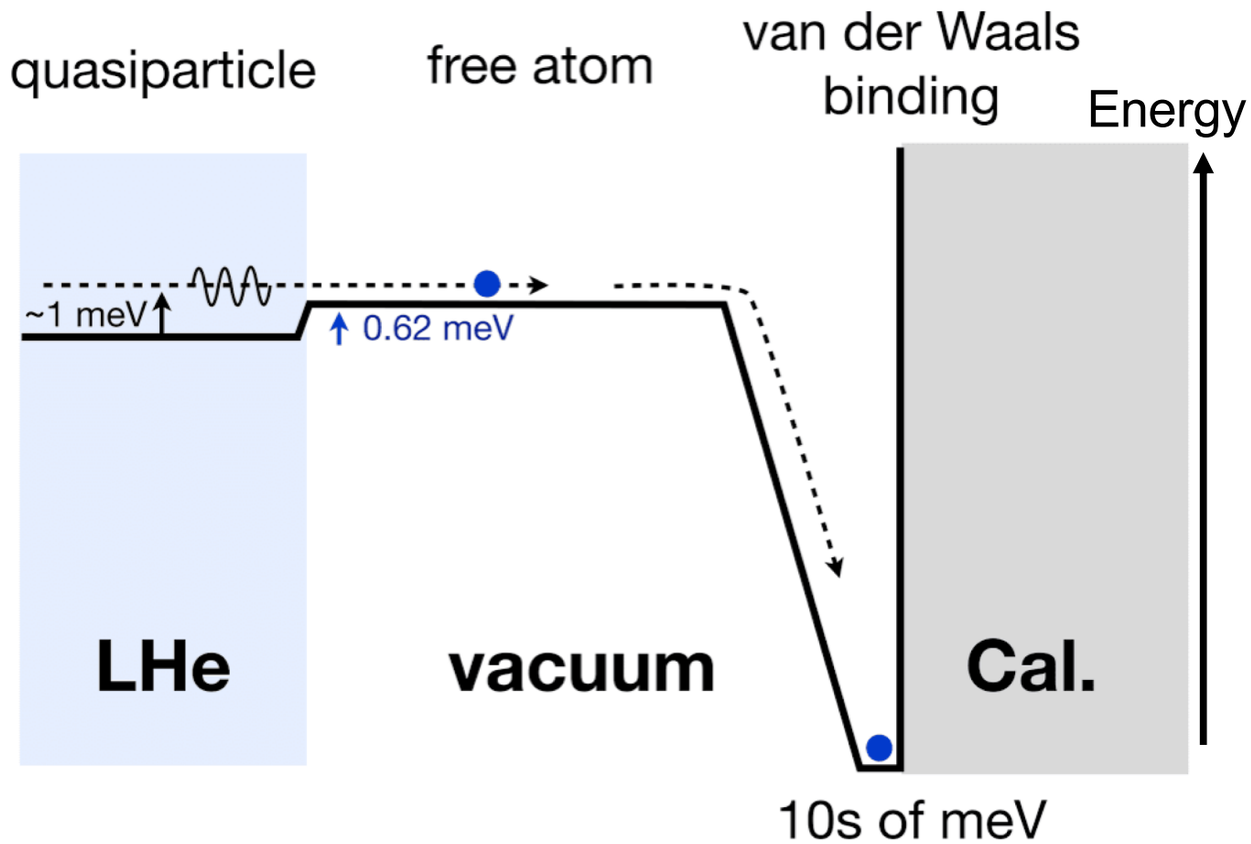


- Operated at ~30-50 mK
- Calorimeters with TES readout
  - submerged in liquid
    - Detect **UV photons**, **triplet molecules** and **IR photons**
  - suspended in vacuum
    - Detect UV photons, IR photons and **He atoms** (evaporated by quasiparticles)

Quasiparticle readout - Quantum evaporation of helium atom



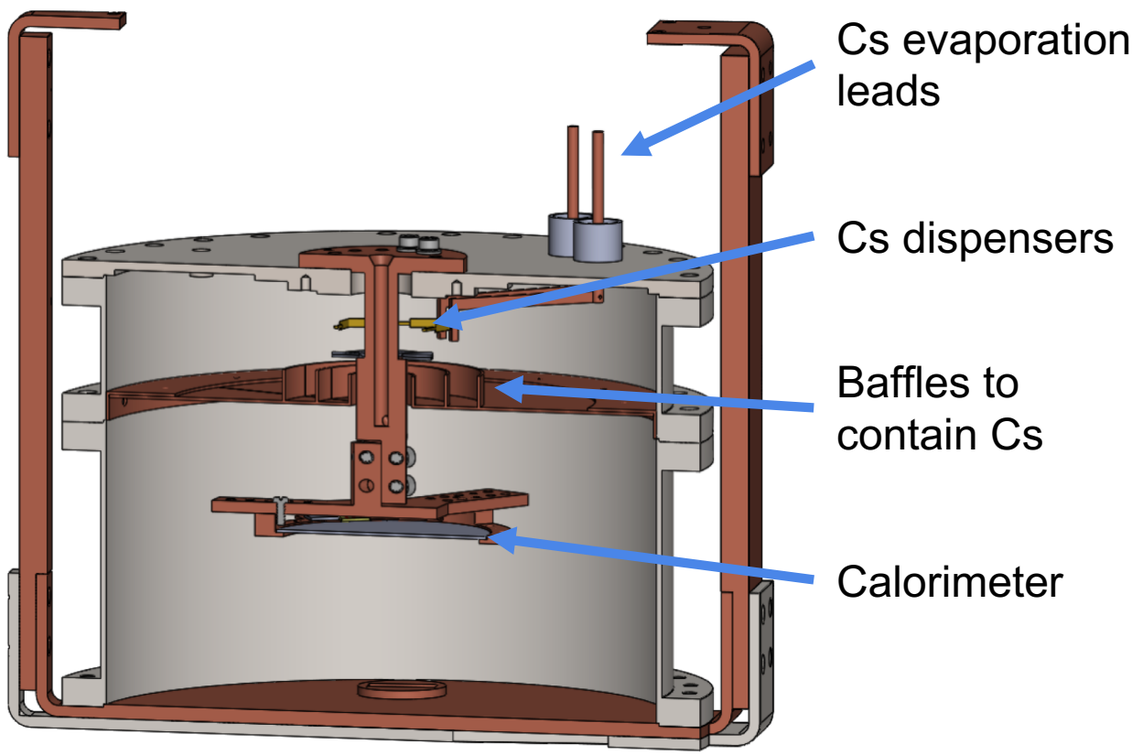


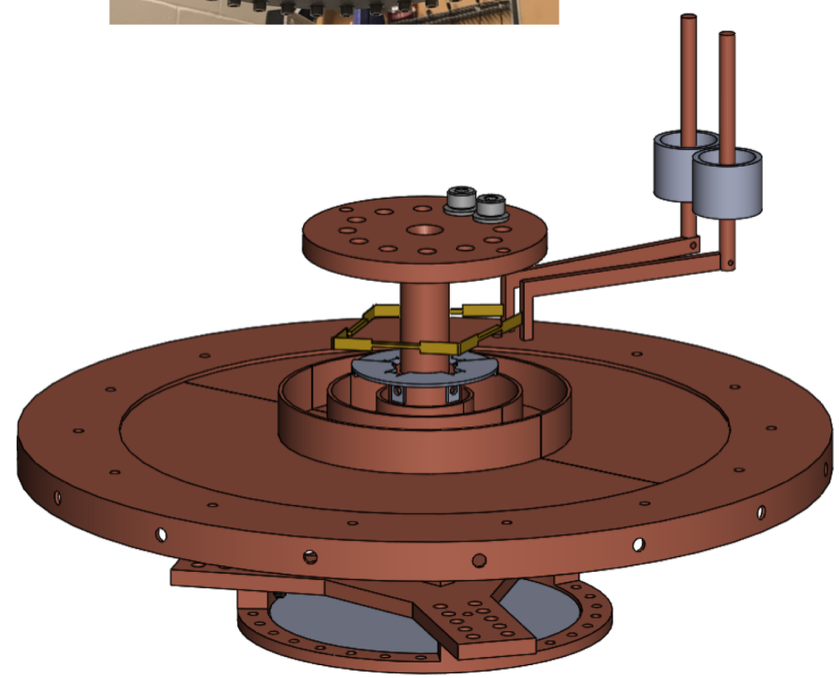


- 1 meV roton energy becomes up to 40 meV observable
  - × 40 amplification
  - Graphene-fluorine surface

UMass Cs-based Film Blocking

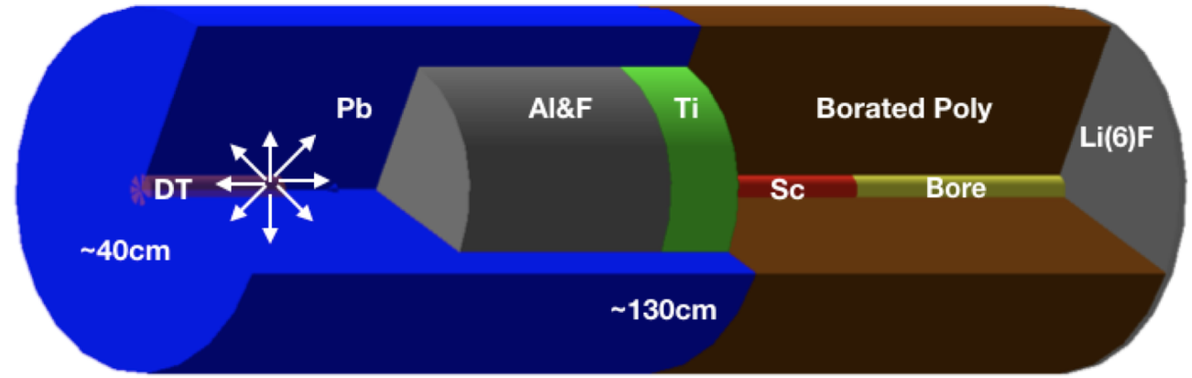
- Superfluid ^{4}He film creeps on surfaces
  - Detrimental to calorimeter and amplification
- ^{4}He film blocking tests
  - Cs surface



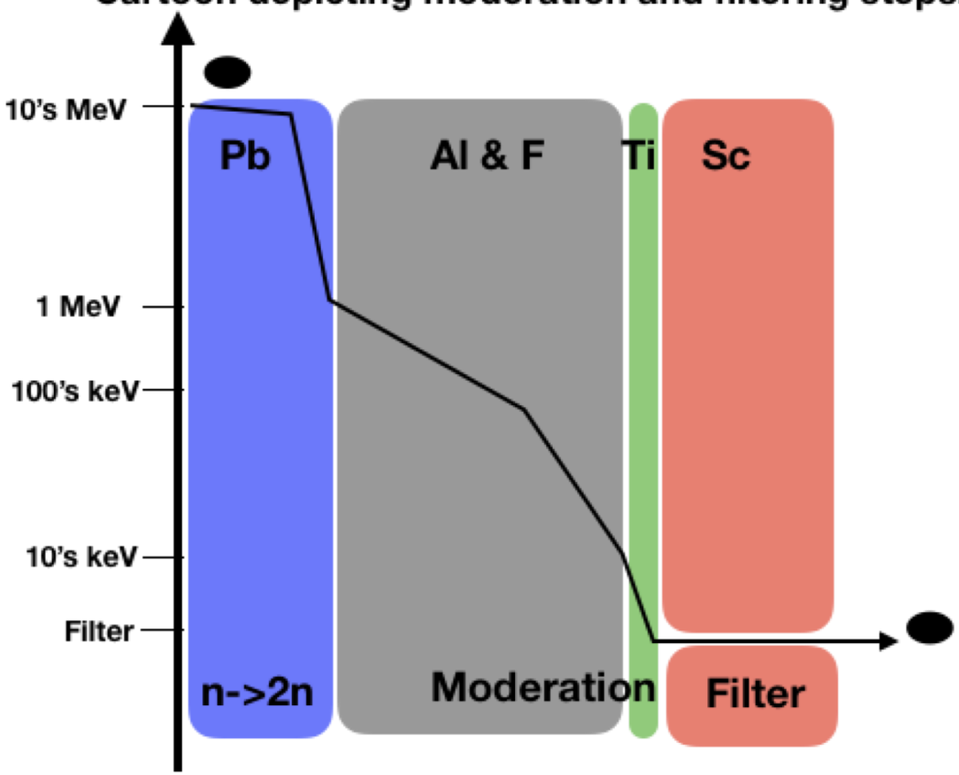


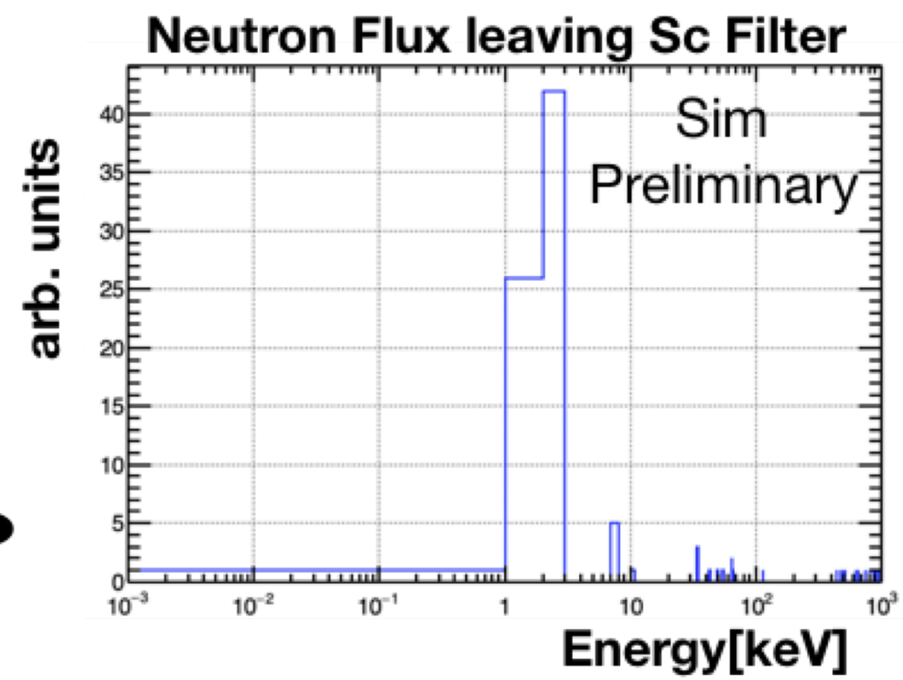
UMass Pulsed keV neutron sources

- Pb: neutron booster
- Al/F: efficient moderation <100 keV
- Ti: further moderate <10 keV
- Sc: filter using cross-section dip at 2 keV

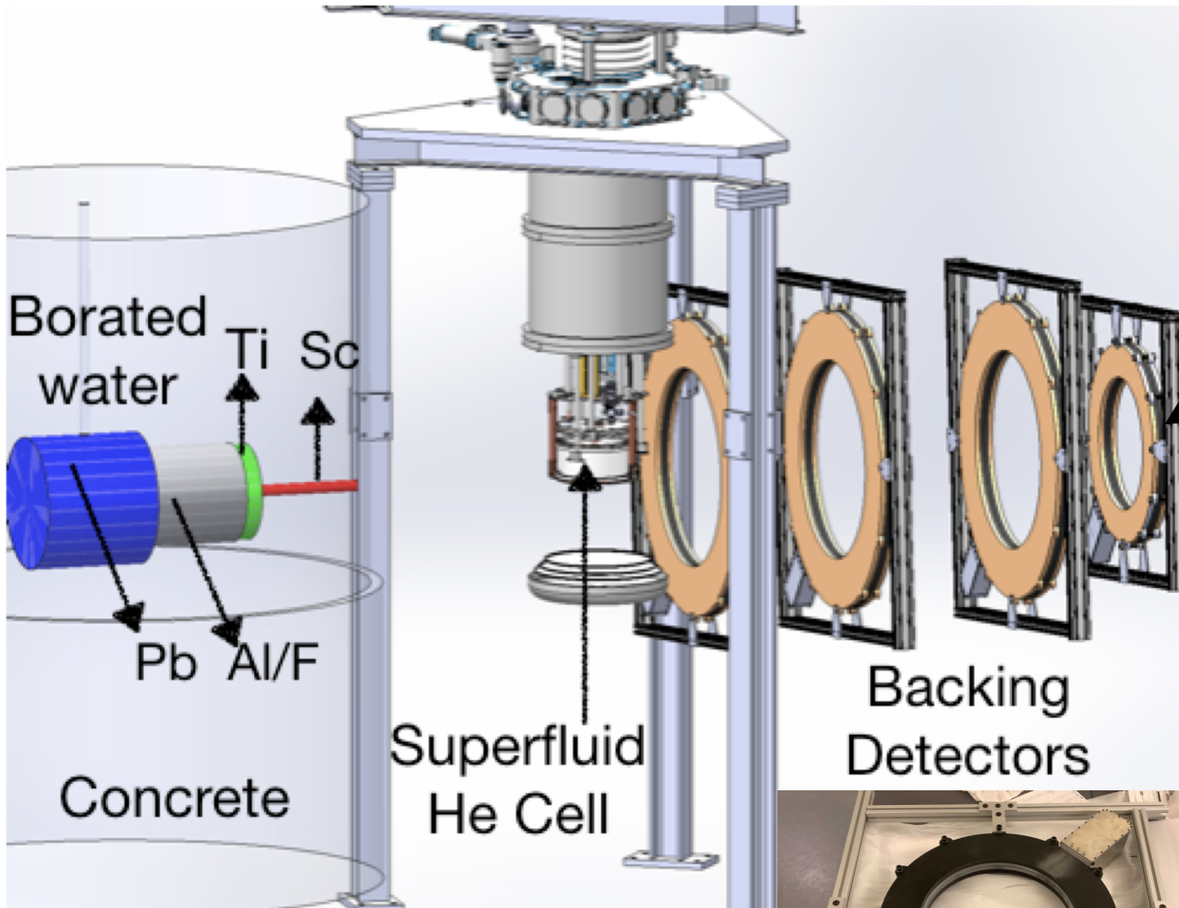


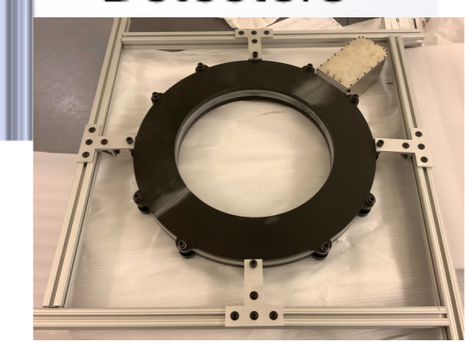
Cartoon depicting moderation and filtering steps:

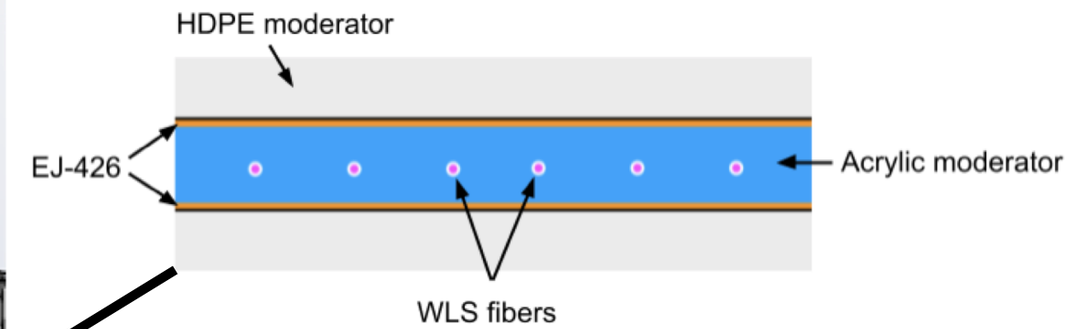


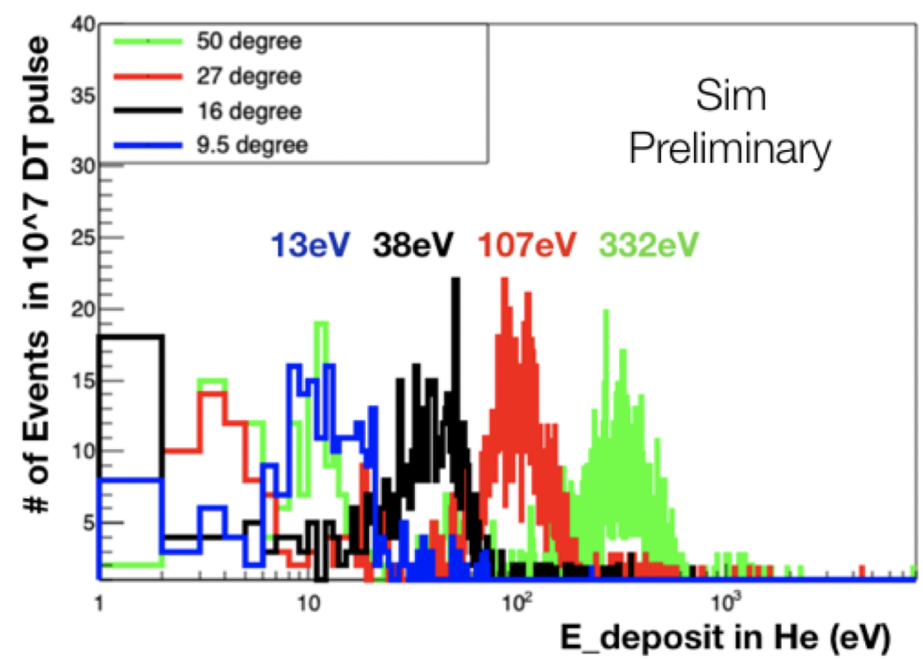


UMass <keV NR Calibration Setup

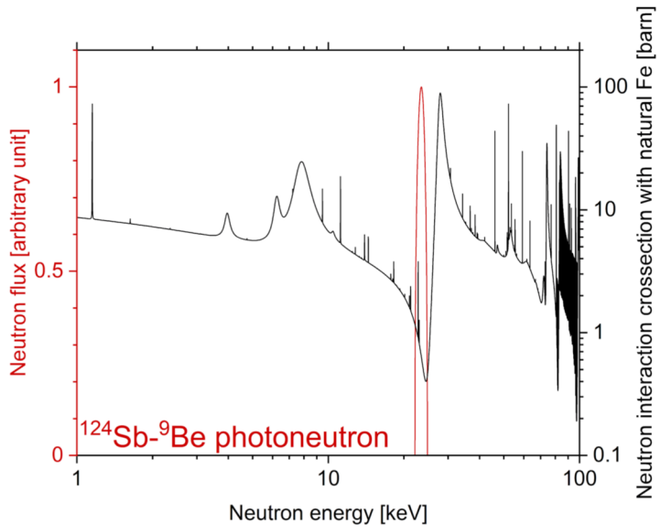


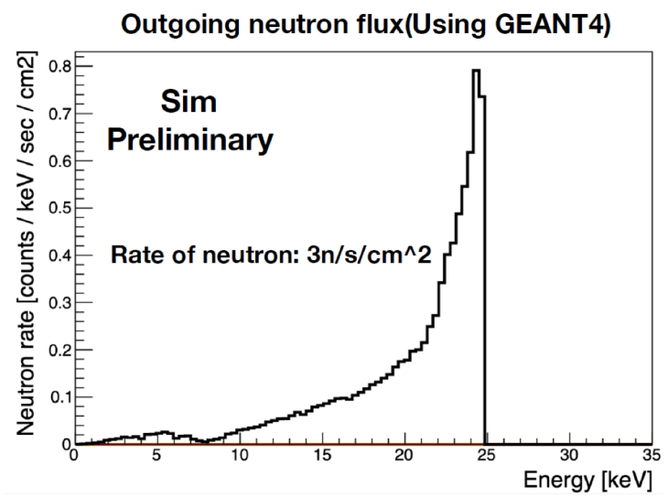


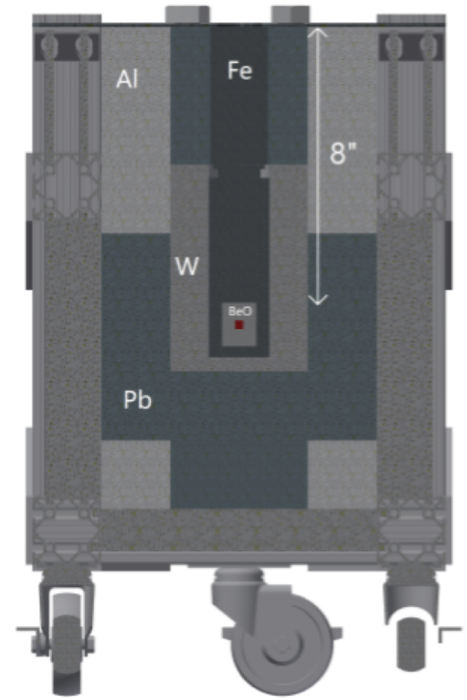


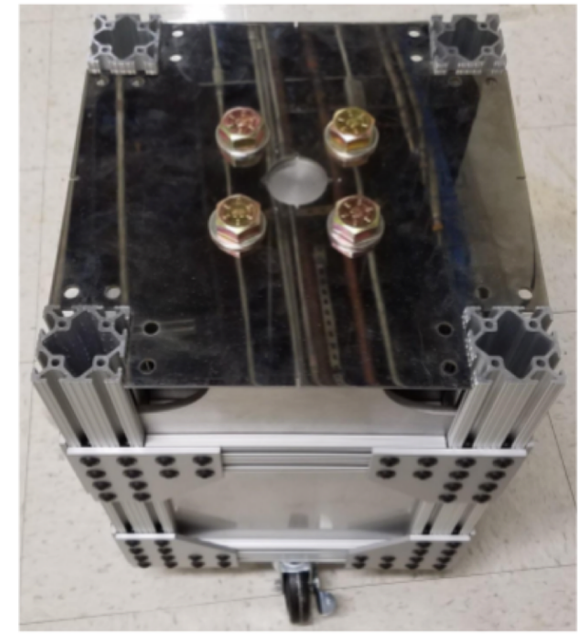


SbBe source with iron filter



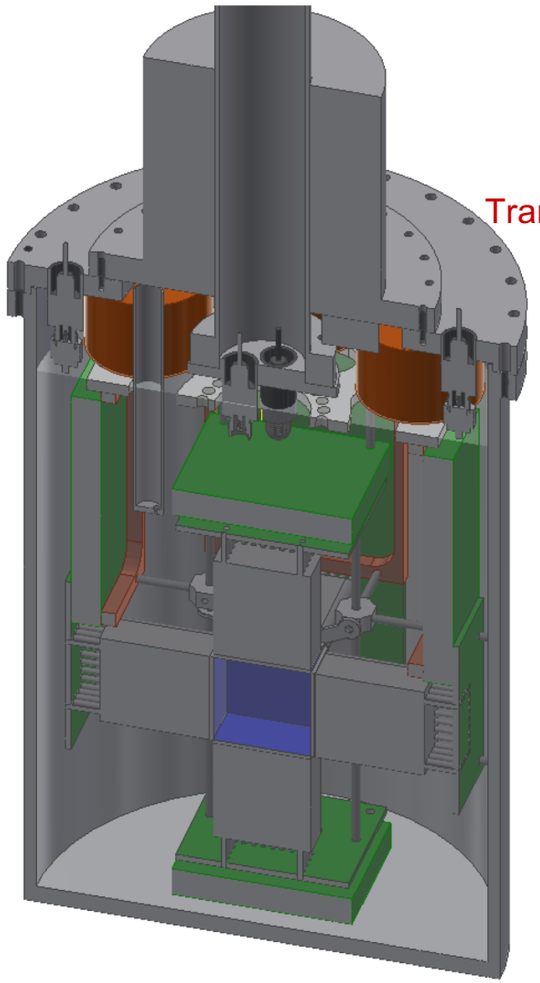


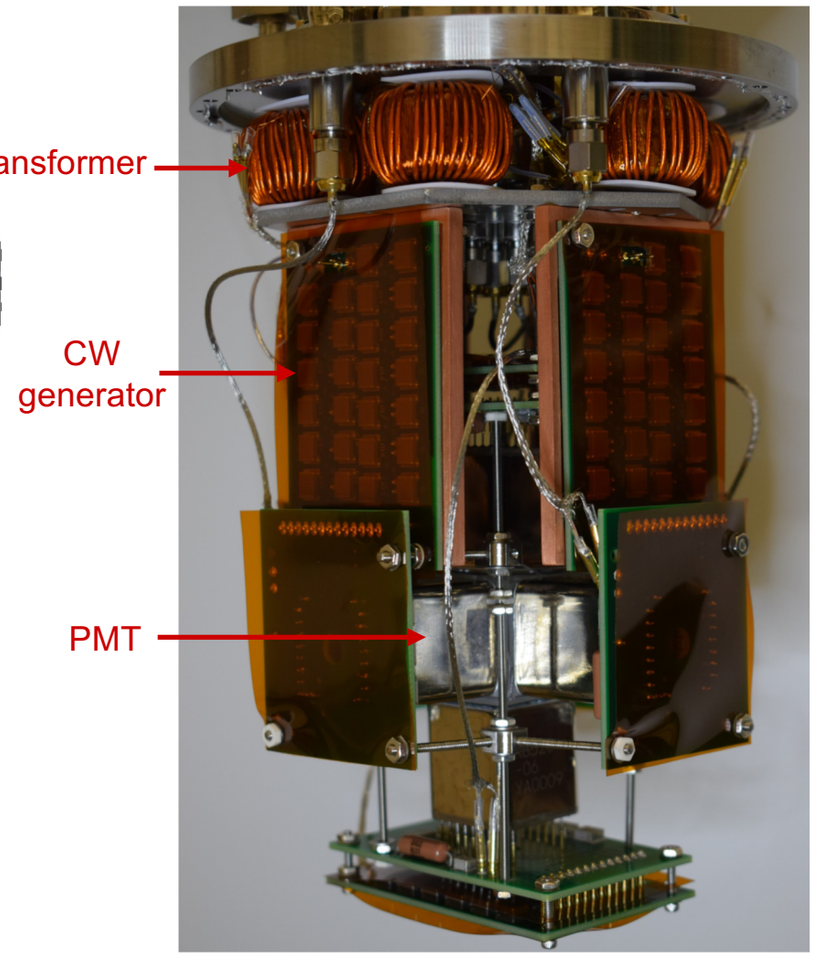




- 24 keV photo-neutron from ^{124}Sb-^{9}Be
- Iron cross-section dip at 24 keV neutrons
- 1-GBq Sb produced in nuclear reactor
- Currently being characterized

Light yield measurement of superfluid He-4

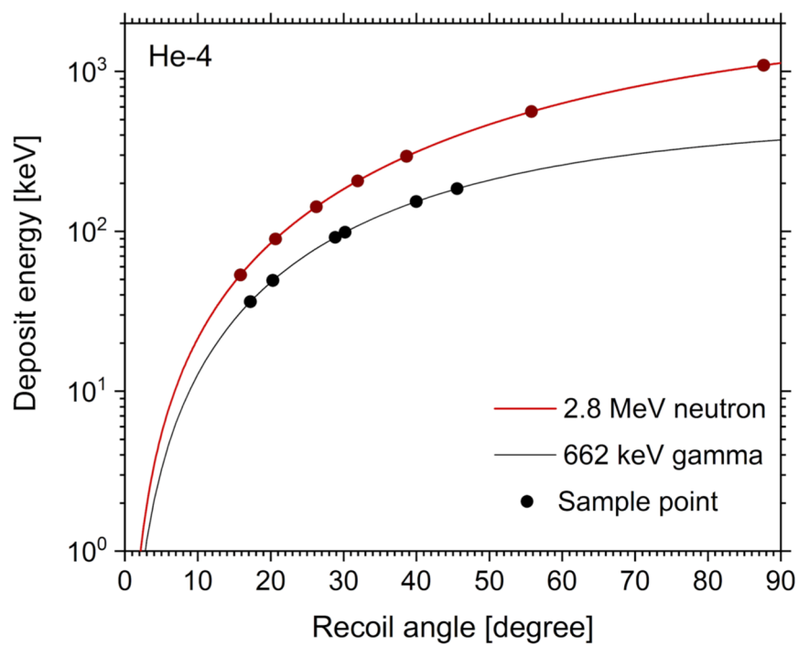


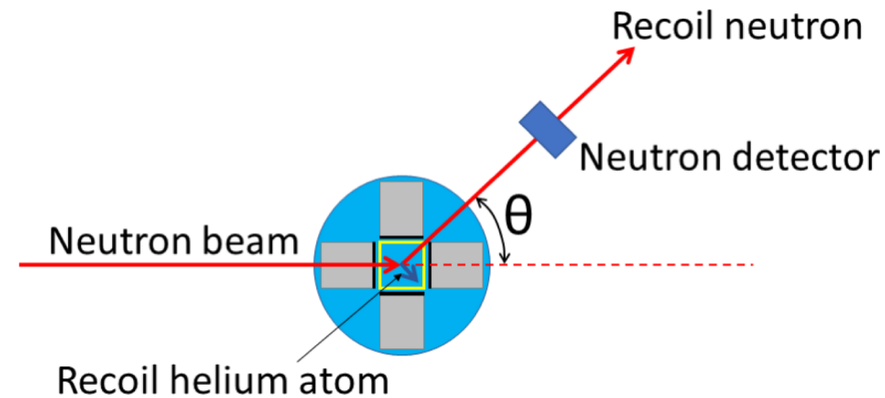


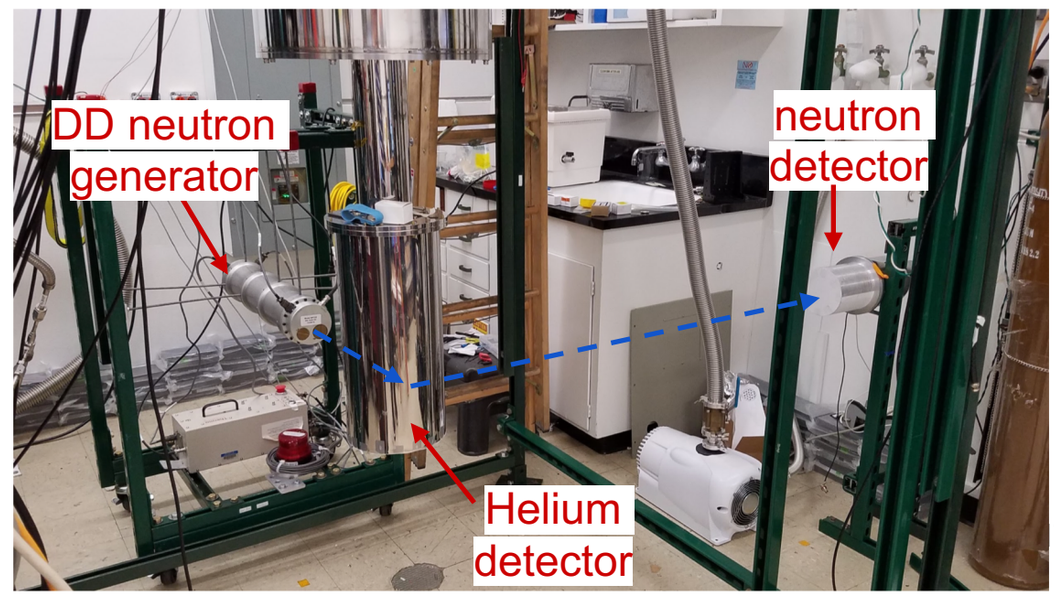
- Data taken at 1.75K
- Cockcroft–Walton (CW) generator
  - No voltage divider for PMT
  - No resistive heat
  - Suitable for down to ~mK
- High light yield
  - ~1.1 PE/keV$_{ee}$

Light yield measurement of superfluid He-4

- NR: 2.8 MeV neutrons from DD
  - Liquid scintillator tagging
- ER: 667 keV gamma from ^{137}Cs
  - NaI detector tagging



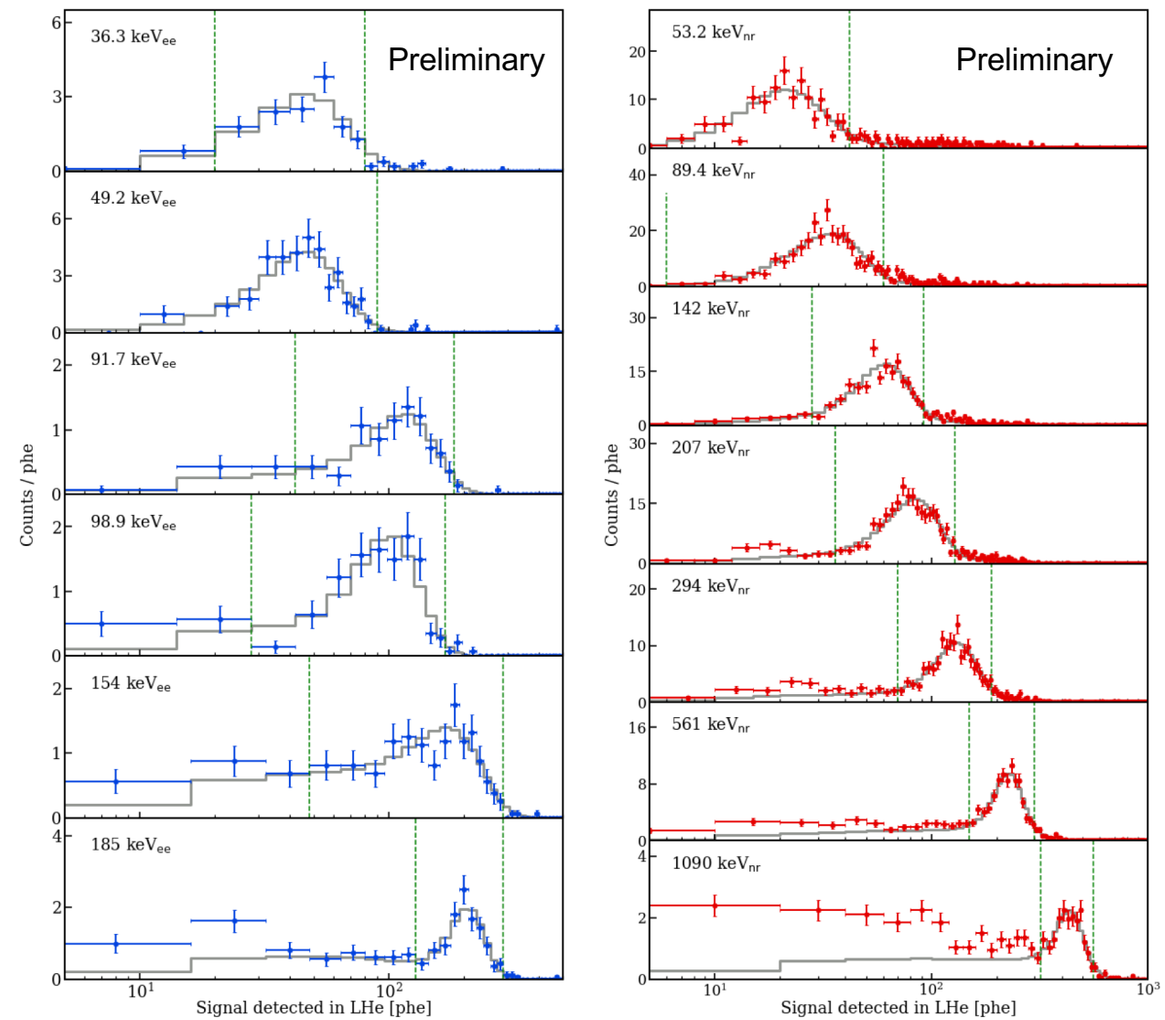




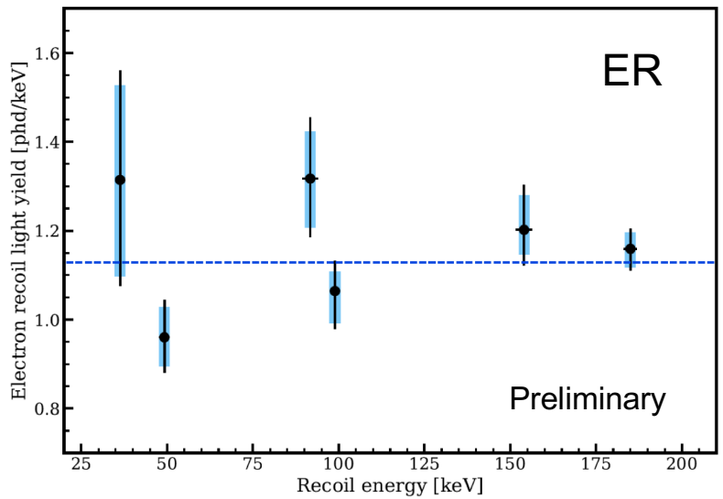
Light yield measurement of superfluid He-4

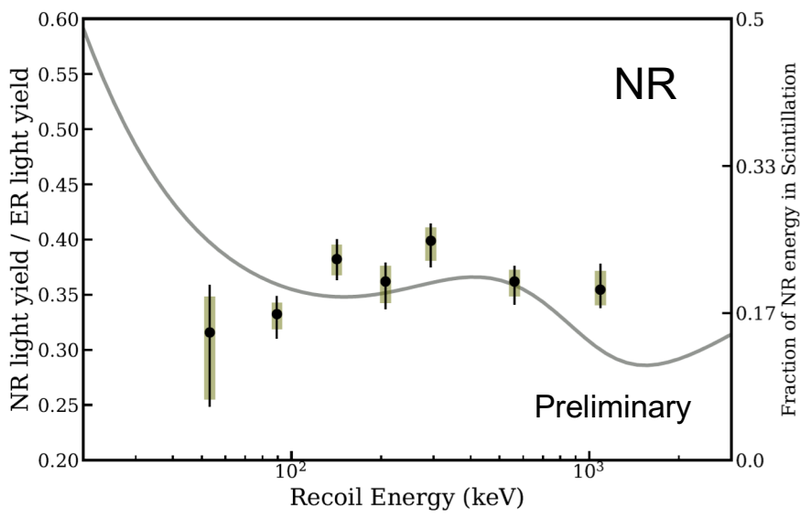
- Data selection cuts
  - Time of flight
  - Pulse shape discrimination (LS detector)
  - Deposit Energy (NaI detector)

- Fit data with MC sims



Light yield measurement of superfluid He-4





- First measurement of LHe scintillation in tens of keV. Publication draft nearly complete.
- ER yield relatively flat (as expected)
- NR yield agrees with pre-defined model
- Working on lower energy (keV) measurements
  - ER: Compton scattering from Co-57 source
  - NR: SbBe with iron filter

Summary

- TESSERACT is developing different targets for DM search.
- DM targets include polar crystals (SPICE) and superfluid helium (HeRALD)
- R&D is just beginning on TES, athermal phonon sensors, coupling these to multiple targets, and calibration. R&D will ramp down by 2023
- First R&D results on superfluid helium light yield, SbBe neutron beam.
- In parallel, TESSERACT design, engineering, and project management is ramping up, should end pre-project phase by 2024. Project would begin in 2025.