Northwestern

Northwestern NEXUS Experimental Underground Site @Fermilab



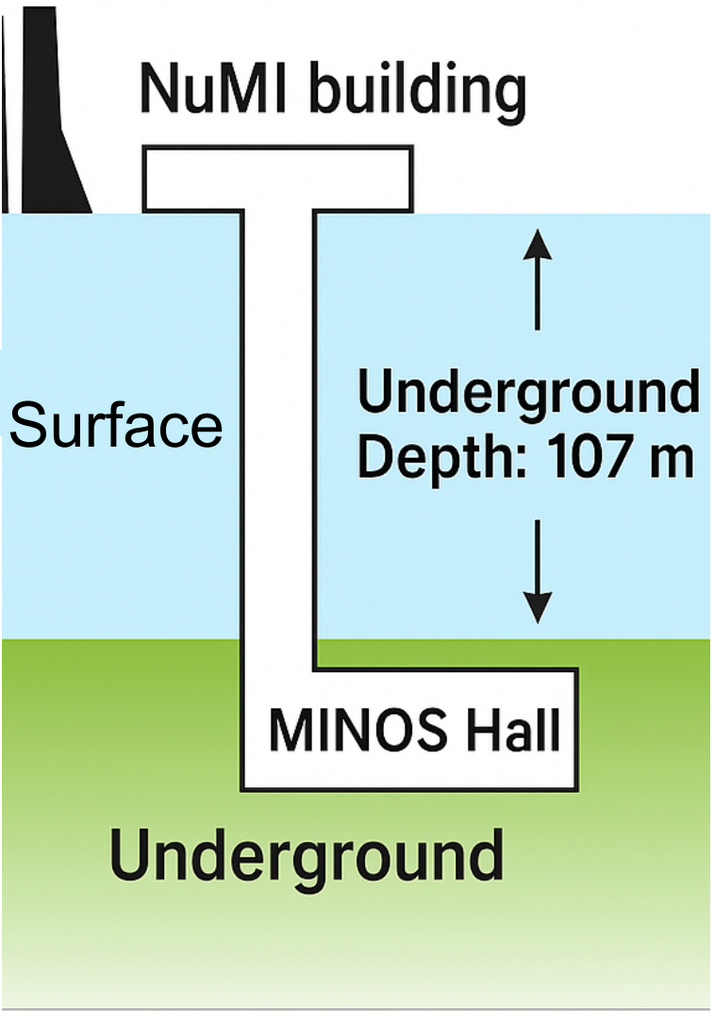
Progress towards a Sub-keV Nuclear-Recoil Facility @ MINOS, Fermilab

Pratyush Patel on behalf on SCDMS collaboration
(Figueroa Group, Northwestern University)

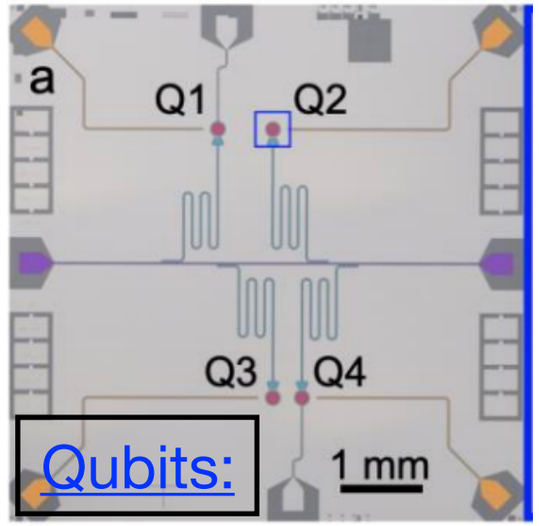
CPAD, 2026 @ Seattle

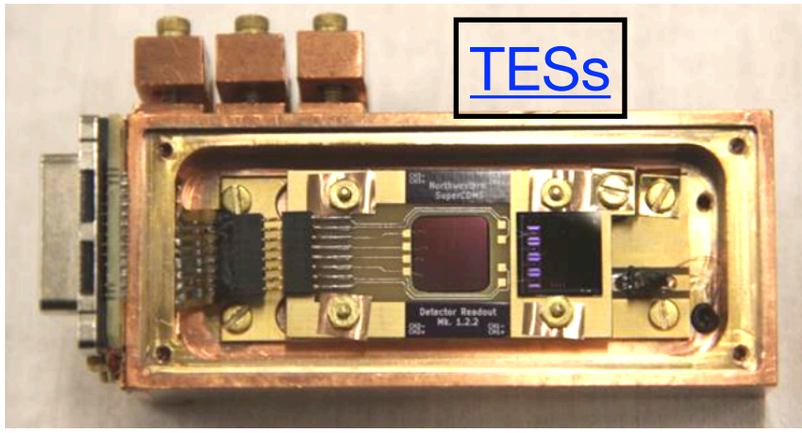
Northwestern EXperimental Underground Site @FNAL

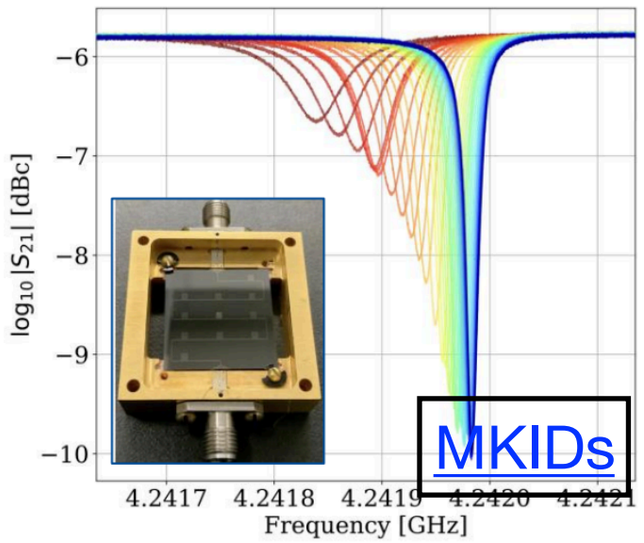
- A low-background testbed for cryogenic dark-matter detectors and solid-state qubits
- Located in the MINOS experimental hall at Fermilab, 100 meters underground, developed as a collaboration between the Fermilab detector R&D program, SuperCDMS, and Northwestern University



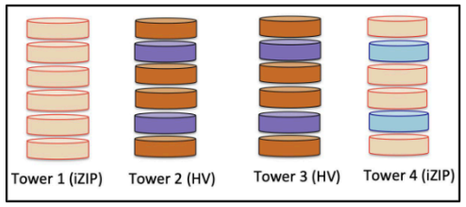




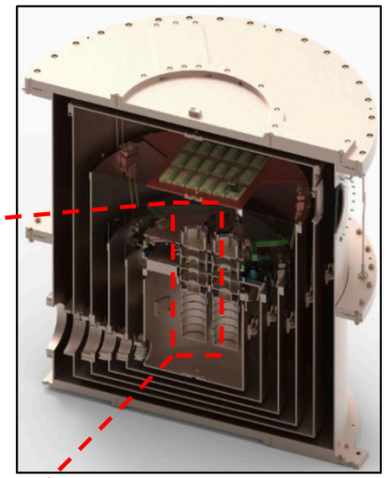




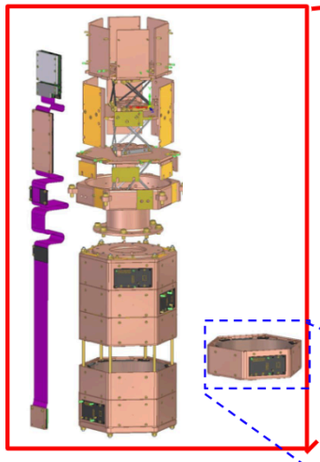
Super Cyrogenic Dark Matter Search @SNOLAB



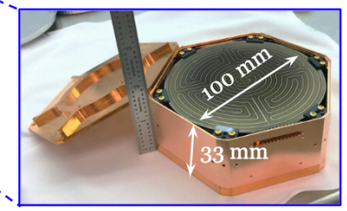
SNOBOX



Detector Tower



Detector



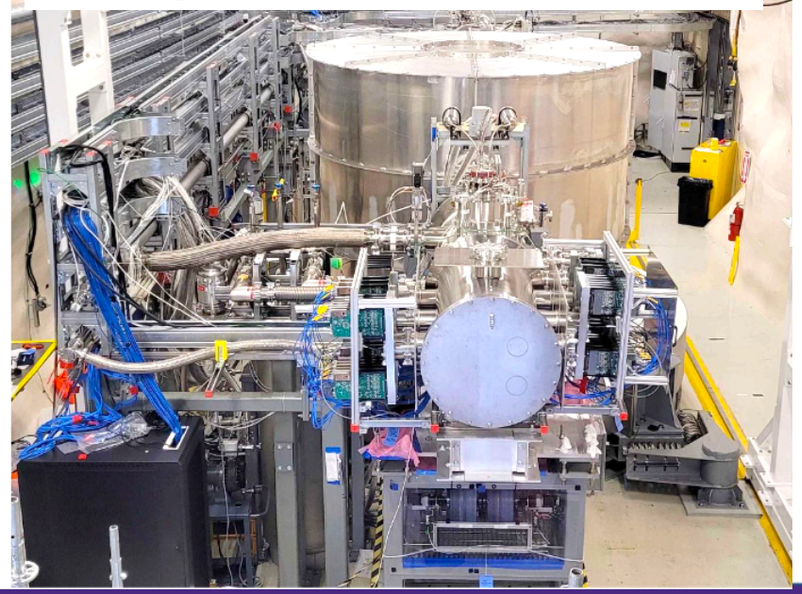
Primary science goal : search for nucleon-coupled dark matter in the 0.5-5 GeV/c^2 mass range

- Ultra pure semiconductor (Ge, Si) crystals as target
- Two iZIP towers & Two HV towers
- Total mass ~ 30 kg
- Current Status of SCDMS:
  Comissioning : Jan 2026- July 2026
  Science Run 1a : Aug 2026-Oct 2026

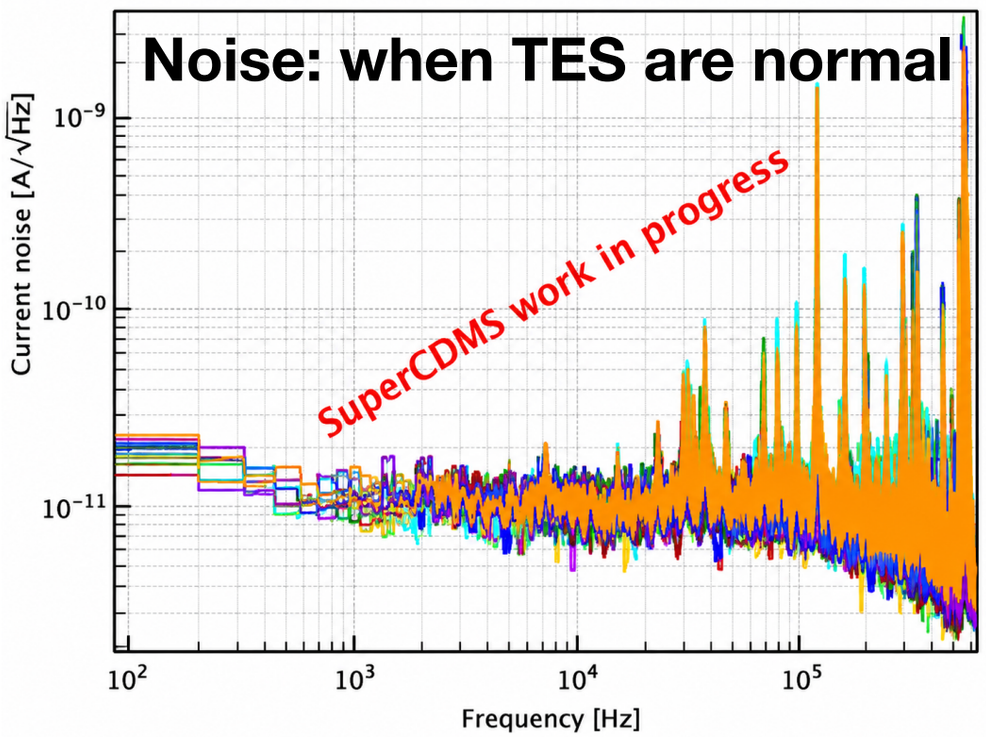
March 2024



Completion I&I: Jan 2026



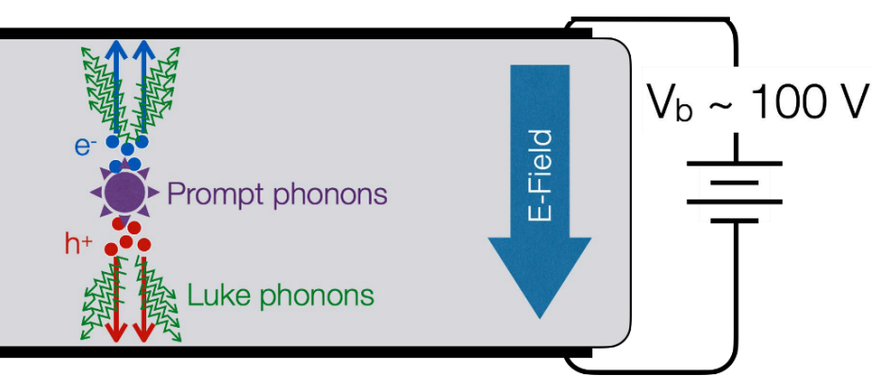
Noise: when TES are normal

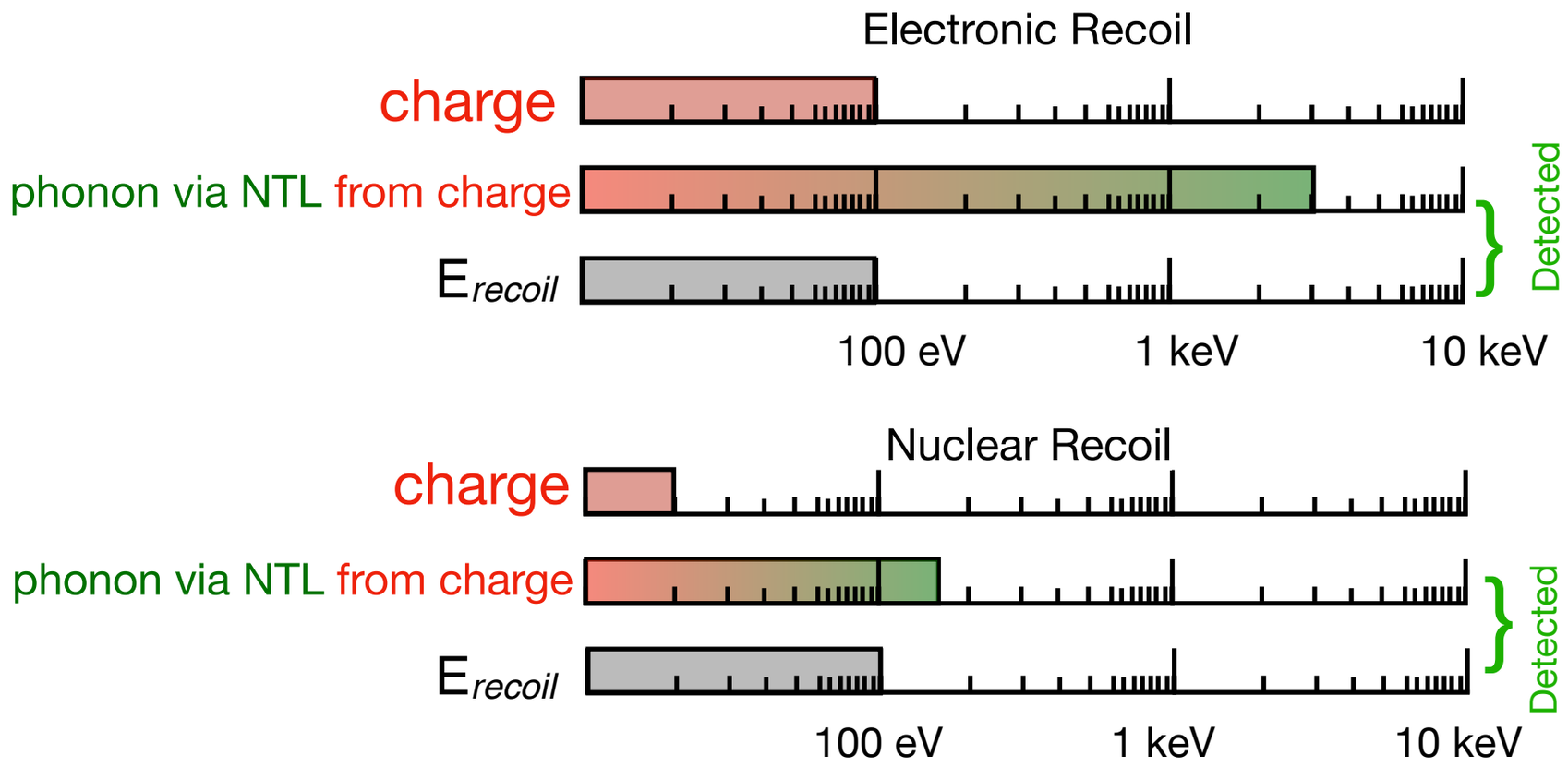


Ionization Yield

$E_{phonon} = E_{recoil} + n_{eh} * e^* V_b$

E_{recoil} = Prompt phonon + phonon from charge recombination at surface





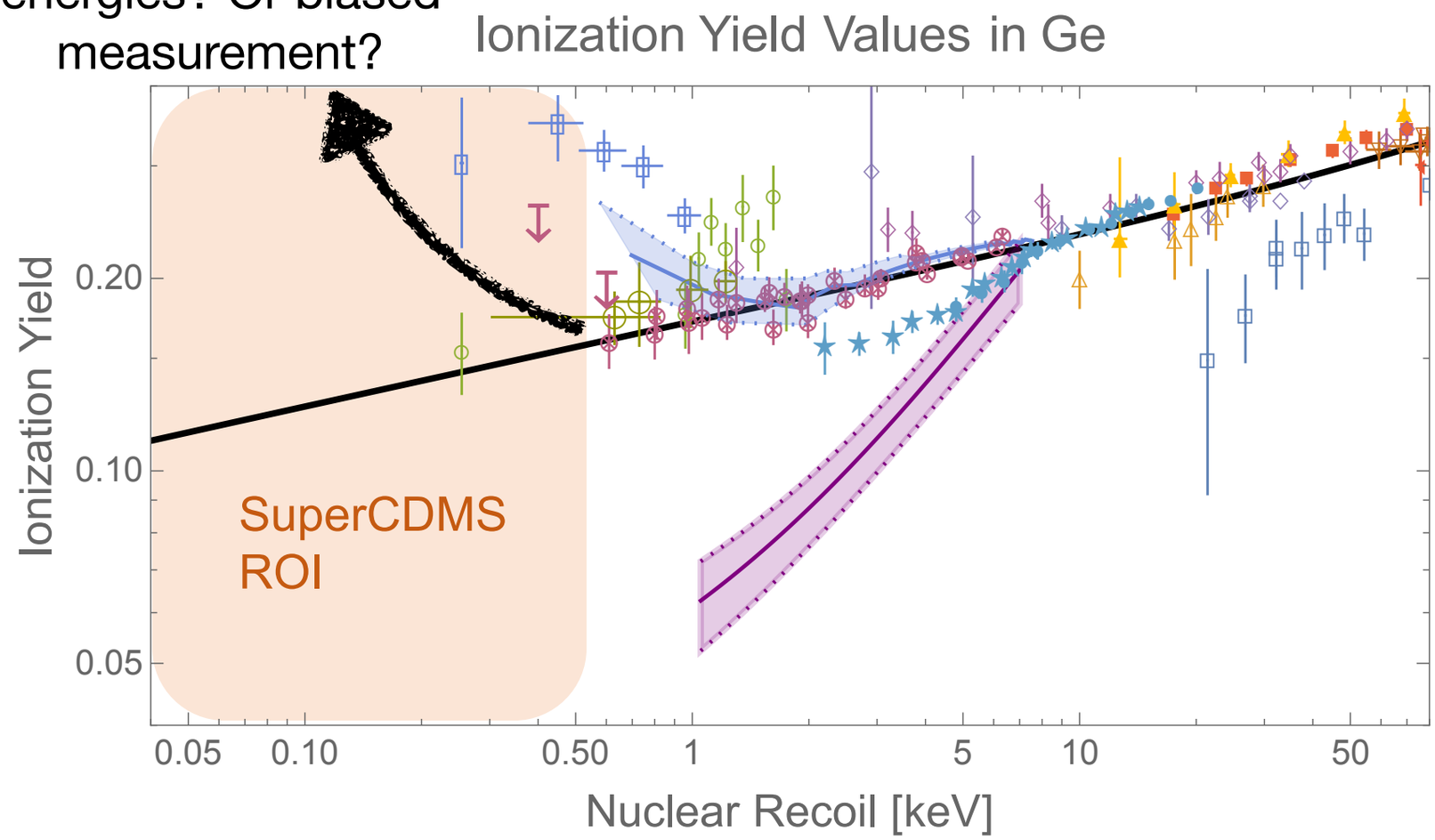
- Detectors (e.g., scintillators, ionization detectors, cryogenic detectors) respond **less efficiently to nuclear recoils** (from neutrons or WIMPs) than to electron recoils (from gammas or betas)

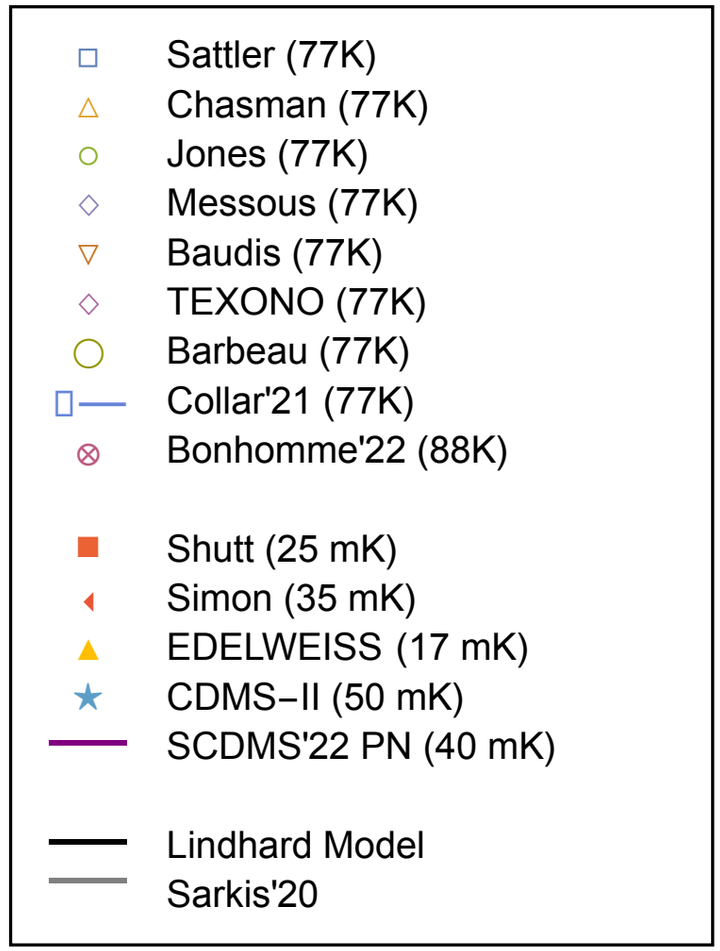
$$\textbf{Quenching Factor (QF)} = \frac{\text{Detected signal from nuclear recoil}}{\text{Detected signal from electron recoil of same energy}}$$

- Accurate quenching factor (QF) or ionization yield measurements are essential to correctly reconstruct recoil energy and infer the dark-matter particle mass

Ionization Yield History for Germanium

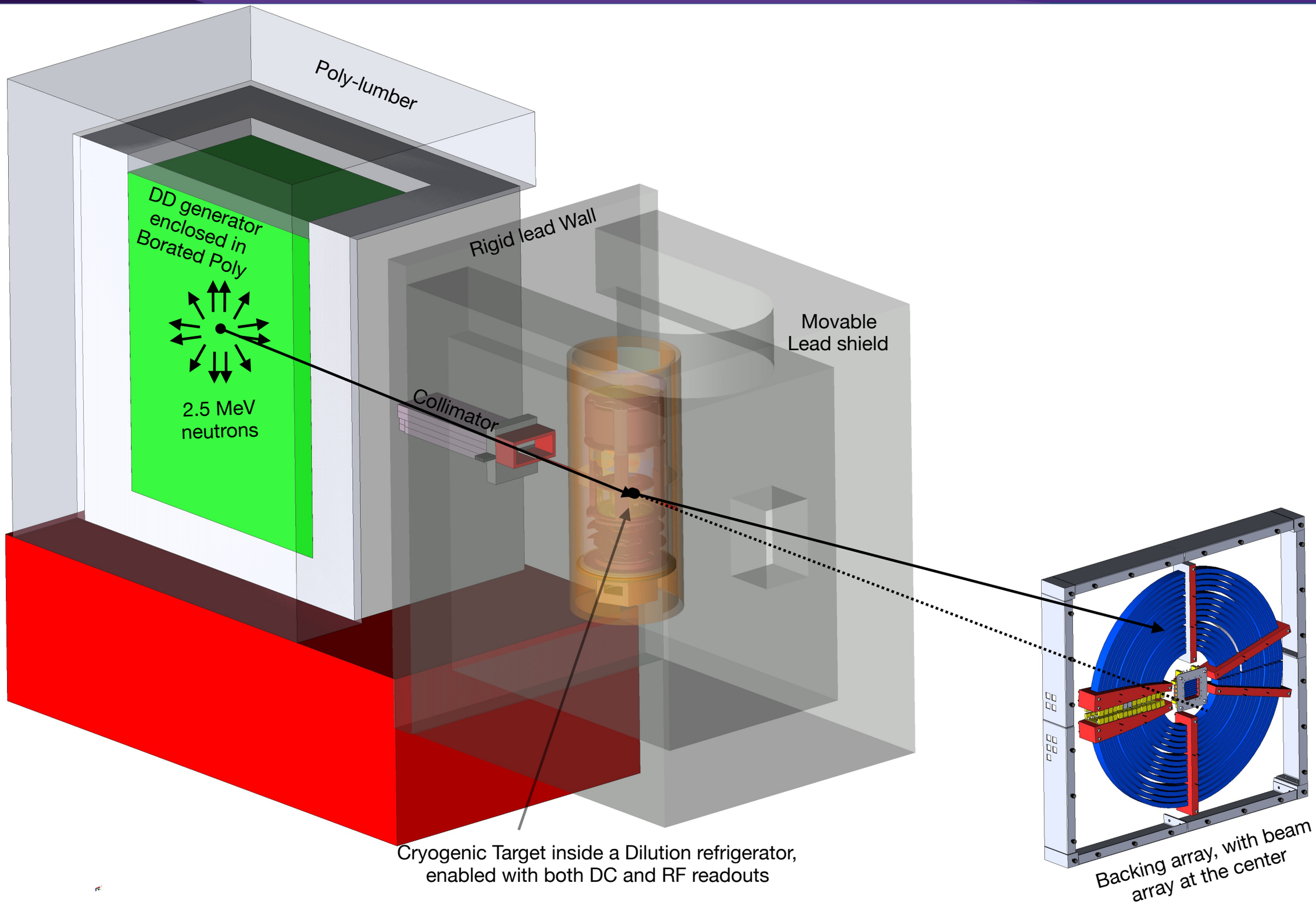
Increases at low recoil energies? Or biased measurement?





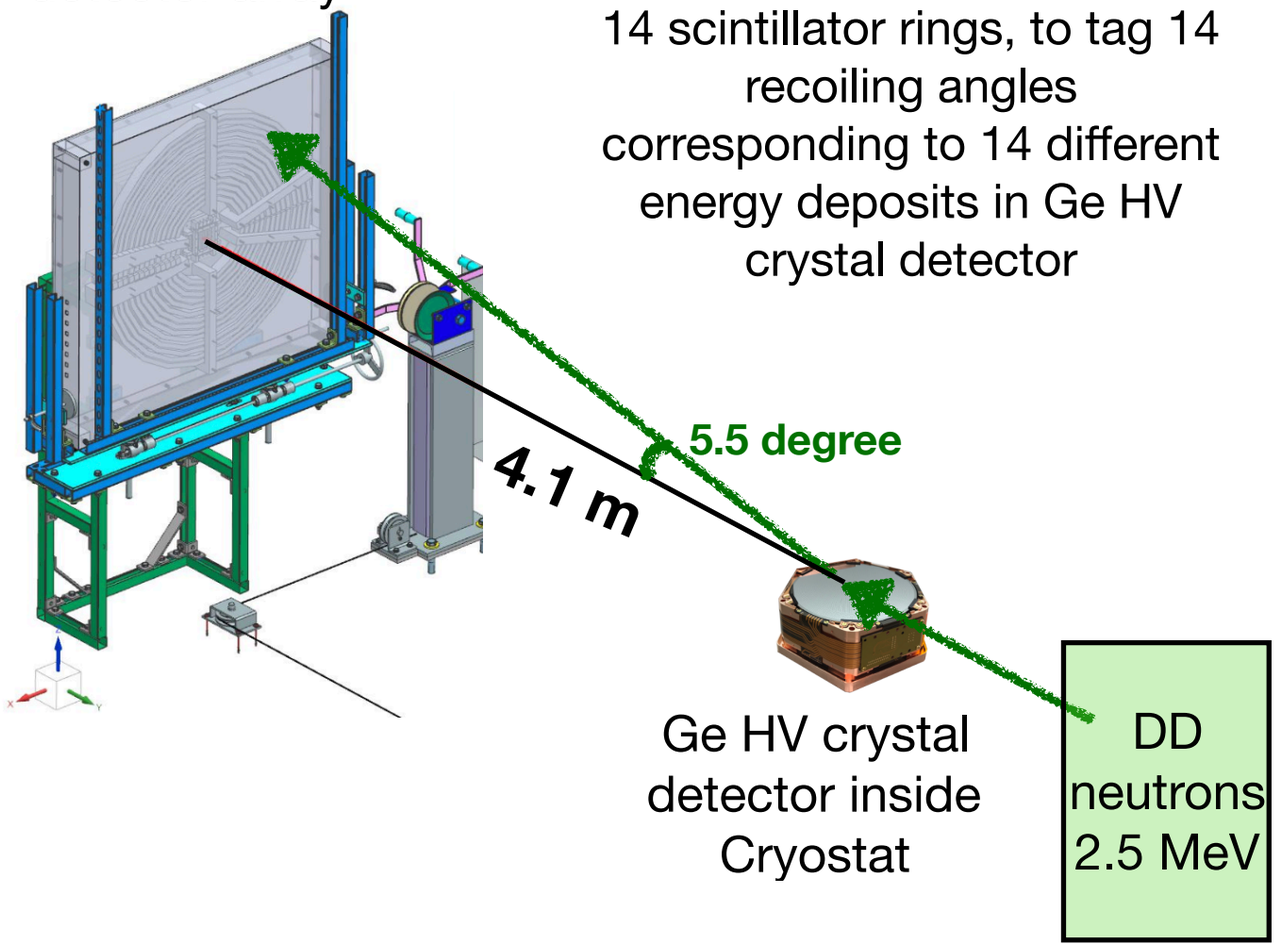
- Measurements of the ionization yield in germanium (and to a lesser extent in silicon) at low energies have shown strong discrepancies from one measurement to the other
- Variations in operating temperature, electric field and experiment-specific parameters suggest a more nuanced yield response at low recoil energies is needed

Ionization Yield Setup



Ionization Yield Setup

Backing detector array



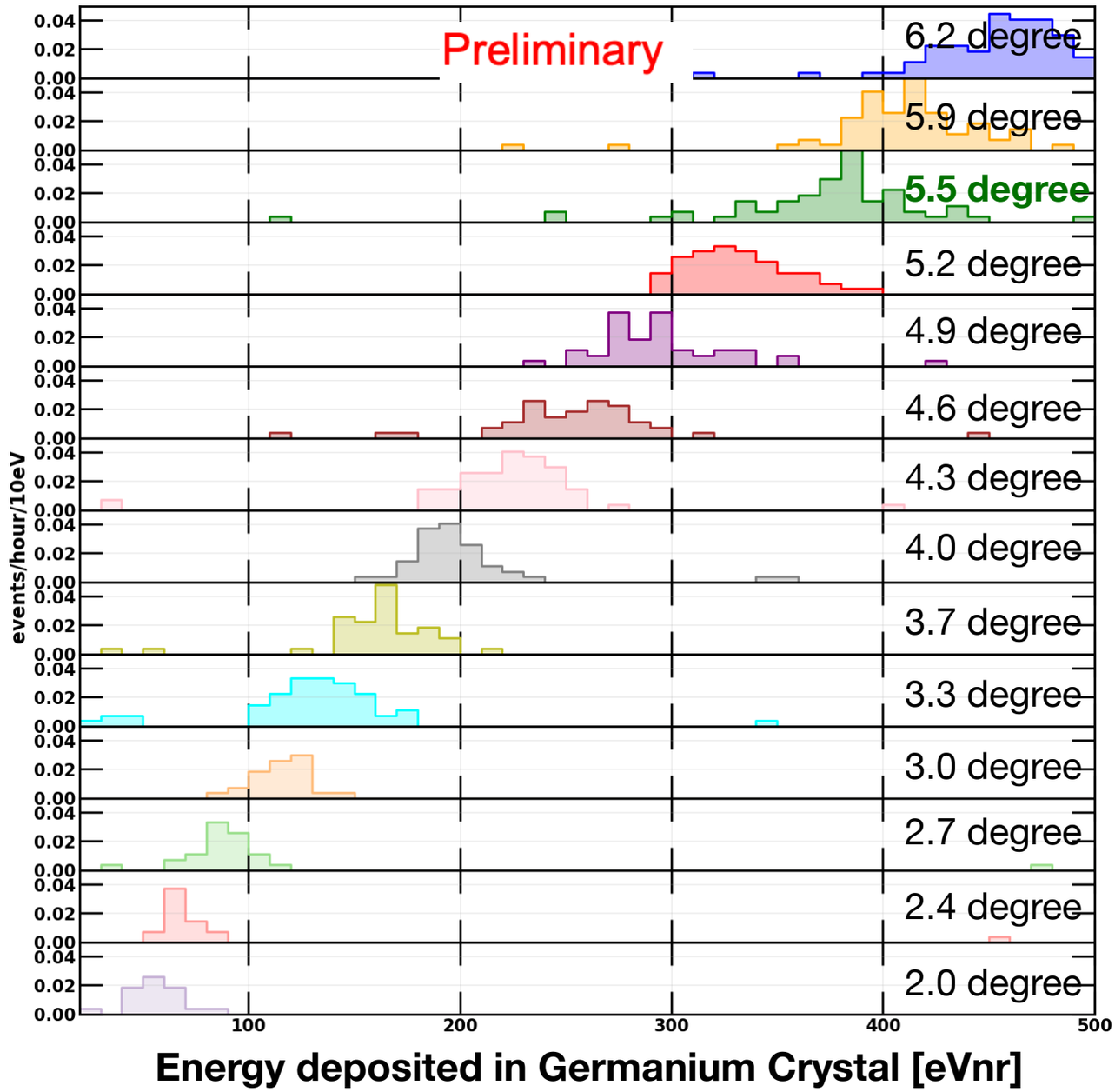
Backing detector array: set of 14 scintillator rings, to tag 14 recoiling angles corresponding to 14 different energy deposits in Ge HV crystal detector

Ge HV crystal detector inside Cryostat

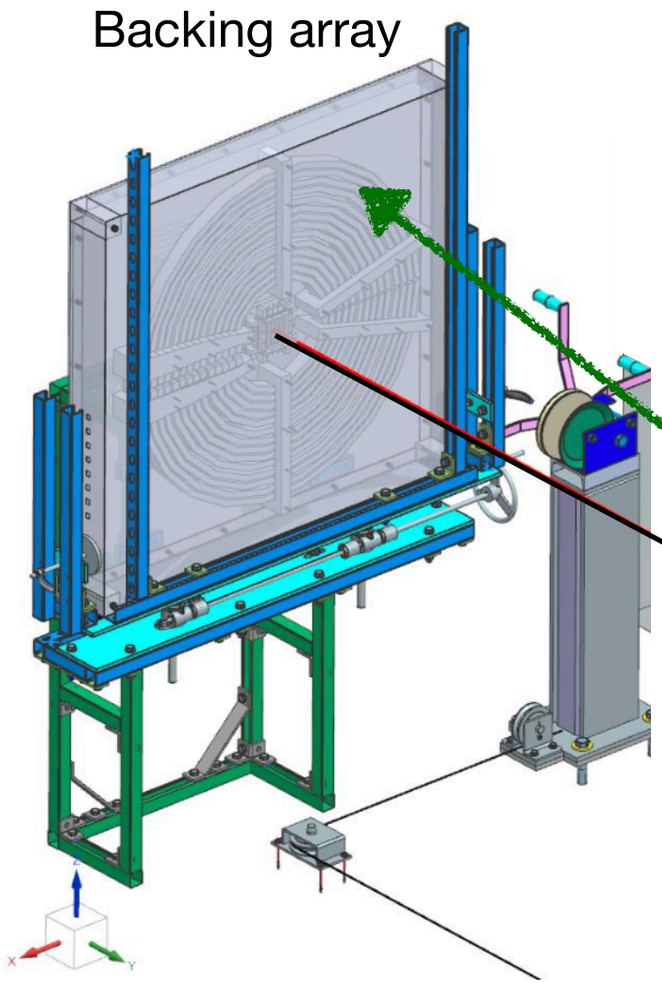
DD neutrons 2.5 MeV

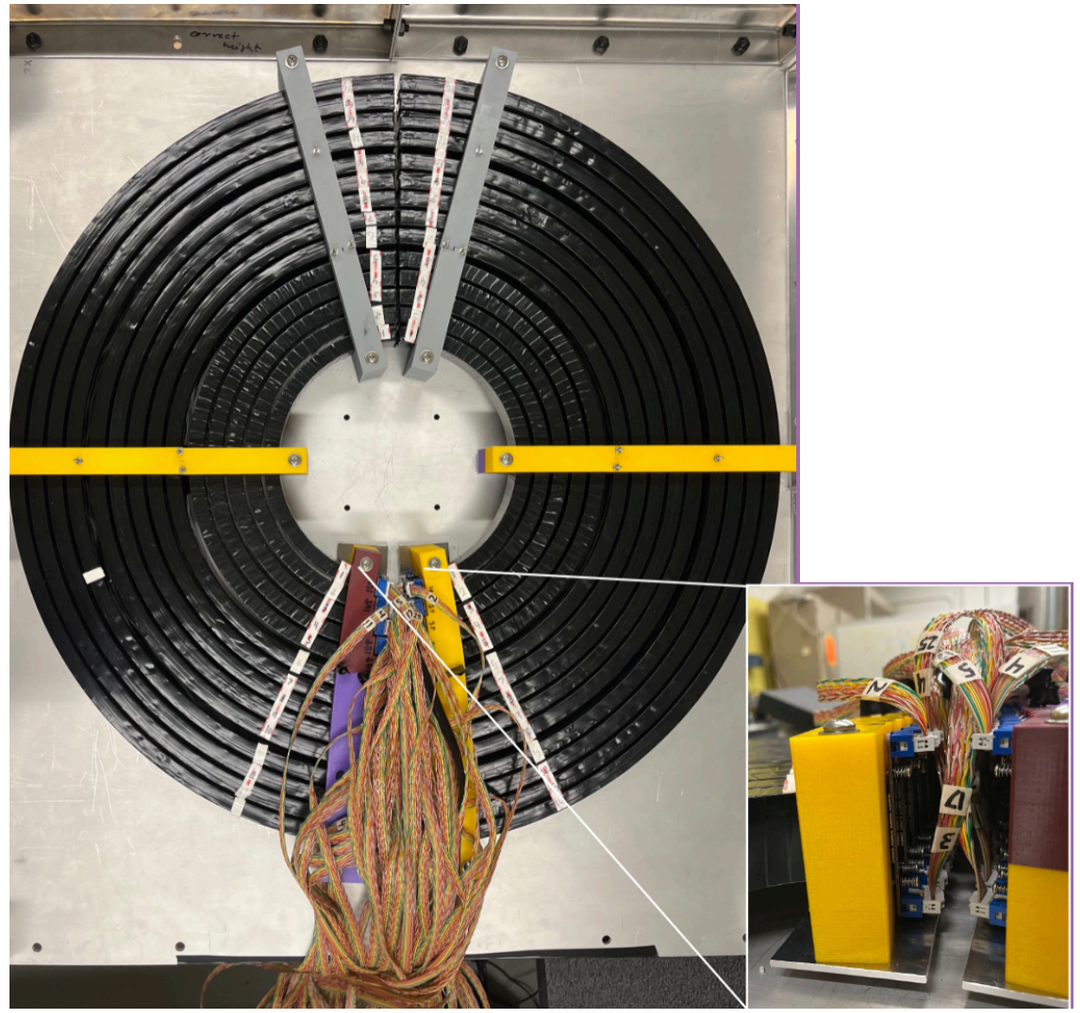
- In simulations, a neutron is tagged when it deposits at least **200 keV [NR]** in a single scintillator bar. Based on the assumed light yield and photon-detection efficiency, this corresponds to an **average of approximately four detected photons** per bar

Simulation [no HV applied]



Status of Backing Detector





5.5 degree

4.1 m

Ge HV crystal detector inside Cryostat

DD neutrons 2.5 MeV

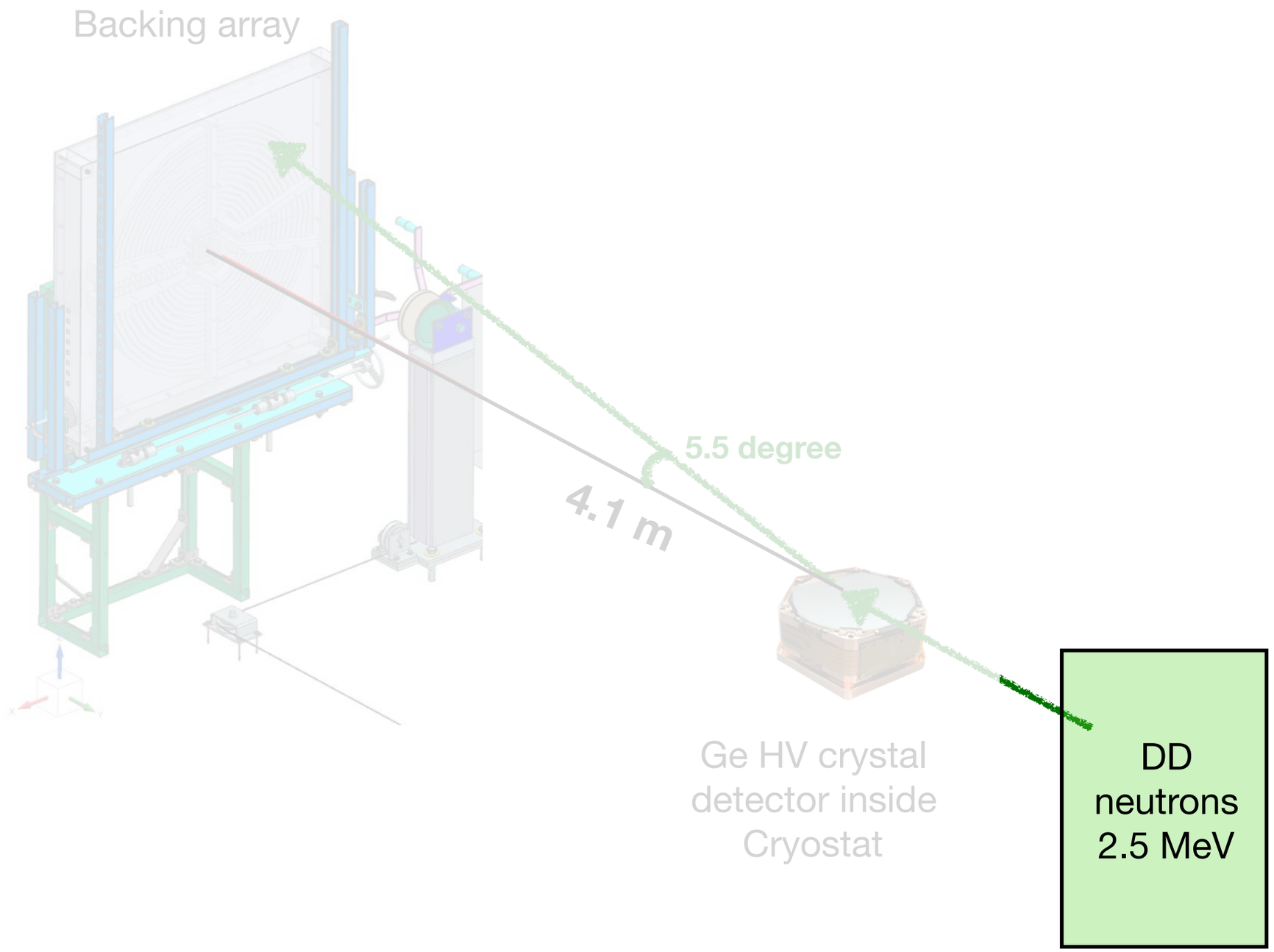
Status of Backing Detector

224 channels, four CAEN boards



Hear more from Isabella's talk

Status of DD Generator

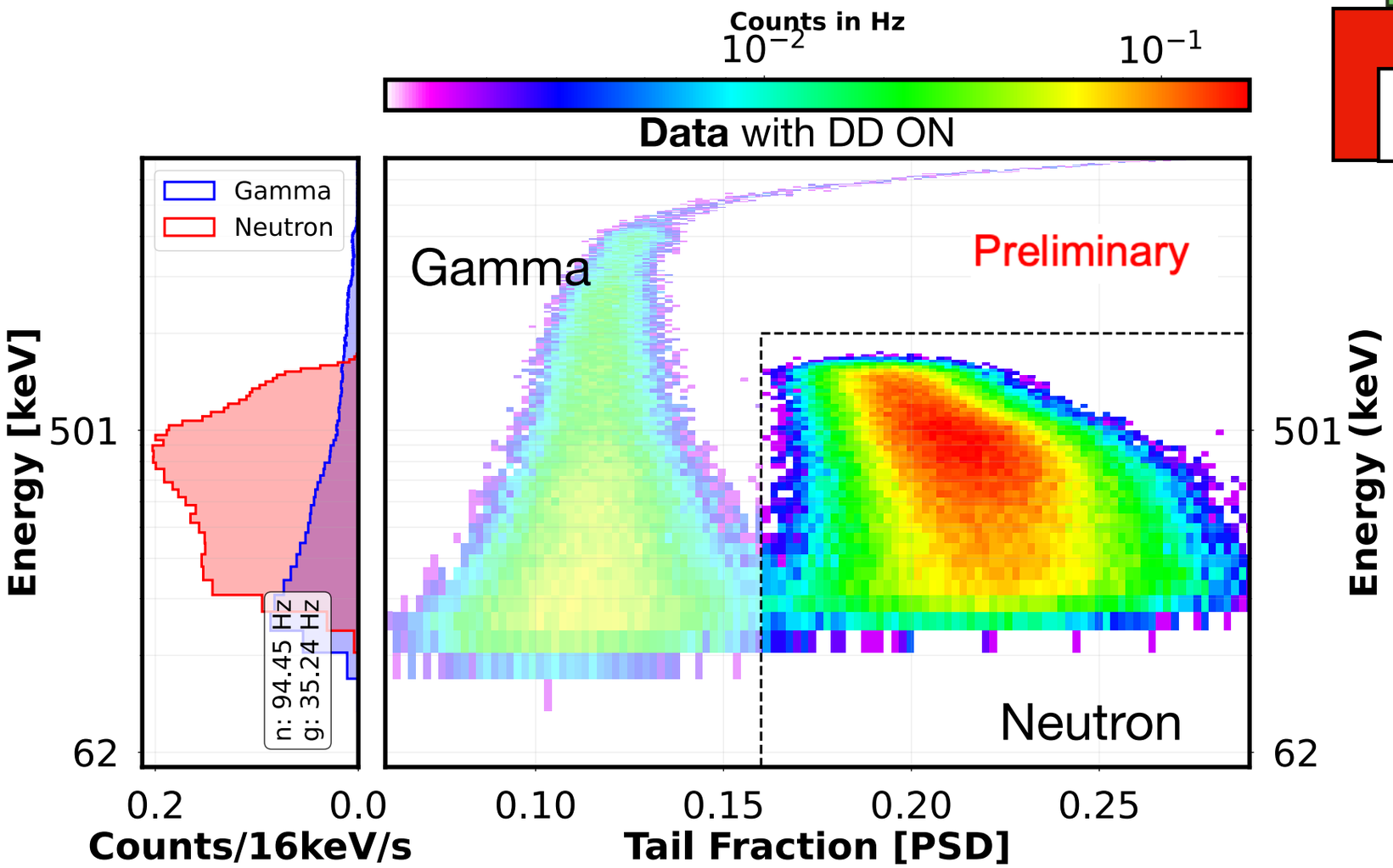


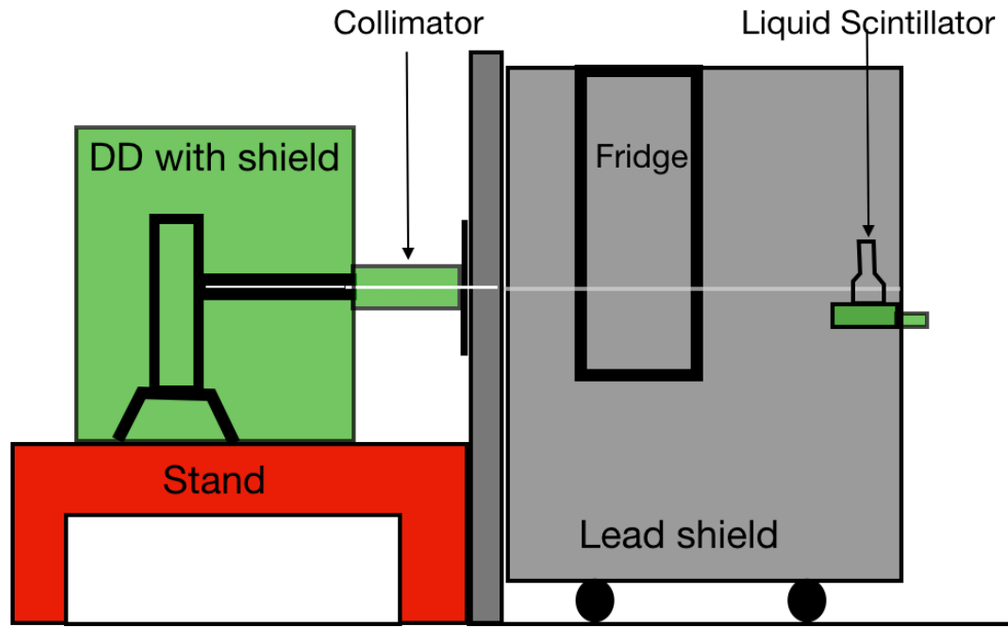
Status of DD Generator

- Neutron/Gamma ratio ~ 2.68, in continuous mode, gamma are generated from the n-capture and inelastic n-recoil from surrounding materials

- Quenching factor of ~ 0.15

Currently working on studying the n-flux in pulsed mode operation





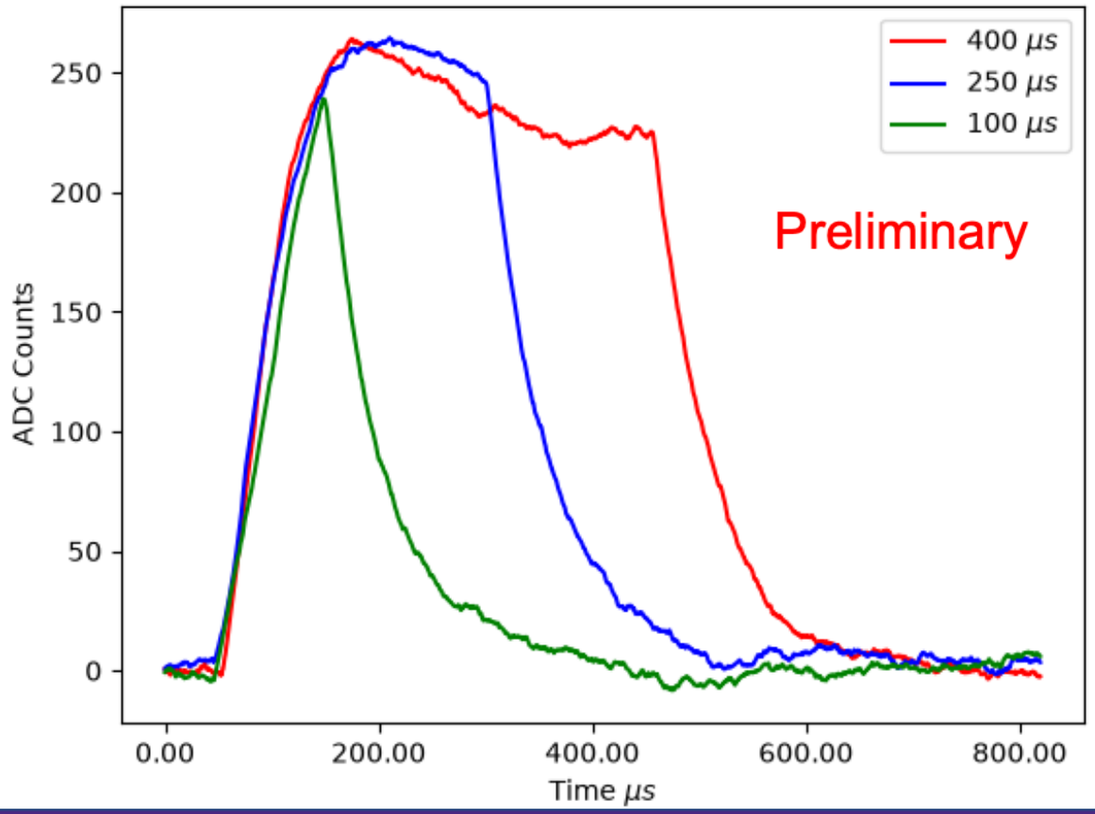
Discrimination ability of EJ 301 Liquid Scintillator for neutrons:

$$TF = \frac{A_{\text{tail}}}{A_{\text{prompt}} + A_{\text{tail}}},$$

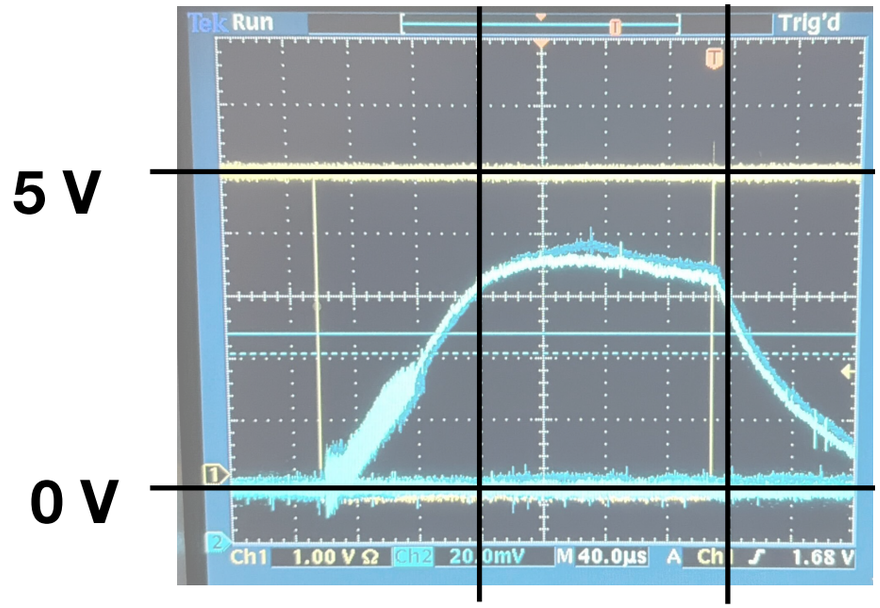
Status of DD Generator

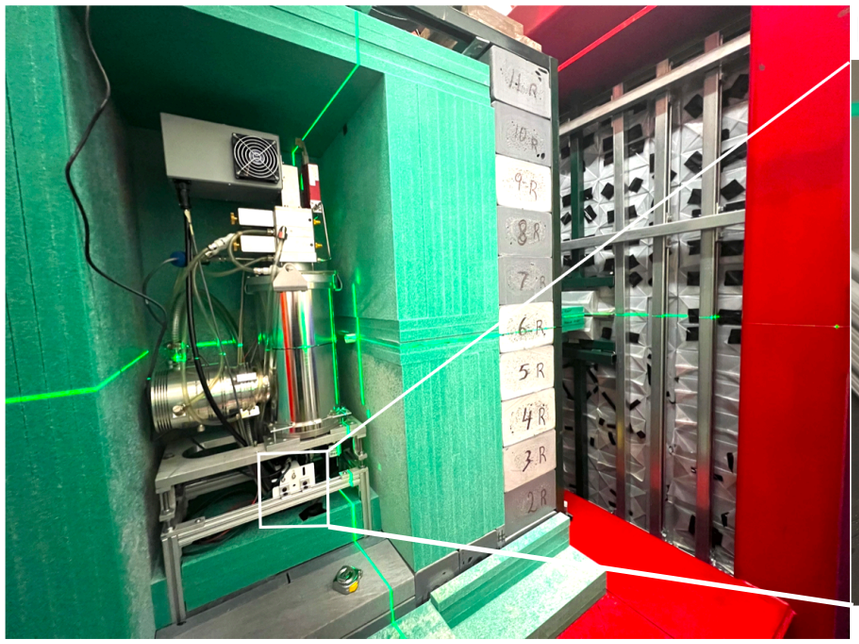
- Opened up the shield, connected a photodiode and looked at the plasma production
- Need to characterize the neutron rate after pulsing, and than implement adaptive filtering, so that we can have fixed window where we get neutrons - limit unstable plasma operation

Varying the TTL window size and observing the photodiode signal

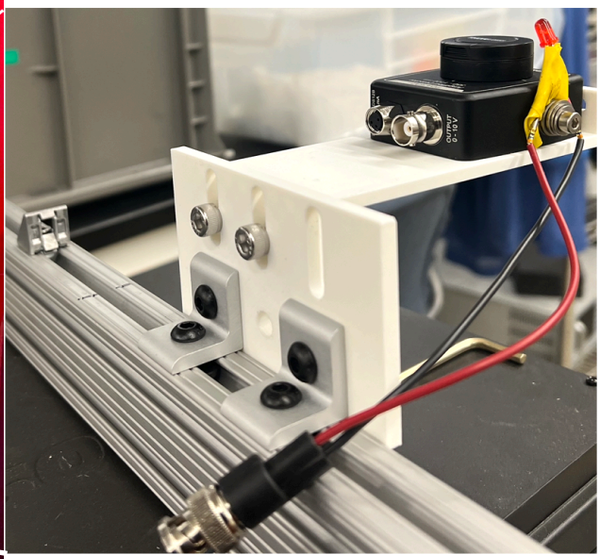


250us inverted TTL: 160us of stable plasma





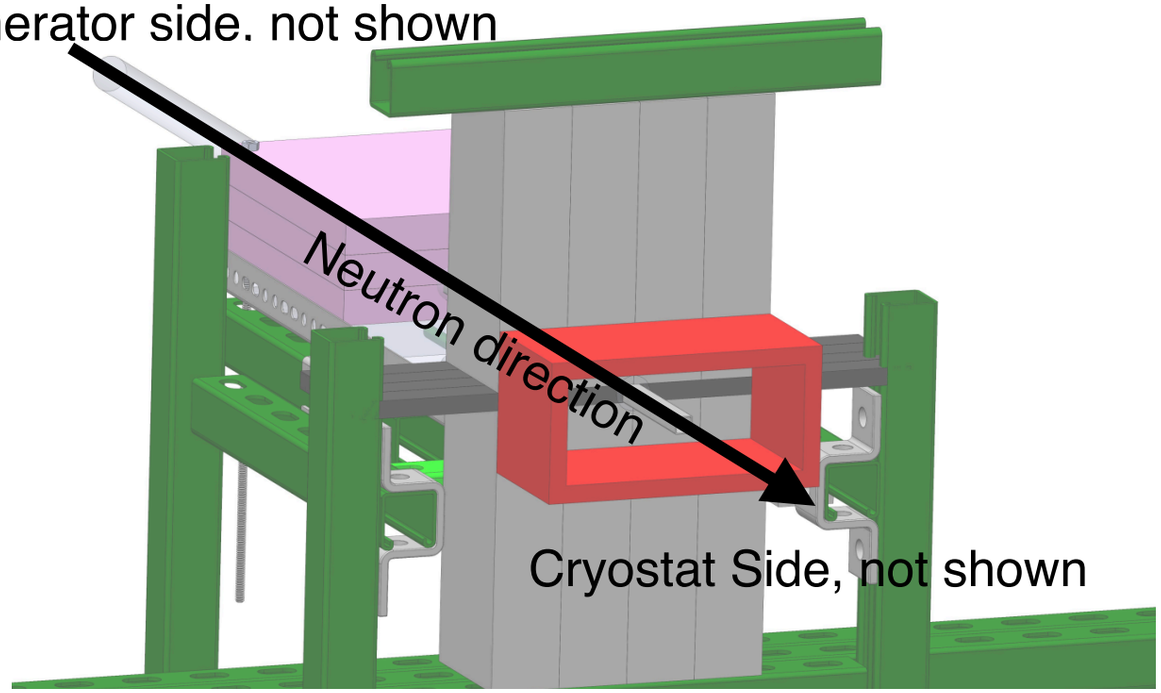
Photodiode:



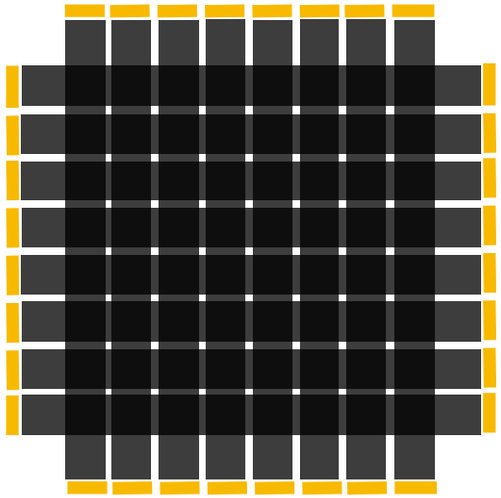
Status of DD Generator



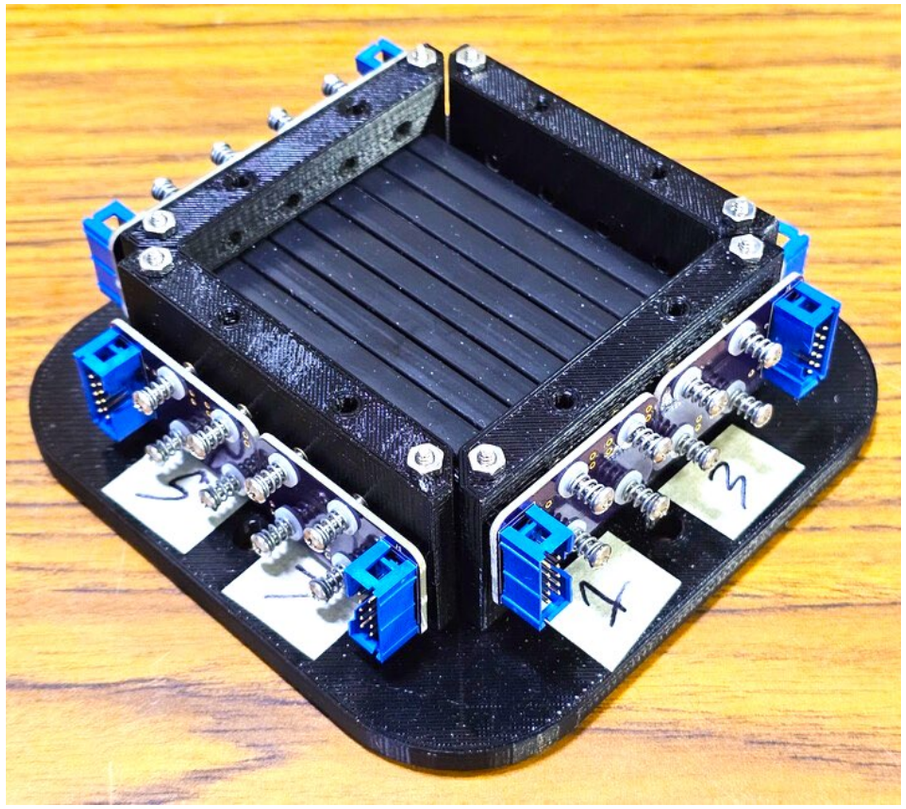
DD Generator side. not shown



SIPM instrumented on both ends

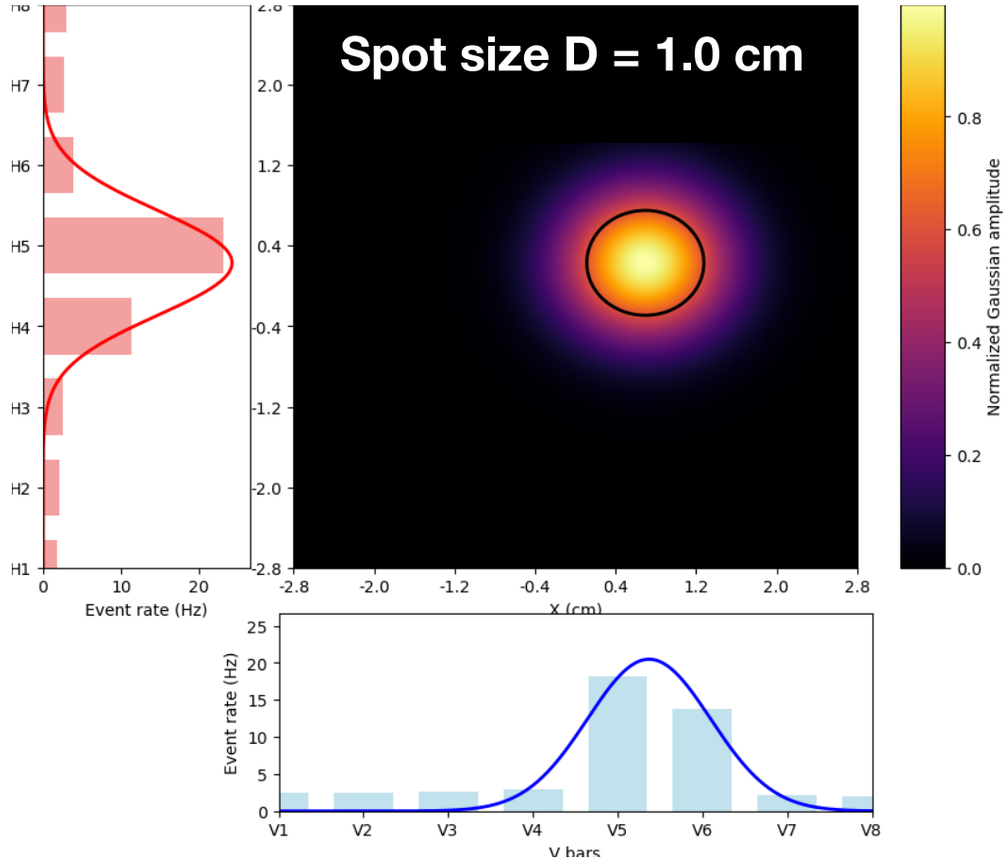


Beam array: set of 8 horizontal and
8 vertical scintillators-bars to trace n-beam spot

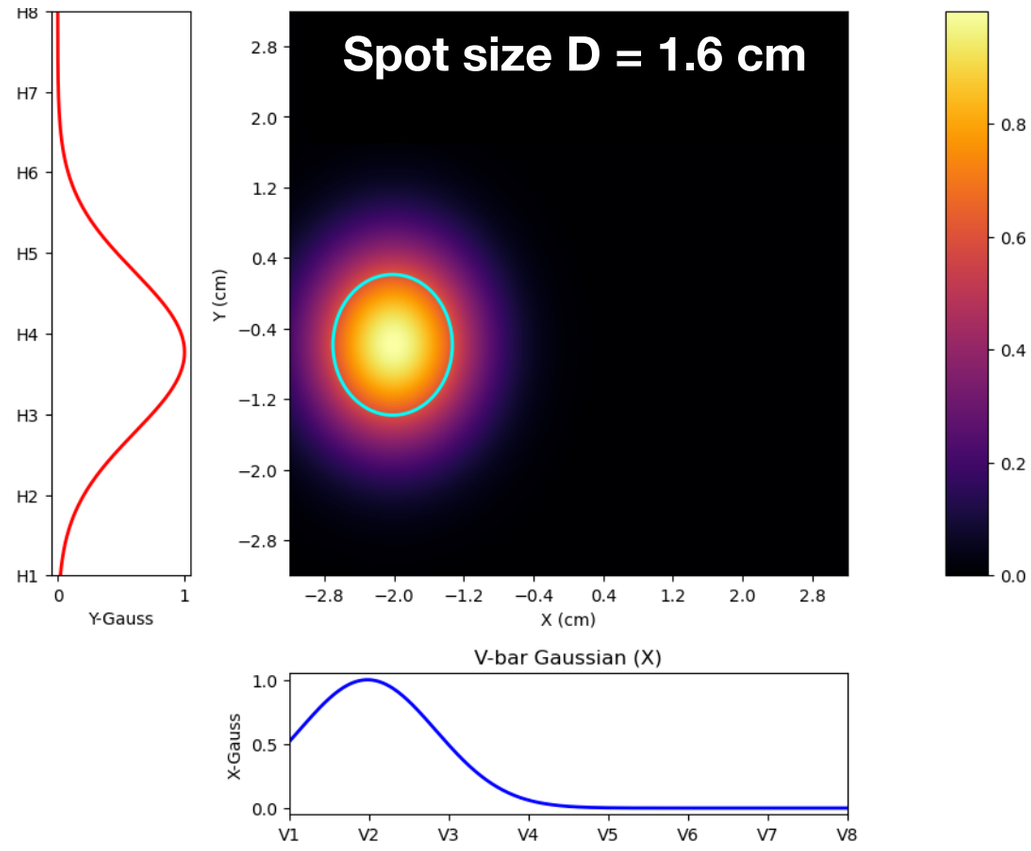


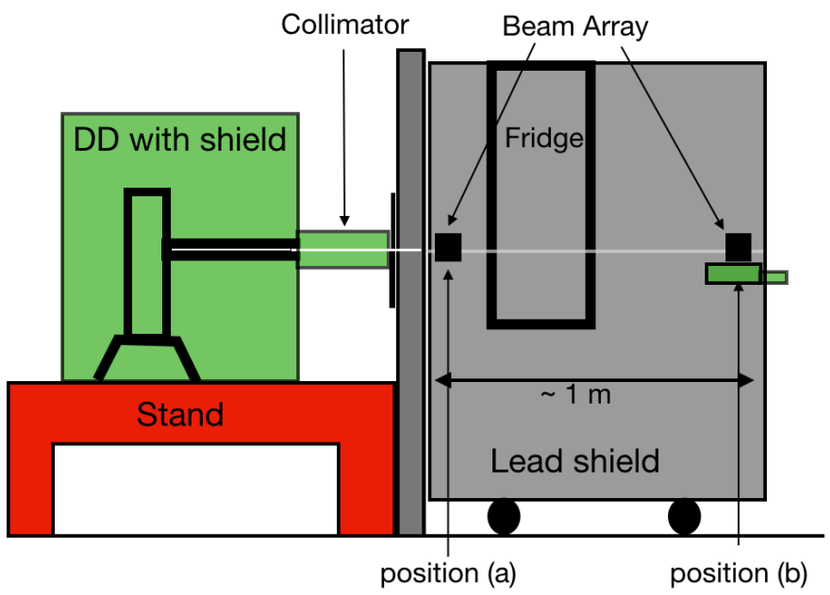
Status of DD Generator

a) near the collimator



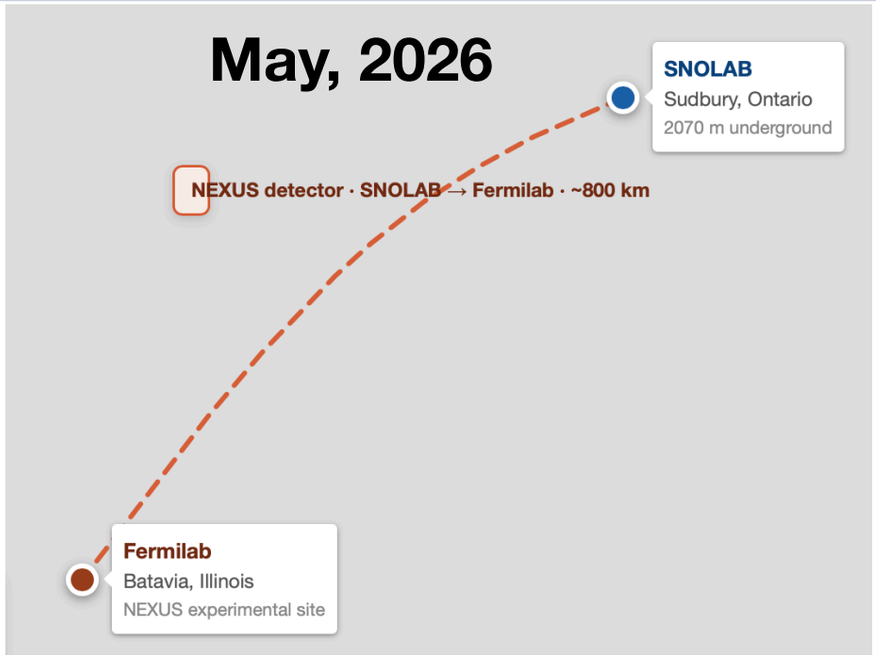
b) ~ 1 m away from the collimator ***





- Neutron beam spot near collimator: ~ 1.0 cm diameter
- Beam spot at 1 m distance: ~ 1.6 cm diameter
- Provides sufficiently localized neutron irradiation for detector calibration studies

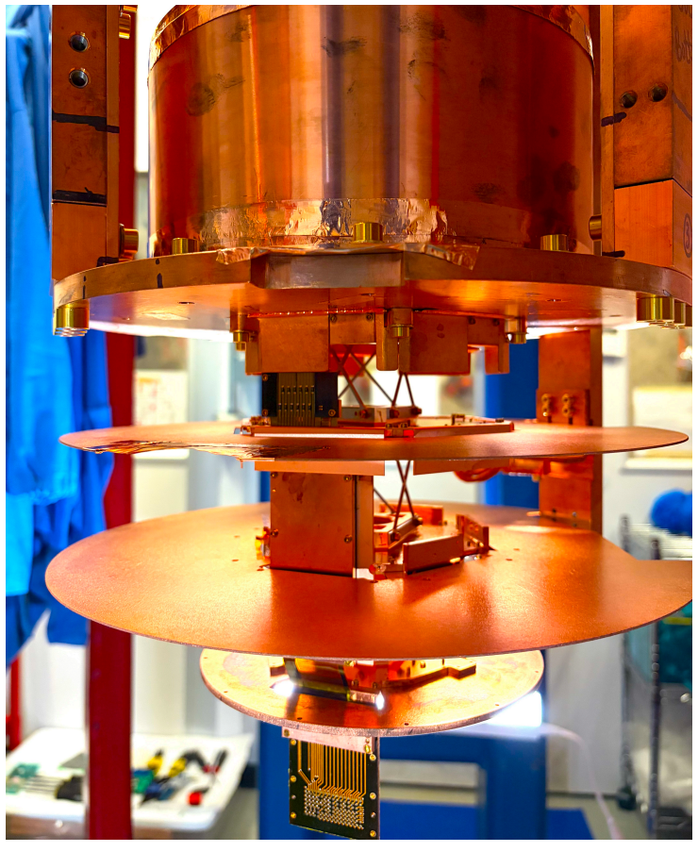
Status of SCDMS detector NEXUS



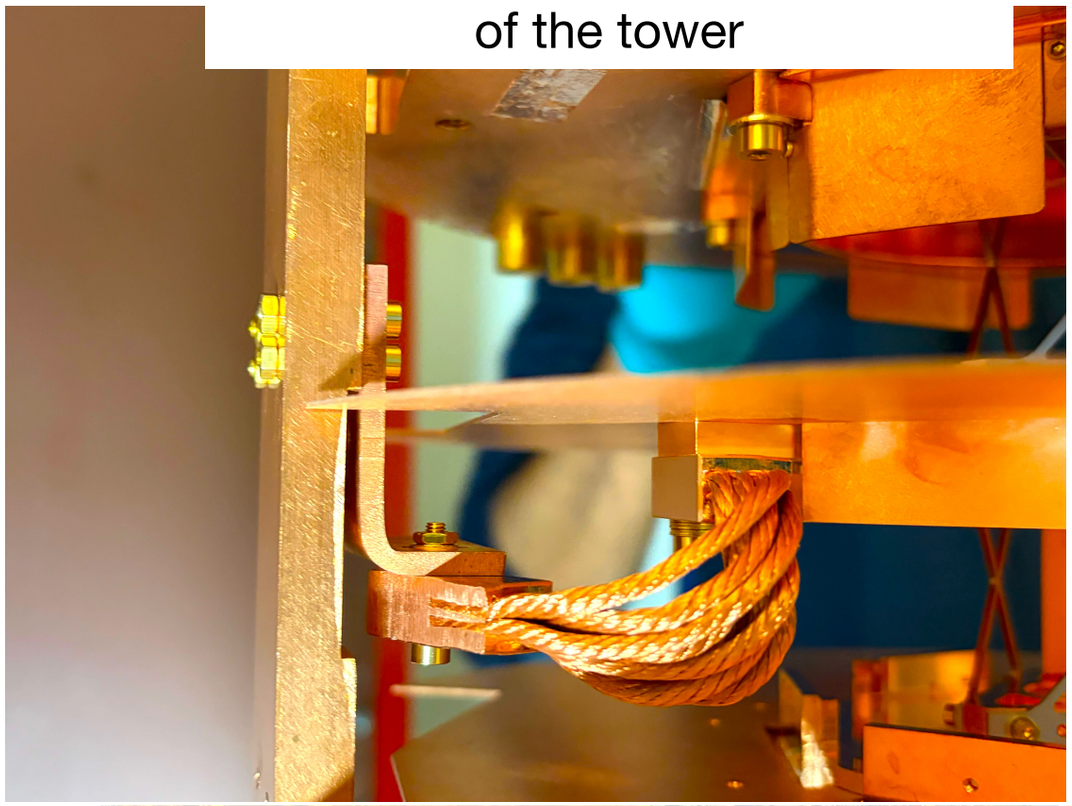


Status of SCDMS detector NEXUS

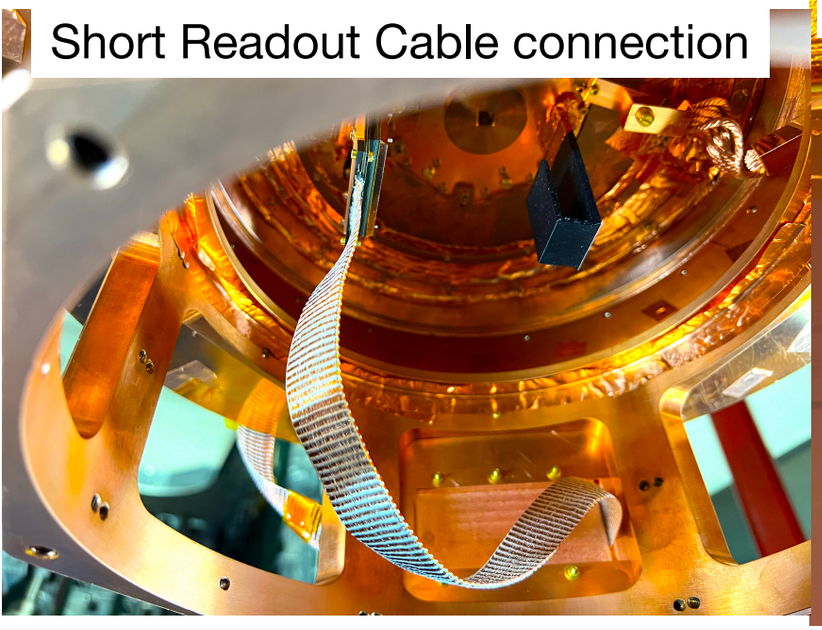
Final assembly with all the IR rings



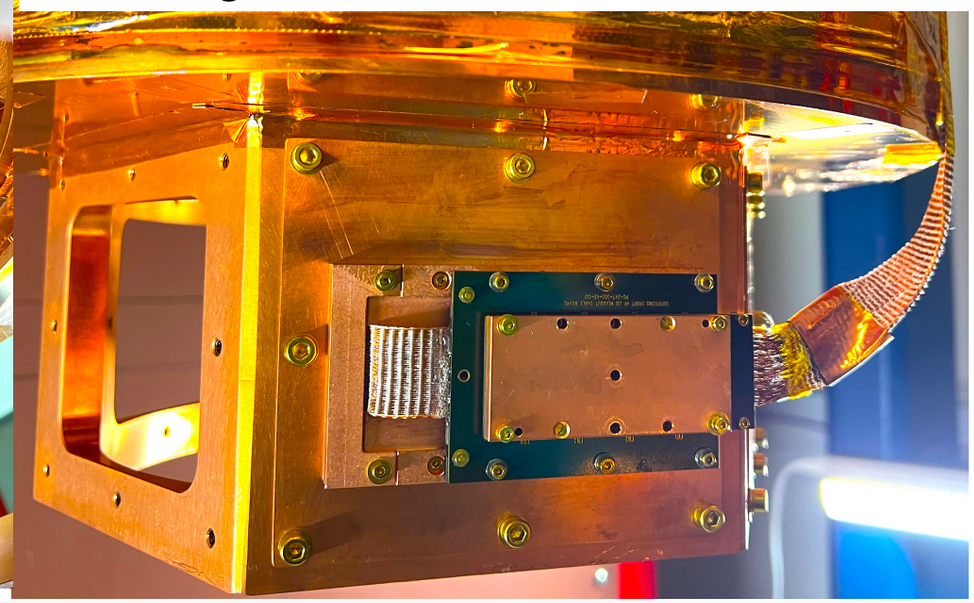
Thermal strap to the 100mK stage of the tower

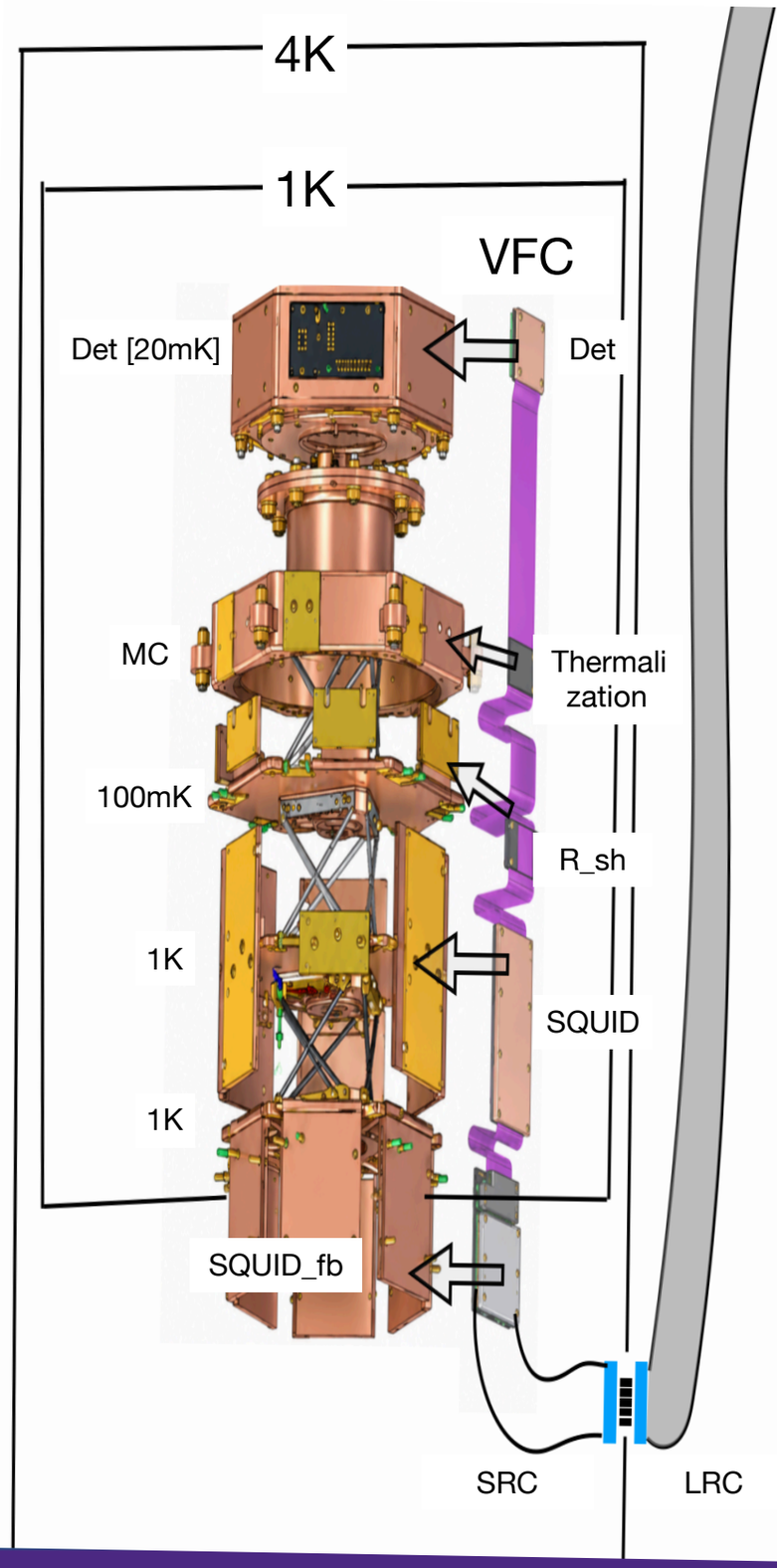


Short Readout Cable connection



Long Readout Cable connection

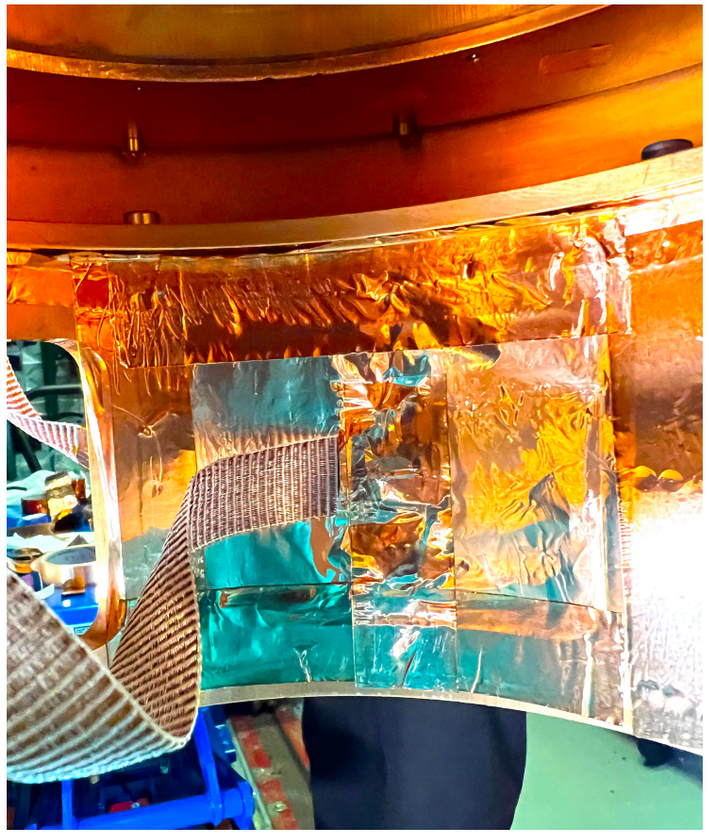


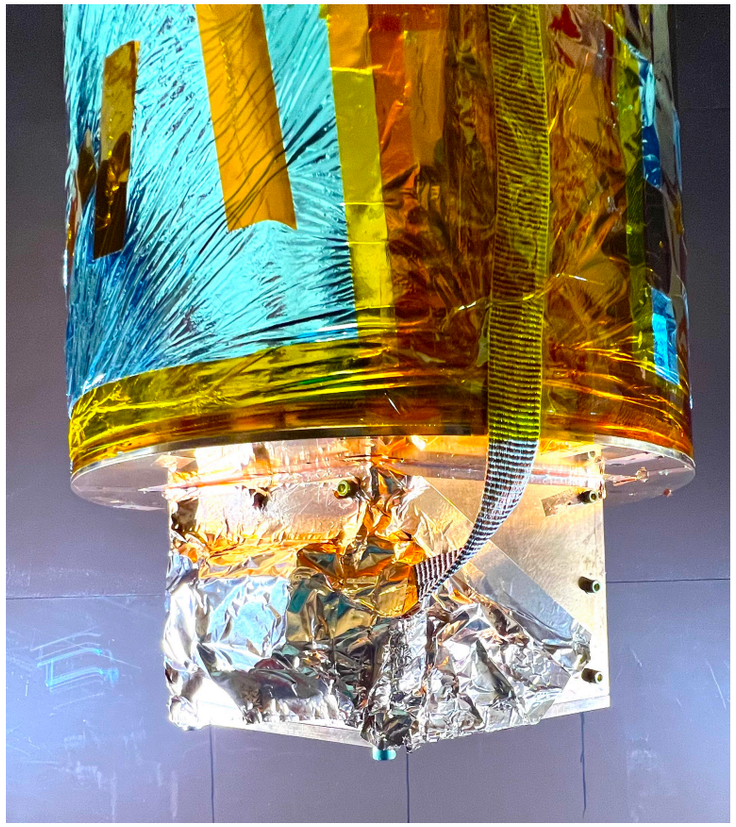


Status of SCDMS detector NEXUS

IR Blockage Efforts:



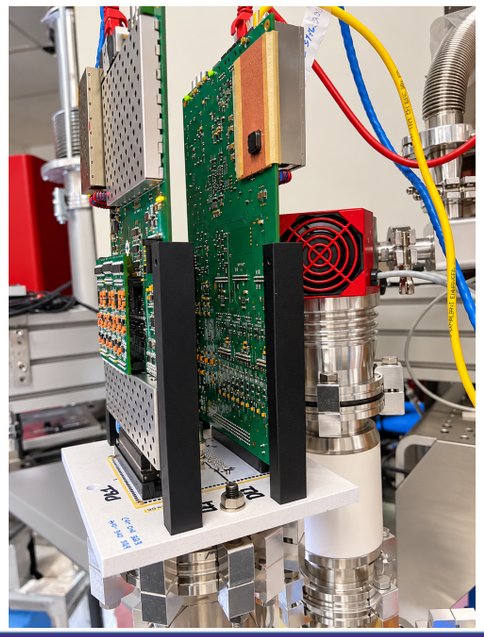




No Mu-metal shield at 1K, we have two metglass blanket around OVC:



Readout Board at room temperature



Conclusion:

Backing-array:

Optimising readout architecture, to lower the deadtime and improve trigger efficency

DD generator:

Demonstrated continuous operation of the D–D neutron generator, producing a neutron beam with an approximately **1 cm beam width**.

Optimizing pulsed-mode operation of the D–D neutron generator to improve beam timing and stability.

Detector :

0. MC = 7.8mK
1. Detector stage of Tower ~ 20mK
2. CP stage of Tower ~ 108mK
3. Still stage of Tower ~ 880mK

Seeing high parasitic resistance, still in detector-debugging mode

Special Thanks to!!

SNOLAB: Andy, Matt S., Macro, Tristan and others



SLAC: Matt Ch., Richard, Tina and Paul
Northeastern University: Junwen





U Toronto: Ziqing, Ariel, Tyler Sola, Tom and Stefan

U South Dakota: Joel, Manish, Joseph

U of Florida group : Tarek, Moaaz, Nick

U Minnesota : Zach, Chi, Yan and Prisca

Fermilab: Lauren, Vika and Dan Baxter, Juan Estrada, Andrew L.

Northwestern U: Tali, Chris, Isabella, Lily and Giana

Thanks



@SuperCDMS

supercdms.slac.stanford.edu

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Arthur B. McDonald Canadian Astroparticle Physics Research Institute

NSERC CRSNG

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DAE

Emmy Noether-Programm
DFG Deutsche Forschungsgemeinschaft

Thank You!