Directional DM detectors: anisotropic scintillating crystals with CCDs

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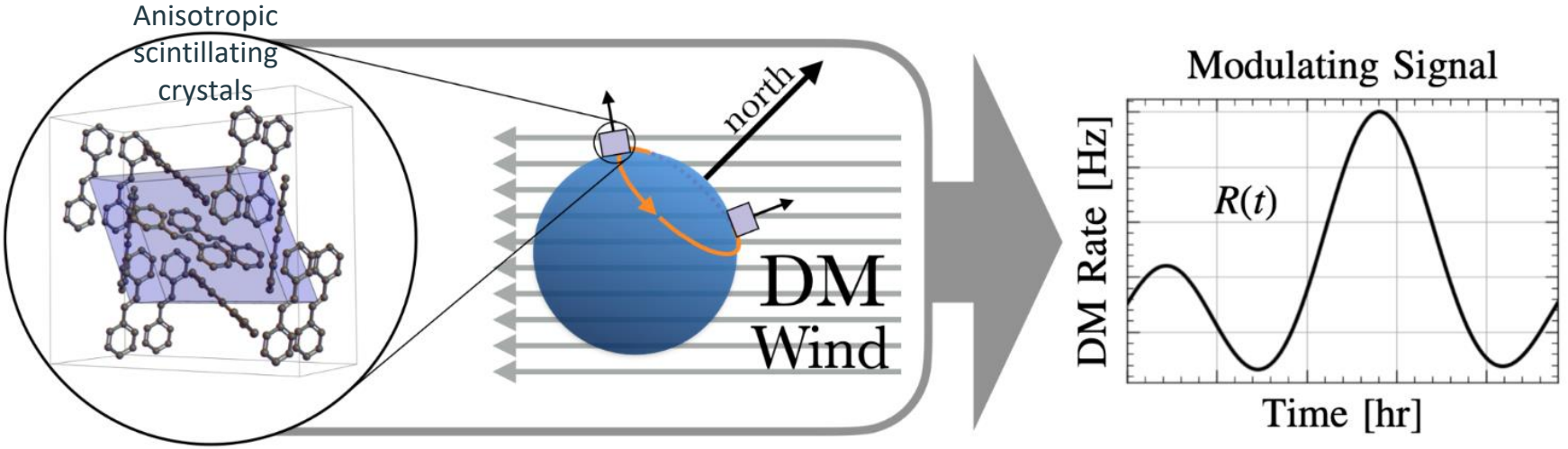
Challenges for direct detection of low-mass DM with low-threshold detectors

- **Low Energy Excess: seen by multiple experiments, probably from multiple sources**
- **Backgrounds: neutrino fog, cosmogenic activation floor**
- **Scalability: cost per unit target mass**

Challenges for direct detection of low-mass DM with low-threshold detectors

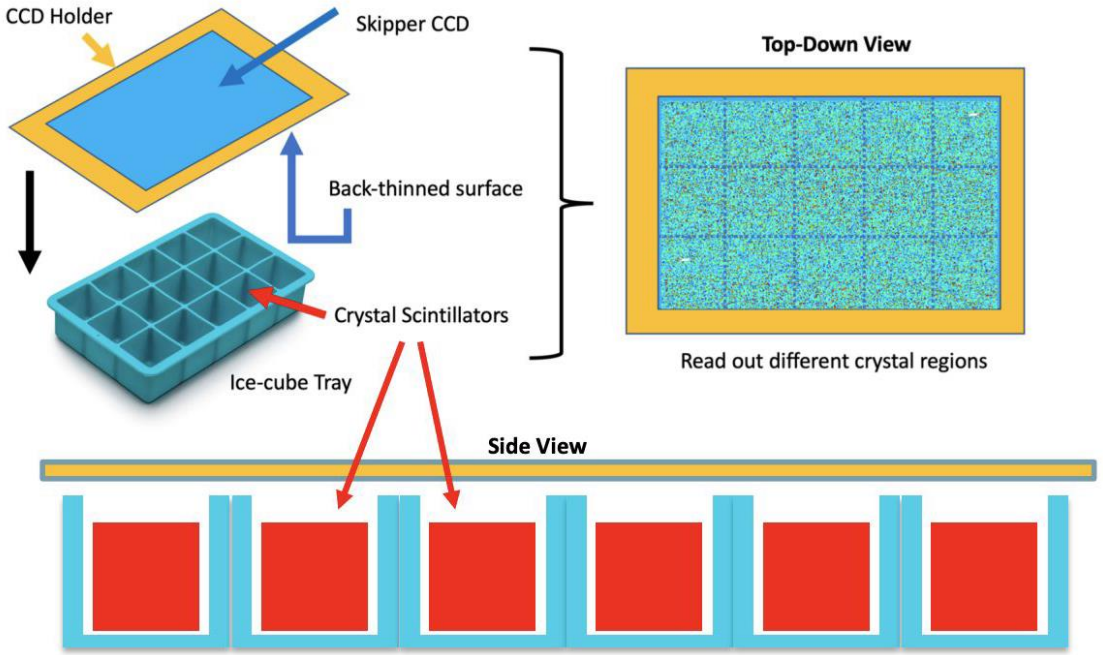
- **Low Energy Excess**
- **Neutrino fog, cosmogenic activation floor**

Exploit Earth's daily rotation w.r.t. DM wind direction -> daily modulation signal rate, distinct from all known background sources



Challenges for direct detection of low-mass DM with low-threshold detectors

- **Scalability (cost per unit target mass)**



Decouple scattering target from readout sensors

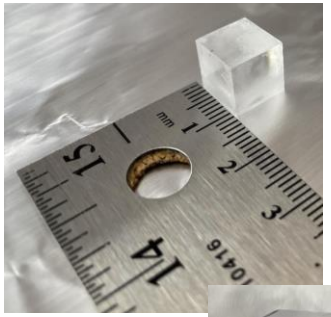
Crystals optically coupled to Skipper-CCD photosensors

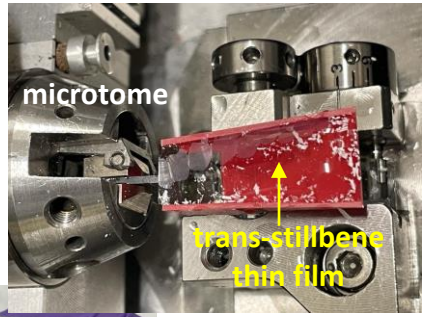
Organic Scintillator Crystal

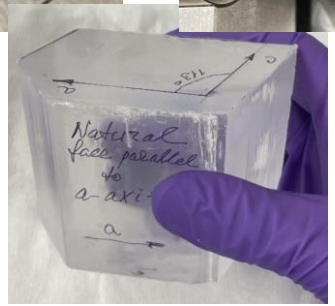
For proof-of-concept prototype, trans-stilbene ($C_{14}H_{12}$)

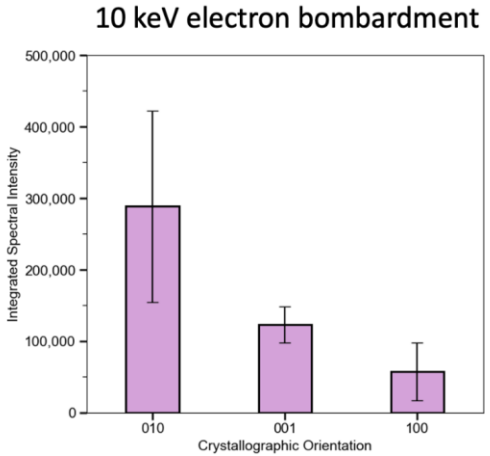
- Fairly generic, with gram-scale single crystals commercially-available
- Can grow ourselves -> control radiopurity and select primary crystal axis
- Scintillation light peaks ~380 nm (deep-purple to near-UV, ideal for CCDs)
- Good anisotropic response at the energies of interest

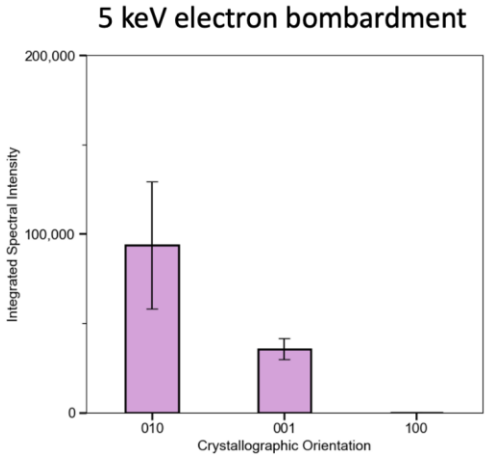
ML framework to identify other (better?) crystal materials for future





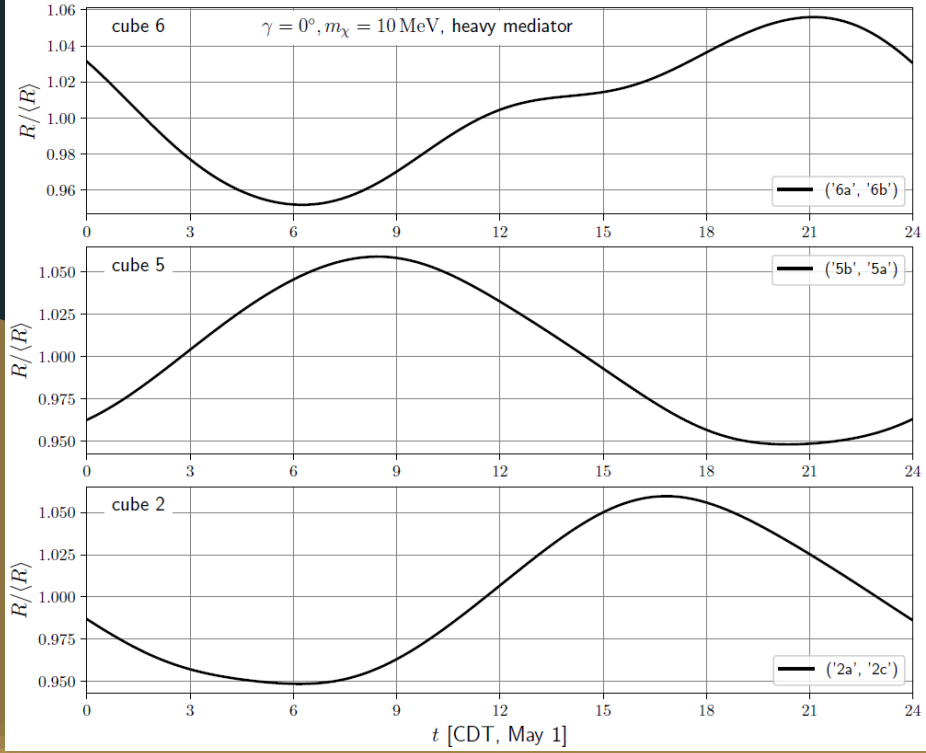


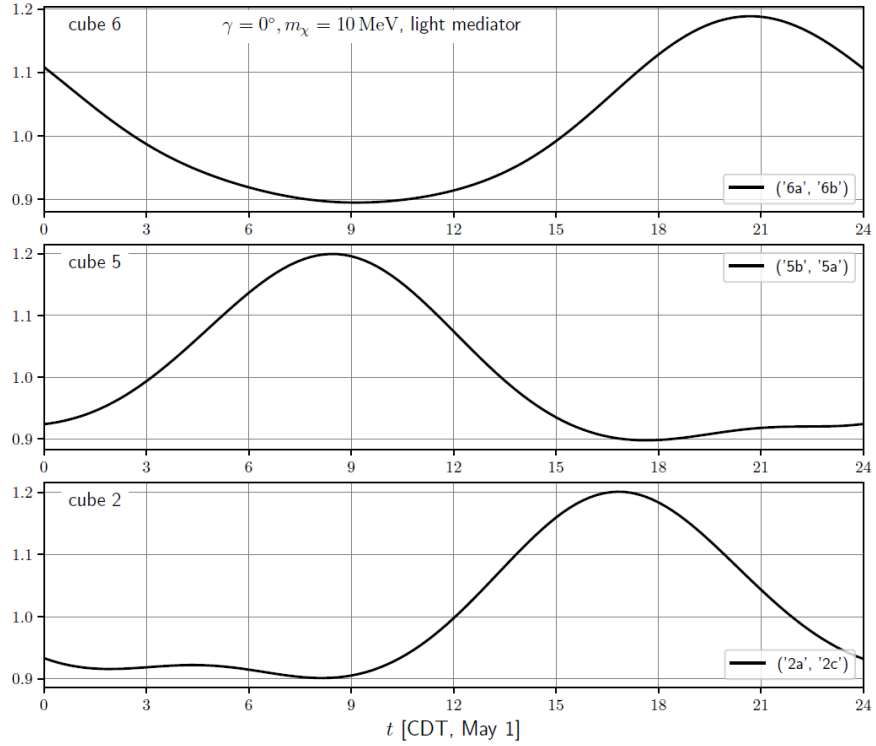




Expected trans-stilbene anisotropic signal

Daily modulation: predicted normalized rate *R(t)/<R(t)>* for particular orientations of sample cubes, at Fermilab location





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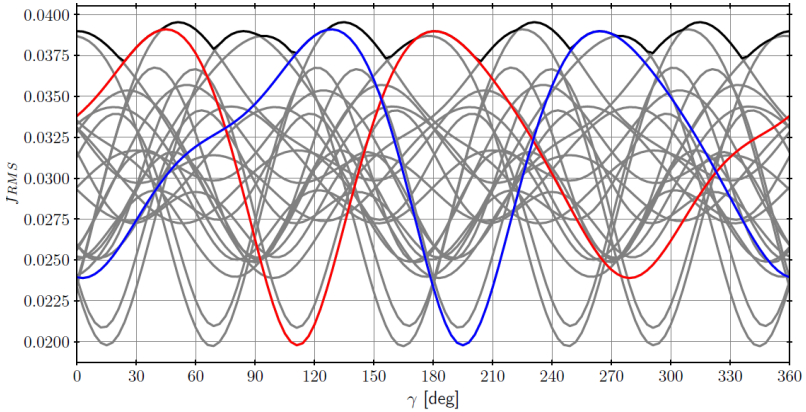
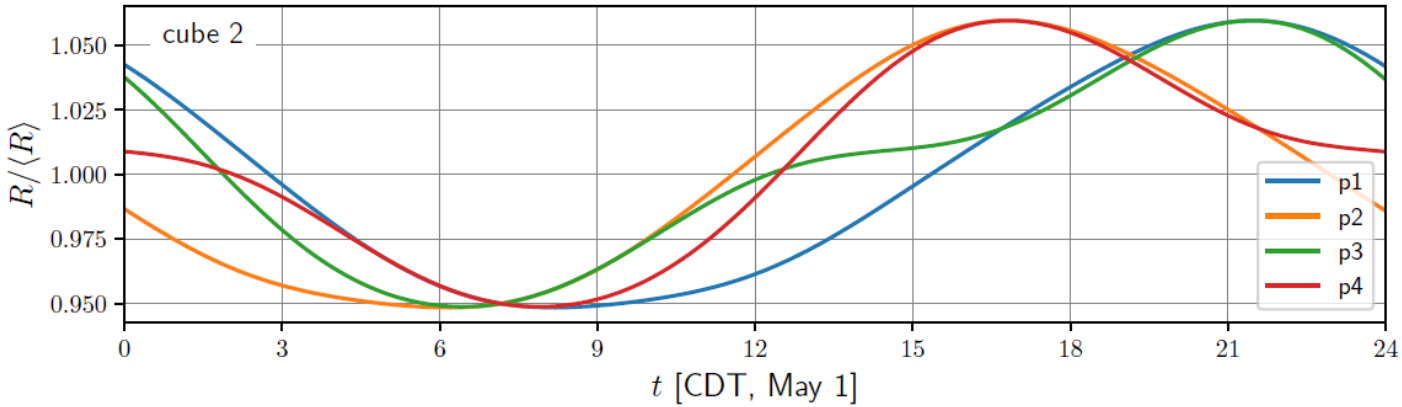
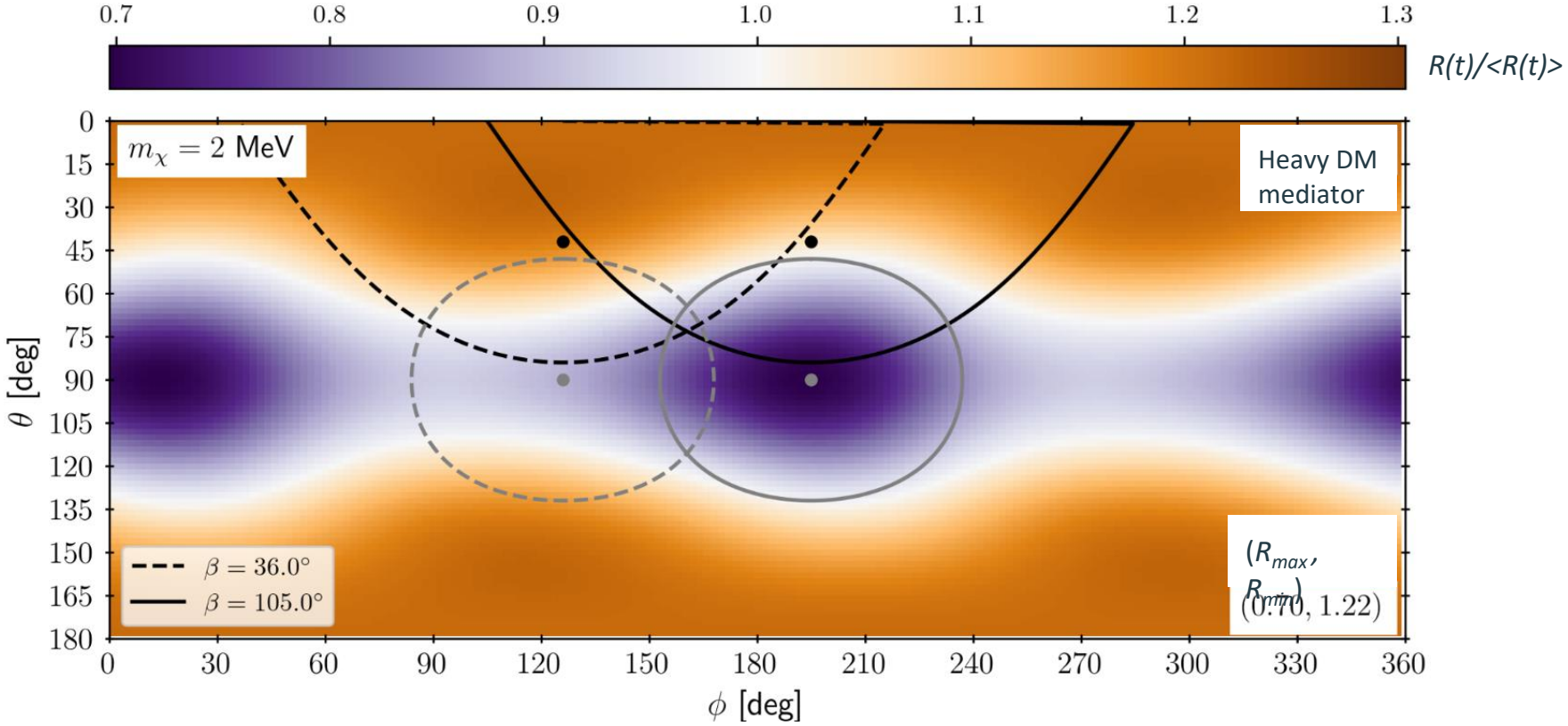


Modulation amplitude f_{RMS}, for each of 24 possible cube orientations, vs CCD angle γ.
Red and blue highlight two particular orientations
Heavy DM mediator,
m_{DM} = 10 MeV



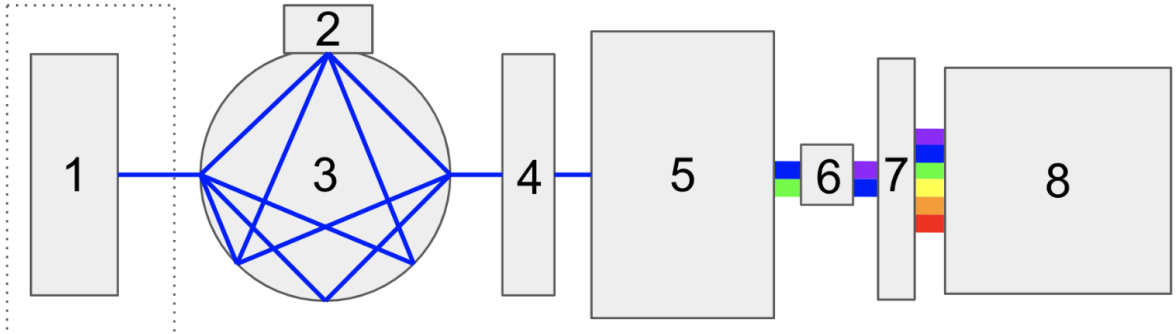
Predicted normalized rate $R(t)/\langle R(t) \rangle$ for the 4 cube orientations **p** that give greatest modulation (ranked 1-4) by f_{RMS}
Heavy DM mediator,
γ=0, m_{DM} = 10 MeV

Expected trans-stilbene anisotropic signal

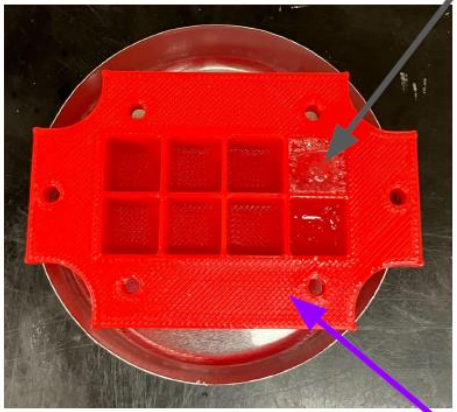


Optical testing setup

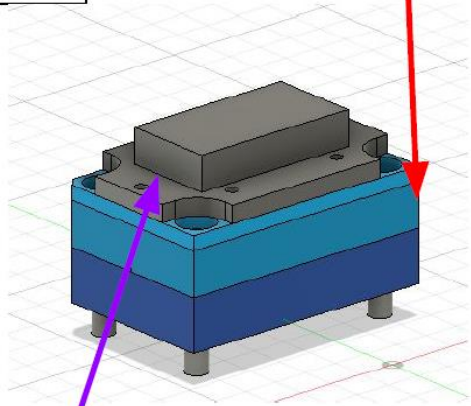
(1) Vacuum chamber containing CCD
(2) Photodiode attached to top of …
(3) … integrating sphere
(4) Optical shutter
(5) Monochromator
(6) 3 g trans-stilbene sample
(7) Filter wheel
(8) Broadband Xe lamp



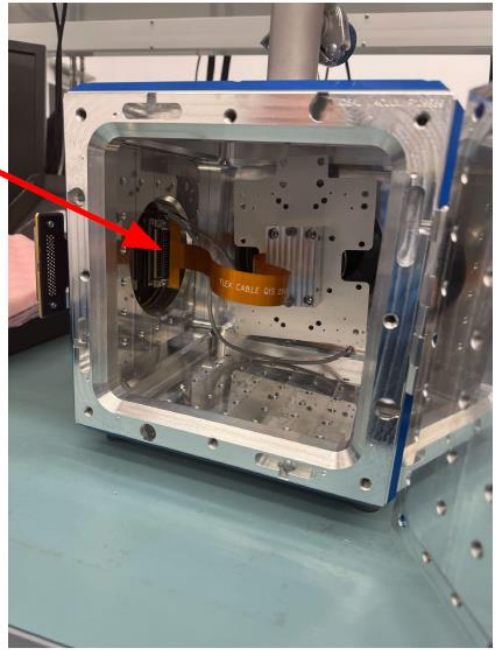
Prototype detector setup



Epoxied Crystal



Skipper CCD



“Ice cube tray”

Upcoming paper

- Selection & preparation of organic scintillator target crystals
- Skipper CCD calibration & response to near-UV scintillation light
- Direct measurement of spectral shape of the crystal scintillation light using CCDs
- Measurement of crystal's anisotropy to scintillation production
- Prototype detector design integrating these components, to be deployed underground at MINOS@Fermilab this summer
- Sensitivity projections for DM-electron scattering, for the various phases of a full experiment

Eventually, run in SNOLAB

- Following end of DAMIC SNOLAB runs: reuse their cryostat and readout
- Significant interest from DAMIC collaboration
- Exciting science potential, logical extension of CCD program at SNOLAB
- Scaleable!