MAGNETO-DM: Sub-GeV Dark Matter Detection using Diamond and Magnetic Sensors

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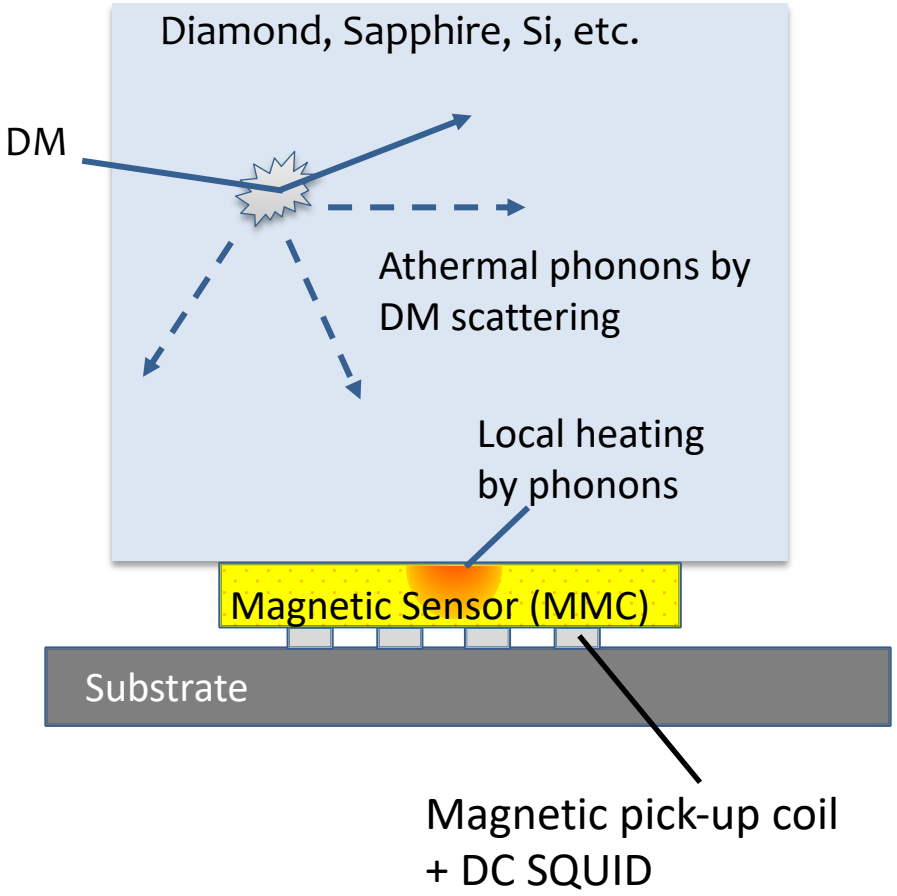
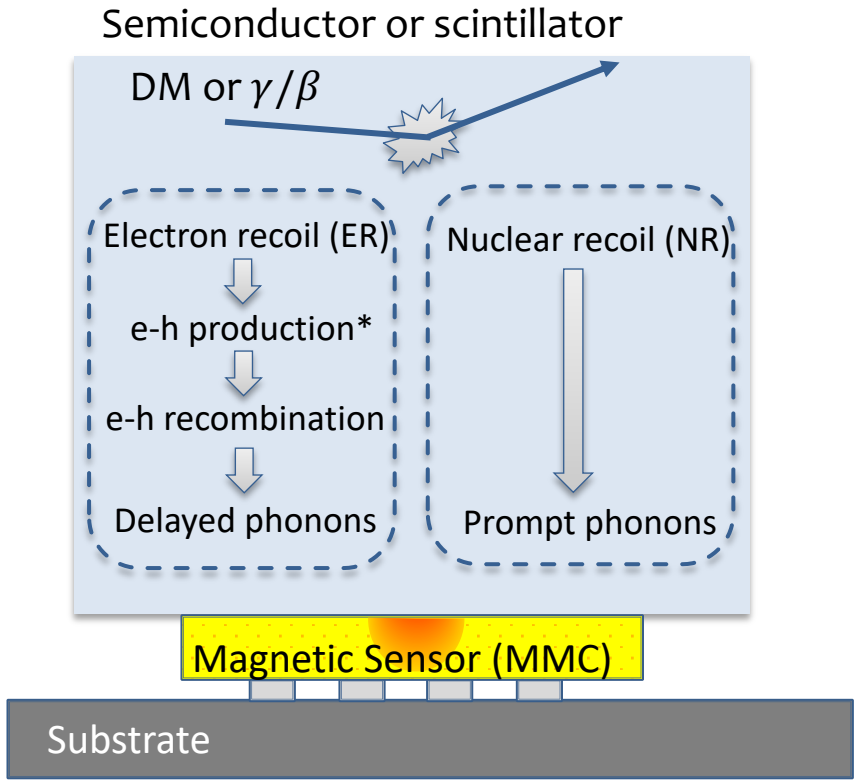
MAGNETO-DM: Fast Phonon Sensing for Sub-GeV DM Detection



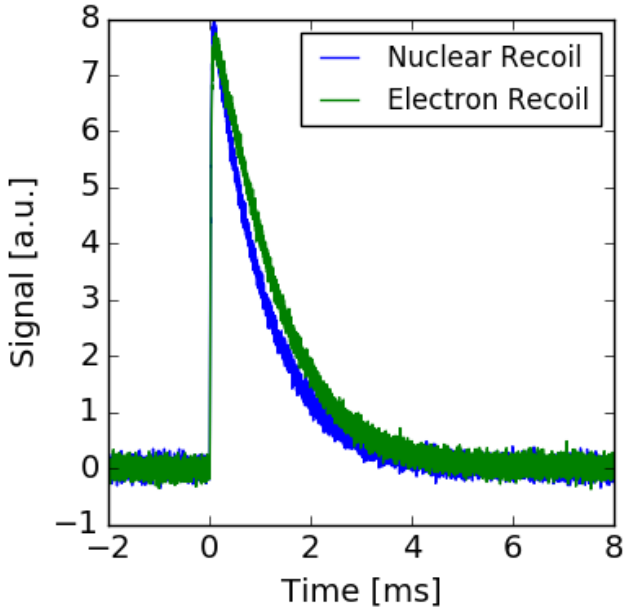
Detection Material	Diamond, Si, Ge, $CaMoO_4$, or other semiconductor and scintillating crystals.
Readout	Athermal phonon sensing with metallic magnetic calorimeter (MMC)
Key performance	1. Phonon pulse shape discrimination (PSD) with fast timing resolution (~100 ns) 2. No direct sensor fabrication to crystals → Advantageous for scaling up.

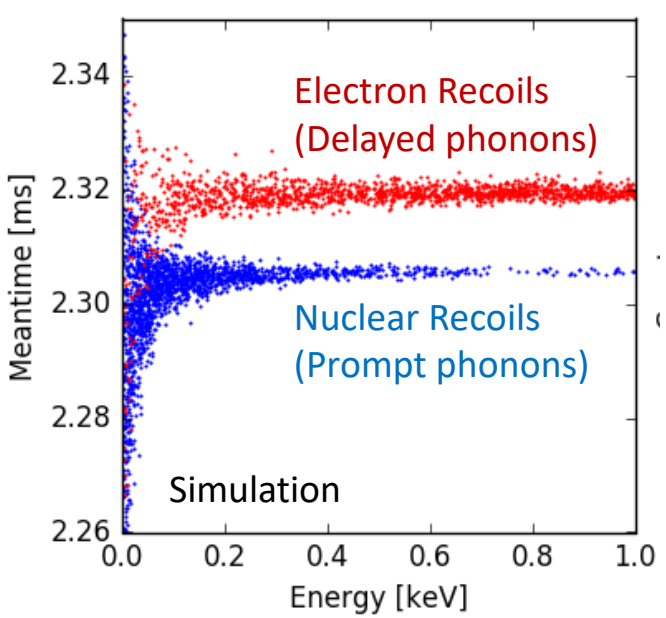
Phonon Pulse Shape Discrimination



**Electron excitation in scintillator cases*

J. low Temp. Phys. 199.3 (2020)

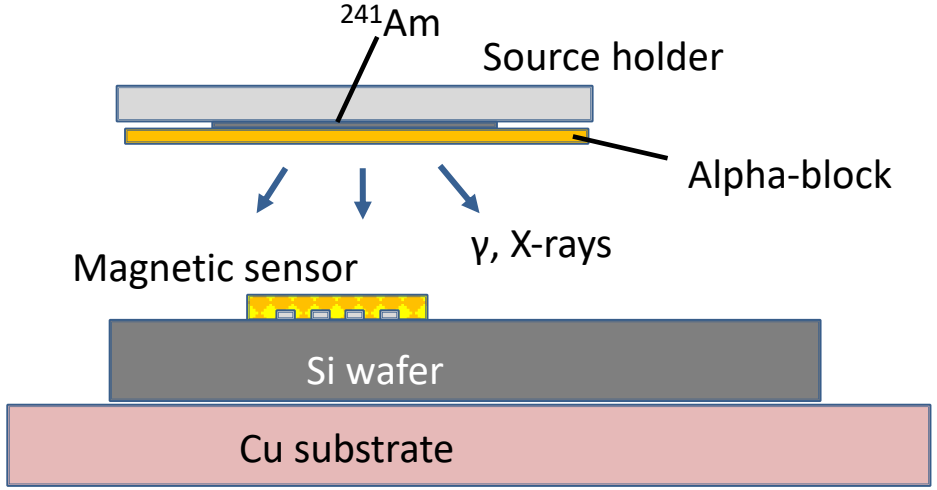




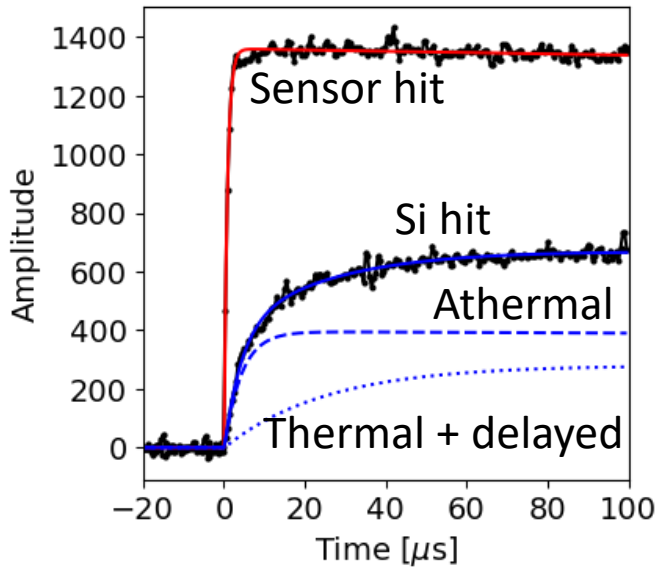
For experimental evidence, see Adv. High Energy Phys. 817530 (2015)

Proof-of-Concept Experiments

- Directly fabricated MMC on Si wafer
- Exposed to uncollimated gamma source

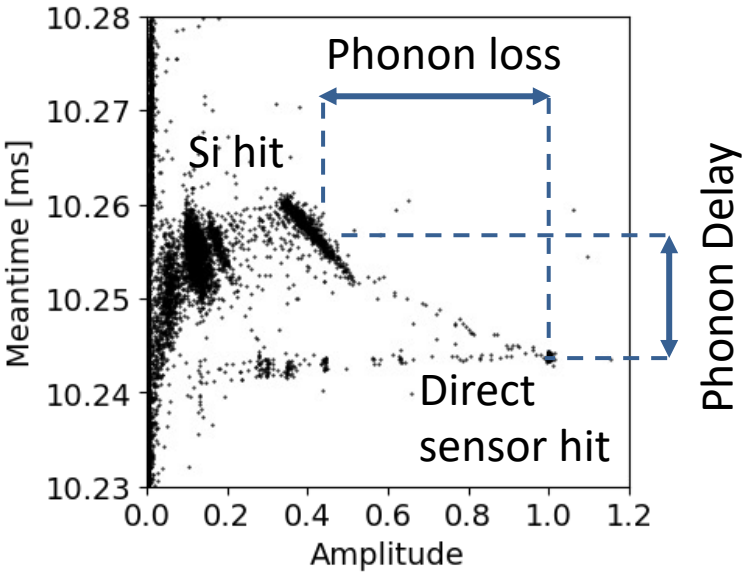


Phonon Signals with model fit



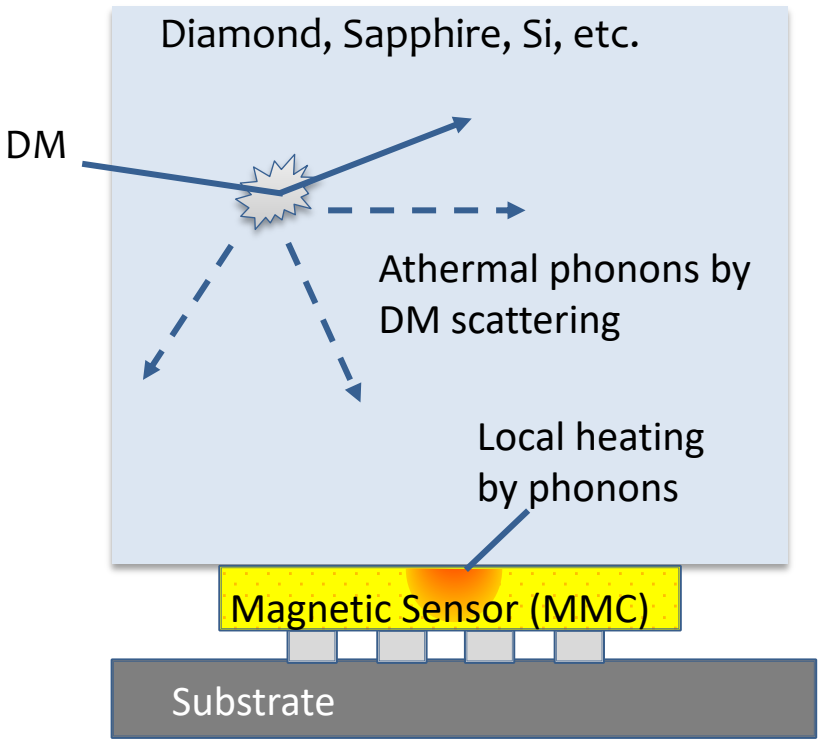
- Measured 60 keV single phonon pulses
- <1us timing resolution

Pulse Shape Discrimination



- Strong separation of events with different origin

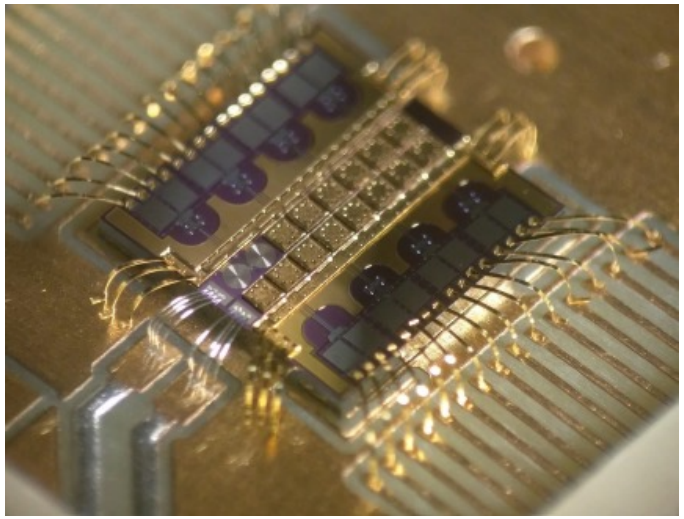
Detector Development Strategy



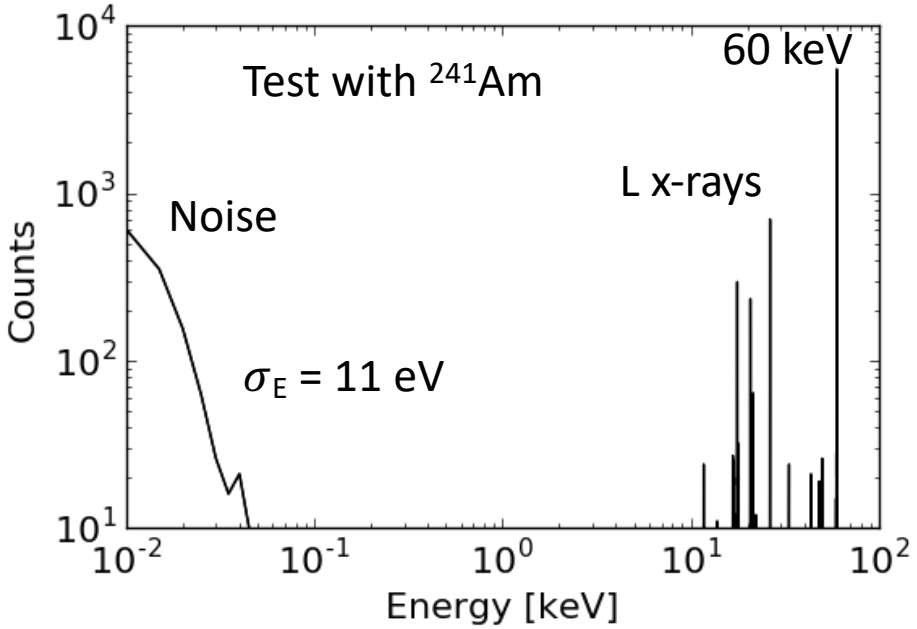
Three R&D Thrusts

Crystal	- High athermal phonon collection - Long e-h pair lifetime (long scintillation decaytime)
Sensor	- Magnetic sensor material development - High resolution - Fast timing resolution
Scaling	- Multiplexing

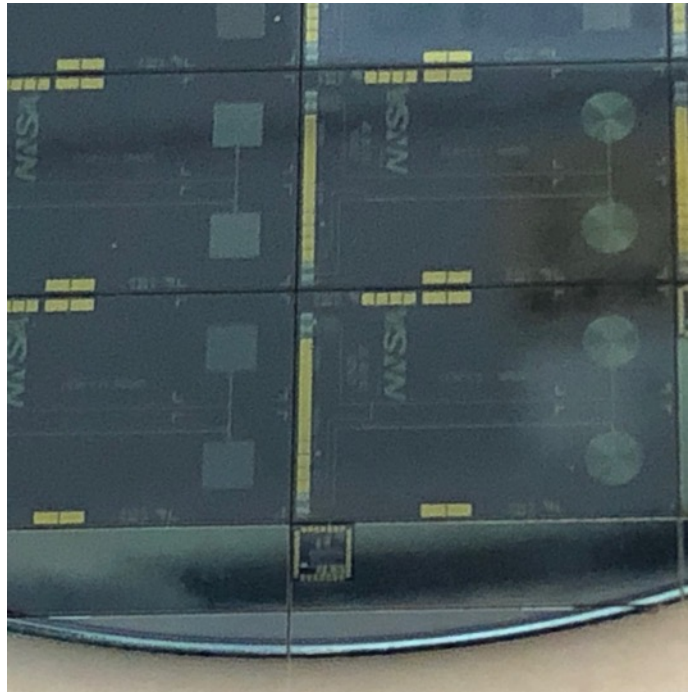
Sensor Development - Design Optimization



- 16-pixels MMC array developed for gamma-ray spectroscopy.

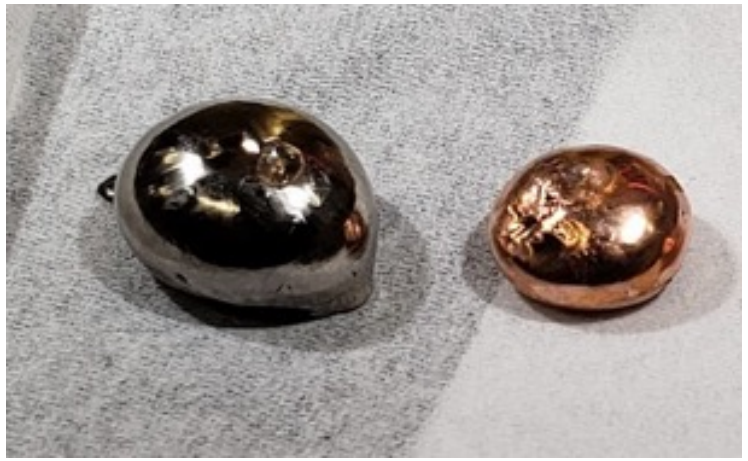


- 11 eV resolution has been demonstrated.
- There is a room for further improvement (SQUID direct coupling, improved noise)



- 2-pixels bare pick-up coil devices (1cm spacing) for prototype detector

Sensor Development – Magnetic Gold Synthesis



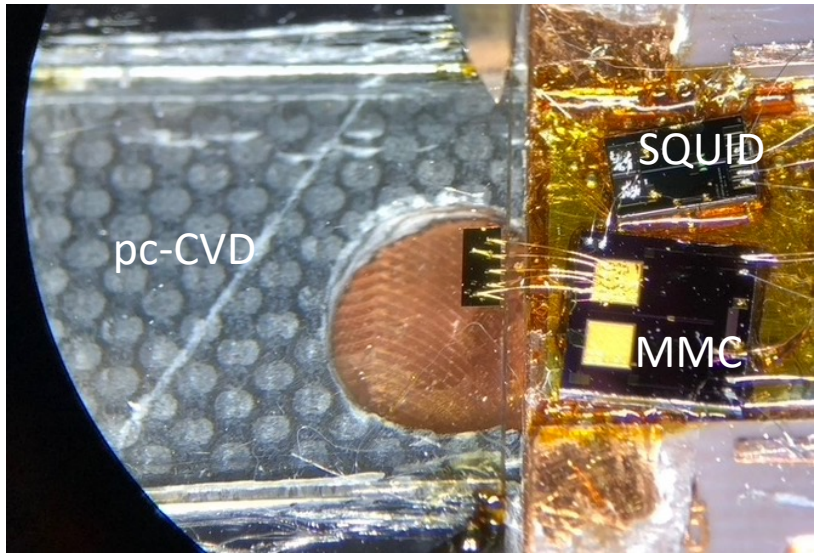
Home-made Au:Er pellets

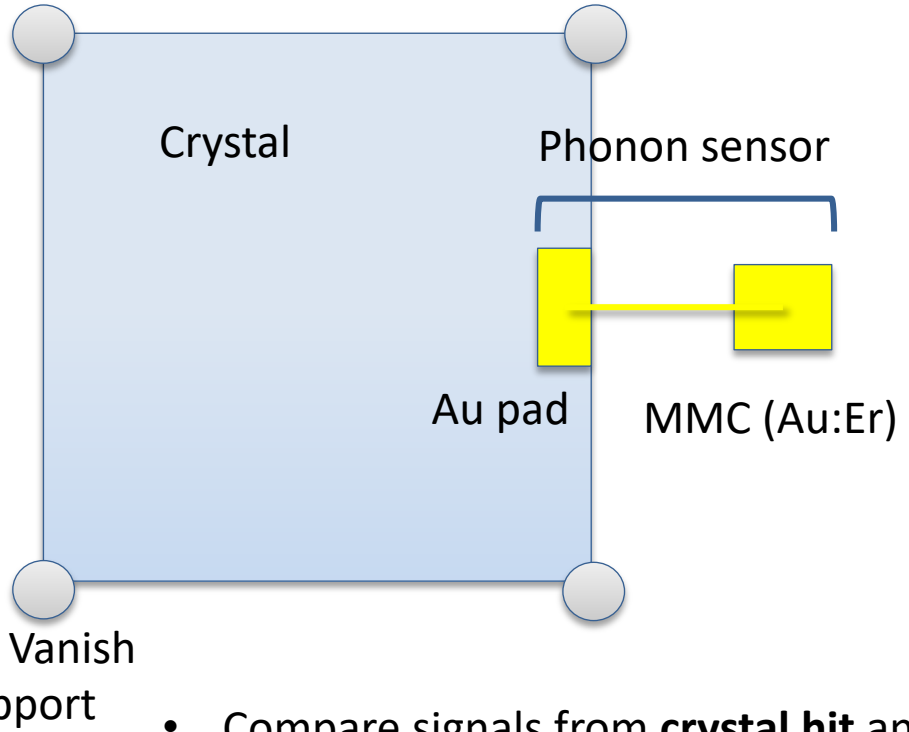
Rolled magnetic gold foil

Rolled to 13 um for test

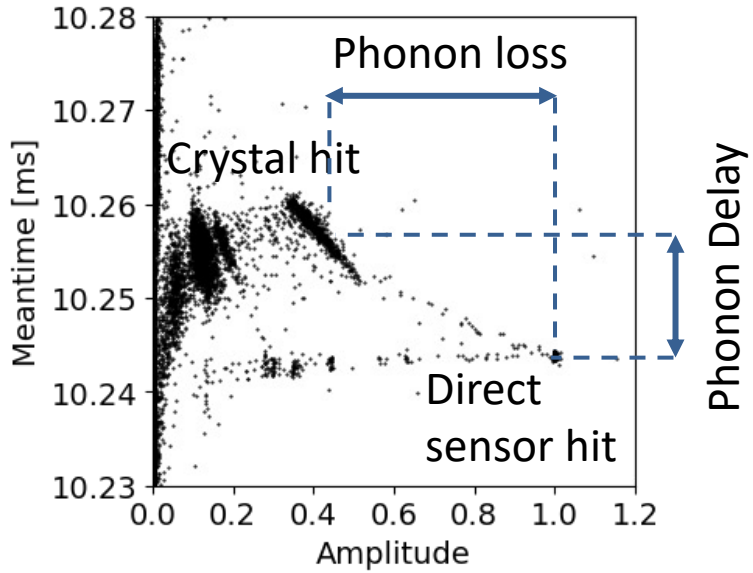
Crystal Selection – Athermal Phonon Collection Efficiency

Tested various crystals for phonon propagation study





Pulse Shape Discrimination



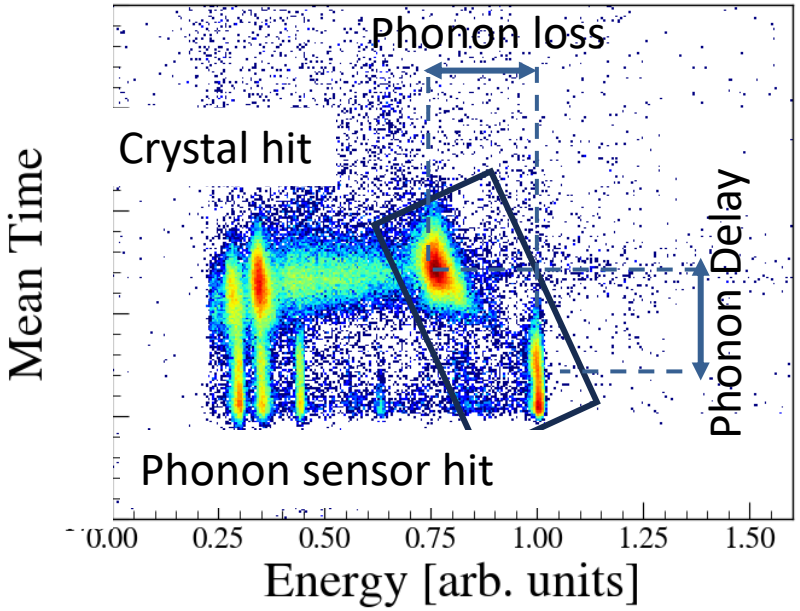
- Compare signals from **crystal hit** and **phonon sensor hit**
- Extract phonon collection efficiency and timescale

Crystal Selection – Athermal Phonon Collection Efficiency

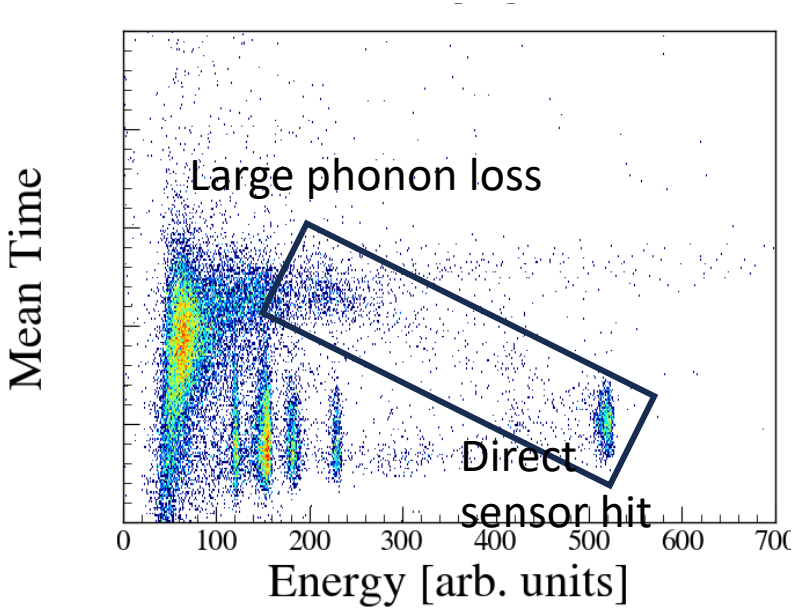
Quantification of athermal phonon collection efficiencies

I. Kim et al, LTD-20

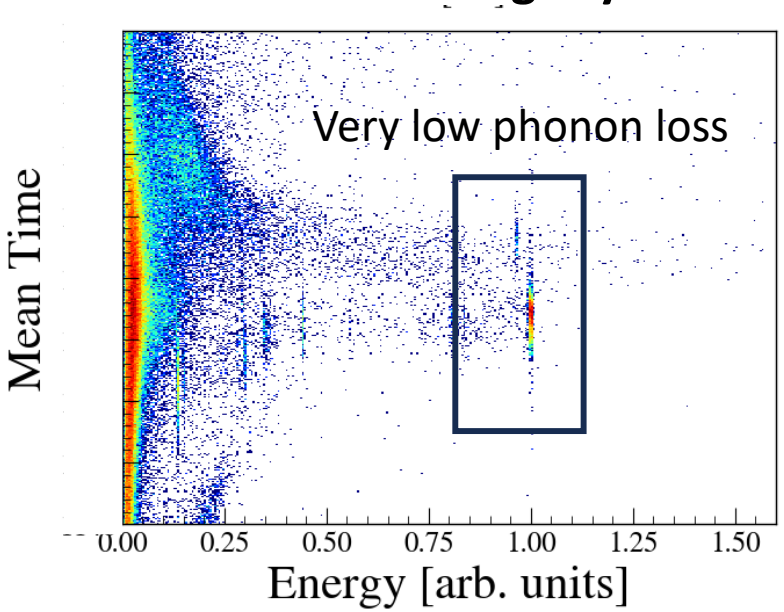
Most Promising Crystal!



Sapphire 5mm x 5mm x 500um
Similar result with 1cm x 1cm x 1mm



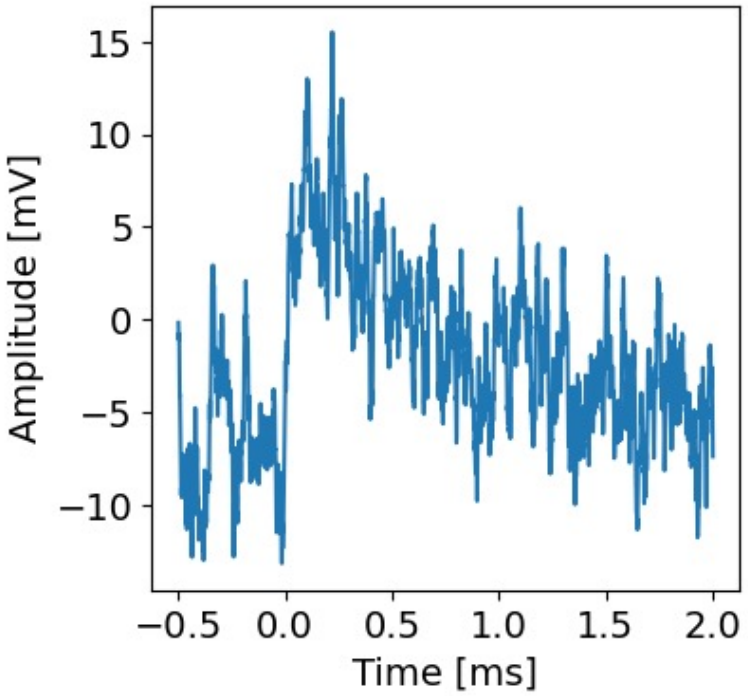
sc-CVD 5mm x 5mm x 250um



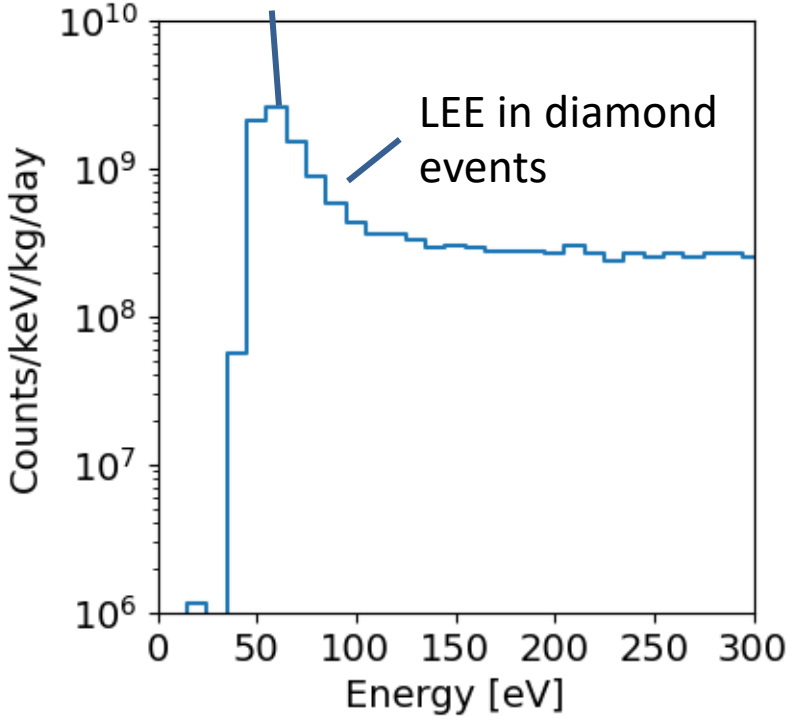
pc-CVD 1cm x 1cm x 500um

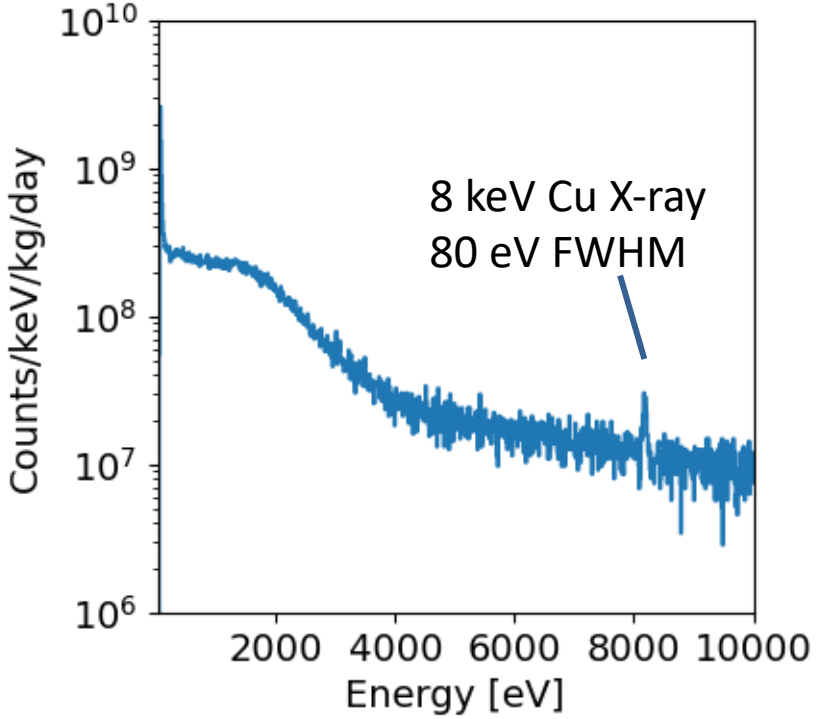
Low Energy Analysis in pc-CVD Data

Single pulse at 100 eV



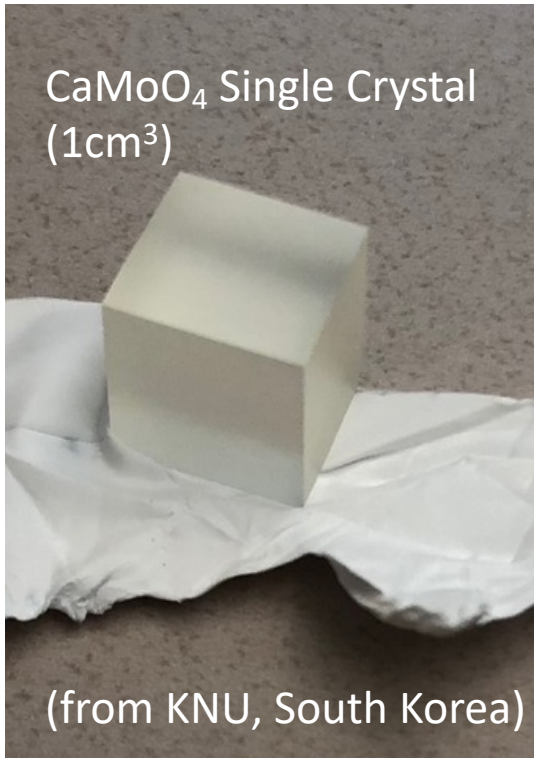
70 eV threshold



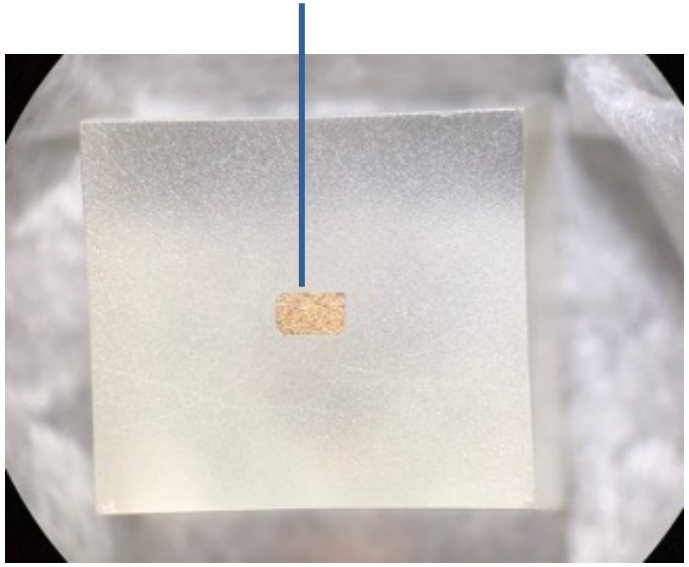


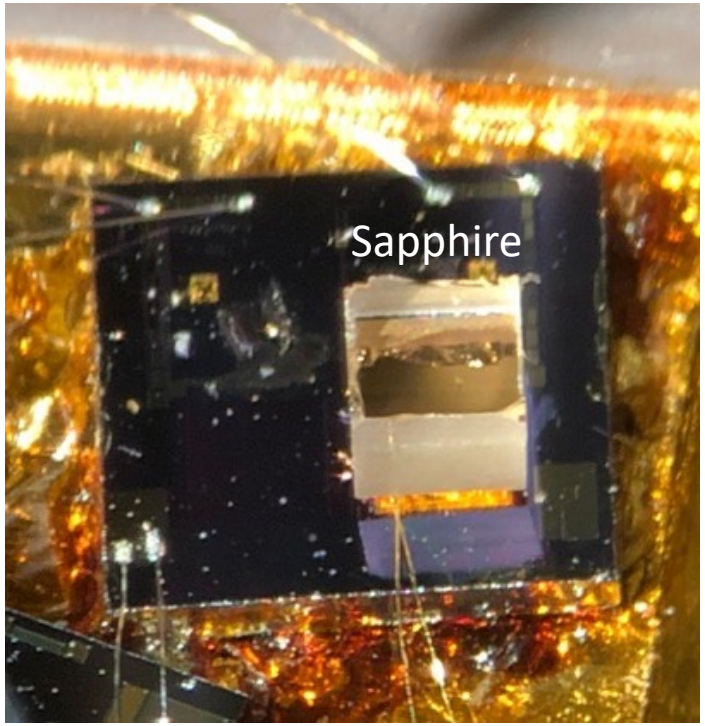
- Very promising result from non-optimal detector set-up
- Room for further improvement: SQUID noise (x5), prototype-like integrated set-up (x??)
- However, LEE reduction and ER/NR separation are still challanges

Toward Prototype



Magnetic sensor will be deposited like this



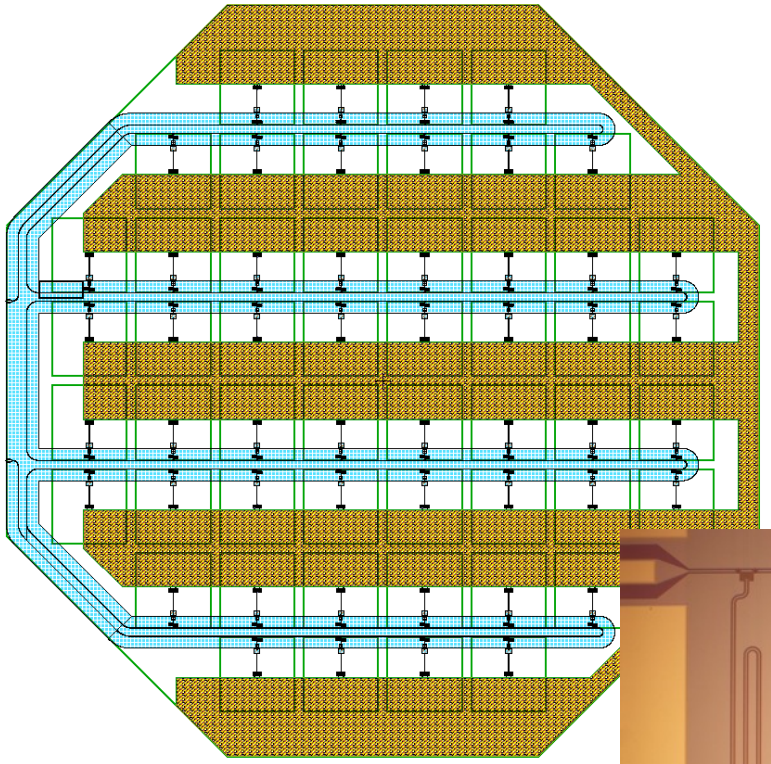


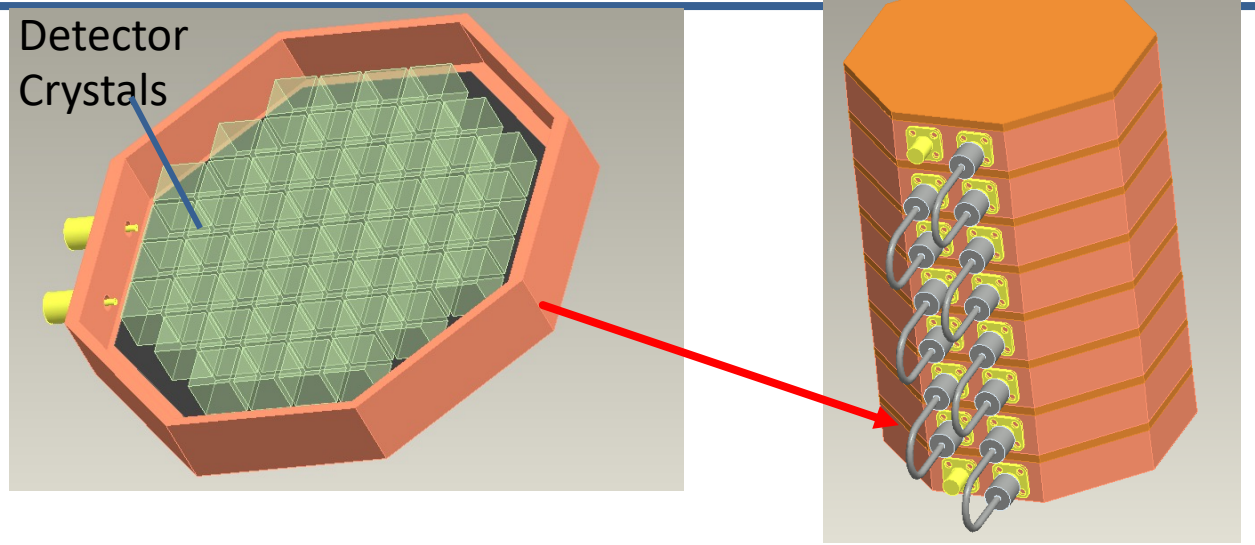
Prototype-like set-up

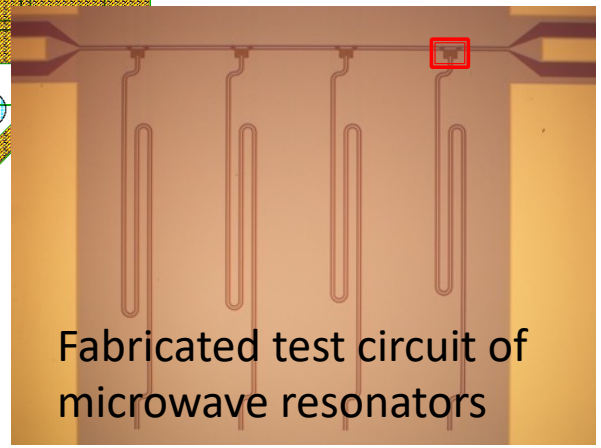
Scaling with Microwave Multiplexing

8 wafer stacks → 416 detectors by a single readout

4-inch wafer for 52 of 1cm^3 detectors







- >=1cm Spacing (4 inch wafer)
- Placing resonators adjacent to MMC sensors eliminates parasitic inductance, maximizes signal coupling
- For increased detector mass, shielded boxes are stacked and daisy-chained
- up to 8 boxes can be stacked using a single 4GHz HEMT readout channel
  - ~2.1kg with 0.73 cm^3 BGO as shown here

Summary

- MAGNETO-DM is to develop large array sub-GeV dark matter detectors using MMC-based fast athermal phonon sensors for phonon pulse shape discrimination (PSD).
- Three R&D thrusts: Sensor optimization, crystal selection, and multiplexing.
- Poly-crystal CVD (diamond) crystal exhibited excellent performance in athermal phonon sensing. 70 eV energy threshold (preliminary) and 80 eV FWHM resolution @ 8 keV were obtained.
- Prototype detector is being built (~2024) for improved detector performance and better phonon PSD.