Phonon Tracking for the Cryogenic Dark Matter Search

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The Cryogenic Dark Matter Search

- CDMS searches for evidence of dark matter

- WIMP dark matter may deposit energy in ordinary matter via nuclear recoils

- In semiconductor crystals, nuclear recoils can be discriminated from electron recoils

- CDMS is situated deep underground to reduce the cosmogenic neutron flux

Soudan underground lab, Minnesota.
Depth: 0.7 km (2020 mwe)

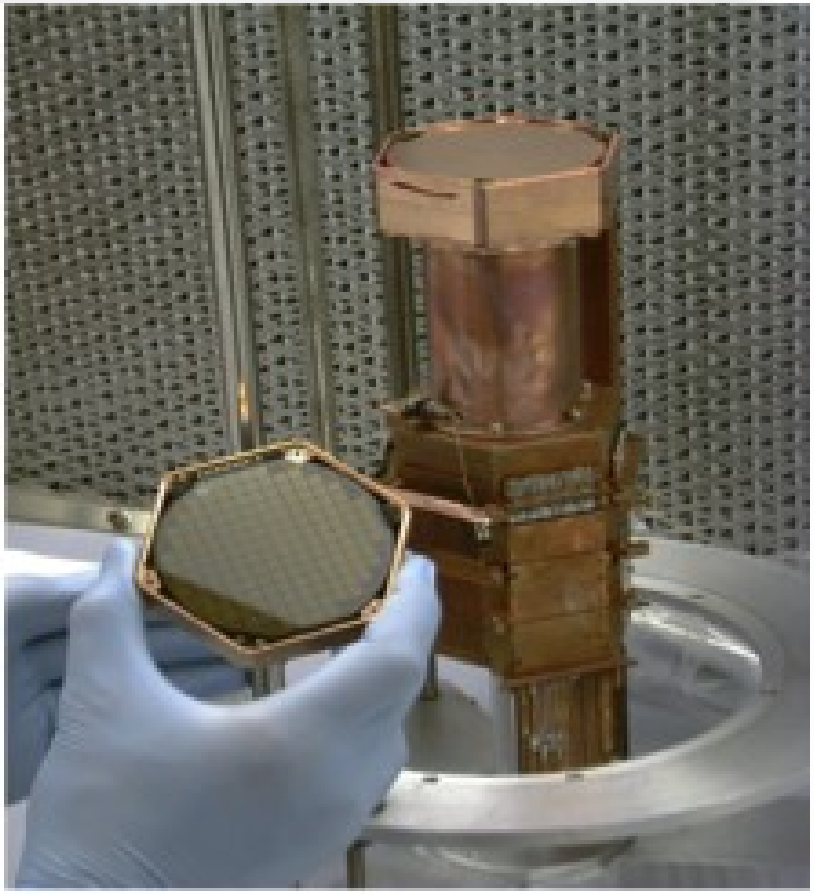
A simulation to support CDMS

- Project motivation: build a Monte Carlo model for CDMS which includes detector and background simulation

- CDMS detector concept similar to many rare event searches: large absorber crystal with cryogenic detectors

- Simulate e^-/h^+ pairs and phonons in absorber

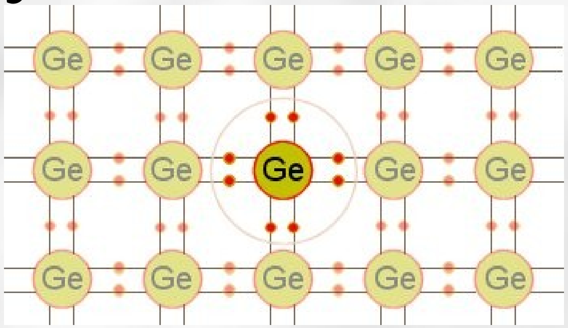
- The same Monte Carlo model may be applicable to other experiments



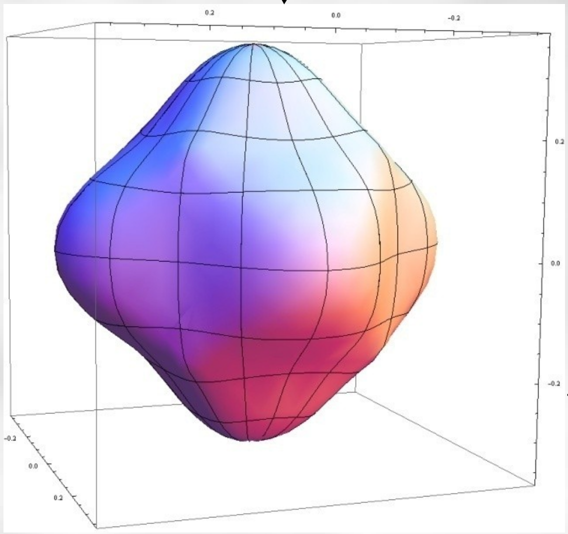
A CDMS detector in its housing

Image taken from http://cdms.berkeley.edu/

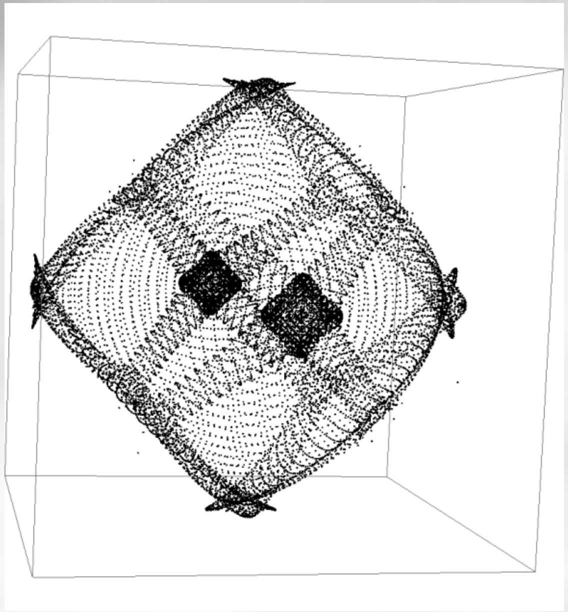
Crystal structure in geant4 - I



Solve for eigen-vectors of 3 dimensional wave equation

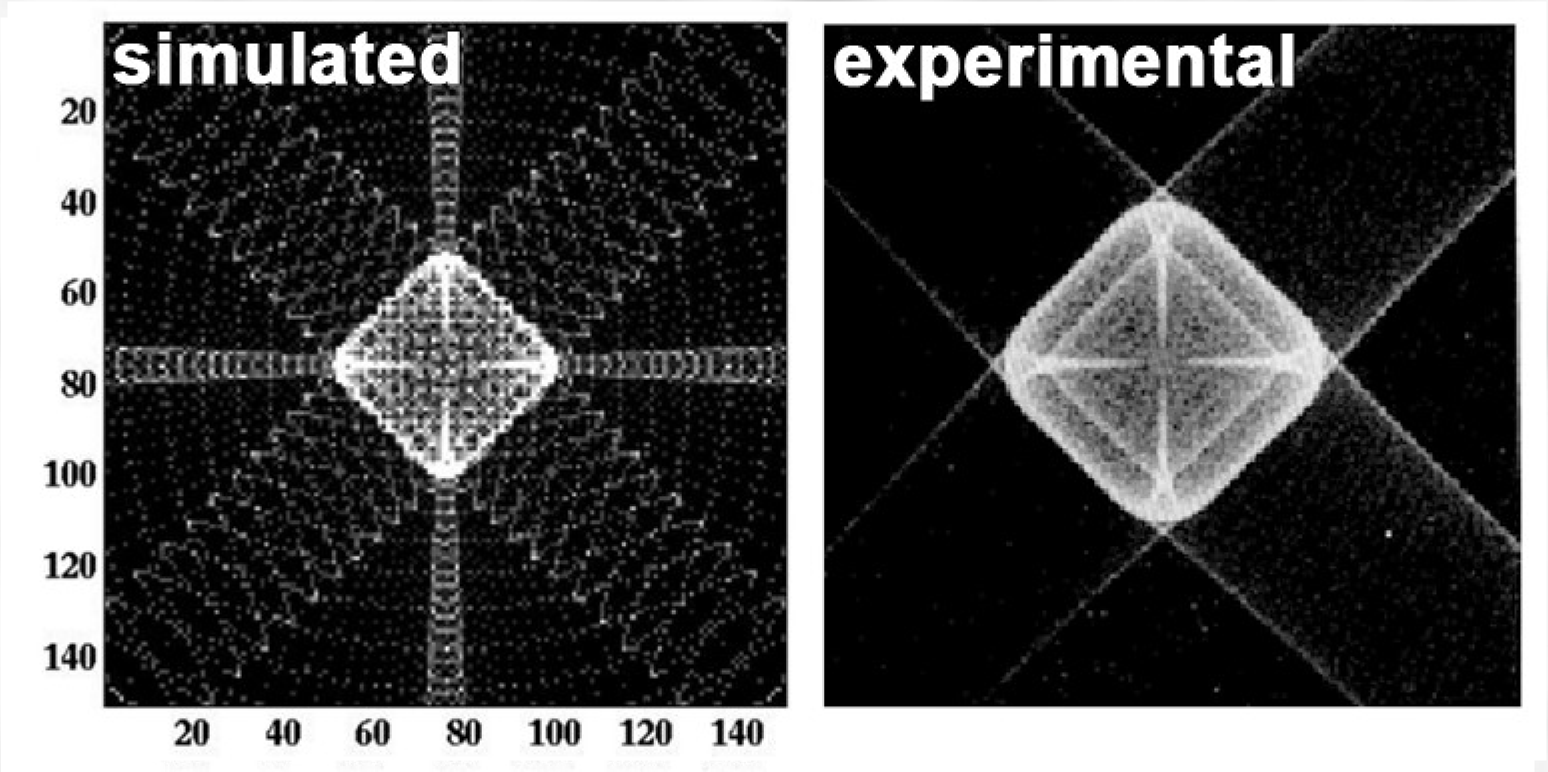


Gradient of slowness surface yields group velocities



Phonon focusing

Anisotropies in the elasticity tensor lead to phonon focusing into complicated intensity patterns.



Phonon flux intensity on a Ge crystal face resulting from a point source at the crystal center.
Left: *simulated with geant4* ***Right:*** *as observed by Nothrop and Wolfe*

Crystal structure in geant4 - II

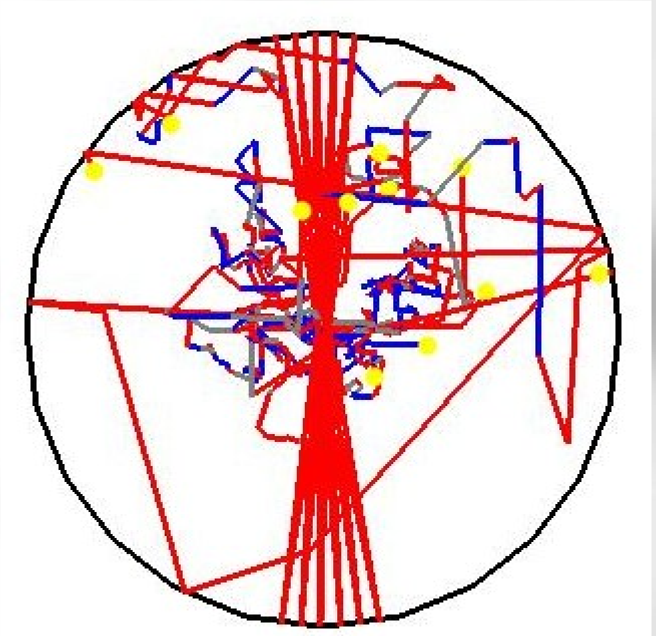
•*LogicalLattice* holds information about elastic constants. *PhysicalLattice* links these to a physical volume. Static *LatticeManager* manages access to lattices.

```
LogicalLattice logical(initialization constants);
PhysicalLattice physical(G4VPhysicalVolume*, LogicalLattice*);
LatticeManager::registerLattice(PhysicalLattice*);
```

•*G4Track* has been modified similarly to optical photons, to allow mapping of k-vector to group velocity.

```
G4Track::GetVelocity() { ...
        If(is_phonon){
                G4ThreeVector kVector=this->GetUserInformation()->getK();
                return LatticeManager::mapKtoV(fpTouchable->GetVolume(), kVector);
        }
```

Simulating phonon propagation

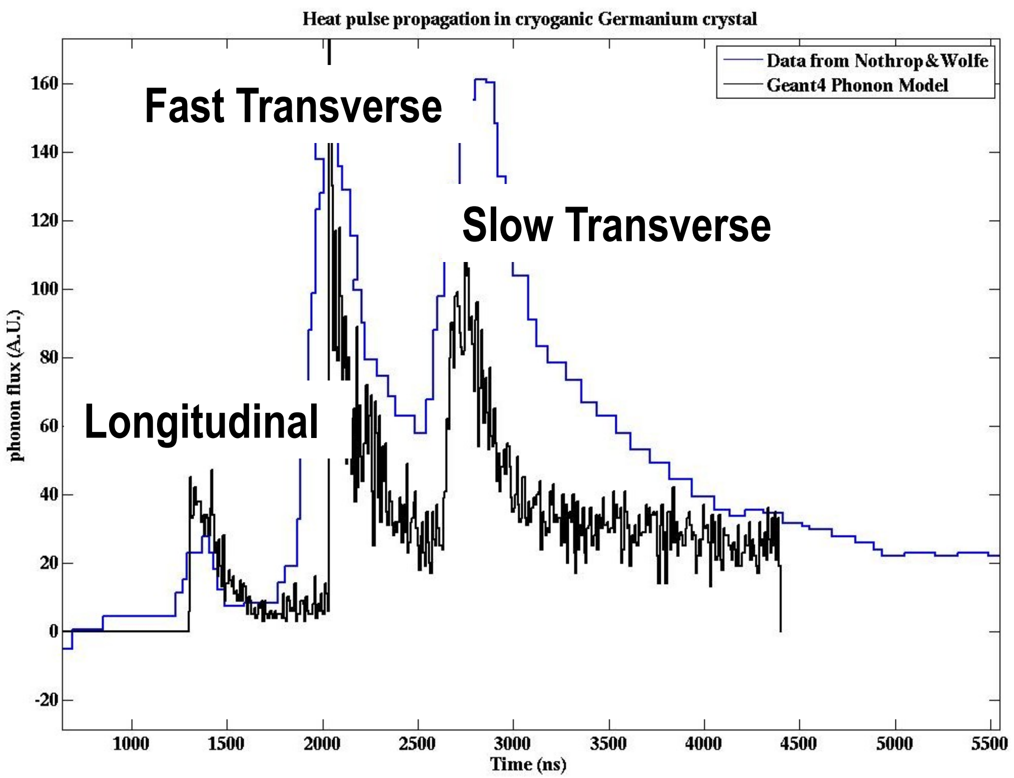


Phonon trajectories in a 75 mm Ge crystal, simulated with geant4. Trajectory color indicates polarization state, dots are absorbtion events.

- Phonons of different energies have vastly different mean free paths

- Down conversion causes phonons to change mean free path dramatically

Validating phonon transport code

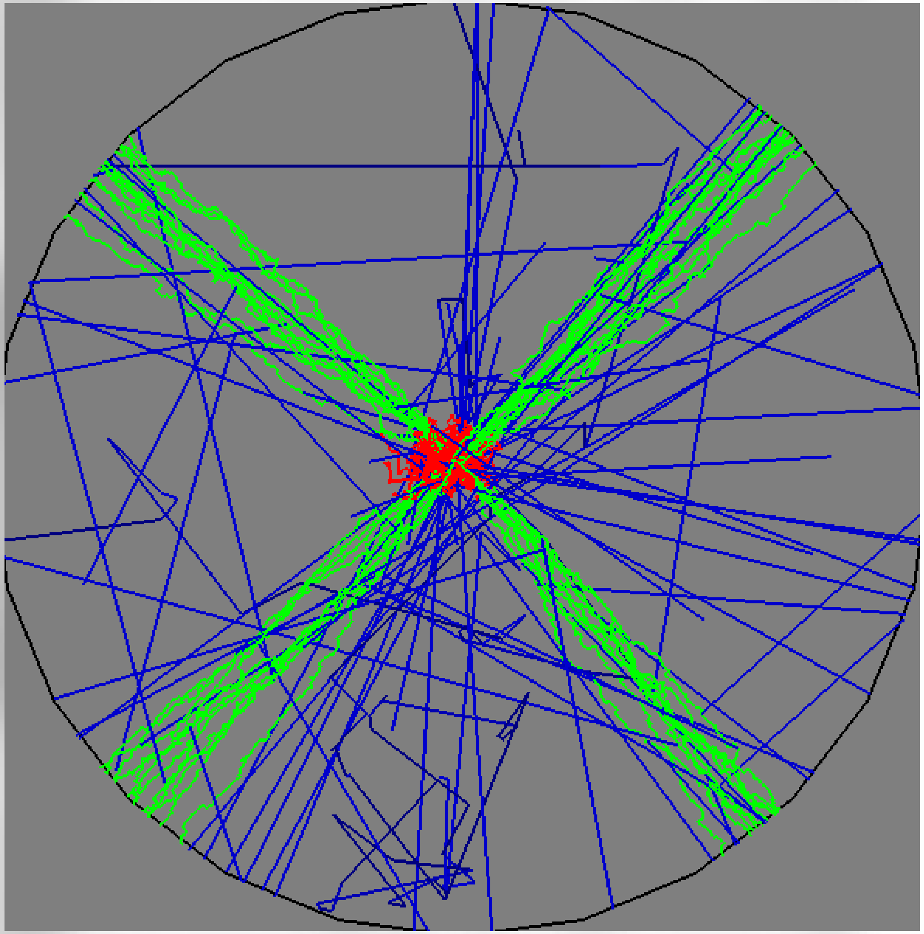


Phonon flux timing histograms, simulated (black) and observed by Nothrop & Wolfe (blue)

- Heat pulse propagation through a crystal is a good test of phonon transport model
- Simulated heat pulse reproduces three peaks
- Simulation yields right branching ratios
- Discrepancies in onset time and Slow Transverse fall off are due to laser pulse shape and e^-/h^+ recombination

Charge transport

- Charge transport is in the form of drifting electrons and holes
- Subclass *G4FieldManager* and *G4EquationOfMotion* to allow for anisotropic charge transportation in crystals
- Charges moving at the speed of sound emit phonons – crystal equivalent to Cerenkov radiation



Signal propagation in Ge.
Electric field direction into the page.
Red=hole, green = electron, blue = phonon

Summary

•A Monte Carlo simulation is under development for phonon and charge transport in cryogenic crystals, constituting the first solid state physics framework in geant4.

•The phonon transport code has reached the validation stage and simulated data shows good qualitative agreement with observation

•Other cryogenic detector experiments have expressed an interest in using the framework

•It would be a great help if G4Track allowed subclassing or other access to GetVelocity so our framework can be used without recompiling geant4