Report from RISQ G4CMP Workshop Day

Ryan Linehan - Fermilab Cosmic Physics Center, Quantum Science Center

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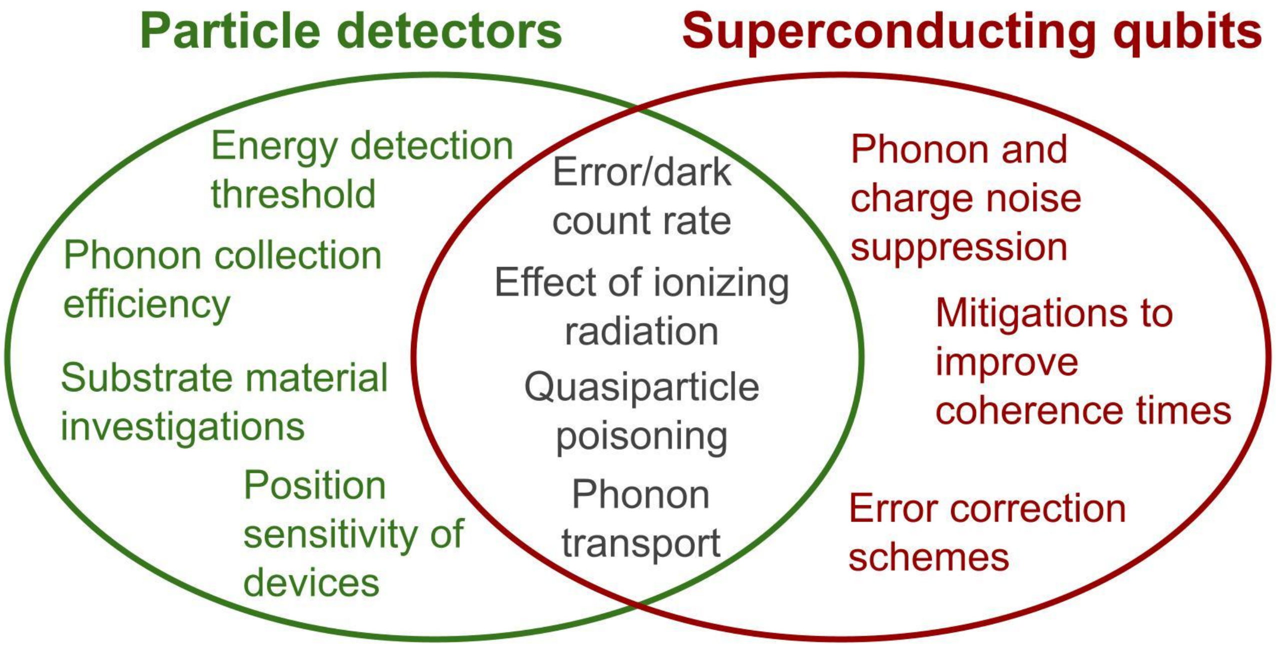
Context

Several shared problems between building cryogenic particle detectors and building superconducting quantum computing hardware:



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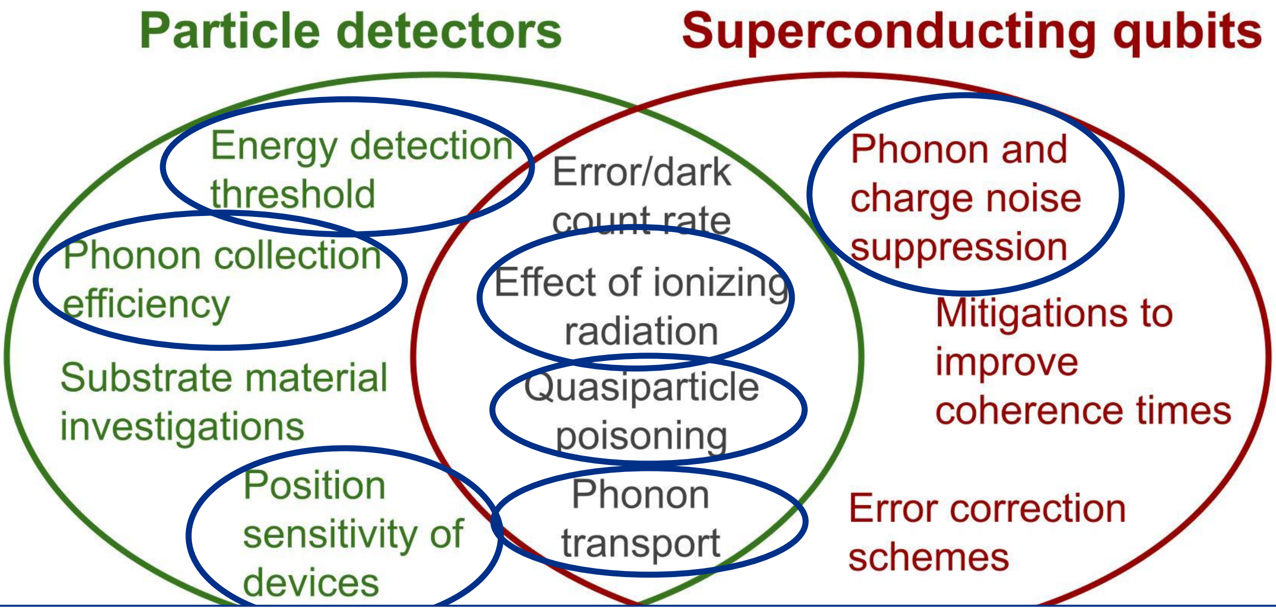


We see places where simulation tools traditionally used in the high-energy particle physics community (Geant4) can be extended to help better understand some of these effects.

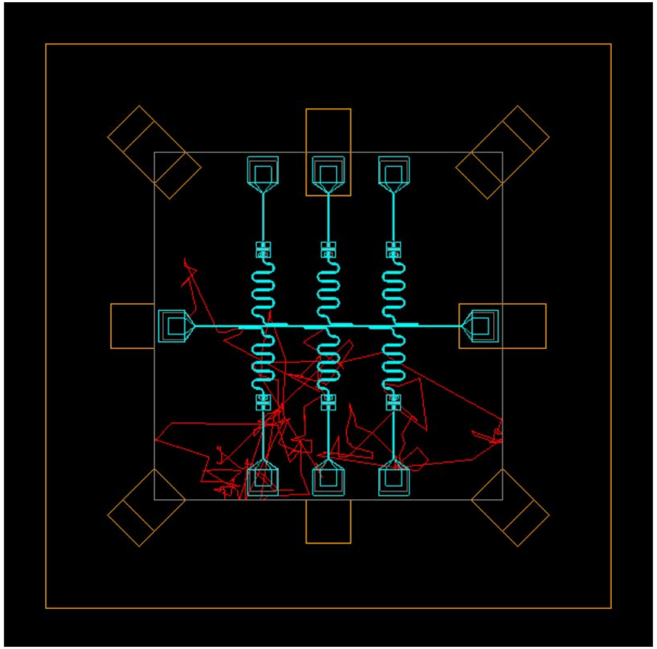
What is G4CMP?

Geant4 Condensed Matter Physics: code package for particle-tracking-style simulation of low-energy physics phenomena in cryogenic devices.

Current capabilities:

- Supported for Ge and Si
- e/h production, transport within crystal
- e/h scattering and radiation of phonons under applied field
- e/h trapping, recombination
- Acoustic phonon propagation: diffusive and ballistic (~meV scale and above)
- Acoustic phonon downconversion, isotopic scattering
- Coarse handling of Bogoliubov QP processes (pairbreaking, phonon radiation, etc.)

Simulation of a six-transmon chip in G4CMP

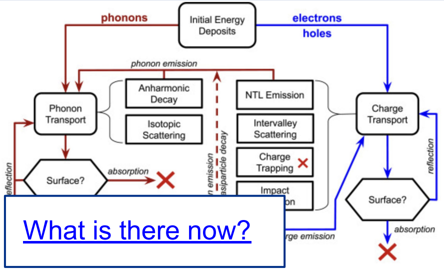


5 meV

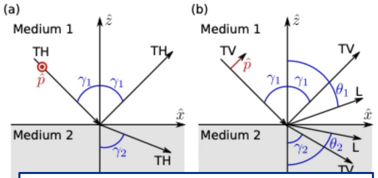
(Phonon energy launched in chip)

What did we discuss yesterday?

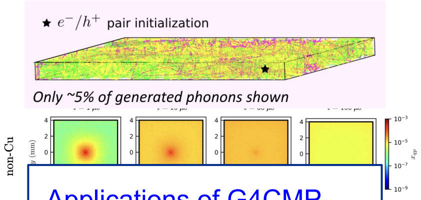
Indico page link



What is there now?

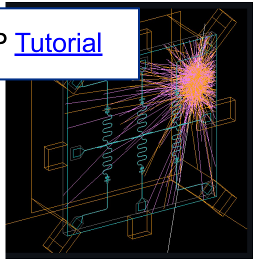


What needs to be added?

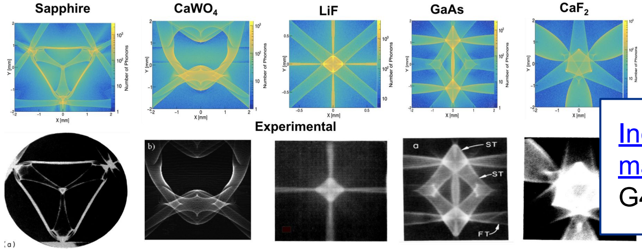


Applications of G4CMP

Morning session: G4CMP's capabilities, applications, and wishlist

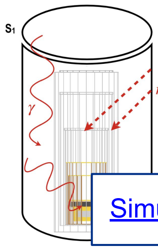


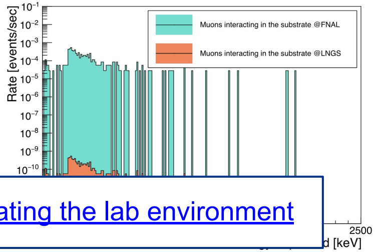
G4CMP Tutorial



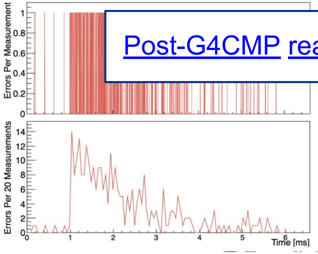
Incorporating new materials into G4CMP

Early-afternoon session: "How to get started:" advanced tutorial and how get some of the quantities we need to simulate materials

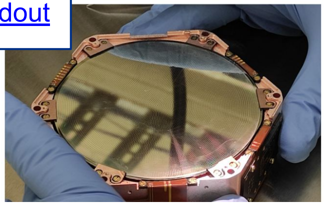




Simulating the lab environment



Post-G4CMP readout



Late-afternoon session: Auxiliary tools: detector response code and community organization around those

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Physics Interests: Discussion

Materials

New substrate materials

- Common QIS materials: sapphire, etc.
- Common DM materials: GaAs, $CaWO_4$, etc.
- What are other relevant materials for QIS? For sensing?
- How do we do quanta propagation (phonons, e/h, photons) in these?

Multiple superconducting materials/thicknesses on same chip

- What is a generalizable way to do this?

Processes

3D Quasiparticle Tracking

- Phonon pairbreaking, QP diffusion, phonon radiation, recombination
- How do we get this to run in finite time?
- Once tracking is running, how do we include engineered QP traps/barriers?
- How much should we care about n2 recombination (hard for G4)?

Photon interactions in substrates and superconductors

- What are the most relevant processes to model?
  - Photon emission/reabsorption in substrate?
  - QP recombination into IR photons?
- Which to prioritize? How to get into G4CMP?

How can we reasonably model large energy depositions?

- Downsampling! (Where does this work best?)
- Adaptive QP tracking (integrating boltzmann solvers into G4 paradigm)

For which processes and applications is G4CMP the right tool?

- Where to draw the line? At the substrate/SC interface?
- For what devices/conditions is QP tracking more advantageous than Boltzmann solvers?
- Dynamic charge/field environments hard to model within G4CMP – how best to handle these for people that need it?

G4CMP advantageous in handling feedback cycle between SC layer and chip.

Community Organization: Discussion

Technical organization: How can we bring resources together to minimize work and standardize simulations tools?

Want general repository/project providing a location for:

1. Core G4CMP code
2. Fridge+environment simulation tools: geometries, sources, simulation strategies
3. Post-processing of G4CMP output: readout chains

Administrative organization: How do we self-organize to ensure long-term support for these simulation tools?

Lots of discussions, with some broad questions:

1. To what degree should we establish a steering committee to organize prioritize development work? What is the structure for collaborating between different user groups?
2. Institutional support for G4CMP seems helpful – to what degree should we find a “host” institution?
3. How are we incentivized to collaborate and work on features even when a feature is not exactly what I need for my physics right now?
4. How can we optimize approach to funding opportunities to financially support development/maintenance?
5. Discussions must continue!

Current next steps:

- Establishing mailing list for interested parties to increase centralized dialogue about self-organization
- Short term, make code development task space (JIRA) accessible to non-CDMS folks
- Long term, figure out best way to establish new Github organization to achieve goals

Conclusions

- Lots of progress on developing low-energy simulation tools for QIS/Sensing!

- Lots of progress on self-organizing to support these tools

- If you have any interest in using these tools or joining in these discussions, please come talk to me!