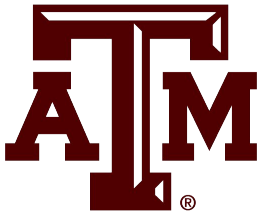
# Texas A&M Activities for G4CMP ARO Grant



David Toback, Iman Ataee-Langroudy, Michael Kelsey,
Wade Lamberson, Dylan Monteiro, Nolan Tenpas

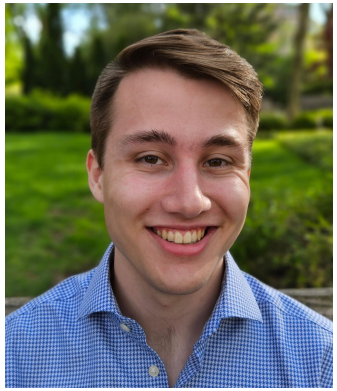
*ARO Program Manager Visit, SLAC, 11 Dec 2025*

Prof. David Toback
Principal Investigator

Michael Kelsey
Senior Research Scientist

Iman Ataee-Langroudy
Graduate Student

Wade Lamberson
Graduate Student



Dylan Monteiro
Graduate Student

Nolan Tenpas
Graduate Student

# Texas A&M Group

A&M has a large group with a long history of G4CMP leadership and development for both dark matter detectors and QIS

- Development and ongoing support of G4CMP by Kelsey supports both the SuperCDMS simulation effort and QIS device design and simulation

Four graduate students currently involved at various levels working on their degrees under the supervision of Toback

- Ataee-Lagroundy is completing his Ph.D. thesis soon
- Lamberson is completing his ramp-up as a full-time expert

# Outline of A&M Activities

Overall G4CMP management, releases

Consultation for QIS community members

Migration to Geant4 11

Charge transport and surface interactions

Phonon surface modes (creation and pseudo-transport)

Theoretical calculation of phonon normal modes

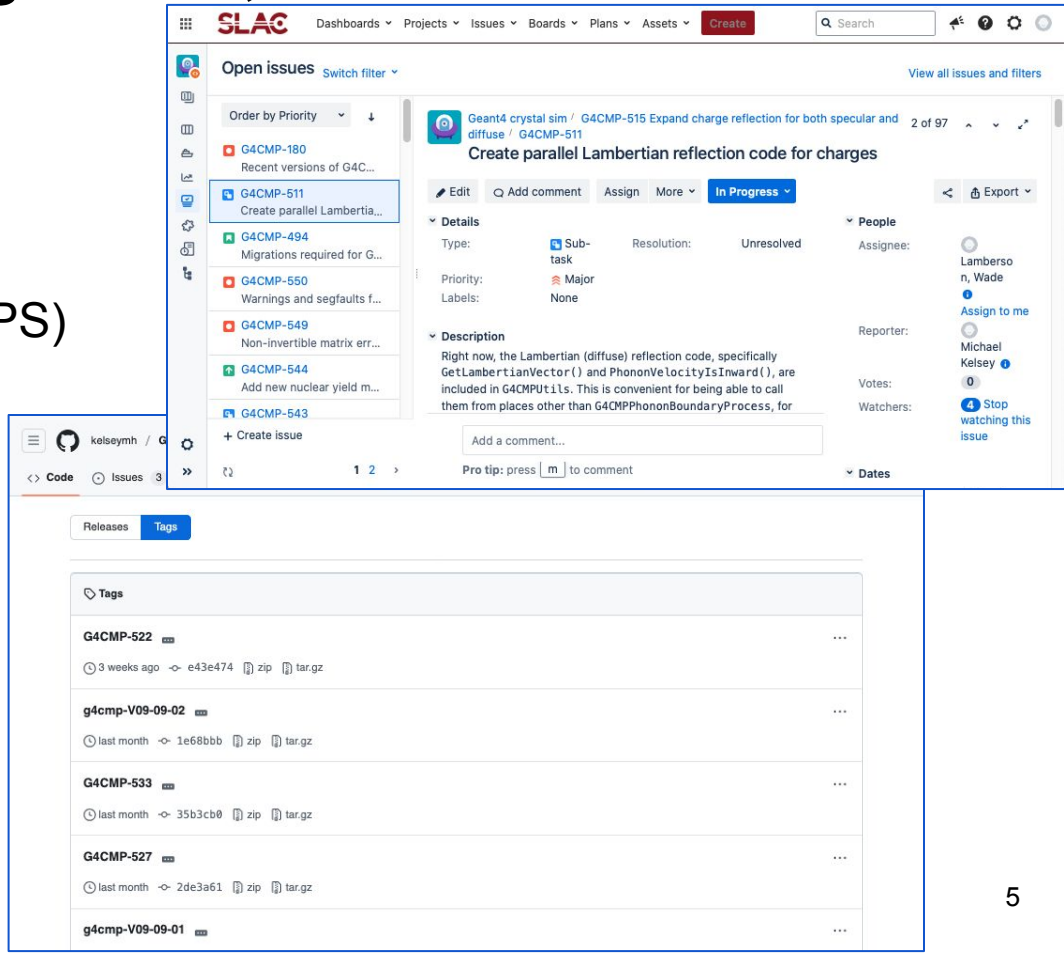
Dominant G4CMP issues for decoherence

# Overall G4CMP Management, Releases

**Kelsey** (Senior Research Scientist)

- JIRA ticketing system
  both bugs and new features
- Coding guidelines (Yamaoka, LPS)
- Code reviews before integration
- Single line of development
  feature → develop → main
- Frequent (1-2 month) releases

Software reviews usually include experienced G4CMP developers



# Consultation for QIS Community Members

## Kelsey

We provide guidance and suggestions on how to use G4CMP for several QIS investigators, and will continue to do so

- Spin-qubit systems, with charge transport (Lutz, Sandia)
- Modeling of MKID sensors (**Kurinsky**, **Dang**, SLAC)
- Phonon propagation across thin films (Hebenstiel, IU)

As a member of the Geant4 Collaboration, Kelsey has also acted as a liaison with Geant4 experts to improve overall simulation performance, migrate to G4 11, etc.

# Migration to Geant4 Version 11

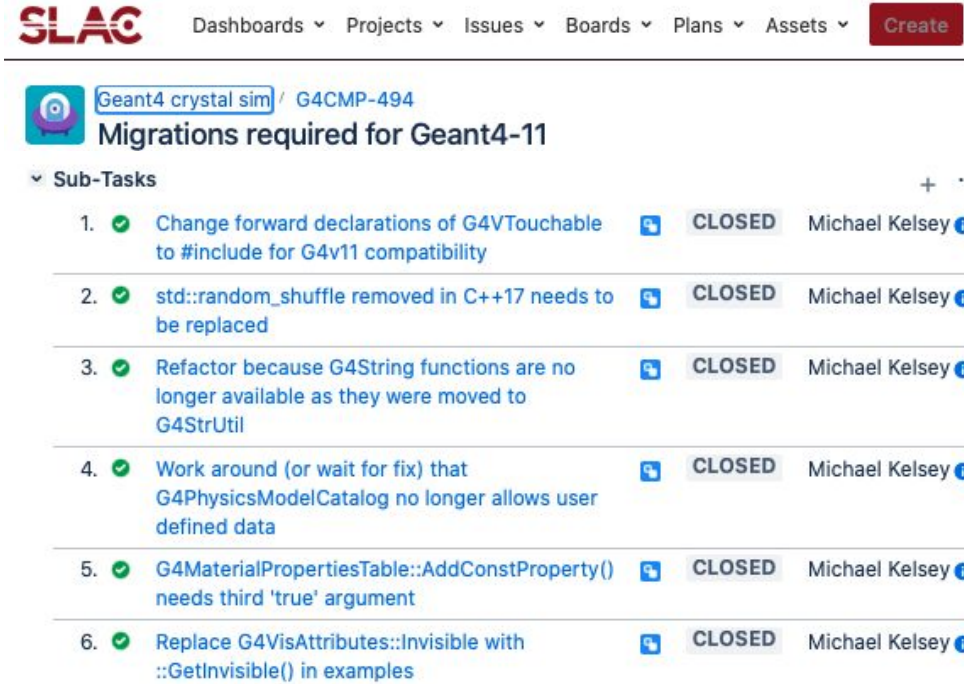
Inman (PNNL), Johnson (LLNL), **Kelsey**, **Linehan** (NW), **Zatschler** (SNOLAB)

G4CMP compatible with Geant4 10.07.p04, ~4 years past end of life

Support for Geant4 11.3.2 (11.4.0) strongly desired by QIS community

Required nine modification to code (tracked with JIRA tickets)

- G4String/G4StrUtil, G4VTouchable, MPT, std::shuffle, ParticleChange, G4VisAttributes
- G4PhysicsModelCatalog apparent blocker being resolved with patches on Geant4 side
- Additional issues identified and resolved with runtime testing



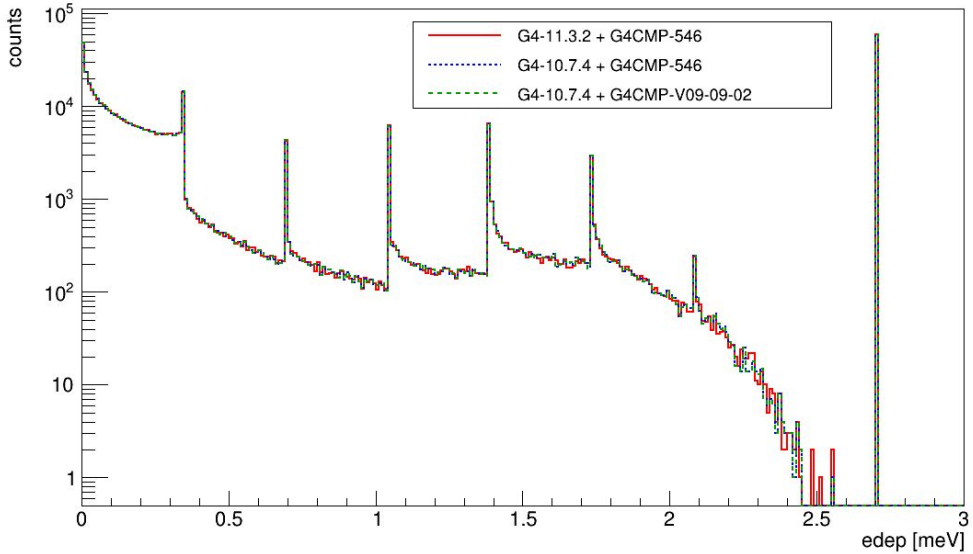

All modifications implemented to be compatible with both G4 v10 and v11

# Migration to Geant4 Version 11

Tested using G4CMP Phonon example

- Last release tag with 10.07.p04
- Migration branch with 10.07.p04
- Migration branch with 11.3.2

Results statistically identical (G4 v11 has slightly different random sequence)




Histogram shows energy absorbed by aluminum QET fins on surface of detector: spikes at 2Δ, 4Δ, 6Δ, 8Δ, 10Δ, 12Δ. Primary 2.8 meV phonons and phonon < 2Δ can be absorbed directly by tungsten TES

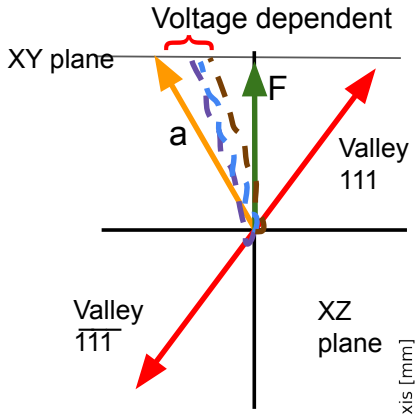
# Charge Transport Intervalley Tuning

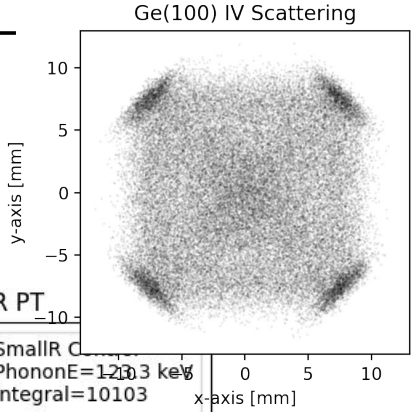
**Ataee-Langroudy**, **Monteiro** (Graduate Students)

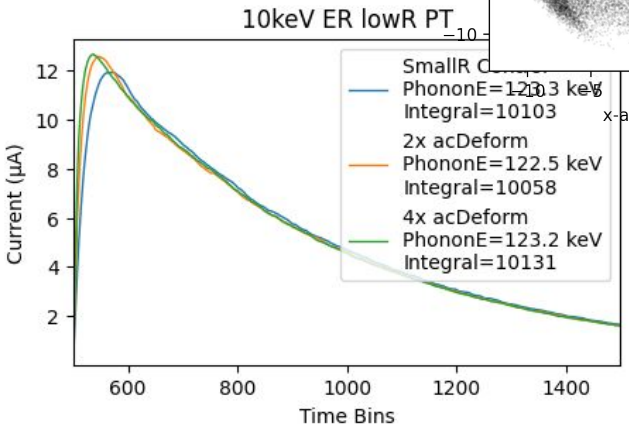
Ataee completed a major revision of physics-based electron transport and scattering in 2024

- Completing his thesis in next month
- Will publish as a short paper after

Monteiro is validating and tuning physics-based intervalley scattering model (**Michaud**/SNOLAB)



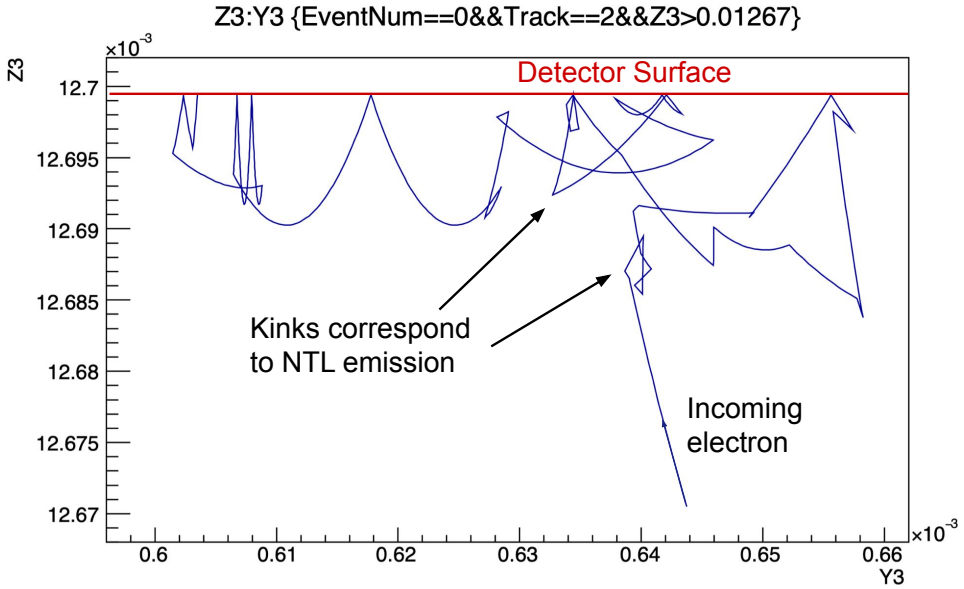
# Charge Carrier Surface Interactions

**Kelsey**, **Lamberson** (Graduate Student)

Enable charges to reflect off surfaces

Electron reflection has non-trivial effects due to valleys and anistropic mass tensor

Lamberson working on improving model for charge reflection under these conditions.




Upcoming: incorporate charge recombination in crystal bulk, when charge momentum drops below threshold for NTL emission (complicated with E-field!)

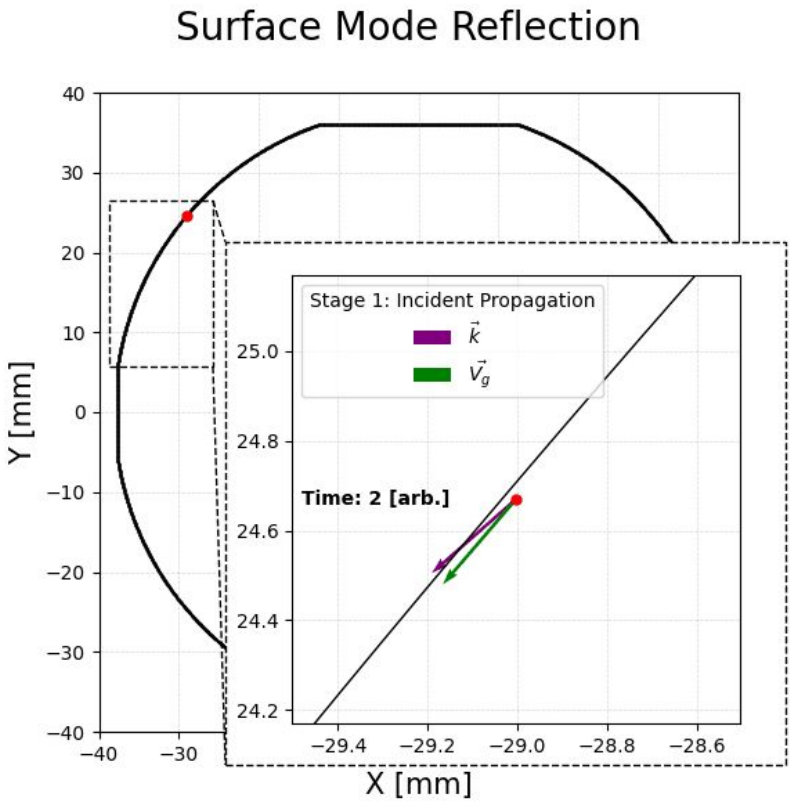
# Phonon Surface Modes

**Lamberson**, **Tenpas** (Graduate Student)

Phonons reflection at polished surfaces can fail

Dispersion relation may direct group velocity (Vg, **green**) out of crystal, even if reflected wave vector (k, **purple**) is inward

Developed and deployed a comprehensive framework to handle this, emulating surface mode as displacement of position to where Vg is inward




Note: All vectors have been scaled equally for visual effect

# Phonon Surface Splitting

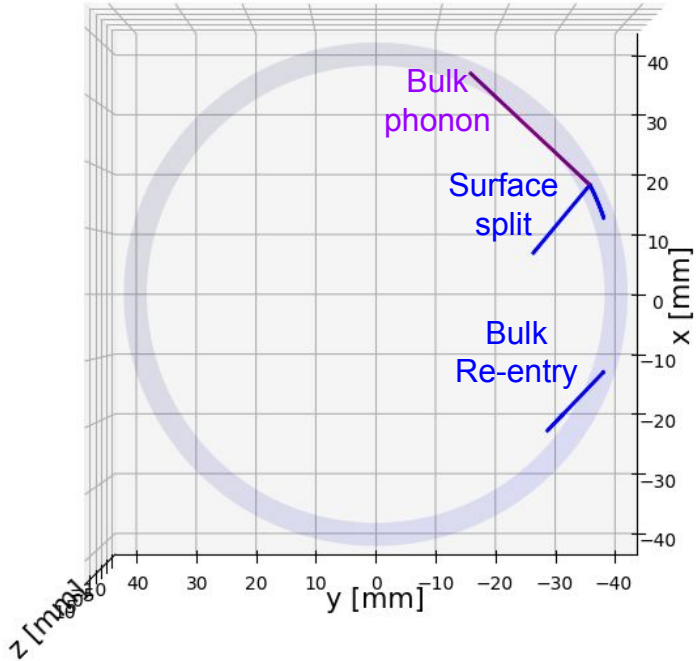
**Lamberson**, **Tenpas**

Converting phonons to and from surface modes is not physically correct, should be $B \rightarrow B\,R$

Surface mode energy would be $\mathcal{O}$(neV) vs. $\mathcal{O}$(meV) for bulk phonons:  not worth implementing?

Considering computing "lost" energy as part of diffuse scattering

Would make some event-level sanity checks (e.g., $E_{expected}$ vs. $E_{collected}$) more difficult




*CDMS-style crystal viewed from above*

# Calculation of Phonon Normal Modes

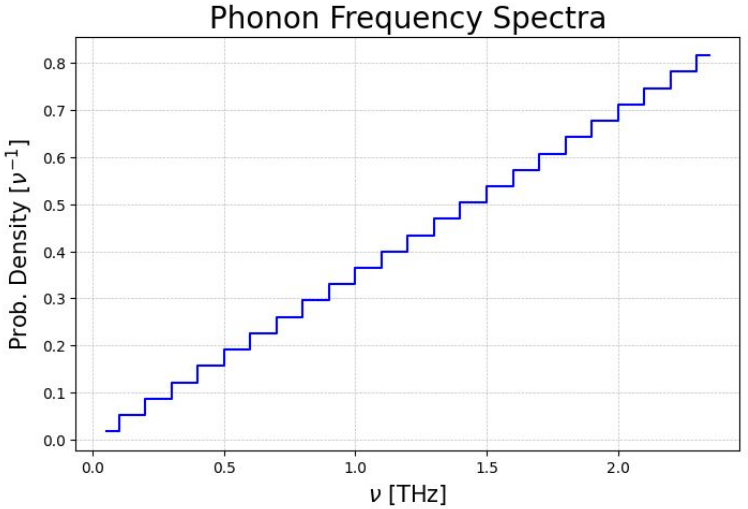
## Tenpas

Working with Prof. Valery Pokrovsky (A&M) to complete an analytical 3D calculation of phonon normal modes in a cylindrical detector (CDMS-style)

Includes the full stiffness matrix formalism and phonon dispersion relations to obtain energy spectra and limits

This work (paper in preparation) significantly improves our grounding in theoretical dynamics of phonons in crystals

Gives us insight into physically motivated boundary conditions, distribution functions, and spectra (PDFs) for G4CMP processes



# Dominant Issues for Decoherence

## Lamberson

Identifying the dominant issues related to qubit decoherence effects which should be simulated or simulatable with G4CMP

- Time-Dependent Quasiparticle Diffusion, Recombination, and Trapping in Superconducting Films (**Linehan**, G4CMP-219)
- Improved Modeling of QP Generation at Substrate-Superconductor Interfaces (Golwala/Caltech, G4CMP-331, G4CMP-332)
- Gap Engineering and Variable Superconducting Properties, Additional Materials (**Linehan**)
- Non-Ionizing Phonon Sources from Mechanical Stress and Thermal Contraction (CDMS HVeV and others)
- Spatiotemporal Correlations and Large-Scale Device Geometries in QIS Arrays (**Linehan**, G4CMP-219 and RISQ Tutorial)

This study expected to be **Lamberson**'s Master's topic, and may become his Ph.D. topic

# Summary and Upcoming Work

G4CMP is fully functional and in use by an increasing number of groups

Contributions are well organized and tracked from request/report to deployment

Improvements to the physics of phonon and charge transport continue incrementally, along with significant new features (**Kelsey**, **Lamberson**, **Monteiro**, **Tenpas**)

Expect **Ataee**'s thesis on electron transport to be completed in next month

In the next few months, expect to complete work on charge reflection (**Lamberson**), evaluate effect on phonon arrival time distributions

Coordinating final integration of **Linehan**'s QP tracking and RISQ Tutorial

Develop **Lamberson**'s work on decoherence into a more concrete plan, identifying which issues are already in process, and which we should take on ourselves