# Charge transport in semiconductor crystals

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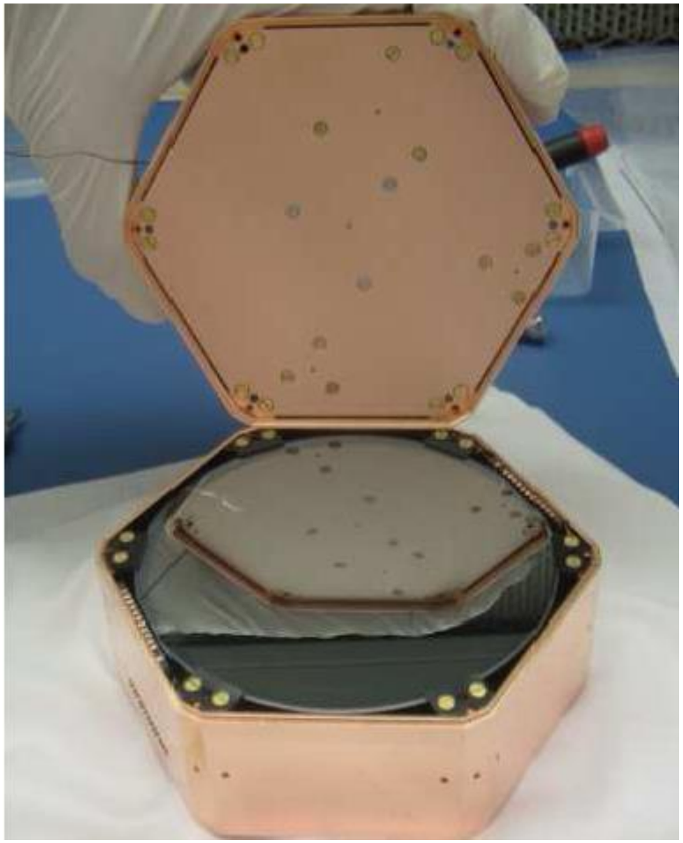
# Introduction



- The CDMS detectors are 100mm diameter Ge crystals
- At 50 mK there are no free carriers
- Particle interactions create free carriers (e- / h+)
- The low density of free carriers and absence of background phonons make charge transport very complicated

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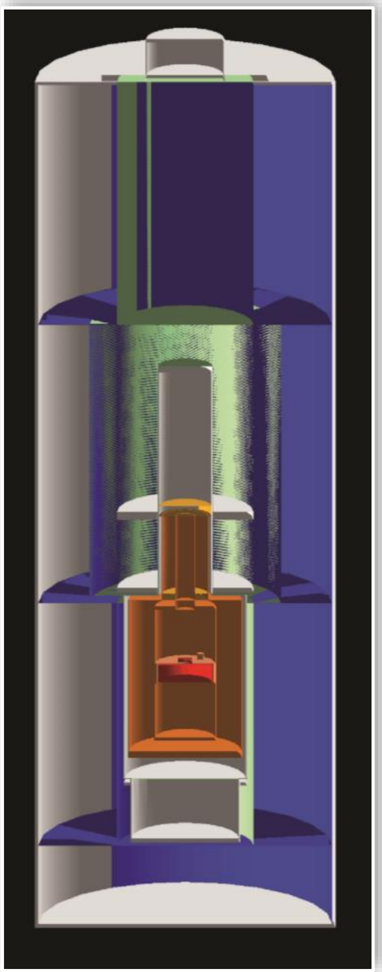
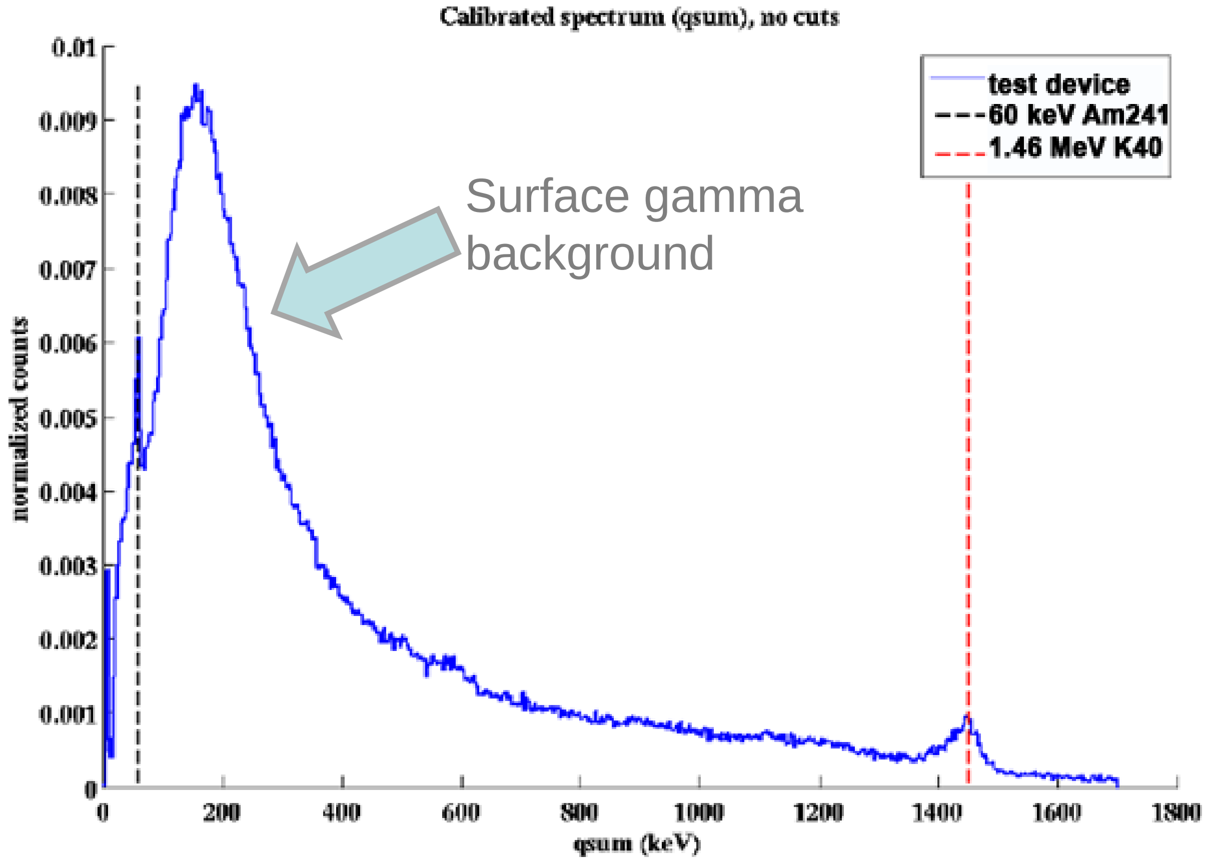
# Simulation of CDMS test facility

- Cryostat provides some shielding from lab background
- Background simulation implemented using the Geant4
- Simulation captures all major lab background sources
- ***Right:*** *Cryostat geometry at UMN surface test facility*



# Test device spectrum

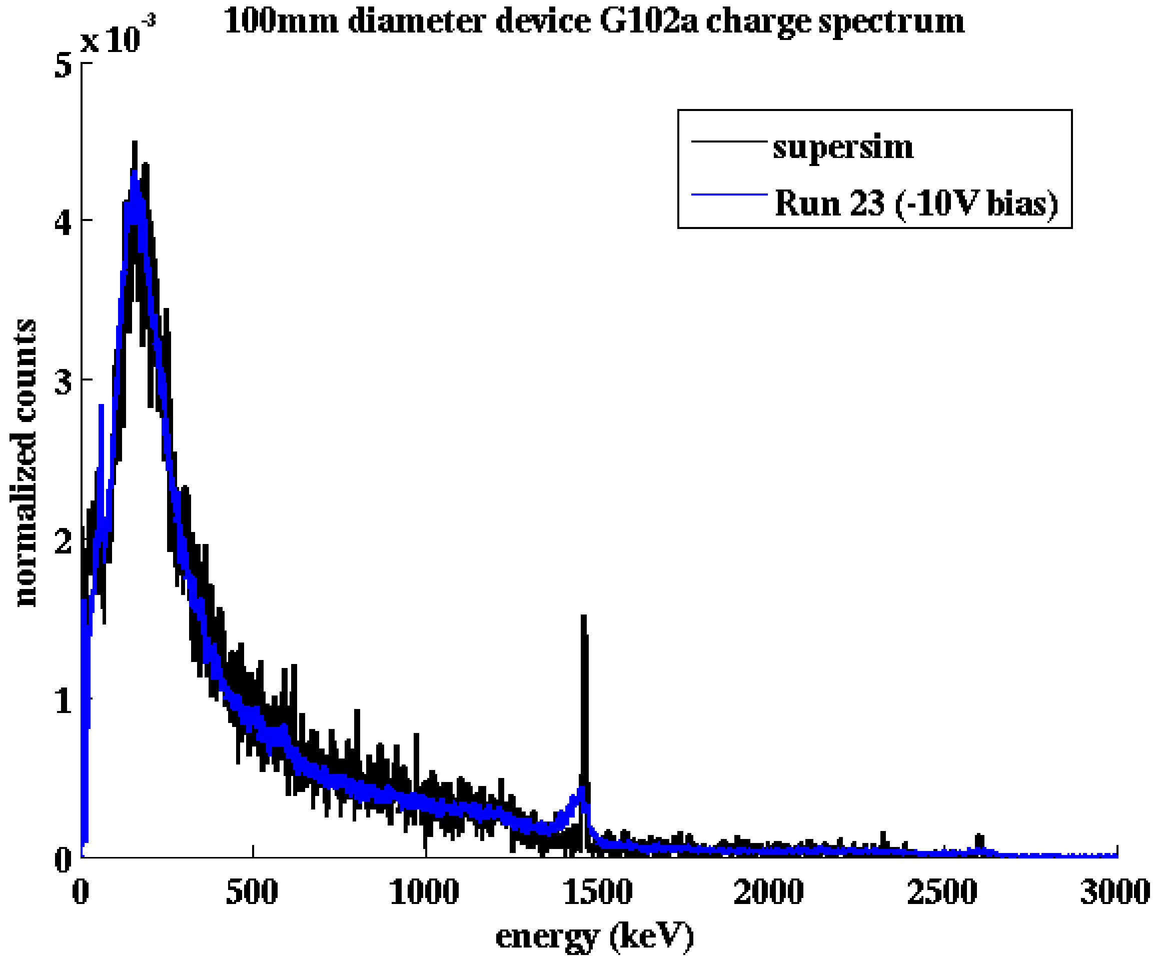
- Recorded spectrum using test device
- 60 keV Am241 test source was used
- Both the 60 keV Am 241 peak and a 1.46 MeV K40 peak are clearly visible




**Above:** *Charge spectrum recorded under -8V bias (blue) with 60 keV (black-dashed) and 1.46 MeV (red-dashed) features indicated*

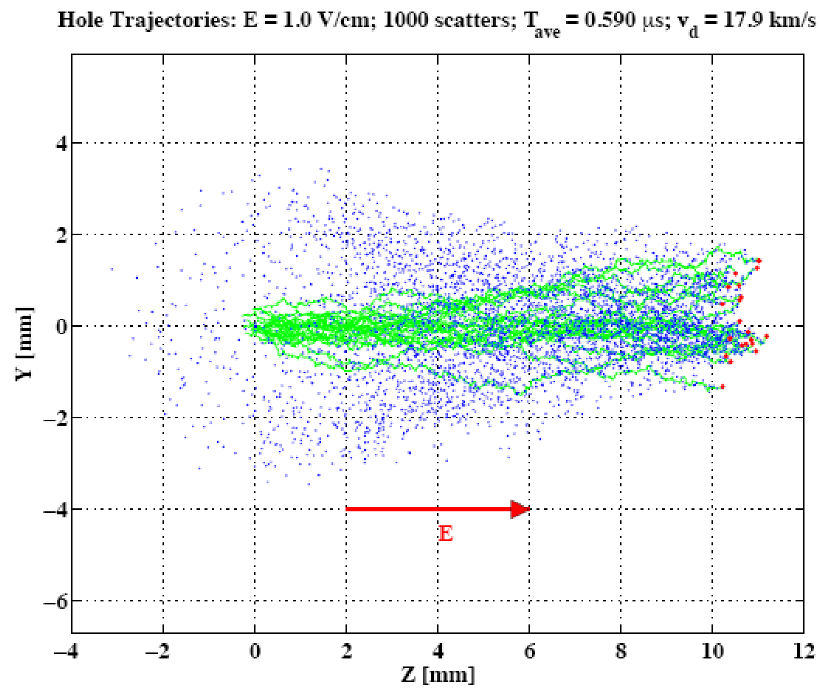
# Monte Carlo simulation of surface gamma spectrum

- Simulated and observed background spectrum are in good agreement (right)
- In order to capture broadening of K40 line, need detector simulation



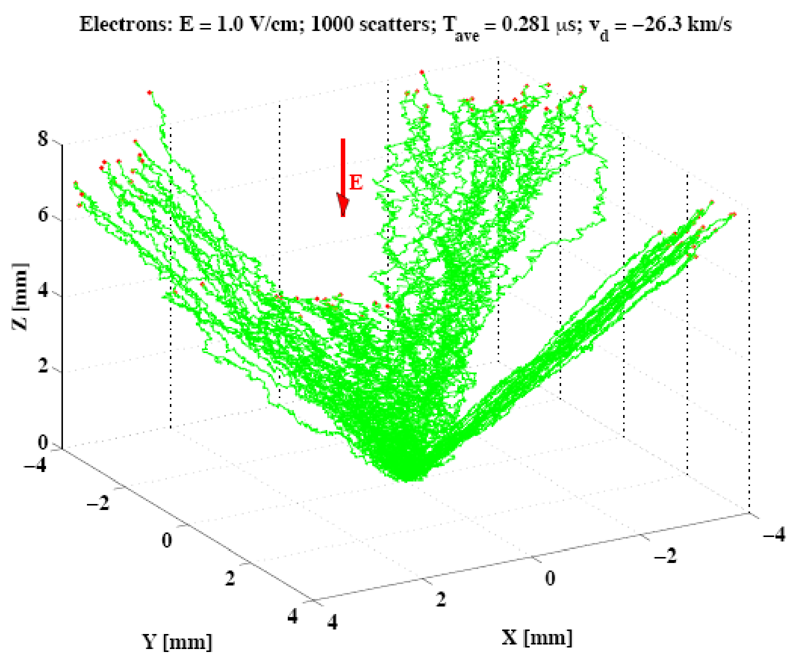
# Detector Monte Carlo simulation - I

- Capture all event physics:
  - e- / h+ propagation
    - Carrier scattering
    - Oblique propagation
    - Impurity trapping
    - Surface trapping
  - Phonon
    - Focusing
    - Down conversion
    - Emission by carriers




***Above:*** *Accelerated h+ (green trajectories) scattering and emitting phonons (blue). Image from Cabrera et al., 2010*

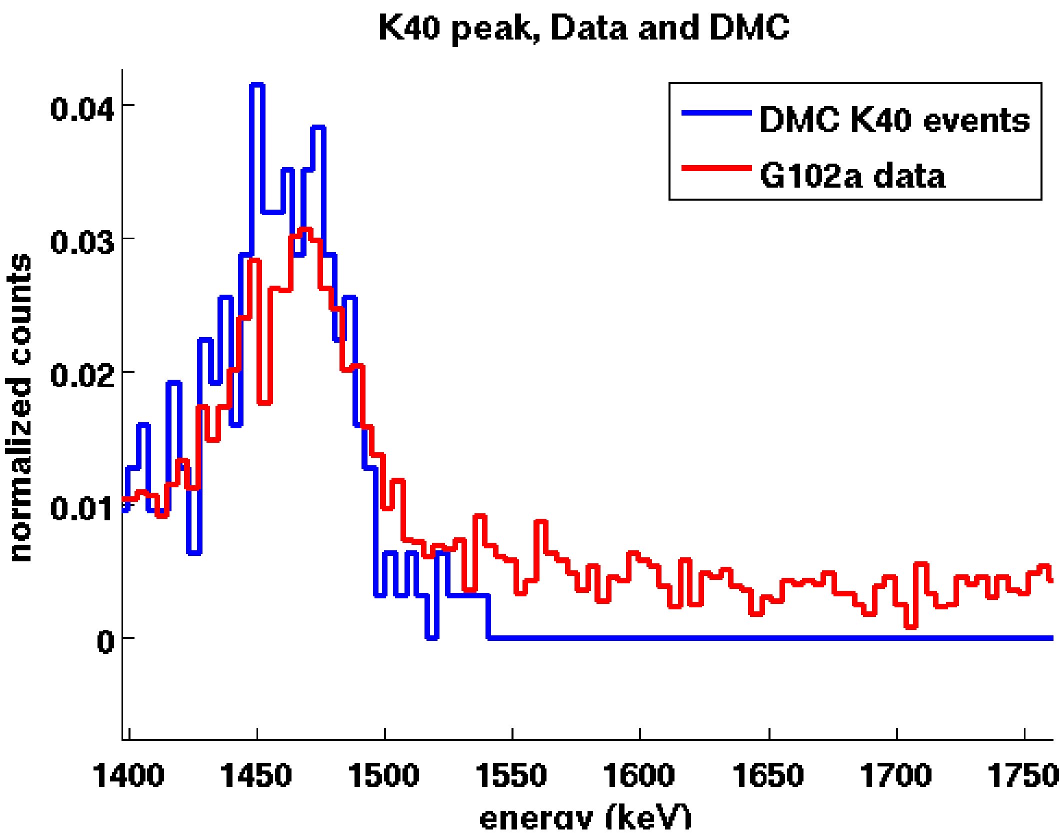
# Detector Monte Carlo simulation - II




***Above:*** *e- (green) propagating in different conduction band minima. Image from Cabrera et al., 2010*

- Conduction band is the energy vs. momentum relationship for e-
- The Ge conduction band is anisotropic at minimum
- Consequently e- mass appears anisotropic

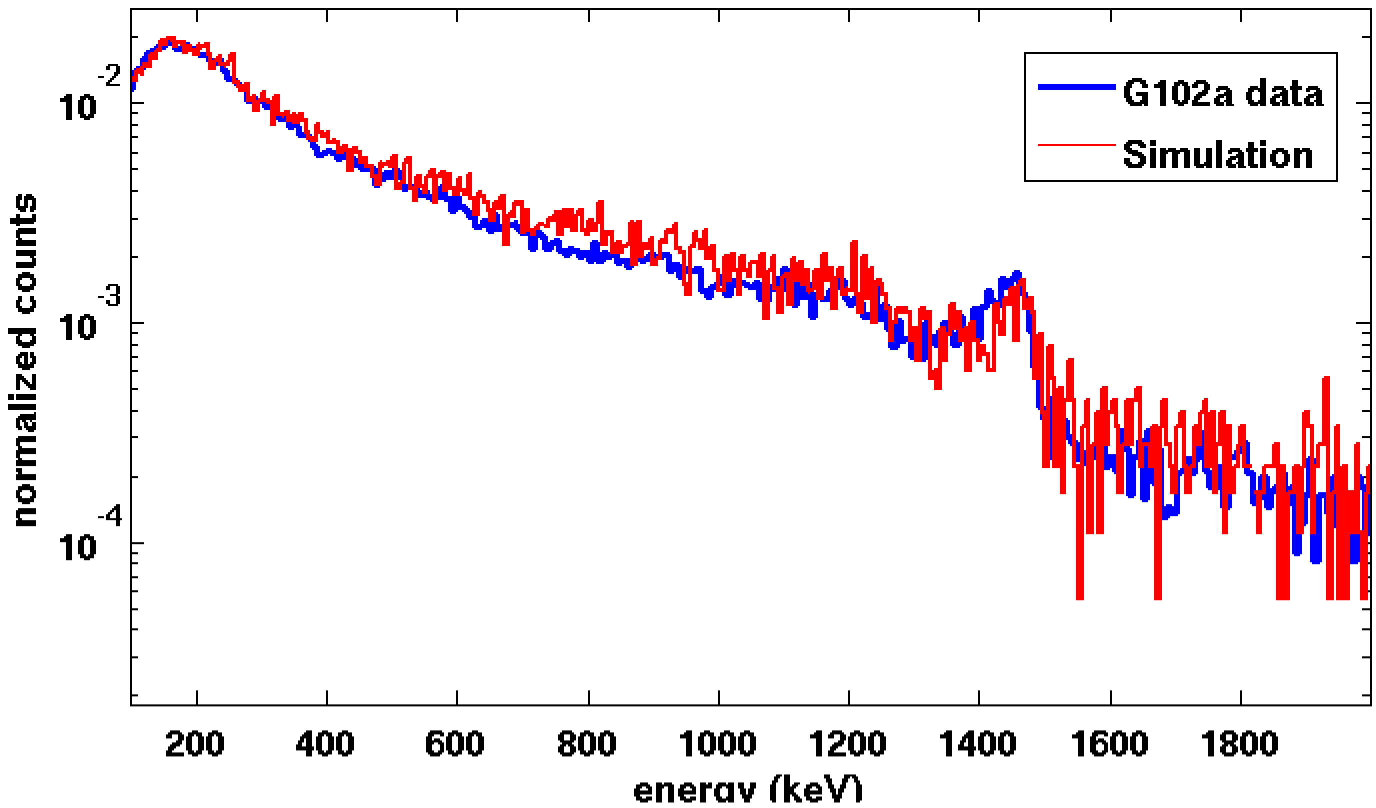
# Detector Monte Carlo: spectral broadening




- ***Left:** Broadened K40 peak as observed (red) and simulated (blue)*
- There is good agreement between simulation and data
- K40 line broadening due to variance in charge collection efficiency with event location

# Comparing simulated and recorded spectra

- The figure shows good agreement between simulated (red) and recorded (blue) charge spectra



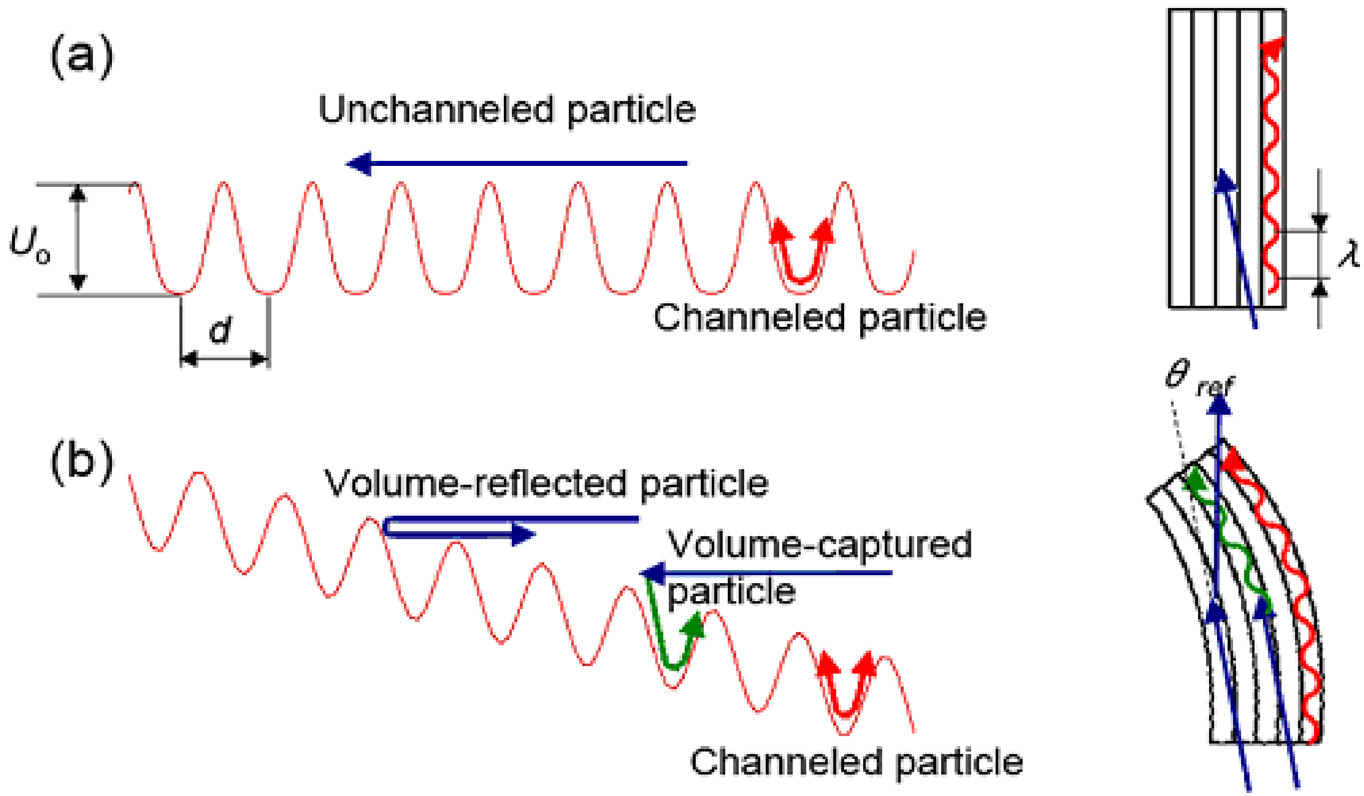
# ***Future developments: Channeling***

*Under development with Enrico Bagli, Ferrara University / INFN*

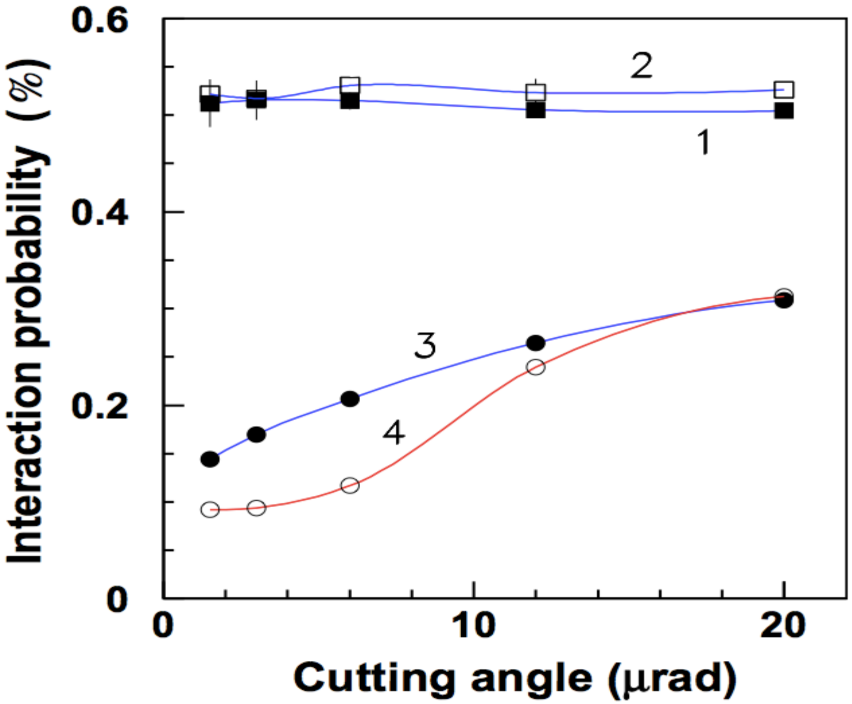
# Channeling - I

**Straight crystals**:
Particles can be trapped between crystal planes. This increases their mean free path.

**Bent crystals**:
Particles can be forced onto curved trajectories using channeling



# Channeling - II

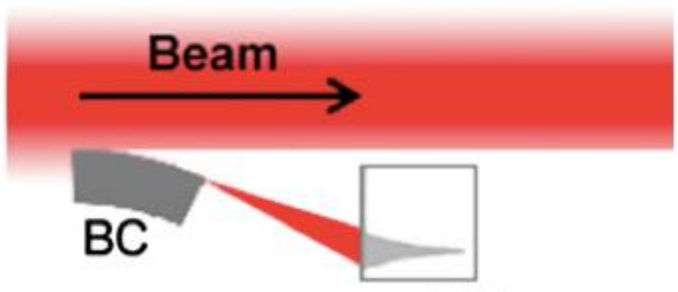


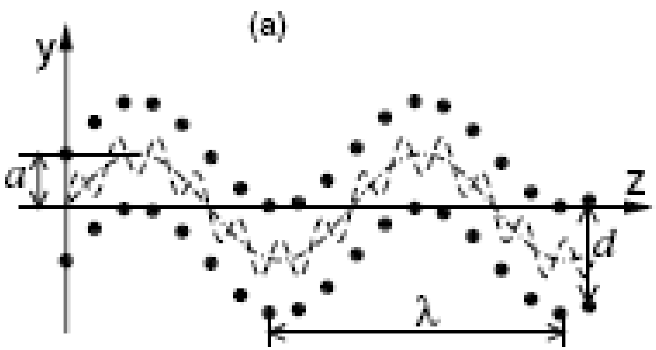

400 GeV/c proton on Si

Nucl. Instr. Meth. Phys. Res. B **268** (2010), 2655

- Channeling increases mean free path
  - » Due to the particle spending more time far from the nucleus
- Channeling also increases ionization yield of heavy ion impacts
  - » Important for dark matter direct detection

# Channeling - III




- Bent crystals could be used as baffles at LHC
  - Guide particles away smoothly
- Periodically deformed crystals can generate synchrotron radiation
  - Crystal fields are much bigger than any macroscopically generated fields

# Summary

- We have build a charge transport code for drifting e- /h+ pairs in cryogenic crystals
- The code successfully reproduces CDMS detector performance
- Next step is the inclusion of channeling effects
- Wide range of applications: dark matter direct detection, Si trackers, x-ray focusing, beam shaping, energetic synchrotron sources...
- Strong international interest - Collaborating with Ferrara Univeristy under SPINNER Global Grant

# The SuperCDMS collaboration

**California Institute of Technology**
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**FT-UAM/CSIC and Universidad Autonoma de Madrid**
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**University of Minnesota**
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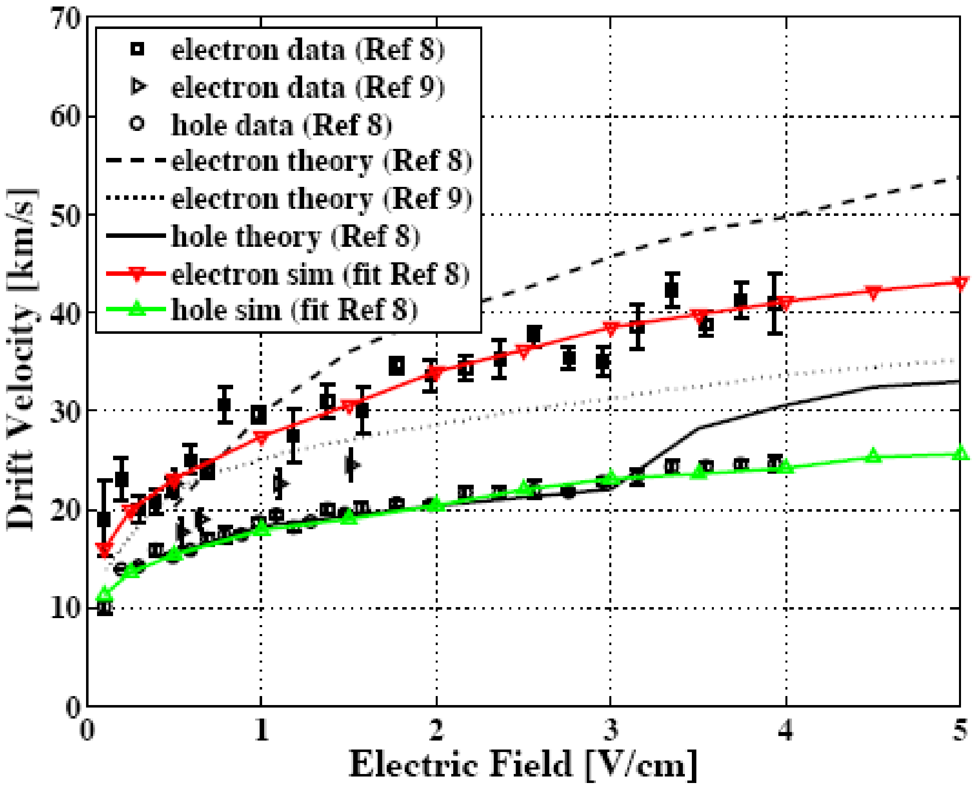
# Backup slides

# Validating carrier propagation model



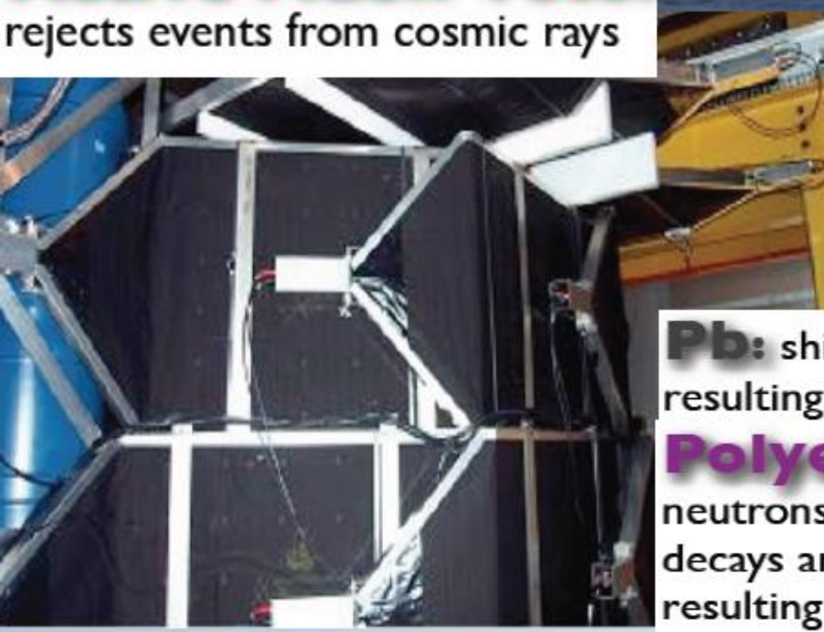

*Cabrera et. al, arxiv:1004.1233v1*

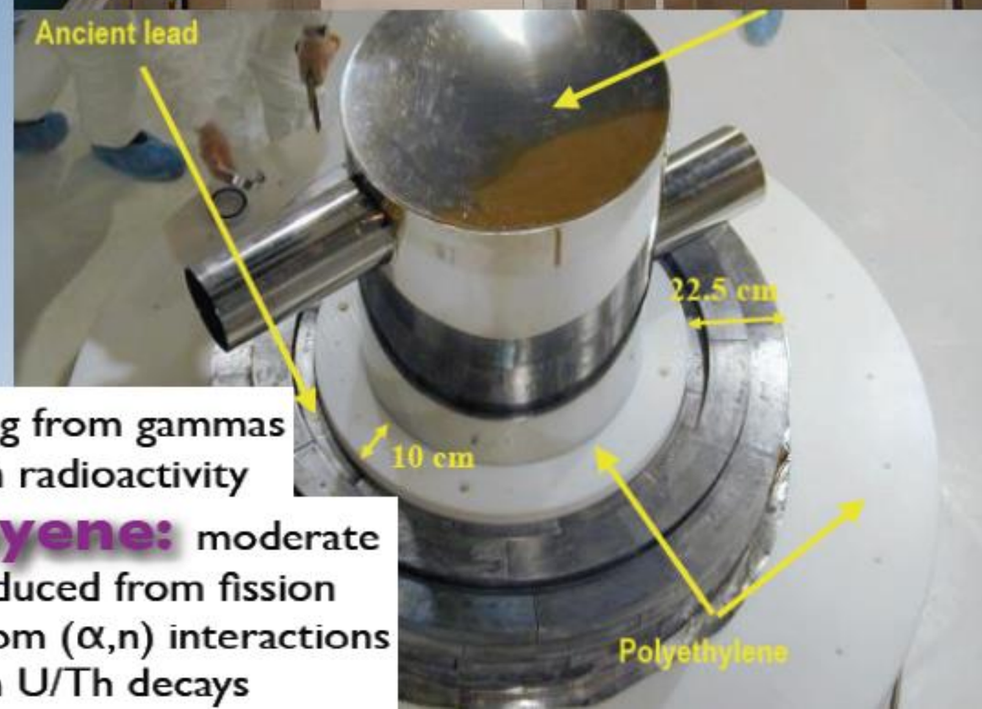
- Figure shows simulated e- drift velocity (red) and h+ drift velocity (green) as a function of drift field
- Drift velocities are in good agreement with experimental data
- This agreement indicates accurate oblique propagation and phonon emission models

# 2100 mwe underground

# Passive Shielding

**Active Muon Veto:**
rejects events from cosmic rays



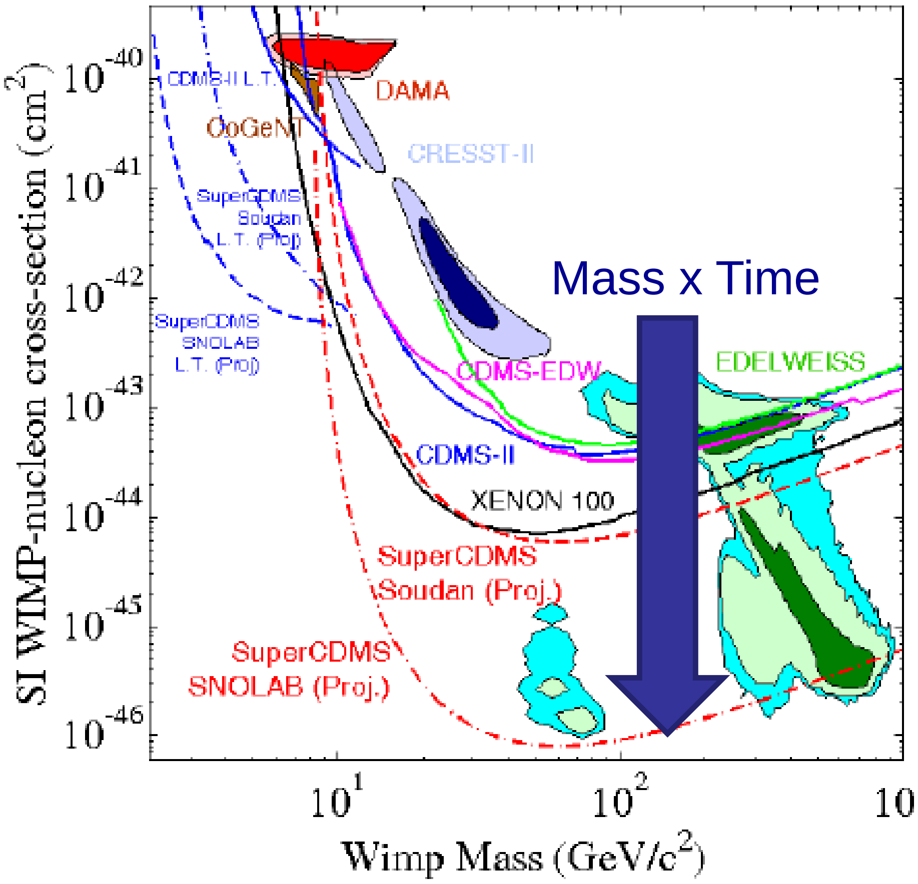



**Pb:** shielding from gammas resulting from radioactivity

**Polyethyene:** moderate neutrons produced from fission decays and from (α,n) interactions resulting from U/Th decays

# Current and Projected Limits

- SuperCDMS Soudan will match current XENON 100 limit
- SuperCDMS Lite will produce world leading low-mass limits
- SuperCDMS SNOLAB to improve limit by two orders of magnitude

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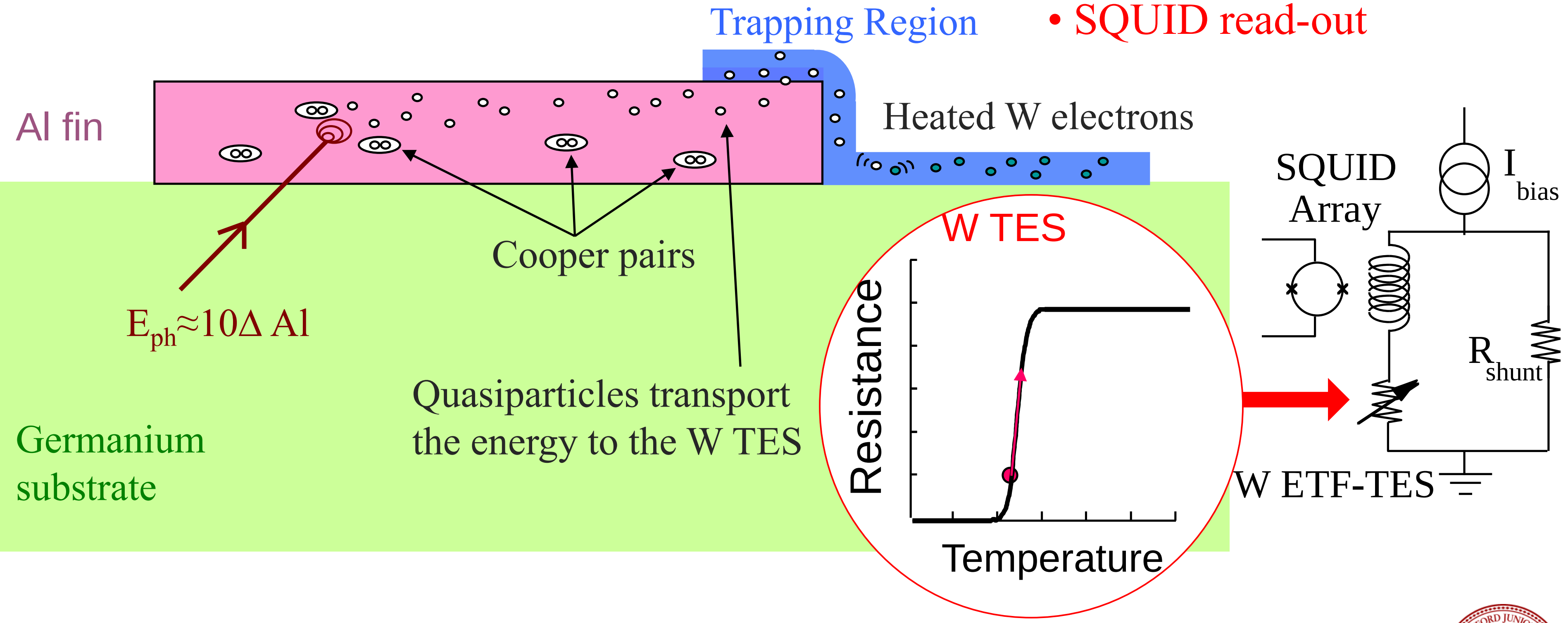
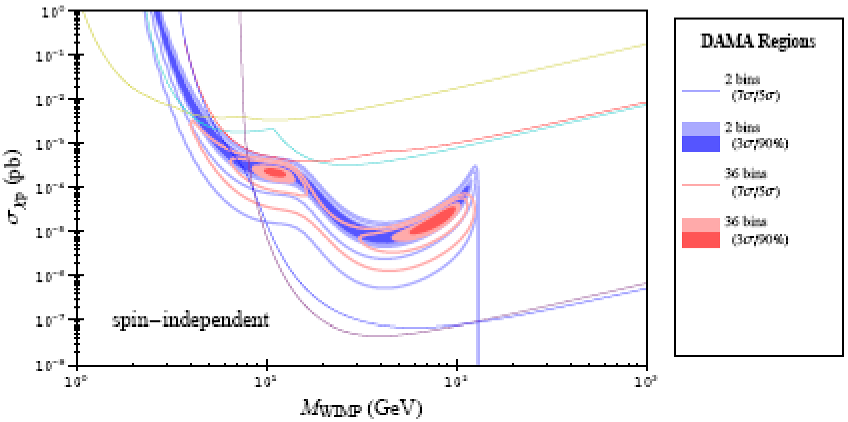
# Phonon detection in CDMS

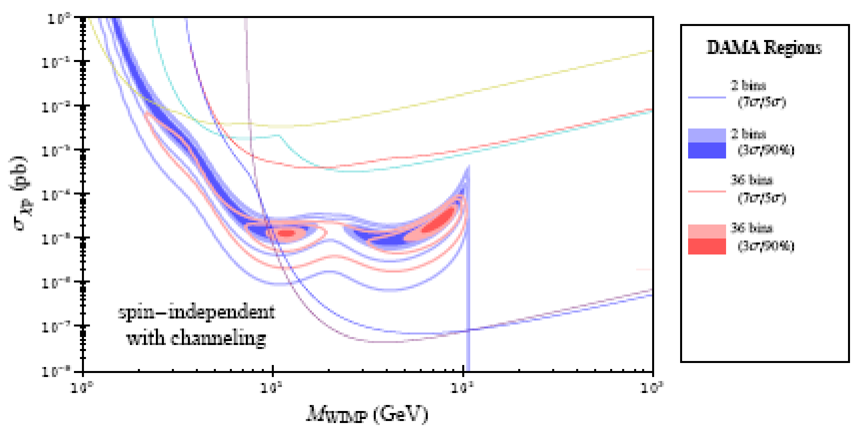
- Recoil event occurs in Germanium substrates, 76 mm diameter, 25 mm thick
- Aluminum fins 300 nm thick absorb phonons
- Fins connect to Tungsten transition edge sensors (W TESs)

- W $T_c$ ~ 80 mK
- SQUID read-out



# DAMA – with and without channeling




- Strong channeling effects can shift DAMA detection region
- Images from Savage et al., 2008, http://arxiv.org/abs/arXiv:0808.3607