Material Science and Security Application domains

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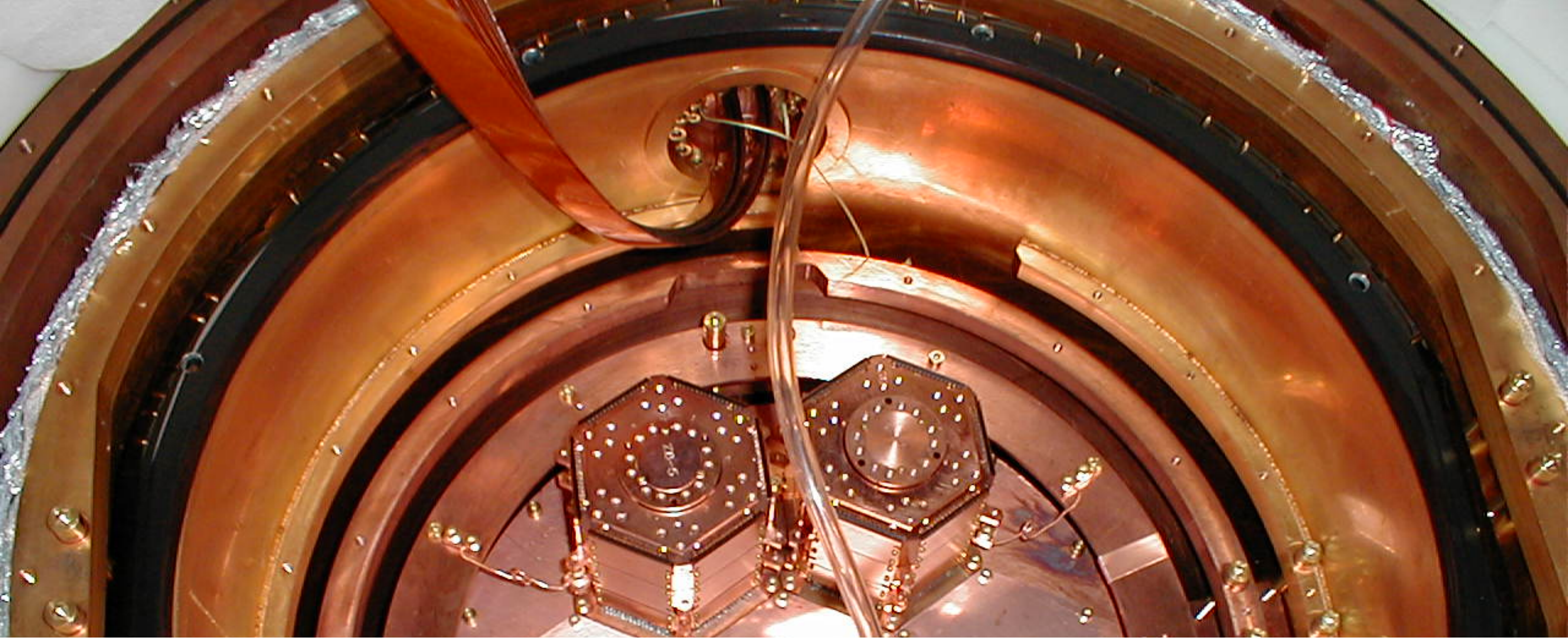
Outline

- CDMS: Cryogenic Dark Matter Search
- Instrument for neutron scattering facilities.
- UA9: Beam Collimation With Bent crystal
- Security Applications: Cargo radiography
- Radionuclide contaminated forest



Phonons Propagation and Carriers Drifting in Crystals With Geant4

CDMS: CRYOGENIC DARK MATTER SEARCH

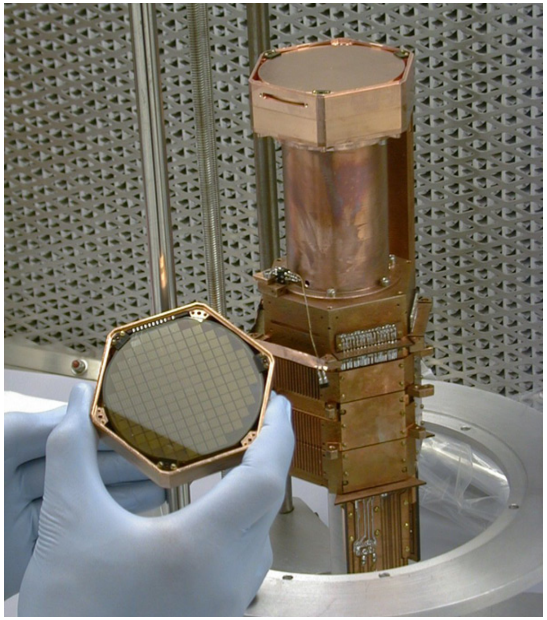
Geant 4

Sensor and Semiconductor Laboratory

CDMS: Cryogenic Dark Matter Search

- Goals:
  - The CDMS experiment aims to **measure the recoil energy imparted to a nucleus due to collisions with WIMPs** by employing detectors which are highly sensitive to the ionization and phonon signals that results from a WIMP-nucleus collision.

- Simulation Requirements:
  - **Phonon propagation** in ultra-cold crystals:
    - Isotope scattering and mode mixing
    - Anharmonic down conversion
    - Reflection processes
  - **Carrier drifting** in conduction bands:
    - Oblique propagation
    - Luke Scattering



G4CMP

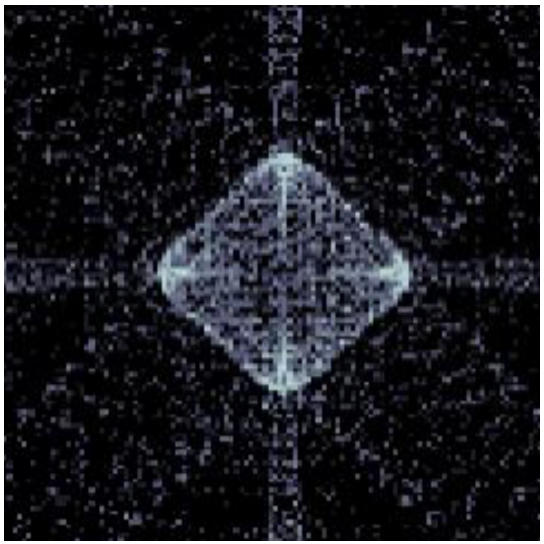
- "Developed for the low-temperature community, the package support production and propagation of acoustic phonons and electron-hole pairs through solid crystals such as germanium."

- Source code available on GitHub at https://github.com/ragnese/G4CMP

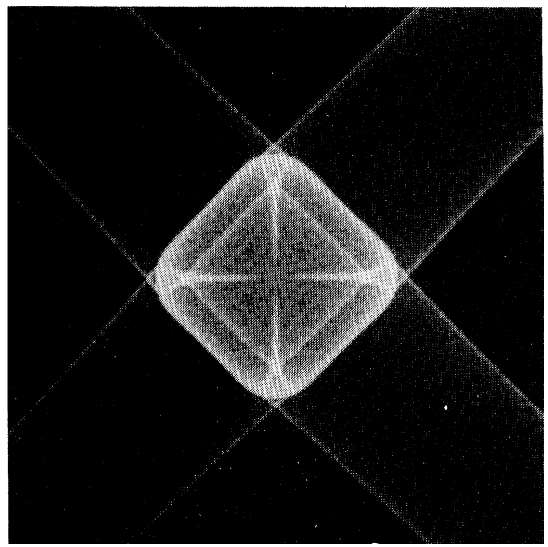
- Physics model description available on ArXiv at https://arxiv.org/pdf/1403.4984.pdf

Phonon Focusing

Geant4

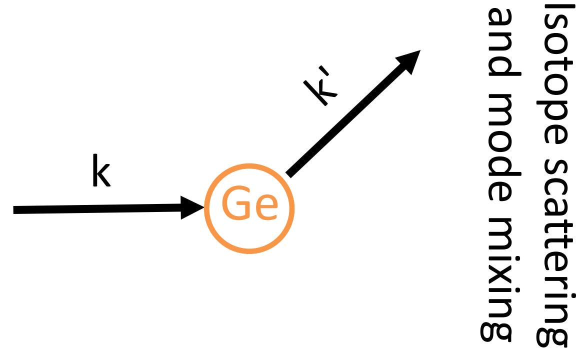


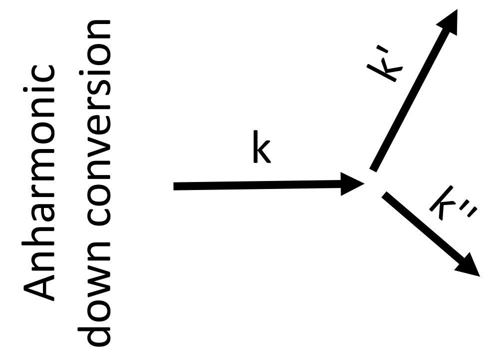
Experimental



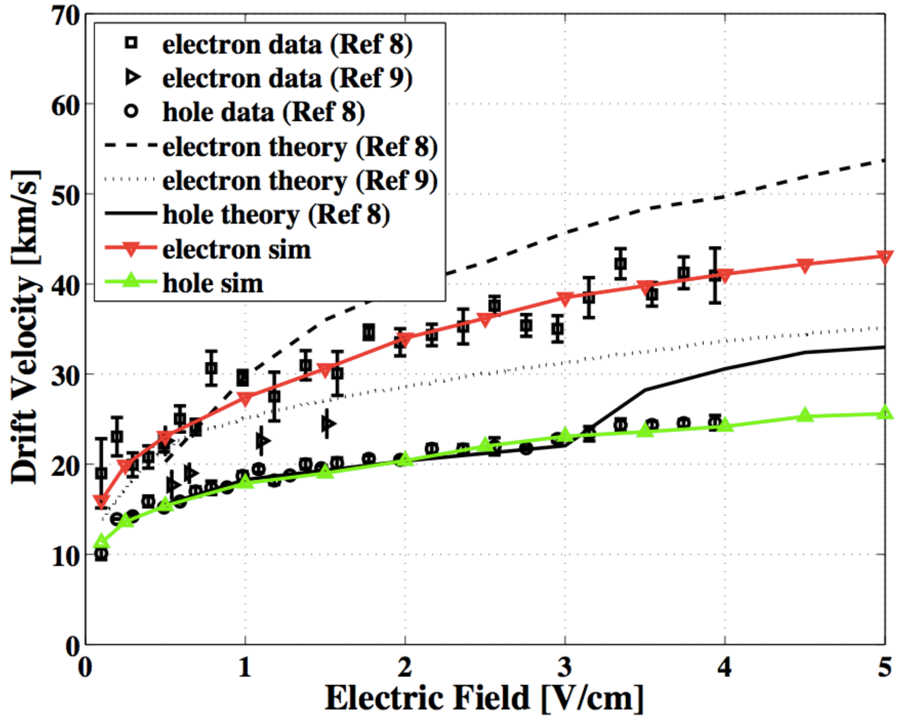
Phonon flux intensity on a Ge crystal face resulting from a point source at the crystal center.

Processes



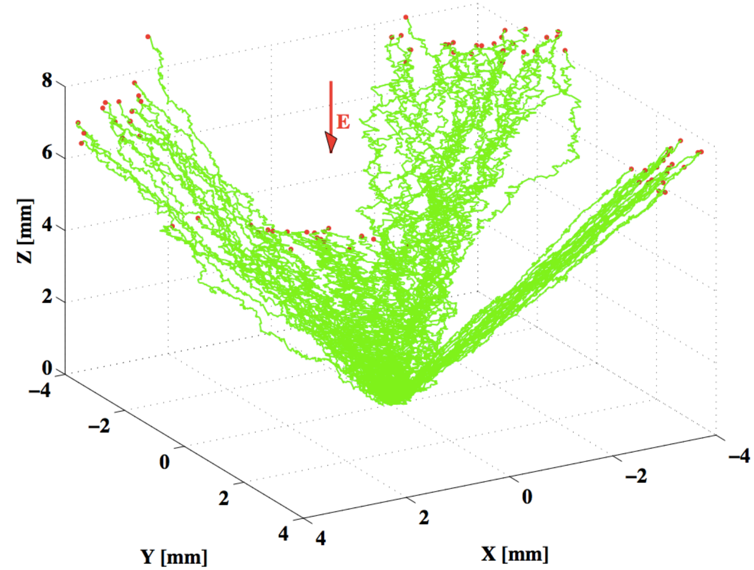


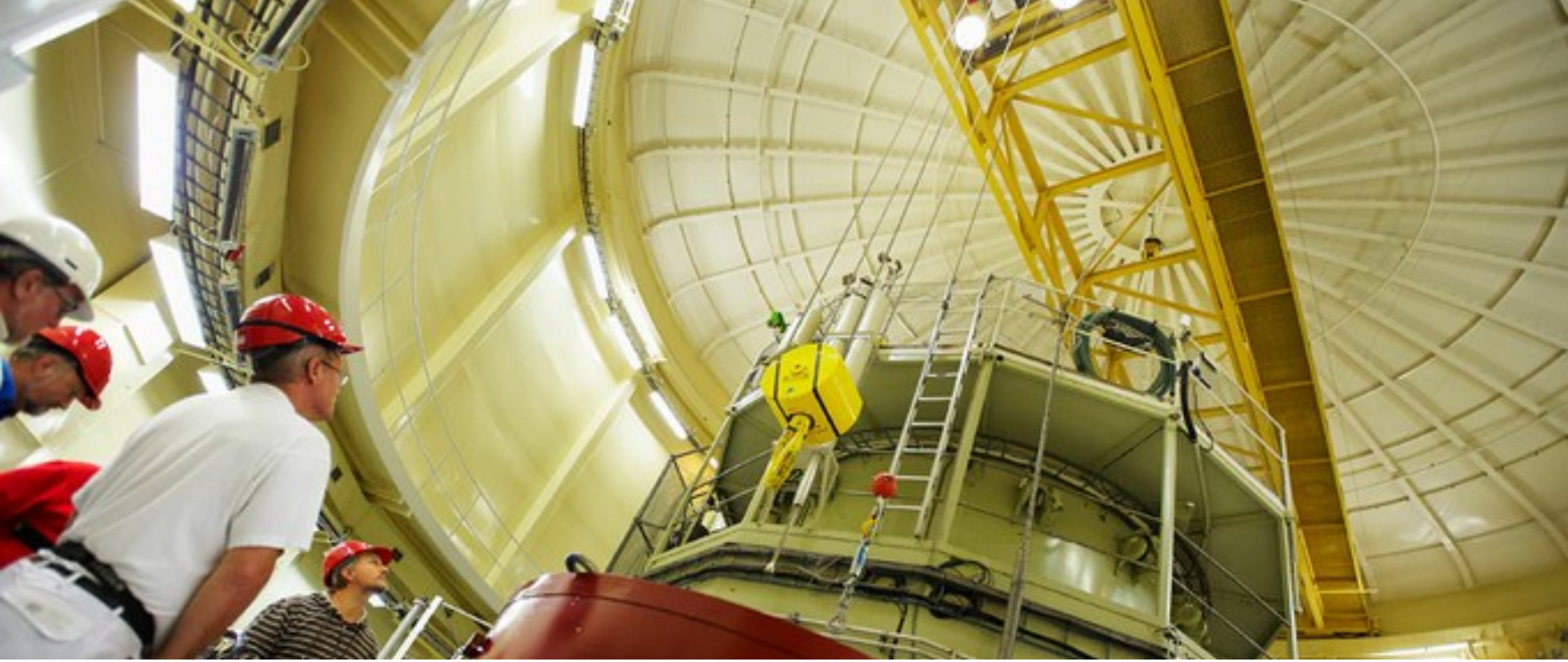
Carrier drifting



Comparison of the measured and simulated drift velocities as a function of electric field along [100] axis for ultrapure Ge crystals at 31 mK

Simulation of electron propagation through Germanium crystal at zero temperature with a 1 V/cm applied electric field along the -z axis



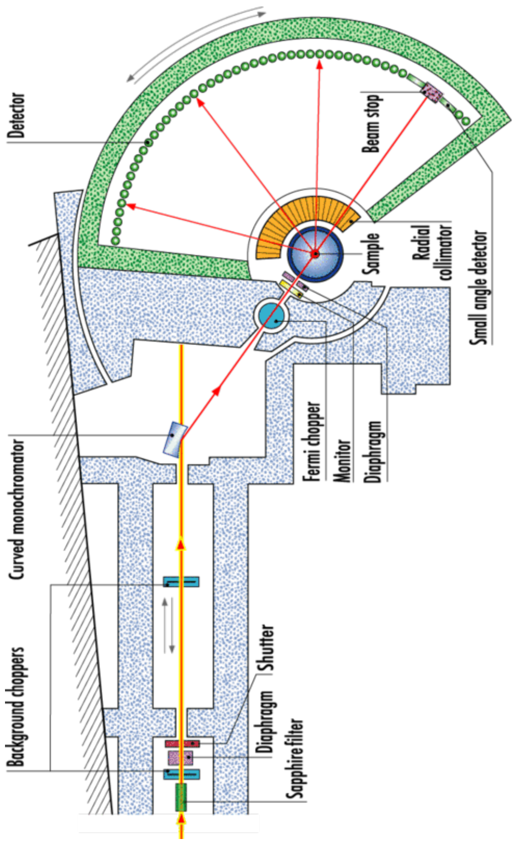


Complete simulation of the instruments with Geant4

INSTRUMENTS FOR NEUTRON SCATTERING FACILITY

Instruments for neutron scattering facility

- Goals:
  - State of instrument simulations use dedicated codes with custom models of components, e.g. McStats for the low-E neutron scattering, MCNP for model shielding, source, detectors. The main goal is the possibility to simulate all the components of the instruments for neutron scattering facility via Geant4.

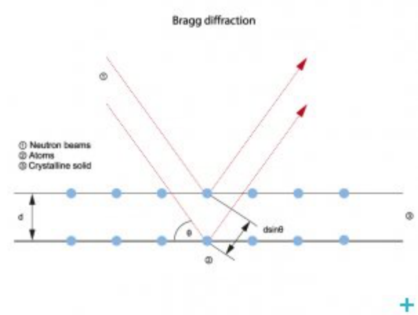


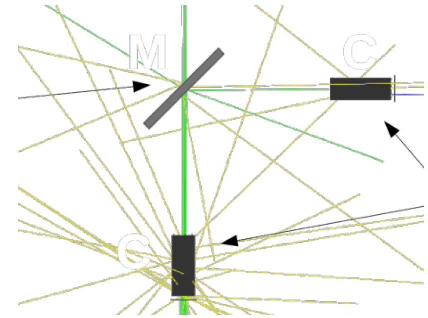
- Simulation Requirements:
  - Integration into Geant4 of the neutron Bragg diffraction and phonon propagation in crystals.

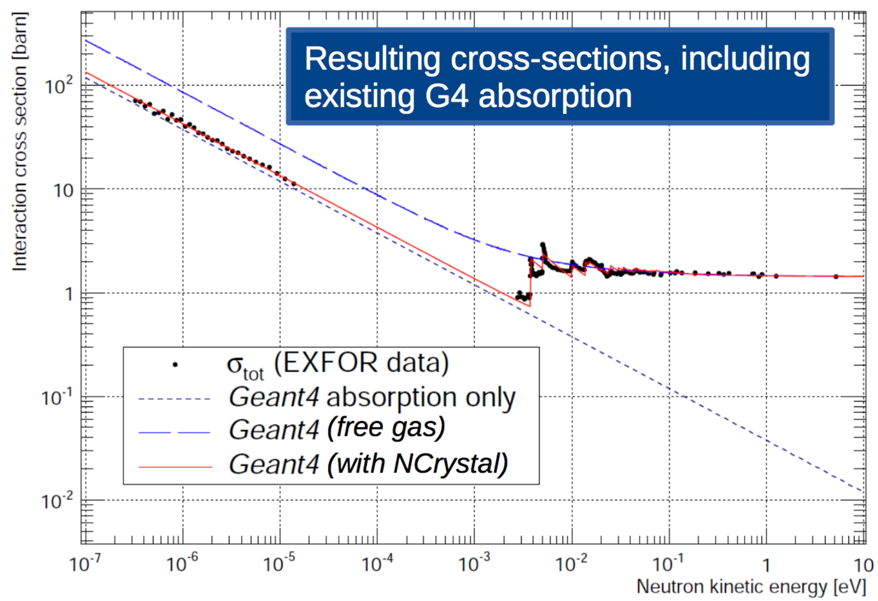
NCrystal

- Scattering cross-sections and sampling of scatter angle and energy transfer
  - Bragg diffraction (based on NXSLib and SgInfo)
  - Phonon scattering
    - Complete models on the way (simple model)

- Low energy (<0.1eV) neutrons in poly- and single-crystals.





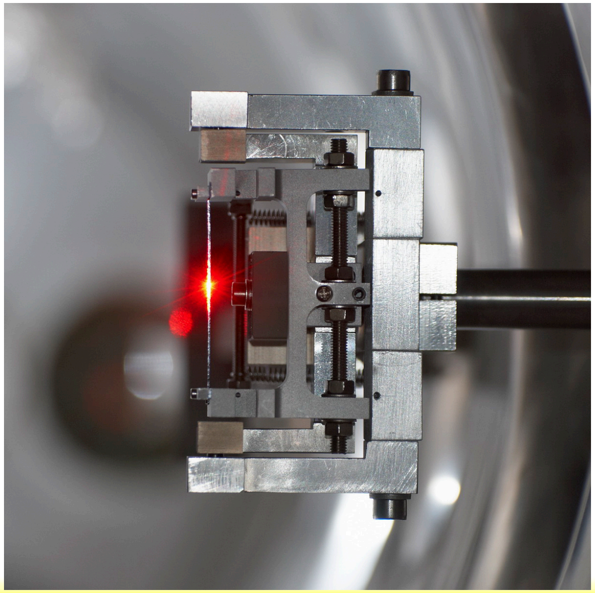


Proton Channeling in Bent Crystals With Geant4

UA9: BEAM COLLIMATION WITH BENT CRYSTAL

Beam Collimation With Bent Crystal

- Goals:
  - Crystal channeling is a promising technology for sophisticated beam manipulations in high-energy particle accelerators. Bent silicon crystals acting as primary collimators are expected to direct the beam halo promptly onto secondary absorbers thus ideally reducing outscattering, beam losses and the radiation load in critical regions of the ring.

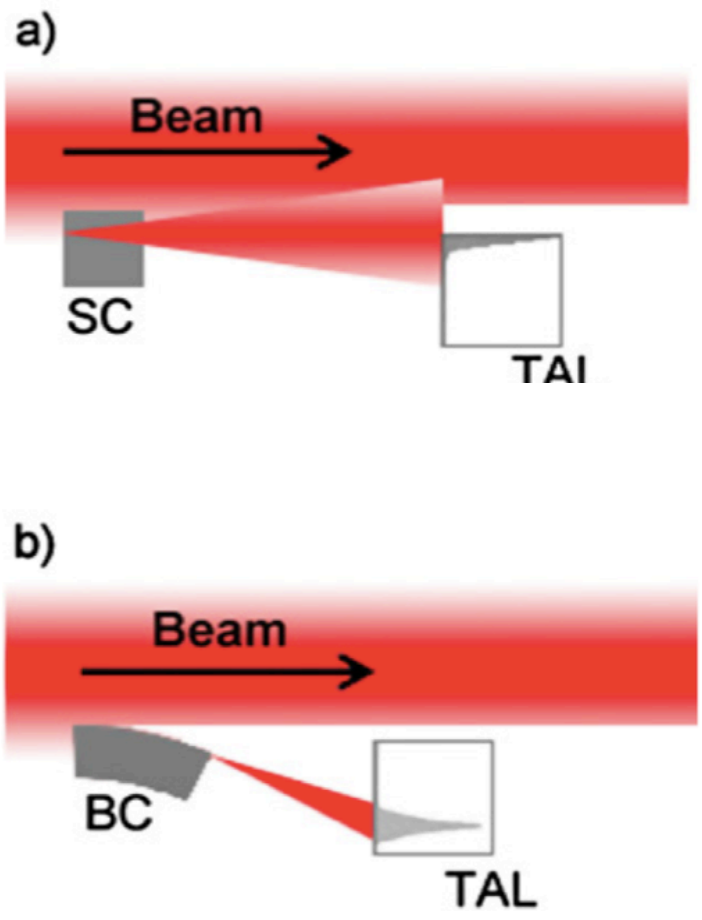


- Simulation Requirements:
  - Coherent effects in bent crystals
    - Channeling
    - Volume reflection
    - Modified particle energy loss

Crystal collimation scheme

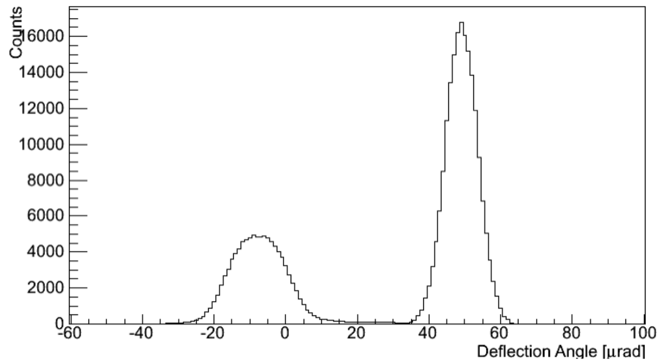
- Crystal can be used as a primary collimator to deflect particles of the halo toward a secondary collimator.
- Main advantage is the possibility to deflect the beam out and reduce the beam losses.

a) standard collimation system
b) crystal collimation system

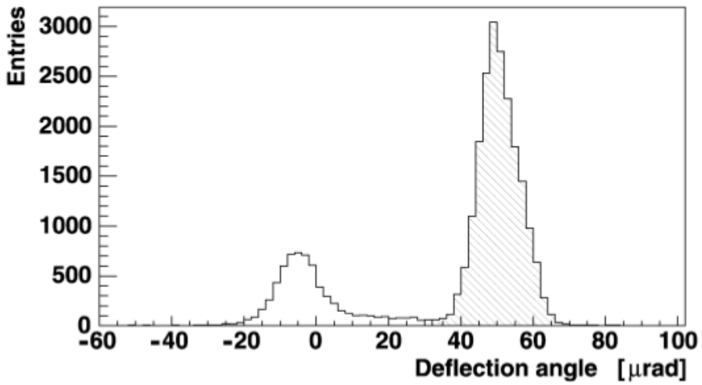


Channeling in Bent Crystal

Geant4

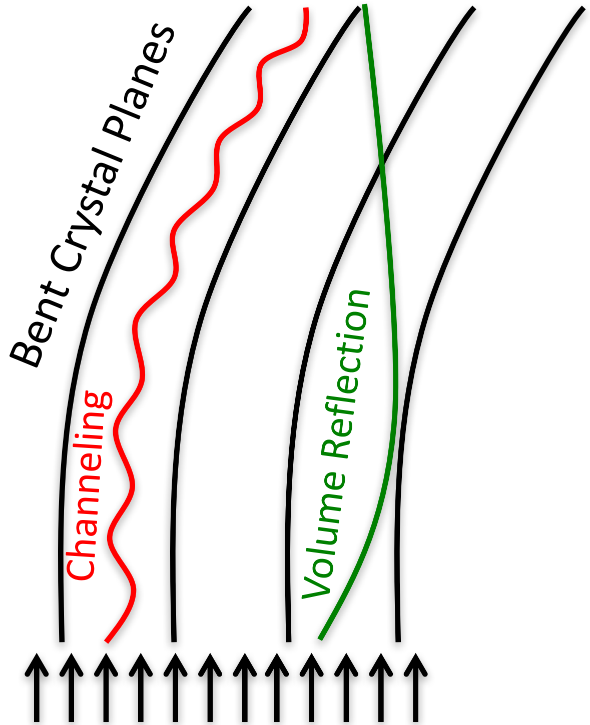


Experiment



Angular distribution of a 400 GeV/c proton beam after interaction with bent Si crystal under channeling alignment

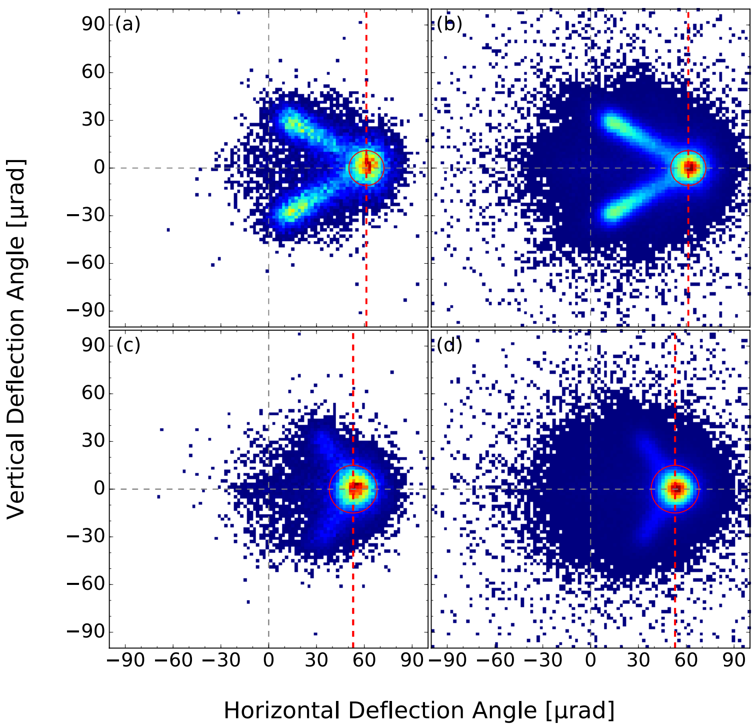
Processes



Axial Channeling in Bent Crystals

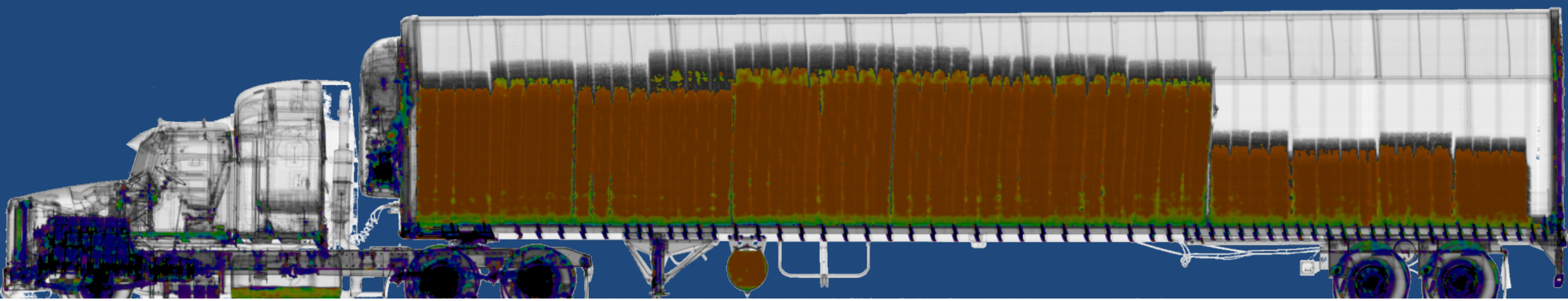
<111> and <110> axes

W. Scandale, Phys.Lett. B 760 (2016) 826-831



UA9 Experiment

- Experiment with 2 mm Si crystals with 400 GeV/c protons under axial case required the update of the channeling model to take into account axial effets.
- Crystals oriented for axial channeling <111> (top) and <110> (bottom), for experimental data (left) and Geant4 (right)

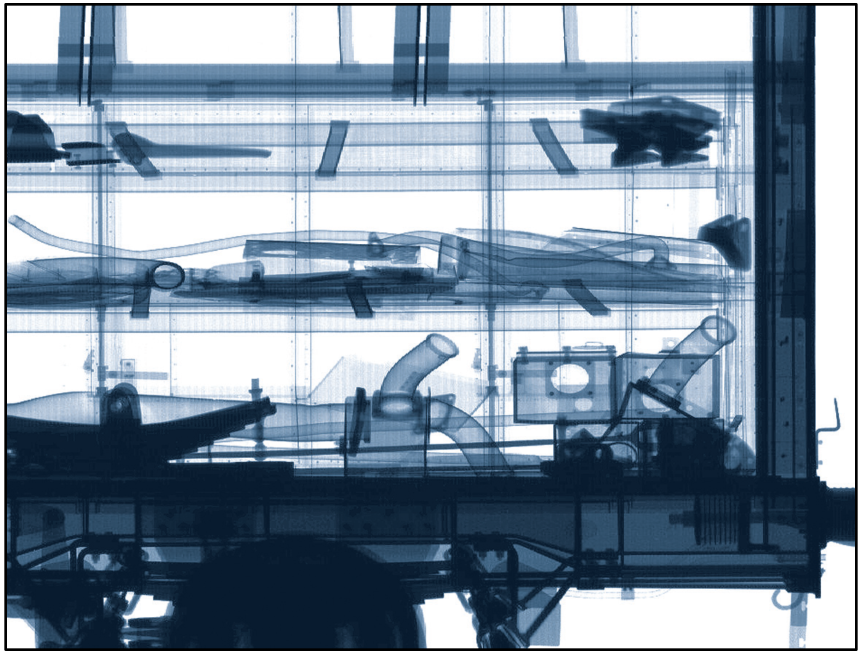


X-ray, low-energy nuclear reaction imaging and muon tomography

SECURITY APPLICATIONS: CARGO RADIOGRAPHY

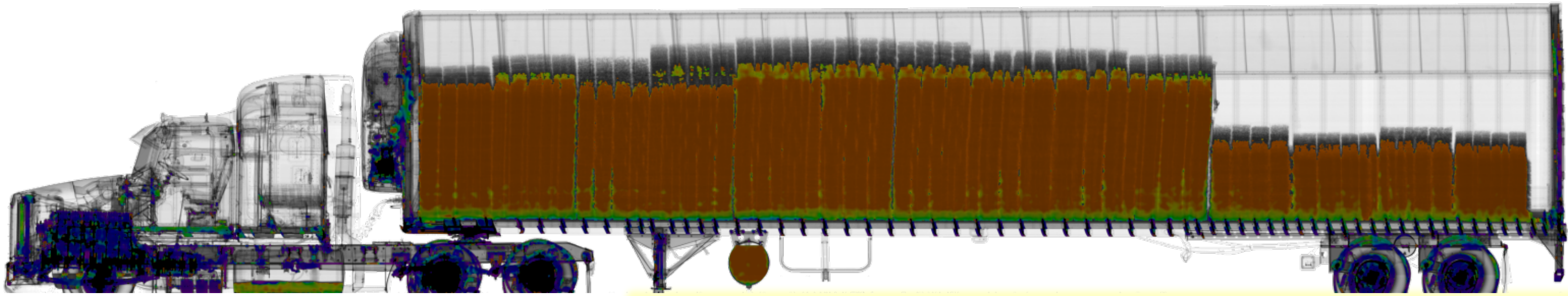
Security Applications: Cargo radiography

- Goals:
  - Searching weapons-grade uranium and plutonium in standard cargo containers during transit has been described as "searching for a needle in a haystack". X-ray and low-energy nuclear reaction imaging can be used for this purpose.



X-ray cargo radiography

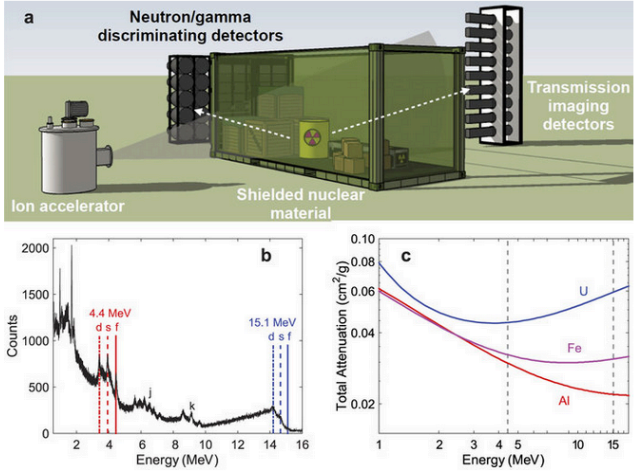
- X-ray tomography can penetrate up to 30–40 cm of steel in vehicles moving with velocities up to 13 km/h. A LINAC is used to generate a high energy bremsstrahlung spectrum with energy in the 5-10 MeV.

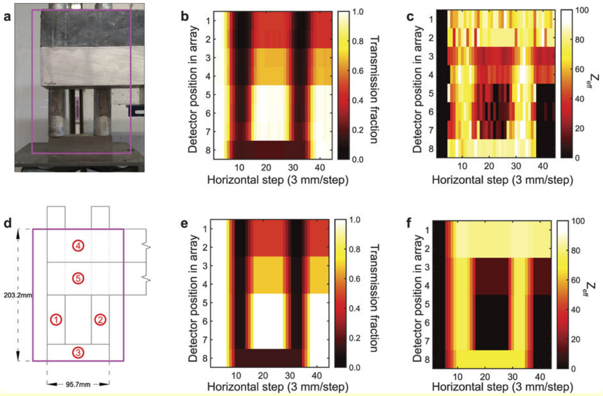


Low-energy nuclear reaction imaging

- Low-energy nuclear reaction imaging exploits the physics of interactions of multi-MeV mono-energetic photons and neutrons to simultaneously measure the material's areal density and effective atomic number, while confirming the presence of fissionable materials by observing the beta-delayed neutron emission.

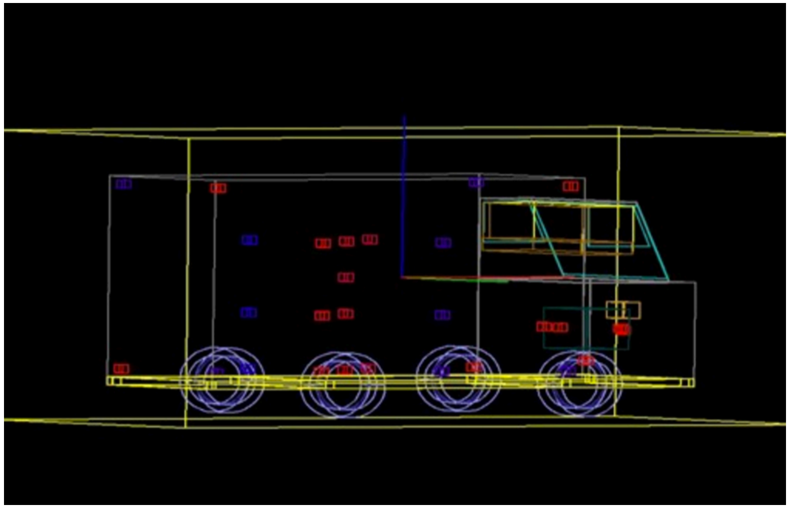
P. B. Rose et al., Scientific Reports 6, 24388 (2016)

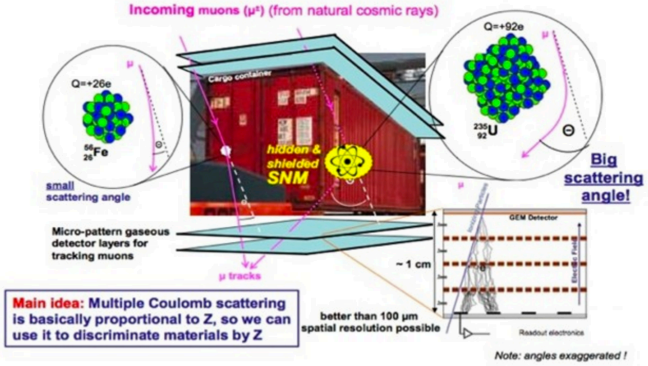


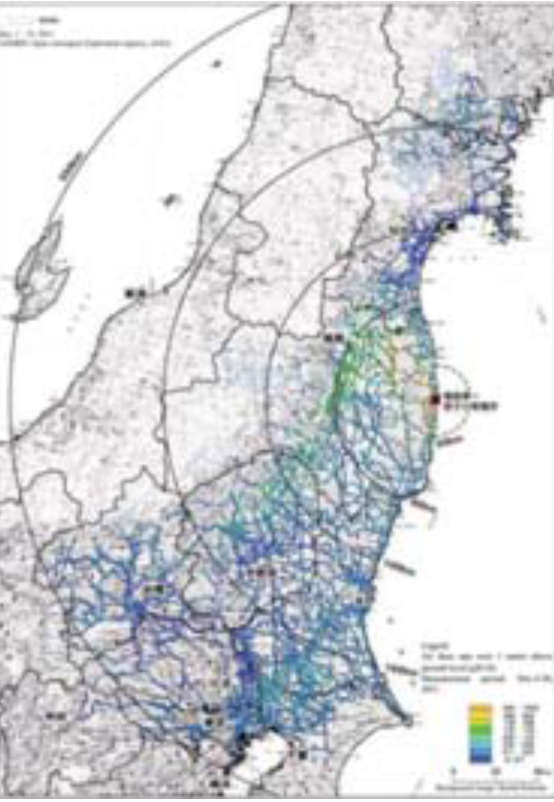


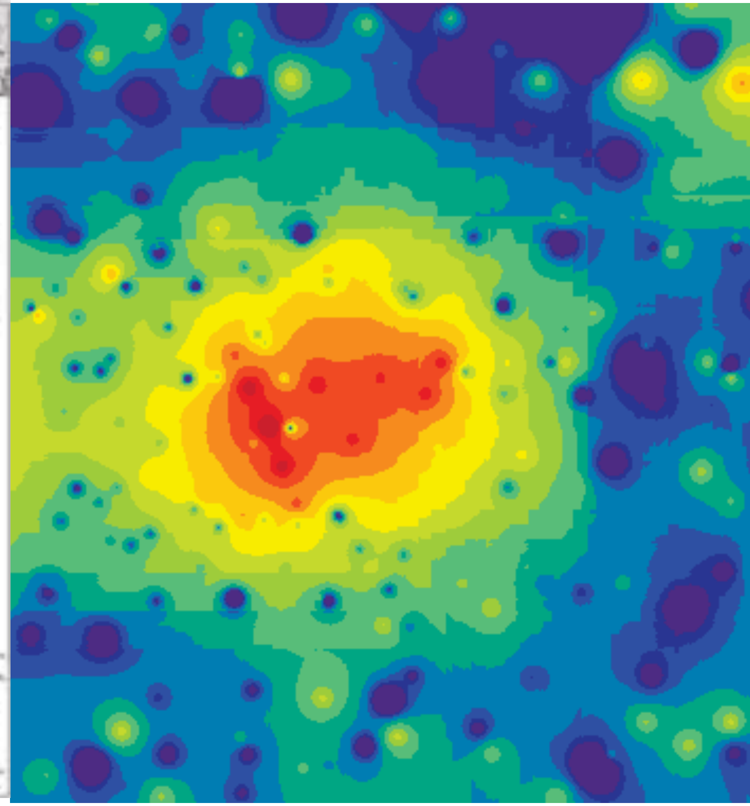
Muon tomography

- Tomography based on the measurement of multiple scattering of atmospheric cosmic ray muons traversing shipping containers is a promising candidate for identifying threatening high-Z materials (in the simulated truck, the Red Boxes are Uranium, the Blue ones are lower Z Materials)









Evaluation using radiometric measurements

RADIONUCLIDE CONTAMINATED FOREST

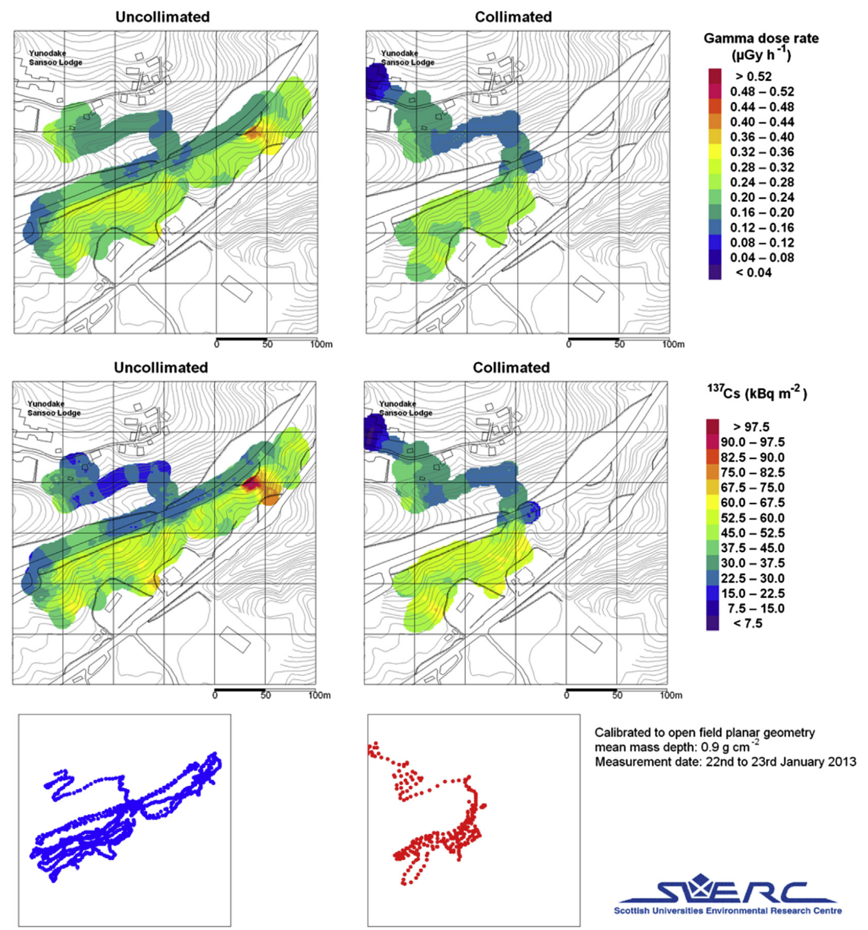
Geant 4

Sensor and Semiconductor Laboratory

Evaluating remediation of radionuclide contaminated forest

- Time-series, collimated, radiometric survey methods allow to accounting for the distribution and changes in radionuclide inventory within contaminated forests.

- Preliminary Geant4 simulations of a generic forest, with activity uniformly distributed in a canopy of uniform density between 2 and 5 m above the ground surface, are consistent with the experimental measurements.



DC Sanderson et al., J Environ Radioact 162-163, 118-128 (2016)

Conclusions & Perspectives

- Extensions to Geant4 are able to reproduce experimental data for various kind of experiment concerning crystalline materials:
  - Phonon and charge carrier propagation at ultra-low temperature
  - Channeling at high-energy
  - Diffraction and scattering of thermal neutron

- The description of crystal structure of matter has been introduced for specific use cases: CDMS, UA9, Neutron Facilities. A unique code for the managing of crystal structure is under development.

- Geant4 has proved to be able to handle the requirements needed by several security applications, e.g., cargo radiography and evaluation of the remediation of radionuclide contaminated forest. Further applications of Geant4 in this domain can pave the way to the usage of the toolkit for business purposes.