Modelling detector response functions to NORM and source radiation for arbitrary detector geometries

T. Doughney (1,2), J. Gillam (2), D. Marinaro(2), A. Roufos (1), A. M. Hooker (1), C. Kalnins (1), N. A. Spooner (1)

(1) University Of Adelaide, North Tce, 5005 Adelaide, South Australia, Australia.

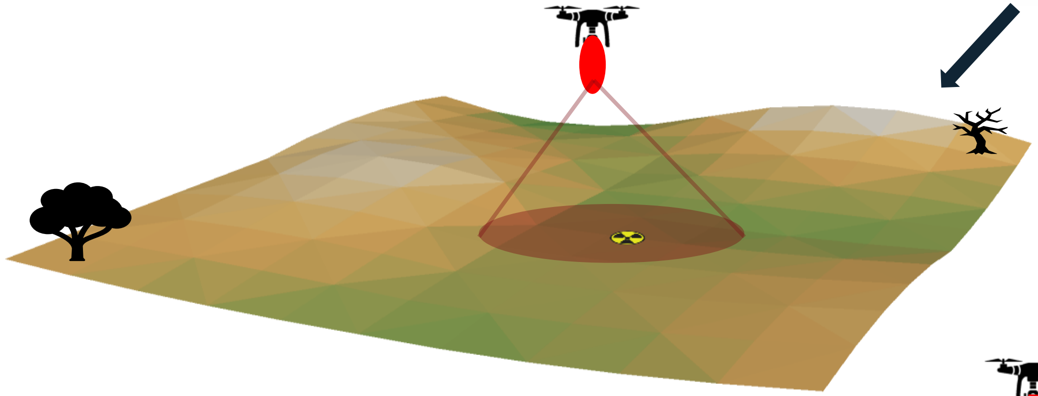
(2) Defence Science and Technology Group, 506 Lorimer St, 3207 Port Melbourne, Victoria, Australia.

Centre for Radiation Research Education and Innovation

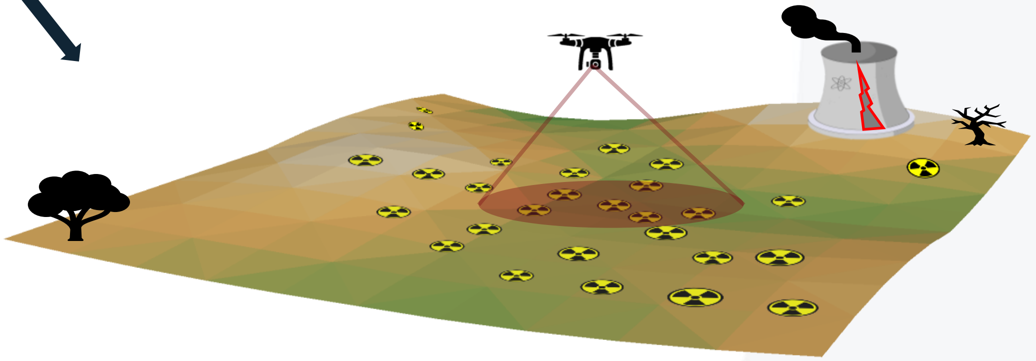
Australian Government
Department of Defence
Science and Technology

THE UNIVERSITY of ADELAIDE

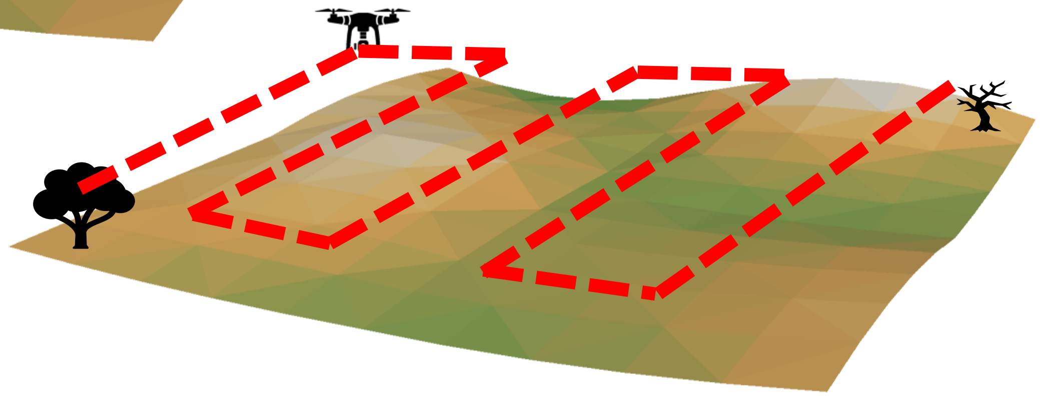
Uses of UAV-borne Gamma Radiation detection



Searching for lost or stolen radioactive material

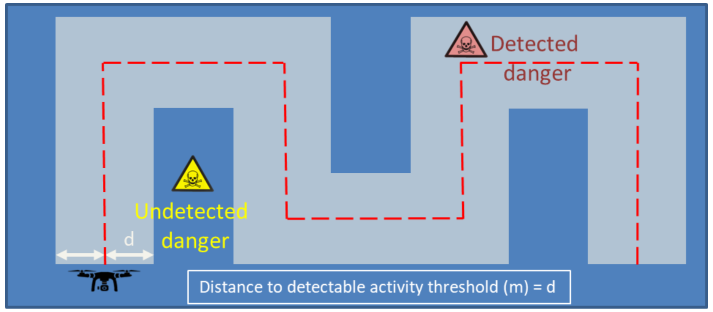


Contamination mapping from a radiological event

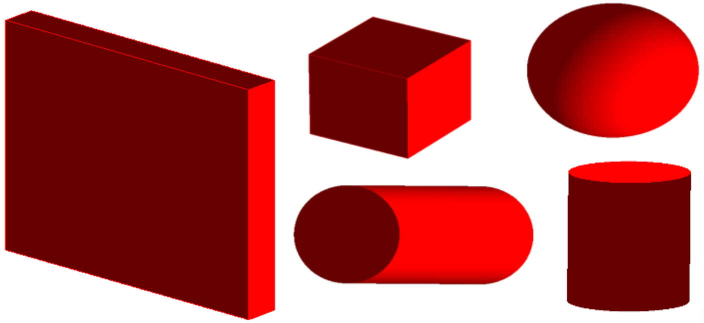


Environmental Survey for baseline studies, environmental management, resource exploration, mining plant management

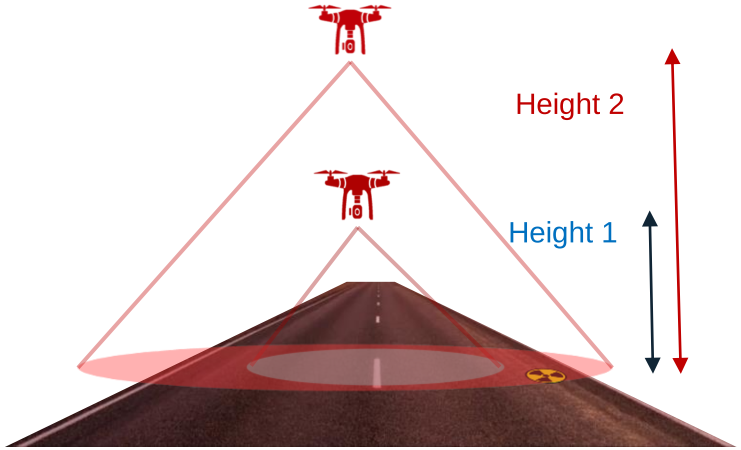
Why the need to model



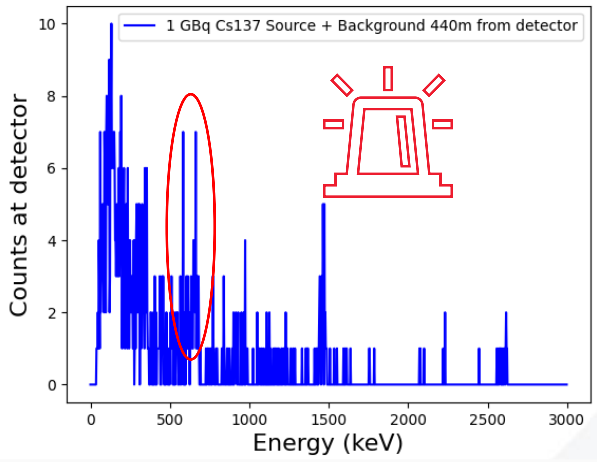
Understand minimum detectable activity (MDA) that a detector will see in the scene.



Optimise detector geometries to suit operational parameters



Determine optimal UAV flying height and speed to find a lost source of known strength.



Create large varying datasets for the development of inversion algorithms

THE UNIVERSITY of ADELAIDE

Forward Models – Detailed vs Fast

Forward models are defined by propagating a scene to a detector. Given the scene, what does the detector see?
They are an integral part of solving the inverse problem. Given what the detector sees, what can we infer about the scene
To use statistical models to solve inverse problems, many realisations of forward models are used

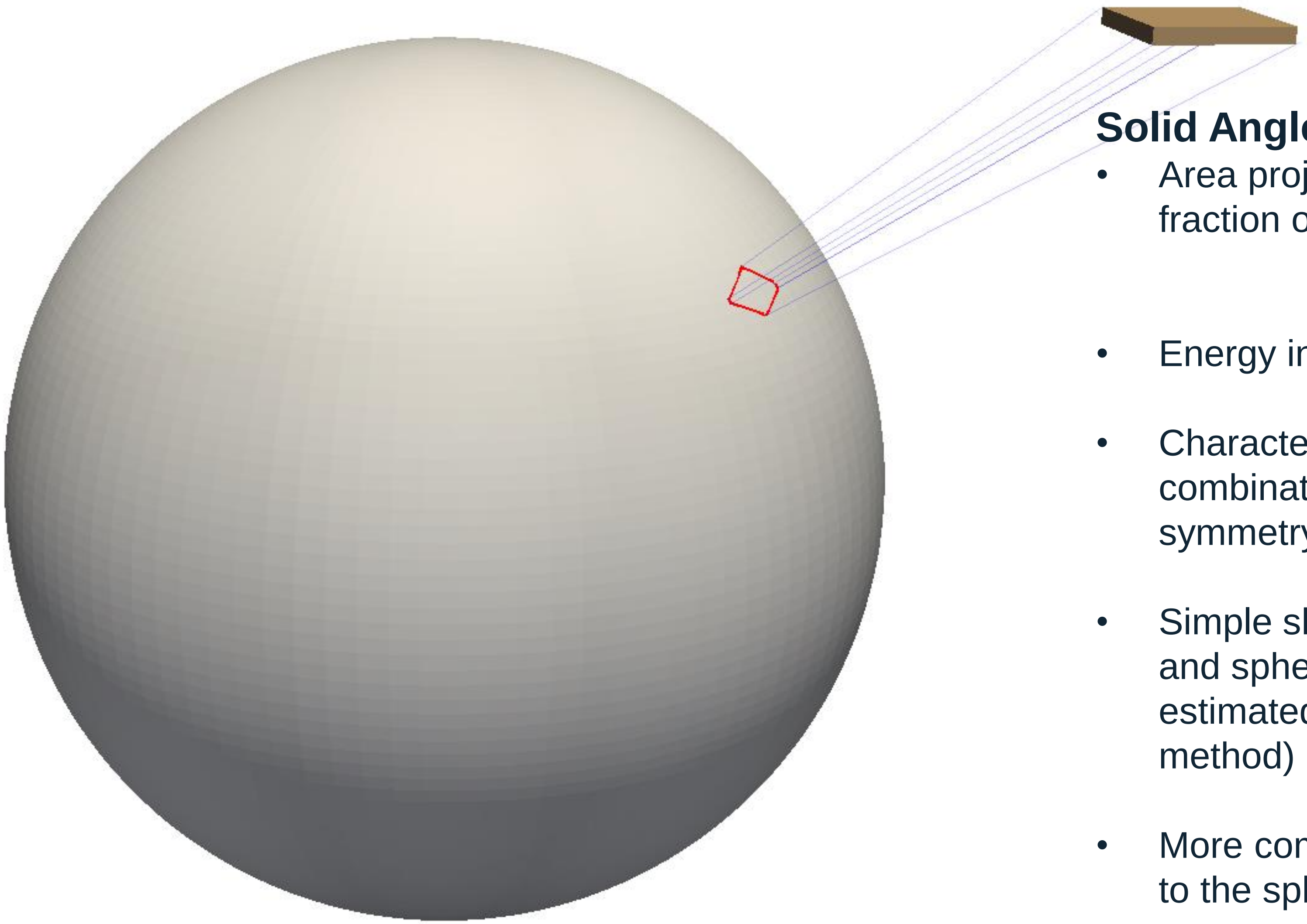
Monte Carlo

- Pros
  - Simulation tool kits available like Geant4 and MCNP that have extensive validated physics
  - Uses physics realistic processes to transport particles such as multiple scattering and absorption
  - Fully stochastic, best mimic of real-world radiation transport – statistical variations to Bayesian solver
- Cons
  - Computationally expensive, requires supercomputer for useful number of realisations for realistic scenes

Fast analytical

- Pros
  - Fast! Can provide multiple Poisson realisations of a complex scene in a fraction of the time
  - Fast and (potentially) accurate enough to be used for basic simulations, such as footprint calculations and on scene mission planning with limited time
- Cons
  - Limited physics, no scattering (or limited)
  - Non stochastic. Deterministic probability distribution for each realisation could lead to statistical artifacts

THE UNIVERSITY of ADELAIDE



Solid Angle

- Area projected onto unit sphere as a fraction of sphere surface area

- Energy independent

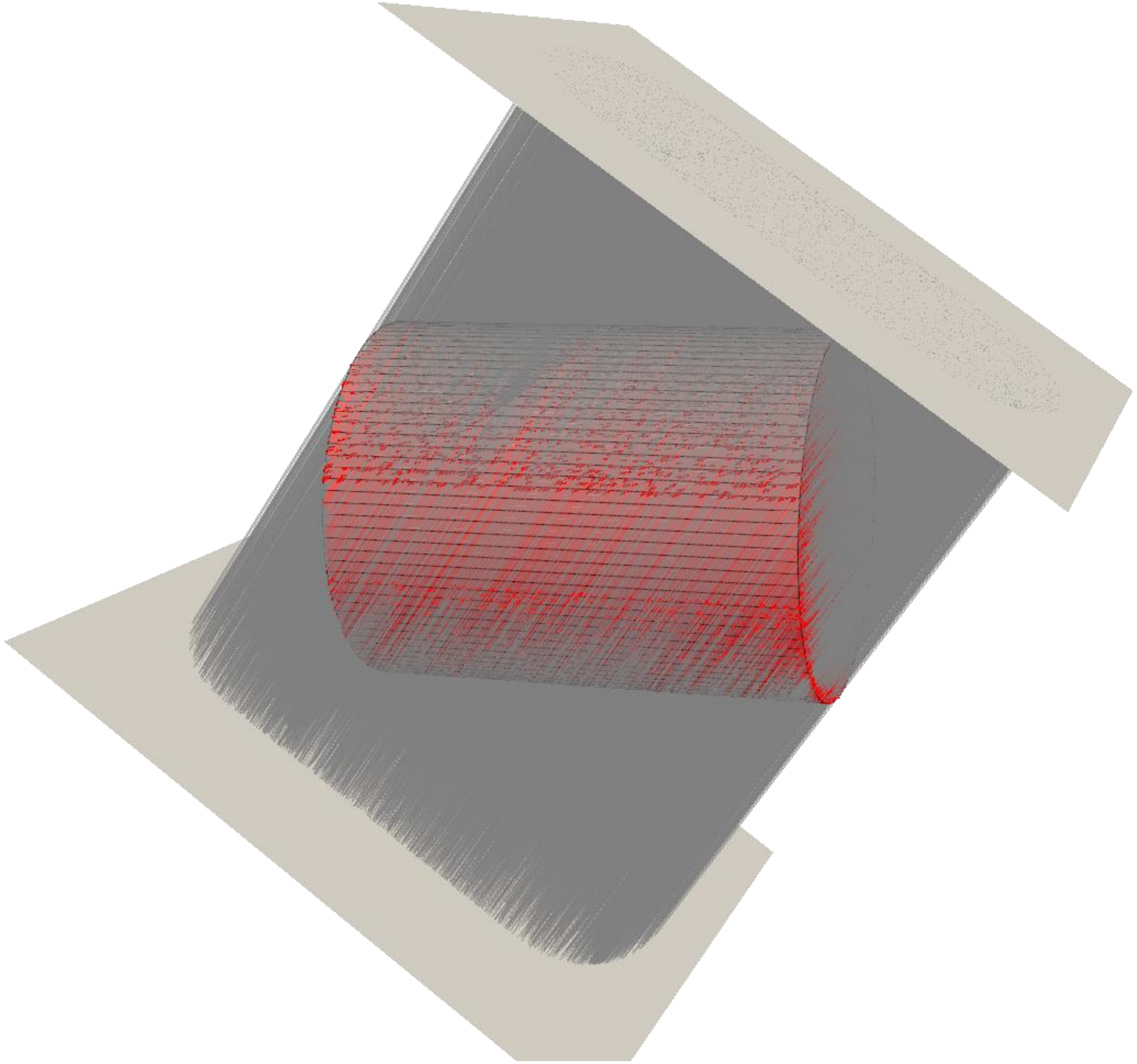
- Characterised for all azimuth and elevation combinations. Can be reduced for symmetry

- Simple shapes such as cylinders, cuboids, and spheres solid angle can be accurately estimated with simple geometry (fastest method)

- More complex shapes, the points projected to the sphere and meshed.

- Girard’s Theorem can be used to obtain exact area of spherical polygon

THE UNIVERSITY of ADELAIDE

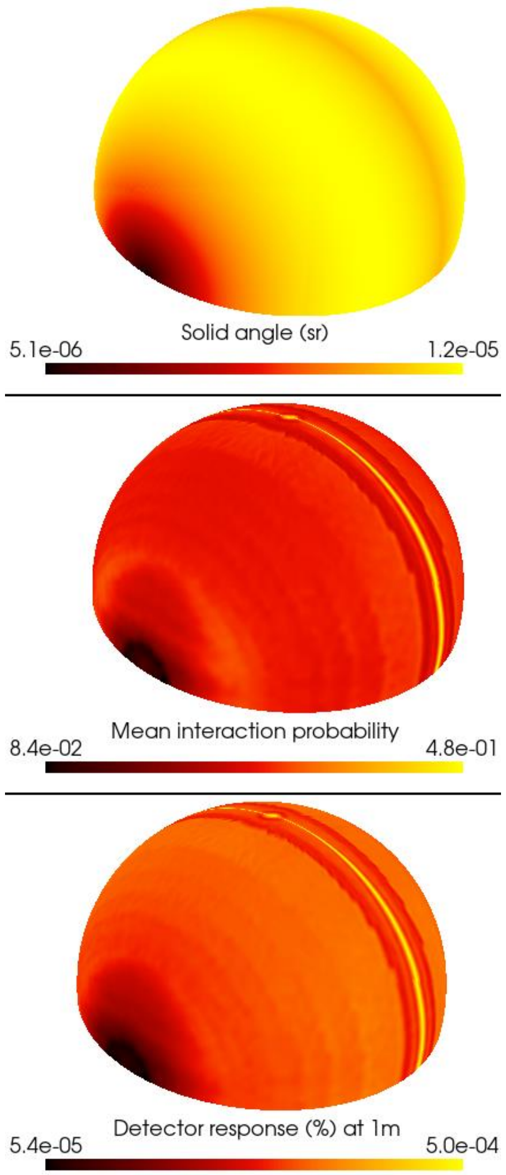


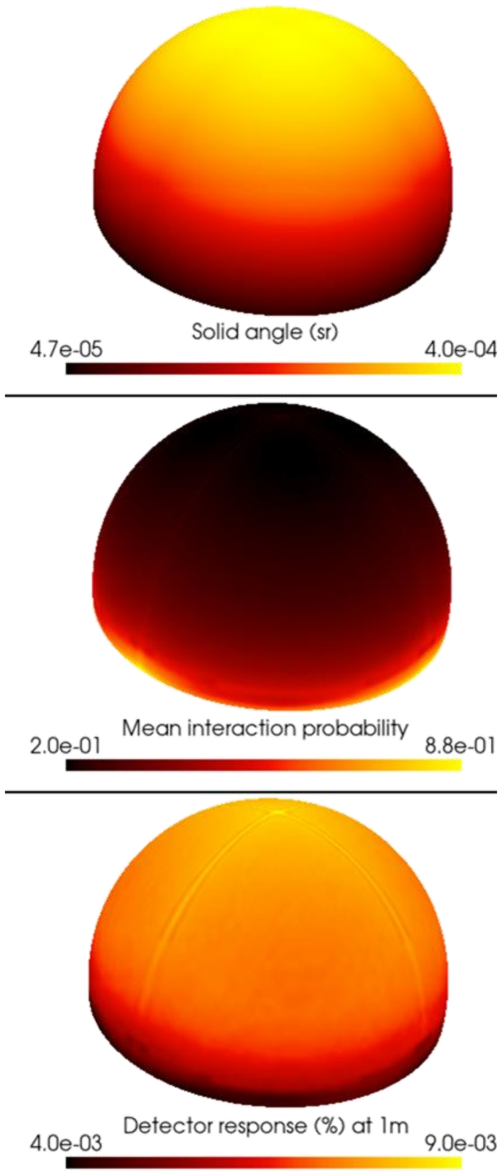
Interaction Probability

- Fraction of incident radiation that interacts with detector
- Path lengths calculated using ray tracing
- Rays are generated within shadow
- 5000 rays
- Interaction probability calculated using NIST mass attenuation coefficients
- Interaction probabilities for each path are averaged
- Process repeated for each energy
- Rays are all parallel (small error)
- Output stored in an interpolation function

Mirion SPIR-Explorer

Shape:	Cylinder (H)
Dimensions:	5.1 (L) x 3.2 (dia)
Material:	NaI(Tl)
Density:	3.67 g/cm^3
Volume:	41 cm^3
Mass:	151 g
μ (662 kev):	3.51 cm^{-1}
α (662 kev):	0.285 cm





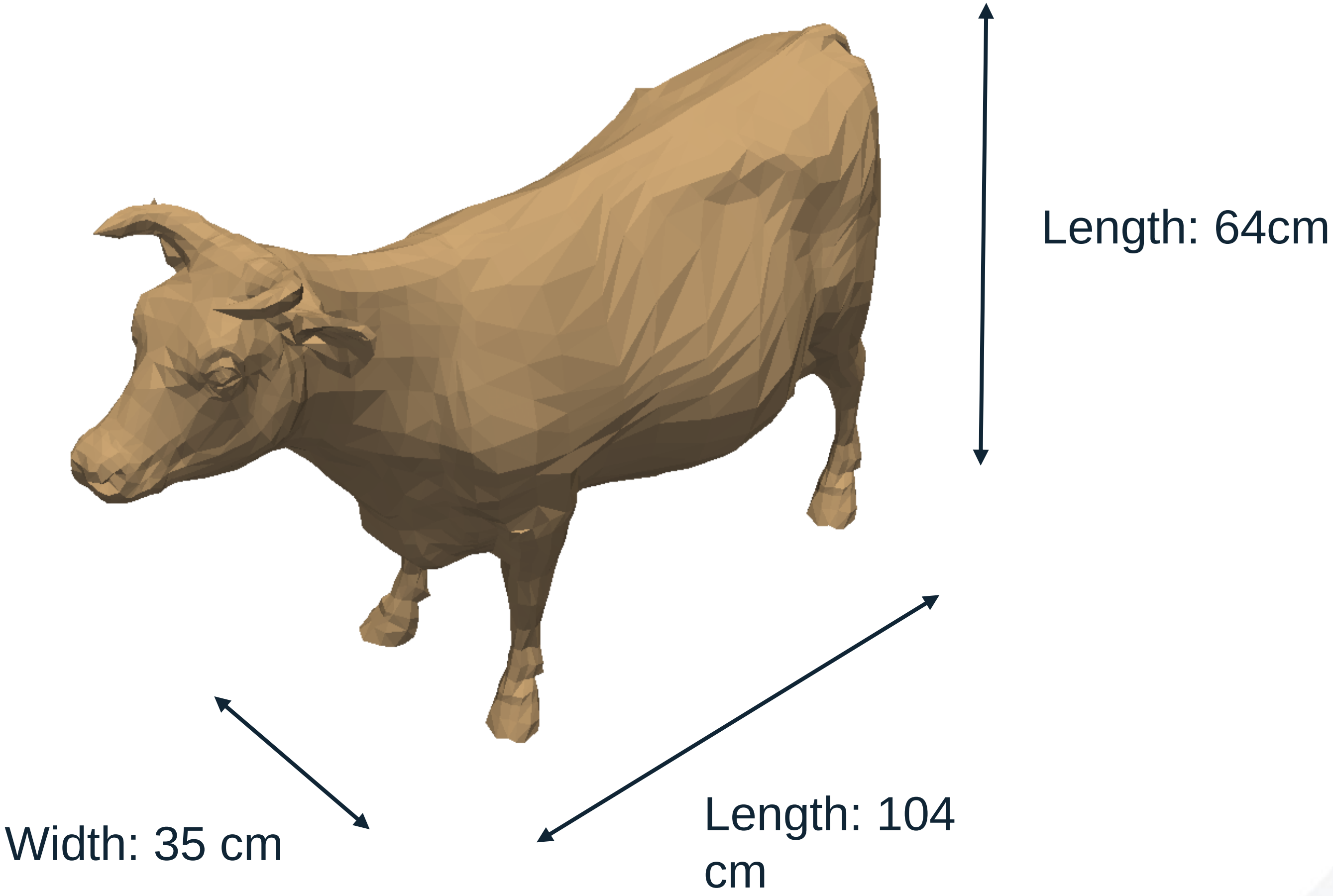
Eljen Plastic Scintillator

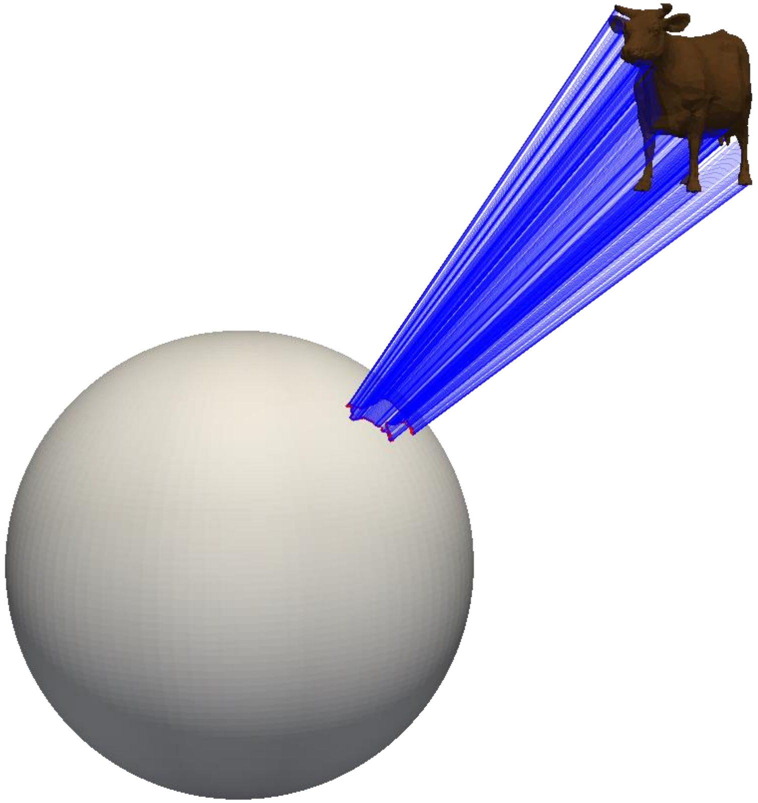
Shape:	Planar
Dimensions:	25 (H) x 25 (w) x 3 (T) cm
Material:	EJ200
Density:	1.023 g/cm^3
Volume:	1875 cm^3
Mass:	1918 g
μ (662 kev):	0.086 cm^{-1}
α (662 kev):	11.6 cm

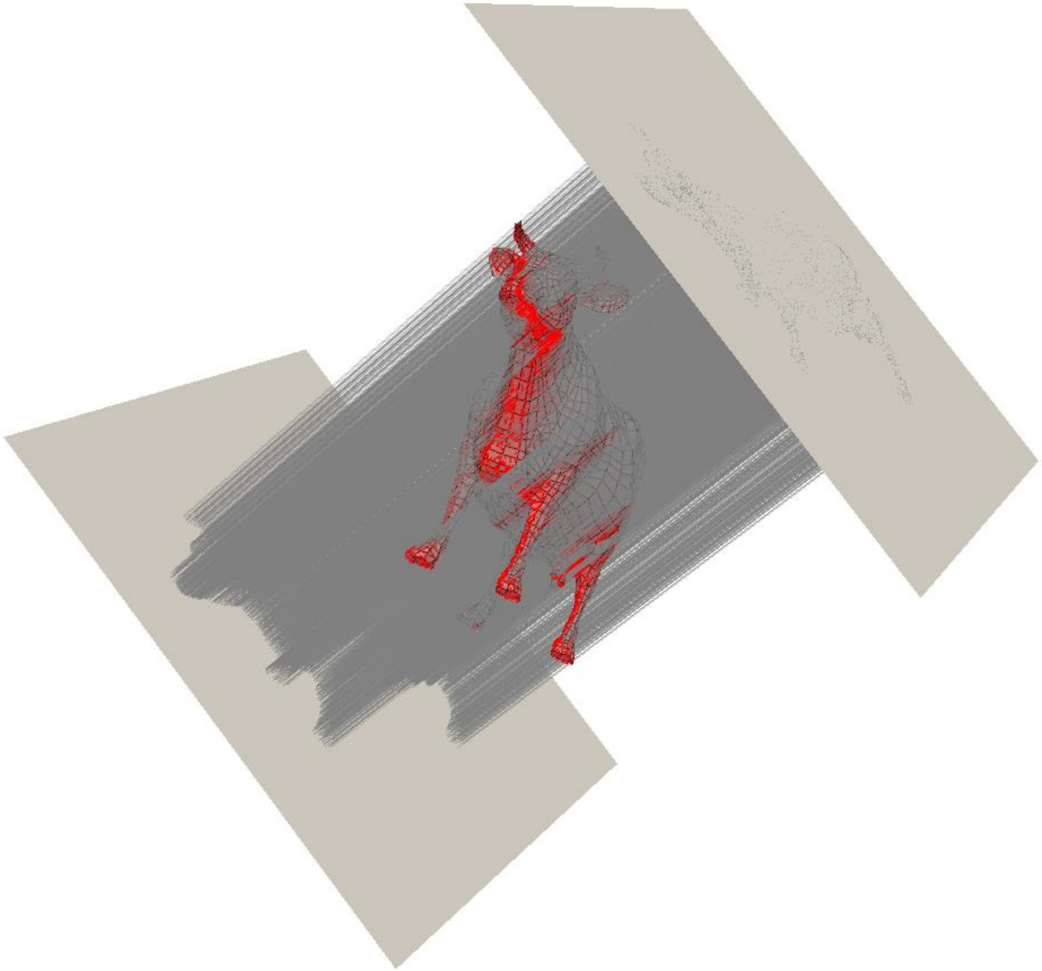
THE UNIVERSITY of ADELAIDE

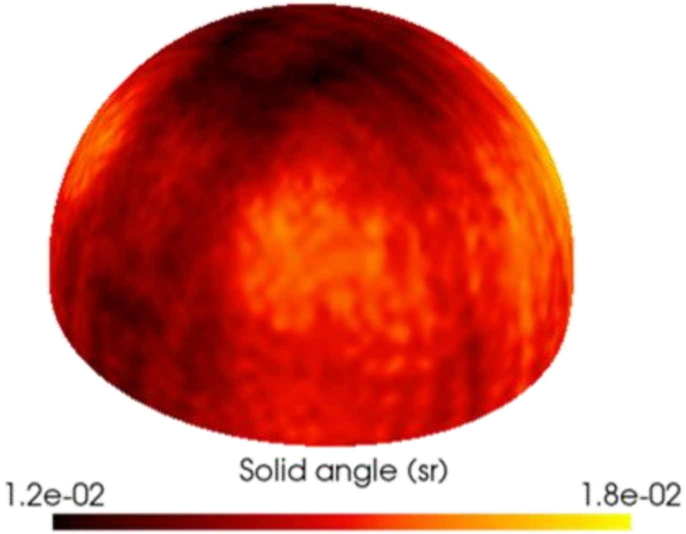
DaisyRad 200

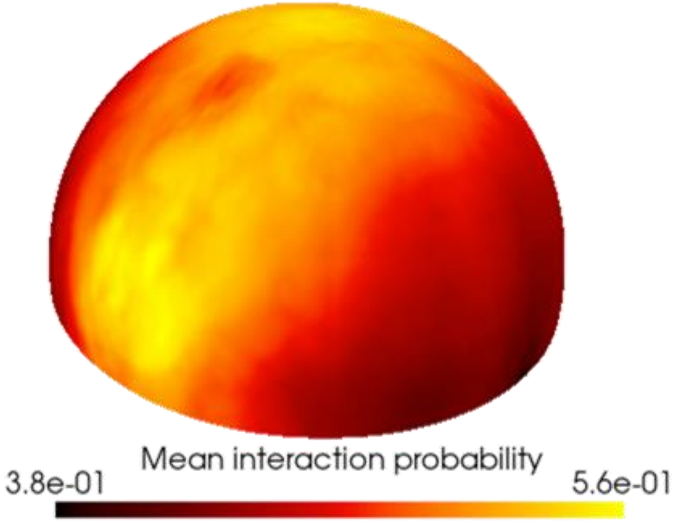
Material: EJ200
Density: 1.023 g/cm^3
Volume: 53573 cm^3
Mass: 54.8 kg
μ (662 kev): 0.086 cm^{-1}
α (662 kev): 11.6 cm

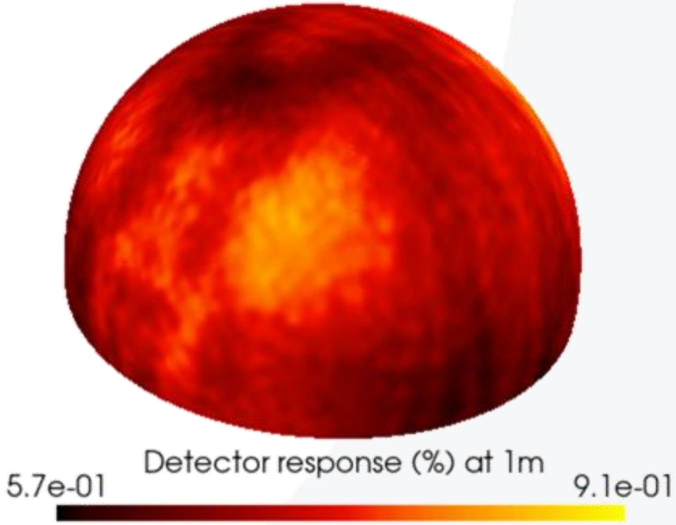




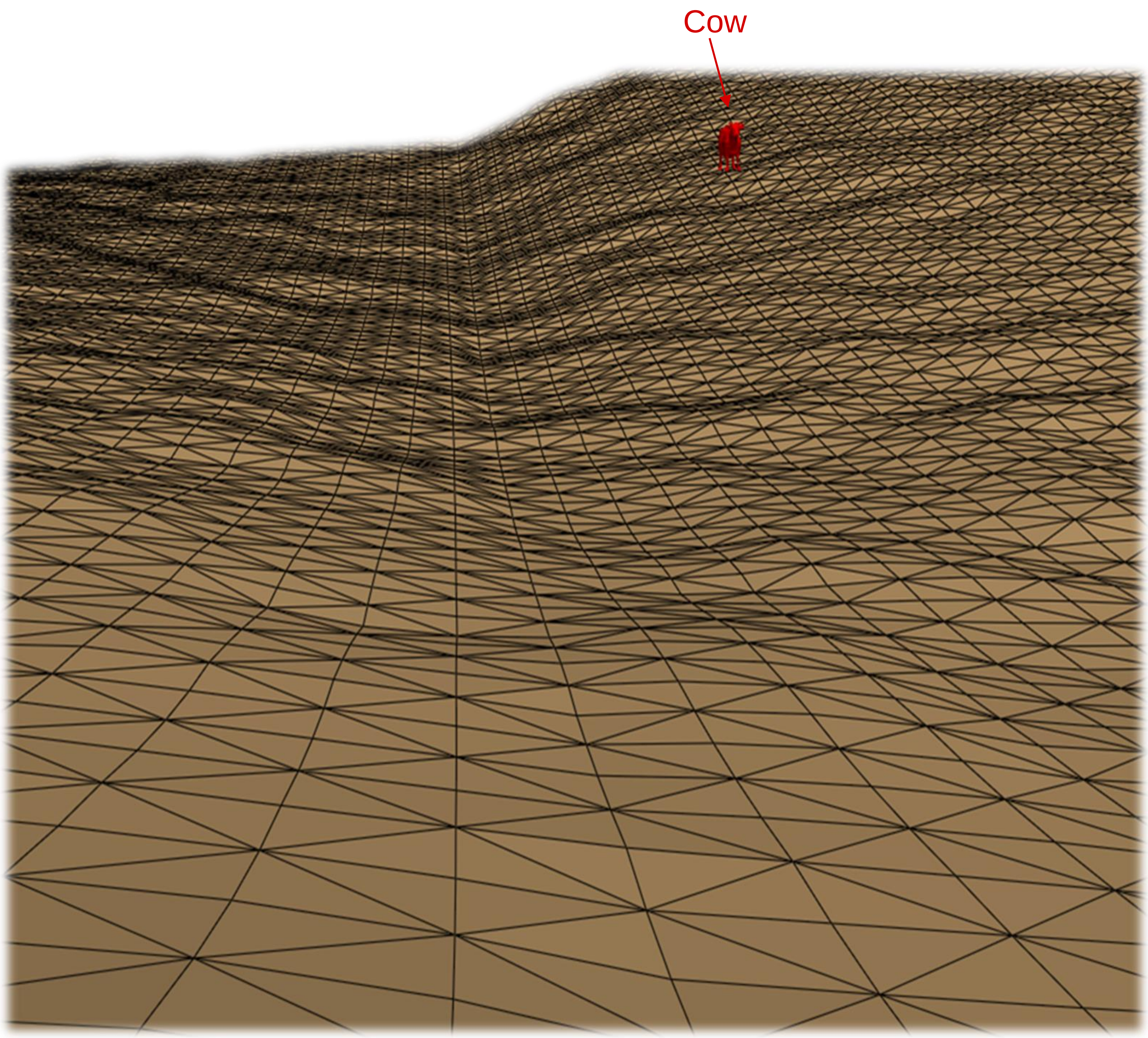








THE UNIVERSITY of ADELAIDE



Detector Response to complex scene

Mesh complex environment into cells

Each Cell Contains:

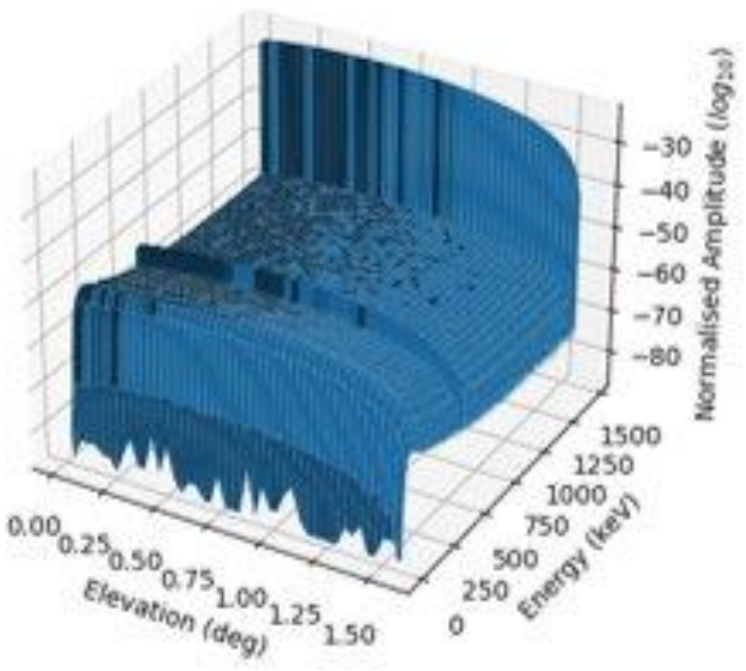
- Solid angle
- Attenuation
- Detector Interaction Probability
- Distance (r^2)
- Background Flux
- Background Angular Dependance
- Cell area

Source Strength calculated for each cell

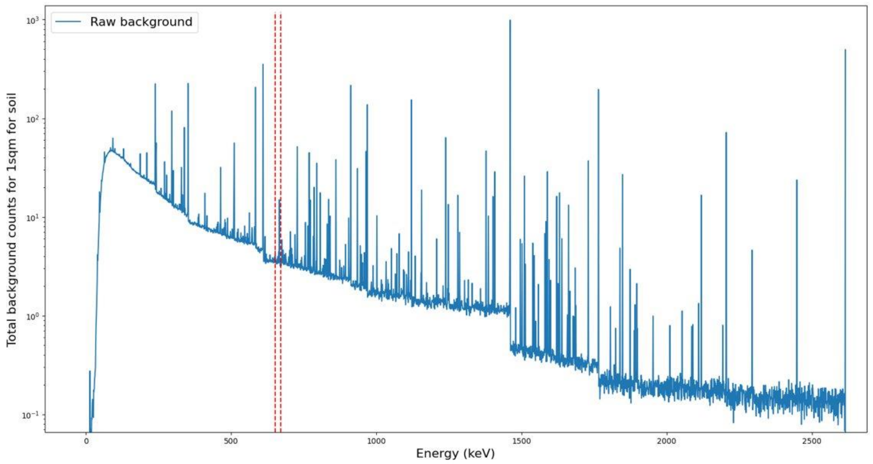
Background calculated for whole environment

THE UNIVERSITY of ADELAIDE

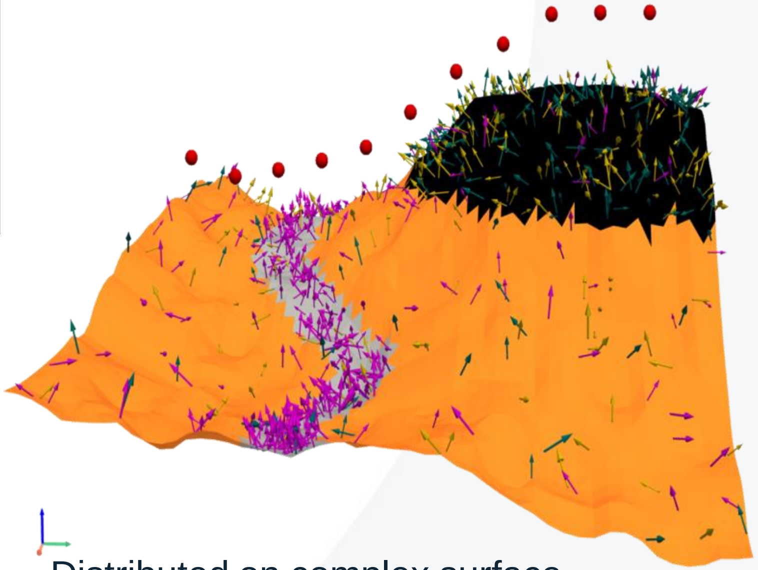
BACKGROUND MODEL



Energy and elevation from surface characterised from surface flux

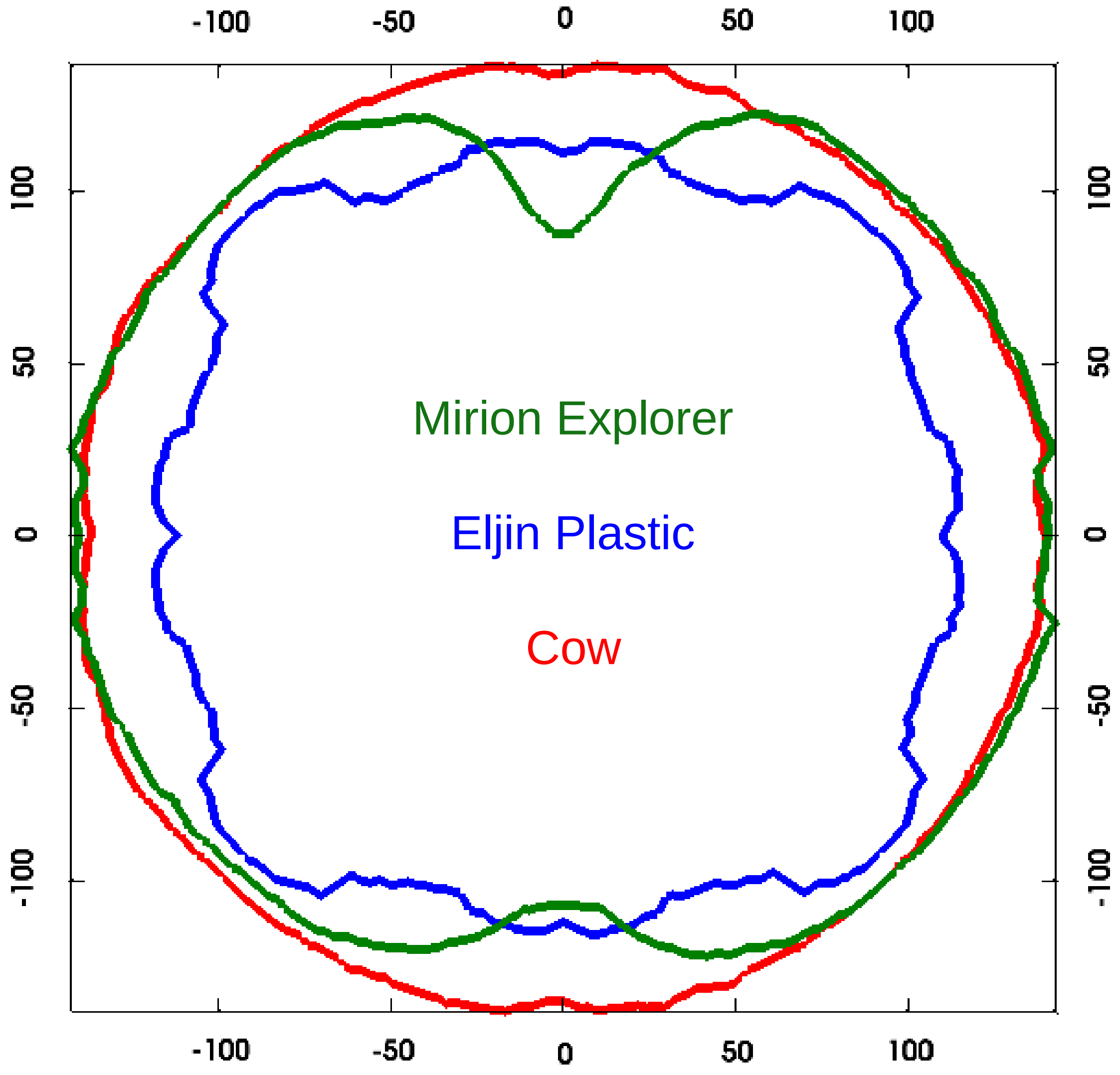


NORM probabilities and surface flux to create spectrum



Distributed on complex surface

Doughney, T, *IEEE NSS & MIC,* Milano, Italy 2022



Detector Footprints

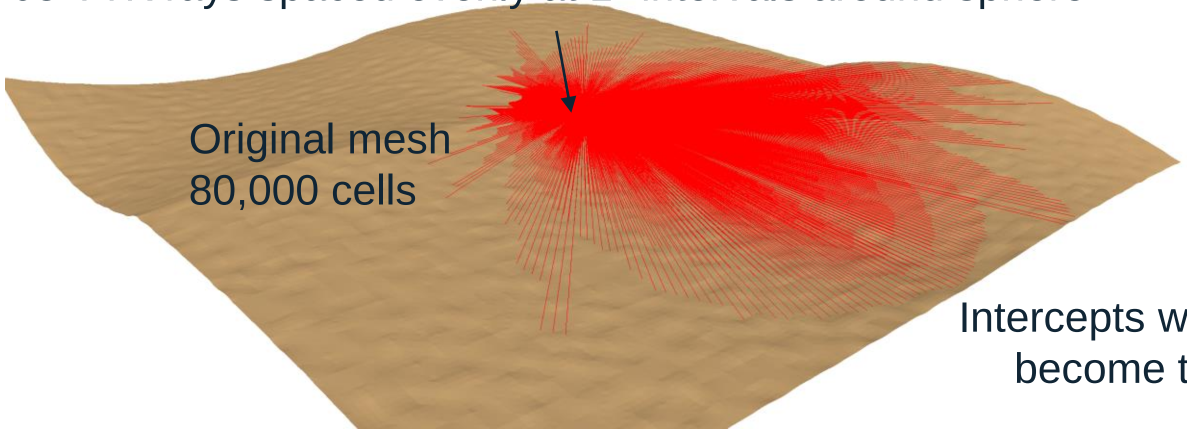
- 99% of total background incident at detector is contained
- Reduces computational resources required

How?

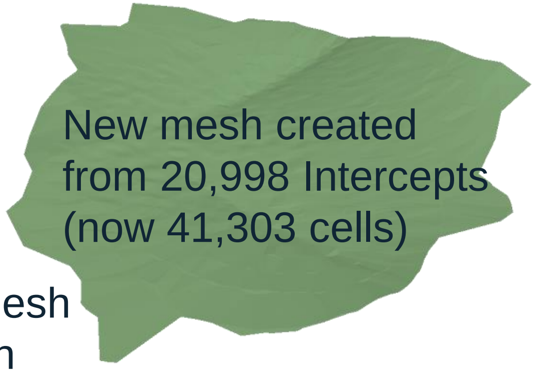
- 1^{o} slice extending out to horizon
- Source strength measured at 1m intervals
- Cumulatively summed
- Determine where 99% contribution is

Resampling the terrain

41708 VTK rays spaced evenly at 1^{o} intervals around sphere



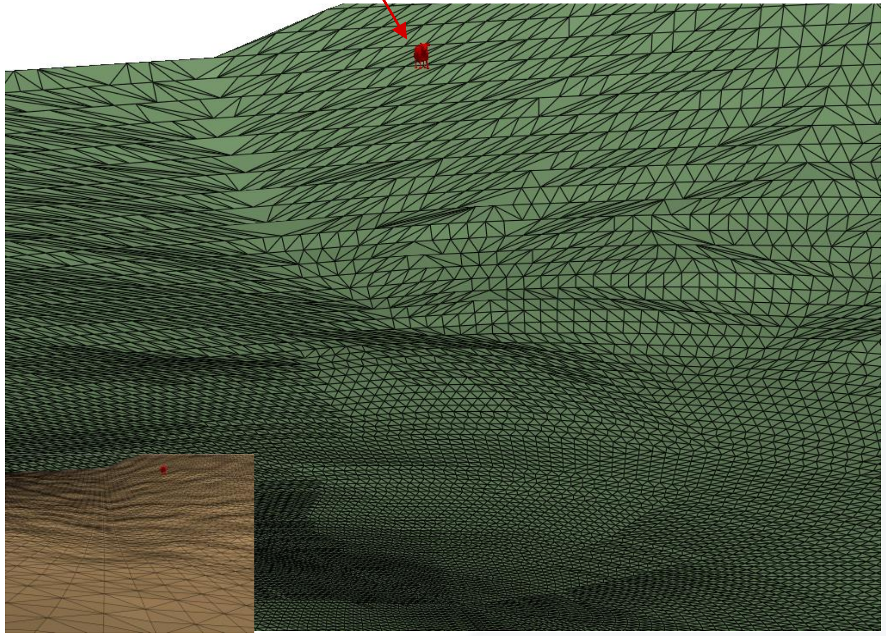
Original mesh
80,000 cells



New mesh created
from 20,998 Intercepts
(now 41,303 cells)

Intercepts with original mesh
become the new mesh

Cow

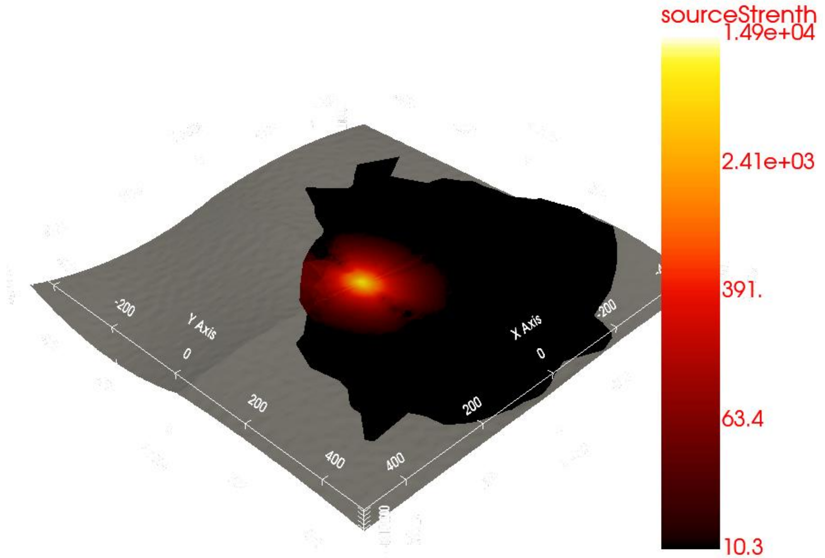


<u>Why</u>

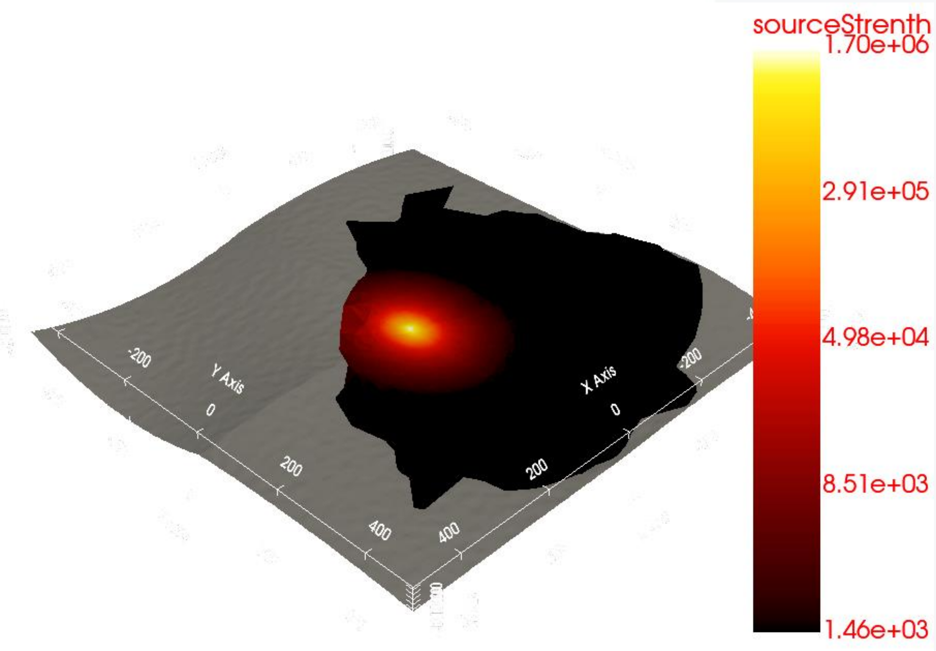
- Old mesh can be too big
- Deals with obstructions.
- Reduces errors.
- Angular error now less than 1^{0}

Detector response

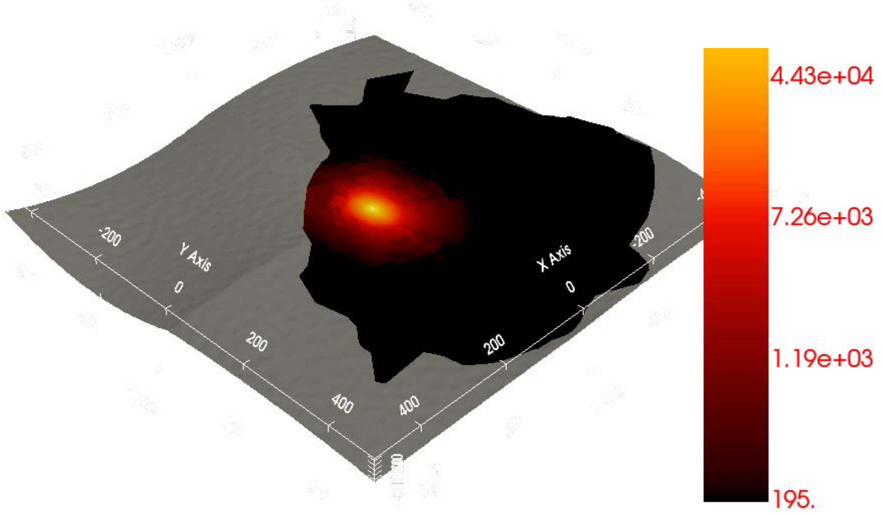
Source: 1GBq Cs137 sou



Mirion explorer



Cow



Eljen Plastic

Background threshold
Source cannot be detected under threshold

16

Summary:

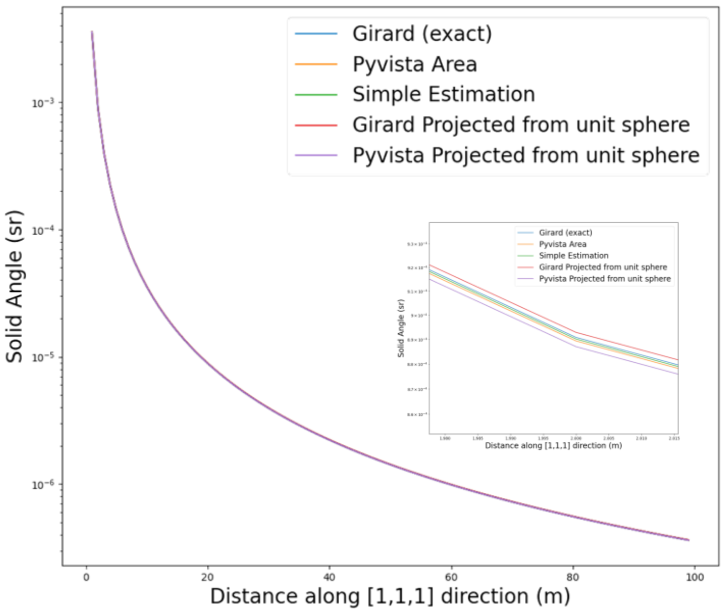
- Solid angle and Average Detector Interaction probability calculated for detector geometry
- Method works with simple and complex geometries
- Measured for a set of all Azimuths and Elevations, stored in interpolation function
- Background radiation used from Surface Distribution model
- Source and background projected through space to detector
- Resampled terrain using ray tracing
- Footprint for background created to reduce computation time

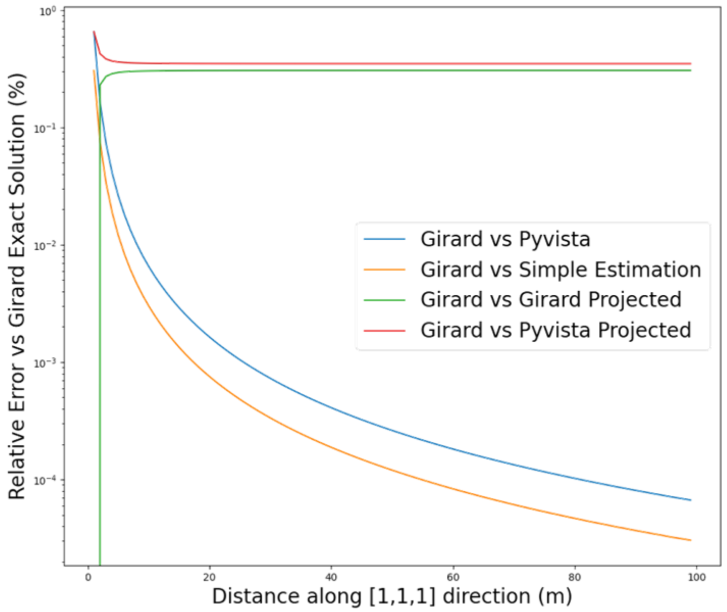
Next Steps

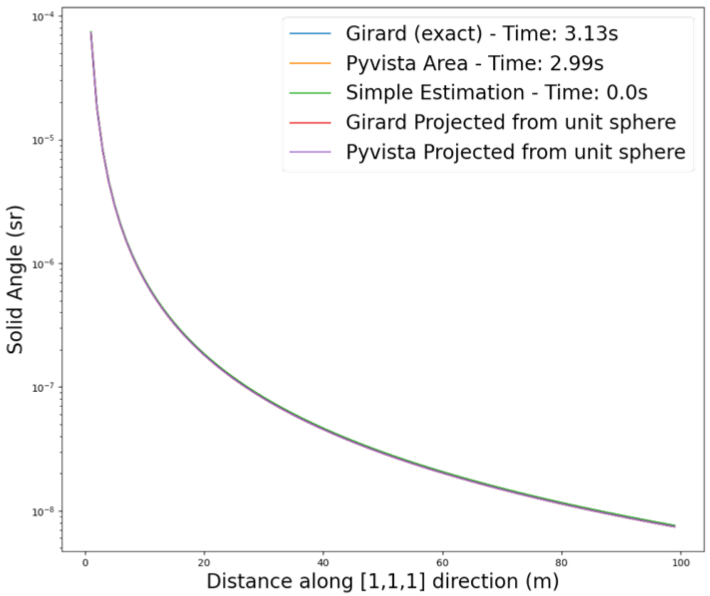
Fast Forward Model ⇨ Full Monte Carlo Model ⇨ Real World Data

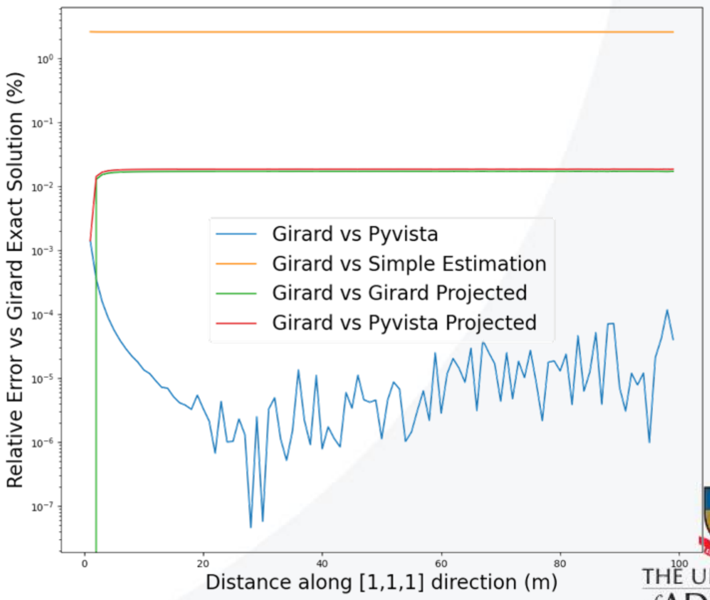
THE UNIVERSITY of ADELAIDE

QUESTIONS?

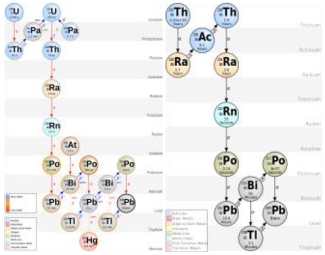

Girard (exact)
Pyvista Area
Simple Estimation
Girard Projected from unit sphere
Pyvista Projected from unit sphere
Solid Angle (sr)
Distance along [1,1,1] direction (m)


Girard vs Pyvista
Girard vs Simple Estimation
Girard vs Girard Projected
Girard vs Pyvista Projected
Relative Error vs Girard Exact Solution (%)
Distance along [1,1,1] direction (m)

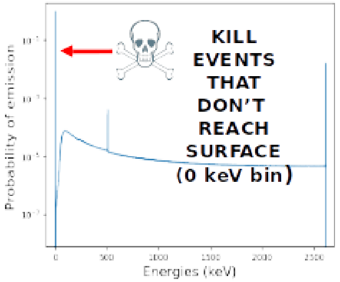

Girard (exact) - Time: 3.13s
Pyvista Area - Time: 2.99s
Simple Estimation - Time: 0.0s
Girard Projected from unit sphere
Pyvista Projected from unit sphere
Solid Angle (sr)
Distance along [1,1,1] direction (m)


Girard vs Pyvista
Girard vs Simple Estimation
Girard vs Girard Projected
Girard vs Pyvista Projected
Relative Error vs Girard Exact Solution (%)
Distance along [1,1,1] direction (m)

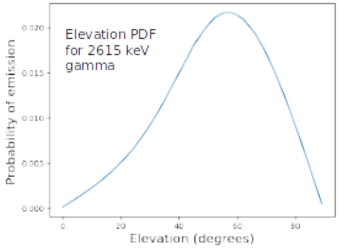
BACKGROUND MODEL STEPS



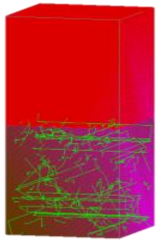
NORM: 40^{K} – 238^{U} – 232^{Th}



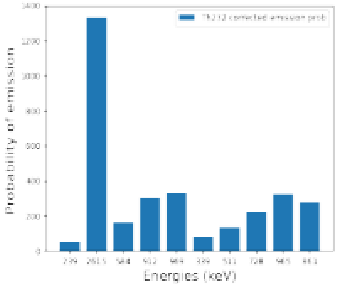
Surface Output energies for 2615 keV photon



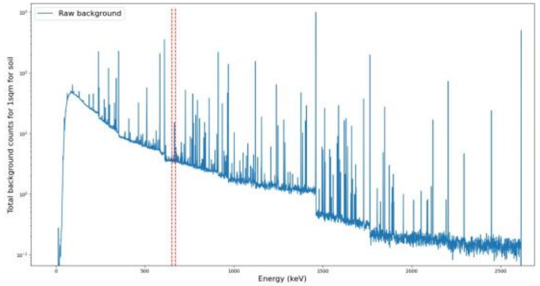
Surface elevation angles for 2615 keV output photon



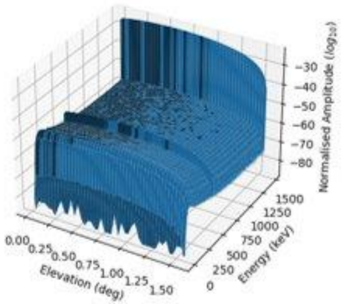
Periodic Boundary model in Geant4. Sensitive Detector in Red



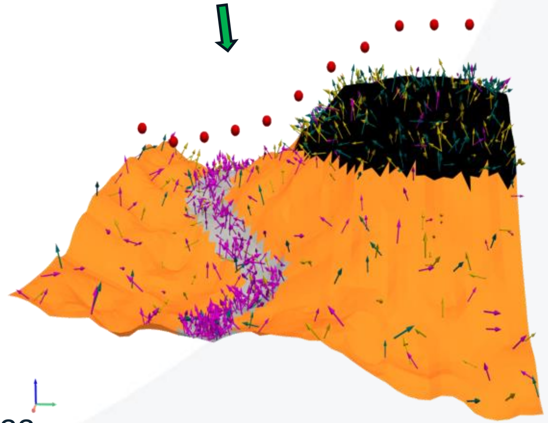
Depth weighted probabilities for first 10 energies in the ^{232}Th chain



Detector independent Background spectrum for Gamma flux from 1m^{2} of soil



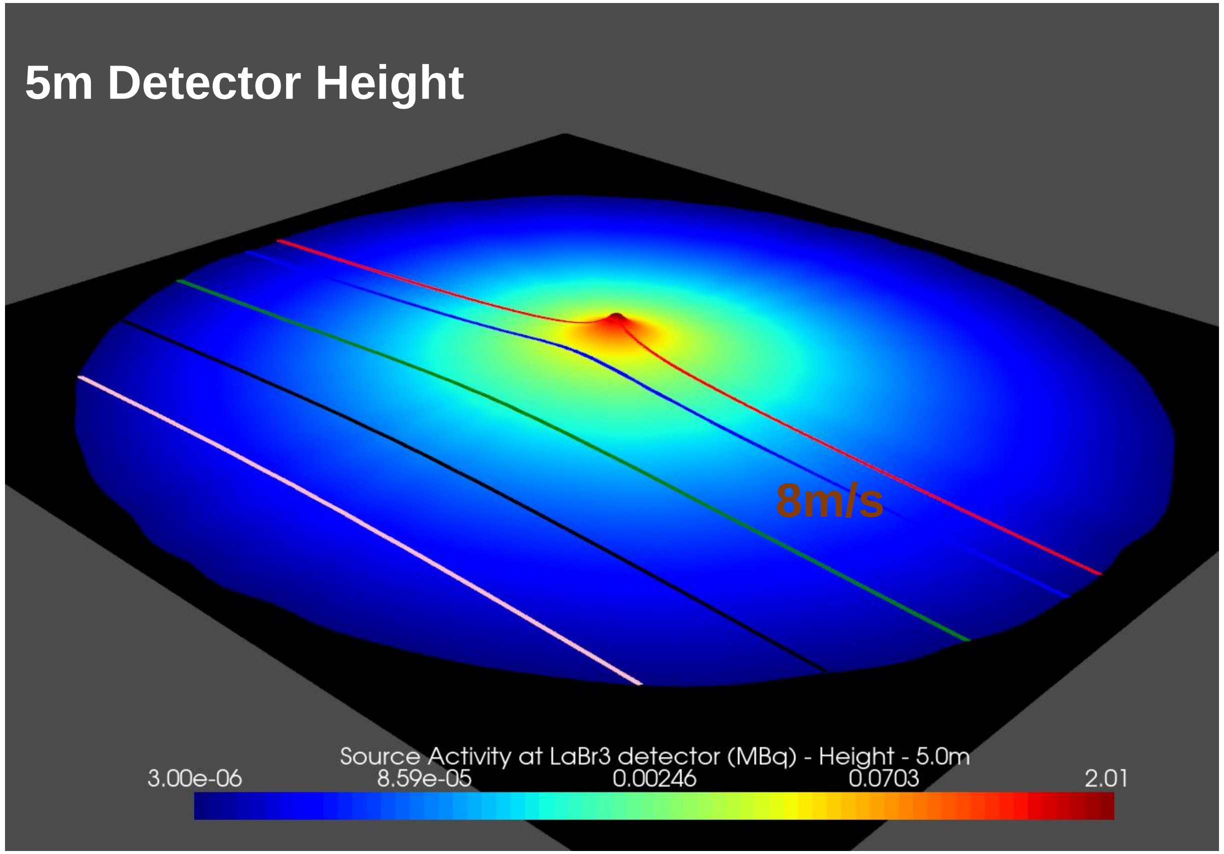
Energy and elevation from surface



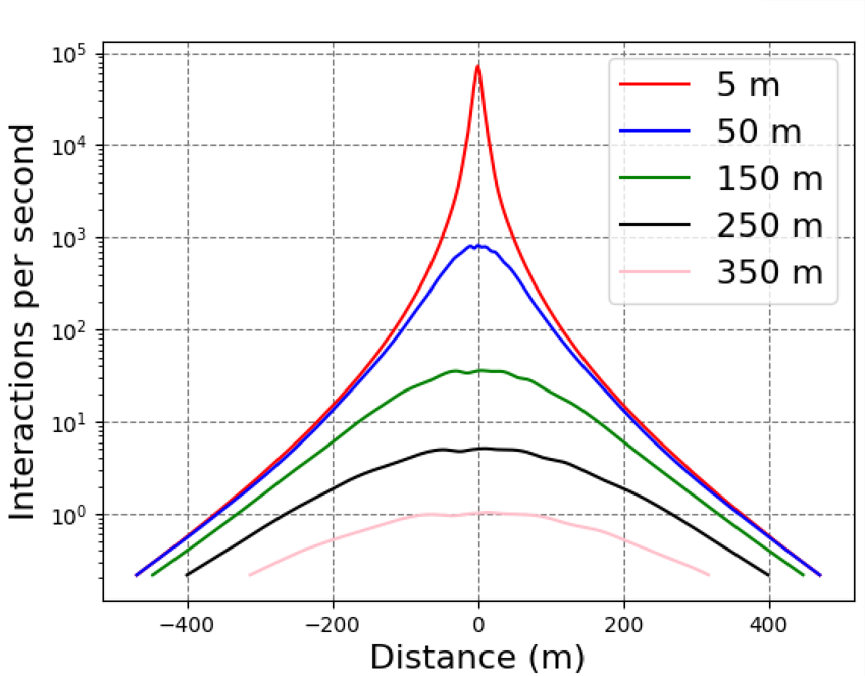
Doughney, T, *IEEE NSS & MIC,* Milano, Italy 2022

THE UNIVERSITY of ADELAIDE

Driving (or flying) at 50km/h = 13.8m/s



Sorce counts at LaBr3 detector at 5m detector heights. Black represents below threshold. Lines represents UAV path relative to source at lateral placements of [5,50,150,250,350] m



5m high LaBr3 detector profiles for varying lateral standoff distances with a source strength of 19 GBq

Simple model does not include:

- Shielding from (Car, terrain, rocks, shielding, a little old rock
- Cosmic Radiation
- Background variations (material, height, concentrations)
- Detector counting efficiency
- Detector noise

THE UNIVERSITY of ADELAIDE