HT NUCLEAR

Novel In-field Technologies for Source Localization

Harri Toivonen HT Nuclear Oy

Mark Dowdall Norwegian Radiation and Nuclear Safety Authority

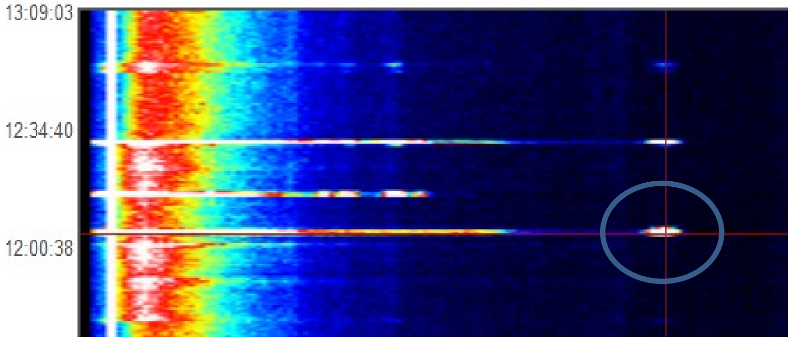
Sakari Ihantola Radis Technologies Oy

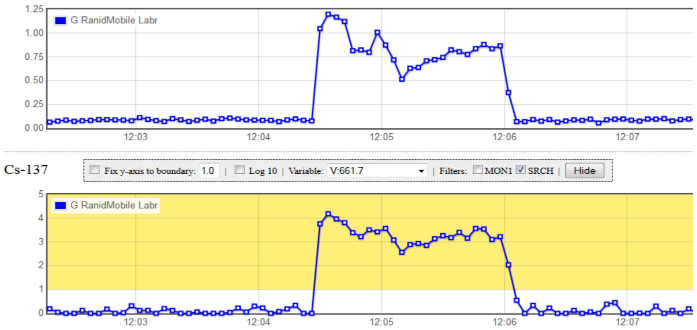
NKS GammaSkill
27-28 Sep 2023, STUK, Finland

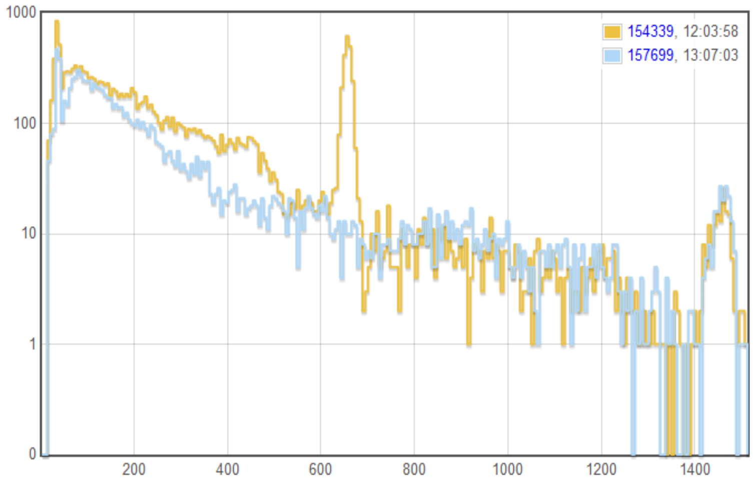
harri.toivonen{at}htnuclear.fi
www.htnuclear.fi

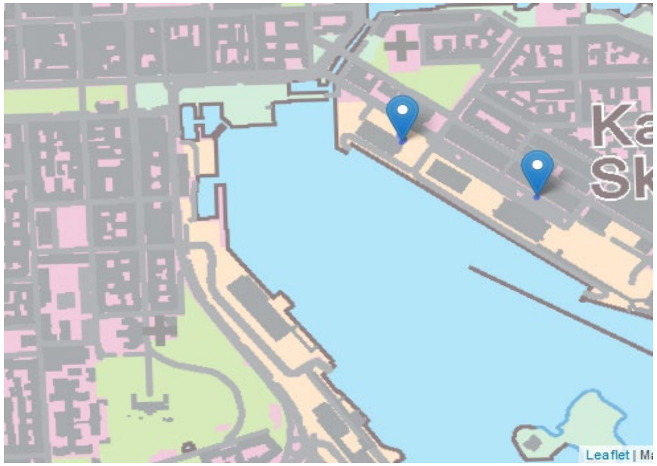
Contents

Typical in-field search mission for MORC
Mobile teams provide continuously geodata and spectral data









Waterfall plot
Alarm spectrum vs background

Time series of counts (cps in ROI)
Labelling of alarm locations

Job done or is it?

Source localization capability needed for mobile, static and dynamic situations

Data processing from two or more detectors!

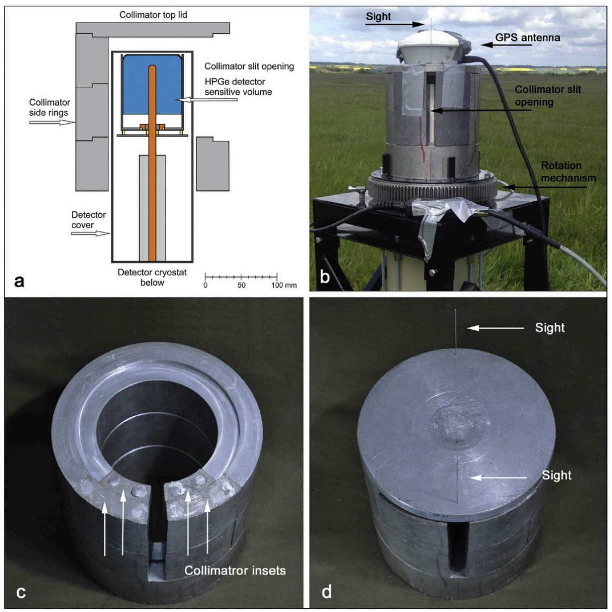
Source Localization

Choke point monitoring is the current operational approach but more efficient technical solutions are warranted.

1/8. Rotating collimator

- Computer controlled cylindrical rotating slit collimator
- Detector placed in the cylinder

Sweden

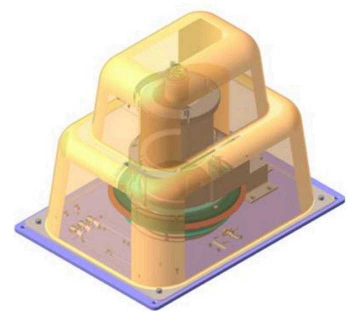


Mounted on a car-towed trailer

Jonas M.C. Nilsson, Robert R. Finck, Christopher L. Rääf

https://doi.org/10.1016/j.jenvrad.2017.07.007

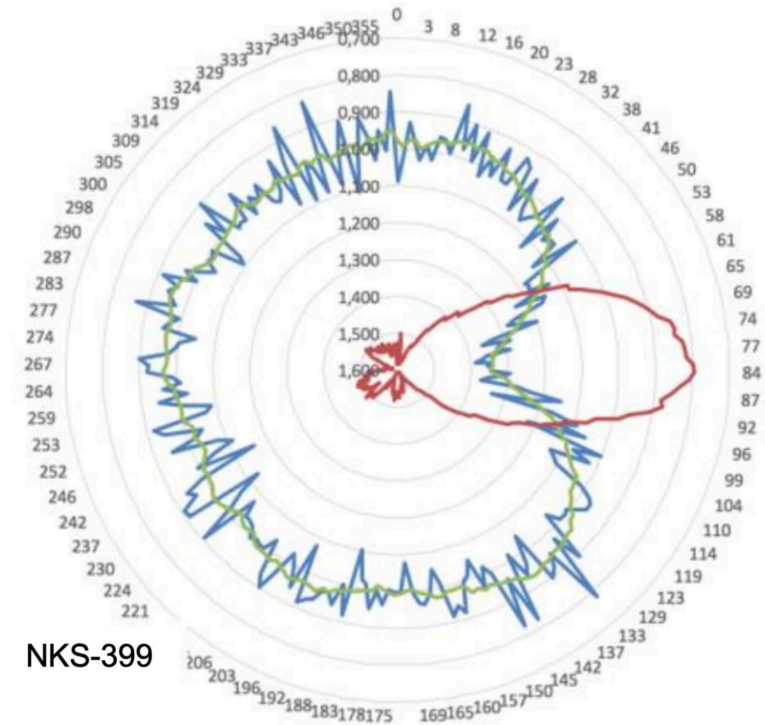
Russia



2/8. Rotating anticollimator

A small shield rotates
360 degrees in 12 seconds.

The source is where the count rate is the lowest.



NKS-399

RanidPro200, Environics Ltd

NKS RadShield 2017

3/8. Advanced analysis of pre-amplified pulses

- Direction-sensitive information is embedded in the shape of the pre-amplified HPGe signals.
- Machine learning techniques for linking the shape of the signal pulses and the direction of the gamma-ray entering the active volume of the detector
- Rough initial guidance on the location of the source

  https://doi.org/10.1016/j.nima.2022.167067

4/8. Coded Aperture

- Mask in front of the detector
- Incident source radiation casts multiple overlapping shadows on the detector array
- Signal processing is then used to reconstruct an image
- Reduced sensitivity due to the presence of the mask. Suitable for low-energy gamma emitters, such as Am-241, Tc-99m and neutrons

  https://doi.org/10.1016/j.radmeas.2016.08.002

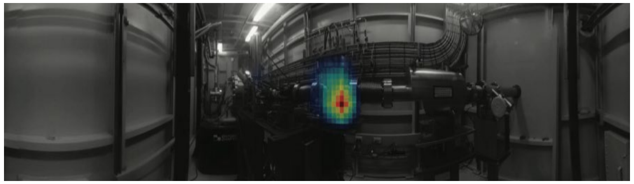
5/8. Single-pixel imaging and compressed sensing

- Single-pixel imaging (SPI) uses a single-pixel detector instead of a detector array
- Compressed sensing is a signal-processing technique for acquiring and reconstructing a signal. It finds a solution to underdetermined linear systems.
- The recorded intensity is sampled by SPI to reconstruct the target image.

https://www.mdpi.com/1424-8220/23/10/4678 (China)

CORIS360® - ANSTO

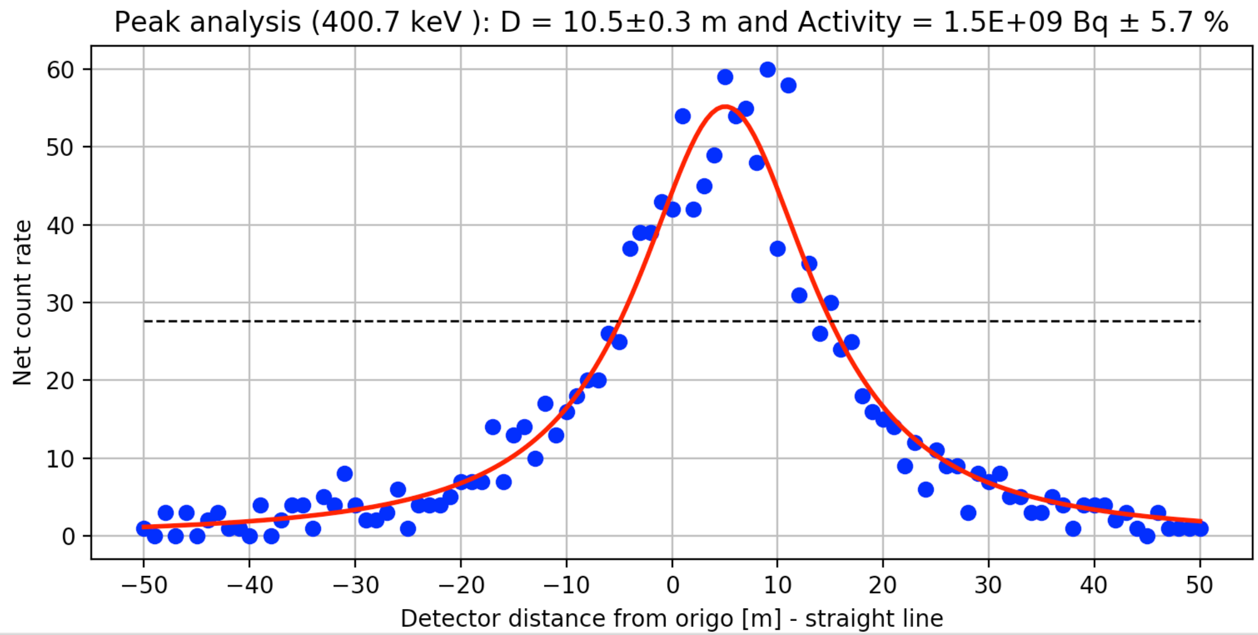
- SPI (CLLBC Gamma-Neutron Scintillator)
- Two nested cylindrical tungsten masks that independently rotate around the detector
- 360° × 90° gamma and optical field-of-view (FOV)



https://accelconf.web.cern.ch/ibic2021/papers/tupp36.pdf

6/8. Combined measurements in different locations

Simulated data



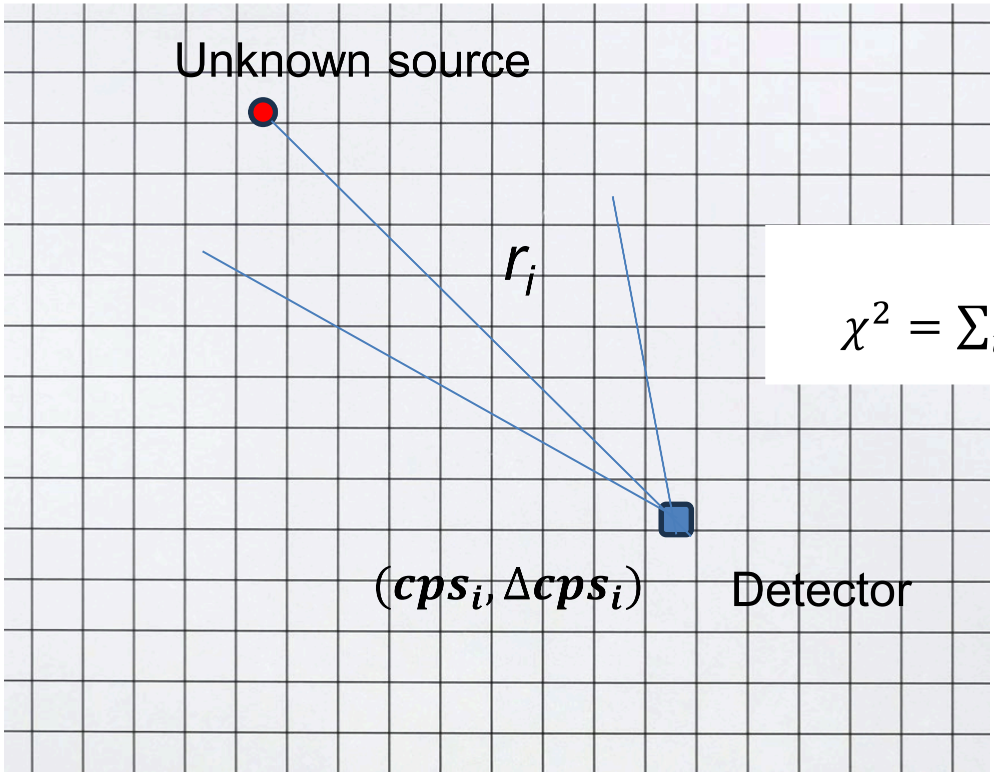
Passing a source on straight line

Fitting is fine – but problems

- Which side of the road?
- Unsymmetrical shield?
- Statistics
- Uncertainty analysis
- Practical implementation difficult

More efficient tools are required to handle uncertainties involved

Likelihood principle for source localization



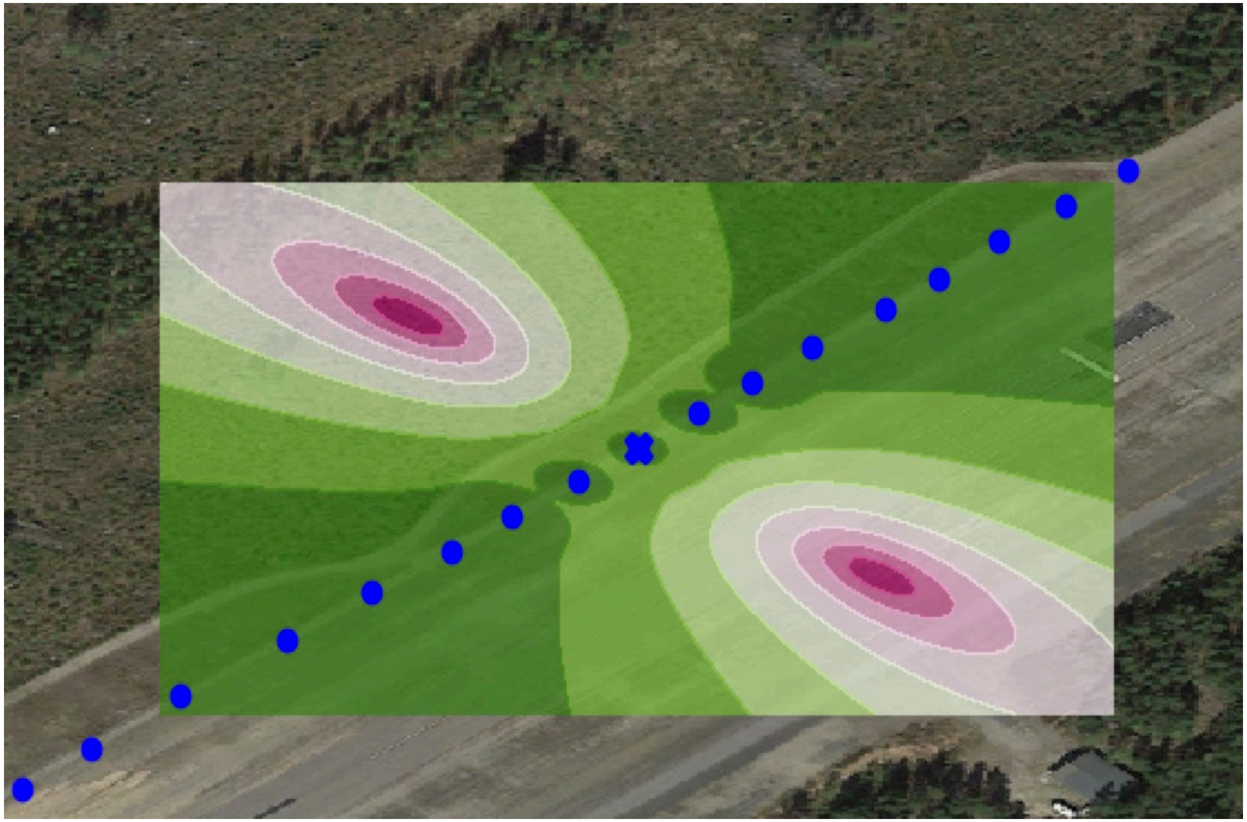
$$\chi^2 = \sum_i \frac{1}{\Delta cps_i}\left(cps_{calc,i} - cps_{meas,i}\right)^2$$

χ^2 calculated for every pixel

- Three measurements are enough for localization.
- Four or more measurements provide credibility.

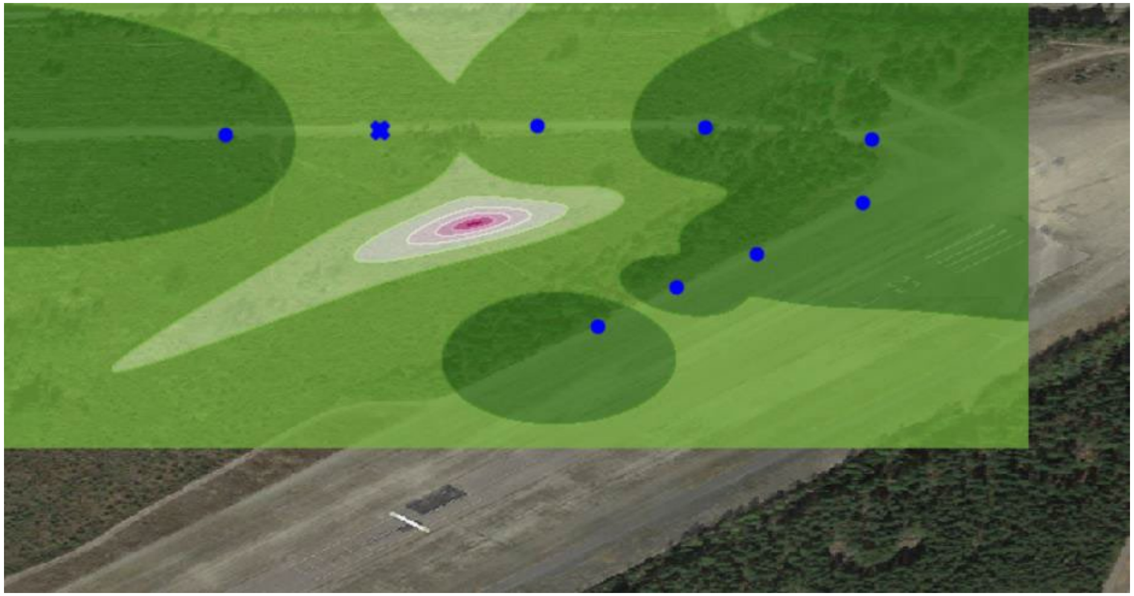
H. Toivonen, M. Dowdall, M. Baron, E. Kroeger
https://doi.org/10.1016/j.apradiso.2023.110842

Simulated data



Likelihood map of possible source locations

https://drive.google.com/file/d/1oymK4EF5gGnhfcJ45SoL33aJoPwstTq1/view?usp=sharing

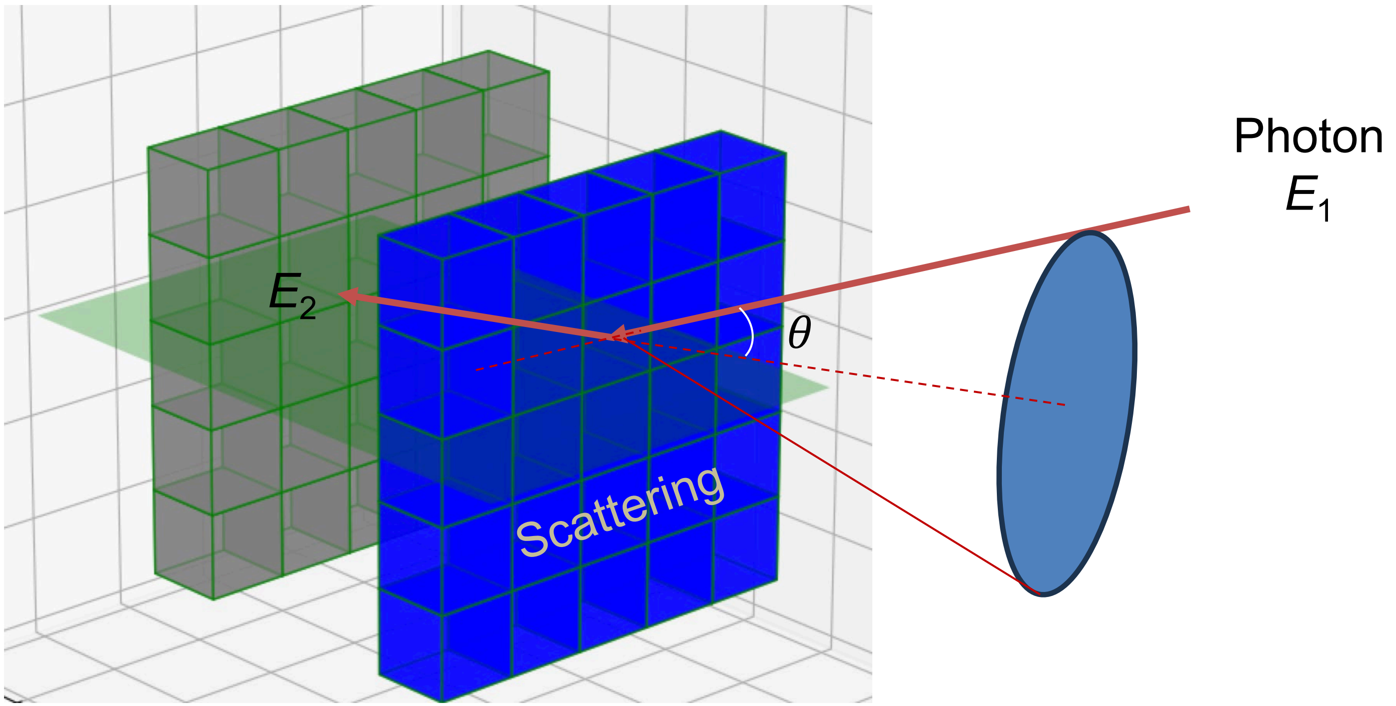


Simulated data

In-field measurements with a backpack

AmBe $6.3x10^6$ neutrons/s - BfS, Germany

7/8. Compton imager

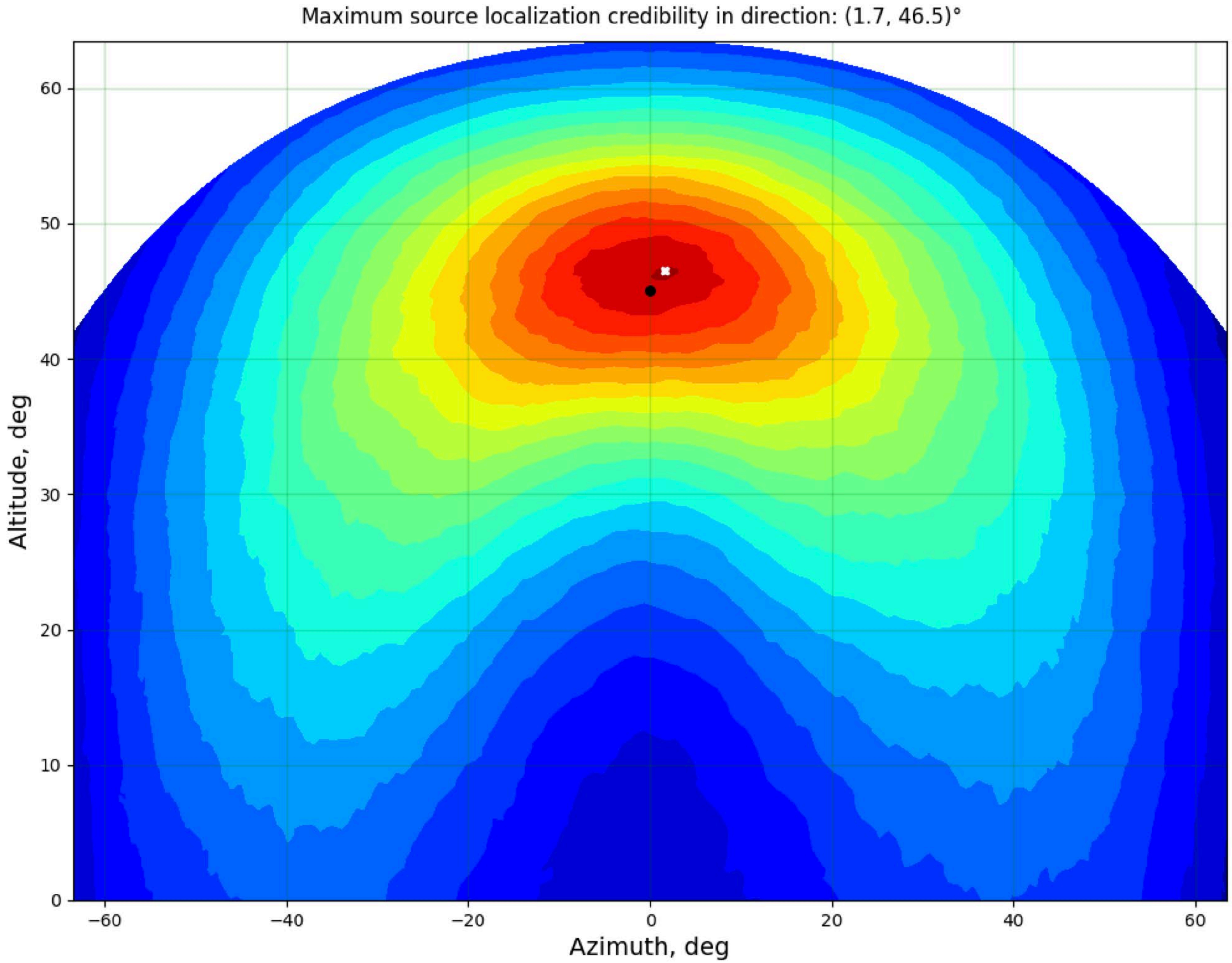


Parameters:

- Front panel size (n,n)
- Back panel size (m,m)
- Separation between panels
- Detector materials: resolutions/price/complexity

High-sensitive Compton telescope

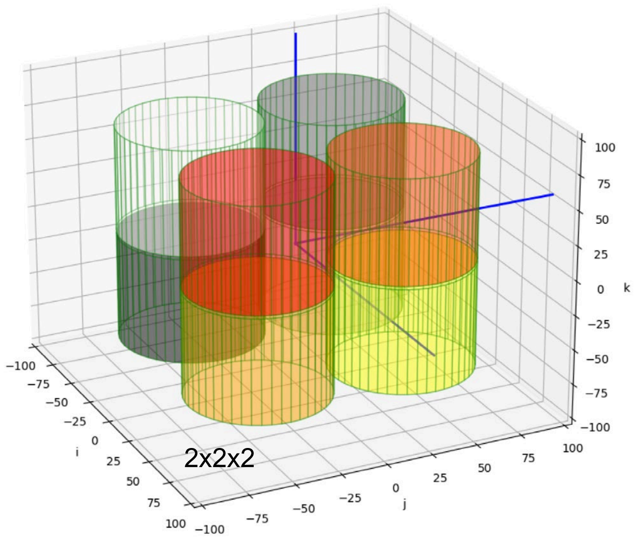
Cs-137 source in direction (azimuth, elevation) = (0, 45) deg

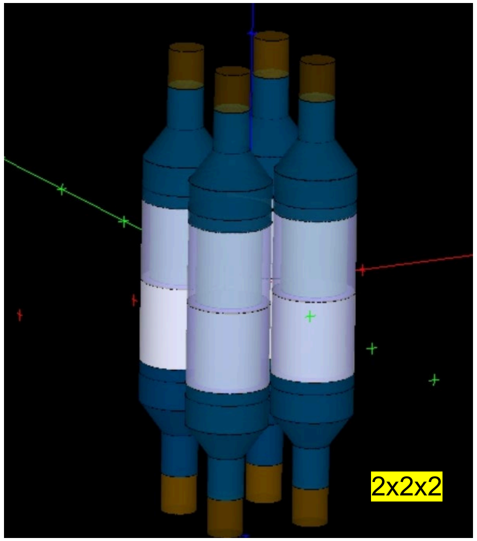


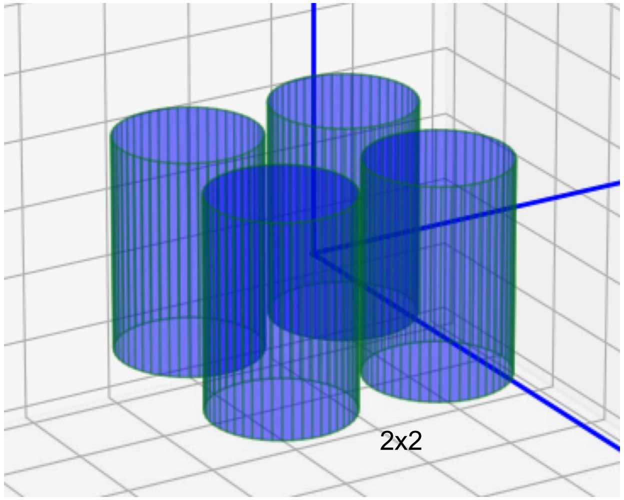
Data from Geant4 simulations

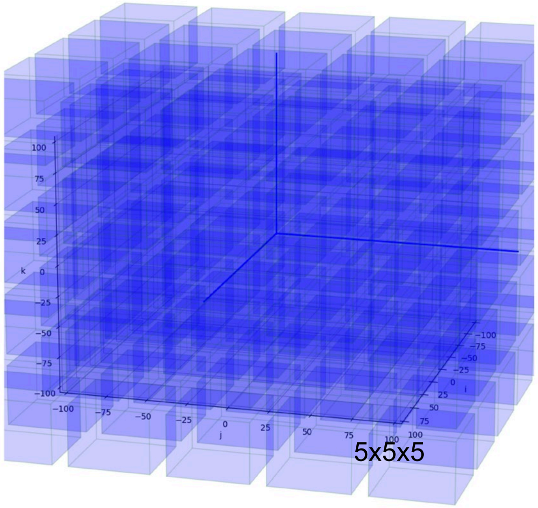
Front panels:	8x8 (plastic)
Back panels:	4x4 (NaI)

8/8. Detection array









Symmetry model for source directional analysis

1. Array of detectors provides an inherent detection advantage for those voxels which are nearest to the source.

2. If a photon interaction takes place in any of the voxels there may be another location within the array which is geometrically symmetrical relative to this interaction location (symmetrical exposure situation).

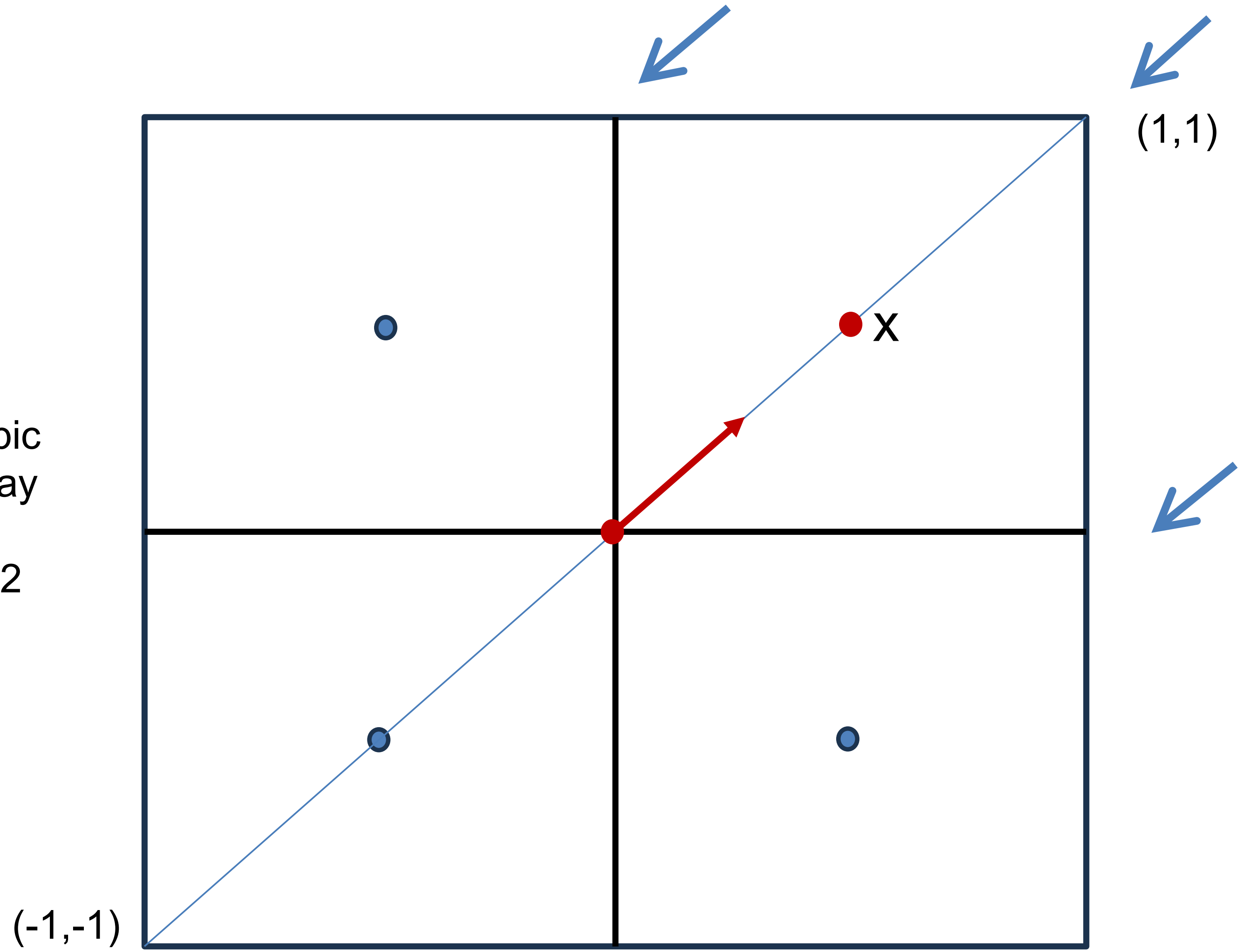
3. The average location of the photon interactions indicates the source direction.

4. A good surrogate for the average hit location can be computed from the known voxel centre coordinates.

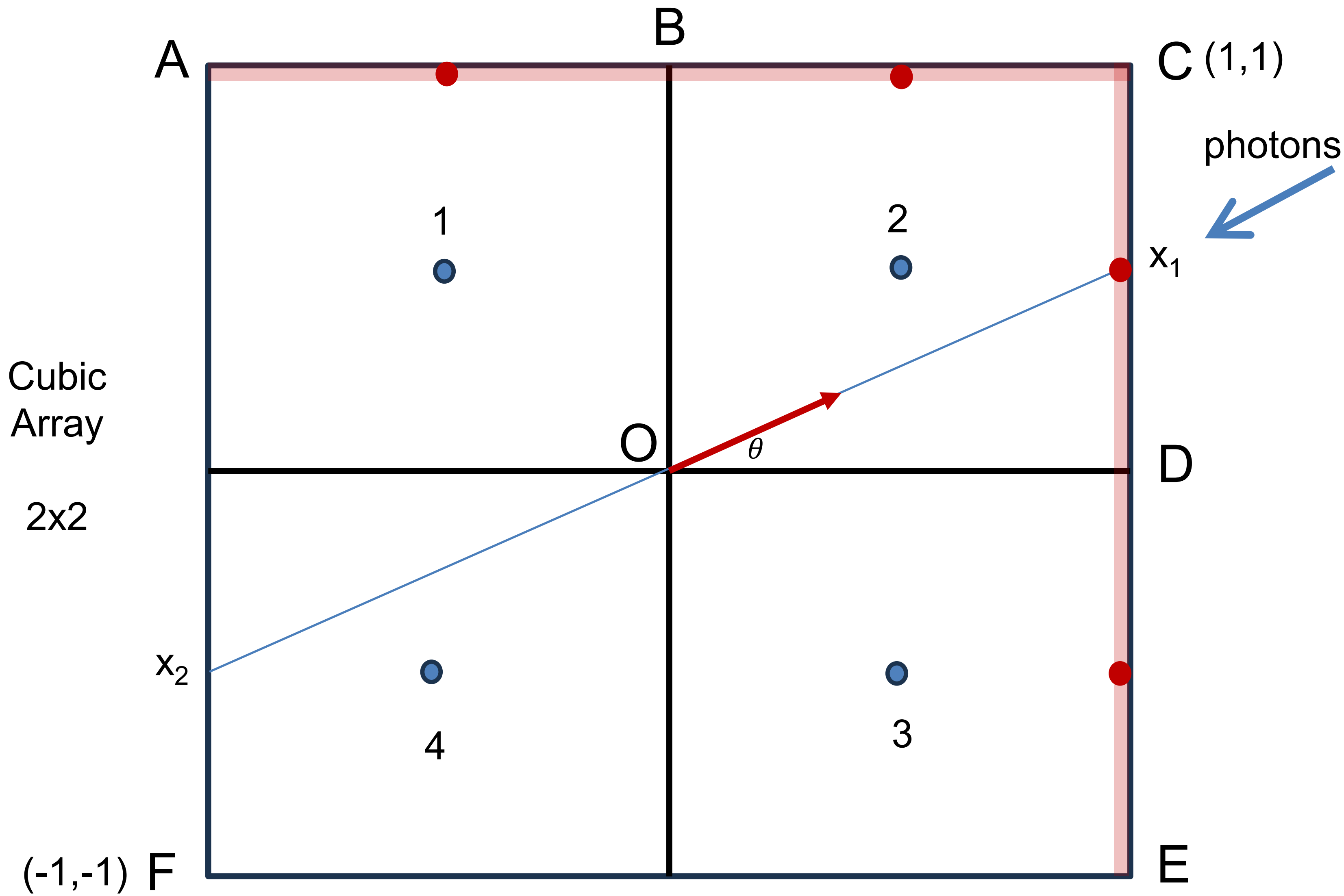
Complete symmetry at the angles of 0, **45** and 90 degrees

Cubic Array

2x2

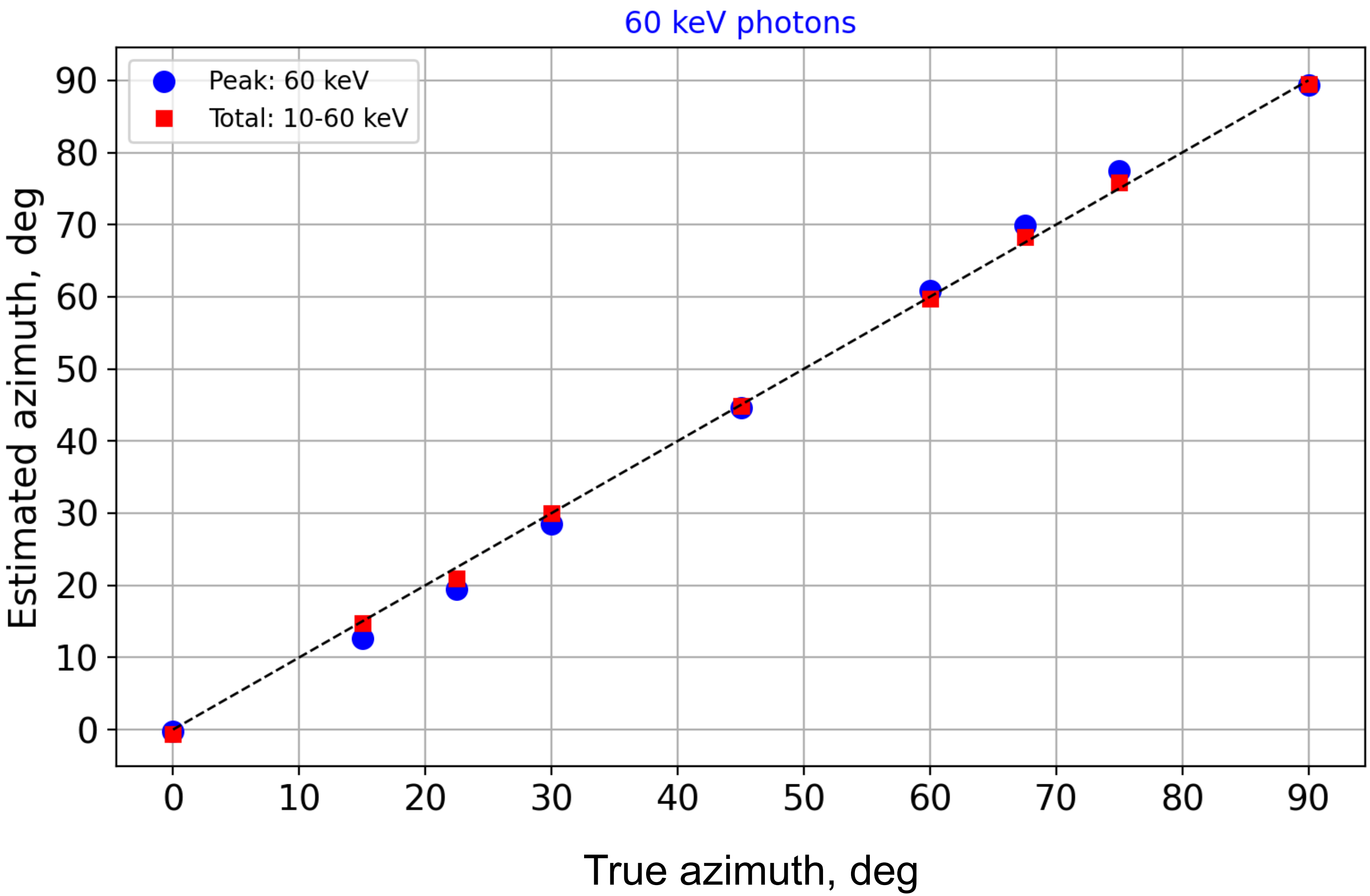


Low-energy radiation arriving from angle theta

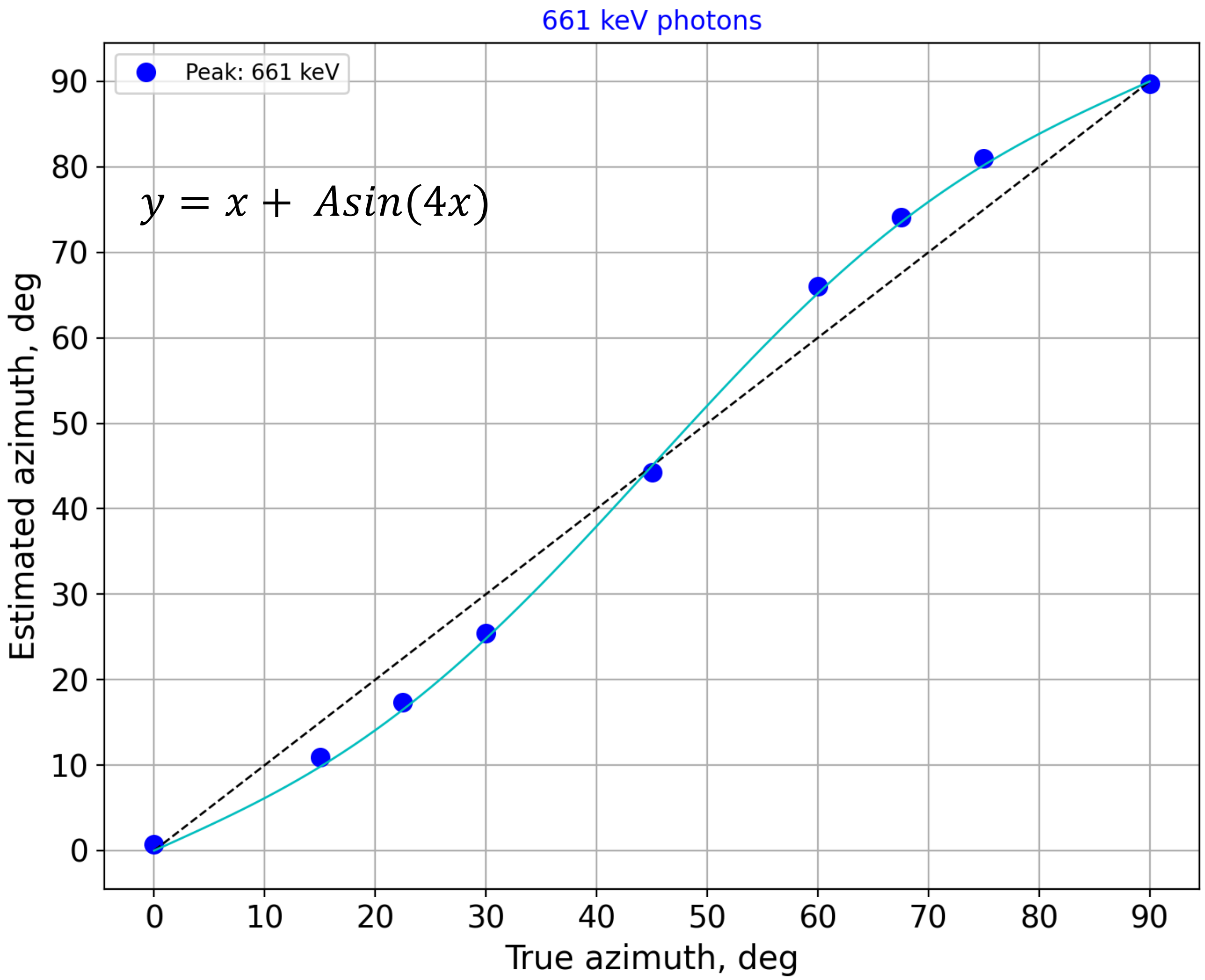


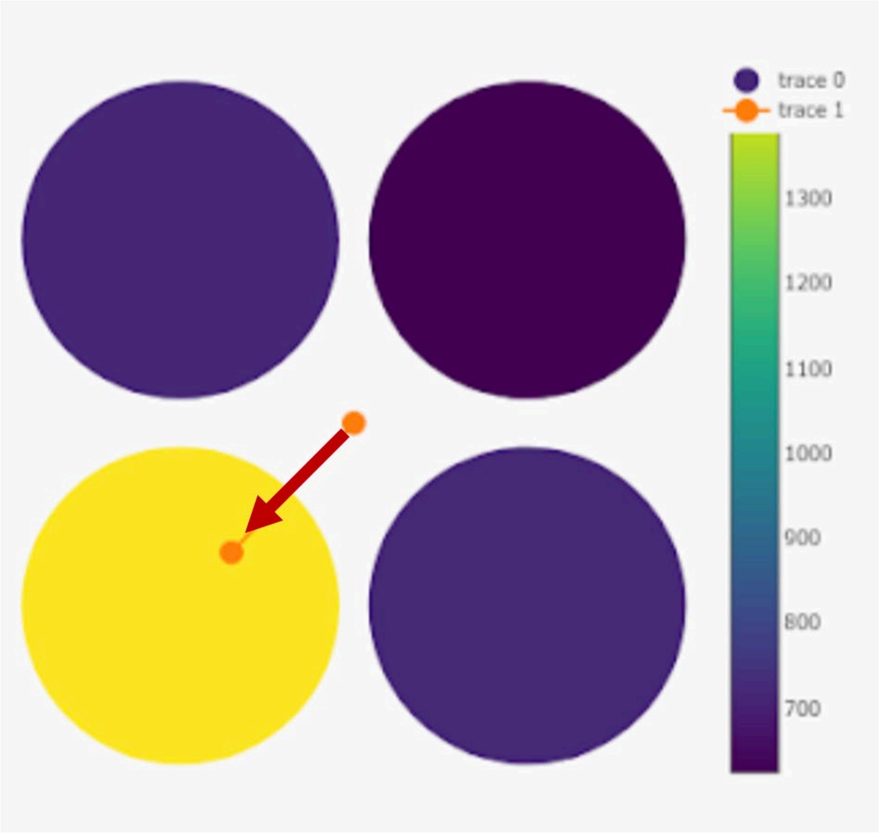
Directional analysis based on centre coordinates (1,2,3,4) of the voxels gives the correct source direction.

Directional response in 2x2 NaI array for 60 keV photons



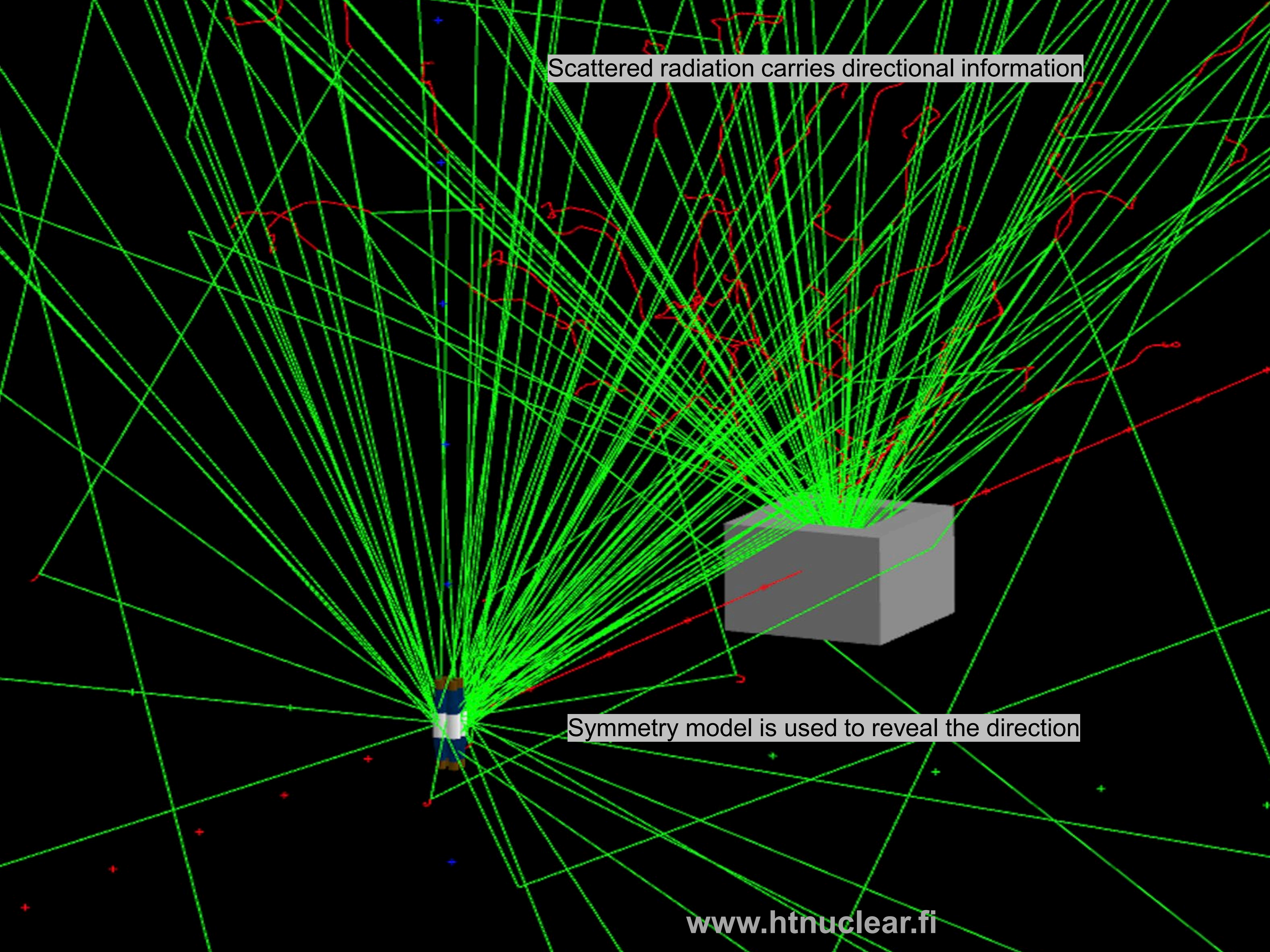
Directional response in 2x2 NaI array for 661 keV photons





The direction of the source can be calculated from the counts recorded by the NaI detectors.

Funded by the Scientific Advisory Board For Defence (MATINE) Project Matrix, 2023.



www.htnuclear.fi