Geant4 Simulation Study of Reinforced Concrete Blocks With Muon Imaging Techniques

Dr Guangliang Yang

University of Glasgow

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BAM

LINKEOS TECHNOLOGY LTD

Contents

Current NDT techniques

Techniques	Benefits	Concerns	
X-ray (Transmission)	3D high resolution images	Expensive, concern to the effect to human bodies and the environment	
Ultrasound (Echo)	Safe, fast, great penetration depth, excellent to detect voids, cracks, geometry.	Not possible to inspect beyond large objects, cracks or delaminations.	Both: Limited resolution and accuracy. Tradeoff between depth of penetration and resolution
Ground penetrating radar (Echo)	Safe, rapid, effective method, especially sensitive to metal .	Not possible to inspect beyond dense reinforcement	

Cosmic Ray Muon

- It has high penetrating power.

Relatively large elementary particles and travel at relativistic speeds, can penetrate tens of meters into rocks and other matter before attenuating as a result of absorption or deflection by other atoms.

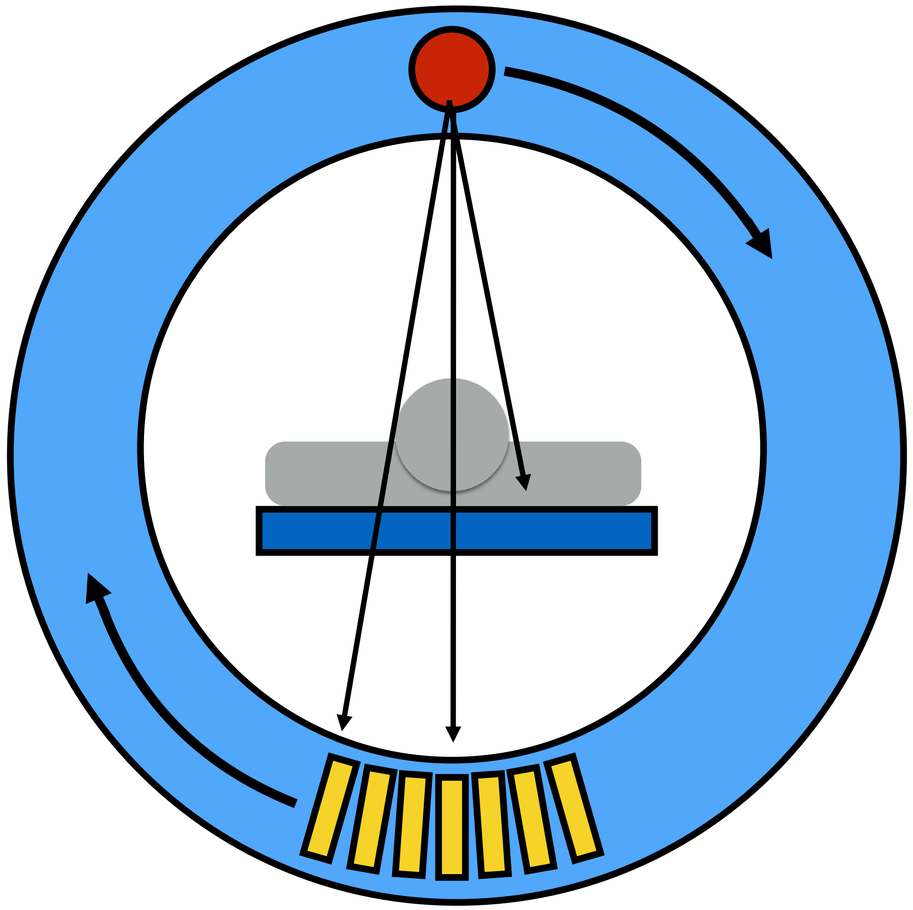
- It is cheap and safe.

It has no extra radiation dose to the people involved, and all natural occurring muons on earth are due to cosmic rays, so there are no additional cost for the particle source.

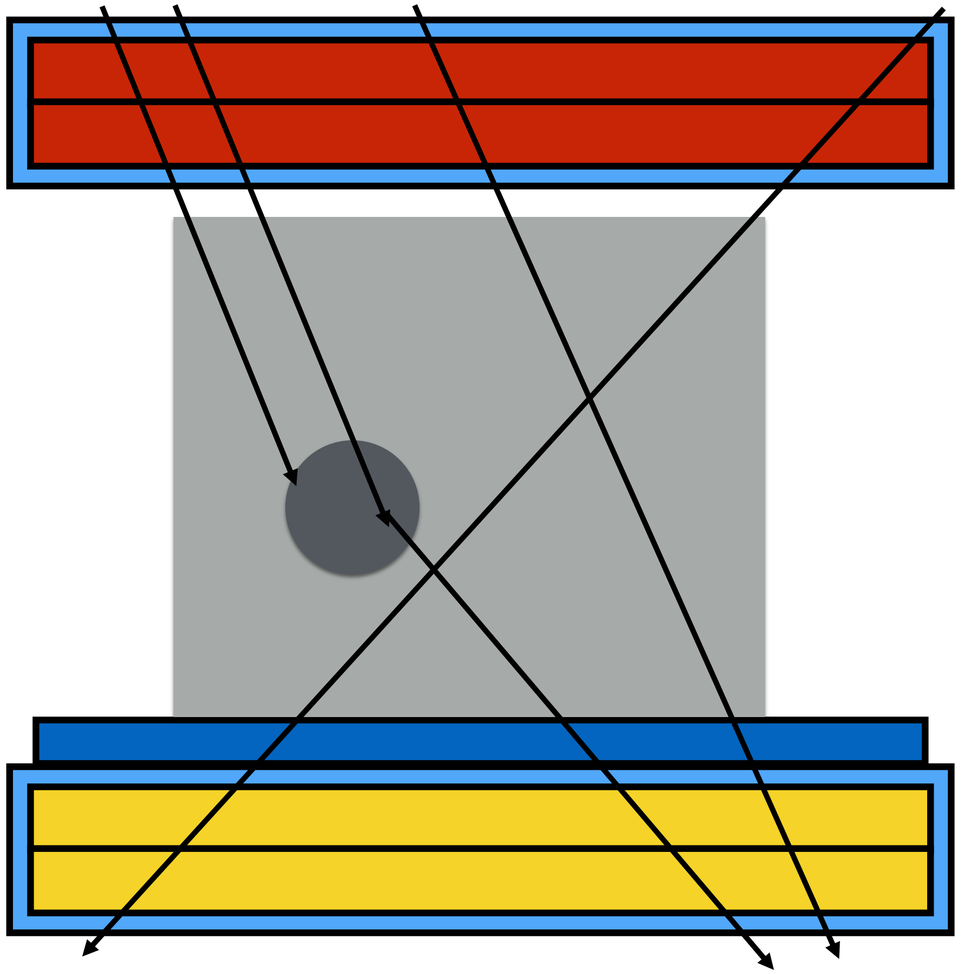
Multiple scattering

- When passing through matter, a muon is deflected by many small angle scatters.
- The multiple scattering has been very well studied.
- The scattering angle can be linked to the materials properties like the atomic number and density by using equations like the Rossi equation.
- the scattering angle can be easily measured precisely.
- With the multiple scattering information, materials properties can be reconstructed.

Muon Tomography



+- 180º
Absorption
Density



+- 70º (or geometry)
Absorption & Scattering
Density & Atomic Number Z

Image Reconstruction Method :POCA

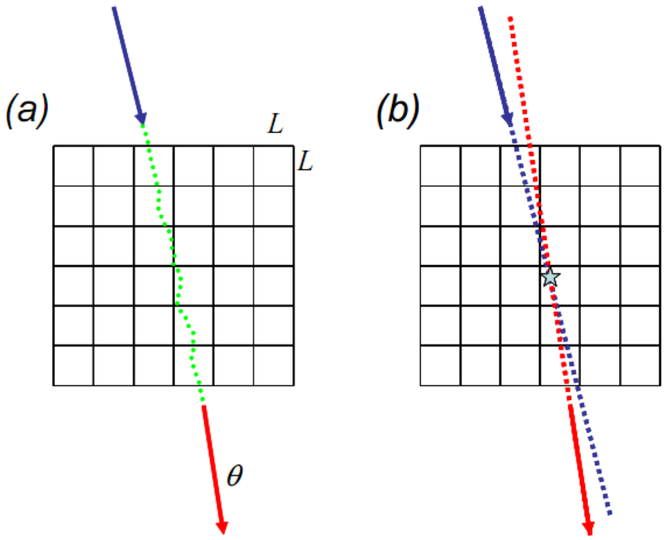


Illustration of the PoCA algorithm

- It is assumed that the scattering is a single event, or only one point is involved in the scattering.
- It ignores any underlining physics of scattering.
- It is a purely geometric algorithm.

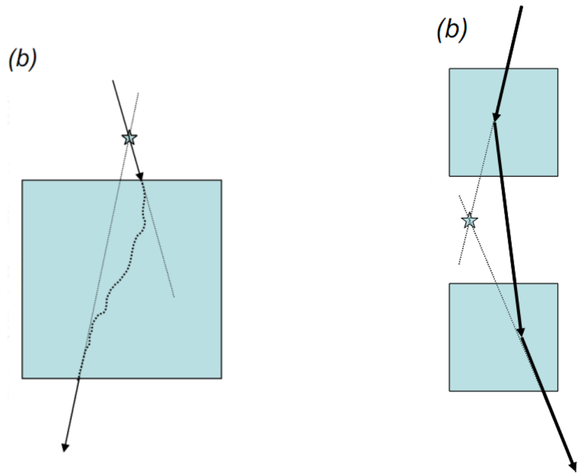
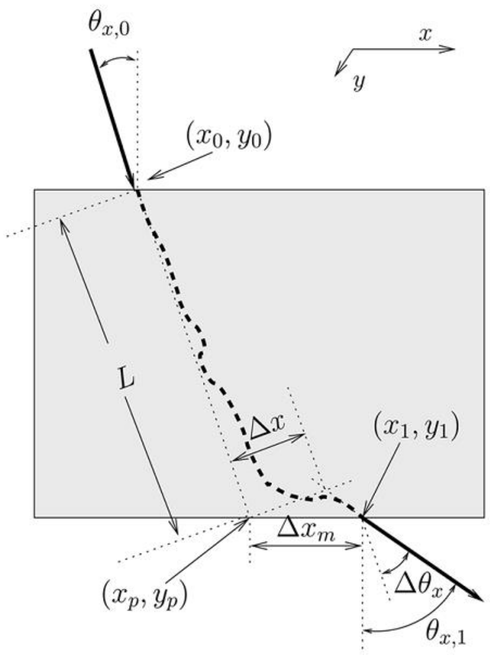


illustration of mechanism for erroneous scattering localization

Image Reconstruction Method: MLEM



Assume that the multiple scattering has a Gaussian distribution:

$$\sigma = \frac{15MeV}{pc\beta}\sqrt{\frac{l}{X_0}}$$

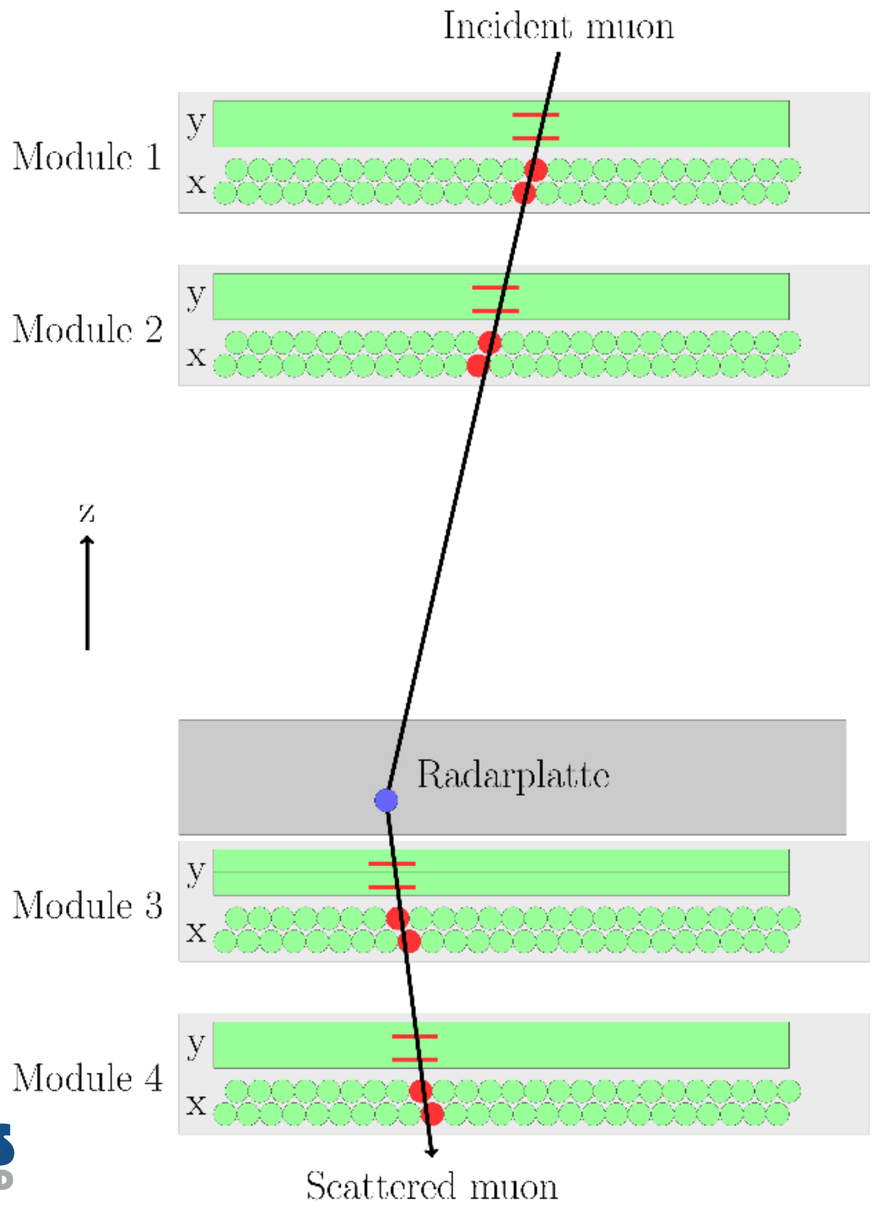
For mixture or compound:

$$\frac{1}{X_0} = \sum \frac{w_j}{X_j}$$

For each muon, the Gaussian distribution density function:

$$P_i = \frac{1}{\sigma_i 2\pi} e^{\frac{-\theta_i^2}{2\sigma_i^2}}$$

Muon Imaging System



Experimental parameters

Source	**Cosmic ray muons (1-100 GeV)**
Detector	**Lynkeos Muon Imaging System (MIS)** **1024 x 1024 Fibres (Resolution <2 mm)** **Exposure time = 1203 hours** **Trigger rate = 11 Hz**
Reconstruction	**Voxel size 3.4 mm x 3.4 mm x 10 mm** **Volume size 300 x 300 x 178 Voxels (1060 x 1060 x 1780 mm^3)**

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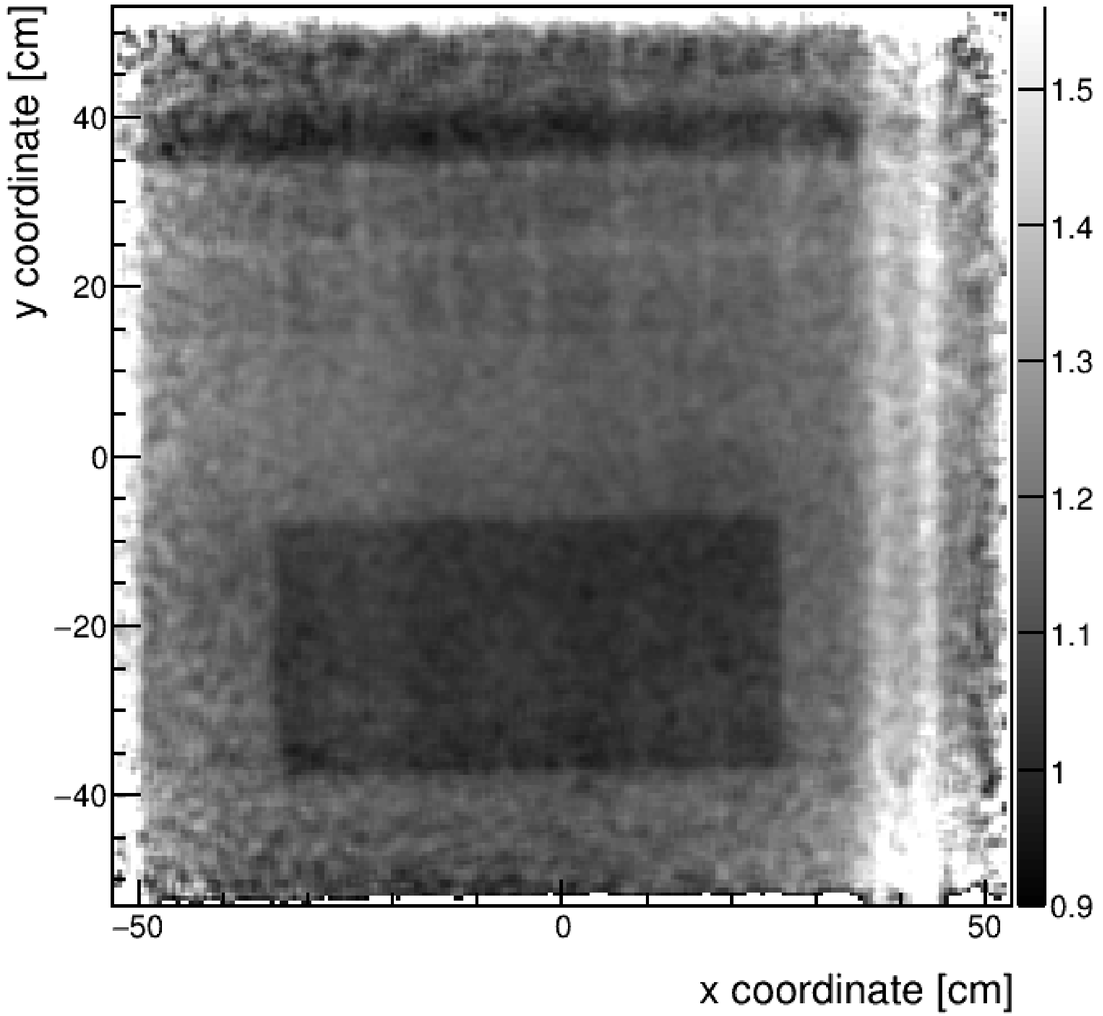
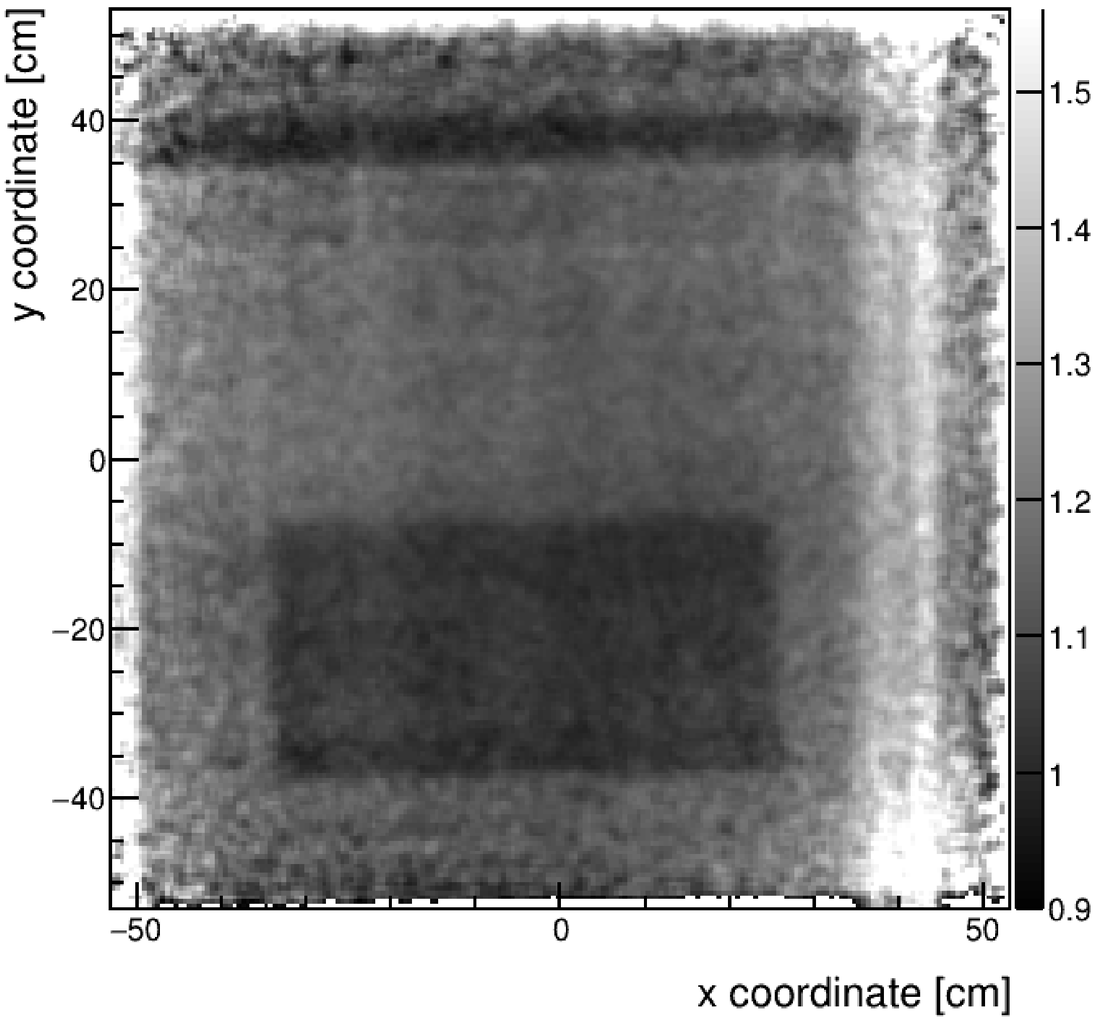
Experimental results of a reinforced concrete block



Niederleithinger et al., https://doi.org/10.1007/s10921-021-00797-3

Experimental results of a reinforced concrete block



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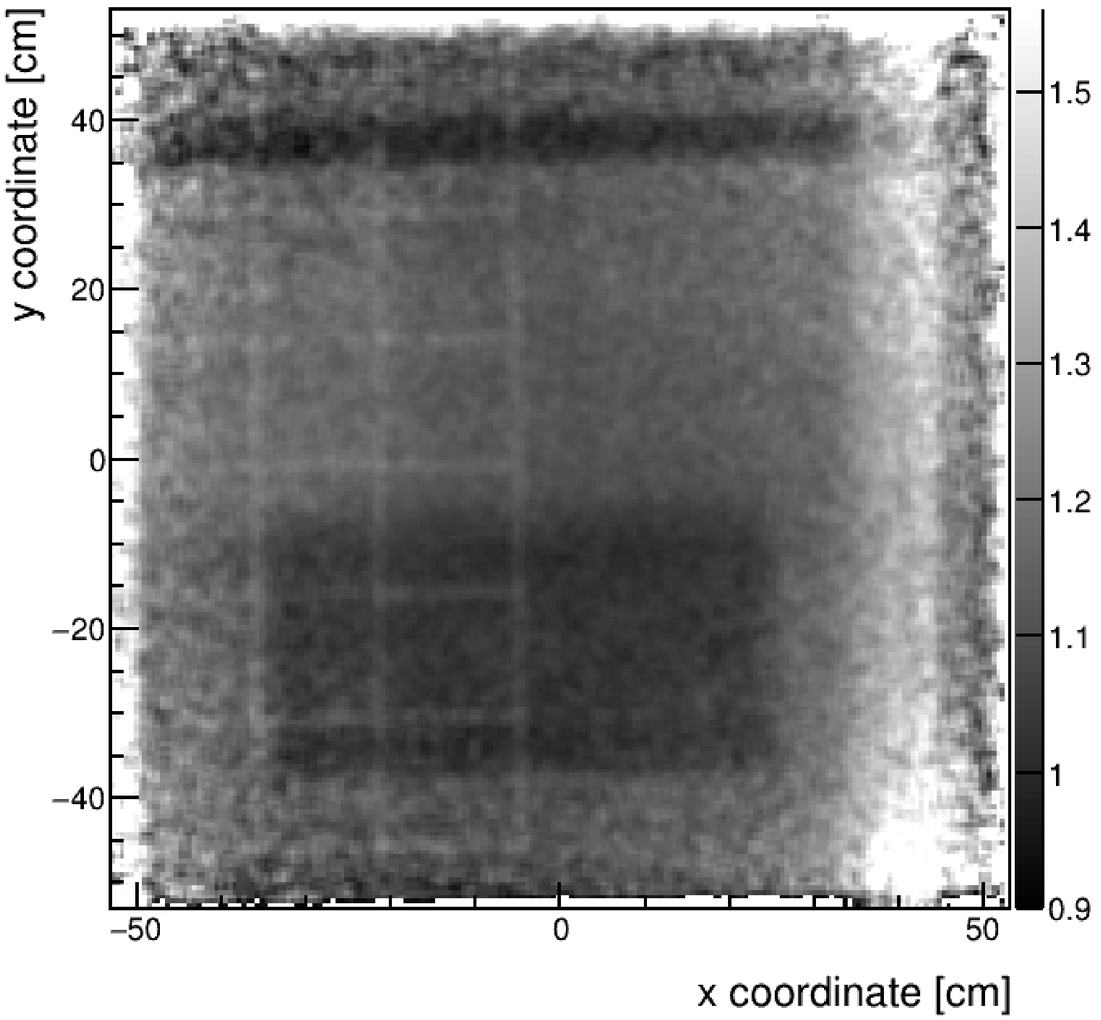
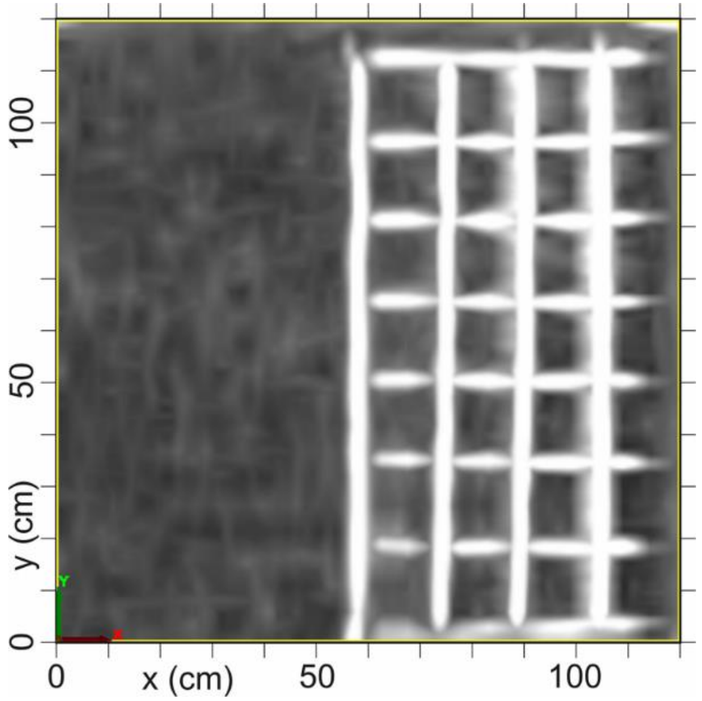
Experimental results of a reinforced concrete block

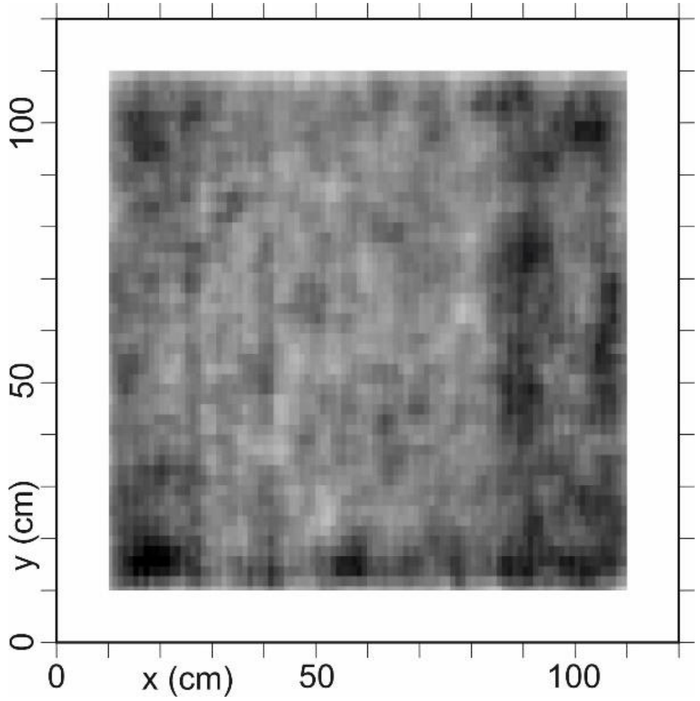


Niederleithinger et al., https://doi.org/10.1007/s10921-021-00797-3

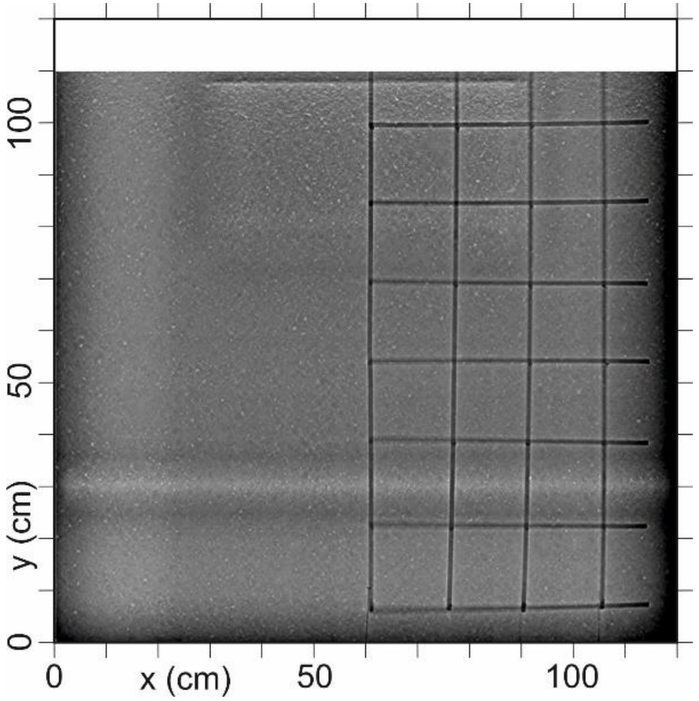
Results of other NDT methods



Radar



Ultrasound



X-ray

Niederleithinger et al., https://doi.org/10.1007/s10921-021-00797-3

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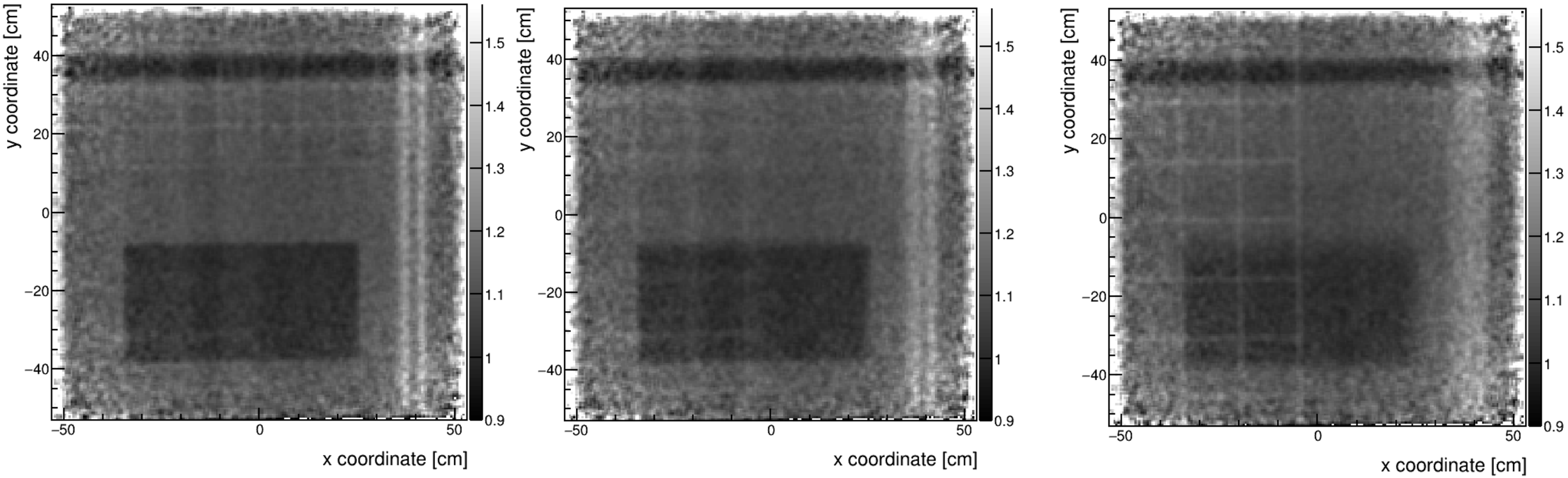
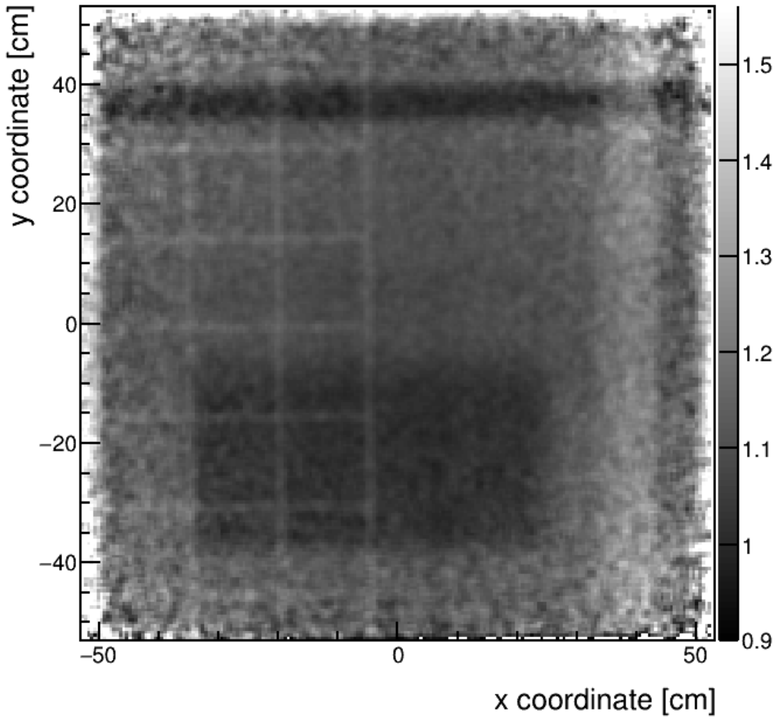
Geant4 simulations

- Geant4.10.07.p02 and root 6.22.03g9 were used for the simulation.
- Physics process emstandard_opt0 was used in the Geant4 Physics list.
- Scintillation detector was used in the simulation, the fibre size is 2 mm.
- Everything else is as close to the experimental parameters as possible.

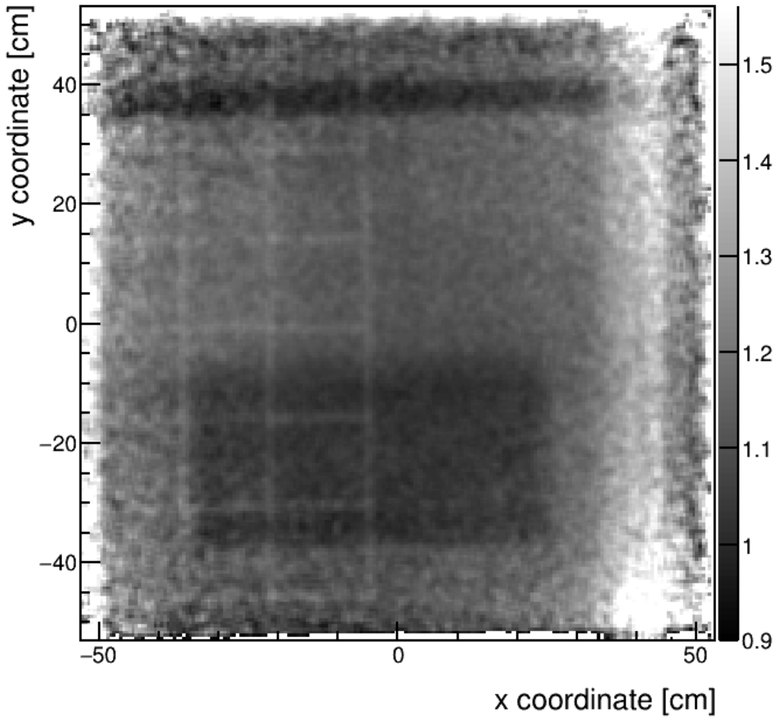
Geant4 simulation results



Comparing the Geant4 simulation with the experimental results



Geant4 simulation result



Experimental result

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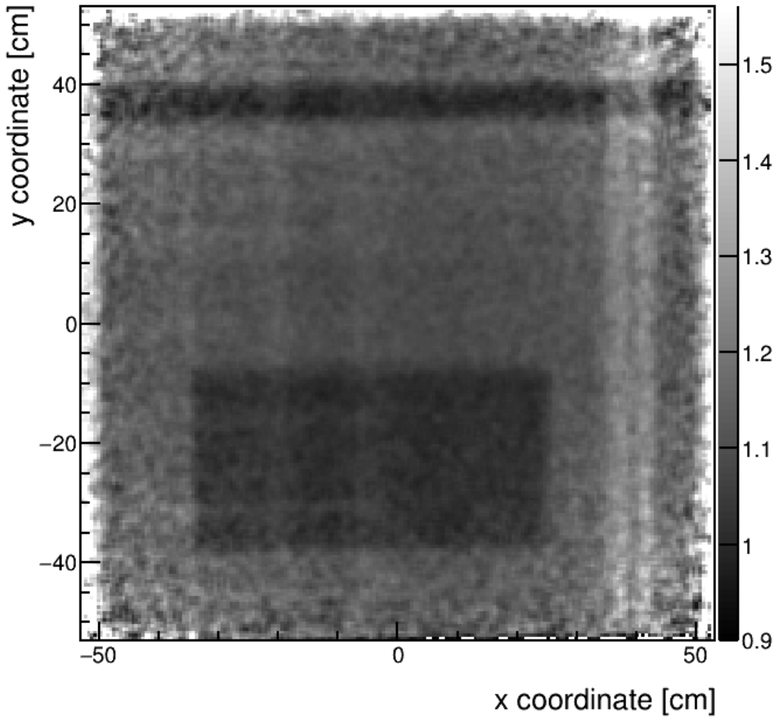
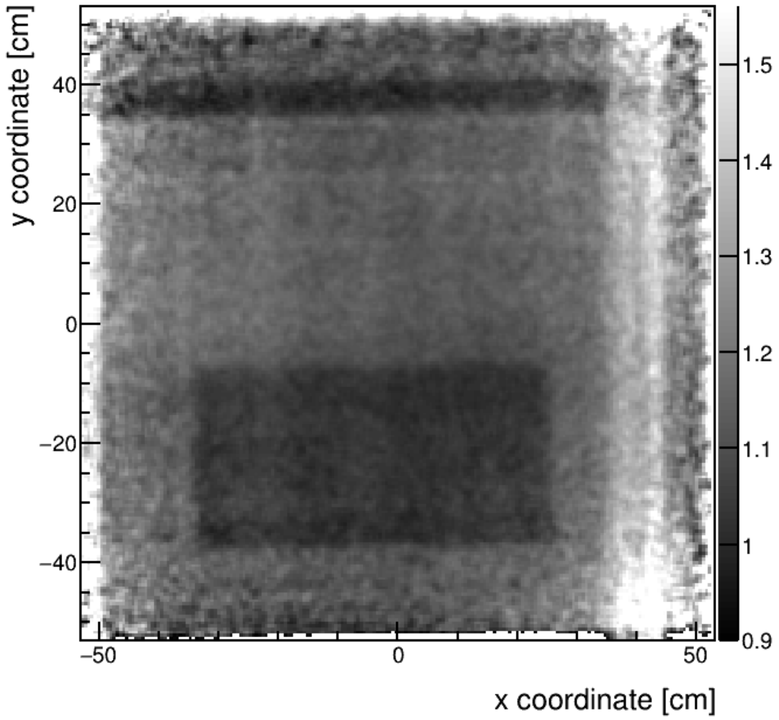


Geant4 simulation result



Experimental result

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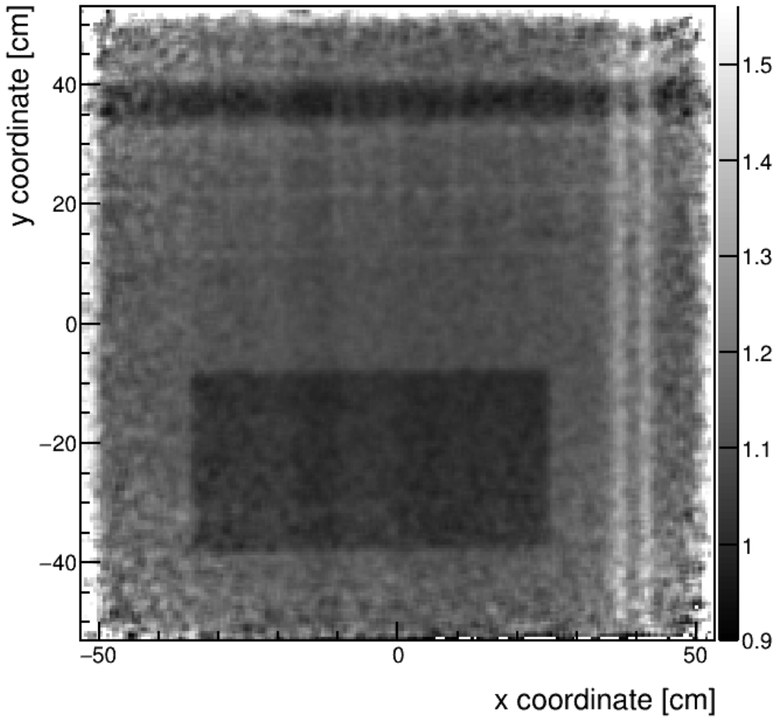
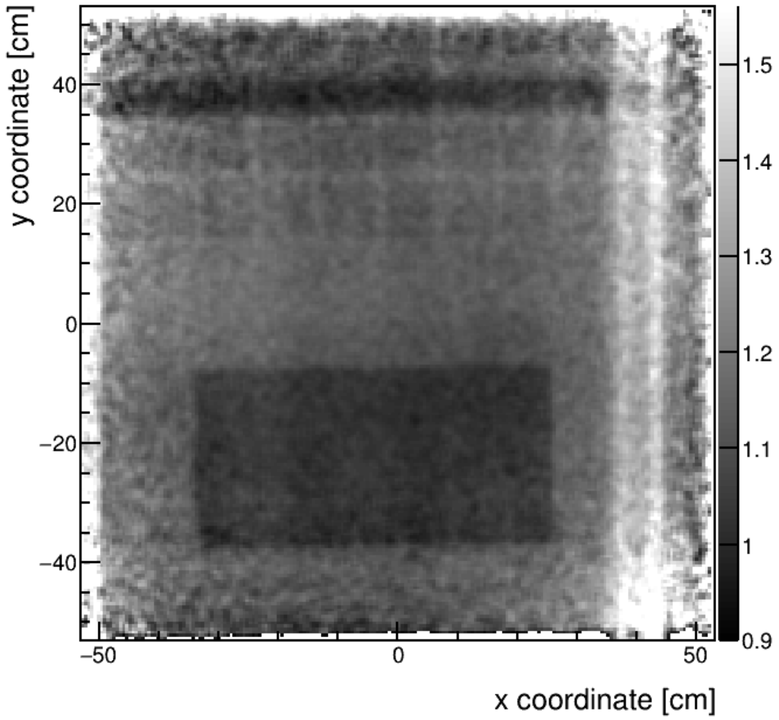
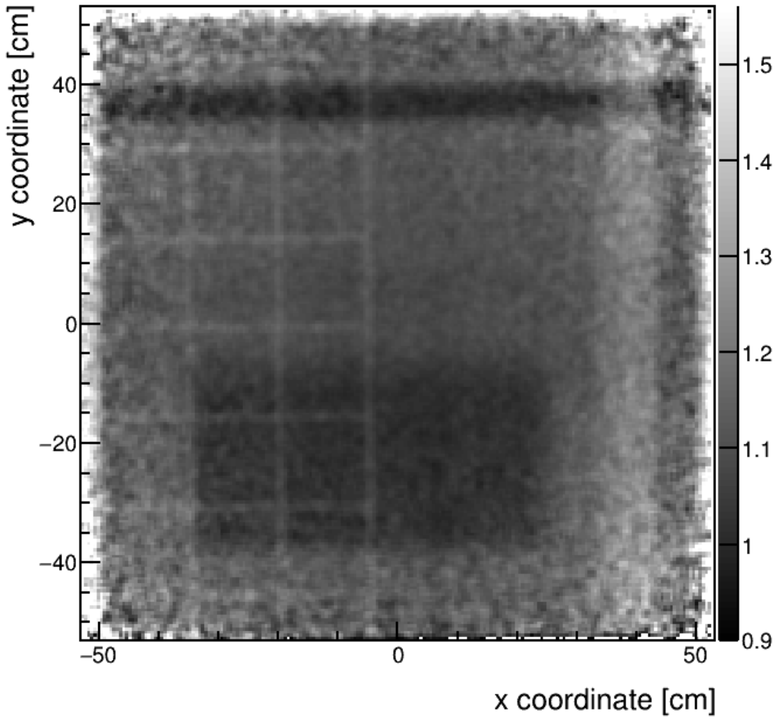


Geant4 simulation result

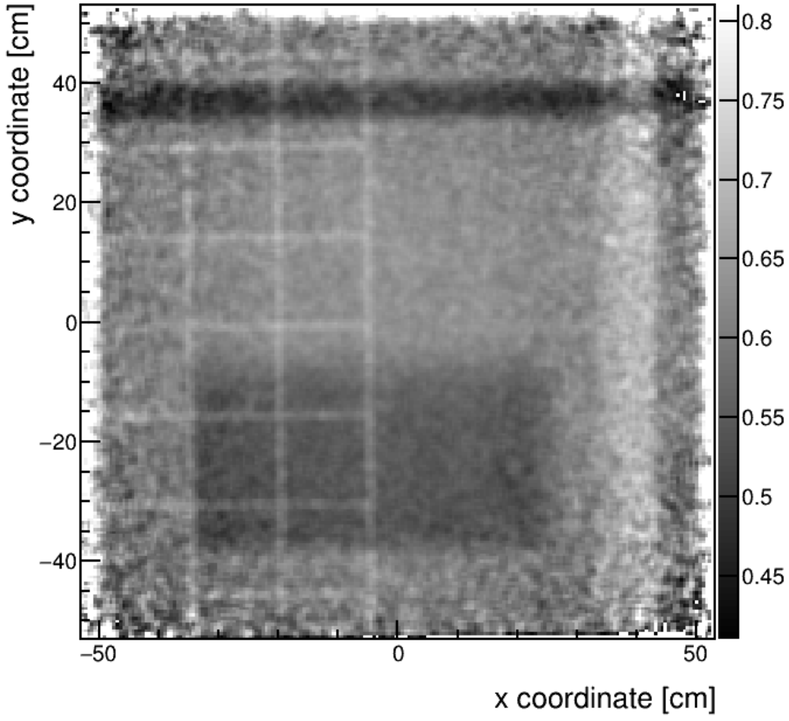


Experimental result

Comparing the Geant4 simulation results

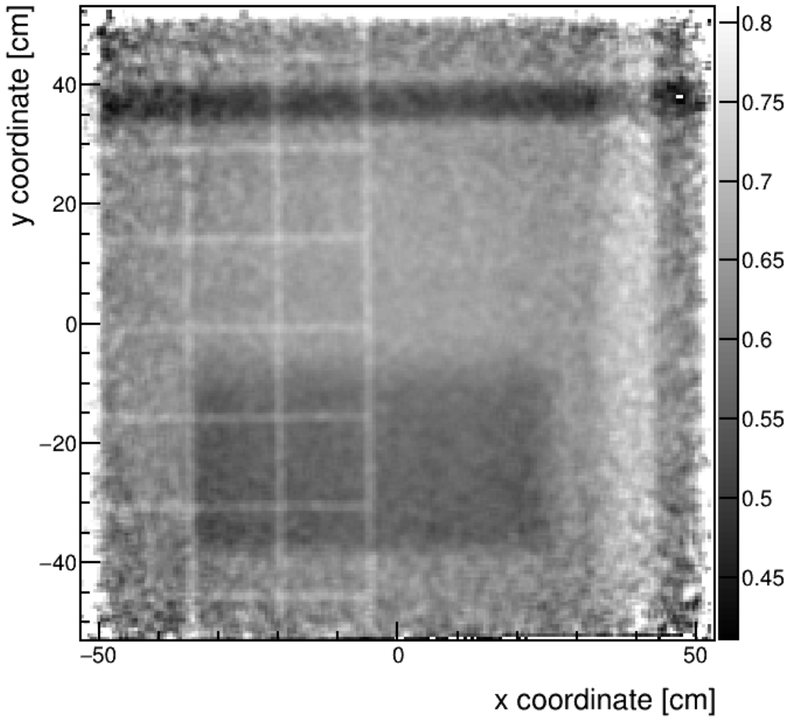


Current imaging system

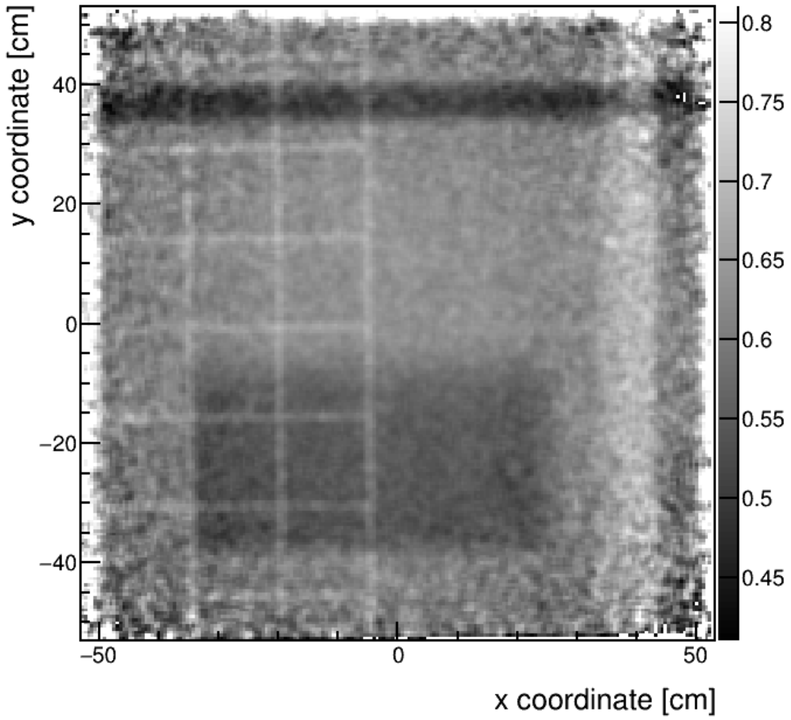


Improved imaging system

Comparing the Geant4 simulation results

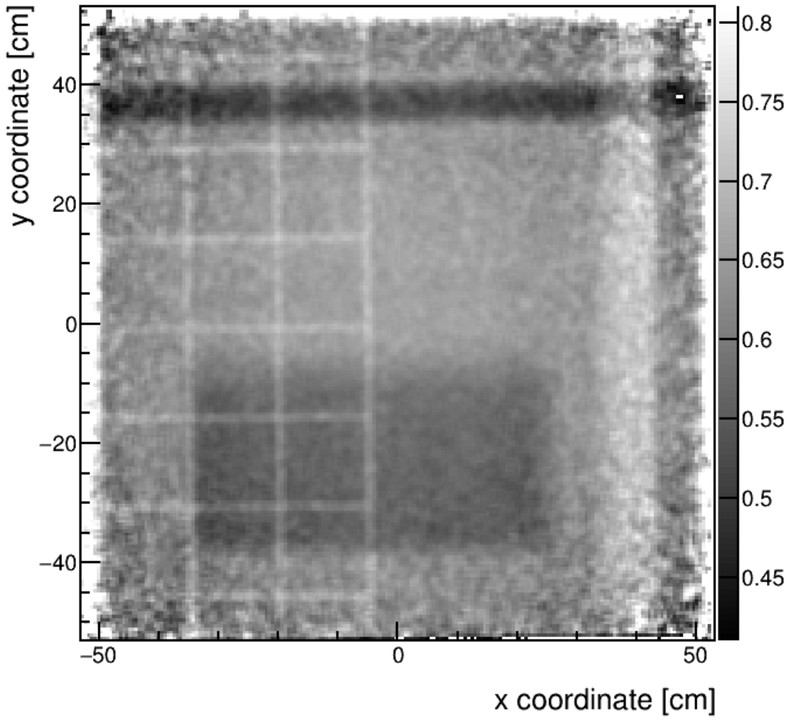


1mm fibre

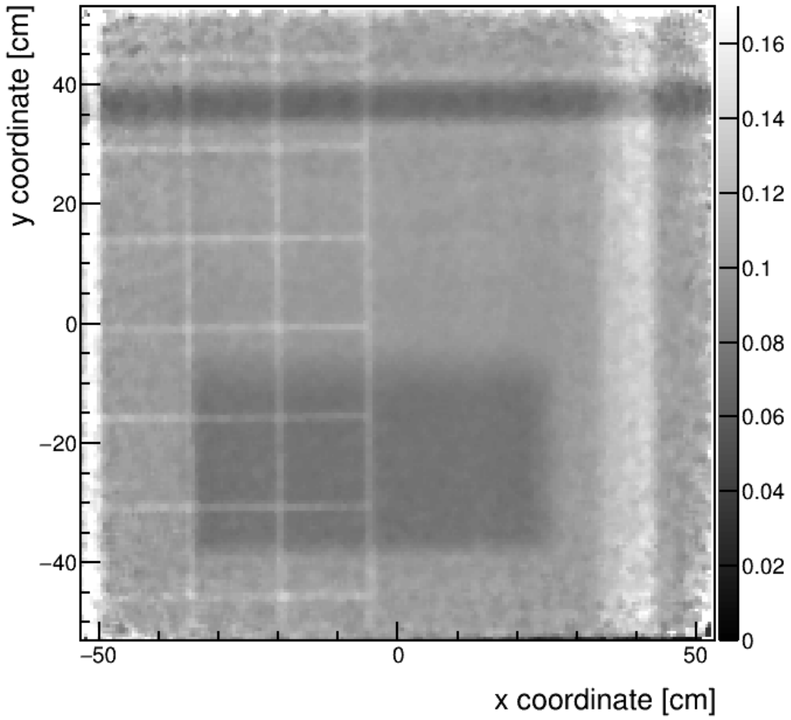


4mm fibre

Comparing the Geant4 simulation results



1mm fibre



Ideal detector

Conclusions

- First ever experiment with muon tomography of a reinforced concrete block was successful. All built in features were detected and correctly identified.
- Geant4 simulation result was compared with the experimental result. The Simulation and experiment results agree with each other.
- By changing the parameters of Geant4 simulation, better image quality has been achieved. Which pointed out the way about how to improve the detector system.

Thank you!