Feasibility study of detection of high-Z material in nuclear waste storage facilities with atmosperic muons

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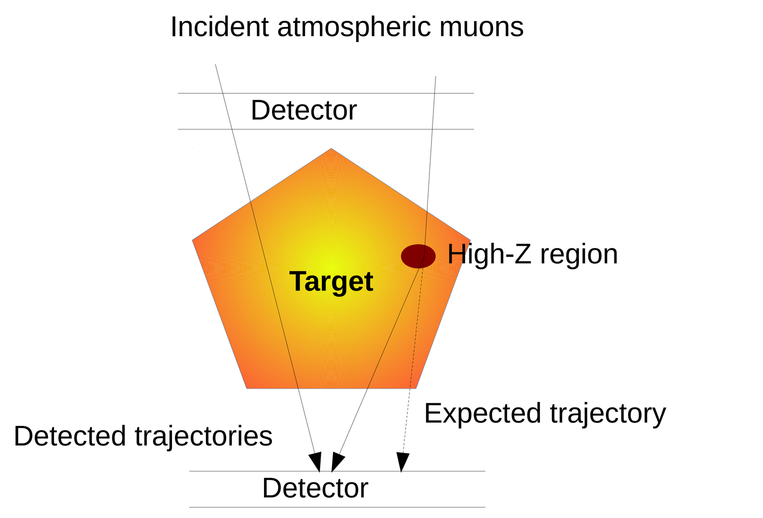
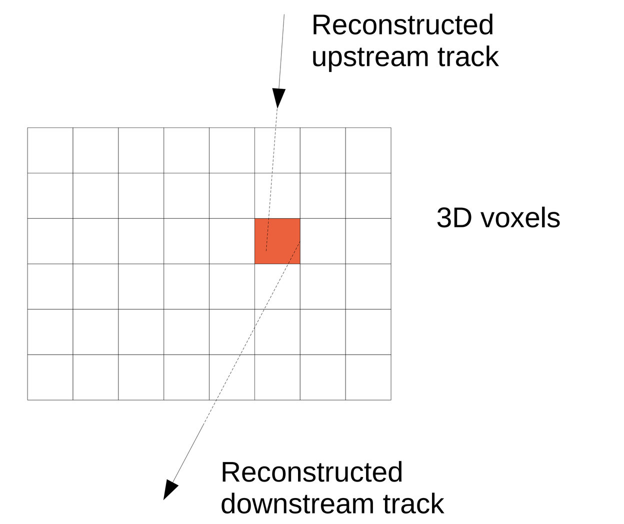
Muon radiography

Muon radiography is a well-established technique for investigating the internal density structure of a target body. Atmospheric muons crossing the target undergo multiple scattering and ionization energy loss processes: these result either in a deviation of the original trajectory or in a muon loss because of absorption inside the target. By investigating these two observables the internal density structure of the target can be probed.

Multiple scattering

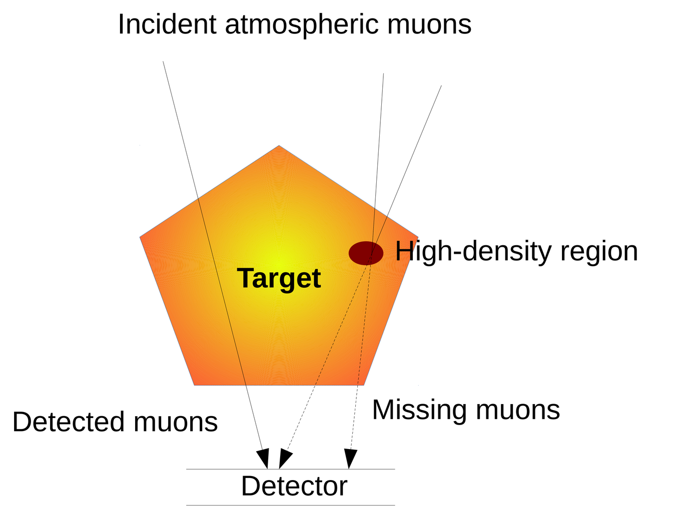


When traversing high-Z materials, muons suffer from large scattering angles. Placing one track detector upstream of the target and another one downstream it is possible to identify largely-scattered events. For these, the scattering point can be identified e.g. as the Point of Closest Approach (PoCA) of upstream and downstream tracks:

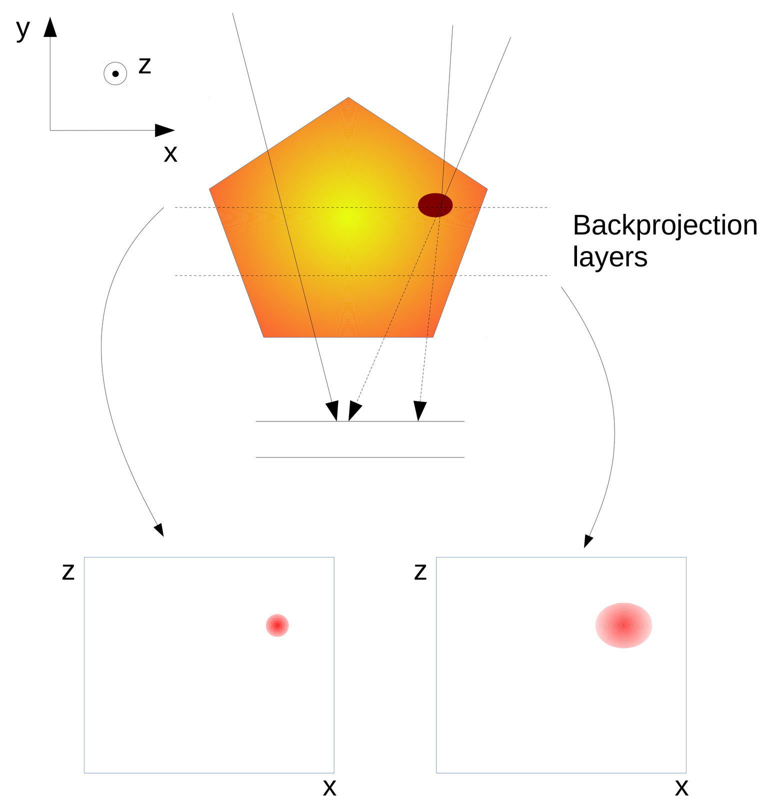


Having identified the PoCA for all the muons, the scattering density λ for each voxel can be computed using an iterative Maximum Likelihood Expectation Maximization (MLEM) algorithm. From λ a density map can be obtained.

Absorption



Having an estimate of the expected number of muons (e.g. open-sky measurements and/or Monte Carlo simulations) the number of missing muons can be estimated for each arrival direction. If the size of the target is comparable to the size of the detector the full 3D position of the high density part of the target can be obtained with a tomographic scan:



Missing tracks 2D histograms

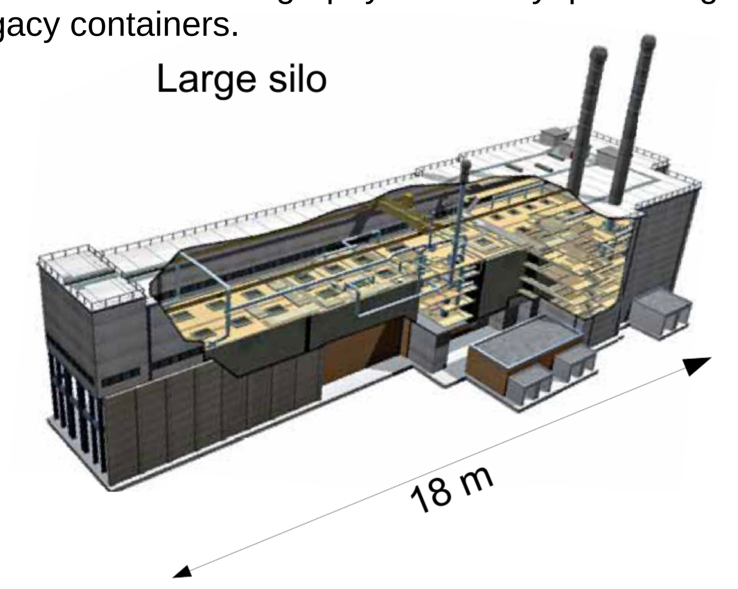
The density of missing tracks defines a signal region in the histograms. The intensity of the signal increases and the size of the signal region decreases as the backprojection layer approaches the high-density portion of the target

Legacy nuclear waste storage

Legacy containers for nuclear waste from the half of last century now pose significant challenges in terms of ensuring a safe disposal route as well as protection of the environment. In the past there perhaps wasn't the same safety culture and detailed record keeping procedures as there are now, which of course means that for these legacy waste containers there is a strong need to better characterise the contents of these containers. Muon radiography is a very promising technique for safe, non-invasive interrogation of legacy containers.

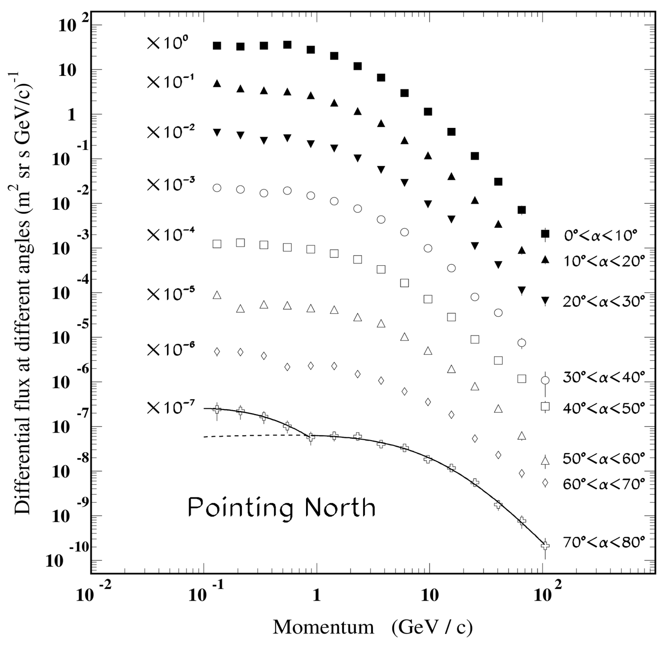
Box

Large silo

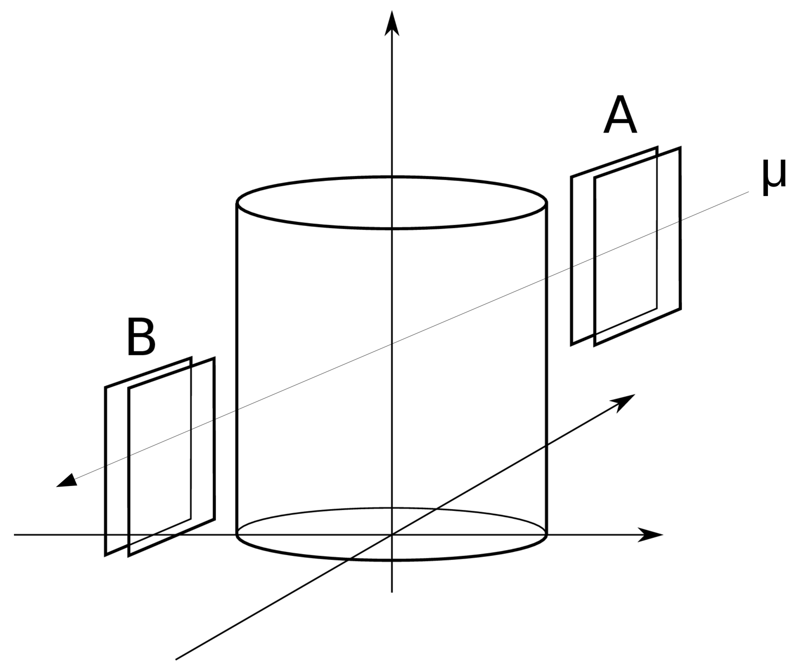


Monte Carlo simulations

A cylindrical storage silo with diameter 3.5 m and height 4 m has been simulated with Geant4. The silo is filled with concrete and contains cubic uranium samples with size 2, 5, 10 and 20 cm in different positions. The detector is made of two 2x2 m² tracking layers separated by 50 cm, with a position resolution of 0.3 cm. The input muon spectrum is modeled after ground measurements taken with a magnetic spectrometer.



Input muon spectrum
(Bonechi, L., et al., Intl. Cosmic Ray Conf. Proc. (2005), 283)



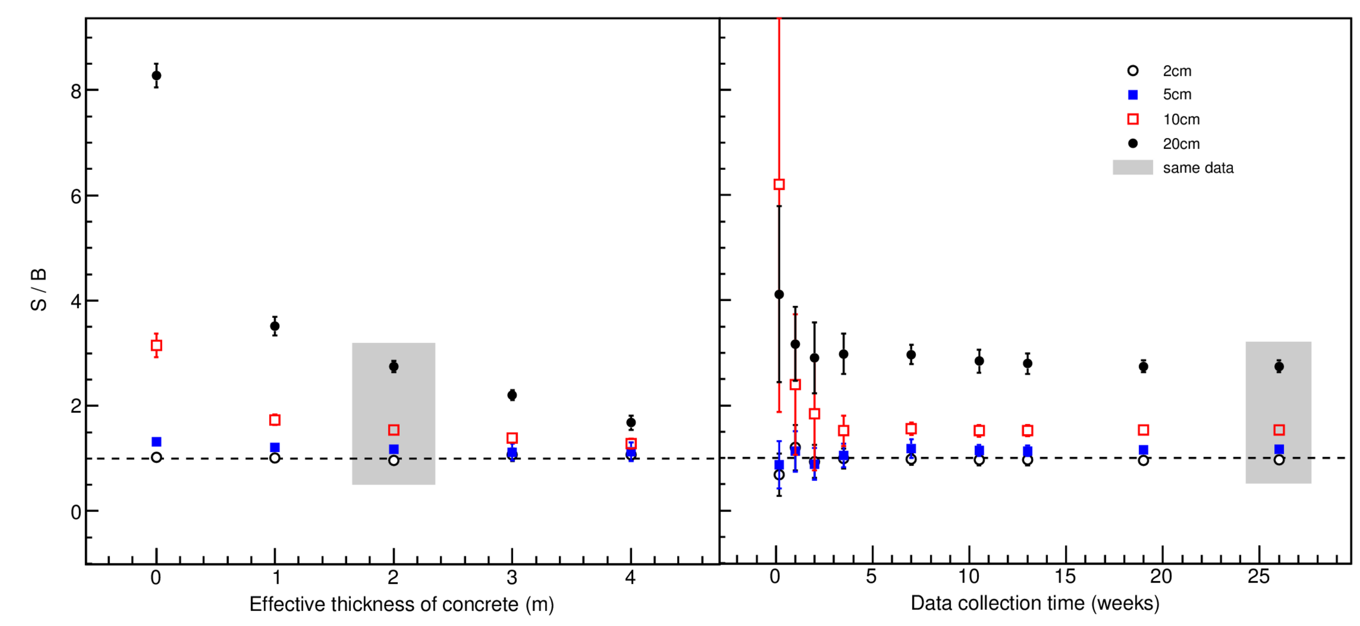
The simulated scenario. Detector A is present only in multiple scattering simulations

Results

Data have been analyzed with different methodologies for multiple scattering and for absorption studies. Both analyses rely on the *a priori* known positions of the uranium samples, since the main goal is to assess the entity of an eventual signal.

Multiple scattering

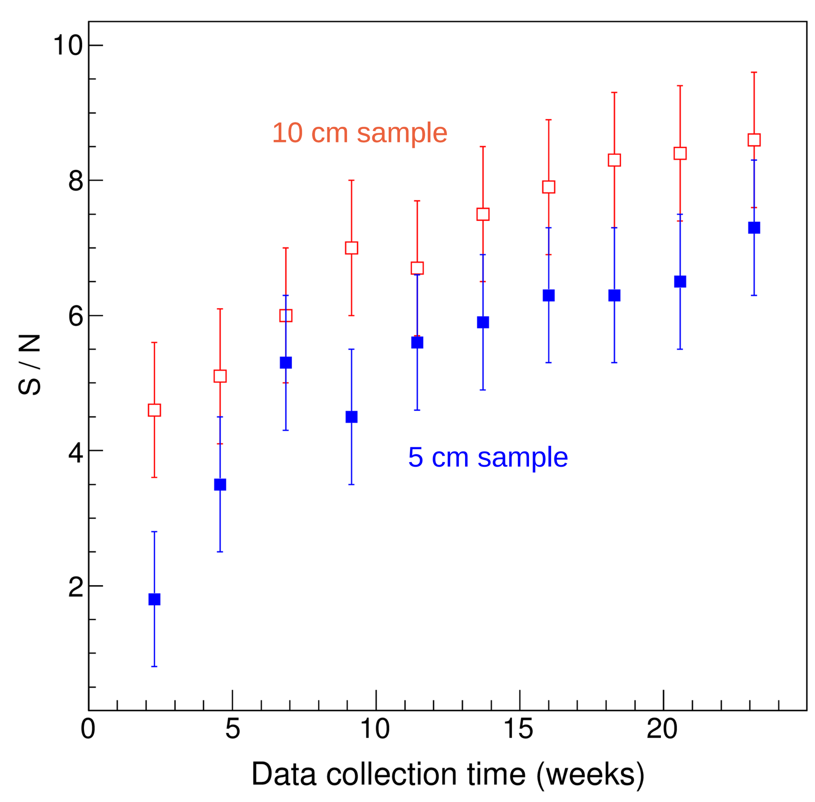
For multiple scattering analysis, the Signal-over-Background (S/B) has been defined as the ratio of the scattering length obtained for the uranium sample over the scattering length obtained for concrete. This parameter has been computed for uranium samples of different sizes placed at the center of the silo and for different effective thickness of the concrete.



All the samples are detectable, except the 2 cm one. The 5 cm sample requires a data collection time of ~ 20 weeks, while for bigger ones shorter periods are required.

Absorption

For absorption analysis, the Signal-to-Noise (S/N) has been defined as the ratio of the difference between the muon count difference (expected - measured) and its statistical error. The detection threshold has been put at S/N = 5, since there is only a 0.08% probability of having a statistical fluctuation of this entity over the whole backprojection map.



As for multiple scattering, 2 cm uranium samples are not detectable, regardless of their position. Bigger samples are detectable depending on their position: a 10 cm sample can be detected when it is placed at the center of the silo, while a 5 cm one needs to be placed near to the detector, in order to minimize the traversed concrete.

The 10 cm sample can be detected in ~ 5 weeks, while the 5 cm one requires ~ 10 weeks

References

- F. Ambrosino et al., *Assessing the feasibility of interrogating nuclear waste storage silos using cosmic-ray muons*, JINST 10 (2015) T06005
- A. Clarkson et al., *GEANT4 Simulation of a Scintillating-Fibre Tracker for the Cosmic-ray Muon Tomography of Legacy Nuclear Waste Containers*, Nucl. Instrum. Meth. A746 (2014) 64
- L. Bonechi et al., *A projective reconstruction method of underground or hidden structures using atmospheric muon absorption data*, JINST 10 (2015) P02003