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Identification and three-dimensional localization of cavities at the Temperino mine (Tuscany-Italy) with the muon imaging technique

Diletta Borselli[1,2], Guglielmo Baccani[3], Tommaso Beni[4], Lorenzo Bonechi[2,3], Massimo Bongi[2,3], Debora Brocchini[5], Nicola Casagli[4], Roberto Ciaranfi[2], Luigi Cimmino[6,7], Vitaliano Ciulli[2,3], Raffaello D'Alessandro[2,3], Chiara Del Ventisette[4], Andrea Dini[8], Giovanni Gigli[4], Sandro Gonzi[3], Silivia Guideri[5], Luca Lombardi[4], Massimiliano Nocentini[4], Pasquale Noli[6,7], Nicola Mori[2,3], Giulio Saracino[6,7], and Lorenzo Viliani[2,3]

[1]University of Perugia, Department of Physics and Geology, Italy (borsellid@fi.infn.it)
[2]INFN-FI, Florence, Italy
[3]University of Florence, Department of Physics and Astronomy, Florence, Italy
[4]University of Florence, Department of Earth Sciences, Florence, Italy
[5]Parchi Val di Corchia S.p.A., Piombino, Italy
[6]University of Naples Federico II - Department of Physics, Naples, Italy
[7]INFN-NA, Naples, Italy
[8]CNR-Institute of Geosciences and Georesources, Pisa, Italy

Muon radiography is a non-invasive imaging technique that allows, through cosmic muon absorption measurements, to obtain two-dimensional and three-dimensional images of the internal structure and average density of very large material volumes. Its applications currently range from many fields: geological, archaeological, industrial, civil and nuclear safety. The technique of muon radiography being non-invasive represents a valid alternative to the common survey techniques in these fields of applications. In this presentation I will show some results obtained with this technique in the geological field for the three-dimensional imaging of cavities and tunnels within the Temperino mine located in the San Silvestro Archaeological Mining Park near Campiglia Marittima in the province of Livorno in Tuscany (Italy). The Temperino mine has ancient etruscan origins and still has areas which are not mapped in the available documentation. The mining activities of the area have always been focused on the search for a hard and dense rock called skarn in which there are metallic sulphides of Cu, Ag, Pb, Zn, Fe. Currently only one of the most superficial levels of the mine is accessible to the public through a tourist route. The muographic measurements on this site therefore have a dual objective, on the one hand to test the imaging technique on known cavities, on the other hand to discover new cavities whose knowledge could be useful, for example, for important assessments concerning historical and safety aspect of the site. All measurements were carried out with the muon detector MIMA (Muon Imaging for Mining and Archaeology) designed and built at the National Institute of Nuclear Physics (INFN) in Florence. MIMA is a cubic tracker of approximate dimensions (50x50x50) $cm^3$and is equipped with a special protective aluminum mechanism that allows its altazimuth orientation. Various measurements were made within the tourist gallery located about 50 m below ground

level for the observation of areas above. By comparing muon transmission measurements with simulations, it was possible to generate two-dimensional angular maps of average density of material observed in every direction within the detector's acceptance. The presence of some low-density anomalies associated with the presence of cavities was thus identified. Through algorithms based on the triangulation technique and on a track backprojection technique, the cavities were located in three-dimensions. For the known cavities it was also possible to compare the reconstructed development with their real profile that was acquired with the laser scanner technique, finding a good compatibility (average deviation below 1 m for a 7 m high cavity located 20 m above the detector's installation location). These measurements therefore validate the muon radiography technique in the geological field for the search for cavities inside mines. The technique can be applied to identify not only low-density anomalies or voids, but also high-density areas: the application of the muon imaging technique for the identification of dense ore bodies is being studied at Temperino mine.