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Muon radiography by nuclear emulsions - Report on activity in Italy
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The nuclear emulsions technology has entered the field of muon radiography of volcanic edifices and faults in the last decade, and progressively attracted the interest of nuclear emulsion laboratories and experts from various countries. The historical first muographic image of a volcano was indeed generated by using this nuclear emulsion technology. In earlier times, large-scale application was limited by the readout time and manpower needs as the emulsion films had to be scanned by eye; modern fast automatic microscopes solved both issues with limited cost, and the readout and analysis speed increased by several orders of magnitude, opening the door to access muography that requires large statistics. The Italian nuclear emulsion groups of the Universities of Salerno, Napoli and Padova and the Laboratori Nazionali del Gran Sasso (INFN) have built an Italian network of scientists working on muography, establishing tight collaboration links with the Tokyo University Earthquake Research Institute; more Italian groups could join in the near future. The network performs many activities, from the preparation of emulsion film exposure, on-site data taking campaigns, to readout and data analysis.

Nuclear emulsions are usually cast in the shape of thin films (thickness in the range of 20-100 micrometers) coating transparent plastic bases. Even a single film can provide 3D tracks marking the passage path of ionizing particles, when observed by a dedicated microscope. Normally emulsions films are exposed in stacks, piling several sheets, so that a single particle, after development, leaves several aligned tracks, one in each film.

Automatic emulsion readout systems allow track detection and measuring on several m^2 of surface in few weeks, collecting large statistics, which is needed to investigate regions of high cosmic muon absorption. Angular resolution of the order of a few milliradians is commonly achieved, which gives the ability to discriminate relatively small details, depending on the distance between the detector and the observed volume. Currently, one line of research aims at developing faster and cheap film readout systems, based on commercial hardware, to increase the current data-taking speed by a factor 10 or better.

Emulsions are continuously sensitive, since the time of their production: while this is an advantage because they need no power supply, the lack of time discrimination makes data analysis for such detectors a delicate task. The high combinatorial background of 3D tracks, due to many months' pile-up, can be greatly reduced by exploiting the micrometric alignment precision of emulsion tracks. Application of nuclear emulsion data to muon radiography requires also particle identification. Multi-film stacks with interleaved slabs of dense scatterers (such as iron or lead), allow distinguishing soft particles, typically electrons/positrons from electromagnetic showers, from hard muons with 1 GeV/c momentum or higher. Dedicated simulation of the passage of hard muons through rock and in the emulsion-instrumented volume allows optimizing selection criteria and estimating purity and efficiency of the selection. Systematic errors on the predicted integrated flux, which is compared to the measured integrated flux, should be kept as small as possible; in turn, this requires proper modelling of the expected cosmic-ray muon flux, which demands specific efforts in some regions of the angular and energy spectrum, where the statistics is intrinsically lower. Simulation and modelling activities require specific software and sizeable computing resources and are shared amoung the collaborating groups.

Accounts are given of the status of muon radiography campaigns in which the Italian groups are mostly involved. The cases covered are Stromboli, Teide and the La Palma fault. For each case, the present situation, possible developments and future plans are also envisaged.

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