Contribution ID: **179** Type: **Poster presentation only**

Snow water equivalent measurement using Muon Radiography

Muons reach the surface of the earth with an approximately constant flux and deviate their trajectory when crossing matter. These deviations can be measured in order to obtain information or density maps about the inner state of preferably dense and big objects. Previous work done by the company Muon Systems, presenting the capacity of Muon Radiography to help in industrial problems can be consulted in [1]. Here we present a new application of Muon Radiography, the non-destructive measurement of snow water equivalent (SWE), that is, the water content of a snowpack. In this case study, the measurement target is a column of snow with a base of approximately 1 m2 and a height varying from 0 to 2 m, suitable for the available detection system. On the other hand, the density of the snow is low compared to other materials measured in traditional Muon Radiography applications, which makes this challenge more demanding in terms of angular resolution.

Despite its hydrological importance, real time SWE monitoring remains challenging for hydro-meteorological networks. This new application of Muon Radiography would contribute to enhance the SWE monitoring capabilities of the water agencies and land managers, improving the estimation of the mountainous water resources and the river discharge forecast. Nowadays, other technologies are employed to carry out measurements of SWE, but difficulties and uncertainty sources have been noticed [2].

To analyse this problem by Muon Radiography, firstly the snow has been simulated. We have used the energy and mass balance snow model Snowpack, forced by means of the global ERA5-Land surface reanalysis in the Spanish Pyrenees, in a location at 2041 meters above sea level in the Monte Perdido massif. The simulations cover five years with a changing number of snow layers, containing information including the density, height and the ice, liquid water and air content of each layer (Figure. 1).

Secondly, Geant4 simulations have been performed to propagate and measure muons passing through the snow layers previously simulated. The approach of the Muon Radiography analysis is to interpret the physics behind the muon measurements and characterise them in an optimal way. Preliminary results for a constant snowpack height of 1 m, show a coefficient of determination of R2=0.94 between mean absolute muon deviation of one-hour measurements and snowpack bulk density. The goal is to detect density changes in a time frame that would allow a successful monitoring of SWE, improving the performance of other technologies and reducing uncertainty sources like natural variability at small scales, instrumental bias and errors induced by observers.

To conclude, more sophisticated algorithms based in Machine Learning and advanced statistics will be presented and discussed. The development of those algorithms can lead to more accurate results regarding the layer density determination and the automation of field applications.

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Session Classification: Poster session 1

Track Classification: Highlighted sessions