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Inspection of Alpine glaciers with cosmic-ray muon radiography

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Radiography using cosmic-ray muons represents a challenging method for probing the bedrock topography beneath Alpine glaciers. We present the current status of our feasibility study at Eiger glacier, situated on the western flank of the Eiger in the Jungfrau region, Central Swiss Alps.

The muon radiography is a technique that has been recently developed to investigate the internal density profiles of geoscientific targets. It is based on the measurement of the absorption of the cosmic-ray muons inside a material. Because the energy spectrum of cosmic-ray muons and the energy dependence of muon range have been studied well during the past years, the attenuation of the muon flux can be used to derive the column density, i.e. the density integrated along the muon trajectories, of geoscientific targets. This technique has recently been applied for non-invasive inspection of volcanoes, nuclear reactors, seismic faults, caves and etc.

The greatest advantage of the method in the field of glacier studies is that it yields a unique solution of the density underneath a glacier without any assumption of physical properties inside the target. Large density contrasts, as expected between glacier ice ($\sim 1.0\,\mathrm{g/cm^3}$) and bedrock ($\sim 2.5\,\mathrm{g/cm^3}$), would allow us to elucidate the shape of the bedrock in high resolution. Accordingly, this technology will provide for the first time information on the bedrock surface beneath a steep and non-accessible Alpine glacier, in a complementary way with respect to other exploration methods (drilling, ground penetrating radar, seismic survey, gravity explorations and etc.).

Our first aim is to demonstrate the feasibility of the method through a case study at the Eiger glacier, situated in the Central Swiss Alps. The Eiger glacier straddles the western flank of the Eiger between 3700 and 2300 m above sea level (a.s.l.). The glacier has shortened by about 150 m during the past 30 years in response to the ongoing global warming, causing a concern for the potential risk of rock fall on the onsite railway.

We installed prototype detectors at two sites inside the Jungfrau tunnel crossing the Eiger mountain. The first site is located at 3160 m a.s.l. where the tunnel crosses the eastern flank of the Eiger. There, the thickness of the rock, which muons have to penetrate, ranges from 600 m to 1500 m. The second site is located at 3250 m a.s.l., just beneath the western flank of the Eiger. At this second site, the rock thickness is 300 – 1000 m. We chose emulsion films as muon detectors because they do not require power supply, a clear advantage in the harsh mountain environmental conditions. The effective area of the detectors is $1000\,\mathrm{cm}^2$ for both sites. The foreseen exposure time will be 2 to 3 months.

After this prototype experiment, we will install larger detectors in several sites in the tunnel. The stereo observation would make it possible to reconstruct the three-dimensional shape of the bedrock beneath the Eiger glacier.