# Using Muon Radiography to map the bedrock geometry underneath an active glacier: A case study in the central Swiss Alps

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## 1. Muon Tomography

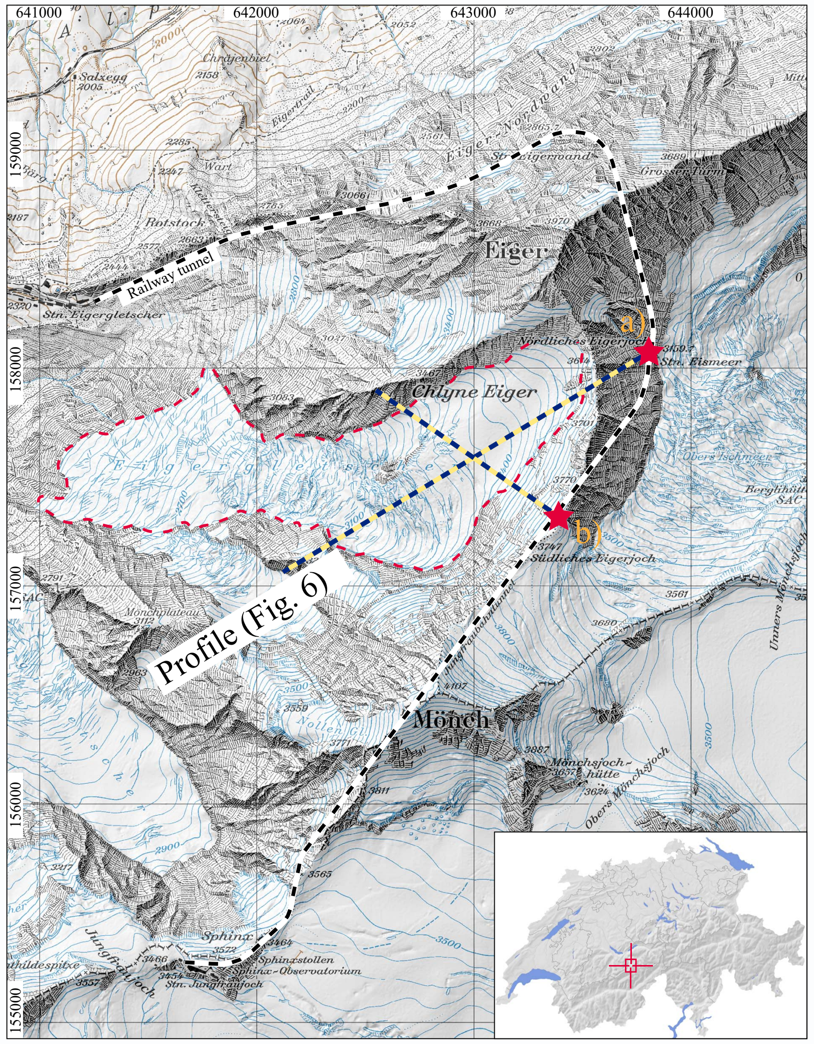
Imaging technique, sensitive to density and of traversed material.

Muons can be used to „x-ray“ material above the detector.

Has already been used to look for hidden chambers in the Chephren Pyramid in Gize (Alvarez et al., 1970).

Recently, earth scientists started to apply it to geological problems, e.g. volcanoes (Lesparre et al., 2012; Nishiyama et al., 2014).

## 3. Project & Detectors




▲ Fig. 1: Map showing Eiger glacier (dashed red line) (© Federal Office of Topography, swisstopo, 2015). Red stars: Detector positions *a)*: Eismeer railway station, *b)* inside railway tunnel. Yellow-blue dashed lines: Profile traces perpendicular to the detector planes.

**Prototype experiment**

Detector frames installed at 2 locations (fig. 1, *a* & *b*)

1 Detector frame holds 4 pouches (fig. 2)

1 pouch = 8 emulsion films & 7 lead plates in between

Detector area: 0.1m²

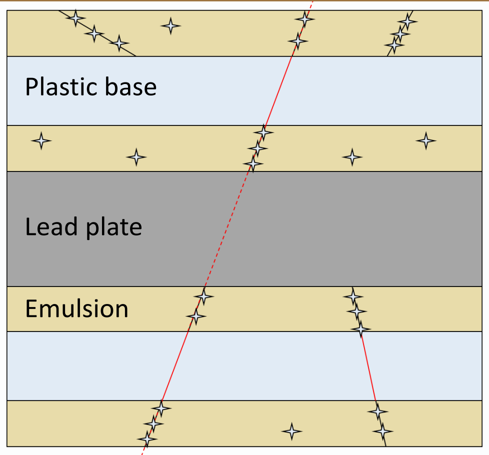
Exposure time: 112 days

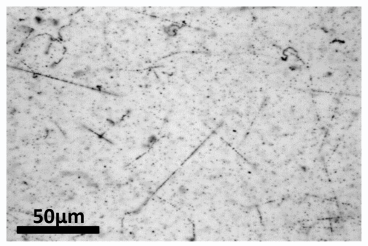
▲ Fig.2: Photograph of detector frame installed at Eismeer station (Fig. 1 *a*).

## 2. Goals

- Apply muon tomography for the first time to a glacier, using nuclear emulsion films
- Reconstruct 3D glacier bedrock geometry
- The resulting tomographic model will be used by geologists (contribution Mair et al., 2016) to investigate active subglacial processes

## 4. Nuclear emulsion film




▲ Fig. 4: Microscopic view of a developed emulsion film. The visible lines are recorded tracks, made by charged particles that passed through the detectors.

▲ Fig. 3: Excerpt of a filled detector pouch. Alternating layers of double sided emulsion film with lead plates in between. Stars show developed silver grains (dots in fig. 4). Several dots in one layer connect to a microtrack (lines in fig. 4). Two microtracks in the upper and lower emulsion layer connect to a basetrack (solid red line). A reconstructed muon track is build of matching basetracks (dashed red line) through the detector.

Nuclear emulsion film detector is made of alternating layers of emulsion film and lead plates (fig. 3).

Use reconstructed muon tracks that penetrate whole detector.

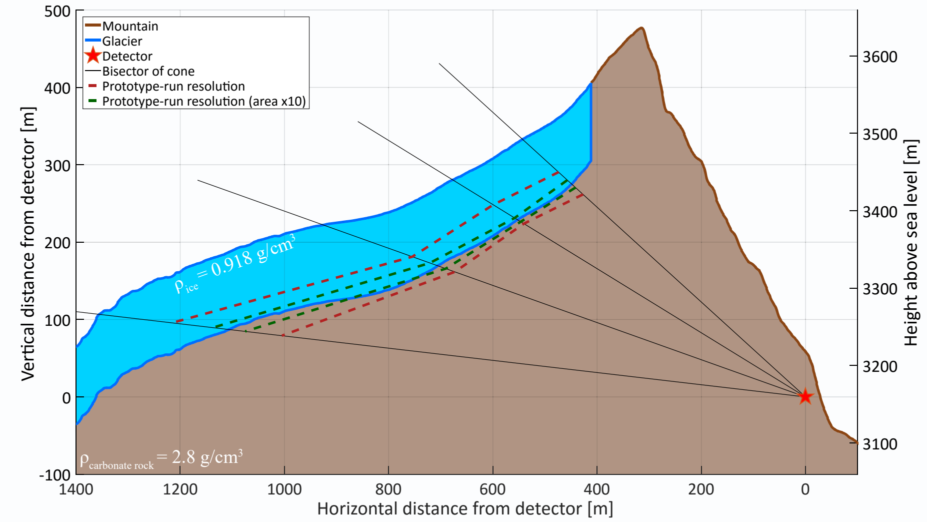
**Advantages**

- Power supply not needed↔ passive recording
- Has high angular resolution (up to 0.29°)

**Drawback**

- No timing information, only time integrated data

## 5. Expected Resolution




▲ Fig. 5: Estimation of intrinsic uncertainty at Eismeer station (red star, fig. 3 *b*). The glacier bedrock was assumed to lie 100m below the topography. Solid black lines depict the angle bisectors of the 4 cones sensitive to the glacier. Red and green dashed lines show the 1$\sigma$-bounds (±30m & ±10m) for the inverted glacier bedrock for two different detector configurations (0.1m², 100days) and (1.0m², 100days) respectively.

Measured number of muons ($N_{\mu,obs}$) has an intrinsic uncertainty, whose relative error reduces with rising $N_{\mu,obs}$:

$$N_{\mu,obs} \pm \sqrt{N_{\mu,obs}} \longrightarrow \epsilon_{N_{\mu,obs}} = \frac{1}{\sqrt{N_{\mu,obs}}}$$

Increasing exposure time (T), detector area (A) or cone size (Ω), increases the number of detected muons, resulting in smaller errors on tomographic results.

$$N_{\mu,obs} = I_{\mu,obs} * A * \Omega * T \longrightarrow \epsilon_{N_{\mu,obs}} = \frac{1}{\sqrt{I_{\mu,obs} * A * \Omega * T}}$$

Prototype-run detector configurations (0.1m², 100days) resulted in an glacier thickness estimation error of ±30m, whereas the planned main-run configuration (1.0m², 100days) reduced this error to ±10m.

## 6. Outlook

Insights gained from the prototype run, will determine the design and placement of additional detectors.

The nature of the data is inherently 3D, which will be used to reconstruct the 3D glacier bedrock geometry.

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