A new muon tomography detector for glaciers melting monitoring

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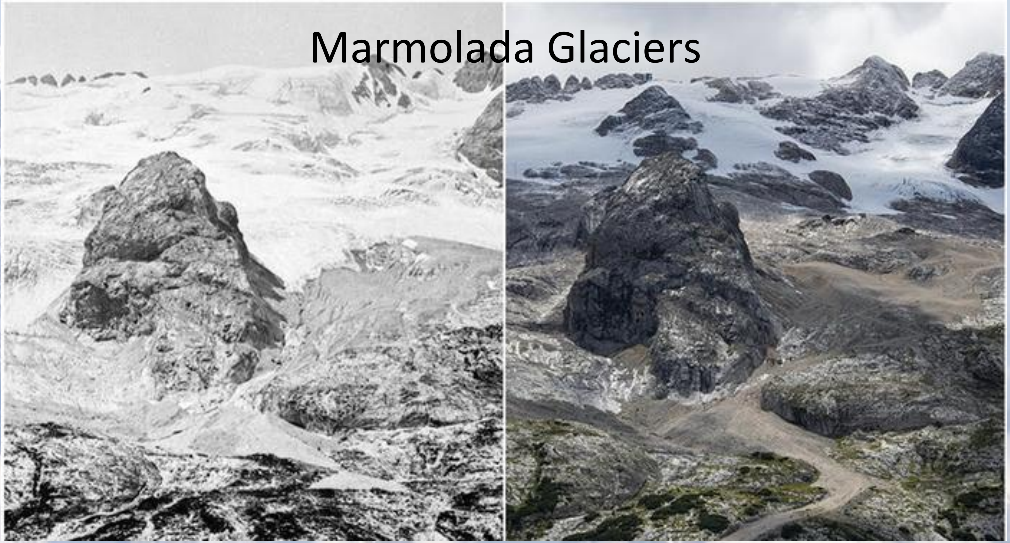
Project Goal

Glacier melting is one of the most visible effects of global warming.

Glacier monitoring has been done using different techniques over the past years, however it relied either on caves under the target glaciers or indirect measurements

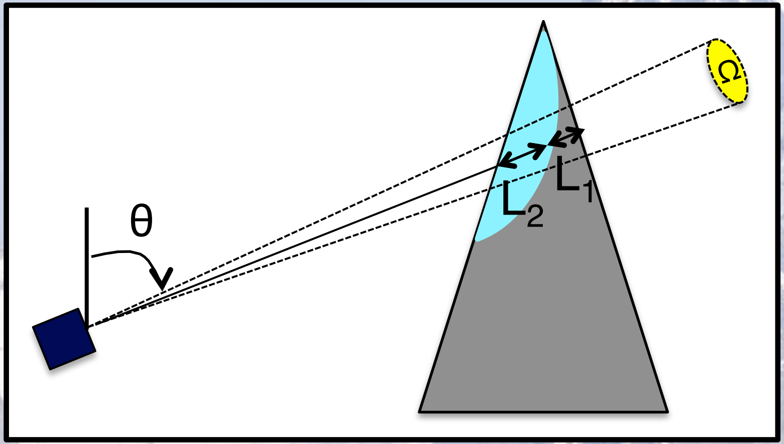
As most glaciers do not offer underground access we present a novel design for an open-sky operable, low maintenance, and low cost muon tomographer to perform glacier monitoring



Marmolada Glaciers

A detector with high resolution and high efficiency would make it possible to monitor the process of melting itself

Principle of operation



$$\Phi(p, \theta, l) = \Phi_0 * e^{-l/X}$$

$$X = L_1\ \rho_{rock} + L_2\ \rho_{ice}$$

$$T = L_1 + L_2$$

By measuring muon flux it is possible to infer the depth of ice-bedrock interface.

Seasonal variation in flux can offer information on varying ice depth.

If resolution allows we can infer the presence of **internal cavities** in the glacier, by observing **density variation** in the same ice volumes.

An assumption is made on the total thickness of the bedrock+ ice thickness T

The ice-bedrock interface is obtained by measurement of the opacity of the target w.r.t the expected flux

Detector Requirements & Challenges

Good tracking resolution

Goal to measure thickness with ~5m error in thickness and reconstruct small volumes

Need resolution better than 5mrad for incoming muon tracks

Fast detector

Need to reject background from muon not traversing the target and secondaries

Trigger and fast response needed, >1kHz sampling

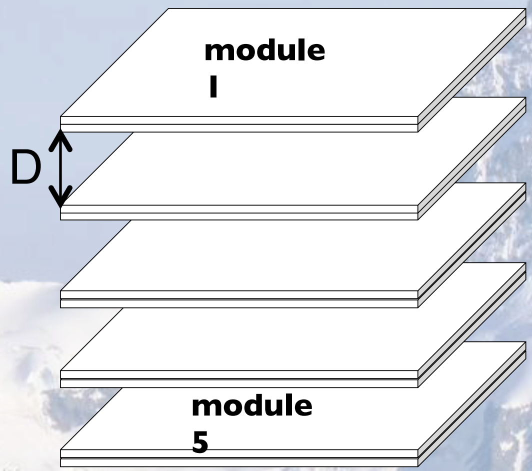
Low maintenance and simple design

The detector should be able to operate in open-sky, for long period of times

Low power consumption, able to operate in adverse weather, reliable and with enough redundancy.

Simple Scintillating fiber detector
Light detection with SiPM
Low number of channels ~2000
Commercially available powering and readout systems

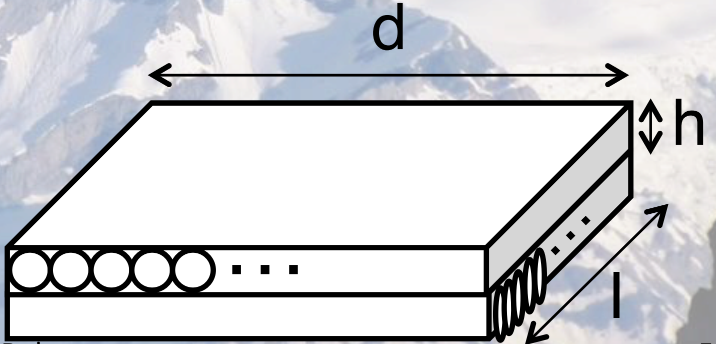
Detector Design & Optimization



GEANT4 based simulations were used to optimize the detector design

The base element is composed of 5 modules each composed of two layers of scintillating fiber bundles embedded in a plastic cladding to provide mechanical stability

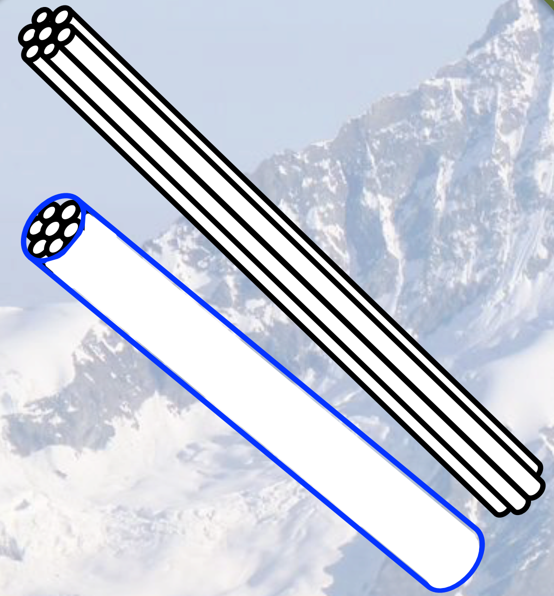
Three different distance (D) between modules are tested: 18 cm, 27 cm, 36 cm. Corresponding to total detector length of 0.99 m (basic), 1.44 m (medium), 1.89 m (long).



Each layer of 110 bundles of scintillating fibers running along orthogonal directions with respect to each other.

Layer dimension
h = 0.9 cm l = 99 cm d = 99 cm

Detector Design: Fiber Bundles



Bundles (d_{bundle} = 2.7 cm) are composed by an active part of **7 scintillating fibers** in the core (black) and a coating of plastic material (blu)

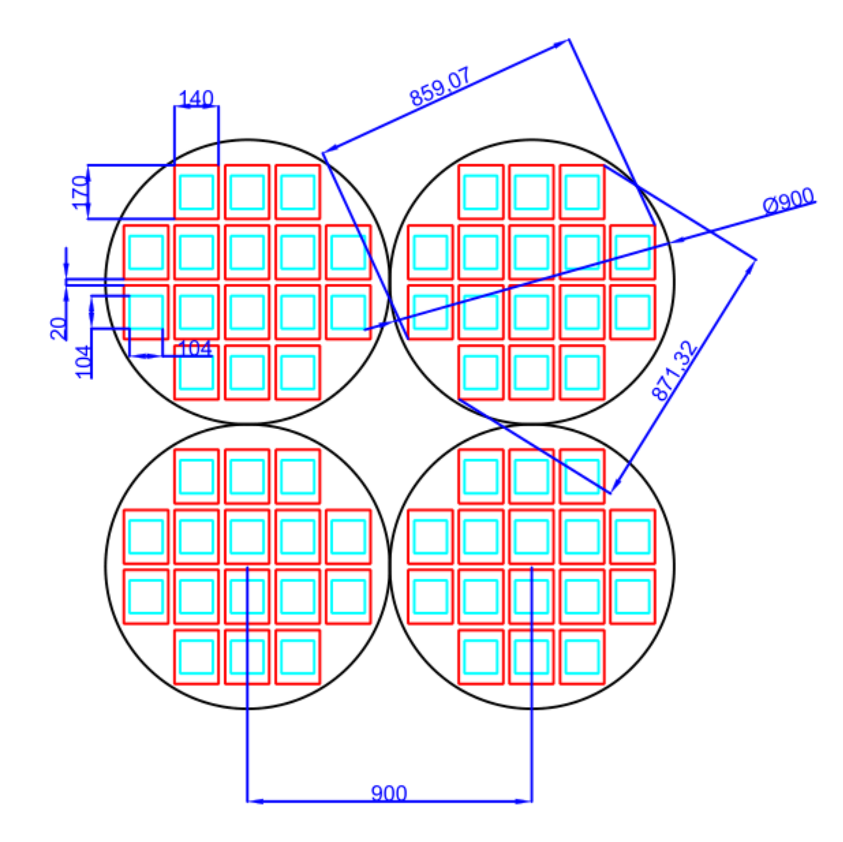
Fibers are bundled inside each layer in group of 7 single fibers.

Each bundle represent a single readout element and read independently by a SiPM array.

For the present study the light is considered to be integrated over the whole fiber bundle with a binary readout system

In the future the information on the number of fired SiPM in the array will be used to provide additional tracking information through the building of tracklets inside the bundle

Detector Design: Readout



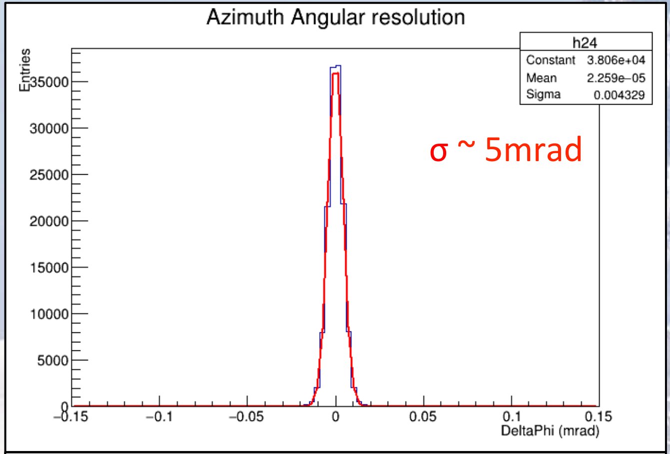
Different geometries were tested for SiPM matching to fibers, with different array arrangements

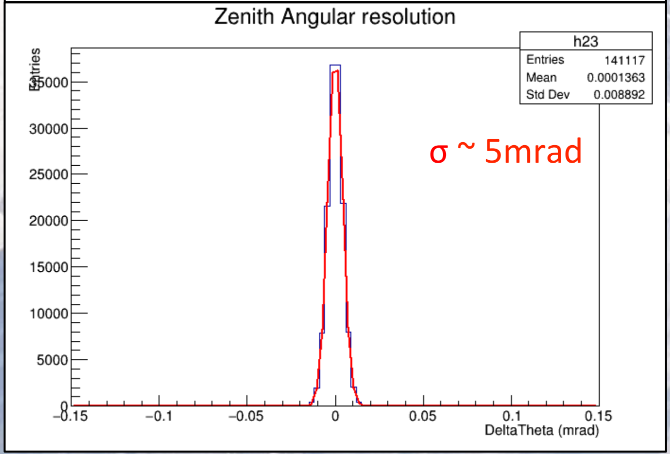
2000 array in total, with 16SiPM/array.

1mmx1mm SiPM in 1cmx1cm array

Commercial powering and readout systems are available for these devices, different options are currently being evaluated for the first prototype design.

Detector Simulation: resolutions





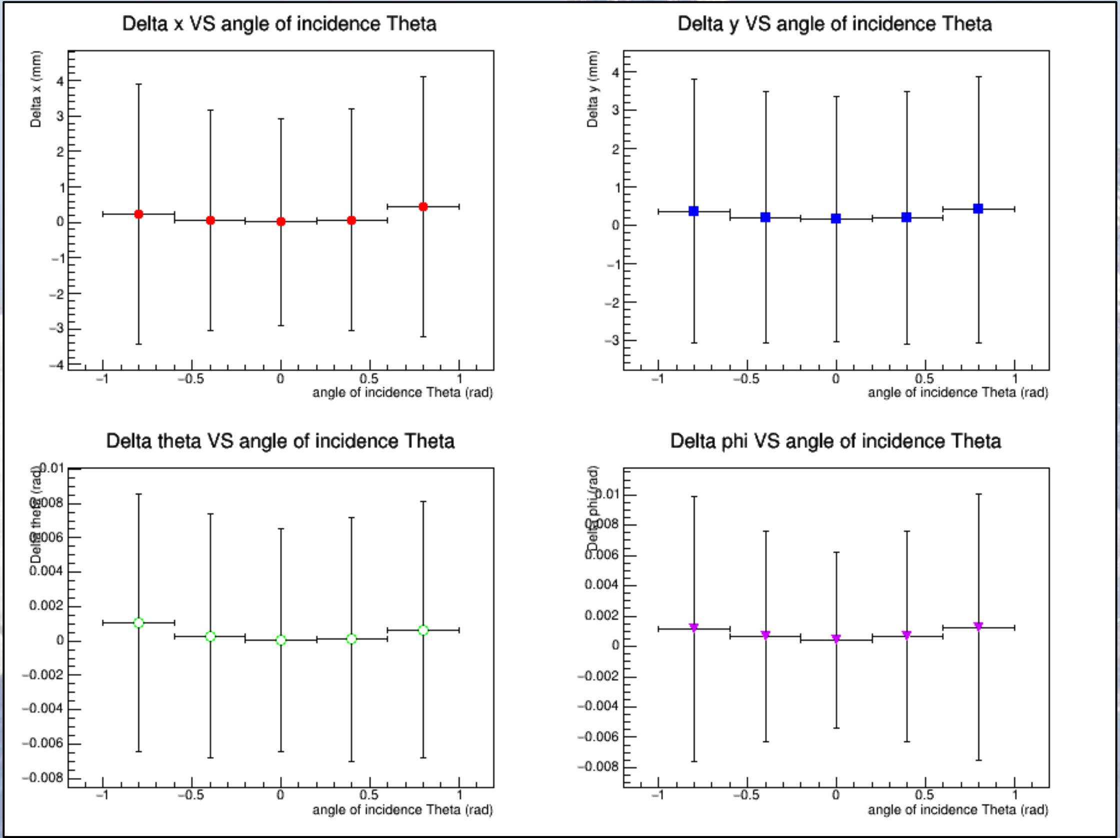
GEANT4 simulation were used to evaluate muon response for the detector.

Three detector length tested 0.99 m (basic), 1.44 m (medium), 1.89 m (long).

Resolution ranging from 10 mrad (basic) to 5 mrad (long)

The simulation results are well within the requirement for ice-bedrock interface depth resolution of ~5m and observe internal glacier structures

Detector response uniformity



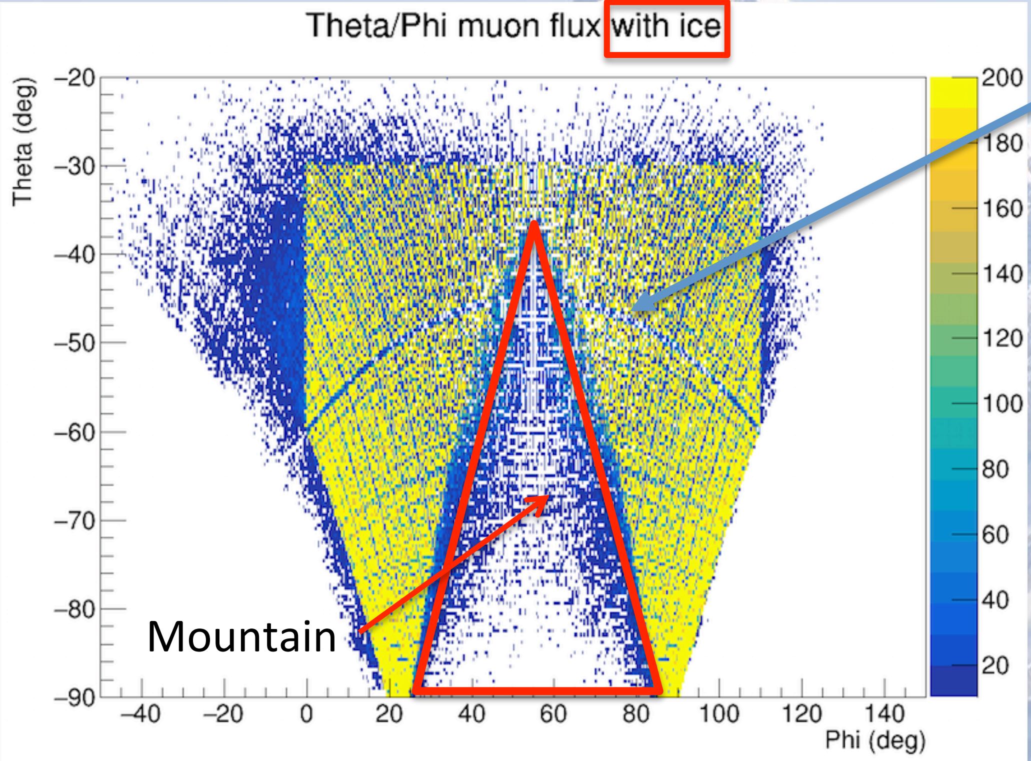
To evaluate the resolution stability over field of view, angular resolution was evaluated at varying impinging angles

Results were produced for residuals and angle reconstruction

↓

Angular resolution worsen for high impinging angles for less than 3%

Results with simulated target



Low statistic simulation for two configurations:

- Mountain with ice
- Mountain without ice

Conical mountain (h = 1560 m and r = 520 m) at 1 km from the detector.

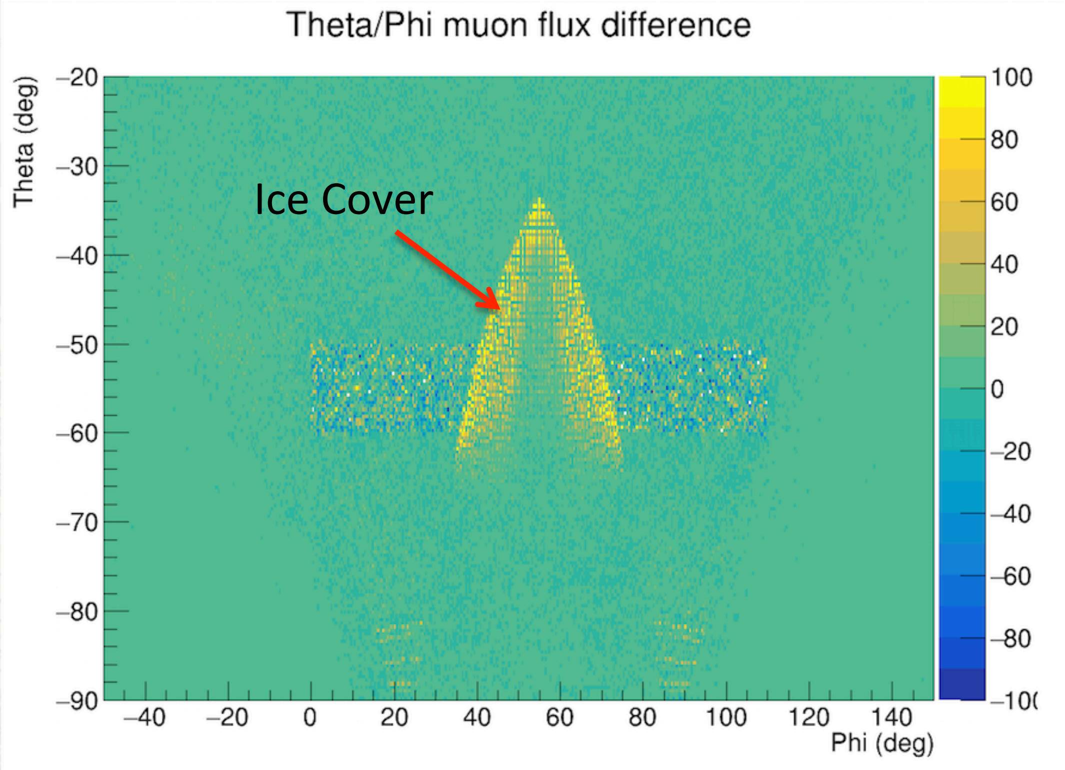
Generated 2M muons for each 10° slice in polar angle

E > 400 GeV

The detector can reconstruct the mountain profile even at low statistics

→ Next step: **increase the simulated data set**

Low Statistics analysis



By using the two low stat samples muon flux difference can be evaluated

Each pixel in the plot represent ~5x5m and the thickness sensitivity is being evaluated

These results are obtained with an equivalent exposure time of $O(10^6)$s satisfying the goal of a seasonal monitoring of glacier thickness

Outlook

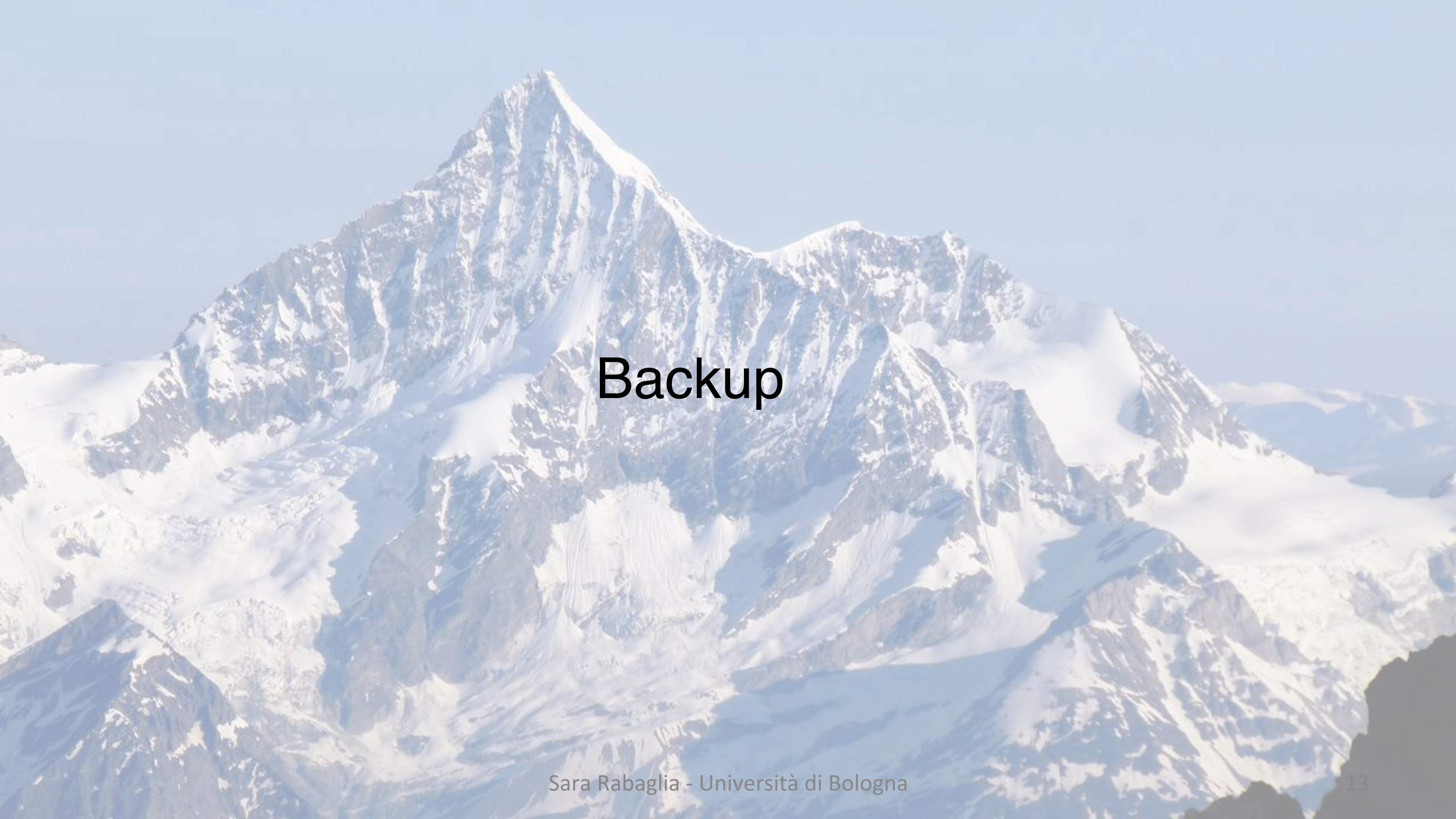
- We presented a conceptual design for a new muon tomographer operable in open-sky condition for in-situ glacier monitoring

- Our preliminary results, based on GEANT4 simulation show promising prospects for the design, with expected resolution of <10mrad for tracking reconstruction, high background rejection, and good stability over the field of view

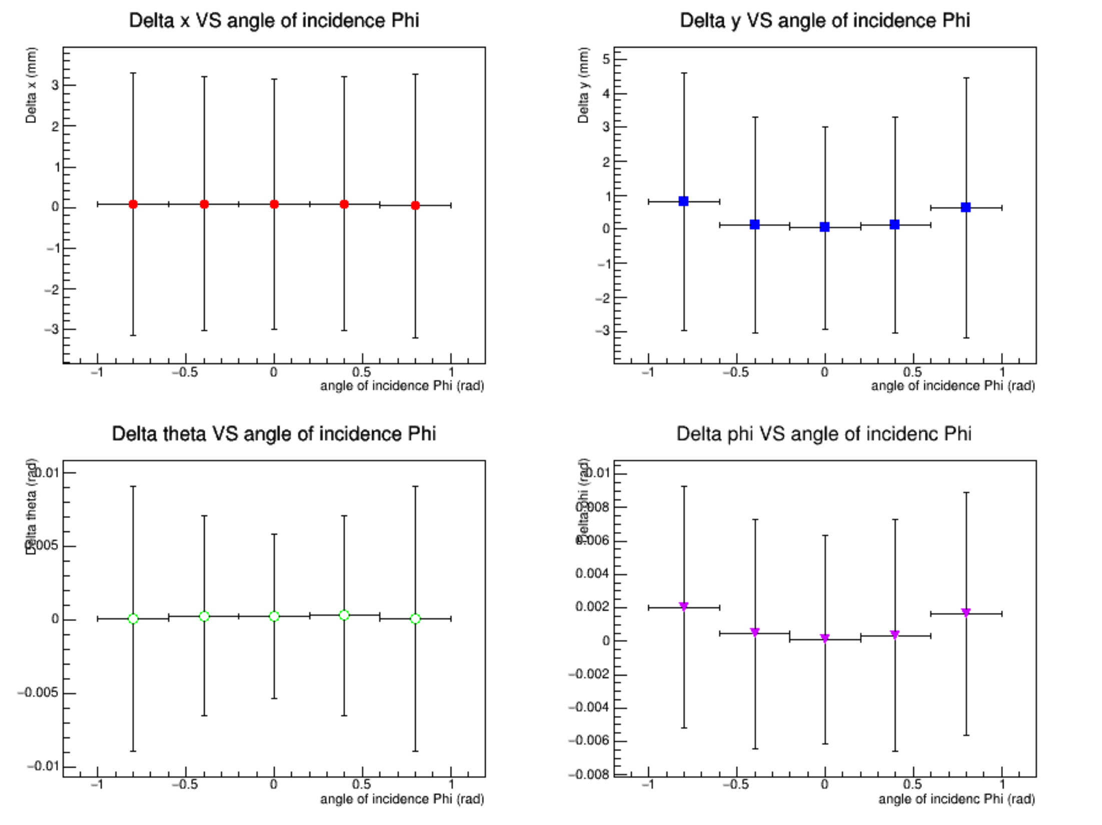
- First analyses on flux reconstruction have been presented on a small dataset of simulated muons. First results show that good resolution on ice-bedrock interface depth can be obtained with 1 month integrated flux allowing for seasonal variation studies.

- We plan to build the first module for this detector next year, and the rest will follow suit, stay tuned!

Backup

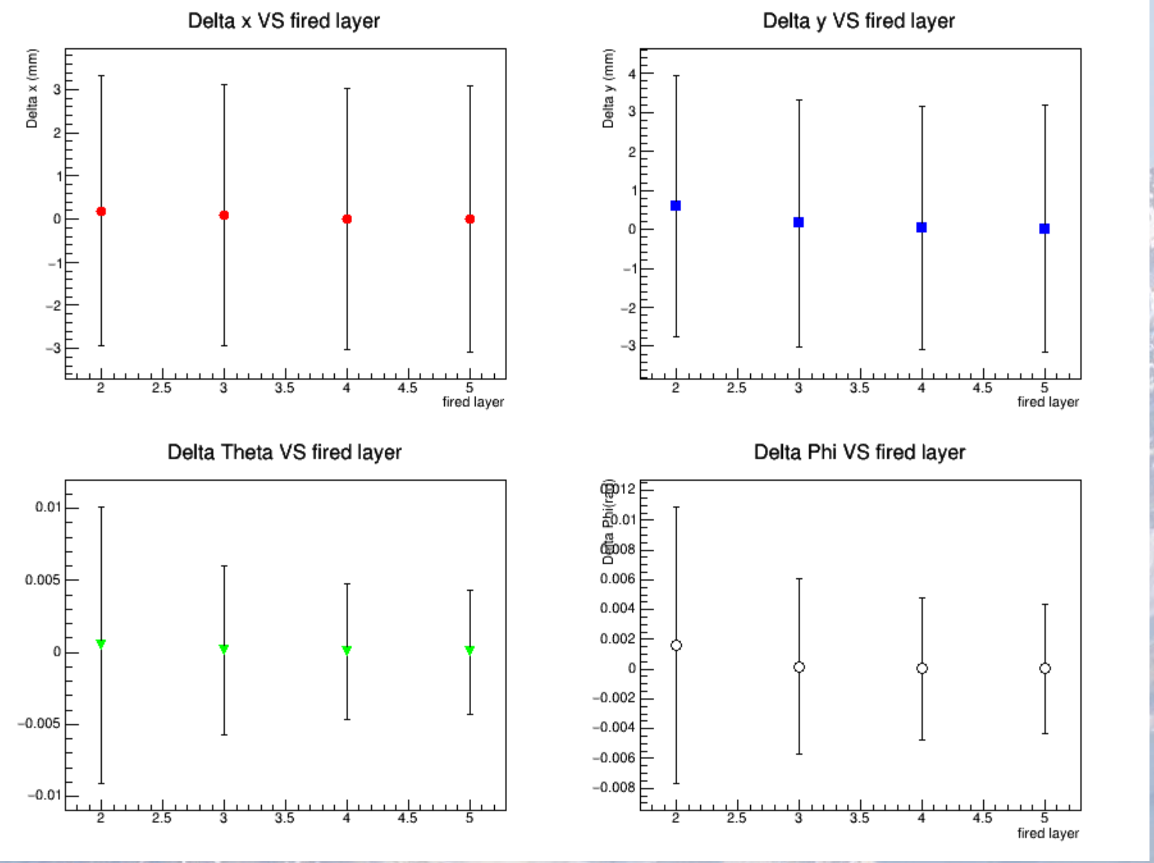


Simulation



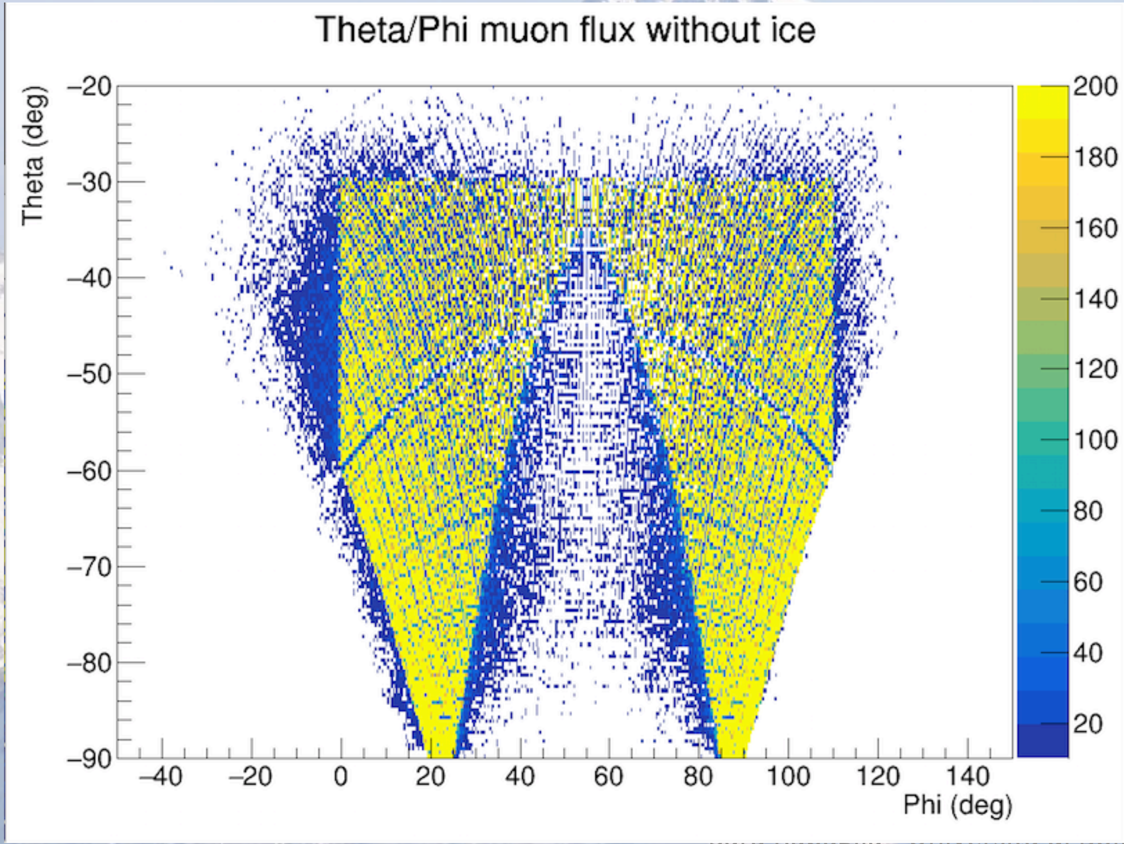
Plot that shows the uncertanty on the reconstructed track with respect to and Azimuth angle.

Simulation



Plot that shows the uncertanty on the reconstructed track with respect to fired layer.

Simulation



Muon flux with respect to Theta and Phi in the configuration without ice.

Less muon can pass through the mountain
→ More evident along mountain bounds