

# Kann man einen Berg röntgen ?

Physik am Freitag

9.3.2018

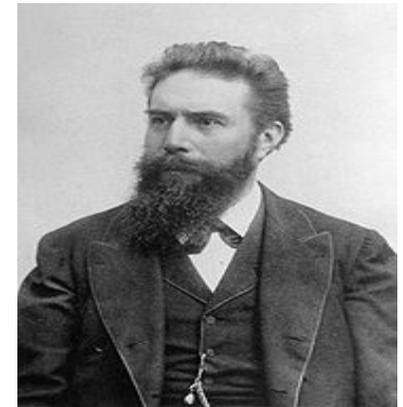
M. Weber

Universität Bern

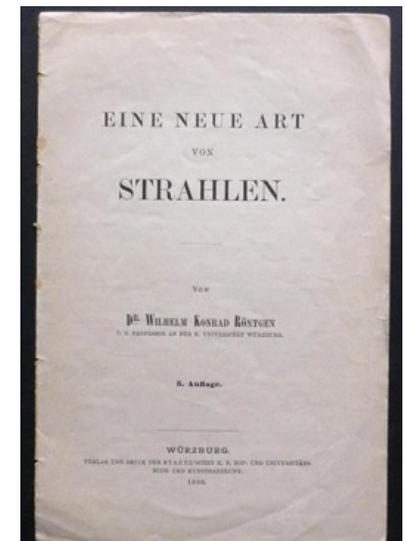


# Röntgen

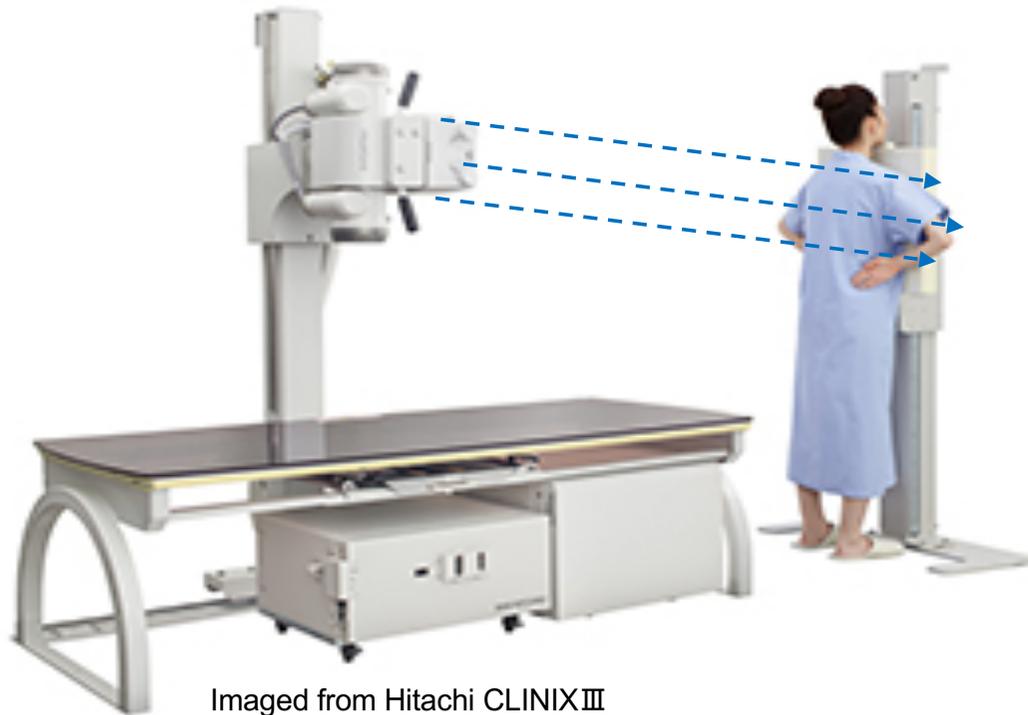
- > Nobelpreis 1901 für Wilhelm Röntgen „für seine Arbeit über die Entdeckung von Röntgenstrahlung“ (erster Nobelpreis, der verliehen wurde)
- > Röntgen entdeckte die X-Strahlen 1895, bei einem Experiment mit einer Kathodenstrahlröhre
- > Röntgenstrahlung wurde schon früher erzeugt, die Bedeutung der Entdeckung wurde nicht erkannt und nicht publiziert
- > Sie werden (Deutsch) unter Missachtung seines Testaments Röntgenstrahlen benannt



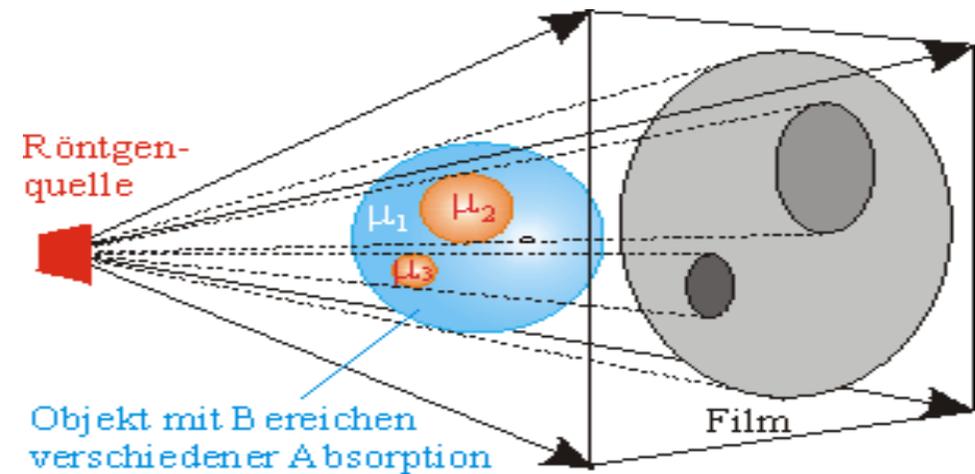
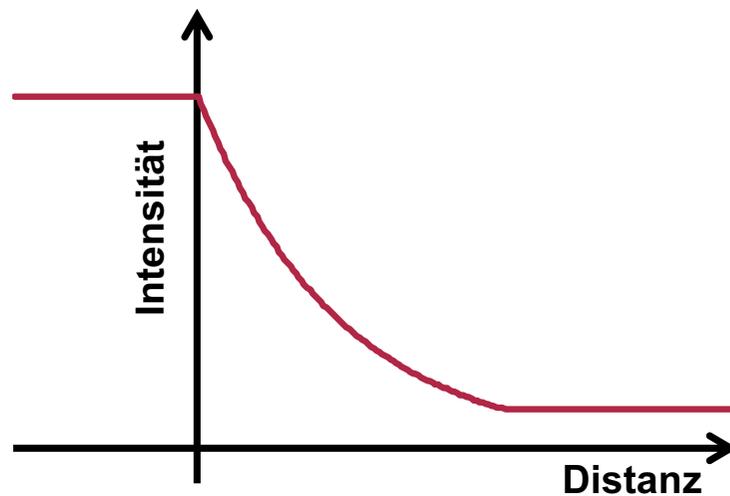
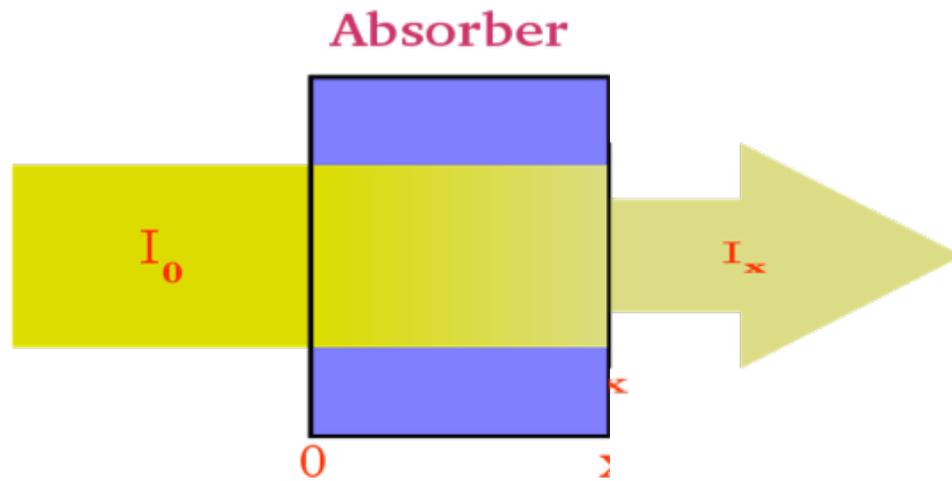
**Wilhelm Röntgen**  
(1845 - 1923)



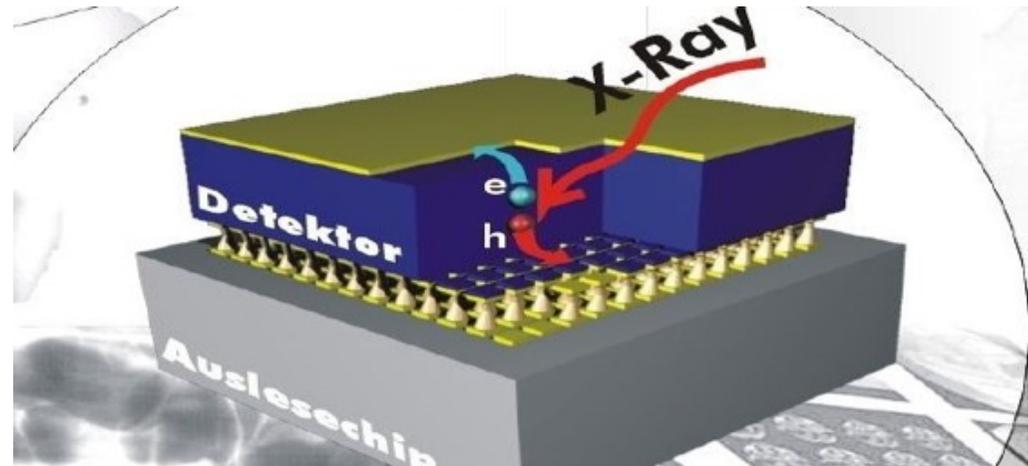
# Röntgenbilder



# Röntgenbilder



# Bilder



# Kann man einen Berg röntgen ?



Maximal Meter...

Also: eigentlich nicht.

**Aber wir können es doch !**

# “Röntgen”: Konzept verallgemeinern

## Strahlen

## Absorption

## Aufzeichnung

Röntgen

1 m max

Photo-Emulsion, CMOS

Protonen

Meter

Teilchendetektoren

Neutrino

1 Lichtjahr

Neutrino-Detektor

Myon

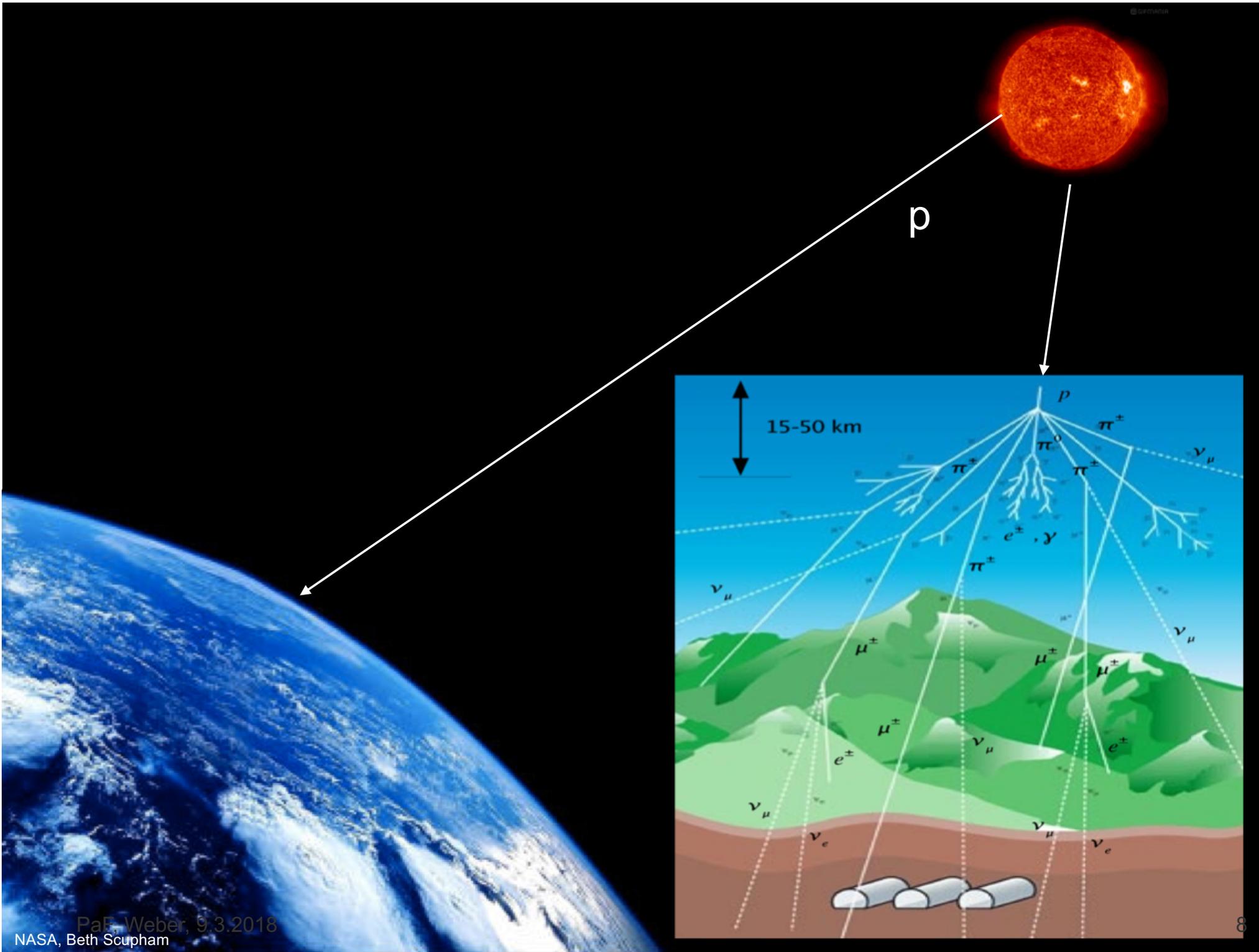
Kilometer

Teilchendetektoren

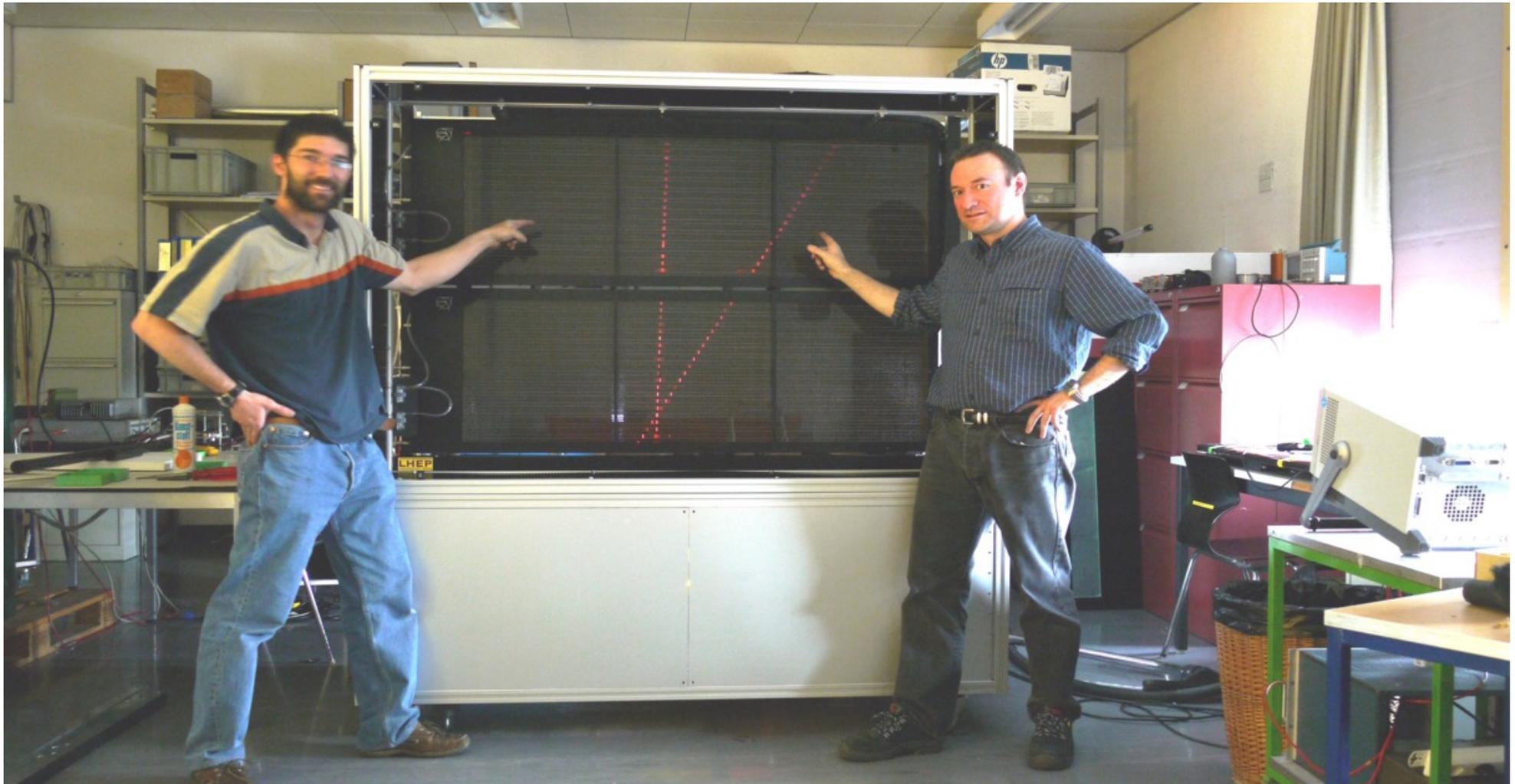
Teilchen/Welle

...

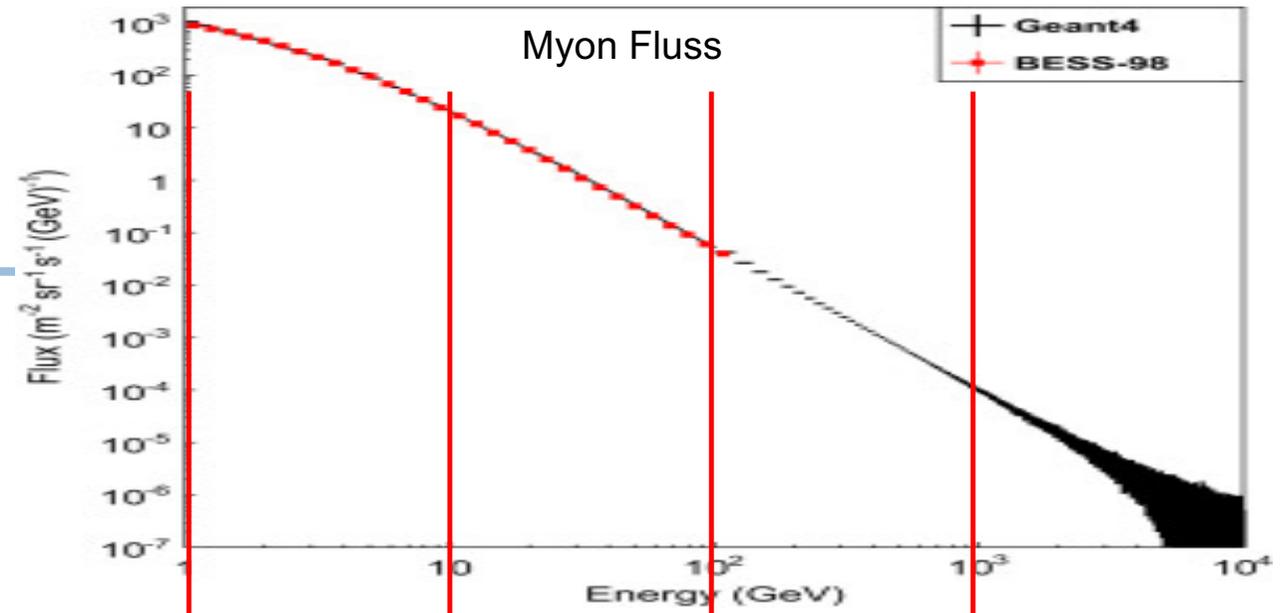
Teilchendetektoren



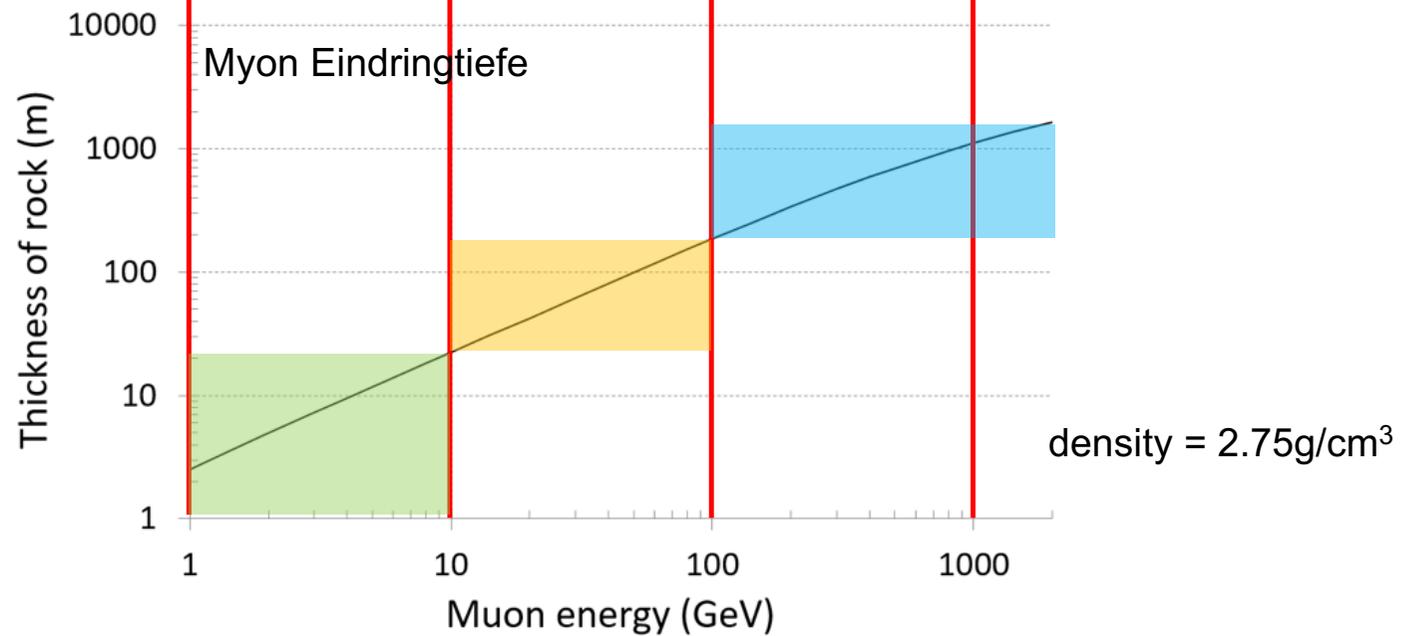
# Kosmische Myonen



Wie viele Myonen ?



Wie tief dringen die Myonen ein ?



# “Röntgen” mit Myonen

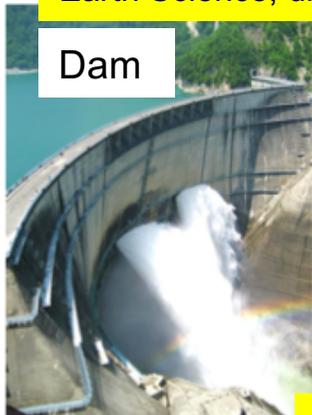


Nuclear Power Plant



Industrial plants

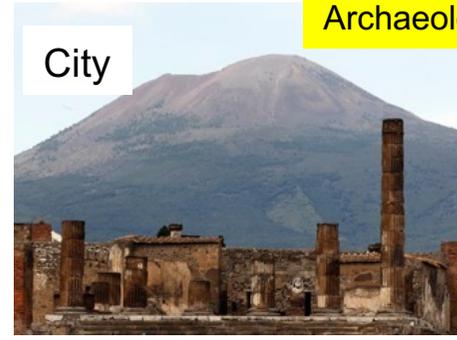
Earth Science, disaster prevention



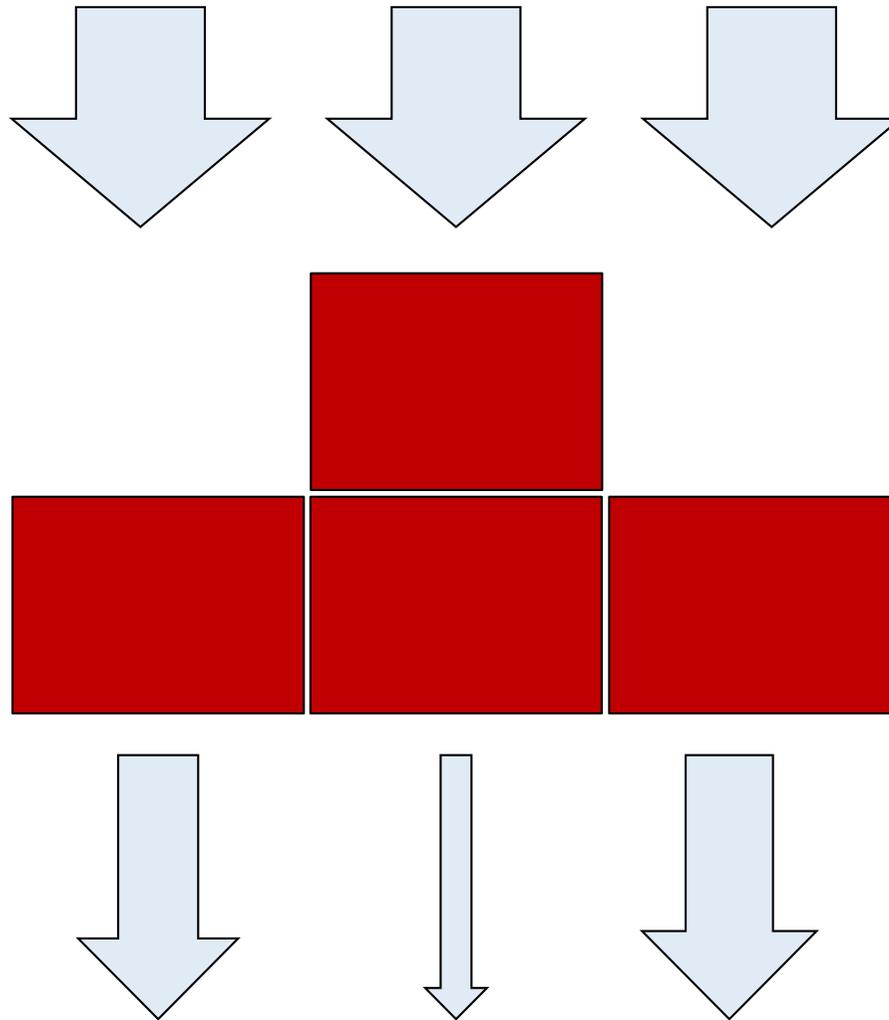
Geological survey  
Infrastructure Inspection



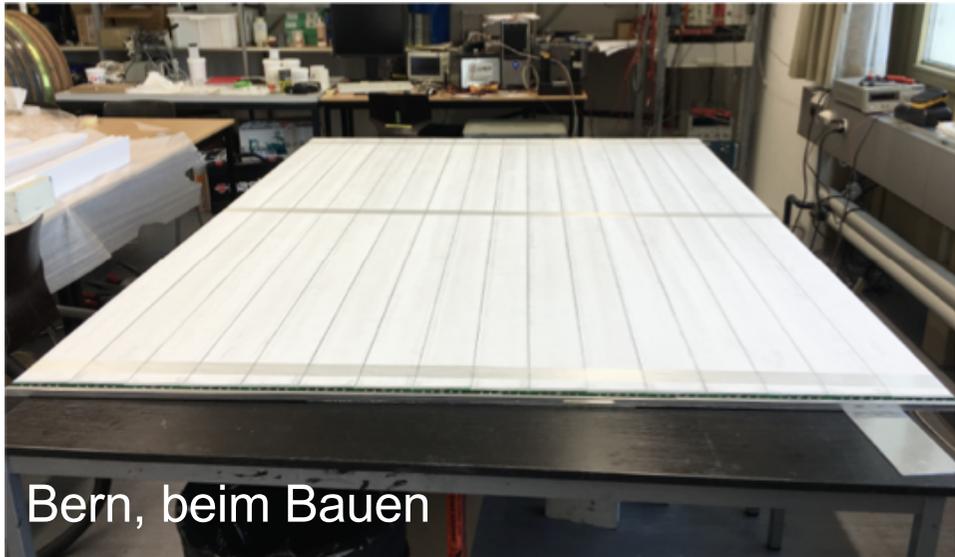
Cultural Assets  
Archaeology



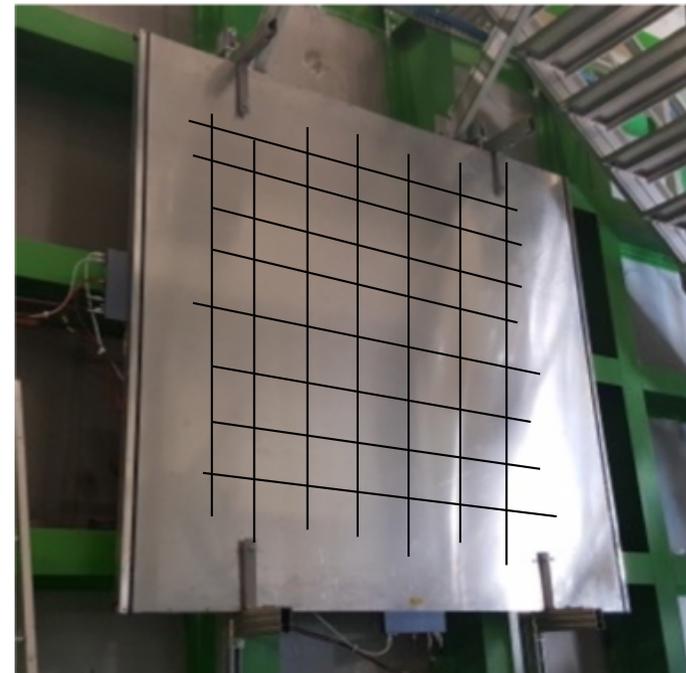
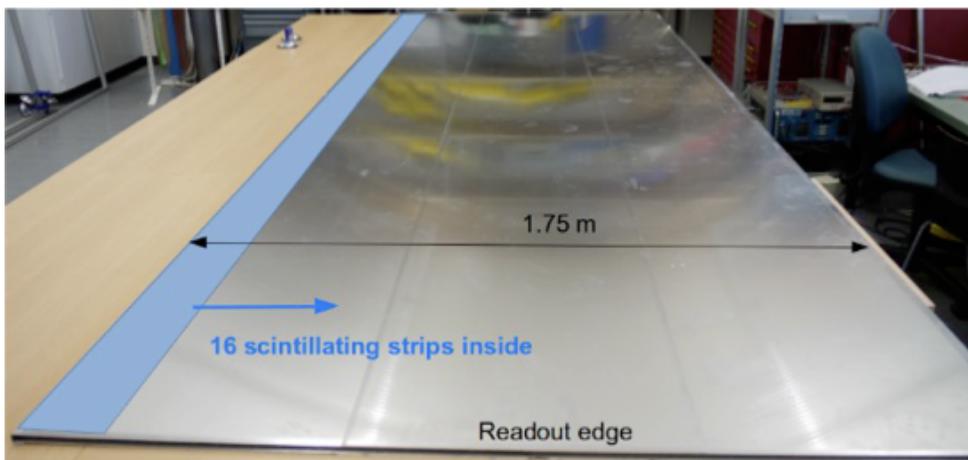
# Myon Tomographie



# Szintillator “Wände”

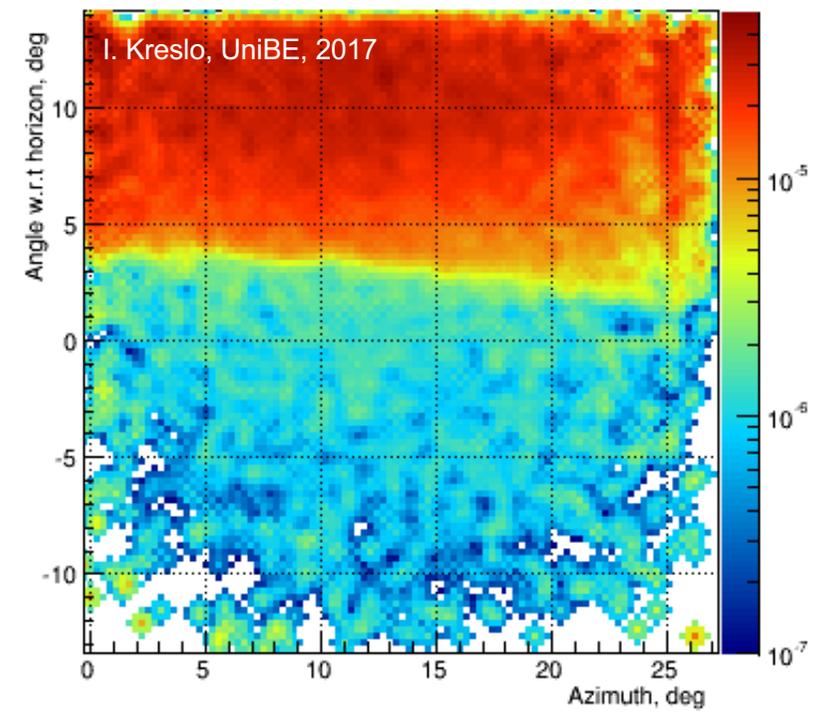


CERN  
Neutrino Detektor

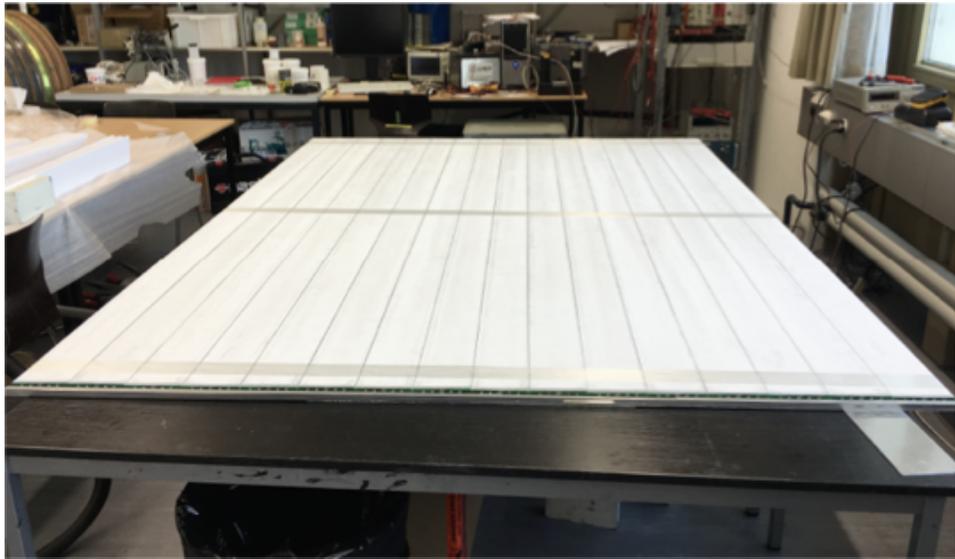




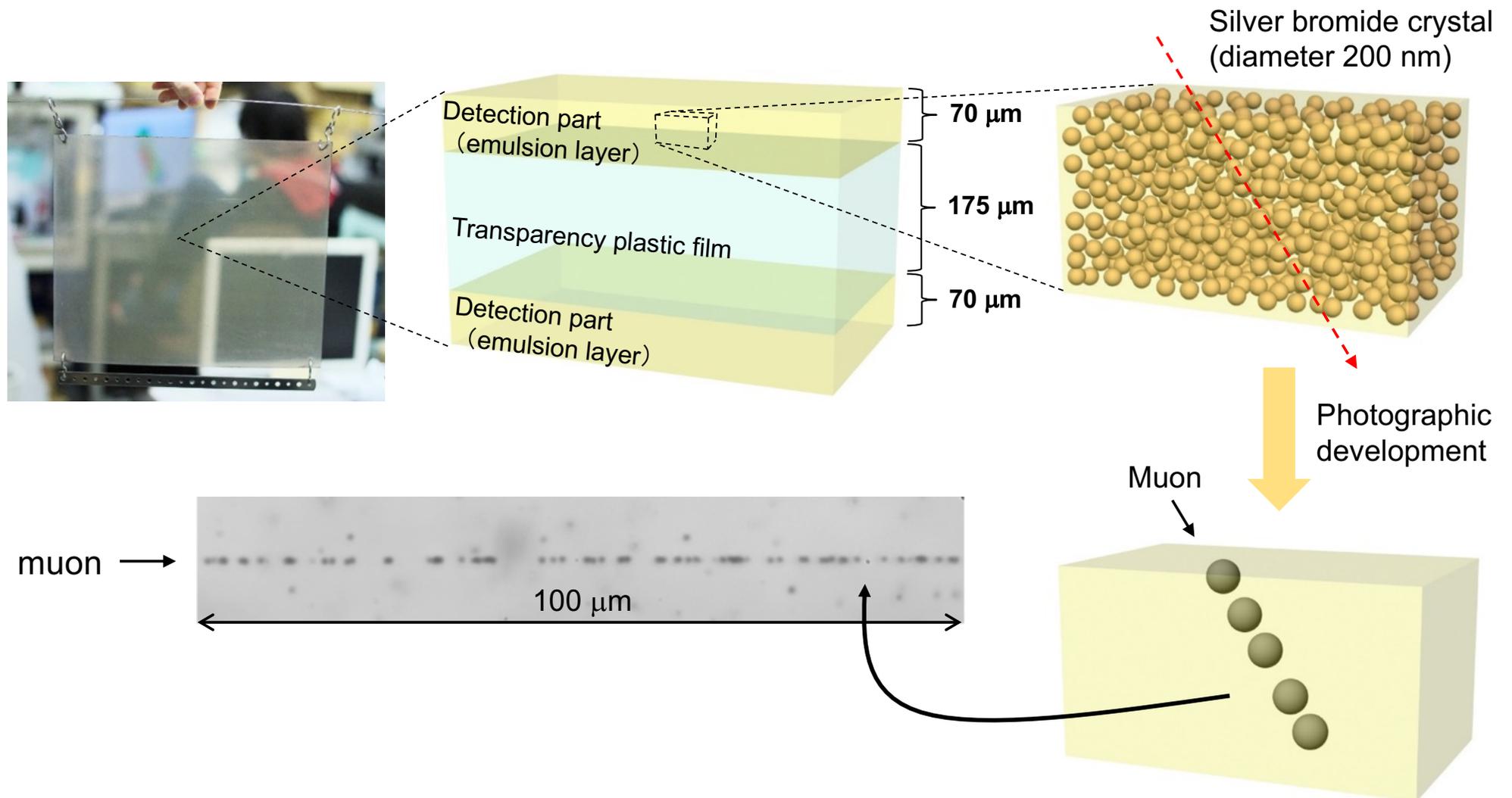
Muon flux, from NW



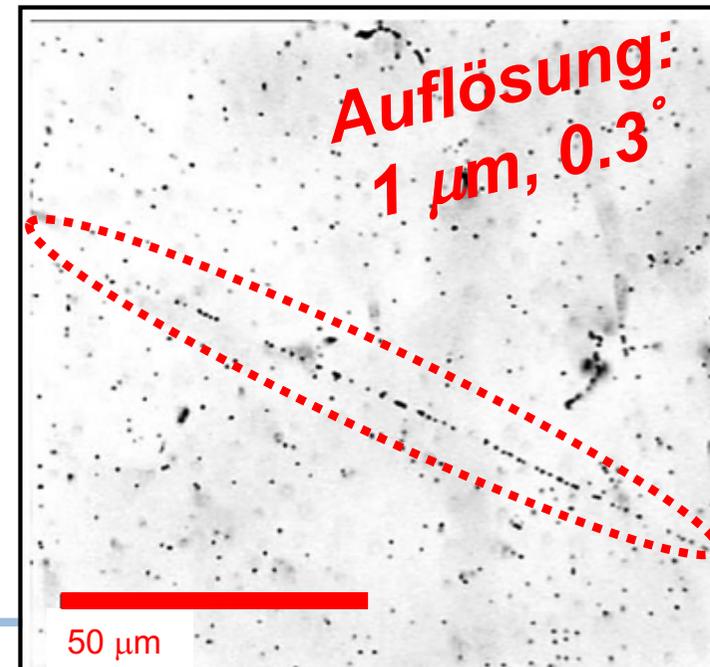
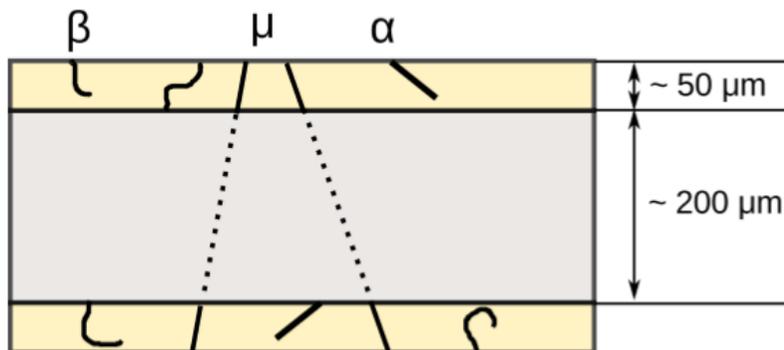
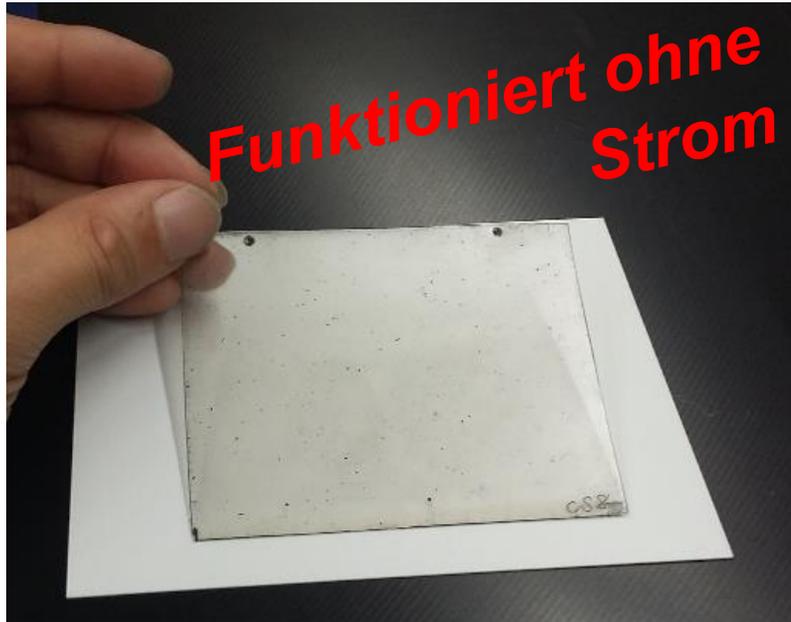
# Bessere Auflösung



# Photo-Emulsionen als Hochauflösender Teilchendetektor



# Myonen Detektor: Emulsionsfilme

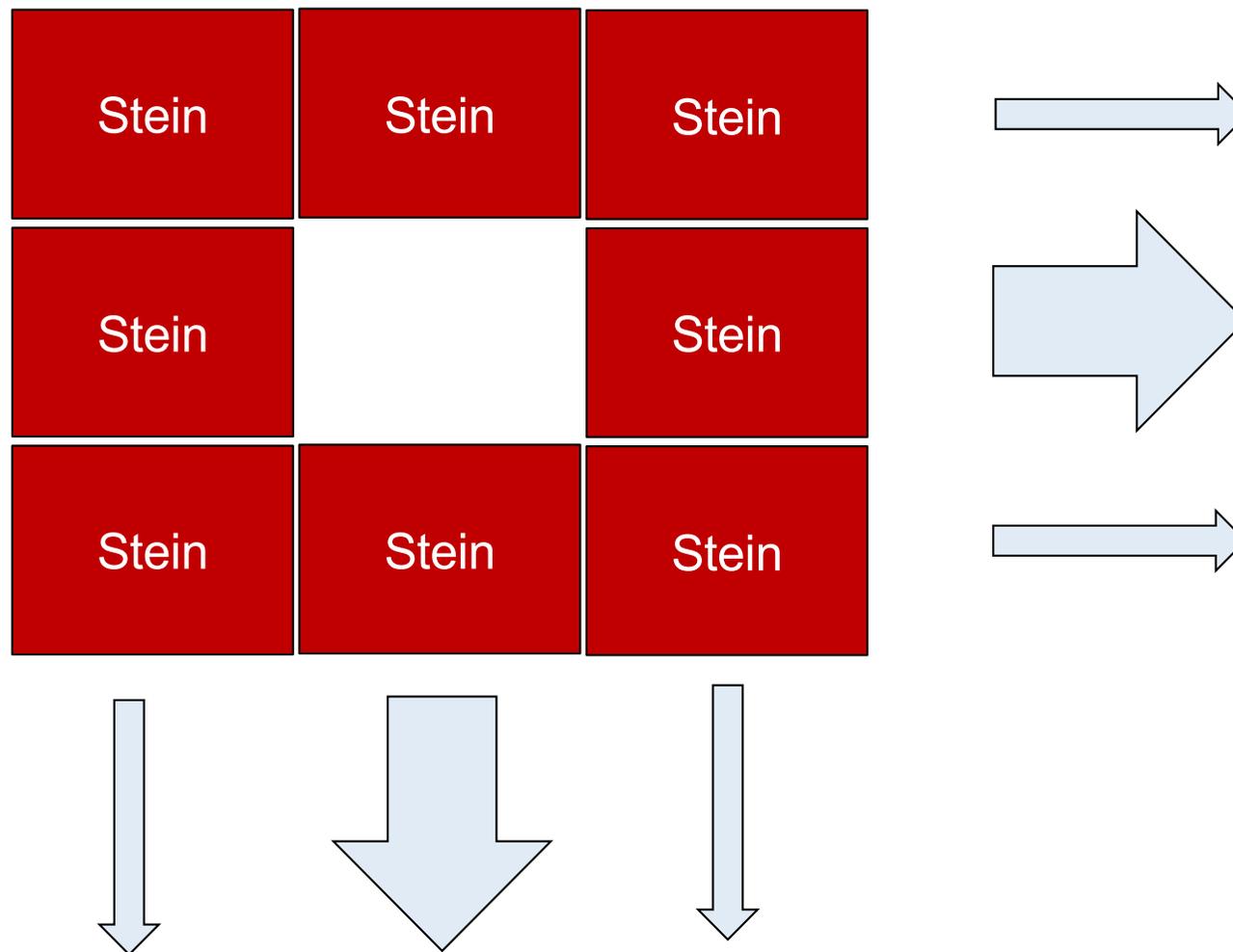




**25'000 dpi, 3D**

150  $\mu\text{m}$  x 120  $\mu\text{m}$  x 50  $\mu\text{m}$

# Myon Tomographie

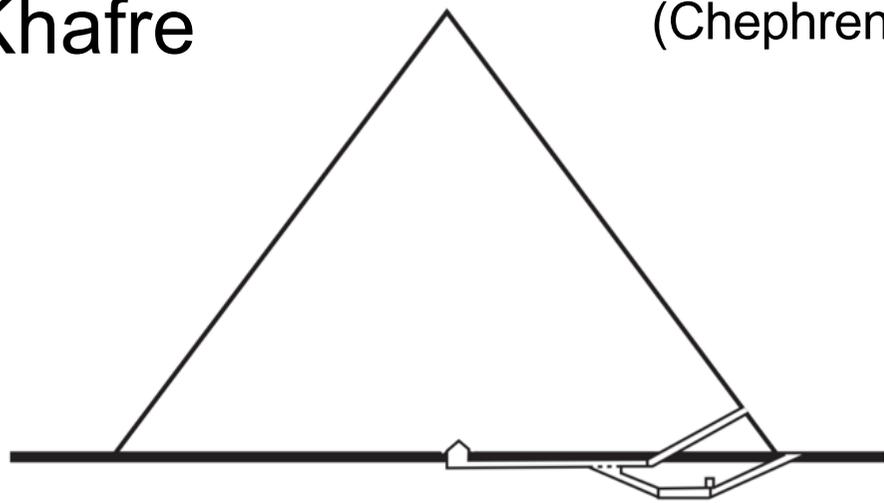


# Pyramiden von Giseh



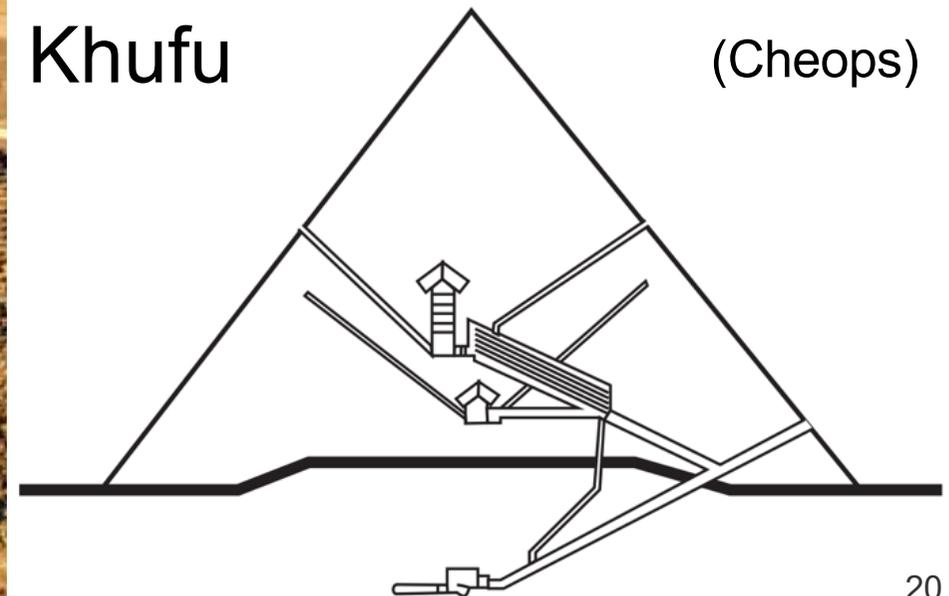
Khafre

(Chephren)



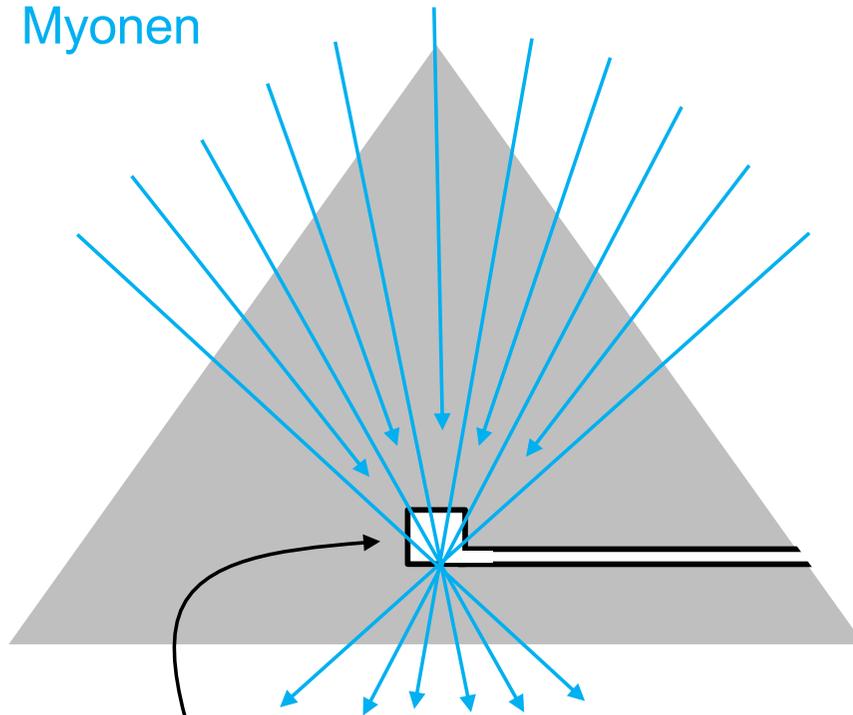
Khufu

(Cheops)



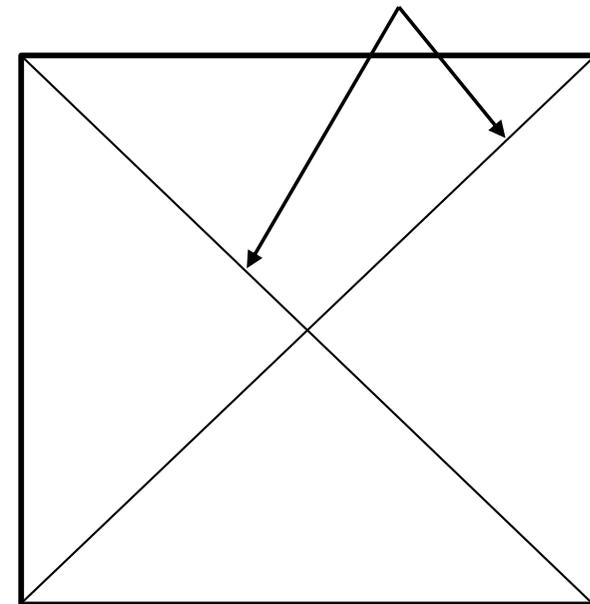
# Myon Tomographie einer Pyramide

Myonen



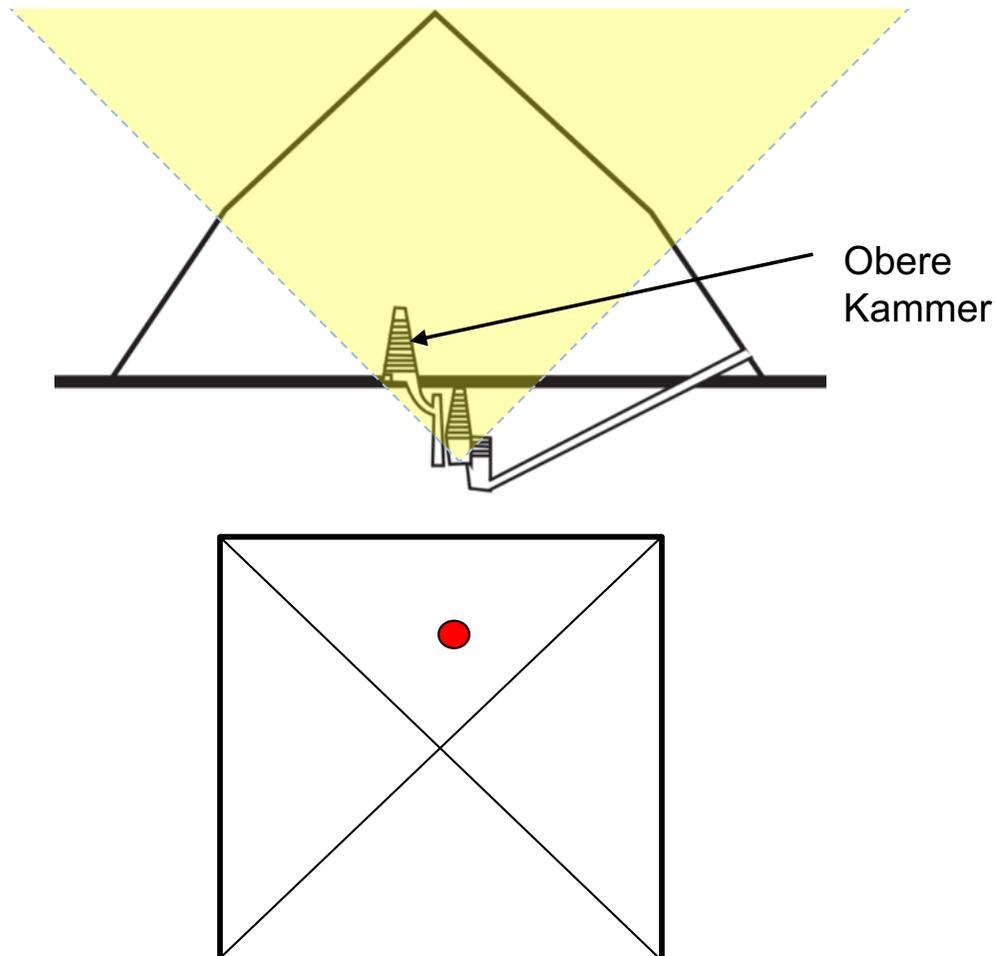
Muon Detektor

Kanten der Pyramide

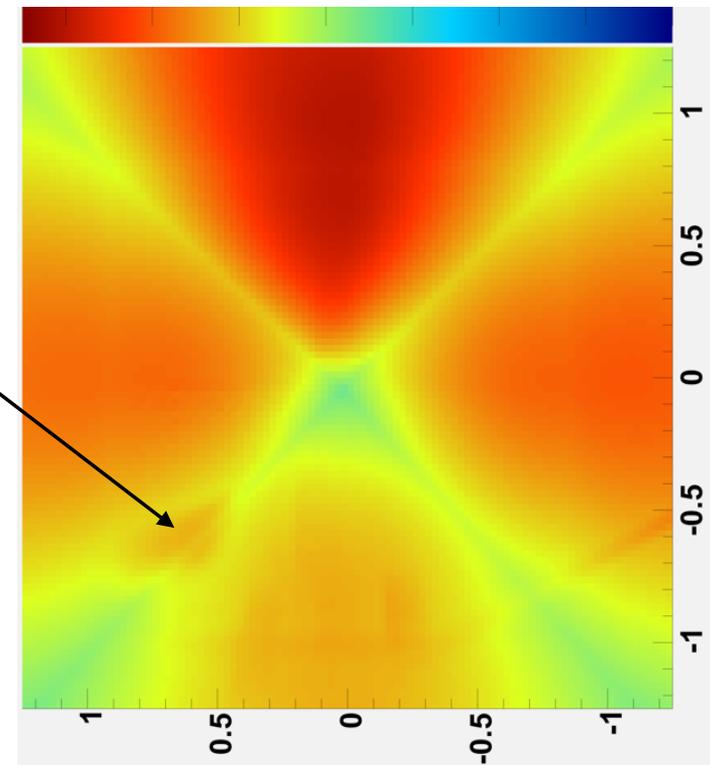


Ansicht von Oben

# Simulation



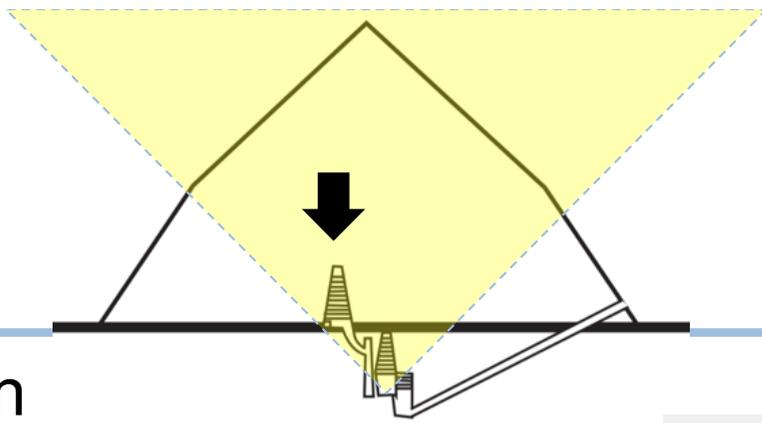
# Erwartete Messung



Muon Fluss

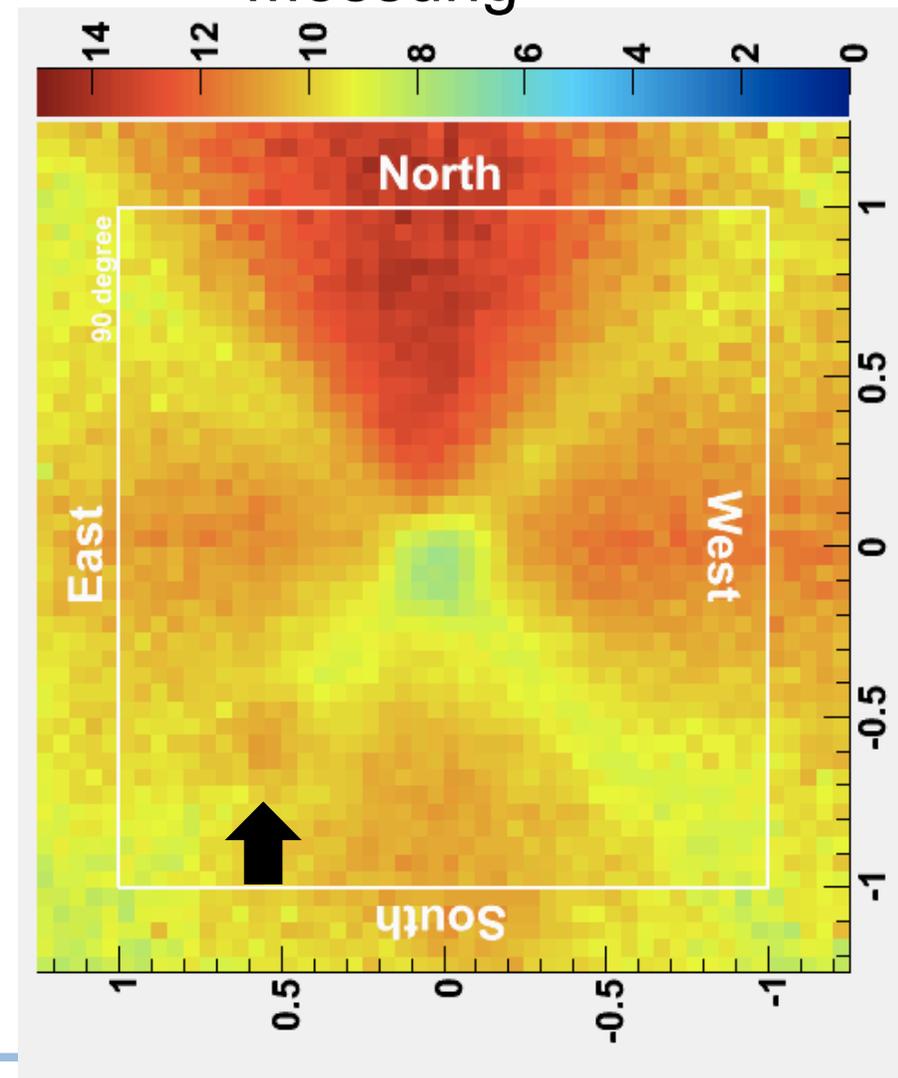
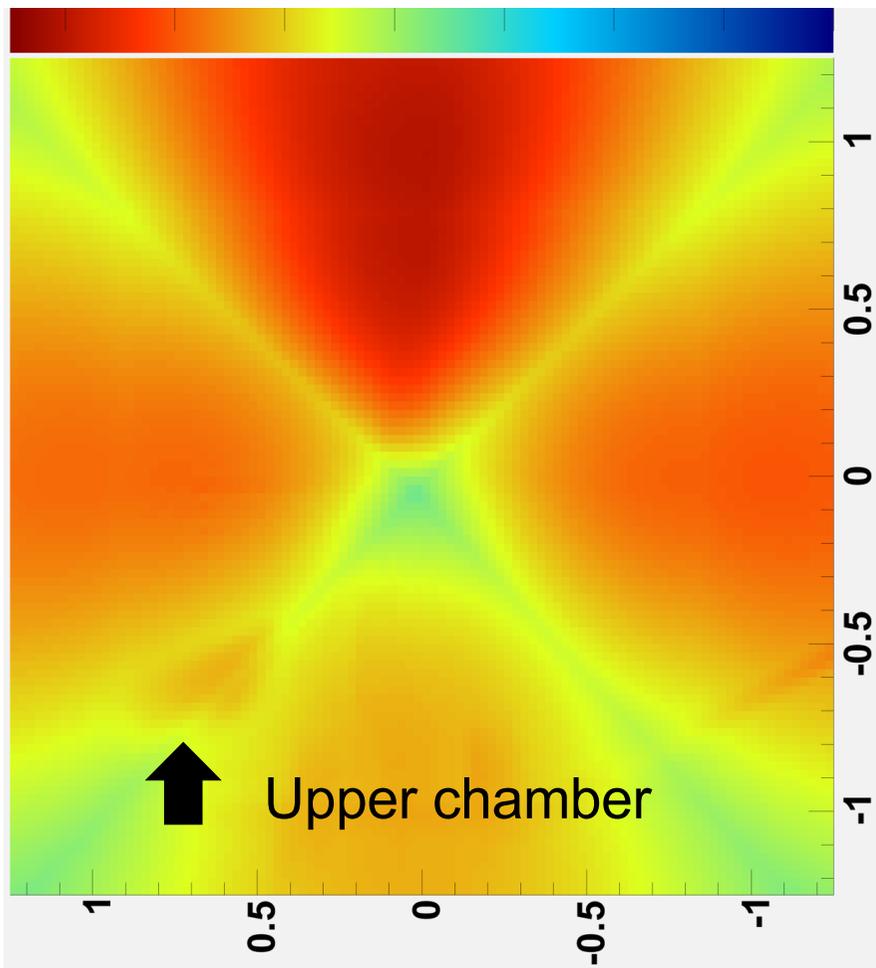
Rot = viele Myonen

Blau = wenige Myonen

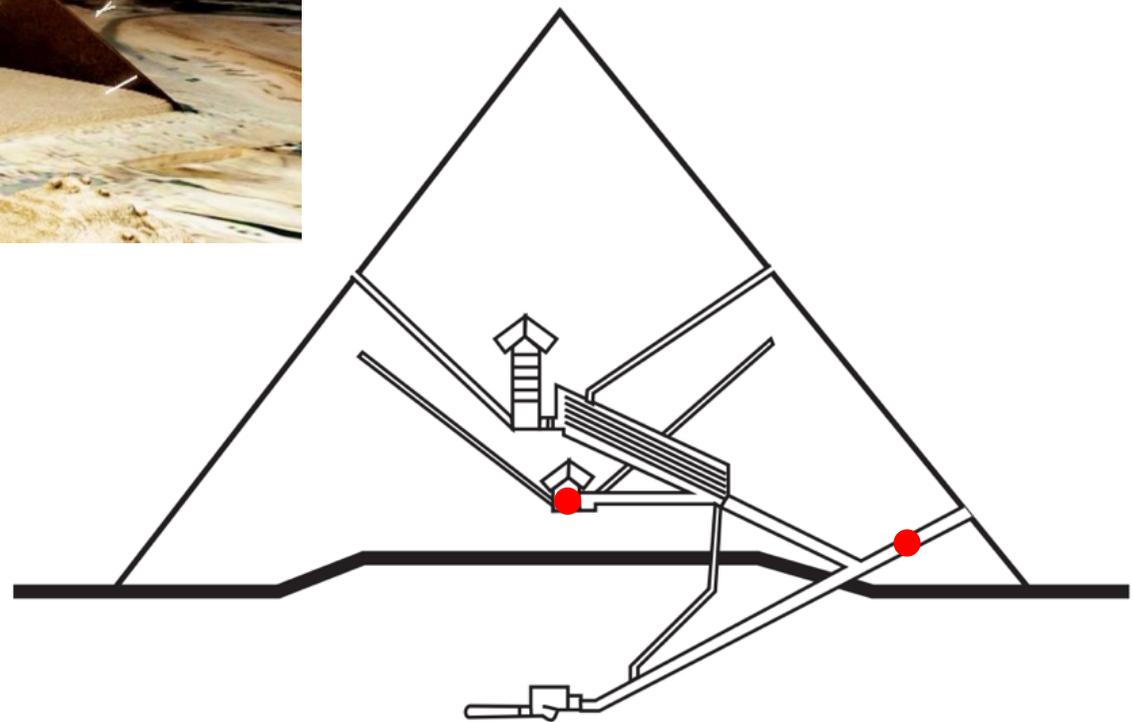


Simulation

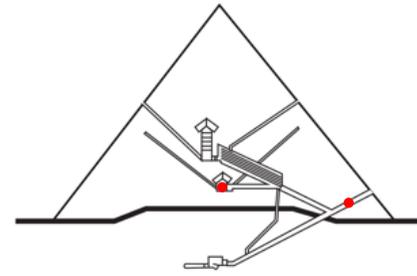
Messung



# CHEOPS

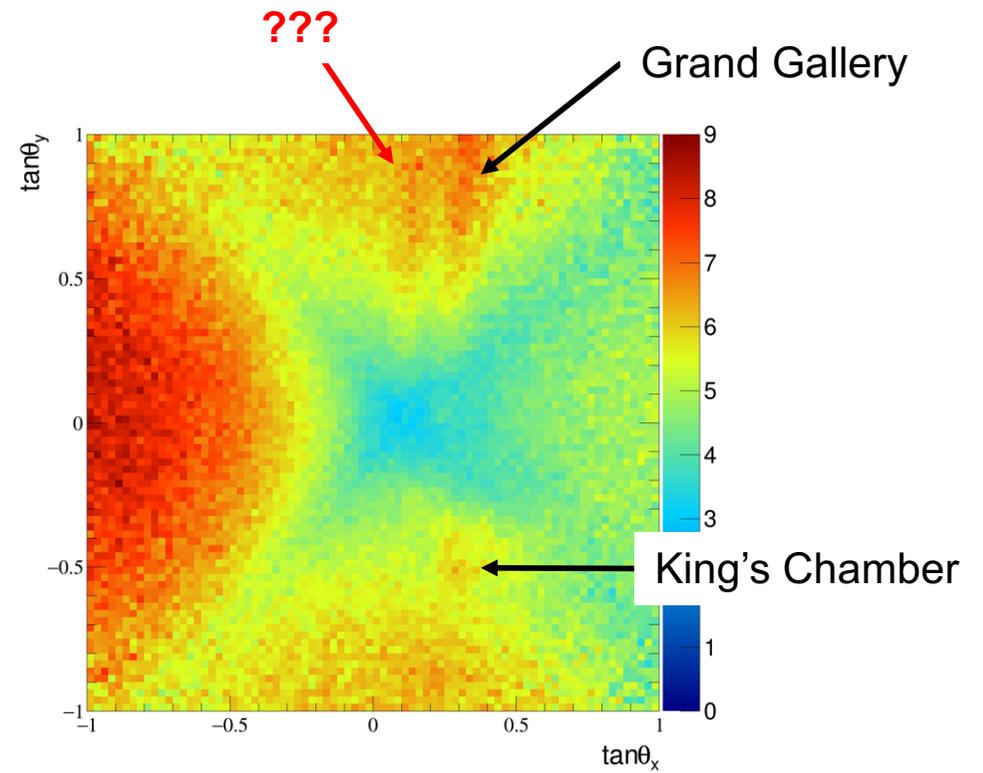
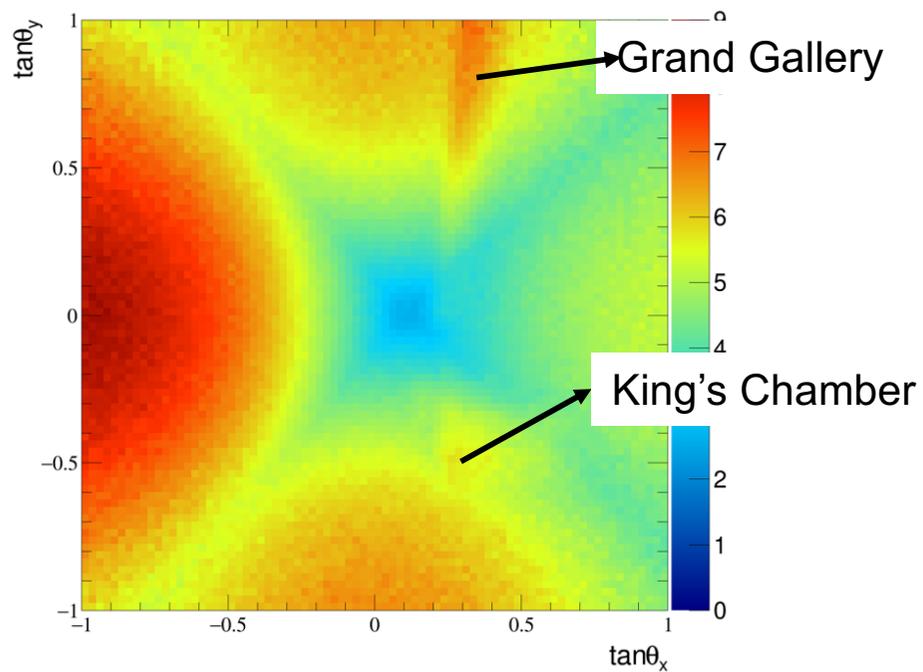


# Simulation und Messung



## Simulation

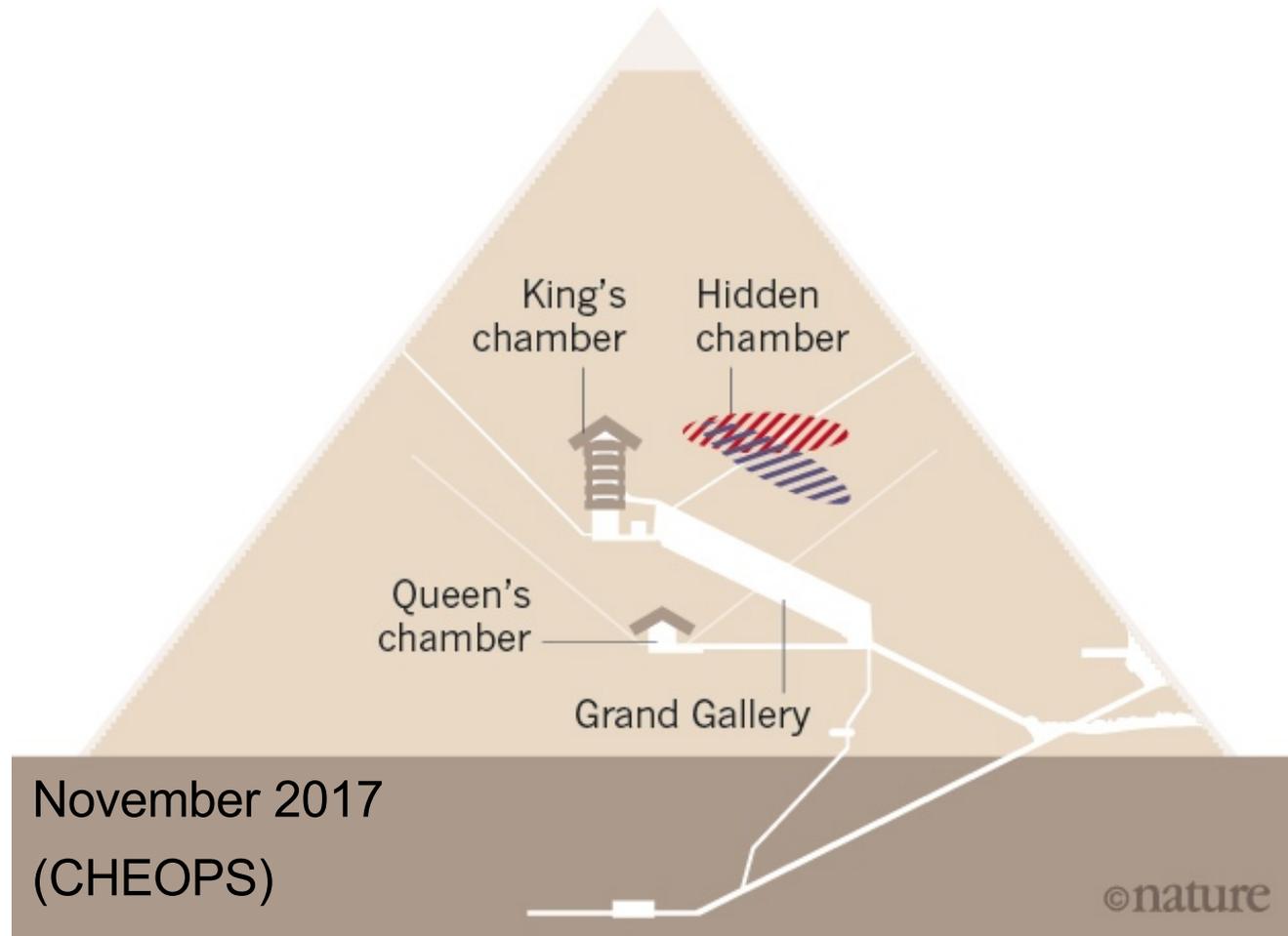
## Messung



# THE GREAT PYRAMID'S BIG SECRET

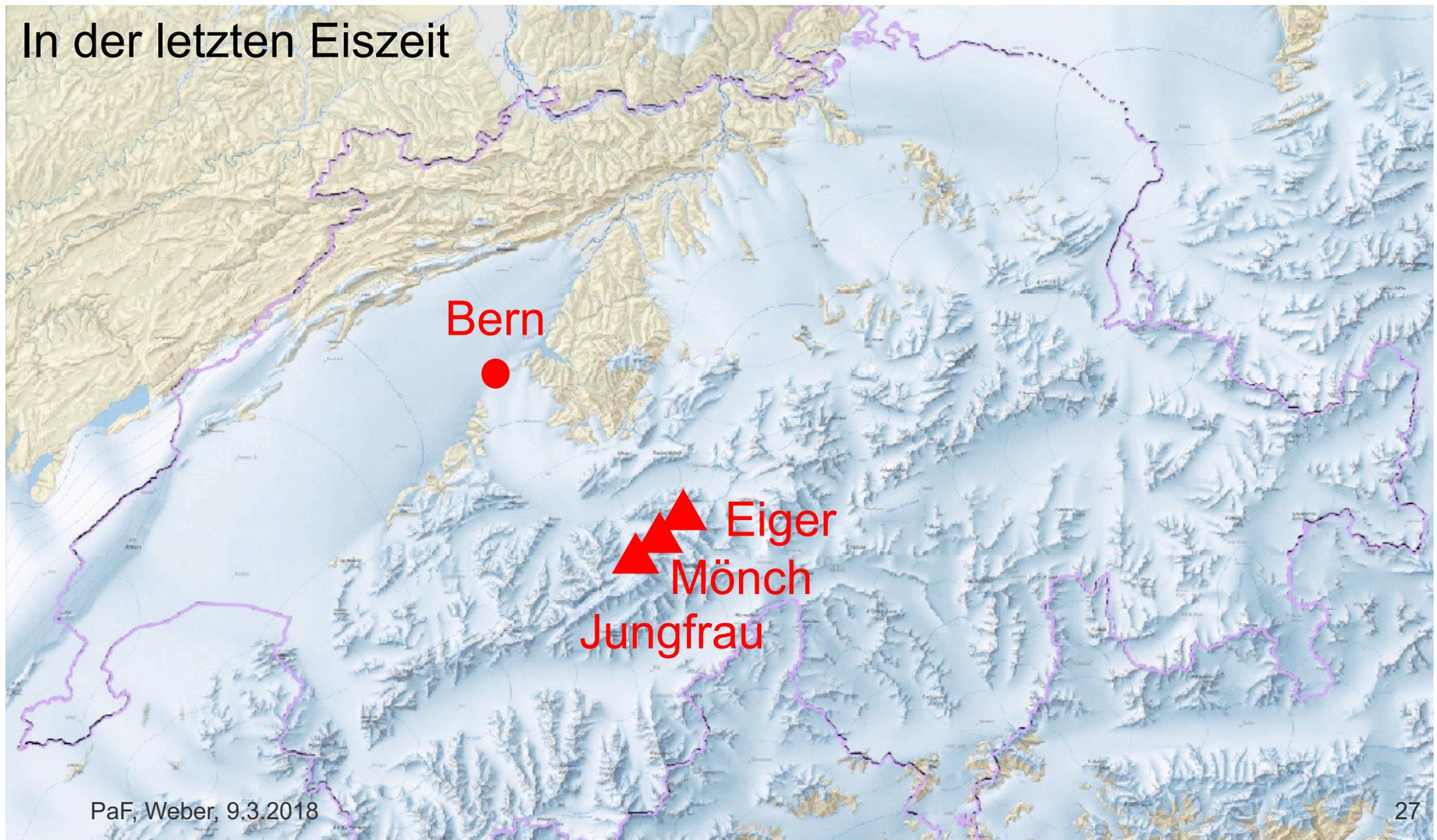
A large, previously unknown chamber at Khufu's Pyramid, Giza, has been revealed by imaging muons. These particles are partially absorbed by stone, so by placing muon detectors inside and outside the pyramid, researchers were able to infer the presence of a space where more muons than expected hit the sensors.

Possible orientations of void: ■ Inclined ■ Horizontal

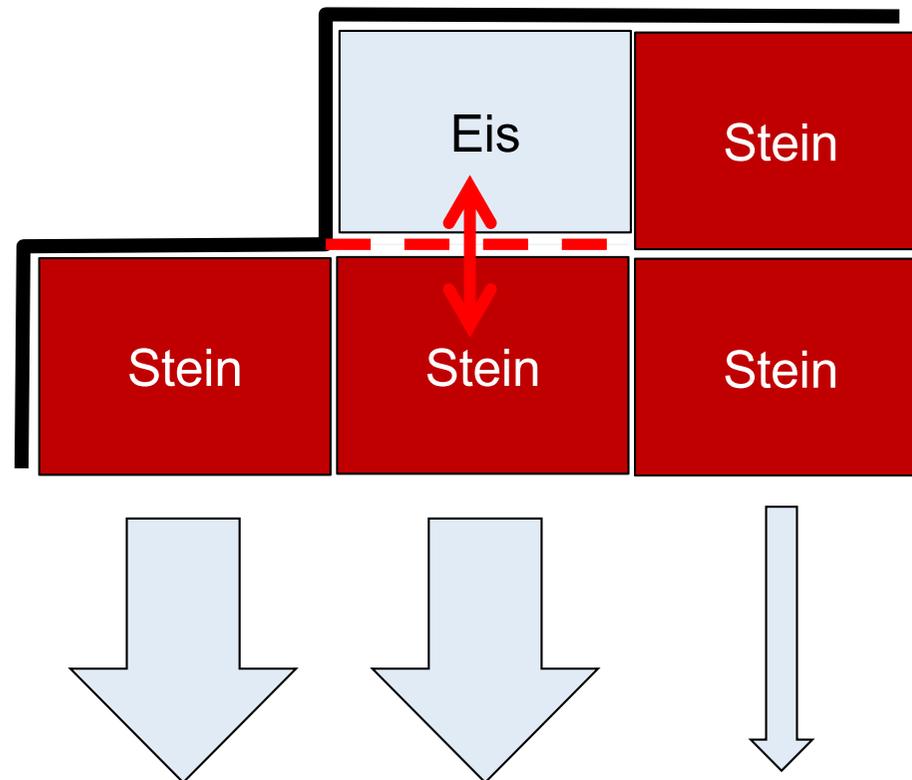


# Gletscher in der Schweiz

In der letzten Eiszeit

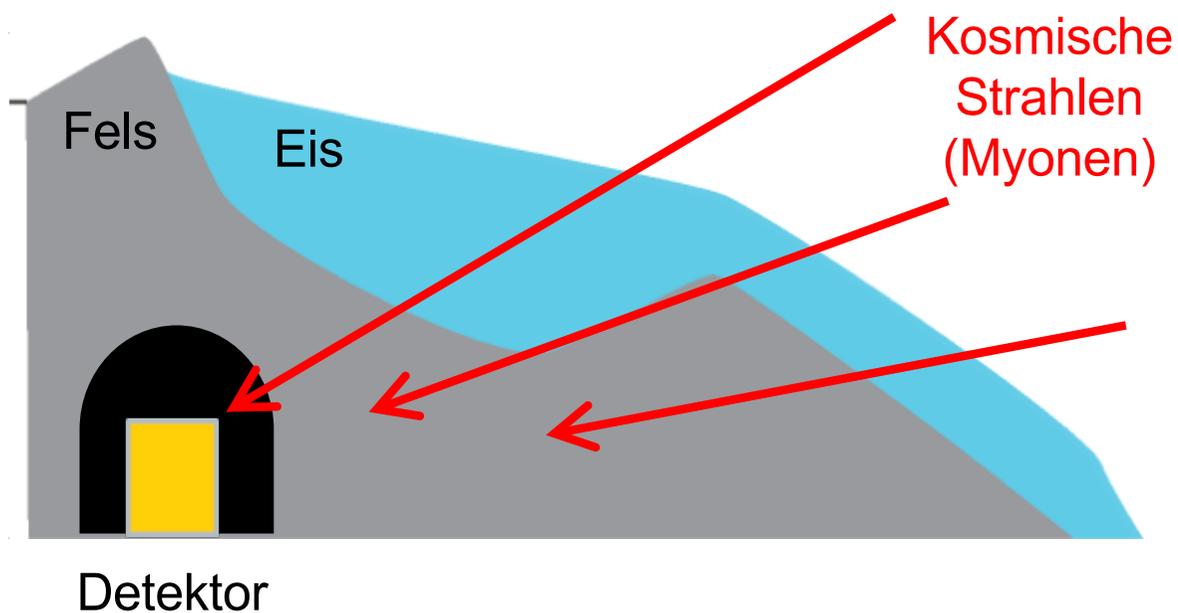


# Myon Tomographie

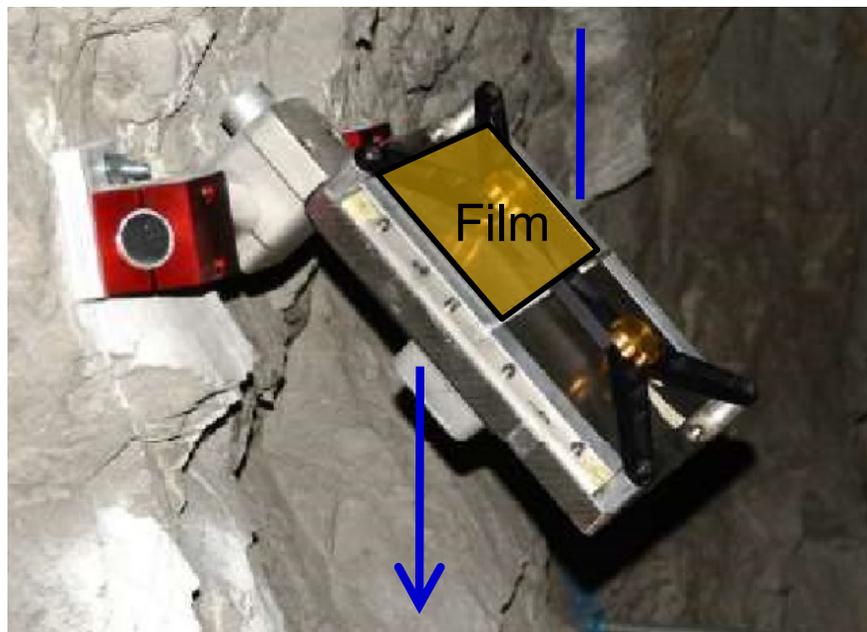
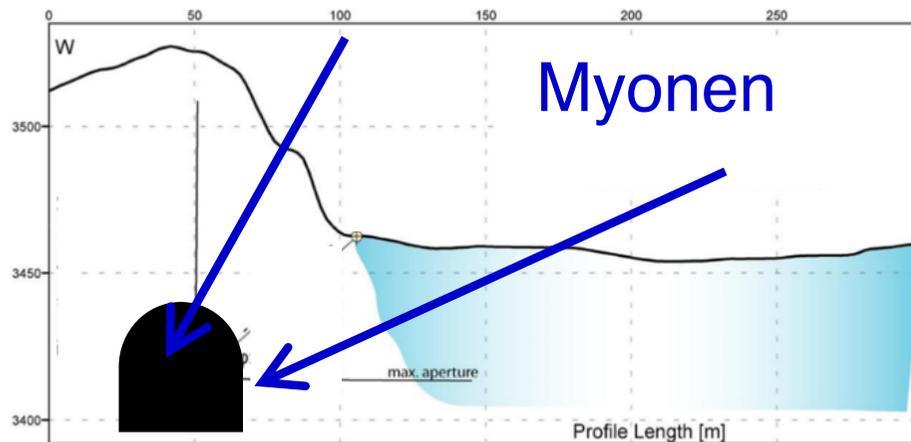


# Gletscher "röntgen"

## „Röntgen“ mit Myonen



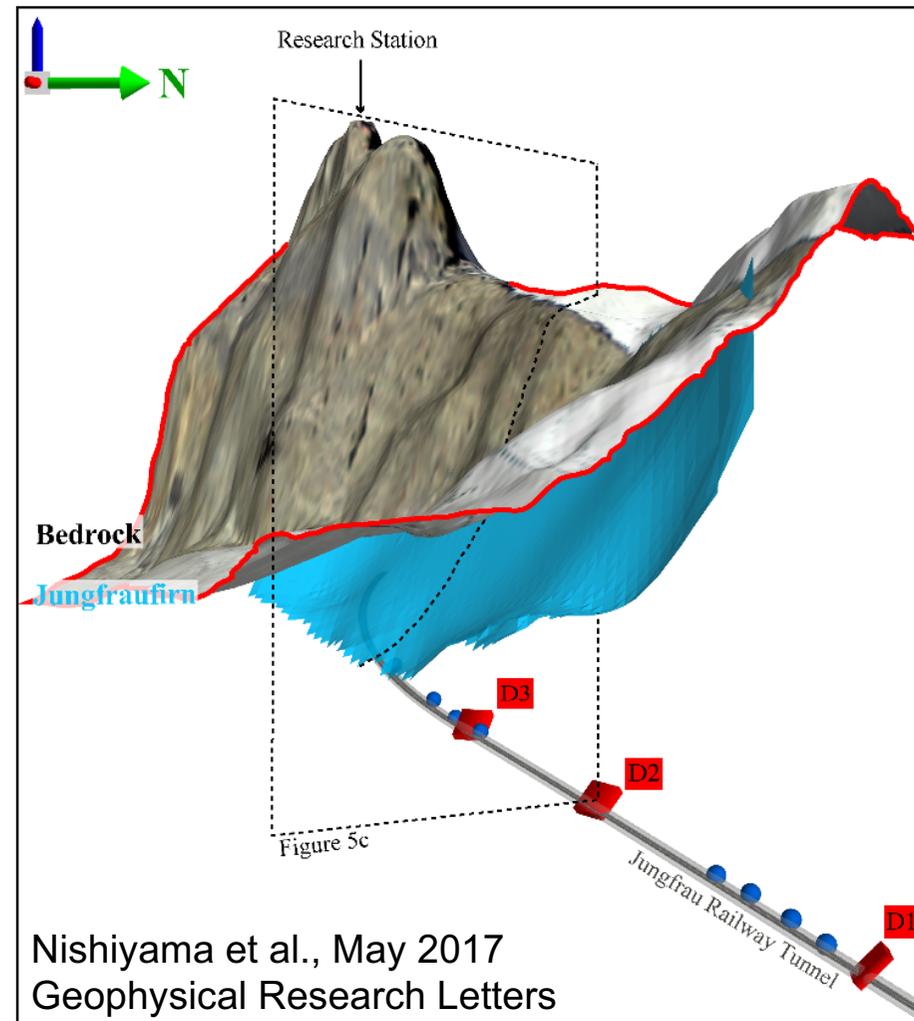
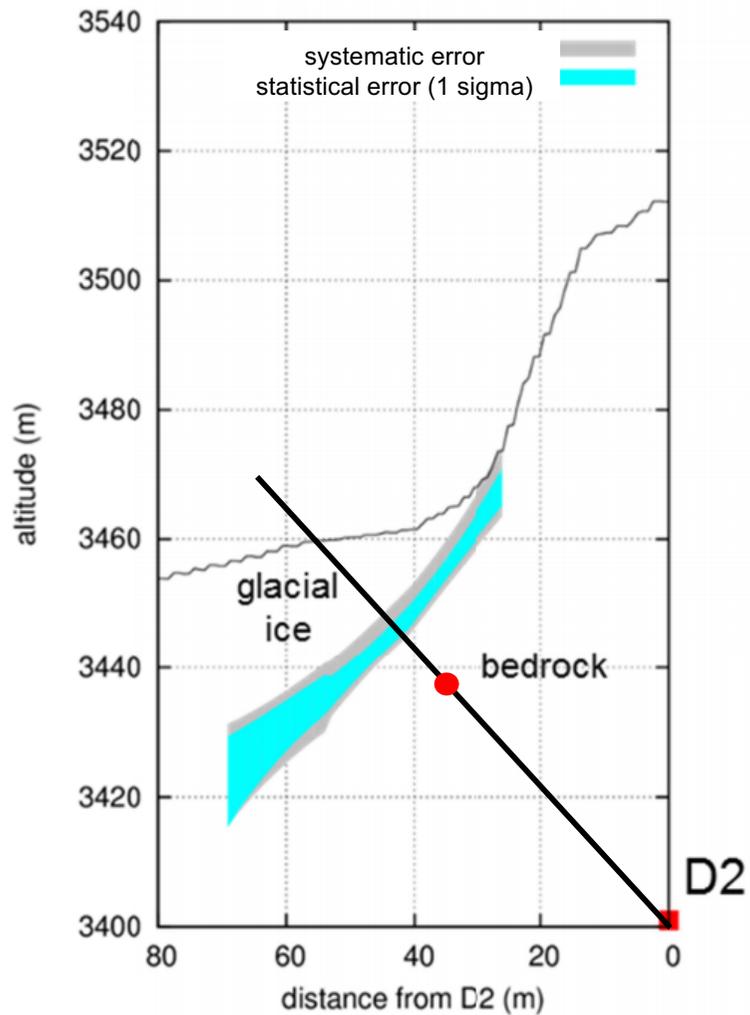
# Experiment @ Aletschgletscher (Jungfraubahn)



Jan.-Feb. 2016 (50 Tage)

Detektorstandort unter dem  
Aletschgletscher.

# Felsoberfläche unter dem Aletschgletscher

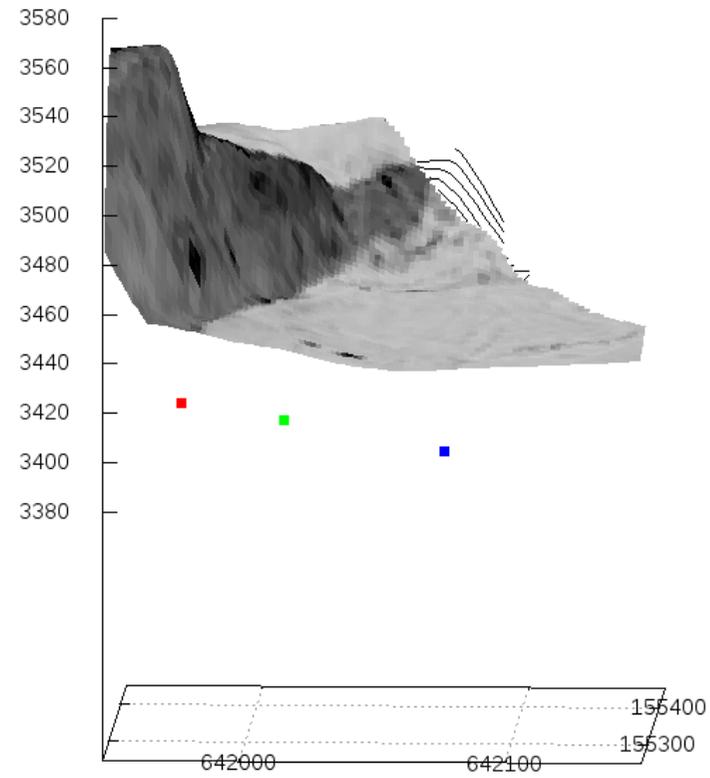


Nishiyama et al., May 2017  
Geophysical Research Letters

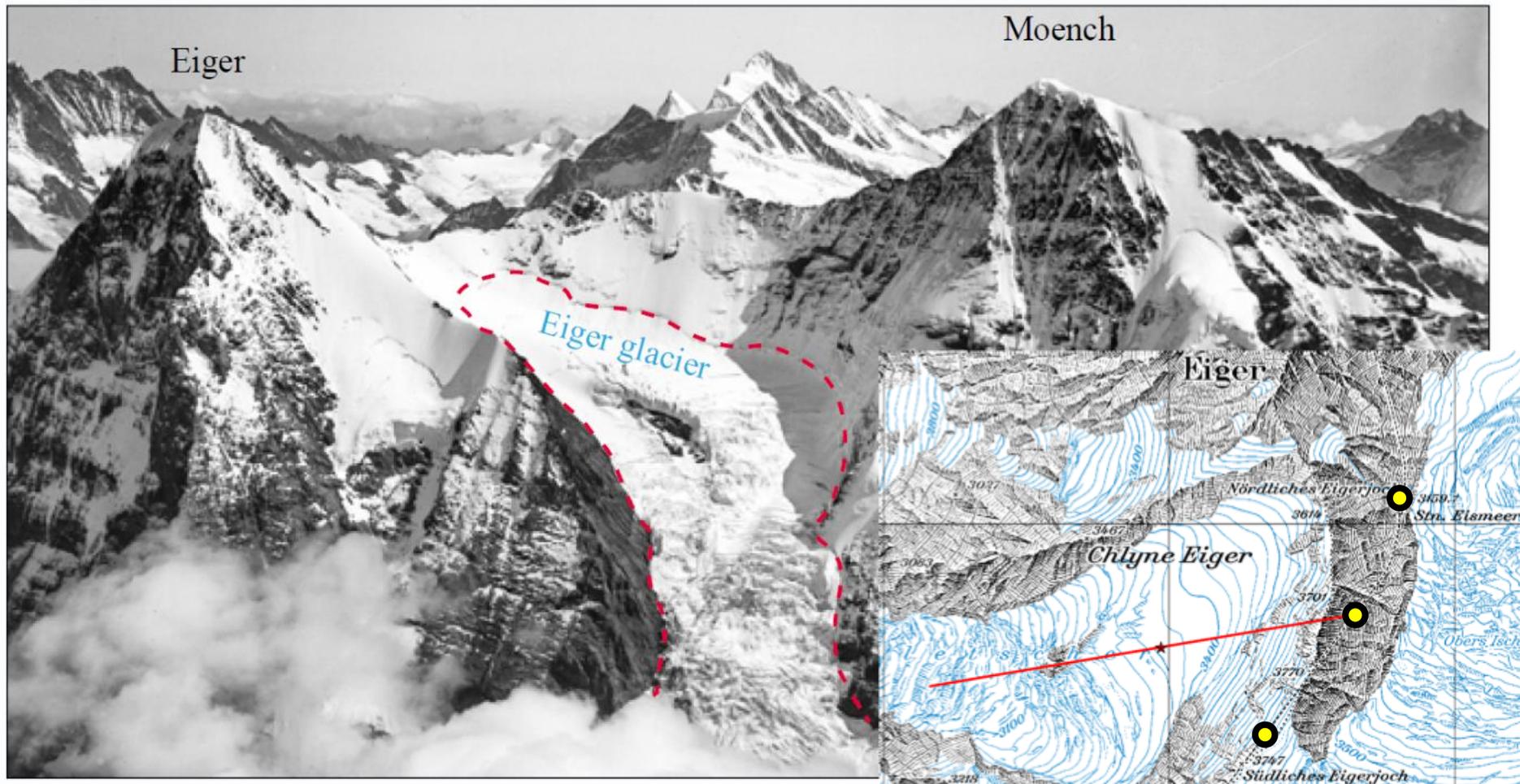
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**Wir haben einen  
Berg “geröntgt”!**

**(gemyont ?)**



# Was kommt als Nächstes?



Eigergletscher (~ 1 km), Messung abgeschlossen, Auswertung läuft

# Zusammenfassung

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- > Röntgen Strahlen sind in der Medizin weit verbreitet
- > Röntgen (X-Rays) haben eine Reichweite von Meter
- > Kosmische Myonen haben Reichweiten von Kilometer
- > Detektoren der Teilchenphysik haben hohe Auflösung und werden verwendet
- > Pyramiden, Berge, ....
  
- > Wir freuen uns über weitere Studierende und Forschende !