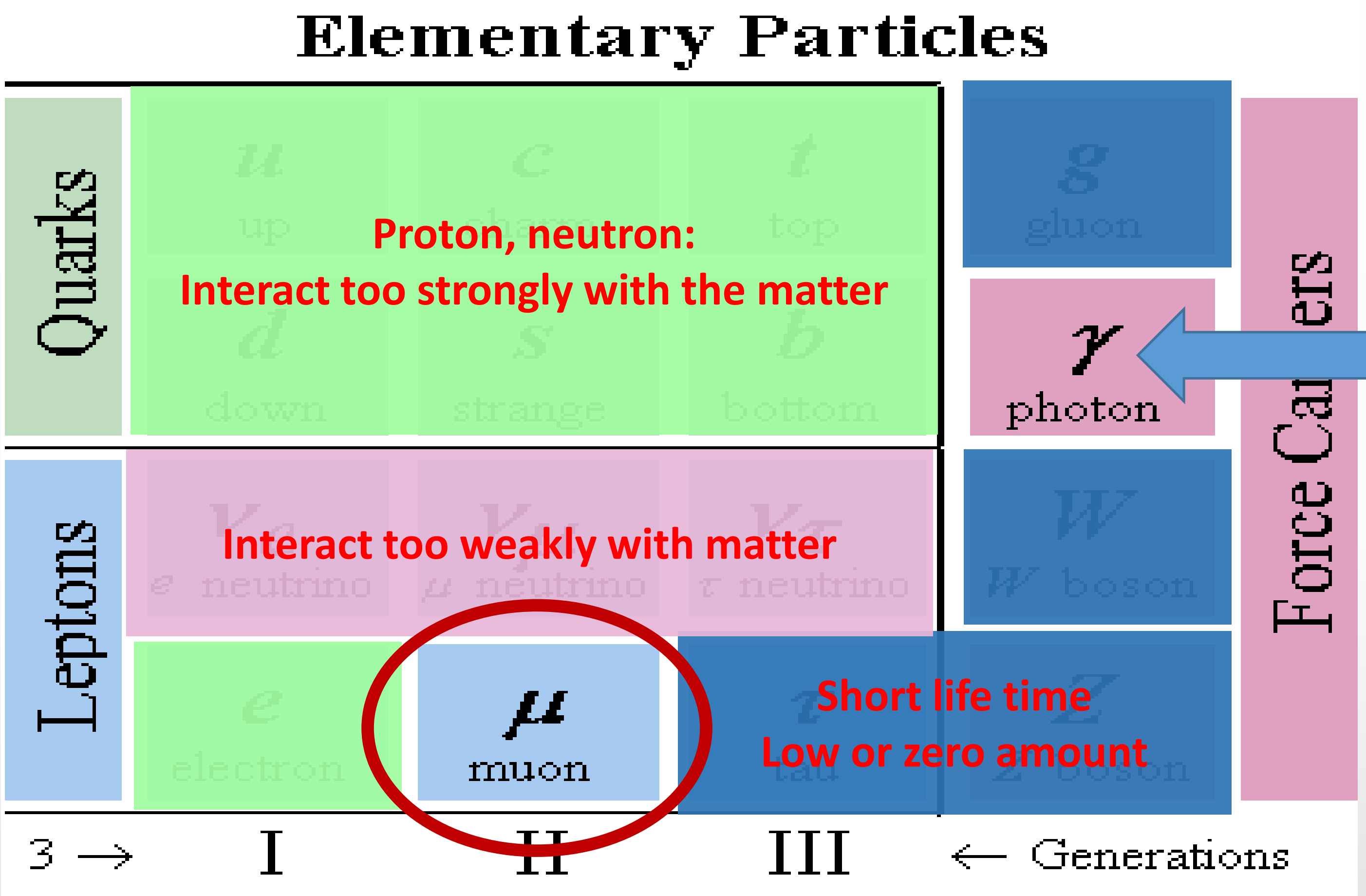
Muon Radiography of large size industrial and natural objects

Better choise



Radio frequency sondage

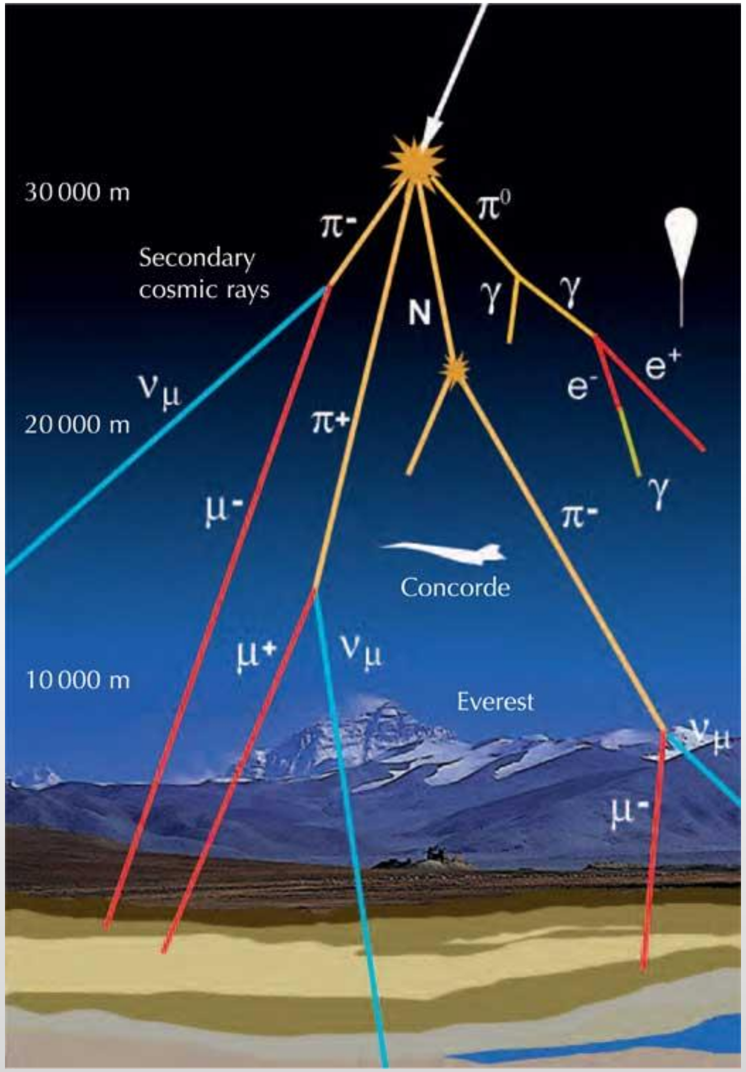
X-ray radiography

Gamma – radiography

Short- range methods…

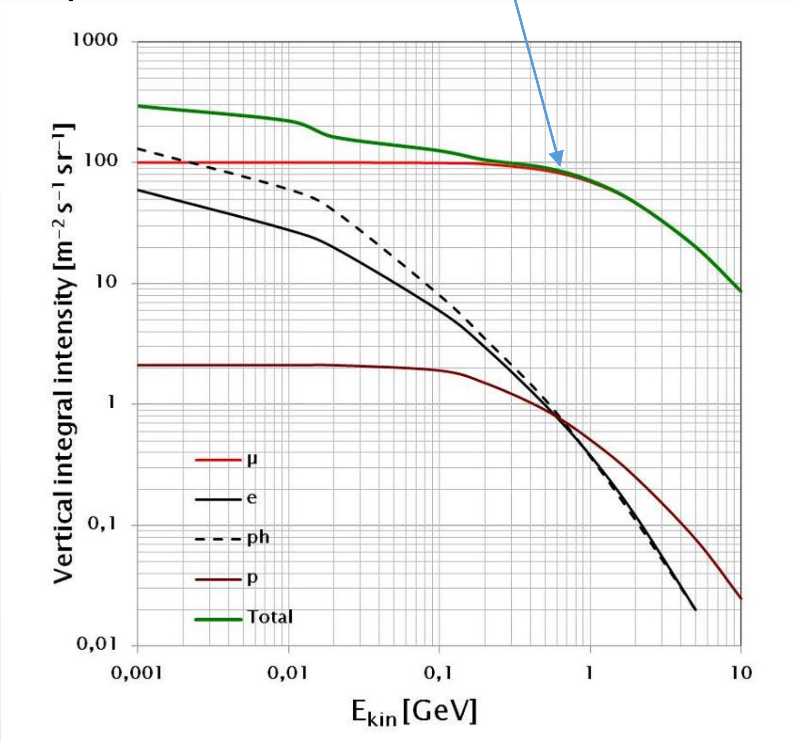
Atmospheric muons

Muons produced by protons coming from space in the upper layers of atmosphere

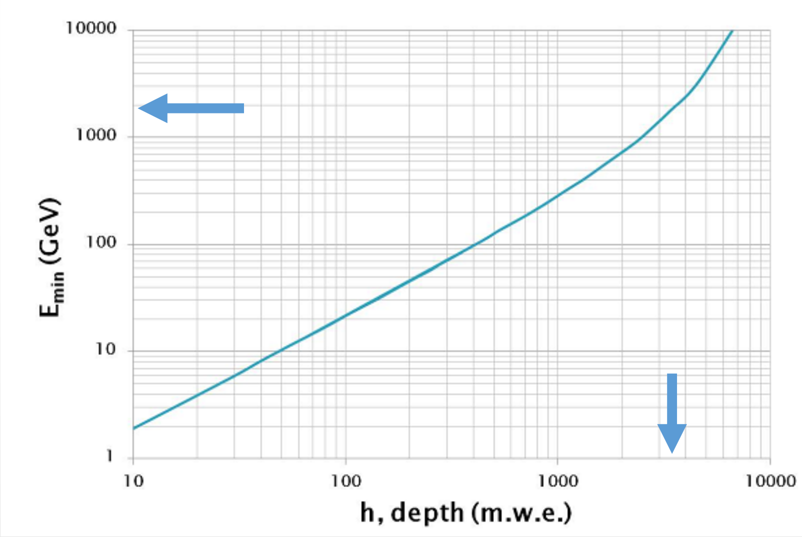


Muons flux is well studied and quite stable in time at the energies exceeding 1 GeV

Them are dominating ionizing particles at sea level



Muons are highly penetrating and cross thick layers of material if have enough initial energy: 2TeV -> 3 km w.e.



Can be used for radiography of bulky objects

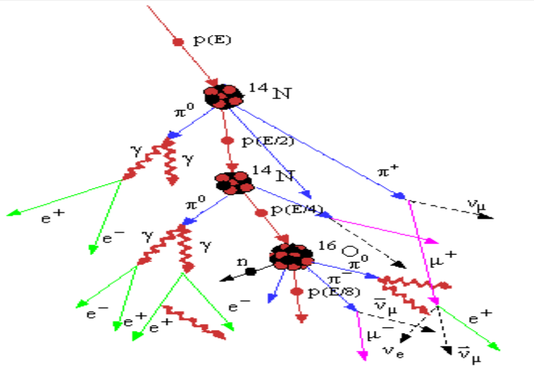
Penerating properties of muons

THE MUON , A TYPE OF LEPTON, UNSTABLE CHARGED ELEMENTARY PARTICLE WITH A SPIN OF ½

The muon has properties similar to those of an electron, but a mass 207 times greater (106 MeV);

- **The muon flux is the penetrating component of cosmic rays;**
- **Muons flux at the Earth's surface is about 10,000 particles per m2 per minute;**
- **The maximum depths at which highest energy muons have been detected is 8, 600m in terms of a water equivalent, which corresponds to about 2km of rock;**
- **Muon radiography can be applied to even kilometer-size objects located above the position of a radiographic detector.**

ITS GREAT PENETRATING CAPABILITY IN COMBINATION WITH AN ABSORPTION COEFFICIENT DIRECTLY PROPORTIONAL TO THE DENSITY OF THE MATTER UNDER INVESTIGATION (AT ENERGIES OF A FEW DOZEN OR A FEW THOUSAND GEV) MAKES MUON RADIOGRAPHY A CONVENIENT METHOD FOR UNDERGROUND



L AND ENGINEERING SURVEYS.

E = 1 GeV

$\tau = \tau_0 \gamma \approx 21\ \mu s$

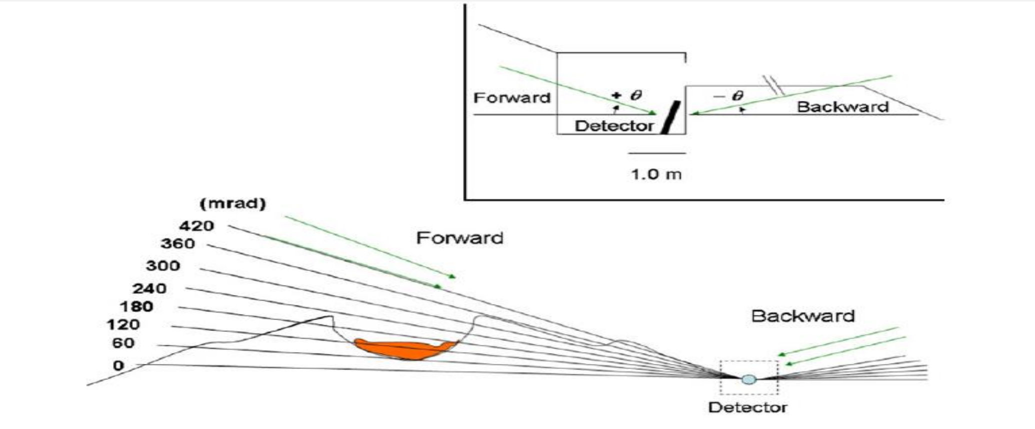
Average flight distance $c\tau \approx 6.3$ км

Principle behind the method

When passing through a layer of matter (e. g. rock or construction material), a muon beam is fully or partially absorbed. Unabsorbed particles are registered with the help of a sensitive device, such as a nuclear emulsion track detector.

To obtain an image of the layer in question, the detector is placed at a shallow depth underground, with the aim of imaging a volume that is higher in elevation adjacent to the detector, owing to the probe radiation flux's direction.

The intensity of an image element is determined by the attenuation of the flux of incident cosmic-ray muons, as they are absorbed by the object under investigation.

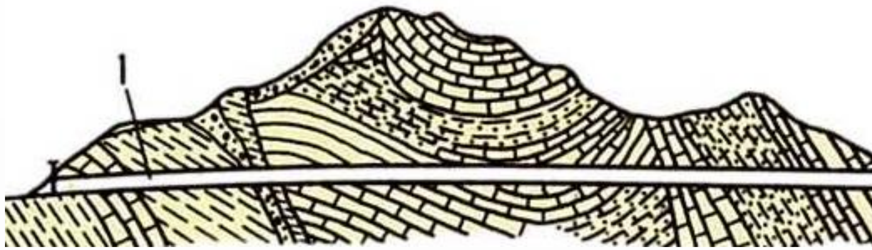


Muon radiography detector layout

A proposal to make use of cosmic radiation for resolving problems of geological prospecting (investigation of resources of the lead ore deposits of the Sadon Ore Field) was first voiced by Petr Petrovich Lazarev, founder and first Editor-in-Chief of the journal Uspekhi Fizicheskikh Nauk (UFN), back in 1926 at a session of the section of physical and mathematical sciences of the General Assembly of the USSR Academy of Sciences.

After nearly 30 years, in 1955, P P Lazarev's ideas were partially realized in Australia in measuring the attenuation of a vertical flux of cosmic muons, aimed at assessing the thickness of rocks above a mountainous tunnel. In these studies, a counter telescope was utilized, namely, a detector comprising four rows of Geiger counters. In order to register only the hard component of cosmic radiation, layers of lead 10 cm thick were inserted between the rows of counters. Only particles that passed through all four rows of counters were registered. Thus, any effects related to the background influence of radioactive radiation were excluded.

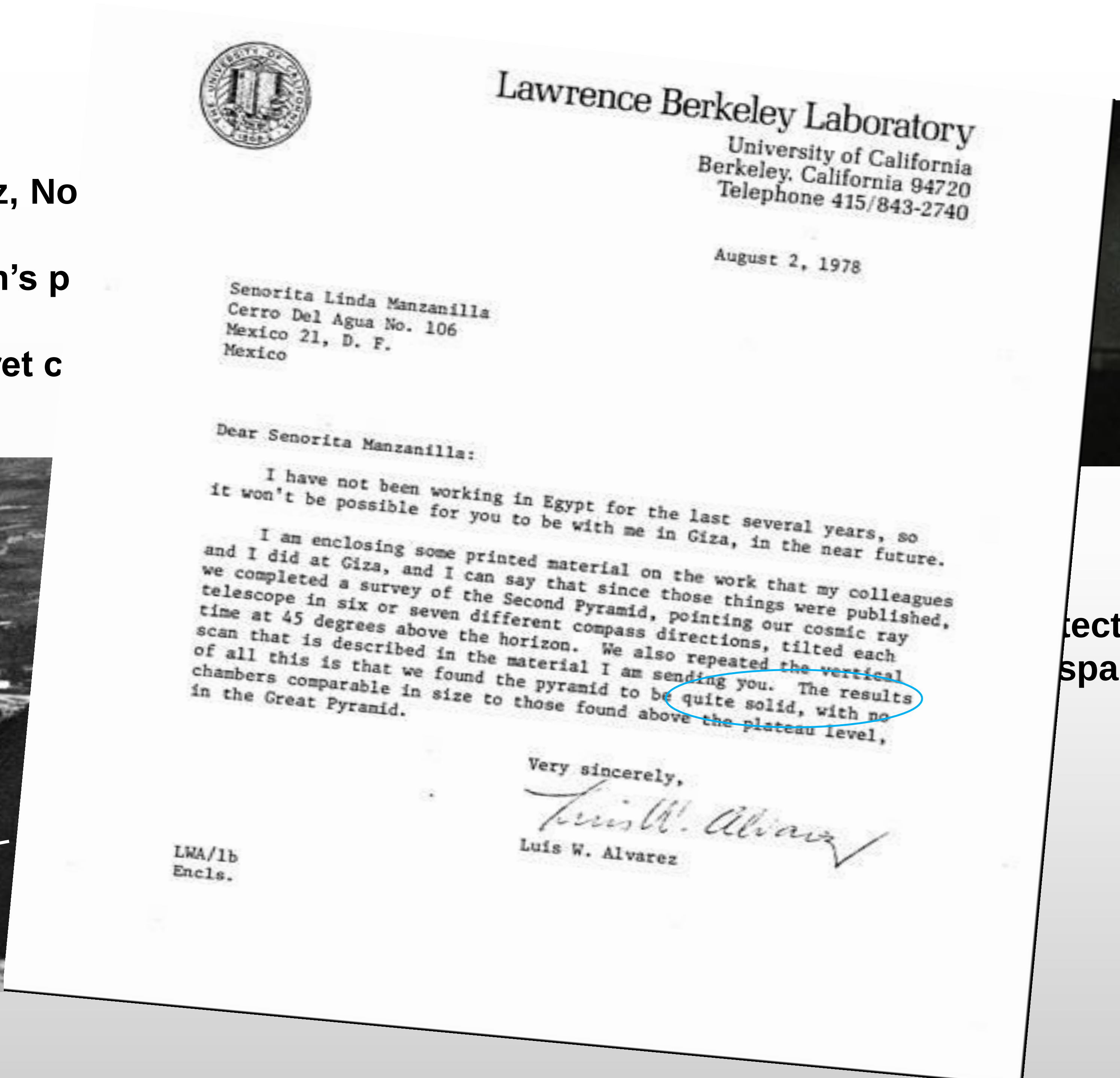
The thickness and mass of rocks was determined by comparing the cosmic ray intensities registered at different sites in the tunnel with the calibration curve. The depth of the tunnel, found with an accuracy of 5%, turned out to be 163 m.w.e.



Dr. Luis Alvarez, No

1963, Chephren's p

Is there a "secret c



Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720
Telephone 415/843-2740

August 2, 1978

Senorita Linda Manzanilla
Cerro Del Agua No. 106
Mexico 21, D. F.
Mexico

Dear Senorita Manzanilla:

I have not been working in Egypt for the last several years, so it won't be possible for you to be with me in Giza, in the near future.

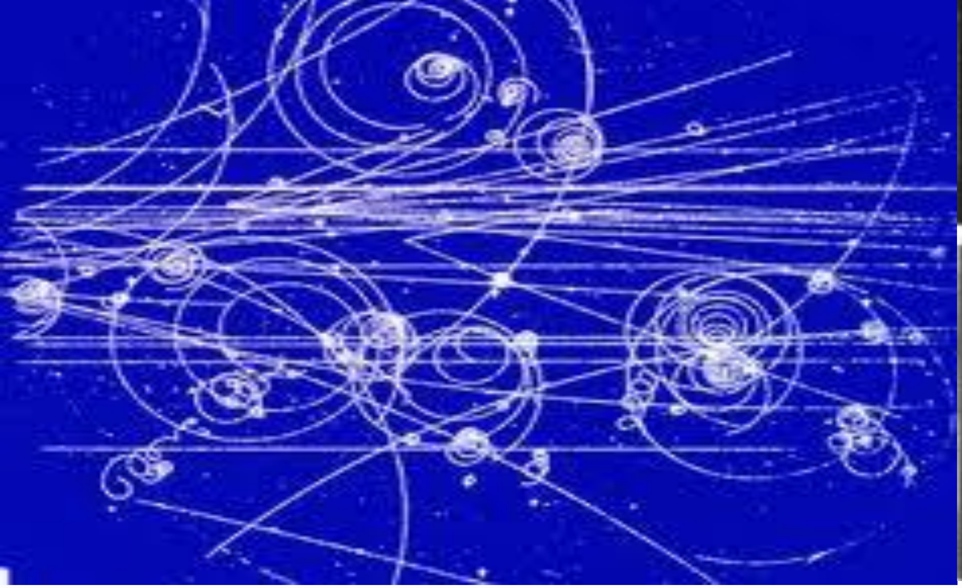
I am enclosing some printed material on the work that my colleagues and I did at Giza, and I can say that since those things were published, we completed a survey of the Second Pyramid, pointing our cosmic ray telescope in six or seven different compass directions, tilted each time at 45 degrees above the horizon. We also repeated the vertical scan that is described in the material I am sending you. The results of all this is that we found the pyramid to be quite solid, with no chambers comparable in size to those found above the plateau level, in the Great Pyramid.

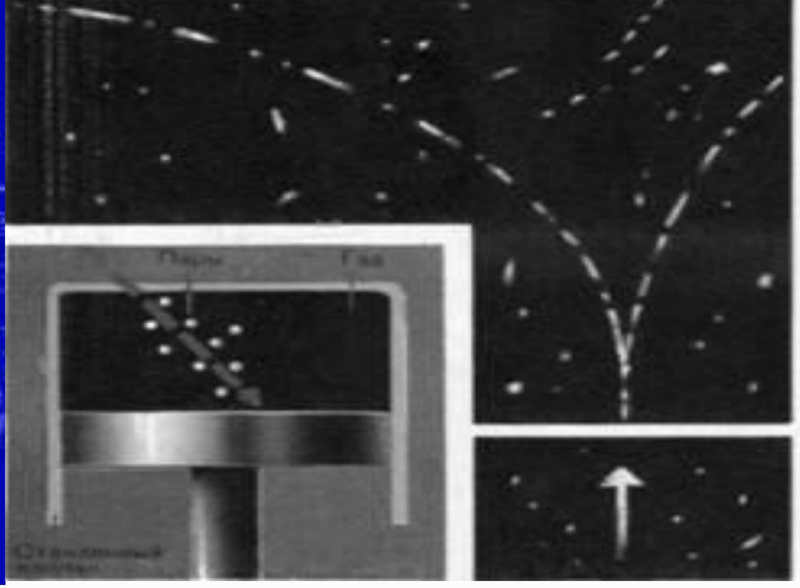
Very sincerely,

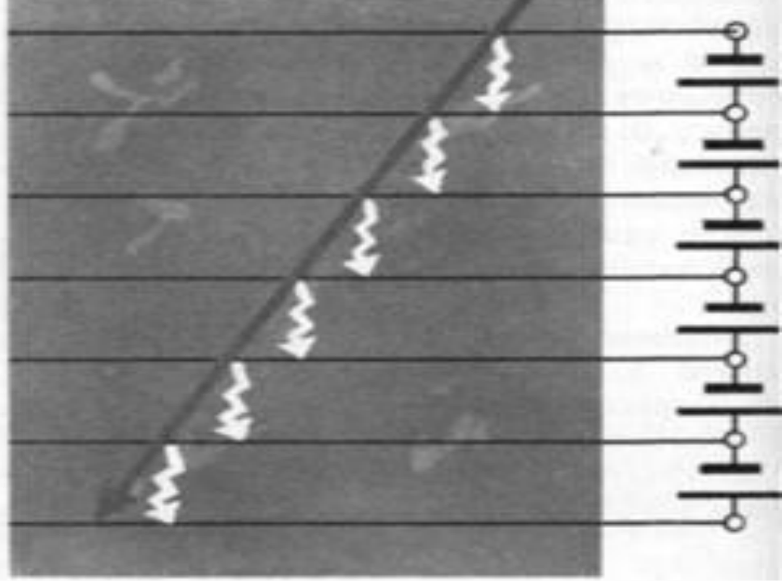
Luis W. Alvarez

LWA/lb
Encls.

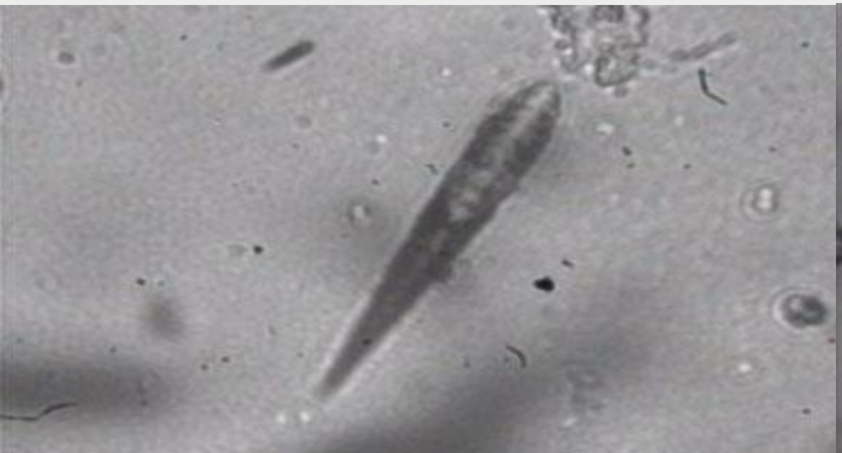
tector on the basis
spark chambers

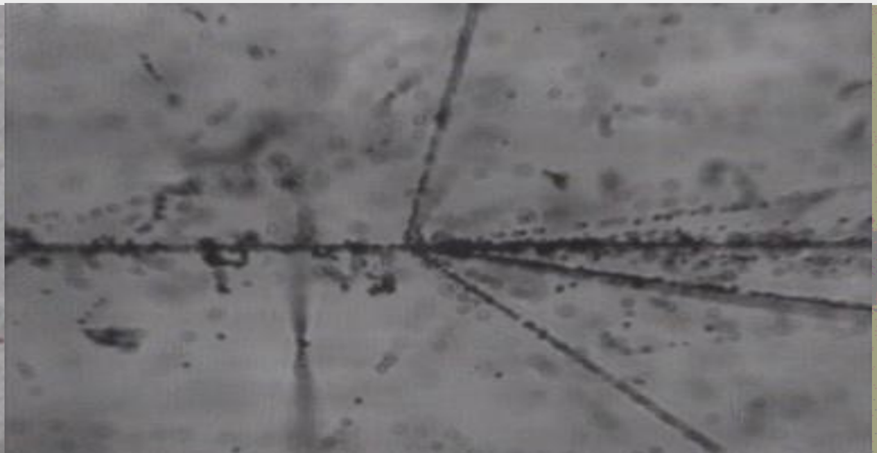


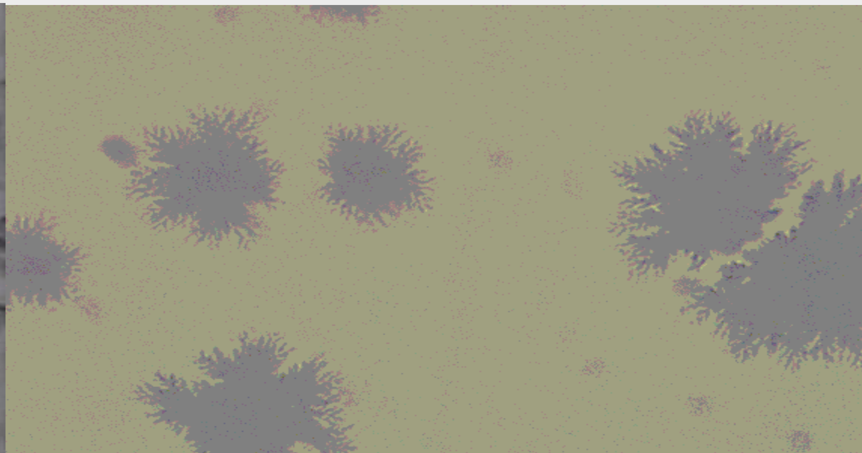




Track detectors have been widely used in experiments in fundamental particles physics for many decades. This lengthy life of the technique is undoubtedly due to the unique space resolution and the possibility it provides for discrimination of particles tracks. Among the virtues of the technique are its descriptiveness and the reliability of detection of patterns of particles interaction.







Discovery of Radioactivity

The phenomenon of radioactivity was discovered by A. Becquerel in 1896.

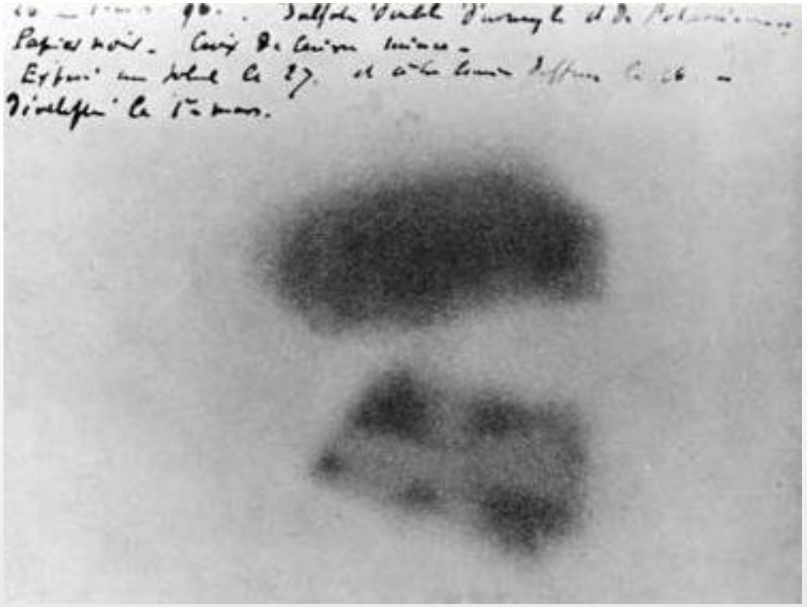
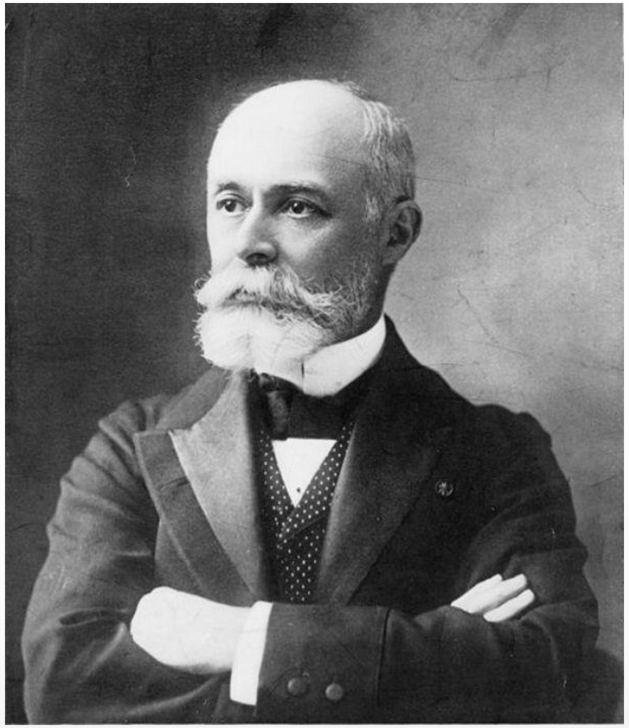
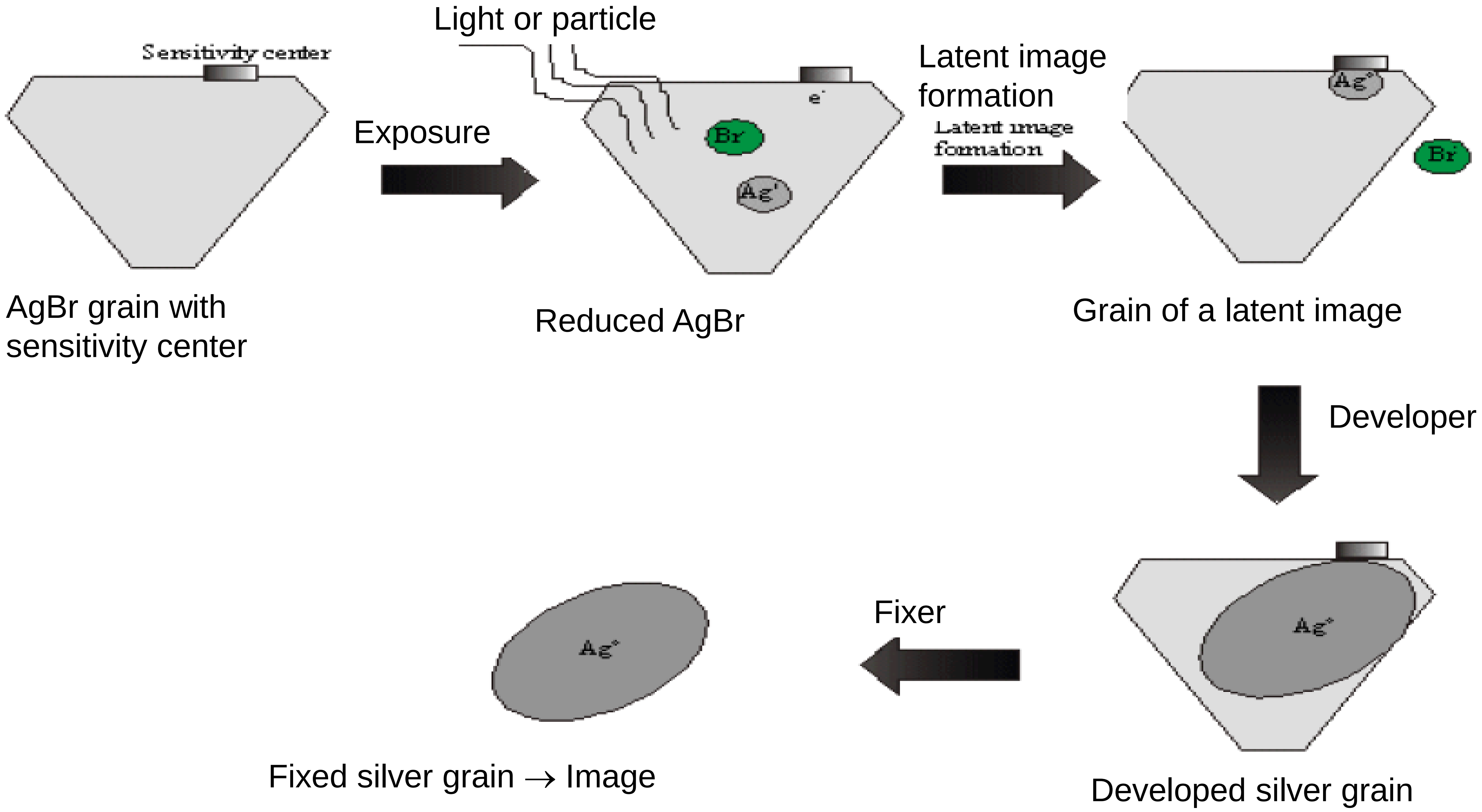


Image of Becquerel photographic plate, which was illuminated by the radiation of uranium salts. Clearly visible is the shadow of a metallic Maltese cross placed between the plate and the uranium salt.

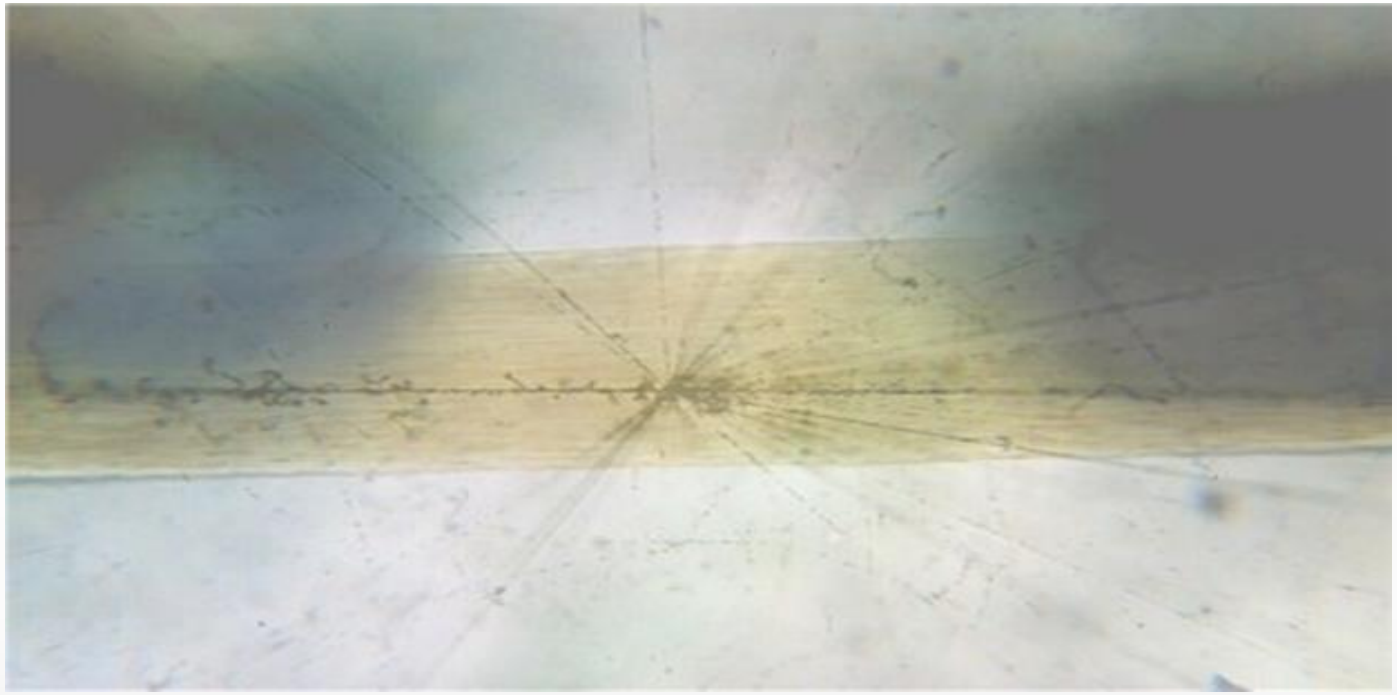


A. Becquerel
(1852-1908)

Nuclear emulsion : basic processes



Nuclear Emulsion Composition



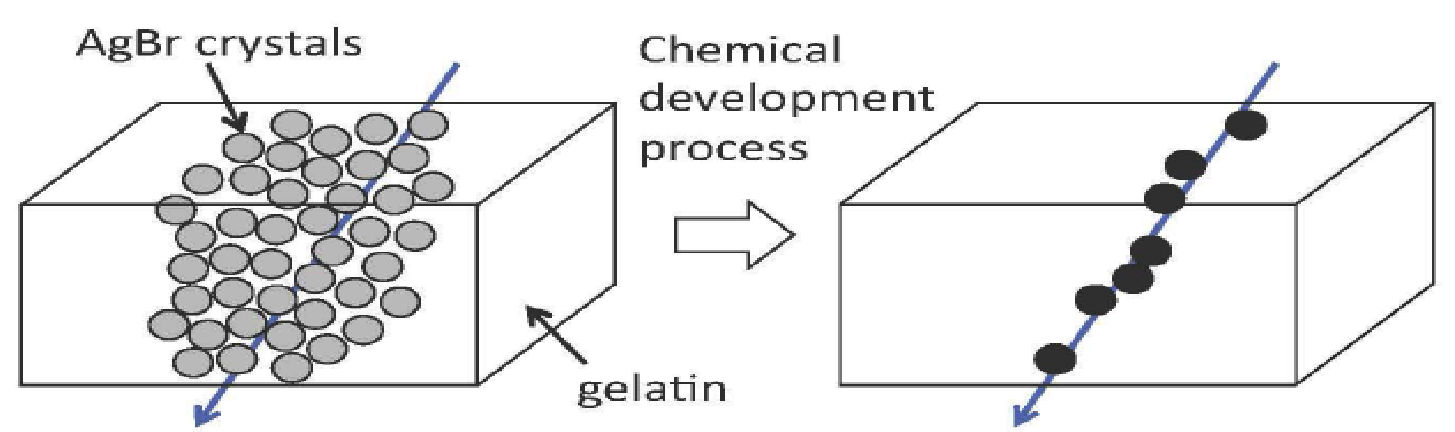
Combined photos of the interaction of the relativistic sulfur nucleus in a nuclear emulsion and a human hair 60 microns thick, taken with a microscope and a digital camera.

Constituent	Mass Fraction
AgBr-I	0.78
Gelatin	0.17
PVA	0.05

(a) Constituents of nuclear emulsion

Element	Mass Fraction	Atomic Fraction
Ag	0.44	0.12
Br	0.32	0.12
I	0.019	0.003
C	0.101	0.172
O	0.074	0.129
N	0.027	0.057
H	0.016	0.396
S	0.003	0.003

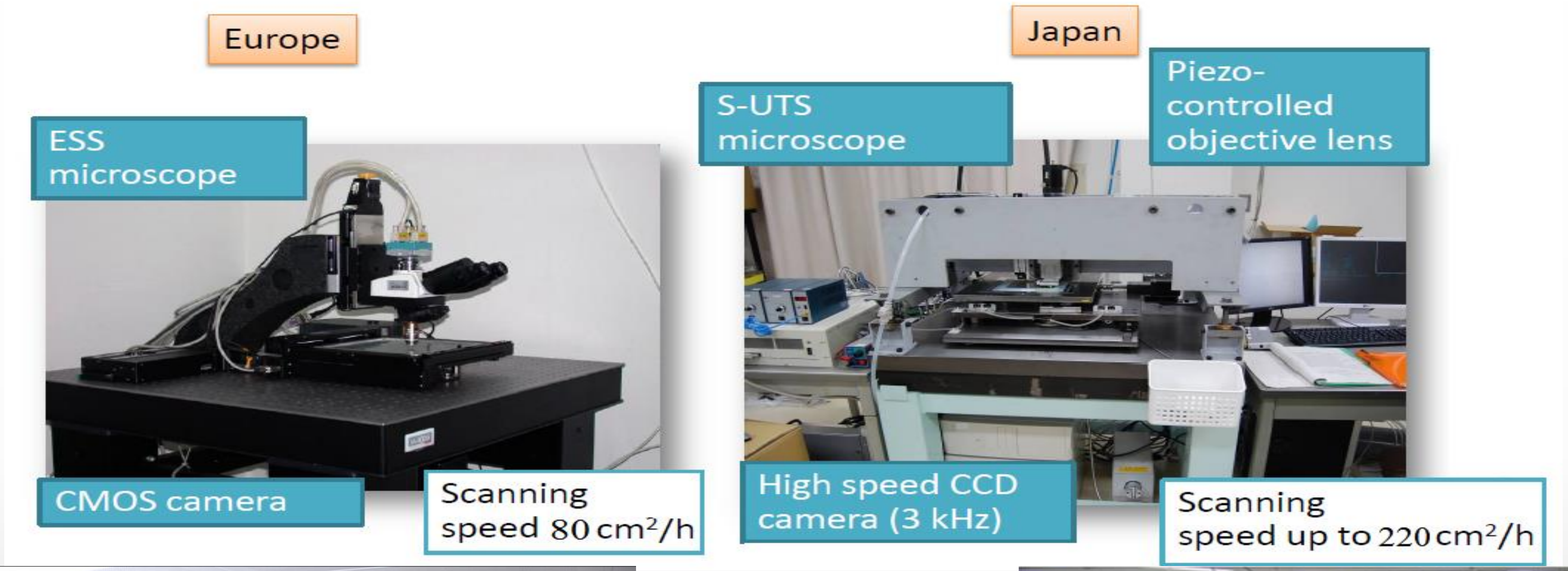
(b) Elemental composition



The nuclear emulsion advantages

- High space resolution (~ 1 micron)
- High efficiency of formation of charged particles tracks (30 - 40 grains per 100 microns)
- Allows you to determine the energy, charge, mass and momentum of a particle
- Can be placed in a magnetic field.
- Ability to conduct exposure in the absence of the experimenter, reliability, not necessary energy, small size and weight.
- The possibility of long-term accumulation of rare events
- Simplicity, low cost and visibility
- Study of reactions with complex decay topologies
- Direct detection of particles with short lifetimes

Scanning complexes



In Russia - Completely Automated Measuring Complex-PAVICOM

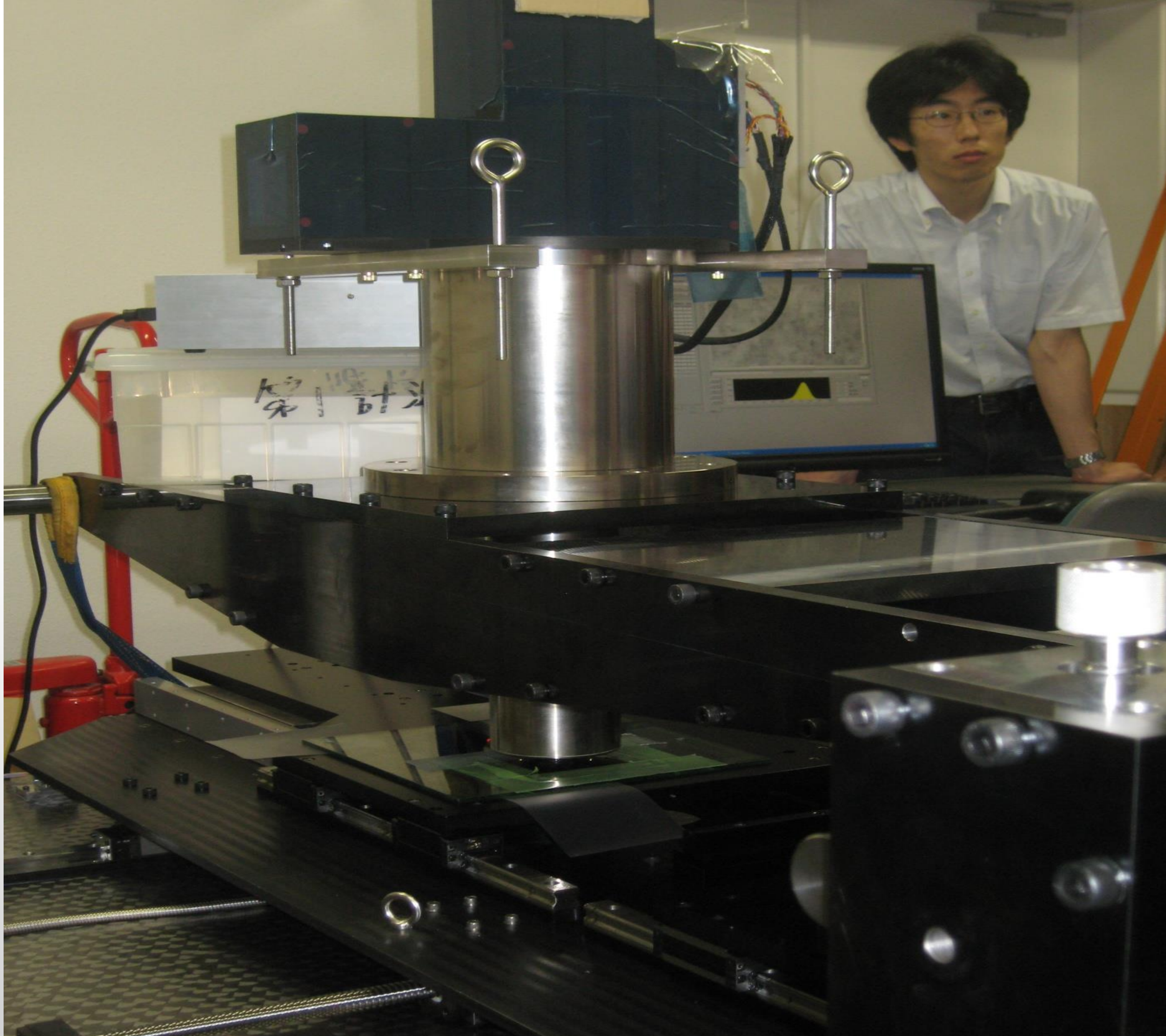
Microscope Nikon;
the motorized movable stage MiCos;
range of motion: X = 200 mm, Y = 200 mm, Z = 45 mm;
accuracy of coordinate measurement: 0.25 mkm;
CMOS- video camera Mikrotron MC-1310 with 1024 grey levels;
Image size: 1280 x 1024 pixels, shooting speed up to 500 frames per second;
a dual-processor workstation based on Intel Pentium 4 Xeon 3.6 GHz;
digitizing board and the image processing Matrox Odyssey Xpro;
the microcontroller to operate the step motors National Instruments PCI 7344.

HTS concept

Enormous Objective

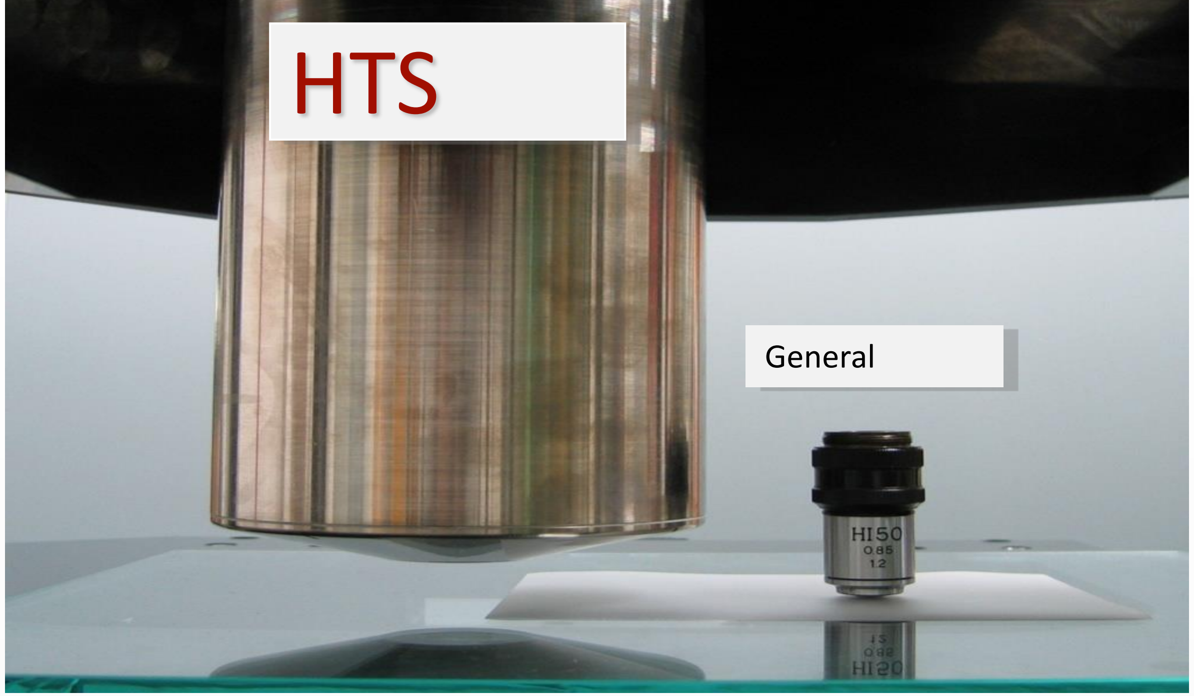
Field of view 5x5mm

80kg



HTS concept

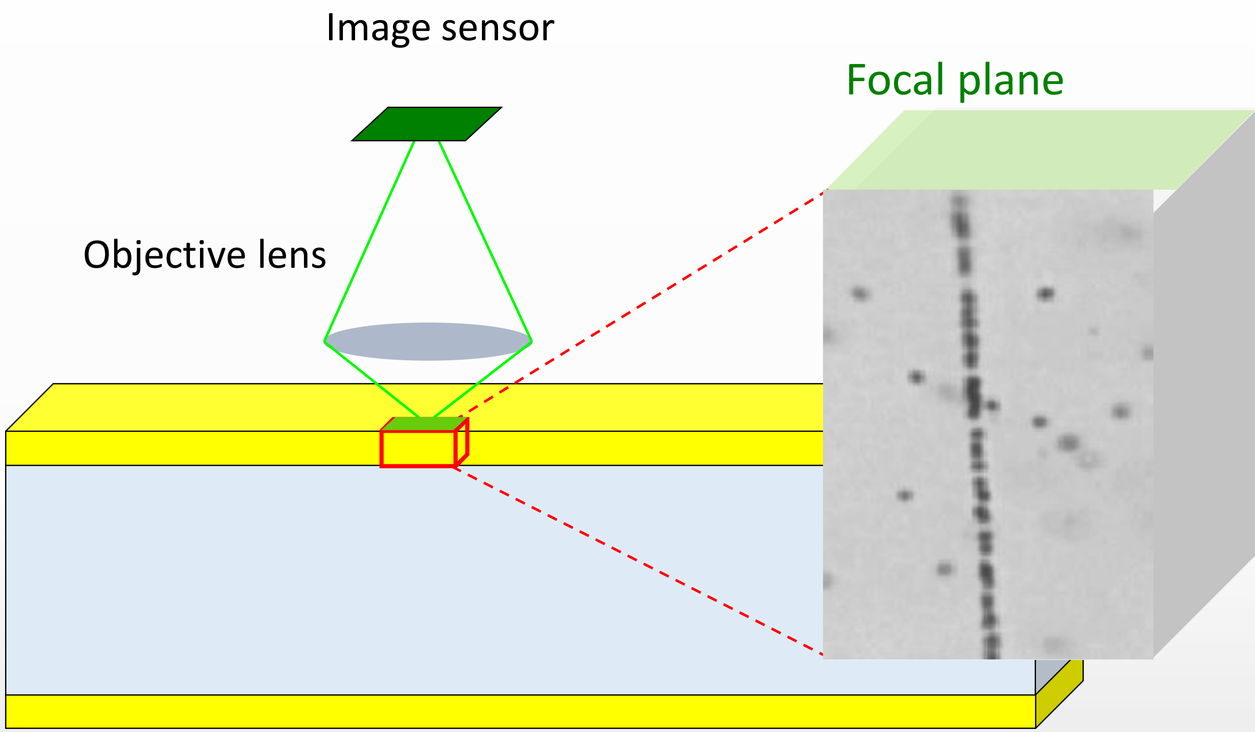
- Very large field of view
  5 x 5 mm²
- Extremely quick stage using
  the linear motor
- GPGPU based image processing



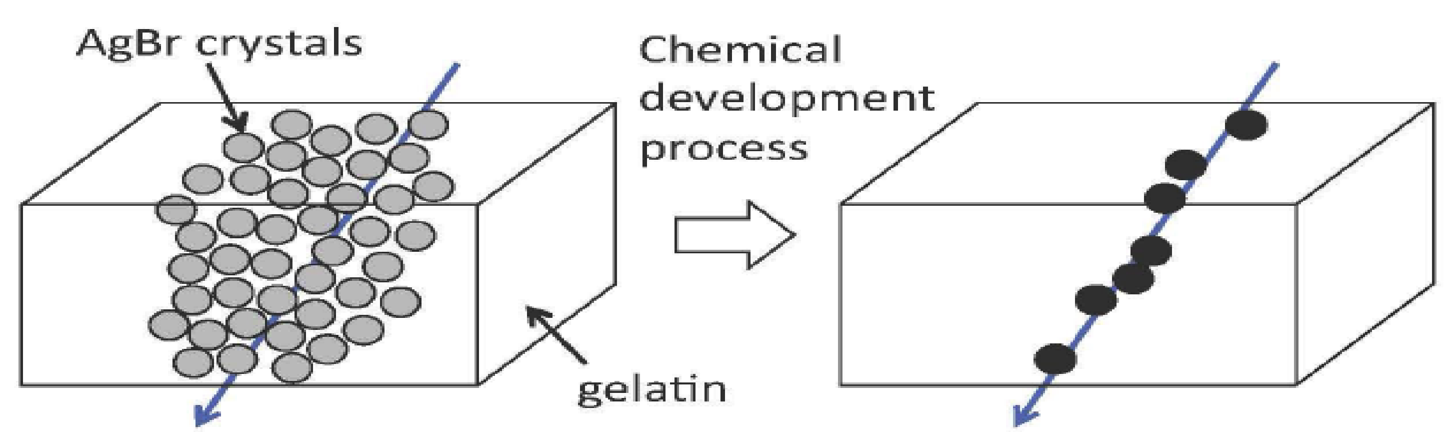
	F.O.V	Frequency	Scan speed
S-UTS	$0.05mm^2$	40Hz	$72cm^2/h$
HTS(in progress)	$25mm^2$	10Hz	$9000cm^2/h$
Achievement	$4mm^2$	5Hz	$750cm^2/h$
Rate	x500	x1/4	x125

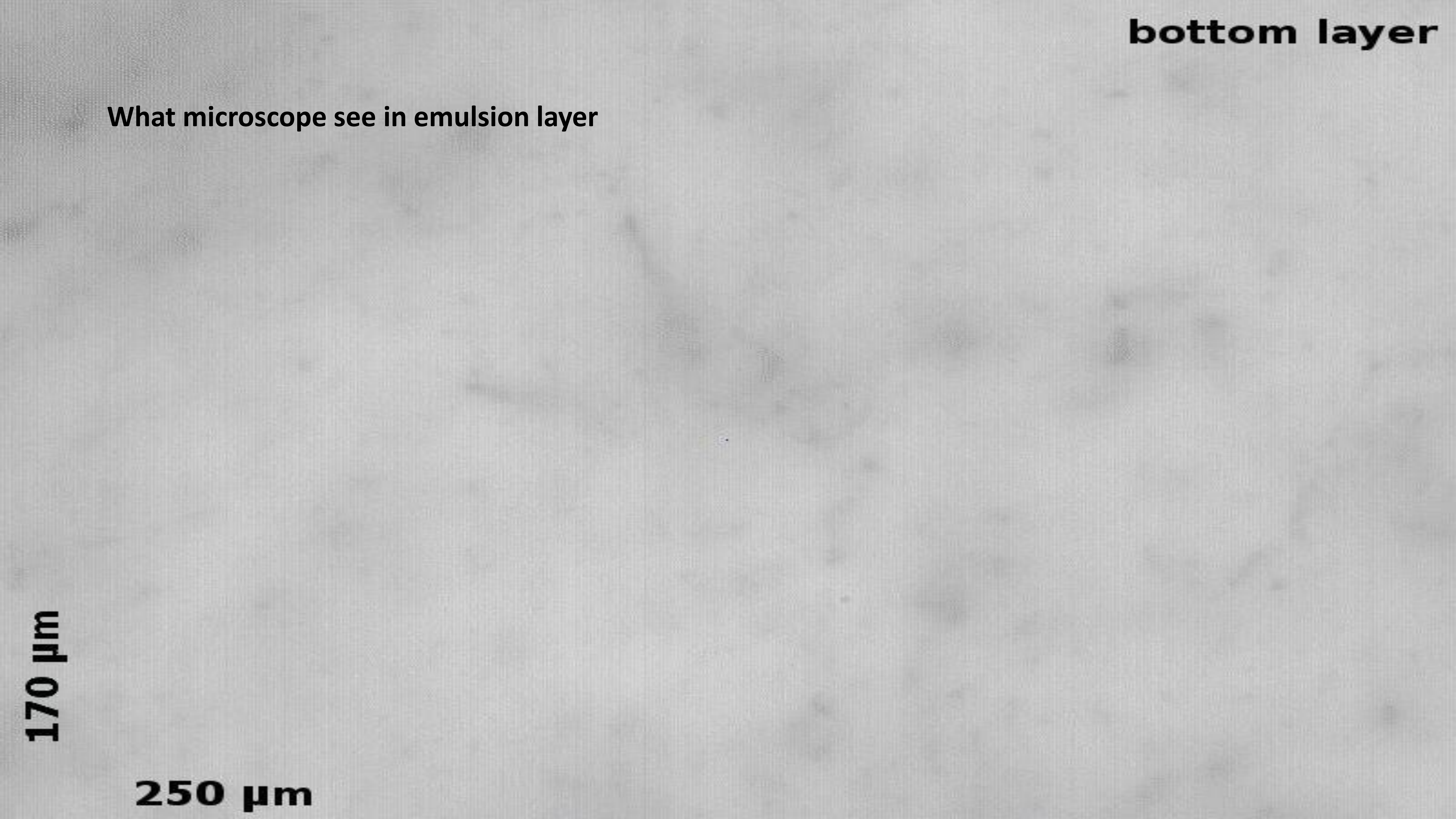
The MR method has been actively developing in the world over the past 20 years due to using nuclear emulsion as a detector

The principle of image processing in nuclear emulsion when scanning on automated complexes

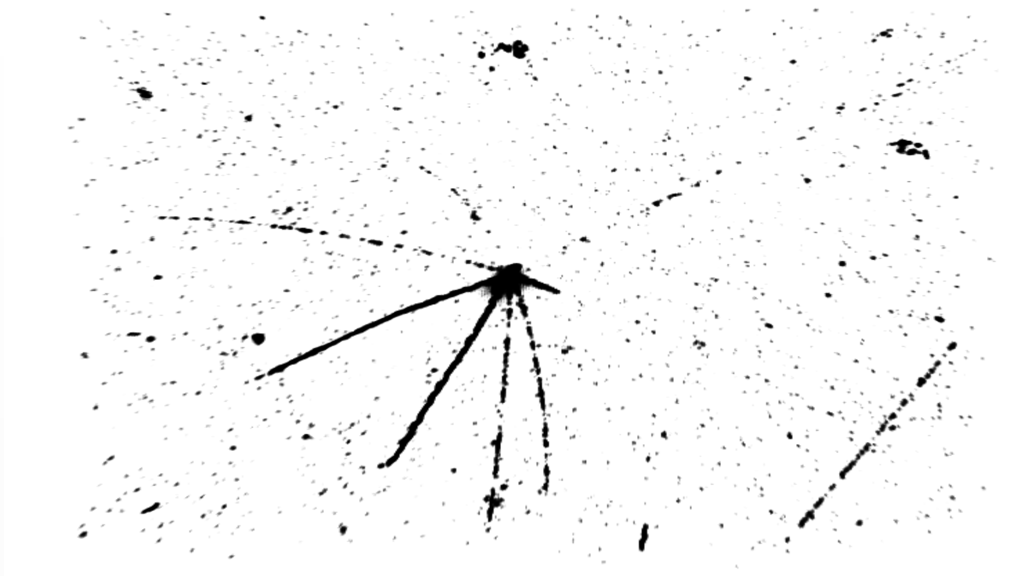


Formation of a muon track in a nuclear emulsion during its passes through a detector




bottom layer
What microscope see in emulsion layer
170 µm
250 µm

Emulsion technology



Hardware
- Detector production
- Development

Scanning
- Microscope readout
- Reconstruction

Physics experiments
- OPERA
- T2K
- AEgIS
- SHiP

Accelerator
- Beam monitoring

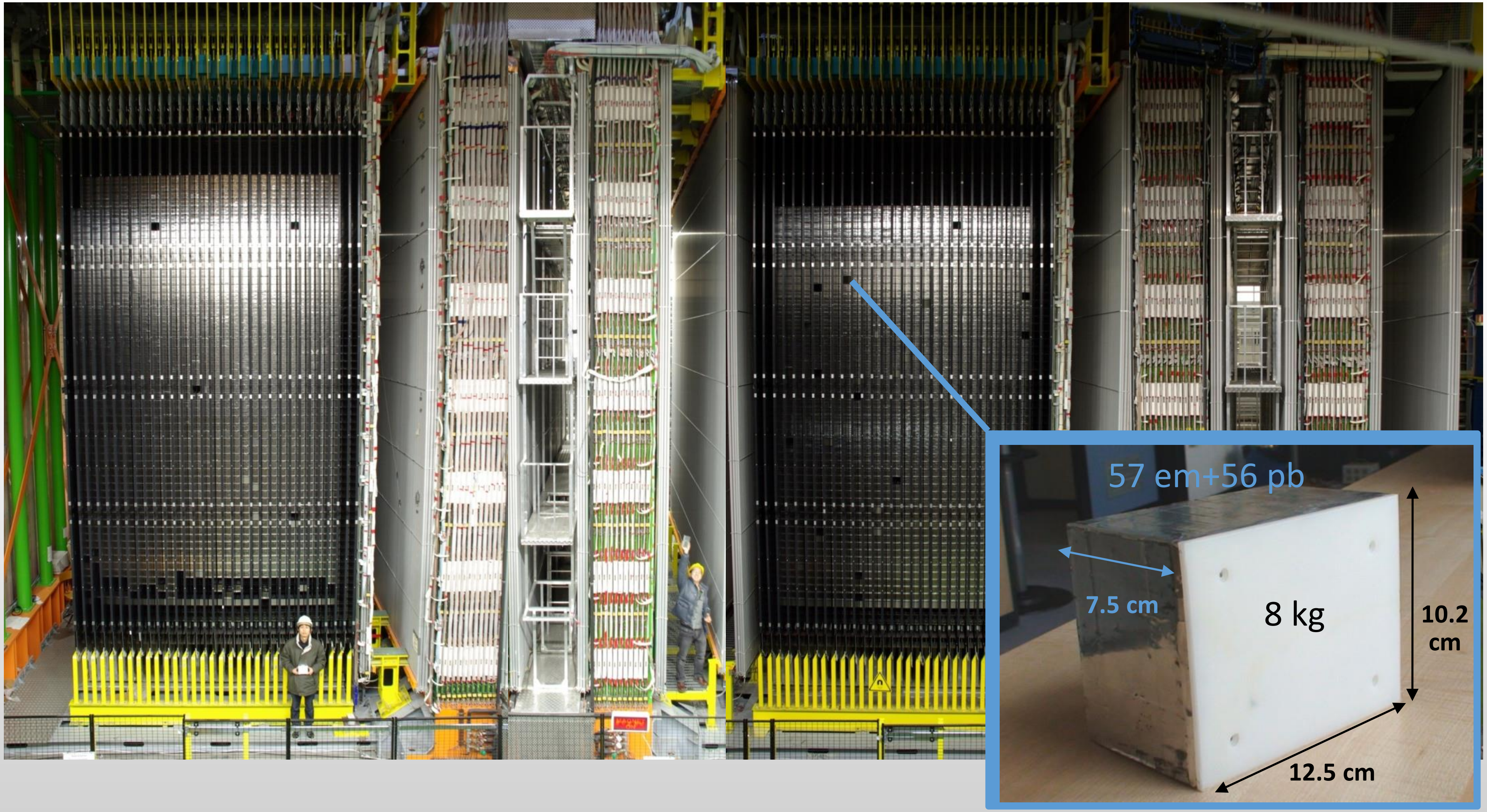
Medical application
- Neutron dosimetry
- Proton radiography
- Beam characterization in proton therapy

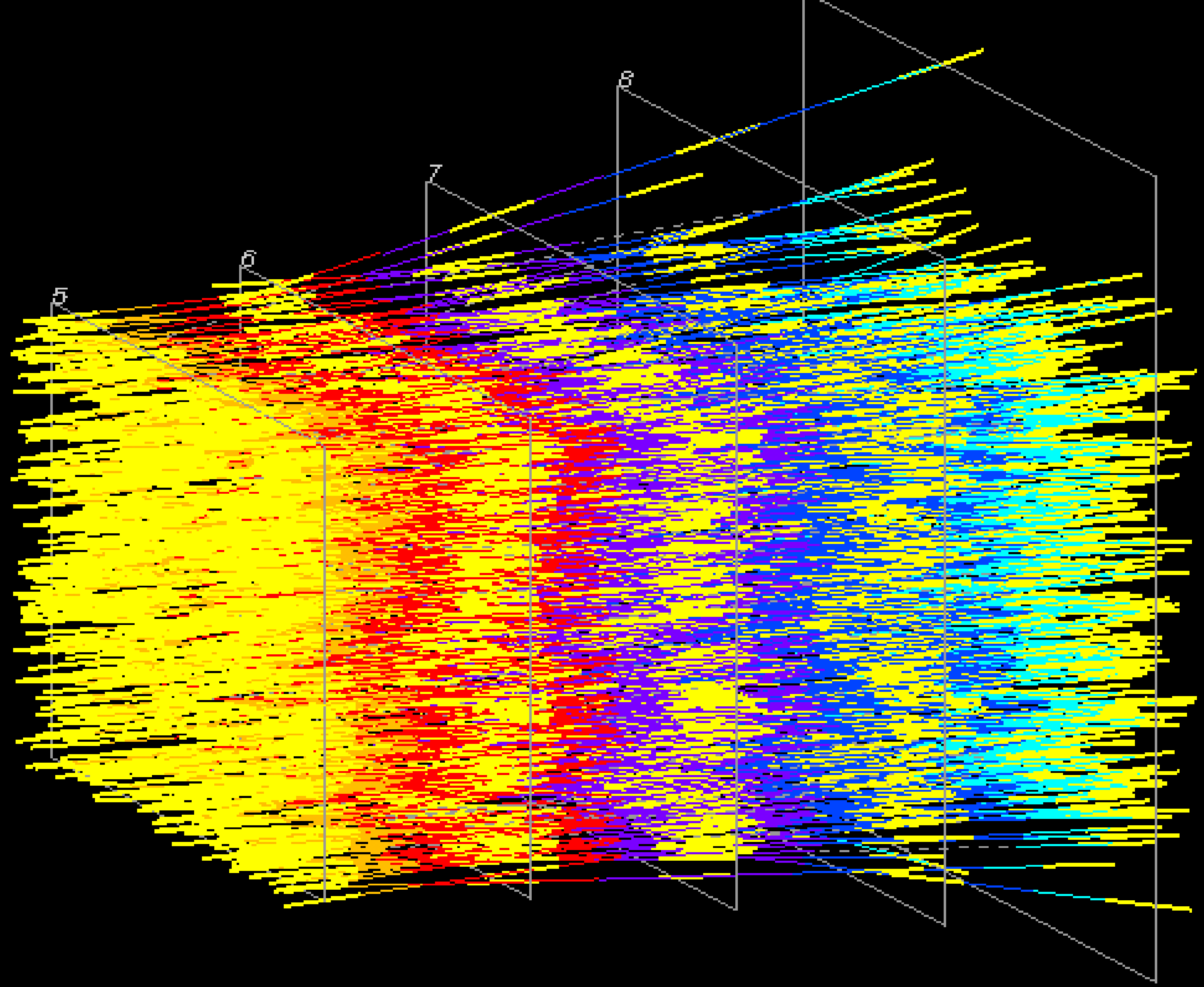
Geosciences
- Muon radiography

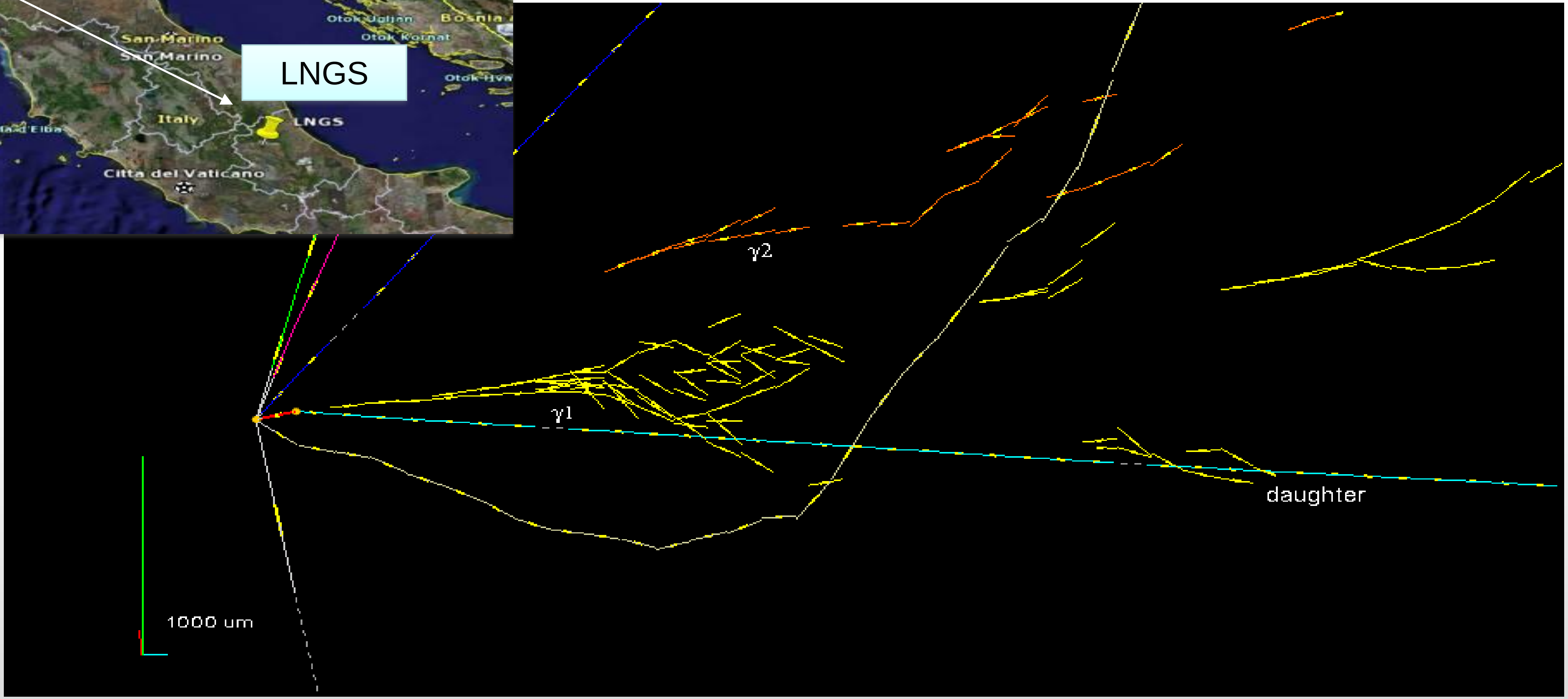
Cosmic Ray Physics
- Balloon

The OPERA detector: 9 millions of films for a total surface of 110,000 m^2 , about 8 football fields

SM1 10x10x50 meters construction **SM2**




5
6
7
8



The OPERA detector at LNGS exposed from 2008-2012

A total 17.97 x 10^{19} protons on target resulted in 19505 ν interactions

OPERA final results

PRL **115**, 121802 (2015) PHYSICAL REVIEW LETTERS week ending 18 SEPTEMBER 2015

Discovery of τ Neutrino Appearance in the CNGS Neutrino Beam with the OPERA Experiment

PHYSICAL REVIEW LETTERS **120**, 211801 (2018)

Editors' Suggestion Featured in Physics

Final Results of the OPERA Experiment on ν_τ Appearance in the CNGS Neutrino Beam

10 events observed, discovery with 6.1 sigma significance

First measurement of Δm^2 in appearance mode

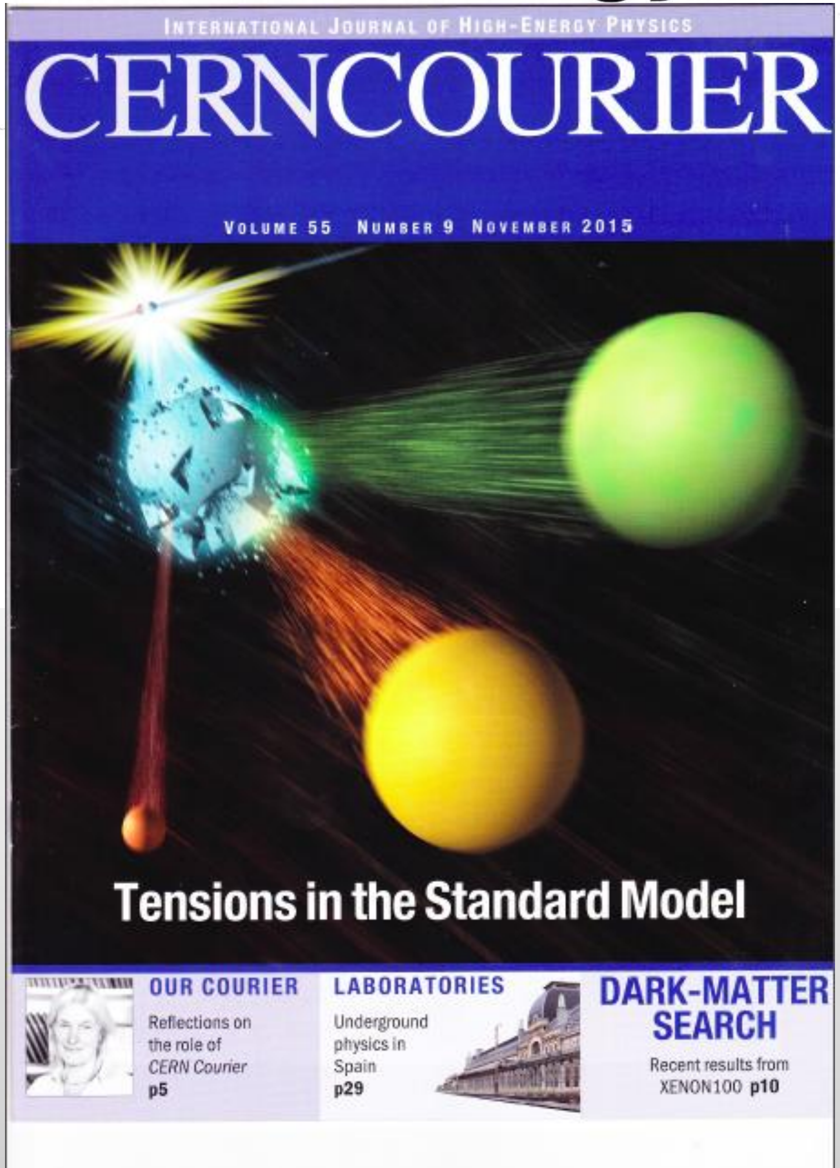
First cross-section measurement

First direct observation of the leptonic number of ν_τ

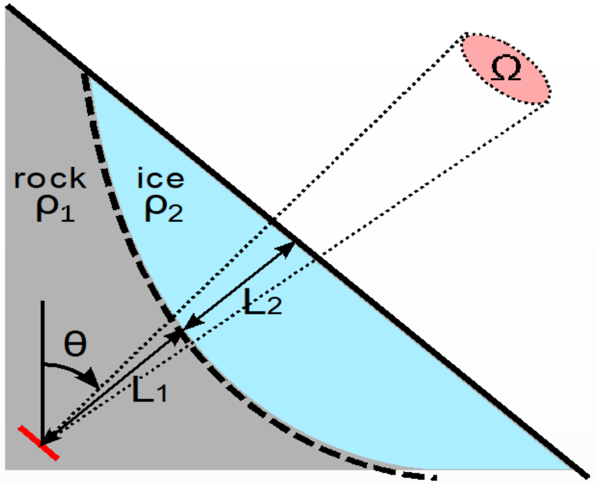
What's next for OPERA's emulsion-detection technology?

While working on the analysis of their data, the collaboration is also looking into possible developments of their emulsion-detection technology, to be implemented in future experiments.

Luciano Maiani, Università La Sapienza and INFN Roma 1,
and **Giovanni De Lellis**, Università Federico II and INFN Napoli.



Muon Radiography - objects of interest underground

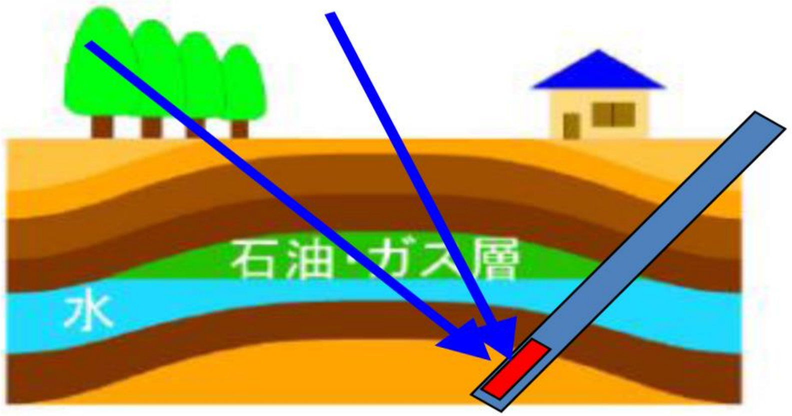


Attenuation (X) of muon rate ~ density pass (ρL)

$L = L_1 + L_2$, $X = \rho_1 L_1 + \rho_2 L_2$

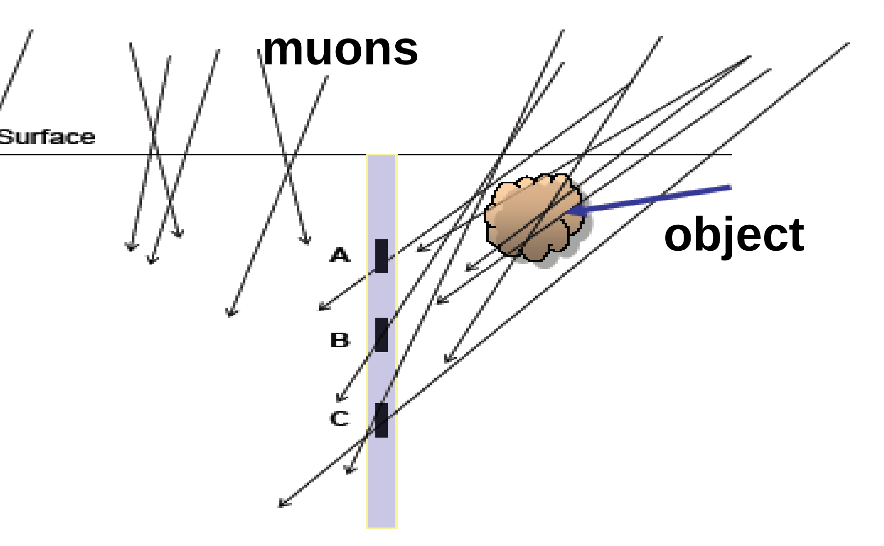
Performing observations at different orientations to the object allows a computed axial tomography

資源探査

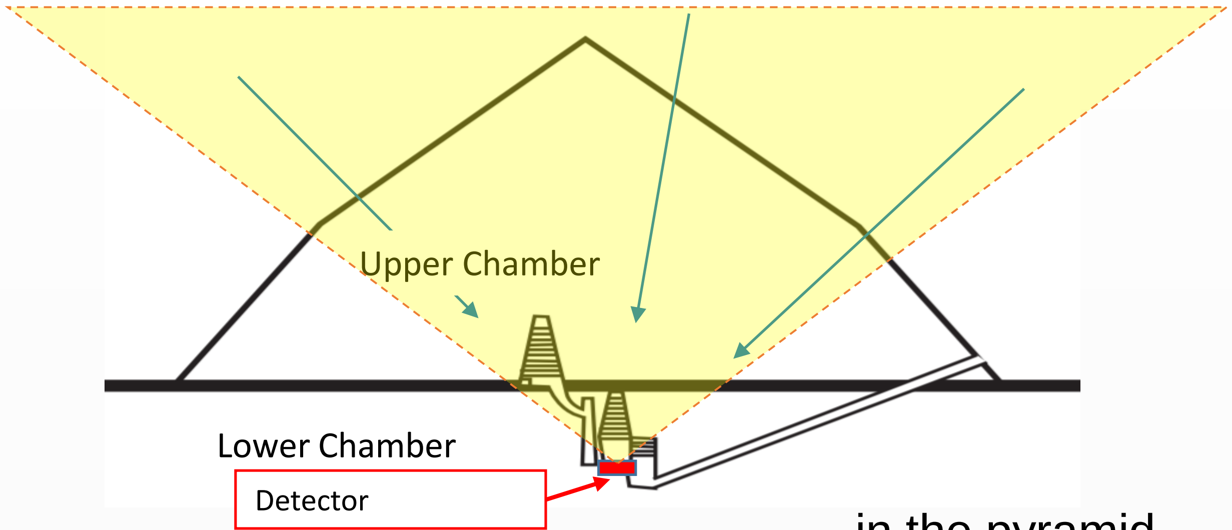


細いボーリング孔へ設置可能

Examples of placement of detectors with nuclear emulsion:



In a shallow well



in the pyramid

On the volcano

The conditions for the location of detectors during monitoring interesting objects and their environment:

The detector should be located below the area under investigation;

All time of exposure, the detector must be stationary;

In the presence of an aggressive environment, a sealed container;

To restore the volume picture is necessary installation of detectors from at least two observation points;

After exposure, the emulsion is developed and scanned on automated complexes such as PAVICOM**.**

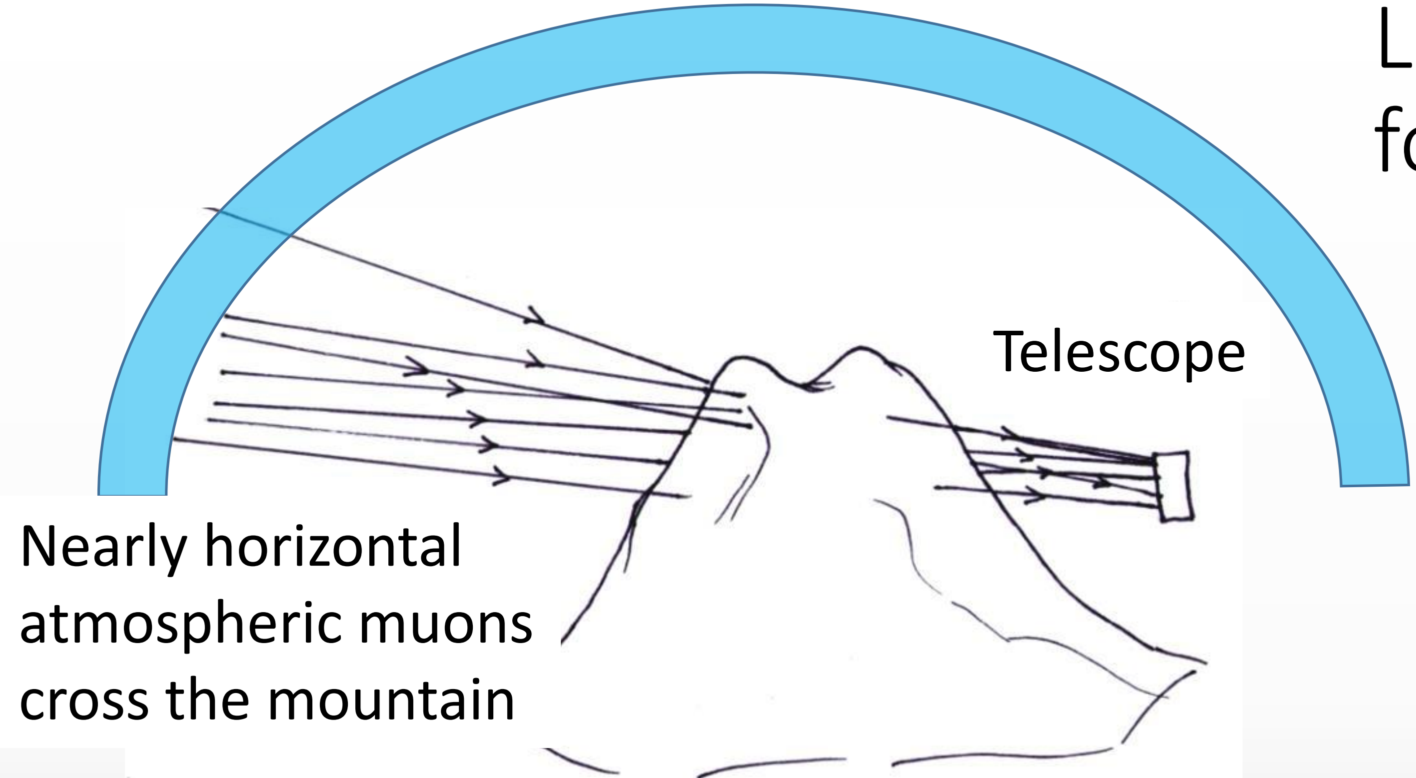
Cosmic-ray Photograph of a Volcano (Showa-Shinzan)

Determining the internal structure of such objects provides information for predicting possible earthquakes and eruptions, which is extremely important for seismic and volcanic-dangerous areas, such as Italy, Japan, and California.

A photograph in cosmic rays of the Showa Sinzan Volcano, Japan.
Each point is a cosmic-ray muon, recorded in a nuclear photo-emulsion plate.

A usual photo of the same object.

Limits and requirements for volcanoes radiography



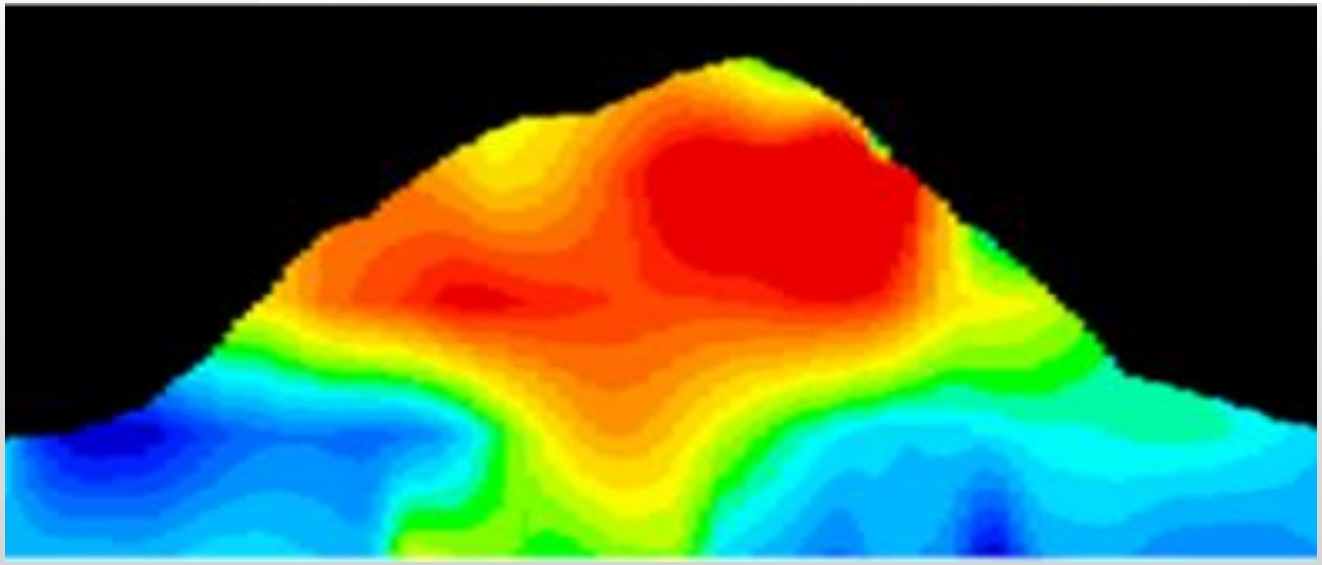
- The method is limited to the upper part of the mountain above the detector
- Low muons rate do not allow to have short exposure – months is a typical time scale
- 1 km of the rock thickness is an approximate upper limit for 1-few m^2 detectors with few months exposure

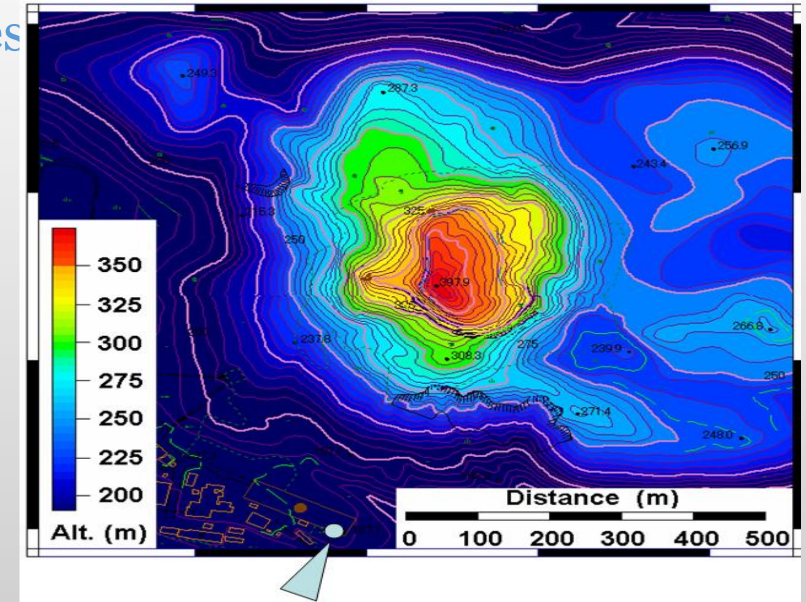
- It's assumed that the muon flux and spectrum is well known and nearly stable in time
- Assumed the precise knowledge about the mountain shape (DEM)
- What we can obtain is the angular map of the average rock density using the muons **absorption** information
- **Detector should provide a precise angle for each particle passed through**

An alternative method of seismic analysis

Scanning the internal structure of sites such as thes
experts can predict volcanic eruptions, which is vital
eruption-prone areas such as Italy, Japan or California.

Size of object ~ 1 km
Size of detector 0.4 m²
Exposure time 60 days
Res

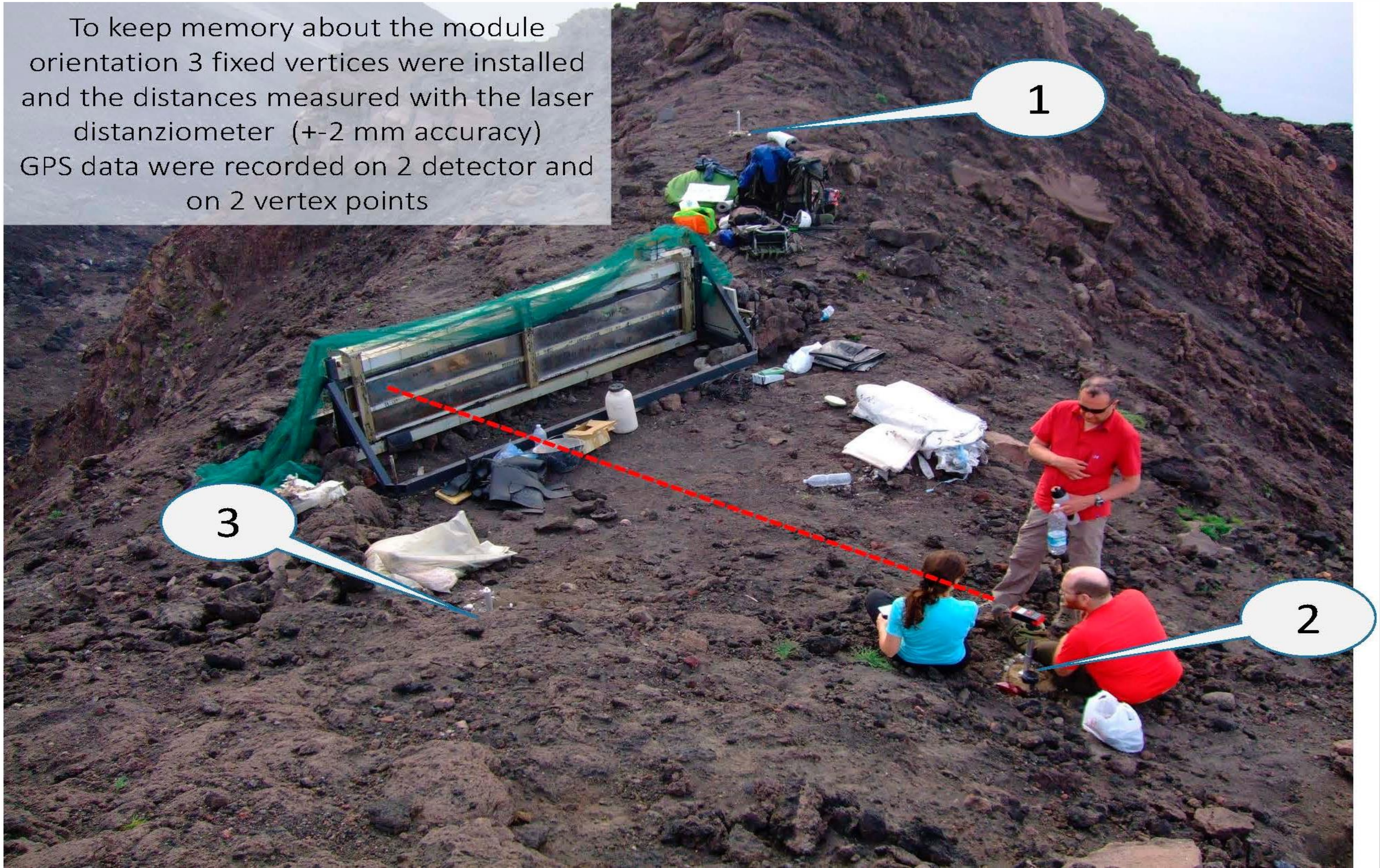


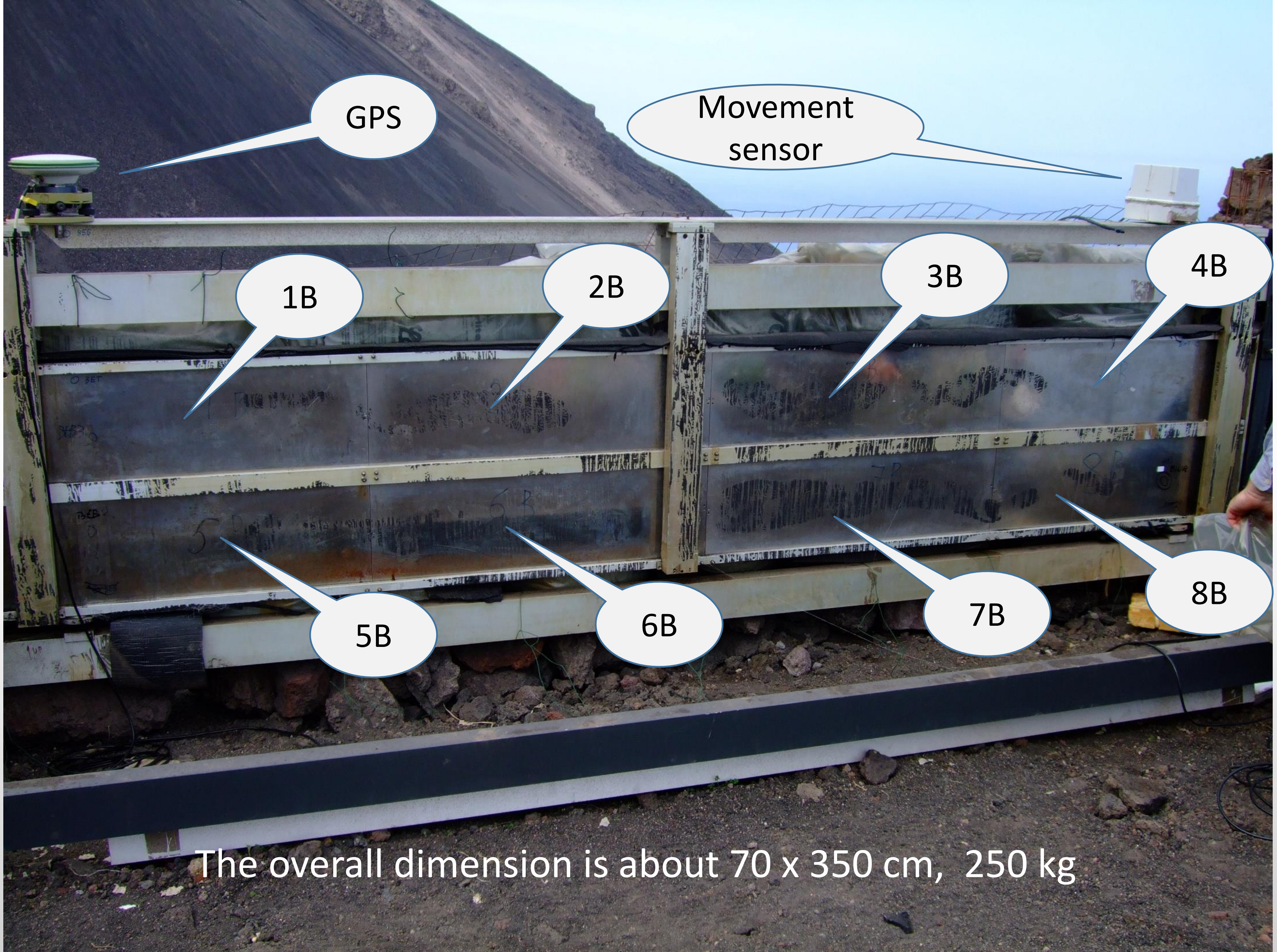


Muongraphy emulsion projects with participation of Italian laboratories

- Unzen – contributed to data scanning and analysis (2011)
- Stromboli – Design, installation and data analysis (2012)
- Teide – exposure is completed, scanning is started (2013)
- La Palma – modules design, installation, analysis started (2014)

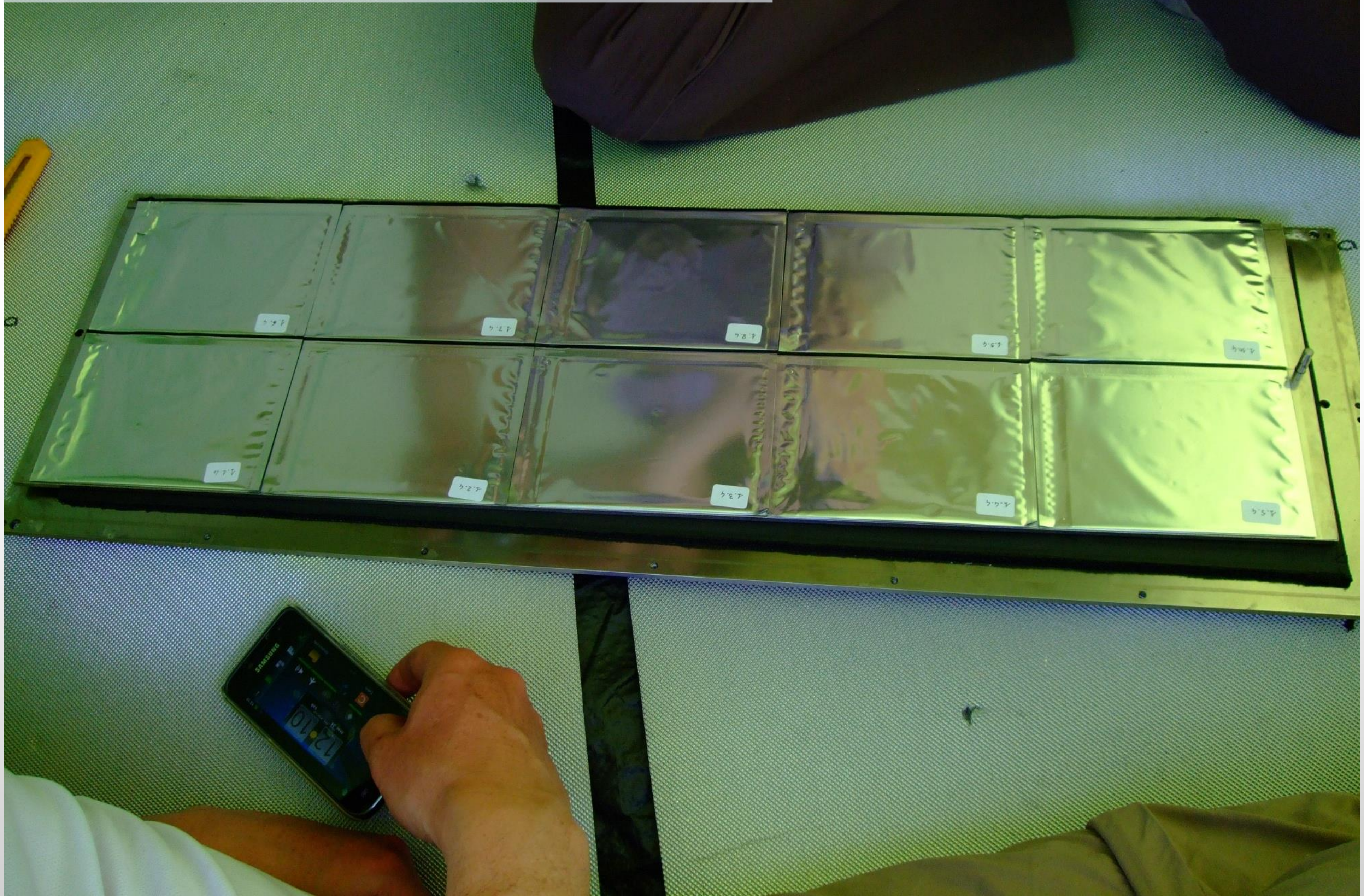
Volcano muon radiography



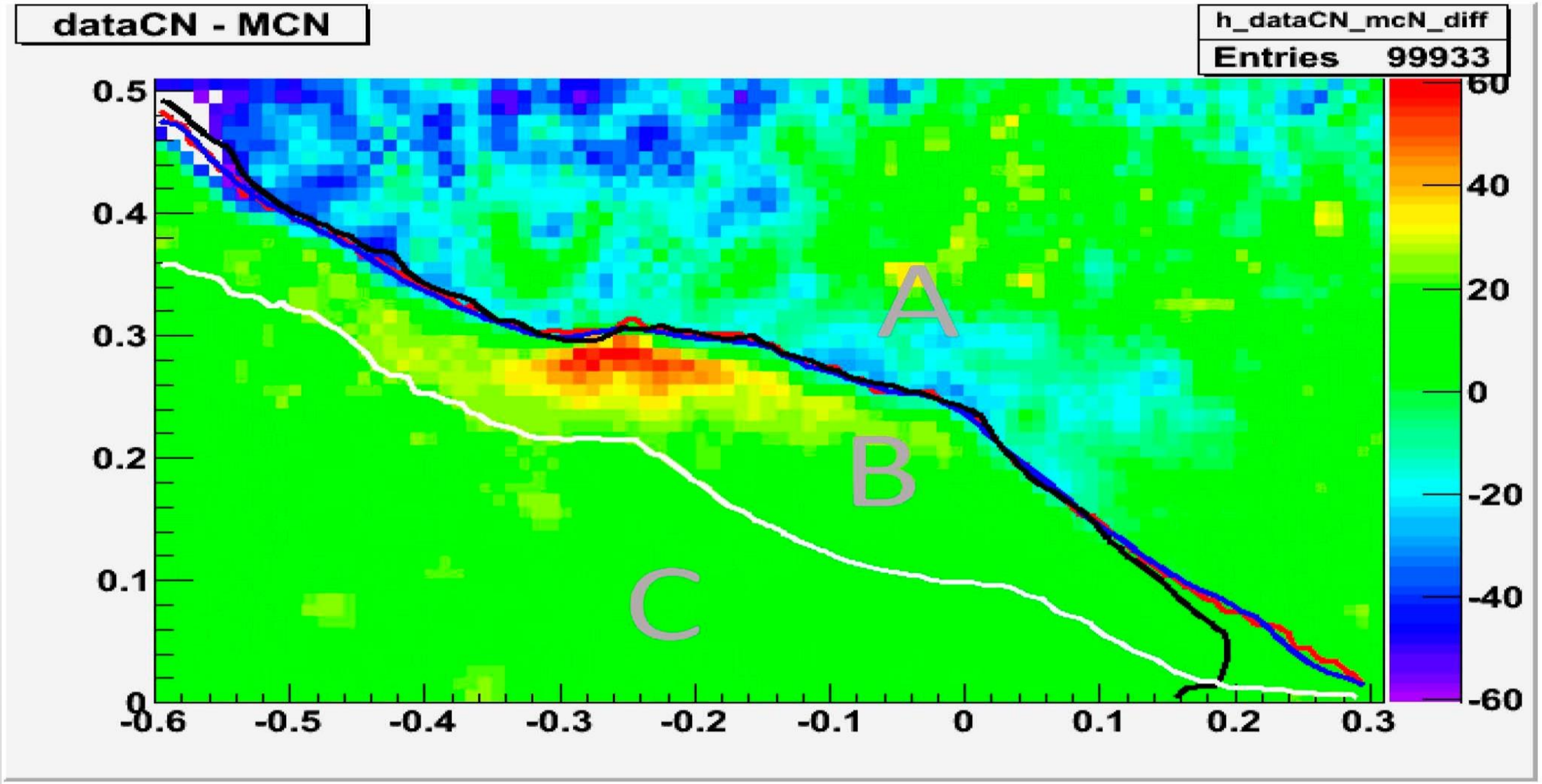


The overall dimension is about 70 x 350 cm, 250 kg

Emulsions extraction after 5 months exposure.
The envelopes are in a good shape



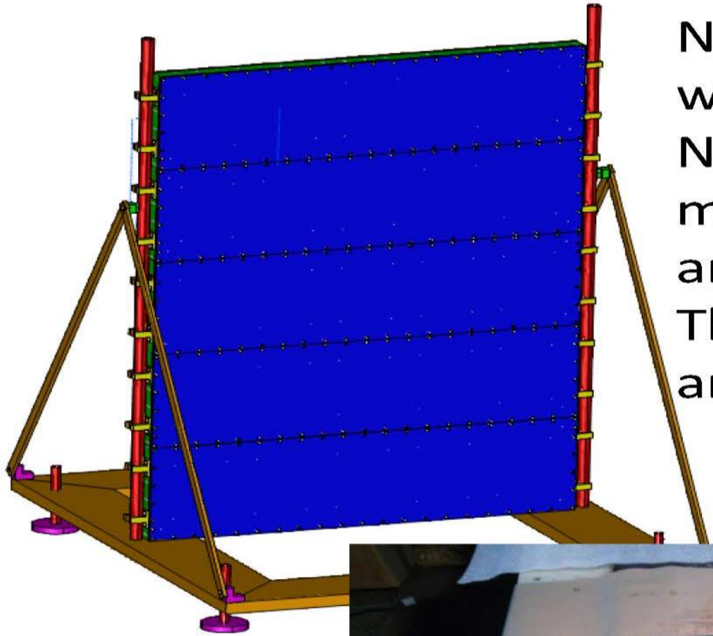
Volcano muon radiography



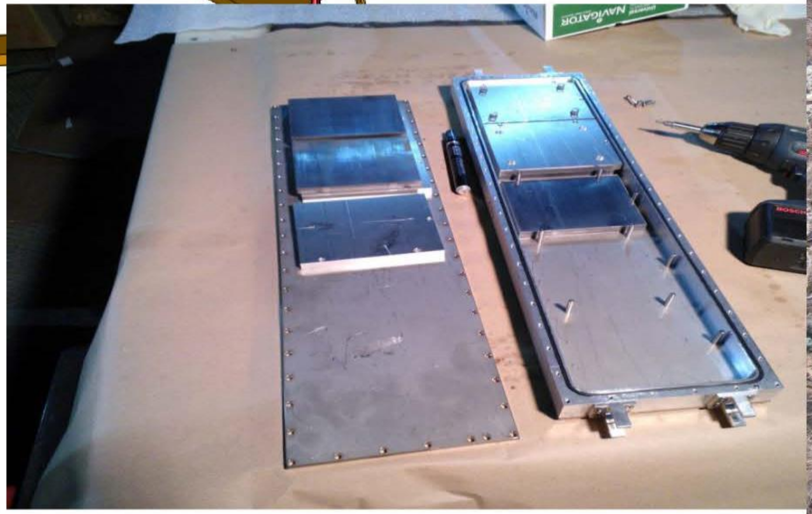
Data and
Normalized MC
Flux are
Subtracted

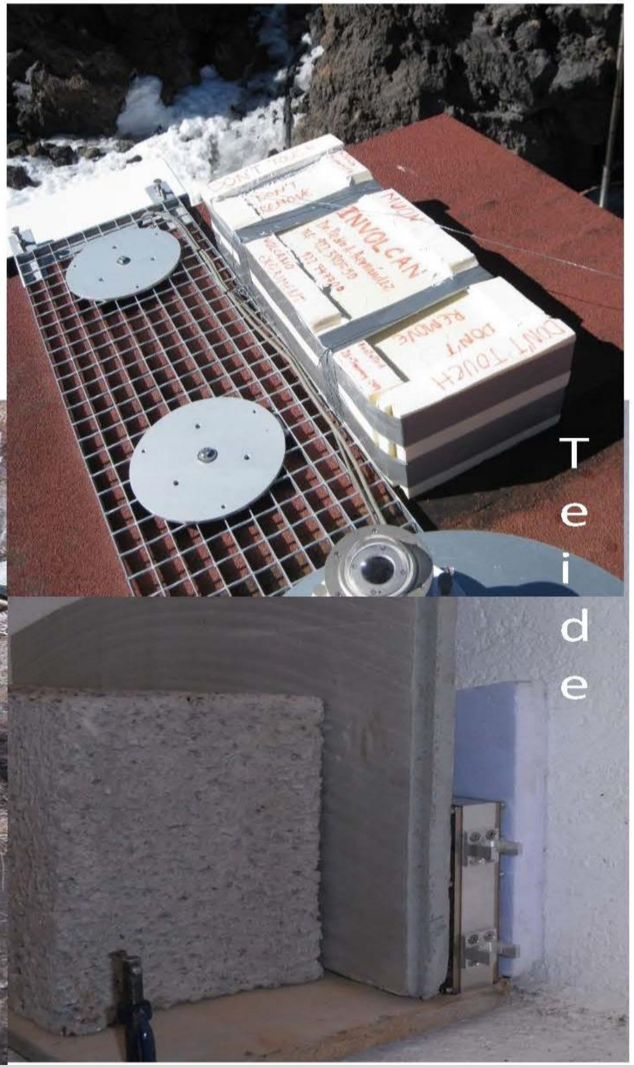
They observe
Significant muons
Excess in the
Craters region

Geological muon radiography



New compact ECC modules for muography were designed and constructed in INFN Napoli for Canary exposures. These modules were installed in 2014 on La Palma and on Teide mountain.
The modules are precise, robust, reusable and versatile





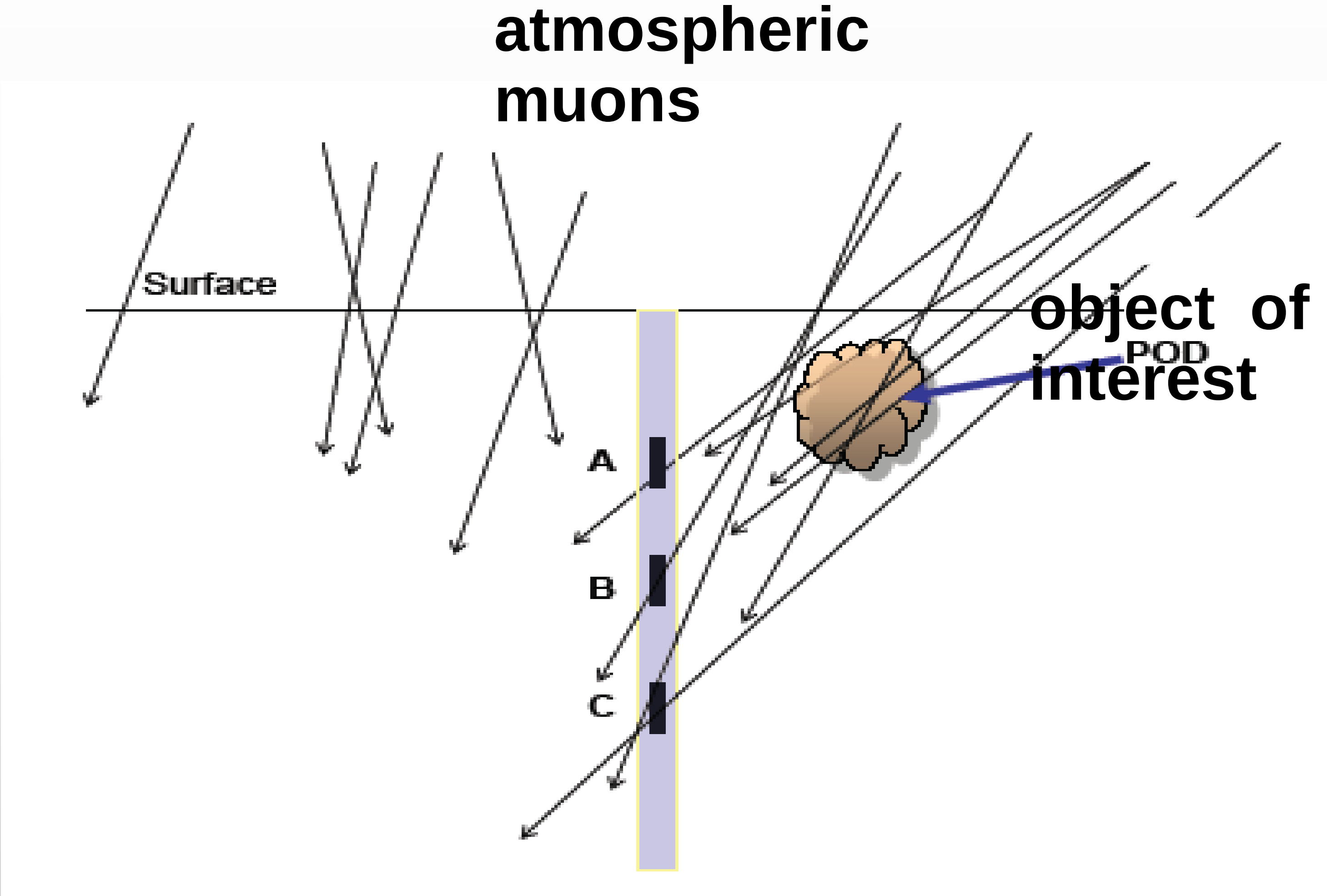
Muon geo-radiography: detector inside a bore hole

Compact detector modules are needed (bore diameter ~15 cm)

Module orientation measuring system is necessary

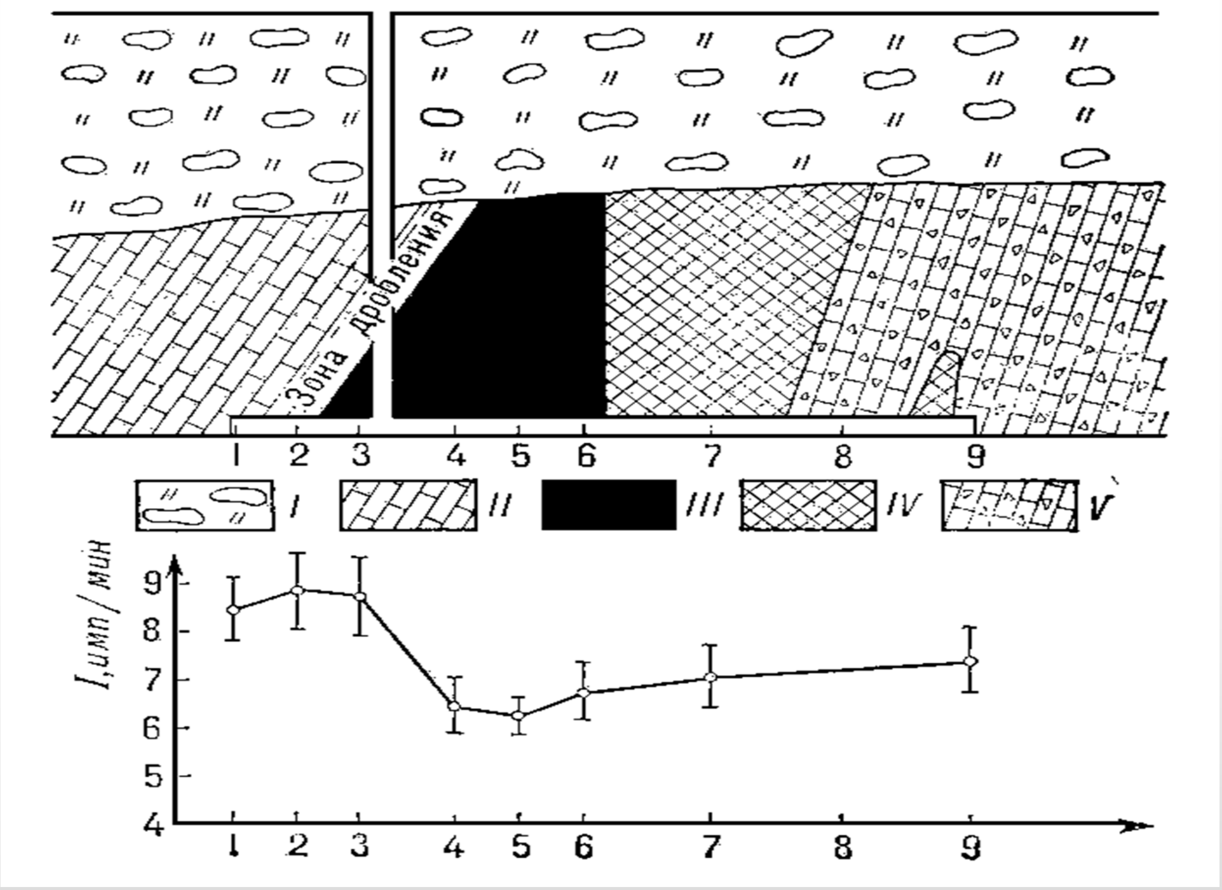
Combine 2-D projections from a number of detectors to reconstruct the
3-D picture

R&D in this direction is ongoing towards a first test in a bore hole



Geological exploration of mineral and water deposits

Using a counter telescope to measure the intensity of cosmic rays in tunnels and then comparing the results with the already known absorption curves for cosmic rays in water or earth, experts can pinpoint or clarify the position of ore bodies and voids, as well as measure the gravity load of above-ground structures.



This drawing illustrates the exploration of a mineral deposit through measurement of the intensity of the muon component of cosmic rays:

a — cross-section of a polymetallic field (I — silt, II — limestone, III — rich ore, IV — poor ore, V — ingrained mineralization);

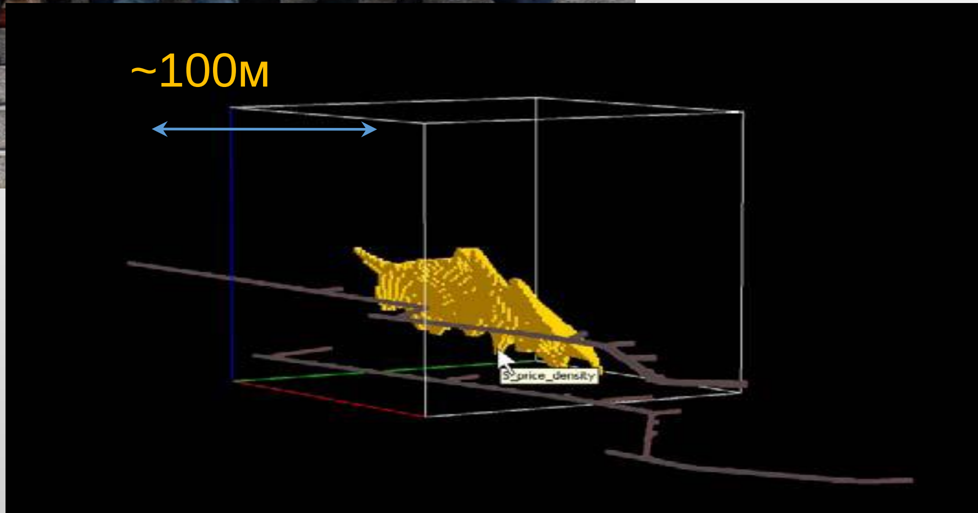
b — the intensity of cosmic rays, as measured by a counter telescope (vertical lines along the curve indicate measurement errors).

Search by a group of Bern University gold field in Canada

Detector – emulsion film modules

Test site – Price Mine, Vancouver Island, BC, Canada

Large known object (100m) and small dense unknown object

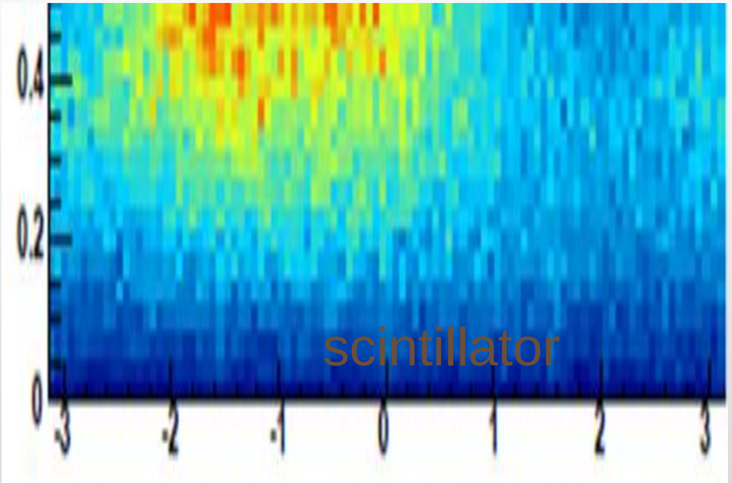


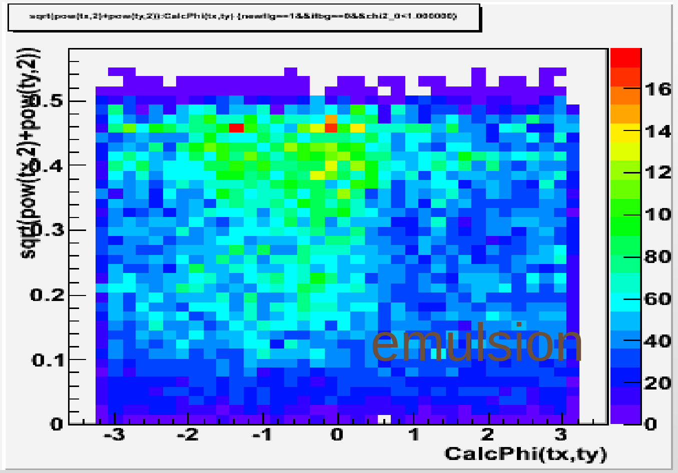
Search by a group of Bern University gold field in Canada

PURPOSE:
3D RECONSTRUCTION OF MINERAL DEPOSIT IN VANCOUVER MINE, CANADA.

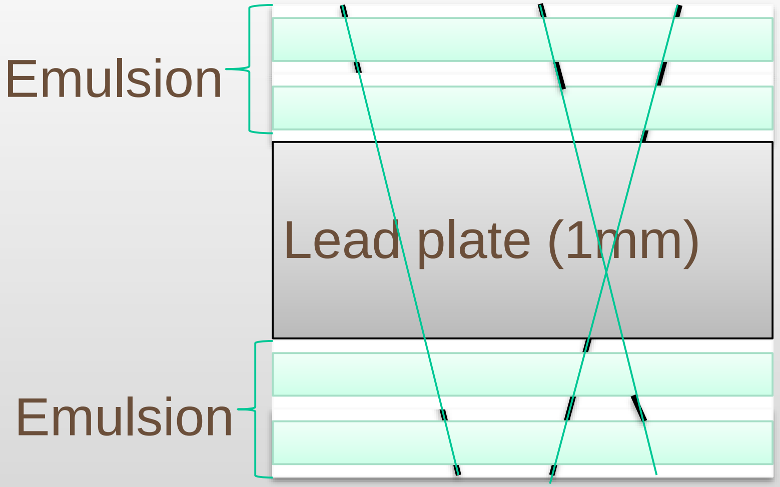
140 days exposure in the mine at 10 places.
Exposure was done,
Scanning & Analysis is now on going.

Set emulsion films in the mine





Comparison with scintillator and emulsion result



Detector structure

MR in Glaciology (work of Bern University group)

Several models for glacial erosional process proposed from the observation of “past” glaciers, c. 24 Kys ago

However, no measurement of “active” glaciers, particularly where they originate

The models left experimentally untested, because no appropriate method to study bedrock morphology

Radar (conductivity): does not work where ice and water exist and danger

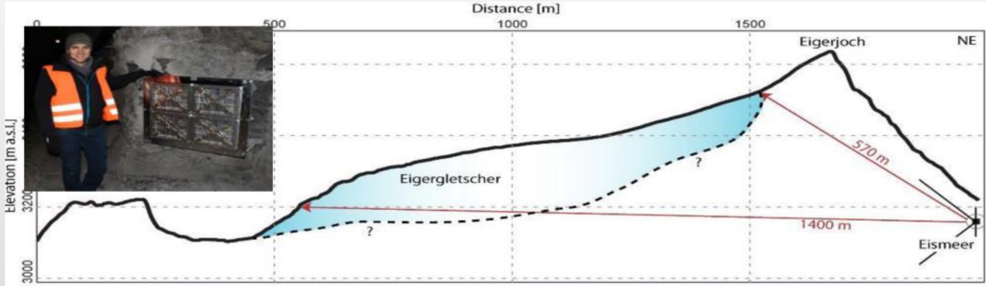
Gravity (mass): intrinsically limited in 3D reconstruction and danger

Borehole only gives 1-D info and no info about the shape and danger

Seismic survey will not properly work because the cirques are hardly accessible plus water content strongly attenuates shear waves and danger

Muon radiography (density) is an excellent method

to study the bedrock morphology



Eiger-μ GT project

"Development and scientific application of nuclear emulsion particle detectors to geological problems in 3D"

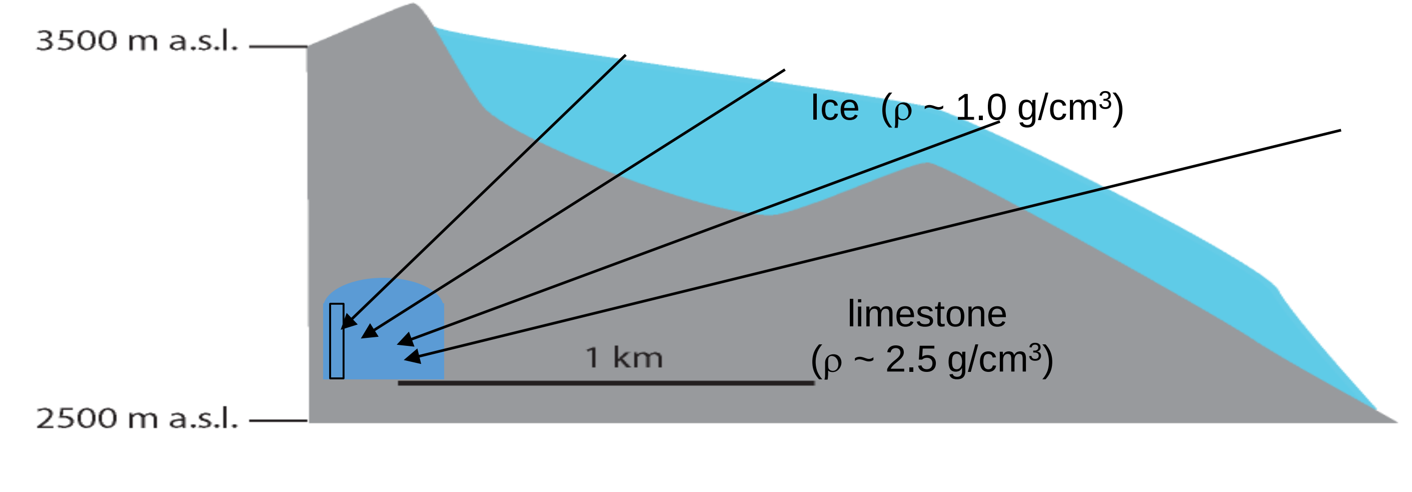
Establishment of methodology (resolution a few 10 m)

Demonstration at "active" Eiger glacier

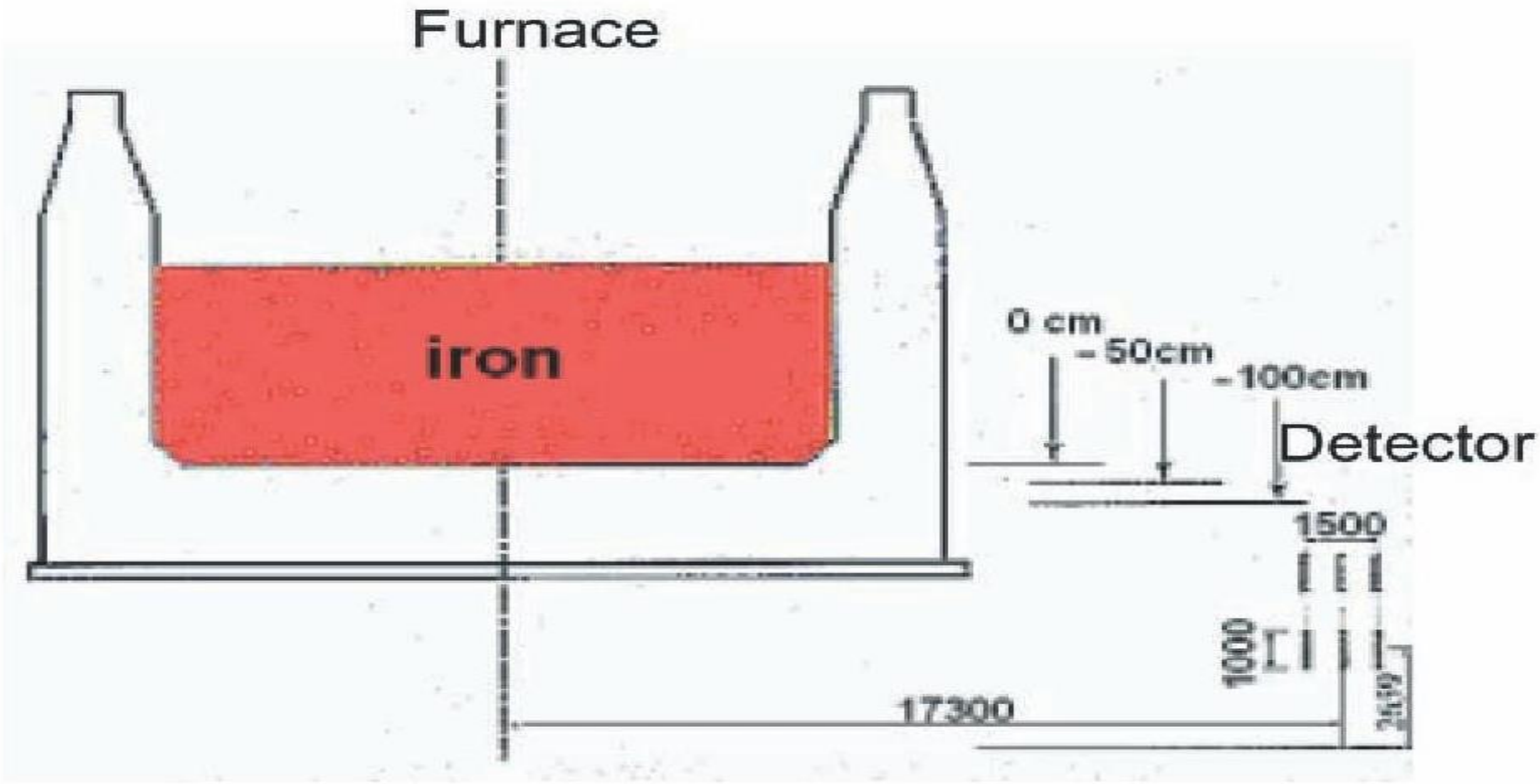
Study of erosional process

Interdisciplinary project approved by Swiss National Science Foundation

1 M $ for 3 years

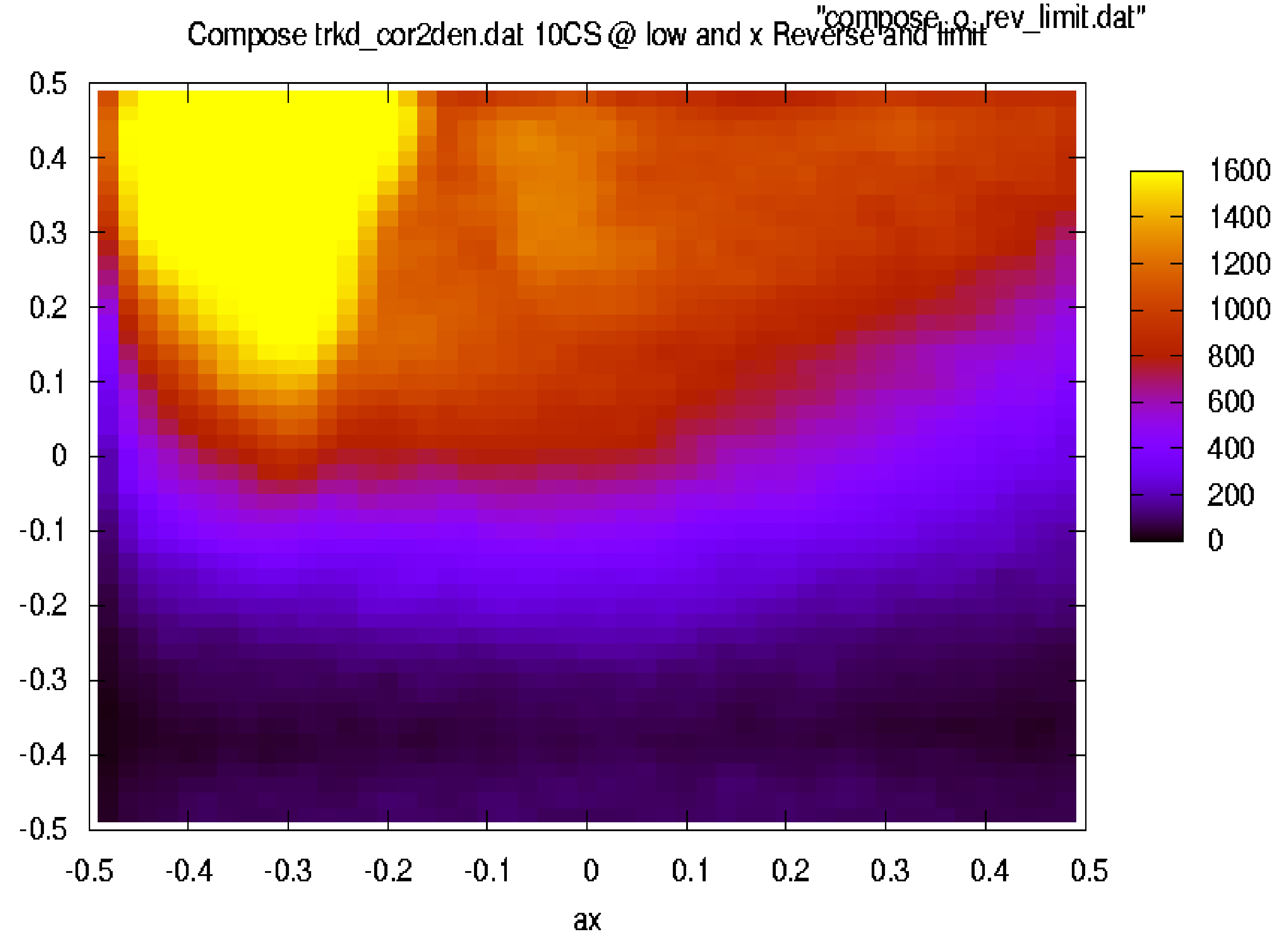


Investigation in the Blast Furnace

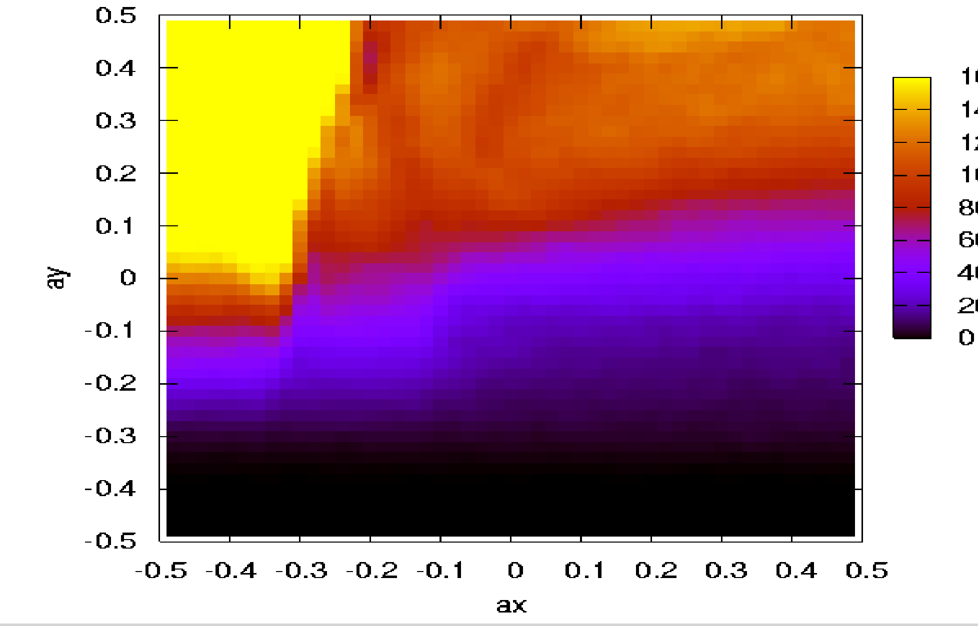


Investigation in the Blast Furnace

Observed DATA (1000cm^2,2 month)

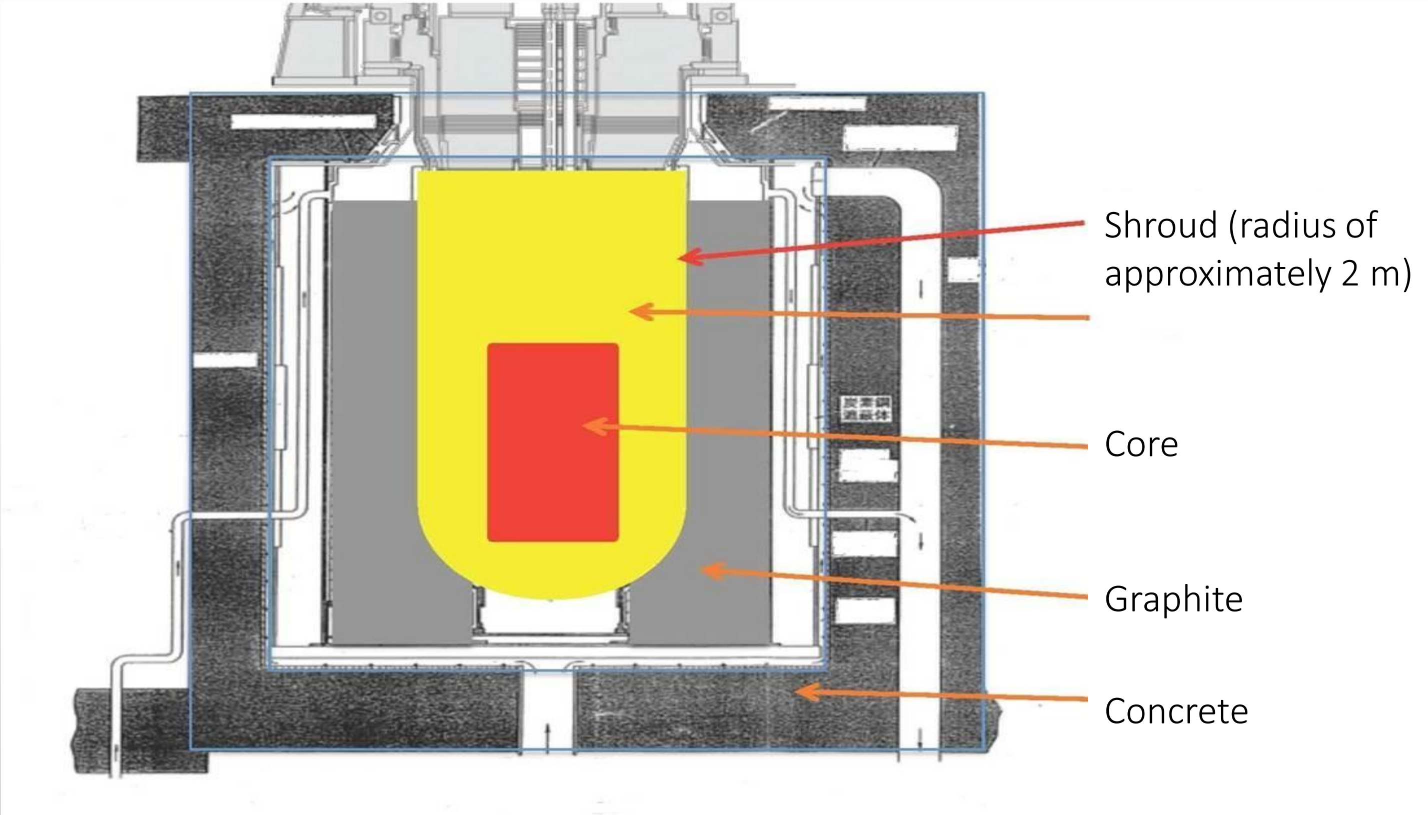


Estimated



Application in the nuclear energy industry

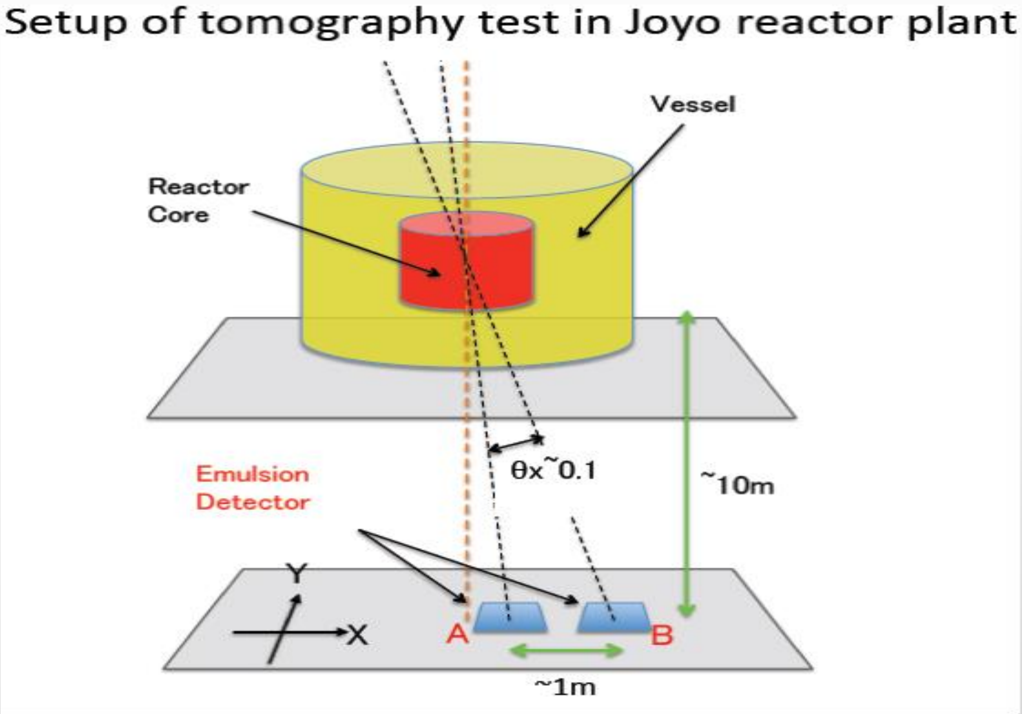
Muon radiography can be used to image the cores of nuclear reactors when they are faulty and/or other measurement methods can't be used.

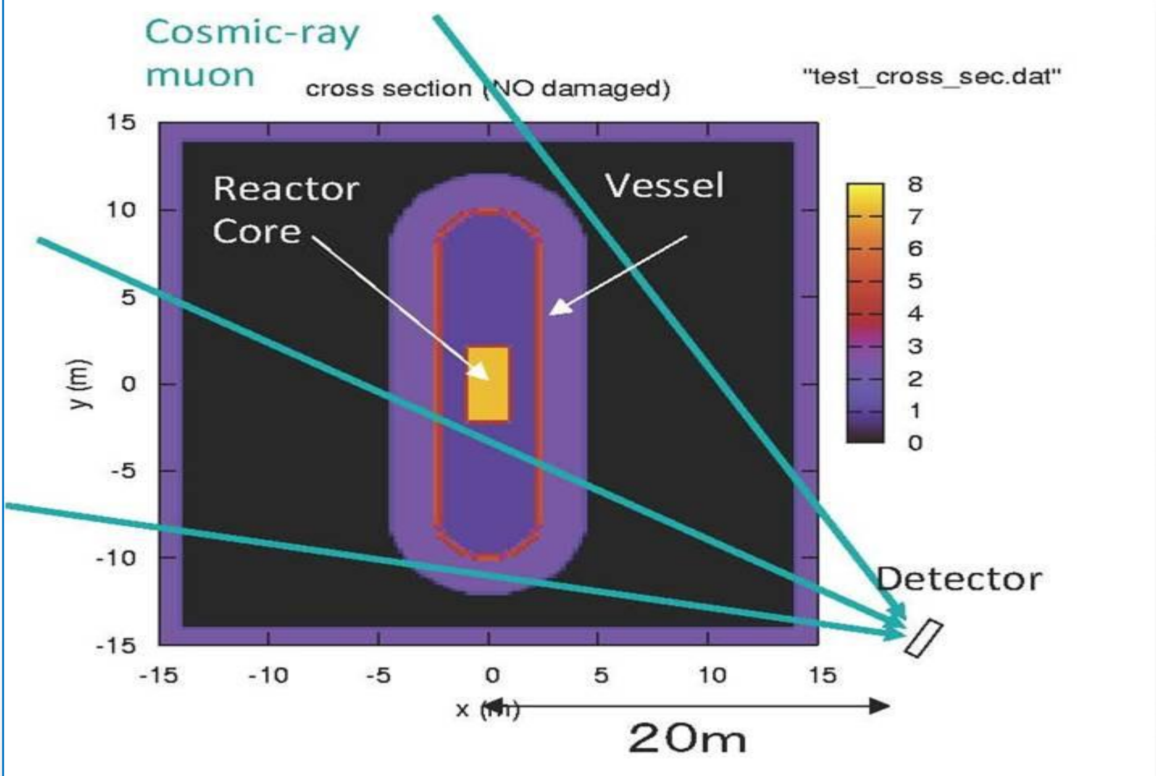


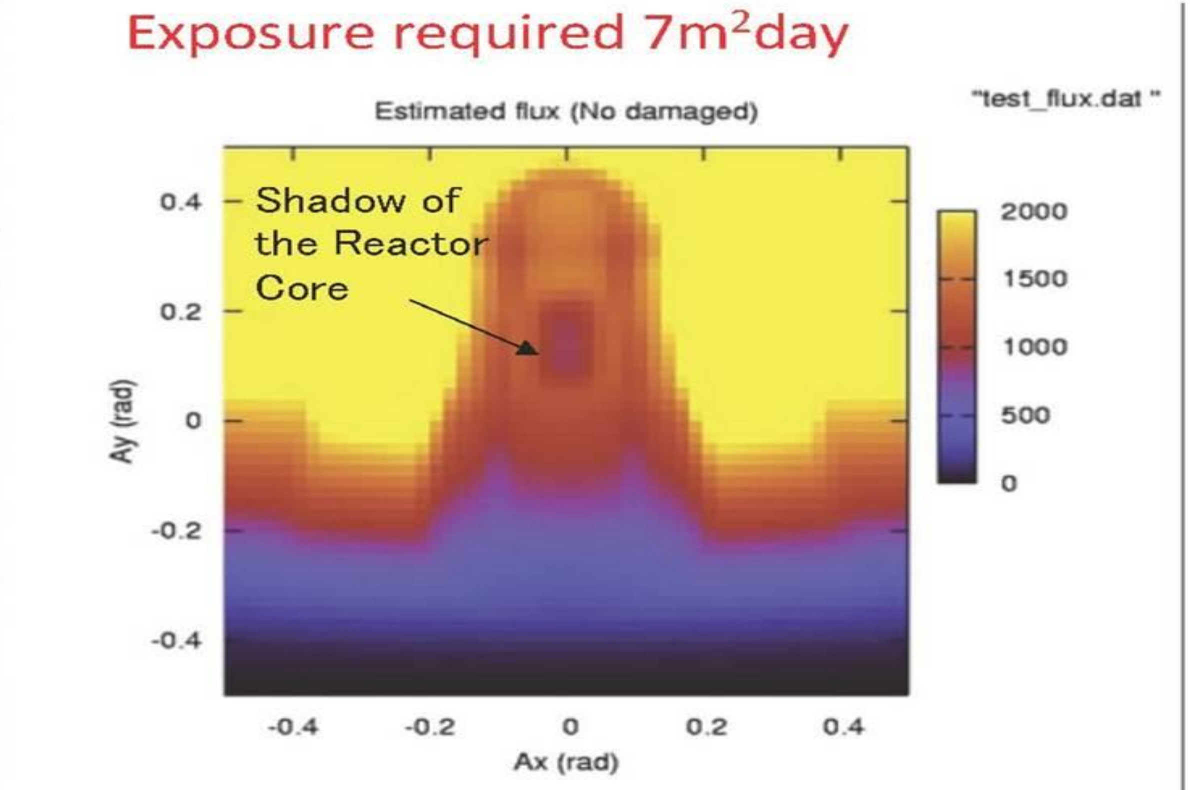
Cross-section of a nuclear reactor.

Monitoring of nuclear power facilities

Muon radiography was used to scan the reactor at Japan. The diagram below shows the placement of emulsion detectors to inspect the condition of an operational reactor using muon radiography.

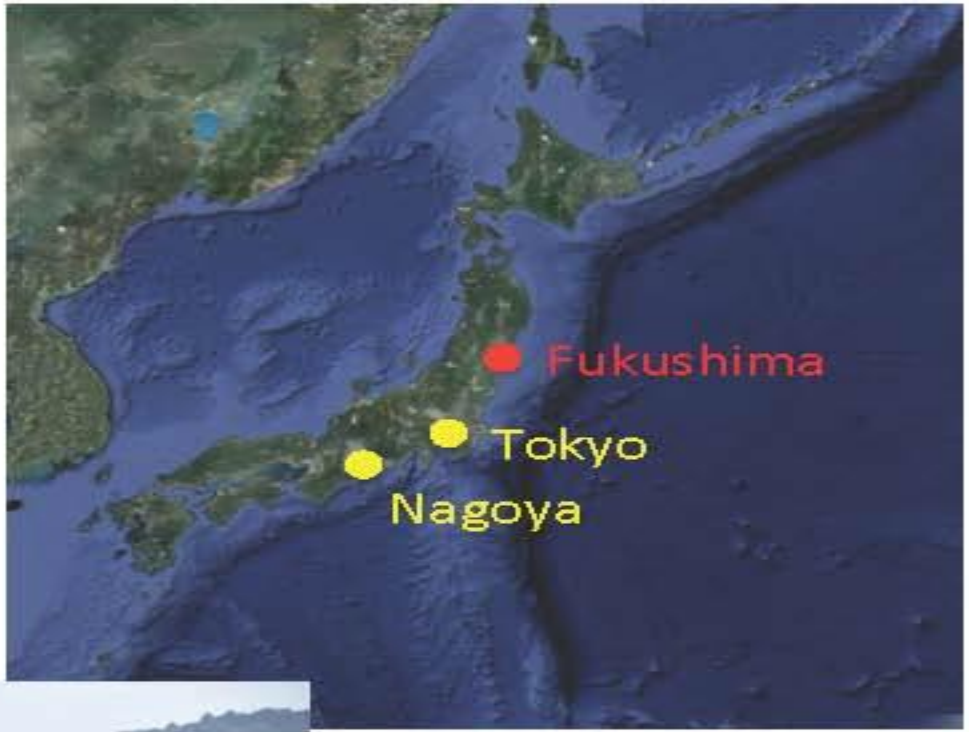






On the left - the location of the detector during conducting muon radiography and the trajectory of muons. On the right are the results of muon radiography after exposure of 7 m2 · day (the active reactor zone is visible).

The Great East Japan Earthquake 2011.3.11



The Fukushima Daiichi Nuclear Power Plant Accident

A cooling system stopped and it is thought that the meltdown of the nuclear reactor happened.

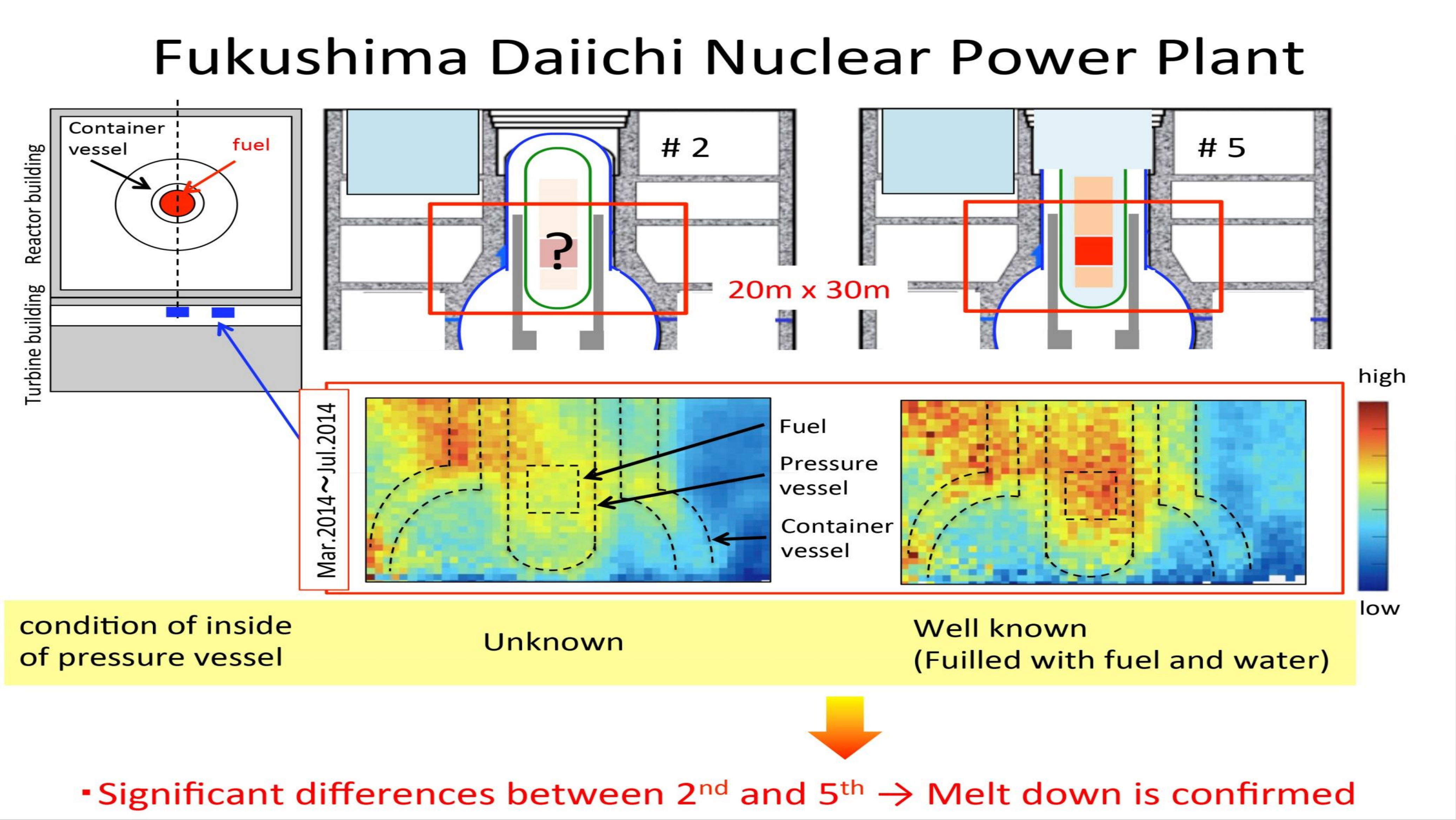
Monitoring of nuclear power facilities

The problem in observation

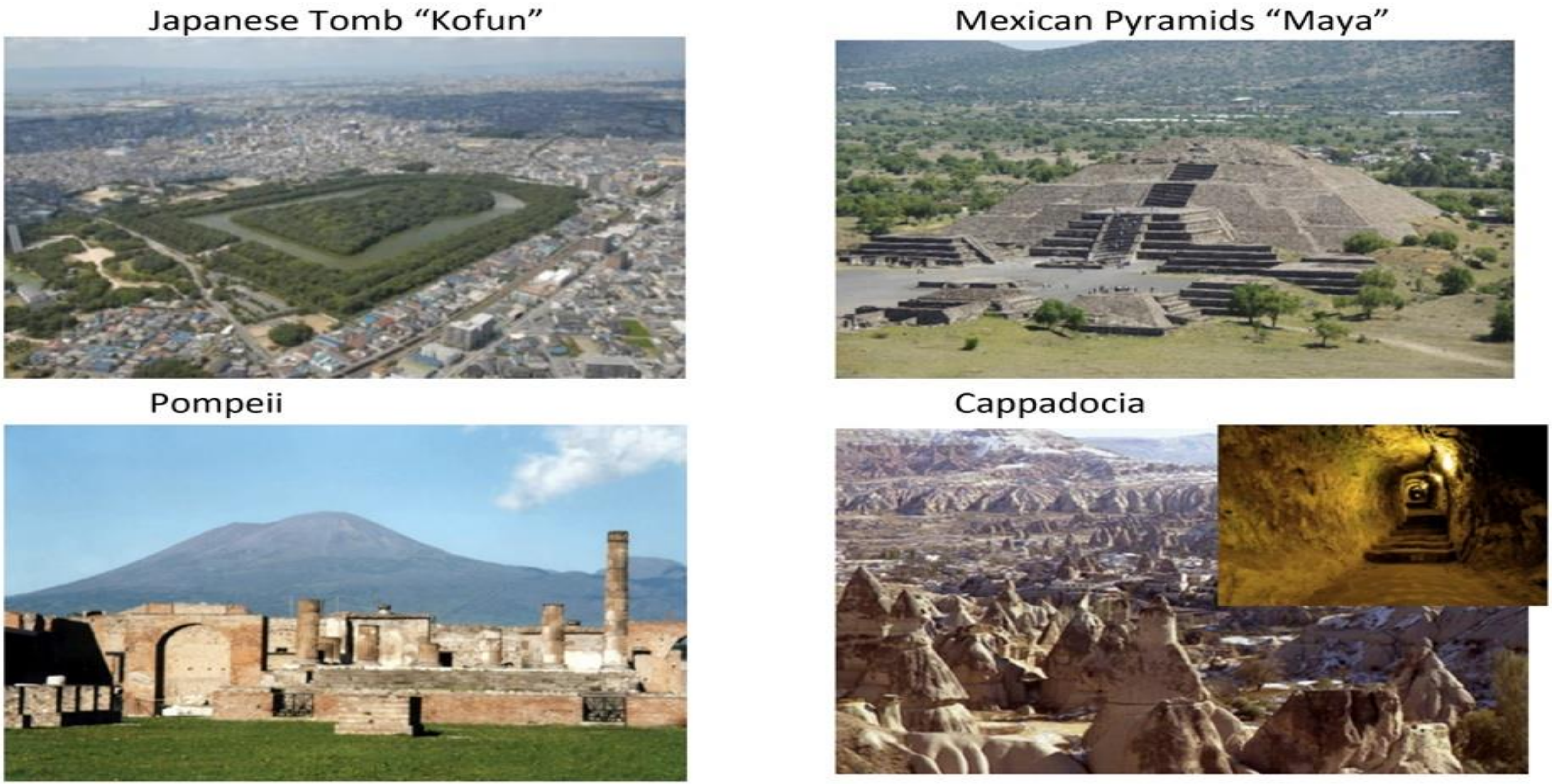
- High radioactive environment
  - Shielding is needed
- Limitation of installation space
  - Rubbled area
- power supply is difficult

→ **Emulsion is better solution**

Monitoring of nuclear power facilities



Archaeological Applications of Muon Radiography



Pyramid of the Sun in Teotihuacan (Mexico)

In 2010-2013 Arturo Menchaca et al. was carried out a muon tomography of this pyramid from a tunnel dug under the pyramid to search for the cause of its collapse. It turned out that the density of the soil filling the stone shell on different sides of the pyramid differs by 20% due to the drying of the soil on one side.

Cosmic ray muon radiography of Egyptian pyramids with nuclear emulsions in the Scan Pyramids project

K. Morishima

Nagoya University

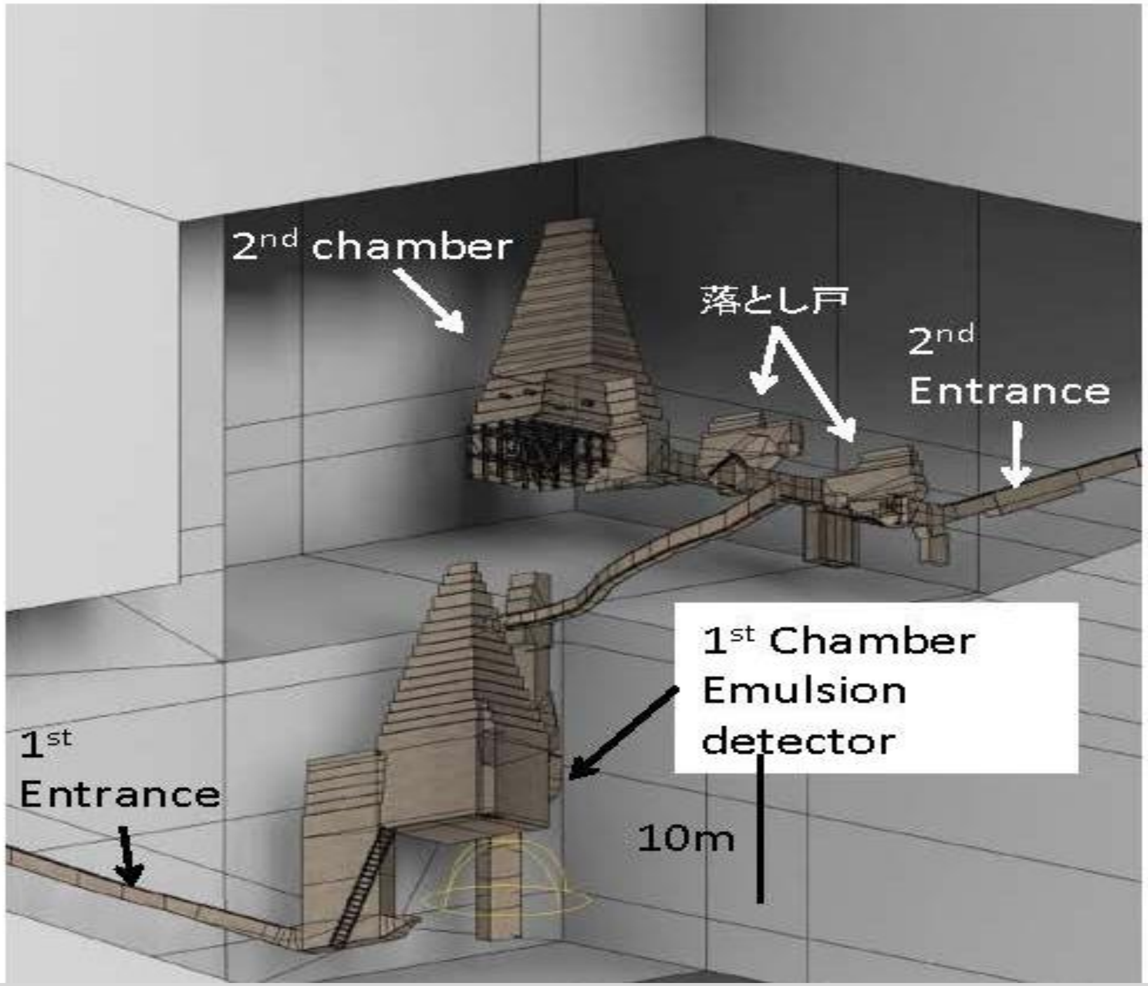
Hidden Structures inside Pyramids ?

Observation of Bent Pyramid -2015

Aim

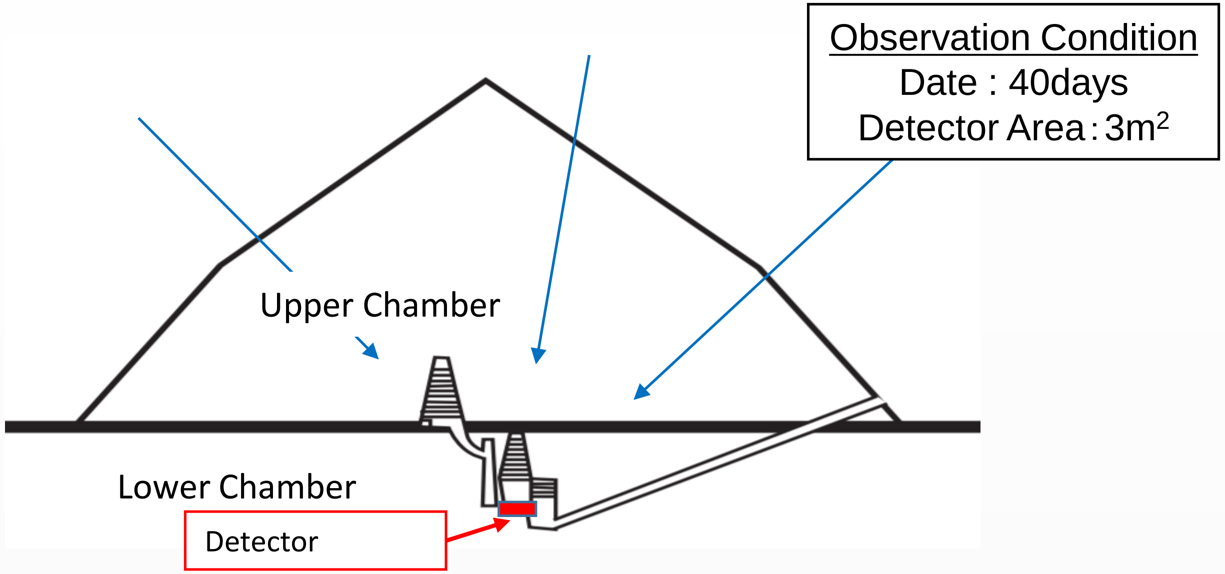
1. Validation of imaging of known chamber
2. Search for hidden chamber

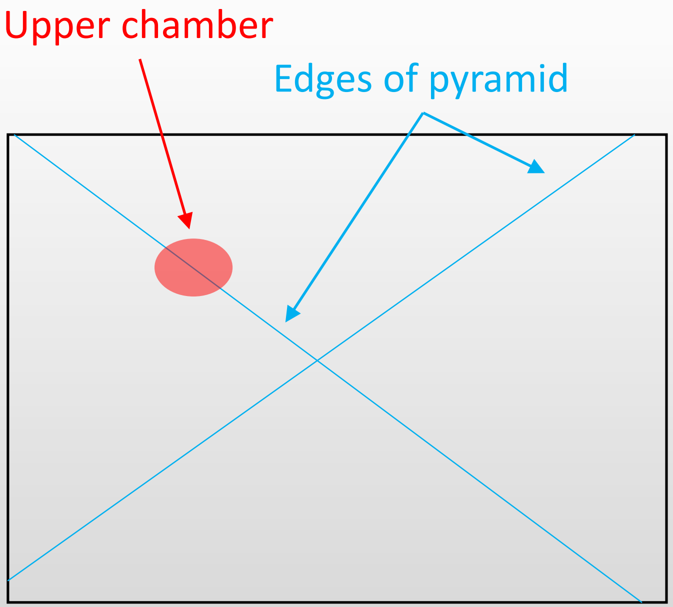
Limestone thickness : 100m
Density 2.2g/cm^3 ? (Unknown)
Muon penetration rate ~ 0.3%
Area x Period ~ 1m^2 x 1month



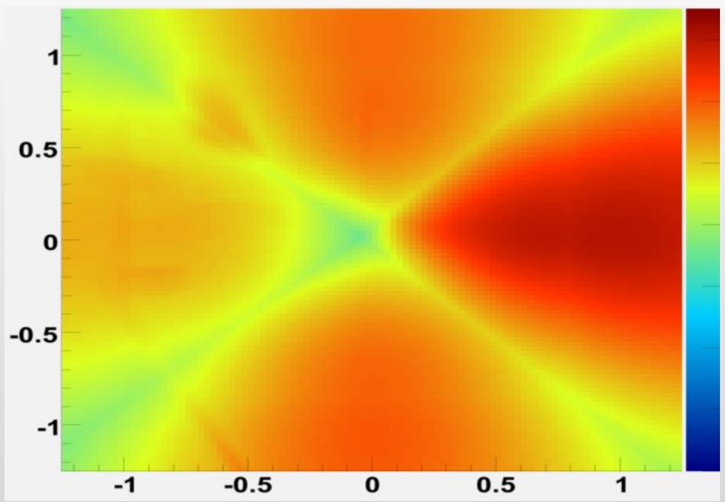
Installation

Imaging of Bent Pyramid



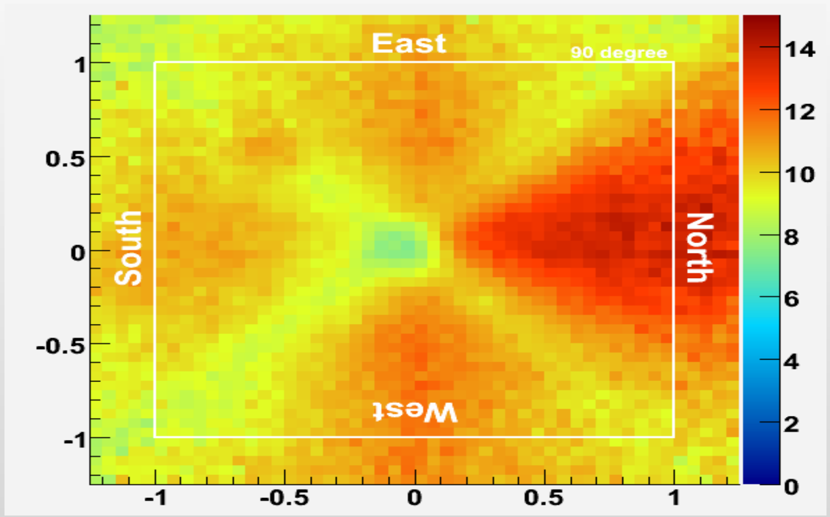


Expectation from Simulation



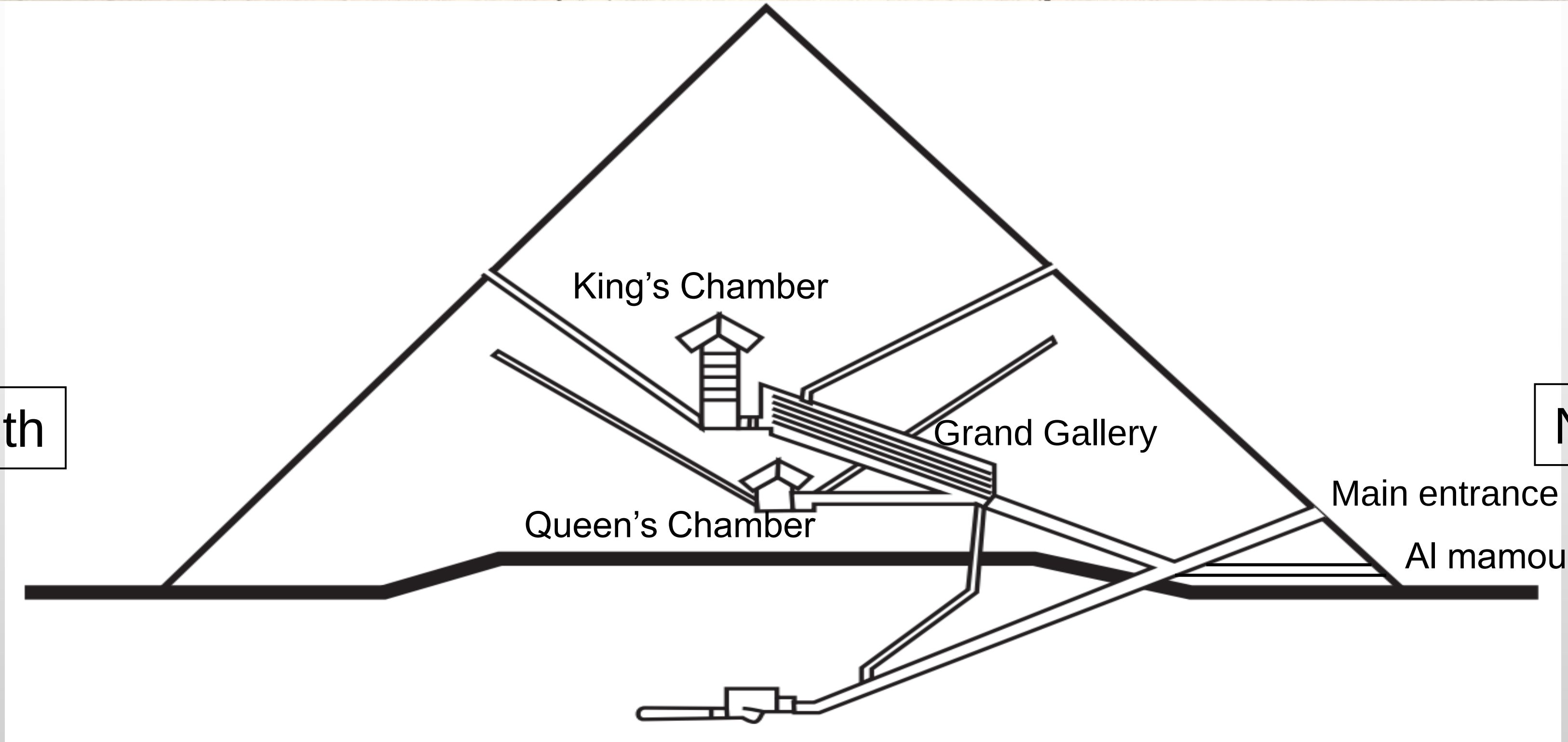
Result from Data

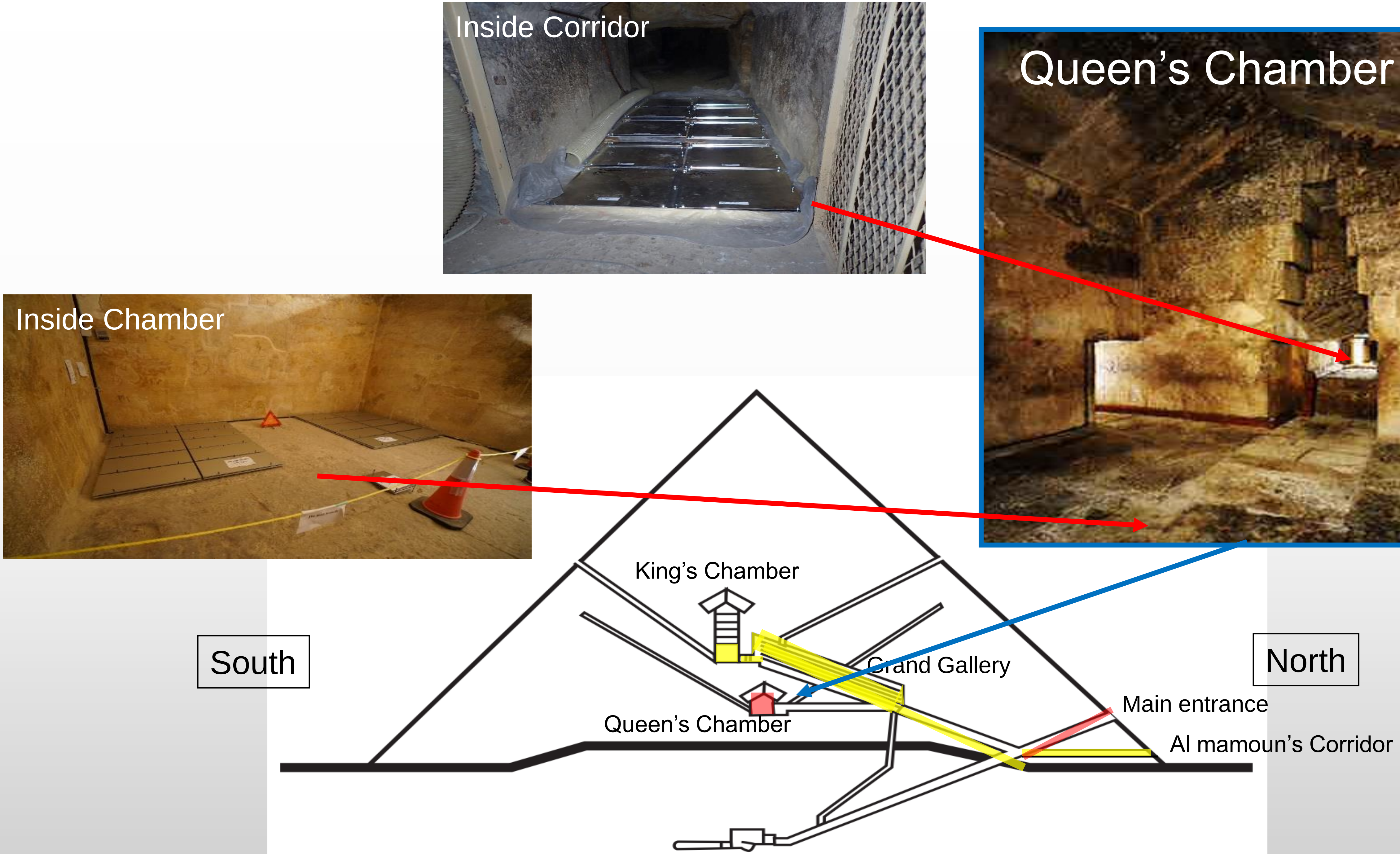
(cm²/Sr/day)

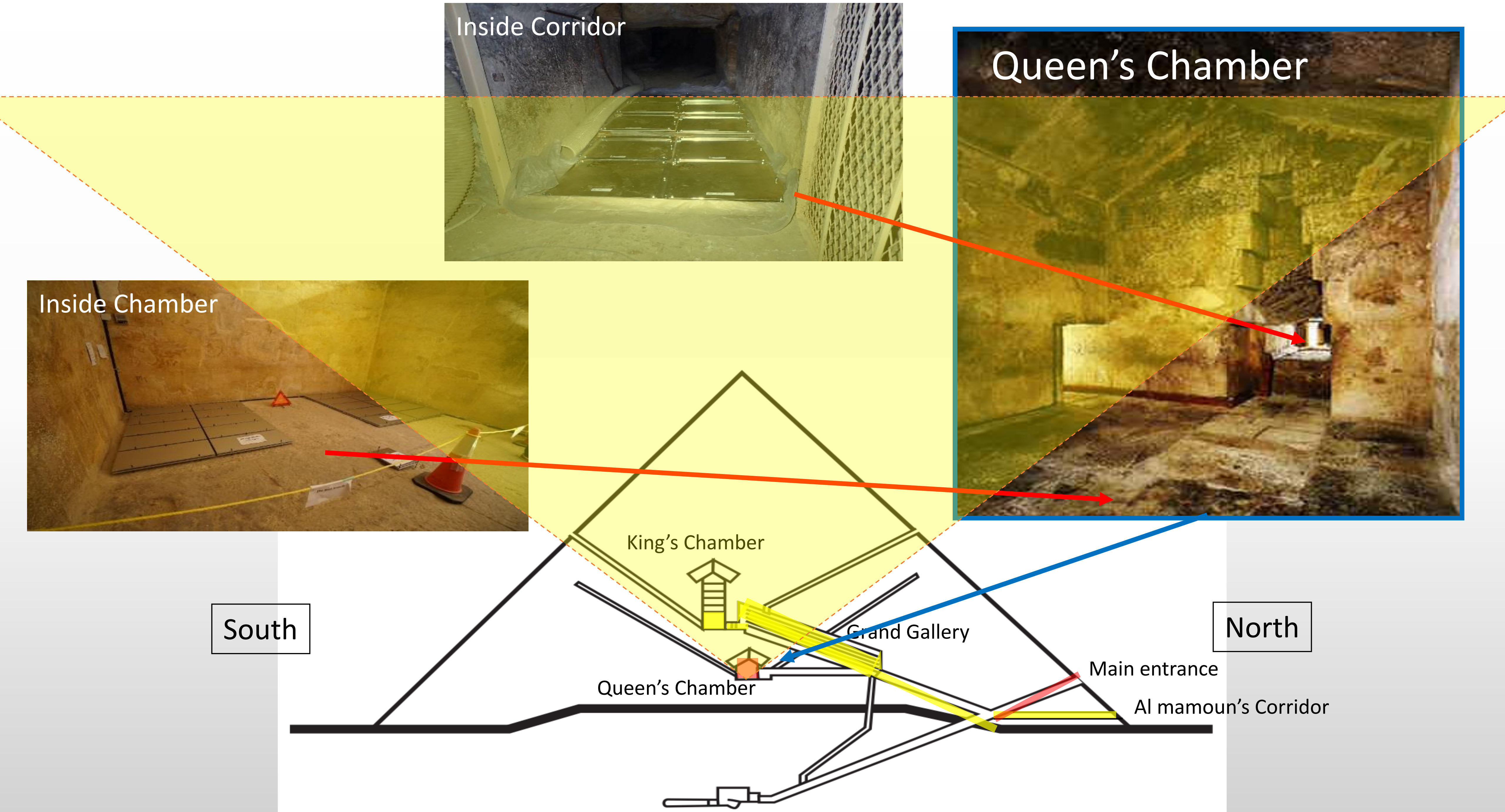


First Validation of the capability of imaging like Xray of inner structure of pyramid

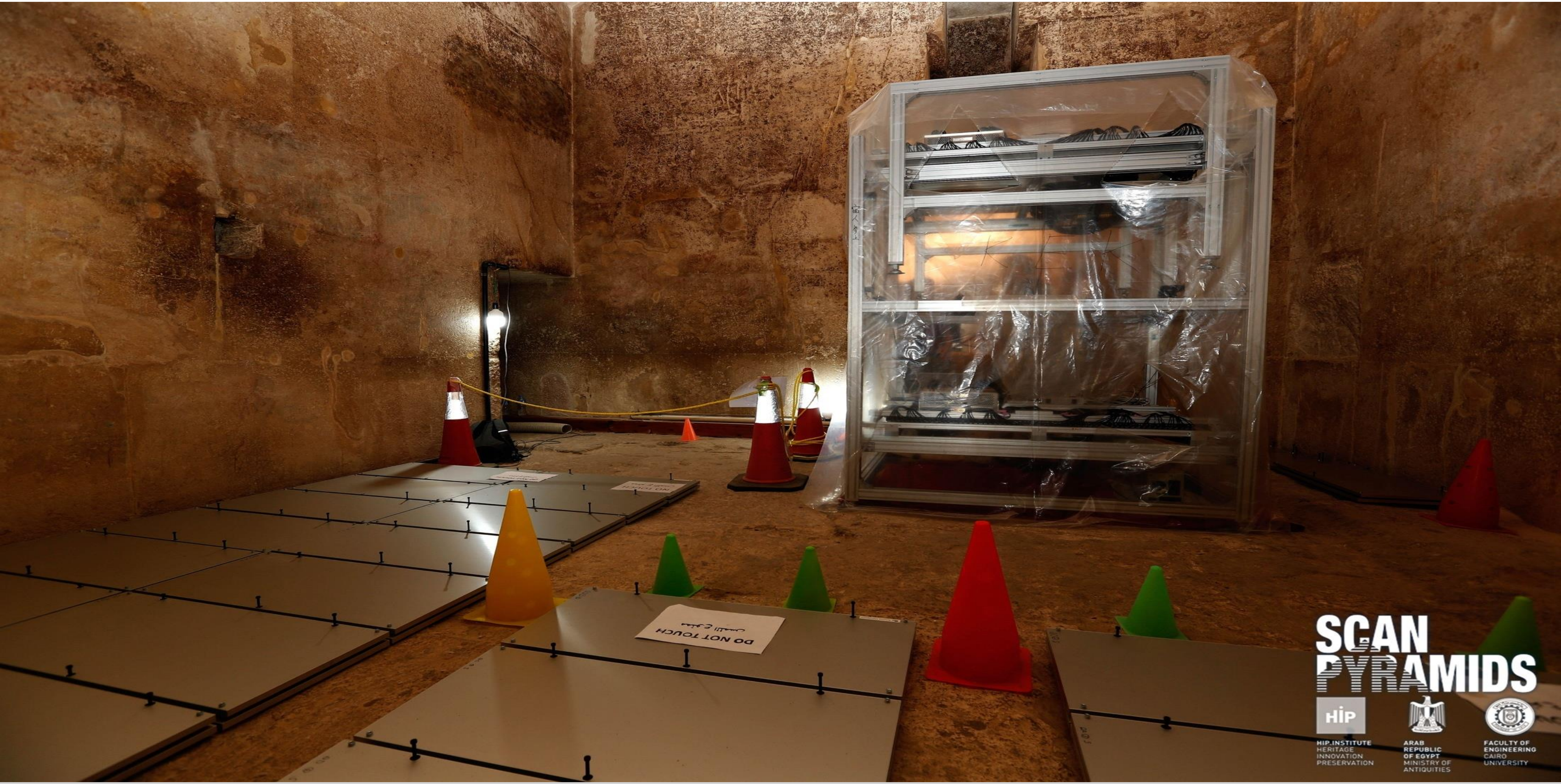
Khufu's Pyramid



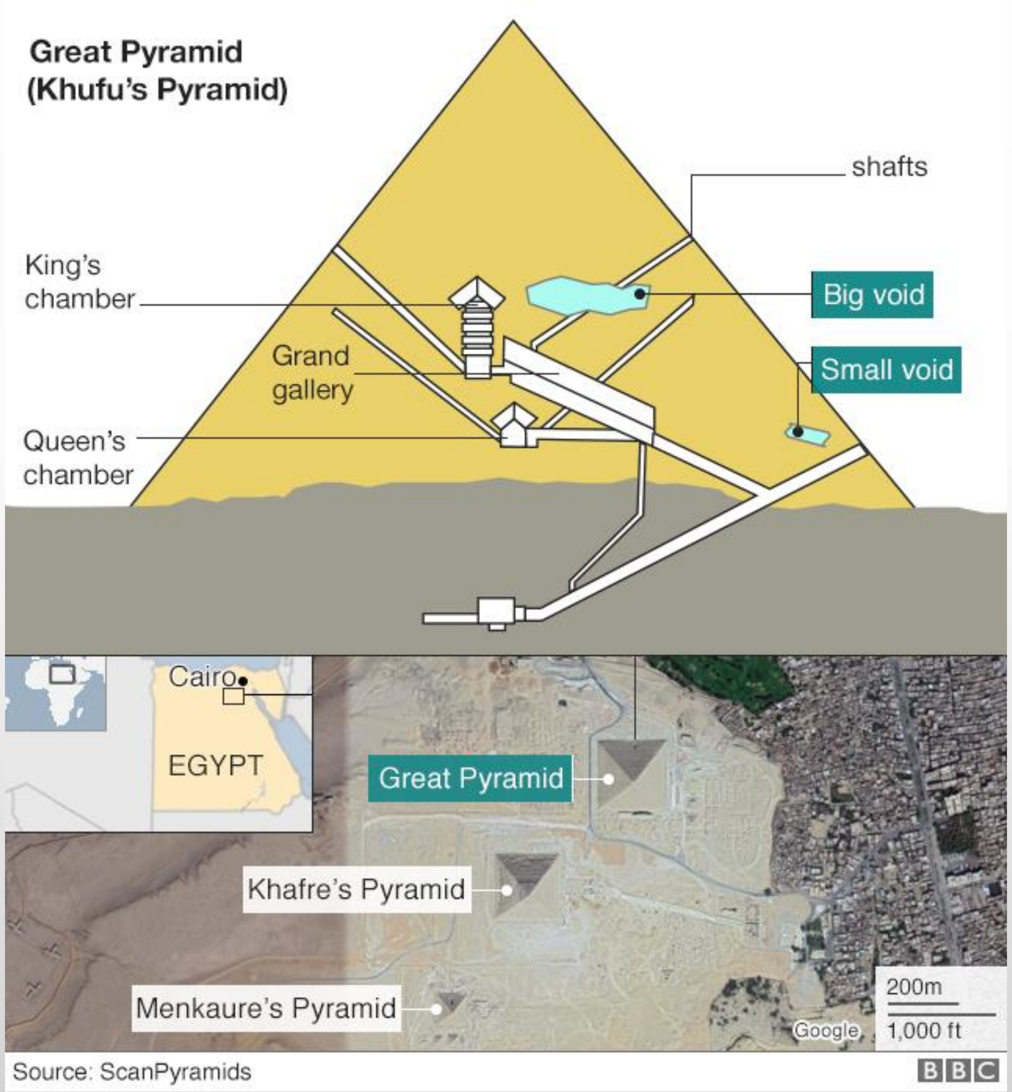

Inside Corridor
Queen's Chamber
Inside Chamber
King's Chamber
South
Grand Gallery
North
Main entrance
Queen's Chamber
Al mamoun's Corridor

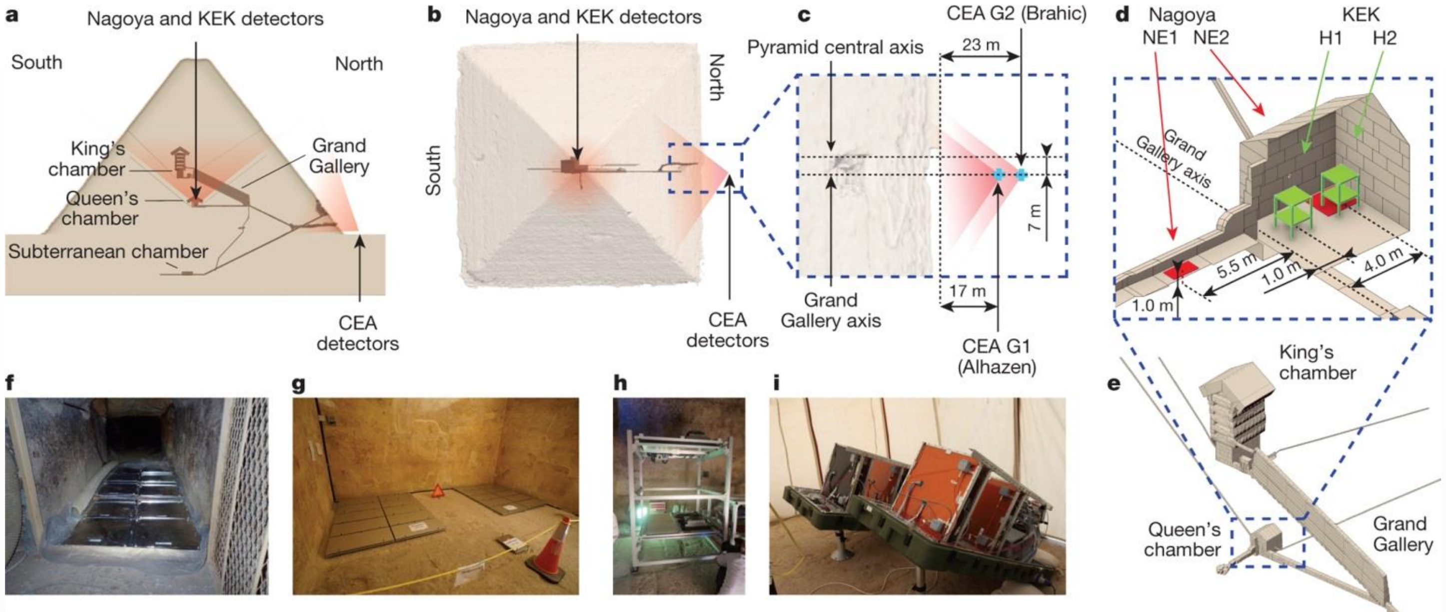


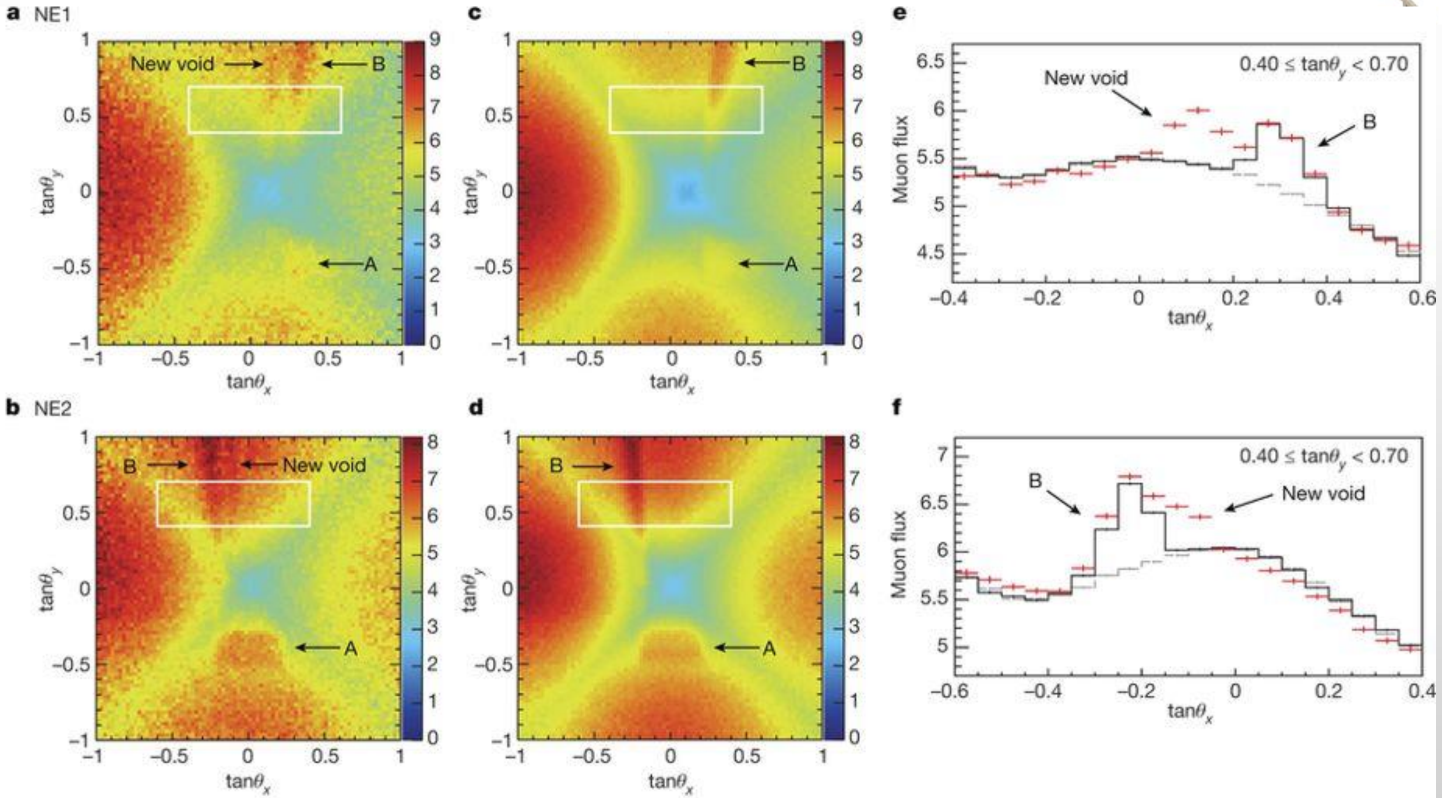
Inside Corridor
Queen's Chamber
Inside Chamber
King's Chamber
South
Grand Gallery
North
Main entrance
Queen's Chamber
Al mamoun's Corridor


DO NOT TOUCH
SCAN PYRAMIDS
HIP
HIP.INSTITUTE HERITAGE INNOVATION PRESERVATION
ARAB REPUBLIC OF EGYPT MINISTRY OF ANTIQUITIES
FACULTY OF ENGINEERING CAIRO UNIVERSITY

2017: The hidden void in Great Pyramid was found by the emulsion detector!





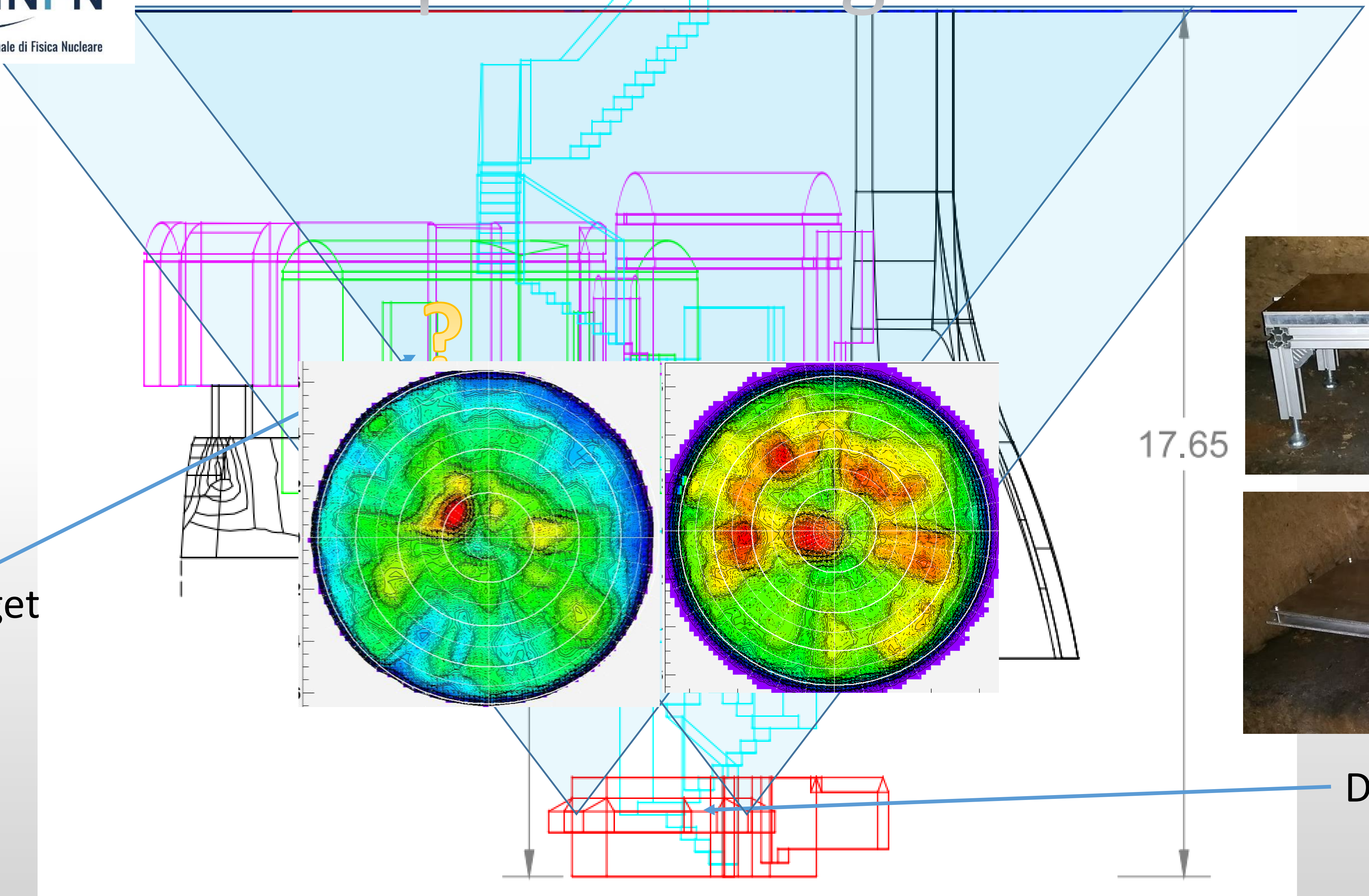


Nature, volume 552, pages 386–390 (21 December 2017)

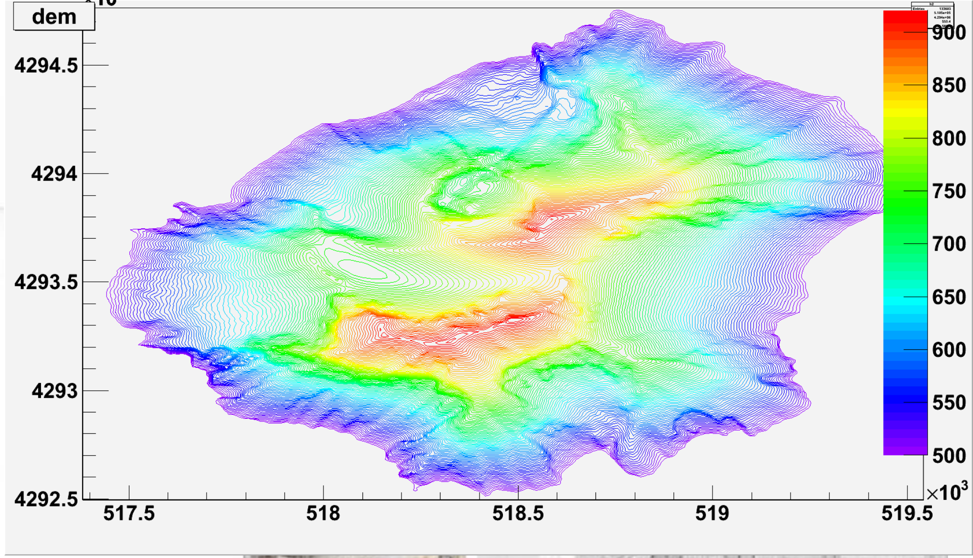
Exposure of emulsion track detectors by physicists from Nagoya, conducted during 67 days in the summer of 2016, with high confidence 5σ, confirmed the assumption of the existence of an unknown previously empty chamber 30 meters in length and cross-section similar to the Great Gallery in the pyramid of Cheops. This camera is the first large internal structure found in the pyramid since the 19th century.

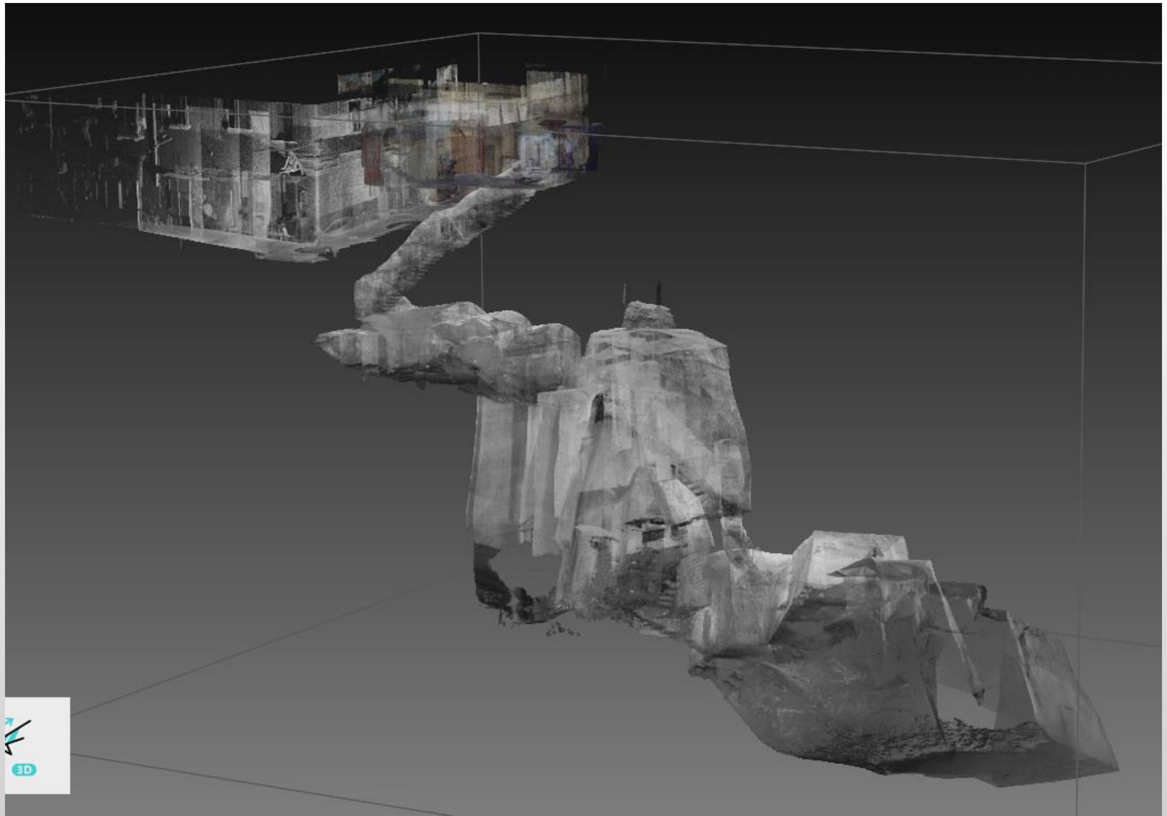
INFN
Istituto Nazionale di Fisica Nucleare

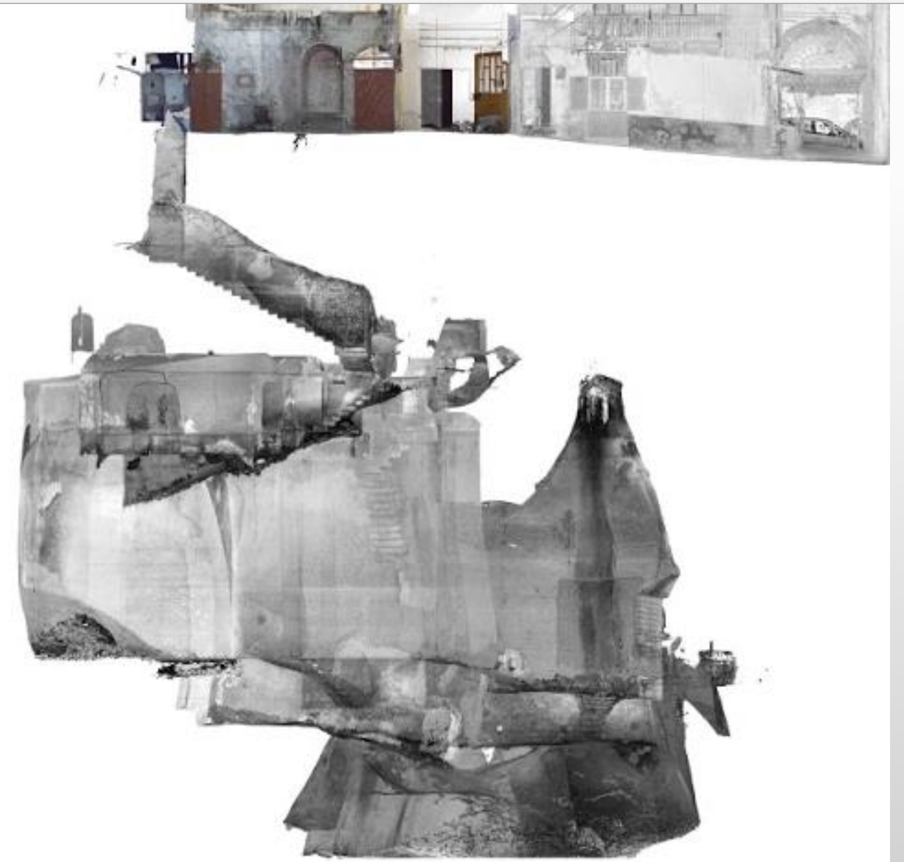
Napoli Underground



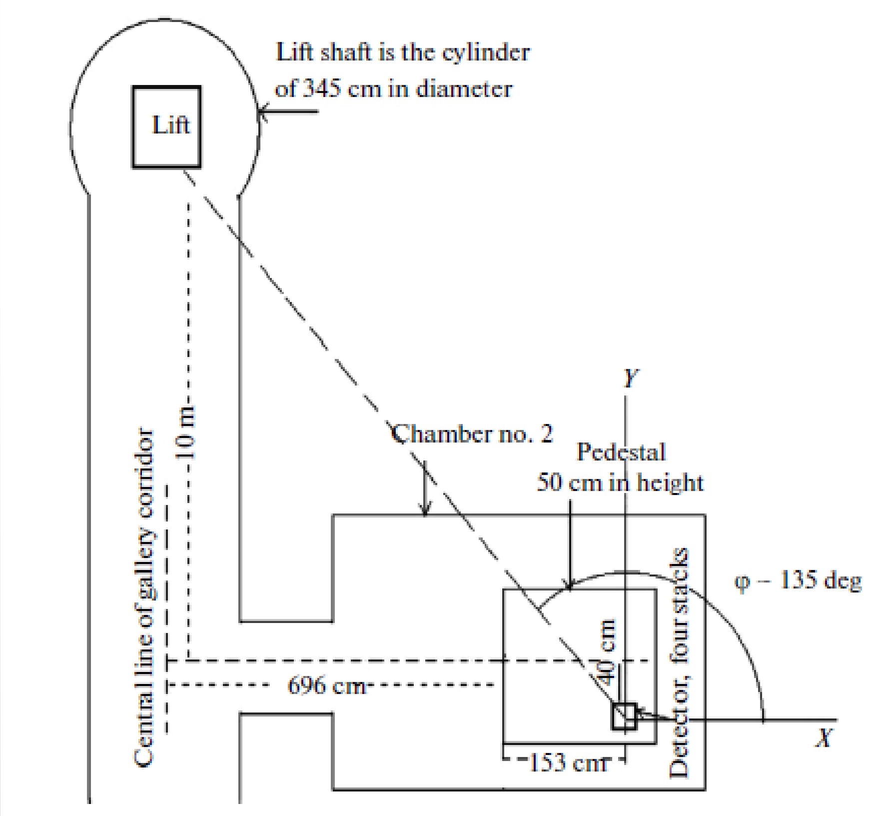
Digital model or Digital Elevation Model (DEM) is necessary to define correctly the muons path inside the material and for results interpretation

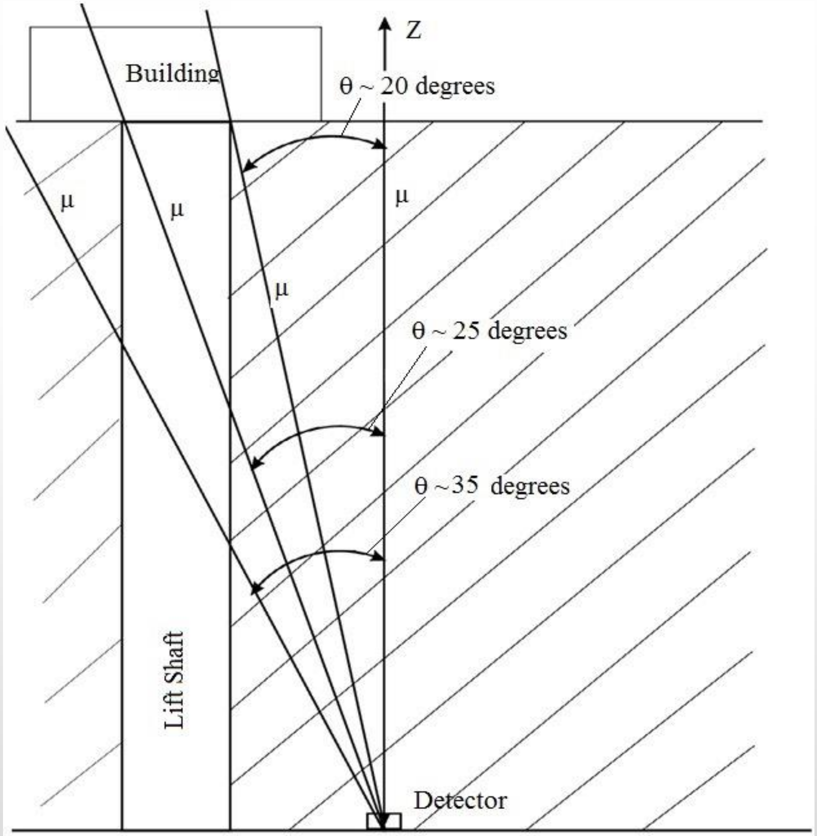






Experimental exposure of emulsion detector in Obninsk, Russia

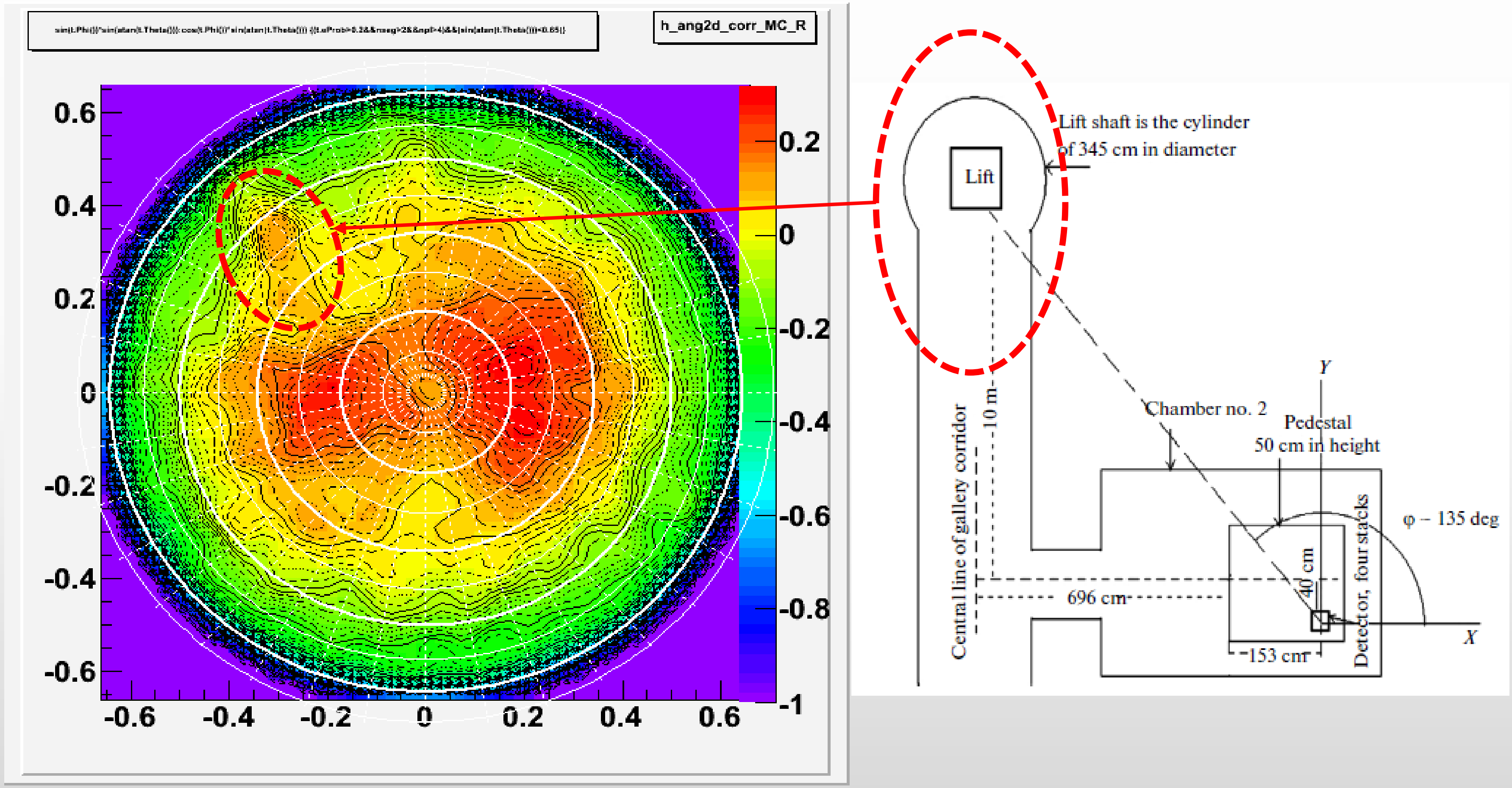




Experimental exposure of emulsion detector in Obninsk, Russia

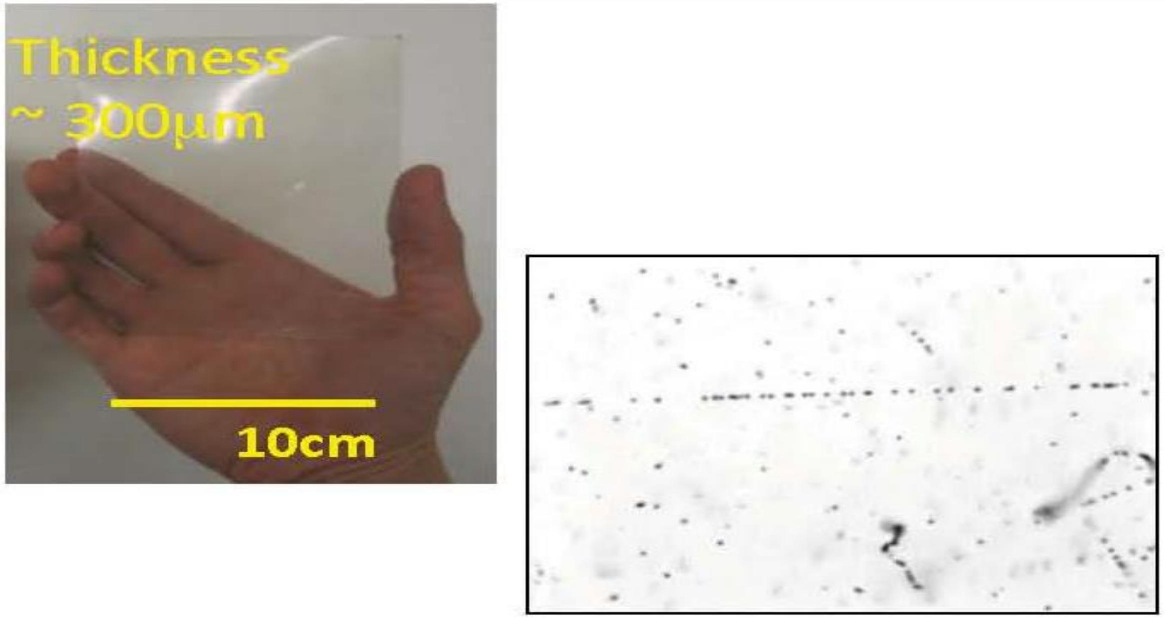
This experiment was carried out in an underground mine at a depth of 30 m. One aim was to register the difference between the fluxes of atmospheric muons at the surface and those occurring deep inside the mine after passage through the soil layer. For this purpose, two detectors were installed at different levels of observation. The other aims were to evaluate the feasibility of detecting a cavity (a lift shaft) in the soil column using an emulsion detector at a depth of 30 m, and to determine the optimum exposure time (detectors were exposed for 2 and 4 months).

Analysis of Obninsk experimental data

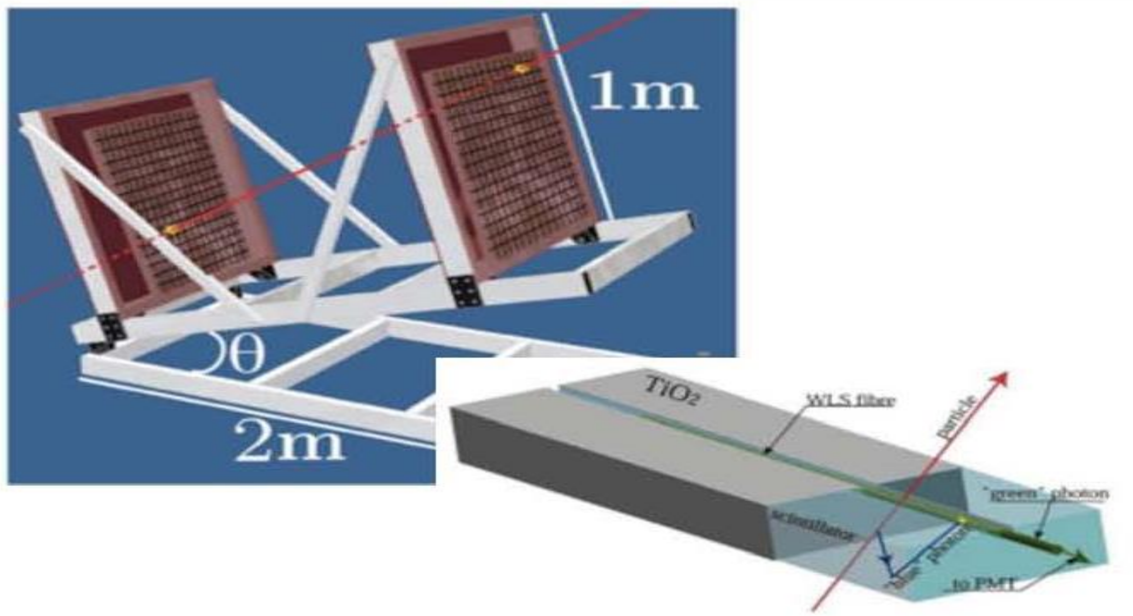


Samples of detectors

Nuclear Emulsion
High resolution, no power supply



Electric Detector
Real-time responsobility

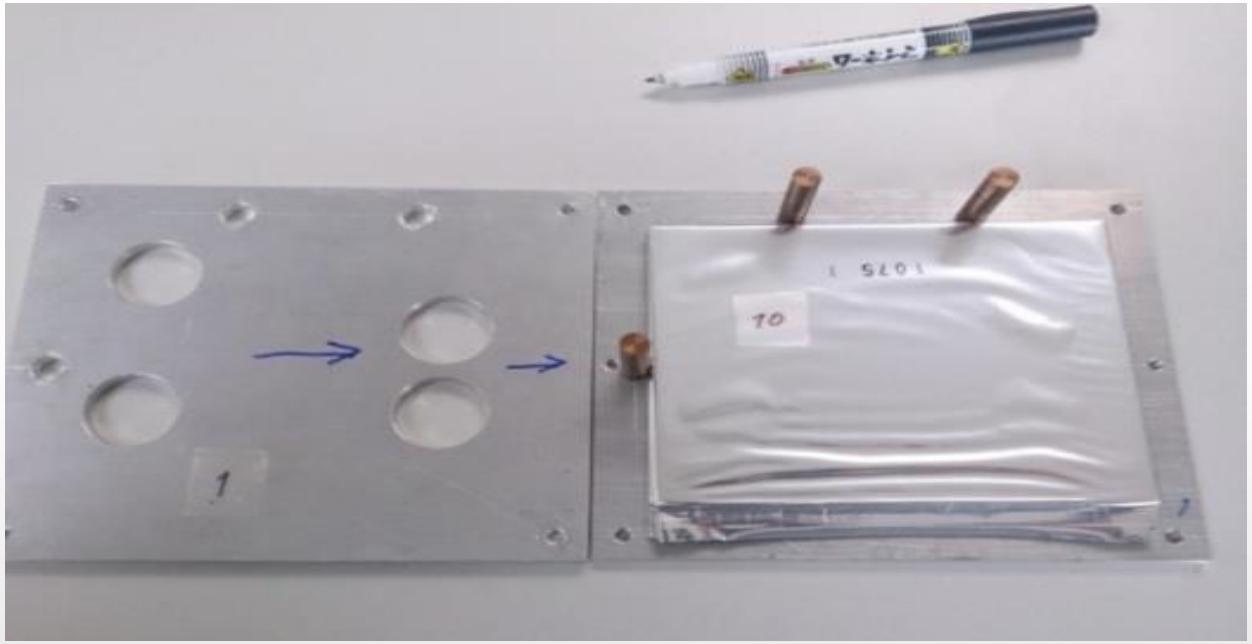


Detector unit size is
Silver grain (1μm)

Detector unit size is
Fiber (1mm), bar(10-100mm)

DETECTOR SIZE:
EMULSION IS ABLE TO BE 1000 (1MM/1MM) TIMES SMALLER IN EACH DIMENSION TO ACHIEVE THE SAME RESOLUTION

Detector used in Obninsk



Data from such a single detector measuring 10 cm x 12 cm made it possible to "detect" a 3.5 m diameter elevator shaft at a depth of 30 meters, to measure the distribution of muon fluxes in the mine and their attenuation (50 times) as compared with the flow on the surface

Декабрь 2017 г. Том 187, № 12

УСПЕХИ ФИЗИЧЕСКИХ НАУК

ПРИБОРЫ И МЕТОДЫ ИССЛЕДОВАНИЙ

Метод мюонной радиографии для фундаментальных и прикладных исследований

А.Б. Александров, М.С. Владимиров, В.И. Галкин, Л.А. Гончарова, В.М. Грачёв, С.Г. Васина, Н.С. Коновалова, А.А. Маловичко, А.К. Манагадзе, Н.М. Окатьева, Н.Г. Полухина, Т.М. Роганова, Н.И. Старков, В.Э. Тюков, М.М. Чернявский, Т.В. Щедрина

Изложены основы метода мюонной радиографии, представлен обзор основных наиболее крупных экспериментов. Приведены результаты первых в России исследований, осуществлённых авторами на основе данного метода с использованием эмульсионных трековых детекторов.

Ключевые слова: мюонная радиография, ядерная фотоэмульсия, распознавание образов, трековые детекторы

PACS numbers: 07.05.Fb, 07.05.Hd, 07.05.Kf, **29.40. –h** DOI: https://doi.org/10.3367/UFNr.2017.07.038188

Содержание

А.Б. Александров, М.С. Владимиров, Л.А.Гончарова, С.Г. Васина, Н.С. Коновалова, Н.М. Окатьева, Н.И. Старков, М.М. Чернявский, Т.В. Щедрина. Физический институт им. П.Н. Лебедева РАН, Ленинский просп. 53, 119991 Москва, Российская Федерация
В.И. Галкин. Московский государственный университет им. М.В. Ломоносова, Научно-исследовательский институт ядерной физики им. Д.В. Скобельцына, Ленинские горы 1, стр. 2, 119991 Москва, Российская Федерация; Московский государственный университет им. М.В. Ломоносова, физический факультет, Ленинские горы 1, стр. 2, 119991 Москва, Российская Федерация
В.М. Грачёв. Национальный исследовательский ядерный университет МИФИ, Каширское шоссе 31, 115409 Москва, Российская Федерация
А.А. Маловичко. Федеральный исследовательский центр "Единая геофизическая служба Российской академии наук", просп. Ленина 189, 249035 Обнинск, Калужская обл., Российская Федерация

1. Введение

Космические лучи, традиционно являющиеся источником информации о процессах в космическом пространстве, дают также возможность изучать физические процессы, протекающие на Земле. Изучение потоков мюонов космического происхождения легло в основу метода мюонной радиографии (МР) — метода неразрушающего контроля, основанного на "просвечивании" объекта ионизирующим мюонным излучением и регистрации излучения, прошедшего через этот объект. Анализ особенностей прохождения потоков космических мюонов через вещество позволяет исследовать внутреннее состояние крупных природных и промышленных объектов

Photo of part of the territory of the fortress Naryn-Kala in Derbent; behind the wall of the fortress is seen a wire dome installed over a ground-covered building (presumably a Christian temple).

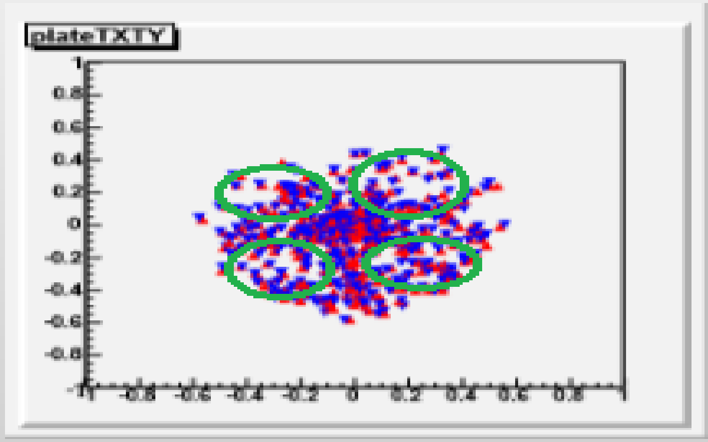
A wire dome installed over a land-covered building

The interior of the building under the wire dome

The interior of the building under the wire dome

Muon Radiography in Naryn-Kala (Derbent)

Photo of part of the territory of the fortress Naryn-Kala in Derbent; a wire dome, which is presumably a Christian temple, is installed behind the wall of the fortress over a ground-covered building

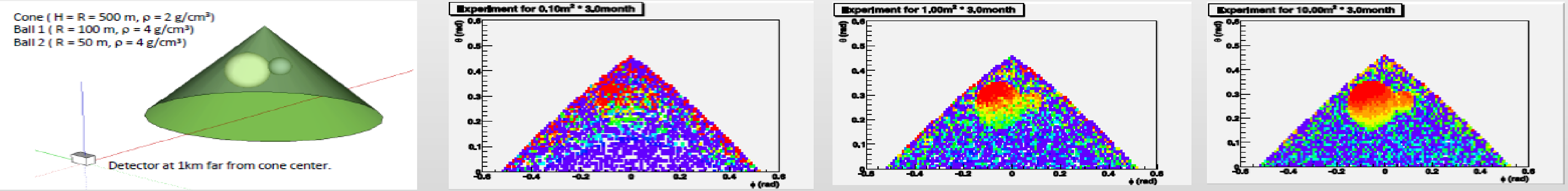


Analysis of data, taken with emulsion detectors, has started!
Non-uniformities seen in the angular distribution of cosmic muons indicate some underground structures (shown in green)

Condition assessment of industrial installations

Muon radiography can be used to assess the condition of major industrial installations such as bridges, dams, blast furnaces, etc., when experts need to evaluate their technical condition and safety.(Such radiography can reveal, for example, the presence of cracks, the condition of inner structures, the level of ground water, etc.)

These drawings show the image modeling of a massive structure with the help of muon radiography: a — schematic diagram of the structure’s computer model; b — image obtained with the use of a 0.1 m2 emulsion track detector; c — image obtained with the use of a 1 m2 emulsion track detector; d — image obtained with the use of 10 m2 emulsion track detector.

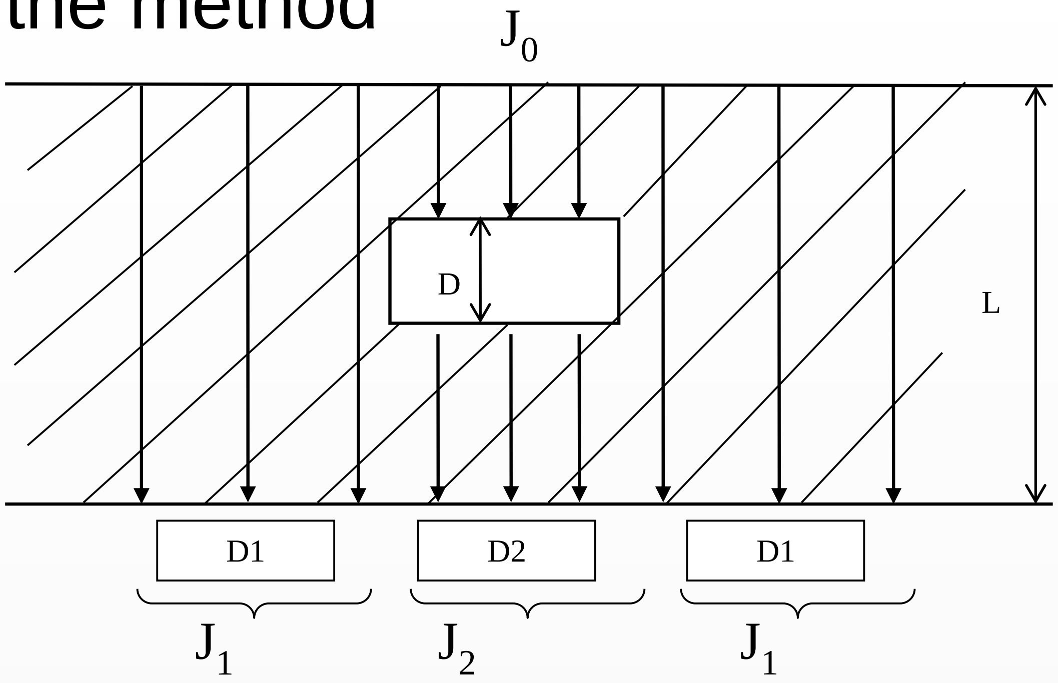


Detection area S on the ground surface, depending on the depth of the detector H at a detecting angle of ± 45 degrees

H, m	S
3	28 m^2
10	314 m^2
30	2800 m^2
100	0.03 km^2
300	0.28 km^2
500	0.8 km^2
1000	3 km^2
2000	12.5 km^2

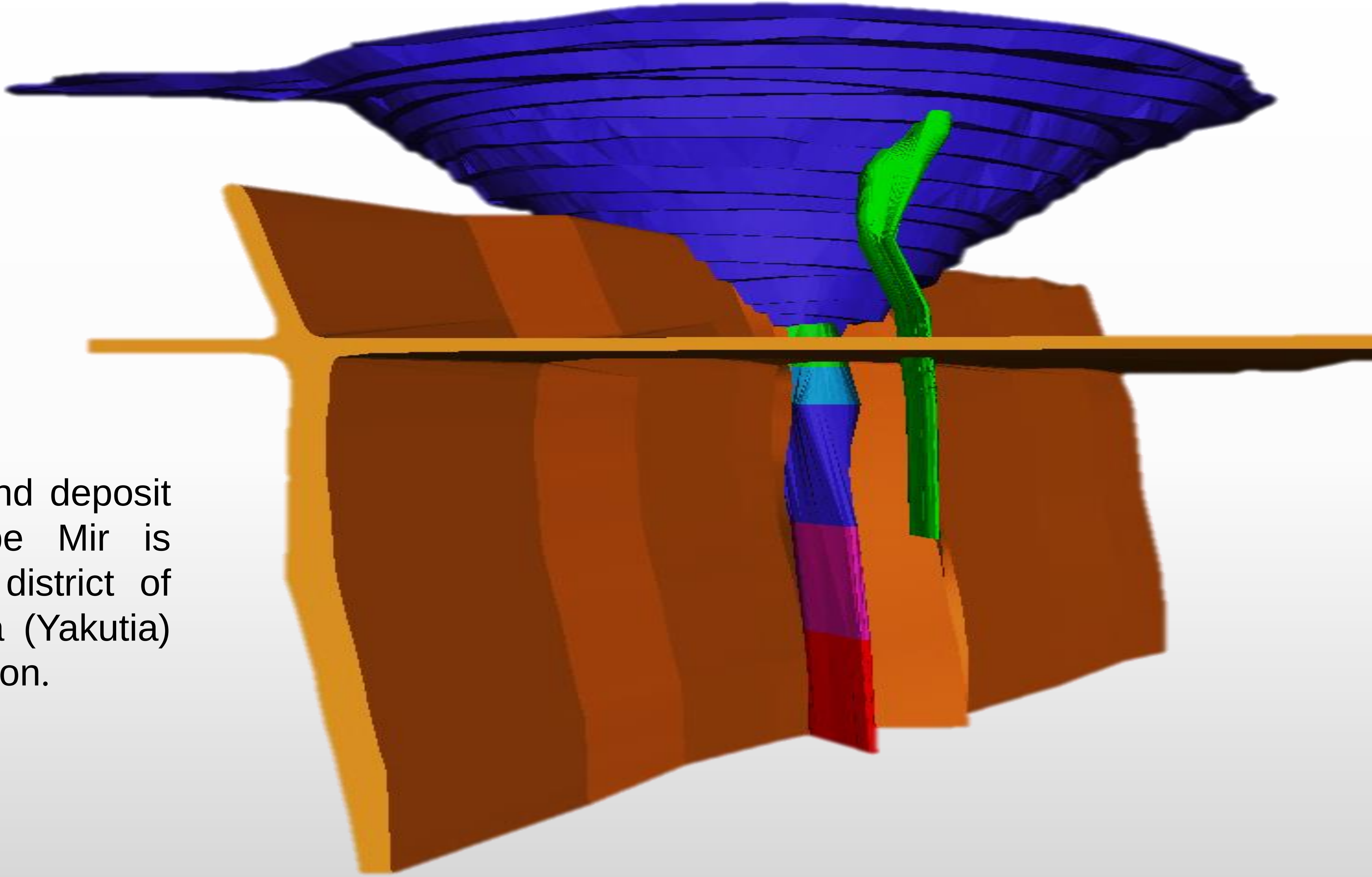
Estimates of the sensitivity of the method

Let us assume a cavity of dimension D exists in a layer of ground of thickness L. This layer is irradiated by a flux of cosmic muons, J0, and registered by the lower row of detectors D1; D2. The fluxes in the detectors registering muon fluxes that do not pass J1 and that do pass J2 through the cavity differ from each other. If the observable flux is J, we denote by ΔJ the minimum difference between muon fluxes distinguishable by a detector, and by S= Δ J/J the detector sensitivity. Then, for given values of L and S there is a minimum dimension d of the cavity that can be distinguished by the detector. The corresponding condition is
given by (J2 - J1)/J1 = S. In Table 1, relations are presented among L, D, and S for ground of density 2.3 g cm**3, obtained taking into account the degree of absorption of cosmic muons and their spectrum.



L, m	Sensitivity S, %			
	5	10	20	30
50	D = 1 m	D = 2 m	D = 5 m	D = 8 m
100	D = 3 m	D = 5 m	D = 7 m	D = 14 m

The indigenous diamond deposit is the kimberlite pipe Mir is located in Myrninsky district of the Republic of Sakha (Yakutia) of the Russian Federation.

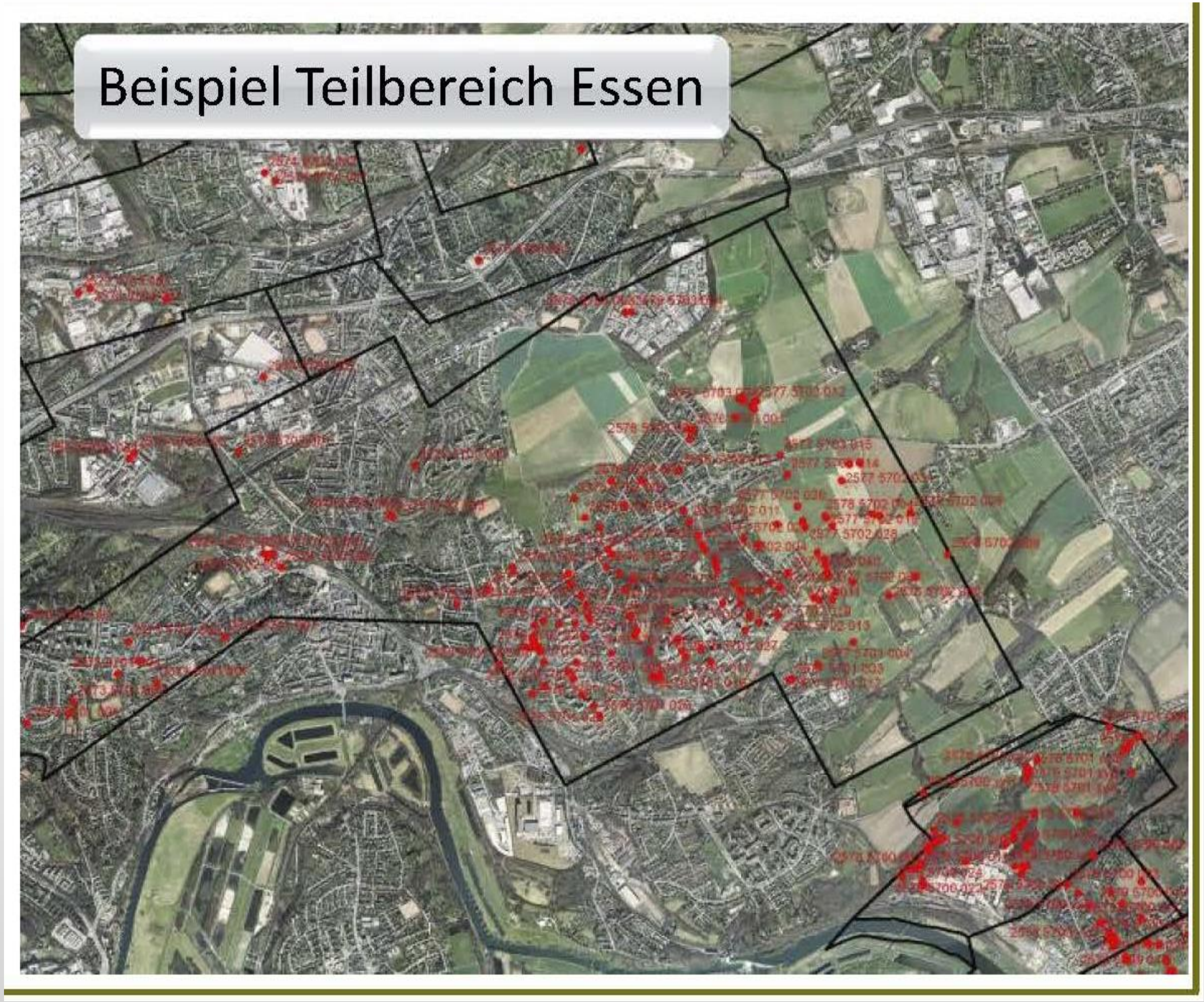


Possible applications of MR in Russia which we discussed now

Monitoring of coal dumps

Monitoring of mines

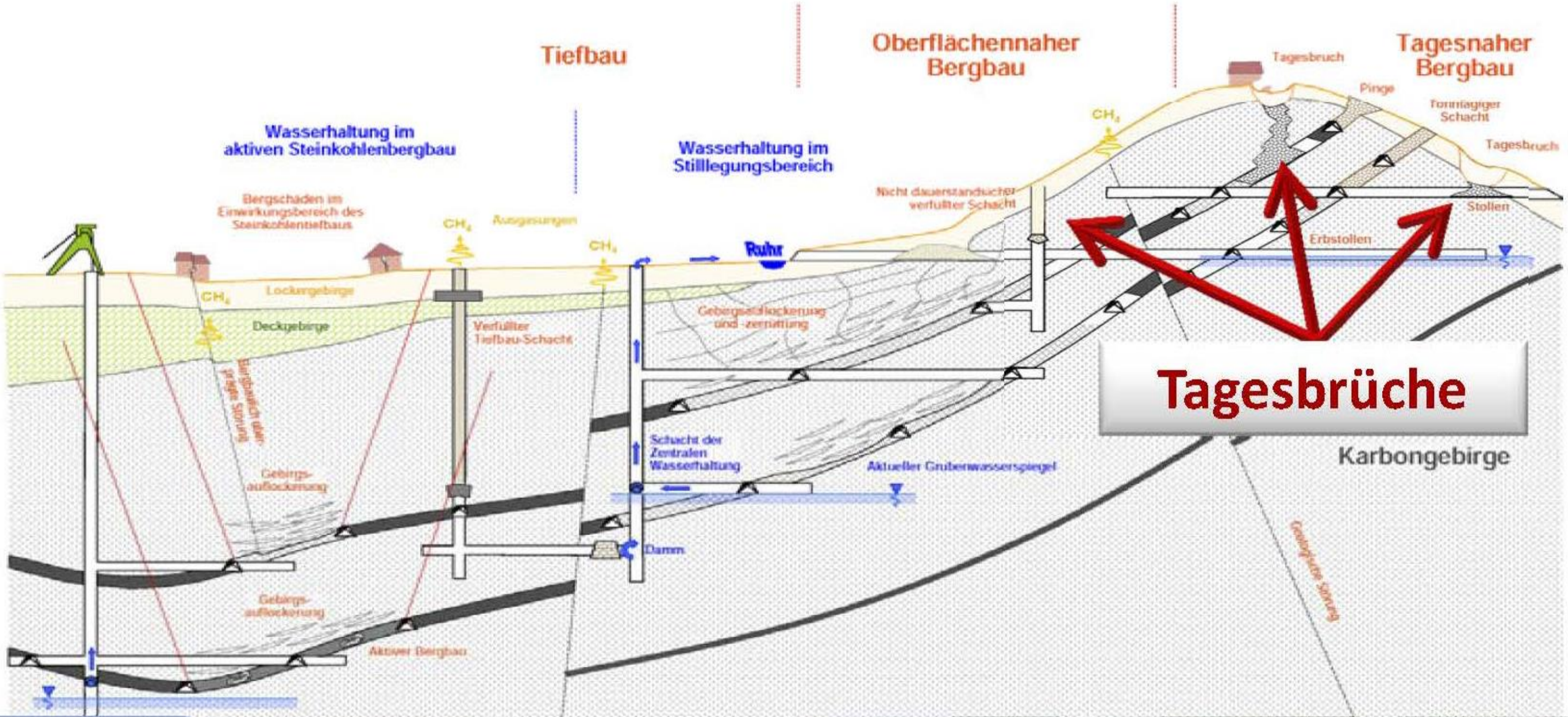
MR for Essen region, Germany



Geografische Zuordnung

Norden

Süden




RUHRGEBIET HEUTE


ESSEN UM 1910


ZECHE VOLLMOND


SCHRÄGSCHACHT


HASPELSCHACHT


STOLLENBERGBAU

Risikomanagement und Monitoring im Nachbergbau der RAG

Reaktive Bearbeitung

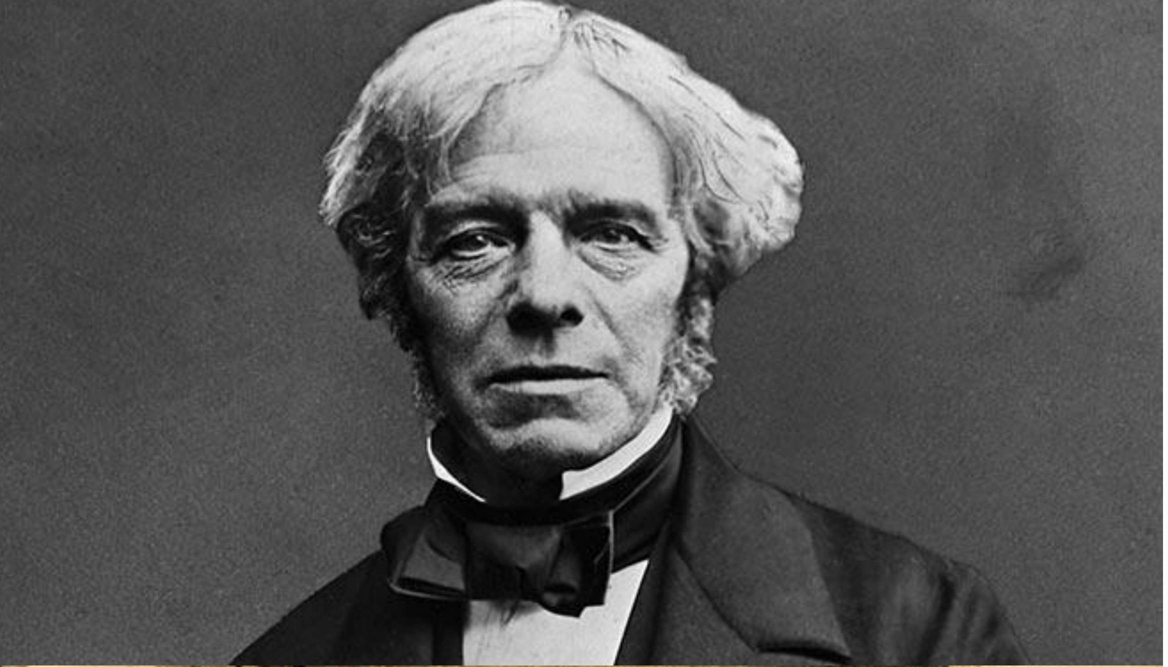
Beispiele:

- Reaktion auf Bauanfragen
- Reaktion auf Hinweise aus eigenem Monitoring
- Reaktion auf externe Hinweise

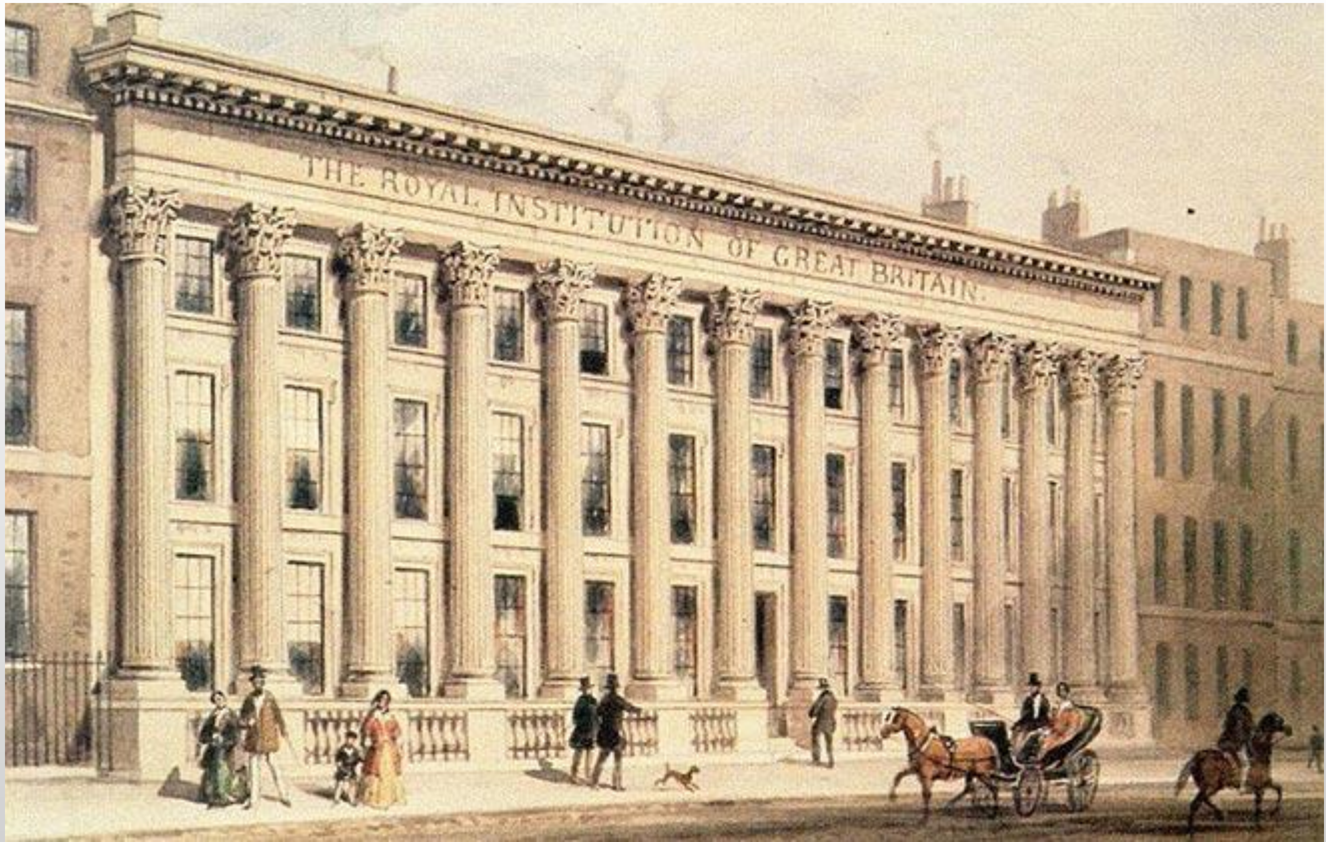
Gap of soil in Solikamsk mine

Proposal for monitoring large objects using the method of muon radiography based on nuclear photo emulsions

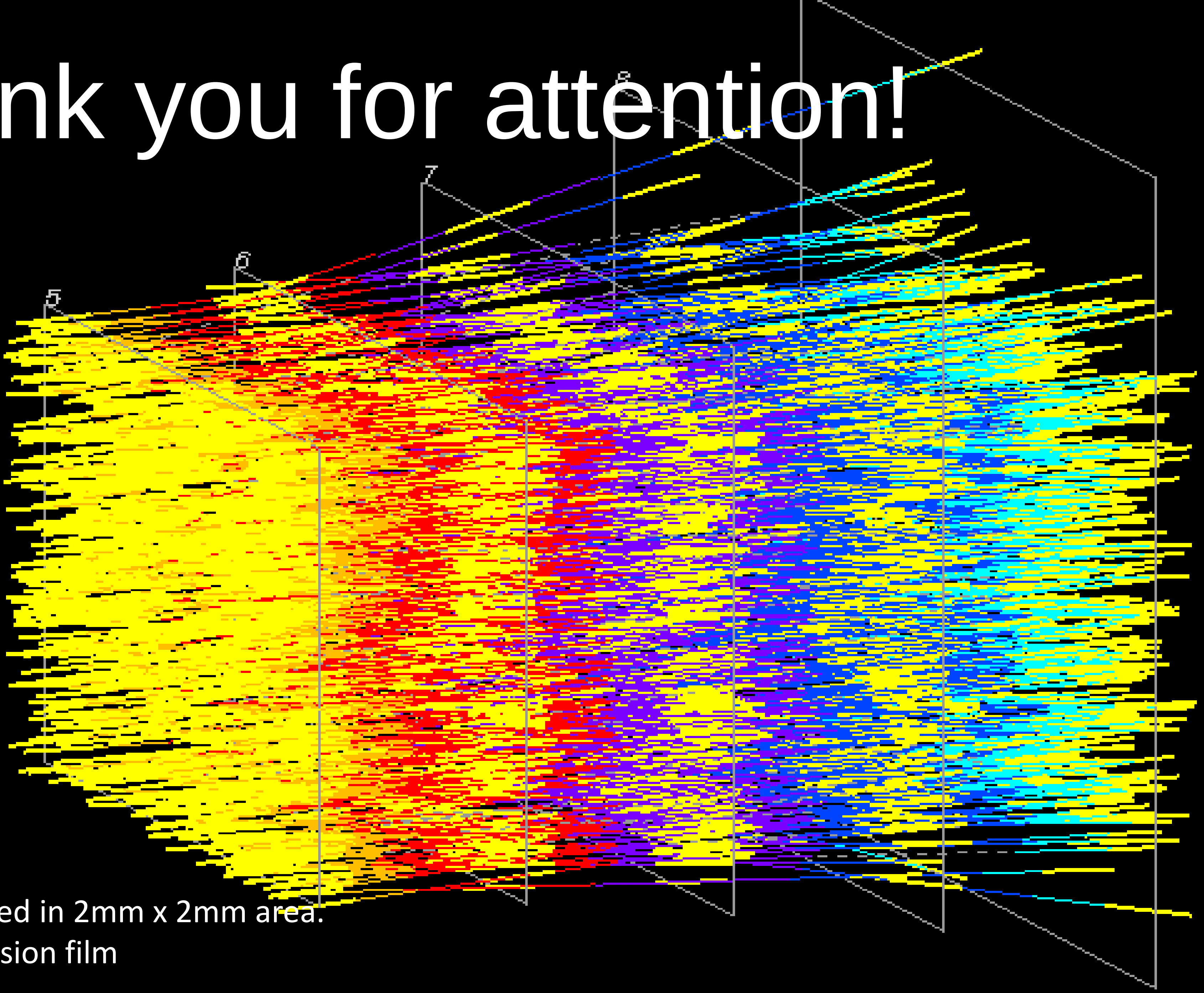
- Depth of detection - up to 2 km (the deeper - the smaller the particles and the longer the exposure time);
- The effective detection angle is ± 45 degrees;
- The detector is assembled from the plates of a photoemulsion of 10 * 12 square centimeters to the maximum possible area at the observation site;
- Drilling additional wells is not required if it is possible to lower the detector in any available vertical cavity to place it below the area under investigation;
- In the presence of an aggressive environment, a sealed container for the detector is required;
- The method makes it possible to effectively detect heterogeneities in the object with their difference in density of not less than 5%;
- Exposure time up to 4 - 6 months when working deep underground;
- Timing of data analysis and construction of a 3-dimensional model of a hidden object 2-4 months;
- Resolution from 5% to 20% for different depths of the deposit



At the beginning of the 19th century English physicist Faraday studied electricity, which then nobody knew. Once he was invited to speak at a meeting of the Royal Society in London. And when Faraday finished the story, one of the members of the society said: “Your electricity is certainly very interesting. But why do we need it? ”Faraday answered:“ I don’t know. But after a hundred years, one of your descendants will impose a tax on the use of my invention.”



Thank you for attention!



Tracks reconstructed in 2mm x 2mm area.
Yellow line is emulsion film