

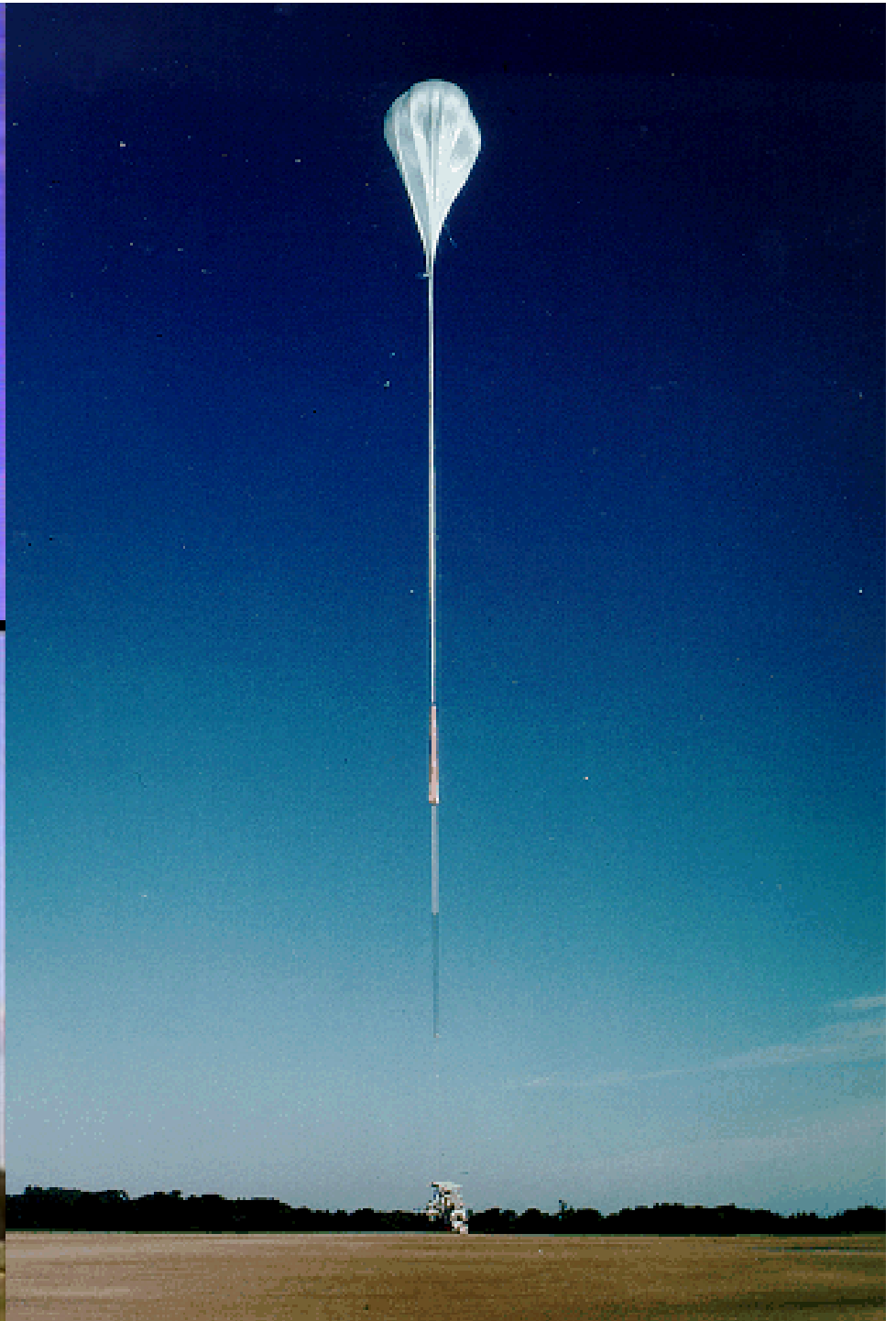
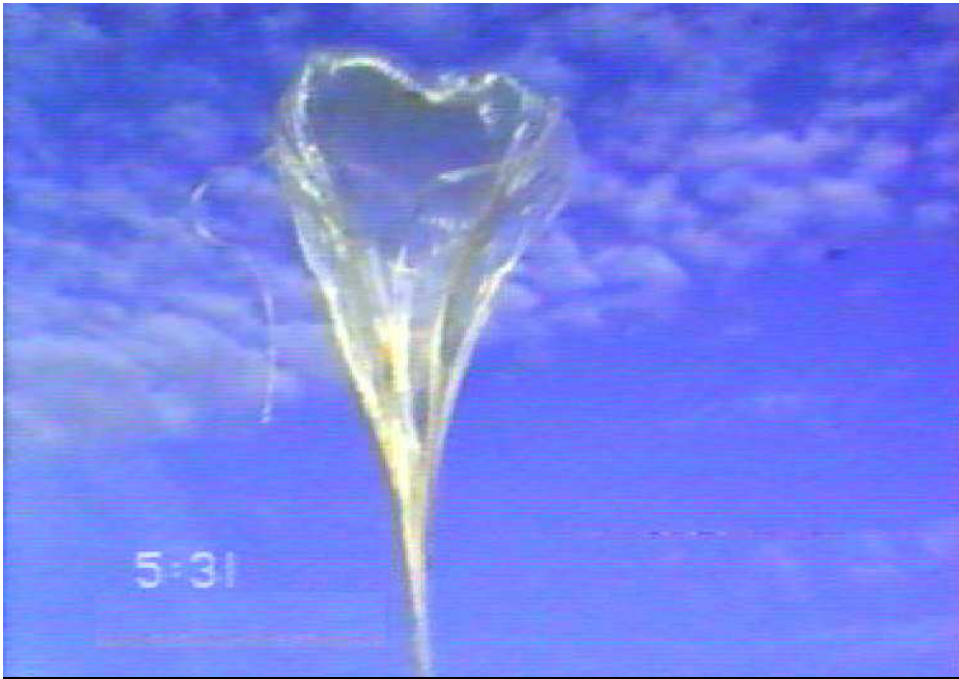
A grayscale microscopic image showing a dense population of small, dark, irregularly shaped particles dispersed in a lighter, granular matrix. The particles vary in size and shape, some appearing as small dots while others are more elongated or irregular. The overall texture is heterogeneous and porous.

# Перспективы эмульсионных экспериментов

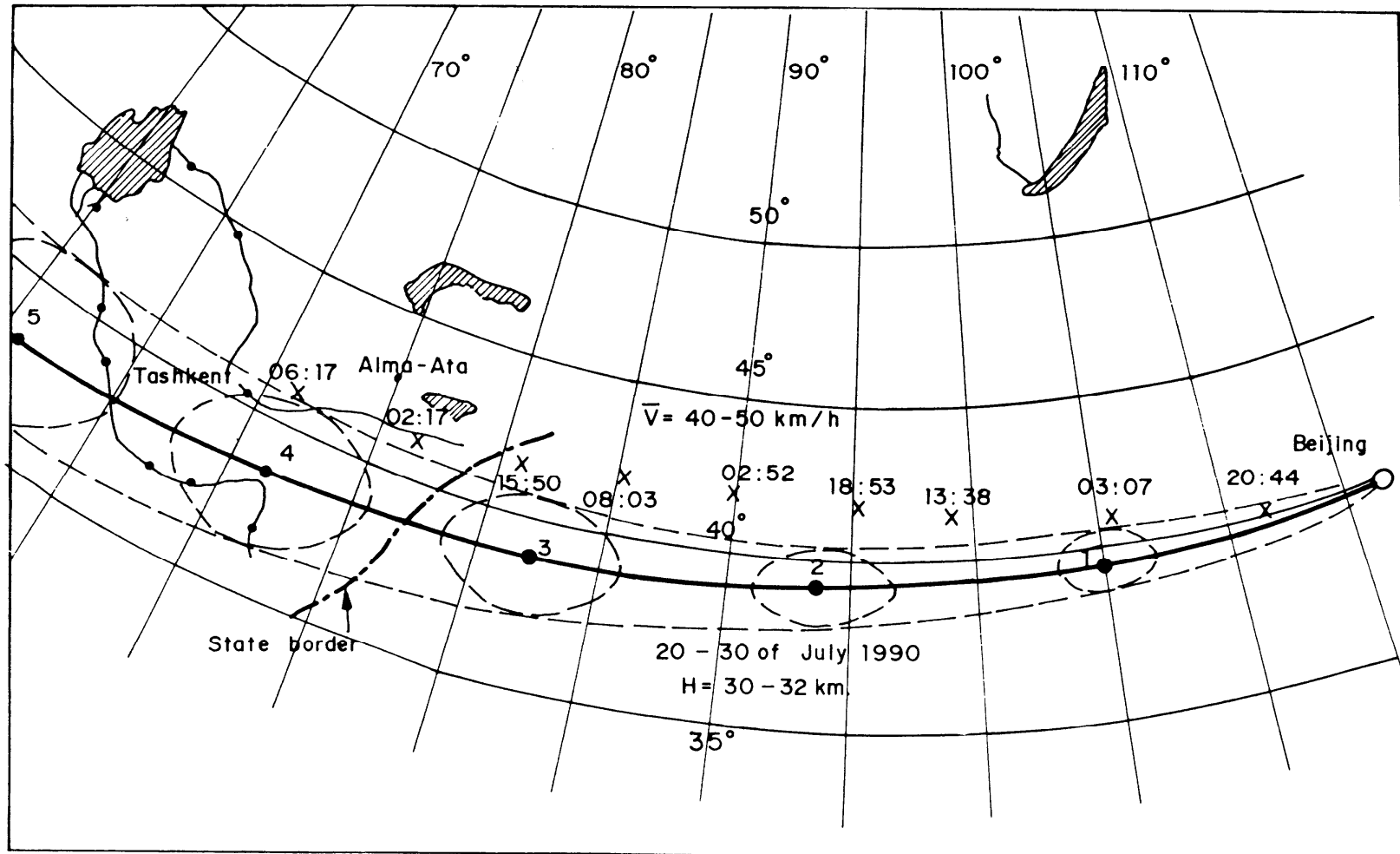
Н.Г.Полухина  
ОИЯИ, 10 июня 2013 г.

# Ядерная фотоэмульсия

- Высокое пространственное разрешение ( $\sim 1$  мкм)
- Высокая эффективность образования треков заряженных частиц (30 – 40 зёрен на 100 мкм)
- Позволяет определить энергию, заряд, массу и импульс частицы
- Может быть помещена в магнитное поле
- Возможность проводить экспозиции в отсутствие экспериментатора, надёжность, энергонезависимость, незначительные размеры и вес.
- Возможность длительного накопления редких событий
- Простота, дешевизна и наглядность
- Изучение реакций со сложными топологиями распадов
- Прямое детектирование частиц с малыми временами жизни



# AUGUST, 1990



-Map showing the trajectory of the balloon flight launched from Xianghe in China and recovered in Chimkent in the USSR. (The solid line and the dashed lines are, respectively, the expected flight path and its deviations. The crosses indicate the actual trajectory of the balloon. The dash-dotted line indicates the border between USSR and PRC.)



# CHINA DAILY

10 No. 2814

Monday, August 6, 1990

Price: 30 fen; 35 fen (airmail)

*Chinese and Soviet scientists send an experimental balloon skyward yesterday after a year's preparation. A Soviet expert is filling the balloon with hydrogen at a station in Hebei Province. The balloon will fly over 33 kilometres high out of China from Kashi in the Northwest and is scheduled to be retrieved near the Caspian Sea in the Soviet Union, covering 5,000 kilometres in three days.*

*China Daily photo by Wu Zhiyi*



## 中苏高空科学观测气球升空

### 预计飞行四天行程万里

本报北京8月5日讯 记者孙明河、董志翔报道 今后4天,我国北方7省区北纬40°左右广大地区的天文爱好者,可能看到一只白色气球,以每小时的70公里的速度,自东向西飞过。

今天19点30分,中苏联合高空科学观测气球,在河北省香河县中国科学院气球发放场,克服近地层湍流气流的干扰,以每分钟约400米的速度徐徐升高,它的目的地是苏联里海东岸。

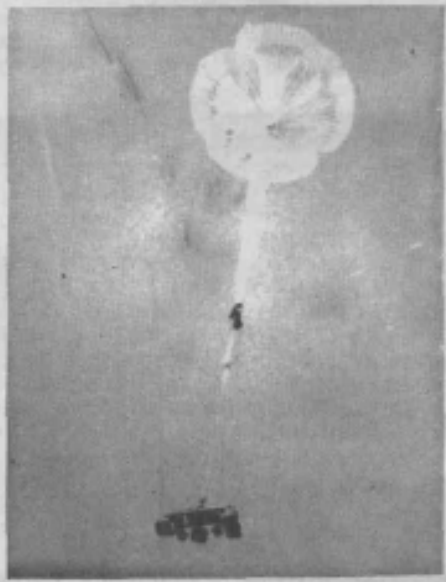
这只容积18万立方米的气球,虽然在地面只充进的1/100体积的氦气,但负载1.4吨重的观测仪器,升空时仍显得轻松自如。

科学家们说,随着高度上升,空气越来越稀薄,气球会逐步膨胀,达到预定的33公里高度时,升力和重力平衡。而后,沿着平流层大气由东向西飘移。据悉,这次飞行搭载了接受高能宇宙射线的乳胶室和生物样品。

在预期4天的飞行途中,中苏双方将通过国际救援卫星对它密切关注。如果成功,将是迄今北半球距离最长的一次国际空间气球飞行。

这个堪称亚洲大陆高空的探险者将受到强烈的太阳辐射和摄氏零下50度低温的考验。除了有限地自动调整高度外,它将得不到人们的其他帮助。为此,筹备工作进行了1年半之久。

今天,发放场天气异常潮湿闷热,中苏16位科学工作者大汗淋漓,紧张工作了5个小时。21点30分,气球已顺利达到预定高度,进入正常飞行状态。



(上图)气球升空时的情景。

(中图)中苏双方专家在现场进行升空前最后检查。

(下图)科学工作者们正紧张地给气球准备充气。

本报记者 董志翔 摄



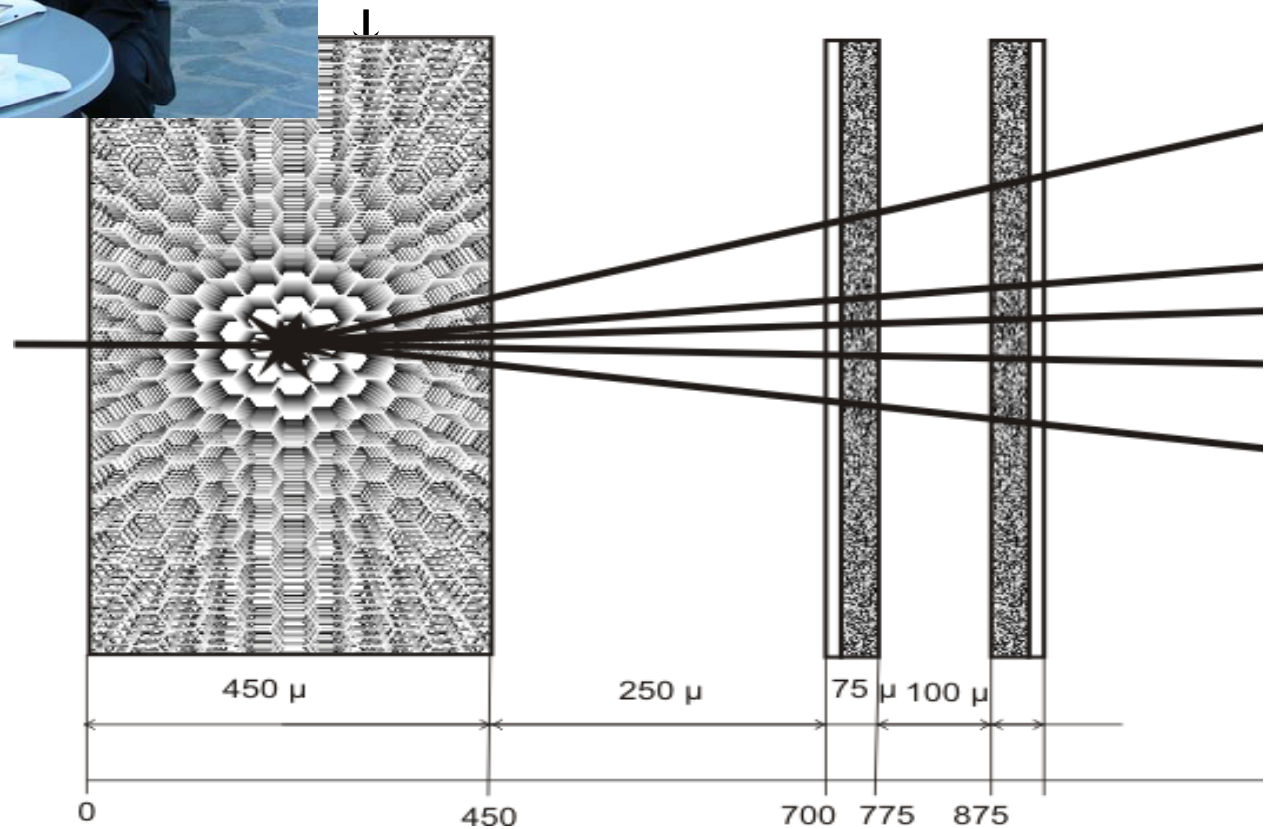


# Эксперимент ЕМУ-15

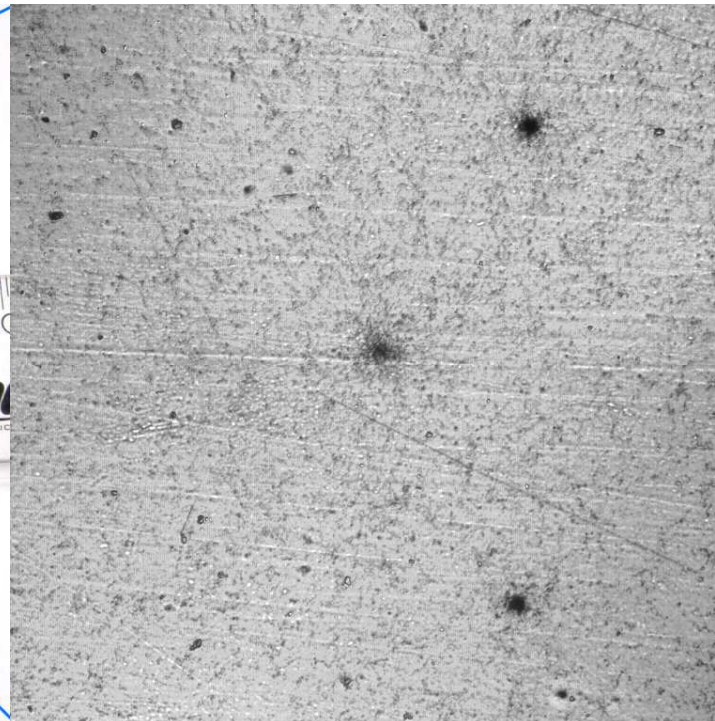
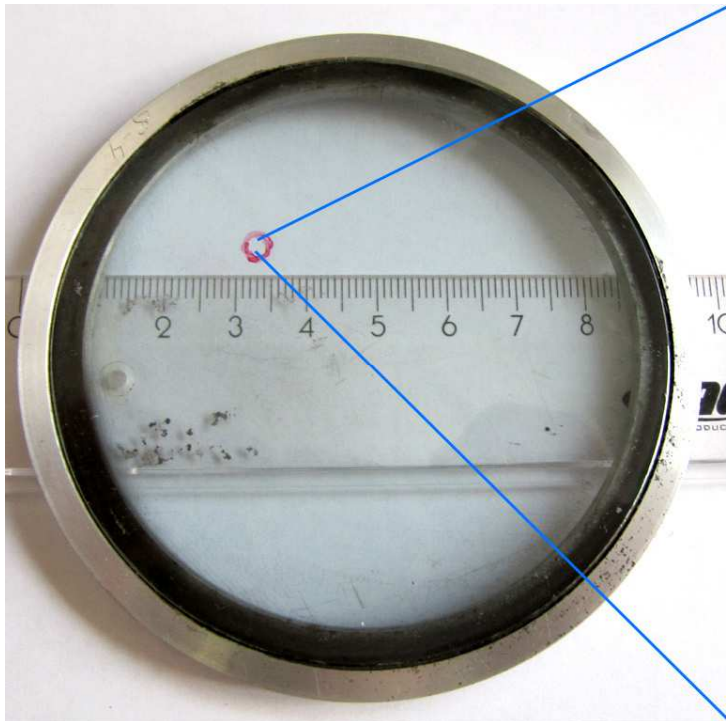
Мишень (*Pb*)

Эмульсия

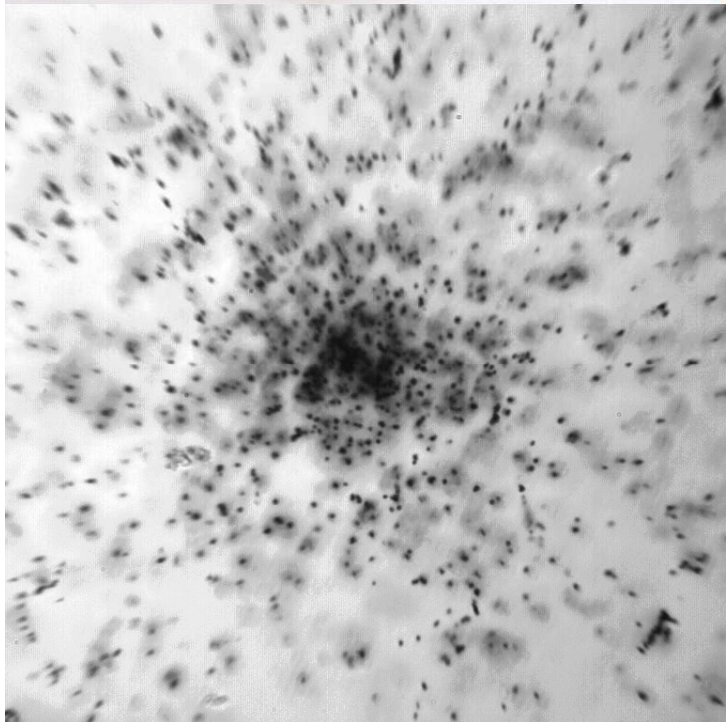
Ядро  
*Pb*



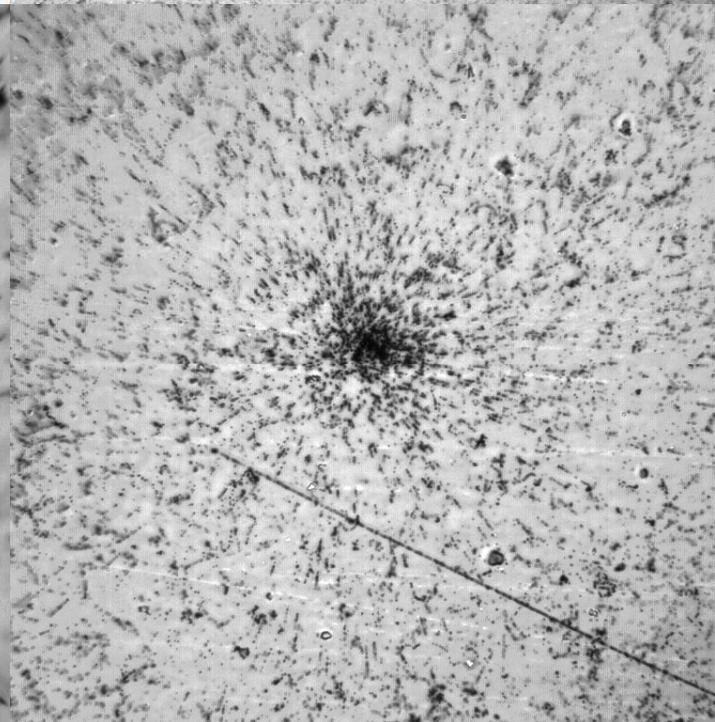




**8×**  
820 × 820  
MKM<sup>2</sup>



**60×**  
115 × 115  
MKM<sup>2</sup>



**20×**  
330 × 330  
MKM<sup>2</sup>

# Ongoing emulsion experiments

Experiments	Country	Area	Gel weight (dry)	Producer	Film/ Gel	Status	Special requirements
OPERA experiment	International	100,000 m <sup>2</sup>	~30,000kg	Fuji	Film	Produced	Refreshing function.
Double Hyper nuclei	Japan		a few 1000 kg	<b>Not decided</b>	Gel	Doing R&D	For thick type emulsion
Balloon cosmic-ray	Japan	10 m <sup>2</sup>	3 kg	Fuji	Film	Produced	
Dark Matter	Japan, Italy		1 kg (1-2 year)	Nagoya / to be done	Gel	Doing R&D	crystal size ~ 10nm
Muon radiography single experiment. ~10 experiments	Bern, Italy, Japan	a few m <sup>2</sup> /exp. ~ 50m <sup>2</sup> /total	a few kg/exp 15 kg/total	Fuji or Nagoya	Film	Produced or to be produced.	
Medical applications hadron therapy basic study	Japan	10 m <sup>2</sup>	3 kg	Fuji / done	Film	Produced	
beam study	Bern	1 m <sup>2</sup>	0.3kg	Fuji / done	Film	Produced	
Proton radiography	Bern	1 m <sup>2</sup>	0.3kg	Fuji /	Film	Produced	
Dosimetry R&D	Bern	5 m <sup>2</sup>	1.5 kg		Film	Produced	

OPERA film = gel (dry) ~0.3 kg/m<sup>2</sup>

# Эксперименты, использующие большие объёмы ЯФЭ

Эксперимент	Год	Цель	Масса ЯФЭ	Поверхность ЯФЭ	Сканирующие системы
CHORUS	1994 - 1997	Поиск $\nu_\mu \leftrightarrow \nu_\tau$ осцилляций	770 кг	500 м <sup>2</sup>	TS, NTS, UTS, S-UTS
DONUT	1997	Прямое наблюдение $\nu_\tau$	200 кг	200 м <sup>2</sup>	UTS, S-UTS
OPERA	2006	Поиск $\nu_\mu \leftrightarrow \nu_\tau$ осцилляций	100 т	110·10 <sup>3</sup> м <sup>2</sup>	S-UTS, ESS

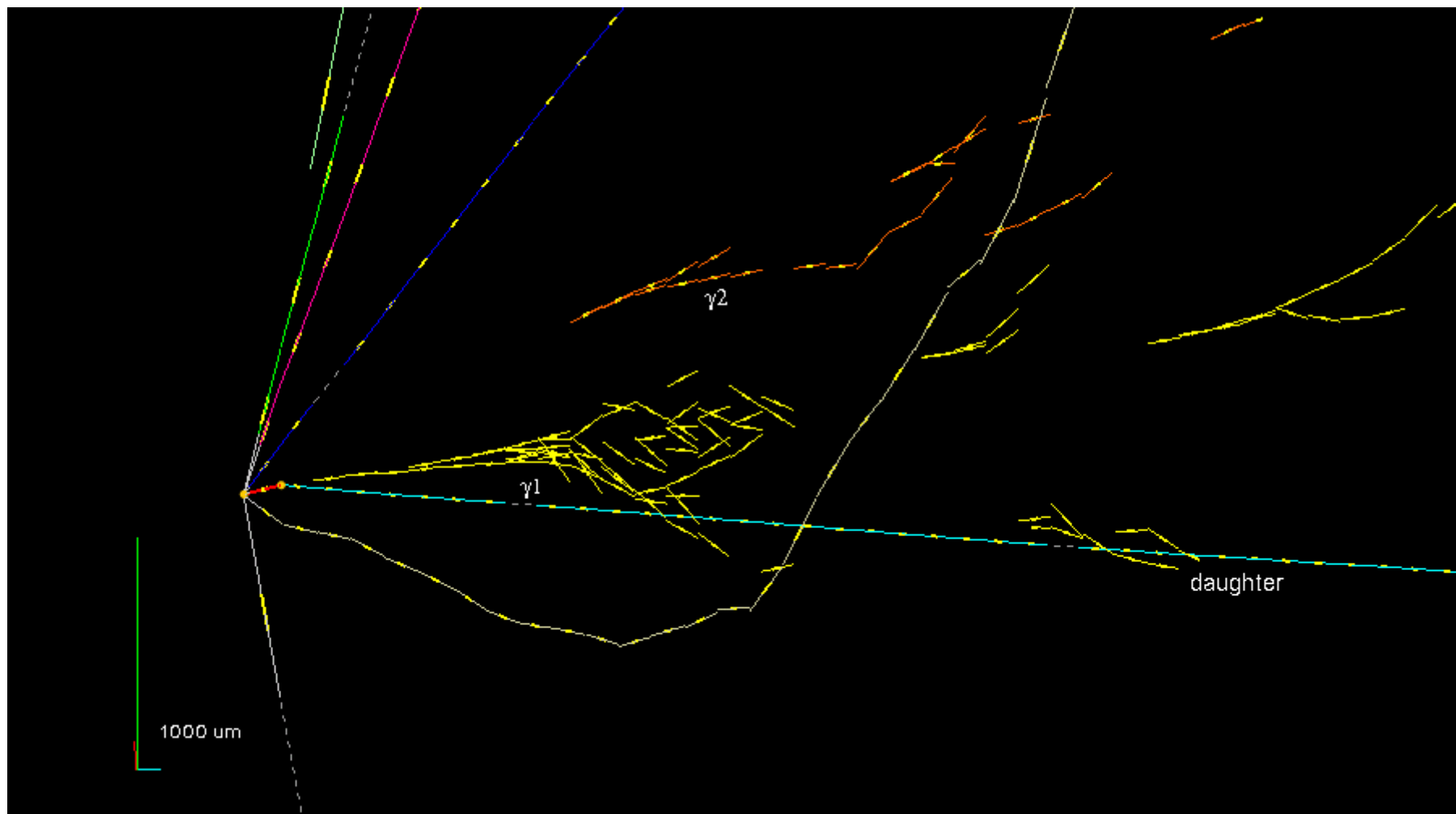






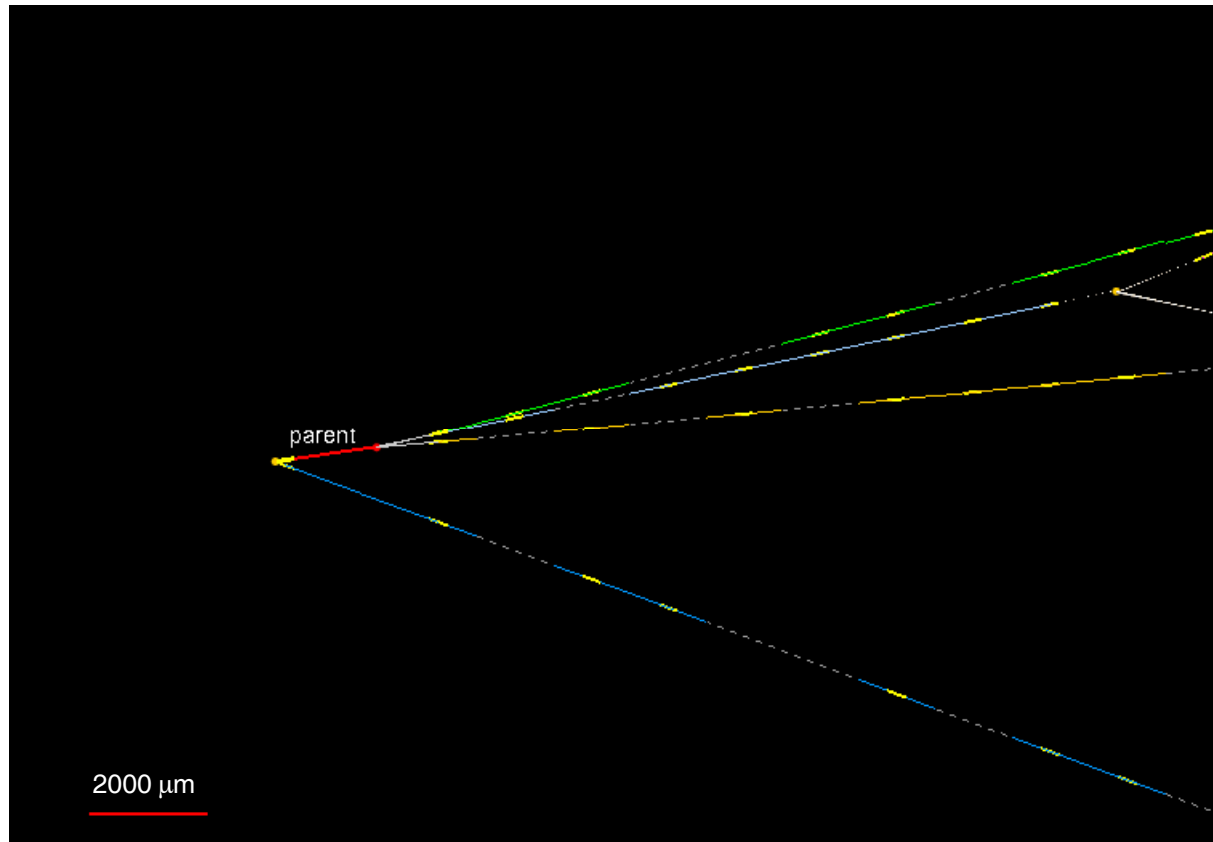
Наблюдение первого события – кандидата на таонные нейтрино ( $\nu_\tau$ )  
в эксперименте ОПЕРА

$$\tau \longrightarrow h - (n\pi_0) \nu_\tau \quad (2,36 \sigma)$$



# $\nu_\mu \rightarrow \nu_\tau$ oscillation search

## New $\nu_\tau$ candidate



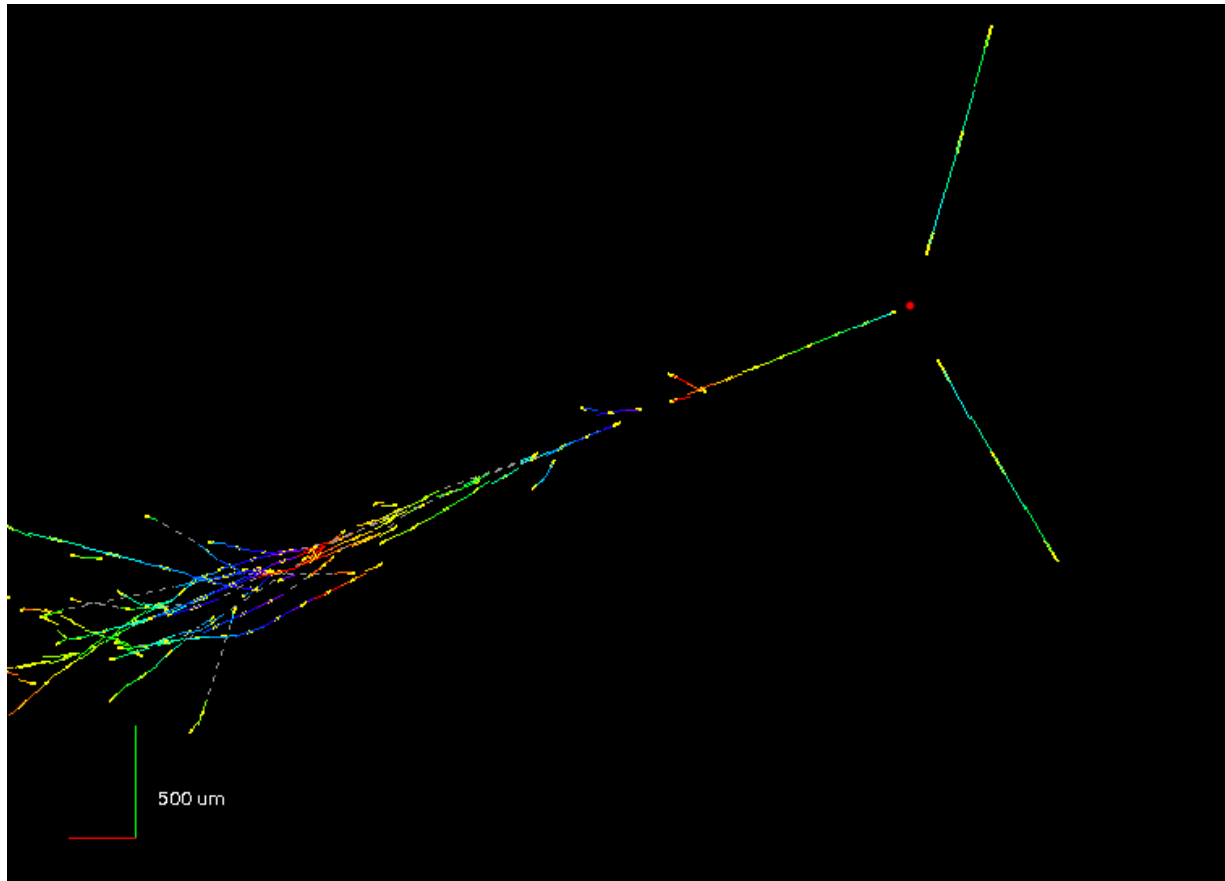
2-prong  $\nu$  interaction with one track showing a secondary vertex compatible with the hypothesis of  $\tau \rightarrow h^+ h^- h^- \nu_\tau$

# $\nu_{\mu} \rightarrow \nu_e$ oscillation search

Systematic search for electron neutrinos applied to 505 events without muon in the final state (runs 2008 – 2009)

Expected events: 19.2 (beam) + 1.5 (oscillated) Observed events: 19  $E_{\nu} = 15.6 \text{ GeV}$   $E_{\nu} < 20 \text{ GeV}$  (improve S/N ratio)

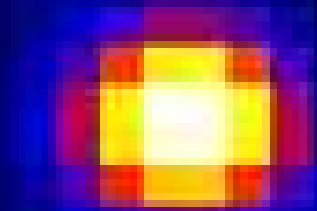
Expected events: 3.7 (beam) + 1.1 (oscillated) Observed events: 4



# Balloon-borne emulsion gamma-ray telescope

## Crab nebula for each energy

High energy gamma-ray  
(Fermi Gamma-ray Space Telescope  
consisting of silicon tracker launched by NASA on June/2008)



High energy emission has been observed all over the world, actively.  
The resolution of high energy gamma-ray is not enough compared with another energy region.  
It is important to improve the resolution of high energy gamma-ray.

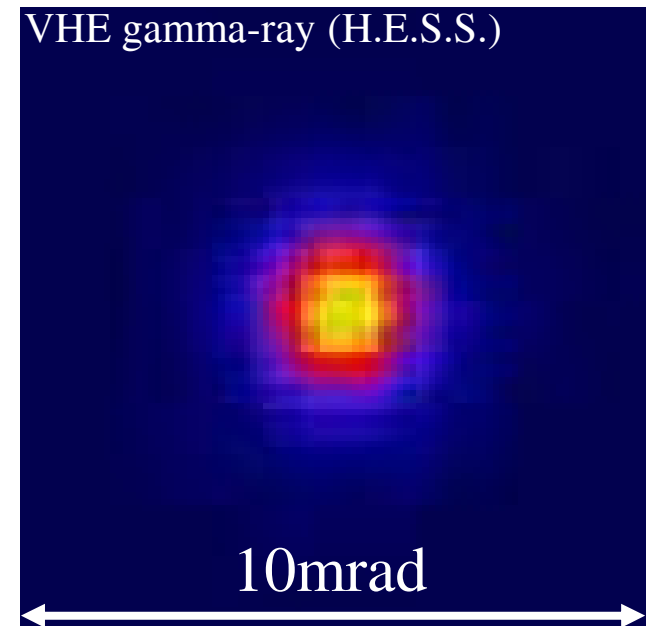
100mrad

X-ray (Chandra)



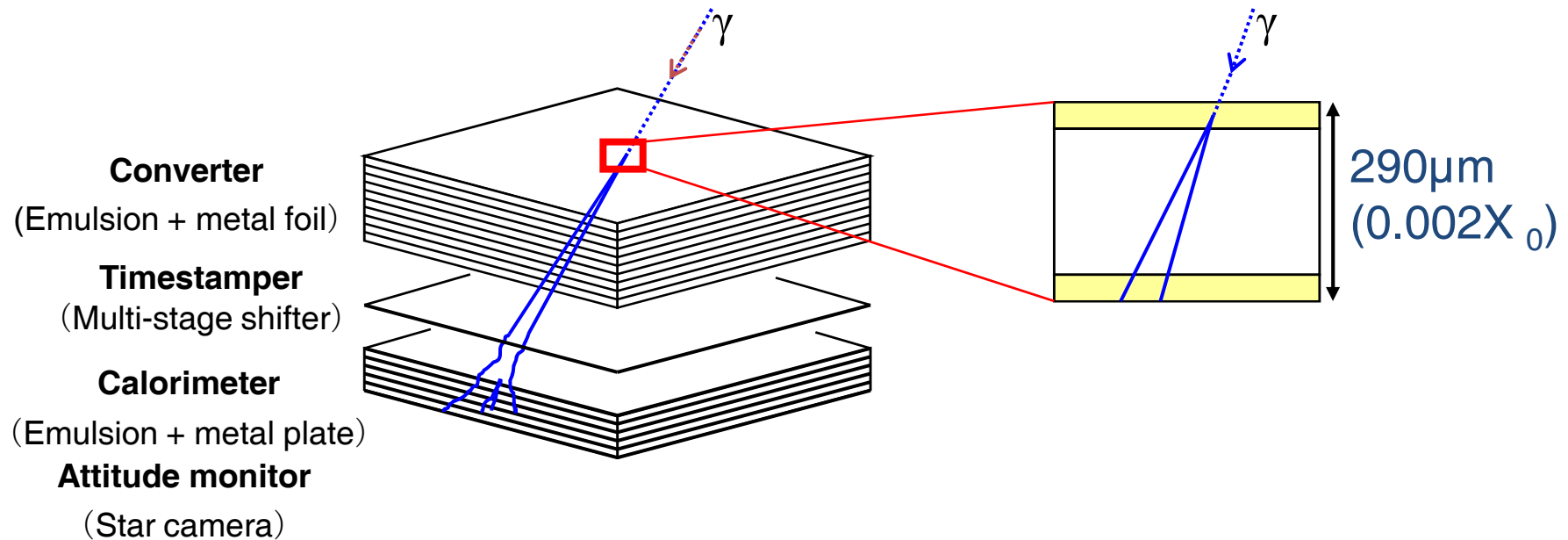
1mrad

VHE gamma-ray (H.E.S.S.)



10mrad

# Emulsion gamma-ray telescope



## Converter

- Converter consists of emulsion films and metal foils stack.
- Starting point of electron pair is detected and gamma-ray direction is determined precisely.

## Timestamper

- Timestamper consists of multi-stage shifter.
- Multi-stage shifter attach the event time to emulsion.
- By combining the event time and attitude monitor information, gamma-ray direction is pointed on the celestial sphere.

## Calorimeter

- Calorimeter consists of emulsion films and metal plates stack.
- Gamma-ray energy above GeV is measured by electron shower measurement.
- (Gamma-ray energy below GeV is measured at converter by multiple coulomb scattering)

# Performance

	Emulsion telescope	Fermi LAT
Angular resolution @ 100MeV	10mrad	61mrad
@ 1GeV	1.4mrad	10mrad
Energy range	10MeV ~ 100GeV (under R&D below 50MeV)	20MeV ~ 300GeV
Polarization sensitivity	Yes (under R&D)	No
Aperture area	>1m <sup>2</sup>	1m <sup>2</sup>
Field of view (full width)	>90° (1.6sr, 12.5% all of sky)	120° (2.4sr, 19.1% all of sky)
Dead time	No dead time	26.5μsec (readout time)
Area×Time [m <sup>2</sup> · day]	25(current)	365
	625(future)	

Emulsion scanning power in a year

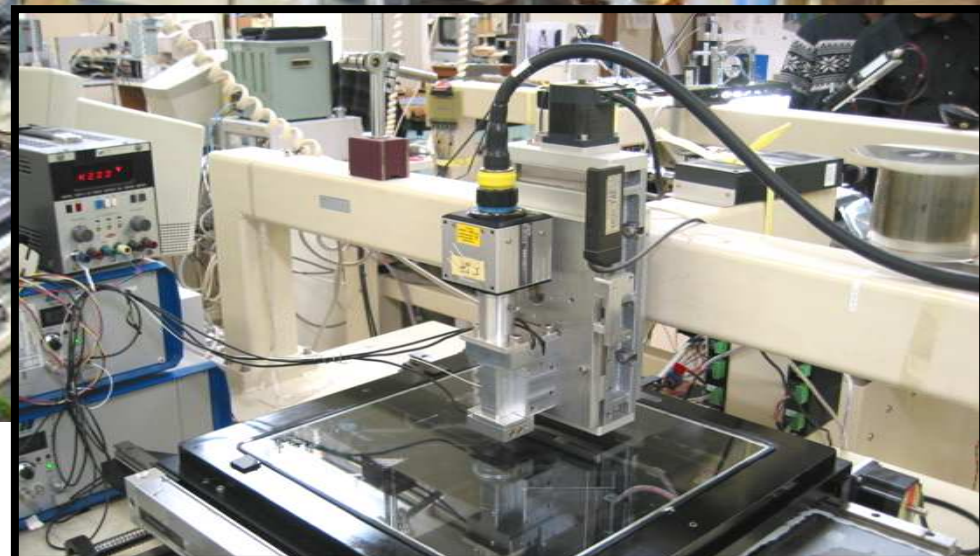
Current system : 4m<sup>2</sup> · flight

Future system : 100m<sup>2</sup> · flight

(Flight duration : 150hours(6.25days))

Long duration flight(150hours)  
Repeating flight(>4flights/year)

# Emulsion scanning facility @Tono mine



- **Running scanning power is  $1.6\text{m}^2 \cdot \text{flight}/\text{year}$ .**
  - 5 SUTSs are running everyday.
  - 4 SUTSs are scanning with  $50\text{cm}^2/\text{h}$  and 1 SUTS is scanning with  $33\text{cm}^2/\text{h}$ .
- **Maximum scanning power with current systems is  $4\text{m}^2 \cdot \text{flight}/\text{year}$ .**
  - SUTSs become high speed up to  $121\text{cm}^2/\text{h}$ .
- **Scanning power with future system is  $100\text{m}^2 \cdot \text{flight}/\text{year}$ .**
  - Future scanning system is being designed with  $1\text{m}^2/\text{h}$ .

Automatic Emulsion Scanning System  
“S-UTS I”  $33\text{cm}^2/\text{h}$



# Energy range

LCSガンマ線ビーム@UVSOR

221 2314379

$E=28[\text{MeV}]$

$p\beta_1=13+4-2[\text{MeV}/c]$

$p\beta_2=15+4-3[\text{MeV}/c]$

大気ガンマ線@乗鞍

131 3741965

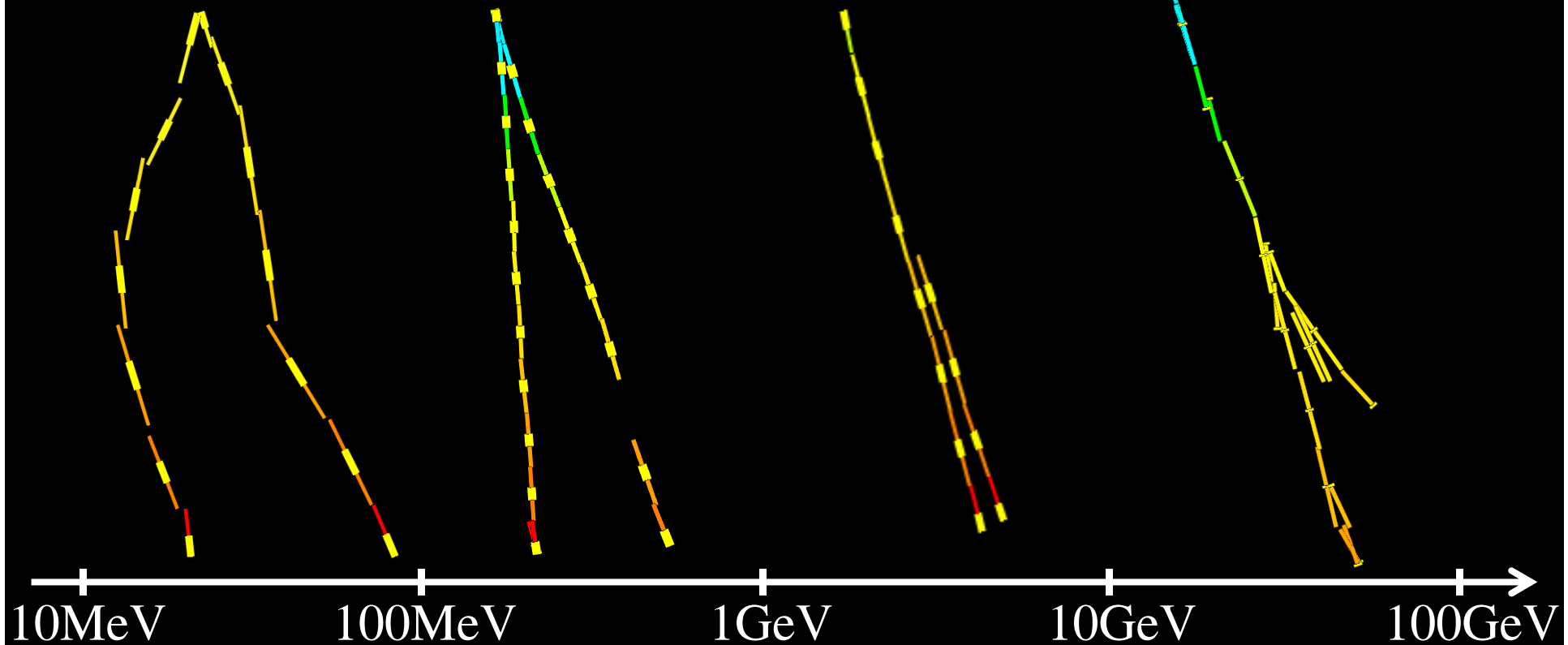
$E=150[\text{MeV}]$

$p\beta_1=50+12-7[\text{MeV}/c]$

$p\beta_2=100+36-13[\text{MeV}/c]$

LCSガンマ線ビーム@SPring-8

MSC 大気ガンマ線@上空



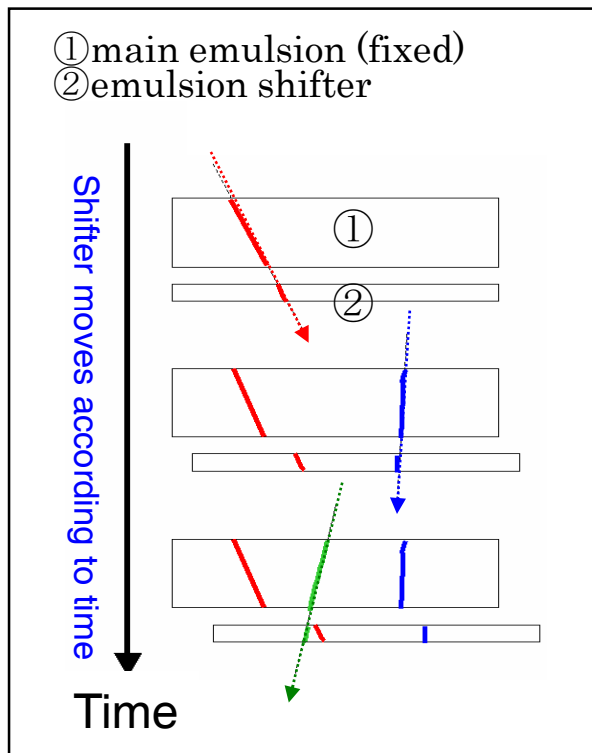
These are gamma-ray events for each energy detected by emulsion.  
Emulsion gamma-ray telescope can observe for wide energy region.

# Emulsion Multi Stage Shifter

The emulsion which has the time resolution below a second

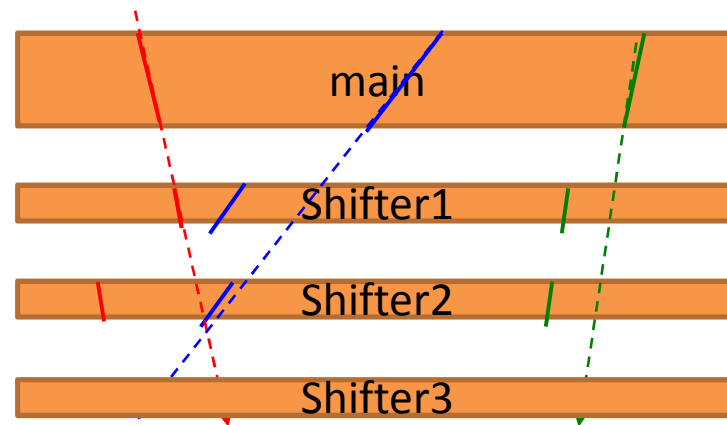
“Emulsion Shifter”(2004)

Expansion



## “Multi Stage” Shifter

Multiple emulsion films are moved with the different cycle.



like a analog clock !

hour

min

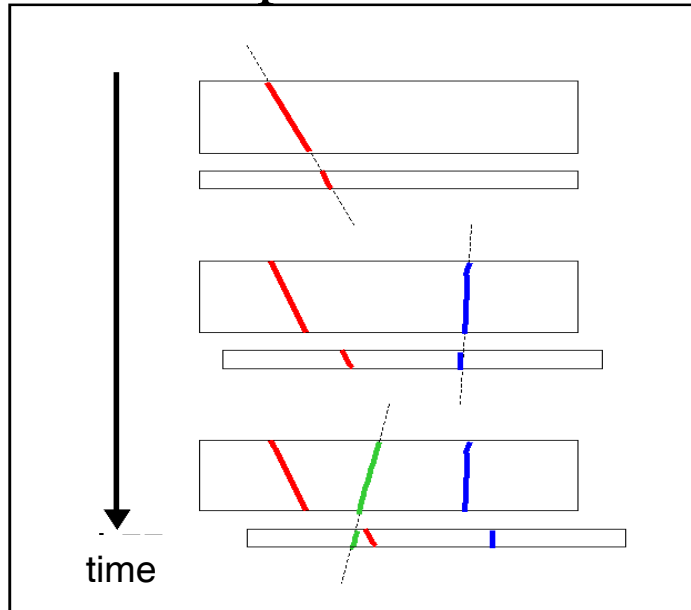
sec



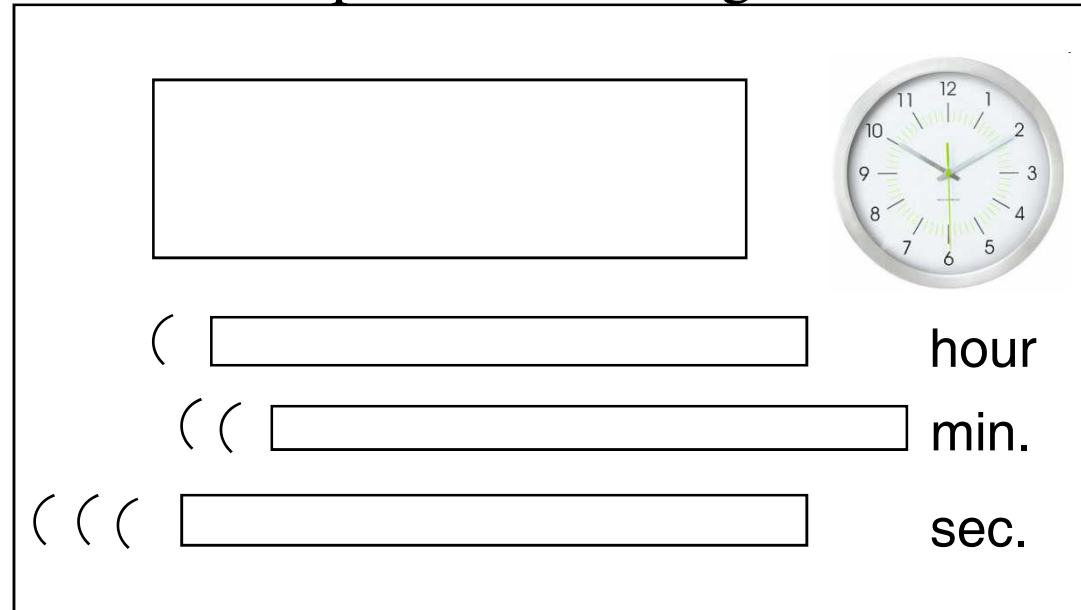
By the combination of multiple position displacements, the emulsion has enough brief time resolution even with the observation of long duration.

# Multi-stage shifter

## Principle of shifter



## Principle of multi-stage shifter



The shifter creates a position displacement of a track corresponding to the recorded time.

The time can be reconstructed from the position displacement.

The multi-stage shifter has two or more stages shifted with individual cycles.

In the multi-stage shifter, the combination of position displacement of the track between each stages can be taken and a great many independent time-dependent states are obtained.

As a result, it has good resolution for longer time periods.

It is similar to an analog clock which shows 12 hours with accuracy of one second by the combination of hands moving at a different cycle (hour, minute and second hand).

Moreover, by increasing number of stages with a shorter cycle, the time resolution improve.

Multi-stage shifters using emulsion films are **simple by design, compact, light, high voltage free, low power and dead-time free**. This is suitable for balloon experiment.

# Flight model of multi-stage shifter

Co-development with Mitaka  
Kohki Co., Ltd.

Size : 44cm×22cm×6cm

Weight : 4.7kg

**Effective area : 12cm×10cm**

# of Stages : 3

Gap : 2mm

Thickness of effective area : 5mm

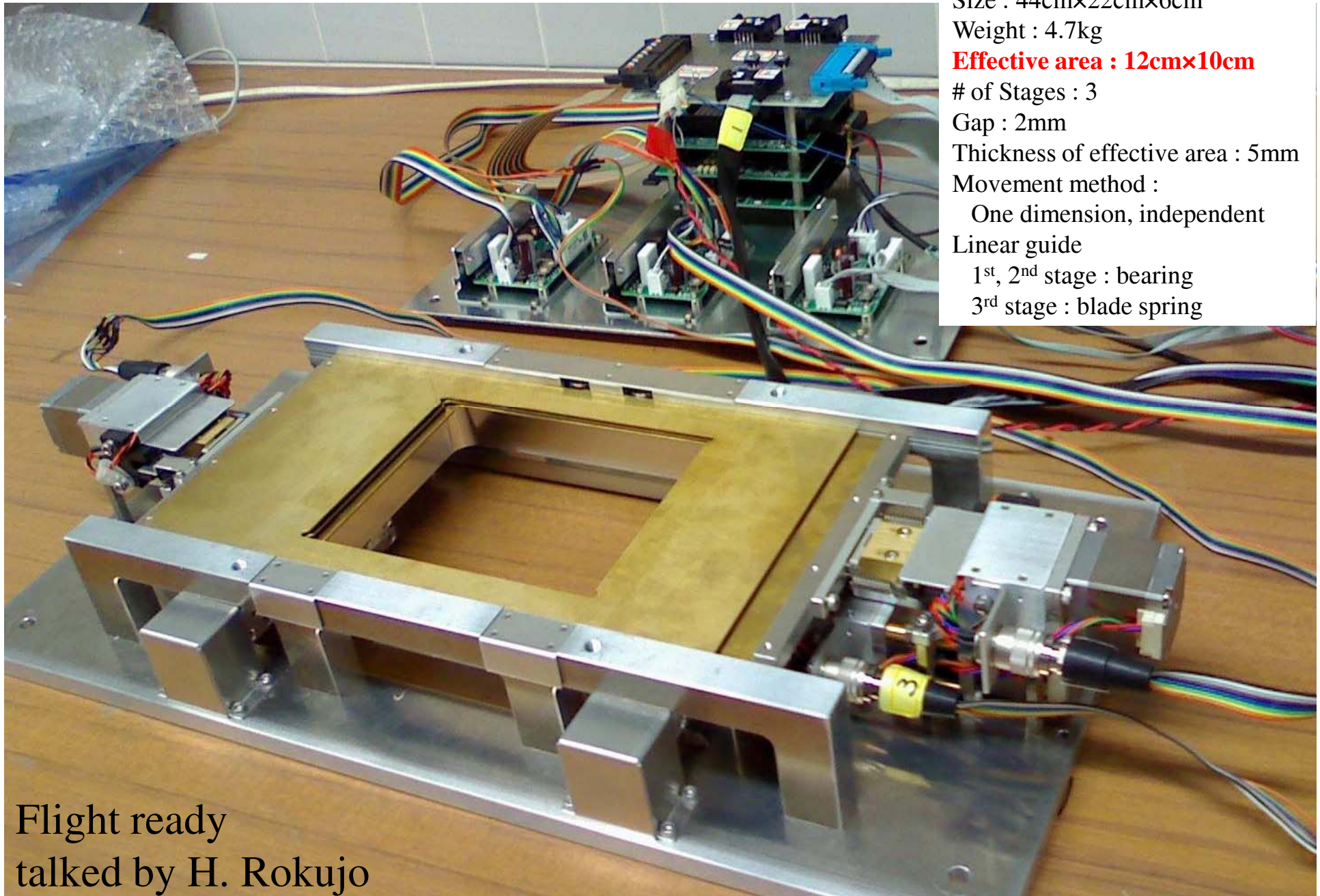
Movement method :

One dimension, independent

Linear guide

1<sup>st</sup>, 2<sup>nd</sup> stage : bearing

3<sup>rd</sup> stage : blade spring



Flight ready  
talked by H. Rokujo

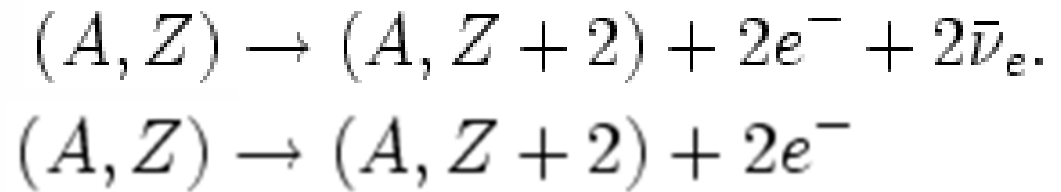
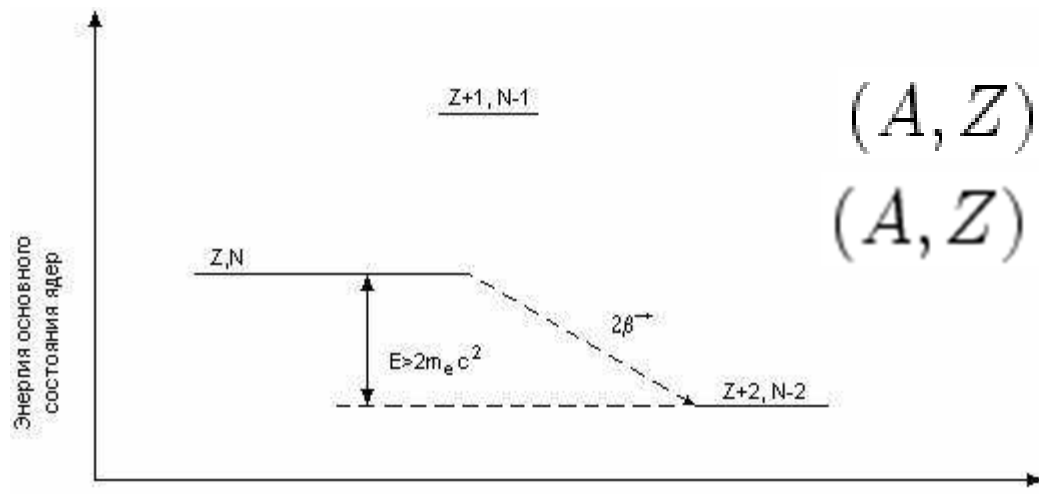
# Possible future emulsion experiments

- Physics
  - tau neutrino cross-section
  - $0\nu$  neutrino double-beta decay
  - Antimatter gravity experiment
  - Neutrino Factory
- Geosciences
  - Muon radiography
- Medical application
  - Proton radiography
  - High precision beamline study
  - Neutron monitoring

# Ядерная фотоэмульсия с молибденовым наполнением для наблюдения $2\beta$ - распада.

В.Д.Ашитков, А.С.Барабаш, В.Я.Браднова. В.А.Дитлов,  
В.В.Дубинина. Н.П.Егоренкова, С.И.Коновалов, Е.А.Пожарова,  
Н.Г.Полухина, В.А.Смирнитский, Н.И.Старков,  
М.М.Чернявский, Т.В.Щедрина, В.И.Юматов





"...Всего за полвека из ускользящей сущности нейтрино превратилось в фундамент нашего существования... Произошла "нейтринная революция". Эта революция затрагивает самые фундаментальные основы мира, в котором мы живем. Она произвела переворот и в нашем подходе к физическим явлениям".

Я.Б. Зельдович, М.Ю. Хлопов, 1981 г.

Переход	Изотопная распростран. %	Разность масс, кэВ
$^{46}\text{Ca} \rightarrow ^{46}\text{Ti}$	0,0033	$985 \pm 5$
2 $^{48}\text{Ca} \rightarrow ^{48}\text{Ti}$	0,185	$4271 \pm 5$
3 $^{70}\text{Zn} \rightarrow ^{70}\text{Ge}$	0,62	$1001 \pm 5$
4 $^{76}\text{Ge} \rightarrow ^{76}\text{Se}$	7,67	$2038 \pm 1$
5 $^{80}\text{Se} \rightarrow ^{80}\text{Kr}$	49,82	$135 \pm 15$
6 $^{82}\text{Se} \rightarrow ^{82}\text{Kr}$	9,19	$3005 \pm 15$
7 $^{86}\text{Kr} \rightarrow ^{86}\text{Sr}$	17,37	$1249 \pm 8$
8 $^{94}\text{Zr} \rightarrow ^{94}\text{Mo}$	2,80	$1148 \pm 7$
9 $^{96}\text{Zr} \rightarrow ^{96}\text{Mo}$	17,40	$3350 \pm 6$
10 $^{98}\text{Mo} \rightarrow ^{98}\text{Ru}$	23,75	$110 \pm 8$
11 $^{100}\text{Mo} \rightarrow ^{100}\text{Ru}$	9,62	$3032 \pm 9$
12 $^{104}\text{Ru} \rightarrow ^{104}\text{Pd}$	18,50	$1301 \pm 9$
13 $^{100}\text{Pd} \rightarrow ^{110}\text{Cd}$	12,70	$2014 \pm 24$



## **Нами предложен метод:**

на стадии производства **ядерная фотоэмульсия** **наполняется мелким порошком нужного изотопа.** Таким образом, ядерная эмульсия является одновременно и мишенью и детектором.

**Основным достоинством** такого подхода при изучении  $2\beta$ -распада является визуализация полезных событий и возможность **измерения всех характеристик распада:**

**суммарной энергии,  
энергии отдельных электронов  
и углов их разлета.**

**Для проверки предложенного метода**

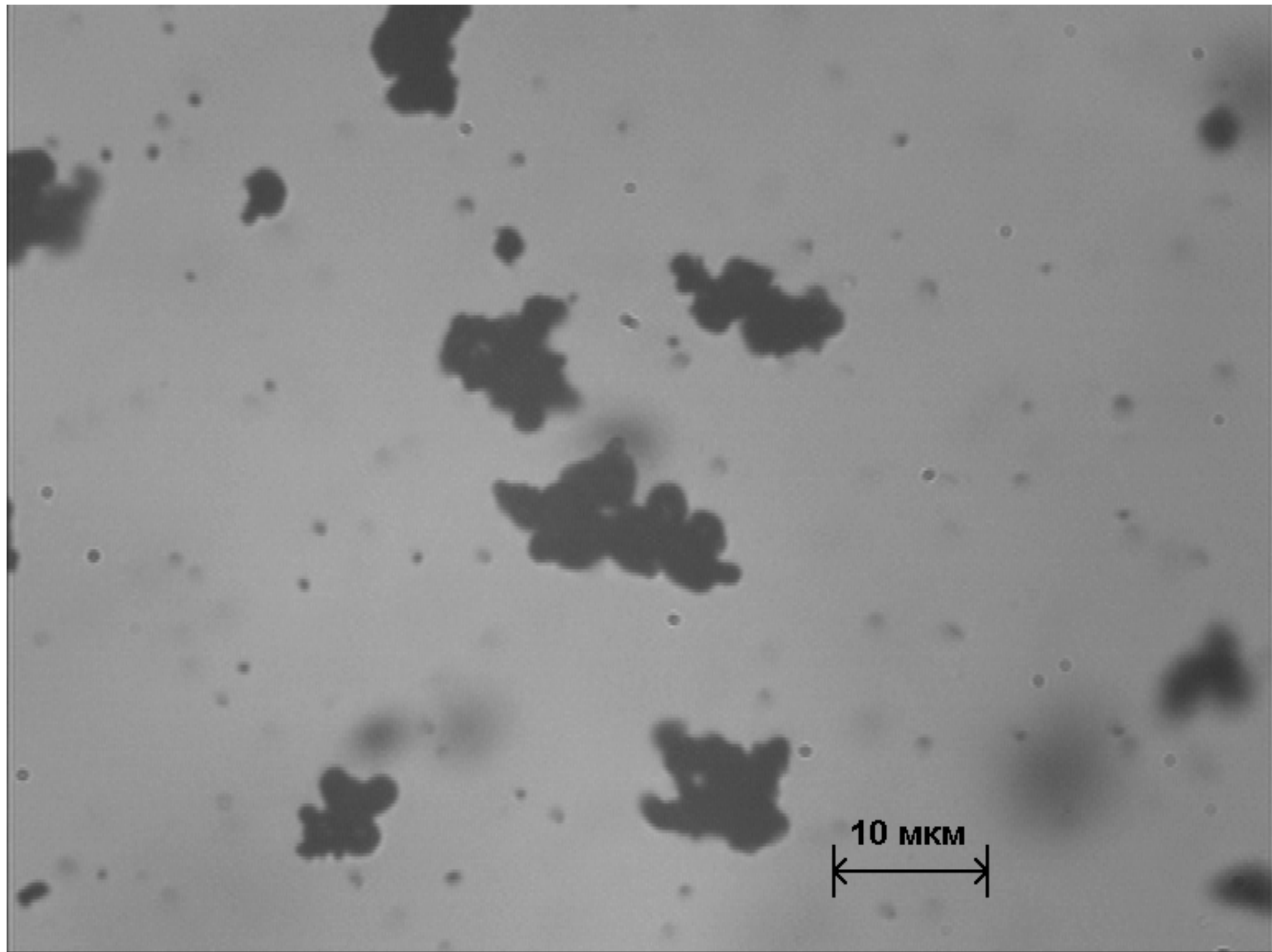
мы провели **R&D** с использованием промышленного мелкозернистого порошка молибдена.

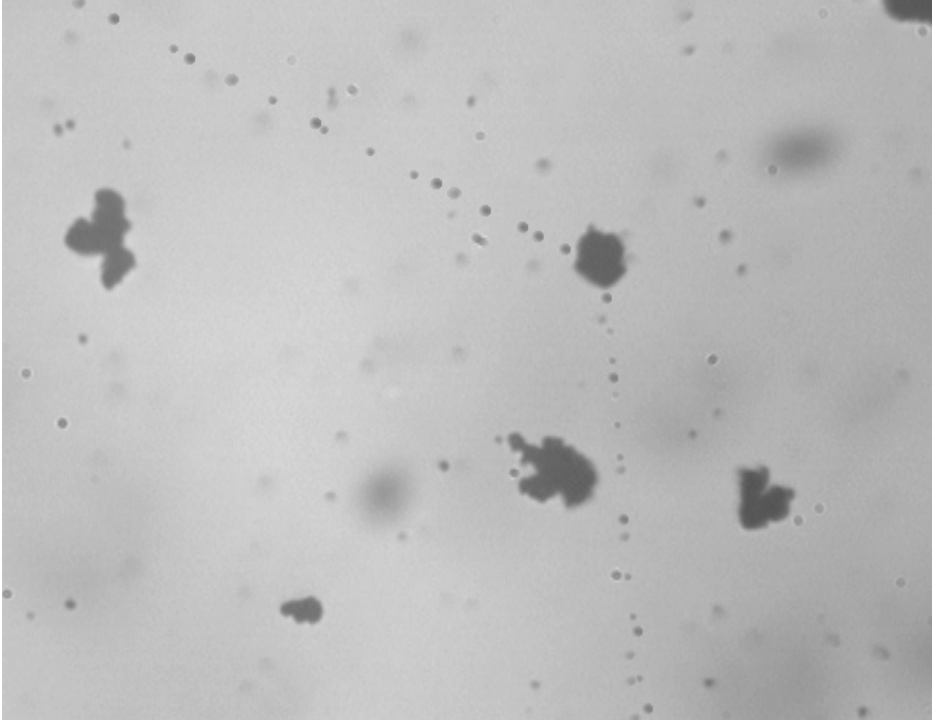
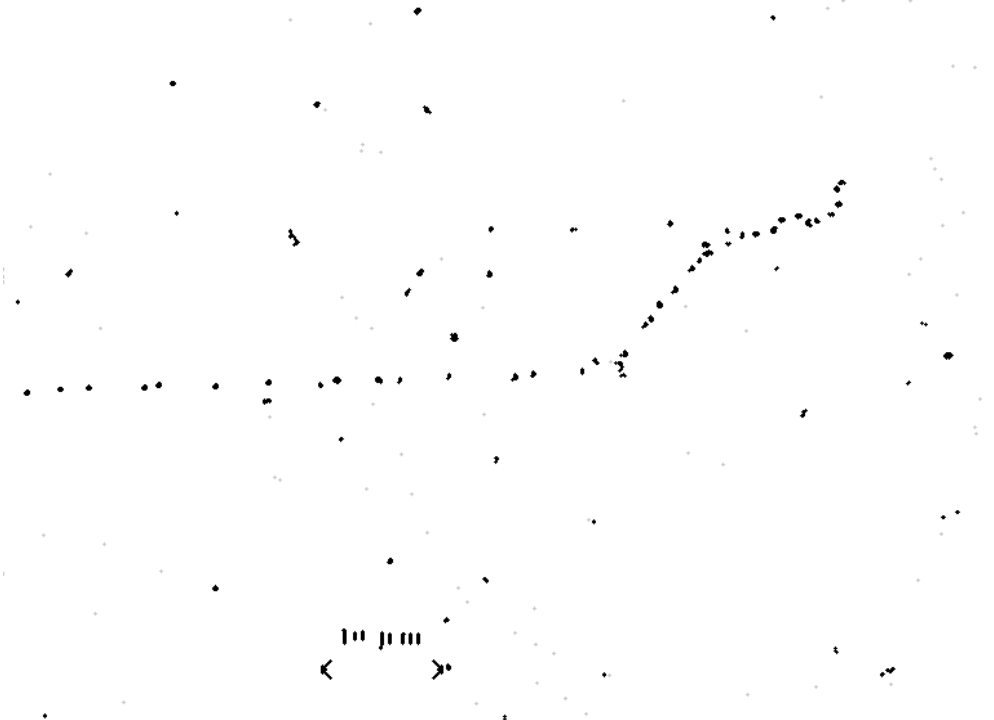
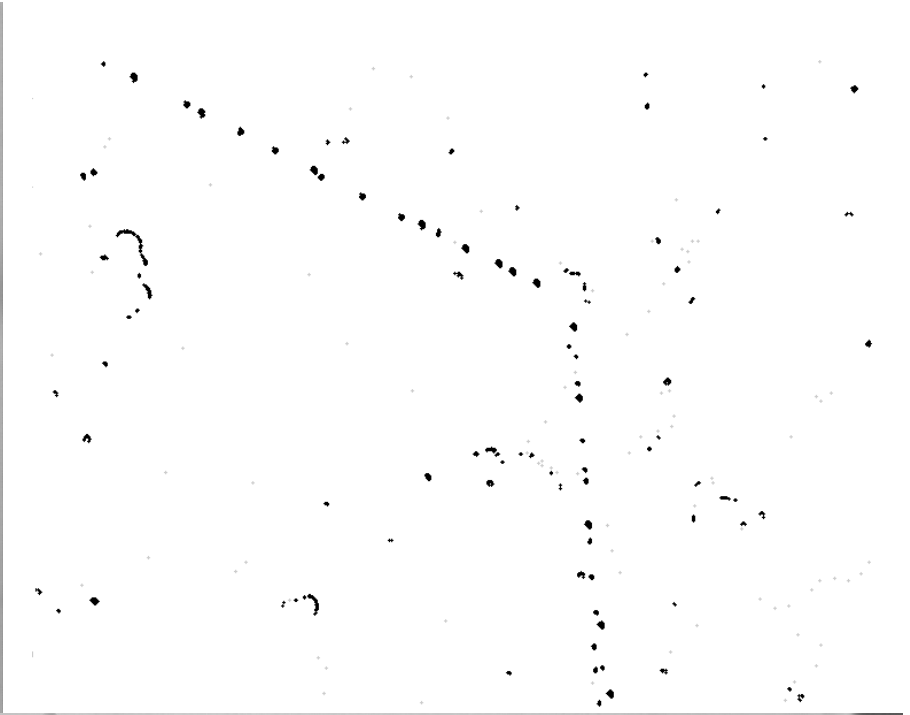
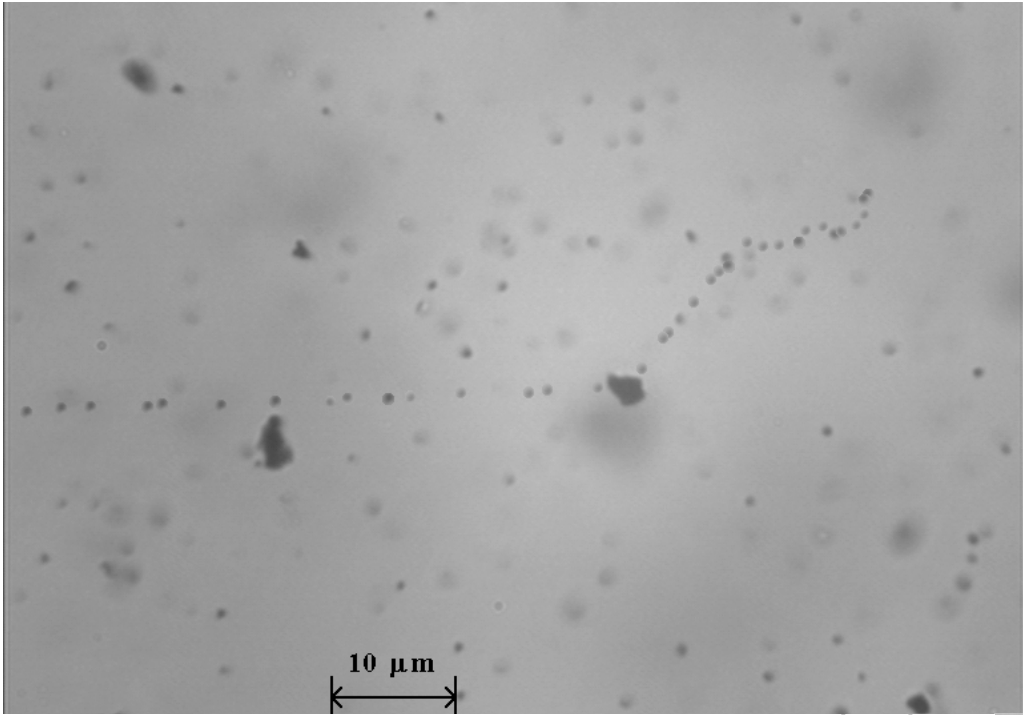
**Изготовлено: 10 пластинок (9x12x0.0075)см<sup>3</sup>**

**(Vэм =8.1см<sup>3</sup>), наполнение 1.43гр. Мо (4.6% по весу сухой эмульсии)**

**Установлено:**

Молибден не «портит» ядерную фотоэмульсию и порошок не мешает просмотру и сканированию на микроскопах.





## ИТОГ

### 1.Результат

Для опыта с 1 кг.<sup>100</sup>Mo → 65.5 кг. геля,  
860 эм. слоев (9x12x0.06) см<sup>3</sup>, если увеличить наполнение в 1.5 – 2 раза,  
то будет 570 – 430 эм. слоев (10 -12 эм.камер).

**10 – 12** эмульсионных камер, наполненных **1 кг 100Mo**, обрабатываются на  
трех сканирующих микроскопах за **1 год**. Ожидаемый результат измерения  
периода полураспада ~**1.5x10<sup>24</sup> лет**.

### 2. Фон (ββ)

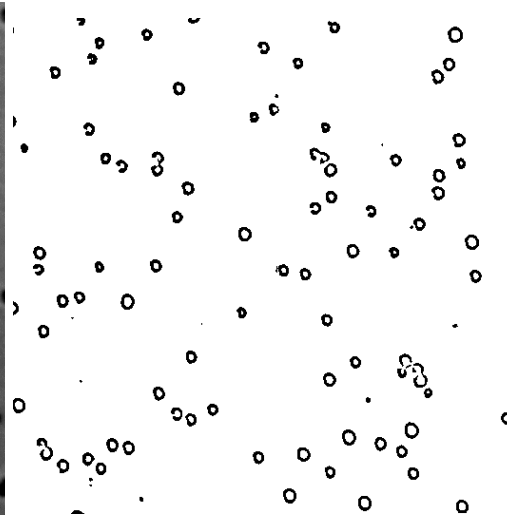
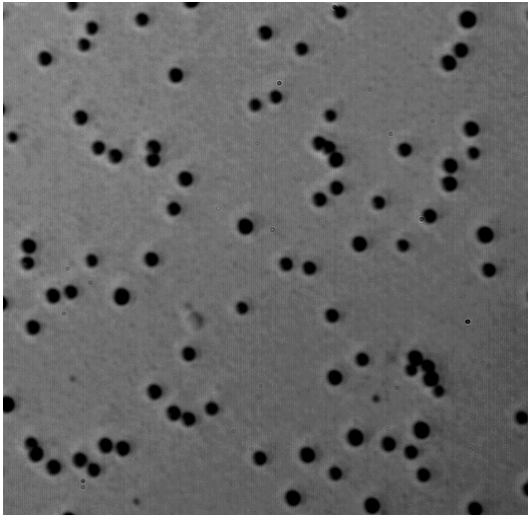
Фон от **40K** ~5/год и **<1** событие в области **(3±0.3) МэВ**. Фон от **90Sr** ~1  
соб./год с энергией электронов **>2.8 МэВ**. Фон от естественной  
радиоактивности практически полностью исключается.

Точность измерения энергии  
заряженных частиц по их пробегу в  
ядерной фотоэмульси.

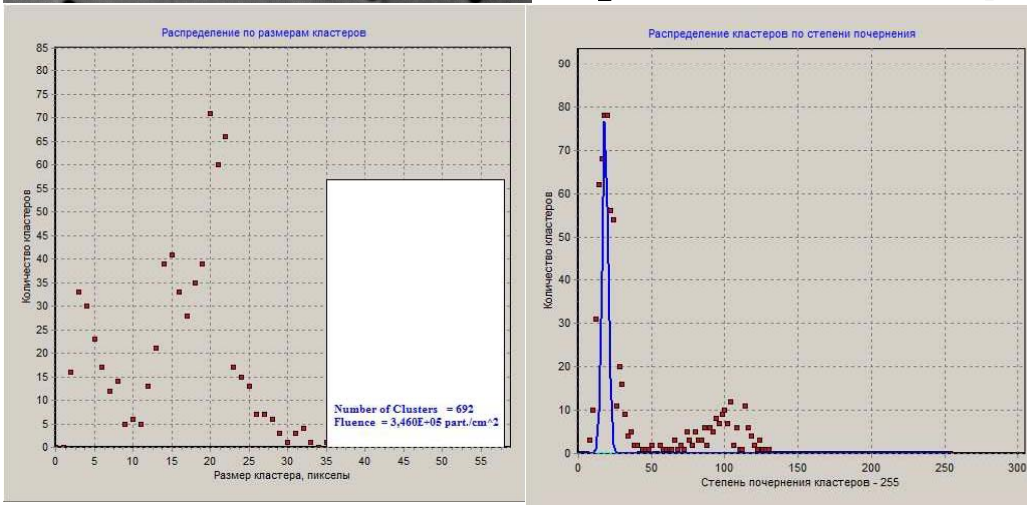
Энергия мюонов в  $\pi \rightarrow \mu \nu$  распаде строго  
монохроматическая.

По нашим измерениям  $E_{\mu} = (4.12 \pm 0.1)$   
МэВ

## Дозиметрия пучка углерода с энергией 200 МэВ/н с помощью полимерного детектора CR-39 (ИТЭФ)



Детекторы такого типа обеспечивают получение данных не только о средних значениях энергии частиц и энерговыделении частиц в объекте, но и о распределении плотности пучка в его сечении, количестве и месте попадания частиц, разбросе энергий частиц.



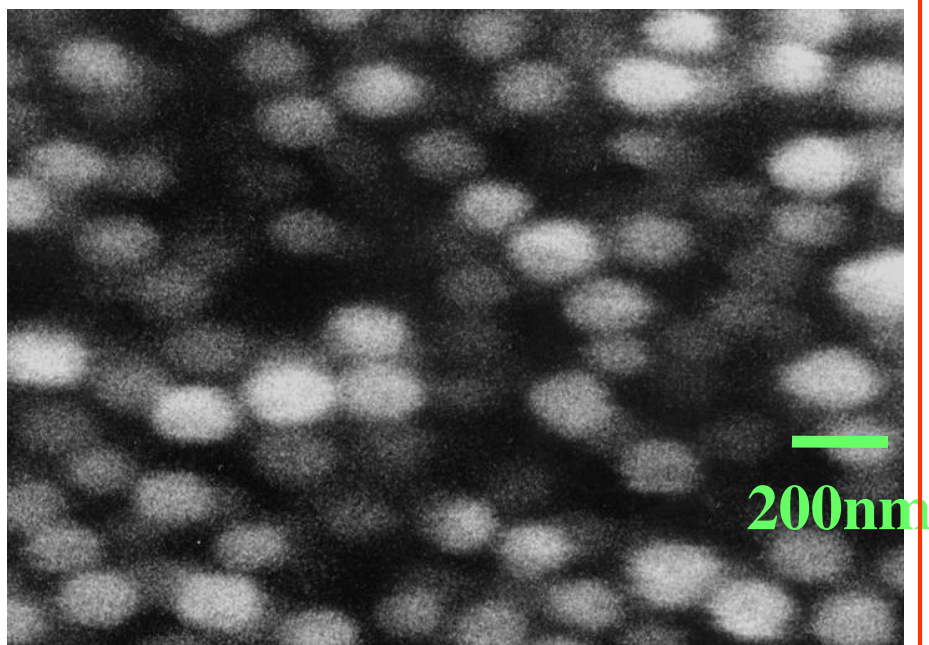
*Зависимость количества треков от их диаметра и количество треков на пластине*

Диаметр поля пучка 45 мм, размер пластин 2см на 2см. Для подсчета числа частиц, а также измерения размера кластеров производилось сканирование части пластины размером 5мм на 5 мм. Использовался объектив с увеличением x100 (размер каждого кадра 420x350 микрон).



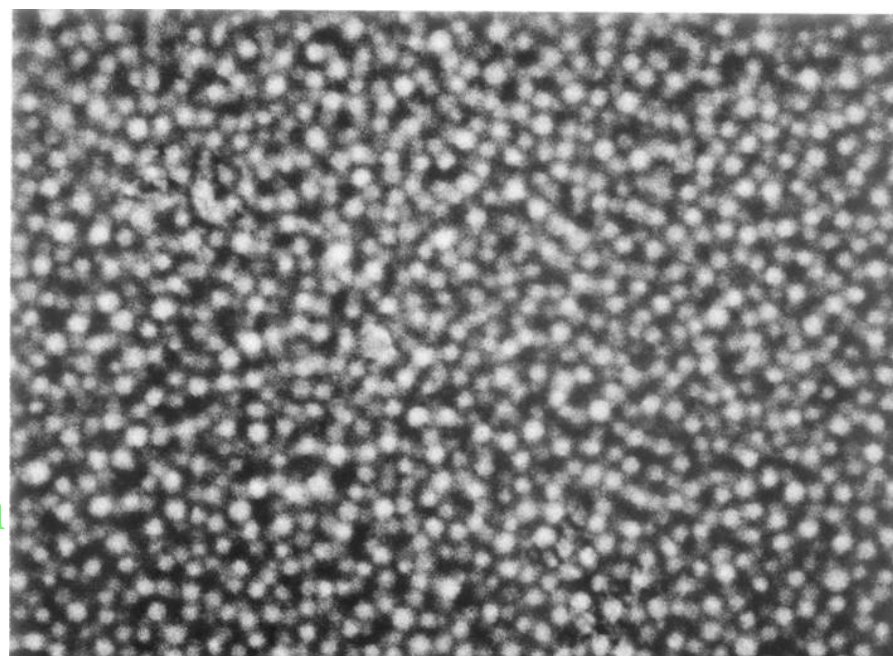
# Наноразмерная ядерная эмульсия (Nano Imaging Tracker:NIT)

OPERA



OPERA:AgBr crystal size ~200nm  
2.3 AgBr/ $\mu\text{m}$

NIT



NIT:AgBr crystal size ~40nm  
11 AgBr/ $\mu\text{m}$

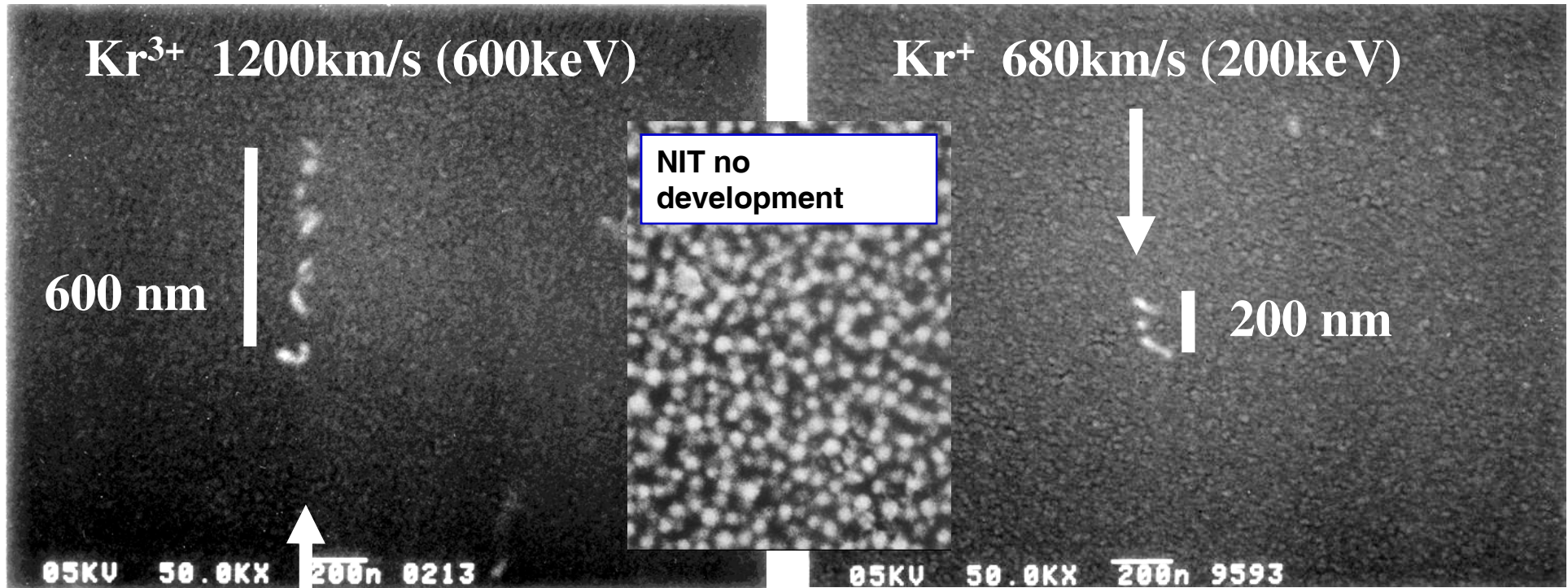
5 times resolution for OPERA!

# Tracking test by low velocity Kr



Supposition **Br** recoil

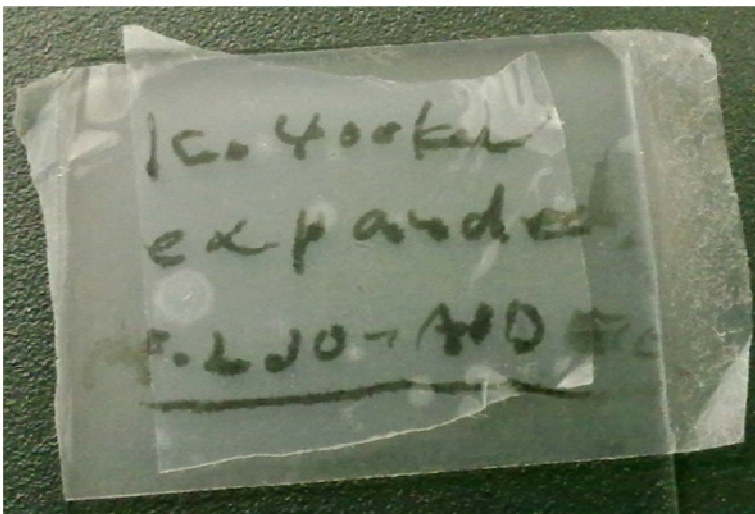
SEM image



# Emulsion Samples

## Krypton

- Krypton 400 keV
- Emulsion NNK032 with PVA
- $41 \pm 9$  nm crystal size
- $\sim 150$  nm grain size
- 2x expansion

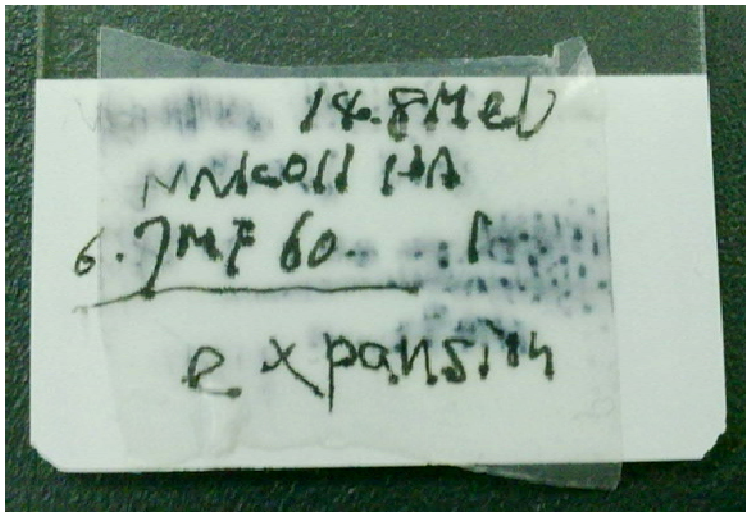




# Emulsion Samples

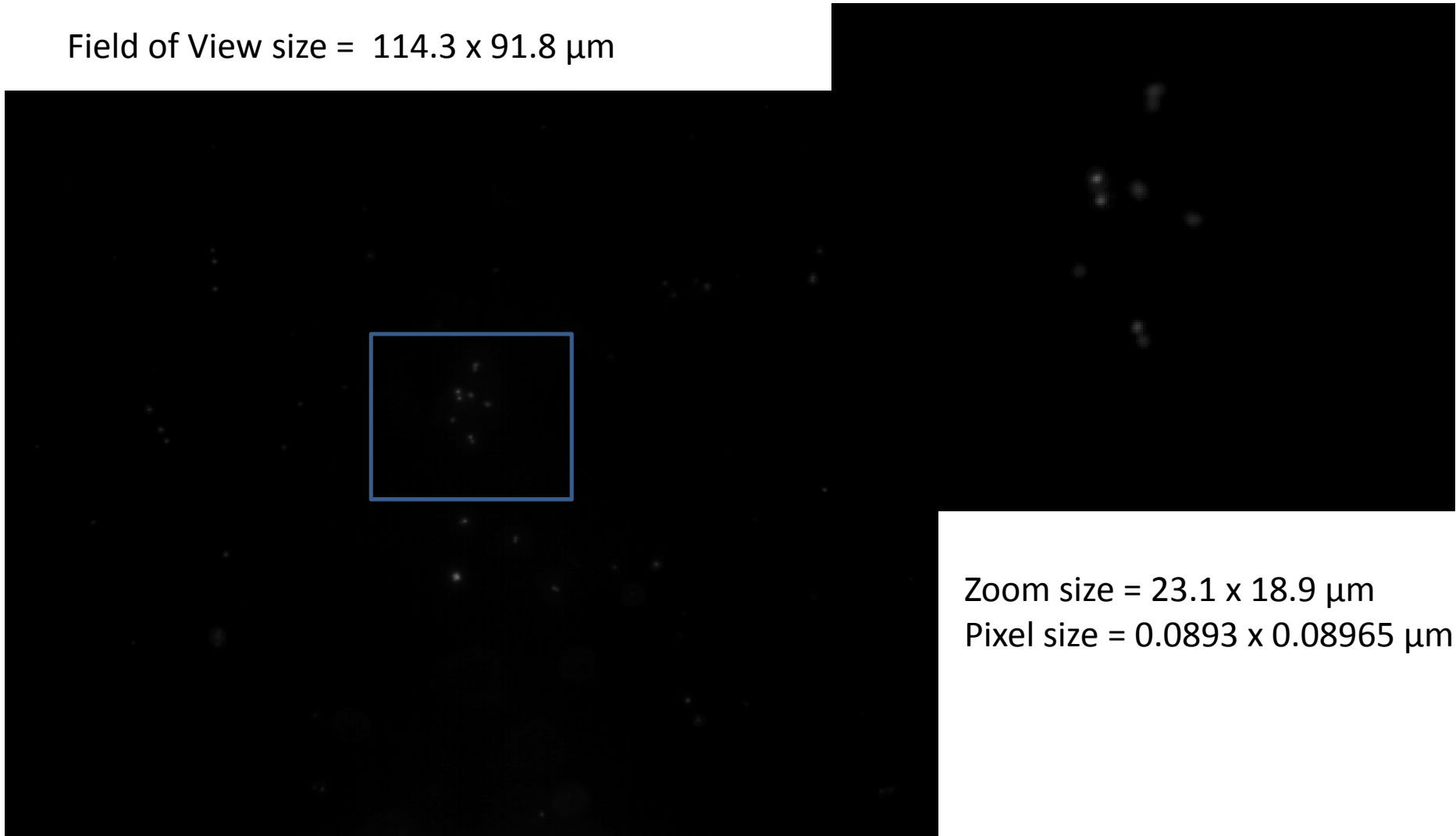
## Neutron

- Neutron 14.8 MeV
- Emulsion NNK011
- ~50 nm crystal size
- ~150 nm grain size
- 2x expansion



# Neutron sample image

Field of View size = 114.3 x 91.8  $\mu\text{m}$



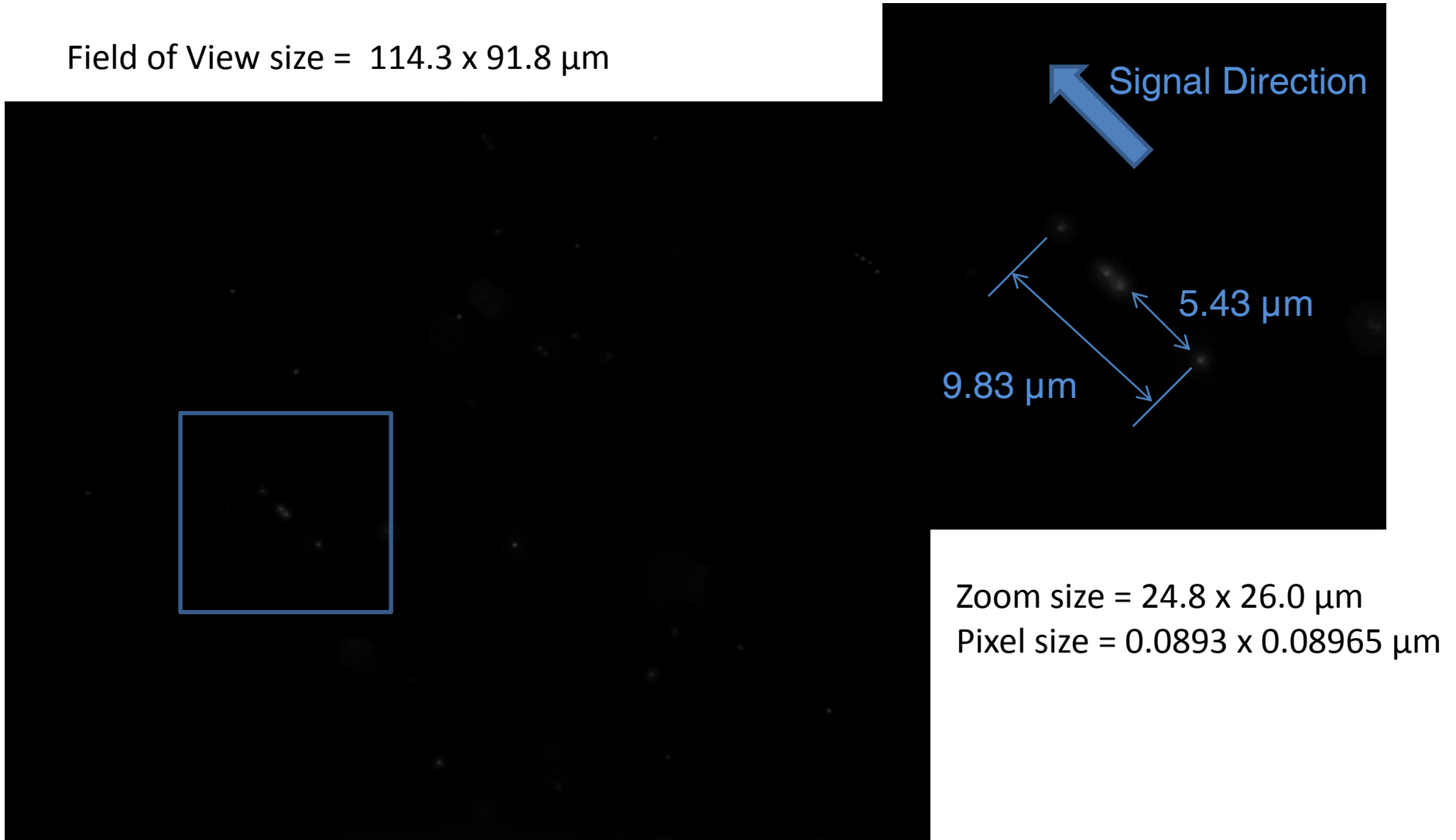
Zoom size = 23.1 x 18.9  $\mu\text{m}$

Pixel size = 0.0893 x 0.08965  $\mu\text{m}$

# Neutron sample

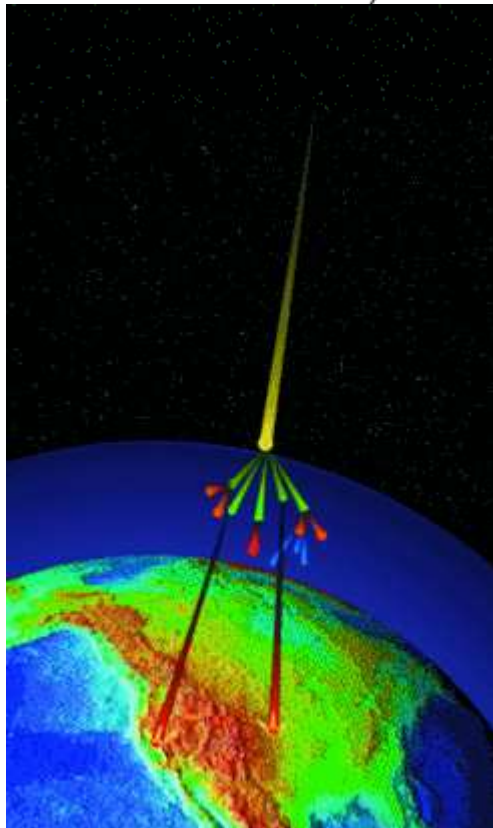
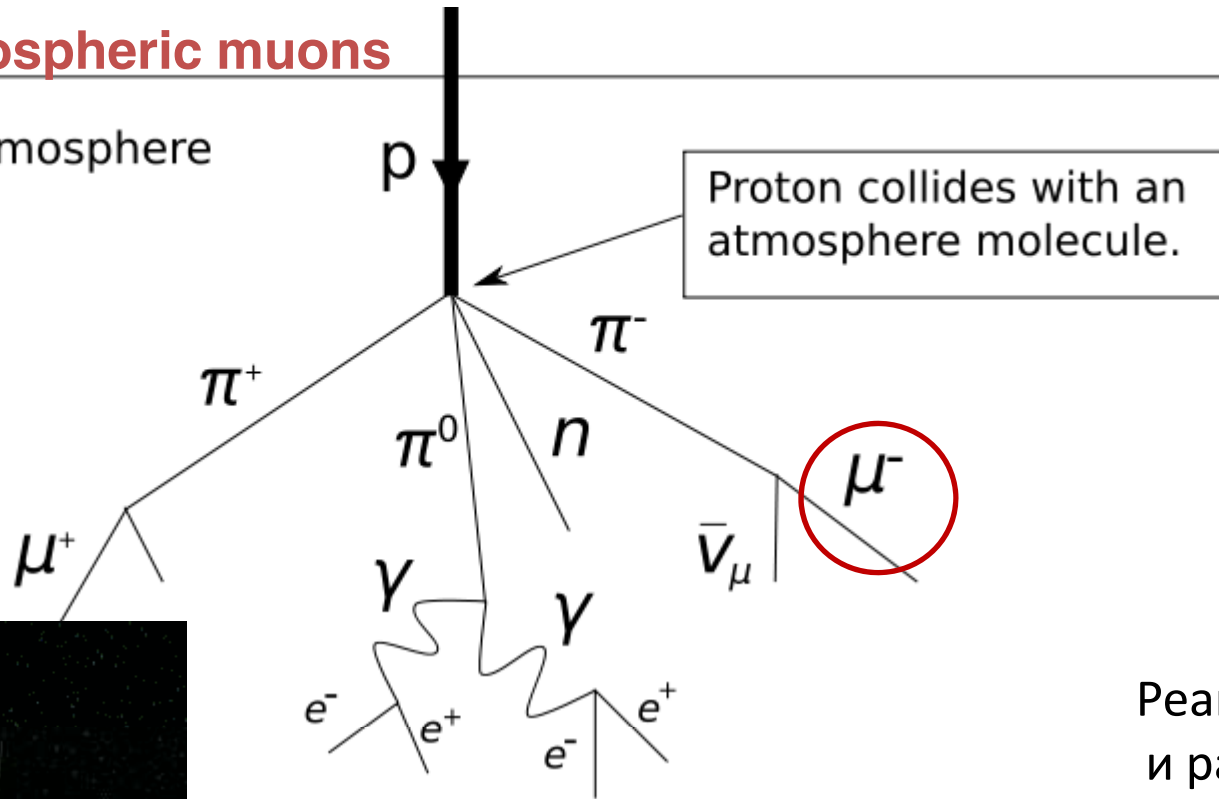
## A real track?

Field of View size =  $114.3 \times 91.8 \mu\text{m}$



# Atmospheric muons

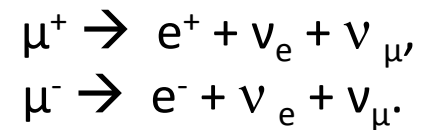
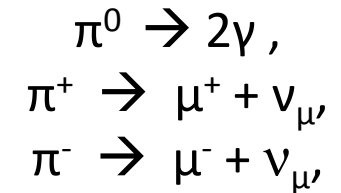
Top of the atmosphere



Многие свойства мюона и электрона близки, но масса мюона (106 МэВ) в 207 раз больше массы электрона. С этим связан тот факт, что **пробег** мюонов в тысячи раз больше пробега электронов. Время жизни 2.2 мксек.

Мюоны проникают через поверхность планеты с интенсивностью около 10 тысяч частиц на квадратный метр в минуту

Реакции генерации и распада мюонов



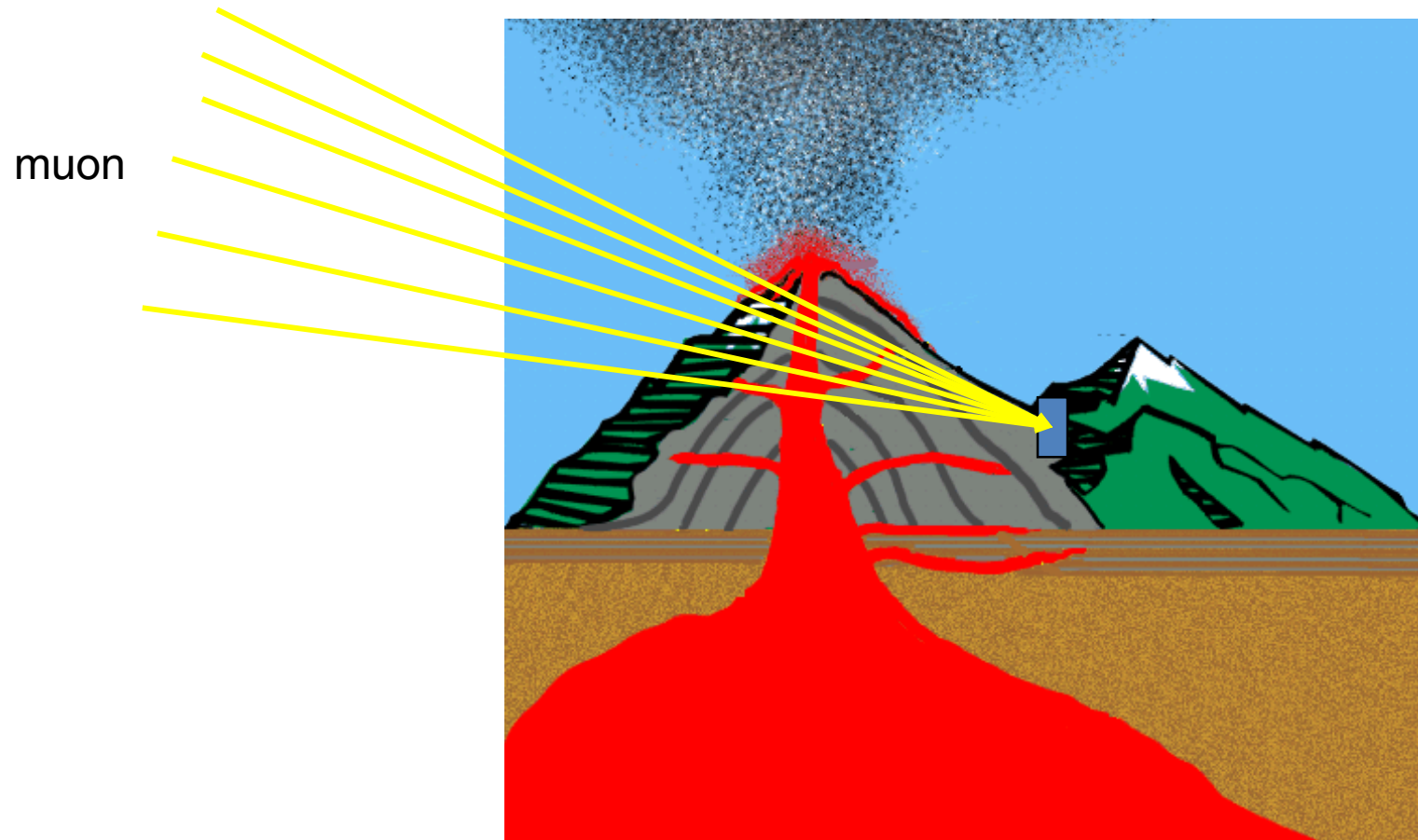
# Проникающая способность мюонов

Поток мюонов представляет собой проникающую компоненту космических лучей. Даже при сравнительно умеренной энергии 10 Гэв мюон может не только пройти сквозь всю земную атмосферу, но и проникнуть далеко в глубь Земли. Максимальная глубина, на которой регистрировались мюоны наиболее высокой энергии, составляет около 8600 м в переводе на водный эквивалент.

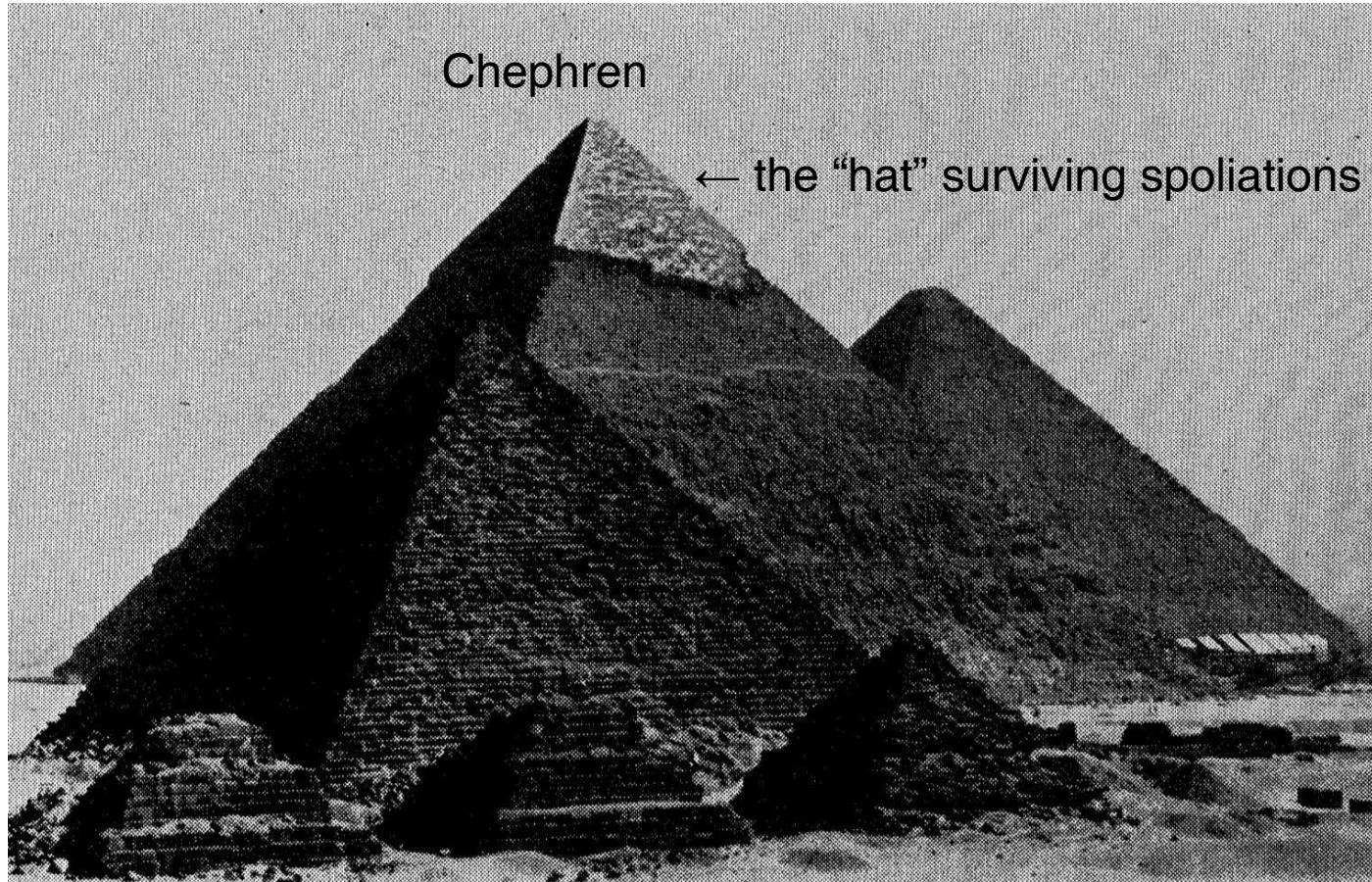
Высокая проникающая способность в сочетании с прямо пропорциональным плотности вещества коэффициентом поглощения при умеренных энергиях (десятки и сотни Гэв) делает проникающую компоненту КЛ очень удобным средством для подземной геофизической и инженерной разведки .



**Мюон — заряженная частица, его обнаружение происходит непосредственно и не вызывает дополнительных сложностей. Типичные горизонтально прибывающие мюоны космических лучей с энергией 1 ТэВ могут проникать 2.6 км воды. Таким образом мюонная радиография может применяться для объектов даже километрового размера, расположенных обязательно выше детектора.**



## The first application of Muon Radiography



**Search for hidden chambers in the Chephren's Pyramid**

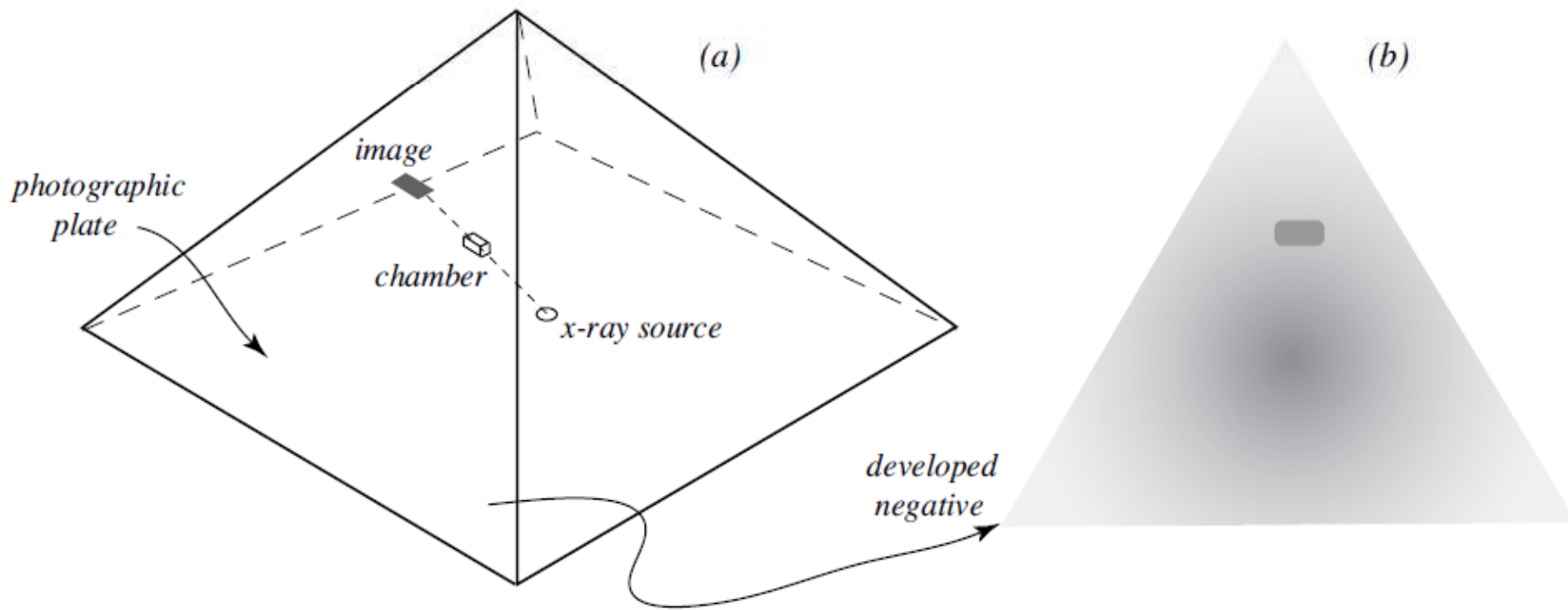
L.W. Alvarez et al. Science 167 (1970) 832



**Dr. Luis Alvarez, Nobel Prize Winner**

**1963, Chephren's pyramid, Giza**

**Is there a "secret chamber" ?**



## No hidden chamber in the pyramid

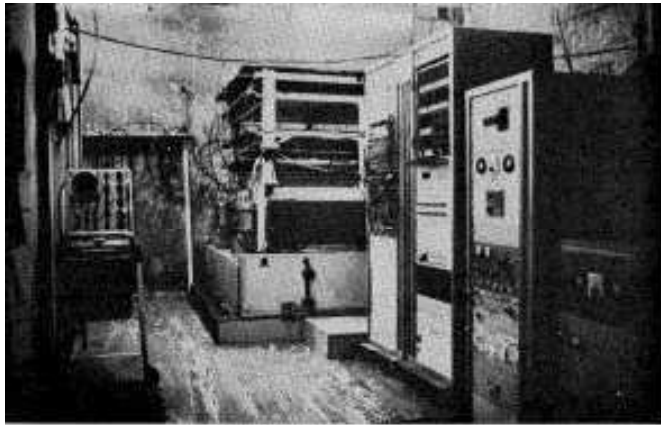
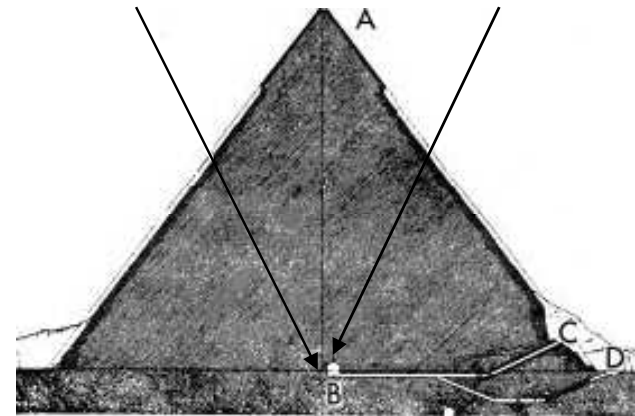


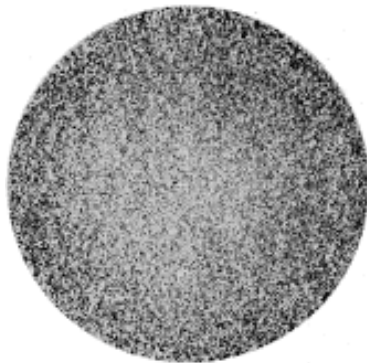
Fig. 6 (left). The equipment in place in the Belzoni Chamber under the pyramid.

Spark chamber “muontelescope”



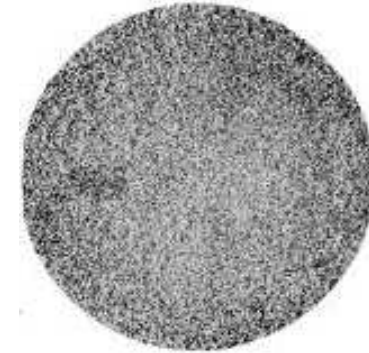
Telescope in Belzoni chamber

**Data**



Data and simulation are corrected for pyramid structure and telescope acceptance

**Simulation with hidden chamber**



Dr. Luis Alva

1963, Chept

Is there a “s



Lawrence Berkeley Laboratory

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

August 1, 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 these 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 niarese level, in the Great Pyramid.

Very sincerely,

*Luis W. Alvarez*  
Luis W. Alvarez

LWA/lb  
Encls.



## **Области применения и преимущества мюонной радиографии**

- **Высокая проникающая способность.**
- **Отсутствие необходимости создавать искусственные источники излучения.**
- **Высокое разрешение и трехмерная картинка**
  
- **МР мониторинг установок ядерно-энергетического комплекса**
- **Фундаментальные научные задачи астрофизики и ядерной физики**
- **Неразрушающий МР контроль промышленных объектов (доменные печи), опор мостовых конструкций.**
- **Альтернативный геофизическим методам способ анализа сейсмических процессов.**



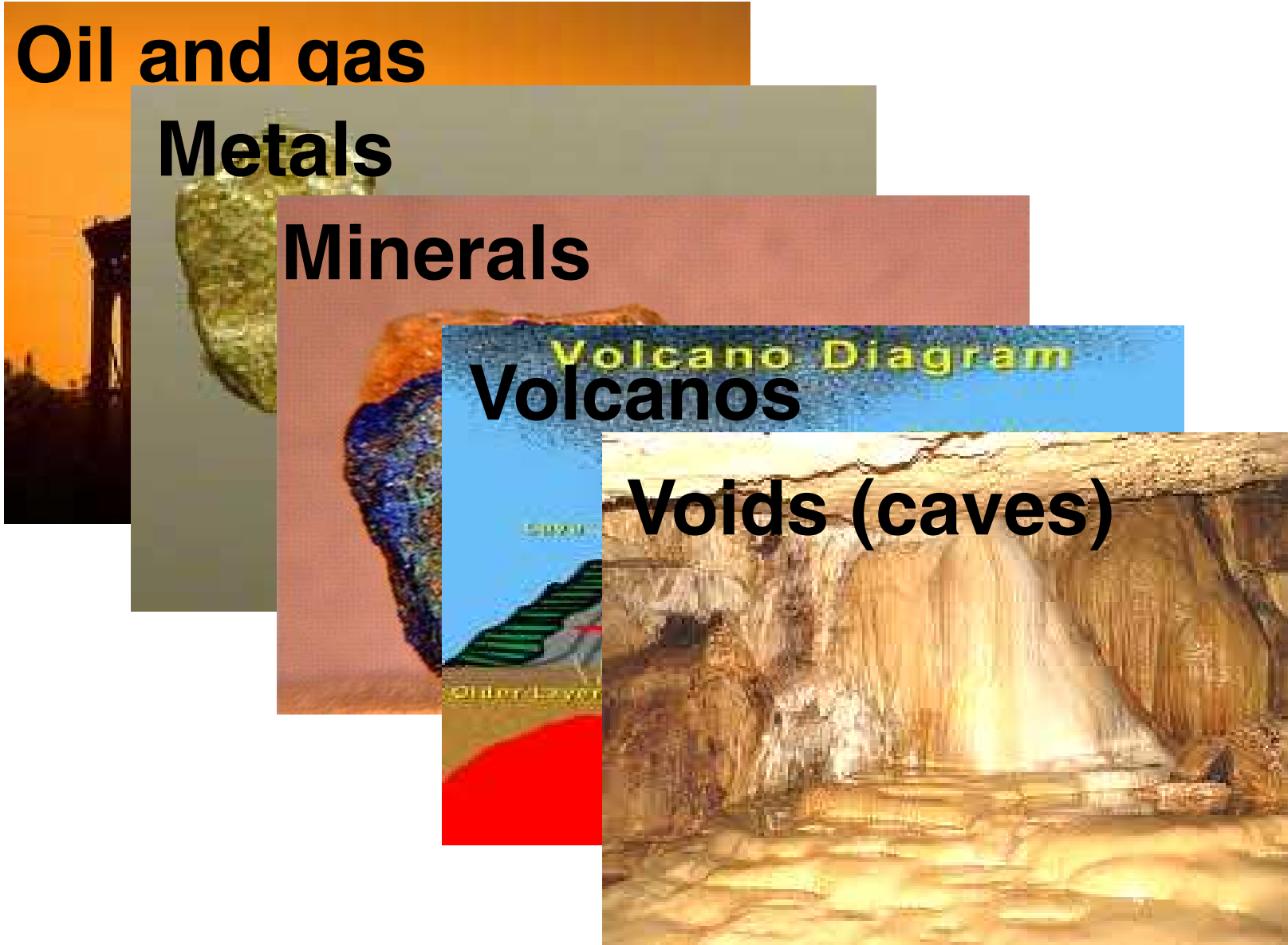
**Oil and gas**

**Metals**

**Minerals**

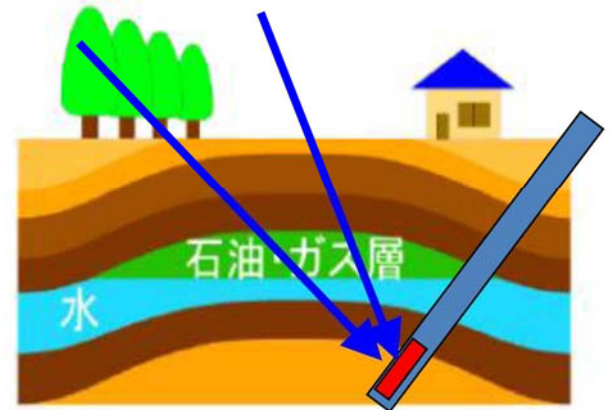
**Volcanos**

**Voids (caves)**



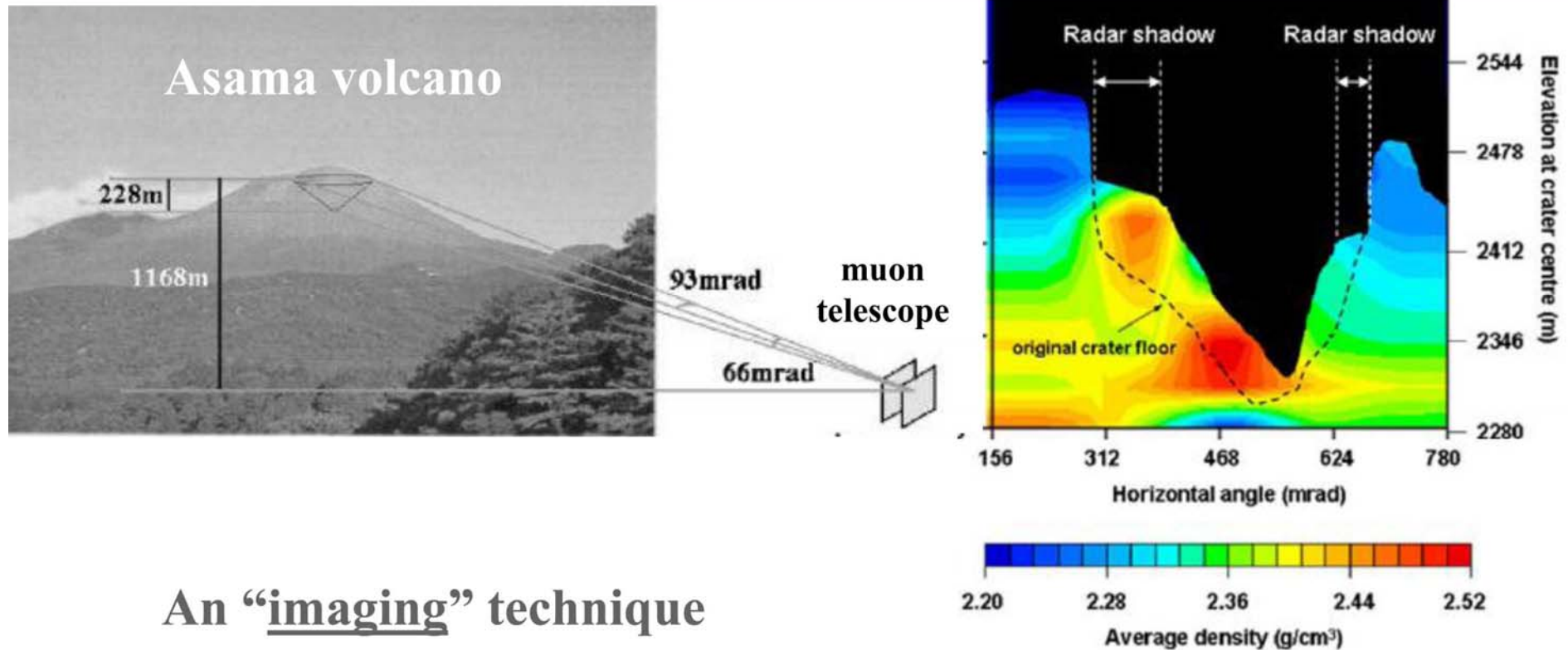


## 資源探査



細いボーリング孔へ設置可能

# Pioneering radiographies in Japan since 2003



An “imaging” technique

Resolution (tens of meters)  
unattainable with conventional  
“indirect” techniques  
(gravimetric, seismic, ...)

**A region of higher density  
(red) visible in the caldera**

**Below it, one sees (blue) a  
region with lower density**

H.T.M. Tanaka and coll.  
EPS Lett. 263 (2007) 104



# Горы Asama, Япония



Простой детектор частиц на основе эмульсионной камеры как инструмент для мюонной радиографии вулканов.

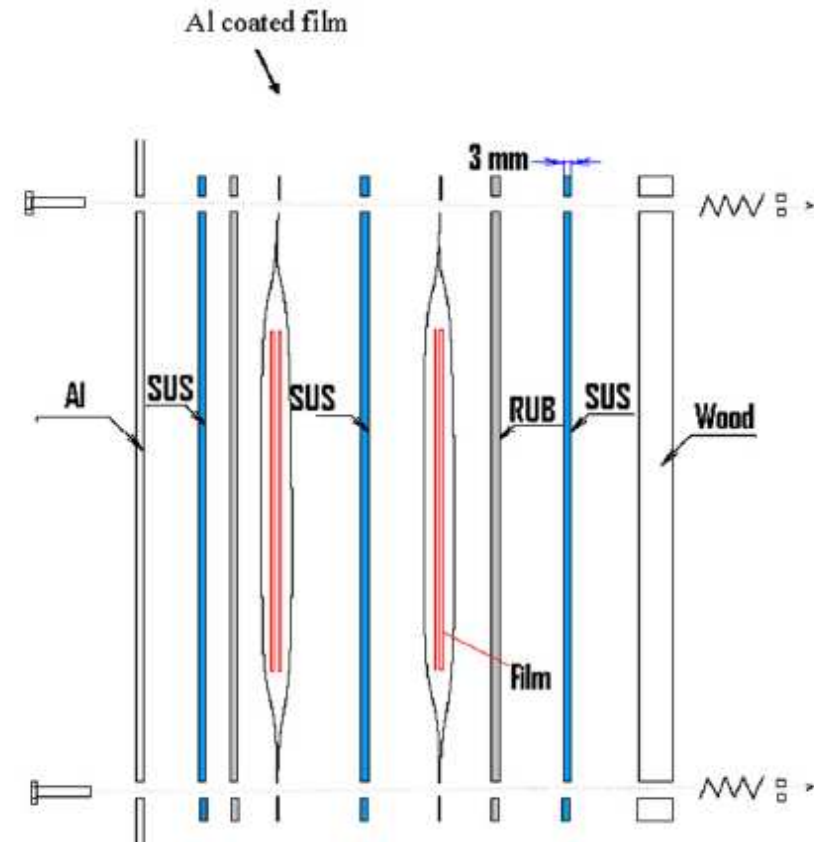
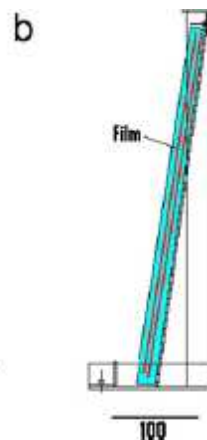
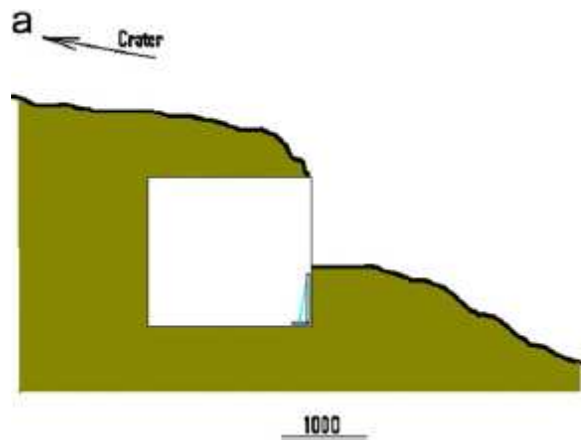
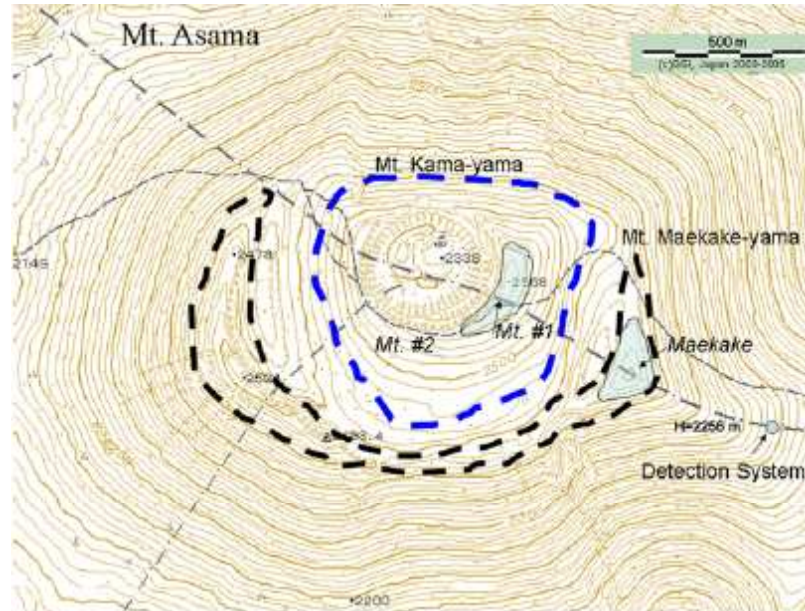
Измерение внутренней структуры горы Кама-уата со стороны горы Маекаке-уата.

Используя значение плотности для горы, определили, что объем заполнения нижней области кратера (в месте между кромкой кратера и 100 м ниже кромки) составляет 8.1%.

Определена плотность породы горы Кама-уата –  $2.25 \text{ г/см}^3$ .

Один из самых активных вулканов.

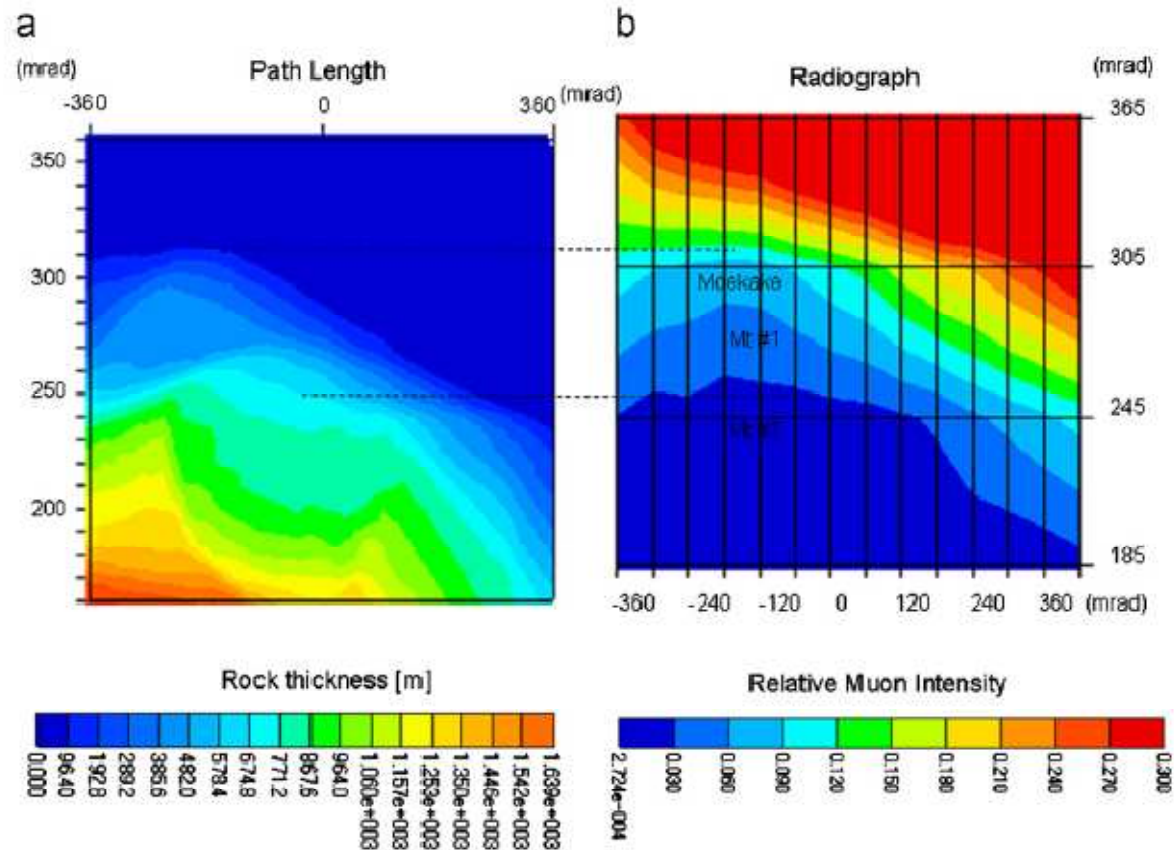
# Детектор (Asama)



Emulsion chamber comprising two sets of emulsion films in coincidence, three iron plates, and four rubber sheets. The thickness of each iron plate is 3 mm.

Расположение детектора относительно гор

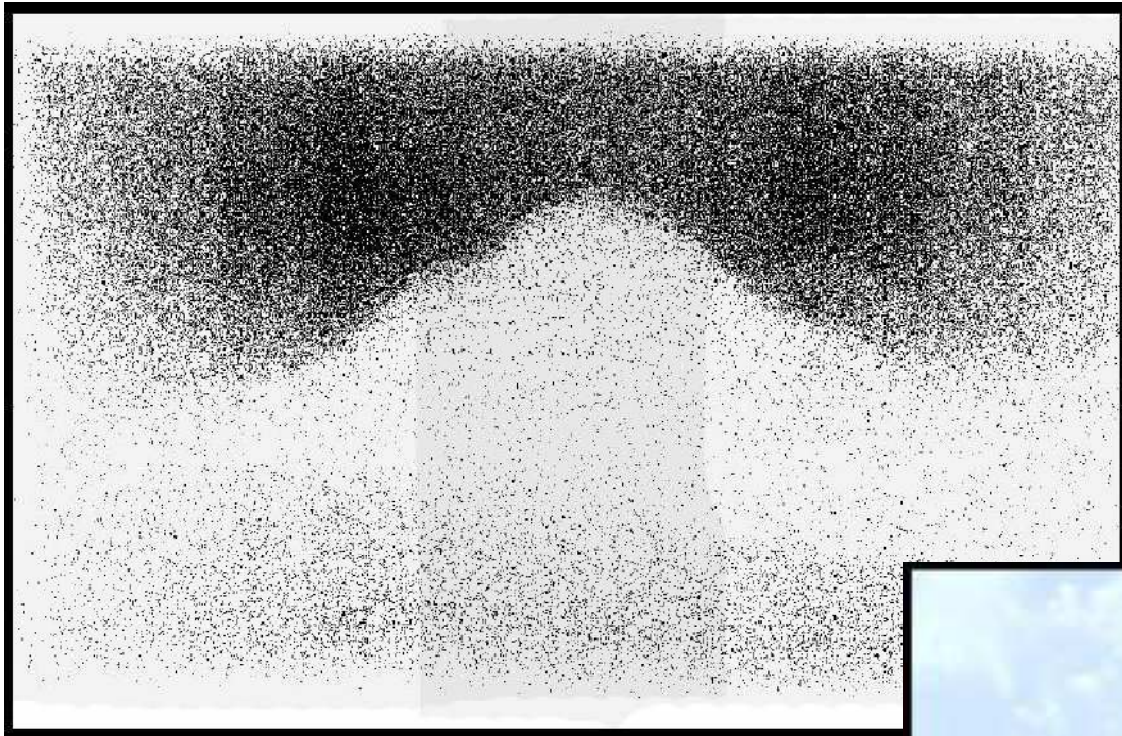
# Результаты (Asama)



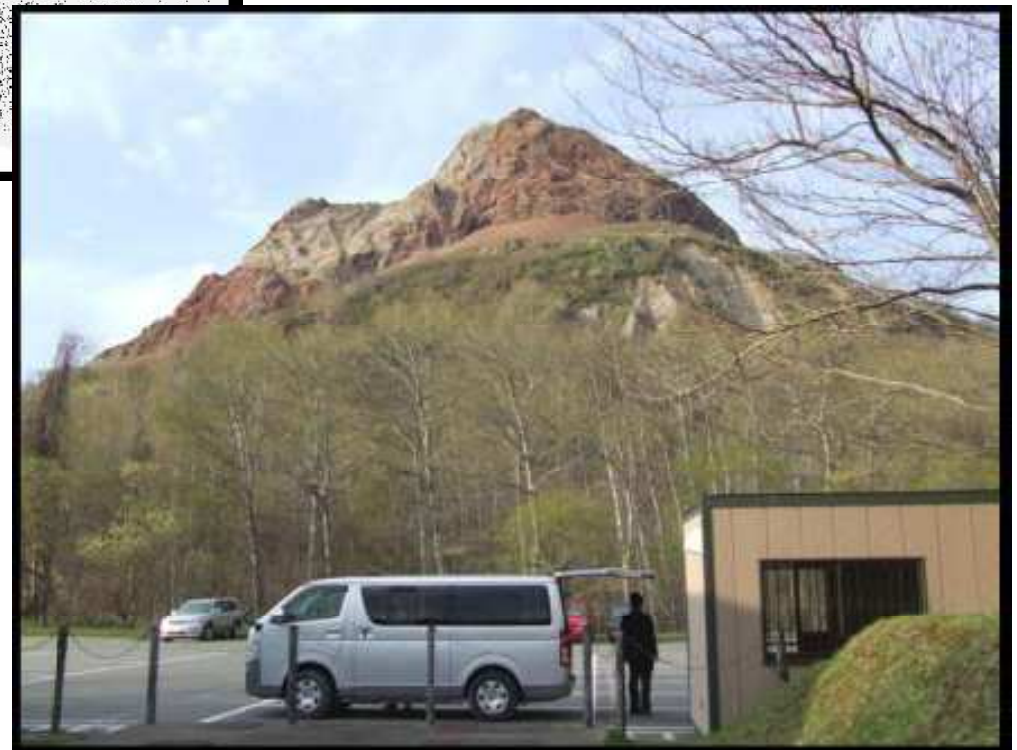
Angular distribution of path length from the topographic map in the top region of Mt. Asama as viewed from Maekake observation point (a). The unit is in meter. (b) The cosmic-ray muon radiograph as plotted with relative muon intensity  $n(y, f)$  is shown in the same angle region. The shadow features in the radiograph indicated by Maekake, Mt. #1, and Mt. #2 correspond to the peaks.



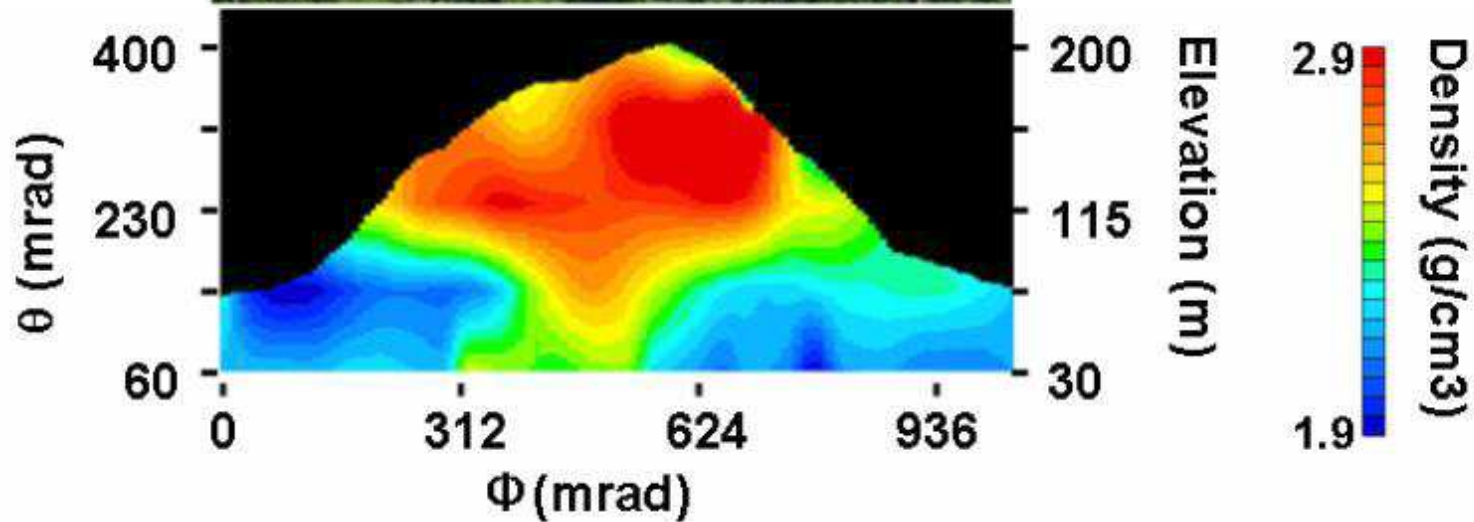
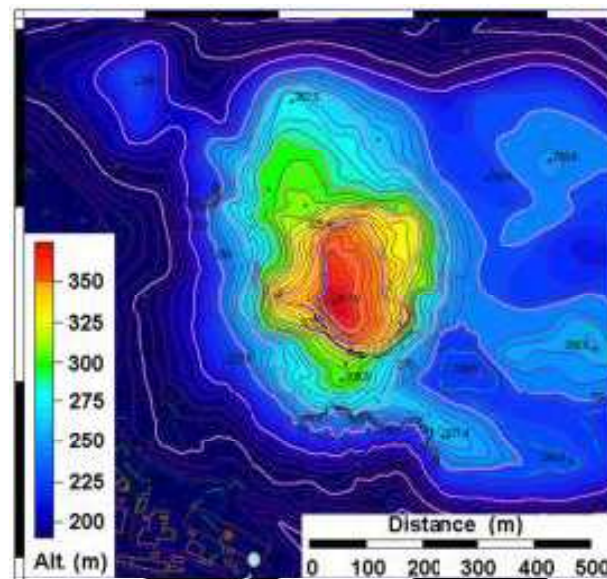
# Cosmic-ray Photograph of a Volcano (Showa-Shinzan)



1dot=1muon  
Angular space distribution



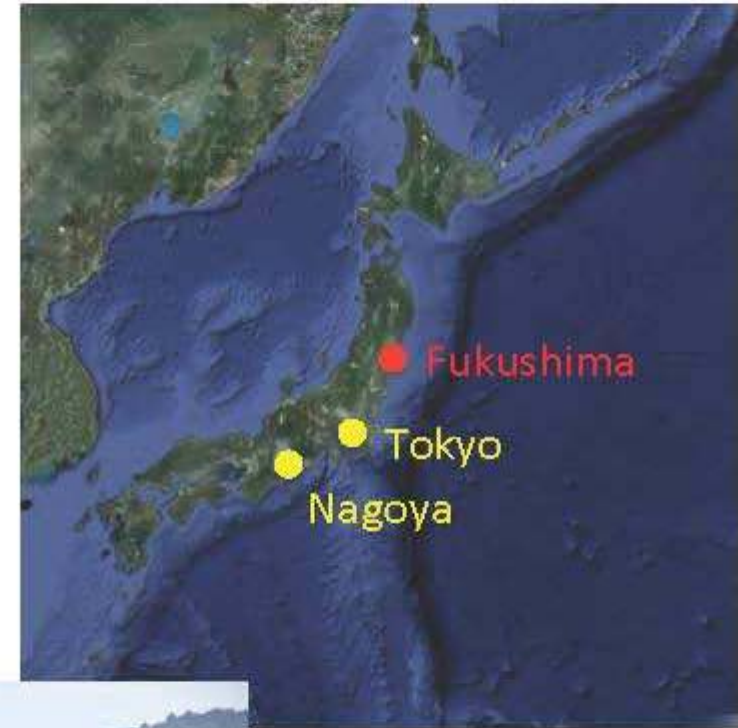
# Density analysis of Mt. Showa-Shinzan





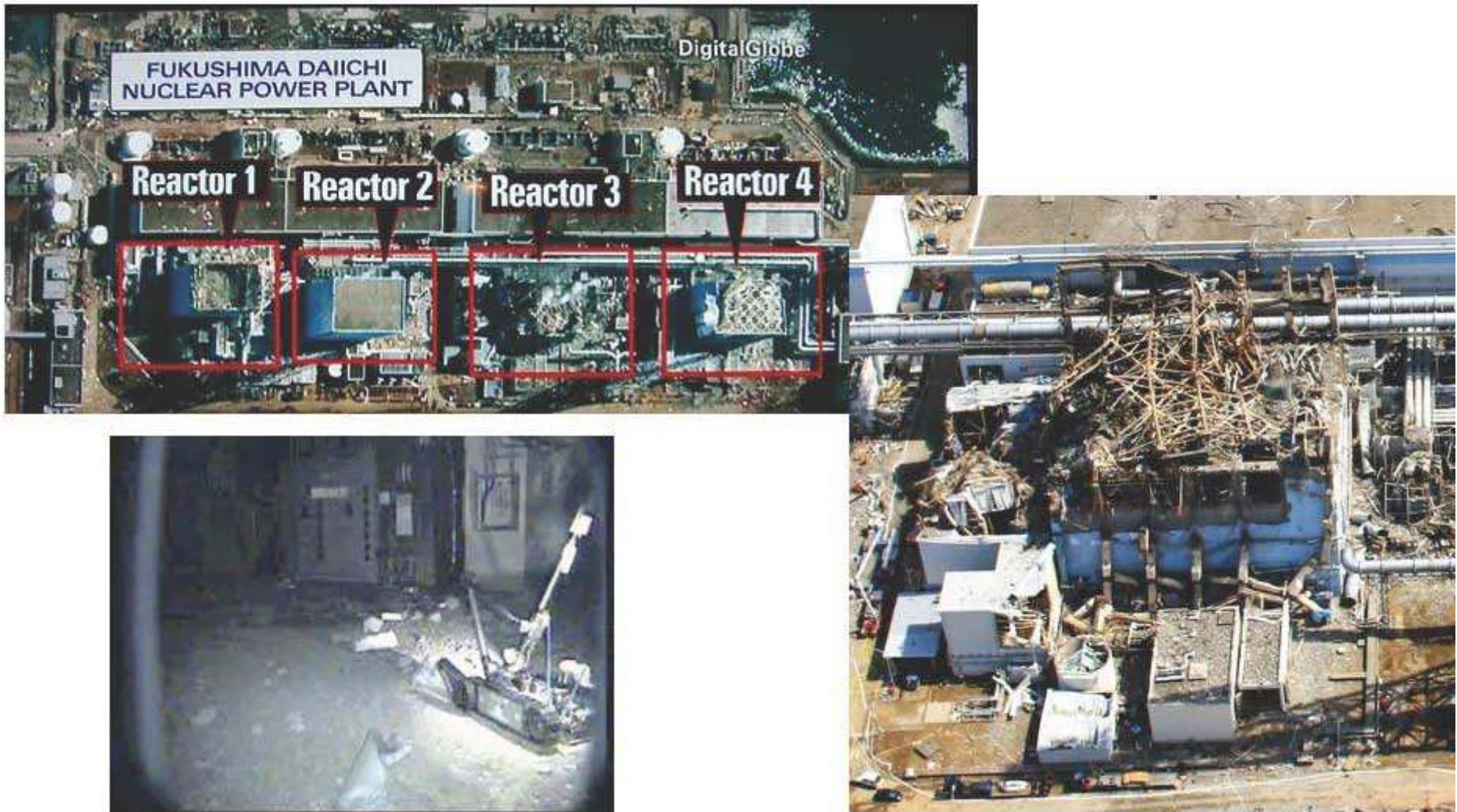
# The Great East Japan Earthquake

## 2011.3.11





# The Fukushima Daiichi Nuclear Power Plant Accident

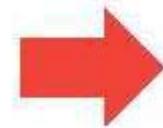


A cooling system stopped and it is thought that the meltdown of the nuclear reactor happened.

# The problem in observation



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



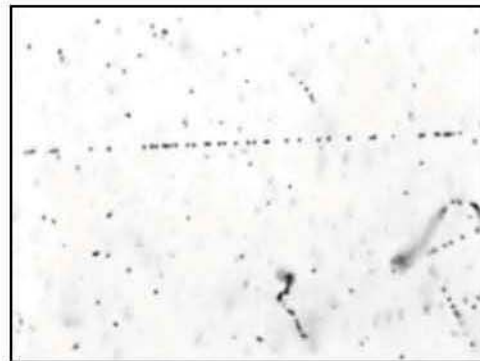
**Emulsion  
is better solution**



# Candidates of detectors

## Nuclear Emulsion

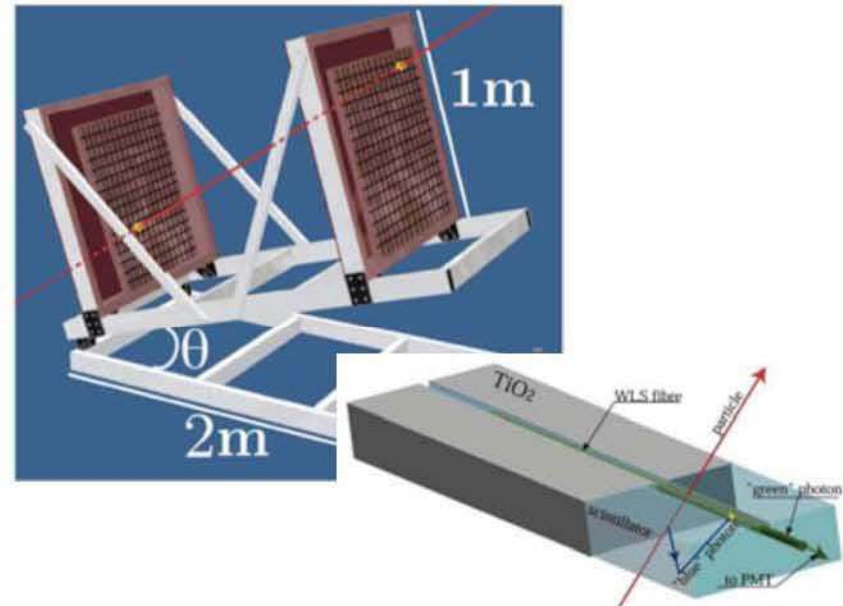
High resolution, no power supply



Detector unit size is silver grain (1 $\mu$ m)

## Electric Detector

Real-time responsibility



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

Detector Size :

Emulsion is able to be 1000 (1 $\mu$ m/1mm) times smaller in each dimension to achieve the same resolution

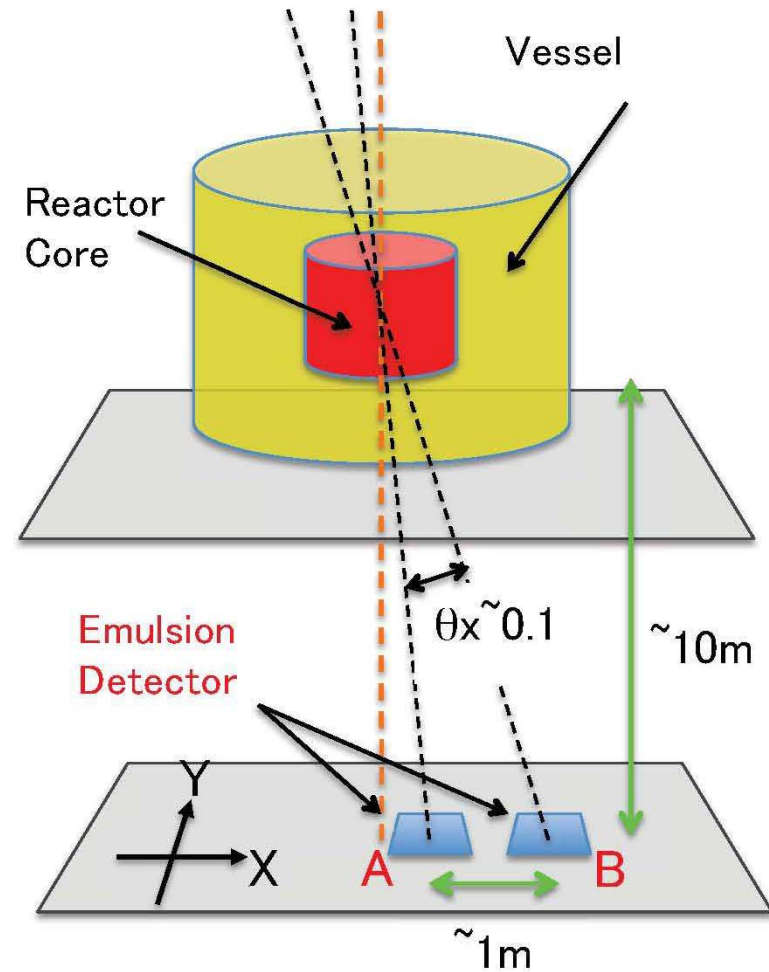
# Test experiment using experimental fast reactor : Joyo



It is inapplicable to Fukushima daiichi before a technical actual proof because the work under high radioactive environment is needed.

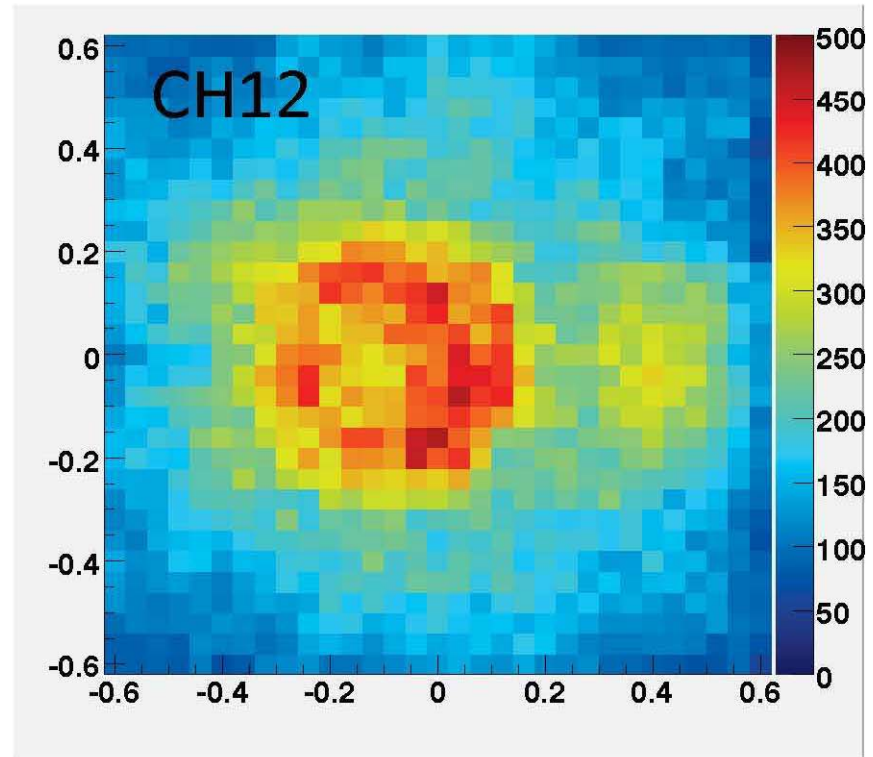
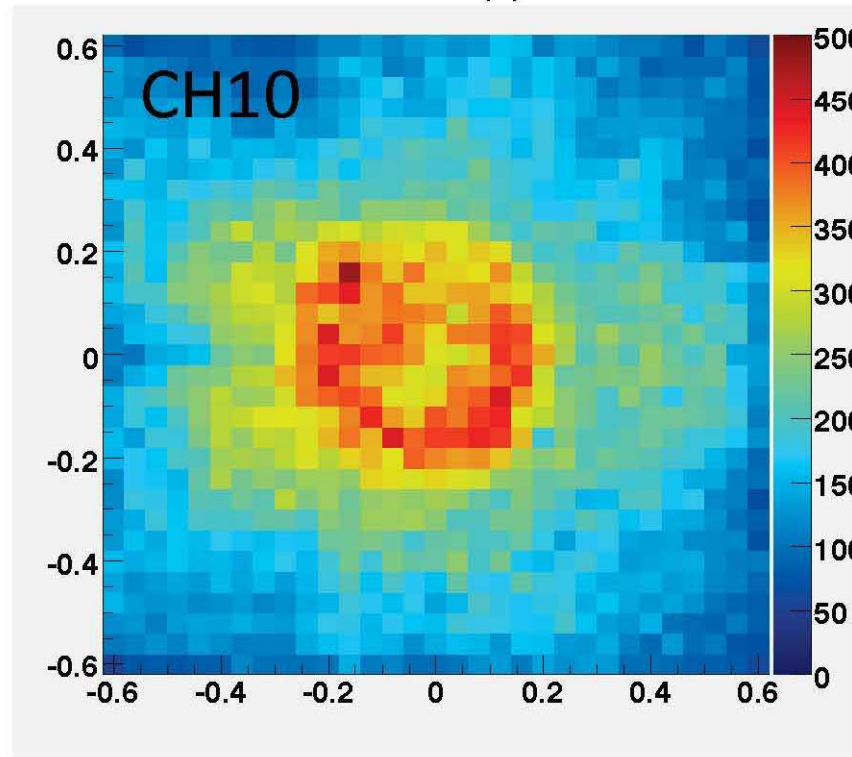
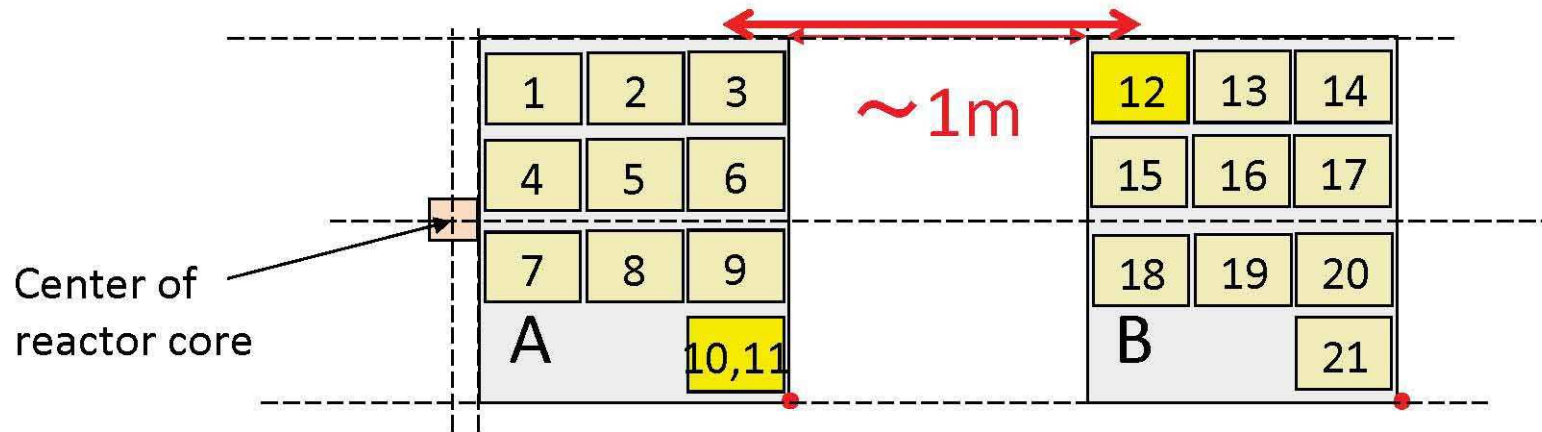


Detector was made in Nagoya-Univ.  
Exposure time in Joyo : 21days  
Developed in Nagoya-Univ.





# Comparison between 2 chambers



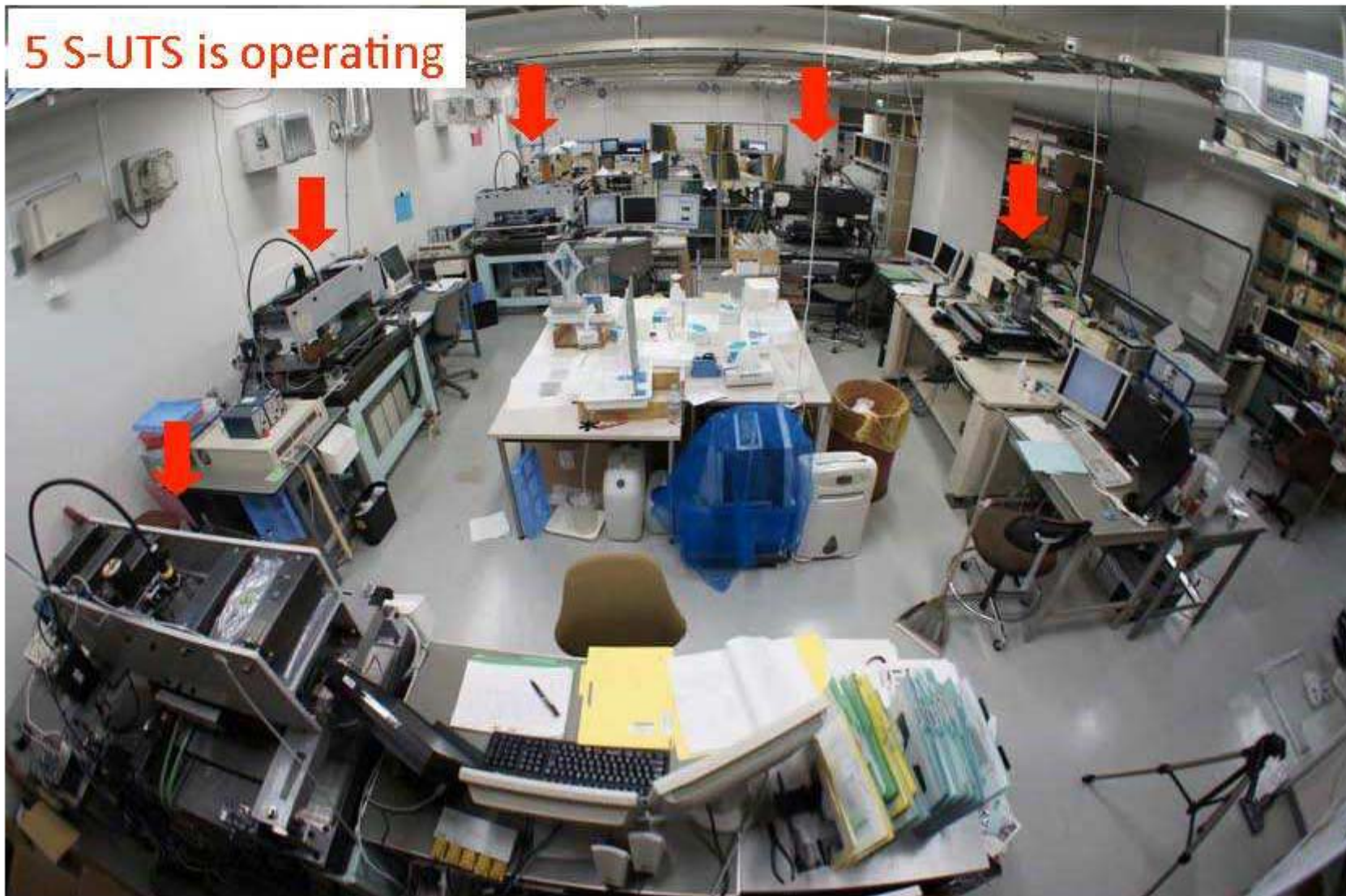
# Emulsion Scanning System in Japan

## Super-Ultra Track Selector





# Read out of emulsion @ Scanning facility at Nagoya University

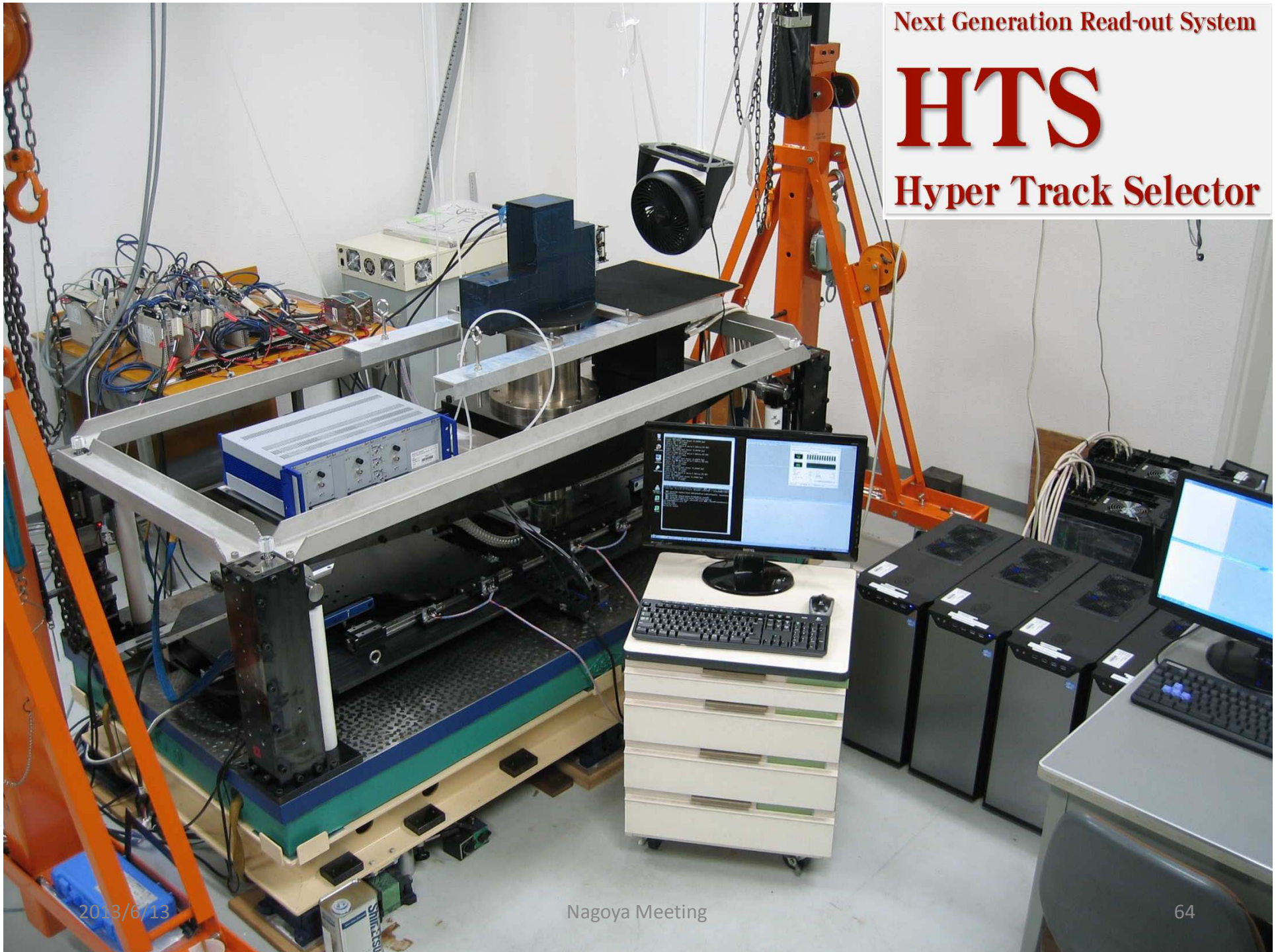




Next Generation Read-out System

# HTS

## Hyper Track Selector



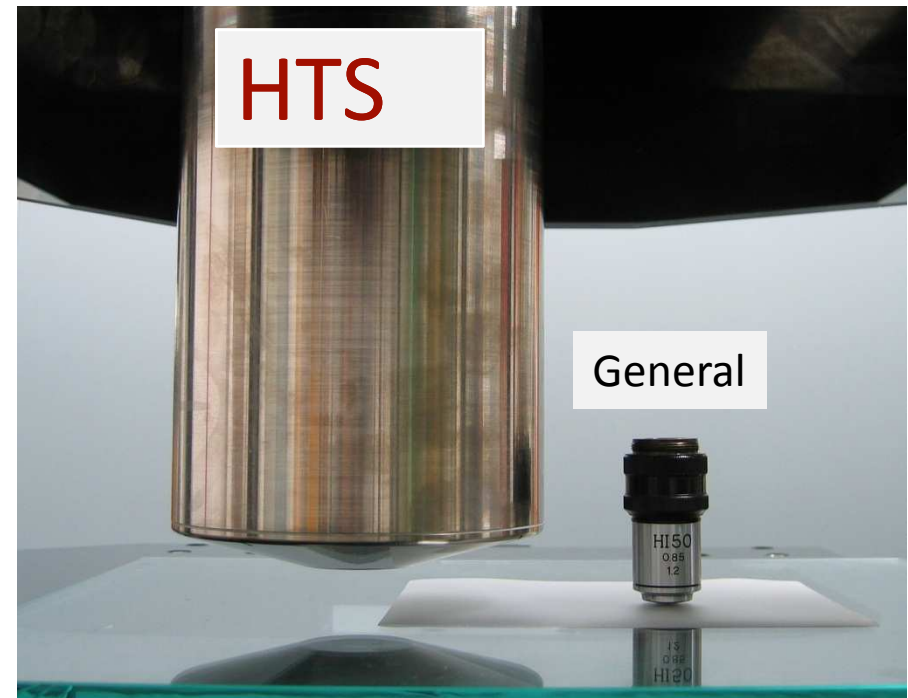
2013/6/13

Nagoya Meeting

64

# HTS concept

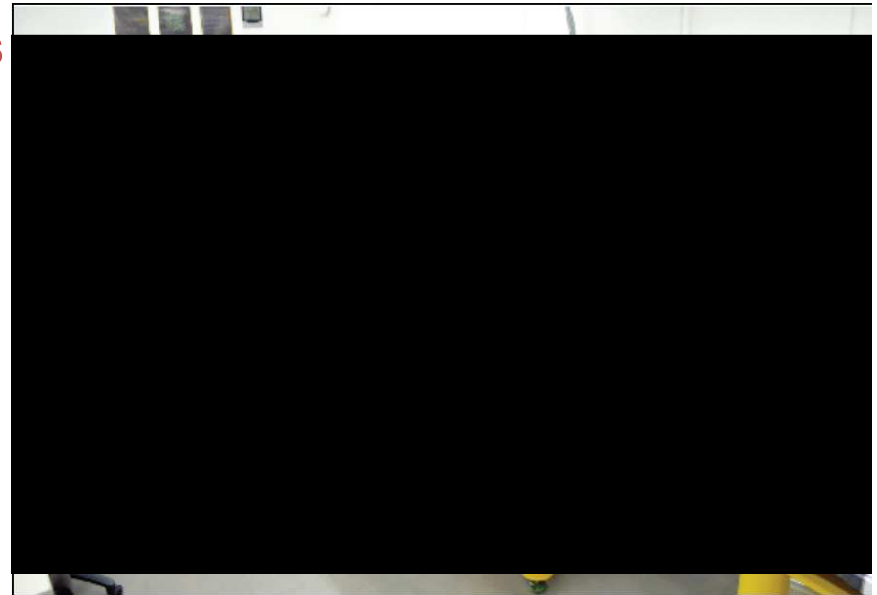
- Very large field of view  
5 x 5 mm<sup>2</sup>
- Extremely quick stage using  
the linear motor
- GPGPU based image processing



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

# Muon Geo-radiography with emulsions

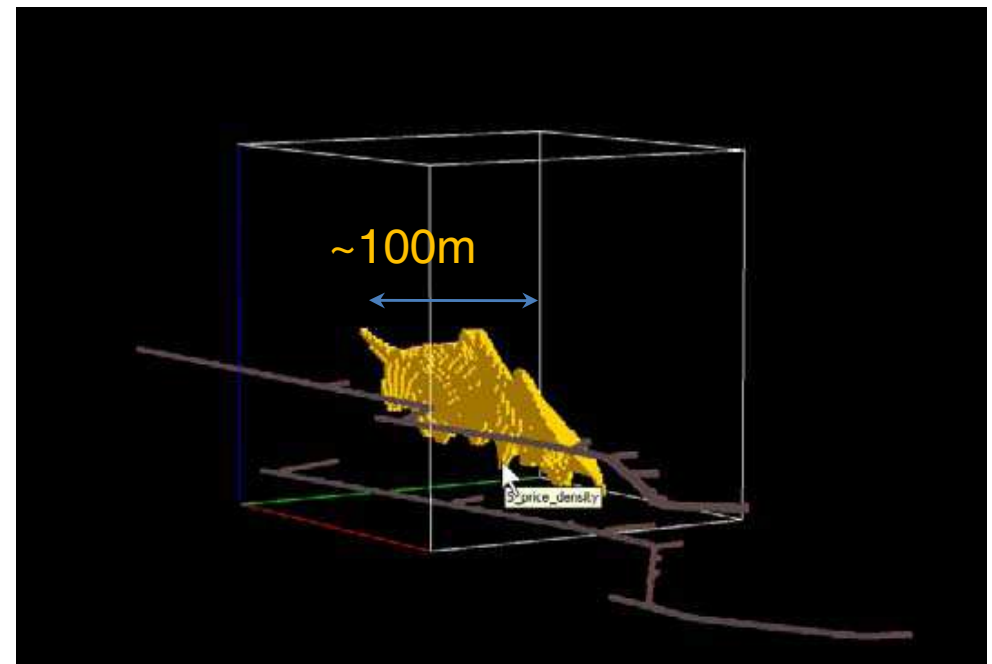
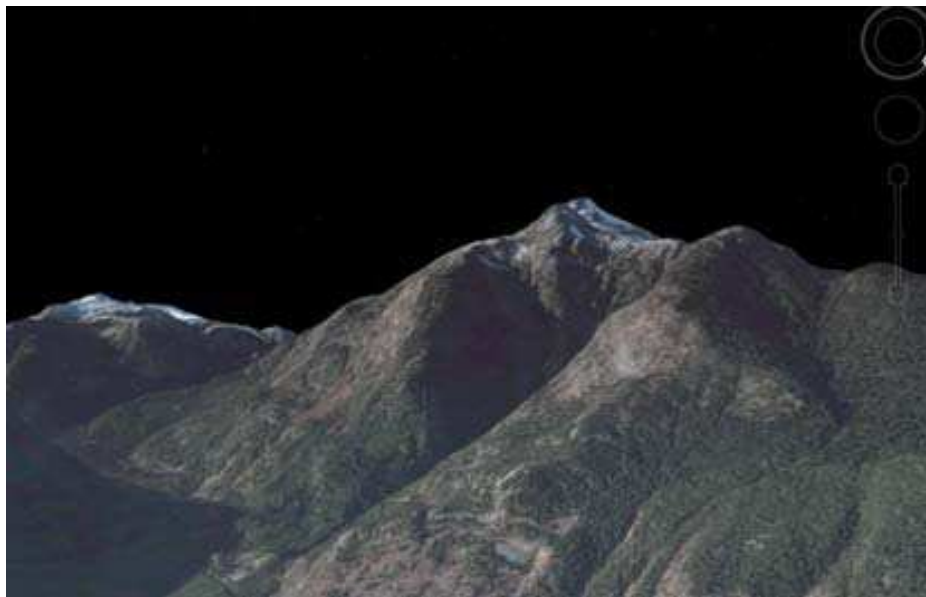
1. Muons
2. Detector – emulsion film modules
3. Scanning facility
4. Analysis power



Time for prototype test

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

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

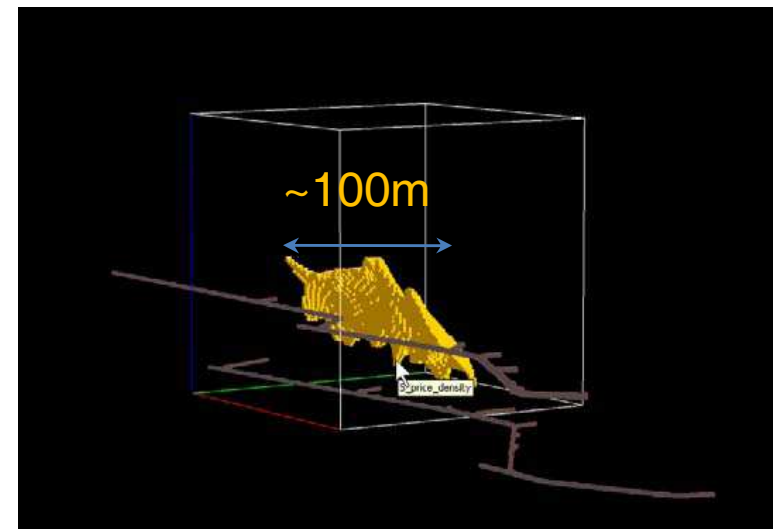




## Muon Geo-radiography with emulsions

1. Test site is chosen: large known object + small unknown! **Gold?**
2. Muons are available
3. Detector – 10 emulsion film modules placed in tunnels around the object
4. Scanning facility ready in Bern
5. 3D analysis from 10 x 2D projections
6. Calculations promise success... ( density resolution ~10% )

Prototype test is ongoing!





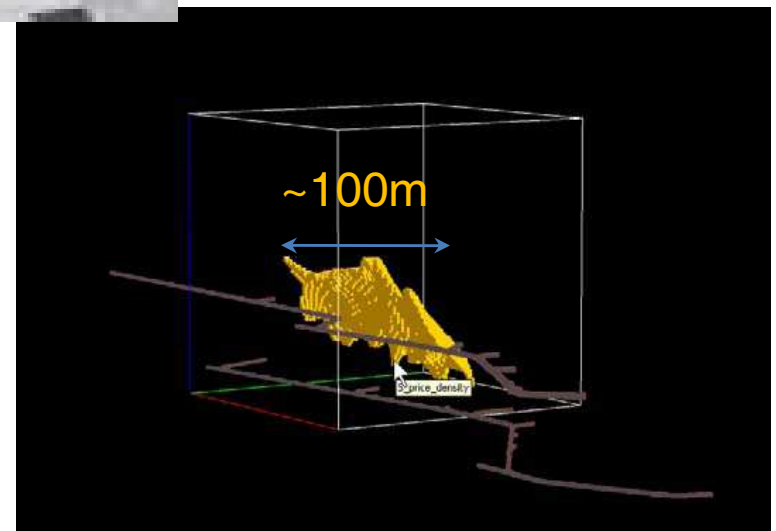


emulsions

own!

els around the object

~10% )



# ITALY

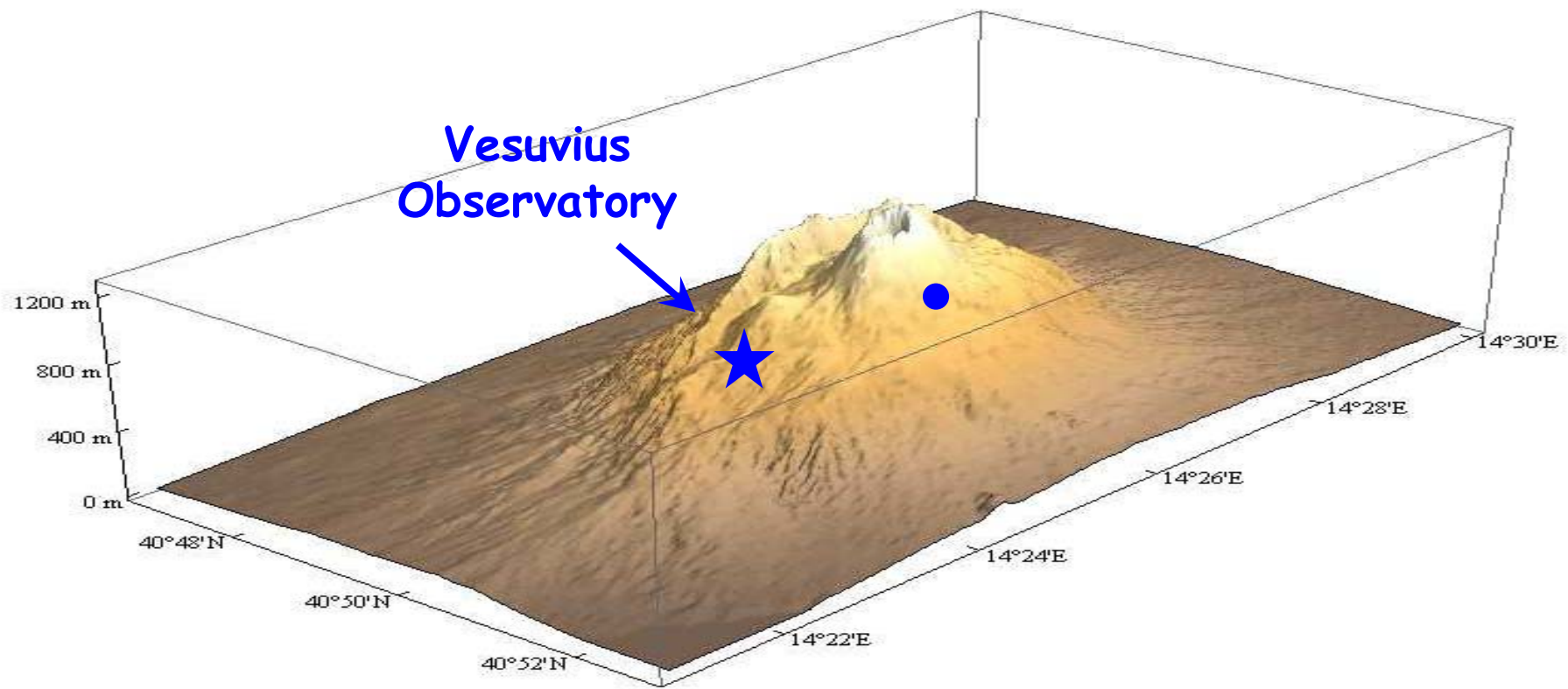
- Active (after 1944 quiescent) volcano, 1280 m high
- Grown in the caldera of an older, larger volcano (Mt. Somma)

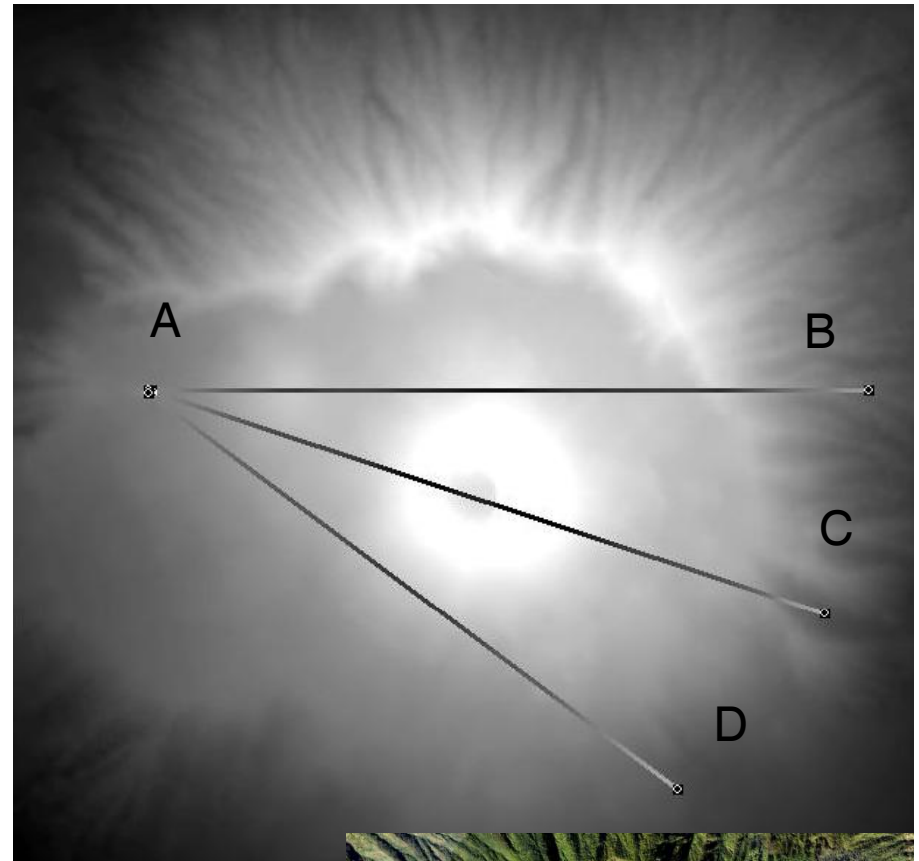
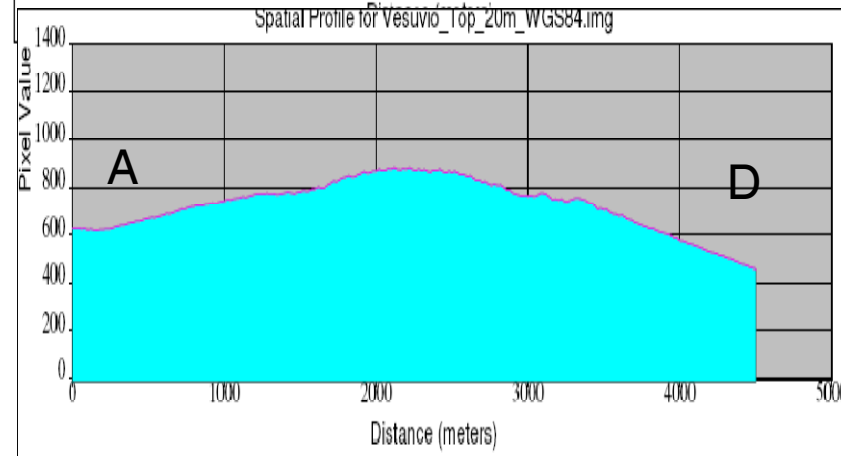
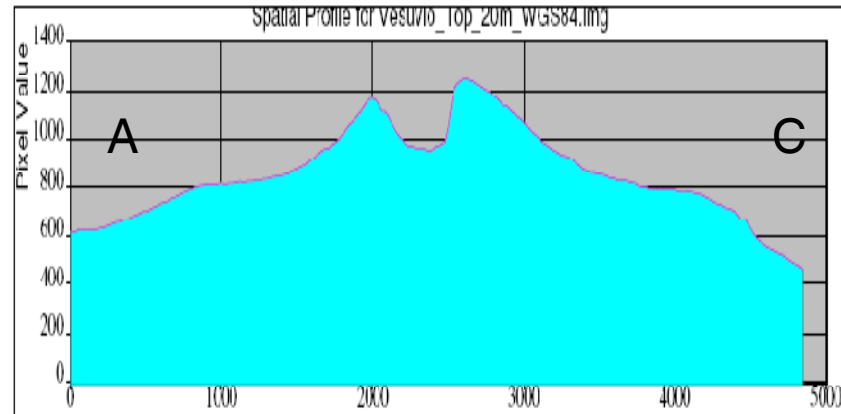
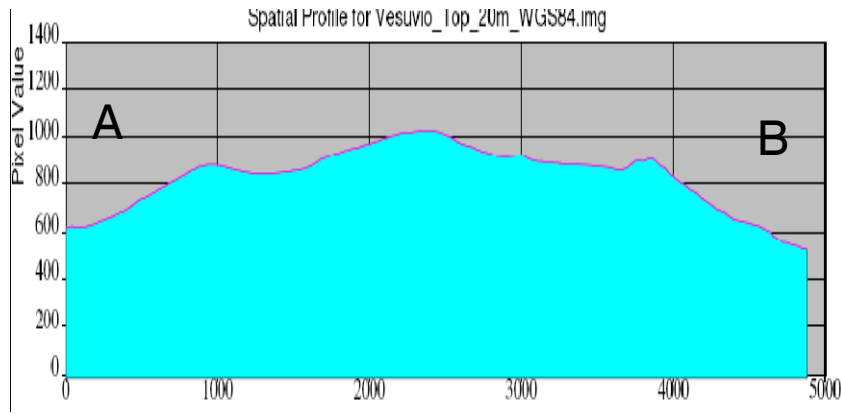












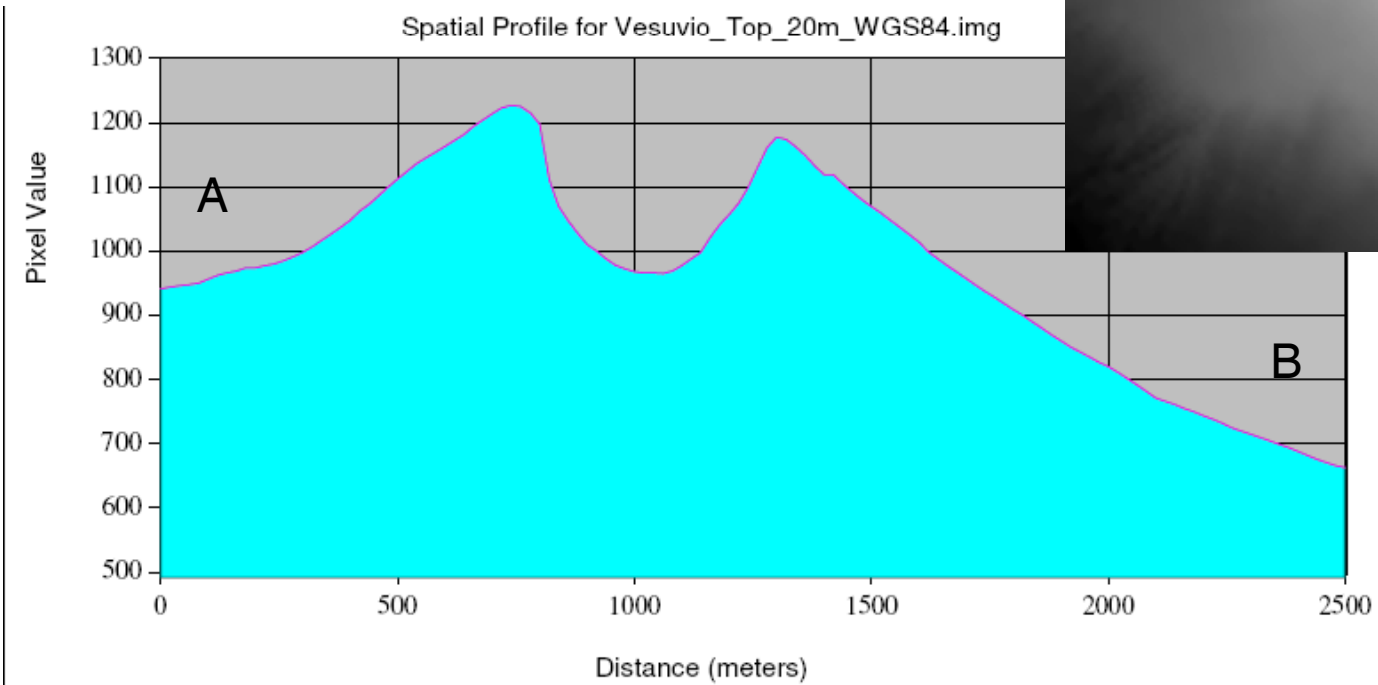
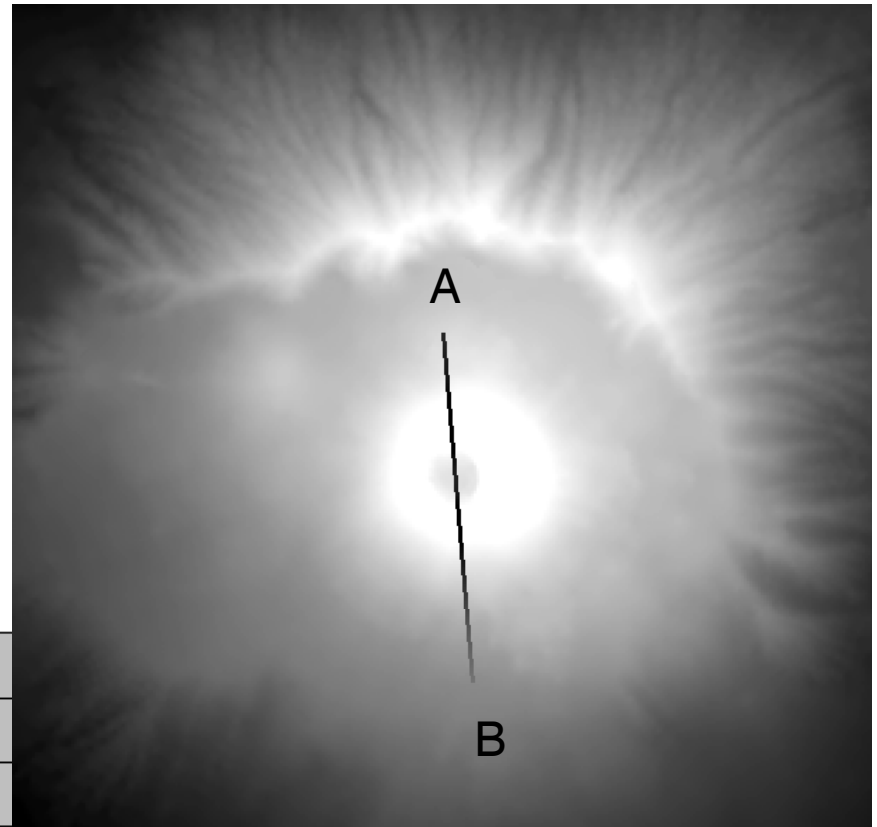
## Osservatorio Vesuviano



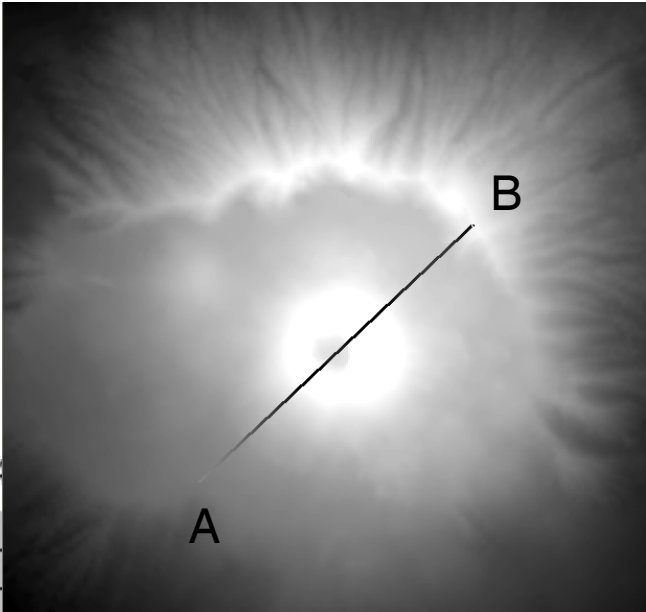




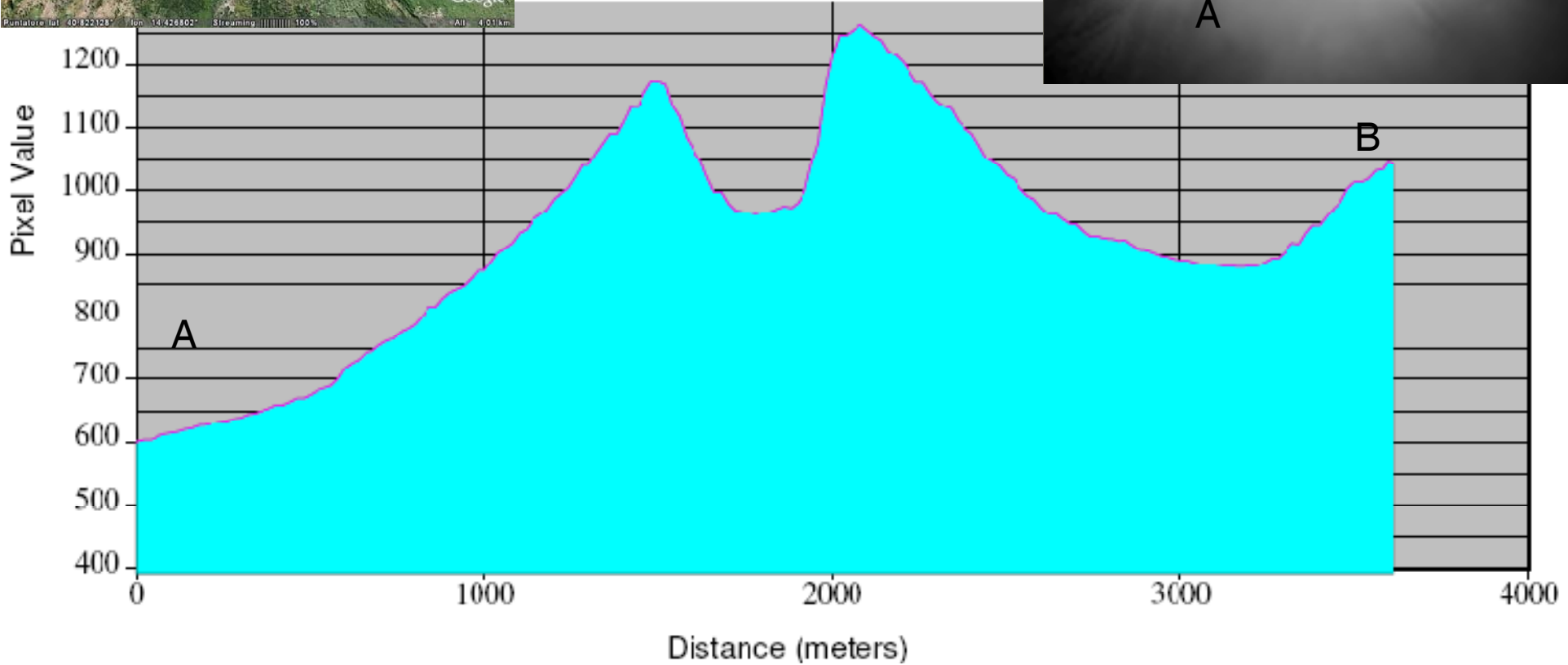
**N Site**



# Baracche Forestali

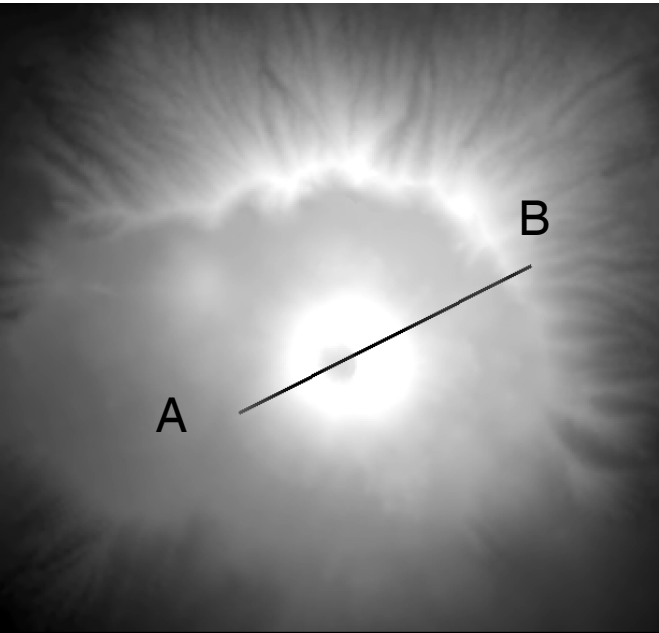


Partial Profile for vesuvio\_top\_20m\_wgs84

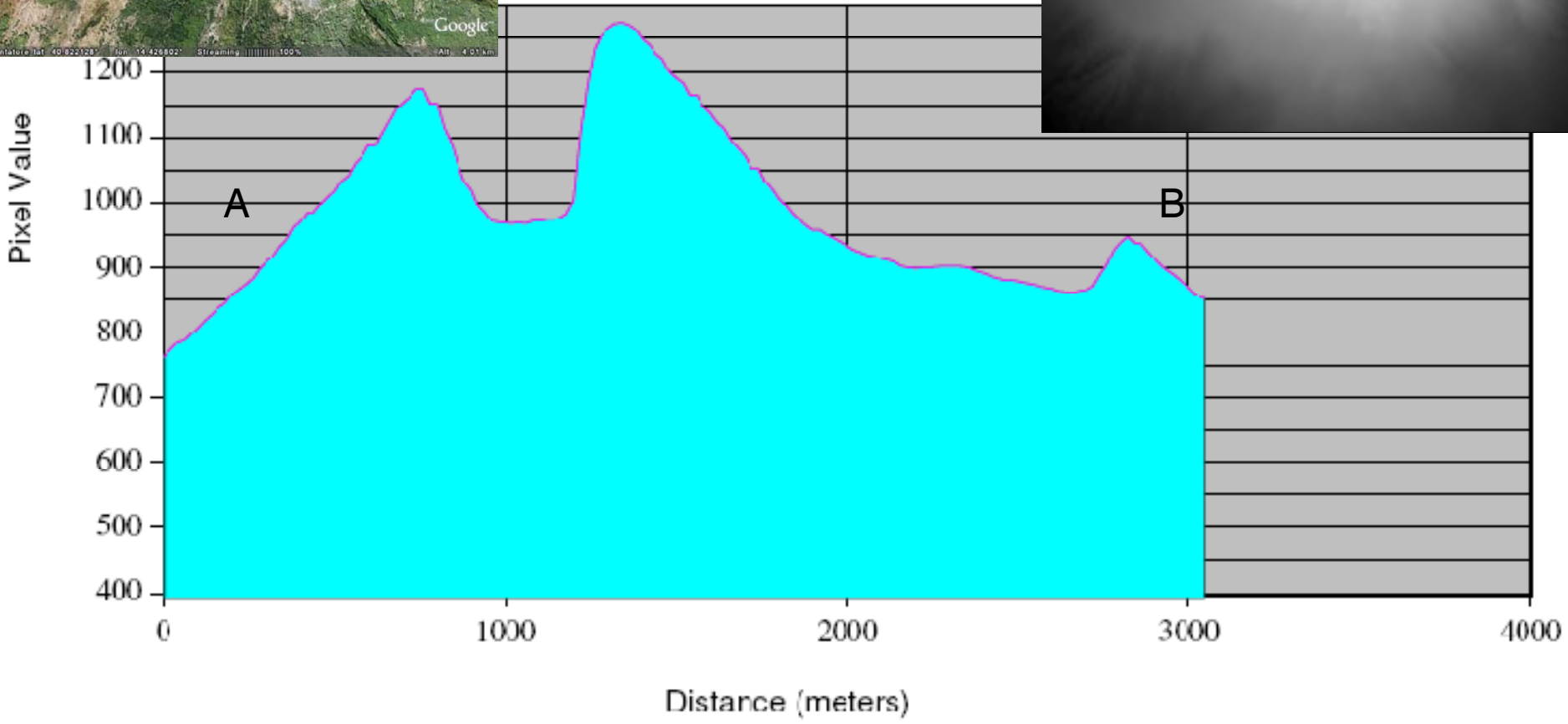




**Seggiovia  
(Cable Cab)**



Profile for Vesuvio\_Top\_20m\_WGS







Allegri alla partenza 20/10/2011 ore 10:00



## Saluto del Vulcano ore 11:01

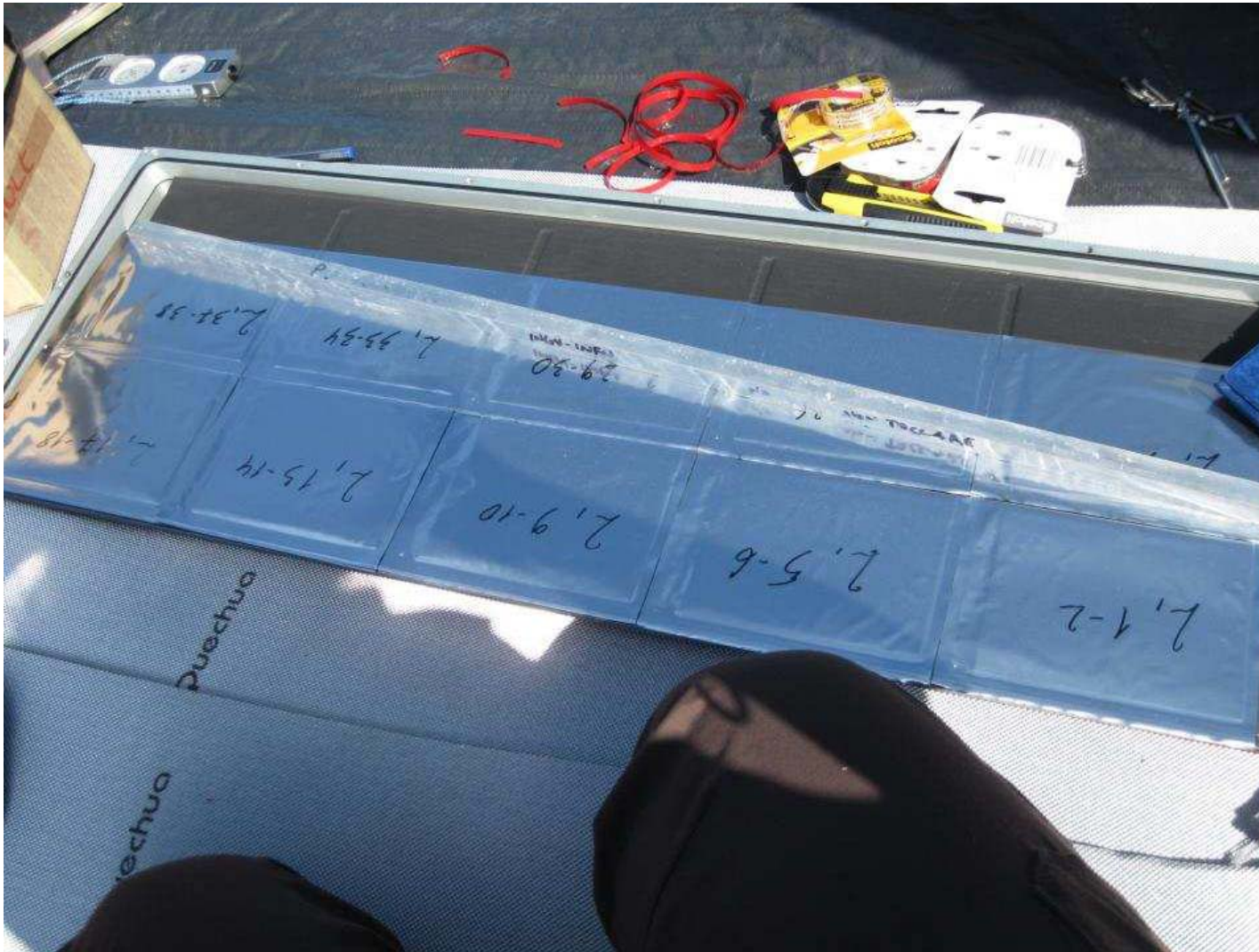


## Primo posizionamento ore 11:35





## Incollaggio pilota ore 12:20



Temperatura percepita : 30° C segue veloce montaggio tenda !!

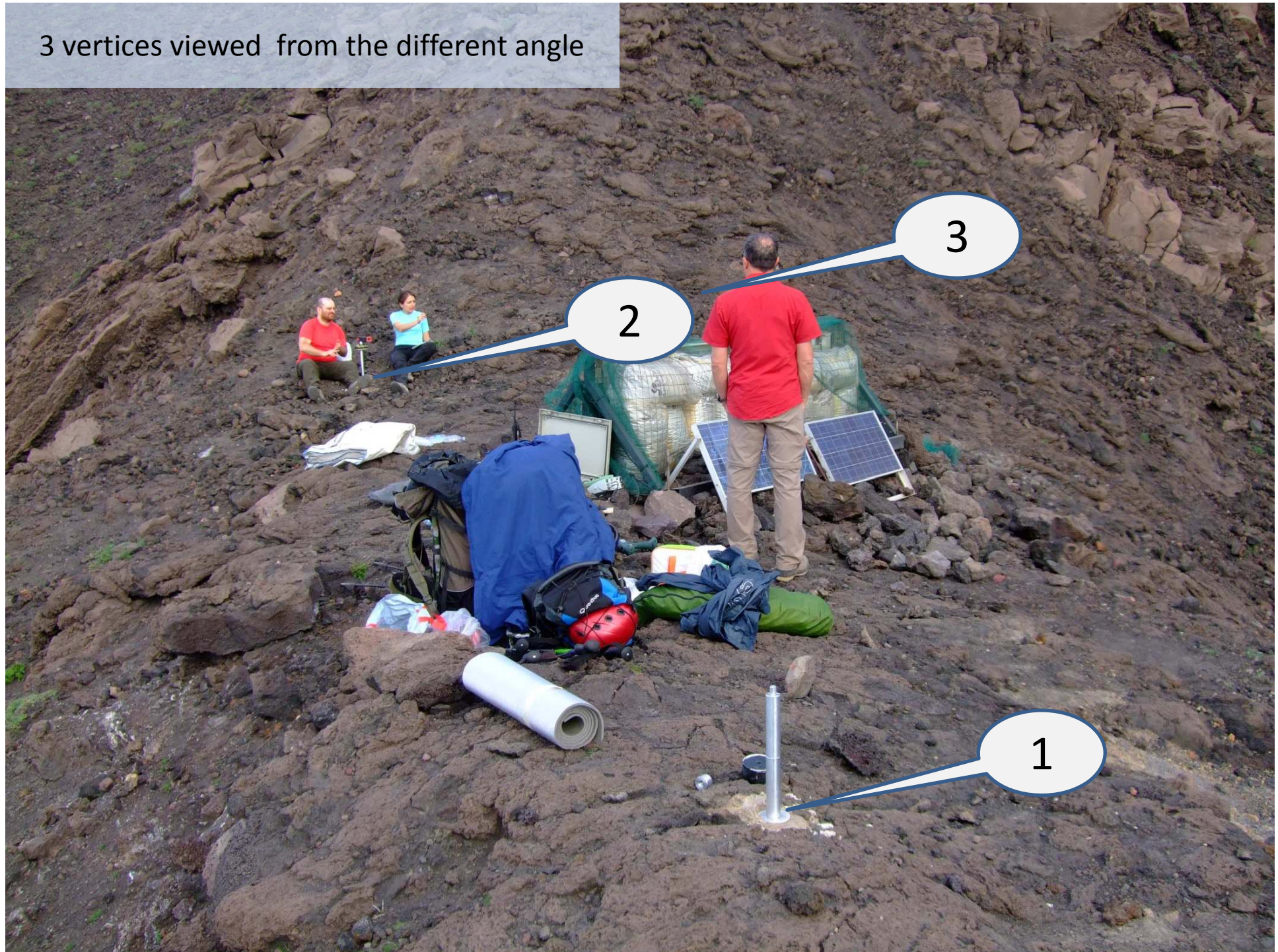


We found the detector as we left it 5 months before:  
22/10/2011 – in a good condition, well protected from  
sun and rain by rubber foam (armaflex) and by Ex-clay  
sacks (argilla espansa)



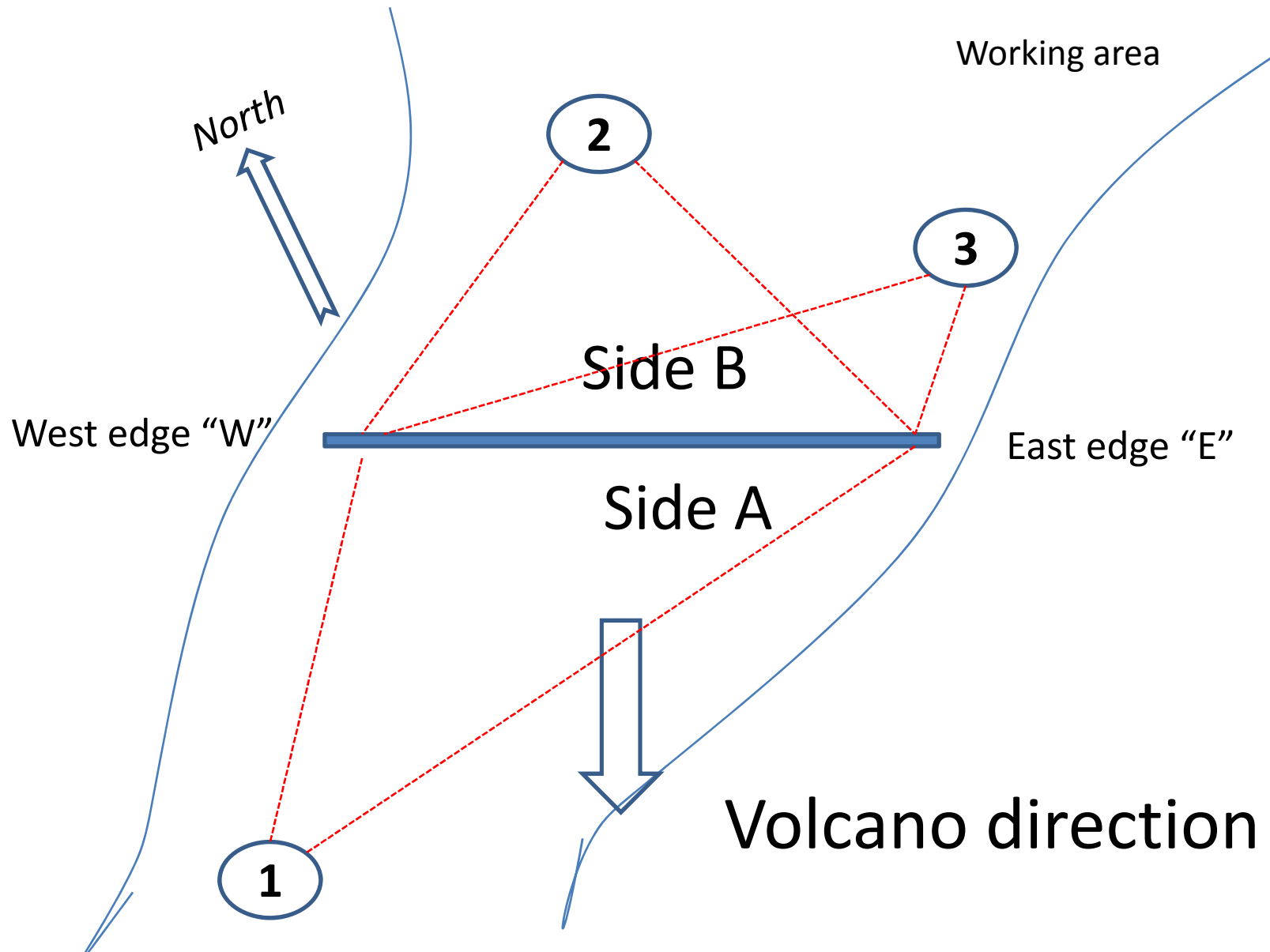


3 vertices viewed from the different angle





# The scheme of the reference vertices (top view)

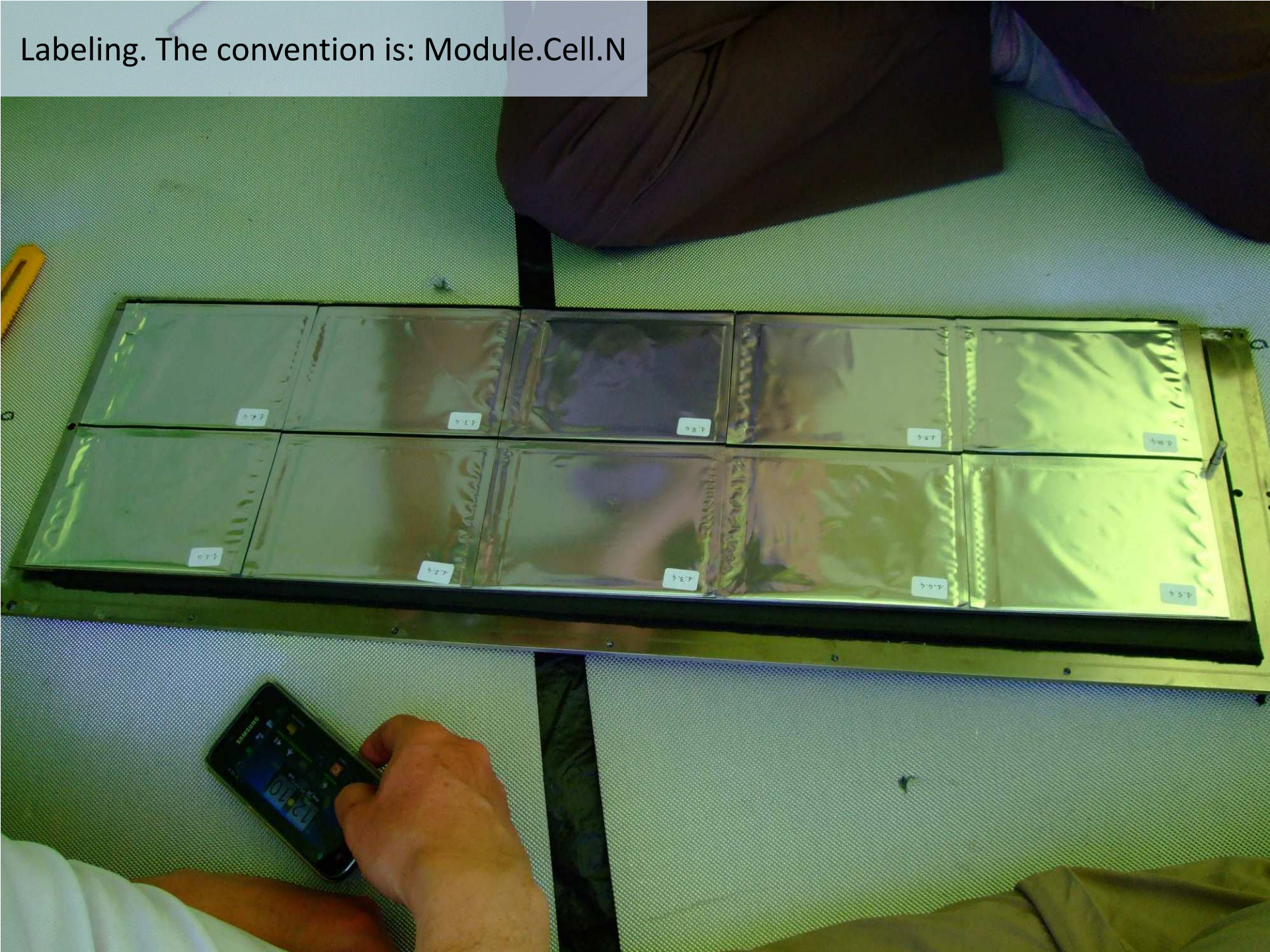


Emulsion envelopes seems to be in a good condition





Labeling. The convention is: Module.Cell.N



# **Muon radiography test of nuclear emulsion detector method, LPI RAS + SINP MSU:**

Emulsion stacks were inserted within the body of a steel metal column of SINP MSU accelerator frame and outside

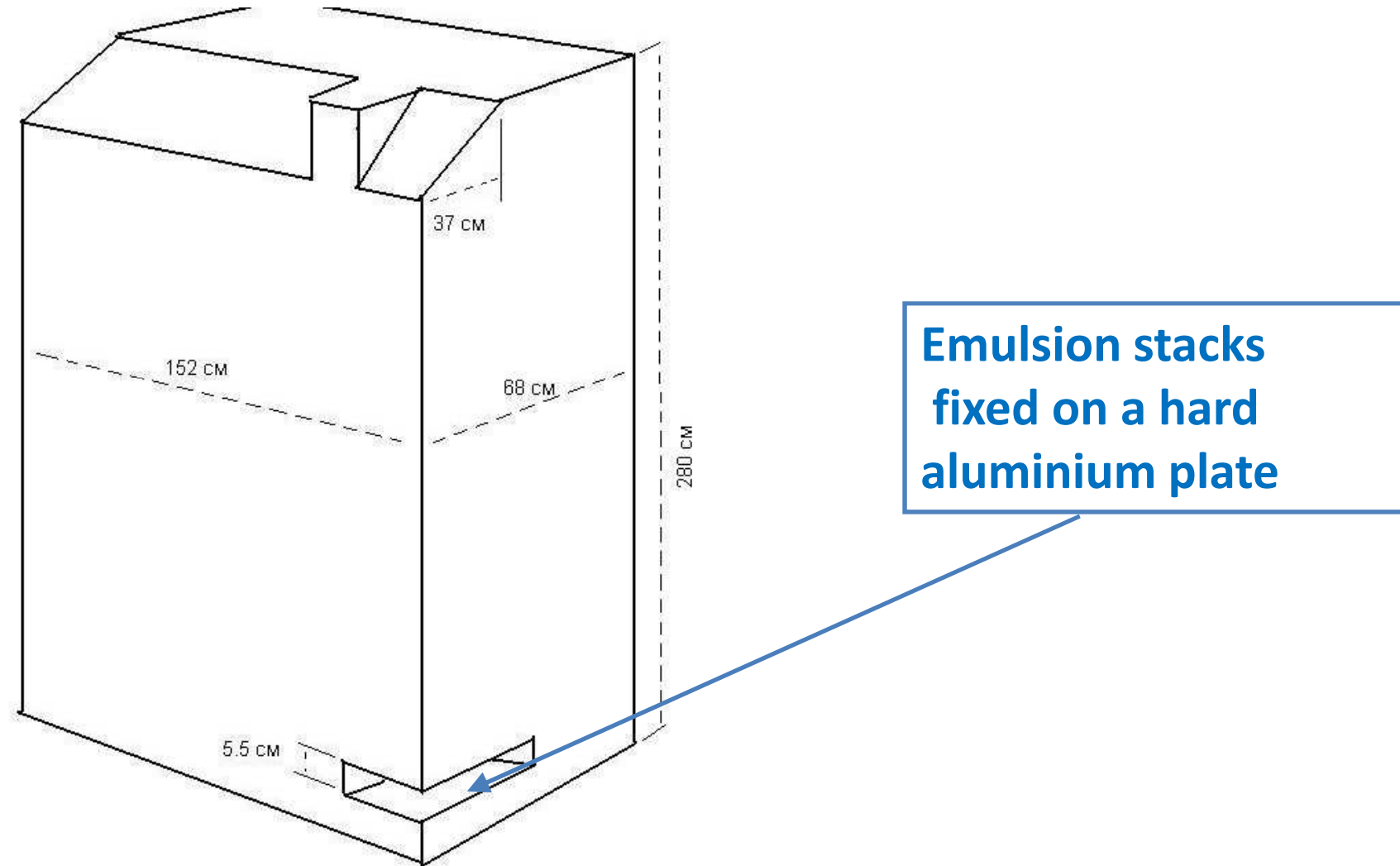


# Metal column of the accelerator frame





# Steel column, which is the part of an accelerator frame



# Prepared stacks of emulsions and aluminium plate with fixed stacks



## Structure of emulsion stacks:

- 1. “Slavich”** emulsion — 3 single layer emulsion plates + metal plate + 3 single layer emulsion plates.
- 2. Fuji-OPERA** emulsion — Changeable sheet stack + metal plate + Changeable sheet stack (12 layers in total).
- 3. Fuji-OPERA** emulsion — 4 emulsion layers.



# Arrangement of emulsion stacks into metal column



# Estimations and expected results of the test

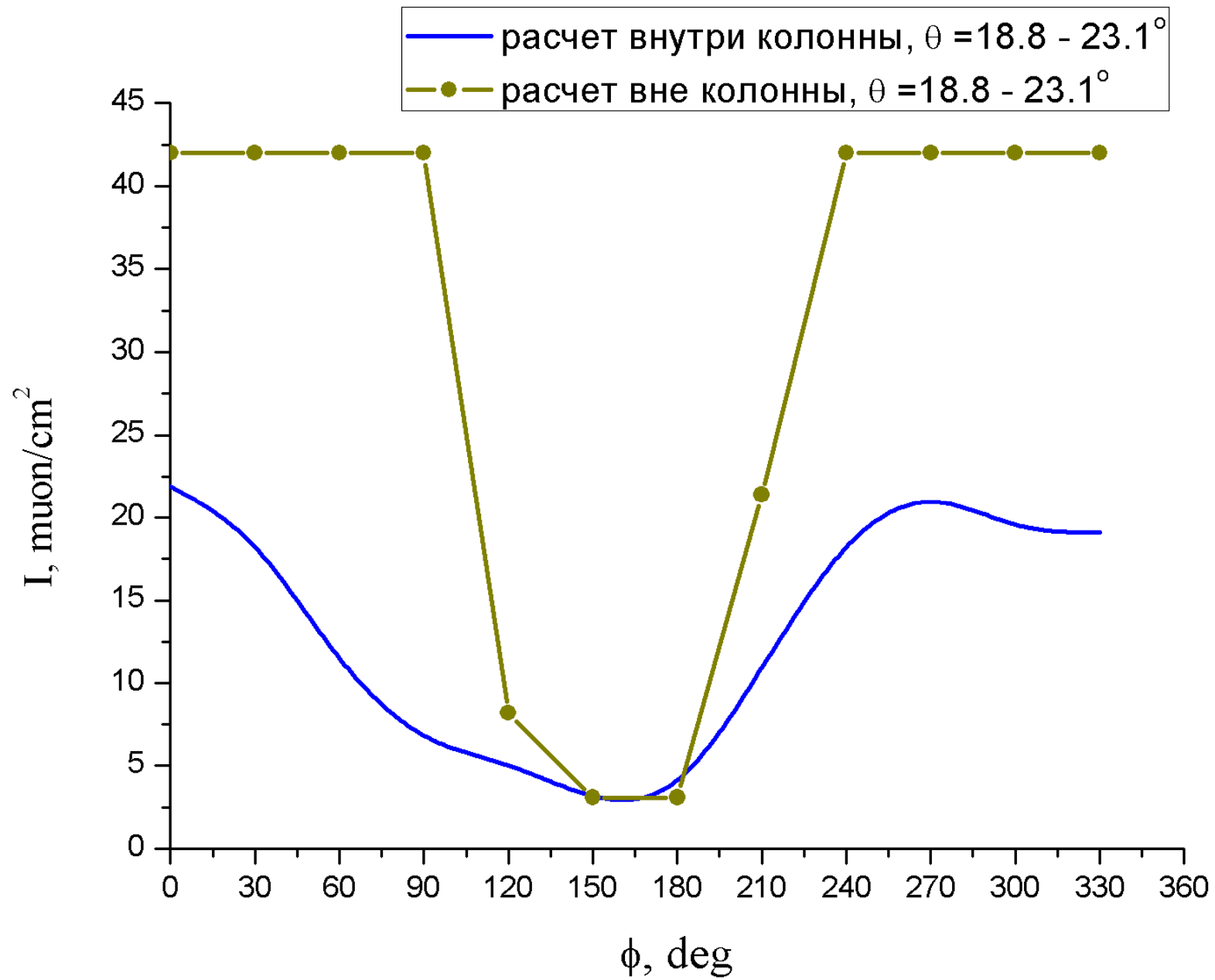
## Assumptions:

$$I(E > 0.3 \text{ GeV}) \approx 7 \cdot 10^{-3} \text{ cm}^{-2} \text{ sec}^{-1} \text{ sr}^{-1}$$

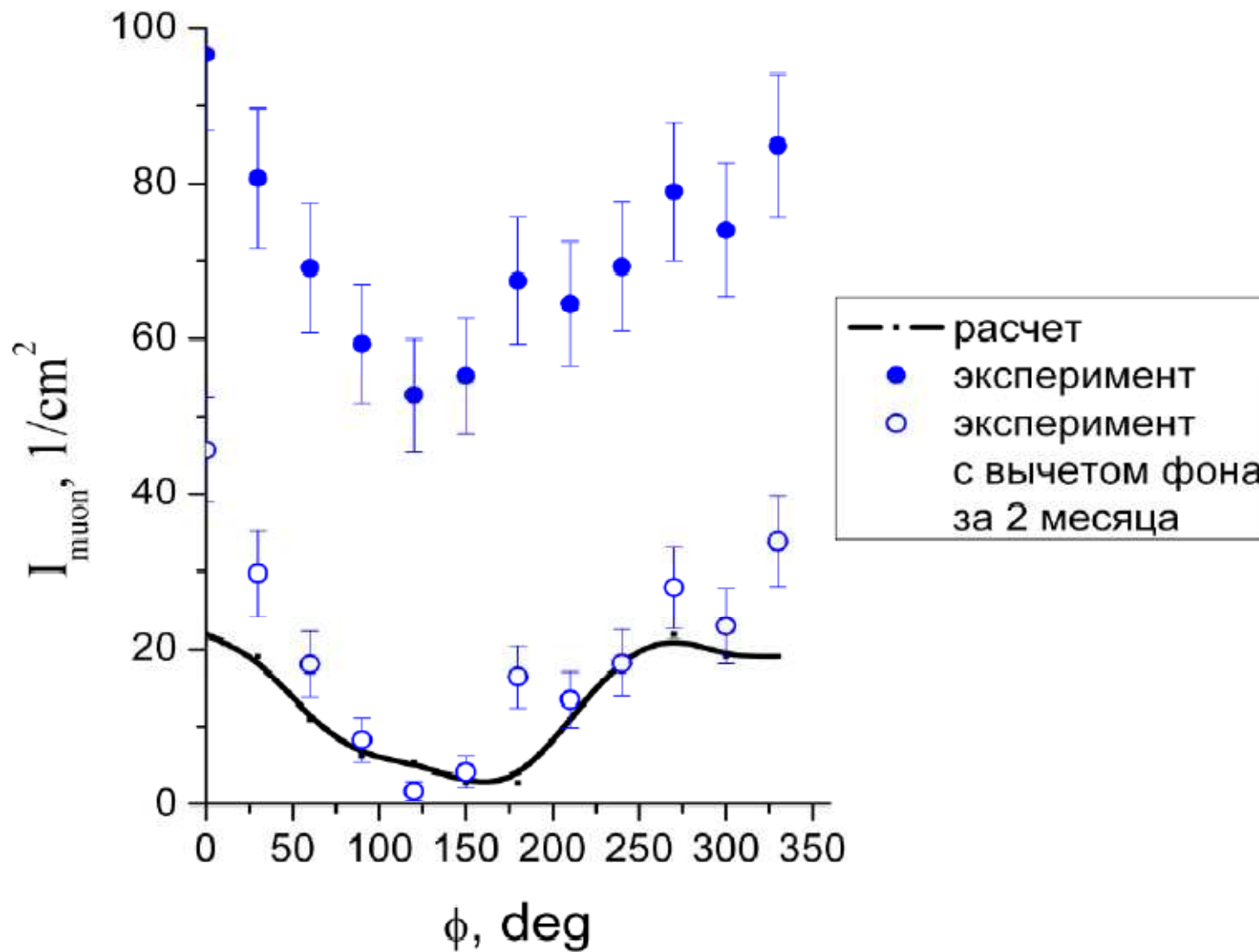
Effective zenith angle range —  $30^\circ$

Exposition duration — 49 days

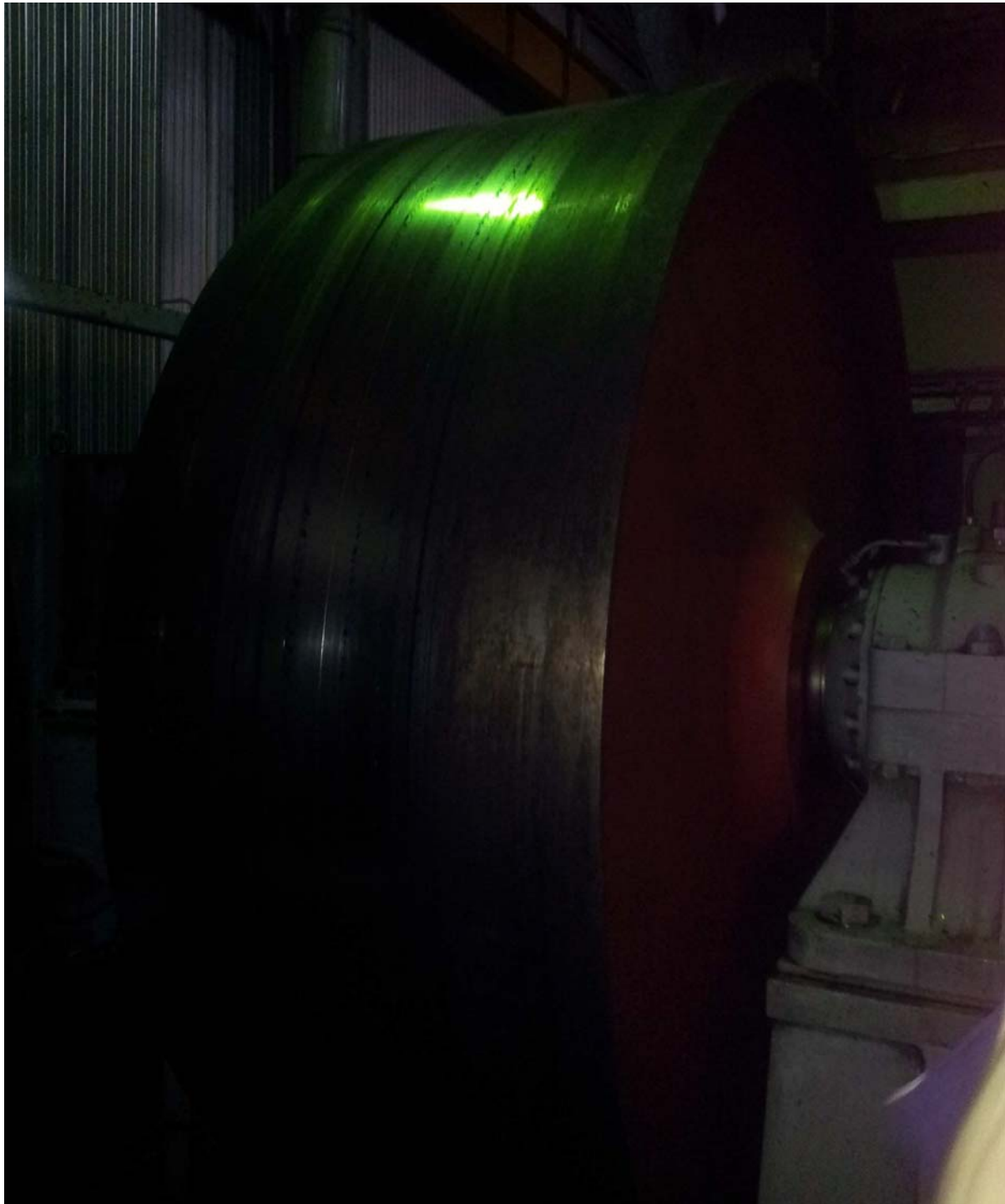
Then  $I_{\text{local outside}} / I_{\text{local under Fe}} \approx 10$

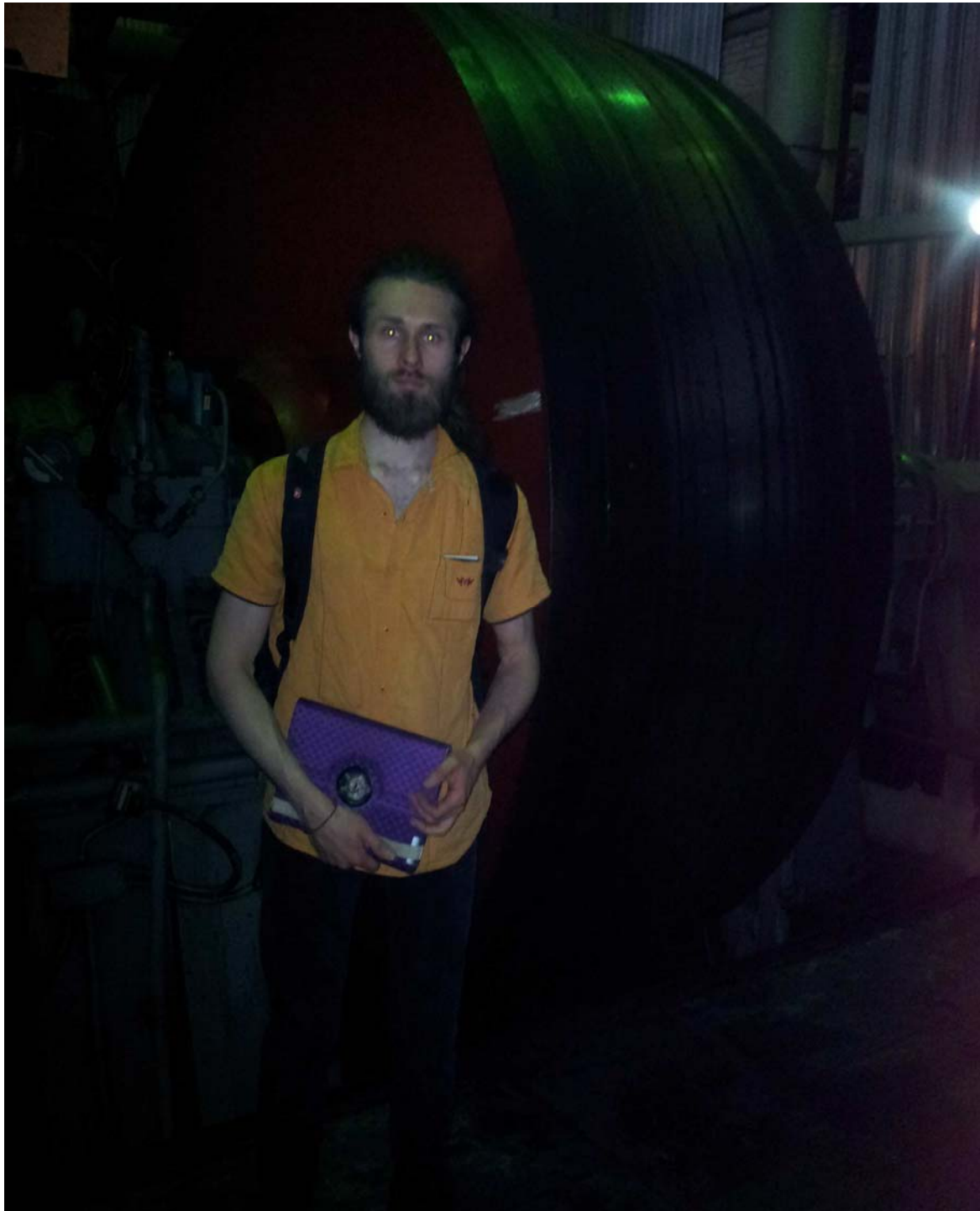






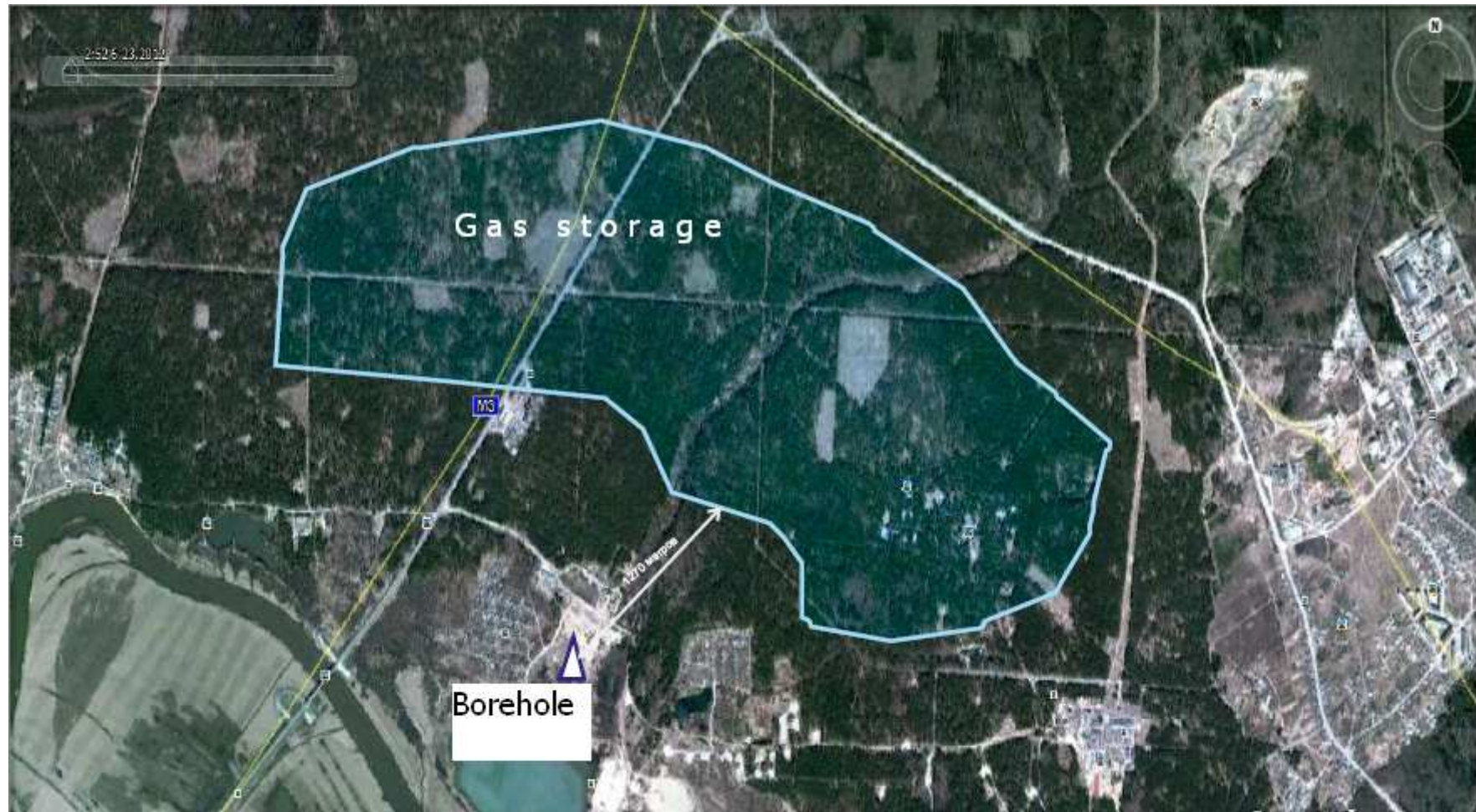
Сравнение угловых распределений потоков мюонов при разных азимутальных углах  $\phi$  и фиксированном диапазоне зенитных углов  $\theta = 21,6^\circ$  в проведенном модельном расчете тестового эксперимента и в самом эксперименте



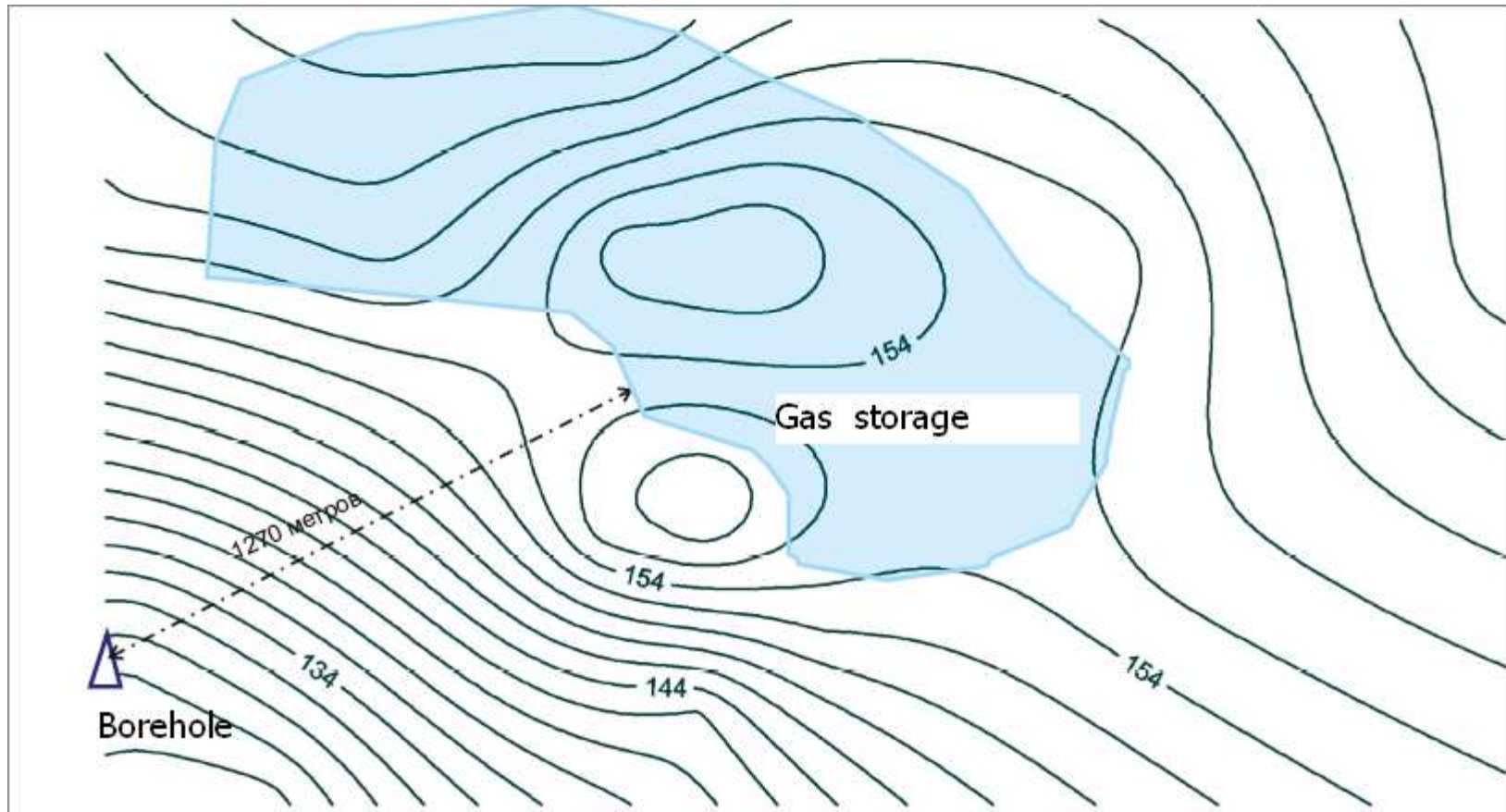




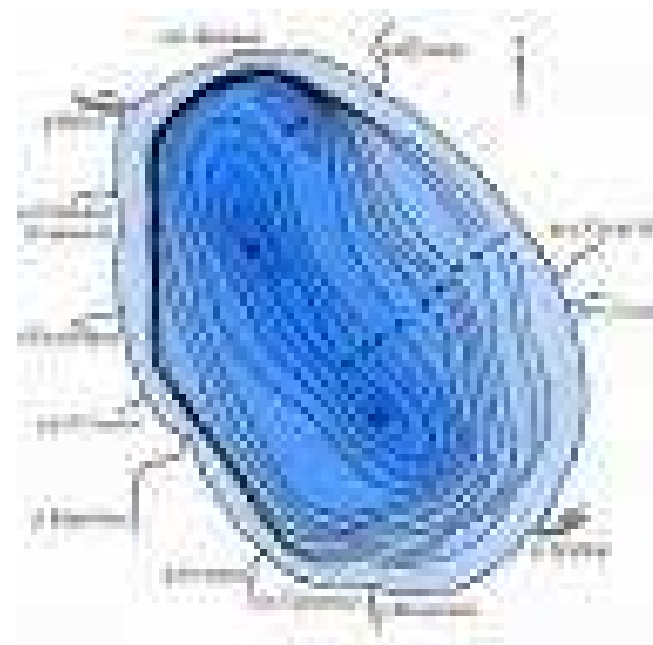
# Disposition of the borehole and the gas storage in the site of expected method testing



# Disposition of the gas storage and isolines of local topography









# Summary

- many ideas for physics and applications with a large amount of emulsion consumption.
- however, we need R&D to proof the principle of experiments.
- we need good emulsion gel for R&D
- we hope to receive good quality gels from Slavich.

