

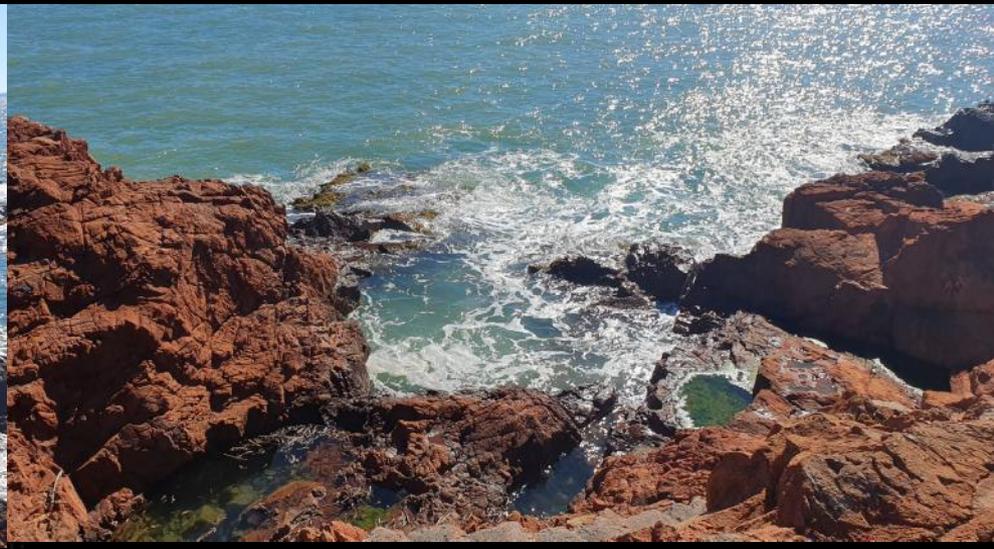
Détecteurs en Vrac

11 Mars au 13 Mars, Fréjus

- 1/ Détecter quoi ↔ pourquoi (1h)
- 2/ Interaction particules matière (1h)
- 3/ Généralités sur les détecteurs (1h)
- 4/ Application sociétales (1h)
- 5/ Exemple avec D0/ATLAS (Fermilab/CERN) (1h)



laurent chevalier



laurent chevalier



Applications sociétales

Technologies de l'information et de la communication

microélectronique
semi-conducteurs
technologies de l'information
infrastructure Internet
économie mondiale → WWW

ACCUEIL > HIGH TECH > CE QUE PÈSE INTERNET DANS L'ÉCONOMIE MONDIALE

Ce que pèse internet dans l'économie mondiale

Créé le 04-10-2012 à 16h30 - Mis à jour à 18h04



Par Marco Mosca



Selon l'OCDE, le chiffre d'affaires des 250 plus grandes entreprises du secteur des technologies de l'information et des Télécommunications a atteint 4.600 milliards de dollars en 2011.

Imagerie et détection → muographie

archéologie → pyramides
radiographie de sécurité → centrales nucléaires, volcans
sécurité publique → détection d'explosifs

Ordinateur quantique

Formation scientifique et éducation

AGLAÉ (Accélérateur Grand Louvre d'Analyse Élémentaire)
Accélérateur mobile pour Patrimoine culturel in situ Analyse non destructive



Applications sociétales → santé

Instrumentation médicale :

- détection de particules ionisantes
- détecteurs de rayons X et gamma
- capteurs de particules
- scanner

Imagerie médicale :

- recherche en neurosciences
- diagnostic médical
 - Tomographie par émission de positrons (TEP)
 - Tomographie par émission de photons uniques (SPECT)
 - Résonance magnétique nucléaire (RMN) → ISEULT

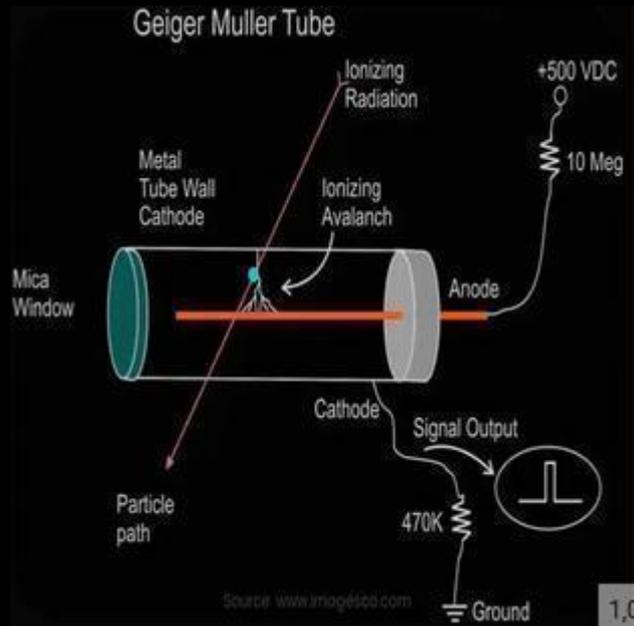
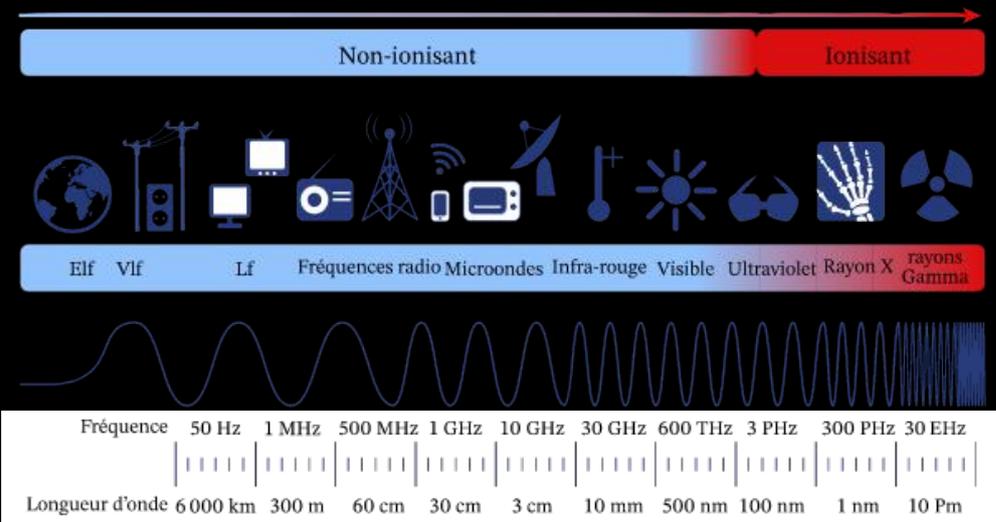
Radiothérapie :

- accélérateurs de particules
 - brûler des tumeurs
 - hadronthérapie
 - création atomes radioactifs

Applications sociétales → santé

Instrumentation médicale :

- détection de particules ionisantes
- détecteurs de rayons X et gamma
- capteurs de particules
- scanner



Applications sociétales → santé

Instrumentation médicale :

- détection de particules ionisantes
- détecteurs de rayons X et gamma
- capteurs de particules
- scanner

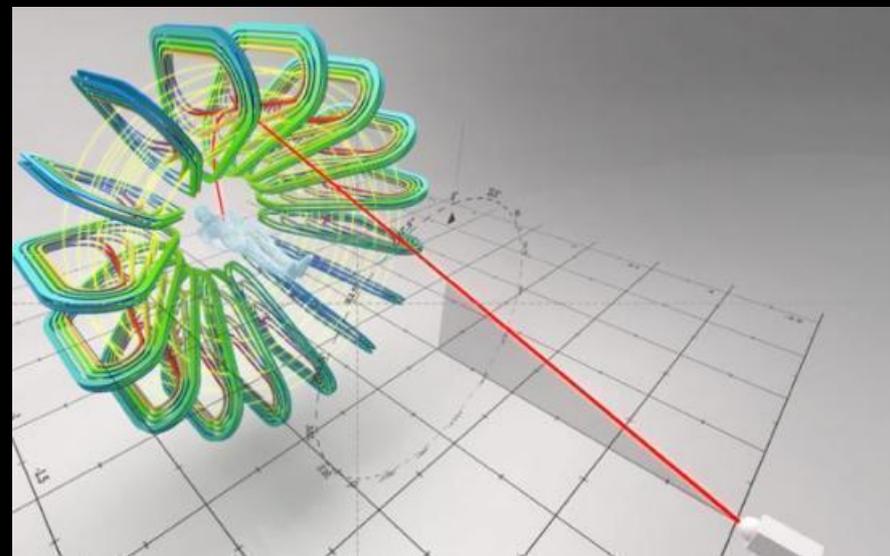
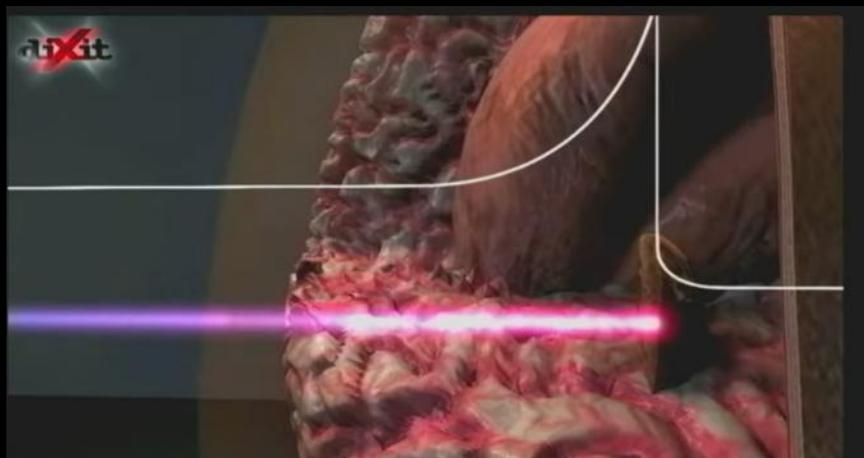
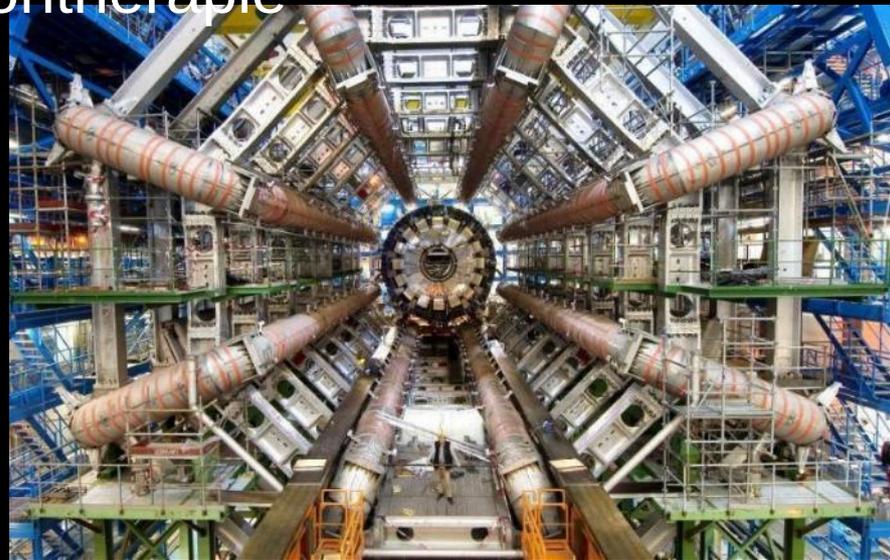
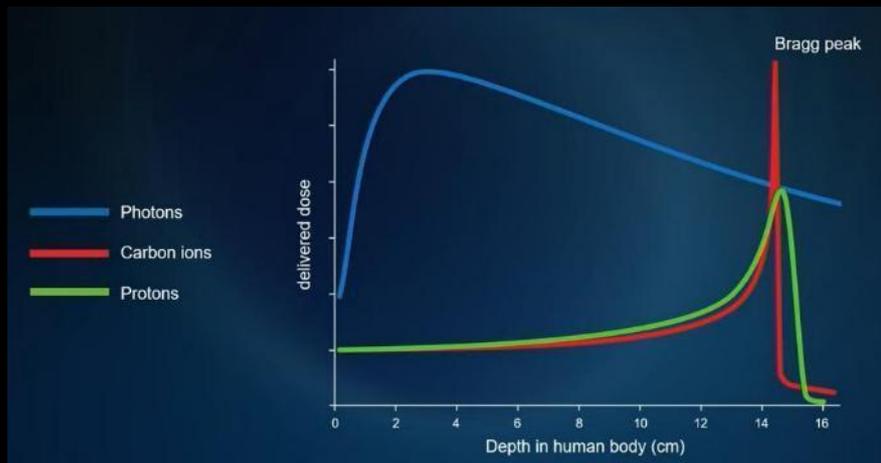
Imagerie médicale :

- recherche en neurosciences
- diagnostic médical
 - Tomographie par émission de positrons (TEP)
 - Tomographie par émission de photons uniques (SPECT)
 - Résonance magnétique nucléaire (RMN) → ISEULT

Radiothérapie :

- accélérateurs de particules
 - brûler des tumeurs
 - hadronthérapie
 - création atomes radioactifs

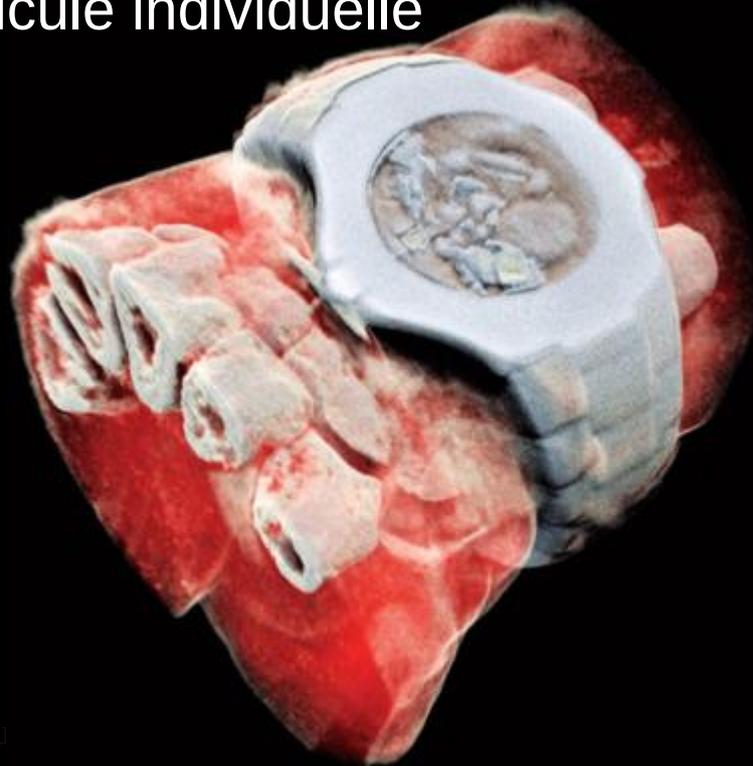
Applications sociétales → santé → hadronthérapie



laurent chevalier

Applications sociétales → santé

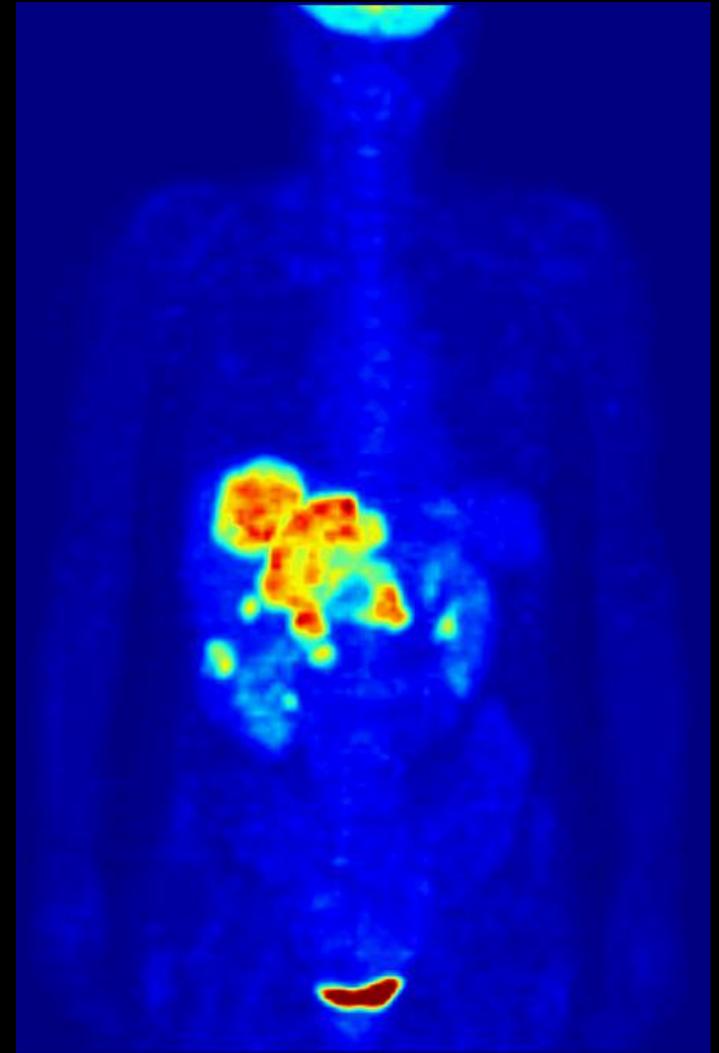
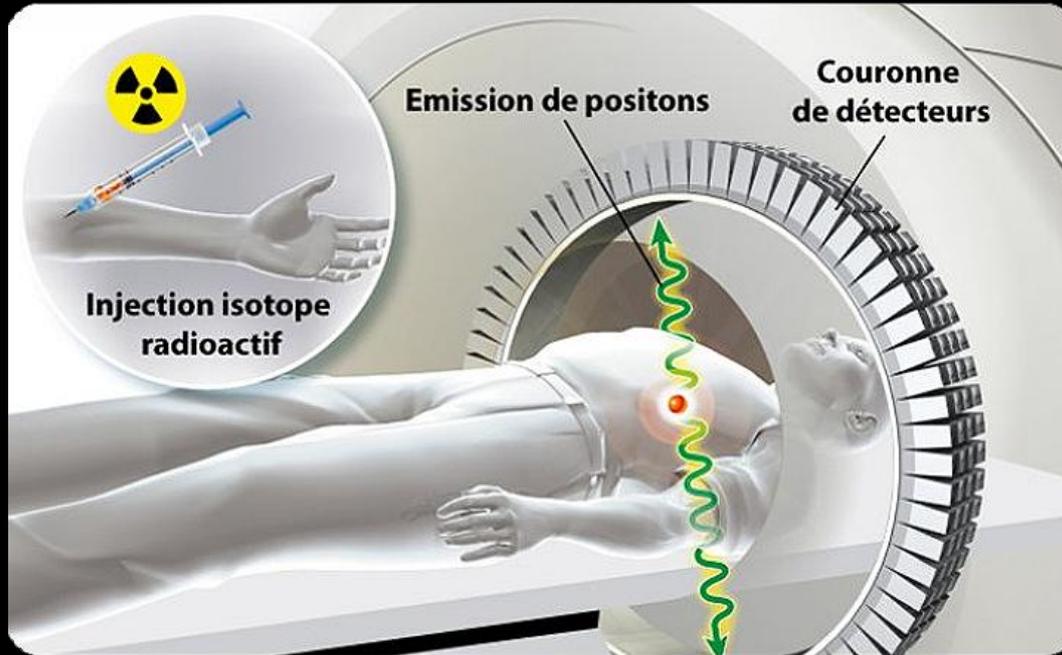
technologie développée au CERN → première radiographie 3D couleur
puces de lecture Medipix → trajectographe LHC
CMOS
détecte et compte chaque particule individuelle



lau

Applications sociétales → santé

TEP

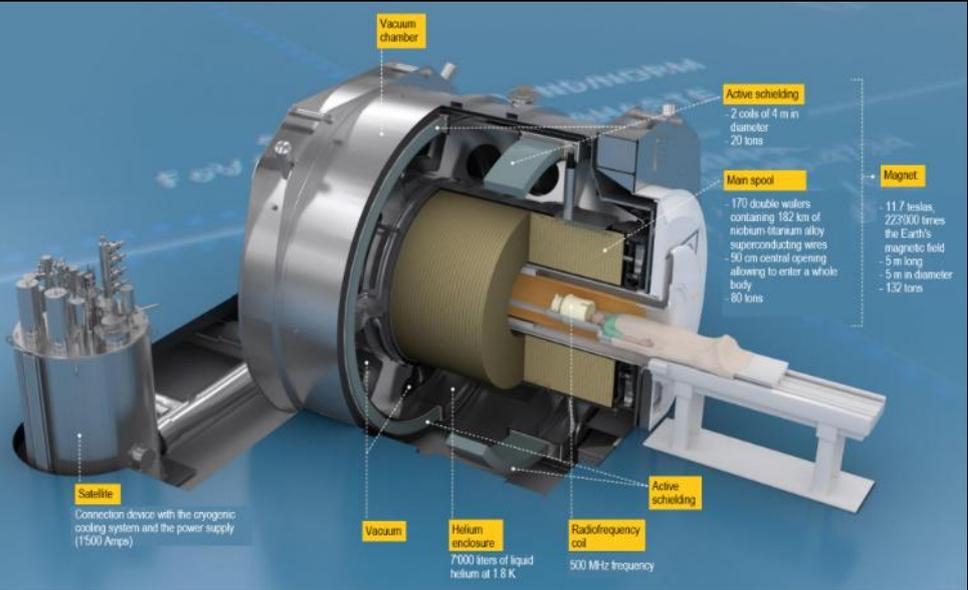


laurent chevalier

Applications sociétales → santé



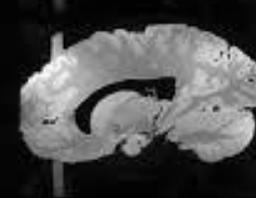
RMN



Phase-shimming



Parallel Transmission



Applications sociétales → santé

Instrumentation médicale :

- détection de particules ionisantes
- détecteurs de rayons X et gamma
- capteurs de particules
- scanner

Imagerie médicale :

- recherche en neurosciences
- diagnostic médical
 - Tomographie par émission de positrons (TEP)
 - Tomographie par émission de photons uniques (SPECT)
 - Résonance magnétique nucléaire (RMN) → ISEULT

Radiothérapie :

- accélérateurs de particules
 - brûler des tumeurs
 - hadronthérapie
 - création atomes radioactifs

Applications sociétales → santé → radio-isotopes & médecine nucléaire

Established isotopes → Industrial suppliers

^{99m}Tc , ^{18}F , $^{123,125,131}\text{I}$, ^{111}In , ^{90}Y

Emerging isotopes → Small innovative supplier

^{68}Ga , ^{82}Rb , ^{89}Zr , ^{177}Lu , ^{188}Re

R&D isotopes → Research labs

$^{44,47}\text{Sc}$, $^{64,67}\text{Cu}$, ^{134}Ce , ^{140}Nd , $^{149, 152, 155, 161}\text{Tb}$, ^{166}Ho
 ^{195m}Pt , ^{211}At , $^{212, 213}\text{Bi}$, ^{223}Ra , $^{225}\text{Ac}, \dots$

Applications sociétales

→ accélérateur

Area	Application	Beam	Accelerator	Beam energy/MeV	Beam current/mA	Number
Medical	Cancer therapy	e	linac	4-20	10^{-2}	>14000
		p	cyclotron, synchrotron	250	10^{-6}	60
		C	synchrotron	4800	10^{-7}	10
	Radioisotope production	p	cyclotron	8-100	1	1600
Industrial	Ion implantation	B, As, P	electrostatic	< 1	2	>11000
	Ion beam analysis	p, He	electrostatic	<5	10^{-4}	300
	Material processing	e	electrostatic, linac, Rhodatron	≤ 10	150	7500
	Sterilisation	e	electrostatic, linac, Rhodatron	≤ 10	10	3000
Security	X-ray screening of cargo	e	linac	4-10	?	100?
	Hydrodynamic testing	e	linear induction	10-20	1000	5
Synchrotron light sources	Biology, medicine, materials science	e	synchrotron, linac	500-10000		70
Neutron scattering	Materials science	p	cyclotron, synchrotron, linac	600-1000	2	4
Energy - fusion	Neutral ion beam heating	d	electrostatic	1	50	10
	Heavy ion inertial fusion	Pb, Cs	Induction linac	8	1000	Under development
	Materials studies	d	linac	40	125	Under development
Energy - fission	Waste burner	p	linac	600-1000	10	Under development
	Thorium fuel amplifier	p	linac	600-1000	10	Under development
Energy - bio-fuel	Bio-fuel production	e	electrostatic	5	10	Under development
Environmental	Water treatment	e	electrostatic	5	10	5
	Flue gas treatment	e	electrostatic	0.7	50	Under development

Muography ou tomographie muonique

Applications

- Archéologie → pyramides
- Sécurité → conteneurs
- Géosciences → volcans
- Sûreté nucléaire → surveillance des réacteurs, étude de déchets

Muography

Applications

- Archéologie → pyramides
- Sécurité → conteneurs
- Géosciences → volcans
- Sûreté nucléaire → surveillance des réacteurs, étude de déchets

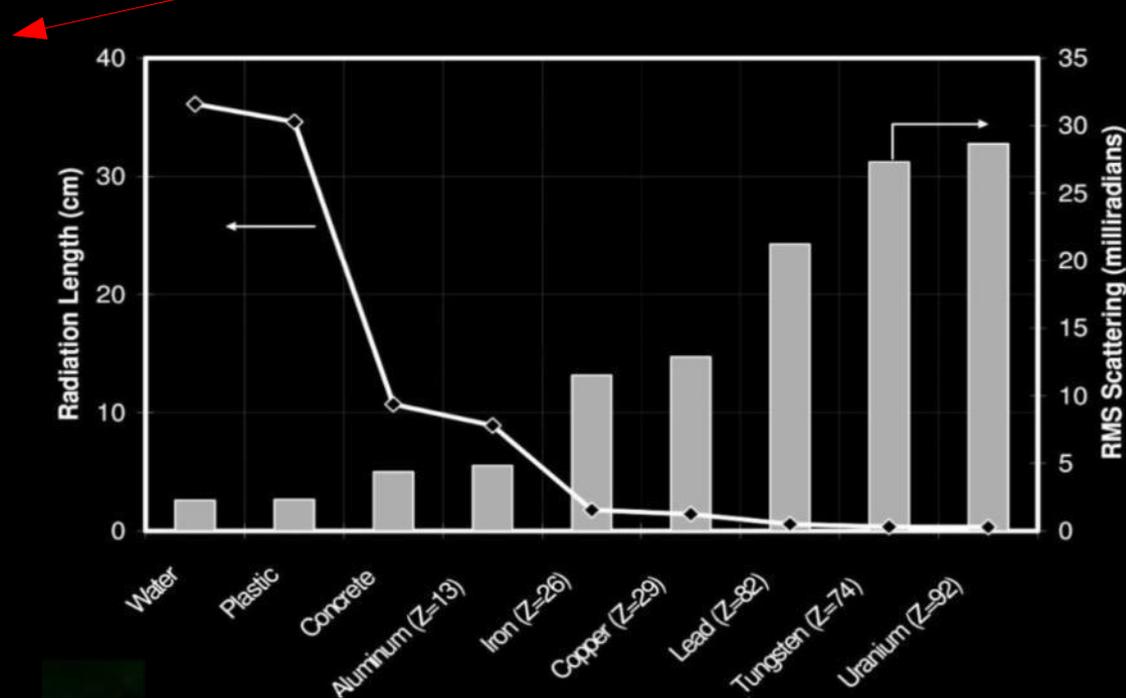
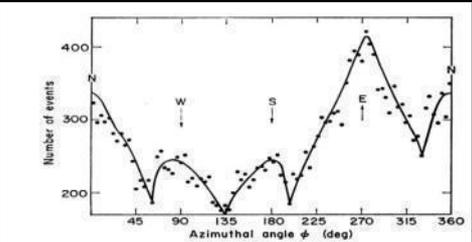
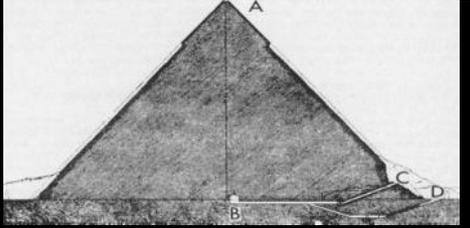
Muography

- the probability of muon absorption is proportional to the density
Muon flux \rightarrow density map
- Use cosmic muons to analyze Archaeology, Volcanology, buildings structure,...

Search for Hidden Chambers in the Pyramids

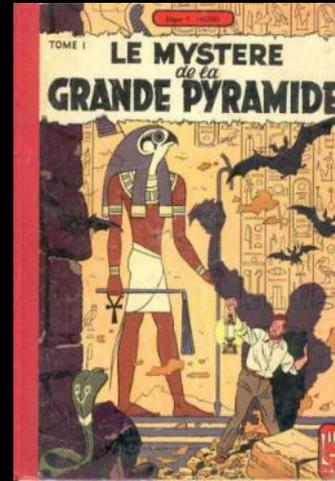
The structure of the Second Pyramid of Giza is determined by cosmic-ray absorption.

Luis W. Alvarez, Jared A. Anderson, F. El Bedwei,



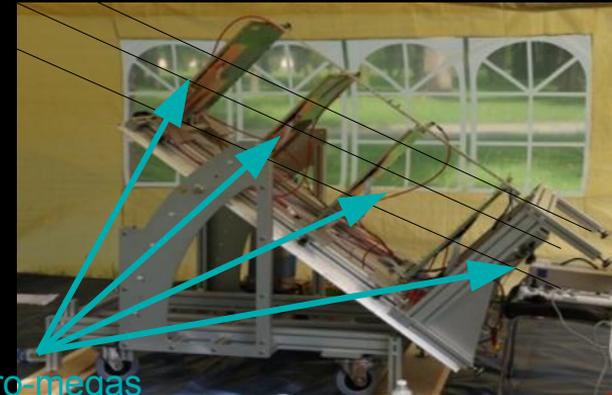
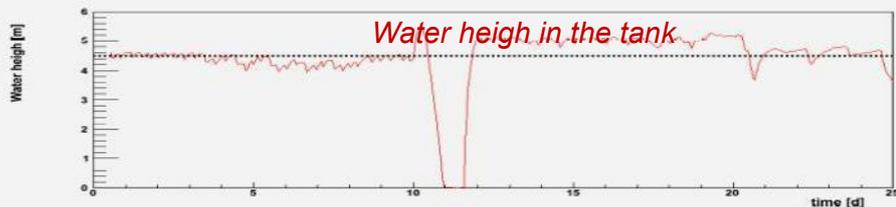
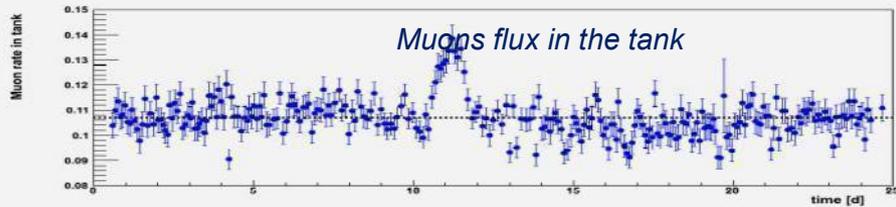
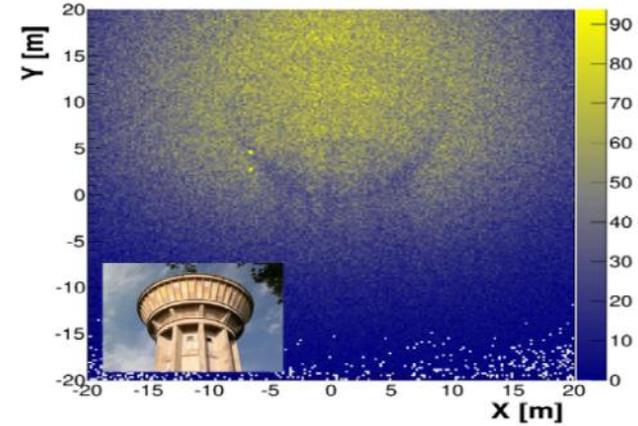
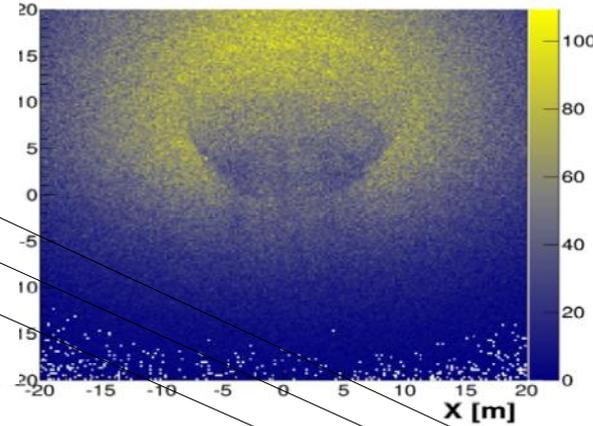
Hidden room in the pyramid? \rightarrow

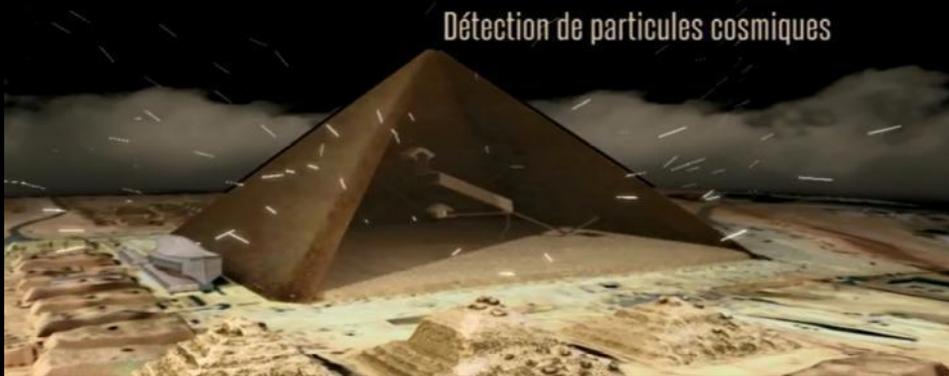
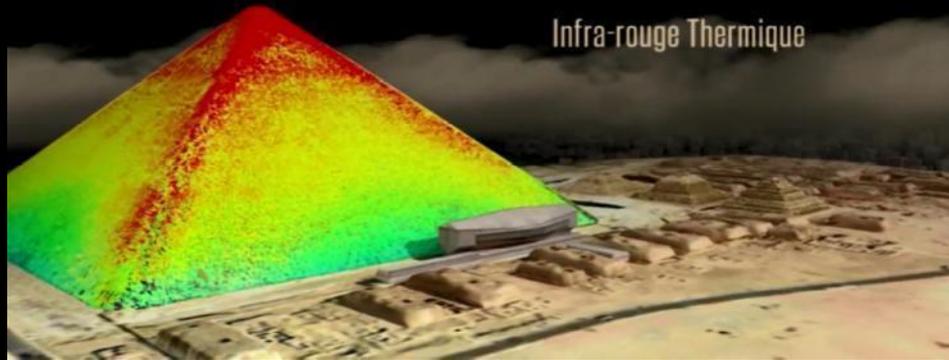
laurent chevalier



Muography

- the probability of muon absorption is proportional to the density
Muons flux \rightarrow density map
- Use cosmic muons to analyze Archaeology, Volcanology, buildings structure,...





Discovery of a big void in Khufu's Pyramid by observation of cosmic-ray muons

Kunihiro Morishima¹, Mitsuaki Kuno¹, Akira Nishio¹, Nobuko Kitagawa¹, Yuta Manabe¹, Masaki Moto¹, Fumihiko Takasaki², Hirofumi Fujii², Kotaro Satoh², Hideyo Kodama², Kohji Hayashi², Shigeru Odaka², Sébastien Procureur³, David Attié³, Simon Boutelle³, Denis Calvet³, Christopher Filosa³, Patrick Magnier³, Iraki Mandjavidze³, Marc Riallot³, Benoît Marini⁴, Pierre Gable⁵, Yoshikatsu Date⁶, Makiko Sugiyara⁷, Yasser Elshayeb⁸, Tamer Elmadry⁹, Mustapha Ezzy⁸, Emmanuel Guerriero⁹, Vincent Steiger⁴, Nicolas Serikoff⁴, Jean-Baptiste Mouret^{10,11,12}, Bernard Charle¹³, Hany Helal^{14,8} & Mehdi Tayoubi^{14,13}

The Great Pyramid, or Khufu's Pyramid, was built on the Giza plateau in Egypt during the fourth dynasty by the pharaoh Khufu (Cheops)¹, who reigned from 2509 BC to 2483 BC. Despite being one of the oldest and largest monuments on Earth, there is no consensus about how it was built^{2,3}. To understand its internal structure better, we imaged the pyramid using muons, which are by-products of cosmic rays that are only partially absorbed by stone^{4–6}. The resulting cosmic-ray muon radiography allows us to visualize the known and any unknown voids in the pyramid in a non-invasive way. Here we report the discovery of a large void (with a cross-section similar to that of the Grand Gallery and a minimum length of 30 metres) situated above the Grand Gallery. This constitutes the first major inner structure found in the Great Pyramid since the nineteenth century¹. The void, named ScanPyramids' Big Void, was first observed with nuclear emulsion films^{7–9} installed in the Queen's

chamber, then confirmed with scintillator hodoscopes^{10,11} set up in the same chamber and finally re-confirmed with gas detectors¹² outside the pyramid. This large void has therefore been detected with high confidence by three different muon detection technologies and three independent analyses. These results constitute a breakthrough for the understanding of the internal structure of Khufu's Pyramid. Although there is currently no information about the intended purpose of this void, these findings show how modern particle physics can shed new light on the world's archaeological heritage.

The pyramid of Khufu is 139 m high and 230 m wide^{1,13}. There are three known chambers (Fig. 1), at different heights of the pyramid, which all lie in the north-south vertical plane¹: the subterranean chamber, the Queen's chamber, and the King's chamber. These chambers are connected by several corridors, the most notable one being the Grand Gallery (8.6 m high × 46.7 m long × 2.1–1.0 m wide). The Queen's

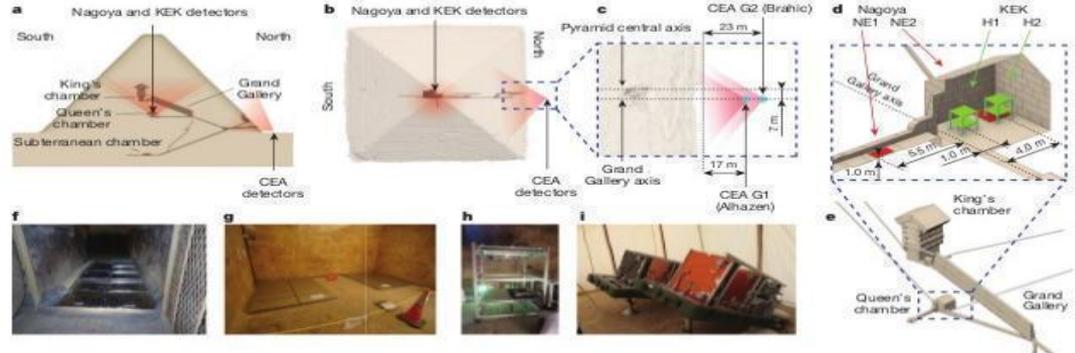
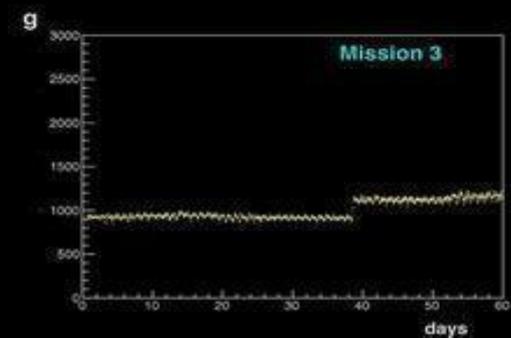
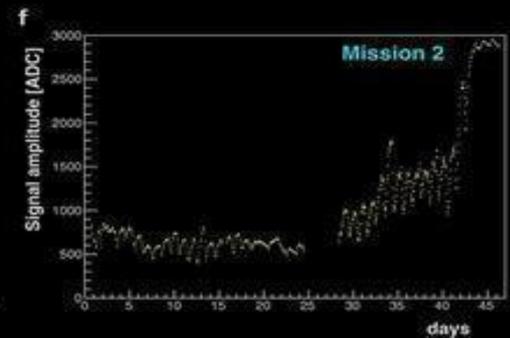
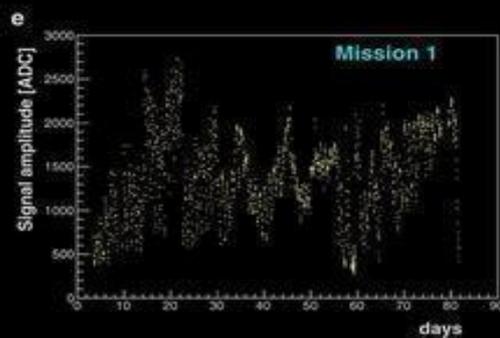
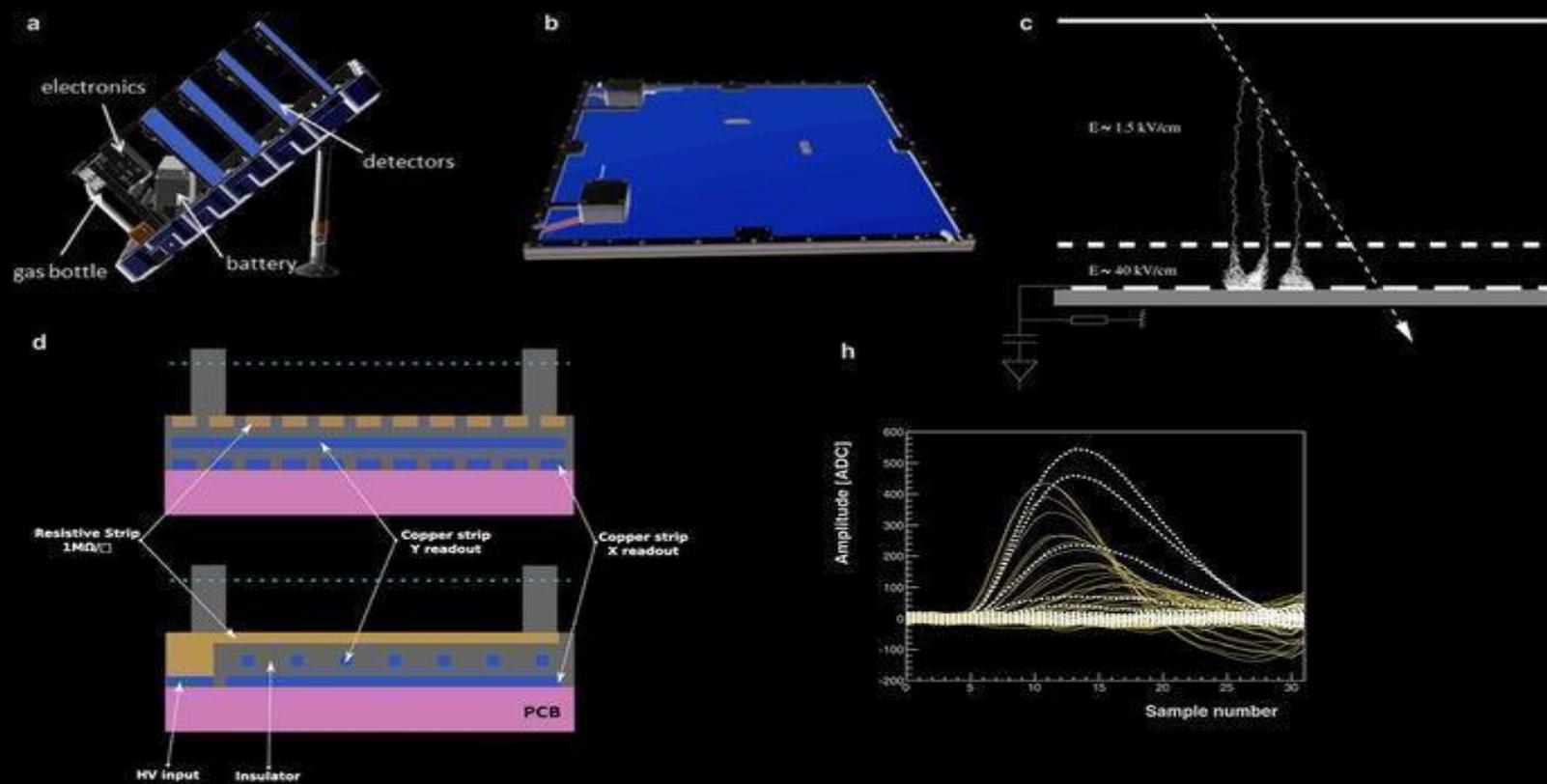


Figure 1 | Muon detectors installed for Khufu's Pyramid. **a**, Side view of the pyramid, with sensor positions and indicative field of view. **b**, Top view. **c**, Close view of the position of the gas detectors Brahic and Alhazen. **d**, Orthographic view of Queen's chamber with nuclear emulsion films (Nagoya University, red positions NE1 and NE2) and scintillator

hodoscopes (KEK, green positions H1 and H2). **e**, Orthographic view of the main known internal structures. **f**, Nuclear emulsion plates in position NE1 (Nagoya University). **g**, Nuclear emulsion plates in position NE2 (Nagoya University). **h**, Scintillator hodoscope setup for position H1 (KEK). **i**, Gas detectors (muon telescopes, CEA).

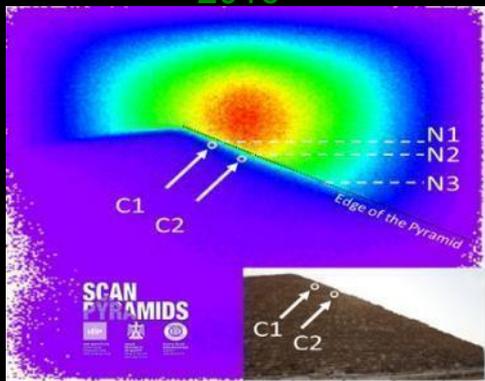
¹F-lab, Nagoya University, Furo-cho, Chikusa-ku, Nagoya, Aichi 464-8602, Japan. ²High Energy Accelerator Research Organization (KEK), 1-1 oho, Tsukuba, Ibaraki 305-0801, Japan. ³Institut de Recherche sur les lois Fondamentales de l'Univers (IRFU), Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA), Université Paris Saclay, 91191 Gif-sur-Yvette, France. ⁴IFIP Institute, 50 rue de Rome, 75008 Paris, France. ⁵Emission, 71 rue de Provence, 75009 Paris, France. ⁶INIK Enterprises, Inc. (NEP), 4-14 Kamiyama-cho, Shibuya-ku, Tokyo 150-0047, Japan. ⁷Suave Images, N-2 Maison de Shiro, 3-30-8 Kamineguro, Meguro-ku, Tokyo 153-0051, Japan. ⁸Cairo University, 9 At Gamaeya, Giza, Giza Governorate, Egypt. ⁹San Sarras University, Kasr el-Za'aban, Abbasiya, Cairo, Egypt. ¹⁰INRIA, Villers-lès-Nancy F-54600, France. ¹¹ONRS, Vandœuvre-lès-Nancy F-54500, France. ¹²Université de Lorraine, Vandœuvre-lès-Nancy F-54500, France. ¹³Dasault Systèmes, 1-0 Rue Marcel Dasault, 78140 Vélizy-Villacoublay, France.



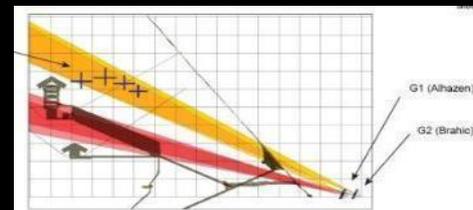
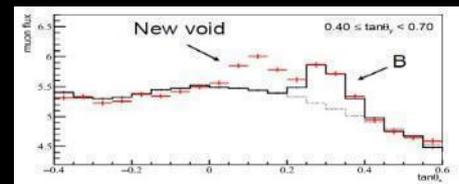
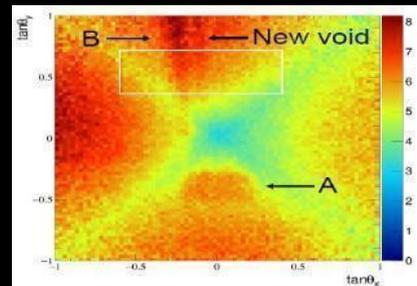
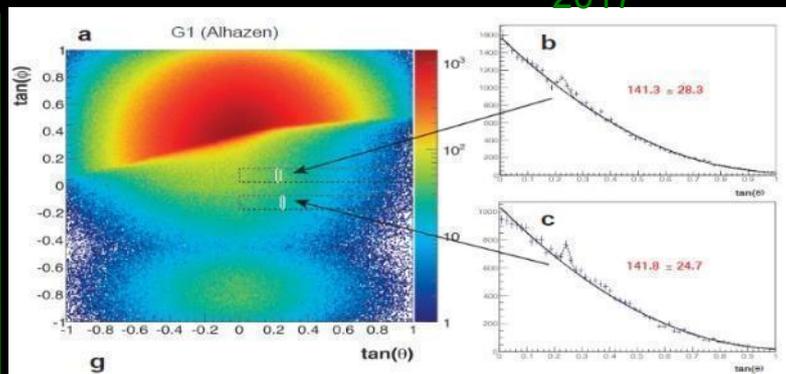
RESULTS

Discoveries of new cavities large void above the Grand Gallery

2016



2017



Muon Tomography of the Great Pyramid | 23/01/2018 | 21

Great Pyramid (Khufu's Pyramid)



King's chamber

Queen's chamber

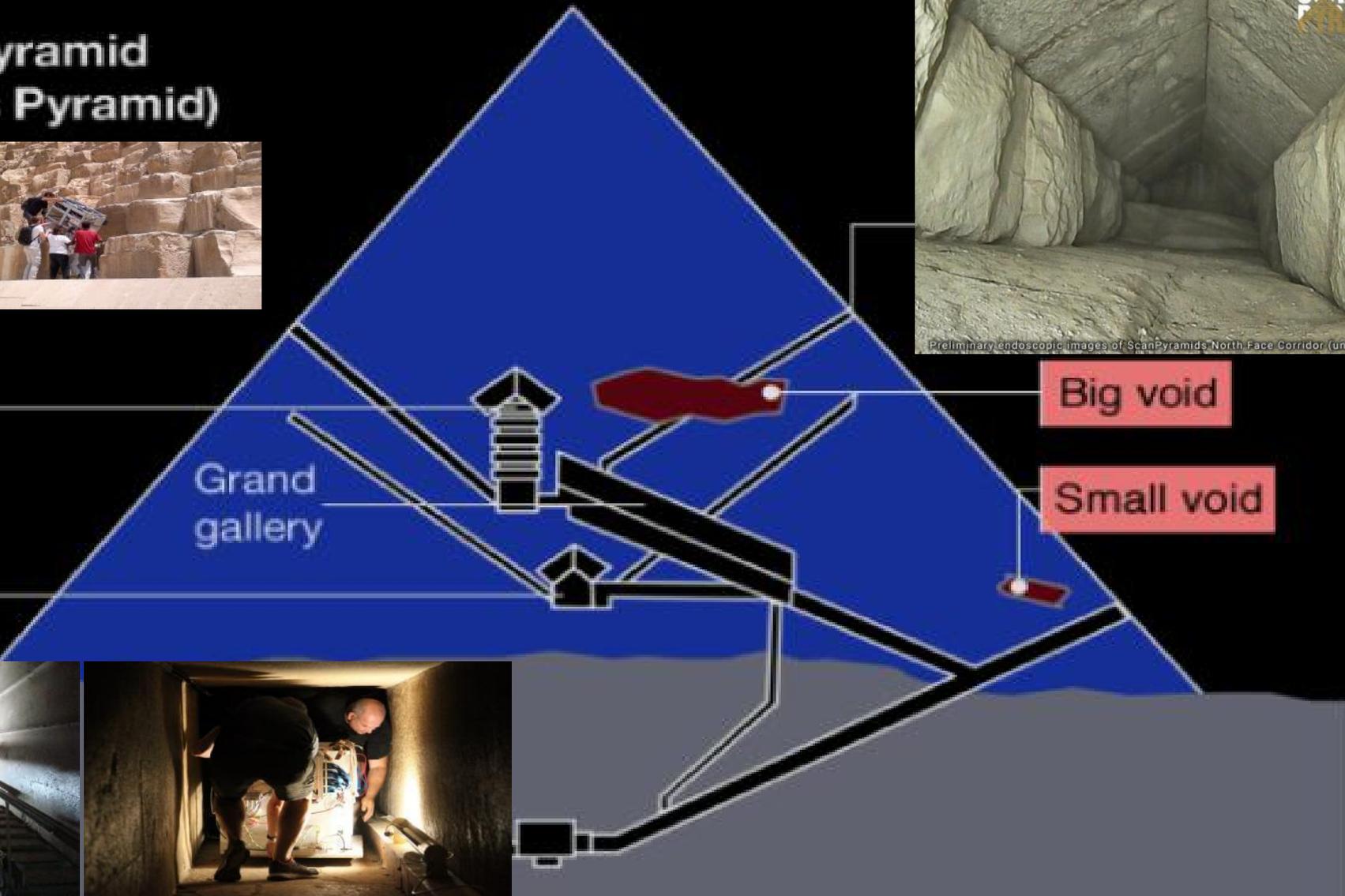
Grand gallery

Big void

Small void



Preliminary endoscopic images of ScanPyramids North Face Corridor (under analysis)



Muography

Applications

Archéologie → pyramides

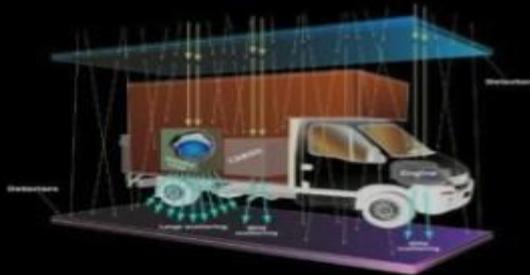
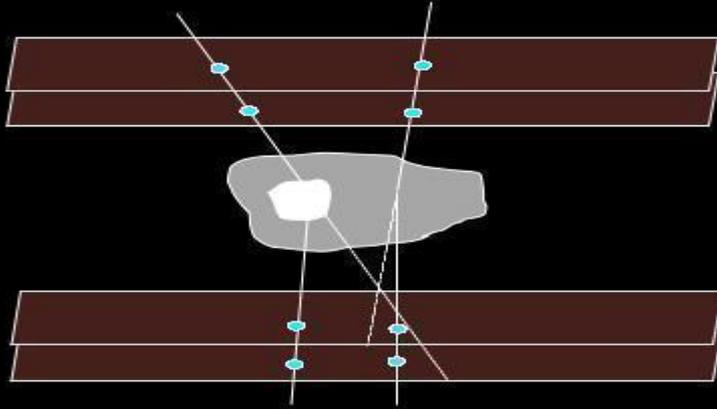
Sécurité → conteneurs

Géosciences → volcans

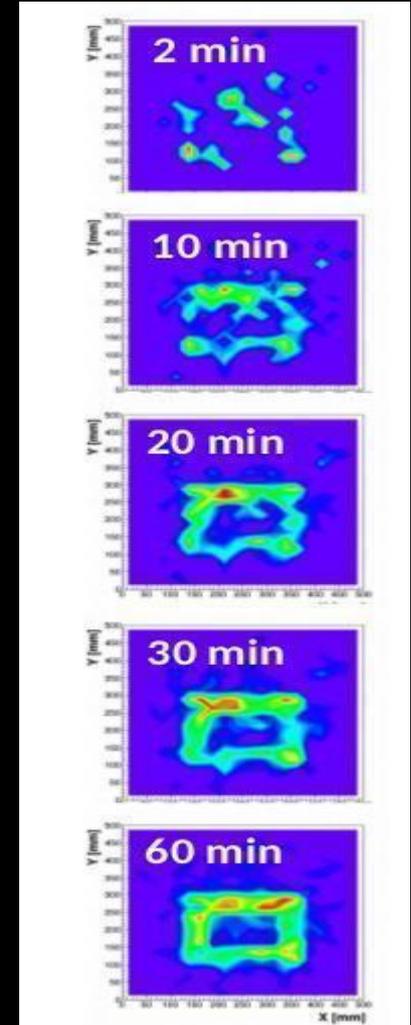
Sûreté nucléaire → surveillance des réacteurs, étude de déchets

Muography

- Use cosmic muons to analyze truck, container....
- Multiple diffusion:
 - 2 detectors: deviation angle
 - fast (~mn), 3D,



it chevalier





MUON CARGO

Non-invasive container inspection

Learn more



Muography

Applications

Archéologie → pyramides

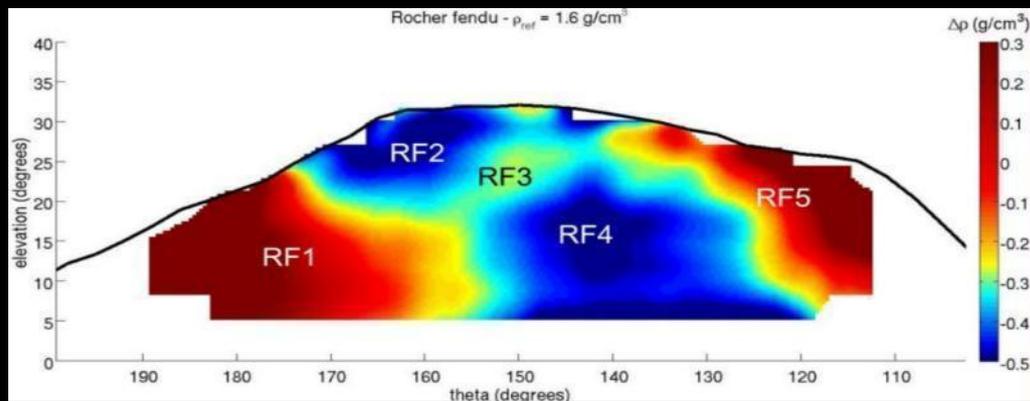
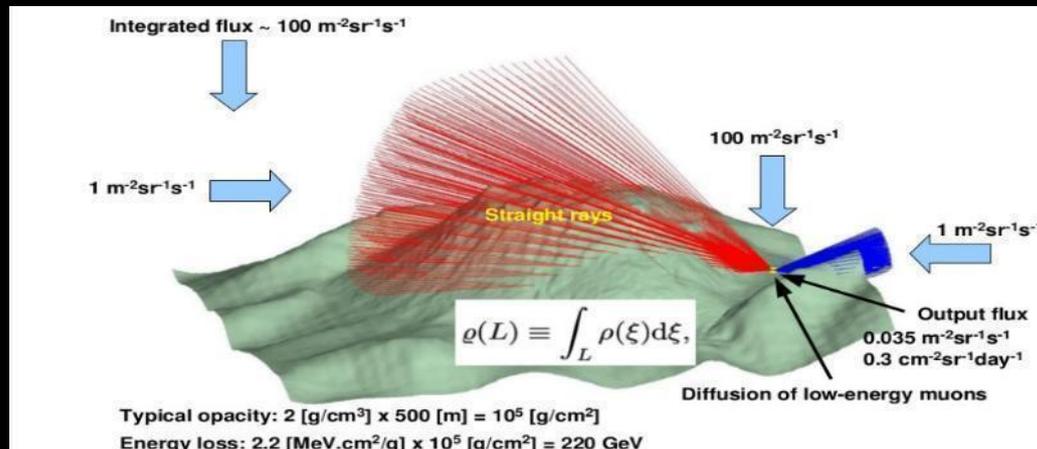
Sécurité → conteneurs

Géosciences → volcans

Sûreté nucléaire → surveillance des réacteurs, étude de déchets

Muography

- the probability of muon absorption is proportional to the density
Muon flux \rightarrow density map
- Use cosmic muons to analyze Archaeology, Volcanology, buildings structure,...



Muography

Applications

Archéologie → pyramides

Sécurité → conteneurs

Géosciences → volcans

Sûreté nucléaire → surveillance des réacteurs, étude de déchets

Muography

Sûreté nucléaire

- Réacteurs de Marcoule G2 et G3 démantèlement
- 1958-1984



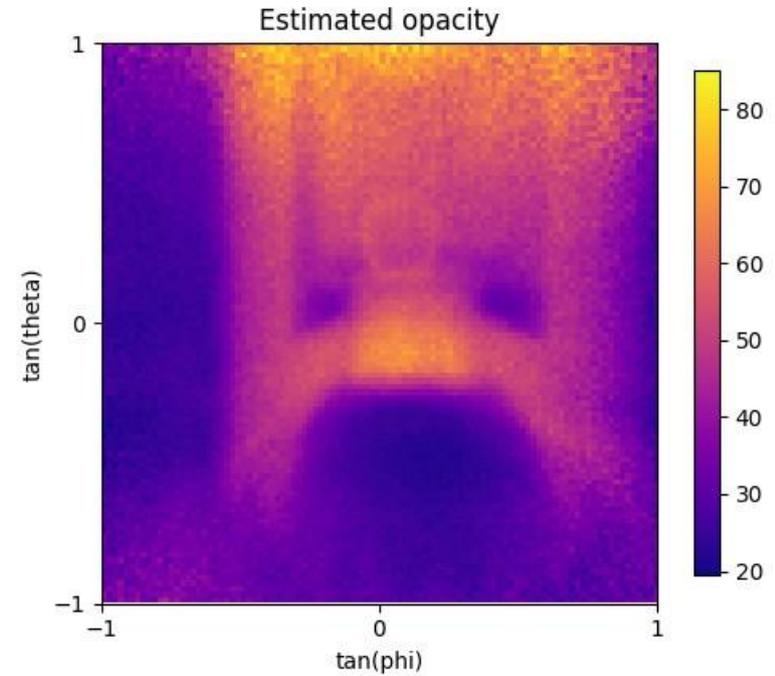
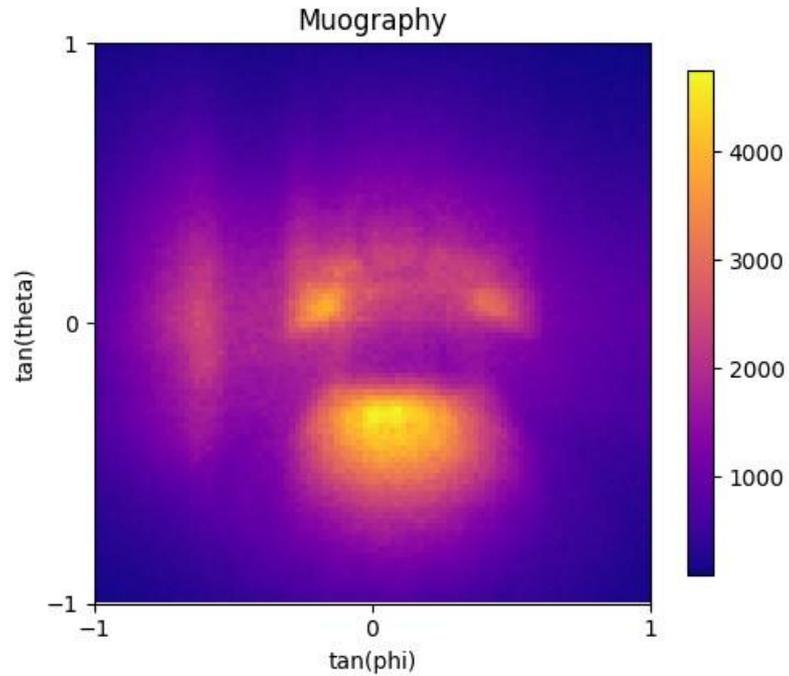
- compare structure interne et plan (<1958...)
- préparation de du génie civil
- identifier des anomalies potentielles

remarques :

- structure interne pas accessible à des humains
- X-rays et ultrasons ne peuvent pénétrer



Muography



laurent chevalier

Muography

G2

G3

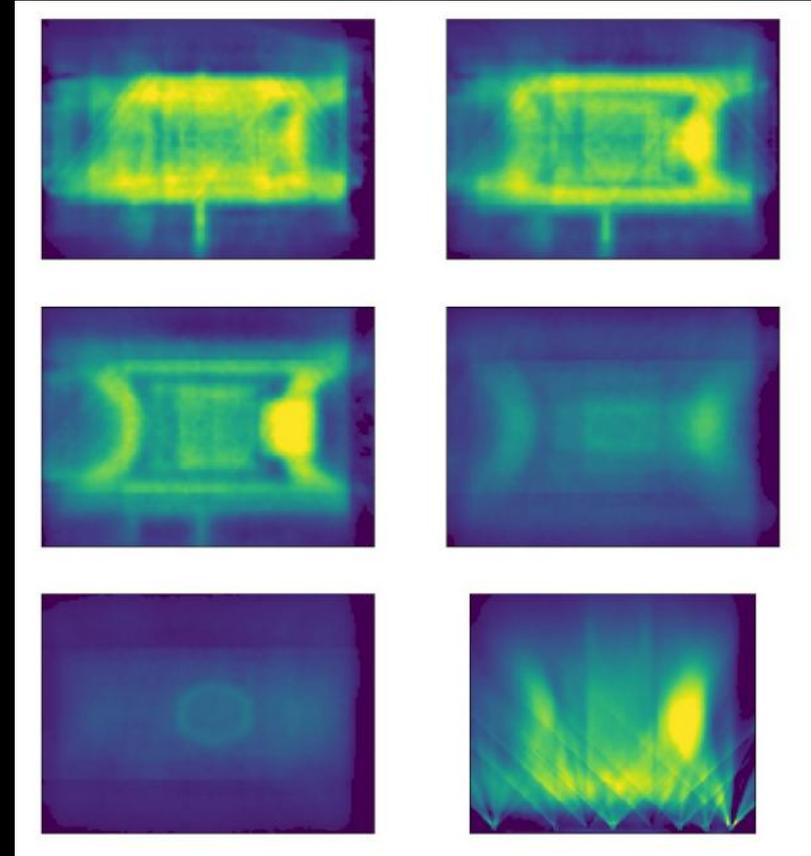
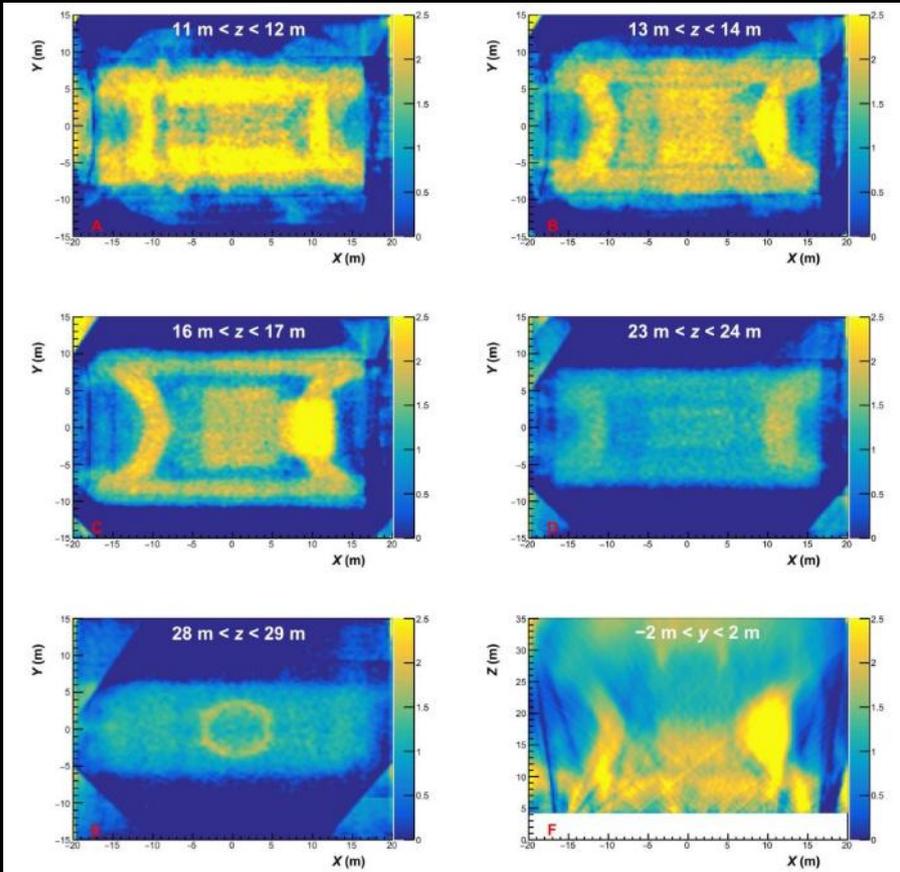
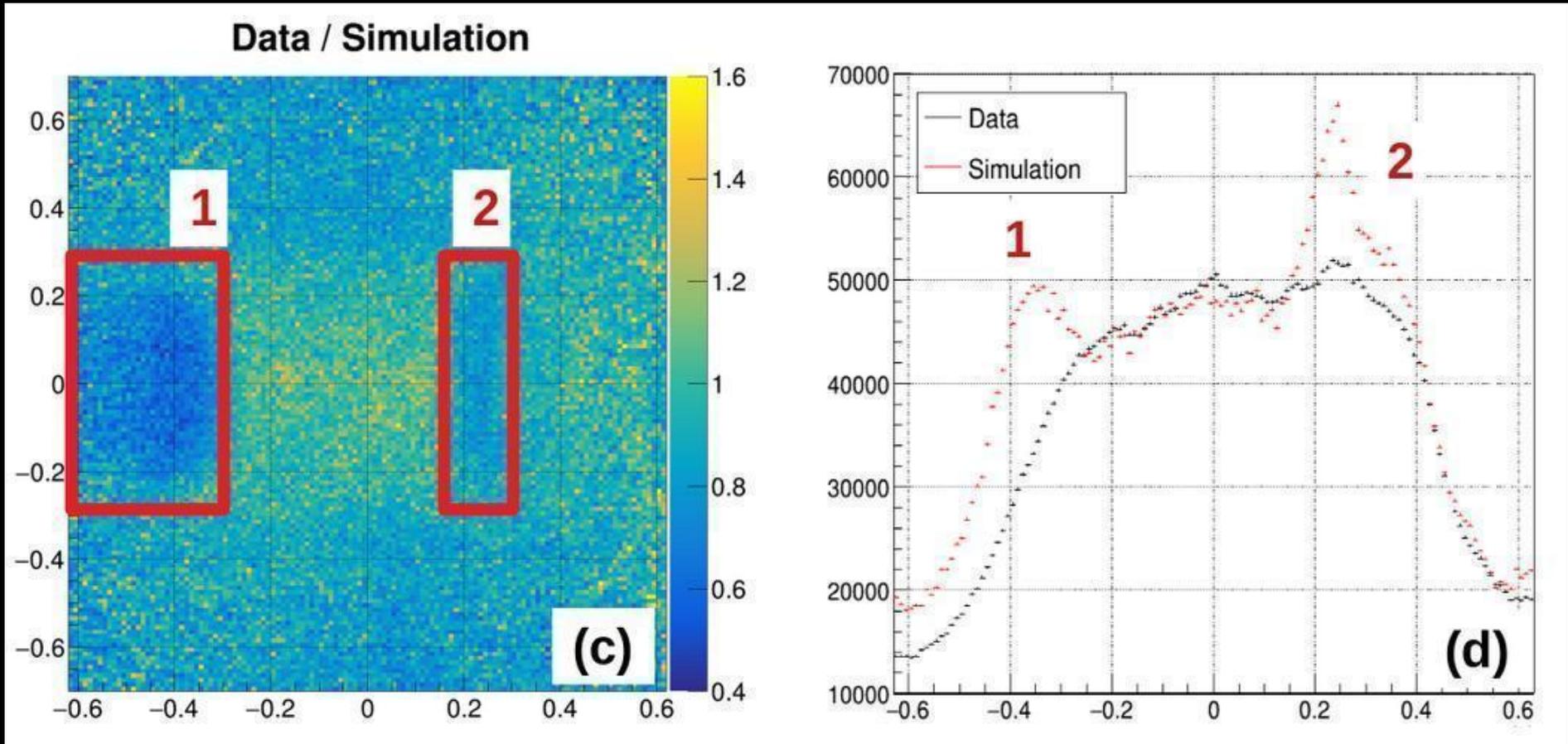


Fig. 4. Some tomographic slices obtained from the 3D reconstruction of the reactor, revealing several details of the structure. (A to E) $x-y$ slices at different heights. (F) $x-z$ slices close to the y axis. See text for more details.

laurent chevalier

Muography

identifier des anomalies



Détecteurs en Vrac

11 Mars au 13 Mars, Fréjus

- 1/ Détecter quoi \leftrightarrow pourquoi (1h)
- 2/ Interaction particules matière (1h)
- 3/ Généralités sur les détecteurs (1h)
- 4/ Application sociétales (1h)
- 5/ Exemple avec D0/ATLAS (Fermilab/CERN) (1h)



laurent chevalier