Physique

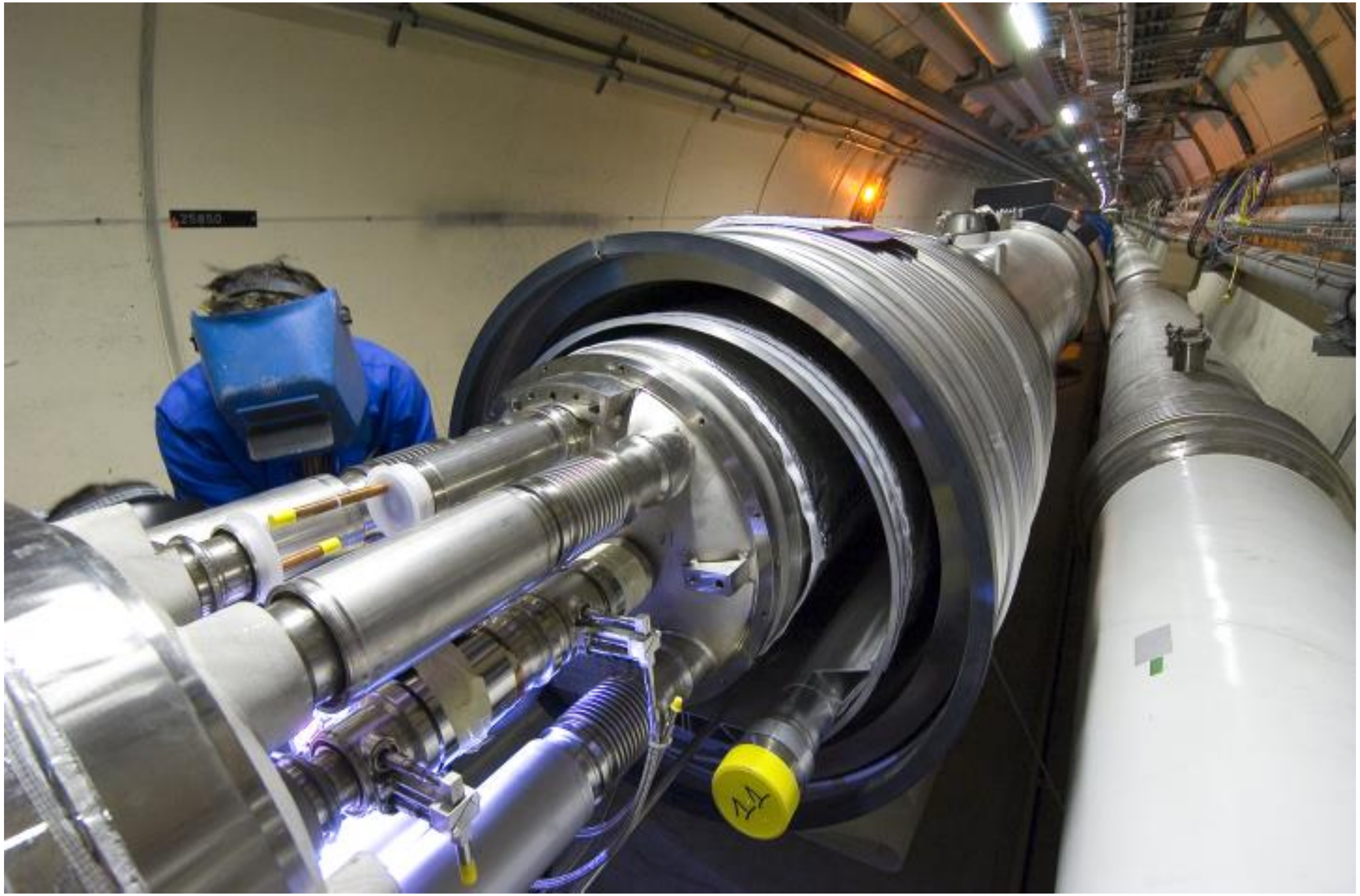
et

Imagerie Médicale

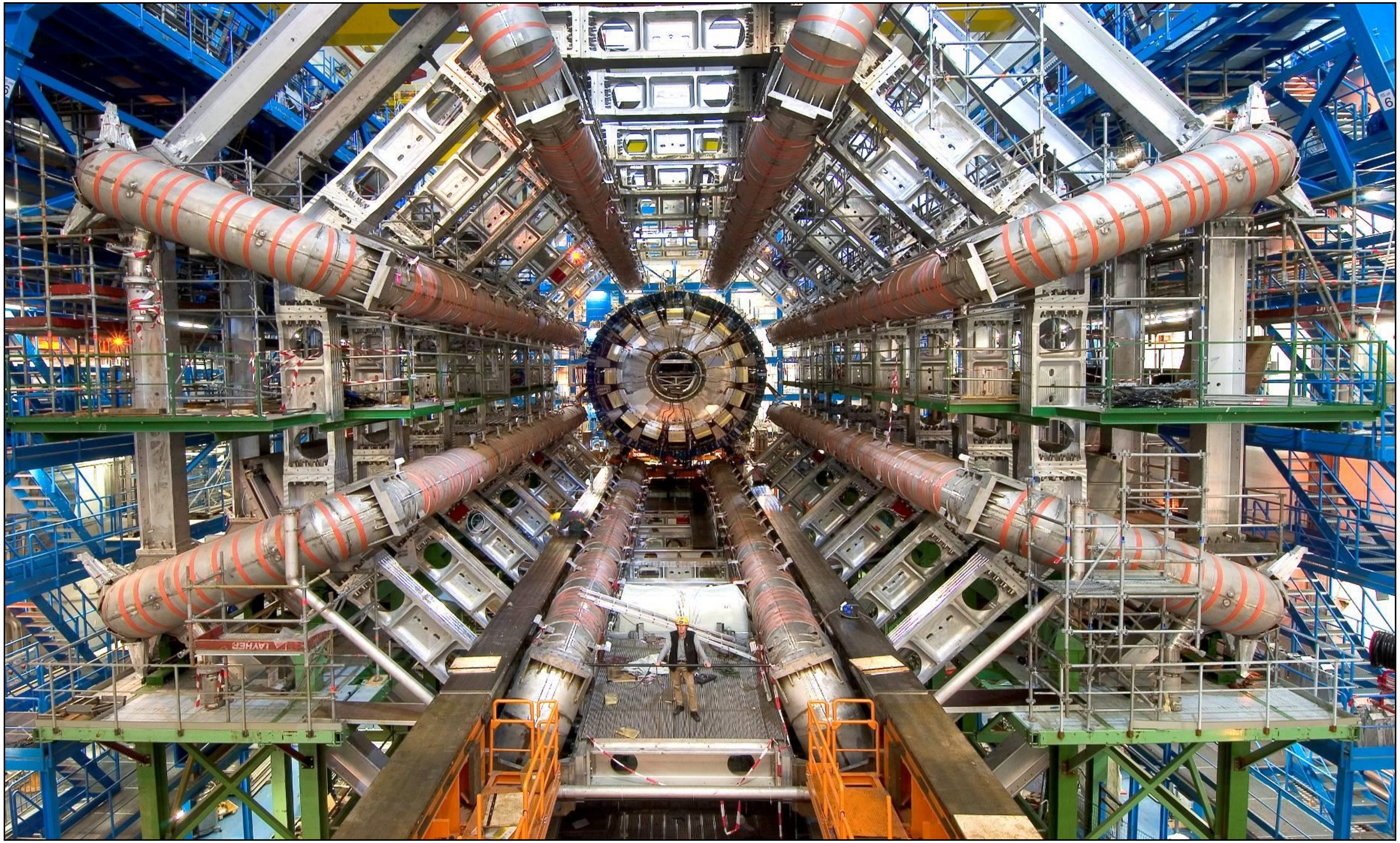
Paul Lecoq

CERN, Genève

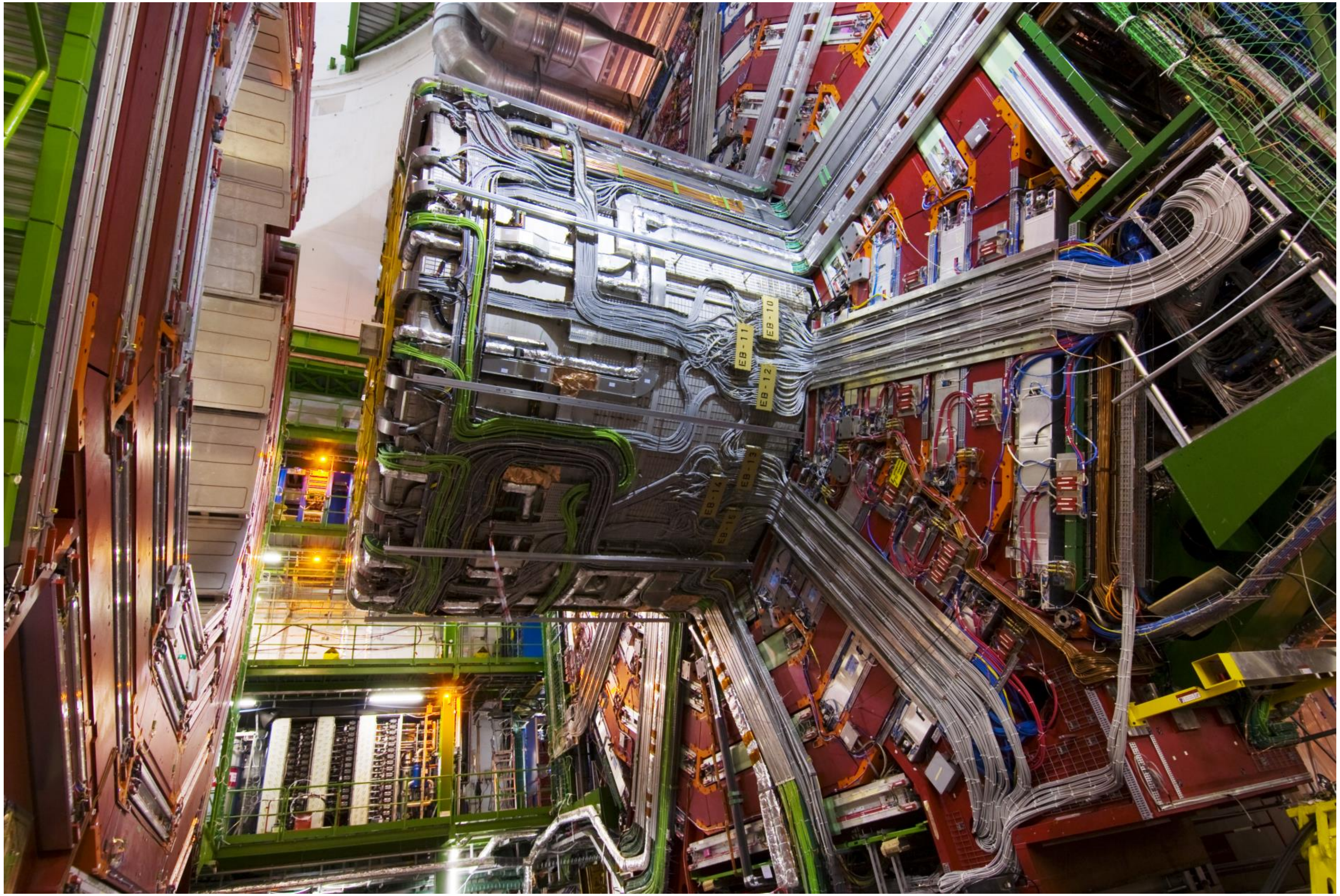
LHC - Installation des aimants supraconducteurs (27km)



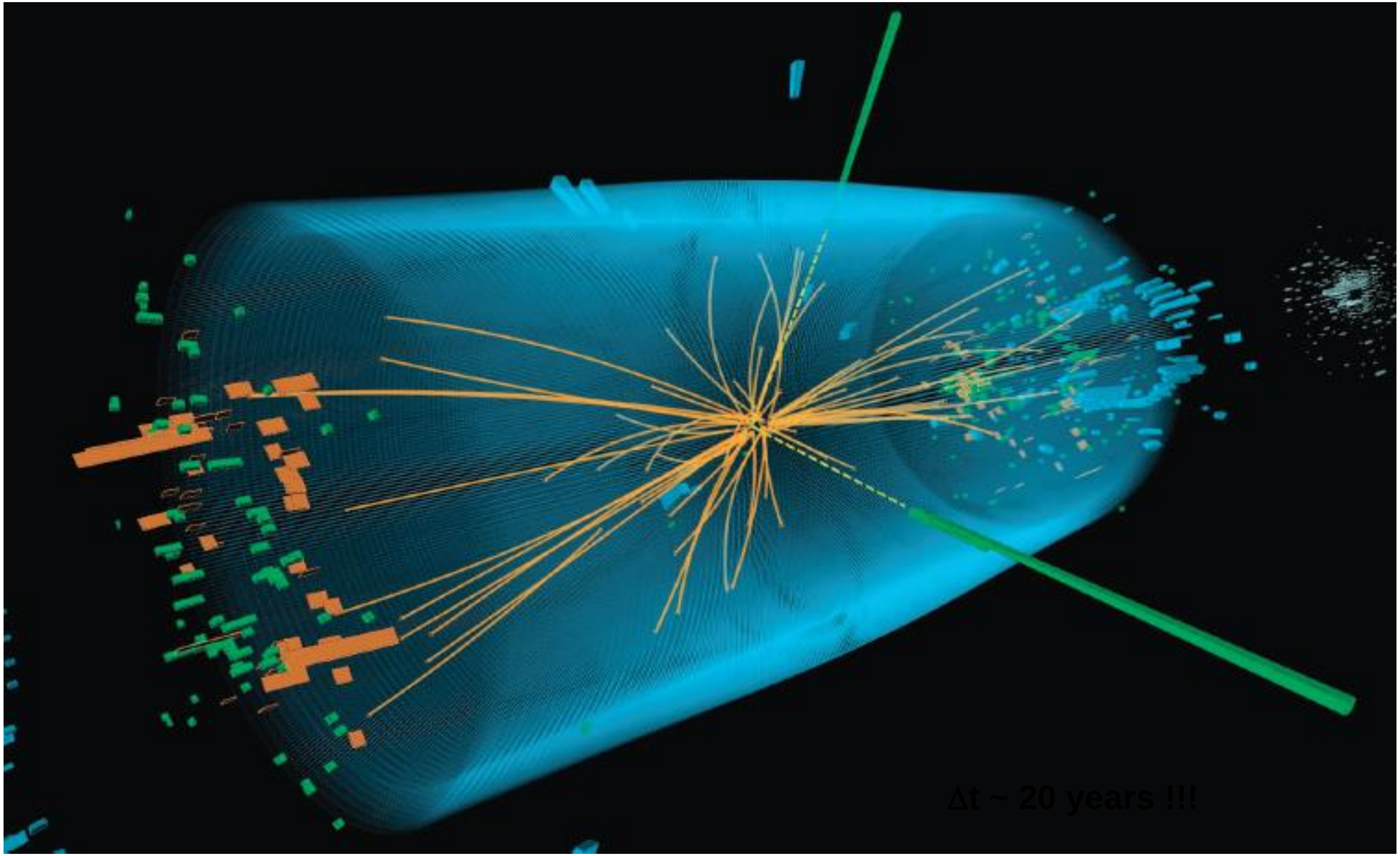
L’aimant toroïdal d’Atlas



Montage de l’expérience CMS



July 4, 2012 : The Higgs Boson!!



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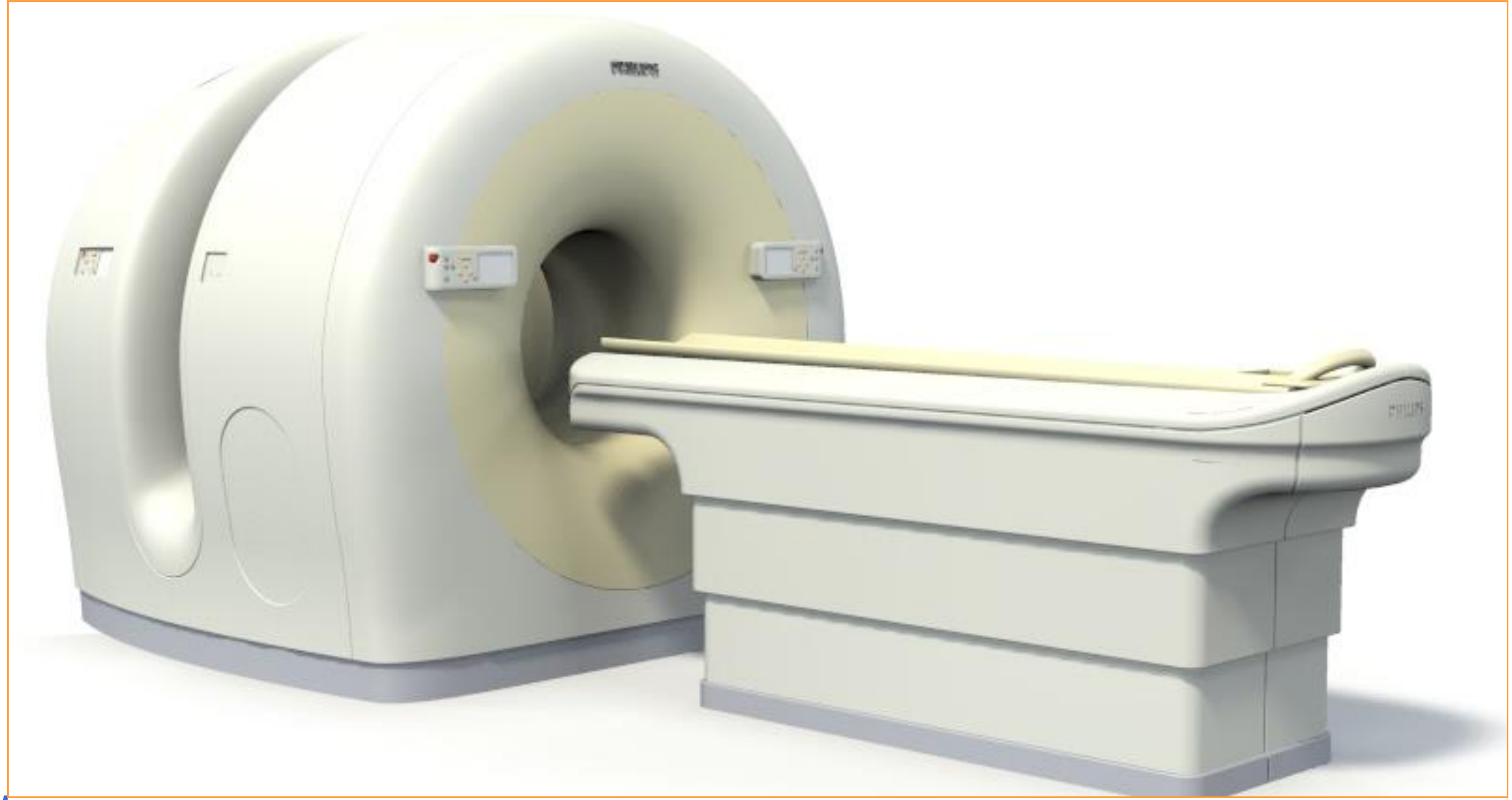
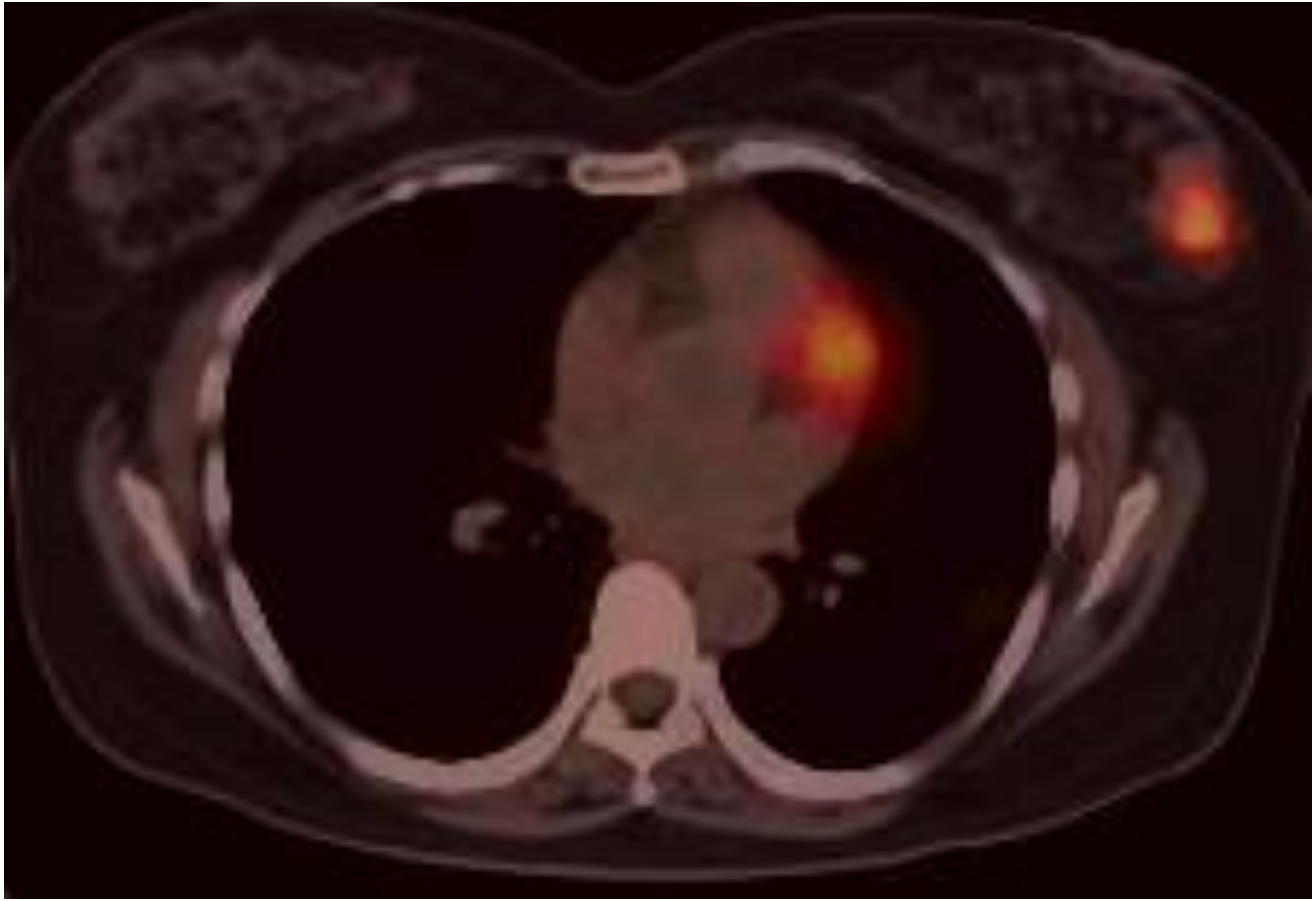
Scanner TEP/CT



Imagerie anatomo-fonctionnelle non invasive



Patiente traitée pour un cancer du colon révélant à l'examen un cancer du sein additionnel

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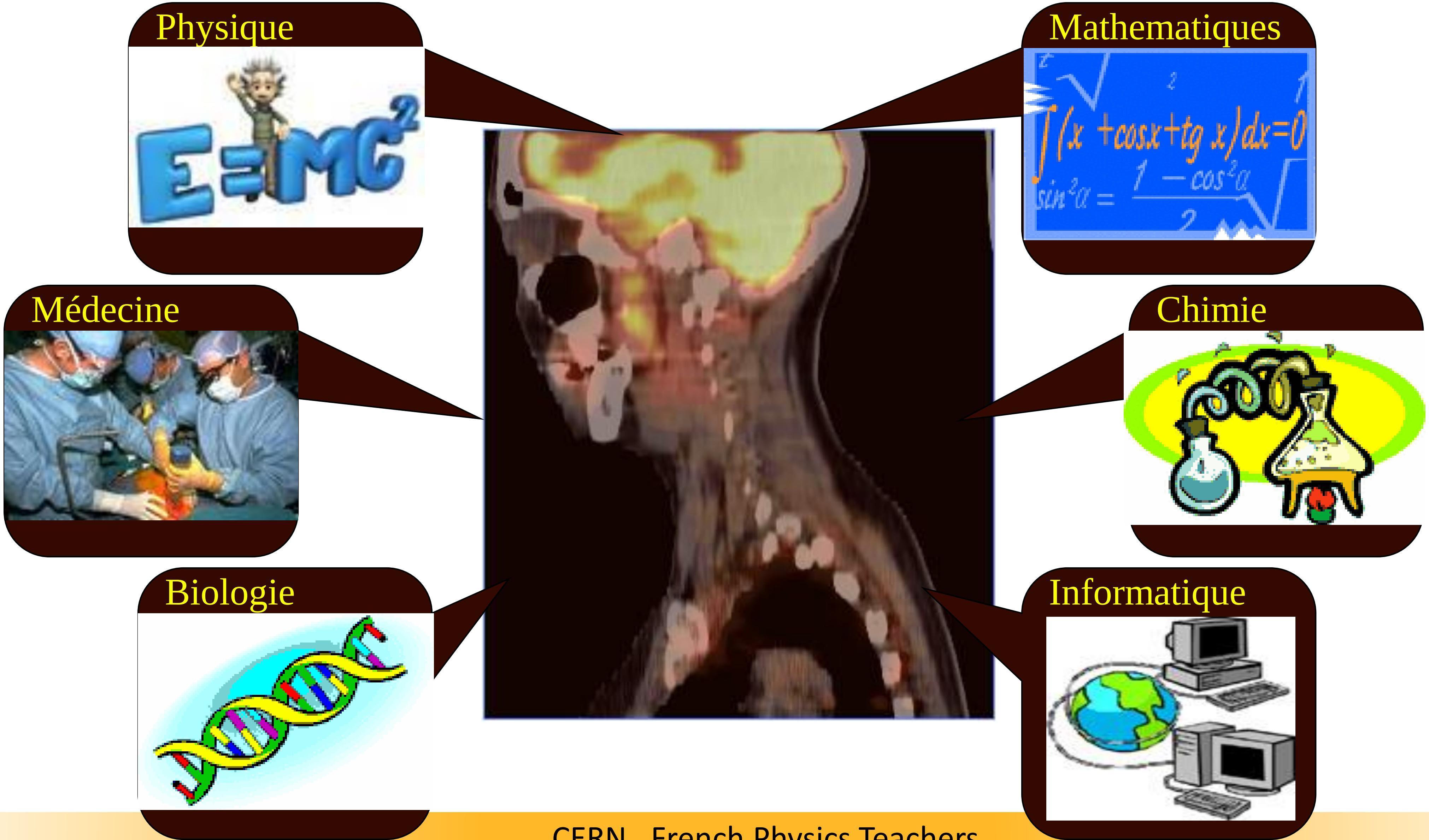
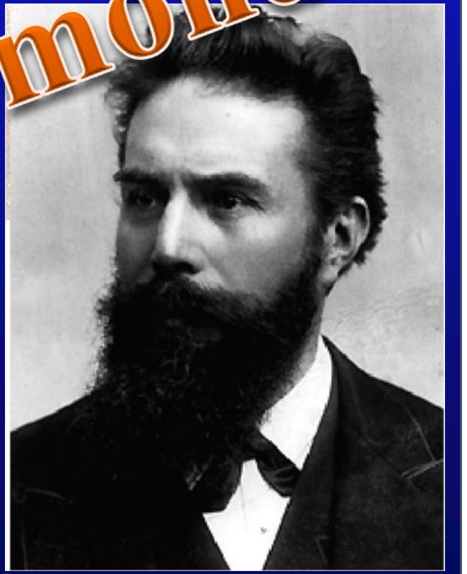
L'imagerie médicale: une approche pluridisciplinaire



La découverte des Rayons-X

- Le 8 November 1895 Röntgen découvre les Rayons X
- Le 22 November 1895 il prend le premier cliché de la main de son épouse

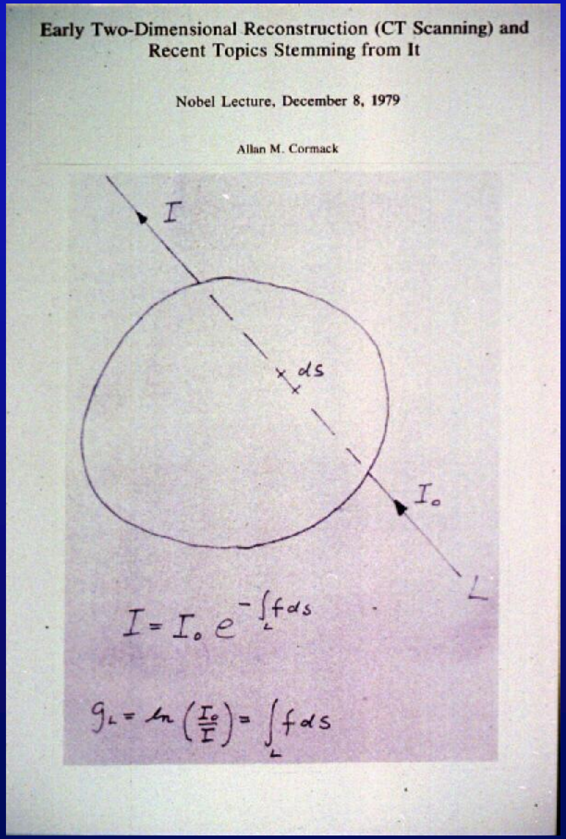
500’000’000 d’examens RX chaque année dans le monde

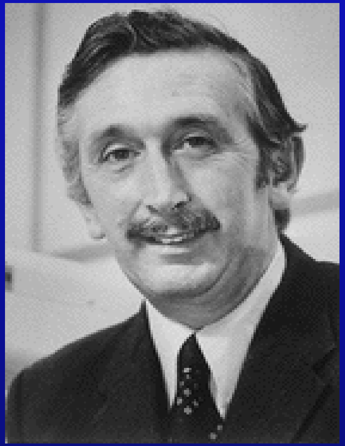


Röntgen obtient le **1er prix Nobel de physique** en 1901

CAT Scanner
Le principe de la tomographie

Prix Nobel de Physiologie et Médecine 1979

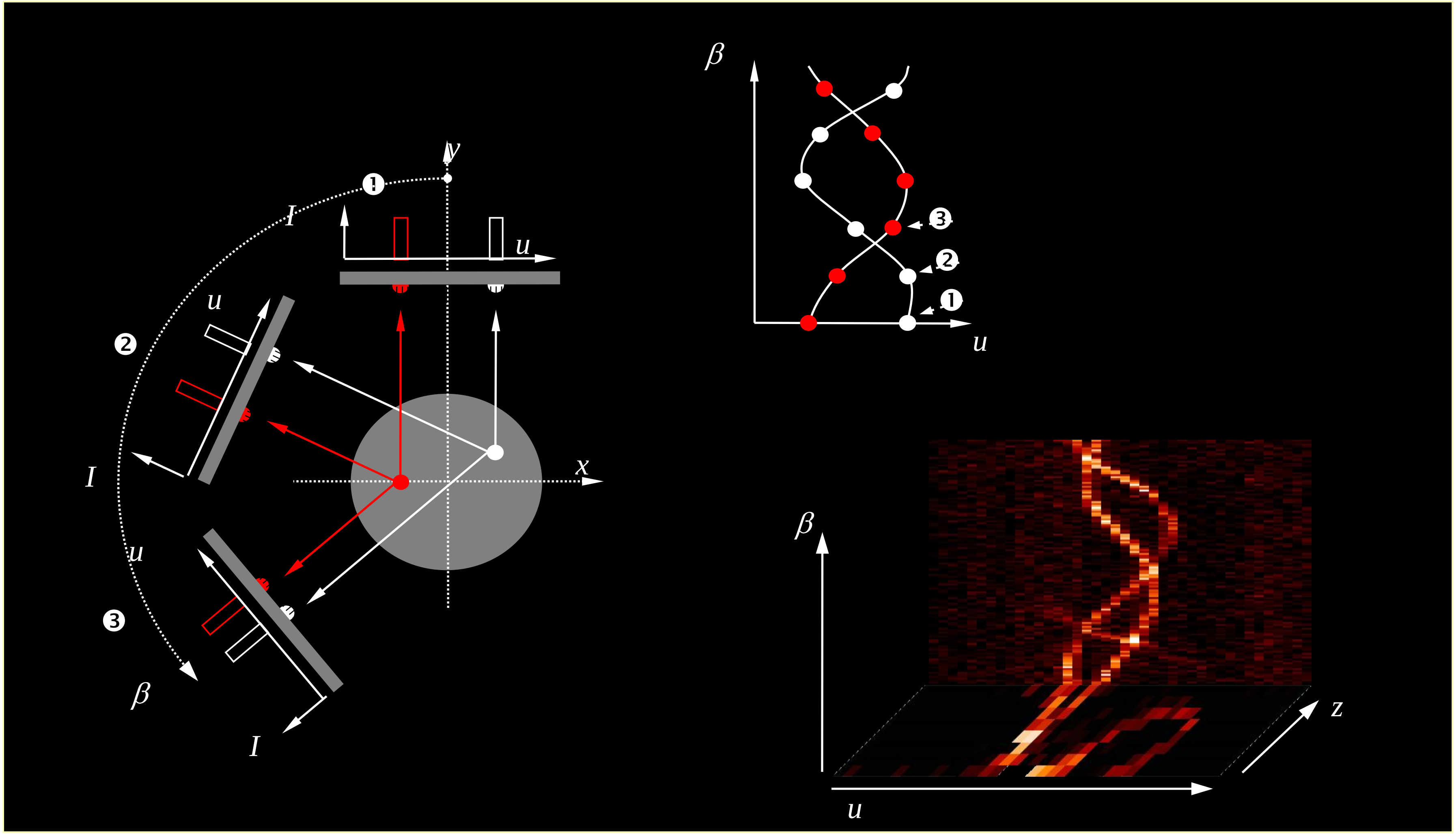




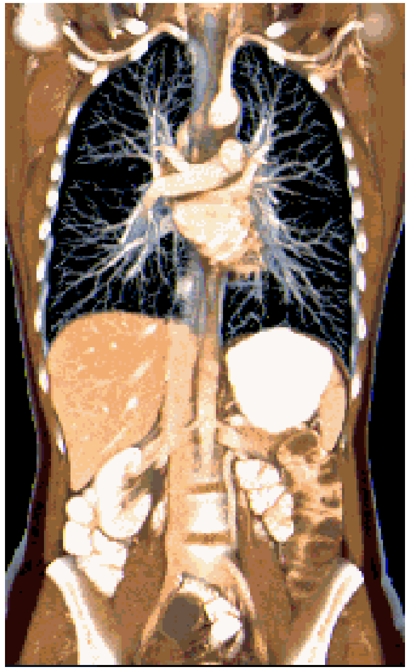
Allan MacLeod **Cormack**
Physicien Nucléaire
Cape Town
Harvard University
Tufts University

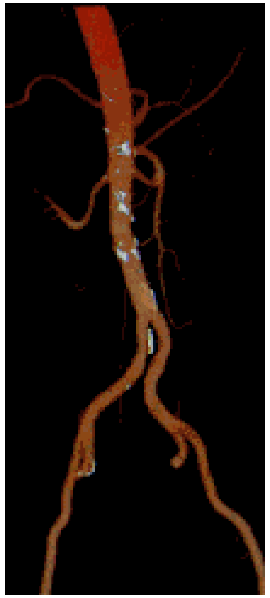
Sir Godfrey N. **Hounsfield**
Ingénieur électricien anglais
EMI Research

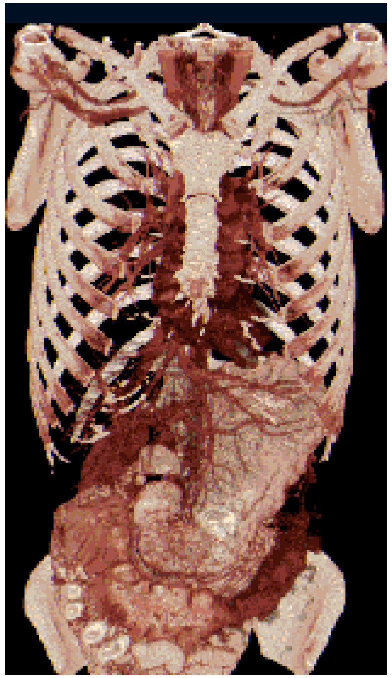
Principe de la Tomographie



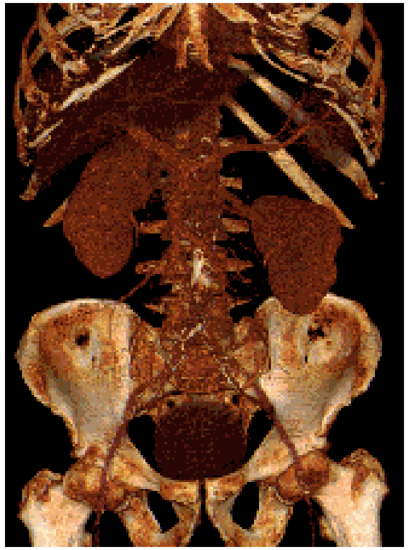
Tomographie volumétrique

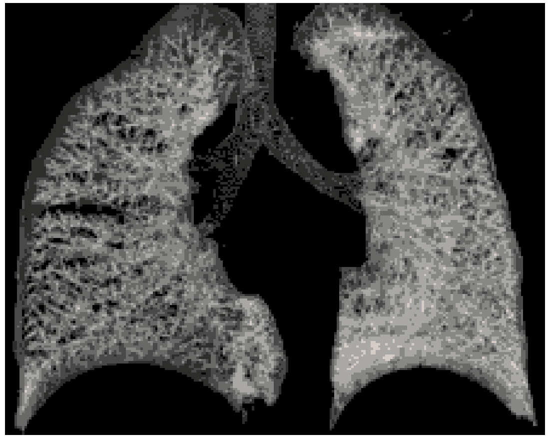






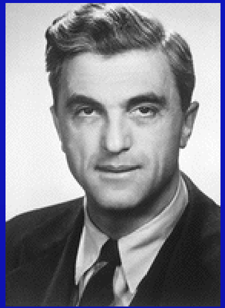
< 0,4 sec/ rotation
Organ in a sec (17 cm/sec)
Whole body < 10 sec



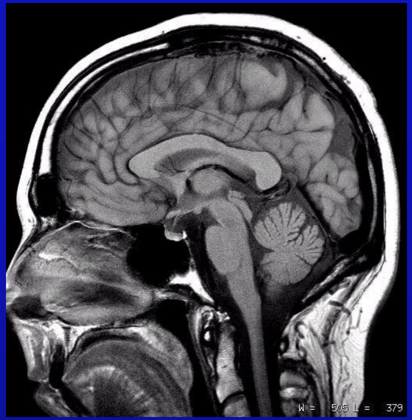


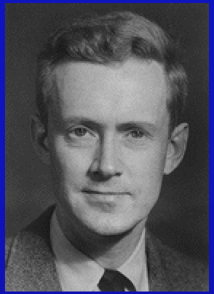
IRM, imagerie par résonance magnétique

Prix Nobel de Physique 1952



Felix Bloch
Physicien Stanford

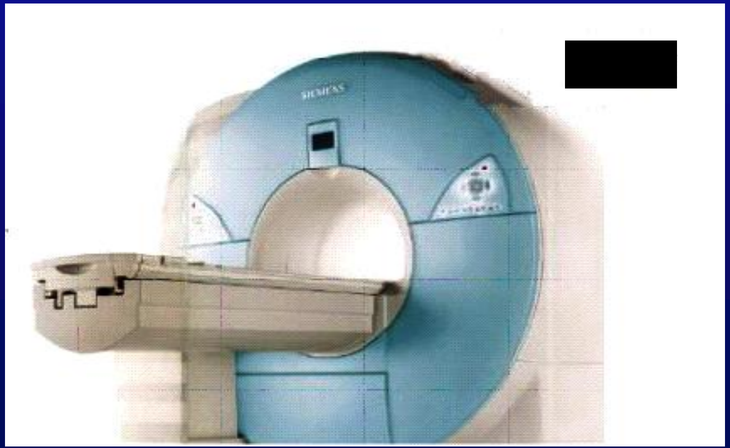




Edward M. Purcell
Physicien Harvard

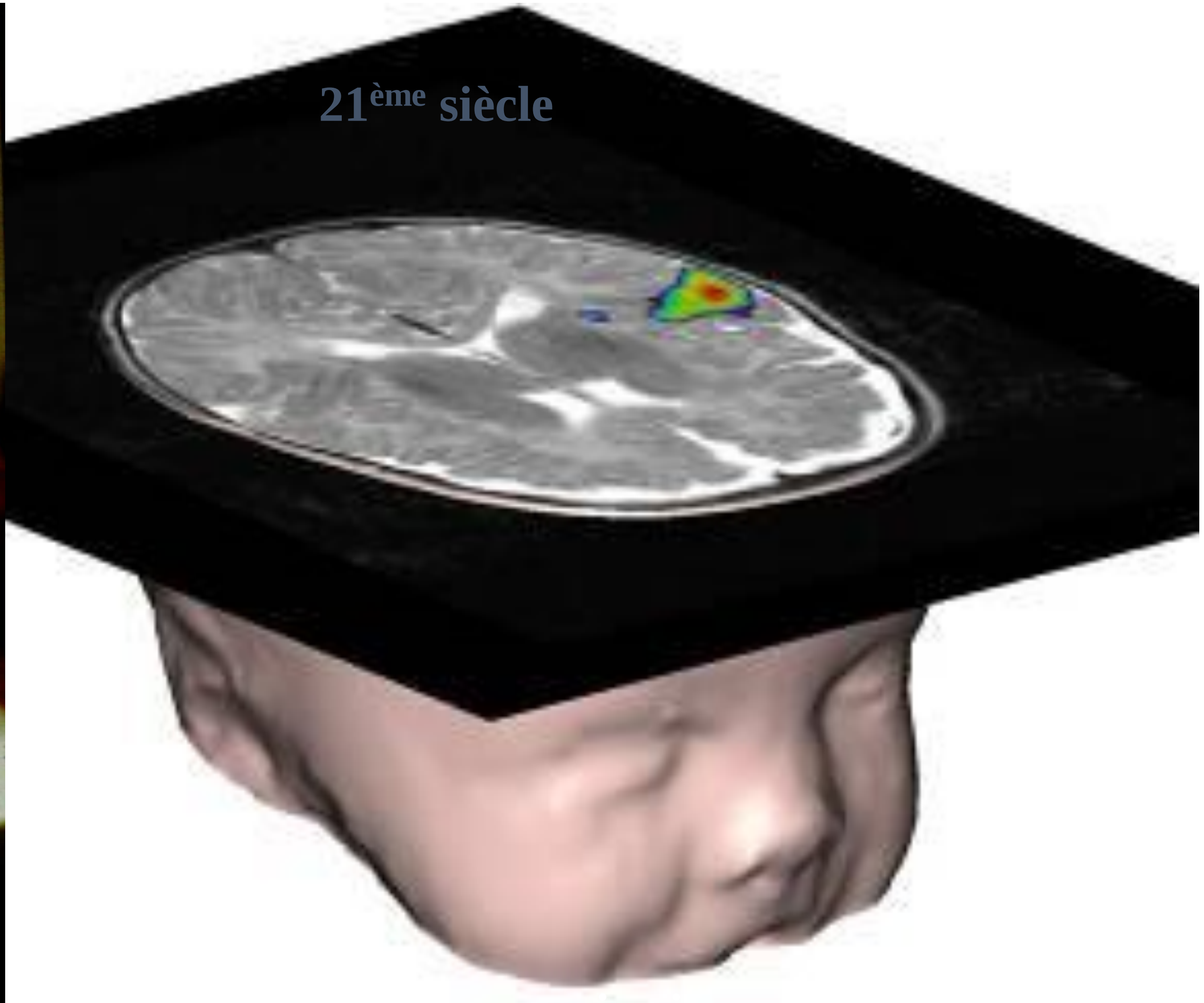
Prix Nobel de Physiologie et Médecine 2003

Sir Peter **Mansfield**
Physicien Nottingham



Paul C. **Lauterbur**
Chimiste Uni. Illinois

Petite histoire résumée de l’imagerie in-vivo



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Differents types d'imagerie pour différents types d'information

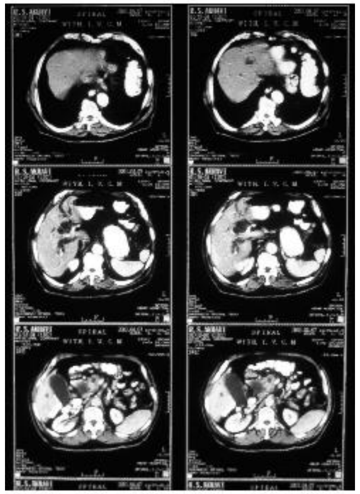
- Imagerie anatomique
  - Localiser des masses ou des lésions
  - *Optique, CT, ultrasons, IRM*

- Imagerie fonctionnelle
  - Quantifier des modification dynamique du métabolisme au niveau des organes
  - *Ultrasons (Doppler), IRM (Bold), Imagerie nucléaire (PET/SPECT)*

- Imagerie cellulaire
  - Etudier les échanges des cellules entre elles, et avec leur environnement (stroma)
  - *Optique, IRM, Imagerie nucléaire (PET/SPECT)*

- Imagerie moléculaire
  - Etudier les chemins moléculaires impliqués dans la production de protéines, d'enzymes, différents métabolites (sucres, acides aminés, acides gras, etc…)
  - *Imagerie nucléaire (PET/SPECT)*

Imaging Modalities

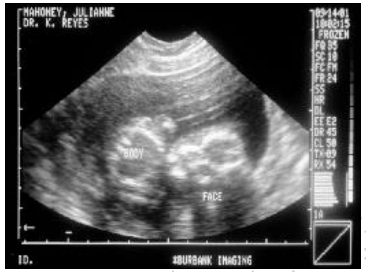


CT

A

Tissue Density, Z
20-50 µm

Ultrasound



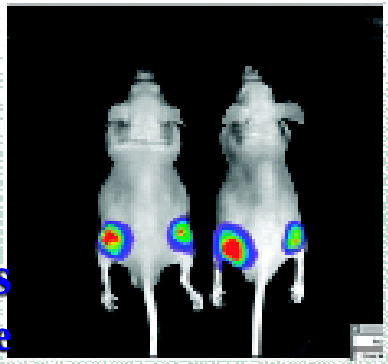
A F

Structure
0.1 mm
Doppler

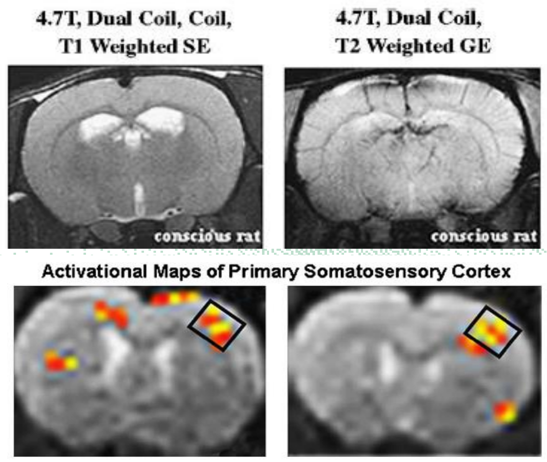
Optical
(Bioluminescence, fluorescence)

A M

Topography
µm to mm
~10³ cells
≠ quantitative



Photons involved



MRI

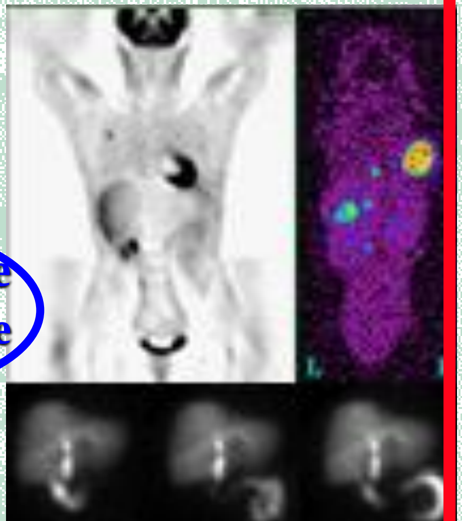
A F M

H Concentration
0.1 mm
BOLD, DCE
β-galactocidase
0.1 µmole H / µmole ³¹P

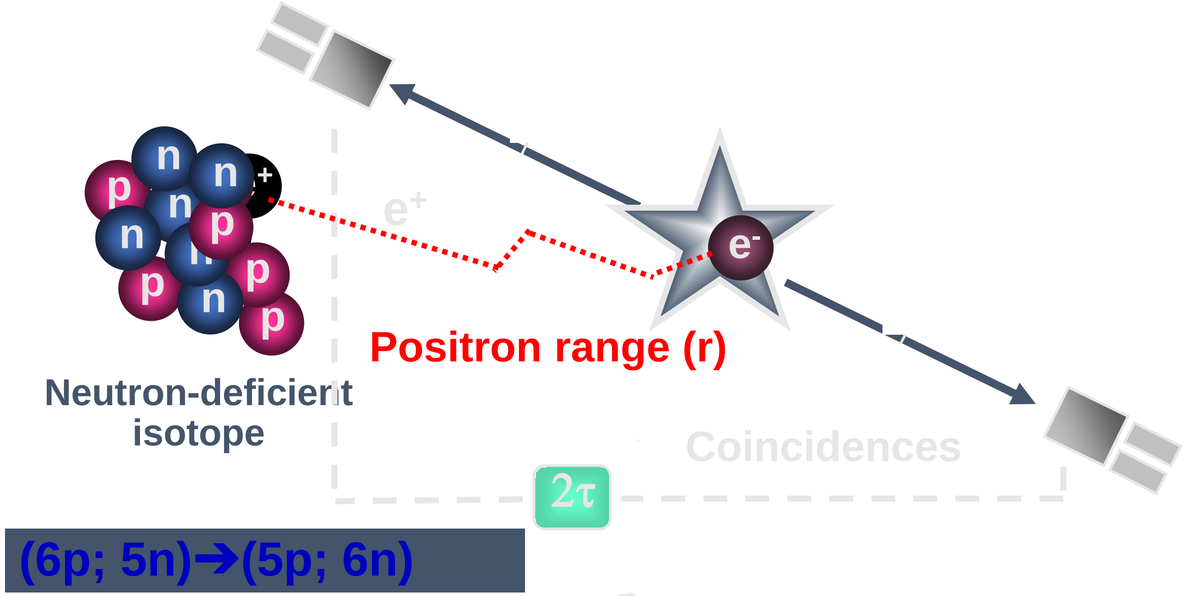
PET/SPECT

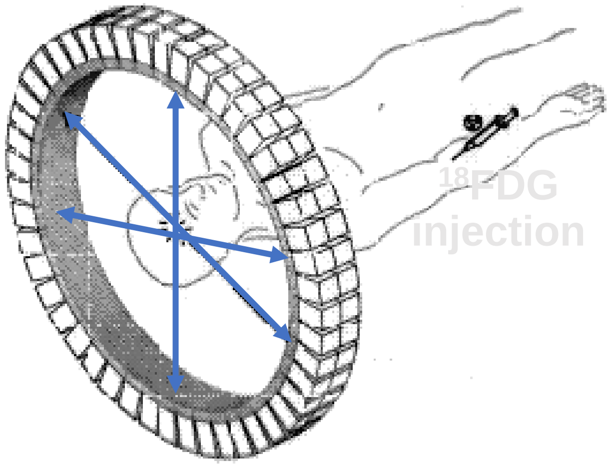
F M

Radiotracer
~1-2 mm
<10⁻¹² mole
= quantitative

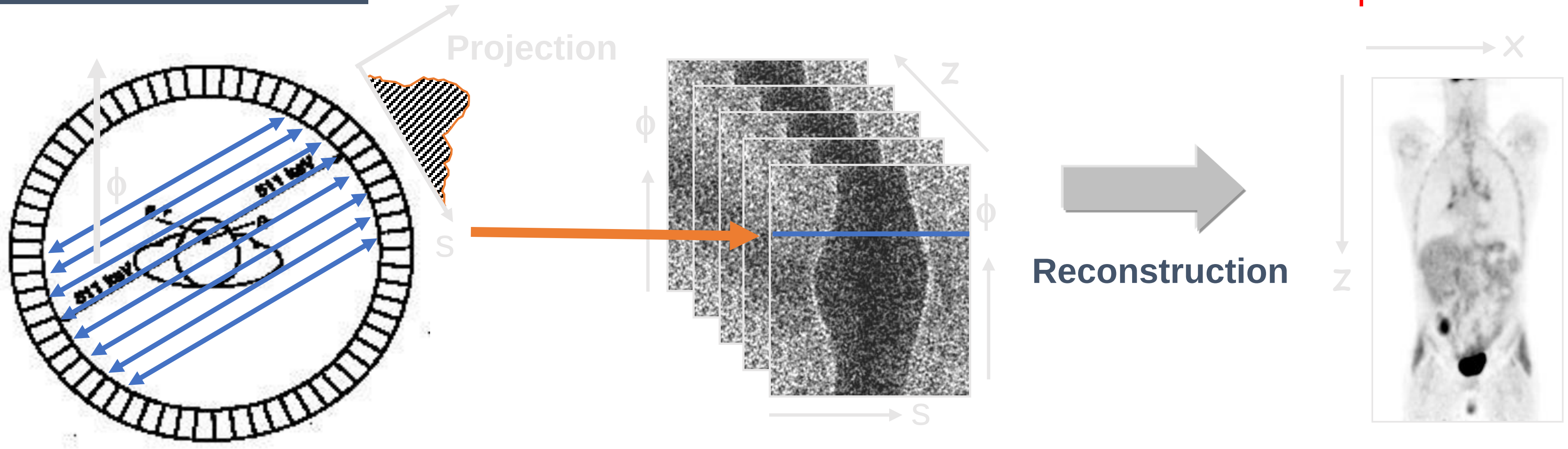


PET Principle





PET data acquisition

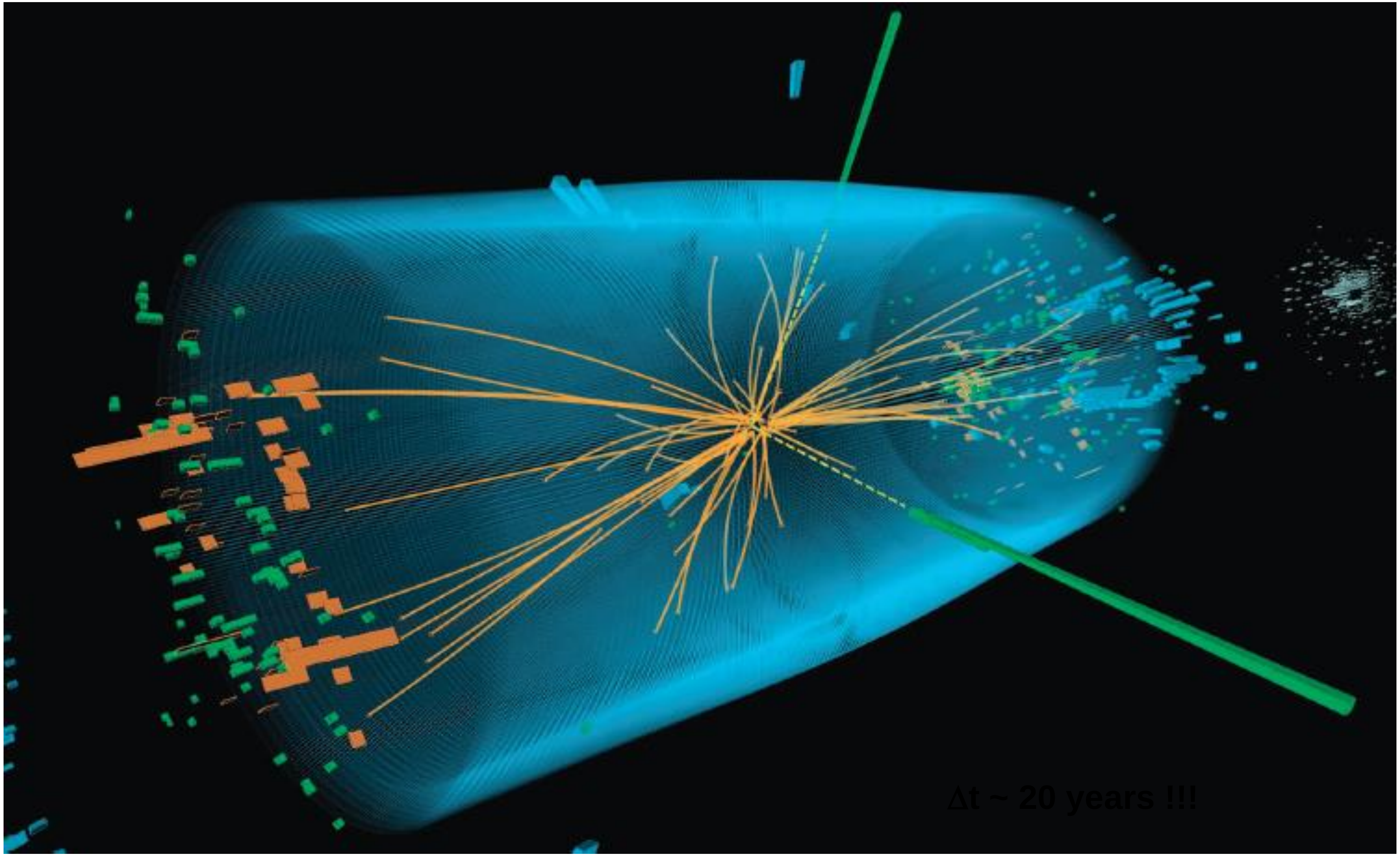


Parallel projections

PET data (sinograms)

PET images

July 4, 2012 : The Higgs Boson!!



The PET World Picture

Need to Image

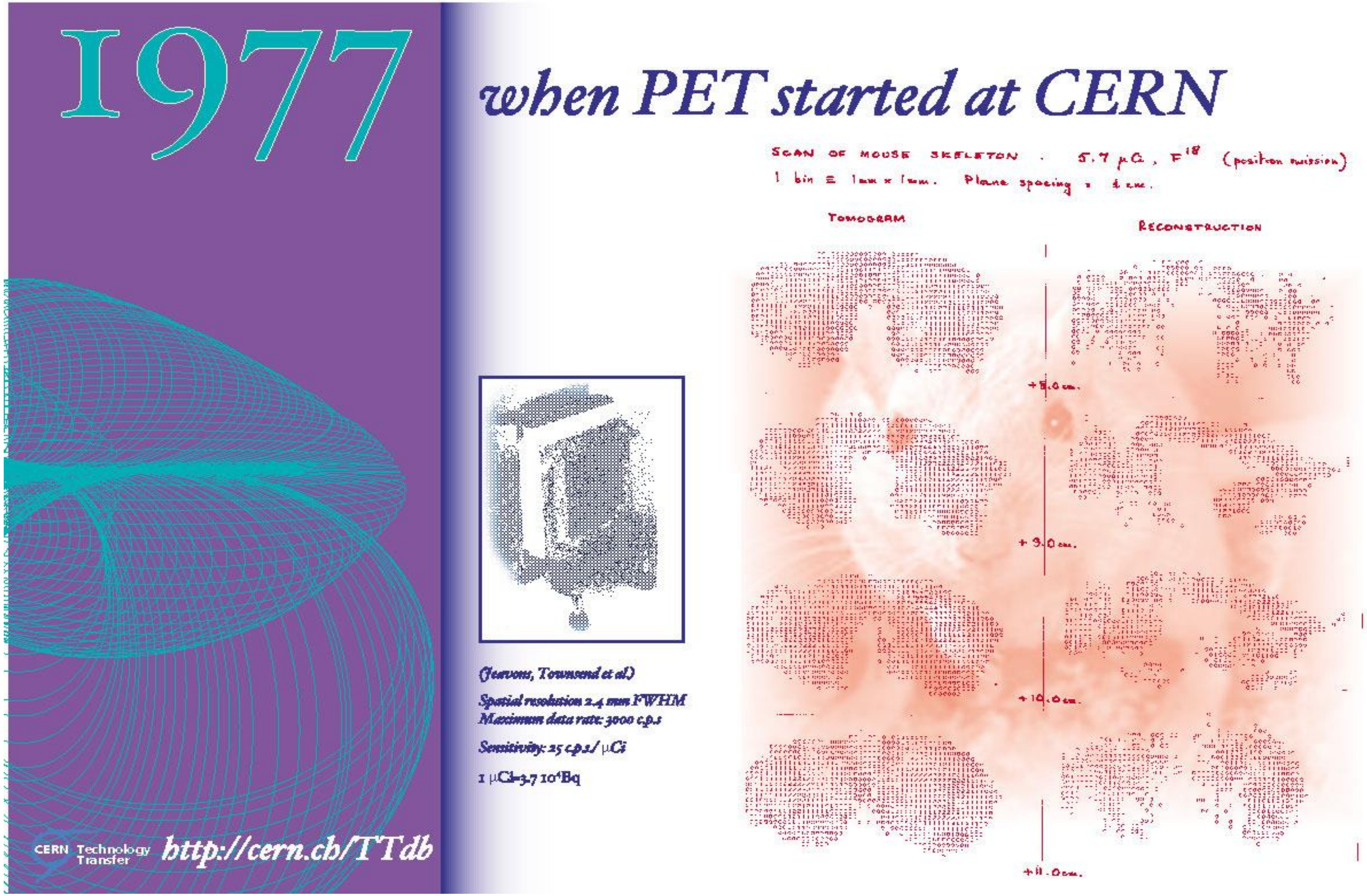
0.000000511 TeV*

Photons

Signal Levels Are Very Low

***511 keV**

Un peu d'histoire



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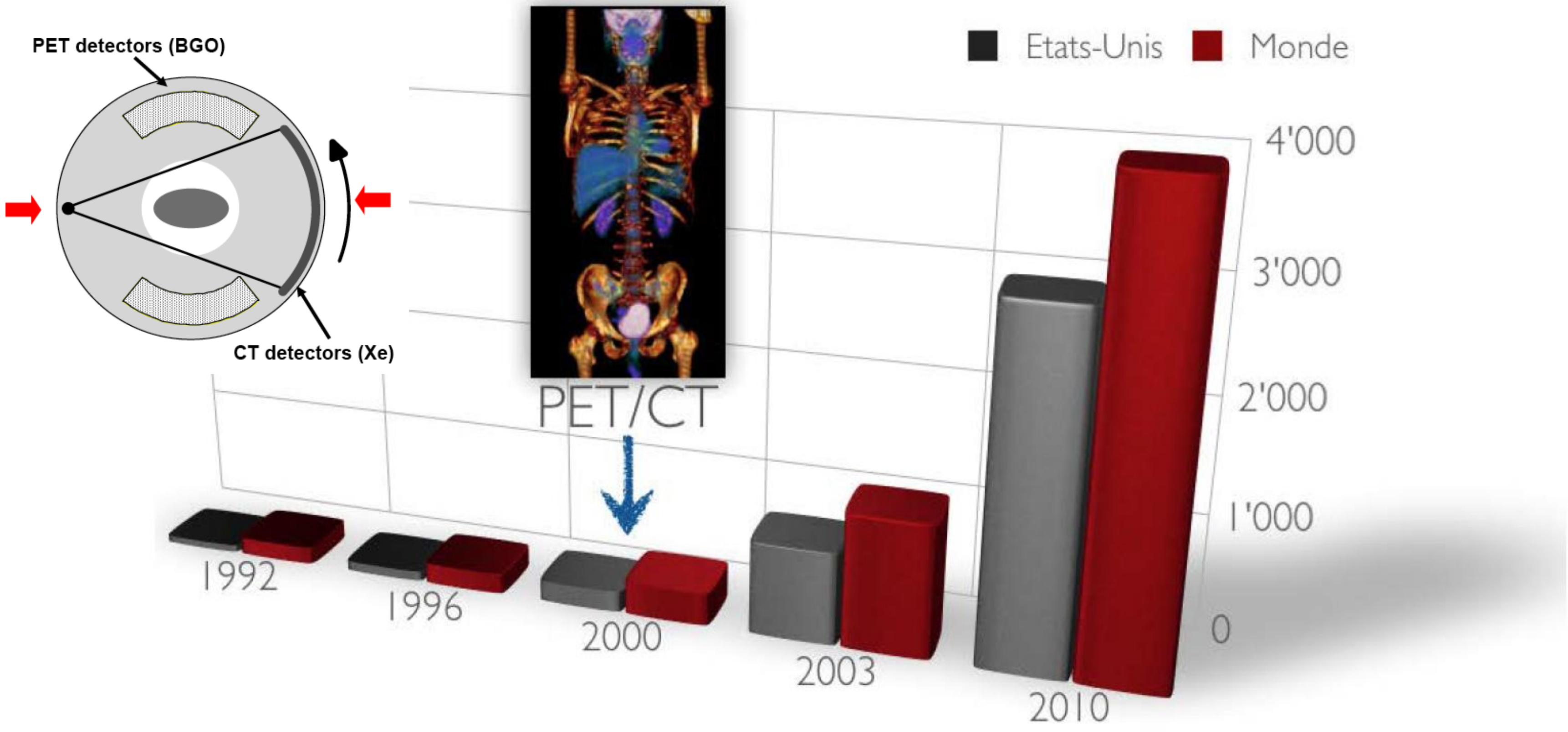
Invention of the PET/CT

PET/CT

Disruptive Technology

TIME
DECEMBER 4, 2000

Time Magazine's Medical Invention of the Year 2000



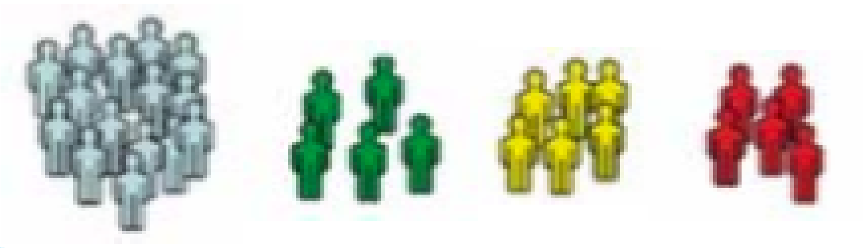
PET/CT Invention

David Townsend
(former CERN)

Médecine personnalisée

Approche globale

Médecine personnalisée



Un diagnostic

Un traitement

Diagnostic moléculaire

Imagerie moléculaire

+ Génomique

Traitement individualisé

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L'imagerie pour une meilleure prise en charge du patient

Recueillir une information détaillée de chaque individu pour:

- Diagnostiquer la maladie à un stade précoce
- Déterminer les paramètres de la maladie, comme son agressivité, son potentiel métastasique
- Optimiser l'action thérapeutique en fonction du génotype du patient
- Evaluer instantanément l'efficacité du traitement

Implique une nouvelle génération de systèmes d'imagerie

L'imagerie: quelle qualité pour voir quoi et dans quelles conditions?

L’imagerie médicale du futur

- Voir des lesions plus petites
- Examens plus rapides
- Correction de mouvements
  - Respiration
  - Battements cardiaques
  - Bolus digestif
- Etudes dynamiques
- Quantification
- Multimodalité
- Réduire la dose aux patients

AMELIORER

- Résolution spatiale
- Résolution temporelle
- Rapport Signal/Bruit
- Sensibilité

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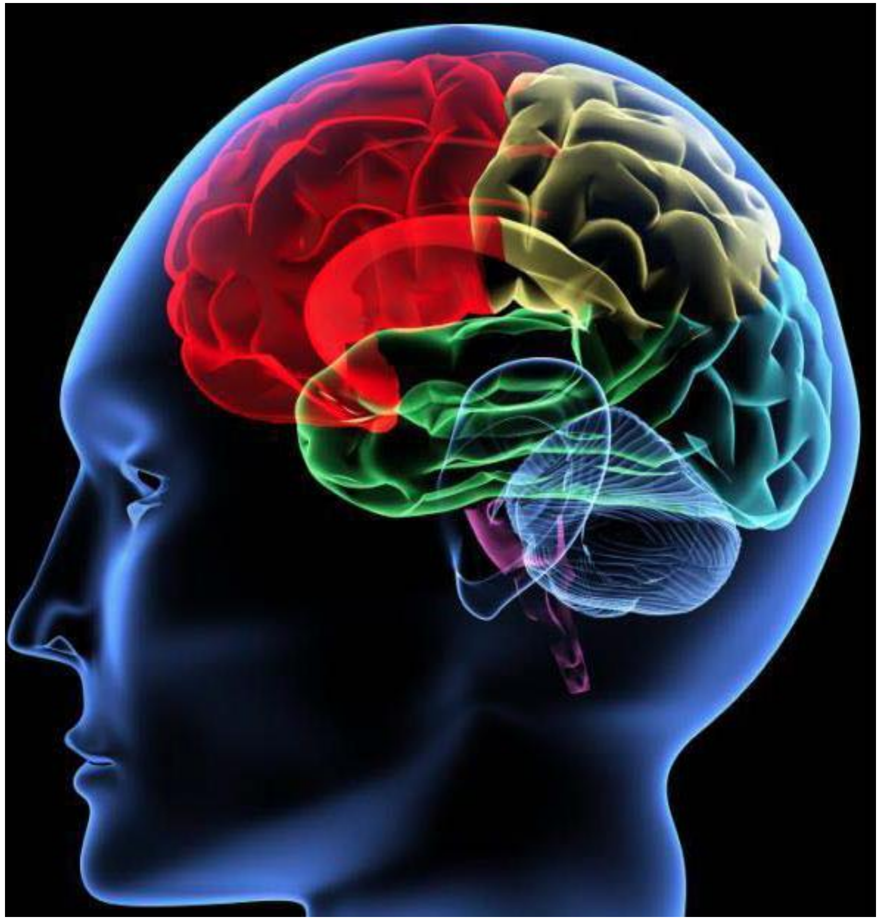
Etudes de plus en plus spécifiques sur modèles animaux

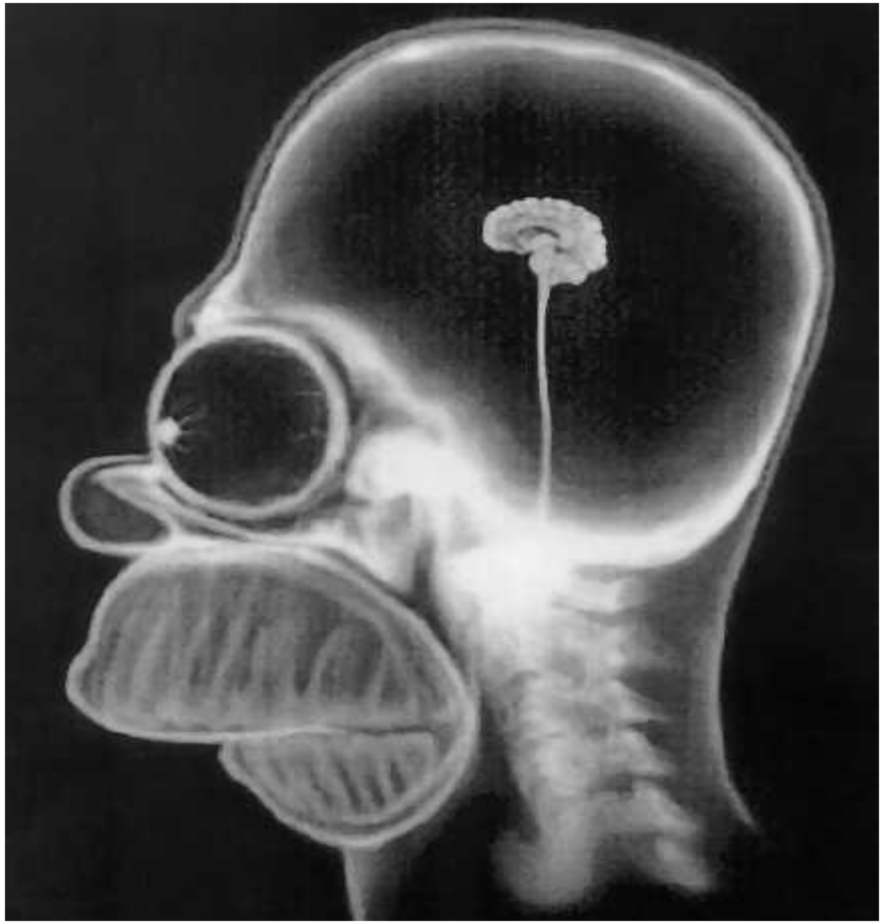
- L'imagerie petit animal se fait généralement sous anesthésie
- L' anesthesie modifie les fonctions cervicales et biaise les études neuro-physiologiques
- RATCAP, developé à BNL est un TEP miniaturisé et portable pour animal éveillé
- 12 blocs de 4x8 cristaux de LSO 2x2x5mm^3 lus par des matrices de 4x8 APD et 0.18µm CMOS ASIC

•C. Woody et al. Several papers in conference records of NSS/MIC2004, Rome

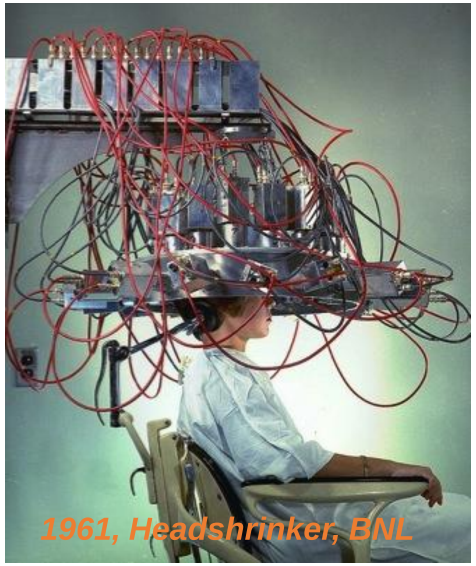

Courtesy of C. Woody,BNL

Brain Imaging



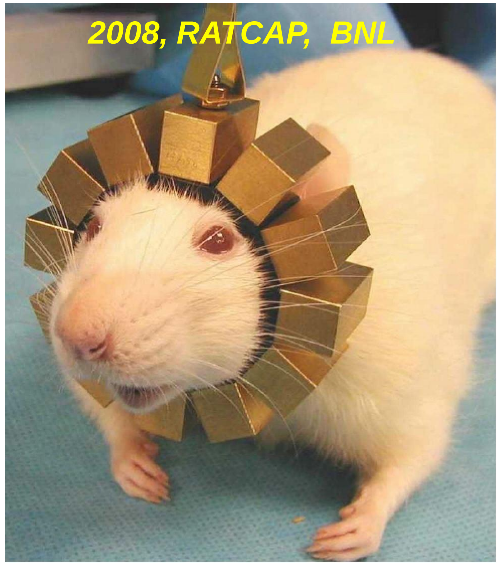


Brain Imaging


1961, Headshrinker, BNL


2011, PETHAT, Hamamatsu


2013, BrainPET, Hamamatsu


2008, RATCAP, BNL

2012, HELMETPET, Majewski


2015, HELMET_CHIN, Yamaga

Courtesy: S. Majewski, West Virginia University

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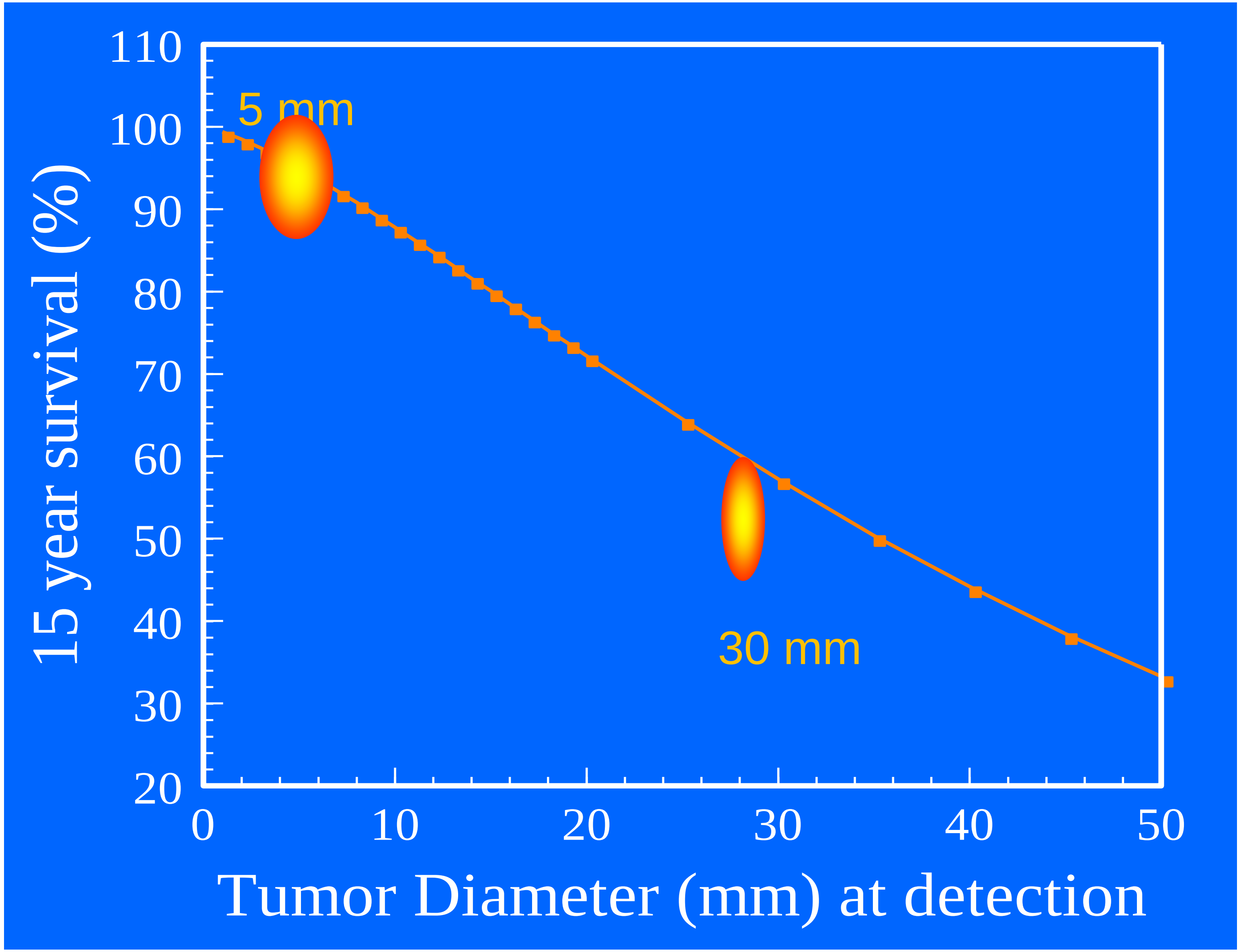
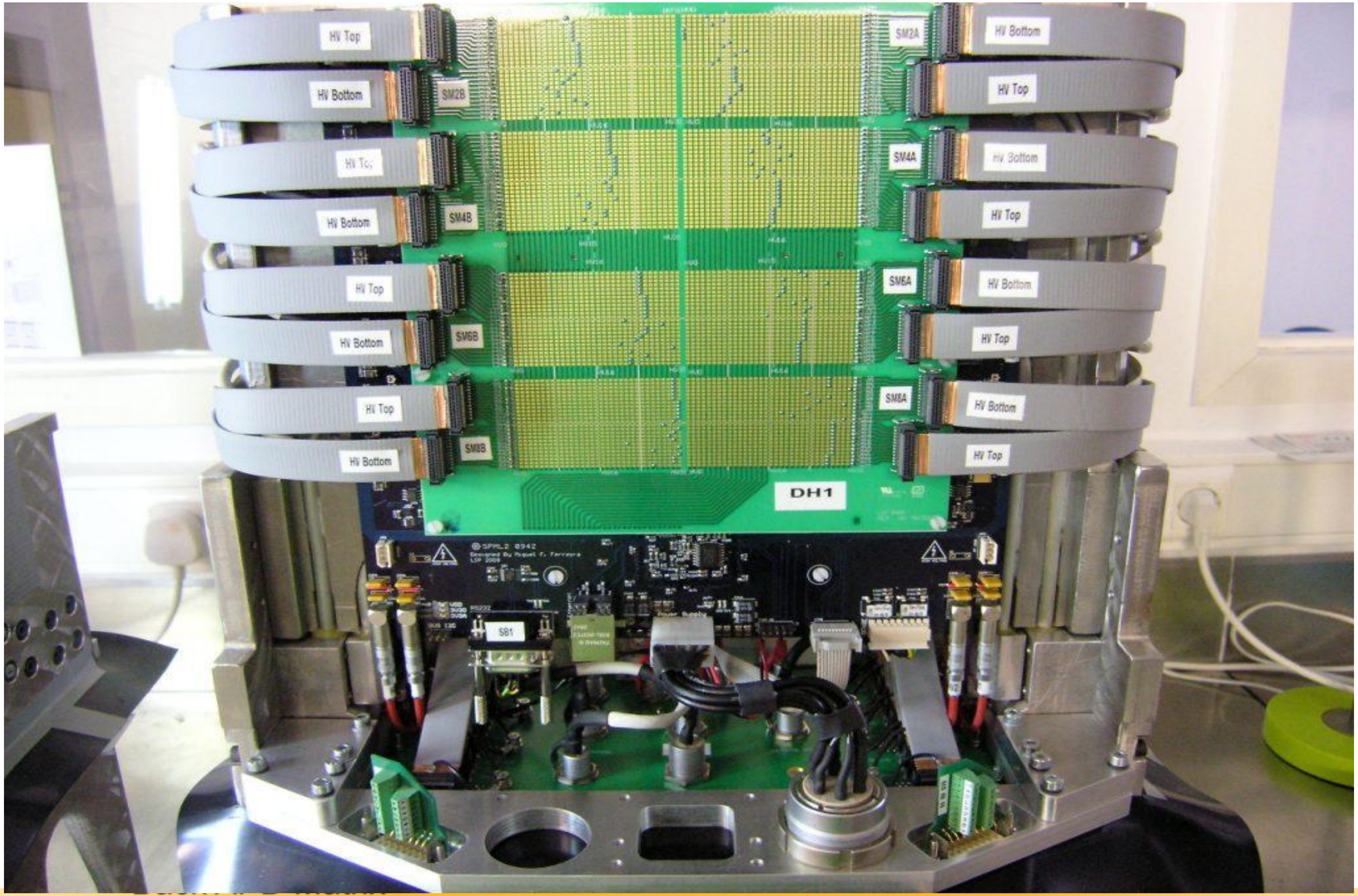
Breast Cancer



ClearPEM-Sonic a collaborative project between physicians and physicists

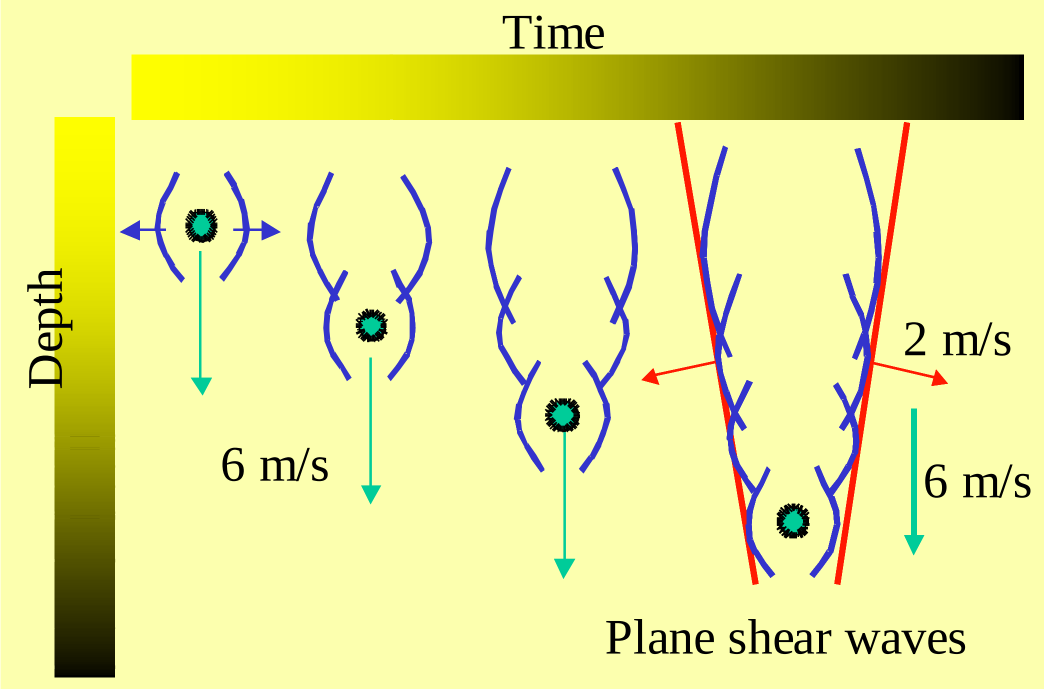
Objective: Detect 3mm tumors and define their cancerous status

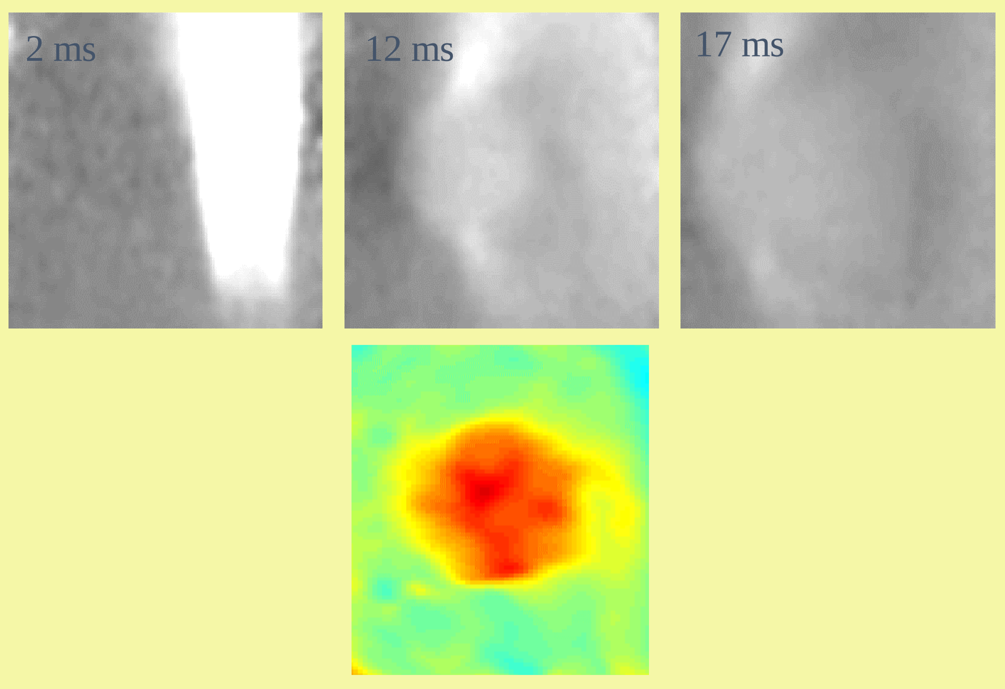
Des technologies d'avant-garde: ClearPEM



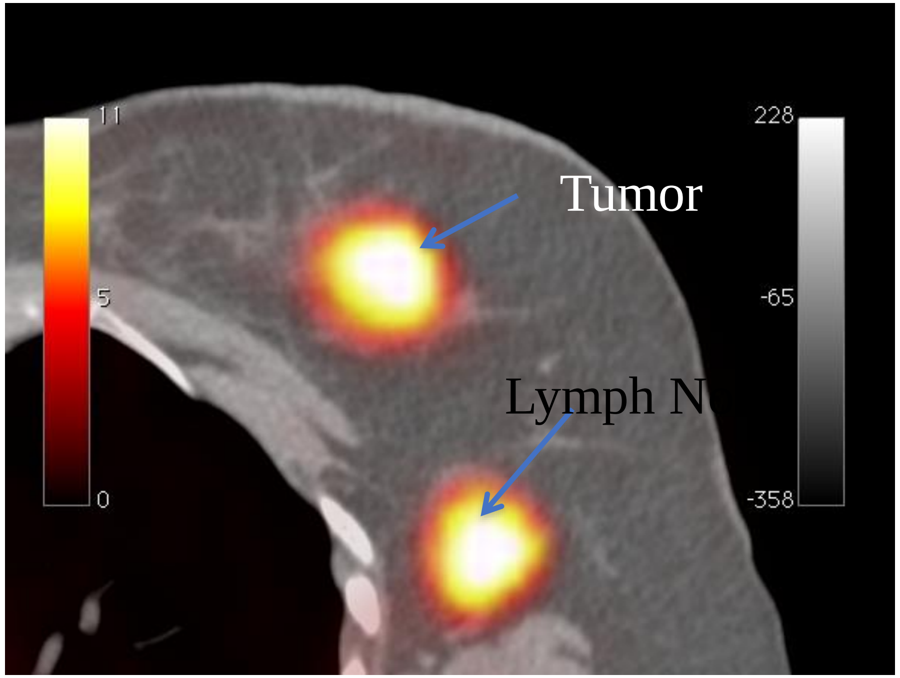
Des technologies d'avant-garde: Ultrasons

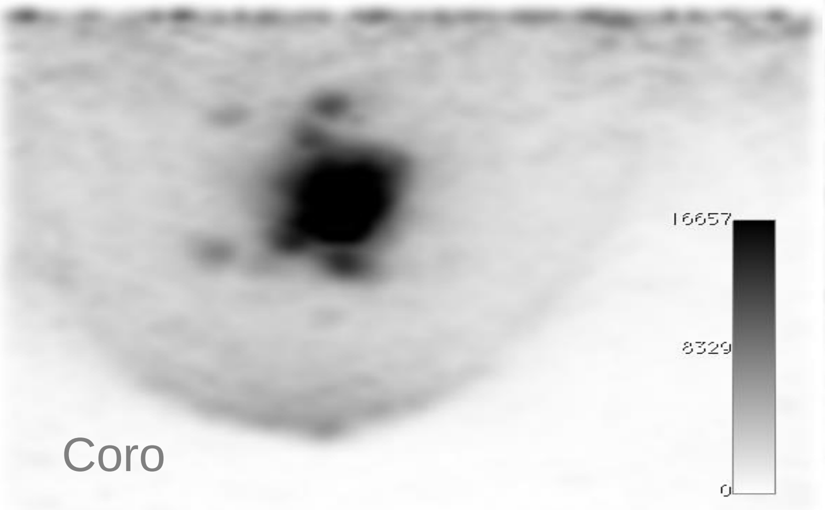
- Focus ultrasound beam in tissue
- Propagate focal point a t supersonic speed in breast
- Measure the deformation of the shock wave by a tumor

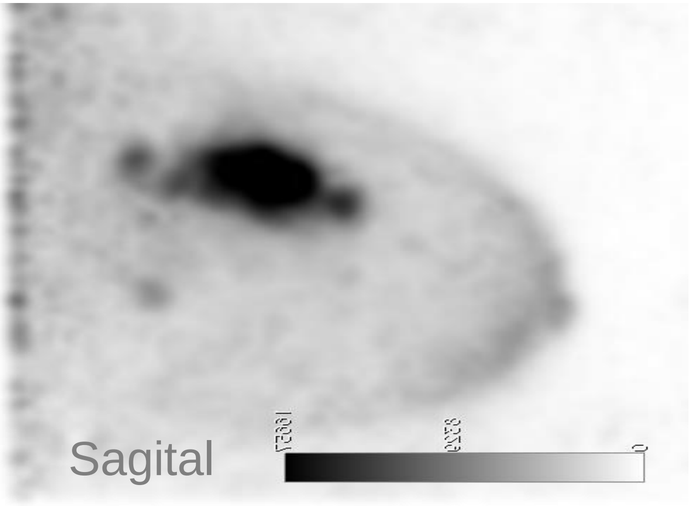




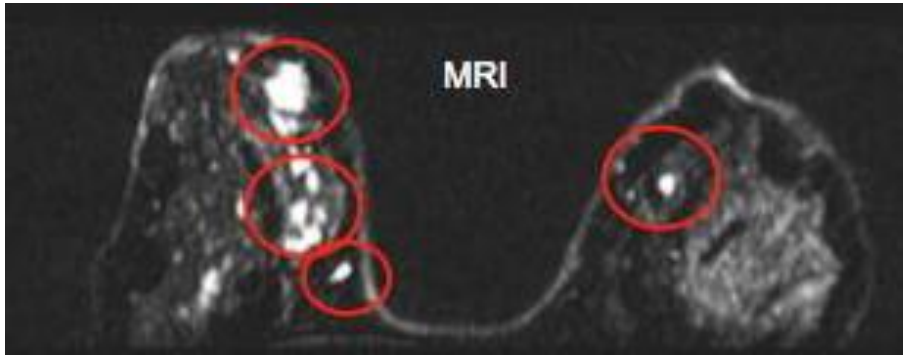
Benefit of dedicated breast PET imaging







PET/MRI complementarity



4 lesions identified on MR image

Only one suspicious lesion identified on PET image

Subsequent biopsy and histology of all four lesions confirmed that only the lesion seen on PET image was cancerous

Courtesy: Dr. José Ferrer, ERESA, Hospital General Universitario de Valencia, Spain

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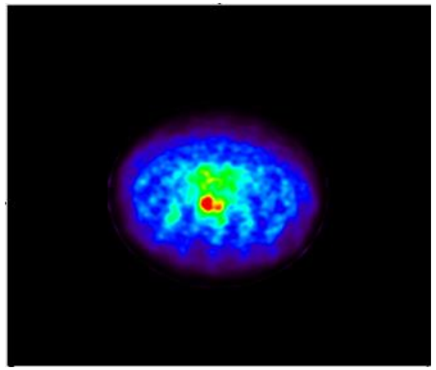
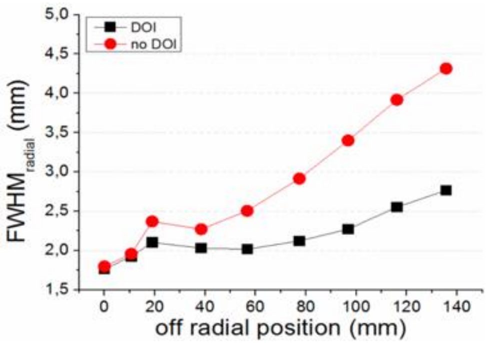
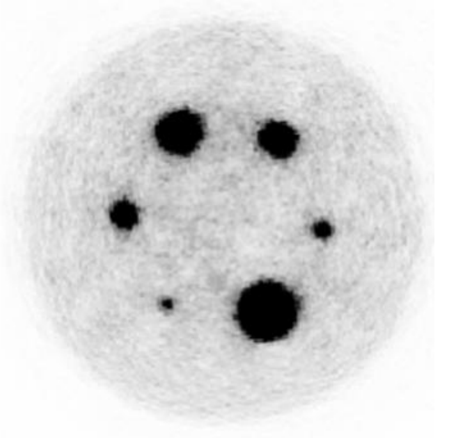
Other organ specific PET

ProsPET

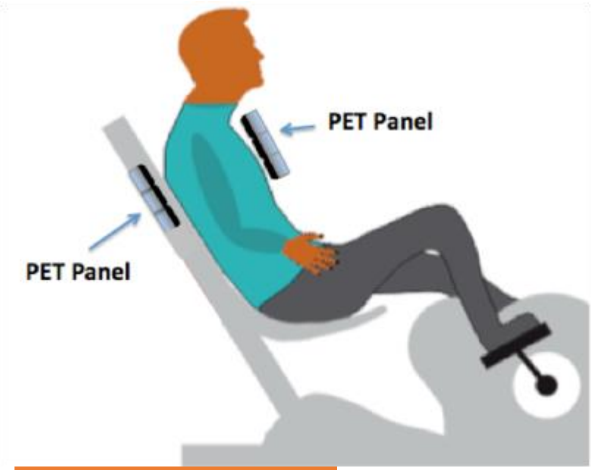


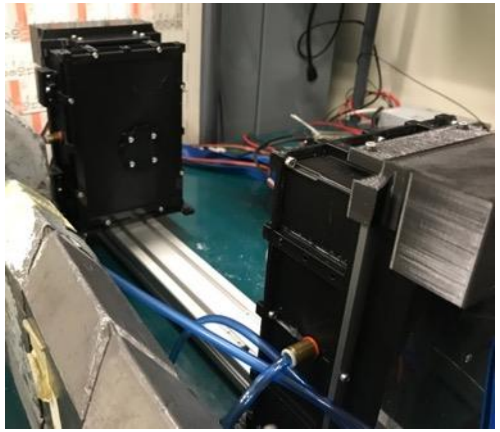


GeminiTF



ProsPET





State-of-the-Art results

- Timing resolution < 250 ps
- Energy resolution near 11.5@511keV
- Spatial resolution 3 mm

CardioPET

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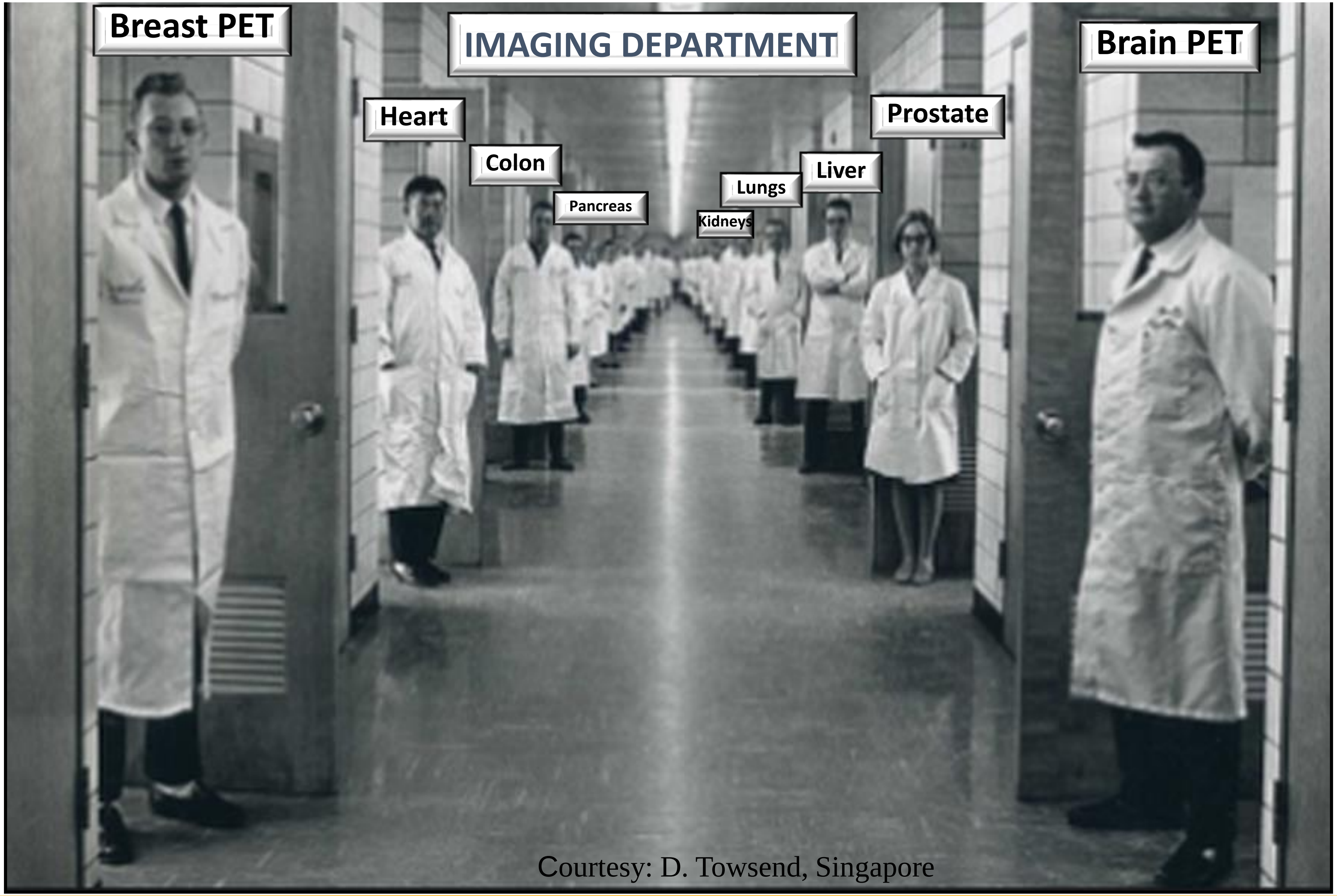
Personalized medicine ➔ Organ-specific imaging devices



Courtesy: D. Towsend, Singapore

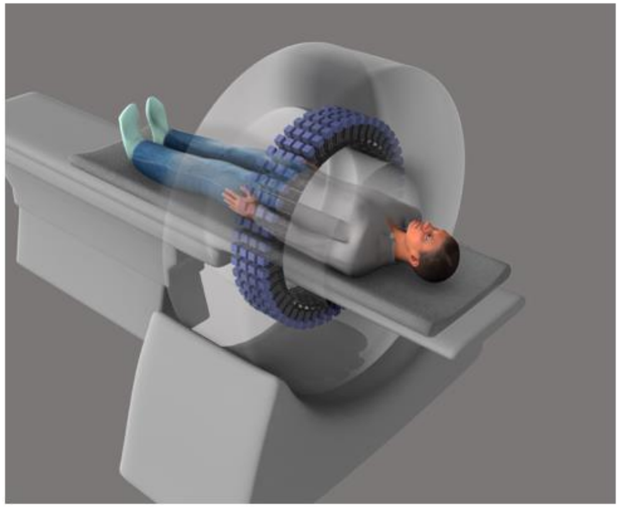
Increasing effective PET sensitivity

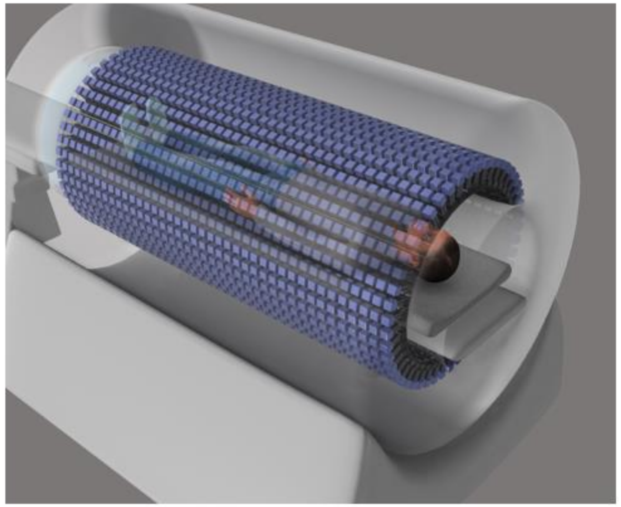
- PET is the imaging modality with the highest sensitivity, at the picomolar level
- New medical challenges require a significant sensitivity increase
  - Tracking small number of cells
    - Stem cells biodistribution and differentiation studies
    - Immune cells tracking for immonutheraty
  - Precise pharmacodynamic studies
  - Dose reduction and opening PET scans to new categories of patients (pregnant women, children, fœtus)

Improve solid angle coverage

- **Increase solid angle coverage**

The EXPLORER project

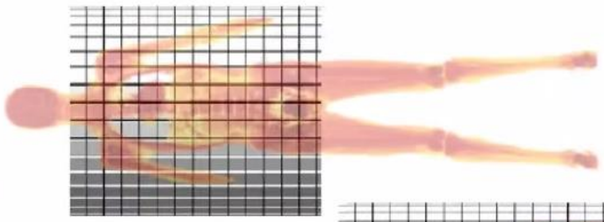




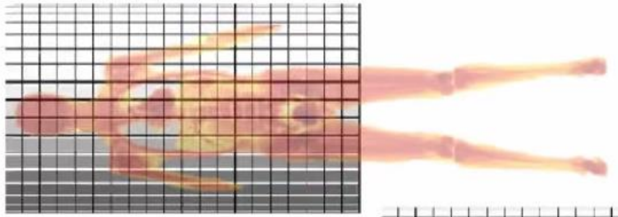
~40-fold increase for total-body imaging

Total Body PET cost issue

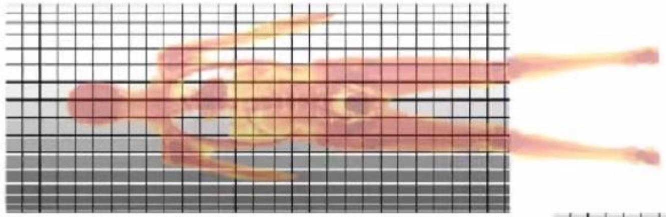
20 cm



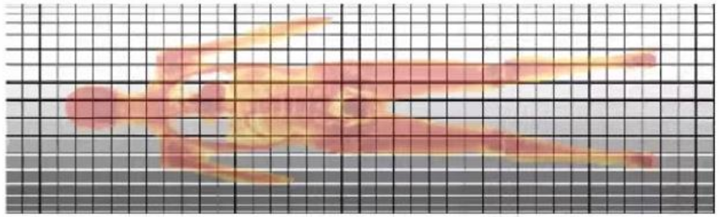
70 cm



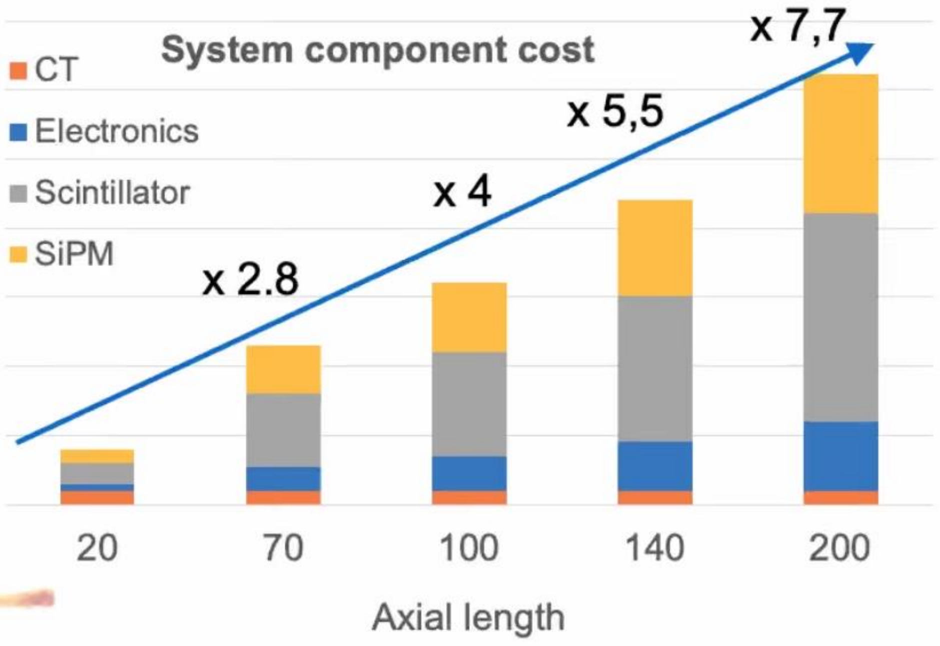
100 cm



140 cm



200 cm



Standard PET-CT: 2-3 Meuro

TB PET: 8-15 Meuro

Even with a
2x - 3x higher
througput financially difficult
for most centers

State of the art in total body PET

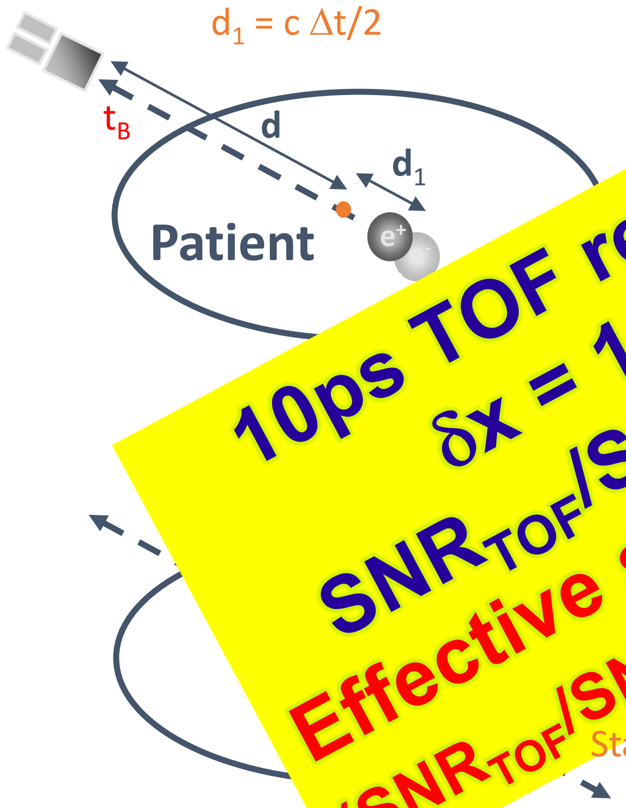
Stefaan Vandenberghe, Pawel Moskal & Joel S. Karp

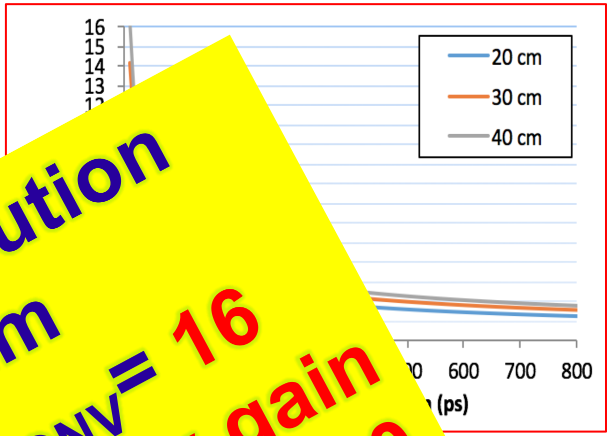
EJNMMI Physics 7, Article number: 35 (2020) | Cite this article

Time of Flight PET

$\Delta t = t_A - t_B = [(d+d_1) - (d-d_1)]/c$

$d_1 = c\,\Delta t/2$





10ps TOF resolution

δx = 1.5mm

SNR_{TOF}/SNR_{CONV} = 16

Effective sensitivity gain

$(SNR_{TOF}/SNR_{CONV})^2/1.47$ = 180

[illegible]	[illegible] (cm)	SNR*
10	0.15	16
100	1.5	5.2
200	3.0	3.6
500	7.5	2.3

State-of-the-art

Biograph Vision

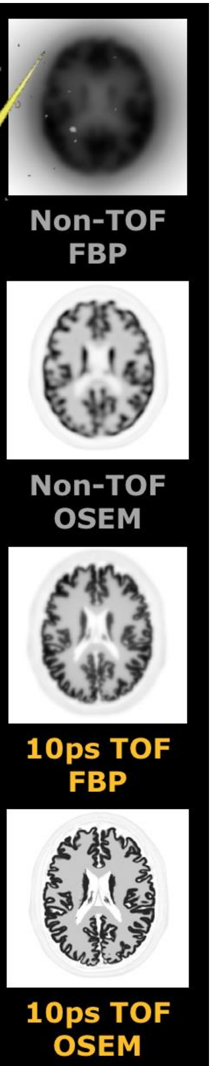
** SNR gain for 40cm phantom*

The 10ps challenge: a step toward reconstructionless TOF-PET

The 10ps challenge:
- a spur on the development of fast timing
- an opportunity to get together
- an incentive to raise funding
- a way to shed light on nuclear instrumentation for medical imaging

One unique challenge launched for 5 to 10 years and operated by an international organisation with rules issued by the community based on the measurement of CTR combined to sensitivity

Several milestones and prices:
- 3 years after the launch of the challenge: 1M€ expected for the Flash Gordon prices for the realisation of 3 important milestones
- until the end of the challenge: 1M€ expected for the Leonard McCoy price for the first team meeting successfully the specifications of the challenge



Following an idea of C. Morel in the Crystal Clear collaboration

Officially endorsed by

EANM
European association of Nuclear Medicine

EIBIR
European Institute for Biomedical Imaging Research

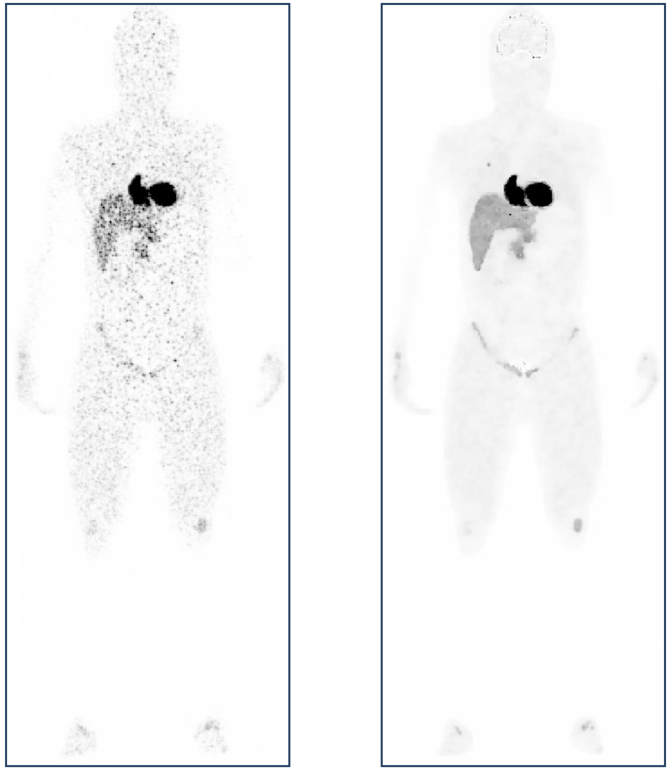
WMIS
World Molecular Imaging Society

Crystal Clear collaboration
31 Institutions worldwide

+
a number of prestigious individuals

Image Better

- **> 15-fold improvement in SNR**
  - Reconstruct at higher spatial resolution
  - Detect smaller lesions
  - Detect low-grade disease
  - Better statistics for kinetic modeling



Conventional PET **10ps TOFPET**

Adapted from S. Cherry, UC Davis

Image Longer

- **200-fold greater dynamic range**

  can image for seven more half lives

- **^{11}C**

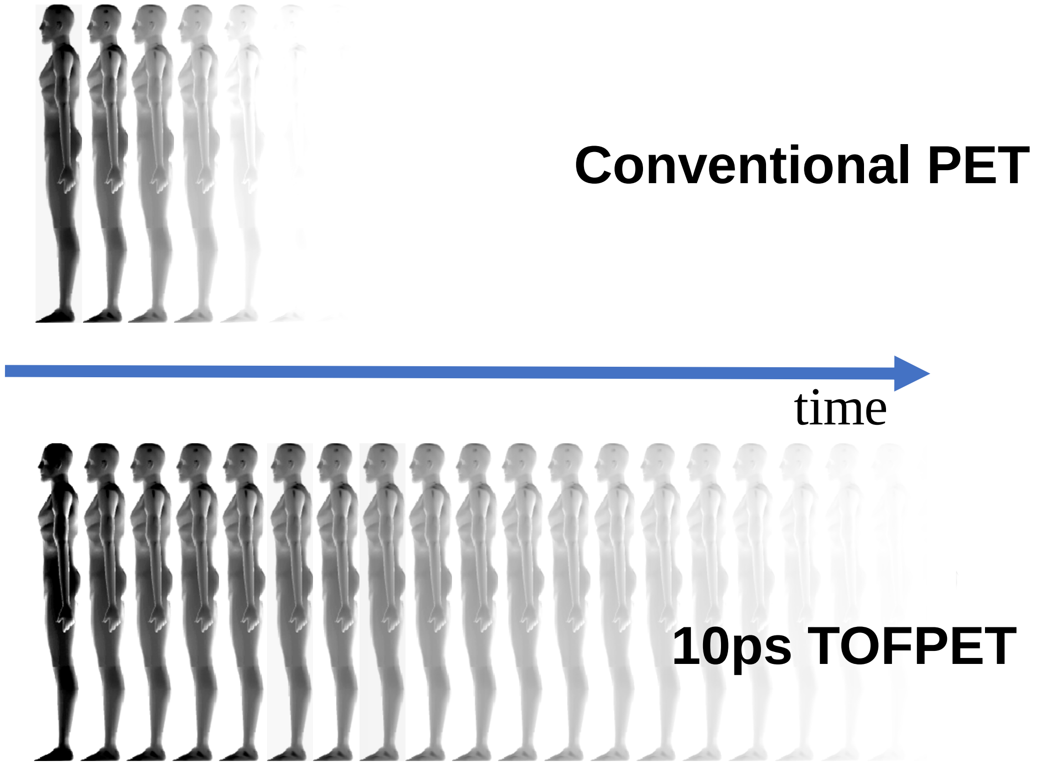
  Up to 4 hours

- **^{18}F**

  Up to 20 hours

- **^{89}Zr**

  Over 30 days



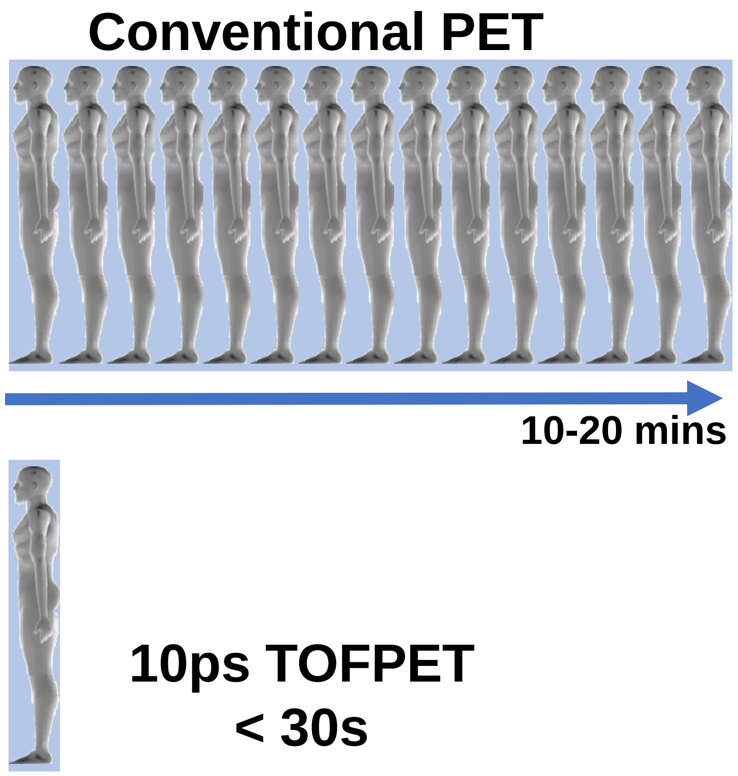
Adapted from S. Cherry, UC Davis

Image Faster

10ps TOFPET

5 seconds/bed position

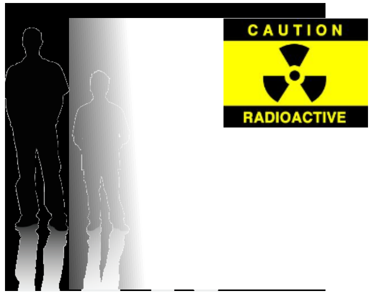
- Image in a single breathhold
- Reduce respiratory/cardiac/bolus motion
- Higher resolution
- Total-body kinetic imaging with high temporal resolution



Adapted from S. Cherry, UC Davis

Image Gently (Low Dose)

- **200-fold reduction in dose**
  - Whole-body PET at ~0.03 mSv
  - Annual natural background is ~2.4 mSv
  - Return flight (SFO-FRA) is ~0.11 mSv
  - PET can be used with minimal risk – new populations



Conventional PET

10ps TOFPET

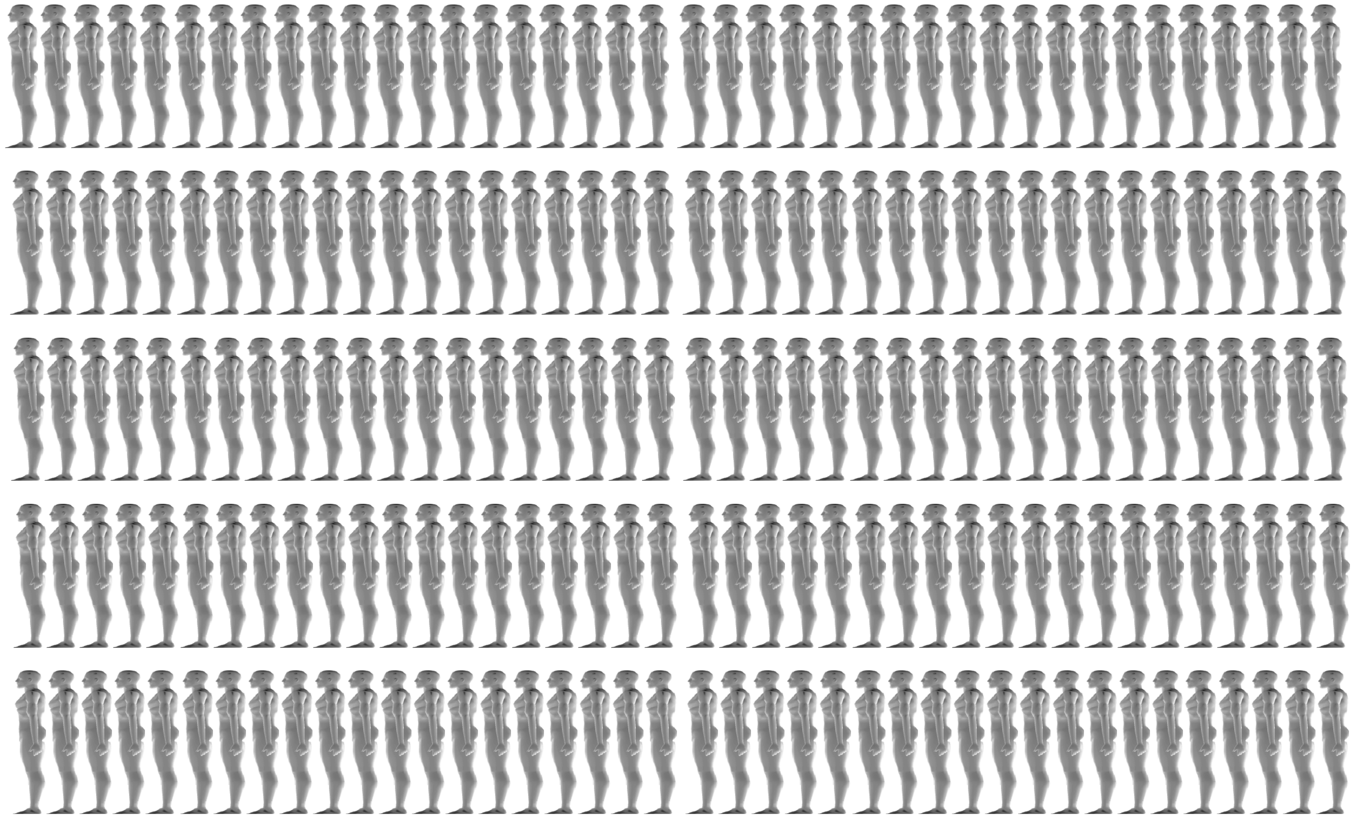
Adapted from S. Cherry, UC Davis

www.cern.ch/cerimed/

Image More Often

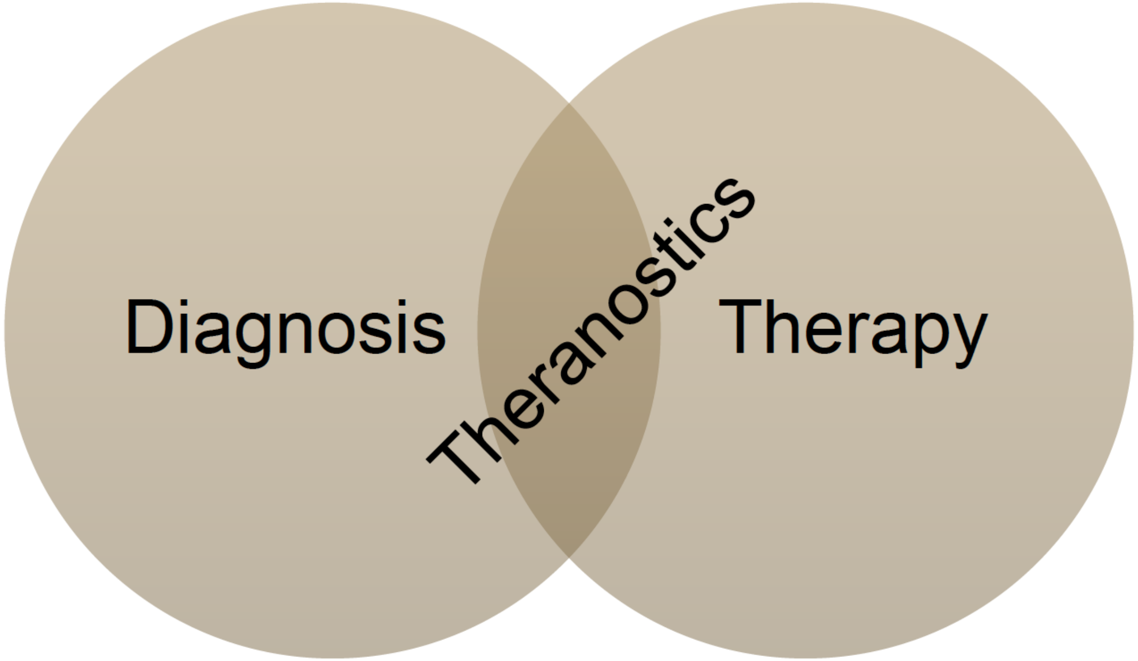
Conventional PET

10ps TOFPET



Adapted from S. Cherry, UC Davis

Radiopharmaceutical applications



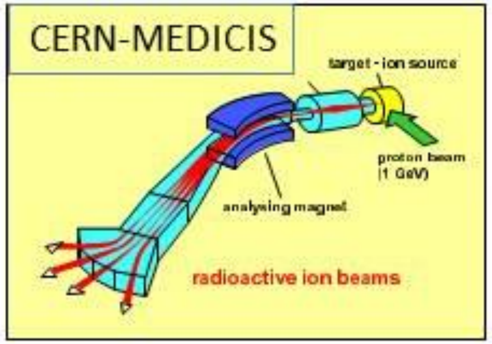
^{68}Ga-PSMA + ^{111}In-PSMA for diagnosis and therapy of prostate cancer

^{68}Ga-DOTATATE and ^{177}Lu-DOTATATE for diagnosis and treatment of neuroendocrine tumours

CERN MEDICIS

MEDICIS-PROMED: Innovative treatments based on radioactive ion beam production, transport and preclinical studies

Pure innovative Radioisotope beams from 2015 on



Mass purification at medical cyclotrons

New packaging

Radiopharmaceuticals targeting ovarian cancer

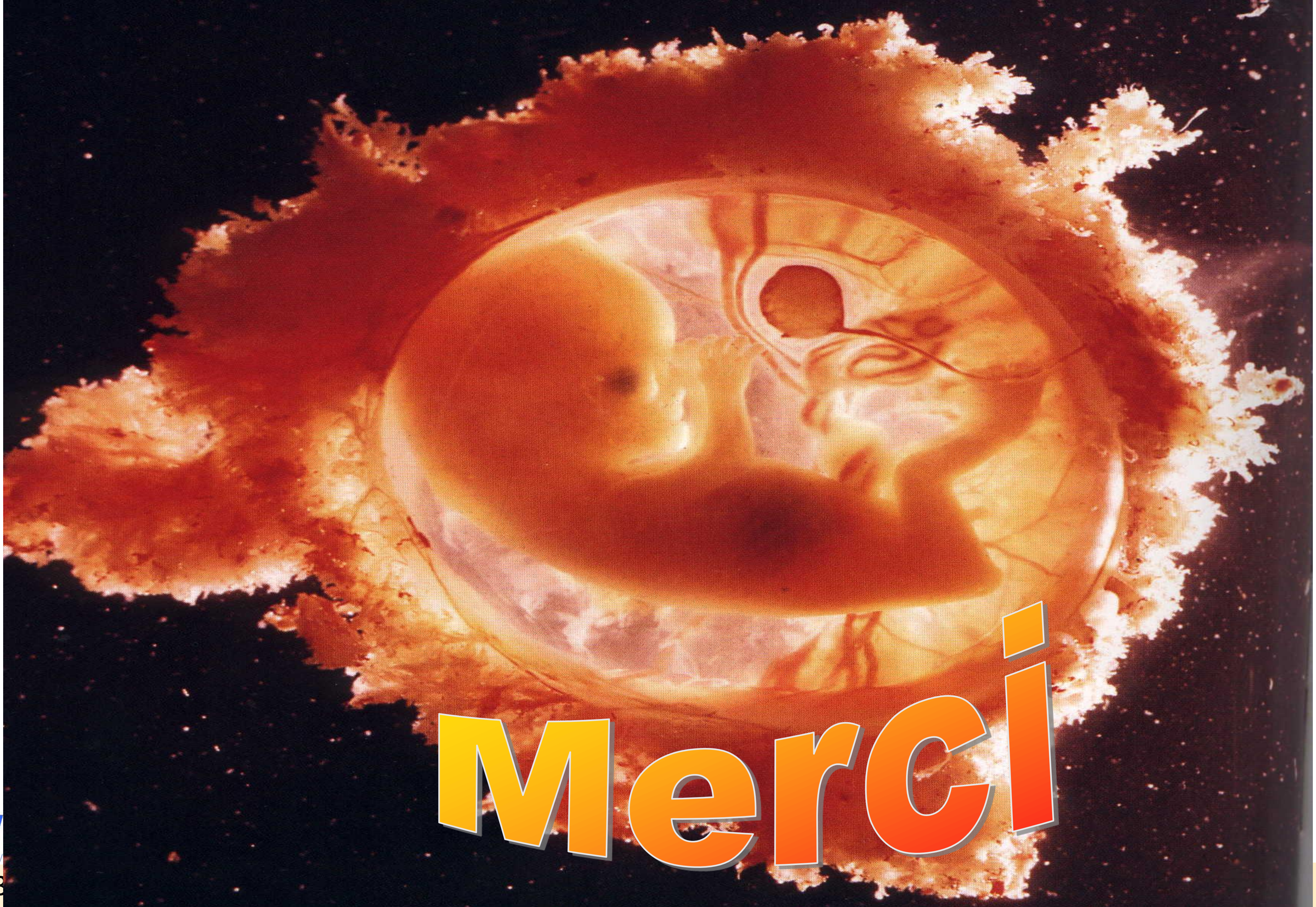
Transport

Functional Imaging

New Personalized Treatment

11C PET aided hadrontherapy

α, β^+	β^+	Auger	β^-


Merci