Applications

IPARCOS

IPARCOS

- Motivation (this slide)
- Training
- Improvements in the description of the interaction of radiation and matter
- Instrumentation
- Applications and transfer to industry

Medical Applications in IPARCOS

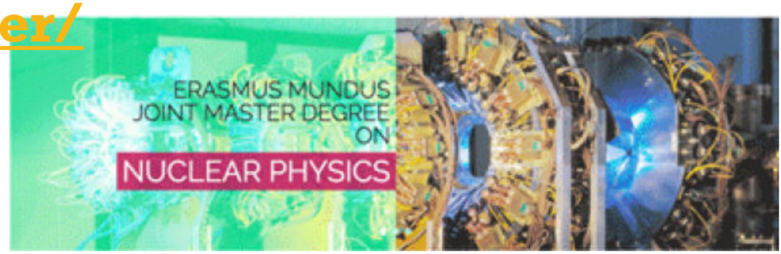
- Following the lead of…
  - Institut Curie in France
  - Most large international particle and/or nuclear physics and/or cosmology/astrophysics institute or large national labs have a division for applications in medicine: GSI (Germany), CERN, BNL, INFN

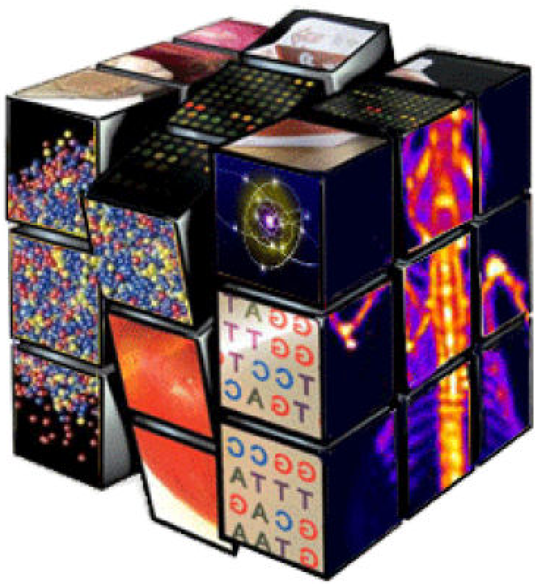
In Spain: CIEMAT, IFIC/IFIMED, IFAE, CNA, IGFAE, …. not quite the same

Training: IPARCOS has access to one of the largest number of physics graduates in Europe

•Master in Biomedical Physics, coordinated by Fernando Arqueros
https://www.ucm.es/masterfisicabiomedica/fisica-biomedica

•Interuniversitary Master in Nuclear Physics and European Master in Nuclear Physics (NUPHYS), coordinated at UCM by José M. Udías
http://nuclear.fis.ucm.es/master/
http://www.emm-nucphys.eu/





•PhD Program in Physics

•Favourite student pick: More than 50 MSc projects about applications in medicine during the last years. About 10 PhD defended.

IPARCOS

Instrumentation: essentially the same devices are used for applications and for state of the art experiments
For instance: Characterization and modelling of SiPMs

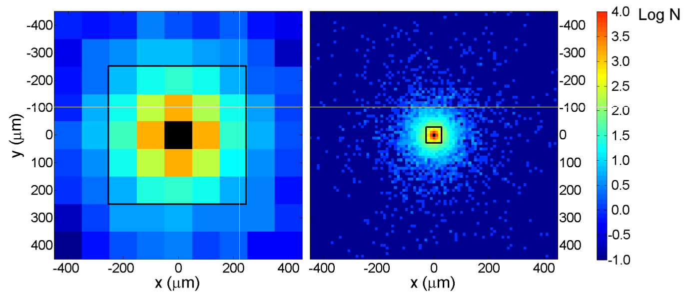
Activities:

- Experimental characterization and waveform analysis
- Statitistical models of afterpulsing and crosstalk
- Modelling of nonlinear response
- Gamma-ray spectroscopy with scintillation crystals

Collaborations:

- Hamamatsu
- Institute of Microelectronics of Barcelona (IMB-CNM)

Setup for gamma-ray spectroscopy with scintillator, J. Rosado et al.



Simulation of optical crosstalk

Setup for PET detector, JM Udías et al.
Proyecto RTC-2015-3772-1 with SEDECAL Molecular Imaging (SMI)

References:

- L. Gallego, J. Rosado, F. Blanco and F. Arqueros, 2013 JINST 8 P05010
- J. Rosado and S. Hidalgo, 2015 JINST 10 P10031
- J. Rosado, NIMA 912 (2018) 39-42

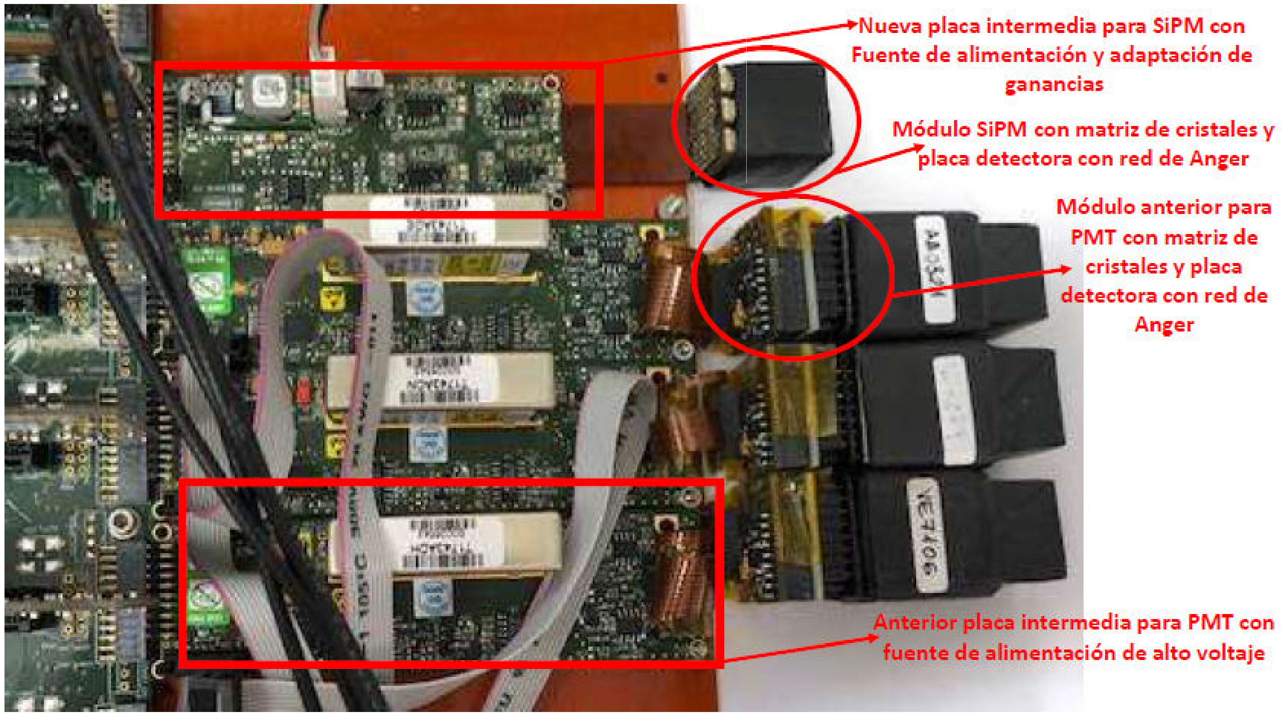
MRI COMPATIBLE DOI-ToF PET DETECTOR

IPARCOS

- Designed and developed by SEDECAL in partnership with UC3M and IPARCOS (Proyecto Retos Colaboración RTC-2015-3772-1, gobierno de España)

http://nuclear.fis.ucm.es/webgrupo_2014/proyectos/Retos-colaboracion-2015.html

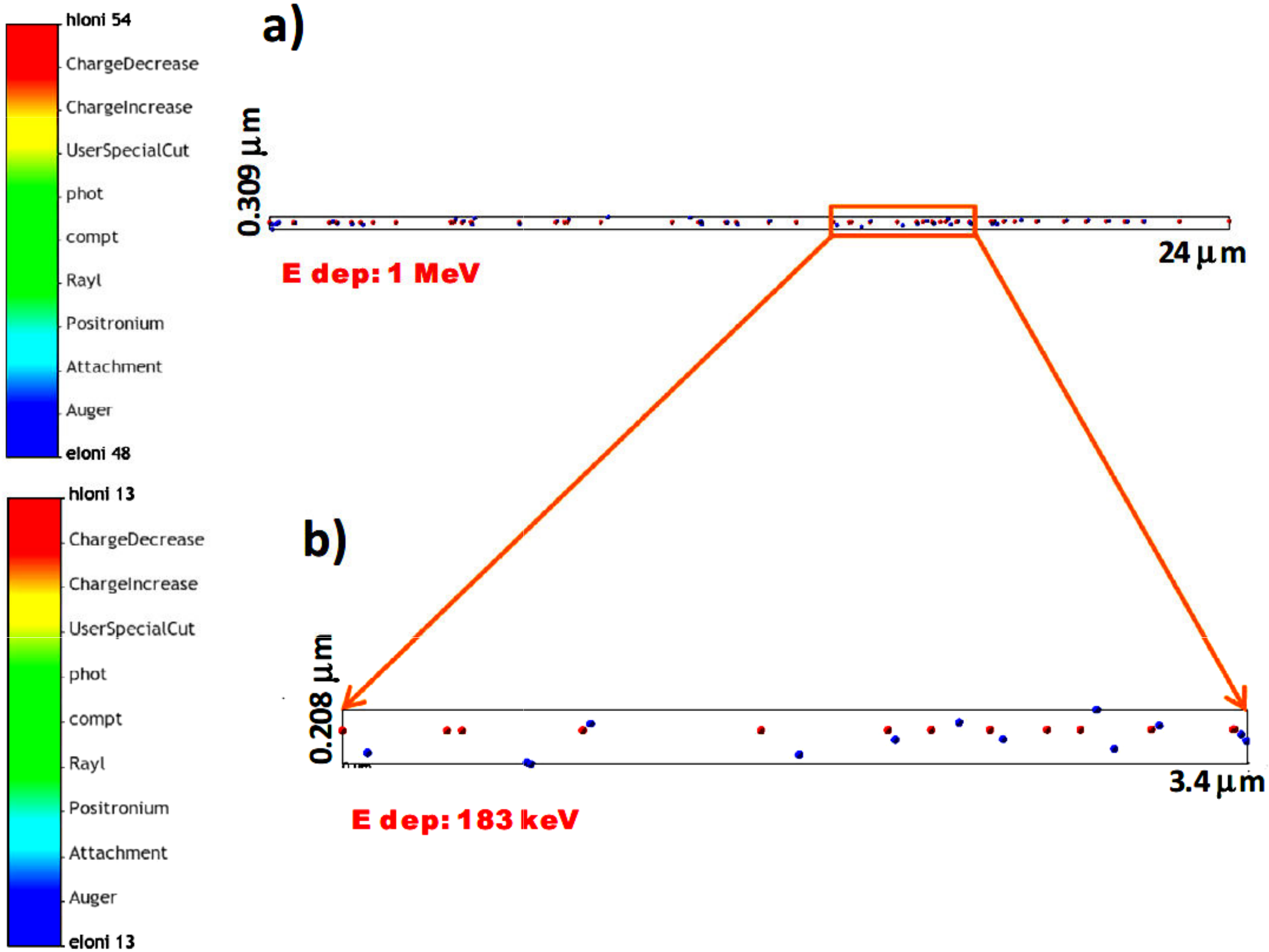
- **High sensitivity, high spatial (< 1 mm) and time resolution (< 250 ps) detector, MRI compatible**
- **Substitute PMT by SiPM**
- **New array of scintillators and electronics**
- **New RF and magnetic materials and shieldings**
- **Tested in a system, with new and old detectors**



Fundamental Physics: Detailed calculations of radiation-matter interactions. Towards nano-dosimetry

LOW ENERGY PARTICLE TRACK SIMULATION

Francisco Blanco *et al.*



1 MeV protons, GEANT4 standard

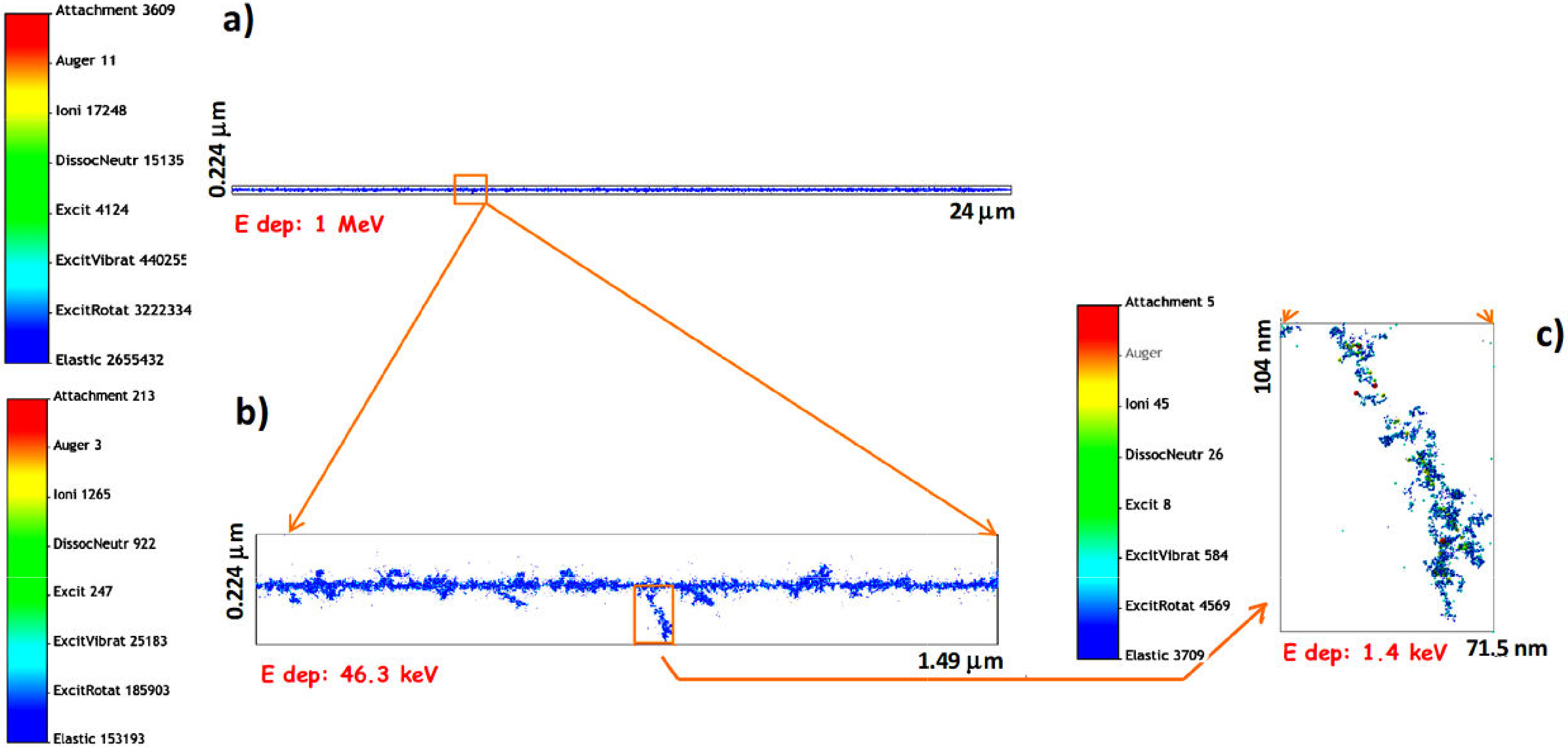
Detailed predictions of radiation-matter interactions

Towards nano-dosimetry

LOW ENERGY PARTICLE TRACK SIMULATION (LEPTS)

Francisco Blanco *et al.*, Radiation Physics and Chemistry 130 (2017) 371–378

The European Phys. J. D (2015) 69: 188



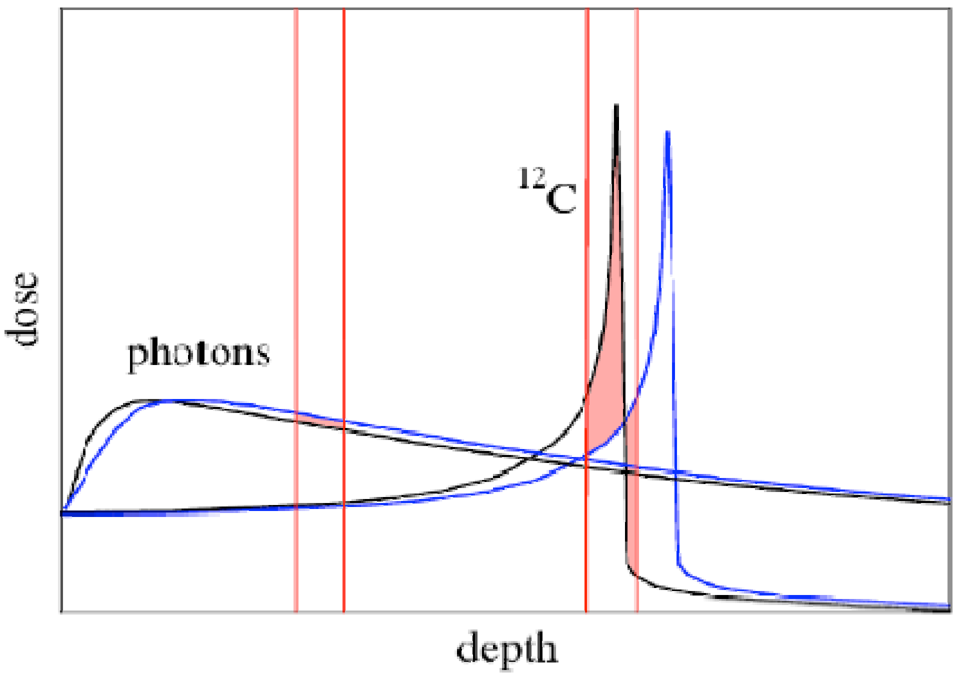
GEANT4-DNA y LEPTS to track electrons. Interactions considered down to very low energies, including ionizing disociations, excitations and attachement.

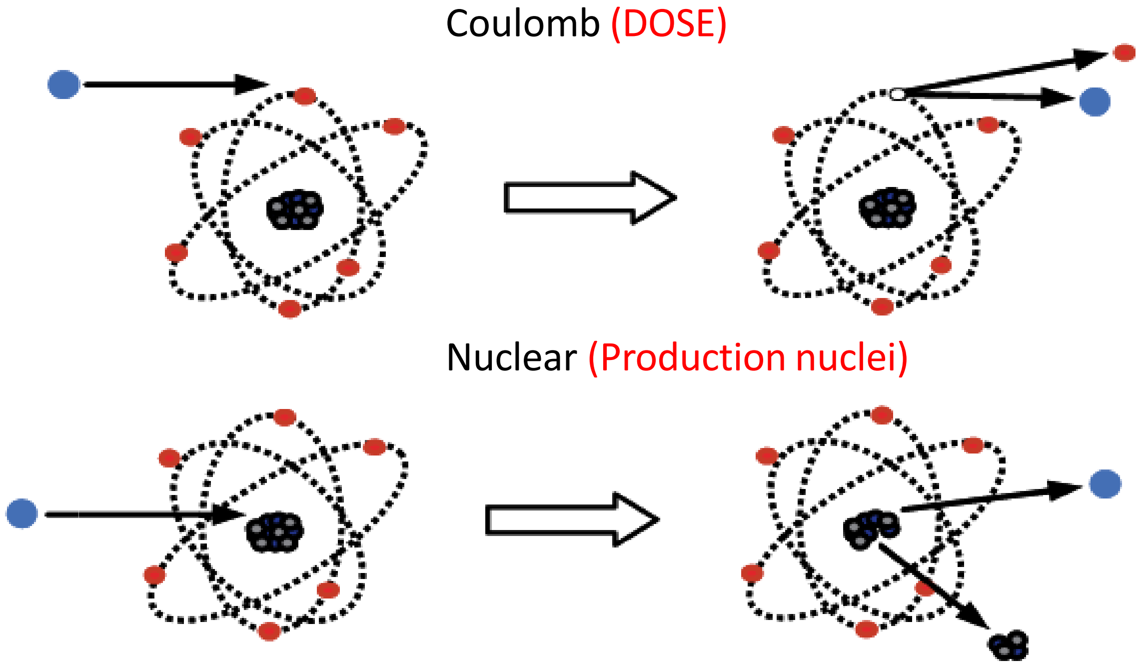
Fundamental tool to understand RBE of protons and heavy ions

Nuclear Activation during hadrontherapy

Towards accurate proton range verification tools

PRONTO: Protontherapy and Nuclear Techniques for Oncology
LM Fraile, coordinator



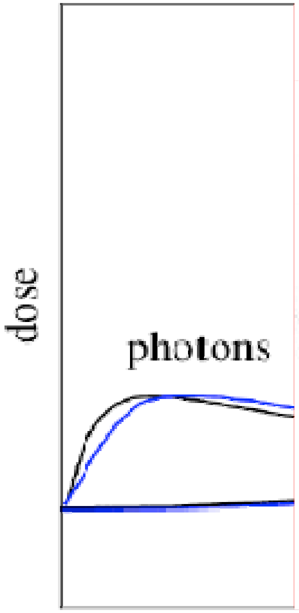


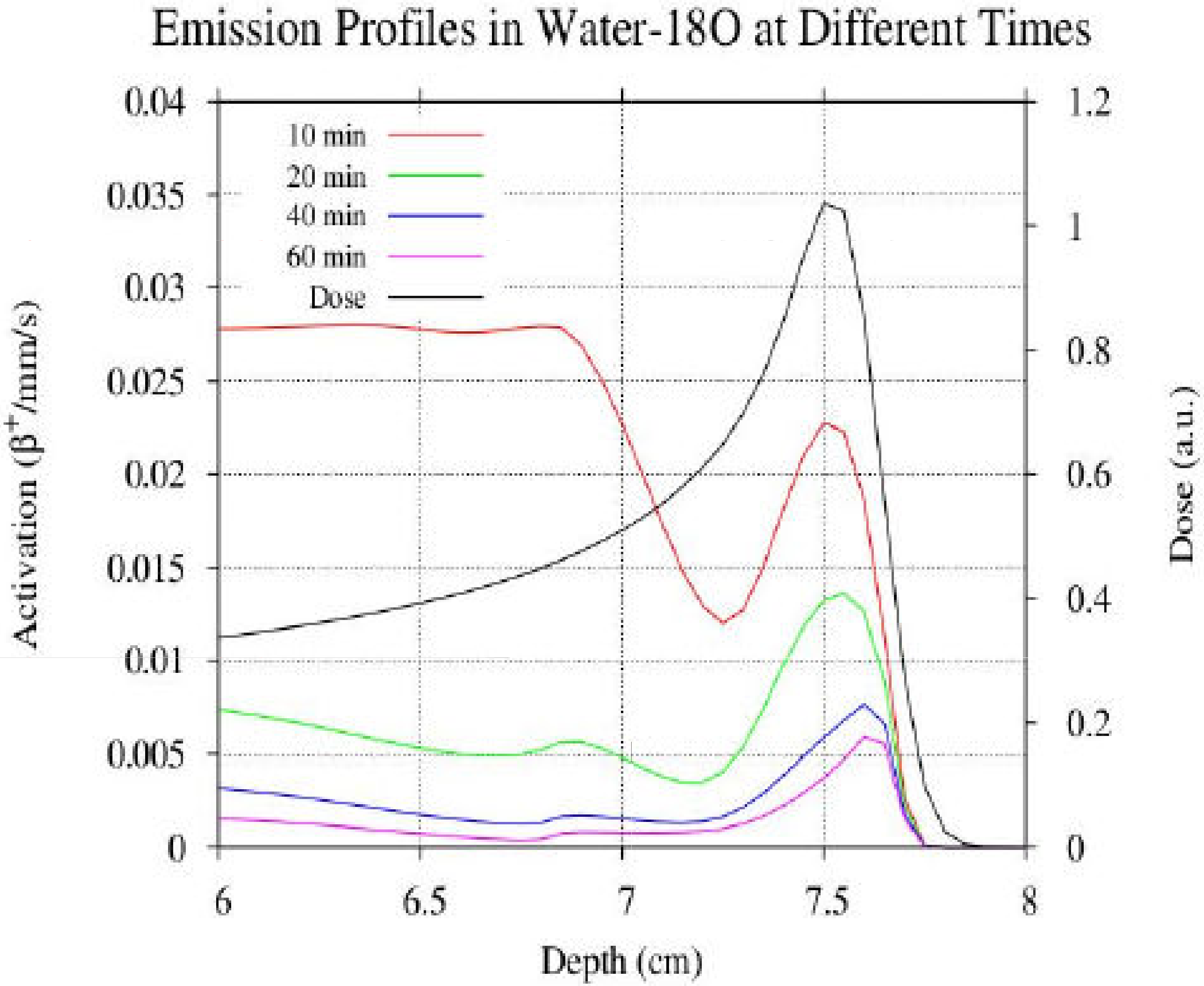
Nuclear reactions and projectile fragmentation contribute to dose and to nuclear activation. Radiation from activated nuclei can be used for range verification

Proof of concept experiment performed at CMAM. Irradiating natural Zn foils with 10 MeV protons and imaging on a high resolution PET scanner. LM Fraile et al., NIMA 814, 110 (2016)

Nuclear Activation during hadrontherapy

Towards accurate proton range verification tools



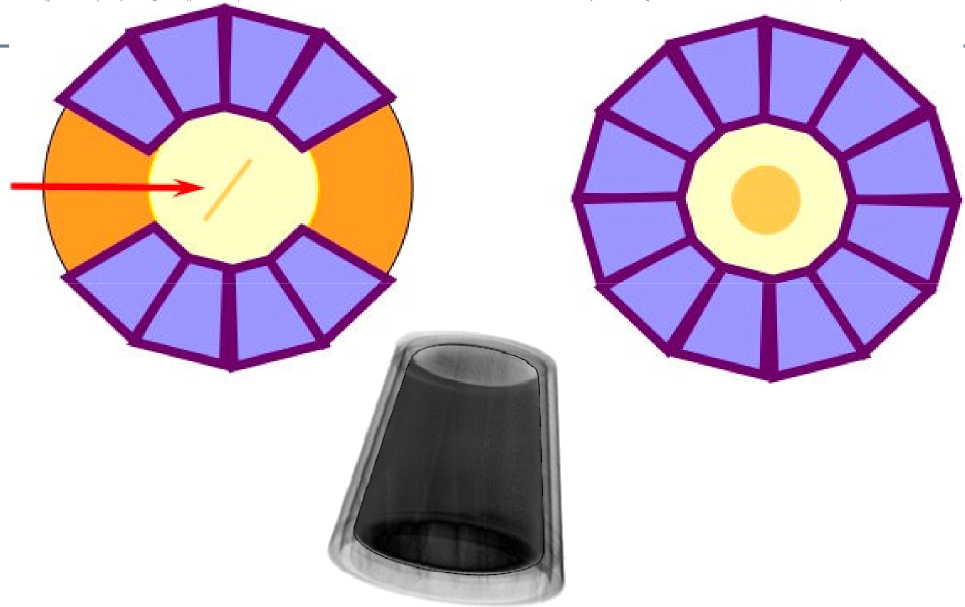


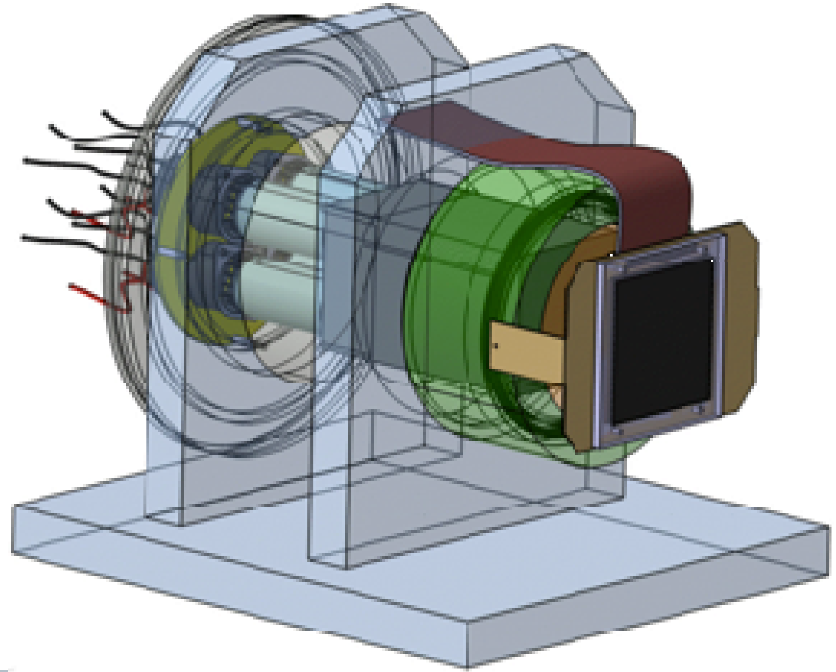
Nuclear re ... clear

activation.

verificatio

- Detector developments
  - PG detector based on FATIMA technology
    - comparison with SEDECAL design
    - Fast and efficient detectors
  - Adapt CEPA detector for proton range verification
    - Protons and gamma-rays
    - Good energy range
- Clinical application
  - Guide research by realistic objectives and utility for future practice
    - Contact with facility and oncologists





Some examples of technology transfer to companies

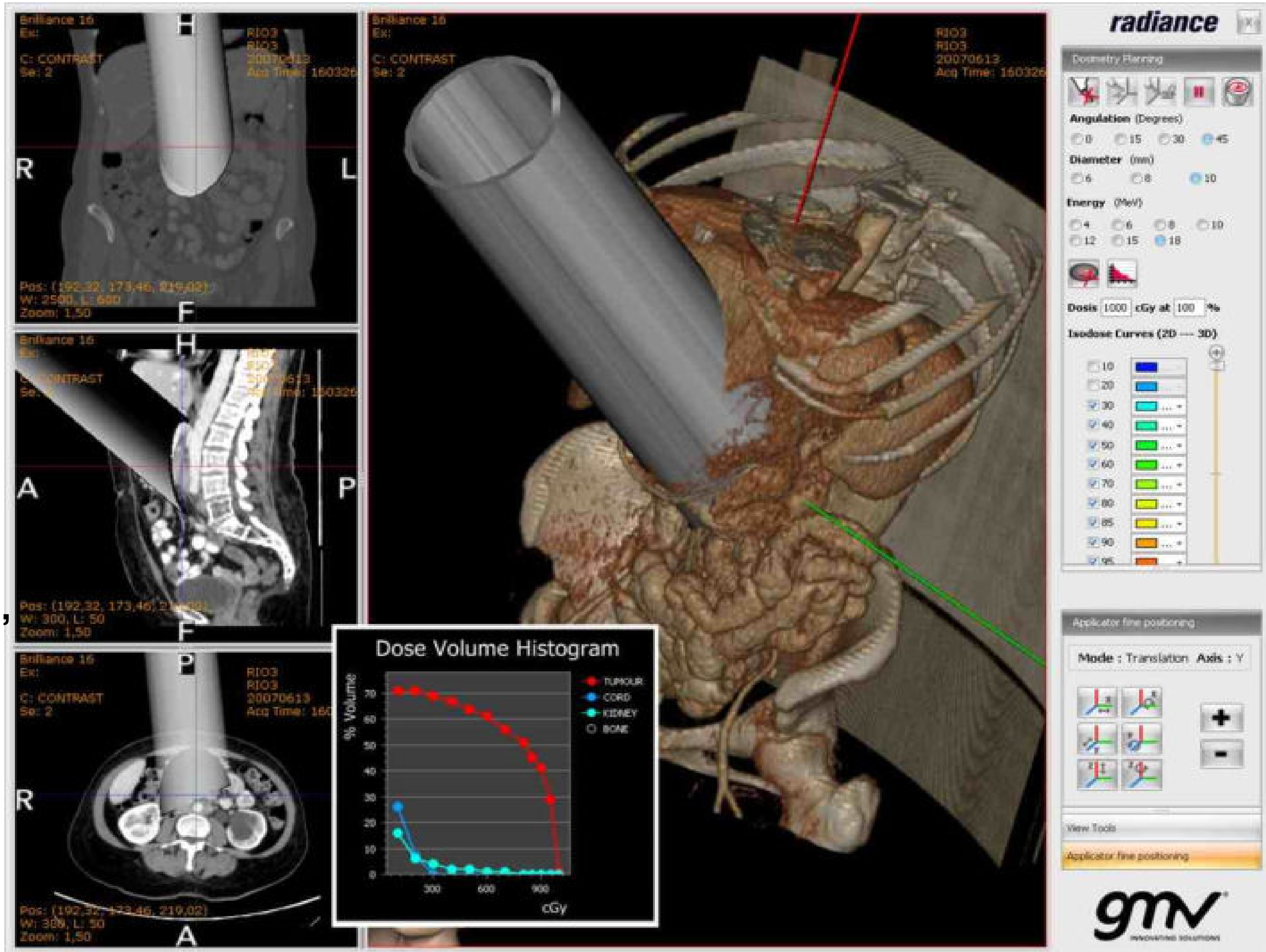
X-ray Intra-Operative Radiation Therapy (XIORT)

- **Mobile accelerator:**
  - 50 keV electron beam into a target
  - Low energy X-Rays (up to 50 kV)
  - Needle, spherical, flat and surface applicators:

Intrabeam (Carl Zeiss Meditec)

- **Objectives:**
  - To generate optimized Phase-space files for each applicator
  - To compute fast and accurate dose from simple data
  - To validate the whole dose calculation process against simulations and measurements (homogeneous and heterogeneous phantoms)

MonteCarlo dose calculation incorporated into Radiance, the FIRST dose planning tool available in IOERT, worldwide, developed by GMV Aerospace in collaboration with researchers from IPARCOS. Electrons: Elena Herranz, PhD thesis (2013), Intrabeam: Paula Ibáñez, PhD thesis (2017) at IPARCOS



Transl. Cancer Res, 42, 196-209 (2015)

PERFORMANCE STUDY

Particles and simulation time needed to reach the same noise level in water (less than 5% at D50, 3 cm spherical applicator)

CPU		
Code	**Particles**	**CPU time (1 core)**
MC	10^{10}	55:30:00
Hybrid	$5 \cdot 10^6$	00:22:00

GPU		
Code	**Particles**	**GPU time**
MC	10^{10}	00:02:10
Hybrid	$5 \cdot 10^6$	00:00:25

GPU: NVIDIA 1080 Ti (3584 cores, 1.58 MHz, 11 GB, approx 700 euros)
CPU: (1 core): Intel Xeon E5-2650 (2 GHz) (8 cores per cpu)

PERFORMANCE STUDY

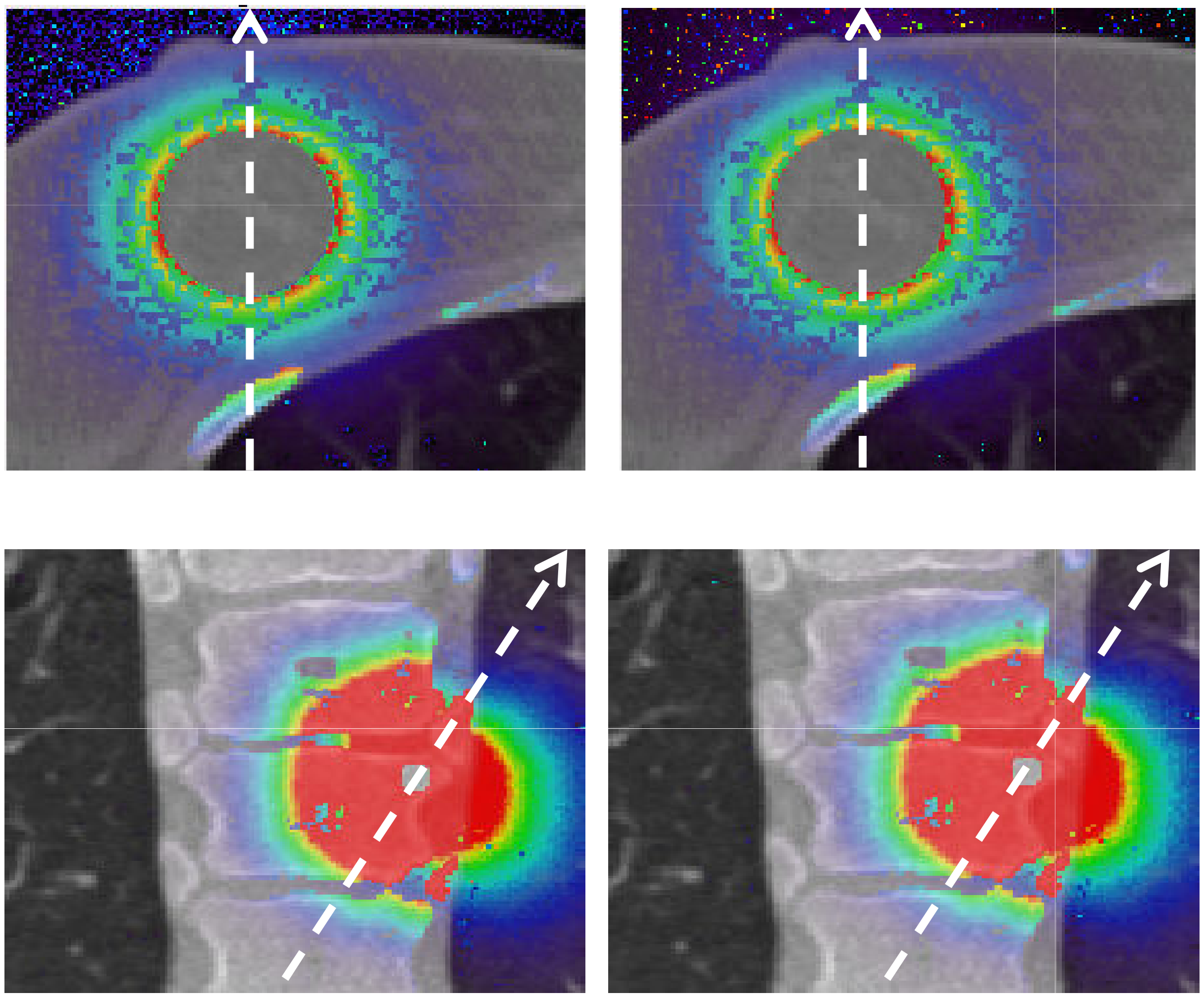
Particles and simulation time needed to reach the same noise level in water (less than 5% at D50, 3 cm spherical applicator)

CPU		
Code	**Particles**	**CPU time (1 core)**
MC	10^{10}	55:30:00
Hybrid	$5 \cdot 10^{6}$	00:22:00

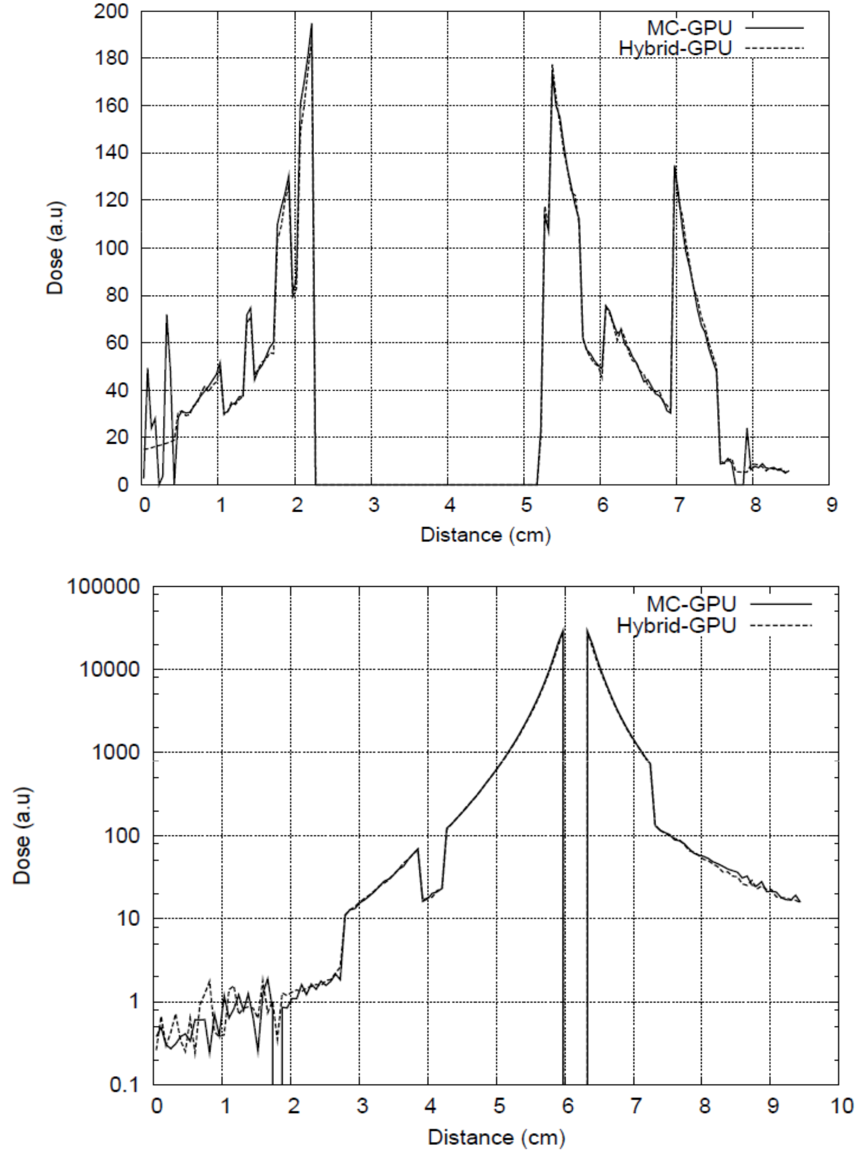
GPU		
Code	**Particles**	**GPU time**
MC	10^{10}	
Hybrid	$5 \cdot 10^{6}$	

GPU: NVIDIA 1080 Ti (3584 cores, 1.58 MHz, 11 GB, approx 700 euros)
CPU: (1 core): Intel Xeon E5-2650 (2 GHz) (8 cores per cpu)

RESULTS



MC-GPU **Hybrid-GPU**



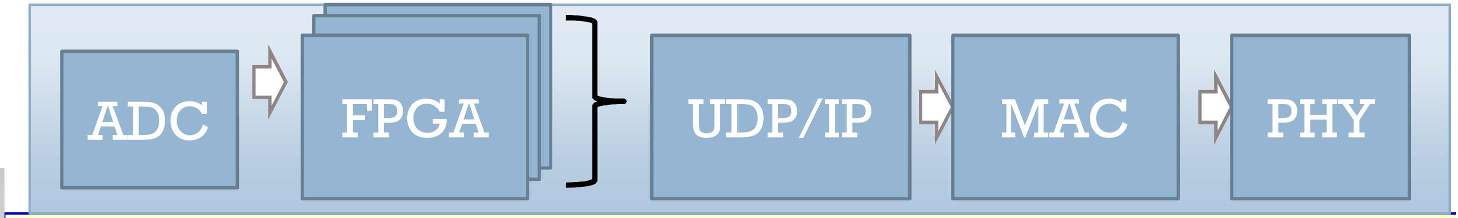
SuperArgus extended FOV preclinical scanner

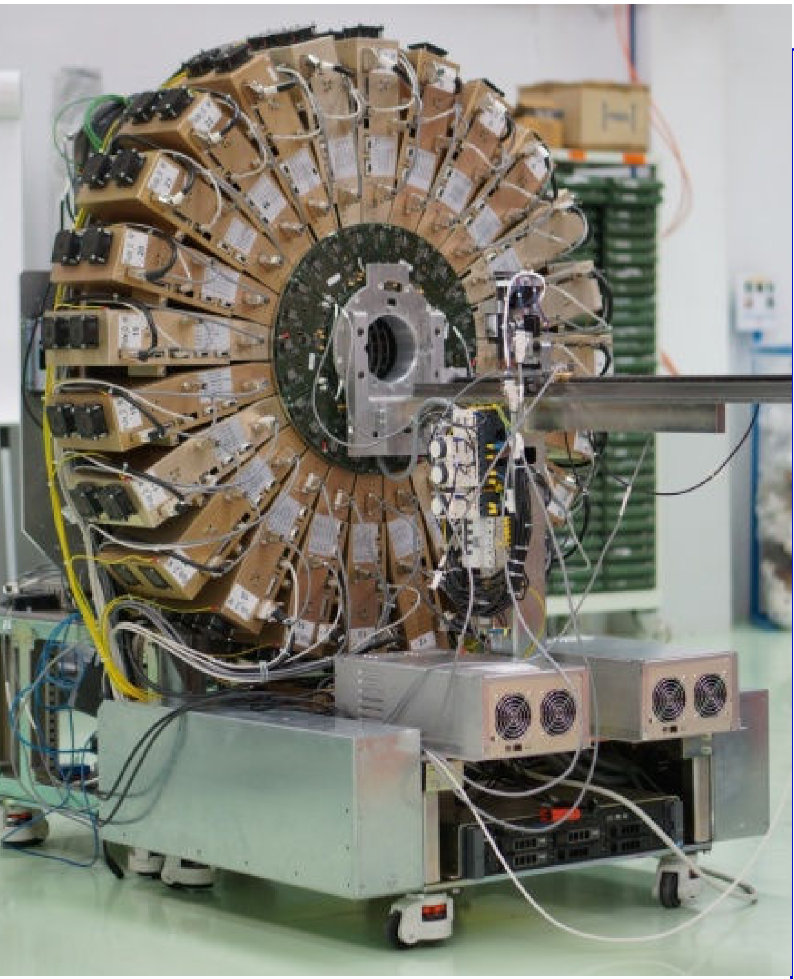
IPARCOS

- Designed and developed by SEDECAL in partnership with UC3M, UPM and IPARCOS
- (CDTEAM and AMIT projects, CENIT@INGENIO)

http://nuclear.fis.ucm.es/webgrupo_2014/web-ingles/technology-transfer/superargus.html

Fully modular electronics





- **144 dual layer detectors**
- **42000 individual pixels**
- **500 millions of lines of response**
- **30 ps electronics jitter time**

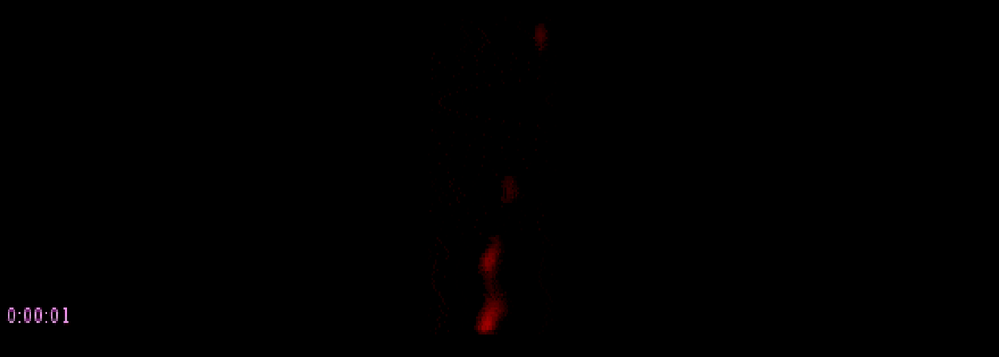
•DAQ: 48 FPGA, 128 ports 10 GB switch, 40 cores CPU+powerful GPU

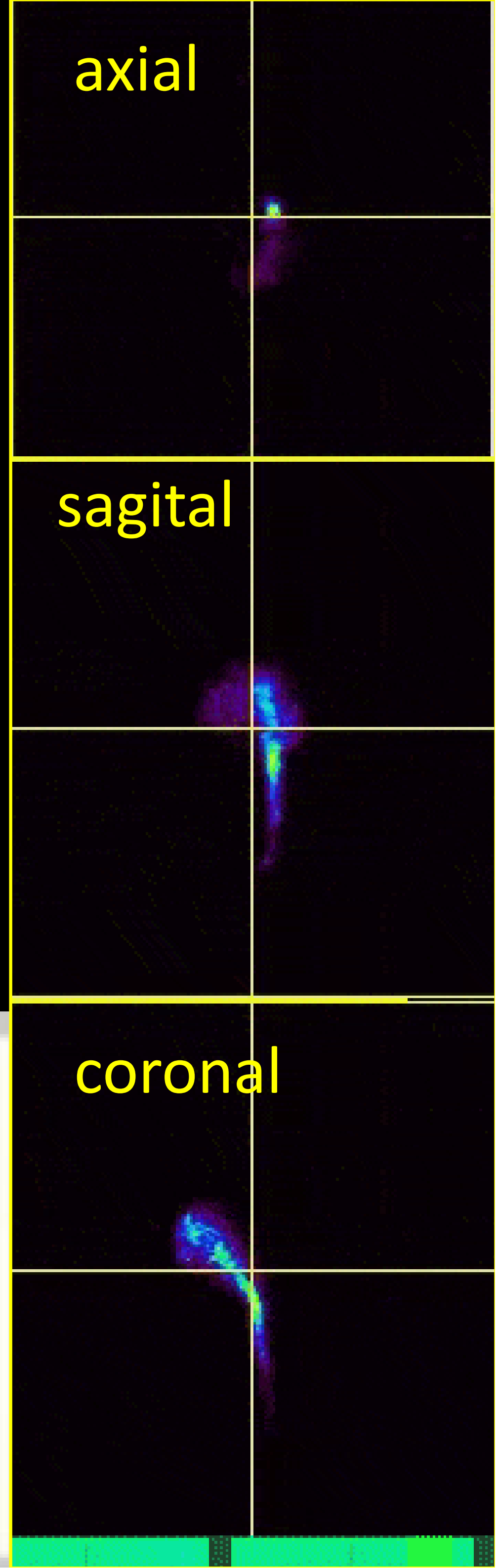
•World record processing capabilities:

- **•+100 millions of single events per second**
- **•+10 million coincidences per second sorted out to disk**

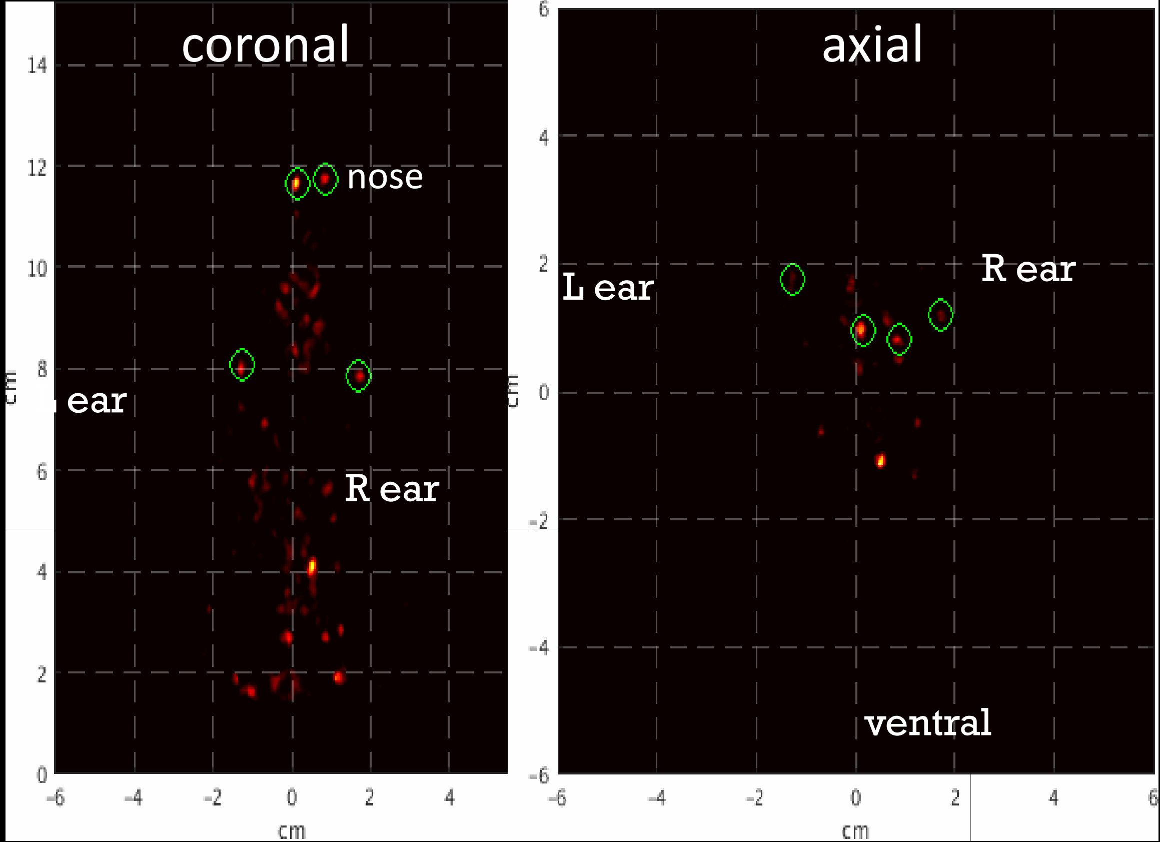
•Only existing PET scanner with real time imaging capability

Real time imaging:
Wixtar rat, 520 g, 410 uCi FDG
irst-pass dynamic study with 150 ms frames
https://www.youtube.com/watch?v=7SotIU_XZoI





Slow motion render (25x slower)
First-pass 100 ms frames afterwards longer frames



Unrestrained awake animal real time imaging: Female Wixtar rat (250 g) injected with 500 uCi of FDG and four 7 uCi point sources attached to the head. Frames of 20 ms

Following the work of Miranda et

https://www.youtube.com/watch?v=LaSSuvcLr

Conclusion: Excellent Basic Research can lead to applications eventually translated into commercial products

Fast Iterative Reconstruction Algorithm for PET (FIRST): licensed to SEDECAL for the Argus small animal PET/CT scanner, distributed in nearly 50 research centers worlwide. For several years it settled a world record for spatial resolution (< 1 mm) with scintillator-based PET scanners. Ongoing collaboration with SEDECAL for the new SuperArgus scanner already sold in USA (four), China, Corea and other countries. Two in Spain

http://www.sedecal.com/sedecal.com/es/divisiones/division_prod.php?p=52&c=5

UltraMC dose calculation and phase space generation tools developed at the GFN-UCM for IOERT and Intrabeam (Carl Zeiss Meditec), licensed to the company GMV, who has included algorithms developed in IPARCOS within ©Radiance, the first and only world-wide commercially available platform for dose planning and simulation in intraoperatory radiotherapy. FDA and UE approved

http://www.gmv.com/en/Healthcare/radiance/

14 hospitals have acquired Radiance in 2018. 9 for intrabeam, 5 for IOERT
None of them in Spain

IPARCOS

IPARCOS Applications

People

>4 permanent staff, >4 postdocs, >9 students