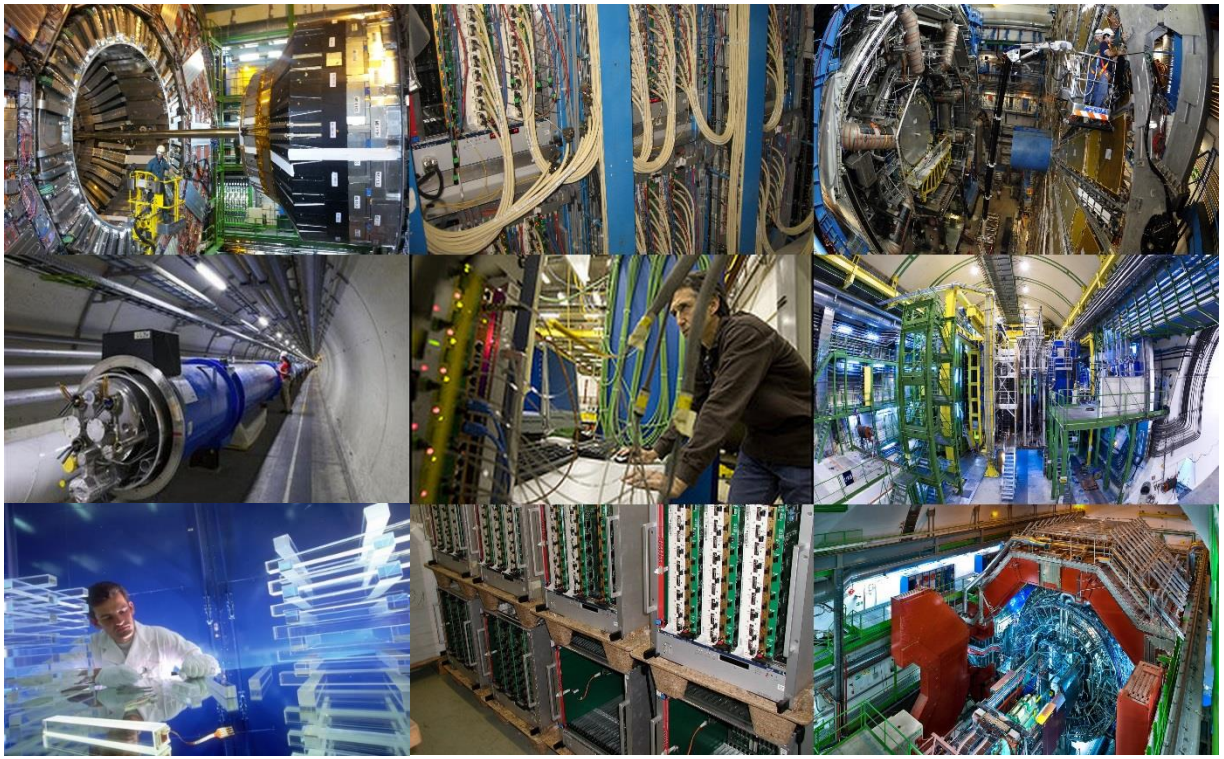
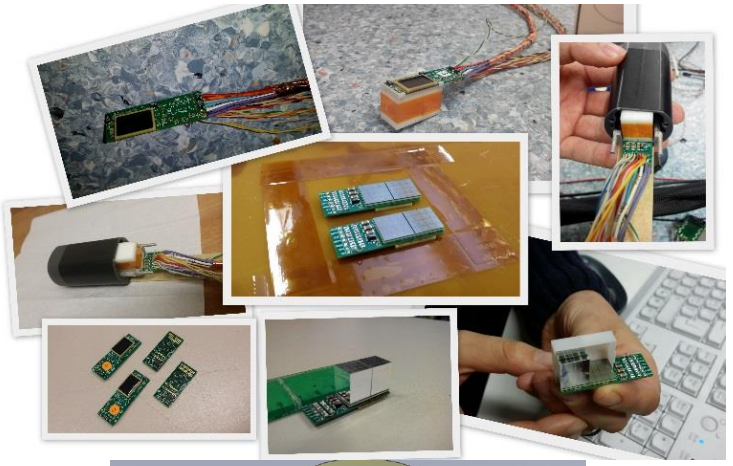
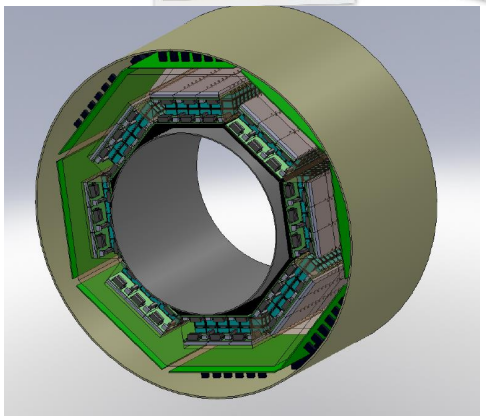
Da física de altas energias a aplicações médicas

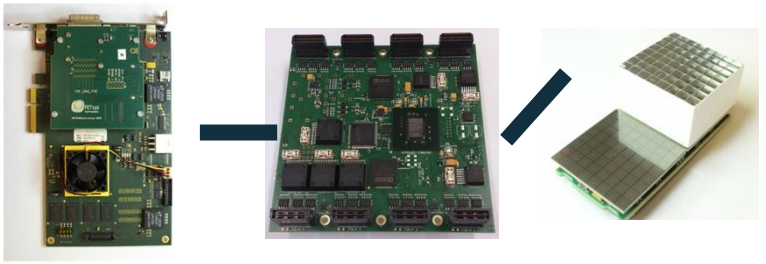






Jose C. da Silva

08/09/2022

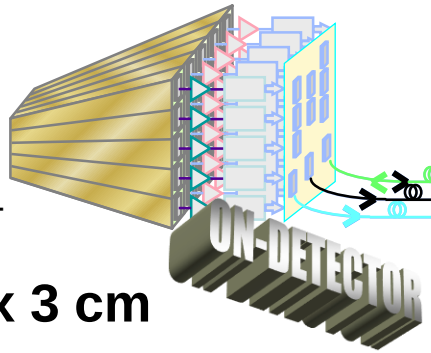


Da Física de Partículas …

Exemplo ECAL :

~76000 sensores

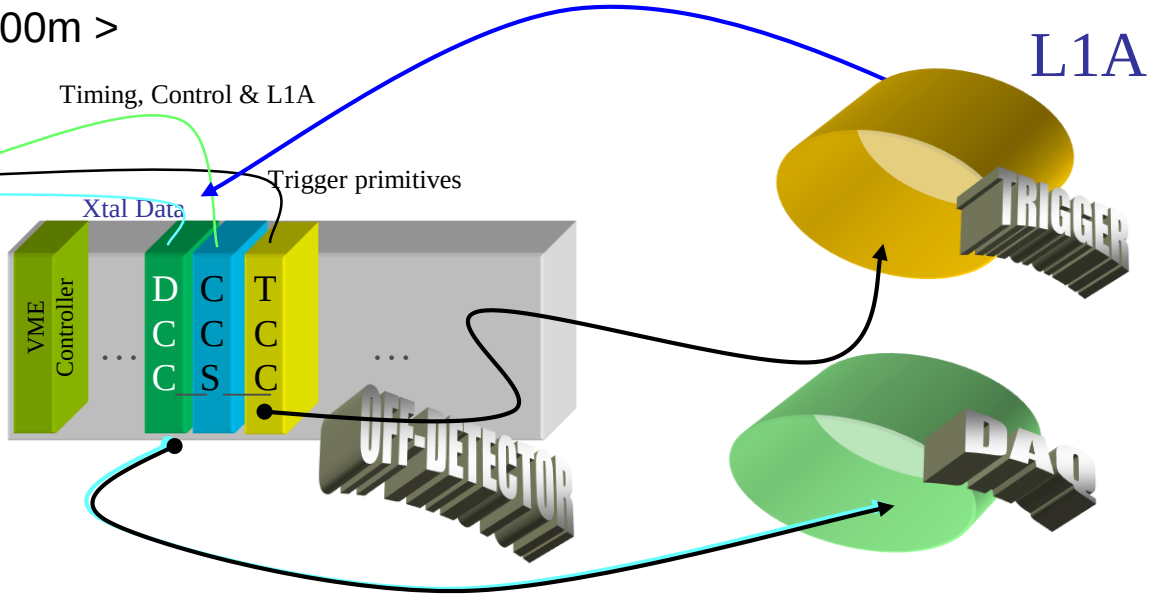
Modulo 68 sensores



PwO4

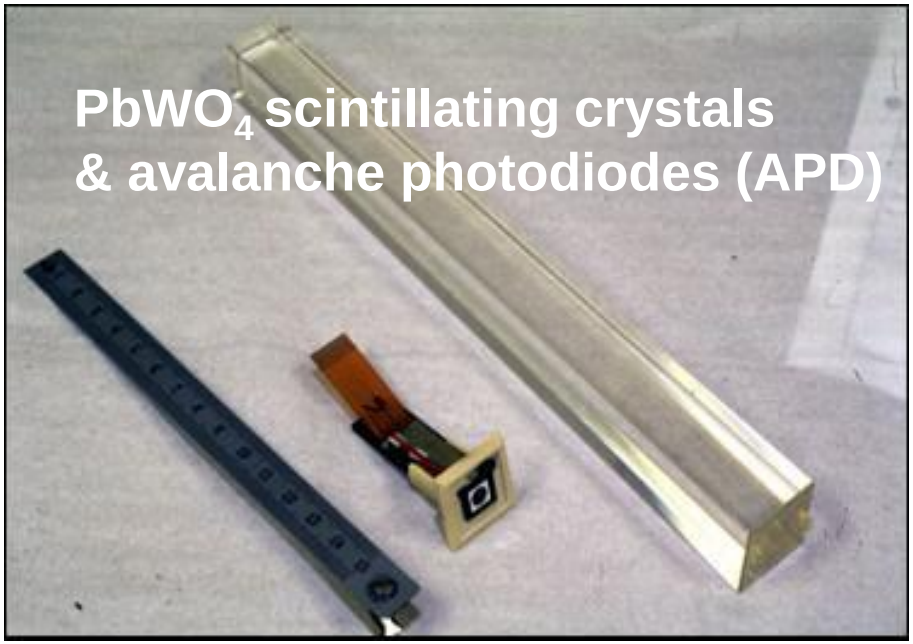
20 x 3 x 3 cm

FE ASICs para seleccao (Trigger) e leitura de dasdos (readout)



PwO4

Electron and photon detection



Parameter	Barrel	Endcaps
# of crystals	**61200**	**14648**
Volume	**8.14m^3**	**2.7m^3**
Xtal mass (t)	**67.4**	**22.0**

Objetivo: Medir a energia dos fotões vindos do decaimento do bosão de Higgs com precisão de 0.5%

Fotões de alta energia o LHC

- 50.000 Milhões de vezes mais energéticos que os do sol
- γ (gamma)

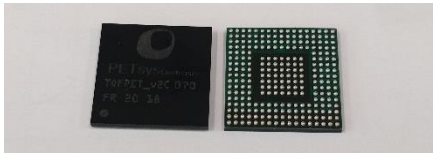
Cristais: absorbe gamma; converte-os energia em Luz

APD/SIPM : convertem luz em sinal elétrico

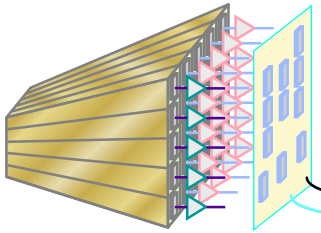
… a aplicações medicas

Exemplo CLEAR PEM :

6144 canais
Modulo 32 sensores



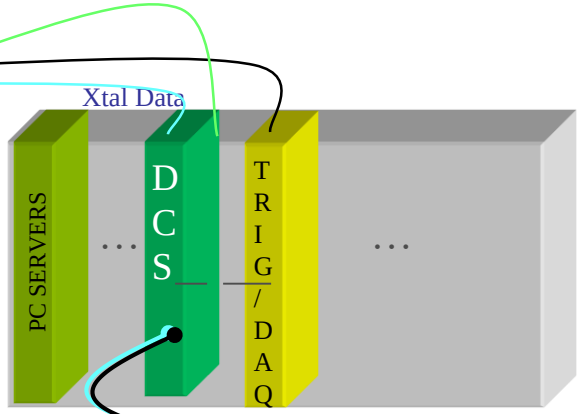
ASIC de leitura com alta qualidade de medida temporal

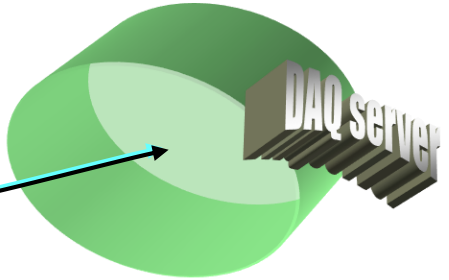


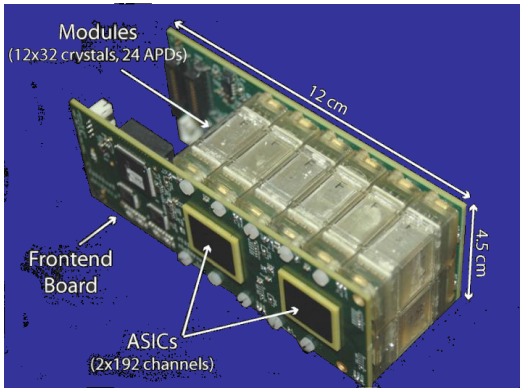
LYSO

20 x 3 x 3 mm

160MHz

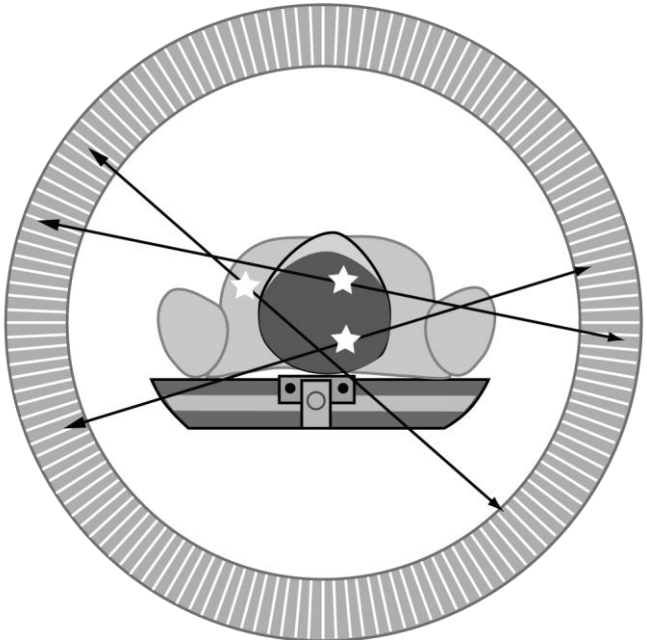






Positron Emission Tomography

PET scanner = ring of detectors



Gammas em PET são 200 vezes mais energéticos que os da luz visível

Tecnologia de imagiologia para detecção de cancro

- **o paciente recebe uma droga com um istotopo de emissão de positrões**
- Os positrões aniquilam-se emitindo dos **gamma em sentidos opostos**
- PET scanner e' geralmente um anel de detectores
- Dois detectores opostos definem um linha
- Uma grande quantidade dessas deteções permitem uma reconstrução espacial em 3D da dispersão da droga

The CLEAR PEM collaboration

To build an high performance detector for breast cancer detection with unprecedented resolution

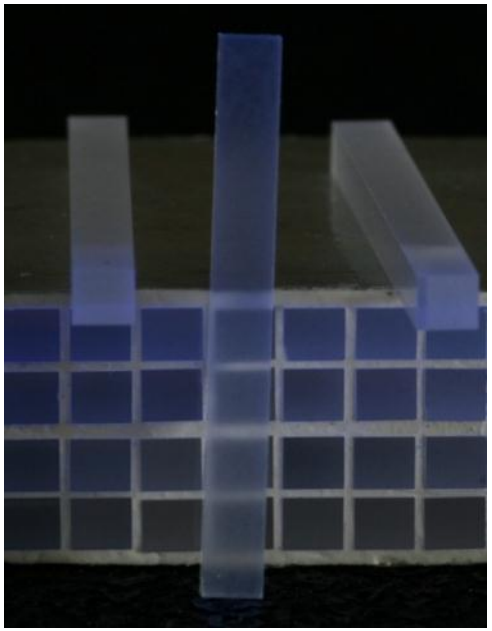
- 6 years of I&D
- 6 M€ funding

Supported by:

Detector Technology

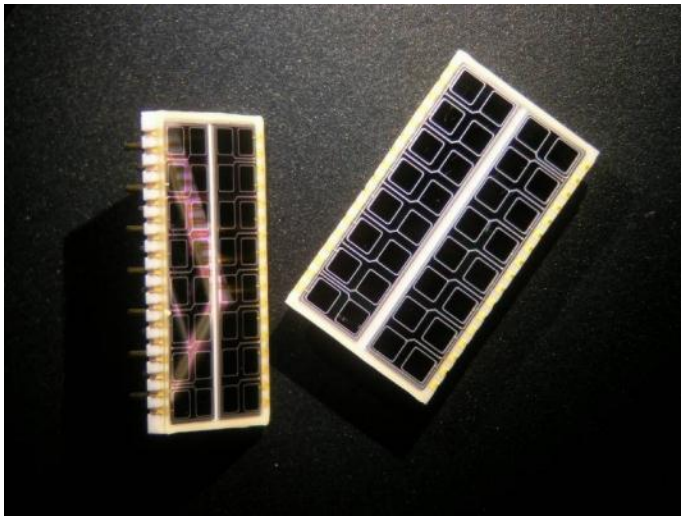
Crystals LYSO:

- Density: 7.4g.cm^{-3}
- Emission Peak: 420nm



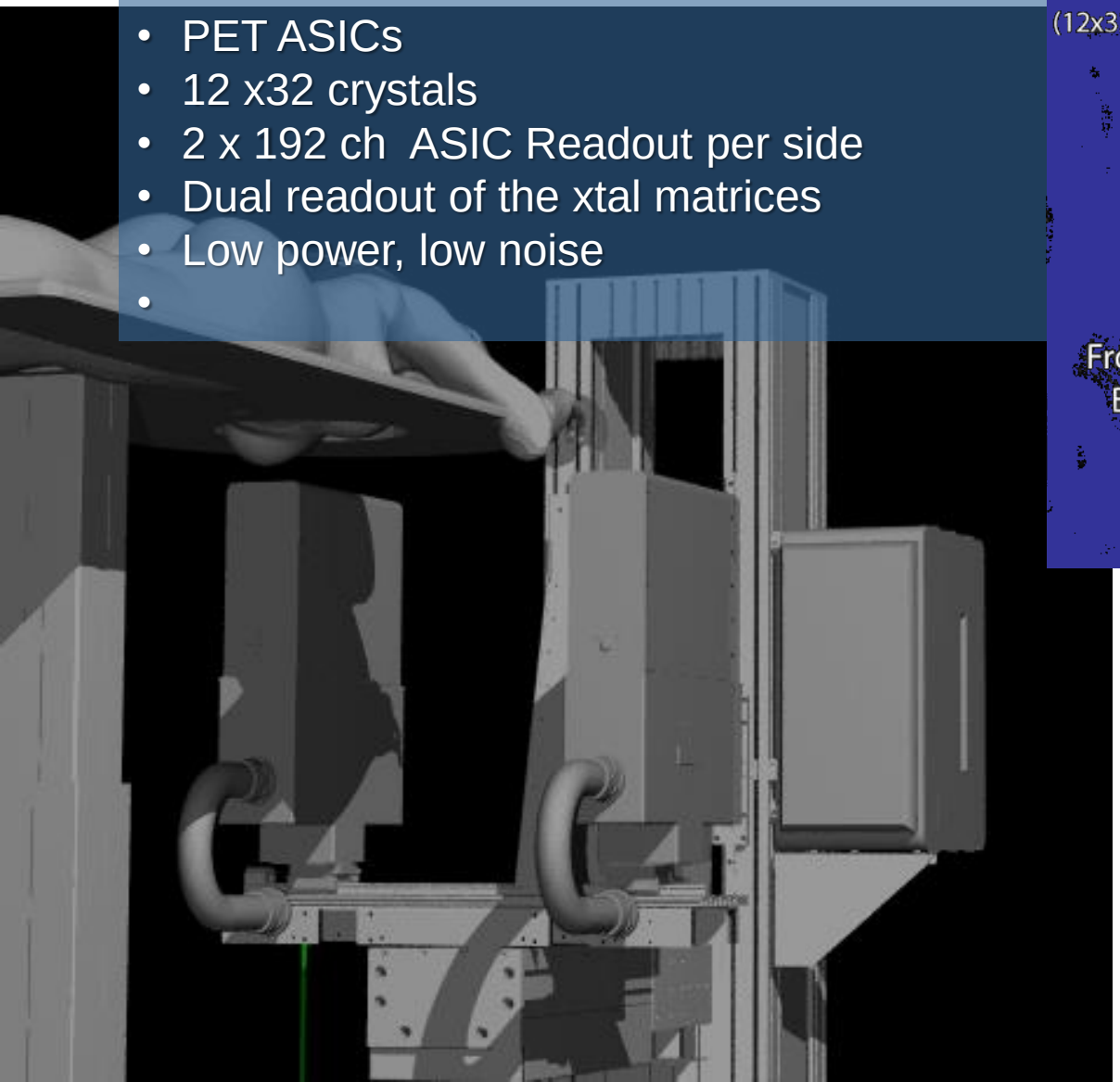
Avalanche Photodiodes (APD):
Hamamatsu S8550

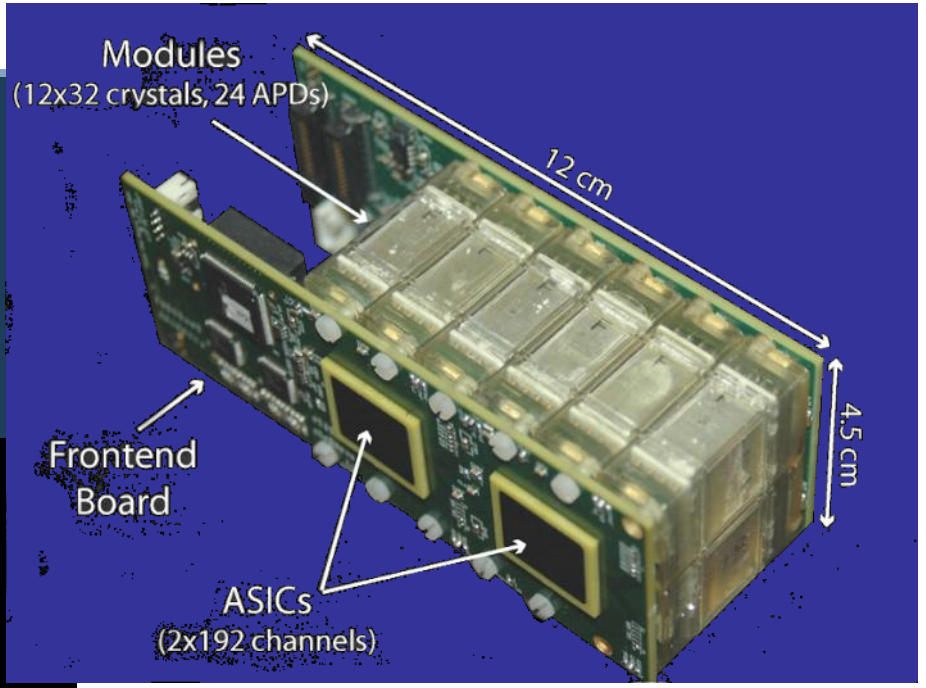
- Gain ~ 150
- Dark Current: ≤10nA / pixel

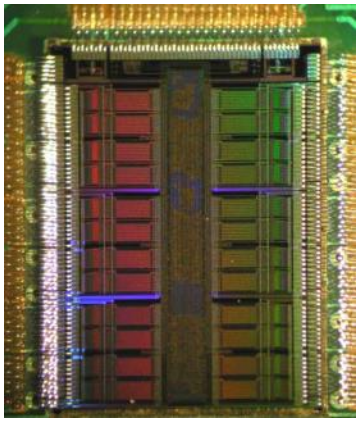


Basic detector module : a Supermodule

- PET ASICs
- 12 x32 crystals
- 2 x 192 ch ASIC Readout per side
- Dual readout of the xtal matrices
- Low power, low noise
-



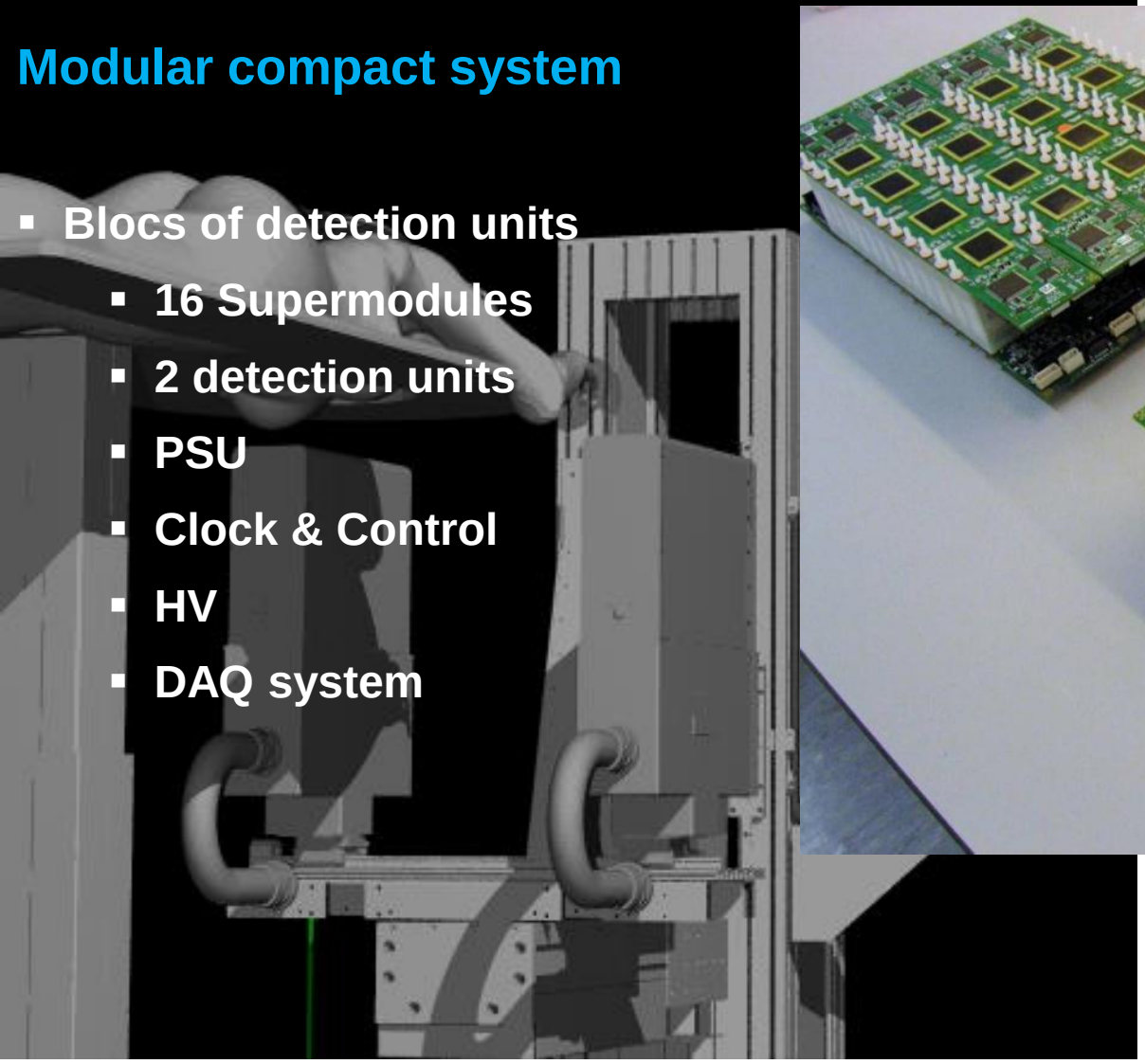


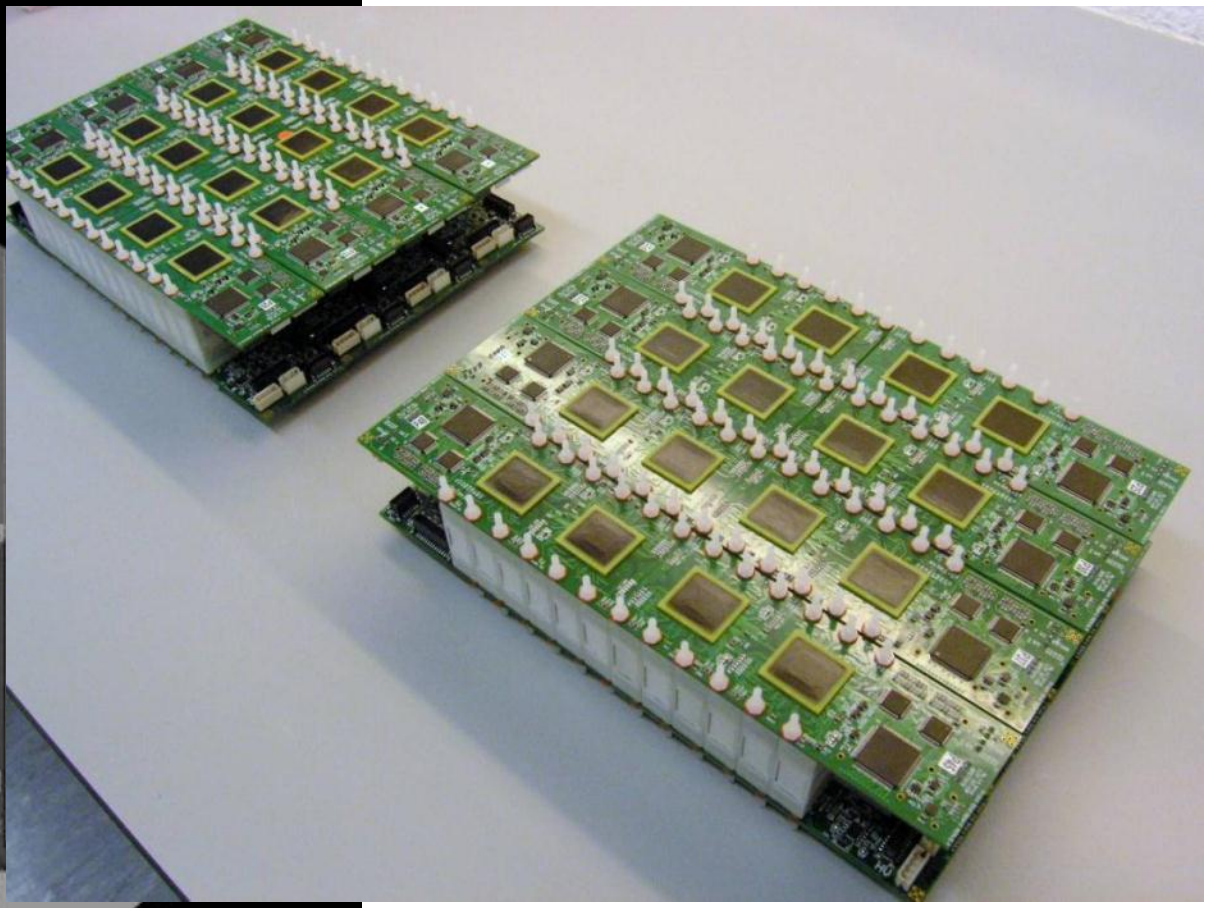


FE – Integração II

Modular compact system

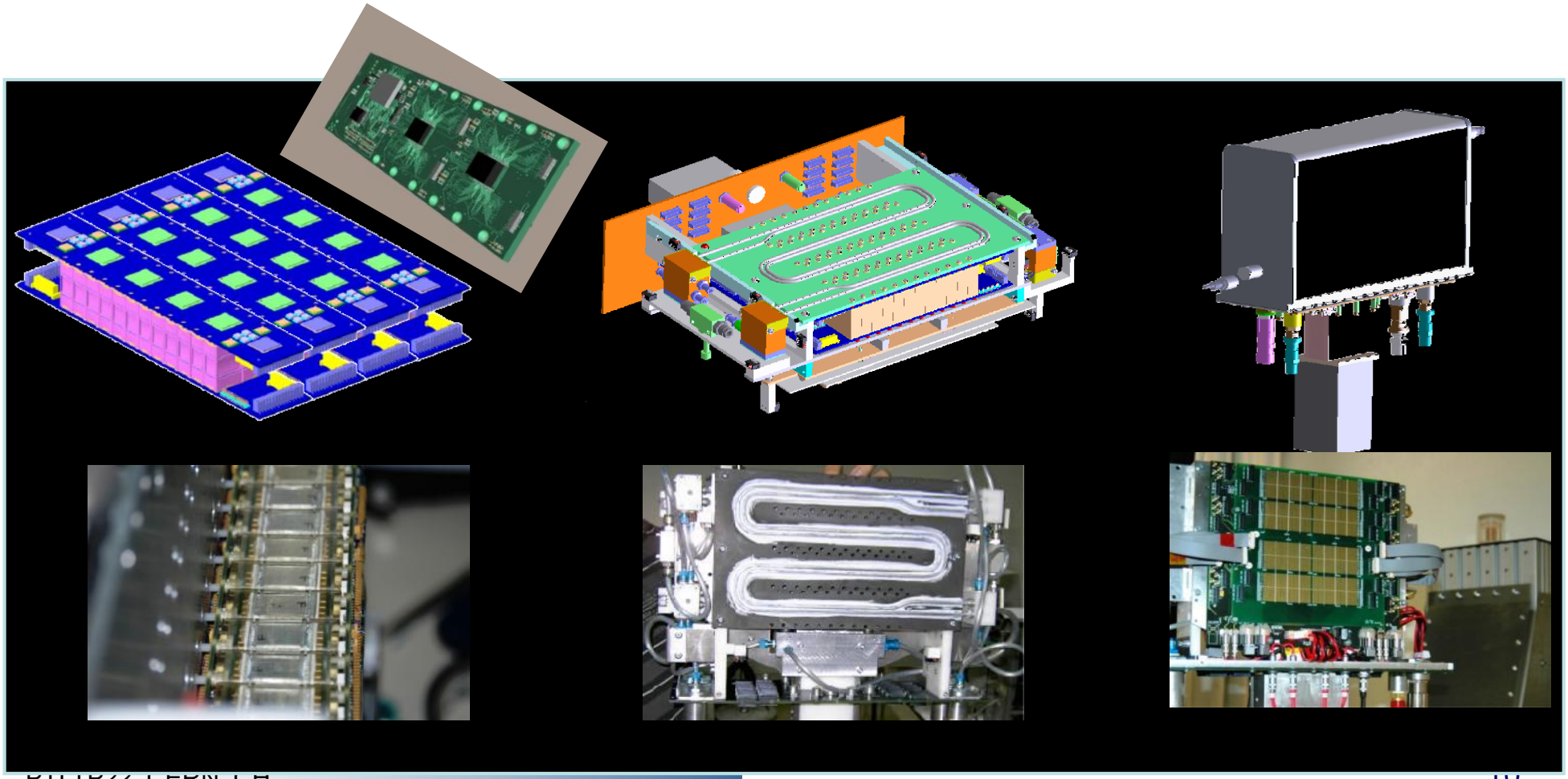
- Blocs of detection units
  - 16 Supermodules
  - 2 detection units
  - PSU
  - Clock & Control
  - HV
  - DAQ system



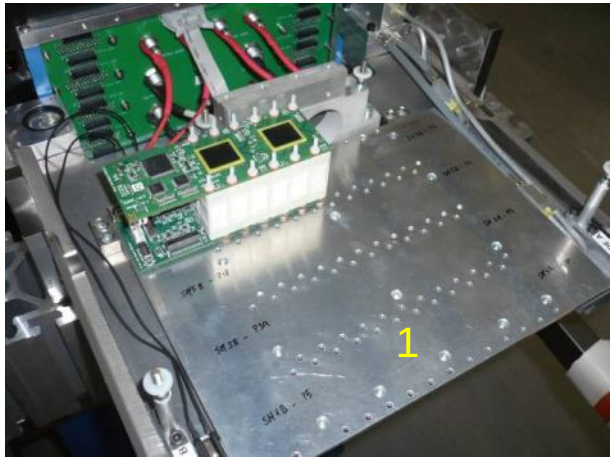


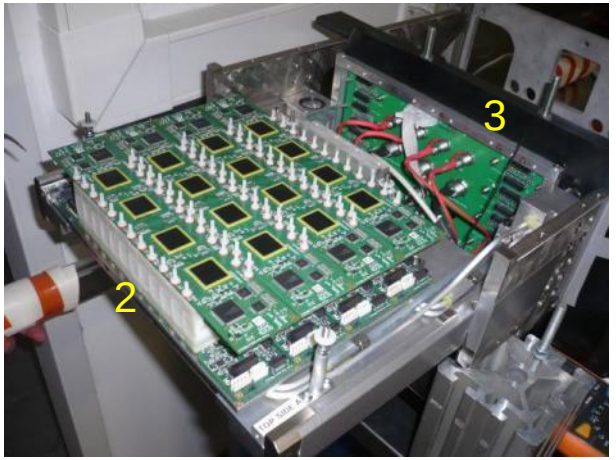
Da Modelização à Realização

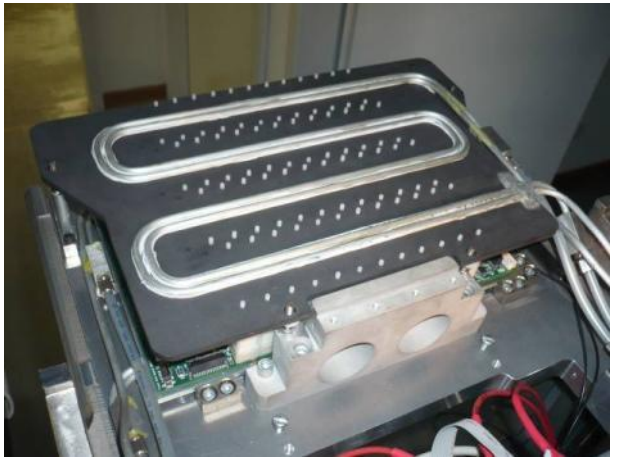
The full project , from electronics to mechanics, was first emulated with 3D CAD/CAE systems , and manufactured only after.

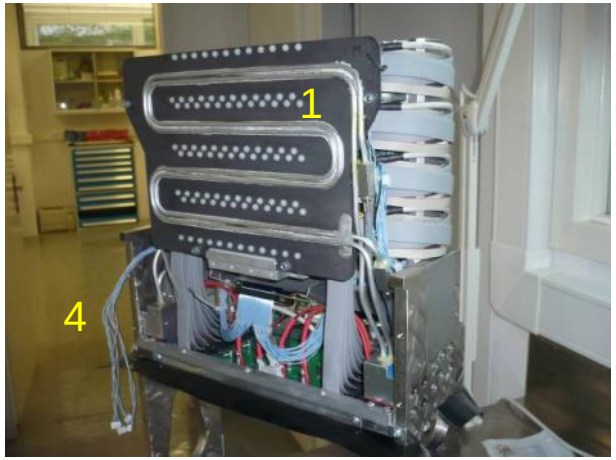


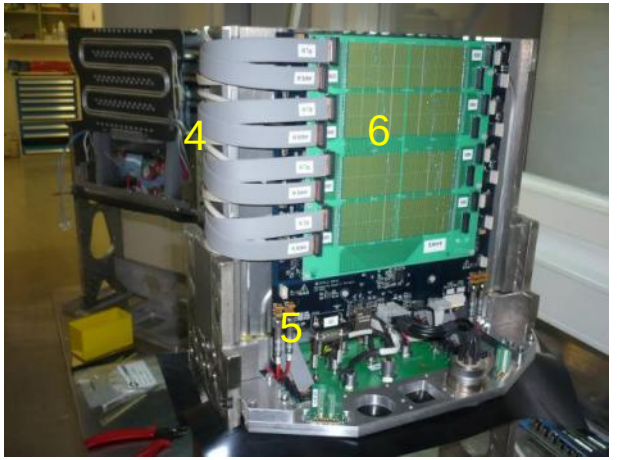
FE – Integração III

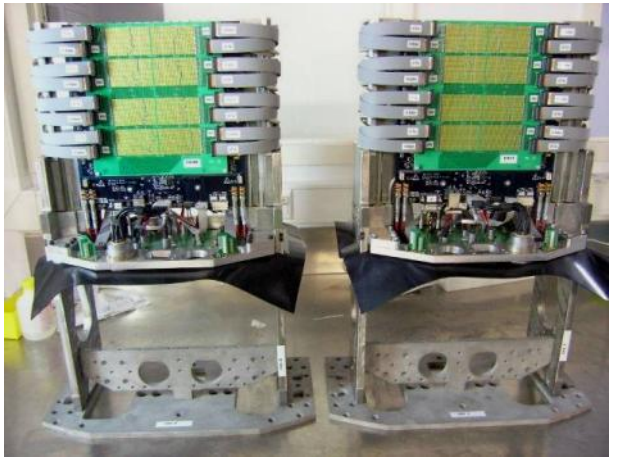








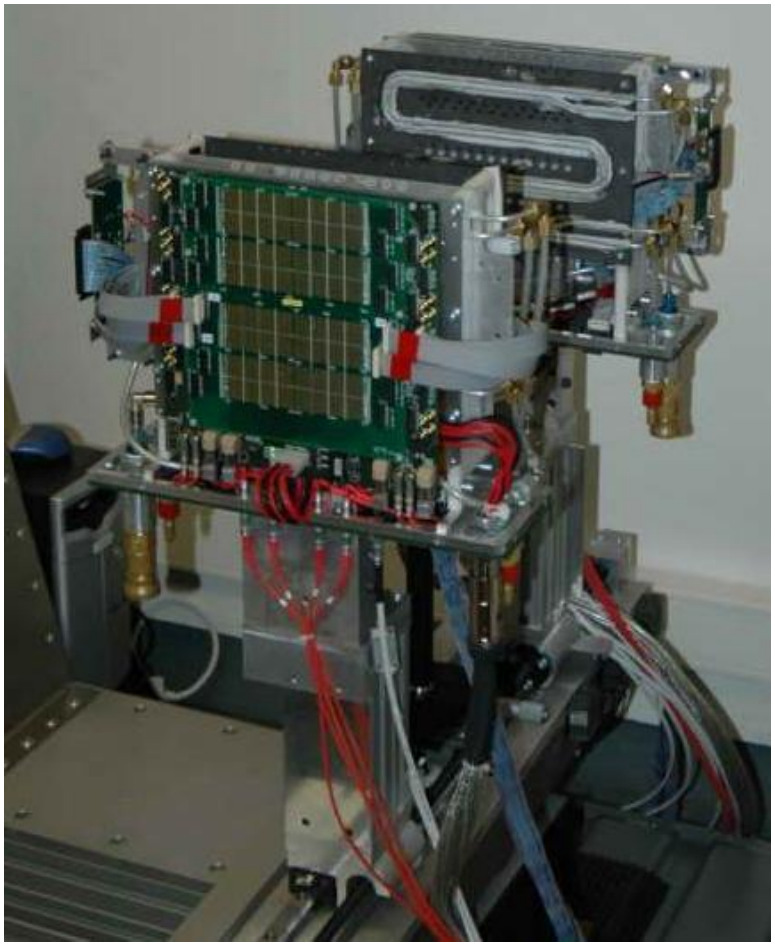


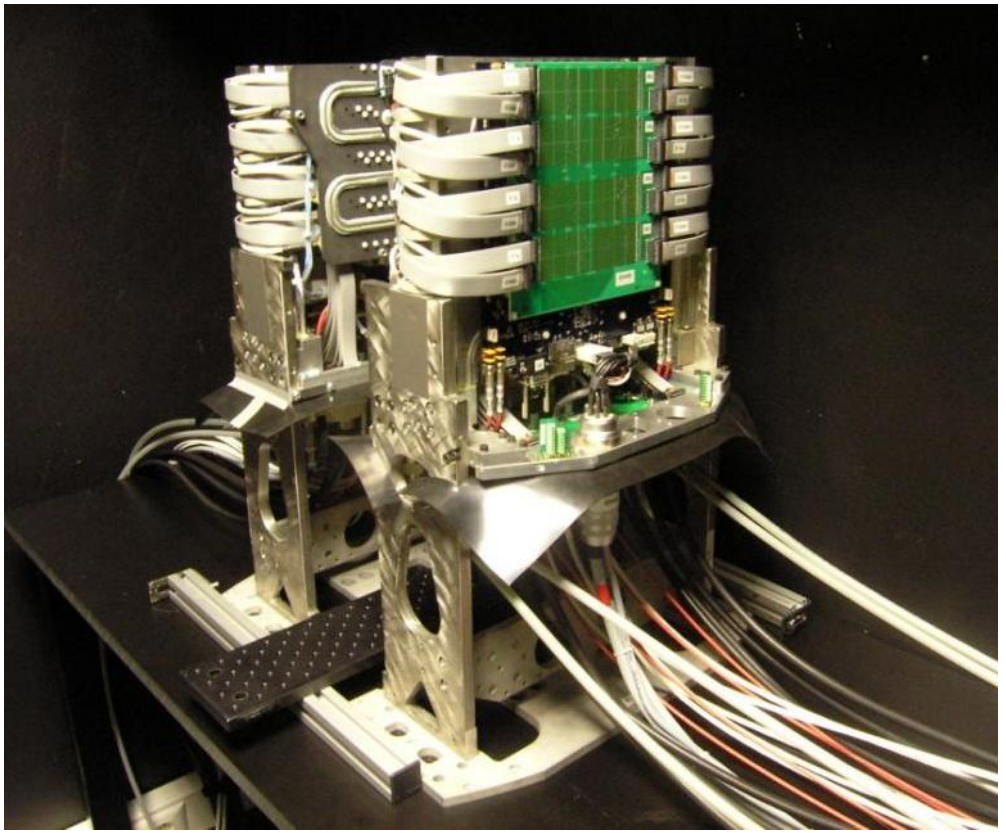


1. Water cooling plates 2. Supermodulos 3.connexion panel)

4. Cables assembly 5 : Service Board (LV , HV, CLOCK, DATA) 6. HV Matrix (HV distribution)

Detector Heads Final



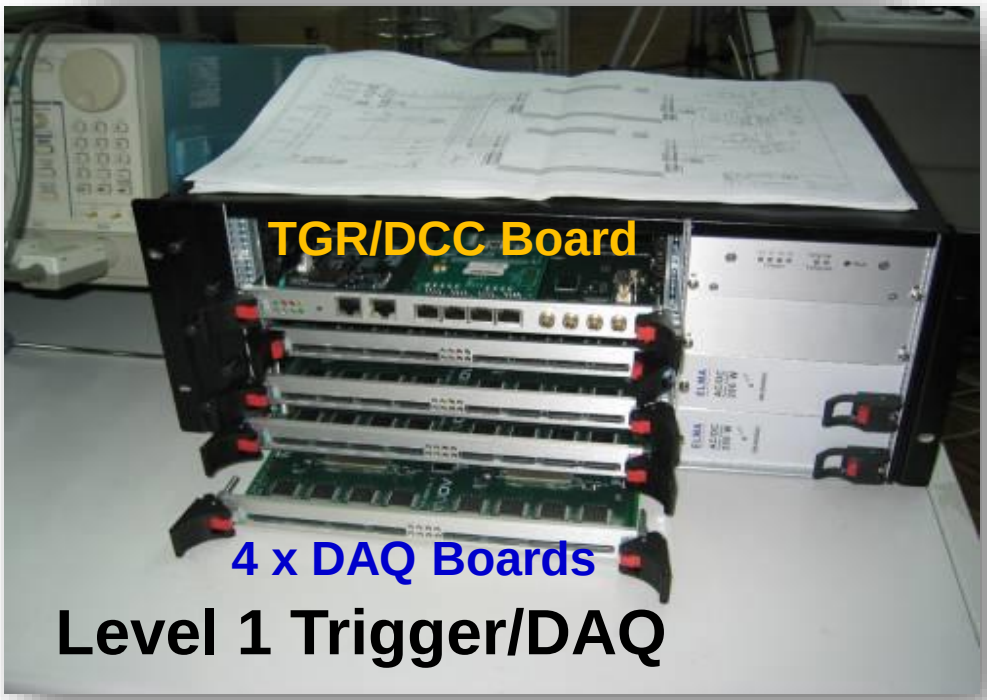


DAQ and Trigger units

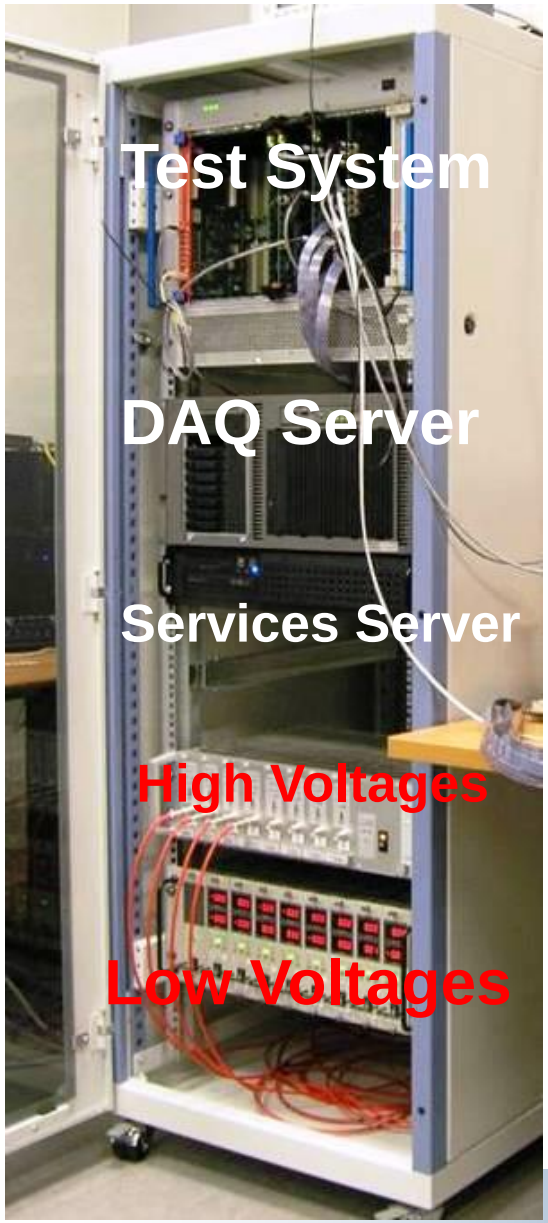
- The L1 trigger and DAQ boards are assembled in one external crate

- Complex trigger algorithm (36K calibration constants)

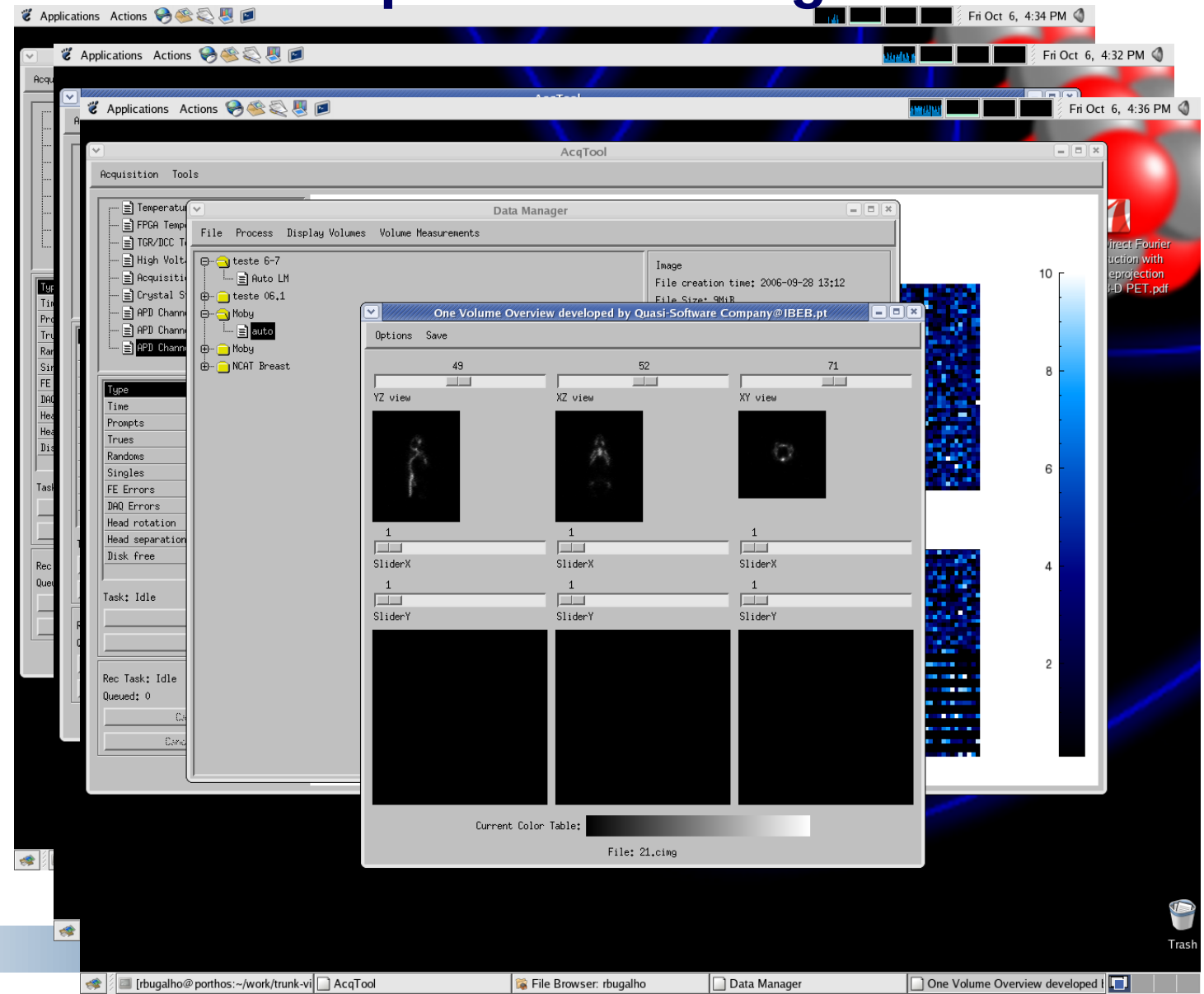
•Frontend - L1 Trigger - ate 156 Gb/s
•Level 2 DAQ: Servidor high-end
•L1–L2 bandwidth up to 800 MB/s



Data Acquisition System

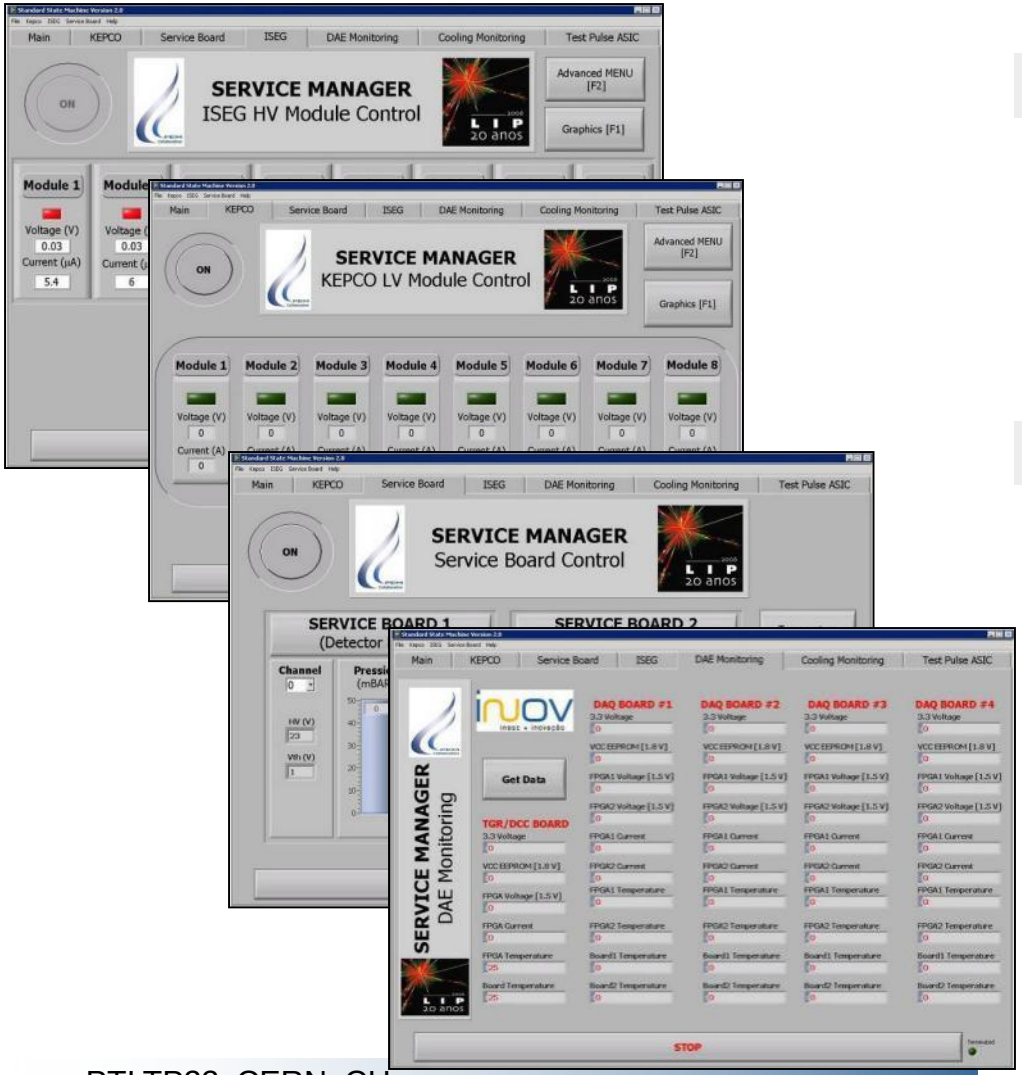


Acquisition Manager



DCS software

Control panels



DAQ test system

DAQ Server

8 cores, 2 TB disk array

Service Manager

2 cores, 0.5 TB disk array

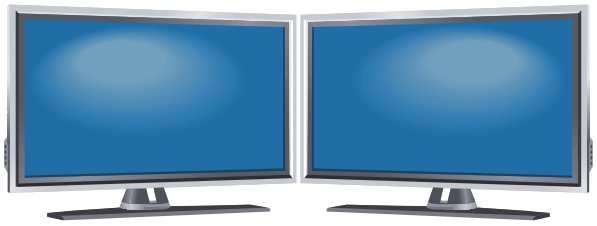
Gigabit Switch

High Voltage Supply

Low Voltage Supply

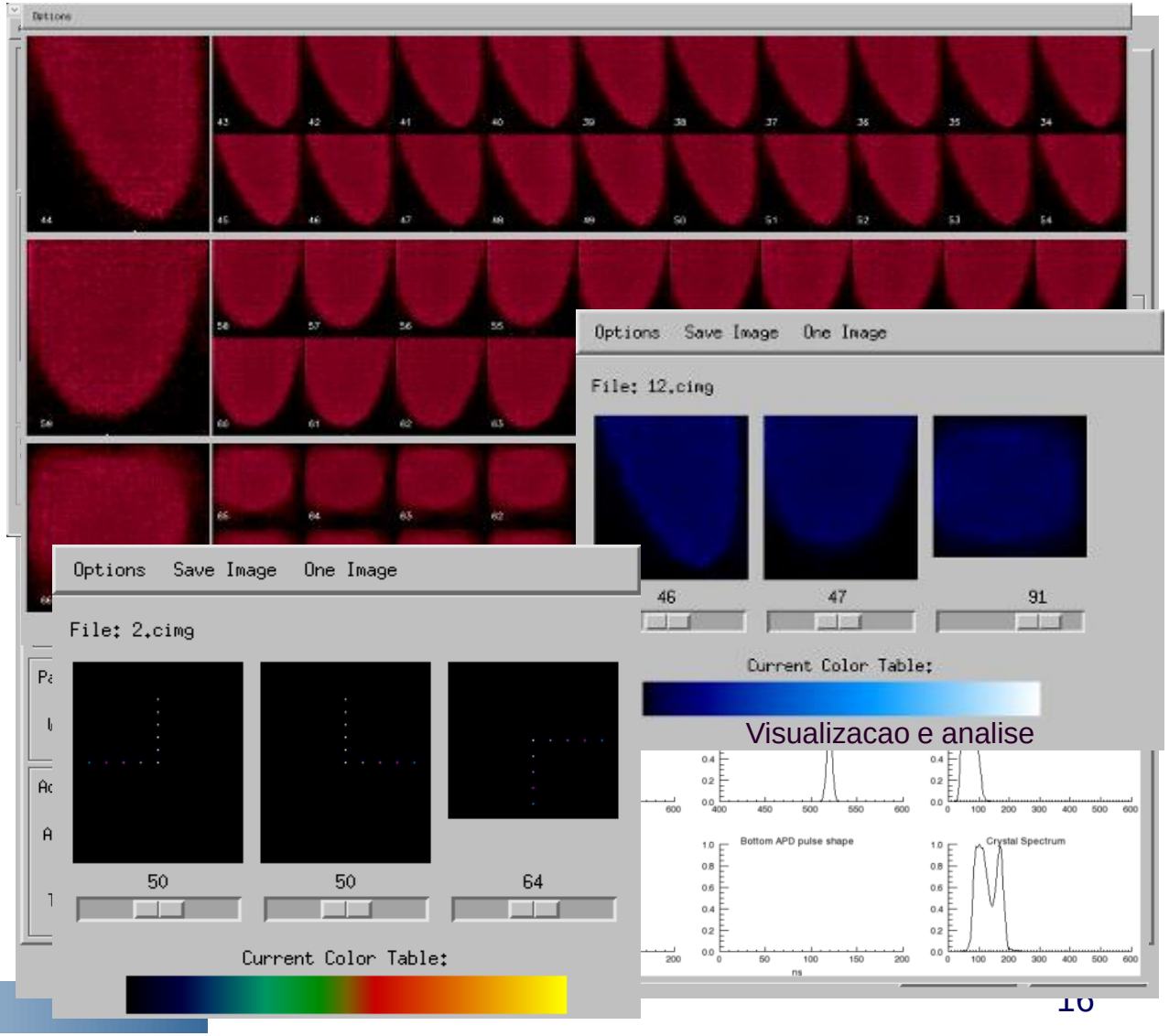
Isolation Transformer

DATA Server



4 cores, 4 GB RAM, 1 TB disk array

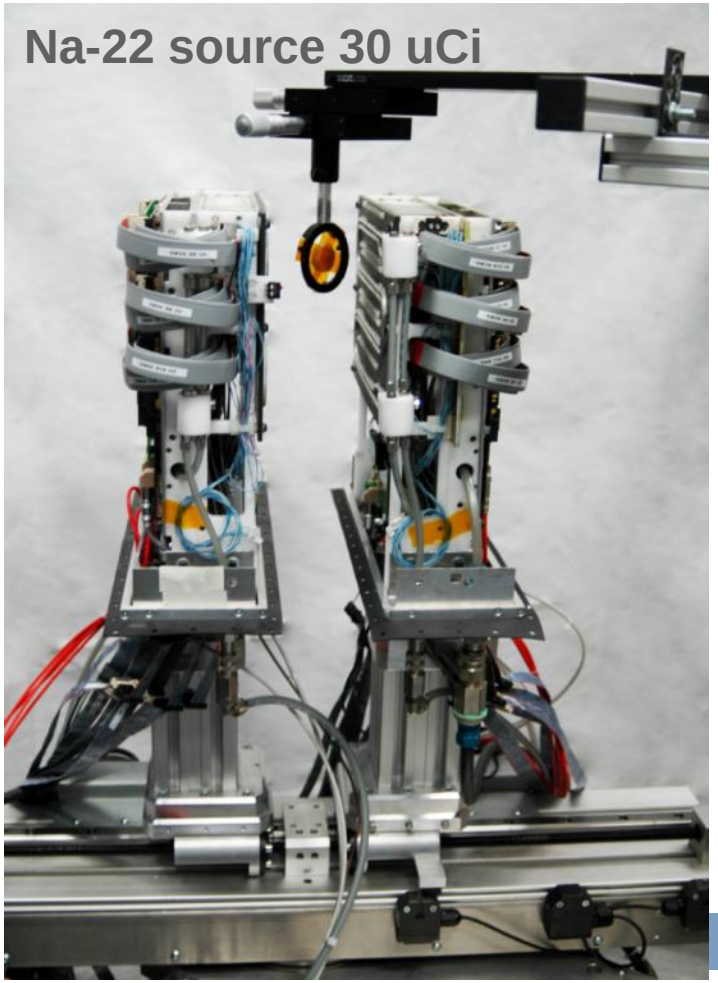
Operation, Monitoring, Reconstruction and visualisation software

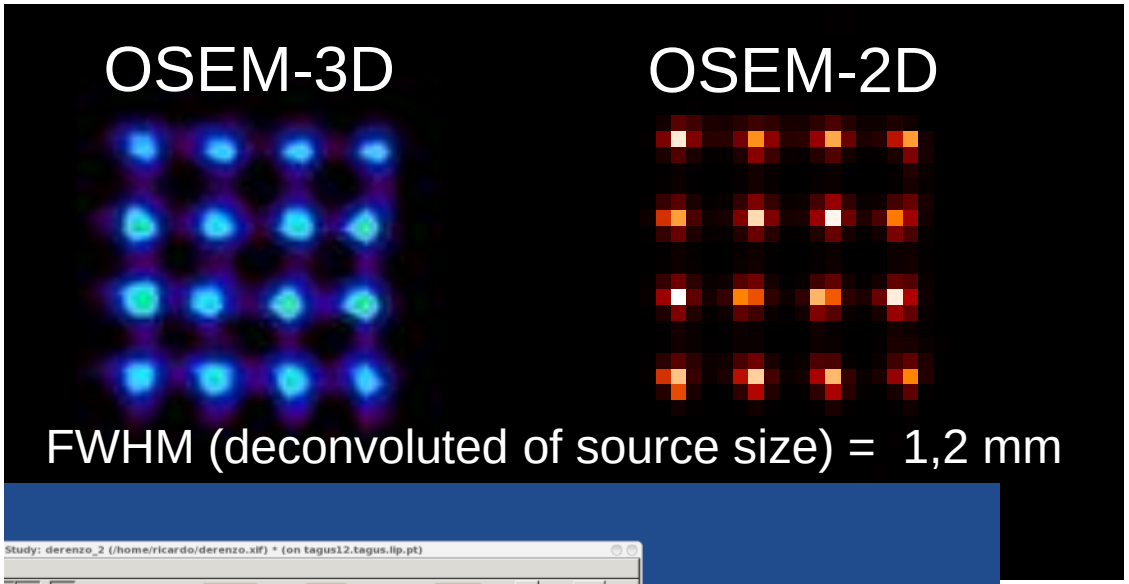


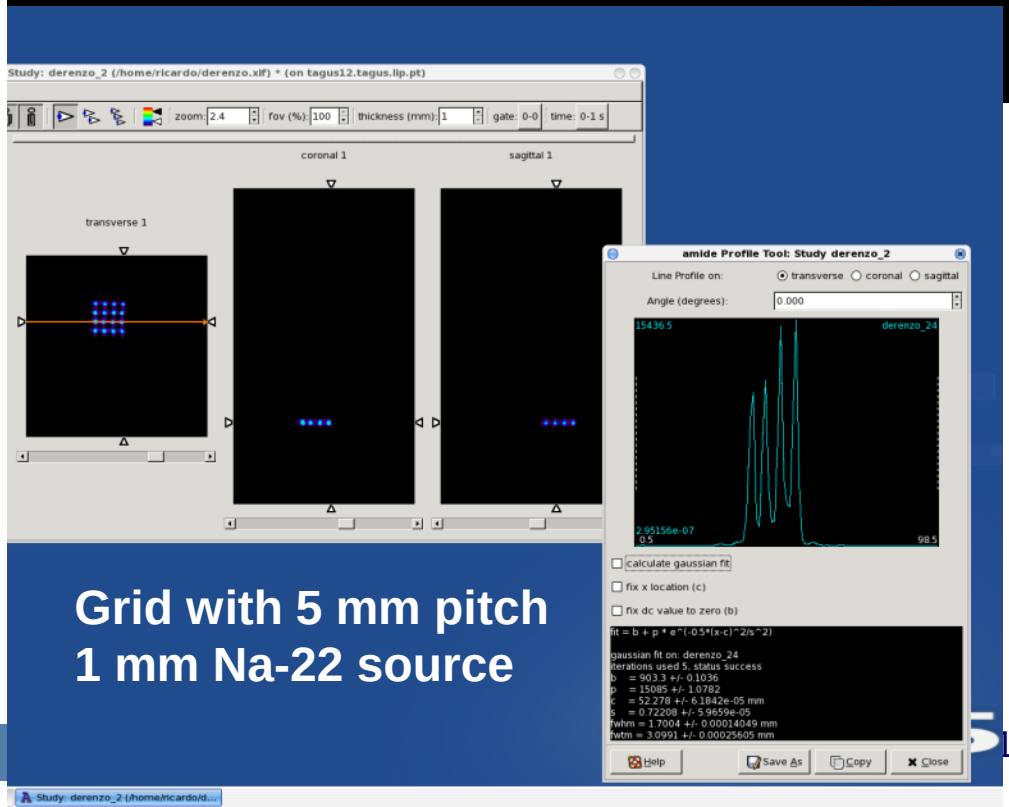
Visualizacao e analise

ClearPEM Images

- Two acquisition per position
- (400-600 keV)
- Simultaneous reconstituion with 16 acquisition points



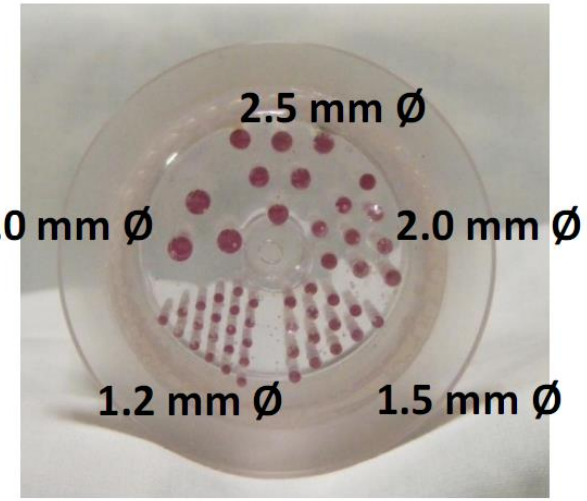


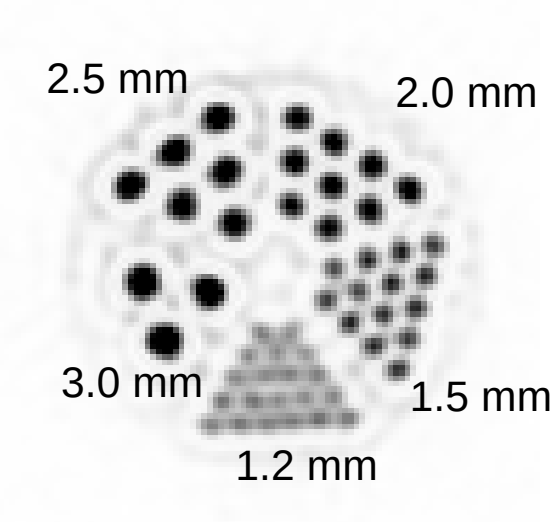


SPACIAL RESOLUTION

Development concluded in 2008

- The PET Scanner with the best spacial resolution (1.3mm)
- The only PET in the market with DOI measurement and without paralax
- The highest density of integration

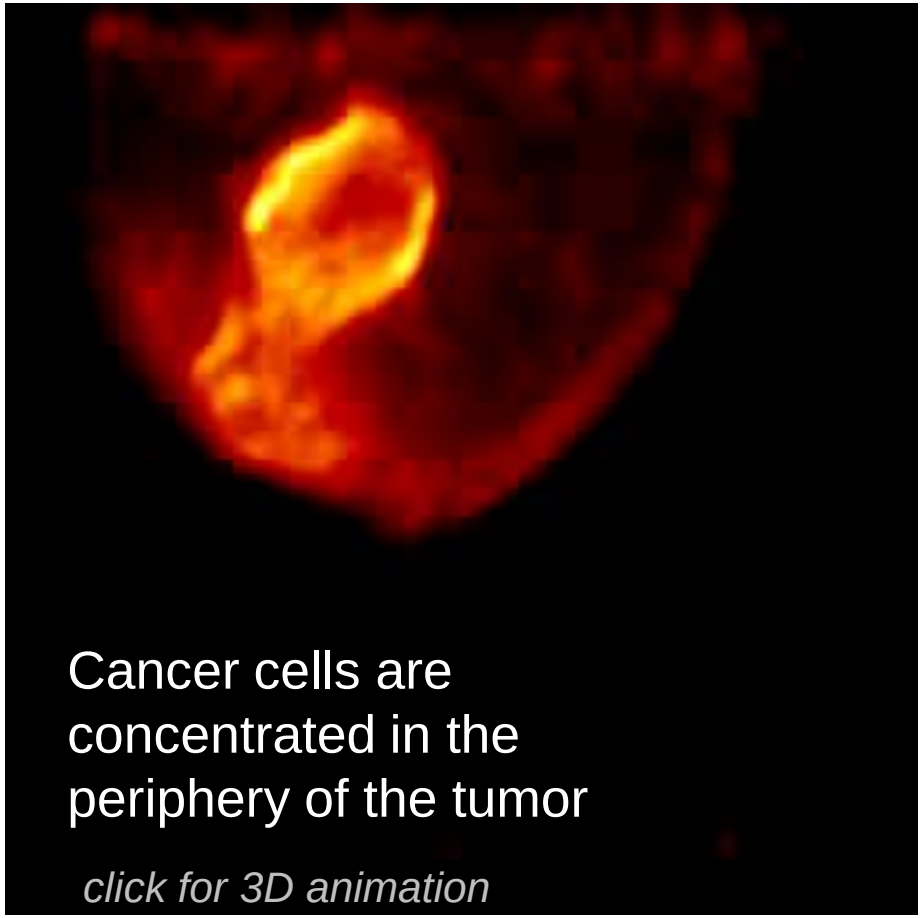


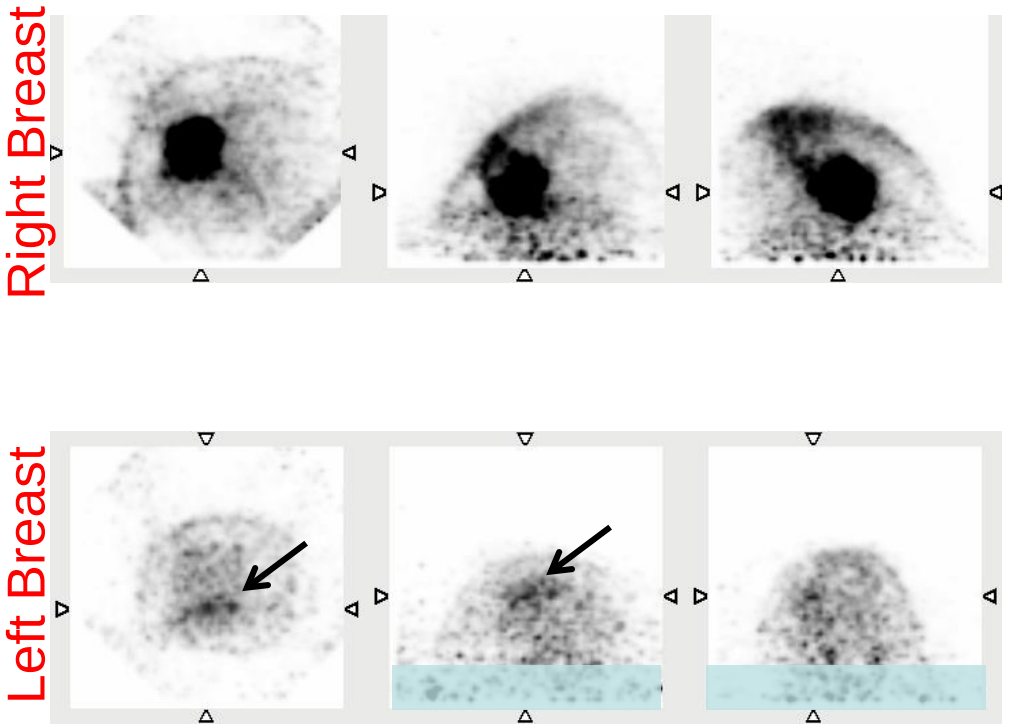


Clinical trials results

- We have fully developed two PET scanners
  - CLEAR PEM and CLEAR PEM SONIC
- The validity of the results was demonstrated on clinical trails in Coimbra (Portugal) and in the Hopital Nord, in Marseilles (France)
- We have identified several cases of cancers that were invisible in the full body PET scanners.
- Still ongoing:
  - Clinical trials at Hospital San Gerardo, Monza, Italy
  - PET Markers studies (ICNAS, Coimbra)

Clinical Case : bilateral breast cancer





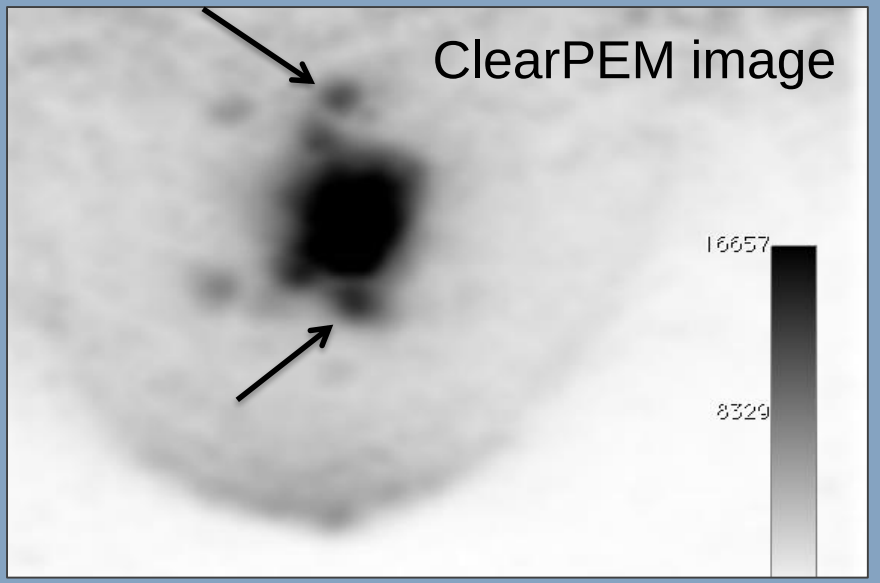
Clinical Case : multifocal breast cancer

Patient with breast cancer tumors imaged both with whole-body PET and with ClearPEM

PET/CT exam:
Resolution is insufficient to identify multiple focus

PEM:
- **Multifocal Lesions are observed**
- **Strong impact on surgery planning**

Supine position

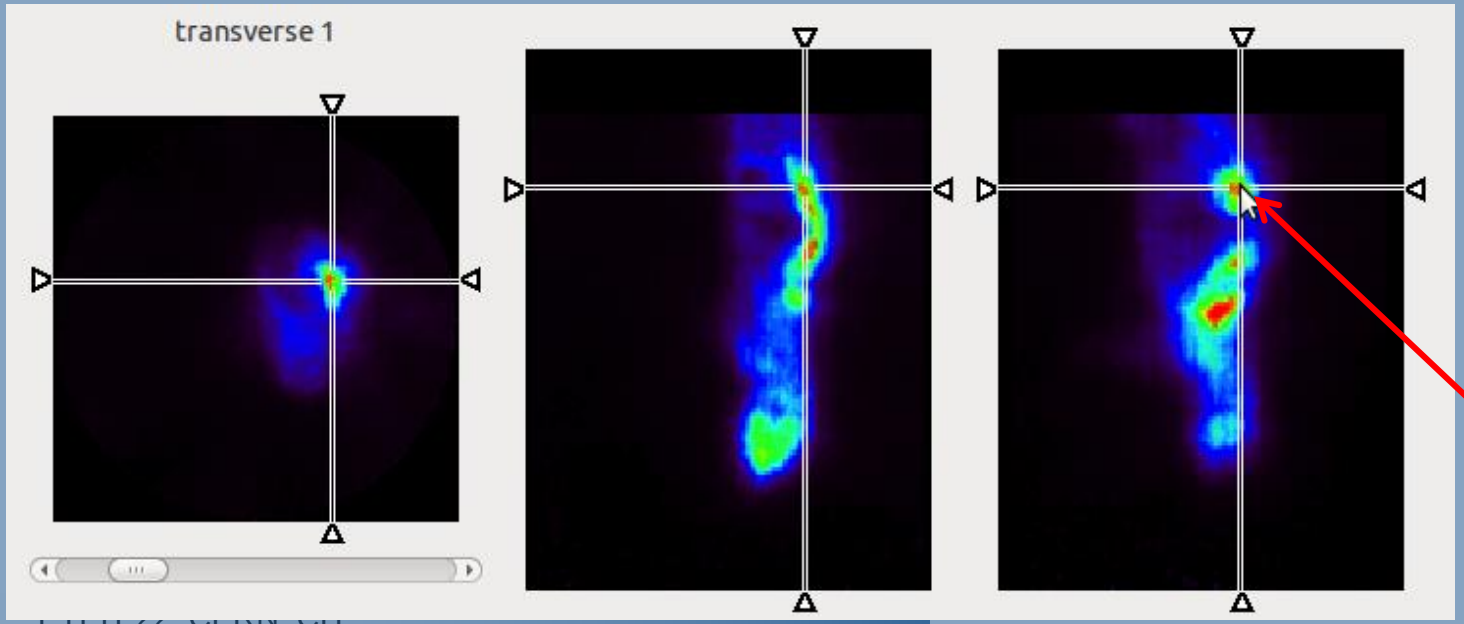


Prone position

Images obtained at Hospital Université de la Méditerranée

Colon tumor detection

Image obtained with PETsys scanner installed at ICNAS, Faculdade de Medicina, Coimbra

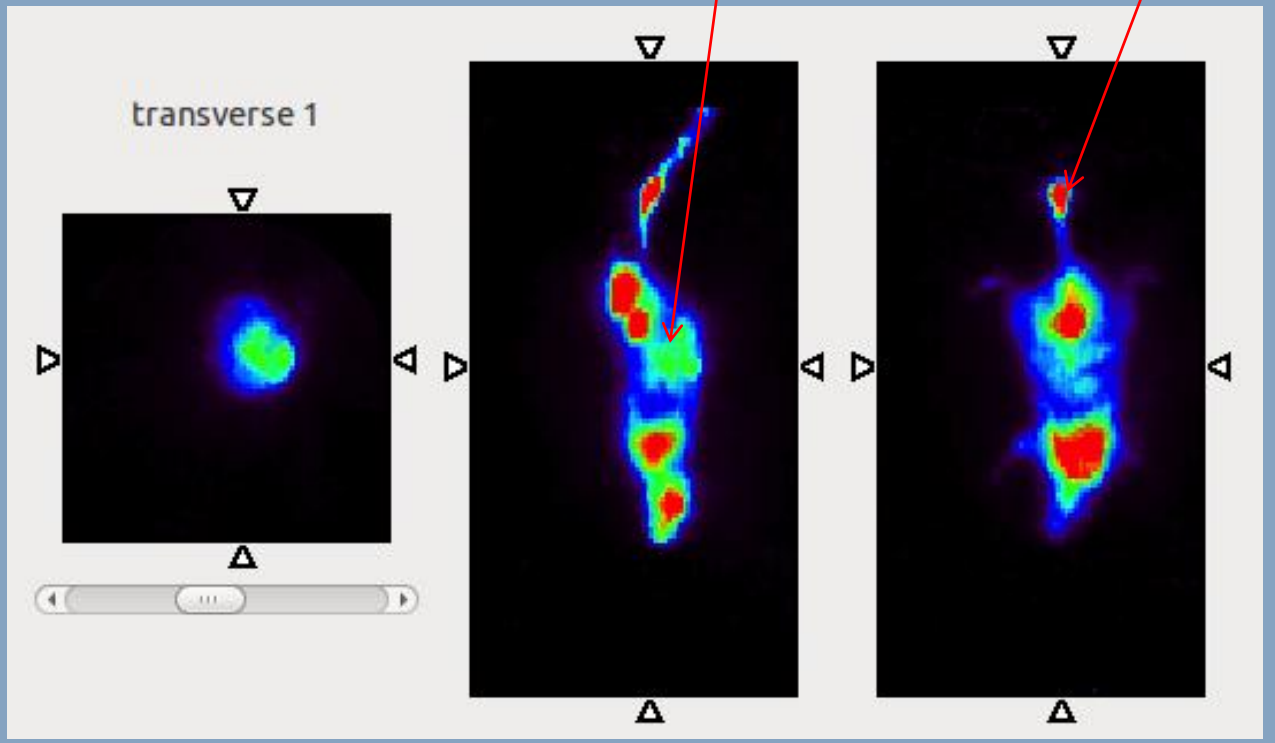


FDG scan
A = 1,2 mCi
Weight = 180g
Colon tumor

Colon tumor

Melanoma detection

Image obtained with PETsys scanner installed at ICNAS, Faculdade de Medicina, Coimbra



FDG scan

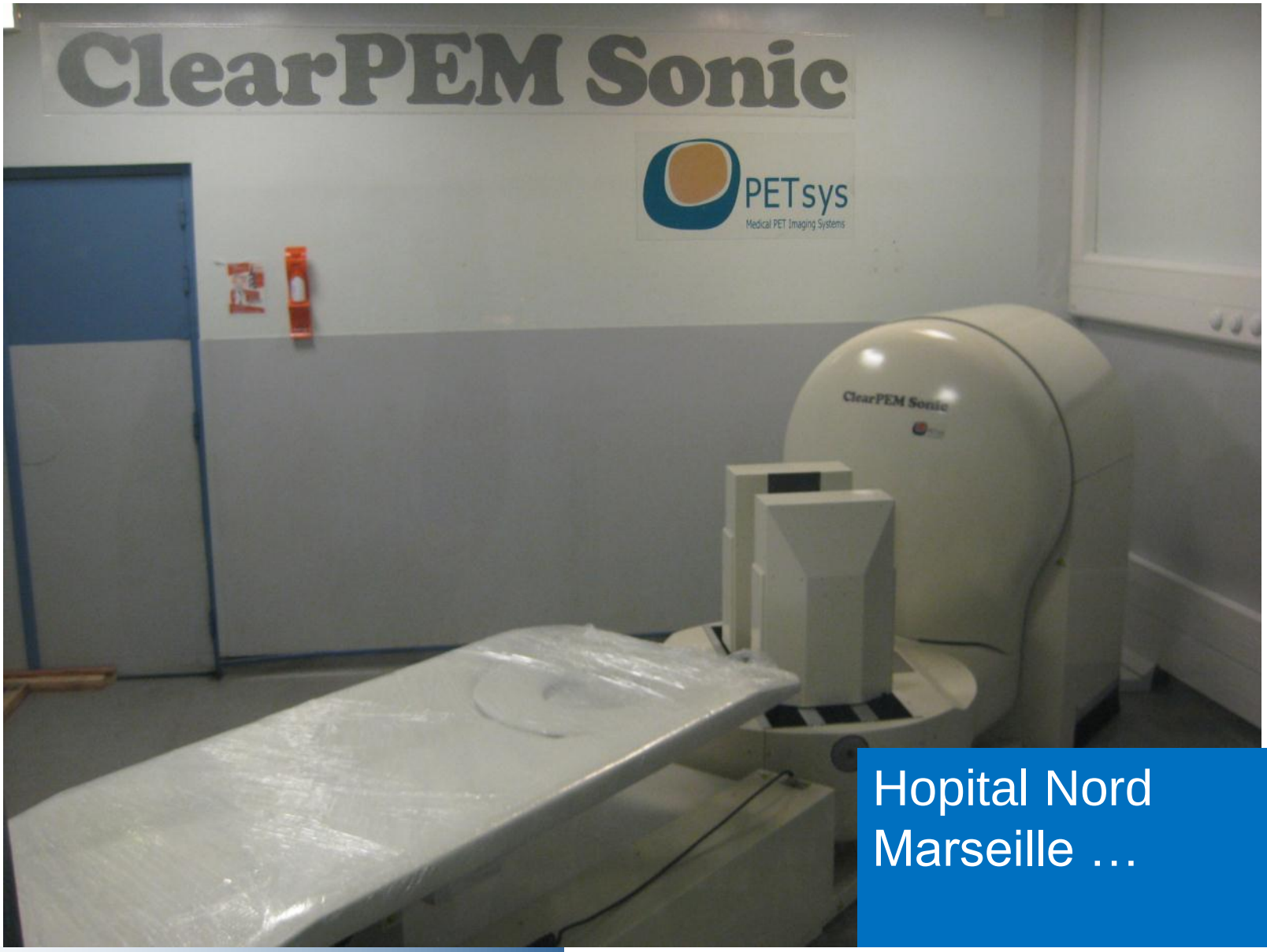
A = 170 µCi

Weight = 18g

Melanoma

@ICNAS , COIMBRA

@Marseille

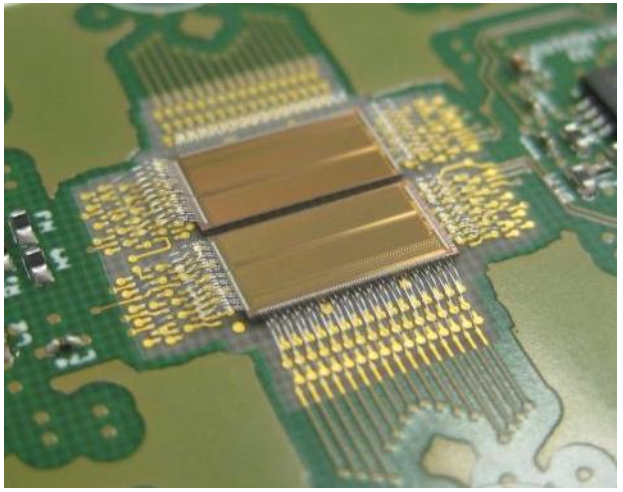


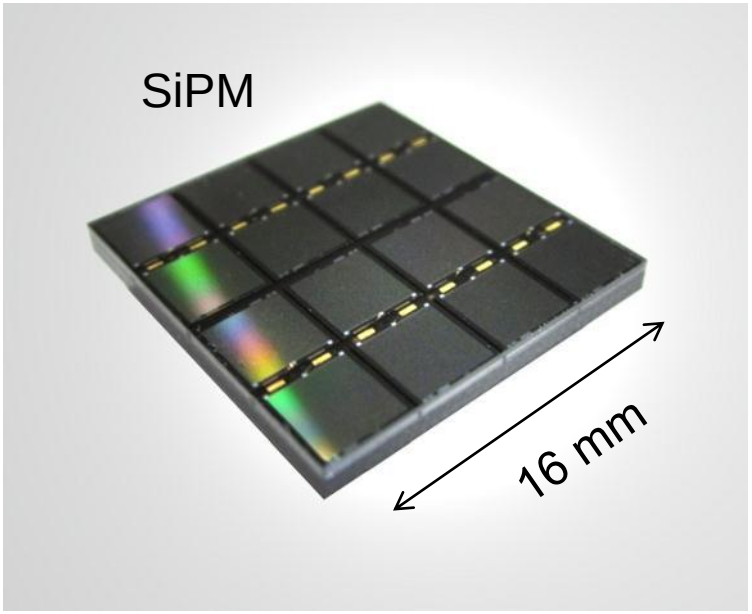
Hopital Nord
Marseille …

@Monza

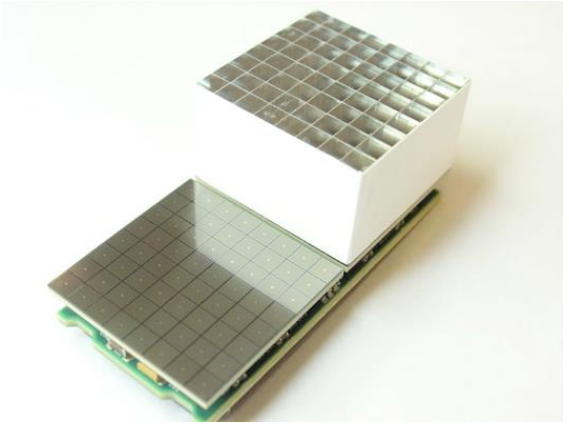
Monza Hospital

Novas tecnologias
Novos detectores
Novas aplicações





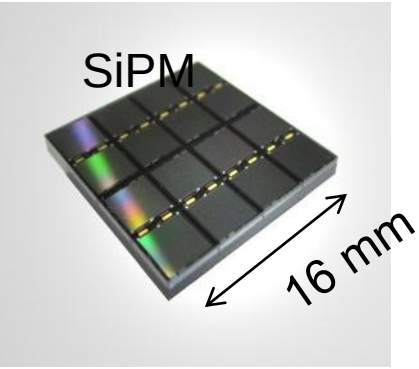
New technologies
New detectors
New applications



New technologies

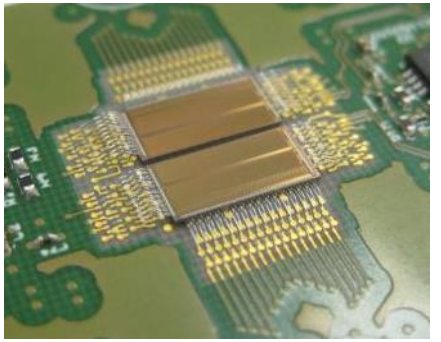
High sensitivity:

- New PET modules with higher sensitivity
- New photodetectors (APDs->SIPM)



PET Time-of-Flight

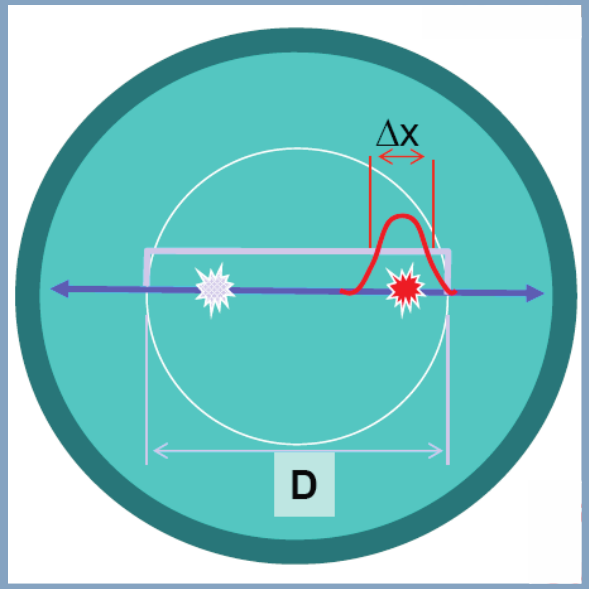
- New time-of-flight PET detectors, SiPM (Silicon Photomultipliers)
- New ASIC for time-of-flight PET detectors



Trigger/DAQ for large scanner systems

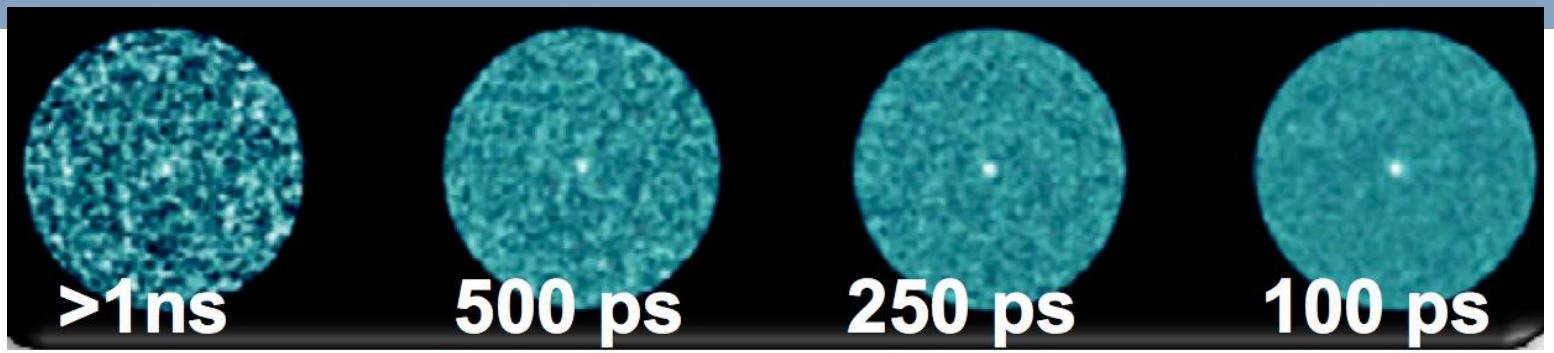
- New DAQ high performance system
  . (for brain abd full body PET)
- New DAQ formats from market(uTCA)
- DAQ goes optical

PET TOF



Better time resolution will dramatically improve the PET image quality

- The accuracy of the source localization depends on the coincidence time resolution (CTR)
- Δx= uncertainty in position along LOR = (speed of light) × CTR/2
- The TOF benefit is proportional to $D/\Delta x$
- With PMTs CTR ≥ 500 ps if great care is taken to get the best CTR

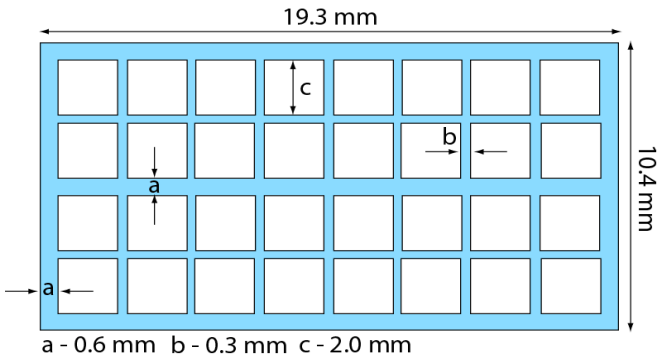


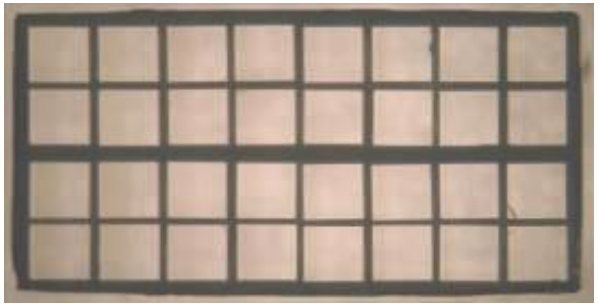
PETsys Detector Modules have CTR ~250 ps

New Crystal Detector Matrices

PETsys Electronics

Sinocera Matrix



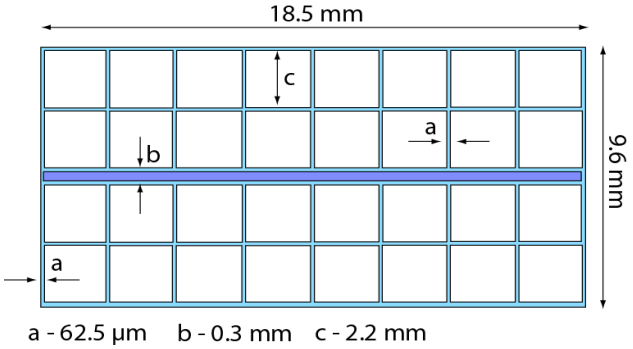


64% **packing fraction**

82% **511 keV interaction probability**

(20 mm crystals)

Proteus Matrix



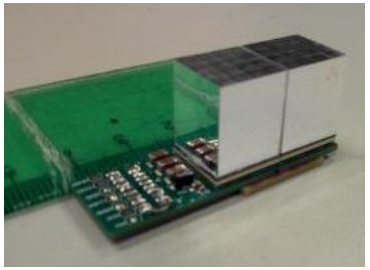
88% **packing fraction**

92% **511 keV interaction probability**

(30 mm crystals)

Better xtal matrices , with reduced gaps, from a direct interaction with manufacturers

ENDOTOFPET project

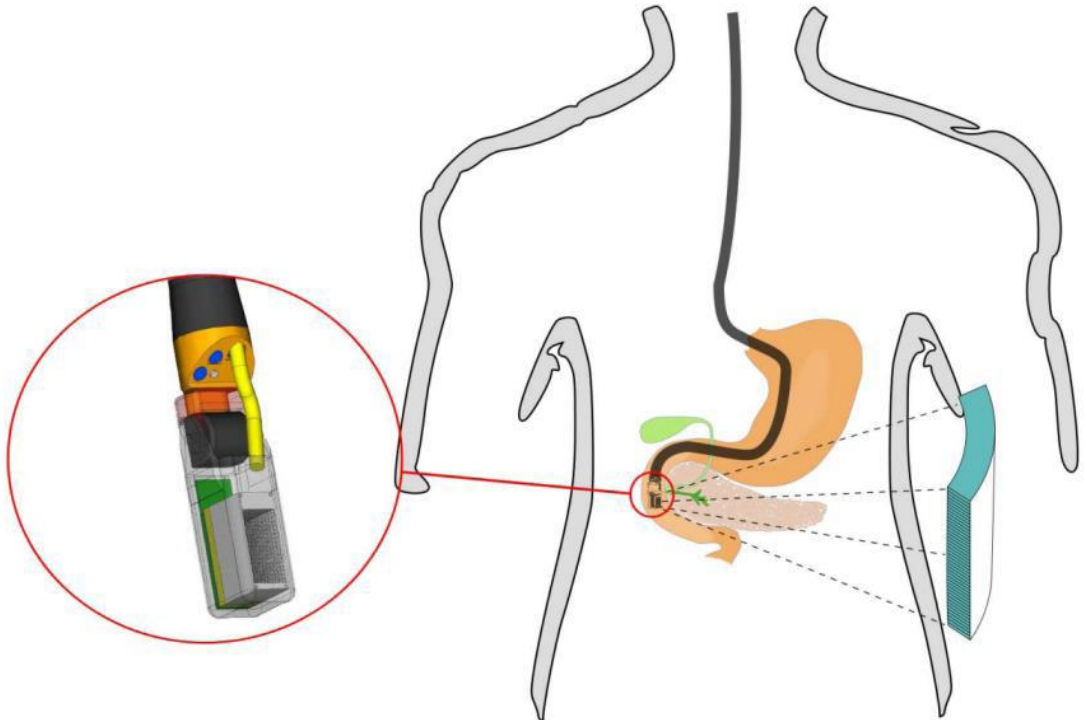


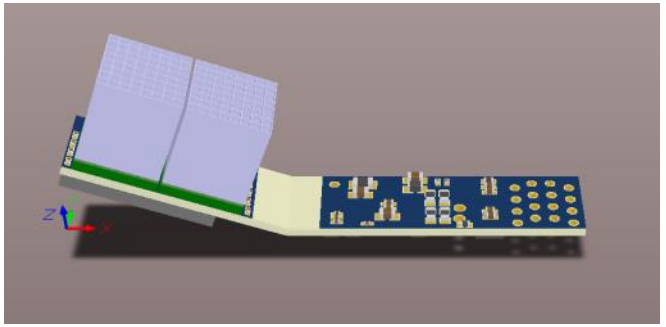
PET HEAD
Using SIPM and
LIP TOFPET ASIC
Prostate version

ENDOTOFPET project

PETsys Electronics

Pancreas PET HEAD
Using SIPM and
LIP TOFPET ASIC
(Under developement)



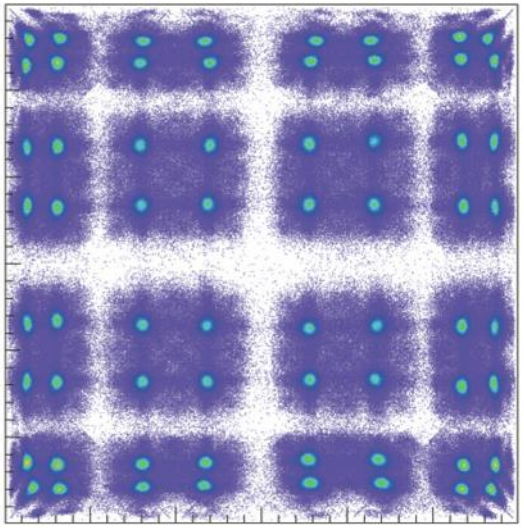


High-resolution Detector Module

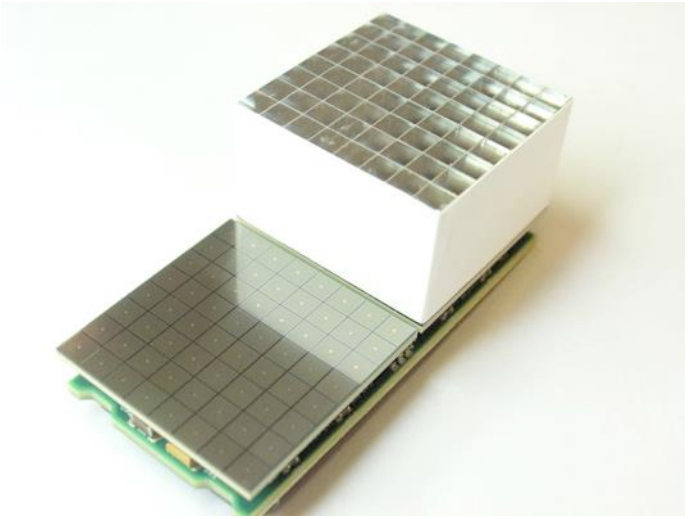
PETsys Electronics

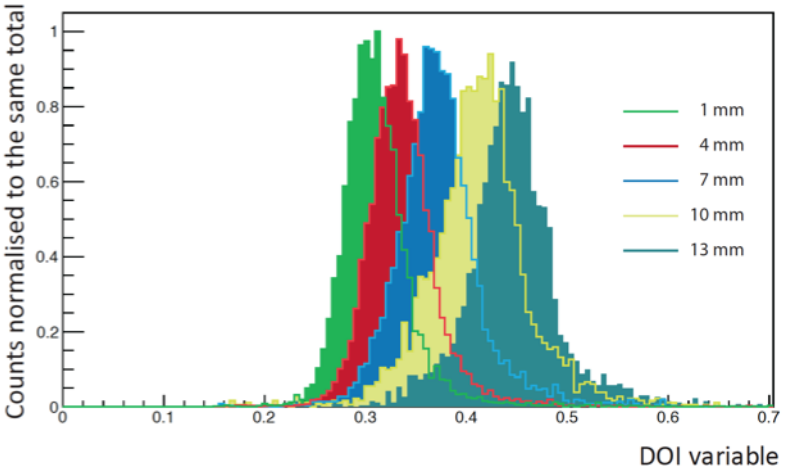
Excellent performance

Detector module based on arrays of 8x8 LYSO pixels of 1.5x15x15 mm



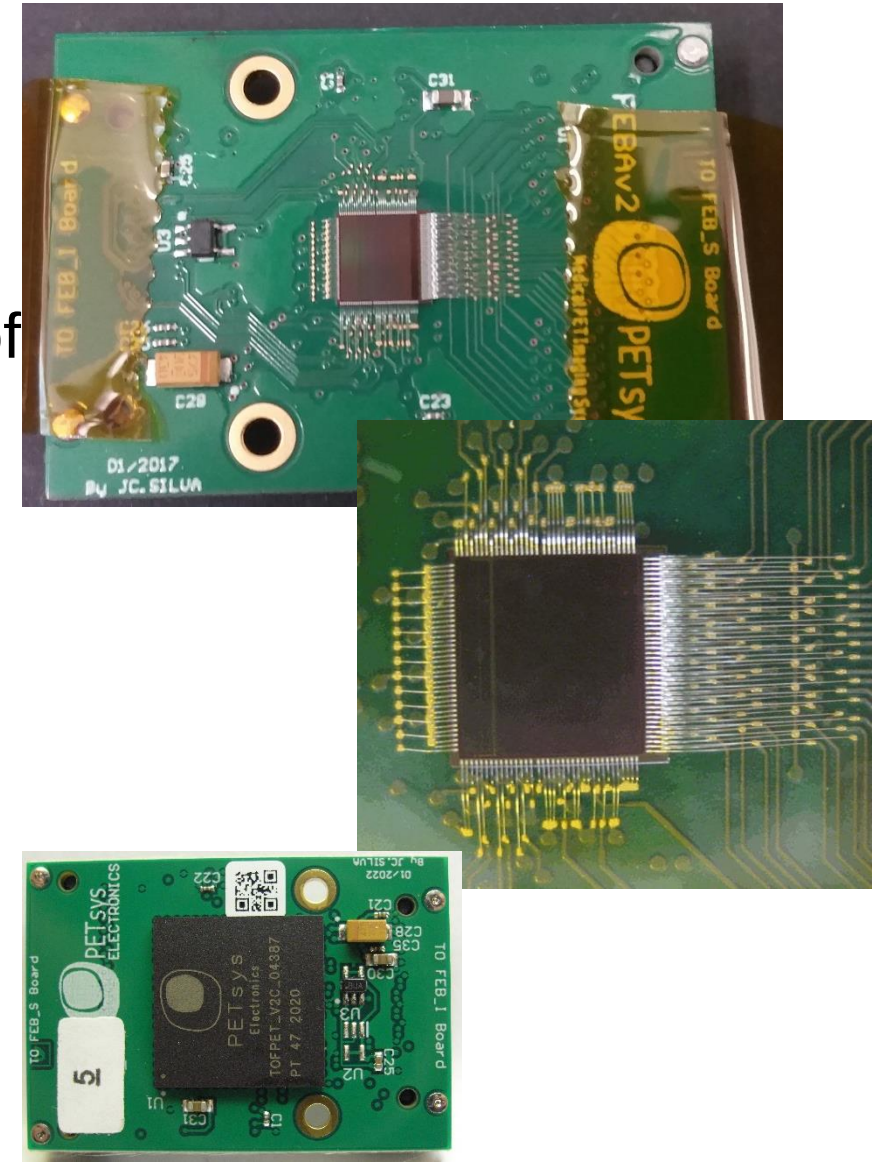
Joint patent PETsys-CERN





High-performance ASIC

The PETsys High Performance TOFPET2 ASIC is a new 64 channel chip for the readout and digitization of signals from fast photon detectors in applications where a high data rate and fast timing is required.



Ext. Clock(MHz)	Bin Width (ps)	Data Rate (Mbit/s)	Event Rate/channel (kHz)
160	50	320	240
200	40	400	300
320	50	640	480
400[1]	40[1]	800[1]	600[1]

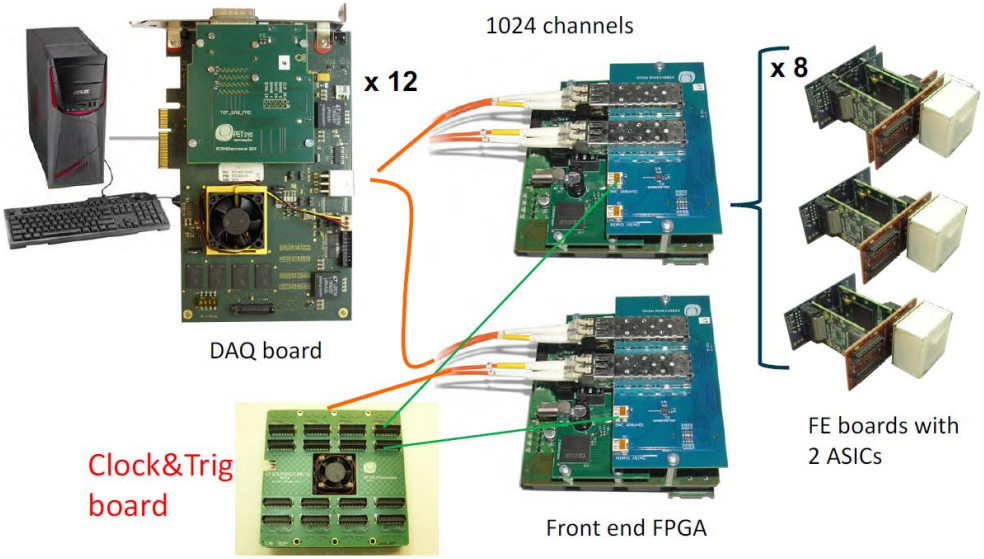
[1] Available for a future version.

Table 1. Clock, resolution and data rate settings available, and relative maximum event rate per channel.

PETsys data acquisition system

- Allows building a PET scanner with several 10'000 channels
- Three large systems are now assembled:
  - PET demonstrator (2048 ch)
  - EndoTOFPET plate (4096 ch)
  - Bruker SA system (6144 ch)
- Operation of these systems is allowing field test and correction of software bugs
- Pushing up the system performance
- Clients are very much attracted by PETsys complete offer (from ASIC to software)

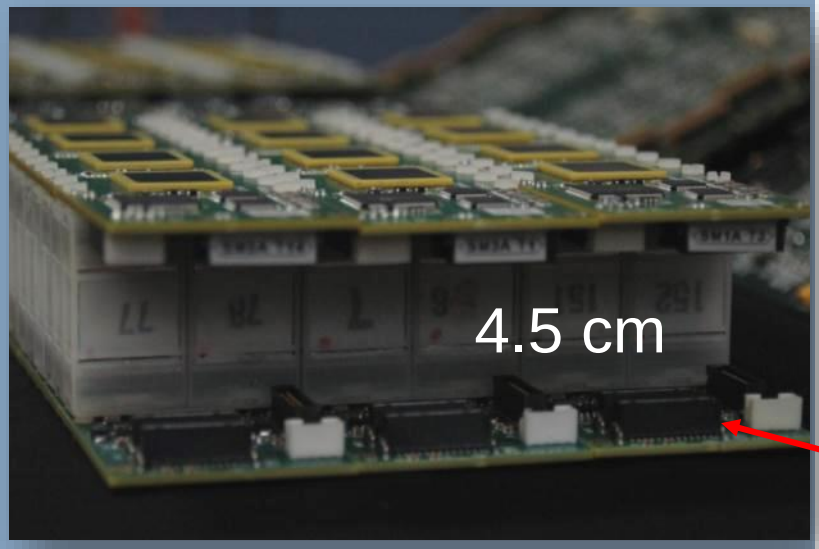
Complete solution from the detector to the data acquisition PC

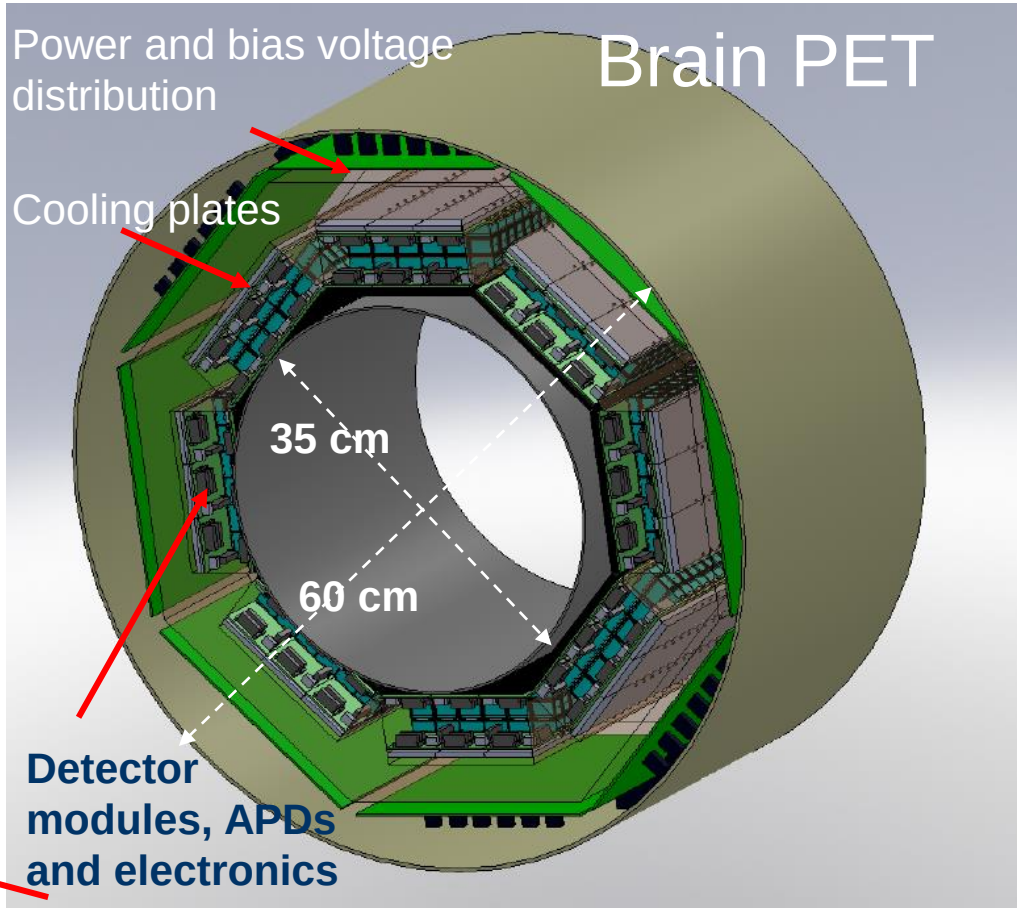


EXAMPLES : Animal PET and Brain PET

PETsys Electronics

Technology using SiPMs

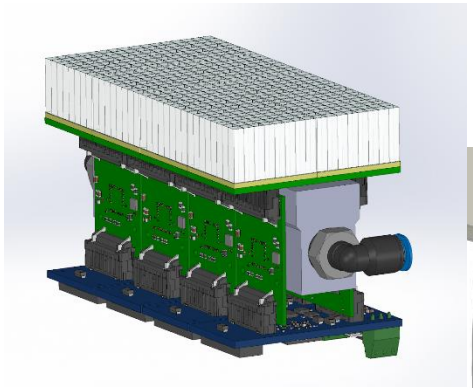


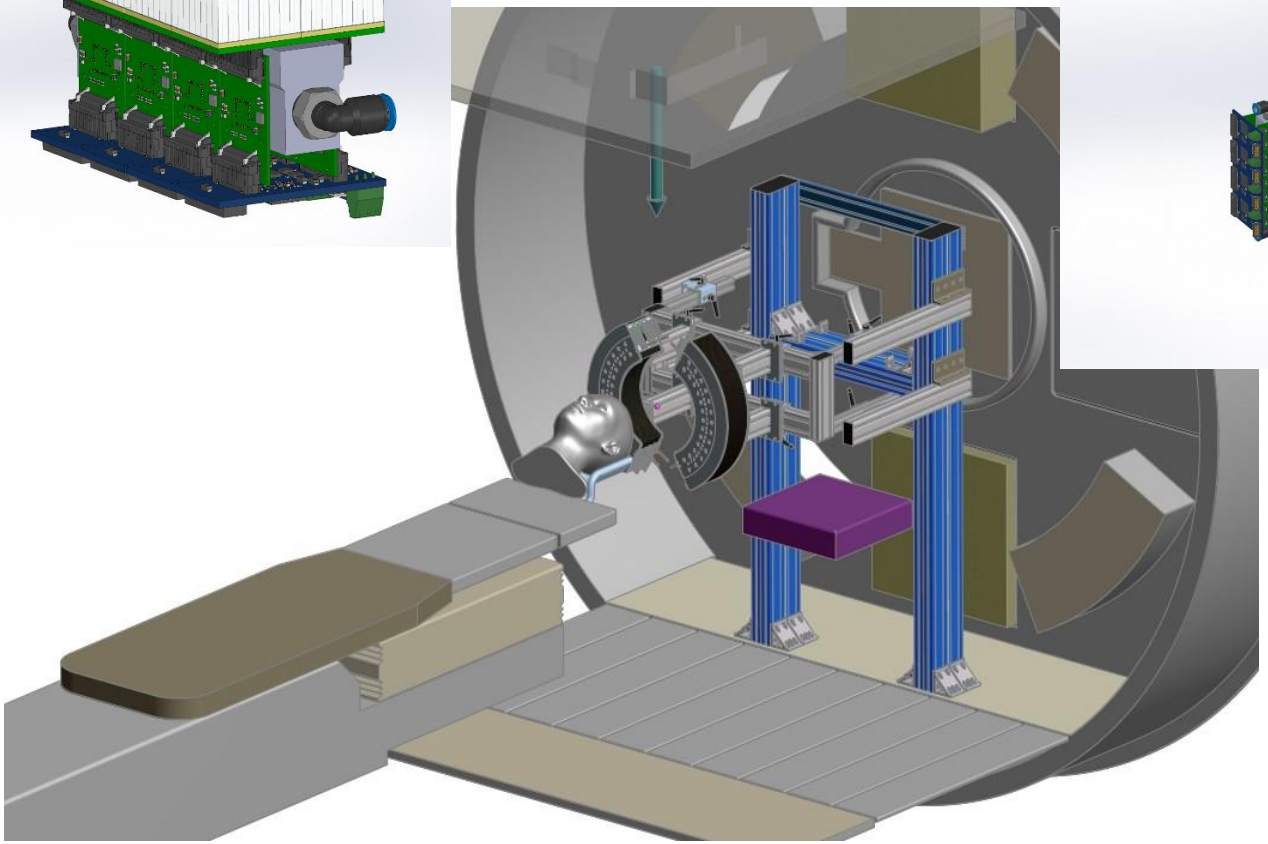


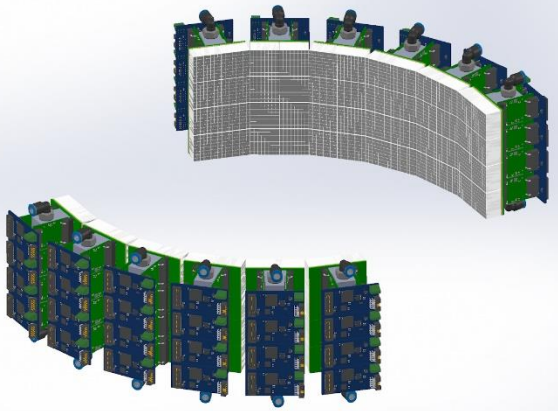
TOF-PET from PROTON Therapy

PETsys Electronics

The aim of the project is to demonstrate the feasibility of Positron Emission Tomography (PET) with very good Time of flight (TOF) for range verification in proton radiation therapy.





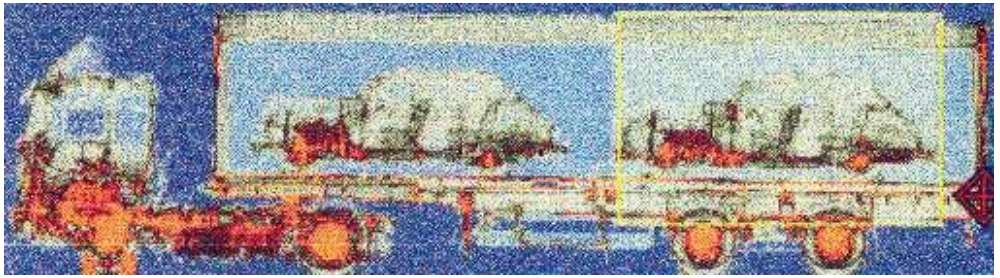


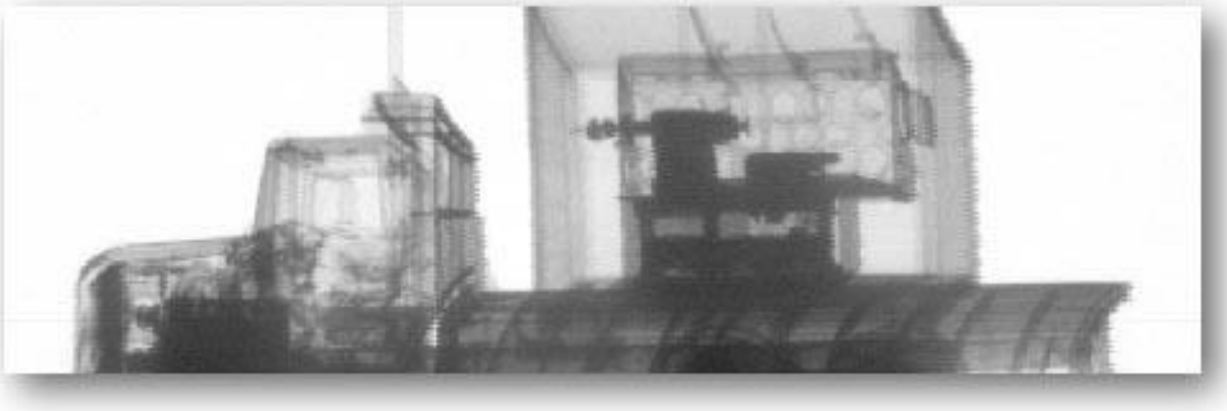
Other SiPM/PET applications

Partnership with First Sensor

First case: cargo/container scanning

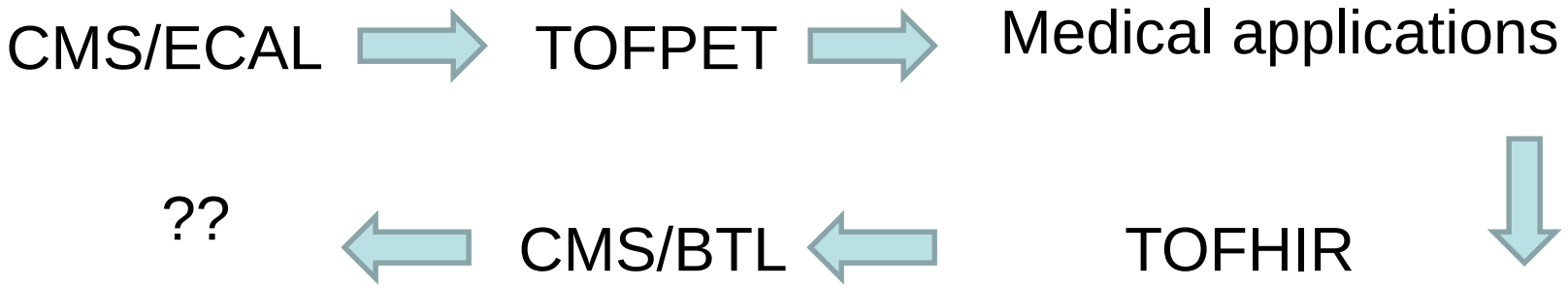
- based on gamma ray radiography
- same detectors as for PET





- Successful technology spin-off:
  - PETsys is now widely known as a supplier of high-performance electronics and detectors based on SiPMs.

- Interplay between CERN, LIP and PETsys has been very useful for all parties



Obrigado

General overview at the beam_4 (002) - PDF-XChange Editor