# Instrumentation : R&D detectors and applications

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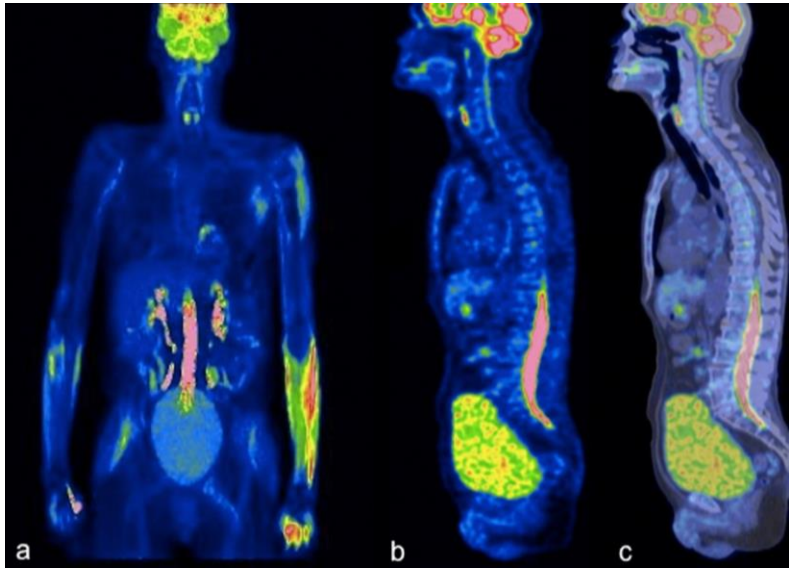
DDays 2017

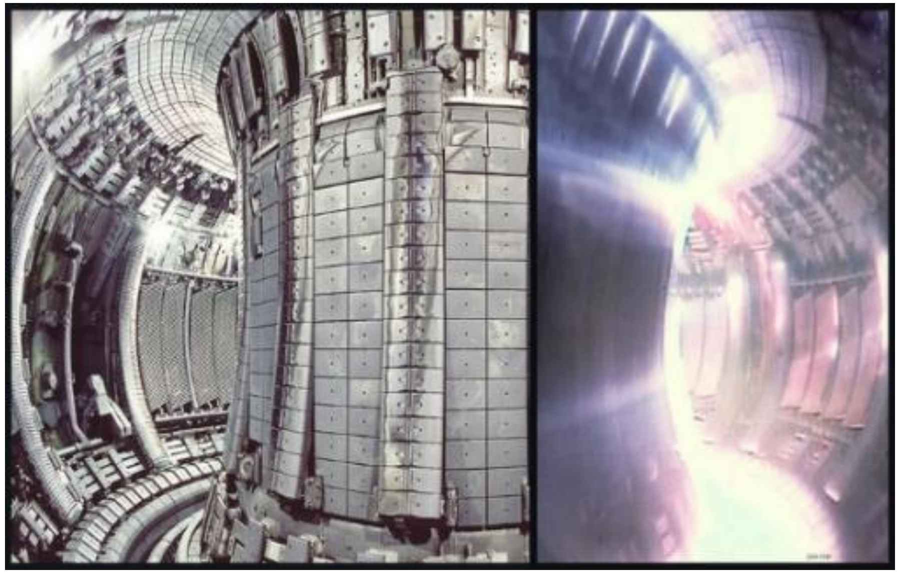
# Detectors and Applications

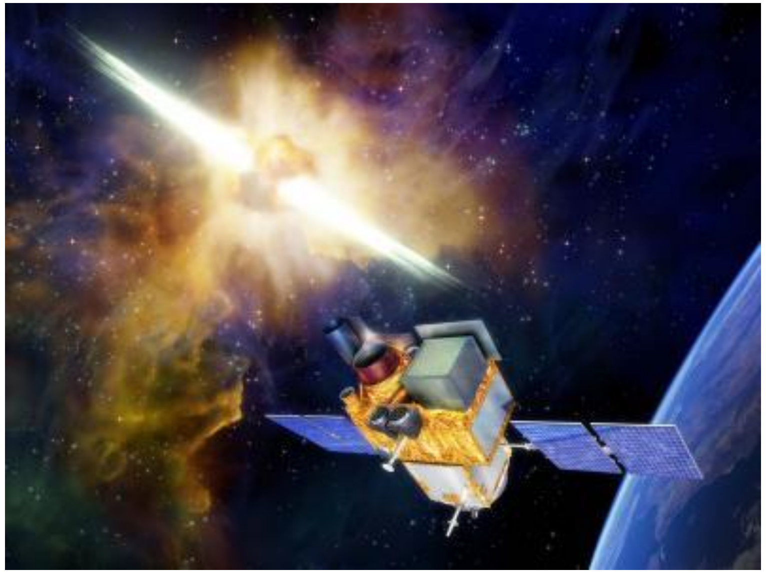
**Medical imaging**

**Superconductivity**

**Space**



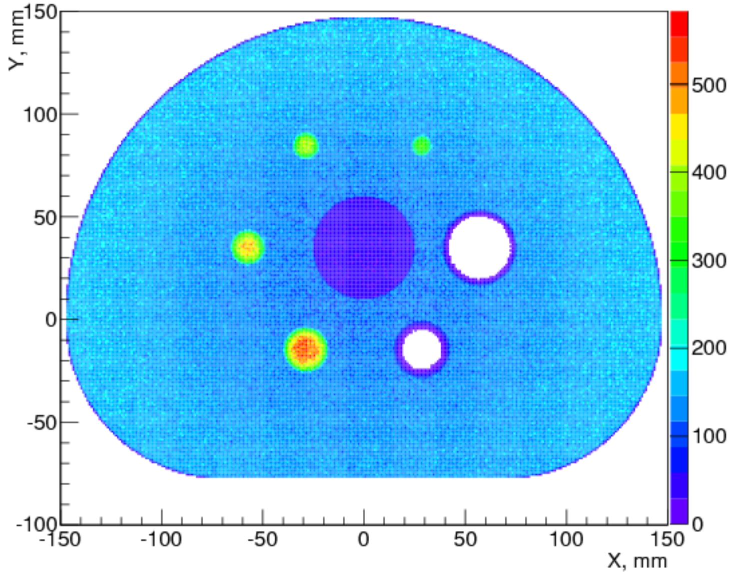


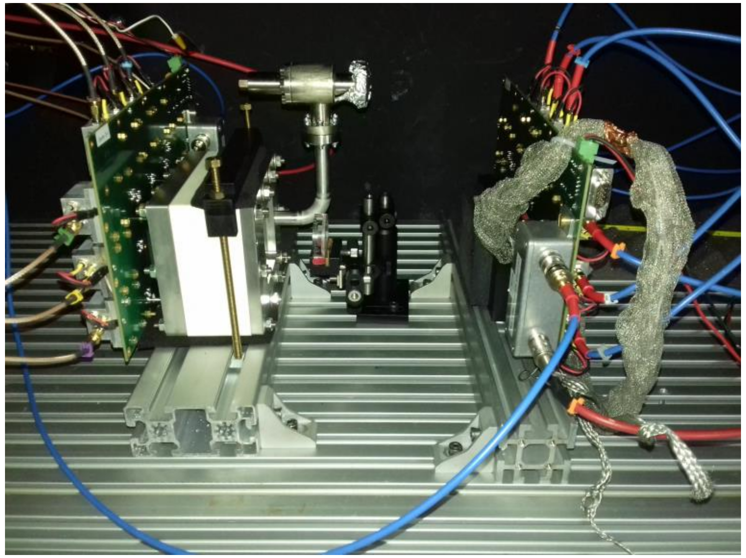
# Research & Development

**Simulation/ Modeling**

**Instrumentation**

**Data analysis**

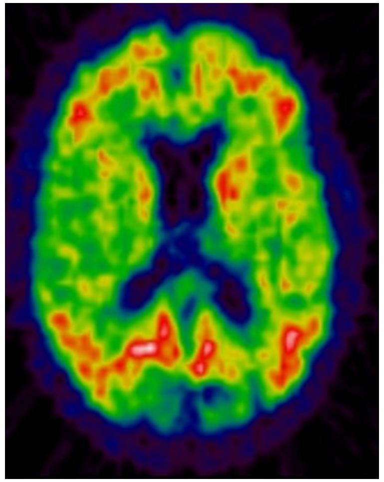


# Fast and efficient 511 keV-gamma detector using Cherenkov light for Positron Emission Tomography (PET)

CLOTILDE CANOT – SPP

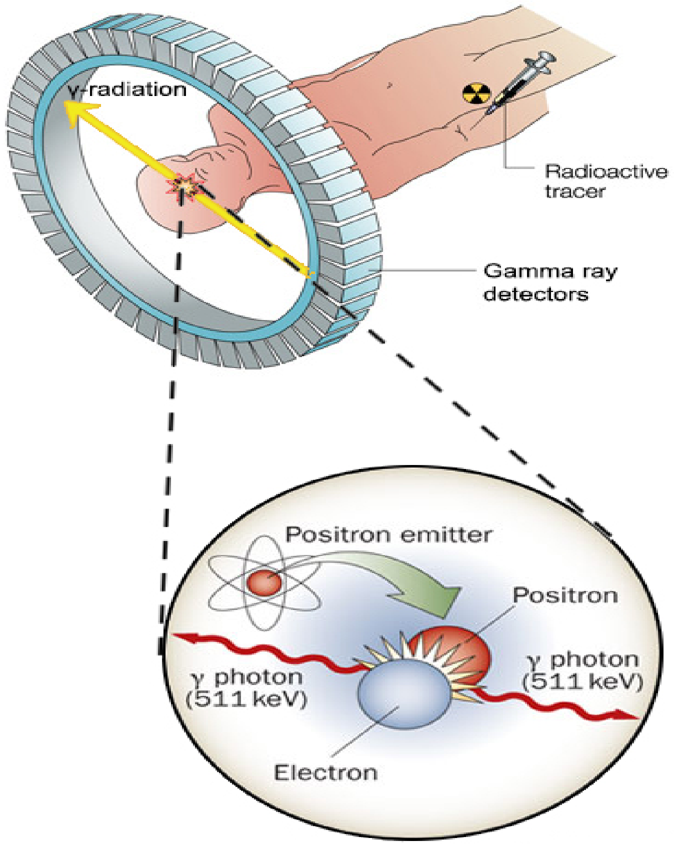
# Positron Emission Tomography (PET)



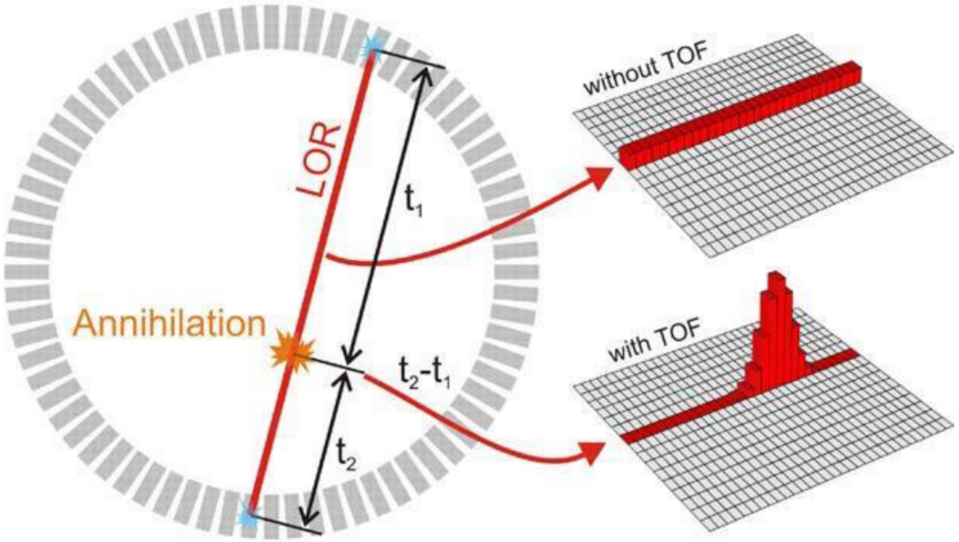
- Functional 3-D imaging technique in nuclear medicine
  - **Oncology** : small tumors and metastases imaging
  - **Neurology** : exams of neurodegenerative diseases (Alzheimer, Parkinson)

# Positron Emission Tomography (PET)

- **Principle :**
  - ✓ **Radioactive tracer** (ex : FDG) is injected in the patient body and then chemically bounded in tissue
  - ✓ **β+ decay** : emission of a **positron**
  - ✓ **Annihilation** with an electron of the tissue :
    **two 511 keV γ** are emitted back-to-back
  - ✓ Detection in **coincidence**
  - ✓ **Image reconstruction**



# Time Of Flight (TOF)




**Time of Flight** technique provides the information on the localisation of the annihilation vertex on the line of response (LOR).

**Reachs time resolution of 100 ps**

**=> localization of 3 cm on the LOR**

**→ Improvement of the signal-to-noise ratio**

# Time Of Flight (TOF)

Improvement of **the signal-to-noise ratio :**

→ reducing of the radiation dose received by the patient while keeping the same image quality,

→ or, alternatively, improvement of the image quality without increasing the received dose.

# PECHE : PET CHERENKOV

Current PET scanner uses scintillation

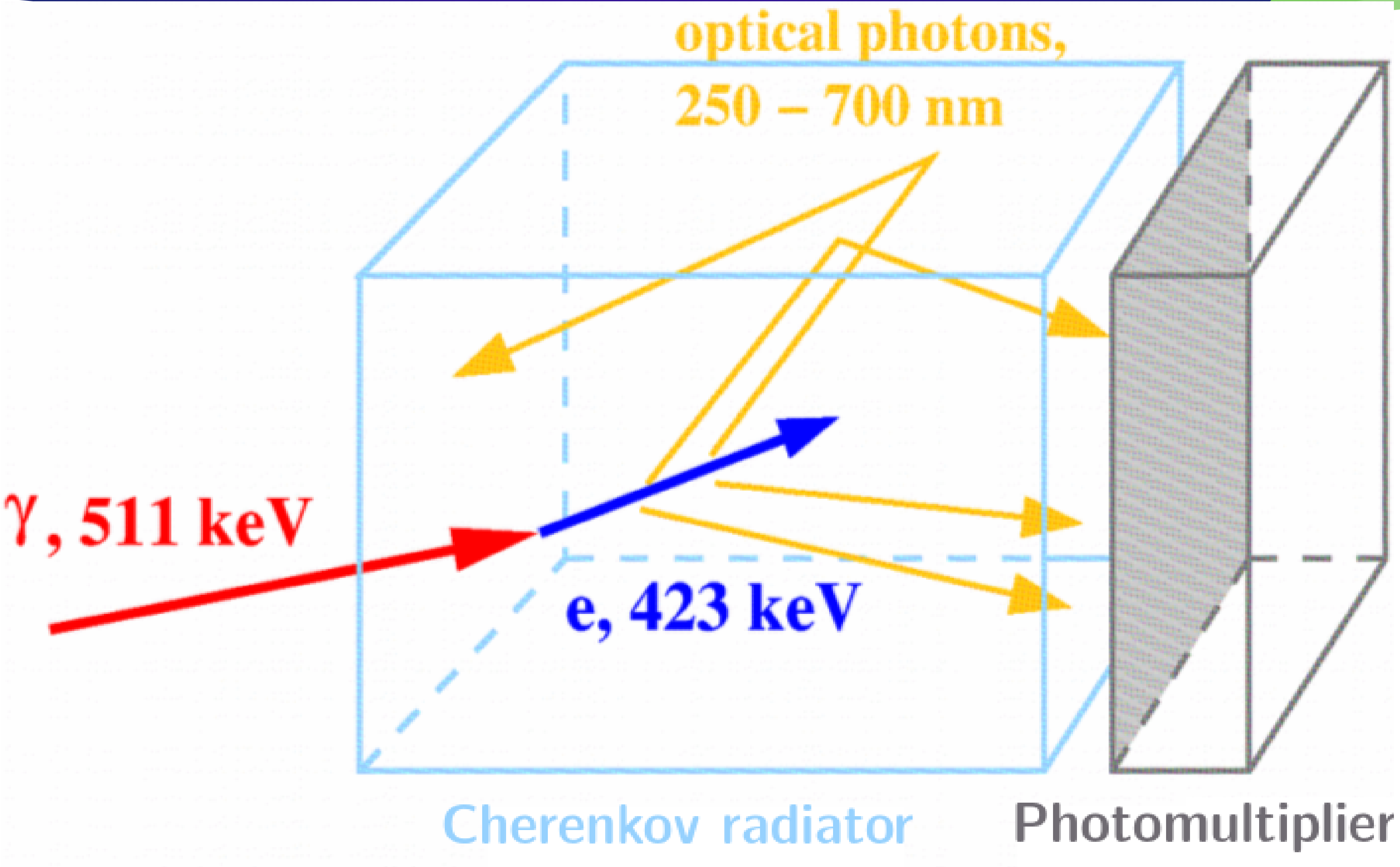
**~ 10 to 50 ns**

To improve the TOF : using of **Cherenkov radiation**

**fast :~ 10 ps**

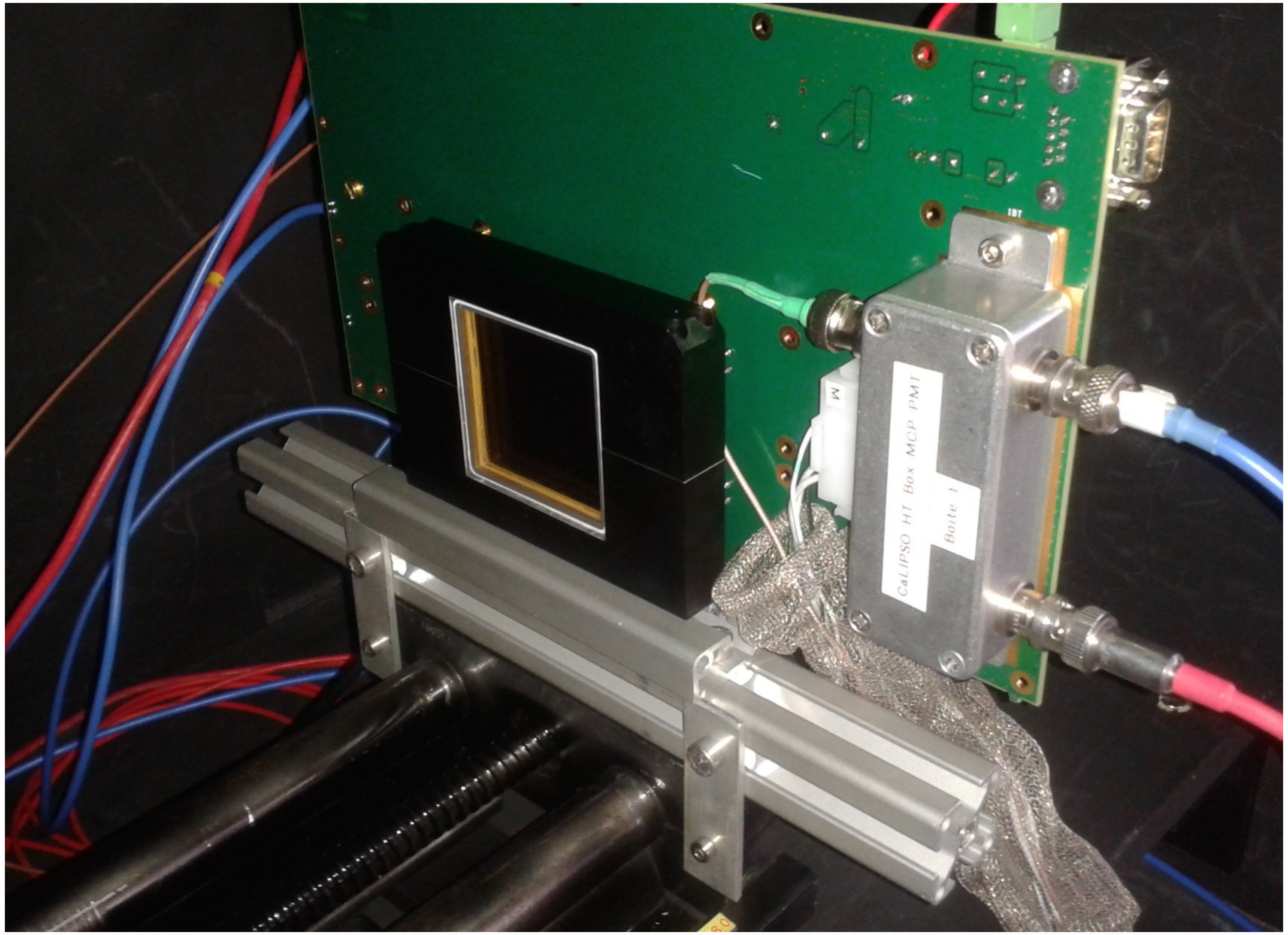
**-> development of an unprecedented project : PECHE**

# PECHE : PET CHERENKOV



# PECHE : PET CHERENKOV

**MicroChannel Plate-PMT**
***(Photonis)***

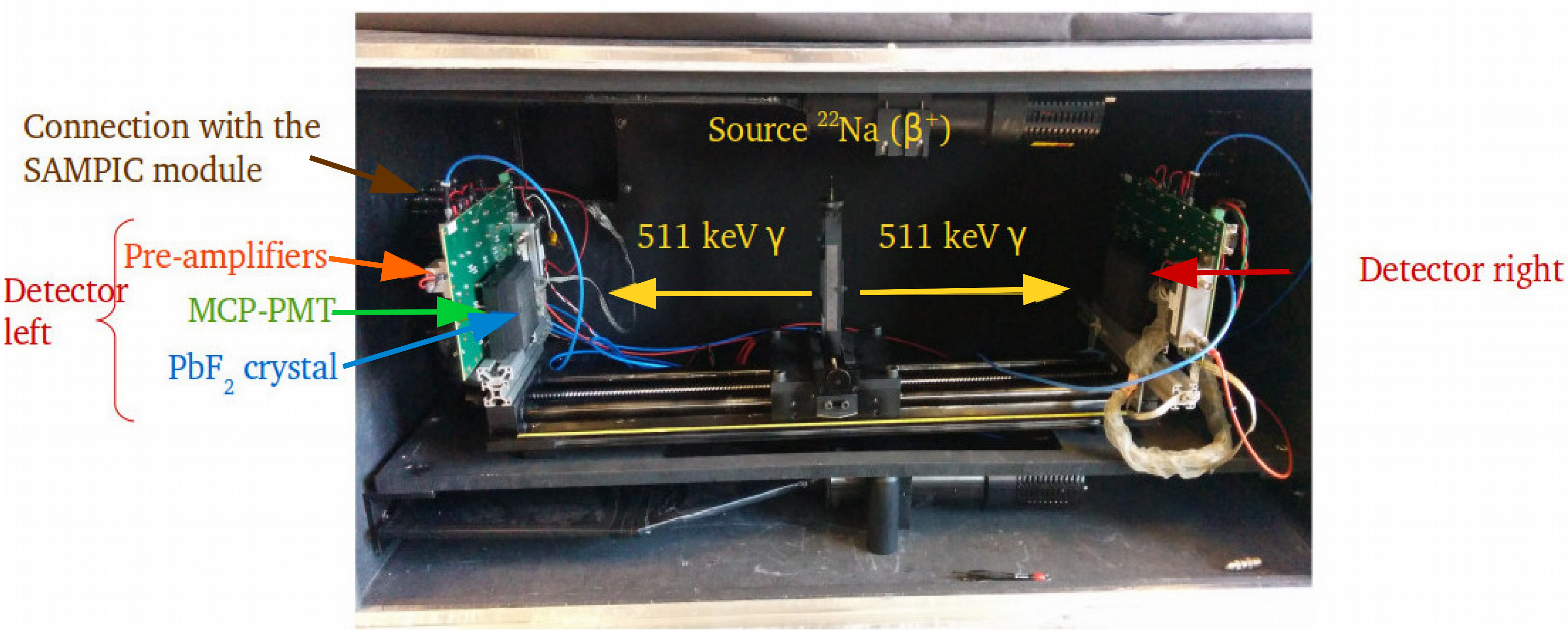


# PECHE : PET CHERENKOV

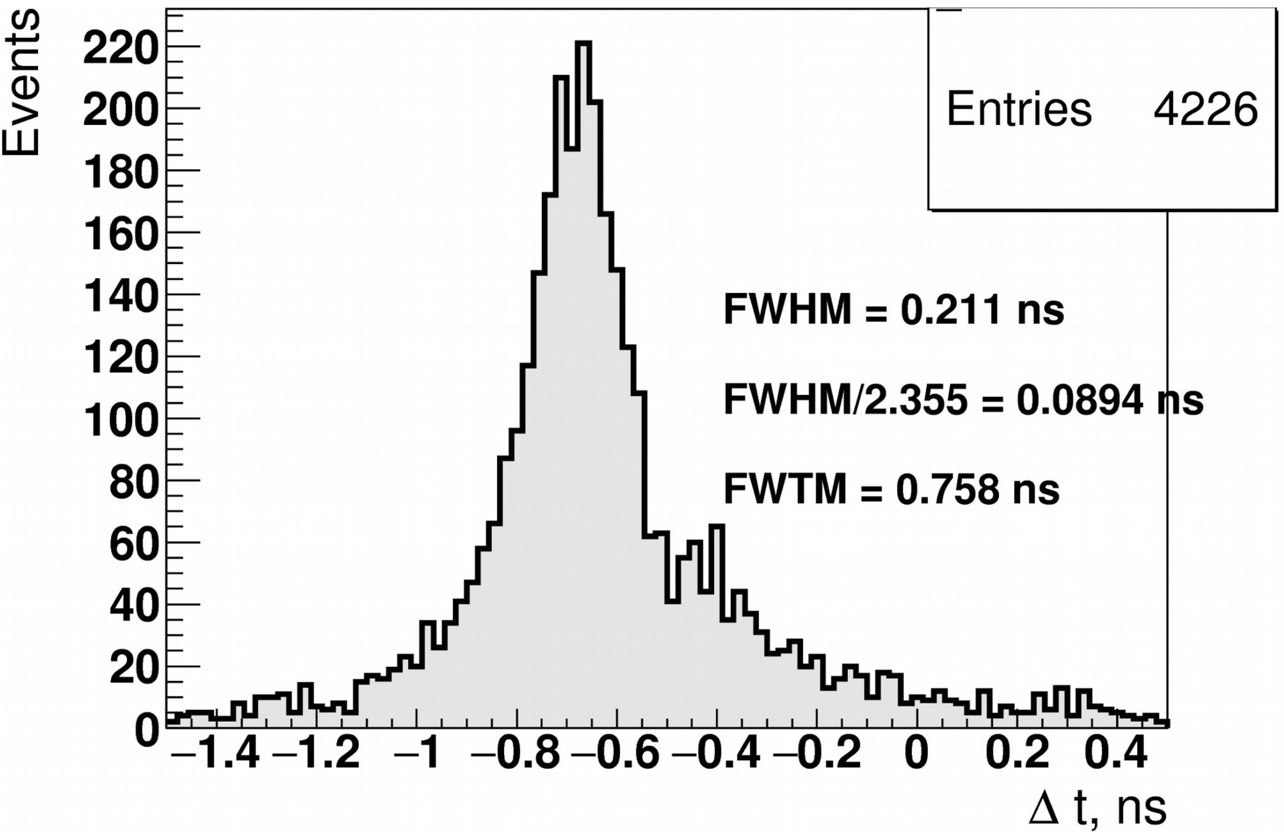
## SAMPIC for signals numerisation


**Developped by IRFU and the LAL**

# Time Resolution



# Time Resolution




For a single detector :

**FWHM = ( 150 ± 10 ) ps**

For two detectors in coincidence :

**FWHM = ( 212 ± 15 ) ps**

# Conclusions

Test of the detector : the results are in agreement with results of the simulation

I am now working on the improvement on the read-out electronics and the optical interface between the $PbF_2$ crystal and the MCP-PMT

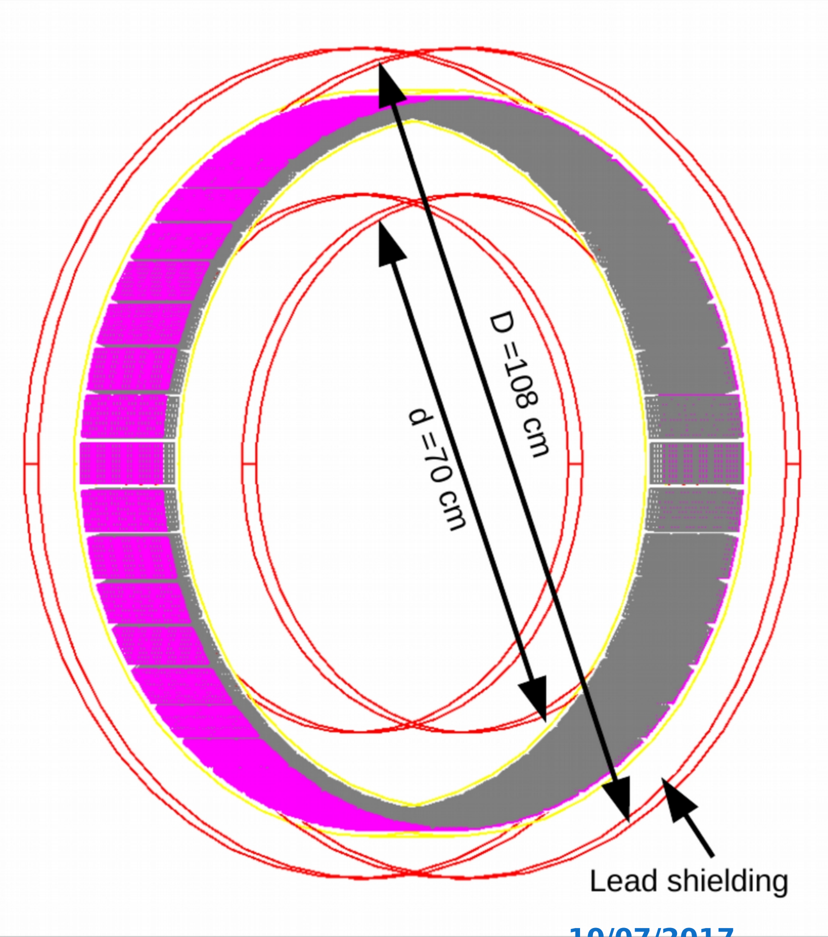
Projection towards the full-body scanner and image reconstruction -> **see next presentationer**

# Simulation and Optimization of the Cherenkov full-body PET scanner

MARHARYTA ALOKHINA – SPP

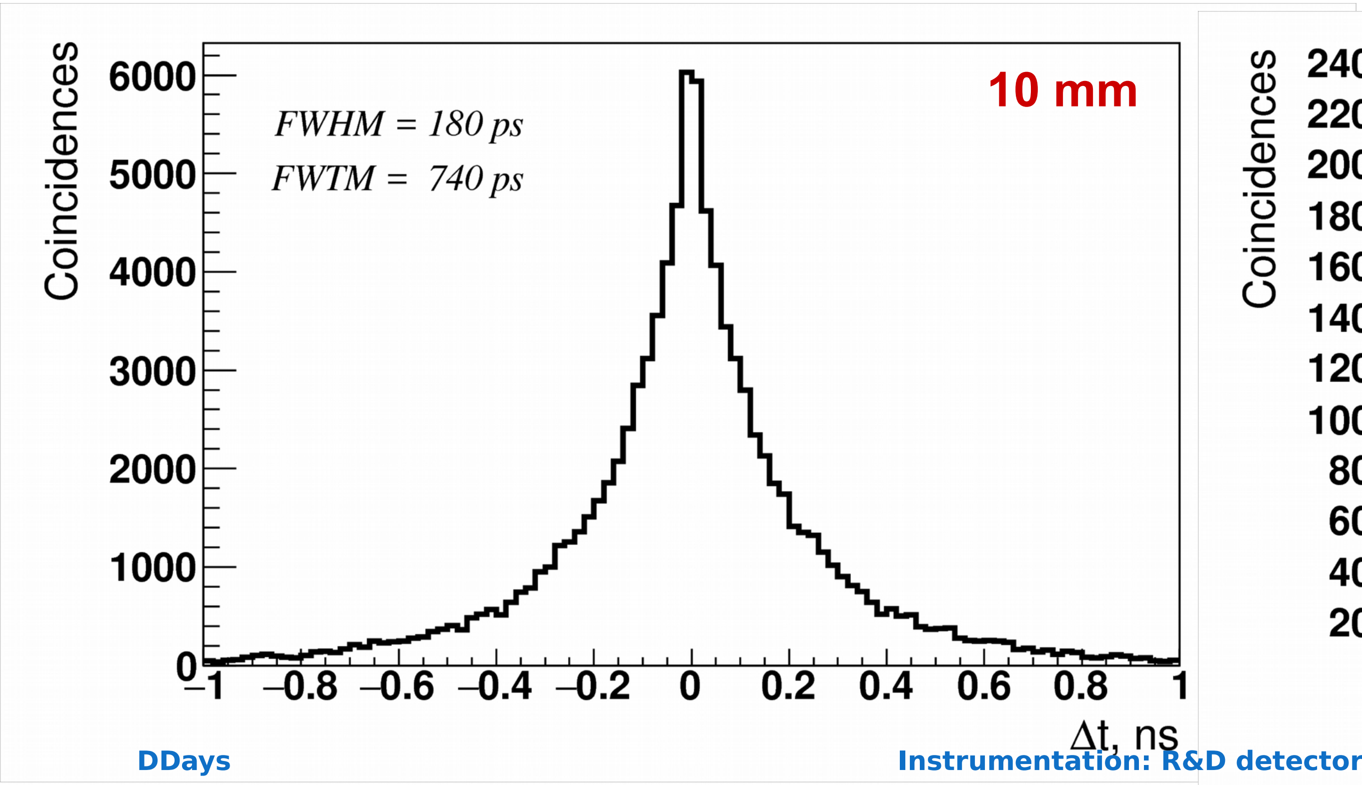
# PECHE: Cherenkov PET TOF Scanner

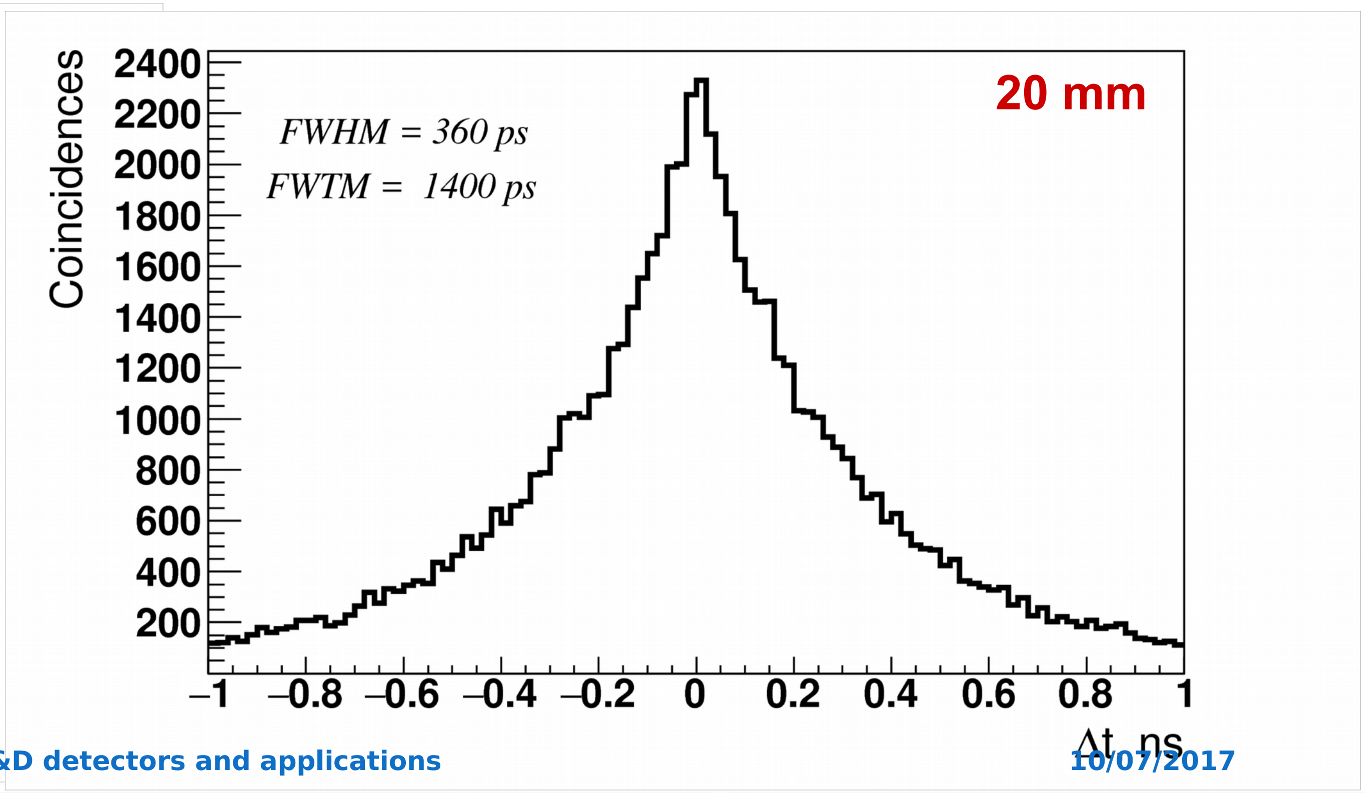
- **Goal:** to investigate the possibility to build the Cherenkov PET TOF full-body scanner with an excellent time resolution and high efficiency.
- **Main idea:** using Cherenkov light instead of scintillation
- **Approach:** tracking of all optical photons in the GATE open source software.
- **Configuration:** $PbF_2$ crystals (density 7.77 g/cm$^3$, transparent $\lambda > 245$ nm, absorption length 9 mm) assembled with MCP-PMTs. Scanner diameter is 910 mm and one ring axial size is 53 mm. One ring contains 48 detectors. Crystal size is 6.5 mm x 6.5 mm x 10 & 20 mm
- The PMT is Photonis Planacon XP85112 with TTS = 80 ps and an active area of 53 mm x 53 mm, 64 anodes (8 x 8 crystals), the thickness of the sapphire window is 1.3 mm



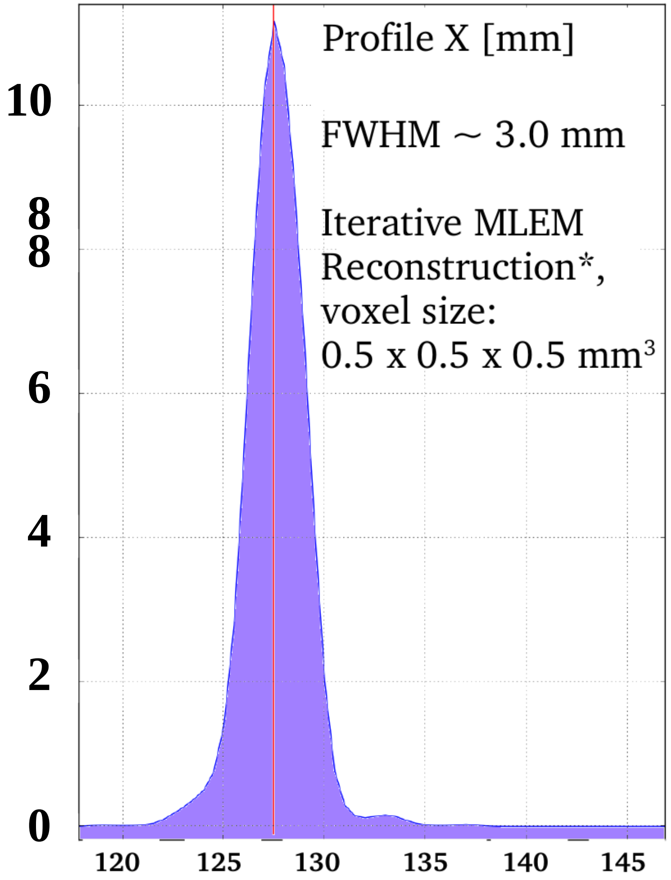
# Coincidence Resolving Time (CRT)

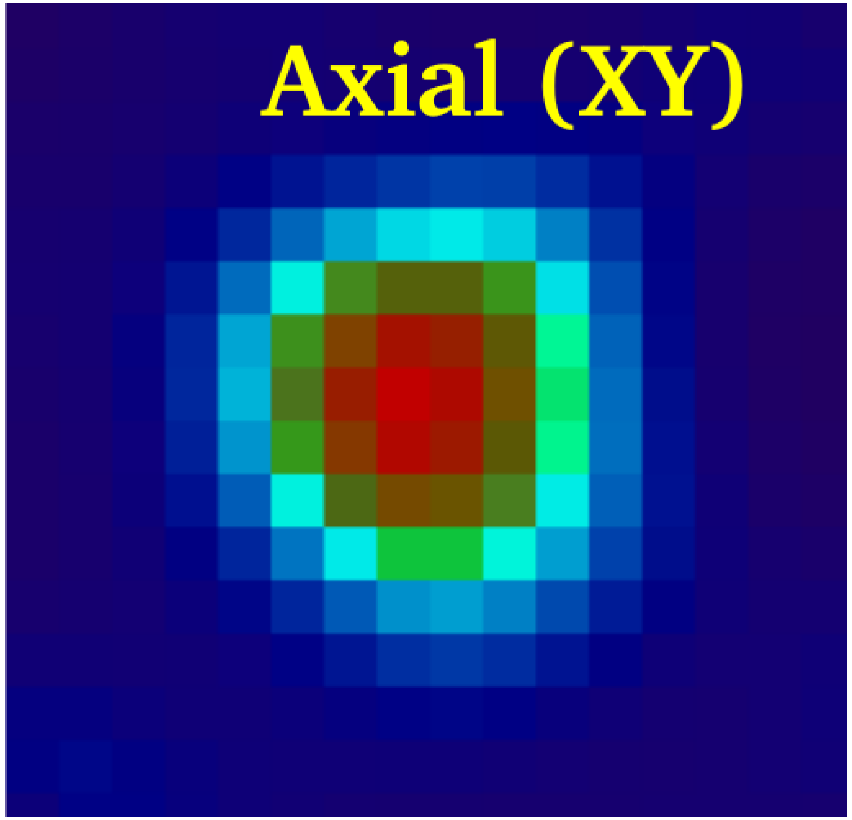
$$\Delta t = t_1 - t_2$$



# Spatial resolution and image reconstruction




Spatial resolution characterizes the widths of the reconstructed image point spread functions of compact radioactive sources according to NEMA Standards NU 22007.

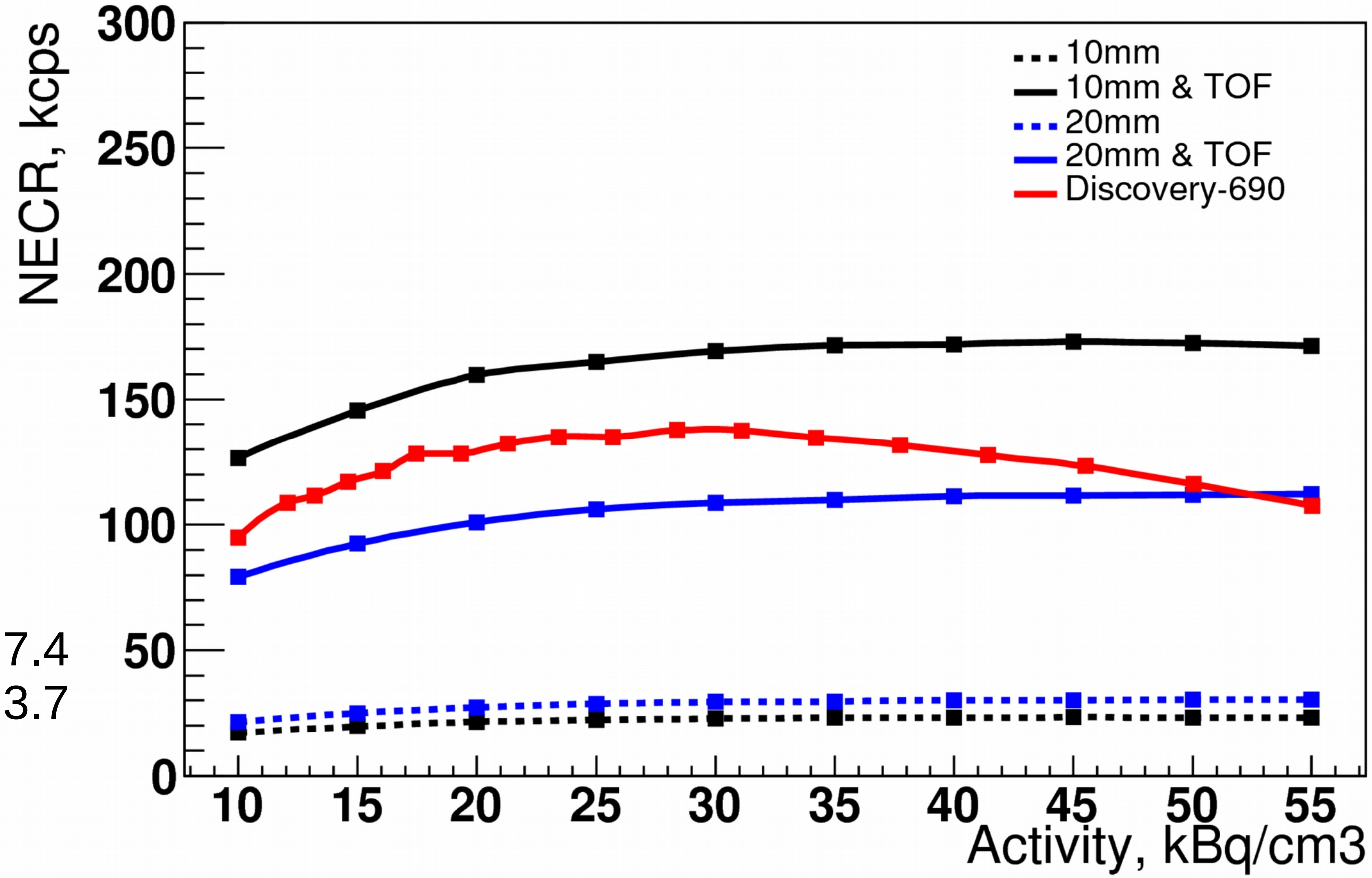
For image reconstruction we use CASToR:
Customizable and Advanced Software for Tomographic Reconstruction
http://www.castorproject.org

# Noise Equivalent Count Rate Estimation

**NECR = T/(T + S + 2R),**
**T — true concidence**
**S — scatter coincidence**
**R — random coincidence**

**$NECR_{TOF}$ ~ D/Δx*NECR**

D =20 cm, Δt ~ 180 ps gives Δ x ~ 2.7 cm → D/ Δx = 7.4
D =20 cm, Δt ~ 380 ps gives Δ x ~ 5.4 cm → D/ Δx = 3.7



# Conclusions

1/ NECR curves are comparable with conventional scintillator based PET scanner;
2/ The photon coincidence resolving time of about 180 ps (FWHM) can be achieved with the single detection efficiency ~ 32 %;
3/ The spatial resolution (~ 3 mm FWHM) of this detector is limited by the size of the crystals in the same manner as for the conventional PET scanner

# Etude et optimisation de la performance scientifique du telescope X à micro-canaux MXT à board de la mission spatiale d'astronomie SVOM

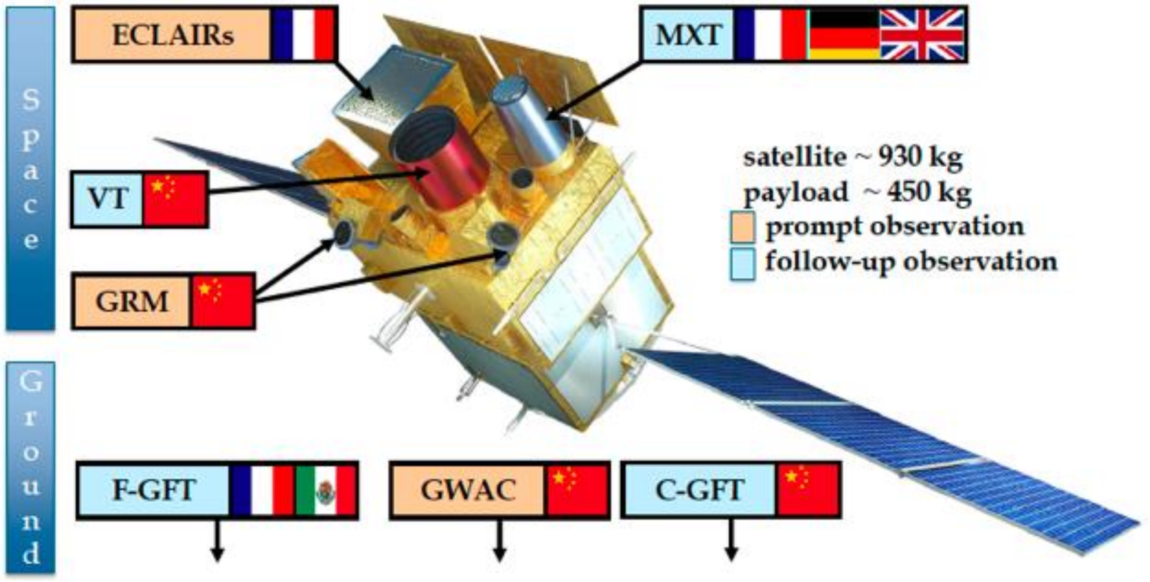
LAURA GOSSET – SAP

# Gamma ray burst

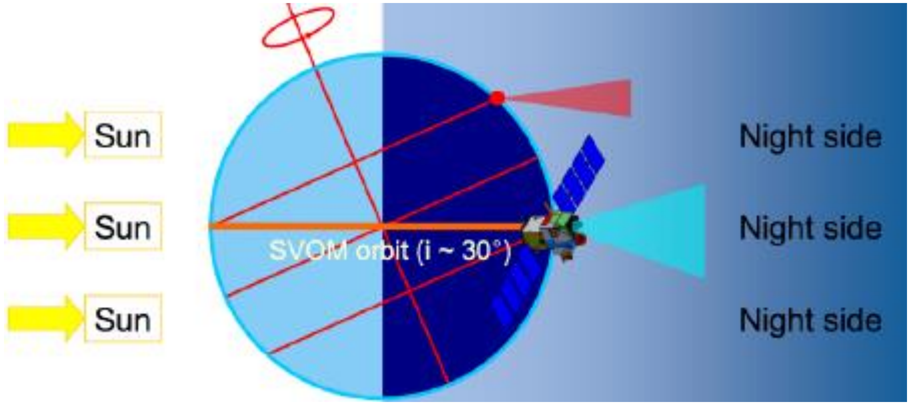
- Very powerful explosions
- <u>Origin</u>
  - Collapse of a massive star
    - > 50 Msun
    - Need energy for the matter ejection
  - Coalescence of 2 compact objects
    - Neutrons stars, black holes

➡ ***Emission of multi-wavelength jets***

# SVOM (Spaced-based multi-band astronomical Variable Object Monitor) mission




- **Aim of the mission** = study GRBs
- SVOM instruments
  - Ground / Space based
- Determination of GRBs' positions
  - Detection by ECLAIRs
  - Reorientation of SVOM (MXT and VT field of view)
  - Better precision by MXT and VT

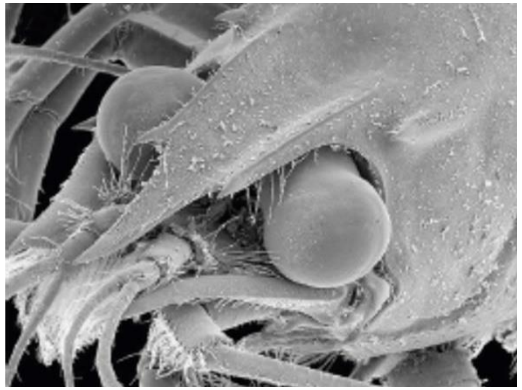


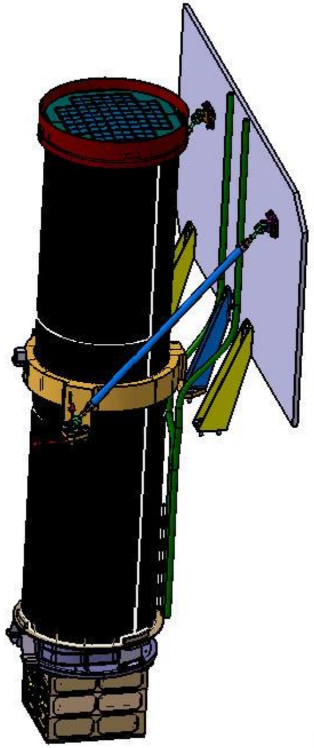

→ **Fast and accurate localization very important**

# MXT (Micro-channel X-ray Telescope)

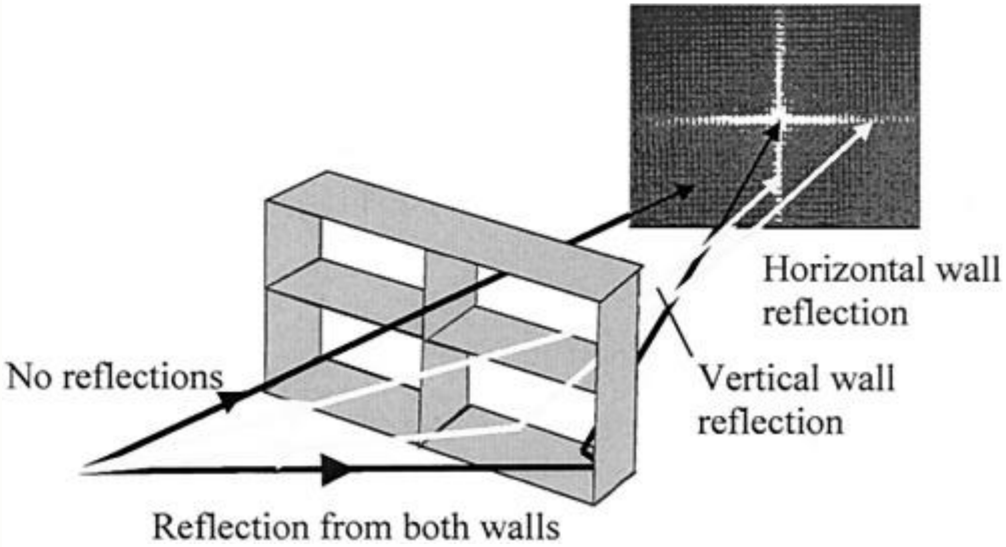
**Goal** = Observe GRBs and afterglows and localize them precisely

- Characteristics
  - Energy range : 0.2 – 10 keV
  - **Field of view : 1° x 1°**
  - Lobster Eye optics
    - Focalise X-rays thanks to reflections in micropores
    - Very light instrument : **~ 30 kg**





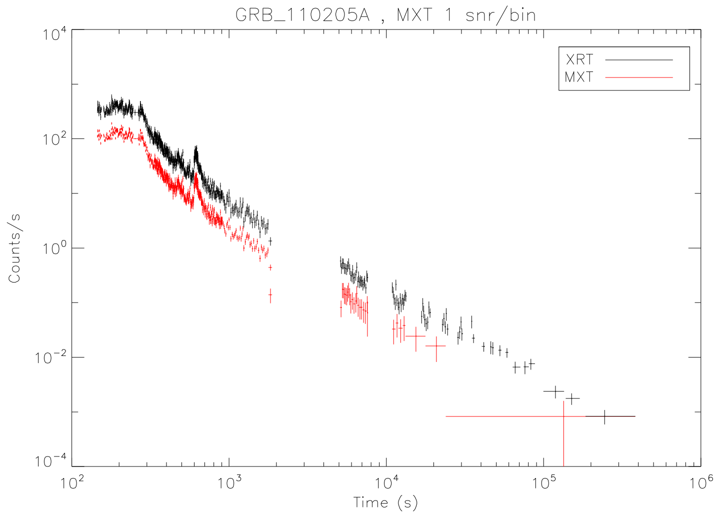
*MXT*

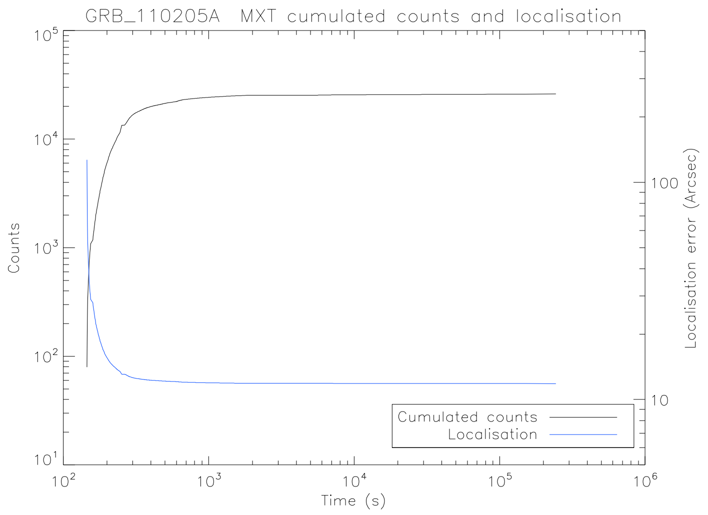



*Lobster Eye pinciple*

**MXT = transmit the position to ground based telescopes in real time**

# PHD work



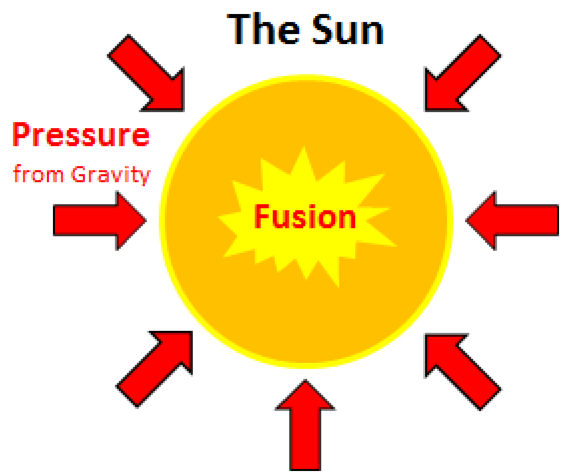

- Simulation of the MXT response
- Develop on-board localization algorithms
- Optimize the search strategy to the recent discovery of gravitational waves sources

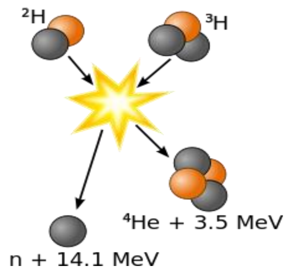
Localisation < 15 arcsec for few hundred seconds

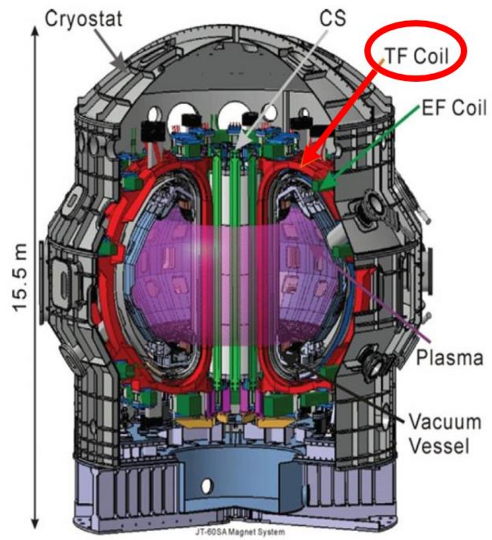
# Study and modelling of the thermo-hydraulics phenomena resulting from the quench of a supreconducting magnet cooled by supercritical helium

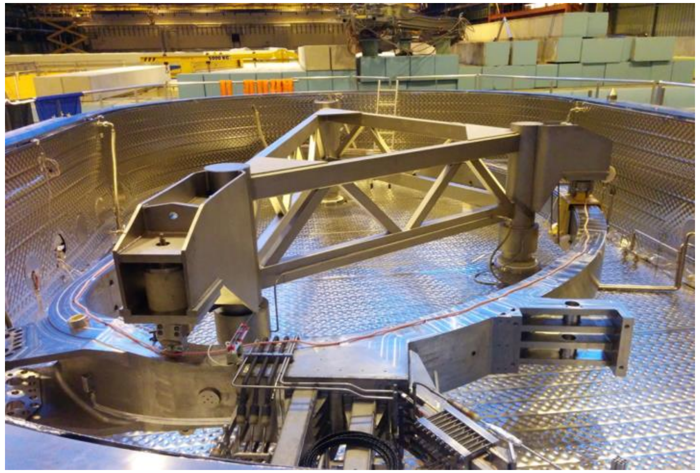
YAWEI HUANG – SACM

# From Sun to Earth



*Fusion energy*

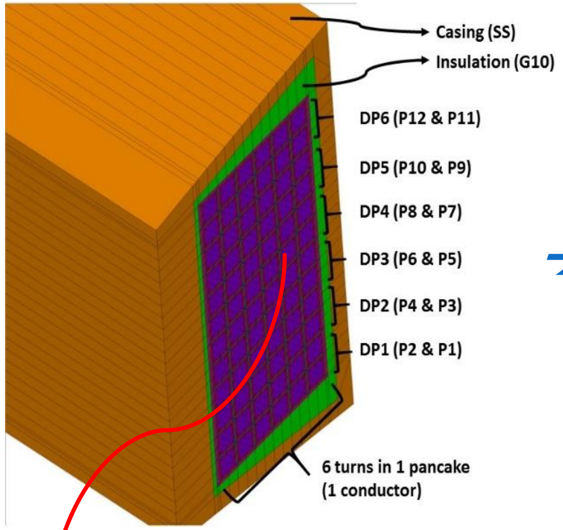
*TF coil quench studies*

$r_{sun} = 695\,700\ km$

$h_{tokamak} = 15\ m$

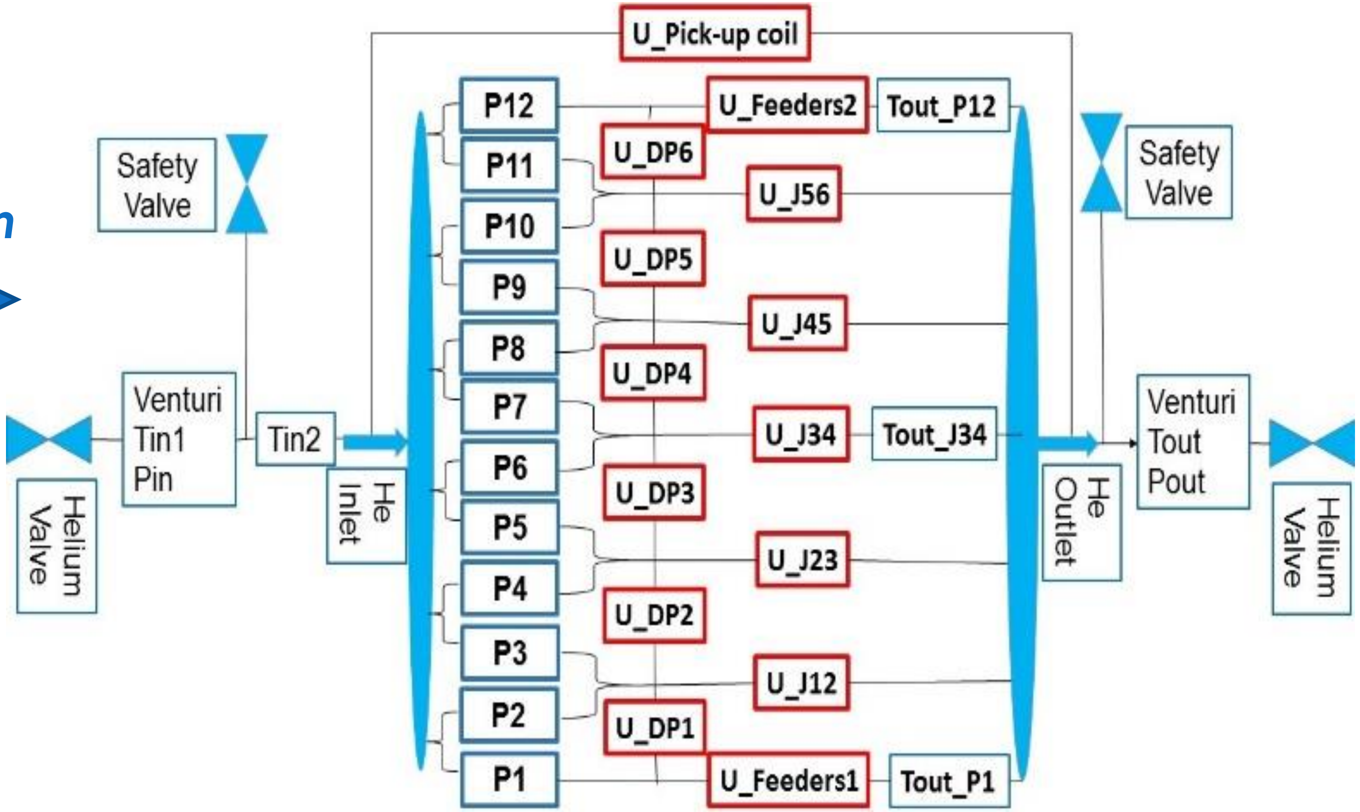
# Temperature, pressure, massflow & voltage measurements

Cross section of **coil**

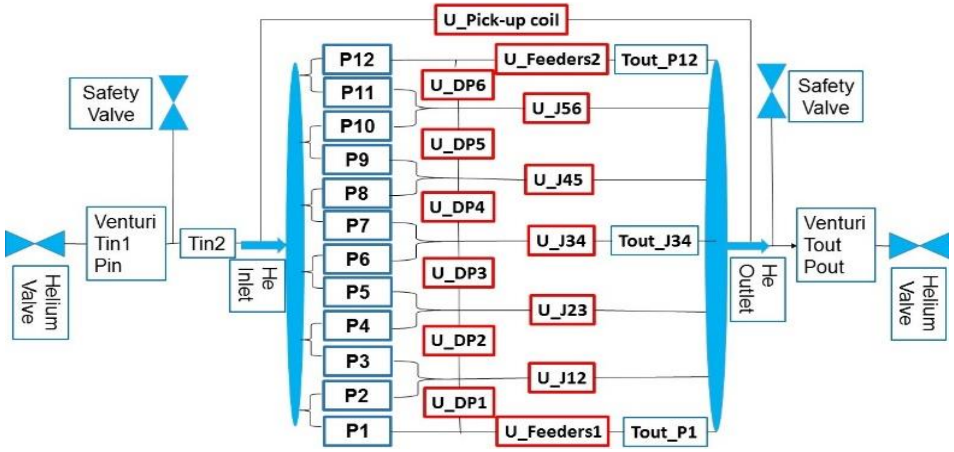


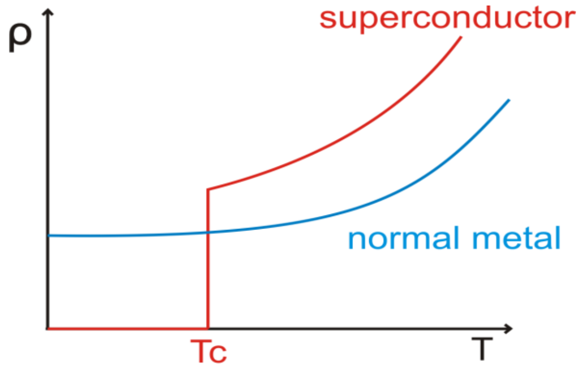

To understand
→ ***instrumentation***

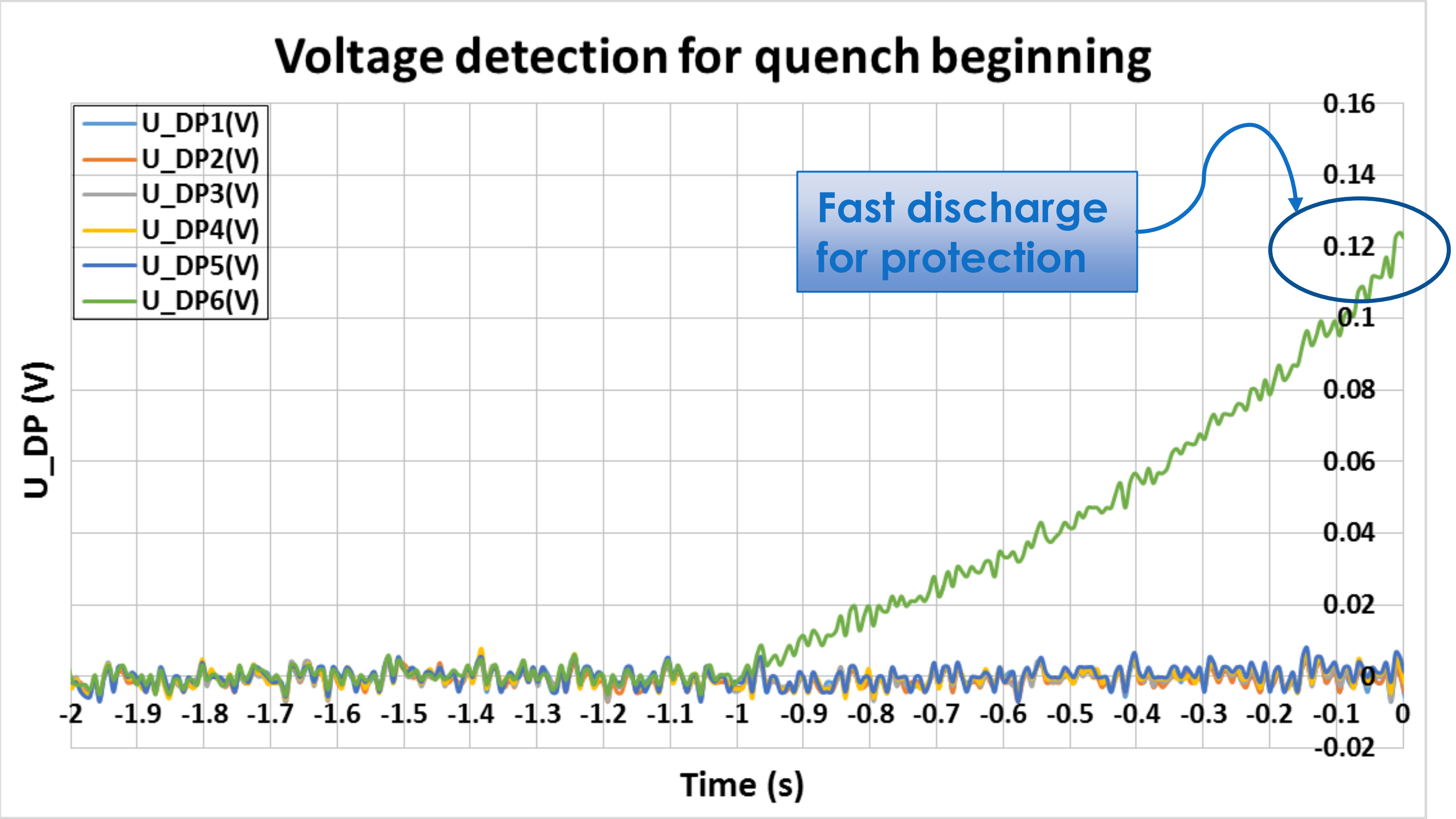
Cross section of **conductor** (NbTi/Cu)



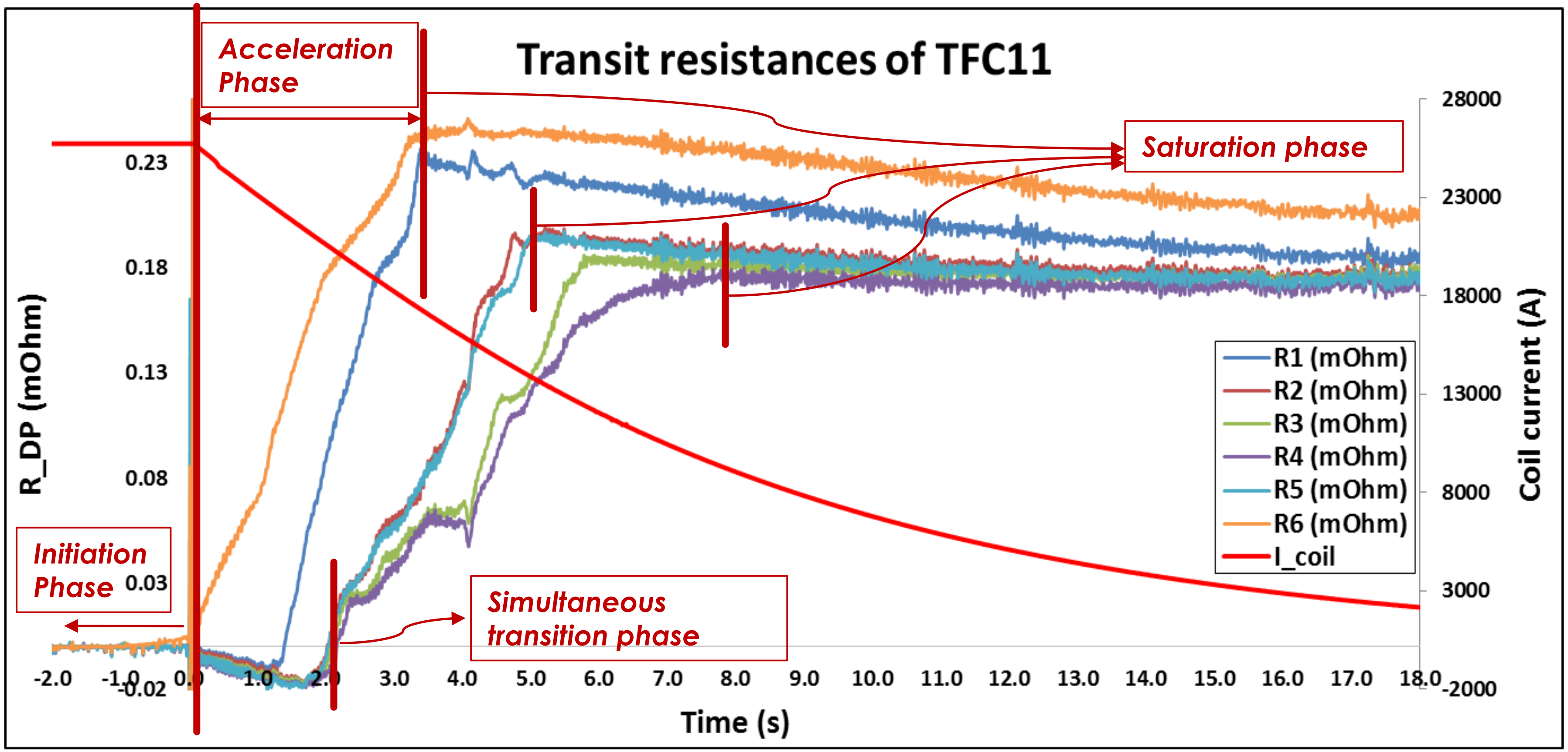
# Quench detection



# PhD Work: quench analysis




## 4 quench dynamic phases:

- Quench **initiation** phase
- Quench **acceleration** phase
- Simultaneous **transition** phase for latter quenched pancakes
- Quench **saturation** phase

## Prospects for the following:

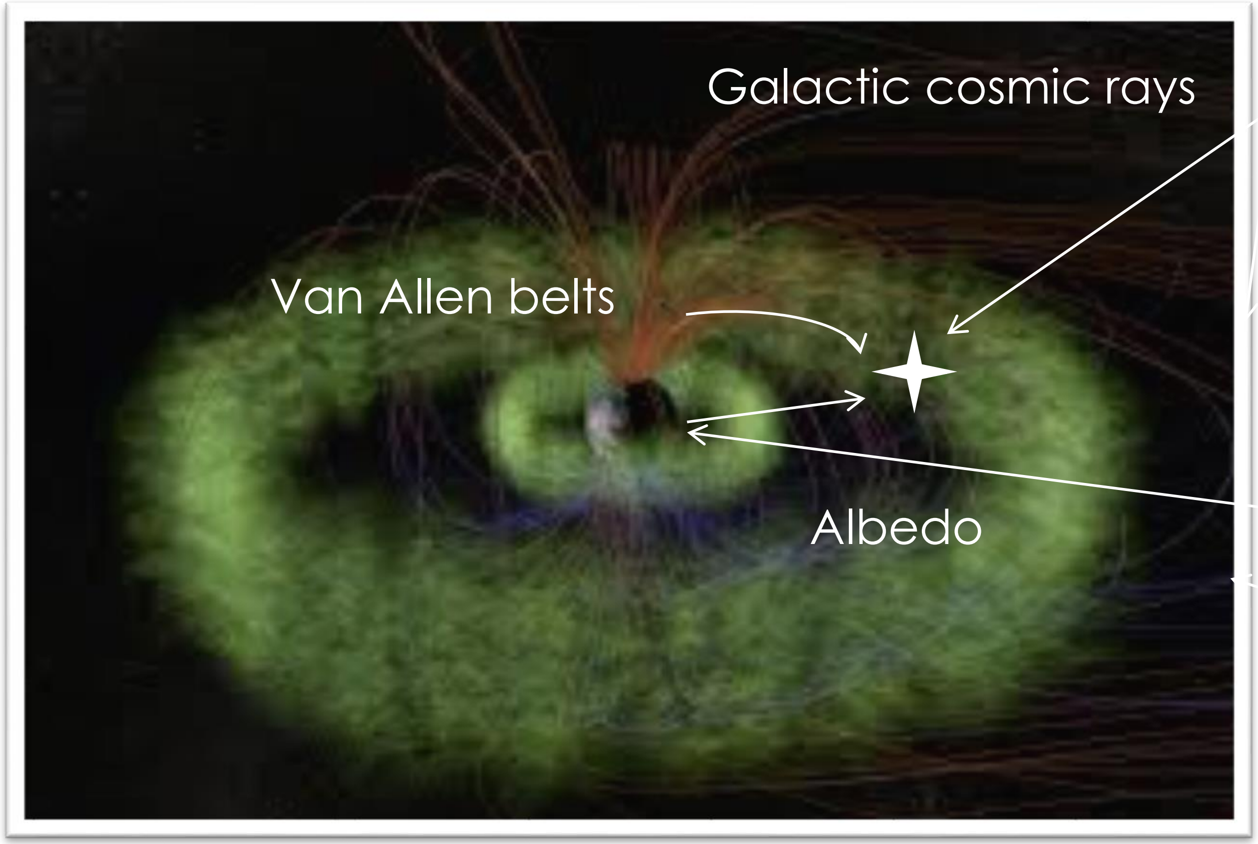
- THEA – **1D** thermo-hydraulic modelling
- Cast3M – **2D** transvers thermal diffusion modelling

# Study of earth albedo and application on low earth orbite systems

*Modélisation de l'abédo terrestre et application aux systèmes embarqués en orbite basse*

NATACHA COMBIER - SAP

# Space environment at low earth orbite




Space radiative environment:

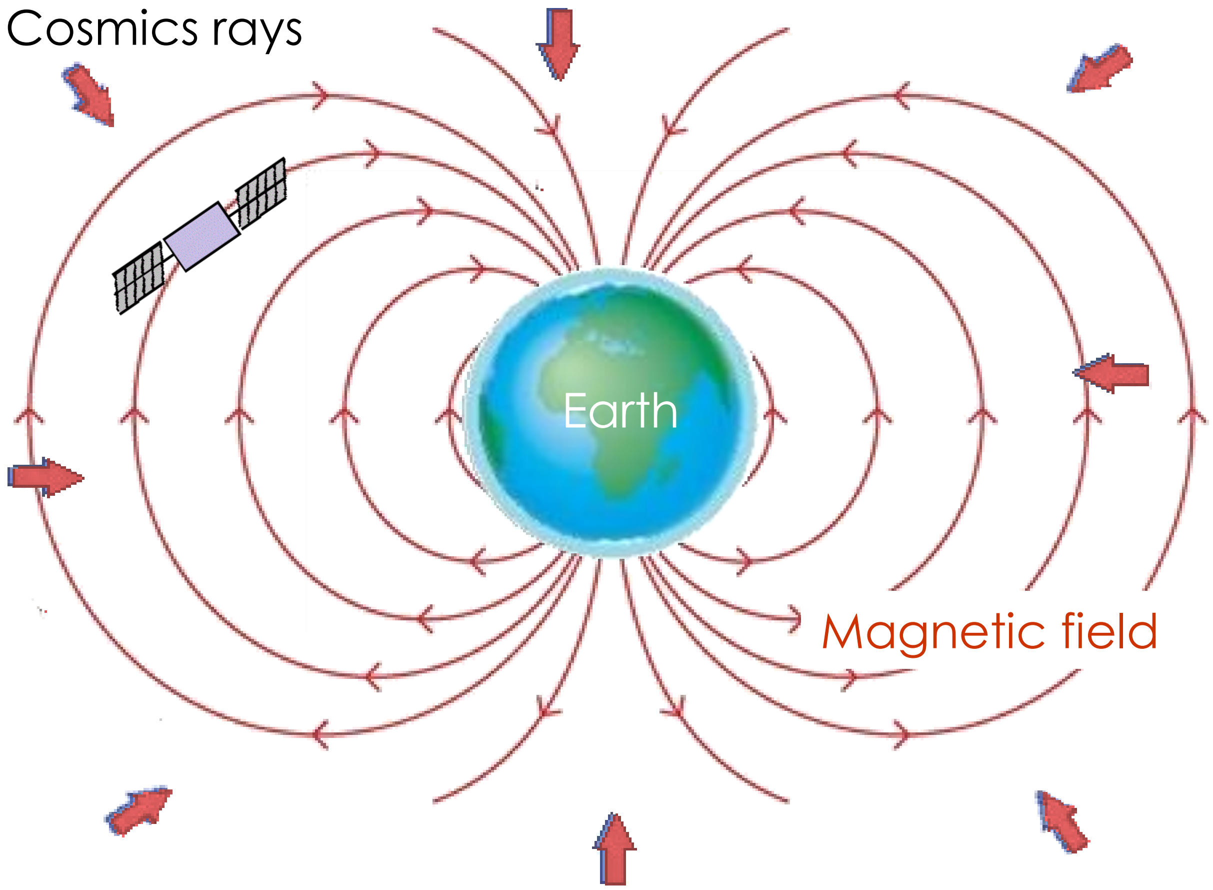
- Galactic Cosmic Rays
- Van Allen belts
- Albedo

Hitomi mission:

- Japonese project JAXA
- Hard X-rays (1,3keV-108keV)
- Launched in June 2016

**The main part of cosmic background is due to neutron albedo.**

# My tools: codes for simulation of the particles interactions

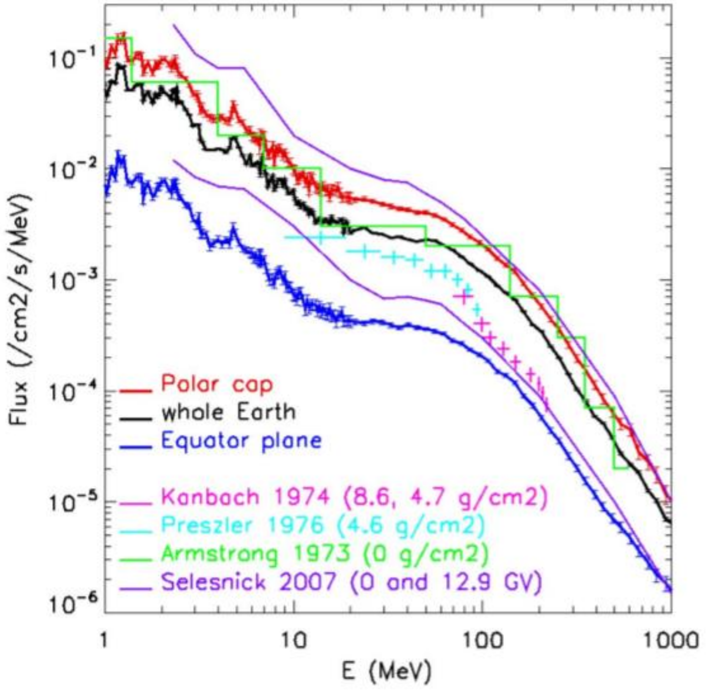



We want to predict the neutron background with our new model, in collaboration with:

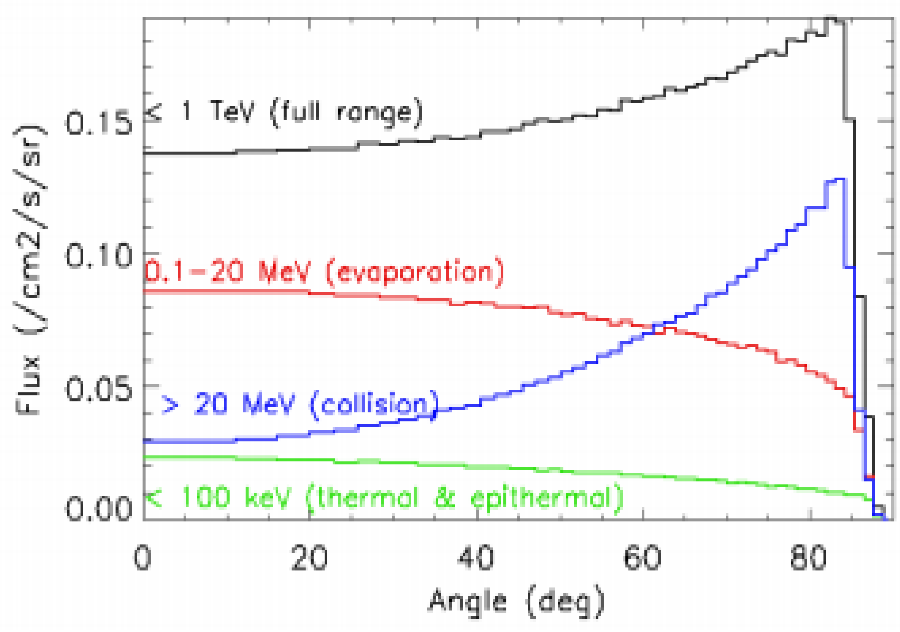
- CERN: earth /atmoshere/magnetic field/ cosmic rays
- ONERA: optimisation of cosmic rays
- JAXA: mass model of HITOMI

CERN ONERA THE FRENCH AEROSPACE LAB JAXA

# My results: a better knowledge of neutron flux

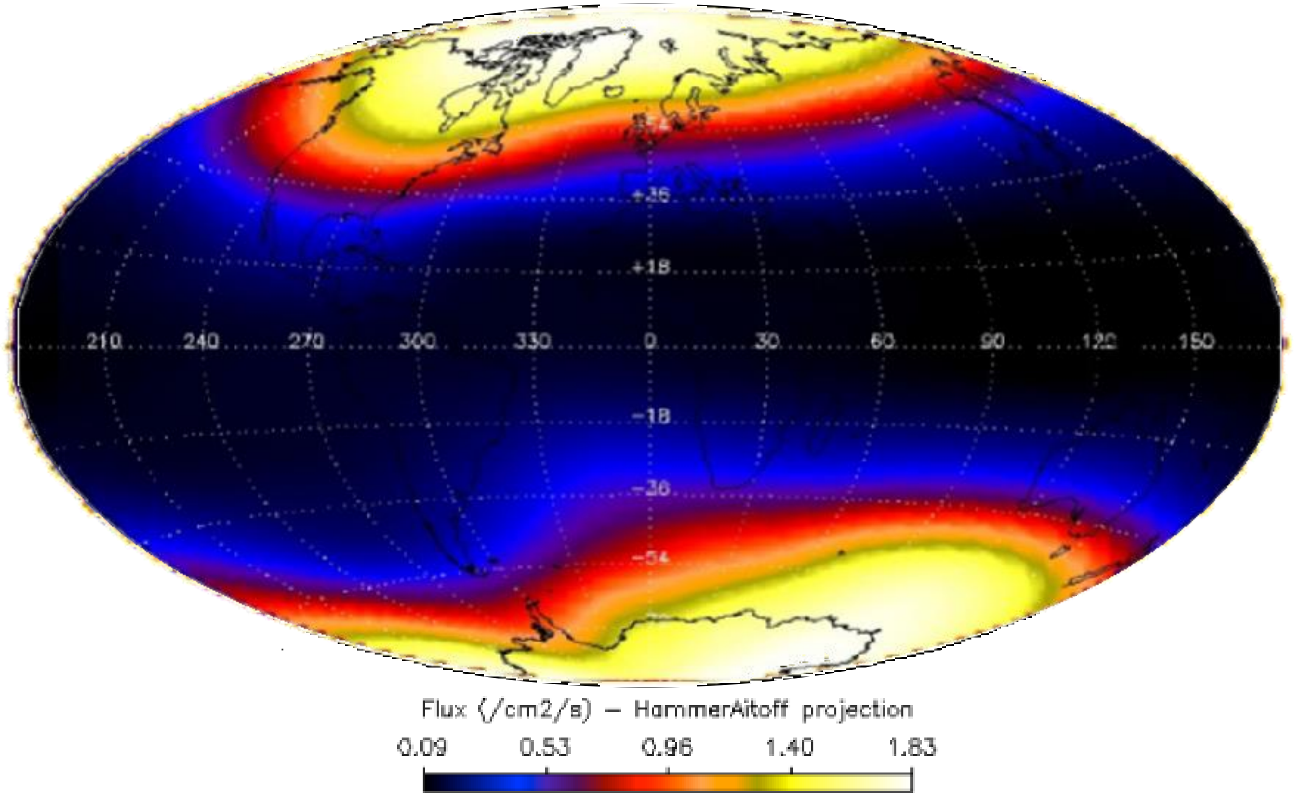



***Differential spectra of albedo neutron at 400km of altitude***
*vs balloon measurements and theoretical calculations.*




***Angular distributions of albedo neutrons flux***
*at a 400 km altitude.*

# My results: a better knowledge of neutron flux




***Map albedo neutrons (0-1TeV) at 75km of altitude in 2015***

# My goals for the last year

- Pedict the activation of HITOMI due to neutron albedo
- Provide a library of spectrums (OMERE,MEGALIB…)
- Use the same model to get:
  - Other particles (Gamma rays…)
  - Other inital conditions (dates, solar ecvents…)
- Keep optimizing the model until simulate the all Univers!