



## *2014 Joint Workshop of the France-Japan (TYL/FJPPL) and France-Korea (FKPPL) Particle Physics Laboratory*

# *New Proposal on Liquid Xenon R&D for Medical Imaging*



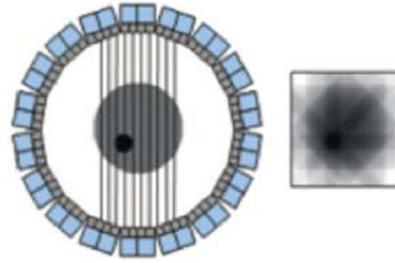
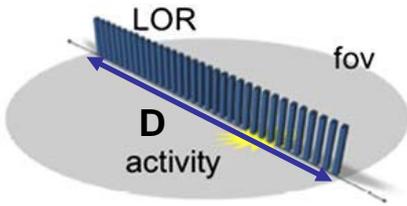
**French PI : D. Thers  
Japan PI : S. Mihara**



# PET and TOF-PET imaging

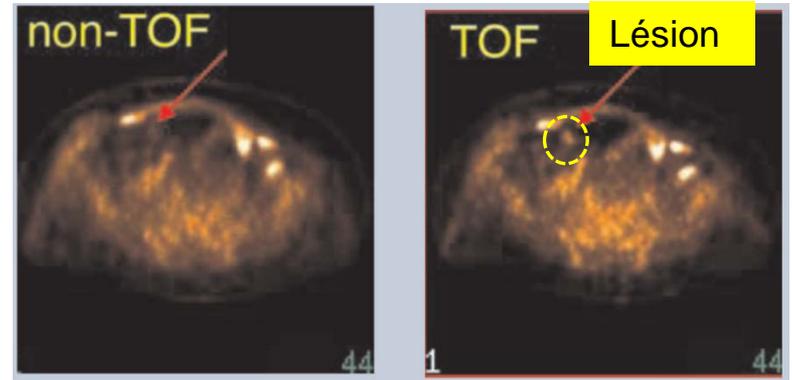
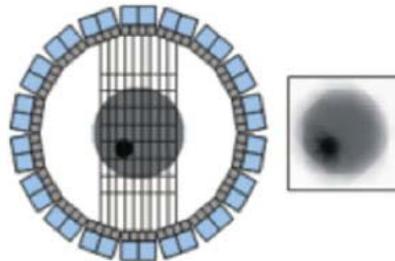
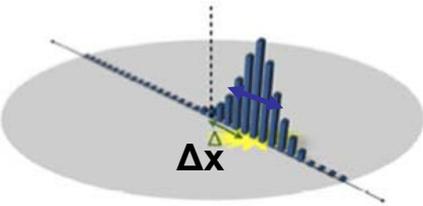
Time coincidence

Conventional PET



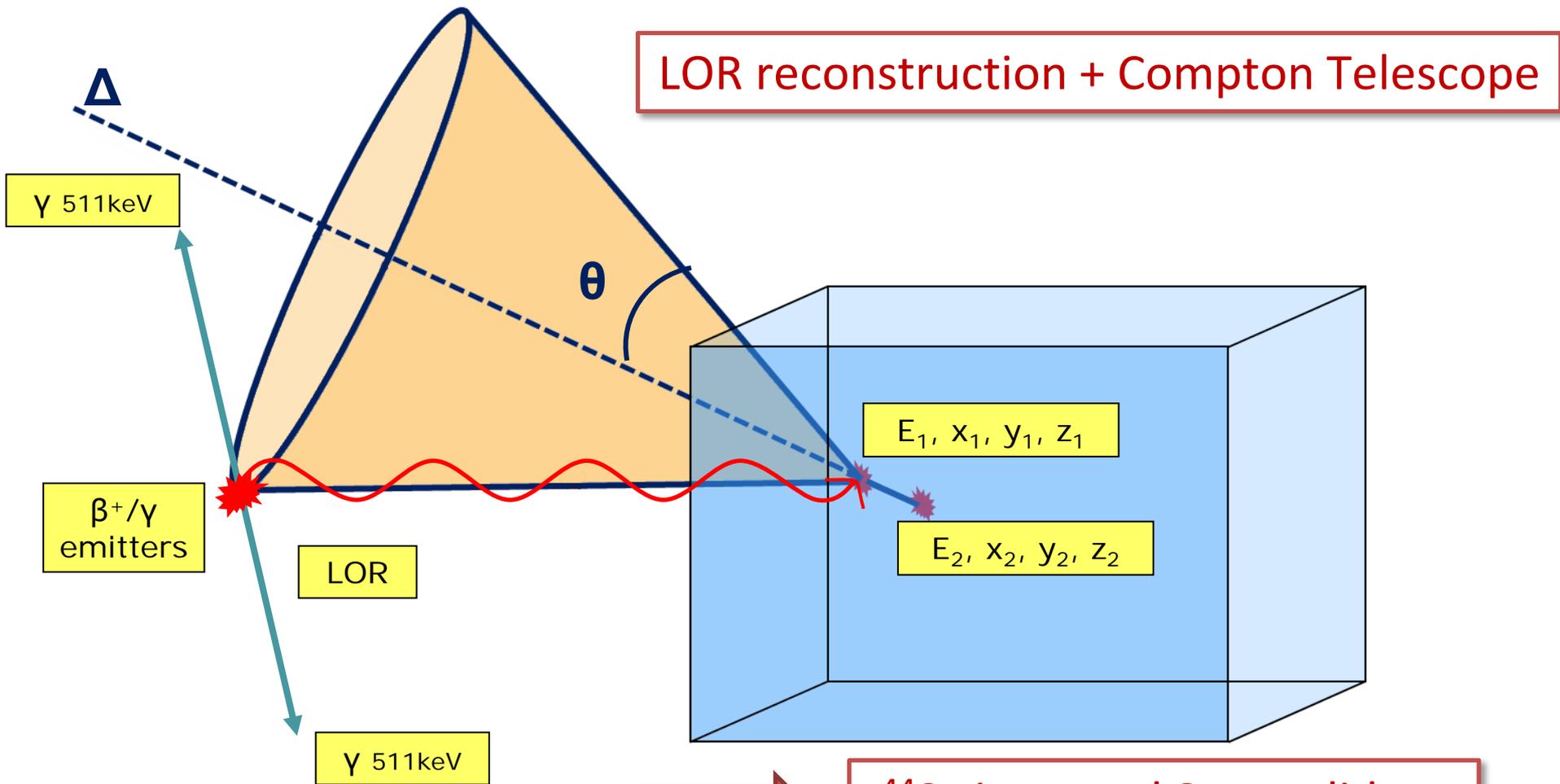
(Signal to Noise Ratio)  $SNR_{TOF} = SNR_{TEP} \sqrt{\frac{D}{\Delta x}}$   
Actual time resolution **500 ps**  $\rightarrow \Delta x = 7,5 \text{ cm}$

Time-of-flight PET



Main long term challenge : cm level achievable ?  
We believe  $3\gamma$  imaging with LXe will do it ...

# $3\gamma$ imaging with LXe



LOR reconstruction + Compton Telescope

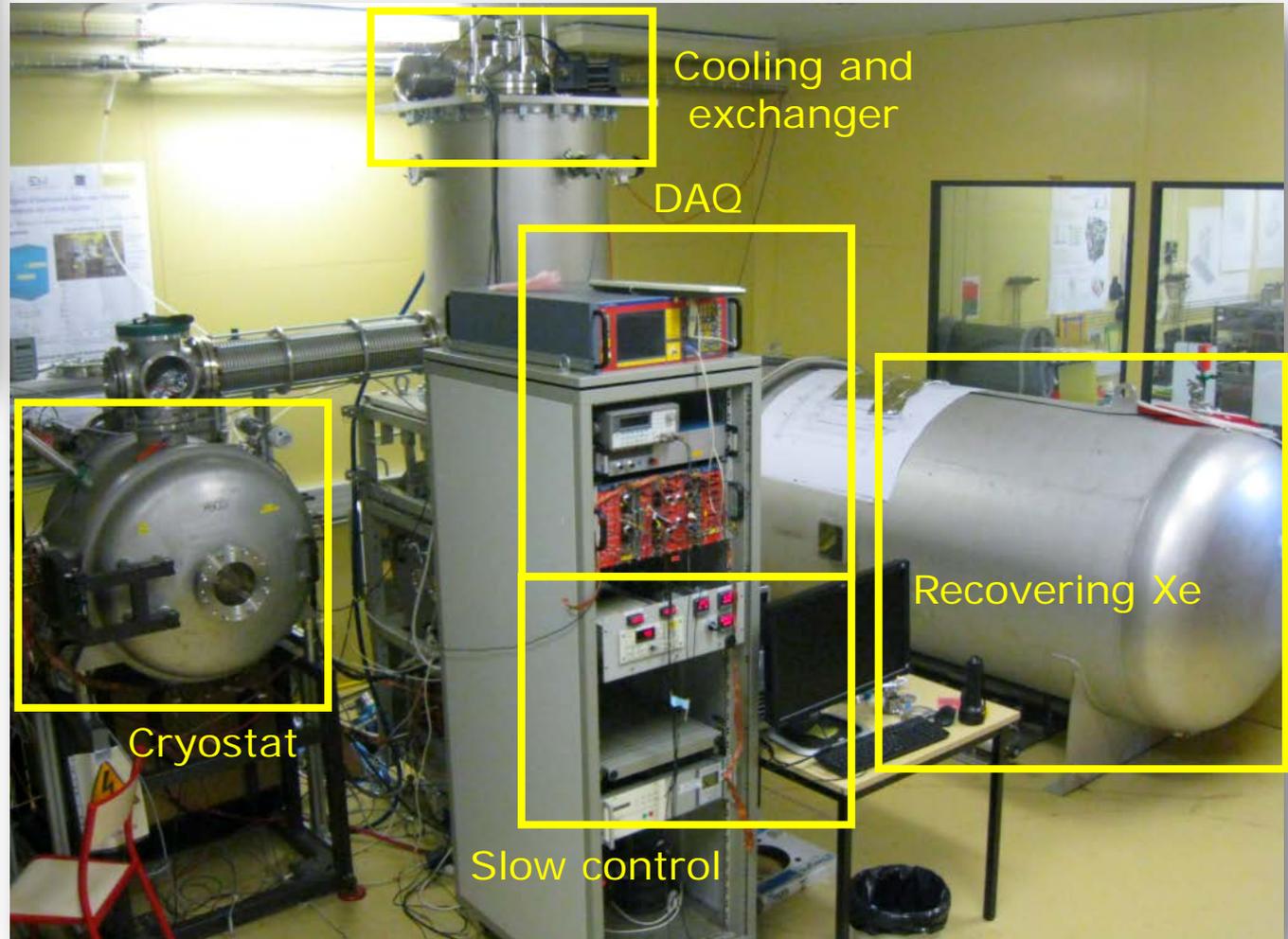
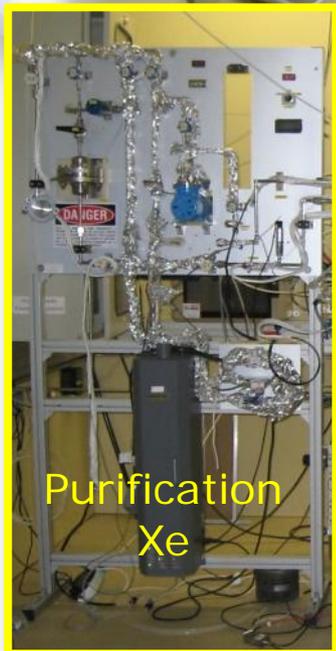
$^{44}\text{Sc}$  is a good  $3\gamma$  candidate



→ Arronax is developing new medicaments with  $^{44}\text{Sc}$

# XEMIS1 facility

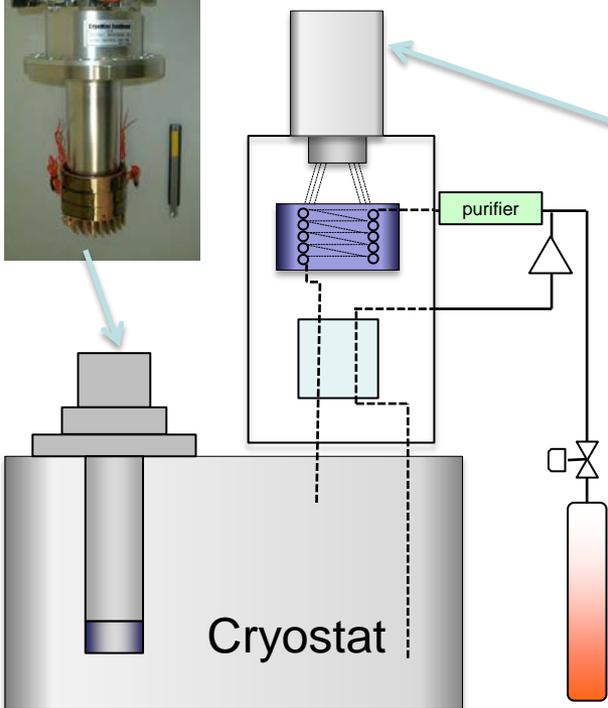
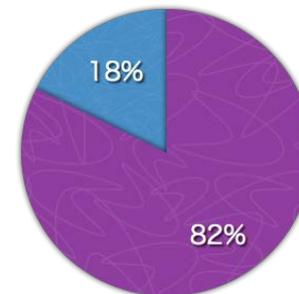
Prototype for the “technical” proof of feasibility with 30kg of LXe



# R&D of pre-cooler at KEK

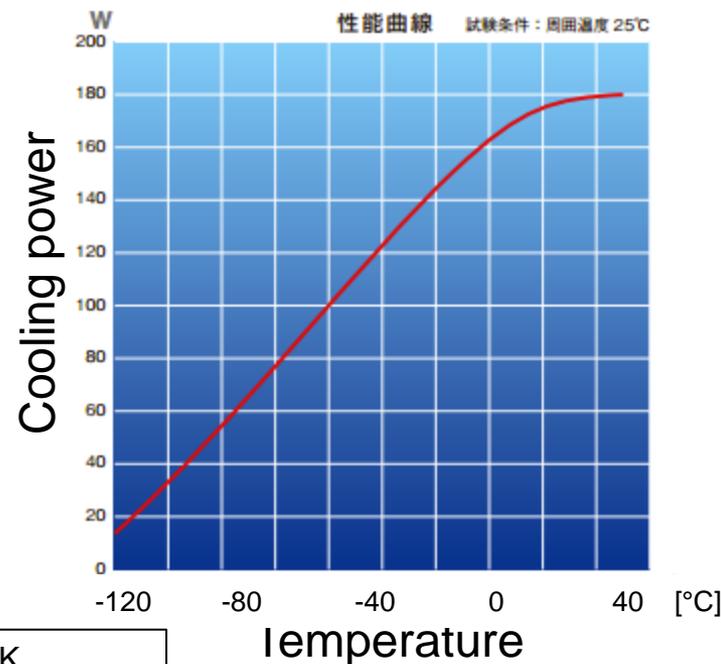
- Improve liquefaction / purification speed
- Liquid filling phase:
  - Gas cooling by the pre-cooler, liquefaction by the main-cooler
- Purification/circulation phase:
  - Latent heat exchange through the heat exchanger
  - Returned gas cooling by the pre-cooler

● Latent ● gas heating



Free piston Stirling refrigerator

Pulse-tube refrigerator 190 W @165K  
Free piston stirling refrigerator 35 W @165K

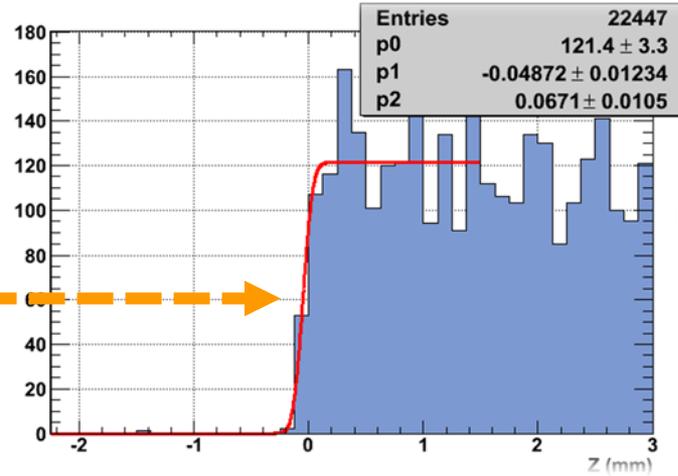
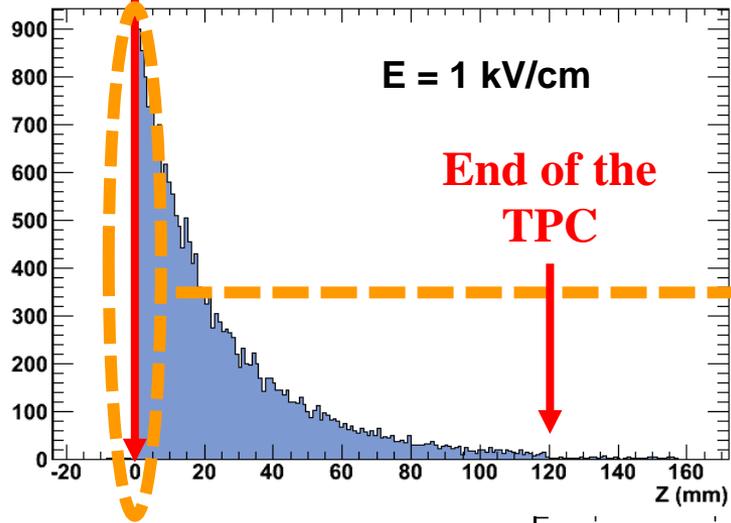


Pulse-tube refrigerator

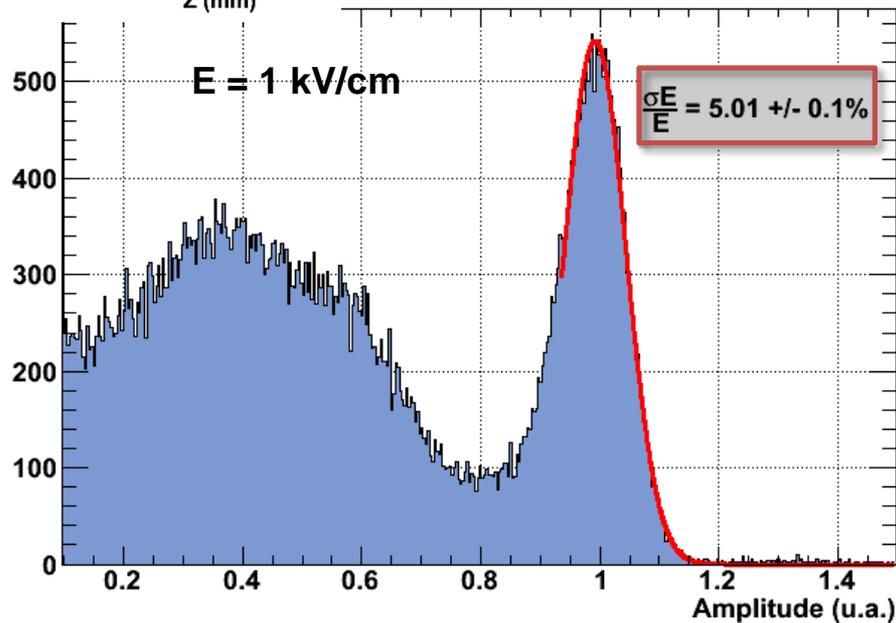
# XEMIS1 : Main results

## Spatial and Energy resolution (@ 511 keV)

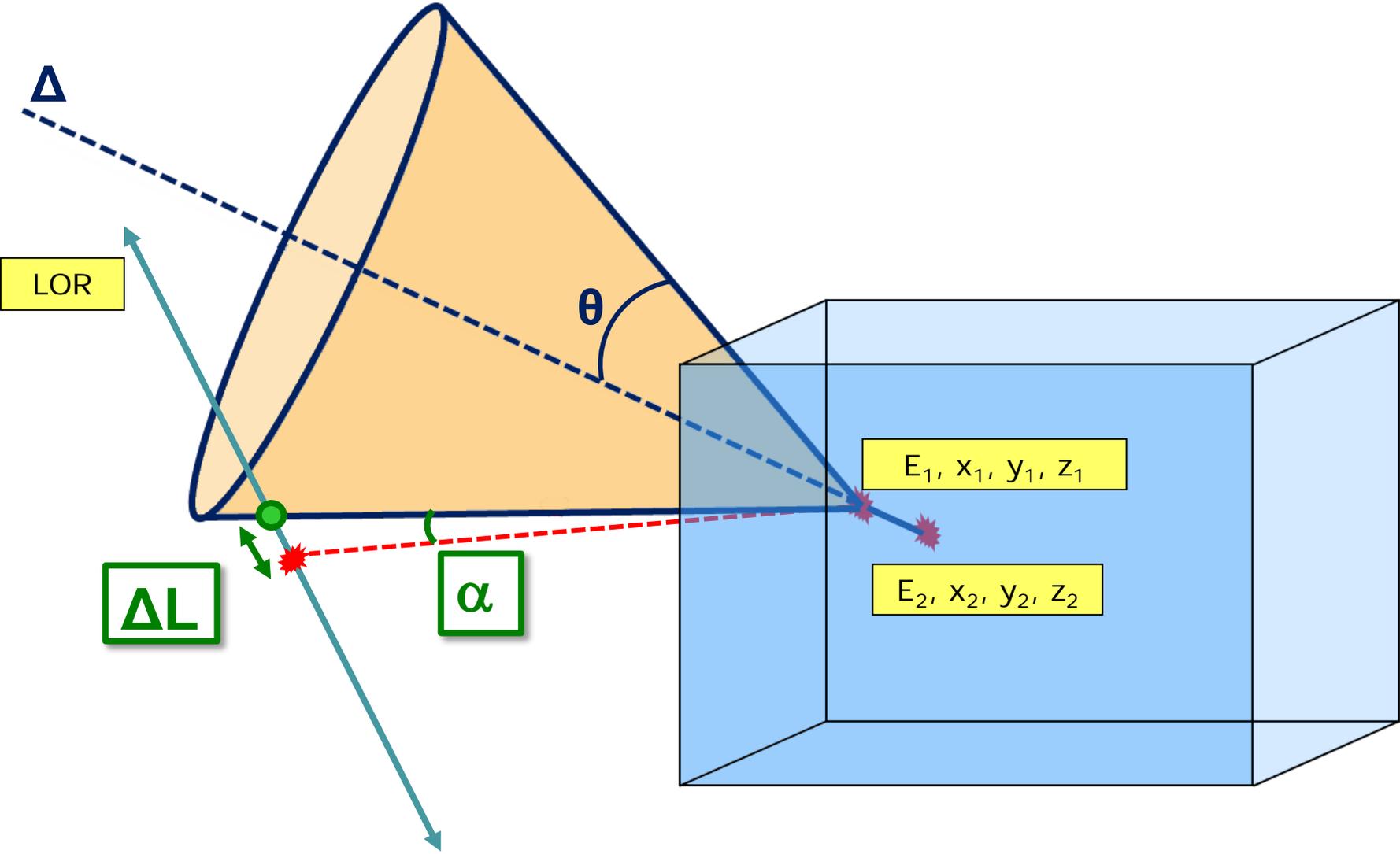
Beginning  
of the TPC



DOI  
resolution:  
 $67 \pm 10 \mu\text{m}$



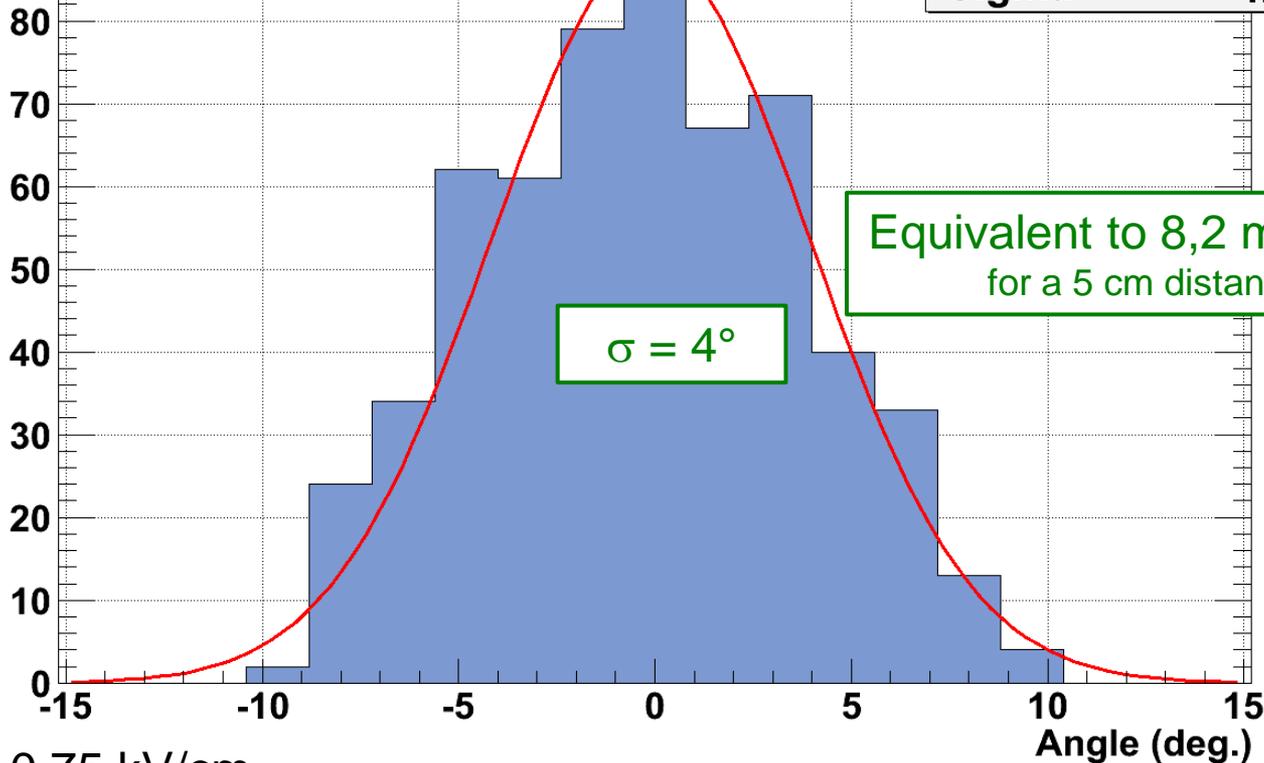
# Cone LOR intersection



# Resolution along the LOR

$\alpha$  distribution

Entries	581
Constant	88.29
Mean	-0.1066
Sigma	4.06



E = 0.75 kV/cm



It works! Very promising

# XEMIS status

“Technical” proof of concept with XEMIS1 achieved with reconstructed cones

... but still lots of works under progress



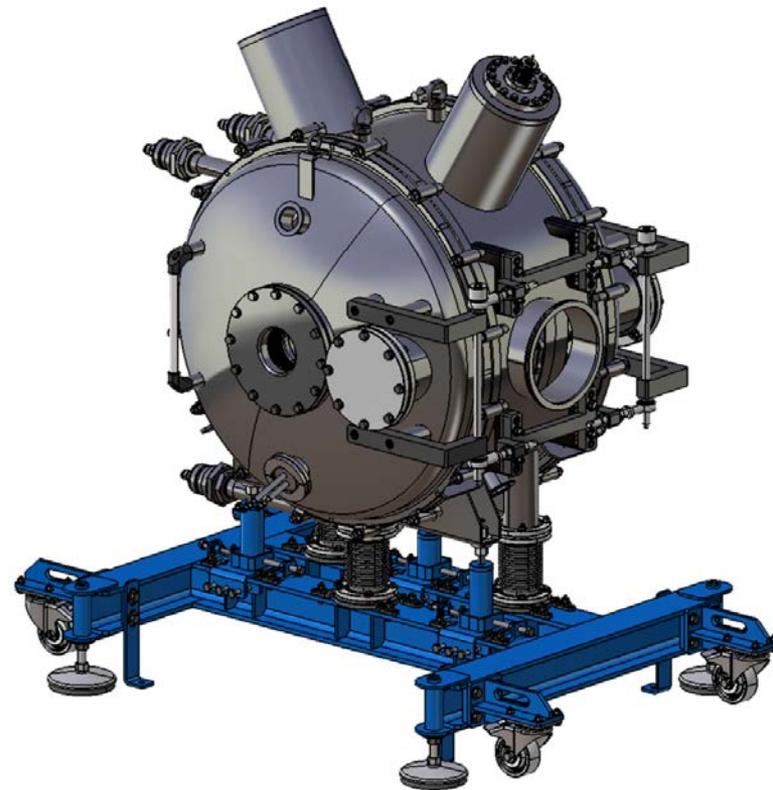
Start of XEMIS2 project

- Advanced simulation with GATE since 2012
- Design study 2013
- Approved experiment since 2013
- Construction 2014
- Test and characterisation 2015

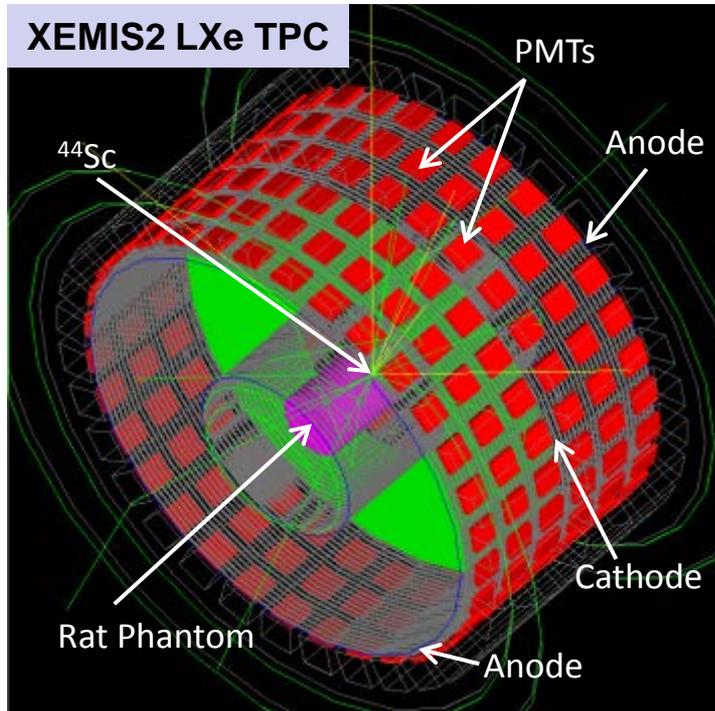


Proof of LXe superiority

- Installation at Nantes Hospital in 2015
- Upgrade of XEMIS2 with R&D



# The XEMIS2 experiment



## Cylindrical camera with $\sim 60$ l of LXe

- Active radius :  $6 < r < 18$  cm
- 1" photo-sensors : 348 (50 at first)
- FEE ionisation channels : 25 000

## Camera characteristics

- Energy resolution : 5% @ 511 keV
- Spatial resolution : 0.5 mm (X, Y and Z)

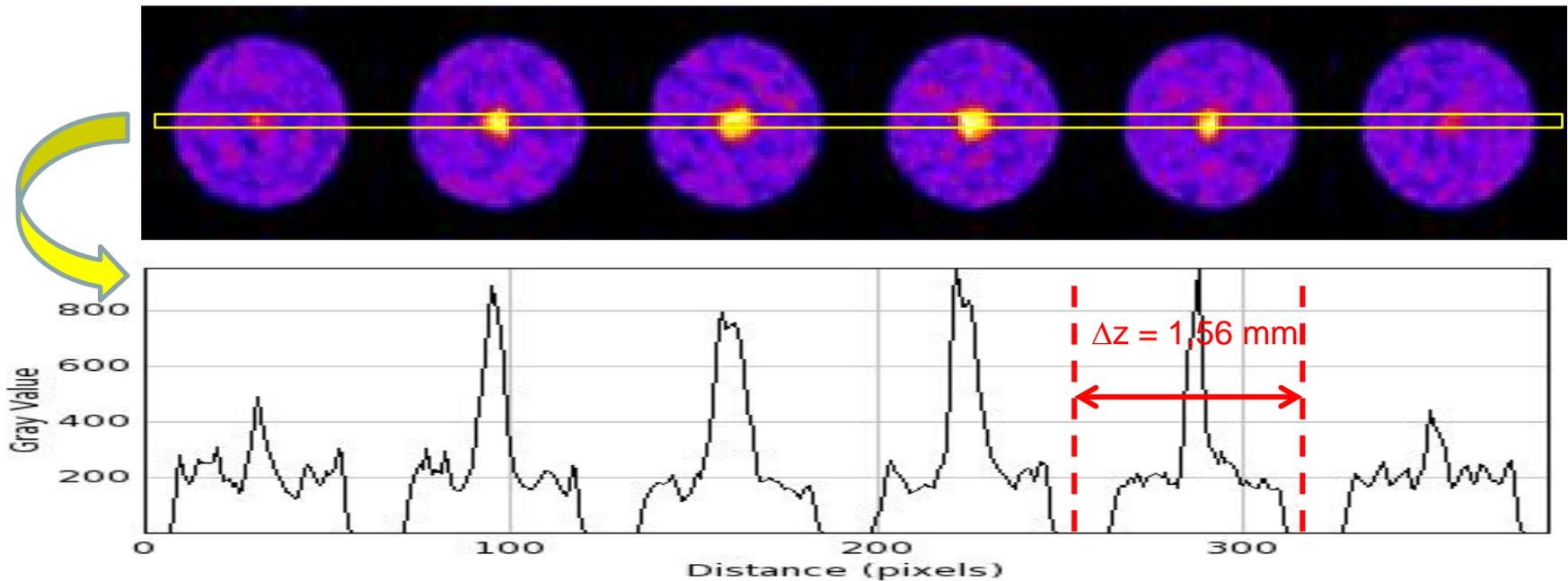
## Simulation (OpenGate)

- Objective  $\sim 1$  cm (FWHM) along the LOR



<sup>1</sup>OpenGATE collaboration: <http://www.opengatecollaboration.org/>

# Simulations of XEMIS2



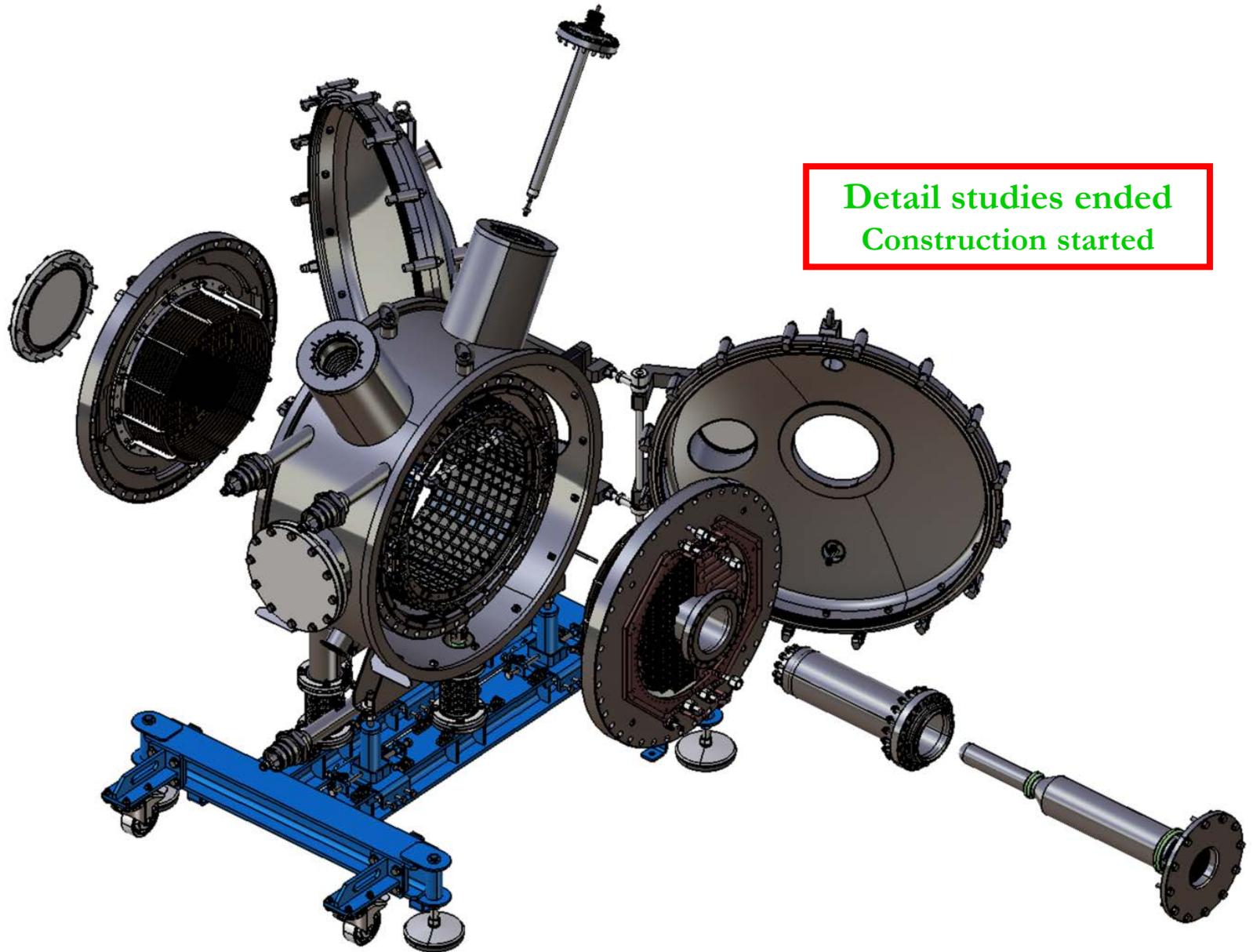
## Image Reconstruction: $3\gamma$ + tomographic list-mode MLEM

- GATE simulation of a cylindrical water phantom uniformly filled with  $^{44}\text{Sc}$  (long. 15 cm, diam. 5 cm), **Low Activity 20 kBq** + sphere at the center with contrast 4 (diam. 10 mm, ie 117 Bq of  $^{44}\text{Sc}$  inside the source)
- Acquisition time 20 minutes



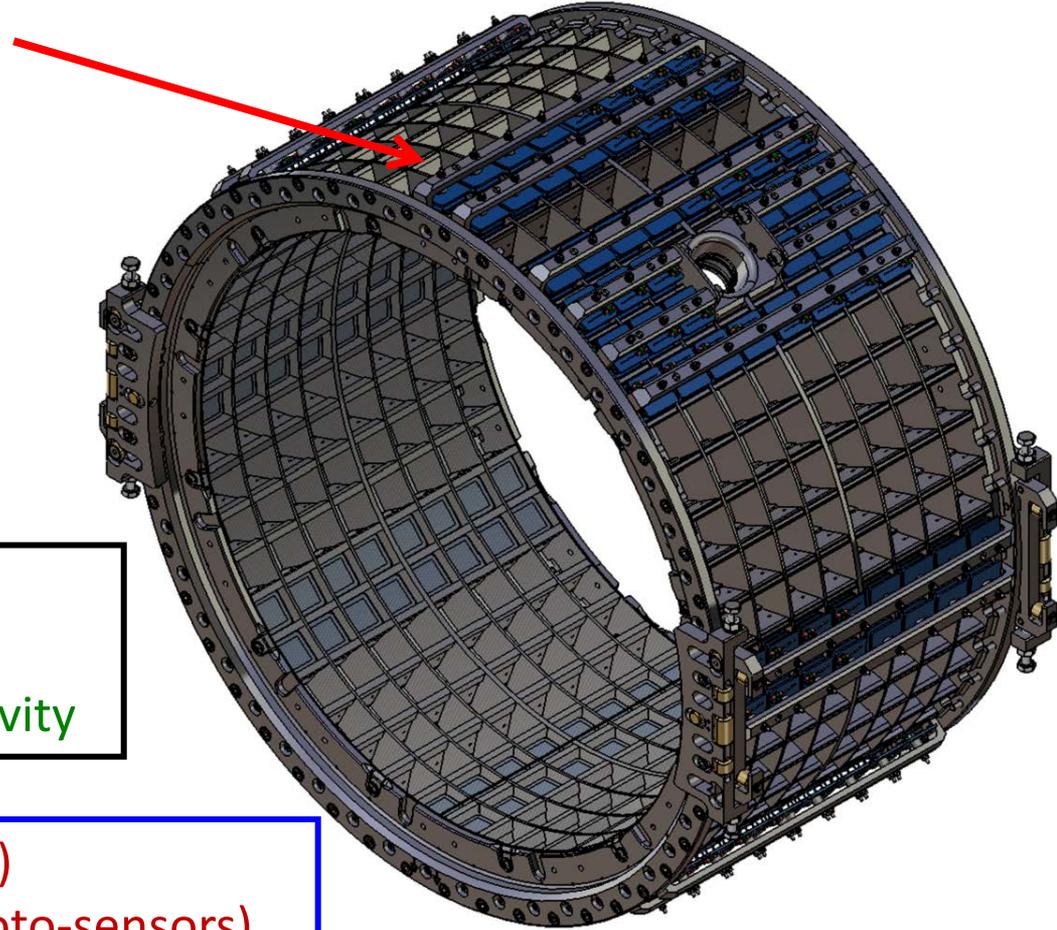
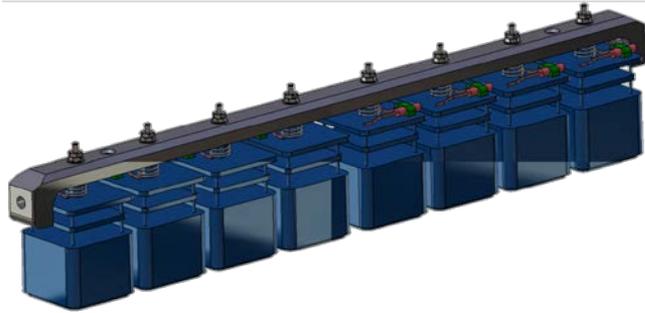
Reconstruction under progress ...  
Activity in the field of view is incredibly low !

# *Design of the XEMIS2 cryostat*



Detail studies ended  
Construction started

# Photo-sensors support of XEMIS2



- XEMIS2 initial programm
  - 50x1'' PMTs light coverage
- Perfectly adapted for 20 kBq activity

- XEMIS2 upgrade (expected in 2016)
  - Full light coverage (348x1'' Photo-sensors)
  - 300 kBq activity targeted (15 times faster)



R&D on light detection for the upgrade

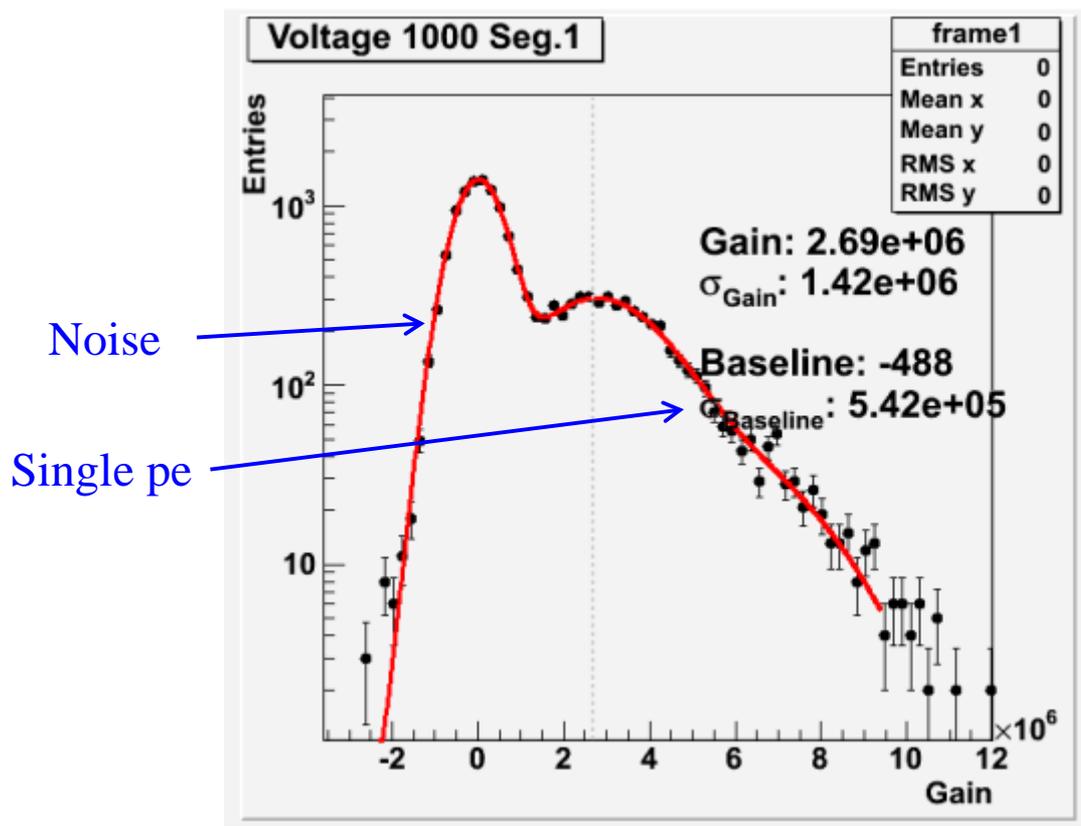
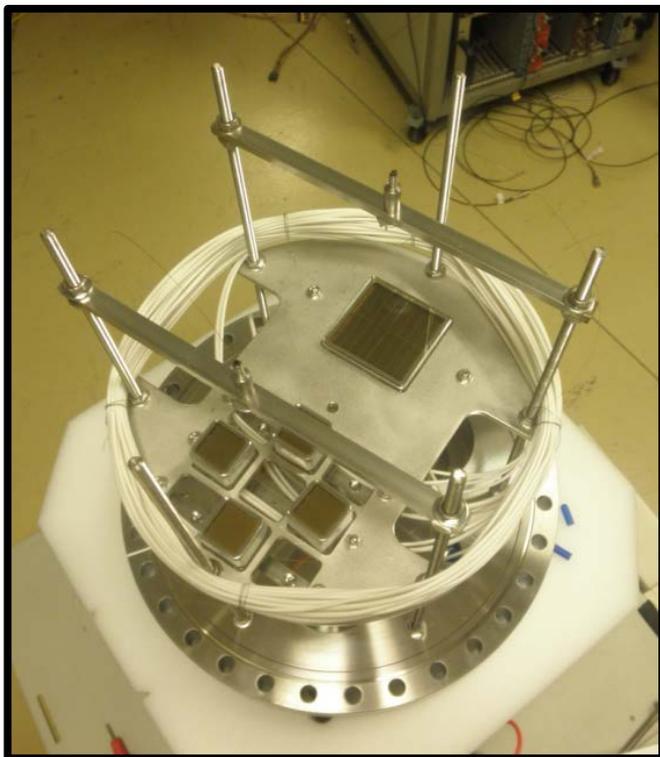
# R&D on Photo-detectors test for XEMIS2 upgrade

## Flat Panel PMT :

Hamamatsu R10551 - 2'' 64 pixels

vs

Hamamatsu R7600 - 1''



- 2 French Engineer students, 3 months internship at KEK in 2013 and 2014
- 1 Japanese Master student, 3 months internship at Subatech in 2013

Full comparison in progress, positive Hamamatsu Co. contacts

# Conclusions

## XEMIS1

“Technical” proof of concept with XEMIS1 achieved with reconstructed cones

Medical imaging with LXe should be considered with high interest for the future

## XEMIS2

We will prove that quality of image with liquid xenon and  $3\gamma$  technics is of interest on living animals

At small rate (20 kBq) first

R&D for the upgrade of XEMIS2 is starting...

It should converge within the 2 next years

