

# **R&D on liquid xenon detector for applied and fundamental researches**

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## **Collaborations**

***KEK (Japan): LXe cryogenic system PTR***

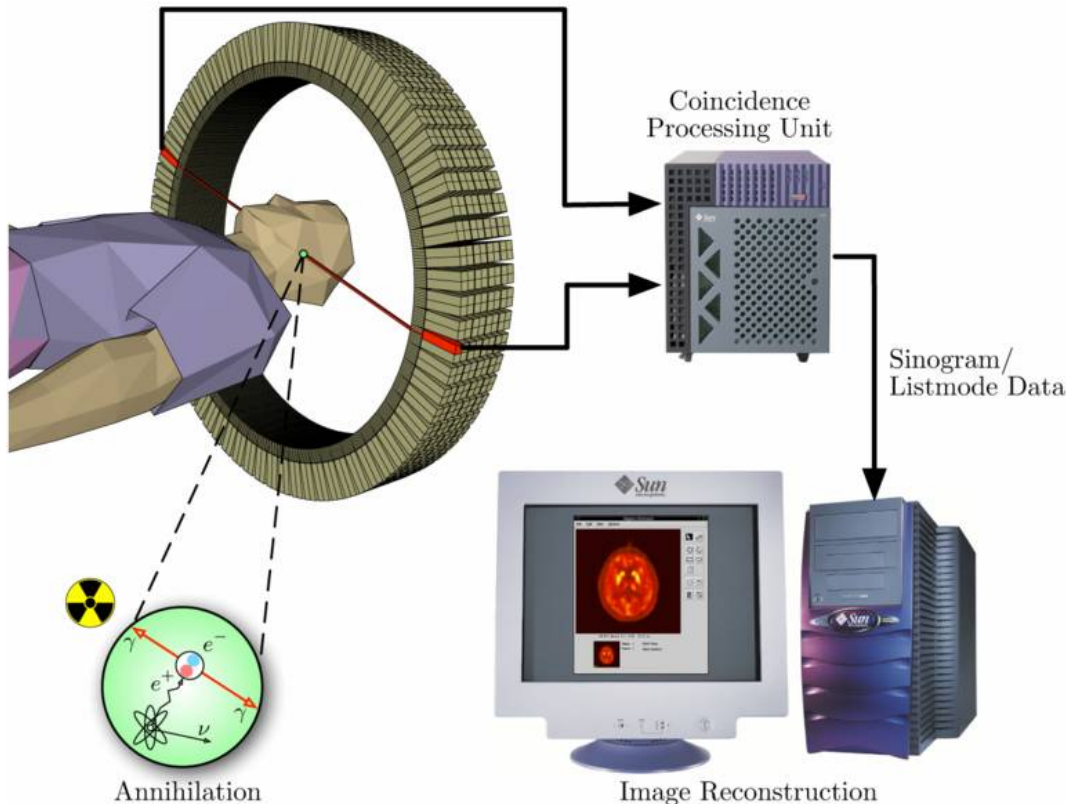
***Weizmann Institute (Israel) : Gaseous Photo Multiplier (GPM)***

## Outline :

- ▶ Introduction : medical imaging - PET
- ▶  $3\gamma$  imaging with LXe
- ▶ XEMIS first prototype
- ▶ Experimental results
  - cryogenics
  - detection
- ▶ Gaseous photomultiplier (GPM) in LXe
- ▶ Conclusion and outlooks

# Positron Emission Tomography (PET)

- Injection of radiotracers ( $\beta^+$  emitters      ex:  $^{18}\text{F}$ -FDG,  $T_{\frac{1}{2}} = 2$  hours,  $T_{\beta\text{max}} = 633$  keV)
- Detection of 511 keV  $\gamma$  in coincidence (BGO crystals)
- Reconstruction of the Line of Response (LOR)



→ efficient diagnostic  
for cancer treatment

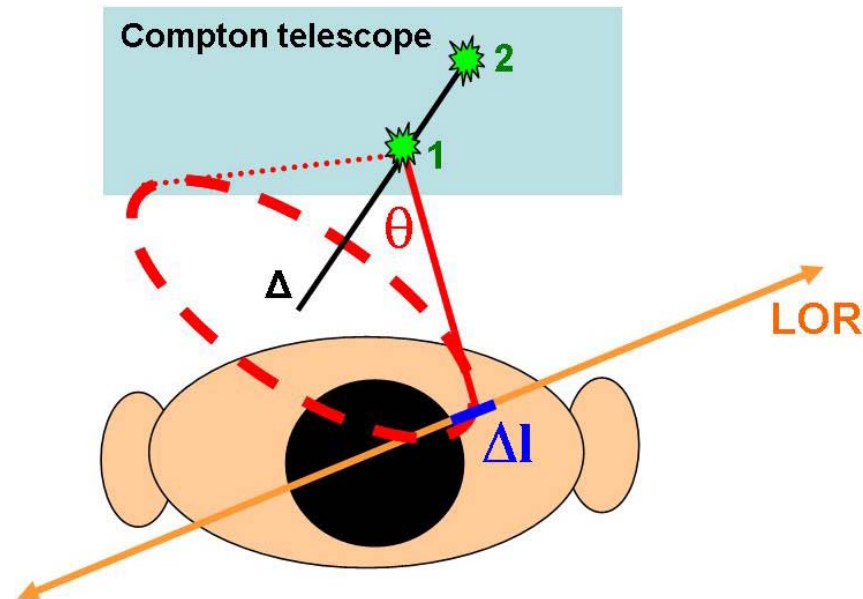
Possible improvements :

- reduction of injected activity
- reduction of exam duration

→ LXe detectors ?

# 3 $\gamma$ medical imaging

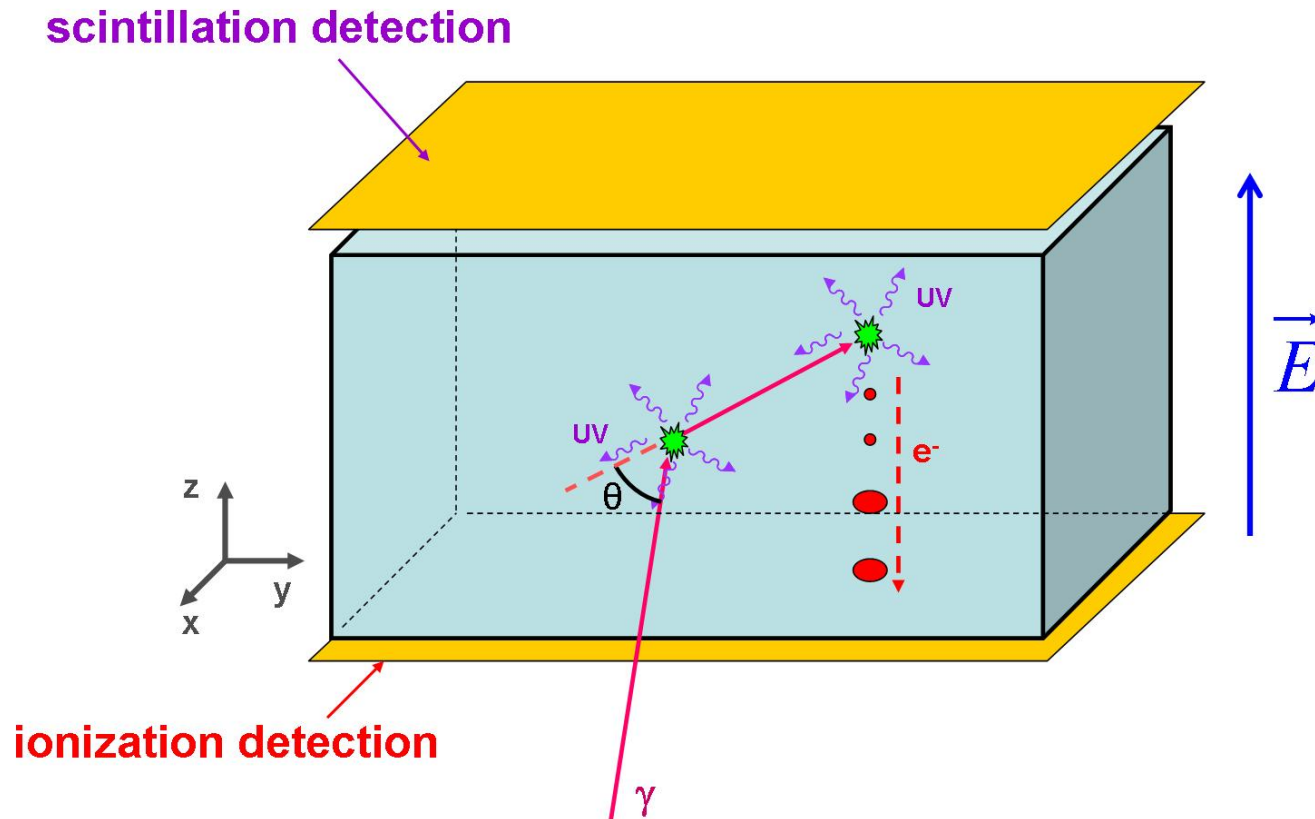
- Principle** :
- $\beta^+$   $\gamma$  emitter ( $^{44}\text{Sc}$  from Arronax cyclotron (sep. 2008)) :
  - classical PET + Compton telescope
  - LOR +  $\gamma$  incident direction - cone ( $\Delta, \theta$ )
- 3D reconstruction event by event
- ⇒ reduction of the incertitude position along the LOR



# Compton telescope

Precise measurement of :  $\left\{ \begin{array}{l} - \text{energy} \\ - \text{3D position} \end{array} \right.$  for each vertex

LXe telescope : scintillation and ionization signals

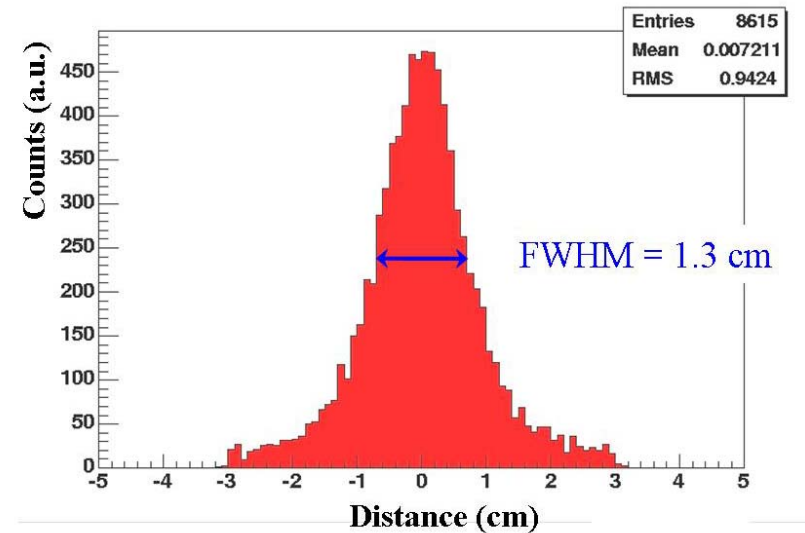
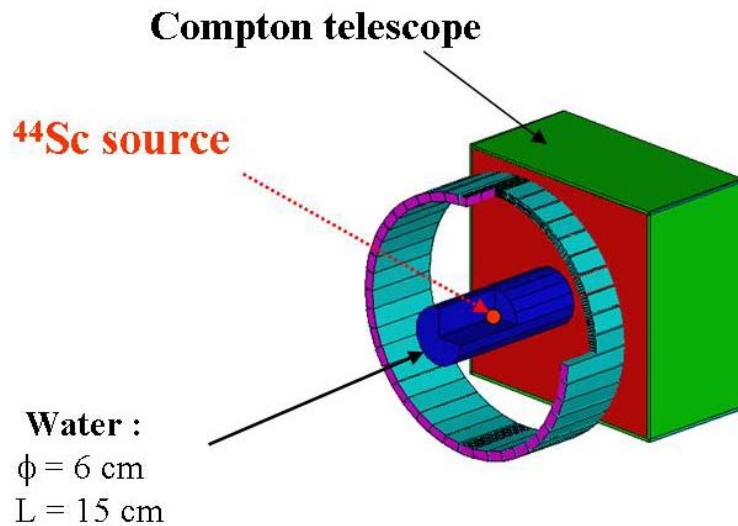


angular resolution of the telescope  $\Leftrightarrow$  energy and position resolutions

# Simulation: Expected performances

Energy and position resolution :  $\sigma_E = 6 \% @ 1 \text{ MEV}$  [ E. April, NIMA 480, 2002 ]

$$\sigma_{xy} = 1 \text{ mm} , \sigma_z = 100 \mu\text{m}$$



[ C. GRIGNON,  
PhD thesis, 2007 ]

- position along the LOR :  $\Delta L < 1.5 \text{ cm}$  for small animal imaging
- image can be improved using reconstruction algorithm (under progress)

# LXe technology @ Subatech

## ■ Xenon liquefaction at low pressure < 2 bars (absolute)

- gas→liquid transition : about -110 °C

ex:  $T_{\text{condensation}} = -108^{\circ}\text{C}$  and  $T_{\text{freezing}} = -112^{\circ}\text{C}$  for  $P = 1$  bar

- precise temperature regulation

- cold head : Pulse Tube Refrigerator (developed @ KEK by T. Haruyama)

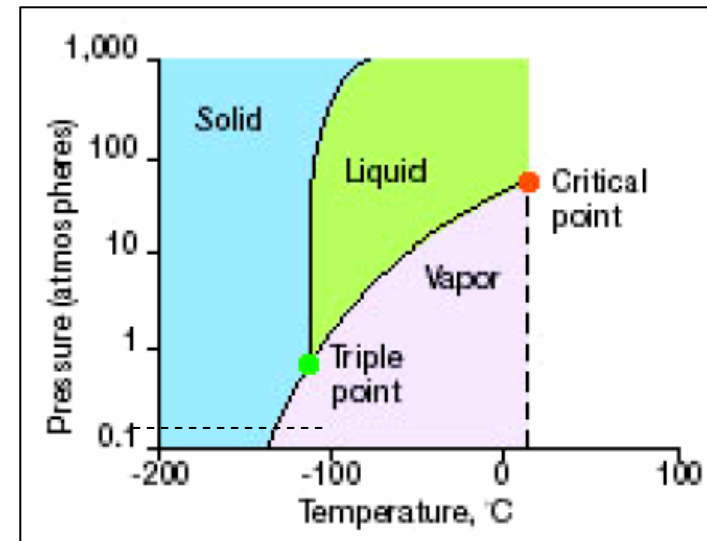
## ■ Xenon purification

- LXe purity level ~ 1ppb ( $\text{O}_2, \text{H}_2\text{O}, \dots$ )

- gas purifiers

- gas circulation

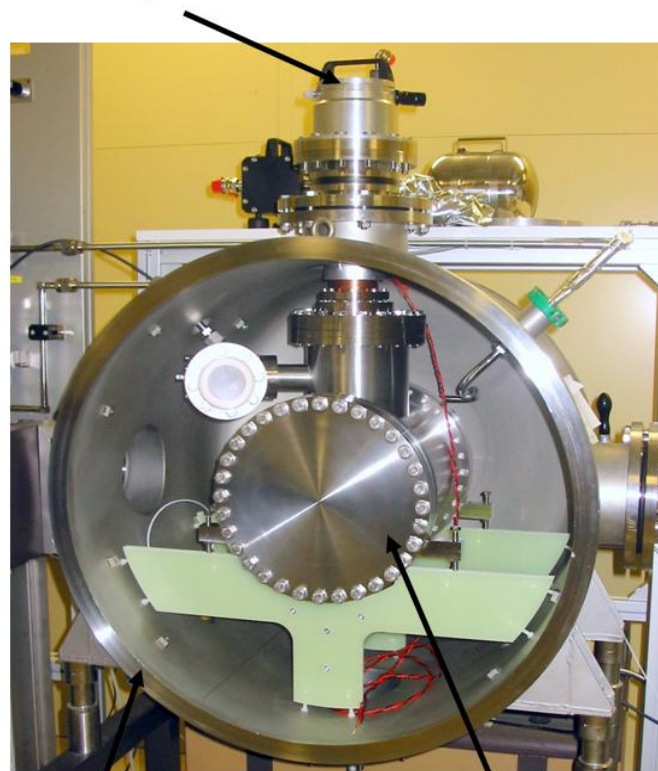
Xenon phase diagram



# XEMIS prototype



## PTR Cryocooler



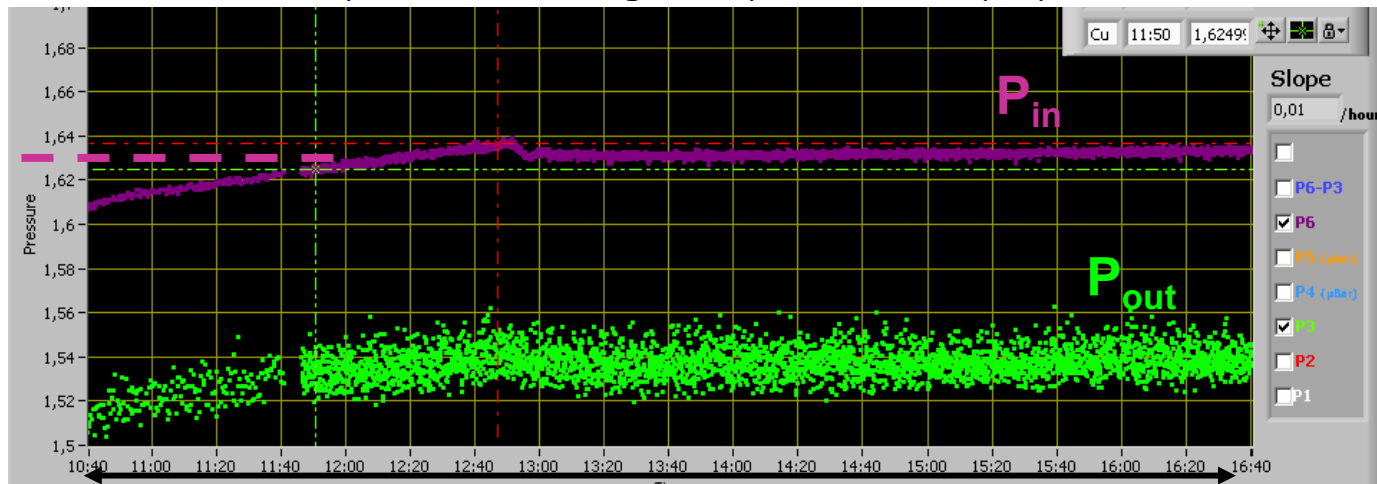
**External  
cryostat**

**Internal  
cryostat**

# Cryogenics

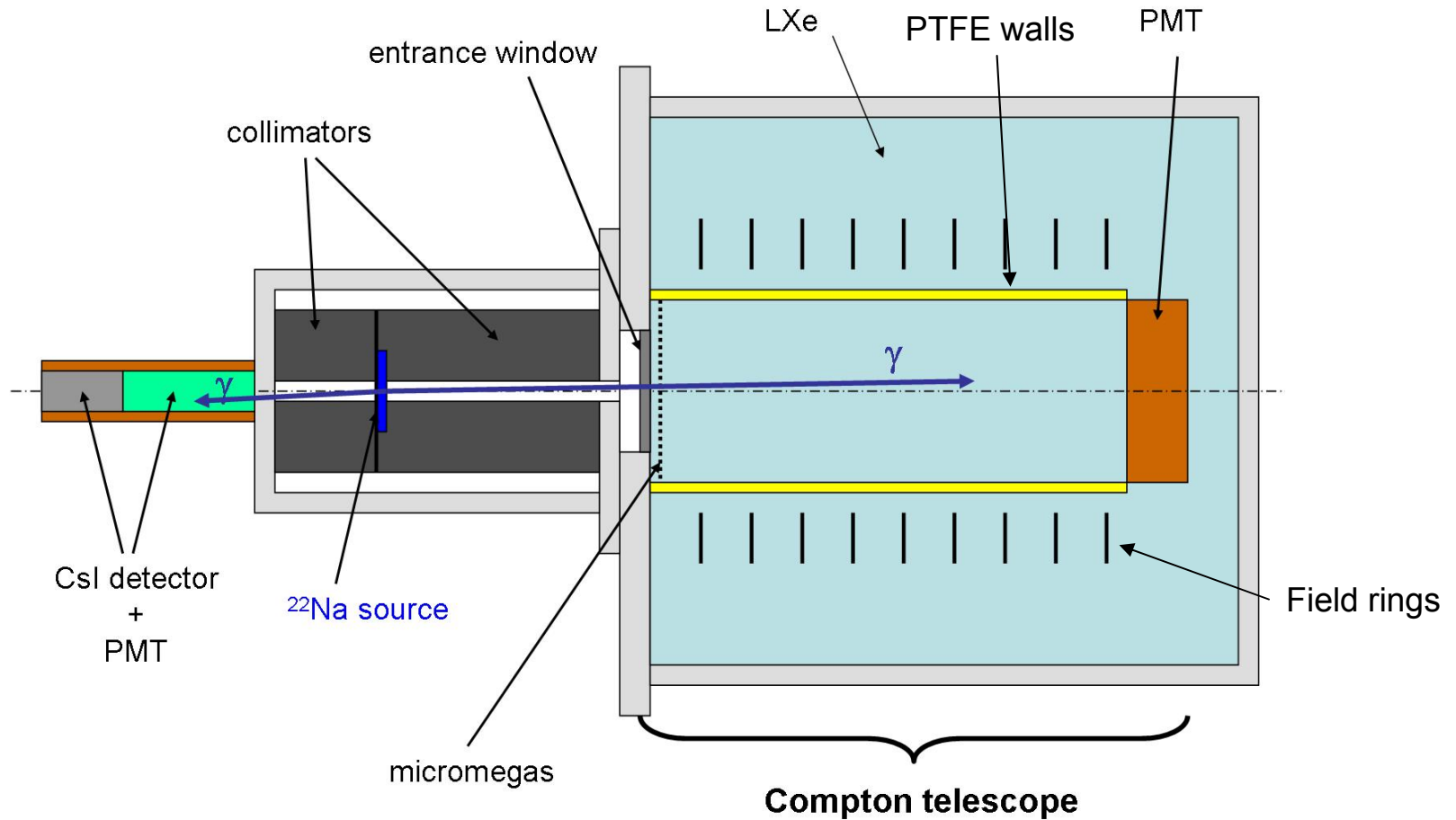
April 2008:

- Liquefaction of 30 kg of Xe @ P=1.63 bar
  - need for a long pre-cooling period of the cryostat
  - new heat-exchanger geometry
  - liquefaction rate : ~ 1.5 kg / hour
- circulation and purification
  - validation of vaporization tube and pump (PTR from KEK)
  - estimated flow : 1 kg / hour
  - stable operation during 6 days → safety system : OK



# Experimental setup

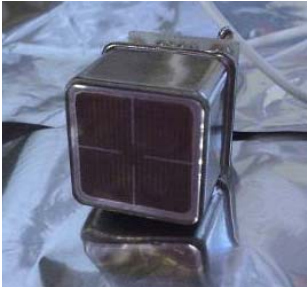
Tests with  $^{22}\text{Na}$  source : measurement in coincidence of 511 keV photons



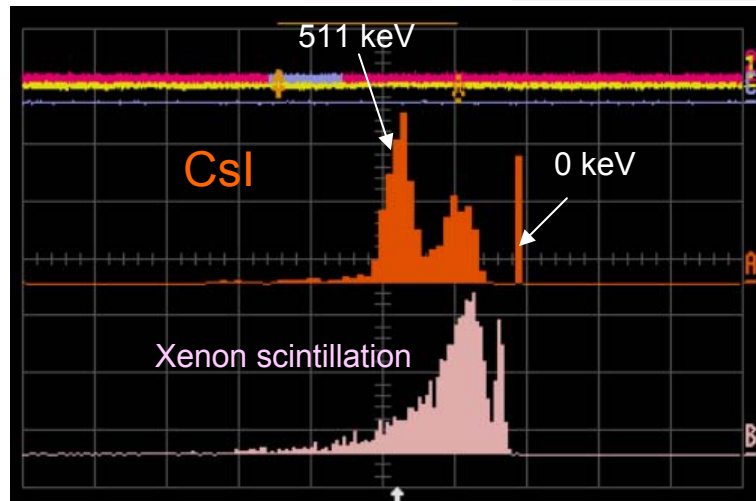
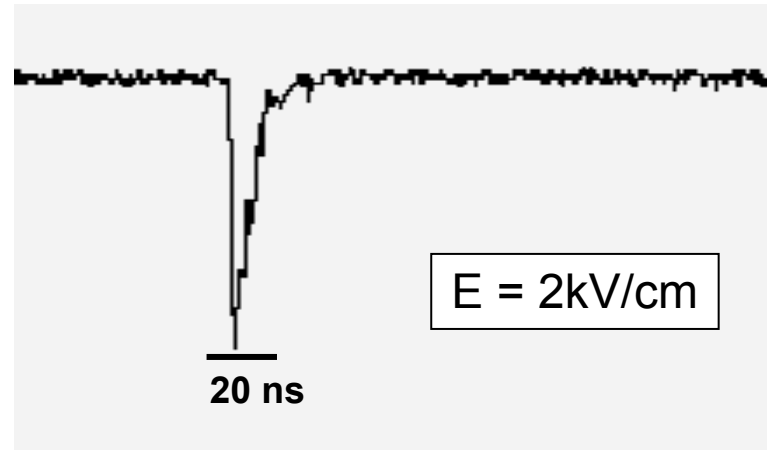
External trigger = CsI detector

# Scintillation signal

Typical scintillation signal from PMT:



PMT Hamamatsu



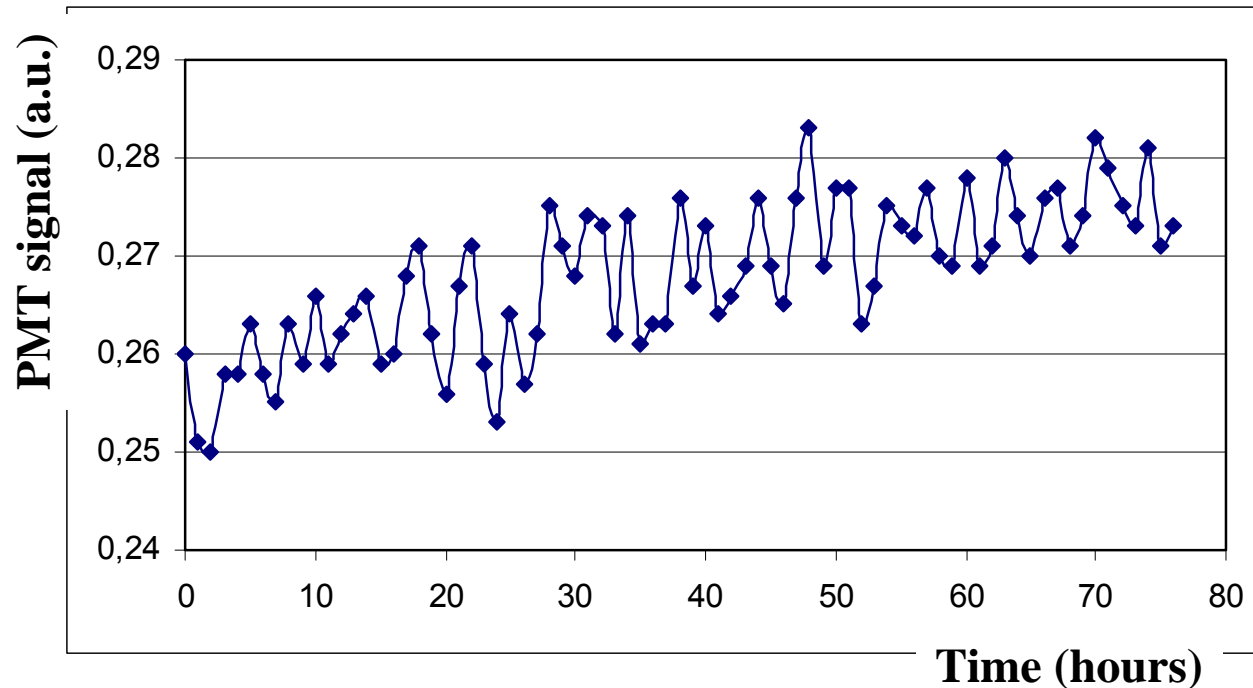
Coincidence with Xenon PMT

→ window on 511 keV (CsI)

⇒ Evidence of 511 keV  $\gamma$  detection in LXe

# Xenon purification

Purification effect on scintillation signal :

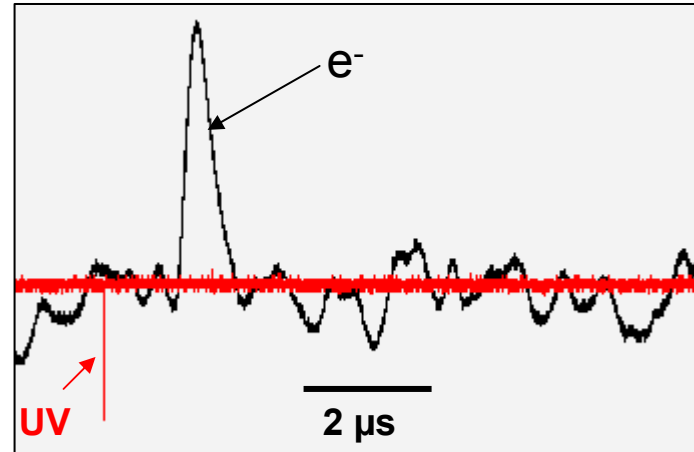
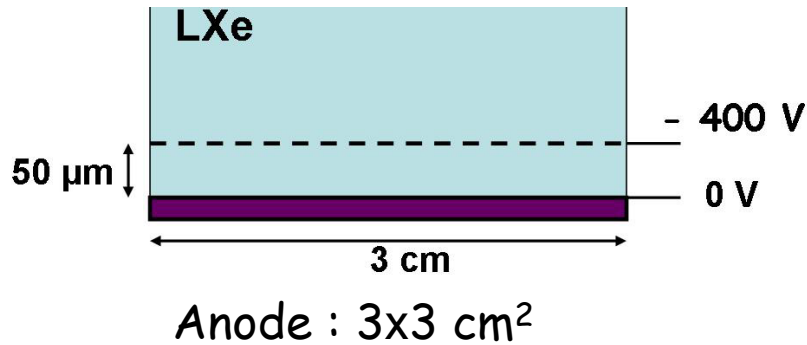


Continuous signal improvement on PMT : ~ 6% in 3 days ( preliminary )

→ Similar tests with charge collection...

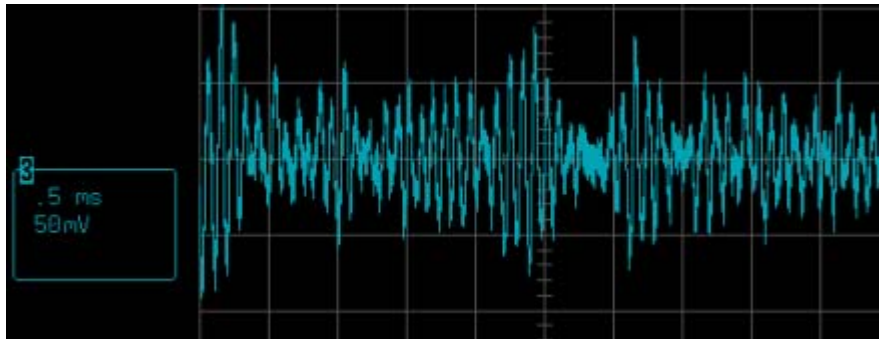
# Ionization signal with micromegas

Ionization signal on anode (micromegas):



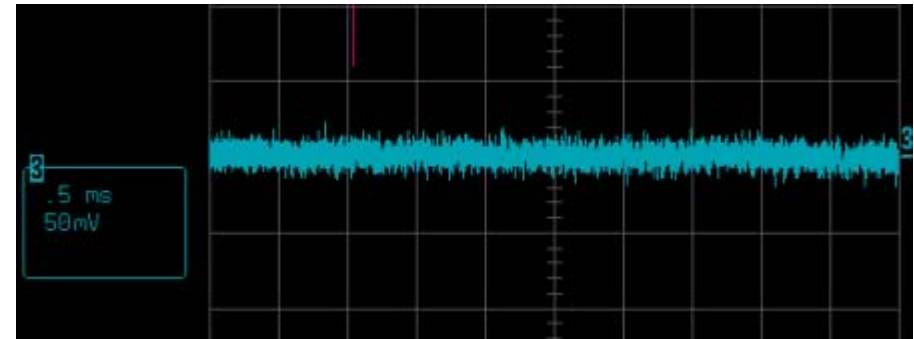
PTR OFF

Electronic noise on anode :



PTR ON

mechanical vibrations from PTR

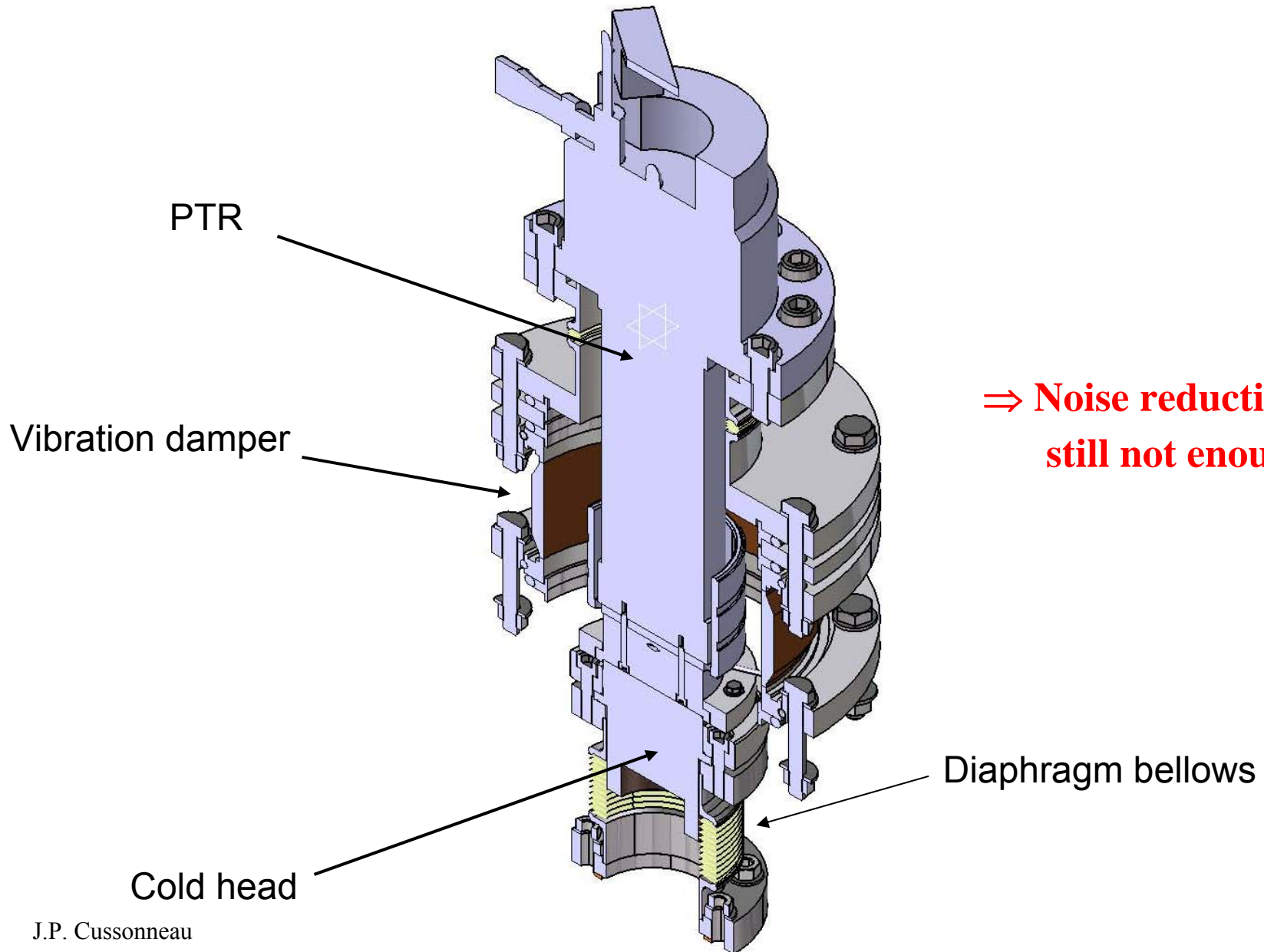


PTR OFF

anode noise :  $\leq 3000$  e<sup>-</sup> with PTR OFF

⇒ important modification on PTR support

# New PTR support april 2008



⇒ **Noise reduction but still not enough**

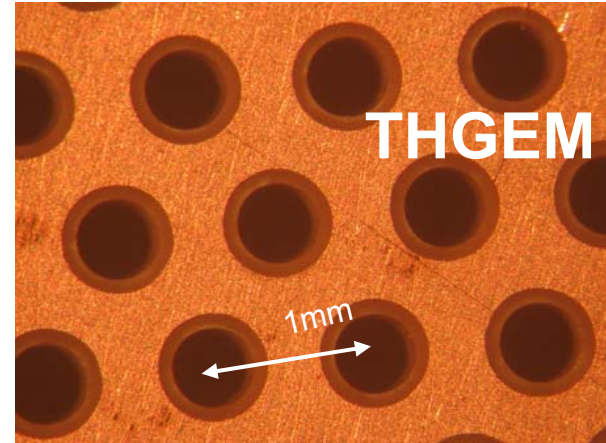
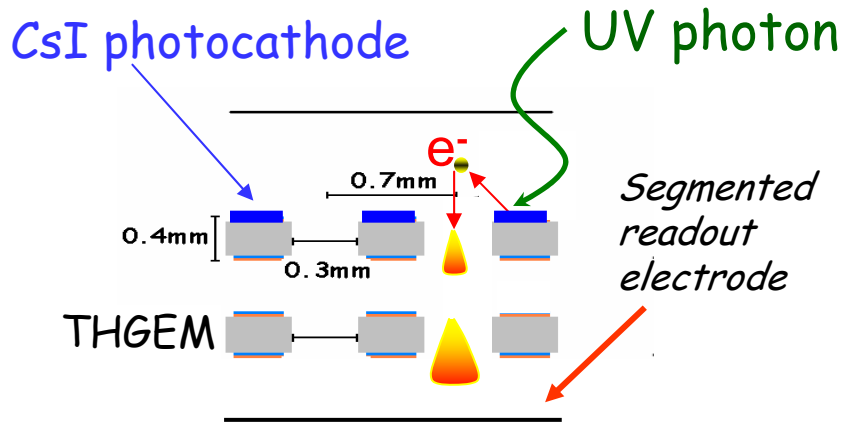
# Conclusion on XEMIS prototype

## XEMIS prototype

- **cryogenic** : 'almost' validated for larger device
  - 30 kg LXe inside the detector
  - safety recovering : **OK**
  - non human assistance : **OK**
  - circulation and purification :
    - first stable operation for 6 days**
    - optimization under progress**
  - investigation on cryogenics for human camera
    - first proposal at the end of 2008 ?**
- **detection** : under progress

# THGEM-GPM (Gaseous Photo Multiplier)

Robust, economic, mechanically drilled PCB



R. Chechik et al., NIM A 553(2005)35  
Developed @ Weizmann Institute

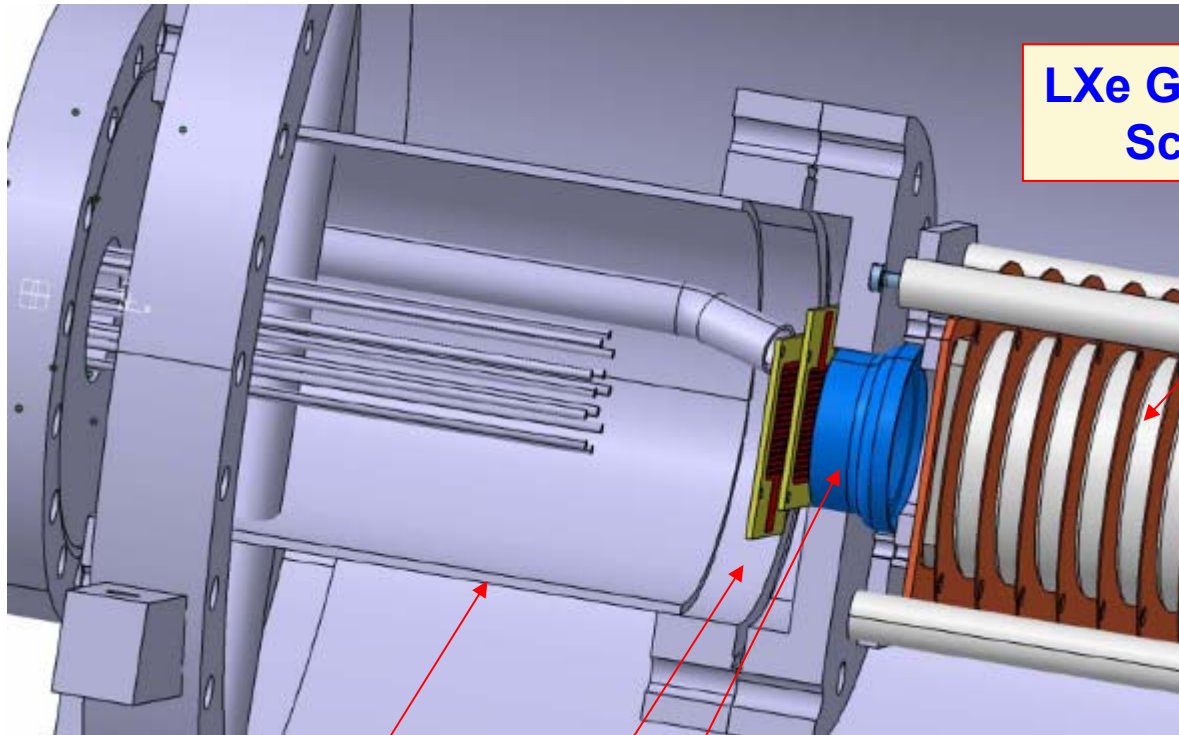


- high 2D precision [0.7 mm]
- high gain [ $>10^6$ ]  $\rightarrow$  single photon sensitivity!
- fast signals [ns]  $\rightarrow$  good timing

## GEM/THGEM WORK IN CRYOGENIC CONDITIONS

A. Bondar et al arXiv 0805.2018 (JINST, in press)

# GPM in LXe



LXe Gamma-interaction volume  
Scintillation & ionization

Sealed GPM with semitransparent  
bialkali photocathode (WIS)

GPM housing

THGEM GPM

MgF<sub>2</sub> window



# Conclusion and outlooks

Work in progress for nuclear medical imaging with pure LXe device  
Since 1 yr of R&D on LXe ...

- Cryogenic requirements are achievable with PTR
- Gaseous xenon circulation should be sufficient
- R&D on new scintillation and ionization read out in pure LXe remained a challenge

DM experiments use dual phase Xenon detectors ...

- good solution for medical imaging ?
- involved complementary technical solutions to the one we are working on

Exciting idea to work in parallel on DM and Medical Imaging with common instrumentation and method