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D_R&D_6 Liquid xenon detector technology

XEMIS project: a liquid Xenon detector for medical imaging

Alain MERY

postdoc, Subatech, Nantes



*Workshop FJPPL'08
May 15-16, 2008, Paris, France*

Outline :

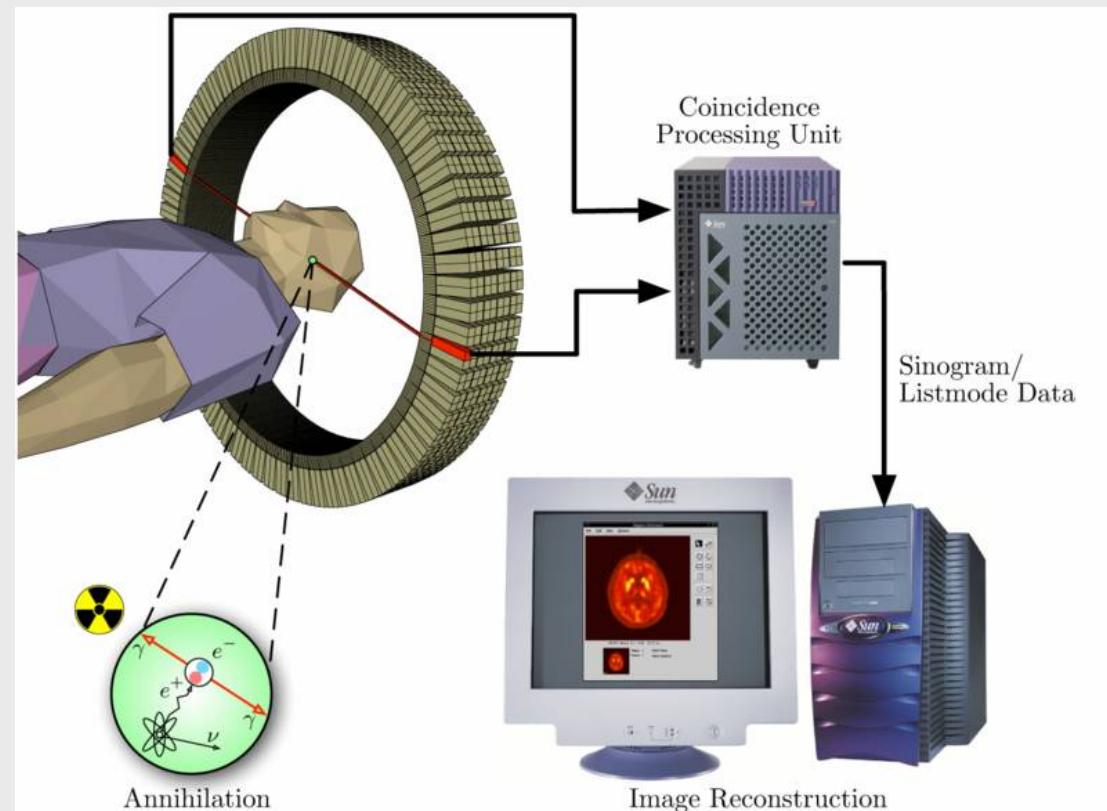
- ▶ Introduction : medical imaging - PET
- ▶ 3γ imaging with LXe
- ▶ XEMIS prototype
- ▶ Experimental results
 - cryogenics
 - detection
- ▶ Conclusion and outlooks

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Introduction: Positron Emission Tomography (PET)

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- Injection of radiotracers (β^+ emitters) ex: ^{18}F -FDG, $T_{\frac{1}{2}} = 2$ hours, $T_{\beta\max} = 633$ keV)
- Detection of 511 keV γ 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 ?

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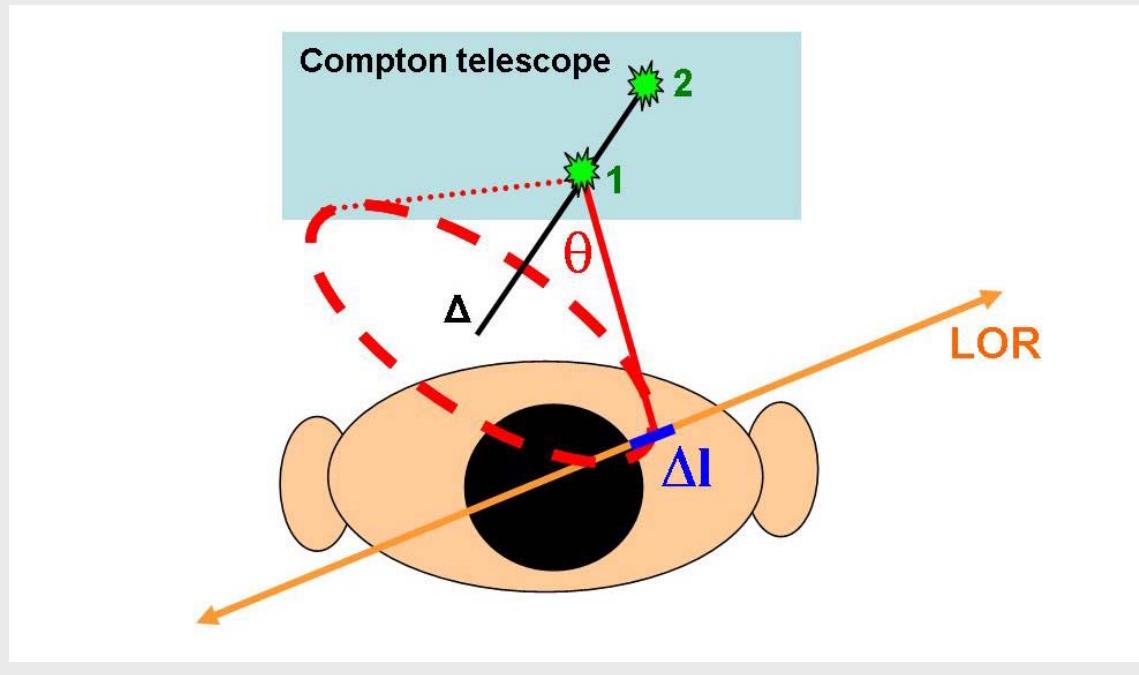
3 γ medical imaging

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Principle : - $\beta^+ \gamma$ emitter (^{44}Sc from Arronax cyclotron (sep. 2008) :

$$T_{\frac{1}{2}} = 4 \text{ hours}, T_{\beta\text{max}} = 1474 \text{ keV}, E_\gamma = 1157 \text{ keV}$$

- classical PET + Compton telescope
- LOR + γ incident direction - cone (Δ, θ)
 - 3D reconstruction event by event
 - ⇒ reduction of the incertitude position along the LOR



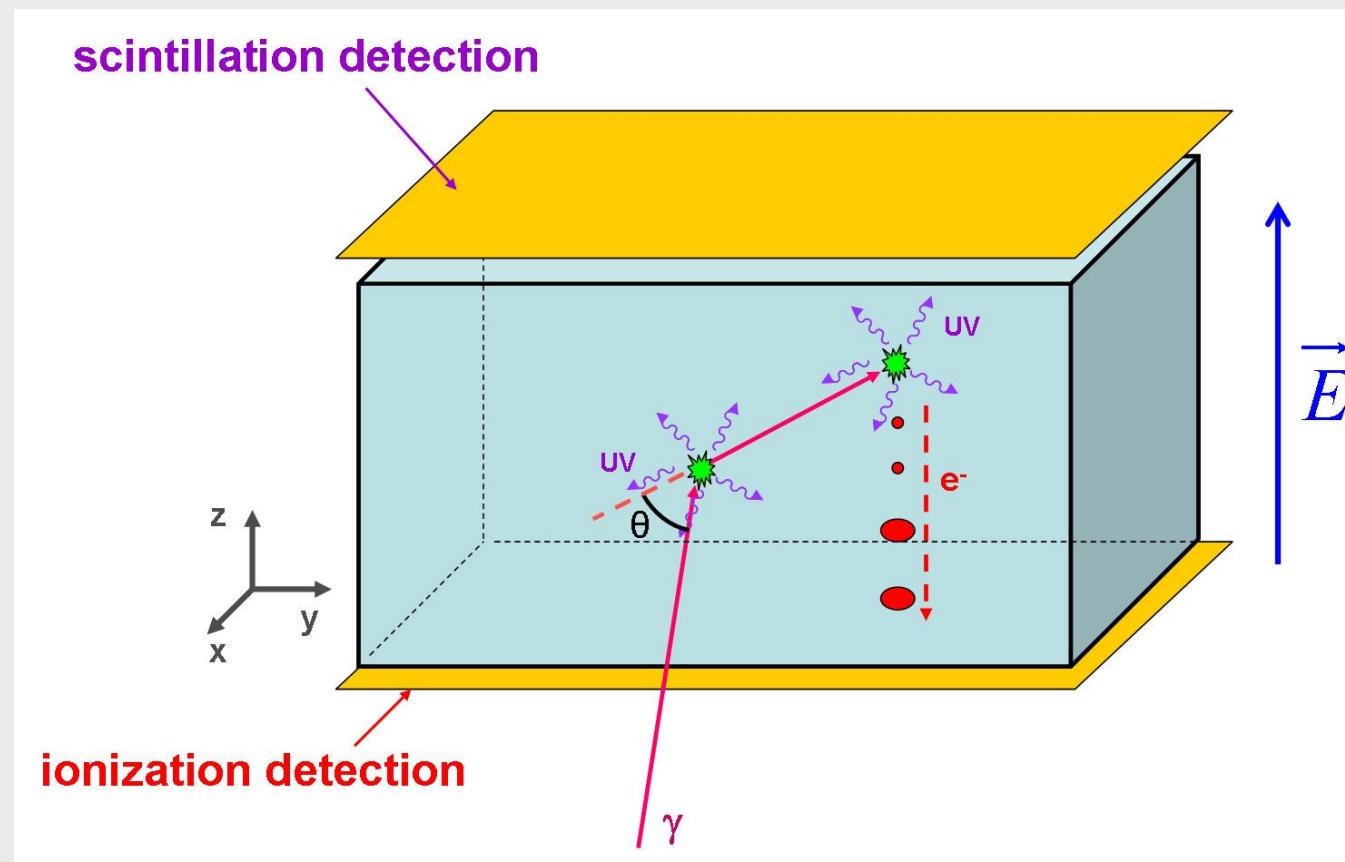
Compton telescope

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Precise measurement of :
- energy
- 3D position

for each vertex

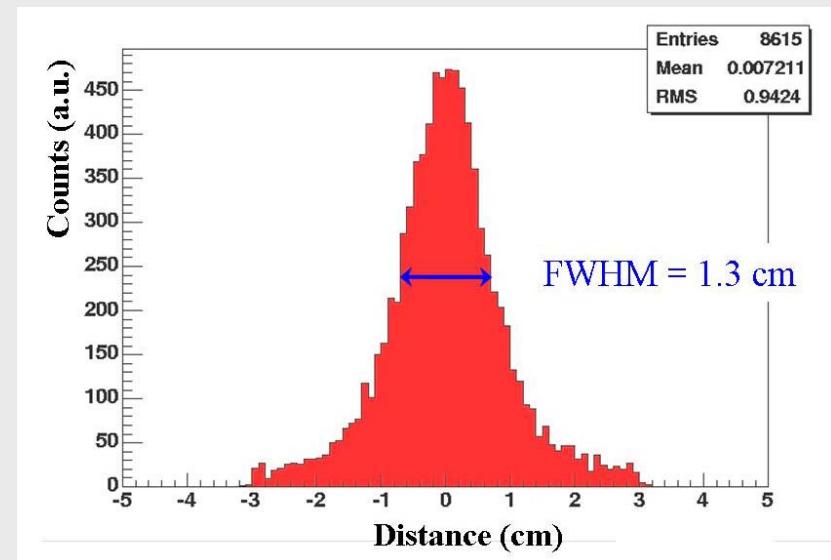
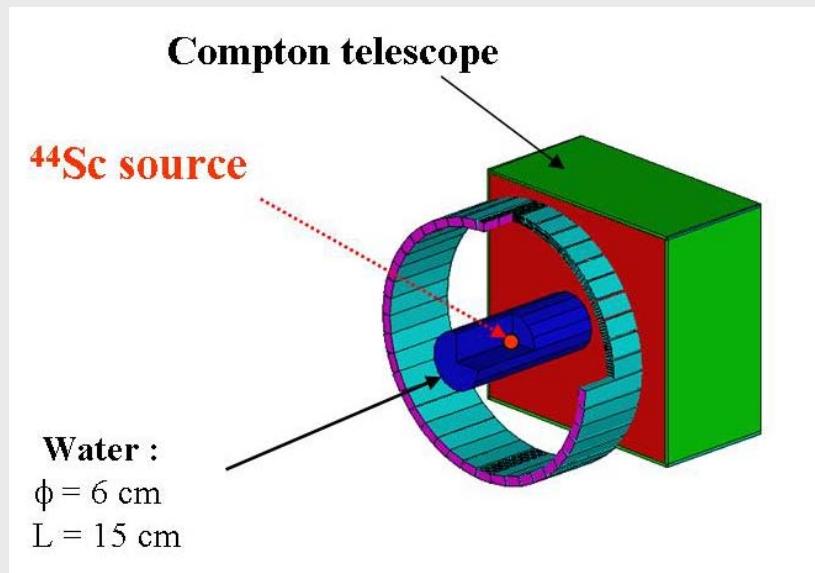
LXe telescope : scintillation and ionization signals



angular resolution of the telescope \Leftrightarrow energy and position resolutions

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
- no reconstruction algorithm

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■ Xenon liquefaction at low pressure (< 2 bars)

- gas→liquid transition : about -110°C

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

- precise temperature regulation

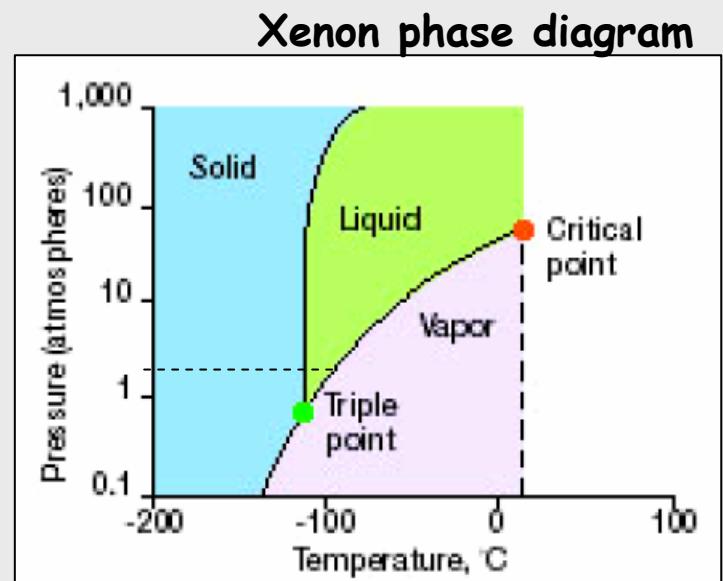
- cold head : Pulse Tube Refrigerator (see Prof. Tom Haruyama's talk)

■ Xenon purification

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

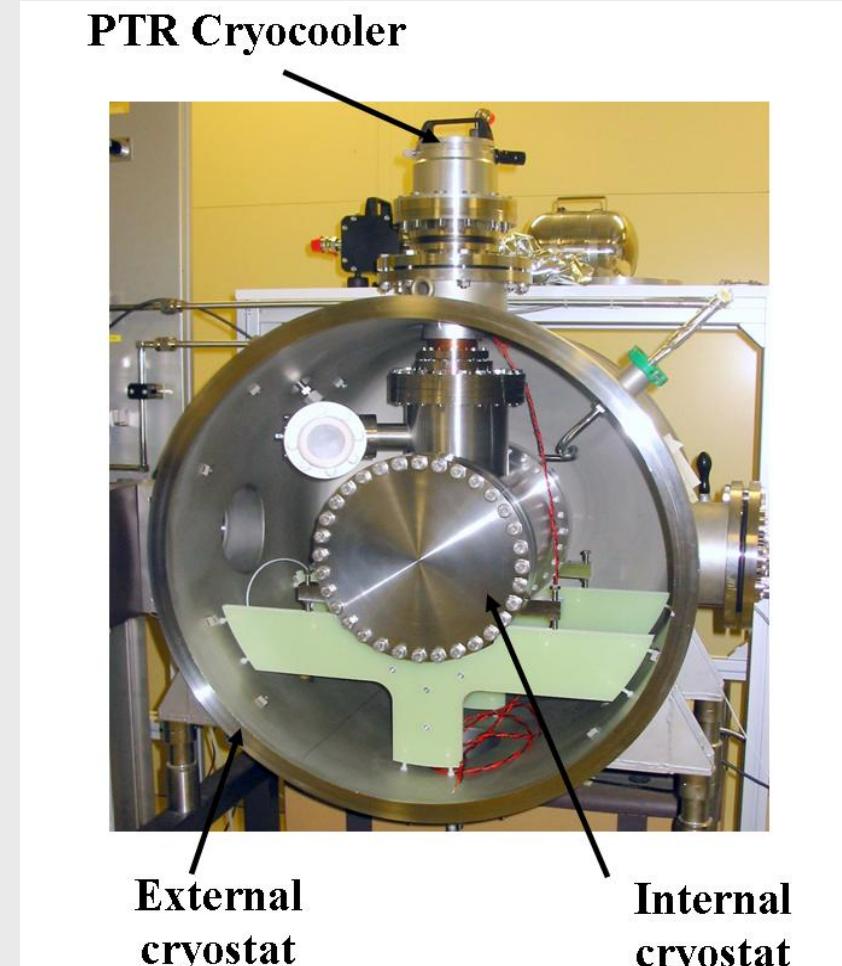
- gas purifiers

- gas circulation



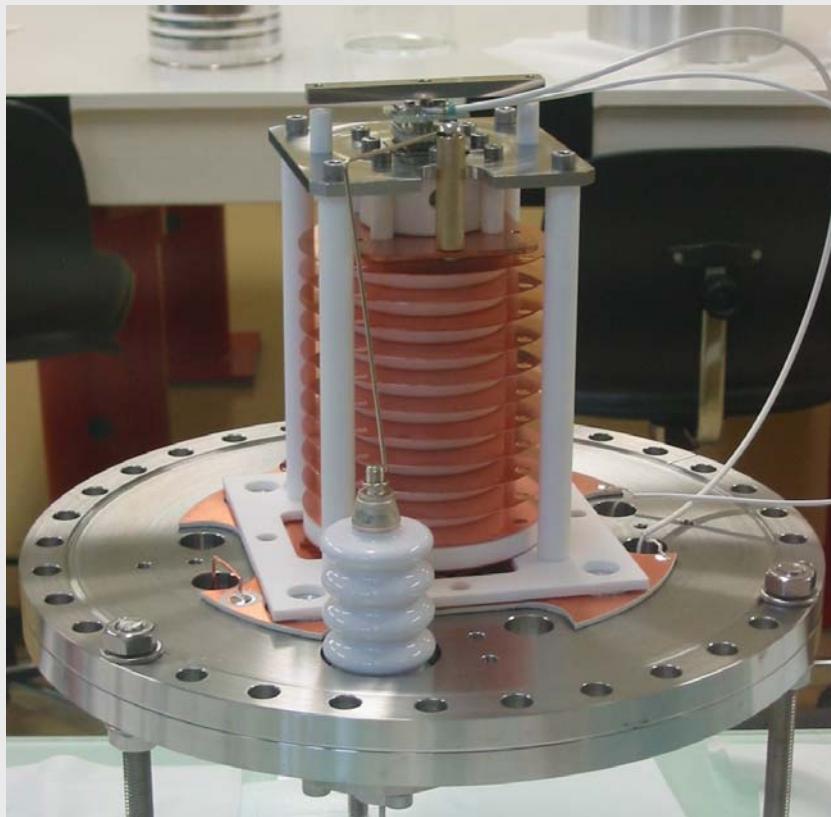
XEMIS prototype

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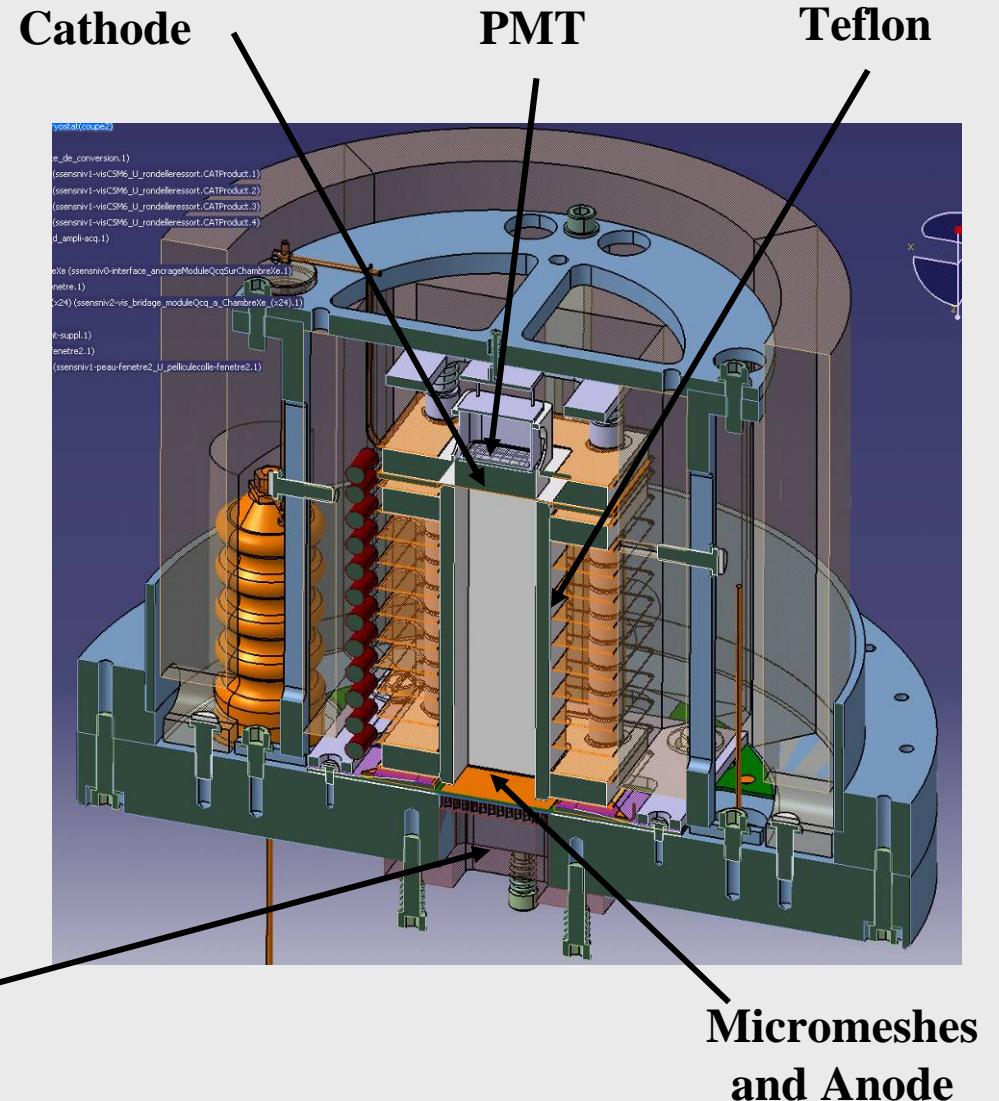


XEMIS prototype

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Entrance
window

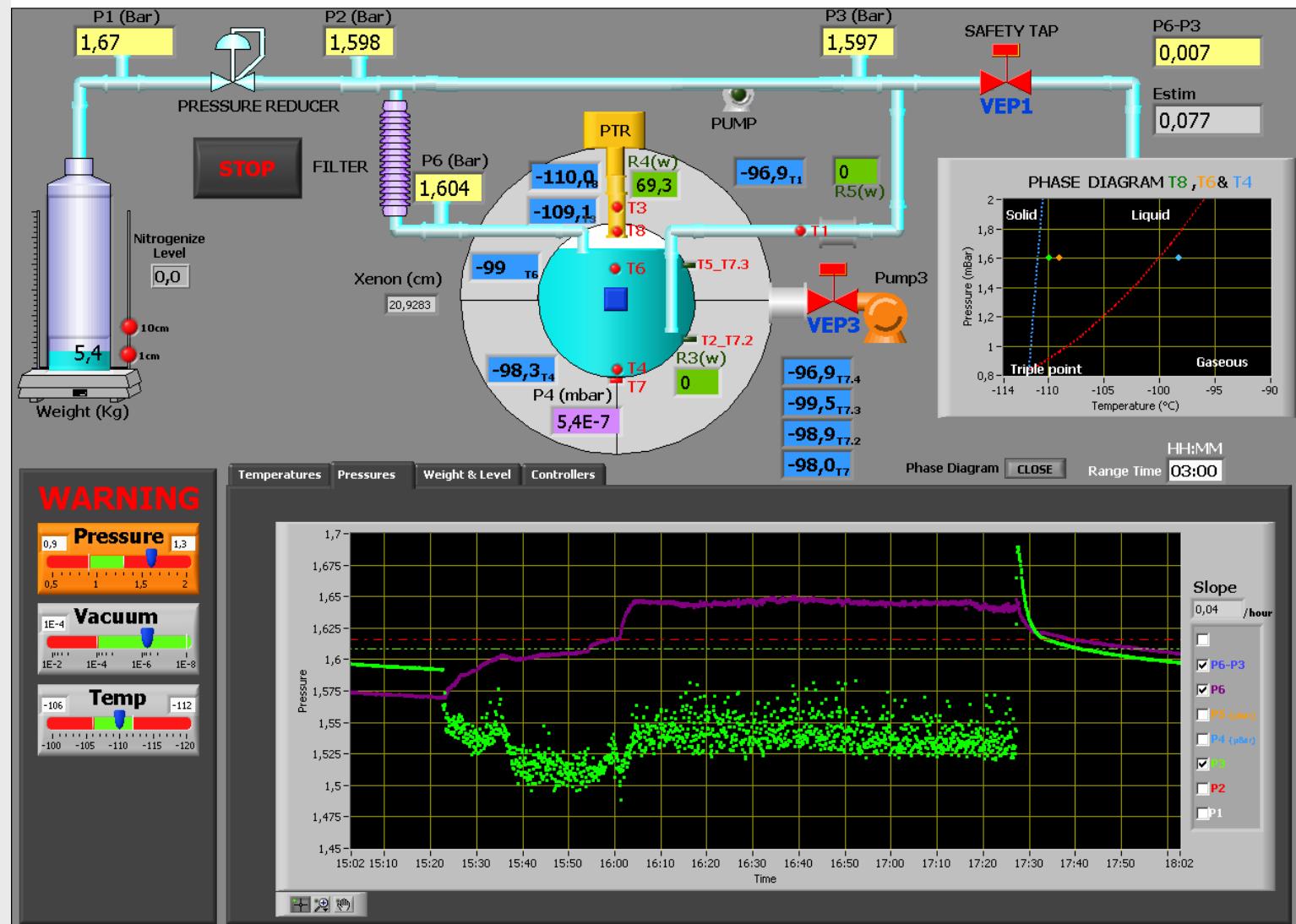


Micromeshes
and Anode

XEMIS prototype

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Control system : using Labview (E. Morteau)



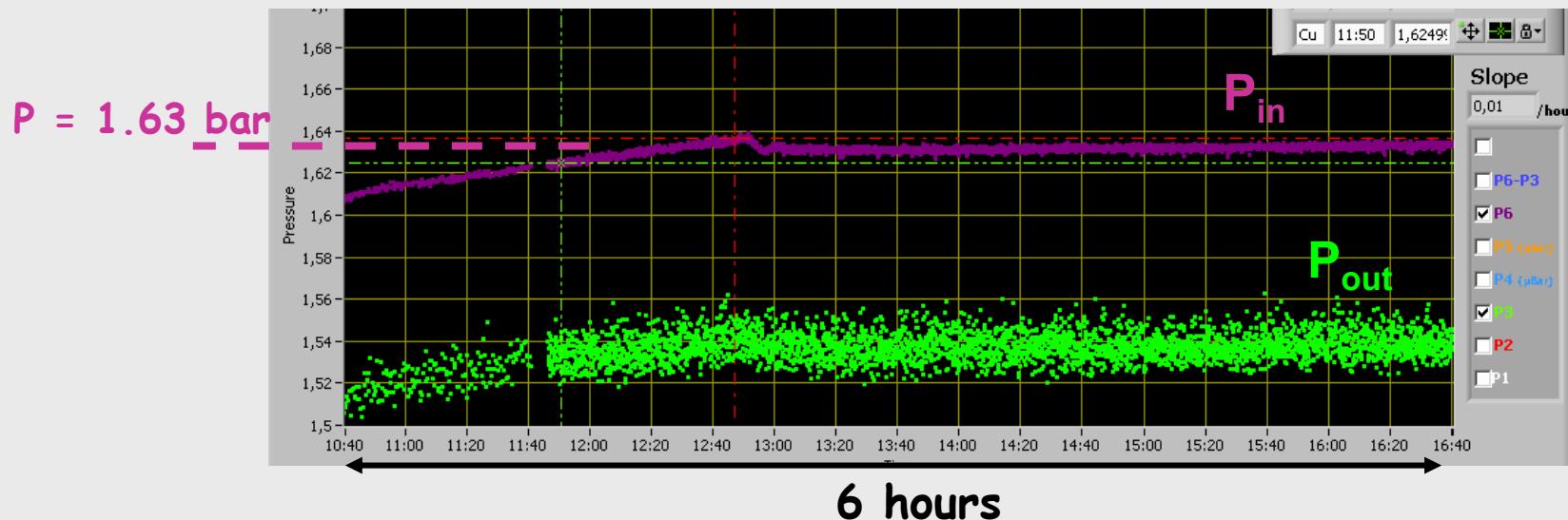
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Experimental results : cryogenics

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April 2008:

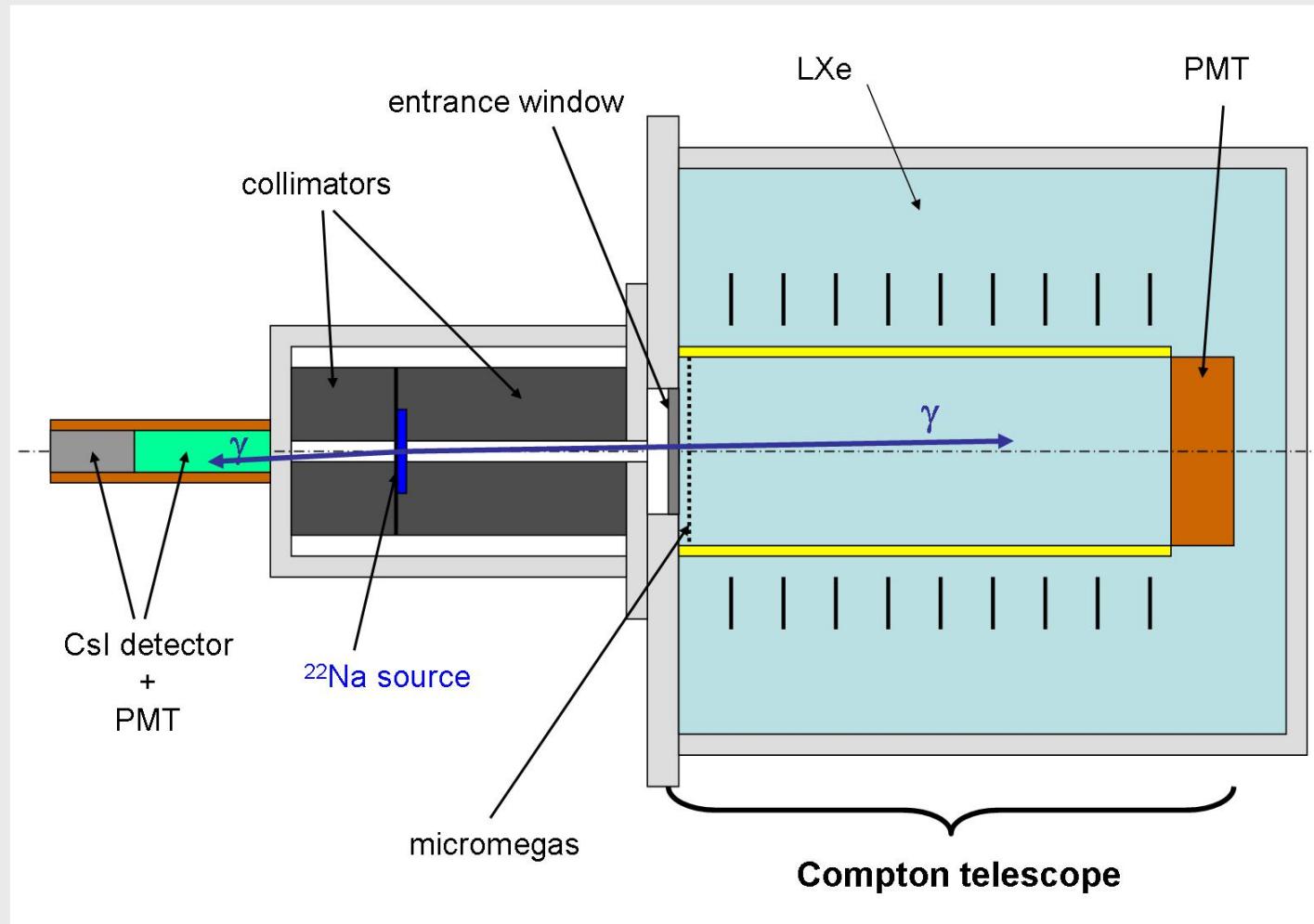
- Liquefaction of 30 kg of Xe @ P=1.63 bar
 - need for a long pre-cooling period of the cryostat
 - new heat-exchanger geometry
 - liquefaction rate : about 1.5 kg / hour
- circulation and purification
 - validation of vaporization tube and pump (from KEK)
 - estimated flow : 1 kg / hour
 - stable operation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



Experimental results : detection

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



External trigger = CsI detector

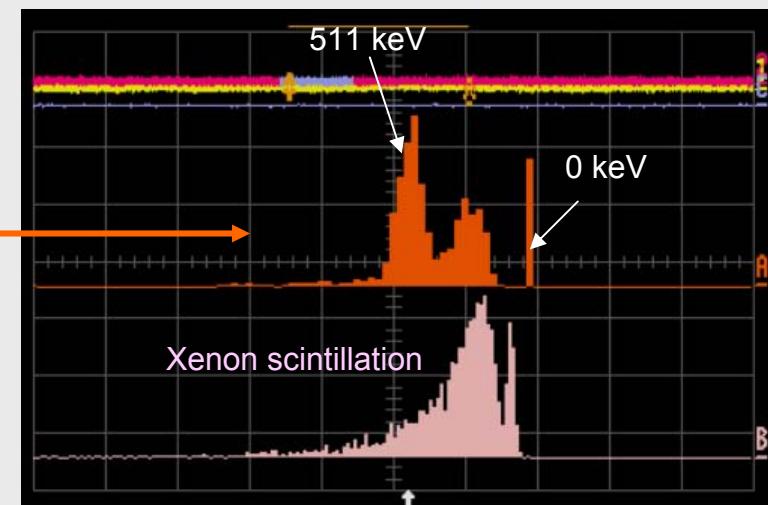
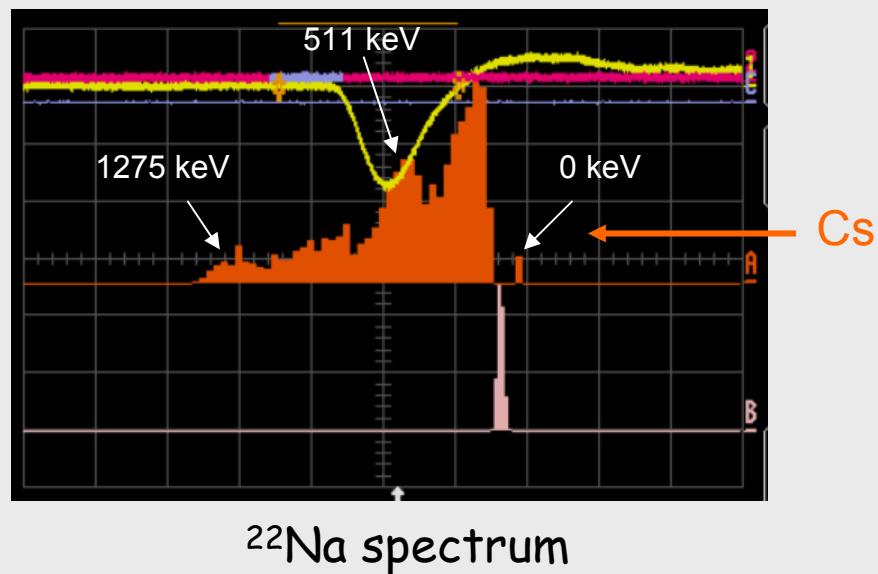
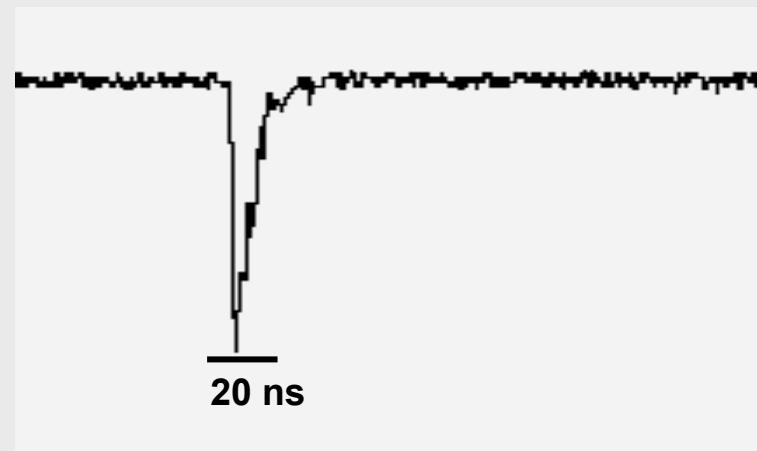
Experimental results : detection

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Typical scintillation signal from PMT:



PMT Hamamatsu



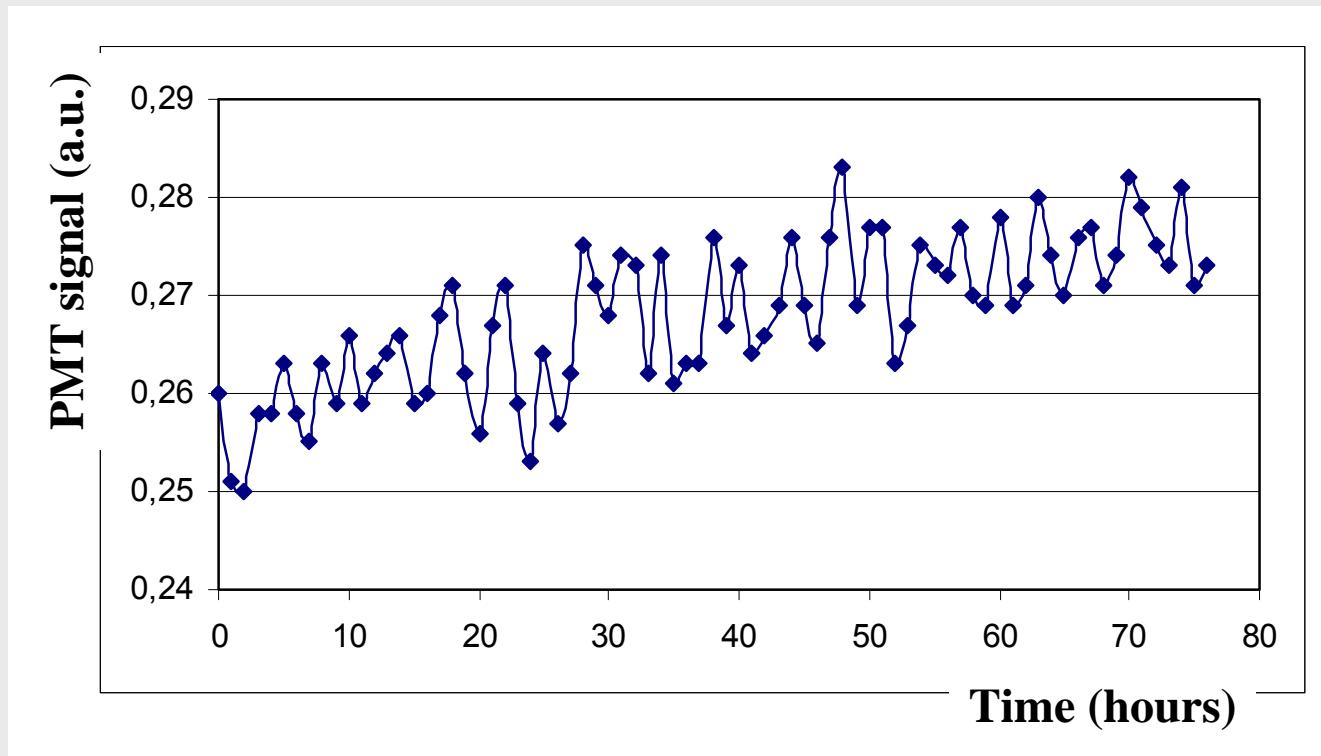
Coincidence with Xenon PMT
possible coincidence window on 511 keV (CsI)

⇒ Evidence of 511 keV γ detection in LXe

Experimental results : detection

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Purification effect on scintillation signal :



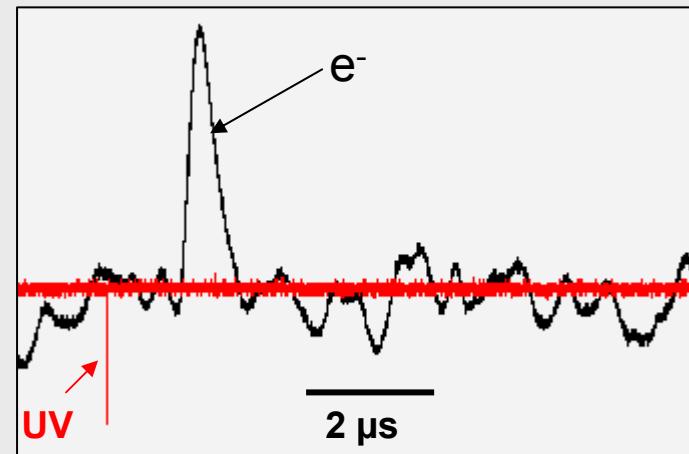
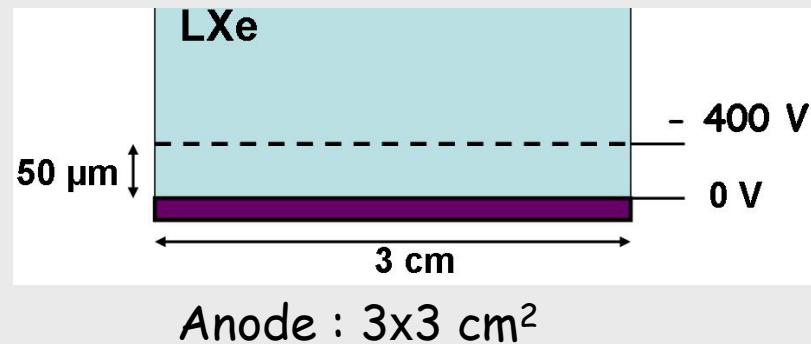
Continuous signal improvement on PMT : ~ 6% in 3 days (preliminary)

→ Similar tests with charge collection...

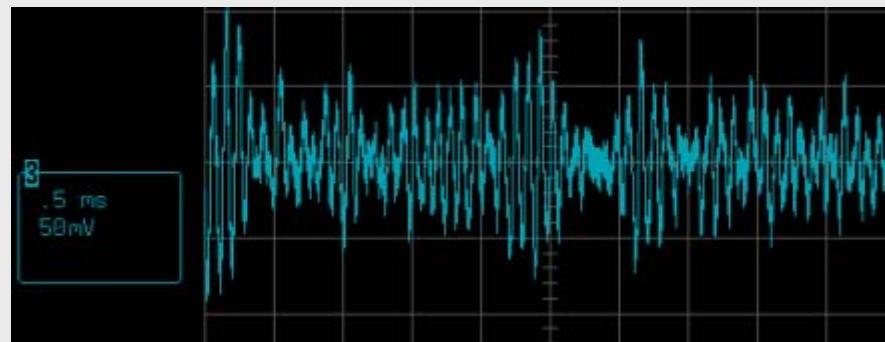
Experimental results : detection

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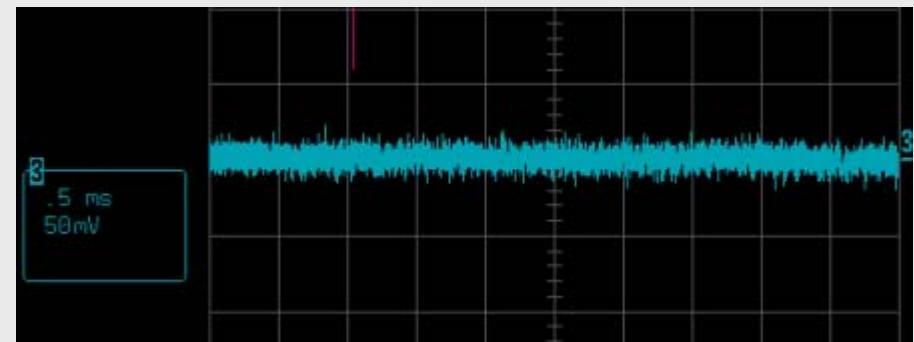
Ionization signal on anode :



Electronic noise on anode :



mechanical vibrations from PTR

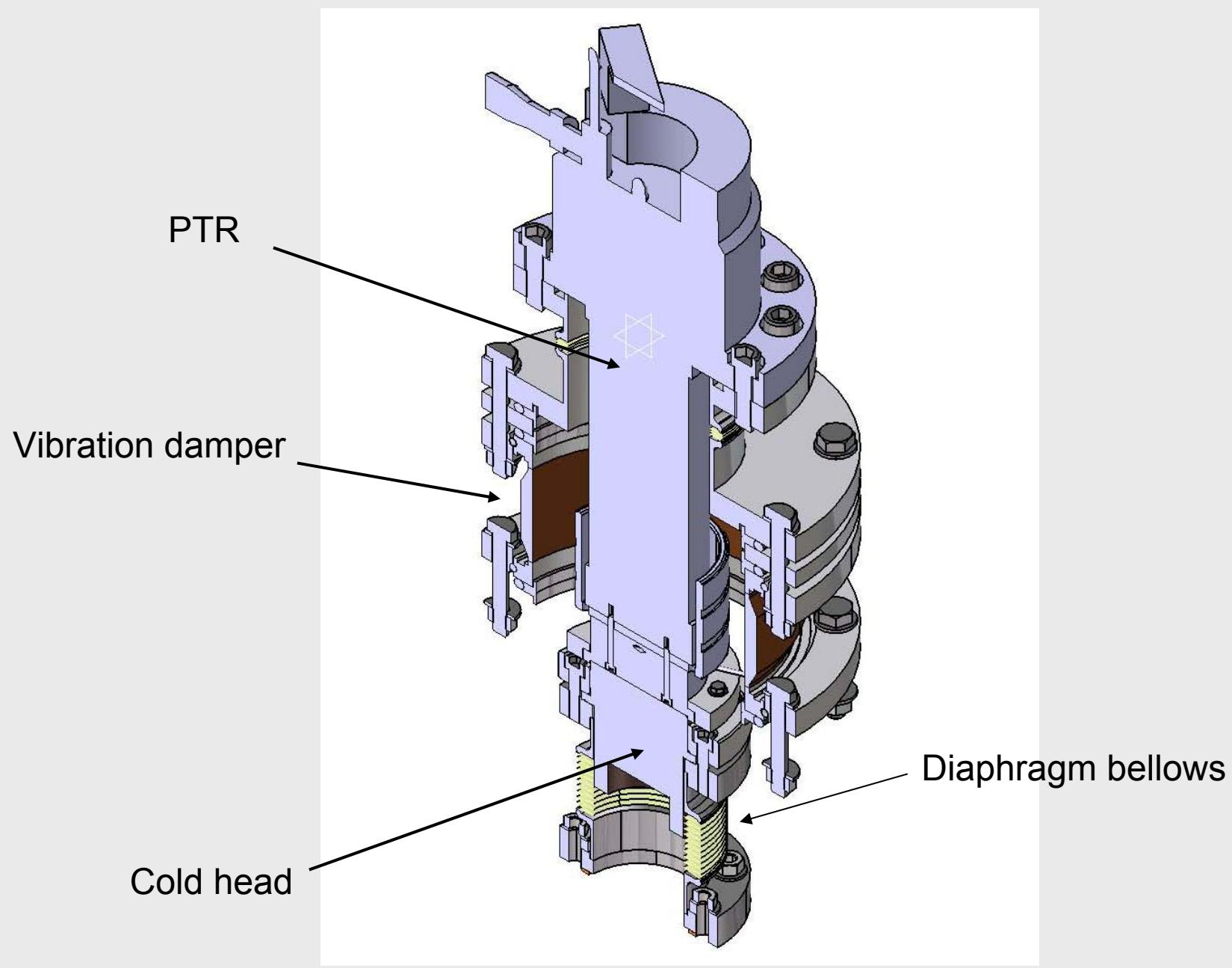


anode noise : ≤ 3000 e⁻ with PTR OFF

⇒ important modification on PTR support

PTR isolation

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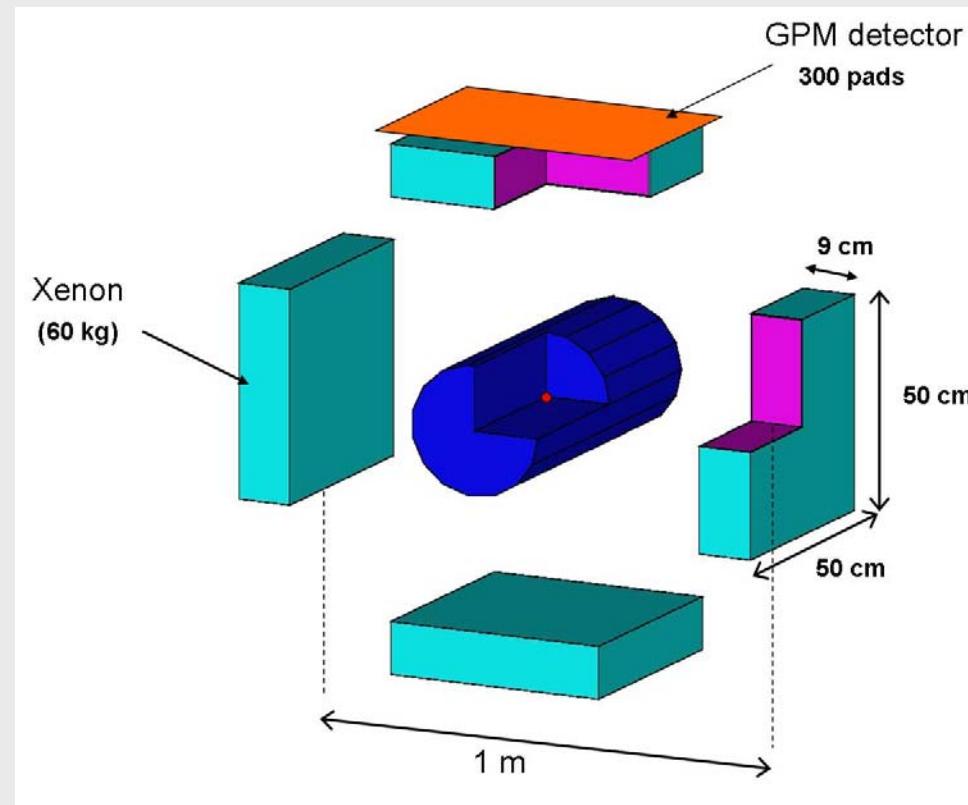
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XEMIS prototype

- cryogenic : 'almost' validate 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 :
 - scintillation : first promising observations
 - ionization : noise reduction → vibration damper on PTR

Classical PET with LXe :

- only scintillation signal
- large volume $\Rightarrow \begin{cases} \text{high sensitivity} \\ \text{large field of view} \end{cases}$



GPM : Gas PhotoMultiplier
[Breskin, [NIMA 530, 2004](#)]

reduction of :

- ▶ duration of medical exam
- ▶ injected activity for patient

→ Simulations are very promising...

XEMIS team :

Dominique Thers

Jean-Pierre Cussonneau

Eric Morteau

Patrick Le Ray

Cyril Grignon

Samuel Duval

Noel Servagent

Alain Méry

Tom Haruyama



mainly founded by :

