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

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Collaborations

KEK (Japan): LXe cryogenic system PTR

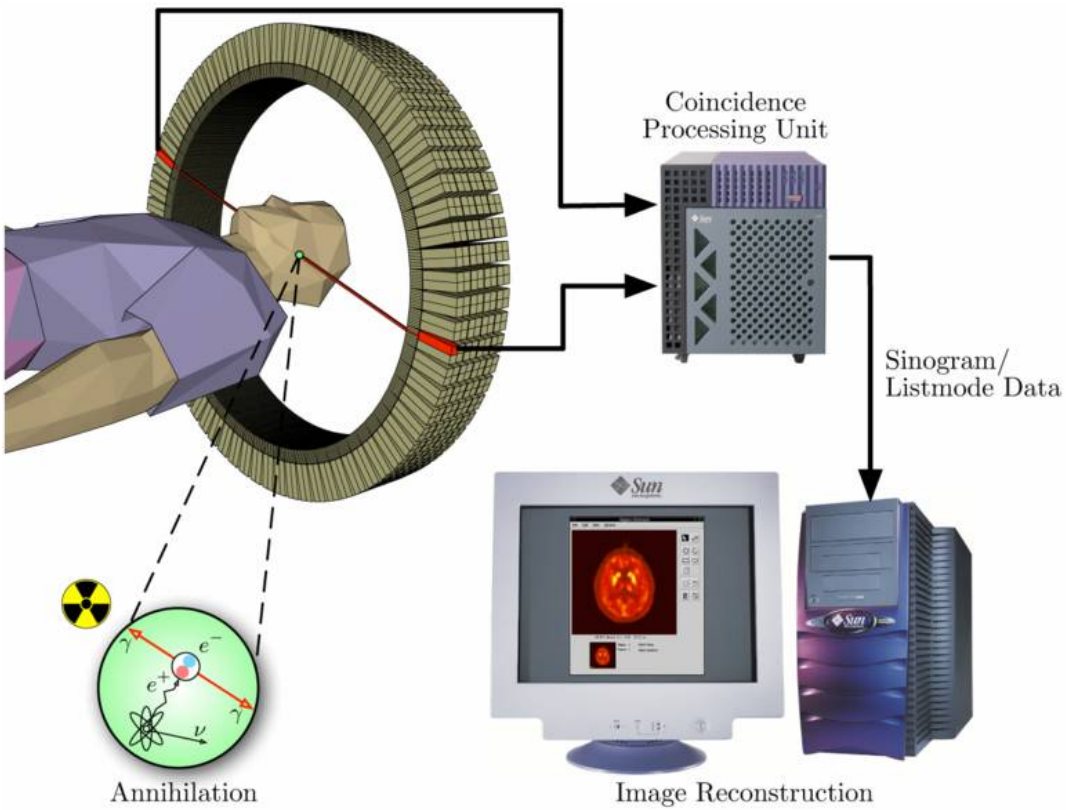
Weizmann Institute (Israel) : Gaseous Photo Multiplier (GPM)

Outline :

- Introduction : medical imaging – PET
- 3γ 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 (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 ?

3γ medical imaging

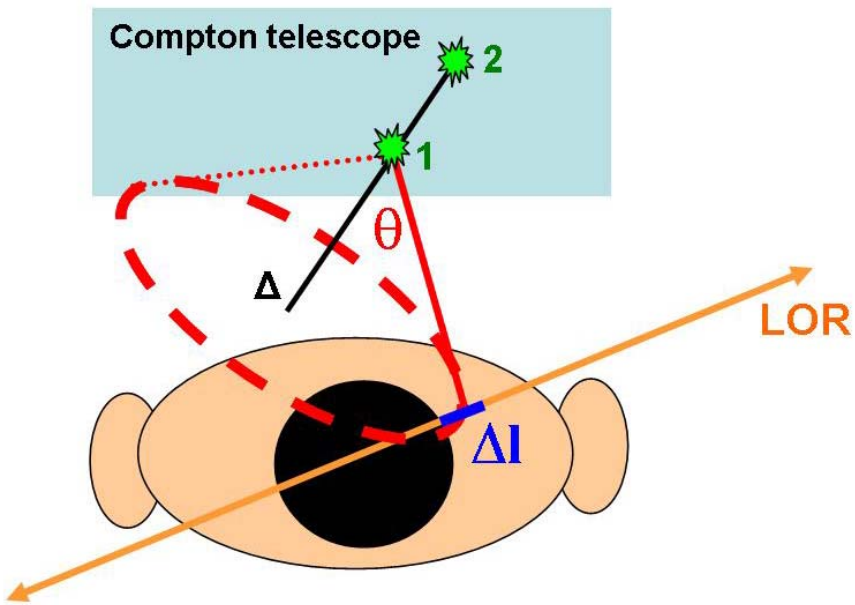
Principle : - β^+ γ emitter (^{44}Sc from Arronax cyclotron (sep. 2008)) :

- classical PET + Compton telescope

- LOR + γ incident direction - cone (Δ,θ)

$\rightarrow$ 3D reconstruction event by event

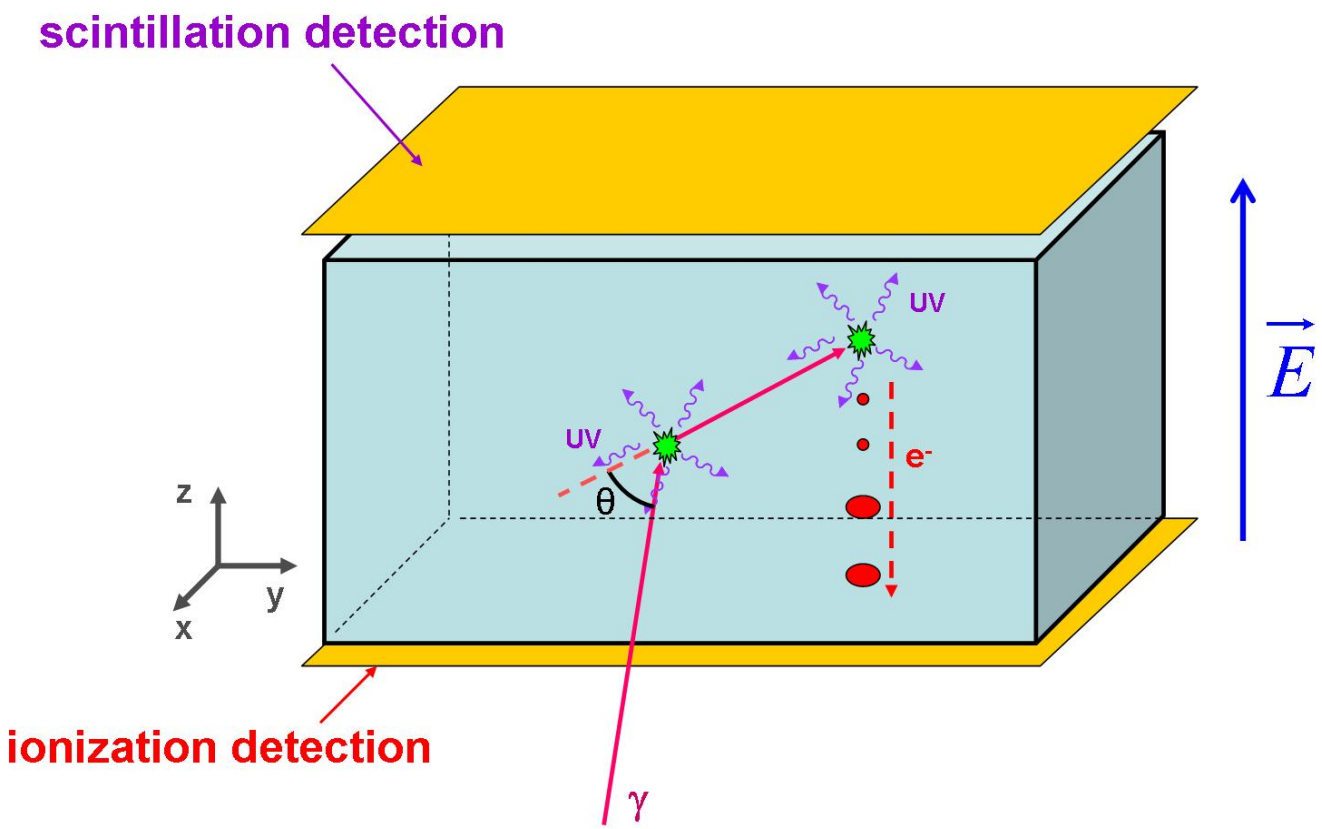
$\Rightarrow$ **reduction of the incertitude position along the LOR**



Compton telescope

Precise measurement of : { - energy for each vertex
- 3D position }

LXe telescope : scintillation and ionization signals

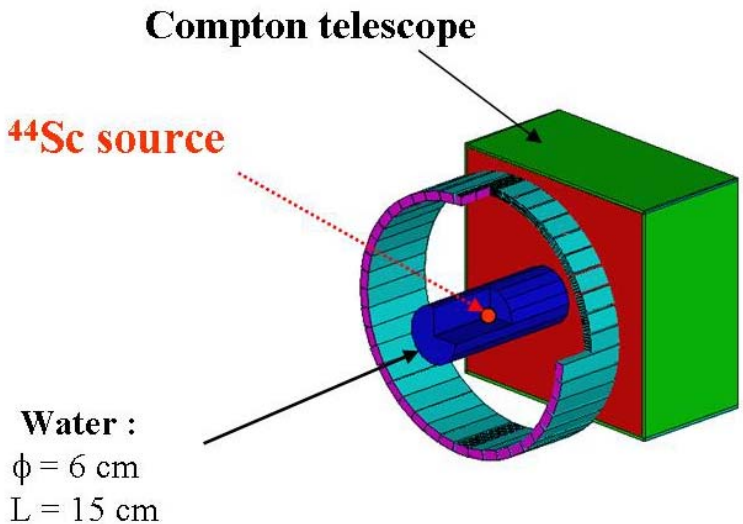


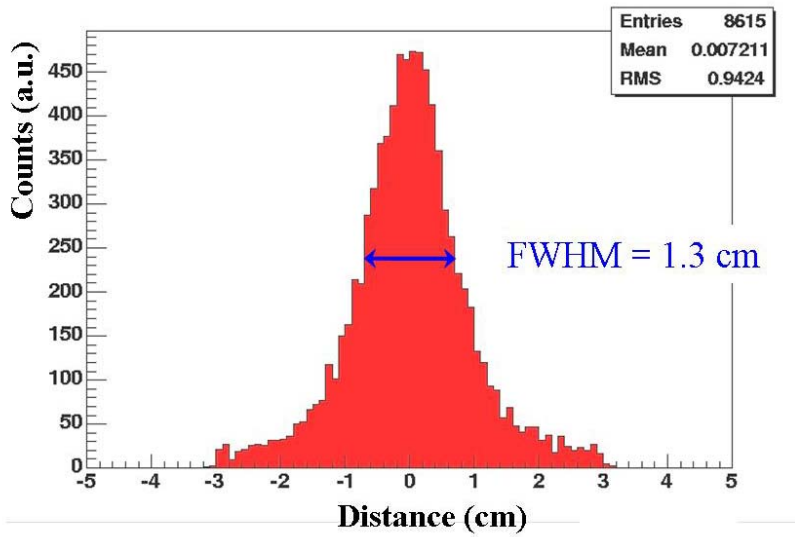
angular resolution of the telescope ⇔ energy and position resolutions

Simulation: Expected performances

Energy and position resolution : σ_E = 6 % @ 1 MEV [E. April, NIMA 480, 2002]

σ_{xy} = 1 mm , σ_z = 100 μm





[C. GRIGNON, PhD thesis, 2007]

→ position along the LOR : $\Delta L < 1.5$ cm for small animal imaging

→ image can be improved using reconstruction algorithm (under progress)

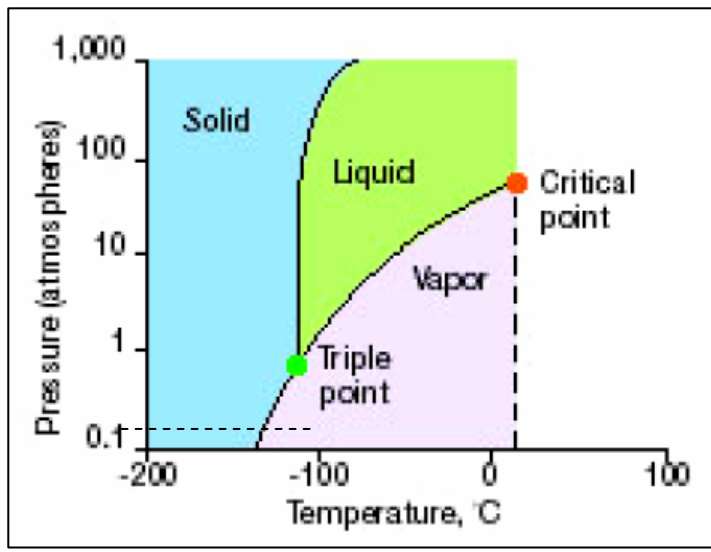
LXe technology @ Subatech

- Xenon liquefaction at low pressure < 2 bars (absolute)
  - gas→liquid transition : about -110 °C

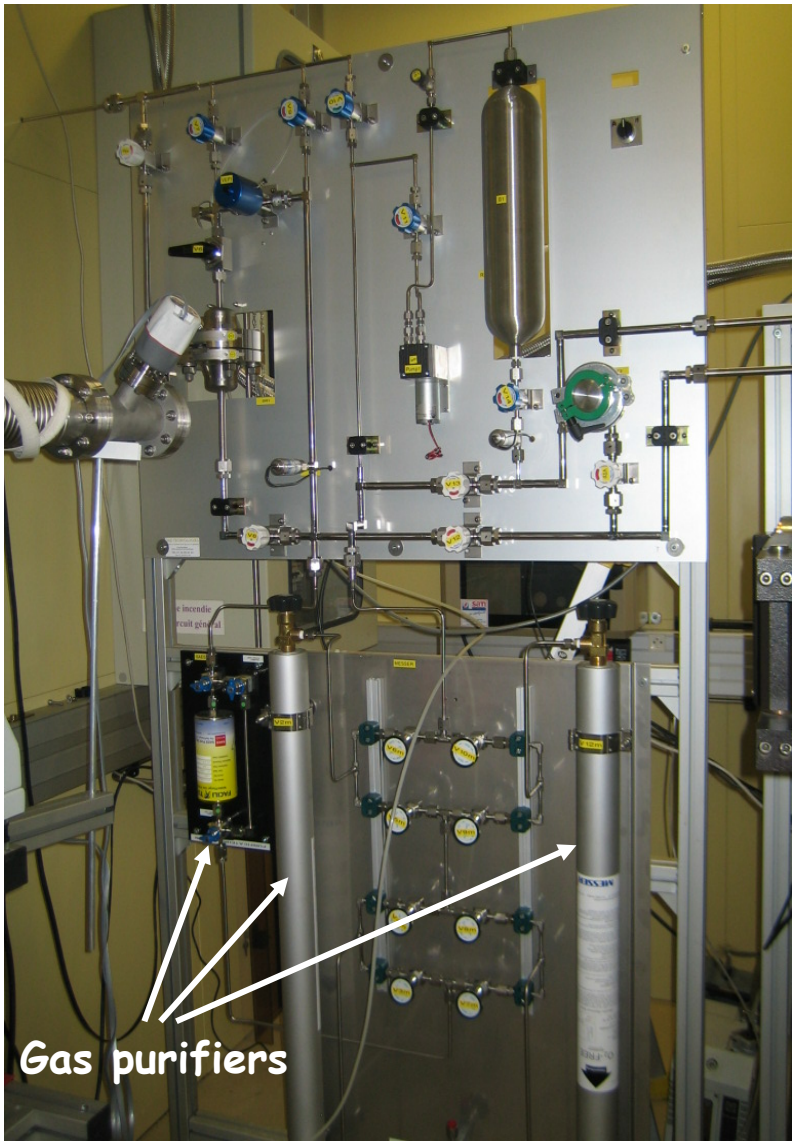
    ex: $T_{condensation}$ = -108°C and $T_{freezing}$ = -112°C for P = 1 bar
  - precise temperature regulation
  - cold head : Pulse Tube Refrigerator (developed @ KEK by T. Haruyama)

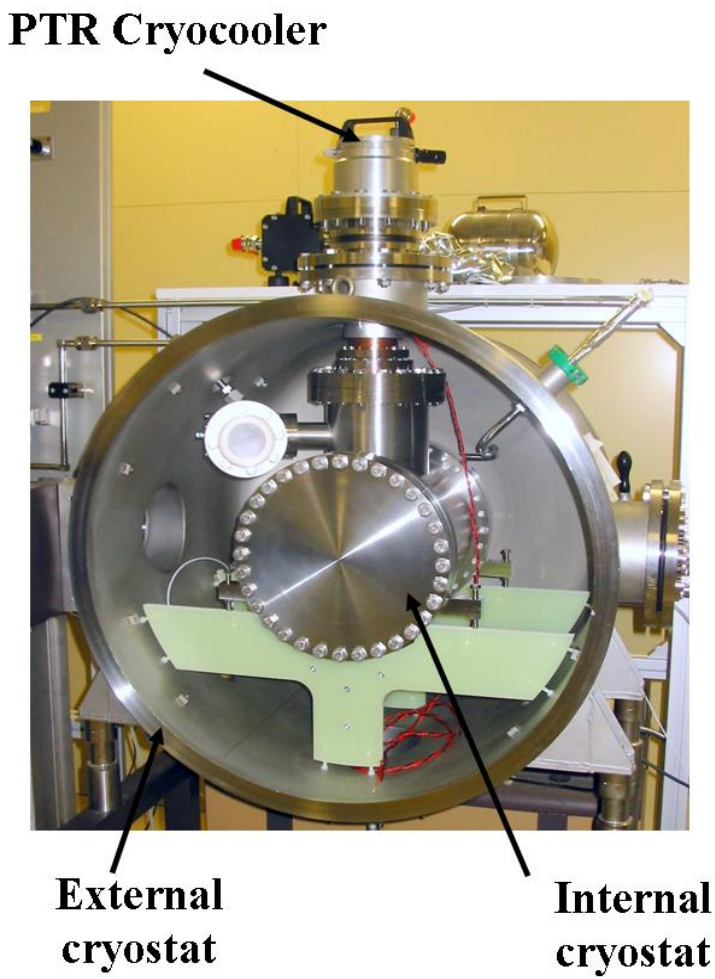
- Xenon purification
  - LXe purity level ~ 1ppb (O_2, H_2O, …)
  - gas purifiers
  - gas circulation

Xenon phase diagram



XEMIS prototype





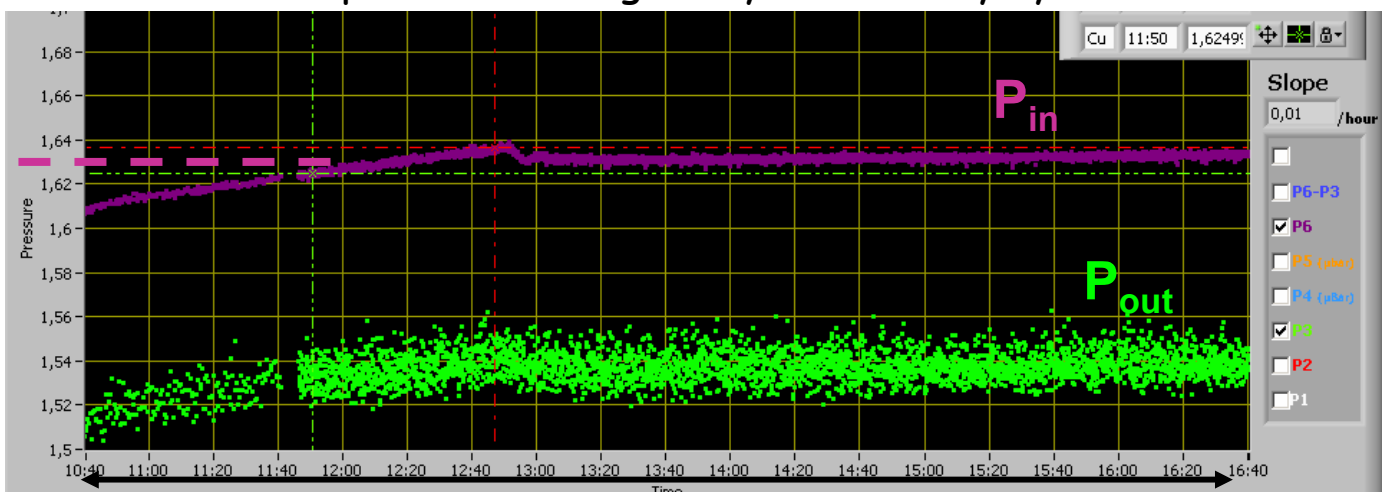
Cryogenics

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

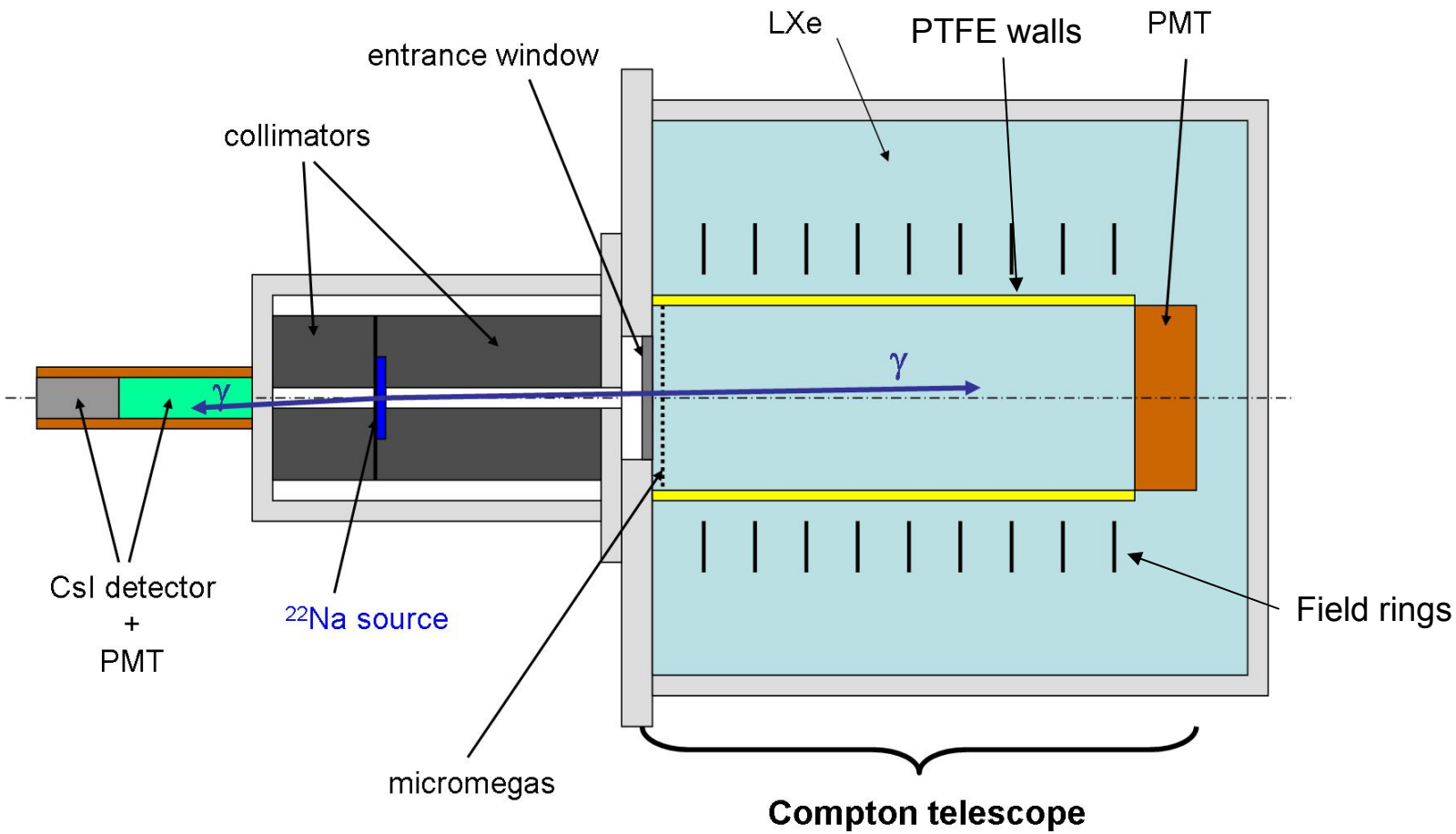
P = 1.63 bar



6 hours

Experimental setup

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

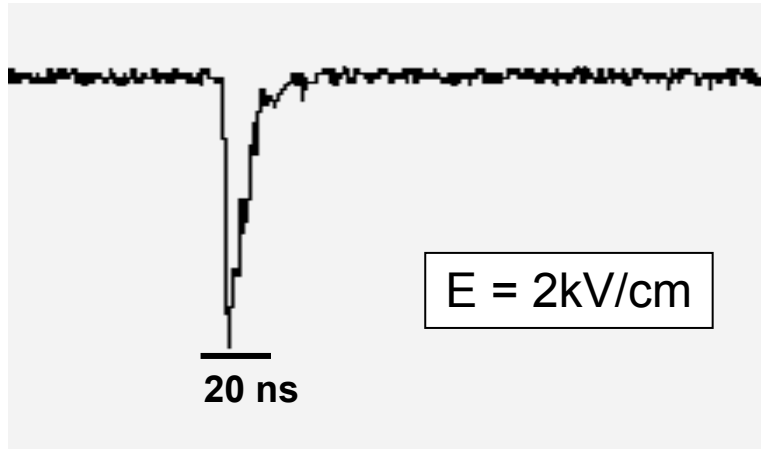


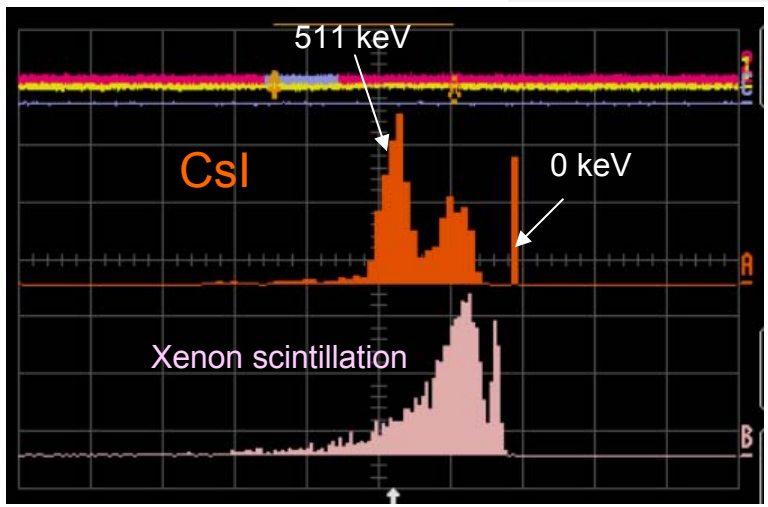
External trigger = CsI detector

Scintillation signal

Typical scintillation signal from PMT:

PMT Hamamatsu





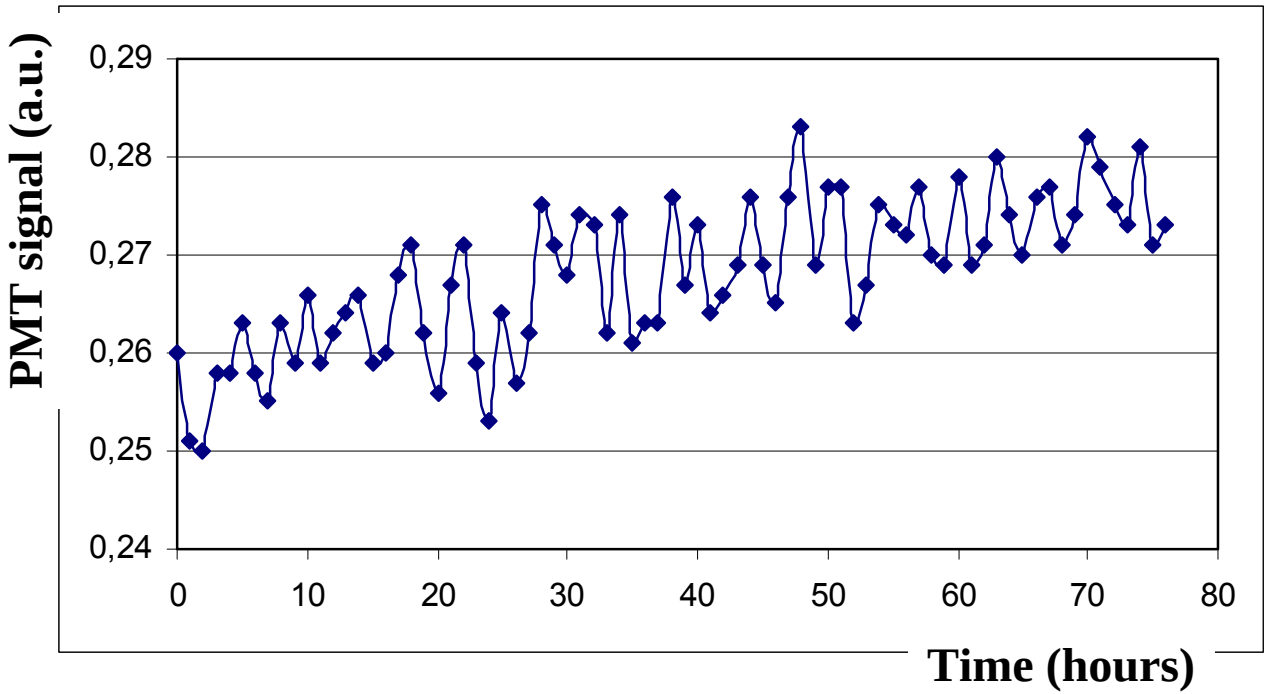
Coïncidence with Xenon PMT

⇒ window on 511 keV (CsI)

⇒ **Evidence of 511 keV γ detection in LXe**

Xenon purification

Purification effect on scintillation signal :

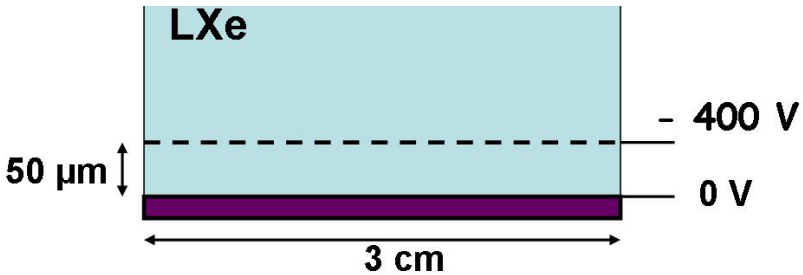


Continuous signal improvement on PMT : ~ 6% in 3 days (preliminary)

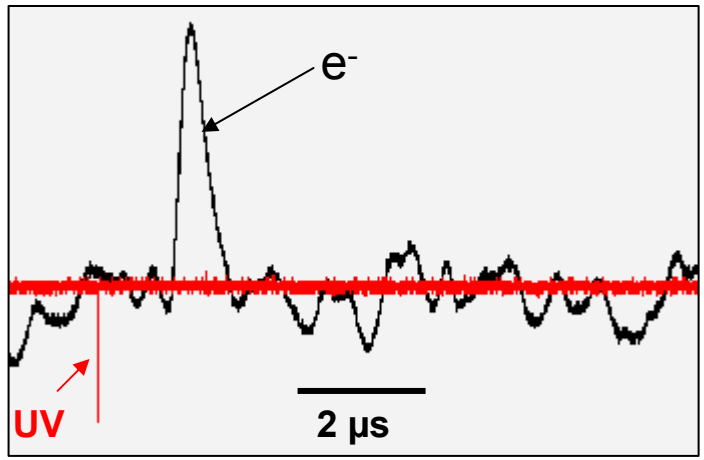
→ Similar tests with charge collection…

Ionization signal with micromegas

Ionization signal on anode (micromegas):

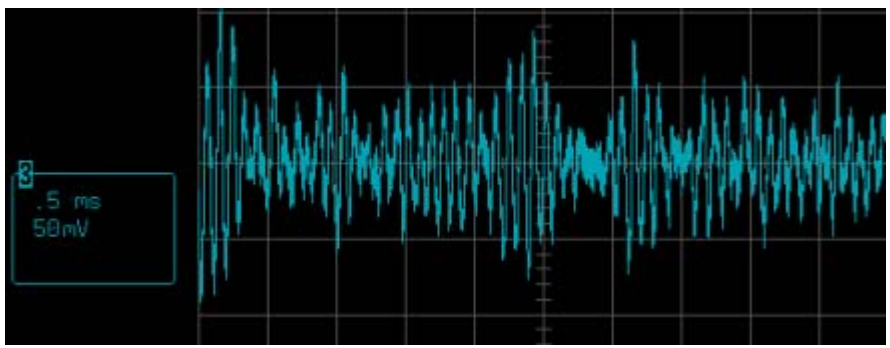


Anode : 3x3 cm²



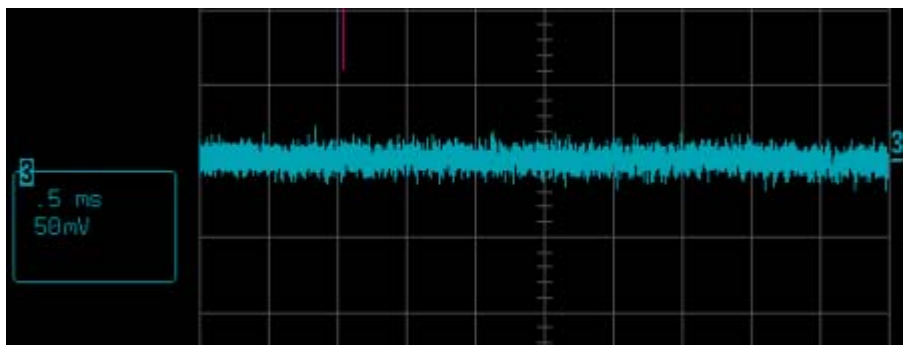
PTR OFF

Electronic noise on anode :



PTR ON

mechanical vibrations from PTR

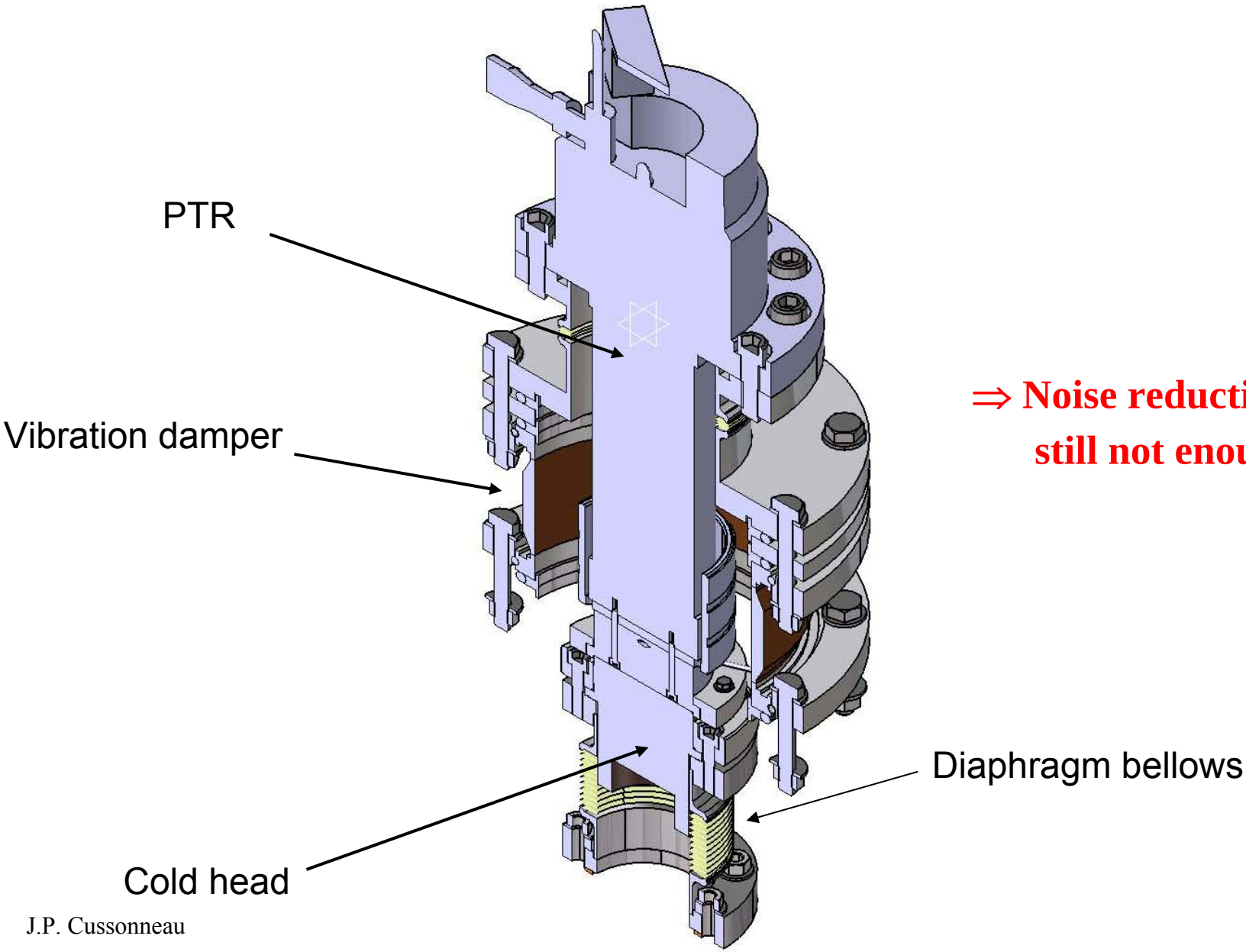


PTR OFF

anode noise : ≤ 3000 e⁻ with PTR OFF

⇒ important modification on PTR support

New PTR support april 2008



⇒ Noise reduction but still not enough

Conclusion on XEMIS prototype

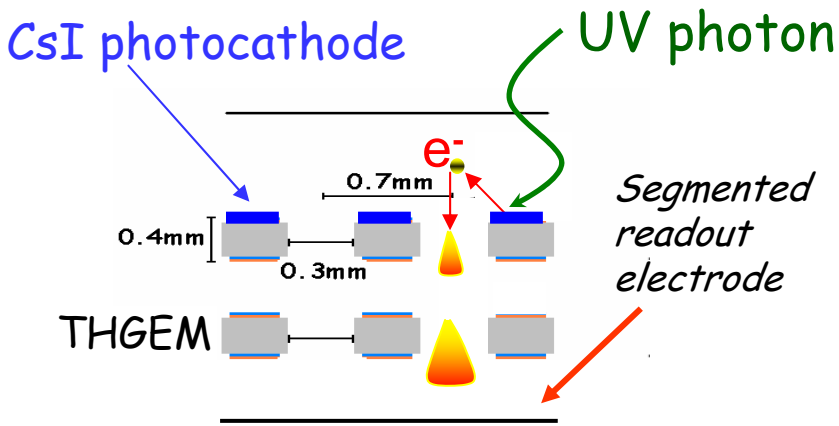
XEMIS prototype

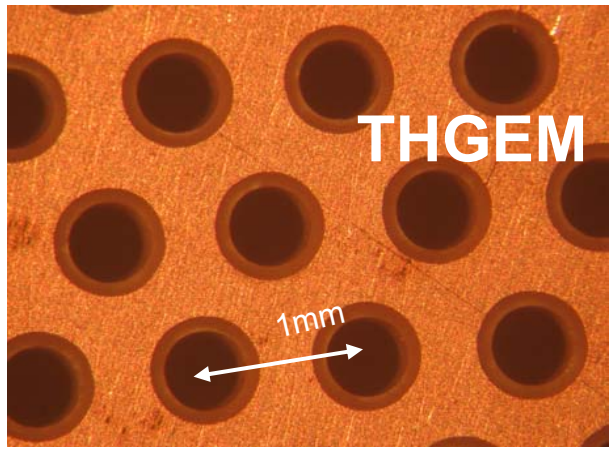
- cryogenic : 'almost' validated for larger device
  - 30 kg LXe inside the detector
  - safety recovering : OK
  - non human assistance : OK
  - circulation and purification :
    first stable operation for 6 days
    optimization under progress
  - investigation on cryogenics for human camera
    first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

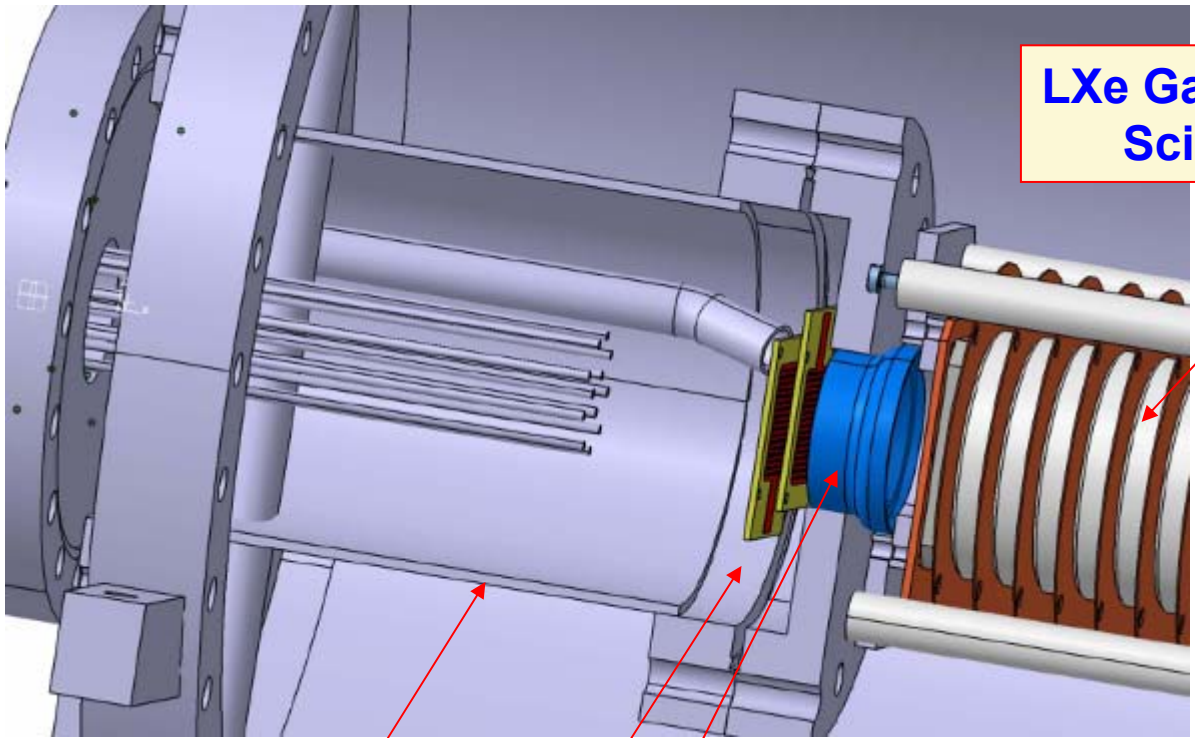
Developed @ Weizmann Institute

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

GEM/THGEM WORK IN CRYOGENIC CONDITIONS

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

GPM inLXe



LXe Gamma-interaction volume
Scintillation & ionization

GPM housing

THGEM GPM

MgF_2 window

Sealed GPM with semitransparent bialkali photocathode (WIS)

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