# MPGDs in Compton imaging with liquid-xenon

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Subatech

**Research group**

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Outline

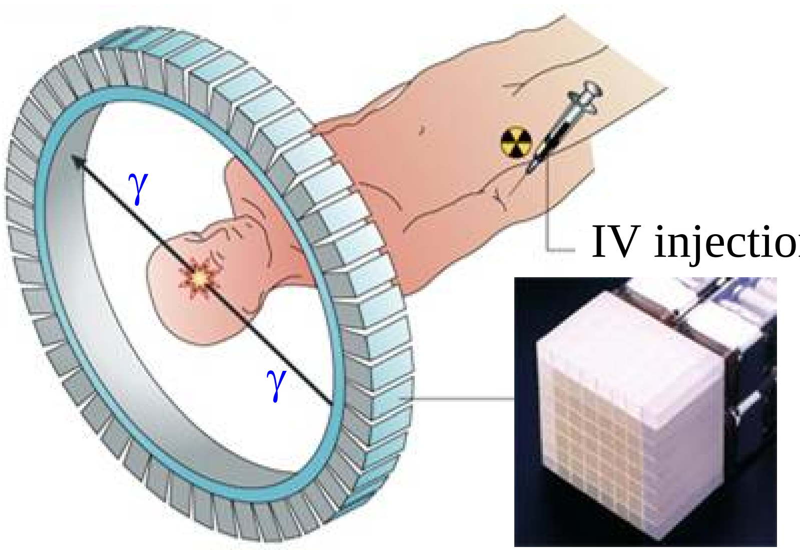
1. "3 $\gamma$ imaging"

2. XEMIS 1 : Compton Telescope prototype

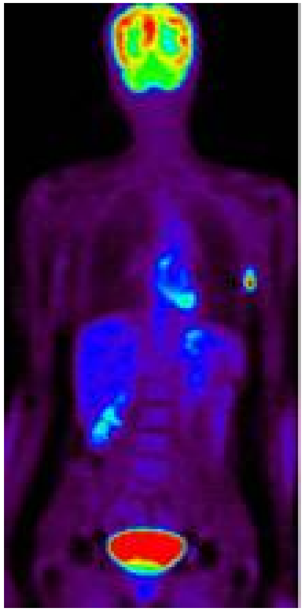
3. XEMIS 2 : demonstrator for small animal imaging

4. A large cryogenic UV-GPM

# Nuclear medical imaging (PET)




PET crystal ring = PMT + crystals coupled



**Quantification is a real challenge in medical imaging**

~~Reconstruction algorithms~~

# 3 γ imaging

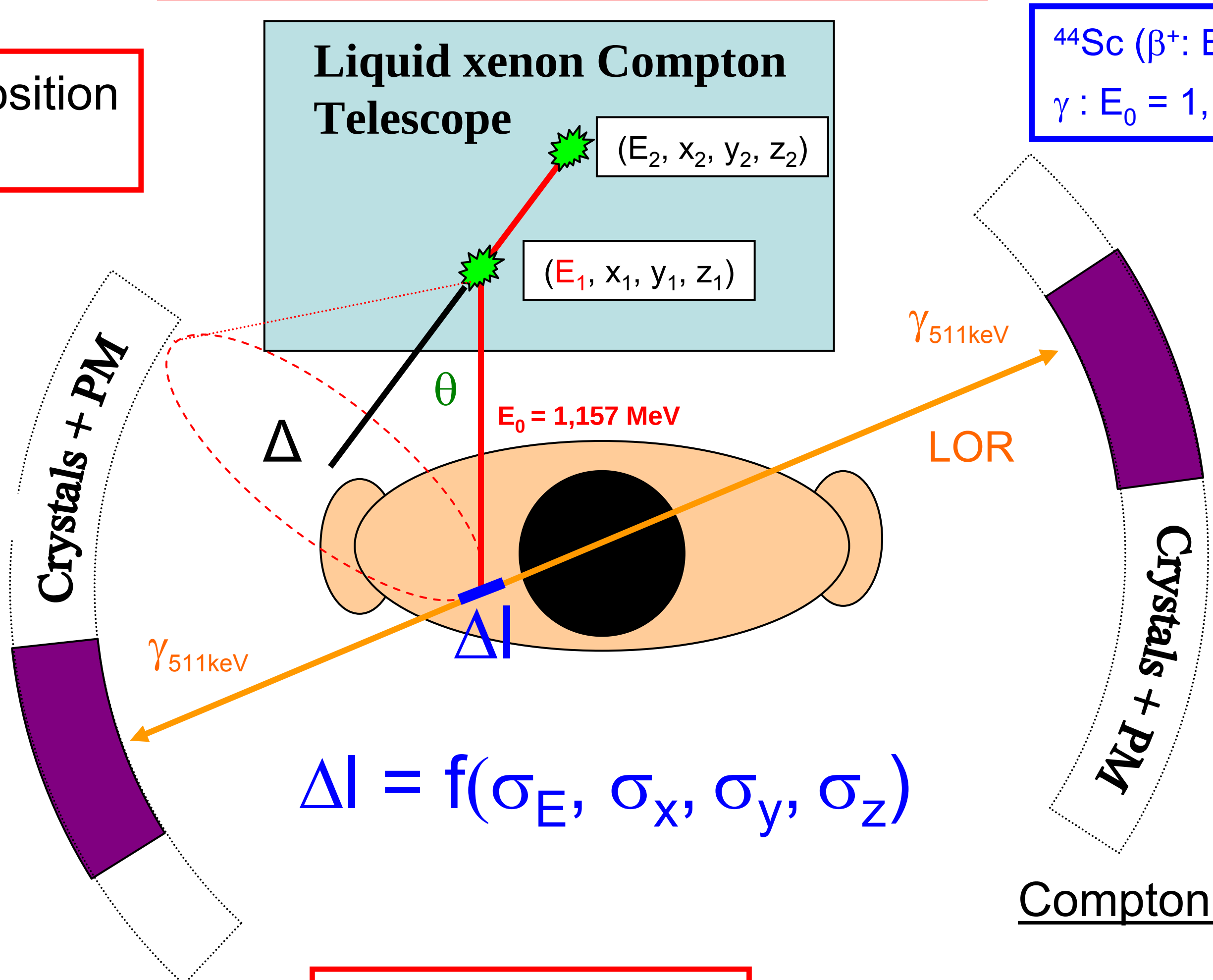
Real-time imaging i.e. event by event

Two first hit position (x, y, z)

↓

Δ

$^{44}Sc$ ($\beta^+$: $E_{max}$ = 1,474 MeV, $\gamma$ : $E_0$ = 1,157 MeV)




$$\Delta l = f(\sigma_E, \sigma_x, \sigma_y, \sigma_z)$$

<u>Compton diffusion :</u>

First hit energy = θ → $$\cos \theta = 1 - m_e c^2 . \frac{E_1}{E_0(E_0 - E_1)}$$

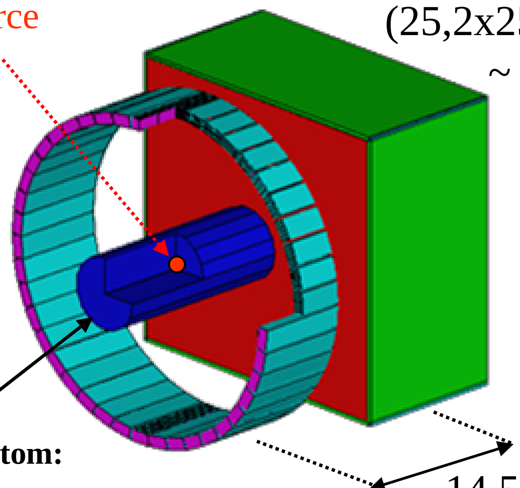
# Simulation results of « 3γ imaging »

## for small animal imaging

**Monolithic LXe Compton Telescope**

Point-like $^{44}Sc$ source

$(25{,}2 \times 25{,}2 \times 12\,cm^3)$ ~ 7,5 L



**Rat water phantom:**
ϕ = 6 cm
L = 15 cm

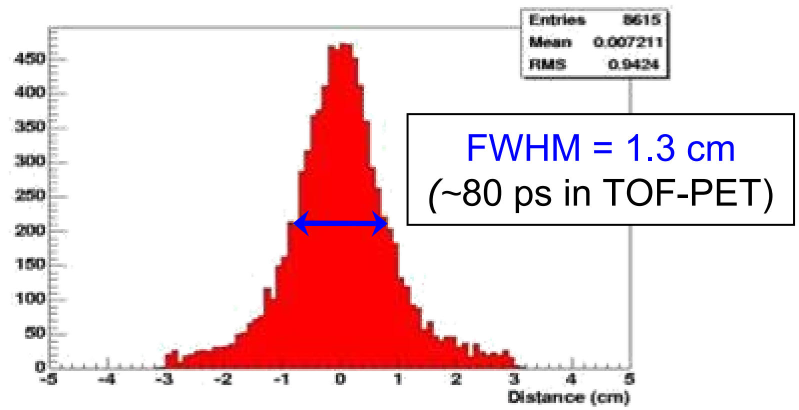
14,5 cm

**μPET (LSO) for LOR measurement**
**Ø = 26 cm, FOV = 7,6 mm**

Energy and spatial resolution inputs:

$\sigma_E$ = 6 % @ 1 MEV (E. Aprile, NIMA 480, 2002)

$\sigma_{xy}$ = 1 mm , $\sigma_z$ = 100 μm

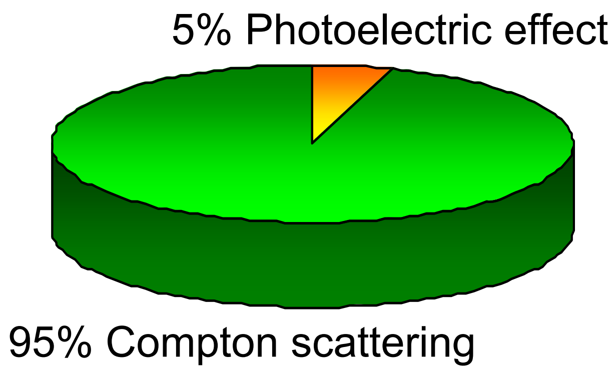



(C. Grignon, PhD thesis, 2007)

# Liquid Xenon

$E_{drift}$ = 2kV/cm

**1 MeV γ-ray**




## Charges

Ionization yield $W_i$ = 17,3 eV
58000 pairs e-/Xe /MeV

## Scintillation

Energy required to create a photon = 61,7 eV
16200 UV/MeV (~NaI)

| Excitation | Ionization |
| --- | --- |
| $Xe + e^- \rightarrow Xe^* + e^-$ | $Xe + e^- \rightarrow Xe^+ + 2e^-$ |
| $Xe^* + 2Xe \rightarrow Xe_2^* + Xe$ | $Xe^+ + 2Xe \rightarrow Xe_2^+ + Xe$ |
| $Xe_2^* \rightarrow 2Xe + h\nu$ | $Xe_2^+ + e^- \rightarrow Xe_2^*$ |
| | $Xe_2^* \rightarrow 2Xe + h\nu$ |

$h\nu$: 178 nm

Fast medium (~LSO)
Scintillation decays :
- $\tau_f$ = 2,2 ns (singlet) 4%,
- $\tau_s$ = 27 ns (triplet) 79%,
- $\tau_r$ = 45 ns (recombination) 17%

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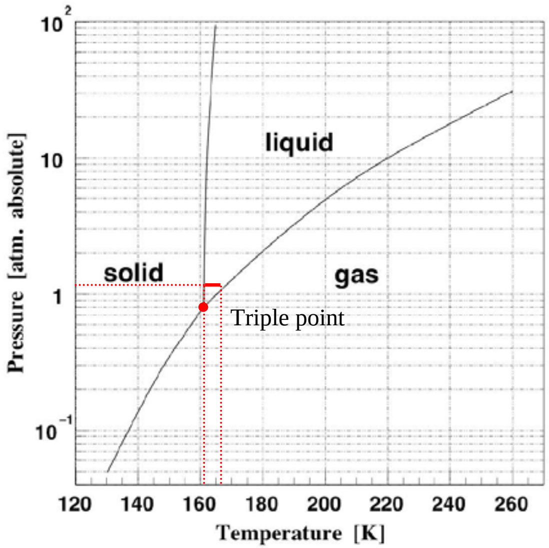
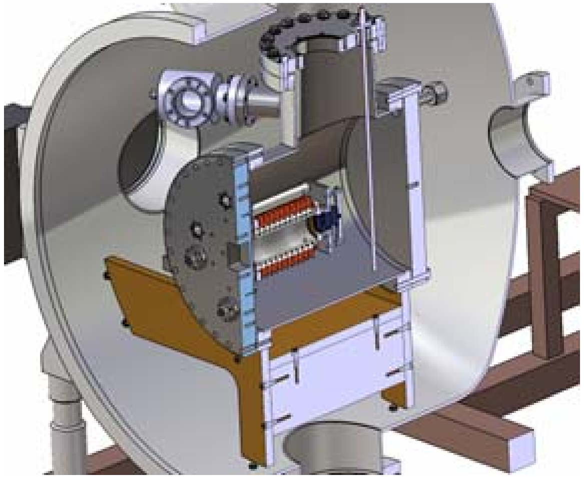
# XEMIS (XEnon Medical Imaging System)

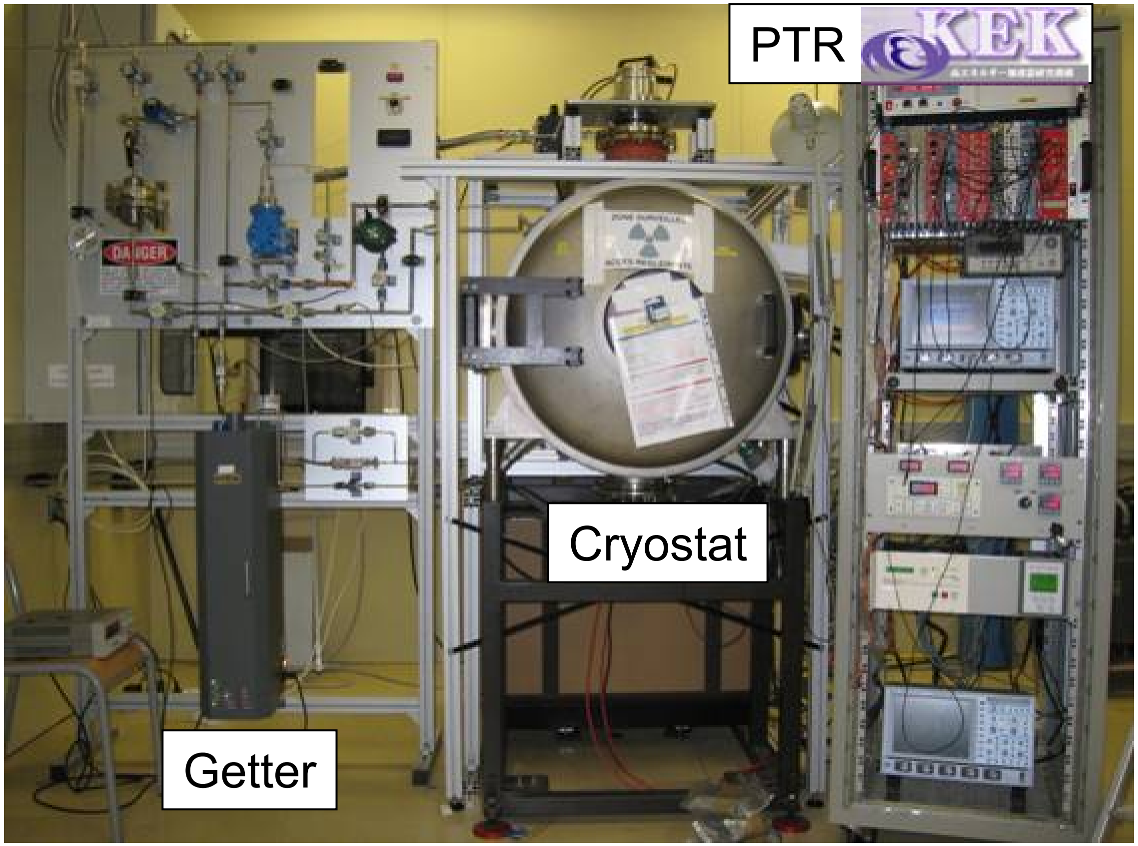



Phase diagram of xenon[1]

Requirements :
- High xenon purity (< 1ppb $H_2$0 and $O_2$ )
- Stable cryogenic device



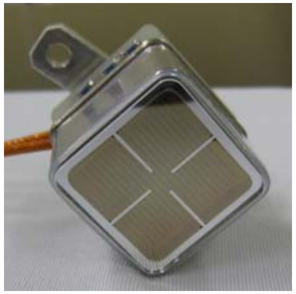
Cryostat cut-away view



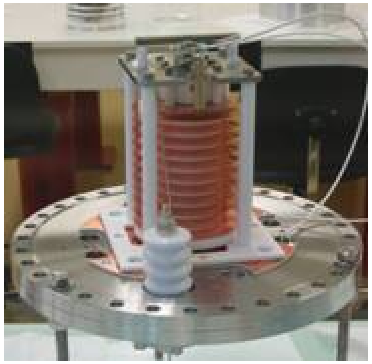

Liquid xenon Compton Telescope set-up

( 1. Hallet, 1961)

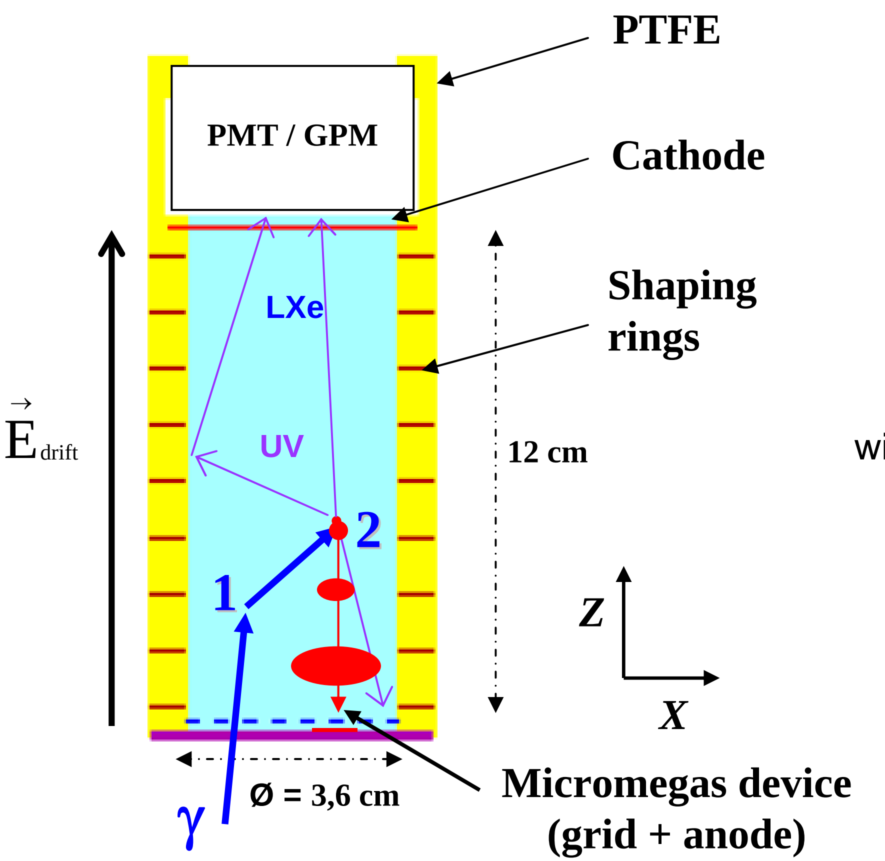
# Liquid-xenon time-projection chamber



PMT Hamamatsu
(R5900-06AL12S-ASSY)



LXe TPC




Triggering

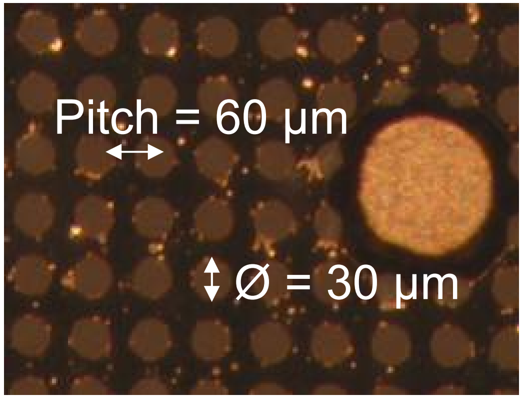
Scintillation signal
with a PMT: $t_0$

Ionization signal
with a MICROMEGAS : $t_1$, E,x,y

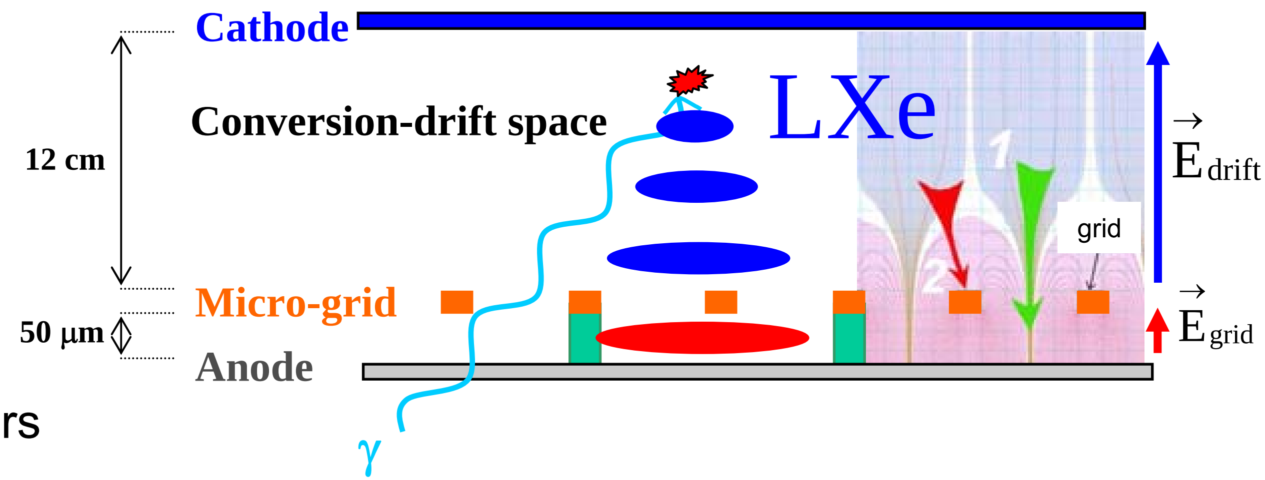
Interaction depth
$z = (t_1 - t_0) \times v_{drift}$

E & (x, y, z) measurements of each interaction

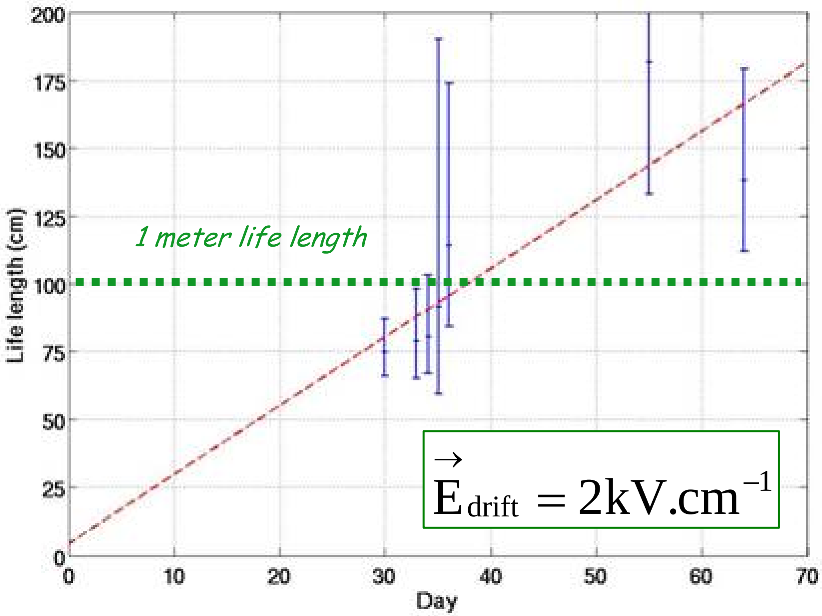
# Ionization signal



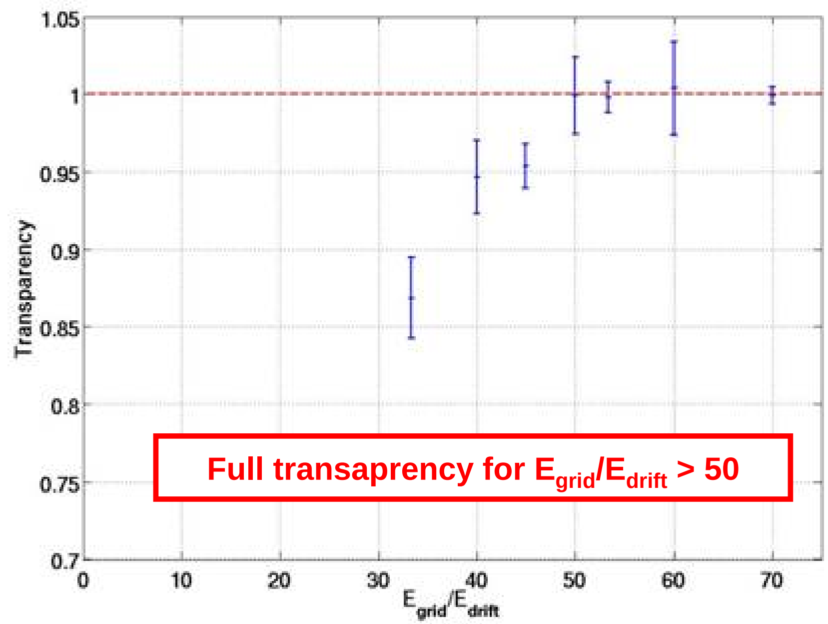

Micromesh with 50 µm pillars




Electron life length




Micromegas transparency into LXe



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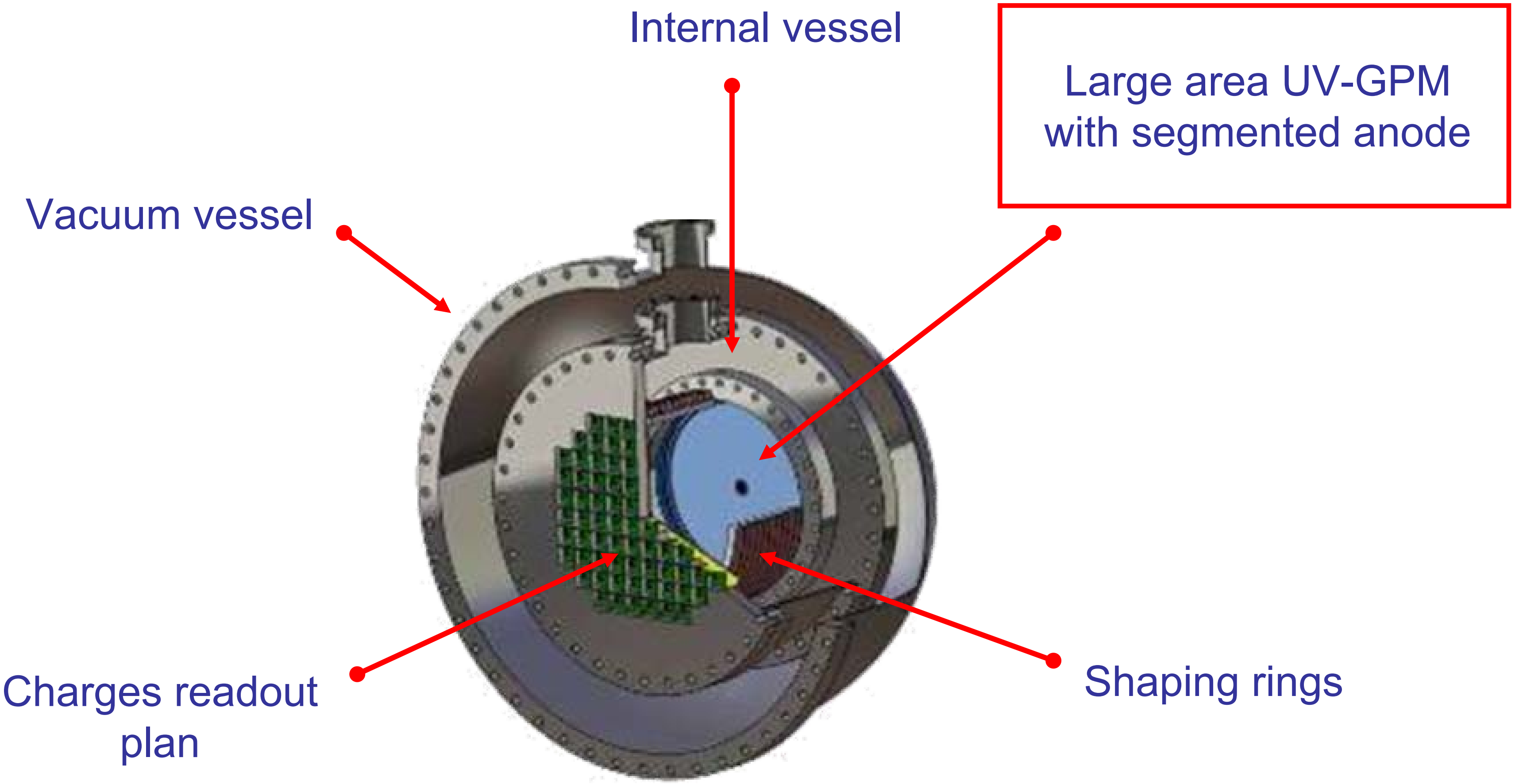
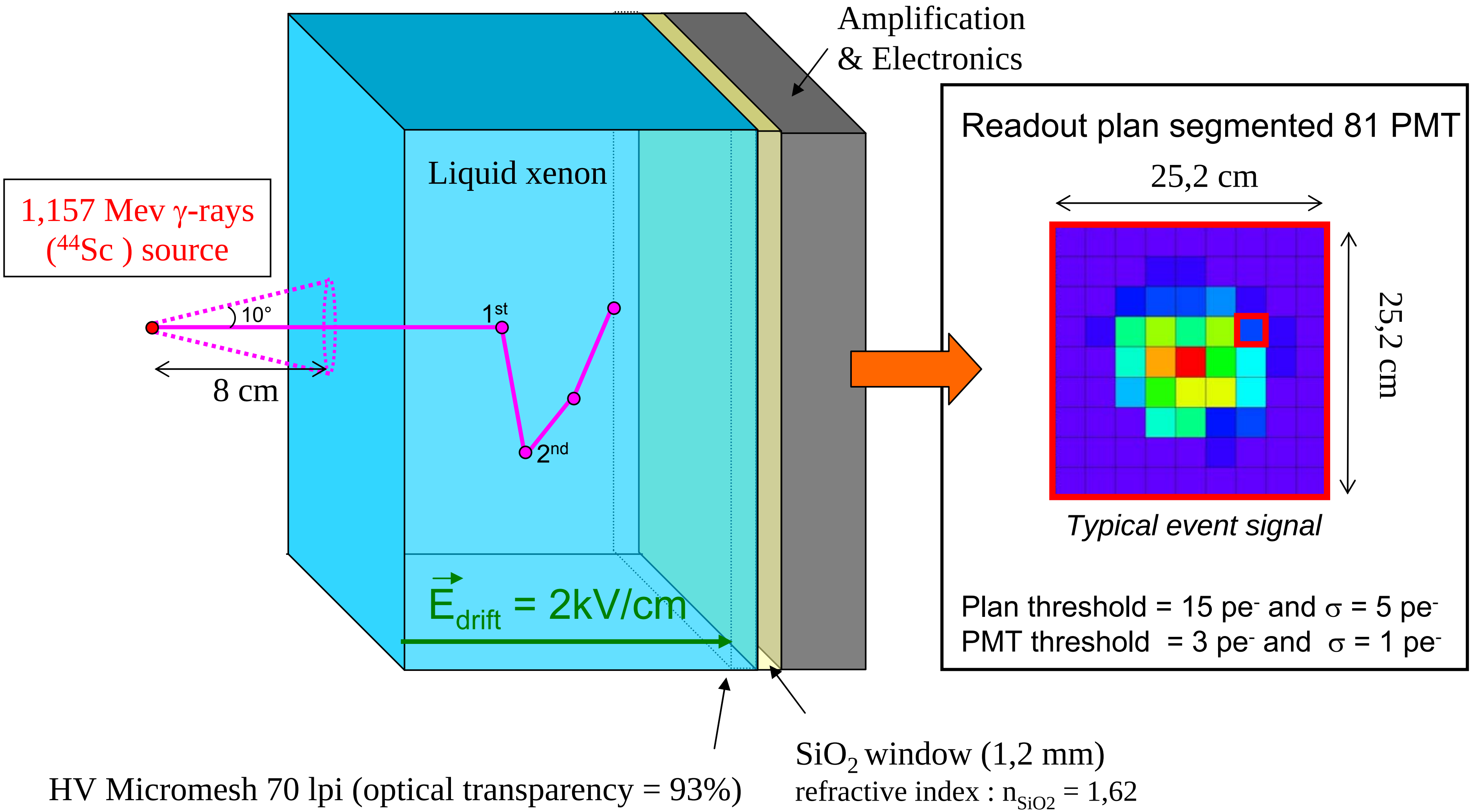
# XEMIS 2




**Cylindrical LXe TPC (Ø = 25 cm)**

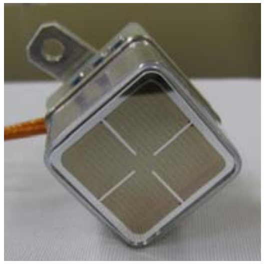
# XEMIS 2 Geometry simulated

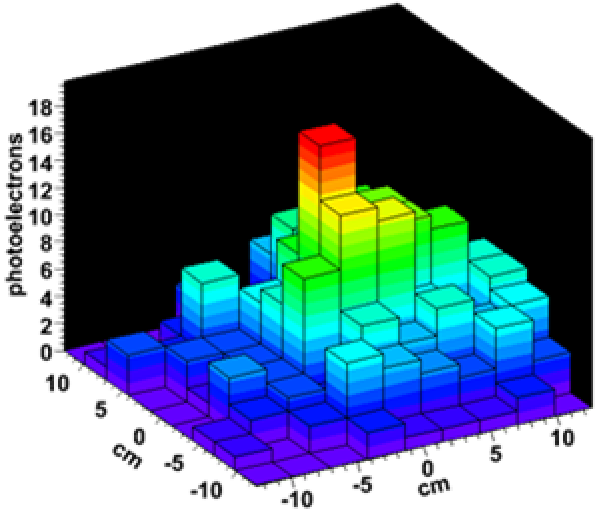
## with Geant4 and VUV transport MC Code (no Rayleigh, $\lambda_{att}$ = 1m)



# Simulation with 81 “1 inch PMT”

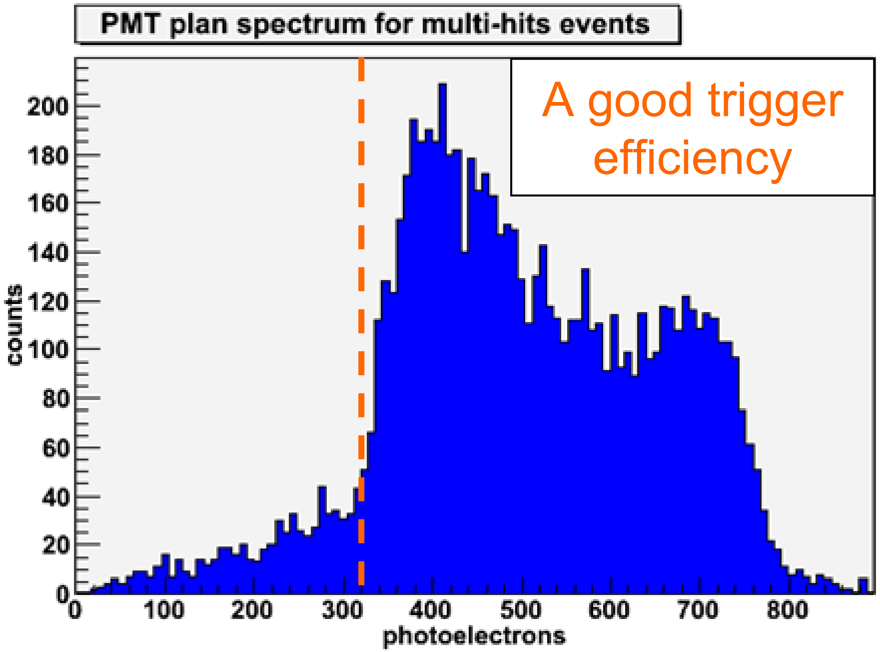
**PMT characteristics**
- QE = 35%
- $t_w$ = 1,2 mm *($SiO_2$ window thickness)*
- sensitive area = 40%






Typical $pe^-$/PMT distribution for a 1,157 MeV $\gamma$-ray

Simulation of 10000 $\gamma$-rays of 1,157 MeV




A trigger is possible with PMT

# Triggering with PMTs

- Challenging with background
- Edge effects
- Dead area
- Non-homogeneous depth response

A possible non-position dependant device…

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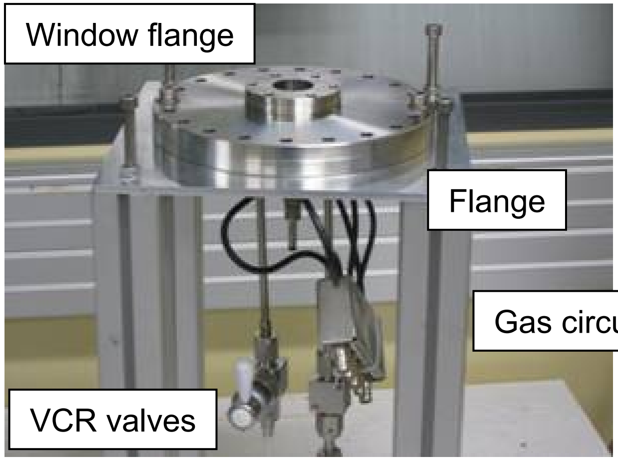
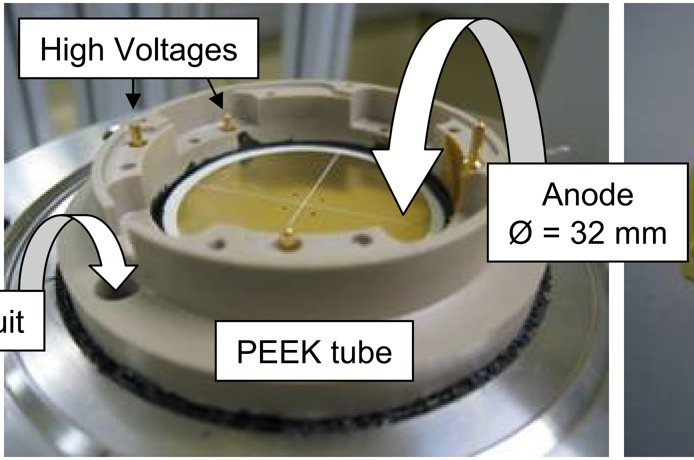
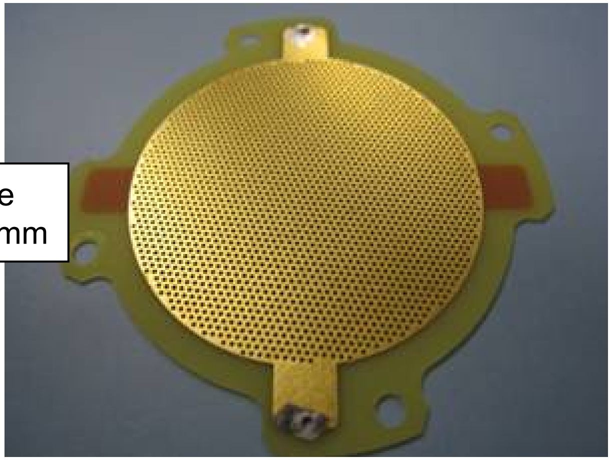
# Gaseous PhotoMultiplier prototype



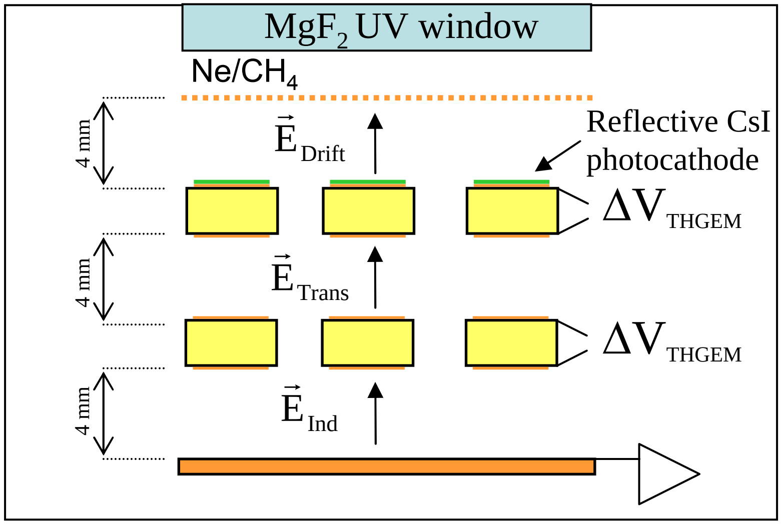

GPM global view




Inside the GPM



THGEM : thickness = 400 μm
hole Ø = 300 μm
hole spacing = 700 μm
rim size = 50 μm




Schematic drawing of the GPM set-up

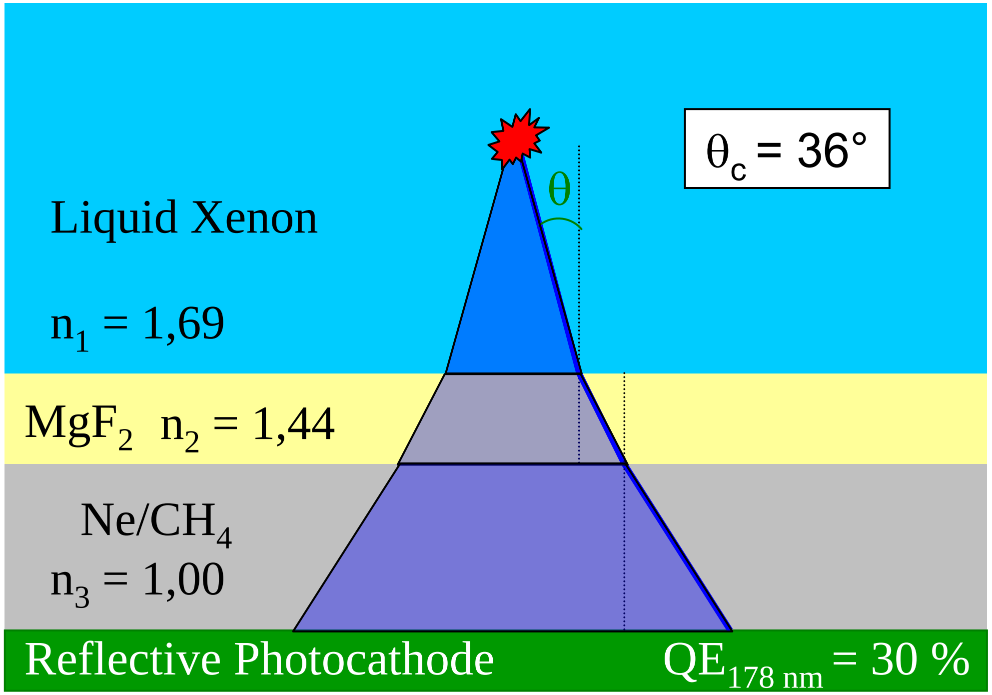
# A large cryogenic UV-GPM

PM QE is better than QE of GPM but …

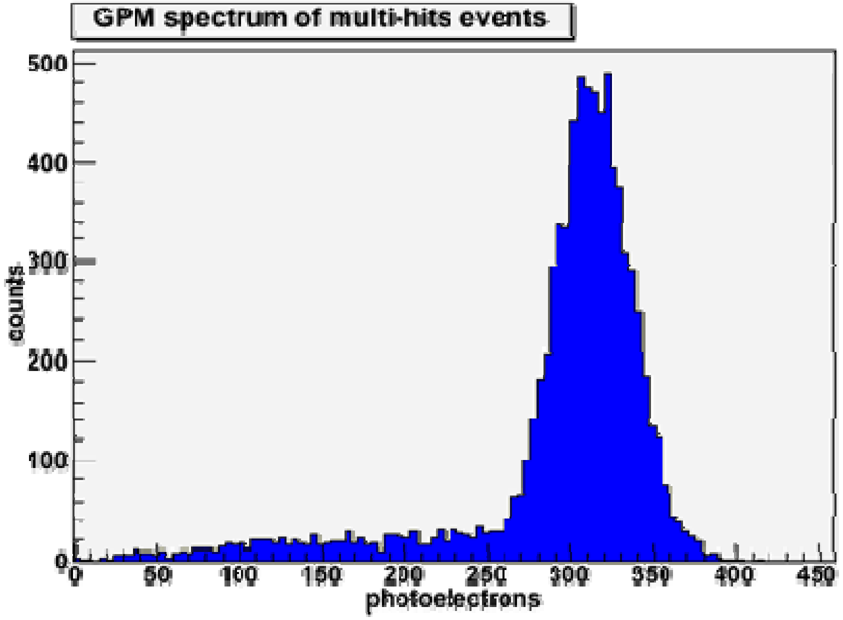
$MgF_2$ is more transparent to VUV light than $SiO_2$

Results of simulations :
- No dead area : homogeneity
- Less position dependant

**GPM characteristics :**
- QE = 30%
- $t_w$ = 0,5 mm *($MgF_2$ window thickness)*

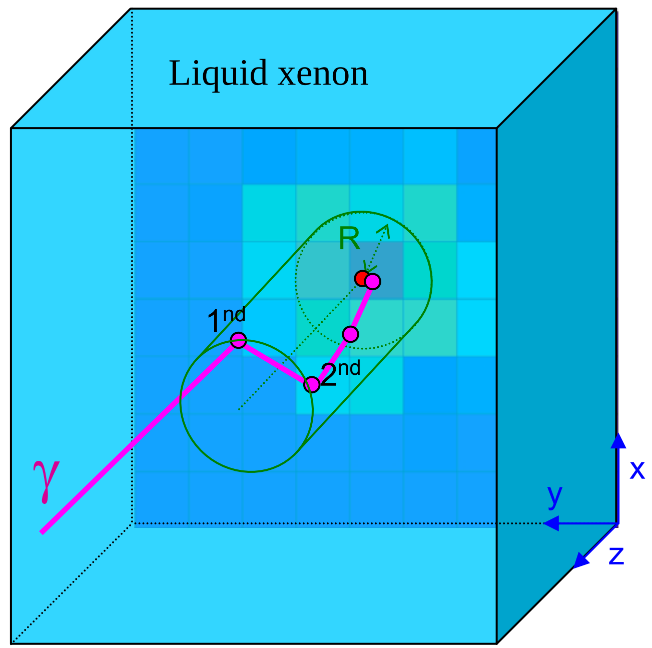


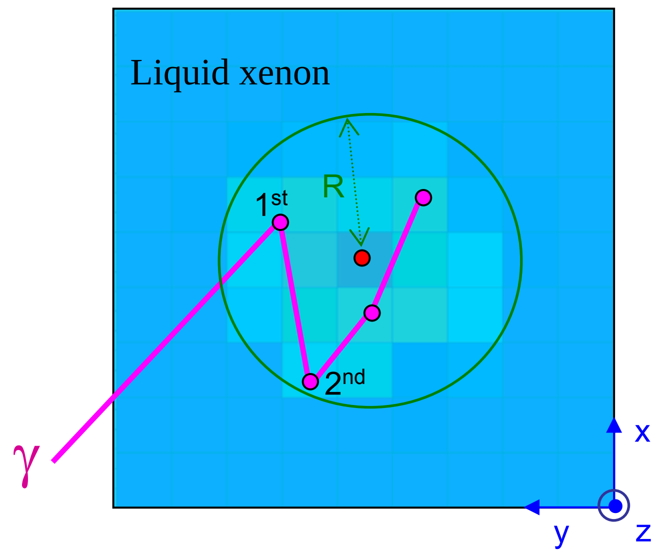

Simulation of 10000 γ-rays of 1,157 MeV



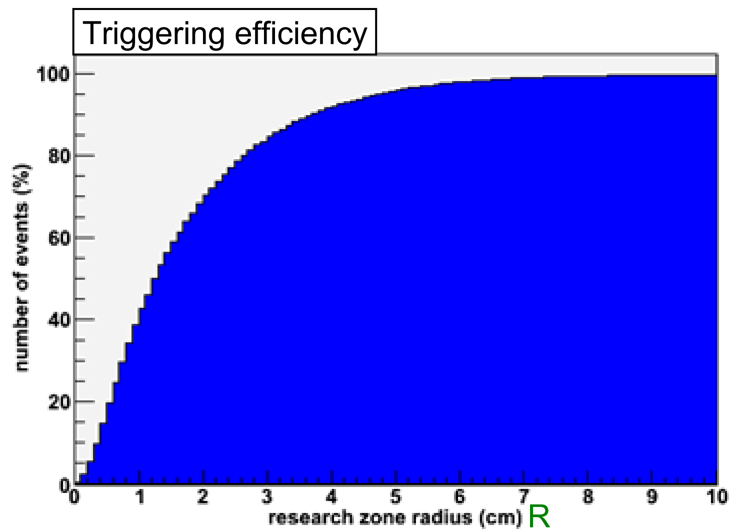
# A possible “local triggering”

Opening research volume for the Compton Sequence



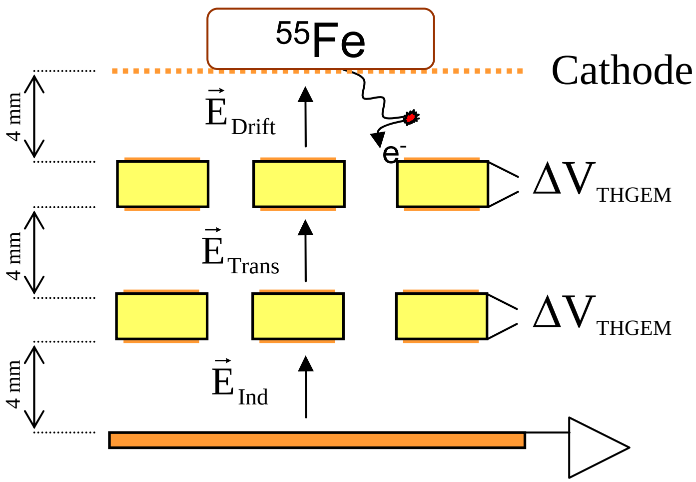



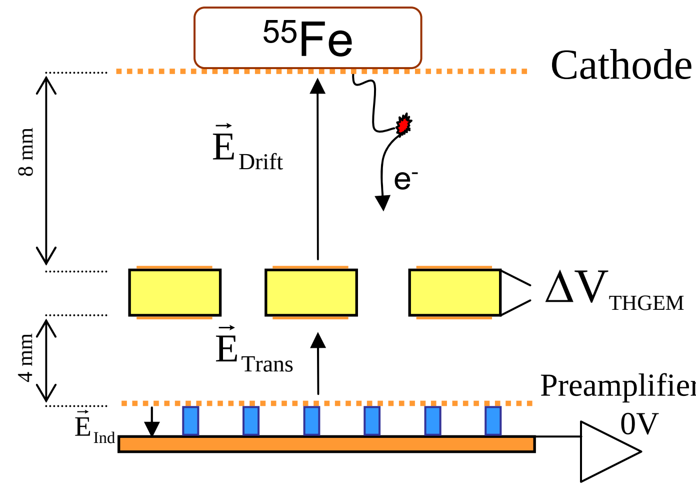

Triggered event
2 firsts hits inside cylinder



# First experimental R&D tests

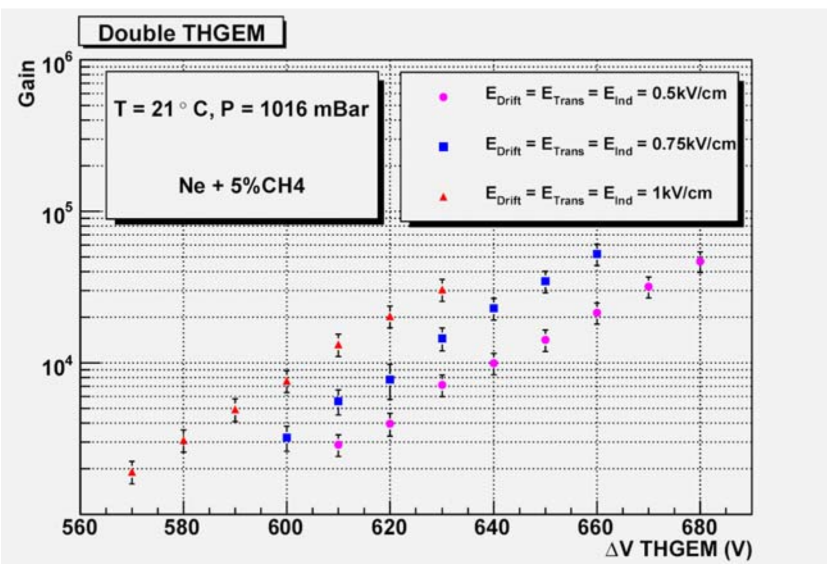
Ne,5%$CH_4$ @ normal P and T

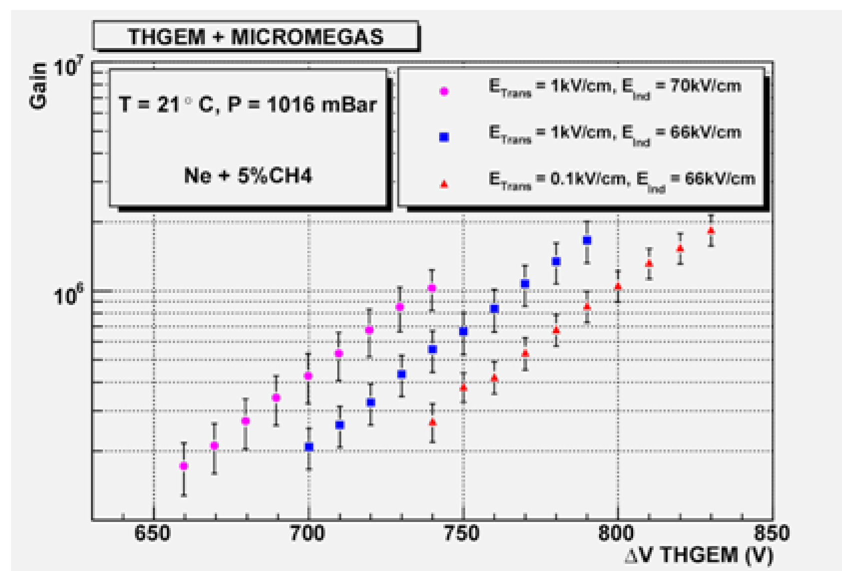



Plotted grid:
- pitch 60 μm
- pillars 50 μm

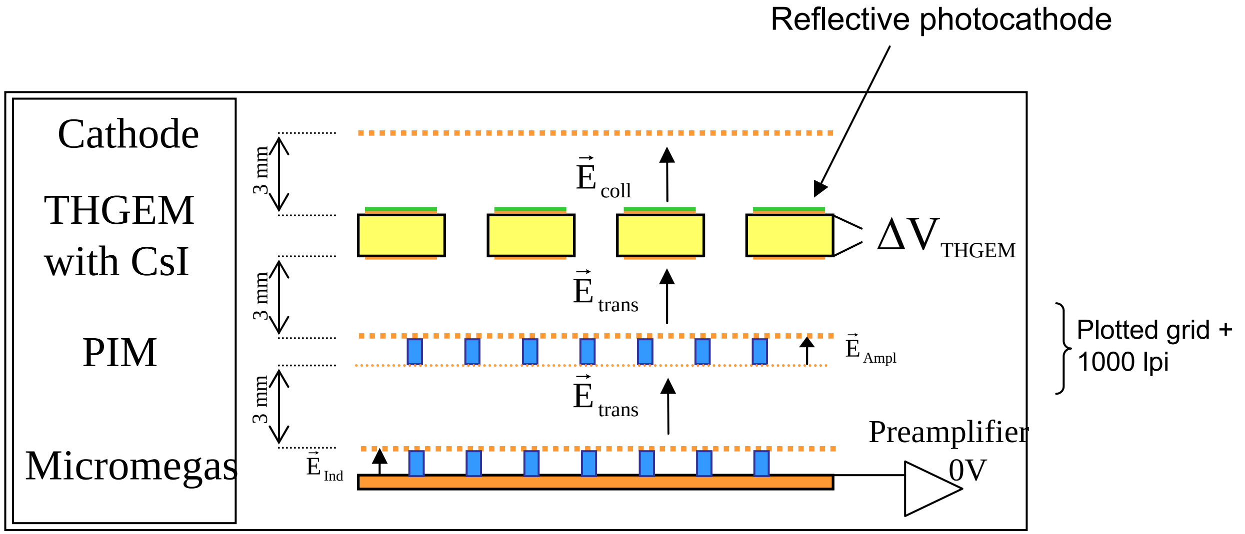
Gain curves obtained with $^{55}$Fe soft X-rays source




Under evaluation

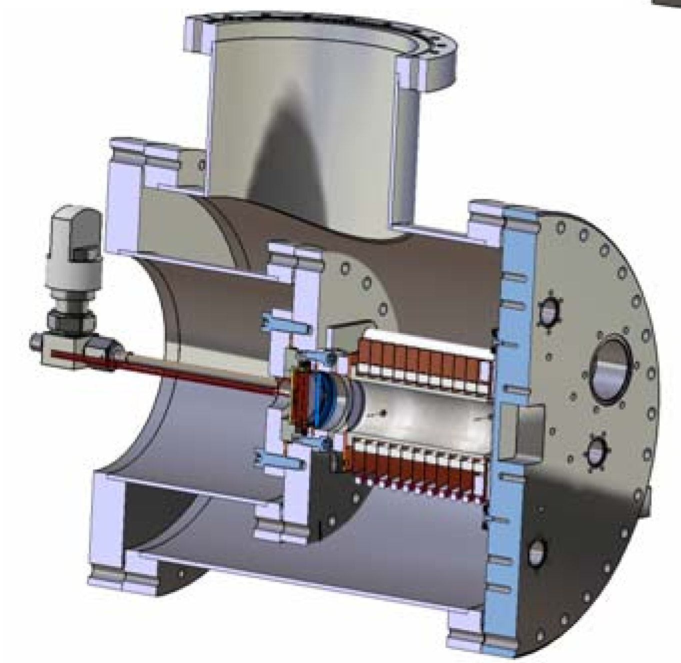
# Prospects



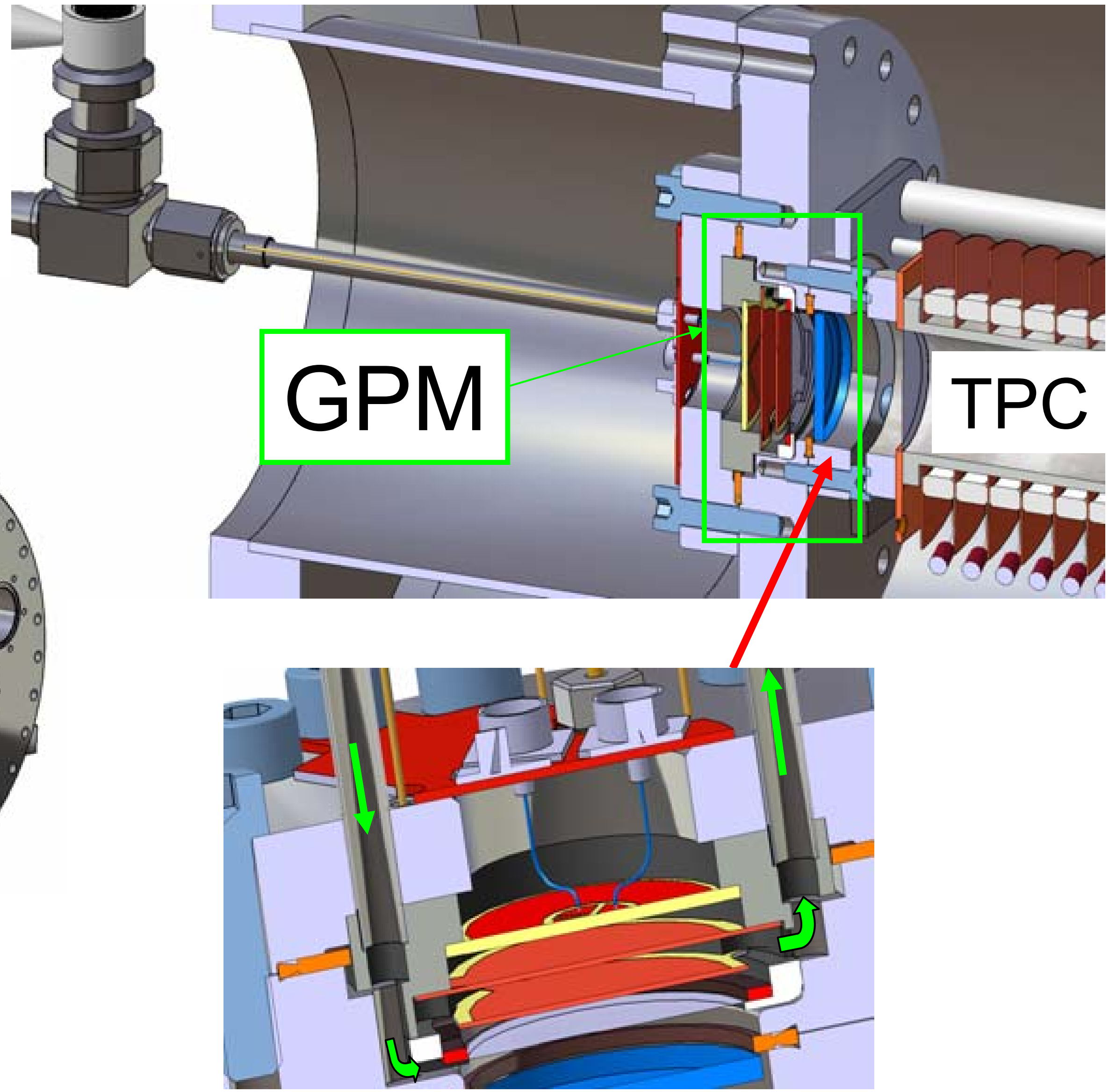

Schematic view of the cryogenic UV photon detector set-up

- Photocathode deposition at the Weizmann Institute of Science
- Characterization in normal conditions
- Immersion in liquid-xenon (XEMIS1)

# GPM into XEMIS 1



Internal vessel



## Thank you !