Experimental study of a liquid xenon PET prototype module

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- Medical imaging and Positron Emission Tomography (PET)
- Why liquid xenon medium for detection in PET ?
- Design of LXe μ-PET and Depth Of Interaction measurement
- The experimental set-up and R&D investigations
- Experimental results

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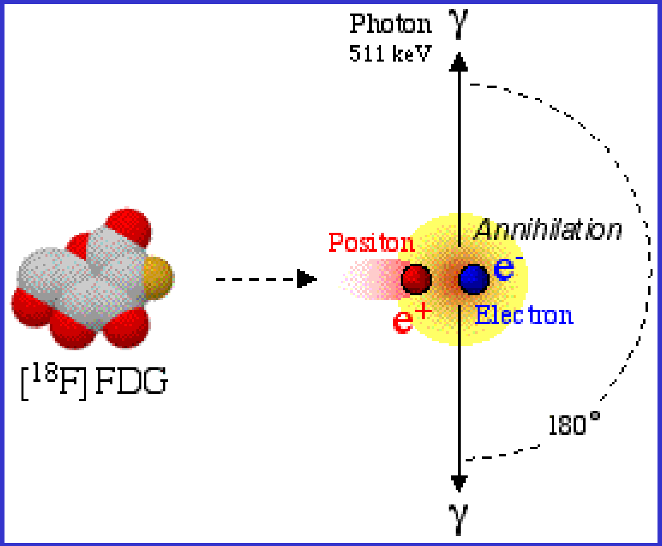
Medical imaging and Positron Emission Tomography

What is PET ?

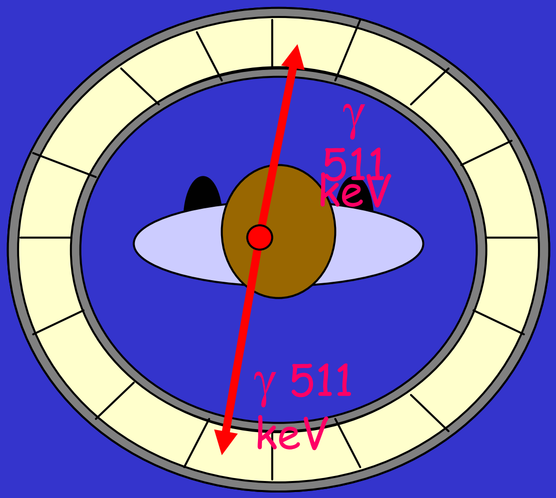
Positron Emission Tomography, or PET allows to examine the heart, brain, and other organs.

PET images show the chemical functioning of an organ or tissue, unlike X-ray or MRI which show only body structure.

How does it work ?



- A short lived radioactive tracer isotope which decays by emitting e^+ is chemically combined with a metabolically active molecule
- The positron annihilates with an electron producing a pair of gamma ray photons moving in opposite direction

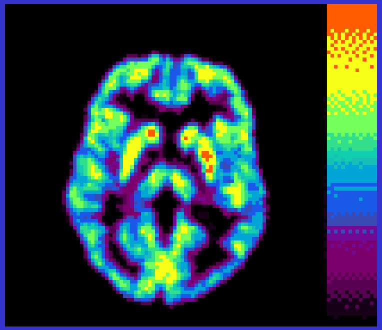


- The photons are detected when they reach a scintillator material creating a burst of light detected by the photo multiplier tubes

- The technique depends on coincident detection of the pair of photons

- The scanner uses the pair detection events to map the density of the isotope in the body in the form of slice images separated by few mm.

- The resulting map shows the tissues in which the molecular probe has been concentrated



Why liquid xenon medium for detection in PET ?

Good scintillation properties for PET

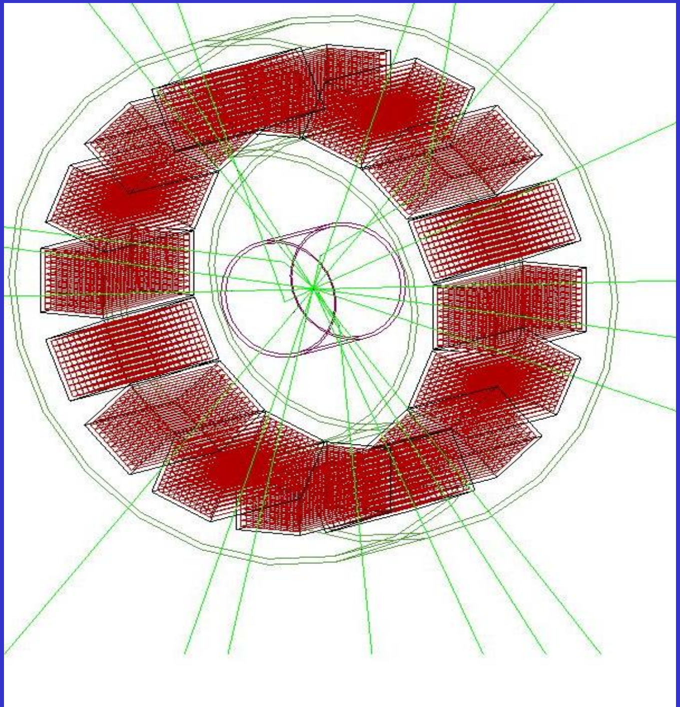
	LXe	BGO	LSO
Time decay (ns)	3 - 30	300	40
Photons/MeV	≈ $4\ 10^4$	$0.64\ 10^4$	$3.2\ 10^4$
Photo Fraction	24 %	42 %	33 %

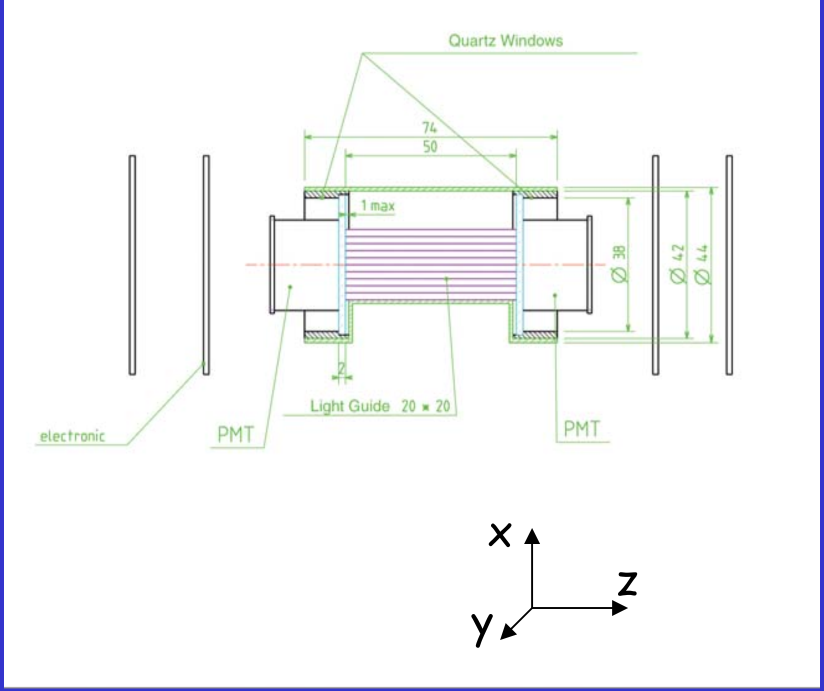
……………………………Some difficulties

	LXe	BGO	LSO
Density ($g.cm^{-3}$)	3.1	7.1	7.4
λ (nm)	178	480	420

Light collection at λ = 178 nm is one of challenging part of this project !

Design of a liquid xenon μ-PET





μ-PET

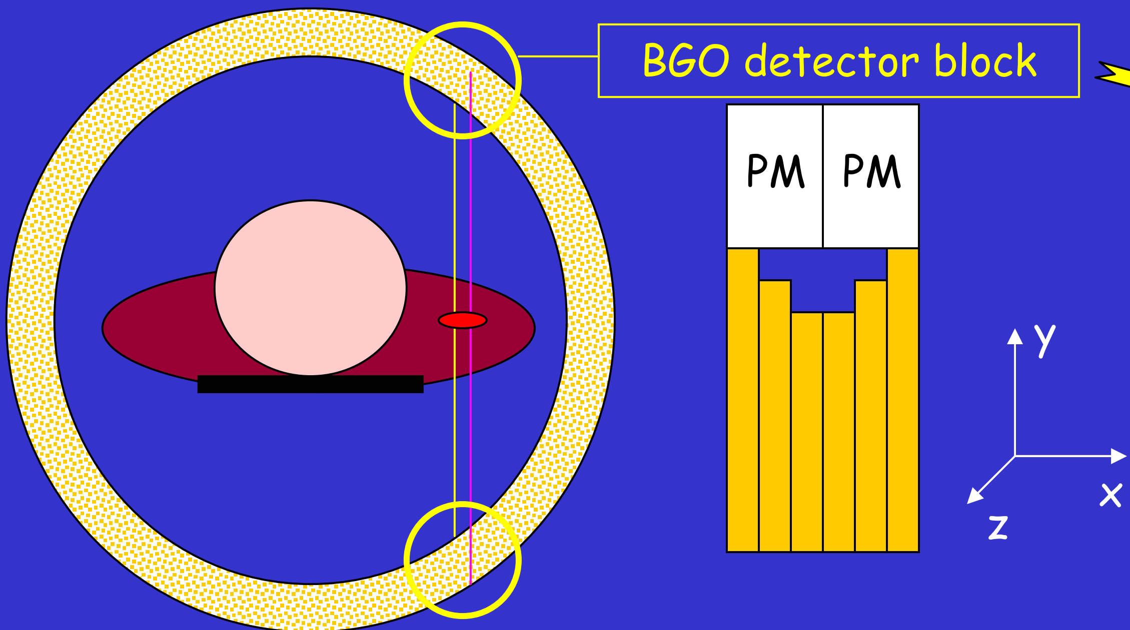
- 16 modules ⟹ 32 PS-PMT
- Axial FOV : 5 cm
- Transaxial FOV : 10 cm

One module :

- 10x10 light guides : Al matrix with deposition of MgF_2 on it
- 2 PS-PMT for light collection
- Active volume : 2 cm in x,y - 5 cm in z

Depth Of Interaction Measurement (DOI)

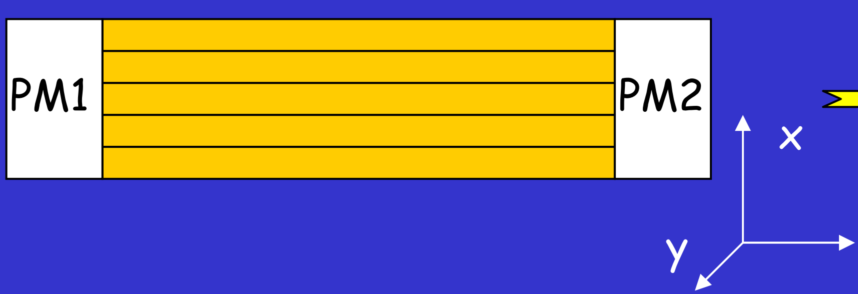
No DOI information with a classical PET system like "BGO Block"



No information about Depth Of Interaction !

Parallax error or radial elongation

DOI measurement with the design of LXe μ-PET



x,y given by the light guide where the energy is deposited

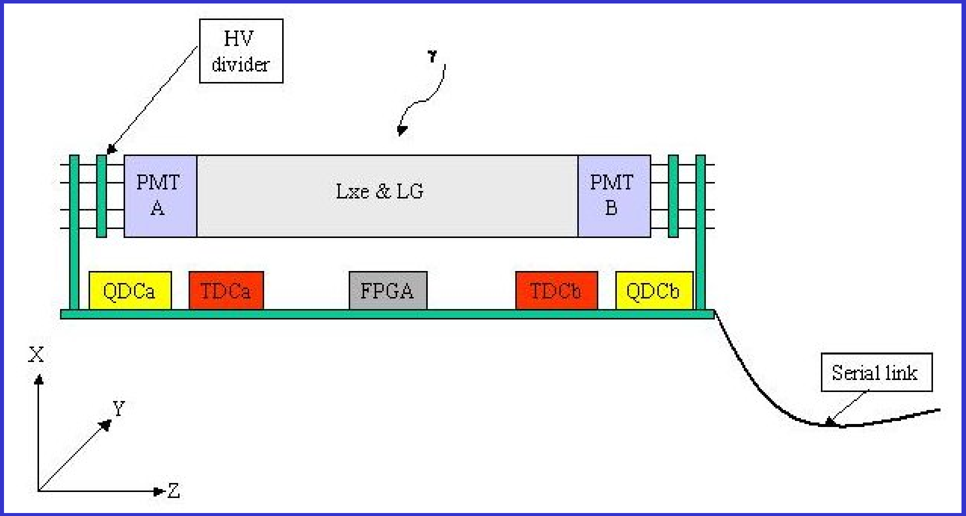
(PM1-PM2)/(PM1+PM2) ⇒ z

x, y, z for each event !

Design of a dedicated self triggered front-end electronics (FEE)

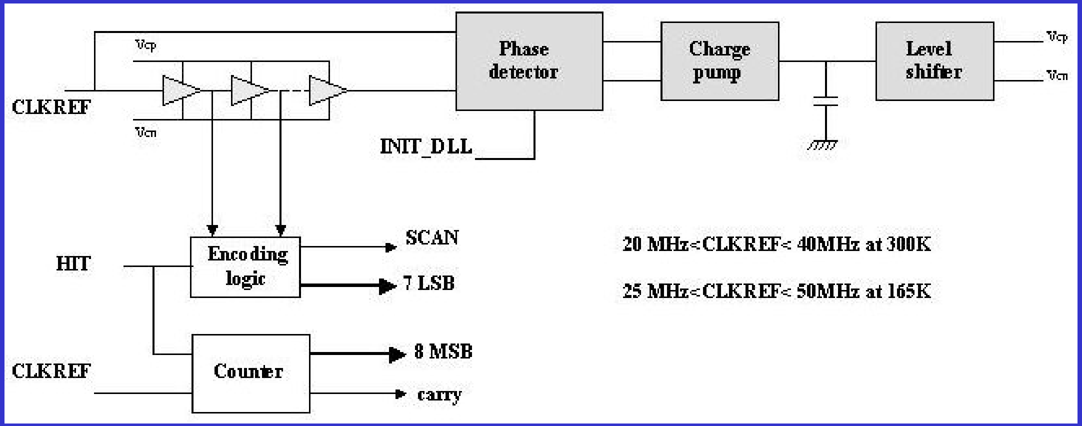
The FEE has to be located close to the photo detectors and to operate at 165K. It performs :

- ★ Charge measurement for each anode
- ★ Time tagging for each event
- ★ x,y and z coordinates calculation
- ★ Data transfer to the room temperature DAQ



A Time to Digital Converter (TDC) was designed (CMOS 0.35 μm) to perform time tagging

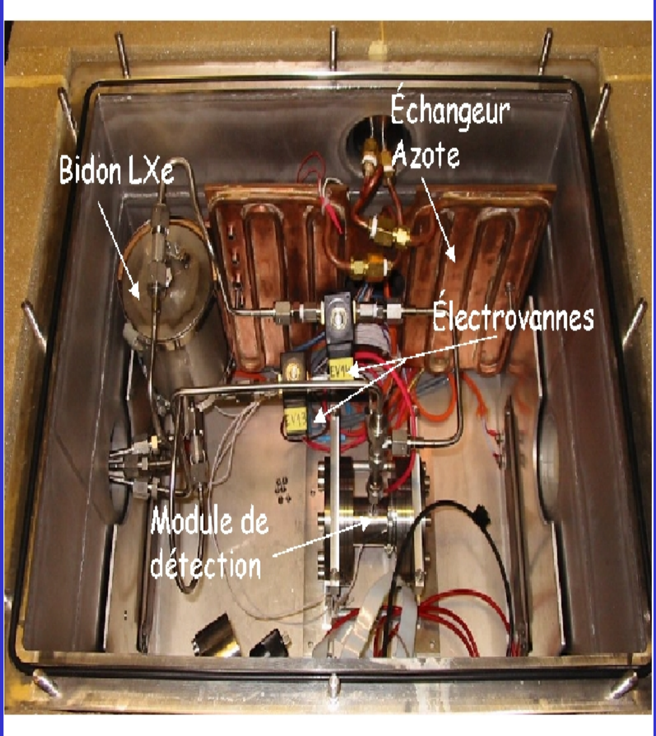
The measured time resolution is 244 ps (presented at the poster session on Wednesday 6th)



The experimental set-up

Cryogenic system - LXe Station + cryostat

- ☆ LXe Station built by Air Liquid - delivered in December 2000



- ☆ Cryostat built at the laboratory
- ☆ Tested at 165 K with liquid xenon

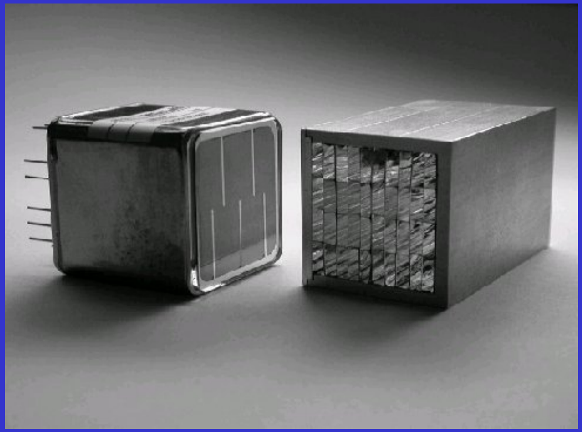
R&D investigations

Light collection : PS-PMT Tests

UV detection at λ = 178 nm

Photo Tube HAMAMATSU R8520-06-C12

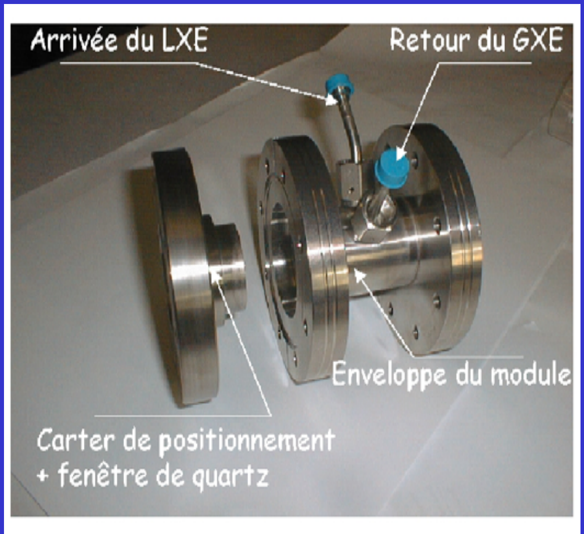
- ★ quartz window
- ★ RbCs photo-cathode
- ★ 6x and 6y cross-plated anodes
- ★ localisation by a centre of gravity calculation
- ★ gain $\approx 10^6$ @ 800 V, quantum efficiency $\approx$ 20 %



Construction of one module

For the LXe μ-PET

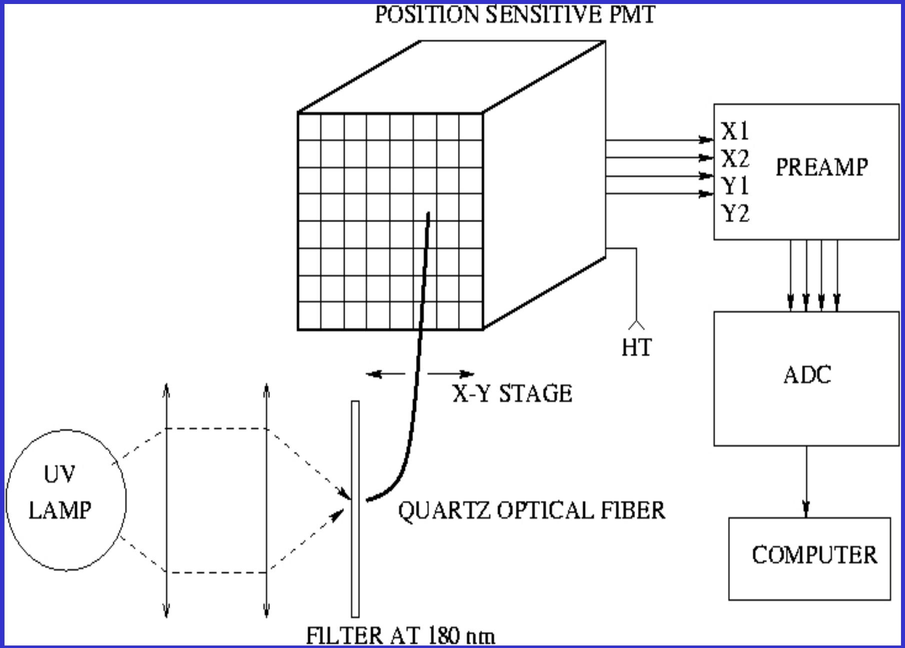
- ★ Deposition of MgF_2 on an Al matrix $\Rightarrow$ 10x10 light guides with 2x2 mm^2 for each one

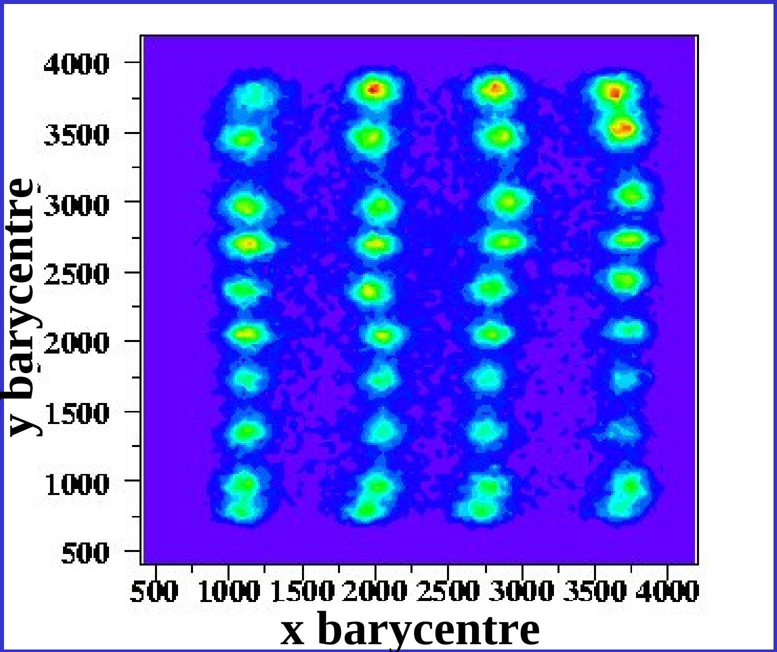


Results of PS-PMT test at 178 nm and 165 K

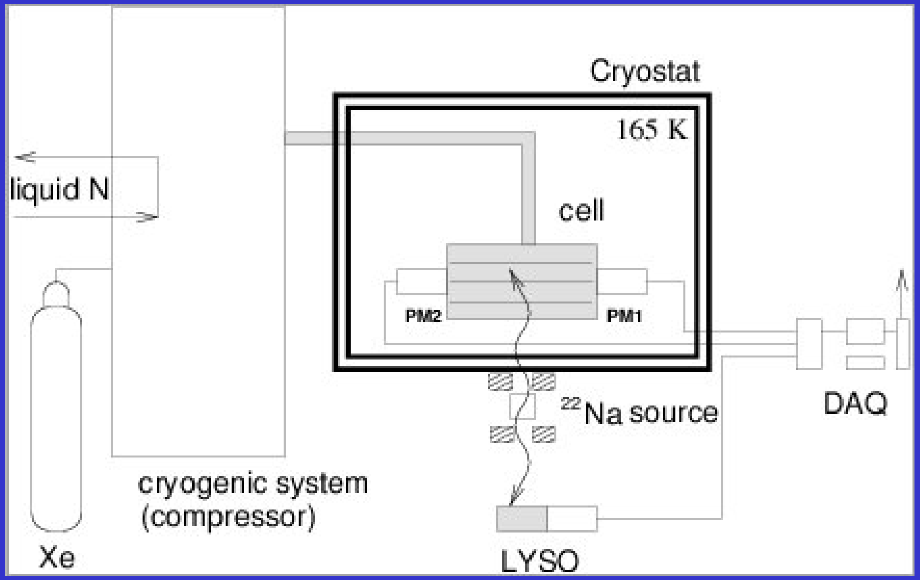
- Profiles of centre of gravity obtained with quartz optical fibre travelling mm/mm : Excellent separation !

- Resolution at FWHM for one centre of gravity distribution : 0.25 mm (fwhm)

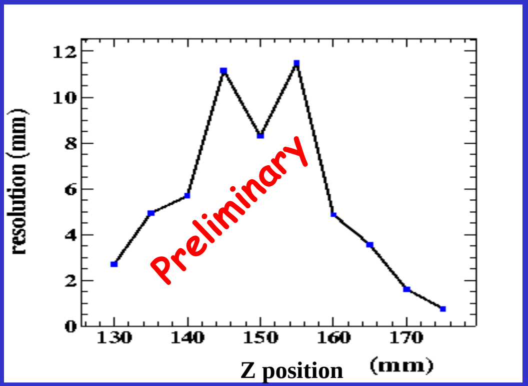




★ An experimental test bench has been built to measure the prototype module resolution in z



★ Resolution as a function of the source localisation



The z coordinate is deduced from the amplitude (A) of the two PMT dynode signals

$$Z \propto \frac{A_{\text{right PM}}(\text{dynode}) - A_{\text{left PM}}(\text{dynode})}{A_{\text{right PM}}(\text{dynode}) + A_{\text{left PM}}(\text{dynode})}$$

This result is preliminary it would be improved by

working on the reflexivity of the light guide

using photo detection units that exhibit higher quantum efficiency APD ?

Conclusion

The specific μPET design aims to take full advantage of the liquid xenon properties and features a promising insensitive dependence to any parallax effect.

The experimental study comprises

- ✓the development of the μPET itself (cryogeny, detection of VUV),
- ✓the first tests of a prototype module
- ✓the design of a dedicated self triggered front-end electronics.

Simulation effort has been made, at first with the development of a Geant 4 based Monte-Carlo program (GePEToS) (S. Jan PhD Thesis)

→ participation to the OpenGATE international collaboration