Design and Performance of Liquid Xenon Detectors for PET

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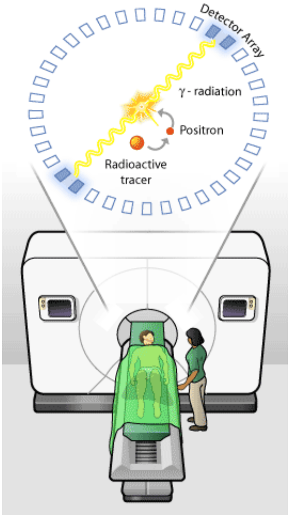
Working principle of PET



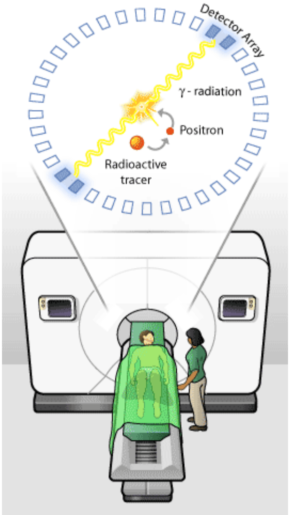
Principle

- Short lived isotopes decays emitting e^+
- e^+ drift range $\approx$ 1mm (FWHM)
- e^+ annihilates into pair of 511 keV γs
- Angle between γs $\approx 180^\circ$
- Reconstruct line of response (LOR)
- Functional imgage (tumor screening)

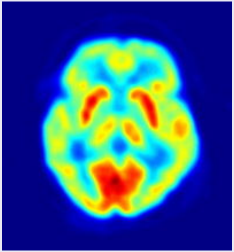
Current Detector

- Scintillating crystals in ring geometry
- Crystal provides discrete location $\rightarrow$ No information about depth of interaction
- Energy resolution $\approx$ 18% (FWHM)

Working principle of PET



Functional Image



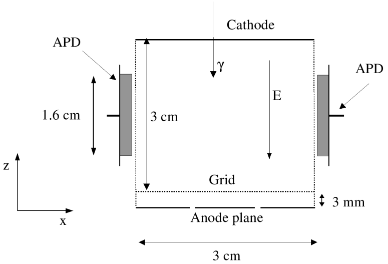
Current Detector

- Scintillating crystals in ring geometry
- Crystal provides discrete location → No information about depth of interaction
- Energy resolution ≈ 18% (FWHM)

Advantages of LXe for PET

- Attenuation length: 36 mm (at 165 K) $\rightarrow$ compact detector
- Produces ionization and scintillation light
  $\rightarrow$ combining both improves energy resolution:
  energy resolution $<$ 10 (FWHM)%
- Compton reconstruction
  $\rightarrow$ 3D localization of first interaction (no parallax error, suppression of random and scatter backgrounds)
- Uniform 3D spatial resolution throughout the field of view:
  $<$ 1 mm in 3D
- Timing resolution: $<$ 1 ns
- Cover large volumes with just one electrode array
  $\rightarrow$ high sensitivity
  $\rightarrow$ Efficiency $>$ 70%
- Inexpensive ($<$ $ 3/cc)

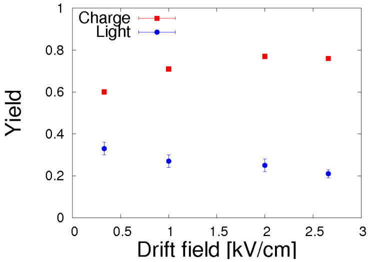
Time Projection Chamber (TPC)



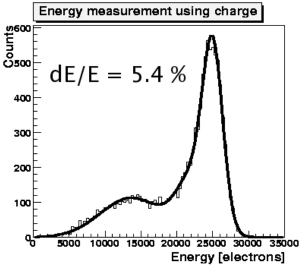
Achievements:

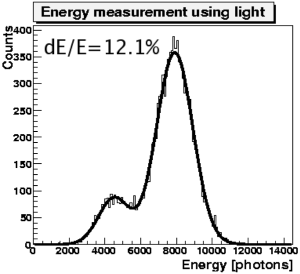
- Measured charge and light
- Studied energy resolution
- Understood detector contribution and limitations

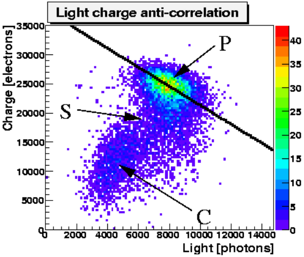
- TPC volume 3x3x3 cm^3
- E=1 kV/cm, v_d =2 mm/μs
- 2 APDs; solid angle $\approx$ 12%
- 511 keV γs from ^{22}Na

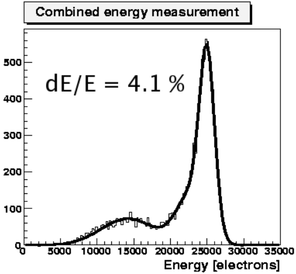


Charge-Light-Anti-correlation









Understanding Error Contributions

Identify error contributions to energy resolution to quantify intrinsic resolution capability:

Charge

Electronics noise (3.5%)

Light

Electronics noise (4.7%)
Gain fluctuations (0.6%)
Solid angle fluctuations (5.6%)

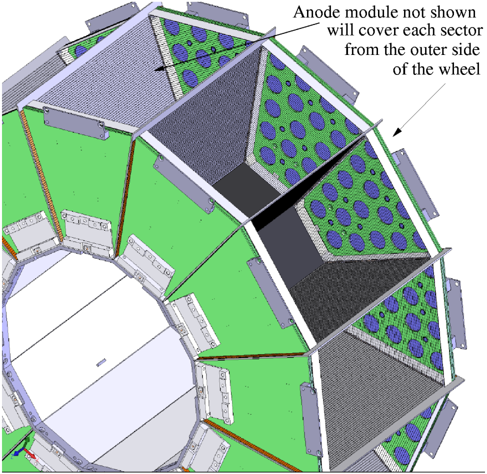
Energy resolutions:

	meas. [%]	intr. [%]
Q	12.1	5.5
L	5.4	4.2
C	4.1	2.5

With position information available from charge, expect:

$\rightarrow$ Light resolution: 10.4%
$\rightarrow$ Combined energy resolution: 3.6% ($<$ 8% FWHM)

Micro-PET Design

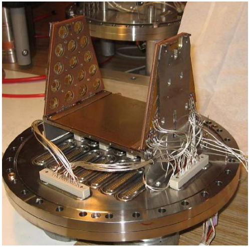


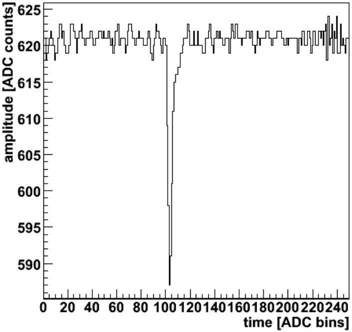
- 12 sectors, 32 APDs per sector, 96 anode wires, 96 anode induction wires
- Radial depth 12 cm
- Minimal dead space between sectors to increase active volume

Prototype Status

Finished test with 16 APDs

- 1st use of liquid purification
- Observed low signal amplitude





Probable Causes

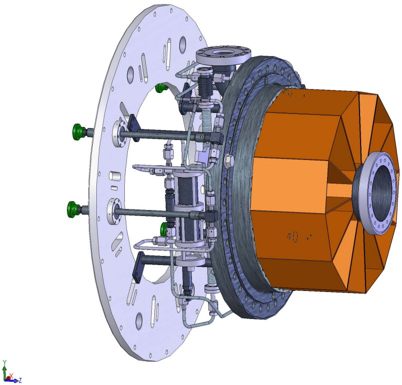
Impurities in LXe like H_2O
$\rightarrow$ Attenuation too high

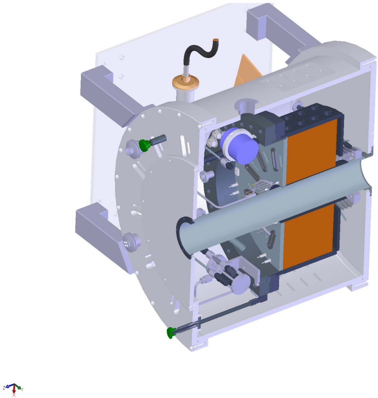
Possible Solution

Use gas and liquid phase purifier + longer high temperature bake-out

Outlook

CHRP Project: Design of cryostat in progress:



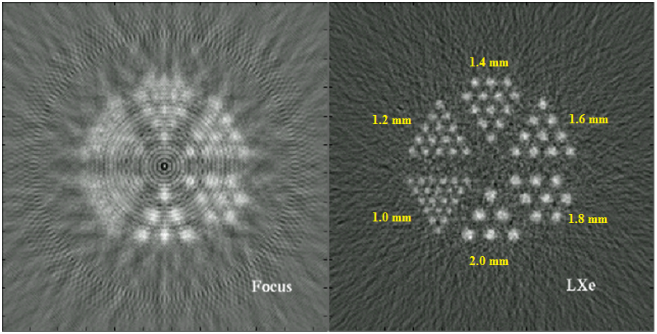


Build two new opposing sectors and operate in coincidence

BACKUP

Image Reconstruction from Simulations

Same simple reconstruction method (Filter-Back Projection) used for both (emphasis on resolution not image quality):



In the simulation, the limitations of the LXe system are primarily due to physics effects such as the positron range.

Position Reconstruction from Fast Light Signal

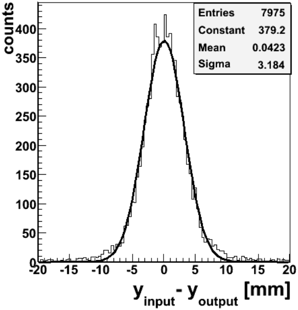
→ Important for high rate operation

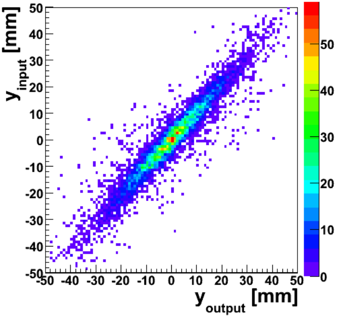
Challenge

Input: 32 APD signals
Looking for 3D position

Solution

Neural Network
Implemented in ROOT/C++





Volume in which interaction can be found can be restricted to ∼ 1 ml depending on noise.

Schedule

Activity	Start	End
Install and test single sector	2009-07	2009-11
Cryostat Design	2008-10	2009-09
Cryostat Construction	2009-06	2009-12
Cryostat Assembly	2009-10	2010-09
Sector Design	2009-01	2009-12
Sector Construction	2009-06	2010-06
Sector Assembly	2010-06	2010-09
Electronics Design	2009-06	2010-03
Data Acquisition System	2010-03	2010-12
Initial operation of multiple sectors	2010-09	2010-12
LXe coincidence meas. (point source)	2011-01	2011-06
LXe coincidence PET meas. (phantoms)	2011-06	2011-09
PET coincidence meas. (at UBC Hospital)	2011-09	2011-12