Liquid Xenon Detectors for Positron Emission Tomography

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Introduction

Positron emission tomography (PET) is a functional imaging technique based on detection of 511 keV annihilation photons following positron decay.

Project objective

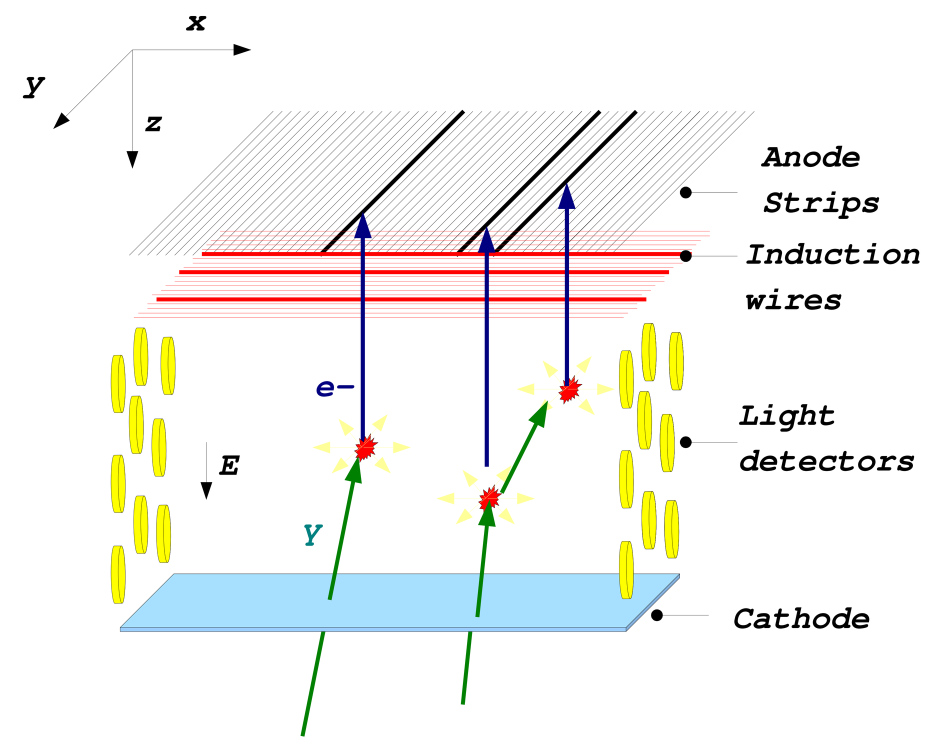
The goal of the project is to develop a PET system that overcomes the limitations of existing PET systems and reduces detector contributions to PET to the level of intrinsic limitations (positron range and photon noncollinearity).

The novel micro-PET scanner under development at TRIUMF makes use of the properties of liquid xenon (LXe). Simultaneous measurement of both scintillation light and ionization charge in LXe leads to a significant improvement in spatial resolution, image quality, and sensitivity.

LXe PET Detector - Principle of Operation

Photons interact in the LXe producing:
- prompt scintillation light (~ 2ns)
  - measured by light detectors (avalanche photodiodes)
- ionization
  - drifts under the applied electric field to the anode (sub-mm resolution in 3D)

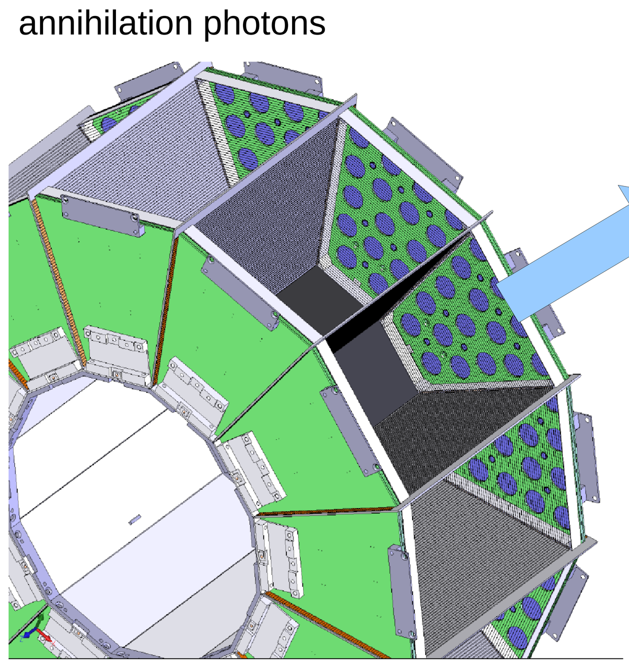
Anode module:
- grid of wires preceding the anode
- anode segmented into strips perpendicular to the wires
- shielding grid



- The electron signal induced on the wires and collected by the anode strips provides the 2D position (x-y) of the interaction
- The z-coordinate is calculated from the drift time and the known drift velocity

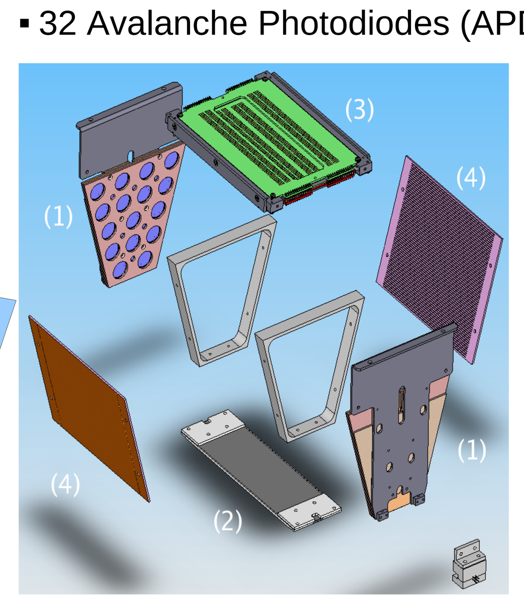
LXe Micro-PET ring

12 trapezoidal sectors arranged in a ring geometry for the detection of the annihilation photons

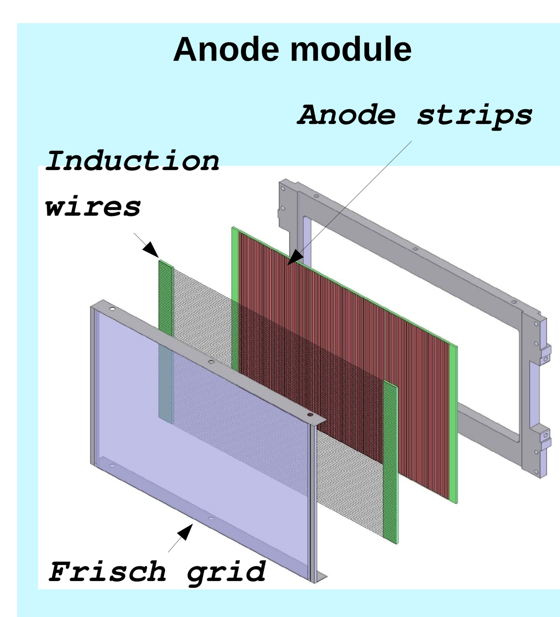


LXe micro-PET ring

LXe micro-PET Sector
- Time Projection Chamber (TPC) filled with LXe
- 32 Avalanche Photodiodes (APDs)

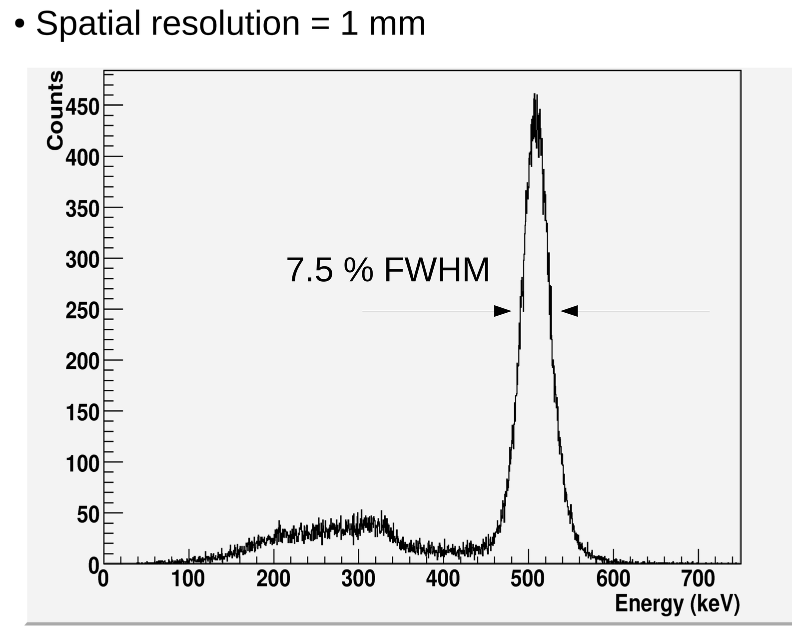


(1) APD module
(2) Cathode
(3) Anode module
(4) Field cage PCB

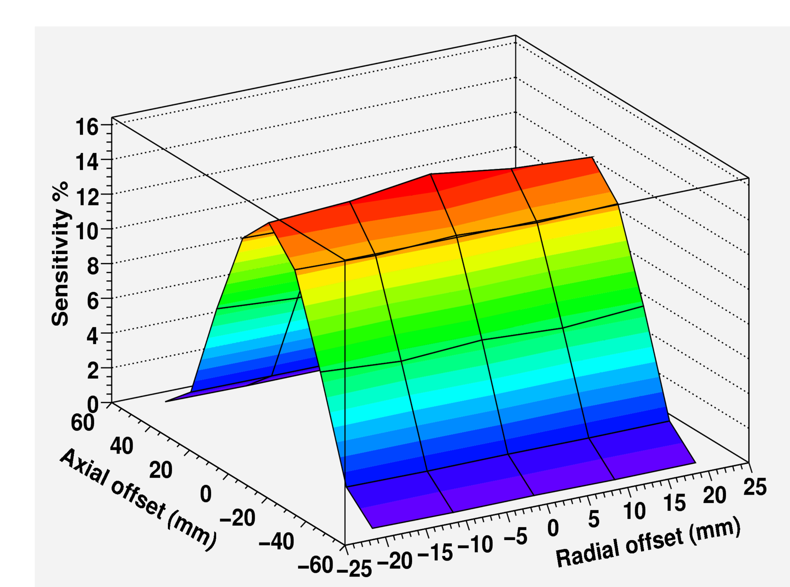


LXe Micro-PET: Simulated Performance

MC Simulation based on Geant4, parametrization of detector response, Compton reconstruction algorithm for event reconstruction
- ***Energy resolution*** at 511 keV = 7.5% (FWHM)
- ***Sensitivity*** at center of FOV = 15%
- Spatial resolution = 1 mm



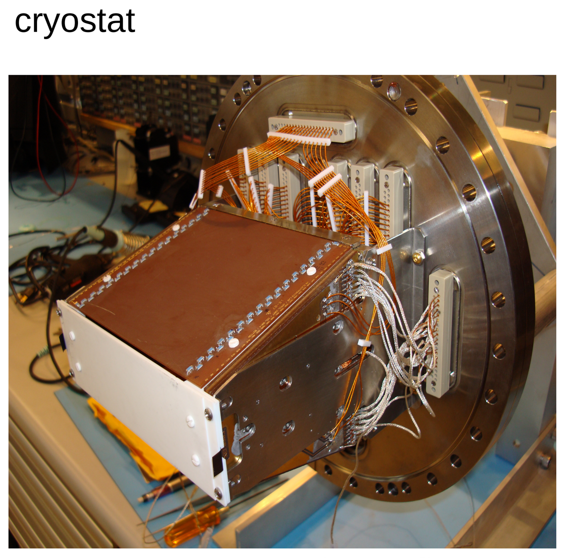
Energy spectrum



3D Sensitivity map

First Results with a LXe Micro-PET Sector

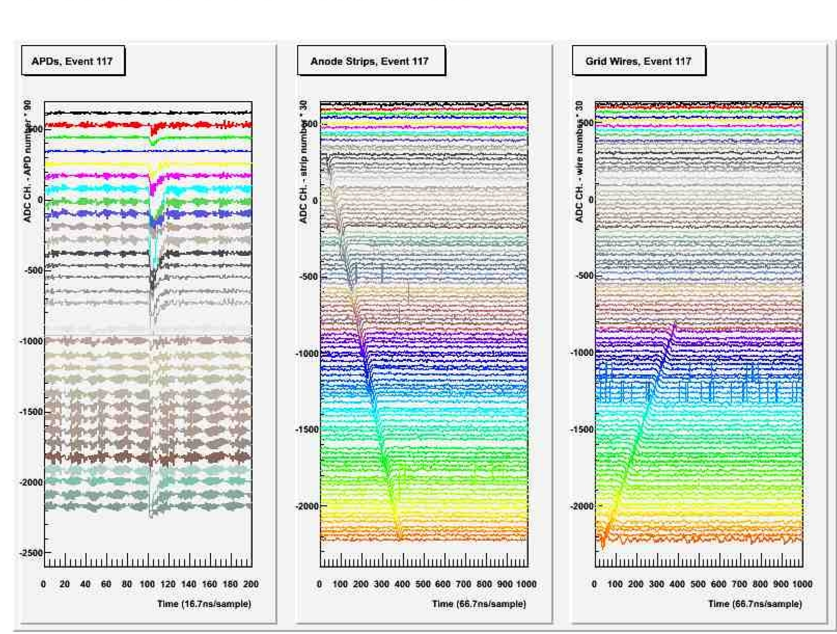
- TPC 1.1l active volume
- Anode module: 96 induction wires and 96 orthogonal anode strips
- 32 APDs
- Sector mounted inside 8.5l cryostat



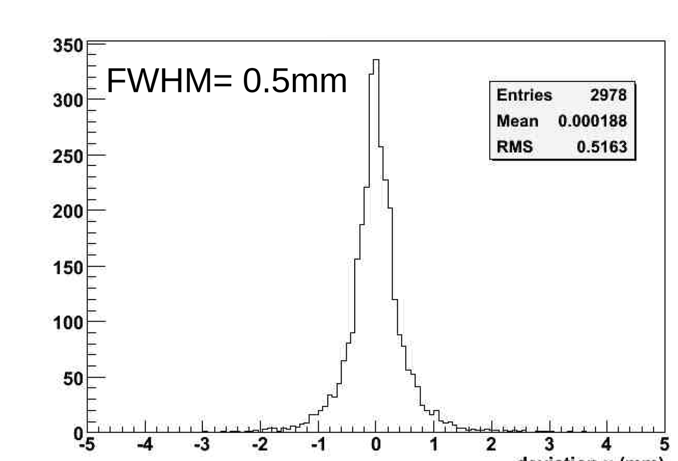
PET sector mounted on a flange

Initial Measurements with Cosmic Rays

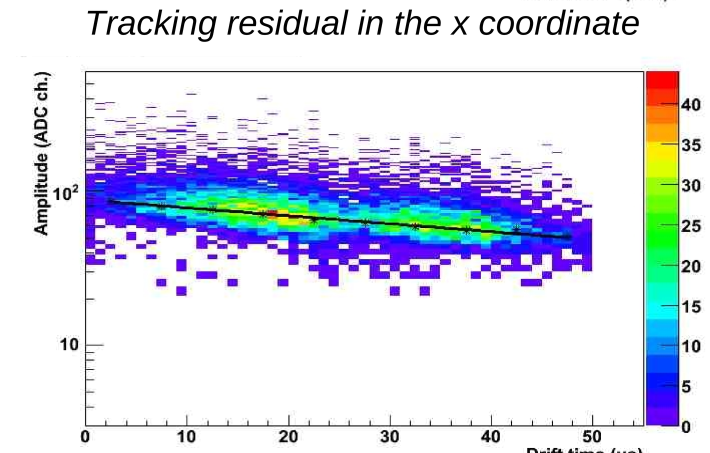
- Cosmic ray tracks were observed
- Tracking residuals < 1 mm were observed in in the drift direction and the x coordinate



Muon track



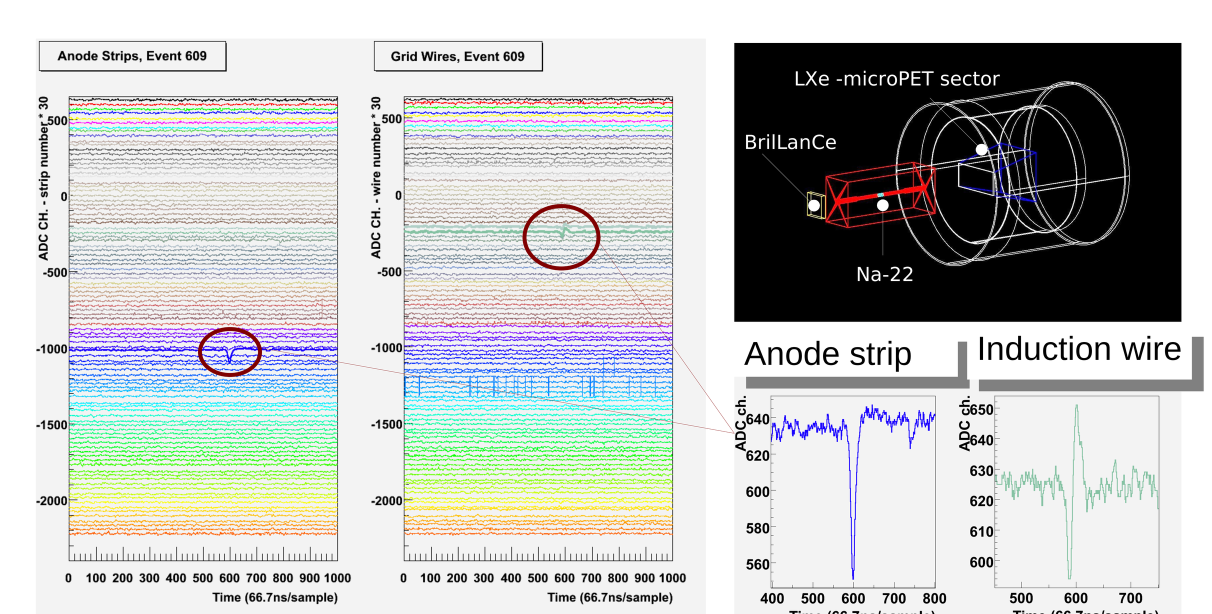
Tracking residual in the x coordinate



Electron lifetime measured with cosmic rays

Coincidence measurements with ^{22}Na source and BrilLanCe detector

- 511 keV photons from ^{22}Na source were observed



511 keV photon detected in the LXe-microPET sector

Future Work

- Further tests with the LXe micro-PET sector
- Design and construction of a ring cryostat and at least two LXe micro-PET sectors for coincidence PET measurements

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