LS-78: Development of Liquid Xenon Detectors for PET

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Detectors for PET

PET is a functional imaging technique based on detection of 511 keV annihilation photons following β+ decay

Requirements for PET detectors:

- High sensitivity
- Sub-mm position resolution
- Good time resolution to decrease the random coincidence rate
- Good energy resolution to reject scattered photons
- High count rate capability
- Uniform response throughout the field of view
- Low cost

Existing PET systems do not satisfy all the requirements simultaneously

Applications of LXePET

Clinical applications in oncology

1. More accurately assess the effects of treatment
   - Improve patient care
   - Save costs
2. Provide better staging information
   - Increase the chance of choosing the corrected treatment

Increase sensitivity --> Reduce radioactivity dose delivered to the subject

(research and diagnosis)

Applications of LXePET

Pre-Clinical cancer studies

1. Receptor imaging: Investigation with receptor-binding tracers will be significantly enhanced
   - Higher resolution --> Smaller area will be explored
   - Higher sensitivity --> Impact of mass effect will be minimized
2. Heterogeneous tumors and necrosis
   - Higher resolution and signal to noise ratio --> Study of heterogeneous tumors and identifying areas of central necrosis will be possible
3. Image two animals simultaneously
   - Uniform resolution and high rate capability --> Imaging two animals simultaneously will have no drawbacks --> The cost of imaging studies will be reduced

LXePET

Objective: Develop a PET system that overcomes the limitations of existing PET systems and reduces detector contributions to PET to the level of intrinsic limitations

- LXePET takes advantages of the properties of liquid xenon (LXe)
- Photons interacting with the LXe produce scintillation light and ionization charge
- Simultaneous measurement of charge and light

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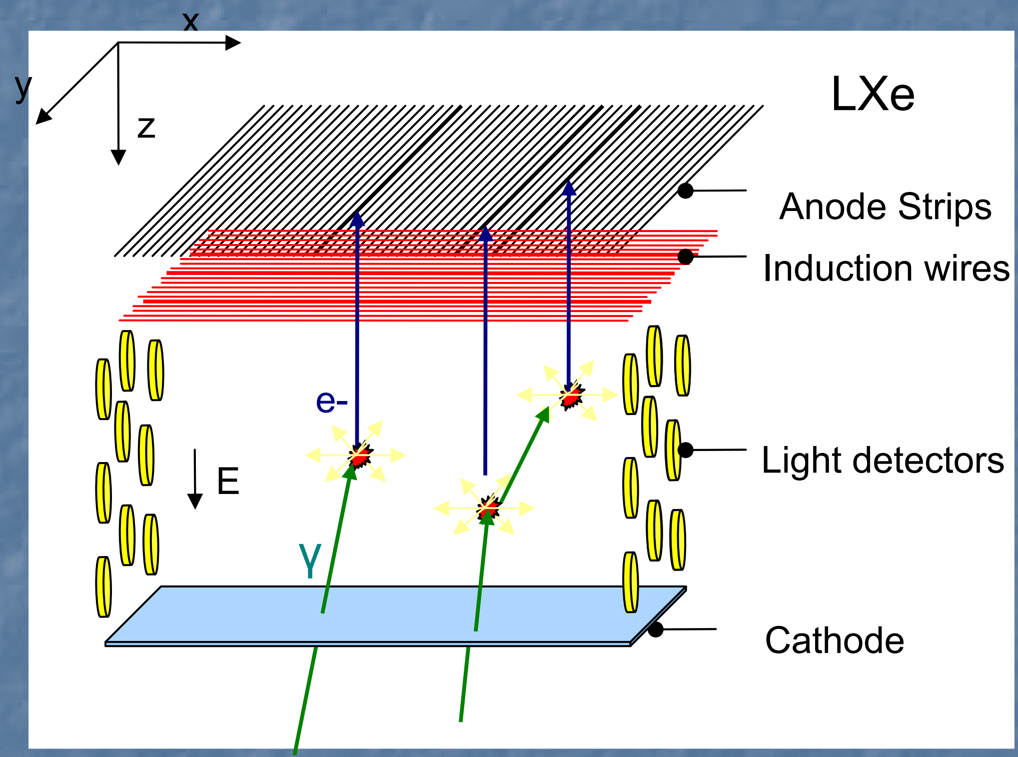
Significant improvement to **spatial resolution, image quality**, and **sensitivity**



LXePET

Objective: Develop a PET system that overcomes the limitations of existing PET systems and reduces detector contributions to PET to the level of intrinsic limitations

Photon interacts with the LXe producing:

- prompt scintillation light (~ 2ns)
  - measured by light detectors
- ionization
  - drifts under the applied electric field to the anode (sub-mm res. in 3D)

Anode module:

- grid of wires preceding the anode
- anode segmented into strips ⊥ wires
- Shielding grid

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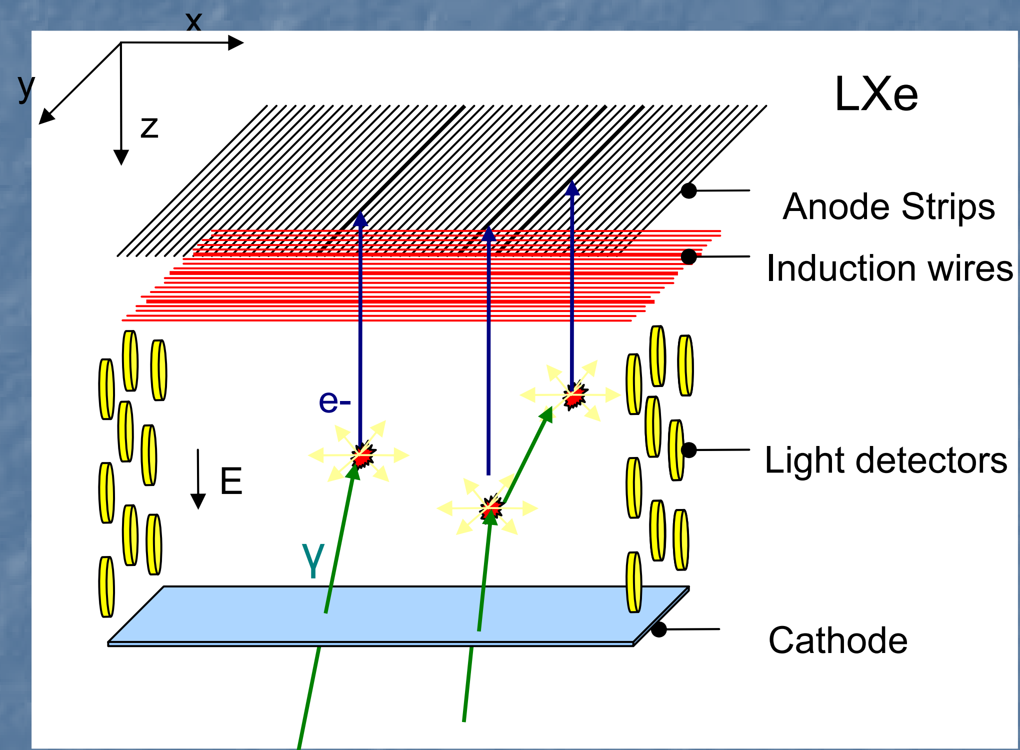
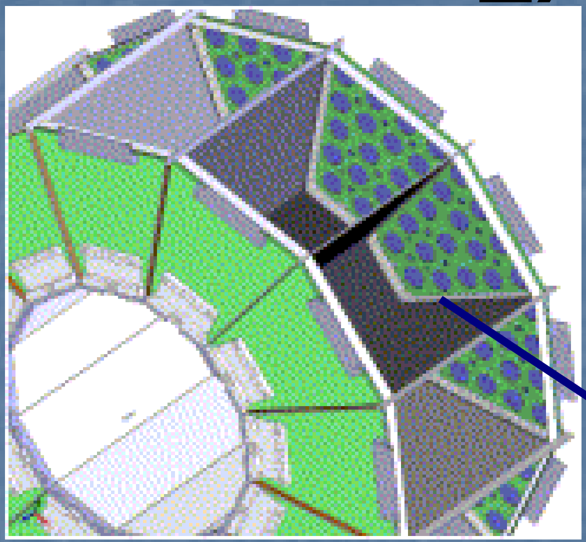
- The electron signal induced on the wires and collected by the anode strips provides the 2D position (x-y) of each interaction
- The z-coordinate is calculated from the drift time and the drift velocity



- Compton scattering reconstruction

LXePET System



12 trapezoidal sectors

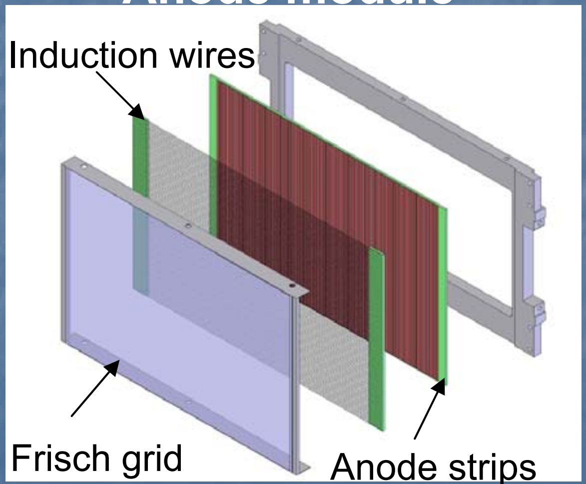
Axial length = 10 cm

Drift length = 12 cm

μ-PET Sector

- TPC filled with LXe
- 32 APDs

Anode module



- Currently testing one micro-PET sector
- Designing and building new cryostat to house 2 or more sectors for coincidence PET measurements

LXePET Performance (simulated)

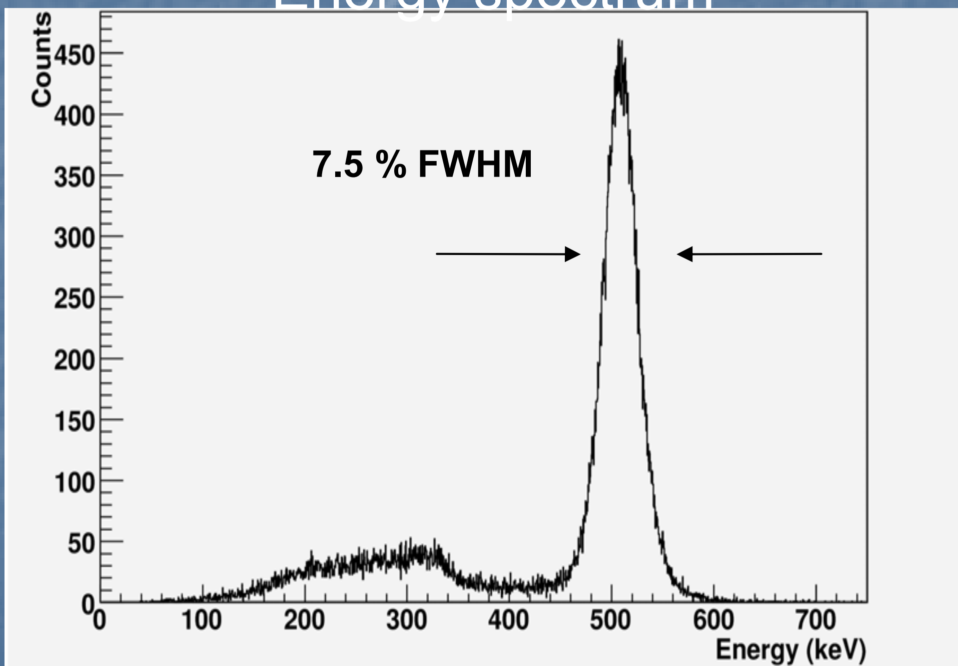
- MC Simulation based on Geant4, parametrization of detector response,

  Compton reconstruction algorithm for event reconstruction

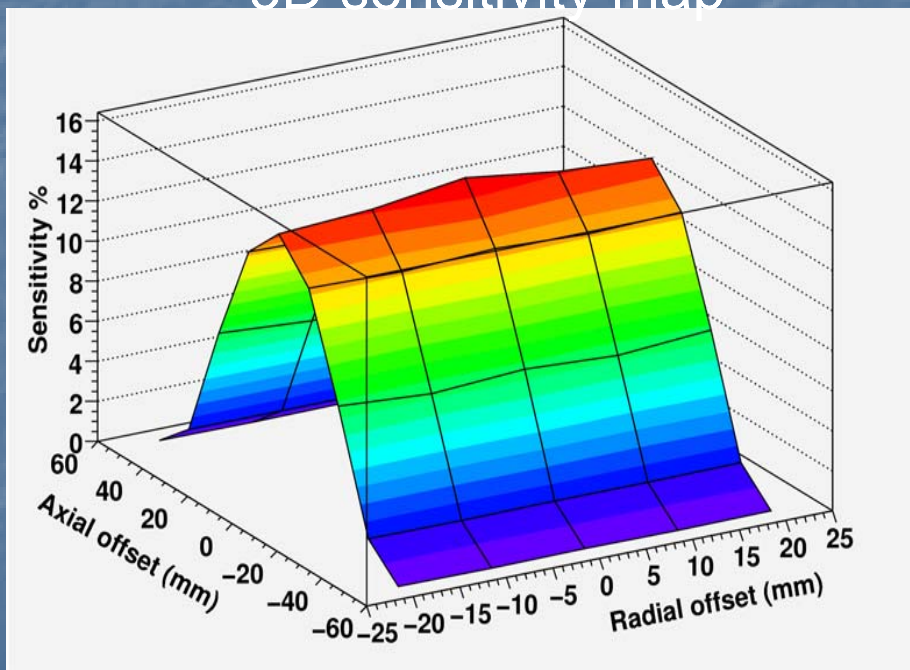
- **Energy resolution** at 511 keV = 7.5% (FWHM)

- **Sensitivity** at center of FOV = 15%

Energy spectrum

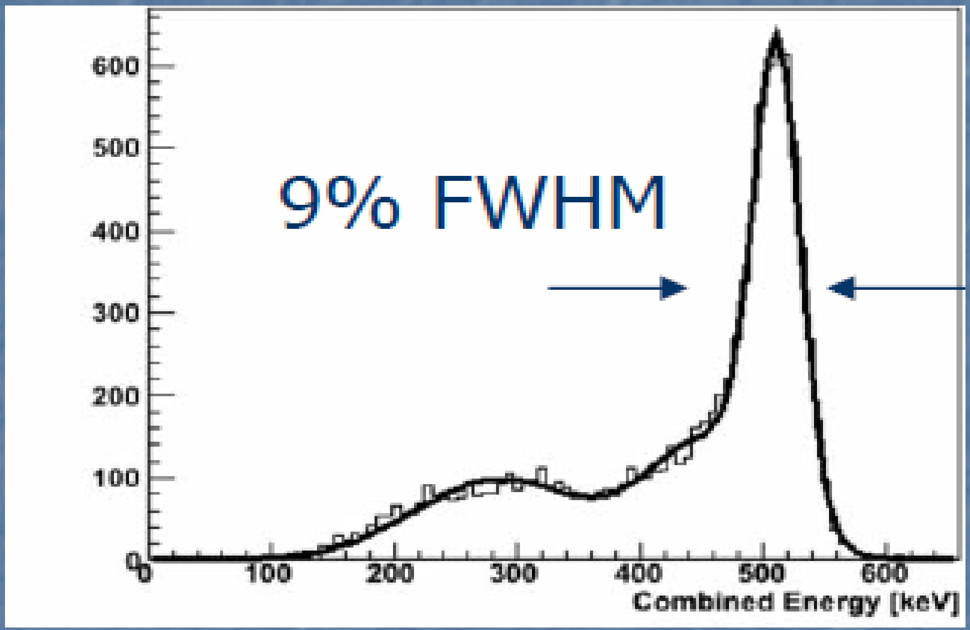


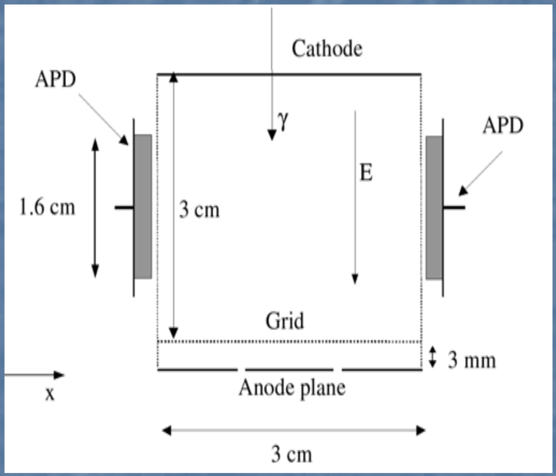
3D sensitivity map

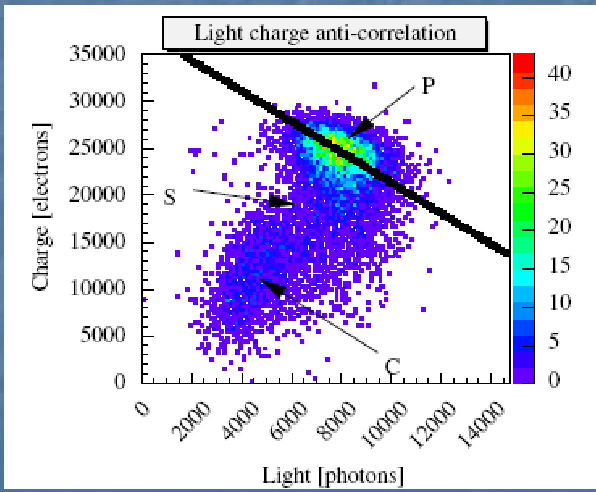


Small Scale Prototype Tests

- Electrons lifetime > 100 μs (purity < 10ppb)
- Energy resolution 9% (FWHM)







P. Amaudruz et al., Nucl. Instr. And Meth. A (2009)

LXePET Sector Prototype

- TPC 1.1l active volume
- Anode module: 96 induction wires and 96

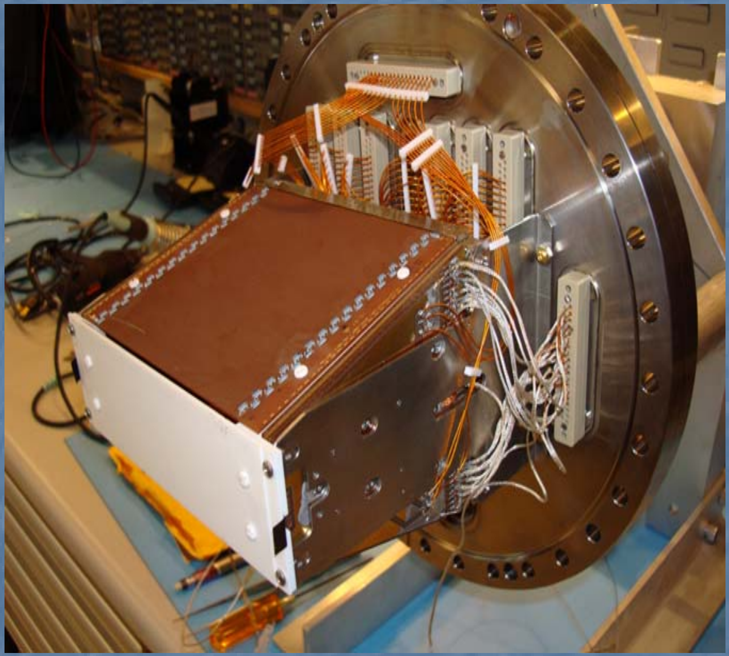
orthogonal anode strips

- 32 APDs
- Sector mounted inside 8.5l cryostat

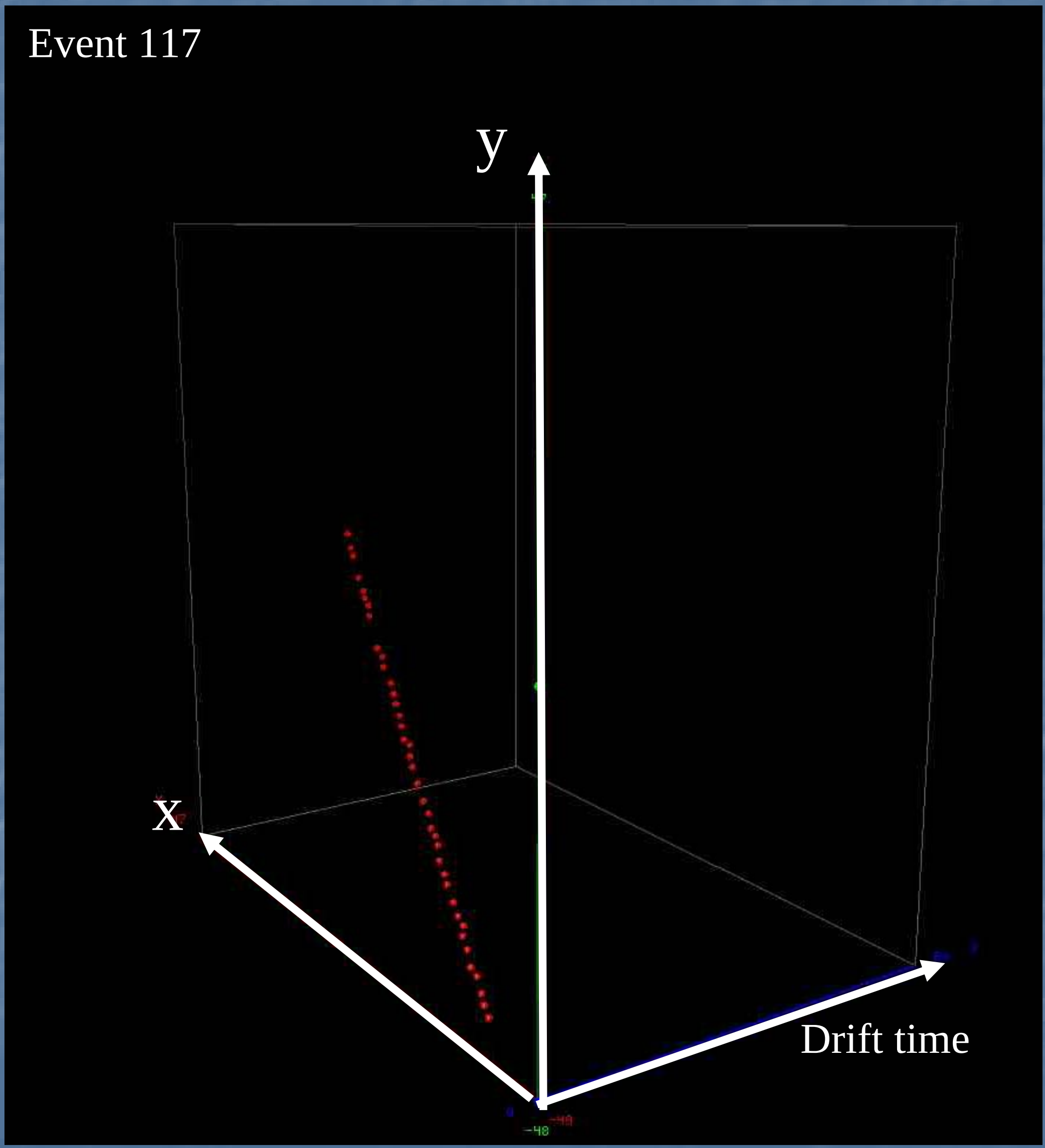
2010 Tests

- Electron lifetime measurements with cosmic rays
- Coincidence measurements with Na-22 source

and BrilLanCe detector

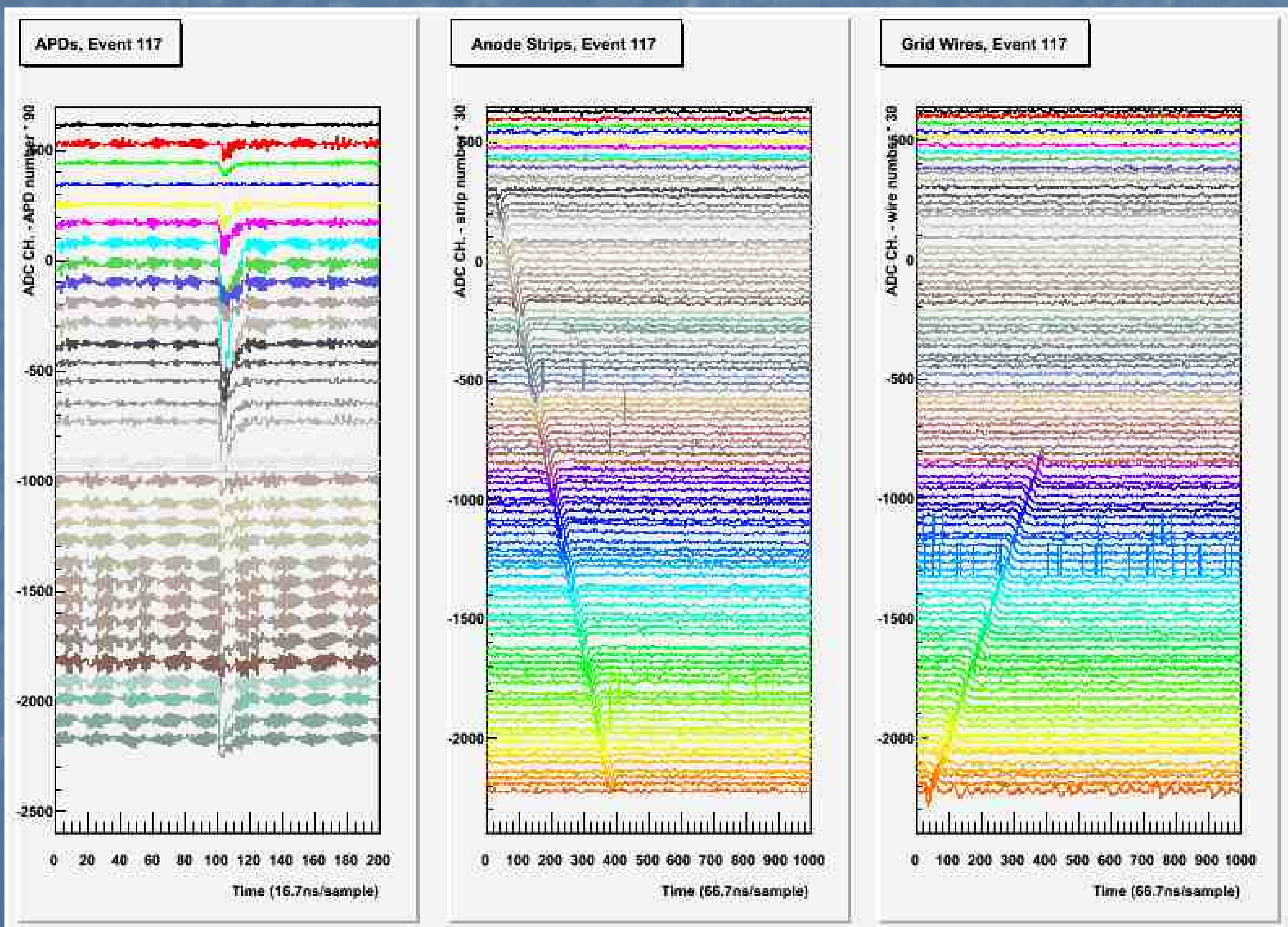


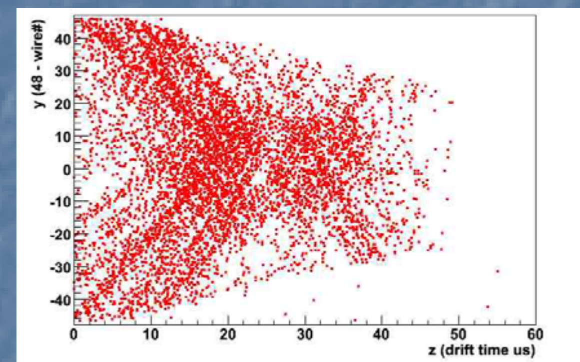
Cosmic ray event – 3D visualization

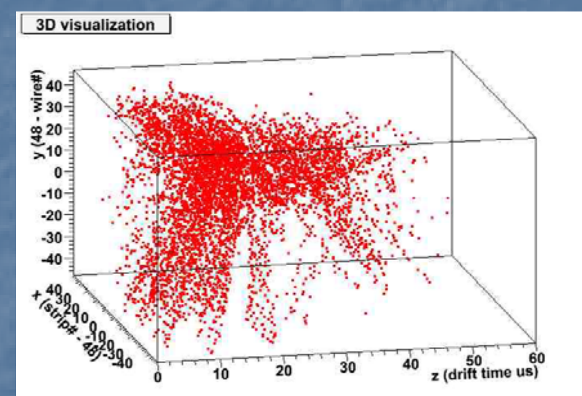


Initial Measurements with Cosmic Rays

- **Cosmic ray tracks**







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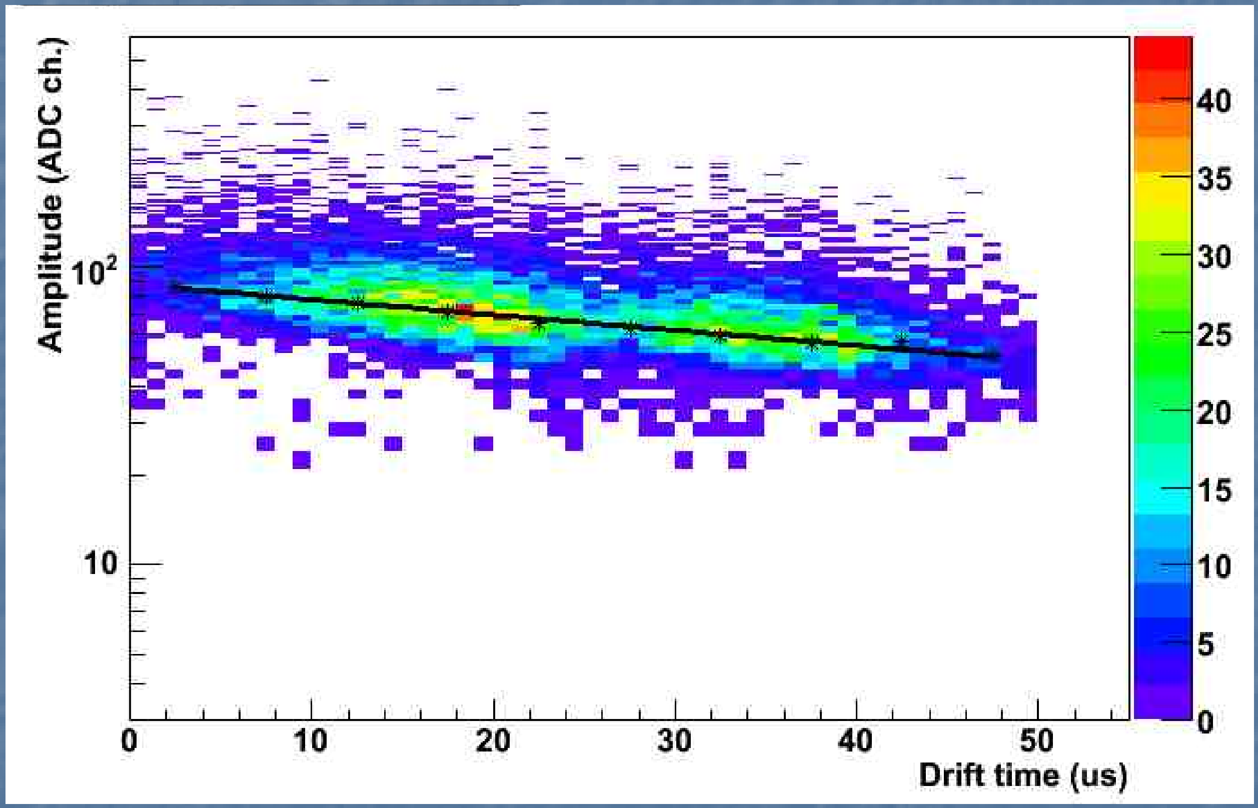
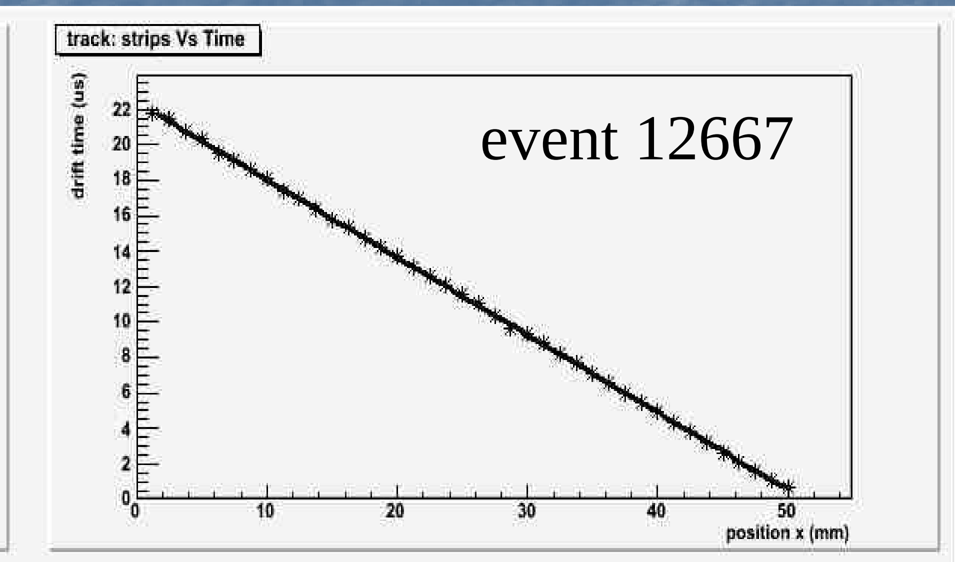
Electron Lifetime Measured with Cosmic Rays

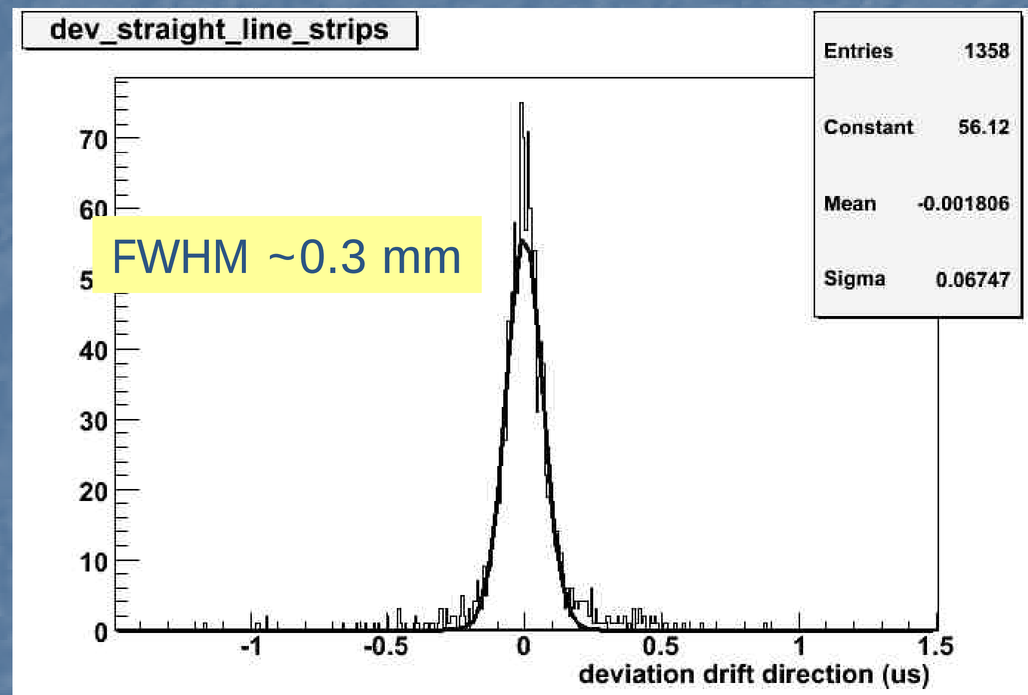
- Electrons lifetime > 70 μs



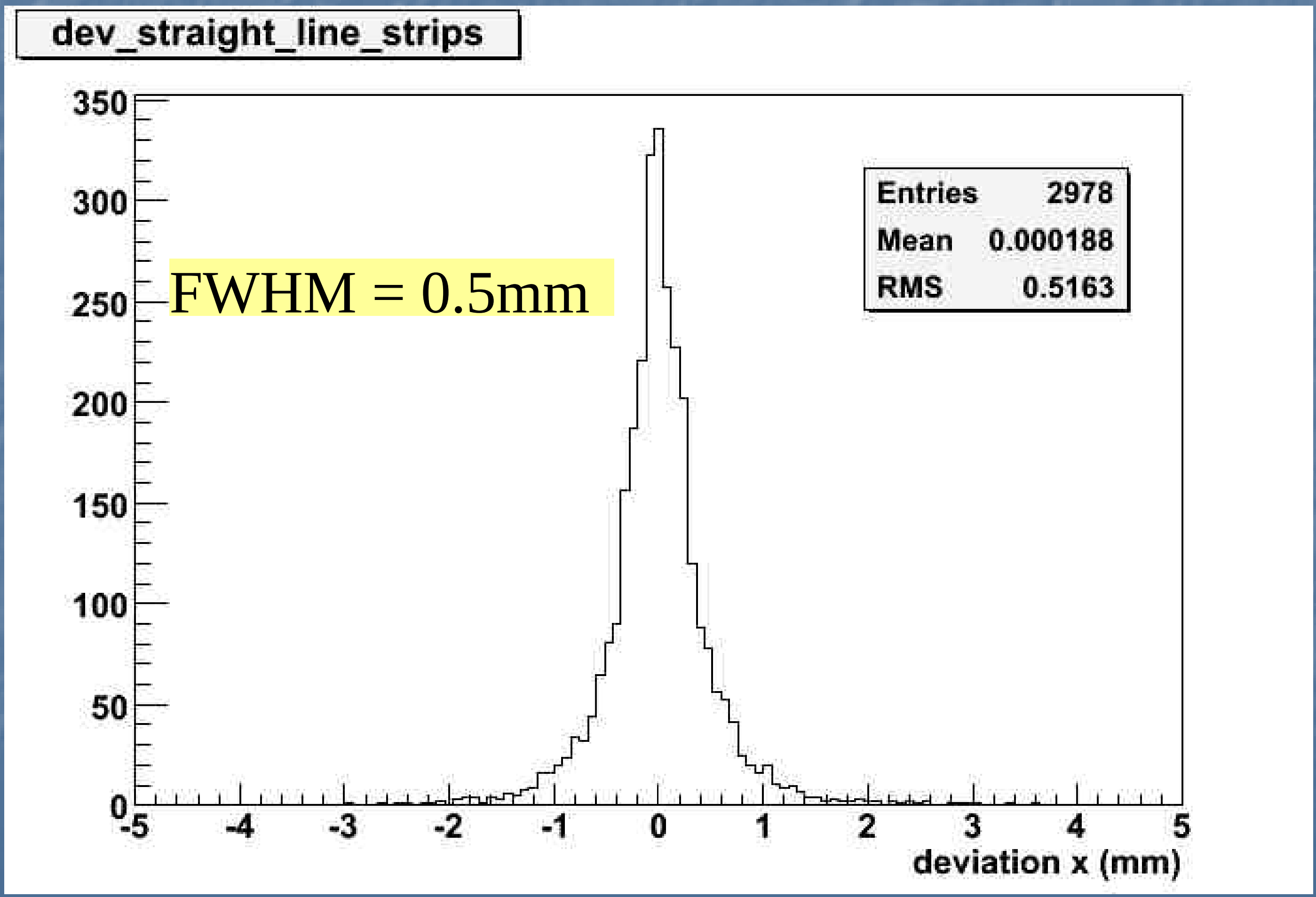
Time (Z) resolution with Cosmic Ray Data

Muon track in XZplane (X = strips, Z = drift time), Strips time = Average Time





X-Position resolution from CR data

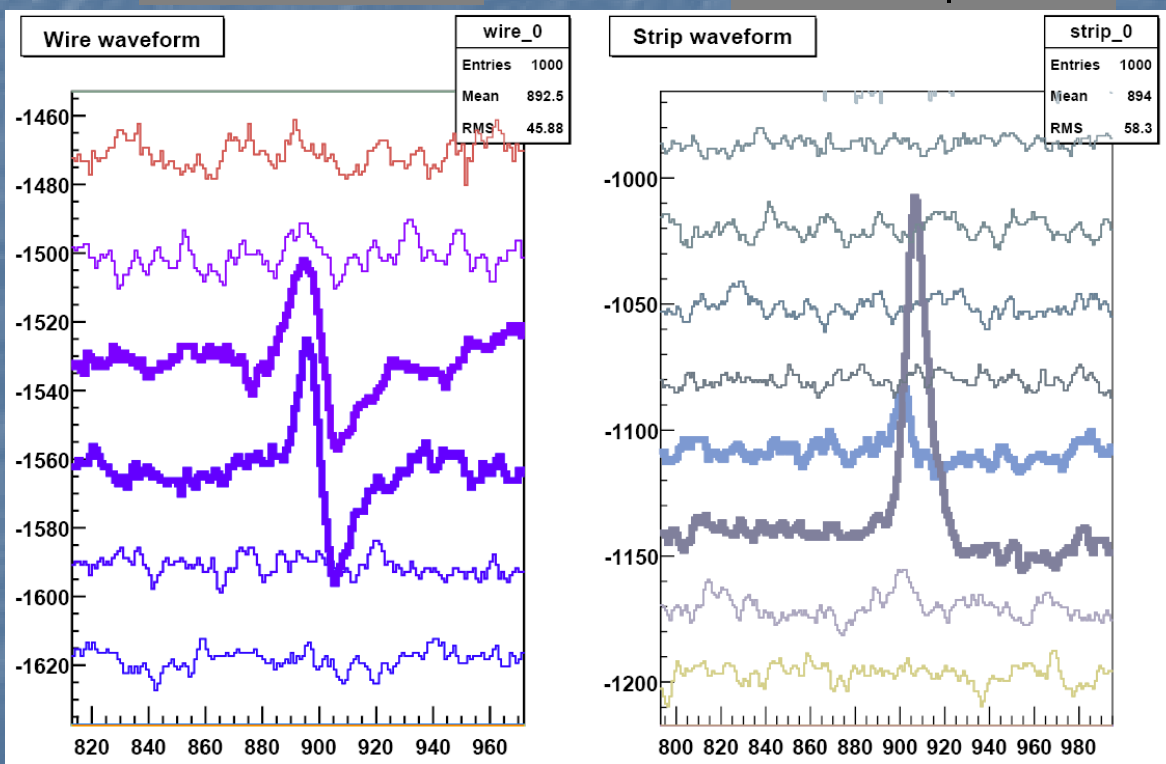


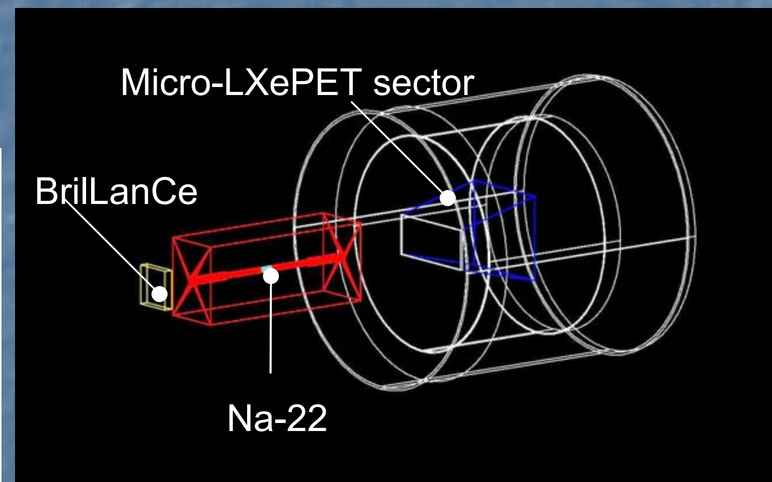
Tests with Na-22 Source

- **511 keV photon detected**

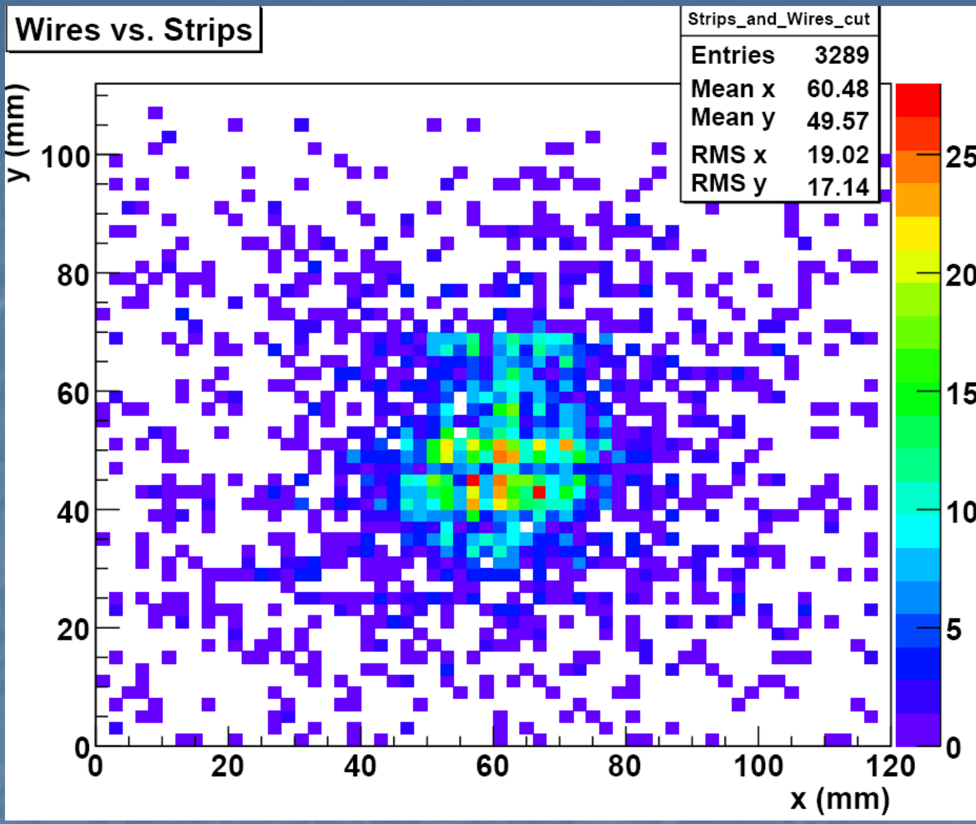
Grid wires

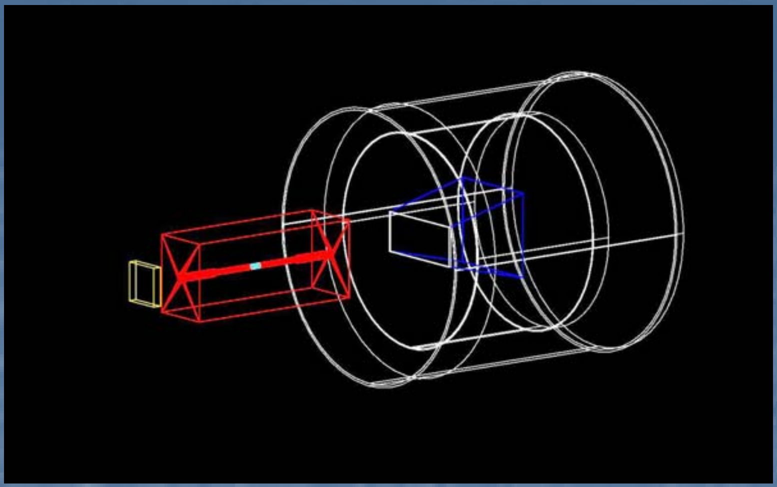
Anode strip

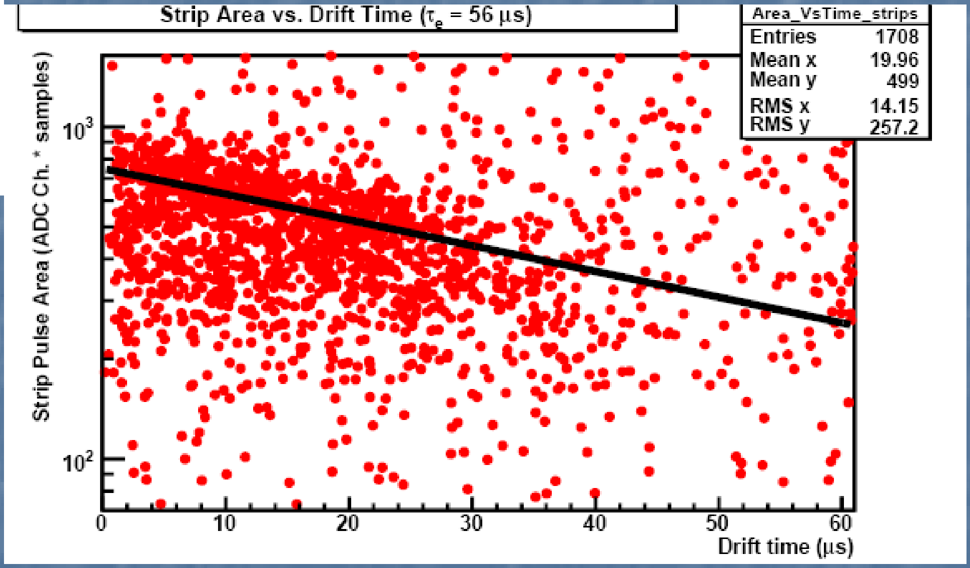




Collimated Source



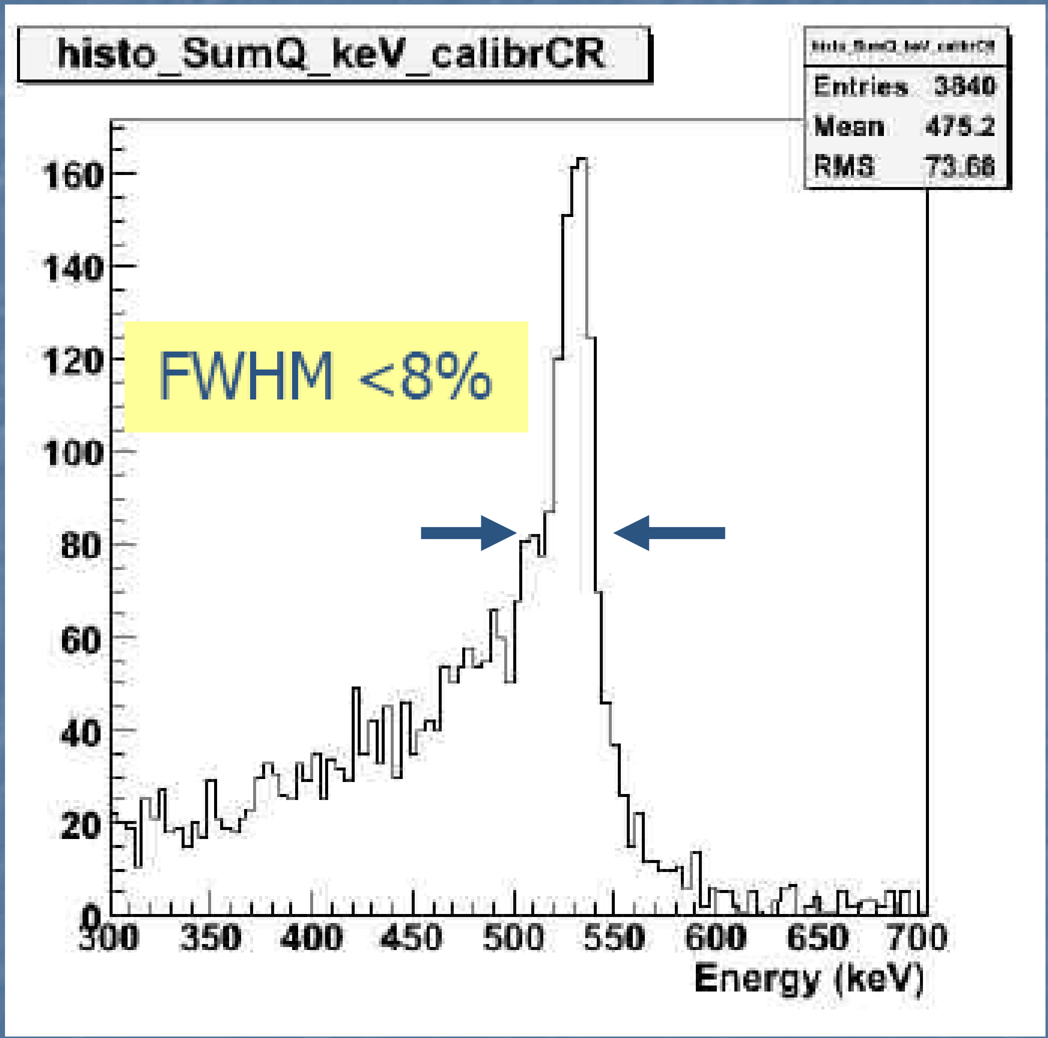




Spectrum Na^{22} source with Brillance Trigger -- single strip hit events

Initial study
Very Preliminary

Non-optimum
run conditions



Sector Test: What's been accomplished so far

- Complex detector operated
- Modest purity achieved
- Position resolutions (x, z) measured:
  FWHM < 1mm
- Energy resolution measured for TPC:
  FWHM ~ 8% at 511 keV

Current Issues and Problems

- Purity – aim to improve by order of magnitude
  - Replace, improve liquid filters and pumps
  - Optimize liquid exchange in chamber
  - Improve cooling system for heated getter flow
- APDs
  - APD module B missing HV : fix HV connection
  - APD module A: fix 2 bad signal connections
  - APD pickup noise – investigate and fix: add coax cables in vacuum; possibly lower bandwidth
- Drift HV Connection
  - Now 10.8 KV (~ optimum for operations)

  Improve -> 20 KV, desirable for tests; likely fix HV feedthrough

Schedule

Schedule

05/2010 – 12/2010

- Test prototype chamber
  - Improve purity
  - Fix APD problems
  - Study Compton reconstruction
- Complete design, manufacture, assemble cryostat, control system and two PET sectors
- Design and manufacture electronics and DAQ for multi-sector test
- Continue Geant4 simulations to optimize event reconstruction
- Develop image reconstruction algorithms

2011

- Coincidence tests with two sectors

BACKUP

LXe properties

LXe properties	
High ionization yield: 64000 e-/MeV at high E field	Large detectable ionization signal
Very small diffusion: for 1us drift 20 um	Sub-mm position resolution
High light yield: 68000 photon/MeV @ E field = 0	Bright scintillator
Fast scintillator: decay time 2.2 ns, 27 ns	Sub-ns time resolution
Wavelength of scintillation light = 178 nm	Special photo-detectors
Boiling point 165.1 K	Easy cool down
Radiation length for 511 keV photons~ 3cm	Compact detector
Purity required < 1ppb O2--> e- lifetime ~ 1ms	Purification is critical

Image quality