LS78: Design and Performance of Liquid Xenon Detectors for PET

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1. **PET and LXe**
   - Why use LXe for PET?
2. **Proof of Principle**
   - Small Prototype
   - Data Analysis
3. **LXe for Micro-PET**
   - Prototype Design
   - Prototype Test
4. **Future Plans**
   - Next Steps
   - Design of full Micro-PET Ring
     - Funding from CHRP (CIHR+NSERC) from 2008 to 2011

Advantages of LXe for PET

- Good 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
- High count rate: $> 10^5 (s^{-1}\ cm^{-2})$
- Cover large volumes with just one electrode array
  $\rightarrow$ high sensitivity
  $\rightarrow$ Efficiency $> 70\%$
- Inexpensive ($<$ \$ 3/cc)

Properties of LXe

- Z=54, A=131 $\rightarrow$ Attenuation length: 36 mm
- Density: 3 g/cc at 165 K $\rightarrow$ compact detector
- Boiling/Melting point temperature: 165 K / 161 K
  $\rightarrow$ needs cryogenic system
- Produces ionization and scintillation light
  $\rightarrow$ combining both improves energy resolution
- Purity important: 1 ppb allows an e^- lifetime of 1ms

Ionization

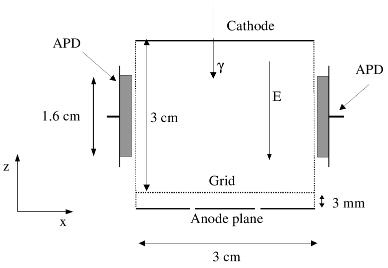
- Yield: 15.6 eV $\rightarrow$ 32800 e^- at 511 keV and $E_d = \infty$
- E_{drift}: 1-2 kV/cm
- v_{drift}: 2 mm/µs

Scintillation

- Yield: 13.8 eV $\rightarrow$ 37000 γs at 511 keV and $E_d = 0$
- γs with $\lambda = 175 - 178$ nm (special photo-detectors)

Time Projection Chamber (TPC)

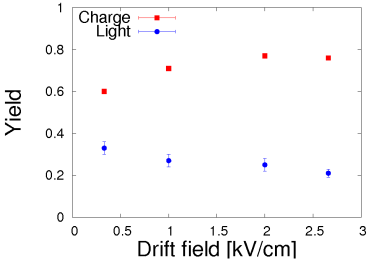
Paper about results ready for submission to Nucl. Instr. Meth. A



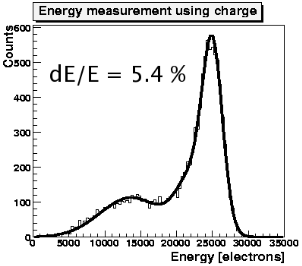
- TPC volume 3x3x3 cm^3
- E=1 kV/cm, v_d =2 mm/µs
- 2 APDs; solid angle ≈ 12%
- 511 keV γs from ^{22}Na

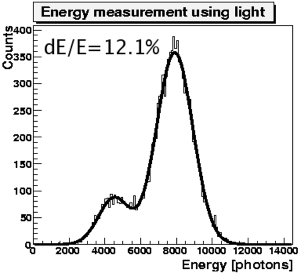
Achievements:

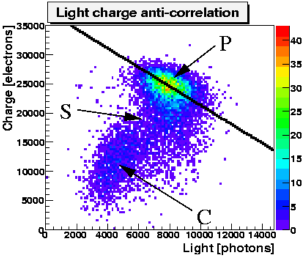
- Measured charge and light
- Studied energy resolution
- Understood detector contribution and limitations

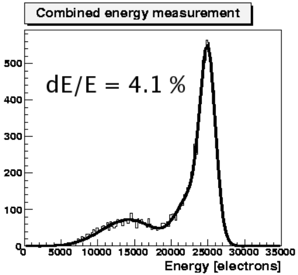


Charge-Light-Anti-correlation









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%)

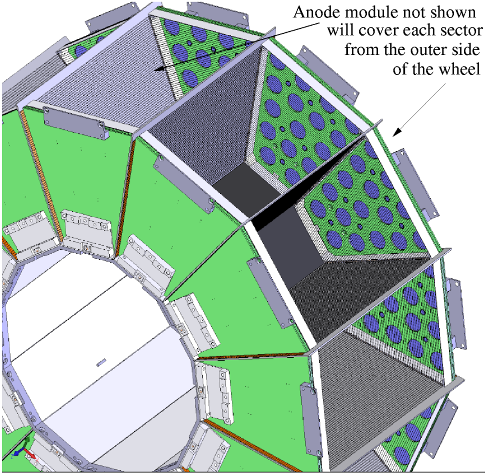
Energy resolutions:

	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

Position Reconstruction from Fast Light Signal

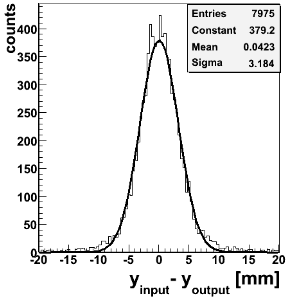
→ Important for high rate operation

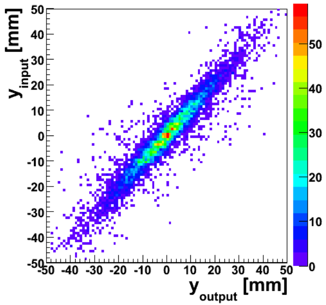
Challenge

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
$\sim$ 1 ml depending on noise.

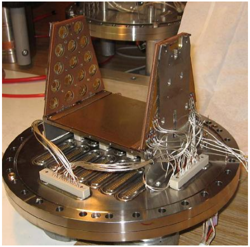
Prototype Status

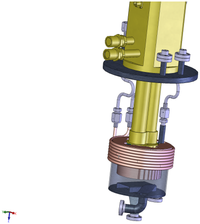
Recent Progress

- Finished test with 16 APDs
- 1st use of liquid purification
- 1st test of pulse tube refrigerator

Problems Solved

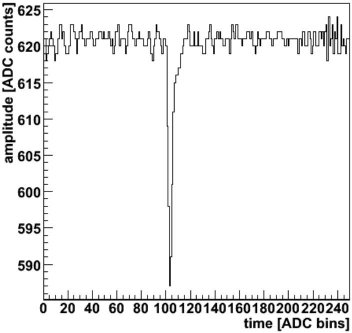
- High voltage issues with APDs in LXe
- APD spring contacts faulty $\longrightarrow$ replaced
- Devised procedure of evacuating, baking and cool down





APD Sector Test (just completed)

APD signals were observed from 511 keV photons from ^{22}Na



Test ended prematurely due to vacuum problem

But:

Signal amplitude lower than expected

Probable Causes

Impurities in LXe like H_2O
$\rightarrow$ Attenuation too high
But: Currently no equipment to measure LXe purity

Possible Solution

Use gas purifier in addition to liquid phase purifier + longer high temperature bake-out

Operating and Testing First Sector Prototype

Now assembling TPC and APDs together
$\longrightarrow$ operational in Summer 2009

Technical Performance

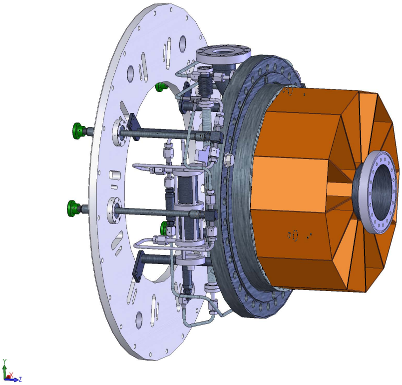
- Purity
- Stability
- Mesh and grid transparency
- APD gain and noise
- Electronics noise
- Crosstalk, etc.

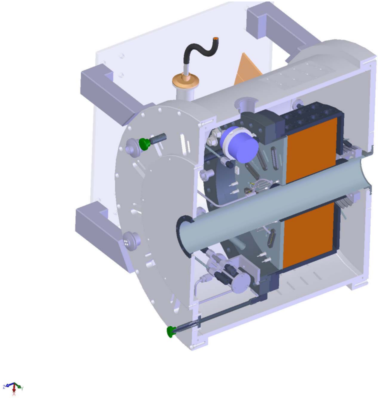
Detector Performance

- Light and charge yield
- Drift velocity
- Position resolution with light and ionization
- Time resolution and rate capability
- Energy resolution with light and ionization

Long Term Plans

CHRP Project: Design of cryostat in progress:





Build two new opposing sectors and operate in coincidence

LXePET Schedule and Resources

Schedule

- 7/2009-11/2009:
  Test Sector Prototype
- 9/2009:
  Complete Cryostat Design
- 1/2010-9/2010:
  Construct Cryostat and Sectors
- 1/2011:
  Testing

Resources

- Mech./Cryo. Eng. (C. Marshall)
- Designer (D.O.)
- Manufacturing (LADD, M.S.)
- Electronics engineer/shop (E.S.)
- Technical Support:
  - Electr. Technologists (R. Bula, M.Constable)
  - Mech. Technologist (C. Lim)
- LADD Cryogenics and Microstructures Labs

BACKUP

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