LS 78:
Development of Liquid Xenon Detectors for PET

L. Kurchaninov

for Collaboration

P.Amaudruz, F.Benard(BCCA) D.Bryman (UBC),
L.Kurchaninov, P.Lu, J.-P.Martin, A.Muennich, F.Retiere,
T.Ruth, V.Sossi, J.Stoessl(UBC)

- ❑ PET detectors
- ❑ Liquid Xenon properties
- ❑ Compton reconstruction
- ❑ TPC prototype tests
- ❑ LXPET design
- ❑ Single sector test status and plans
- ❑ Long term plans
- ❑ TRIUMF resources

PET Detectors

Typical performance

- Spatial resolution 6 mm
- DOI information **NO**
- Time resolution 3 ns (fwhm)
- Energy resolution 20-25% (fwhm, for 511 keV)
- Detection efficiency 85%

Our goals

- High spatial resolution along axial and transaxial directions (~1 mm)
- Depth of interaction sensitivity (DOI) (<1 mm)
- Good time resolution (~1 ns)
- High detection efficiency (>70%)
- Good energy resolution (<10% fwhm)
- High count rate (>10^5 /s/cm^2)
- Low cost
- Use Compton scattering reconstruction to reduce backgrounds

Xe Properties

- Z=54 → high efficiency
- Boiling point 165.1 K → "easy" cool down
- Density of liquid ~3.0 g/cc, radiation length for γ 511 keV ~3 cm → compact detector
- Working point ~2 kV/cm → reasonable HV

- Ionization yield Wi = 15.6 eV (High E field) → detectable signal
- Drift at 2 kV/cm: 2.5 mm/ms or 4μs/cm. → fast signal
- Diffusion for 1μs drift ~20 μm → sub-mm position resolution
- Purity required <1ppb (O_2) → purification is critical

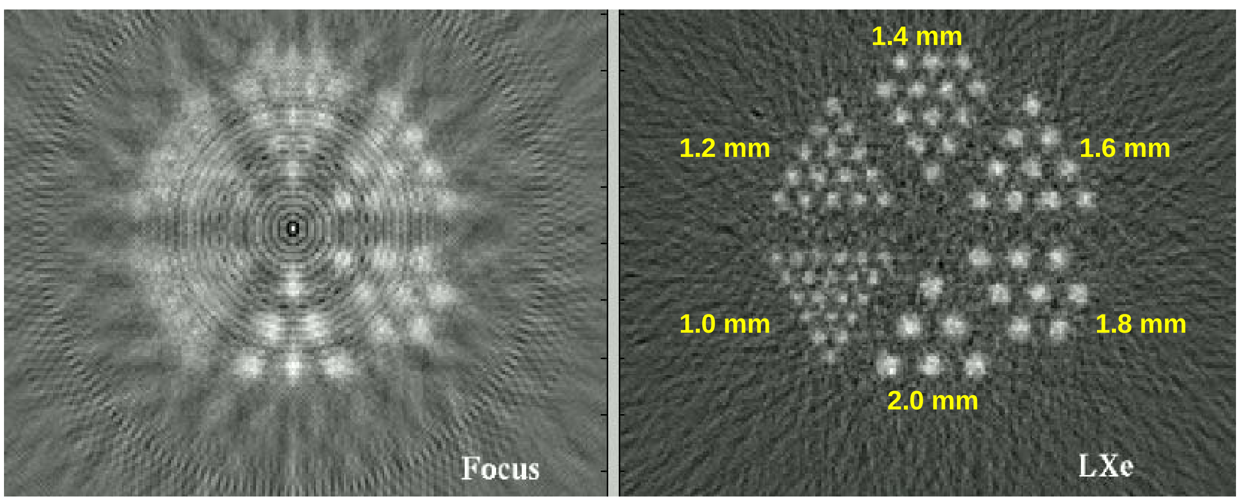
- Scintillation at 178 nm → special photo-detectors
- yield Ws = 14.6 eV (zero E field) → bright scintillator
- Timing of excitation: τs=2.2ns; τt=27ns → sub-ns time resolution
- Attenuation length = 26-36 cm → OK for ~10cm detector

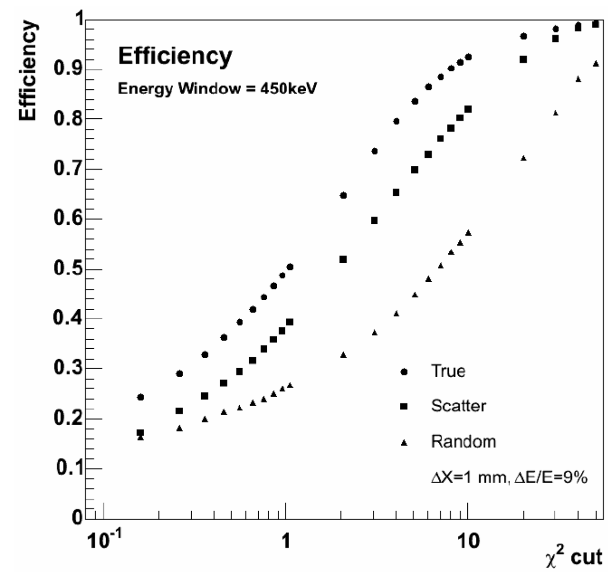
- Available in industrial quantities → reasonable price (~$3/cc)

Simulations of Compton Reconstruction

- Simulations of LXe micro-PET with ID = 15cm, OD = 39cm, axial 12cm
- Positron range included. Non-colinearity not included
- Dead material: SS 1mm
- Assuming ΔE = 9% and ΔX = 1mm (fwhm), dead time 500ns
- Compton events: first interaction point determined by using E-Θ correlations

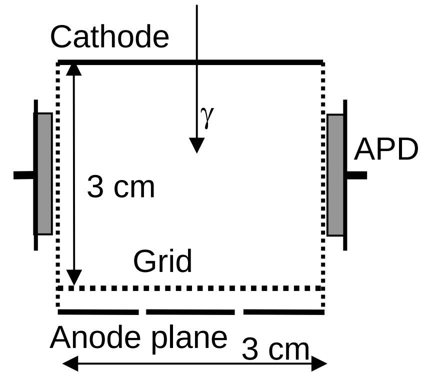
  - Absolute sensitivity 12%
  - Background suppression capability
  - Image quality (phantom rods in water)

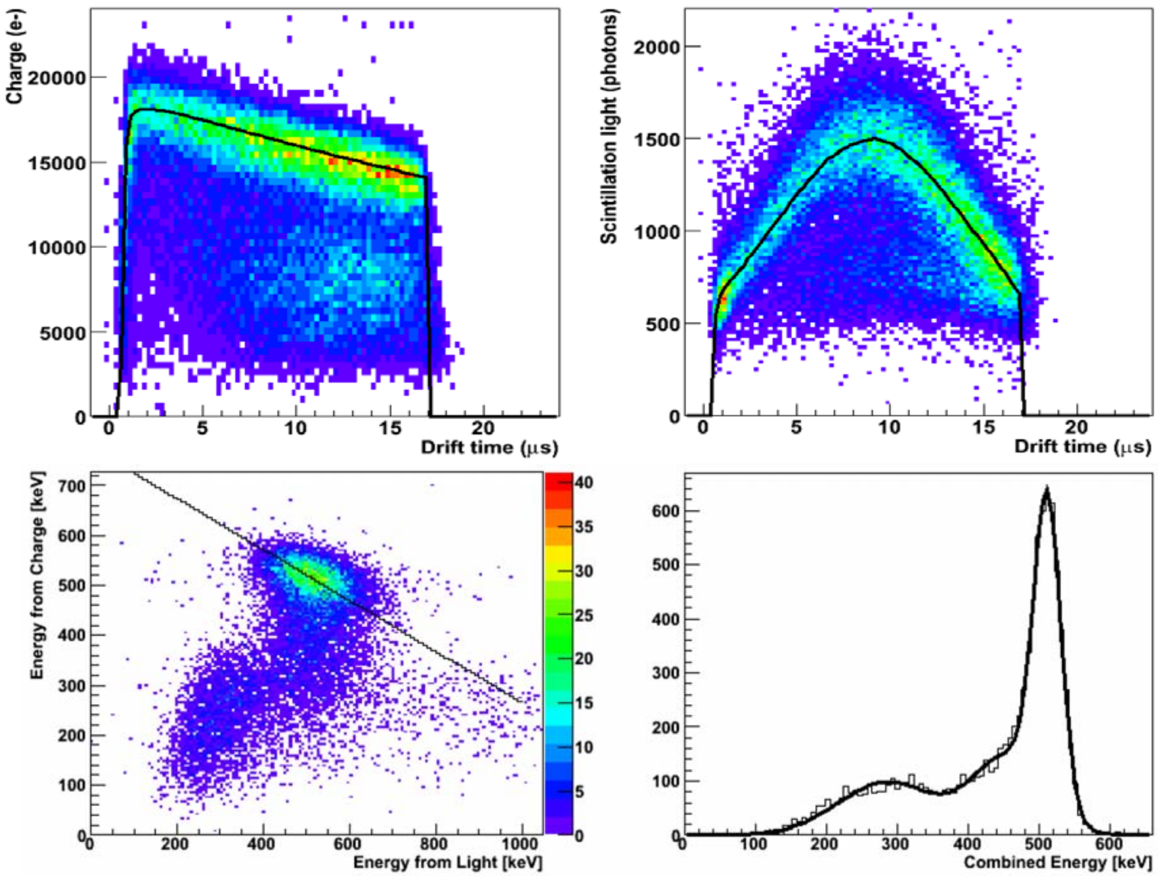




TPC Prototype Tests

- TPC 3x3x3 cm, grid 3 mm, gap 3 mm
- 2 APDs, total solid angle ~ 10%
- 2 anodes: central Dia = 10 mm
- Tests with Na22

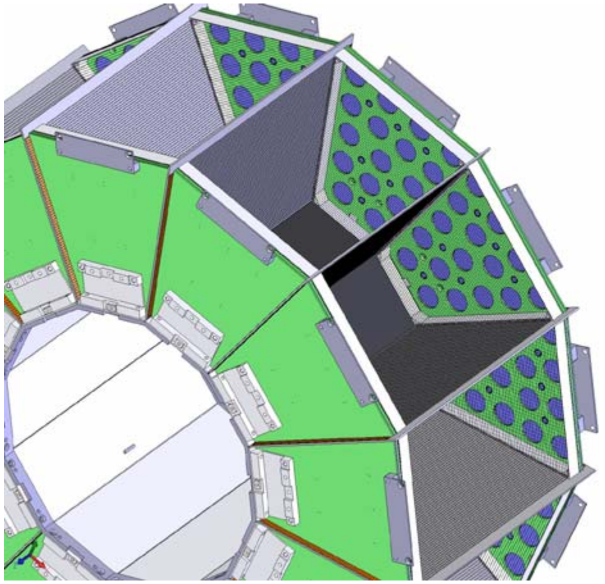


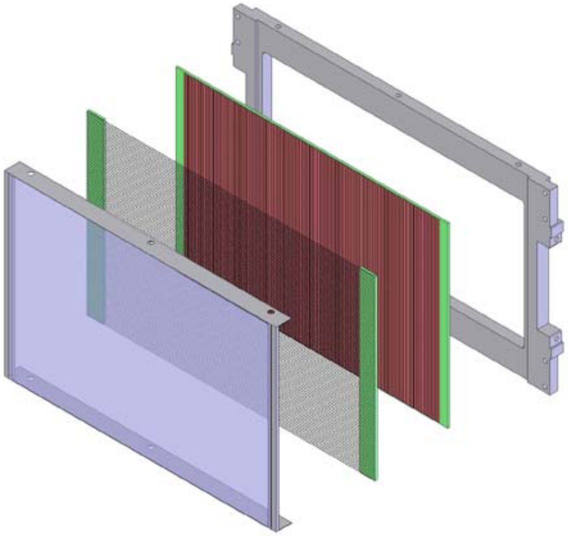


- Electrons lifetime > 100 μs, purity < 10 ppb
- Light resolution (rms) 12.7%
- Charge resolution (rms) 5.5%
- Light and charge (rms) 3.8%

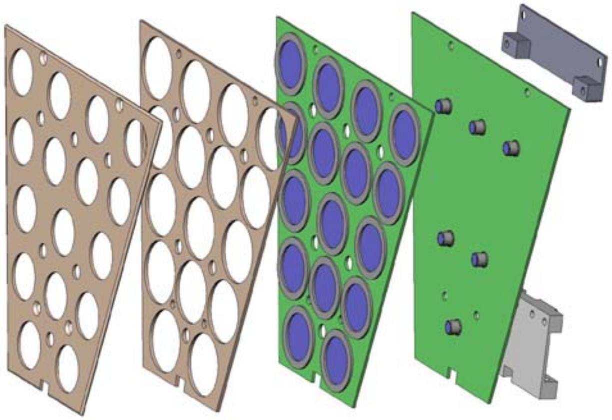
LXPET Design

- 12 sectors.
  - Field cage formed with strips (between sectors) and wires (ends)
  - Cathode: resistive kapton on ceramic plates





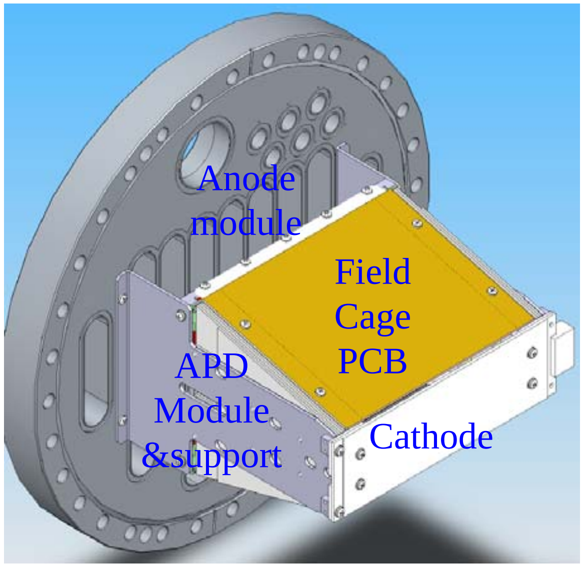
- Anode module
  - 96 wires, 96 strips
  - SS and kapton PCBs
  - AC decoupling with kapton?



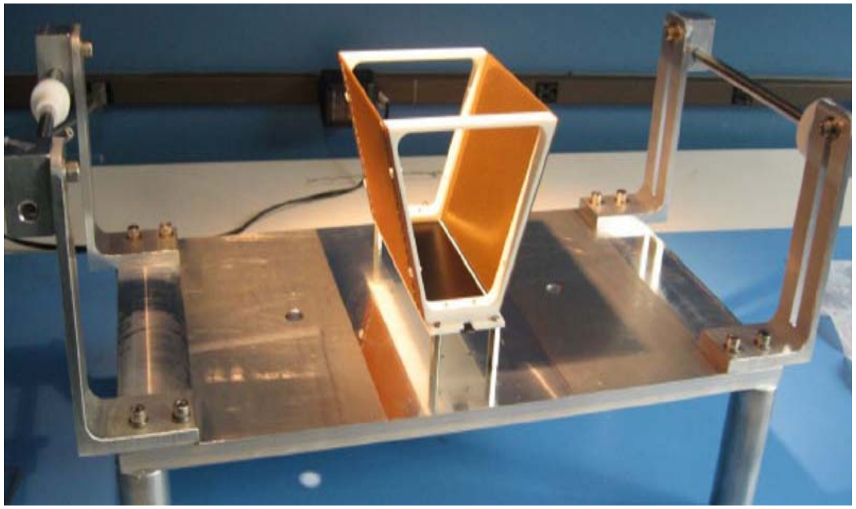
- APD module
  - 16 APDs and 6 LEDs for monitoring
  - 1 HV line and 16 LV lines (HV tuning)

Single Sector Test Status

- ❑ Full-scale sector
  - ✓ Fits into existing cryostat
  - ✓ Designed, parts built
  - ✓ Assembly is going on
- ❑ Cryogenics and controls updated
  - ✓ More cooling power
  - ✓ Better purification

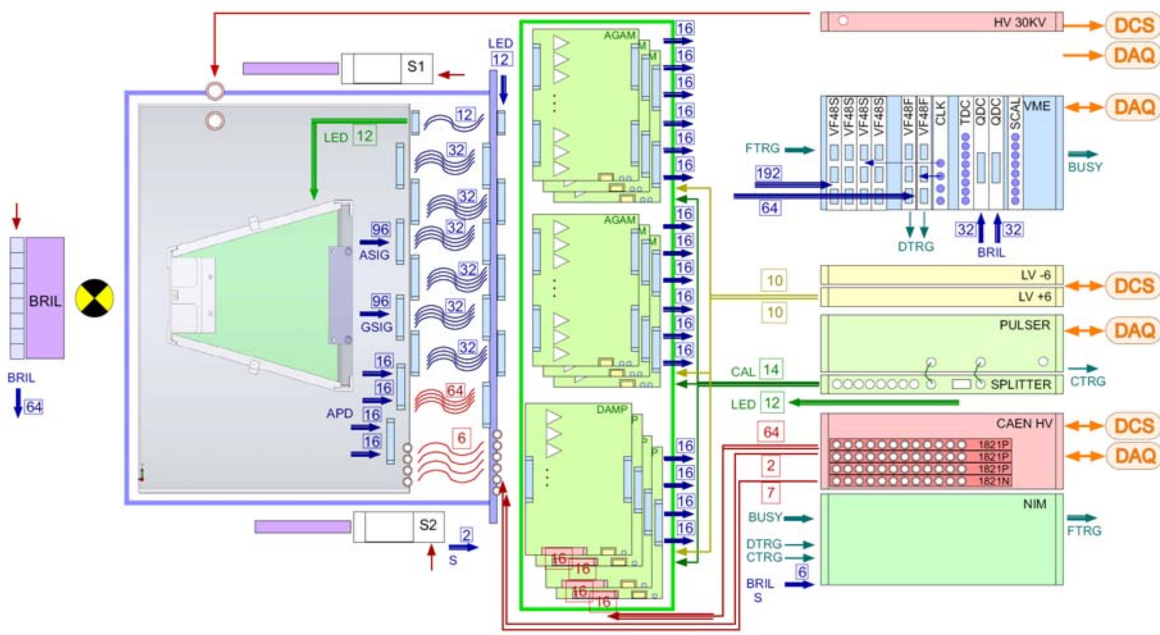


- ❑ FE and RO electronics prepared
- ❑ Assembly is nearly complete
- ❑ DAQ and monitoring are nearly complete
- ❑ First cool-down in progress (with APDs and cables, no field cage)
- ❑ Final Assembly in May
- ❑ Tests in June-December (could continue in 2009)



Single Sector Test Plans

- ❑ Technical studies
  - ➢ Xe purity, stability
  - ➢ Mesh and grid transparency
  - ➢ APD gain and noise
  - ➢ Electronics noise, Xtalk, etc.
- ❑ Basic Xe characteristics
  - ➢ Light yield
  - ➢ Charge yield
  - ➢ Drift velocity
- ❑ Detector performance
  - ➢ Position resolution with APDs and with ionization signals
  - ➢ Time resolution and rate capability
  - ➢ Energy resolution with APDs and with ionization signals
  - ➢ Uniformity, dead area



- ❑ In total ~1 month of technical studies, 1 month of HV curves and 3 month of data taking
- ❑ 20TB of raw data, to be stored: 3-4TB

Long Term Plans

- **Depend on the single sector test results**
- Simulations for PET optimization (number of sectors, dimensions)

Double-sector test

- Next iteration of sector design could be needed (alternative photosensors, anode/grid geometry, gap width, field cage, reflections, etc.)
- Cryogenics developments: new cryostat, custom feedthroughs, purification system, cooling, controls HW and SW
- Electronics developments: FE redesign (look at new technologies like SiGe), fast (200MHz 12bit) digitizer for APDs (or PMTs) with trigger capabilities and fast data transfer, readout driver for data collection and pre-processing, fast trigger processor, calibration system
- Local disk storage (~4-5TB), data analysis farm, SW developments

Half-PET and Full-PET

- If CECR support available

Resources

- ❑ Cryogenics Laboratory space
- ❑ HQP
  - ➢ LADD physicist *Astrid Muennich*
  - ➢ M.Sc student *Philip Lu* (completed)
  - ➢ 2 UBC senior thesis students
- ❑ Technical Personnel (20-40% FTE in 2008)
  - ➢ Cryogenics engineer *Cam Marshall (TRIUMF)*
  - ➢ Mechanical and machining support: *Chapman Lim (LADD/TRIUMF)*
  - ➢ Electronics/control systems technologist *Ray Bula (TRIUMF)*
  - ➢ Electronics (FE) design engineer: *Miles Constable (LADD/TRIUMF)*
  - ➢ Electronics (RO) design engineer: *Chris Ohlman (TRIUMF)*
  - ➢ DAQ support: *Pierre Amadruz (TRIUMF)*
- ❑ Machine shop and electronics shop allocations
- ❑ NRC funds for maintenance
- ❑ CFI IOF (LADD) for upgrades and developments