A Liquid Xenon Detector for PET Applications: Simulated Performance

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Why Liquid Xenon?

- High Z (54) and high density (3g/cm^3)
  → Compact detectors
- Excellent scintillation properties
  - High light yield (70 photons/keV at E field = 0)
    → Large scintillation signals
  - Short scintillation decay time (2.2ns)
    → Sub-ns time resolution
- Good ionization properties
  - High ionization yield (60 e-/keV at high E field)
    → Large ionization signals
  - Low diffusion rate (20μm for 1μs drift)
    → Sub-mm position resolution
- Excellent energy resolution using scintillation + charge (< 4 % FWHM at 662 keV *)
  → Good scatter rejection capability
- Cover large detection volumes with high uniformity
  → High sensitivity

* *Aprile, Phys. Rev. B (2007)*

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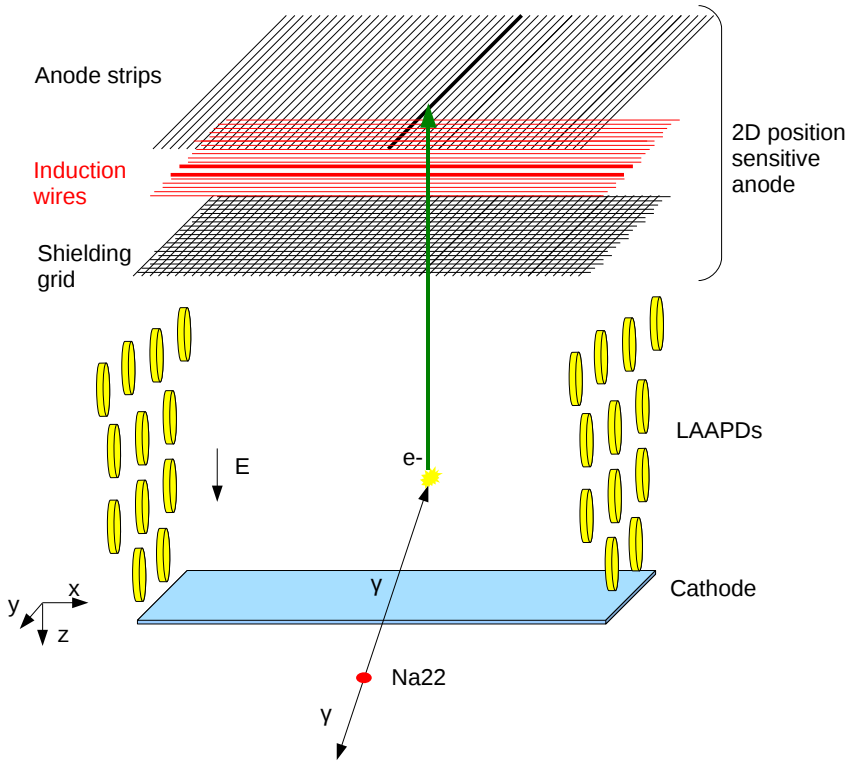
The LXePET Detector

LXe TPC + LAAPDs

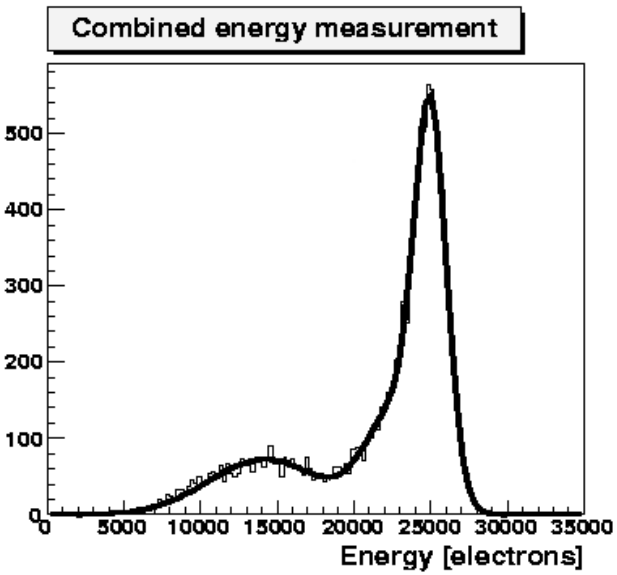
- Annihilation photons interact in LXe
  - → Ionization and scintillation (178nm)
- Scintillation light detected by LAAPDs
- Charge drifts to 2D sensitive anode
- Charge induces signal on induction wires
  → Y coordinate
- Charge collected on anode strips
  → X coordinate

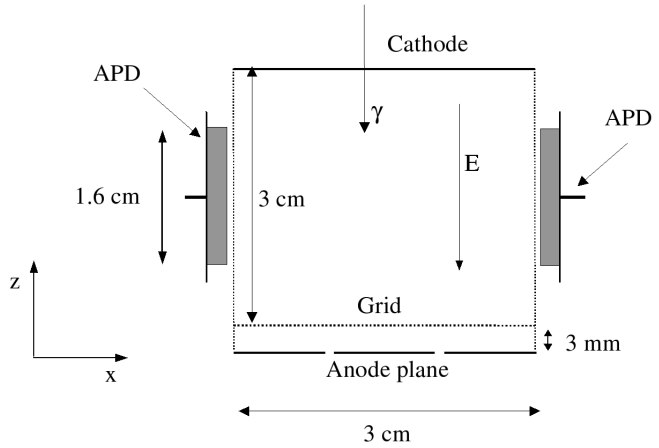
- **3D sub-mm position** measurement
  - 2D position sensitive anode → XY
  - drift time → Z
- **Energy** measurements
  - **Combined light and charge signals**



Small Scale Prototype

- LXeTPC active volume 3 x 3 x 3 cm^3
- 2 Anodes: central disc dia. 10 mm, Grid: 3 mm spacing, gap 3 mm
- 2APDs, total solid angle 10%
- Tests with Na22
- **Energy resolution at 511 keV** = 9% FWHM



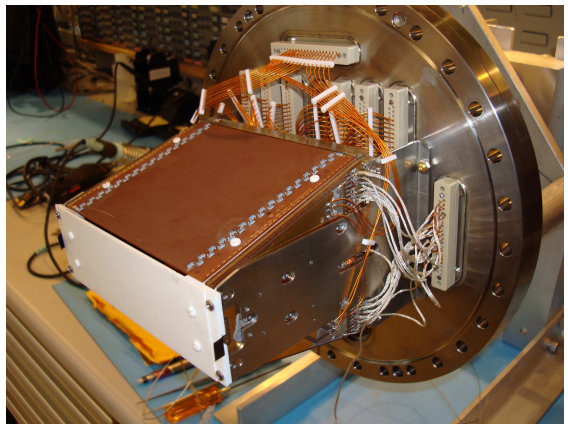


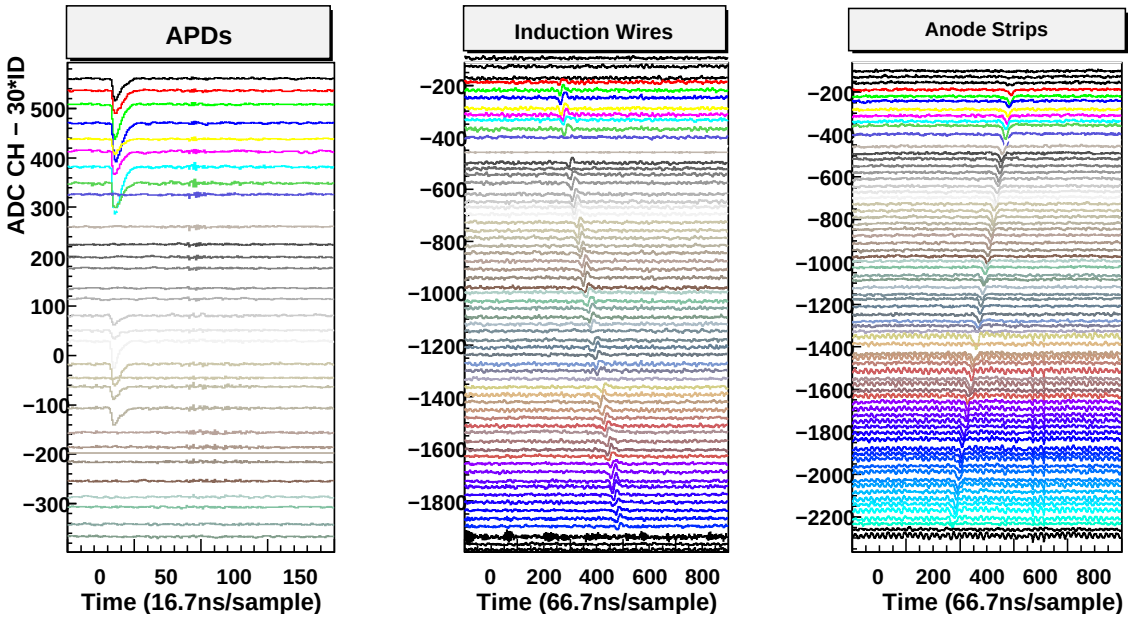
P. Amaudruz et al., Nucl. Instrum. Meth. A 607 (2009)

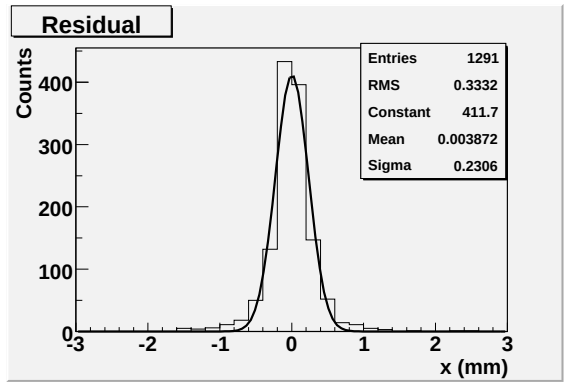
Micro-LXePET detector

- LXeTPC
  - active volume 1l
  - Anode module: 96 anode strips $\perp$ 96 induction wires, spacing 1.1 mm
  - 12 cm drift length
- 32 LAAPDs
- First tests with cosmic rays
- **Position resolution** $= 0.5mm$ **FWHM**

LXePET detector







A. Miceli et al., J. Phys. Conf. Ser. (2011)

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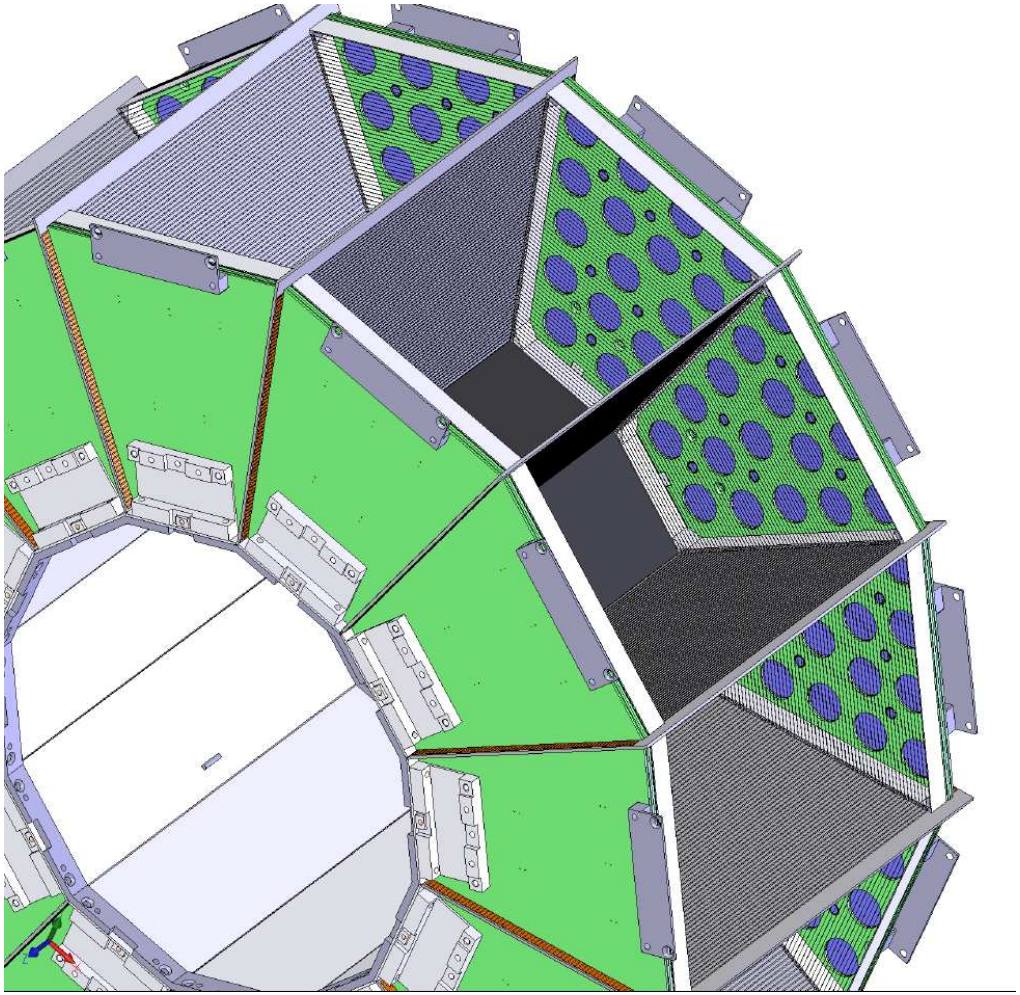
Micro-LXePET system



- Proposed ring geometry
- 12 micro-LXePET detectors
- Axial FOV 10 cm
- Transaxial FOV 12 cm

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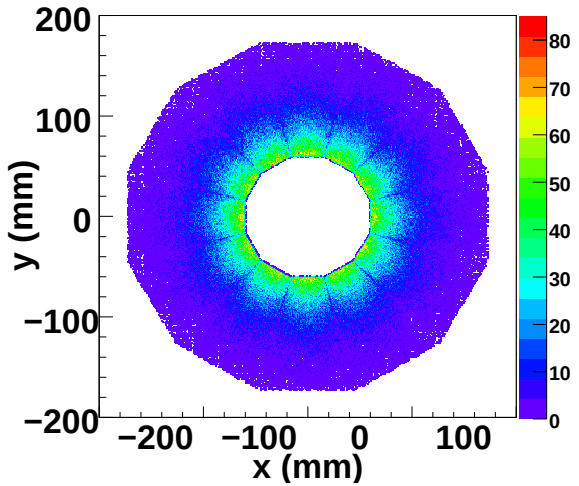
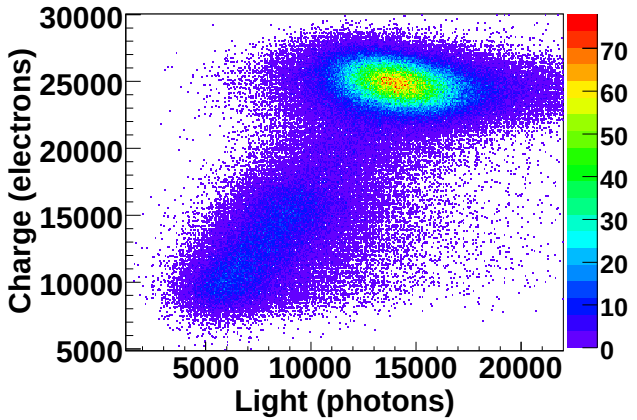
Simulation of the Micro-LXePET system

- Geant4 employed
- Modification of Geant4 annihilation process to include photon non-colinearity due to the non-zero momentum of e+e- pair
- $\longrightarrow$ Positron range and photon non-colinearity included
- LAAPD and TPC responses modeled based on experimental results for a small scale prototype
- Detection rate modeled via Poisson statistics

Simulated Position



Simulated Energy



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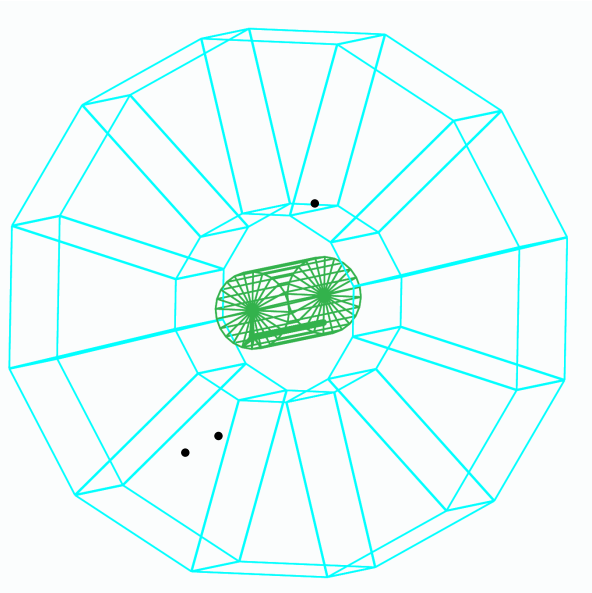
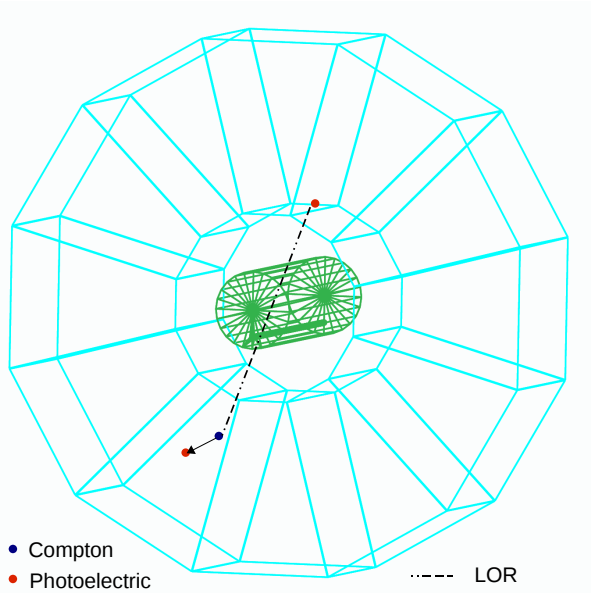
Event Reconstruction

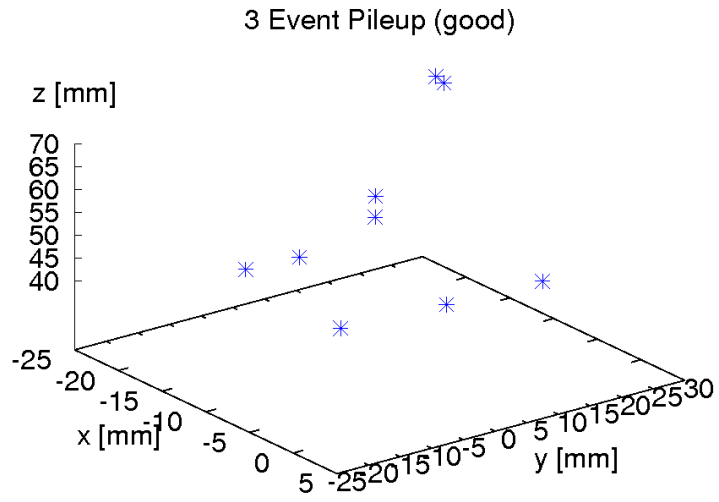
- Photofraction at 511 keV = 22%
- 85% multi-interaction events
- $\rightarrow$ Compton reconstruction algorithm to select the right sequence
  - Calculate scattering angles from energy and geometry for each possible sequence
  - Sequence with the lowest $\chi^2 \equiv$ Correct interaction sequence
  - Average efficiency $>$70 %

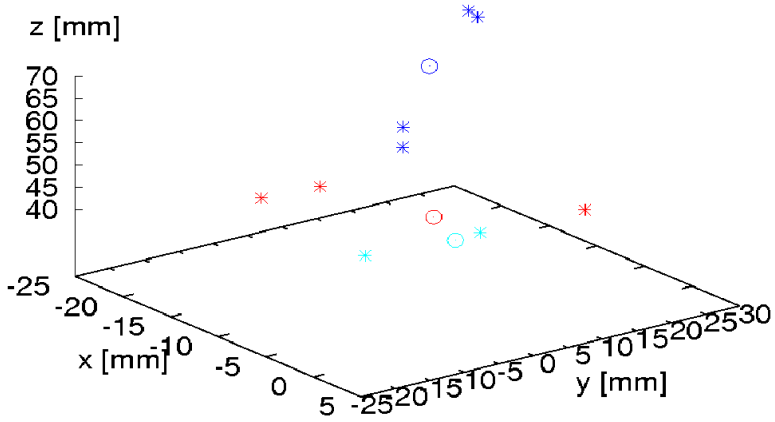




High rate capability

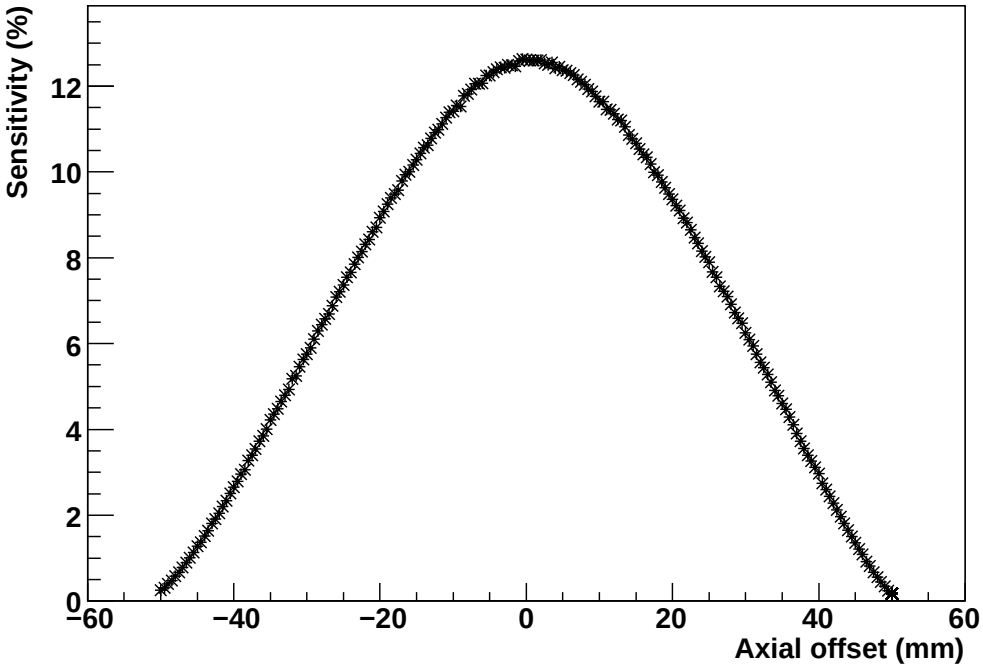
- 3D position extracted from light pattern on LAAPDs (Neural Network)
- Match fast light with slow charge signals using energy and proximity algorithms
- Method efficiency with 2 pile-up events = 99%





Performance micro-LXePET System - Simulation

Absolute sensitivity



- source: ^{22}Na point-source
- **energy window 450- 600 keV**
- method: NEMA-NU4 standard

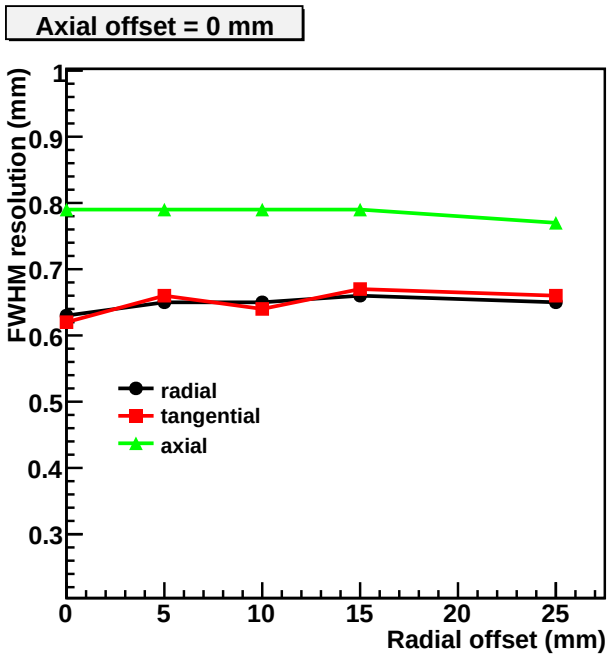
- **Absolute sensitivity at CFOV 12.6%**

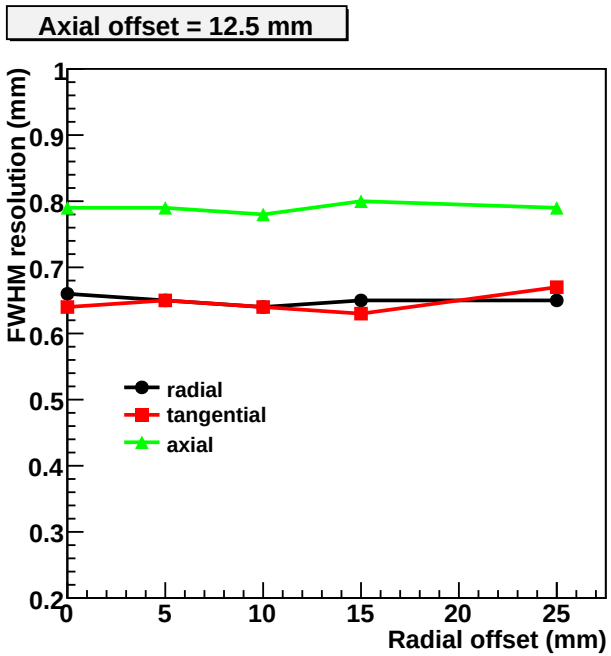
Performance micro-LXePET System - Simulation

Spatial resolution

- source: ^{22}Na point-source
- energy window: 450-600 keV
- method: NEMA-NU4 standard
- reconstruction method: list-mode 3D MLEM iterative algorithm

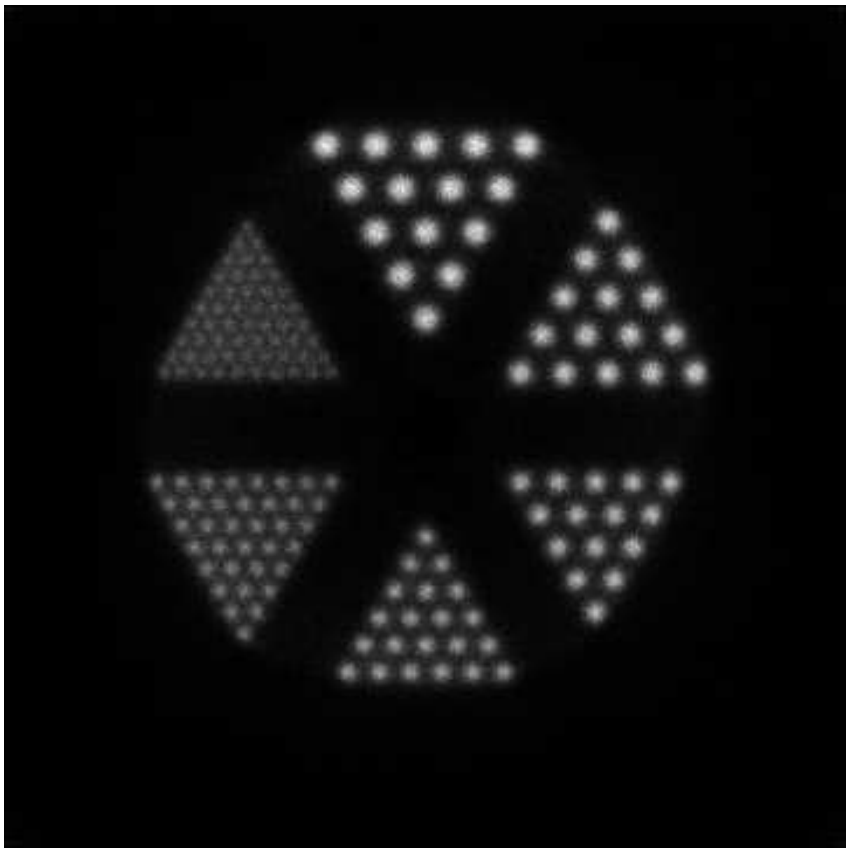
- **Uniform resolution $\leq$ 0.8 mm FWHM throughout FOV**





Performance micro-LXePET System - Simulation

Micro-Derenzo Phantom



- Hot rods dia.:1.6, 1.4, 1.2, 1.0, 0.8, and 0.6 mm
- List-mode 3D MLEM algorithm (100 iterations)
- Voxel size : 0.15 x 0.15 x 0.15 mm
- No attenuation or scatter corrections

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Summary and Outlook

- LXe micro-PET performance (simulation studies)
  - Absolute sensitivity at CFOV with 450-600 keV energy window $= 12.6\%$
  - Spatial resolution ≤ 0.8 mm throughout FOV
  - Image quality: 0.6 mm dia. hot rods visible
- Measurements with one micro-LXePET detector in progress
- Expecting to start tests with two small micro-LXePET detectors in coincidence in the summer 2012

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