XEMIS: The new Compton camera with liquid xenon

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The Compton telescope

Good angular resolution (~ 1) : good energy resolution (~ a few %)
good spatial resolution (< 0.5 mm in each D)

Enough sensitive for γ-rays imaging? if enough interaction lengths
R&D focusing on MeV $\gamma$-rays Imaging with liquid xenon and new radiopharmaceuticals produced by the ARRONAX cyclotron

$^{44}$Sc : detection of the 3$^{\text{rd}}$ 1.157 MeV $\gamma$ in coincidence with the $\beta^+$ decay

Direct 3D reconstruction in counting mode

C. Grignon et al., NIM A 571 (2007) for complements
**The XEMIS2 project**

**Installation in Nantes hospital in 2016**

**Hollow cylindrical Camera (180 kg LXe)**
- $7 < r < 19\text{cm}$
- 50 PMTs Hamamatsu
- 20 000 ultra low noise FEE channels IDef-X HD LXE with 3.175 mm$^2$ pixels
- Integrated recovering system
- $\sim 1\text{cm}$ resolution along the LOR
  - Equivalent to 30ps in TOF-PET
  - GATE\textsuperscript{1} Simulation

**The camera characteristics**
- Energy resolution: 5\% @ 511 keV
- Spatial resolution : 0.5 mm (X, Y et Z)
- Efficiency $3\gamma$: 3\%
- 20 to 100 fold decrease of injected activity

\textsuperscript{1}OpenGATE collaboration: [http://www.opengatecollaboration.org/](http://www.opengatecollaboration.org/)
XEMIS1 goals

3 main challenges to create a technological breakthrough

Cryogenic of Liquid xenon
- Storage
- Liquefaction
- Recovering
- Purification
- Stability
- Safety

Instrumentation of liquid xenon
- Signal extraction
- Scintillation
  - Trigger
  - Time resolution
- Ionisation
  - Energy resolution
  - Spatial resolution

Simulation and studies
- Camera optimization
- Technical feasibility
- GATE development

Very challenging development around a new concept!
Prototype for the “technical” prove of feasibility with 30kg of LXe

- Storage Xe
- Purification Xe
- Cryostat
- Cooling and exchanger
- DAQ
- Recovering Xe
- Slow control
The purification loop

Impurities contamination below the ppb within few days
Purification results

Impurity Evolution (ppb)

[O2]eq < 1 ppb en 24-48 h with the new heat exchanger

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Recoil electrons create both **scintillation** and **ionization** in liquid xenon.

Measurements:
- Energy + 3D Positions of each vertex
  
  \[ (T, E) = \text{cste} \]
  
  \[ Z = v_{\text{drift}} \cdot (t_1 - t_0) \]

**Scintillation light (PMT)**

\[ t_0 \]

**Ionisation (FEE + micromegas)**

Energy + (x, y) + \( t_1 \)

\[ V_{\text{drift}} \text{ known:} \]

\[ (T, E) = \text{cste} \]

\[ Z = v_{\text{drift}} \cdot (t_1 - t_0) \]
A TPC in LXE as Compton Telescope

Field rings

Segmented anode
6.35 x 6.35 mm² pitch

12 cm

2.54 cm

PMT

Micromegas Grid
(not viewable)
Apparatus with 511 keV calibration $\gamma$ line
Depth of interaction resolution (@ 511 keV)

Recorded depth of interaction profile

Beginning of the TPC  End of the TPC

12 cm

Z resolution: 300 µm measured

156 ns x 2 mm/µs
Electronegative impurities absorb electrons drifting in LXe

\[ S(z) = S_0 e^{-\frac{z}{\lambda}} \]

\[ S_0 = 1.7623 \quad 0.0015 \text{ V @511 keV} \]

\[ \lambda = 19.52 \quad 0.16 \text{ cm} \]

\[ S = 1.746 \quad 0.006 \text{ V} \]

\[ S = 1.130 \quad 0.004 \text{ V} \]
Ionisation yield measurement (@511 keV)

Good agreement with the Thomas model

W-T. Chen et al. DSL 2011 for complements
Very promising measured energy resolution
Higher granularity with 64 pixels
Higher granularity to improve XY resolution
Analysis in progress
"Technical" prove of concept with XEMIS1:

- Intrinsic ionization energy resolution of liquid xenon is achievable with the low noise front-end electronics we developed
- Required spatial resolution for Compton reconstruction is achievable with Micromegas and liquid xenon
- Purification of an important liquid xenon volume is achievable

What is missing to end it?

- Higher granularity on the anode in order to record and identify precisely the whole Compton sequence (analysis in progress)