XEMIS: The new Compton camera with liquid xenon

Jérôme Donnard

Subatech

UNIVERSITÉ DE NANTES

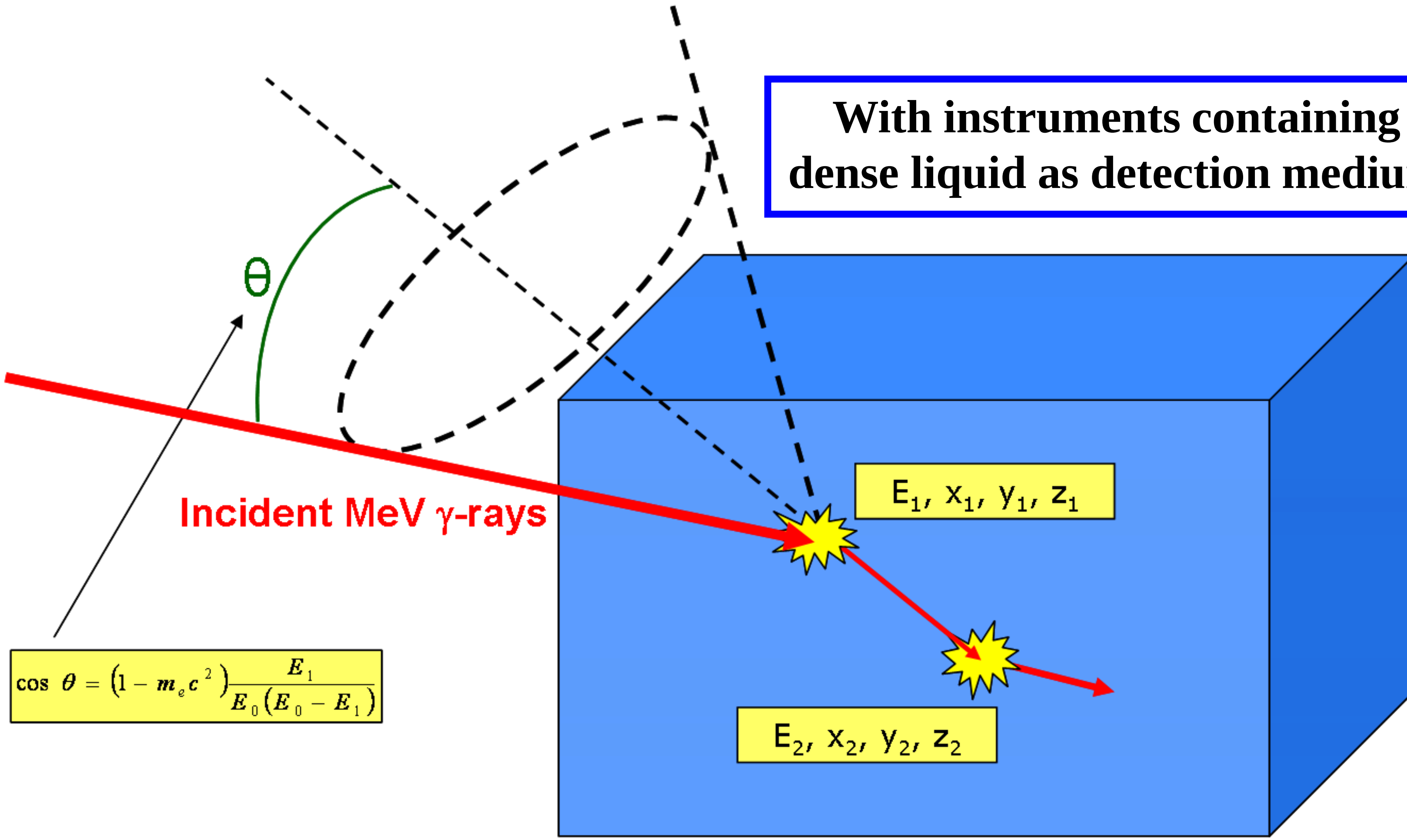
CNRS IN2P3 Les deux infinis

ECOLE DES MINES DE NANTES

Région PAYS DE LA LOIRE

The Compton telescope

With instruments containing dense liquid as detection medium

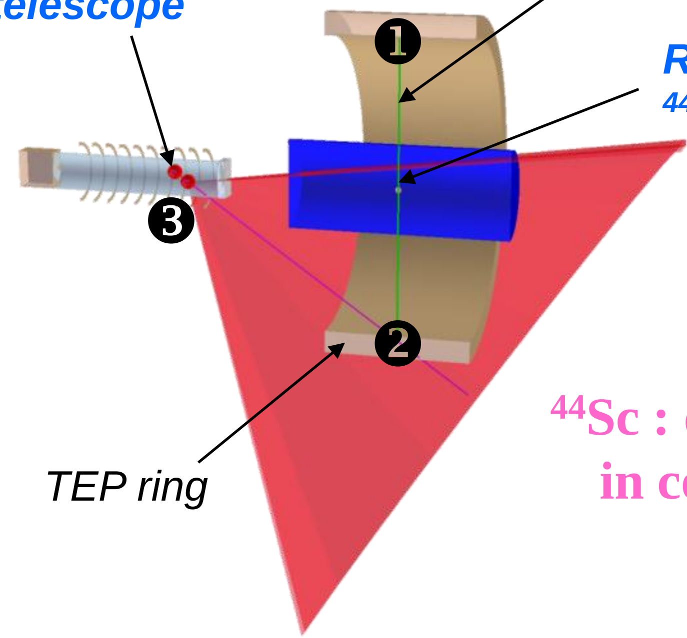


Good angular resolution (~ 1) : good energy resolution (~ a few %)
good spatial resolution (< 0.5 mm in each D)

→ **Enough sensitive for γ-rays imaging ? if enough interaction lengths**

The 3 γ imaging concept

R&D focusing on MeV γ-rays Imaging with liquid xenon and new radiopharmaceuticals produced by the ARRONAX cyclotron



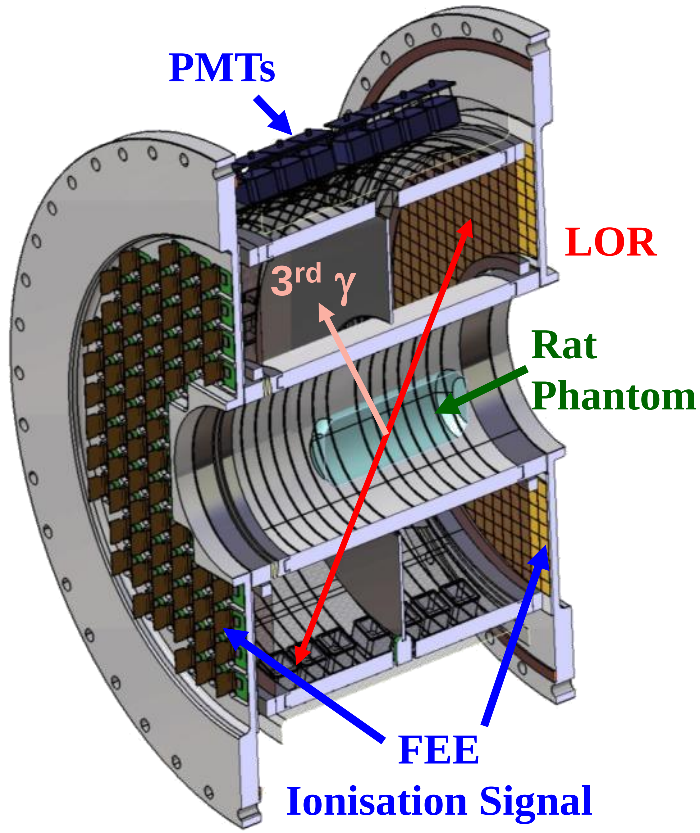
^{44}Sc : detection of the 3rd 1.157 MeV γ in coincidence with the β^+ decay

C. Grignon et al., NIM A 571 (2007) for complements

➡ Direct 3D reconstruction in counting mode

Jérôme Donnard (Subatech IN2P3 / EMN / Université de Nantes) jerome.donnard@subatech.in2p3.fr 25/04/2012

The XEMIS2 project



Installation in Nantes hospital in 2016

Hollow cylindrical Camera (180 kg LXe)

- *7 < r < 19cm*
- *50 PMTs Hamamatsu*
- *20 000 ultra low noise FEE channels IDeF-X HD LXE with 3.175 mm² pixels*
- *Integrated recovering system*

~1cm resolution along the LOR

- *Equivalent to 30ps in TOF-PET*
- *GATE[1] Simulation*

The camera characteristics

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

XEMIS 1: the proof of concept

[1]OpenGATE collaboration: http://www.opengatecollaboration.org/

XEMIS1 goals

3 main challenges to create a technological breaktrough

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

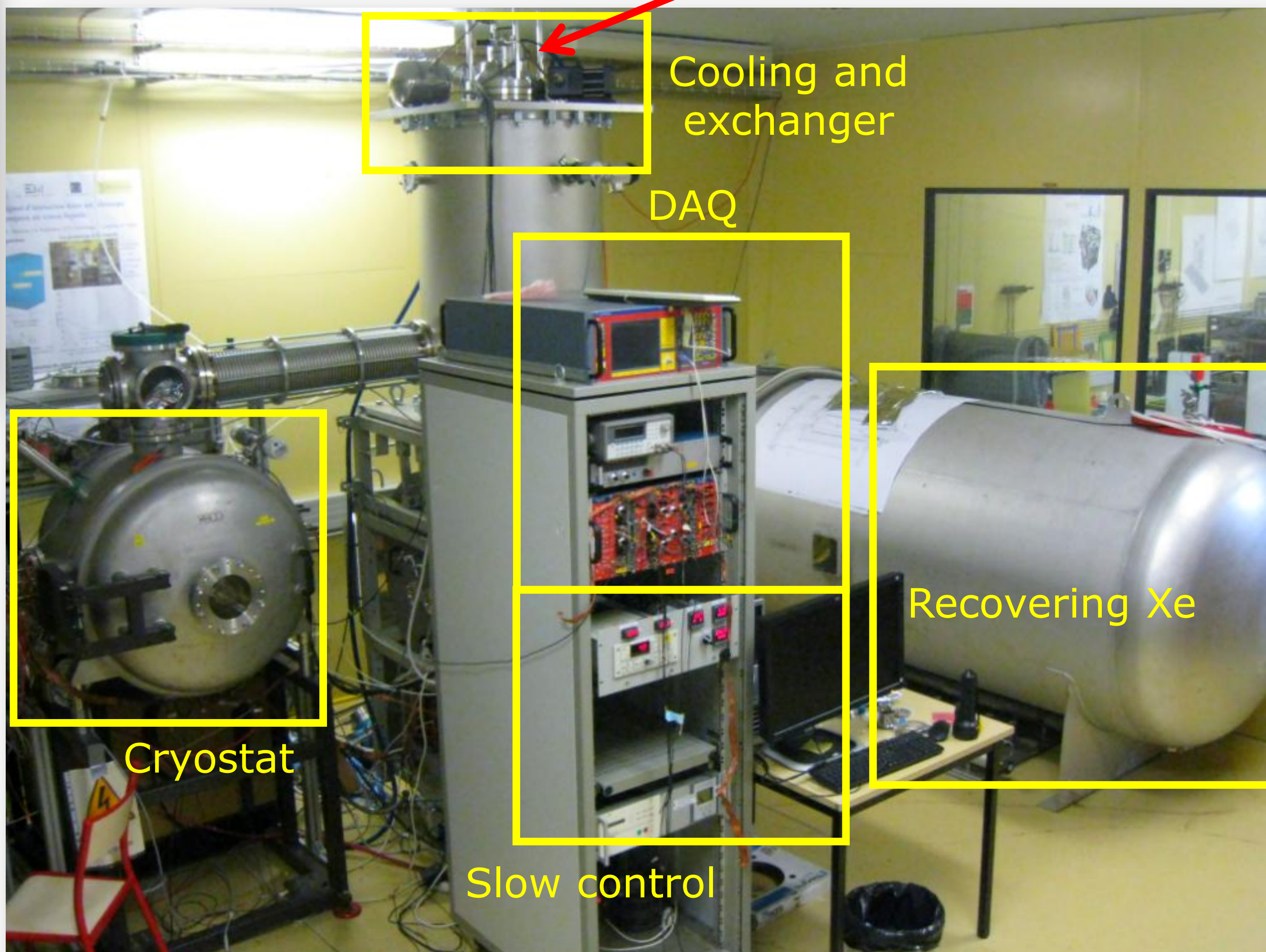
- Camera optimization
- Technical feasability
- GATE development

Very challenging development around a new concept!

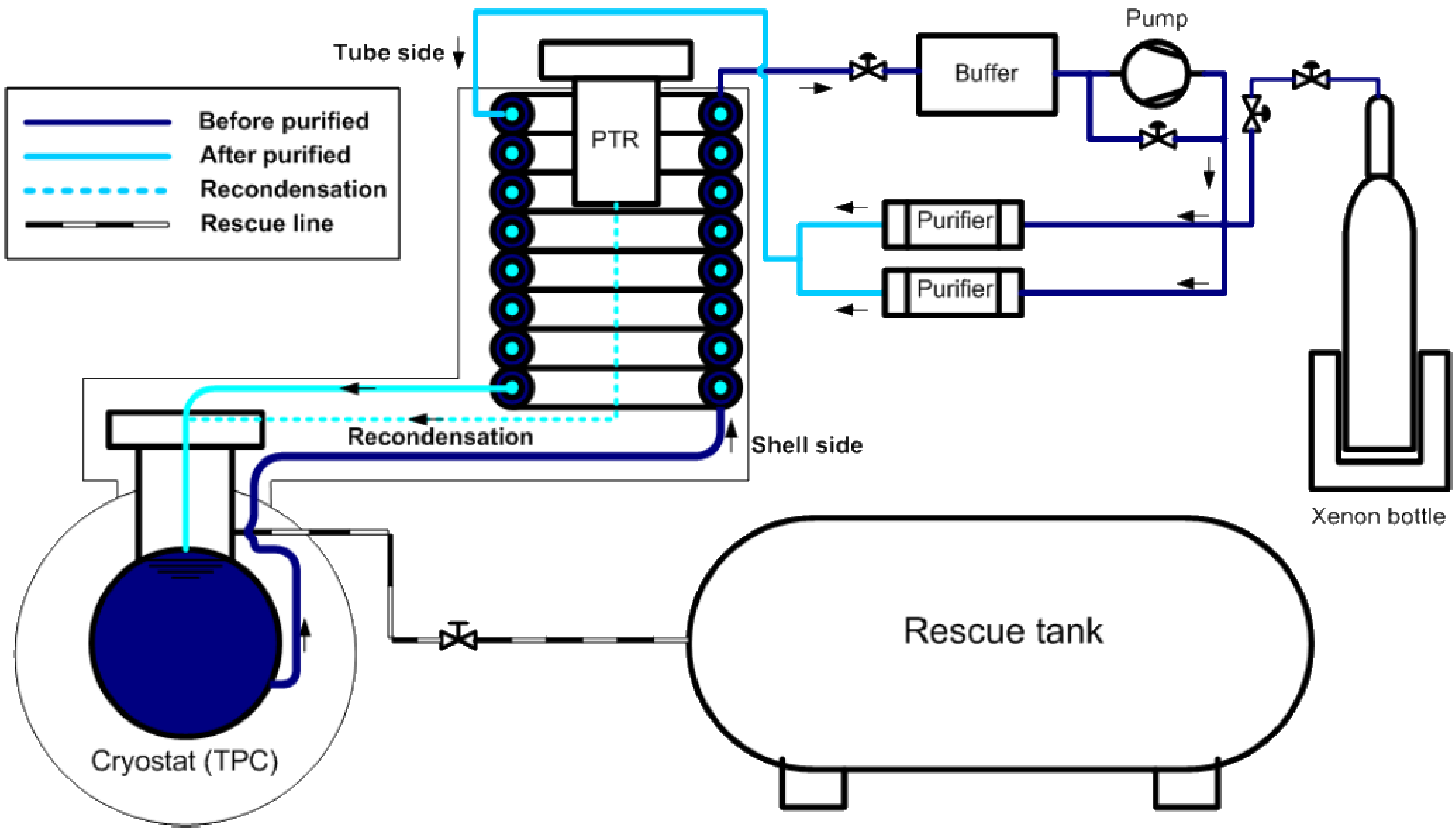
XEMIS1 facility

Prototype for the “technical” prove of feasibility with 30kg of LXe

T. Haruyama team

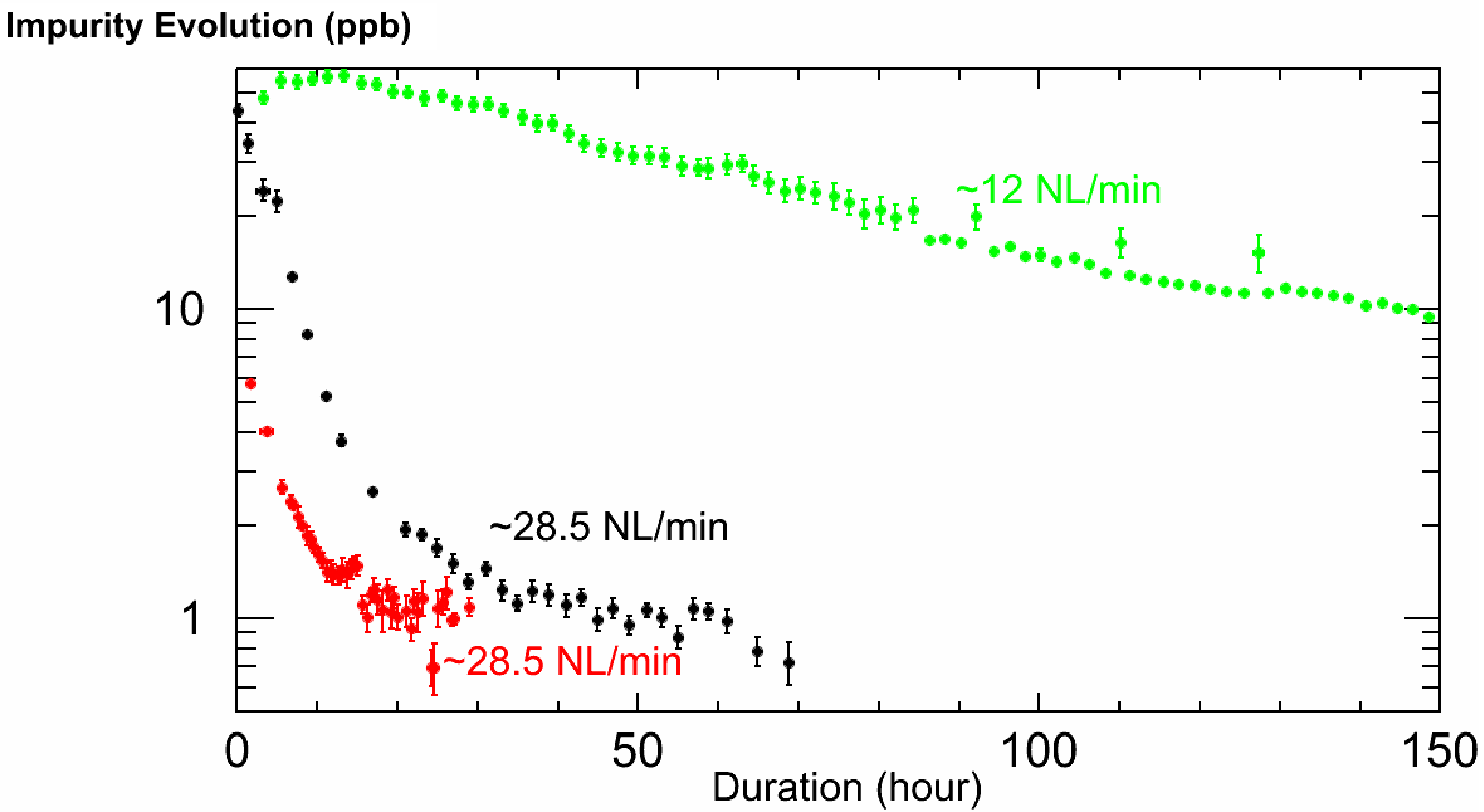


The purification loop



Impurities contamination below the ppb within few days

Purification results

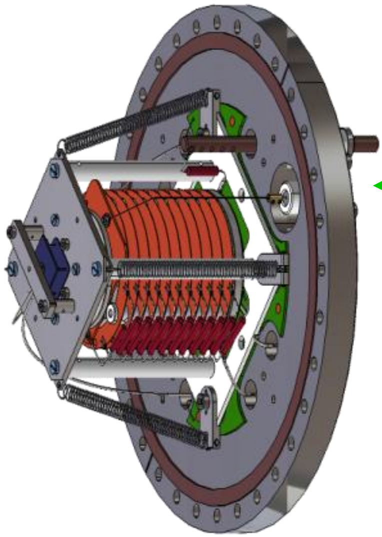


[O2]eq < 1 ppb en 24-48 h with the new heat exchanger

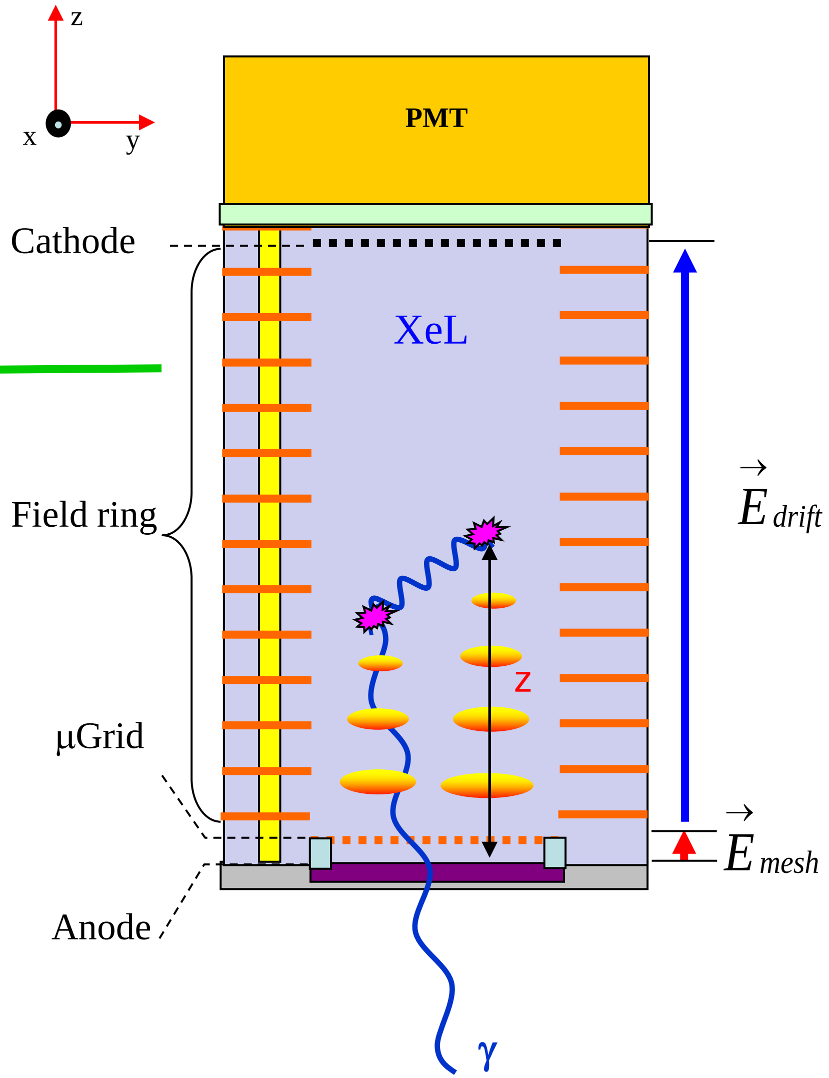
Jérôme Donnard (Subatech IN2P3 / EMN / Université de Nantes) jerome.donnard@subatech.in2p3.fr 25/04/2012

Energy and position measurements

Recoil electrons create both scintillation and ionization in liquid xenon



Active volume



Scintillation light (PMT)
t_0

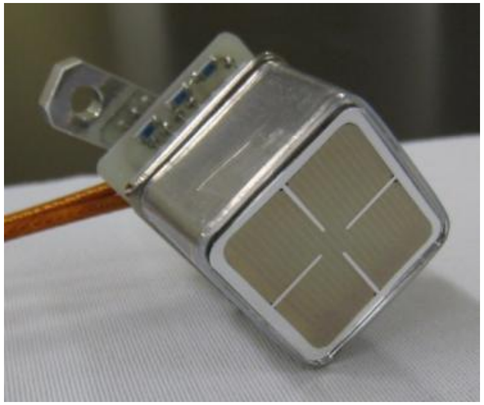
+

Ionisation
(FEE + micromegas)
Energy + (x, y) + t_1

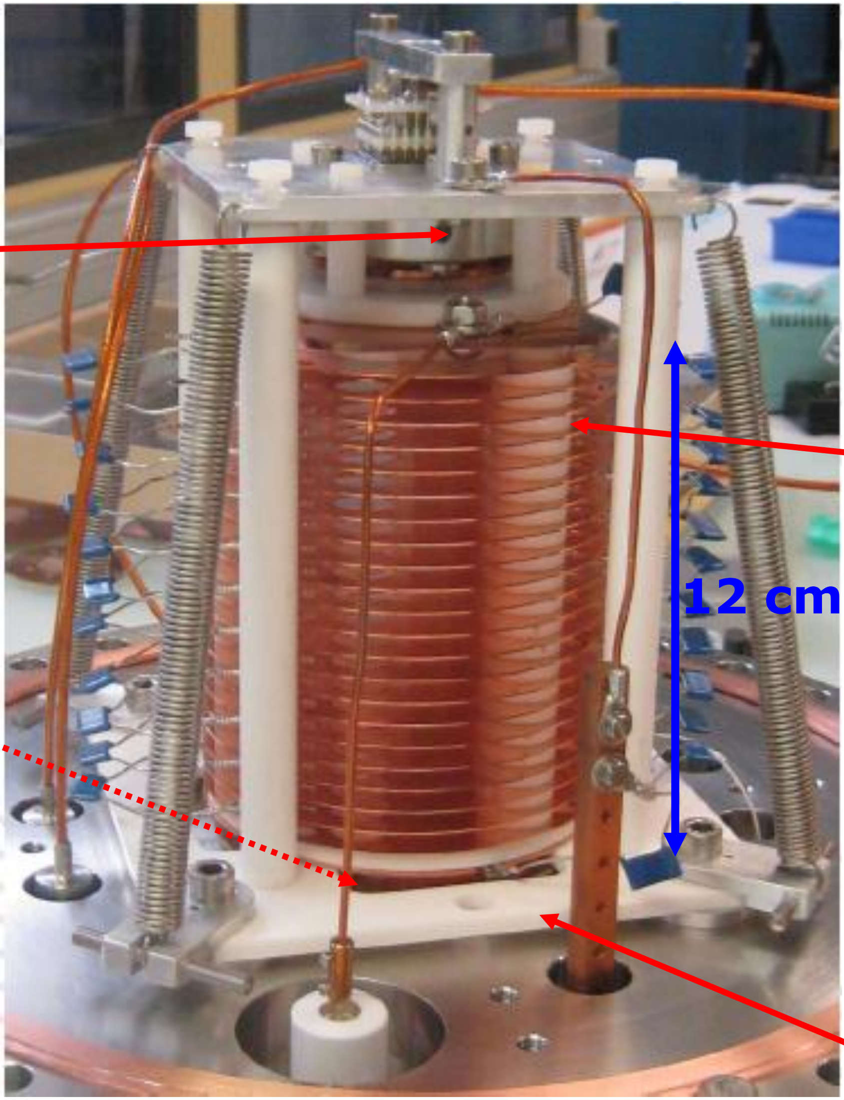
V_{drift} known:
(T,E) = cste
$Z = v_{drift}.(t_1-t_0)$

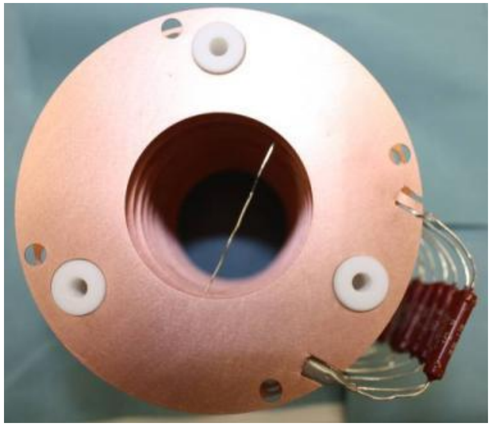
Measurments : Energy + 3D Positions of each vertices

A TPC in LXE as Compton Telescope



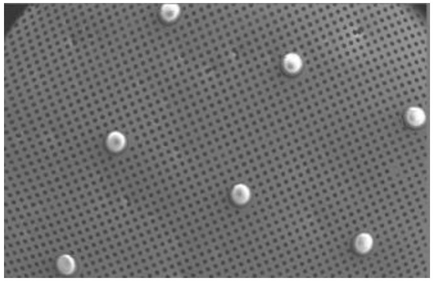
PMT

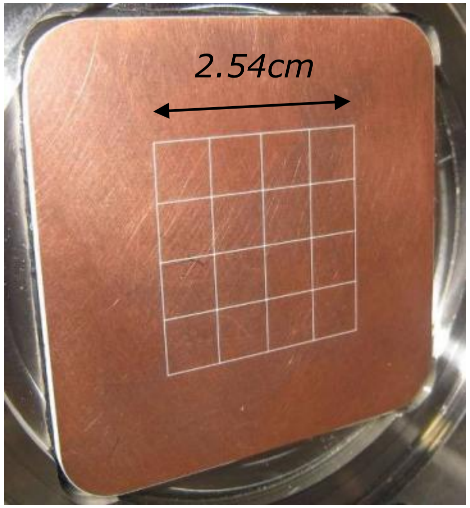




Field rings

Micromegas Grid (not viewable)

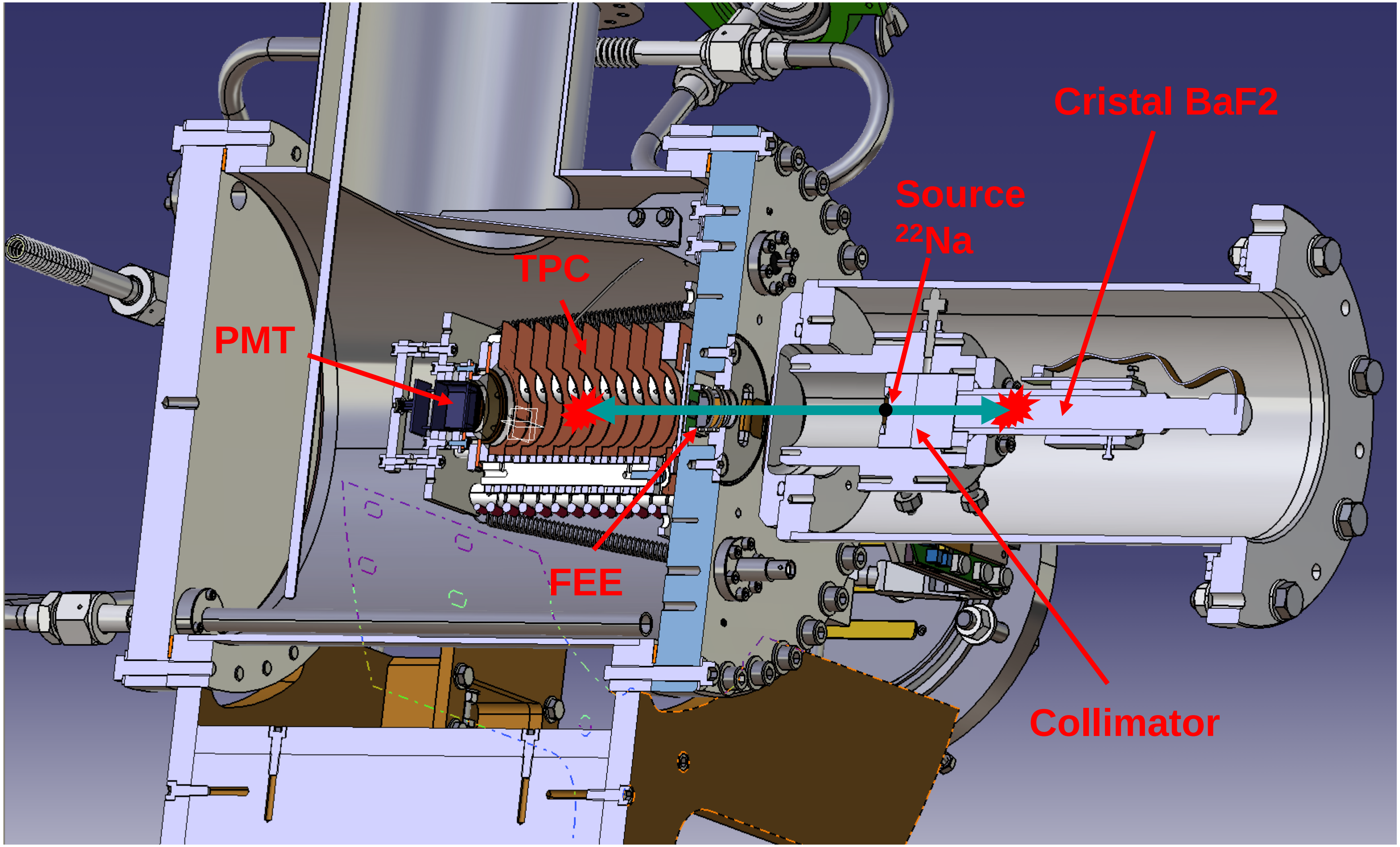




Segmented anode
6.35 x 6.35 mm² pitch

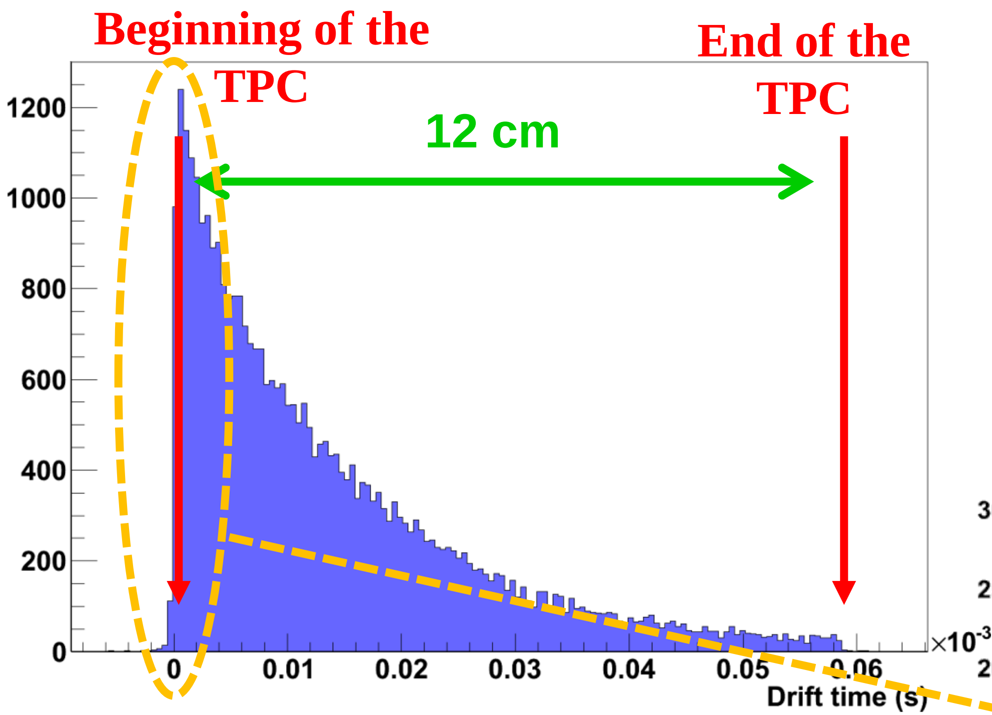
Jérôme Donnard (Subatech IN2P3 / EMN / Université de Nantes) jerome.donnard@subatech.in2p3.fr 25/04/2012

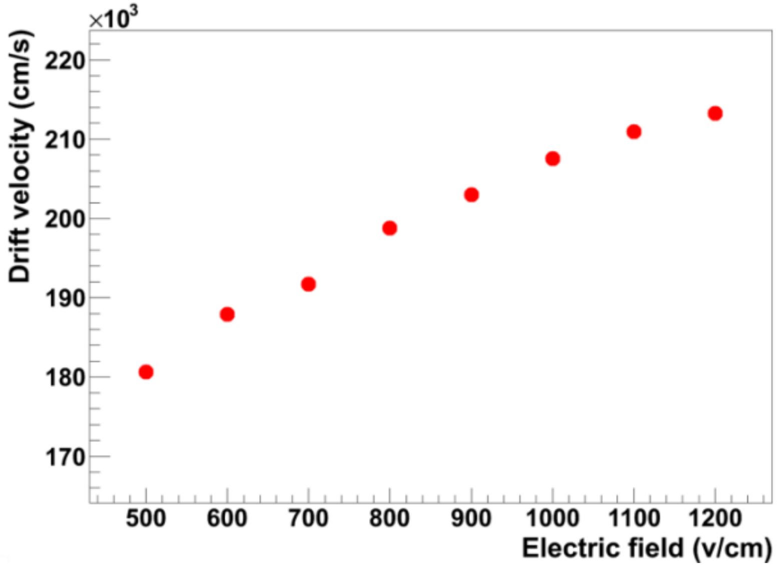
Apparatus with 511 keV calibration γ line

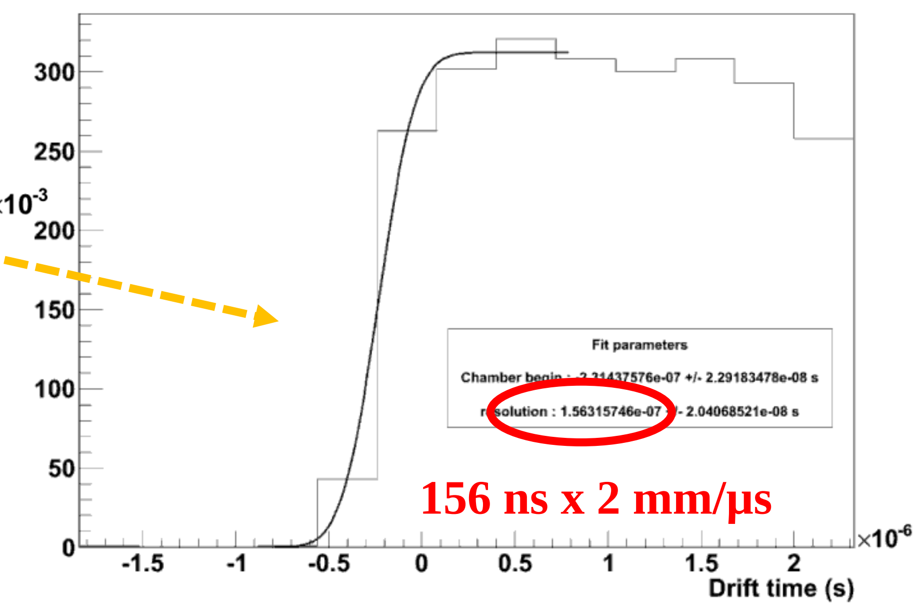


Depth of interaction resolution (@ 511 keV)

Recorded depth of interaction profile





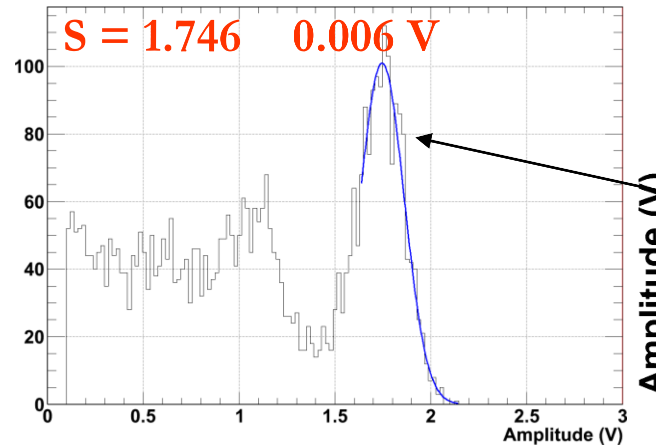


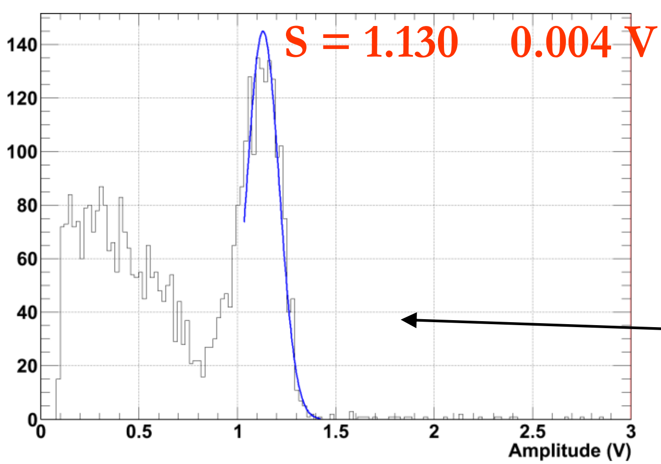
Z resolution:
300 µm measured

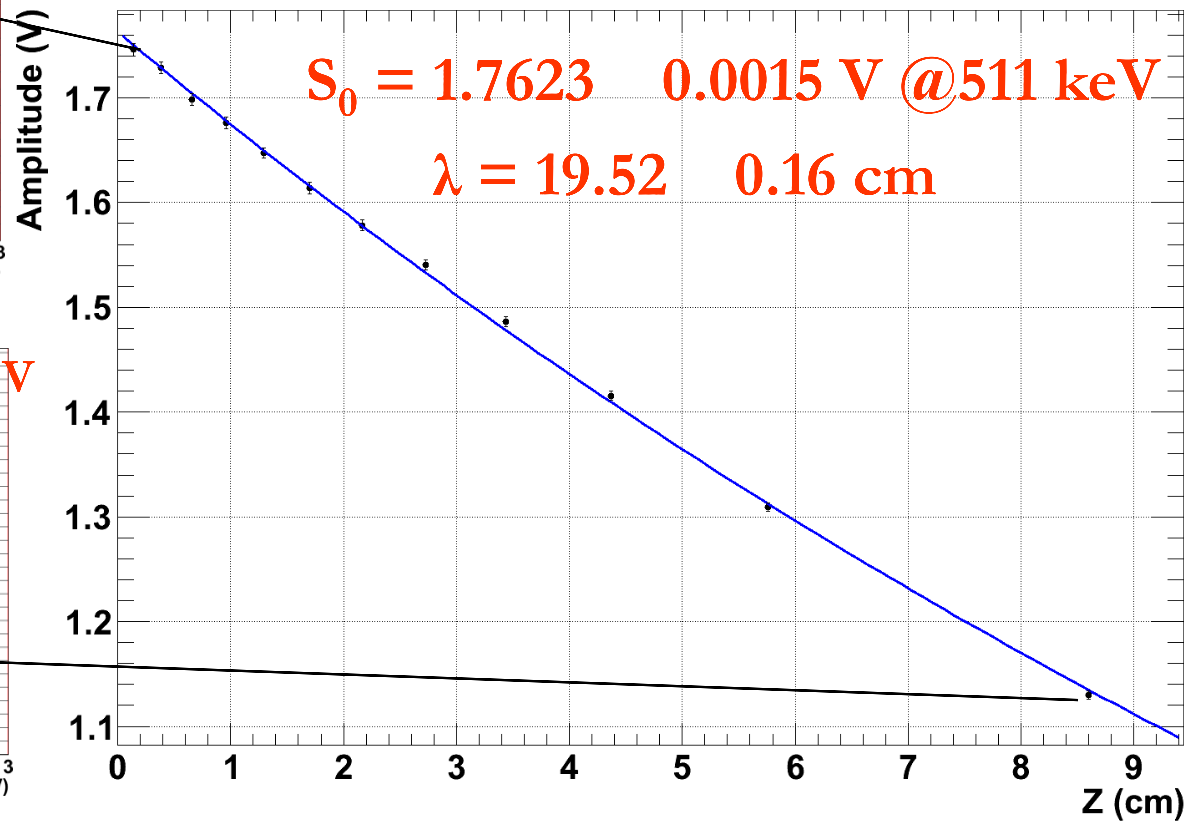
Purity of the xenon monitoring

Electronegative impurities absorb electrons drifting in LXe

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

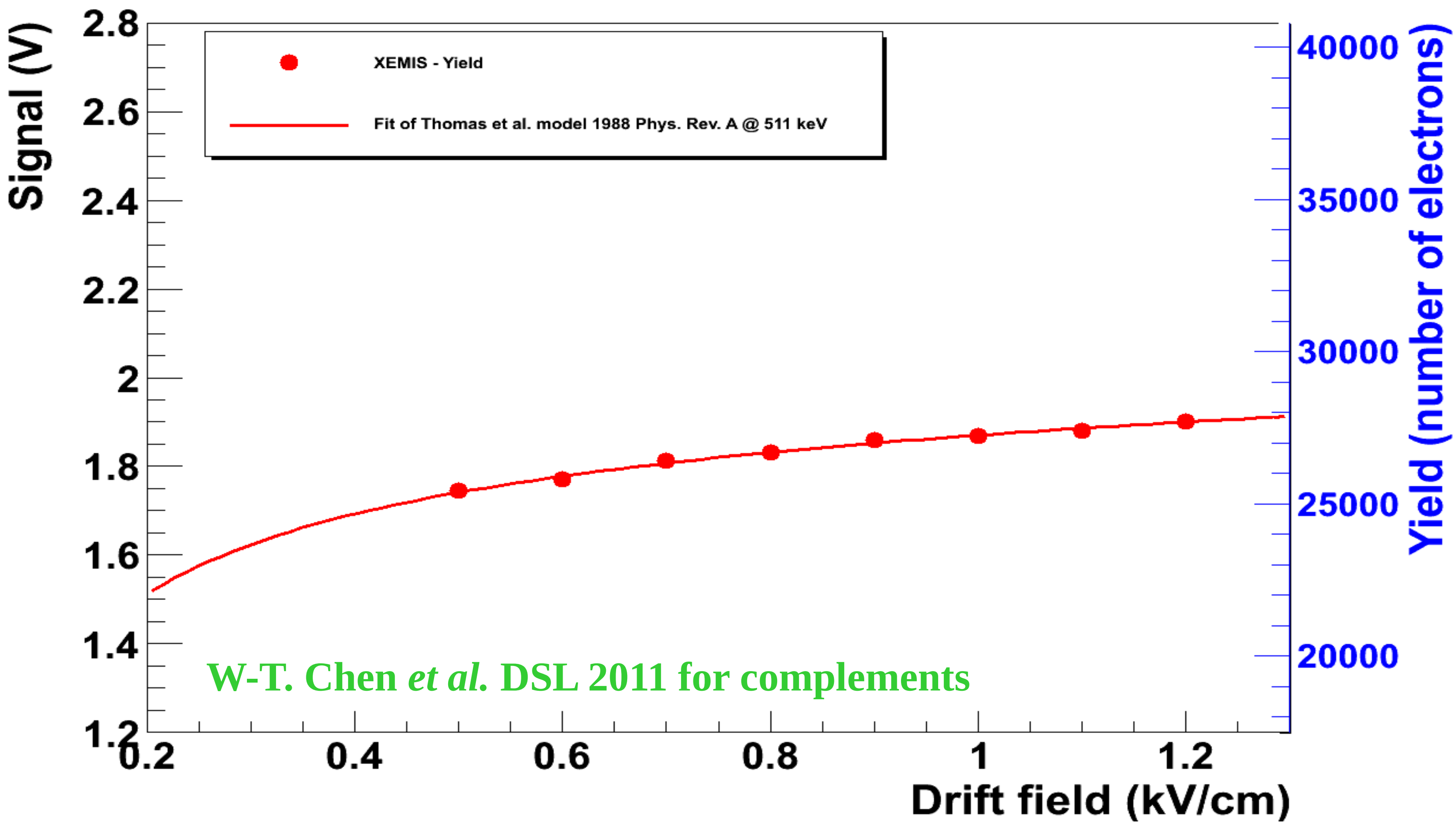






Jérôme Donnard (Subatech IN2P3 / EMN / Université de Nantes)   jerome.donnard@subatech.in2p3.fr 25/04/2012

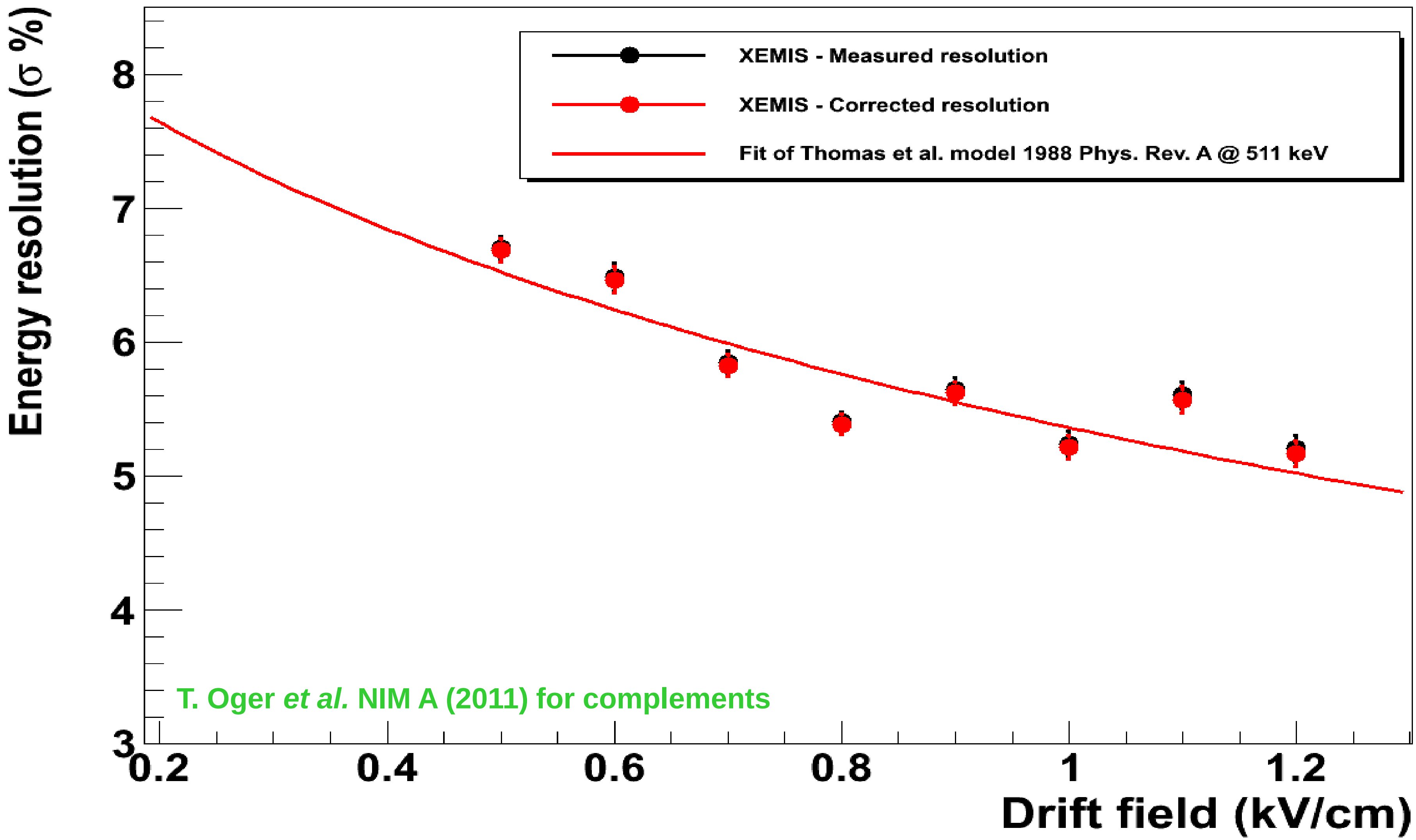
Ionisation yield measurement (@511 keV)



Good agreement with the Thomas model

Jérôme Donnard (Subatech IN2P3 / EMN / Université de Nantes) jerome.donnard@subatech.in2p3.fr 25/04/2012

Energy resolution (@511keV)



Very promising measured energy resolution

Jérôme Donnard (Subatech IN2P3 / EMN / Université de Nantes) jerome.donnard@subatech.in2p3.fr 25/04/2012

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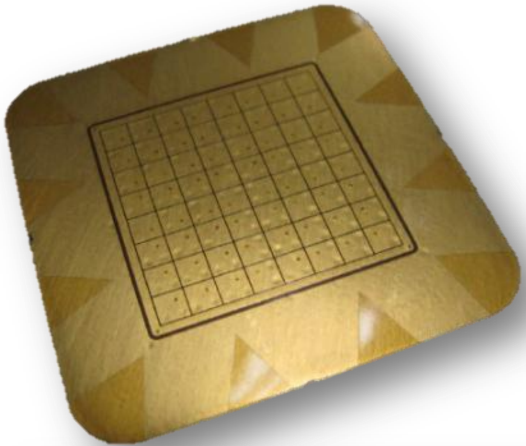
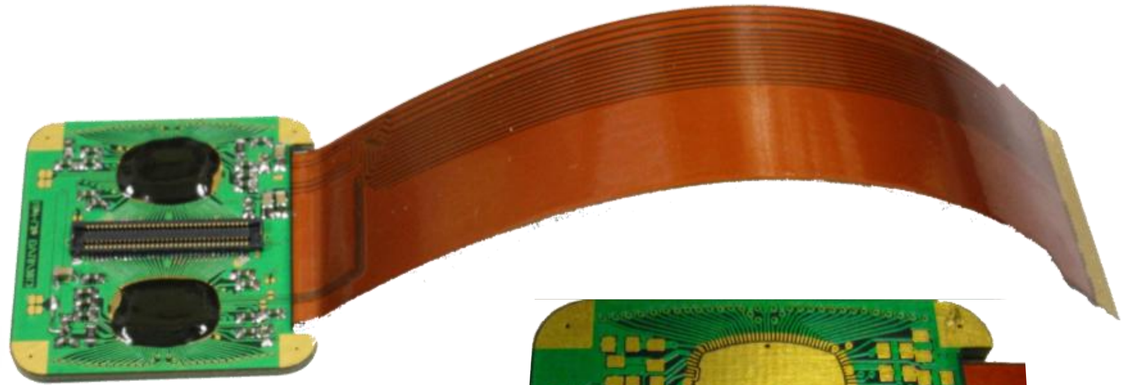
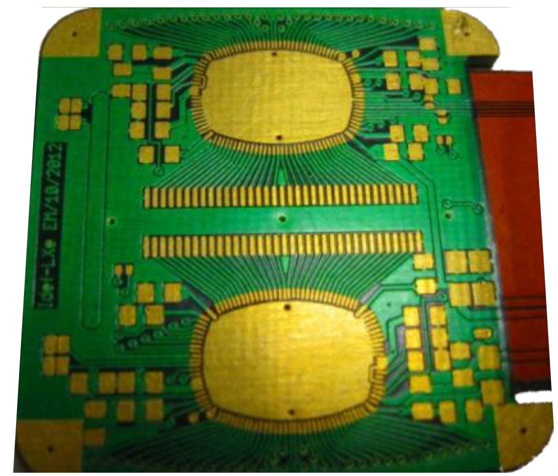
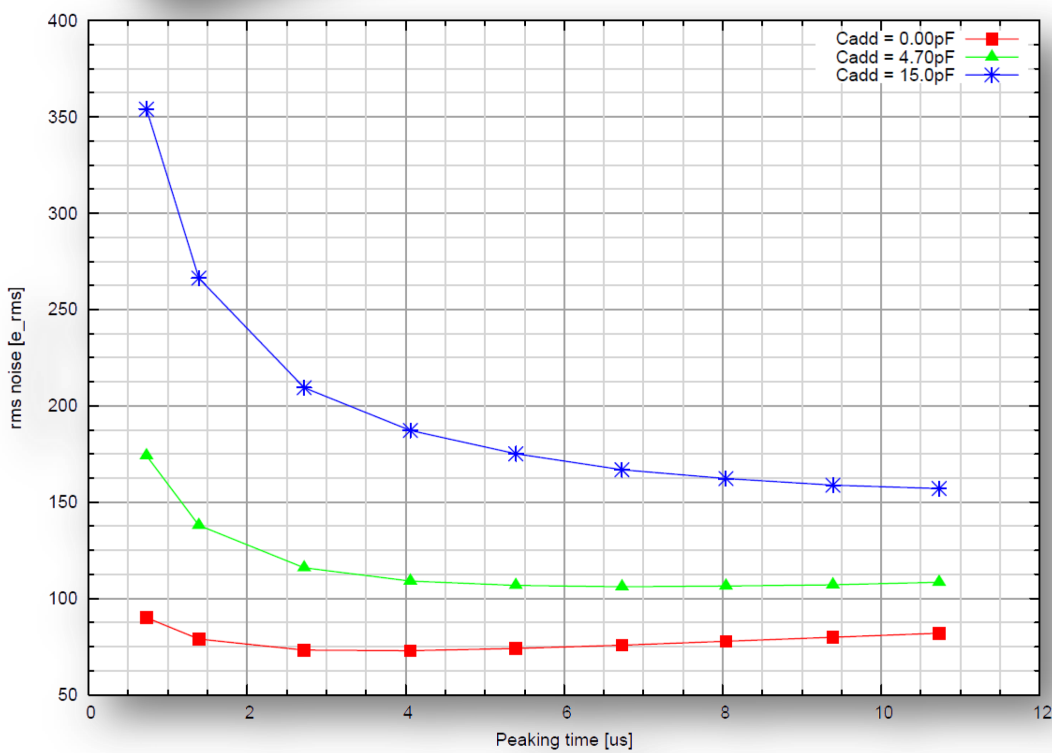
Higher granularity with 64 pixels





25,4 mm





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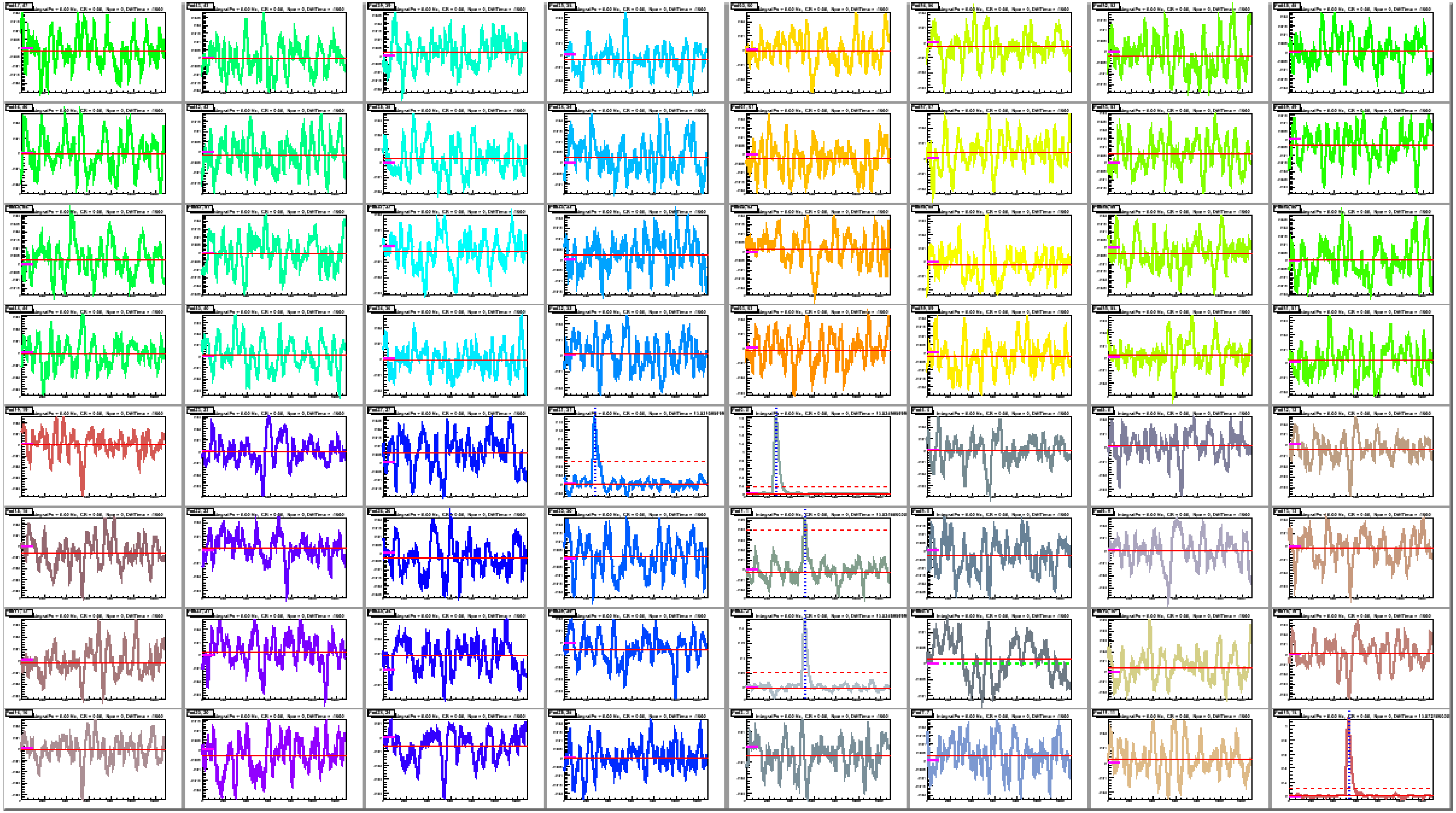
Higher granularity with 64 pixels



Higher granularity to improve XY resolution
Analysis in progress

What do we learn until now ?

"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)

→ Design of XEMIS2 Compton Camera