Hexagonal Pixel Multi-element Germanium Detector For Synchrotron Applications

Simulation of Detector Performance

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Introduction

Performance of fluorescence detectors is one of the major limitations of the XAS experiment at synchrotron facilities. Hence, Technological developments are mandatory:

- **To measure more challenging samples**
- **To cope with the very high photon flux and input count rate of current/future light sources.**

→ A performance study of potential configurations of a monolithic multi-element germanium detector is presented.

Hexagonal Pixel HPGe Detector (DLS-SOLEIL prototype)

A new generation of monolithic multi-element detectors with hexagonal pixels are proposed for XAS experiments:

- **Maximize the compactness and granularity of the traditional detectors.**
- **New monolithic Ge sensor composed of 19 hexagonal pixels of 2 mm inner diameter → (DLS-SOLEIL) prototype.**
- **Review of front-end electronics and design of a new carrier board.**

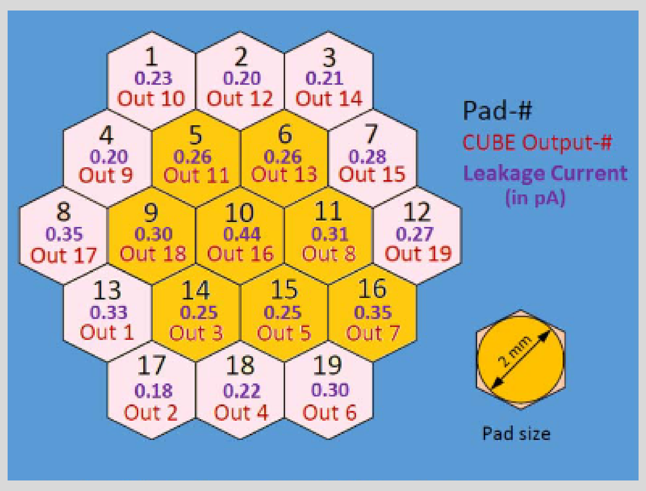

Fig. 1 : Schematic of the current DLS-SOLEIL prototype. The proposed demonstrator is composed of 19 hexagonal pixels of 2 mm inner diameter.

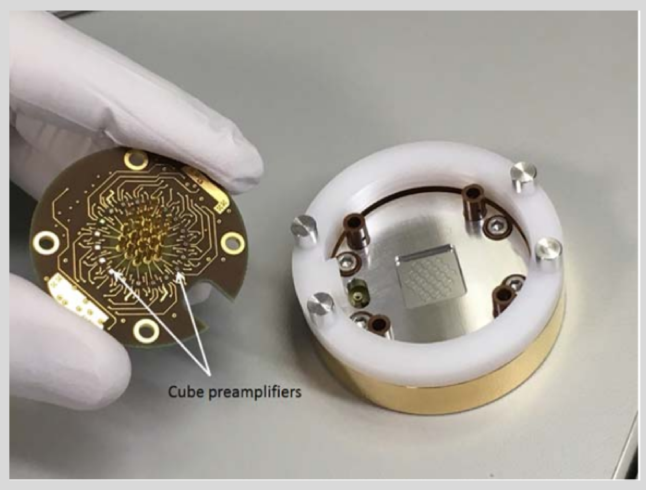

Fig. 2 : The segmented Ge crystal in the crystal holder and the current printed circuit board (PCB).

Simulation Flow & Detector Performance

Detector Layout :

The germanium sensor under study is composed of :

- High purity germanium crystal, with two implanted regions.
- p-type doped collection electrode (pixel region) at the backside
- n-type doped region with a higher doping concentration at the frontside.
- An operational bias voltage of +200 V is applied at the frontside, and the pixel electrode is grounded.

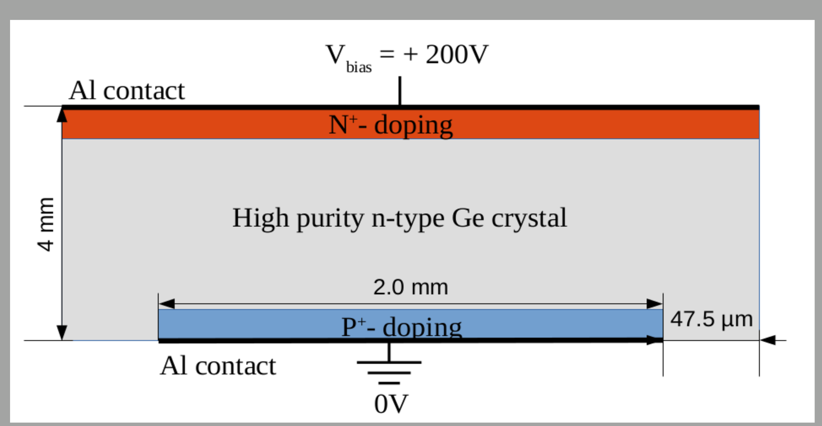

Fig. 3: Schematic representation of the germanium sensor under study.

Simulation Flow :

A simulation chain combining :

- 3D electrostatic field, COMSOL Multiphysics® simulation.
- Allpix-Squared simulation

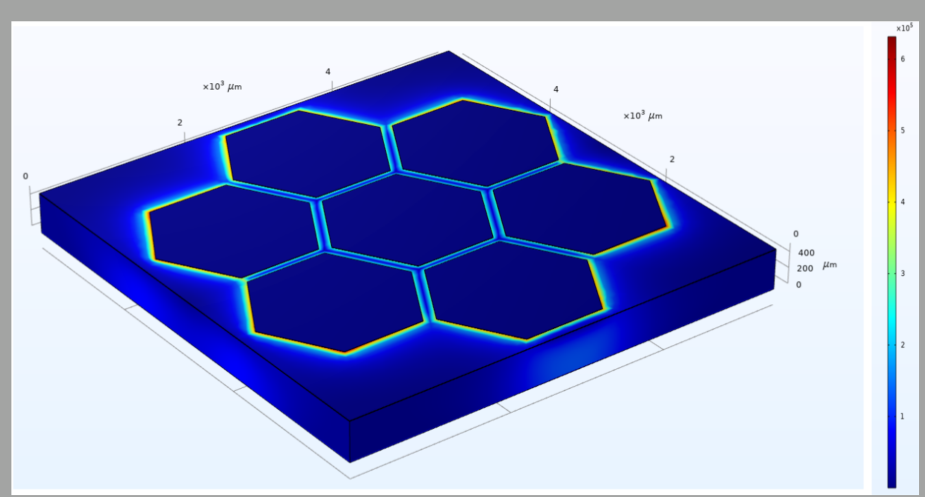

Fig. 4: 3D electric field map, simulated using COMSOL Multiphysics®, of the hexagonal pixel multi-element germanium detector under study.

COMSOL Simulation :

→ Visualization of simulated electric field map in 3D for the hexagonal pixel design.

→ 3D electric field map is exported to allpix-squared framework.

Detector Modelling & Charge Sharing Effect :

A simulation of the multi-element germanium detector under study has been performed using the allpix-squared framework.

Beam direction	Perpendicular (z-axis)
Beam Shape	Square
Beam Size	12 mm x 12 mm
Beam Energy	5-80 keV
Electric Field	Non-linear (COMSOL)
Hexagon side [mm]	1.8
Inter-pixel gap [µm]	95
Sensor Thickness [mm]	4
Active area* [mm^2]	~ 11.5 x 11.5

Table 1: Allpix-squared simulation parameter.

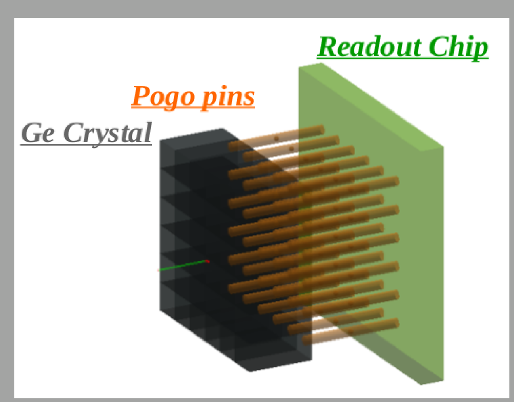

Fig. 5: Detector Geometry, Geant4 simulation.

The cluster size map shows :

- Increase of charge sharing at the pixel corners and towards the pixel edges
- About 13% of the events are shared between two pixels (cluster size =2)
- Less than 2% of the events has a cluster size >=3.

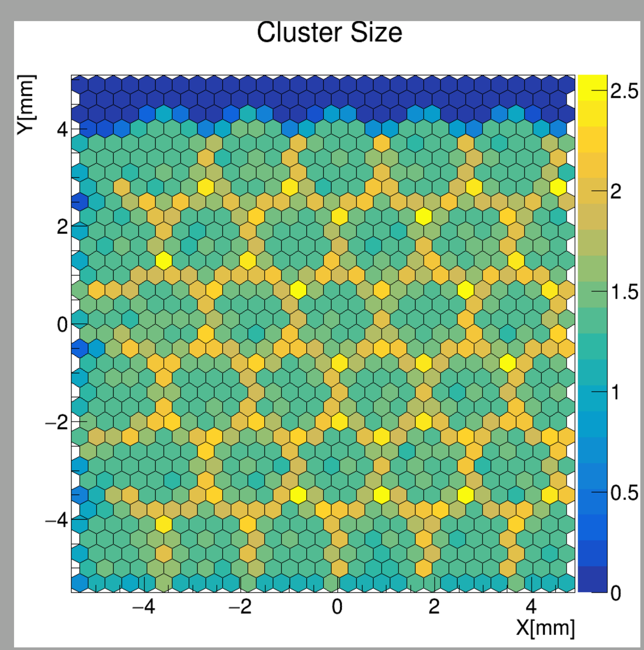

Fig. 6: Cluster size spatial distribution of the multi-element germanium detector under study.

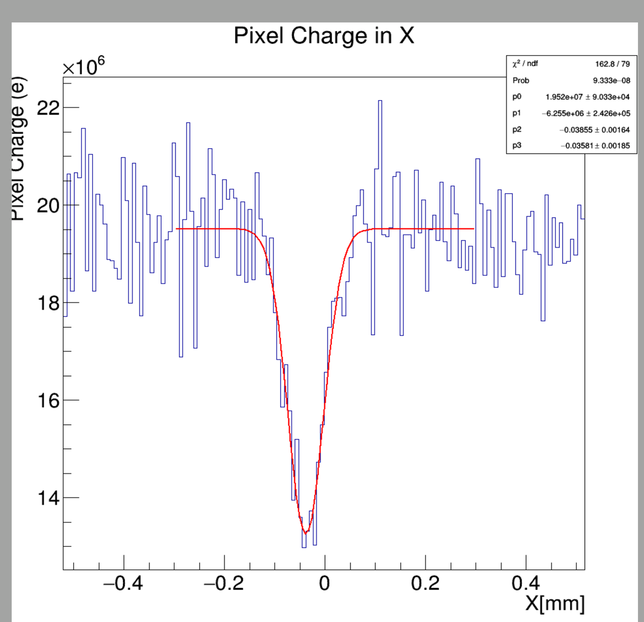

Fig. 7: Pixel charge scan between two adjacent pixels.

→ Pixel charge scan along a horizontal cut-line crossing the middle of a pixel row is fitted using a Gaussian fit.

→ Distance of charge sharing which is about 105 µm in agreement with measurments performed at DLS.

Detector Efficiency

The detector performance has been studied at different beam energies between 5 and 80 keV.

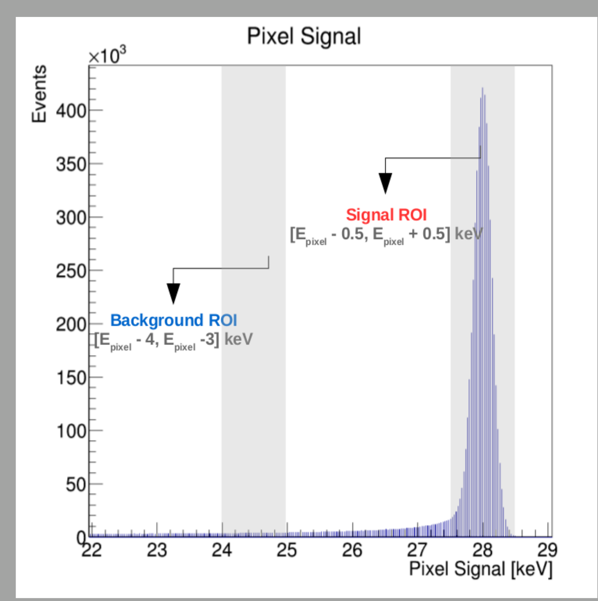

Fig. 8: The energy spectrum for a photon beam of energy 28 keV shows the signal and background RoI regions defined for this study.

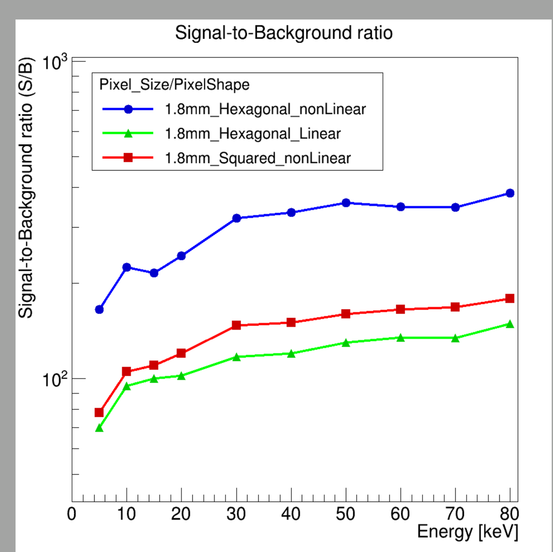

Fig. 9: Signal-to-Background (S/B) ratio as a function of incident photon beam energy.

→ The new detector design with hexagonal pixel shape (blue curve) shows a significant increase of the S/B ratio at all energies compared to a conventional squared pixel shape design (red curve).

→ The new hexagonal pixel design (blue curve) shows a slightly higher percentage of shared events compared to a conventional squared pixel design (red curve).

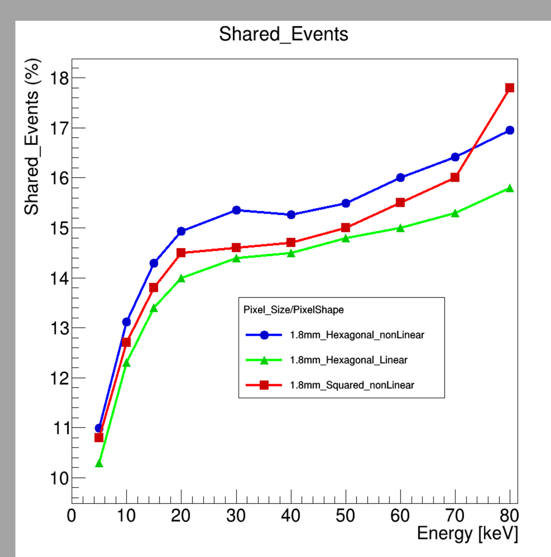

Fig. 10: The number of shared events as a function of incident photon beam energy.

CONCLUSION

1. **Complete simulation chain combining allpix-squared simulation with 3D electrostatic field simulation performed with COMSOL Multiphysics®.**
2. **Performance of the DLS-SOLEIL multi-element Ge detector prototype with hexagonal pixel shape of 2 mm inner diameter has been simulated.**
3. **Hexagonal design allows for a less extensive charge sharing (i.e. cluster size 3 instead of 4) compared to a conventional squared design.**
4. **Preliminary results show that hexagonal pixel design would be beneficial for future applications as it significantly increases S/B ratio in comparison with a conventional squared pixel design.**
5. **This simulation model will be used in studying variant hexagonal-shaped germanium detector and its sensitivity for future applications**

References :

[1] N. Tartoni et al., "Hexagonal Pad Multichannel Ge X-ray Spectroscopy Detector Demonstrator: Comprehensive Characterization", IEEE Transaction on Nuclear Science, vol. 67, NO. 8, (2020)
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[3] S. Spannagel et al., "Allpix 2 : A modular simulation for silicon detectors", Nucl. Instr. Meth. A 910, 165-172 (2018)
[4] Allpix-Squared Code : https://zenodo.org/record/4494619

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