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New generation of 3D detectors for X-ray polarimetry: simulation of performances

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INTRODUCTION

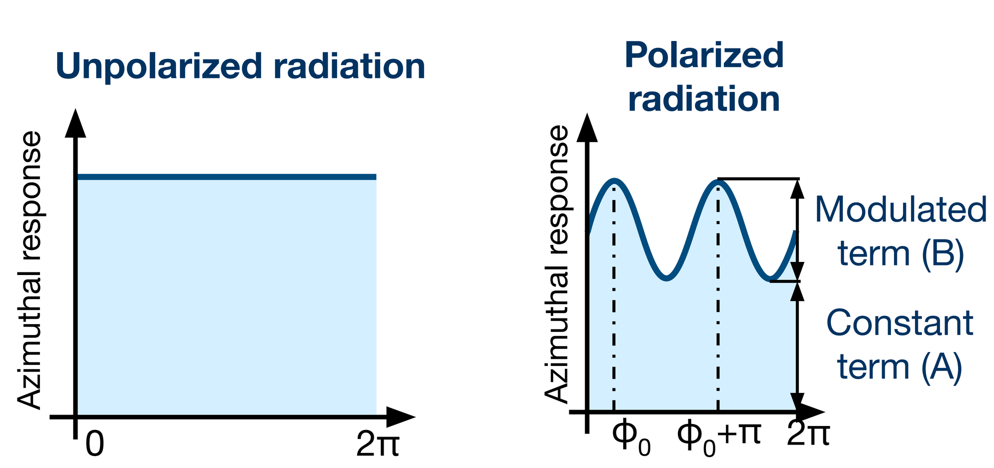
The field of X-ray imaging polarimetry has expanded significantly since the development of Gas Pixel Detectors (GPD) [1] an X-ray polarimeters based on photoelectric effect, currently on board the Imaging X-ray Polarimetry Explorer (IXPE), a NASA/ASI mission [2]. Thanks to the GPD, IXPE is exploring X-ray polarization of several classes of astronomical sources. However, despite its remarkable performance, X-ray polarimetry is still restricted by the brightness of the source and the long exposure time required for faint objects. Therefore, improving sensitivity becomes essential to expand our perspective and delve deeper into the universe with X-ray polarimetry.

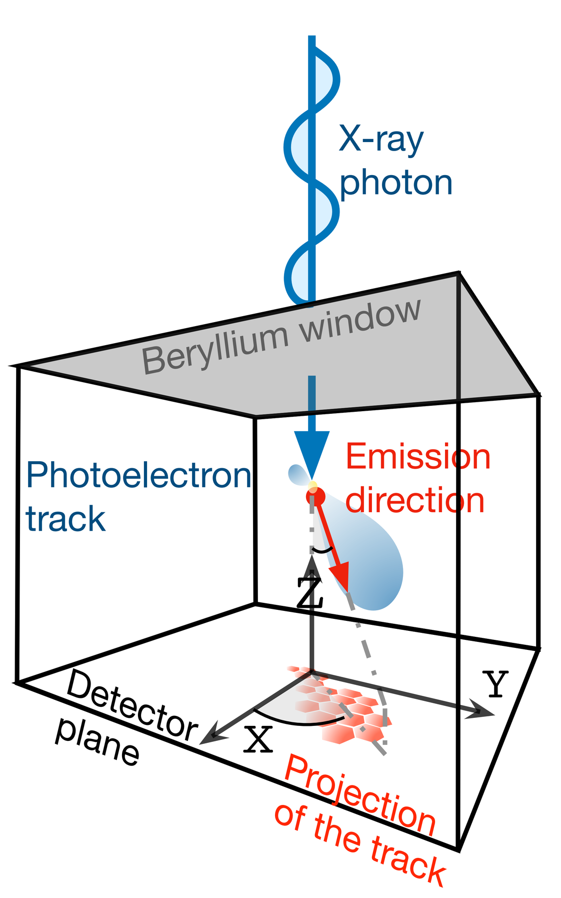
Our new project "High yield polarimetry experiment in X-rays" (Hype-X) seeks to enhance the sensitivity of the X-ray polarimeters by using TIMEPIX3 as the ASIC in a gas detector. TIMEPIX3 will offer single electron sensitivity and 3D tracking enabling the execution of time-resolved X-ray polarimetry with almost no dead time thanks to its parallel read-out system. The reduced death time allows for an improvement in the sensitivity thanks to the coupling with mirrors having larger effective area than in IXPE.

How we measure X-ray polarization?

X-ray polarization in photoelectric polarimeters is determined by the angular distribution of the photoelectron emission directions. Determining this emission direction we can obtain a histogram following the distribution:

$$M(\phi) = A + B\cos^2(\phi - \phi_0)$$





$$\mathrm{PD} = \frac{1}{\mu}\frac{B}{2A+B}$$

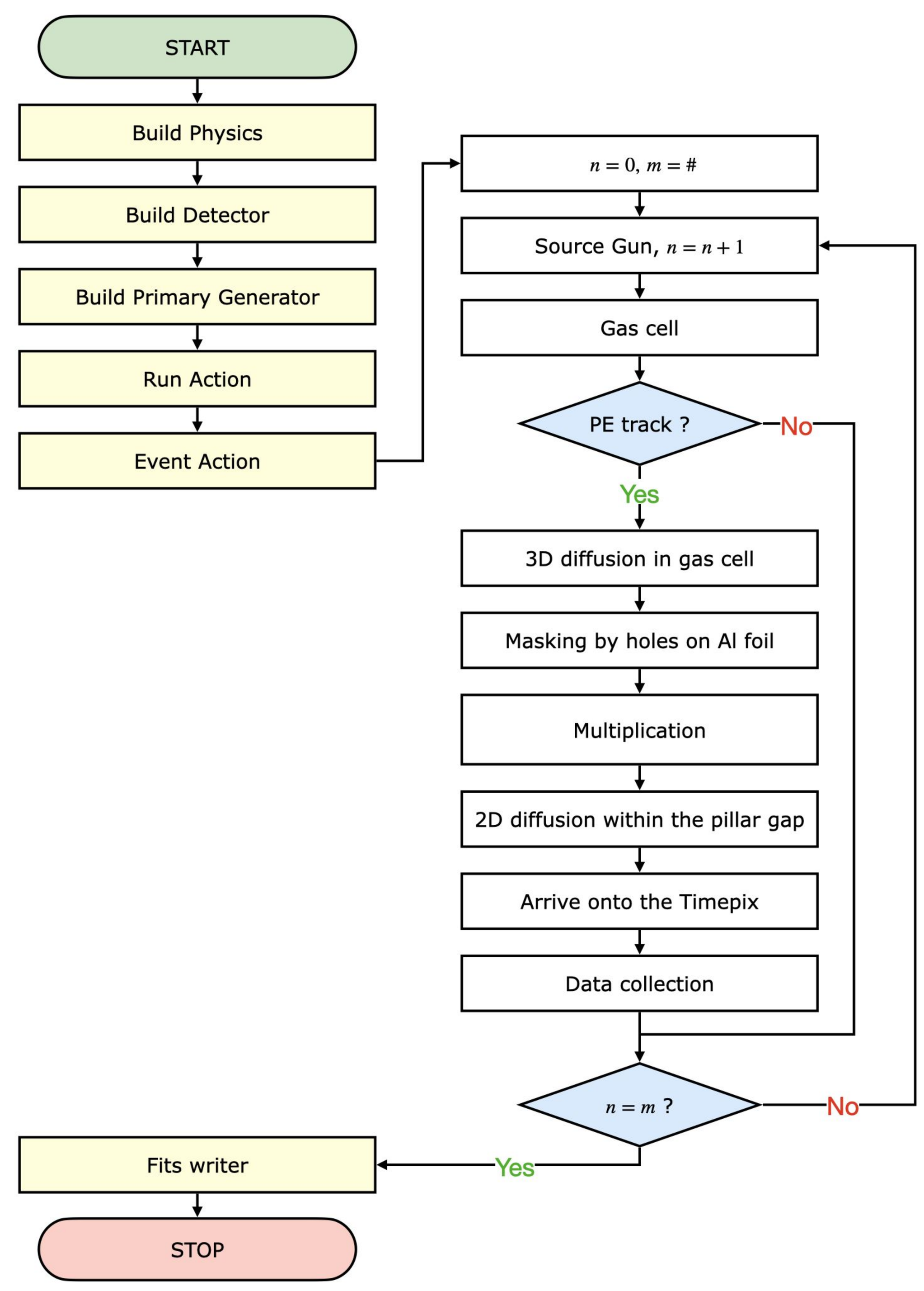
μ is the modulation factor: the modulation measured for X-rays having PD=100%

Science Objectives

- Build a new *Geant4 Monte Carlo simulations*
- Reproduction of 3D simulated photoelectron tracks
- Development of a 3D track reconstruction algorithm
- Quantification of the improvement achieved through the 3D track reconstruction

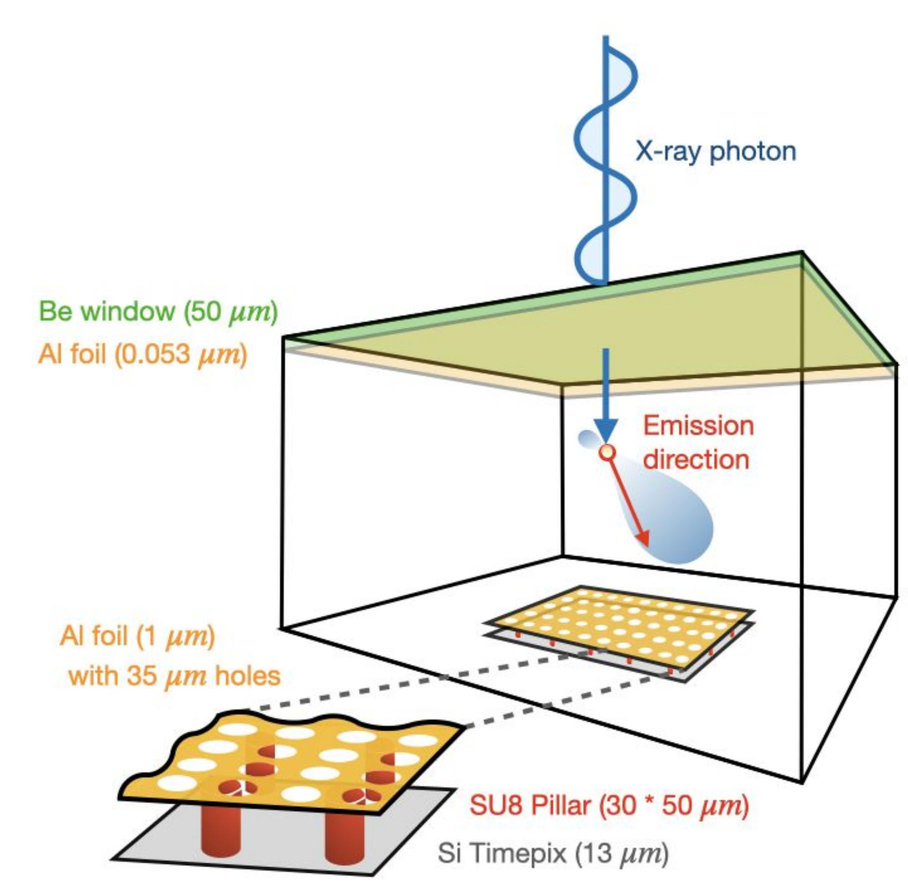
SIMULATOR

The Hype-X simulation is developed by using Geant4 simulation tool [4]. We used the version 10.5.1 with the physics list "G4LivermorePolarizedPhotoElectricGDModel" optimized for measuring linearly polarized X-rays in the energy range of keV [5].



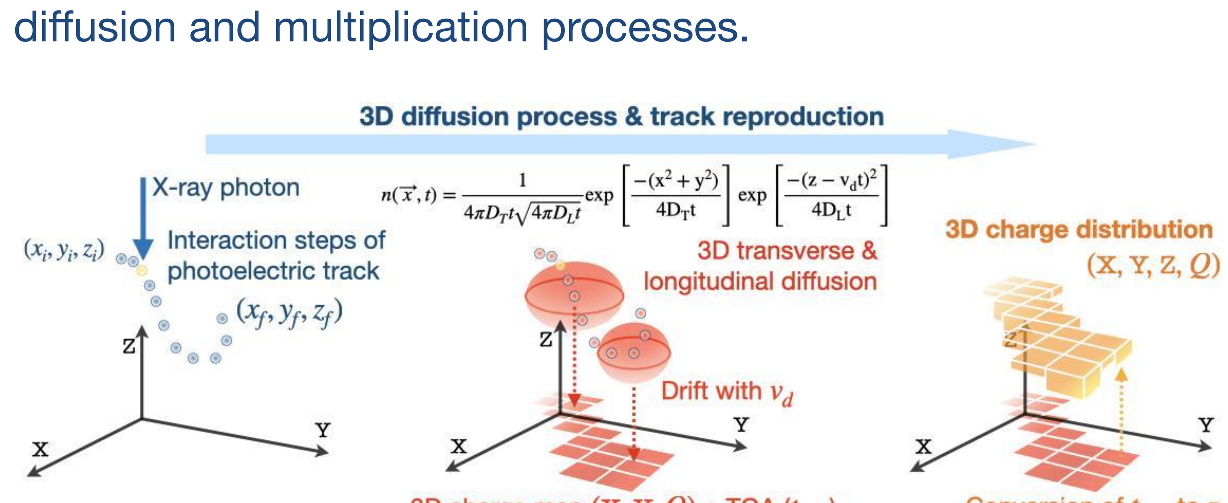
Geometry

In this preliminary work on Hype-X simulation we partially used the geometry adopted in the GPD [6] with DME as filling gas at 800 mbar, a Be window on top with an Al foil, then the gas cell having 10 mm height and on the bottom the InGrid system [7].



Diffusion

In the "Event action" each time an X-ray produces a photoelectron a ionization track made of secondary electrons is generated. Each secondary electron passes through diffusion and multiplication processes.



Simulation logic

- X-ray interacting into the gas cell can produce a photoelectron
- The photolectrons ionize the gas producing secondary electrons in a track
- The secondary electrons are diffused
- Secondary electrons reaching the Al foil in InGrid are multiplied and diffused in the transfer gap
- Secondary electrons reaching the Si TIMEPIX3 ASIC are collected to form a track reproducing the ASIC response

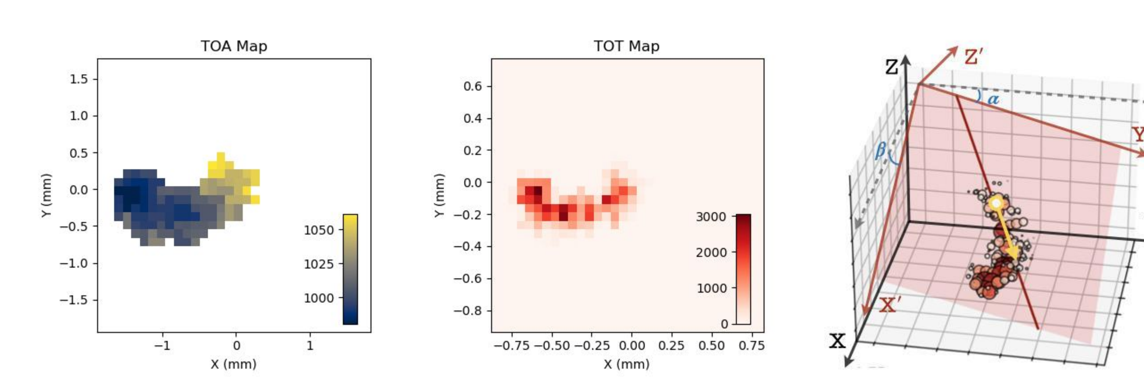
RESULTS

Hype-X 3D tracking capabilities are based on the usage of the TIMEPIX3 [3] which can measure simultaneously time of arrival (ToA) and time-over-threshold (ToT) for each pixel.

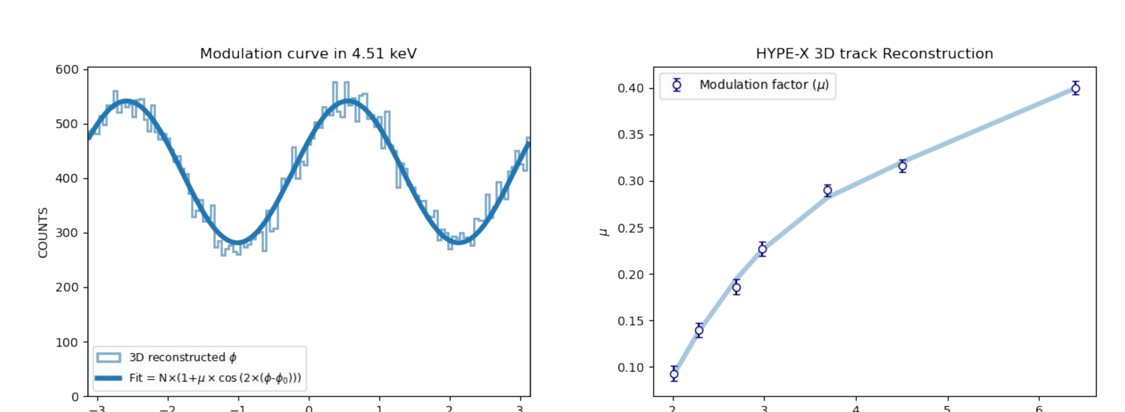
- ToT provides effectively the charge of the track
- ToA provides the starting time of charge collection

Combining the two informations we can generate a 3D representation of the photoelectron track.

The new simulation software allows to obtain maps of ToT and ToA reproducing the Hype-X response. This software will allow to test and optimize 3D reconstruction algorithm [8] and to estimate the sensitivity for a given configuration consisting of: gas mixture (composition, pressure, temperature, …); size of the gas cell; different diffusion coefficients (corresponding to different applied voltages), etc.



CONCLUSIONS



As in these examples of modulation curves and modulation factor as a function of the energy obtained for DME, this new simulator will allow to study Hype-X response and its 3D tracks' reconstruction capabilities. This will help us to investigate possible designs/configurations for the future polarimeters tuned on the energy band of interest.

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