GOSS: GPU-based Optical Simulator of Scintillator Crystals

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Introduction

Accurate simulation of optical photon transport in scintillator-based detectors is crucial for understanding and optimizing their performance metrics like timing and spatial resolution [1, 2].

Monte Carlo (MC) simulations [4, 5], thought being an effective tool, remain limited by different reasons:

- **A priori knowledge of microscopic parameters is required,** (crystal roughness, microstructure of crystal interface reflectors..)
- **Large computation time:** Accurate models require complex simulations, which need to be accelerated (for instance by using GPUs) to achieve results in a reasonable amount of time.

The goal of this work is to introduce and validate **GOSS**, a **GPU-based Optical Simulator of Scintillator crystals**.

Methods

A. GOSS

— Optical model: Optical photons are tracked with straight lines from surface to surface, according to three simple probabilistic parameters, namely transparency, absorption and roughness, which macroscopically define classical reflection and refraction in complex interfaces. These parameters might be obtained from comparison with simple experiments. Physical parameters such as light photon yield, photon attenuation and photon detection efficiency might be accounted as well. Gamma-detector interactions with the deposited energy and position of each interaction, are employed as input (simulations from UMC-PET were used in this work [5]).

— Detector model: GOSS is focused on pixelated arrays of crystals with no restrictions in terms of geometry and light collection from the photosensors.

— Implementation: Code in CUDA-Fortran for NVIDIA GPUs.

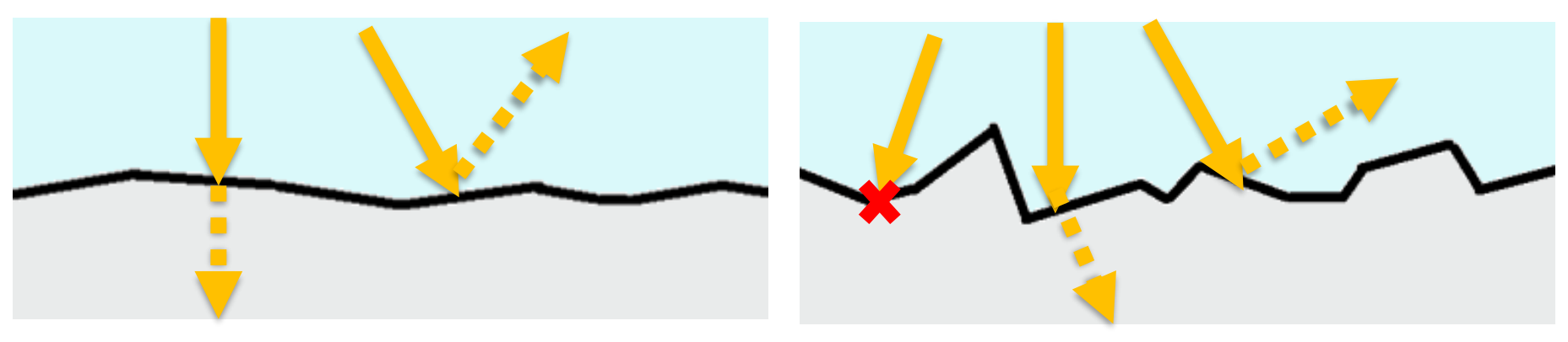


Fig. 1. Depending on the surface microstructure, photons might either cross or reflect (transparency), be absorbed, and/or change direction with certain probabilities.

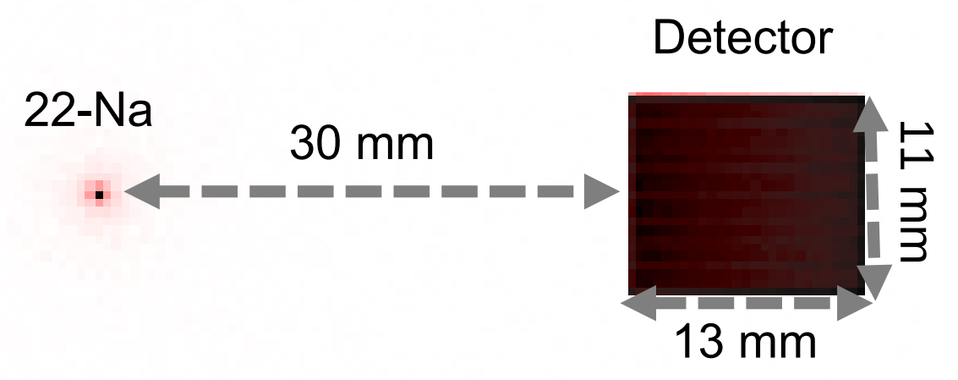


Fig. 2. Basic Scheme of the experimental Setup 1.

B. Experimental setup

Setup 1) A 10x10 array of 11x11 cm^2 and 13 cm depth of polished LYSO crystals with ESR reflector coupled to a 4x4 SiPMs matrix was irradiated with a point source of ^{22}Na located 3 cm apart (fig. 2). Experimental flood field maps and energy histograms are obtained with 400k events.

Setup 2) Two single LYSO crystals with all surfaces polished (**ASP**) and only two surfaces polished (**2SP**) using dual-ended readout [6] were irradiated to determine depth of interaction position (DOI). We studied the relation between the energy deposited in both SiPMs and DOI (10k events at each position).

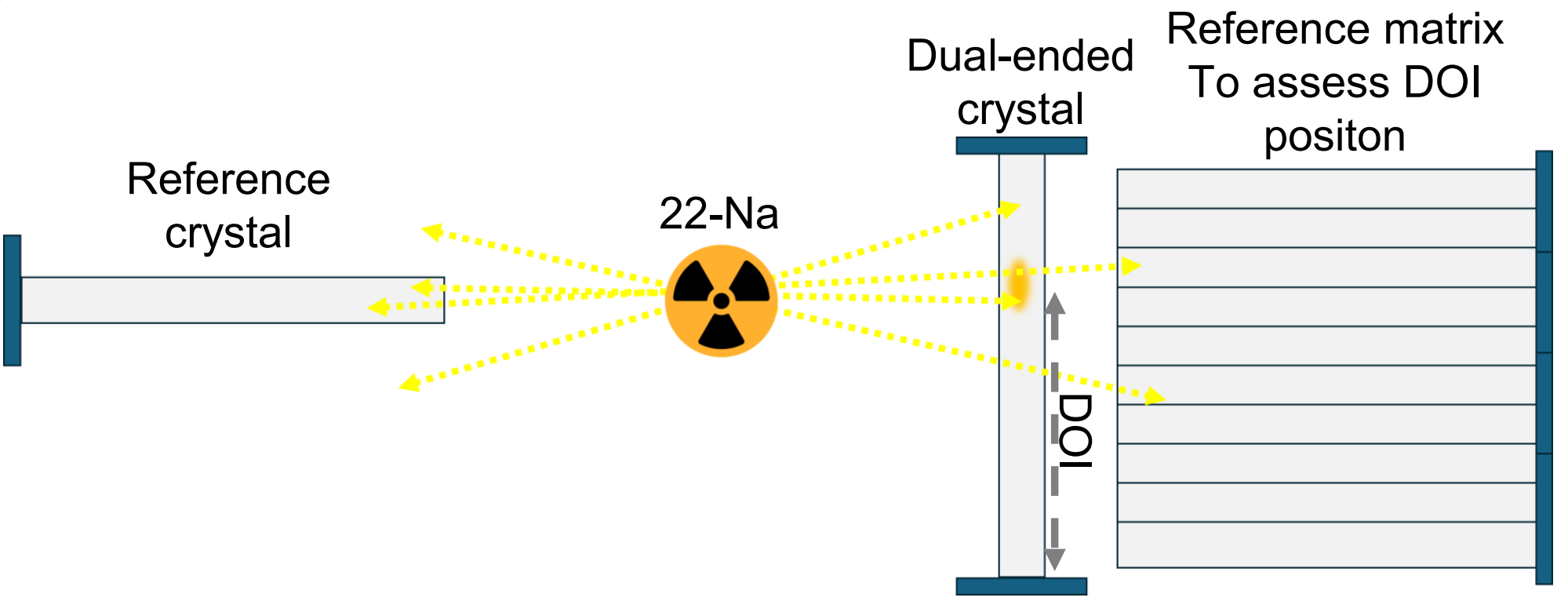
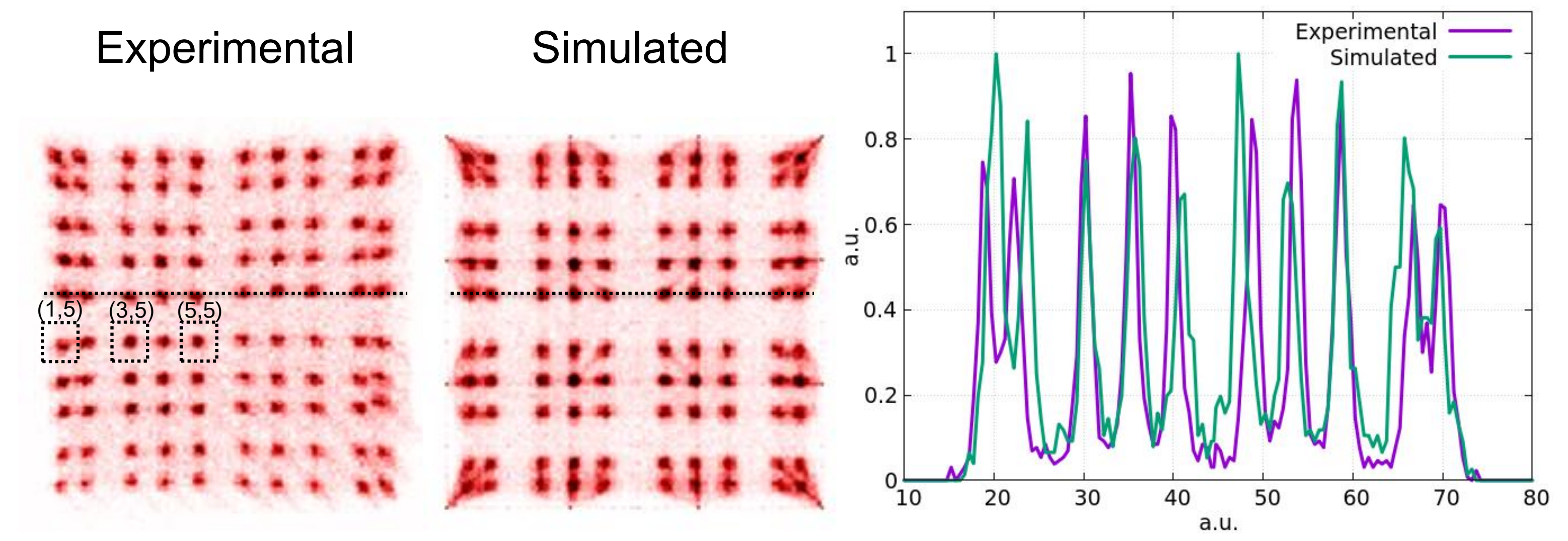
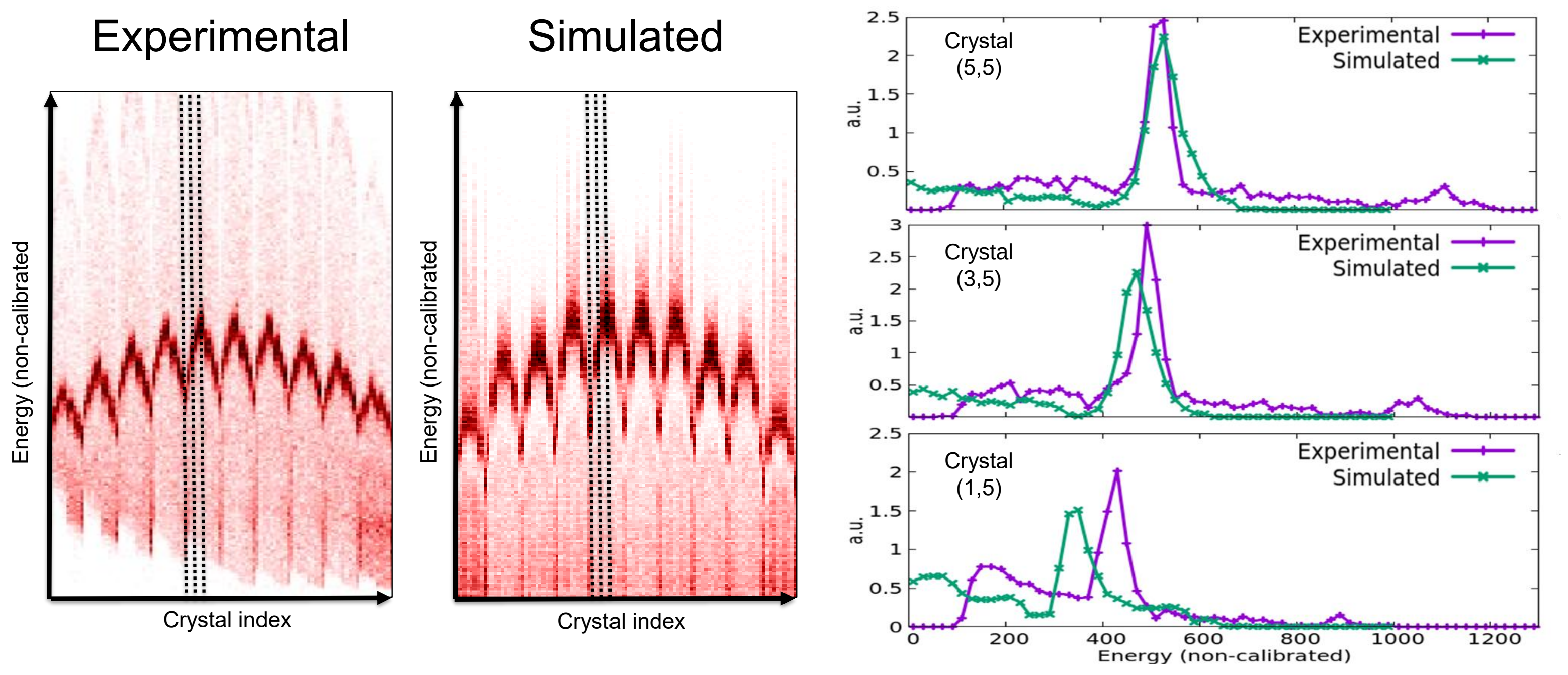


Fig. 3. Scheme of Setup 2. A platform positions the reference crystal, thus allowing to set DOI in the dual-ended crystal with electronic collimation. A reference matrix is included to verify DOI measurements.

Results



a) Floodfield maps



b) Energy histograms

Fig. 4. Experimental and simulated results of setup 1. a) Experimental and simulated flood field maps (a, left) and energy histograms (b, left). Line profiles are shown on the right. Transparency of 30%, 3% absorption and 5% roughness was obtained. Notice ^{22}Na was acquired, showing two energy peaks (511 keV and 1275 keV) whereas we just simulated 511 keV photons. Furthermore, a low-energy cutoff was applied in part of the matrix crystals, showing white in the experimental histograms.

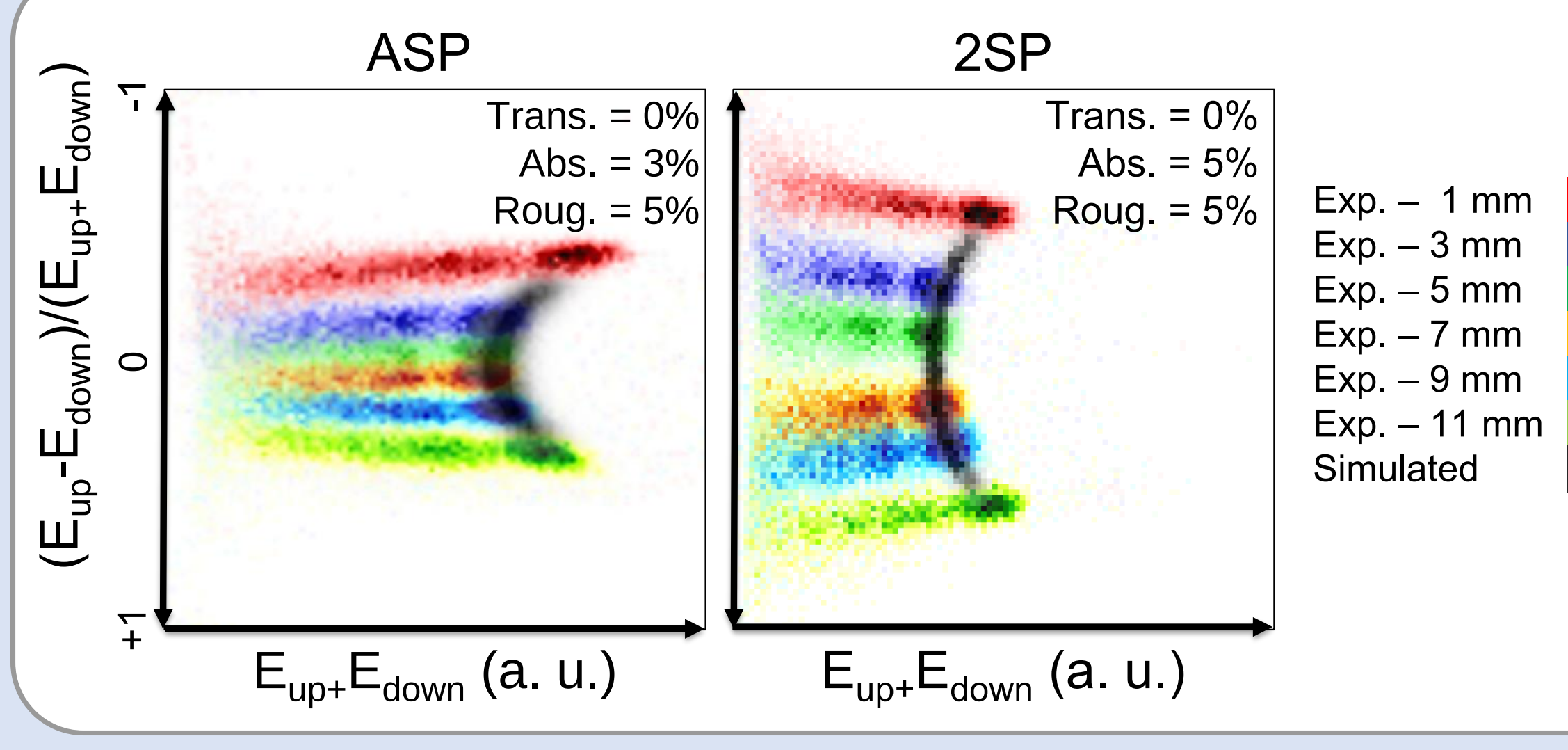


Fig. 5. Experimental distribution of the ratios at 5 positions compared with simulated events of 511 keV.

Conclusions

The dynamic range and peak-to-valley ratio of simulations align well with the flood field maps of actual detector. The centroid distribution shows noticeable differences at the matrix edges, suggesting that further considerations at the edges are needed. Energy histograms show similar behavior, providing fair energy resolution estimation in the center of the matrix.

GOSS reproduces the behavior of DOI and energy distributions observed in the measurements, in both ASP and 2SP, showing a higher energy loss in 2SP that increases the span of the up-down energy asymmetry.

Over 10^7 visible photons/s can be simulated, making possible running multiple tests to fit the simulations to the experiment.

GOSS has shown high potential for detector modeling and data generation for deep learning. In the future, we expect to increase its capabilities for timing applications.

References

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Acknowledgments

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