



MATRIX: SIMULATION AND EXPERIMENTAL STUDY OF GAN PROTON DETECTORS

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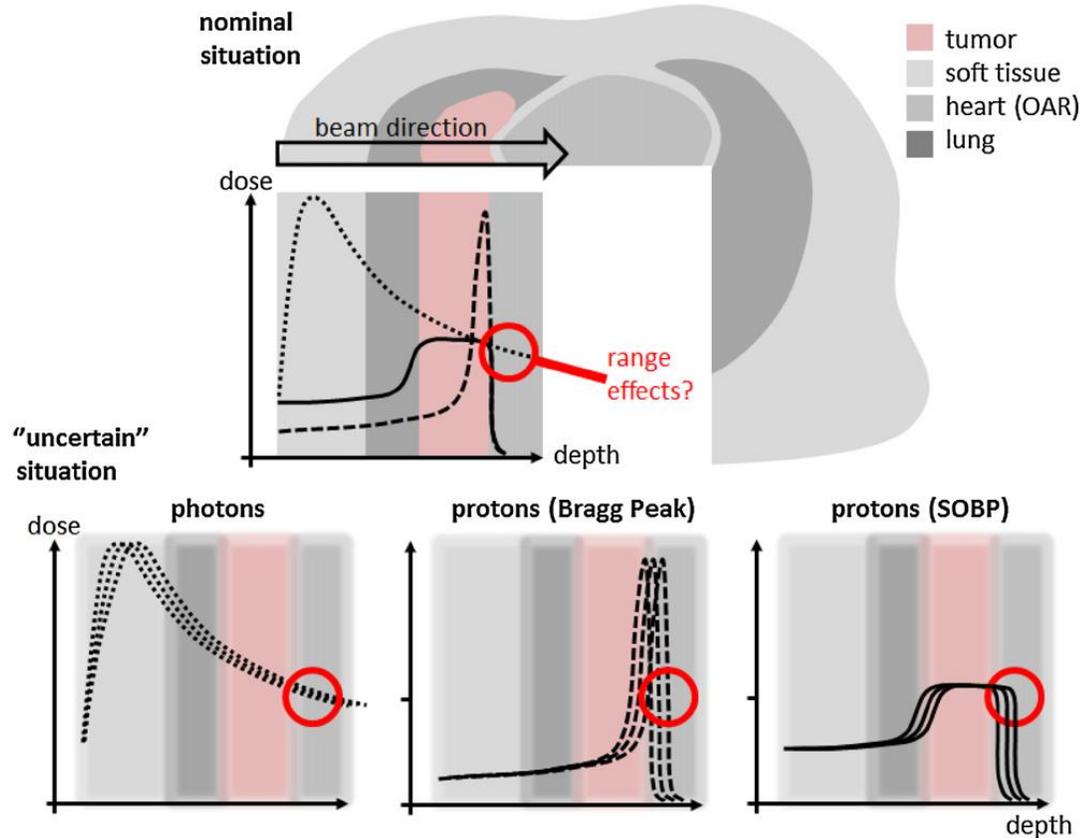
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2 Université de Strasbourg, CNRS, IPHC UMR 7178, F-67000 Strasbourg, France

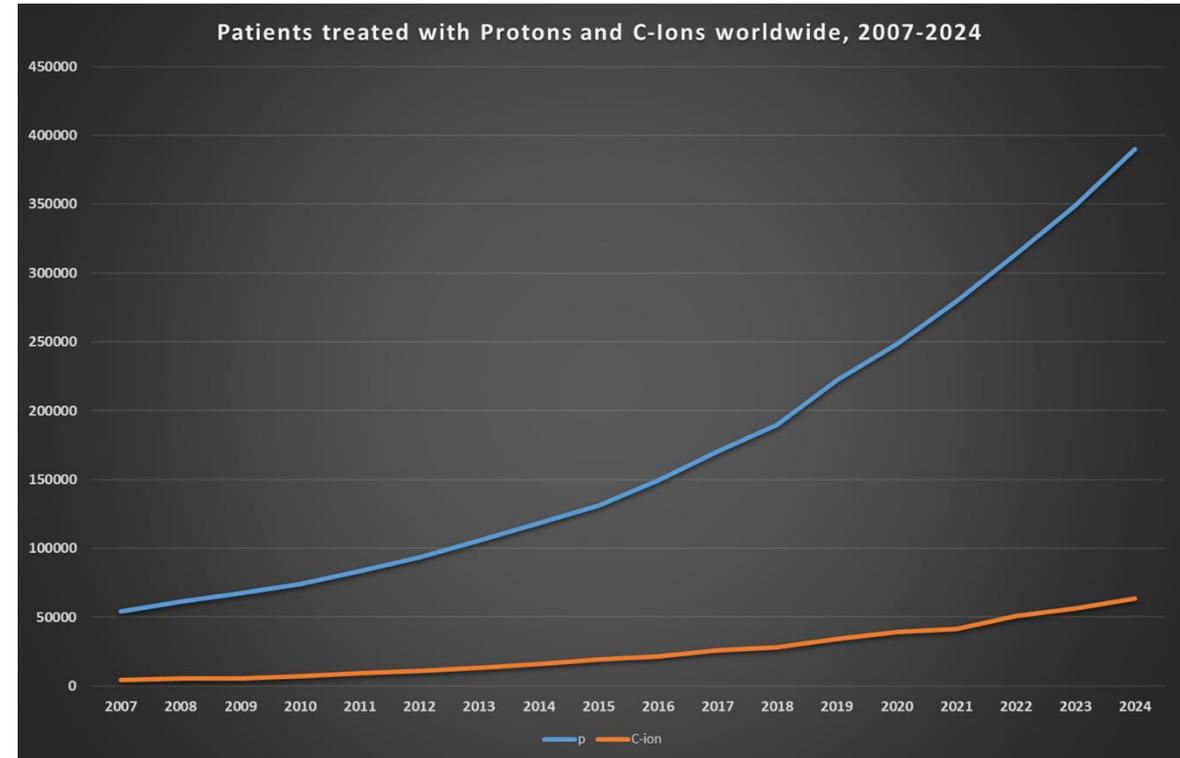
3 Université Côte d'Azur, CNRS, CRHEA, 06560, Valbonne, France



Motivation: Proton therapy



A.-C. Knopf and A. Lomax, "In vivo proton range verification: a review," *Phys. Med. Biol.*, vol. 58, no. 15, p. R131, Jul. 2013, doi: [10.1088/0031-9155/58/15/R131](https://doi.org/10.1088/0031-9155/58/15/R131).



"PTCOG - Patient Statistics." Accessed: Jul. 04, 2025. [Online]. Available: <https://www.ptcog.site/index.php/patient-statistics>

Why Gallium Nitride?

Large bandgap material (3.4 eV @ 300K)

➤ Also, large displacement energies of...

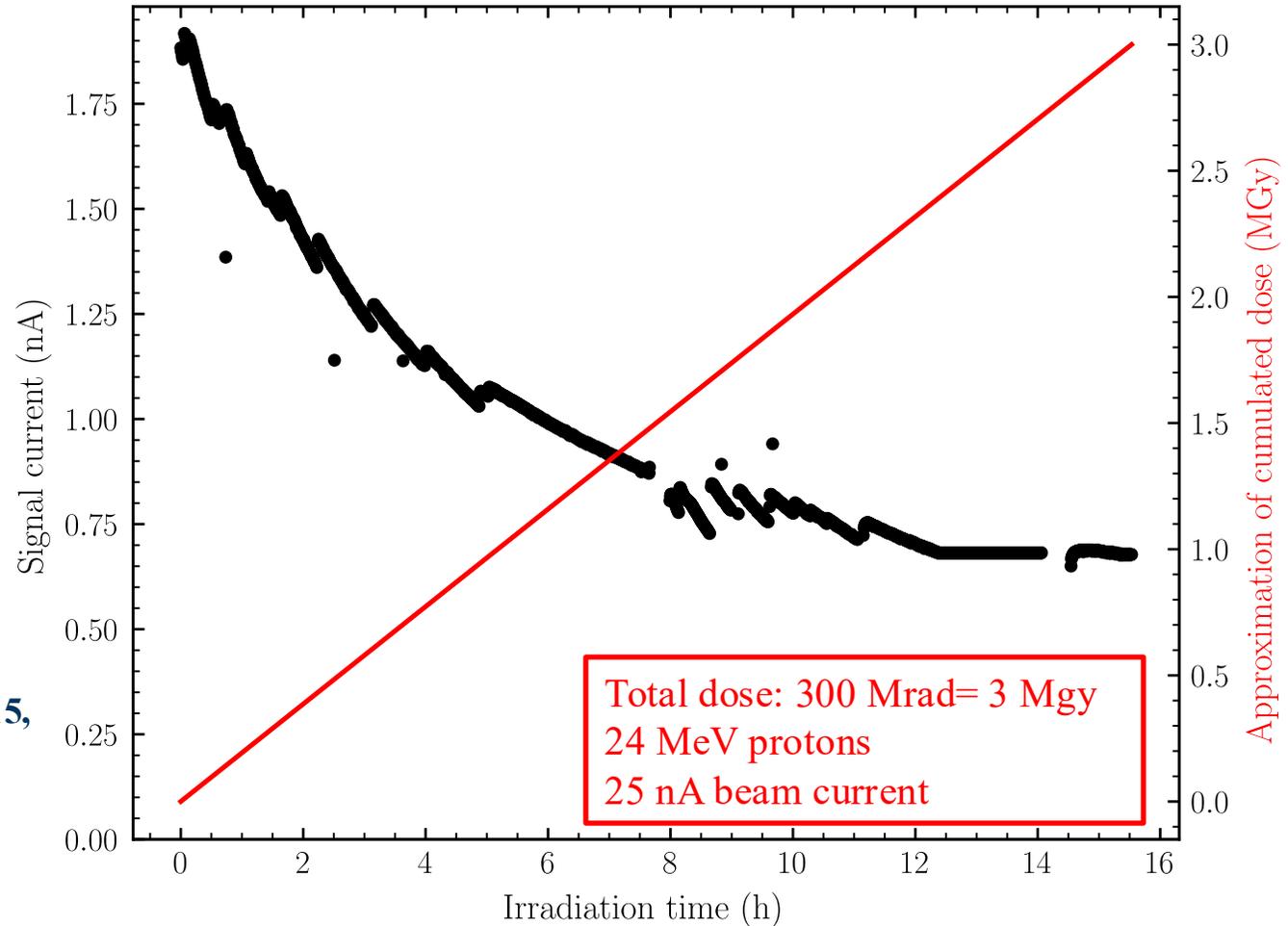
Ga: 45 eV | N: 109 eV

➤ Large radiation hardness?!

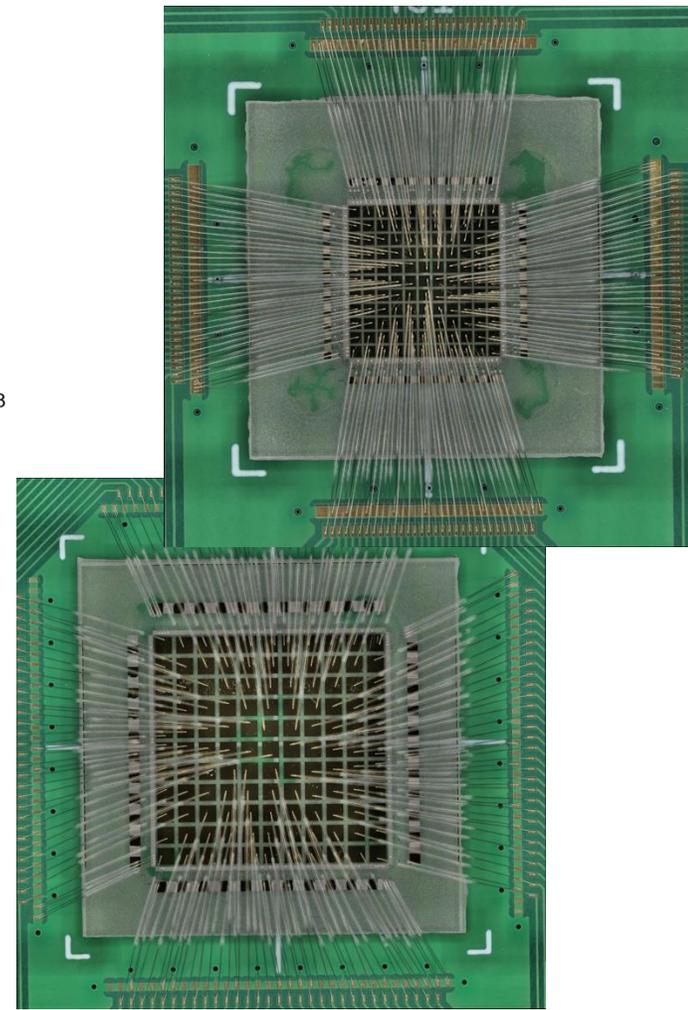
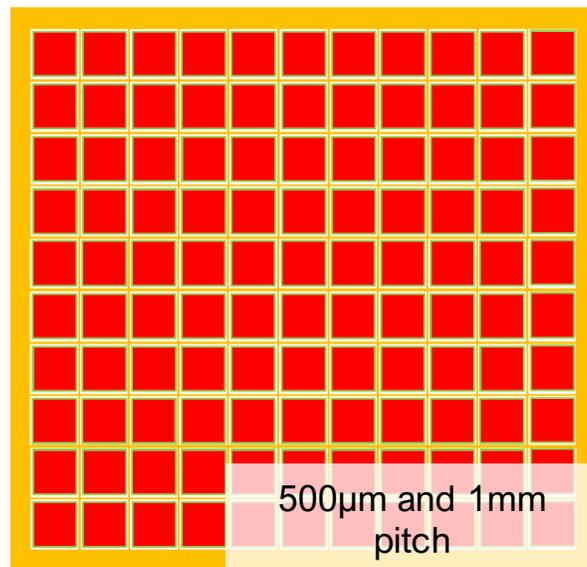
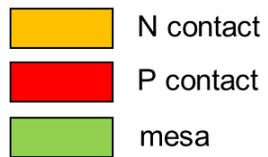
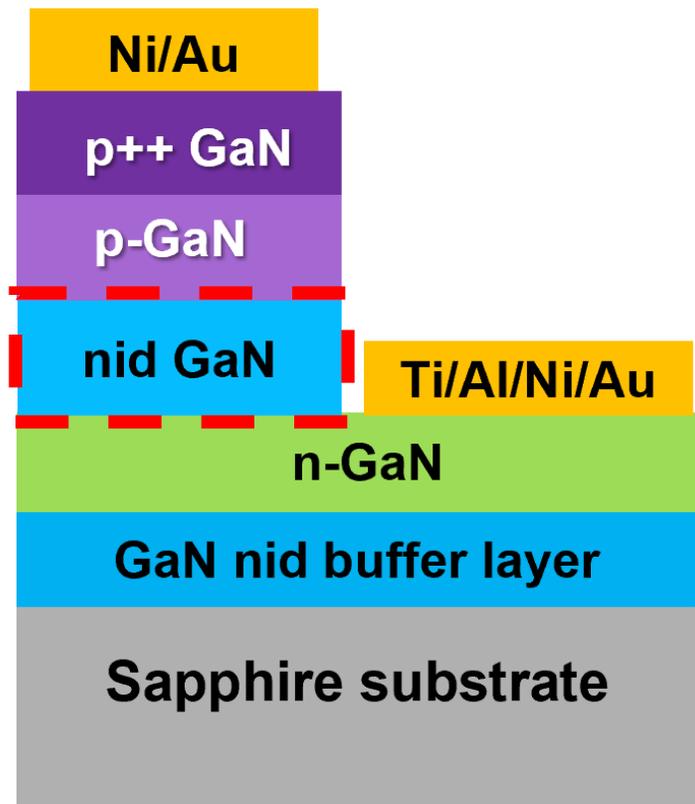
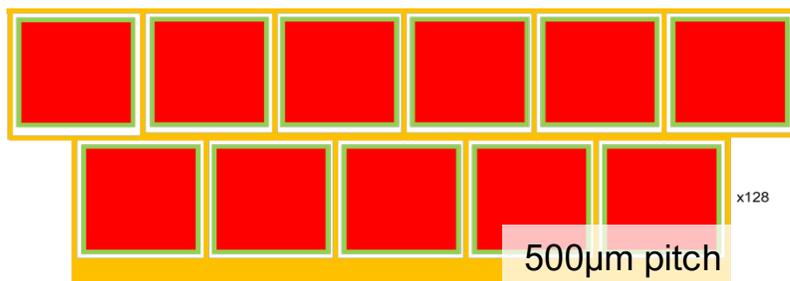
Matured fabrication methods from LED / high power electronics technology

Proof of concept + first steps:

- J.-Y. Duboz et al., “GaN Schottky diodes for proton beam monitoring,” Biomed. Phys. Eng. Express, vol. 5, no. 2, p. 025015, Jan. 2019
- J.-Y. Duboz et al., “Proton Energy Loss in GaN,” Phys. Status Solidi B, vol. 258, no. 8, p. 2100167, 2021
- M. Siviero et al., “GaN diodes comparative study for high energy protons detection,” J. Semicond., vol. 46, no. 0, 2025



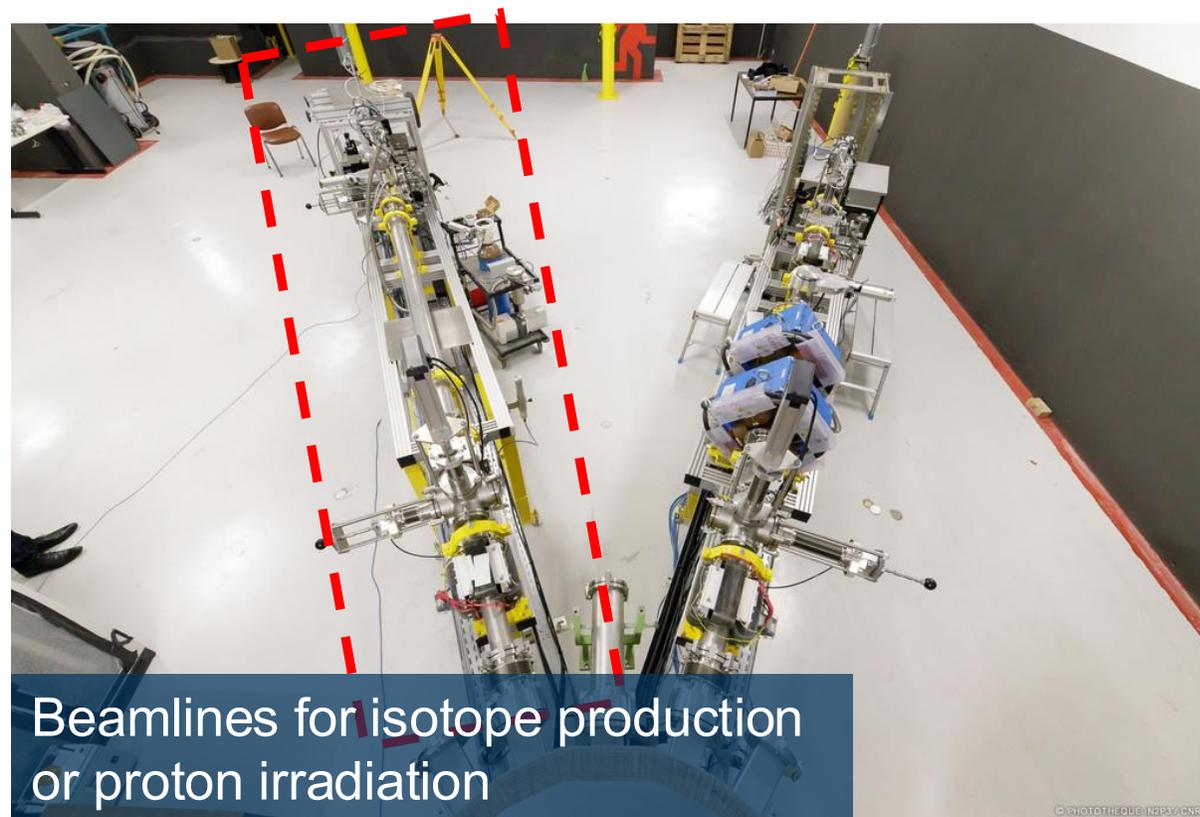
Detector Design



Measurement facility CYRCé



TR24 cyclotron from ACSI:
16 to 25 MeV and 300uA maximum



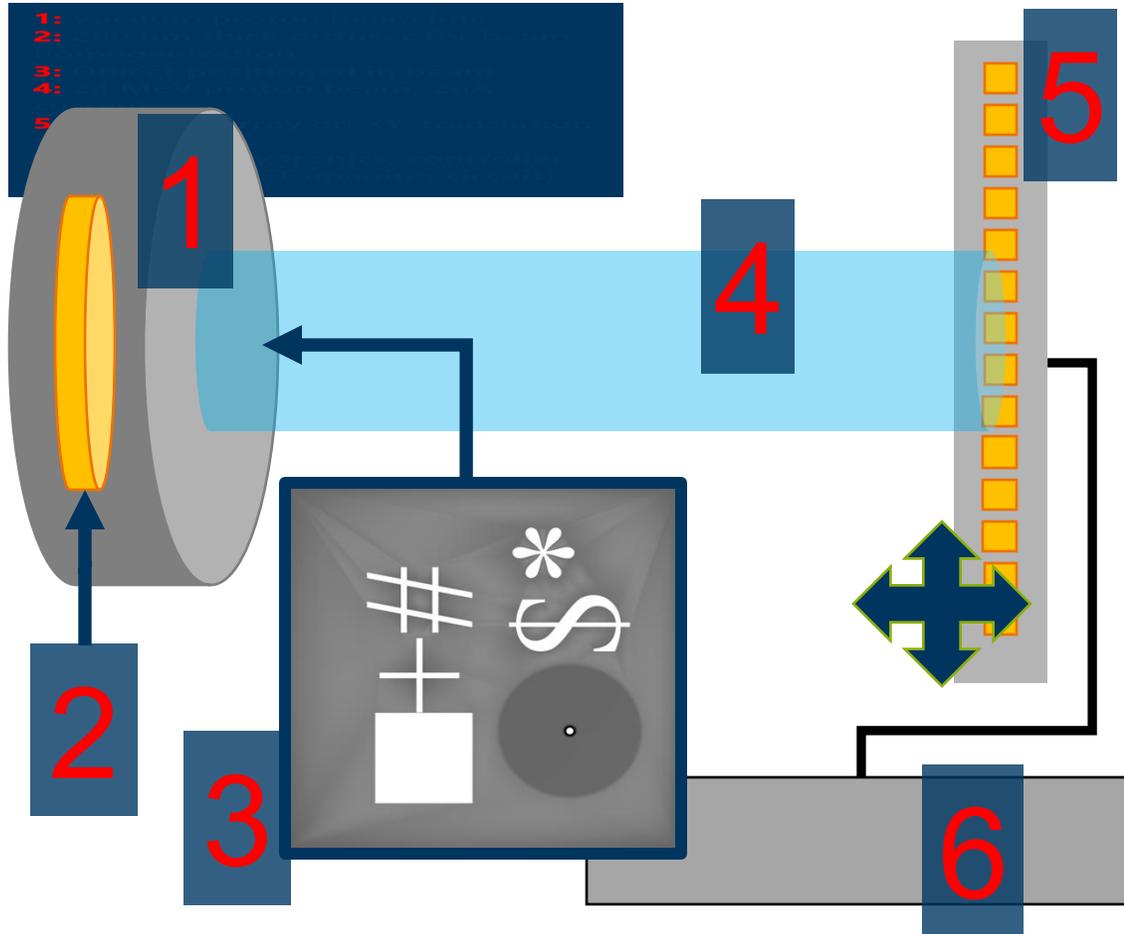
Beamlines for isotope production
or proton irradiation



About CYRCé:

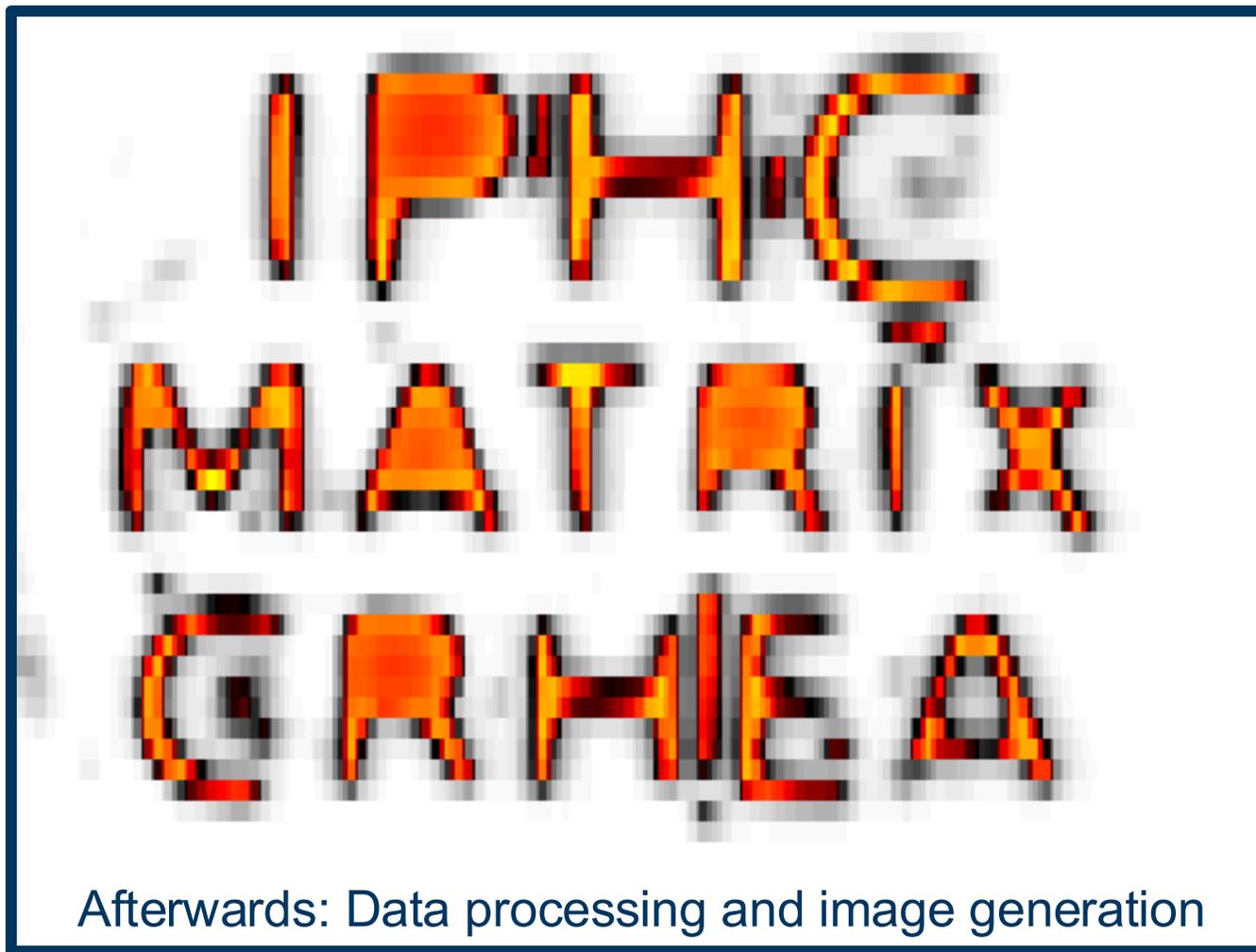
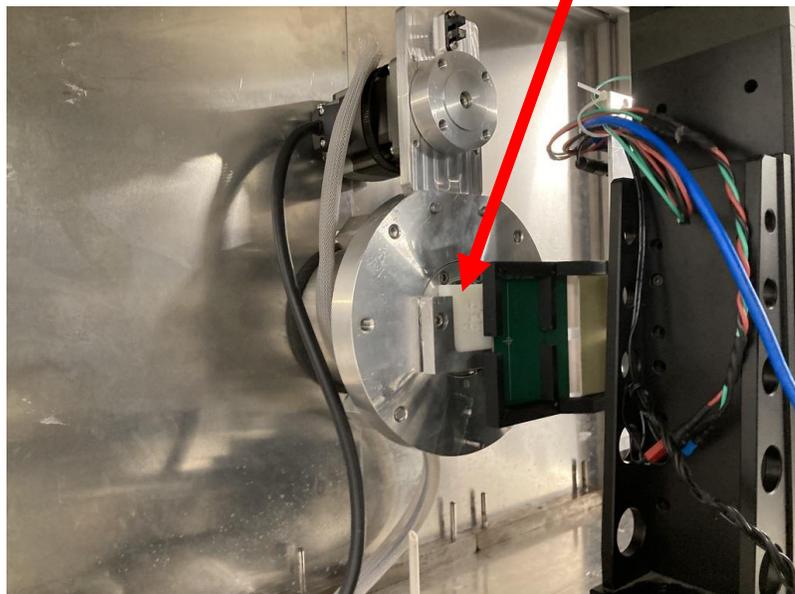
E. Bouquerel et al., "Design and commissioning of the first two CYRCé extension beamlines," Nucl. Instrum. Methods Phys. Res. Sect. Accel. Spectrometers Detect. Assoc. Equip., vol. 1024, p. 166034, Feb. 2022, doi: 10.1016/j.nima.2021.166034.

Measurement Setup



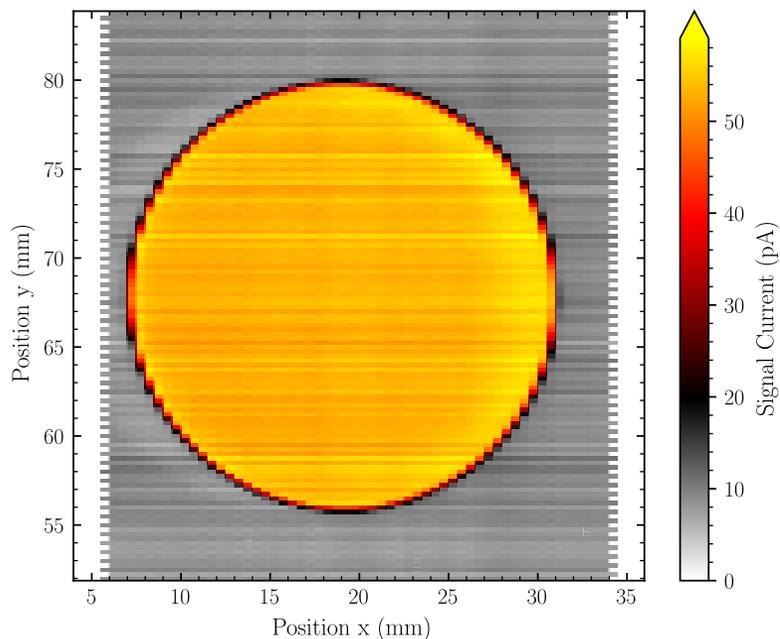
- 1:** Vacuum proton beam line
- 2:** 200 μm thick diffuser for beam homogenization
- 3:** Object positioned in beam
- 4:** 24 MeV proton beam, 2nA current
- 5:** Detector array on XY-translation stage
- 6:** Readout electronics, controller (128-channel CT imaging circuit)

Measurement setup

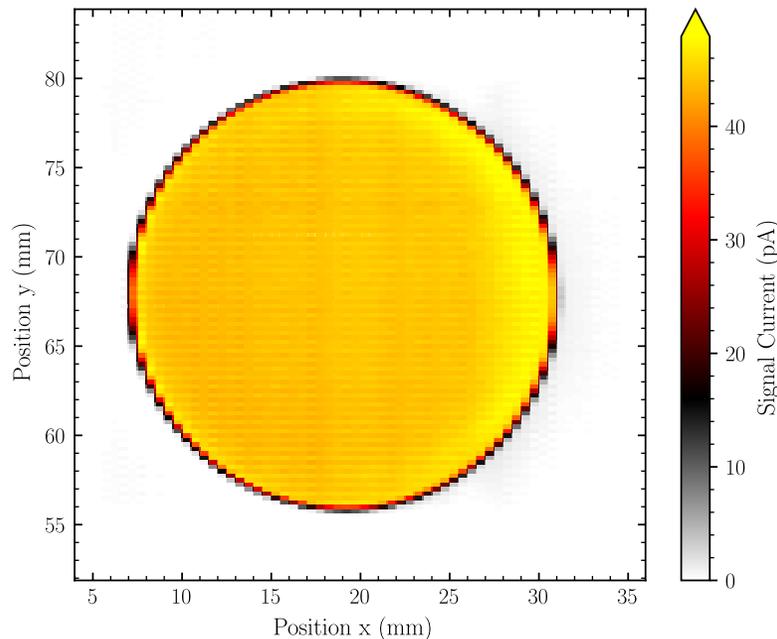


Signal quality

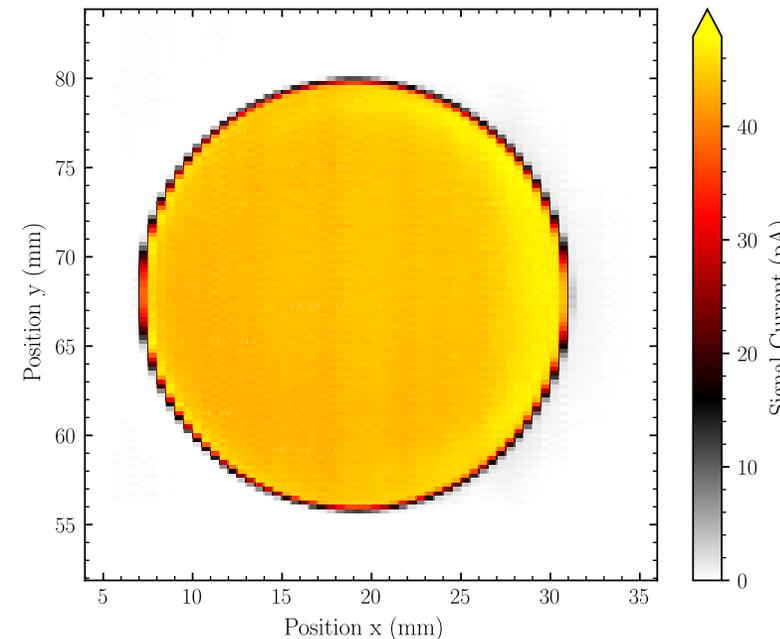
Raw data



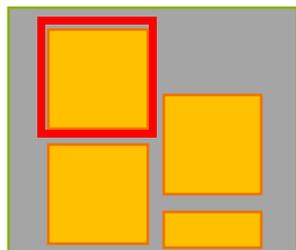
Background Subtraction



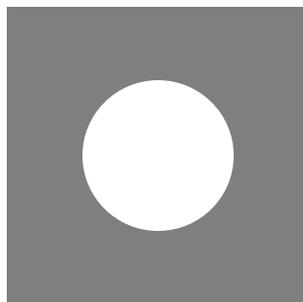
Normalization of response inhomogeneities



0.5 x 0.5 mm²



2 x 64 diodes

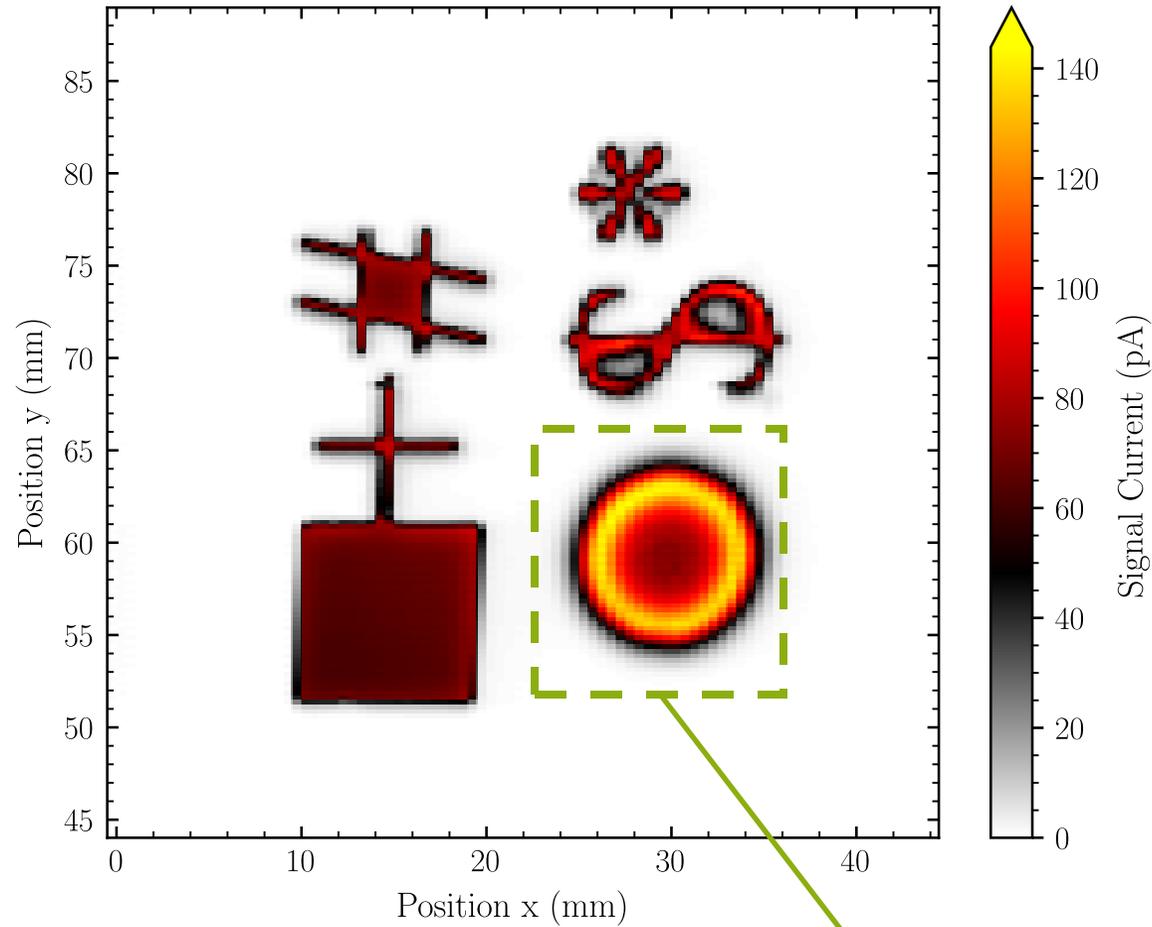


Round apertures in the beamline \approx 25 mm

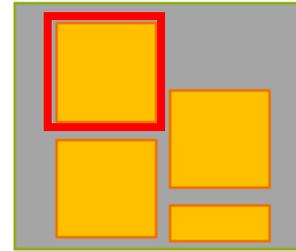
➤ All array diodes are working! - Diode yields 100 %

➤ Response inhomogeneity < 2 %

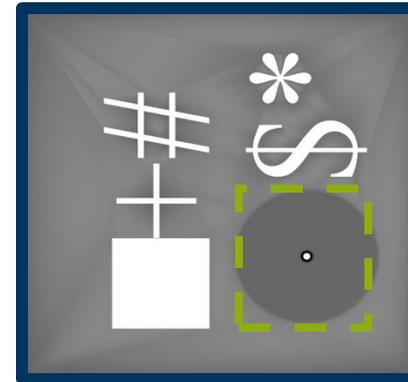
2D Imaging "Misc shape"



0.5 x 0.5 mm²

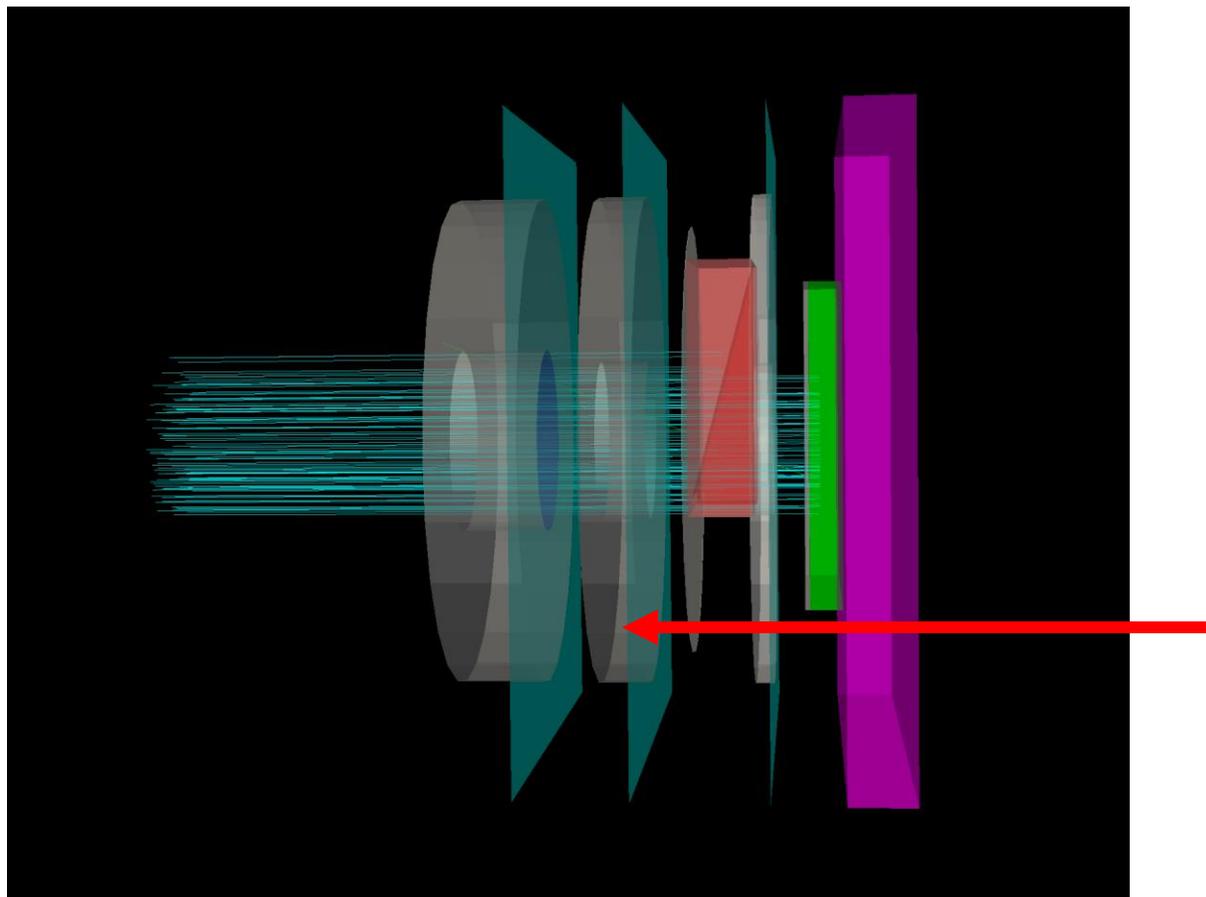


2 x 64 diodes

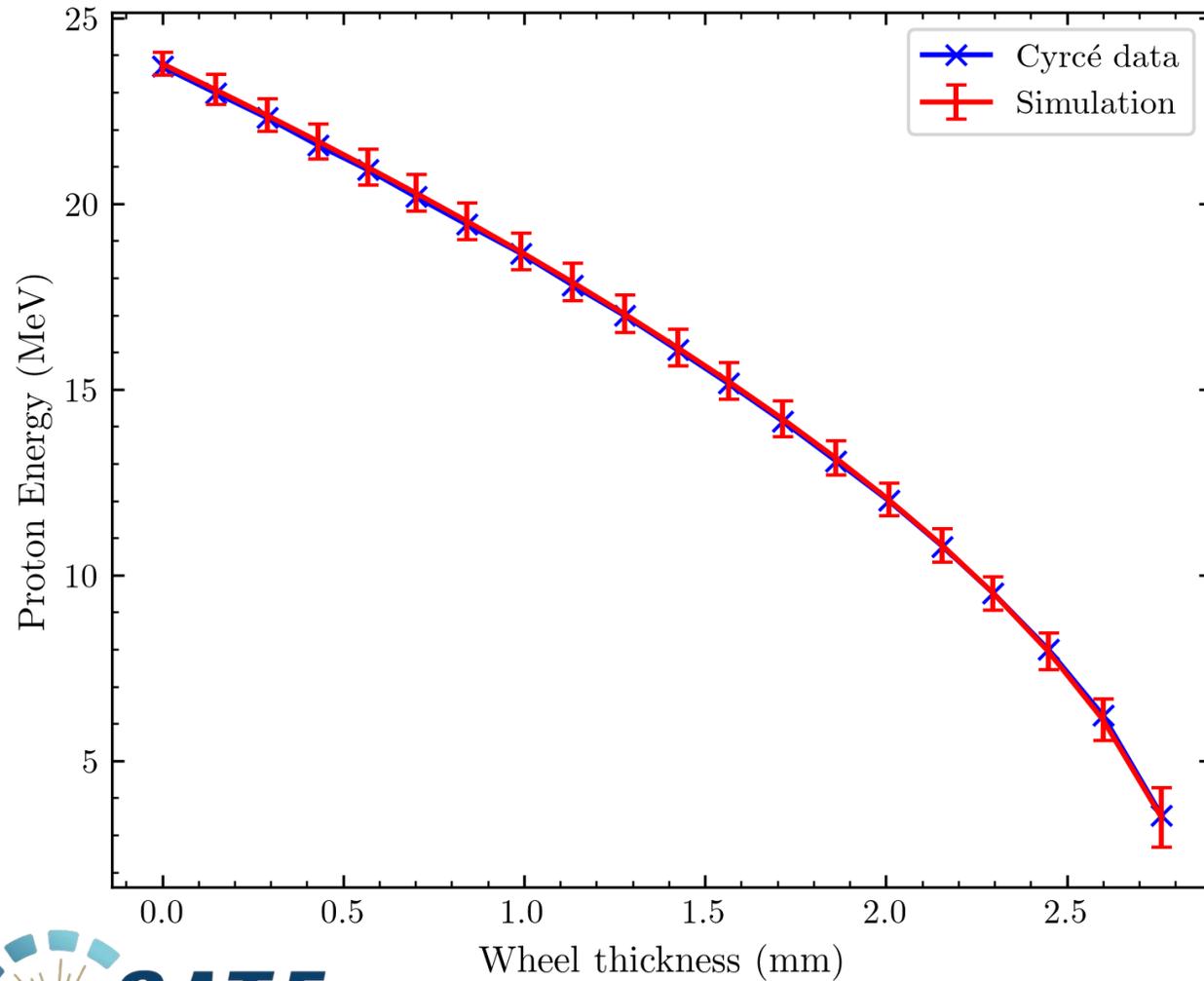


Different energy = different signal!

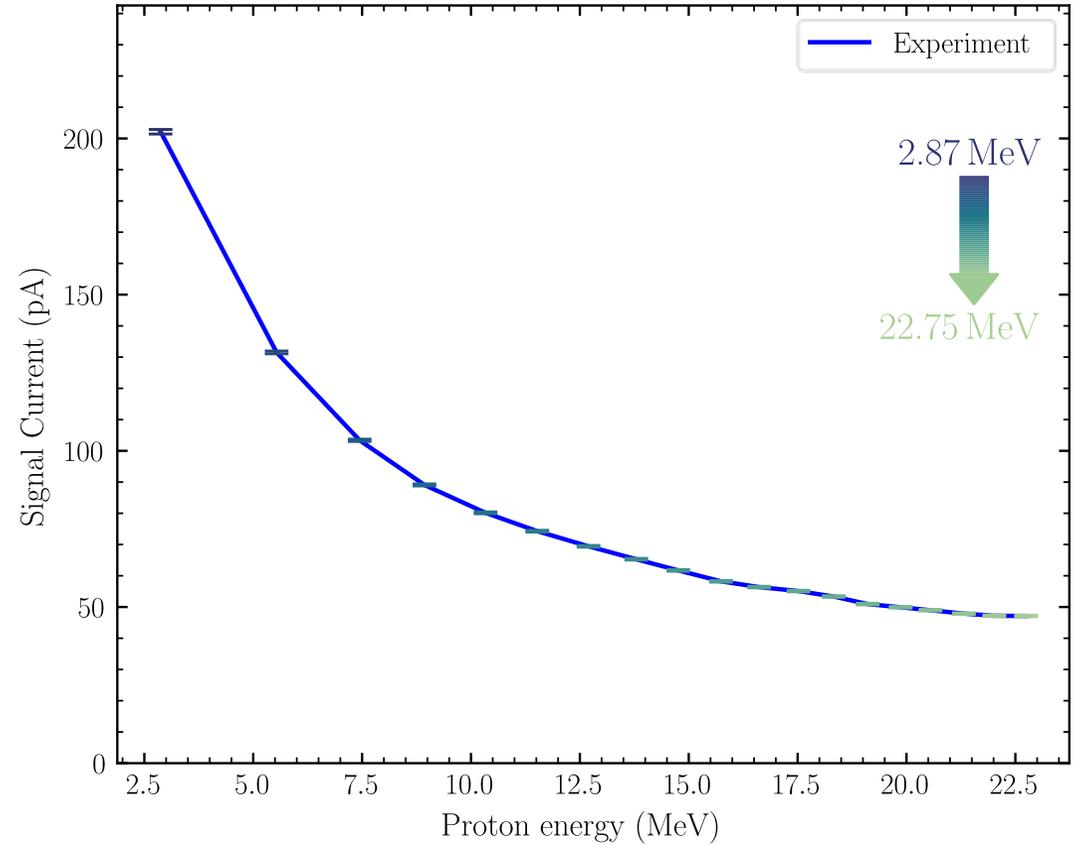
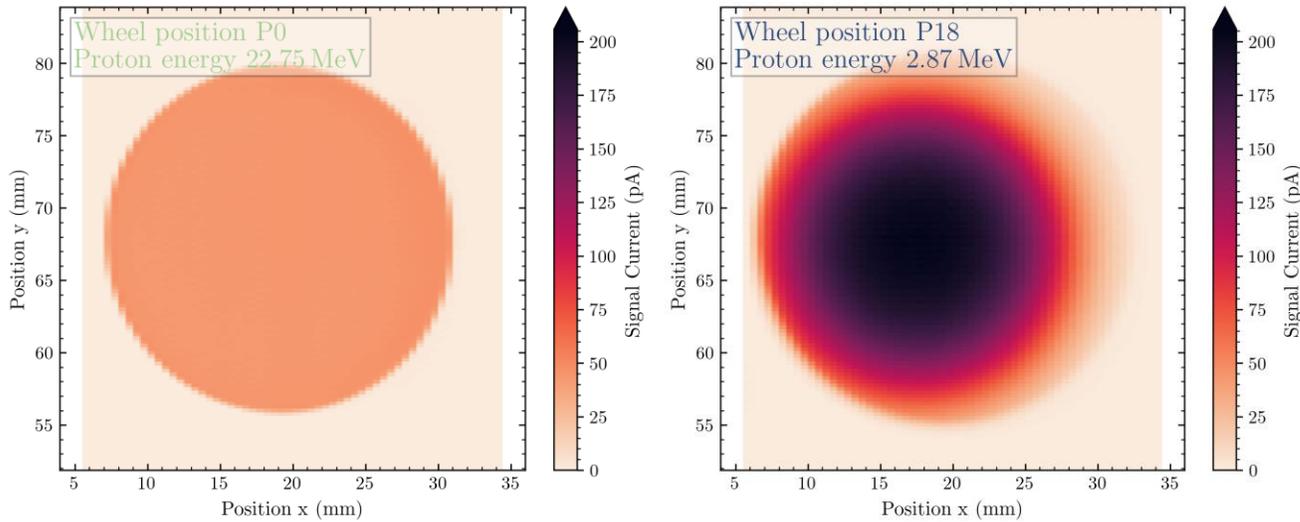
GATE10 Simulation



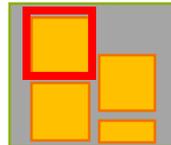
Energy Modulation at CYRCé



MATRIX response at different energies

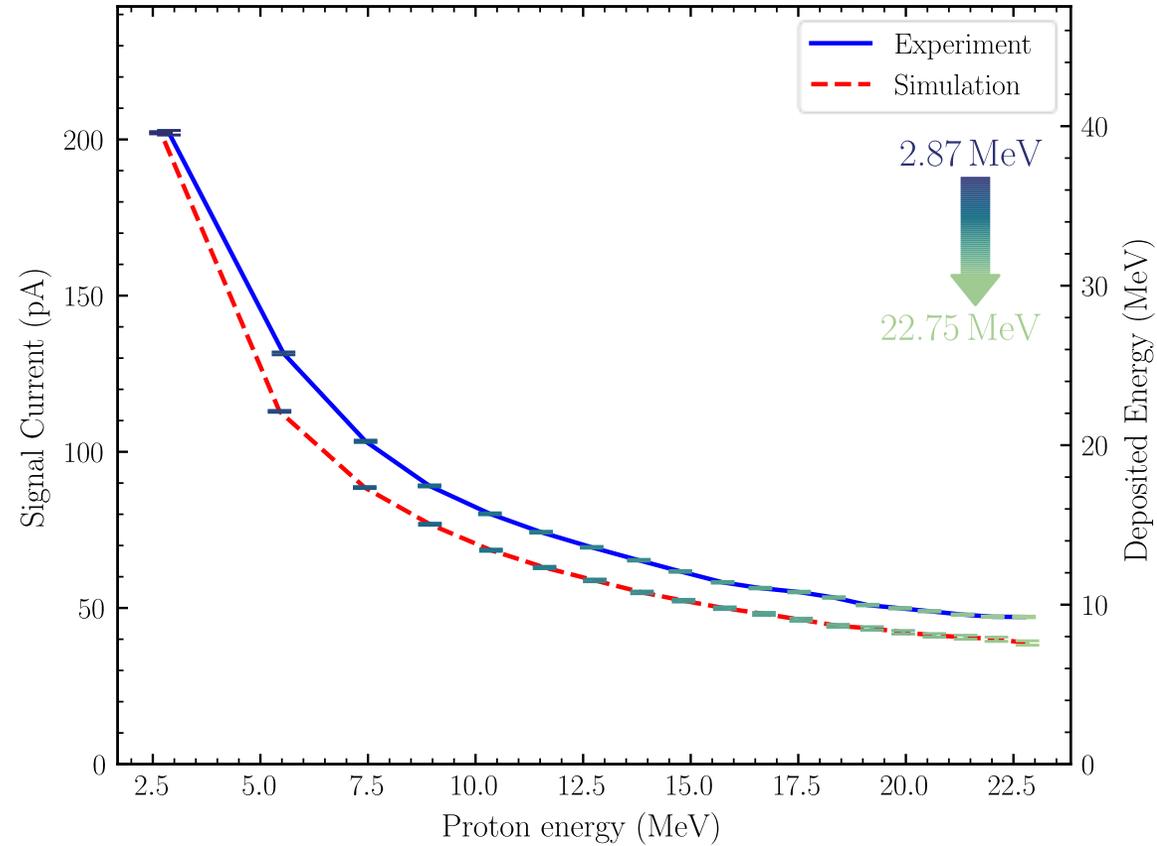
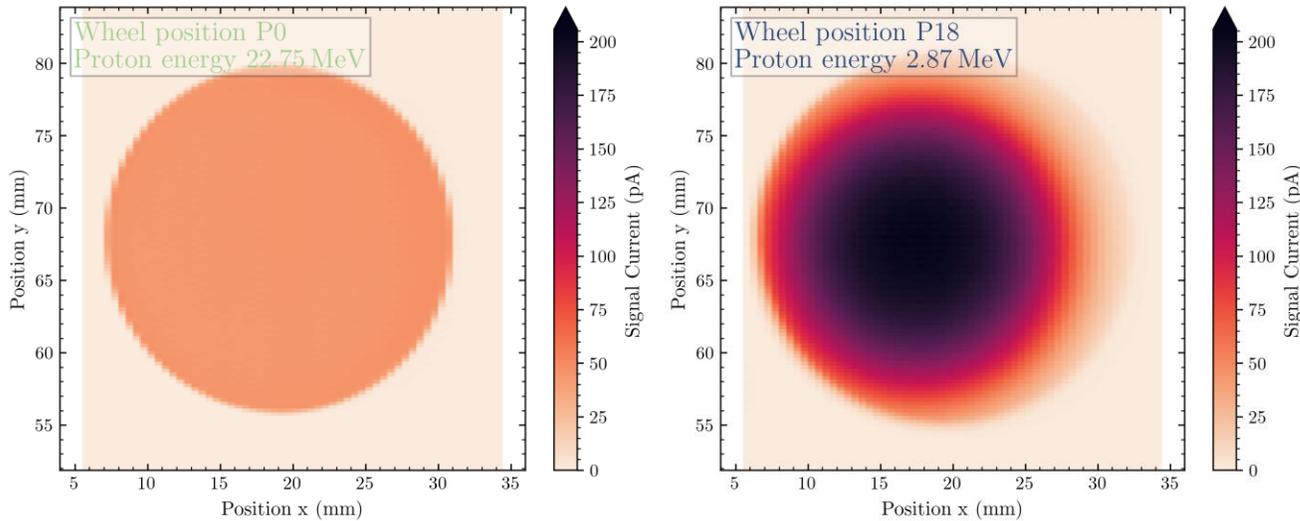


0.5 x 0.5 mm²

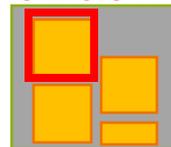


2 x 64 diodes

MATRIX response at different energies

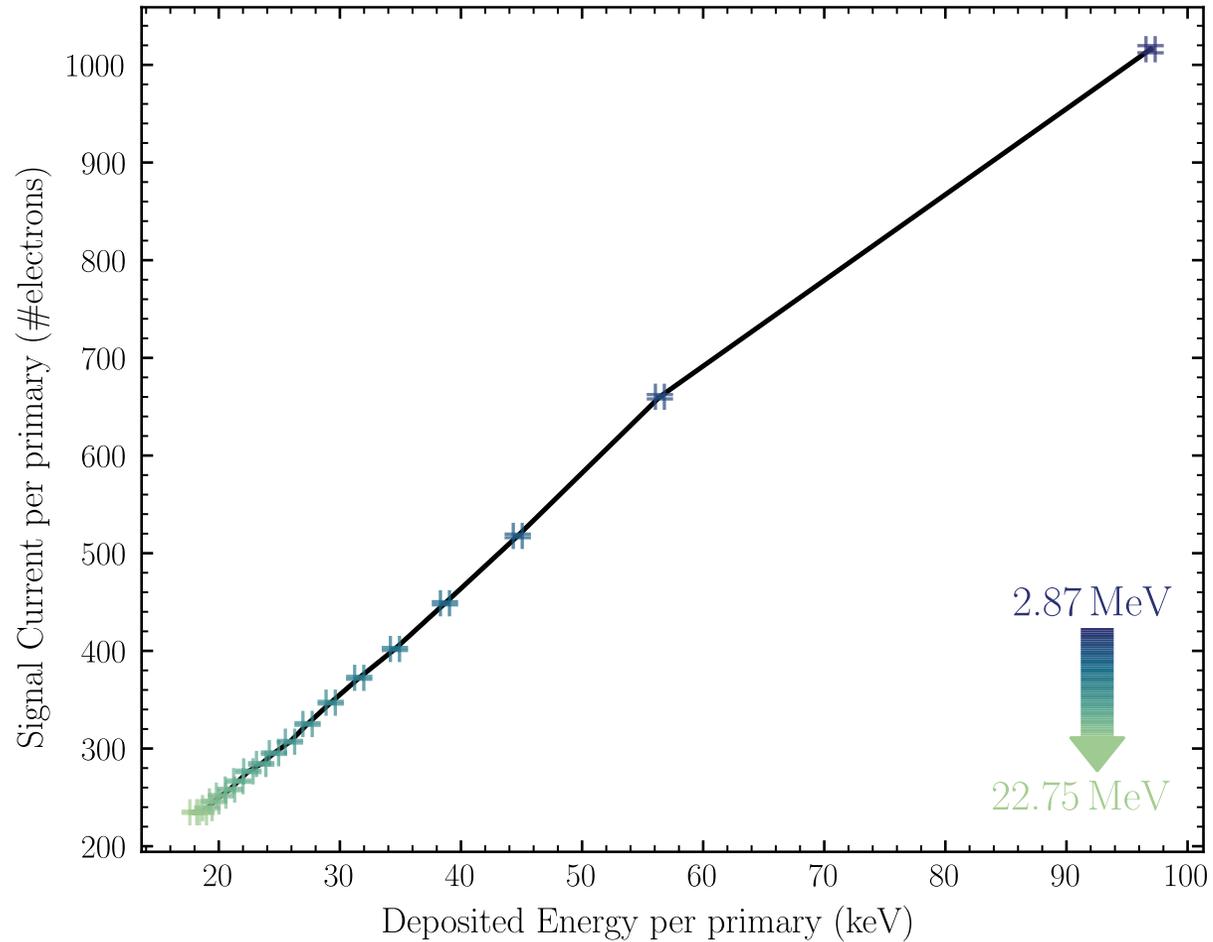


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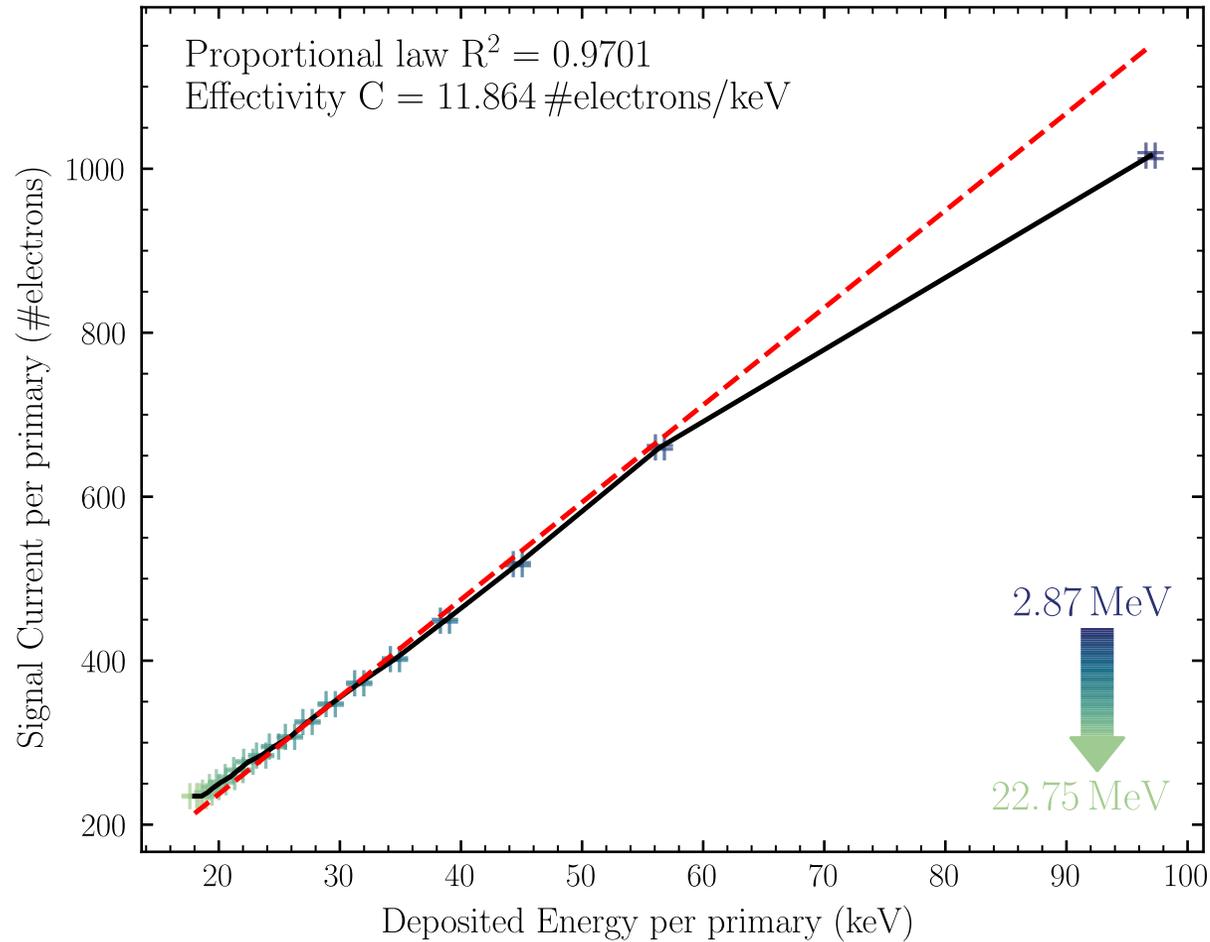


2 x 64 diodes

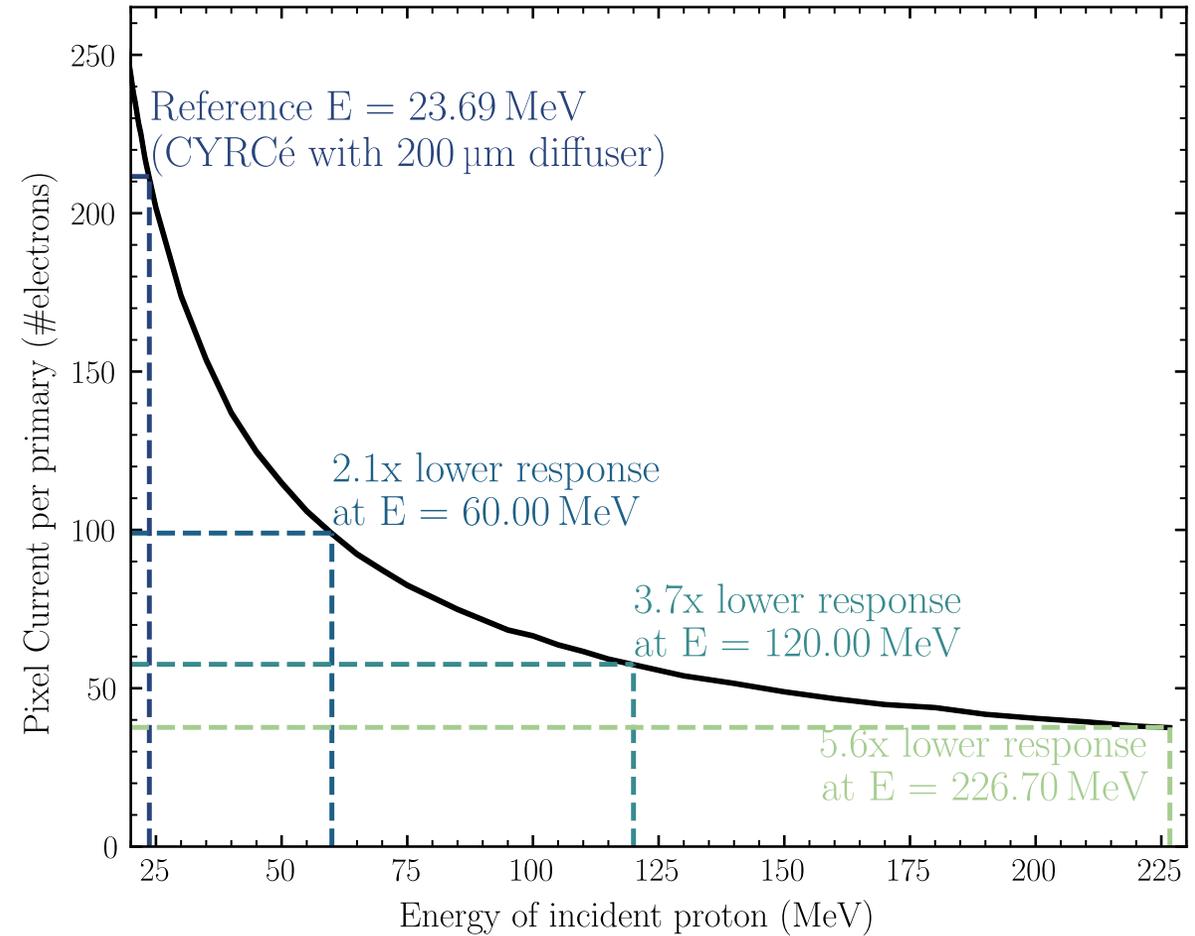
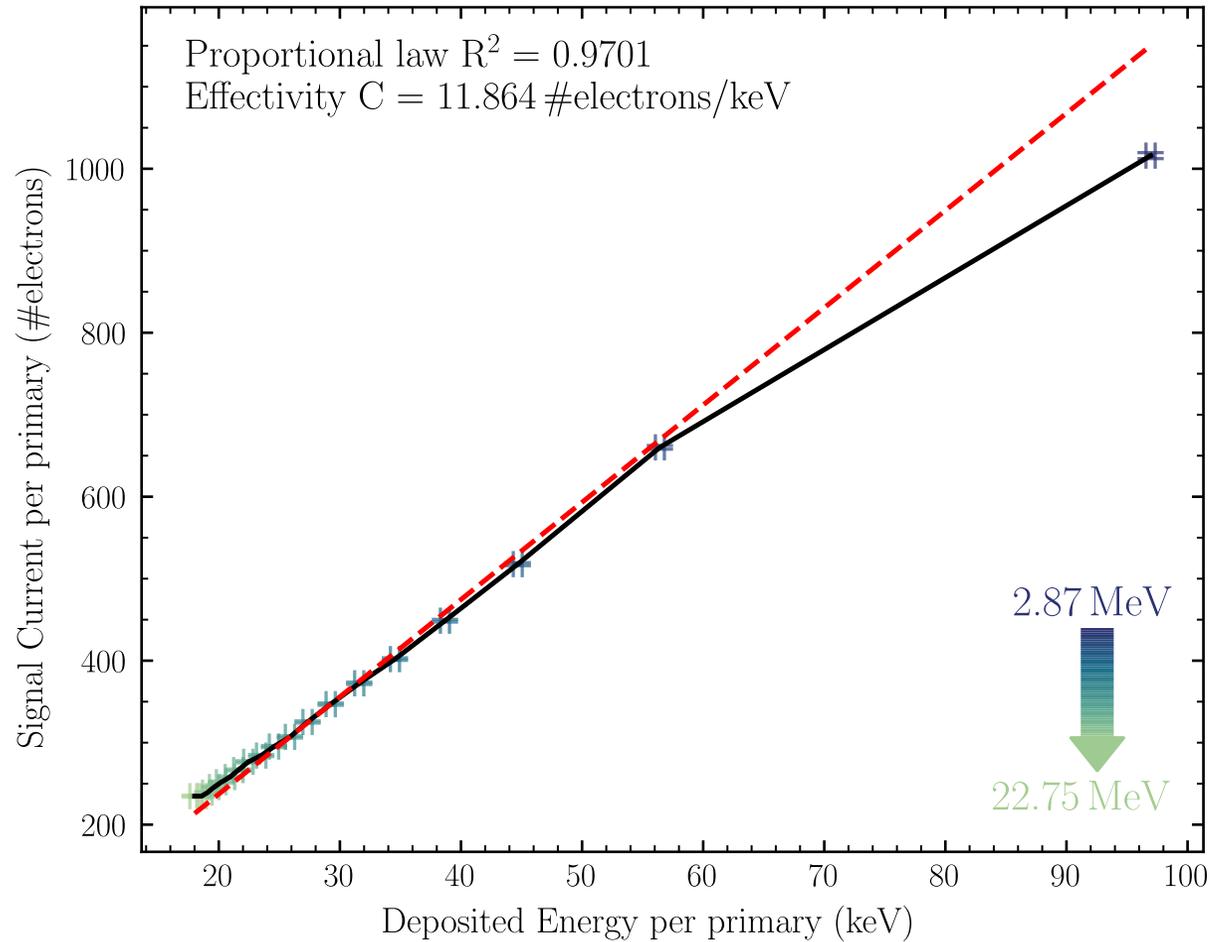
Response vs deposited energy



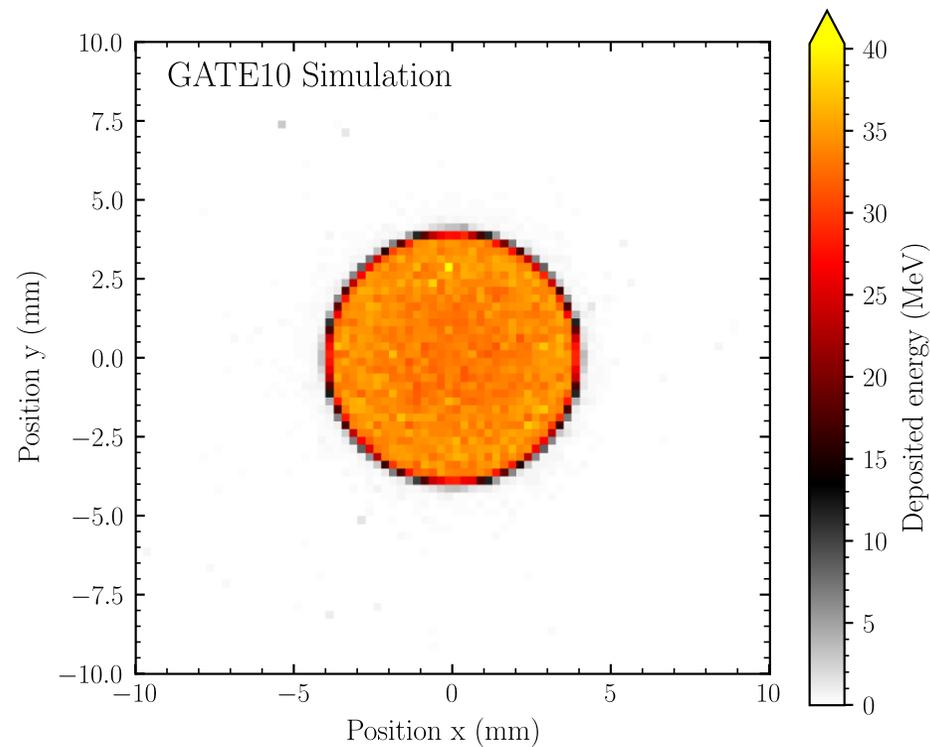
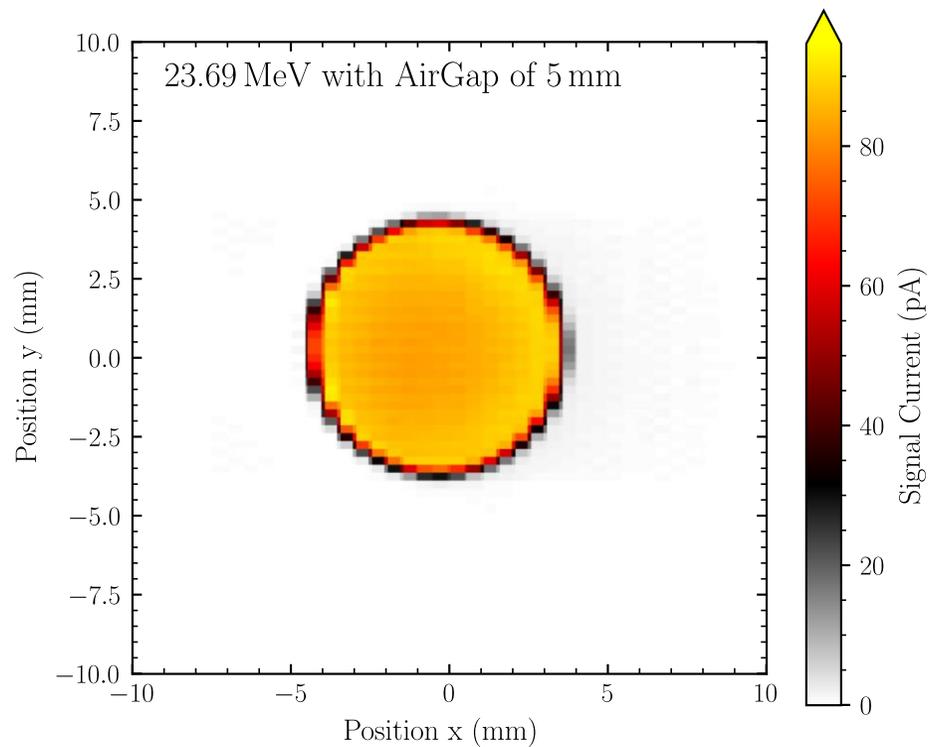
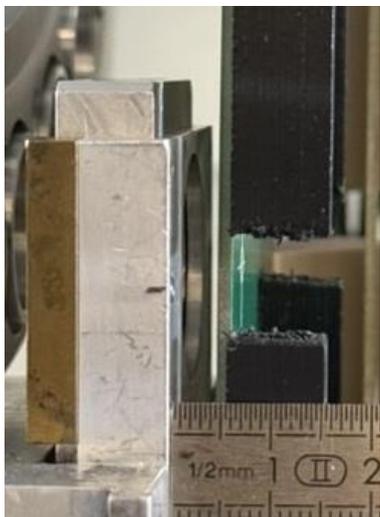
Response vs deposited energy



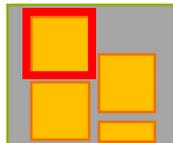
Extrapolation



Straggling?

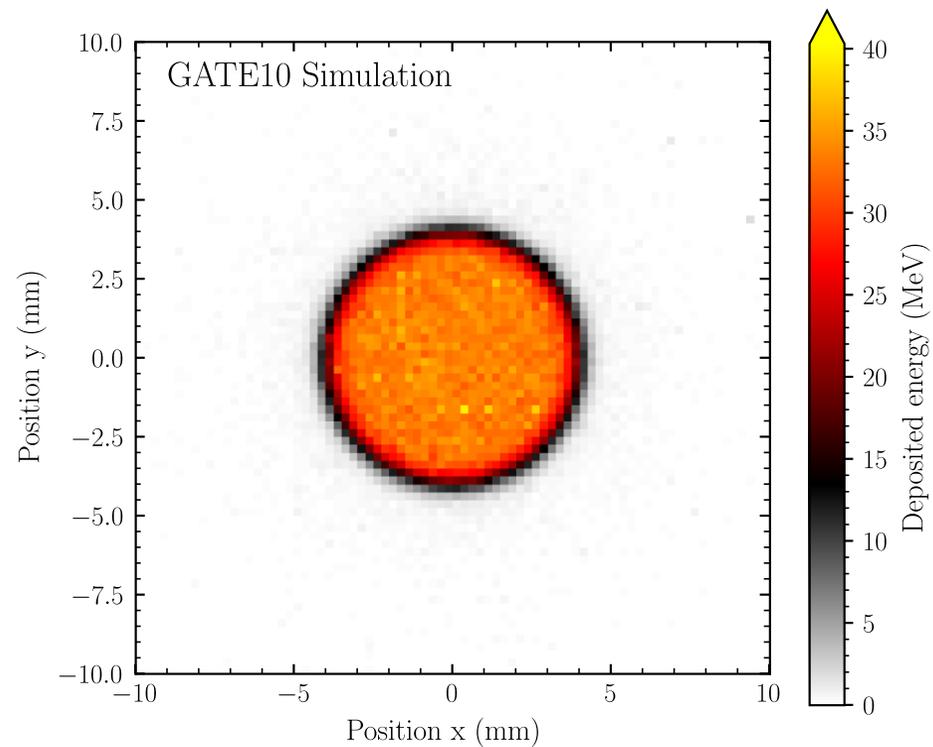
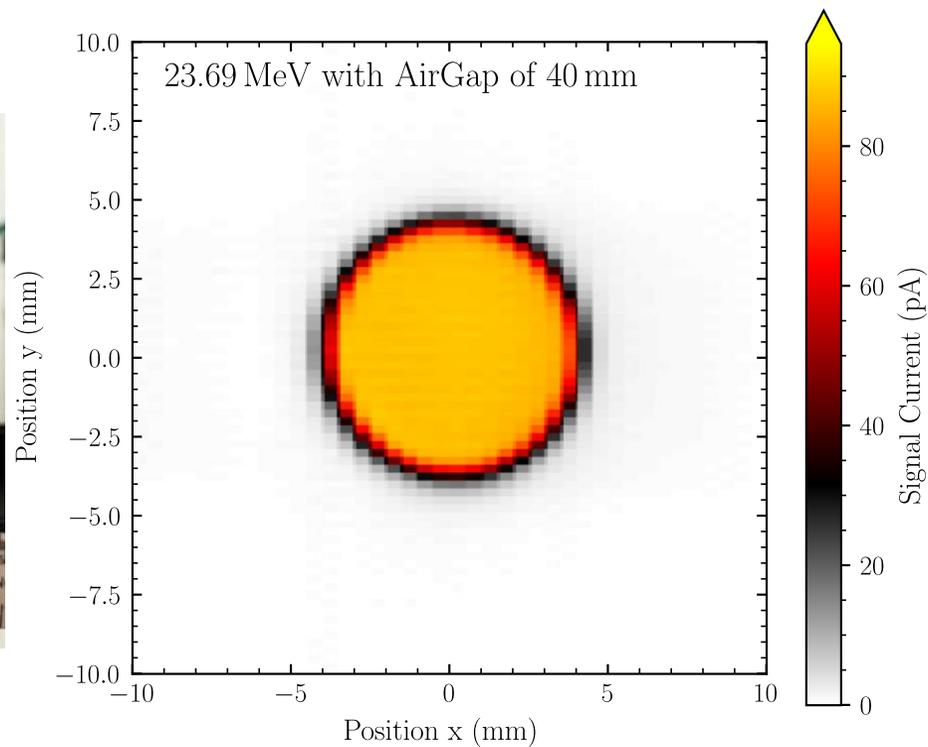
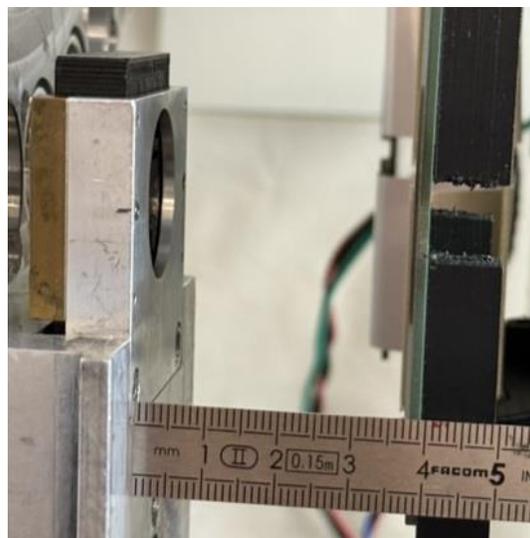


0.5 x 0.5 mm²

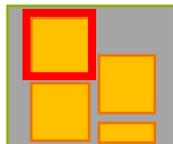


2 x 64 diodes

Straggling?

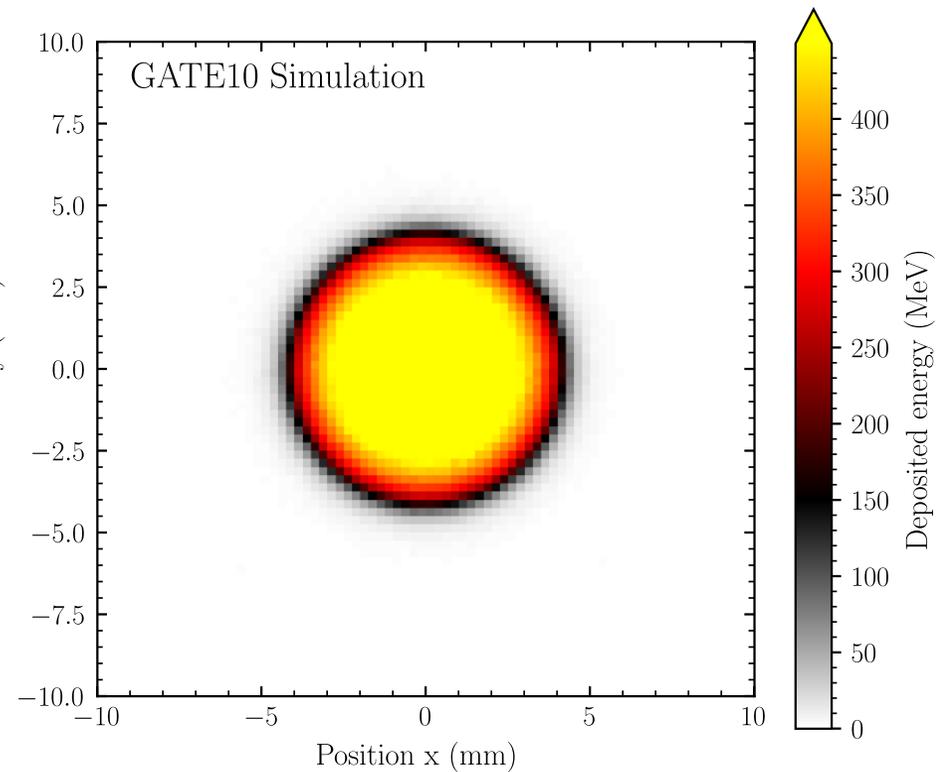
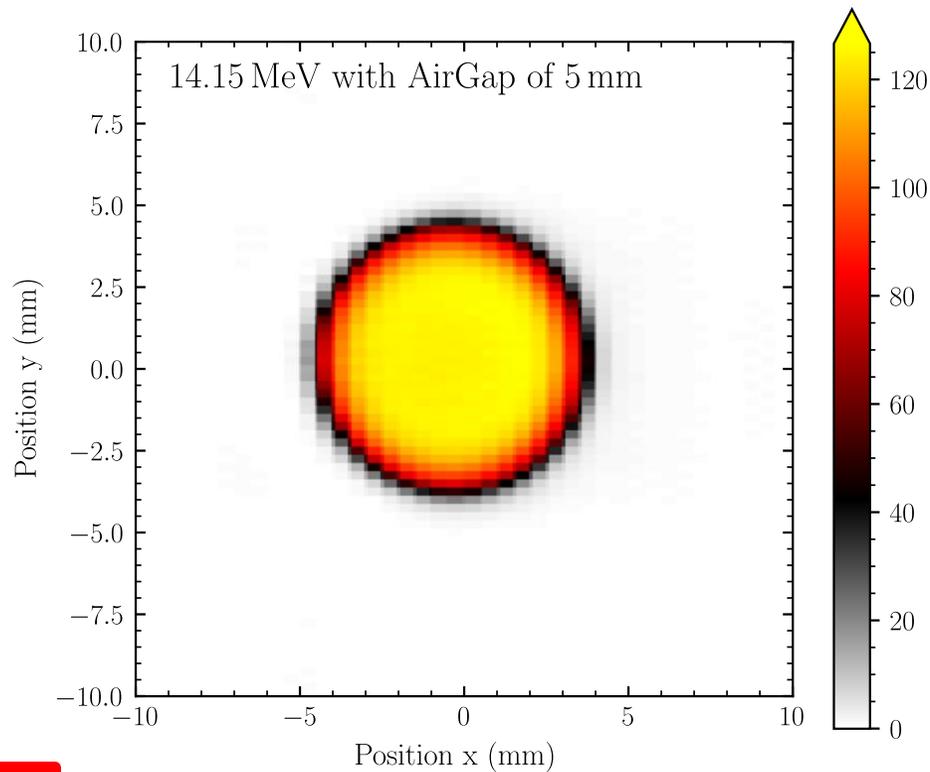
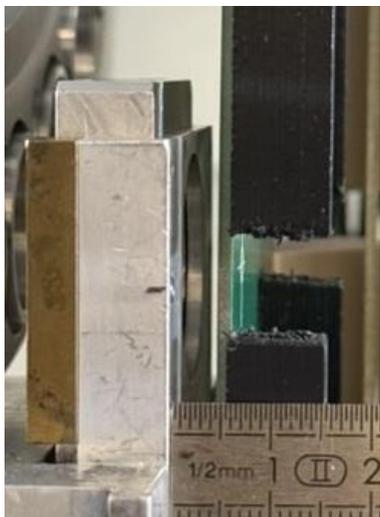


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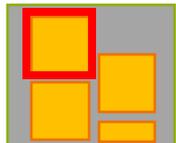


2 x 64 diodes

Straggling?



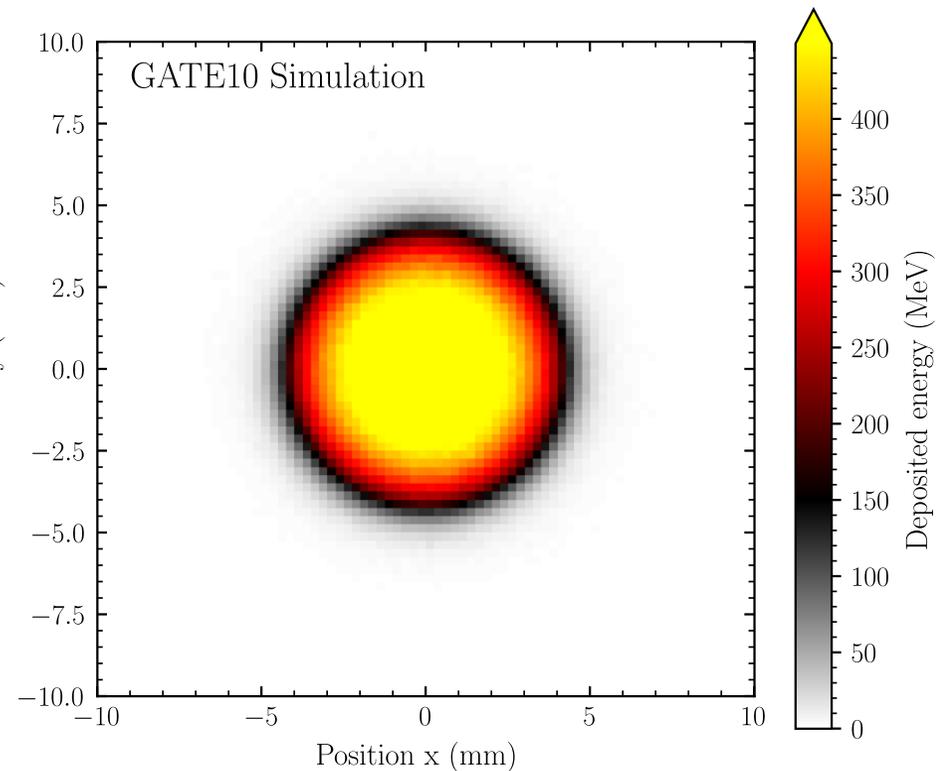
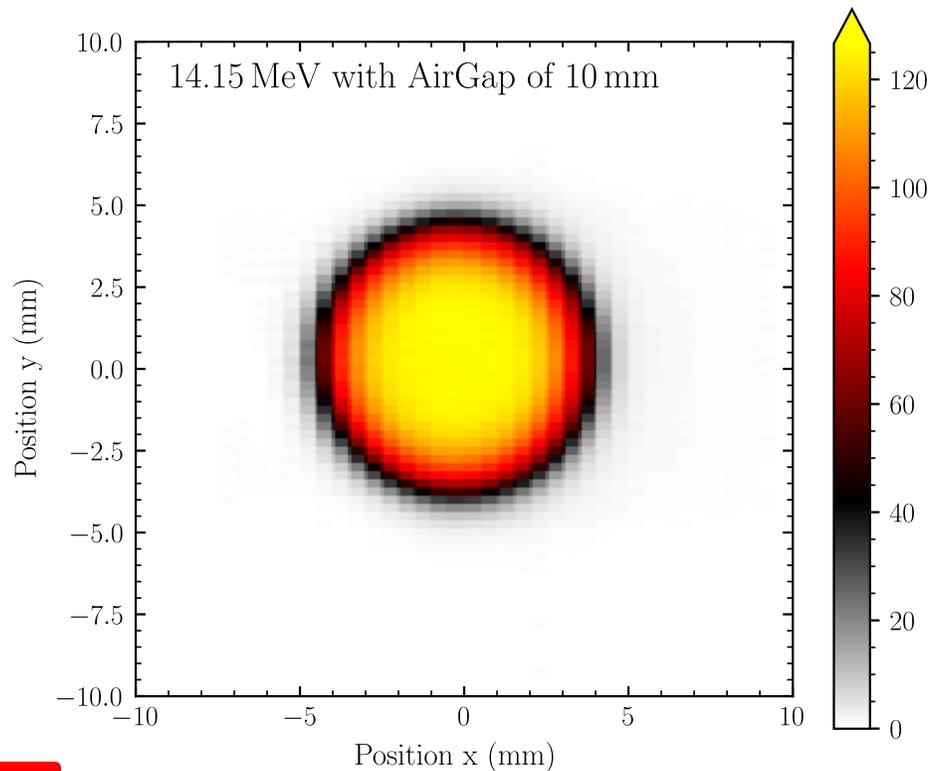
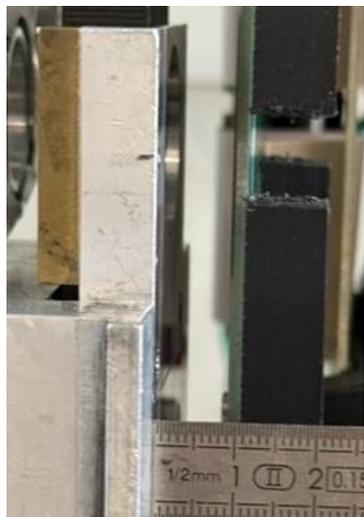
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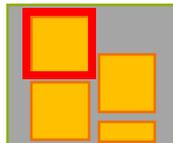
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Straggling?



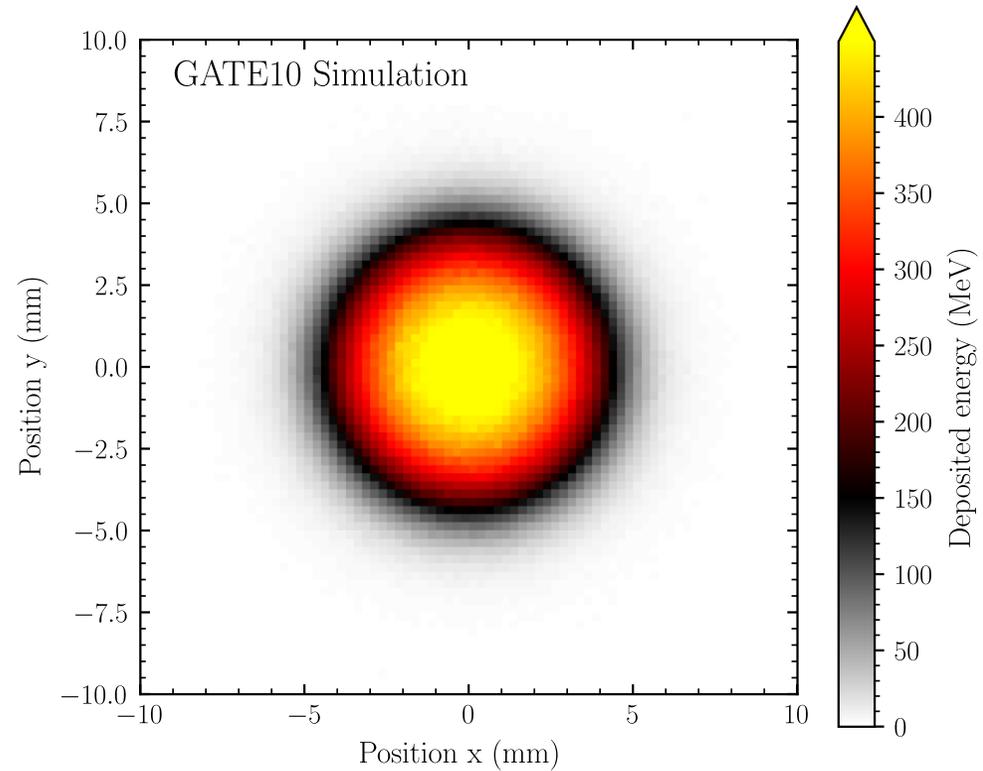
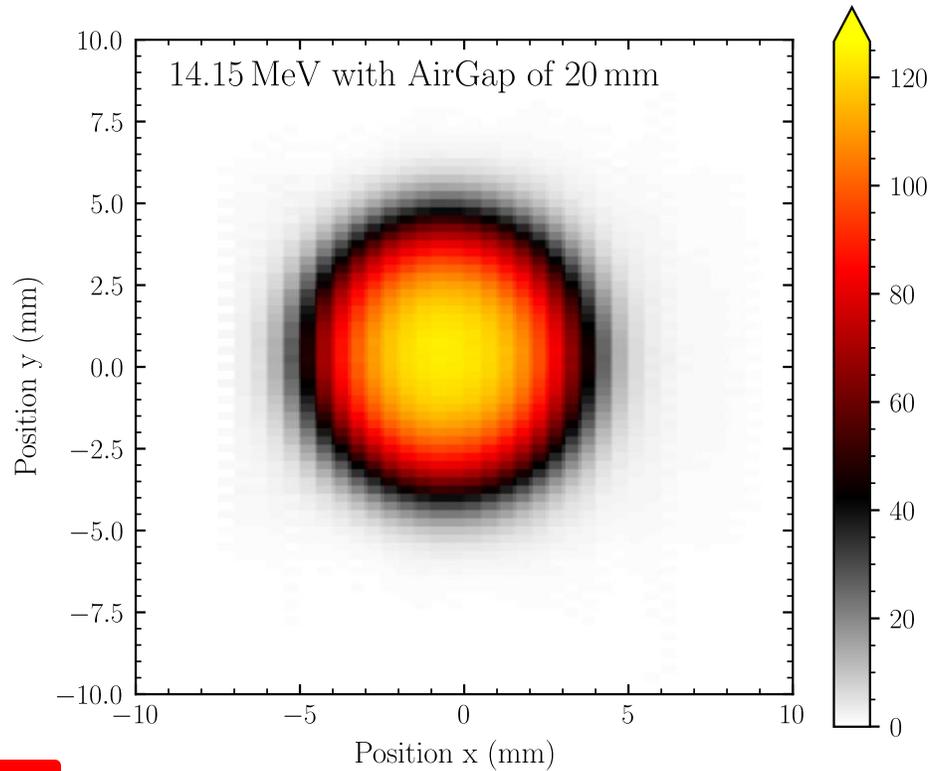
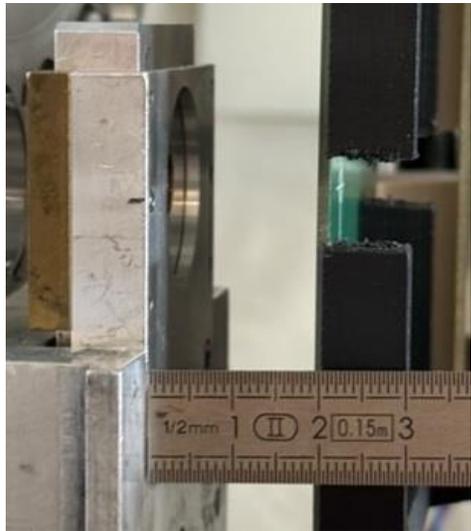
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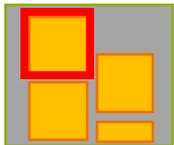
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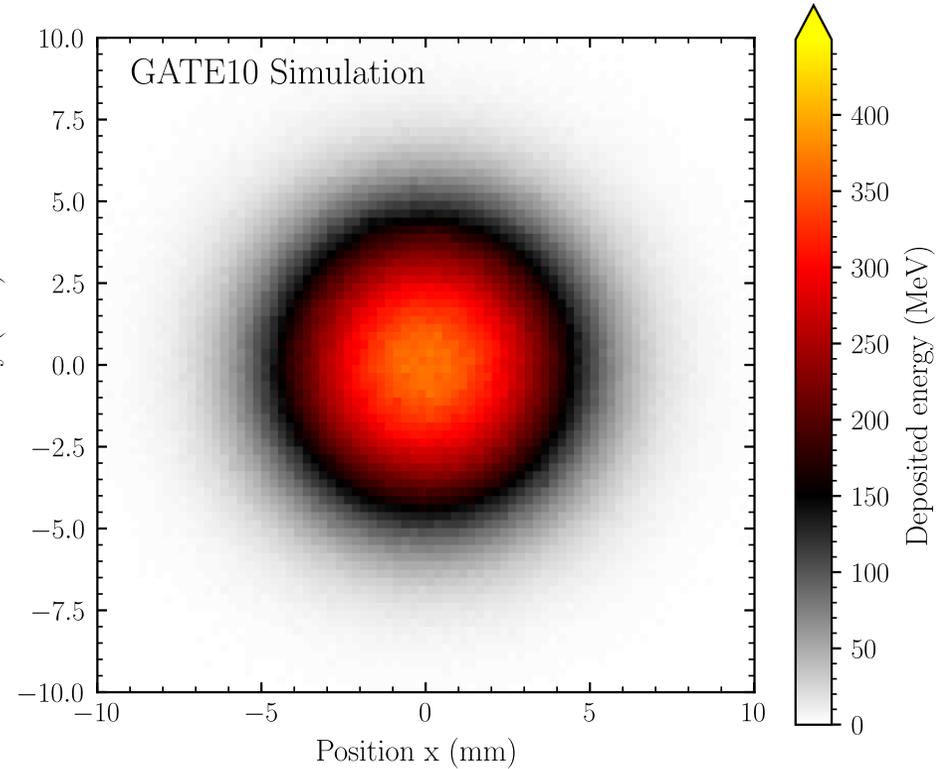
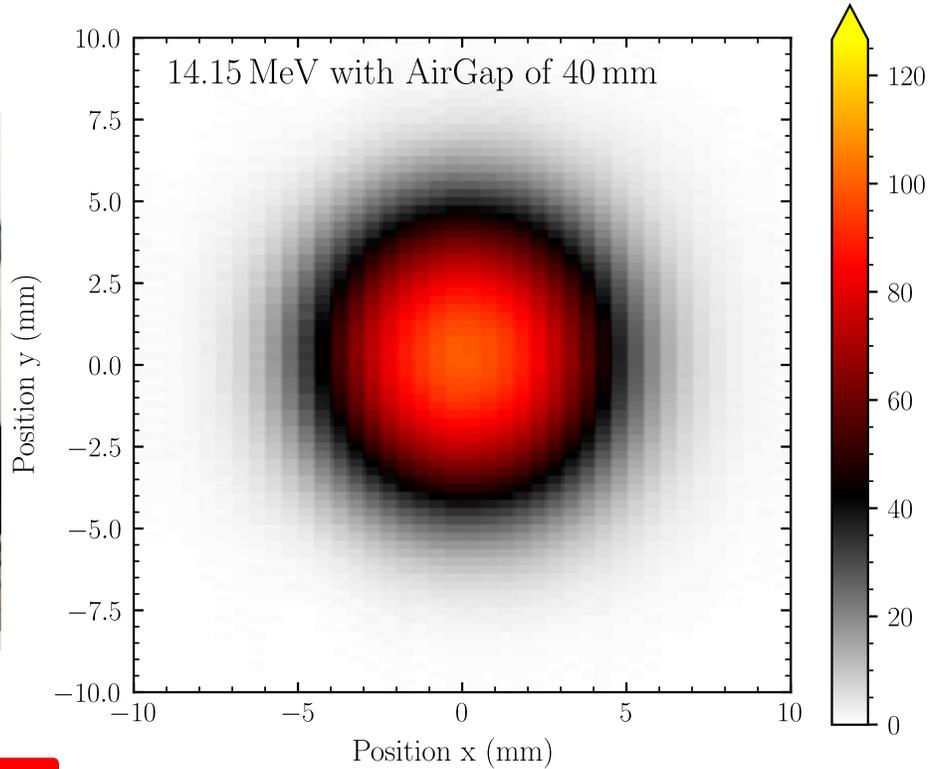
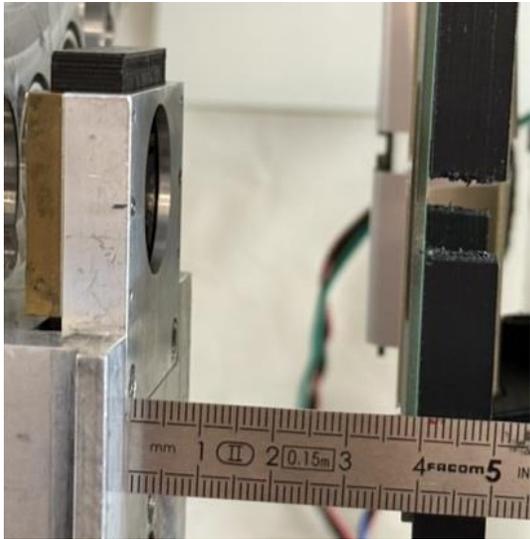
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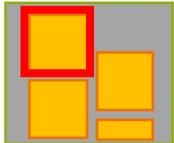
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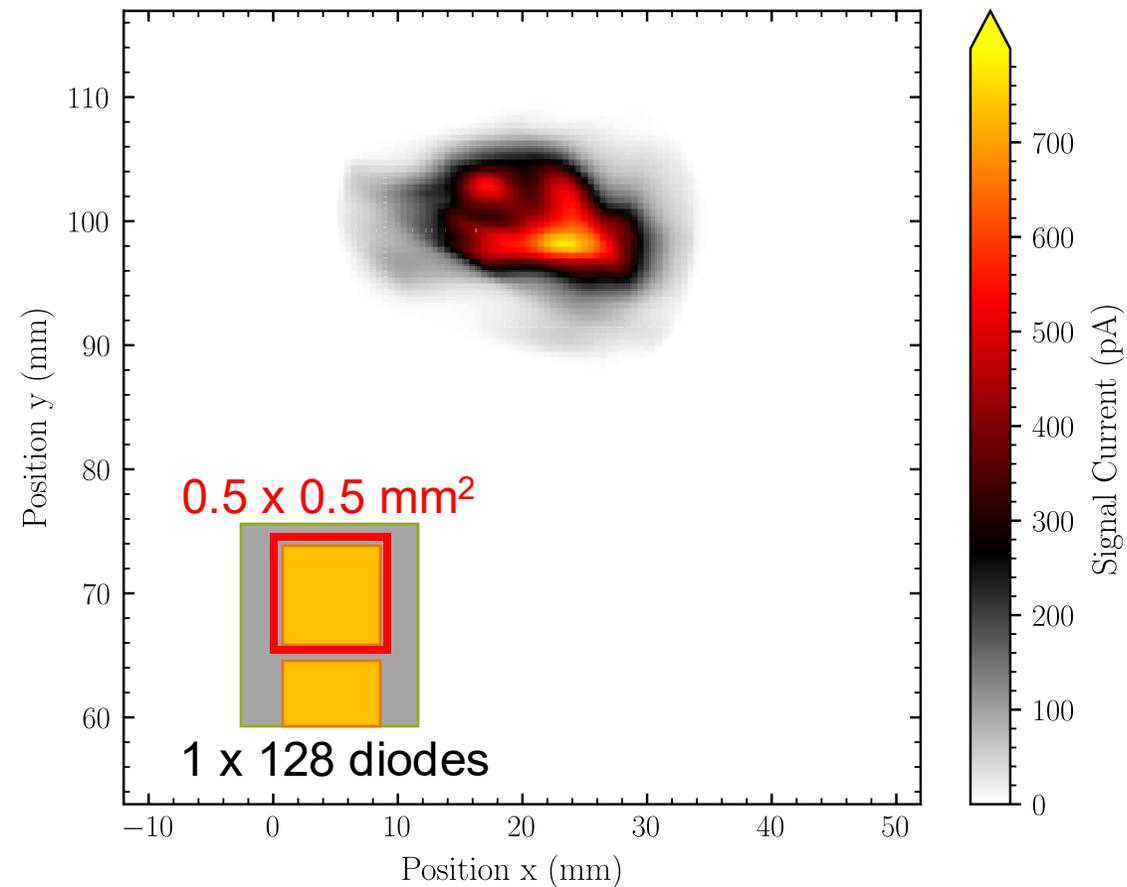
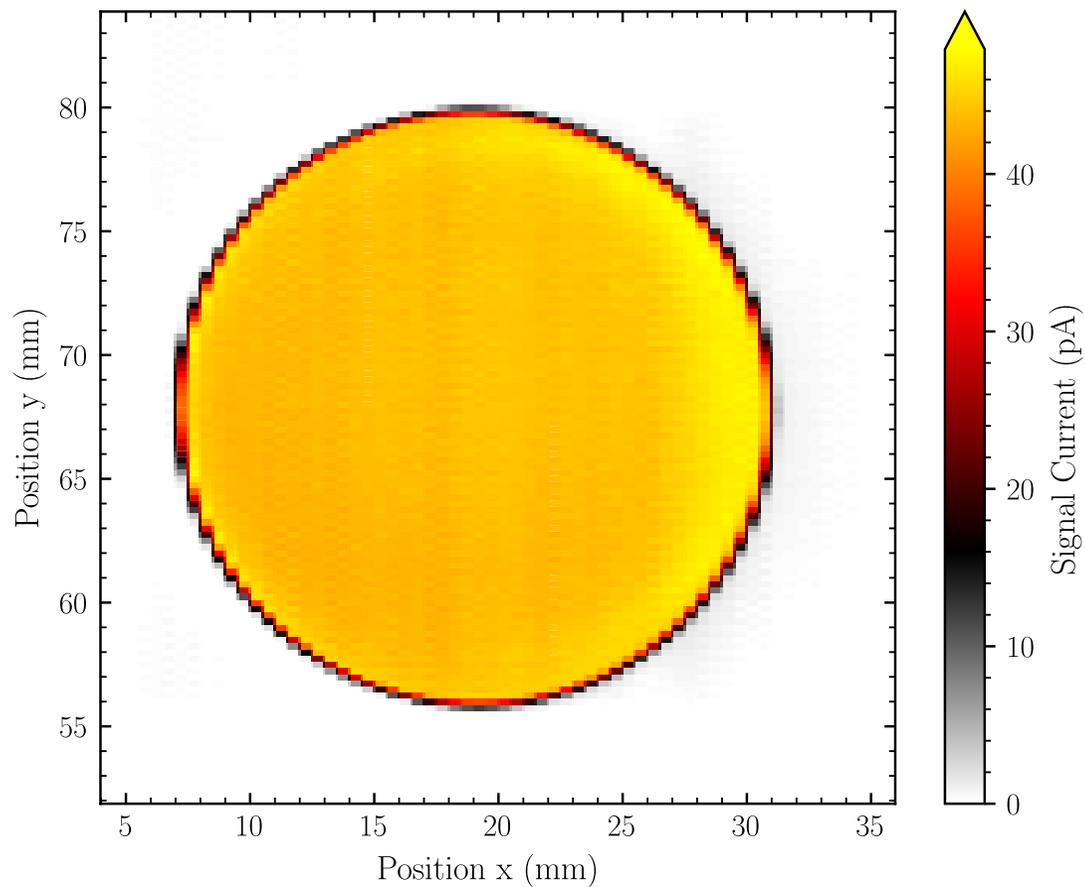
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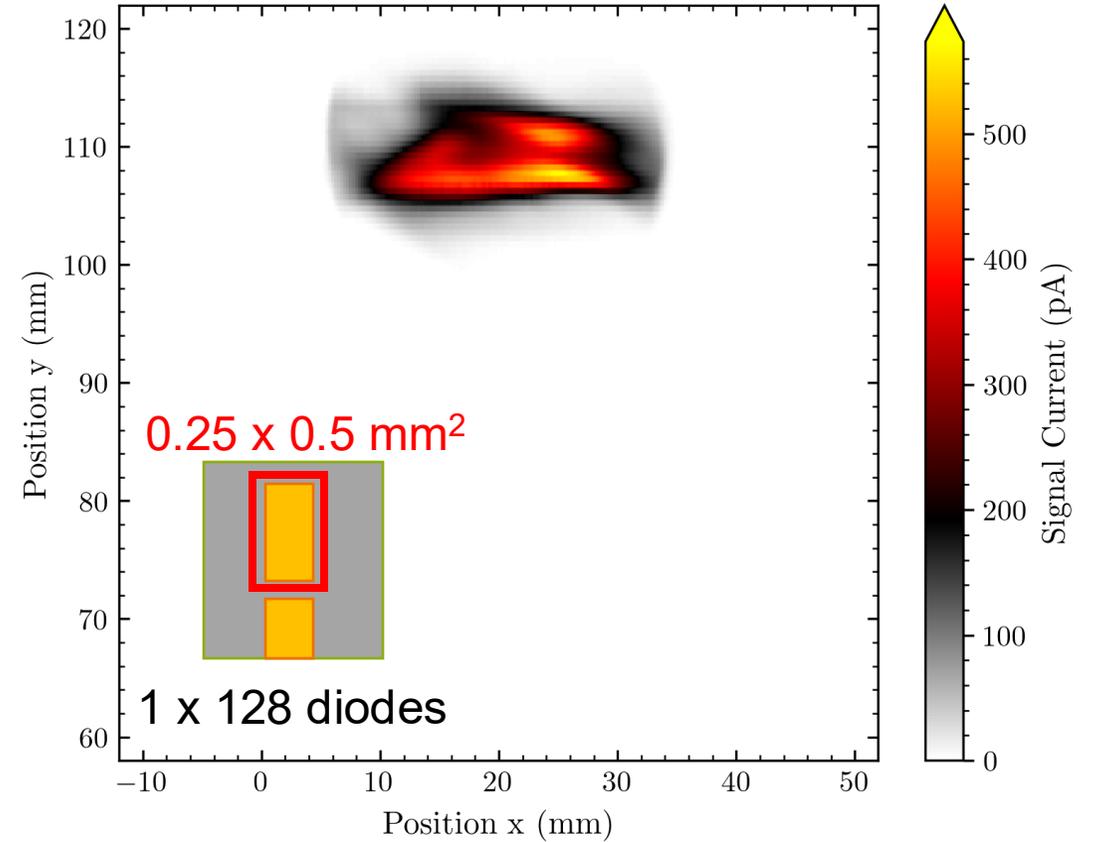
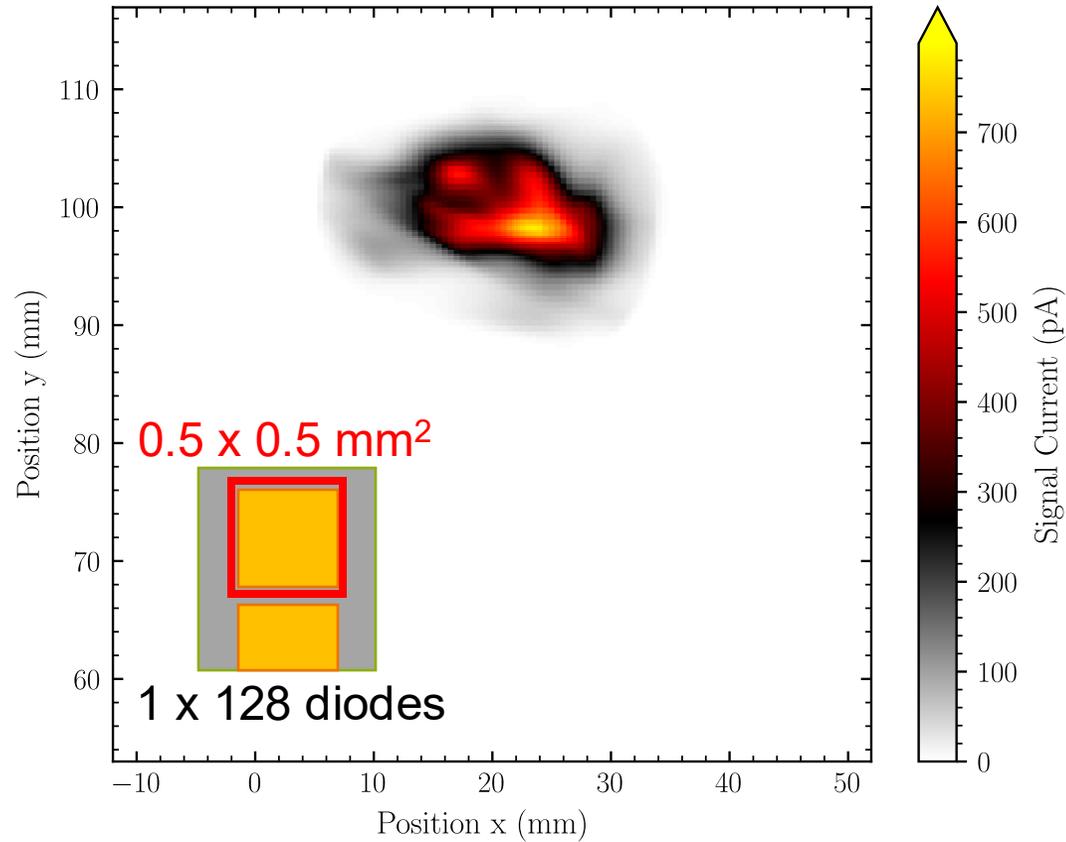
2 x 64 diodes



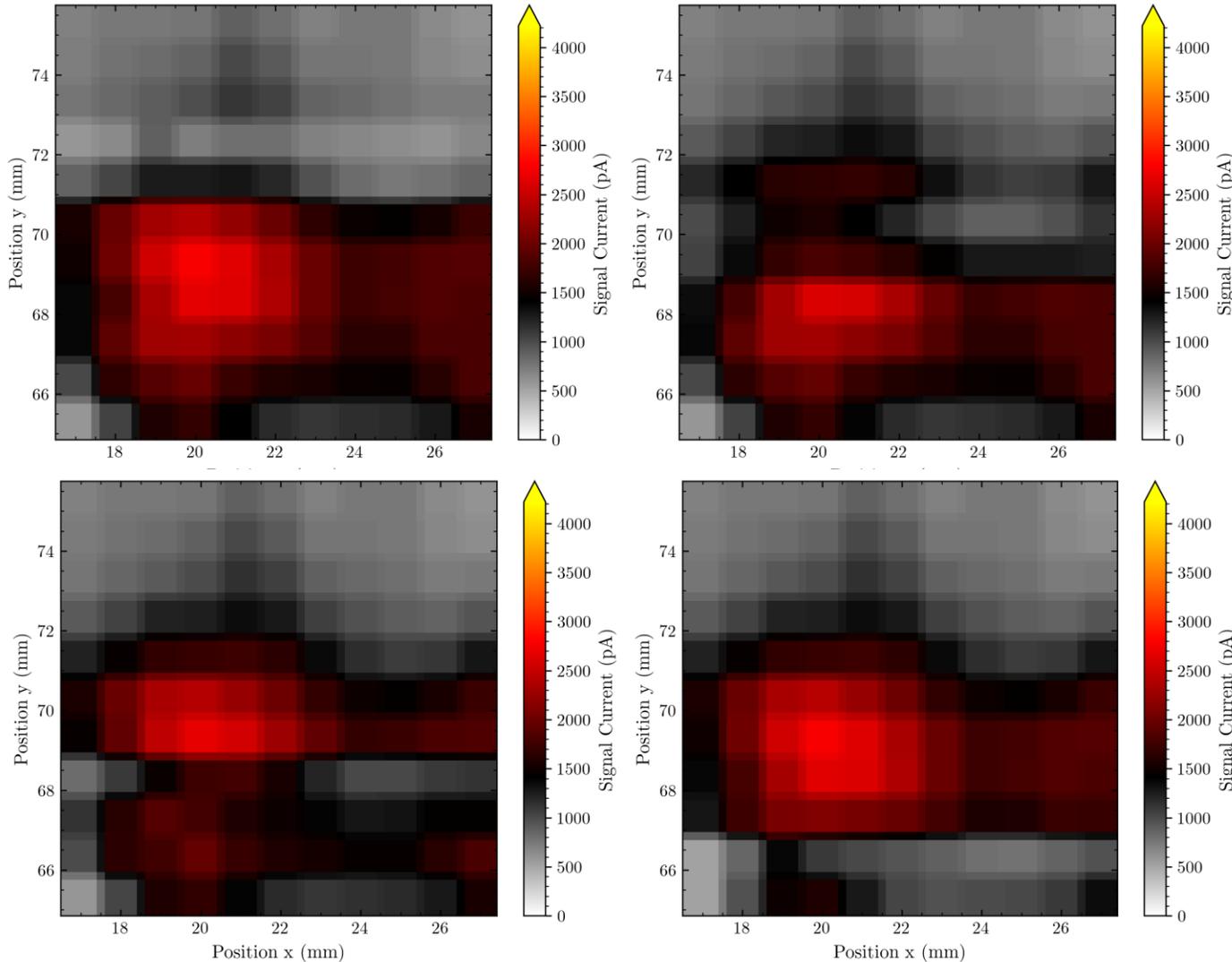
Undiffused Beam



Undiffused Beam



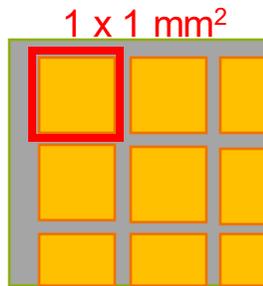
Can we make a movie of how the beam changes (due to, e.g., collimation)? 😊



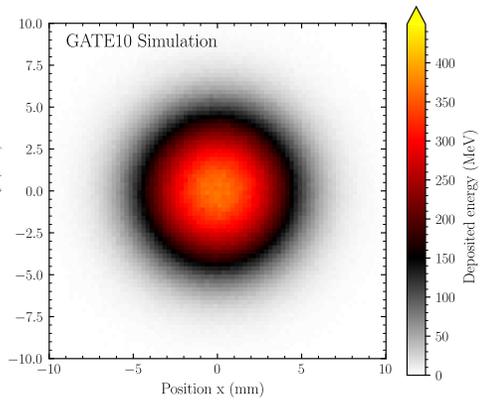
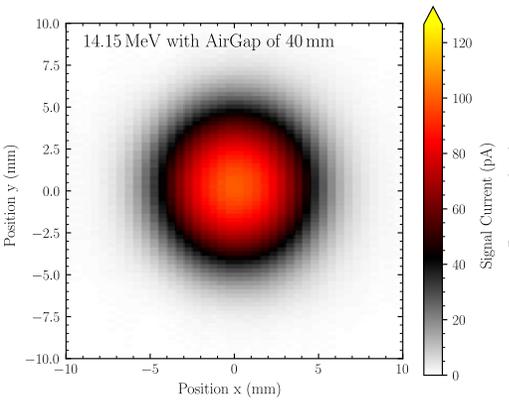
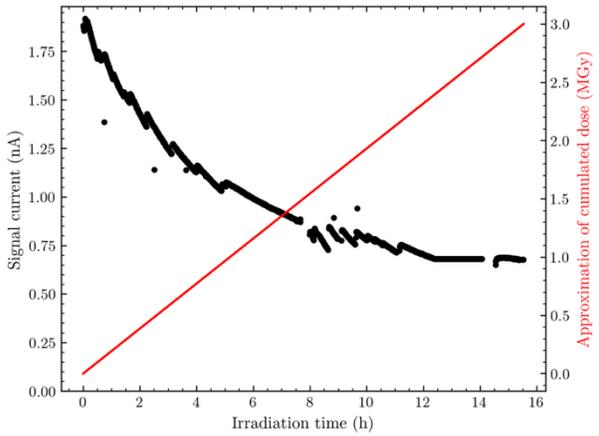
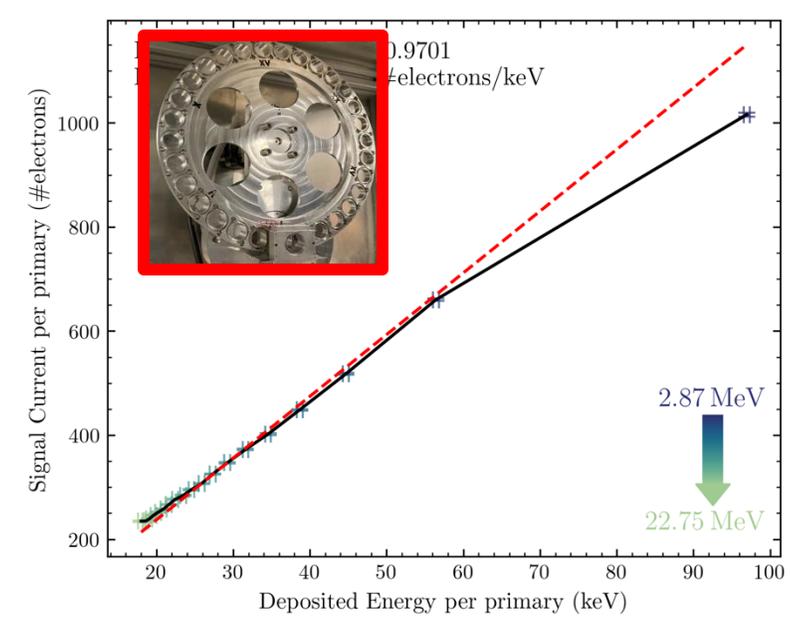
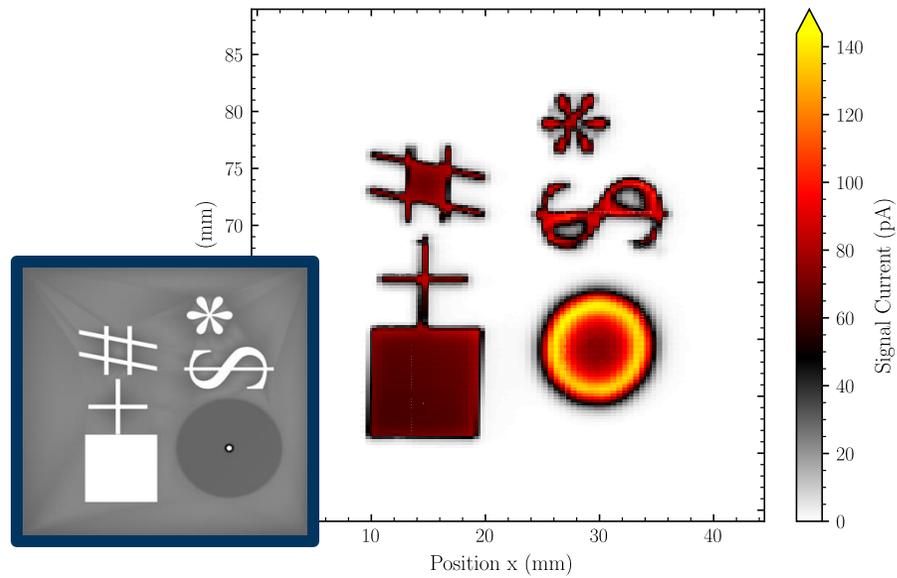
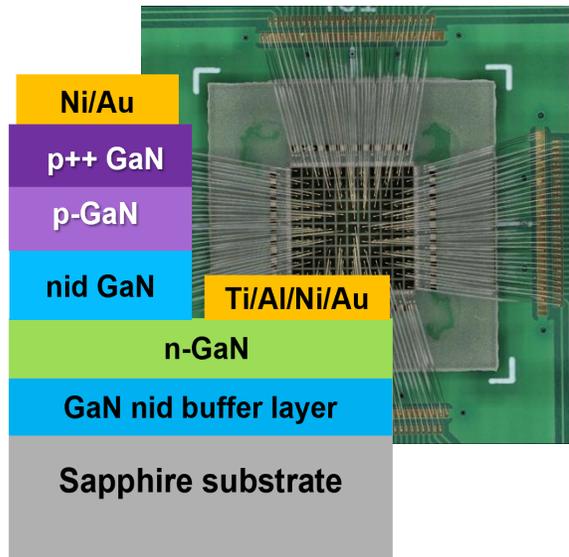
Three phases:

1. Beam stability (no changes)
2. Live changes of beam collimation
3. Wire profiling inside the beamline

(1 fps – currently limited by readout software)



11 x 11 diodes



- Next up:
- Measuring at different facilities
 - Larger multiplexed arrays
 - Assessing the time resolution

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