Muography with Micromegas

New analysis techniques

Baptiste Lefevre, CEA/Irfu

Image : Picture of G2, an UNGG reactor in CEA Marcoule that was reconstruted in 3D with muon tomography by the CEA/Irfu team.

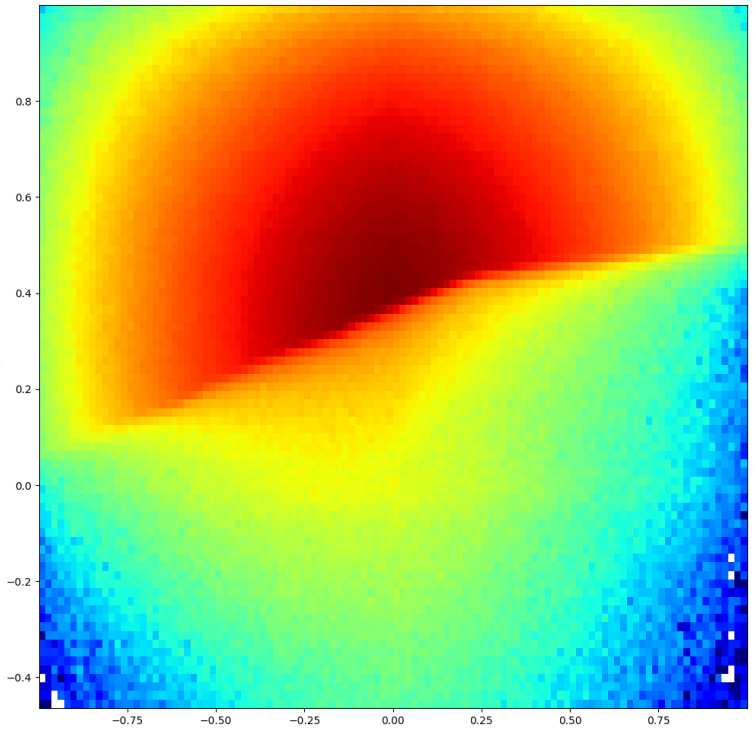
Summary

nature

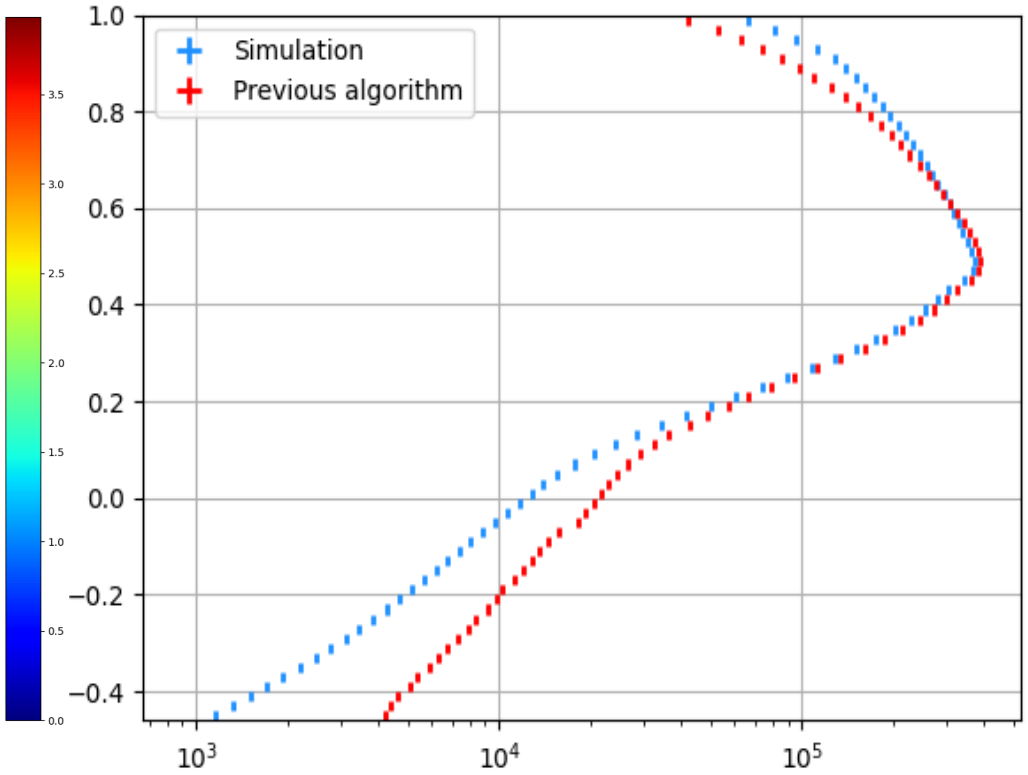
Discovery of a big void in Khufu's Pyramid by observation of cosmic-ray muons

Kunihiro Morishima[1], Mitsuaki Kuno[1], Akira Nishio[1], Nobuko Kitagawa[1], Yuta Manabe[1], Masaki Moto[1], Fumihiko Takasaki[2], Hirofumi Fujii[2], Kotaro Satoh[2], Hideyo Kodama[2], Kohei Hayashi[2], Shigeru Odaka[2], Sébastien Procureur[3], David Attié[3], Simon Bouteille[3], Denis Calvet[3], Christopher Filosa[3], Patrick Magnier[3], Irakli Mandjavidze[3], Marc Riallot[3], Benoit Marini[4], Pierre Gable[5], Yoshikatsu Date[6], Makiko Sugiura[7], Yasser Elshayeb[8], Tamer Elnady[9], Mustapha Ezzy[8], Emmanuel Guerriero[5], Vincent Steiger[4], Nicolas Serikoff[4], Jean-Baptiste Mouret[10,11,12], Bernard Charlès[13], Hany Helal[4,8] & Mehdi Tayoubi[4,13]

Picture facing Khufu's pyramid taken during the ScanPyramids campaign.



Log10 Muography of Khufu's pyramid.



Integrated number of muons for each line of the muography.

Summary

SCIENCE ADVANCES | RESEARCH ARTICLE

PHYSICAL SCIENCES

3D imaging of a nuclear reactor using muography measurements

Sébastien Procureur[1]*, David Attié[1], Laurent Gallego[2], Hector Gomez[1], Philippe Gonzales[3], Baptiste Lefèvre[1], Marion Lehuraux[1], Bertrand Lesage[4], Irakli Mandjavidze[1], Philippe Mas[1], Daniel Pomarède[1]

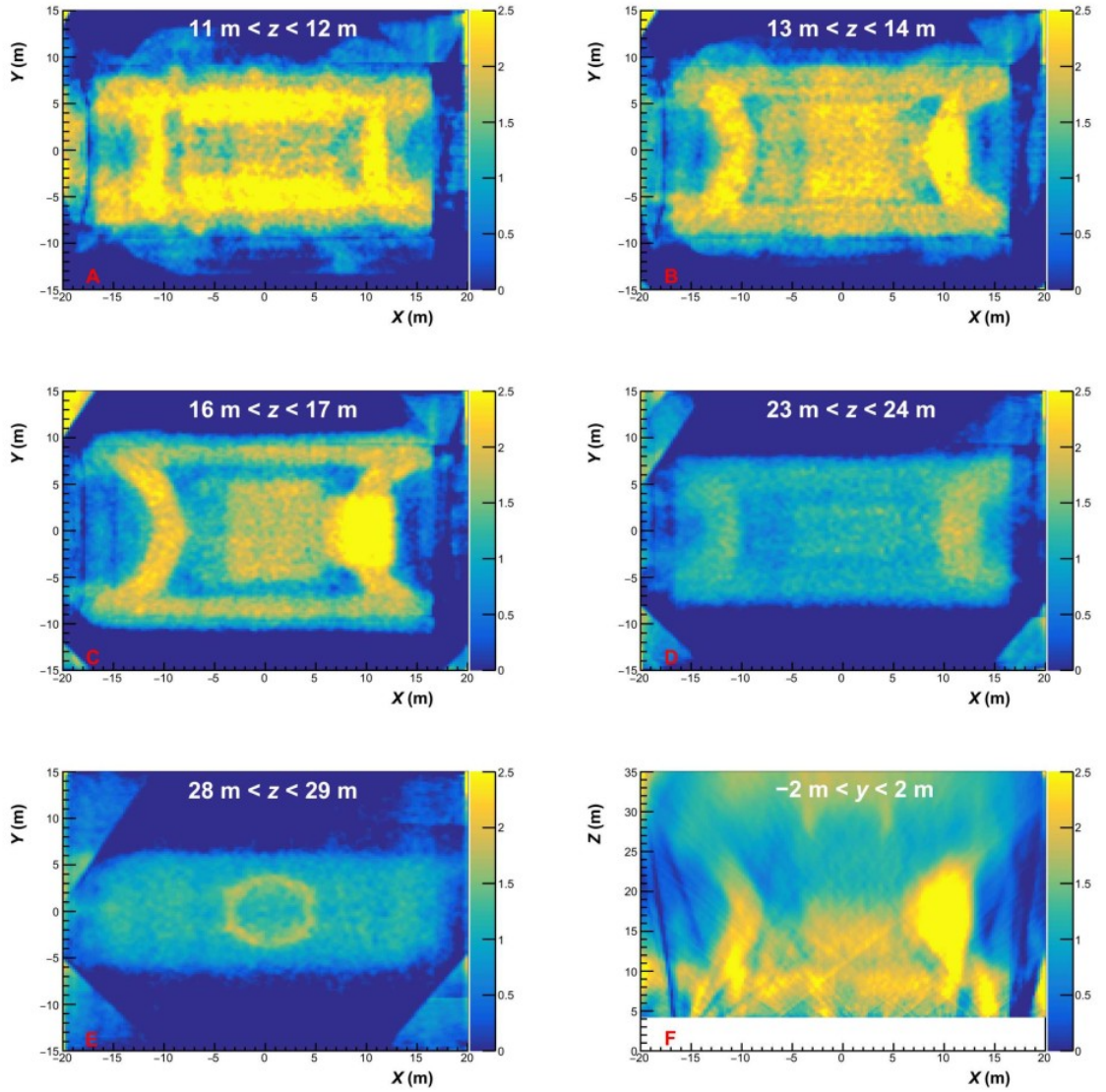
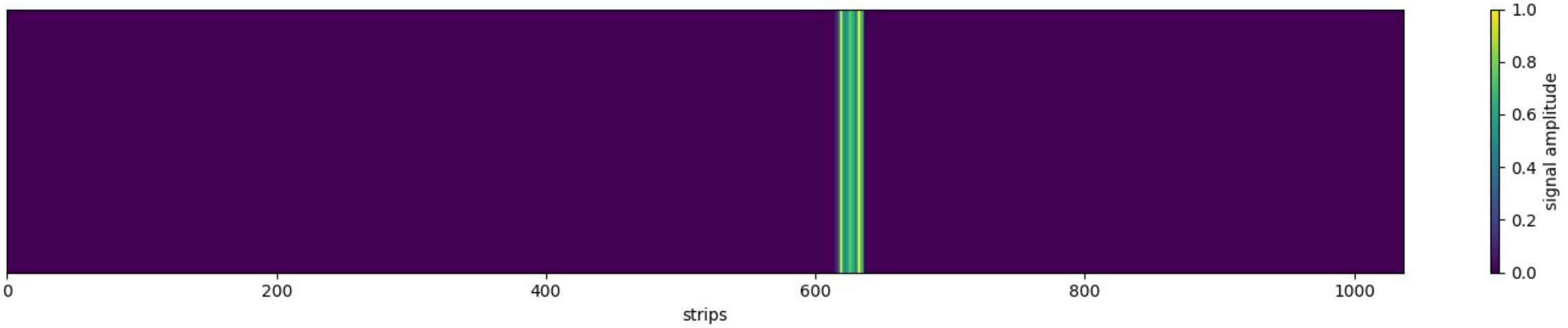


Fig. 4. Some tomographic slices obtained from the 3D reconstruction of the reactor, revealing several details of the structure. (**A** to **E**) *x-y* slices at different heights. (**F**) *x-z* slices close to the *y* axis. See text for more details.

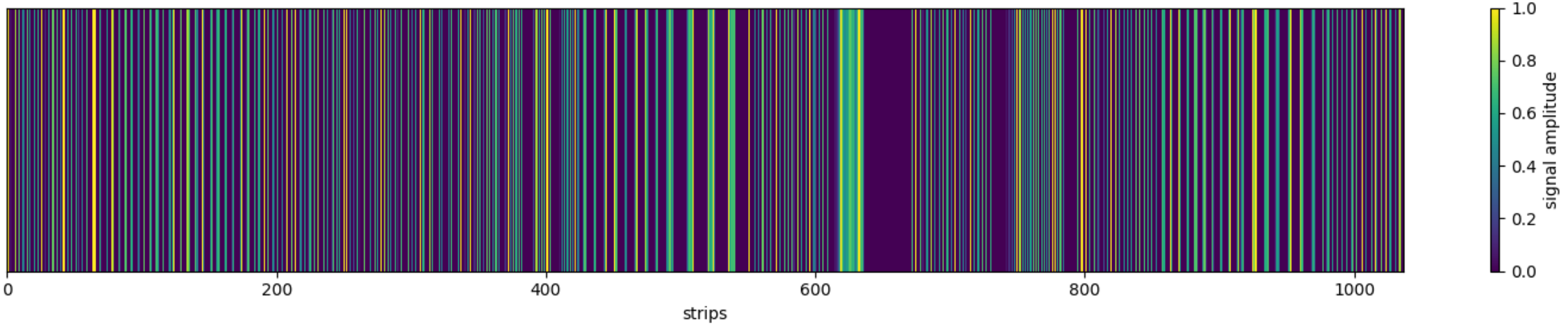
1. Demultiplexing with Convolutional neural networks

Detector multiplexing

Real event



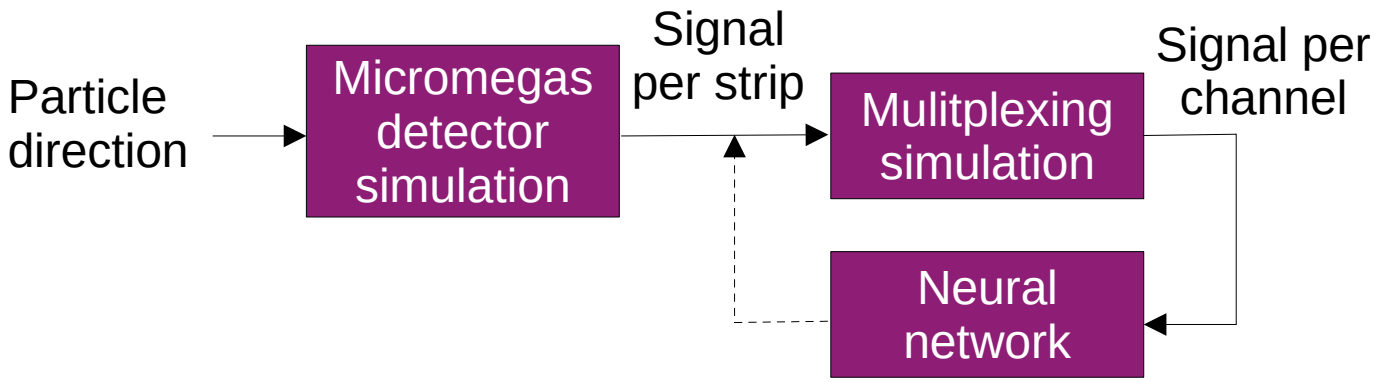
Event measured



Approach

For each detector type :

- Simulate muons in the Micromegas
- Simulate the effect of multiplexing
- **Train** a neural network to « demultiplex » the simulation



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For each detector type :

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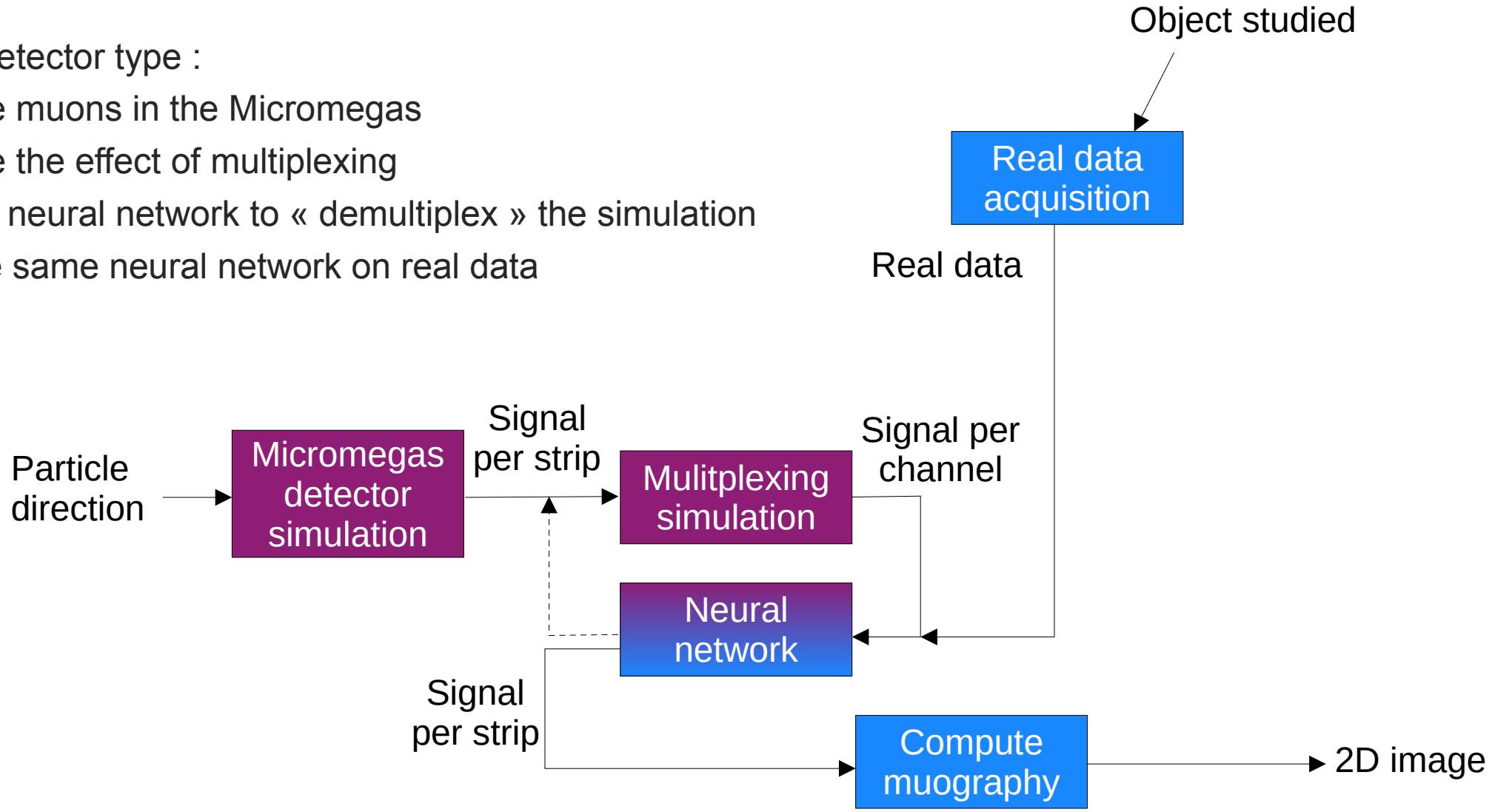
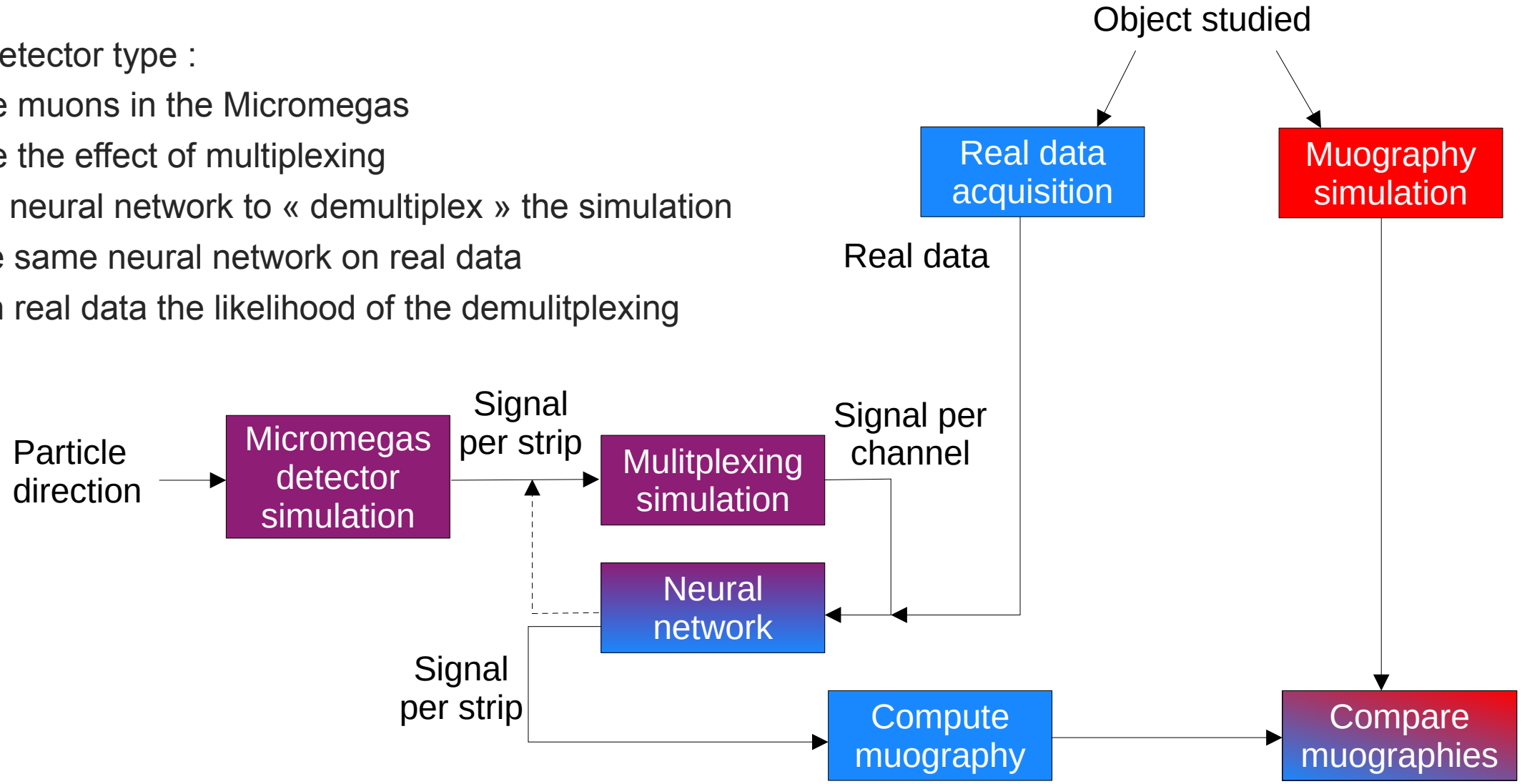
- **Use** the same neural network on real data



Approach

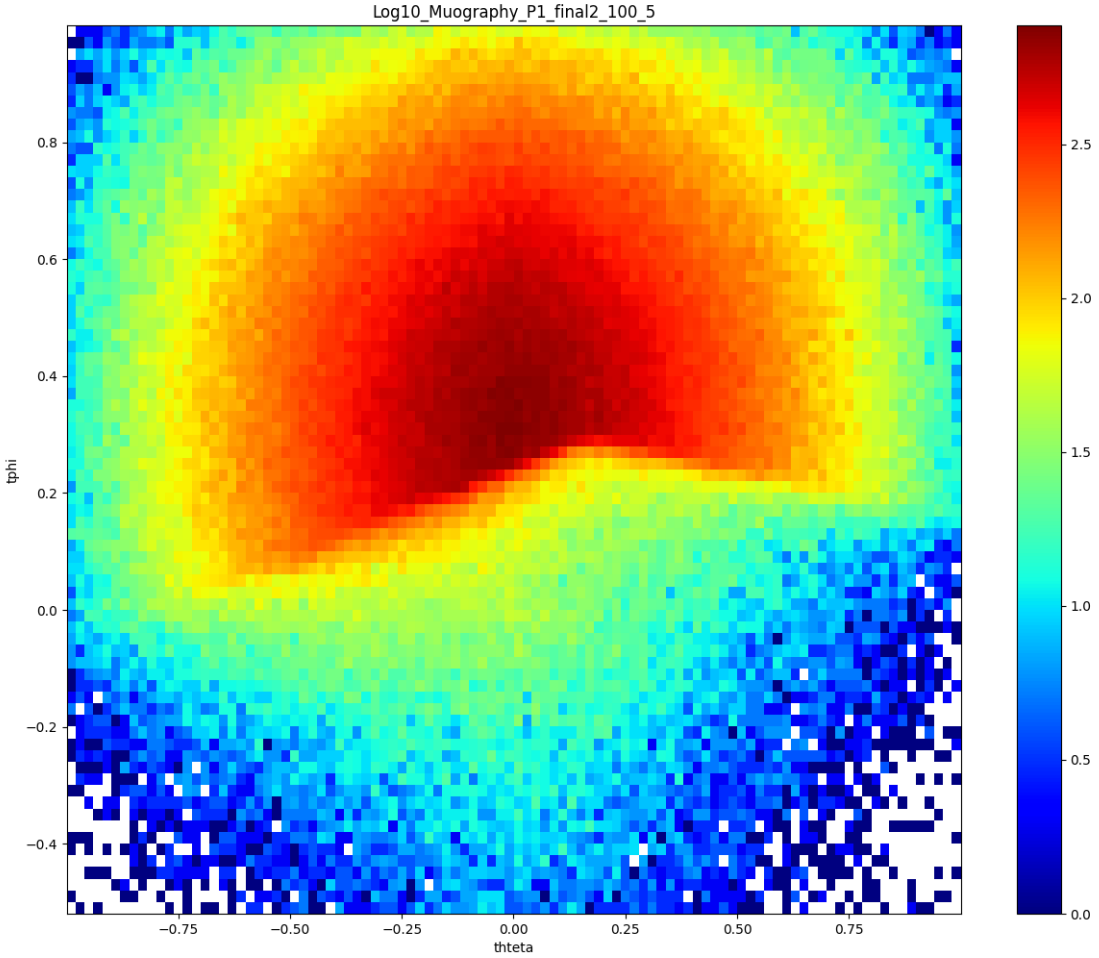
For each detector type :

- Simulate muons in the Micromegas
- Simulate the effect of multiplexing
- **Train** a neural network to « demultiplex » the simulation
- **Use** the same neural network on real data
- **Test** on real data the likelihood of the demulitplexing

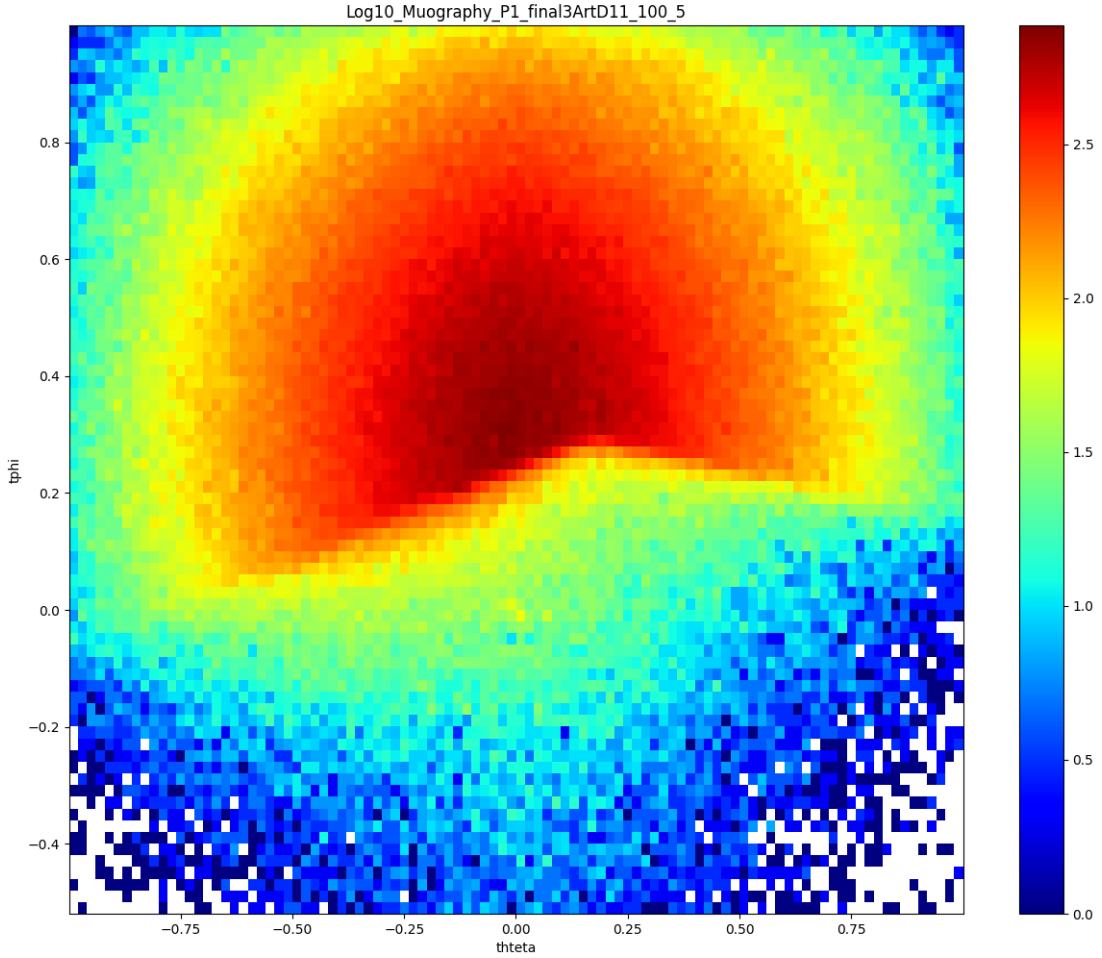


Results

Previous demultiplexing method

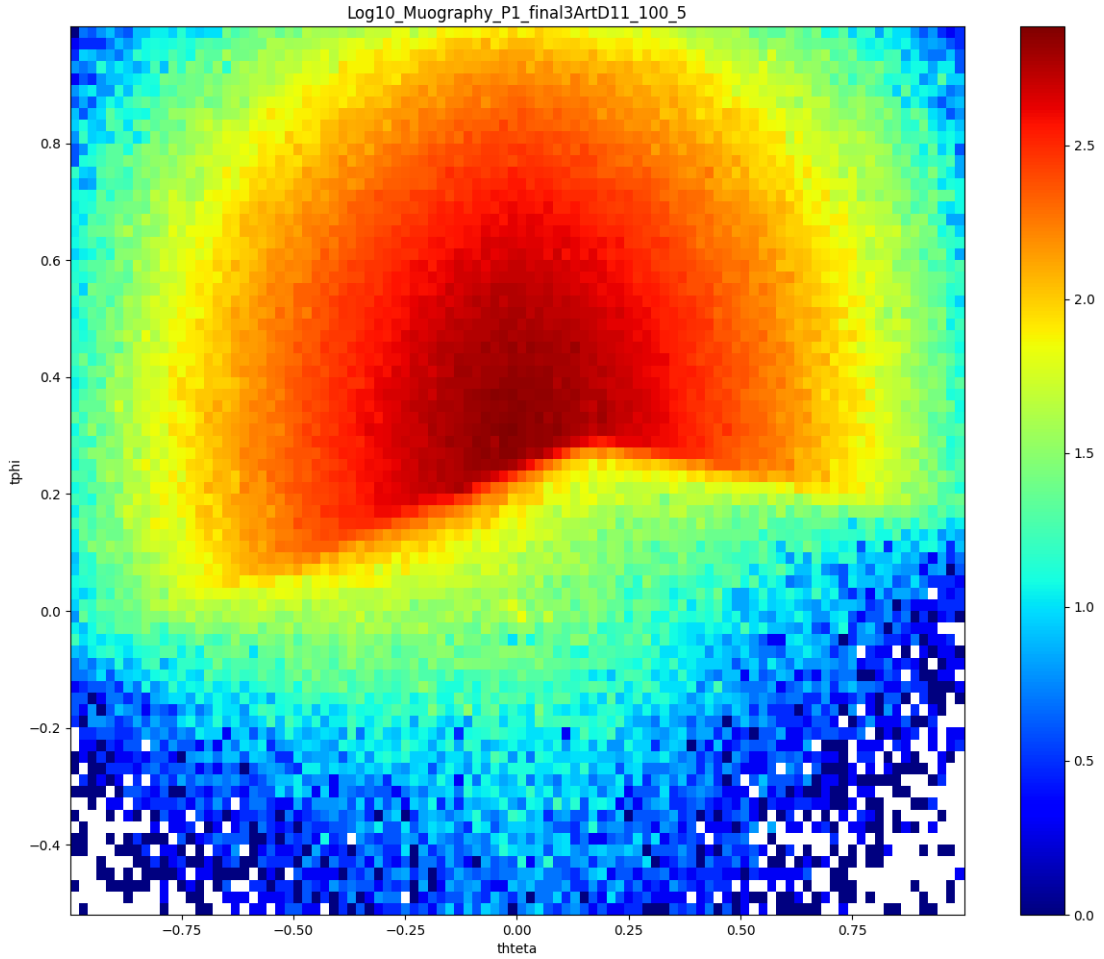


Neural network demultiplexing

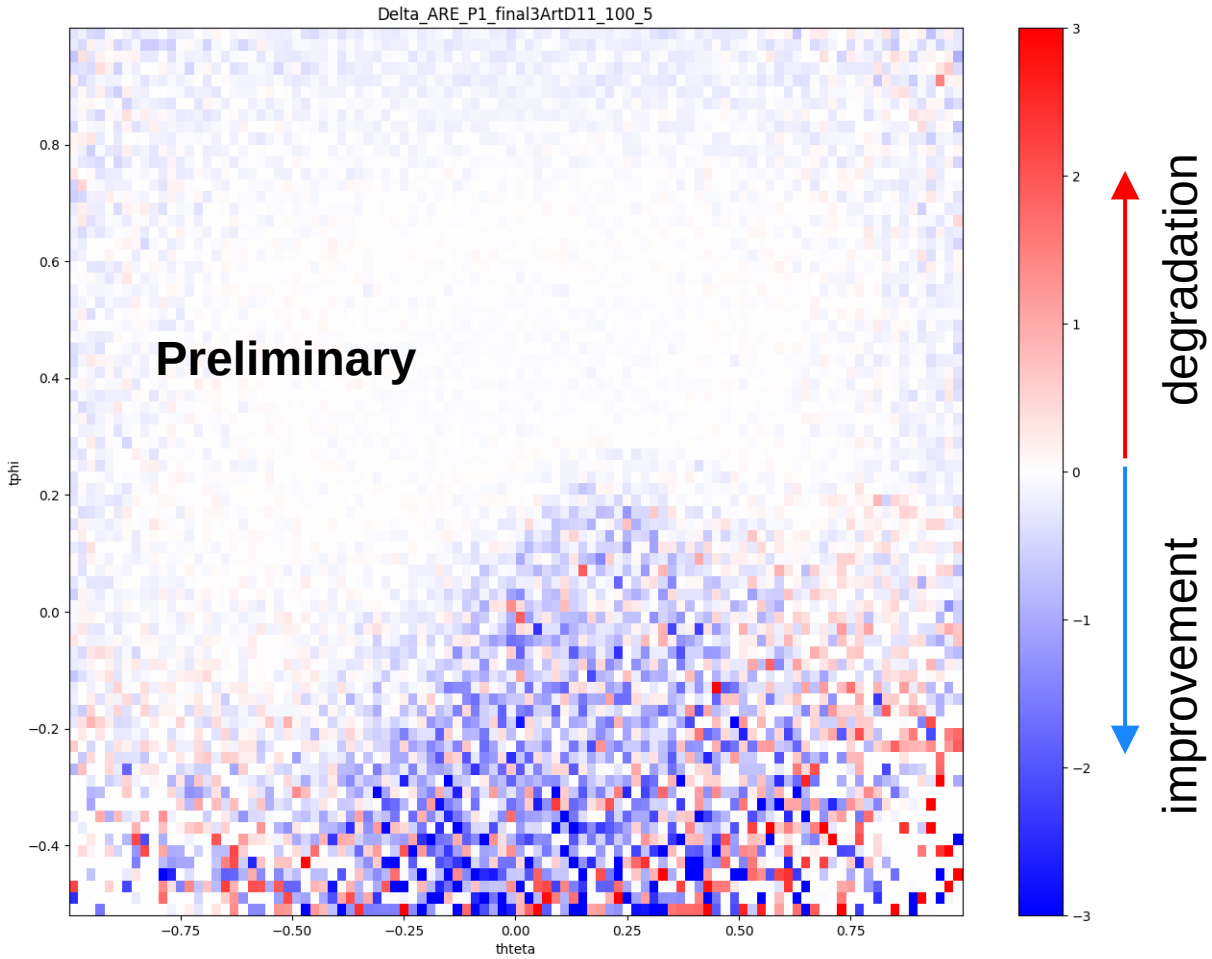


Results

Neural network demultiplexing



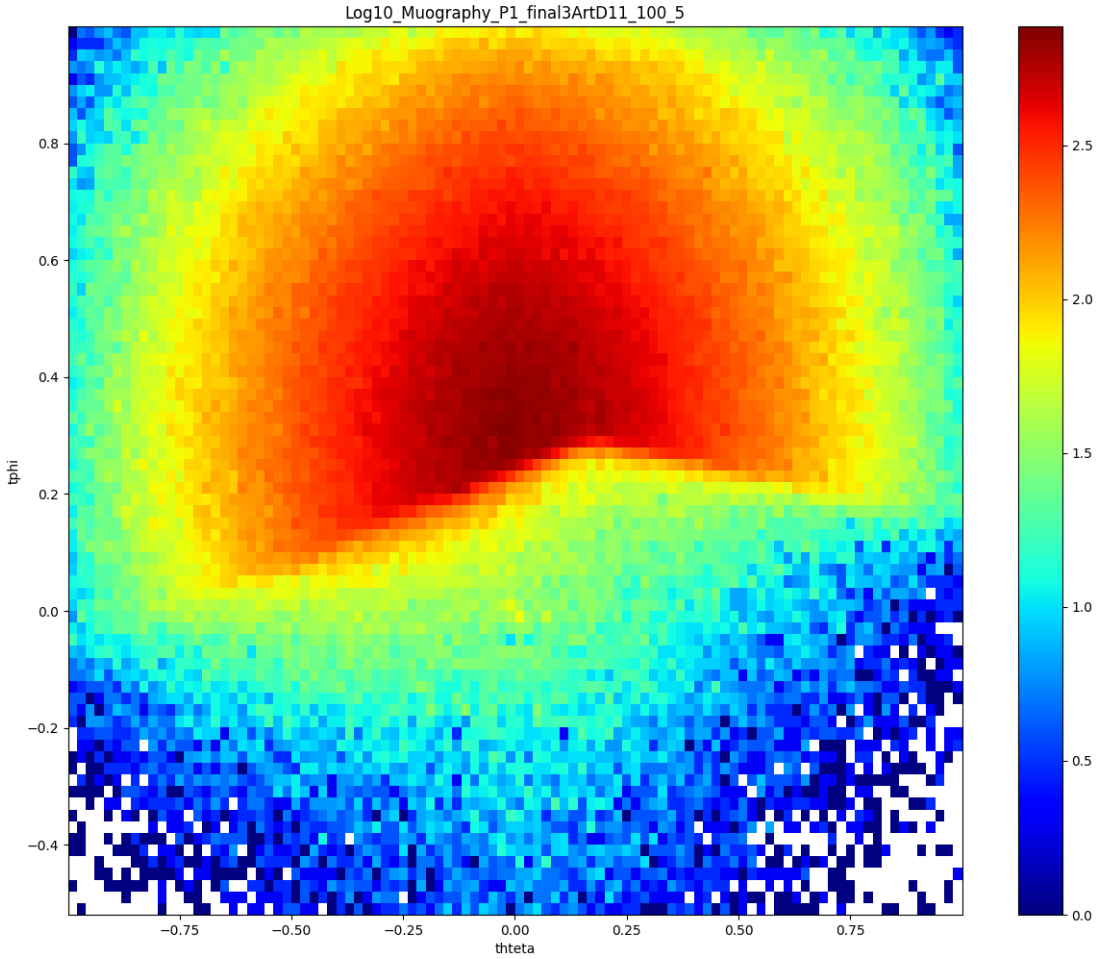
Variation of absolute relative error

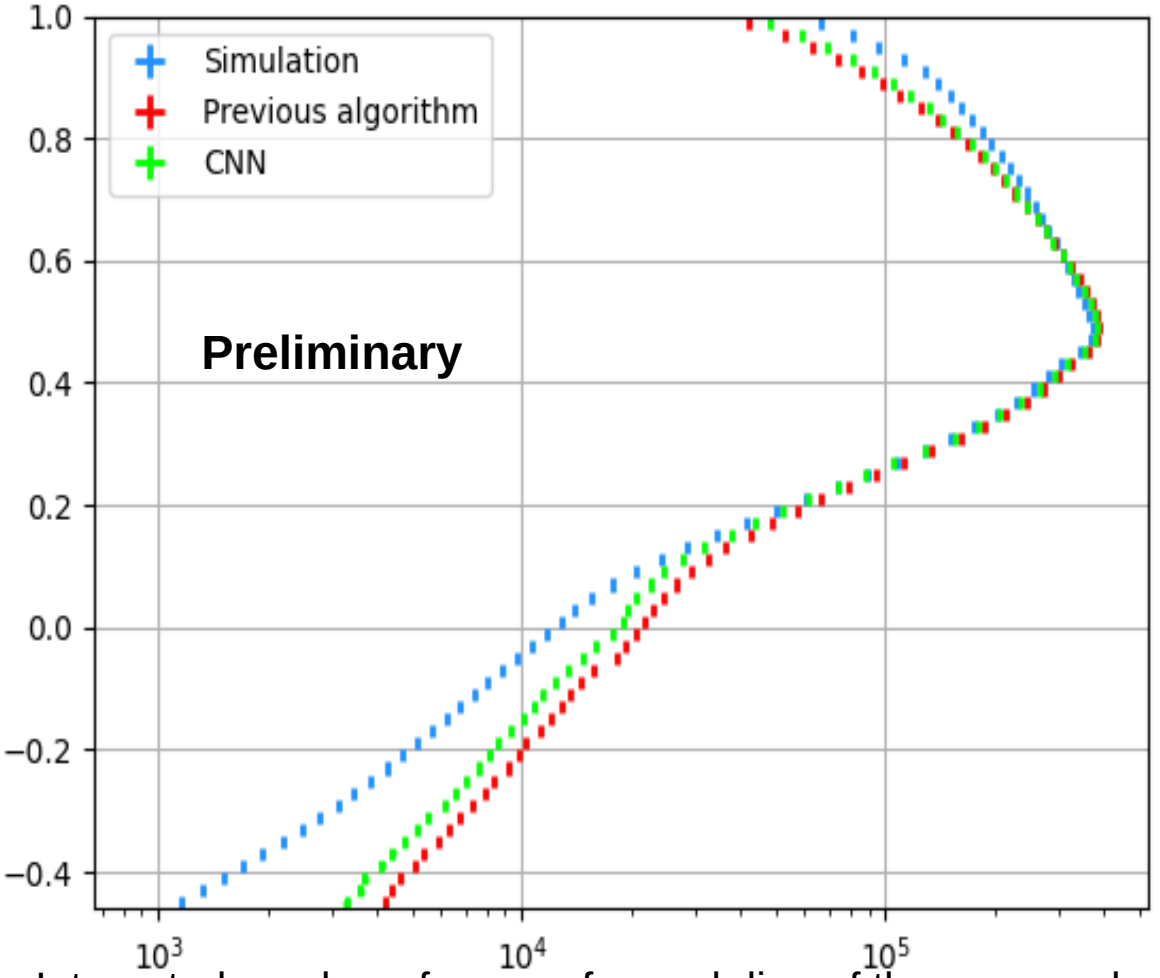


Absolute relative error : decreases **on** 65% of the image (blue pixels)
decreases **of** 19% on the complete image

Results

Neural network demultiplexing





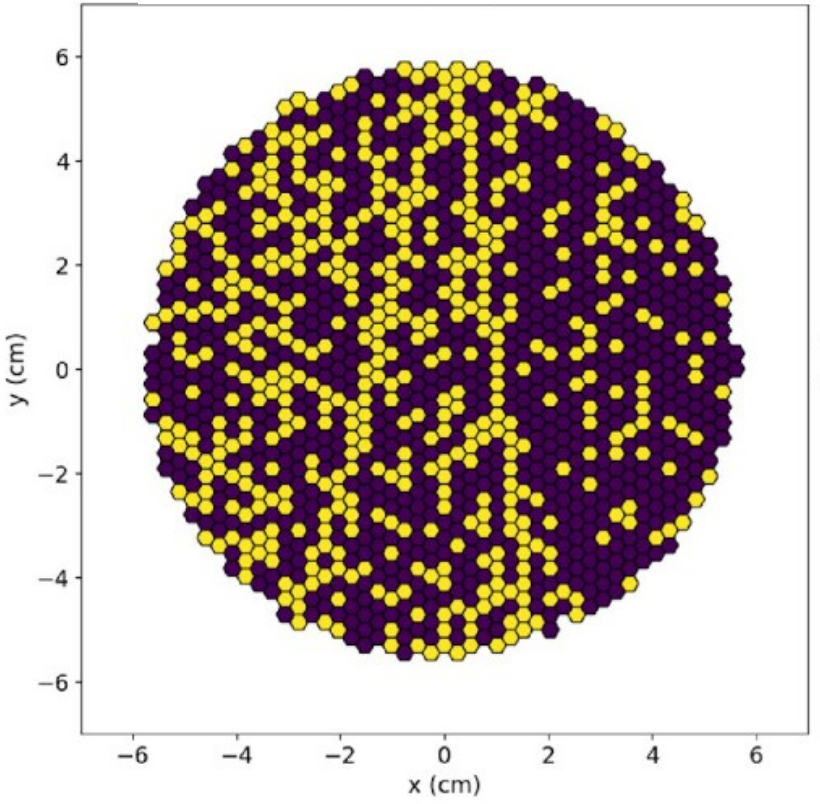
Integrated number of muons for each line of the muography.

Other results – Etienne Gozillon's work

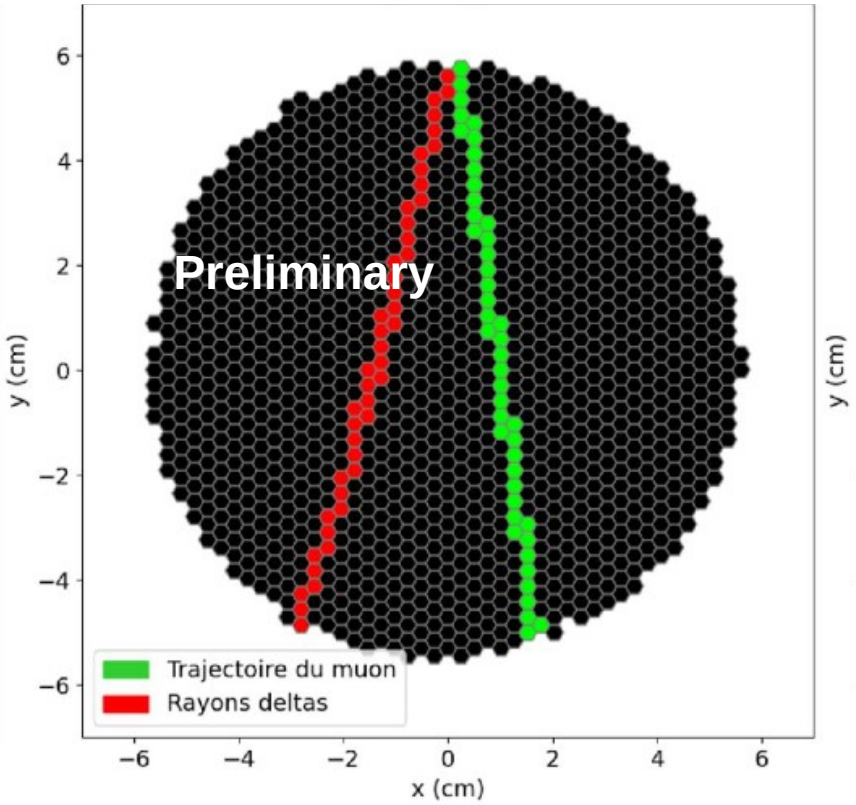
Images from Etienne Gozillon's internship report

D3DT Time Projection Chamber

Multiplexed data



Demultiplexing
and identification



Muon track
Electron track

2. 3D Image and post-processing

The G2 and G3 reactors (1958-1984)

G2 and G3

Inside G2

Images : francetnp.gouv.fr/Marcoule-le-reacteur-plutonigene

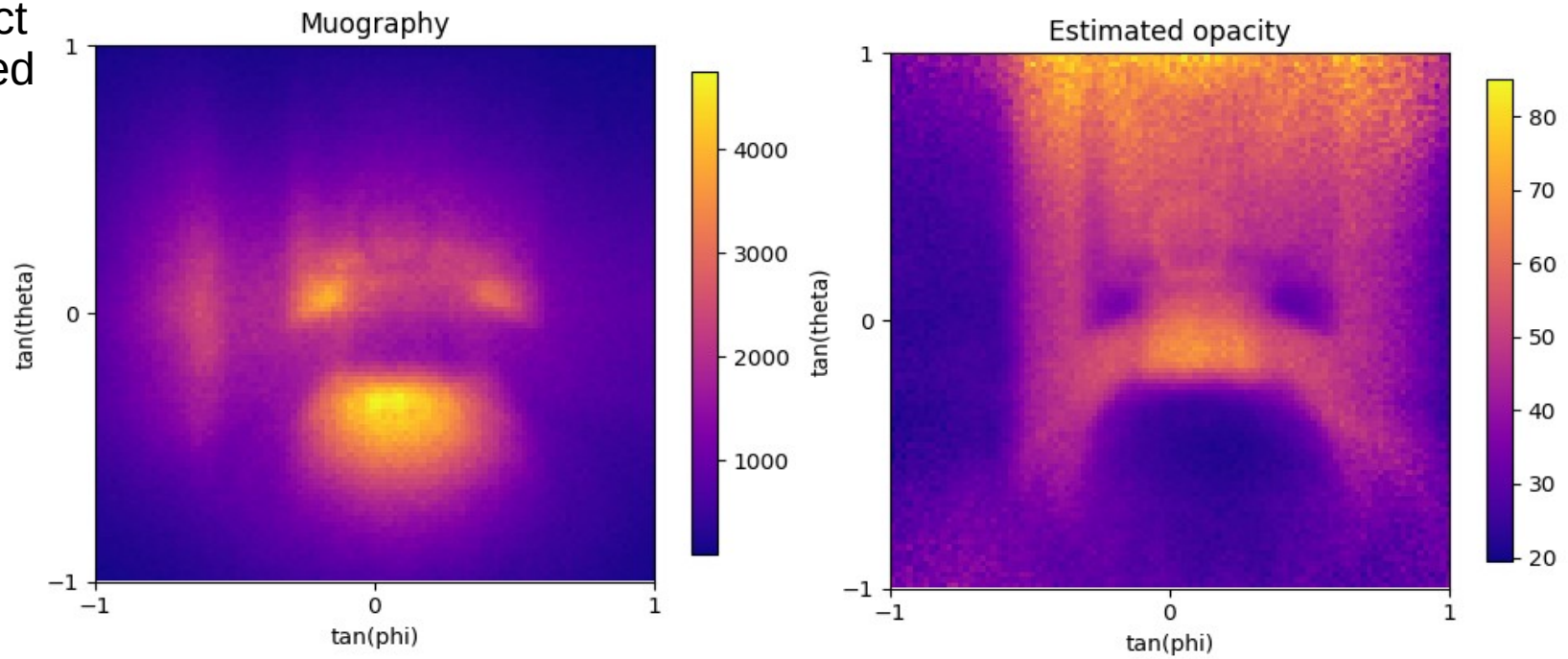
Approach

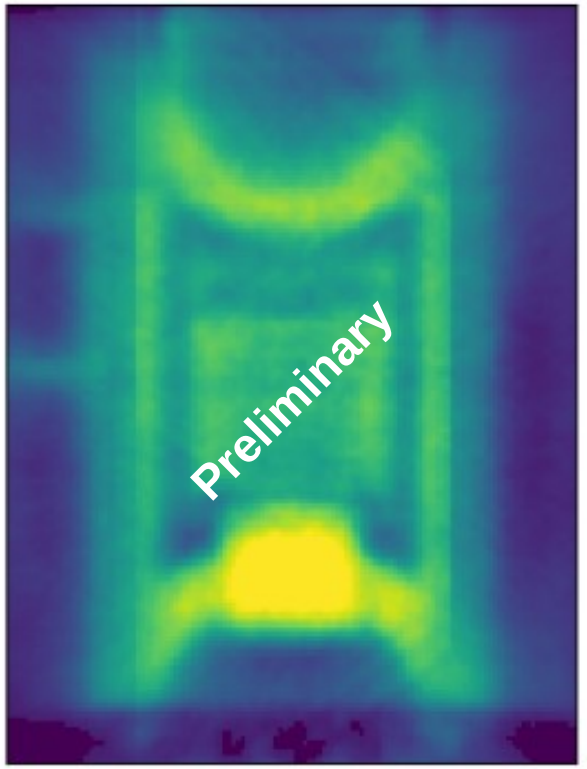
Muographies

Opacities

Acquisition → Opacity estimation → 3D Reconstruction → “Blind” 3D image

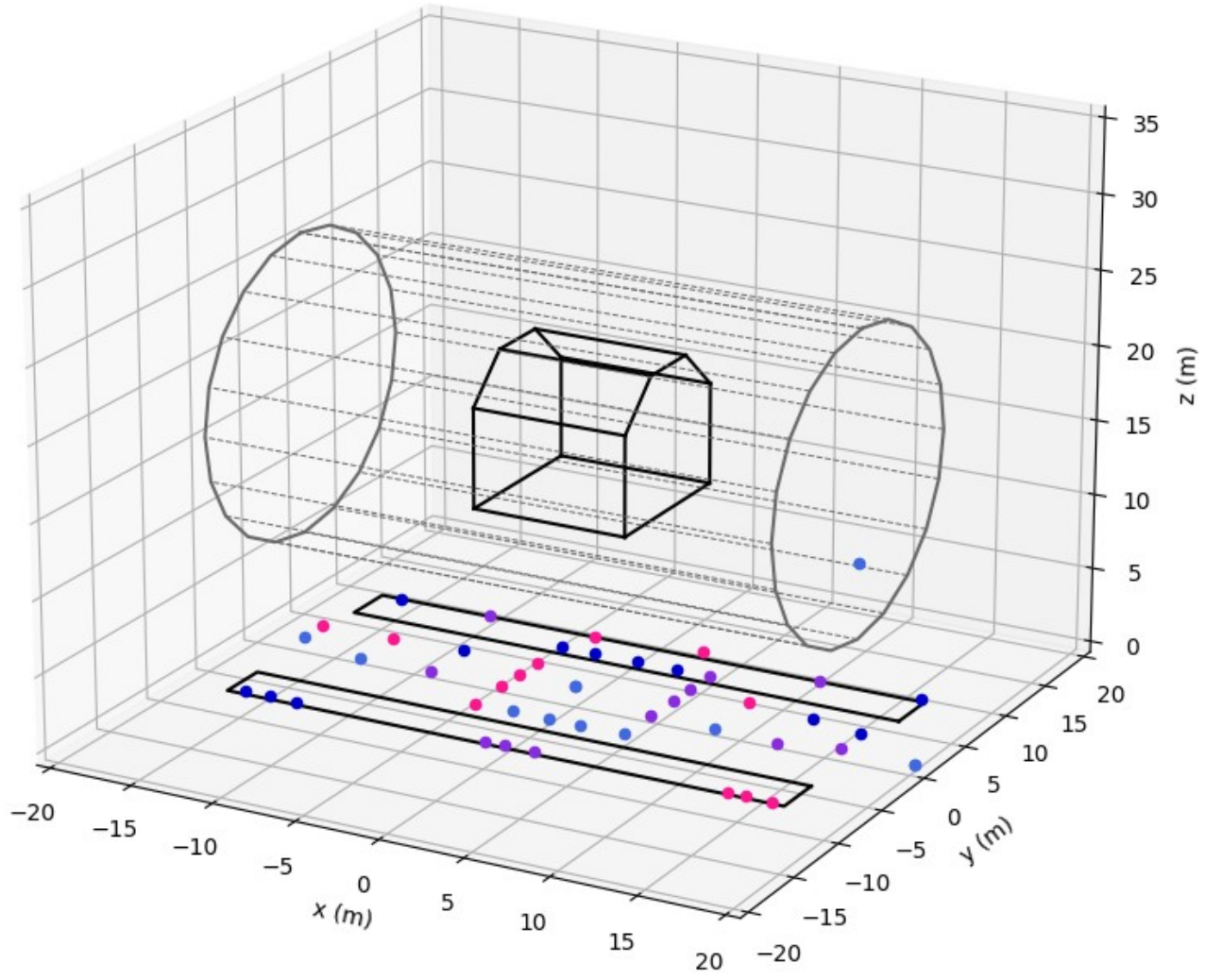
Object studied





Positions at G3

View below the reactor



Map of the positions at the G3 reactor

3D Reconstruction - Preliminary

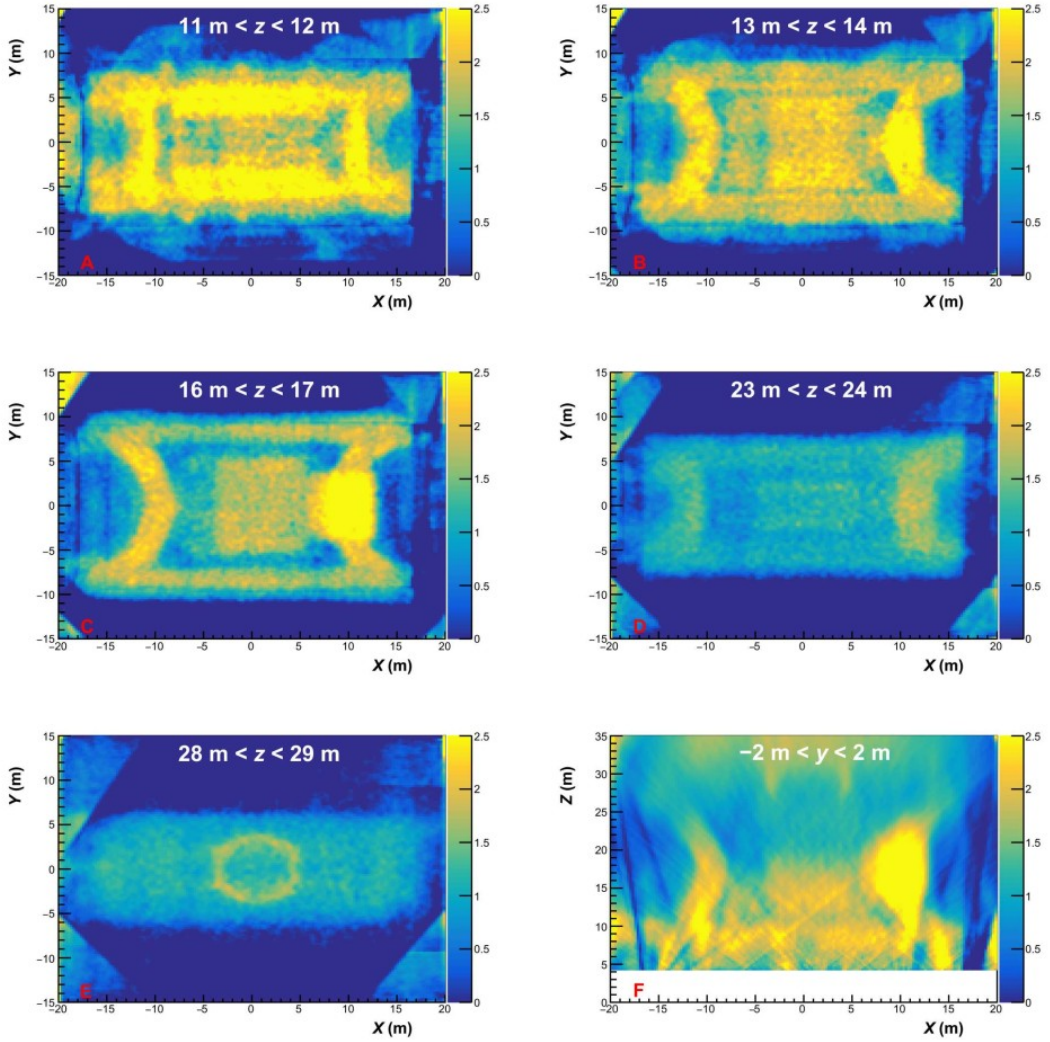
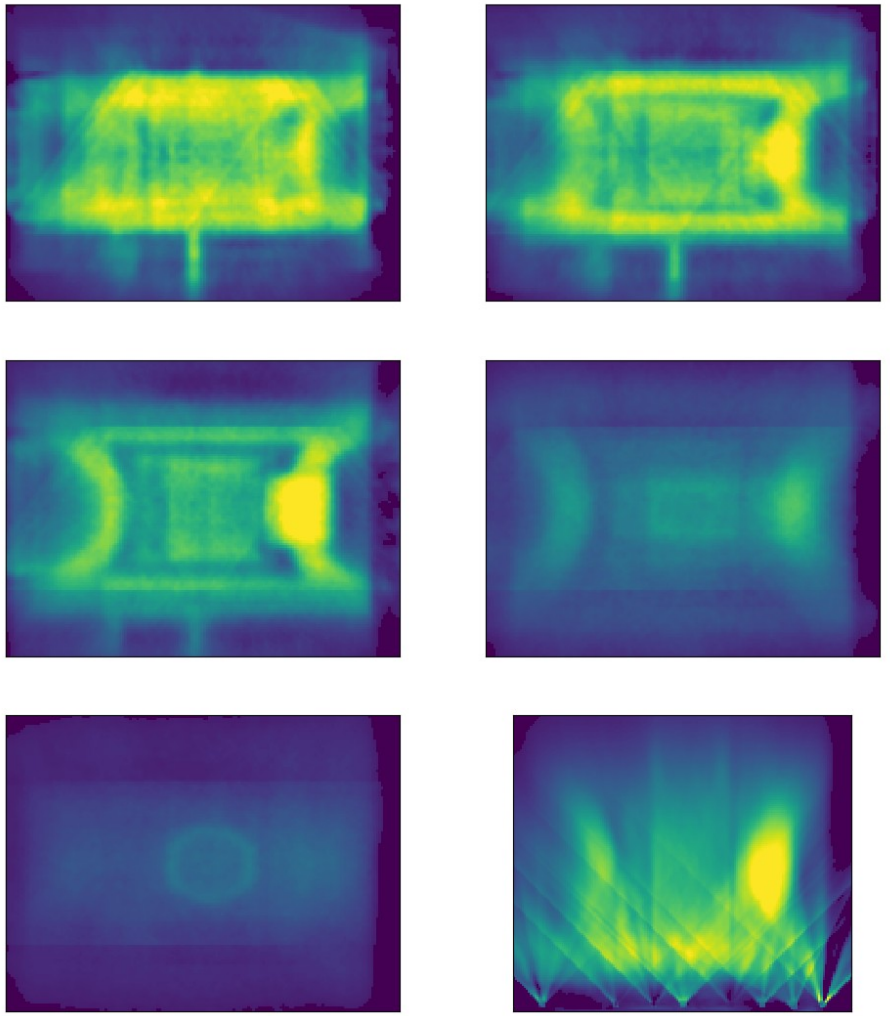


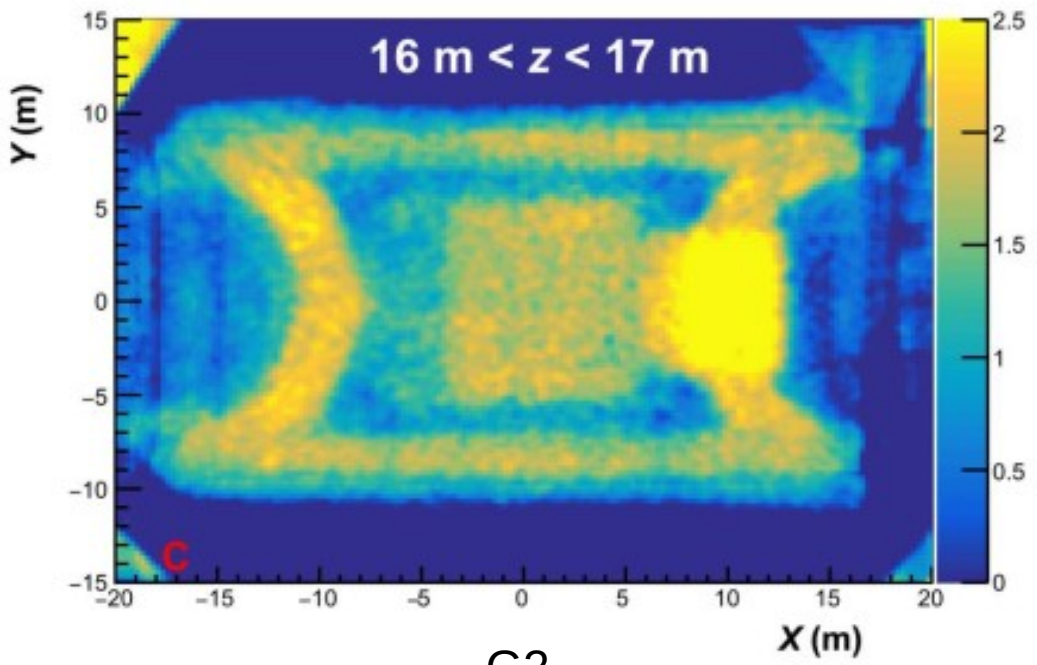
Fig. 4. Some tomographic slices obtained from the 3D reconstruction of the reactor, revealing several details of the structure. (**A** to **E**) *x-y* slices at different heights. (**F**) *x-z* slices close to the *y* axis. See text for more details.



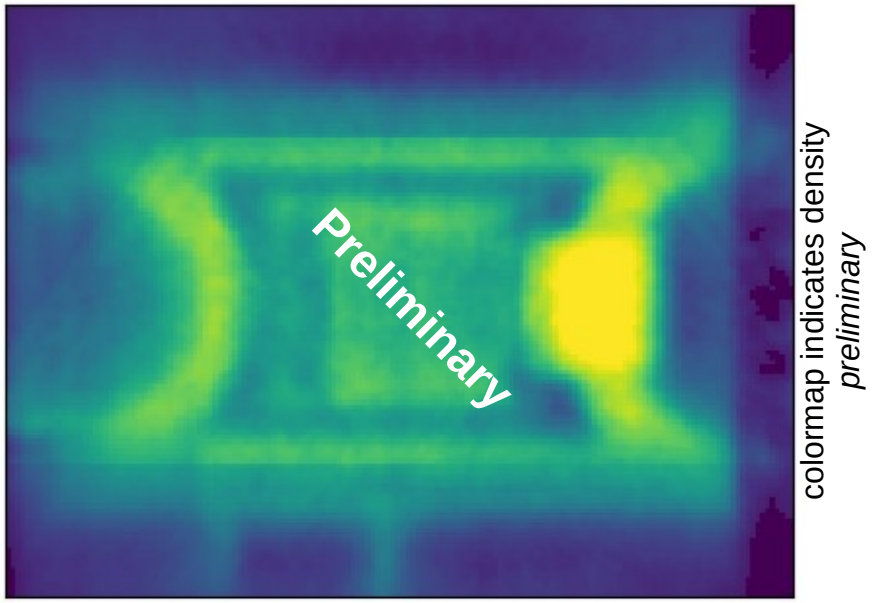
G2

G3

3D Reconstruction - Preliminary



G2



G3

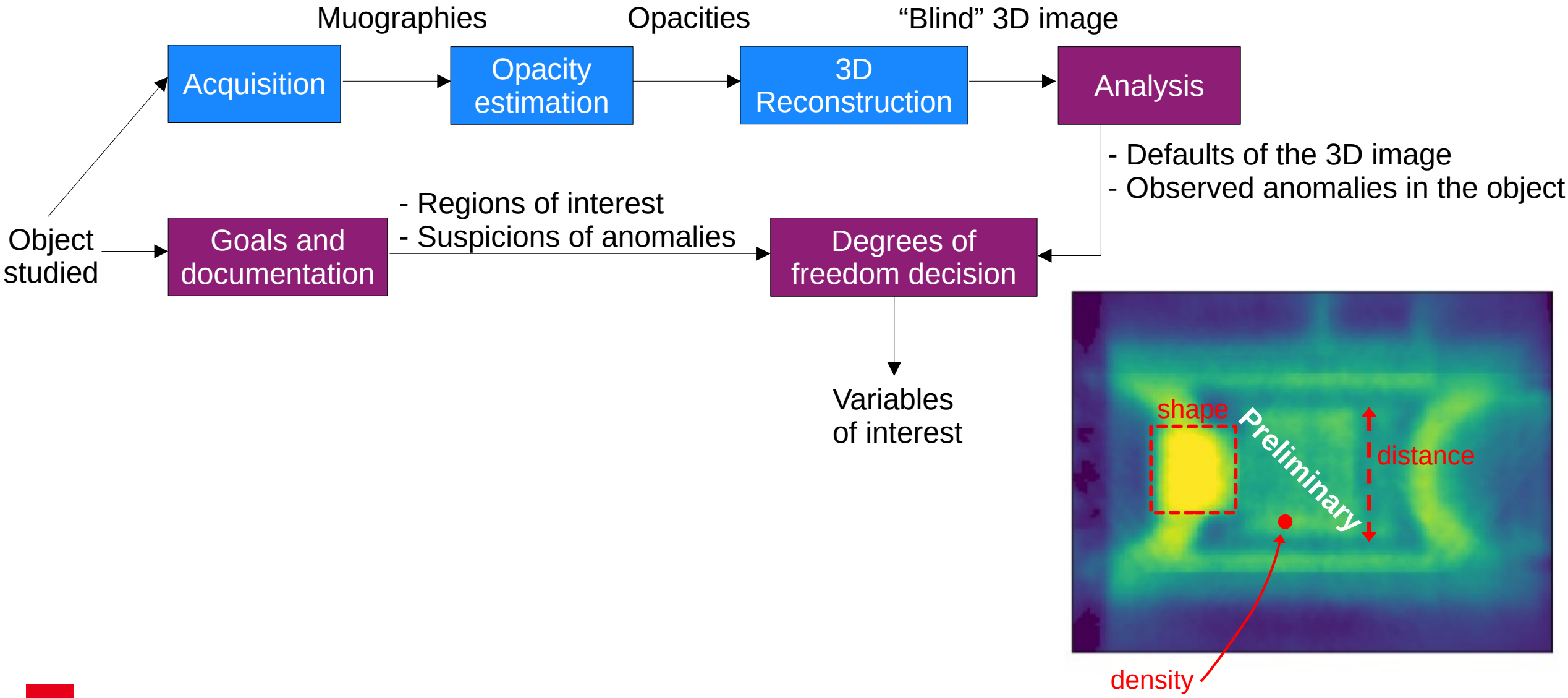
	G2 (published)	G3 (preliminary)
Positions	27	27 used (46 available)
Used duration (months)	24	7 used (12 avalaible)
Iterations	10 000	200

Reconstruction computed with the same number of positions (19 more are available)

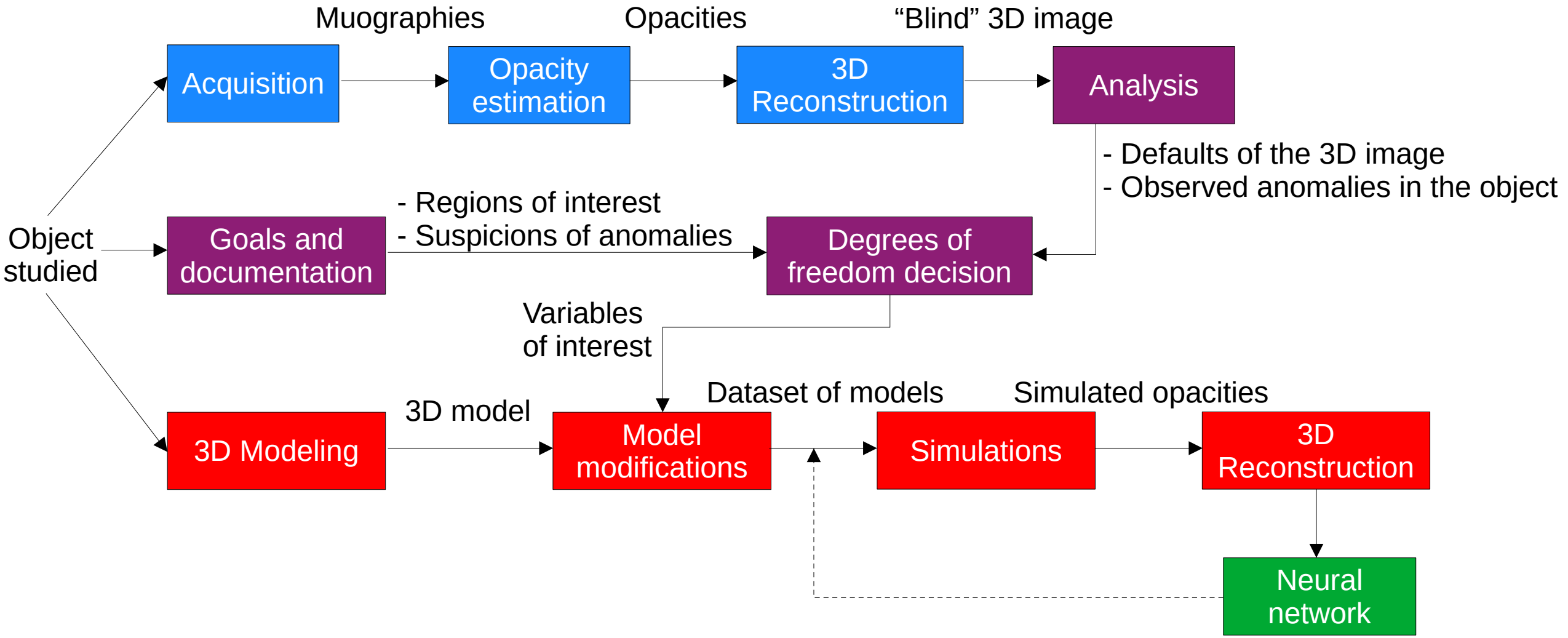
Shorter measurements

Faster computation with modifications in the SART algorithm

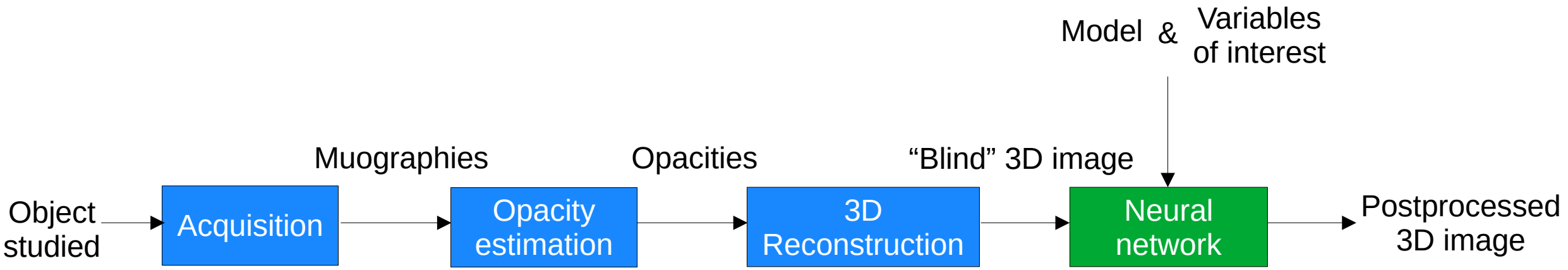
Post-processing approach

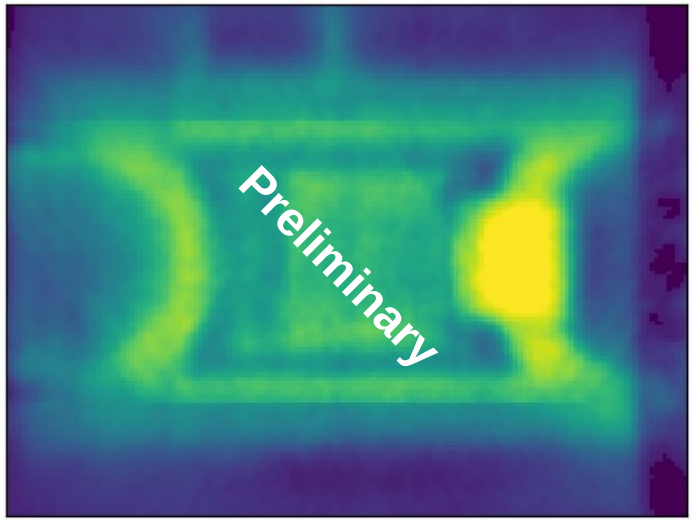


Post-processing approach

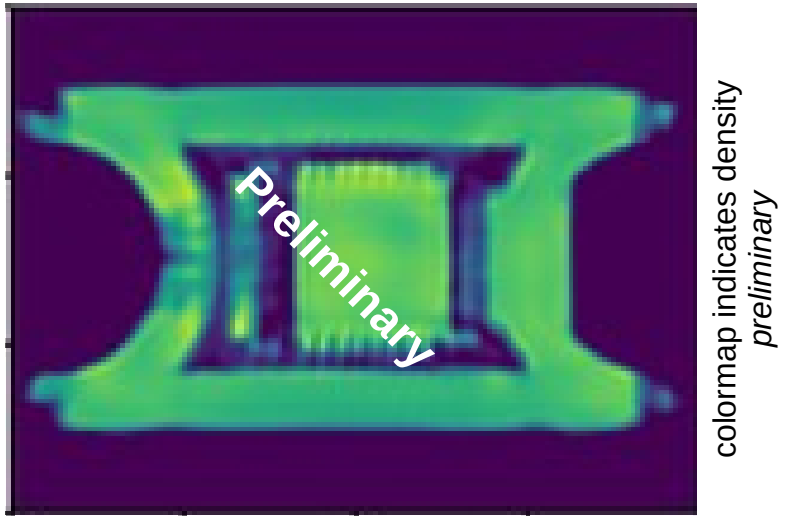


Post-processing approach





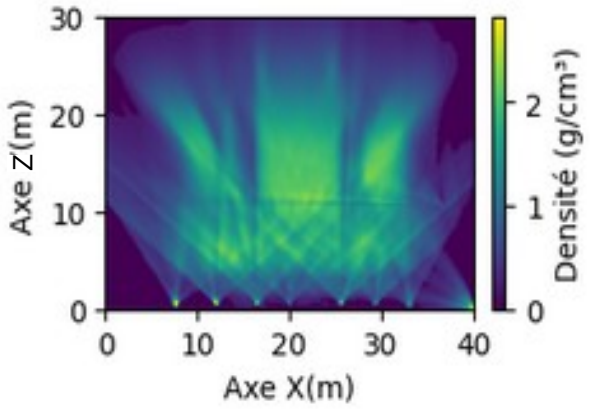
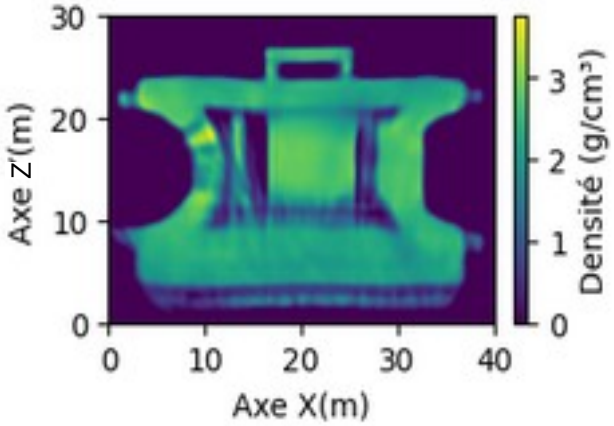
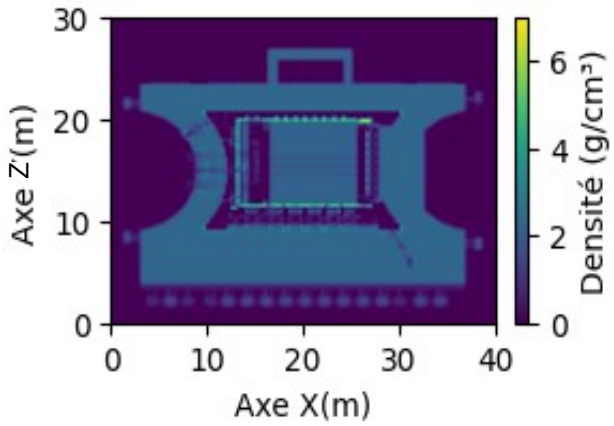
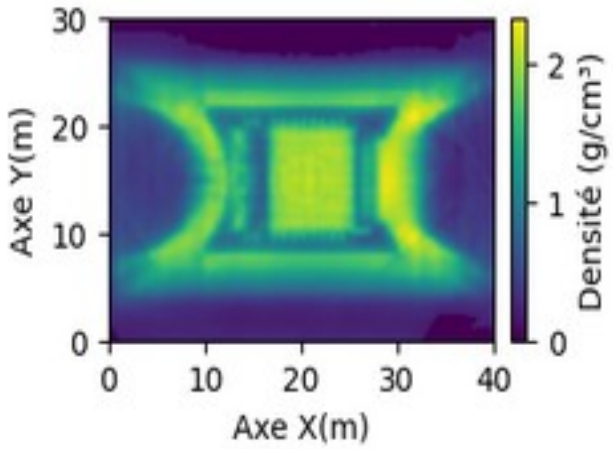
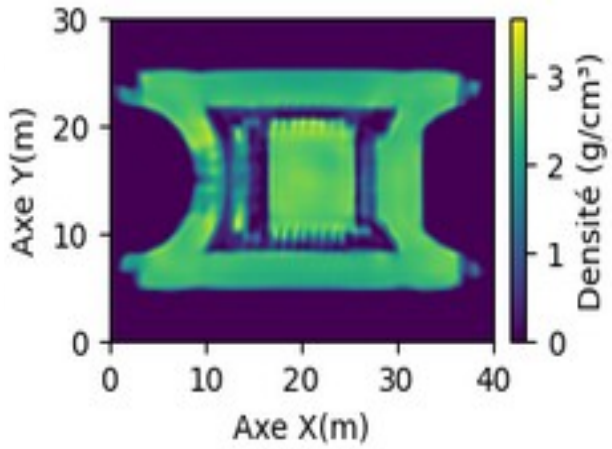
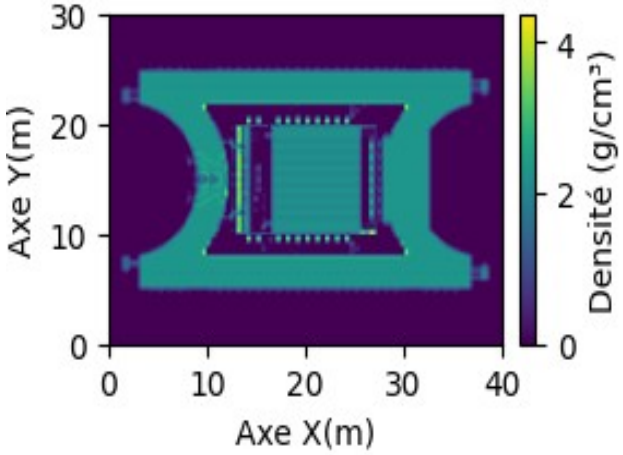
“Blind” 3D image



Postprocessed 3D image
on simulations

Preliminary post-process results

On simulated data : Images from Julien Vogel's internship report

	Blind 3D images	Postprocessed image	True model
Slice in a XZ plane			
Slice in a XY plane			

Conclusion

Conclusion

- Micromegas detectors
  - can be demultiplexed with neural networks
  - have enough resolution to compute 3D images
- Muon tomography images can be improved with neural networks
- Many other new methods are currently considered :
  - More complex muography denoising
  - Faster simulations
  - Better caracterisation of the multiplexing

Thanks !

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