Real-Time Beam Detection and Tracking From Pinhole Imaging System Based on Machine Learning

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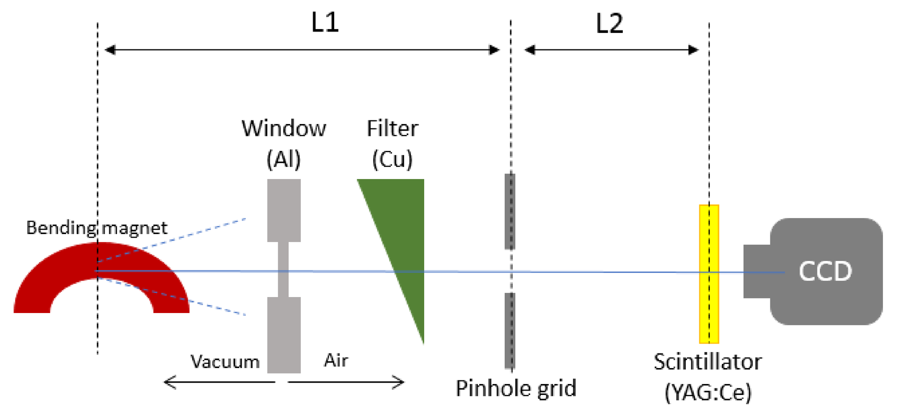
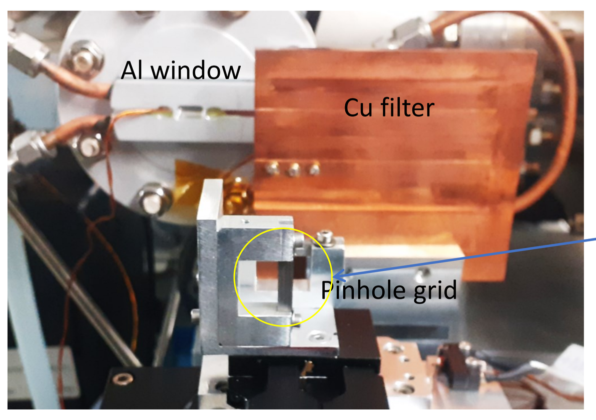
At ALBA Synchrotron each of the two in-air pinhole imaging systems is able to see several beam spots at once due to specific pinhole grid with 3x3 holes placed in the path of the X-ray fan. Each beam image has its own properties, such as source pinhole aperture size, its Point Spread Function (PSF) and copper filter thickness, all of which impact the electron beam size calculation. Until now, these parameters were applied manually to the pinhole device servers for numerical image analysis, so this semi-manual beam size calculator is subject to frequent adjustments and human monitoring.

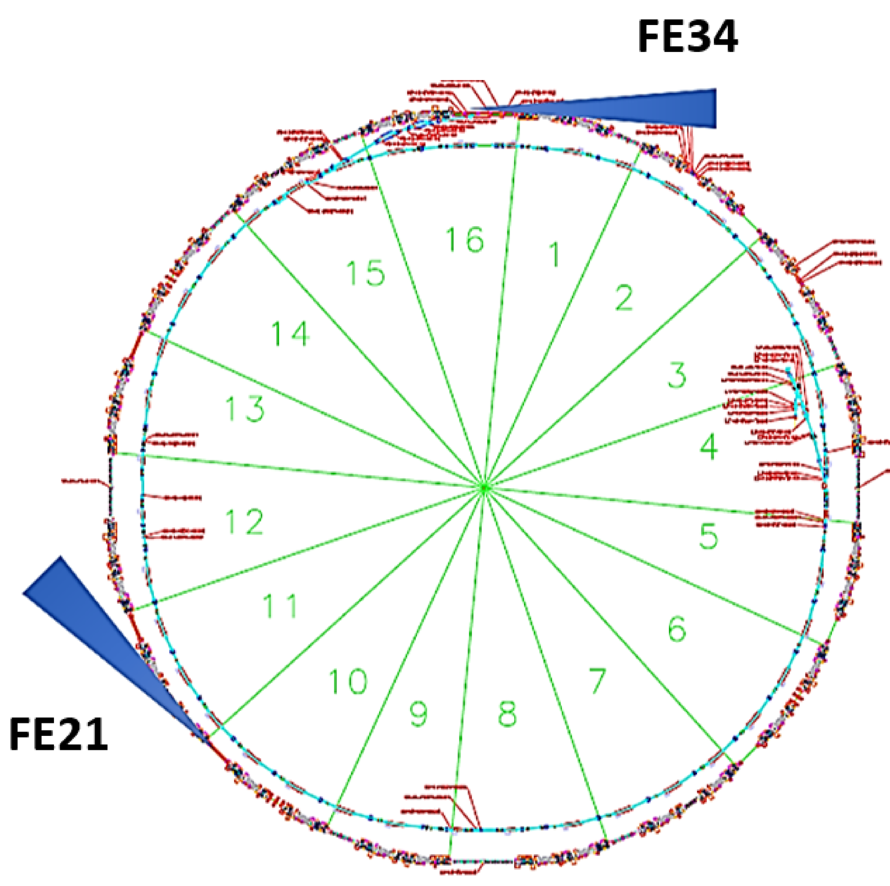
This study looks at feasibility of training and pointing an Artificial Neural Network (ANN) at image stream coming from pinhole cameras in real time, track all detected beam spots and analyze them, with the end goal to automate the whole pinhole beam image processing.

ALBA Pinhole system: Beam size and emittance monitoring with two X-ray pinholes, each tracking predefined ROI



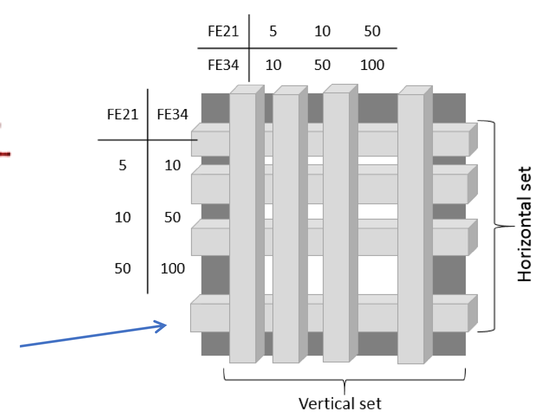
Both ALBA's X-ray pinhole lines are similar and consist of a chain of elements : a dipole source, Al vacuum window, Cu attenuator, motorized pinhole grid and YAG scintillator screen with CCD looking at it.



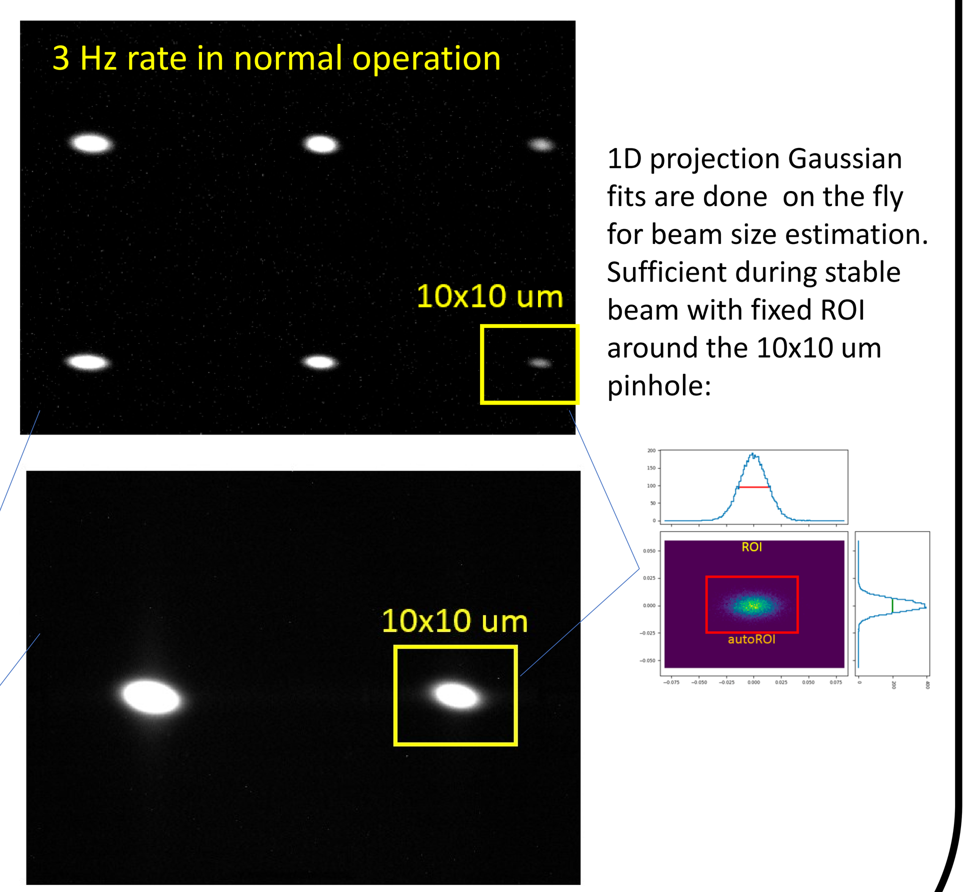


Pinholes installed in Sectors 01 and 11 of the Storage Ring.

The pinhole grid is motorized (lateral, vertical, rotational and pitch motions), made of 1~mm thick tungsten bars crossing into 9 rectangular apertures of different sizes, with 3 squared:



Complete images seen by both pinhole CCDs: both cameras can see up to 8 beam spots combined. But only one is used in each.



1D projection Gaussian fits are done on the fly for beam size estimation. Sufficient during stable beam with fixed ROI around the 10x10 um pinhole:

Computer vision project for Beam Diagnostics: automate pinhole image acquisition and analysis.

Strategy: train an Artificial Neural Net to detect all beam spots in streaming mode and then do 2D image analysis of each spot for beam size and emittance without human interference.

If we want to measure beam size in every spot, we have to take care of the PSF.

The pinhole image is affected by the Point Spread Function (PSF), analytically it is:

$$\sigma_{\rm PSF} = \sqrt{\sigma_{\rm blur}^2 + \sigma_{\rm diff}^2 + \sigma_{\rm scr}^2},$$

where $\sigma_{\rm diff}$ is Fraunhofer diffraction

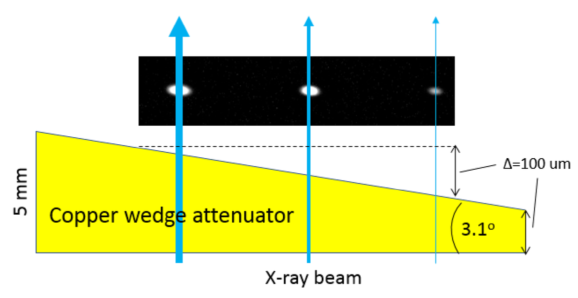
$$\sigma_{\rm diff} = \frac{\sqrt{12}}{4\pi}\frac{\lambda L_2}{w},$$

$\sigma_{\rm blur}$ is blurring due to the finite size of the pinhole

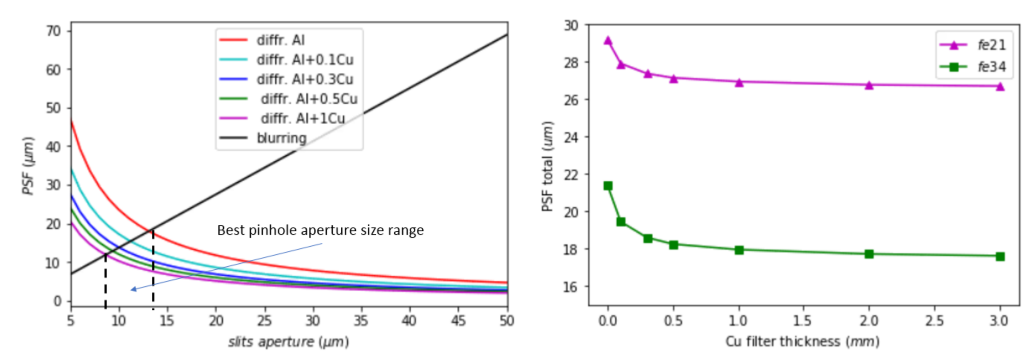
$$\sigma_{\rm blur} = \frac{w(L_1+L_2)}{\sqrt{12}L_1},$$

$$\sigma_{\rm YAG}^2 = (M\sigma_{\rm b})^2 + (\sigma_{\rm PSF})^2,$$

The measured size of a beam spot will be larger than the <u>true electron beam size</u> due to its PSF



Relation between the Cu filter position and beam spots on the CCD image: each spot receives X-ray flux passed through different Cu thickness (not to scale). This is why every detected beam spot requires its own PSF.



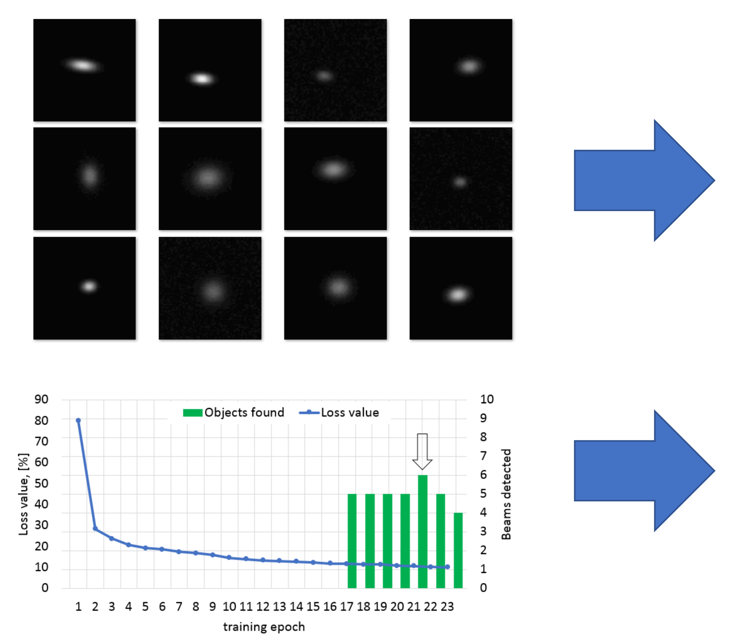
PSF is the beam size measured at the camera screen of a point-like electron beam. PSF strongly depends on the pinhole aperture size and radiation wavelength = copper filter attenuation. In the plots above the PSF is plotted as functions of pinhole aperture and copper thickness. These curves are parameterized and used according to the parameters of detected beam spot.

Machine learning: algorithm selection and model training.

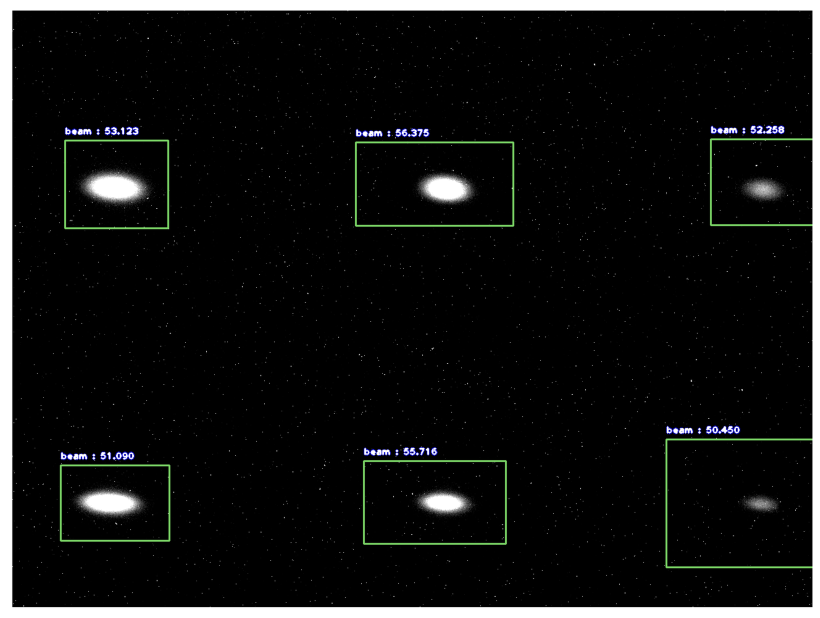
--> YOLOv3: **You Only Look Once** a real-time object detection system based on convolutional ANN.
--> TensorFlow v2.4 backend.

- supervised learning
- object classification ("beam spots")
- train on a set of annotated samples

Train from scratch on a dataset of 300 random 2D Gaussian distributions (100x100 px images) + 50 images as test dataset: 20 learning epochs (2h each)

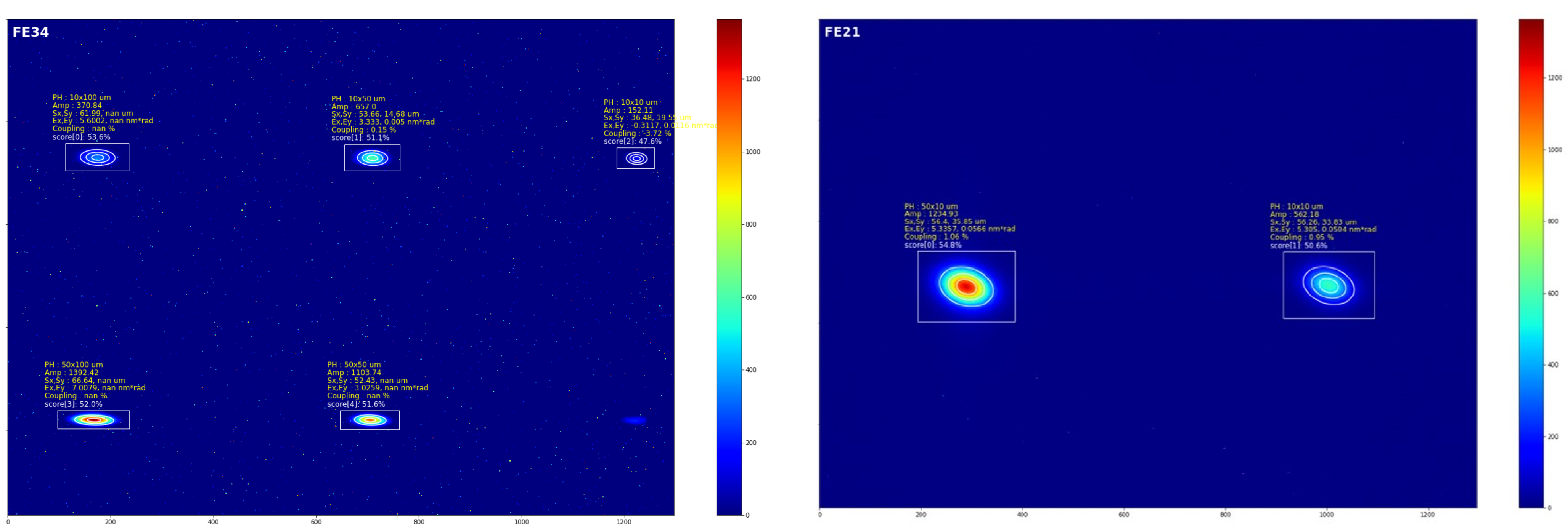


Loss value evolution during training



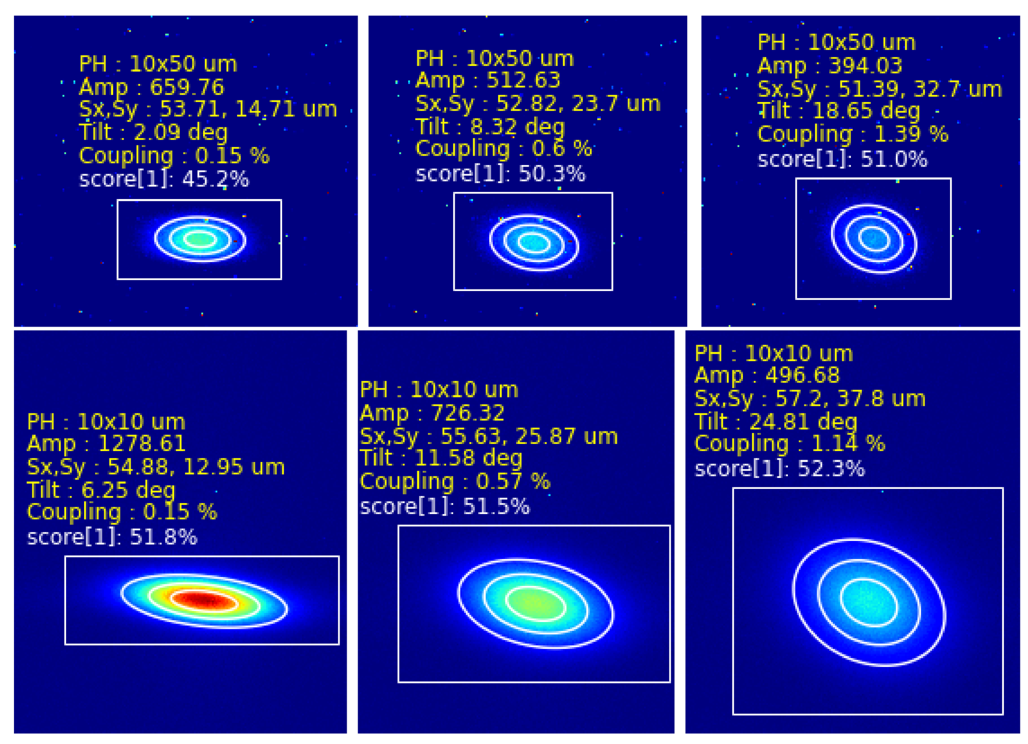
A single pinhole CCD frame with 6 beam spots successfully detected by a trained YOLO model.

Automatic image recognition and 2D numerical analysis on real pinhole images



We process the stream of pinhole images through the artificial neural network, track all beam spots, and using dynamic PSF calculator for every detected beam spot we fit them with the2D Gaussian function, and apply corrections: remove PSF contribution, magnification, and finally scale px to mm to get accurate electron beam size, emittance and coupling.

Using the developed system to track beam coupling changes. Here the ANN is looking at the same beam spot (FE34 top row and FE21 bottom row) while the coupling factor changes from small (0.15%), to nominal (0.6%) to high (1.4%). All values are realistic and expected.



Conclusion. This is work in progress. We have built a working and accurate real-time beam tracking and image analysis software system based on machine learning. The developed system works at the speed of around 0.5-1 fps on a standard PC, which is already feasible for some machine studies in real-time. The detection system still has to be studied to deal with challenges to improve its speed and efficiency.

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REFERENCES

[1] A. Wu Chao, M. Tigner, *Handbook of Accelerator Physics and Engineering*. World Scientific. 1998.
[2] V. Suller, *An X-ray Pinhole Camera Design for the ALBA Synchrotron Light Source*, April 2005.
[3] U. Iriso. *Beam Size and Emittance Measurements using the ALBA Pinhole*, ALBA Internal Note AAD-SR-DI-PINH-01. June 2011.
[4] Ingrid Mases Solé, *Characterization of the PSF for the X-ray pinhole cameras at ALBA Synchrotron*, Treball de Fi de Grau, Facultat de Física, Universitat de Barcelona, 2020.
[5] Redmon Joseph, Farhadi Ali, *YOLOv3: An Incremental Improvement*, arXiv, 2018. https://pjreddie.com/darknet/yolo/
[6] Martín Abadi et al., *TensorFlow: Large-Scale Machine Learning on Heterogeneous Systems*, 2015. https://www.tensorflow.org/