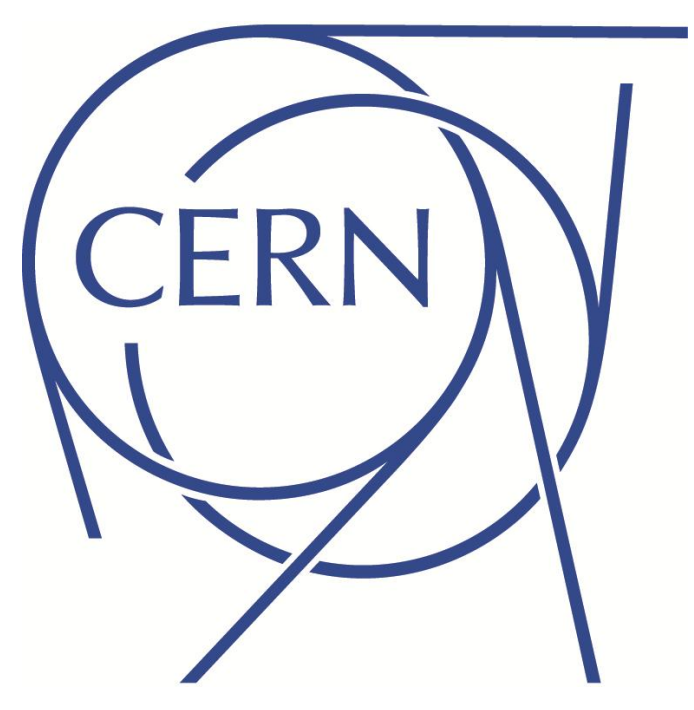




AI ASSISTED CLOSE-RANGE PHOTOGRAMMETRIC MEASUREMENT FOR ACCELERATOR ALIGNMENT

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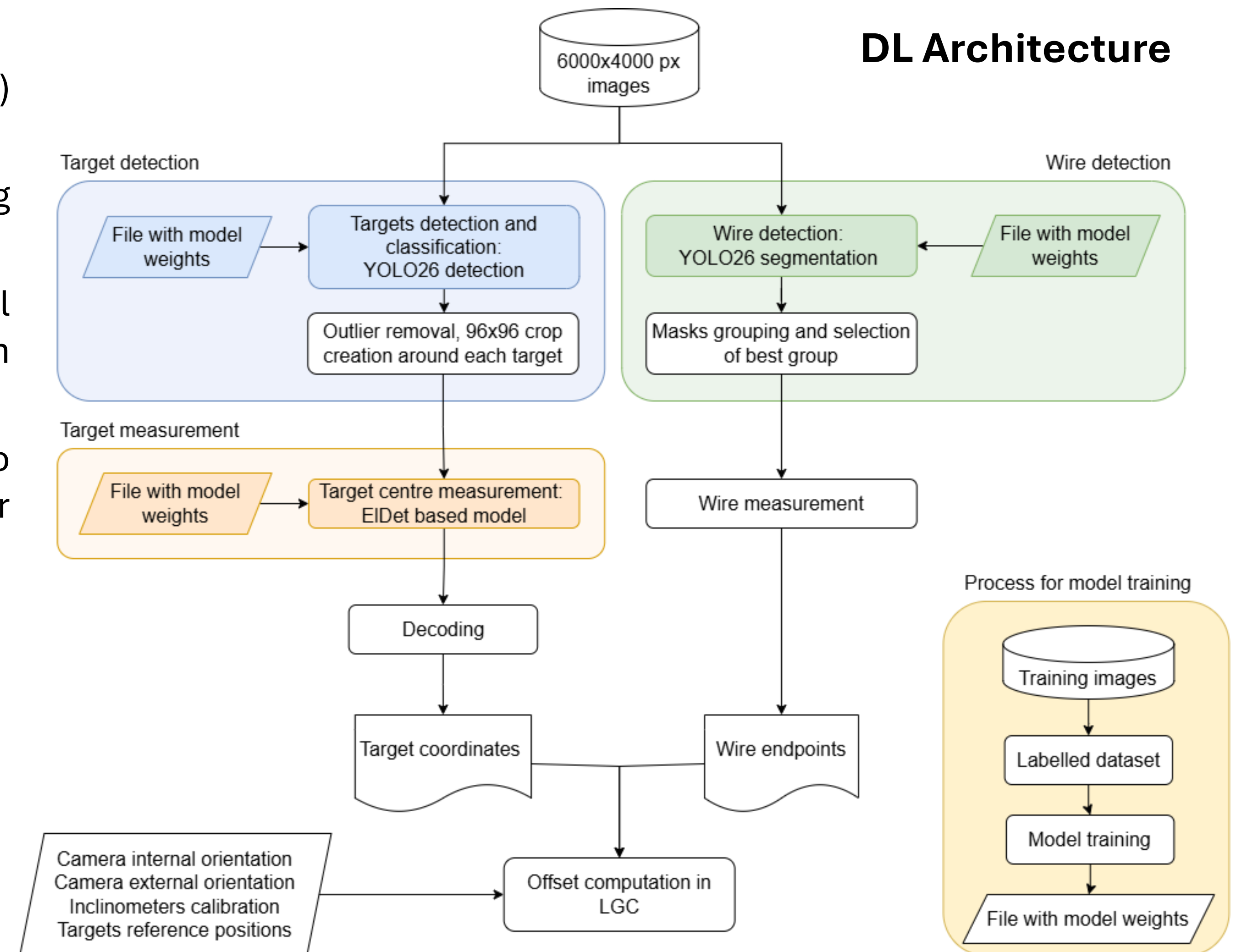
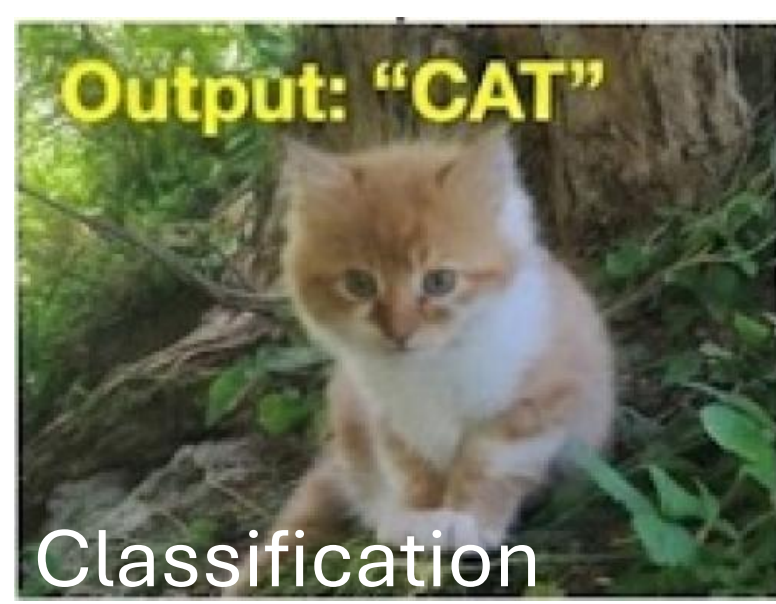
BACKGROUND & MOTIVATION

CERN has developed an automated photogrammetric system for radially aligning accelerator components through offset measurements against a stretched wire. The current analytical pipeline meets the required precision, but its hand-crafted, geometry-specific rules are fragile: variations in illumination, contrast, target appearance, or wire visibility cause missed or false detections, and each new target type requires dedicated development. Deep learning can learn robust features directly from data and provide a single framework for detecting both targets and wires. This work assesses whether its integration improves detection rate, reduces false detections and processing time, and maintains the required measurement precision.

DEEP LEARNING PIPELINE DEVELOPMENT

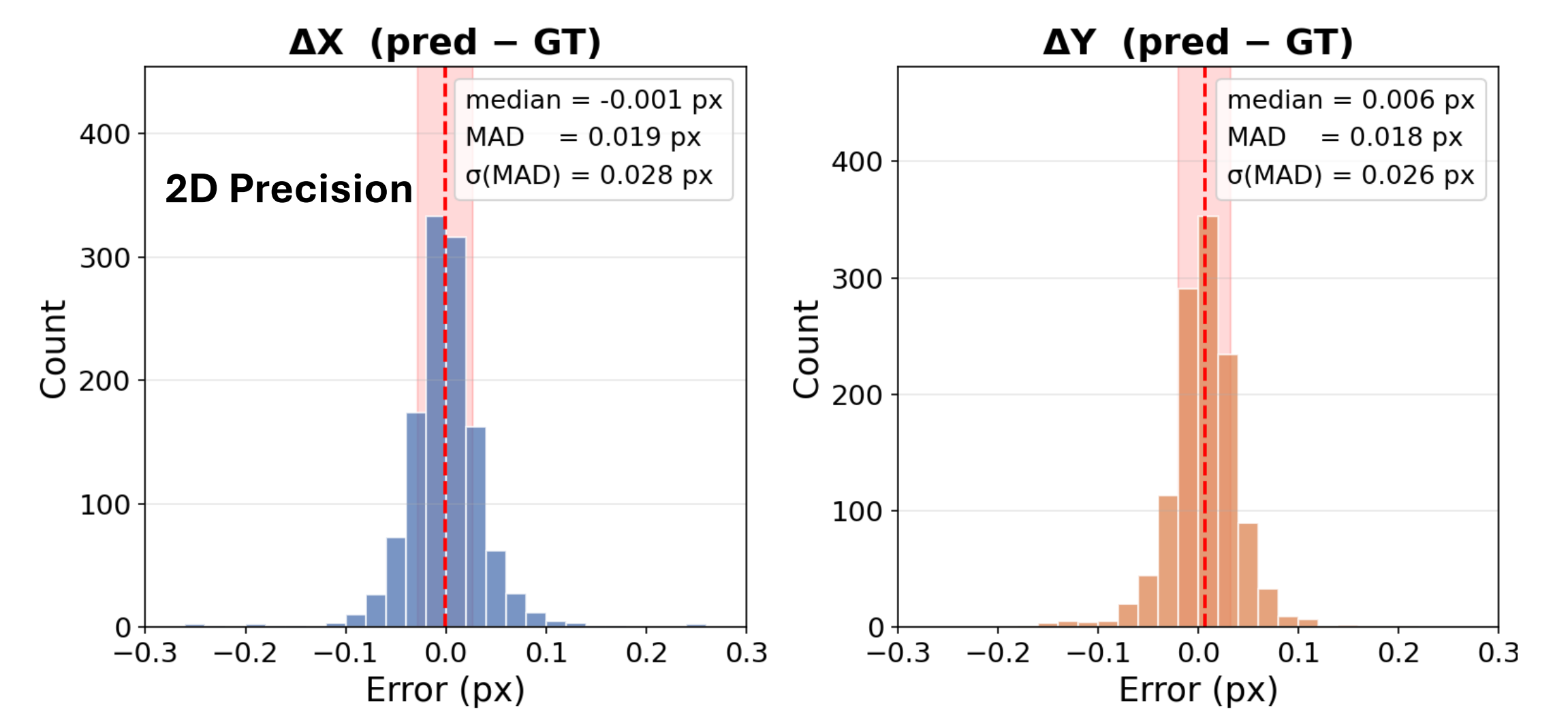
- The Deep Learning pipeline consists of three Convolutional Neural Network (CNN) models:
 - Target detection:** YOLO26s fine-tuned on ~27,000 training samples combining synthetic and real coded targets, uncoded targets, and ceramic spheres.
 - Target-centre measurement:** modified ElDet model that regresses sub-pixel centre coordinates within each detected bounding box, trained on real images with reference centres coordinates.
 - Wire detection:** YOLO26n-seg fine-tuned on full-resolution 416 × 416 px slices to preserve 3-4 px wires; per-slice masks are merged to initialise a region of interest for analytical edge refinement.

Principal CNNs Tasks



EVALUATION & RESULTS

- The evaluation used photogrammetric measurements acquired during a technical stop in the LHC.
- 2D precision:** For coded targets, the centre measurement model achieved median errors of -0.001 px in X and 0.006 px in Y, with standard deviations no greater than 0.028 px.
- 3D adjustment:** Centre measurement model vs. commercial solution - comparable performance was achieved, with median coordinate standard deviations below 4 μm and RMS standard deviations below 5 μm.



Median standard deviations				RMS standard deviations			
	x	y	z		x	y	z
DPA (mm)	0.0034	0.0039	0.0048	DPA (mm)	0.0020	0.0029	0.0029
Centre model (mm)	0.0025	0.0037	0.0046	Centre model (mm)	0.0023	0.0036	0.0034

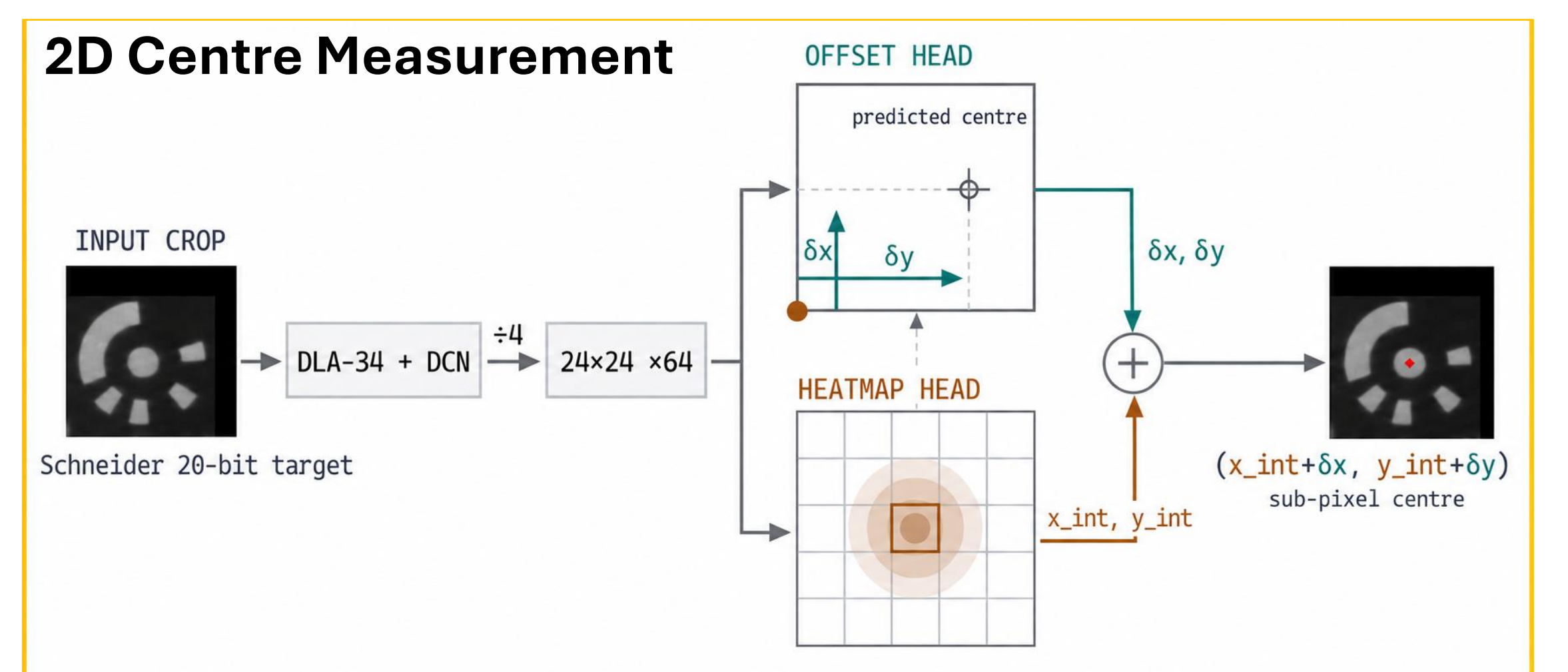
- Robustness:** Wire detection on 644 images: correct-detection rate improved from 95.2 % to 98.9 %, with missed detections cut from 20 to 4 (-80.0 %), incorrect detections from 11 to 3 (-72.7 %)

	Missed	Incorrect	Correct	Tot	%
Proposed	4	3	637	644	98.91
Current	20	11	613	644	95.19

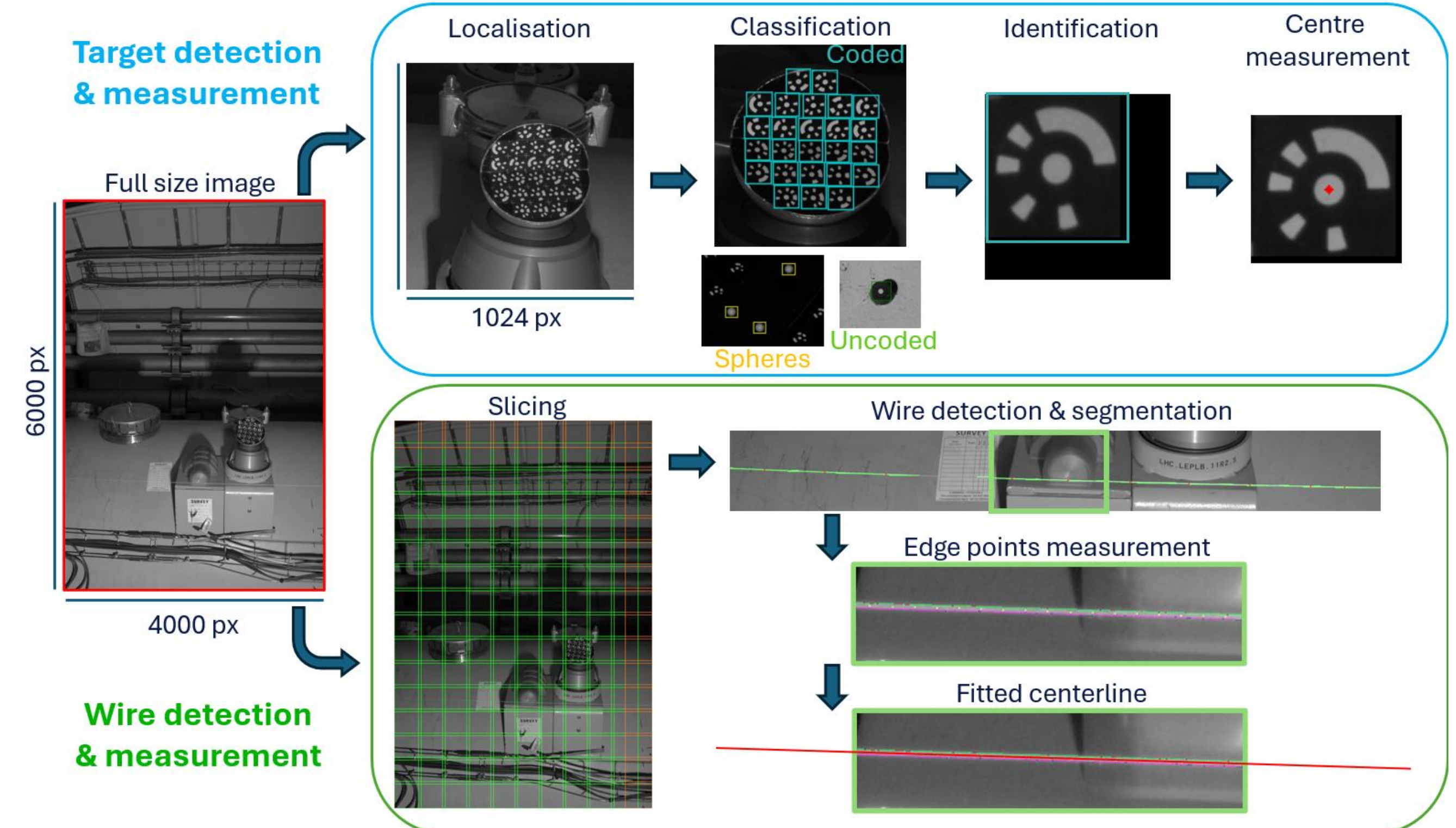
- Aggregate offset precision** across the nine measured wires: achieved sub-20 μm precision, while the proposed pipeline contributed 155 observations to the final adjustment, 6 more than the current pipeline, strengthening measurement redundancy.

	Proposed pipeline		Current pipeline	
	Prec. (mm)	#obs	Prec. (mm)	#obs
Tot	0.018	155	0.019	149

- Processing time:** the AI pipeline processed each image in 7 s compared with 15 s for the current pipeline, a 53.3 % reduction in end-to-end processing time.



Workflow Demonstration



CONCLUSION

This study demonstrates the feasibility of integrating deep learning into a photogrammetric pipeline for accelerator alignment. Across 644 unseen images, wire-detection failures fell by 72.7 % and target-centre errors remained below 0.02 px. Precision reached 18 μm from 155 observations, compared with 19 μm from 149 for the current pipeline, improving redundancy in the final adjustment. Processing time dropped from 15 s to 7 s per image, with sub-3 s expected on upgraded hardware. The proposed approach offers a credible path towards more robust, reliable, and efficient photogrammetric processing for accelerator alignment.