

Supplementary Information

Online Resource 1

Systematic Diagnosis of Cross-Domain Performance Degradation in PCB Defect Detection: A PKU-Source Study

Machine Vision and Applications

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This supplementary file contains Tables S1-S8 cited in the main manuscript. Scientific values are reproduced from the locked publication-facing source-data tables; this document standardizes only presentation, pagination, and typography.

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Table S1. Native-to-canonical class mapping and ontology validation across the four PCB domains

Canonical class	Six-class canonical audit ID	PKU native	MIXED-clean native	SELF native	DeepPCB native	Formal ontology status
mouse_bite	1	mouse_bite (ID 1)	ID 1	ID 2	ID 2	Included - exact across all four domains
open_circuit	2	open_circuit (ID 2)	ID 2	ID 0	ID 0	Included - exact across all four domains
short	3	short (ID 3)	ID 3	ID 1	ID 1	Included - exact across all four domains
spur	4	spur (ID 4)	ID 4	ID 3	ID 3	Included - exact across all four domains
spurious_copper	5	spurious_copper (ID 5)	ID 5	ID 5	ID 4	Included - exact across all four domains
missing_hole	0	missing_hole (ID 0)	ID 0	ID 4	ID 5 (pin-hole; not mapped)	Excluded from the formal K=5 ontology

Note. Only classes with exact one-to-one semantic correspondence across all four domains were admitted to the formal K=5 ontology: mouse_bite, open_circuit, short, spur, and spurious_copper. DeepPCB native ID 5 was reviewed as pin-hole and was therefore not mapped to PKU missing_hole. The ontology validation passed with ERROR=0 and WARNING=0.

Table S2. Formal Common-5 test-set composition and evaluation-chain quality control

Panel A. Before/after Common-5 filtering

Domain	Pre-filter test images	Common-5 test images	Pre-filter boxes	Common-5 boxes	Dropped non-Common boxes	Excluded-only images
PKU	240	200	1114	924	190	40
MIXED-clean	175	175	399	334	65	0
SELF	249	213	656	585	71	36
DeepPCB	150	150	1013	838	175	0

Panel B. Common-5 class composition

Domain	mouse_bite	open_circuit	short	spur	spurious_copper	Total Common-5 boxes
PKU	202	164	158	200	200	924
MIXED-clean	79	91	41	46	77	334
SELF	181	199	53	127	25	585
DeepPCB	207	171	145	165	150	838

Panel C. GT-as-prediction evaluation-chain positive control

Domain	Precision	Recall	mAP50	mAP50-95	Max coordinate round-trip error (px)	Min diagonal IoU	Max metric - ceiling	QC
PKU	1.000	1.000	0.995	0.995	0.000122	0.999991	0.000000	PASS
MIXED-clean	1.000	1.000	0.995	0.995	0.000031	0.999998	0.000000	PASS
SELF	1.000	1.000	0.995	0.995	0.000732	0.999949	0.000000	PASS
DeepPCB	1.000	1.000	0.995	0.995	0.000031	0.999996	0.000000	PASS

Note. Pre-filter counts are from the locked formal test splits before Common-5 ontology filtering. Common-5 counts are the exact images/boxes entering formal cross-domain evaluation after removing non-Common-5 boxes and excluding images containing only non-Common-5 classes. Confidence-1 GT pseudo-predictions reached the evaluator-specific ceiling in all four formal domains (maximum metric difference from ceiling = 0). Independent dataset-label integrity re-audit: PASS; ERROR=0; WARNING=0.

Table S3. Per-seed paired Recall degradation and 95% clustered-bootstrap confidence intervals under controlled imaging perturbations

Panel A. Original DynaFocus

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2024	PKU anchor	PKU	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.9050	0.9050	0.0000	[0.0000, 0.0000]	200/100	0	0
2024	PKU anchor	PKU	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.9050	0.9100	-0.0050	[-0.0150, 0.0000]	200/100	0	1
2024	PKU anchor	PKU	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.9050	0.9050	0.0000	[-0.0150, 0.0150]	200/100	1	1
2024	PKU anchor	PKU	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.9050	0.9050	0.0000	[-0.0150, 0.0150]	200/100	1	1
2024	PKU anchor	PKU	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.9050	0.9100	-0.0050	[-0.0200, 0.0100]	200/100	1	2
2024	PKU anchor	PKU	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.9050	0.9100	-0.0050	[-0.0200, 0.0100]	200/100	1	2
2024	PKU anchor	PKU	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.9050	0.9100	-0.0050	[-0.0250, 0.0150]	200/100	2	3
2024	PKU anchor	PKU	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.9050	0.9050	0.0000	[-0.0300, 0.0300]	200/100	4	4
2024	PKU anchor	PKU	Contrast	C01_CONTRAST_095	1 / 0.95	0.9050	0.9200	-0.0150	[-0.0350, 0.0000]	200/100	0	3
2024	PKU anchor	PKU	Contrast	C02_CONTRAST_090	2 / 0.9	0.9050	0.9250	-0.0200	[-0.0400, -0.0050]	200/100	0	4
2024	PKU anchor	PKU	Contrast	C03_CONTRAST_085	3 / 0.85	0.9050	0.9300	-0.0250	[-0.0500, 0.0000]	200/100	1	6
2024	PKU anchor	PKU	Contrast	C04_CONTRAST_080	4 / 0.8	0.9050	0.9350	-0.0300	[-0.0600, -0.0050]	200/100	1	7
2024	PKU anchor	PKU	Contrast	I2_CONTRAST_075	5 / 0.75	0.9050	0.9300	-0.0250	[-0.0550, 0.0050]	200/100	2	7
2024	PKU anchor	PKU	Contrast	C06_CONTRAST_070	6 / 0.7	0.9050	0.9250	-0.0200	[-0.0550, 0.0150]	200/100	3	7
2024	PKU anchor	PKU	Contrast	C07_CONTRAST_060	7 / 0.6	0.9050	0.9150	-0.0100	[-0.0550, 0.0350]	200/100	7	9
2024	PKU anchor	PKU	Contrast	C08_CONTRAST_050	8 / 0.5	0.9050	0.8600	0.0450	[0.0000, 0.0900]	200/100	15	6
2024	PKU anchor	PKU	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.9050	0.9100	-0.0050	[-0.0150, 0.0000]	200/100	0	1
2024	PKU anchor	PKU	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.9050	0.9150	-0.0100	[-0.0350, 0.0200]	200/100	3	5
2024	PKU anchor	PKU	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.9050	0.9150	-0.0100	[-0.0350, 0.0200]	200/100	3	5
2024	PKU anchor	PKU	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.9050	0.9150	-0.0100	[-0.0350, 0.0200]	200/100	3	5
2024	PKU anchor	PKU	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.9050	0.9150	-0.0100	[-0.0400, 0.0200]	200/100	4	6
2024	PKU anchor	PKU	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.9050	0.9150	-0.0100	[-0.0400, 0.0200]	200/100	4	6
2024	PKU anchor	PKU	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.9050	0.9000	0.0050	[-0.0250, 0.0350]	200/100	6	5
2024	PKU anchor	PKU	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.9050	0.8850	0.0200	[-0.0150, 0.0550]	200/100	10	6
2024	Target	MIXED-clean	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0

Table S3 (continued)

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2024	Target	MIXED-clean	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2024	Target	MIXED-clean	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2024	Target	MIXED-clean	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2024	Target	MIXED-clean	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.0000	0.0050	-0.0050	[-0.0162, 0.0000]	200/101	0	1
2024	Target	MIXED-clean	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.0000	0.0050	-0.0050	[-0.0162, 0.0000]	200/101	0	1
2024	Target	MIXED-clean	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.0000	0.0150	-0.0150	[-0.0337, 0.0000]	200/101	0	3
2024	Target	MIXED-clean	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.0000	0.0100	-0.0100	[-0.0253, 0.0000]	200/101	0	2
2024	Target	MIXED-clean	Contrast	C01_CONTRAST_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2024	Target	MIXED-clean	Contrast	C02_CONTRAST_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2024	Target	MIXED-clean	Contrast	C03_CONTRAST_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2024	Target	MIXED-clean	Contrast	C04_CONTRAST_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2024	Target	MIXED-clean	Contrast	I2_CONTRAST_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2024	Target	MIXED-clean	Contrast	C06_CONTRAST_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2024	Target	MIXED-clean	Contrast	C07_CONTRAST_060	7 / 0.6	0.0000	0.0050	-0.0050	[-0.0156, 0.0000]	200/101	0	1
2024	Target	MIXED-clean	Contrast	C08_CONTRAST_050	8 / 0.5	0.0000	0.0050	-0.0050	[-0.0156, 0.0000]	200/101	0	1
2024	Target	MIXED-clean	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2024	Target	MIXED-clean	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2024	Target	MIXED-clean	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2024	Target	MIXED-clean	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2024	Target	MIXED-clean	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2024	Target	MIXED-clean	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.0000	0.0050	-0.0050	[-0.0158, 0.0000]	200/101	0	1
2024	Target	MIXED-clean	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.0000	0.0050	-0.0050	[-0.0158, 0.0000]	200/101	0	1
2024	Target	MIXED-clean	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.0000	0.0050	-0.0050	[-0.0158, 0.0000]	200/101	0	1
2024	Target	SELF	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0

Table S3 (continued)

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2024	Target	SELF	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Contrast	C01_CONTRAST_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Contrast	C02_CONTRAST_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Contrast	C03_CONTRAST_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Contrast	C04_CONTRAST_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Contrast	I2_CONTRAST_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Contrast	C06_CONTRAST_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Contrast	C07_CONTRAST_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Contrast	C08_CONTRAST_050	8 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	DeepPCB	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0

Table S3 (continued)

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2024	Target	DeepPCB	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Contrast	C01_CONTRAST_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Contrast	C02_CONTRAST_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Contrast	C03_CONTRAST_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Contrast	C04_CONTRAST_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Contrast	I2_CONTRAST_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Contrast	C06_CONTRAST_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Contrast	C07_CONTRAST_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Contrast	C08_CONTRAST_050	8 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	PKU anchor	PKU	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.9400	0.9400	0.0000	[0.0000, 0.0000]	200/100	0	0
2025	PKU anchor	PKU	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.9400	0.9400	0.0000	[0.0000, 0.0000]	200/100	0	0
2025	PKU anchor	PKU	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.9400	0.9450	-0.0050	[-0.0150, 0.0000]	200/100	0	1
2025	PKU anchor	PKU	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.9400	0.9400	0.0000	[-0.0150, 0.0150]	200/100	1	1
2025	PKU anchor	PKU	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.9400	0.9350	0.0050	[-0.0100, 0.0250]	200/100	2	1
2025	PKU anchor	PKU	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.9400	0.9350	0.0050	[-0.0100, 0.0250]	200/100	2	1
2025	PKU anchor	PKU	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.9400	0.9300	0.0100	[-0.0100, 0.0300]	200/100	3	1
2025	PKU anchor	PKU	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.9400	0.9300	0.0100	[-0.0150, 0.0400]	200/100	4	2
2025	PKU anchor	PKU	Contrast	C01_CONTRAST_095	1 / 0.95	0.9400	0.9400	0.0000	[-0.0150, 0.0150]	200/100	1	1
2025	PKU anchor	PKU	Contrast	C02_CONTRAST_090	2 / 0.9	0.9400	0.9400	0.0000	[-0.0150, 0.0150]	200/100	1	1

Table S3 (continued)

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2025	PKU anchor	PKU	Contrast	C03_CONTRAST_085	3 / 0.85	0.9400	0.9400	0.0000	[-0.0150, 0.0150]	200/100	1	1
2025	PKU anchor	PKU	Contrast	C04_CONTRAST_080	4 / 0.8	0.9400	0.9400	0.0000	[-0.0150, 0.0150]	200/100	1	1
2025	PKU anchor	PKU	Contrast	I2_CONTRAST_075	5 / 0.75	0.9400	0.9350	0.0050	[-0.0100, 0.0250]	200/100	2	1
2025	PKU anchor	PKU	Contrast	C06_CONTRAST_070	6 / 0.7	0.9400	0.9350	0.0050	[-0.0150, 0.0300]	200/100	3	2
2025	PKU anchor	PKU	Contrast	C07_CONTRAST_060	7 / 0.6	0.9400	0.9300	0.0100	[-0.0200, 0.0450]	200/100	6	4
2025	PKU anchor	PKU	Contrast	C08_CONTRAST_050	8 / 0.5	0.9400	0.8950	0.0450	[0.0050, 0.0900]	200/100	13	4
2025	PKU anchor	PKU	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.9400	0.9400	0.0000	[0.0000, 0.0000]	200/100	0	0
2025	PKU anchor	PKU	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.9400	0.9450	-0.0050	[-0.0150, 0.0000]	200/100	0	1
2025	PKU anchor	PKU	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.9400	0.9400	0.0000	[-0.0150, 0.0150]	200/100	1	1
2025	PKU anchor	PKU	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.9400	0.9500	-0.0100	[-0.0250, 0.0000]	200/100	0	2
2025	PKU anchor	PKU	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.9400	0.9400	0.0000	[-0.0200, 0.0200]	200/100	2	2
2025	PKU anchor	PKU	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.9400	0.9350	0.0050	[-0.0200, 0.0300]	200/100	4	3
2025	PKU anchor	PKU	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.9400	0.9100	0.0300	[-0.0050, 0.0700]	200/100	9	3
2025	PKU anchor	PKU	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.9400	0.8700	0.0700	[0.0250, 0.1250]	200/100	16	2
2025	Target	MIXED-clean	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Contrast	C01_CONTRAST_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Contrast	C02_CONTRAST_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Contrast	C03_CONTRAST_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Contrast	C04_CONTRAST_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Contrast	I2_CONTRAST_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0

Table S3 (continued)

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2025	Target	MIXED-clean	Contrast	C06_CONTRAST_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Contrast	C07_CONTRAST_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Contrast	C08_CONTRAST_050	8 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	SELF	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Contrast	C01_CONTRAST_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Contrast	C02_CONTRAST_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Contrast	C03_CONTRAST_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Contrast	C04_CONTRAST_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Contrast	I2_CONTRAST_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Contrast	C06_CONTRAST_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Contrast	C07_CONTRAST_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Contrast	C08_CONTRAST_050	8 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0

Table S3 (continued)

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2025	Target	SELF	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	DeepPCB	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Contrast	C01_CONTRAST_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Contrast	C02_CONTRAST_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Contrast	C03_CONTRAST_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Contrast	C04_CONTRAST_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Contrast	I2_CONTRAST_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Contrast	C06_CONTRAST_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Contrast	C07_CONTRAST_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Contrast	C08_CONTRAST_050	8 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0

Table S3 (continued)

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2025	Target	DeepPCB	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	PKU anchor	PKU	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.9350	0.9300	0.0050	[0.0000, 0.0150]	200/100	1	0
2026	PKU anchor	PKU	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.9350	0.9400	-0.0050	[-0.0200, 0.0100]	200/100	1	2
2026	PKU anchor	PKU	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.9350	0.9450	-0.0100	[-0.0300, 0.0100]	200/100	1	3
2026	PKU anchor	PKU	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.9350	0.9450	-0.0100	[-0.0300, 0.0100]	200/100	1	3
2026	PKU anchor	PKU	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.9350	0.9450	-0.0100	[-0.0300, 0.0100]	200/100	1	3
2026	PKU anchor	PKU	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.9350	0.9450	-0.0100	[-0.0300, 0.0100]	200/100	1	3
2026	PKU anchor	PKU	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.9350	0.9500	-0.0150	[-0.0400, 0.0050]	200/100	1	4
2026	PKU anchor	PKU	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.9350	0.9500	-0.0150	[-0.0400, 0.0100]	200/100	2	5
2026	PKU anchor	PKU	Contrast	C01_CONTRAST_095	1 / 0.95	0.9350	0.9500	-0.0150	[-0.0350, 0.0050]	200/100	1	4
2026	PKU anchor	PKU	Contrast	C02_CONTRAST_090	2 / 0.9	0.9350	0.9500	-0.0150	[-0.0400, 0.0050]	200/100	1	4
2026	PKU anchor	PKU	Contrast	C03_CONTRAST_085	3 / 0.85	0.9350	0.9500	-0.0150	[-0.0400, 0.0050]	200/100	1	4
2026	PKU anchor	PKU	Contrast	C04_CONTRAST_080	4 / 0.8	0.9350	0.9550	-0.0200	[-0.0450, 0.0000]	200/100	1	5
2026	PKU anchor	PKU	Contrast	I2_CONTRAST_075	5 / 0.75	0.9350	0.9600	-0.0250	[-0.0500, 0.0000]	200/100	1	6
2026	PKU anchor	PKU	Contrast	C06_CONTRAST_070	6 / 0.7	0.9350	0.9550	-0.0200	[-0.0500, 0.0050]	200/100	2	6
2026	PKU anchor	PKU	Contrast	C07_CONTRAST_060	7 / 0.6	0.9350	0.9400	-0.0050	[-0.0350, 0.0250]	200/100	4	5
2026	PKU anchor	PKU	Contrast	C08_CONTRAST_050	8 / 0.5	0.9350	0.9050	0.0300	[-0.0100, 0.0750]	200/100	11	5
2026	PKU anchor	PKU	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.9350	0.9350	0.0000	[0.0000, 0.0000]	200/100	0	0
2026	PKU anchor	PKU	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.9350	0.9400	-0.0050	[-0.0300, 0.0150]	200/100	2	3
2026	PKU anchor	PKU	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.9350	0.9400	-0.0050	[-0.0300, 0.0200]	200/100	3	4
2026	PKU anchor	PKU	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.9350	0.9450	-0.0100	[-0.0400, 0.0200]	200/100	4	6

Table S3 (continued)

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2026	PKU anchor	PKU	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.9350	0.9500	-0.0150	[-0.0500, 0.0150]	200/100	4	7
2026	PKU anchor	PKU	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.9350	0.9400	-0.0050	[-0.0400, 0.0250]	200/100	6	7
2026	PKU anchor	PKU	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.9350	0.9250	0.0100	[-0.0300, 0.0500]	200/100	9	7
2026	PKU anchor	PKU	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.9350	0.9150	0.0200	[-0.0250, 0.0650]	200/100	12	8
2026	Target	MIXED-clean	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.0150	0.0100	0.0050	[0.0000, 0.0158]	200/101	1	0
2026	Target	MIXED-clean	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.0150	0.0200	-0.0050	[-0.0244, 0.0103]	200/101	1	2
2026	Target	MIXED-clean	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.0150	0.0250	-0.0100	[-0.0311, 0.0097]	200/101	1	3
2026	Target	MIXED-clean	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.0150	0.0200	-0.0050	[-0.0214, 0.0104]	200/101	1	2
2026	Target	MIXED-clean	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.0150	0.0250	-0.0100	[-0.0309, 0.0095]	200/101	1	3
2026	Target	MIXED-clean	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.0150	0.0150	0.0000	[-0.0199, 0.0194]	200/101	2	2
2026	Target	MIXED-clean	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.0150	0.0300	-0.0150	[-0.0404, 0.0101]	200/101	2	5
2026	Target	MIXED-clean	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.0150	0.0200	-0.0050	[-0.0302, 0.0202]	200/101	3	4
2026	Target	MIXED-clean	Contrast	C01_CONTRAST_095	1 / 0.95	0.0150	0.0150	0.0000	[0.0000, 0.0000]	200/101	0	0
2026	Target	MIXED-clean	Contrast	C02_CONTRAST_090	2 / 0.9	0.0150	0.0150	0.0000	[0.0000, 0.0000]	200/101	0	0
2026	Target	MIXED-clean	Contrast	C03_CONTRAST_085	3 / 0.85	0.0150	0.0100	0.0050	[0.0000, 0.0158]	200/101	1	0
2026	Target	MIXED-clean	Contrast	C04_CONTRAST_080	4 / 0.8	0.0150	0.0100	0.0050	[-0.0103, 0.0223]	200/101	2	1
2026	Target	MIXED-clean	Contrast	I2_CONTRAST_075	5 / 0.75	0.0150	0.0100	0.0050	[-0.0103, 0.0223]	200/101	2	1
2026	Target	MIXED-clean	Contrast	C06_CONTRAST_070	6 / 0.7	0.0150	0.0100	0.0050	[-0.0103, 0.0223]	200/101	2	1
2026	Target	MIXED-clean	Contrast	C07_CONTRAST_060	7 / 0.6	0.0150	0.0150	0.0000	[-0.0202, 0.0200]	200/101	2	2
2026	Target	MIXED-clean	Contrast	C08_CONTRAST_050	8 / 0.5	0.0150	0.0100	0.0050	[-0.0154, 0.0274]	200/101	3	2
2026	Target	MIXED-clean	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.0150	0.0150	0.0000	[0.0000, 0.0000]	200/101	0	0
2026	Target	MIXED-clean	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.0150	0.0200	-0.0050	[-0.0157, 0.0000]	200/101	0	1
2026	Target	MIXED-clean	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.0150	0.0150	0.0000	[-0.0147, 0.0150]	200/101	1	1
2026	Target	MIXED-clean	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.0150	0.0100	0.0050	[-0.0103, 0.0223]	200/101	2	1
2026	Target	MIXED-clean	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.0150	0.0100	0.0050	[-0.0103, 0.0223]	200/101	2	1
2026	Target	MIXED-clean	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.0150	0.0150	0.0000	[-0.0201, 0.0194]	200/101	2	2

Table S3 (continued)

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2026	Target	MIXED-clean	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.0150	0.0150	0.0000	[-0.0198, 0.0195]	200/101	2	2
2026	Target	MIXED-clean	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.0150	0.0100	0.0050	[-0.0104, 0.0235]	200/101	2	1
2026	Target	SELF	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.0000	0.0050	-0.0050	[-0.0154, 0.0000]	200/12	0	1
2026	Target	SELF	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.0000	0.0050	-0.0050	[-0.0154, 0.0000]	200/12	0	1
2026	Target	SELF	Contrast	C01_CONTRAST_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Contrast	C02_CONTRAST_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Contrast	C03_CONTRAST_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Contrast	C04_CONTRAST_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Contrast	I2_CONTRAST_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Contrast	C06_CONTRAST_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Contrast	C07_CONTRAST_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Contrast	C08_CONTRAST_050	8 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0

Table S3 (continued)

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2026	Target	DeepPCB	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Contrast	C01_CONTRAST_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Contrast	C02_CONTRAST_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Contrast	C03_CONTRAST_085	3 / 0.85	0.0000	0.0050	-0.0050	[-0.0154, 0.0000]	200/190	0	1
2026	Target	DeepPCB	Contrast	C04_CONTRAST_080	4 / 0.8	0.0000	0.0050	-0.0050	[-0.0154, 0.0000]	200/190	0	1
2026	Target	DeepPCB	Contrast	I2_CONTRAST_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Contrast	C06_CONTRAST_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Contrast	C07_CONTRAST_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Contrast	C08_CONTRAST_050	8 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.0000	0.0050	-0.0050	[-0.0154, 0.0000]	200/190	0	1
2026	Target	DeepPCB	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.0000	0.0050	-0.0050	[-0.0154, 0.0000]	200/190	0	1
2026	Target	DeepPCB	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.0000	0.0050	-0.0050	[-0.0154, 0.0000]	200/190	0	1
2026	Target	DeepPCB	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.0000	0.0050	-0.0050	[-0.0154, 0.0000]	200/190	0	1
2026	Target	DeepPCB	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.0000	0.0050	-0.0050	[-0.0152, 0.0000]	200/190	0	1
2026	Target	DeepPCB	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.0000	0.0100	-0.0100	[-0.0249, 0.0000]	200/190	0	2
2026	Target	DeepPCB	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.0000	0.0050	-0.0050	[-0.0152, 0.0000]	200/190	0	1

Panel note. Role identifies the template-disjoint PKU source anchor or observational target branch. "n / lin." gives selected targets / lineage clusters. R(I0), R(c), and D(c) follow Eq. (5) in the manuscript. The 95% CIs are the locked clustered paired-bootstrap intervals. No training, inference, or bootstrap calculation was rerun for this publication rendering.

Panel B. YOLOv12m Baseline

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2024	PKU anchor	PKU	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.9700	0.9700	0.0000	[0.0000, 0.0000]	200/100	0	0
2024	PKU anchor	PKU	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.9700	0.9700	0.0000	[0.0000, 0.0000]	200/100	0	0
2024	PKU anchor	PKU	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.9700	0.9600	0.0100	[0.0000, 0.0250]	200/100	2	0
2024	PKU anchor	PKU	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.9700	0.9650	0.0050	[-0.0100, 0.0250]	200/100	2	1
2024	PKU anchor	PKU	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.9700	0.9650	0.0050	[-0.0100, 0.0250]	200/100	2	1
2024	PKU anchor	PKU	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.9700	0.9700	0.0000	[-0.0150, 0.0150]	200/100	1	1
2024	PKU anchor	PKU	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.9700	0.9700	0.0000	[-0.0150, 0.0150]	200/100	1	1
2024	PKU anchor	PKU	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.9700	0.9650	0.0050	[-0.0100, 0.0250]	200/100	2	1
2024	PKU anchor	PKU	Contrast	C01_CONTRAST_095	1 / 0.95	0.9700	0.9700	0.0000	[0.0000, 0.0000]	200/100	0	0
2024	PKU anchor	PKU	Contrast	C02_CONTRAST_090	2 / 0.9	0.9700	0.9700	0.0000	[0.0000, 0.0000]	200/100	0	0
2024	PKU anchor	PKU	Contrast	C03_CONTRAST_085	3 / 0.85	0.9700	0.9750	-0.0050	[-0.0150, 0.0000]	200/100	0	1
2024	PKU anchor	PKU	Contrast	C04_CONTRAST_080	4 / 0.8	0.9700	0.9700	0.0000	[-0.0150, 0.0150]	200/100	1	1
2024	PKU anchor	PKU	Contrast	I2_CONTRAST_075	5 / 0.75	0.9700	0.9700	0.0000	[-0.0150, 0.0150]	200/100	1	1
2024	PKU anchor	PKU	Contrast	C06_CONTRAST_070	6 / 0.7	0.9700	0.9700	0.0000	[-0.0150, 0.0150]	200/100	1	1
2024	PKU anchor	PKU	Contrast	C07_CONTRAST_060	7 / 0.6	0.9700	0.9700	0.0000	[-0.0150, 0.0150]	200/100	1	1
2024	PKU anchor	PKU	Contrast	C08_CONTRAST_050	8 / 0.5	0.9700	0.9550	0.0150	[0.0000, 0.0350]	200/100	3	0
2024	PKU anchor	PKU	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.9700	0.9700	0.0000	[0.0000, 0.0000]	200/100	0	0
2024	PKU anchor	PKU	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.9700	0.9750	-0.0050	[-0.0150, 0.0000]	200/100	0	1
2024	PKU anchor	PKU	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.9700	0.9750	-0.0050	[-0.0250, 0.0100]	200/100	1	2
2024	PKU anchor	PKU	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.9700	0.9800	-0.0100	[-0.0300, 0.0100]	200/100	1	3
2024	PKU anchor	PKU	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.9700	0.9750	-0.0050	[-0.0300, 0.0201]	200/100	2	3
2024	PKU anchor	PKU	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.9700	0.9750	-0.0050	[-0.0300, 0.0201]	200/100	2	3
2024	PKU anchor	PKU	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.9700	0.9600	0.0100	[-0.0150, 0.0400]	200/100	4	2
2024	PKU anchor	PKU	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.9700	0.9450	0.0250	[-0.0050, 0.0600]	200/100	7	2
2024	Target	MIXED-clean	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.0600	0.0600	0.0000	[0.0000, 0.0000]	200/101	0	0
2024	Target	MIXED-clean	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.0600	0.0550	0.0050	[0.0000, 0.0156]	200/101	1	0

Table S3 (continued)

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2024	Target	MIXED-clean	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.0600	0.0600	0.0000	[-0.0156, 0.0148]	200/101	1	1
2024	Target	MIXED-clean	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.0600	0.0600	0.0000	[-0.0154, 0.0147]	200/101	1	1
2024	Target	MIXED-clean	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.0600	0.0750	-0.0150	[-0.0347, 0.0000]	200/101	0	3
2024	Target	MIXED-clean	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.0600	0.0750	-0.0150	[-0.0387, 0.0051]	200/101	1	4
2024	Target	MIXED-clean	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.0600	0.0650	-0.0050	[-0.0278, 0.0152]	200/101	2	3
2024	Target	MIXED-clean	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.0600	0.0550	0.0050	[-0.0108, 0.0217]	200/101	2	1
2024	Target	MIXED-clean	Contrast	C01_CONTRAST_095	1 / 0.95	0.0600	0.0700	-0.0100	[-0.0266, 0.0000]	200/101	0	2
2024	Target	MIXED-clean	Contrast	C02_CONTRAST_090	2 / 0.9	0.0600	0.0600	0.0000	[-0.0152, 0.0147]	200/101	1	1
2024	Target	MIXED-clean	Contrast	C03_CONTRAST_085	3 / 0.85	0.0600	0.0650	-0.0050	[-0.0249, 0.0105]	200/101	1	2
2024	Target	MIXED-clean	Contrast	C04_CONTRAST_080	4 / 0.8	0.0600	0.0600	0.0000	[-0.0152, 0.0147]	200/101	1	1
2024	Target	MIXED-clean	Contrast	I2_CONTRAST_075	5 / 0.75	0.0600	0.0550	0.0050	[-0.0188, 0.0290]	200/101	3	2
2024	Target	MIXED-clean	Contrast	C06_CONTRAST_070	6 / 0.7	0.0600	0.0450	0.0150	[-0.0052, 0.0378]	200/101	4	1
2024	Target	MIXED-clean	Contrast	C07_CONTRAST_060	7 / 0.6	0.0600	0.0350	0.0250	[0.0000, 0.0521]	200/101	6	1
2024	Target	MIXED-clean	Contrast	C08_CONTRAST_050	8 / 0.5	0.0600	0.0300	0.0300	[0.0048, 0.0591]	200/101	7	1
2024	Target	MIXED-clean	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.0600	0.0700	-0.0100	[-0.0266, 0.0000]	200/101	0	2
2024	Target	MIXED-clean	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.0600	0.0500	0.0100	[-0.0145, 0.0354]	200/101	4	2
2024	Target	MIXED-clean	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.0600	0.0400	0.0200	[-0.0055, 0.0474]	200/101	6	2
2024	Target	MIXED-clean	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.0600	0.0200	0.0400	[0.0087, 0.0773]	200/101	10	2
2024	Target	MIXED-clean	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.0600	0.0150	0.0450	[0.0101, 0.0825]	200/101	11	2
2024	Target	MIXED-clean	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.0600	0.0100	0.0500	[0.0191, 0.0870]	200/101	11	1
2024	Target	MIXED-clean	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.0600	0.0050	0.0550	[0.0249, 0.0900]	200/101	11	0
2024	Target	MIXED-clean	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.0600	0.0000	0.0600	[0.0297, 0.0978]	200/101	12	0
2024	Target	SELF	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0

Table S3 (continued)

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2024	Target	SELF	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Contrast	C01_CONTRAST_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Contrast	C02_CONTRAST_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Contrast	C03_CONTRAST_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Contrast	C04_CONTRAST_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Contrast	I2_CONTRAST_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Contrast	C06_CONTRAST_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Contrast	C07_CONTRAST_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Contrast	C08_CONTRAST_050	8 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	SELF	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2024	Target	DeepPCB	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.0000	0.0050	-0.0050	[-0.0154, 0.0000]	200/190	0	1
2024	Target	DeepPCB	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.0000	0.0050	-0.0050	[-0.0154, 0.0000]	200/190	0	1
2024	Target	DeepPCB	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.0000	0.0050	-0.0050	[-0.0154, 0.0000]	200/190	0	1

Table S3 (continued)

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2024	Target	DeepPCB	Contrast	C01_CONTRAST_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Contrast	C02_CONTRAST_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Contrast	C03_CONTRAST_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Contrast	C04_CONTRAST_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Contrast	I2_CONTRAST_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Contrast	C06_CONTRAST_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Contrast	C07_CONTRAST_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Contrast	C08_CONTRAST_050	8 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2024	Target	DeepPCB	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	PKU anchor	PKU	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.9300	0.9300	0.0000	[0.0000, 0.0000]	200/100	0	0
2025	PKU anchor	PKU	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.9300	0.9300	0.0000	[0.0000, 0.0000]	200/100	0	0
2025	PKU anchor	PKU	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.9300	0.9300	0.0000	[0.0000, 0.0000]	200/100	0	0
2025	PKU anchor	PKU	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.9300	0.9300	0.0000	[0.0000, 0.0000]	200/100	0	0
2025	PKU anchor	PKU	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.9300	0.9300	0.0000	[0.0000, 0.0000]	200/100	0	0
2025	PKU anchor	PKU	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.9300	0.9300	0.0000	[0.0000, 0.0000]	200/100	0	0
2025	PKU anchor	PKU	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.9300	0.9300	0.0000	[-0.0150, 0.0150]	200/100	1	1
2025	PKU anchor	PKU	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.9300	0.9200	0.0100	[-0.0100, 0.0300]	200/100	3	1
2025	PKU anchor	PKU	Contrast	C01_CONTRAST_095	1 / 0.95	0.9300	0.9300	0.0000	[0.0000, 0.0000]	200/100	0	0
2025	PKU anchor	PKU	Contrast	C02_CONTRAST_090	2 / 0.9	0.9300	0.9300	0.0000	[0.0000, 0.0000]	200/100	0	0
2025	PKU anchor	PKU	Contrast	C03_CONTRAST_085	3 / 0.85	0.9300	0.9300	0.0000	[0.0000, 0.0000]	200/100	0	0

Table S3 (continued)

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2025	PKU anchor	PKU	Contrast	C04_CONTRAST_080	4 / 0.8	0.9300	0.9300	0.0000	[0.0000, 0.0000]	200/100	0	0
2025	PKU anchor	PKU	Contrast	I2_CONTRAST_075	5 / 0.75	0.9300	0.9300	0.0000	[0.0000, 0.0000]	200/100	0	0
2025	PKU anchor	PKU	Contrast	C06_CONTRAST_070	6 / 0.7	0.9300	0.9300	0.0000	[0.0000, 0.0000]	200/100	0	0
2025	PKU anchor	PKU	Contrast	C07_CONTRAST_060	7 / 0.6	0.9300	0.9300	0.0000	[0.0000, 0.0000]	200/100	0	0
2025	PKU anchor	PKU	Contrast	C08_CONTRAST_050	8 / 0.5	0.9300	0.9200	0.0100	[0.0000, 0.0250]	200/100	2	0
2025	PKU anchor	PKU	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.9300	0.9250	0.0050	[0.0000, 0.0150]	200/100	1	0
2025	PKU anchor	PKU	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.9300	0.9300	0.0000	[-0.0150, 0.0150]	200/100	1	1
2025	PKU anchor	PKU	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.9300	0.9350	-0.0050	[-0.0200, 0.0100]	200/100	1	2
2025	PKU anchor	PKU	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.9300	0.9350	-0.0050	[-0.0200, 0.0100]	200/100	1	2
2025	PKU anchor	PKU	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.9300	0.9350	-0.0050	[-0.0200, 0.0100]	200/100	1	2
2025	PKU anchor	PKU	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.9300	0.9300	0.0000	[-0.0200, 0.0200]	200/100	2	2
2025	PKU anchor	PKU	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.9300	0.9200	0.0100	[-0.0101, 0.0350]	200/100	4	2
2025	PKU anchor	PKU	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.9300	0.9050	0.0250	[-0.0050, 0.0550]	200/100	7	2
2025	Target	MIXED-clean	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.0300	0.0300	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.0300	0.0300	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.0300	0.0300	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.0300	0.0300	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.0300	0.0300	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.0300	0.0250	0.0050	[0.0000, 0.0158]	200/101	1	0
2025	Target	MIXED-clean	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.0300	0.0450	-0.0150	[-0.0347, 0.0000]	200/101	0	3
2025	Target	MIXED-clean	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.0300	0.0400	-0.0100	[-0.0315, 0.0097]	200/101	1	3
2025	Target	MIXED-clean	Contrast	C01_CONTRAST_095	1 / 0.95	0.0300	0.0350	-0.0050	[-0.0160, 0.0000]	200/101	0	1
2025	Target	MIXED-clean	Contrast	C02_CONTRAST_090	2 / 0.9	0.0300	0.0300	0.0000	[-0.0146, 0.0148]	200/101	1	1
2025	Target	MIXED-clean	Contrast	C03_CONTRAST_085	3 / 0.85	0.0300	0.0250	0.0050	[0.0000, 0.0158]	200/101	1	0
2025	Target	MIXED-clean	Contrast	C04_CONTRAST_080	4 / 0.8	0.0300	0.0250	0.0050	[0.0000, 0.0158]	200/101	1	0
2025	Target	MIXED-clean	Contrast	I2_CONTRAST_075	5 / 0.75	0.0300	0.0250	0.0050	[0.0000, 0.0158]	200/101	1	0
2025	Target	MIXED-clean	Contrast	C06_CONTRAST_070	6 / 0.7	0.0300	0.0250	0.0050	[0.0000, 0.0158]	200/101	1	0

Table S3 (continued)

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2025	Target	MIXED-clean	Contrast	C07_CONTRAST_060	7 / 0.6	0.0300	0.0200	0.0100	[0.0000, 0.0248]	200/101	2	0
2025	Target	MIXED-clean	Contrast	C08_CONTRAST_050	8 / 0.5	0.0300	0.0200	0.0100	[0.0000, 0.0248]	200/101	2	0
2025	Target	MIXED-clean	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.0300	0.0300	0.0000	[0.0000, 0.0000]	200/101	0	0
2025	Target	MIXED-clean	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.0300	0.0400	-0.0100	[-0.0303, 0.0093]	200/101	1	3
2025	Target	MIXED-clean	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.0300	0.0350	-0.0050	[-0.0377, 0.0212]	200/101	3	4
2025	Target	MIXED-clean	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.0300	0.0300	0.0000	[-0.0302, 0.0248]	200/101	3	3
2025	Target	MIXED-clean	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.0300	0.0200	0.0100	[-0.0203, 0.0377]	200/101	4	2
2025	Target	MIXED-clean	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.0300	0.0000	0.0300	[0.0051, 0.0583]	200/101	6	0
2025	Target	MIXED-clean	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.0300	0.0000	0.0300	[0.0051, 0.0583]	200/101	6	0
2025	Target	MIXED-clean	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.0300	0.0000	0.0300	[0.0051, 0.0583]	200/101	6	0
2025	Target	SELF	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Contrast	C01_CONTRAST_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Contrast	C02_CONTRAST_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Contrast	C03_CONTRAST_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Contrast	C04_CONTRAST_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Contrast	I2_CONTRAST_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Contrast	C06_CONTRAST_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Contrast	C07_CONTRAST_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Contrast	C08_CONTRAST_050	8 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0

Table S3 (continued)

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2025	Target	SELF	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	SELF	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2025	Target	DeepPCB	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.0000	0.0050	-0.0050	[-0.0153, 0.0000]	200/190	0	1
2025	Target	DeepPCB	Contrast	C01_CONTRAST_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Contrast	C02_CONTRAST_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Contrast	C03_CONTRAST_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Contrast	C04_CONTRAST_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Contrast	I2_CONTRAST_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Contrast	C06_CONTRAST_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Contrast	C07_CONTRAST_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Contrast	C08_CONTRAST_050	8 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0

Table S3 (continued)

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2025	Target	DeepPCB	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2025	Target	DeepPCB	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	PKU anchor	PKU	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.9550	0.9550	0.0000	[0.0000, 0.0000]	200/100	0	0
2026	PKU anchor	PKU	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.9550	0.9550	0.0000	[0.0000, 0.0000]	200/100	0	0
2026	PKU anchor	PKU	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.9550	0.9600	-0.0050	[-0.0151, 0.0000]	200/100	0	1
2026	PKU anchor	PKU	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.9550	0.9500	0.0050	[-0.0150, 0.0300]	200/100	2	1
2026	PKU anchor	PKU	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.9550	0.9500	0.0050	[-0.0150, 0.0300]	200/100	2	1
2026	PKU anchor	PKU	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.9550	0.9500	0.0050	[-0.0150, 0.0300]	200/100	2	1
2026	PKU anchor	PKU	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.9550	0.9500	0.0050	[-0.0150, 0.0300]	200/100	2	1
2026	PKU anchor	PKU	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.9550	0.9600	-0.0050	[-0.0350, 0.0250]	200/100	2	3
2026	PKU anchor	PKU	Contrast	C01_CONTRAST_095	1 / 0.95	0.9550	0.9550	0.0000	[0.0000, 0.0000]	200/100	0	0
2026	PKU anchor	PKU	Contrast	C02_CONTRAST_090	2 / 0.9	0.9550	0.9600	-0.0050	[-0.0151, 0.0000]	200/100	0	1
2026	PKU anchor	PKU	Contrast	C03_CONTRAST_085	3 / 0.85	0.9550	0.9600	-0.0050	[-0.0151, 0.0000]	200/100	0	1
2026	PKU anchor	PKU	Contrast	C04_CONTRAST_080	4 / 0.8	0.9550	0.9650	-0.0100	[-0.0250, 0.0000]	200/100	0	2
2026	PKU anchor	PKU	Contrast	I2_CONTRAST_075	5 / 0.75	0.9550	0.9650	-0.0100	[-0.0300, 0.0100]	200/100	1	3
2026	PKU anchor	PKU	Contrast	C06_CONTRAST_070	6 / 0.7	0.9550	0.9650	-0.0100	[-0.0300, 0.0100]	200/100	1	3
2026	PKU anchor	PKU	Contrast	C07_CONTRAST_060	7 / 0.6	0.9550	0.9700	-0.0150	[-0.0450, 0.0100]	200/100	1	4
2026	PKU anchor	PKU	Contrast	C08_CONTRAST_050	8 / 0.5	0.9550	0.9700	-0.0150	[-0.0500, 0.0200]	200/100	2	5
2026	PKU anchor	PKU	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.9550	0.9550	0.0000	[0.0000, 0.0000]	200/100	0	0
2026	PKU anchor	PKU	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.9550	0.9650	-0.0100	[-0.0250, 0.0000]	200/100	0	2
2026	PKU anchor	PKU	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.9550	0.9650	-0.0100	[-0.0250, 0.0000]	200/100	0	2
2026	PKU anchor	PKU	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.9550	0.9800	-0.0250	[-0.0500, -0.0050]	200/100	0	5

Table S3 (continued)

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2026	PKU anchor	PKU	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.9550	0.9850	-0.0300	[-0.0600, -0.0050]	200/100	0	6
2026	PKU anchor	PKU	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.9550	0.9800	-0.0250	[-0.0550, 0.0000]	200/100	1	6
2026	PKU anchor	PKU	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.9550	0.9750	-0.0200	[-0.0550, 0.0150]	200/100	2	6
2026	PKU anchor	PKU	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.9550	0.9700	-0.0150	[-0.0500, 0.0200]	200/100	3	6
2026	Target	MIXED-clean	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.0900	0.0900	0.0000	[0.0000, 0.0000]	200/101	0	0
2026	Target	MIXED-clean	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.0900	0.0950	-0.0050	[-0.0158, 0.0000]	200/101	0	1
2026	Target	MIXED-clean	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.0900	0.1000	-0.0100	[-0.0250, 0.0000]	200/101	0	2
2026	Target	MIXED-clean	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.0900	0.0950	-0.0050	[-0.0217, 0.0104]	200/101	1	2
2026	Target	MIXED-clean	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.0900	0.1050	-0.0150	[-0.0314, 0.0000]	200/101	0	3
2026	Target	MIXED-clean	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.0900	0.1000	-0.0100	[-0.0250, 0.0000]	200/101	0	2
2026	Target	MIXED-clean	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.0900	0.1100	-0.0200	[-0.0394, -0.0047]	200/101	0	4
2026	Target	MIXED-clean	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.0900	0.1000	-0.0100	[-0.0370, 0.0156]	200/101	3	5
2026	Target	MIXED-clean	Contrast	C01_CONTRAST_095	1 / 0.95	0.0900	0.0900	0.0000	[0.0000, 0.0000]	200/101	0	0
2026	Target	MIXED-clean	Contrast	C02_CONTRAST_090	2 / 0.9	0.0900	0.0850	0.0050	[0.0000, 0.0159]	200/101	1	0
2026	Target	MIXED-clean	Contrast	C03_CONTRAST_085	3 / 0.85	0.0900	0.0950	-0.0050	[-0.0212, 0.0105]	200/101	1	2
2026	Target	MIXED-clean	Contrast	C04_CONTRAST_080	4 / 0.8	0.0900	0.1050	-0.0150	[-0.0355, 0.0052]	200/101	1	4
2026	Target	MIXED-clean	Contrast	I2_CONTRAST_075	5 / 0.75	0.0900	0.1050	-0.0150	[-0.0355, 0.0052]	200/101	1	4
2026	Target	MIXED-clean	Contrast	C06_CONTRAST_070	6 / 0.7	0.0900	0.1000	-0.0100	[-0.0332, 0.0108]	200/101	2	4
2026	Target	MIXED-clean	Contrast	C07_CONTRAST_060	7 / 0.6	0.0900	0.1050	-0.0150	[-0.0448, 0.0141]	200/101	3	6
2026	Target	MIXED-clean	Contrast	C08_CONTRAST_050	8 / 0.5	0.0900	0.1100	-0.0200	[-0.0524, 0.0105]	200/101	4	8
2026	Target	MIXED-clean	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.0900	0.0950	-0.0050	[-0.0156, 0.0000]	200/101	0	1
2026	Target	MIXED-clean	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.0900	0.1100	-0.0200	[-0.0487, 0.0053]	200/101	2	6
2026	Target	MIXED-clean	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.0900	0.1100	-0.0200	[-0.0547, 0.0142]	200/101	4	8
2026	Target	MIXED-clean	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.0900	0.1050	-0.0150	[-0.0531, 0.0236]	200/101	6	9
2026	Target	MIXED-clean	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.0900	0.0700	0.0200	[-0.0195, 0.0603]	200/101	10	6
2026	Target	MIXED-clean	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.0900	0.0250	0.0650	[0.0286, 0.1070]	200/101	15	2

Table S3 (continued)

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2026	Target	MIXED-clean	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.0900	0.0200	0.0700	[0.0311, 0.1122]	200/101	16	2
2026	Target	MIXED-clean	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.0900	0.0000	0.0900	[0.0531, 0.1292]	200/101	18	0
2026	Target	SELF	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Contrast	C01_CONTRAST_095	1 / 0.95	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Contrast	C02_CONTRAST_090	2 / 0.9	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Contrast	C03_CONTRAST_085	3 / 0.85	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Contrast	C04_CONTRAST_080	4 / 0.8	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Contrast	I2_CONTRAST_075	5 / 0.75	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Contrast	C06_CONTRAST_070	6 / 0.7	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Contrast	C07_CONTRAST_060	7 / 0.6	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Contrast	C08_CONTRAST_050	8 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0
2026	Target	SELF	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.0000	0.0000	0.0000	[0.0000, 0.0000]	200/12	0	0

Table S3 (continued)

Seed	Role	Domain	Factor	Condition	Level / value	R(I0)	R(c)	D(c)	95% CI	n / lin.	TP->FN	FN->TP
2026	Target	DeepPCB	Brightness	B01_BRIGHTNESS_095	1 / 0.95	0.0050	0.0050	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Brightness	B02_BRIGHTNESS_090	2 / 0.9	0.0050	0.0050	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Brightness	B03_BRIGHTNESS_085	3 / 0.85	0.0050	0.0050	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Brightness	B04_BRIGHTNESS_080	4 / 0.8	0.0050	0.0100	-0.0050	[-0.0152, 0.0000]	200/190	0	1
2026	Target	DeepPCB	Brightness	I1_BRIGHTNESS_075	5 / 0.75	0.0050	0.0100	-0.0050	[-0.0152, 0.0000]	200/190	0	1
2026	Target	DeepPCB	Brightness	B06_BRIGHTNESS_070	6 / 0.7	0.0050	0.0150	-0.0100	[-0.0254, 0.0000]	200/190	0	2
2026	Target	DeepPCB	Brightness	B07_BRIGHTNESS_060	7 / 0.6	0.0050	0.0150	-0.0100	[-0.0254, 0.0000]	200/190	0	2
2026	Target	DeepPCB	Brightness	B08_BRIGHTNESS_050	8 / 0.5	0.0050	0.0150	-0.0100	[-0.0254, 0.0000]	200/190	0	2
2026	Target	DeepPCB	Contrast	C01_CONTRAST_095	1 / 0.95	0.0050	0.0050	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Contrast	C02_CONTRAST_090	2 / 0.9	0.0050	0.0050	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Contrast	C03_CONTRAST_085	3 / 0.85	0.0050	0.0050	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Contrast	C04_CONTRAST_080	4 / 0.8	0.0050	0.0050	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Contrast	I2_CONTRAST_075	5 / 0.75	0.0050	0.0050	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Contrast	C06_CONTRAST_070	6 / 0.7	0.0050	0.0050	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Contrast	C07_CONTRAST_060	7 / 0.6	0.0050	0.0000	0.0050	[0.0000, 0.0152]	200/190	1	0
2026	Target	DeepPCB	Contrast	C08_CONTRAST_050	8 / 0.5	0.0050	0.0000	0.0050	[0.0000, 0.0152]	200/190	1	0
2026	Target	DeepPCB	Blur	G01_GAUSSIAN_BLUR_K3_S0P5	1 / 0.5	0.0050	0.0050	0.0000	[0.0000, 0.0000]	200/190	0	0
2026	Target	DeepPCB	Blur	I3_GAUSSIAN_BLUR_K5_S1	2 / 1	0.0050	0.0000	0.0050	[0.0000, 0.0152]	200/190	1	0
2026	Target	DeepPCB	Blur	G03_GAUSSIAN_BLUR_K7_S1P5	3 / 1.5	0.0050	0.0000	0.0050	[0.0000, 0.0152]	200/190	1	0
2026	Target	DeepPCB	Blur	G04_GAUSSIAN_BLUR_K9_S2	4 / 2	0.0050	0.0000	0.0050	[0.0000, 0.0152]	200/190	1	0
2026	Target	DeepPCB	Blur	G05_GAUSSIAN_BLUR_K11_S2P5	5 / 2.5	0.0050	0.0000	0.0050	[0.0000, 0.0152]	200/190	1	0
2026	Target	DeepPCB	Blur	G06_GAUSSIAN_BLUR_K13_S3	6 / 3	0.0050	0.0000	0.0050	[0.0000, 0.0152]	200/190	1	0
2026	Target	DeepPCB	Blur	G07_GAUSSIAN_BLUR_K15_S3P5	7 / 3.5	0.0050	0.0000	0.0050	[0.0000, 0.0152]	200/190	1	0
2026	Target	DeepPCB	Blur	G08_GAUSSIAN_BLUR_K17_S4	8 / 4	0.0050	0.0000	0.0050	[0.0000, 0.0152]	200/190	1	0

Panel note. Role identifies the template-disjoint PKU source anchor or observational target branch. "n / lin." gives selected targets / lineage clusters. R(I0), R(c), and D(c) follow Eq. (5) in the manuscript. The 95% CIs are the locked clustered paired-bootstrap intervals. No training, inference, or bootstrap calculation was rerun for this publication rendering.

Table S4. Target-minus-PKU domain-characteristic differences with 95% clustered-bootstrap confidence intervals

Target domain	Descriptor	Median diff.	95% CI	SMD	PKU clusters	Target clusters
DeepPCB	entropy	-4.259354	[-4.551021, -4.193058]	-9.650767	100	150
DeepPCB	bg_entropy	-4.290996	[-4.578993, -4.227281]	-9.613524	100	150
DeepPCB	gray_std	79.446127	[77.354311, 82.460624]	5.949969	100	150
DeepPCB	bg_gray_std	78.930019	[76.698369, 81.922352]	5.660351	100	150
DeepPCB	canonical_objects_per_megapixel	11.426649	[11.394551, 13.888532]	4.680907	100	150
DeepPCB	canonical_mean_short_side_ratio	0.027673	[0.026014, 0.029042]	4.025106	100	150
DeepPCB	size_tertile_analysis_medium_prop	0.666667	[0.600000, 0.732143]	4.004898	100	150
DeepPCB	canonical_total_box_area_ratio	0.014738	[0.013737, 0.016637]	2.720756	100	150
MIXED-clean	canonical_mean_short_side_ratio	0.054574	[0.051519, 0.058440]	4.233113	100	78
MIXED-clean	size_tertile_analysis_large_prop	1.000000	[1.000000, 1.000000]	4.068554	100	78
MIXED-clean	canonical_objects_per_megapixel	4.102430	[4.070332, 4.134951]	3.354509	100	78
MIXED-clean	size_tertile_analysis_small_prop	-1.000000	[-1.000000, -1.000000]	-24.840485	100	78
MIXED-clean	canonical_mean_area_ratio	0.008323	[0.007633, 0.009241]	3.118201	100	78
MIXED-clean	bg_gray_std	17.307792	[16.076721, 18.815931]	2.348185	100	78
MIXED-clean	gray_std	17.120128	[15.689565, 18.520510]	2.312069	100	78
MIXED-clean	canonical_total_box_area_ratio	0.013202	[0.011155, 0.016304]	2.185554	100	78
SELF	local_contrast_mean	3.232478	[2.928970, 3.486060]	5.250971	100	10
SELF	bg_local_contrast_mean	3.227009	[2.924023, 3.460722]	5.238792	100	10
SELF	bg_laplacian_variance	331.277454	[261.985337, 401.779045]	3.798389	100	10
SELF	laplacian_variance	331.876820	[267.813900, 409.515987]	3.789517	100	10
SELF	edge_density	0.028528	[0.025360, 0.036557]	2.702714	100	10
SELF	bg_edge_density	0.028704	[0.024967, 0.036660]	2.682421	100	10
SELF	gray_std	17.249860	[13.494440, 19.943492]	2.270391	100	10
SELF	bg_gray_std	17.234786	[13.624652, 19.994147]	2.268109	100	10

Note. Median diff. = target median - PKU median. All rows use 2000 clustered bootstrap repetitions with analysis_cluster_id as the resampling unit. PKU uses the template-disjoint Common-5 formal population (100 lineages); target cluster counts are inherited from the locked Stage29 formal population. SMD = standardized mean difference. These statistics are descriptive and are not causal contributions to detector degradation.

Table S5. Robustness of multivariate domain separation to spatial normalization, feature-space composition, and cluster-level resampling

Panel A. Spatial-normalization robustness of five-dimensional centroid distances

PCA space	Domain pair	Scope	Native D5	Normalized D5	Delta D5	Norm./native	Pearson r	Spearman rho
Visual-only	PKU - MIXED-clean	PKU-to-target	1.482	2.512	+1.031	1.696	0.941	0.829
Visual-only	PKU - SELF	PKU-to-target	2.248	1.247	-1.001	0.555	0.941	0.829
Visual-only	PKU - DeepPCB	PKU-to-target	5.909	6.307	+0.397	1.067	0.941	0.829
Visual-only	MIXED-clean - SELF	target-to-target	1.368	2.254	+0.886	1.647	0.941	0.829
Visual-only	MIXED-clean - DeepPCB	target-to-target	5.776	5.550	-0.226	0.961	0.941	0.829
Visual-only	SELF - DeepPCB	target-to-target	5.664	5.540	-0.124	0.978	0.941	0.829
Visual + background	PKU - MIXED-clean	PKU-to-target	2.077	3.541	+1.463	1.704	0.941	0.771
Visual + background	PKU - SELF	PKU-to-target	3.149	1.755	-1.394	0.557	0.941	0.771
Visual + background	PKU - DeepPCB	PKU-to-target	8.329	8.904	+0.574	1.069	0.941	0.771
Visual + background	MIXED-clean - SELF	target-to-target	1.918	3.175	+1.257	1.655	0.941	0.771
Visual + background	MIXED-clean - DeepPCB	target-to-target	8.136	7.807	-0.329	0.960	0.941	0.771
Visual + background	SELF - DeepPCB	target-to-target	7.998	7.822	-0.176	0.978	0.941	0.771
Combined	PKU - MIXED-clean	PKU-to-target	5.608	6.330	+0.722	1.129	0.970	1.000
Combined	PKU - SELF	PKU-to-target	3.359	2.419	-0.940	0.720	0.970	1.000
Combined	PKU - DeepPCB	PKU-to-target	9.271	9.848	+0.577	1.062	0.970	1.000
Combined	MIXED-clean - SELF	target-to-target	4.208	4.896	+0.688	1.164	0.970	1.000
Combined	MIXED-clean - DeepPCB	target-to-target	9.048	8.745	-0.303	0.967	0.970	1.000
Combined	SELF - DeepPCB	target-to-target	8.619	8.432	-0.188	0.978	0.970	1.000

Note. D5 is Euclidean distance between domain centroids in PC1-PC5. Spatial normalization used isotropic resizing to a fixed long side of 640 px with no crop or padding. Native median long-side resolutions were PKU 2759.0 px, MIXED-clean 640.0 px, SELF 1024.0 px, and DeepPCB 640.0 px. Pearson and Spearman statistics compare native and normalized distances across all six domain pairs within each PCA space.

Panel B. Normalized-condition stability under cluster-level resampling

PCA space	Domain pair	PCA refit median D5 [95% CI]	Refit CV	Centroid bootstrap median D5 [95% CI]	Centroid CV	PC1-PC5 subspace similarity median [95% lower]	PC1-PC5 cumulative EV median
Visual-only	PKU - MIXED-clean	2.515 [2.500, 2.525]	0.003	2.515 [2.345, 2.688]	0.036	0.984 [0.958]	0.989
Visual-only	PKU - SELF	1.250 [1.228, 1.262]	0.007	1.251 [1.174, 1.350]	0.035	0.984 [0.958]	0.989
Visual-only	PKU - DeepPCB	6.307 [6.299, 6.310]	0.000	6.309 [6.174, 6.446]	0.011	0.984 [0.958]	0.989
Visual-only	MIXED-clean - SELF	2.260 [2.247, 2.264]	0.002	2.259 [2.077, 2.439]	0.042	0.984 [0.958]	0.989
Visual-only	MIXED-clean - DeepPCB	5.549 [5.539, 5.552]	0.001	5.552 [5.404, 5.703]	0.014	0.984 [0.958]	0.989
Visual-only	SELF - DeepPCB	5.539 [5.530, 5.541]	0.000	5.542 [5.391, 5.708]	0.015	0.984 [0.958]	0.989
Visual + background	PKU - MIXED-clean	3.544 [3.524, 3.558]	0.002	3.547 [3.296, 3.800]	0.036	0.984 [0.959]	0.989
Visual + background	PKU - SELF	1.760 [1.728, 1.777]	0.007	1.765 [1.654, 1.905]	0.036	0.984 [0.959]	0.989
Visual + background	PKU - DeepPCB	8.904 [8.893, 8.908]	0.000	8.905 [8.730, 9.100]	0.011	0.984 [0.959]	0.989
Visual + background	MIXED-clean - SELF	3.184 [3.162, 3.188]	0.002	3.186 [2.923, 3.453]	0.043	0.984 [0.959]	0.989
Visual + background	MIXED-clean - DeepPCB	7.806 [7.790, 7.810]	0.001	7.810 [7.605, 8.031]	0.014	0.984 [0.959]	0.989
Visual + background	SELF - DeepPCB	7.821 [7.810, 7.824]	0.000	7.821 [7.617, 8.084]	0.015	0.984 [0.959]	0.989
Combined	PKU - MIXED-clean	6.313 [6.080, 6.459]	0.016	6.336 [5.984, 6.714]	0.030	0.769 [0.643]	0.848
Combined	PKU - SELF	2.223 [1.900, 2.520]	0.069	2.421 [1.695, 3.903]	0.231	0.769 [0.643]	0.848
Combined	PKU - DeepPCB	9.809 [9.662, 9.866]	0.005	9.858 [9.658, 10.062]	0.010	0.769 [0.643]	0.848
Combined	MIXED-clean - SELF	4.883 [4.672, 5.011]	0.019	4.955 [3.809, 5.900]	0.109	0.769 [0.643]	0.848
Combined	MIXED-clean - DeepPCB	8.737 [8.564, 8.820]	0.008	8.756 [8.506, 9.014]	0.015	0.769 [0.643]	0.848
Combined	SELF - DeepPCB	8.377 [8.220, 8.451]	0.007	8.463 [8.150, 8.867]	0.022	0.769 [0.643]	0.848

Note. PCA refit used 500 balanced cluster-level refits; centroid bootstrap used 2000 repetitions. The resampling unit was analysis_cluster_id. Visual-only uses 11 whole-image descriptors and is label-free. Visual + background adds annotation-assisted background descriptors. Combined adds geometry, scale composition, and class composition. Subspace similarity is reported for PC1-PC5. All PCA/centroid results are descriptive robustness evidence and are not causal fractions of cross-domain detector degradation.

Table S6. PKU source-estimator and rotation-lineage robustness

Panel A. PKU source-estimator robustness

Model	PKU source scope	Inventory	All files mean ± SD [95% CI]	Original only mean ± SD [95% CI]	Rotation only mean ± SD [95% CI]	Rotation - original Delta [95% CI]
Original DynaFocus	Stage23 template-disjoint Common-5 test	200 files / 100 lineages	0.4466 ± 0.0207 [0.4285, 0.4743]	0.4473 ± 0.0225 [0.4311, 0.4735]	0.4567 ± 0.0171 [0.4372, 0.4881]	+0.0094 [0.0001, 0.0212]
YOLOv12m Baseline	Stage23 template-disjoint Common-5 test	200 files / 100 lineages	0.4827 ± 0.0122 [0.4644, 0.5109]	0.4723 ± 0.0154 [0.4551, 0.5017]	0.5018 ± 0.0117 [0.4817, 0.5318]	+0.0295 [0.0181, 0.0410]
RT-DETR-L (confirmation)	Stage23 template-disjoint Common-5 test	200 files / 100 lineages	0.4723 ± 0.0107 [0.4550, 0.4994]	0.4673 ± 0.0080 [0.4509, 0.4944]	0.4833 ± 0.0146 [0.4651, 0.5117]	+0.0160 [0.0071, 0.0253]

Note. All rows use the same Stage23 template-disjoint Common-5 PKU test: 200 images, 100 original-rotation lineages, and 924 GT boxes. Point estimates are mean ± sample SD across three seeds; 95% CIs follow the locked 2000-draw class-stratified parent-lineage bootstrap. Primary-model source replays reproduce the verified Stage25 lineage; RT-DETR-L values are from the Stage25R source+target run.

Panel B. Target-retention robustness under the three PKU source estimators

Model	Target domain	All files mean $\pm$ SD [95% CI] (%)	Original only mean $\pm$ SD [95% CI] (%)	Rotation only mean $\pm$ SD [95% CI] (%)
Original DynaFocus	MIXED-clean	0.134 $\pm$ 0.056 [0.126, 0.140]	0.134 $\pm$ 0.055 [0.126, 0.139]	0.131 $\pm$ 0.055 [0.123, 0.137]
Original DynaFocus	SELF	0.0048 $\pm$ 0.0043 [0.0046, 0.0050]	0.0048 $\pm$ 0.0043 [0.0046, 0.0050]	0.0047 $\pm$ 0.0042 [0.0045, 0.0050]
Original DynaFocus	DeepPCB	0.0059 $\pm$ 0.0066 [0.0056, 0.0062]	0.0059 $\pm$ 0.0065 [0.0056, 0.0061]	0.0058 $\pm$ 0.0065 [0.0054, 0.0061]
YOLOv12m Baseline	MIXED-clean	1.497 $\pm$ 0.741 [1.414, 1.557]	1.533 $\pm$ 0.769 [1.444, 1.593]	1.438 $\pm$ 0.706 [1.356, 1.497]
YOLOv12m Baseline	SELF	0.0257 $\pm$ 0.0153 [0.0243, 0.0268]	0.0262 $\pm$ 0.0156 [0.0247, 0.0273]	0.0248 $\pm$ 0.0148 [0.0234, 0.0258]
YOLOv12m Baseline	DeepPCB	0.219 $\pm$ 0.277 [0.207, 0.229]	0.226 $\pm$ 0.285 [0.212, 0.235]	0.210 $\pm$ 0.265 [0.198, 0.219]
RT-DETR-L (confirmation)	MIXED-clean	2.611 $\pm$ 1.464 [2.465, 2.716]	2.634 $\pm$ 1.462 [2.490, 2.731]	2.558 $\pm$ 1.455 [2.409, 2.666]
RT-DETR-L (confirmation)	SELF	1.706e-04 $\pm$ 1.542e-04 [1.615e-04, 1.771e-04]	1.726e-04 $\pm$ 1.565e-04 [1.632e-04, 1.787e-04]	1.666e-04 $\pm$ 1.501e-04 [1.575e-04, 1.733e-04]
RT-DETR-L (confirmation)	DeepPCB	0.179 $\pm$ 0.156 [0.169, 0.187]	0.181 $\pm$ 0.157 [0.171, 0.188]	0.176 $\pm$ 0.153 [0.165, 0.183]

Note. Retention is computed seed-wise before cross-seed summarization. Primary-model target/source values retain the verified Stage25 lineage. RT-DETR-L uses fresh target mAP50-95 values and fresh PKU source estimators from the same Stage25R seed-group run; no historical RT-DETR-L target value is mixed with a new denominator. Bootstrap CIs resample PKU source lineages only. The largest 95% upper bound is 2.7308% for RT-DETR-L (confirmation), MIXED-clean, original-only source estimator.

Table S7. Sensitivity of floor classification and imaging-onset assignment to the prespecified analysis thresholds

Panel A. Primary analysis criterion and primary outcomes

Model	Domain	I0 Recall	Status	Brightness onset	Contrast onset	Blur onset
DynaFocus	DeepPCB	0.0000	Floor	-	-	-
DynaFocus	MIXED-clean	0.0050	Floor	-	-	-
DynaFocus	PKU	0.9267	Interpretable	No onset	No onset	No onset
DynaFocus	SELF	0.0000	Floor	-	-	-
YOLOv12m	DeepPCB	0.0017	Floor	-	-	-
YOLOv12m	MIXED-clean	0.0600	Interpretable	No onset	No onset	3.5 (drop 0.052)
YOLOv12m	PKU	0.9517	Interpretable	No onset	No onset	No onset
YOLOv12m	SELF	0.0000	Floor	-	-	-

Note. Primary criterion: mean I0 selected-target Recall <= 0.005 defines Floor; otherwise imaging onset is the first tested severity with mean Recall degradation >= 0.05 and positive degradation in all three seeds. Under this criterion, YOLOv12m on MIXED-clean has blur onset at 3.5 (drop 0.052). DynaFocus on MIXED-clean and YOLOv12m on DeepPCB are floor-limited.

Panel B1. Complete threshold-sensitivity matrix - floor threshold = 0

Model	Domain	IO Recall	Drop threshold	Status	Brightness	Contrast	Blur	Primary
DynaFocus	DeepPCB	0.0000	0.025	Floor	-	-	-	
DynaFocus	MIXED-clean	0.0050	0.025	Interpretable	No onset	No onset	No onset	
DynaFocus	PKU	0.9267	0.025	Interpretable	No onset	0.5 (drop 0.040)	4 (drop 0.037)	
DynaFocus	SELF	0.0000	0.025	Floor	-	-	-	
YOLOv12m	DeepPCB	0.0017	0.025	Interpretable	No onset	No onset	No onset	
YOLOv12m	MIXED-clean	0.0600	0.025	Interpretable	No onset	No onset	2.5 (drop 0.025)	
YOLOv12m	PKU	0.9517	0.025	Interpretable	No onset	No onset	No onset	
YOLOv12m	SELF	0.0000	0.025	Floor	-	-	-	
DynaFocus	DeepPCB	0.0000	0.05	Floor	-	-	-	
DynaFocus	MIXED-clean	0.0050	0.05	Interpretable	No onset	No onset	No onset	
DynaFocus	PKU	0.9267	0.05	Interpretable	No onset	No onset	No onset	
DynaFocus	SELF	0.0000	0.05	Floor	-	-	-	
YOLOv12m	DeepPCB	0.0017	0.05	Interpretable	No onset	No onset	No onset	
YOLOv12m	MIXED-clean	0.0600	0.05	Interpretable	No onset	No onset	3.5 (drop 0.052)	
YOLOv12m	PKU	0.9517	0.05	Interpretable	No onset	No onset	No onset	
YOLOv12m	SELF	0.0000	0.05	Floor	-	-	-	
DynaFocus	DeepPCB	0.0000	0.075	Floor	-	-	-	
DynaFocus	MIXED-clean	0.0050	0.075	Interpretable	No onset	No onset	No onset	
DynaFocus	PKU	0.9267	0.075	Interpretable	No onset	No onset	No onset	
DynaFocus	SELF	0.0000	0.075	Floor	-	-	-	
YOLOv12m	DeepPCB	0.0017	0.075	Interpretable	No onset	No onset	No onset	
YOLOv12m	MIXED-clean	0.0600	0.075	Interpretable	No onset	No onset	No onset	
YOLOv12m	PKU	0.9517	0.075	Interpretable	No onset	No onset	No onset	
YOLOv12m	SELF	0.0000	0.075	Floor	-	-	-	

Panel note. Positive-seed requirement = 3/3 for every row. A dash denotes a floor-limited cell for which onset is not interpreted. "No onset" denotes an interpretable cell in which no tested severity met the stated onset criterion. Rows marked Primary correspond to the manuscript primary policy (floor threshold 0.005; drop threshold 0.05). Exact onset values are operational under the stated criterion, not universal physical thresholds.

Panel B2. Complete threshold-sensitivity matrix - floor threshold = 0.0025

Model	Domain	IO Recall	Drop threshold	Status	Brightness	Contrast	Blur	Primary
DynaFocus	DeepPCB	0.0000	0.025	Floor	-	-	-	
DynaFocus	MIXED-clean	0.0050	0.025	Interpretable	No onset	No onset	No onset	
DynaFocus	PKU	0.9267	0.025	Interpretable	No onset	0.5 (drop 0.040)	4 (drop 0.037)	
DynaFocus	SELF	0.0000	0.025	Floor	-	-	-	
YOLOv12m	DeepPCB	0.0017	0.025	Floor	-	-	-	
YOLOv12m	MIXED-clean	0.0600	0.025	Interpretable	No onset	No onset	2.5 (drop 0.025)	
YOLOv12m	PKU	0.9517	0.025	Interpretable	No onset	No onset	No onset	
YOLOv12m	SELF	0.0000	0.025	Floor	-	-	-	
DynaFocus	DeepPCB	0.0000	0.05	Floor	-	-	-	
DynaFocus	MIXED-clean	0.0050	0.05	Interpretable	No onset	No onset	No onset	
DynaFocus	PKU	0.9267	0.05	Interpretable	No onset	No onset	No onset	
DynaFocus	SELF	0.0000	0.05	Floor	-	-	-	
YOLOv12m	DeepPCB	0.0017	0.05	Floor	-	-	-	
YOLOv12m	MIXED-clean	0.0600	0.05	Interpretable	No onset	No onset	3.5 (drop 0.052)	
YOLOv12m	PKU	0.9517	0.05	Interpretable	No onset	No onset	No onset	
YOLOv12m	SELF	0.0000	0.05	Floor	-	-	-	
DynaFocus	DeepPCB	0.0000	0.075	Floor	-	-	-	
DynaFocus	MIXED-clean	0.0050	0.075	Interpretable	No onset	No onset	No onset	
DynaFocus	PKU	0.9267	0.075	Interpretable	No onset	No onset	No onset	
DynaFocus	SELF	0.0000	0.075	Floor	-	-	-	
YOLOv12m	DeepPCB	0.0017	0.075	Floor	-	-	-	
YOLOv12m	MIXED-clean	0.0600	0.075	Interpretable	No onset	No onset	No onset	
YOLOv12m	PKU	0.9517	0.075	Interpretable	No onset	No onset	No onset	
YOLOv12m	SELF	0.0000	0.075	Floor	-	-	-	

Panel note. Positive-seed requirement = 3/3 for every row. A dash denotes a floor-limited cell for which onset is not interpreted. "No onset" denotes an interpretable cell in which no tested severity met the stated onset criterion. Rows marked Primary correspond to the manuscript primary policy (floor threshold 0.005; drop threshold 0.05). Exact onset values are operational under the stated criterion, not universal physical thresholds.

Panel B3. Complete threshold-sensitivity matrix - floor threshold = 0.005

Model	Domain	IO Recall	Drop threshold	Status	Brightness	Contrast	Blur	Primary
DynaFocus	DeepPCB	0.0000	0.025	Floor	-	-	-	
DynaFocus	MIXED-clean	0.0050	0.025	Floor	-	-	-	
DynaFocus	PKU	0.9267	0.025	Interpretable	No onset	0.5 (drop 0.040)	4 (drop 0.037)	
DynaFocus	SELF	0.0000	0.025	Floor	-	-	-	
YOLOv12m	DeepPCB	0.0017	0.025	Floor	-	-	-	
YOLOv12m	MIXED-clean	0.0600	0.025	Interpretable	No onset	No onset	2.5 (drop 0.025)	
YOLOv12m	PKU	0.9517	0.025	Interpretable	No onset	No onset	No onset	
YOLOv12m	SELF	0.0000	0.025	Floor	-	-	-	
DynaFocus	DeepPCB	0.0000	0.05	Floor	-	-	-	Yes
DynaFocus	MIXED-clean	0.0050	0.05	Floor	-	-	-	Yes
DynaFocus	PKU	0.9267	0.05	Interpretable	No onset	No onset	No onset	Yes
DynaFocus	SELF	0.0000	0.05	Floor	-	-	-	Yes
YOLOv12m	DeepPCB	0.0017	0.05	Floor	-	-	-	Yes
YOLOv12m	MIXED-clean	0.0600	0.05	Interpretable	No onset	No onset	3.5 (drop 0.052)	Yes
YOLOv12m	PKU	0.9517	0.05	Interpretable	No onset	No onset	No onset	Yes
YOLOv12m	SELF	0.0000	0.05	Floor	-	-	-	Yes
DynaFocus	DeepPCB	0.0000	0.075	Floor	-	-	-	
DynaFocus	MIXED-clean	0.0050	0.075	Floor	-	-	-	
DynaFocus	PKU	0.9267	0.075	Interpretable	No onset	No onset	No onset	
DynaFocus	SELF	0.0000	0.075	Floor	-	-	-	
YOLOv12m	DeepPCB	0.0017	0.075	Floor	-	-	-	
YOLOv12m	MIXED-clean	0.0600	0.075	Interpretable	No onset	No onset	No onset	
YOLOv12m	PKU	0.9517	0.075	Interpretable	No onset	No onset	No onset	
YOLOv12m	SELF	0.0000	0.075	Floor	-	-	-	

Panel note. Positive-seed requirement = 3/3 for every row. A dash denotes a floor-limited cell for which onset is not interpreted. "No onset" denotes an interpretable cell in which no tested severity met the stated onset criterion. Rows marked Primary correspond to the manuscript primary policy (floor threshold 0.005; drop threshold 0.05). Exact onset values are operational under the stated criterion, not universal physical thresholds.

Panel B4. Complete threshold-sensitivity matrix - floor threshold = 0.01

Model	Domain	IO Recall	Drop threshold	Status	Brightness	Contrast	Blur	Primary
DynaFocus	DeepPCB	0.0000	0.025	Floor	-	-	-	
DynaFocus	MIXED-clean	0.0050	0.025	Floor	-	-	-	
DynaFocus	PKU	0.9267	0.025	Interpretable	No onset	0.5 (drop 0.040)	4 (drop 0.037)	
DynaFocus	SELF	0.0000	0.025	Floor	-	-	-	
YOLOv12m	DeepPCB	0.0017	0.025	Floor	-	-	-	
YOLOv12m	MIXED-clean	0.0600	0.025	Interpretable	No onset	No onset	2.5 (drop 0.025)	
YOLOv12m	PKU	0.9517	0.025	Interpretable	No onset	No onset	No onset	
YOLOv12m	SELF	0.0000	0.025	Floor	-	-	-	
DynaFocus	DeepPCB	0.0000	0.05	Floor	-	-	-	
DynaFocus	MIXED-clean	0.0050	0.05	Floor	-	-	-	
DynaFocus	PKU	0.9267	0.05	Interpretable	No onset	No onset	No onset	
DynaFocus	SELF	0.0000	0.05	Floor	-	-	-	
YOLOv12m	DeepPCB	0.0017	0.05	Floor	-	-	-	
YOLOv12m	MIXED-clean	0.0600	0.05	Interpretable	No onset	No onset	3.5 (drop 0.052)	
YOLOv12m	PKU	0.9517	0.05	Interpretable	No onset	No onset	No onset	
YOLOv12m	SELF	0.0000	0.05	Floor	-	-	-	
DynaFocus	DeepPCB	0.0000	0.075	Floor	-	-	-	
DynaFocus	MIXED-clean	0.0050	0.075	Floor	-	-	-	
DynaFocus	PKU	0.9267	0.075	Interpretable	No onset	No onset	No onset	
DynaFocus	SELF	0.0000	0.075	Floor	-	-	-	
YOLOv12m	DeepPCB	0.0017	0.075	Floor	-	-	-	
YOLOv12m	MIXED-clean	0.0600	0.075	Interpretable	No onset	No onset	No onset	
YOLOv12m	PKU	0.9517	0.075	Interpretable	No onset	No onset	No onset	
YOLOv12m	SELF	0.0000	0.075	Floor	-	-	-	

Panel note. Positive-seed requirement = 3/3 for every row. A dash denotes a floor-limited cell for which onset is not interpreted. "No onset" denotes an interpretable cell in which no tested severity met the stated onset criterion. Rows marked Primary correspond to the manuscript primary policy (floor threshold 0.005; drop threshold 0.05). Exact onset values are operational under the stated criterion, not universal physical thresholds.

Table S8. Selected-target IO state frequencies across nine one-factor-at-a-time inference settings and low-threshold candidate diagnostics

Panel A1. Original DynaFocus - state frequencies (mean $\pm$ SD across seeds 2024, 2025, and 2026)

Domain	Setting	imgsz	conf	match IoU	TP	E1 missed target	E2 localization	E3 classification	Dominant
MIXED-clean	conf=.01	960	0.01	0.50	0.033 $\pm$ 0.028	0.520 $\pm$ 0.058	0.070 $\pm$ 0.017	0.377 $\pm$ 0.014	E1
MIXED-clean	conf=.05	960	0.05	0.50	0.018 $\pm$ 0.024	0.688 $\pm$ 0.039	0.063 $\pm$ 0.015	0.230 $\pm$ 0.020	E1
MIXED-clean	conf=.10	960	0.10	0.50	0.010 $\pm$ 0.017	0.772 $\pm$ 0.053	0.055 $\pm$ 0.018	0.163 $\pm$ 0.020	E1
MIXED-clean	conf=.50	960	0.50	0.50	0.002 $\pm$ 0.003	0.953 $\pm$ 0.031	0.008 $\pm$ 0.010	0.037 $\pm$ 0.018	E1
MIXED-clean	imgsz=640	640	0.25	0.50	0.145 $\pm$ 0.045	0.708 $\pm$ 0.051	0.053 $\pm$ 0.019	0.093 $\pm$ 0.024	E1
MIXED-clean	imgsz=800	800	0.25	0.50	0.040 $\pm$ 0.030	0.792 $\pm$ 0.085	0.048 $\pm$ 0.021	0.120 $\pm$ 0.056	E1
MIXED-clean	match=.30	960	0.25	0.30	0.017 $\pm$ 0.020	0.905 $\pm$ 0.049	0.008 $\pm$ 0.008	0.070 $\pm$ 0.030	E1
MIXED-clean	match=.70	960	0.25	0.70	0.003 $\pm$ 0.006	0.905 $\pm$ 0.049	0.020 $\pm$ 0.020	0.072 $\pm$ 0.028	E1
MIXED-clean	primary	960	0.25	0.50	0.005 $\pm$ 0.009	0.905 $\pm$ 0.049	0.018 $\pm$ 0.018	0.072 $\pm$ 0.028	E1
SELF	conf=.01	960	0.01	0.50	0.002 $\pm$ 0.003	0.823 $\pm$ 0.053	0.058 $\pm$ 0.018	0.117 $\pm$ 0.046	E1
SELF	conf=.05	960	0.05	0.50	0.000 $\pm$ 0.000	0.902 $\pm$ 0.043	0.050 $\pm$ 0.022	0.048 $\pm$ 0.021	E1
SELF	conf=.10	960	0.10	0.50	0.000 $\pm$ 0.000	0.925 $\pm$ 0.031	0.037 $\pm$ 0.013	0.038 $\pm$ 0.020	E1
SELF	conf=.50	960	0.50	0.50	0.000 $\pm$ 0.000	0.985 $\pm$ 0.005	0.008 $\pm$ 0.008	0.007 $\pm$ 0.003	E1
SELF	imgsz=640	640	0.25	0.50	0.000 $\pm$ 0.000	0.952 $\pm$ 0.028	0.022 $\pm$ 0.003	0.027 $\pm$ 0.029	E1
SELF	imgsz=800	800	0.25	0.50	0.000 $\pm$ 0.000	0.947 $\pm$ 0.016	0.022 $\pm$ 0.003	0.032 $\pm$ 0.014	E1
SELF	match=.30	960	0.25	0.30	0.000 $\pm$ 0.000	0.958 $\pm$ 0.008	0.022 $\pm$ 0.003	0.020 $\pm$ 0.010	E1
SELF	match=.70	960	0.25	0.70	0.000 $\pm$ 0.000	0.958 $\pm$ 0.008	0.022 $\pm$ 0.003	0.020 $\pm$ 0.010	E1
SELF	primary	960	0.25	0.50	0.000 $\pm$ 0.000	0.958 $\pm$ 0.008	0.022 $\pm$ 0.003	0.020 $\pm$ 0.010	E1
DeepPCB	conf=.01	960	0.01	0.50	0.000 $\pm$ 0.000	0.940 $\pm$ 0.054	0.013 $\pm$ 0.012	0.047 $\pm$ 0.043	E1
DeepPCB	conf=.05	960	0.05	0.50	0.000 $\pm$ 0.000	0.987 $\pm$ 0.012	0.000 $\pm$ 0.000	0.013 $\pm$ 0.012	E1
DeepPCB	conf=.10	960	0.10	0.50	0.000 $\pm$ 0.000	0.993 $\pm$ 0.006	0.000 $\pm$ 0.000	0.007 $\pm$ 0.006	E1
DeepPCB	conf=.50	960	0.50	0.50	0.000 $\pm$ 0.000	1.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	E1
DeepPCB	imgsz=640	640	0.25	0.50	0.000 $\pm$ 0.000	0.997 $\pm$ 0.003	0.000 $\pm$ 0.000	0.003 $\pm$ 0.003	E1
DeepPCB	imgsz=800	800	0.25	0.50	0.000 $\pm$ 0.000	1.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	E1
DeepPCB	match=.30	960	0.25	0.30	0.000 $\pm$ 0.000	0.998 $\pm$ 0.003	0.000 $\pm$ 0.000	0.002 $\pm$ 0.003	E1
DeepPCB	match=.70	960	0.25	0.70	0.000 $\pm$ 0.000	0.998 $\pm$ 0.003	0.000 $\pm$ 0.000	0.002 $\pm$ 0.003	E1
DeepPCB	primary	960	0.25	0.50	0.000 $\pm$ 0.000	0.998 $\pm$ 0.003	0.000 $\pm$ 0.000	0.002 $\pm$ 0.003	E1

Panel note. The primary setting is imgsz=960, conf=0.25, and match IoU=0.50. The nine unique settings vary input size, confidence threshold, or matching IoU one factor at a time; the primary setting is counted once. TP, E1, E2, and E3 are mutually exclusive selected-target states.

Panel A2. YOLOv12m Baseline - state frequencies (mean $\pm$ SD across seeds 2024, 2025, and 2026)

Domain	Setting	imgsz	conf	match IoU	TP	E1 missed target	E2 localization	E3 classification	Dominant
MIXED-clean	conf=.01	960	0.01	0.50	0.112 $\pm$ 0.051	0.613 $\pm$ 0.065	0.108 $\pm$ 0.012	0.167 $\pm$ 0.033	E1
MIXED-clean	conf=.05	960	0.05	0.50	0.085 $\pm$ 0.048	0.733 $\pm$ 0.059	0.072 $\pm$ 0.003	0.110 $\pm$ 0.026	E1
MIXED-clean	conf=.10	960	0.10	0.50	0.070 $\pm$ 0.033	0.773 $\pm$ 0.025	0.072 $\pm$ 0.013	0.085 $\pm$ 0.026	E1
MIXED-clean	conf=.50	960	0.50	0.50	0.045 $\pm$ 0.031	0.882 $\pm$ 0.050	0.033 $\pm$ 0.018	0.040 $\pm$ 0.023	E1
MIXED-clean	imgsz=640	640	0.25	0.50	0.362 $\pm$ 0.060	0.500 $\pm$ 0.079	0.087 $\pm$ 0.030	0.052 $\pm$ 0.018	E1
MIXED-clean	imgsz=800	800	0.25	0.50	0.157 $\pm$ 0.016	0.725 $\pm$ 0.035	0.050 $\pm$ 0.010	0.068 $\pm$ 0.023	E1
MIXED-clean	match=.30	960	0.25	0.30	0.090 $\pm$ 0.036	0.827 $\pm$ 0.043	0.025 $\pm$ 0.015	0.058 $\pm$ 0.025	E1
MIXED-clean	match=.70	960	0.25	0.70	0.007 $\pm$ 0.006	0.827 $\pm$ 0.043	0.105 $\pm$ 0.039	0.062 $\pm$ 0.024	E1
MIXED-clean	primary	960	0.25	0.50	0.060 $\pm$ 0.030	0.827 $\pm$ 0.043	0.055 $\pm$ 0.028	0.058 $\pm$ 0.025	E1
SELF	conf=.01	960	0.01	0.50	0.000 $\pm$ 0.000	0.865 $\pm$ 0.031	0.073 $\pm$ 0.010	0.062 $\pm$ 0.028	E1
SELF	conf=.05	960	0.05	0.50	0.000 $\pm$ 0.000	0.898 $\pm$ 0.019	0.057 $\pm$ 0.012	0.045 $\pm$ 0.018	E1
SELF	conf=.10	960	0.10	0.50	0.000 $\pm$ 0.000	0.915 $\pm$ 0.015	0.048 $\pm$ 0.006	0.037 $\pm$ 0.010	E1
SELF	conf=.50	960	0.50	0.50	0.000 $\pm$ 0.000	0.972 $\pm$ 0.006	0.012 $\pm$ 0.003	0.017 $\pm$ 0.008	E1
SELF	imgsz=640	640	0.25	0.50	0.000 $\pm$ 0.000	0.965 $\pm$ 0.010	0.018 $\pm$ 0.003	0.017 $\pm$ 0.010	E1
SELF	imgsz=800	800	0.25	0.50	0.000 $\pm$ 0.000	0.943 $\pm$ 0.016	0.027 $\pm$ 0.010	0.030 $\pm$ 0.010	E1
SELF	match=.30	960	0.25	0.30	0.000 $\pm$ 0.000	0.950 $\pm$ 0.005	0.023 $\pm$ 0.003	0.027 $\pm$ 0.003	E1
SELF	match=.70	960	0.25	0.70	0.000 $\pm$ 0.000	0.950 $\pm$ 0.005	0.023 $\pm$ 0.003	0.027 $\pm$ 0.003	E1
SELF	primary	960	0.25	0.50	0.000 $\pm$ 0.000	0.950 $\pm$ 0.005	0.023 $\pm$ 0.003	0.027 $\pm$ 0.003	E1
DeepPCB	conf=.01	960	0.01	0.50	0.002 $\pm$ 0.003	0.962 $\pm$ 0.028	0.000 $\pm$ 0.000	0.037 $\pm$ 0.025	E1
DeepPCB	conf=.05	960	0.05	0.50	0.002 $\pm$ 0.003	0.977 $\pm$ 0.020	0.000 $\pm$ 0.000	0.022 $\pm$ 0.018	E1
DeepPCB	conf=.10	960	0.10	0.50	0.002 $\pm$ 0.003	0.982 $\pm$ 0.018	0.000 $\pm$ 0.000	0.017 $\pm$ 0.015	E1
DeepPCB	conf=.50	960	0.50	0.50	0.000 $\pm$ 0.000	0.995 $\pm$ 0.005	0.000 $\pm$ 0.000	0.005 $\pm$ 0.005	E1
DeepPCB	imgsz=640	640	0.25	0.50	0.000 $\pm$ 0.000	0.988 $\pm$ 0.016	0.000 $\pm$ 0.000	0.012 $\pm$ 0.016	E1
DeepPCB	imgsz=800	800	0.25	0.50	0.000 $\pm$ 0.000	0.982 $\pm$ 0.028	0.000 $\pm$ 0.000	0.018 $\pm$ 0.028	E1
DeepPCB	match=.30	960	0.25	0.30	0.002 $\pm$ 0.003	0.987 $\pm$ 0.013	0.000 $\pm$ 0.000	0.012 $\pm$ 0.010	E1
DeepPCB	match=.70	960	0.25	0.70	0.002 $\pm$ 0.003	0.987 $\pm$ 0.013	0.000 $\pm$ 0.000	0.012 $\pm$ 0.010	E1
DeepPCB	primary	960	0.25	0.50	0.002 $\pm$ 0.003	0.987 $\pm$ 0.013	0.000 $\pm$ 0.000	0.012 $\pm$ 0.010	E1

Panel note. The primary setting is imgsz=960, conf=0.25, and match IoU=0.50. The nine unique settings vary input size, confidence threshold, or matching IoU one factor at a time; the primary setting is counted once. TP, E1, E2, and E3 are mutually exclusive selected-target states.

Panel B. Low-threshold diagnostics

Model	Domain	Class-agnostic Recall at conf=0.01	Primary E1 pooled n	No canonical-overlap n	Pooled share of E1	Seed-wise share mean ± SD	n seeds
Original DynaFocus	MIXED-clean	0.077 ± 0.040	543	228	42.0%	42.2 ± 6.7%	3
Original DynaFocus	SELF	0.012 ± 0.003	575	365	63.5%	63.4 ± 11.0%	3
Original DynaFocus	DeepPCB	0.000 ± 0.000	599	438	73.1%	73.1 ± 19.2%	3
YOLOv12m Baseline	MIXED-clean	0.132 ± 0.055	496	221	44.6%	44.2 ± 11.3%	3
YOLOv12m Baseline	SELF	0.022 ± 0.003	570	414	72.6%	72.6 ± 5.1%	3
YOLOv12m Baseline	DeepPCB	0.018 ± 0.015	592	543	91.7%	91.7 ± 5.3%	3

Note. Panel B reports class-agnostic Recall at conf=0.01 and a conf=0.001 diagnostic candidate audit at the primary setting. Candidate-audit proportions use primary-point E1 cases as the denominator. A "no canonical-overlap candidate" case has no Common-5 prediction above the 0.001 capture threshold with positive box overlap with the selected target. The low-threshold diagnostic does not change the formal E1/E2/E3/TP state assignment.