



SHANGHAI IC R&D CENTER  
上海集成电路研发中心有限公司



# Machine Learning Hotspot Prediction Significantly Improve Capture Rate on Wafer

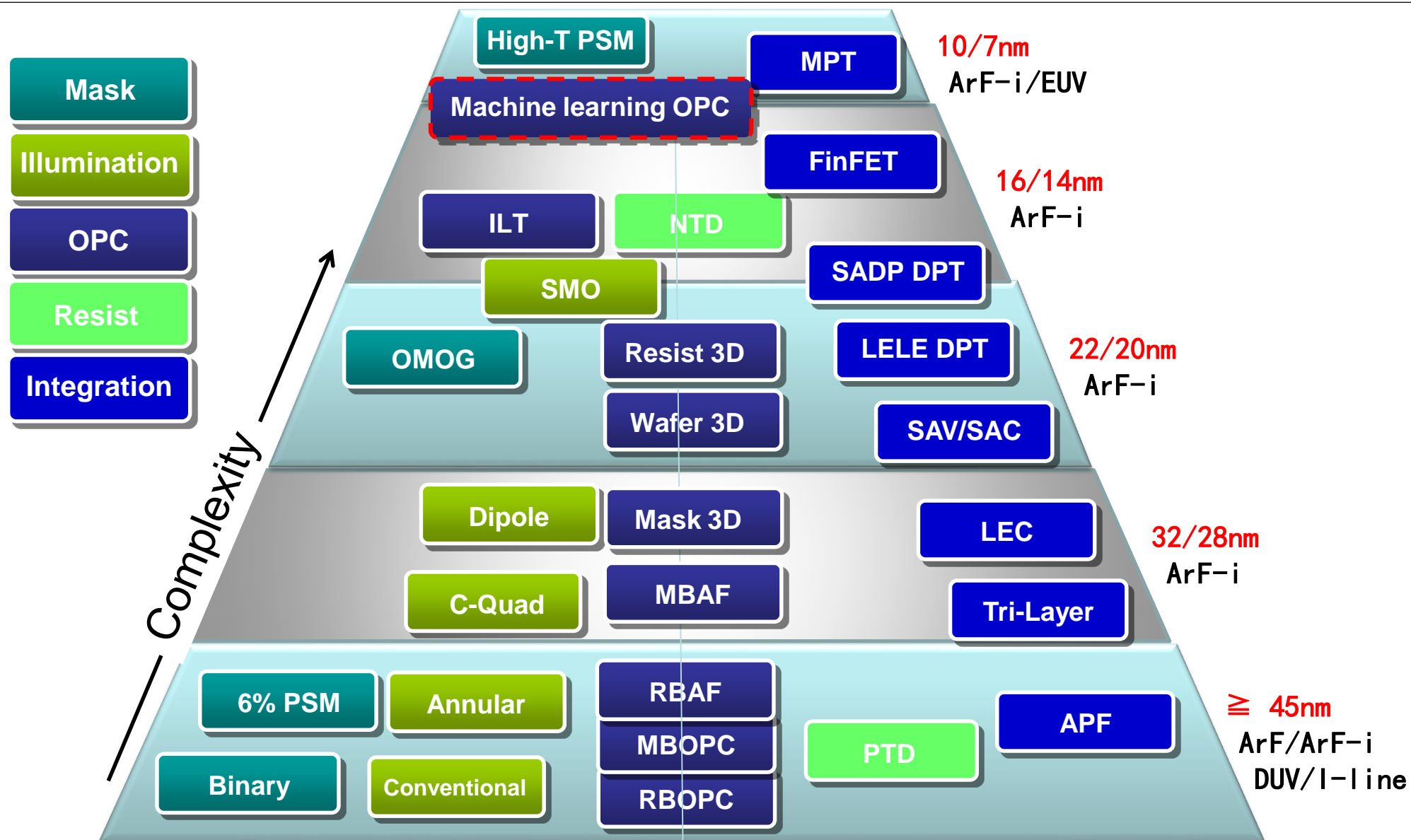
Wei.Yuan  
ICRD/ASML  
2020.11.06

# >>> Outline

---

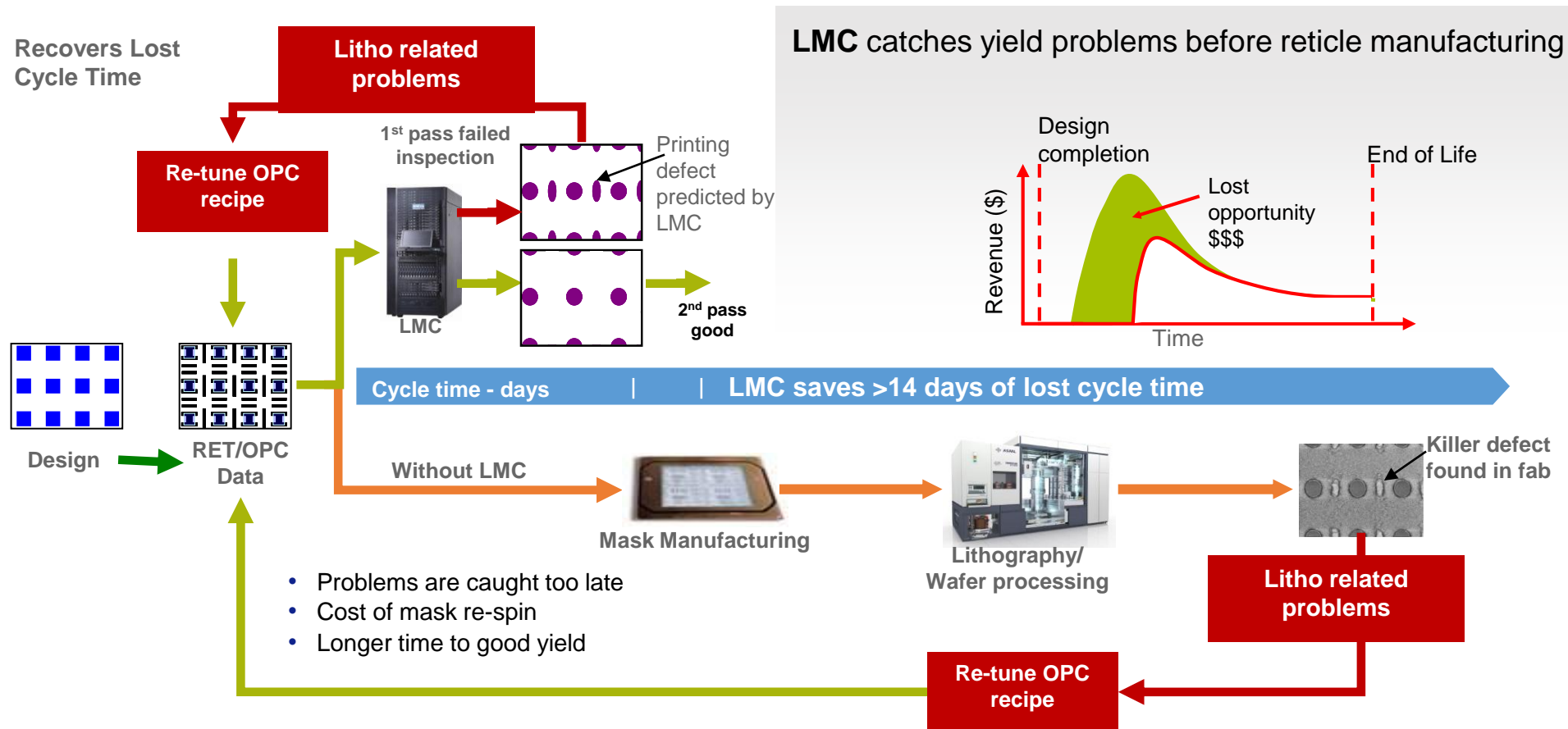
- Patterning Technology Roadmap
- Hotspot Prediction Background
- Machine Learning Hotspot Prediction
- Wafer Data Verification and Result Analysis
- Summary

# >>> Patterning Technology Roadmap



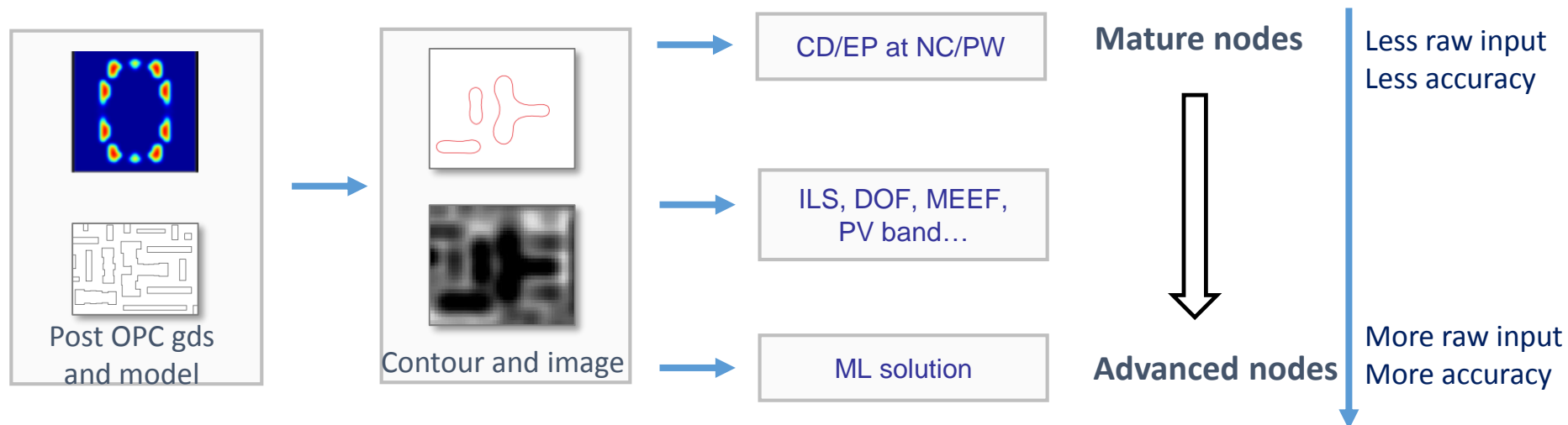
# >>> Hotspot Prediction Background

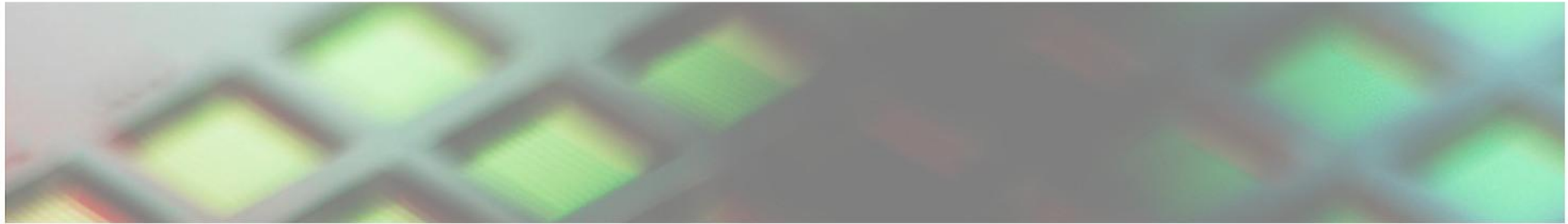
- OPC verification(LMC) is playing the role after OPC correction to verify OPC quality.
- Key value of OPC verification is to distinguish risky patterns and safe patterns.



# >>> Verification become more and more complex

- Traditional verification methods could not capture all mask related defects.
  - Simple CD/EP inspection.
  - Cross condition inspections, image contrast inspections.
  - Solution: Construct more KPI; Introduce more accurate models.
- More complex but powerful solutions are required as process keep shrinking on.
  - ML solution?

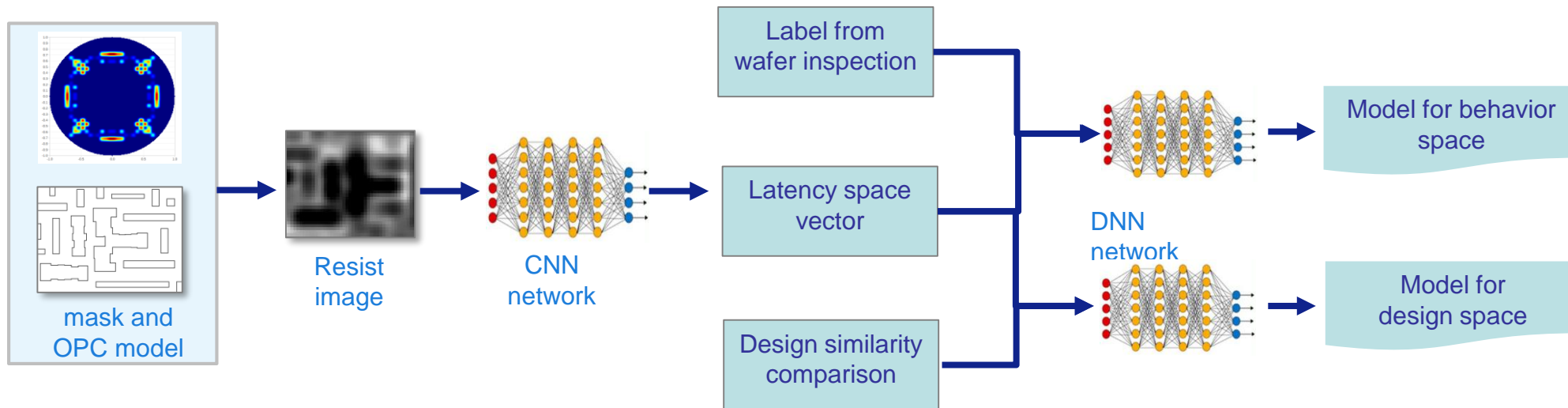




# **MACHINE LEARNING HOTSPOT PREDICTION**

# >>> Newron Hotspot Prediction – Training Flow

- Image based defect defection flow constructed on DCNN.
- Makes full use of whole simulated images in order to generate prediction information.
- Multiple projecting routines are supported.
  - To design space. Trained by huge amount simulation data.
  - To behavior space. Trained by limited wafer data.



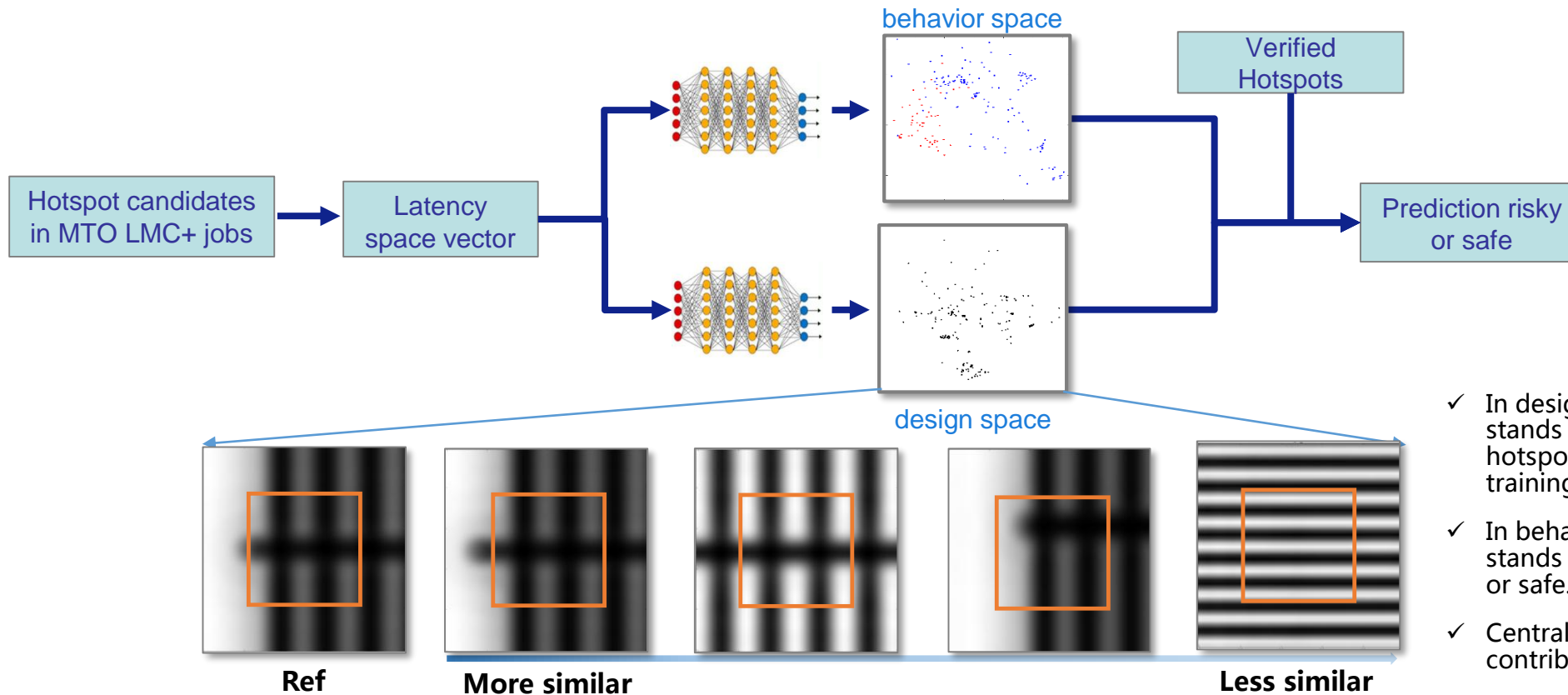
1) Generate resist image around hotspot location by applying OPC model; Crop and convert whole resist image to latency space vector via CNN.

2) Prepare the training data; ADI patterns with design similarity comparison and labels (manually labeled 'r/s' for these ADI images by CDSEM value).

3) Feed training data into Newron engine to train two separate prediction models.

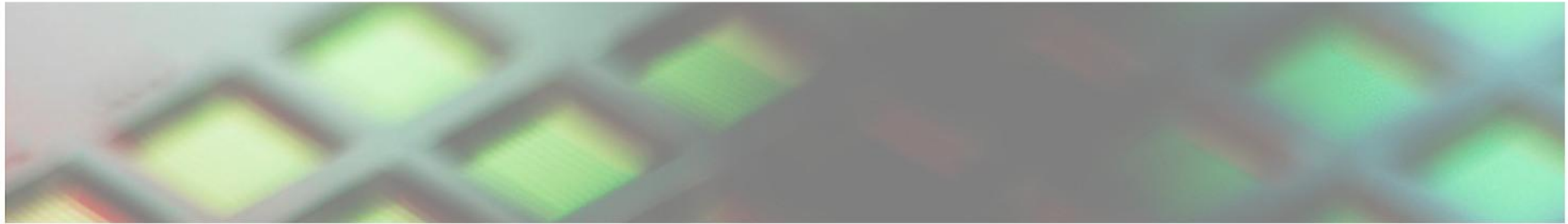
# >>> Newron Hotspot Prediction – Application Flow

- Generate resist image, convert to latency space vectors for new hotspots.
- Latency space vectors are projected to new feature spaces by prediction models.
- Generate final prediction label by considering the two feature space distribution.



- ✓ In design space the Euclidean distance stands for the design similarity of one hotspot candidate to other hotspots in training set.
- ✓ In behavior space the Euclidean distance stands for the probability of being risky or safe.
- ✓ Central region of one hotspot image contribute more to the final similarity.

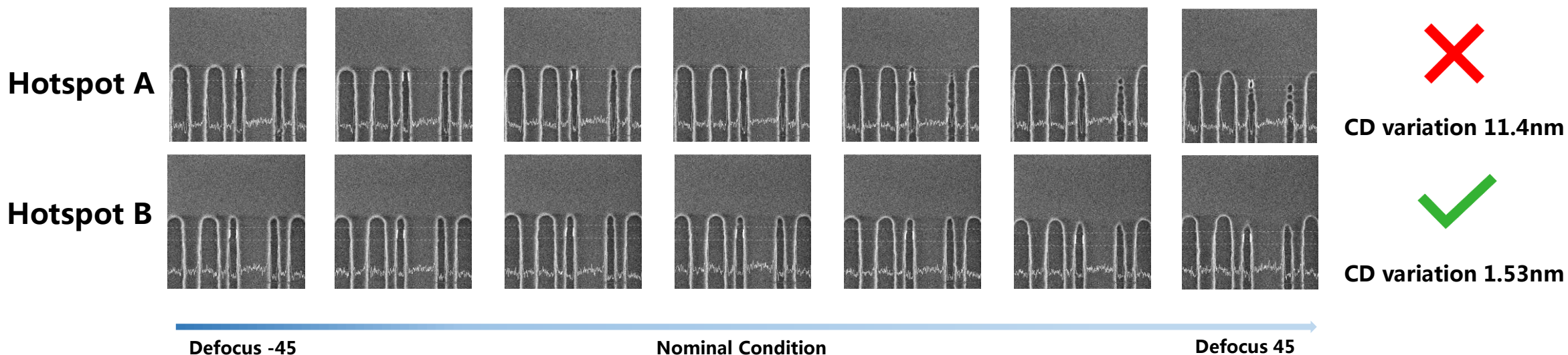




# **WAFER DATA VERIFICATION AND RESULT ANALYSIS**

# >>> Ground truth labeling based on real wafer data

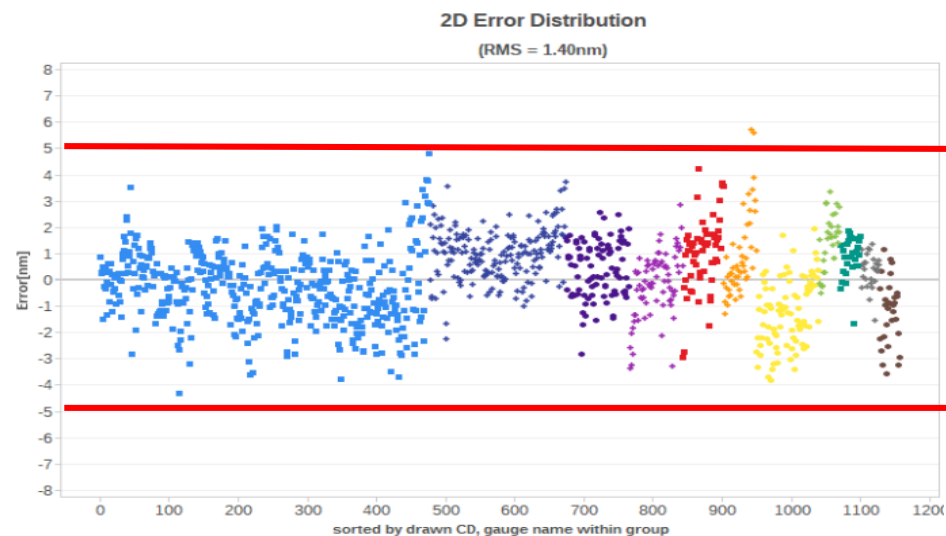
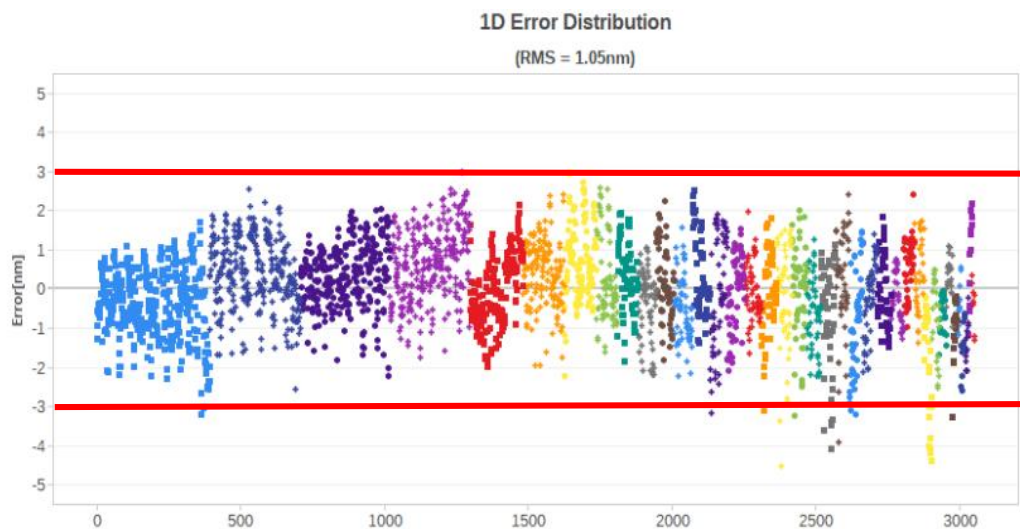
- Total 375 unique hotspot candidates verified on wafer. (7 conditions\*10shots\*375=26250 measurements)
  - KPI #1: CD variation in PW conditions.
    - The top 125 candidates with biggest CD variation --- "Risky"
    - The rest 250 candidates with smallest CD variation --- "Safe"



- KPI #2: ADI model error at nominal condition.
  - The worst 125 candidates with biggest model error --- "Risky"
  - The best 250 candidates with smallest model error --- "Safe"

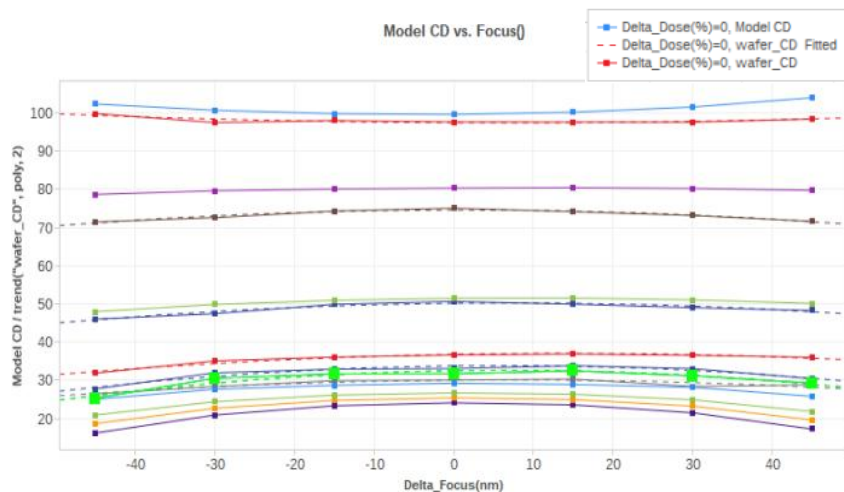
# >>> Baseline ADI model performance

- Baseline ADI model has a good performance both on 1D and 2D patterns.

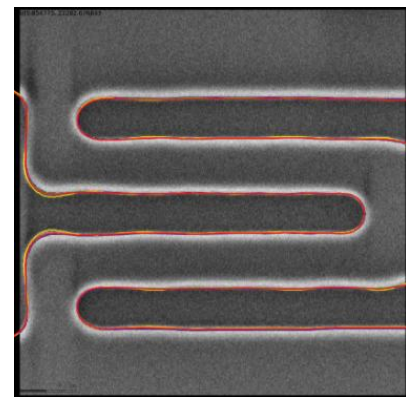


14nm M1 NTD Model Performance

Type	In Spec ratio	Overall RMS	Anchor error
1D	96.7%	<b>1.05</b>	
2D	99.8%	<b>1.4</b>	
Total		1.24	-0.09

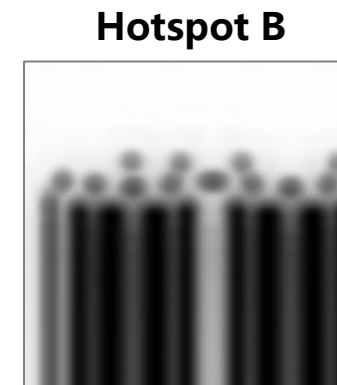
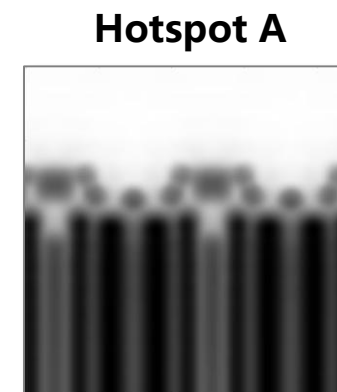
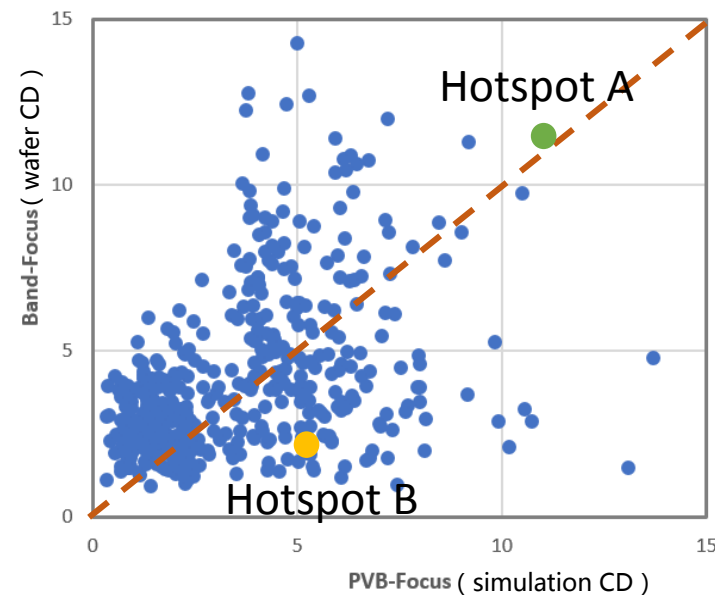
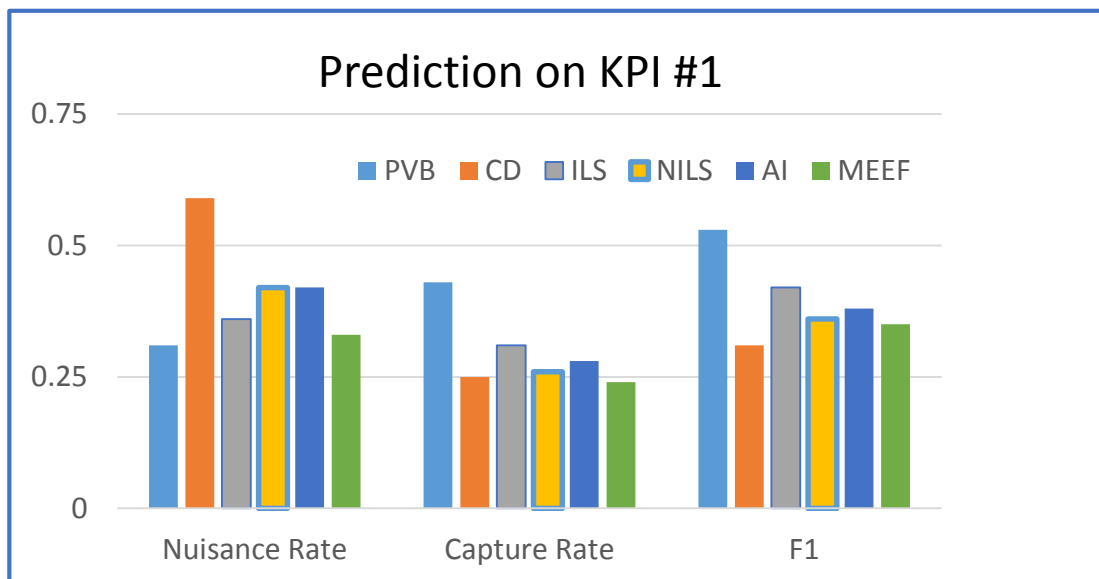


SEM Prediction



# >>> Use traditional detectors as baseline prediction solutions

- PVB-Focus has the most relevant physical meaning with through-focus band in wafer. Thus PVB detector shows best prediction accuracy.



		Prediction	
		Risky	Safe
Ground Truth	Risky	True Positive (TP)	False Negative (FN)
	Safe	False Positive (FP)	True Negative (TN)

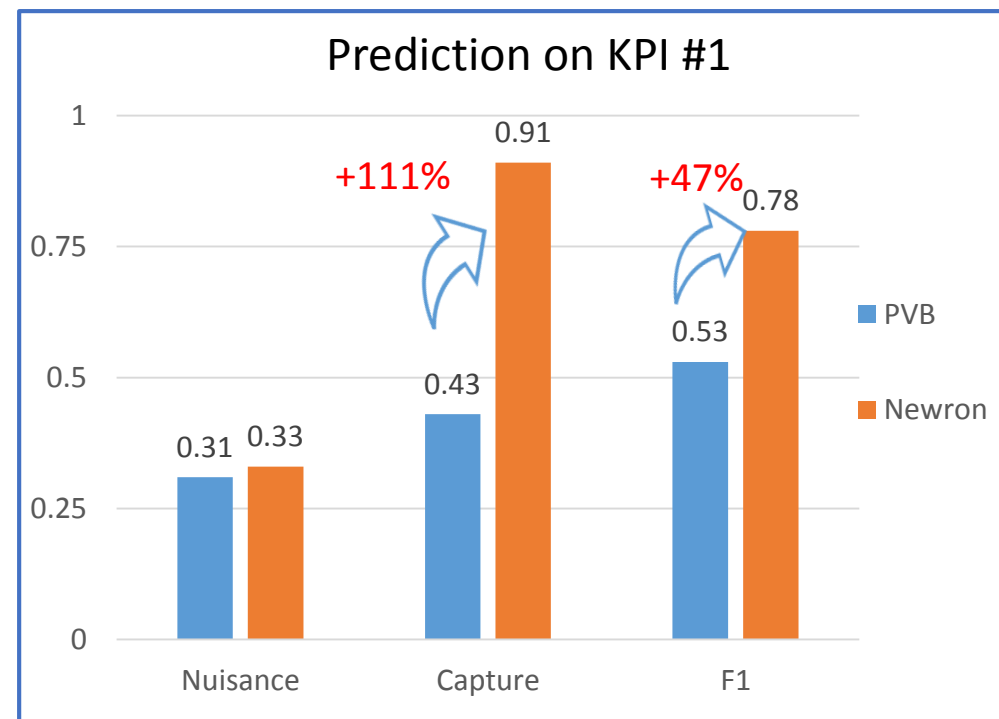
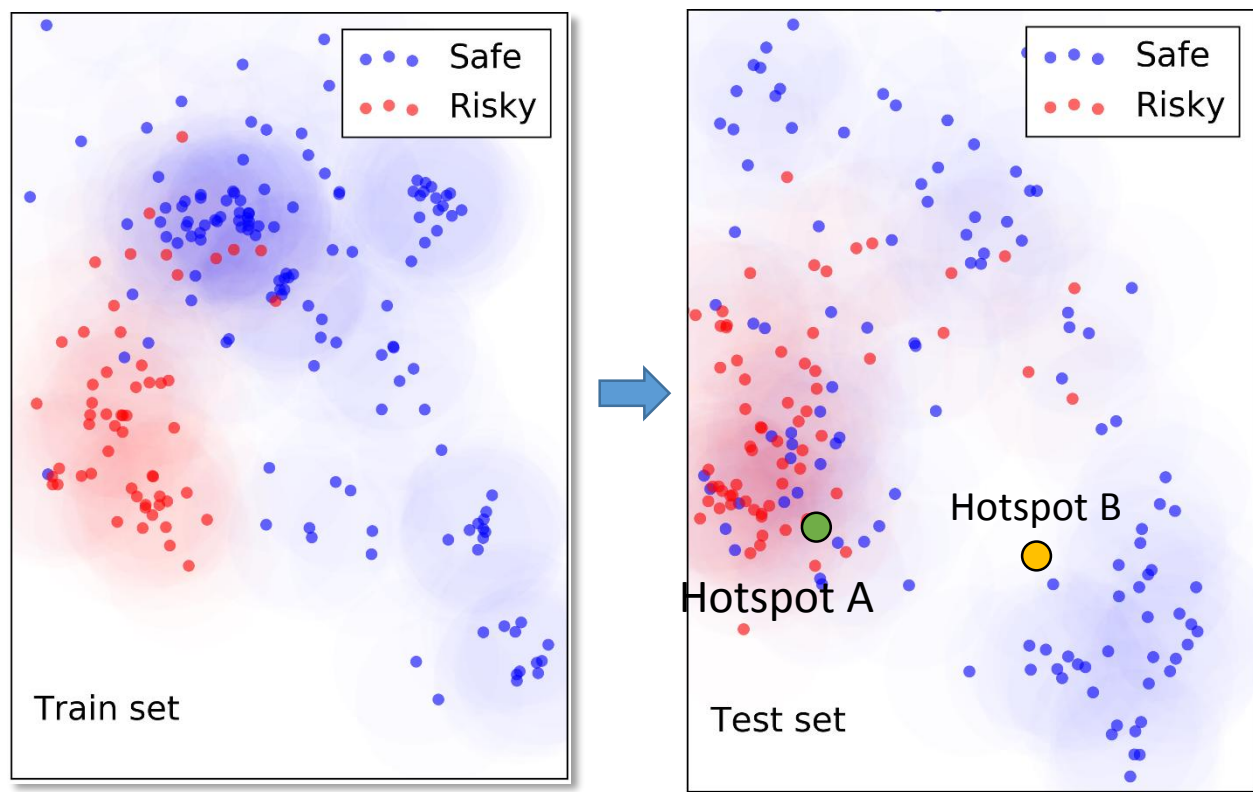
✓ Nuisance =  $\frac{FP}{TP+FP}$ , the lower the better

✓ Capture =  $\frac{TP}{TP+FN}$ , the higher the better

✓ F1 =  $\frac{2}{\text{Capture}^{-1} + (1 - \text{Nuisance})^{-1}}$ , the higher the better

# >>> Newron hotspot prediction result comparison

- Risky and safe hotspots show clear separation in feature space.
- Final F1 score get ~47% improvement in KPI#1.

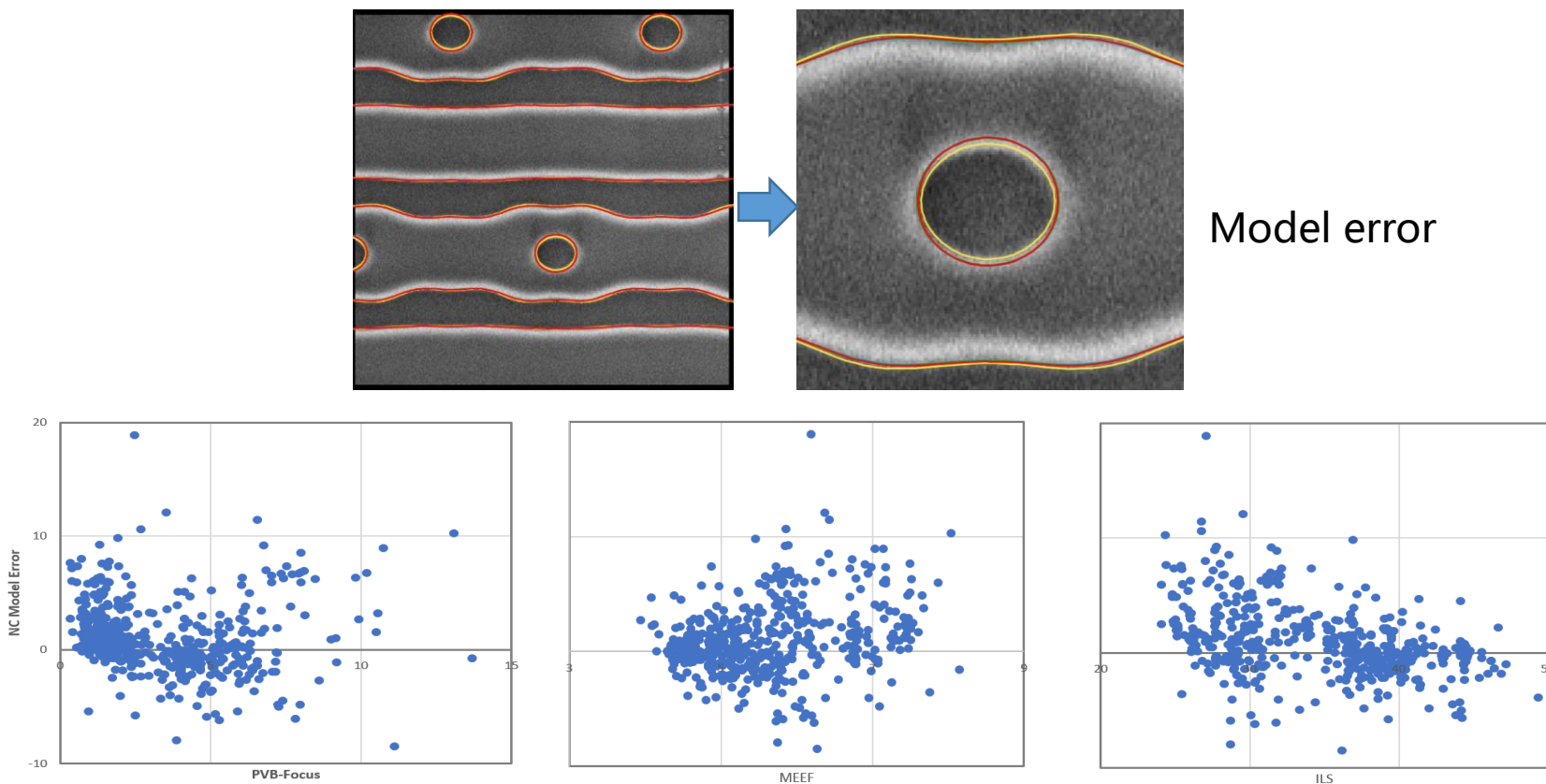


✓ Although some safe hotspot are mixed with risky hotspot in test set, the overall distribution matched well to train set.



# >>> Newron can handle more complex predictions

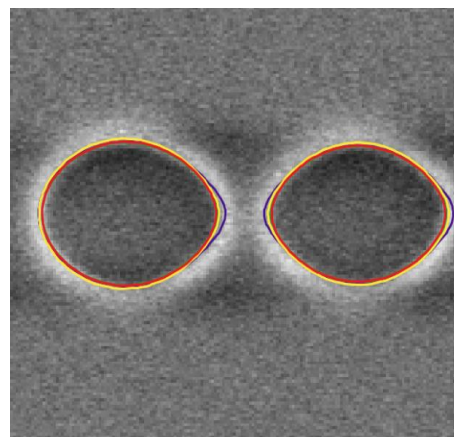
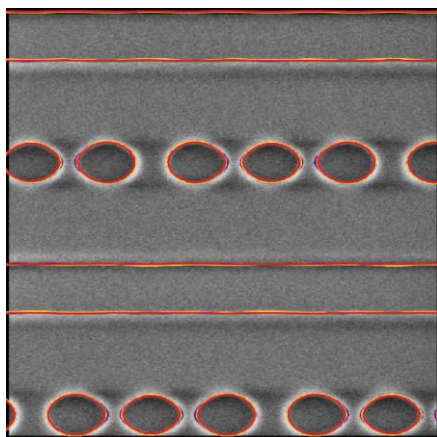
- Traditional detectors do not have the capability to predict the model error because all the detectors use the information simulated by the model itself.



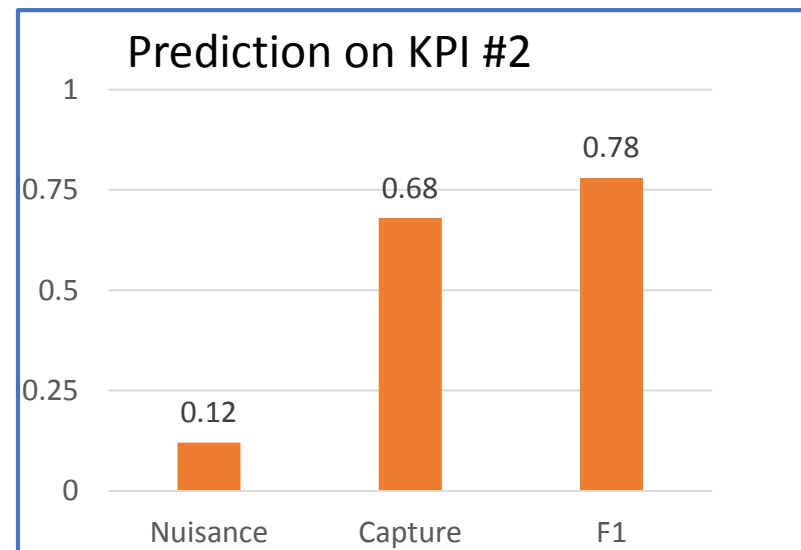
✓ There's no obvious correlation between NC model error and PVB-Focus, MEEF or ILS.

# >>> Newron can handle more complex predictions

- Resist image contain sufficient info for such kind of KPI ;
- Machine learning solution can achieve good enough prediction.



Model error



- ✓ Newron solution result on model error at NC.
- ✓ Capture the model error by ML method.

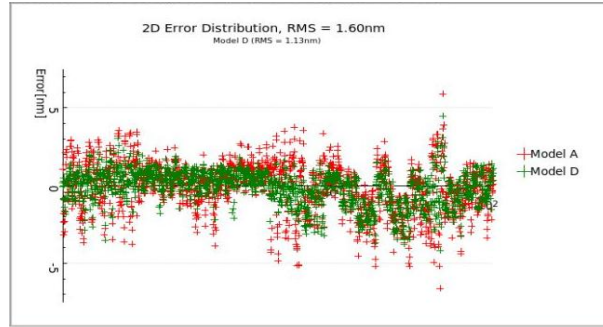
## >>> Summary

---

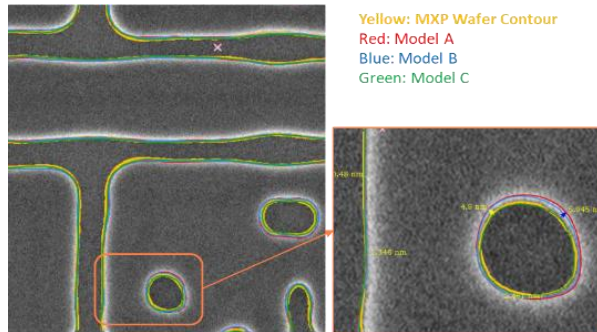
- ICRD and ASML-Brion co-worked to evaluate an innovative machine learning hotspot prediction method on 14nm metal layer process.
- Traditional detectors are insufficient to predict wafer hotspots for advanced tech node.
- To predict the ground truth labeled by CD variation in PW conditions, Newron Hotspot improves the prediction F1 score by 47% compared with baseline detectors.
- Newron Hotspot achieved a breakthrough in predicting model error with 68% capture rate and 12% nuisance rate while there is no traditional solution yet.
- It has been proved that Newron Hotspot flow can be flexibly adjusted to handle various prediction targets.



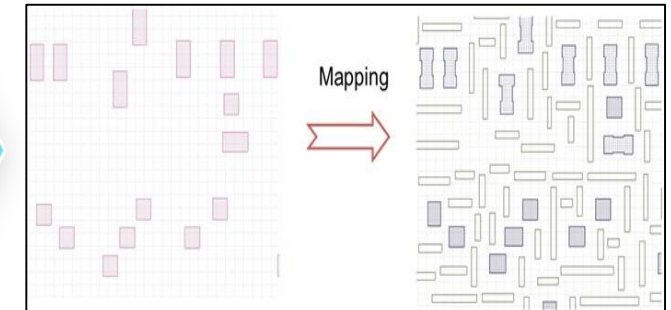
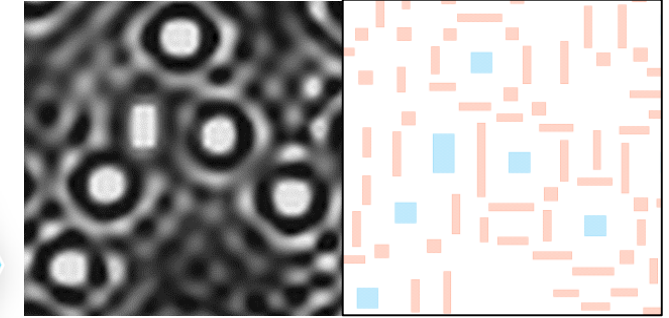
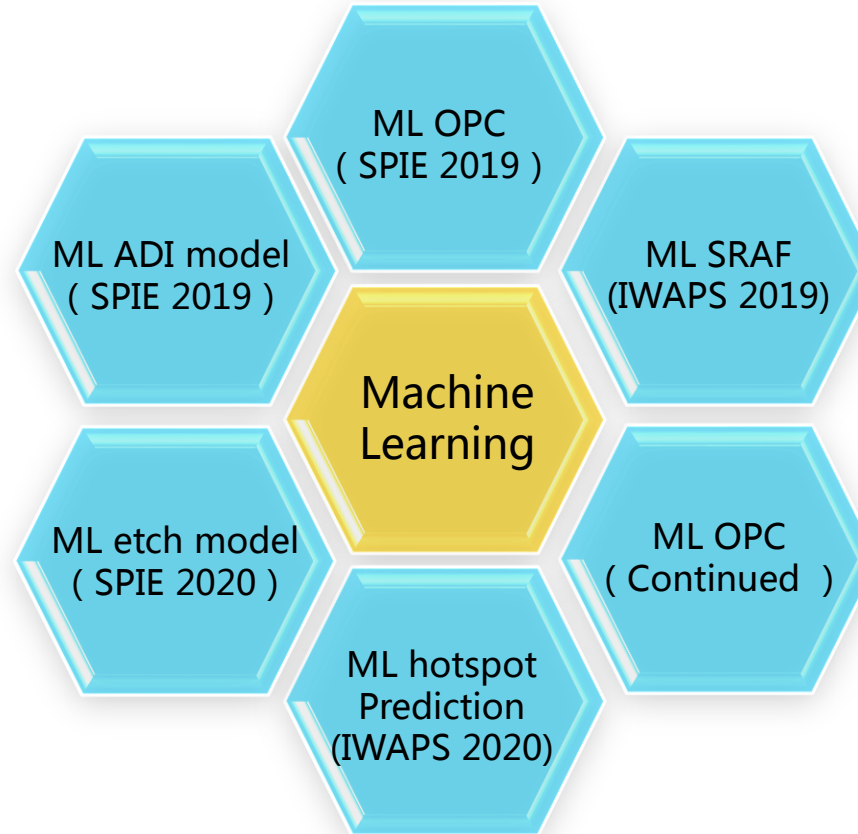
# >>> More Study on ML



ML ADI model



ML AEI model



- Machine Learning technologies have high potential to be applied in OPC area and will bring significant benefit to improve the OPC performance.

# >>> Acknowledgement

---

- Thank ICRD OPC team and ASML-Brion LMC/MKT team' s great support and co-work to finish this study.



Wei Yuan  
Yifei Lu  
Ming Li  
Bingyang Pan  
Ying Gao  
Yu Tian

Zhi-qin Li  
Liang Ji  
Ying Huang  
Hao Chen  
Yueliang Yao  
Yan jun Xiao

# Thank you.



INNOVATION \* EFFICIENCY \* PERSISTENCE \* EXCEED

ICRD is a registered trademark of SHANGHAI IC R&D CENTER.

Names of ICRD products and services are the registered trademarks and/or trademarks of SHANGHAI IC R&D CENTER or its Group companies.

Other company names and product names are registered trademarks and/or trademarks of the respective companies.