EXPLAINABLE MACHINE LEARNING FOR PRECISE FATIGUE CRACK DETECTION

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Outline

- Introduction
- Crack detection
  - Segmentation
  - Regression
  - *ParallelNets*
- Explainable AI
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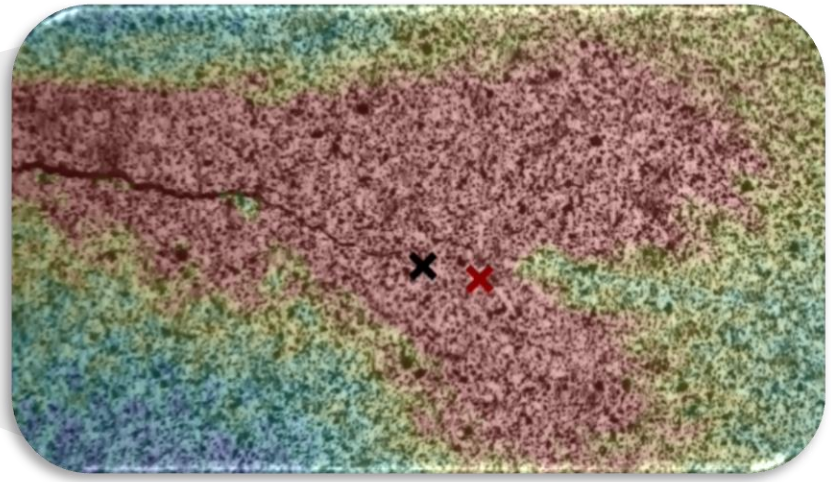
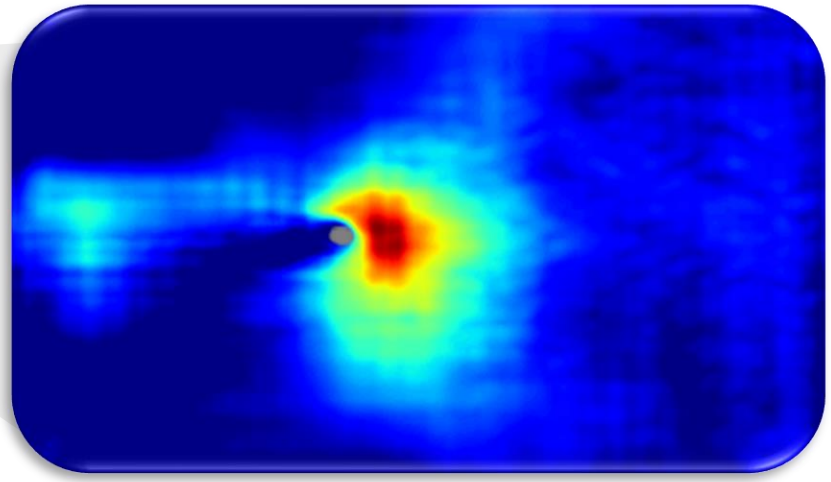
- Conclusion





INTRODUCTION

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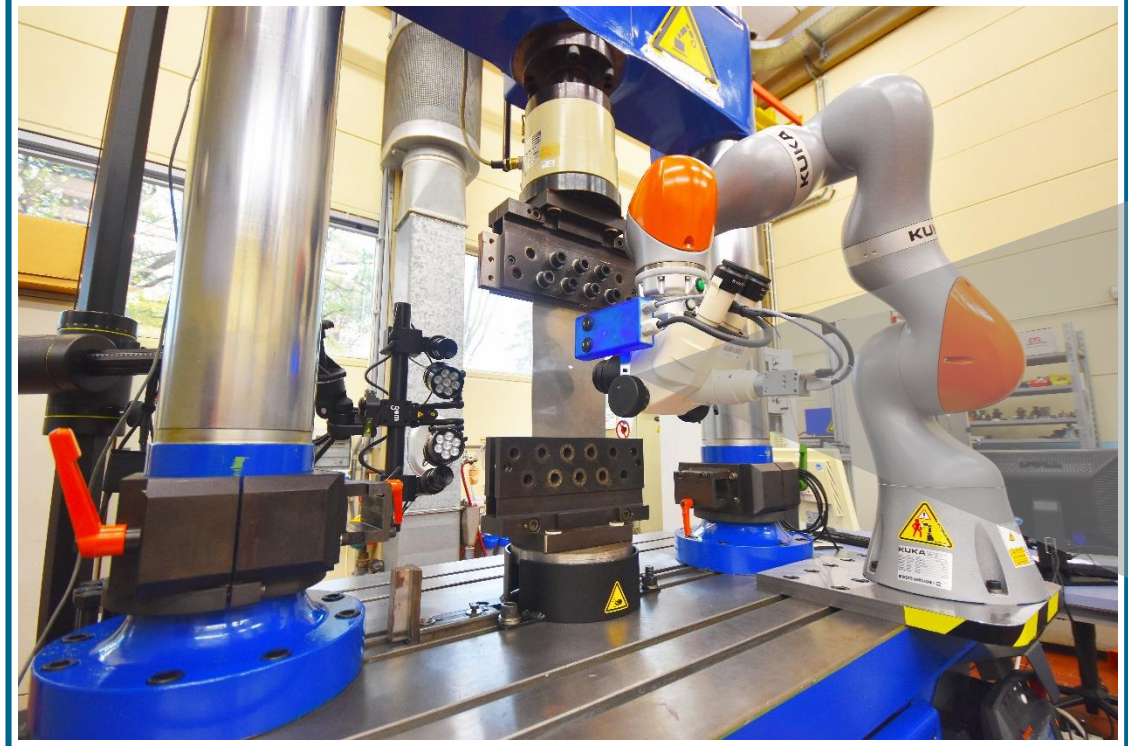
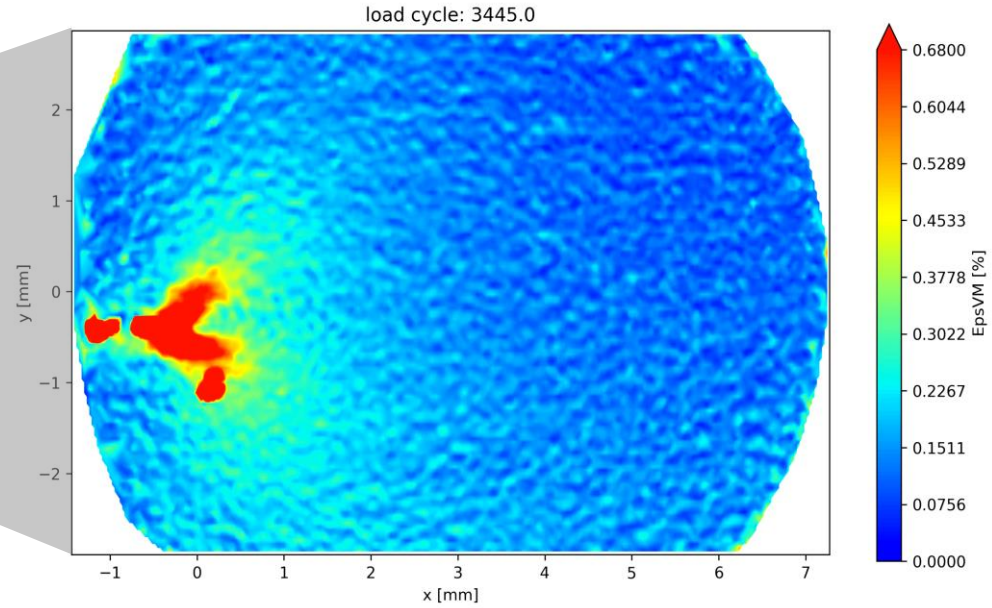
Advanced mechanical testing

Robotic automatic testing

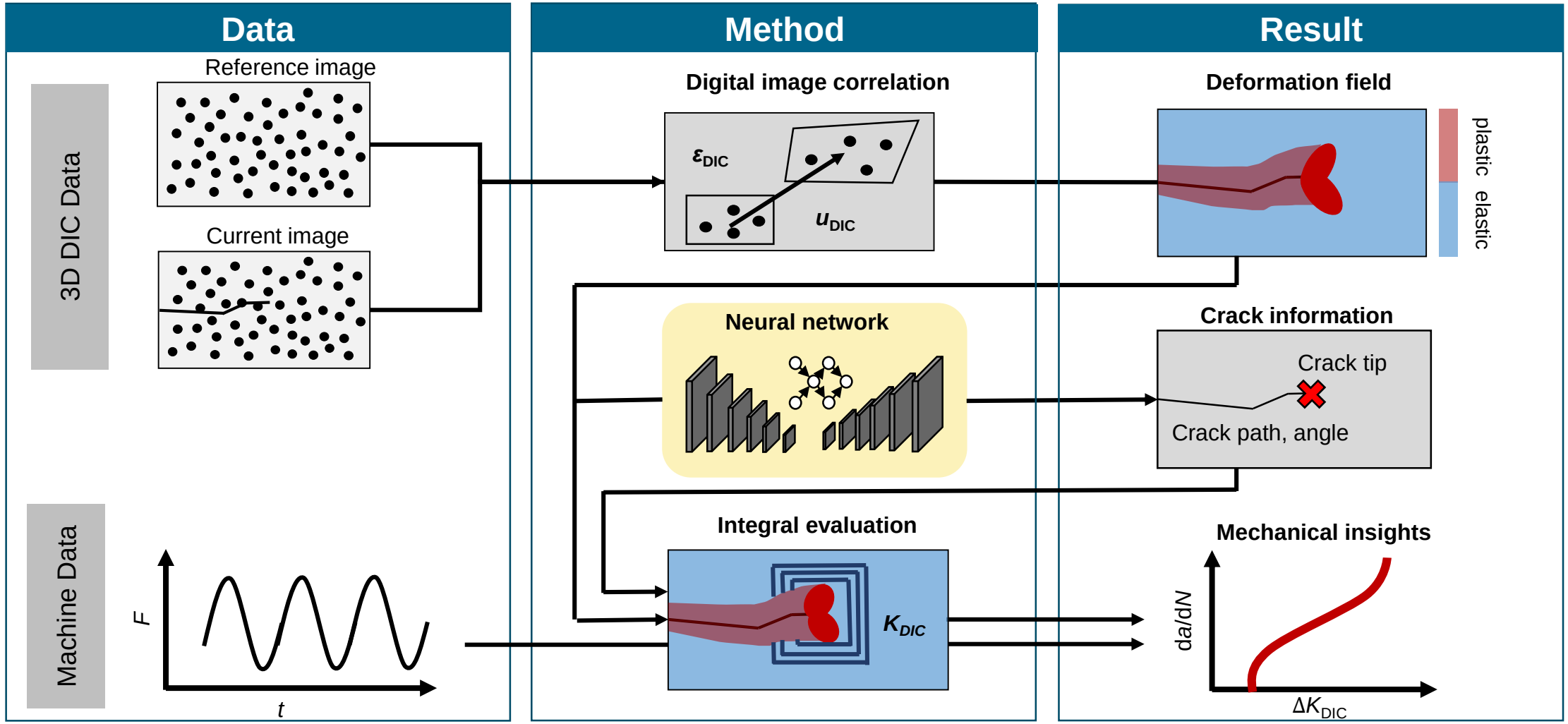


Microscope DIC

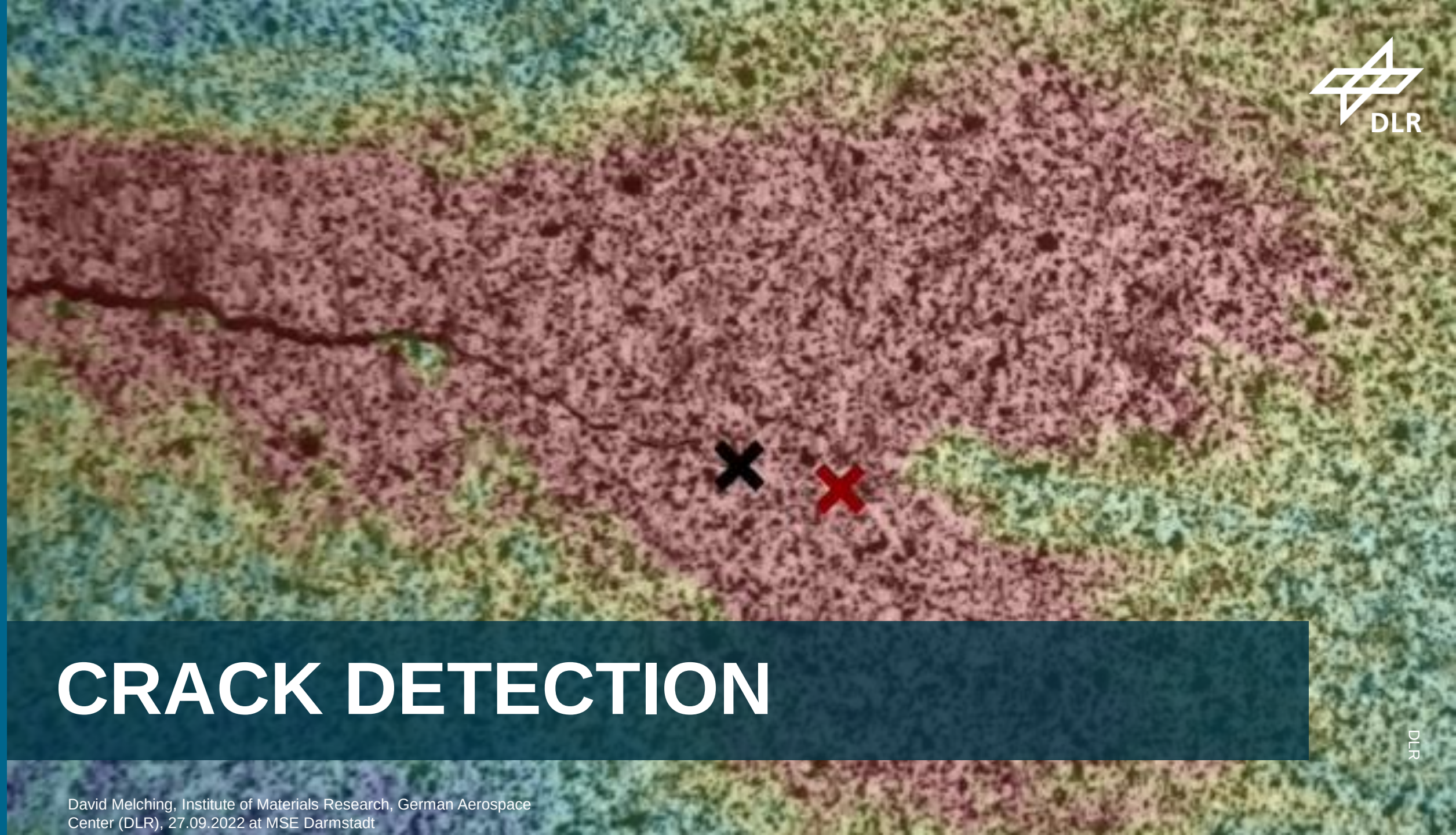


- Roughly 500 GB of raw data per experiment !

Digital experiment evaluation



Strohmann et al. (in preparation) Experimental Mechanics in the 2020th: Fatigue Crack Growth



CRACK DETECTION

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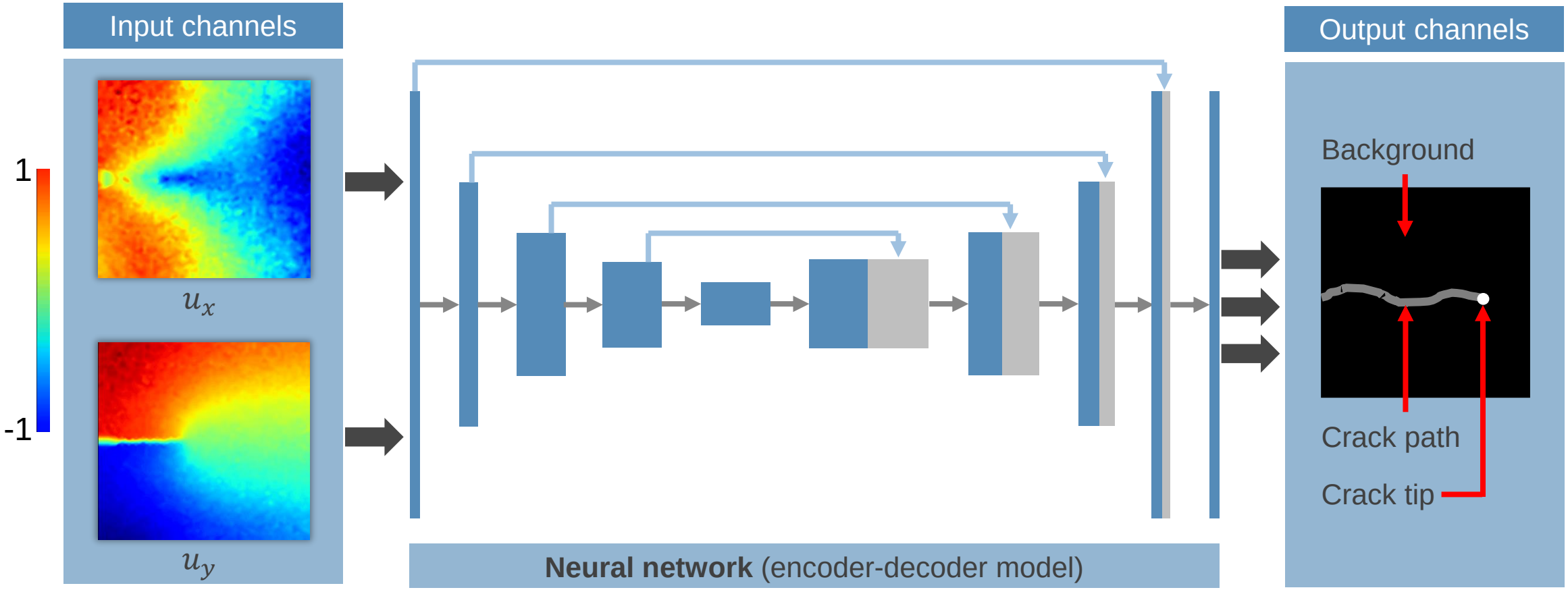
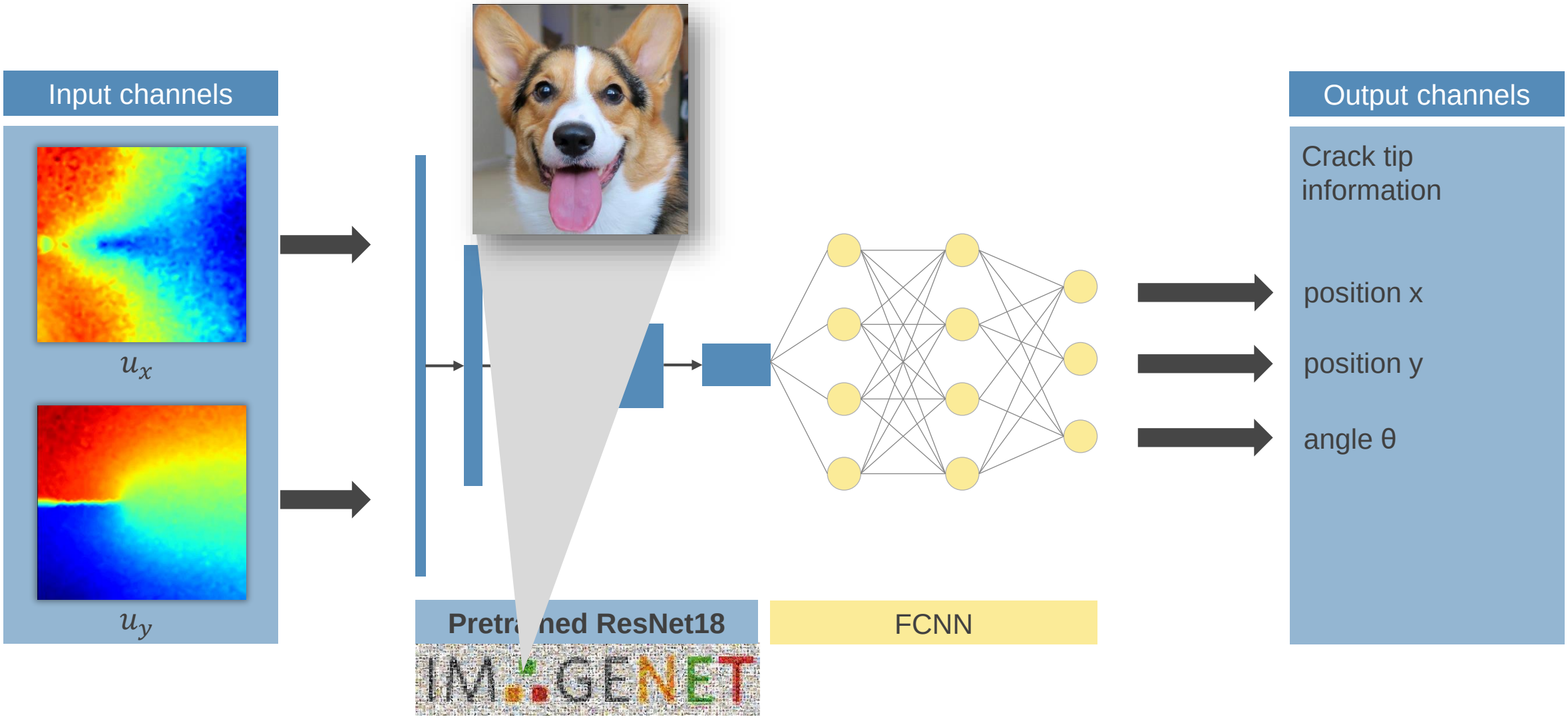
DLR

Crack segmentation



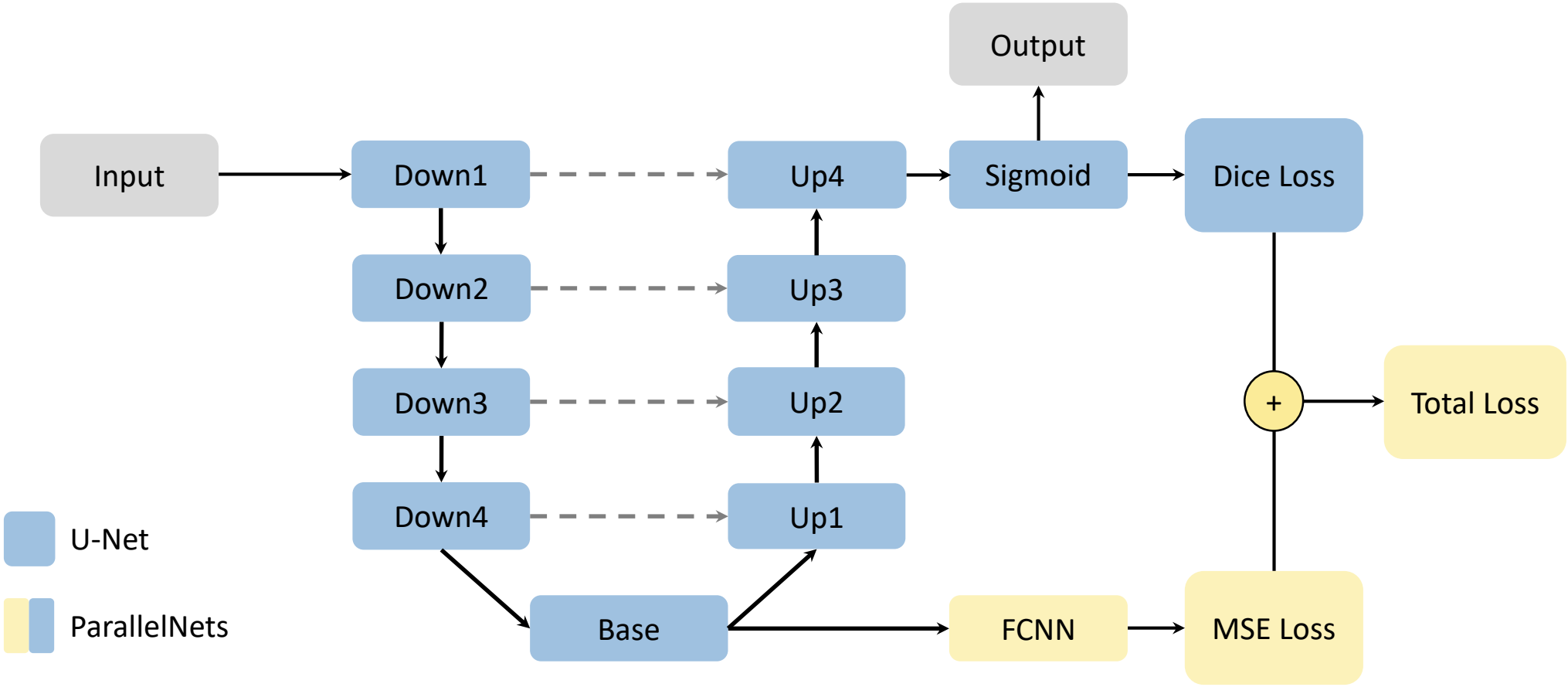
Strohmann et al. (2021) Automatic detection of fatigue crack paths using DIC and CNNs.

Deep regression using transfer learning



Lathuilière et al. (2020) A comprehensive analysis of deep regression.

ParallelNets = U-Net + Deep Regression



Melching et al. (2022) Explainable machine learning for precise fatigue crack tip detection.

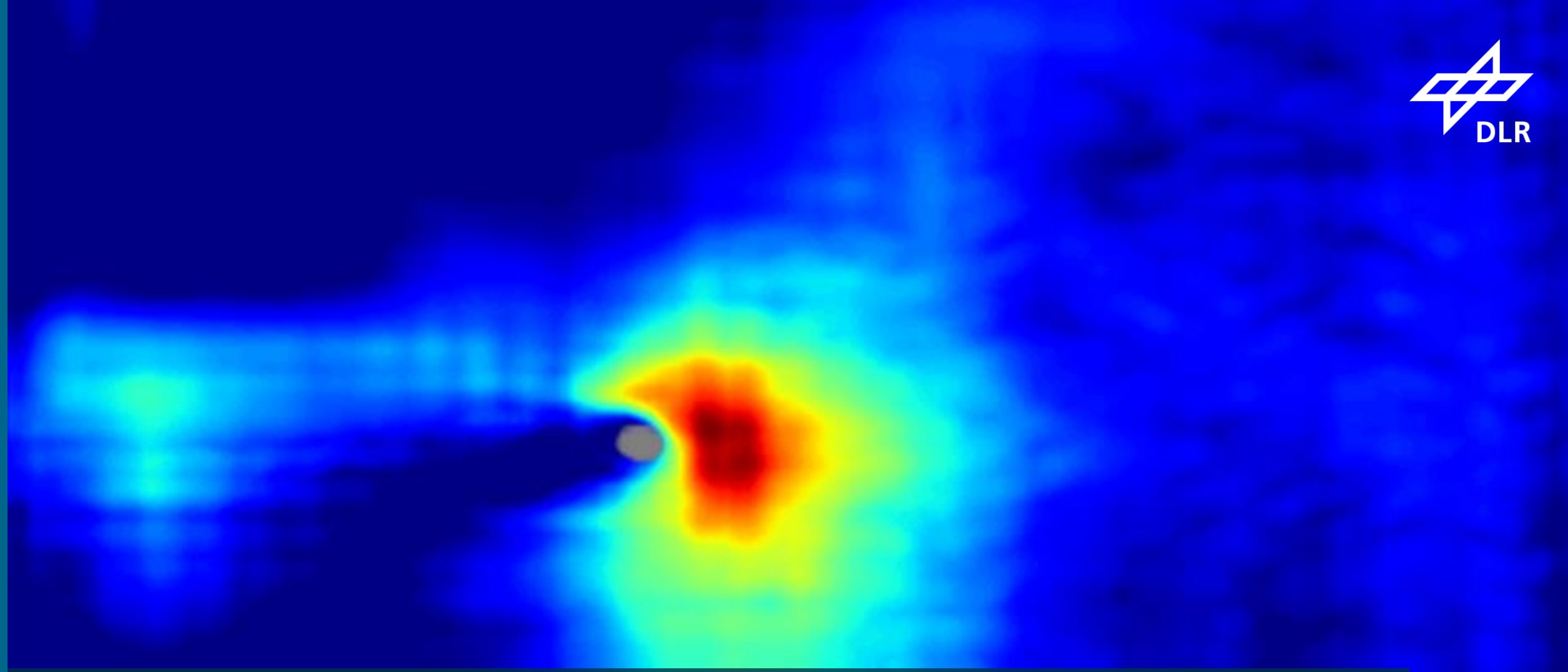
Performance results

	Training			Validation			Test (*large*)	Test (*small*)
	Dice	*reliability*	*deviation*	*Dice*	*reliability*	*deviation*	*reliability*	*reliability*
U-Net-1	**0,246**	**87,9%**	**0,78**	**0,355**	**92,3%**	**0,50**	**80,4%**	**68,5%**
U-Net-2	0,465	98,1%	0,41	**0,310**	**99,9%**	**0,79**	95,8%	93,6%
ParallelNets	**0,517**	**100%**	**0,39**	0,333	98,9%	0,68	**99,2%**	**96,4%**

Performance measured by…

- *Dice coefficient*
- *reliability* in %
- *(mean) deviation* from the ground truth in mm.

Melching et al. (2022) Explainable machine learning for precise fatigue crack tip detection.



EXPLAINABILITY

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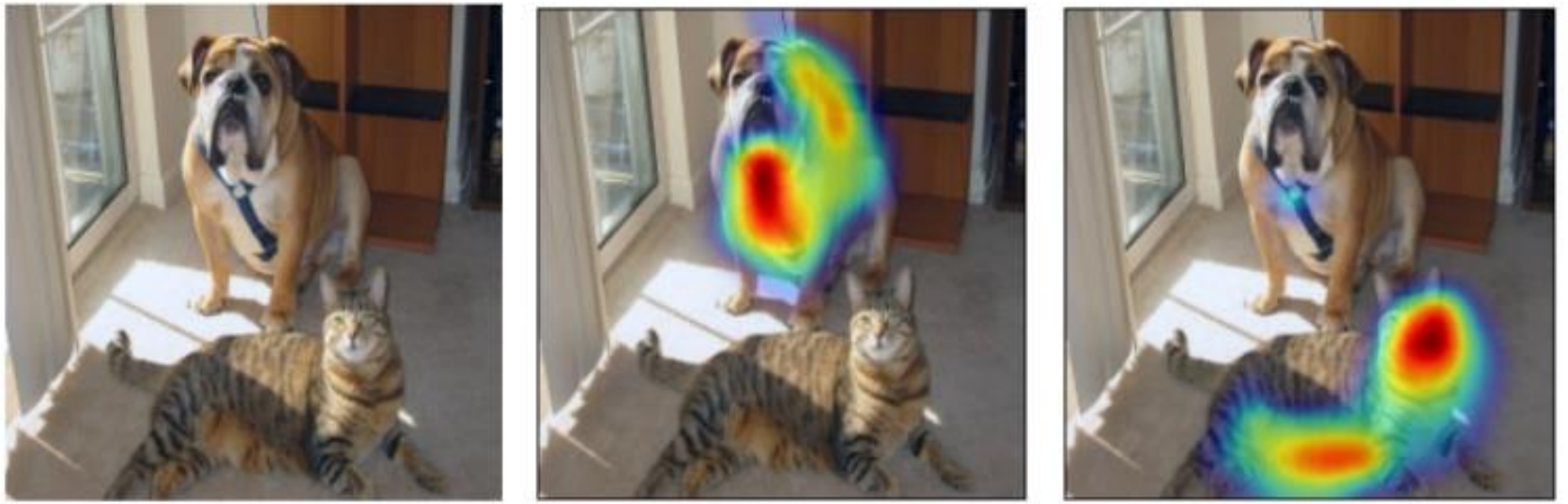
Grad-CAM method

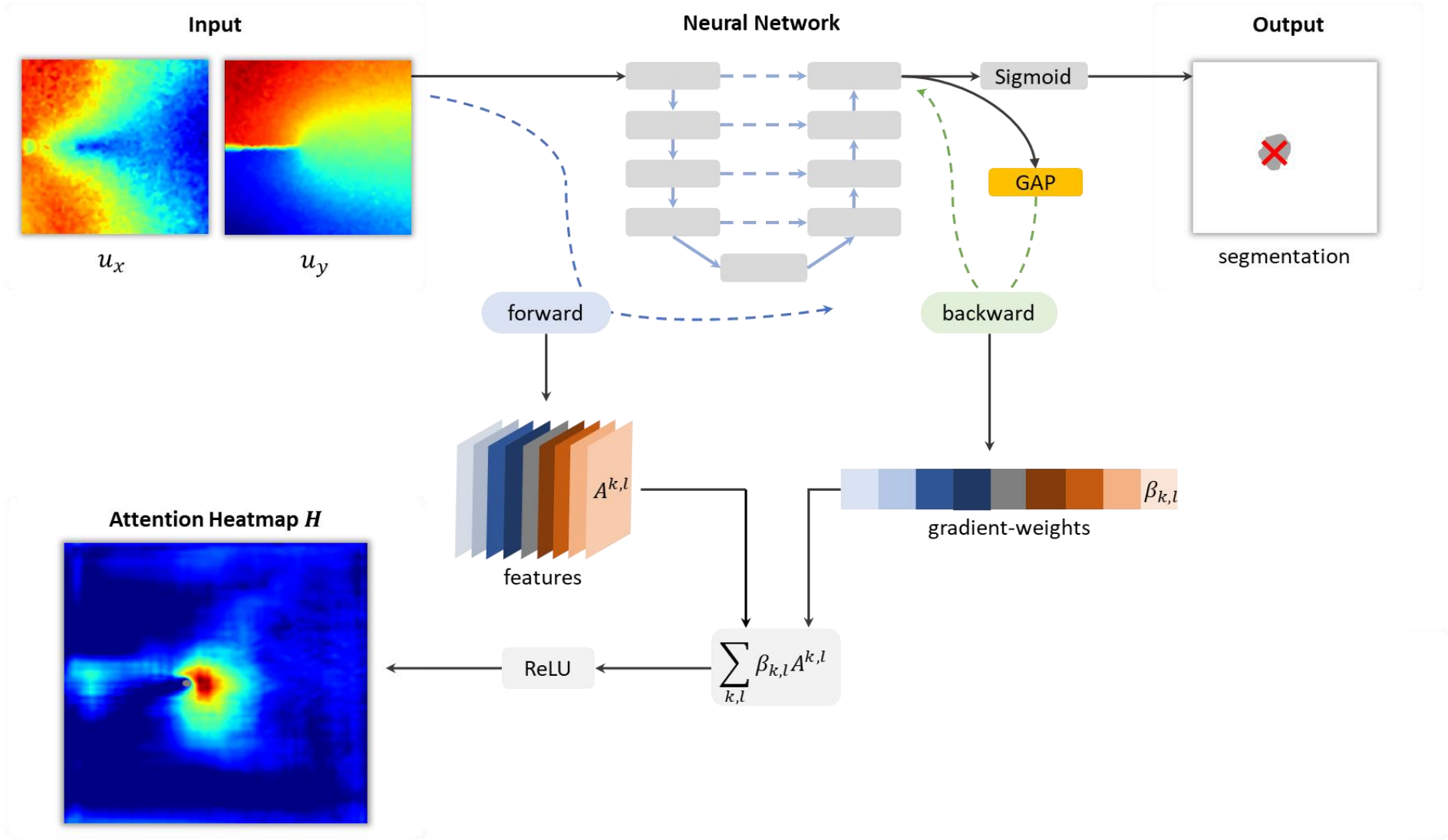


(a) Original Image (b) Cat Counterfactual exp (c) Dog Counterfactual exp

- **Heatmaps** showing areas of **high attention**
- Suitable for CNN-based **classification** models
- No architectural changes or re-training

Selvaraju et al. (2019) Grad-CAM: Visual Explanations from Deep Networks via Gradient-based Localization.

Explainable crack tip detection

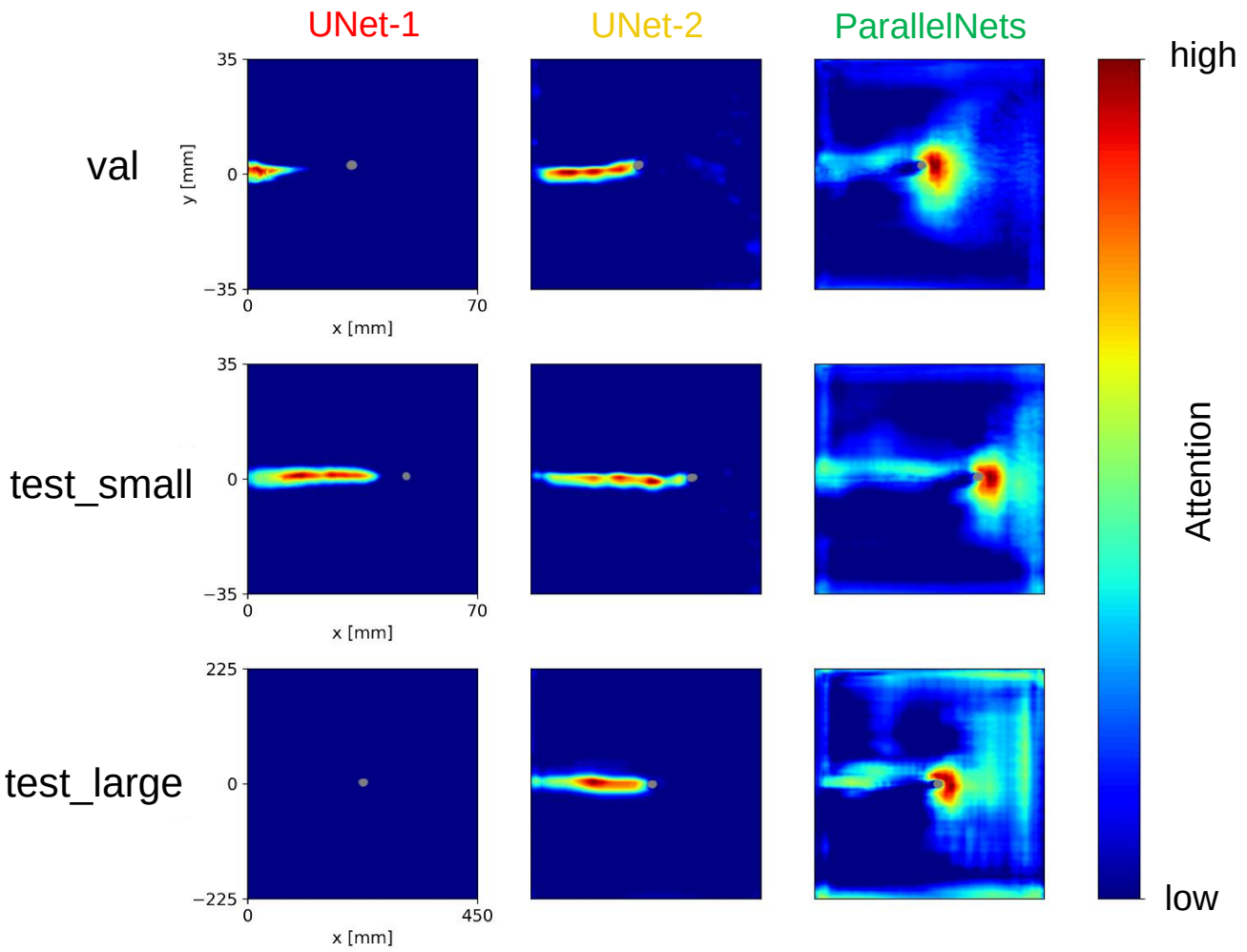


Melching et al. (2022) Explainable machine learning for precise fatigue crack tip detection.

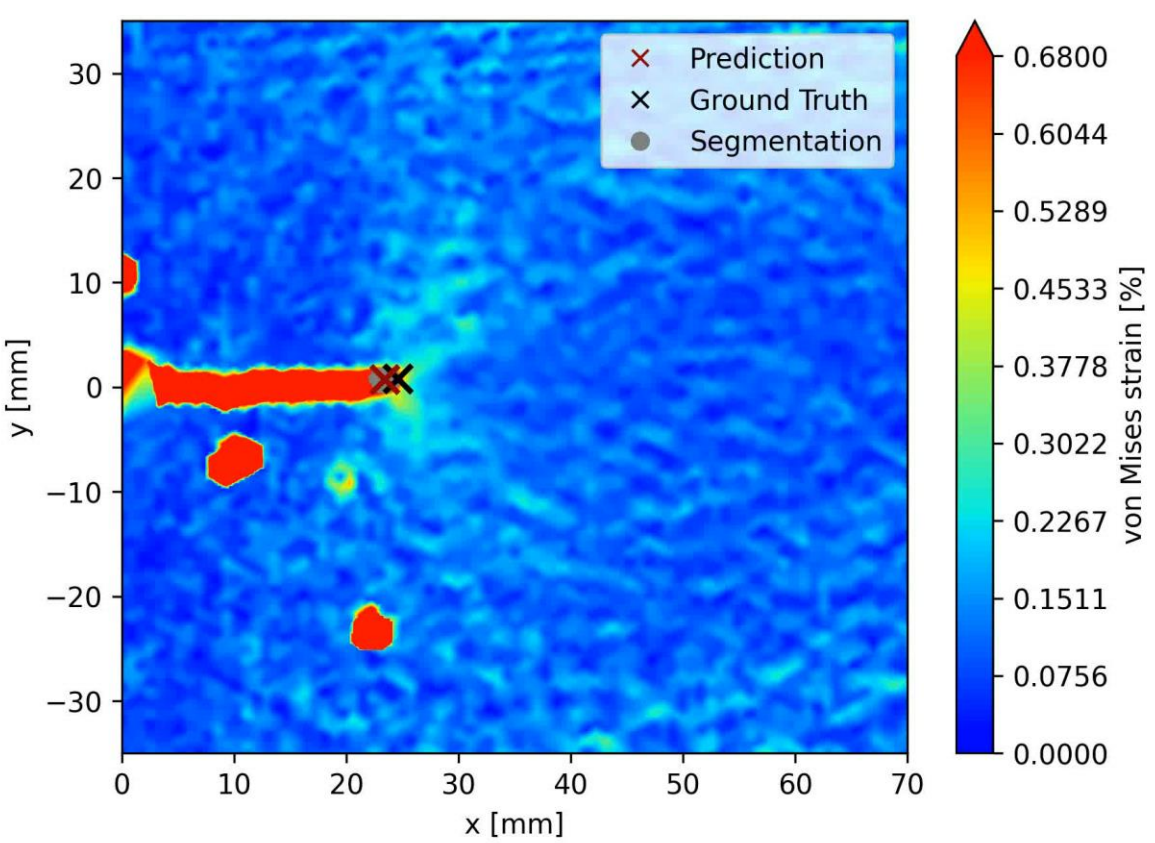
Model comparison

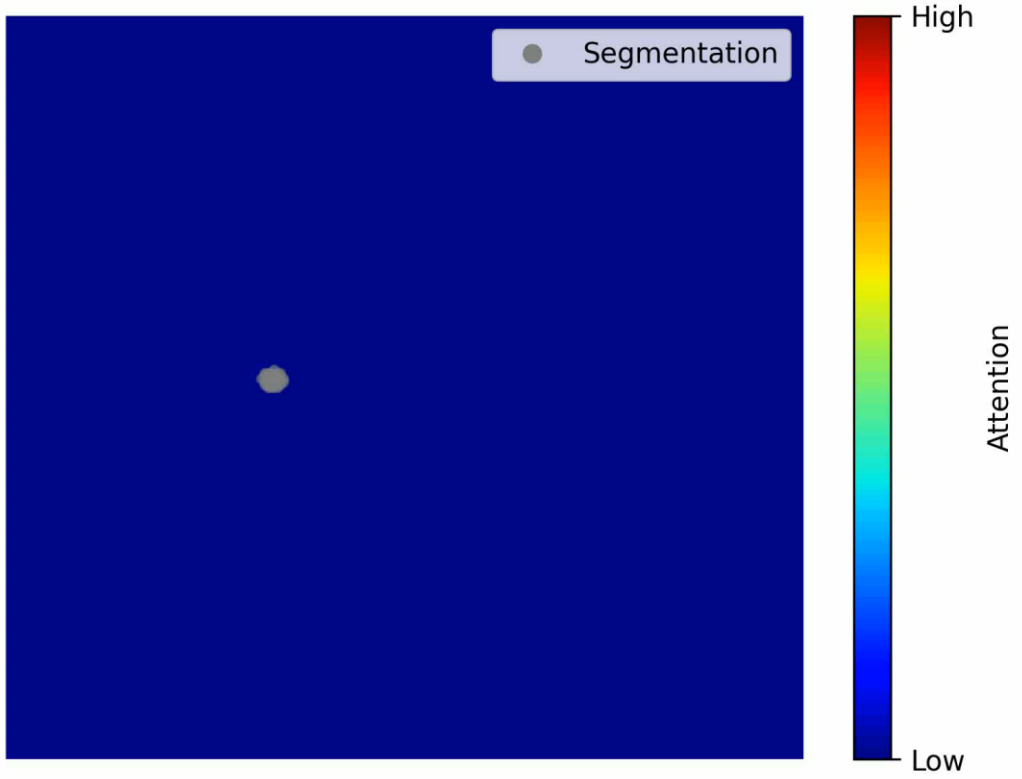
Grad-CAM heatmaps

- Instable crack path attention
  - ➢ U-Net-1
- Stable crack path attention
  - ➢ U-Net-2
- Stable crack tip attention
  - ➢ ParallelNets



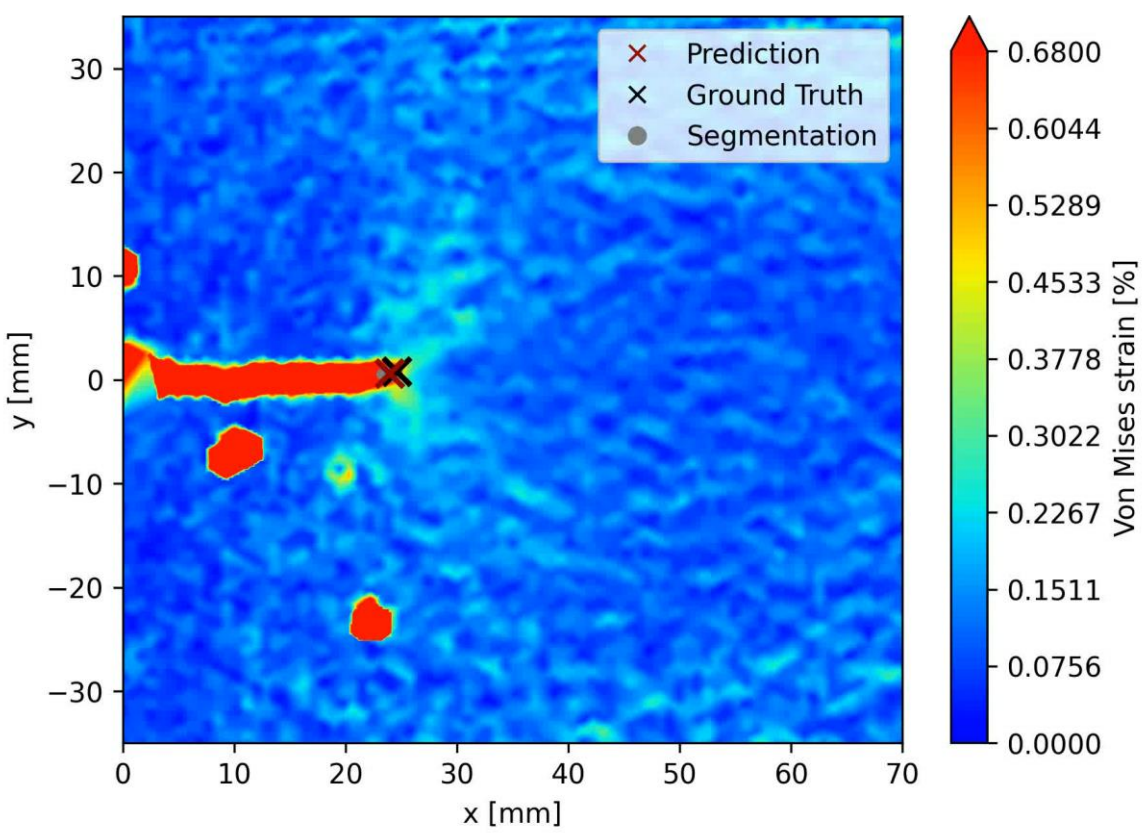
Attention of U-Net-1

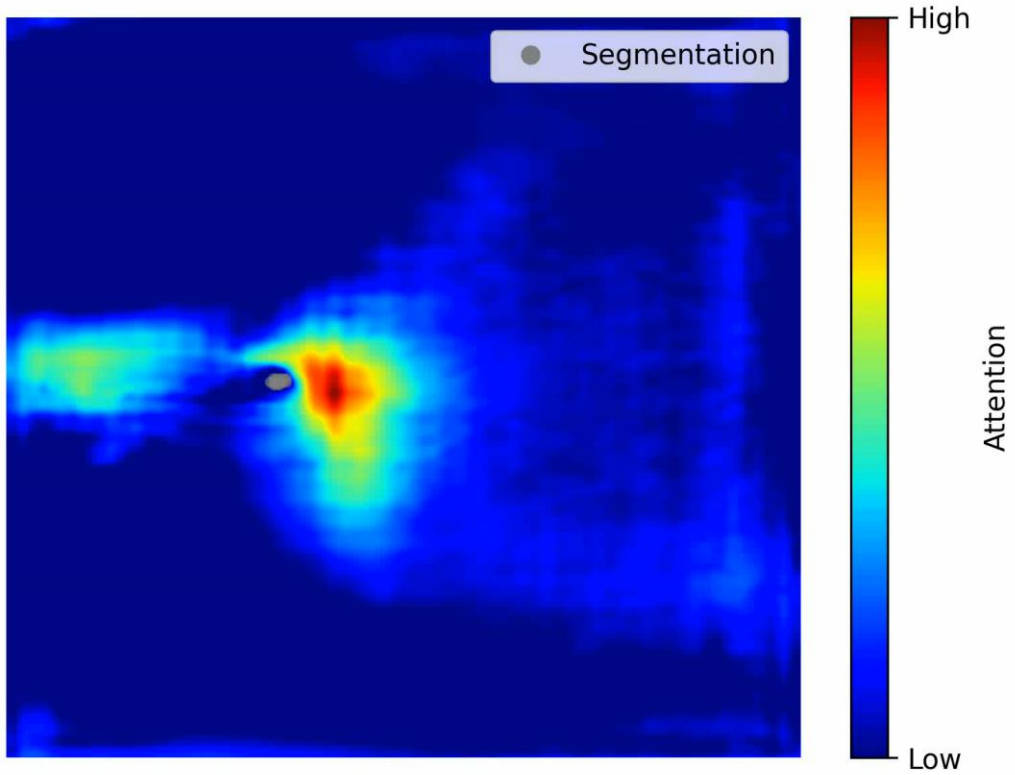




→ Badly trained weak model

Attention of ParallelNets





→ Well trained strong model

CONCLUSION

- *ParallelNets* **combines two approaches**:
  - segmentation of crack tip pixels
  - deep regression of crack tip positions
  - in a **single network trained end-to-end**

- This multi-model…

  ✓ leeds to more robust and **stable predictions**

  ✓ produces models focusing on the **physical crack tip field**

  – is **harder to train than** simple U-Net

DLR

Questions?

Data

- https://doi.org/10.5281/zenodo.5740216

Code

- https://github.com/dlr-wf/explainable-crack-tip-detection

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Impressum

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