Data-driven stability maps for friction induced vibrations

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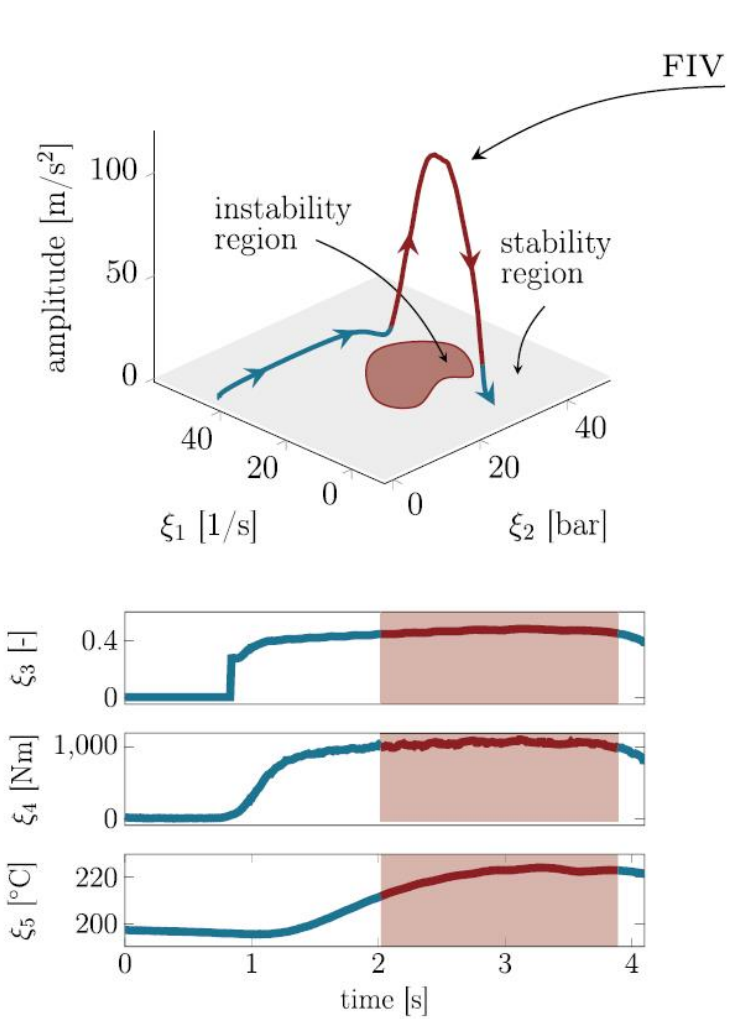
Friction induced vibrations

- Application case: brake squeal
- Complex system:
  - many parameters
  - many degrees of freedom
  - hidden variables
  - multiple time scales
- Limited physics-based modelling
- Bifurcation pattern poorly understood

→ data-based bifurcation maps



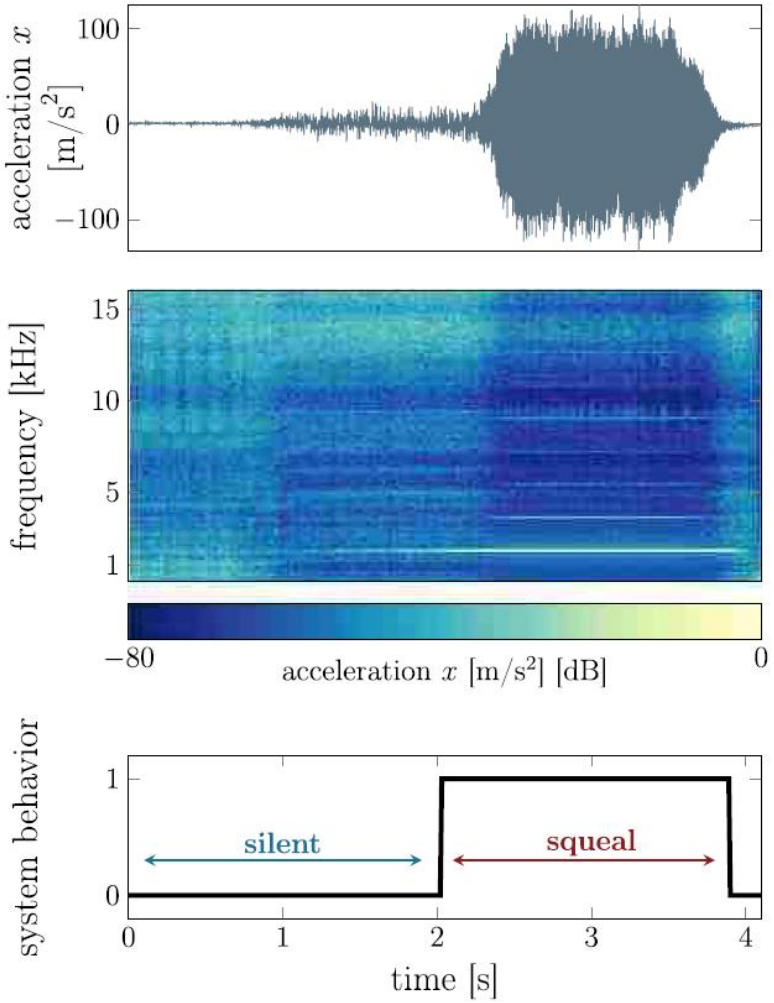
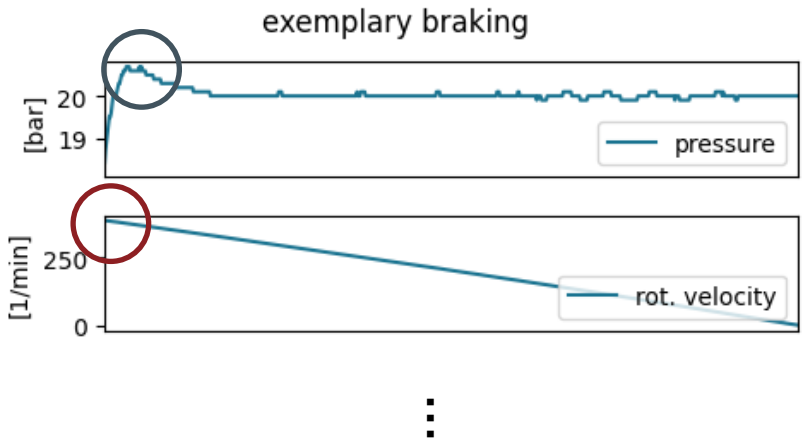
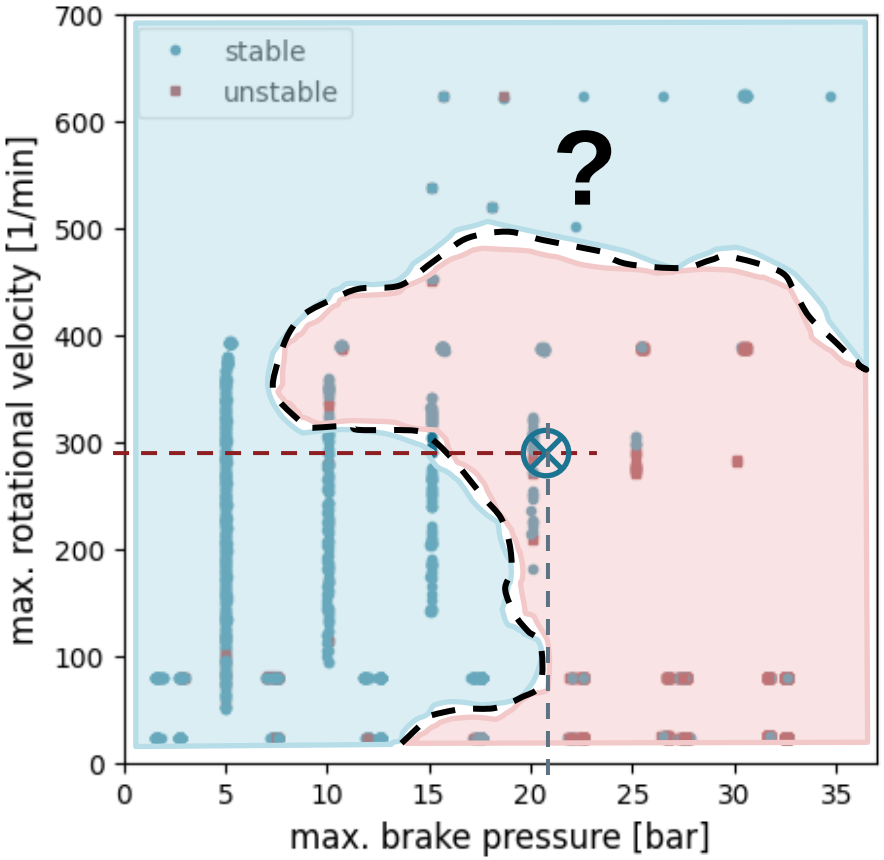


Figure from: M. Stender, D. Schoepflin, D. Spieler, M. Tiedemann, N. Hoffmann and S.Oberst: *Deep learning for brake squeal: Brake noise detection, characterization and prediction*. Mechanical Systems and Signal Processing, 149, 2021

Data-driven stability maps

- neural networks are a powerful tool for the prediction of brake noise
- Now: exploit data-based models for systematic study of system stability





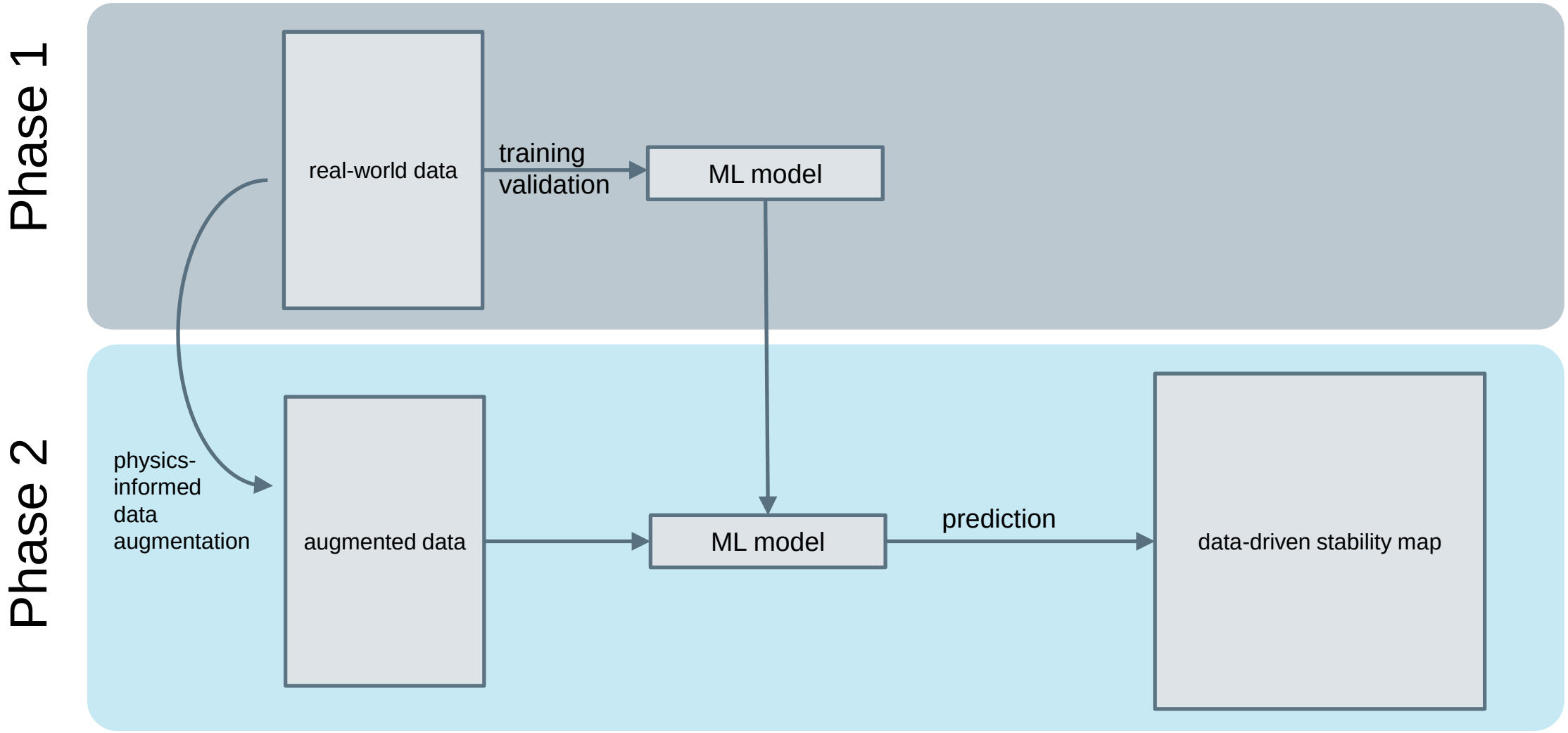
→ purely data-driven approach

Work flow

Phase 1:
Model generation

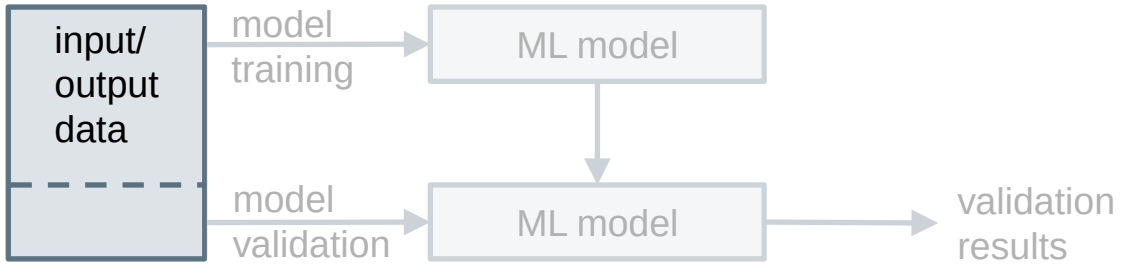
Phase 2:
Model deployment:
Stability map computation

Work flow


Phase 1
real-world data
training
validation
ML model
Phase 2
physics-
informed
data
augmentation
augmented data
ML model
prediction
data-driven stability map

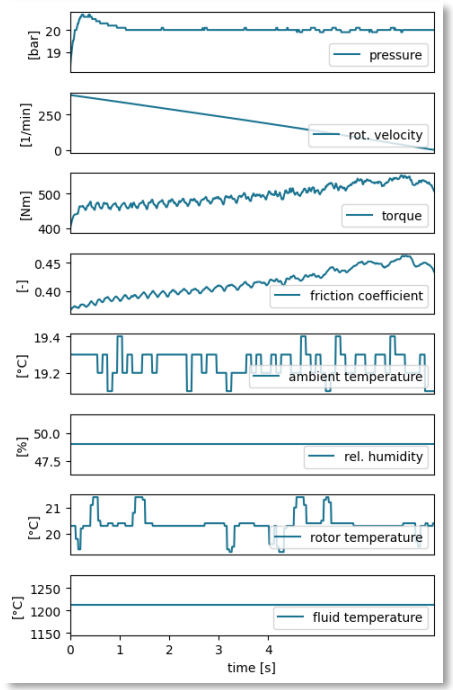
Input/output data

Phase 1



Raw data:
measurement data from standard NVH-tests at Hitachi Astemo

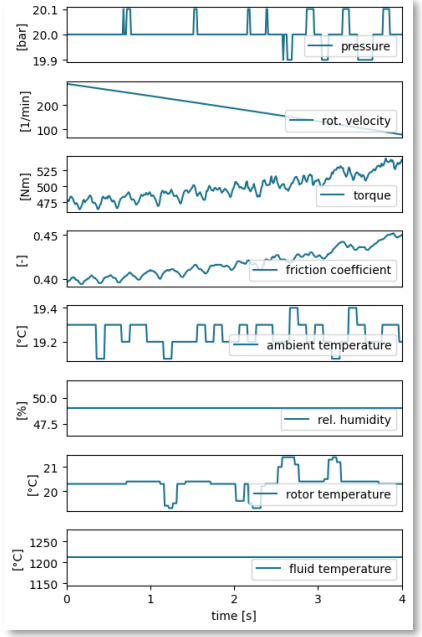
- 2498 brakings
- 34.8 % noise occurrence
- noise start time and duration



Sliding-window preprocessing
Label generation

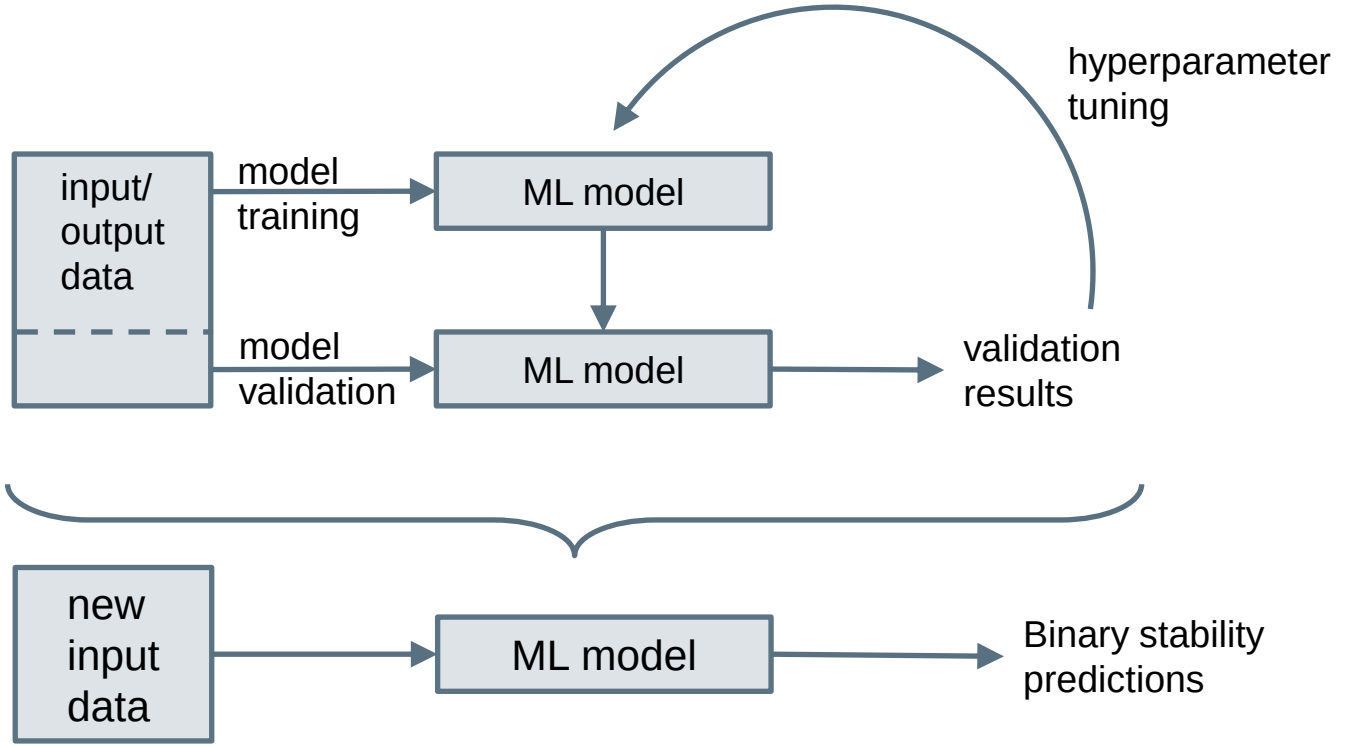
Input/output data:
- 9771 samples à 4s
- 36% noise occurrence

Binary labels per sample:
0 = stable / no noise
1 = unstable / noise



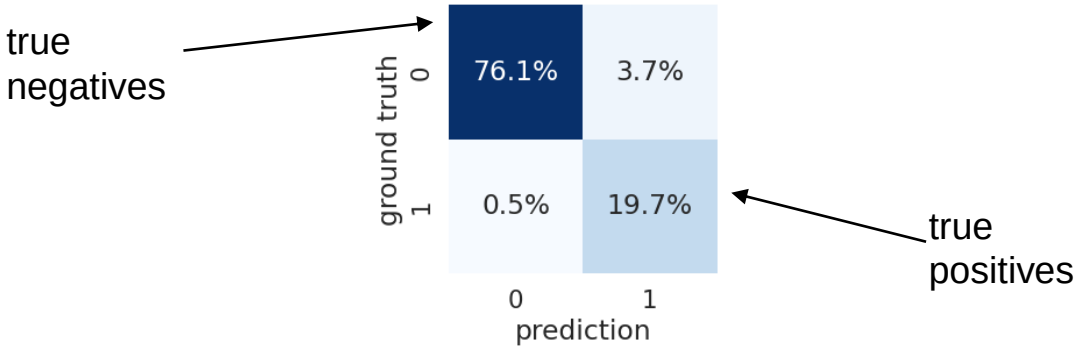
Model

Phase 1

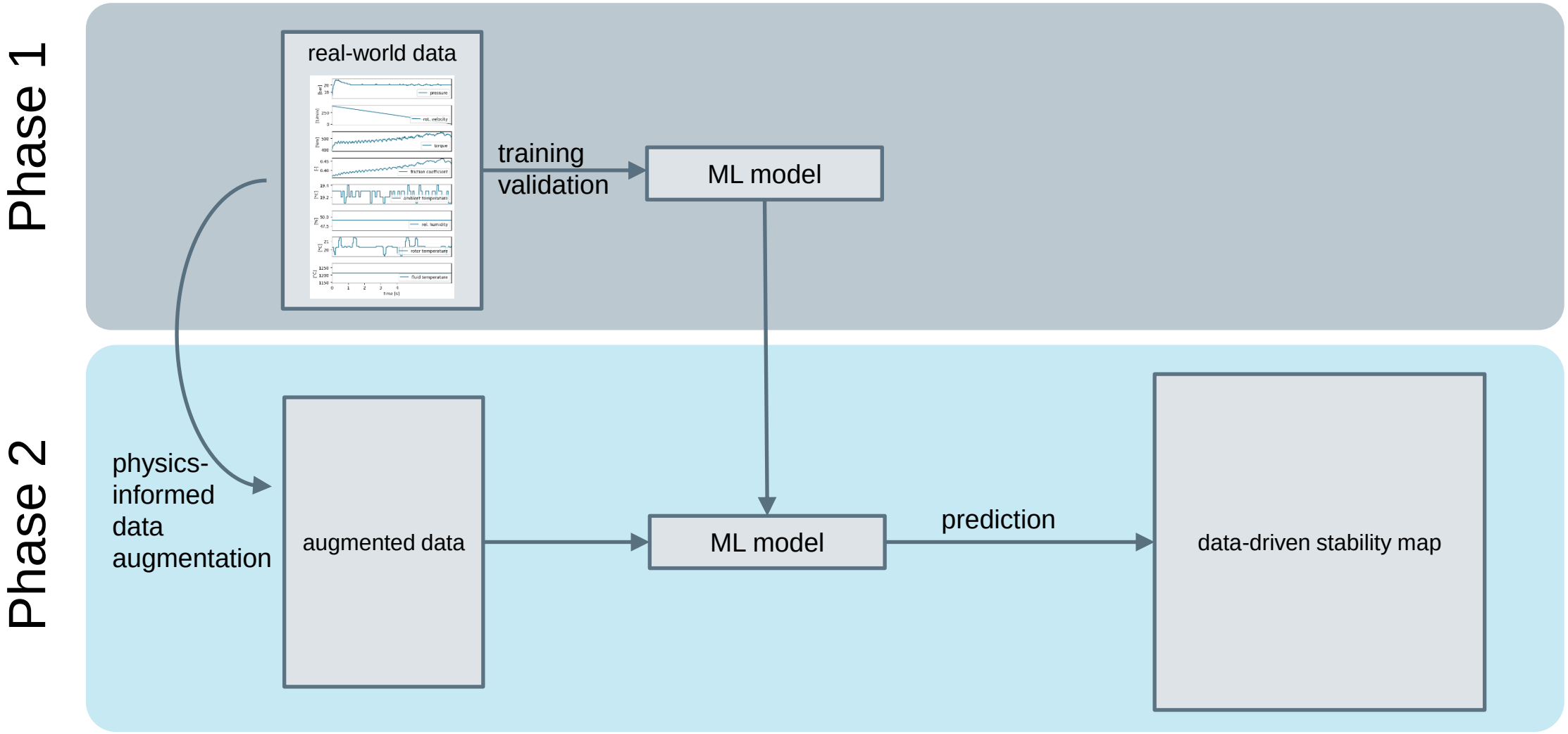


Model performance:

Accuracy: 0.97
MCC: 0.90



Work flow


Phase 1
real-world data
training
validation
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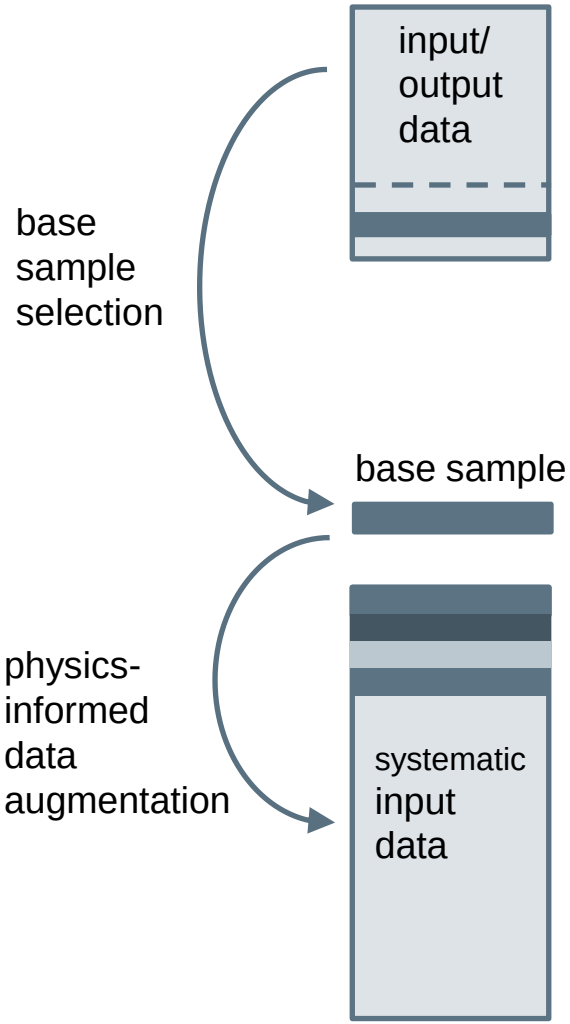
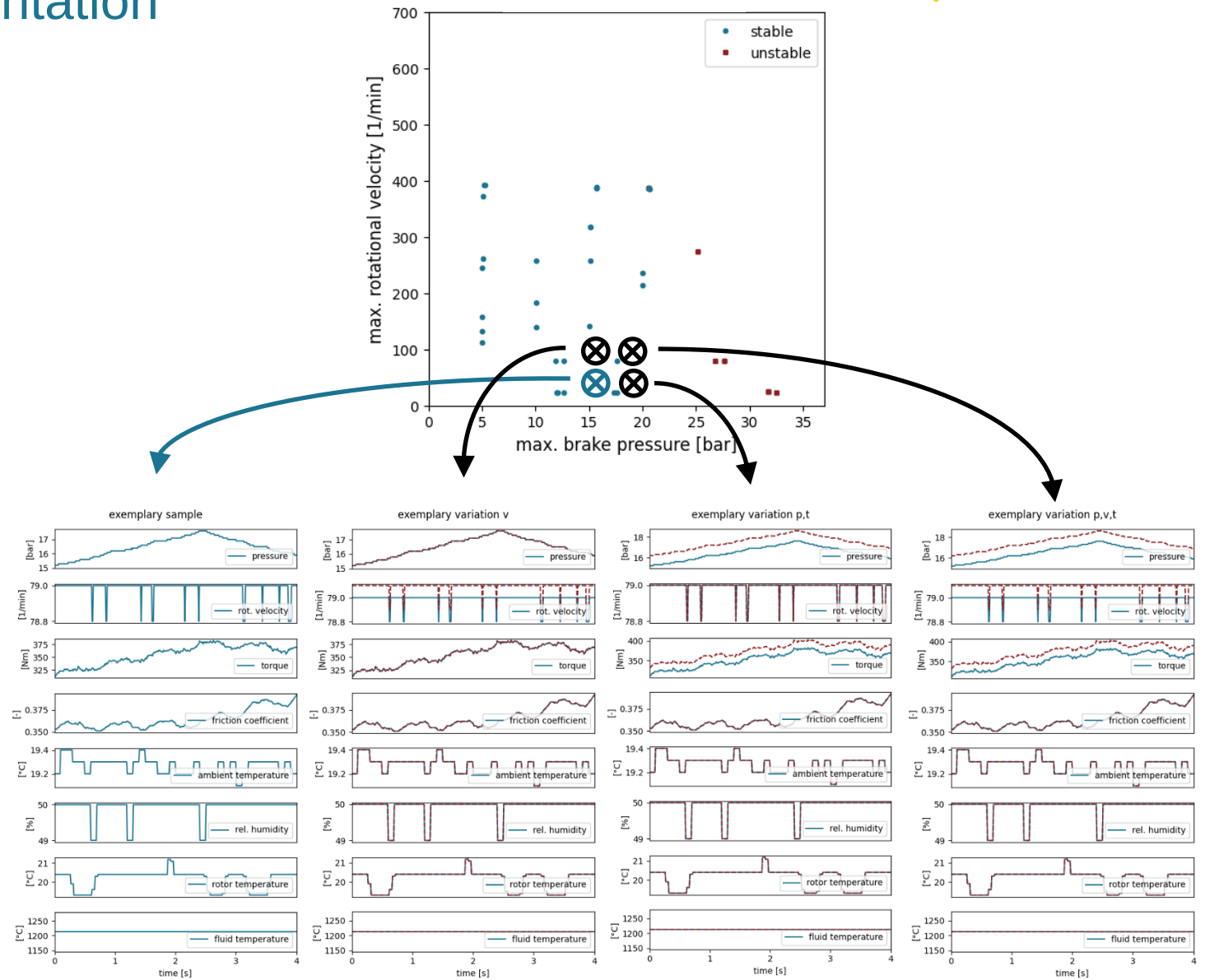
data-driven stability map

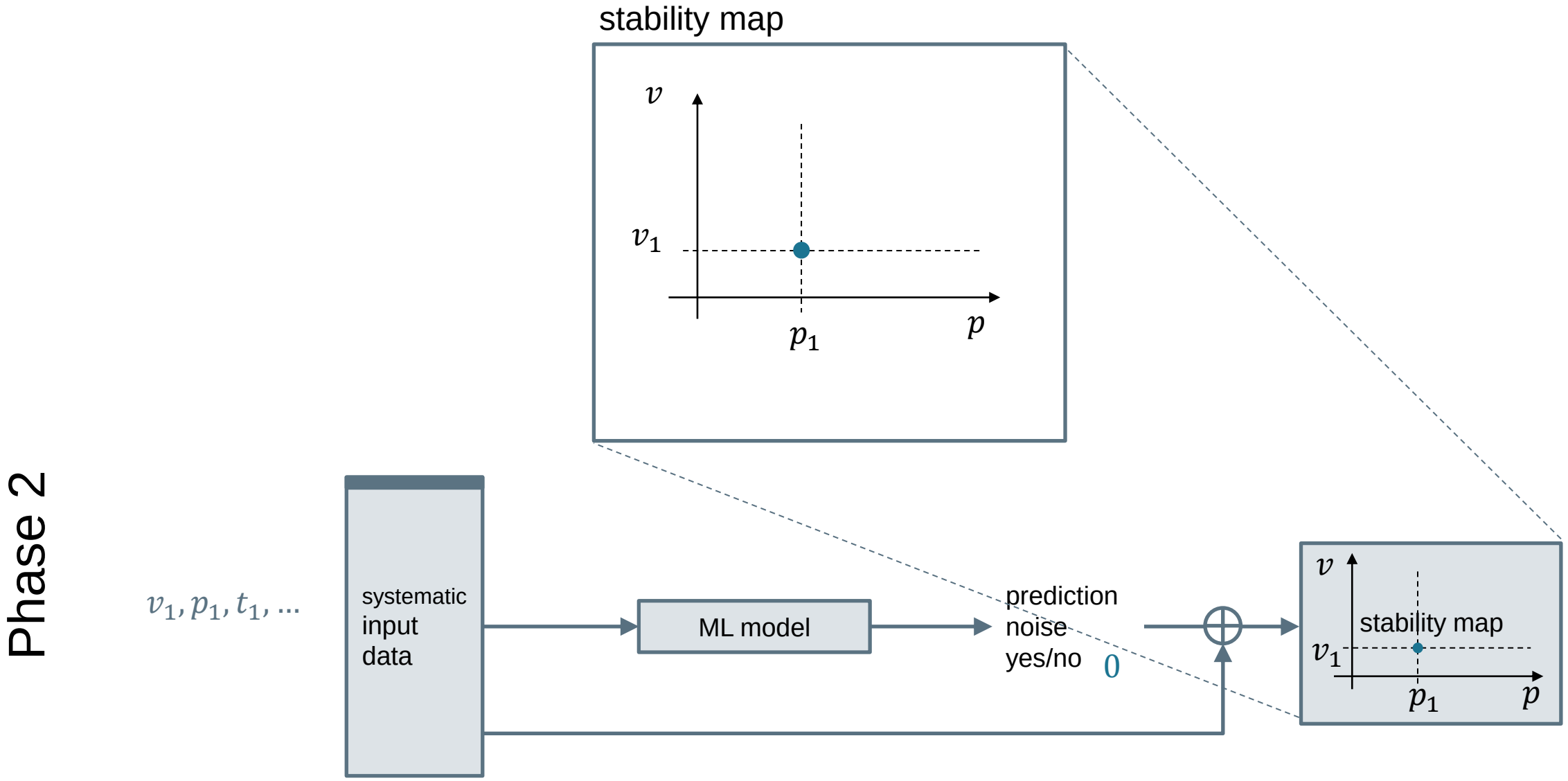
Physics-informed data-augmentation

Phase 2

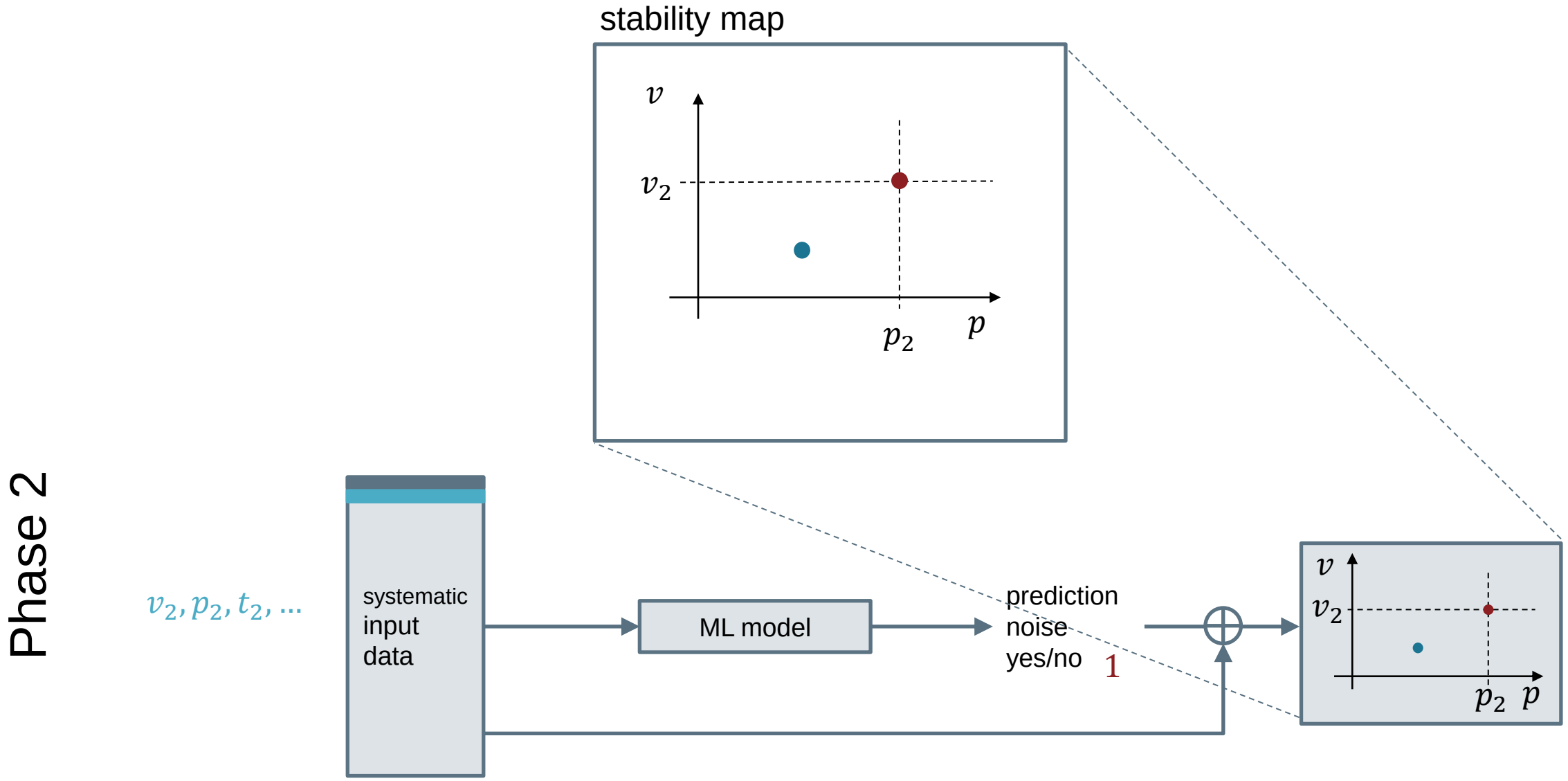




Stability map generation

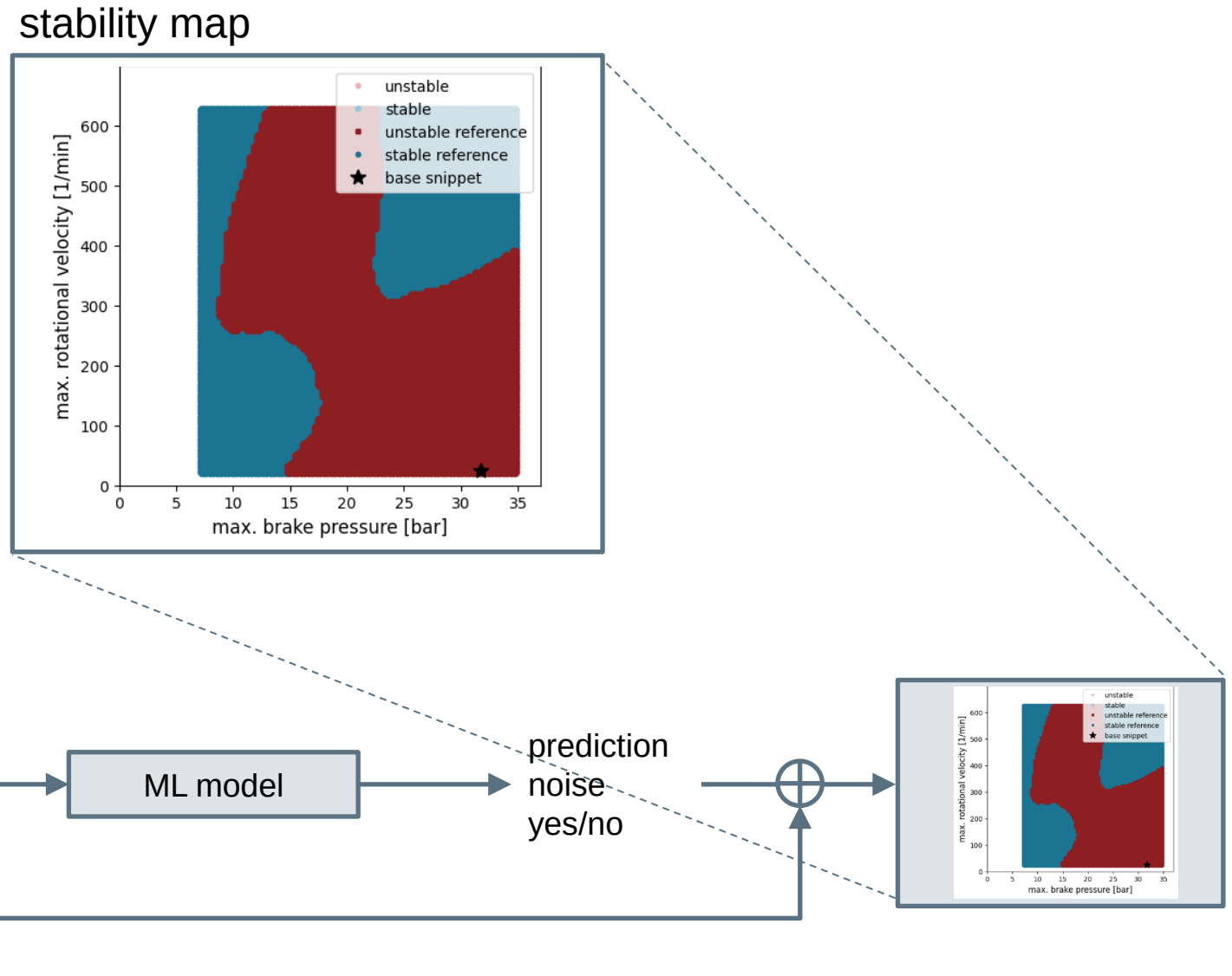


Stability map generation

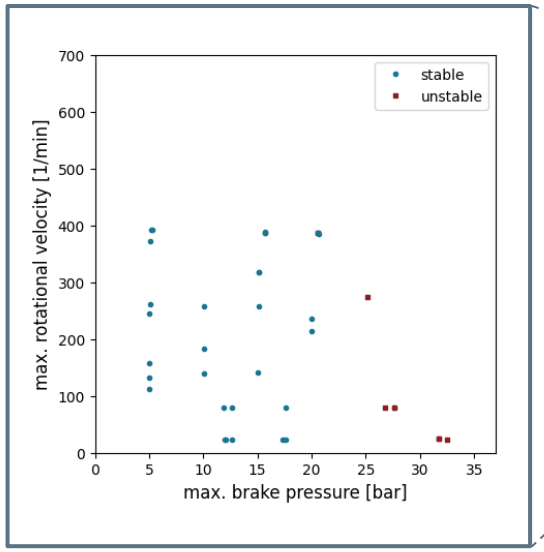


Stability map generation

Phase 2

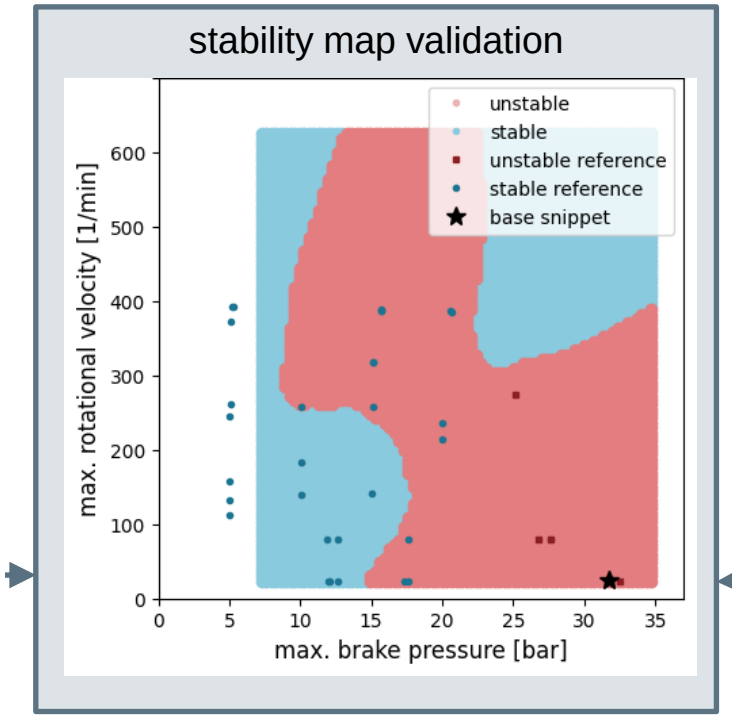


Stability map validation



input/
output
data

choose comparable
samples

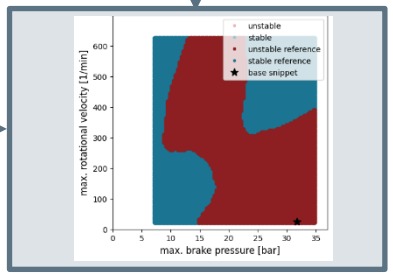


Phase 2

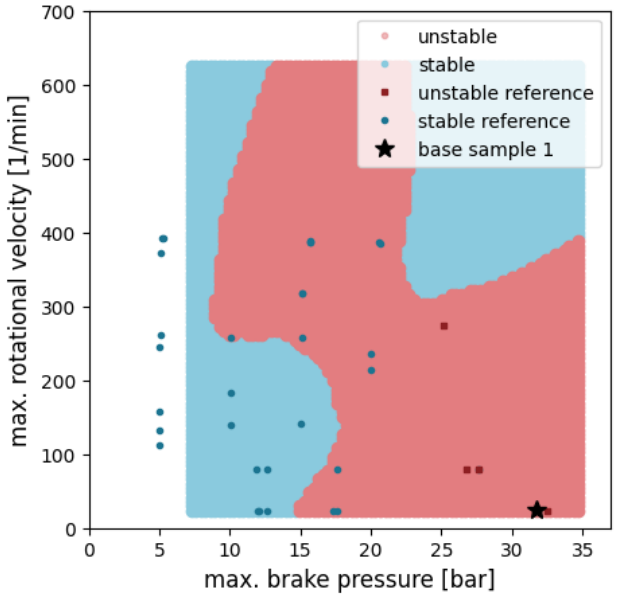
systematic
input
data

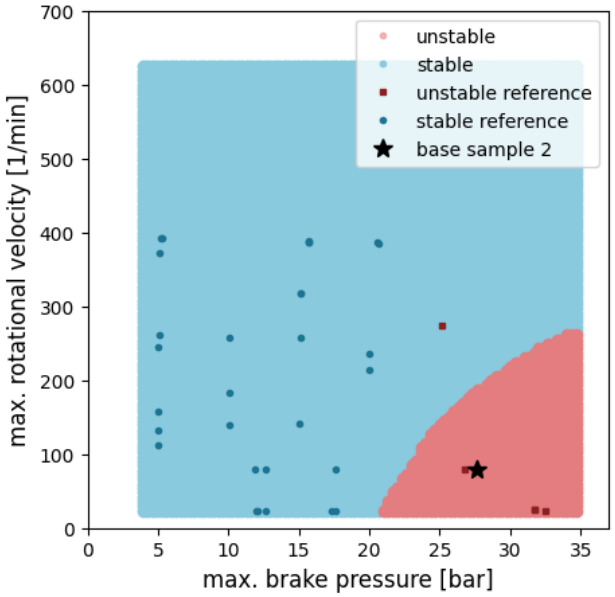
ML model

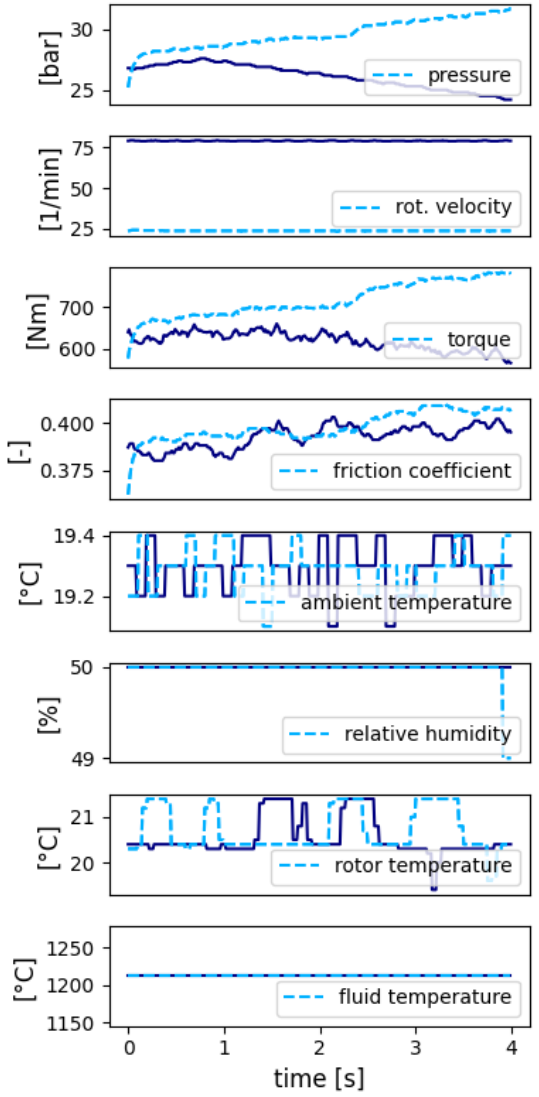
predictions



Stability maps



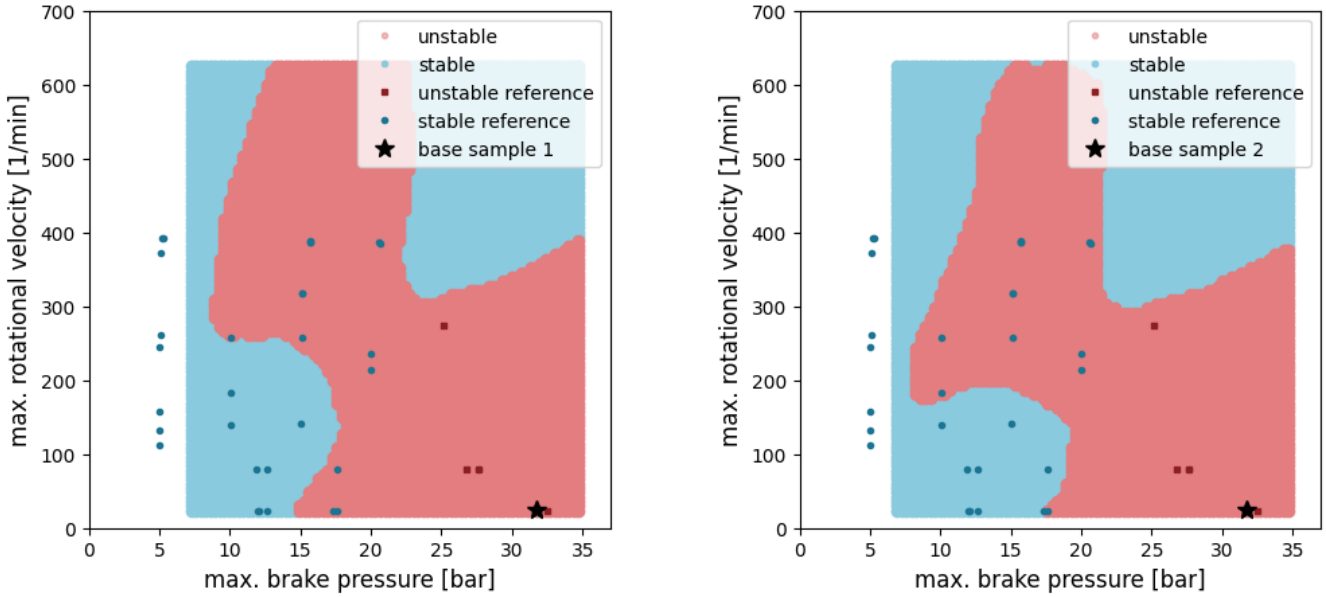


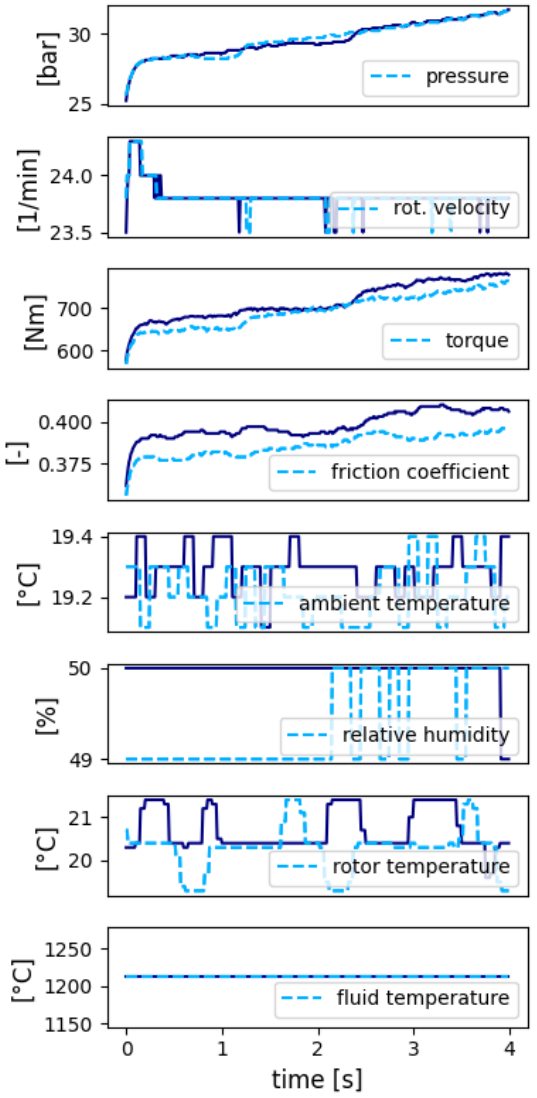


Seemingly similar basis sample points yield completely different bifurcation maps

→ **Model uses hidden dimensions** (e.g. pressure and torque slopes)

Stability maps

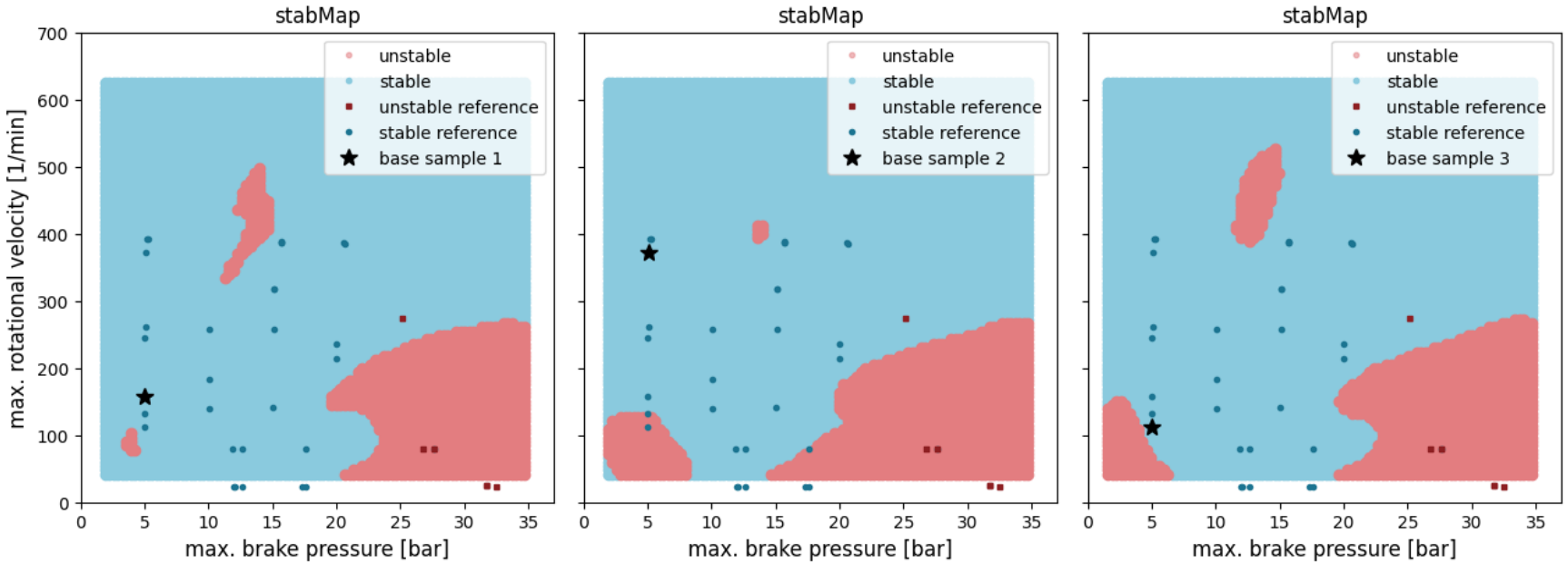


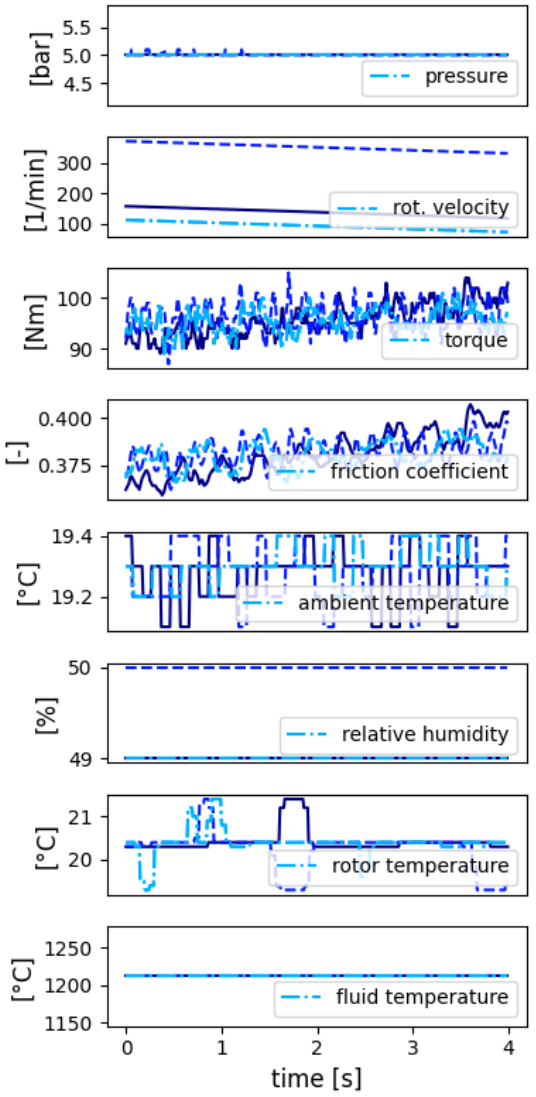


"Truly" similar basis sample points result in similar bifurcation maps

→ **Method yields consistent results**

Stability maps

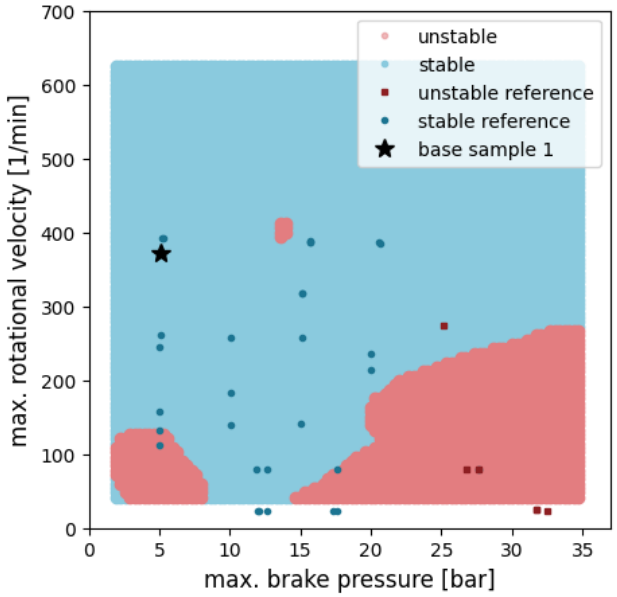


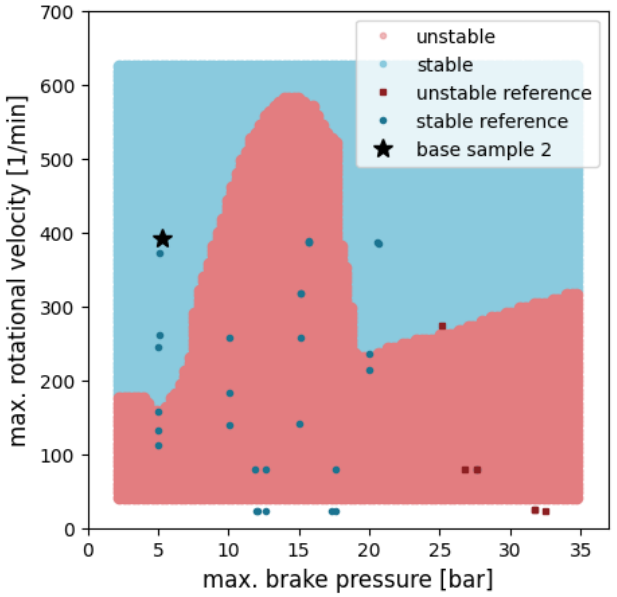


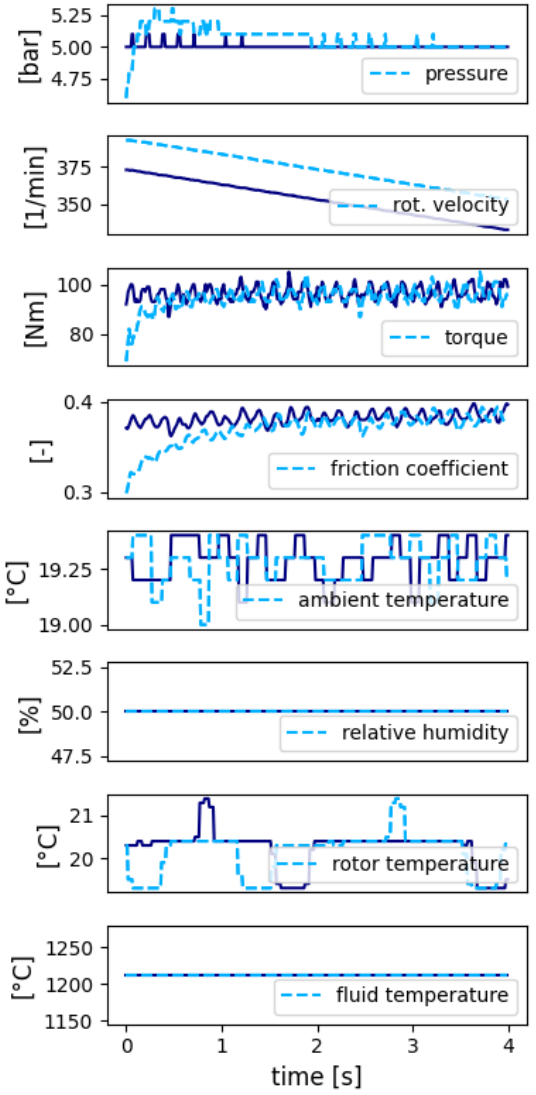
Basis sample points with qualitatively similar behavior result in similar bifurcation maps

→ **Maps are not biased by max. rotational velocity of basis sample**

Stability maps



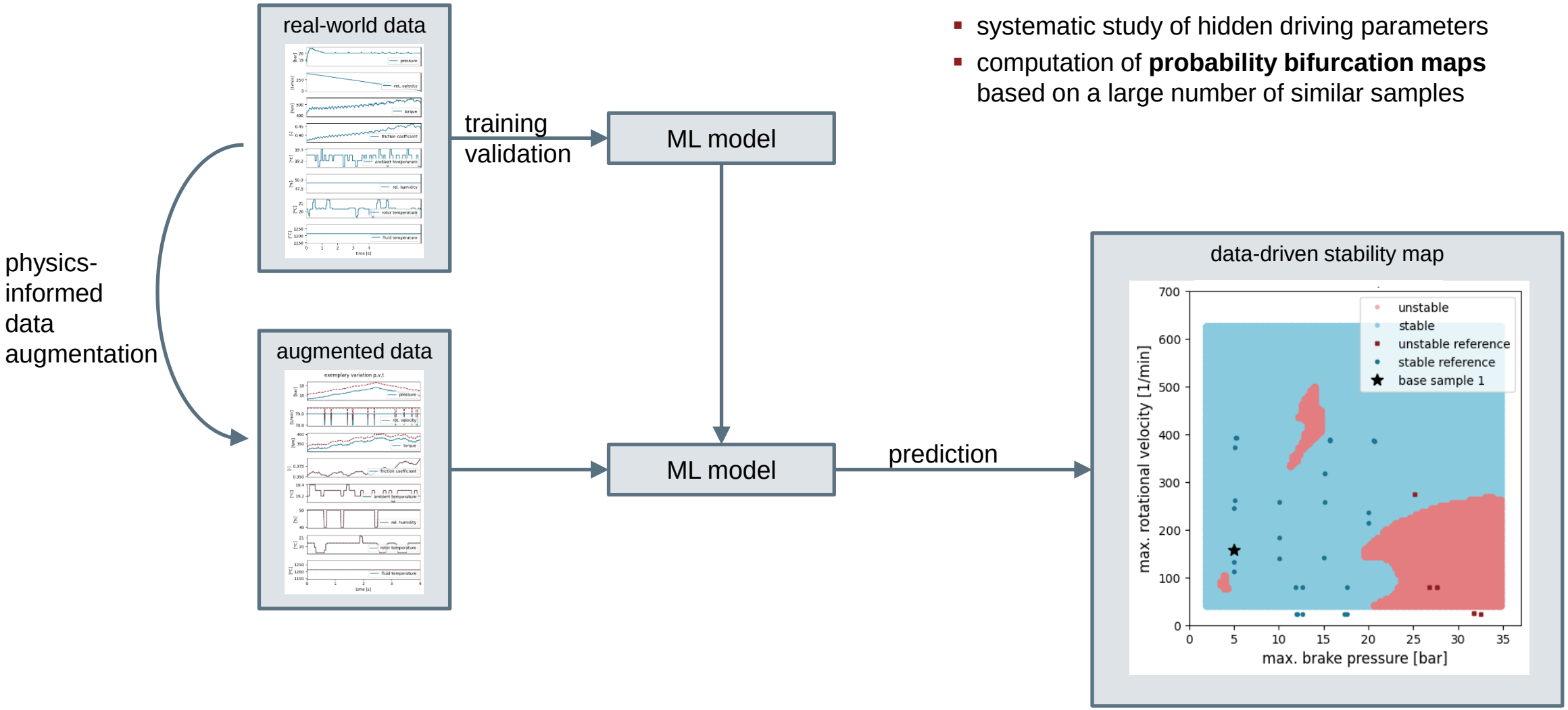




Qualitatively different behavior in sample points results in different bifurcation maps

→ **Detection of hidden mechanisms/responsible dimensions possible!**

Summary & outlook



Outlook:

- systematic study of hidden driving parameters
- computation of **probability bifurcation maps** based on a large number of similar samples

Thank you!

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