# ABS Control for Two-Wheeled Vehicles using Deep Reinforcement Learning

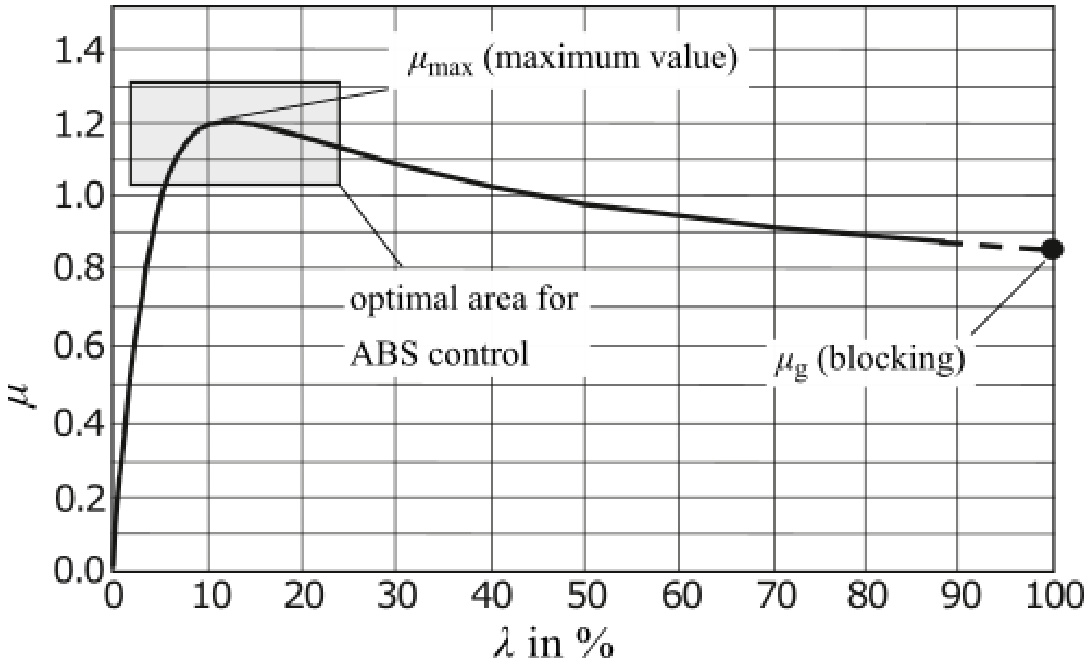
14th International Motorcycle Conference

Nicolas Häffner
Robert Bosch GmbH

# Introduction
## Motorcycle ABS

- ABS
  - Wheel Slip Controller
  - Mitigates a lock-up of the wheel

- Motorcycle specific challenges
  - Slip estimation challenging
  - Dynamic overbraking of the front wheel
  - Rear wheel lift-up





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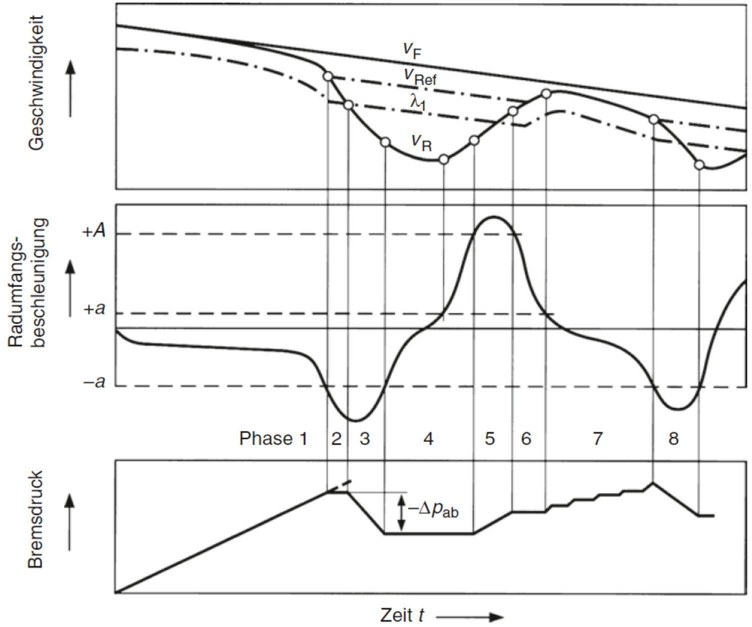
# Introduction

## State of the Art

| | Tracking performance | Realization difficulty | Robustness | Amount of parameters | Easy to tune | Computational load | Adaptability | Implementation intensity |
|---|---|---|---|---|---|---|---|---|
| RB | ◔ | ◔ | ◕ | ● | ○ | ○ | ◕ | ● |
| FLC | ○ | ◑ | ◑ | ◕ | ◔ | ◔ | ◔ | ◔ |
| NNC | ◔ | ◑ | ◔ | ◕ | ◔ | ◑ | ◔ | ◔ |
| PID | ◕ | ○ | ◑ | ○ | ● | ○ | ◔ | ◑ |
| LQR | ◕ | ◑ | ◑ | ◔ | ◑ | ◑ | ◑ | ◔ |
| SMC | ◕ | ◕ | ◕ | ◑ | ◑ | ◑ | ● | ◑ |
| Robust | ◑ | ◕ | ● | ◕ | ◔ | ◕ | ◑ | ○ |
| MPC | ● | ● | ◕ | ◑ | ◕ | ● | ◕ | ◔ |

● Highest ◕ High ◑ Average ◔ Low ○ Lowest




F. Pretagostini, L. Ferranti, G. Berardo, V. Ivanov, and B. Shyrokau, "Survey on Wheel Slip Control Design Strategies, Evaluation and Application to Antilock Braking Systems," *IEEE Access*, vol. 8, pp. 10951–10970, 2020.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# Introduction
## Motivation

- Heuristic approach leads to…
  - …high calibration effort
    - Typical ABS calibration is carried out by a highly trained and experienced engineer
    - → Associated costs can be prohibitive especially in low volume projects
  - …convoluted architecture
    - Exceptions to the norm must be identified manually and fixed (i.e. Spanish bumps)
    - → High SW efforts

Self calibrating ABS controller

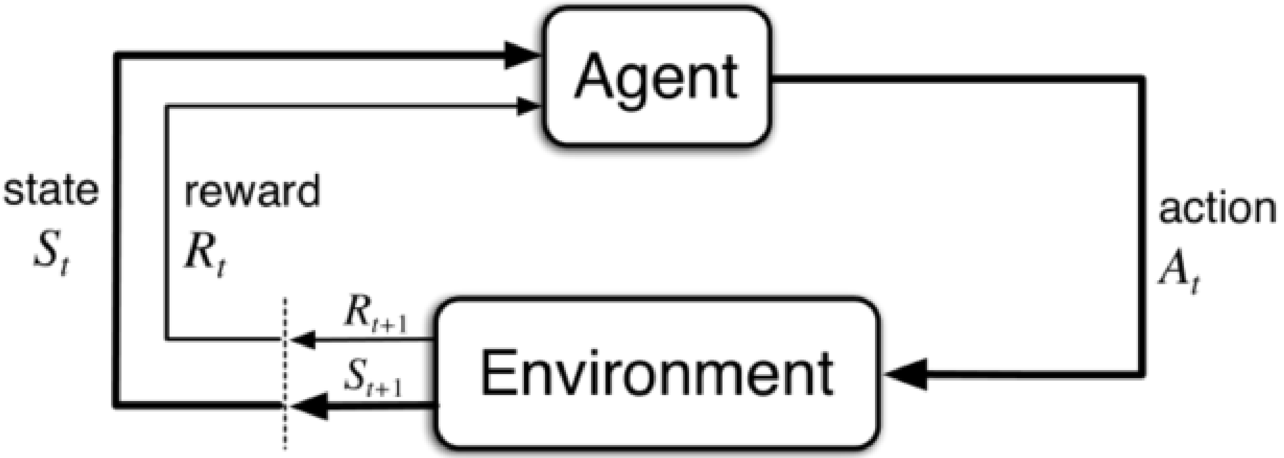
# Introduction
## State of the Art

*“Lastly, one of the weak-investigated directions and in the starting point of the research in WSC [Wheel Slip Control] is the usage of reinforcement learning […] and deep learning.”*

F. Pretagostini, L. Ferranti, G. Berardo, V. Ivanov, and B. Shyrokau, “Survey on Wheel Slip Control Design Strategies, Evaluation and Application to Antilock Braking Systems,” *IEEE Access*, vol. 8, pp. 10951–10970, 2020.

# Introduction
## Deep Reinforcement Learning - MDPs

Sutton, Barto; Reinforcement Learning; 2020




Objective: *Maximize the (expected and discounted) cumulative sum of future rewards.*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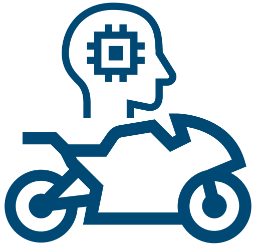
# Implementation

## Simulation Setup



### Sensor Readings

- Wheel speed front/rear
- Wheel acceleration front/rear
- Longitudinal acceleration sprung mass

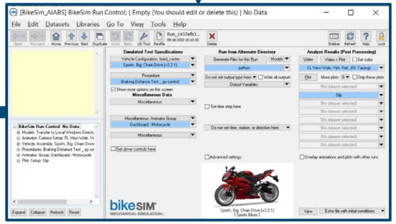
### Pressure Action

- Pressure increase or decrease front/rear

### Reward

### Python Wrapper

```
if __name__ == '__main__':
    env = Continous(config='no_action', imu=['x', 'ay'], pressure=[2, 0])
    obs = env.reset()
    done = False
    while not done:
        state, reward, done, _ = env.step()
```



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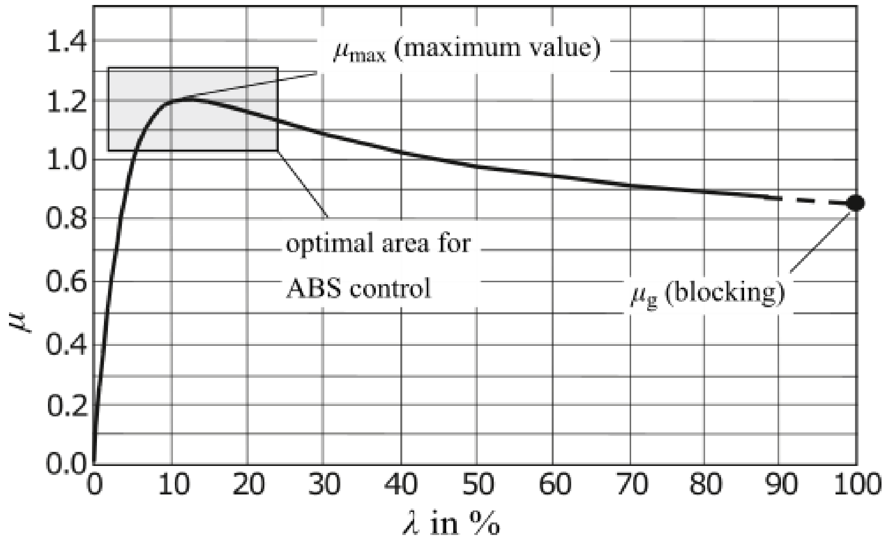
# Implementation
## Reward

- Deceleration as basis for reward
  - Main objective of ABS
  - Beak in friction-ratio-slip-relation at low slip values → highest possible deceleration at stable slip conditions
- Environment has integrating behavior
  - Braking half as hard takes twice as long
  - Linear reward → constant return




$$R = \begin{cases} 0, & if\ \lambda < -0.99 \\ 100, & if\ episode\ done \\ -a_x, & else \end{cases}$$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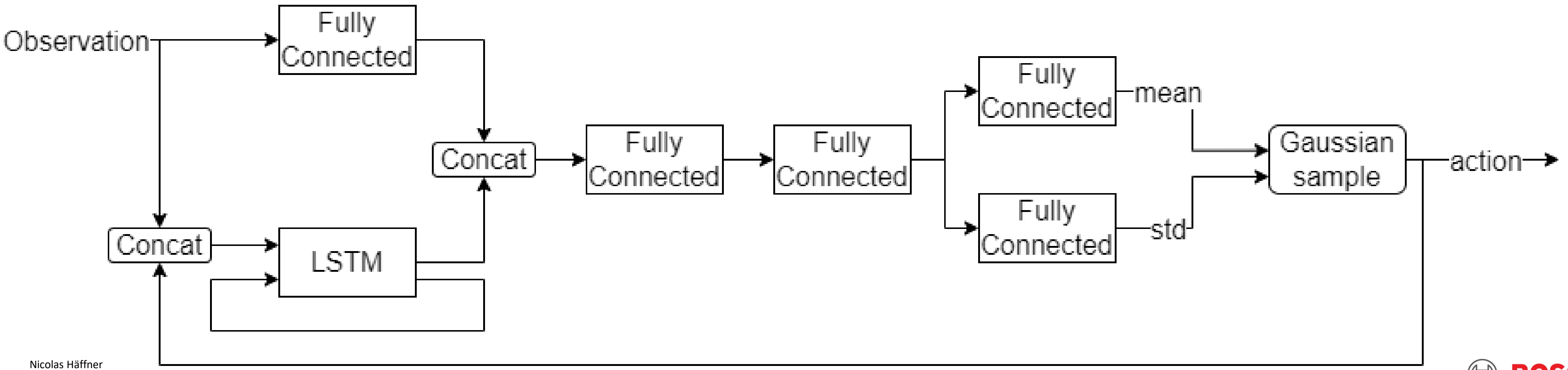
# Implementation

## Partial Observability – Model Architecture

- *"given the present, the future does not depend on the past"* (Markov property)
  - State definition must be sufficient to capture whole dynamic of the problem
  - Typically done by giving the agent a history of datapoints
- ABS Problem is partially observable by nature (slip is not directly measurable)

→ Adding recurrency (LSTM)

  - Agent can "remember" latent representation of the state (believe state)





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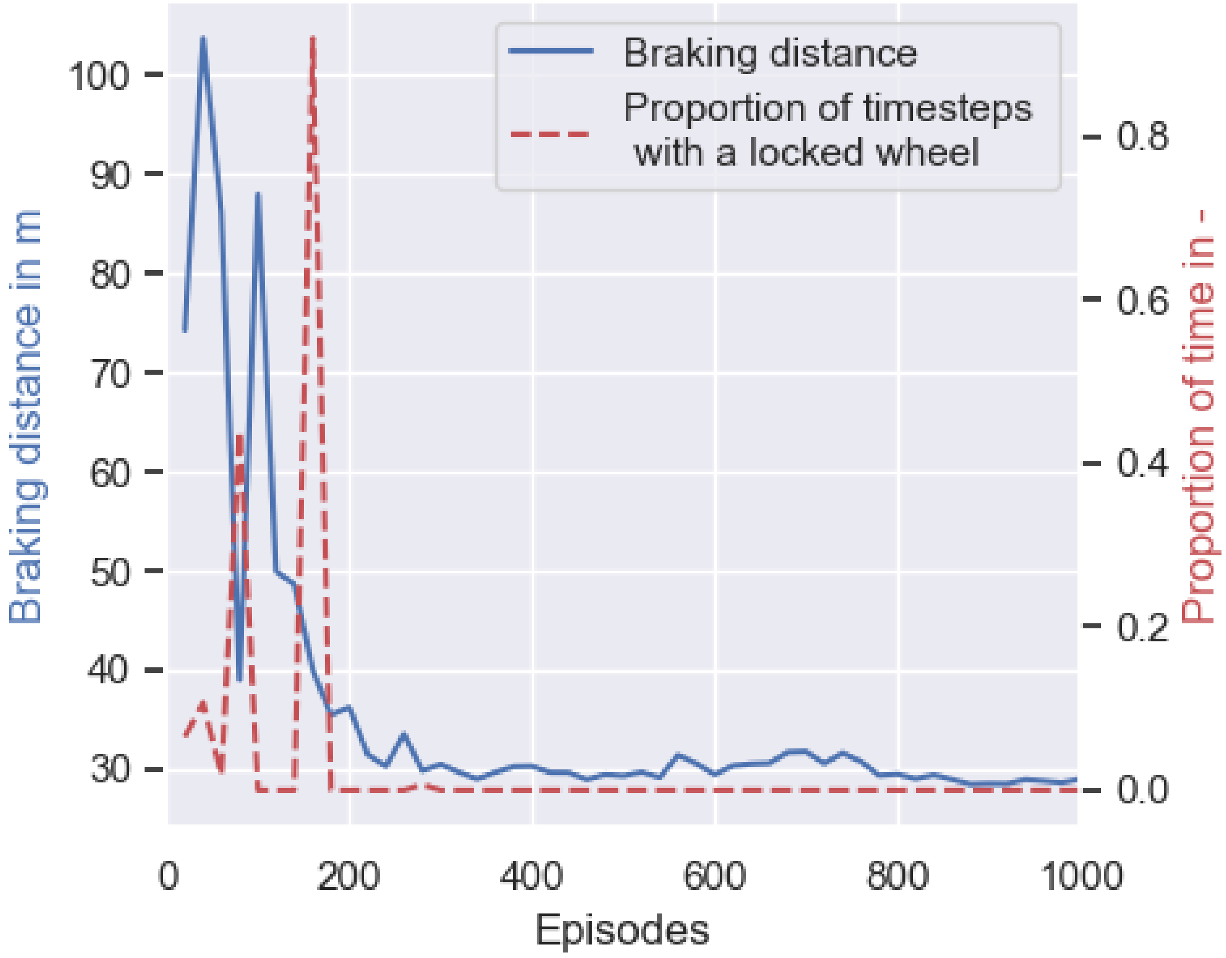
# Results
## Training




- Randomly initialized brake maneuvers
  - Friction coefficient (including jumps)
  - Rider input
  - Rider mass
- Evaluation run every 20 episodes
- With IMU (only longitudinal)

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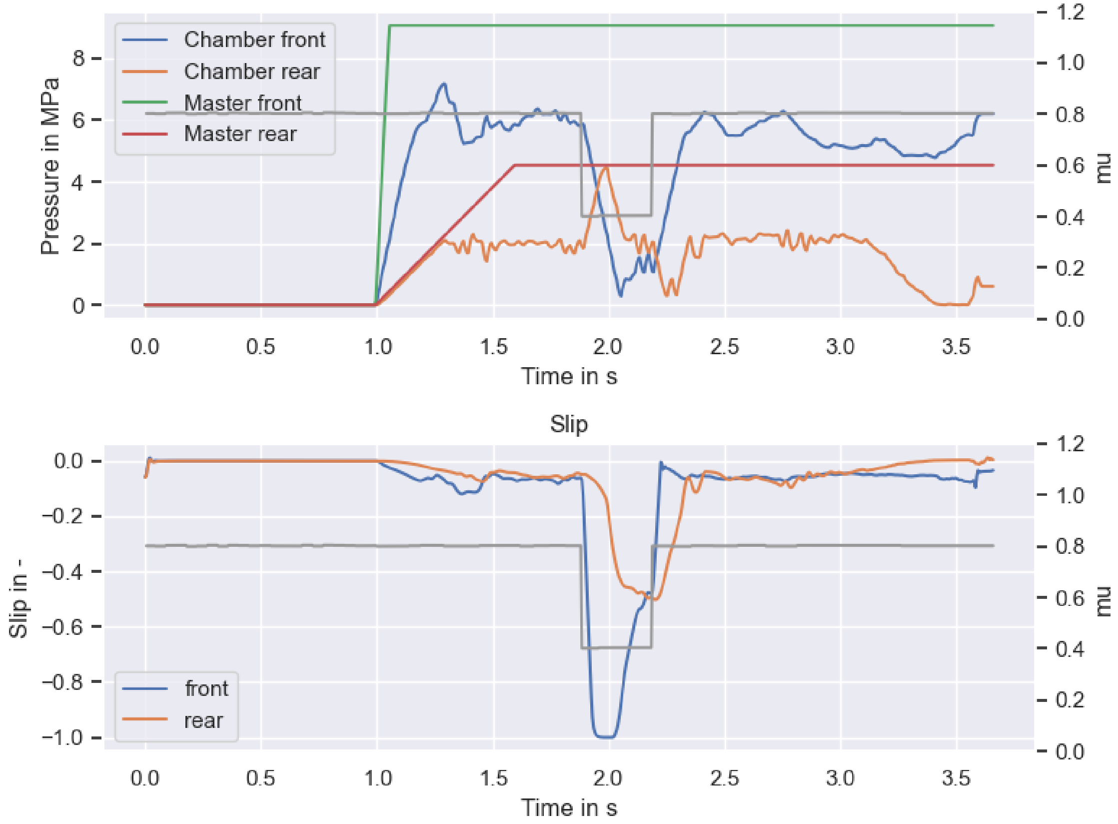
zen.

# Results

## μ-jump 0.8 – 0.4 – 0.8





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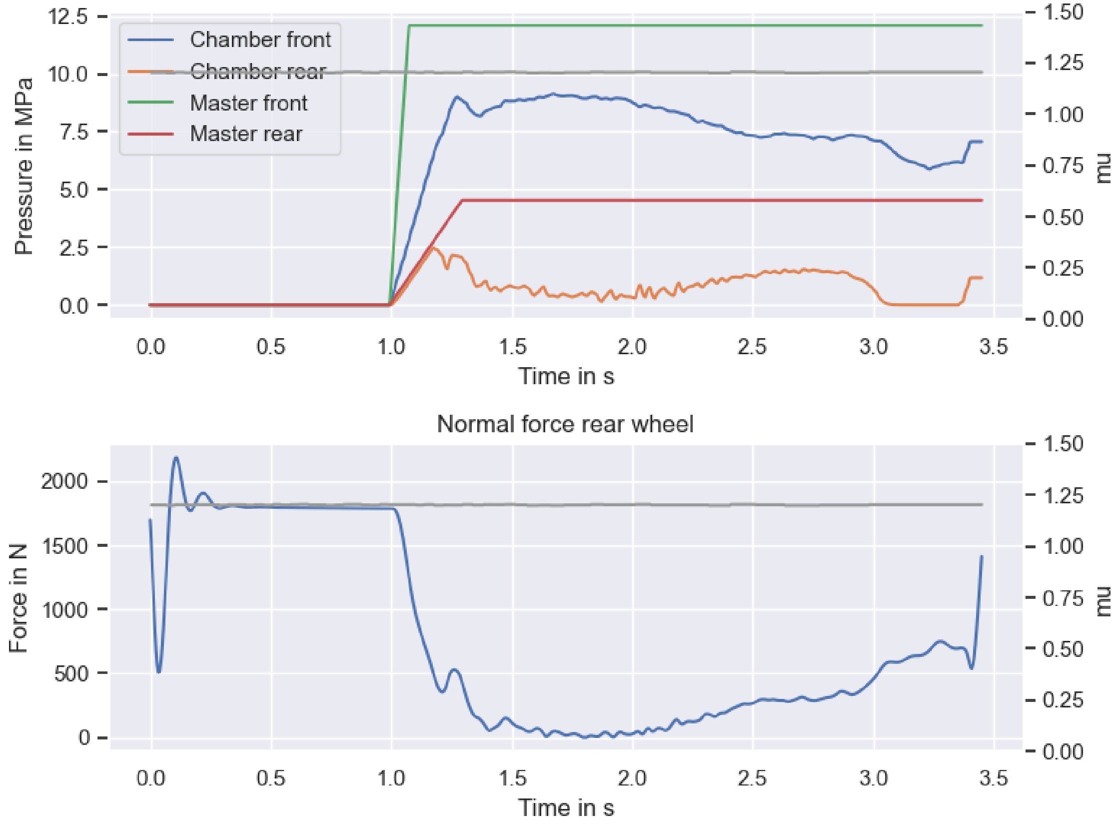
# Results

## Rear Wheel Lift-up Mitigation





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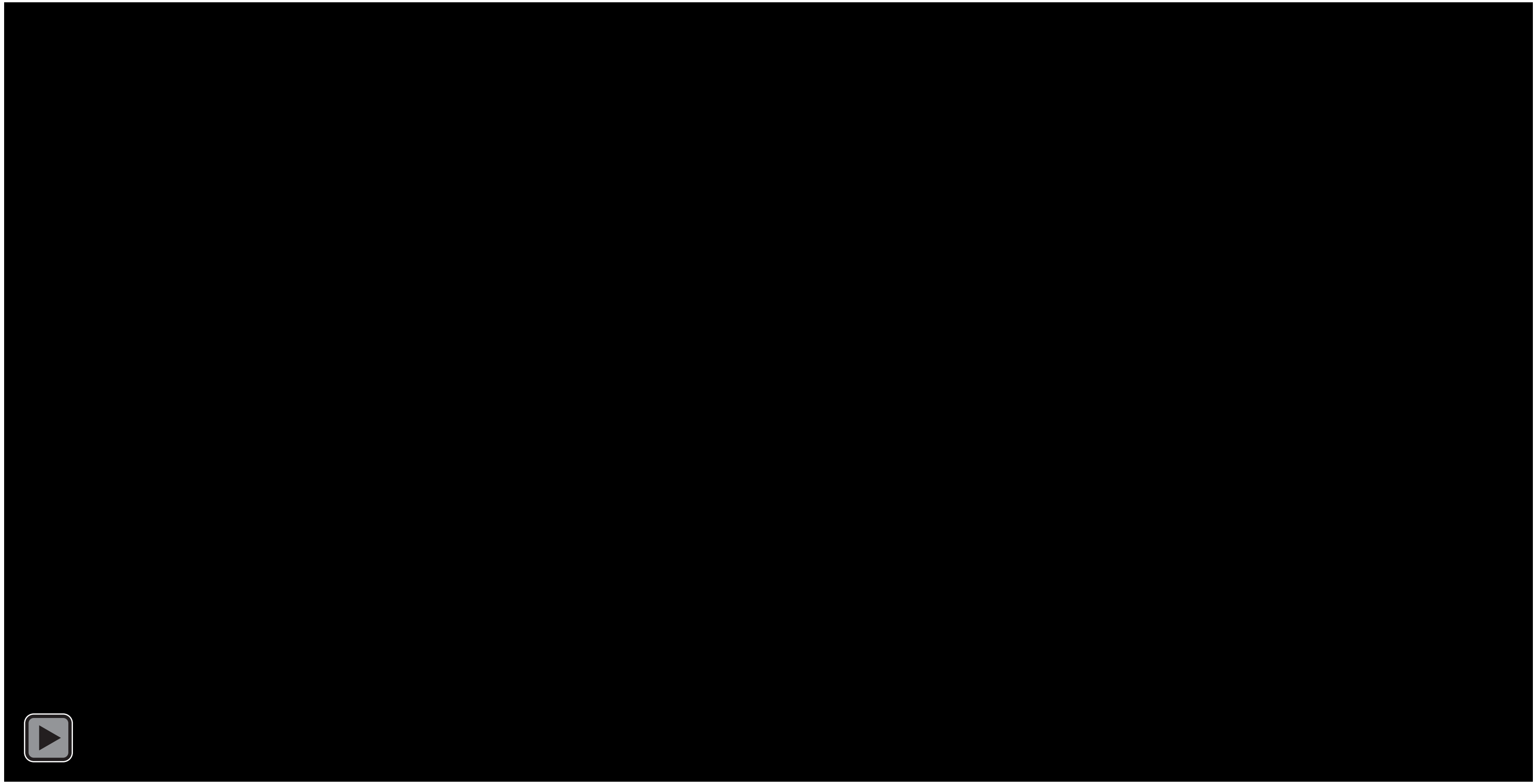
# Results

## Comparison RWLM with and without IMU (longitudinal)




Nicolas Häffner


Nicolas Häffner

Robert Bosch GmbH

Two-Wheeler and Powersports
Engineering Electrification and Safety
(2WP/EES4-EU)

+49 7062 911-5548

Nicolas.Haeffner@bosch.com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