

A Physics-Driven Framework for Online Minimum-Time Vehicle Motion Planning and Control

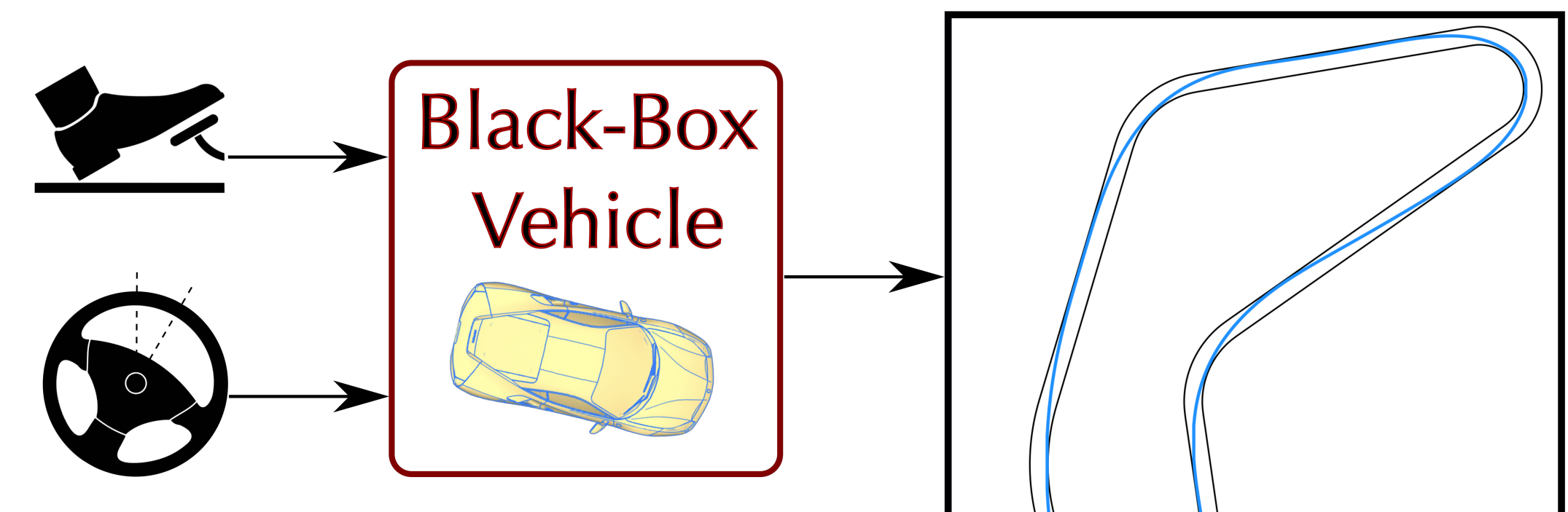
Mattia Piccinini ¹, Sebastiano Taddei ^{1,2}, Matteo Larcher ¹, Mattia Piazza ¹, and Francesco Biral ¹

¹Department of Industrial Engineering, University of Trento, 38123 Trento, Italy.

²Department of Electrical and Information Engineering, Politecnico di Bari, 70125 Bari, Italy.

MOTIVATION

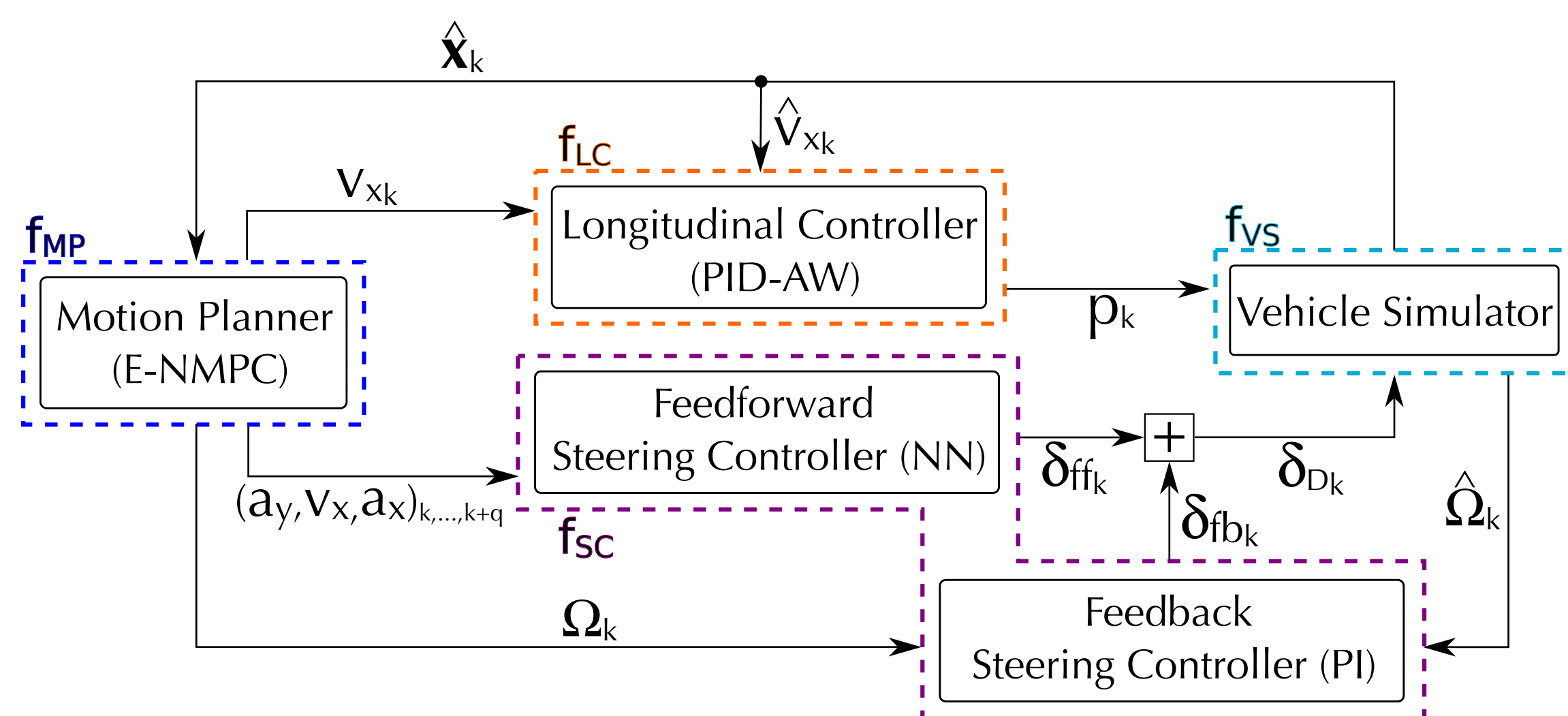
- Set the **best lap times** with a **black-box autonomous vehicle**
- Plan feasible **emergency manoeuvres** for passenger cars
- Develop a framework to **learn vehicle dynamics and low level vehicle control loop**



METHODS

ARCHITECTURE

- Hierarchical **motion planning & control** framework



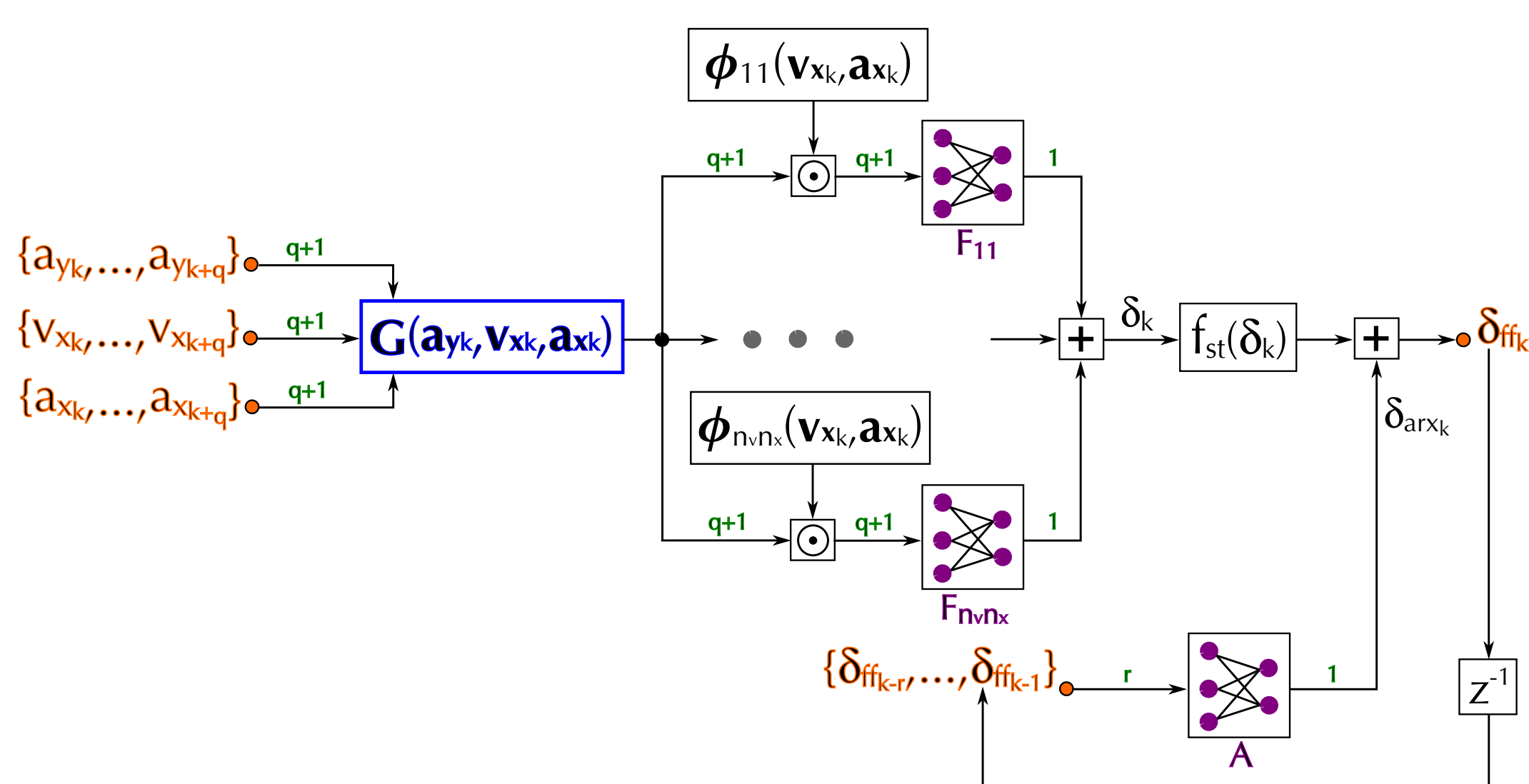
MOTION PLANNER

- Kineto-dynamical vehicle model with a **novel lateral speed prediction model** inspired by the lateral velocity diagram

$$\begin{cases} \dot{v}_x(t) = a_x(t) \\ \tau_{a_x} \dot{a}_x(t) + a_x(t) = a_{x0}(t) \\ \tau_{\Omega} (v_x(t)) \dot{\Omega}(t) + \Omega(t) = \Omega_{0_s}(t) \cdot \Omega_{\max_s}(v_x(t)) \\ \tau_{v_y} (v_x(t)) \dot{v}_y(t) + v_y(t) = F_{v_y}(a_y(t), v_x(t), a_x(t)) \end{cases}$$

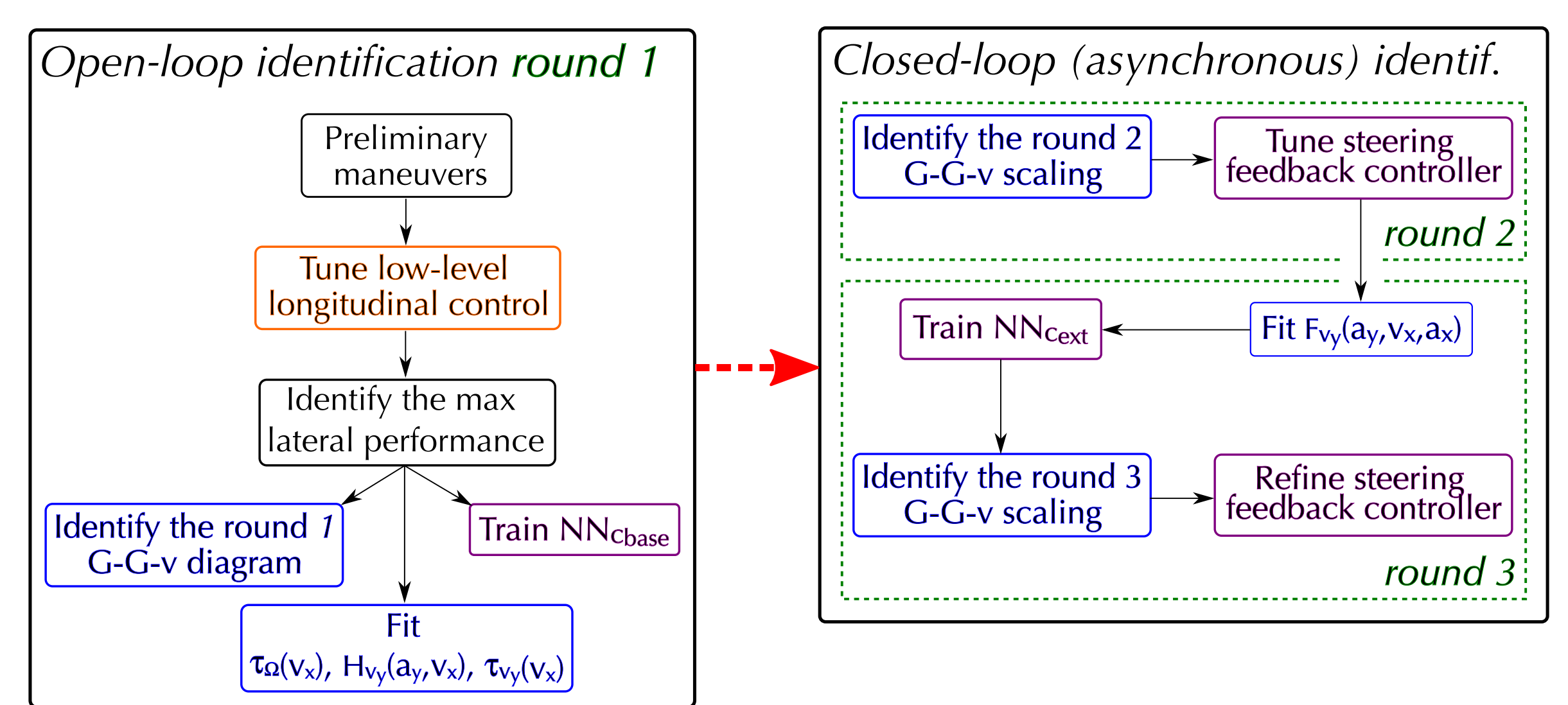
STEERING CONTROLLER

- **Novel physics-informed neural network** inspired by the handling diagram



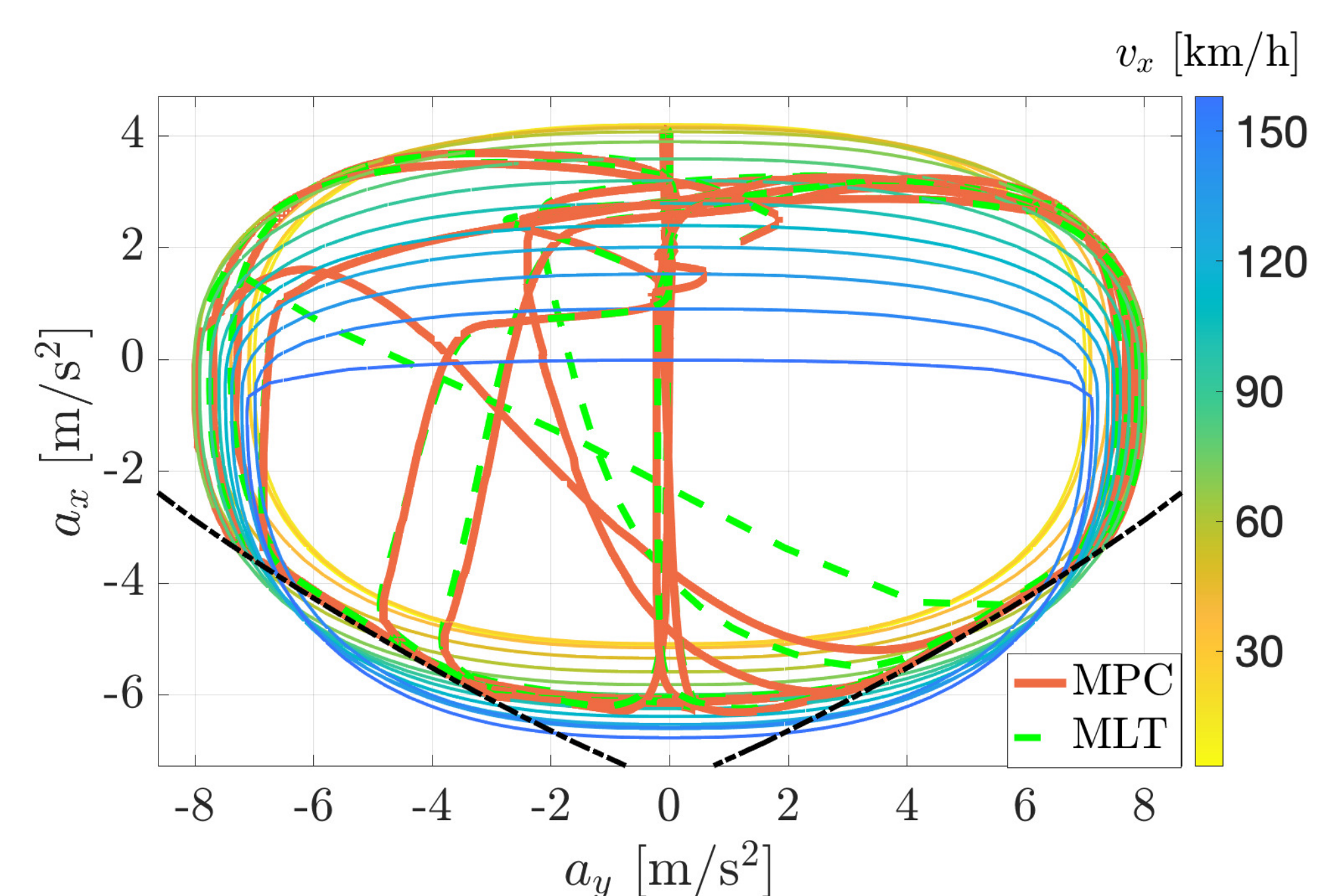
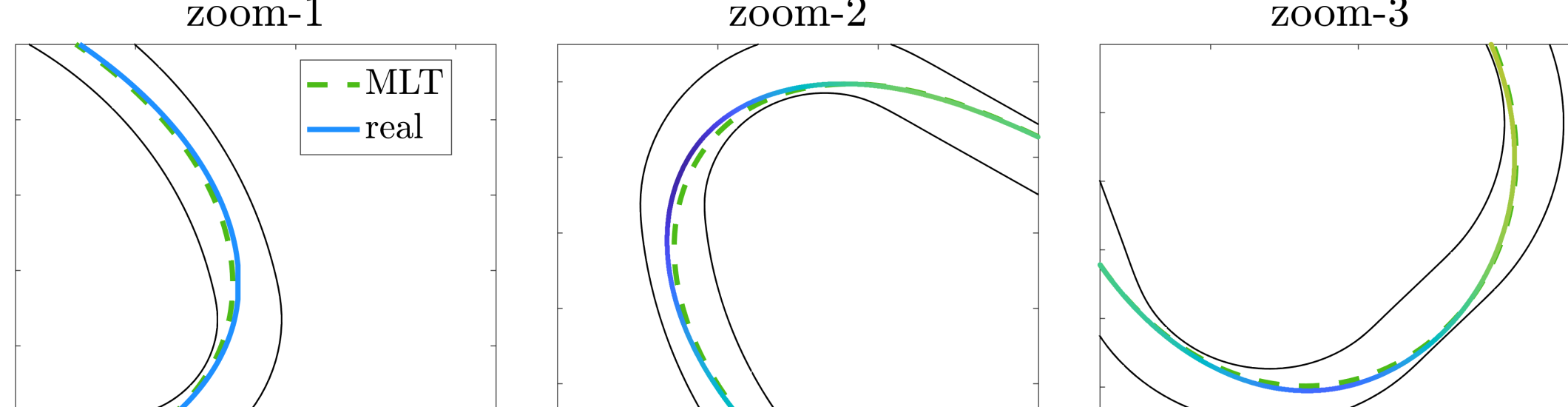
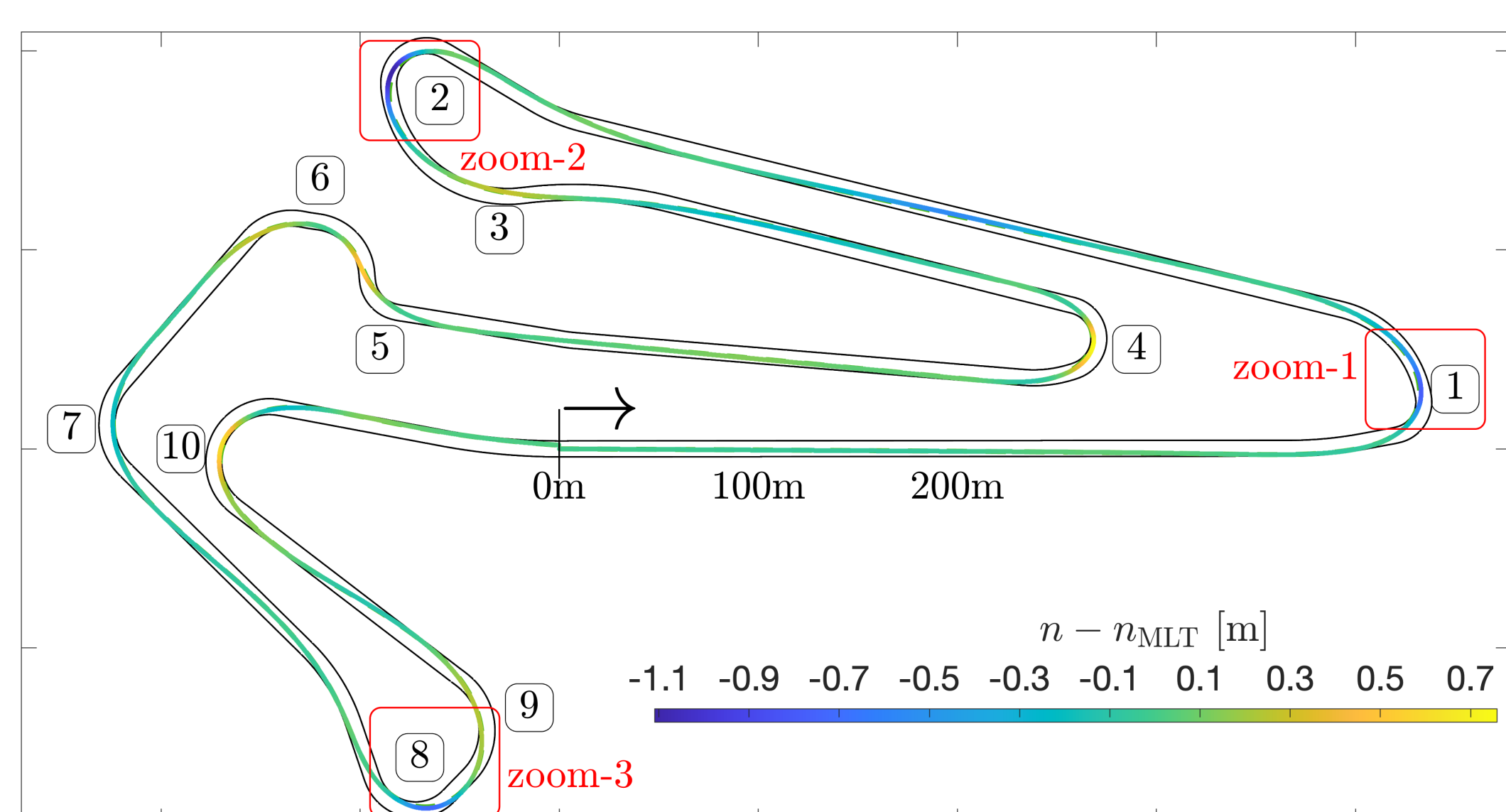
LEARNING METHOD

- **Three-round learning scheme** to incrementally learn complex dynamical models



RESULTS

- The **lap times** on unseen circuits are only 0.175 s from the benchmark **performance limits**
- Good **robustness** to variations of 15% in the vehicle mass



REFERENCES

- [1] M. Piccinini, S. Taddei, M. Larcher, M. Piazza and F. Biral, "A Physics-Driven Artificial Agent for Online Time-Optimal Vehicle Motion Planning and Control", in IEEE Access, vol. 11, pp. 46344-46372, 2023, doi: 10.1109/ACCESS.2023.3274836.
- [2] M. Piccinini, M. Larcher, E. Pagot, D. Piscini, L. Pasquato, and F. Biral, "A predictive neural hierarchical framework for on-line time-optimal motion planning and control of black-box vehicle models", Vehicle System Dynamics, 2022.
- [3] E. Pagot, M. Piccinini, and F. Biral, "Real-time optimal control of an autonomous RC car with minimum-time maneuvers and a novel kineto-dynamical model", in 2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2020, pp. 2390-2396.

Watch me!

