MAGNETIC TRAIN LOCALIZATION: HIGH-SPEED AND TUNNEL, EXPERIMENT AND EVALUATION

Oliver Heirich, Benjamin Siebler, Andreas Lehner, Thomas Strang, Stephan Sand

Onboard Train Localization

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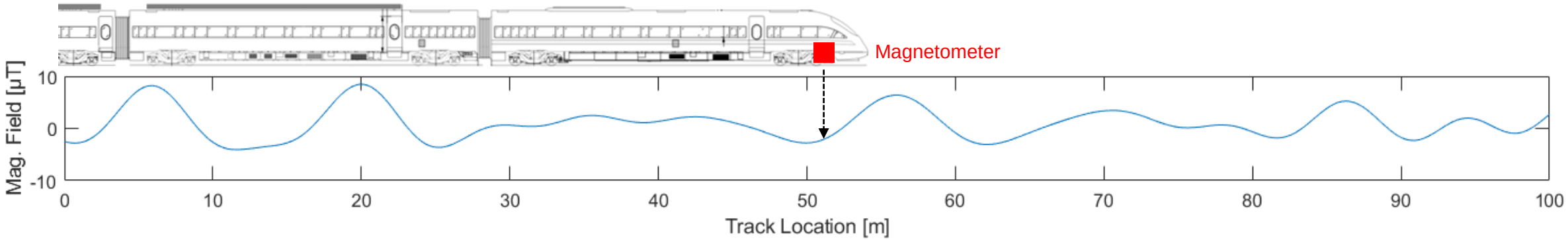
- **Onboard Train Localization**
  - GNSS, IMU, odometry, magnetometers
  - Digital track map
  - Localization algorithm with sensor fusion and map
- **Safe Train Localization**
  - Integrity, optimized for railway environment
  - Multi-sensor fusion with fault detection and exclusion (FDE)
- **Magnetic Train Localization**
  - Redundancy to GNSS
  - Improves track-selectivity
  - Tunnel solution

Magnetic Signatures in the Railway Environment

Magnetic Signature Applications for Localization

1. Absolute train localization (requires map)



2. Relative train localization (distance on tracks, no map)

3. Train odometry (speed and traveled distance, no map)

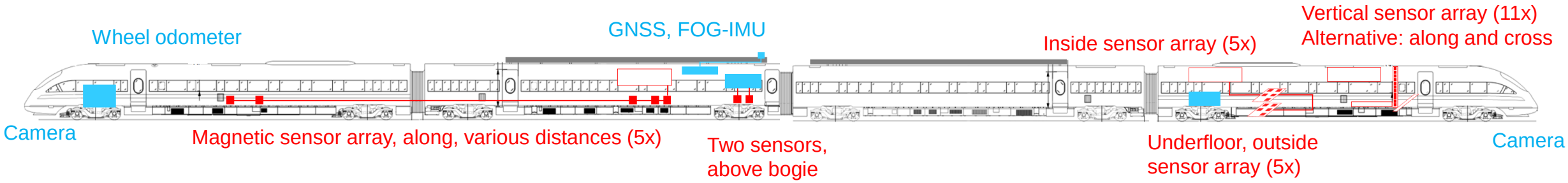
Overview of Research Questions for the Experiment

- What is the **accuracy** and **availability** of a magnetic train localization in urban and high-speed scenarios?
- How good does it work in **long tunnels** in terms of availability and accuracy?
- Is it possible to **identify a track change** at a switch inside the tunnel?
- What is the accuracy and availability of the **magnetic odometry**?
- How do **different measurement locations** and **heights** affect the localization?
- Is it possible to use different mounting positions, or **different trains** for a localization?
- How do generators, power lines, and motors affect the magnetic train localization in terms of **electro-magnetic combability** (EMC)? Are there **unfortunate mounting locations** in the train?
- How does a **magnetic emergency brake** affect the measurements, localization and a possible map?

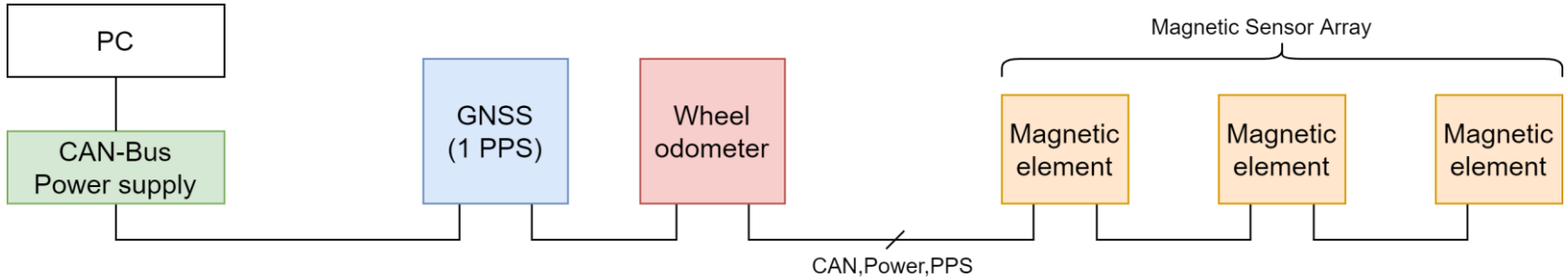
High-speed Train Experiment

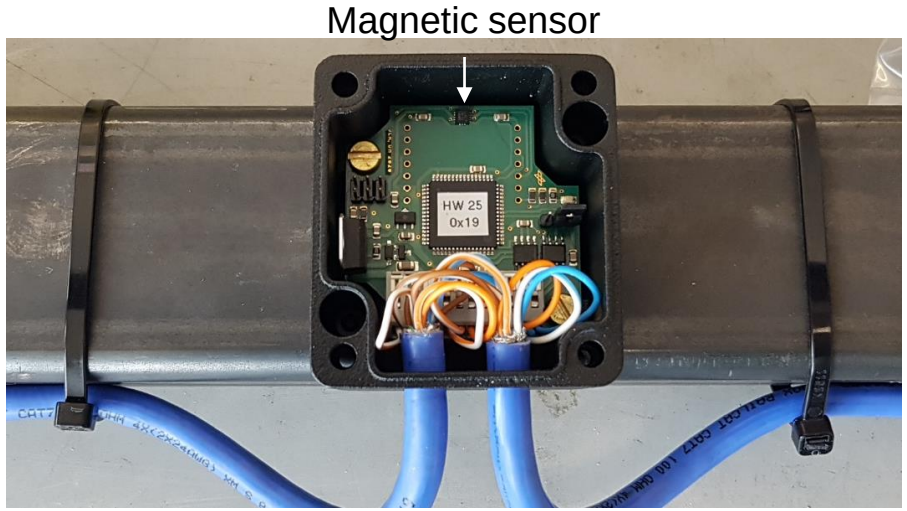
Experiment Vehicle: High-Speed Train

- Deutsche Bahn: Advanced TrainLab (ICE TD BR 605)
- 4 cars, 106 m length, 216 t mass
- Diesel electric generators on each car: 4 x 560 kW = 2.2 MW
- 200km/h top speed
- **28 magnetic sensors**
- Reference sensors: wheel odometry, high-end GNSS, IMU



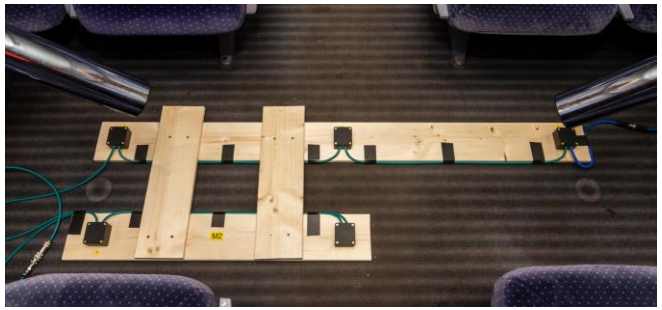
Experiment Sensors: Magnetic Sensor Array

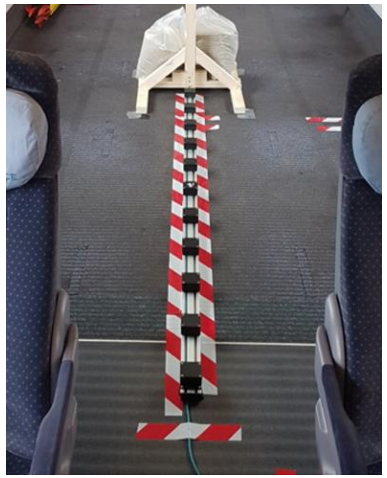


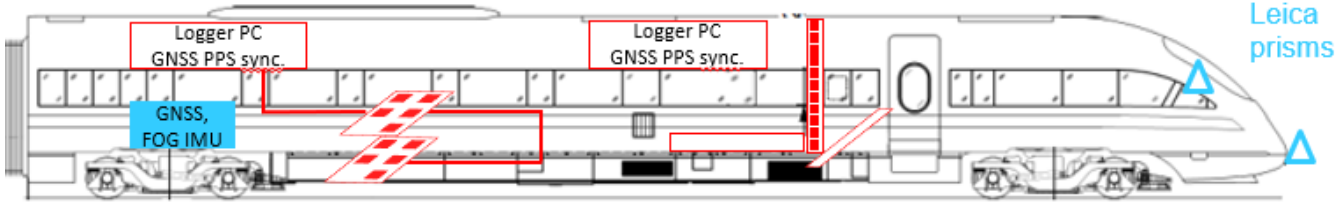


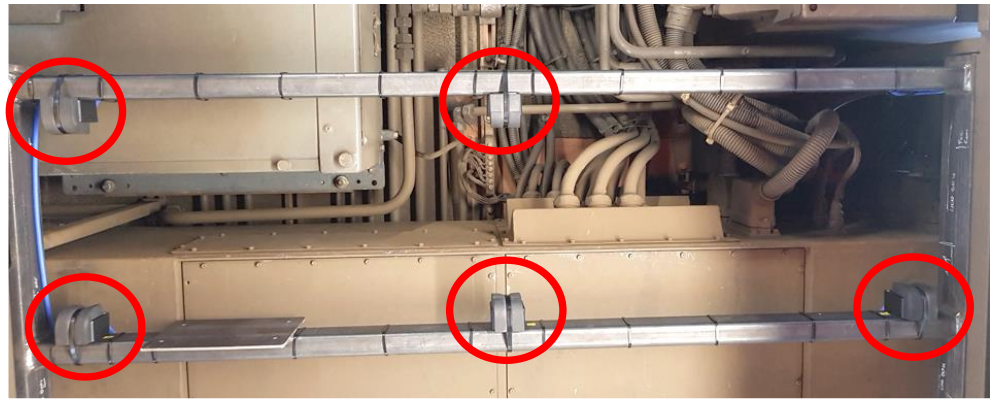
→ ION fair exhibit @ DLR booth

Experiment Setup: Magnetometers, rear part



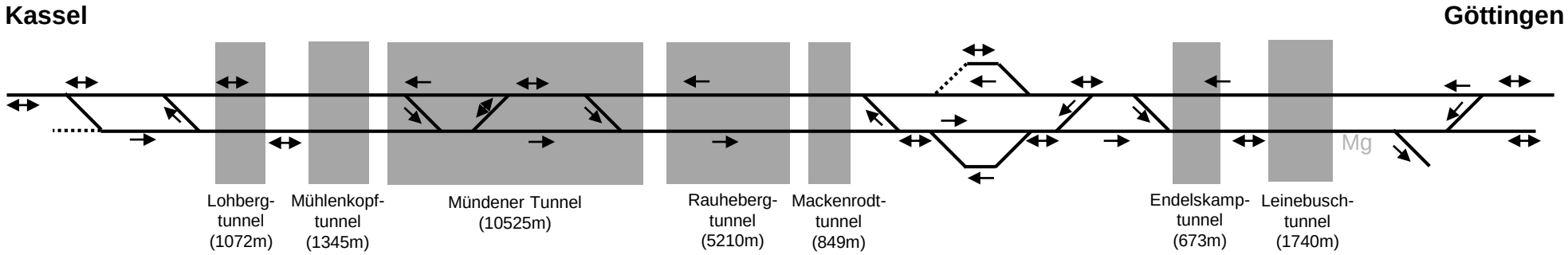






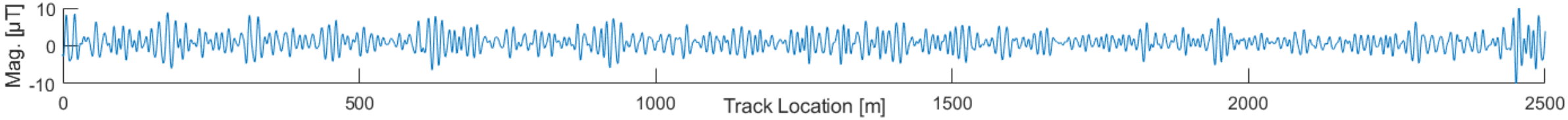
Routes & Scenarios

- 8 measurement days, 2000km total
- Urban and low speed scenario: Berlin
  - Accuracy analysis with GNSS reference
- High-speed & tunnel scenarios: Göttingen-Kassel
  - 42 km total length, 26 km tunnels , 4 runs (forth & back)
  - Multiple track changes, also in tunnels
  - Speeds: 100 – 200 km/h
  - Magnetic track brake experiment



Evaluation Method

- Reference signature from run A (map)

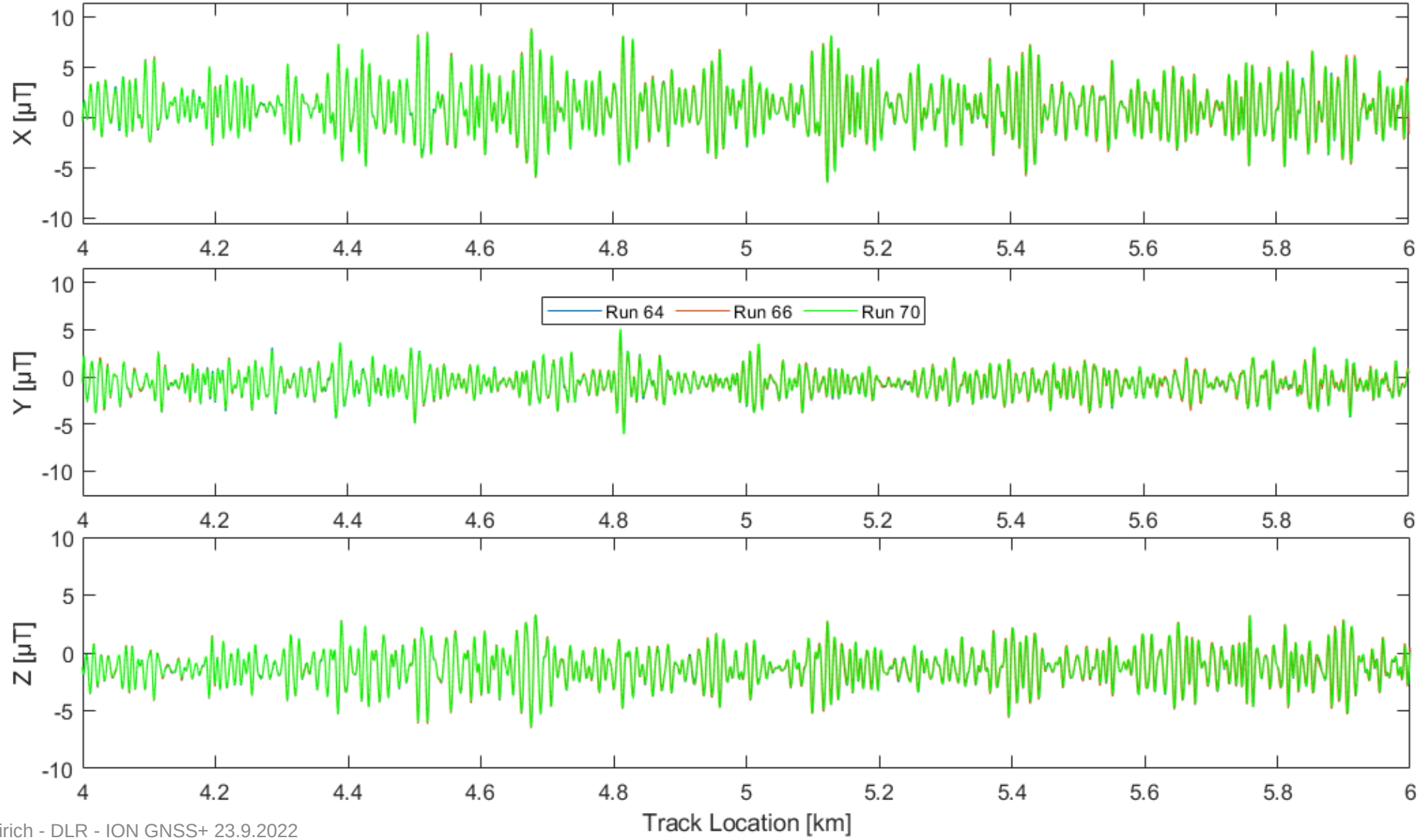


- Test signature from run B with cutout of 50m

- Similarity via correlation of the test signature at all possible positions (every 0.1m) of the reference signature
- Compute highest similarity from three correlation scores (X,Y,Z axes)
- Accuracy: evaluate over all 50m cutouts of test signatures from multiple runs
  - Ground-truth for accuracy: post-processed GNSS
  - Tunnel: map + odometry

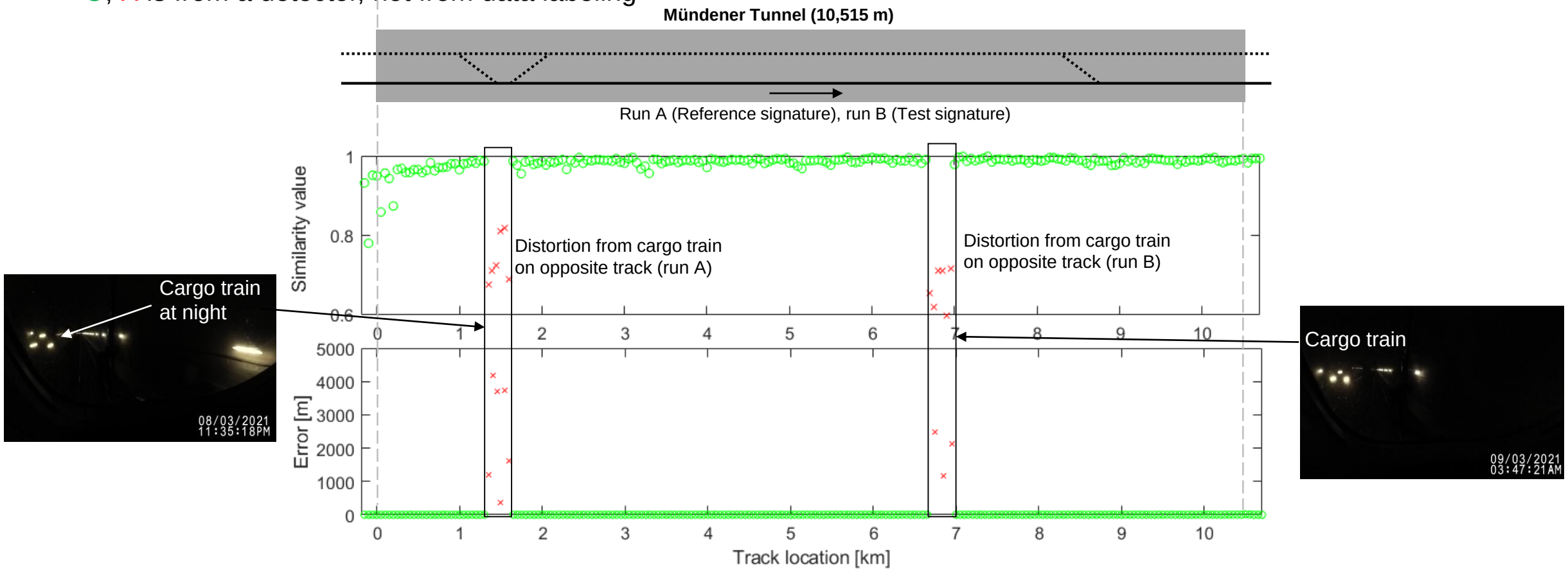
Evaluation Results

Tunnel Signatures: Example over 2 km



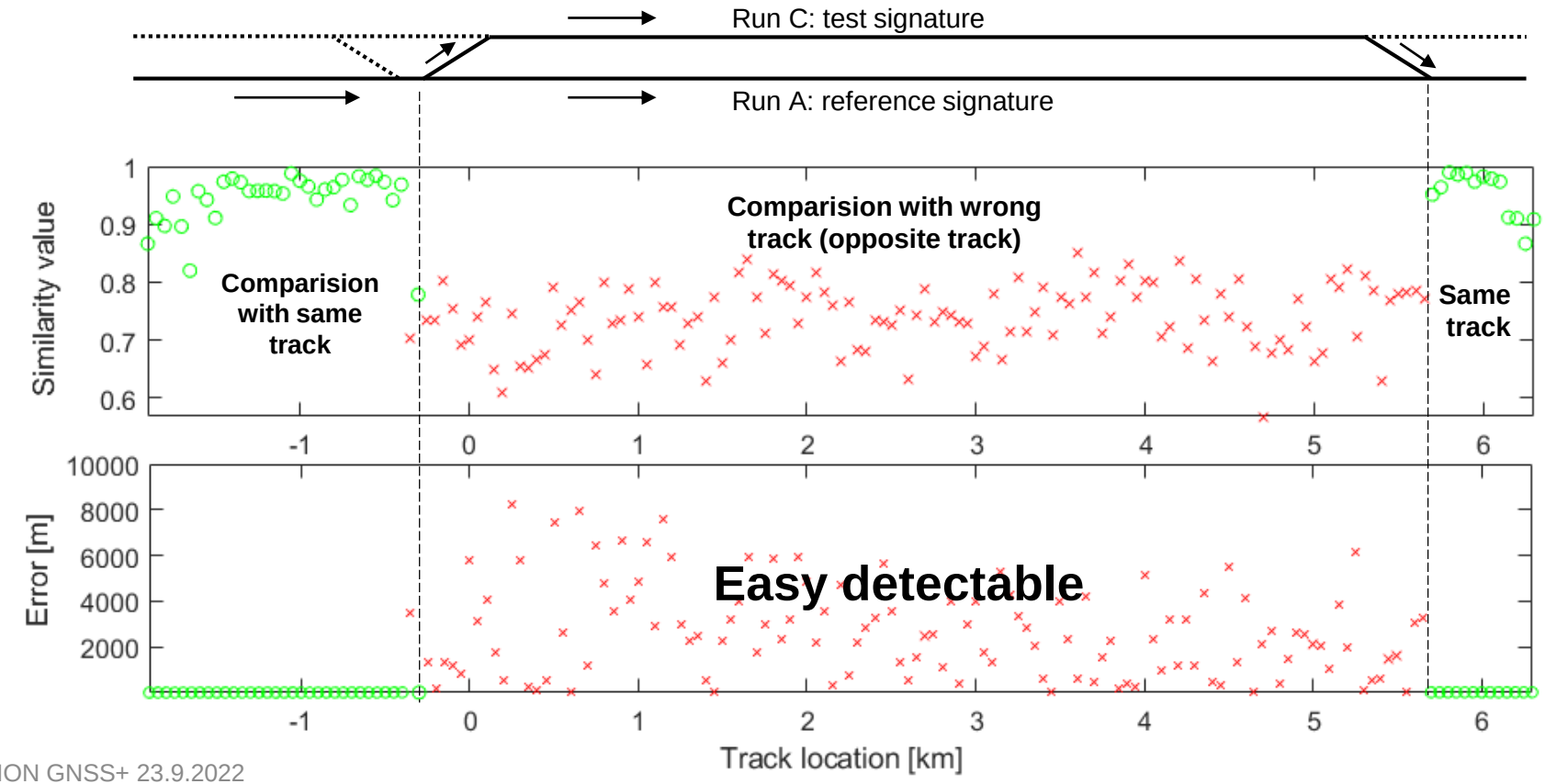
Tunnel Results

- Along-track localization: positioning availability with detected and excluded distortions is > 98%
- O, X is from a detector, not from data labeling

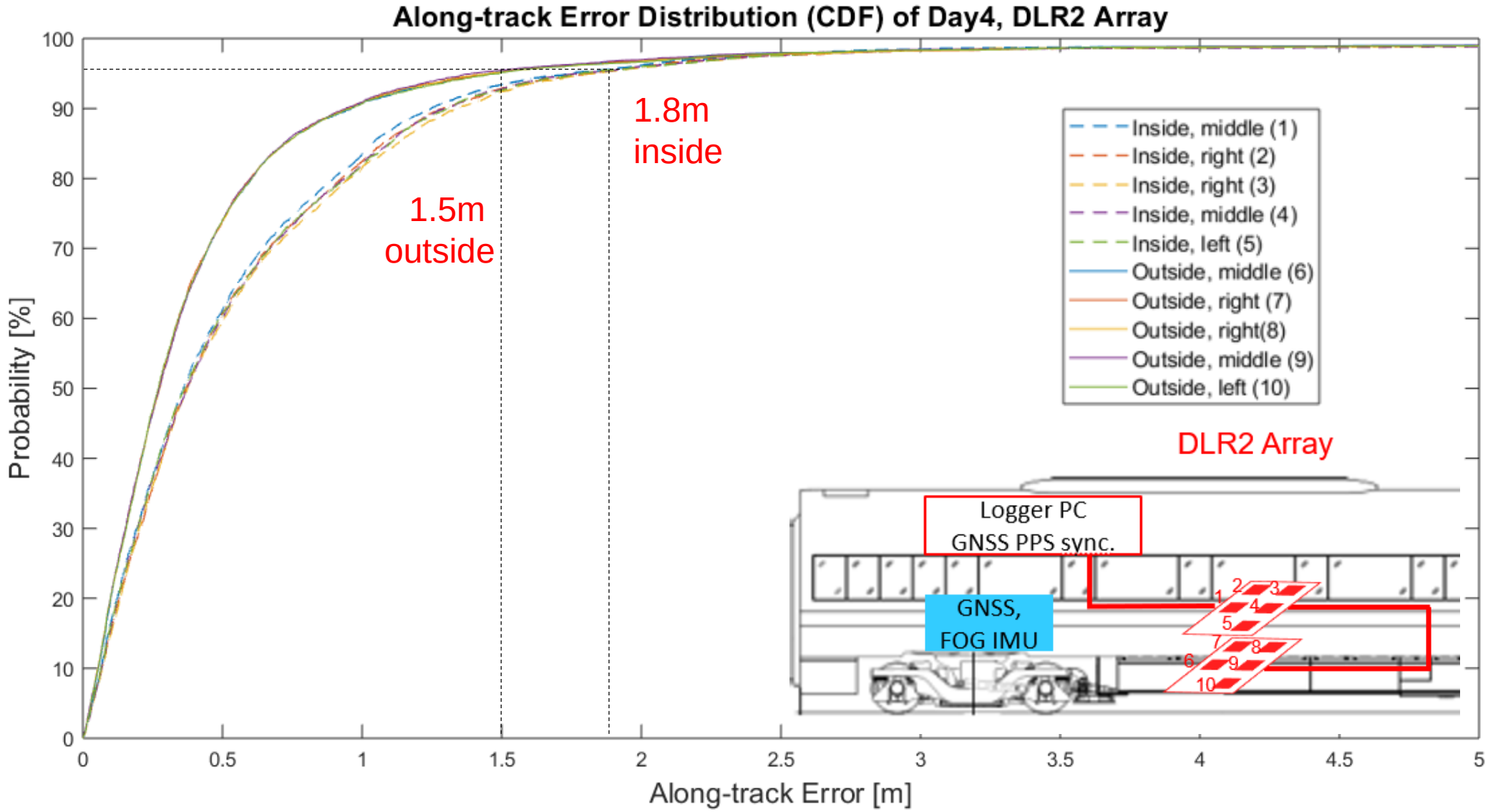


Tunnel Results

- Cross-track: switch & track identification inside tunnel
- O, X is from a detector, not from data labeling



Along-track Accuracy Results



Findings

- Accuracy in along-direction is comparable to GNSS (1.5m outside, 1.8m inside)
- Track-selectivity: It is possible to identify the track and a track change at a switch, also tunnels
- Evaluations of signatures from different sensors:
  - Different sensors with different along-track positions: similar performance as with same sensors
  - Different sensors with different heights and different cross-track positions degrade the correct evaluations
- Other trains cause distortions: can be easily detected & handled with error detection
- No general speed dependency after signal-processing
- EMC: No problems on outside sensors, inside at some positions with degraded results at full power
- Emergency brake: magnetic track brake (see & cite)

A. Lehner, T. Strang, O. Heirich, B. Siebler, S. Sand, P. Unterhuber, D. Bousdar Ahmed, C. Gentner, R. Karasek, S. Kaiser
Impact of Track Brakes on Magnetic Signatures for Localization of Trains.
5th International Conference on Railway Technology: Research, Development and Maintenance 2022, Montpellier, Frankreich.

Conclusions

- Magnetic train localization works in long tunnels and for high and low-speeds
- Magnetic train localization: key is synchronization, calibration, signal-processing and robust algorithms with error detection
- Goal is to combine magnetic signature localization with GNSS, IMU, odometer & digital track map including integrity monitoring for a safe and continuous train localization

Magnetic Train Localization: High-Speed and Tunnel, Experiment and Evaluation

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