Particle Number Emission of Light-Duty Vehicles during Real-World Driving

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INTRODUCTION

The EU Commission works on development and implementation of 'Real Driving Emissions' regulations for Euro-6.2. This is driven by air quality NO_2 standards, which were exceeded at 12% of the stations in the EU (2006-2010) including Germany, Netherlands, Sweden, France, UK etc. Roadside measurements and real world driving tests by Member States indicate that real driving NOx has not decreased as fast as expected, which is mainly attributed to increasing dieselization and different off-cycle NOx performance

Light duty vehicle Real Driving Emissions (RDE) of regulated gaseous compounds are under development with PEMS, Portable Emissions Measurement Systems. Real driving Particle Number (PN) emissions are currently subject of research and on-board instrumentation is under development.

EXPERIMENTAL SET-UP

The current laboratory PN instruments according to the PMP protocol / R83 regulation are not suited for mobile application. In this study a NanoMet3 pre-series instrument was used. It samples undiluted raw exhaust, which is then treated similar to R83, i.e. it is hot diluted and passes an evaporator to remove volatiles. Instead of a PNC a DiSCmini detector is used. Particles are charged by a corona discharge and the transported charge is measured on different stages downstream , which allows calibration of particle number concentrations.

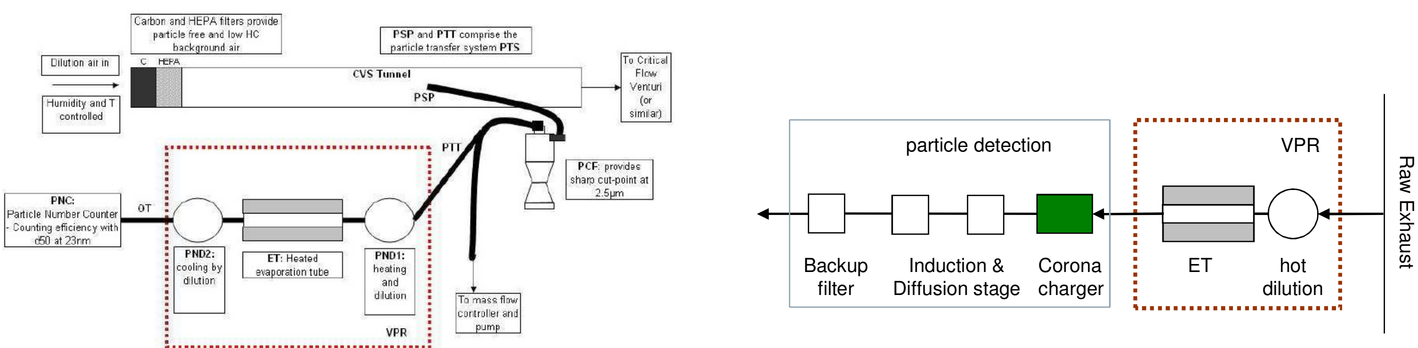

Figure 1: Schematic of particle sampling system in the R-83 regulation (left) and the NanoMet3 pre-series instrument for raw exhaust, which can be used for mobile applications.

CORRELATION WITH CVS

Parallel measurements were done with the NanoMet3 PN-PEMS in raw exhaust at tailpipe and a CVS dilution tunnel at a chassis dynamometer. For time alignment between particle concentration and exhaust flow a calculation of least squares was applied. The resulting emission factors of a Euro-5 gasoline vehicle were similar with PEMS and at the dyno. A fair correlation of peaks was observed, however the PEMS peaks were higher and narrower. This is most probably caused by sampling raw exhaust.

For a Euro-5 diesel vehicle more than one order of magnitude difference in emission factor was observed at the 10^8 to 10^{10} km^{-1} level. Time alignment by least squares calculation resulted in poor correlation of peaks for this vehicle. A linear fit of all diesel vehicle data showed for NanoMet3 PN 43% higher values than for CVS. The limit of detection was ~1 x 10^{10} km^{-1}. This is at the level of the observed emissions, but a factor of ~60 below the Euro-5/6 PN limit for diesel vehicles.

A good correlation between Nanomet3 and R83 PMP (slope 0.85) was observed for all tested vehicles, Euro5 Diesel & Gasoline on NEDC, WLTC and RDE example cycles (figure 2).

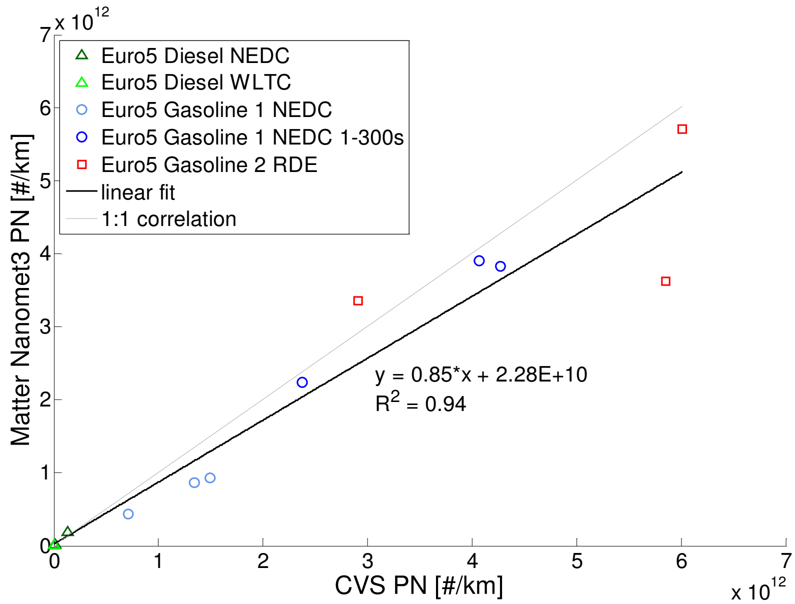

Figure 2: Linear fit of PN measured with the NanoMet3 PN-PEMS and using the regulation method with a CVS dilution tunnel.

For all tests the instrument calibration was used as delivered from the manufacturer and not changed.

REAL WORLD DRIVING

For real world driving tests a diesel and a gasoline vehicle were equipped with a Semtech-DS gas PEMS, an EFM3 exhaust flow meter and the NanoMet3 PN PEMS. The additional weight of both PEMS and the batteries was ~210 kg.

Figure 3: Test vehicle equipped with Semtech-DS gas PEMS, EFM3 exhaust flow meter and the NanoMet3 PN PEMS.

Two standard routes were selected: 1) a ~30 min 15.6 km trip through the city of Aachen and in its vicinity and 2) a ~40 min 50.5 km Autobahn trip with a short rural section.

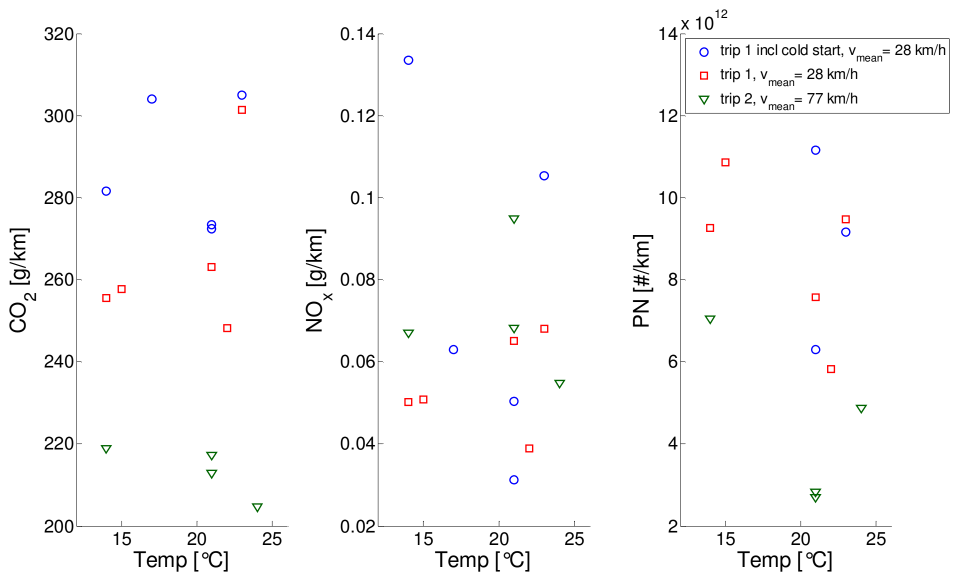

Figure 4: Real world driving emissions of a DI gasoline vehicle during cold and hot start urban driving and the selected Autobahn trip.

Emissions of CO_2 were clearly different for the 3 driving situations. NO_x and PN emissions were much less reproducible, so that only a range for real world driving could be reported. Within the temperature range of 14 to 24°C 25% - 47% variability of the PN emissions could be observed. (figure 4), whereas for CO_2 it was 3% - 6%. The time resolved data show a small cold start effect for PN and HC in the first 100-200 s of the test drive. An AVL M.O.V.E PM PEMS was connected in parallel during 3 lab and 2 real driving tests. The PN/soot ratios of 1.3 x 10^{12} #/mg in the lab and 1.4 x 10^{12} #/mg for real world driving were very similar.

CONCLUSIONS

- Laboratory comparison of the NanoMet3 with R83 PN measurement resulted in a good correlation at the 10^{12} km^{-1} level with deviations <15%.
- At a level of 10^{11} km^{-1} up to 43% difference were observed, the limit of detection was ~1 x 10^{10} km^{-1}.
- The direct injection gasoline vehicle (Euro-5) had a small cold start effect at 14 to 24°C. The PN emission level was higher than for the DPF diesel vehicle. The Coefficient of variance (CoV) for CO_2 was 3% - 6% for the situations, but significant variability was observed for NOx and PN with CoV = 24% - 55% for NOx and 25% - 47% for PN.
- Real world driving PN emissions were in the range of results reported in literature or measured with RDE example cycles and WLTC in the laboratory.
- For application as legal procedure much more work is needed:
  - further correlations and robust characterization of the internal calibration of PN vs. measured current,
  - reduction of extra weight and power consumption, development of package solutions,
  - definition of boundary conditions and evaluation method.

ACKNOWLEDGMENTS

The authors would like to thank Andreas Neidel, Pascal Winistörfer and Dr. Luis Cachón from Matter Aerosol AG for their support and valuable discussions.

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INTRODUCTION

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- This is driven by air quality NO_2 standards, which were exceeded at 12% of the stations in the EU (2006-2010) including Germany, Netherlands, Sweden, France, UK etc.
- Roadside measurement / real world driving by Member States indicates real driving NOx has not decreased as fast as expected – attributed to increasing dieselization and different off-cycle NOx performance.
- Real Driving Emissions (RDE) of regulated gaseous compounds are under development with Portable Emissions Measurement Systems (PEMS) for Light Duty (LD) vehicles.
- Real driving Particle Number (PN) emissions are currently subject of research. Instrumentation under development.
- The EU has started to investigate methods for real driving PN assessment. PN PEMS instrumentation appears to be a viable method.

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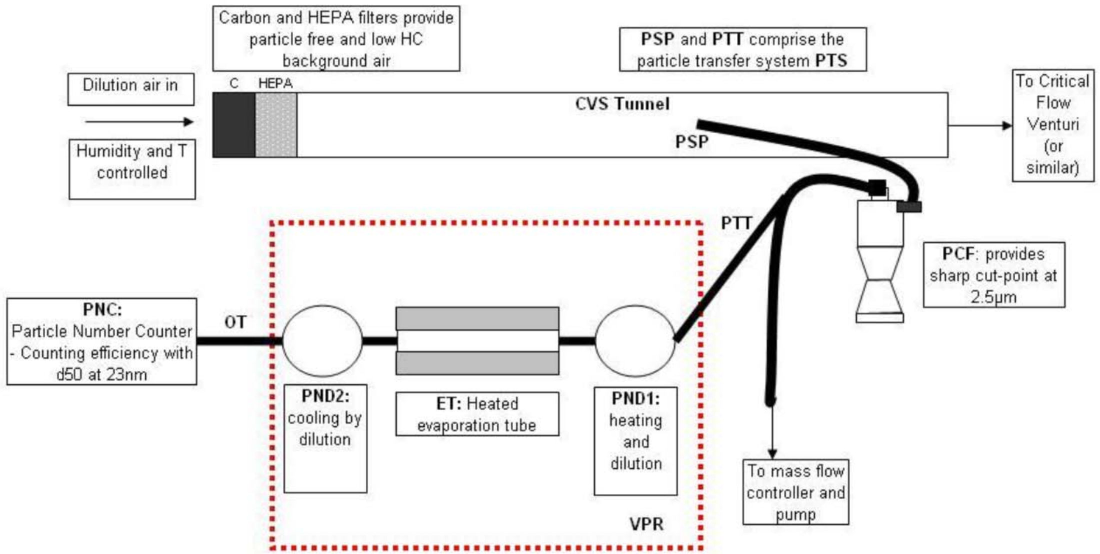
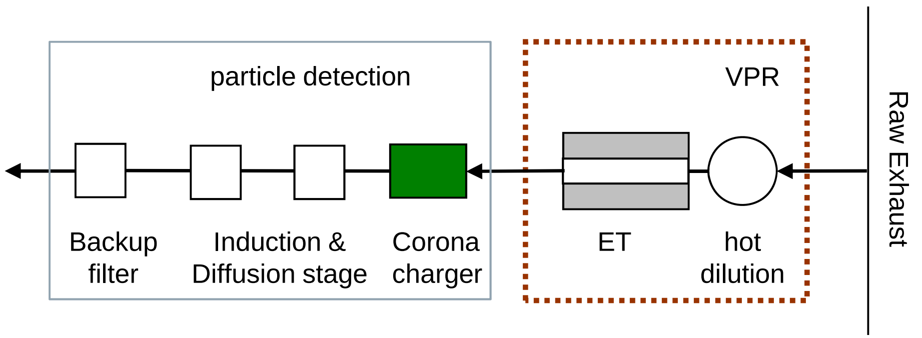
COMPARISON OF R83 PN WITH NANOMET3

- The current laboratory PN instruments according to the PMP protocol / R83 regulation are not suited for mobile application.



- In the NanoMet3 instrument undiluted raw exhaust is sampled and treated similar to R83. A different detector is used instead of a PNC.



NanoMet3, Matter Aerosol AG / Testo

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LABORATORY SET-UP

- Parallel measurement of NanoMet3 sampling raw tailpipe exhaust and constant volume sampler (CVS) diluted exhaust R83 PN measurement

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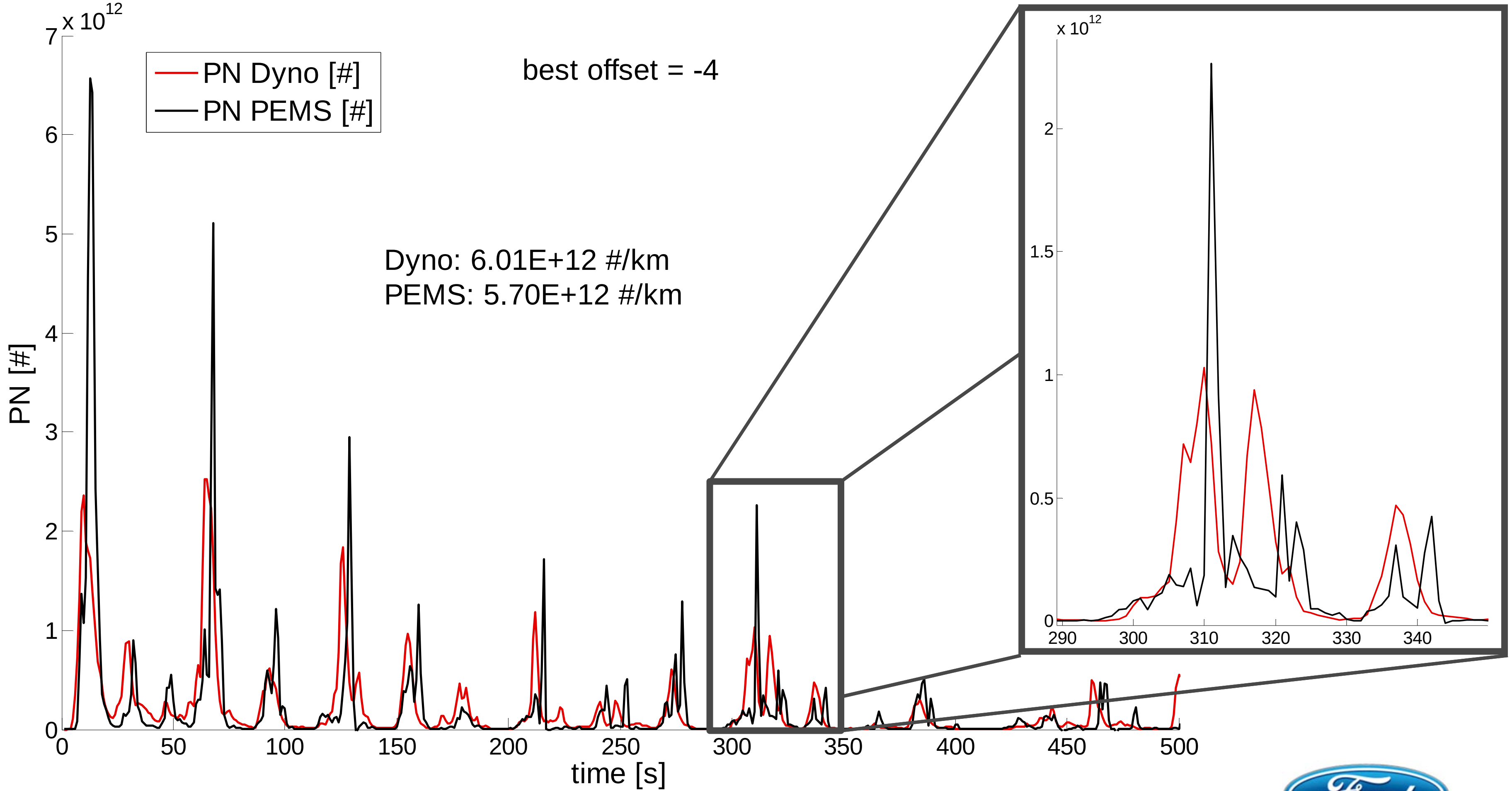
EXAMPLE OF CORRELATION WITH CVS

- Euro-5 DI gasoline vehicle: similar emission factors with PEMS and Dyno
- Time alignment by calculation of least squares
- Fair correlation of peaks, however higher and narrower PEMS peaks



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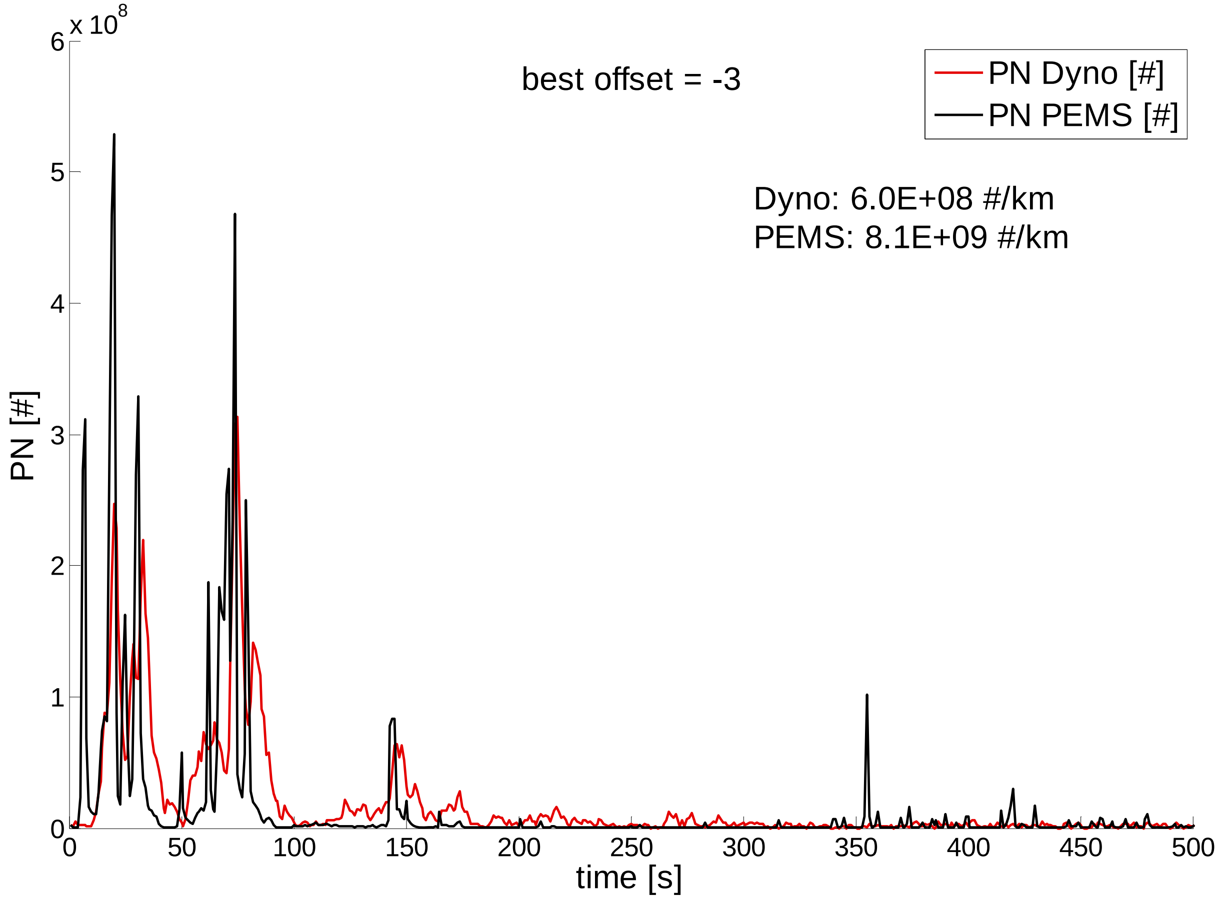
CORRELATION WITH CVS

- Euro-5 diesel vehicle: more than one order of magnitude difference in emission factor
- Poor correlation of peaks, (time alignment by least squares)



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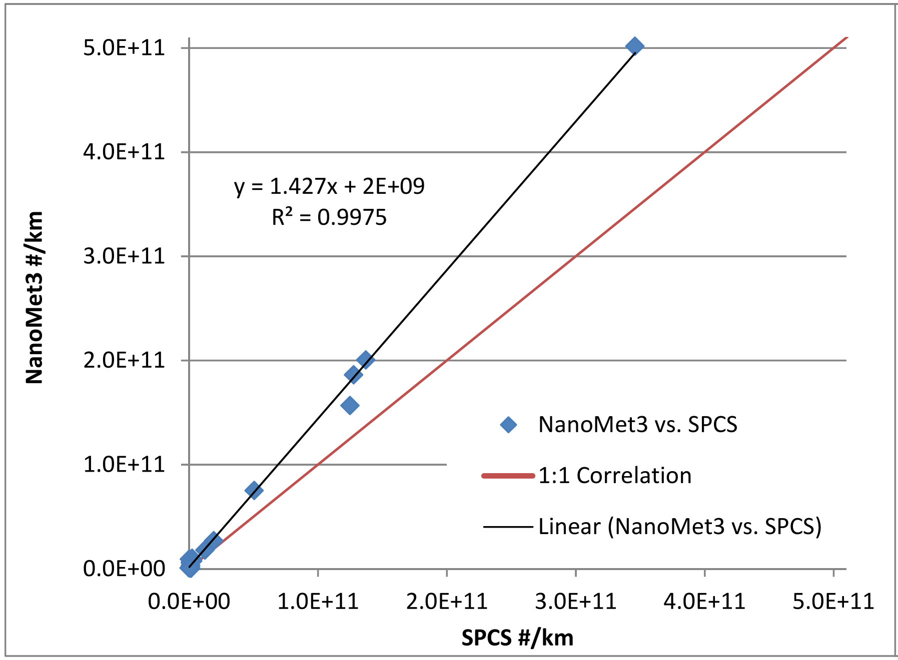
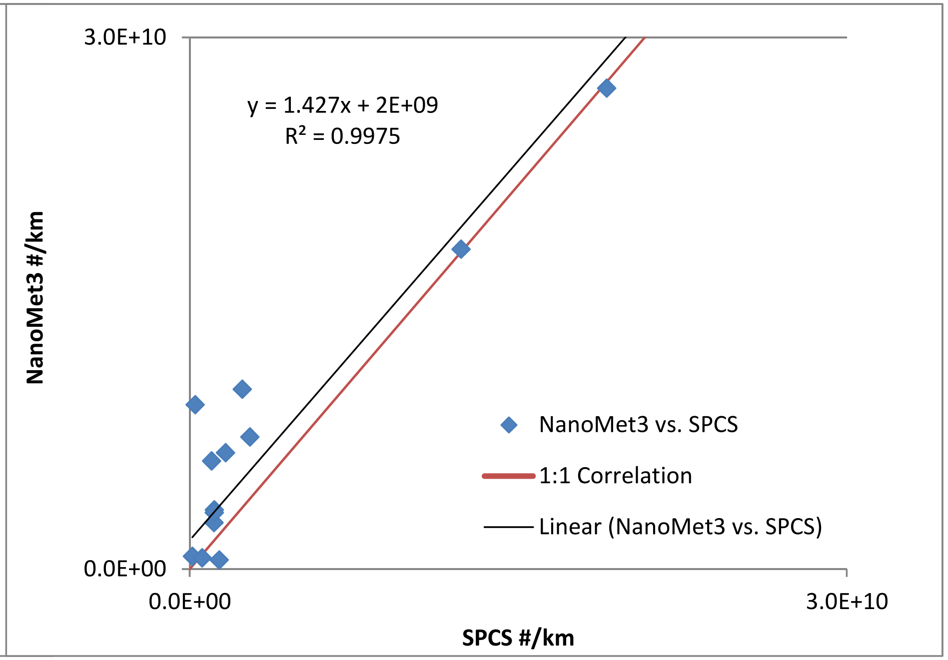
CORRELATION WITH CVS FOR DIESEL CARS

- Diesel vehicles: NanoMet3 PN 43% higher than CVS.
- Limit of detection ~1 x 10^{10} km^{-1}.
- Smaller difference between NanoMet3 and CVS for all tested vehicles, when also higher emissions are included.





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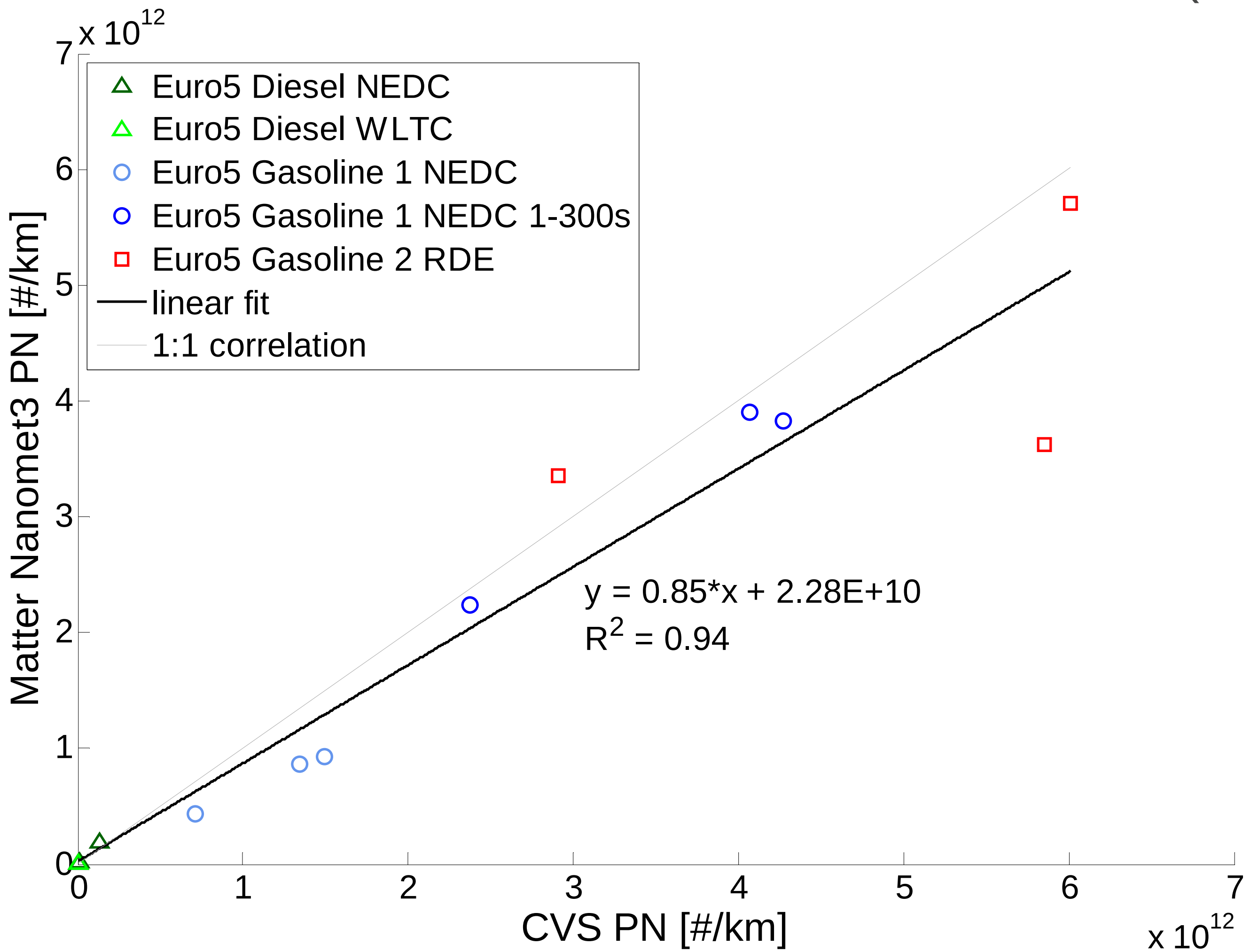
CORRELATION MAP PN PEMS – CVS I

- Euro5 Diesel & DI gasoline on NEDC, WLTC, RDE example cycles
- Good correlation between NanoMet3 and R83 PMP (slope 0.85)



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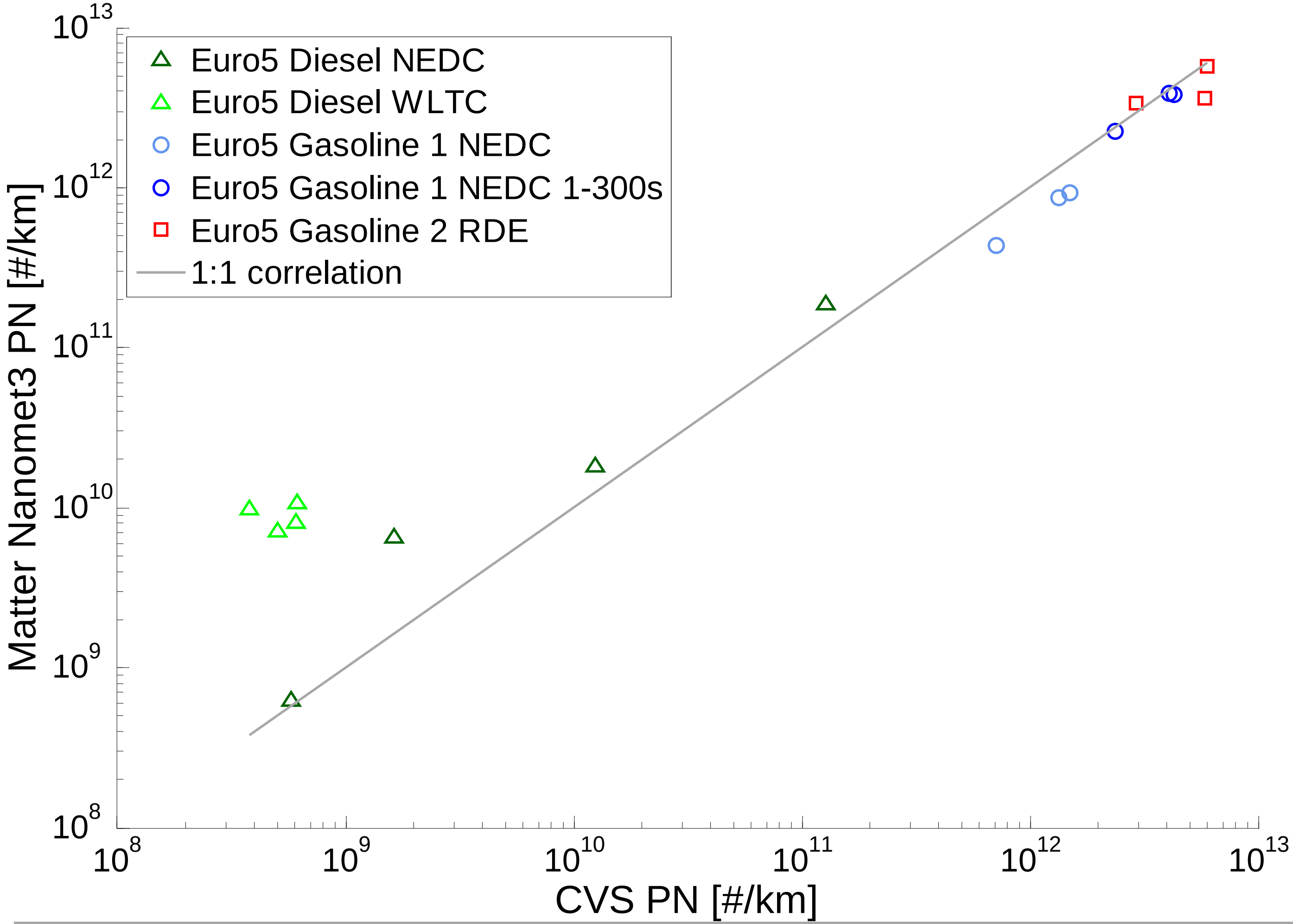
CORRELATION MAP PN PEMS – CVS II

- Euro5 Diesel & DI gasoline on NEDC, WLTC, RDE example cycles.
- Detection limit of ~1 x 10^{10} km^{-1} visible.



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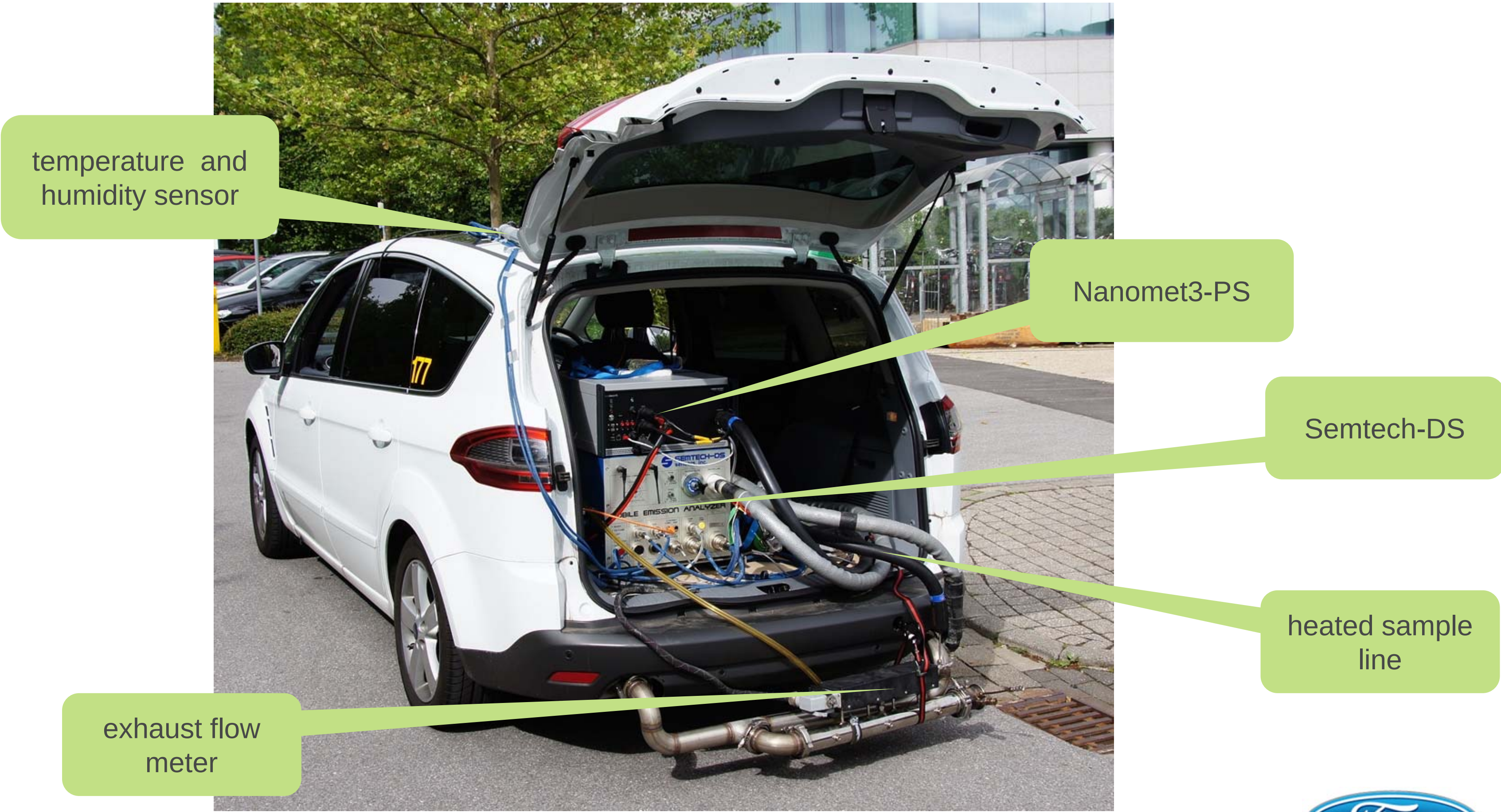
PEMS SETUP FOR REAL WORLD DRIVING

- Semtech-DS gas PEMS and NanoMet3 PN PEMS connected both to EFM3 exhaust flow meter. Power supply by lead acid batteries.
- Additional weight of both PEMS and batteries ~210 kg.



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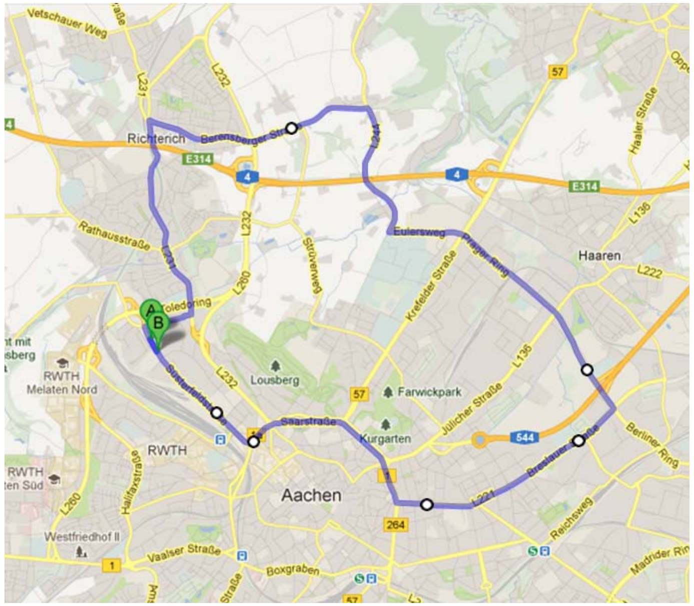
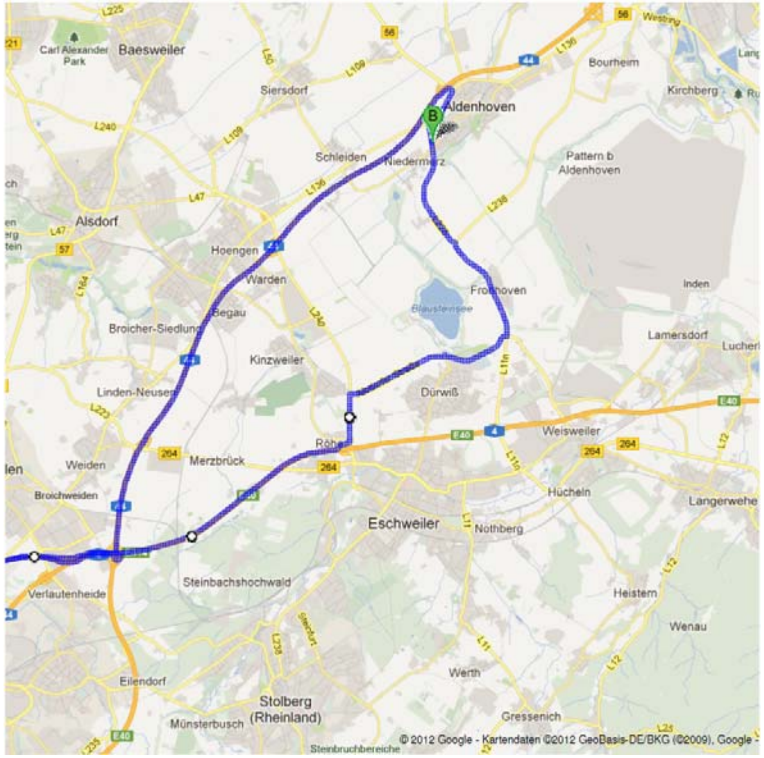
PEMS REAL WORLD TRIPS

- Urban trip:
  - – Mainly urban trip through Aachen including cold start phase
  - – Small amount of high speed parts between 50 and 70 km/h
  - – 15.6 km, ca. 32 min
  - – $v_{average}$ = 28 km/h, v_{max} = 70 km/h



- Autobahn route:
  - Hot start
  - 50.5 km, ca. 40 min
  - $v_{average}$ = 77 km/h, v_{max} = 140 km/h



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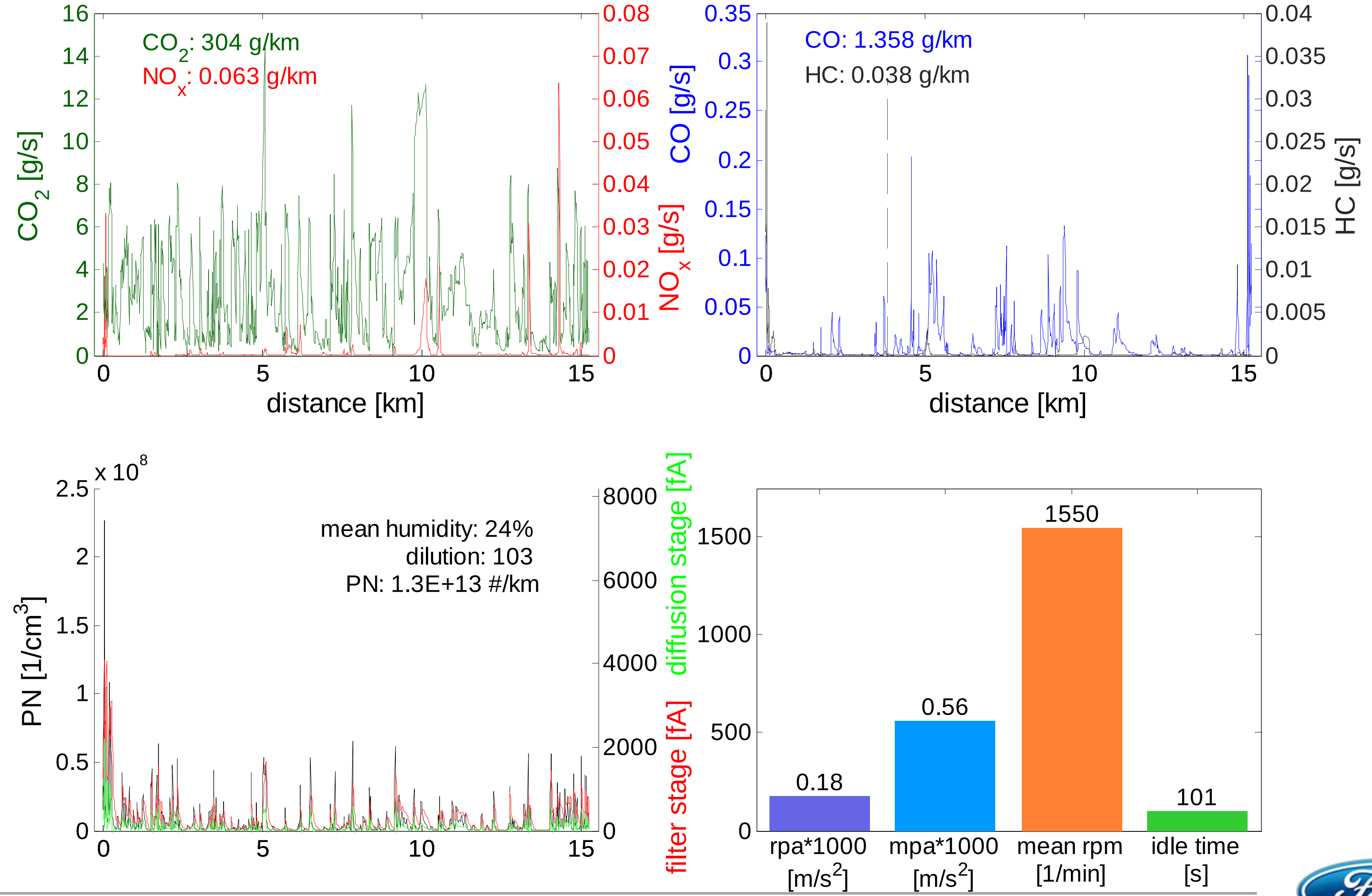
REAL WORLD RESULT

- Euro-5 DI gasoline: small cold start effect for PN, CO and HC

JG130423A, cold, 17°C, 1956 s, 15.232 km



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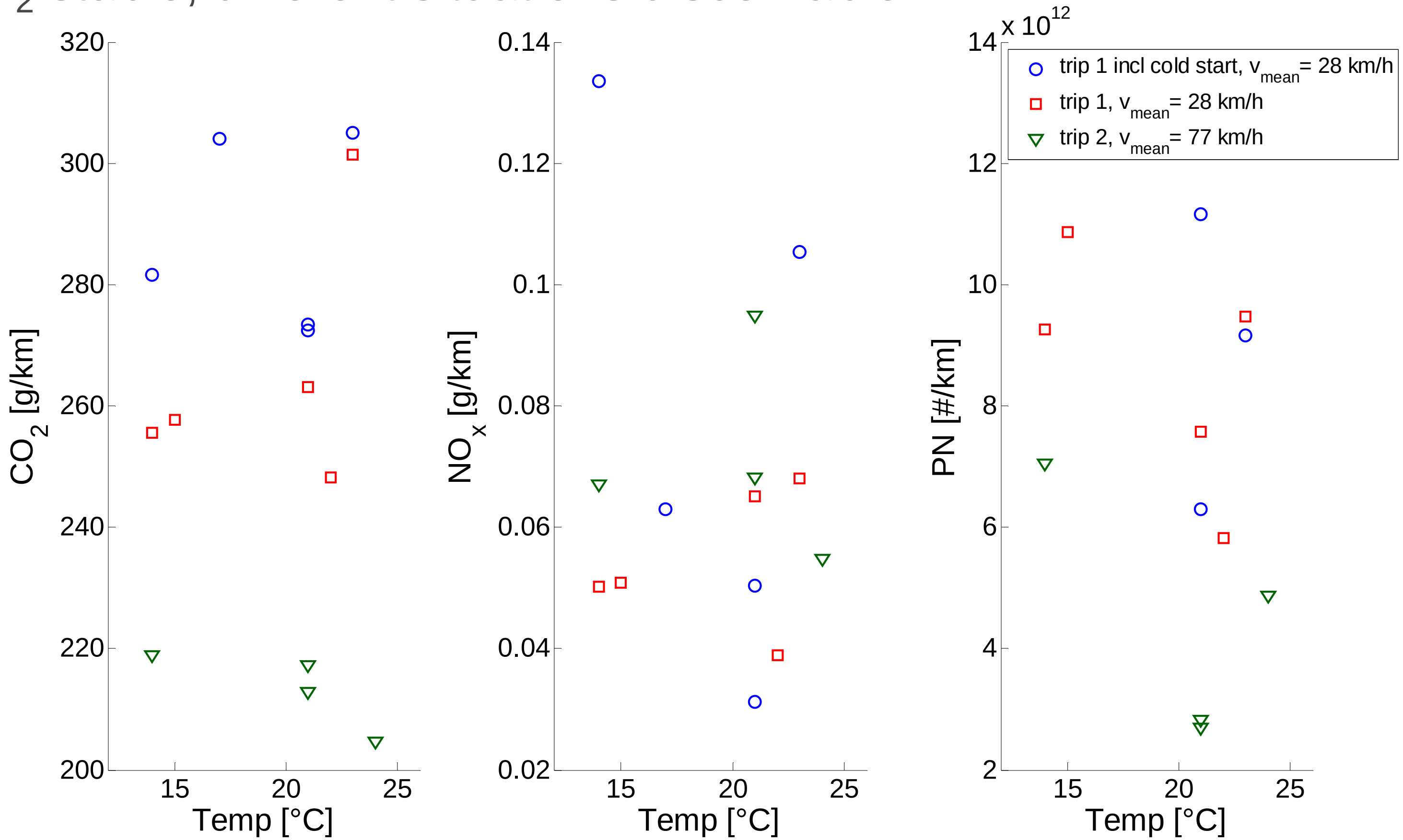
REAL WORLD RESULT EURO-5 DI GASOLINE

- CO_2 stable, different situations discernable



- Under ambient conditions (14 to 24°C) significant variability. Coefficient of variance (CoV) for CO_2 between 3% and 6% for the situations, but CoV = 24% - 55% for NOx and 25 - 47% for PN.

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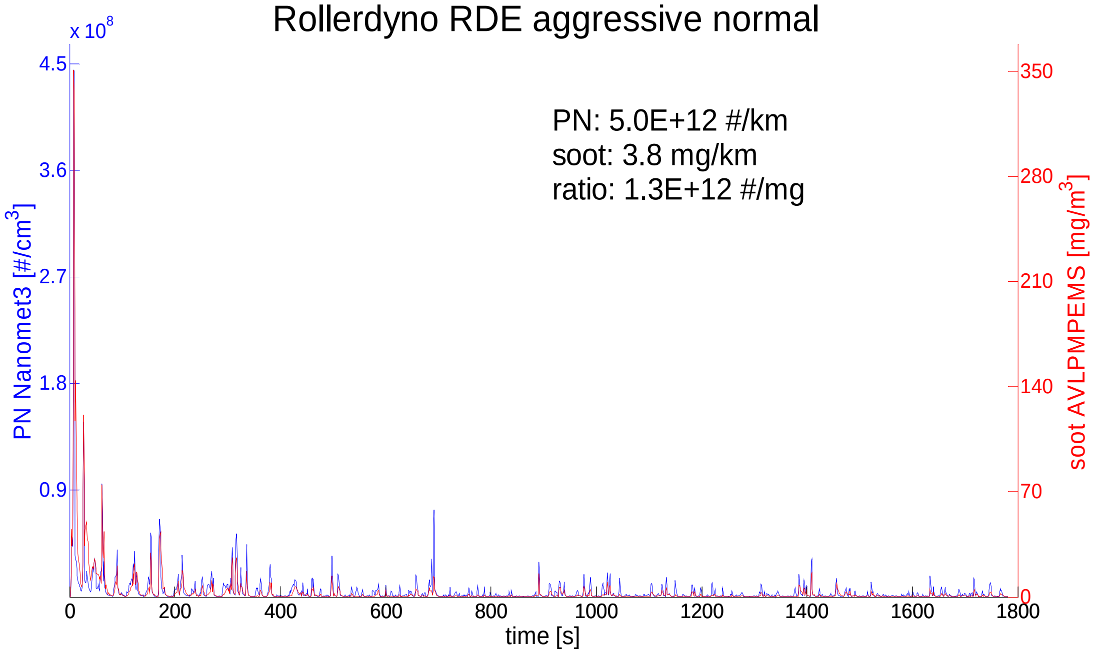
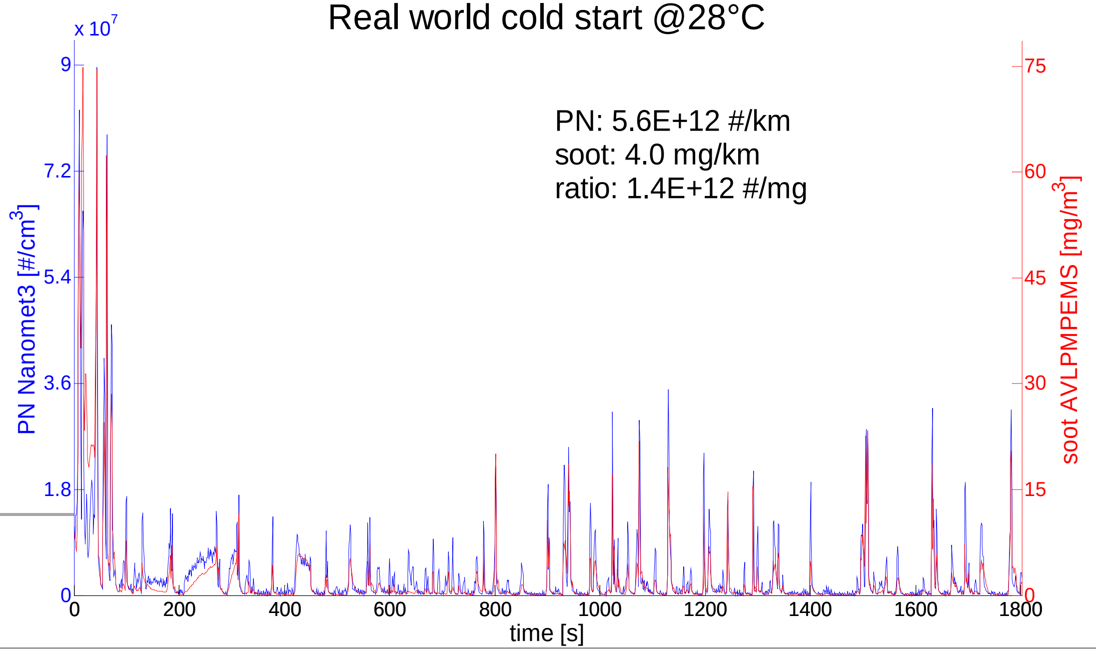
COMPARISON OF PN / SOOT RATIO

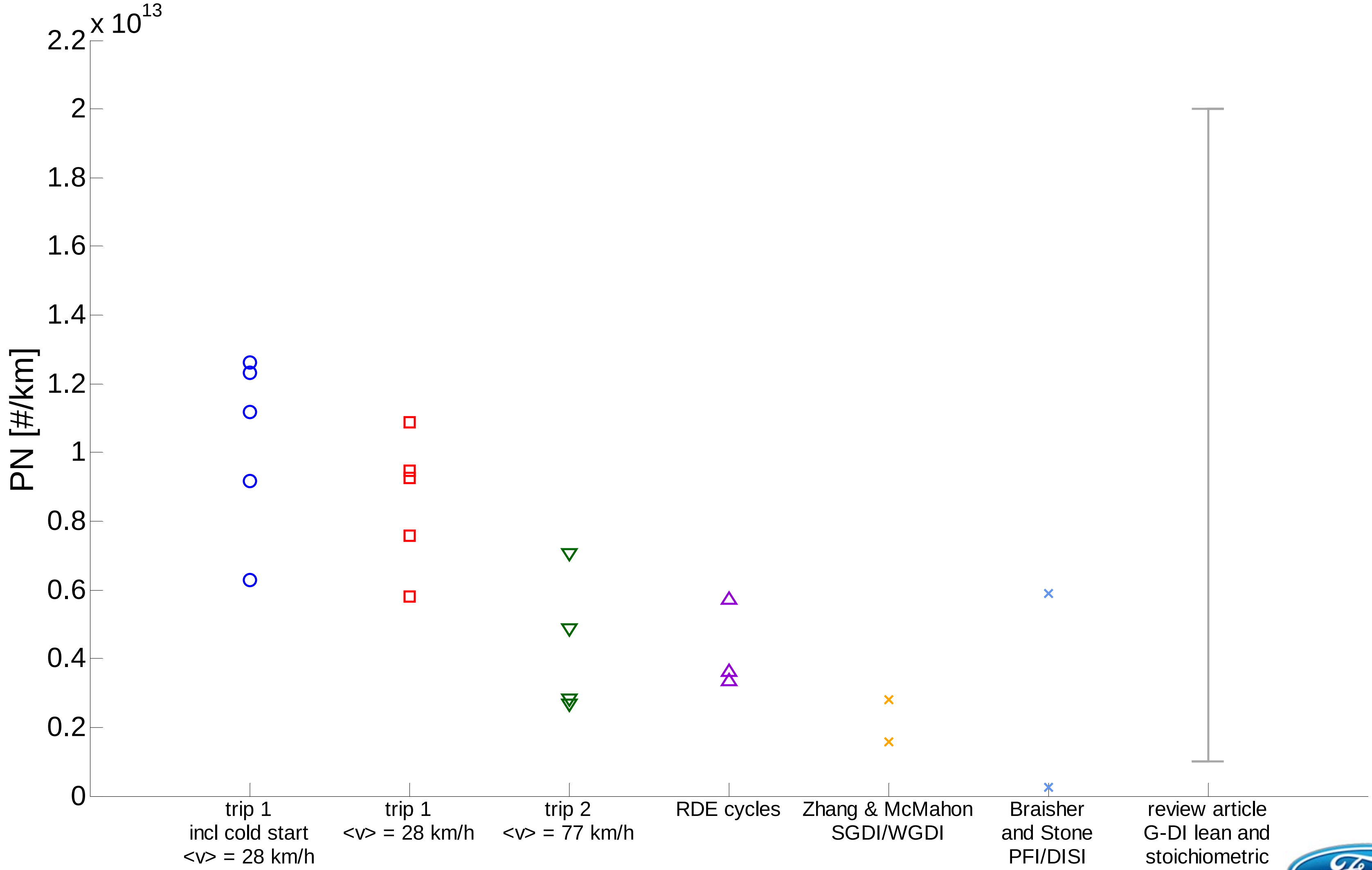
- Ratio of PN to soot as independent method to compare NanoMet real world results. Use of AVL M.O.V.E PM PEMS during some tests.
- PN to soot ratio of three RDE chassis dyno tests: $1.3\text{x}10^{12}$ +/- $2.8\text{x}10^{10}$
- PN to soot ratio of two real world trips: $1.4\text{x}10^{12} \pm 3.2\text{x}10^{10}$
- Similar ratio for real world and lab indicates constant performance of PN PEMS (e.g. no influence of vibrations).





PN EMISSION OF EURO-4/5 VEHICLES

- Real World Trips are in the same range as literature values



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SUMMARY AND CONCLUSIONS

- Laboratory comparison of NanoMet3 with R83 PN measurement: good correlation at 10^{12} km^{-1} level with deviations <15%.
- At a level of 10^{11} km^{-1} up to 43% difference, limit of detection ~1 x 10^{10} km^{-1}.
- Under ambient conditions (14 to 24^{o}C) significant variability: Coefficient of variance (CoV) for CO_2 3% - 6% for the situations, but CoV = 24% - 55% for NOx and 25% - 47% for PN.
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