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Real-Driving Emissions (RDE)
Update on Particle Number (PN) measurements with Portable Emission Measurement Systems (PEMS)

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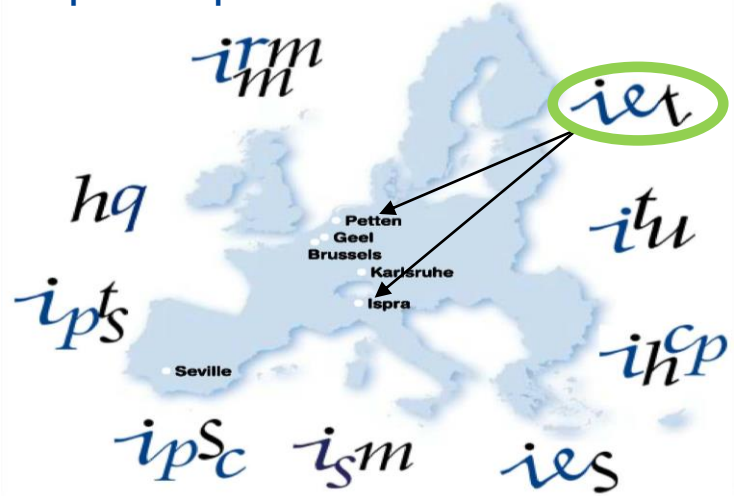
- JRC is the European Commission's in-house science service
- 7 Institutes - Institute for Energy and Transport operates 9 vehicle test facilities (VeLA labs)

How do we work?

- Own scientific and technical initiative
- Request from policy DGs in Brussels
- Technical co-operation with academia, industry and technical services



History of PEMS testing

- Early 2000s: First efforts in the US to verify compliance of heavy-duty engines
- PEMS testing at JRC
  - Since 2004: Heavy-duty vehicles (EURO VI implementing measures adopted under Regulation 582/2011)
  - Since 2007: Light-duty vehicles
  - Since 2008: Non-road mobile machinery
  - Since 2015: L-category vehicles with mini-PEMS

History of the Real-Driving Emissions (RDE) Test Procedure

- November 2010: JRC presentation diesel-NOx emissions on the road
- January 2011: Kick-off RDE working group
- 2011 and 2012: Evaluation of:
  - (i) complementary fixed test cycles, (ii) emissions modelling, (iii) PEMS on-road testing, (iv) random test cycles (development of a random cycle generator)
- 2013-2014: Development of a PEMS on-road test procedure
  - Boundary conditions
  - Data evaluation
- May 2015: Adoption of 1st RDE package (2016/427)
- October 2015: Adoption of 2nd RDE package (2016/646)

Annex IIIA to Regulation 692/2008

1st RDE package (2016/427) defines:

- Test protocol, boundary conditions, U/R/M shares
- Performance requirements of PEMS
- Evaluation methods for driving severity and enable a fair assessment of cars

2nd RDE package (2016/646) defines:

- Boundary conditions on driving dynamicity (speed*positive acceleration)
- Cumulative elevation gain ≤ 1200 m/100 km
- Conformity factors for new type approvals/all new registrations:
  - 2.1 – applicable from Sept. 2017/2019
  - 1.5 – applicable from Jan. 2020/2021
- Recital 14 of RDE Annex: Annual review of conformity factors

On-going and future JRC activities on RDE

- 2016 (3rd RDE package)
  - Developing a dedicated cold-start test procedure
  - Adapting the data evaluation to accommodate hybrid vehicles
  - Particle Number testing
- 2016 (4th RDE package)
  - Defining the provisions for in-service conformity and market surveillance testing
- 2016-2017
  - Reviewing RDE procedure and adapting provisions to ensure practicality and effective emissions testing

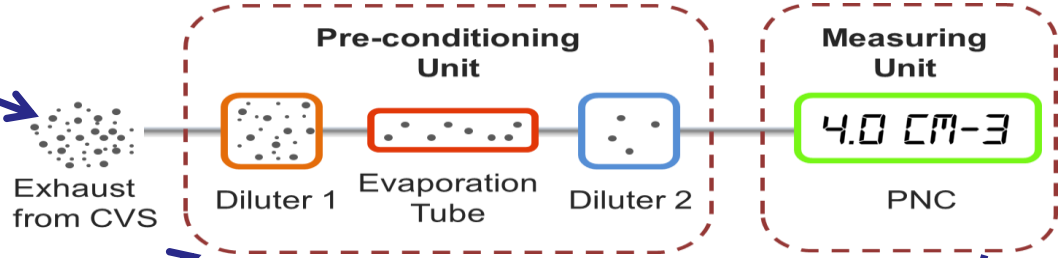
History of PN-PEMS

- Regulation 715/2007 introduced the possibility to use Portable Emission Measurement Systems (PEMS) for Real-Driving Emissions (RDE)
- Regulation 459/2012 focused on the emissions of Gasoline Direct Injection (GDIs) vehicles under real driving conditions
- Nov. 2012 call of interest for Particle Number PN-PEMS
- Use of PN-PEMS or Random Cycle (Jan 2016)
- PN-PEMS procedure and error analysis (April 2016)
- Conformity Factors (CF) (July 2016)
- PN-PEMS part of 3rd package to be voted in 2016

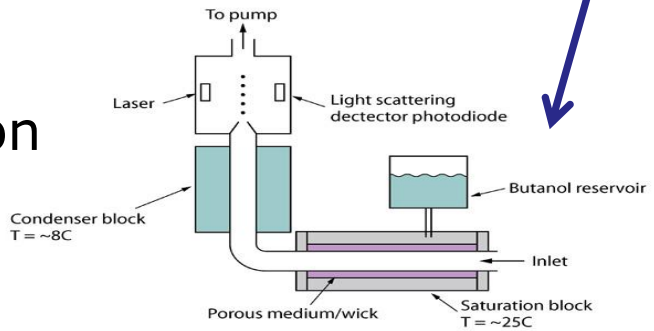
PN-PEMS project overview

- Theoretical evaluation of Diffusion Chargers (DC) (2013)
- Phase I (2013): Feasibility study
  - Assessment of application and performance of portable PN instruments relative to a reference (Particle Measurement Program PMP)
  - Update of specifications (i.e. dilution and sampling system and efficiency of diffusion-chargers)
- Phase II (2014): Confirmation of Phase I findings
  - Calibration procedures and more accurate estimates of uncertainty
- Inter-laboratory correlation exercise (2015)
- On-road vs lab evaluation (2013-2015)

Solid PN regulated method (PMP)

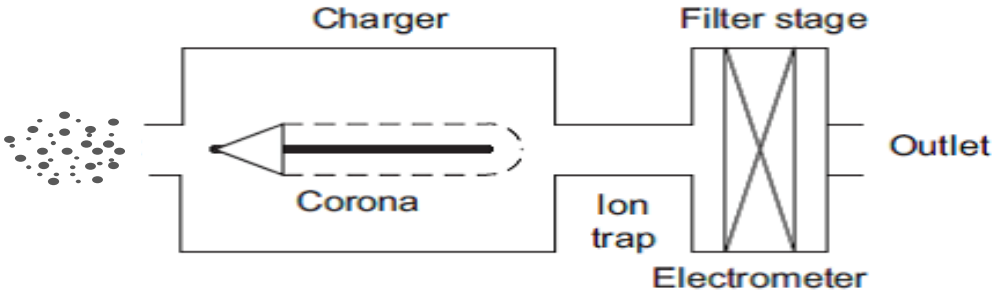


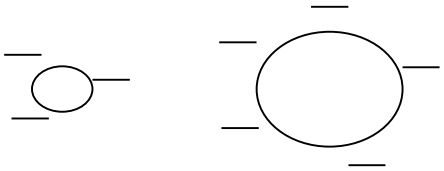
Condensation
Particle
Counter



Giechaskiel et al. (2008) Meas. Sci. Technol. 19:095401

Diffusion charger (DC)





Particle size has an effect on the signal

Giechaskiel et al. (2014) J. Aerosol Sci. 67:48–86

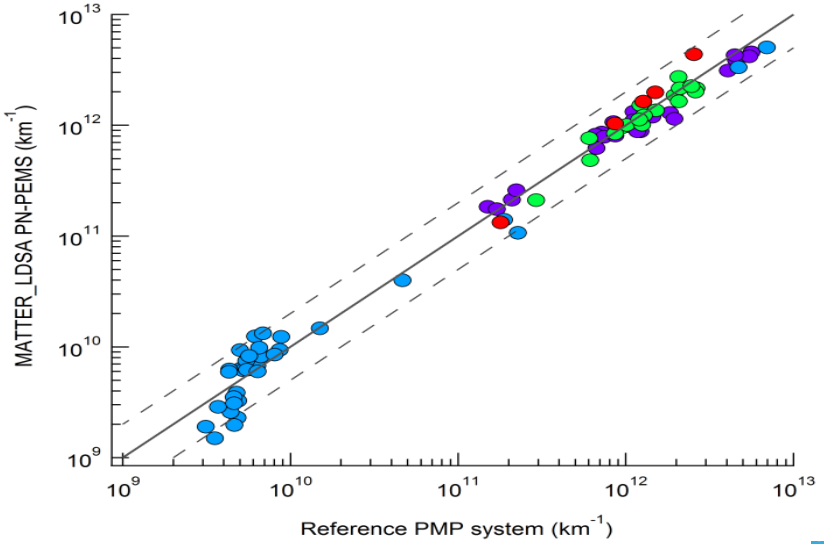
Phase I Testing

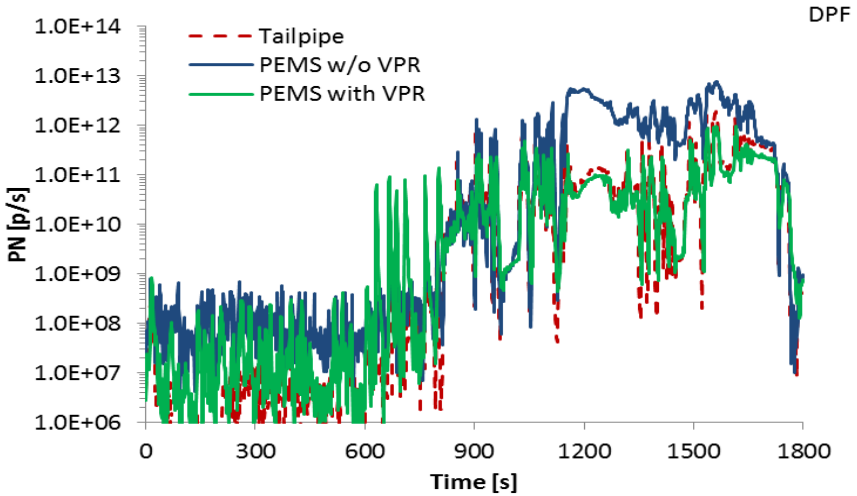
- Test vehicles
  - 3 GDIs
  - 1 PFI (low emissions)
  - 1 DPF (regeneration)
  - 1 Moped (sub 23 nm challenge)
- Testing period:
  - Preparation phase: Sep – Oct 2013
  - Main campaign: Oct-Dec 2013
- 5 PN-PEMS (DC based)

- Presentation available

Phase I Results

- DC based systems are a feasible option: Two of the 5 candidate systems had very good behaviour
- Thermal pre-treatment is necessary (like PMP)





Riccobono et al. (2014) ETH

Phase II Testing

- Test vehicles
  - 7 GDIs (5 were Euro 6) $<10^{11}$ … 3x 10^{13} p/km
  - 2 PFIs (low emissions)
  - 2 DPF (regeneration)
  - 4 Motorcycles (sub 23 nm challenge)
- Testing period:
  - Preparation phase: Aug – Oct 2014
  - Main campaign: Nov 2014
  - Extra evaluation: Dec 2014 +
- 8 PN-PEMS (3 CPC based)
- Report available: Giechaskiel et al. (2015) – JRC report 27451

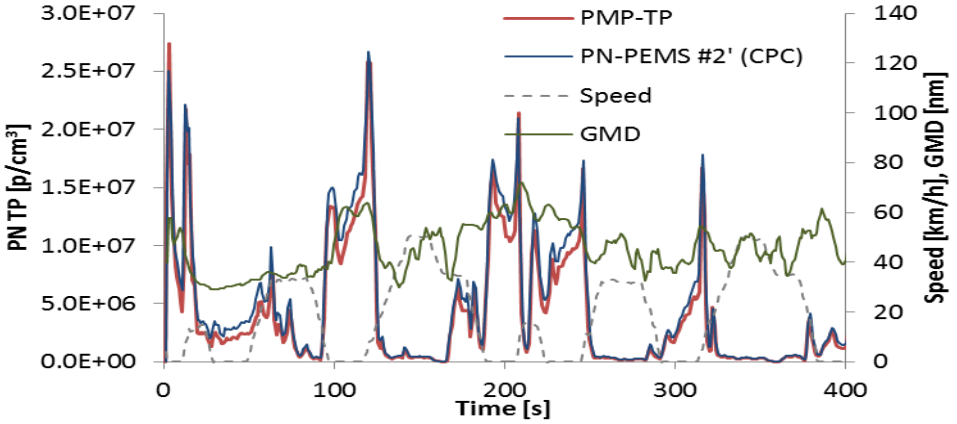
PN-PEMS Phase II Topics

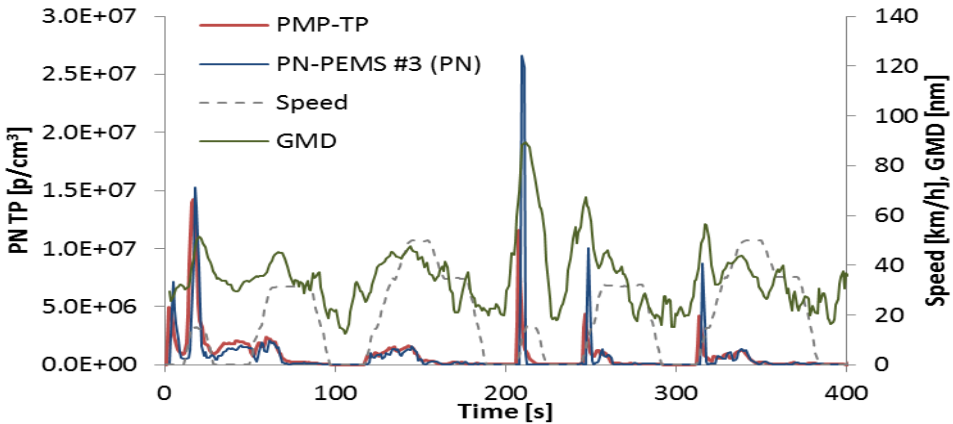
- Calibration
- Real-time signal
- Comparison with PMP systems
- Dependency on particle size
- Ambient temperature effect
- Challenge aerosol (solid sub 23 nm)
- Volatile removal efficiency (moped 2-stroke)
- Regeneration
- Bias and precision
- PASS or FAIL success rate
- Calibration at the CVS

Giechaskiel et al. (2015) JRC report 27451

Real-time signals

- CPC based systems follow exactly the reference PMP
- DC based systems can have differences when the mean size of particles changes





Giechaskiel et al. (2015) JRC report 27451

PMP-TP vs PMP-CVS

Results within

0.95 - 1.40

Reasons:

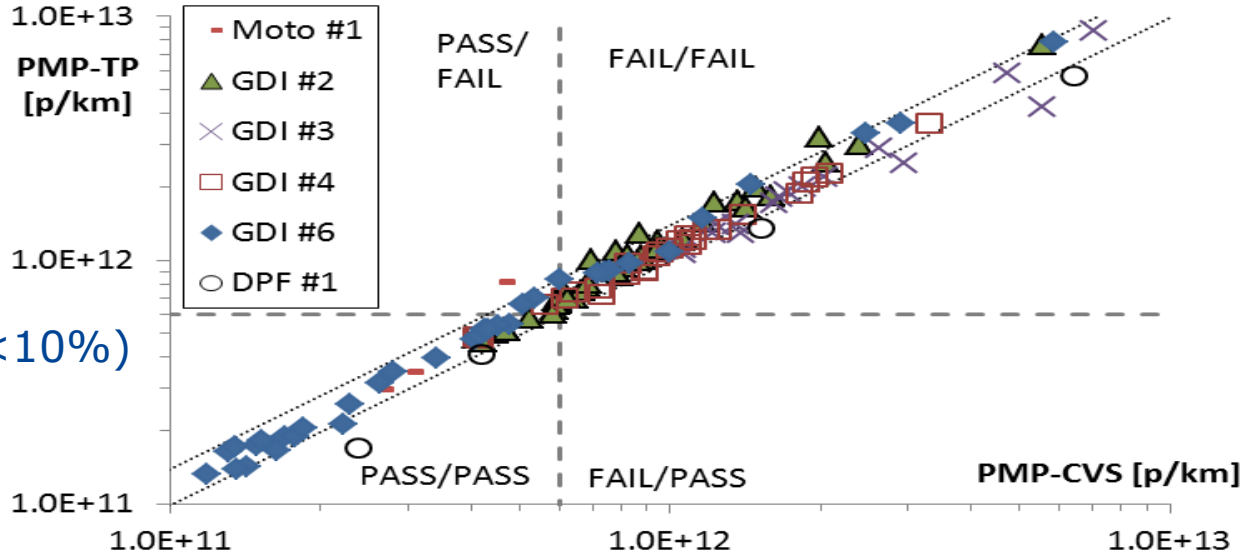
-Time alignment (<10%)

-Exhaust flow accuracy (<10%)

-Thermophoretic losses+

-Diffusion losses (<5%)

-Agglomeration (<15%)



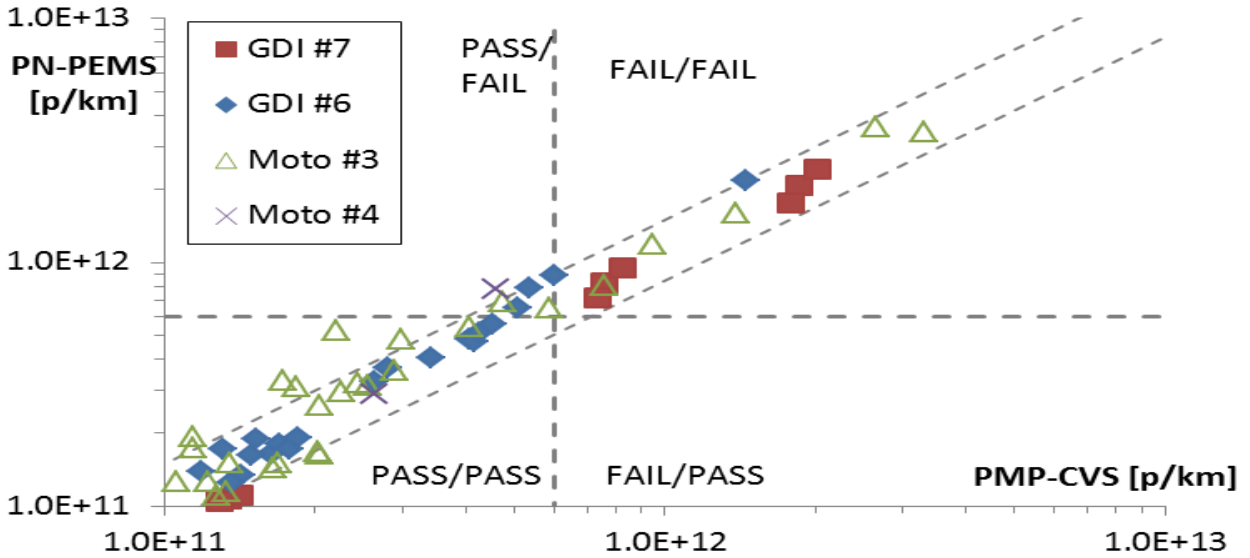
Giechaskiel et al. (2015) JRC report 27451

PN-PEMS (CPC) vs PMP-CVS

Results within

0.85 - 1.50

Limited no of tests



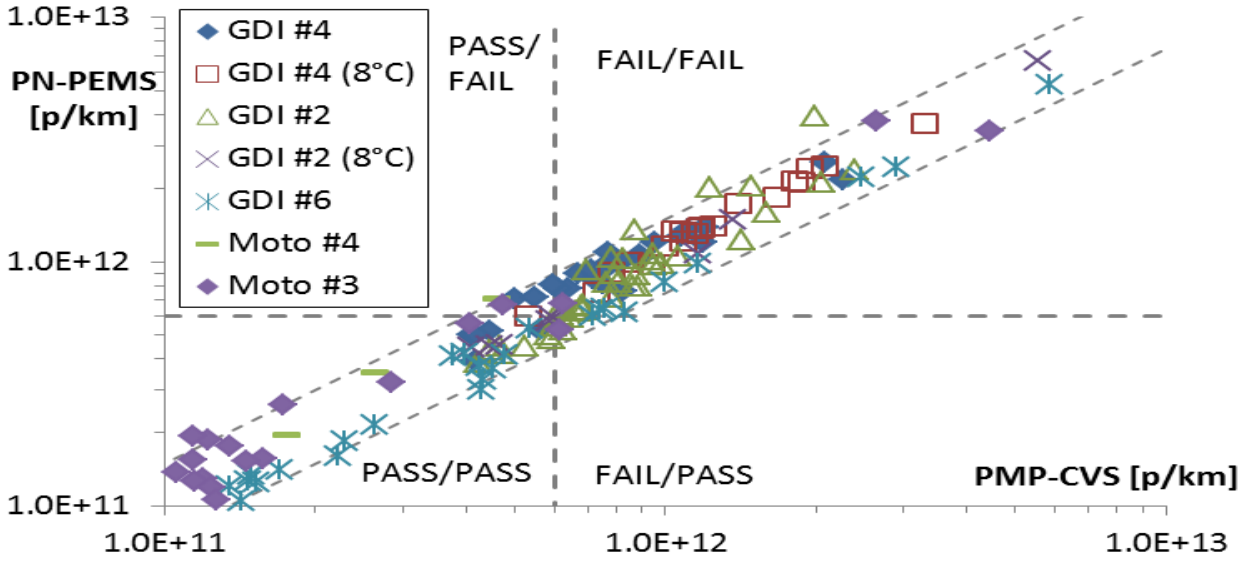
Giechaskiel et al. (2015) JRC report 27451

PN-PEMS (DC adv.) vs PMP-CVS

Results within

0.75 - 1.50

Concentration corrected for estimated mean size of particles



Giechaskiel et al. (2015) JRC report 27451

Phase II – Conclusions

- PMPs at CVS vs TP had differences of ±20% (±15%)
- PN-PEMS vs PMP at TP have differences of ±30% (±20%)
- PN-PEMS vs PMP at CVS have differences of ±50% (±25%) (all vehicles, including mopeds)
- This difference is due to the sampling location + PN-PEMS uncertainty; it refers to small cycles of >10min
- PN-PEMS could efficiently remove volatiles (high dilution or catalytic stripper)
- 2 DC based and 1 CPC based (limited tests) systems exhibited very good behaviour. A third DC had very good behaviour as well (like Phase I)
- The technical requirements were drafted

Giechaskiel et al. (2015) JRC report 27451

Inter-Laboratory Correlation Exercise (ILCE)

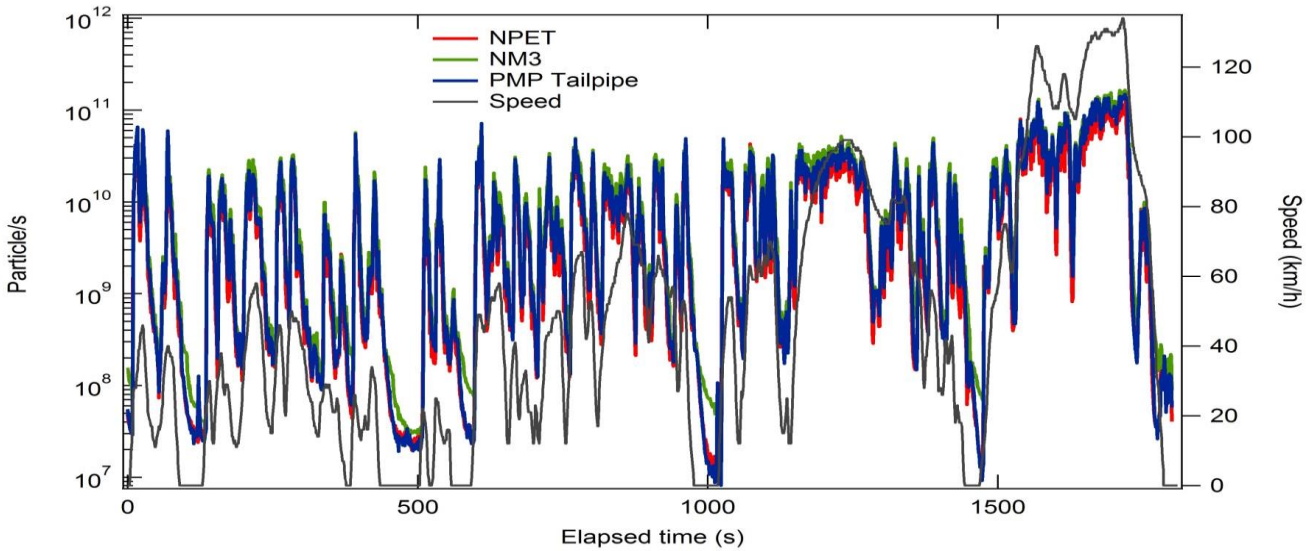
- Objectives:
  - Direct involvement of stakeholders (industry and technical services) in the PN-PEMS activities
  - Assessment of accuracy and precision of the PN measurement with two different PN-PEMS on one vehicle in different laboratories
  - Comparison of RDE results on different roads at different locations
- Instrumentation
  - Golden vehicle (VW Golf, GDI, Euro 5b)
  - Gas-PEMS (Sensors Semtech LDV)
  - PN-PEMS (CPC based, Horiba mod. NPET)
  - PN-PEMS (DC based, Testo NanoMet3)
  - PMP for the tailpipe (AVL, adv. APC 489)

Inter-Laboratory Correlation Exercise (ILCE)

- Experimental
  - Lab tests (cold NEDC, hot WLTC)
  - On-road tests according to the RDE procedures
- Labs
  - Audi
  - Bosmal
  - Honda
  - JRC
  - TUV Nord
  - Volvo
  - VW

Inter-Laboratory Correlation Exercise (ILCE)

- Example of (excellent) agreement of instruments



Chassis and on-road tests comparisons

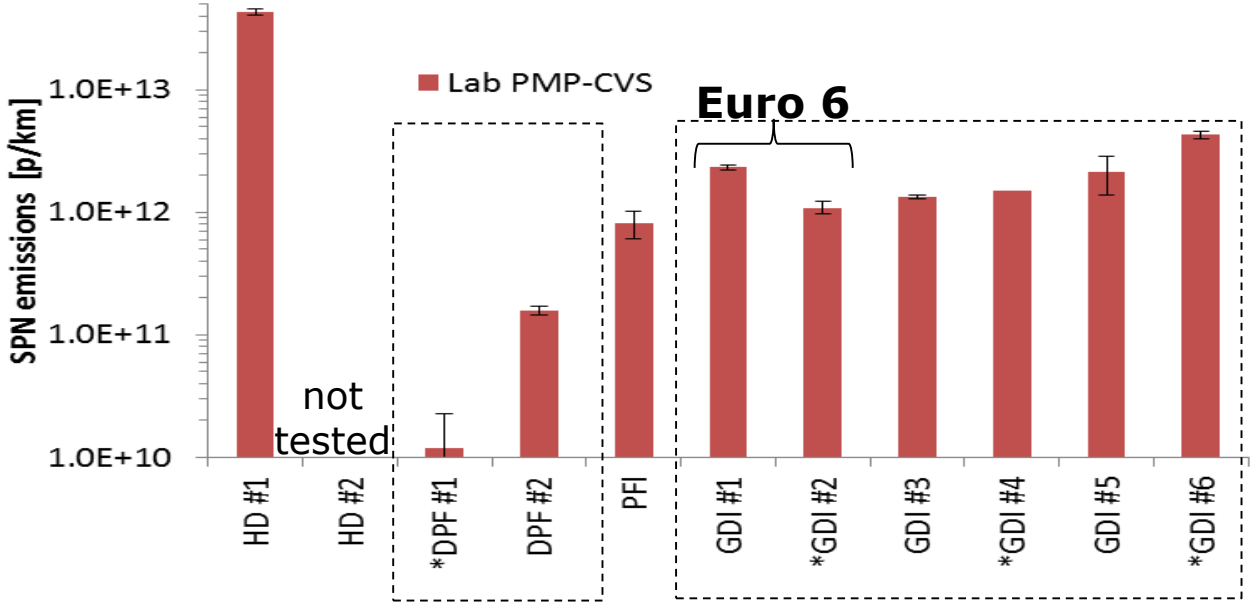
- Objective: Evaluate the emission of the same vehicle both in the laboratory and on-road

- Vehicles (Euro 5 and 6) tested both in the chassis dynamometer and on-road
- Reference cycle: WLTC
- On-road tests composed of urban, rural, motorway driving
- Ambient conditions typically 5-25^{o}C
- Elevation 200-400m (few exceptions up to 1100m)
- PMP and PN-PEMS both on-board in some cases

Giechaskiel et al. (2015) Frontiers in Env. Sci. 3:82. doi: 10.3389/fenvs.2015.00082

Chassis and on-road tests comparisons

Lab results:
Emission levels
as expected



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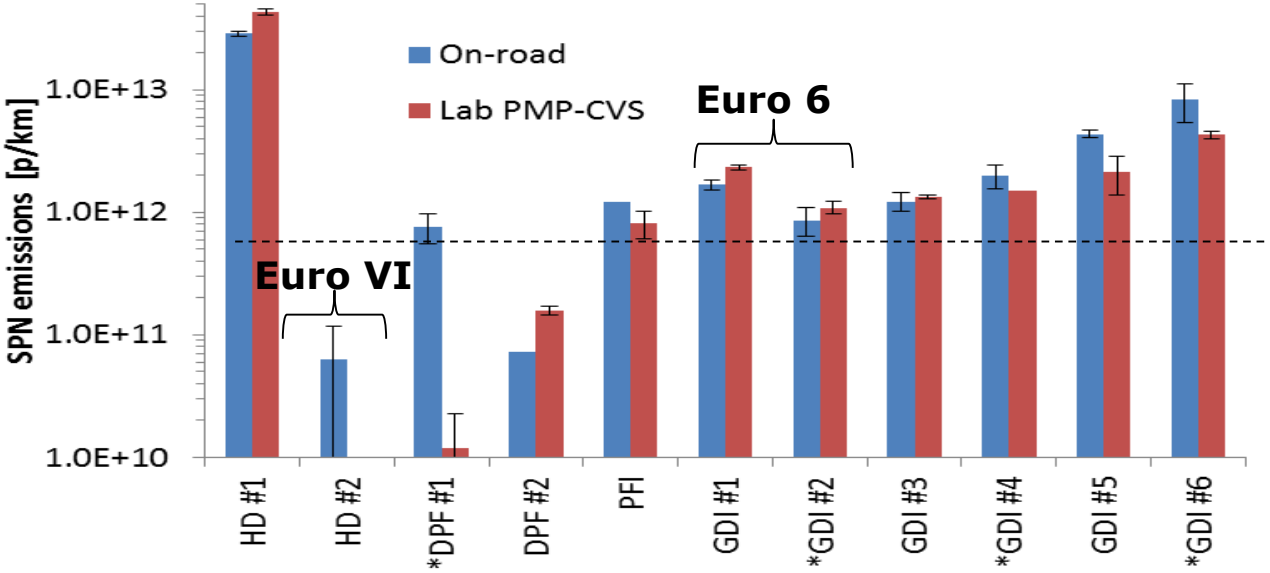
On-road and lab evaluation

Differences <2

Parameters:
-Accelerations
-Temperature
-Cold start
-Extra weight



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PN-PEMS for HDV

- Call of interest (22 Oct 2015)
- Technical specifications definitions (Nov 2015)
  - Based on light-duty
- JRC evaluation (Jan – June 2016)
  - N2, N3, (truck), CNG
  - Focus on extreme conditions (-7°C to +35°C, regenerations)
  - Lab and on-road tests
  - Different PN-PEMS
- Validation program (July 2016+)
  - OEMs
  - Instruments in parallel

Thank you for your attention!