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Real Driving Emissions (RDE)
Portable Emission Measurement Systems (PEMS)
Particle Number (PN)
Implementing PN-PEMS for RDE procedures

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Introduction

- Particles have negative health effects
- Smaller (ultra-fine) particles might be more dangerous due to their higher specific surface area
- Exceedance of Particulate Matter (PM) limits in cities is known. Particle Number (PN) has also been addressed recently:

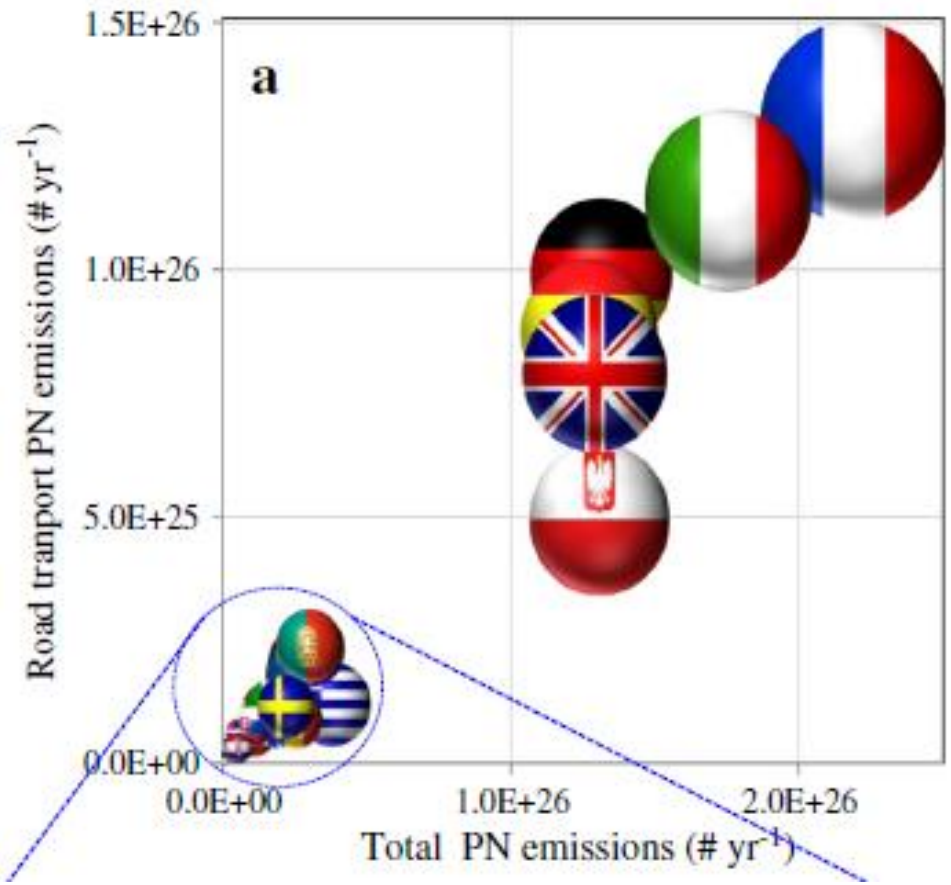
- Contribution to total PN of:
  - Road transport: 60%*
  - Non-road transport (+ship traffic): 19%
  - Domestic combustion: 13%

*32% (Greece) to 97% (Luxemburg)

Kumar et al. Env. Int. 66 2014

PN emissions

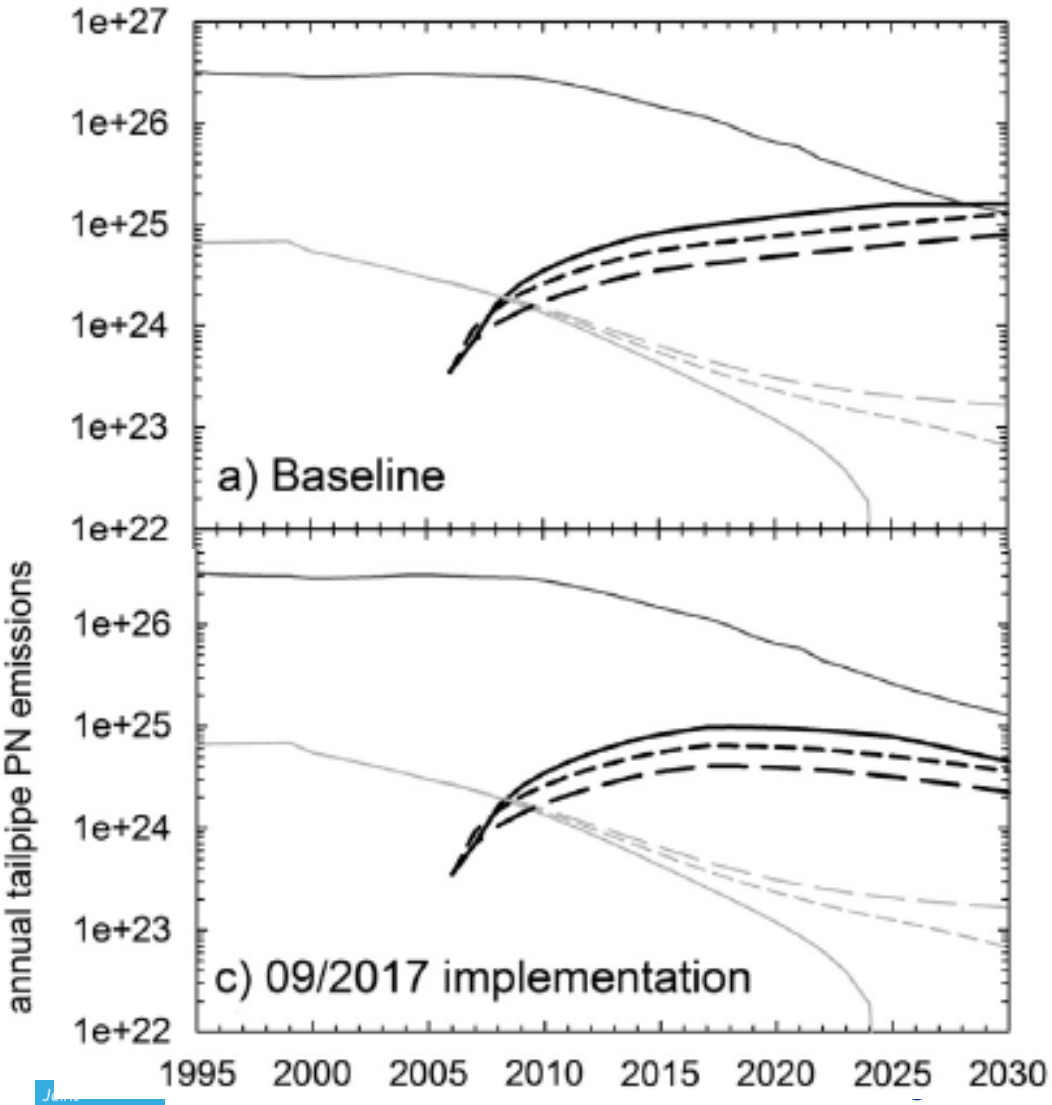
France, Italy, Germany, Spain, UK and Poland are the top six PN emitters in the EU28 and together, their road traffic contributes nearly 3/4 (~72%) of the total traffic-induced PN emissions in the EU28.



Kumar et al. Env. Int. 66 2014

Solid PN emissions

- Solid PN emissions projections
- Reduction of GDI emissions was necessary
- Limit of 6x10^11 p/km from 2017

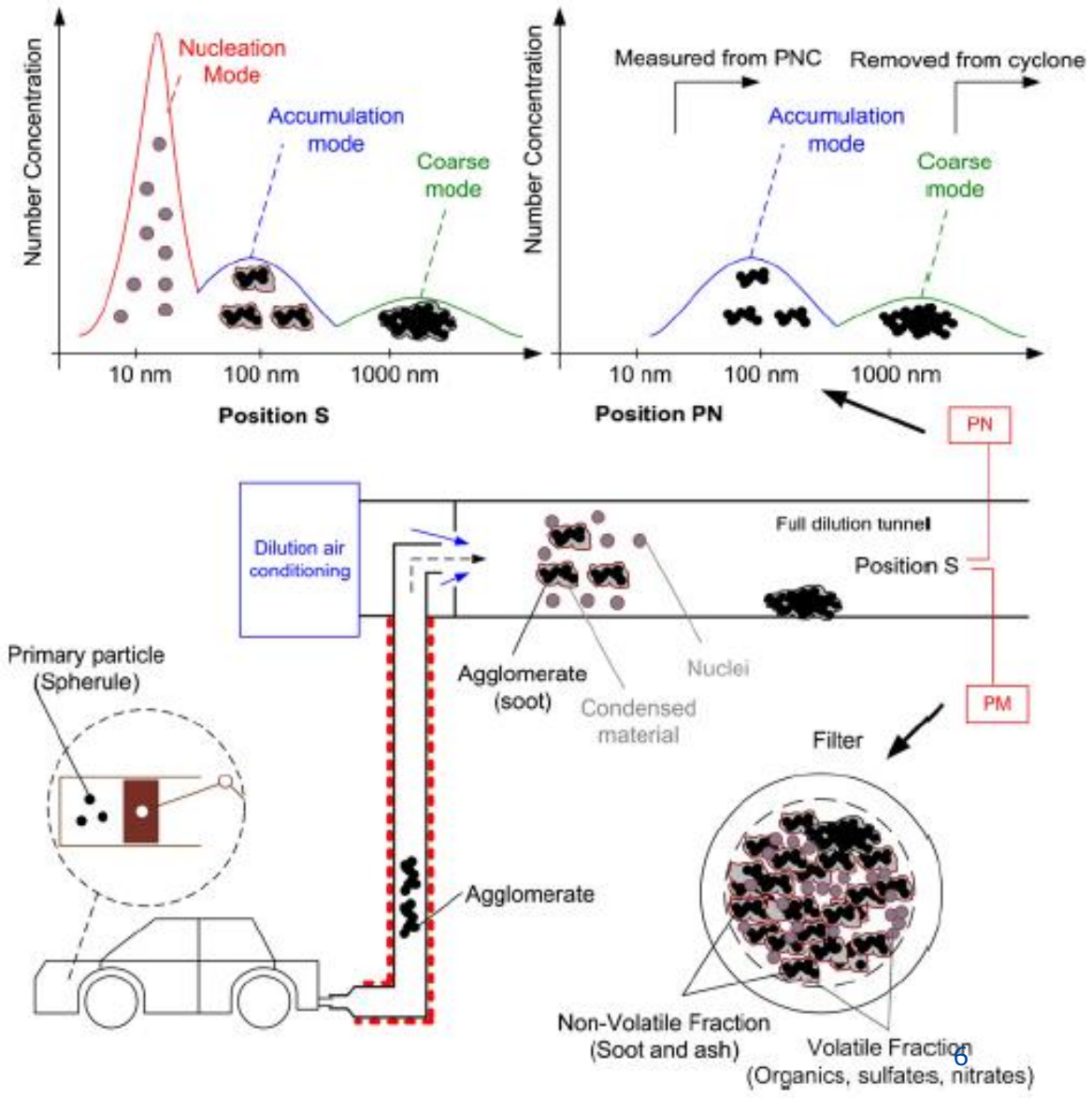


	GDI	PFI	diesel
high GDI penetration	———	———	———
medium GDI penetration	– – –	– – –	———
low GDI penetration	— —	— —	———

Mamakos et al. (2013) AtmEnv 77:16-23

PM & PN

Particulate Matter (PM) on a filer
Particle Number (PN) airborne



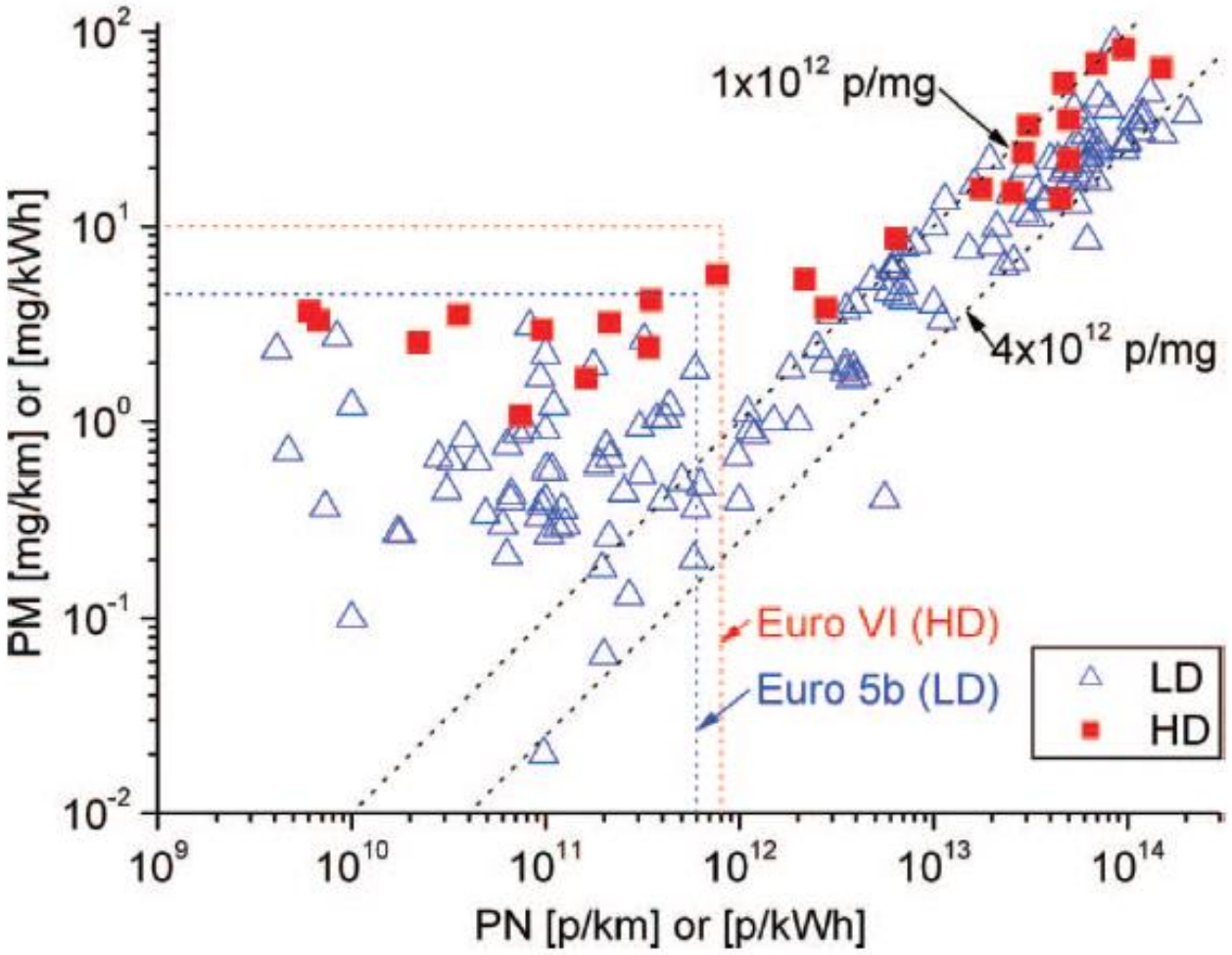
Giechaskiel et al. (2010) MST 21 045102

PN vs PM

Correlation at high concentrations
1 mg ~ 2x10^12 p

No correlation at low levels

Sensitivity of filter method
Artifacts on filter

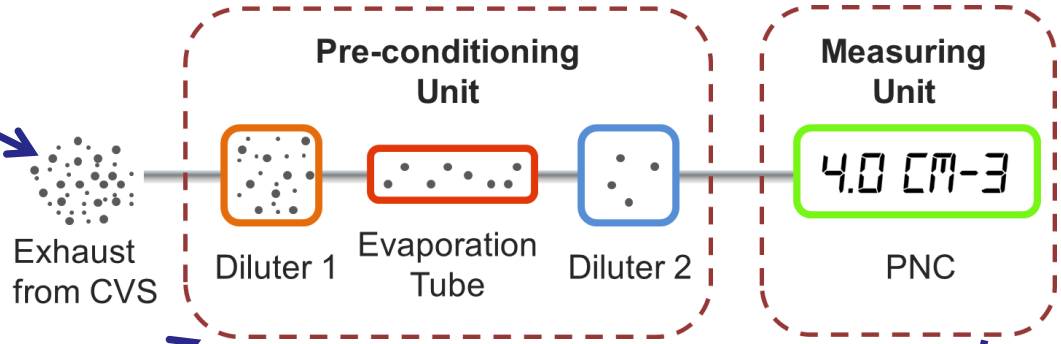


Giechaskiel et al. (2012) AST 46:719–749

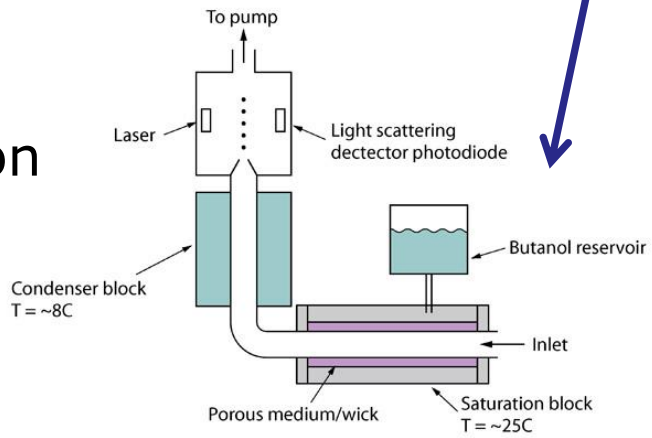
RDE regulation for light-duty vehicles

- 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 conditions
- Nov. 2012 call of interest for Particle Number PN-PEMS
- RDE Part of Euro 6 legislation, Appendix IIIA of 692/2008
- Monitoring phase until 2017/2018

Solid PN regulated method (PMP)

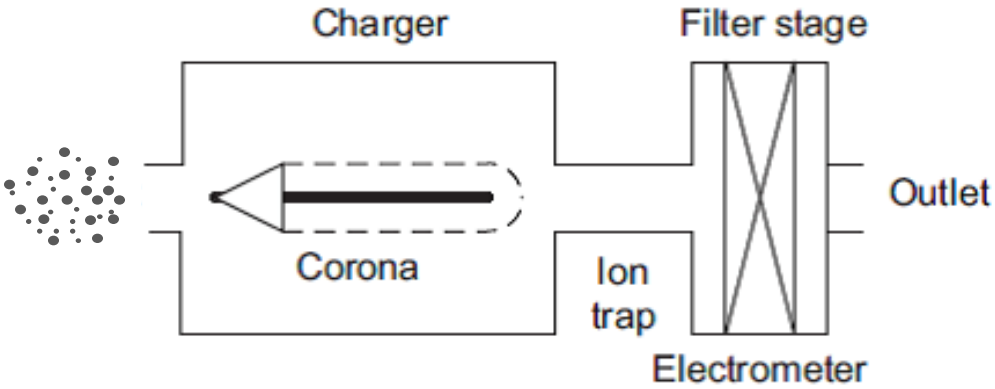


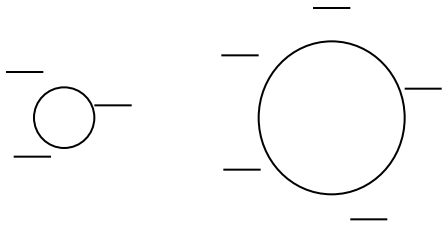
Condensation
Particle
Counter



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

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)

CPC vs DC

- DC: Size dependency
- Possible to optimize them for typical size distributions

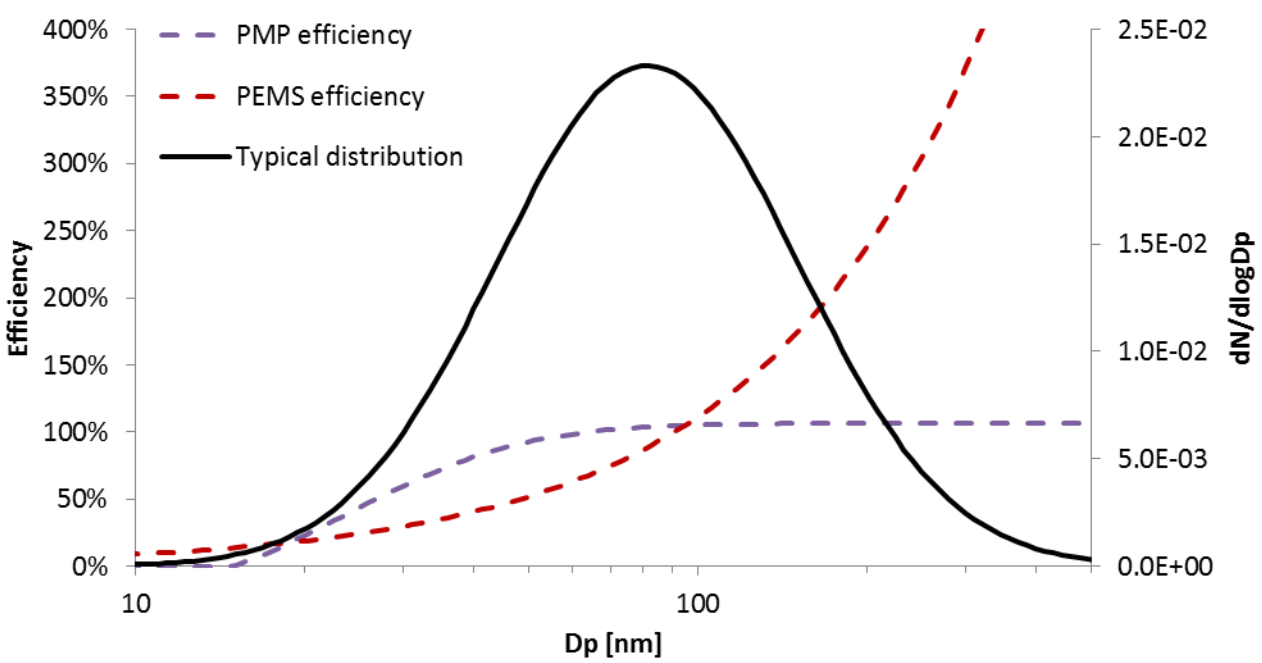
Efficiency *E* is defined as ratio of Reading *R* of instrument (after internal corrections) to the true inlet concentration *PN*

$E = R / PN$

Typically

$R(DC) = c\ d_p^x$

x=1.3 for soot



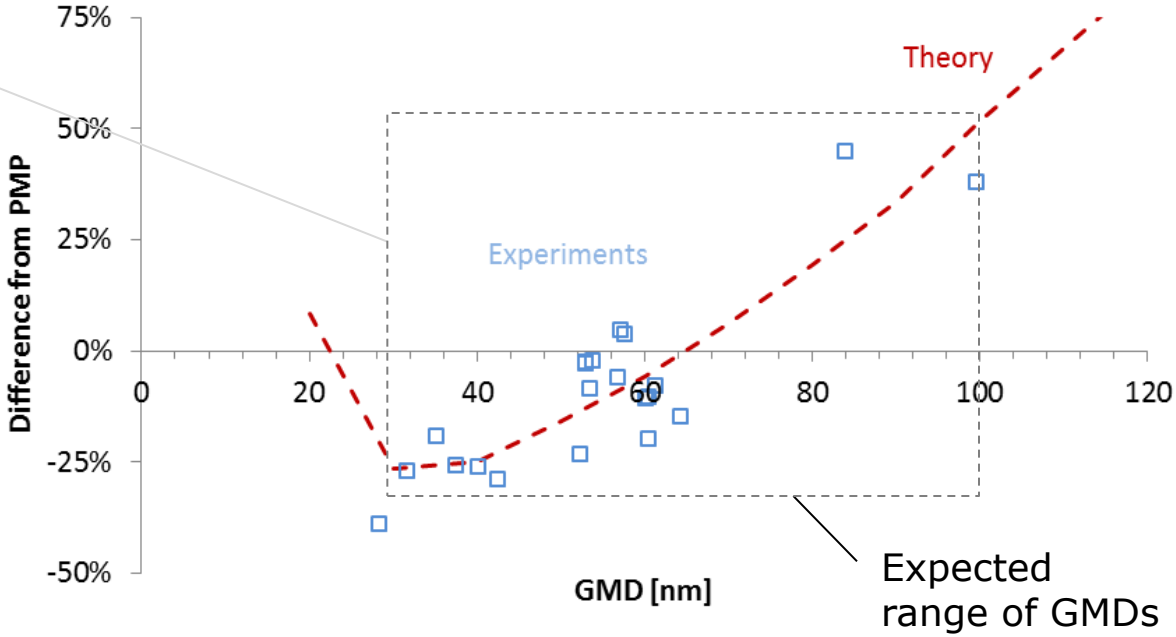
Giechaskiel et al. (2014) JRC report 26997

Calibration : Comparison DC – CPC

- Difference PMP – DC for polydisperse aerosol
- Calibrated at 60 nm polydisperse GMD (example)
  - GMD=Geometric Mean Diameter

Acceptable difference:
-33% to +50%

Then the same calibration could be used for all vehicles, technologies etc (diesel, gasoline, light-duty, heavy-duty, NRMM)



Giechaskiel et al. (2014) JRC report 26997

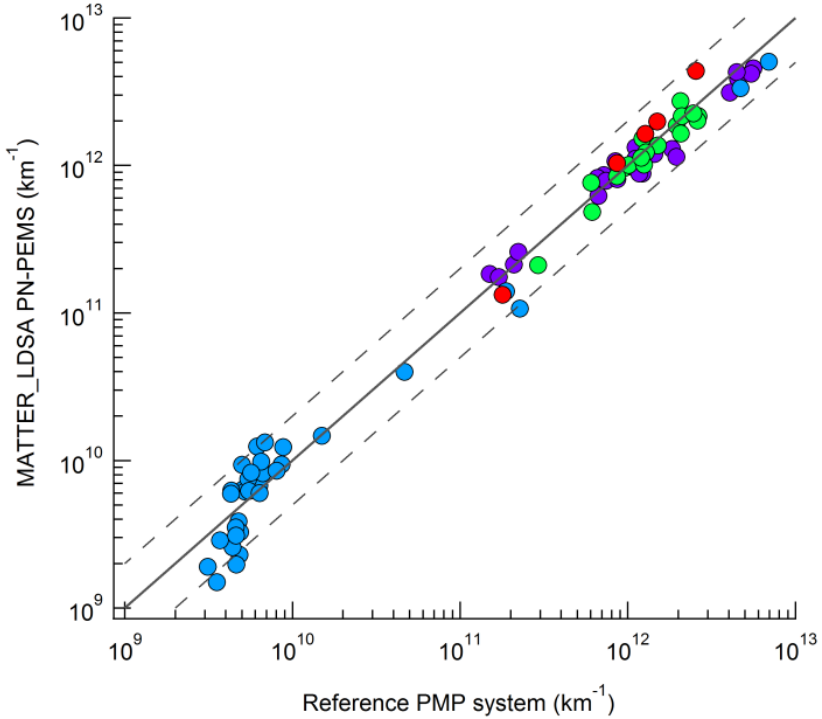
Geometric **M**ean **D**iameter

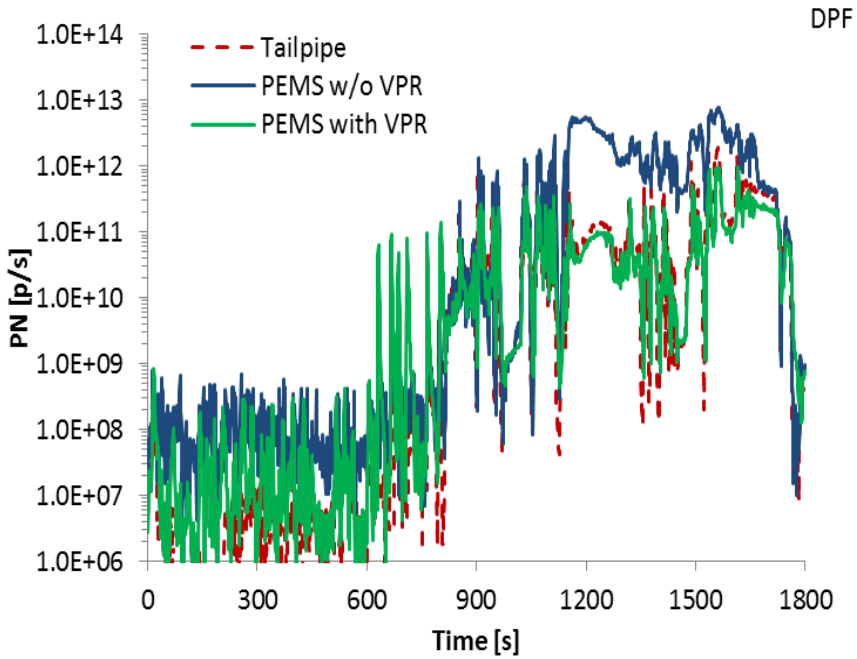
Phase I Testing

- Test vehicles
  - 3 GDIs
  - 1 PFIs (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 is 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

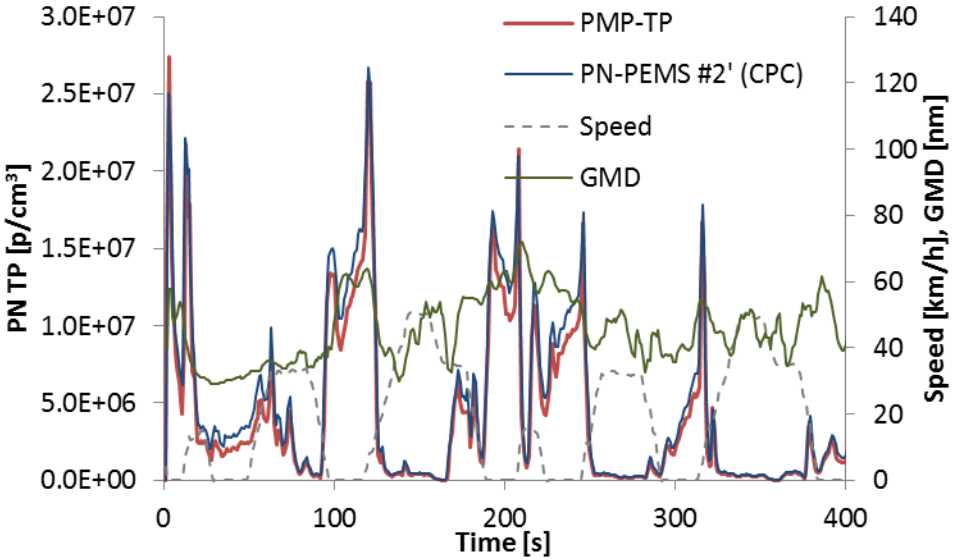
PN-PEMS Phase II Topics

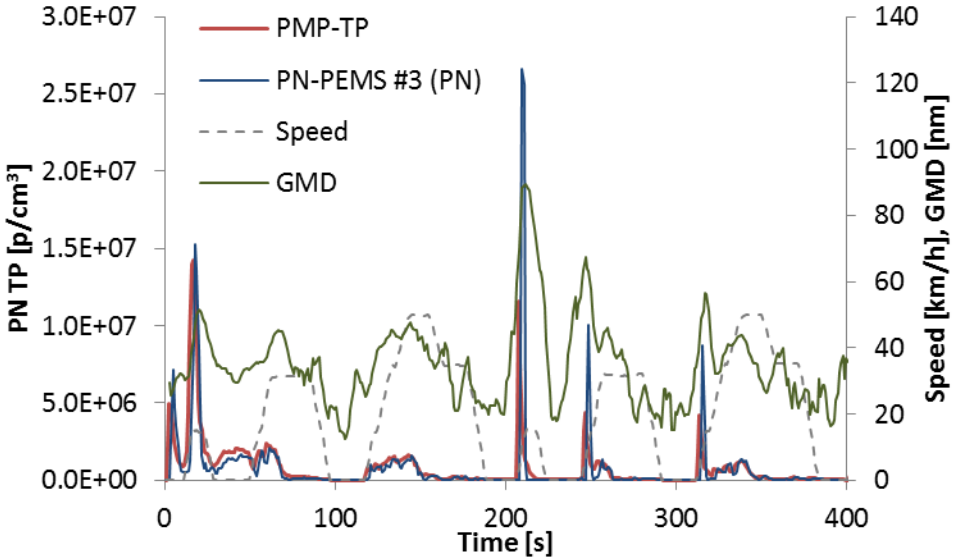
- Calibration
- Real time signal
- Comparison with PMP systems
- Dependency on particle size
- Ambient temperature effect
- Challenge aerosol (solid sub 23 nm)
- Volatile removal efficiency (moped 2-stroke)
- Regeneration
- Bias and precision
- PASS or FAIL success rate
- Calibration at the CVS

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





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PMP-TP vs PMP-CVS

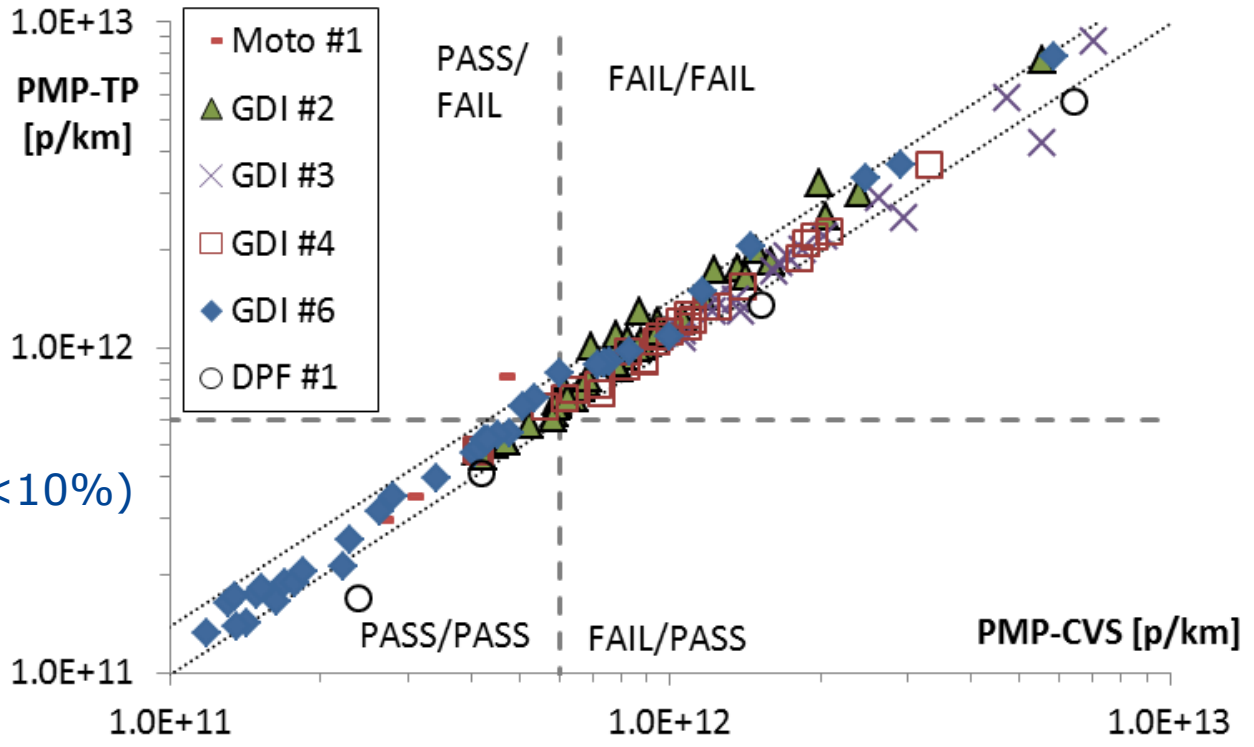
Results within

0.95 - 1.40

Reasons:

-Time alignment (<10%)
-Exhaust flow accuracy (<10%)

-Thermophoretic losses+
-Diffusion losses (<5%)
-Agglomeration (<15%)



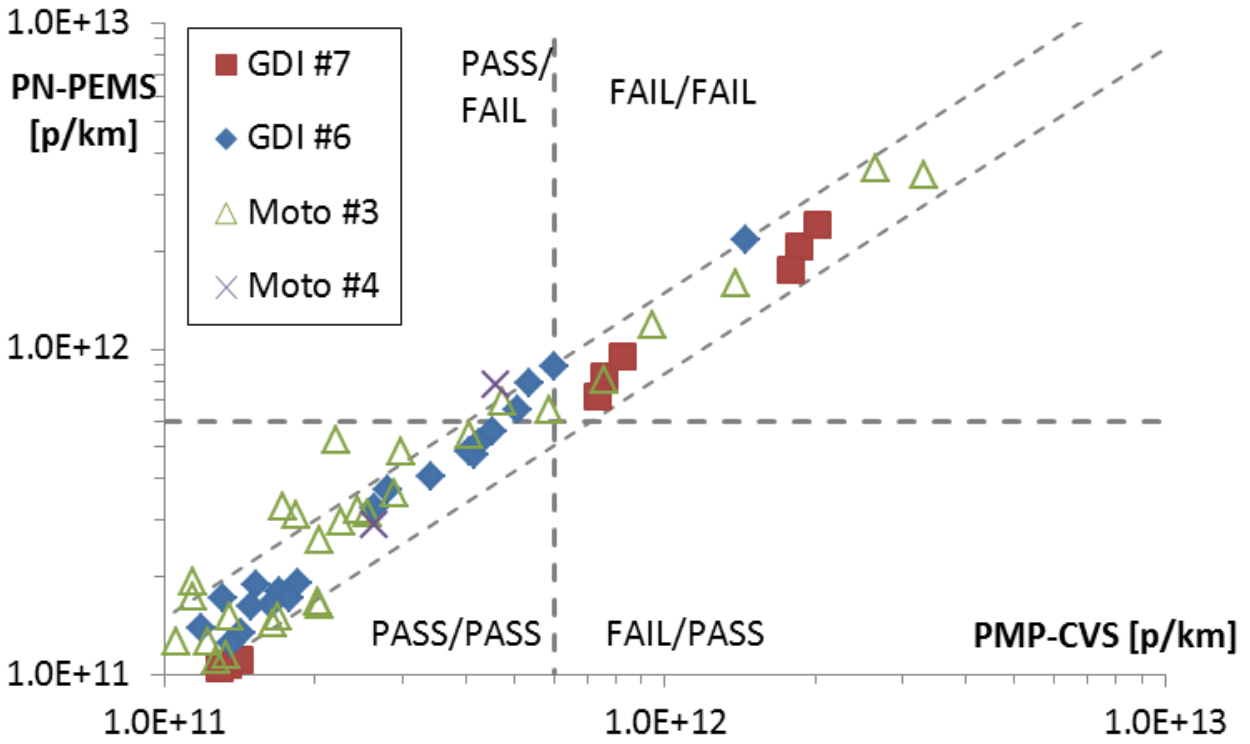
Giechaskiel et al. (2015) JRC report 27451

PN-PEMS (CPC) vs PMP-CVS

Results within

0.85 - 1.50

Limited no of tests



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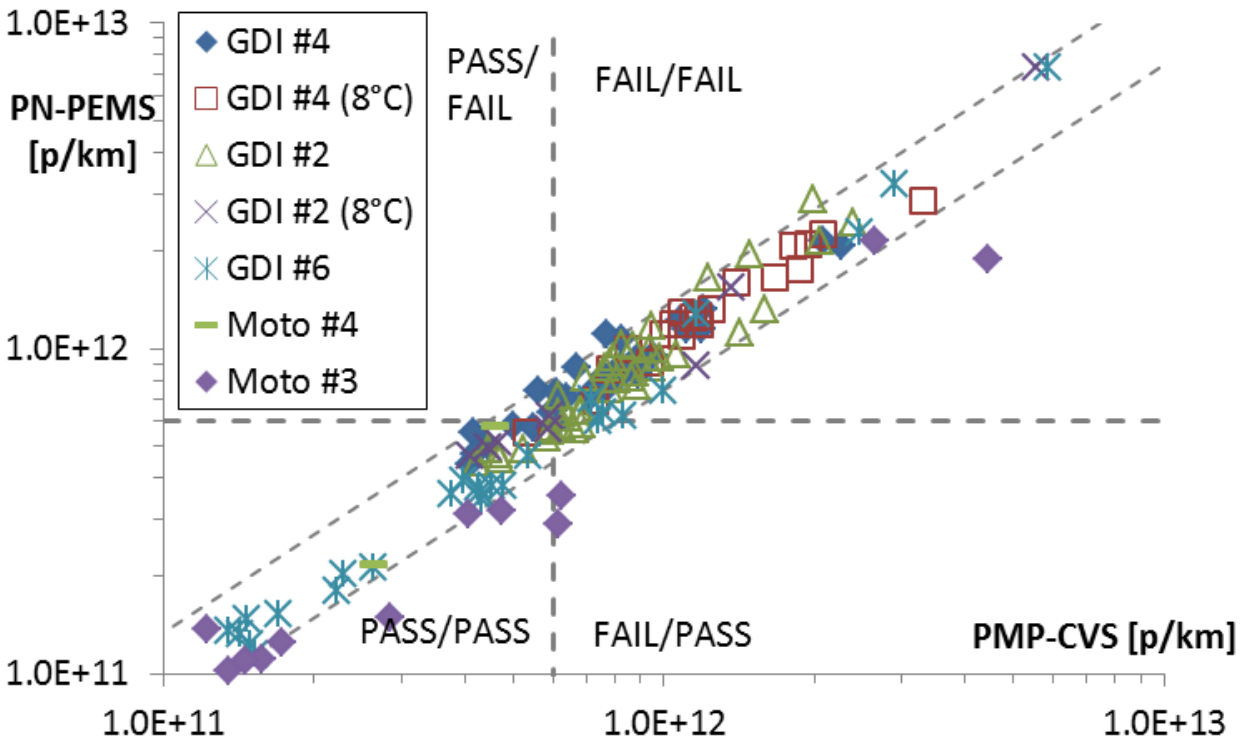
PN-PEMS (DC) vs PMP-CVS

Results within

0.75 - 1.35

Optimized for GDIs



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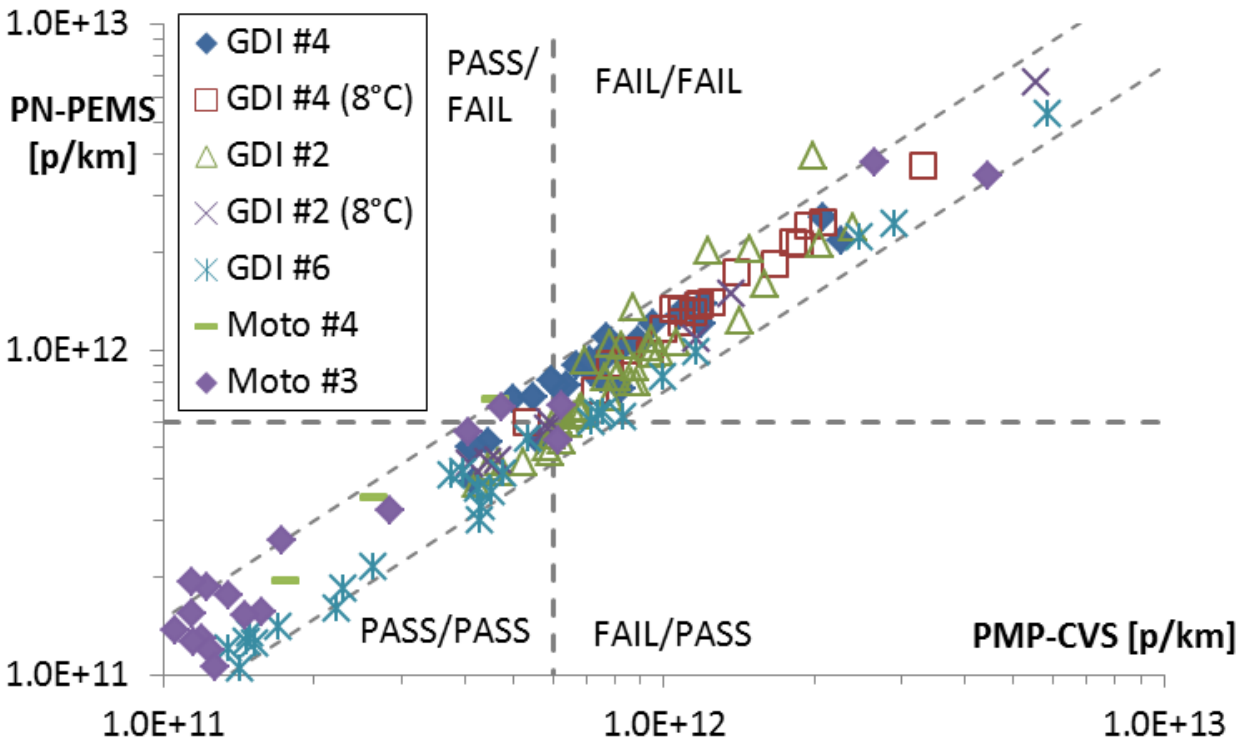
PN-PEMS (DC adv.) vs PMP-CVS

Results within

0.75 - 1.50

Concentration corrected for estimated mean size of particles



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Phase II – Conclusions

- PMPs at CVS vs TP had differences of ±20% (±15%)
- Part of the difference applies only to particles: Thermophoretic losses (<5%), agglomeration (<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.
- GMDs ranged from 20 to 75 nm
- PN-PEMS could efficiently remove volatiles (high dilution or catalytic stripper)
- Special attention has to be given to the robustness of systems (including PMP) for tailpipe measurements

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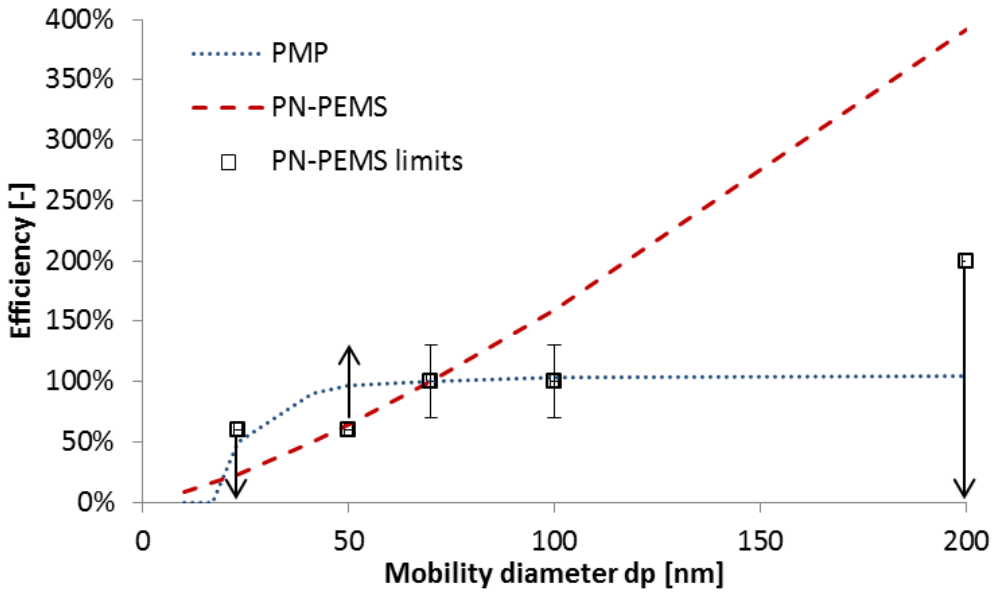
Phase II – Conclusions

- 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)
- Uncertainty estimations were given
- Technical requirements
- Calibration procedures



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Inter-Laboratory Correlation Exercise (ILCE)

- Objectives:
  - Familiarize labs with PN-PEMS, evaluate the robustness of PN-PEMS
  - Assess reproducibility and repeatability of the performance of the PN-PEMS (dyno)
  - Compare the RDE results on different roads at different locations

- Instrumentation
  - Golden vehicle (GDI, Euro 5b)
  - Gas-PEMS
  - PN-PEMS (CPC based)
  - PN-PEMS (DC based)
  - PMP for the tailpipe

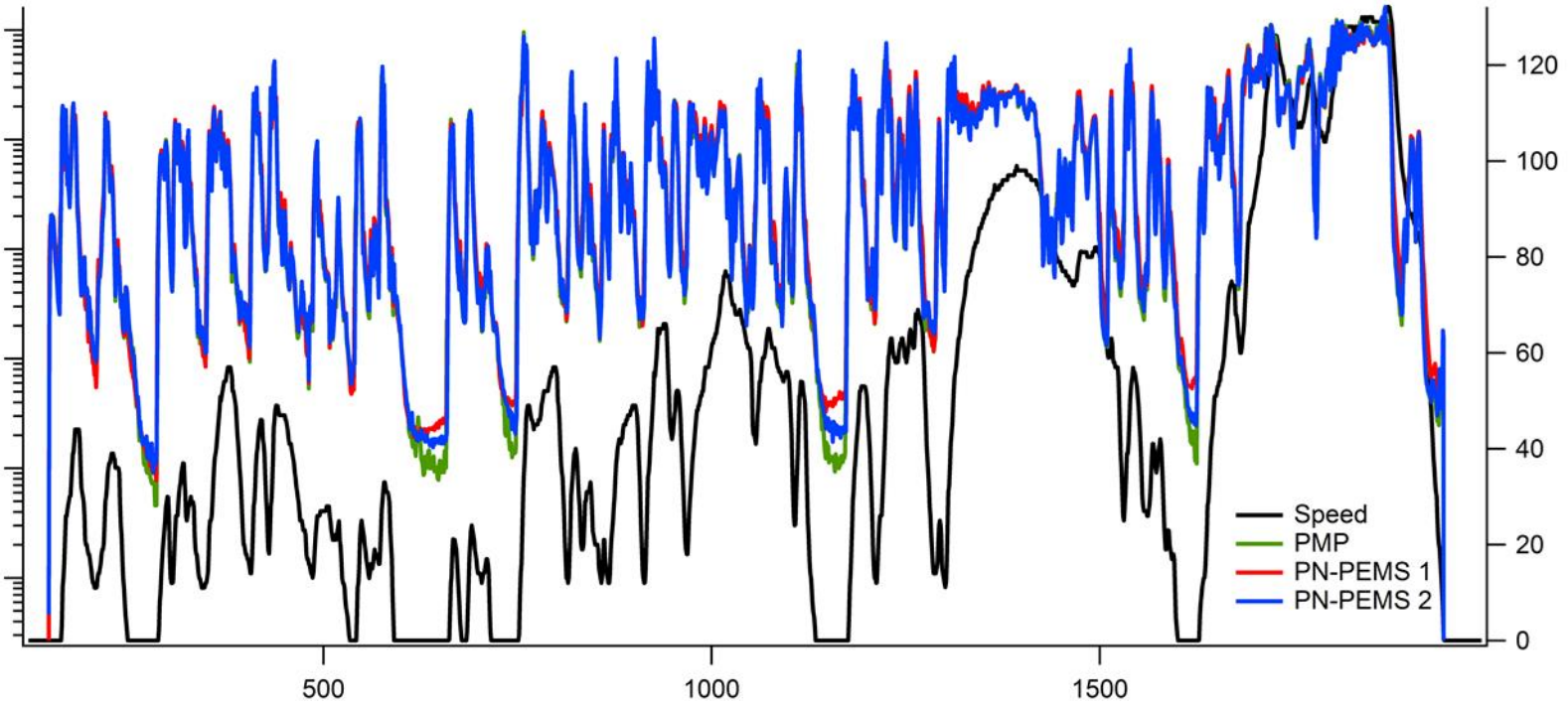
Inter-Laboratory Correlation Exercise (ILCE)

- Experimental
  - Lab tests (cold NEDC, hot WLTC)
  - On-road tests according to the RDE procedures

- Planning
  - JRC (Beginning of September)
  - VW (Mid of September)
  - Bosmal (Beginning of October)
  - Honda (End of October)
  - Audi (Beginning of November)
  - Volvo (end of November)
  - TUV Nord (beginning of December)
  - JRC (End of December)

Inter-Laboratory Correlation Exercise (ILCE)

- Example of (excellent) instruments agreement



Chassis and on-road tests comparisons

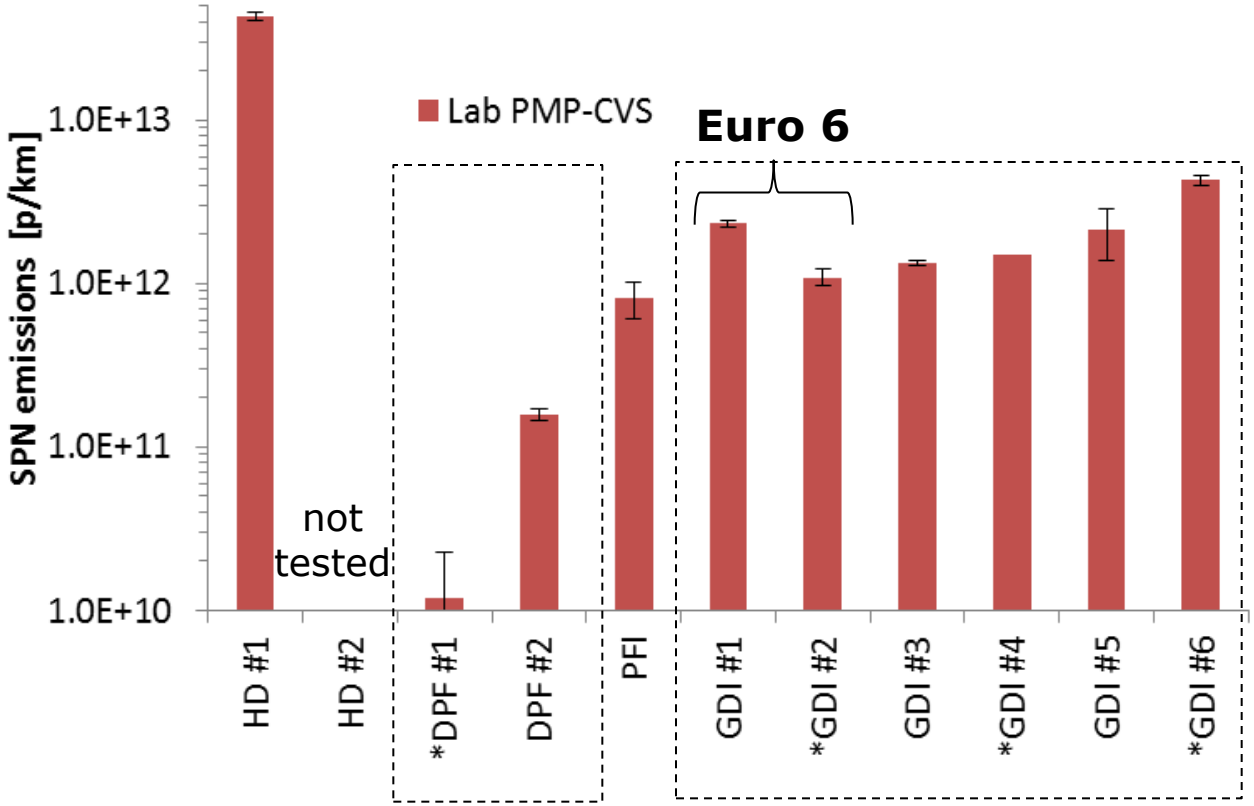
- Objective: Evaluate the emission of the same vehicle both in the laboratory and on-road

- Vehicles (Euro 5 and 6) tested both in the chassis dynamometer and on-road
- Reference cycle: WLTC
- On-road tests mixtures 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. accepted

Chassis and on-road tests comparisons

Lab results:
Emission levels as expected



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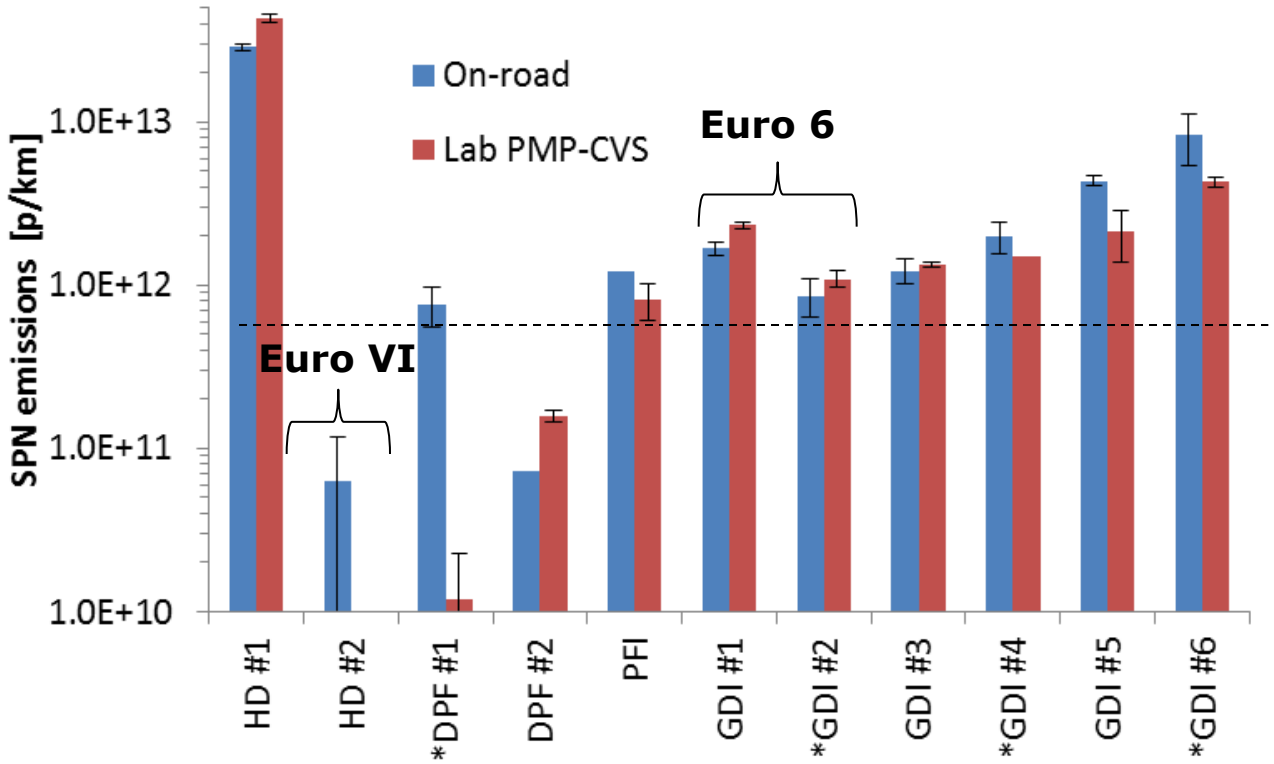
On-road and lab evaluation

Differences <2

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



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Summary

- RDE test procedure approved in May 2015 – Annex IIIA to Regulation 962/2008 (1st package):
  - Performance requirements of PEMS
  - Test protocol, boundary conditions, U/R/M shares
  - Two alternative data evaluation to control for driving severity and enable a fair assessment of cars

- 2nd-4th packages will follow until 2018. To do:
  - Conformity factors
  - Complementary boundary conditions
  - Cold start
  - Data evaluation for Hybrid vehicles

2nd package: Completes gaseous RDE

- Dates and application of NTE (Not-To-Exceed) limits
  - NTE = EURO6 x CF x TF
- Conformity Factors (CF) (not yet approved)
  - NOx Step 1 (2017/8+1): 2.1 → optimization with software existing Euro 6
  - NOx Step 2 (2019/20): 1.5 → Air Quality legislation (Development of hardware might be necessary)
- Transfer Function (TF)
  - Factor that depends on the probability of having specific road conditions
- Error analysis (measurement equipment, trip variations)
- Complementary Dynamic Boundary Conditions
  - Acceleration x speed
  - Relative positive acceleration
  - Positive elevation gain

3rd Package: Complete PN RDE

- PN-PEMS procedure and error analysis (Oct 2015)
- Use of PN-PEMS or Random Cycle (Nov 2015)
- Conformity Factors (CF) (Dec 2015)
  - PN Step 1 (2017/8) → Instrument measurement uncertainty + maturity
  - PN Step 2 (2019/20) → Best available technology (+instrument uncertainty)

3rd Package: Cold start (?)

4th Package: In-Service Compliance

- Administrative rules (March 2016)
- Technical rules (Oct 2016)

PN-PEMS for HD

- Call of interest
- Technical specifications definitions
  - Based on light-duty
- JRC evaluation (1/2 years)
  - N2, N3, (truck), M3 (bus)
  - Different conditions than LD (e.g. temperature, particle nature etc)
  - On-road tests
- Validation program
  - OEMs
  - Instruments in parallel

LD

- Call of interest (end 2012)
- Phase I (end 2013)
- Phase II (end 2014)
- ILCE (end 2015)

Thank you for your attention!