DAIMLER

Real driving emissions at trucks - PN: a challenge for measurement technique

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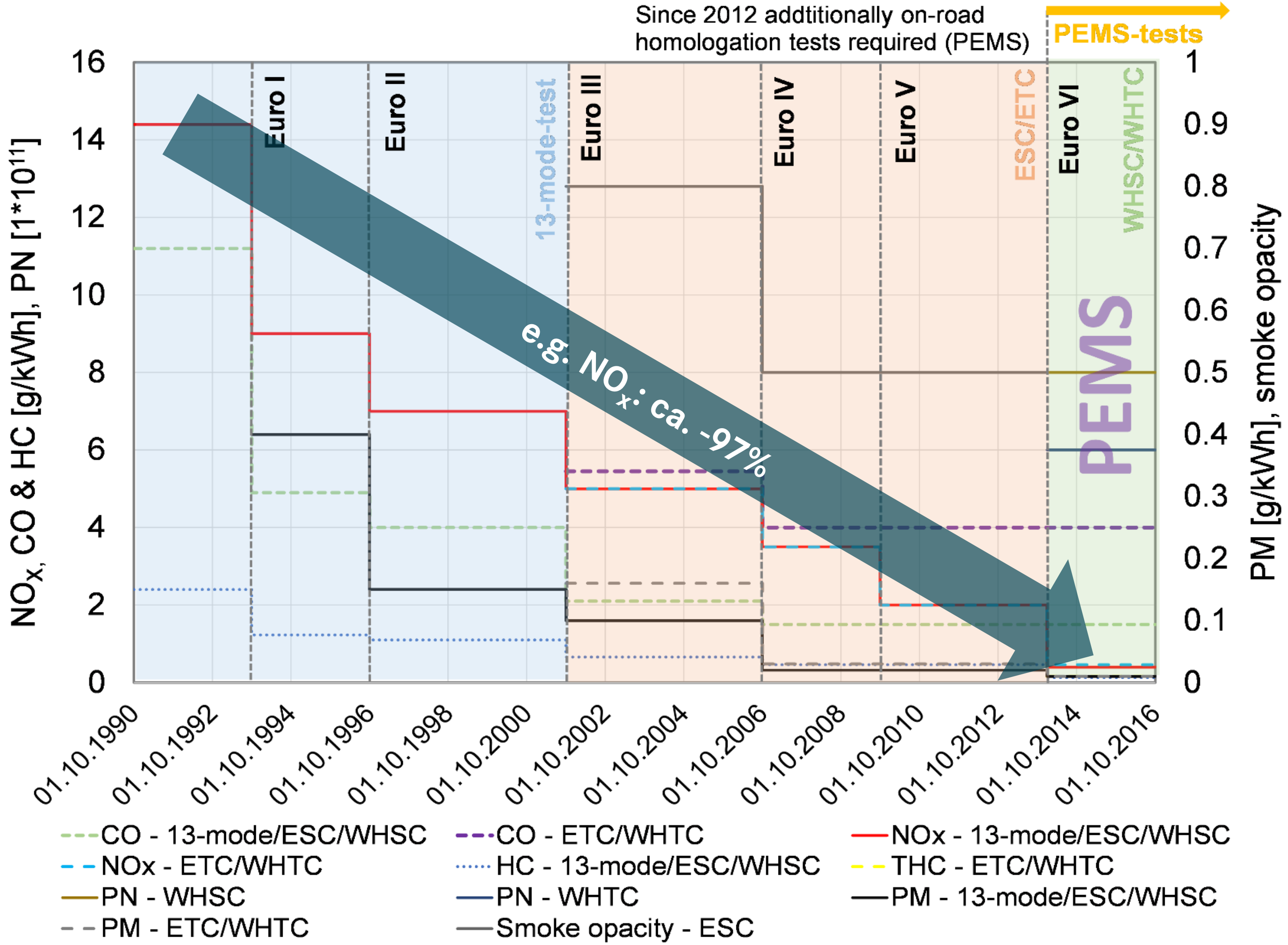
Important steps in EU HD emission threshold development



Current PEMS thresholds (CF=1.5):

CO:

CO_{WHTC} = 4000mg/kWh

CO_{PEMS} = CF * CO_{WHTC} = **6000mg/kWh**

THC:

THC_{WHTC}= 160mg/kWh

THC_{PEMS}= CF * THC_{WHTC} = **240mg/kWh**

NO_X:

NO_{X_WHTC}= 460mg/kWh

NO_{X_PEMS} = CF * NO_{X_WHTC} = **690mg/kWh**

In discussion:

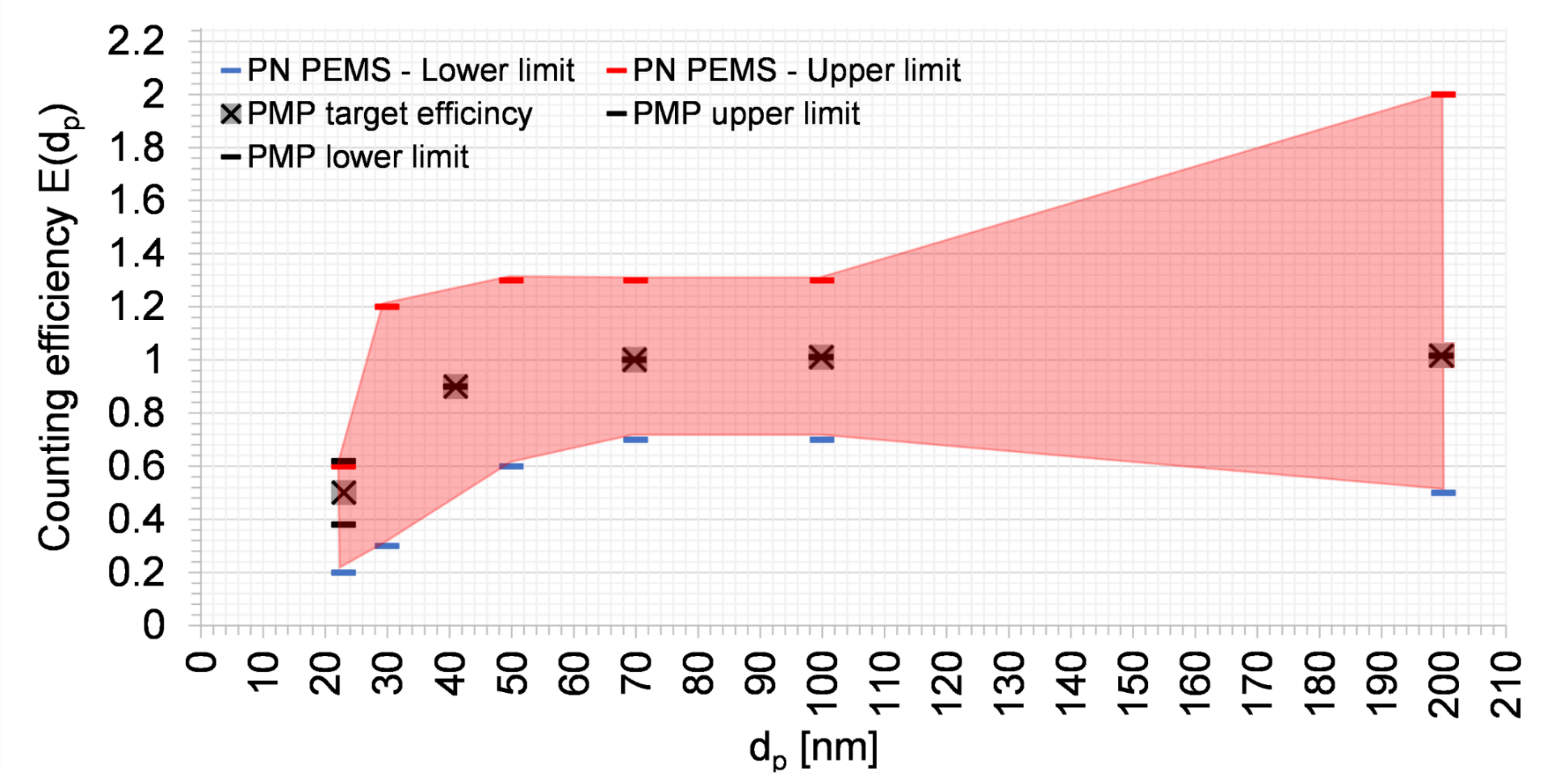
PN

PN_{WHTC} = $6*10^{11}$ #/kWh (since 2012/13)

PN_{PEMS} = CF_{PN} * PN_{WHTC} = $9*10^{11}$ #/kWh

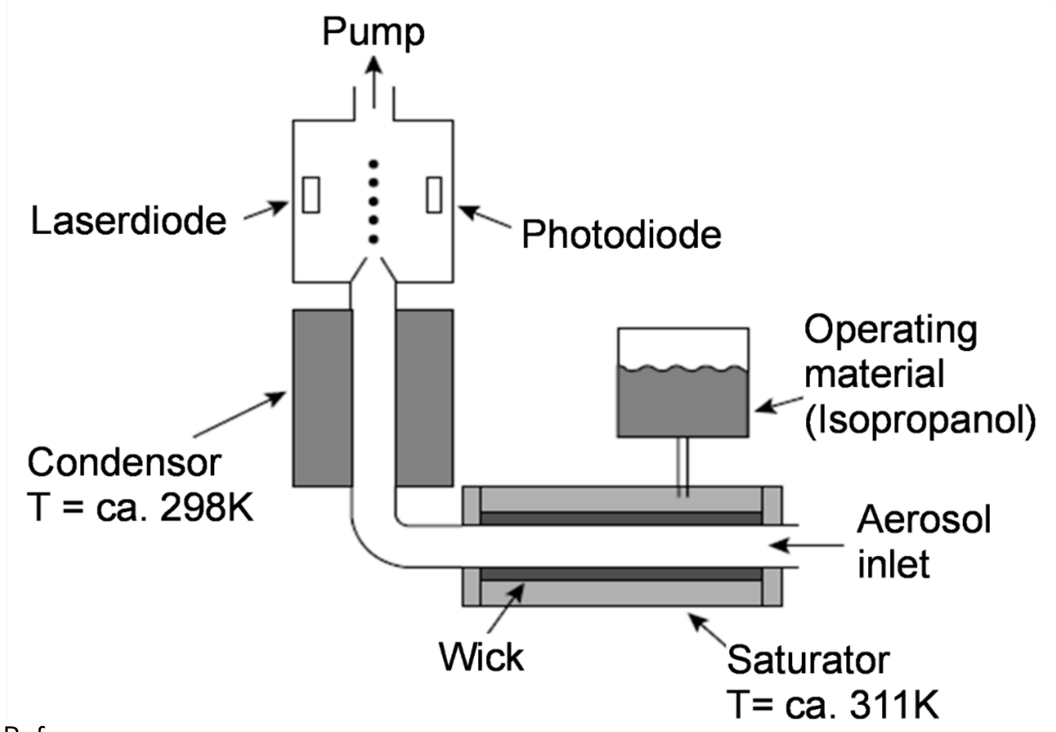
Particle Number (PN) counting regulations

- Stationary Particle Counter: PMP, UN/ECE R.49
- PN PEMS: LD PN PEMS Commission Regulation, (EU) 2017/1154, Annex 2
- PN counting cutoff size at **d=23nm** particle diameter (electromobility) with $E(d_p=23nm)= 0.5$
- Stationary particle counter and PN-PEMS → different counting efficiency $E(d_p)$ at different particle diameter

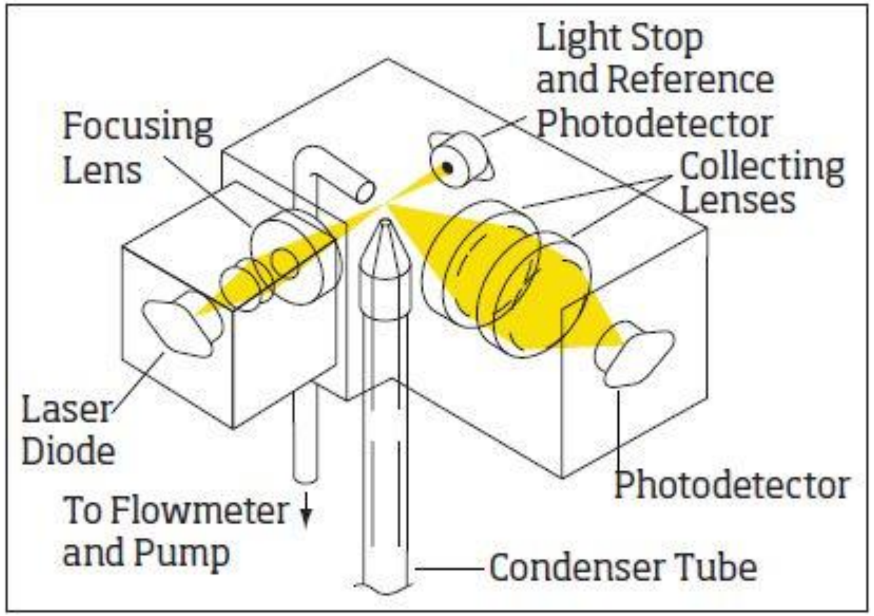


PN PEMS - CPC#1: Condensation Particle Counter

- Working principle: Particle enlargement (factor 100-1000) and light scattering method
- Operation material for particle enlargement: Butanol or Isopropanol
- Pros: accurate at a wide range of PNC (p/ccm)
- Cons: operation material needed

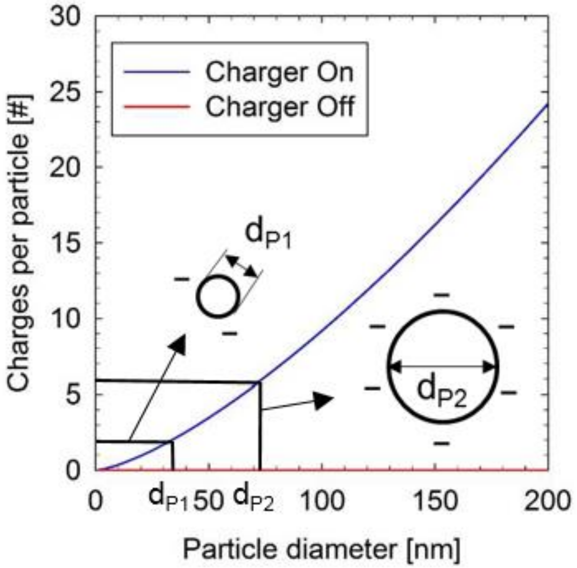


Reference:
Paulweber, Michael; Lebert, Klaus (2014): Mess- und Prüfstandstechnik. Springer Fachmedien Wiesbaden. doi:10.1007/978-3-658-04453-4



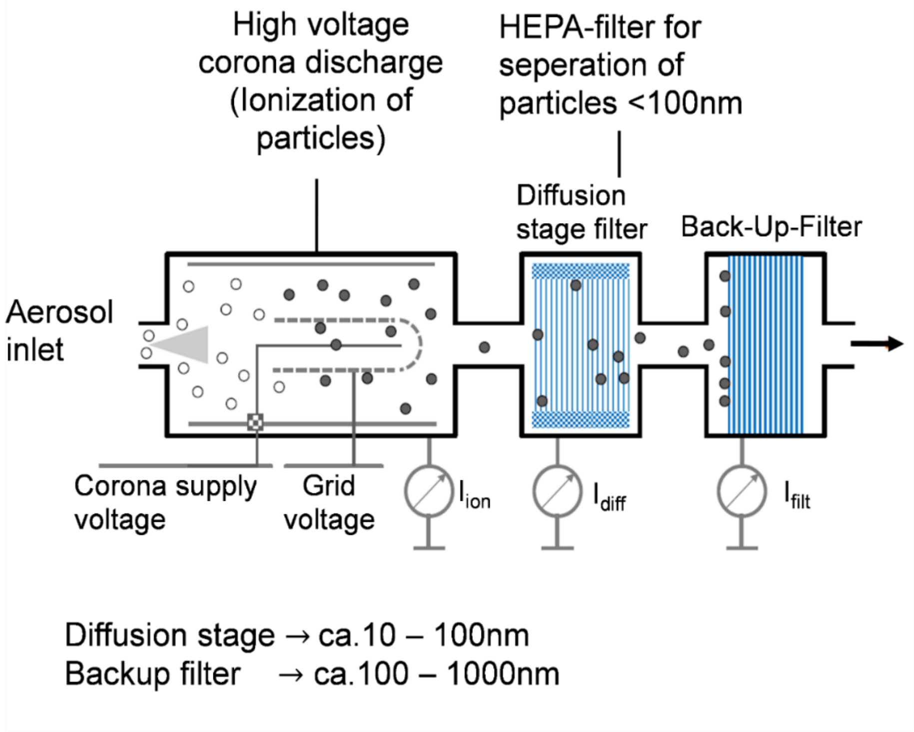
Reference:
http://tsi.com/uploadedFiles/_Site_Root/Products/Literature/Spec_Sheets/3775_2980343.pdf

PN PEMS - DC: Diffusion Charger

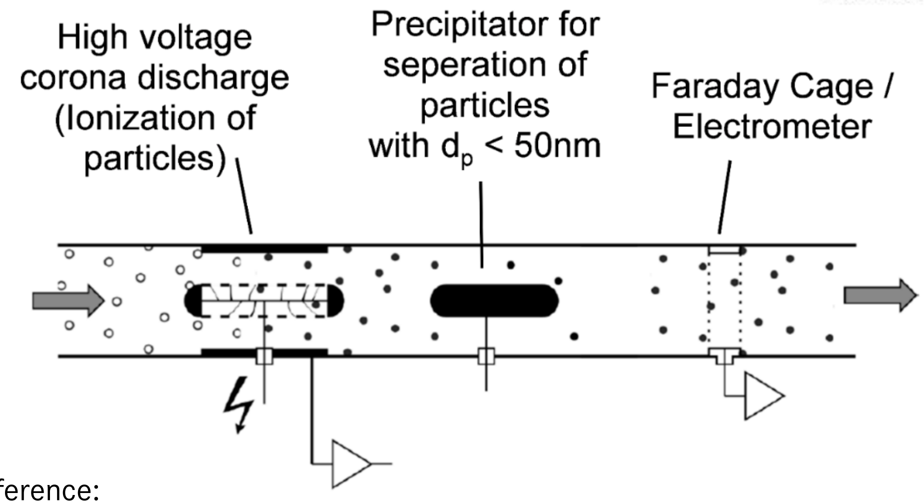


- Working principle: Ionization of particles and counting of induced current at Faraday Cage / Filter
- Pros: No operation material needed
- Cons: Size dependent particle charge

DC#2



DC#1

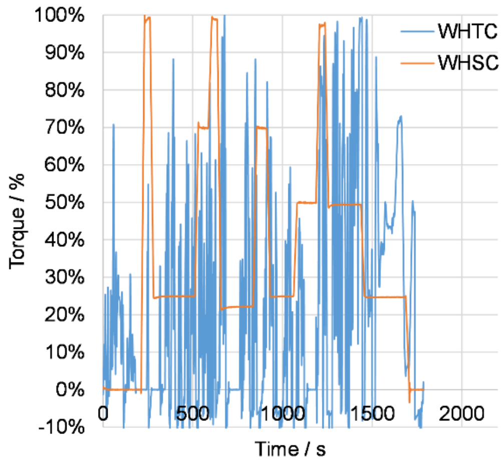


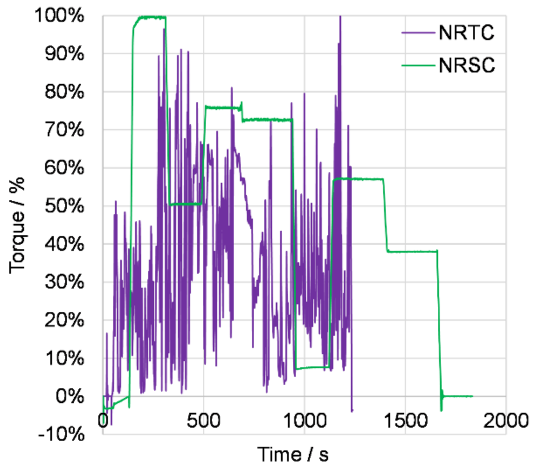
Reference:
Fierz, Martin, Dominik Meier, Peter Steigmeier and Heinz Burtscher. "Aerosol Measurement by Induced Currents." *Aerosol Science and Technology* 48, no. 4 (2014): 350–57. doi:10.1080/02786826.2013.875981.

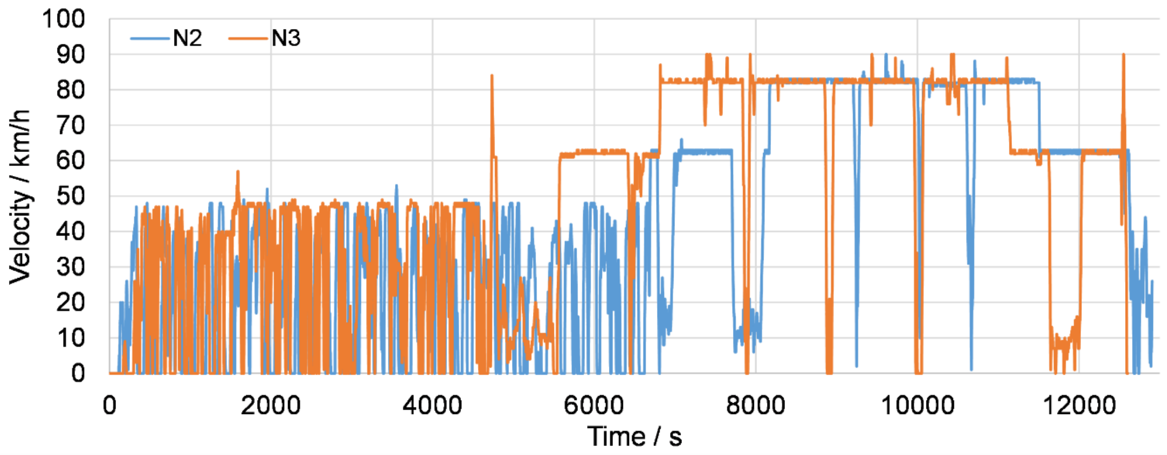
Test program for PN PEMS comparison

1. HEPA filtered (zero) and ambient air test
2. Engine test stand tests → device comparison with the reference system (PMP_CPC)
   - 8 x WHTC (World Harmonized Transient Cycle)
   - 1 x WHSC (World Harmonized Stationary Cycle)
   - 2 x NRTC (Non Road Transient Cycle)
   - 1 x NRSC (Non Road Stationary Cycle)
3. PEMS (on-road) tests → comparison of devices
   - 8 x ISC tests (each 4 for N2 and N3)
4. 3 x active regenerations (1 x N2; 2 x N3)

$\sum$ = 23 tests



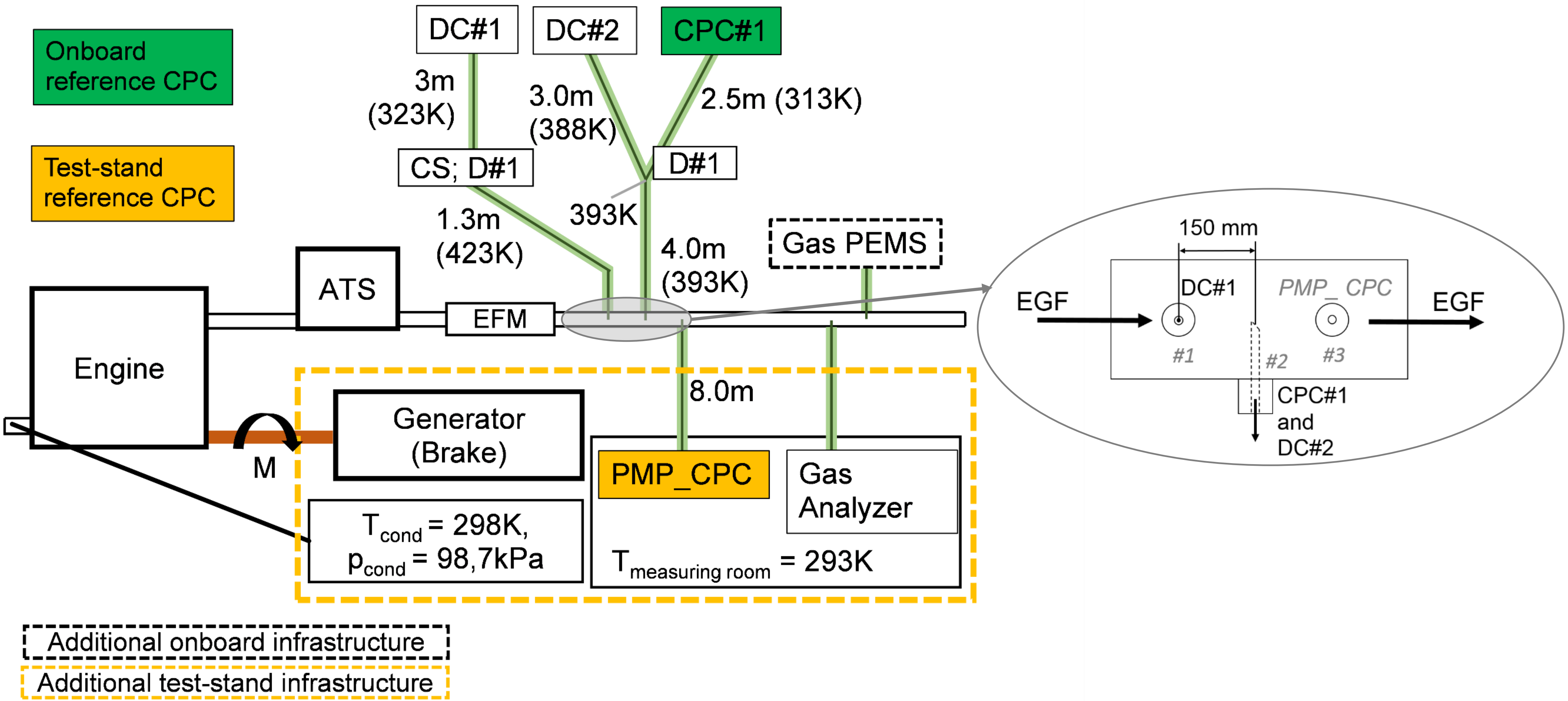




ICE and ATS specifications

	Test stand	Vehicle N2	Vehicle N3
Vehicle Type		Atego	Actros
Engine type	OM 963.2	OM 963.1	OM 473
Number of	6		
Fuel injection	CR, 2400 bar	CR, 2400 bar	CR, 2700 bar
Suction Type	two stage	single stage turbo w. intercooler	
EGR	high pressure EGR		
V_d [l]	7.7	7.7	15.6
P_{max} [kW]	260	220	380
T_{max} [Nm]	1400	1400	2600
ATS	Euro VI (DOC, DPF, SCR, ASC)		
Regeneration	HC-doser, light-off temperature ca. 450°C		
Fuel	market standard low sulphur diesel (EN 590 Norm)		
Oil	5W30		
Mileage	200h	10000km	

Test setup for test rig and PEMS tests



Evaluation method – PN and device performance

1. Total particle number (PN):

$$PN_{total}\,[p] = \sum_{i=0}^{t_{end}} PN_i \left[\frac{p}{s}\right] = \sum_{j=0}^{t\_end} (PNC_j \left[\frac{p}{cm^3}\right] * EGF_j \,[\frac{cm^3}{s}])$$

$$PN_{W\_j}\,[\frac{p}{kWh}] = \frac{PN_{total}}{W_{total}}$$

2. Relative deviation:

$$D_{x_i} = \frac{PN_{W\_j} - PN_{W\_PMP\_CPC}}{PN_{W\_PMP\_CPC}} * 100 \; in \; \%$$

3. Standard deviation of relative deviation:

$$s_{D\_x_i} = \sqrt{\frac{1}{n} * \sum_{i=1}^{n} (D_{X_i} - \overline{D}_{X_i})} \; in \; \%$$

PN_i – Particle Number Emission

PNC_j - Particle Number Concentration

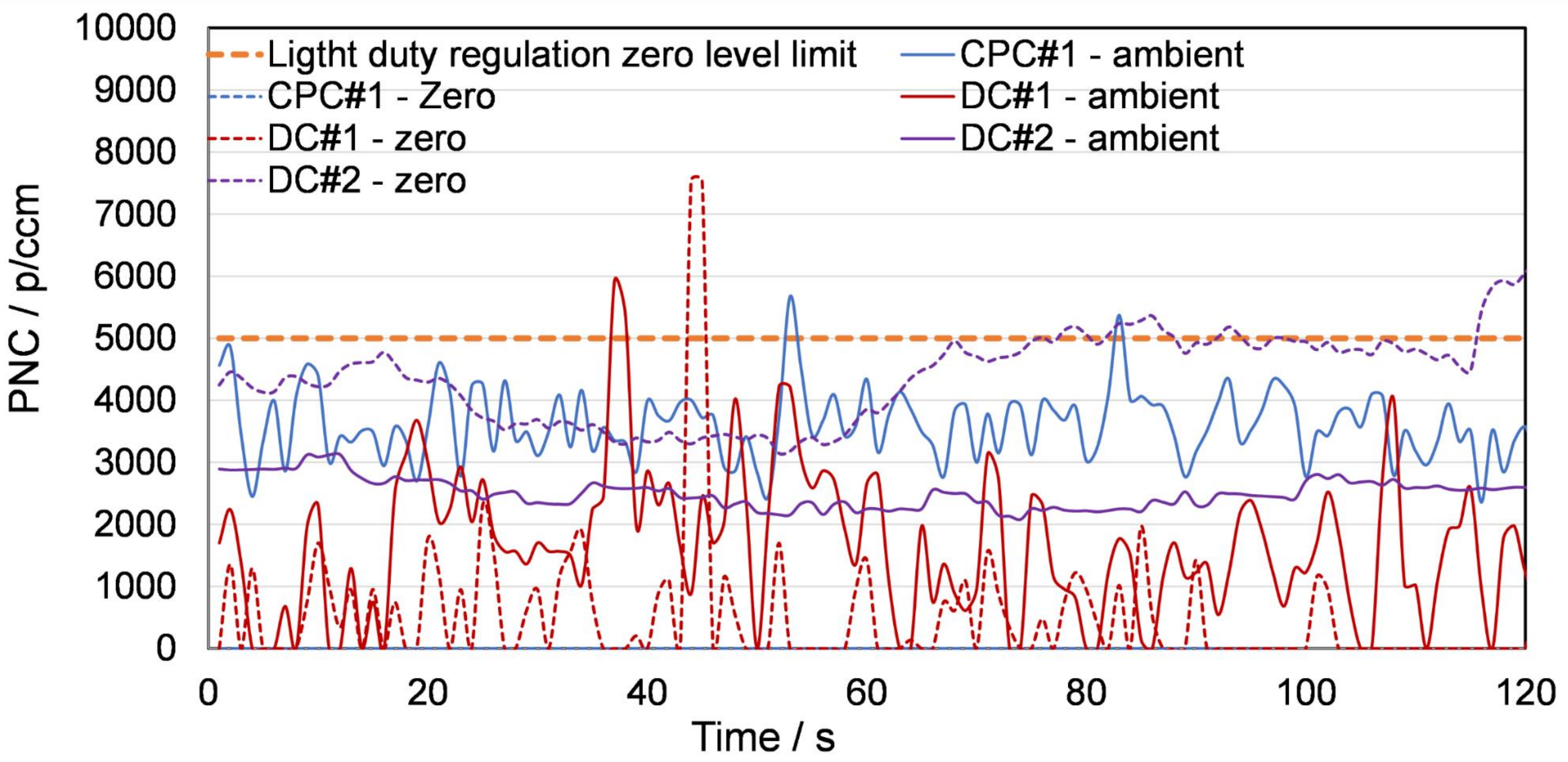
EGF – Exhaust Gas Flow

PN_{W_j} – Engine work based particle number emissions

D_{xi} – Relative deviation

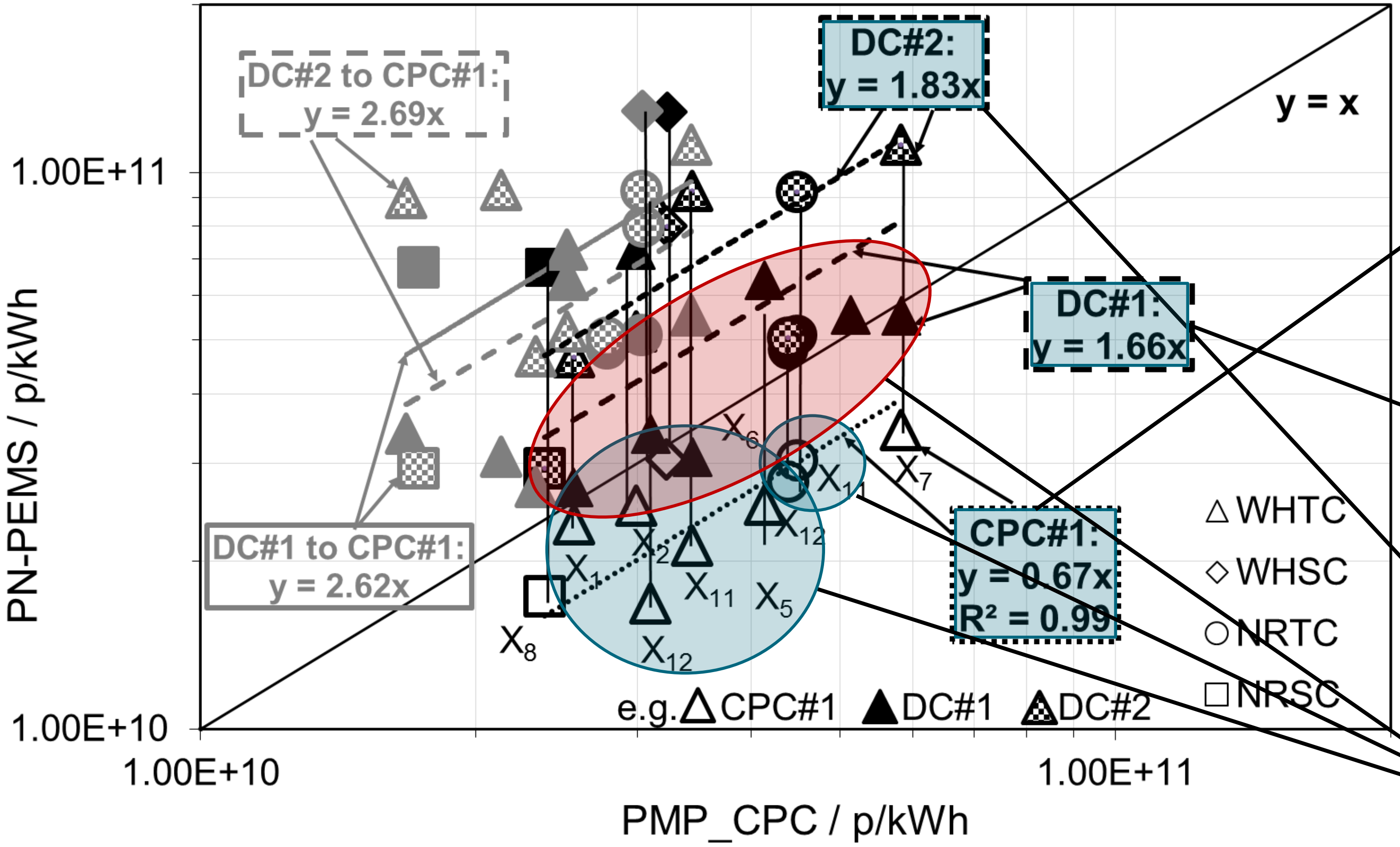
s_{D_xi} = Standard deviation of relative deviation

HEPA filter (zero) and ambient air test



- All PN PEMS show stable PNC at HEPA filter (zero) test
- Ambient PNC (Particle Number Concentration) measured with PN PEMS are comparable
- All PN PEMS results < requested zero level (5000p/ccm) over 2min

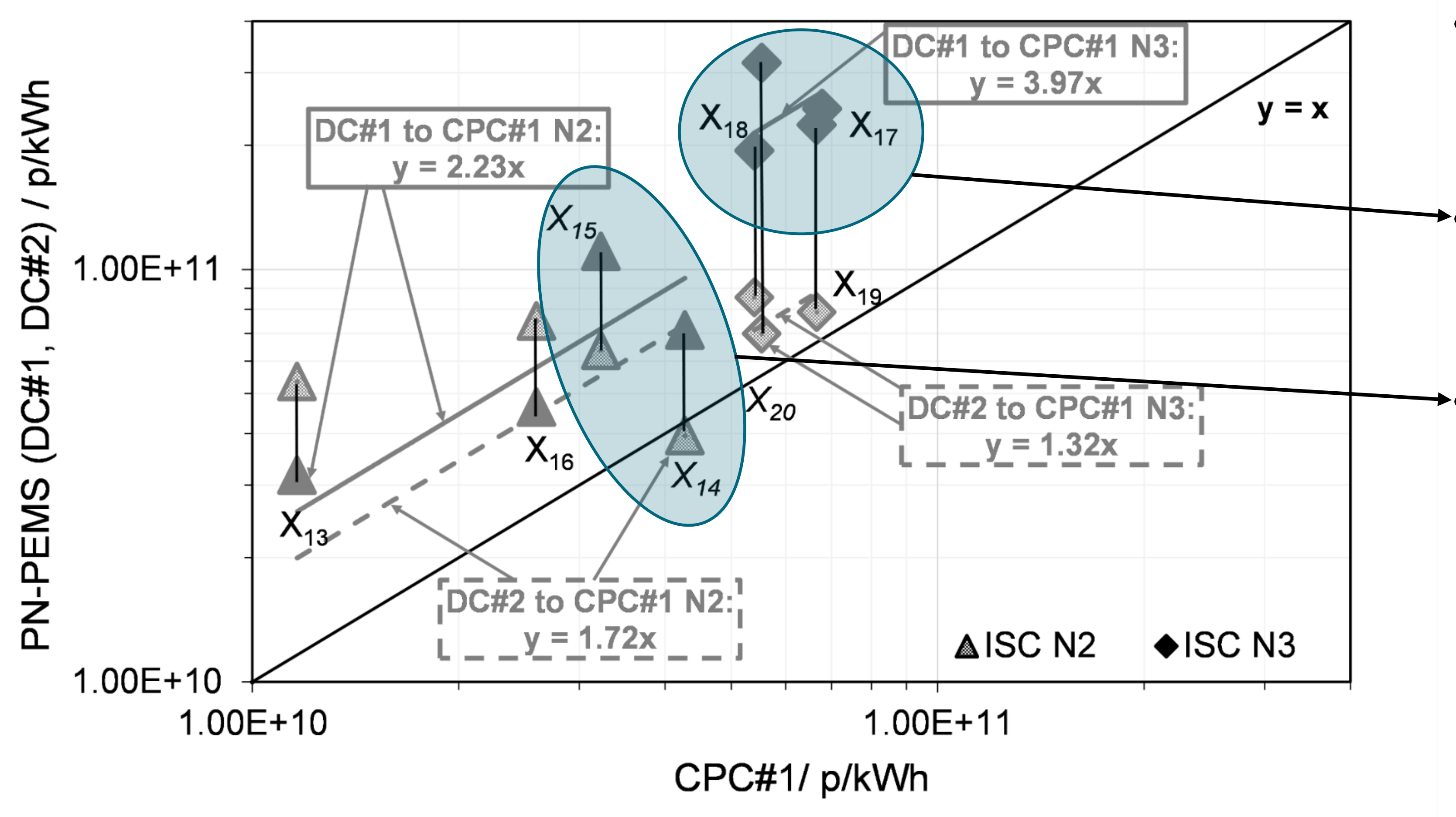
Test rig tests: Correlation PN PEMS to PMP_CPC (Ref.)



→ CPC#1 is reference system for PEMS tests

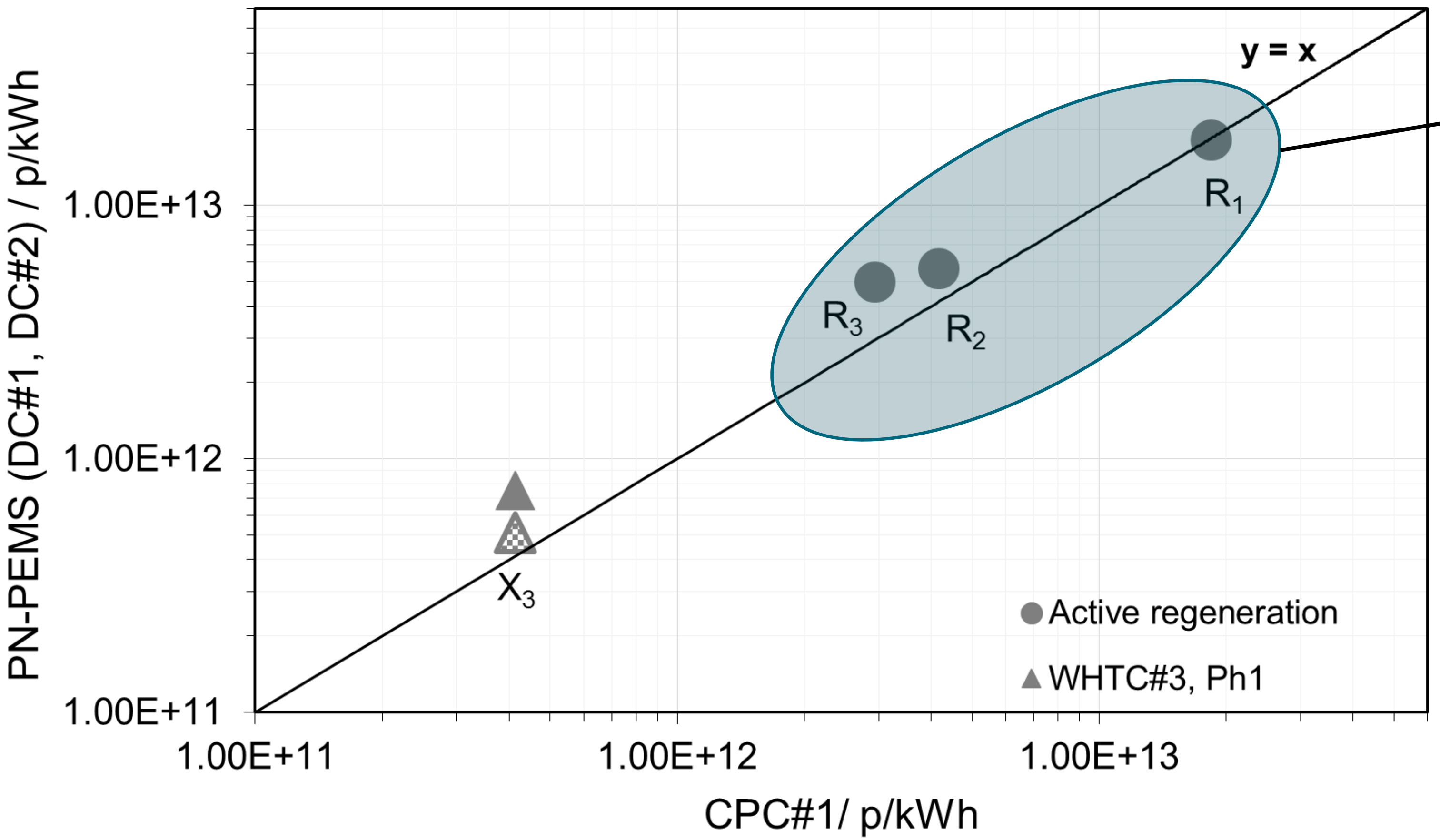
- All PN results beneath suggested PN_{WHTC} threshold ($6 * 10^{11}$ p/kWh)
- CPC#1 (Δ, □, ○) underestimates PNC in average for all tests (ca. -30%)
- DC#1 (▲, ■, ●) overestimates PNC in average (ca. +60%)
- DC#2 overestimats PN in average (ca. +80%)
- CPC#1 and DC#1 show repeatable results for WHTC Δ and NRTC O

PEMS tests: Correlation DC#1 and DC#2 to CPC#1 (Ref.)



- Comparable PN results to test rig tests (< PN_{PEMS} = 9 * 10^{11} #/kWh)
- Overestmation PN by DC systems for N3-vehicles at ISC-tests
- Influence of payload (italic = 100%) for N2-vehicle tests identifiable

Active regeneration: Correlation DC to CPC#1

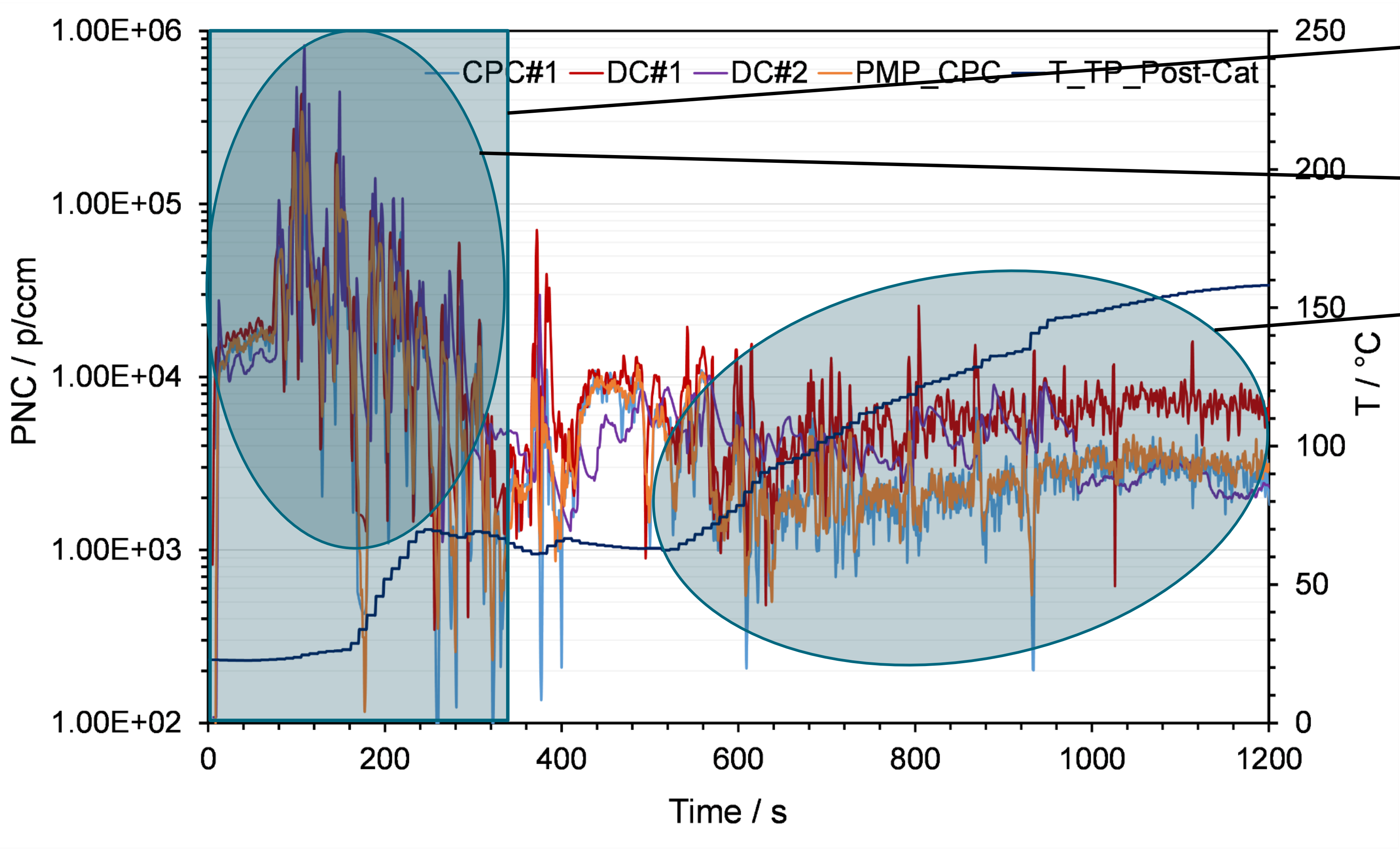


- High PN emissions (> $1*10^{12}$ #/kWh)

→ Good correlation

→ The higher PN the better the correlation

PN PEMS sensitivity evaluation



- High PNC during cold start
- Good sensitivity of PN PEMS at high PNC
- Slight drift of DC PN PEMS compared to CPC (PMP_CPC, CPC#1)

→Reasons?

Summary

- Onboard particle number (PN) measurement is feasible with PN PEMS
- PN PEMS are sensitive and robust
- PEMS Tests with N2 (10% & 100%PL) and N3 vehicles (10% & 20%PL) show low PN emissions
- PN PEMS of test campaign (06/2017):
  - CPC based device underestimates PN
  - DC based devices overestimate PN

Recommendations:

→ Identification of reasons for PN over- / underestimation by devices

→ Further testing with payload variation

Thank you for your attention!