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Summary of the latest PMP related activities

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Summary

Two main activities finalized in 2012

- PMP Heavy Duty Round Robin
- PMP Volatile Particle Remover (VPR) Calibration Round Robin

Two presentations on the above topics were given by Athanasios Mamakos* during a web/phone conference

*(formerly JRC, now at the SwRI, USA)

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Particle Measurement Programme Heavy Duty Round Robin Preliminary Analysis of the Results

Web-conference
12/7/2012

Context

PMP HD Validation Exercise (PMP_VE_HD)	PMP HD Round Robin Exercise (PMP_RR_HD)
Golden Engine (VE-E1: Euro III + DPF, Iveco Cursor 8)	Round Robin Engine (RR-E2: Euro III + DPF, Mercedes OM501)
2 x Golden Particle Measurement Systems	Labs' own Particle Measurement Systems
Golden Engineer and Written Guide	Written Guide only
Fuel and lubricant from single batches	Fuel of defined spec, same lube fill in all labs
Full and partial flow used in parallel	Full and partial flow in initial 3 labs, then partial flow alone permitted
European labs only	European, Asian and N. American Labs
Aims to investigate issues with measurement approaches	Uses repeatability as metric for assessing system
Reproducibility intended to demonstrate stability of dual systems	Reproducibility intended to demonstrate similarity of different systems

- *Test Matrix addresses replicate European and World Cycles*
- *8 repeats of each cycle*

Previous lab	Day 0	Days 1-7	Day 8
	oil change	IFV	IFV
	2h ESC Mode 10	cold WHTC	cold WHTC
	3 x ETC	10 minute soak	10 minute soak
		hot WHTC	hot WHTC
		10 minutes at WHSC mode 9	10 minutes at WHSC mode 9
		WHSC	WHSC
		CP	CP
		ETC	ETC
		CP	CP
		ESC	ESC
*2 hours at ESC Mode 10	Precon	Precon	*2 hours at ESC Mode 10

ESC - European Steady State Cycle for emissions measurement [30 min]
ETC - European Transient Cycle for emissions measurement [30 min]
WHTC - World Harmonised Steady State Cycle for emissions measurement [30 min]
WHTC - World Harmonised Transient Cycle for emissions measurement [30 min]
IFV - Instrument Functional Verification
CP - Continuity Protocol
Precon - 15 miuntes ESC mode 10, 30 minutes ESC mode 7
* DPF regeneration only required if oil change and conditioning not performed

Golden Engine

- Daimler OM501 LA
- 290 kW / 1800 rpm
- 1850 Nm / 1080 rpm
- 11946 cm^3
- Euro III

- Catalyzed DPF
- Sintered metal type

Participants & #PN systems

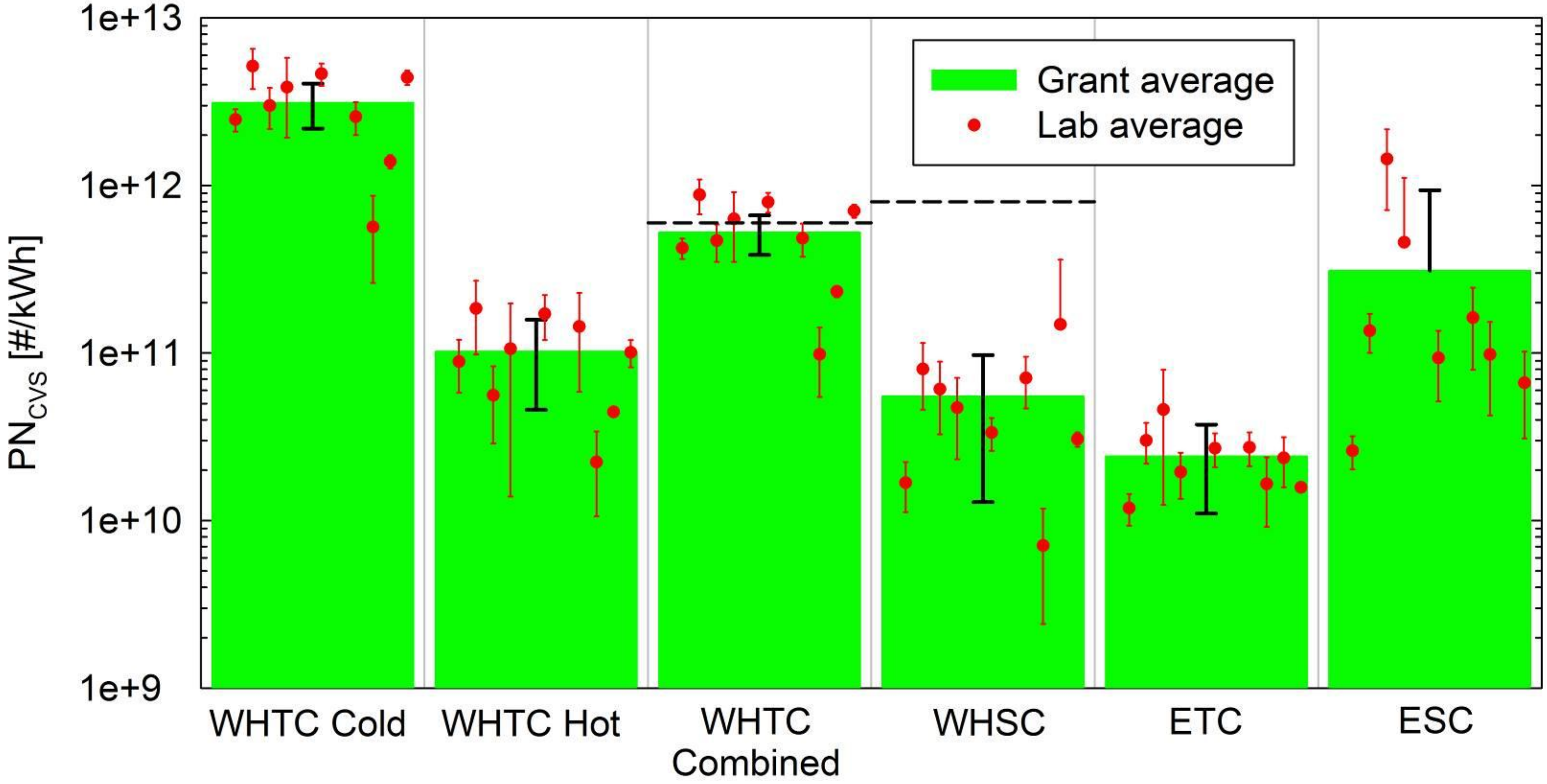
Laboratory	CVS	PFDS
RICARDO	1	1
NTSEL	3	1
JARI	4	-
NIER	1	-
VOLVO	2	1
UTAC	-	1
VTT	3	-
SCANIA	-	1
Env. Canada	1	-
RWTÜV	1	-
Daimler	1	-
JRC	1	1

Calculation checks

- *Calculation cross-checks conducted upon receipt of data revealed a number of errors in the calculations from most laboratories, including:*
  - Synchronization problems
  - Simplified ESC calculations

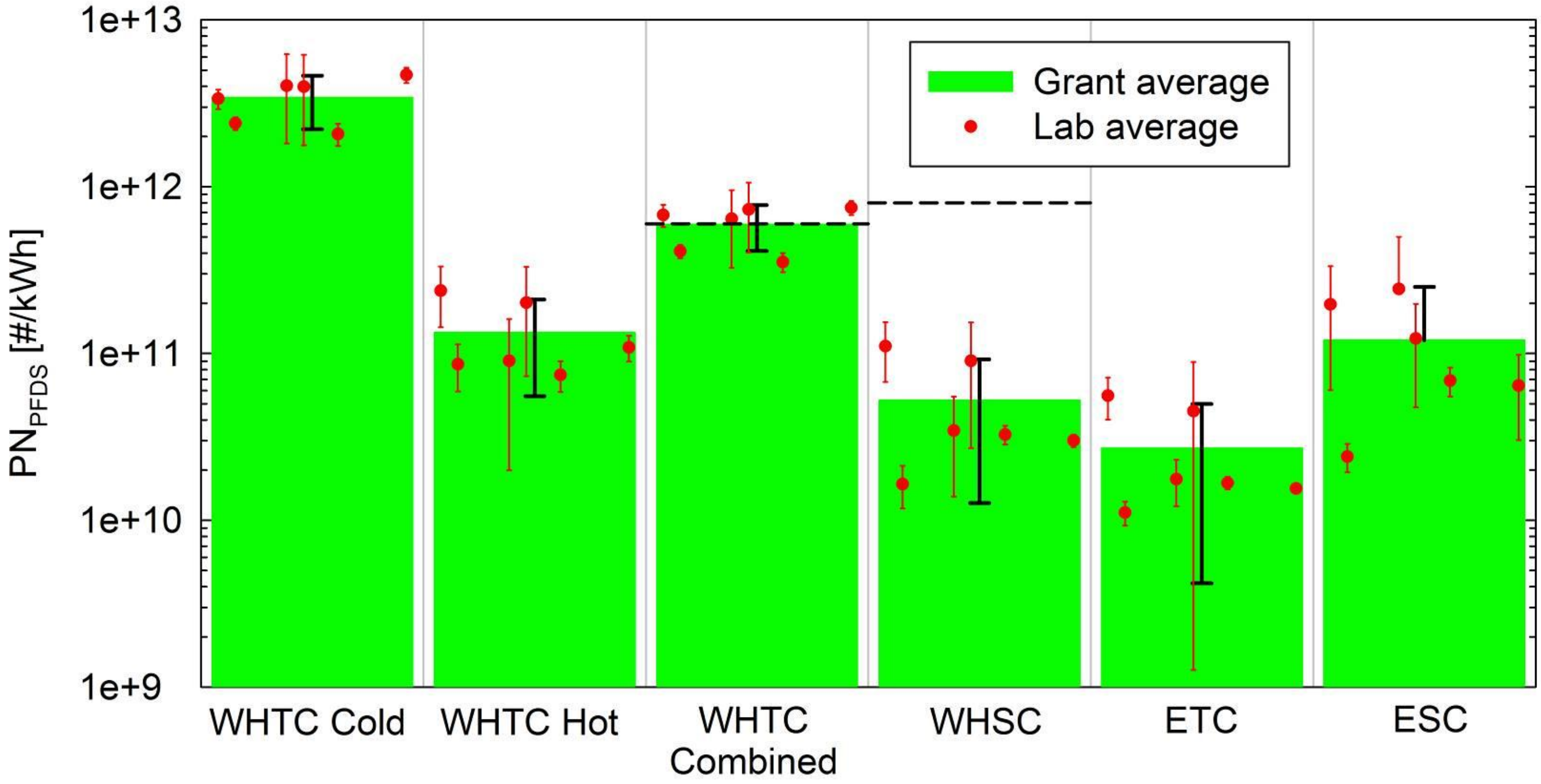
- *The results were recalculated for all labs with the exception of Volvo and Ricardo where no real-time information was available.*

PN_{CVS} overview



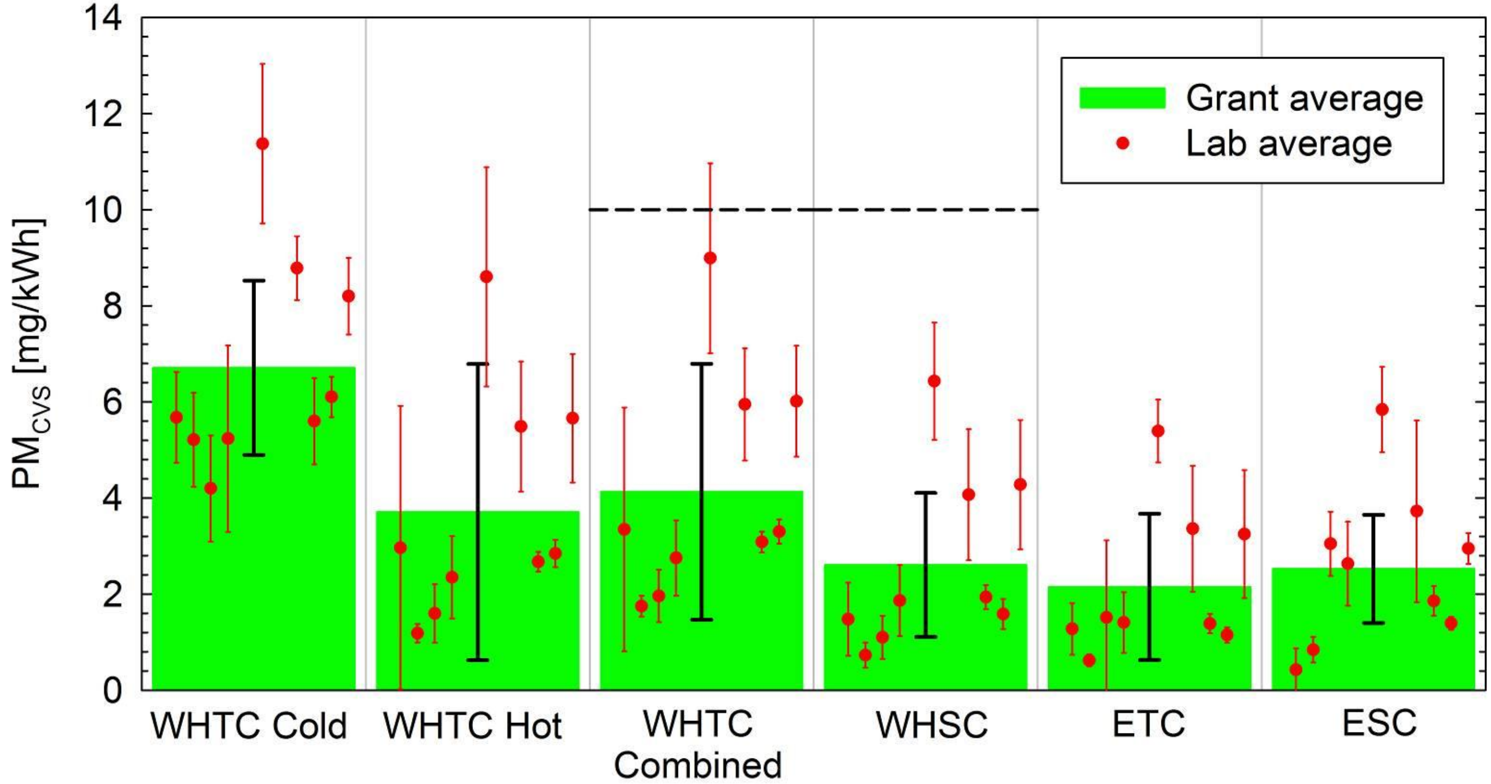
- *PN emissions complied with the WHSC limit (8×10^{11} #/kWh) but were at the threshold value (6×10^{11} #/kWh) over the WHTC (14% cold weighting)*

PN_{PFDS} overview



- *Similar results wth CVS*

PM from CVS



- *PM emissions were consistently below the limit of 10 mg/kWh*
- *Cycle effect was statistically insignificant*

PM from PFDS

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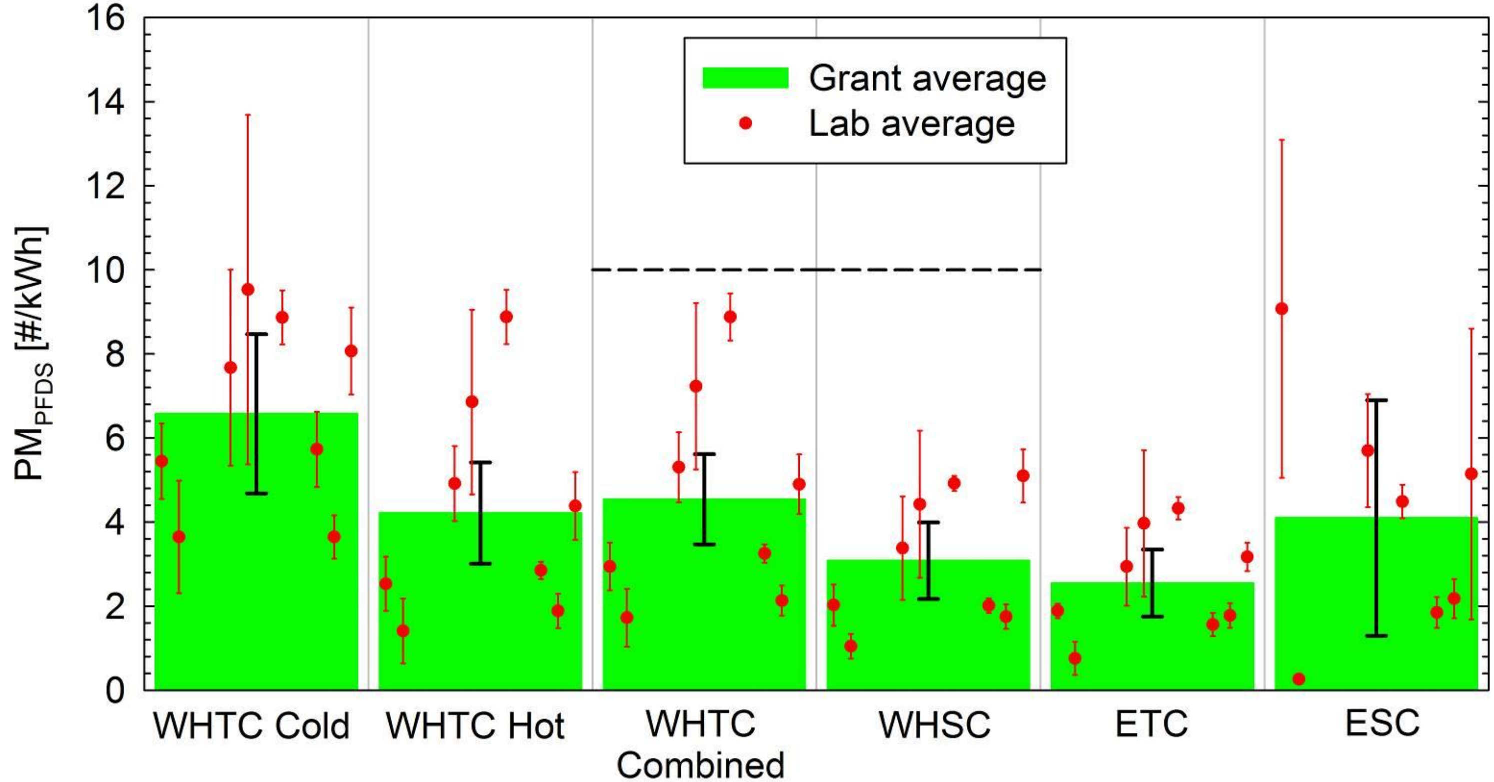
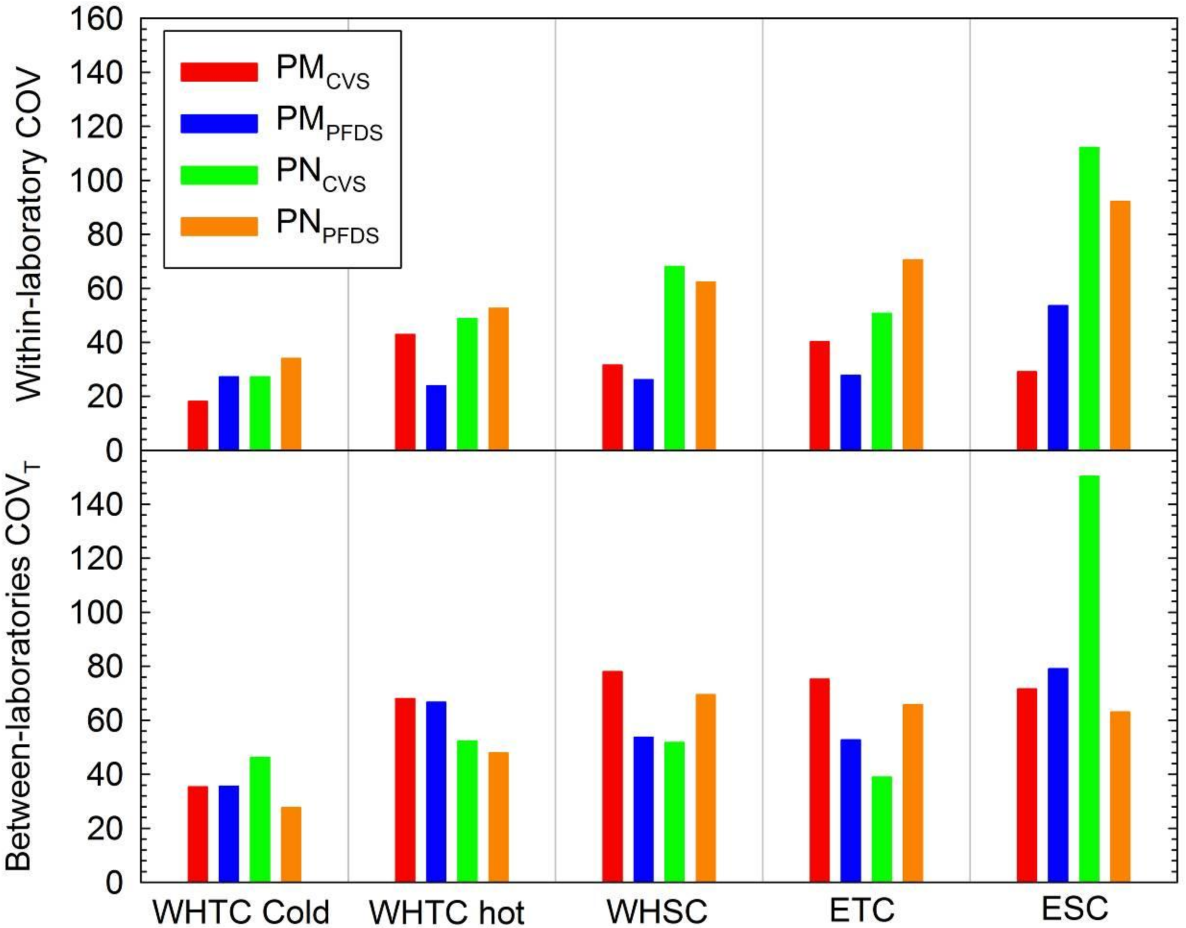


- *Similar results with CVS*

Repeatability & reproducibility

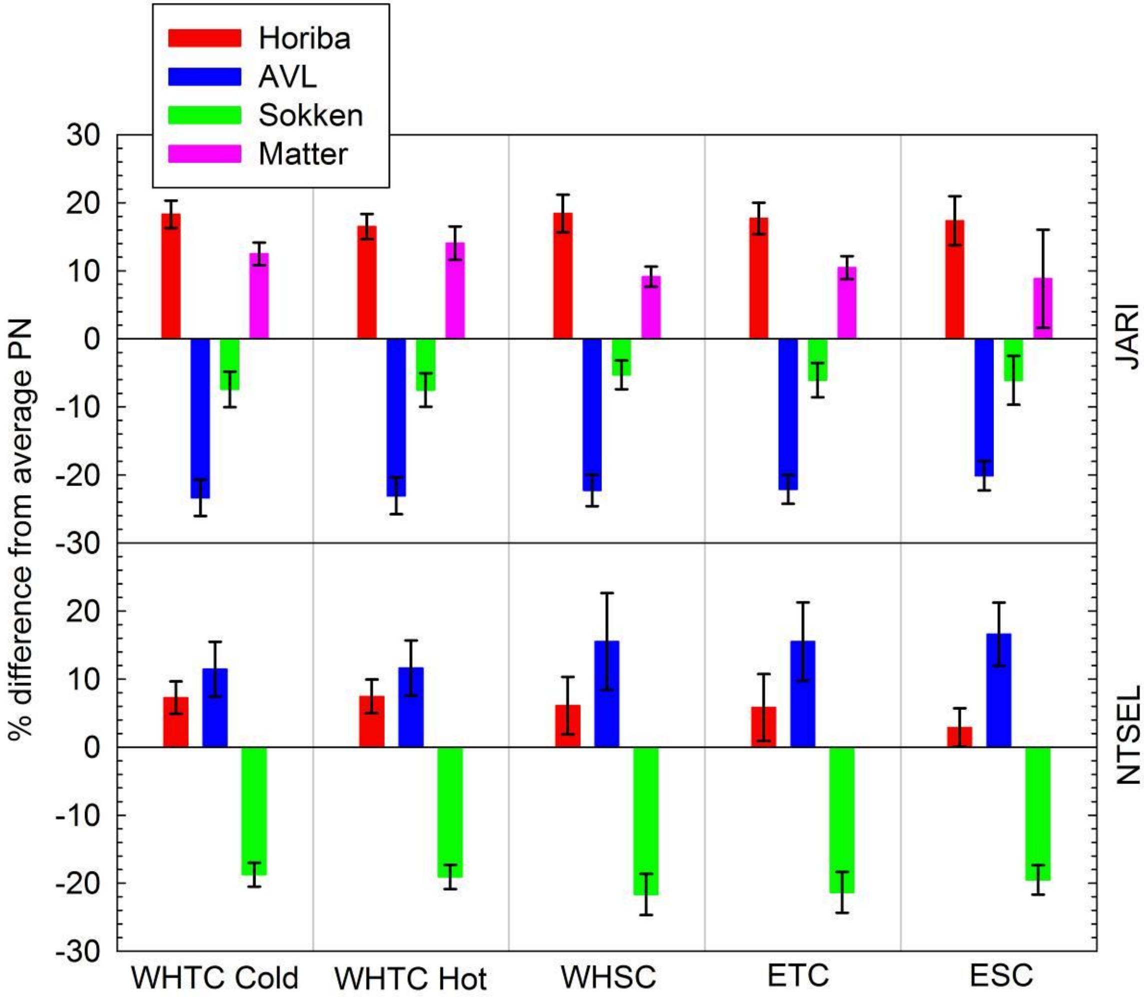
- *PM:*
  - *Repeat: 20-50%*
  - *Repr: 35-80%*

- *PN:*
  - *Repeat & repr: 30-70% in all cycles but ESC*
  - *Over ESC:*
    - 90-110% repeat
    - Up to 150% repr.



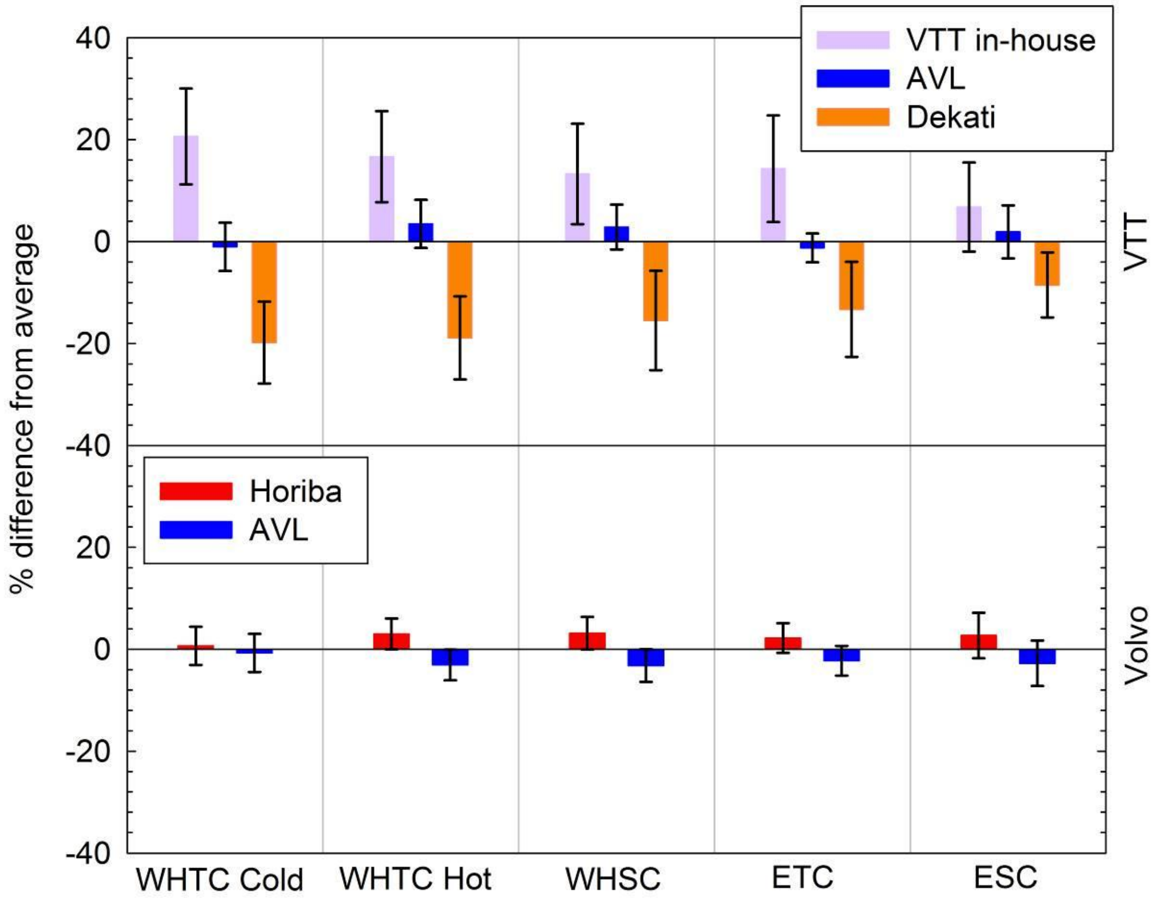
Comparison of different PN systems #1

- *Different PN systems agreed within ±20%*
- *The deviations were consistent across the cycles ⇨ calibration issues*



Comparison of different PN systems #2

- *Different PN systems agreed within ±20%*
- *The deviations were consistent across the cycles ⇨ calibration issues*



PN_{PFDS} vs PN_{CVS}

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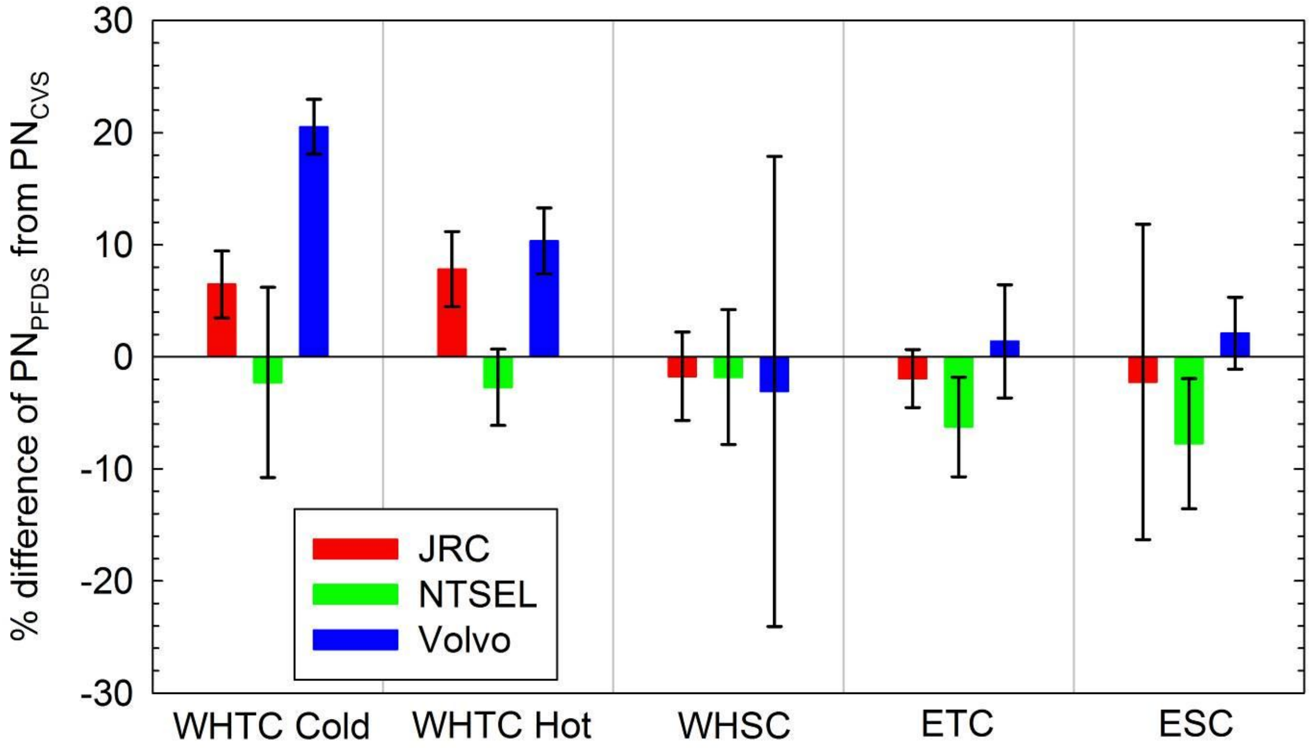
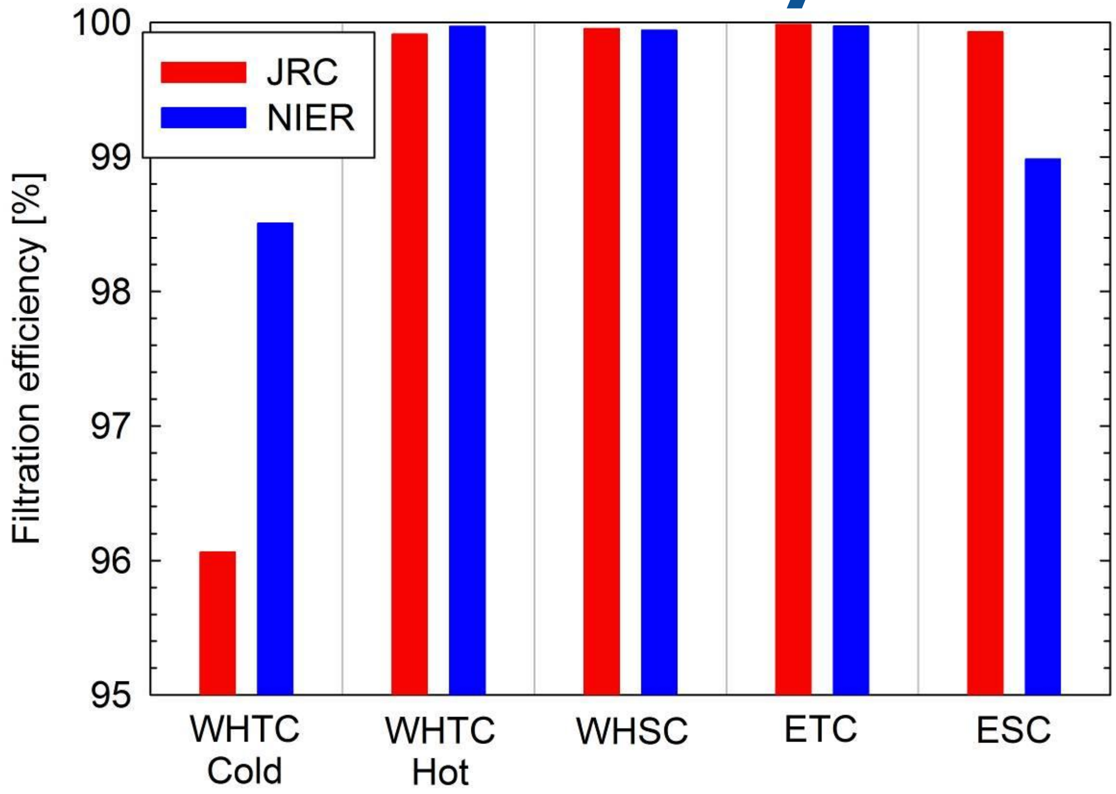


- *On average the difference was generally smaller than ±10%.*
- *Some small dependence on the test cycle, might indicate wrong settings.*

DPF filtration efficiency in PN

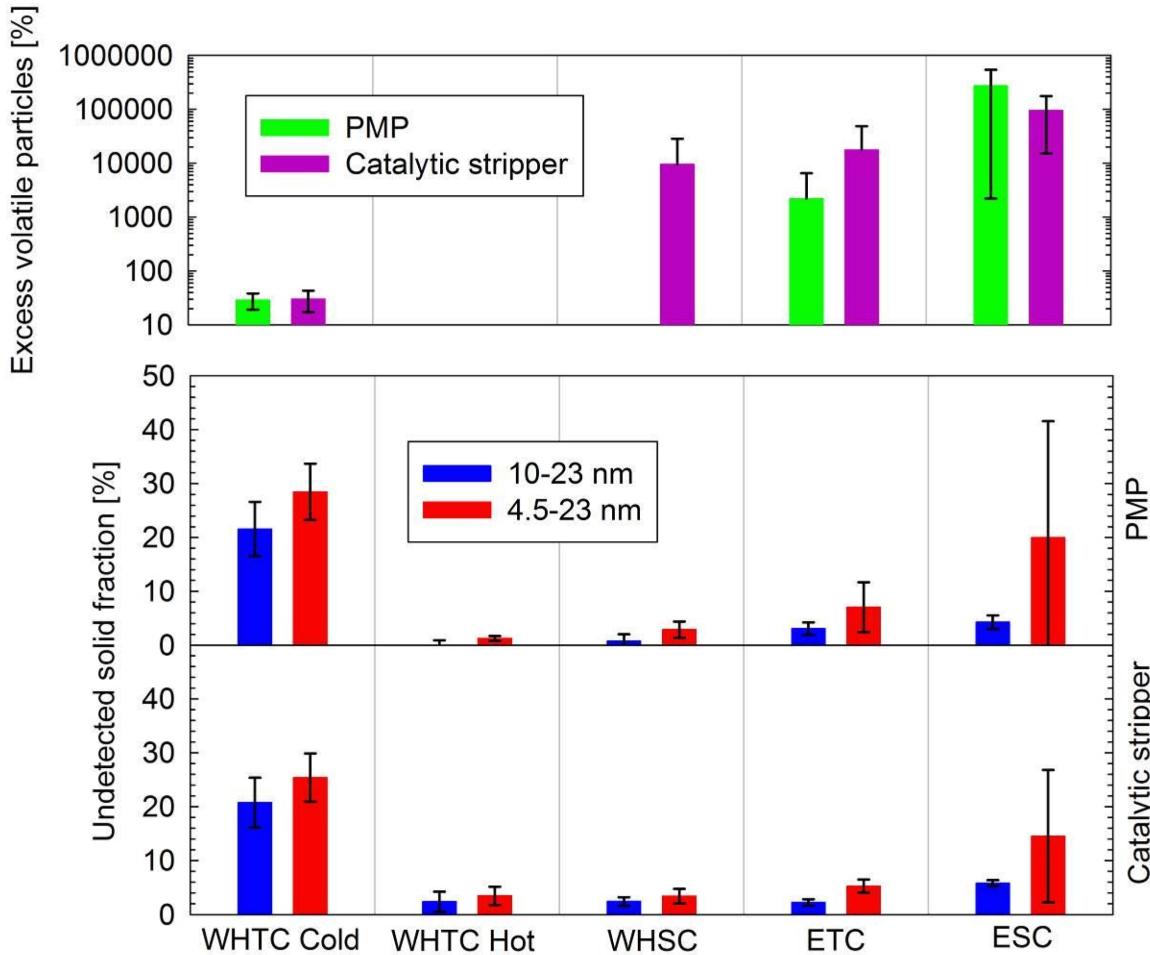


- *>99.9% efficiency over WHTC hot, WHSC and ETC*
- *Reduced efficiency during cold start (WHTC cold) and passive regeneration (ESC)*

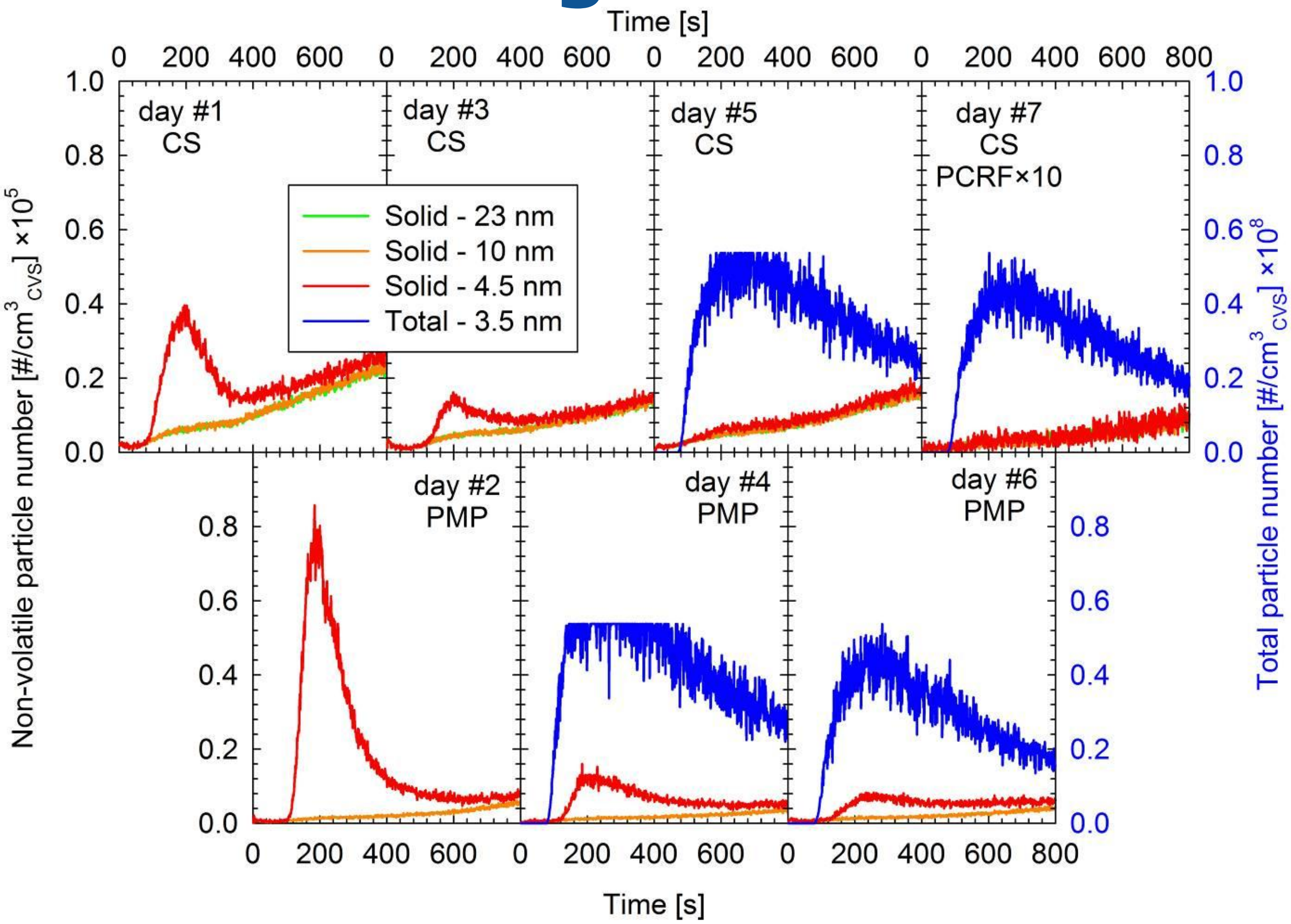
Sub-23 nm particles

- ➢ *Undetected solid fraction:*
  - *20-25% during cold start*
  - *<5% with engine hot*

- ➢ *Volatile artefact during passive DPF regeneration:*
  - *Only with CPC@4.5 nm*
  - *Evident in both PMP and CS*
  - *>99.1% removal*



Volatile artefact – DPF regeneration



Conclusions #1

- PN emissions were ~one order of magnitude higher compared to those of the Golden engine tested in the PMP HD Validation exercise.

- PN emissions complied with the 8×1011 #/kWh limit over WHSC but lied at the threshold of 6×1011 #/kWh over the combined WHTC.

- PM emissions below the 10 mg/kWh limit.

- Repeatability and reproducibility of PN (30-70%) was similar to that of PM (20-55%) over all cycles except ESC. A higher within-laboratory (90-110%)and between-laboratories (65-150%) variability was observed over ESC possibly due to extensive passive regeneration of the DPF.

Conclusions #2

- Different PN systems employed in parallel agreed within ±20% with the relative difference not depending on emission levels or operating conditions ⇨ Calibration issues.
- PN emissions determined from PFDS agreed with that from CVS tunnel within ±10%, well within the established agreement of PN systems.
- The fraction of undetected solid particles was found to be approximately 20-25% over cold start and remained to very low levels (<5%) with the engine hot.

Conclusions #3 – sub-23 nm

- Passive regeneration can lead to significant formation of homogeneously nucleated particles that can exceed in number the solid fraction by more than 4 orders of magnitude.
- At these conditions, there some evidence of volatile artefact interference in the responses of CPC having a d50 at 4.5 nm, despite the more than 99.1% removal efficiency of the PN system.
- The artefact was somehow reduced with the use of a Catalytic Stripper but was not suppressed.

Summary of main conclusions #1

PMP Heavy Duty Round Robin

- The results of the PMP HD Round Robin are consistent with the main conclusions of the HD Validation Exercise

- Passive regeneration over the ESC can increase the variability of the PN measurements highlighting the issue of DPF fill state in the regulatory measurements

- No indications of volatile artifacts could be identified following the regulated PN procedure even under passive regeneration which led to excessive formation of volatile particles (exceeding in number the solid fraction by 4 orders of magnitude). Volatile interference was only observed when employing a CPC with a cut-off at 4.5 nm

- The fraction of undetected sub-23 nm solid particles was rather limited (<25%)

Particle Measurement Programme: Volatile Particle Remover (VPR) Round Robin

Web conference
12/7/2012

Contents

- *Programme description*
- *Characterization of the Golden Instrumentation at JRC*
- *Round Robin results*
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Golden Instrumentation

- *Golden VPR (GVPR): dual ejector & Evaporating Tube (ET) by Dekati.*

- *Golden Aerosol Generator (GAG): Palas DNP 3000 graphite spark generator.*

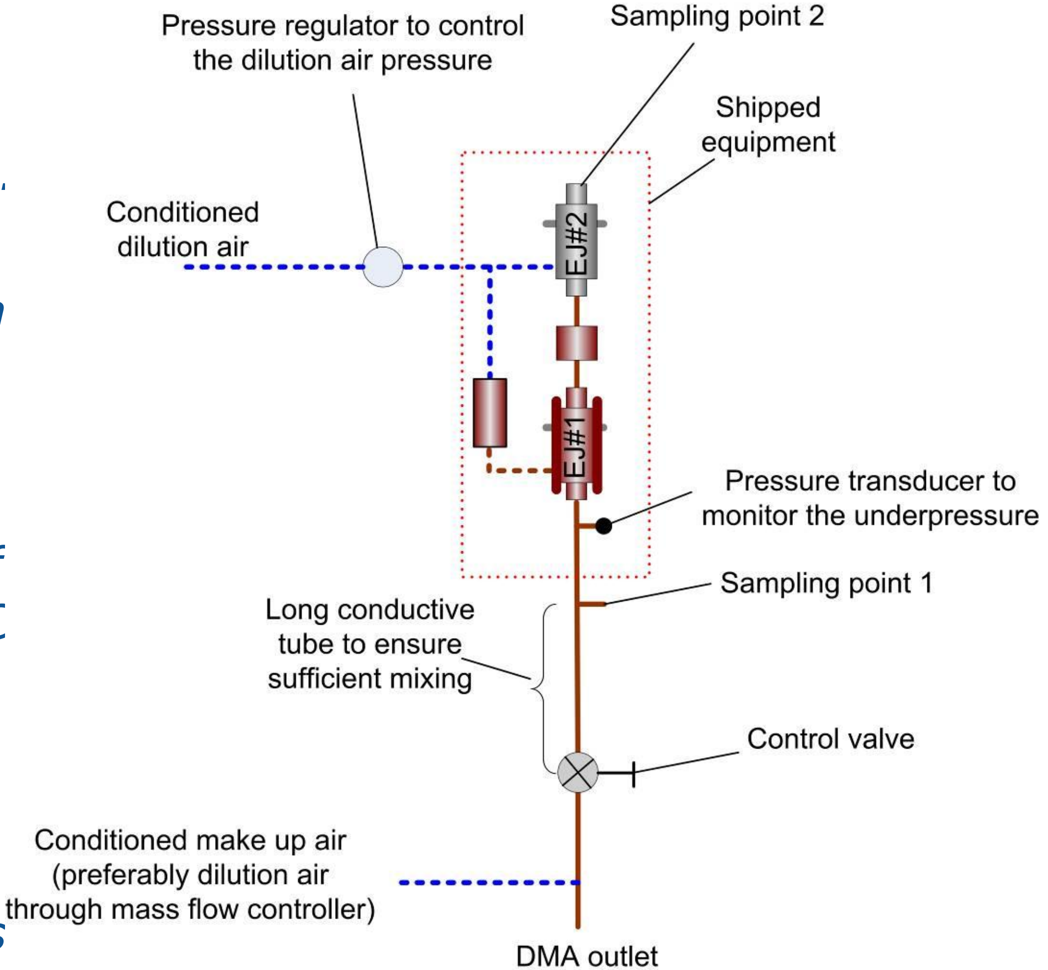
- *Golden Condensation Particle Counter (GCPC): TSI 3790 (d_{50} at 23 nm).*

Participants

Laboratory	Test dates	Alternative calibration aerosol	Additional investigations
JRC	08/2010	-	Definition of the test protocol, Calibration of the GCPC
LAT	12/2010	Thermally treated diesel exhaust	-
AVL	01/2011	Thermally treated mini-CAST	-
Horiba	03/2011	Thermally treated mini-CAST, sodium chloride	Size classification of non-neutralized particles
EMPA	04/2011	Sodium chloride, Palladium	Tandem DMA measurements
Matter Aerosol	05/2011	Thermally treated CAST	PCRF at 15 nm
JRC	07/2011	-	-
NPL	09/2011	-	Calibration of the GCPC against a traceable electrometer
AEAT	10/2011	Thermally treated CAST	-
VW	12/2011	PALAS DNP 3000	-
Maha	02/2012	PALAS DNP 2000	Thermal treatment of graphite particles
JRC	03/2012	-	-

Reference setup

- *No thermal treatment of the aerosol produced by the GAG.*
- *GVPR inlet pressure at -3 kPa (gauge).*
- *GCPC sampling alternatively upstream and downstream of the GVPR. Pump or other CPC to compensate for the GCPC flow. Third CPC downstream of GVPR recommended.*
- *Dilution factor measurements with a trace gas requested.*



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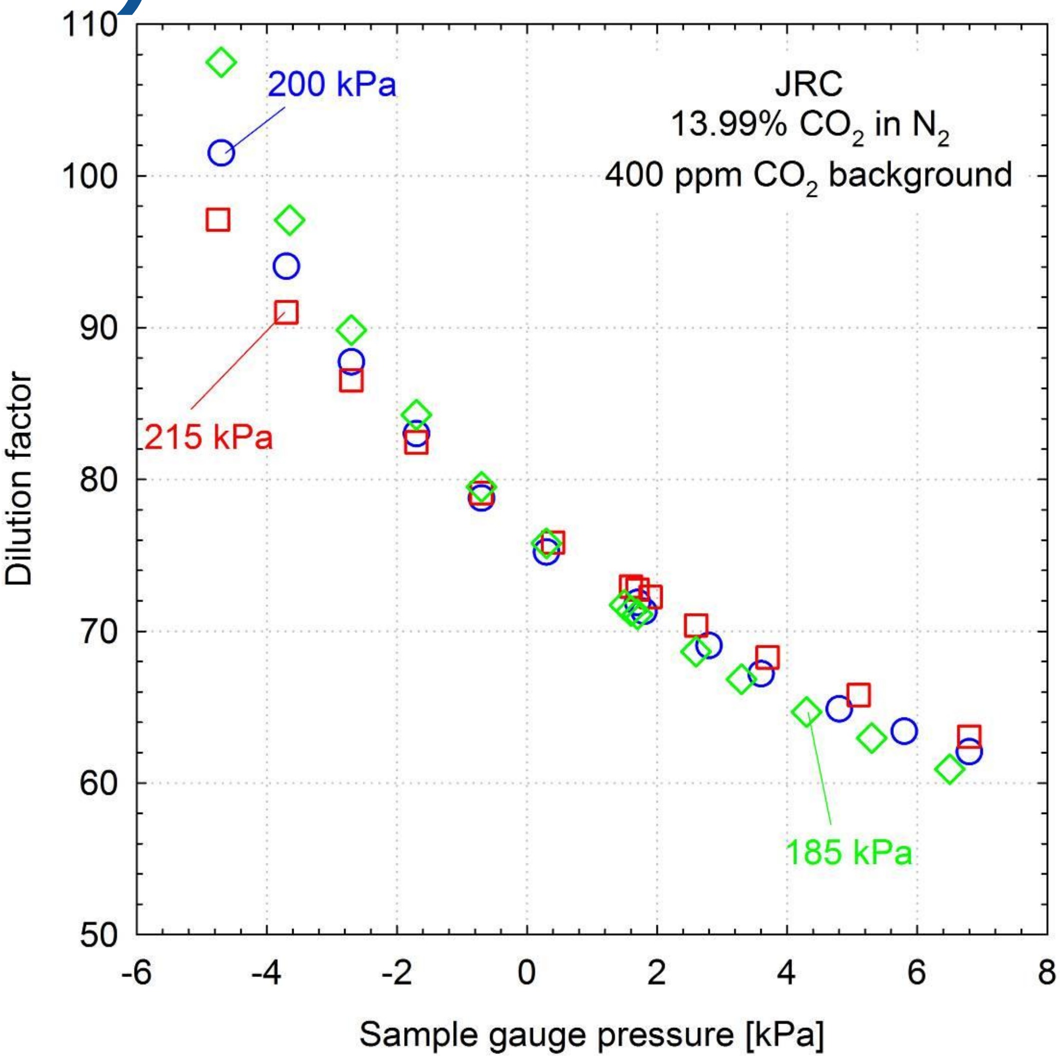
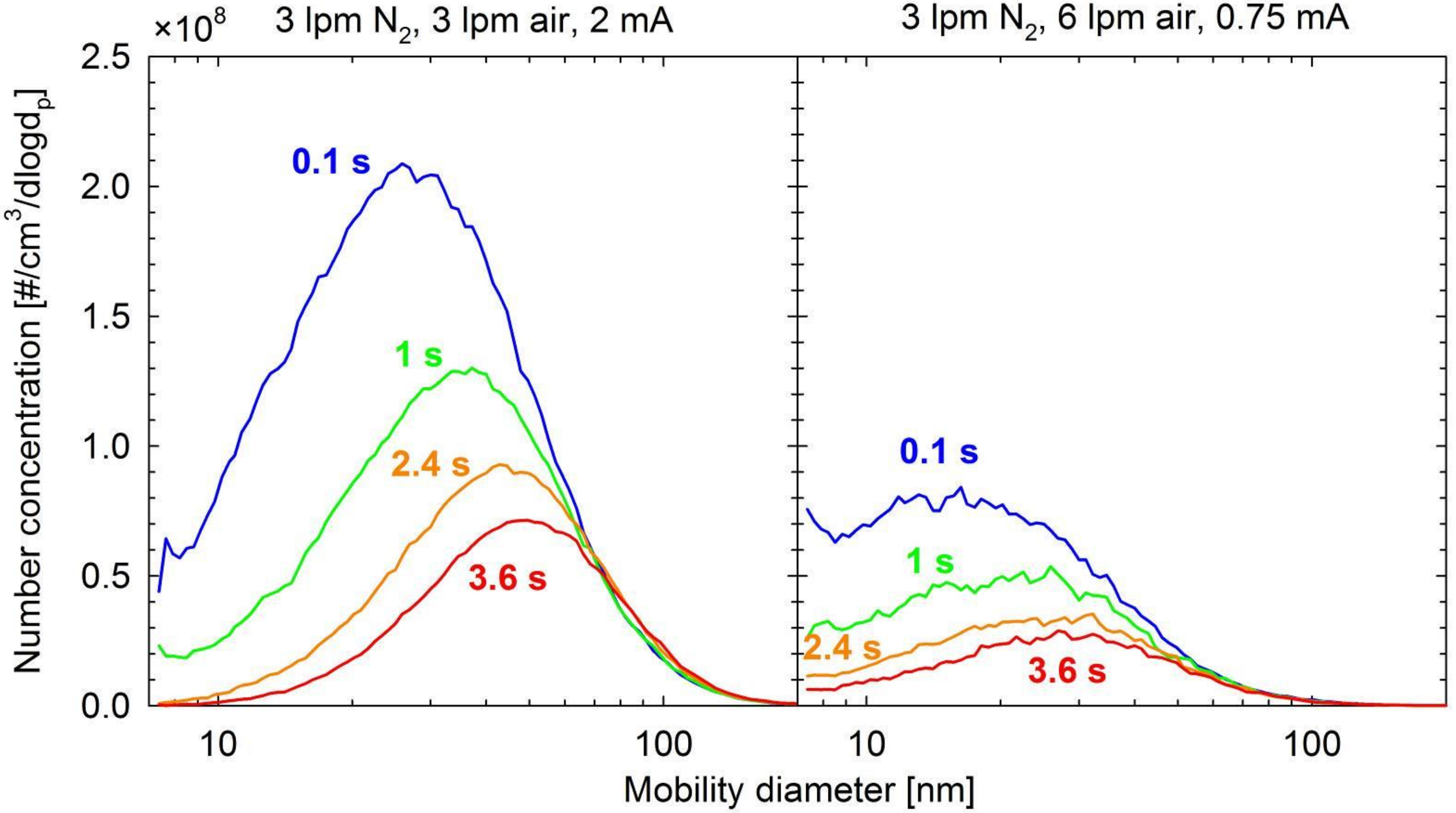
Dilution Factor (DF)

- *DF of the GVPR very sensitive to changes in the sample pressure. A -2.7 kPa underpressure led to 14% higher DF.*

- *DF was also affected by dilution air pressure but to a lesser extent. A 7.5% uncertainty in the dilution air pressure results to ±2.5% uncertainty in DF at -2.7 kPa underpressure.*

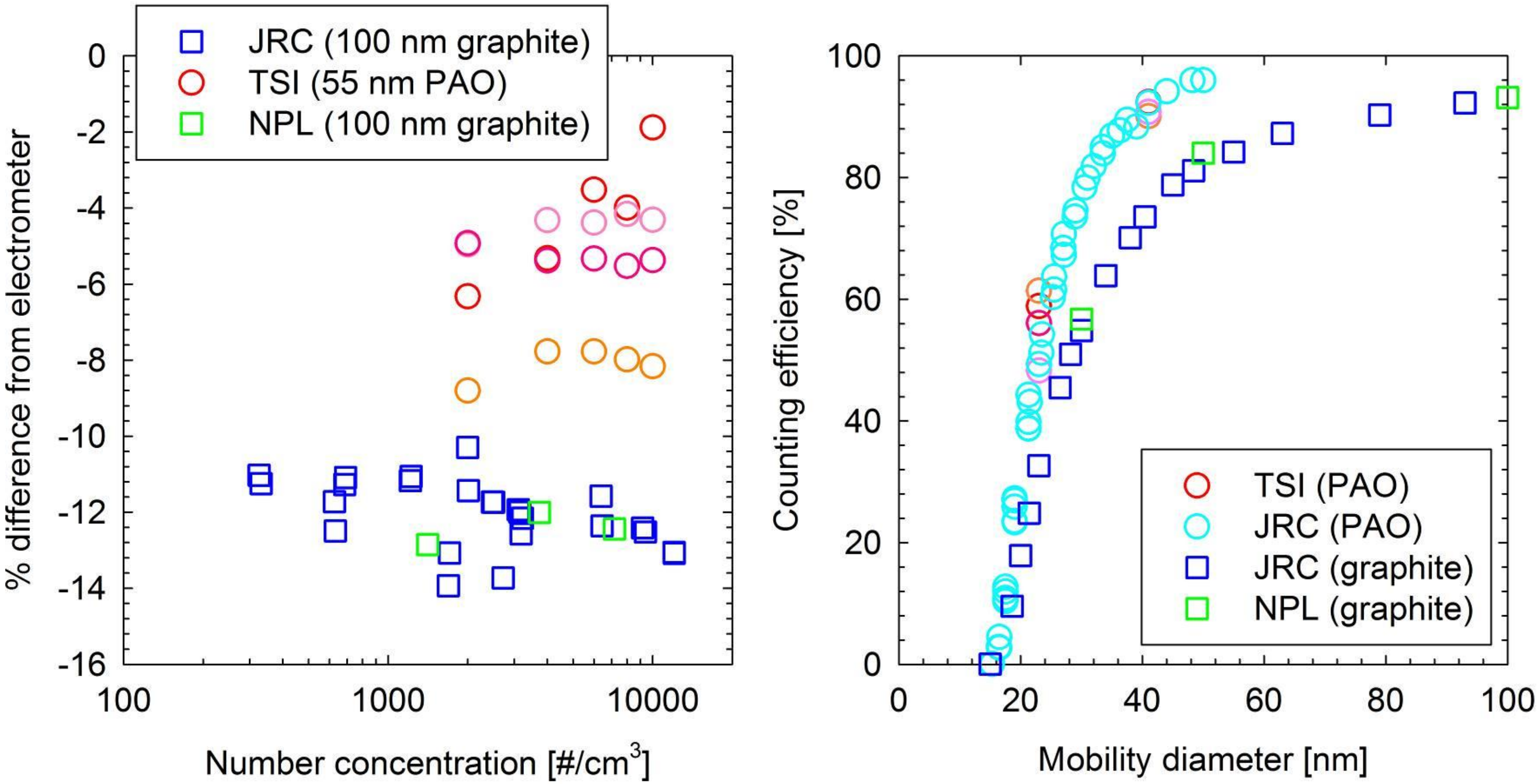


GAG



- *The high number concentration of the aerosol produced by the GAG can lead to significant coagulation, unless immediately diluted.*

GCPC

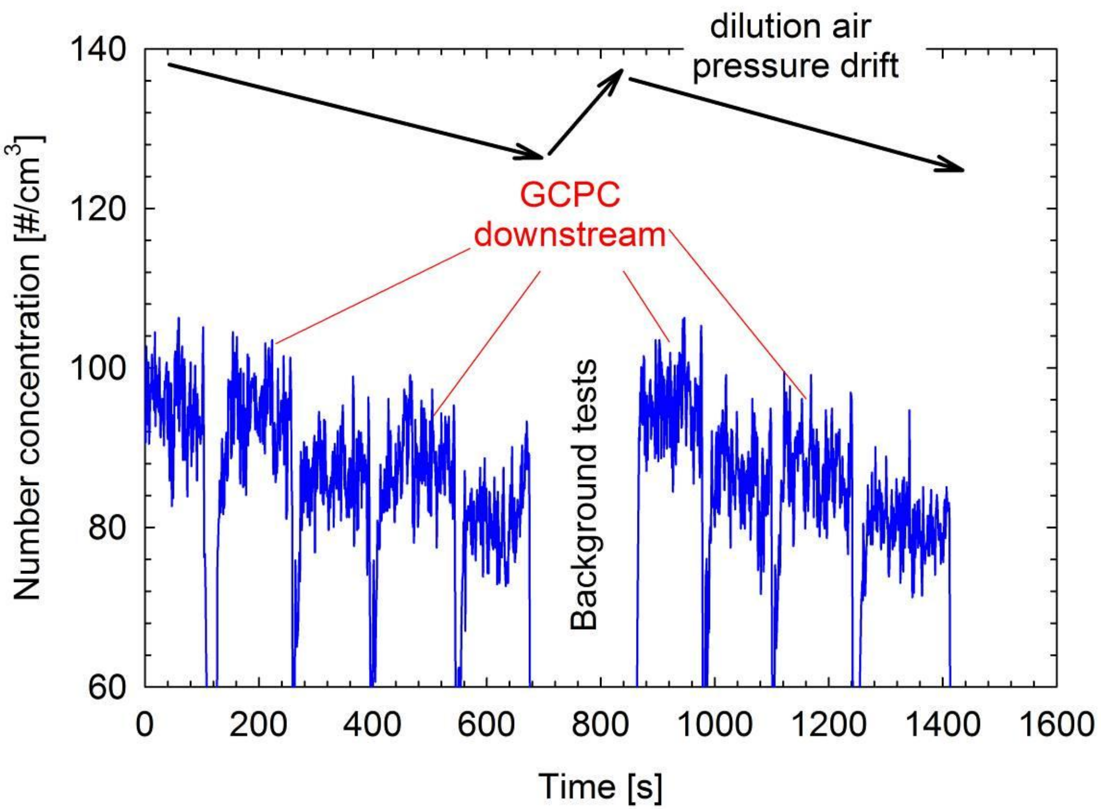


- *GCPC exhibits lower detection efficiency for graphite particles even at 100 nm.*

Stability

- *Downstream concentrations where very sensitive to small drifts of the dilution air pressure (±2.5%) and small differences in the sample flows of the two CPCs (~5%).*

- *Operating the calibration setup at overpressure can improve the stability.*



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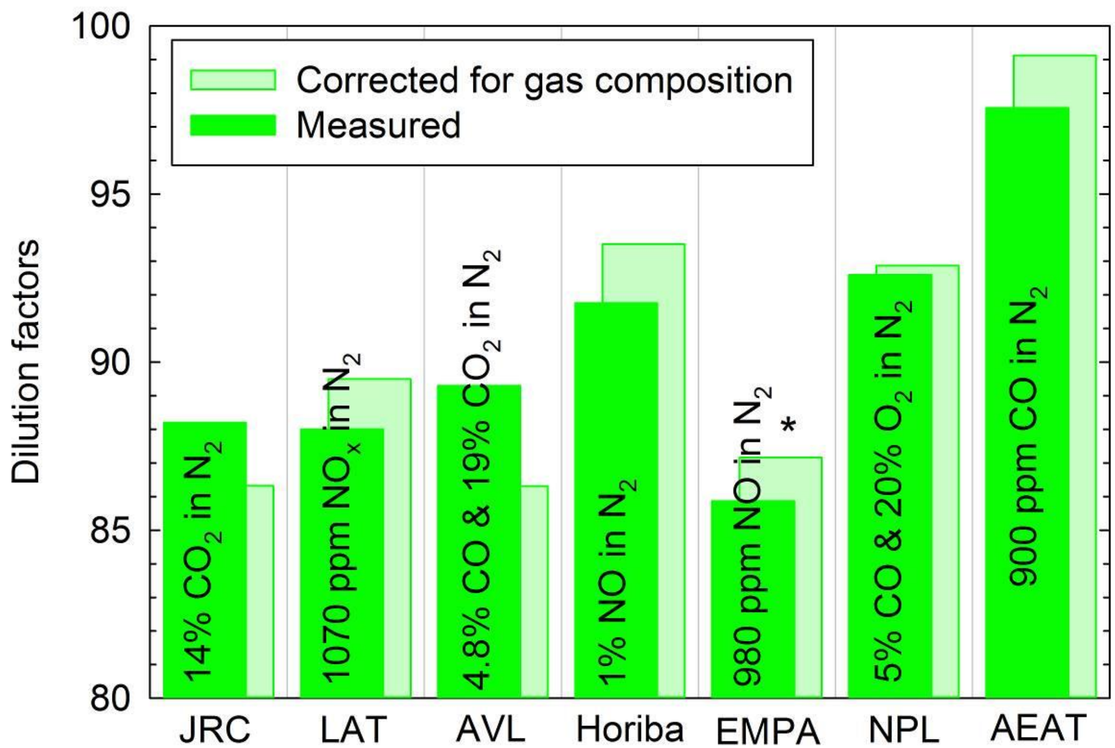
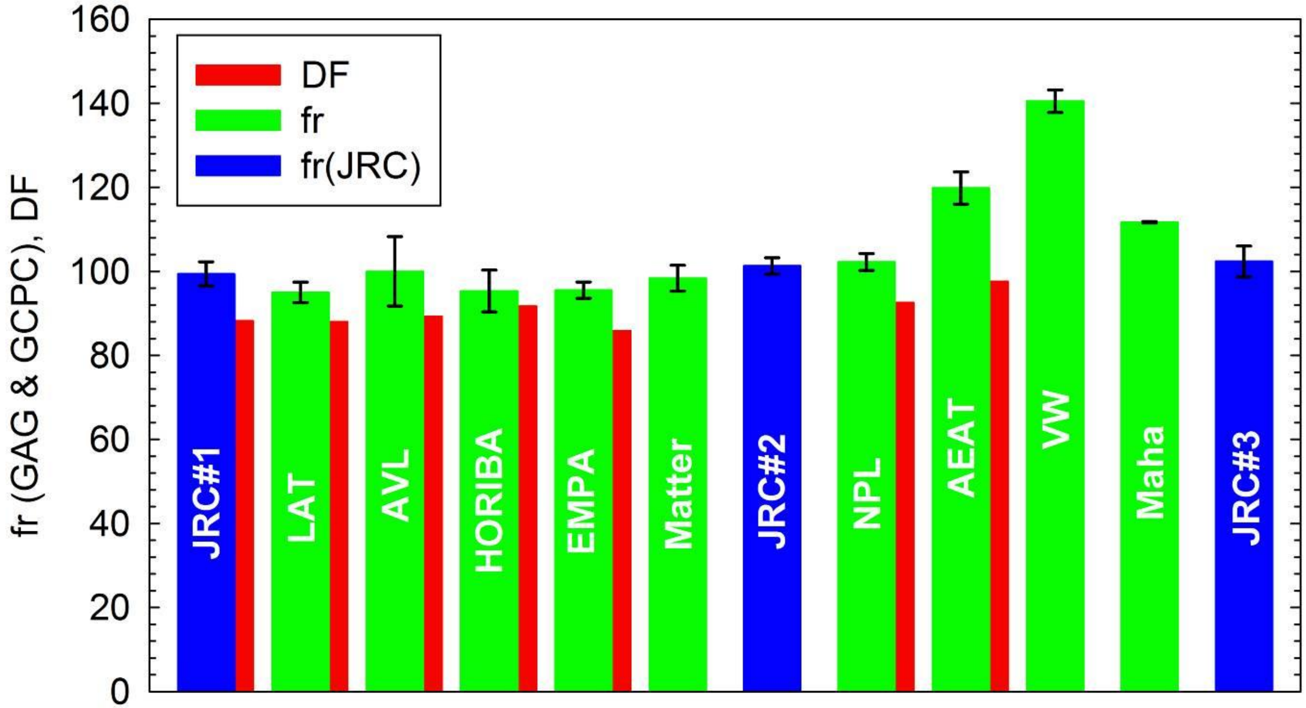
DF results

- *Only 7 laboratories measured the DF.*
- *Measured DFs agreed within ±4%. AEAT stood out as an outlier measuring ~10% above average.*
- *Effect of gas chemical composition was estimated to be less than ±2%.*



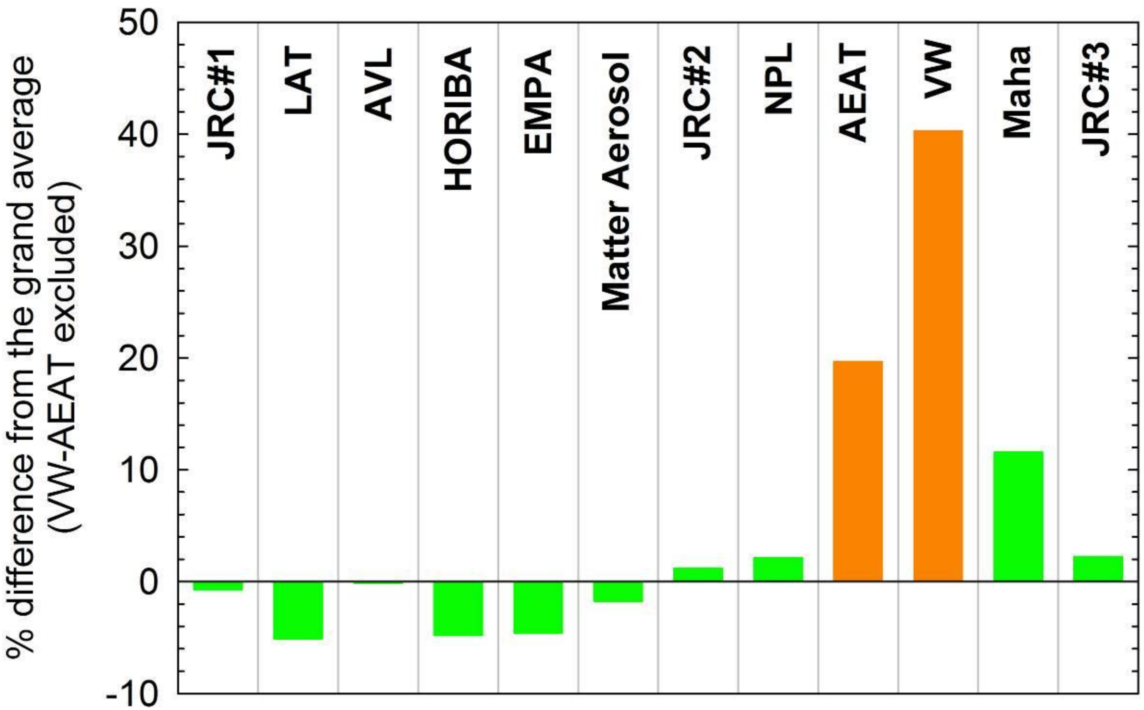
Particle Concentration Reduction Factors



- *Repeated tests at JRC differed by less than 1.5%.*
- *Average losses at 30, 50 and 100 nm ~5-10%.*

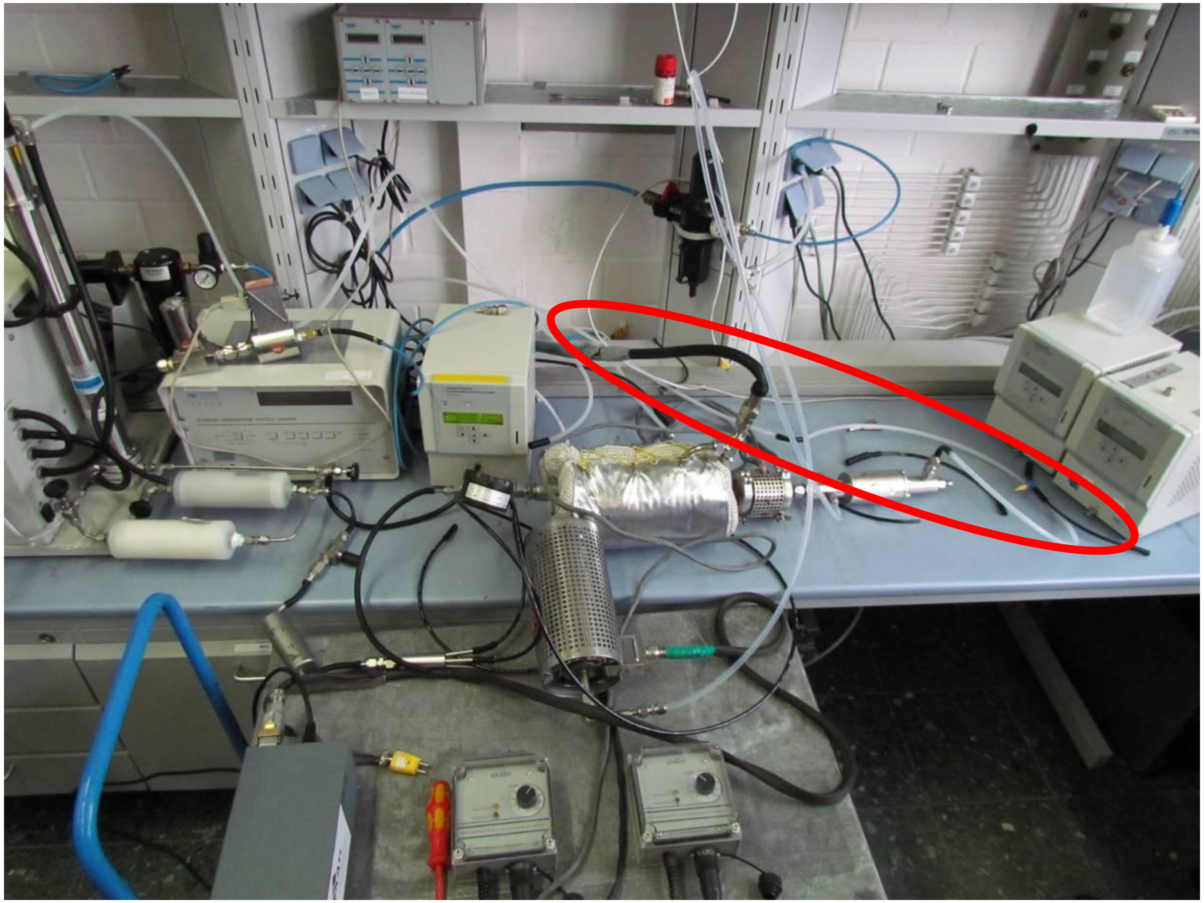
Particle Concentration Reduction Factors

- *Measured values generally differed by less than ±5% with three exceptions:*
  - AEAT: +20% (high DF)
  - VW: +40%
  - Maha: +10%



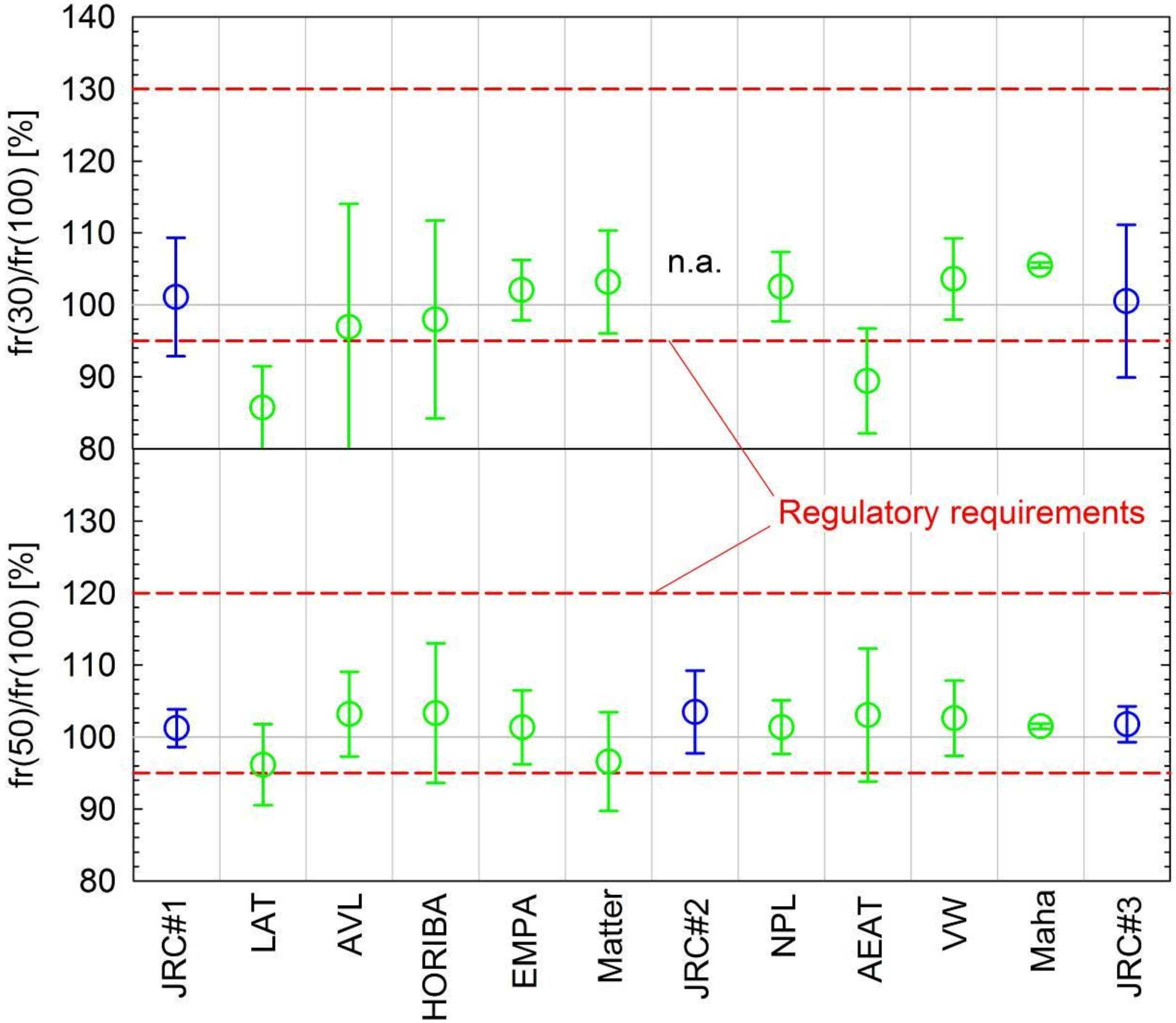
Excessive backpressure at VW

- *The long, narrow tube employed at VW to vent the exhaust of the 2nd ejector probably led to excessive backpressure that can severely affect the DF.*



Size-dependent losses

- *The particle losses in the GVPR were found to be largely size-independent.*



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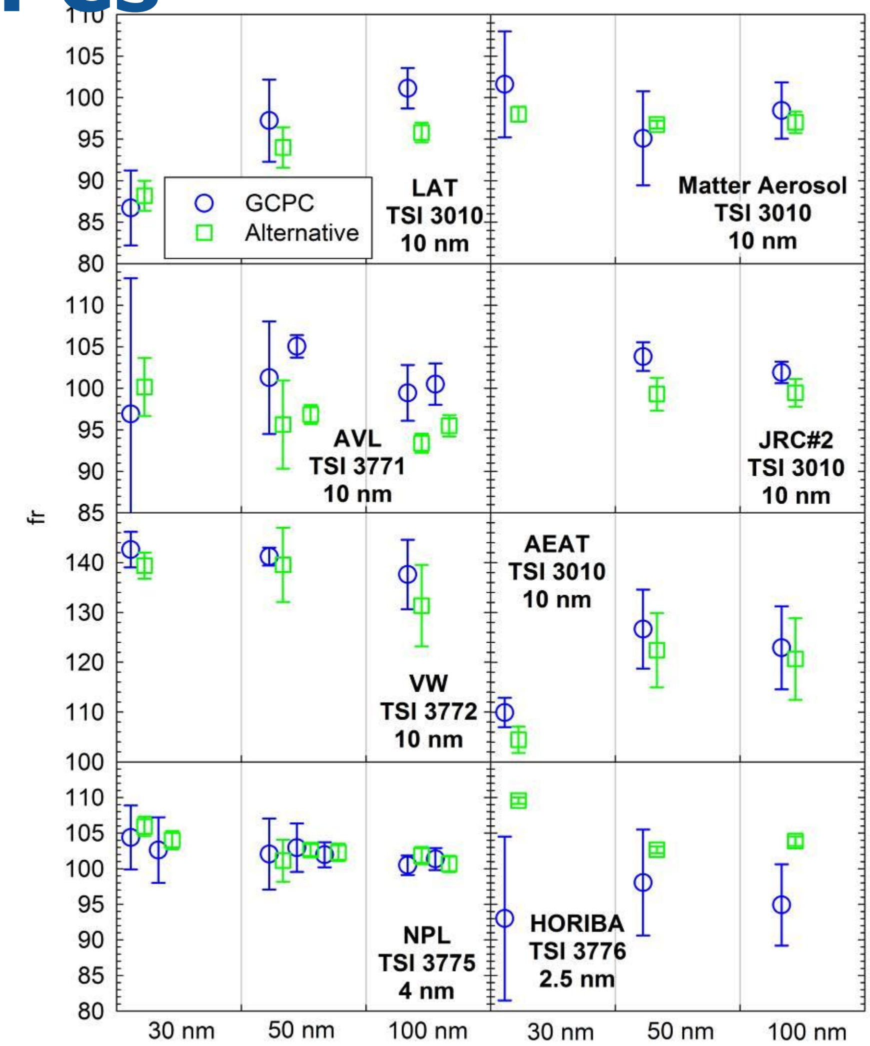
GAG/low cut-off size CPCs

- *The particle concentration reduction factors measured with low cut-off size CPCs agreed within ±5% to those determined with the GCPC.*
- *Individual differences generally lied within the experimental uncertainty.*

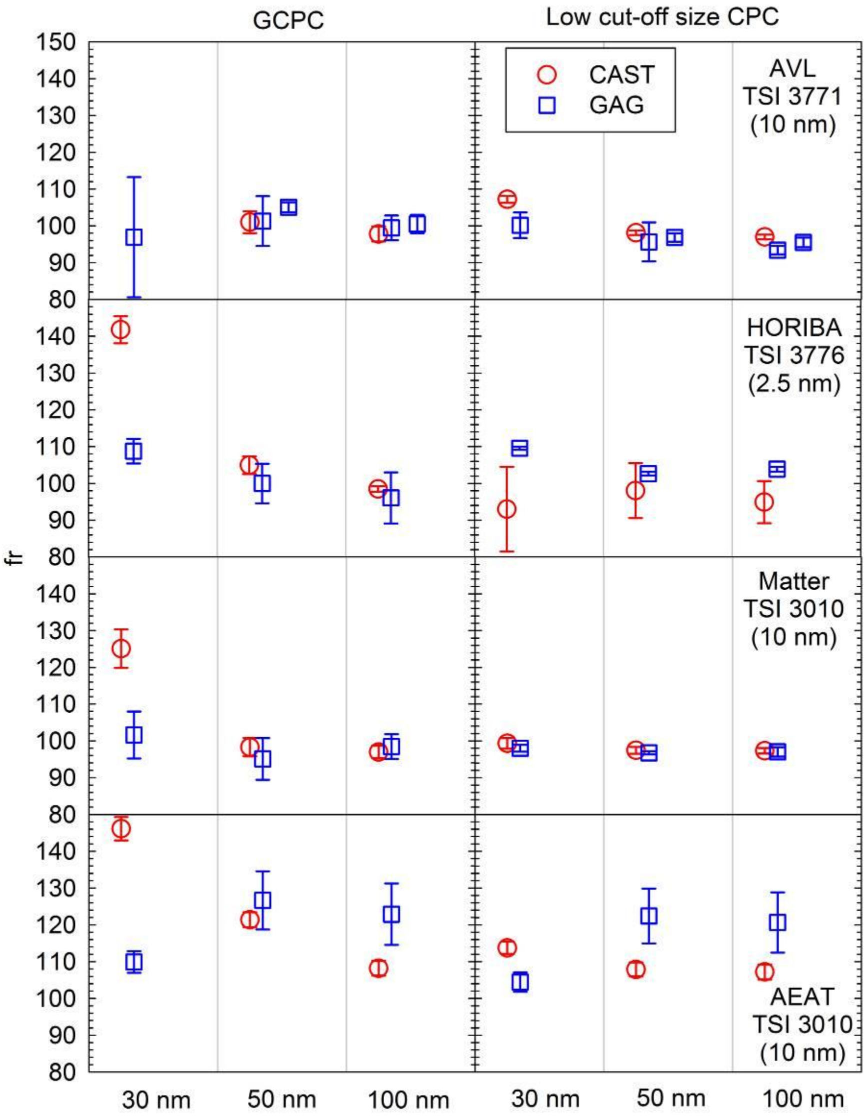


CAST

➢*Low cut-off size CPCs gave similar results for CAST and GAG particles with the individual differences lying within ~±8% at all sizes*

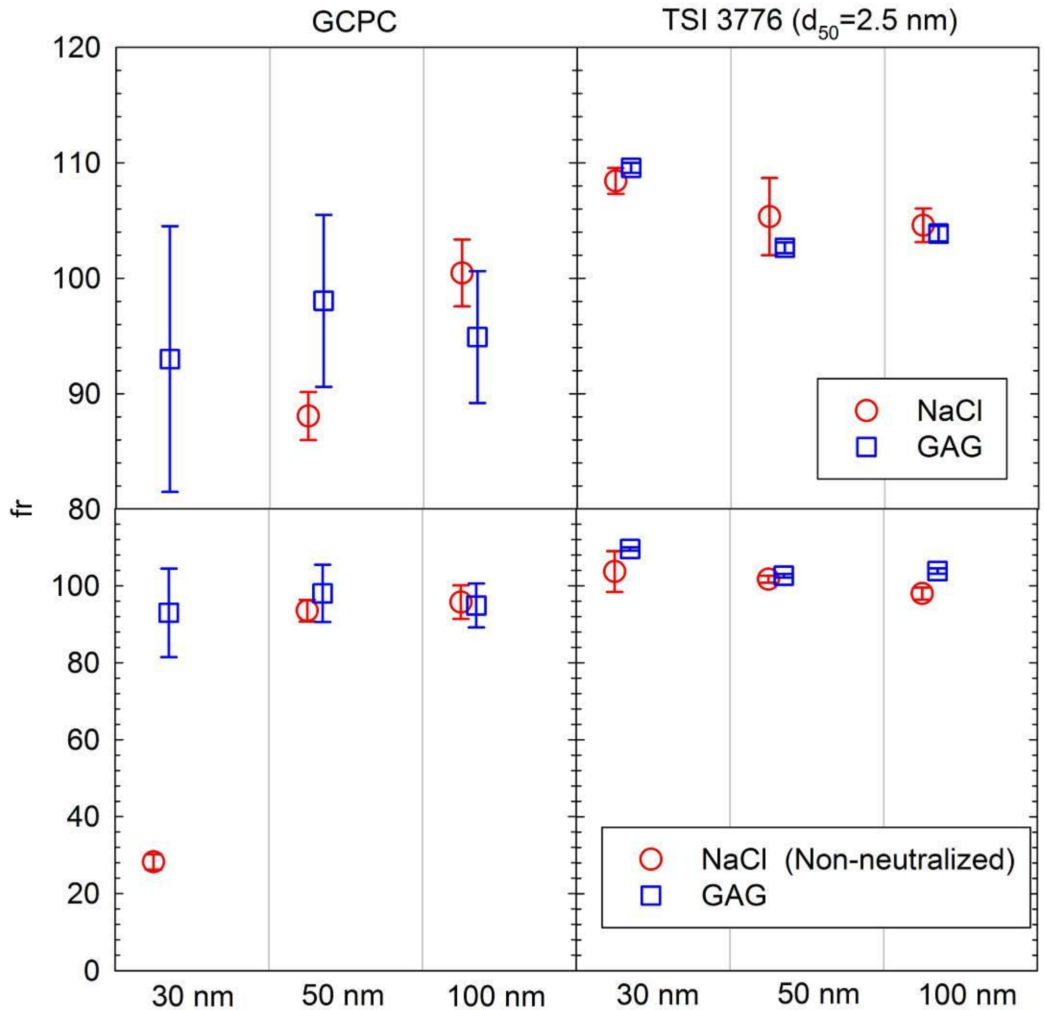
➢*GCPC gave systematically higher particle concentration reduction factors for 30 nm CAST particles (~30% higher than GAG). ⇨ 30 nm CAST particles not thermally stable.*

Lab	Temperature	Dilution
AVL	350° C	3.5:1
Horiba	350° C	Not specified
Matter	300° C	2.5-3.5:1
AEAT	350° C	No

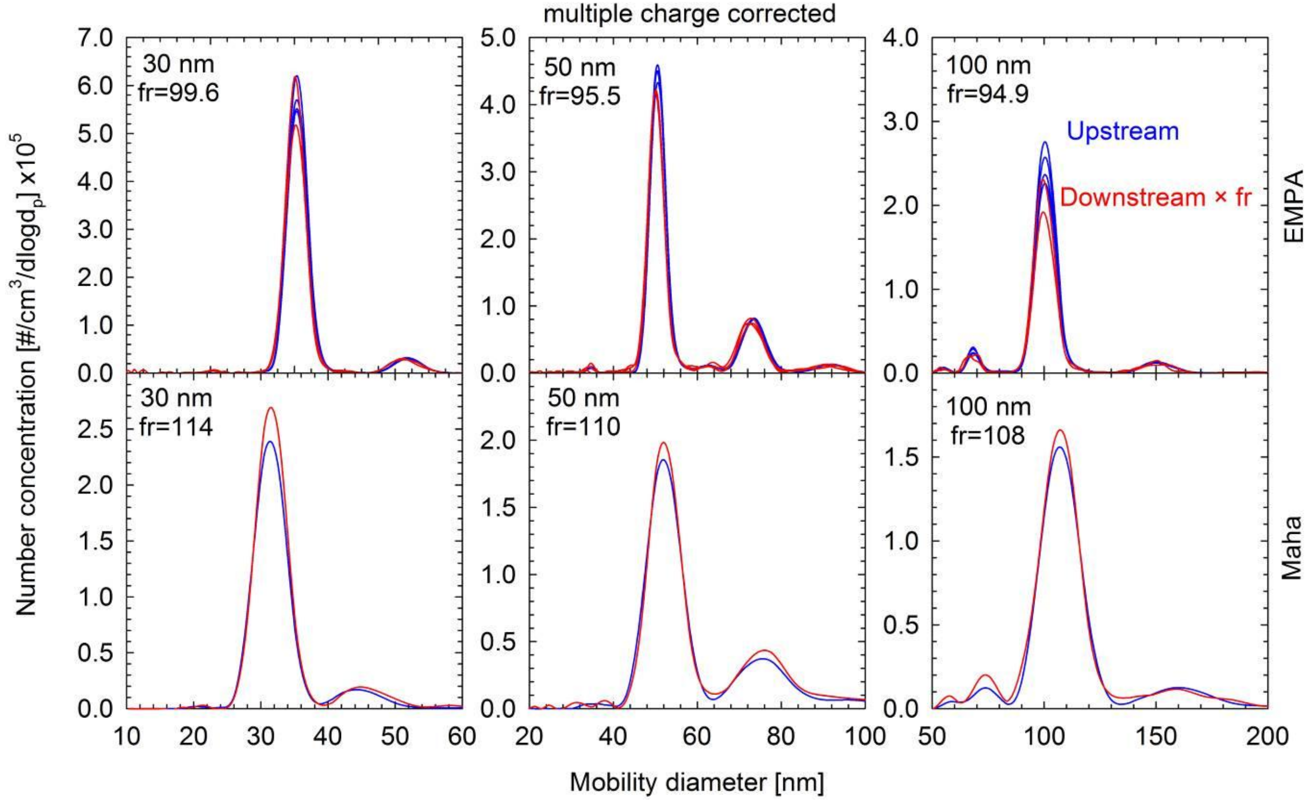


NaCl

- *Low cut-off size CPC: CAST and NaCl results agreed within ±5%*
- *GCPC: Unrealistically low PCRF values were determined with 30 nm NaCl particles. This most probably reflects some hygroscopic growth.*

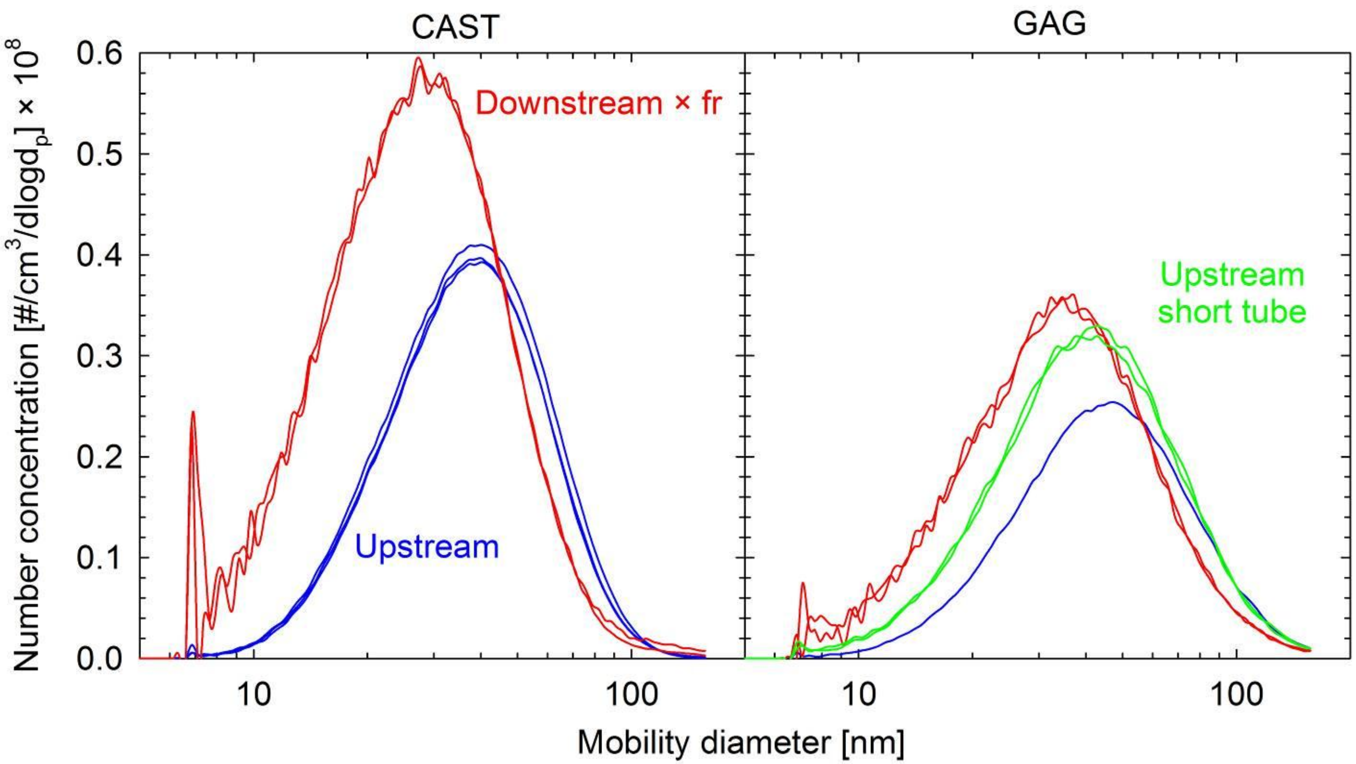


Thermal stability of GAG aerosol



- *Size distributions of DMA-classified graphite particles upstream and downstream of the GVPR suggest that graphite particles are stable at the 300°C of the GVPR ET.*

Polydisperse measurements

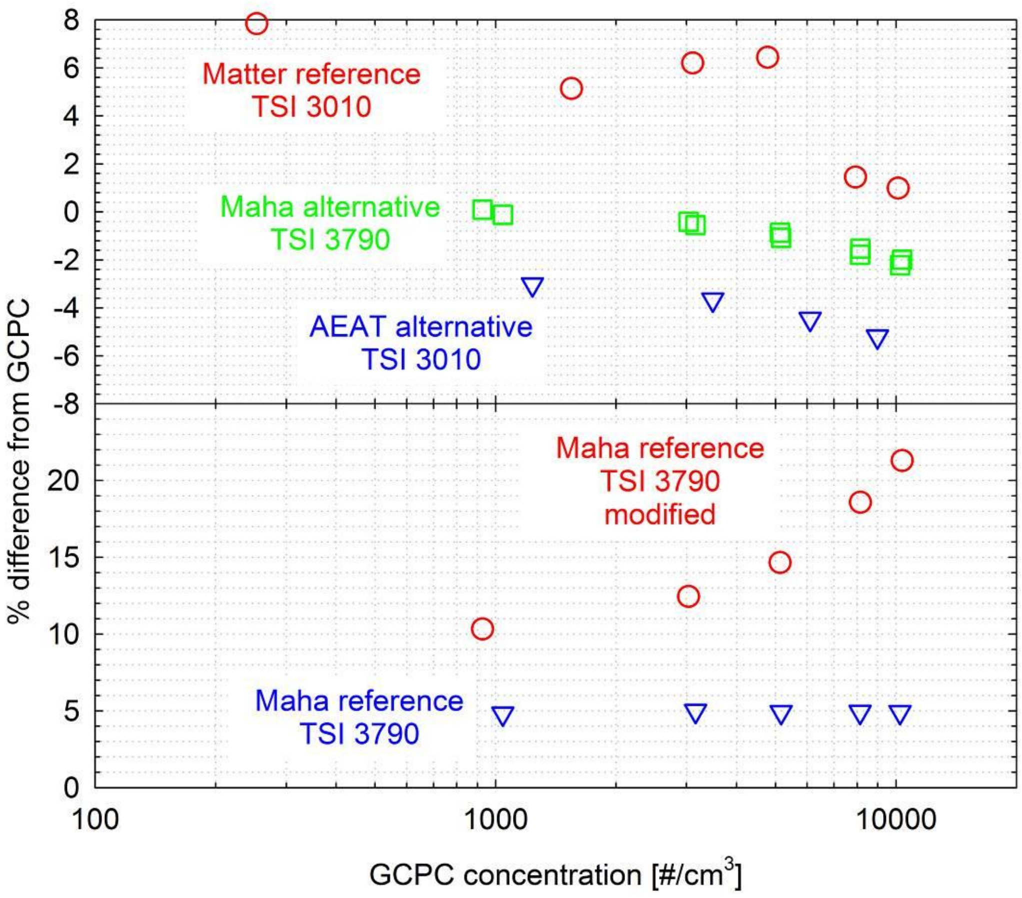


- *The high number concentrations can lead to significant coagulation. Care needs to be taken to ensure similar residence times when sampling upstream and downstream of the VPR*

CPC linearity checks

- *No significant linearity issues were observed in cross checks of 14 in total CPCs against the GCPC.*

- *The change of the operating temperatures of TSI 3790 CPC can lead to a highly non-linear beahaviour however.*



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Conclusions #1

- The dilution factor of the GVPR was very sensitive to the inlet, outlet and dilution air pressure.
- With three exceptions, the measured PCRF values agreed within ±5%. Three labs measured systematically higher values (by 20%, 40% and 10%) and for two of them there exists evidence of dilution missadjustment.
- Graphite particles were found to be thermally stable at least at the 300°C of the GVPR.
- Salt particles and thermally treated CAST particles at 30 nm were not stable, and the GCPC (d50 at 23 nm) yielded 70% lower (NaCl) and 23-33% (CAST) higher PCRF values, respectively.

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Conclusions #2

- The use of low cut-off size CPCs, yielded equivalent results for GAG, CAST and NaCl particles even at 30 nm.
- No significant linearity issues could be identified in the 15 in total CPCs characterized in the campaign. Operation of TSI 3790 CPC at elevated temperature differences can lead to a highly non-linear behaviour and should therefore be avoided.
- Characterization of the GVPR using polydisperse aerosol is a rather challenging task as the high number concentrations can lead to significant particle coagulation.

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Thank you for your attention

- **Acknowledgments:**
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EMRP
European Metrology Research Programme
Programme of EURAMET
The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

Summary of main conclusions #2

PMP VPR Calibration Round Robin

- A VPR being very sensitive to sample conditions was intentionally selected to help identify critical elements of the calibration setup
- Despite that, the measured PCRF values agreed within ±5%, with three exceptions. For two of them there exists evidence of dilution missadjustment.
- Graphite particles were found to be thermally stable at least at the 300°C of the GVPR. Salt particles and thermally treated CAST particles at 30 nm were not stable leading to lower and higher, respectively, PCRF values when using PMP complying CPCs
- For this reason, it is recommended to use low cut-off size CPCs, unless a verified thermally stable aerosol is employed
- Additional recommendations expected from the EU EMRP ENV02 project

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Next steps

- Revision/update of the mandate

- Definition of revised terms of reference as well as tasks and deadlines

  - ✓ Phone/web conference to be organized asap followed by a face to face meeting (JRC-Ispra?)

Open issues on PN-PM emissions

- Investigation of sub-23 nm particles emissions and of a possible need of extending the PMP methodology
- PN measurements during active regeneration (WLTP)
- Calibration related activities carried out within the EMRP ENV 02 project
- Heavy duty related issues?
- WHO statement about the carcinogenicity of the diesel exhaust: Inputs from the PMP WG needed?

Thank you!

Questions?