UNECE GRPE

Particle Measurement Programme

PMP LIGHT DUTY INTER-LABORATORY EXERCISE: FINAL RESULTS

Zurich 13th-15th August 2007

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Outline

- Inter-laboratory Exercise Summary
- Experimental set up
- Mass results
- Number results
- Alternative Particle Number Systems
- Conclusions

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Inter-laboratory Correlation Exercises - Summary

- Heavy-duty programme starts September 2007
- Light-duty Exercise prioritised
- Commenced late summer 2004
- Completed August 2006
- 9 labs participated (11 repetitions)
- Project managed by DG JRC (Ispra, Italy)
- Golden Engineer funded by DfT (UK)

Inter-laboratory Correlation Exercises – (light duty)

- Repeated NEDC tests made at several laboratories (with JRC bookends)
- Traveling 'Golden Engineer' + two of JRC staff to ensure best and reproducible testing practice
- Very low PM 'Golden Vehicle' at all labs (Repeat./Reproduc.)
- Tests on:
  - Gaseous Pollutants
  - Pre-specified modified mass measurement system
  - 'Golden Measurement System' for particle numbers
  - Additional vehicles of various types
  - Alternative systems for particle numbers

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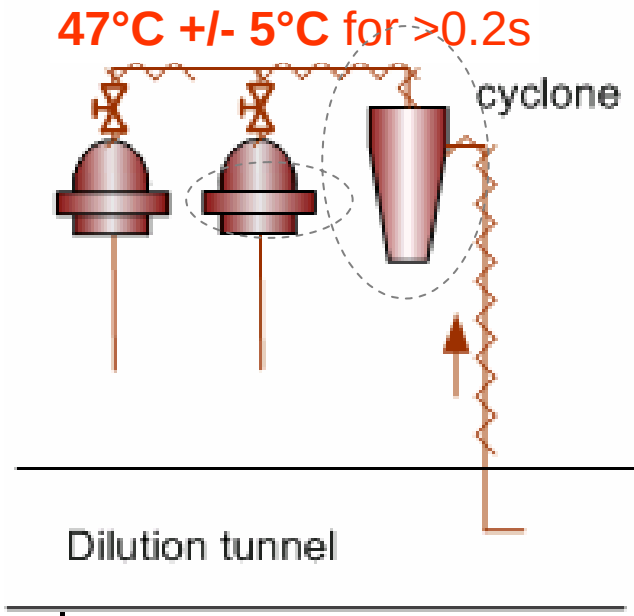
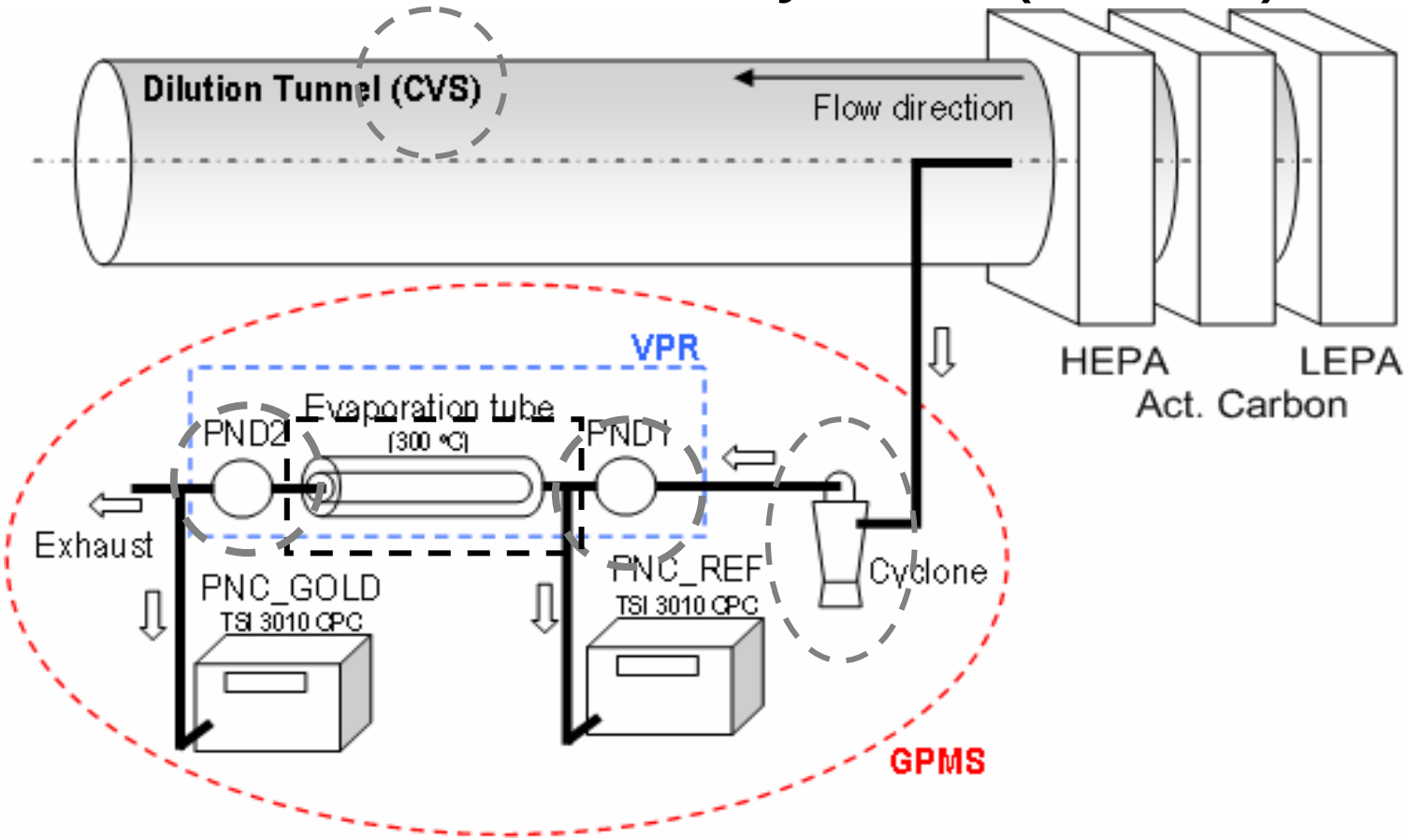
PMP Mass system specifications

- Cyclone (2.5µm to 10µm cut-point)
- Lab modified systems with external heating tapes
  - Zone held at 47°C +/- 5°C for >0.2s
  - Temperatures recorded
  - Filter face velocity (50cm/s to 80cm/s)
- Modified filter holders for even deposition of material
- Pallflex TX40 mandated; single batch for all tests
- No back-up filter
- Single filter for entire NEDC for DPF equipped and gasoline vehicles
- Urban and extra-urban filters for conventional Diesels
- HORIBA HFU-4770 (Heated Particulate Filter Module) (2 labs)



Golden Particle Number System (GPMS)



A particle number method employing a condensation nucleus counter, but using sample pre-conditioning to eliminate the most volatile particles which may contribute significantly to variability.

Other particle number systems tested

- ALTERNATIVE SYSTEMS (same specifications)
  - Clone GPMS: Rotating Disc (MATTER Eng.) + Evaporation Tube + Dilutor (3 lab)
  - OEM: Other manufacturers to the provider of GPMS
    - SPCS: HORIBA Solid particle counting system (2 labs)
    - FPS: DEKATI FPS (modified) - GRIMM modified CPC 5.403 (3 labs) or TSI CPC 3010 lab modified (3 labs)
- ADDITIONAL SYSTEMS (differences)
  - EJ: Dual Ejector dilutor-TSI CPC 3010 lab modified (1 lab)
  - FPS/EJ+TD: Ejector dilutor or FPS + Thermodenuder -TSI CPC 3010 lab modified (1 lab)

Vehicles tested

DPF DIESELS x 6

- PEUGEOT 407 HDi FAP 2000 cc (in all labs)
- BMW 525d catalysed DPF equipped, 2500 cc
- MAZDA Bongo catalysed DPF, 2000 cc
- TOYOTA Avensis D-CAT 2000 cc
- MERCEDES Vito Van DPF 3000 cc
- PEUGEOT 206 HDi FAP

Conventional DIESELS x 6

- BMW 120d PMFC 2000 cc
- AUDI A2, TDi, EURO-4, Oxicat, 1500 cc
- HONDA Accord i-CTDi, Euro 4, Oxicat/deNOx, 2200 cc
- VW, GOLF TDi, non-DPF, 1800 cc
- KIA Pride, non-DPF, 1500 cc
- VAUXHALL Astra, CDTi, 1700 cc

GDI x 3

- MITSUBISHI Carisma, GDI, TWC/deNOx 1800 cc
- VW, GOLF FSI, TWC/deNOx 1600 cc
- TOYOTA Crown G-DI, 3000 cc

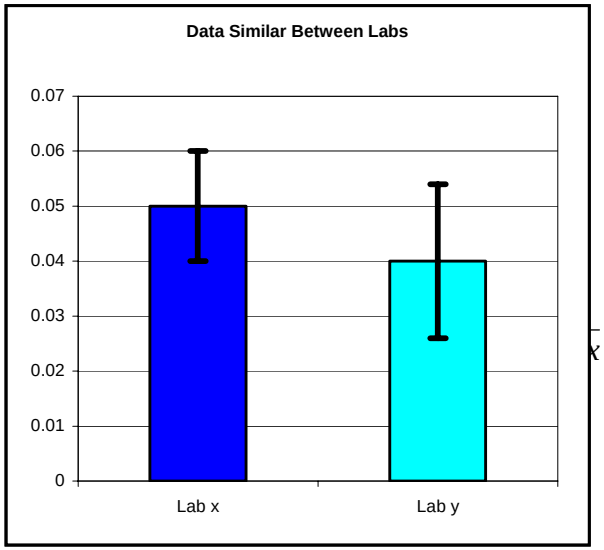
MPI x 1

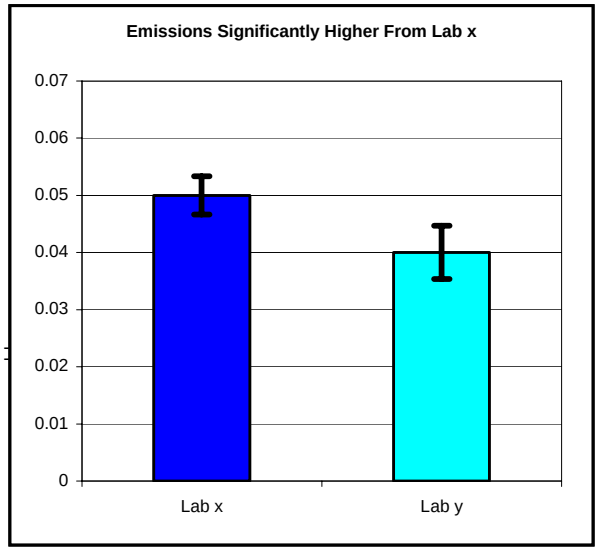
- FIAT, Idea, MPI, EURO-4, TWC, 1400cc

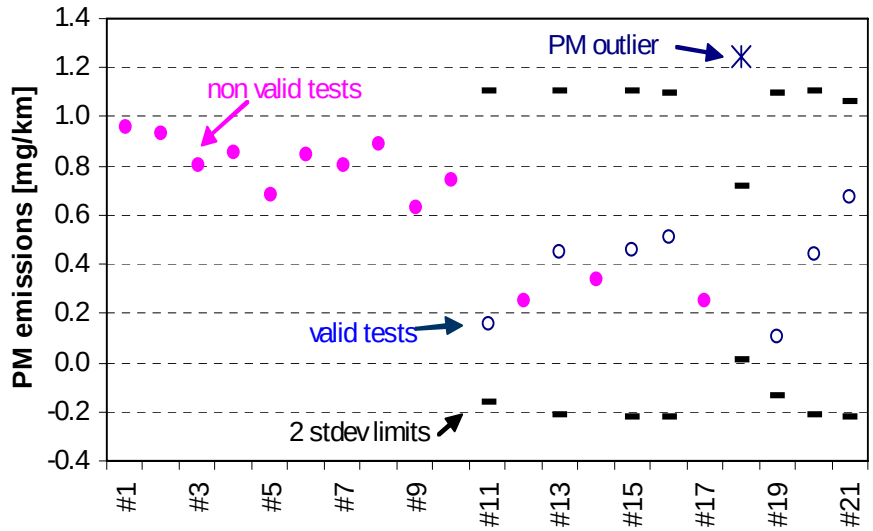
- Significance

$$CI = \bar{x} \pm t_{(a/2,n-1)} \frac{s}{\sqrt{n}}$$

$$95\%\ CI = \bar{x} \pm 2.7 \frac{s}{\sqrt{5}} = \bar{x} \pm 2s$$







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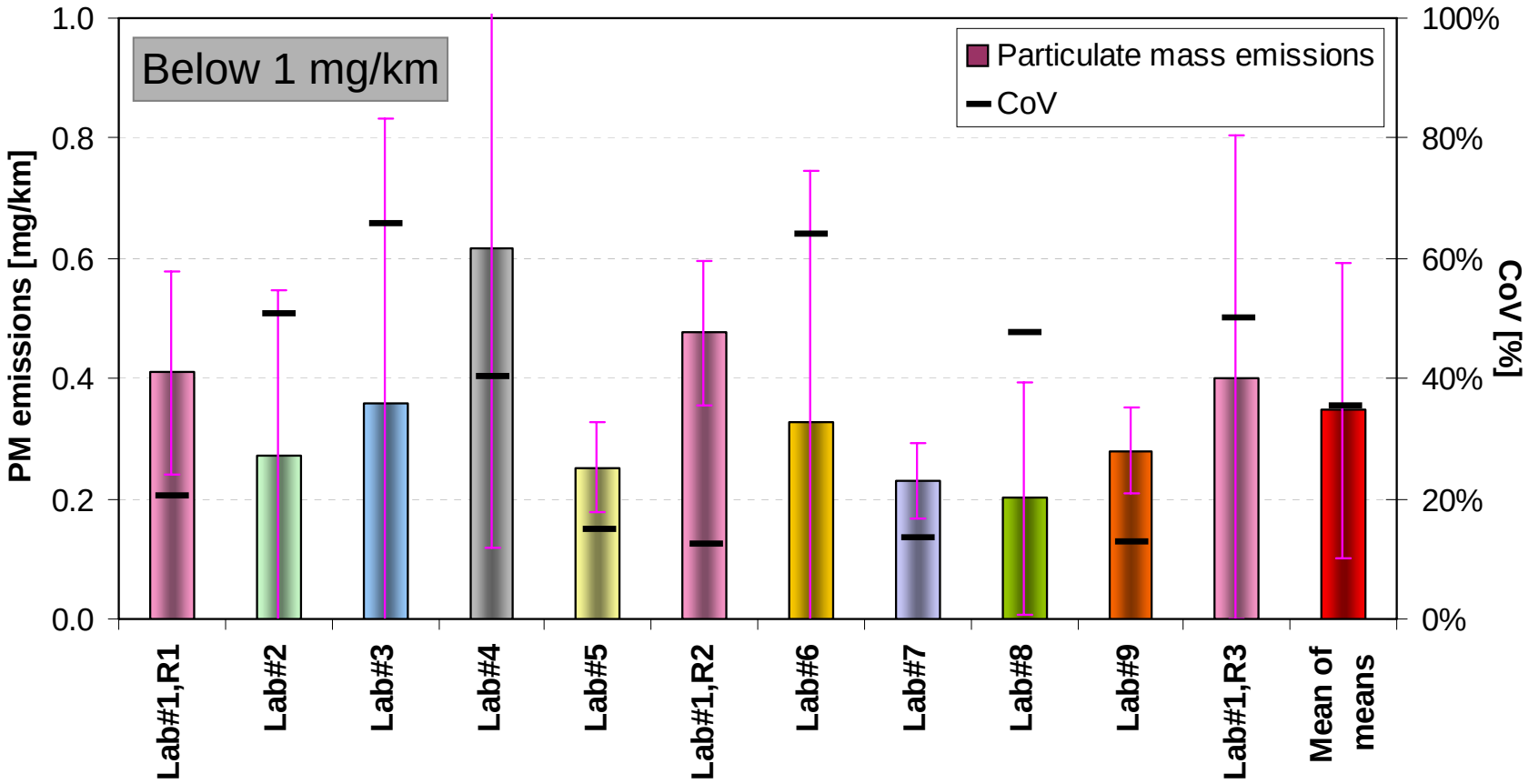
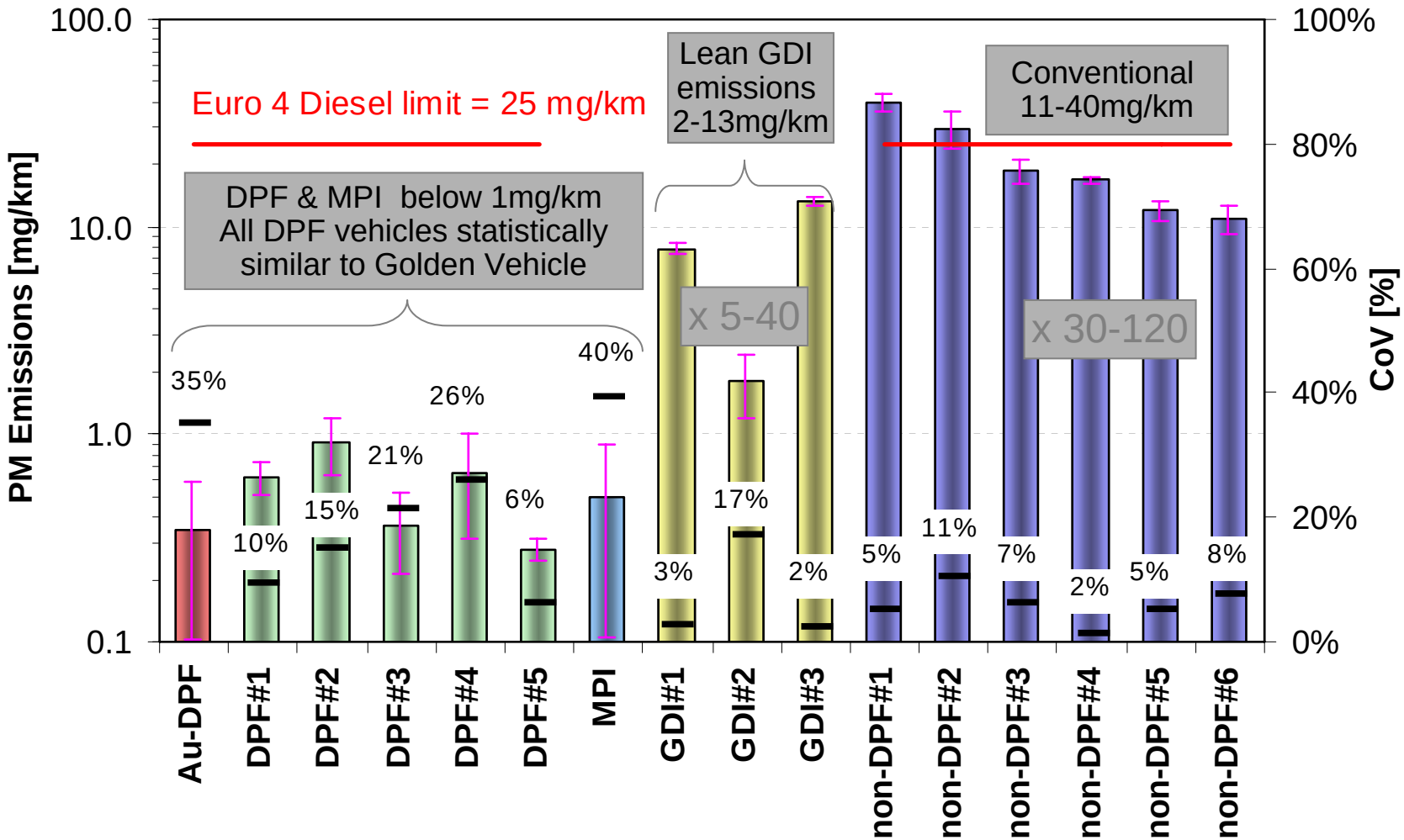
Particulate Mass Emissions NEDC - Golden Vehicle



Emissions: 0.2-0.6mg/km
Repeatability: 12-66%

Emissions: 0.34mg/km
Reproducibility: 35%

Particulate Mass Emissions NEDC - all vehicles



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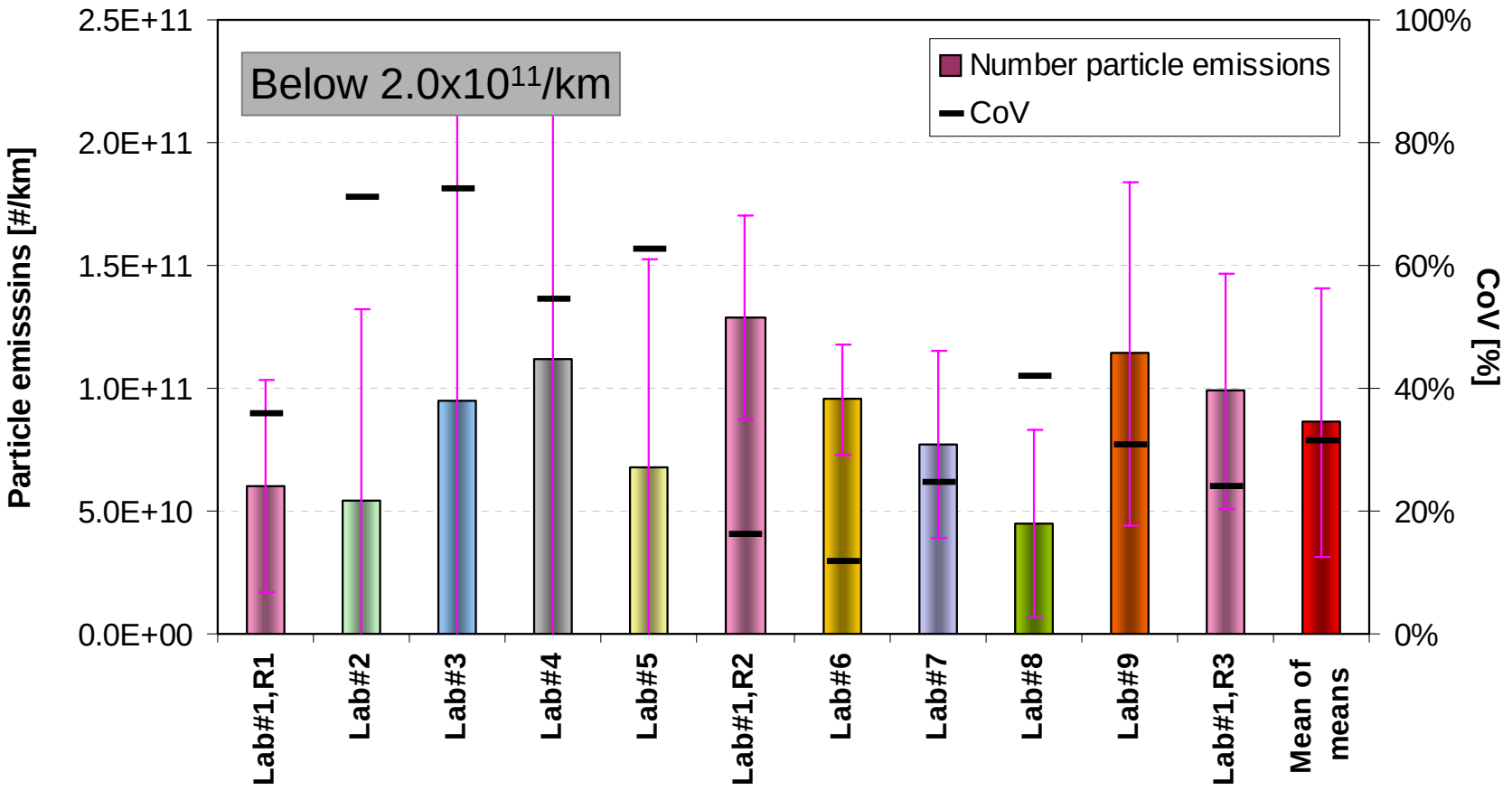
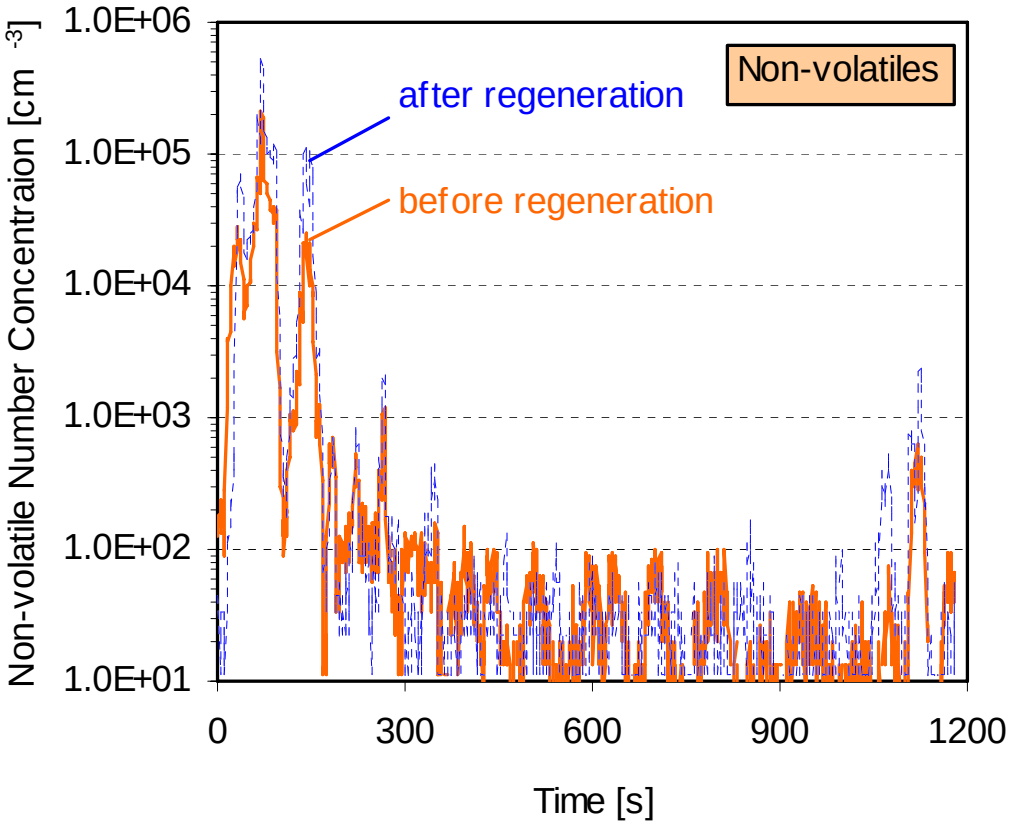
Particle Numbers from NEDC (#/km) - Golden Car

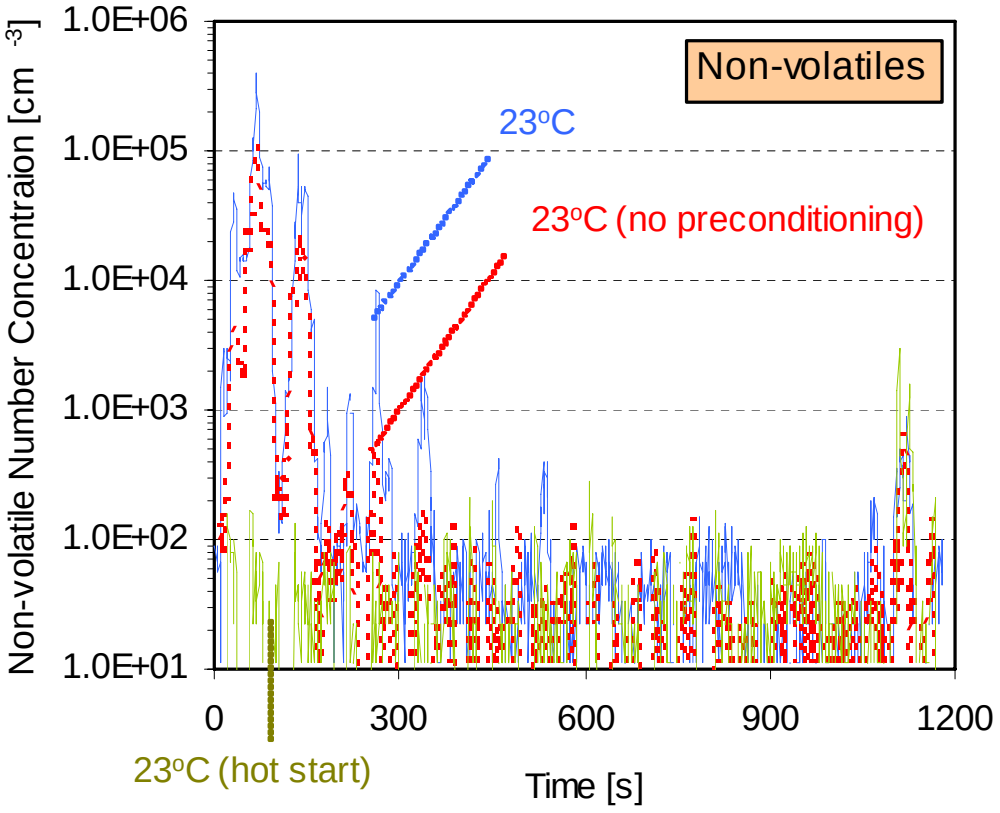


Emissions: 0.5-1.3x10^11/km
Repeatability: 12-72%

Emissions: 8x10^10/km
Reproducibility: 31%

DPF fill state and preconditioning

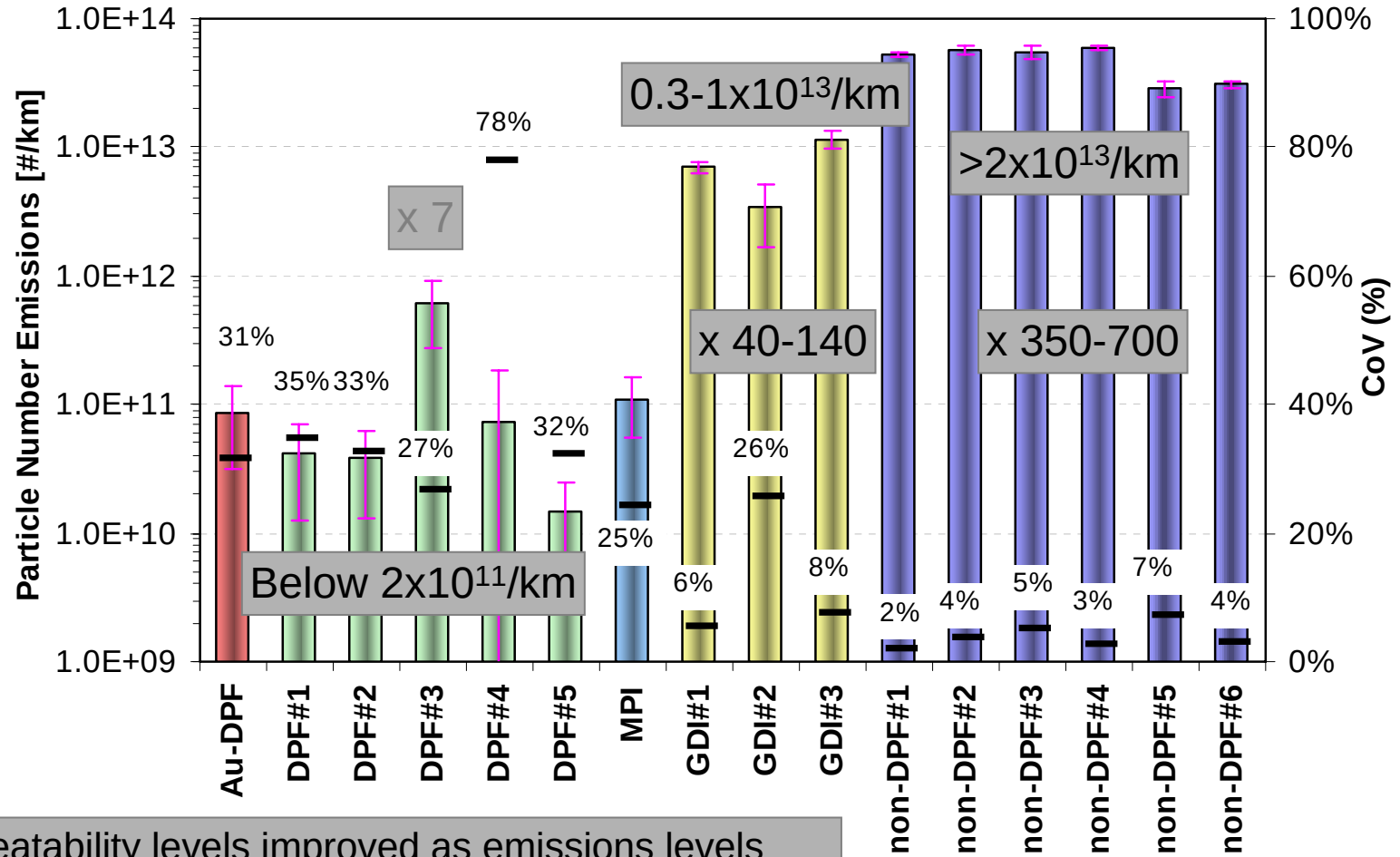




Apparent poor repeatability is manifestation of DPF fill effects and preconditioning

influence particle numbers – and repeatability!

NEDC Particle Numbers (#/km) – Rest vehicles



Repeatability levels improved as emissions levels increased across all vehicle types

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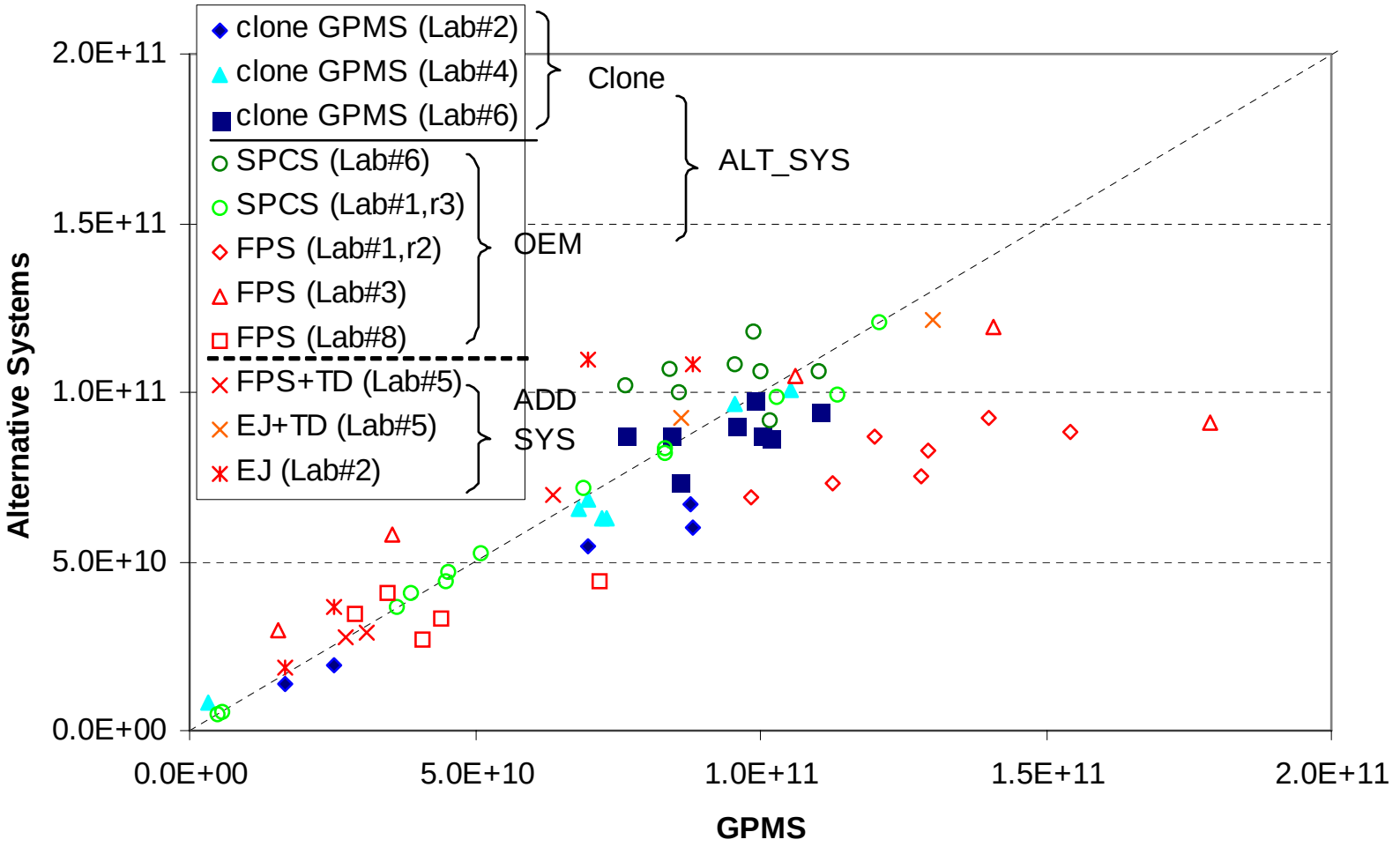
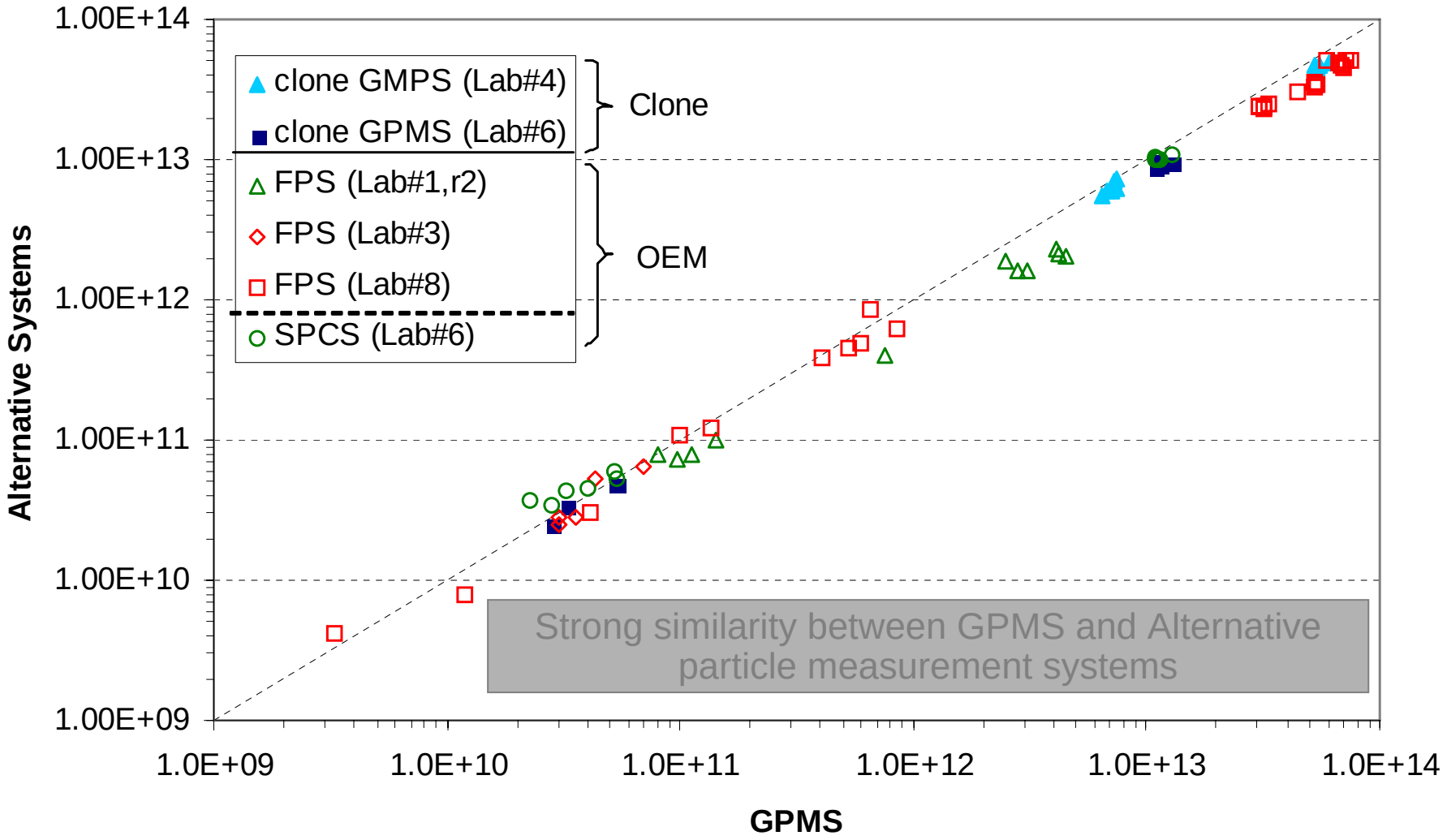
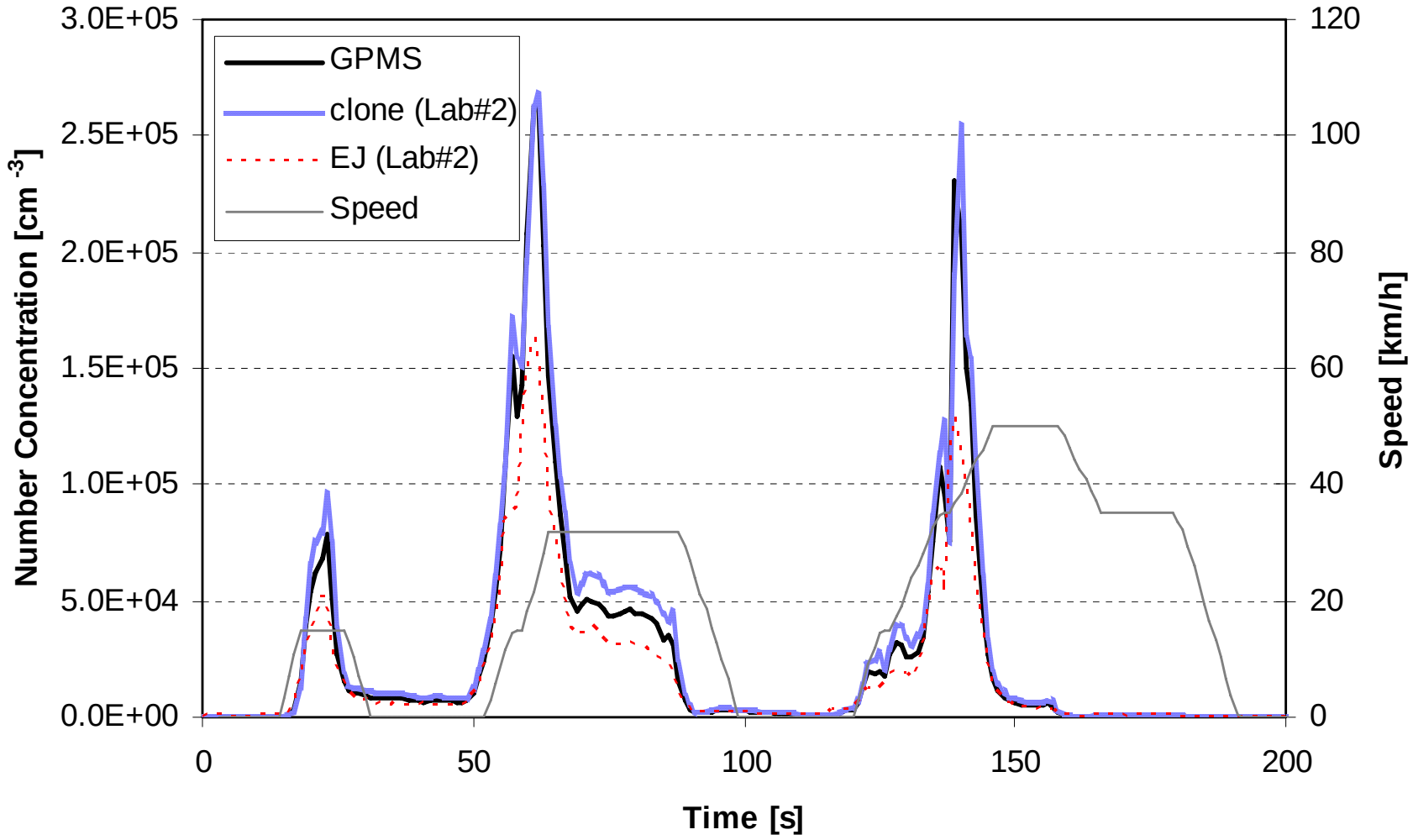
Alternative systems – Golden vehicle



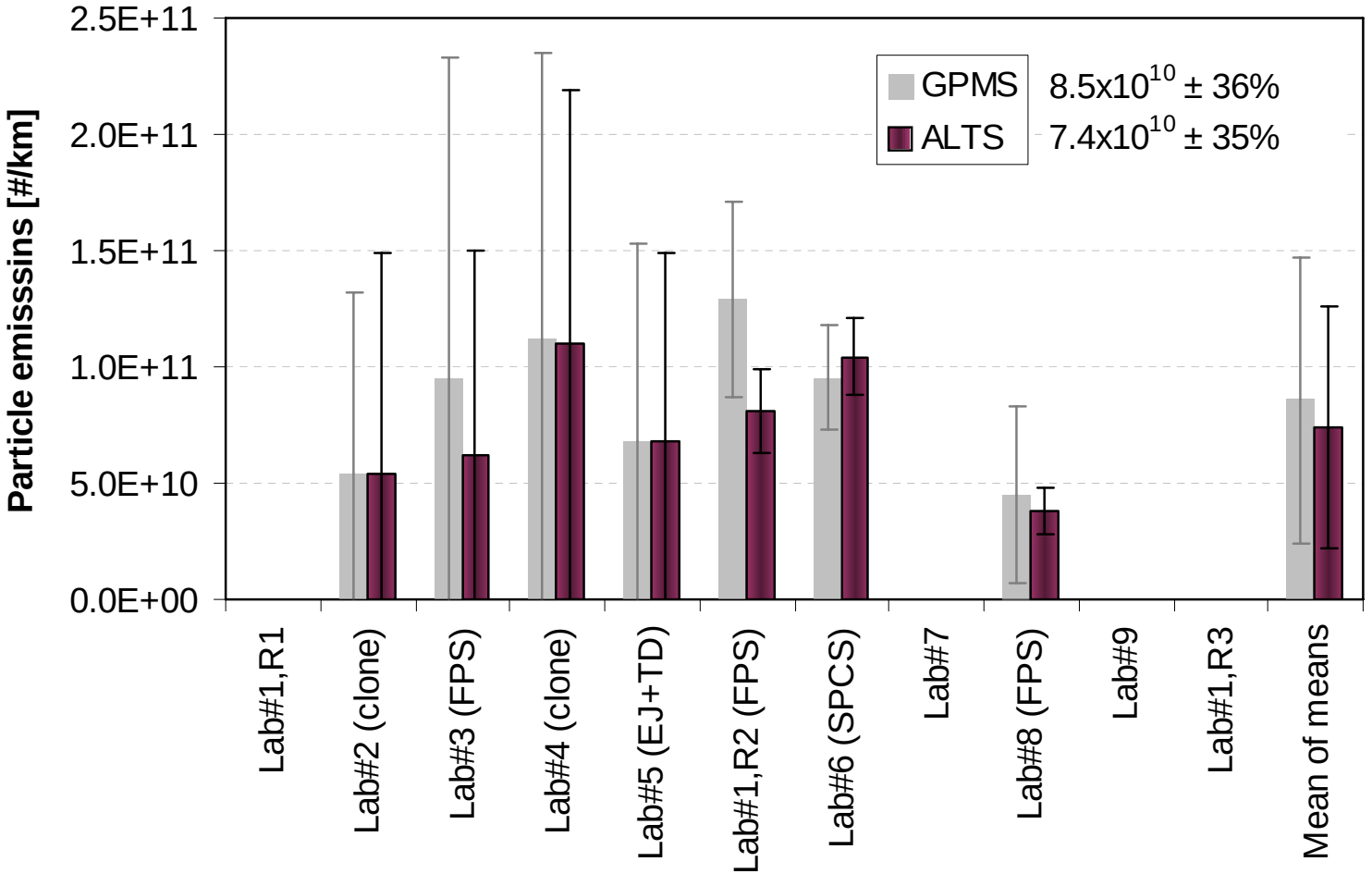
Alternative systems – Rest vehicles



Alternative systems – Real Time comparisons



Validation Exercise and Round Robin simulation



Validation Exerc.

Reproducibility

N:	31%
PM:	35%
CO_2:	4%
NO_x:	10%
HC:	35%
CO:	44%

RR simulation.

Reproducibility

GPMS:	36%
PM:	40%
CO_2:	4%
NO_x:	12%
HC:	45%
CO:	49%

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Conclusions 1/3

- Golden vehicle (2-s method)
  - PM: ~ 0.34 mg/km ± 35%
  - PN: ~ $8x10^{10}$ /km ± 31%

- Rest vehicles
  - PM: Conv. Diesels(11-40mg/km)>G-DI(2-13mg/km)>porous DPF~MPI ~DPF(1mg/km)
  - PN: Conv. Diesels ($5x10^{13}$)>G-DI($5x10^{12}$)>porous DPF($5x10^{11}$)>MPI ~DPF($1x10^{11}$)

- The majority of alternative systems correlated closely with the GPMS
- The validation exercise and a simulation of a Round Robin exercise showed that number method (and mass) have reproducibility levels similar to those of HC and CO.

Conclusions 2/3

- Mass & Number method comparison
  - Both mass and number sufficiently sensitive to discriminate between a DPF equipped Diesel and non-DPF equipped Diesel
  - In this testing, the mass method proved unable to discriminate a porous (cordierite) wall-flow DPF from a more efficient (silicon carbide) one.
  - In this testing, the mass method proved unable to discriminate a low Euro-4 diesel vehicle and a high emitting GDI vehicle

Conclusions 3/3

- Mass & Number method comparison
  - The mass method collects a large gaseous volatile fraction that may be 20 times the mass of the solid particles collected
  - Mass method insensitive to DPF fill state and preconditioning of the vehicle, ‘true repeatability’ masked
  - Number metric provides best sensitivity (15 times better) and avoids uncertainties with volatile components

Acknowledgements

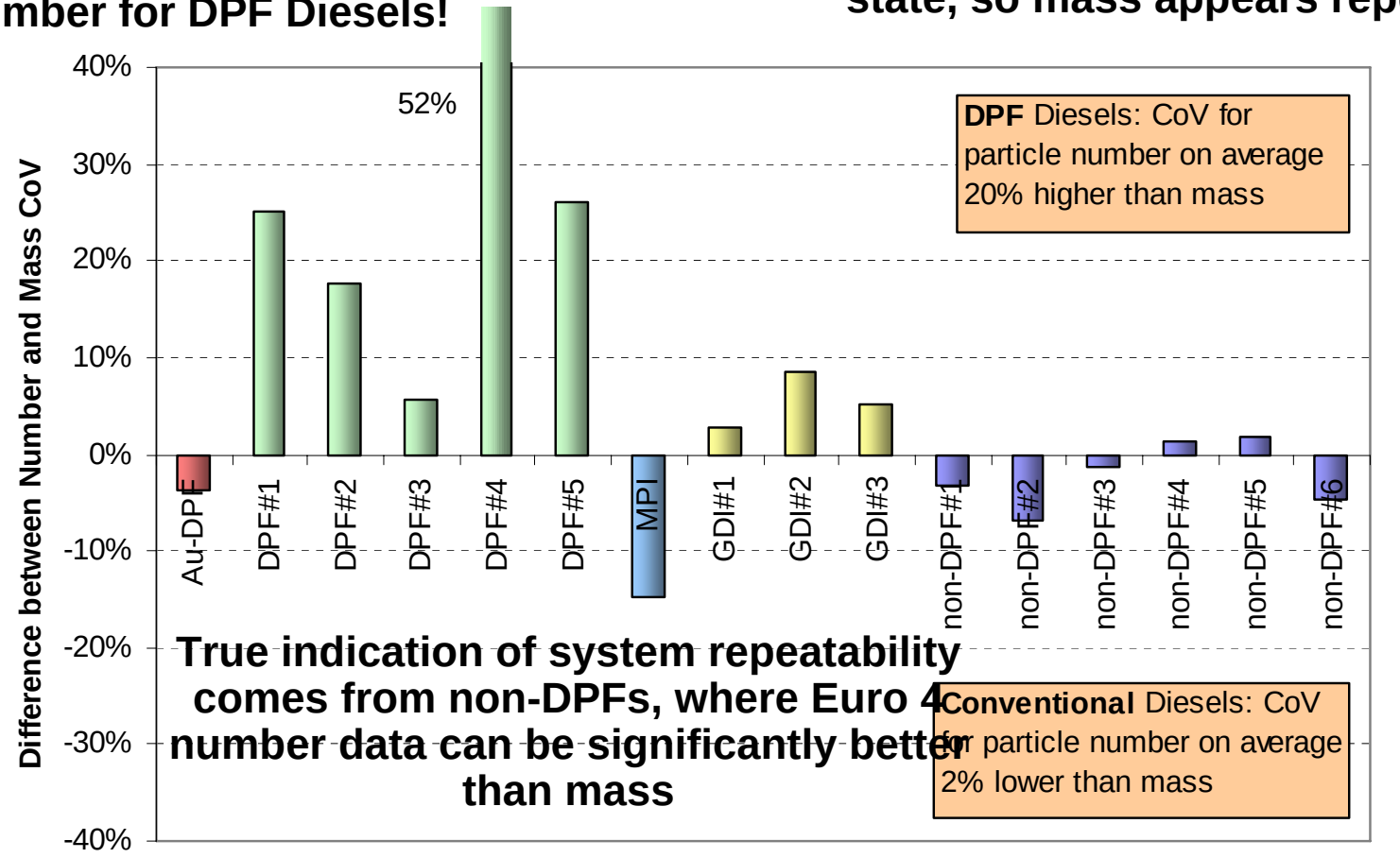
- Labs that participated in the exercise
  - RICARDO, AVL-MTC, RWTUV, LAT, NTSEL, NIER, UTAC, SHELL and JRC
- Companies that provided the instruments, fuel and vehicle
  - AECC, CONCAWE, DEKATI, GRIMM, HORIBA, MATTER, TSI
- AEA Technology for the calibrations of the GPMS
- JRC staff for assisting other labs : Rafael Munoz-Bueno, Urbano Manfredi, Rinaldo Colombo

Thank you very much for your attention!

Number – Mass difference in CoV

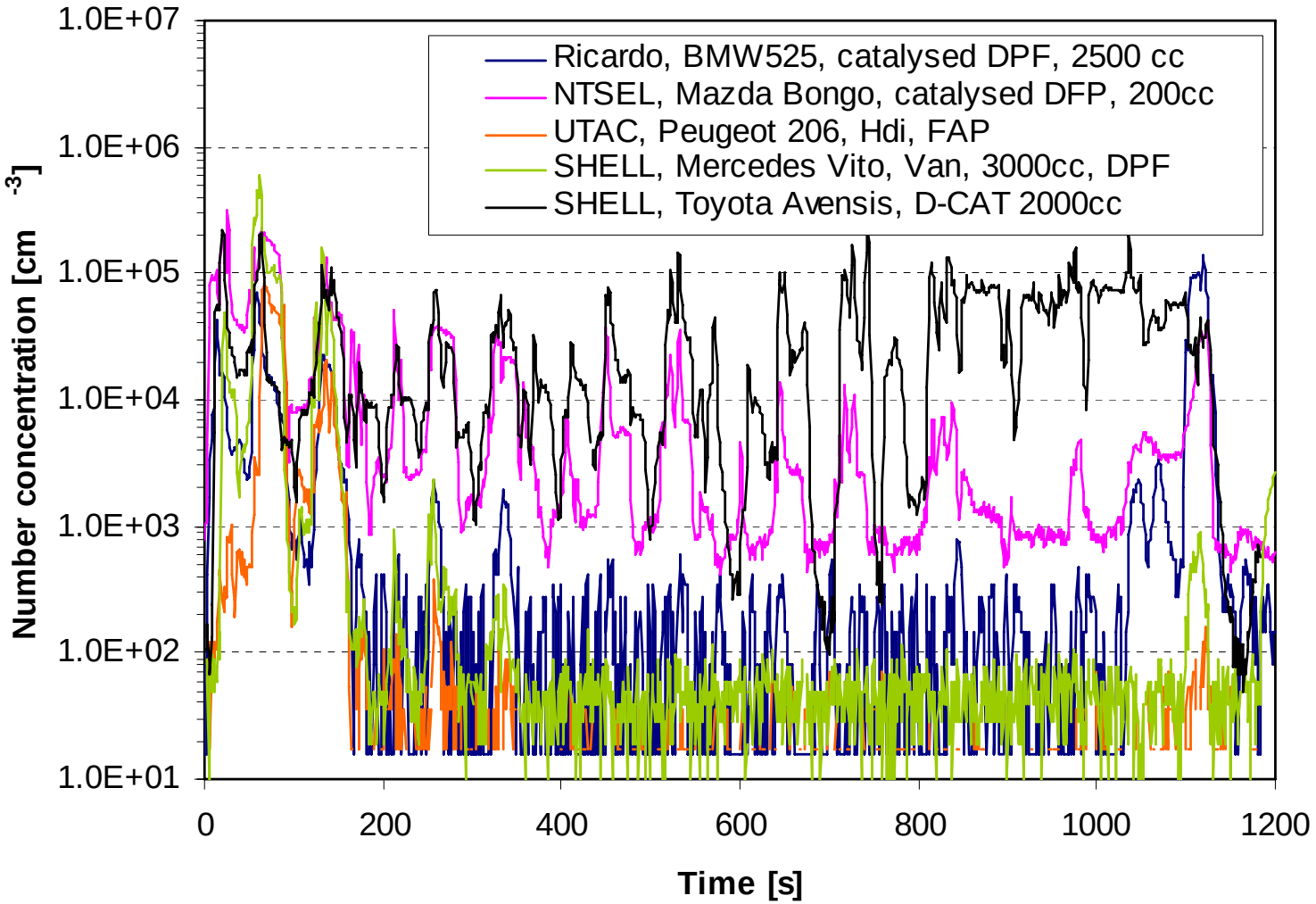
Mass shows better apparent repeatability than number for DPF Diesels!

Mass method is insensitive to DPF fill state, so mass appears repeatable

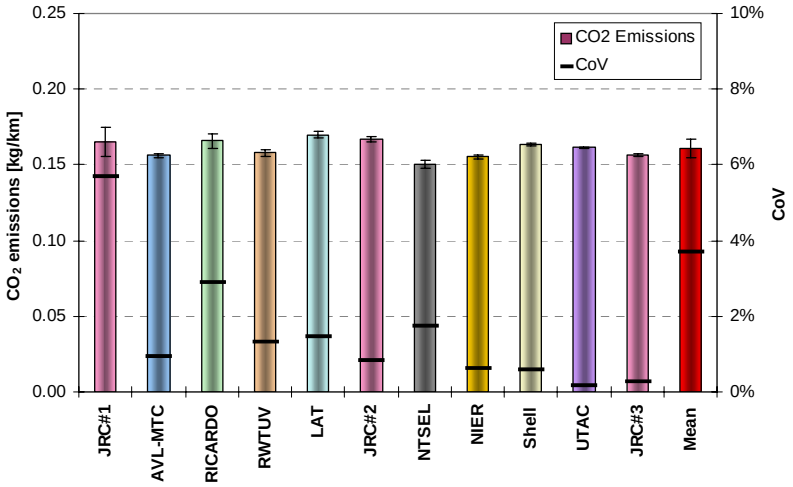


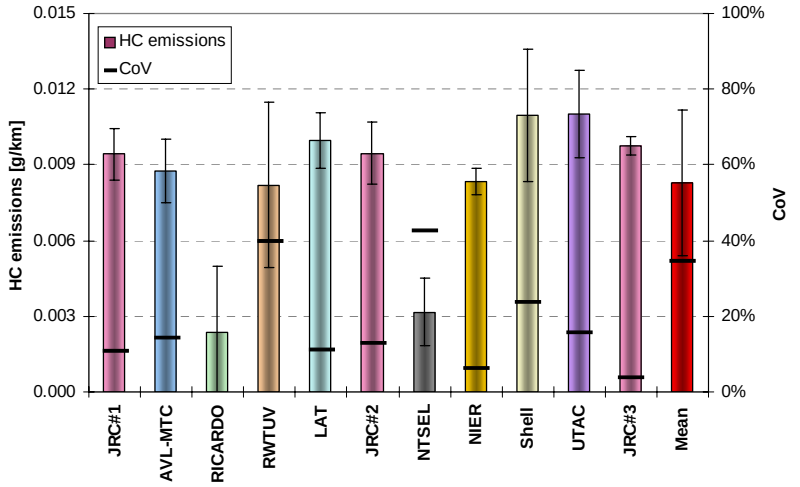
True indication of system repeatability comes from non-DPFs, where Euro 4 number data can be significantly better than mass

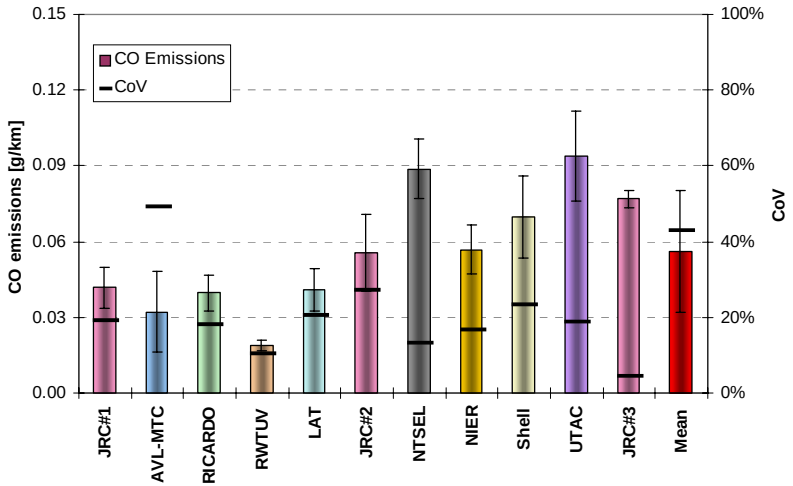
Real time emissions of DPF vehicles

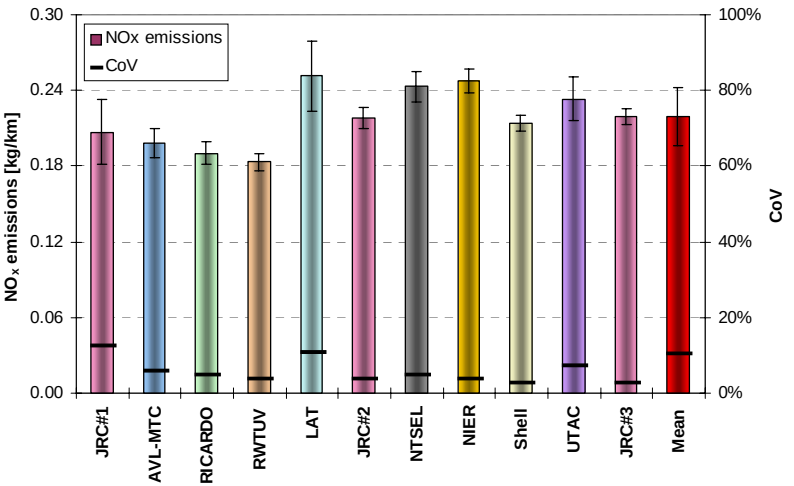


Regulated emissions



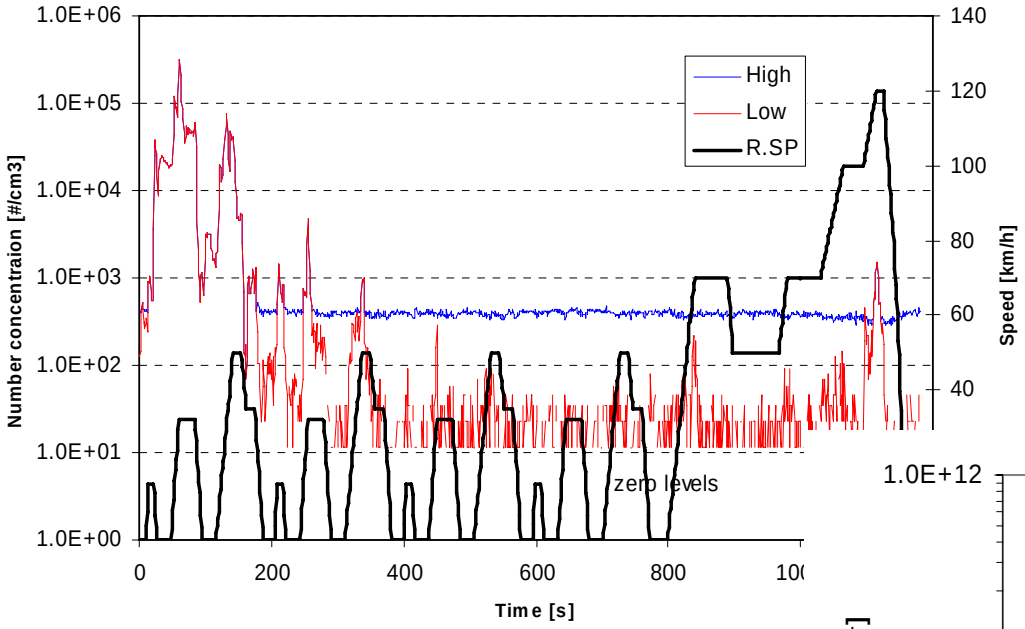




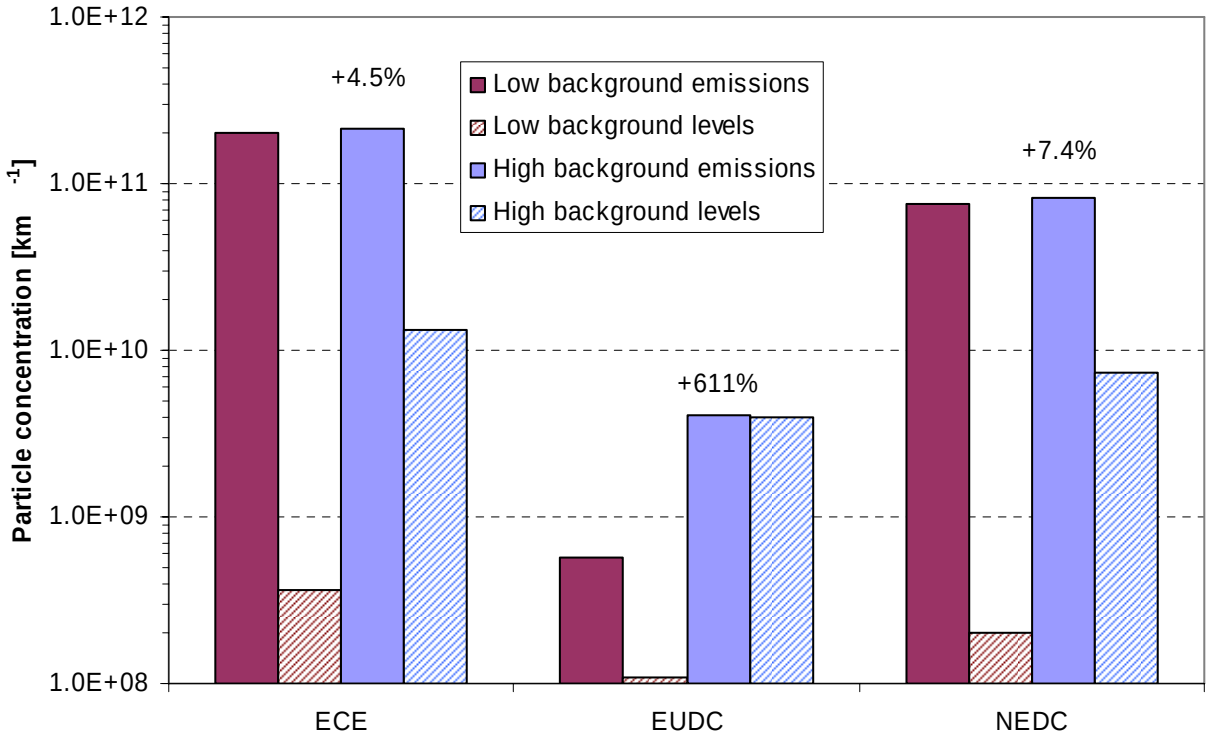


Order	Laboratory	Location	Lab Identifier	Start Date	End Date
1	JRC#1	Ispra, Italy	Lab#1r1	11-Nov-04	17-Nov-04
2	AVL_MTC	Sweden	Lab#2	30-Nov-04	03-Dec-04
3	Ricardo Shoreham Technical Centre	UK	Lab#3	30-Jan-05	07-Feb-05
4	RWTUEV	Essen, Germany	Lab#4	28-Feb-05	11-Mar-05
5	Laboratory of Applied Thermodynamics	Thessaloniki, Greece	Lab#5	06-Apr-05	19-Apr-05
6	JRC#2	Ispra, Italy	Lab#1r2	11-May-05	31-May-05
7	NTSEL	Japan	Lab#6	30-Aug-05	22-Sep-05
8	NIER	Korea	Lab#7	25-Oct-05	11-Nov-05
9	Shell Global Solutions	Chester, UK	Lab#8	22-Mar-06	12-Apr-06
10	UTAC	Paris, France	Lab#9	16-May-06	30-May-06
11	JRC#3	Ispra, Italy	Lab#1r2	13-Jun-06	26-Jun-06

Vehicle	Type	Lab	Code
Peugeot 407 HDi FAP 2000 cc	DPF Diesel [Oxicat, uncoated DPF, FBC]	All	**Au-Vehicle**
BMW 525d catalysed DPF equipped, 2500 cc	DPF Diesel [Oxicat, catalysed DPF]	RICARDO	DPF#1
Mazda Bongo catalysed DPF, 2000cc	DPF Diesel [Oxicat, catalysed DPF]	NTSEL	DPF#2
Toyota Avensis D-CAT 2000cc	DPF Diesel [Oxicat, deNOx, catalysed DPF]	SHELL	DPF#3
Mercedes Vito Van DPF 3000cc	DPF Diesel [Oxicat, catalysed DPF]	SHELL	DPF#4
Peugeot 206 HDi FAP	DPF Diesel [Oxicat, uncoated DPF, FBC]	UTAC	DPF#5
FIAT, Idea, MPI, EURO-4, TWC, 1400cc	Port-injected gasoline	JRC	MPI Vehicle
Mitsubishi, Carisma, GDI, TWC/deNOx 1800 cc	Direct-Injection Gasoline (lean)	RWTUV	GDI Vehicle#1
VW, GOLF FSI, TWC/deNOx 1600 cc	Direct-Injection Gasoline (lean)	JRC	GDI Vehicle#2
Toyota Crown G-DI, 3000cc	Direct-Injection Gasoline (lean)	NTSEL	GDI Vehicle#3
BMW 120d PMFC 2000cc	Conventional Diesel	SHELL	non-DPF#1
Audi A2, TDi, EURO-4, Oxicat, 1500 cc	Conventional Diesel	RICARDO	non-DPF#2
VW, GOLF TDi, non-DPF, Oxicat, 1800 cc	Conventional Diesel	RWTUEV	non-DPF#3
Honda Accord i-CTDi, EURO-4, Oxicat/deNOx, 2200 cc	Conventional Diesel	LAT	non-DPF#4
Kia Pride, non-DPF, 1500cc	Conventional Diesel	NIER	non-DPF#5
Vauxhall Astra, CDTi, 1700cc	Conventional Diesel	SHELL	non-DPF#6



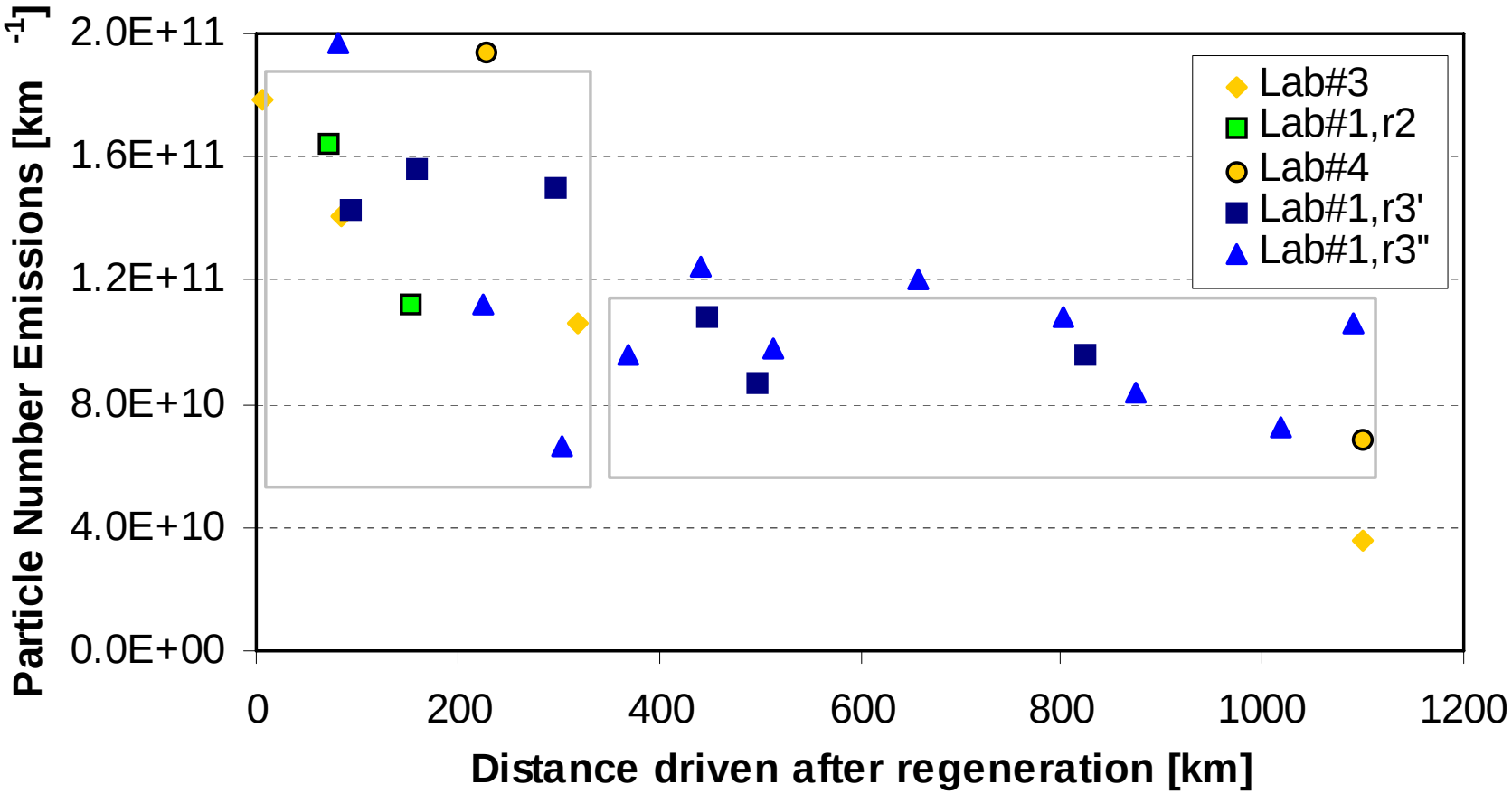
High CVS background



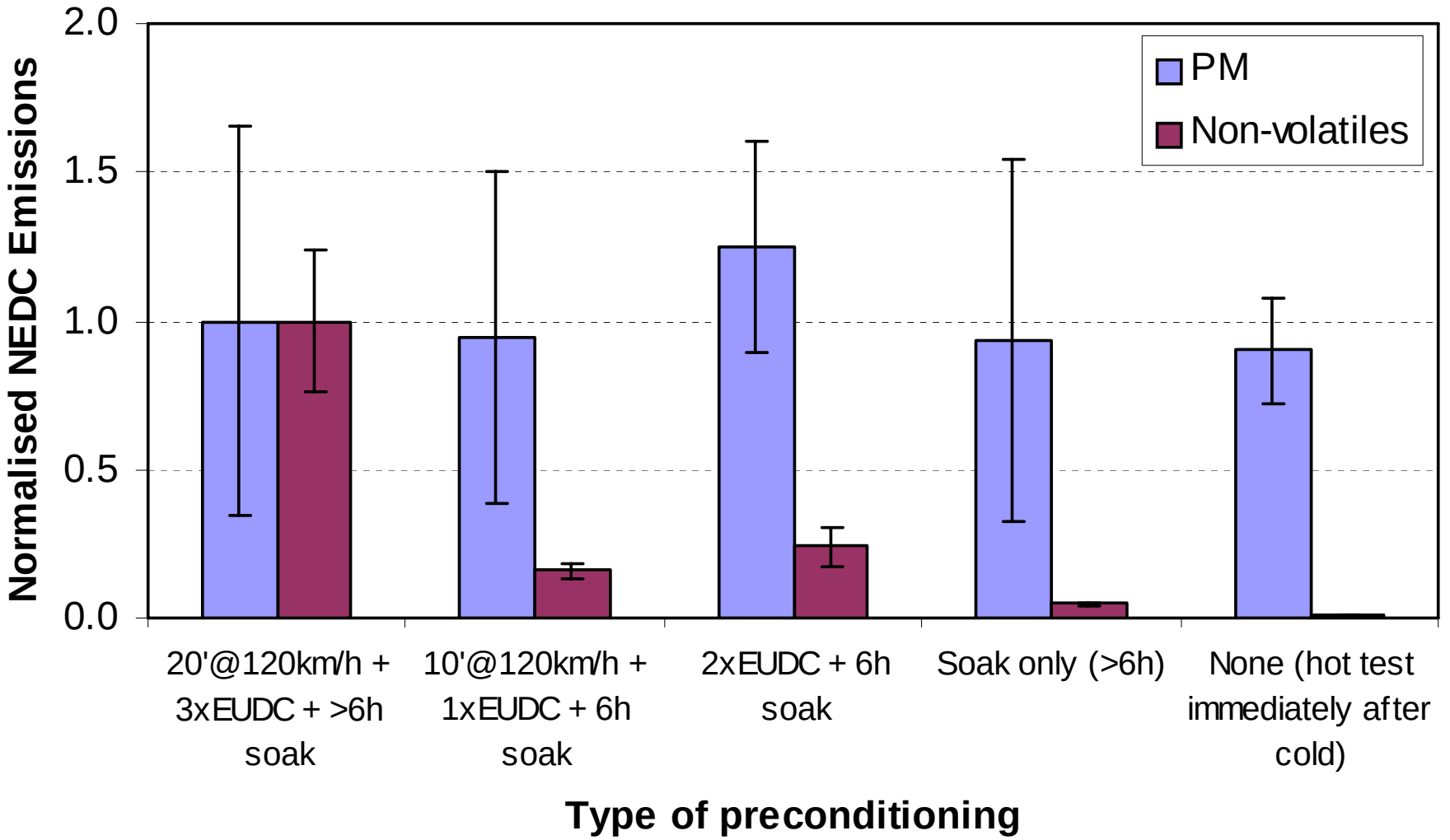
Timetable

No	Address:	PMP testing weeks:
1	**JRC (Ispra, Italy)**	November 04
2	AVL MTC (Sweden)	December 04
	AEA Technology (UK)	*Calibration of Golden Measurement System*
3	Ricardo Consulting Engineers (UK)	February 05
4	RWTÜV (Essen, Germany)	March 05
5	Lab of Applied Thermodynamics (LAT) (Greece)	April 05
6	**JRC (Ispra, Italy)**	May 05
	AEA Technology (UK)	*Calibration of Golden Measurement System*
		June- Transfer to Japan
7	NTSEL, Japan	July 05
8	National Motor Vehicle Emission Research Laboratory, Korea	September 05
		End September 05 – Transfer to Europe
9	Shell Global Solutions (UK)	March 06
10	UTAC (France)	May 06
	AEA Technology (UK)	*Calibration of Golden Measurement System*
11	**JRC (Ispra, Italy)**	June 06
	1st DRAFT FINAL REPORT	*September 06*
	AEA Technology (UK)	*Calibration of Golden Measurement System*
	2nd DRAFT FINAL REPORT	*January 07*
12	CARB, USA	Feb 07
	FINAL REPORT	*April 07*

Stabilisation Distances



Pre-conditioning effect (Blow out)



Pre-conditioning effect (Blow out)

Mass comparisons