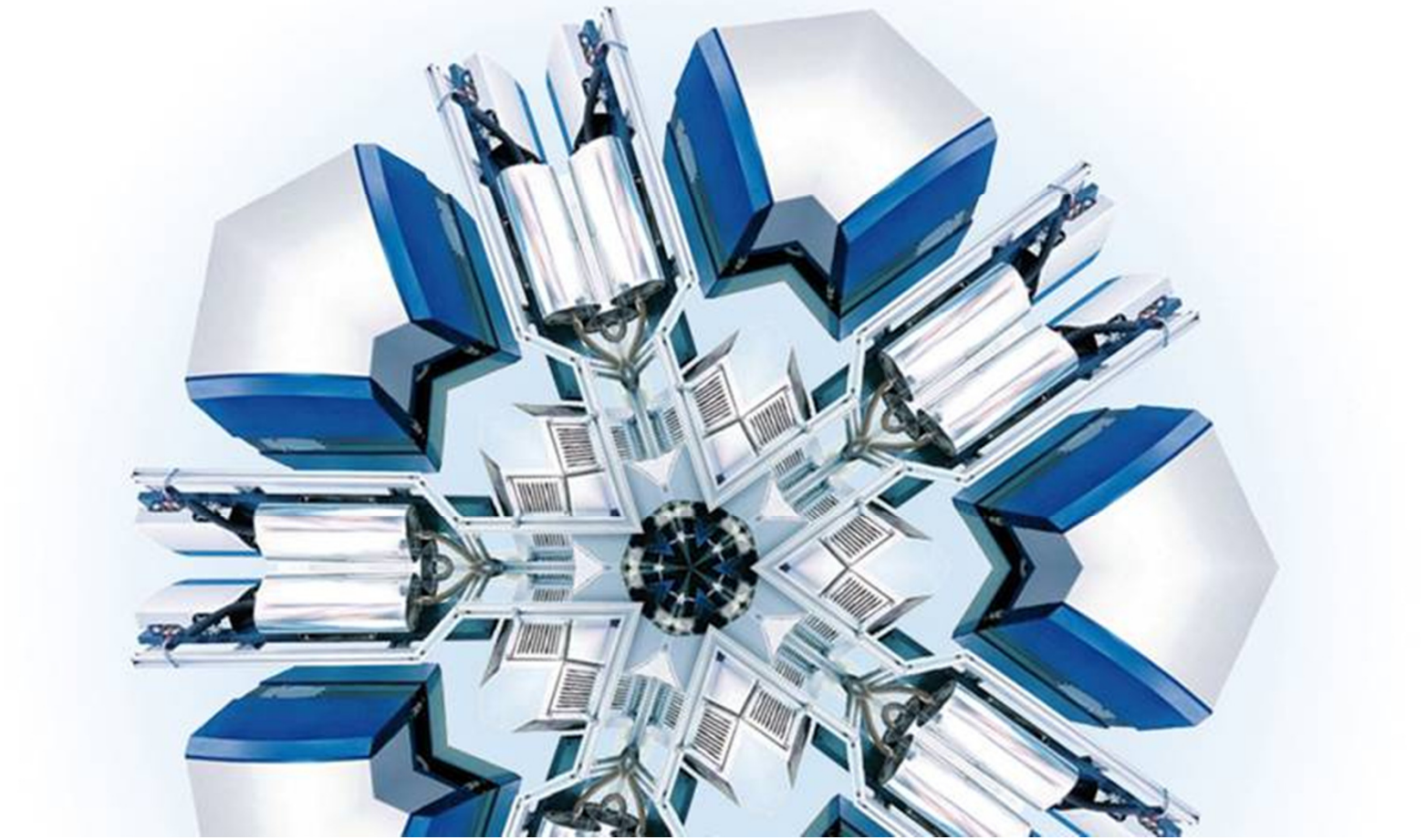
The AVL Particle Counter: APC 489

Experience from VPR and PNC validations

06.12.2011



Outline

Introduction

PNC calibration / validation / check

VPR calibration / validation / check

Conclusions

Past and present

AVL has reported some issues

PNC

- Linearity
- Drift
- CAST and Emery oil differences at 23 and 41 nm

VPR

- Calibration procedures

New topics

- Validation procedures and on-site checks

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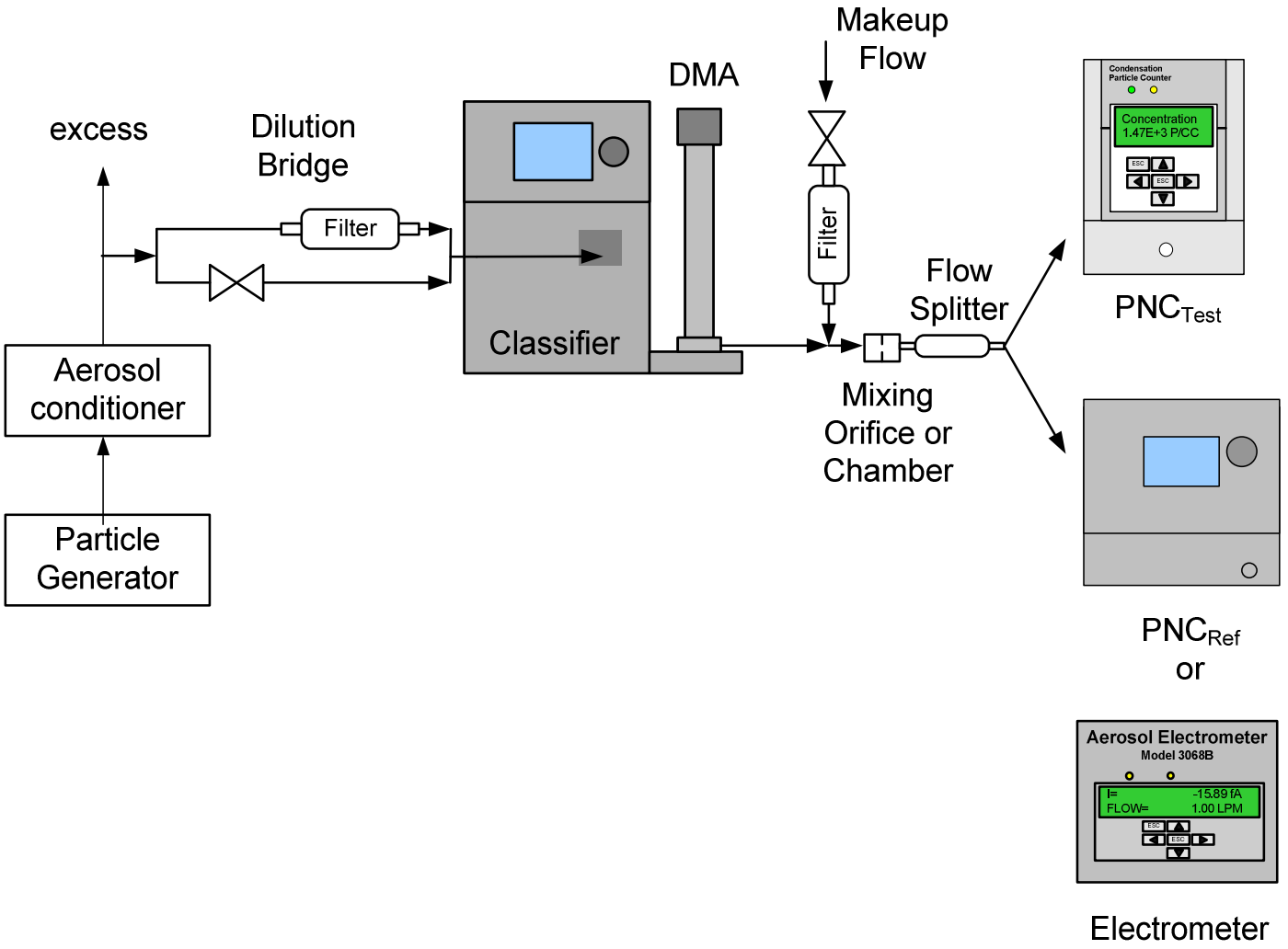
PNC calibration / validation / check

VPR calibration / validation / check

Conclusions

PNC (CPC) calibration / validation setup

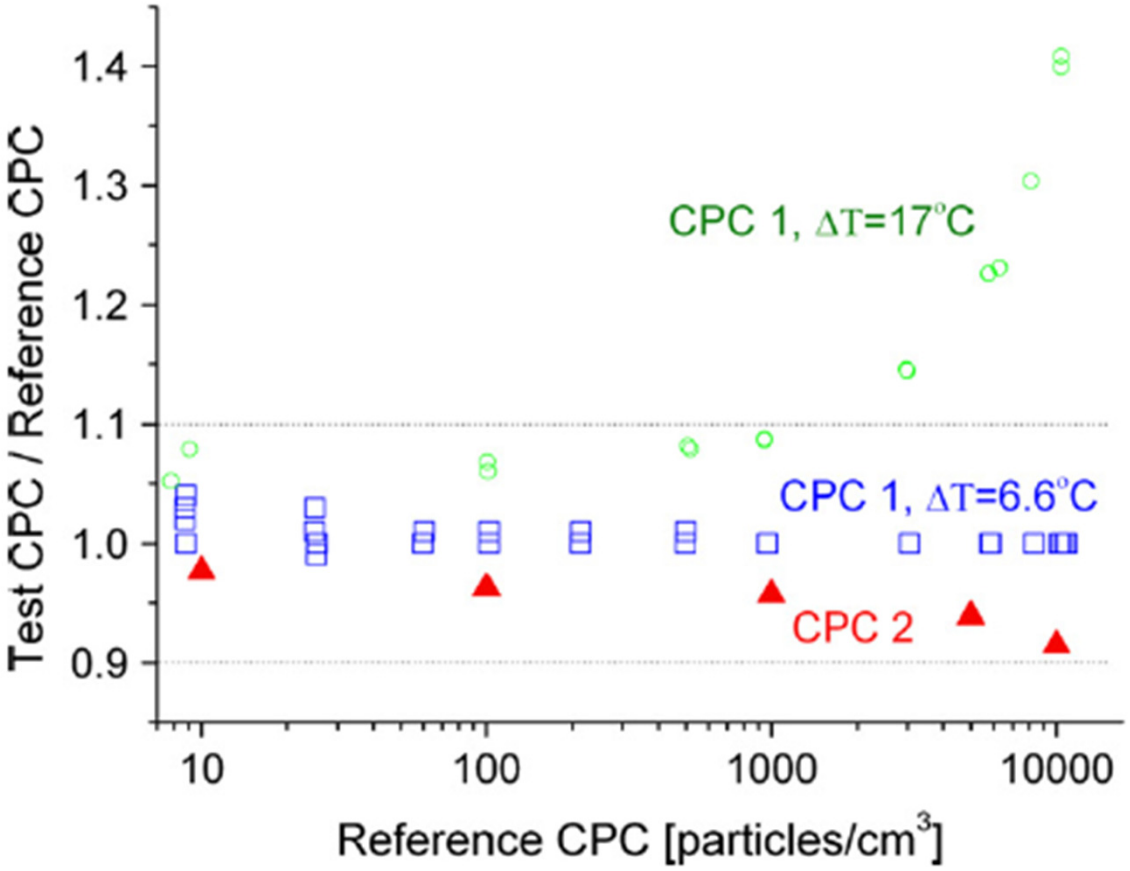


Secondary method
(used by AVL)

Primary method

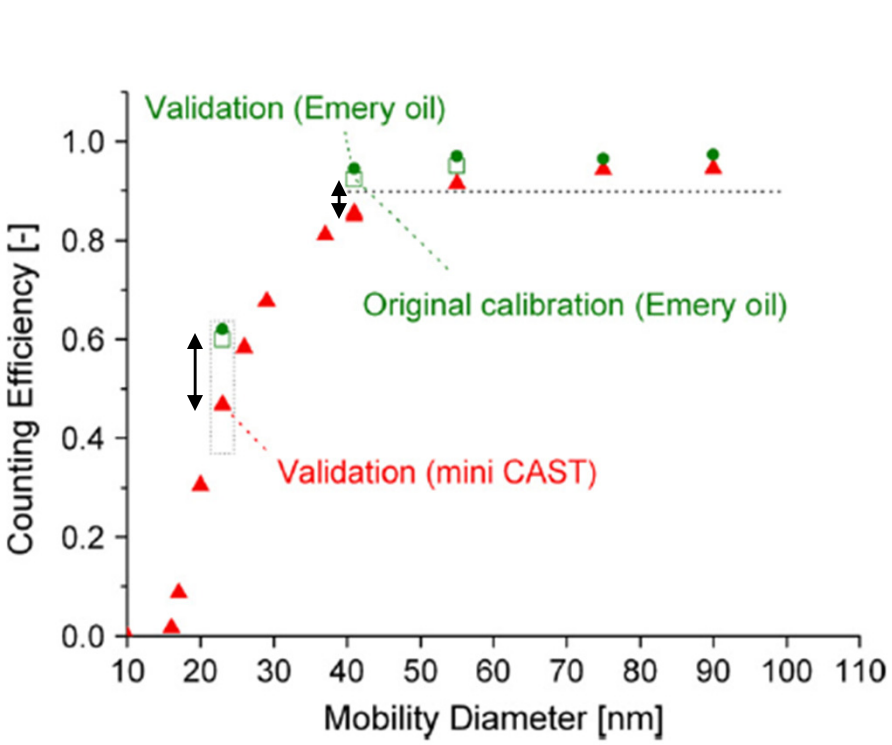
AVL experience

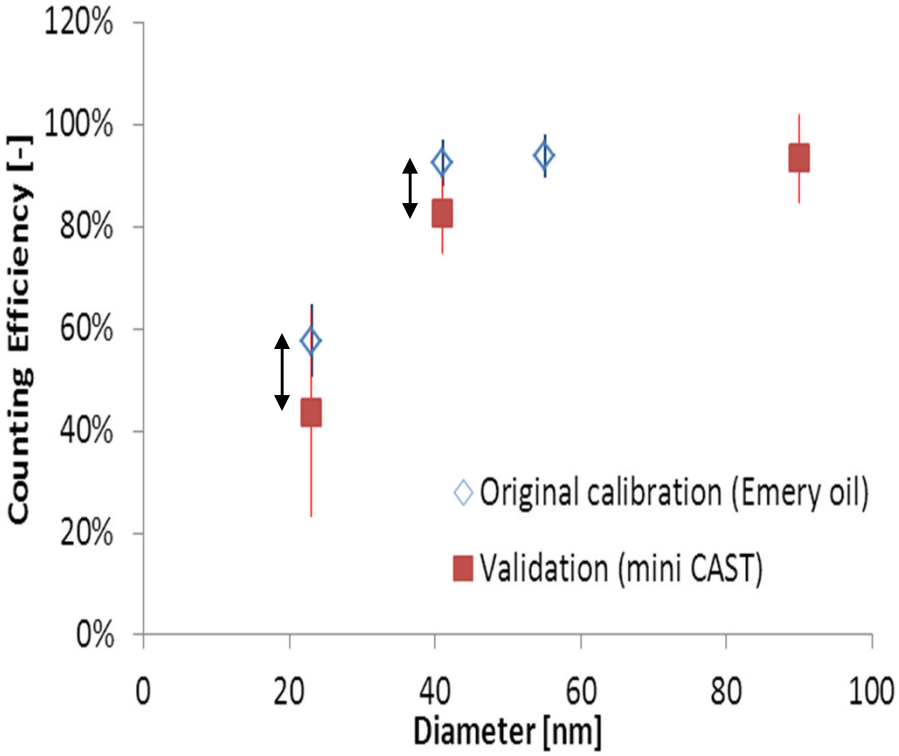
- Non-linearity has been reported for the 3790 (and 3772)
- AVL experience from validations of >40 3790s shows that the non-linearity is usually within +/-3% (or +/-7% with 2 σ).
- This means that max and min concentrations differ by 3% or 7% sometimes



Giechaskiel and Bergmann 2011, JAS, 42, 195-203

AVL experience





- Emery oil and CAST have differences
- Approximately 0.15 at 23 nm and 0.07 at 41 nm
- This difference should be taken into account in the validation of the CPCs
- The >40 validations confirmed this

AVL validations

Decision has to be made for pass / fail criteria corrections applied

no correction for material applied

slope, the most important value

k factor is included

TSI CPC Model 3790 Certificate of Validation

Serial number	70831244
Date	4-May-11

Test Aerosol: Soot (CAST) with thermal pre-treatment

Inlet Flow (Volumetric)		Units	Low Limit	High Limit
0.99	Inlet Flow Rate	l/min	0.95	1.05

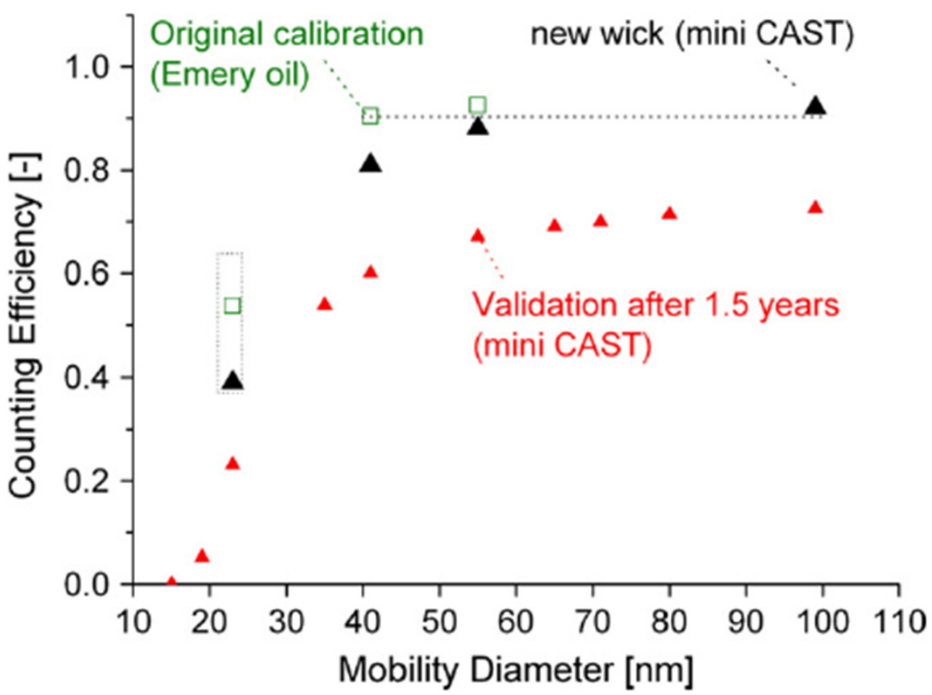
Temperature and Pressure		Units	Low Limit	High Limit
20	Room Temperature	℃	-	-
28	Room Relative Humidity	-	-	-
38.3	Saturator Temperature	℃	38	38.7
31.7	Condensor Temperature	℃	30.5	32
40	Optics Temperature	℃	39.8	40.2
33.6	Cabinet Temperature	℃	20	35
96.8	Ambient Pressure	kPa	88	108
74.6	Pressure Drop across Orifice	kPa	70	88
2.3	Pressure Drop across Nozzle	kPa	1.9	3.2

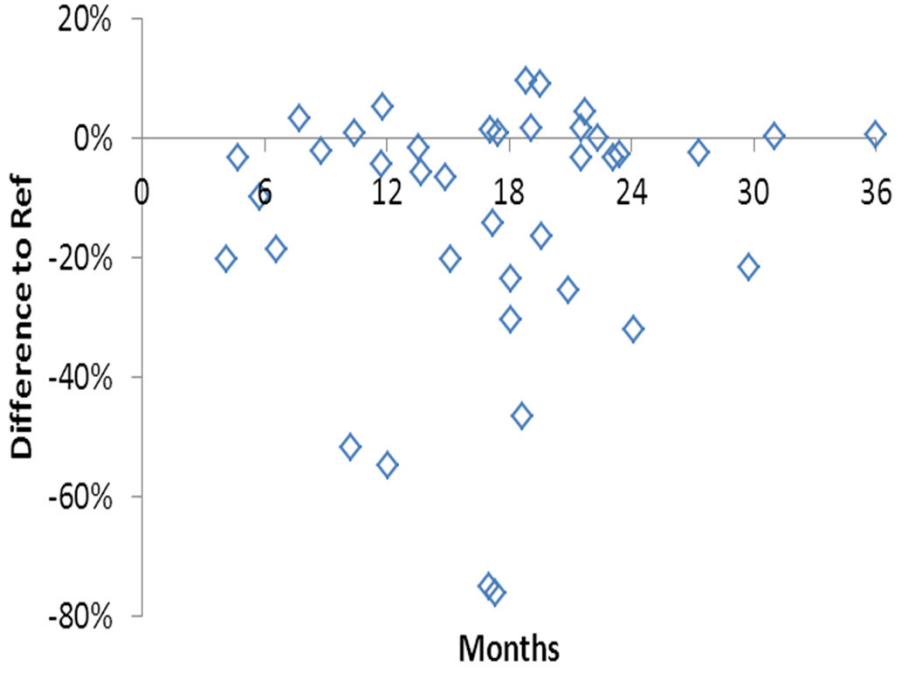
Lower Detection & Concentration Linearity Test Results		Units	Low Limit	High Limit
48.40%	23nm Particle Counting Efficiency	-	38%	62%
89.09%	41nm Particle Counting Efficiency	-	90%	-
98.48%	Linearity Test: Slope (up to 10000p/cm³)	-	90%	110%
1.0000	Linearity of Regression (R^2)	-	0.97	-
1.075	Internal k factor (taken into account)	-	0.9	1.1

Zero Count Test		Units	Low Limit	High Limit
0.001	Concentration Average over 3 Minutes	p/cm³	0	0.001

Linearity Response: CPC vs. Calibrated CPC 3790			Units	Low Limit	High Limit
-2.60%	10 p/cm³	CPC Concentration	% Diff	-10%	10%
-0.10%	100 p/cm³	CPC Concentration	% Diff	-10%	10%
0.50%	1000 p/cm³	CPC Concentration	% Diff	-10%	10%
-0.70%	5000 p/cm³	CPC Concentration	% Diff	-10%	10%
-1.30%	10000 p/cm³	CPC Concentration	% Diff	-10%	10%

Degrading over time





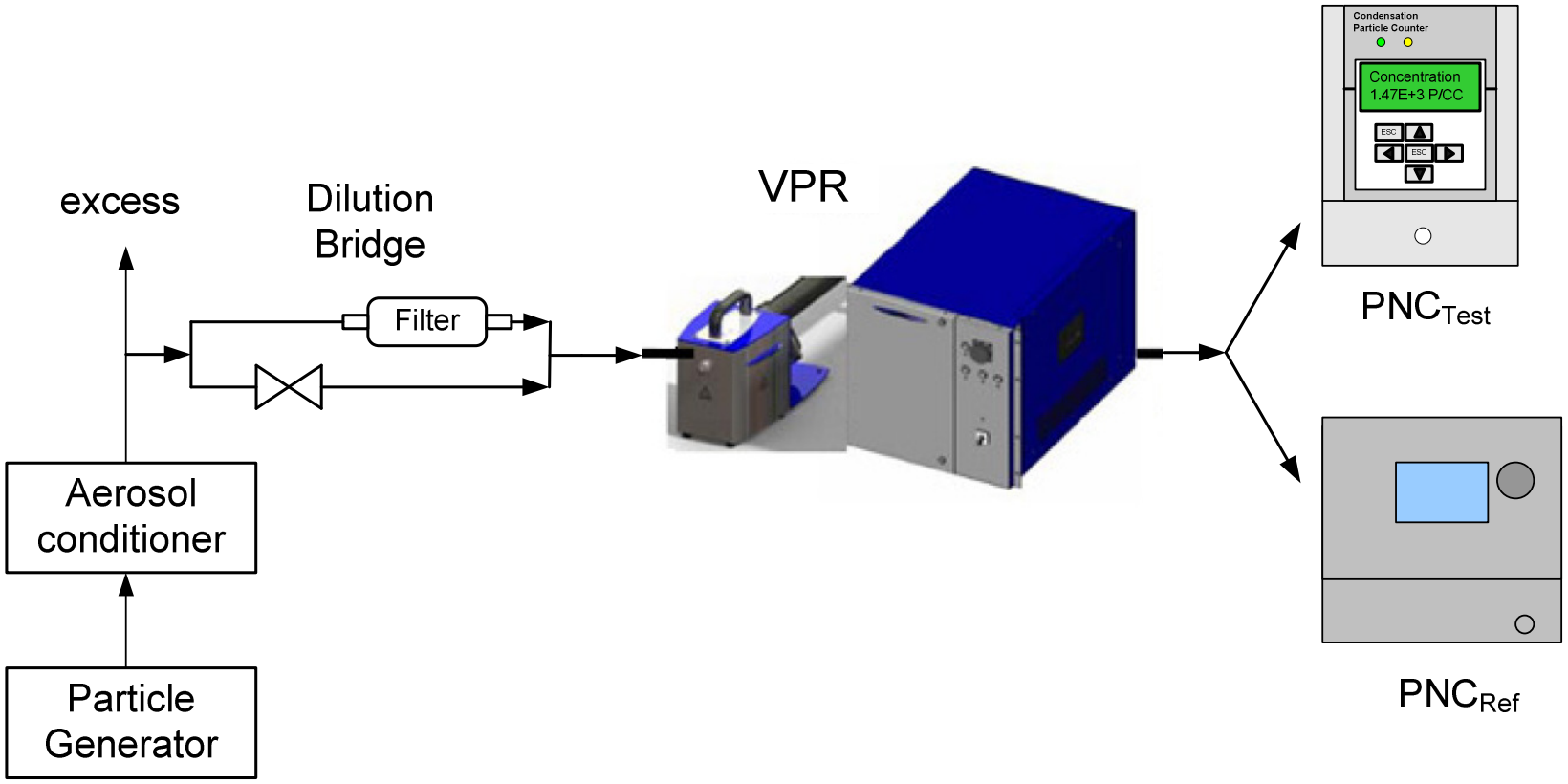
2 out of 5 drifted (40%)
The reason is the wick (where the super-saturation is achieved)
The critical point: **No light indicator identified this degrading**

New results:
15 out of 41 drifted (37%)

Giechaskiel and Bergmann 2011, JAS, 42, 195-203

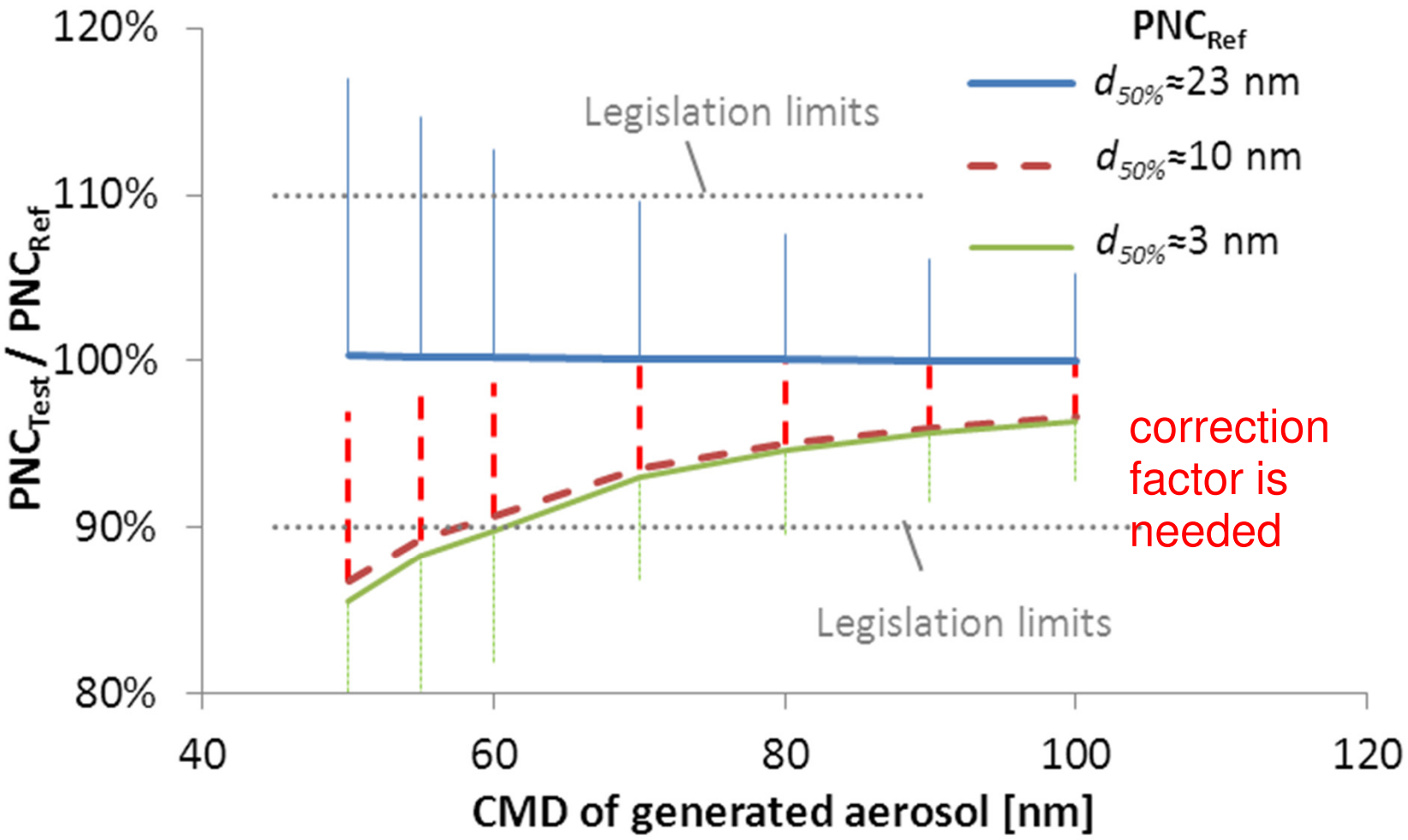
PNC (CPC) on site check

Soot generator
Ref PNC (d50=23 nm)
Linearity check

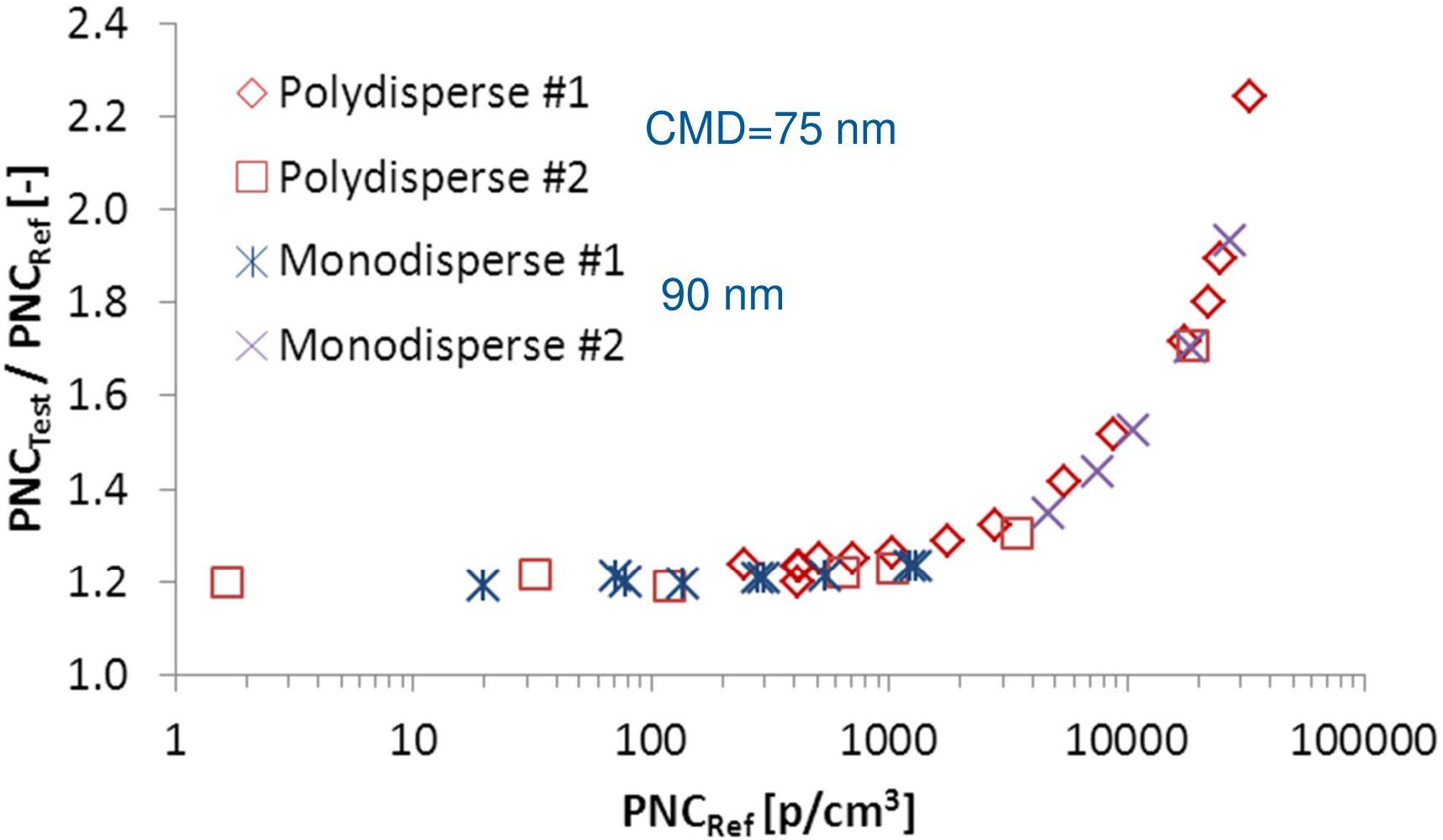


Giechaskiel and Bergmann 2012, submitted SAE World Congress

PNC polydisperse check (theoretically)



Equivalency of mono- and polydisperse checks (experimentally)



Conclusions PNC

Linearity of PNCs is very important. Although the results should be within +/-10%, for a specific PNC the difference between low and high concentrations should be within +/-5% (e.g. from -10% up to 0%).

From 41 CPC validation only a few had a non-linearity issue of 7%, the rest <3%.

Emery oil and CAST have different counting efficiencies. Differences are 0.15 and 0.06 for 23 and 41 nm particles respectively. This should be taken into account for the validations

Drift of PNCs 5-10% every 3-6% is common. From 41 CPC validations 15 (37%) drifted >20%.

Validations check PNC: flow, 23 nm, counting efficiencies, linearity and slope.

k factor should be taken into account or not?

The critical point for PN results is the slope. Flow? 23 nm? +/-10%

Conclusions PNC

The polydisperse on-site check was proven to be equivalent with the monodisperse calibration / validation

A soot generator that produces a size distribution with median around 70 nm and a reference PNC are only needed.

Open issue remains the results that have been conducted with ‘failed’ devices

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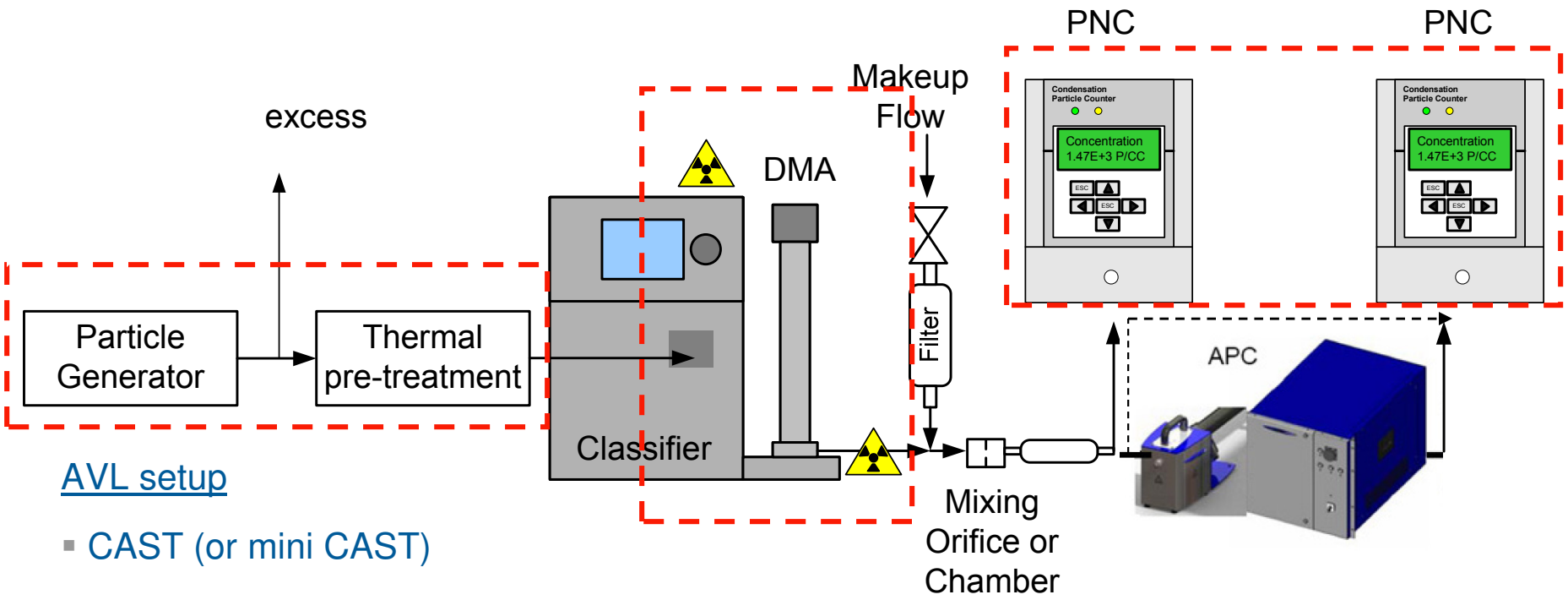
VPR calibration / validation / check

Conclusions

VPR calibration setup



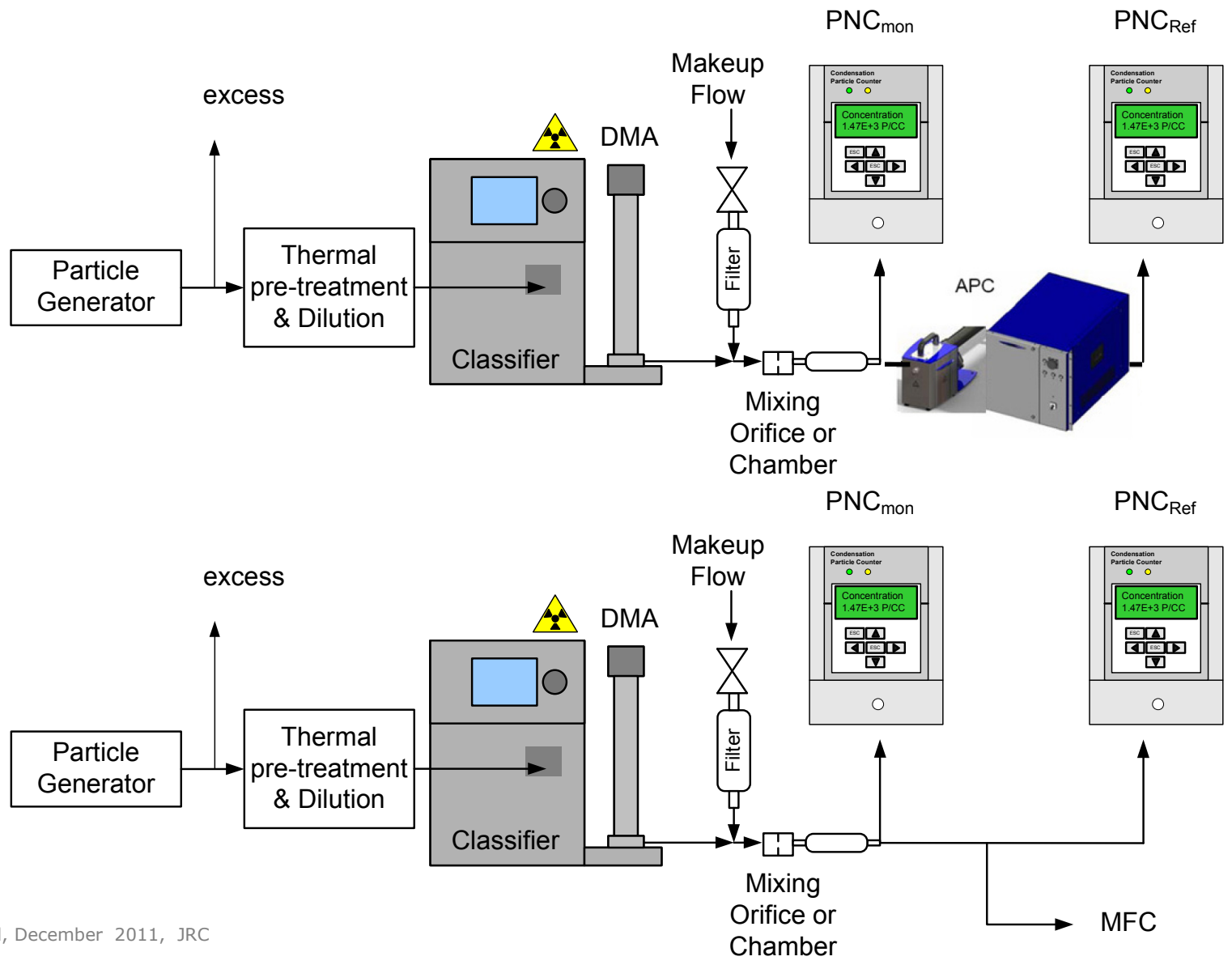
AVL setup

- CAST (or mini CAST)
- Thermal pre-treatment (350 °C)
- One neutralizer upstream (370 MBq)
- Reference PNC for monitoring stability of Generator
- Upstream / downstream same flow rates, correction for PNC inlet pressures
- PNCs with d50=10nm

$PCRF = N_{in} / N_{out}$

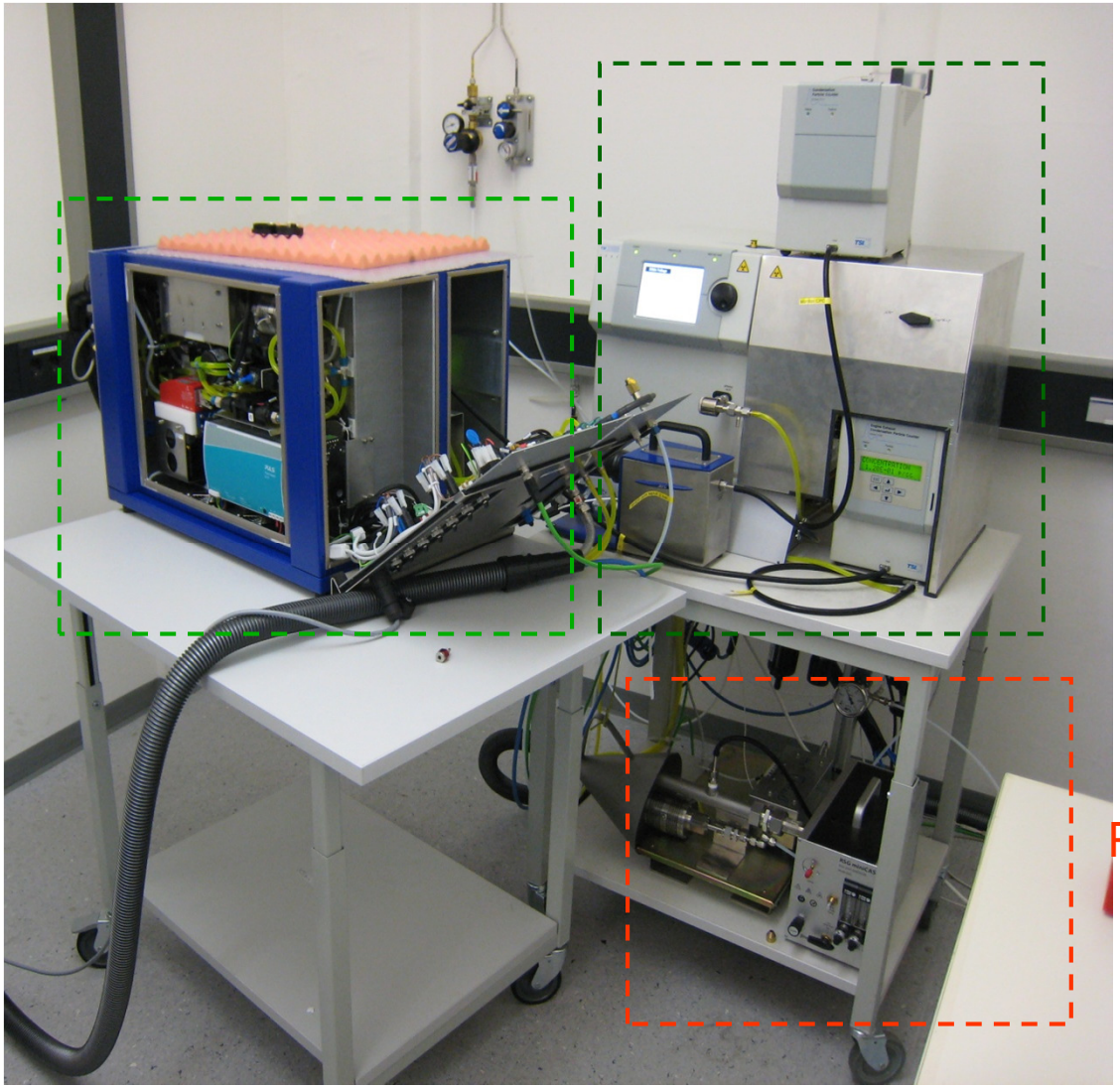
Giechaskiel et al. SAE 2009-01-1115
Giechaskiel et al. 2010, MST, 21, 045102

Calibration set up



VPR calibration setup

System under calibration



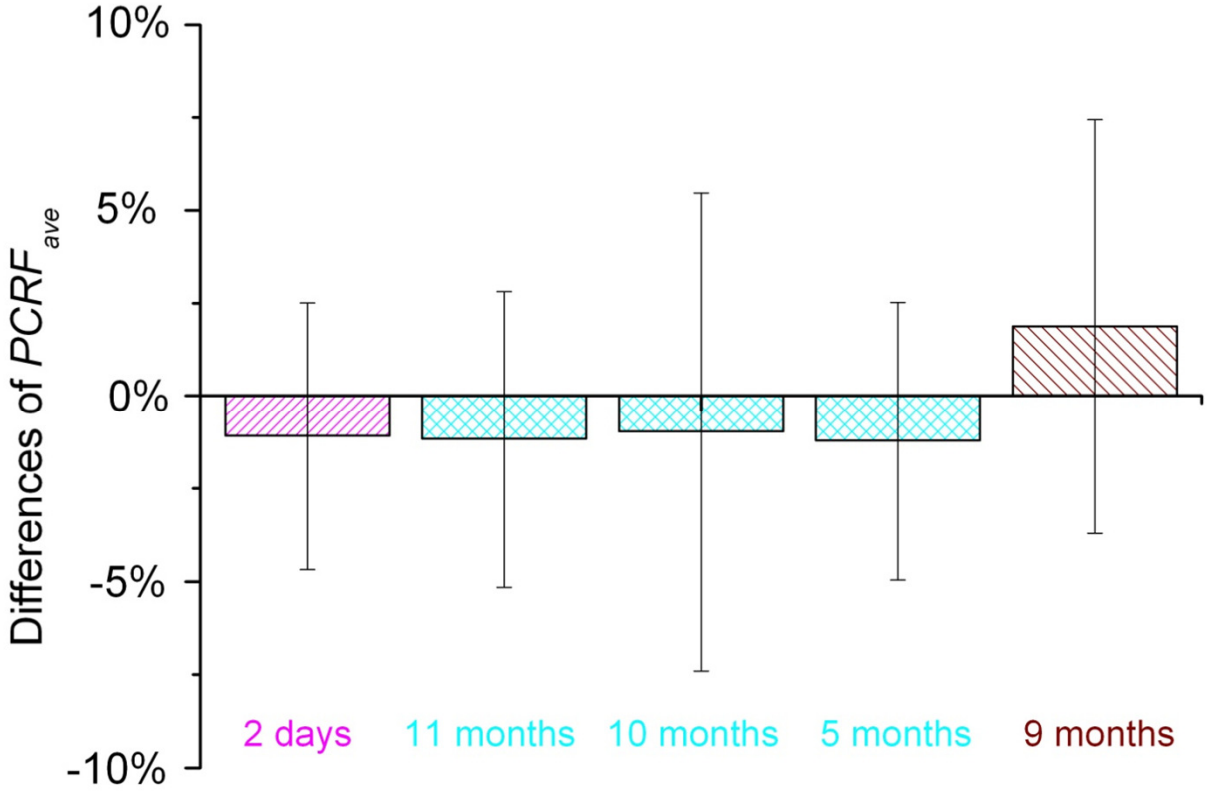
DMA and PNCs

Particle Generator (Mini CAST)

VPR calibration: Repeatability

Repeatability

95% of calibrations within ±6%



Recalibration of five VPRs (APCs from AVL) units after two days (no modification), after 5-11 months (guidance rods and springs were changed) and after 9 months (rotating disk also changed).
Error bars show 2 standard deviations.

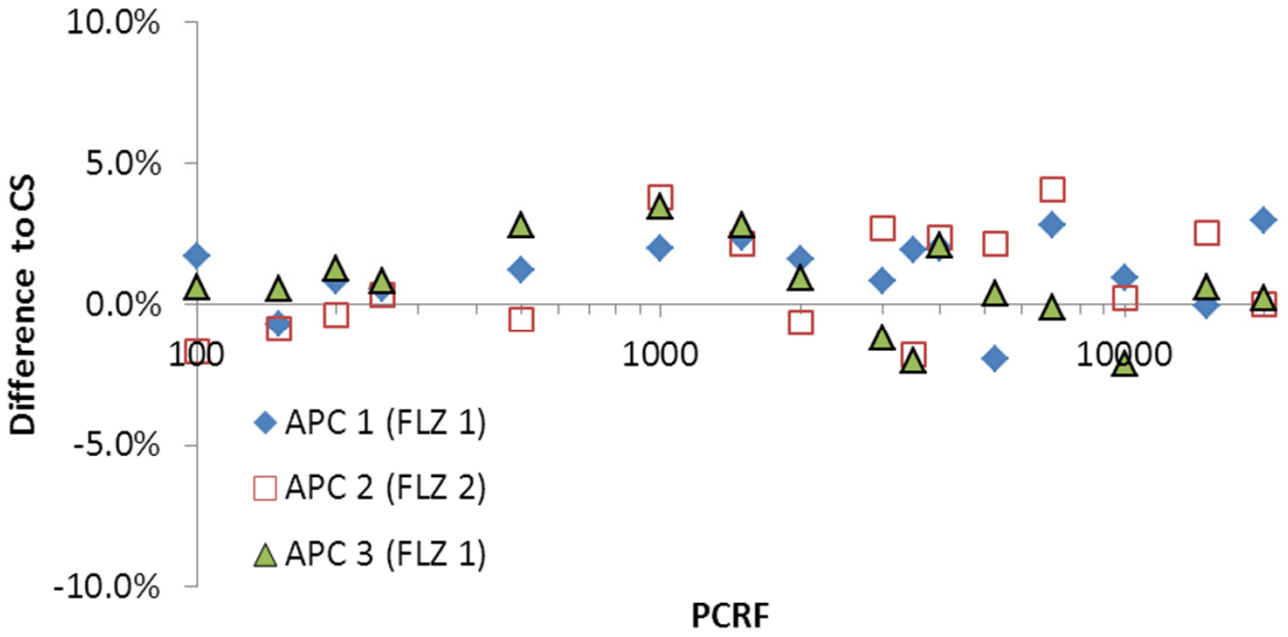
Giechaskiel et al. 2010, MST, 21, 045102

Comparison of AVL's calibration lines

CS: Repair center

FLZ 1: Production 1

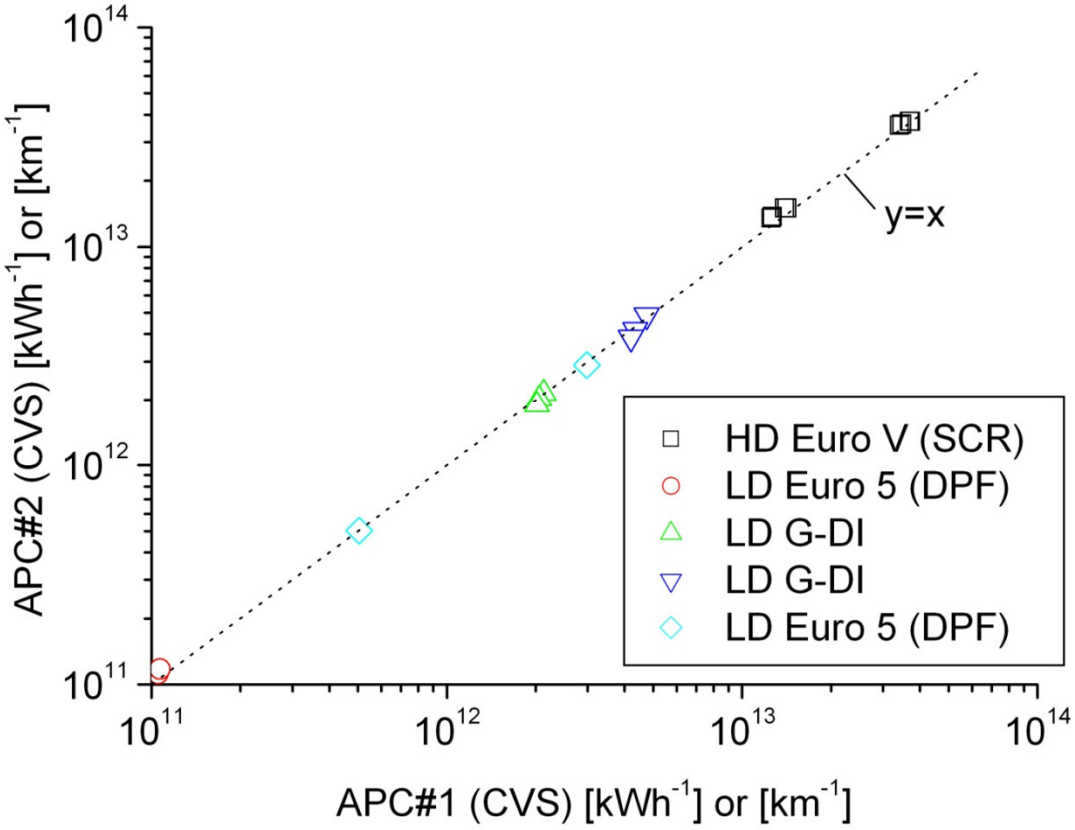
FLZ 2: Production 2



Three APCs were calibrated either at the CS (repair center) or the production lines 1 (FLZ 1) and 2 (FLZ 2). The mean differences were 1% and the 95% of the differences within 4%.

Comparability of APCs

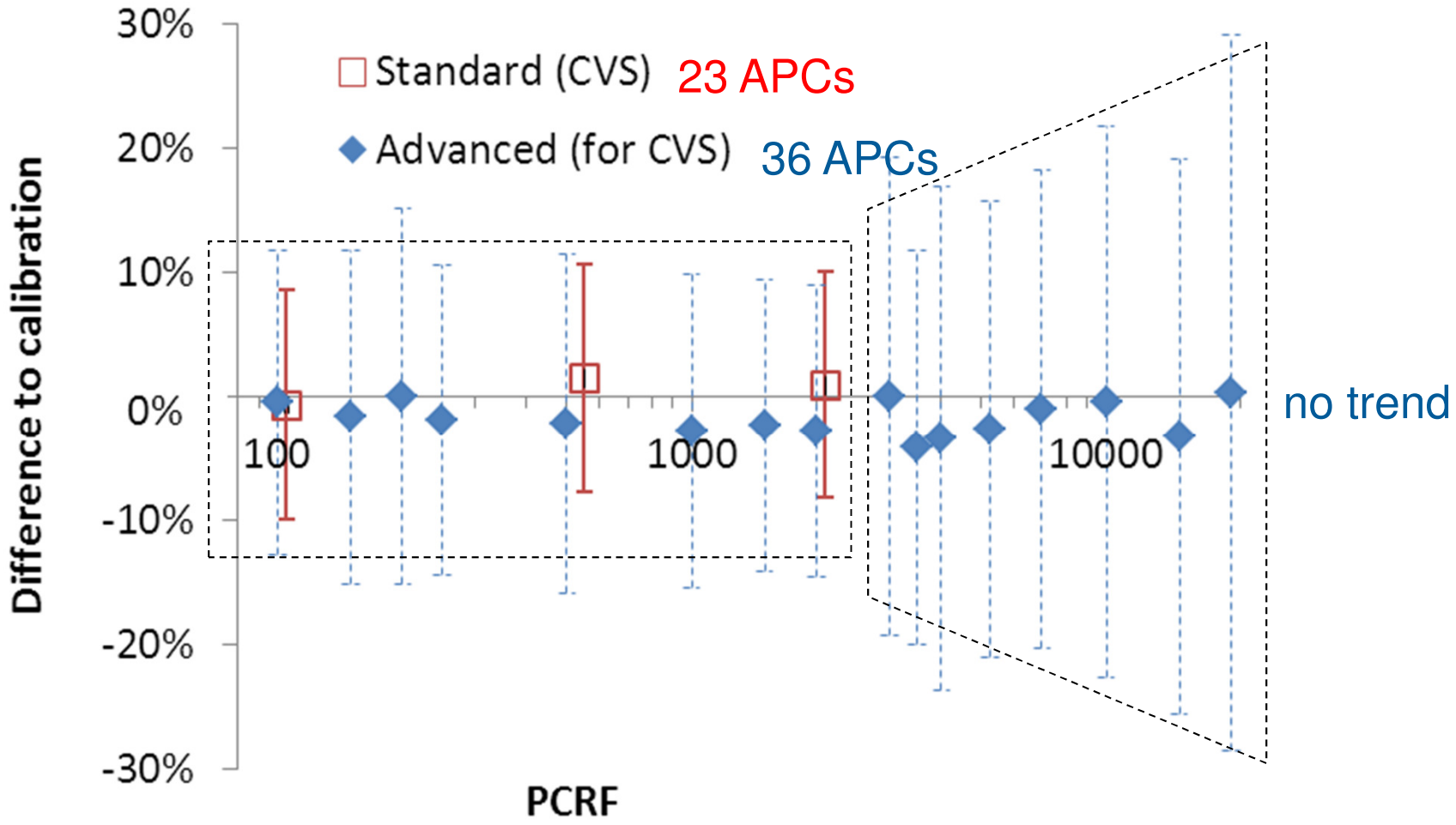
- Two well calibrated systems of the same manufacturer (AVL) on average <4% difference
- 95% of differences within ±10%



Comparison of two PN systems (APCs from AVL) both connected to the CVS for one heavy duty engine (different test cycles) and two different APCs for four different light duty vehicles (for the NEDC cycle).
HD=Heavy Duty, LD=Light Duty, SCR=Selective Catalytic Reduction for NOx, DPF=Diesel Particulate Filter, G-DI=Gasoline Direct Injection.

Giechaskiel et al. 2010, MST, 21, 045102

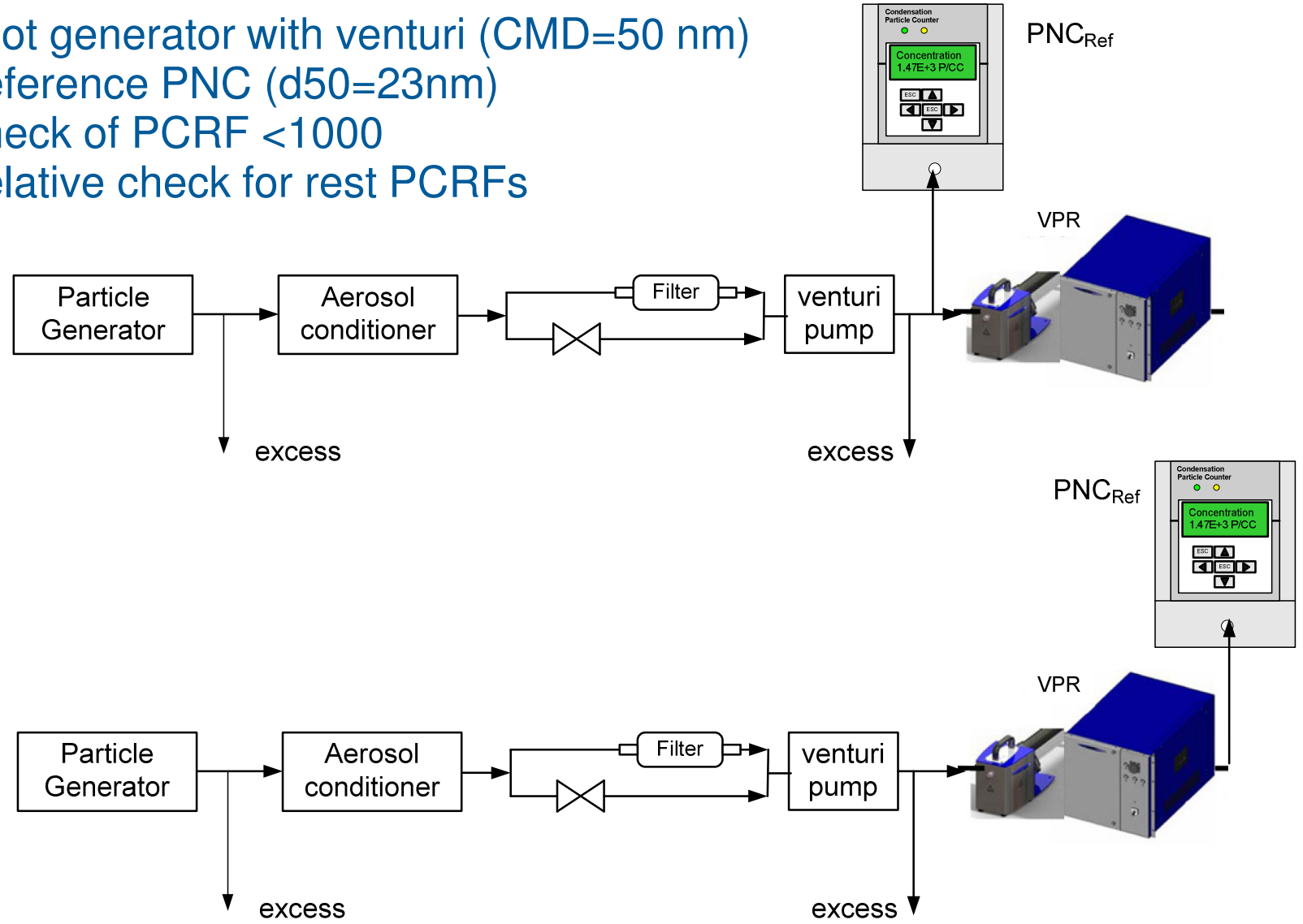
Validations



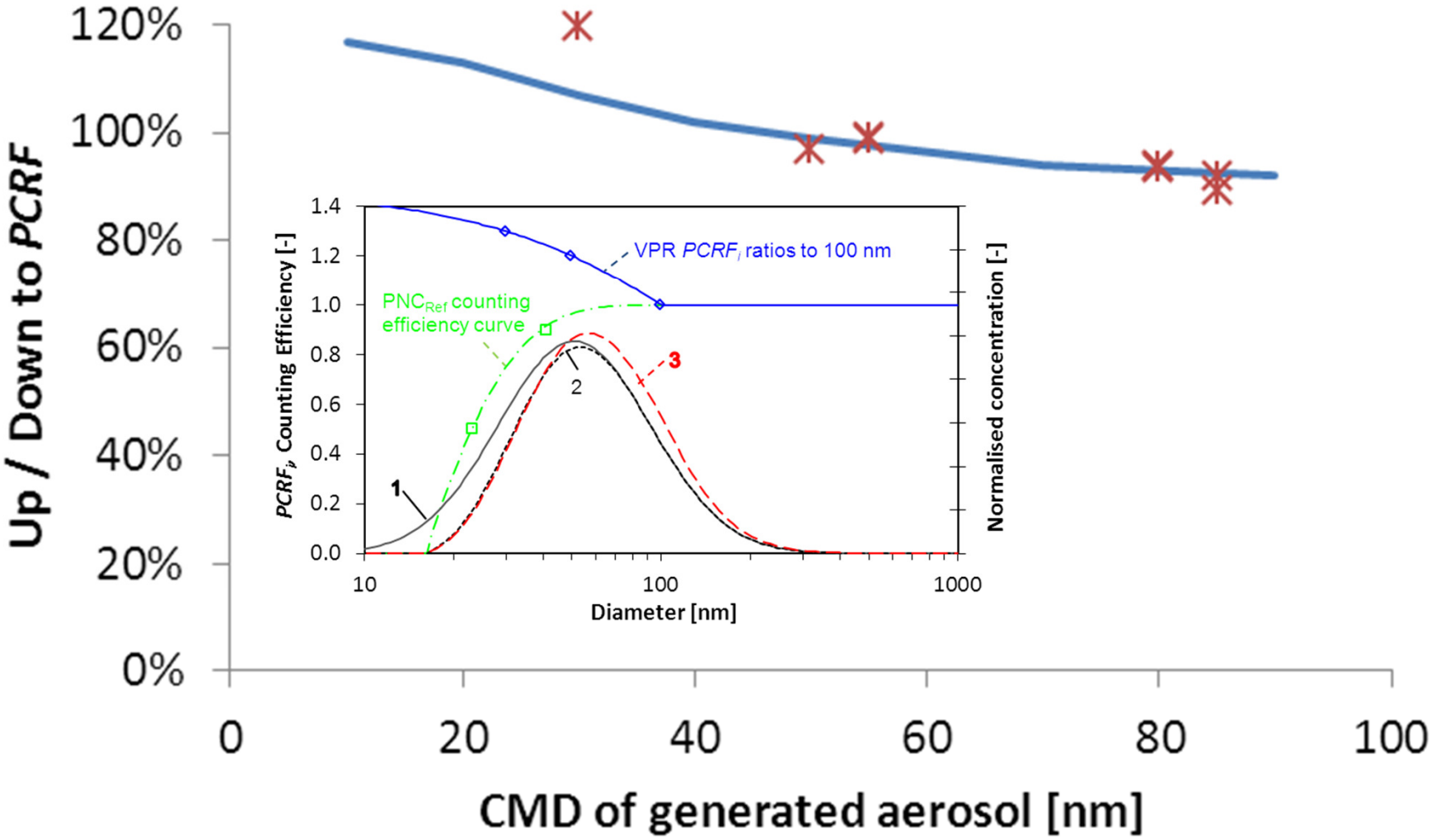
Recalibration of five VPRs (APCs from AVL) units after many months of use at the CVS
Error bars show 2 standard deviations.

VPR on site check

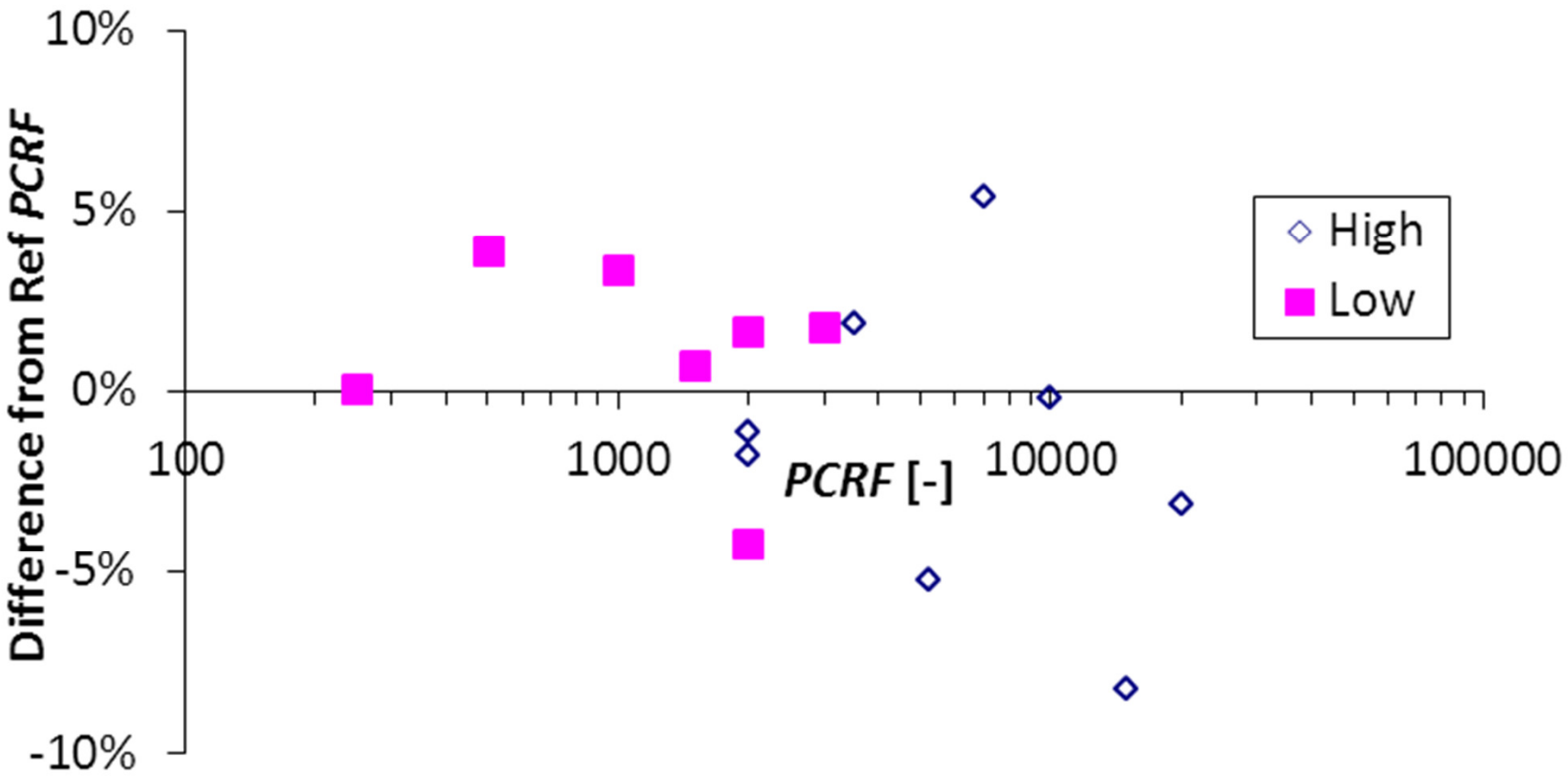
Soot generator with venturi (CMD=50 nm)
Reference PNC (d50=23nm)
Check of PCRF <1000
Relative check for rest PCRFs



Theoretical polydisperse PCRF



Relative checks of PCRFs



VPR conclusions

AVL calibration procedure (CAST with thermal pre-treatment, one neutralizer, monitor PNC, single PNC method with d50=10 nm). The thermal pre-treatment is important

AVL calibration procedure has +/-6% uncertainty (95% of calibrations).

Comparison of two APCs from the the CVS should have less than 5% differences (+/-10%, 95% of the comparisons)

Validation of 60 units showed that there was no drift and

The uncertainty is +/-10% for low PCRFs (<2000) but can reach 30% at very high PCRFs (20000)

On site PCRF check is possible with a reference PNC (d50=23 nm). The generated polydisperse size distribution should have a median of 50 nm.

For higher PCRFs the relative check is recommended (to avoid the 30% uncertainty)

How previous results from failed VPRs are treated?