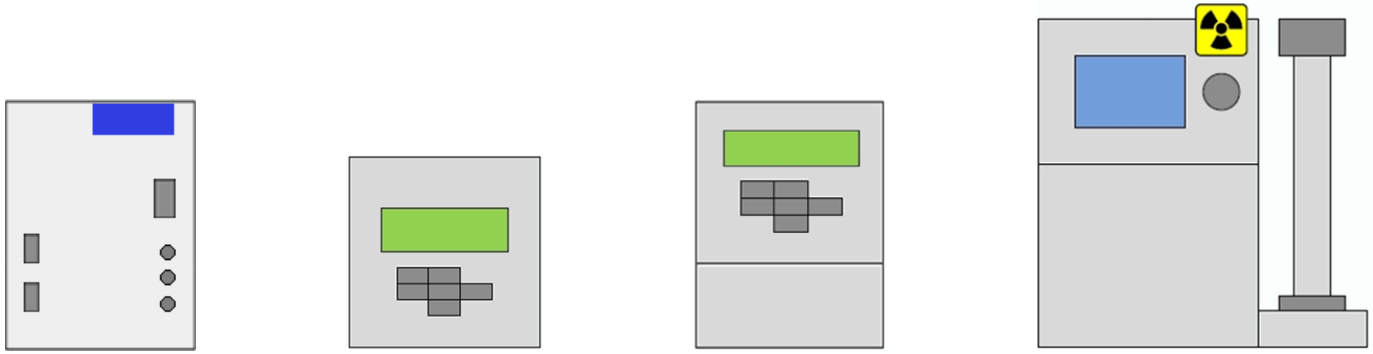
Inter-Laboratory Comparison Exercise
CPC CALIBRATION

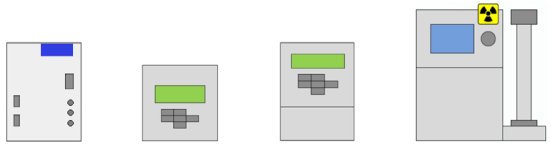
CALIBRATION AEROSOLS AND LABORATORY SETUPS

First Results

2017-03-15
Alexander Terres

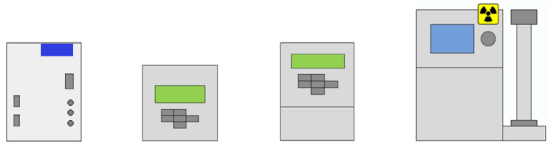


CONTENTS



- Overview of participating laboratories
- Applied data correction procedure
- 23nm CPC calibration
  - Material comparison
  - Laboratory comparison
  - Device comparison
- Flow measurement
- 10nm challenges

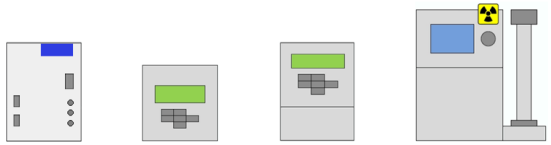
LABORATORY OVERVIEW, SCHEDULE



TIME	LABORATORY	Type
02 / 2016	TSI Germany	Instrument Manufacturer
03 / 2016	JRC	Research Institute
04 – 05 / 2016	AVL Austria	Instrument Manufacturer
06 – 07 / 2016	PTB	National Metrological Institute
07 – 08 / 2016	BMW	Vehicle Manufacturer
09 – 10 / 2016	Ricardo Energy & Environment	Calibration Service
11 / 2016	VW	Vehicle Manufacturer
12 / 2016	TSI Germany	Instrument Manufacturer

All tests are finished!

COMMON DATA CORRECTION



Measurement

- Recording uncorrected **Raw Data**
- No K-factor on devices under test
- Averaging time: 60-240 seconds

Reference

- K-Factor for Reference Device (if available)
- K-Factor **includes flow correction** for Reference

Flow

- Correction: **Nominal / actual Flow**
- Flow measurement type: Volume or Mass

AEM Zero

- Only when reference is Aerosol Electrometer (AEM)
- Correction for **Zero Current**

Charges

- Only when reference is AEM
- Correction for **double charges** only
- Charge distribution: Wiedensohler **OR** measured
- No correction <23nm

COMMON DATA CORRECTION: ISSUES

Measurement

- Recording uncorrected **Raw Data**
- No K-factor on devices under test
- Averaging time: 60-240 seconds

Reference

- K-Factor for Reference Device (if available)
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- No correction <23nm

No Splitter Bias, ≠ ISO 27891

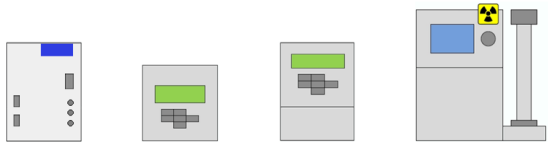
Few stability issues with APG due to strong contamination

Measurement frequency
Recommendation: before and after test

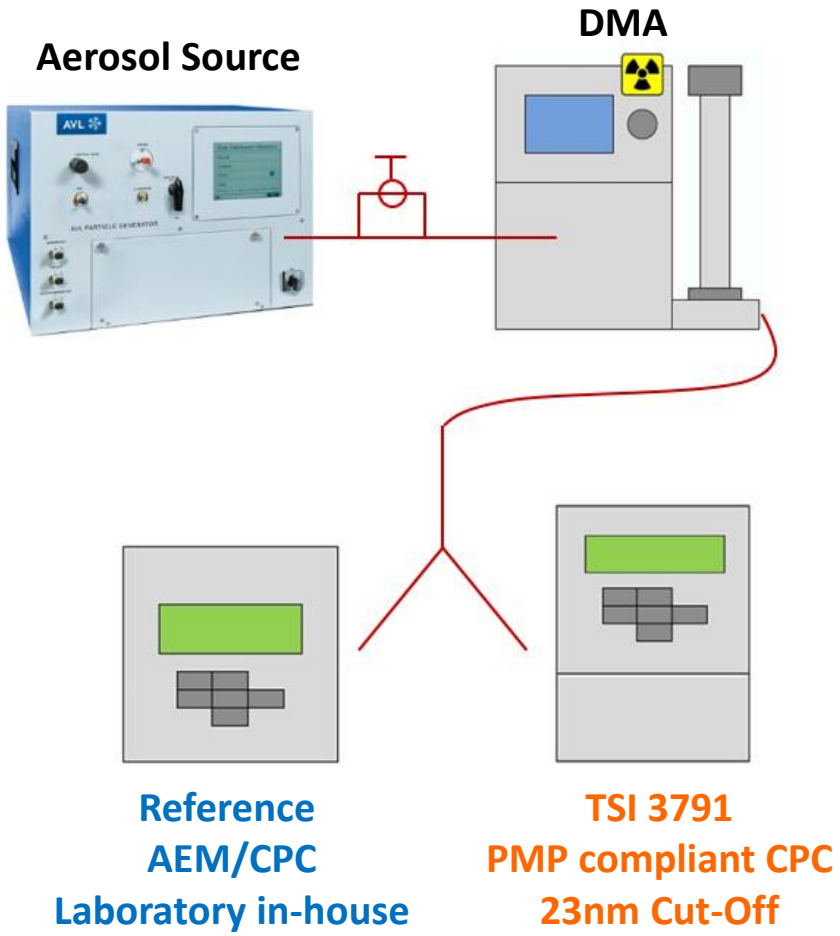
Measurement frequency
Recommendation: alternating measurem

Large influence of correction
Material dependence

23NM CPC CALIBRATION



Example Setup



Calibration of a PMP-compliant engine exhaust CPC

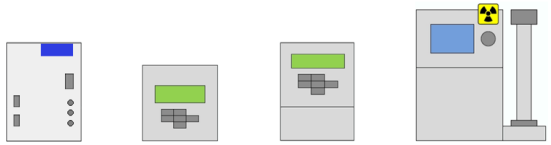
5 different Aerosols:

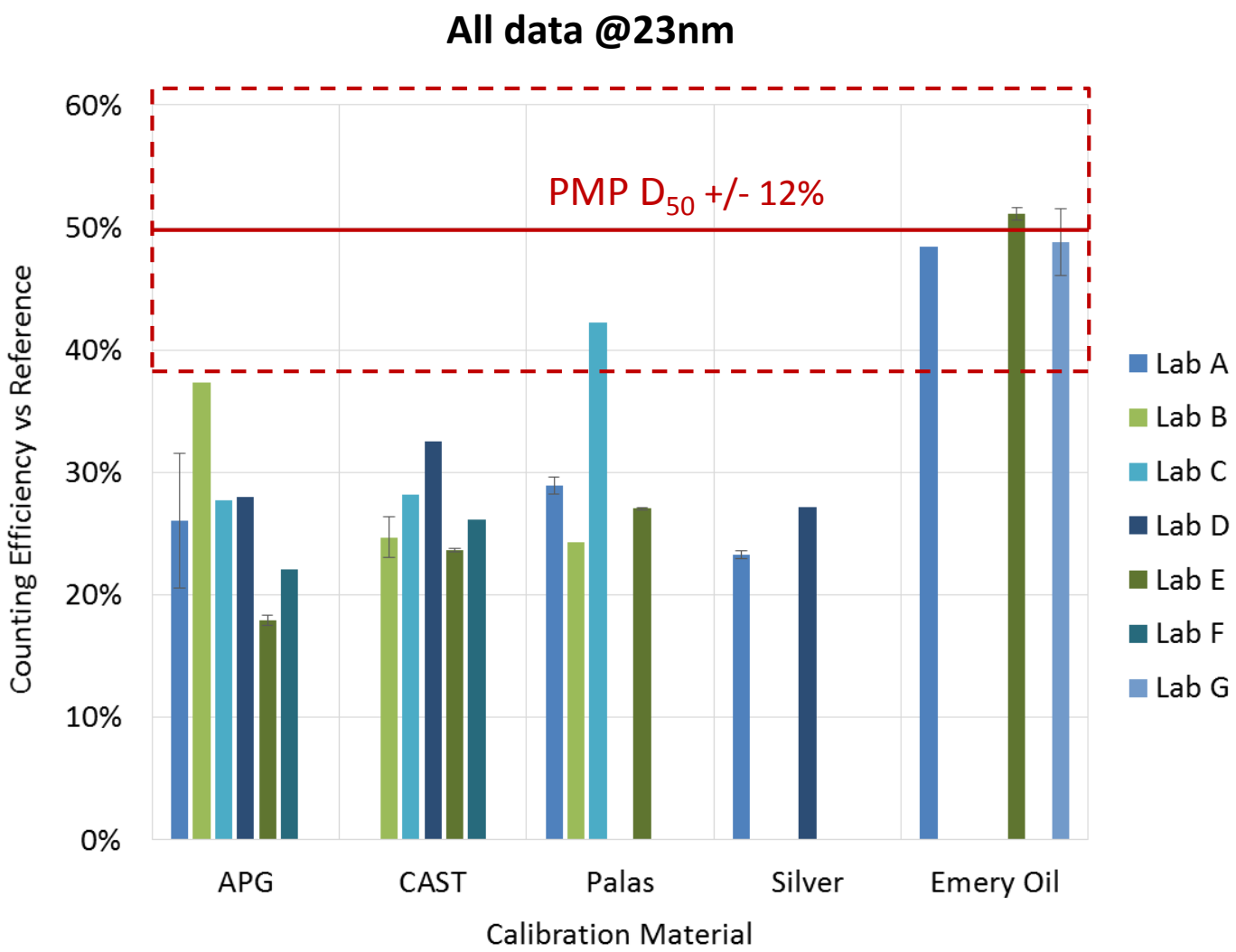
- **APG** AVL Particle generator (circulated)
- **CAST** (in-house)
- **Palas** (in-house)
- **Silver** (in-house)
- **Emery Oil** (in-house)

7 laboratories

7 In-house reference devices (AEM or CPC) and setups

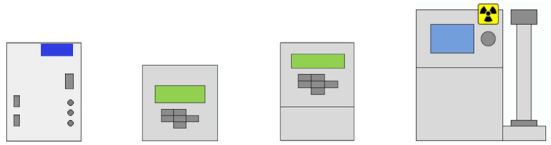
23NM CPC CALIBRATION: MATERIAL

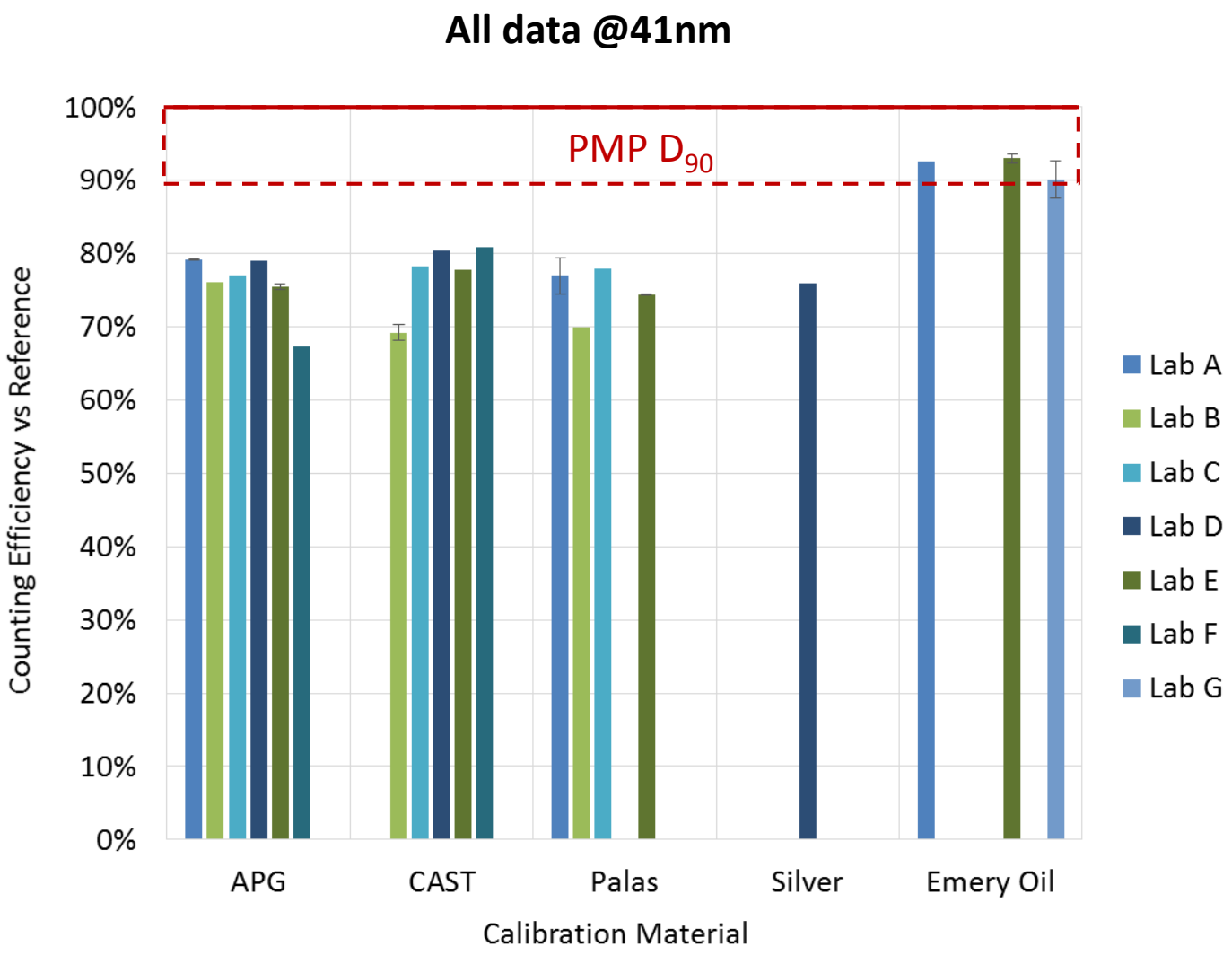




- All Data submitted by the labs for 23nm
- Corrected as described
- Several tests for one lab -> error bar
- Error bar is no quality indicator because of different testing scenarios

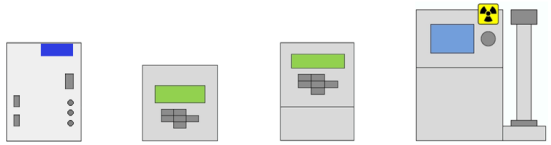
23NM CPC CALIBRATION: MATERIAL

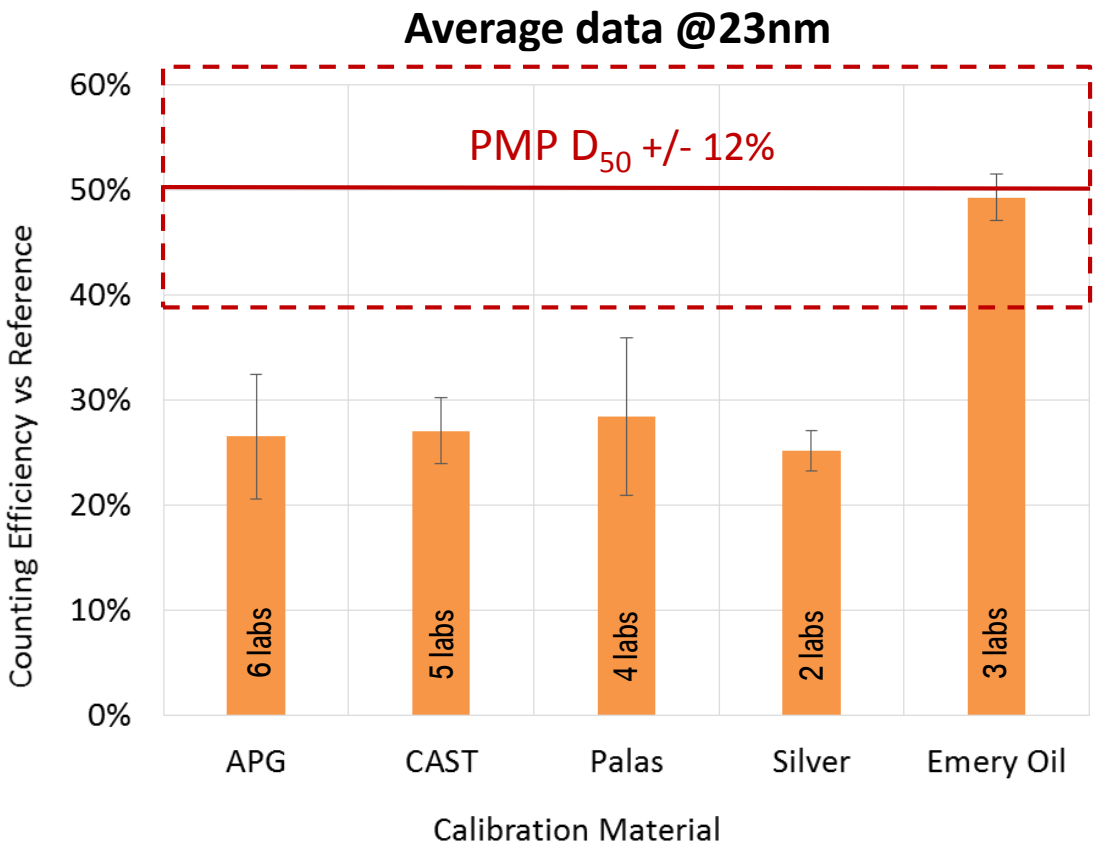


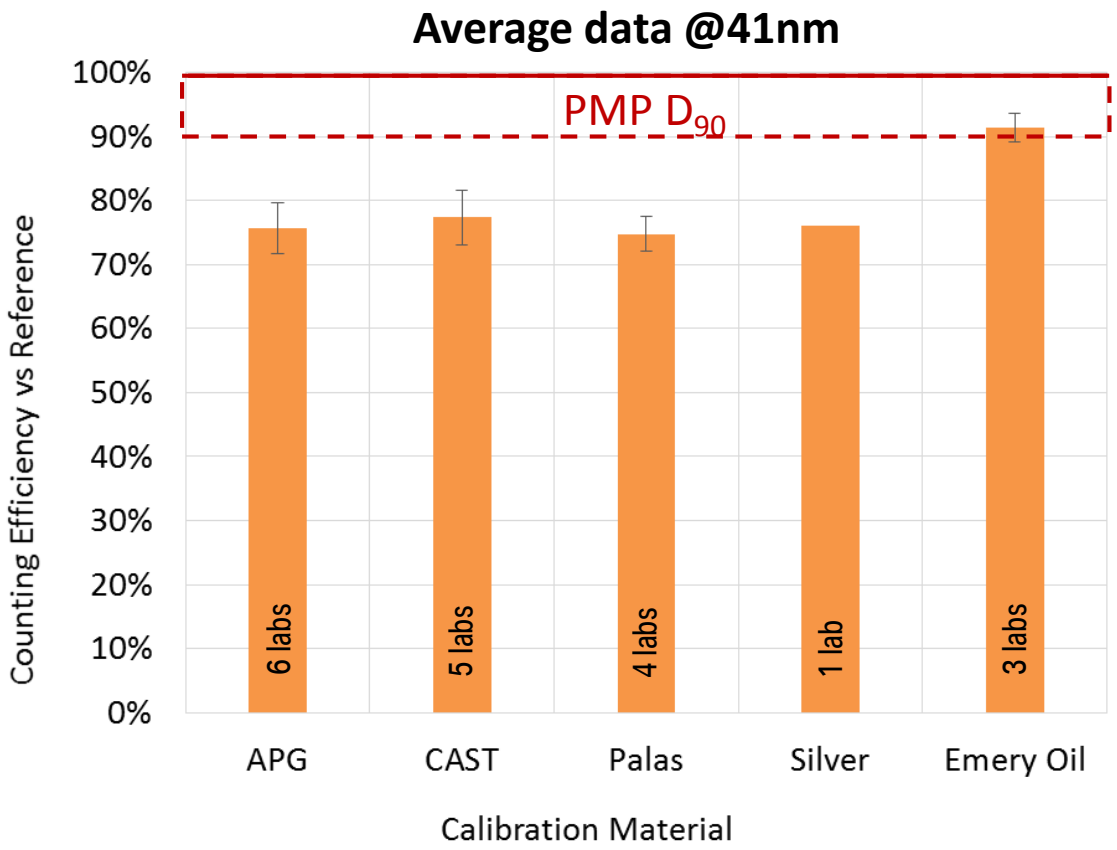


- All Data submitted by the labs for 41nm
- Corrected as described
- Several tests for one lab -> error bar
- Error bar is no quality indicator because of different testing scenarios

23NM CPC CALIBRATION: MATERIAL



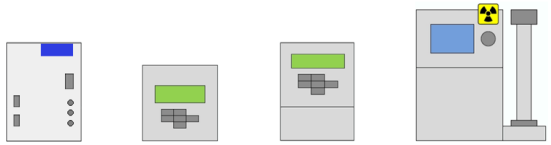


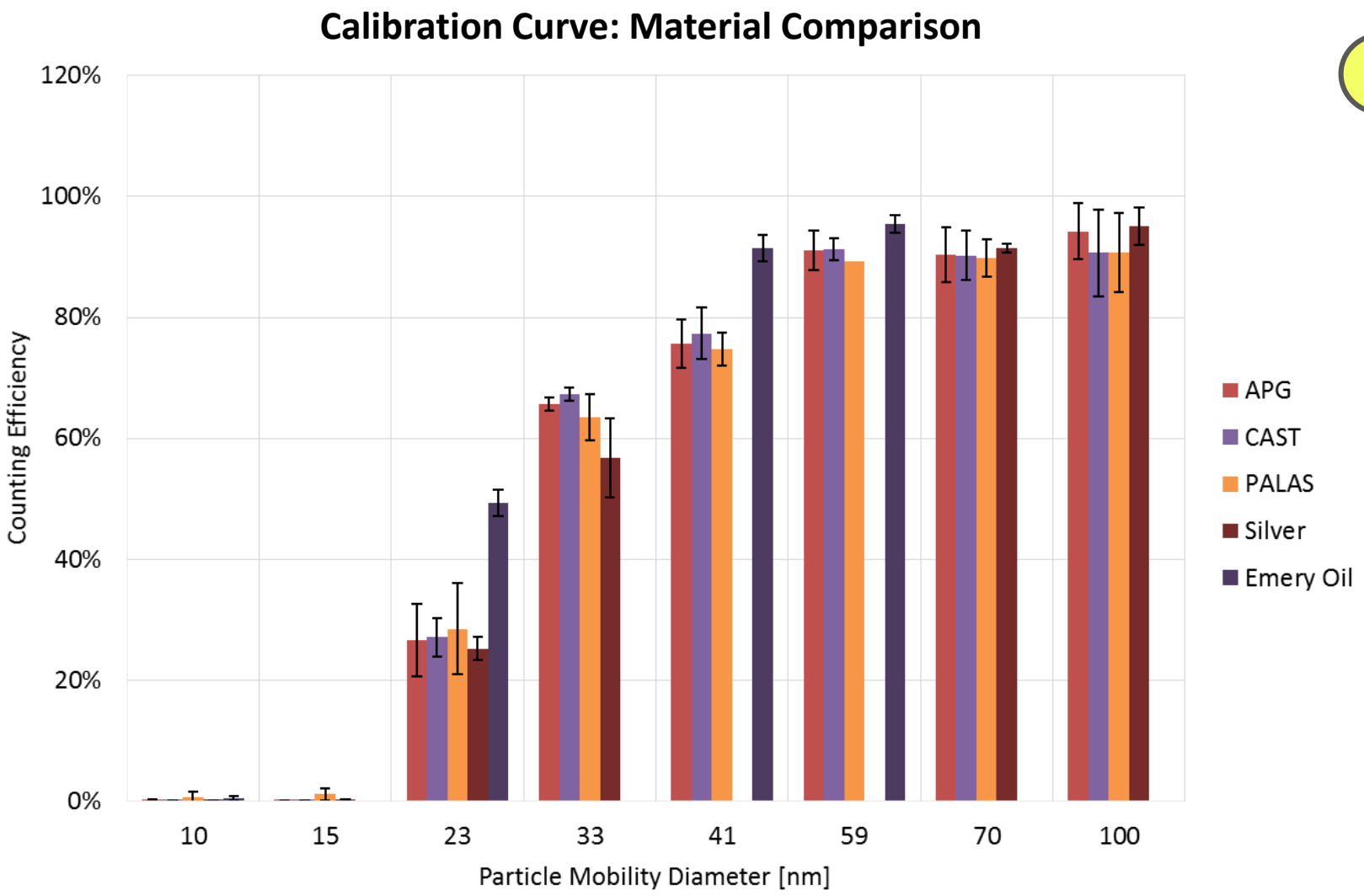


- Average of all labs in one set
- Soot-like aerosols APG, CAST, Palas are very similar
- Emery Oil shows significant difference

- Smaller difference between soot-like and emery oil
- Smaller standard deviation as for 23nm

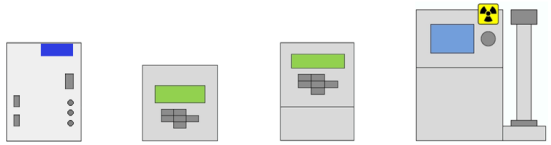
23NM CPC CALIBRATION: MATERIAL

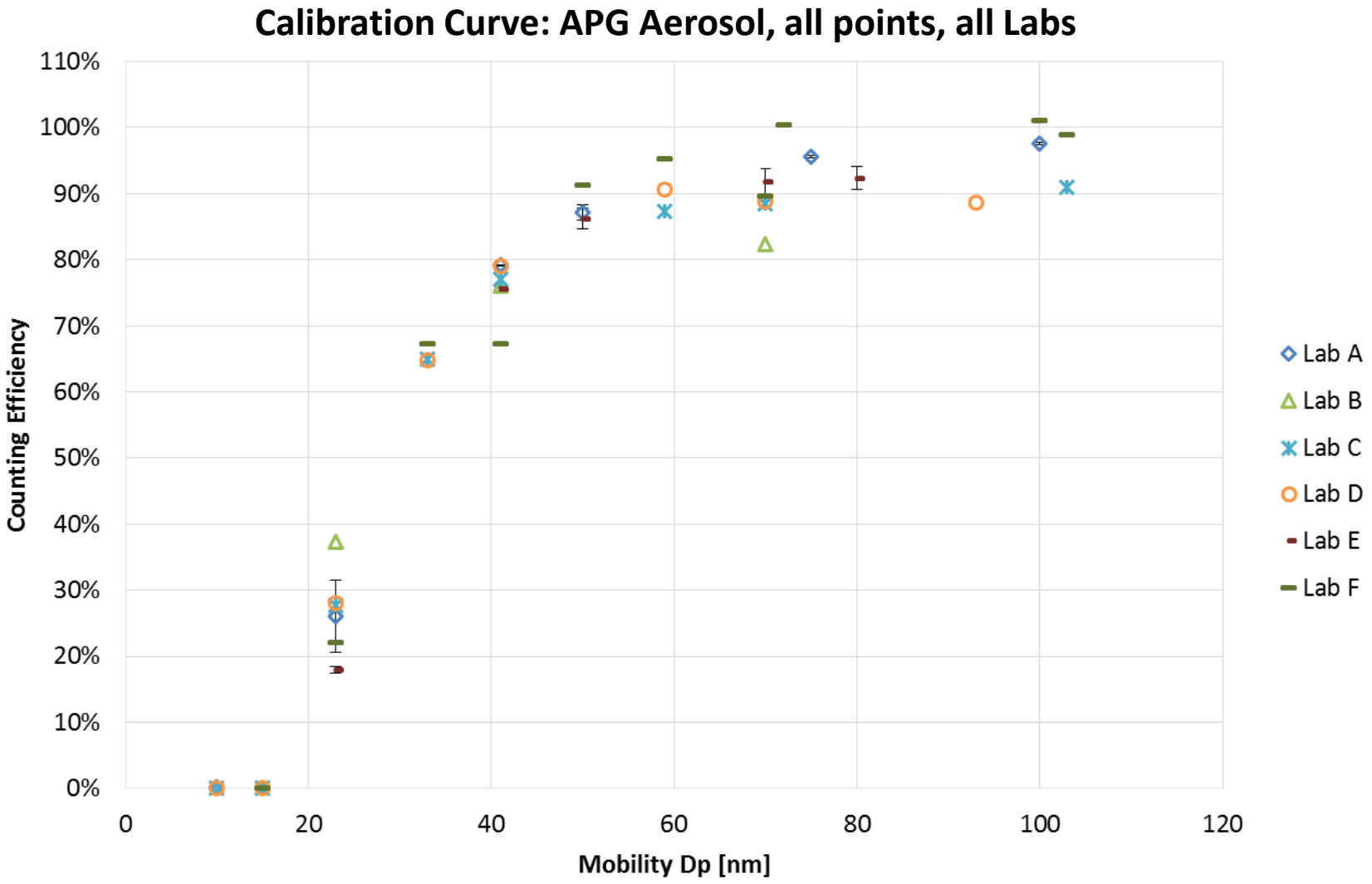




- Small error bars for in-house CAST: Advantage of a well-known setup
- In-house CAST: Small error bars even for 5 different devices and setups
- Emery Oil has much steeper cut-off
- Silver efficiency curve shows better correlation with soot than emery oil
- Small error bars for silver/emery oil: (!) low number of labs

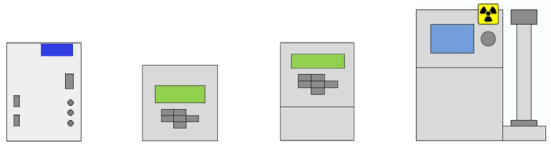
23NM CPC CALIBRATION: LABORATORIES

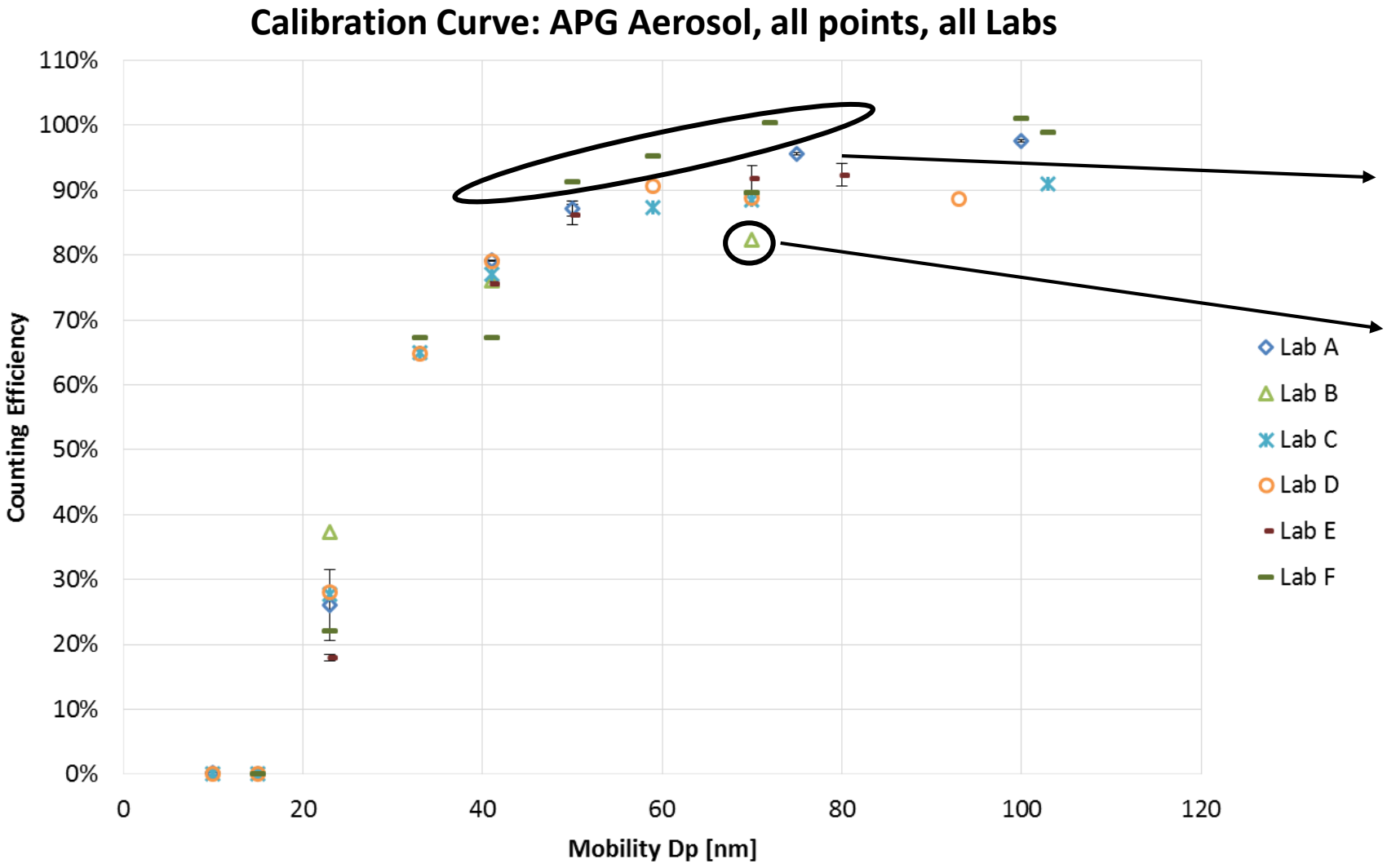




- Several measurements for one lab -> error bar
- Double-checked for mistakes with the labs

23NM CPC CALIBRATION: LABORATORIES





Lab F: instability issues with APG

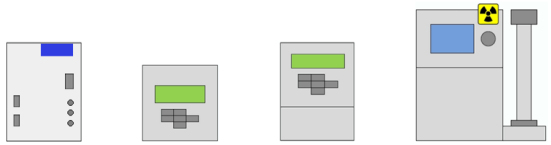
-> Notably larger variation

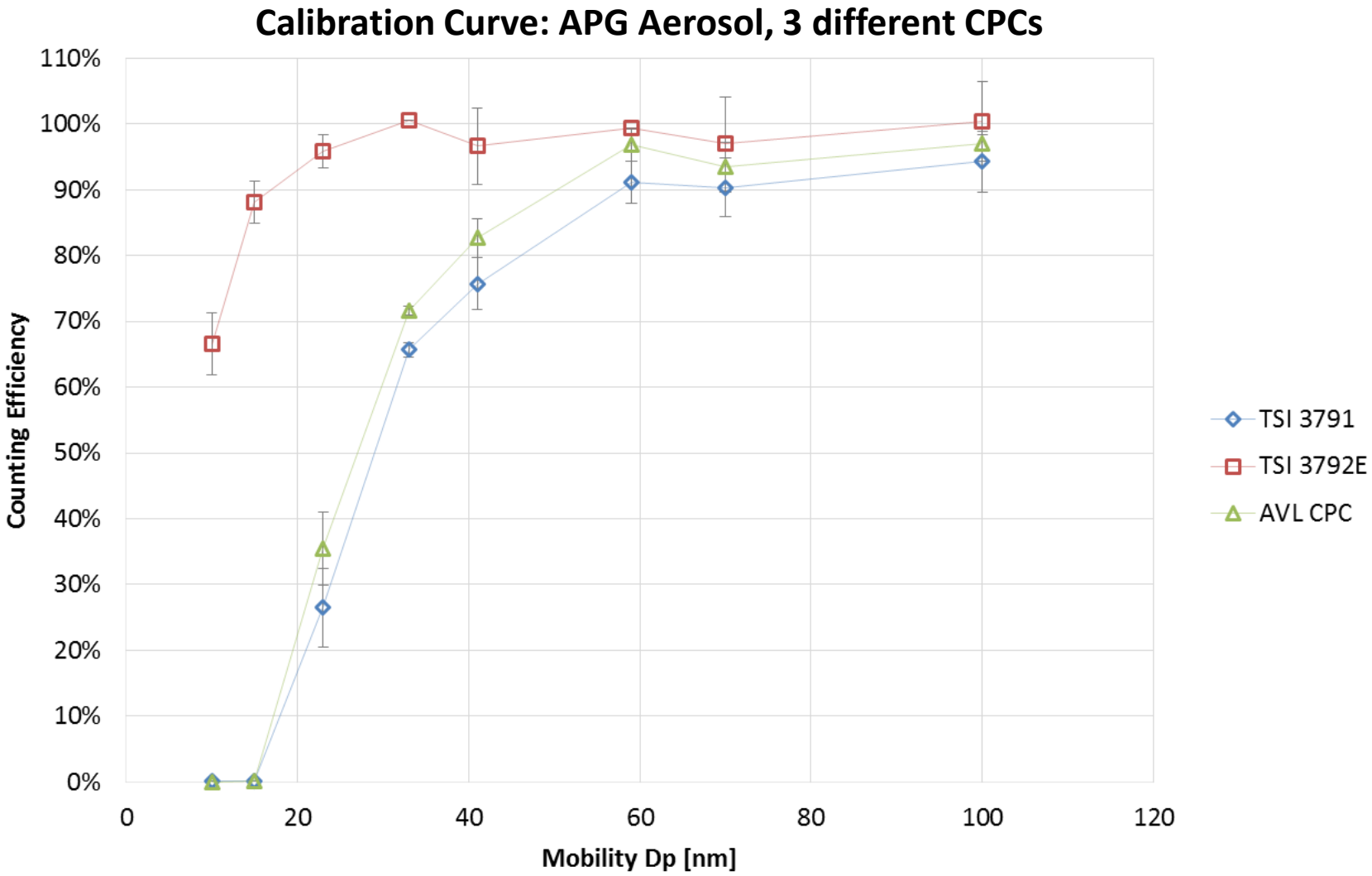
AEM used as reference

-> **Under-estimation** of multiple charges because Wiedensohler charge distribution was applied

No K-Factor on AEM

23NM CPC CALIBRATION: DEVICES





- TSI 3791, AVL CPC: 23nm cut-off PMP-compliant CPCs

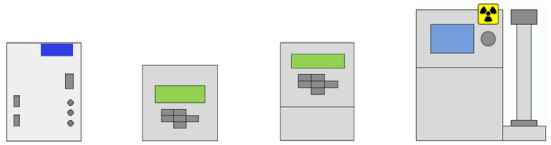
- TSI 3792E: 10nm cut-off

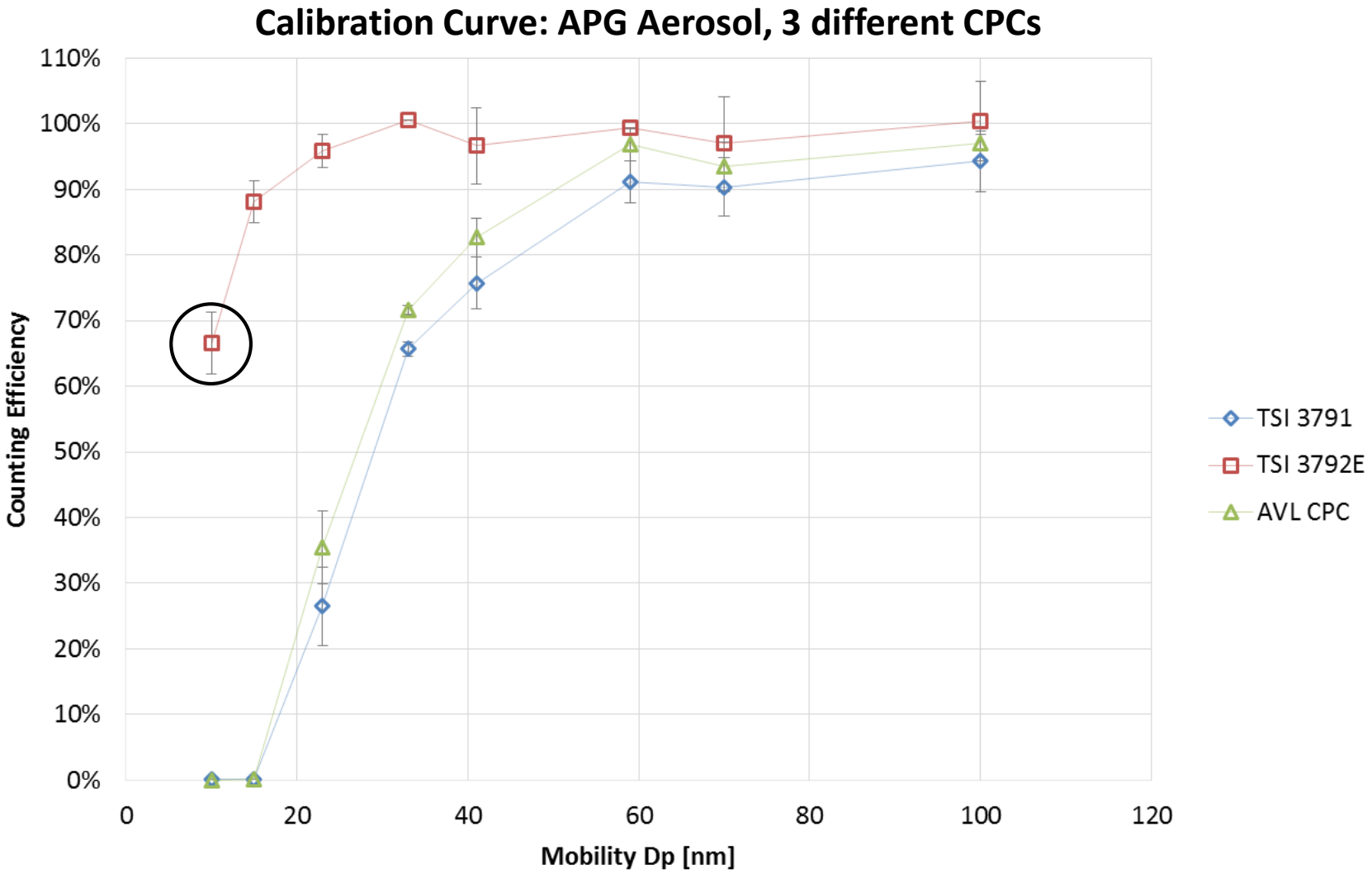
For calibration of 10nm CPC:

only AEM or sub-10nm CPCs **can be used** as a reference

APG aerosol as an example for CAST aerosol

23NM CPC CALIBRATION: DEVICES



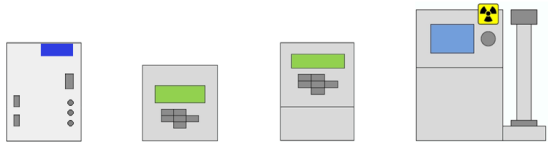


3792E over-estimates at 10nm vs. Emery Oil

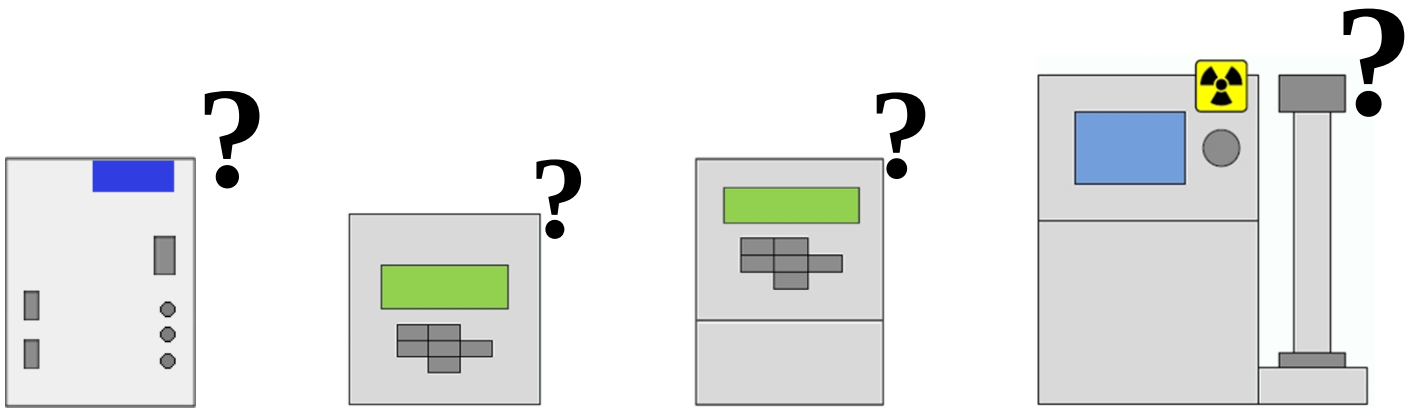
Due to reliability issues with 3792E, it could not be used as general reference device. Needed Service during RR (June '16)

23nm CPCs show very similar performance and cut-off curve

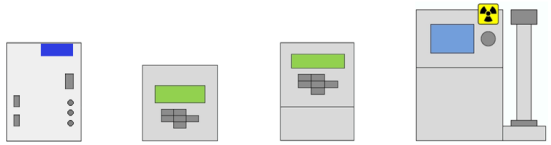
ADDITIONAL ISSUES



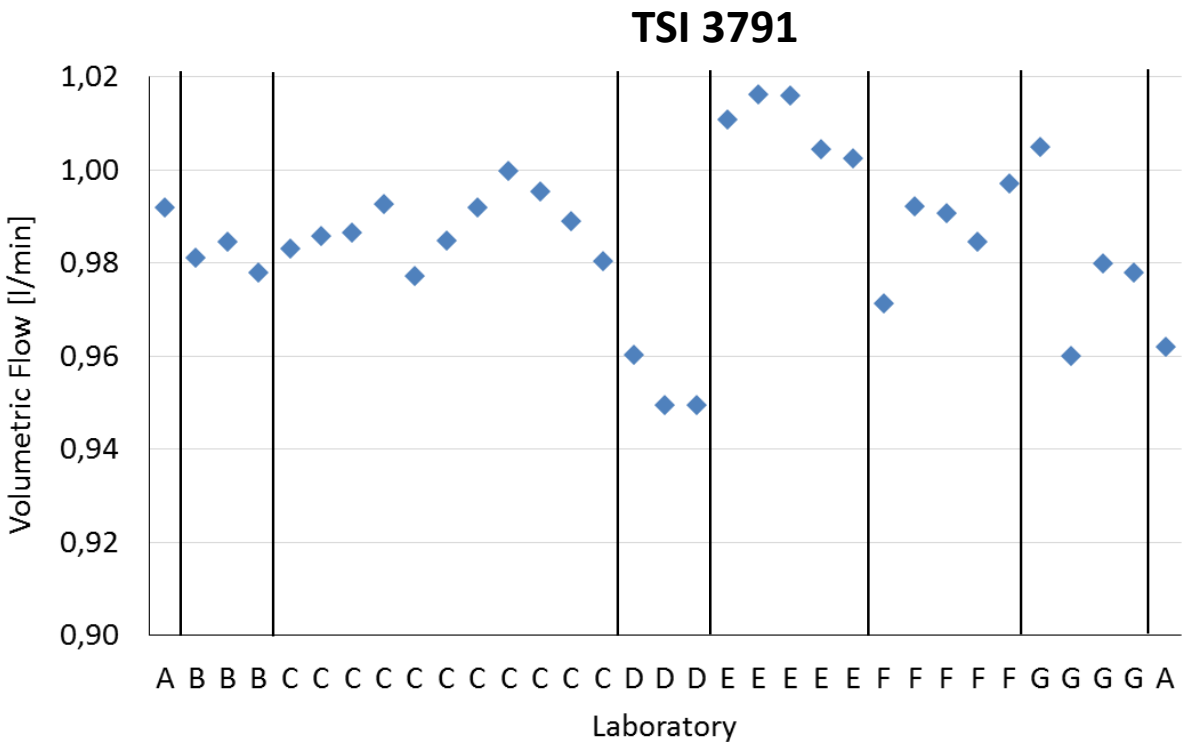
- **Influence of Flow Measurement**
- **Challenges at 10nm**

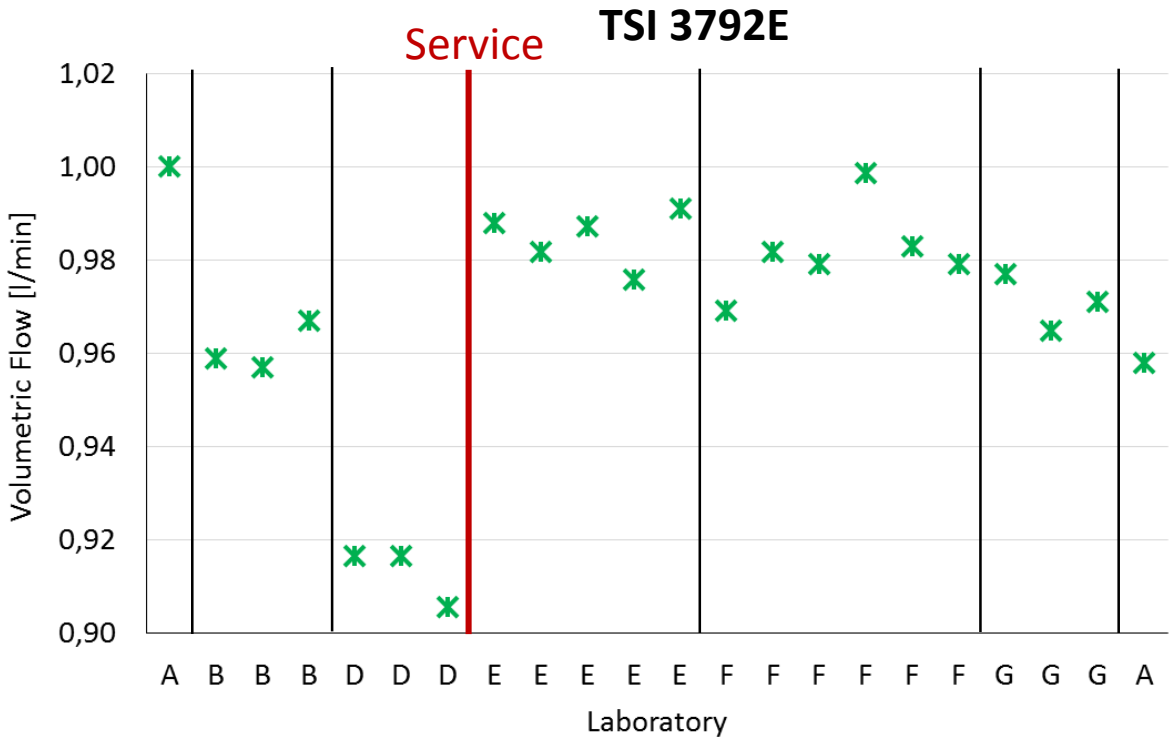


FLOW MEASUREMENT VARIATION



Volumetric Flow

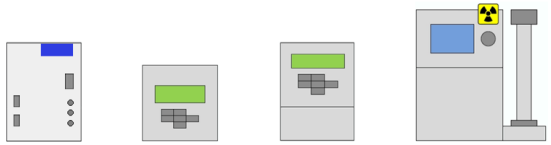




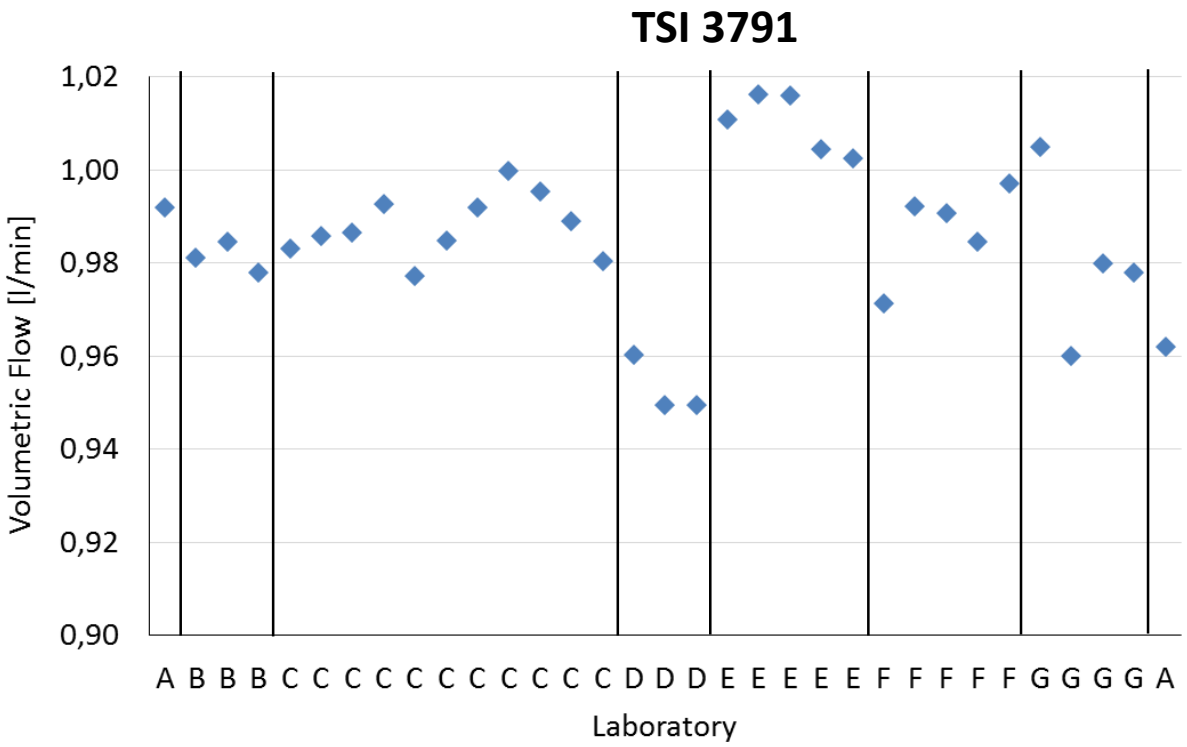
- Measured flow in the range of 0,95 – 1,02 l/min
- Mean: 0,99 l/min
- Std. Dev. 0,017
- Systematic differences between labs

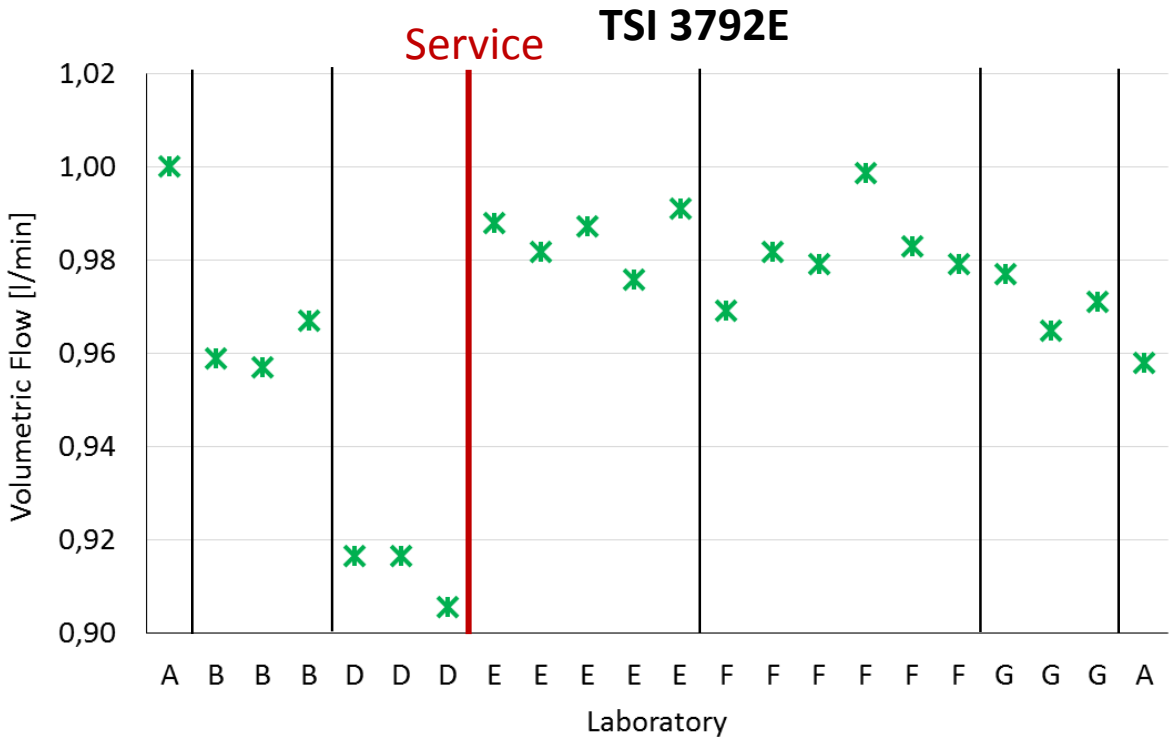
- Measured flow in the range of 0,90 – 1,00 l/min
- Mean: 0,97 l/min
- Std. Dev. 0,025
- Systematic differences between labs

FLOW MEASUREMENT VARIATION



Volumetric Flow



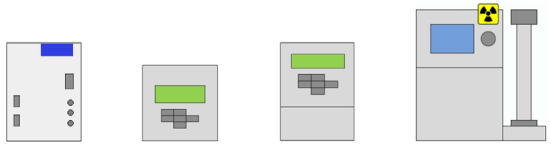


For one lab flows are within +/- 0,02 l/min

-> Relative comparison of devices is possible

Caution when using multiple flow meters

10NM CHALLENGES



Observations from the RR

- **Reference device** must be AEM or <10nm CPC (partial flow CPCs)

- Sufficient **concentration level** must be achieved (e.g. >2000 1/cm³).

Difficulties: Very low charging probability in neutralizer; Dilution in CAST/APG generators; Operating limit of Palas; Parallel calibration not possible

- **Diffusion losses**: In the range of 8% - 15 % (PTB).

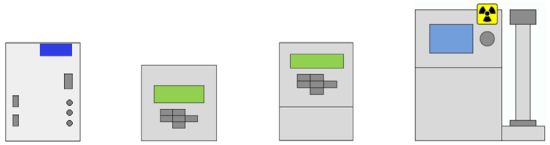
Greater influence of differences in tube length and instrument flow rate (CPC 1l/min vs AEM 3l/min)

- **Emery Oil**: No over-estimation vs soot at 10nm, unlike for PMP-CPCs at 23nm.

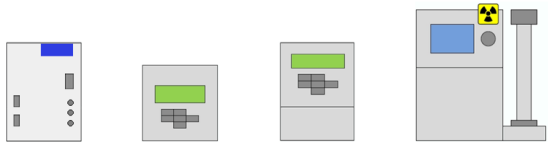
Under-estimation possible ?

Thank you for your attention

BACKUP

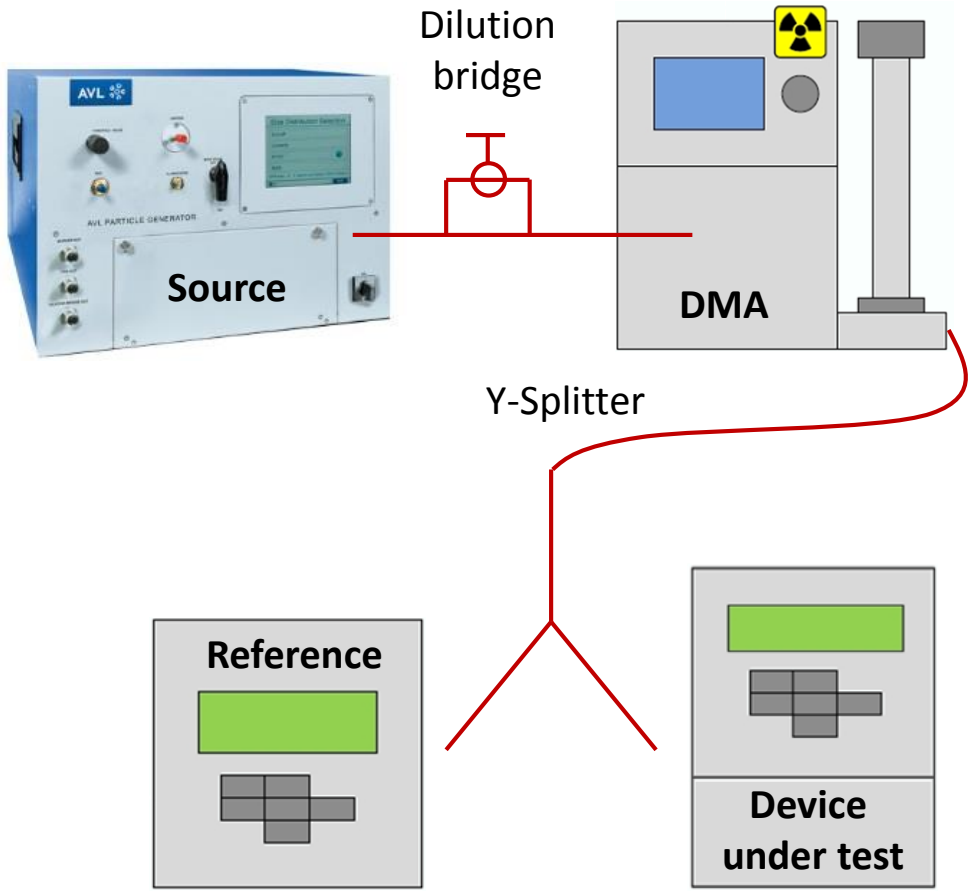


REFERENCE DEVICES & CALIBRATION

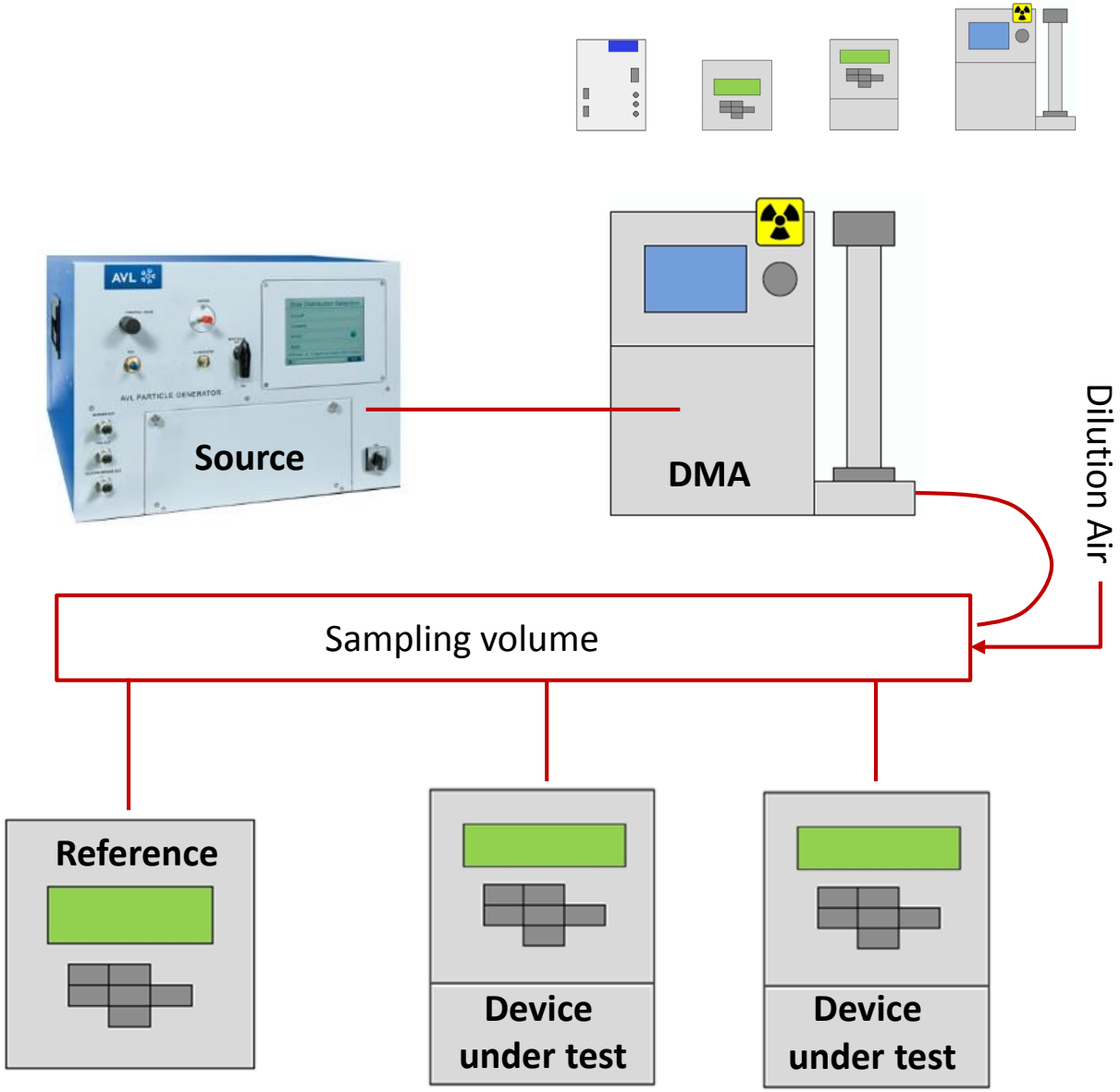


LABORATORY	REFERENCE INSTRUMENT	CALIBRATION TYPE
TSI Germany	Aerosol Electrometer	National Metrological Institute
JRC	Aerosol Electrometer CPC	Manufacturer Calibration In-house
AVL Austria	Aerosol Electrometer	Manufacturer Calibration
PTB	Aerosol Electrometer	In-house
BMW Germany	Aerosol Electrometer CPC	Manufacturer Calibration Manufacturer Calibration
Ricardo Energy & Environment	CPC	National Metrological Institute
VW Germany	Aerosol Electrometer CPC	Manufacturer Calibration In-house

LABORATORY SETUPS

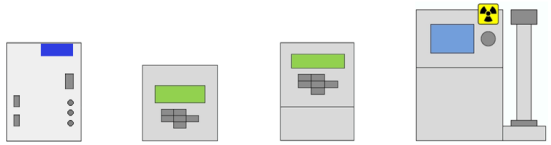


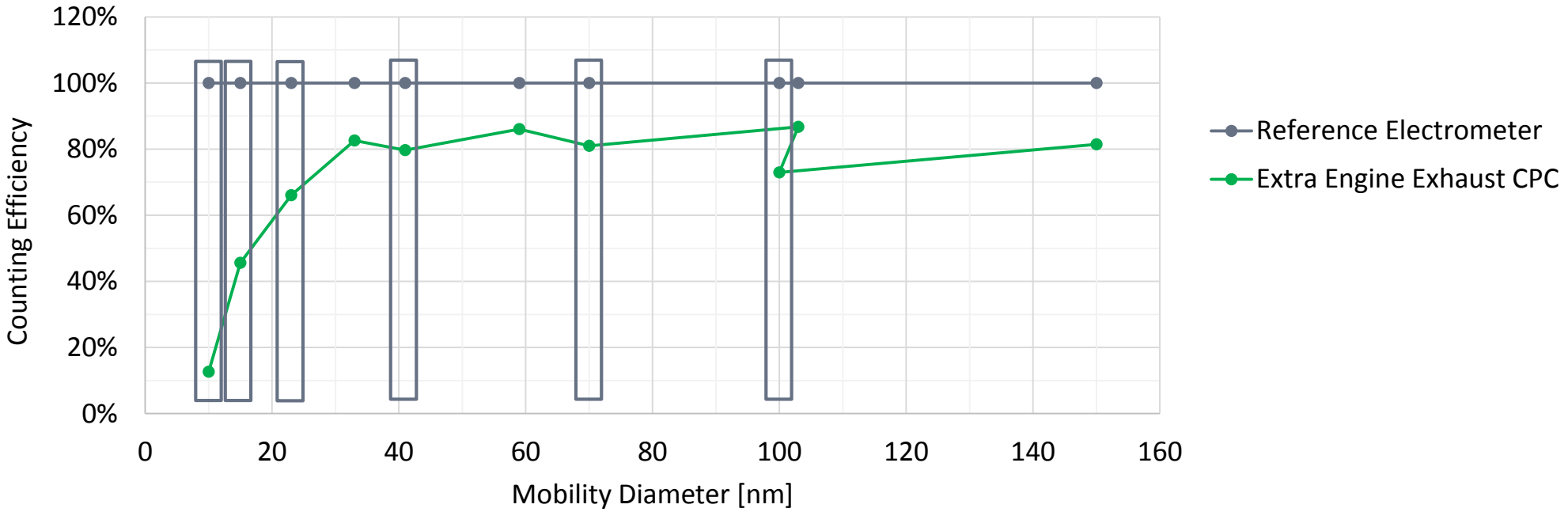
Splitter-type: ISO 27891 compliant setup



Sampling volume-type: not ISO 27891 compliant

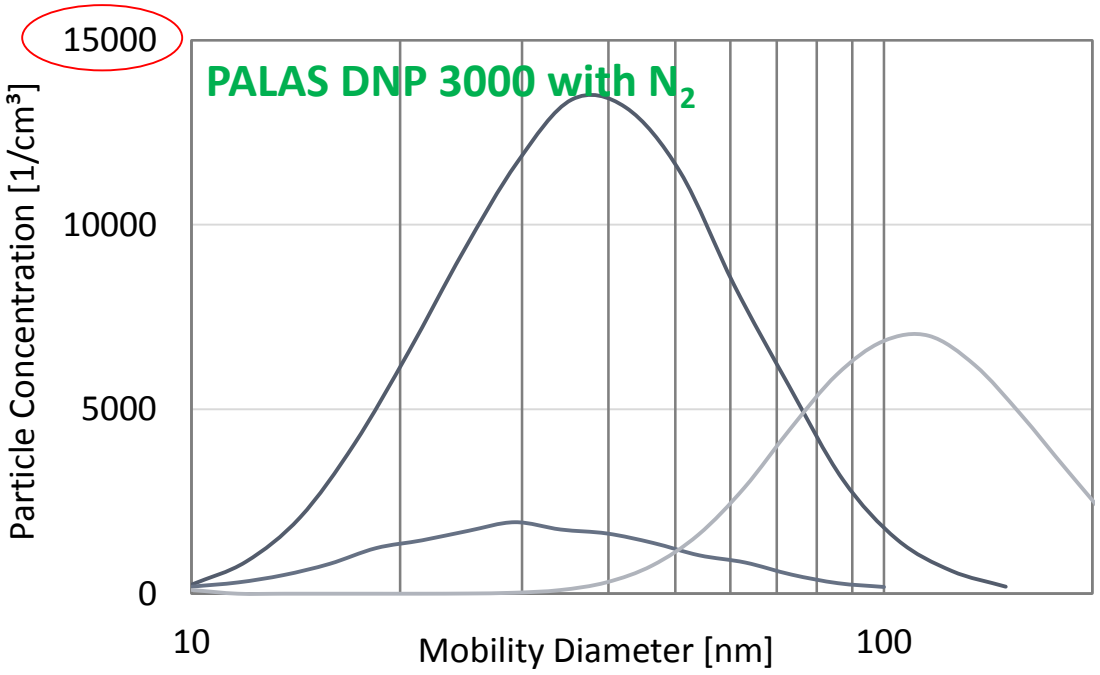
TESTING PROCEDURES: COUNTING EFFICIENCY

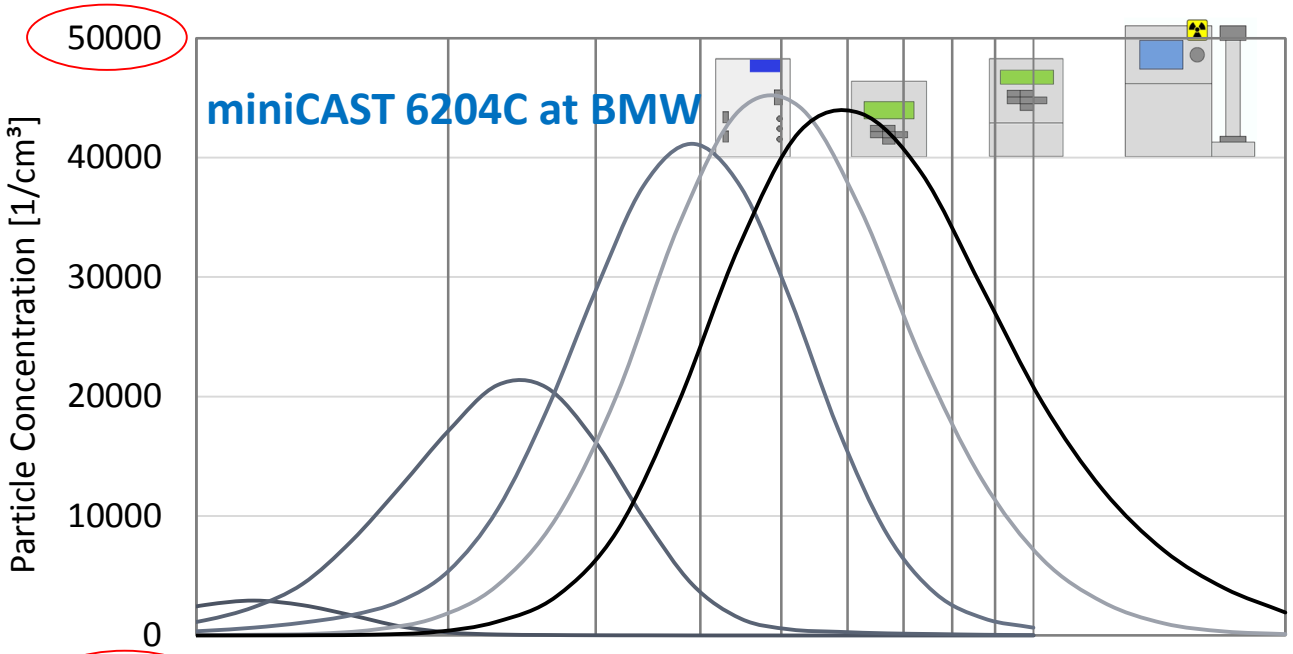


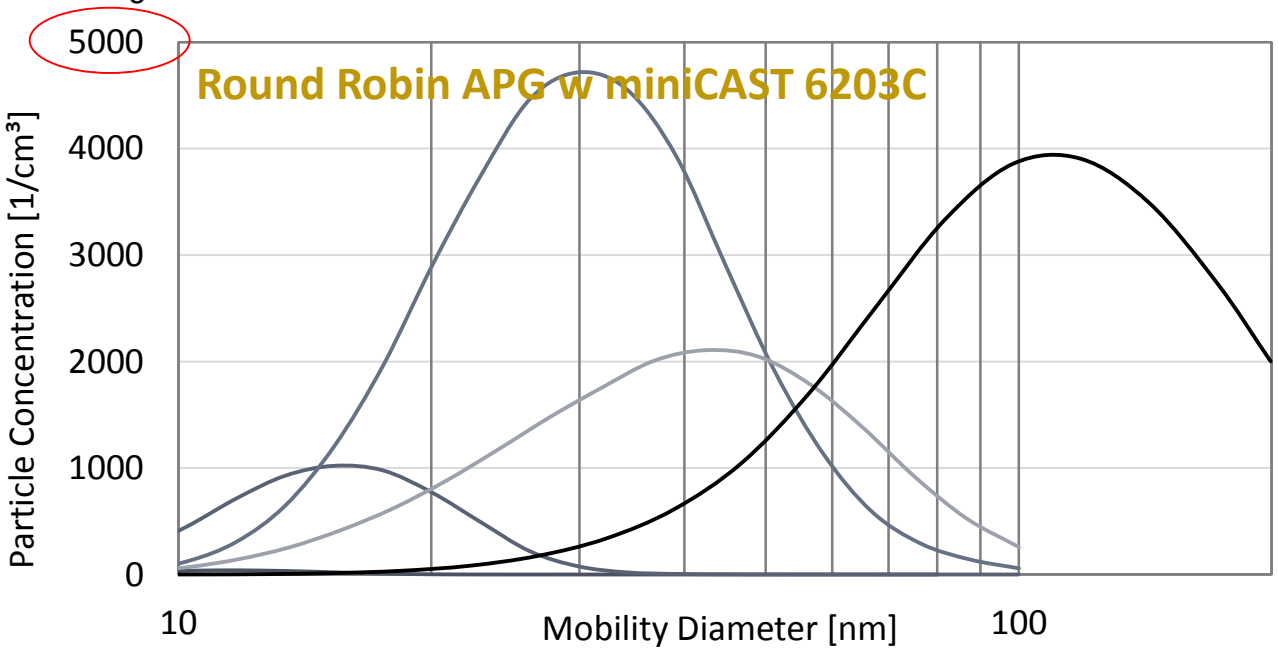


Mobility Diameter	10	15	23	41	70	100
Corresponding Diameter, Double Charges	-	-	33	59	103	150
Burner Operating Point	A	A	B	C	D	E
Motivation	Sub-23	Sub-23	PMP	PMP	Linearity	PN-PEMS

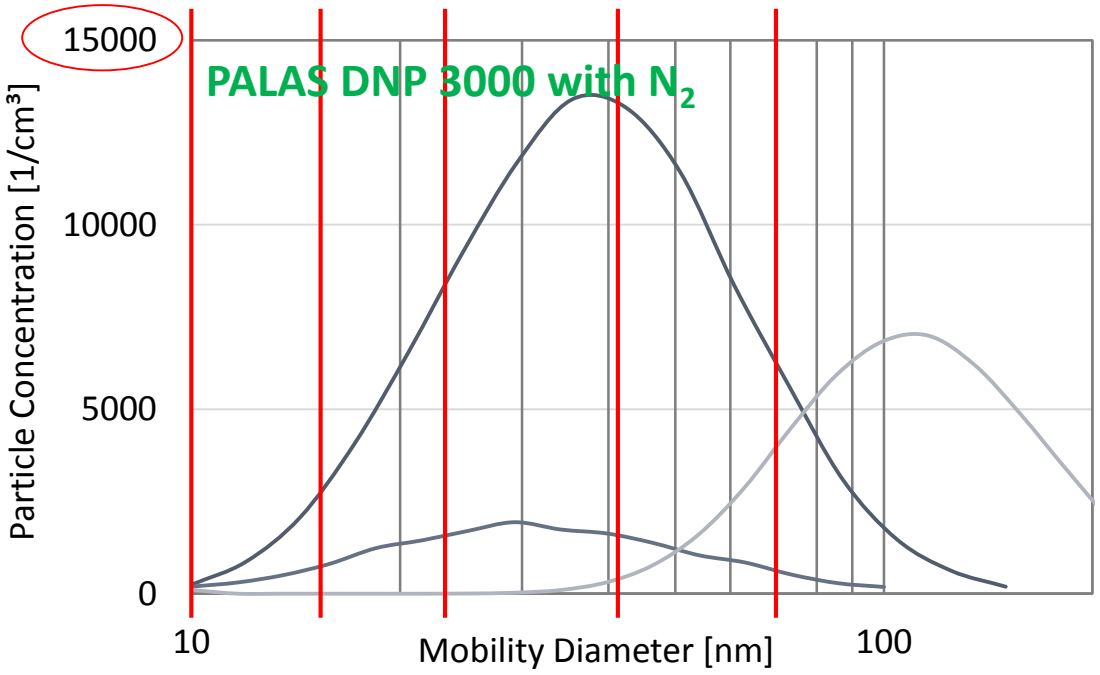
SOOT GENERATORS: SIZE RANGE

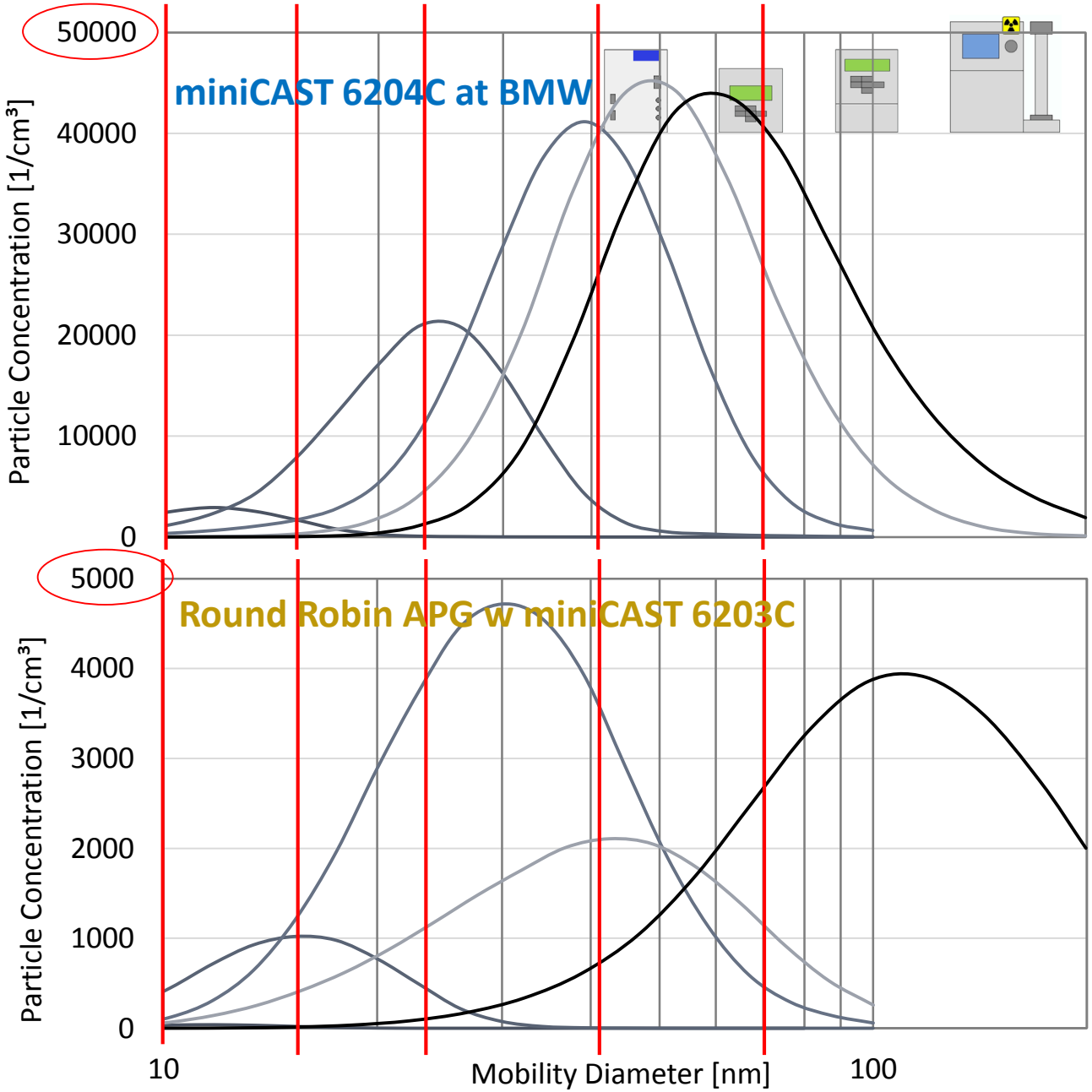






SOOT GENERATORS: SIZE RANGE





SOOT GENERATORS: MAXIMUM CONCENTRATION COMPARISON @10NM

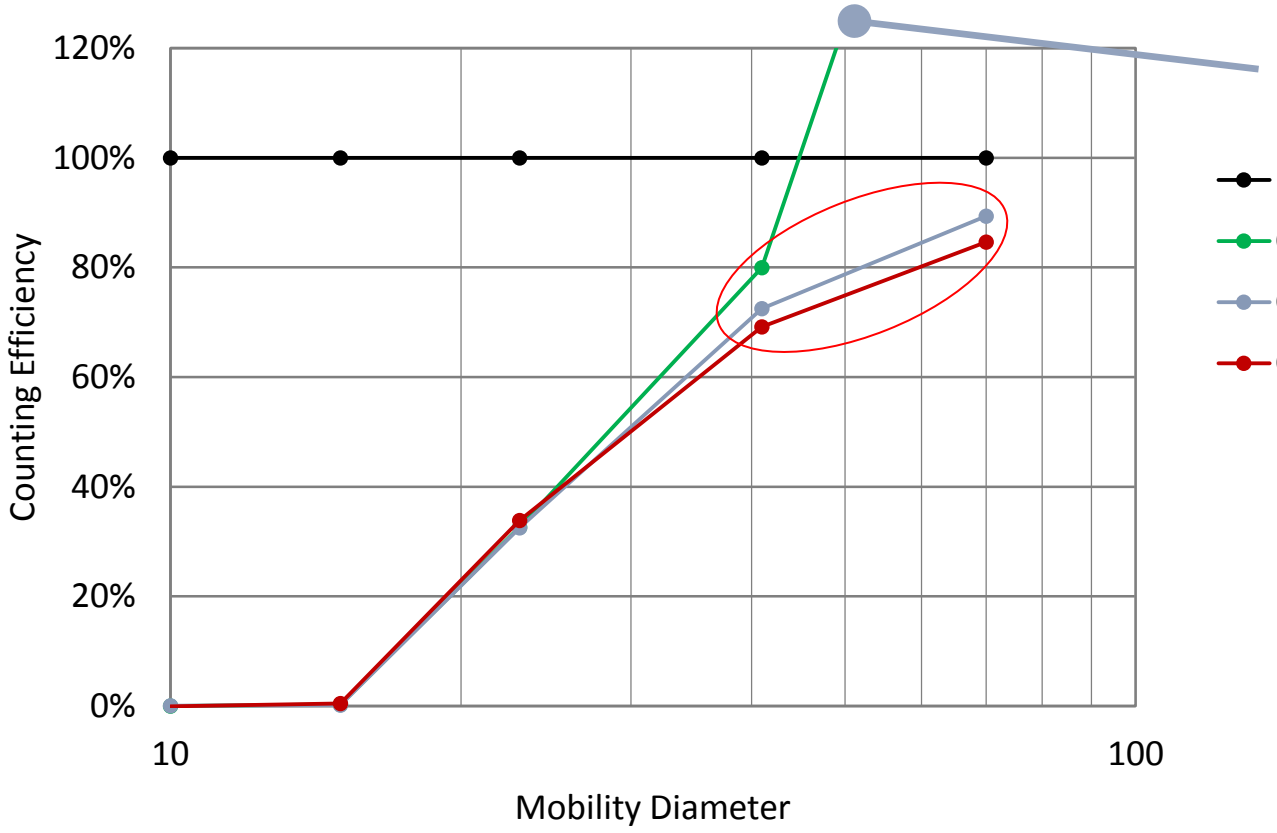
EXAMPLE: Maximum Concentration at BMW laboratory setup (sampling volume, 15l/min dilution air)

	On-site miniCAST		AVL Particle Generator		PALAS DNP 3000	
	GMD	Max. Conc.	GMD	Max. Conc.	GMD	Max. Conc.
10nm	Very small	**2500/cm³**	Very small	35/cm³		
	Small	1300/cm³	Small	**600/cm³**	Small	200/cm³
	Medium	400/cm³	Medium	180/cm³	Medium	**250/cm³**
15nm	Very small	1700/cm³	Very small	25/cm³		
	Small	7900/cm³	Small	1020/cm³	Small	700/cm³
	Medium	1700/cm³	Medium	1200/cm³	Medium	2000/cm³

Going to larger sizes (GMD 20nm – 30nm): No need to worry about multiple charges?

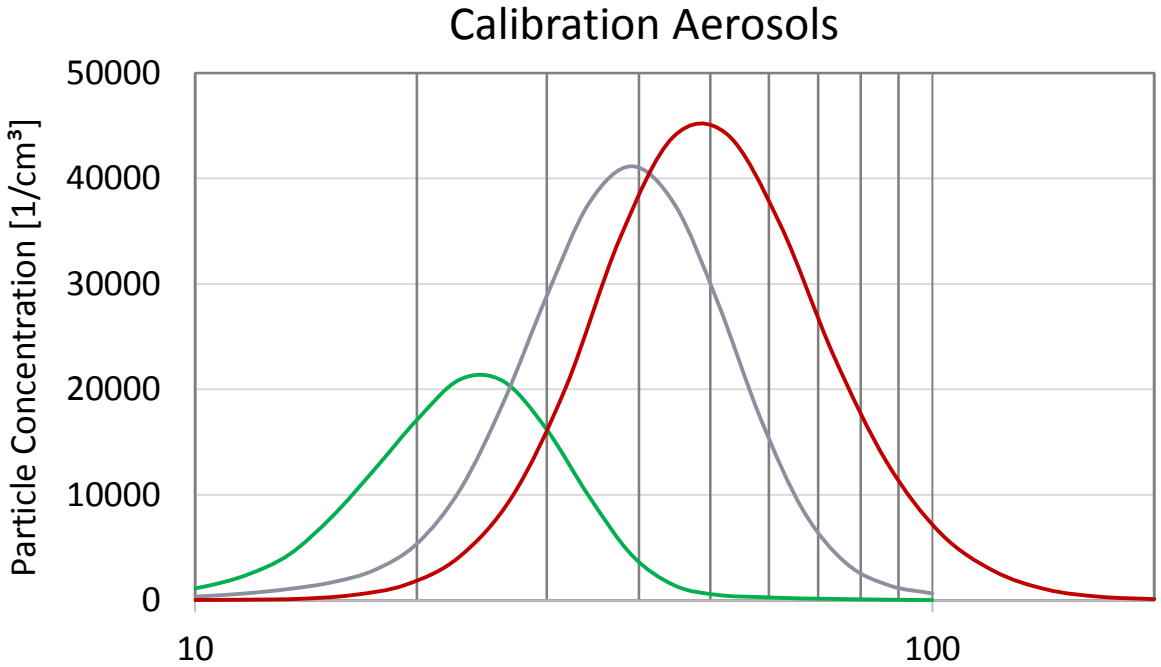
→ 10nm: Insufficient concentration for calibration vs. electrometer with example setup

SOOT GENERATORS: CAST – SINGLE SIZE DISTRIBUTION CALIBRATION



Electrometer Offset
Very low absolute concentration

- Reference Electrometer
- GMD 20nm
- GMD 35nm
- GMD 50nm



- Size distribution influence
  With **double charge correction** applied
- Especially when comparing Electrometer & CPC