CPC CALIBRATION MATERIAL INTER-LABORATORY COMPARISON.
MOTIVATION.

**Harmonized calibration material** in automotive applications for:
- CPC (Condensation Particle Counter).
- VPR (volatile particle remover).
- PN-PEMS.

- **Material influence** on CPC calibration.
- Variation of calibration among 7 laboratories.
- Variation among 7 in-house reference devices and setups.

Device under test:
PMP compliant CPC $D_{50} = 23\text{nm}$.
For engine exhaust measurements.

Aerosol generators:
- APG miniCAST (circulated)
- miniCAST
- Palas DNP
- Silver
- Emery Oil
<table>
<thead>
<tr>
<th>Time</th>
<th>Laboratory</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/16</td>
<td>TSI Germany</td>
<td>Instrument Manufacturer</td>
</tr>
<tr>
<td>3/16</td>
<td>JRC</td>
<td>Research Institute</td>
</tr>
<tr>
<td>4/16</td>
<td>AVL Austria</td>
<td>Instrument Manufacturer</td>
</tr>
<tr>
<td>6/16</td>
<td>PTB</td>
<td>National Metrological Institute</td>
</tr>
<tr>
<td>7/16</td>
<td>BMW</td>
<td>Vehicle Manufacturer</td>
</tr>
<tr>
<td>9/16</td>
<td>Ricardo E&amp;E</td>
<td>Calibration Service</td>
</tr>
<tr>
<td>11/16</td>
<td>VW</td>
<td>Vehicle Manufacturer</td>
</tr>
<tr>
<td>12/16</td>
<td>TSI Germany</td>
<td>Instrument Manufacturer</td>
</tr>
</tbody>
</table>
PROCEDURE.

**Circulated instruments.**
- 1 aerosol generator **propane flame.**
  - APG (miniCAST + thermal treatment)
- 1 reference CPC $D_{50} = 10\text{nm}$.
  - TSI 3792E
- 2 engine exhaust CPC $D_{50} = 23\text{nm}$.
  - TSI 3791
  - AVL CPC (pre-production)

**Data Handling.**

- Calibration at participating laboratories.
- Data collection by JRC.
- Standardized data correction at BMW.
  - Electrometer zero, double charges
  - Reference K-factor
  - Flow
- Evaluation at BMW.
Note: not all labs use an ISO 27891 compliant setup (2-way splitter).
ENGINE EXHAUST CPC CALIBRATION: RAW DATA.

Calibration Curve: APG generator, Reference 23nm CPC, all laboratories.

- Error bar: multiple measurements from one lab.
- Standardized correction applied.

Calibration certificate value
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- Error bar: multiple measurements from one lab.
- Standardized correction applied.

Calibration certificate value
ENGINE EXHAUST CPC CALIBRATION: MATERIAL.

All data at 23nm.

- All Data submitted for 23nm.
- Standardized correction applied.
- Error bar: Indicates multiple measurements submitted by one laboratory.

PMP $D_{50}$ +/- 12%

Calibration certificate value

Counting Efficiency vs Reference

Calibration Material:
- APG
- CAST
- Palas
- Silver
- Emery Oil

Legend:
- Lab A
- Lab B
- Lab C
- Lab D
- Lab E
- Lab F
- Lab G
ENGINE EXHAUST CPC CALIBRATION: MATERIAL.

All data at 41nm.

- All Data submitted for 41nm.
- Standardized correction applied.
- Error bar: Indicates multiple measurements submitted by one laboratory.

Calibration certificate value

Counting Efficiency vs Reference

Calibration Material:
- APG
- CAST
- Palas
- Silver
- Emery Oil

PMP $D_{90}$

All Data at 41nm.
ENGINE EXHAUST CPC CALIBRATION: MATERIAL.

- Soot-like aerosols APG, CAST, Palas very similar.
- Emery Oil shows significant difference.

**Average data at 23nm.**

- Smaller difference between soot-like and emery oil.
- Smaller standard deviation as for 23nm.
Calibration Curve: Material Comparison.

- In-house CAST: Small error bars even for 5 different devices and setups. Advantage of a well-known setup.
Calibration Curve: Material Comparison.

- In-house CAST: Small error bars even for 5 different devices and setups. Advantage of a well-known setup.

- Silver efficiency curve shows good correlation with soot.
Calibration Curve: Material Comparison.

- In-house CAST: Small error bars even for 5 different devices and setups. Advantage of a well-known setup.

- Silver efficiency curve shows good correlation with soot.

- Emery Oil has much steeper cut-off.

- Small error bars for silver/emery oil: (!) low number of labs.
LESSONS LEARNED: CPC COMPARISON.

- Only Electrometer and sub-10nm CPC as reference for 3792E.
- Instabilities: larger error bars for 3792E.

- Similar performance of TSI and AVL engine exhaust CPC.
LESSONS LEARNED: GENERATOR SIZE DRIFT.

APG generator operating point “B” for 23nm.

- Mode range: 13nm – 18.1nm.
- Contamination: generator cleaned at VW (after Ricardo).

APG generator operating point “C” for 41nm.

- Mode range: 21nm – 30.4nm.
CONCLUSION.

– Comprehensive comparison of aerosol sources and setups.

– Soot identified as candidate aerosol for harmonization of calibration in automotive exhaust applications.

– Good correlation of in-house soot generators in spite of different burners and aerosol after-treatment.

– Significant differences between emery oil and soot-like at small particle sizes (important for automotive testing).
CONCLUSION.

– **Comprehensive comparison** of aerosol sources and setups.

– Soot identified as candidate aerosol for **harmonization of calibration in automotive exhaust applications**.

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**Open questions:**

– What is the **quantitative uncertainty** of soot calibration?

– What is the **influence of the laboratory setup**?

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PMP Sub-Group
“PNC Calibration“ led by PTB
2nd stage of the Comparison Exercise
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