OBS-ONE-PN

HORIBAs PN-PEMS solution

04.07.2016; Joel Danzer, Les Hill, Natalie Baltes

HORIBA

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(4) OBS-ONE-PN application opportunities

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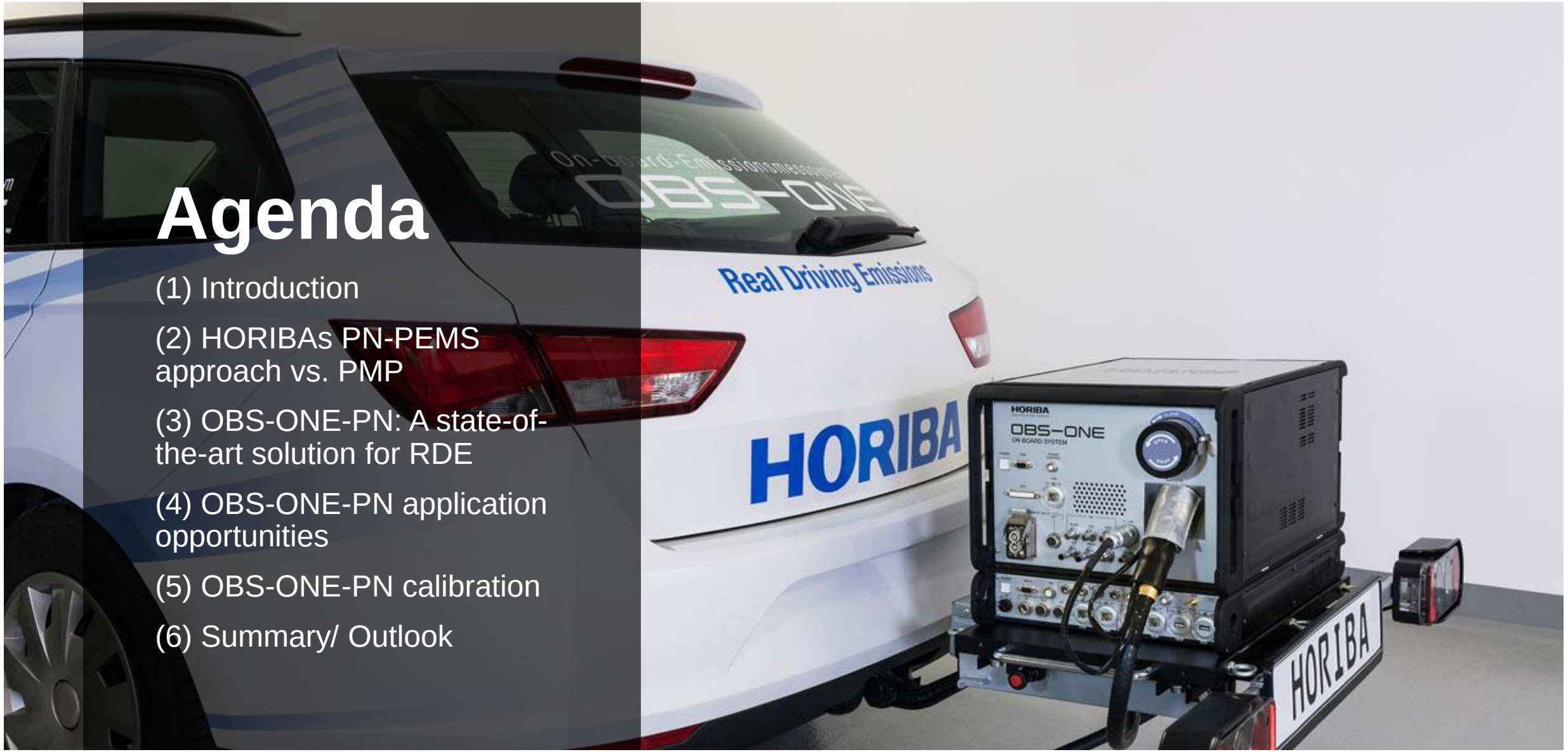
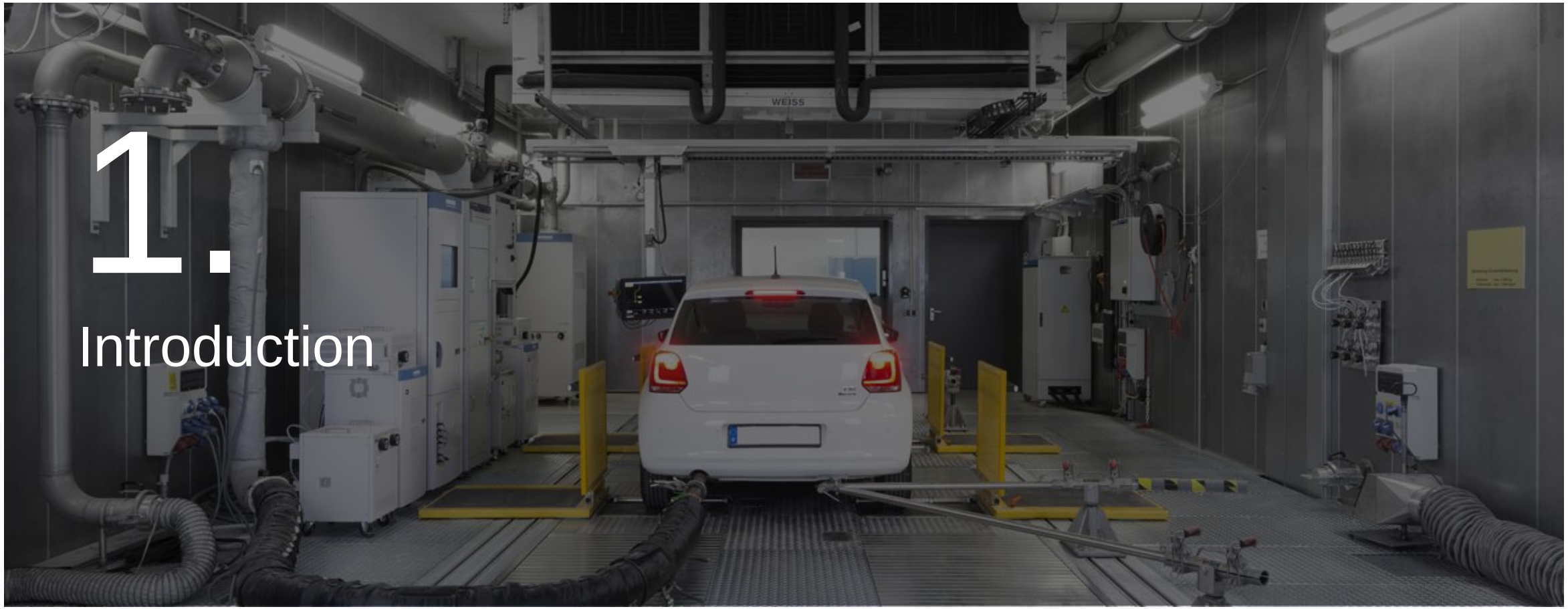


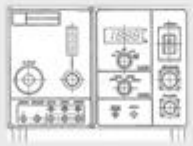


1.

Introduction

Introduction

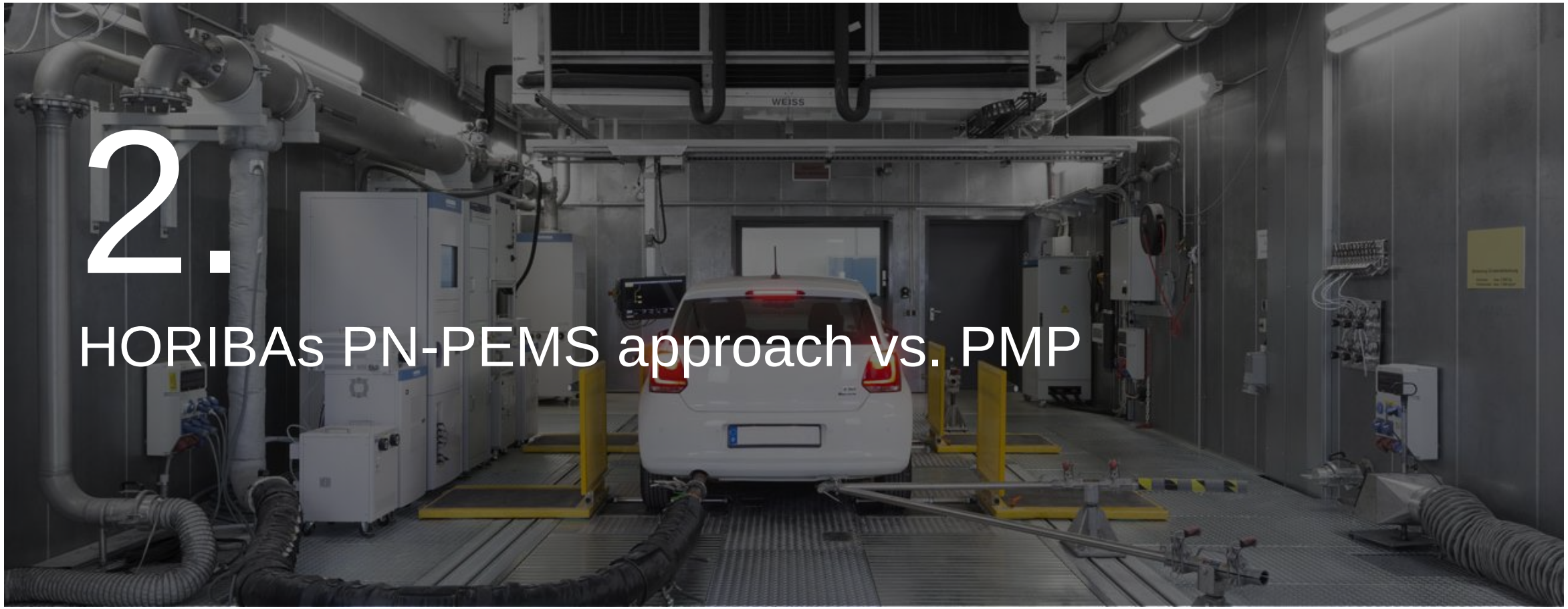
- Real Driving Emission (RDE) regulation will be implemented in Sept. 2017 introducing emission limits for NOx and particle number (PN). A transitional phase for monitoring purpose of gaseous emissions has now commenced in Jan. 2016
- PN-PEMS will be a part of the 3rd RDE-package (A vote at TCMV* is expected to take place in Sept. 2016)
  - The final PN-PEMS specification (incl. calibration requirements) and the conformity factor for PN are still under discussion
- Based on several decades of experience in the development of PEMS, HORIBA introduced the **OBS-ONE-PN as a solution for particle number measurements on the road**

Description	1980	1982	2003	2005	2014-2016
Type	MEXA-1340AFM MEXA-1440AFM	MEXA-1360AFM	OBS-1000 series	OBS-2000 series	OBS-ONE series
Feature					

* PMP= Particulate Measurement Programme
** CVS= Constant Volume Sampler
*** PFDS= Partial Flow Dilution System

Introduction

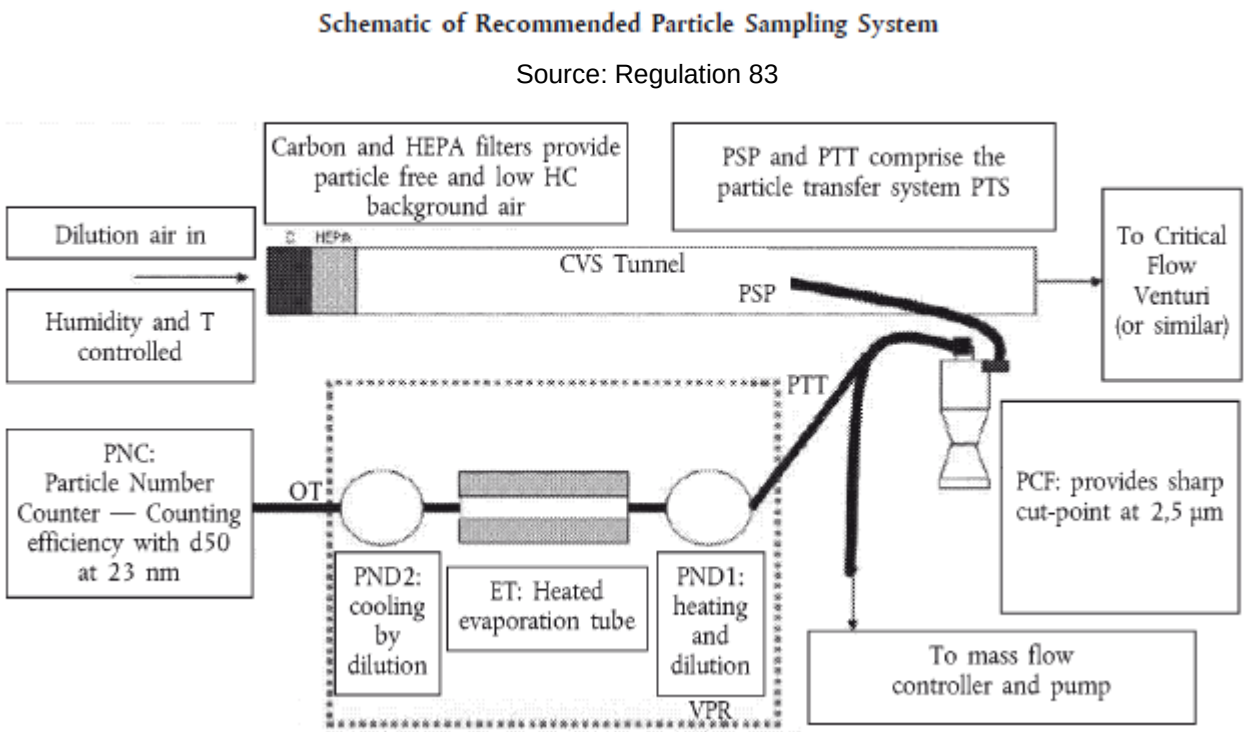
- Specific design and performance requirements for a solid particle counting system were defined by the UNECE-GRPE PMP* working group for type approval testing on the chassis dynamometer. The proposed system design was adopted for Reg. 83/ Reg. 49 and GTR No. 15
- Considering the current PN-PEMS specification such a PMP-compliant instrument could also be used for testing on the road (in combination with an EFM)!
  - **Does this really makes sense with respect to additional requirements for an OnBoard measurement device (size, weight, power consumption, robustness against vibration, challenging boundary conditions,…)?**
- PMP defined a valid approach for particle number measurements sampling from the CVS** or a PFDS***. HORIBAs OBS-ONE-PN introduces a novel approach taking into account the specific requirements for particle number counting on the road



2.

HORIBAs PN-PEMS approach vs. PMP

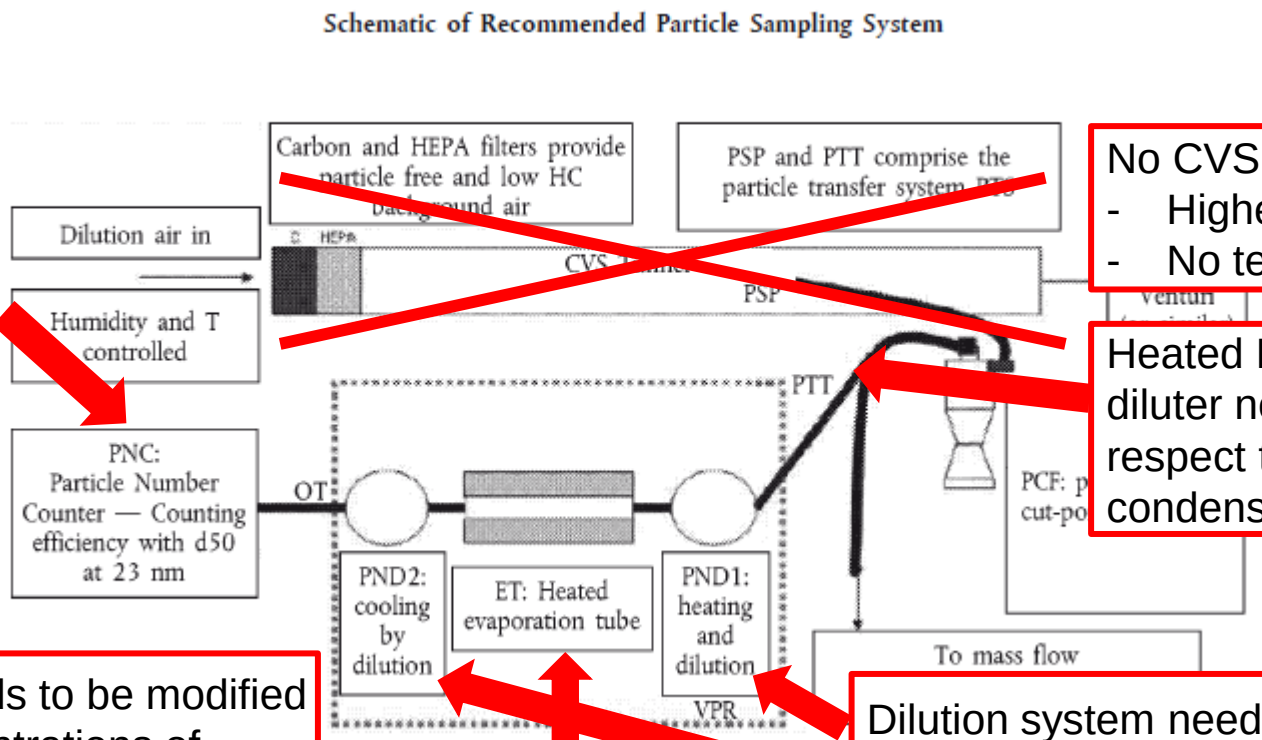
PN counting in the lab: PMP approach



- Is this a reasonable system design also for PN-PEMS? What might be the critical elements?

PMP approach limitations with respect to PN-PEMS

A CPC as specified in the PMP approach can not be used on the road due to
- Inclination issues
- Limited concentration range
- System design
- Reservoir of working fluid
- Temperature control
- Vibration stability



No CVS Tunnel on the road!
- Higher particle concentrations
- No temperature control

Heated PTT* upstream of the first diluter needs to be reconsidered with respect to power consumption, condensation and particle losses

Heated section needs to be modified due to higher concentrations of volatile components

Dilution system needs to be optimized with respect to accuracy, robustness, power consumption

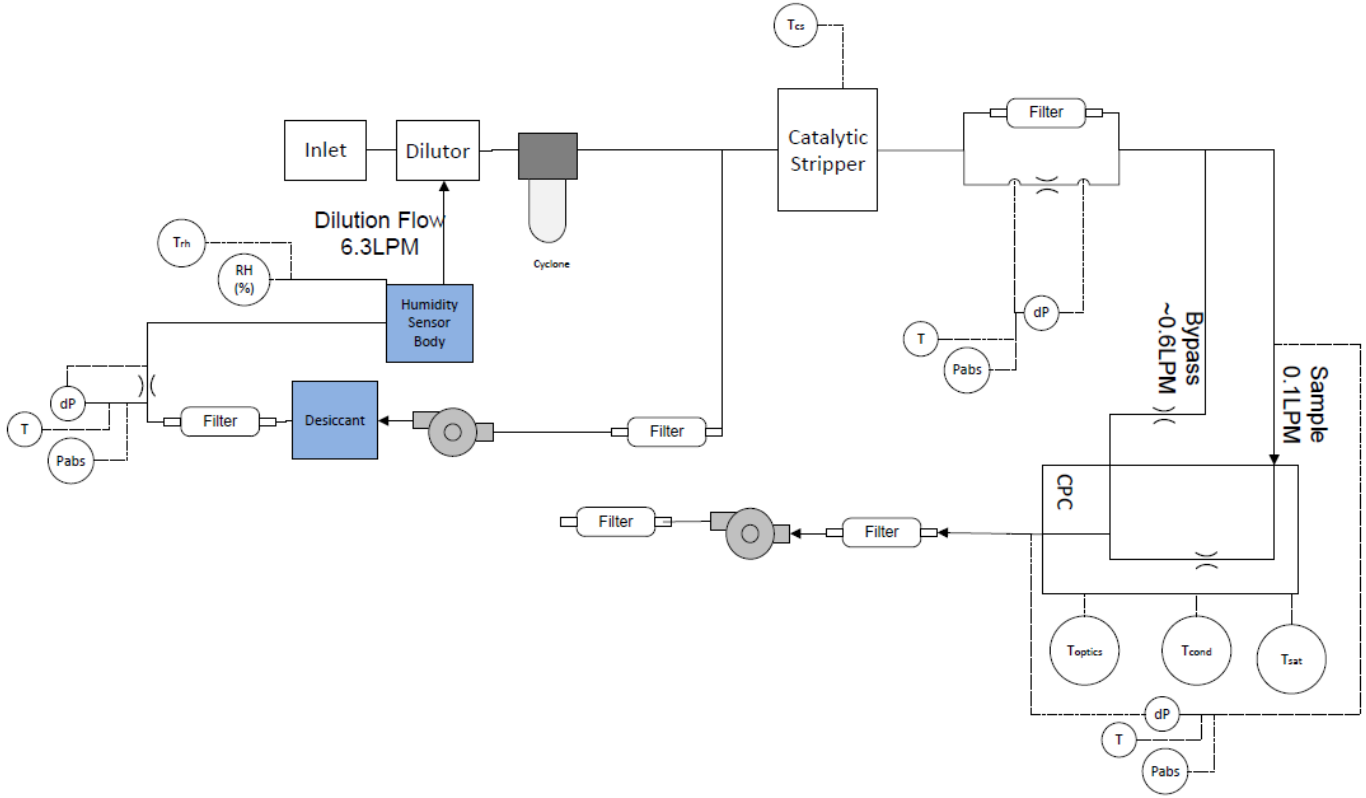
PN counting on the road: Additional requirements

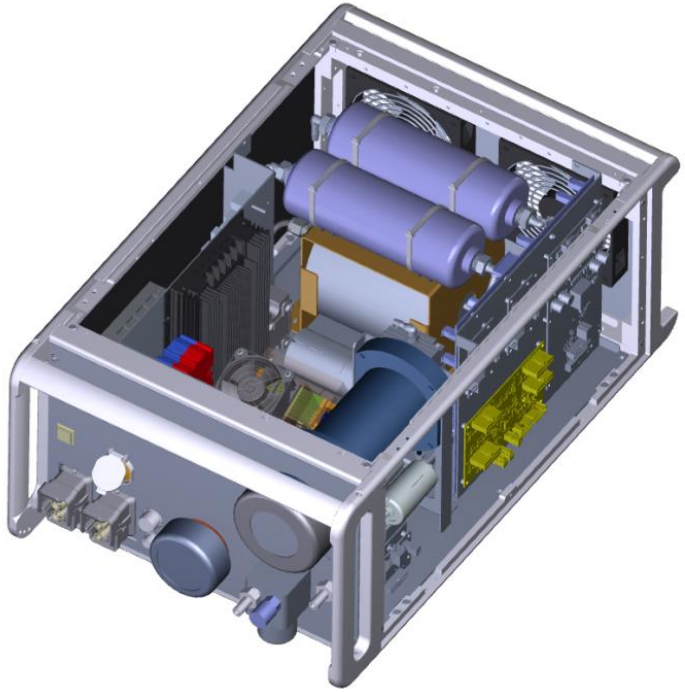
- Considering the limitations of the PMP-approach for PN measurements on the road is only the first step. Additional requirements need to be taken into account:
  - Vibration stability
  - Temperature (-7°C up to 35°C) and altitude (0m up to 1300m) during RDE testing on the road
  - Power consumption, weight and size
  - Measurement technology without any dependencies on particle size distribution and particle composition (market fuel requirement/ different types of combustion and after-treatment systems)

- Furthermore the customer requires a PN-PEMS with an excellent correlation to laboratory reference counter
  - Similar counting efficiency
  - Similar linearity

PN counting on the road: OBS-ONE-PN

- HORIBA considered the specific requirements for measurements on the road in the development of the OBS-ONE-PN

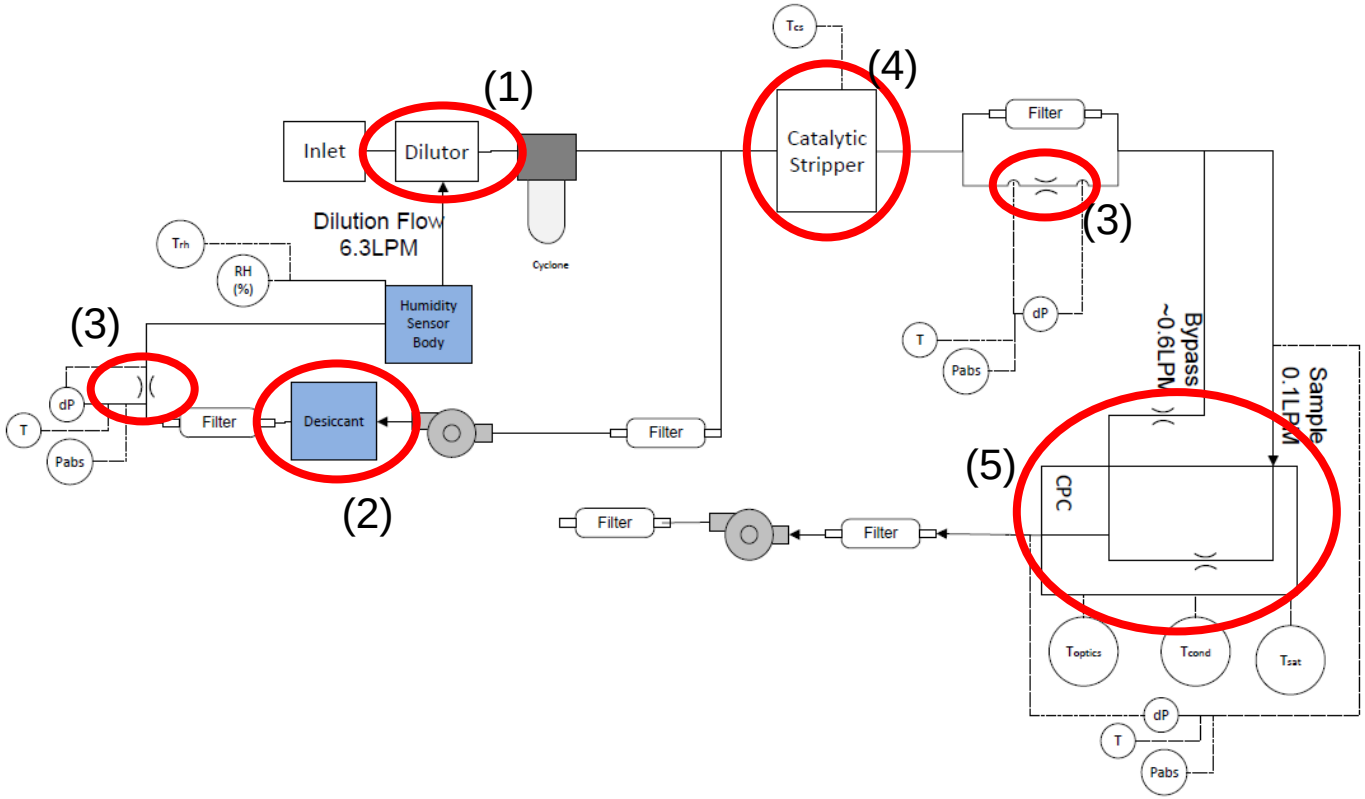




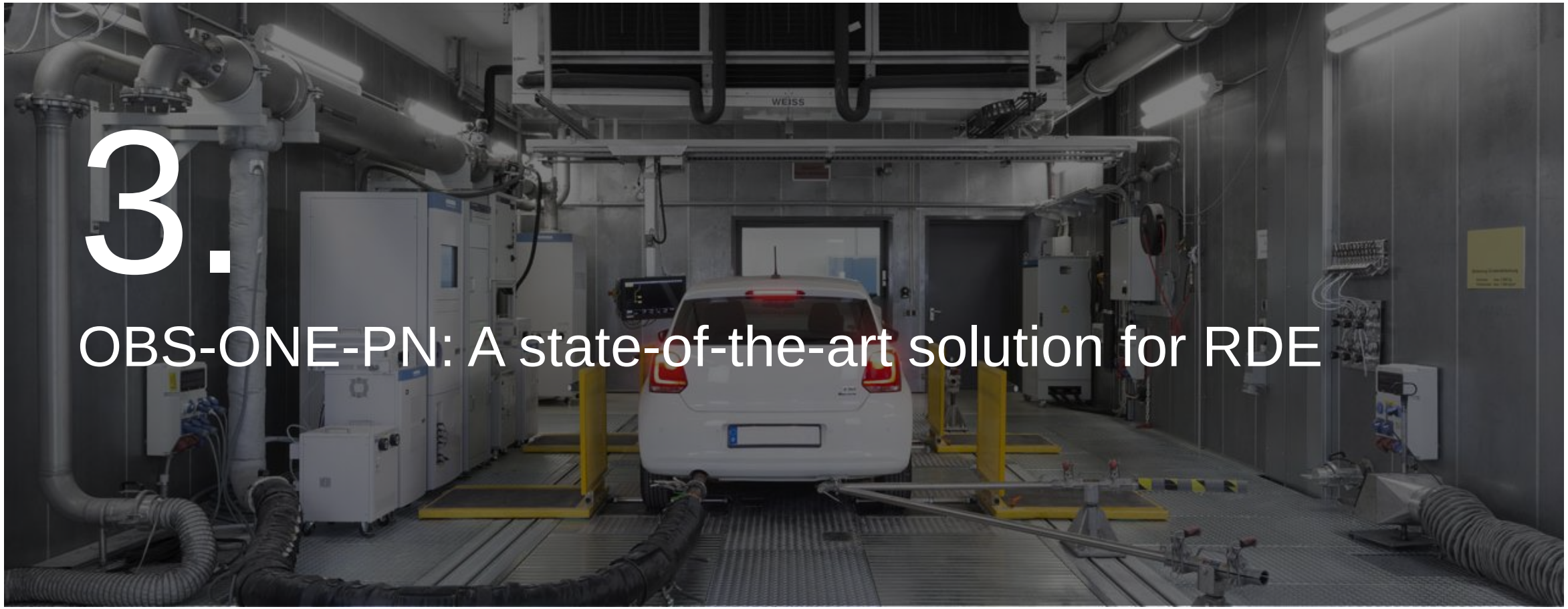
- A detailed analysis of the individual components will be provided on the next slide and in chapter 3

PN counting on the road: OBS-ONE-PN

- HORIBA considered the specific requirements for measurements on the road in the development of the OBS-ONE-PN



(1) First dilution directly at the sample probe
(2) Dilution air is dried by a desiccant
(3) Flow control for both passive dilutors is realized by orifices (no MFCs)
(4) Evaporation tube is replaced by a catalytic stripper
(5) A bypassed CPC is introduced for the OBS-ONE-PN. This CPC is designed for mobile applications taking into account the specific requirements related to inclination (→ CPC design), the concentration range (→ bypass), vibration stability (→ bypass, CPC design and wick optimization), temperature control and spill issues (→ soaked CPC wick only, no reservoir)



3.

OBS-ONE-PN: A state-of-the-art solution for RDE

OBS-ONE-PN: A state-of-the-art solution for RDE

System counting efficiency

- The OBS-ONE-PN shows a system counting efficiency which perfectly fulfills the required PN-PEMS specification
- The counting efficiency of **15 OBS-ONE-PN** units incl. its standard deviation (k=1) can be seen in the following diagram (in comparison to one MEXA 2000-SPCS):

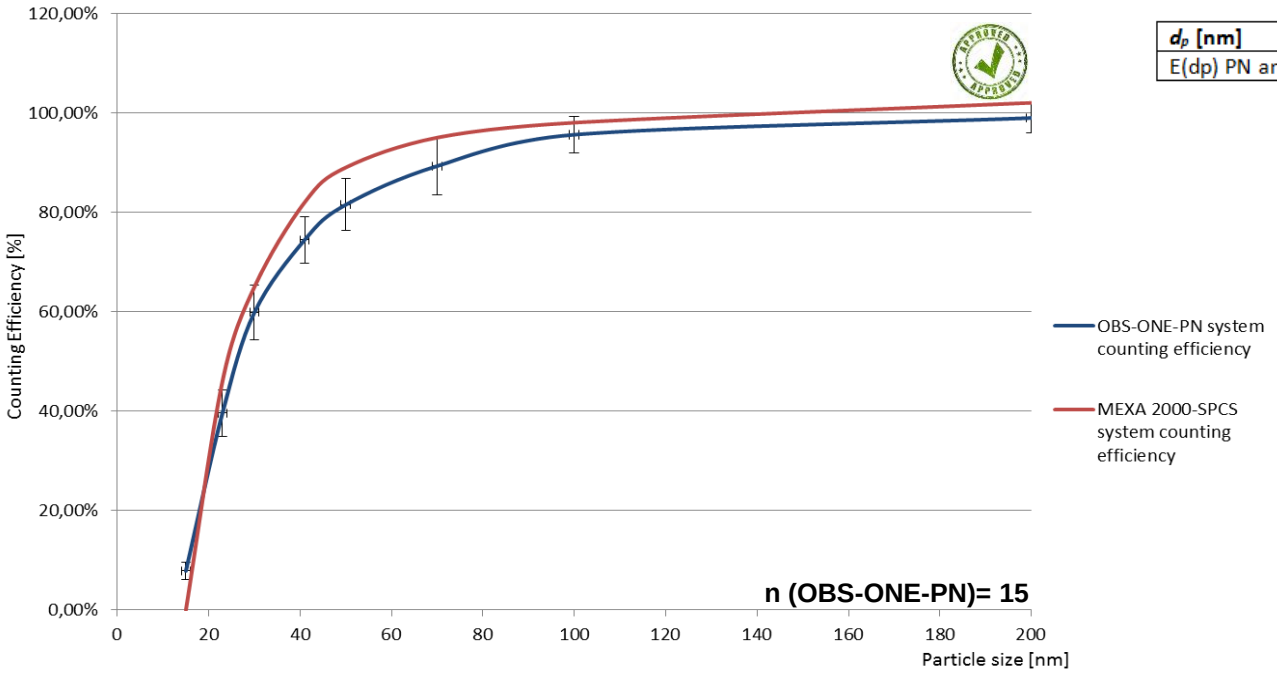


Table YYY: PN analyser (including the sampling line) system efficiency requirements

d_p [nm]	23	30	50	70	100	200
E(dp) PN analyser	0.2 – 0.6	0.3 – 1.2	0.6 – 1.3	0.7 – 1.3	0.7 – 1.3	0.5– 2.0

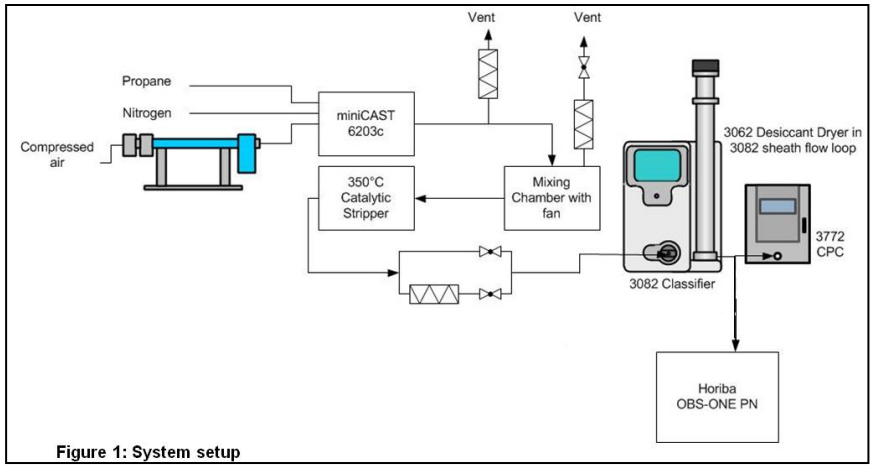
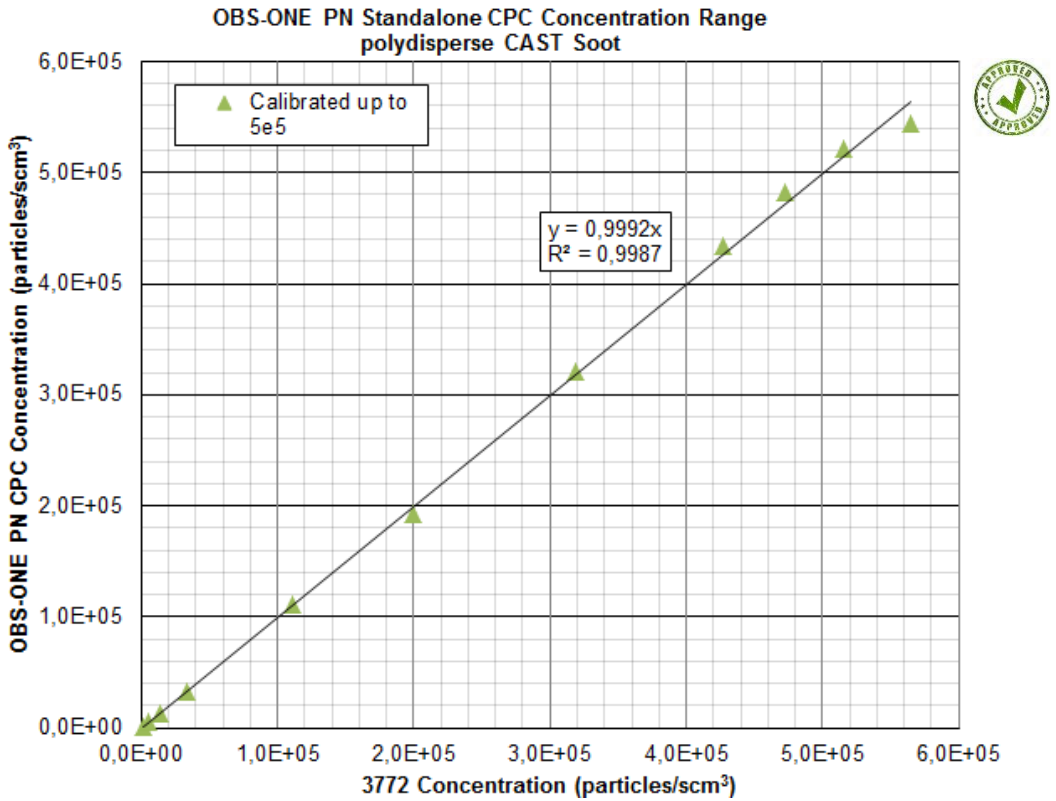


Figure 1: System setup

OBS-ONE-PN: A state-of-the-art solution for RDE

CPC linearity

- The **CPC used in the OBS-ONE-PN is specified in a concentration range between 0 - 500.000 #/cm³** exceeding the concentration range of a reference CPC (such as the model 3772) by the factor of 50. An additional dilutor (DF=100) was added upstream of the reference-CPC to check the OBS-ONE-PN CPC linearity



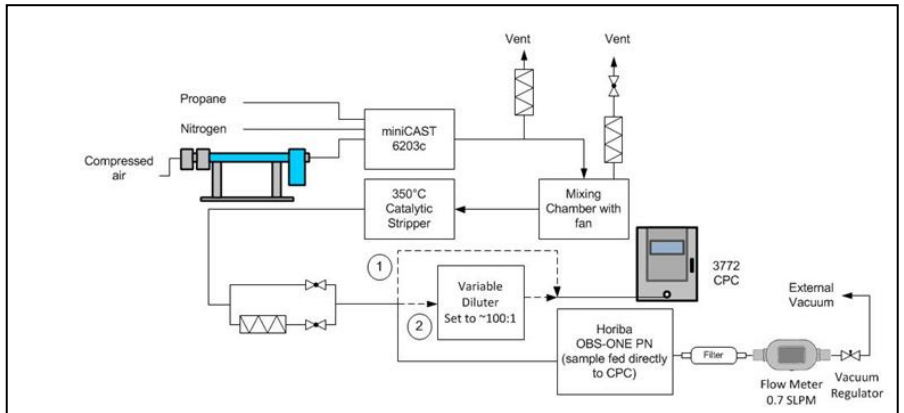


Figure 1: OBS-ONE PN standalone CPC calibration setup

OBS-ONE-PN: A state-of-the-art solution for RDE

Flow rate accuracy

- Due to the large CPC concentration range and its excellent linearity, a fixed dilution ratio of only 100:1 was chosen for the OBS-ONE-PN:
  - Higher accuracy due to the avoidance of a variable dilution
  - A total dilution ratio of 100:1 is sufficient to realize a maximum particle concentration range of 5 x 10^7#/cm³
- The orifice-controlled **flow rates of 15 OBS-ONE-PN were checked against a reference flowmeter** (traceable to National Standards). The HORIBA internal limit is ±5% against the nominal value

	Nominal flow rate [l/min]	Average flow rate measured [l/min]	Average difference to reference flow meter (traceable to National Standard) [%]
CPC			
Sample flow rate	0,100	0,100 ±2,422%	1,10%
Bypass flow rate	0,600	0,598 ±1,310%	-0,19%
1st Diluter			
Dilution flow rate	6,300	6,300 ±0,154%	0,01%
2nd Diluter			
Dilution flow rate	0,080	0,078 ±1,888%	0,08%

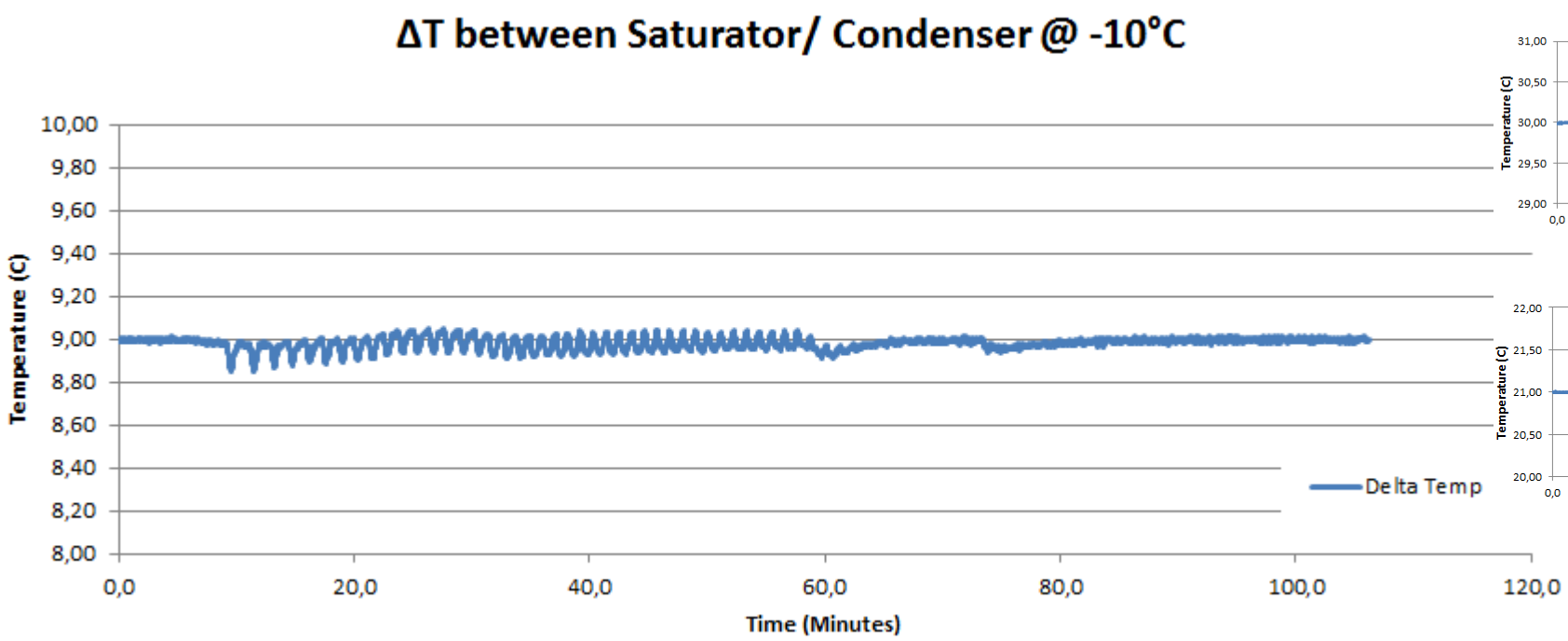
n (OBS-ONE-PN)= 15

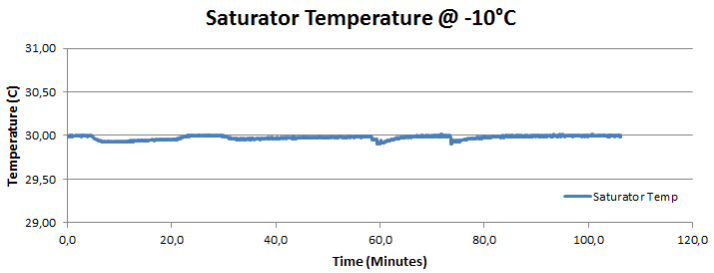
- The flows in the OBS-ONE-PN are pretty accurate with an excellent correlation to a reference flowmeter

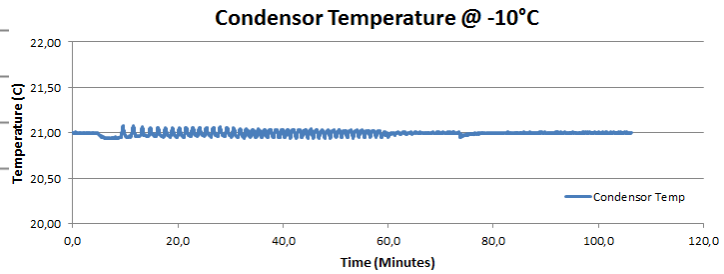
OBS-ONE-PN: A state-of-the-art solution for RDE

Ambient temperature (-10°C)

- Low ambient temperatures are especially critical in terms of maintaining a constant temperature difference in the CPC saturator and condenser





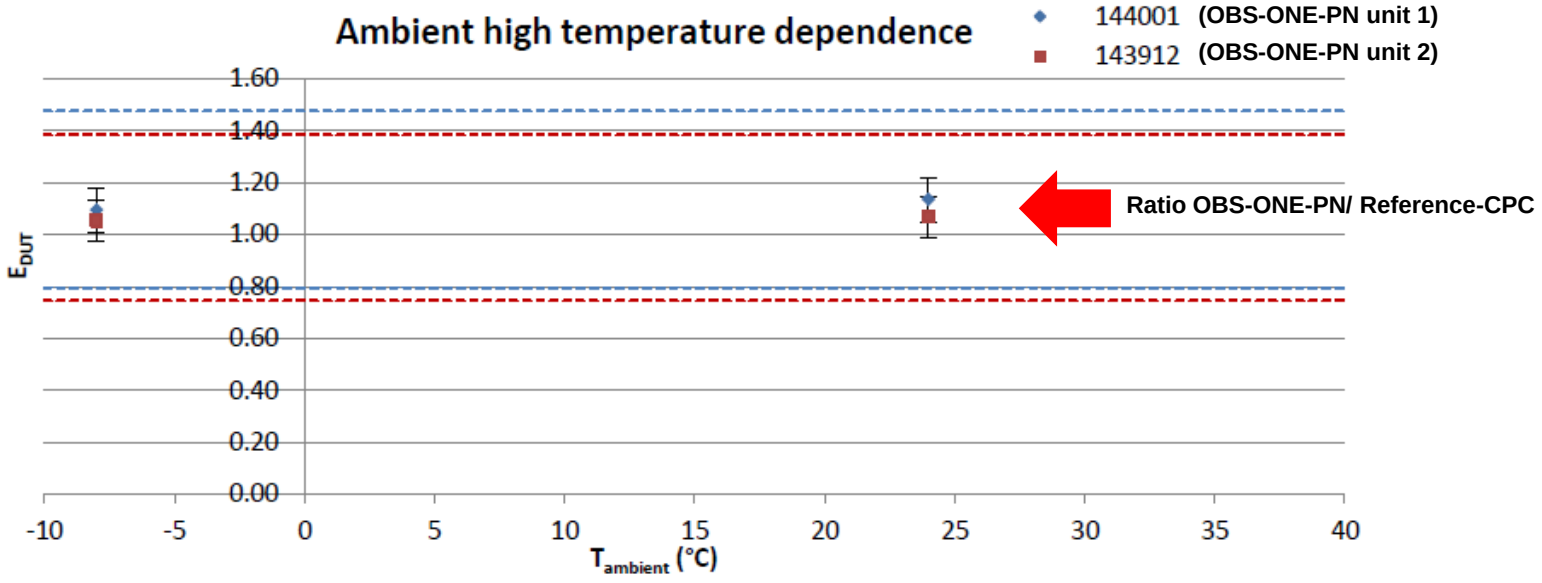


- PID controlled heaters shows an excellent behavior in maintaining a constant temperature!

OBS-ONE-PN: A state-of-the-art solution for RDE

Ambient temperature (-10°C)

- Low ambient temperatures are also critical in terms of condensation issues!
- Two OBS-ONE-PN were compared against a reference-CPC (installed outside of the climate chamber) in a 2-hours tests at 24°C and -8°C at Swiss METAS institute:



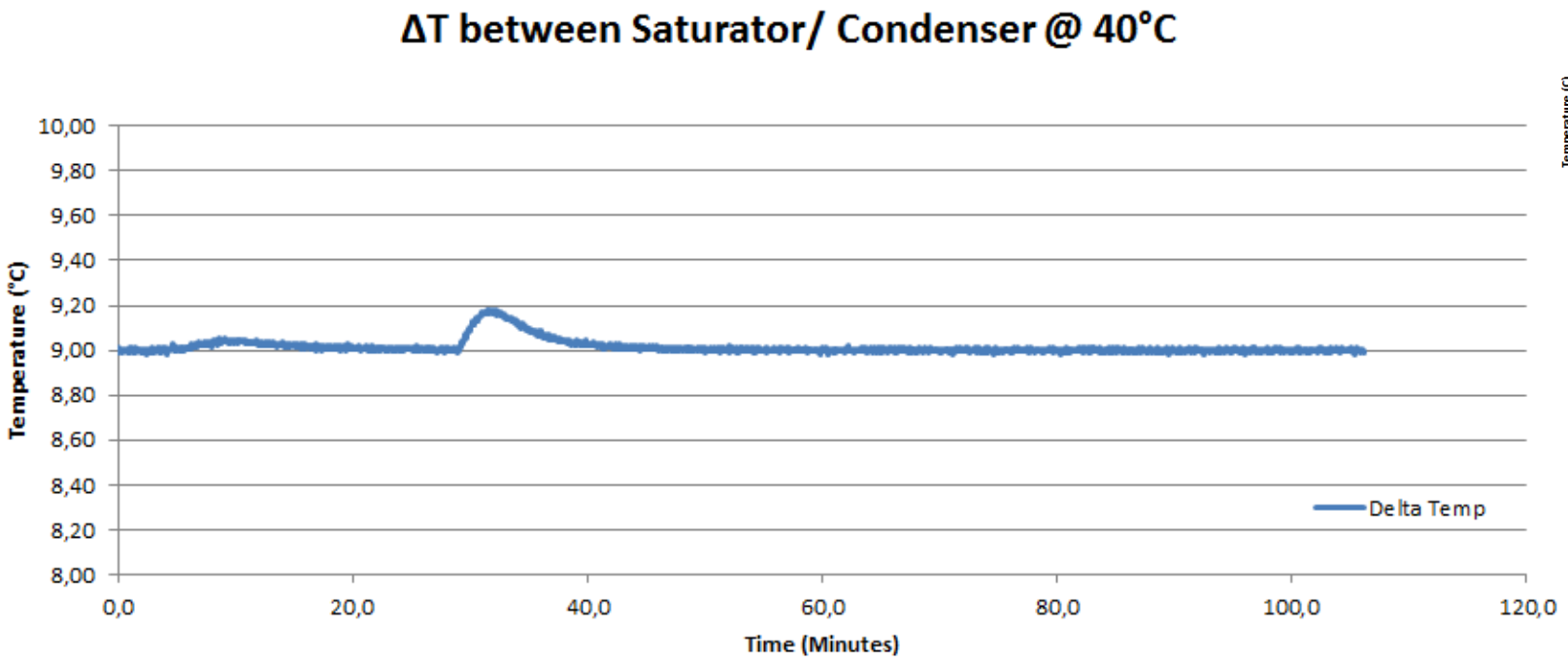
$T_{ambient}$ (°C)	c_{CPC} (#/mL)	$c_{DUT144001}$ (#/mL)	$c_{DUT143912}$ (#/mL)	$E_{DUT144001}$ c_{DUT}/c_{CPC}	U_E	$E_{DUT143612}$ c_{DUT}/c_{CPC}	U_E
24	2.07E+05	2.34E+05	2.20E+05	1.13	0.09	1.07	0.08
-8	2.27E+05	2.48E+05	2.38E+05	1.09	0.08	1.05	0.08

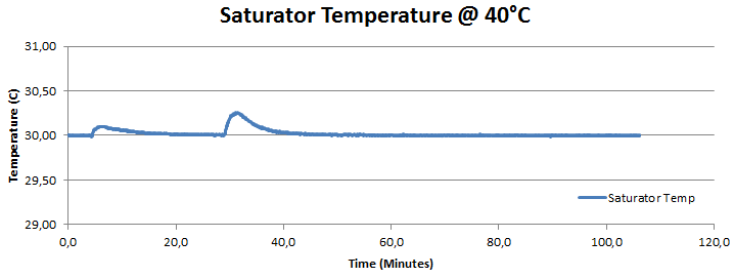
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

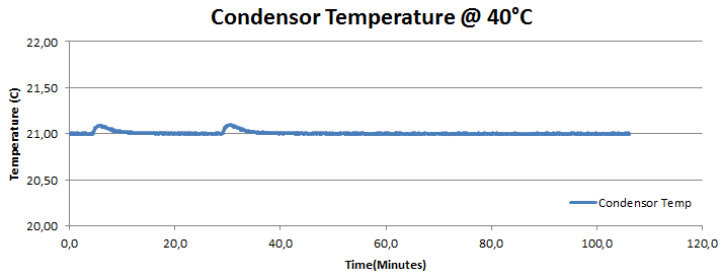
OBS-ONE-PN: A state-of-the-art solution for RDE

Ambient temperature (+40°C)

- High ambient temperatures are especially critical in terms of maintaining a constant temperature difference in the CPC saturator and condenser



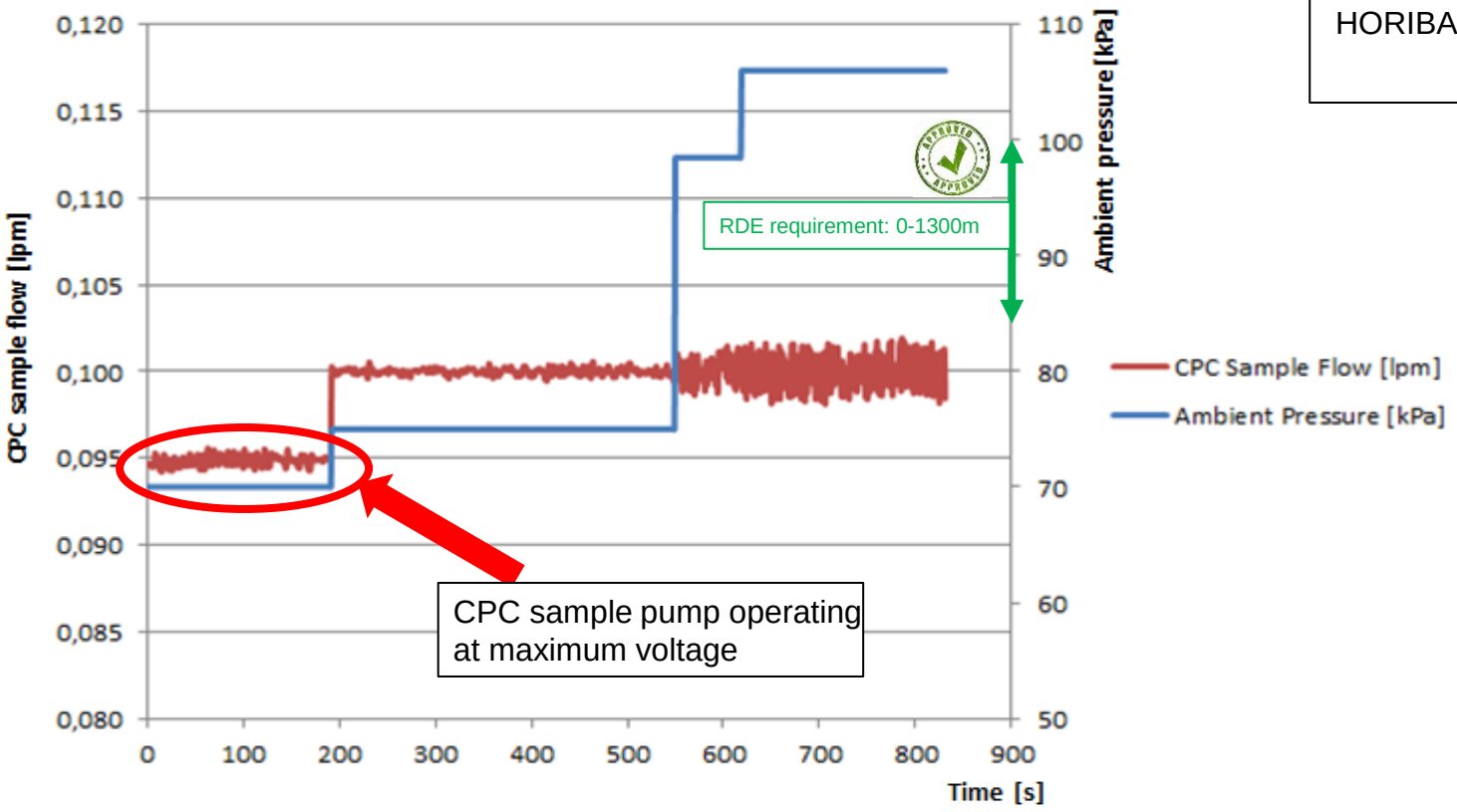




- PID controlled temperature settings show an excellent behavior in maintaining a constant temperature!

OBS-ONE-PN: A state-of-the-art solution for RDE

Ambient pressure



HORIBA internal limit (CPC sample flow):
0,1 lpm ± 0,05lpm

- The OBS-ONE-PN can maintain the flows in an ambient pressure range of 750-1050mbar (HORIBA specifies an altitude range between 0-2000m)

OBS-ONE-PN: A state-of-the-art solution for RDE

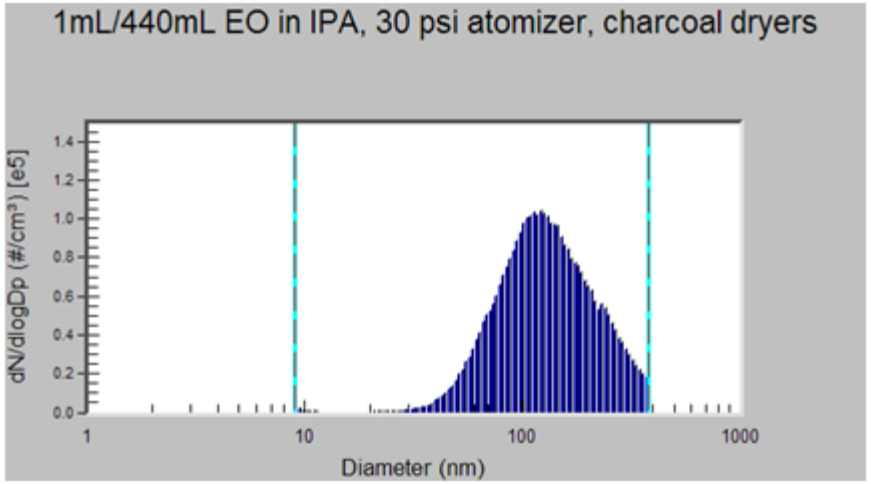
VPR efficiency

	Inlet concentration [#/cm³]	Outlet concentration [#/cm³]	Removal efficiency [%]
Unit 1	52.126,8	176,0	99,7
Unit 2	61.614,0	104,4	99,8
Unit 3	67.639,2	341,1	99,5
Unit 4	631.635,8	2.834,6	99,6
Unit 5	46.749,2	124,9	99,7
Unit 6	43.354,2	174,2	99,6
Unit 7	116.441,5	586,5	99,5
Unit 8	59.253,2	113,4	99,8
Unit 9	80.067,1	355,8	99,6
Unit 10	72.716,4	145,5	99,8
Unit 11	231.275,1	283,7	99,9
Unit 12	389.615,4	421,6	99,9
Unit 13	564.808,6	1.491,2	99,7
Unit 14	53.121,0	431,2	99,2
Unit 15	106.737,9	782,6	99,3
			99,64 Average

6.5 Volatile removal efficiency

The system shall achieve >99% removal of ≥30 nm tetracontane ($CH_3(CH_2)_{38}CH_3$) particles with an inlet concentration of ≥10,000 particles per cubic-centimeter at the minimum dilution.

It is recommended to have a >99% removal efficiency of polydisperse alcane (decane or higher) or emery oil with geometric mean diameter >50 nm and mass >1 mg/m³.



Example 100+nm distribution. Mode=122nm, GMD=128nm

- The VPR efficiency of the catalytic stripper used in the OBS-ONE-PN is excellent. High concentrations of emery oil (GMD > 100nm) can be removed with an efficiency greater than 99%

OBS-ONE-PN: A state-of-the-art solution for RDE

Power consumption

- A minimized power consumption is targeted for a measurement device used in OnBoard applications (A high power consumption requires additional or heavier batteries which should be avoided)
- The OBS-ONE-PN is designed with respect to a low power consumption. In normal operation the power consumption is less than 100W
- The warm-up phase (approx. 25-30 minutes) shows the highest power consumption. Usually the pumps are turned off during warm-up to reduce the power consumption and avoid cooling by the flows

Power Consumption at -10°C		
Horiba OBS-ONE-PN	**Current (Amps)**	**Power (Watts)**
Boot-up (CS, CPC, Pumps off)	1.32	31.68
Warm-up, Pumps Off	5.5	132
Warm-up, Pumps On	6.9	165.6
Temperatures Stable, pumps on	Average 3.485	Average 83.64

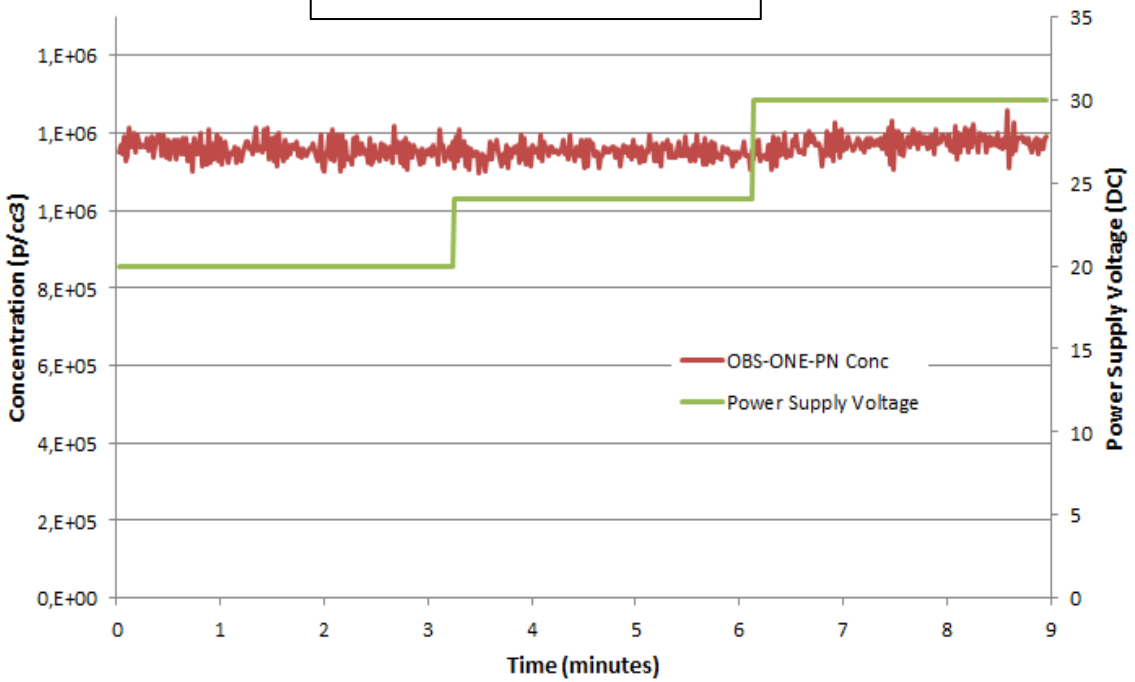
Maximum power consumption during warm-up (with pumps on!)

Power consumption during normal operation

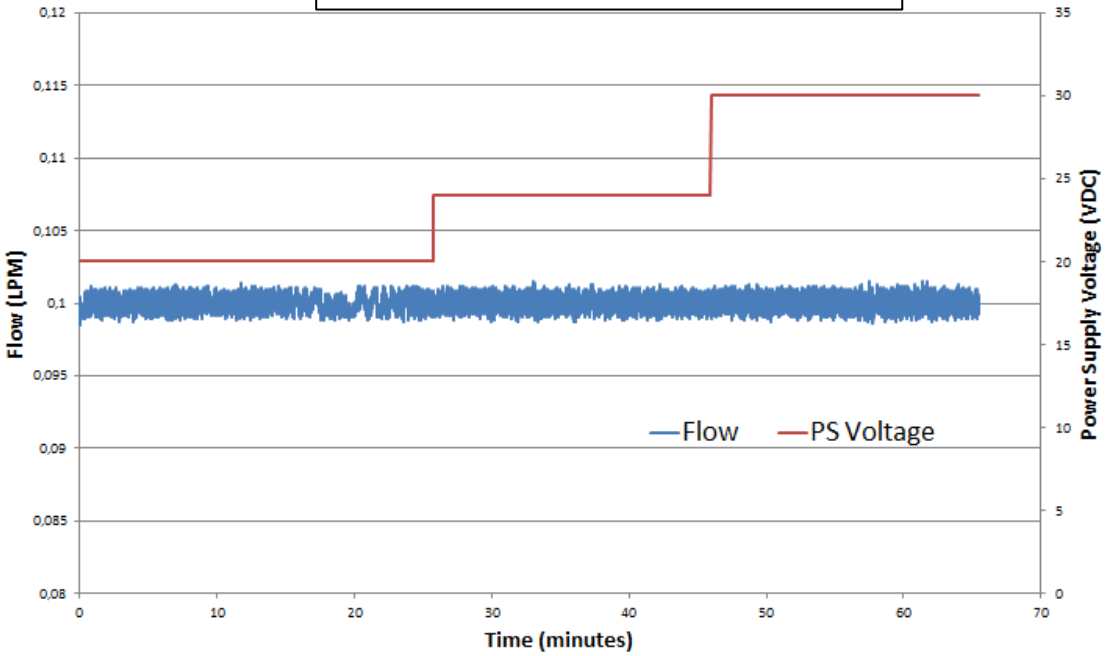
OBS-ONE-PN: A state-of-the-art solution for RDE

Stability during voltage variations

Particle concentration



CPC sample flow (@ -10°C)



- The OBS-ONE-PN is specified for a power supply voltage of 24VDC
- Variations in the power supply voltage does not affect the performance of the OBS-ONE-PN

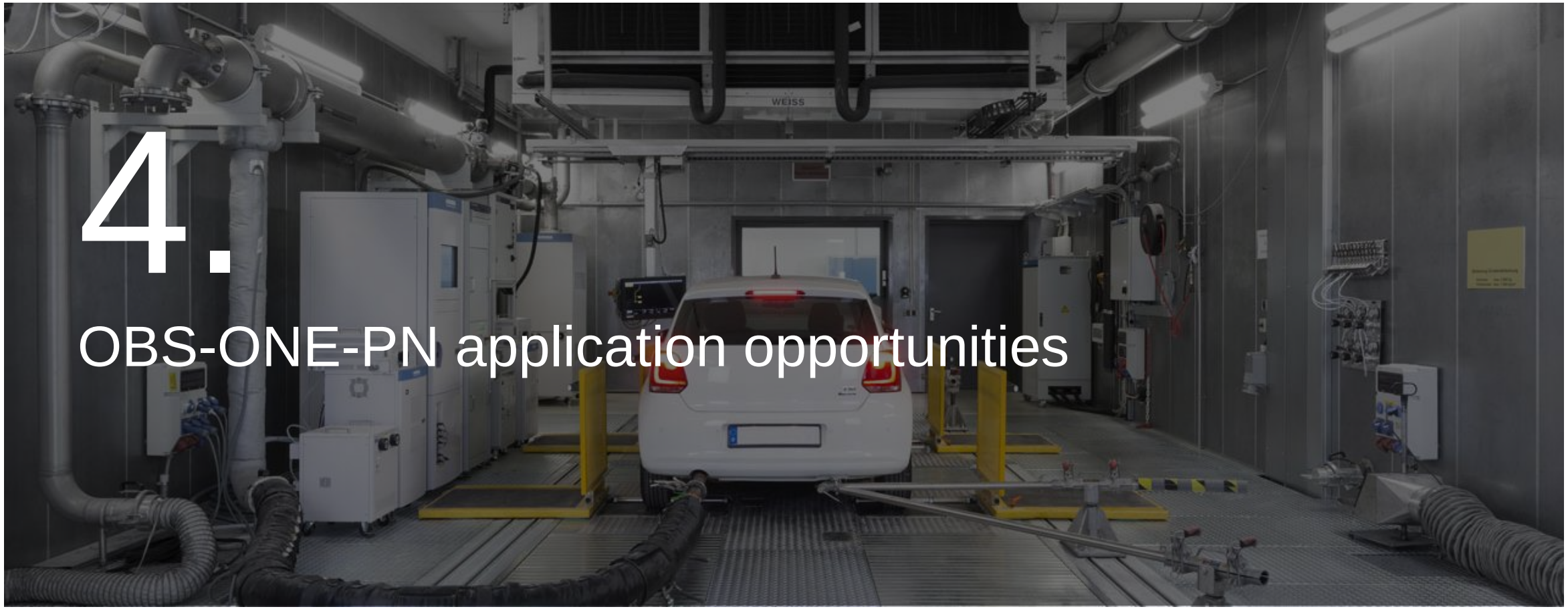
OBS-ONE-PN: A state-of-the-art solution for RDE

OBS-ONE-PN compliance

- The OBS-ONE-PN fulfills several standards to ensure a high-level quality of the product:
  - **EMC tested at Class A** emissions and basic immunity
  - EFT, radiated immunity and surge at Industrial Level
  - CE
  - Compliant to the Low Voltage Directive **EN 61010-1:2010**
  - Compliant to **EN 61010-2-010:2014** (“Safety requirements for electrical equipment for measurement, control and laboratory use”)
  - Compliant to **IEC 60825-1:2014** (“Safety of laser products“)
  - **RoHs compliance**
  - TÜV-certified carrier for an outside installation
  - FC

TÜV SÜD America

TÜV NORD Mobilität



4.

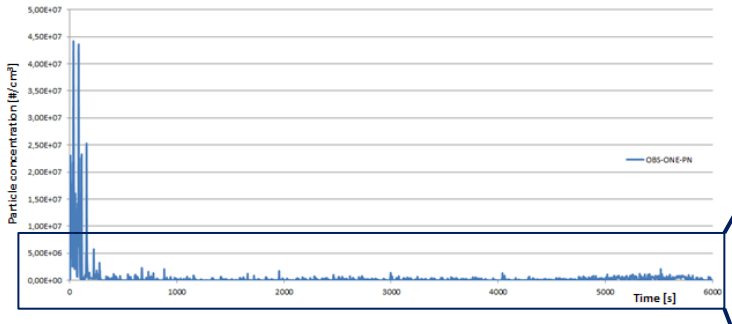
OBS-ONE-PN application opportunities

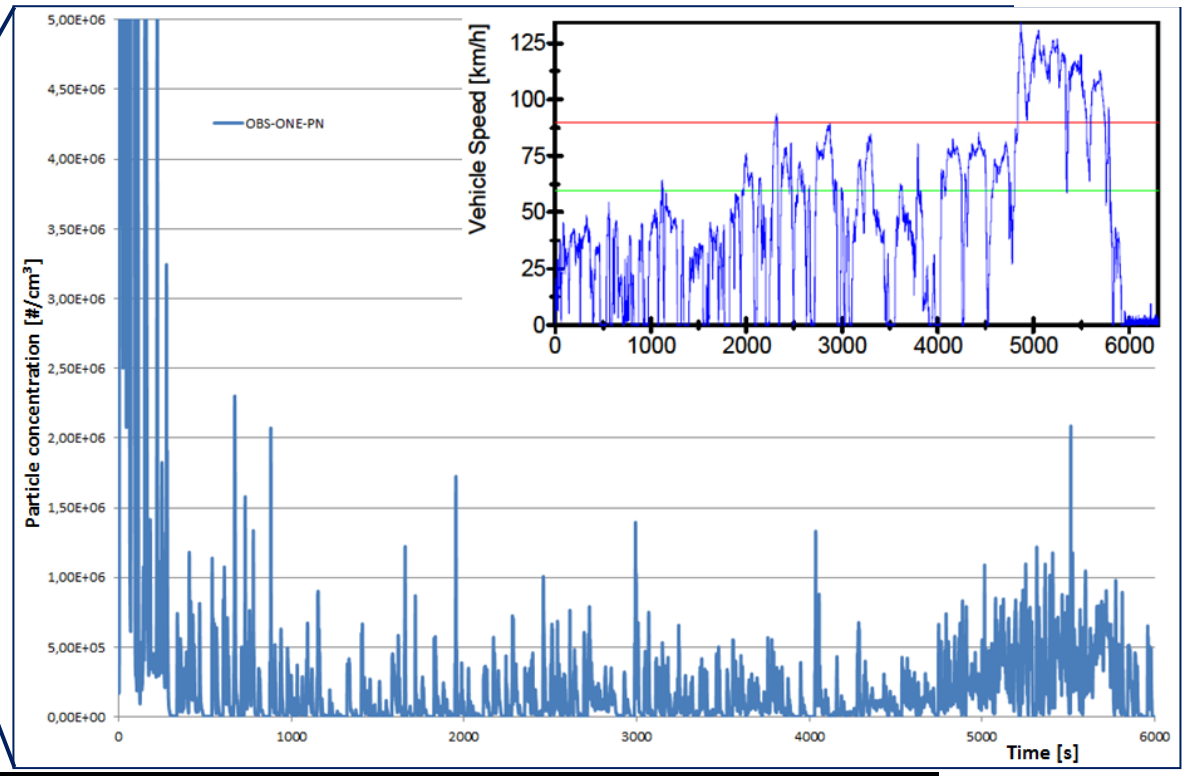
OBS-ONE-PN: Application opportunities

RDE testing on the road

- The OBS-ONE-PN is designed for measurements on the road

Data obtained by HORIBA in a measurement with a 1,2l GDI Euro6 vehicle driven on HORIBAs RDE test route near Oberursel (Germany)



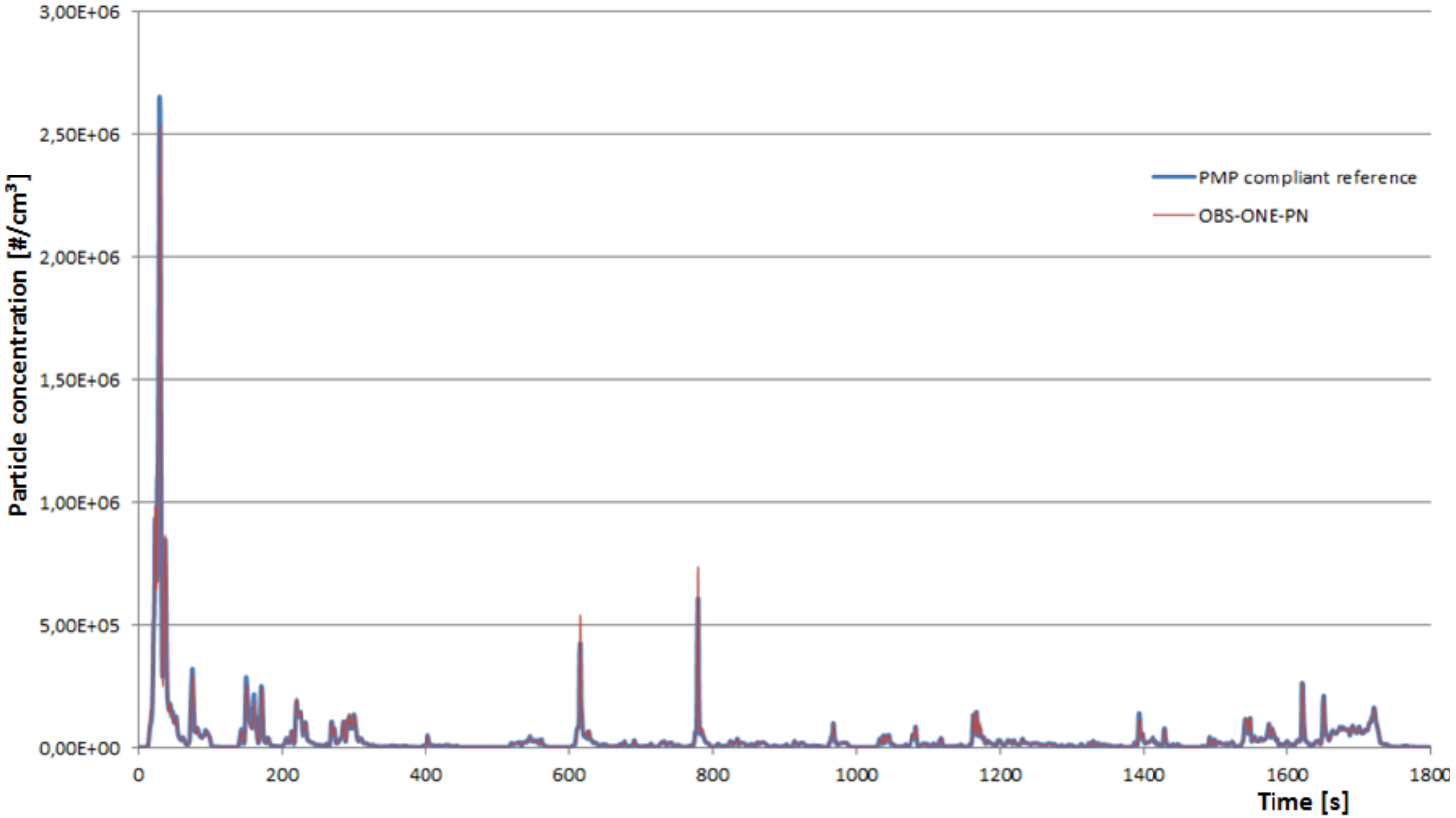


	Urban	Rural	Motorway	Total
PN (#/km)	1.02099E11	8.67834E10	2.18928E11	1.35598E11

OBS-ONE-PN: Application opportunities

Correlation tests on the chassis/ engine test bench for <u>Light-Duty Applications</u>

- The OBS-ONE-PN shows an excellent correlation compared to PMP-compliance reference counters in Light-Duty Applications (WLTC; 1,2l GDI Euro6 vehicle; both the OBS-ONE-PN and the PMP-compliant reference were sampling from the CVS):



Kraftfahrt-Bundesamt

HORIBA

Benennung

Das Kraftfahrt-Bundesamt bestätigt hiermit, dass von

HORIBA Europe GmbH
Testcenter
Hans-Mess-Straße 6
61440 Oberursel

die Forderungen der

DIN EN ISO/IEC 17025:2005
DIN EN ISO/IEC 17020:2012

erfüllt werden und einschlägige technische und genehmigungsrelevante Kenntnisse und Fähigkeiten nachgewiesen wurden.

Die oben genannte Stelle wird als Technischer Dienst der Kategorie A, B und D benannt. (Scope s. Anlage zur Urkunde)

Die Benennung ist gültig ab: 19.12.2015
Die Anlage ist Bestandteil der Urkunde und besteht aus 3 Seiten.
Registrier-Nr.: KBA-P 00071-15

Datum: 21.12.2015
Unterschrift: Im Auftrag

Dr. Jurk

Berninstraße 62
01187 Dresden
Tel.: 0351 47380-0

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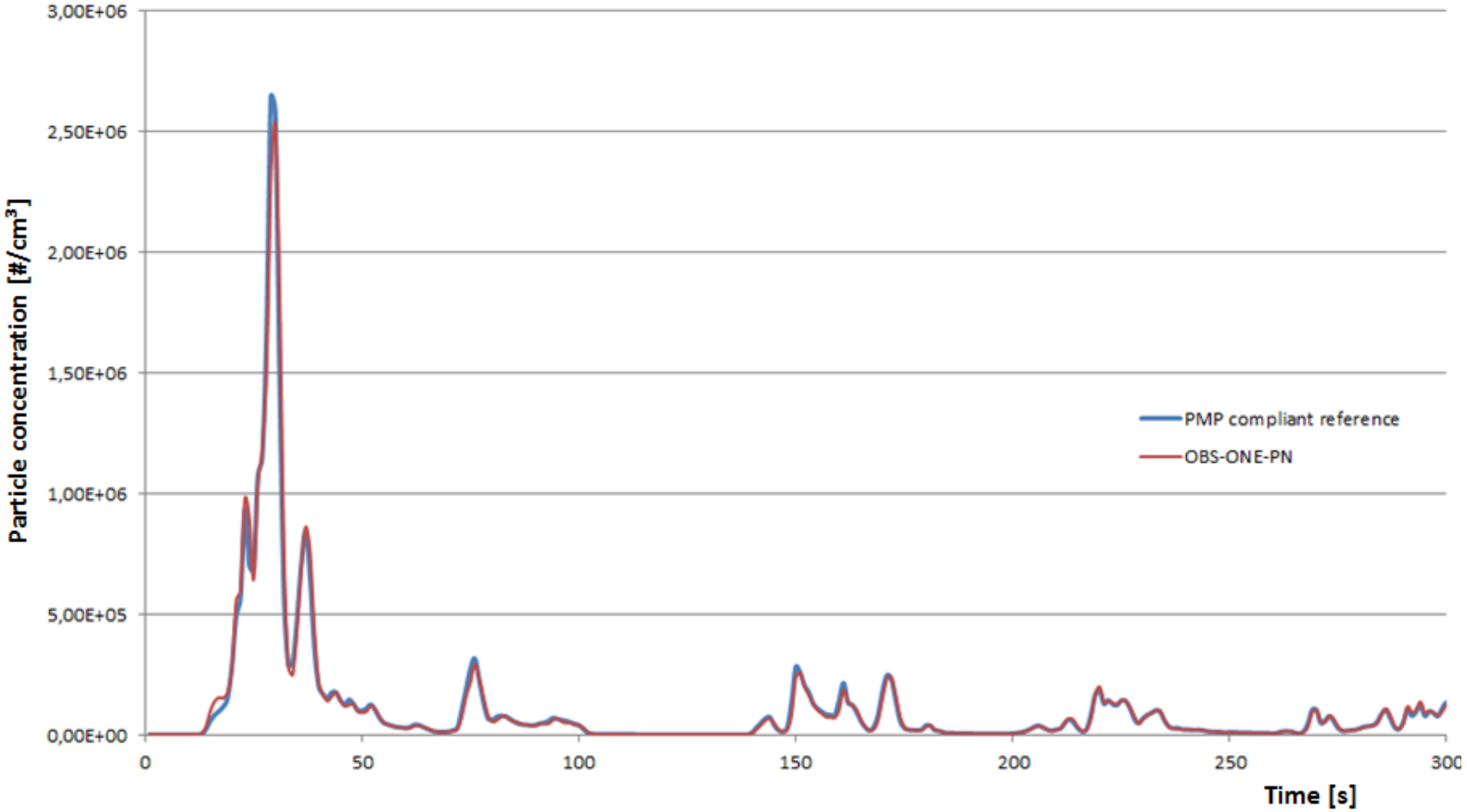
Data obtained by HORIBA based on measurements in the ISO17025 certified test center in Oberursel (designated as a Technical Service by German Federal Motor Transport Authority)

OBS-ONE-PN: Application opportunities

Cold start

- The OBS-ONE-PN shows an excellent performance during cold-start (WLTC; 1,2l GDI Euro6; both the OBS-ONE-PN and the PMP-compliant reference were sampling from the CVS):

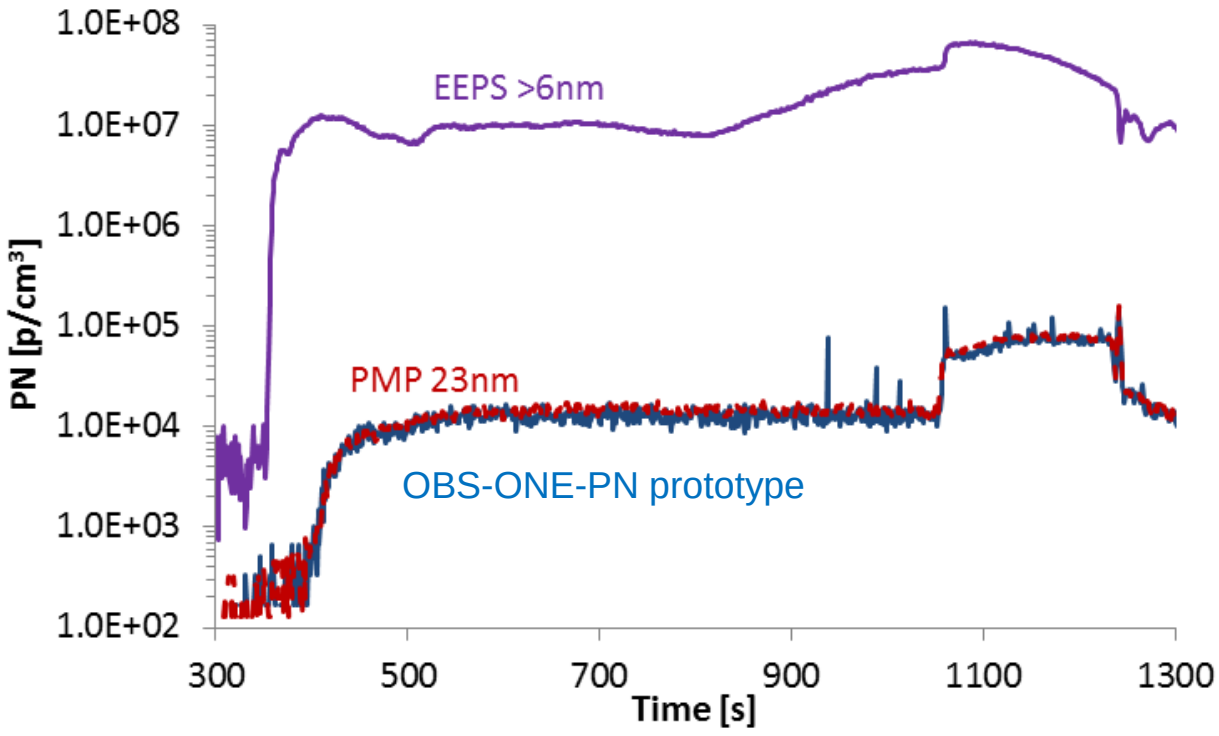


Data obtained by HORIBA based on measurements in the ISO17025 certified test center in Oberursel (designated as a Technical Service by German Federal Motor Transport Authority)

OBS-ONE-PN: Application opportunities

DPF-regeneration

- The OBS-ONE-PN shows an excellent performance in DPF regeneration events:

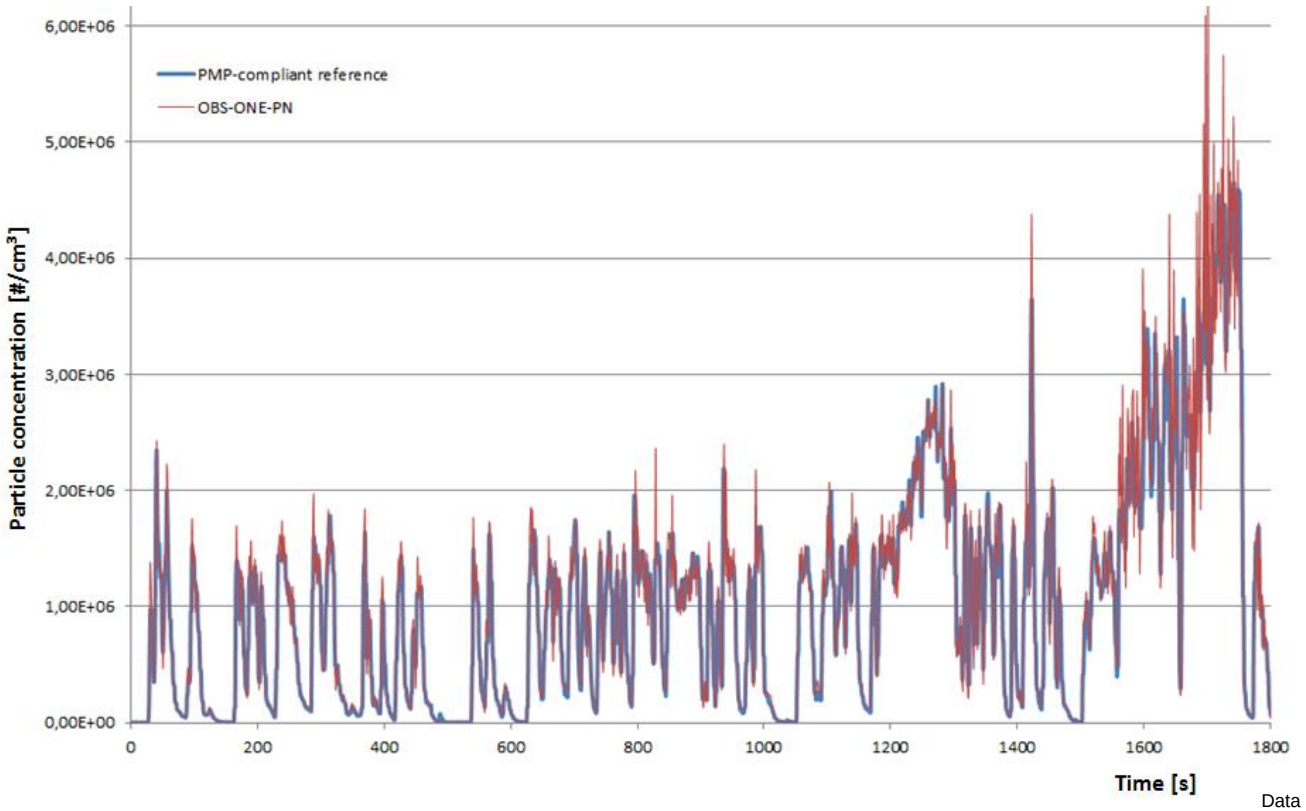


Data obtained by JRC (Giechaskiel B., Riccobono F., and Bonnel P. (2015). Feasibility study on the extension of the Real Driving Emissions (RDE) procedure to Particle Number (PN): Chassis dynamometer evaluation of portable emission measurement systems (PEMS) to measure particle number (PN) concentration: Phase II; EU report 27451, doi 10.2790/74218**)**

OBS-ONE-PN: Application opportunities

Correlation tests on the chassis/ engine test bench for <u>Heavy-Duty Applications</u>

- The OBS-ONE-PN shows an excellent correlation compared to PMP-compliance reference counters in Heavy Duty Applications (WLTC; unknown truck; both the OBS-ONE-PN prototype and the reference-counter were sampling from the tailpipe):

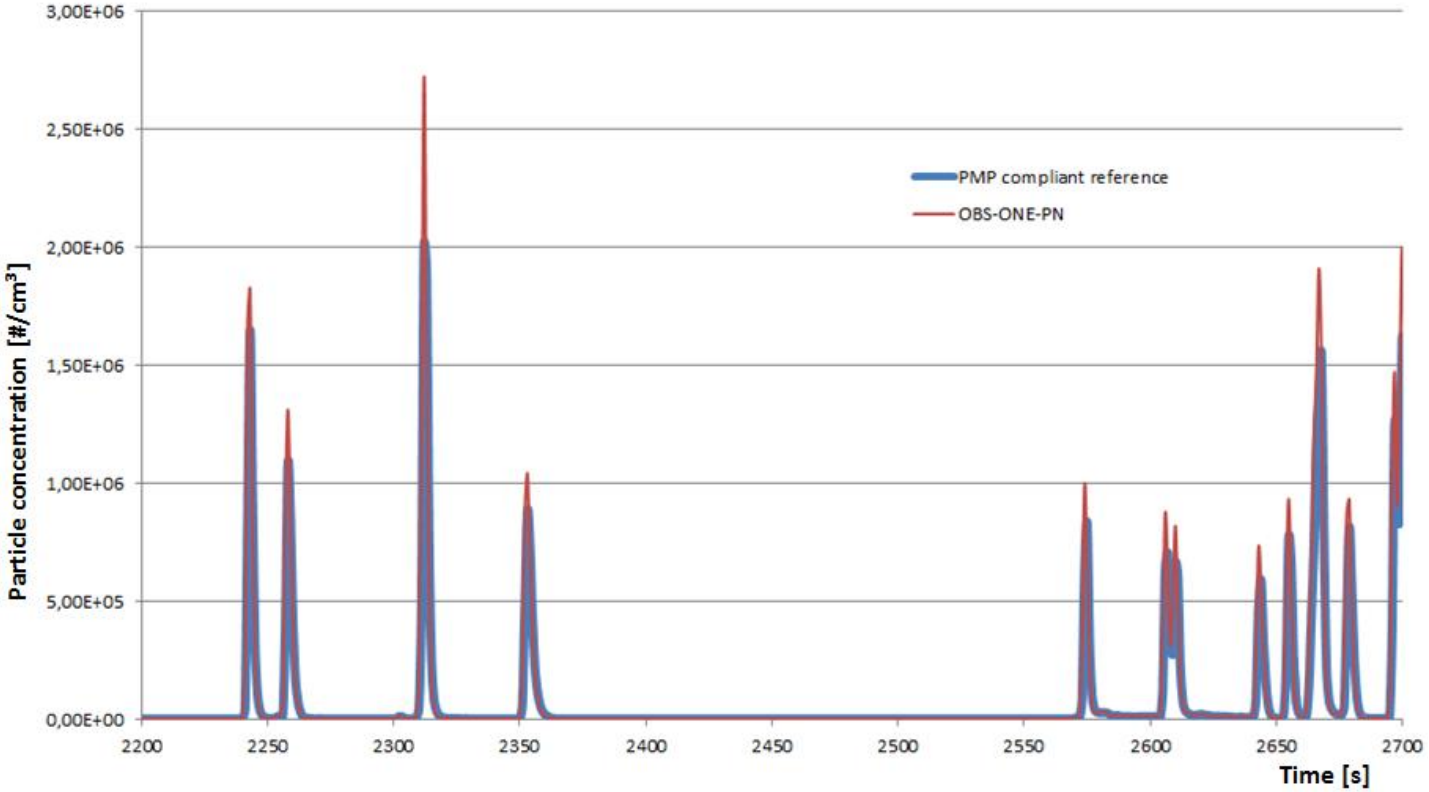


Data obtained by JRC using HORIBAs OBS-ONE-PN prototype

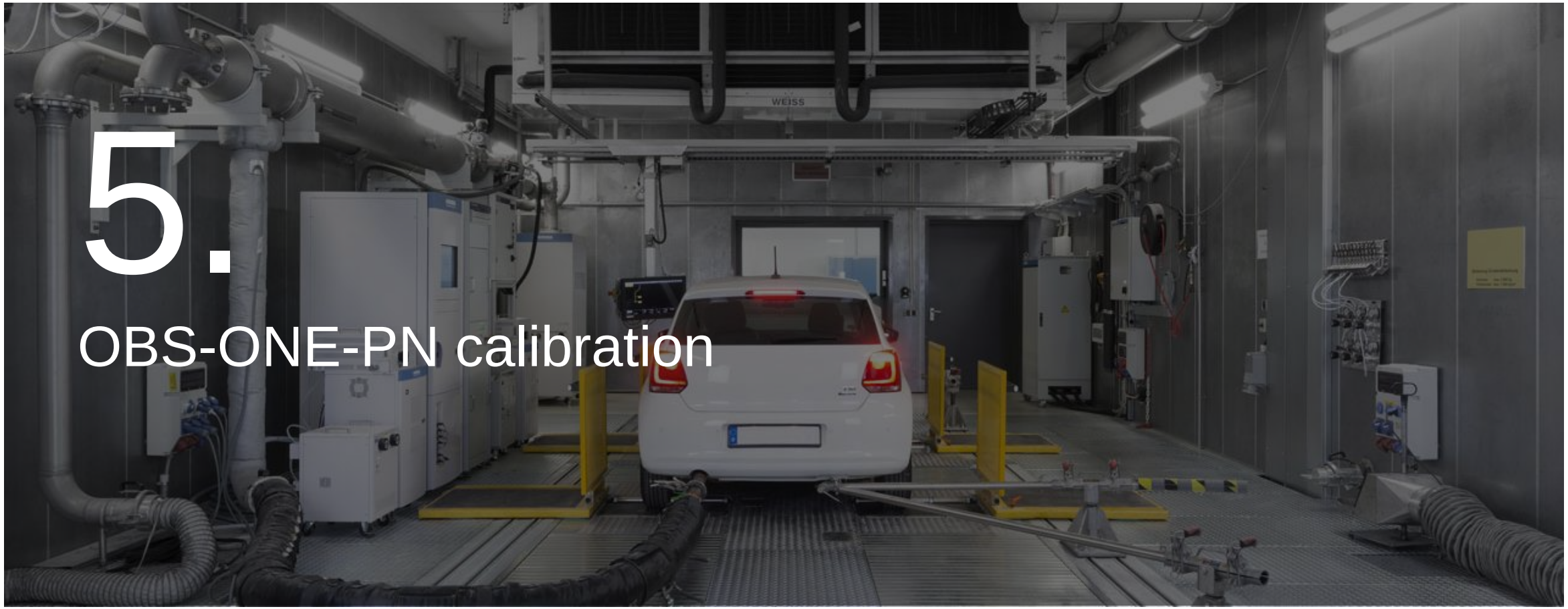
OBS-ONE-PN: Application opportunities

Hybrid vehicles

- Due to the CPC technology, the OBS-ONE-PN can also be used for the testing of hybrid vehicles. Zero emissions during electric driving are not falsified by a lower limit of detection significantly above zero (as might be the case for the DCS-technology)



Data obtained by HORIBA based on measurements in the ISO17025 certified test center in Oberursel (designated as a Technical Service by German Federal Motor Transport Authority)

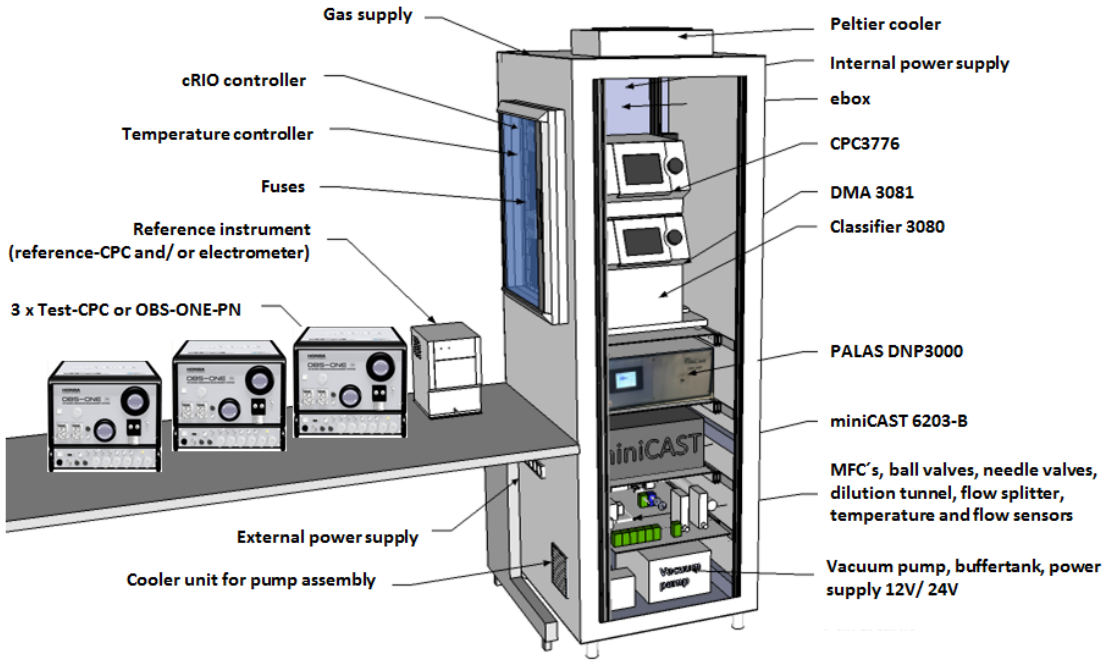


5.

OBS-ONE-PN calibration

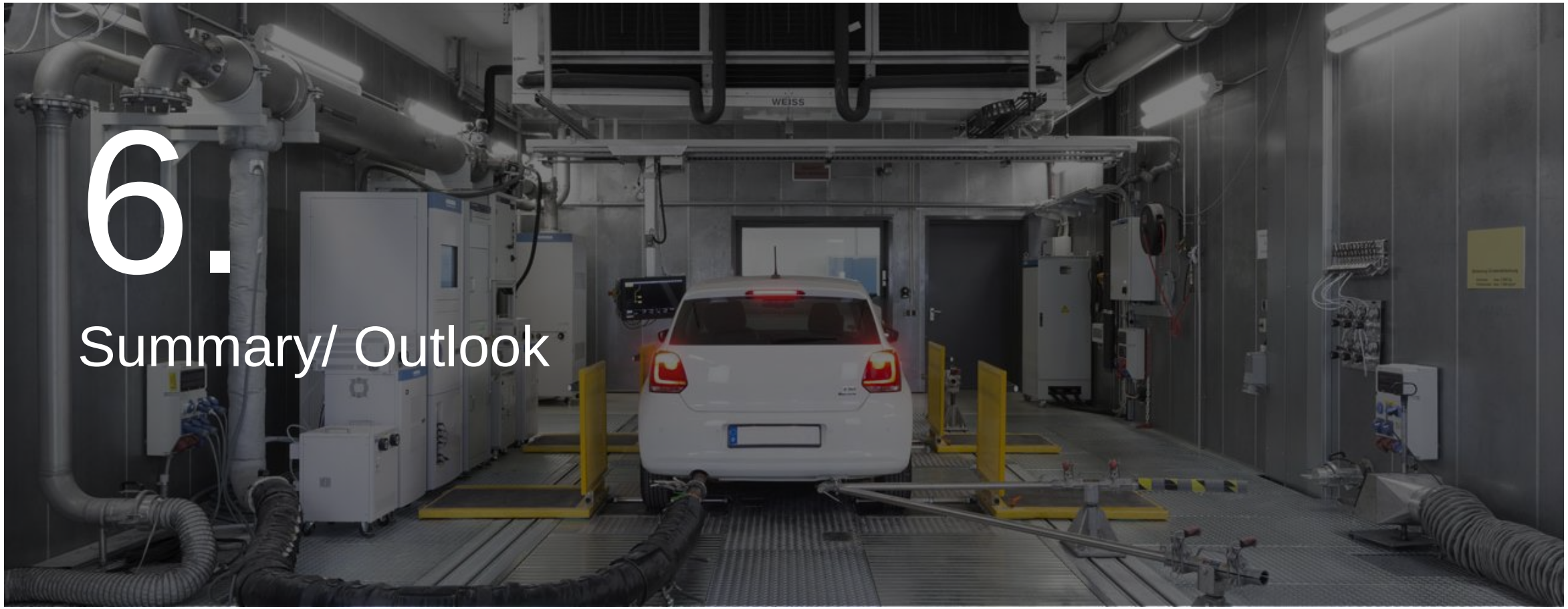
OBS-ONE-PN calibration

- The PN-PEMS calibration procedure is still under discussion!
- HORIBA utilizes its automated calibration rack (ISO27891-compliant) to perform the system counting efficiency check, the linearity check and the zero check
- The calibration rack can be used to calibrate both the individual components (VPR + CPC) or the system as a whole unit. Both approaches will be allowed from the legislation
- All sequences are automated to minimize the influence of the operator
- Maintenance & calibration service of the OBS-ONE-PN can be offered with a turn-around time of approx. 1 week



OBS-ONE-PN calibration

- HORIBA´s fully automated calibration rack for both the CPC100 and the OBS-ONE-PN Service



6.

Summary/ Outlook

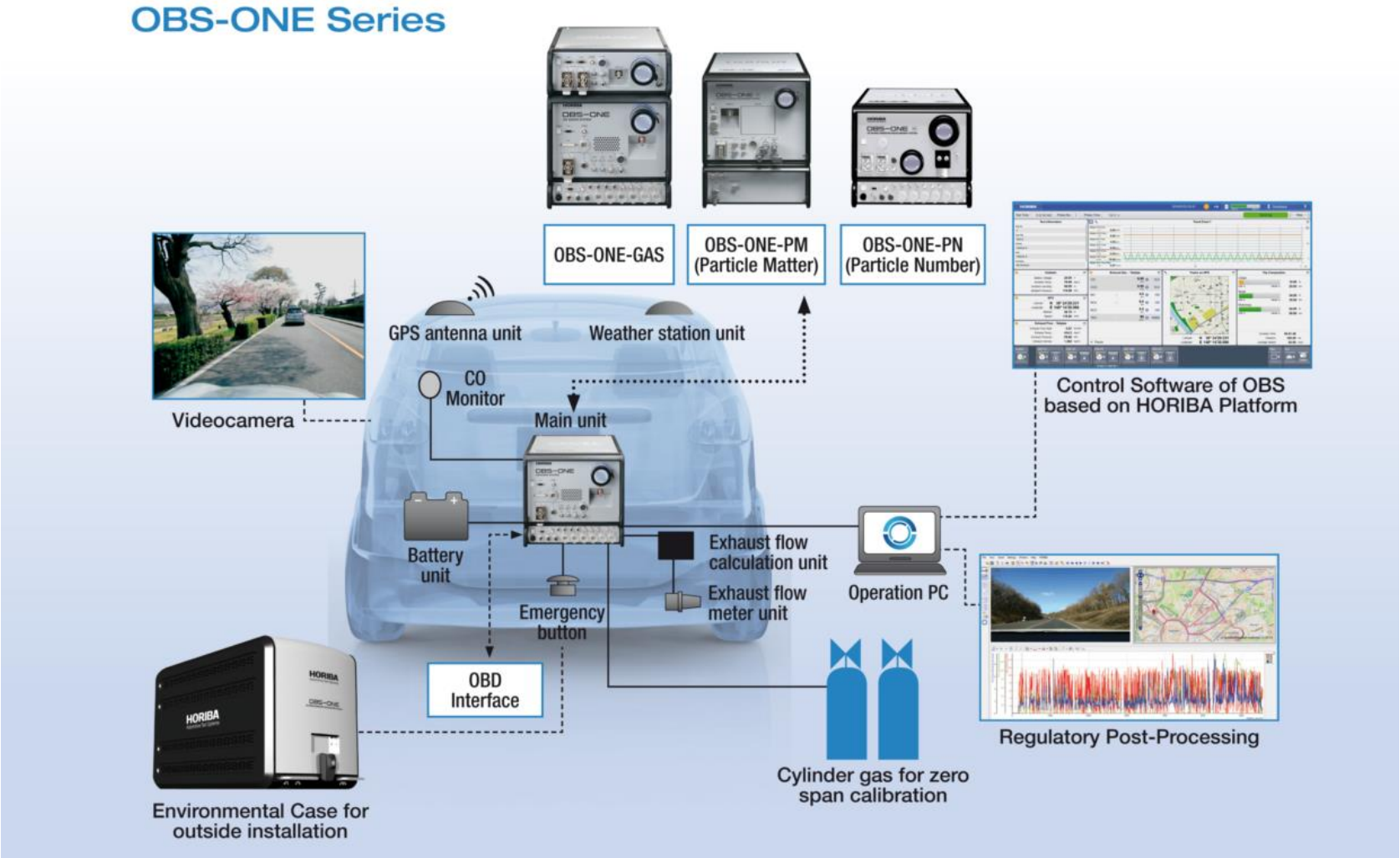
OBS-ONE-PN Summary

HORIBA ONE PLATFORM

- **Technical leadership** due to the **most advanced CPC** and system design optimized for mobile applications (robust under all RDE boundary conditions as well as shock/ vibration)
- **Security of investment** (OBS-ONE-PN is ready for future legislation requirements such as cold-start etc.)
- **Excellent correlation** to PMP-compliant counters
- **Intuitive and robust control software** with integrated and automated check and calibration sequences
- Modular concept enables **fast and flexible installation** on almost any vehicle

Summary

The OBS-ONE-PN as an integrated part of HORIBAs solution for RDE (and many other applications)



Outlook

OBS-ONE-PN as a part of the „PEMS4Nano“ project

- Together with strong partners all over Europe, HORIBA set up a project proposal for the development of particle number measurement procedures down to 10nm, providing a contribution to future regulation on particle emissions, in particular in real driving conditions
- This so called “PEMS4Nano” project was granted by the European Commission as a part of the HORIZON2020 program
- **A prototype of a modified OBS-ONE-PN (measuring particles down to 10nm) will be introduced into that project** to support these activities. A laboratory PN counter (measuring down to 10nm) will also be provided as a reference

Thank you

Cảm ơn

감사합니다

ありがとうございました

Dziękuję

धन्यवाद

Grazie

Merci

谢谢

நன்ற

ขอบคุณครับ

Obrigado

Σας ευχαριστούμε

Děkuji

شُكْرًا

Tack ska ni ha

Danke

Большое спасибо