45th PMP Meeting
07th – 08th November 2017
Joint Research Centre, Ispra

Feasible Methodology for Brake Wear Particles Measurement and Characterization

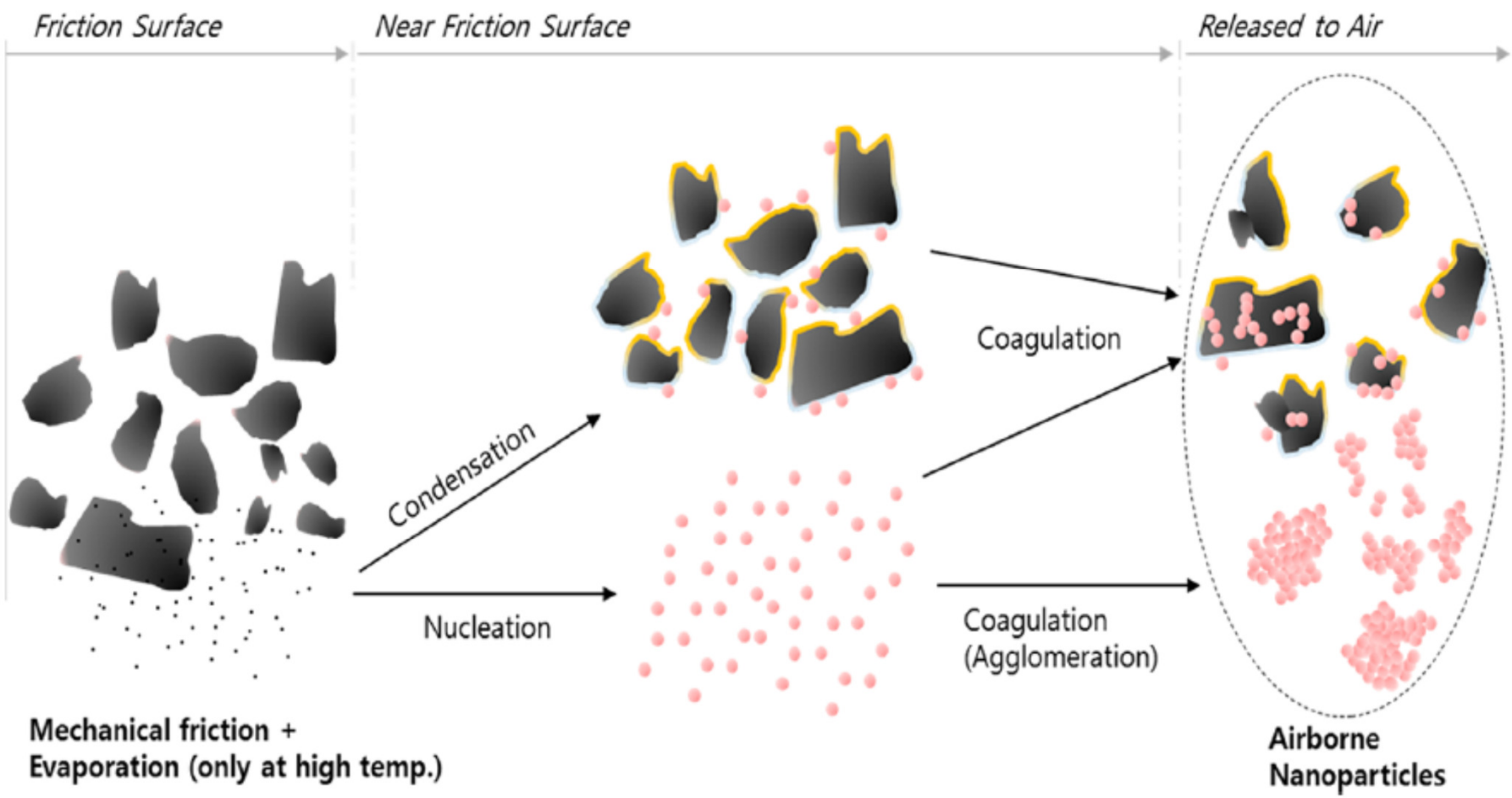
Hiroyuki Hagino
Japan Automobile Standards Internationalization Center (JASIC)

Contents

- **Uncertainty of Brake Wear Particle Emissions**
- **Feasible Sampling Methodology JASO Standardization Concept**
- **Next Steps**

Hypothesis of Brake Particle Emission Mechanism

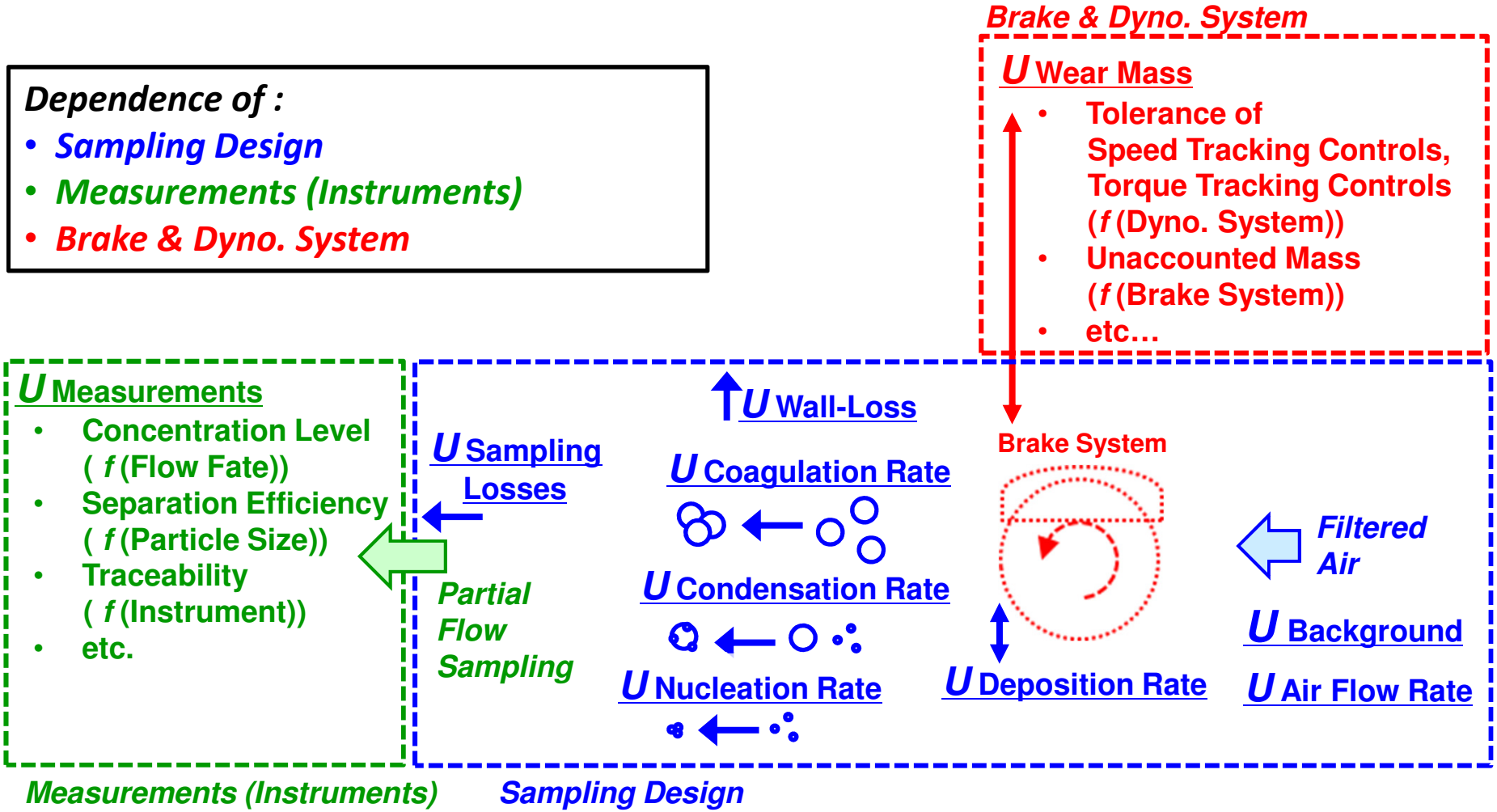
- **Nanoparticles (Dp< 100 nm): Nucleation originated from Gas**
- **Fine/ Coarse Particles : Debris and Milled Particles under Abrasion Processes**
- **Near Surface / Different form Real World Air Samples ?**



Ref: Namgung et al., *Environ. Sci. Technol.* 50, 3453–3461 (2016)

Uncertainties *U* of Brake Wear Particle Emissions

- **The Uncertainties might be distinguish by the three Parameters**
- **Empirically, Simplified System will be much easier to Control Data Quality**
- **Concentration Levels detected by Instruments depends on Air Flow Rate**



Ref : Hagino et al., *EuroBrake2018 in Presentation*

Comparison of Sampling Methodologies

- There are Sweet Spots Flow Rate for Enclosure Design on High Efficient Sampling
- JARI / JASO toward the Feasible Sampling Methodology based on Low Flow Rate

Contents	JARI	JASO (JSAE)	PMP/ISO Discussion
Goal	Research for Air Quality	National Standards for Advance Production Equipment, Improve quality, etc..	Suggestion Common Test Procedure for Sampling and Assessing
Concepts	Feasible Methodology	Feasible Methodology Correlative Concept (Traceable to Wear Mass)	Common Test Procedure
Sampling Design			
Enclosure / Sampling Lines	JARI (See Later)	JARI (See Later) (Fixed)	7 or more Different Design
Air Flow	0.5 ~ 1 m^3/min (Fixed)	1 m^3/min (Fixed)	4 ~ 56 m^3/min
Sampling Efficiency	PM_{10}, PN Coverage (See Later)	PM_{10}, PN Coverage (See Later)	PM, PN Coverage
Filtered Air	20±5 ºC, RH<35%	Room Condition	20±5 ºC, RH 50±10 %
Measurements			
PM	PM_{10}, $PM_{2.5}$ Compositions (XRF, OCEC, TOF-AMS, ICP-TOF etc..)	Highest Priority (Fixed) *Compliance with WHO Air Quality Guidelines* PM_{10}, $PM_{2.5}$	PM
PN	CPC, OPS, APS, FMPS, DMS, EEPS, ELPI etc..	Low Priority (Fixed) Discussion in Next Stage	CPC, OPS, APS, EEPS, ELPI, etc..

JARI
JAPAN AUTOMOBILE RESEARCH INSTITUTE

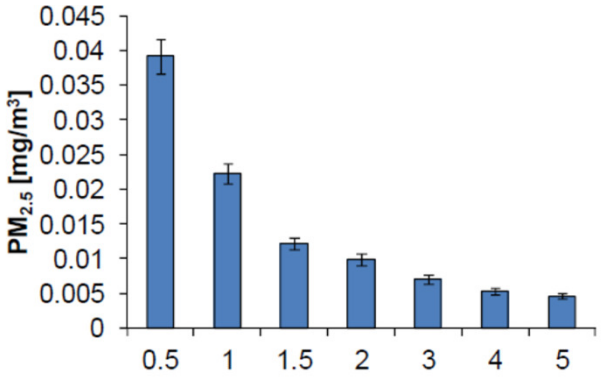
Air Flow Rate vs Emissions

- **There no Significant Difference of Mass Emissions with Flow Rate**
- **If Emission is Constant, High Flow Rate will make the Low Concentration detected by instruments (Low Concentration in Sampling Tunnel)**

The mass emission was defined as:

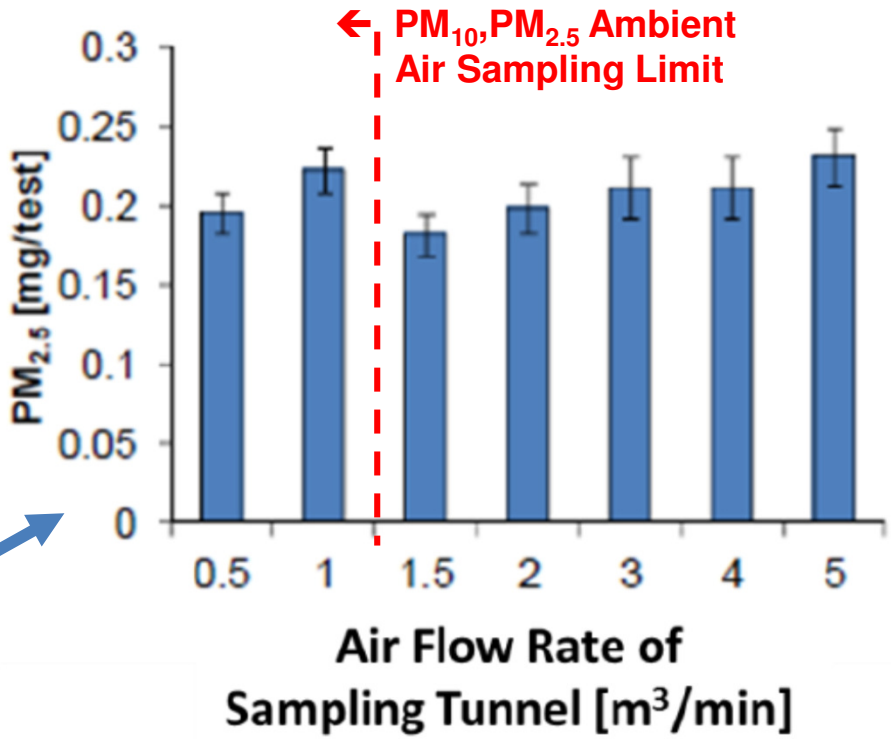
$$E_{wheel} = C_{tunnel} \times V \times t$$
$$= C'_{tunnel} \times V' \times t$$

where E_{wheel} : Mass Emission (mg/test),
C_{tunnel} : Mass concentration in tunnel (mg/m^3),
V_{tunnel} : air flow rate in tunnel (**m^3/min**),
t : test time(**min/test**).



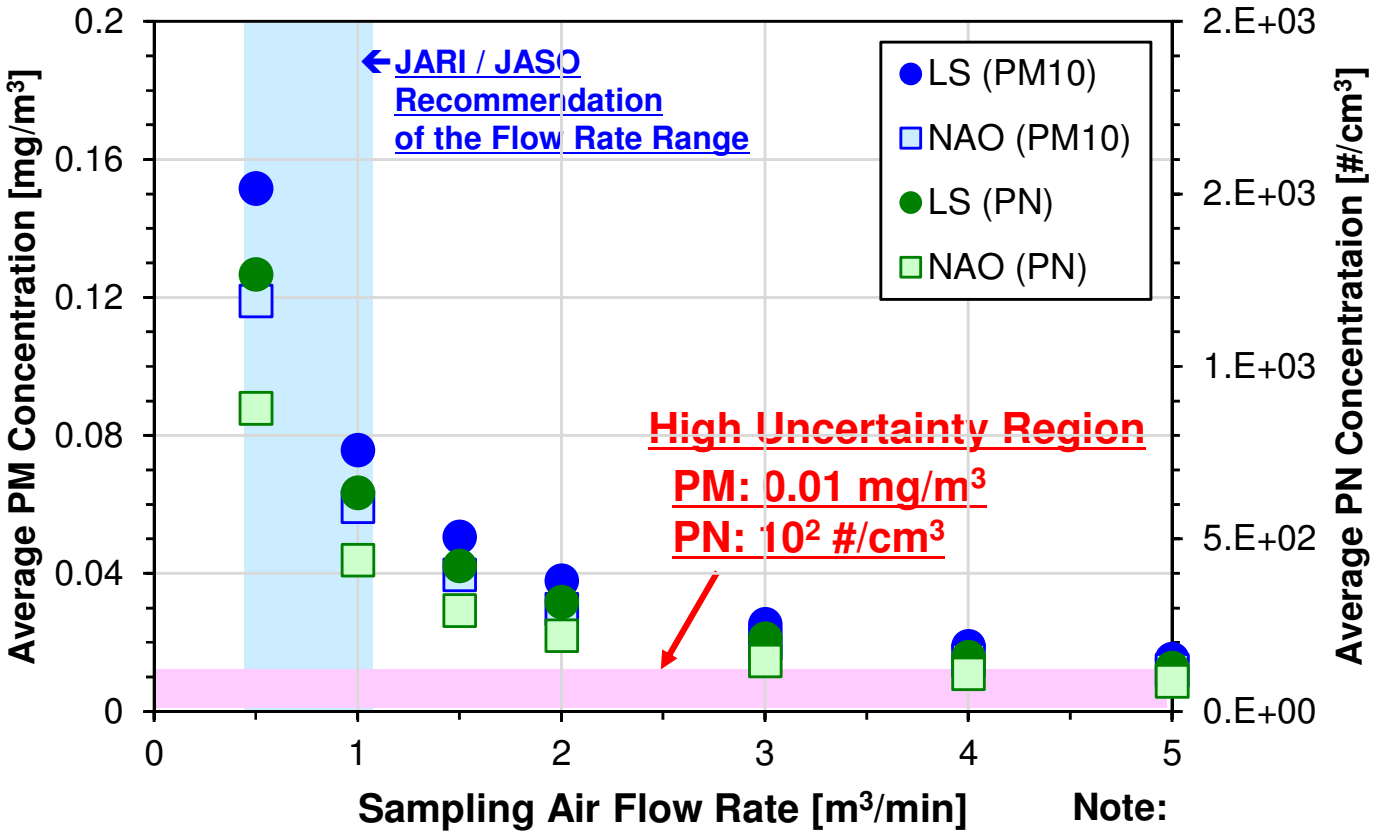
air flow rate in the tunnel (m^3/min)

Mass Emission (mg/test)



Air Flow Rate vs PM,PN Measurements

- **High Flow Rate may Reduce a Reliability, Increasing Uncertainty**
- **To secure the accuracy of Instruments for measuring PM& PN,**
  JARI Methodology chooses Low Flow Rate Condition



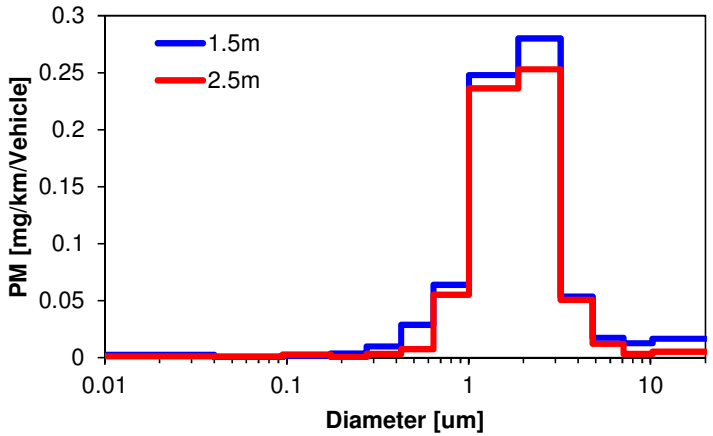
Cycle: WLTC, 30 Repeated
PM data: DustTrak II 8530 corrected by gravimetric measurement
PN data: TSI CPC 3775 (D_{50} = 4 nm) without pretreatment

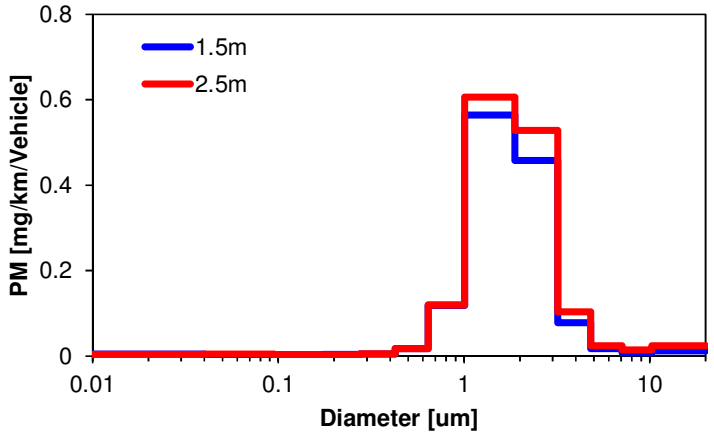
Note:
Flow Rate Variation 0.9%
for 0.5 m³/min during WLTC

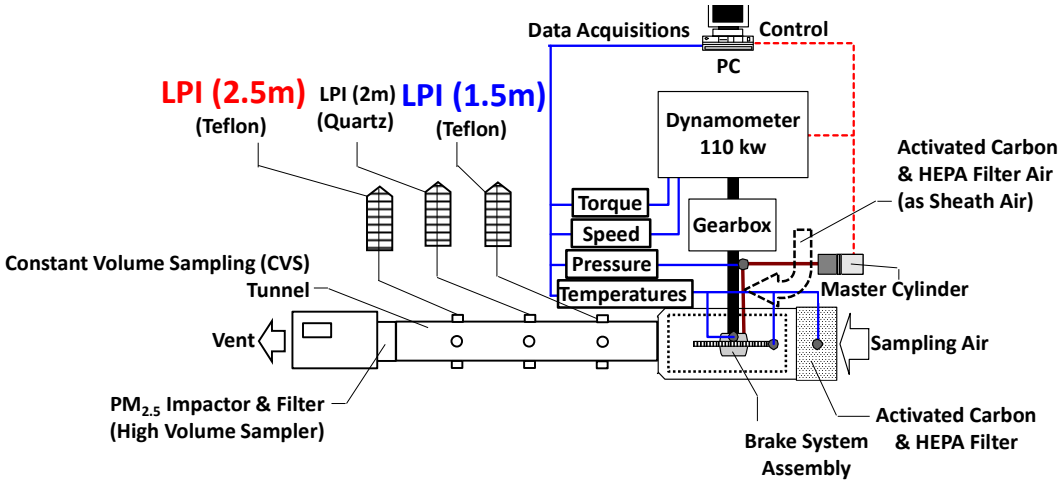
Ref : Hagino et al., *EuroBrake2018 in Presentation*

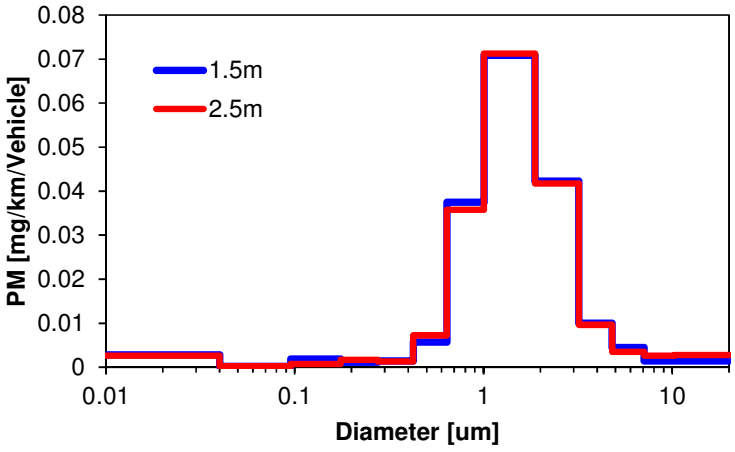
Brake Wear Particle Size

- **Flow Rate 0.5 m^3/min (0.05 m/s), Residence Time < 25s**
- **Low –Pressure Impactor Sampling for Measurement of Mass Emissions**
- **The Difference for Mass Size Distributions are within Sampling Error**









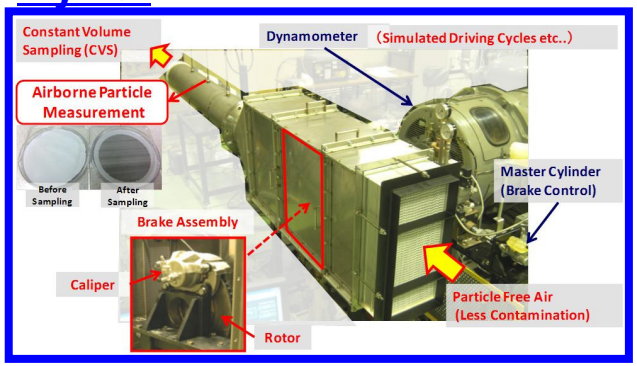
Ref : Hagino et al., *EuroBrake2017 in Presentation*

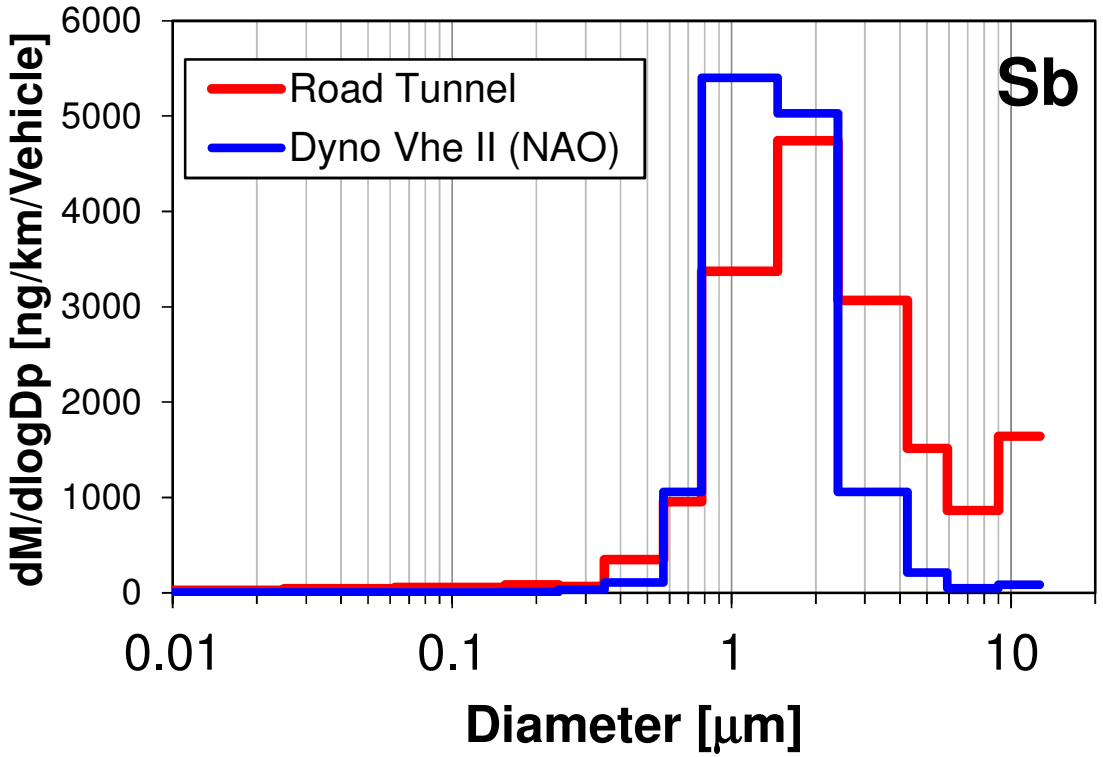
Emission Levels: Road vs. Dyno

- **Road Tunnel: Flow Rate 4.2 m^3/min (1.9 m/s), Residence Time < 520s**
- **Dyno.: Flow Rate 0.5 m^3/min (0.05 m/s), Residence Time < 25s**
- **Comparable Emission Levels between Traffic Road and Dyno. (e.g. Sb)**

Traffic Road Tunnel

Dyno

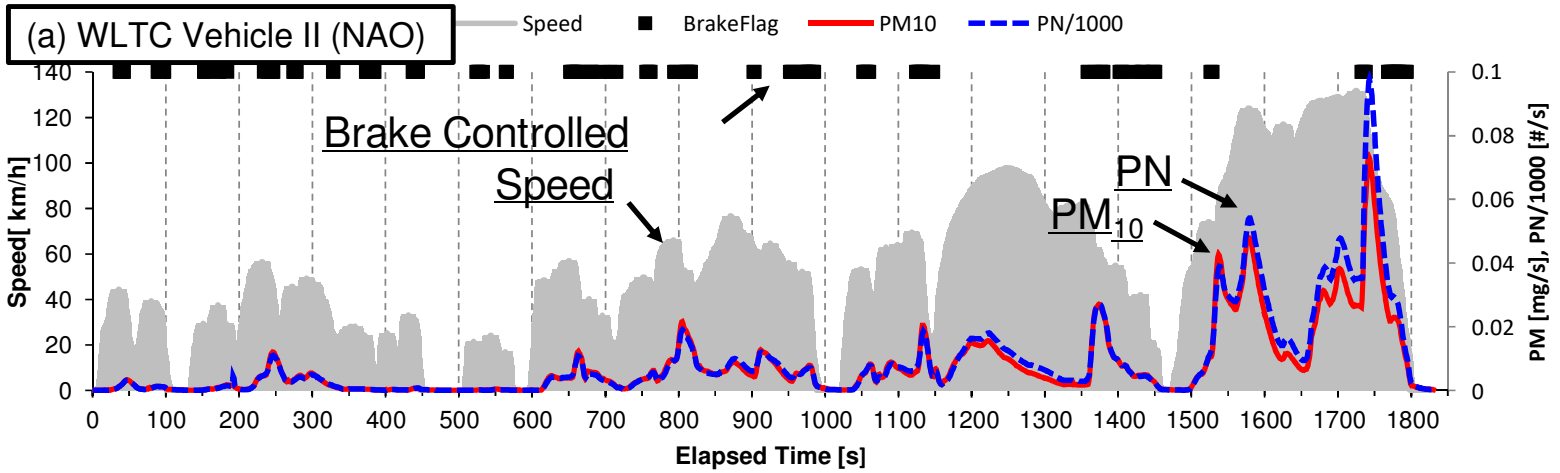




Ref : Hagino et al., *EuroBrake2017 in Presentation*

Simulated Urban City Driving Cycle Tests

- **Comparable Data to Tail-Pipe Emission for the First Step e.g. WLTC test cycle**
- **Non Tail-Pipe Emission : Good Correlation PM mg/km vs PN #/km**
  Detection Levels in 10^9 #/km

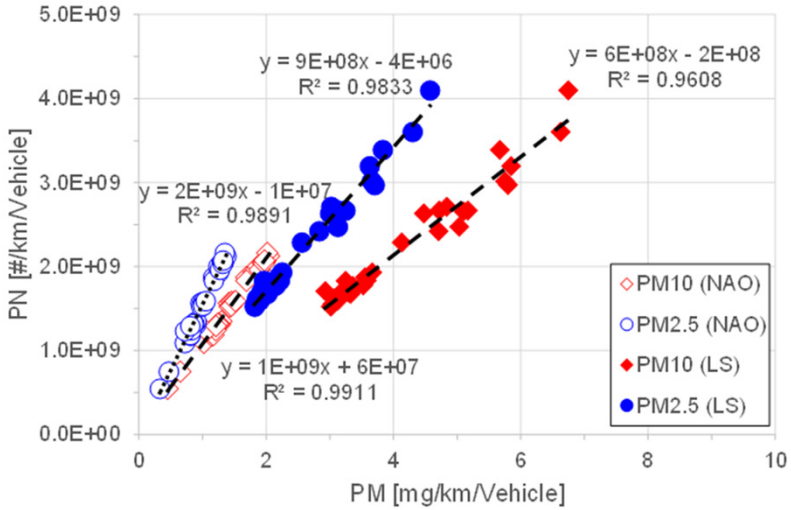


Emission per Vehicle

$$E_{vehicle} = E_{wheel} \times \text{Number}_{front} + E_{wheel} \times \text{Force Distribution} \times \text{Number}_{rear}$$

Emission per Wheel

$$E_{wheel}\ (\text{mg/km/wheel}) = \text{PM}_{tunnel}\ (\text{mg/m}^3) \times \text{Flow Rate}_{tunnel}\ (\text{m}^3/\text{min}) \times \text{Time}_{test}\ (\text{min}) / \text{Distance}_{JC08\ or\ JE05}\ (\text{km})$$



PM data: DustTrak II 8530 corrected by gravimetric measurement
PN data: TSI CPC 3775 (D_{50} = 4 nm) withou t pretreatment

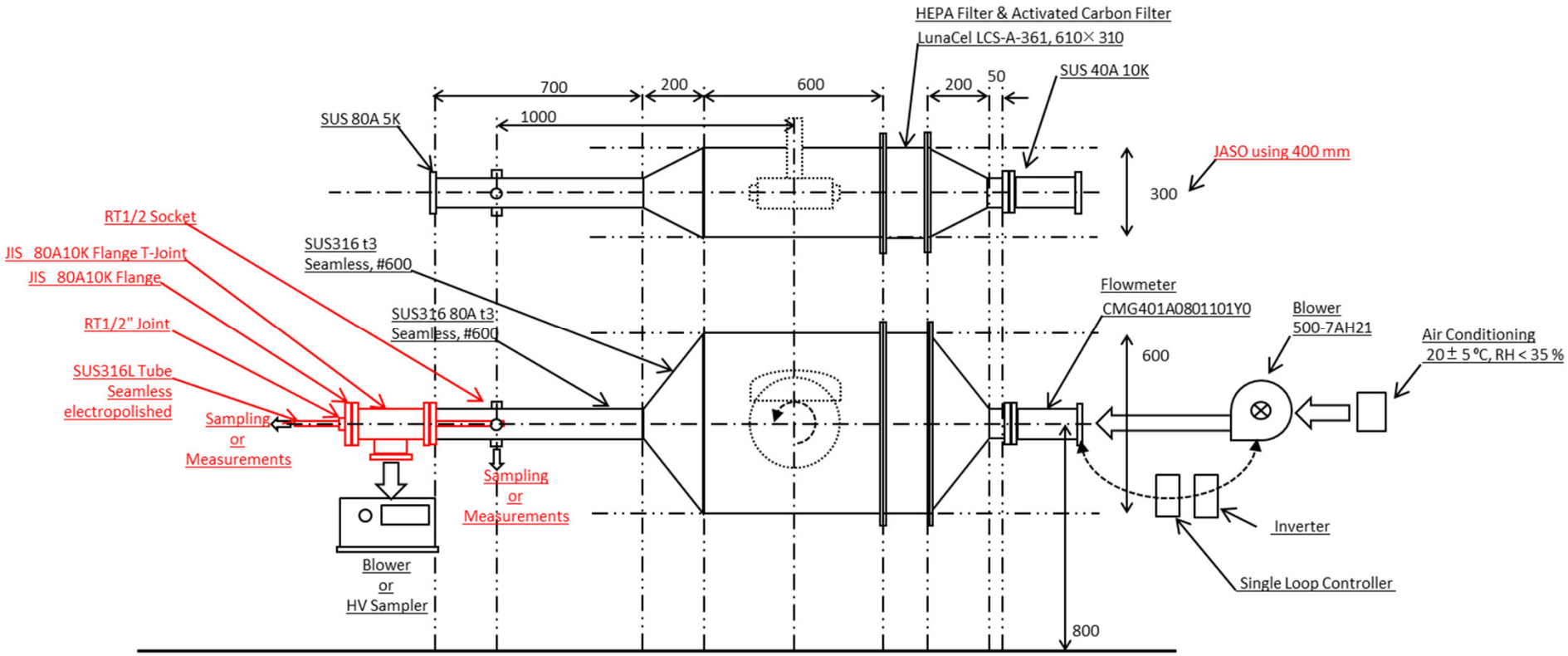
Ref : Hagino et al., *EuroBrake2017 in Presentation*

Contents

- Uncertainty of Brake Wear Particle Emissions
- **Feasible Sampling Methodology JASO Standardization Concept**
- Next Steps

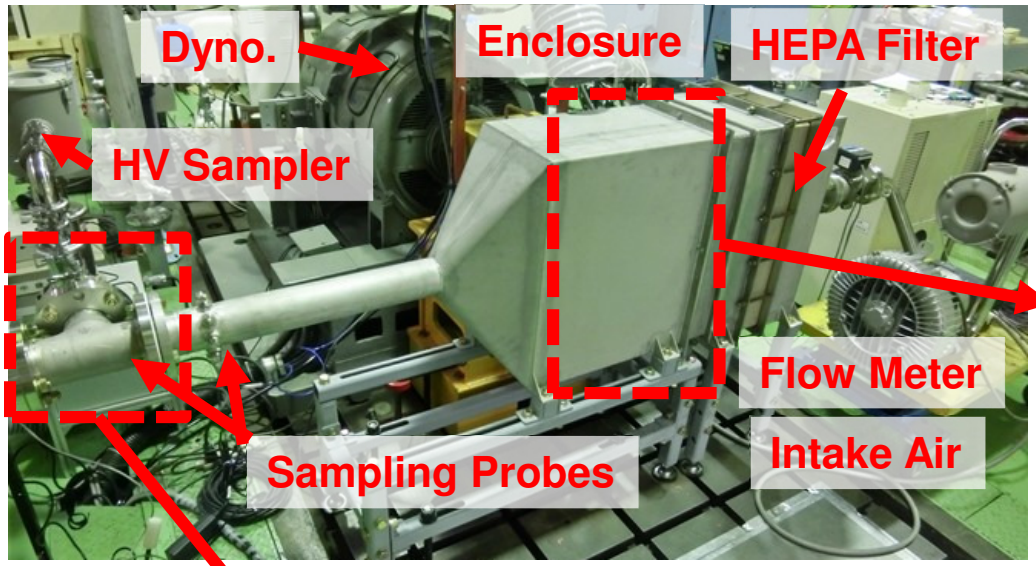
Feasible Sampling Methodology

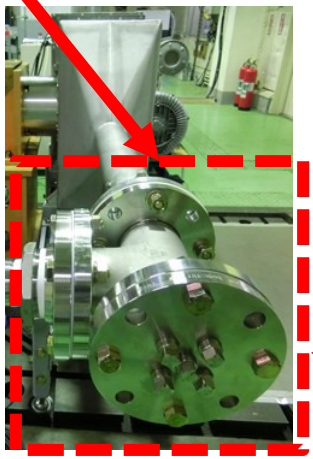
- **Uniformed Model for Society of Automotive Engineers of Japan (JSAE)**
- **JSAE Brake Experts were decided to use New Compact JARI model for PM**
- **Aim: Attachable Enclosure and Sampling System for All Brake Suppliers**
- **JSAE will complete JASO Standard based on JARI Methodology for PM by FY 2019**
- **JARI can provide the design, you can refer and visit our laboratory to see this system**



Feasible Sampling Methodology

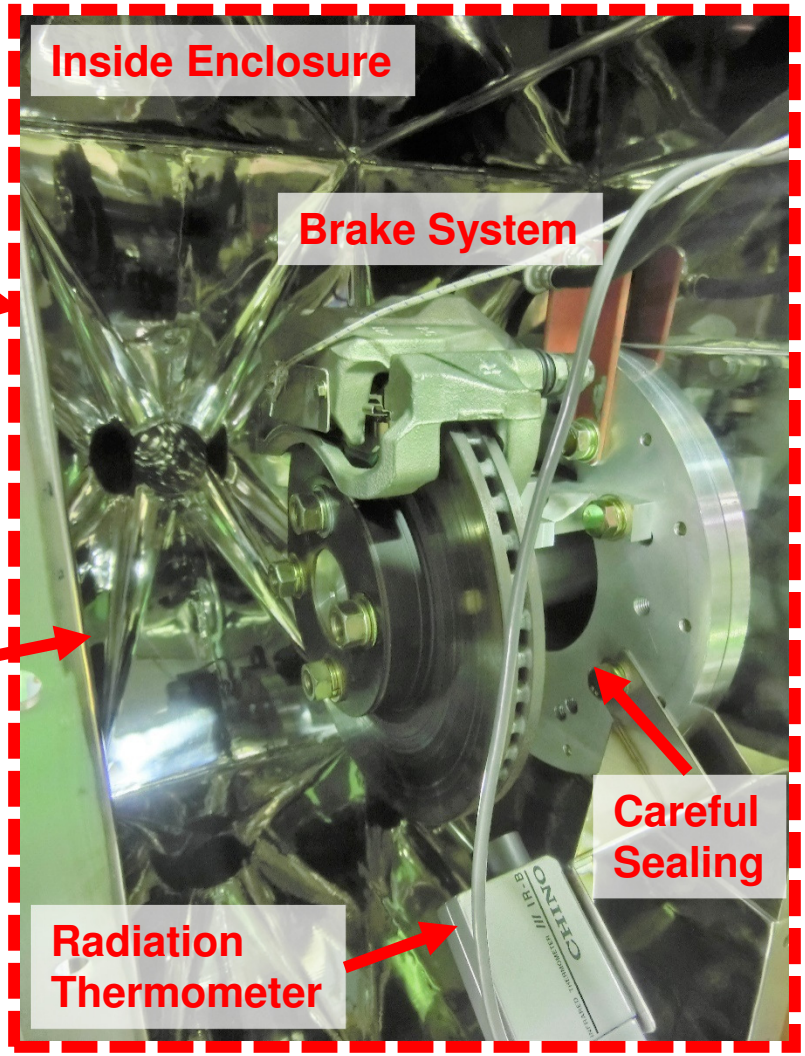
- **Uniformed Model for Society of Automotive Engineers of Japan (JSAE)**
- **JSAE Brake Experts were decided to use JARI model and measure for PM**
- **Aim: Attachable Enclosure and Sampling System for All Brake Suppliers**





Isokinetic Sampling Probe

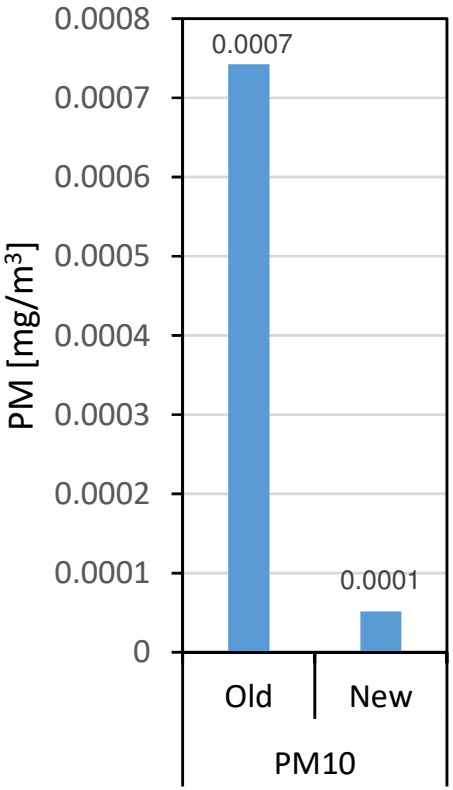
Polished Finish #600

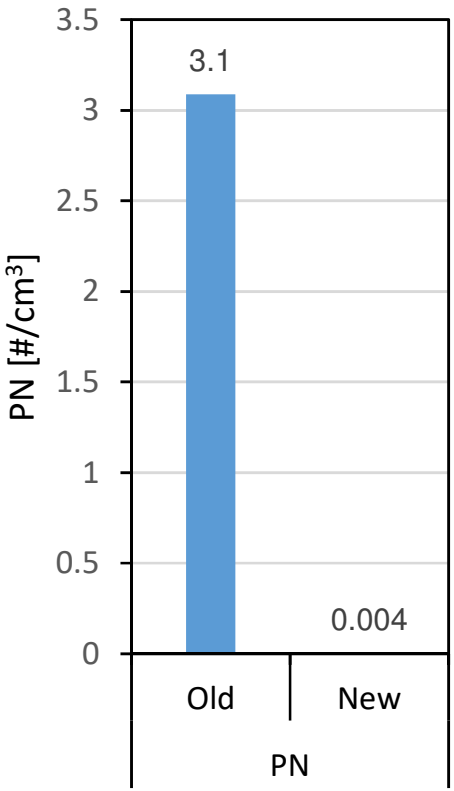


PM PN Back Ground

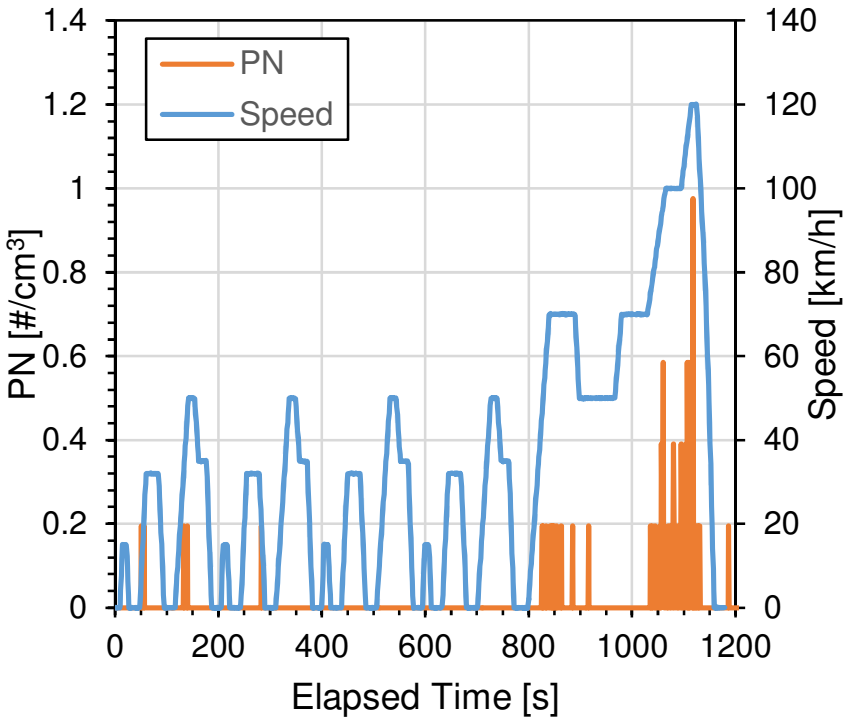
- **Renew Version Enclosure (Careful Sealing) can be Reduce PN background**
- **Some Particles originated from Dyno. Connections Still Exists**
  But very low concentration (<1 #/cm^3)

Averaged Concentrations





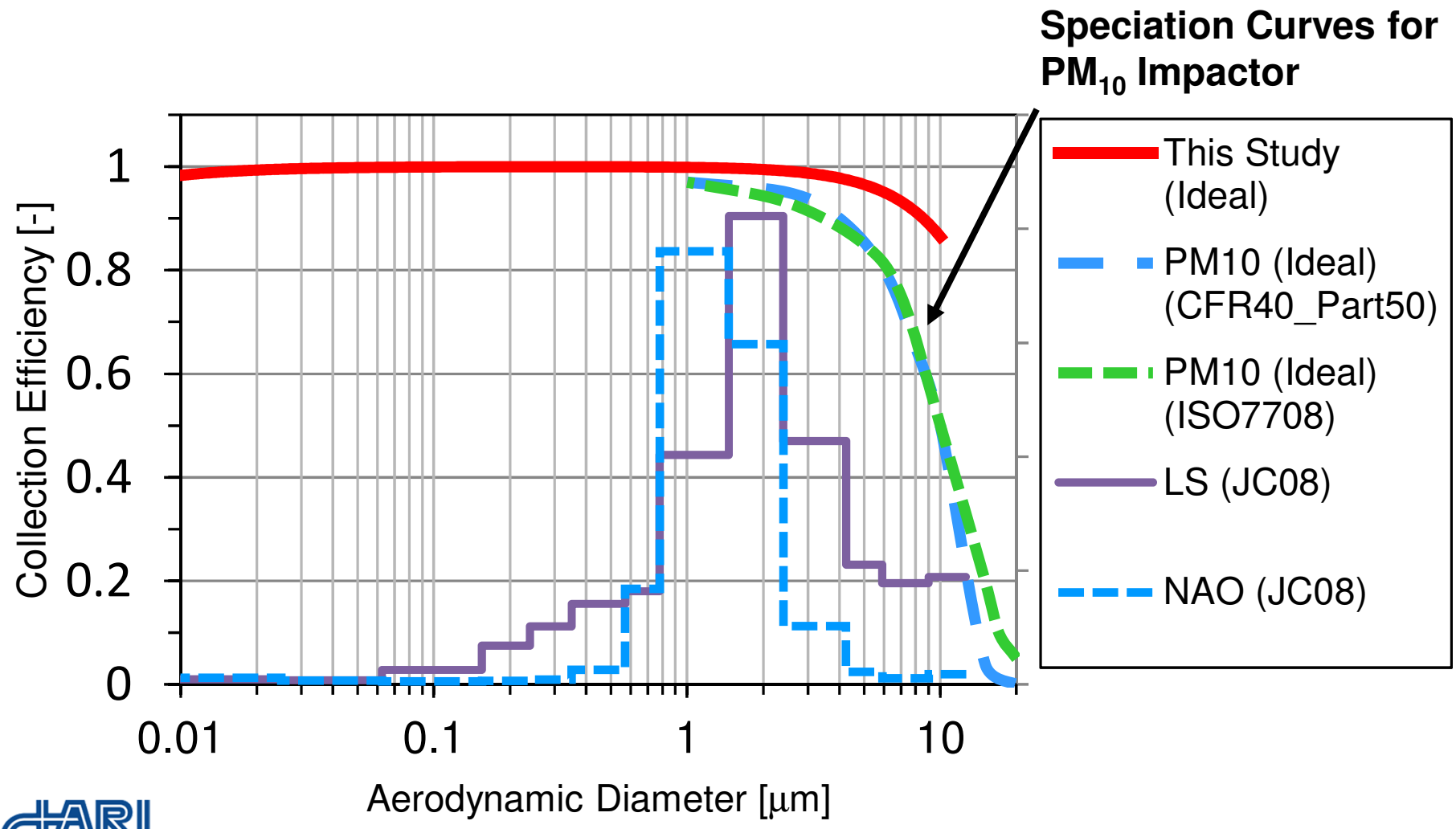
Time Profile (Highest Case for PN)
(Only Renew Version)



Cycle: NEDC, 3 Repeated
PM data: DustTrak II 8530 corrected by gravimetric measurement
PN data: TSI CPC 3775 (D_{50} = 4 nm) without pretreatment

Particle Collection Efficiency

- **PM_{10} and PN Measurement Coverage**
- **Next Step: Needing to Evaluate by Testing Aerosol (PSL)**



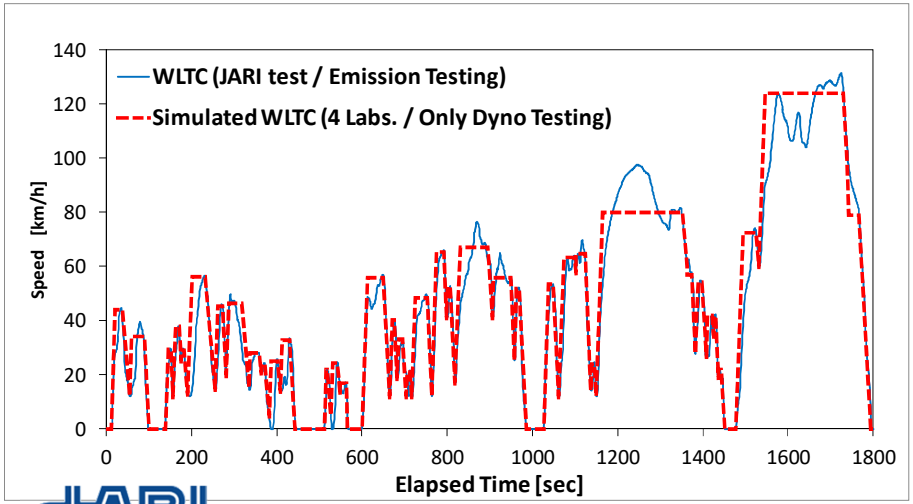
Contents

- Uncertainty of Brake Wear Particle Emissions
- Feasible Sampling Methodology JASO Standardization Concept
- **Next Steps**

Comparison of Brake Wear Testing

- **Four Labs tested for NAO Disc using Existing Dynamometers**
- **Rotor/Brake Temperature did not affected by Lower Flow Rate Condition**
- **Next Step: PM Emission vs. Estimated PM Emission**

Labs.	Difference Pad Thickness	Max Temperatures	Air Flow	Emissions (Calculation)
4 Labs. Only Dyno . Testing	0.11-0.23mm	Rotor 148-163 ºC Depth 0.5 or 1 mm	3 m/s	PM_{10} 2.1 ±1.2 g/km PN $1.6 \pm 0.9 \times 10^{10}$ #/km estimated by JARI test data
Ref. JARI test	0.069-0.095 mm	Brake Pad 78-120 ºC Depth 1 mm	0.05 m/s 0.55 m^3/min	PM_{10} 1.5 ±0.4 mg/km PN $1.6 \pm 0.4 \times 10^{9}$ #/km



Testing Conditions

Pre-conditioning:
Ini. 65km/h, Decel. 3.5m/s², 200 times repeated

Vehicle:
Weight 1,130kg, Ratio 8:2, Eff. Tire Rad. 0.298m

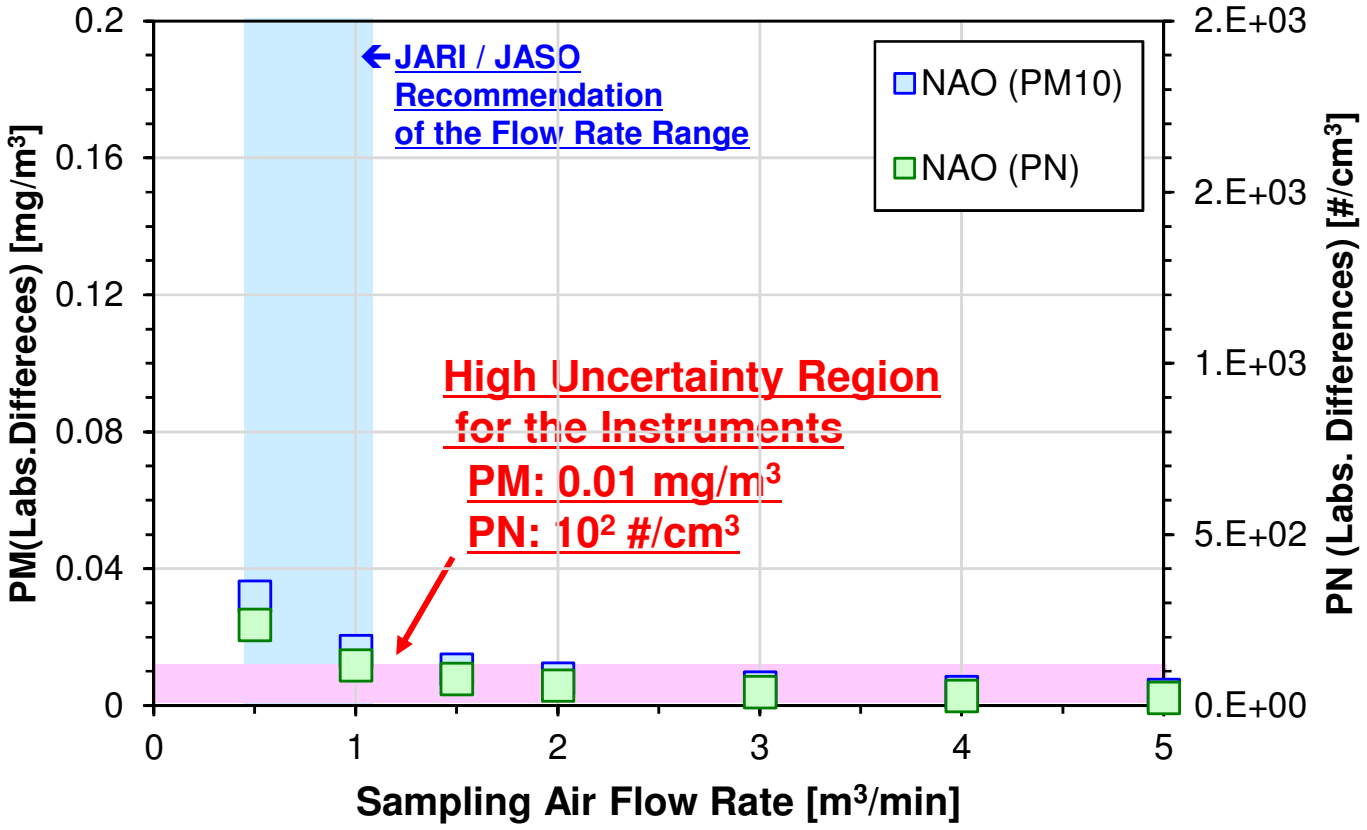
Brake:
NAO Disc (Front)

Test Cycle:
WLTC (JARI Emission Testing),
Simulated-WLTC (Only Dyno. Testing)

Ref : Hagino et al., *EuroBrake2018 in Presentation*

Labs. Difference vs. Air Flow Rate

- **Labs. Difference estimated by JARI Data**
- **Needing to measure of the Variation without being covered with Instrumental Uncertainties**



Cycle: simulated-WLTC, 30 Repeated
PM data: DustTrak II 8530 corrected by gravimetric measurement
PN data: TSI CPC 3775 (D_{50} = 4 nm) without pretreatment

Ref : Hagino et al., *EuroBrake2018 in Presentation*

Conclusions & Next Steps

Conclusions:

- **Importance of Flow Rate to Secure the accuracy of Instruments (Low Flow Rate Sampling (0.5-1 m^3/min) Recommended)**
- **Dyno. Data Comparable with Traffic Road (Real World Emission)**
- **JASO will be complete by 2019 (March of 2020)**
  Based on the Feasible Sampling Methodology (Renew Compact JARI Model)

Next Steps:

JARI

- **Possible Round Robin with TF-II Community**
- **Sampling Methodology (☑ Cal., ☐ PSL Testing)**
- **Driving Cycles (☑ JC08, ☑ WLTP, ☐ NEDC (This Year) , ☐ PMP)**
- **Repeatability (Uncertainties) of Instruments (TBD)**

JASO (JSAE, 4 Labs)

- **Round Robin using JARI Sampling Methodology (TBD)**