# Laboratory brake test variability

## Part 1:

ISO – friction coefficient

## Part 2:

ISO/PMP/SAE – brake emissions

UN PMP 41st meeting
Ispra, Italy
13th October 2016

# 2010-2015 summary

## ISO test variability TF
## brake performance testing


| | |
|---|---|
| **Jaroslaw Grochowicz** | Ford Motor Co. |
| **Carlos Agudelo & Shanglei Li** | Link Engineering Company |
| **Achim Reich** | Continental Corp. |
| **Karl-Heinz Wollenweber** | ZF TRW |
| **Harald Abendroth** | Consultant (Chairman ISO SW brakes) |


2010-2014

# 2010 interlab accuracy study

- Front brake
- Medium-size sedan
- FN3-57 caliper
- Low-steel pad
- 15-inch cast iron rotor
- McPherson knuckle

- All components measured and selected

# Repeatability & Reproducibility
## for dynamometer controls

| Parameter | Repeatability (within-lab) $CD_r$ | Reproducibility (between-lab) $CD_R$ |
|---|---|---|
| Initial speed (kph) | 0.18 | 0.42 |
| Initial temp (°C) | 4 | 8 |
| $Avg_d$ press (bar) | 0.14 | 0.86 |
| $Avg_d$ decel (m/s²) | 0.04 | 0.07 |

# Repeatability (Test-to-Test)

## for friction coefficient


Percent of stops within 0.02 variation

# Reproducibility (Dyno-to-Dyno)

## for friction coefficient

| Any test from lab | Compared to any test from lab: A | B | C | D | E |
|---|---|---|---|---|---|
| A | — | | | | |
| B | 99 | — | | | |
| C | 97 | 98 | — | | |
| D | 82 | 86 | 92 | — | |
| E | 84 | 86 | 90 | 86 | — |

Percent of stops within 0.039 variation

# Main sources of variation

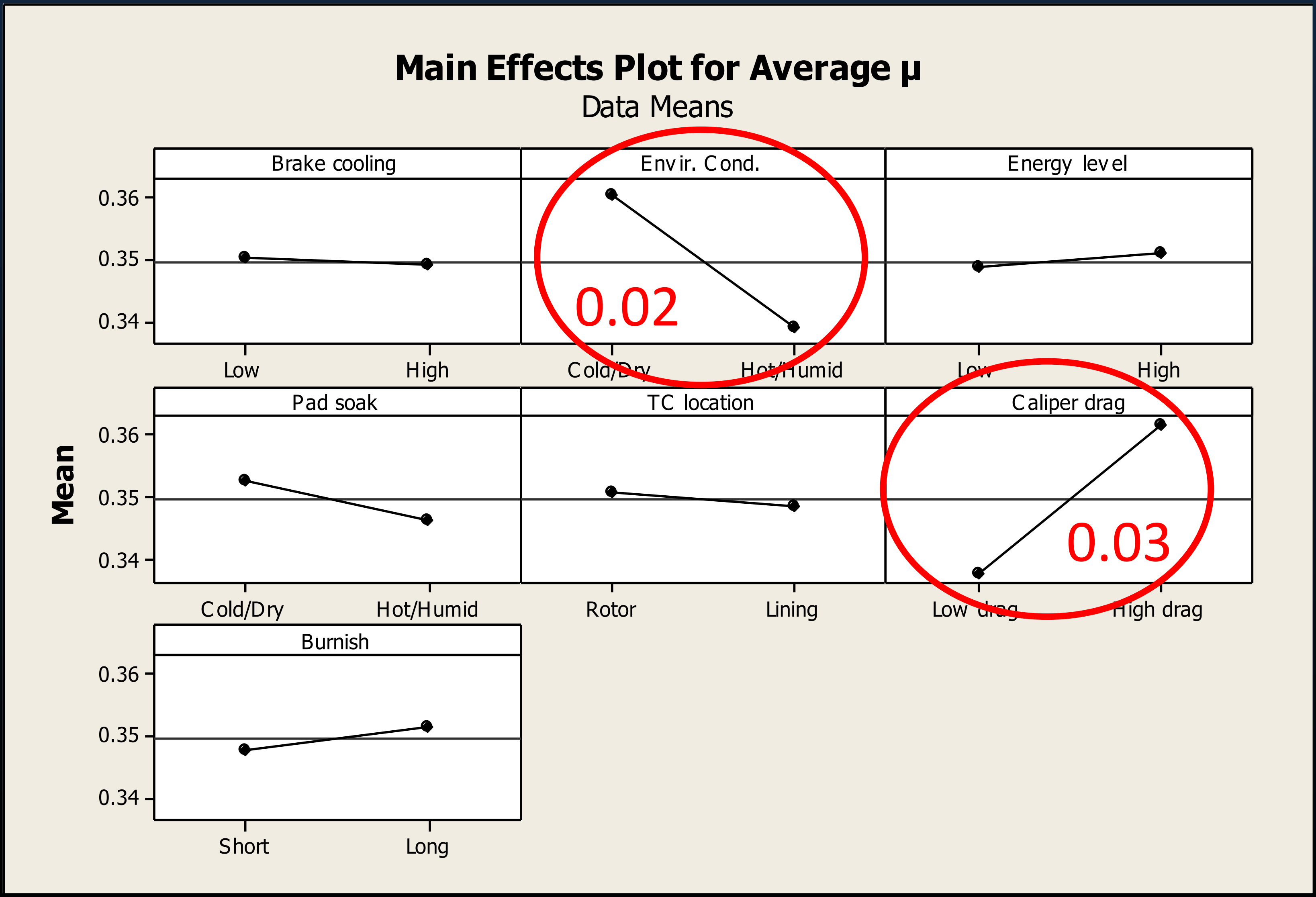
- μ calculation and parameters
- Temperature control
- Airflow direction and volume


2011 DOE

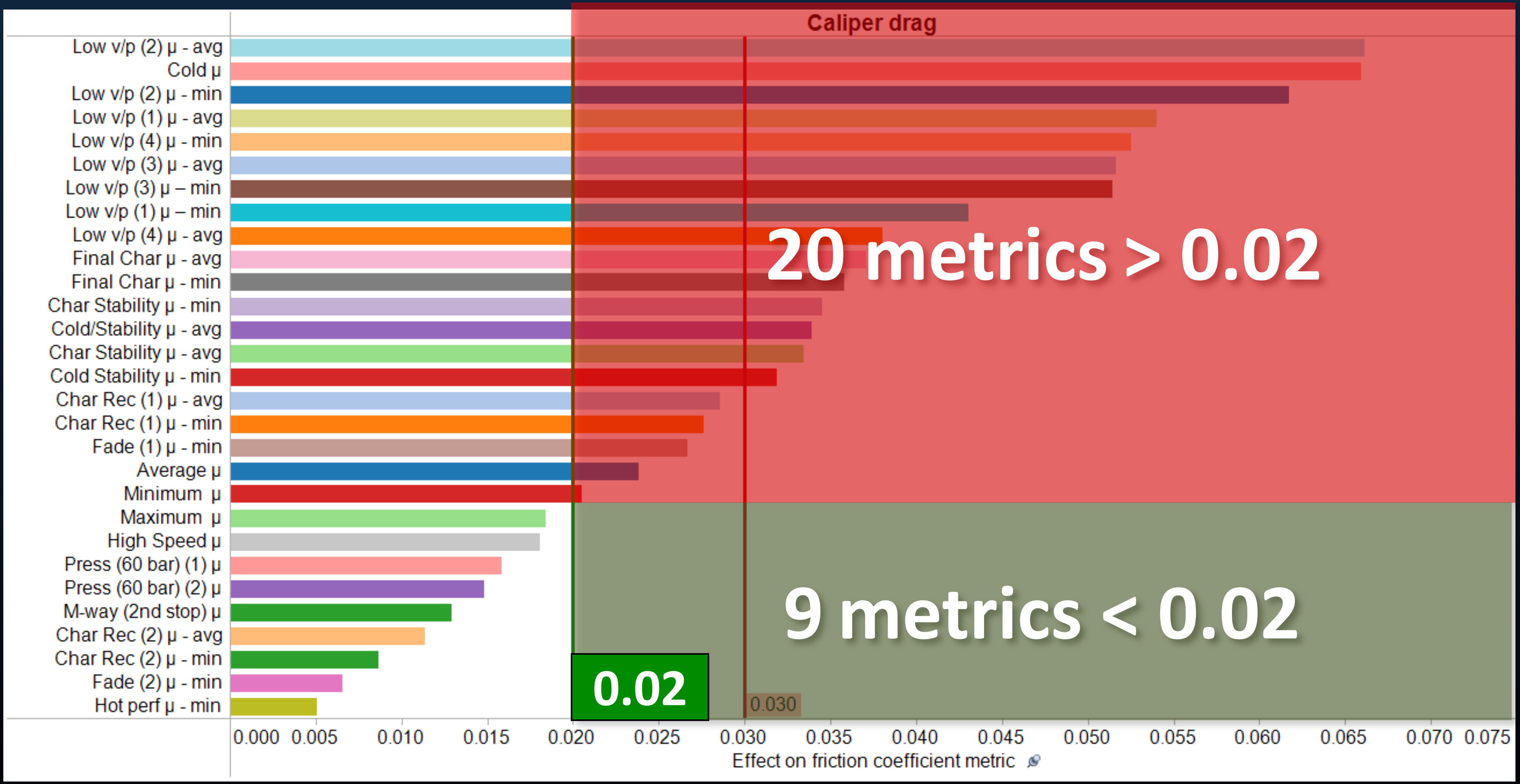
# DOE (7x2 FF) factors

| Factor | | DOE level | |
|---|---|---|---|
| | | Low | High |
| A | Brake Cooling | 400 m³/h<br>onto caliper | 2 000 m³/h<br>opposite to caliper |
| B | Environmental Cond | cold/dry | hot/humid |
| C | Kinetic Energy | 90 % inertia<br>95 % braking speed | 110 % inertia<br>105 % braking speed |
| D | Pad Soak | (5 ± 2) °C<br>at (40 ± 5) % RH<br>cold/dry | (30 ± 2) °C<br>at (95 ± 5) % RH<br>hot/humid |
| E | TC Location | Lining TC | Rotor TC |
| F | Caliper Drag | Zero drag | High drag |
| G | Burnish Cycles | 32 snubs | 192 snubs |

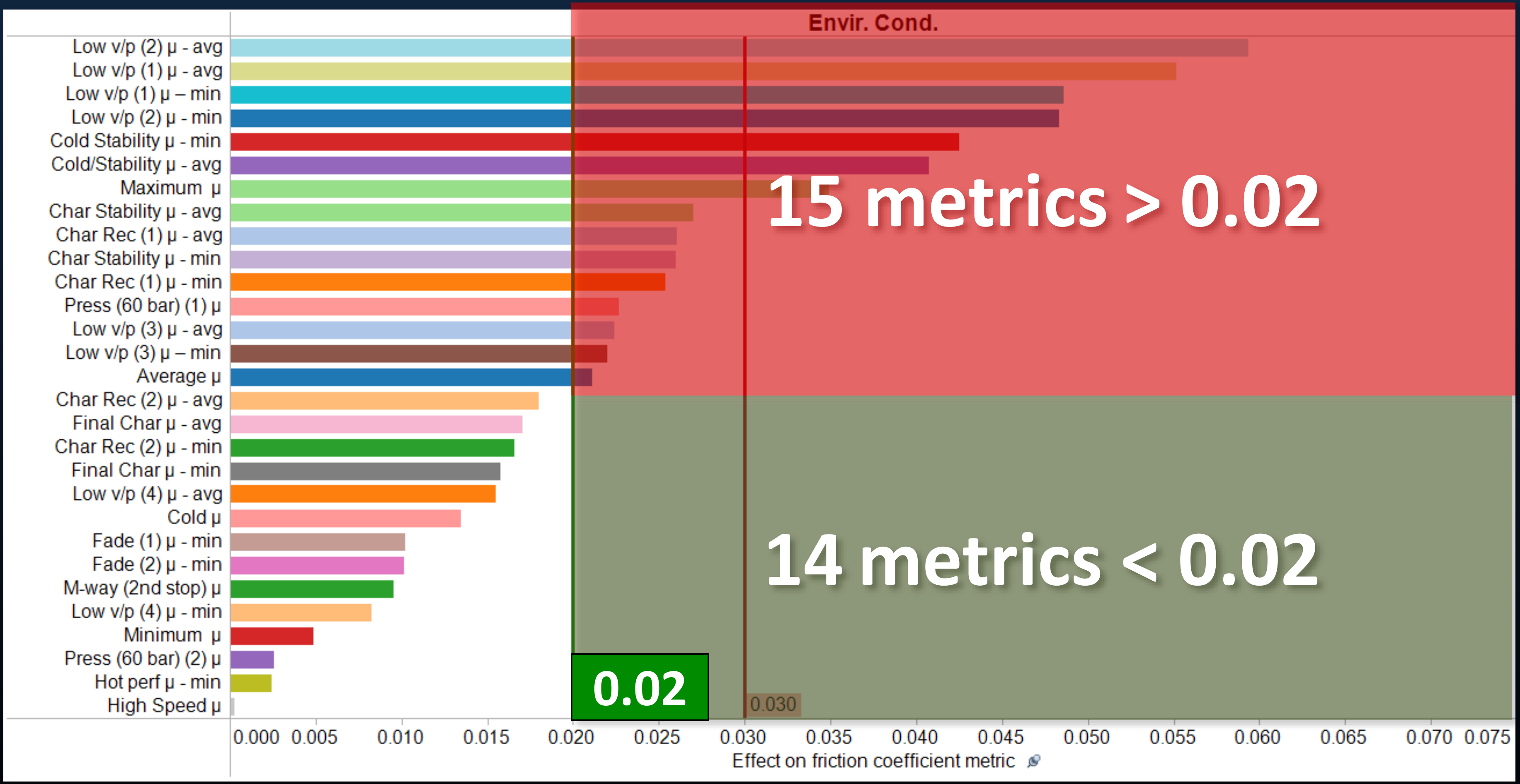
# Main effects
## for friction coefficient



# Effects on friction metrics
## for caliper drag



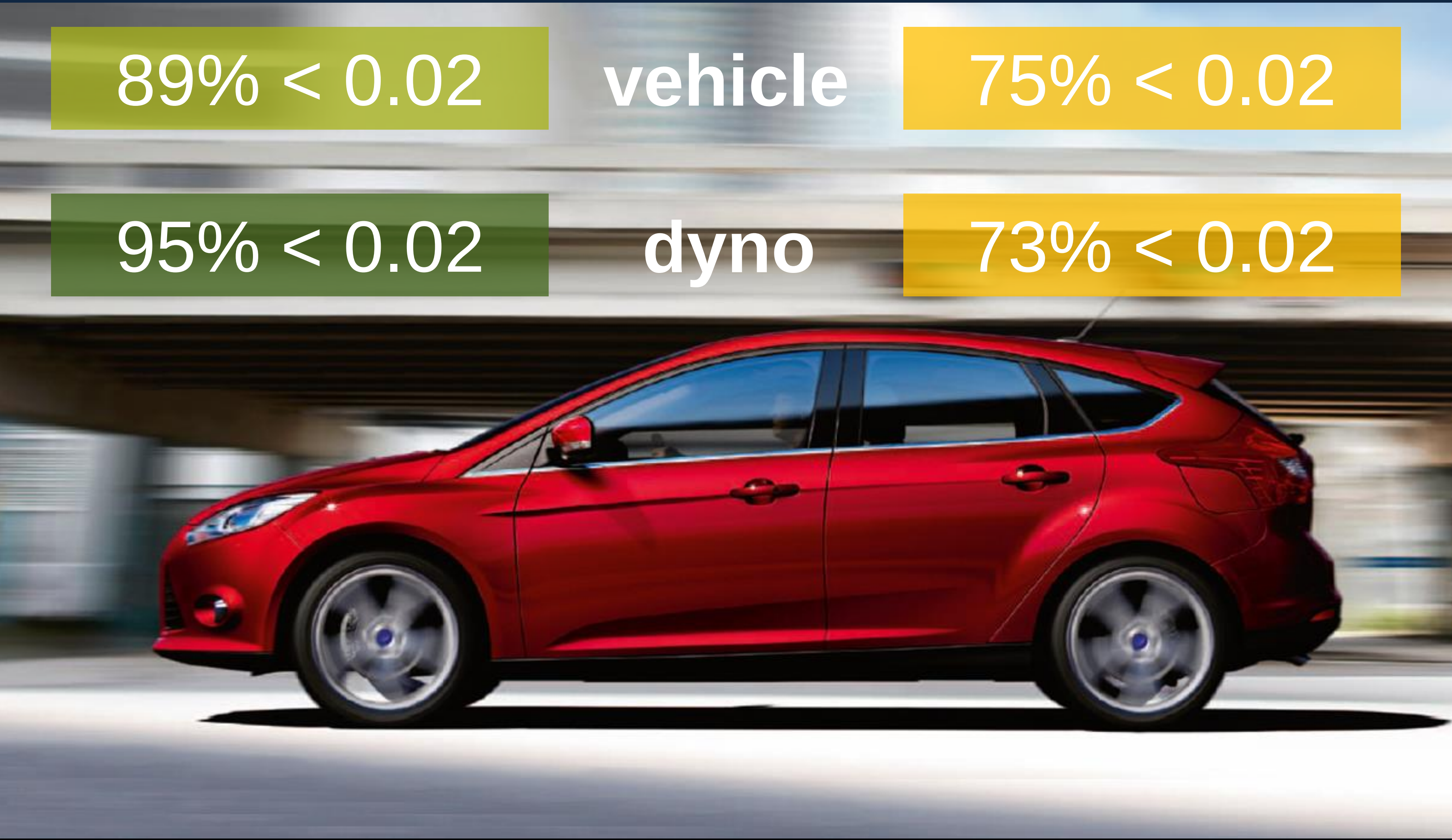
# Effects on friction metrics
## for cooling air temperature and humidy



# 2013 V2D

# Repeatability (vehicle and dyno)

| | | |
|---|---|---|
| 89% < 0.02 | **vehicle** | 75% < 0.02 |
| 95% < 0.02 | **dyno** | 73% < 0.02 |

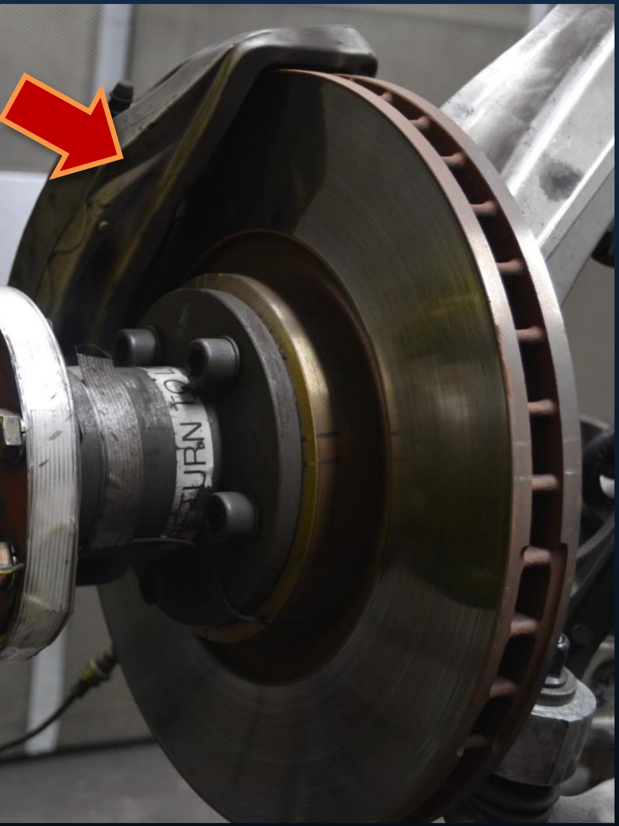


# Correlation (vehicle-to-dyno)

| Diff | Front Axle | | | | |
|---|---|---|---|---|---|
| | V1-D1 | V2-D2 | V4-D4 | V5-D5 | V6-D6 |
| < 0.04 | 93% | 100% | 91% | 98% | 91% |

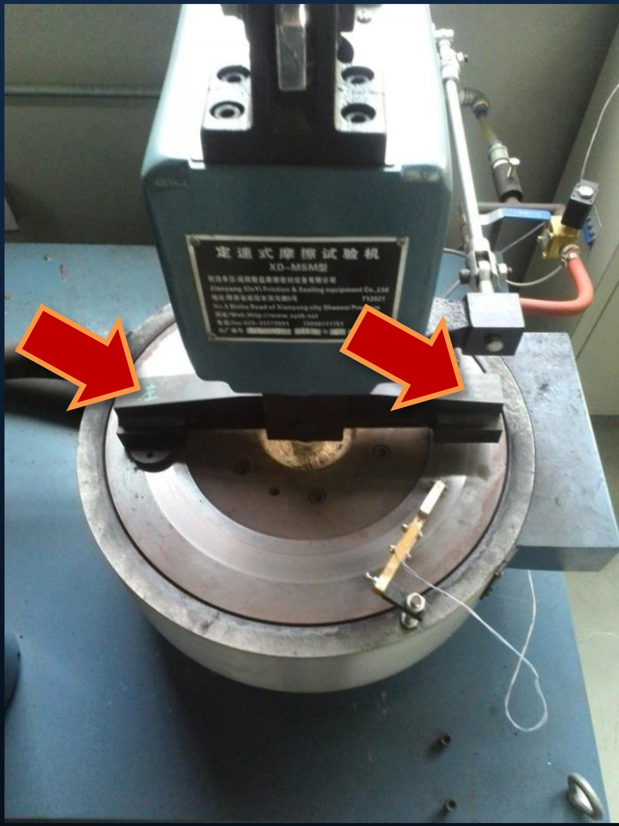
| Diff | Rear Axle | | | | |
|---|---|---|---|---|---|
| | V1-D1 | V2-D2 | V4-D4 | V5-D5 | V6-D6 |
| < 0.04 | 82% | 55% | 84% | 64% | 66% |


2014 M2M



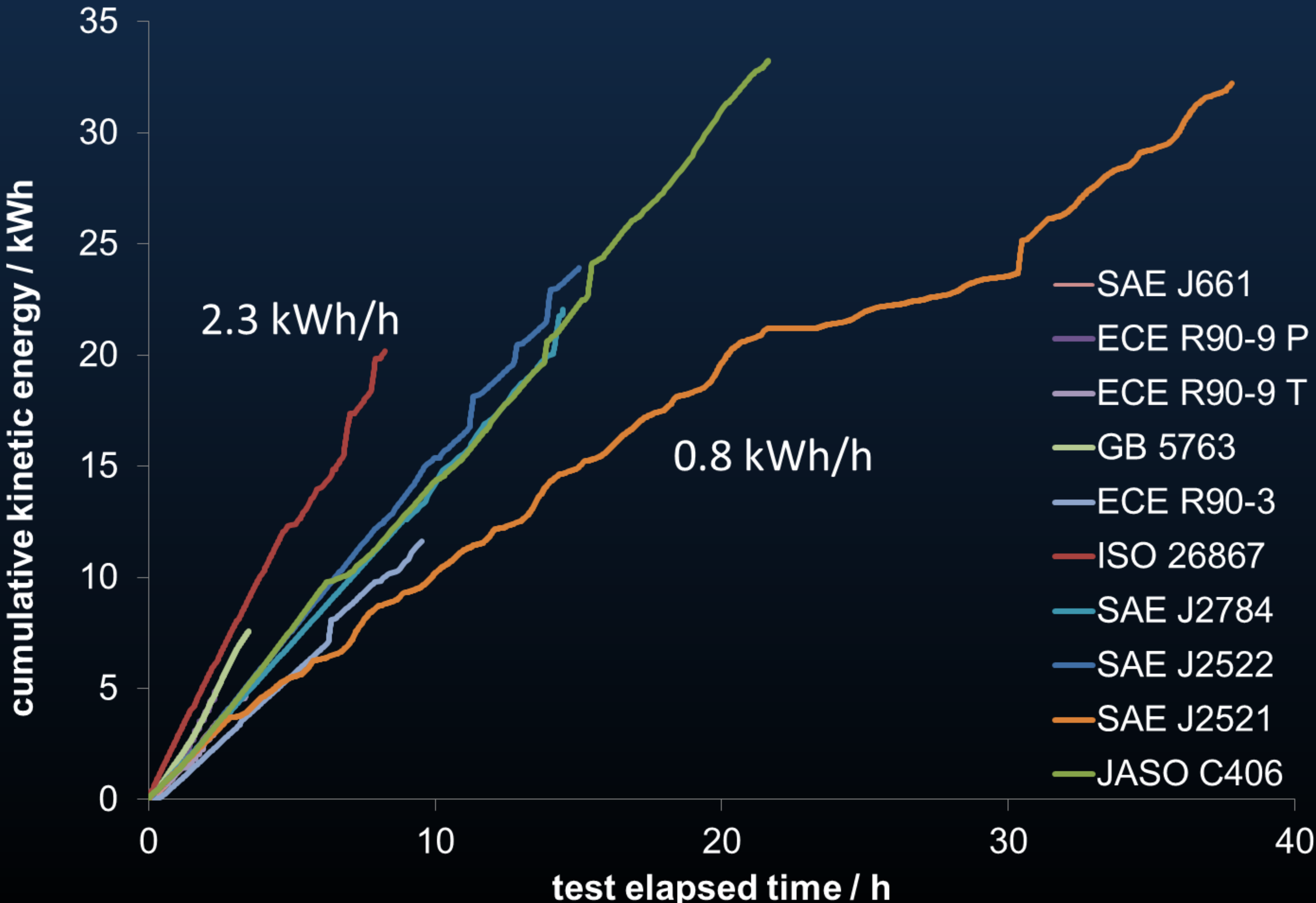
ECE R90-A3
& A9 P/T,
ISO 26867
JASO C406
SAE J2522, J2784

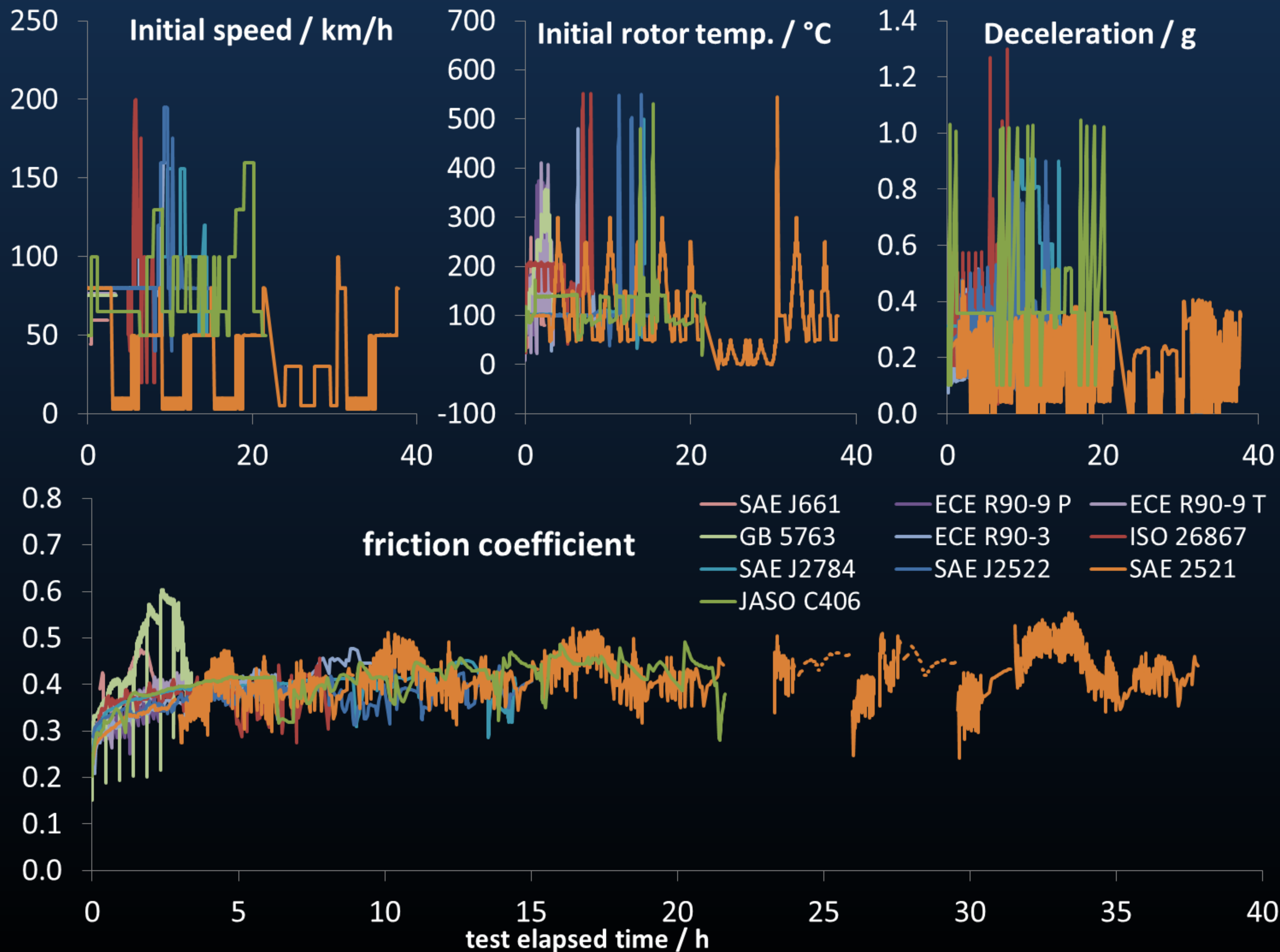
SAE J661



GB5763

# Cumulative kinetic energy





Initial speed / km/h
Initial rotor temp. / °C
Deceleration / g
friction coefficient
SAE J661
ECE R90-9 P
ECE R90-9 T
GB 5763
ECE R90-3
ISO 26867
SAE J2784
SAE J2522
SAE 2521
JASO C406
test elapsed time / h

# M2M – fade & hot performance

| test method | μ | J661 0.451 | R90 A9 0.231 | GB5763 0.518 | R90 A3 - | 26867 0.322 | J2784 0.319 | J2522 0.326 | J2521 0.361 | C406 0.332 |
|---|---|---|---|---|---|---|---|---|---|---|
| J661 | 0.451 | - | | | | | | | | |
| R90 A9 | 0.231 | 0.220 | - | | | | | | | |
| GB5763 | 0.518 | 0.067 | 0.287 | - | | | | | | |
| R90 A3 | - | - | - | - | - | | | | | |
| 26867 | 0.322 | 0.129 | 0.091 | 0.196 | - | - | | | | |
| J2784 | 0.319 | 0.132 | 0.088 | 0.199 | - | 0.003 | - | | | |
| J2522 | 0.326 | 0.125 | 0.095 | 0.192 | - | 0.004 | 0.007 | - | | |
| J2521 | 0.361 | 0.090 | 0.130 | 0.157 | - | 0.039 | 0.042 | 0.035 | - | |
| C406 | 0.332 | 0.119 | 0.101 | 0.186 | - | 0.010 | 0.013 | 0.006 | 0.029 | - |

# Repeatability (T2T)

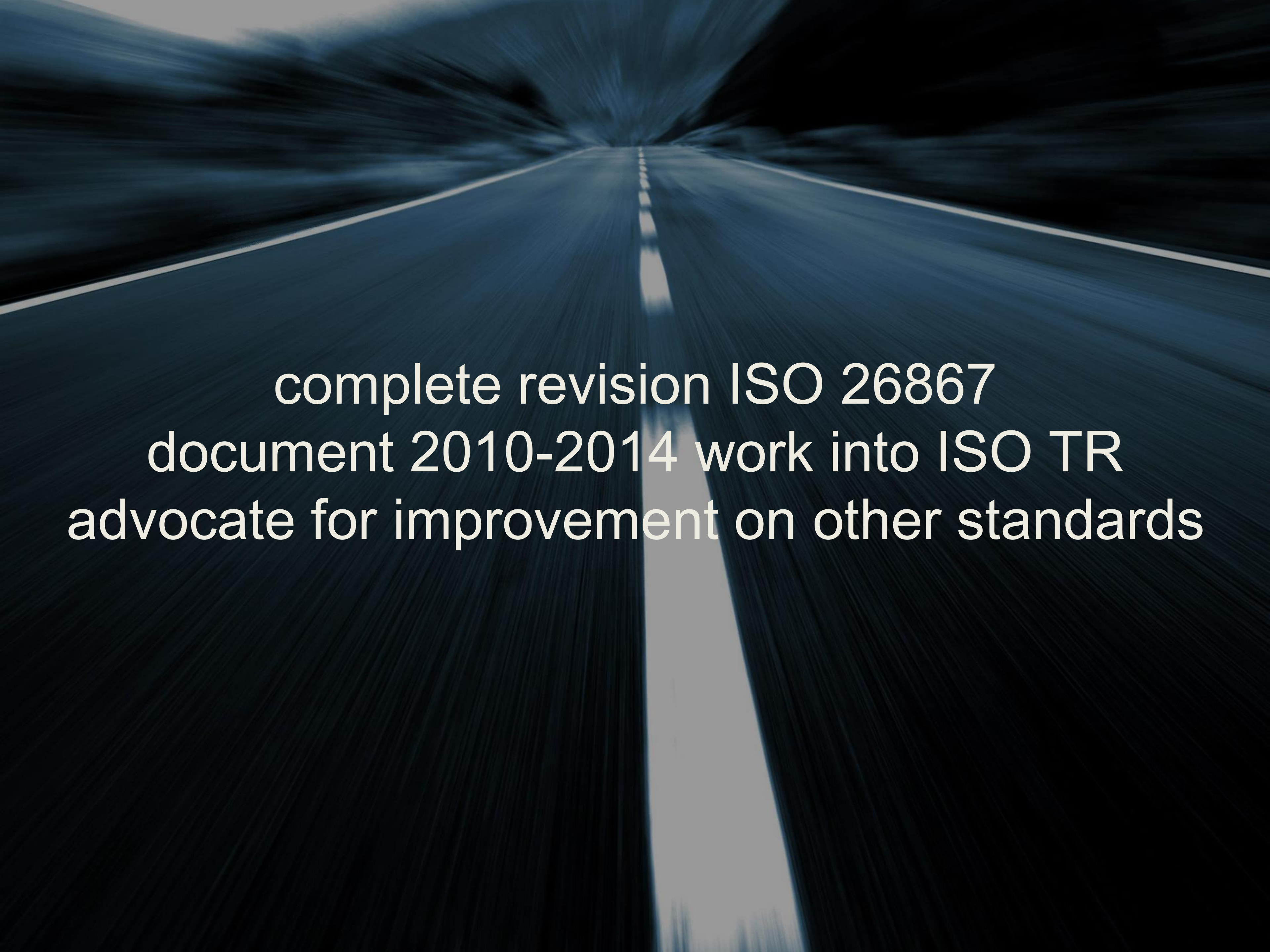
| test method | %brake applications within friction ranges | | | |
|---|---|---|---|---|
| | < 0.02 | 0.02-0.03 | 0.03-0.04 | > 0.04 |
| SAE J661 | 20.1 | 7.3 | 7.3 | 65.3 |
| R90-A9 P | 32.9 | 21.6 | 20.2 | 25.3 |
| R90-A9 T | 72.5 | 7.5 | 17.5 | 2.5 |
| GB 5763 | 1.4 | 2.3 | 4.8 | 91.5 |
| R90-A3 | 99.8 | 0.2 | - | - |
| ISO 26867 | 84.2 | 14.6 | 1.2 | - |
| SAE J2784 | 96.0 | 3.9 | 0.1 | - |
| SAE J2522 | 64.2 | 20.4 | 10.7 | 4.7 |
| SAE J2521 | 100.0 | - | - | - |
| JASO C406 | 95.9 | 4.0 | 0.1 | - |

# Summary

Coupon and drag tests, mainly type approval and QC

Dynamometer testing closer to operational friction

Dynamometer testing provides less variability


complete revision ISO 26867
document 2010-2014 work into ISO TR
advocate for improvement on other standards

*testing*

"ultimately, many ~~software~~ problems are people problems"

# Thank you!

## ISO test variability TF
## brake performance testing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# 2016-2018 proposal

## ISO/PMP/SAE test variability TF on brake emissions

**Carlos Agudelo** Link Engineering Company
**Jaroslaw Grochowicz** Ford Motor Co.

**Cooperate on standardization**
**Compete on implementation**

AUTOSAR

AUTOmotive Open System ARchitecture

# Thus far…

Related (but independent) studies and testing

Performance and high energy dyno schedules

Lack of standard city traffic dyno testing

# What-not-how

## WP1 – dyno test setup

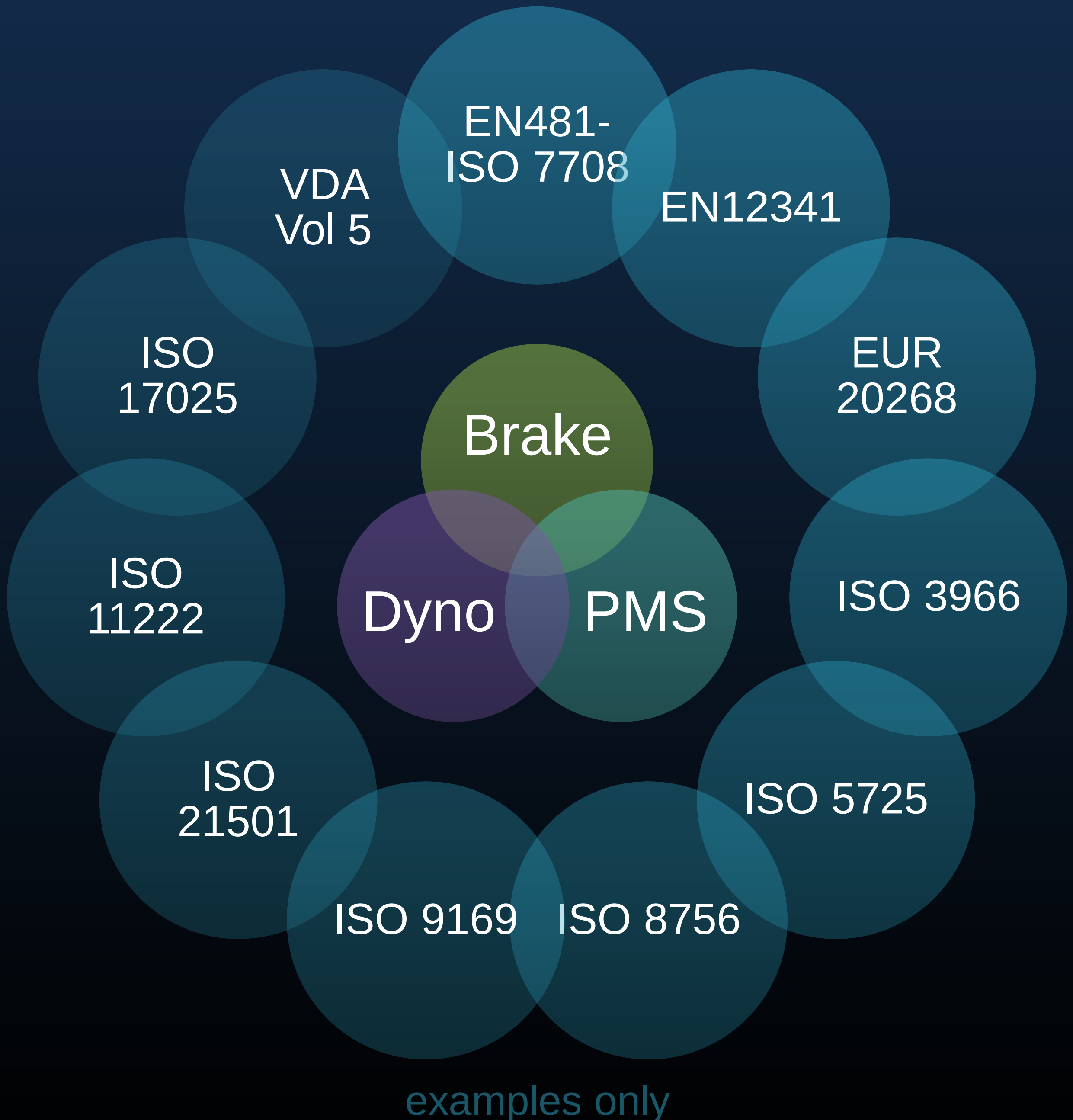
- Enclosure & air handling
- Debris sampling
- PMS specs

## WP2 – test procedure

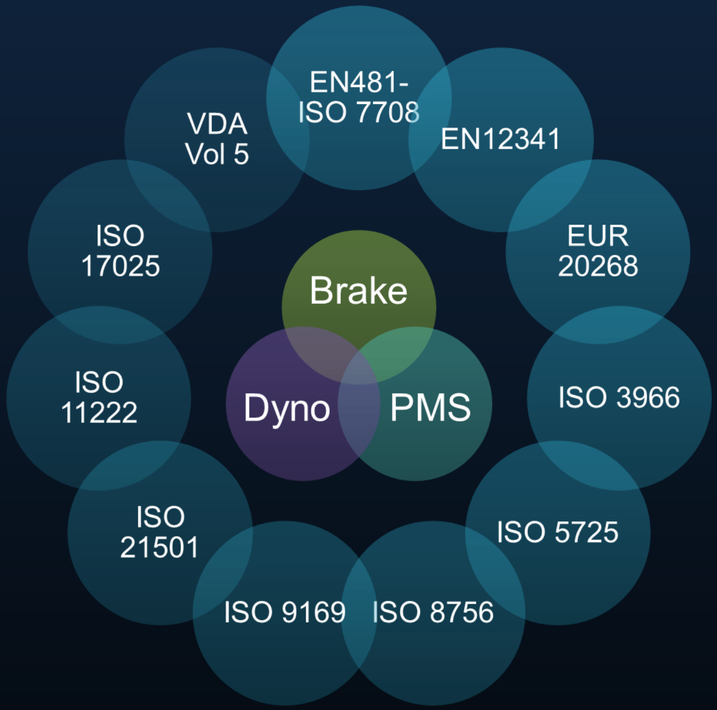
- City traffic test
- Test conditions
- Measurements

## WP3 – test results

- PN & PM
- Key metrics
- Correlations


EN481-
ISO 7708
VDA
Vol 5
EN12341
ISO
17025
EUR
20268
Brake
Dyno
PMS
ISO
11222
ISO 3966
ISO
21501
ISO 5725
ISO 9169
ISO 8756
examples only

- ☑ Open data
- ☑ Sync ISO, JSAE, SAE, and PMP
- ☑ Brake, dyno, and PMS agnostic




- ☒ Toxicology, health aspects, or chemistry
- ☒ Commercial vehicles
- ☒ Regulation or rulemaking

# Further investigation and work

## Step 1 – interlab 1

- 3-5 labs
- 2 brakes
- 2-3 repeats

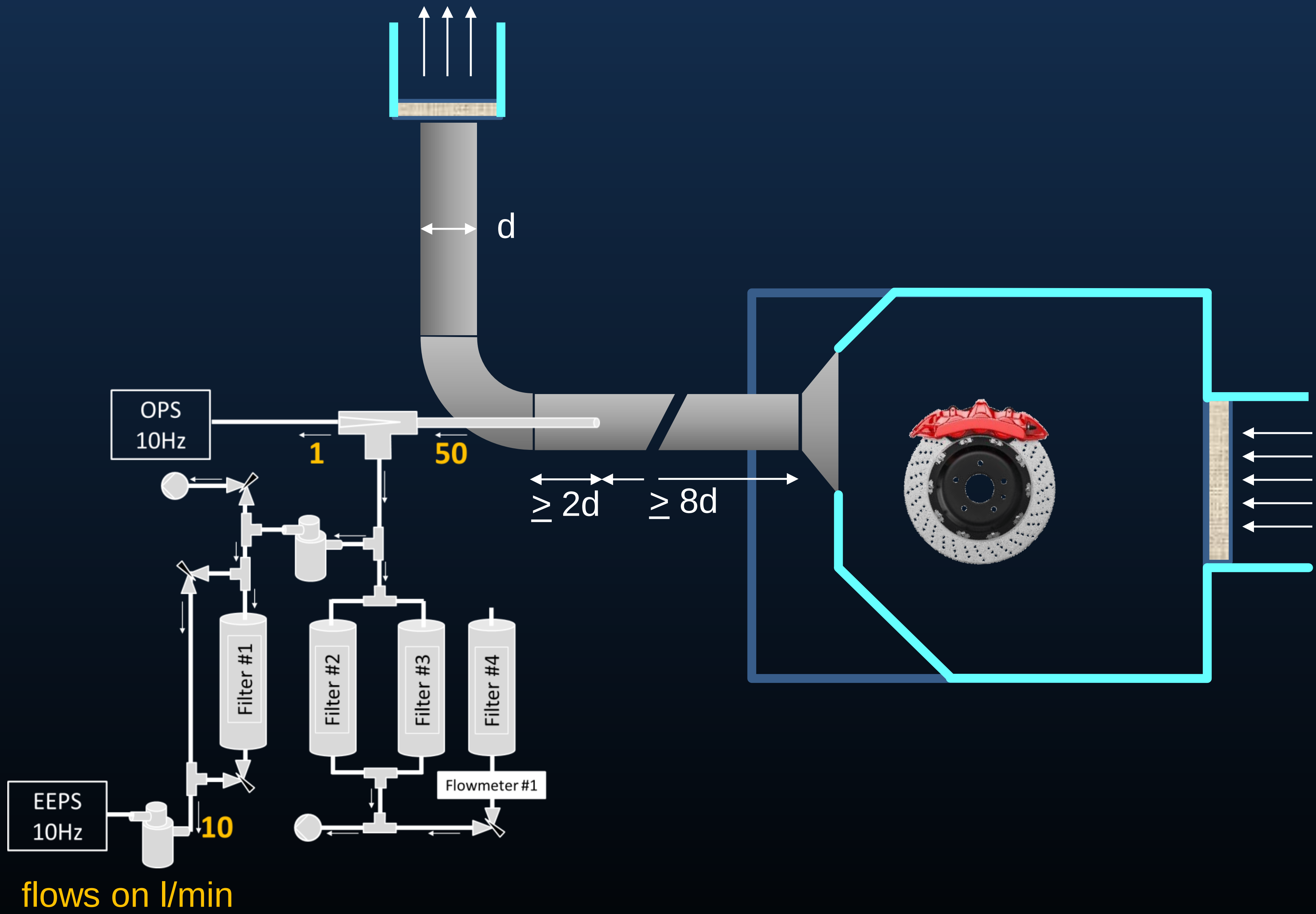
## Step 2 - ruggedness

- 1-2 labs
- DOE for sensitivity
- Tighten controls and repeat (1 lab)

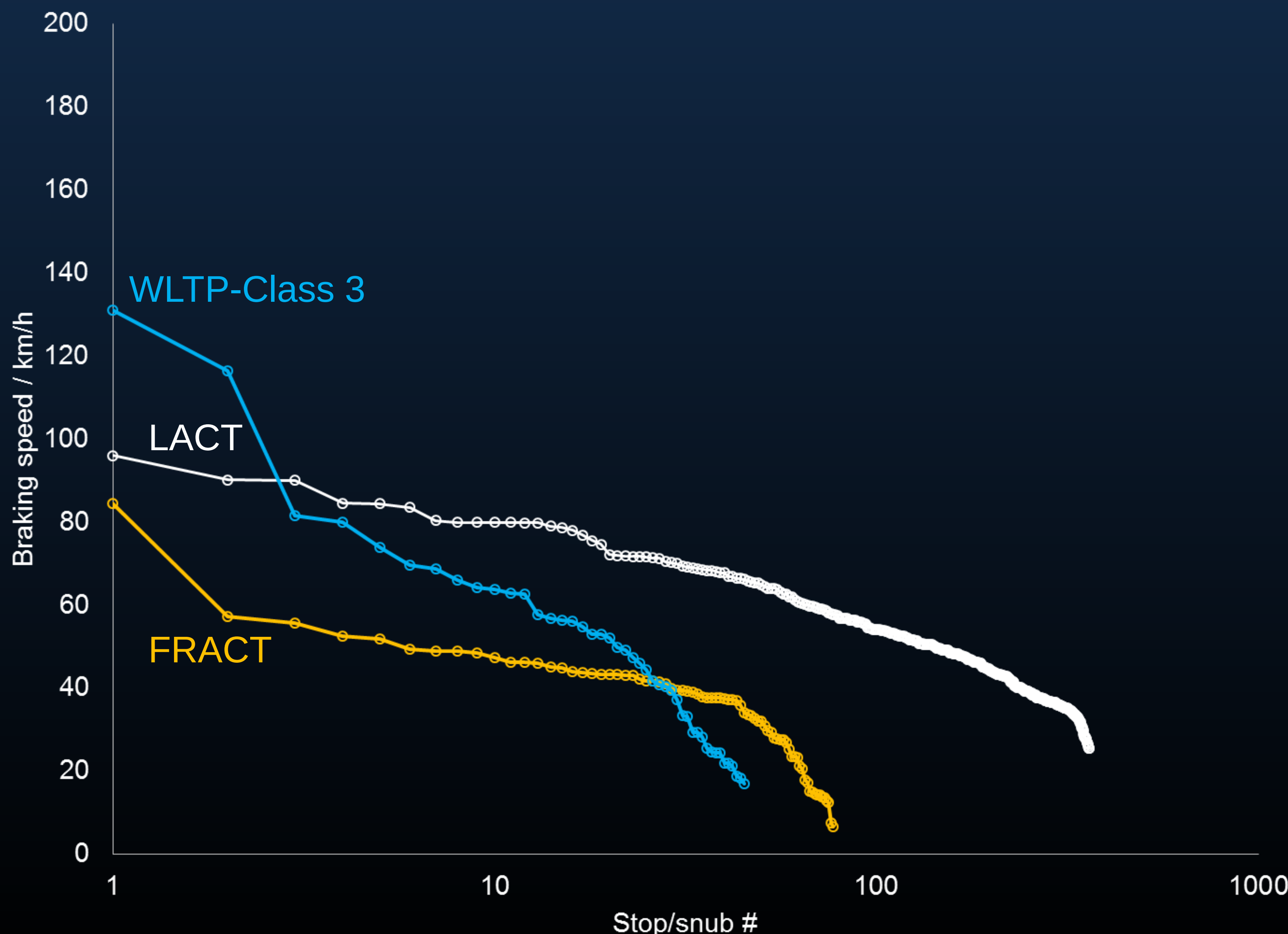
## Step 3 – interlab 2

- Practice
- Final document
- Publication

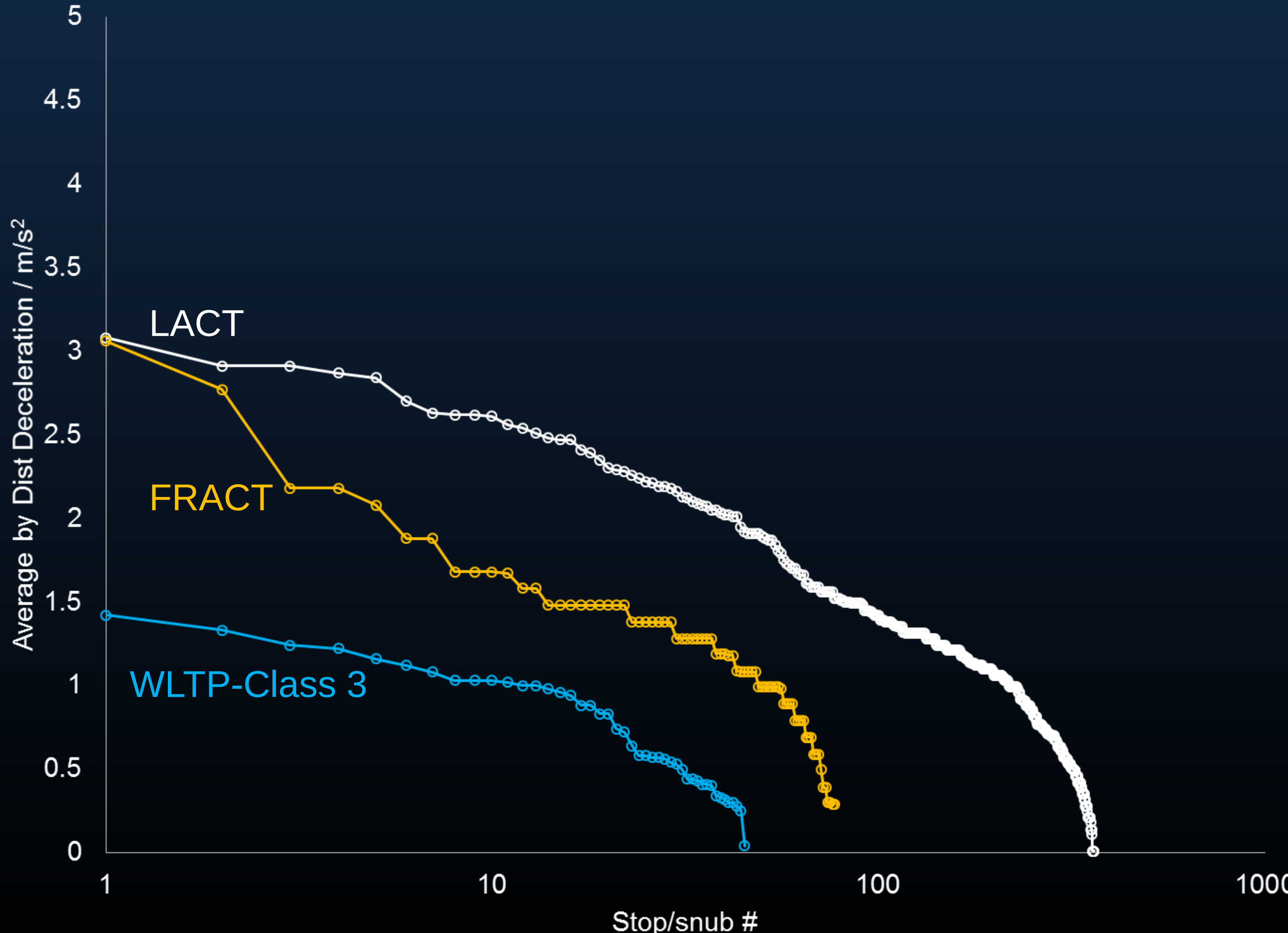
# …one more thing


d
OPS
10Hz
1
50
≥ 2d
≥ 8d
Filter #1
Filter #2
Filter #3
Filter #4
Flowmeter #1
EEPS
10Hz
10
flows on l/min

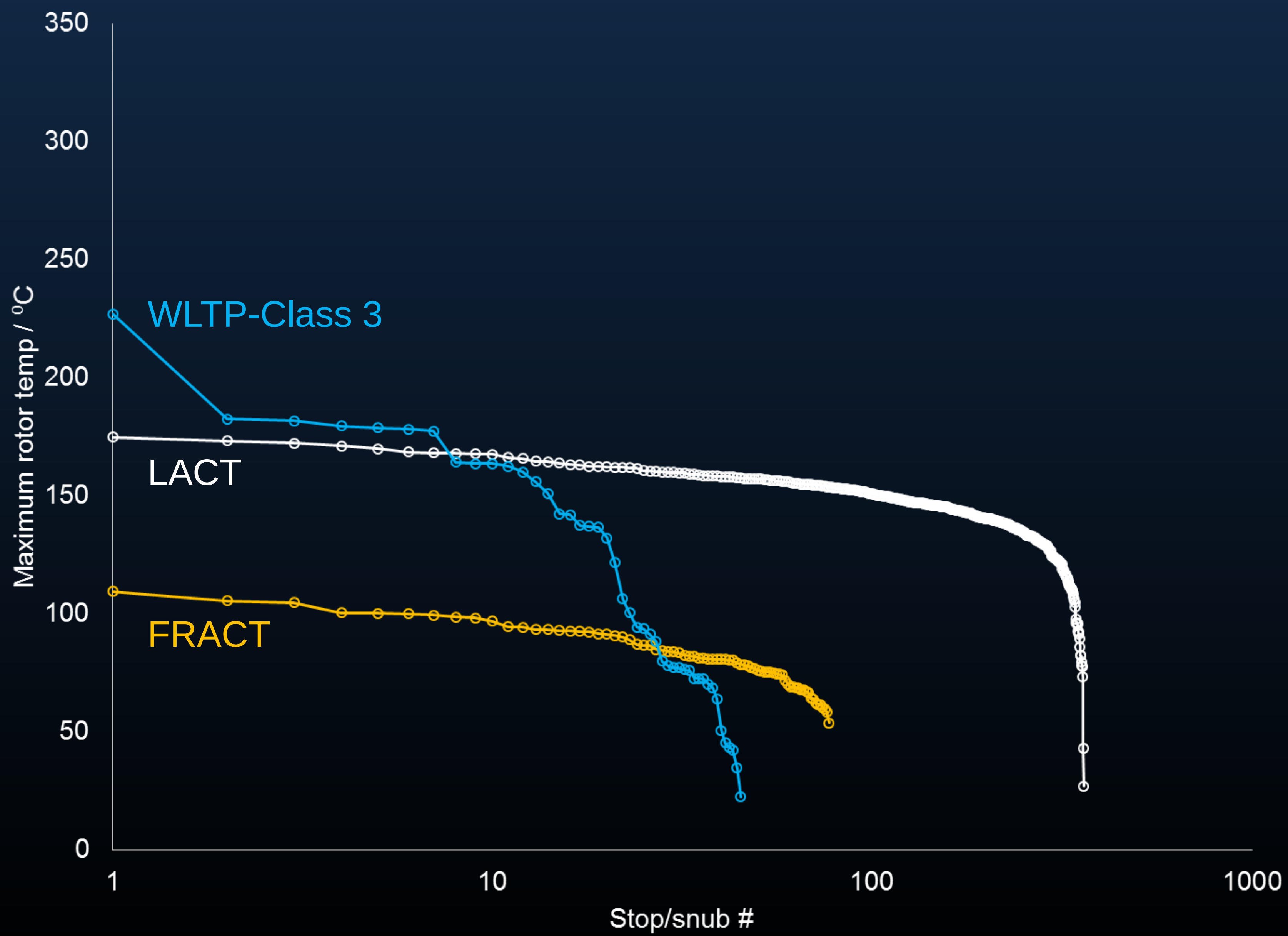
# Collectives for braking speeds



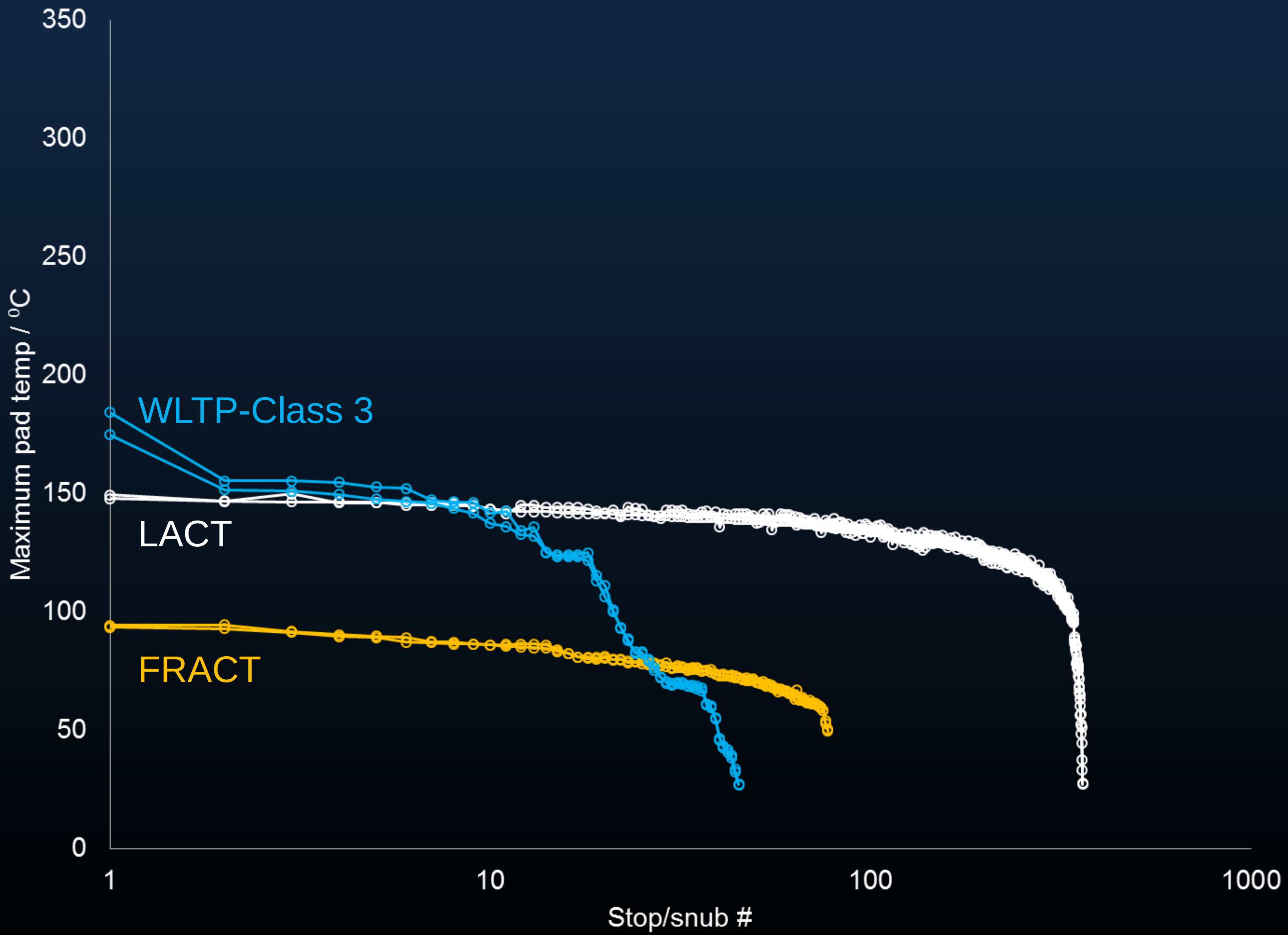
# Collectives for deceleration



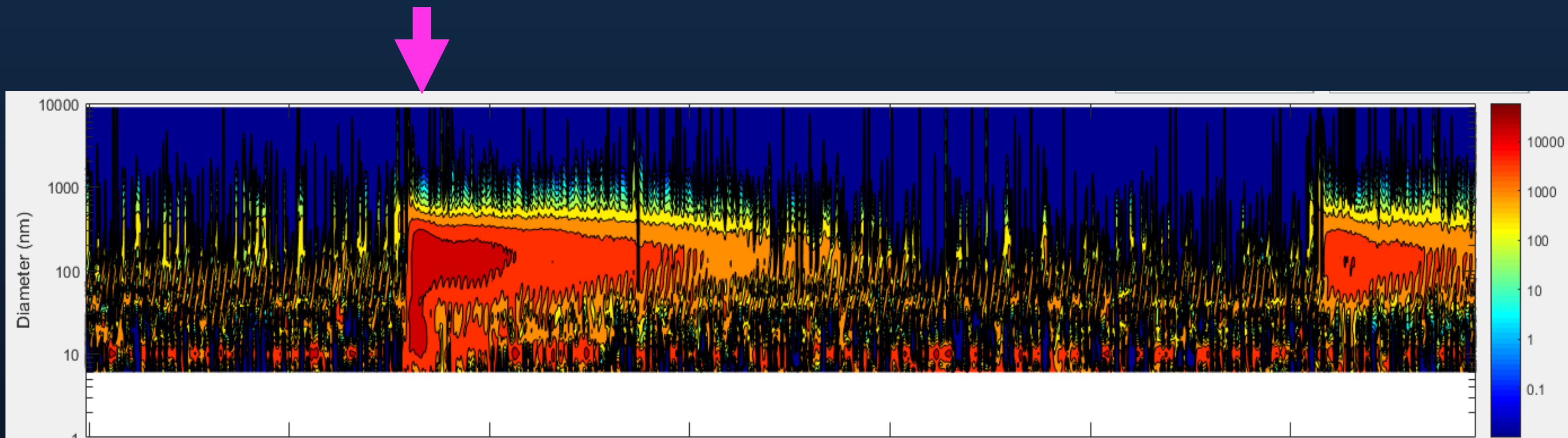
# Collectives for rotor temperatures



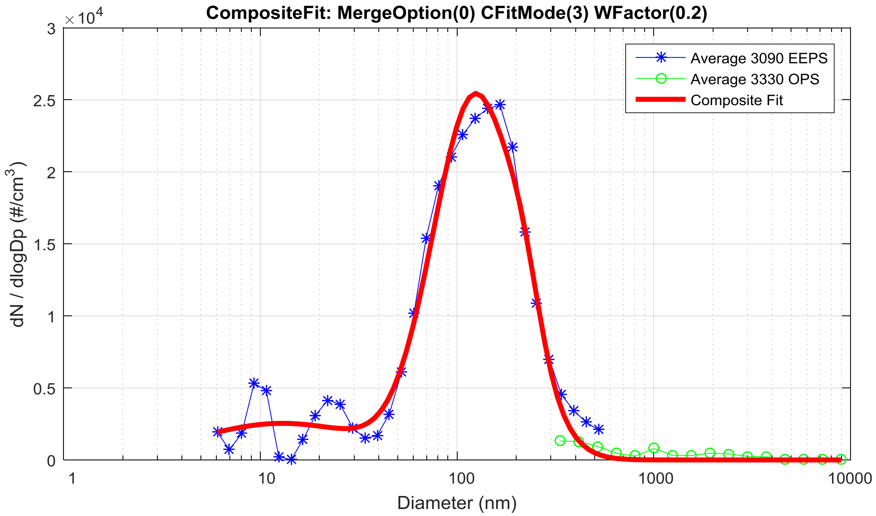
# Collectives for pad temperatures



# LACT

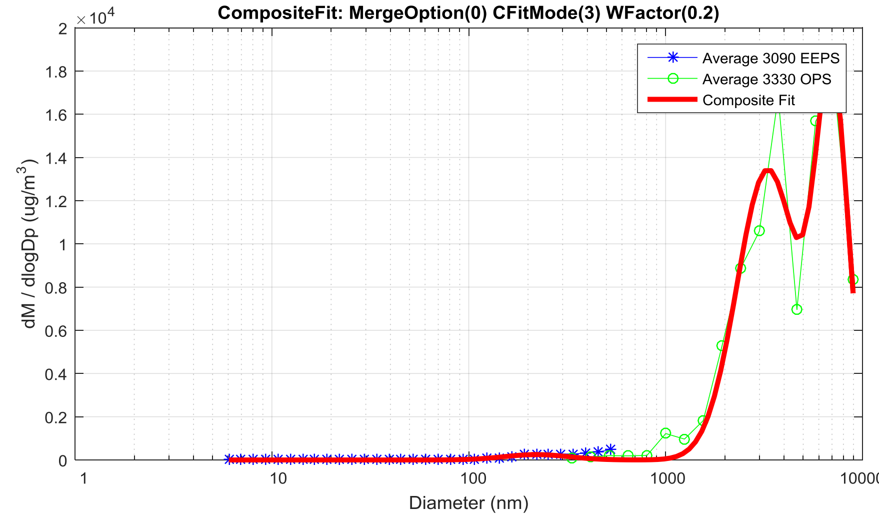



3 x $10^4$



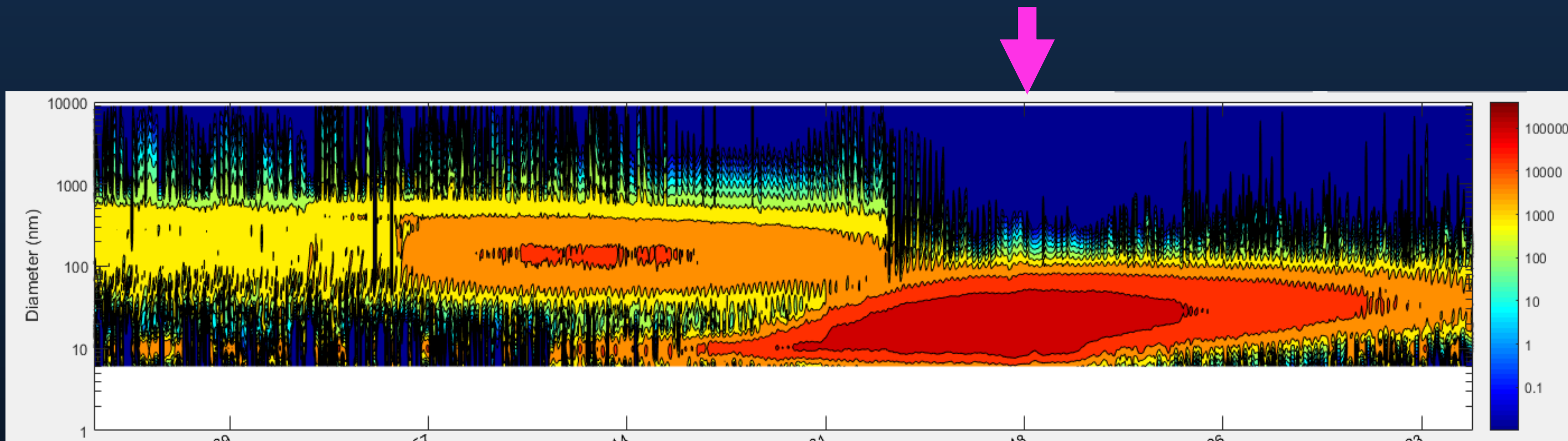

Particle count / 6 nm – 10 µm

2 x $10^4$

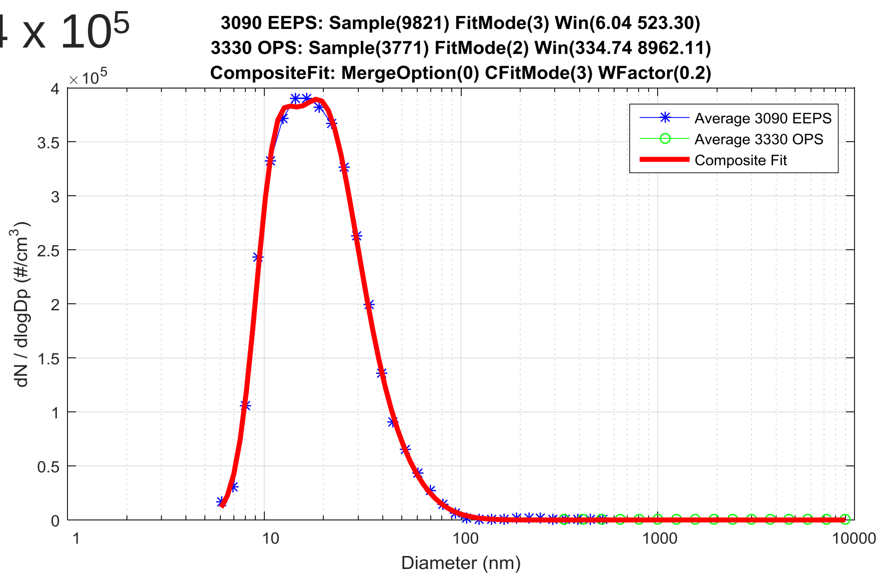



Particle mass / 6 nm – 10 µm

# WLTP

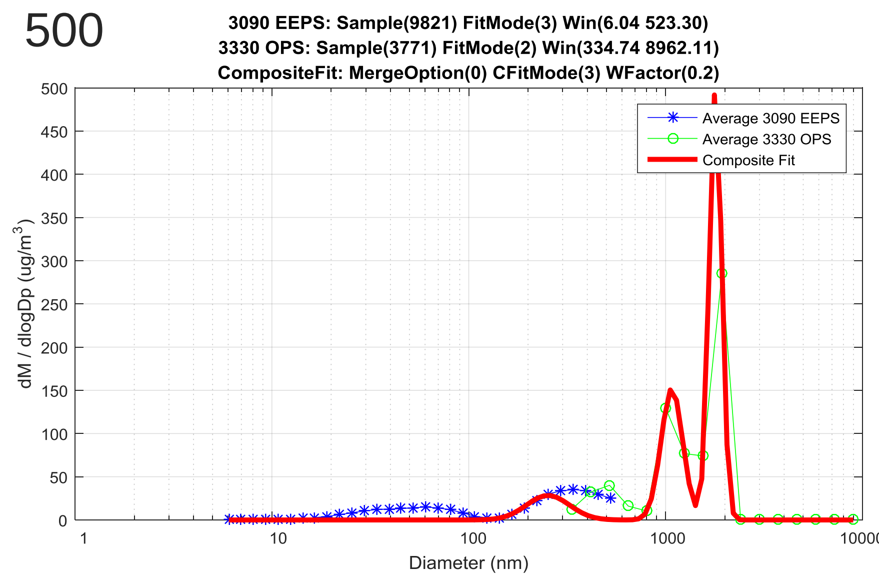



4 x $10^5$



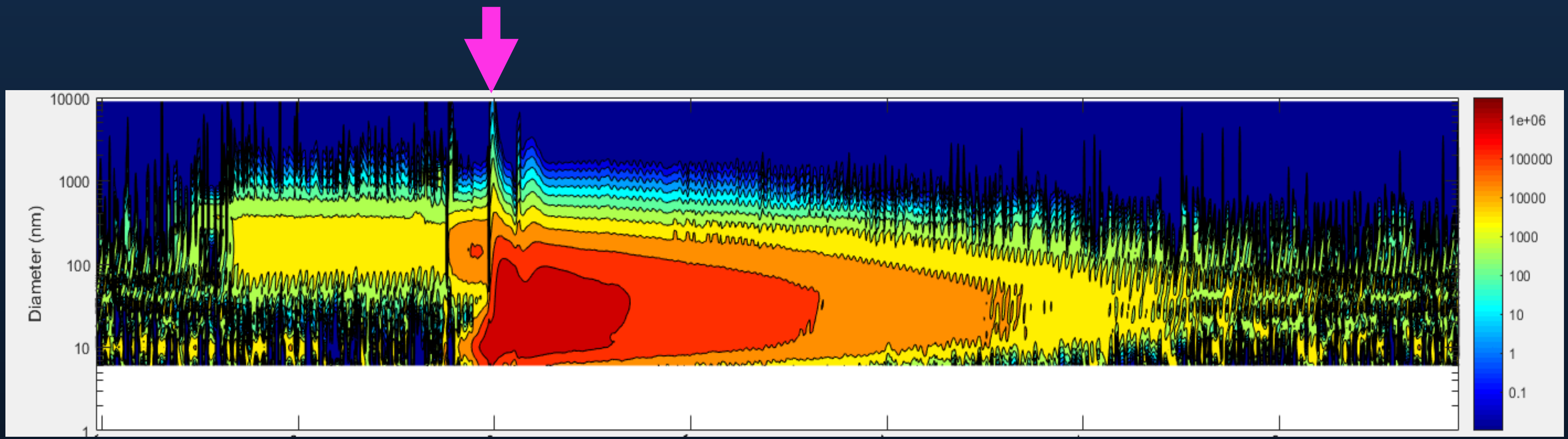

Particle count / 6 nm – 10 µm

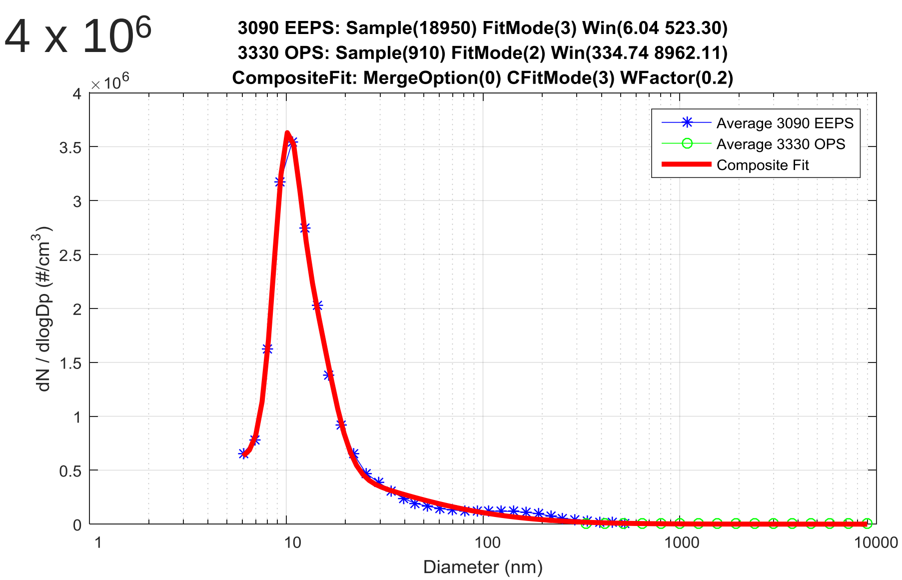
500



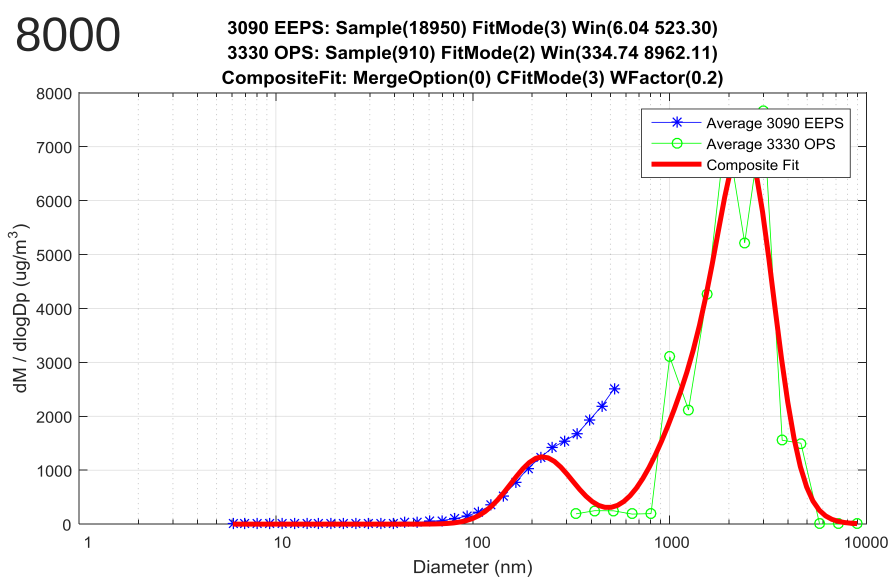

Particle mass / 6 nm – 10 µm

# ISO 26867 fade




Particle count / 6 nm – 10 µm




Particle mass / 6 nm – 10 µm

# Challenges & unknowns

Customer usage and randomness of duty cycle

Dyno/PMS validation and long-term r&R

How to involve academia

# Conclusions

Need to better understand what the results mean

Tribological explanations are still elusive

Economics and global programs will lead integration

**Cooperate on standardization**

**Compete on implementation**

AUTOSAR

AUTOmotive Open System ARchitecture

# Thanks!

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