Review of CE-CERT's Brake and Tire Programs

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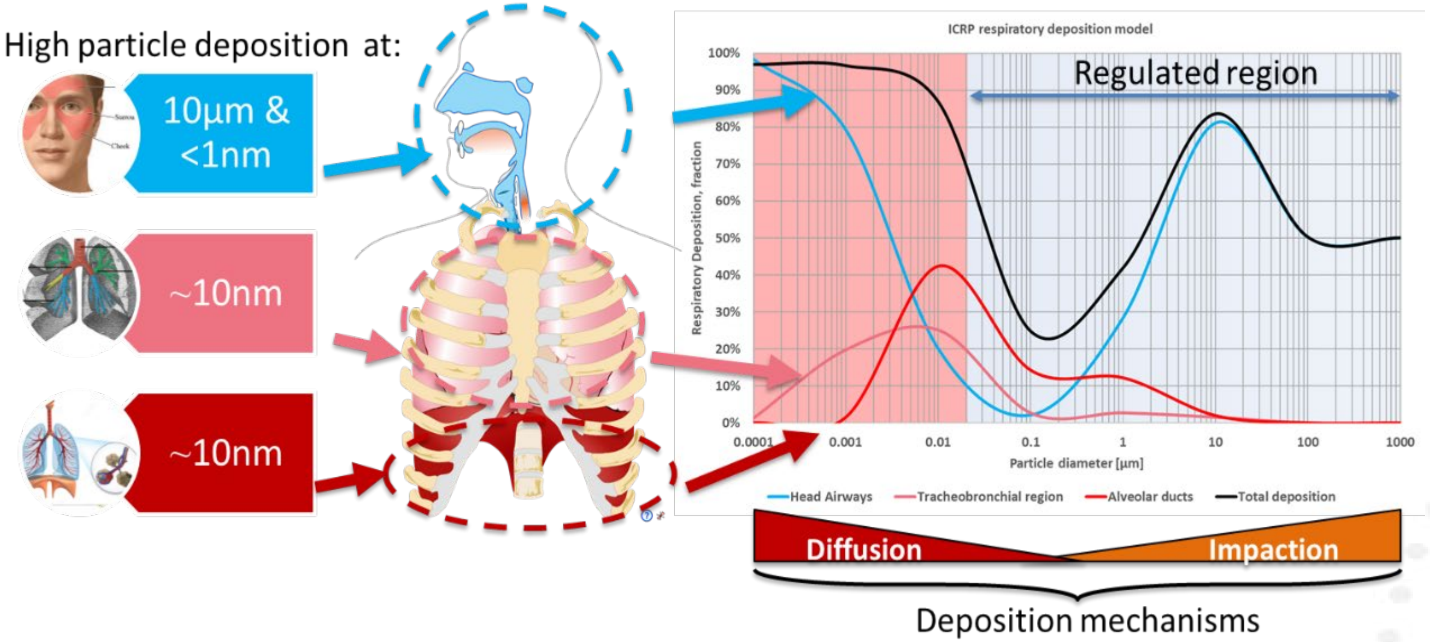
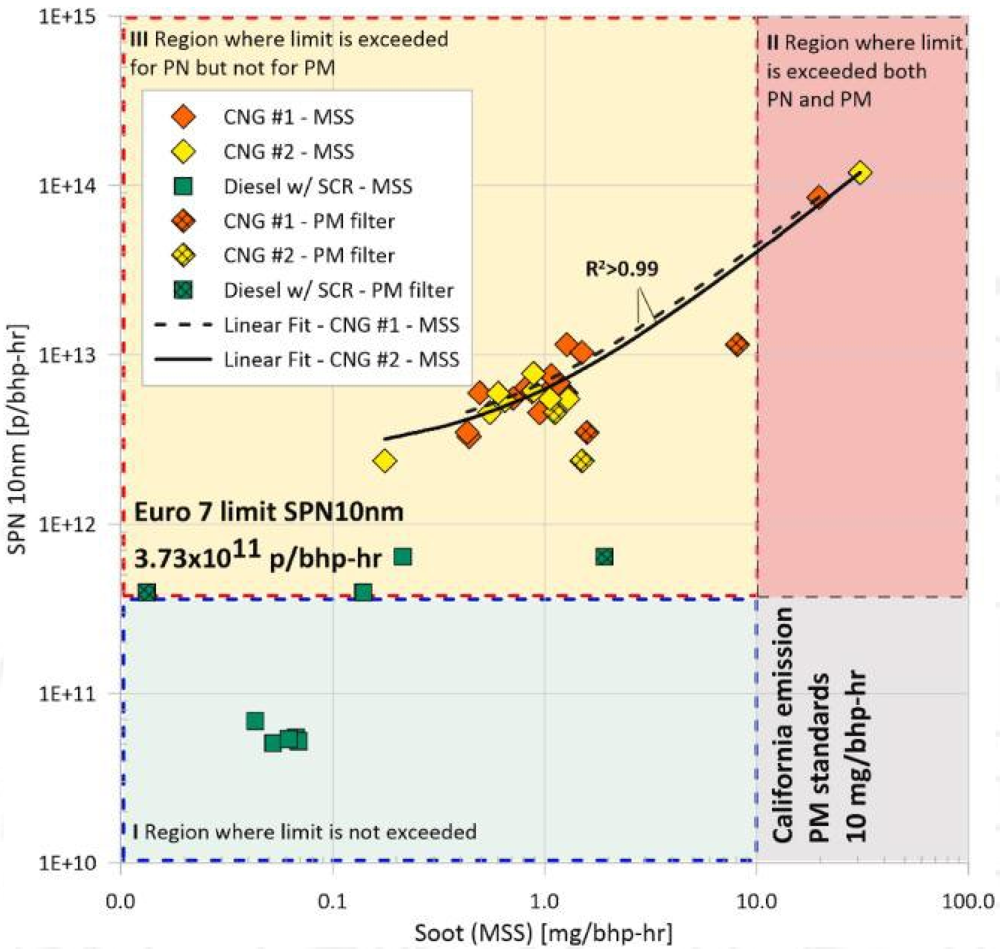
Outline

- Motivation
- Experimental setup
- Results
- Conclusions
- Future Work

Motivation


High particle deposition at:
10µm & <1nm
~10nm
~10nm
ICRP respiratory deposition model
Regulated region
Respiratory Deposition, fraction
Particle diameter [µm]
Head Airways
Tracheobronchial region
Alveolar ducts
Total deposition
Diffusion
Impaction
Deposition mechanisms


III Region where limit is exceeded for PN but not for PM
II Region where limit is exceeded both PN and PM
CNG #1 - MSS
CNG #2 - MSS
Diesel w/ SCR - MSS
CNG #1 - PM filter
CNG #2 - PM filter
Diesel w/ SCR - PM filter
Linear Fit - CNG #1 - MSS
Linear Fit - CNG #2 - MSS
R²>0.99
Euro 7 limit SPN10nm
3.73x10¹¹ p/bhp-hr
I Region where limit is not exceeded
California emission PM standards 10 mg/bhp-hr
SPN 10nm [p/bhp-hr]
Soot (MSS) [mg/bhp-hr]

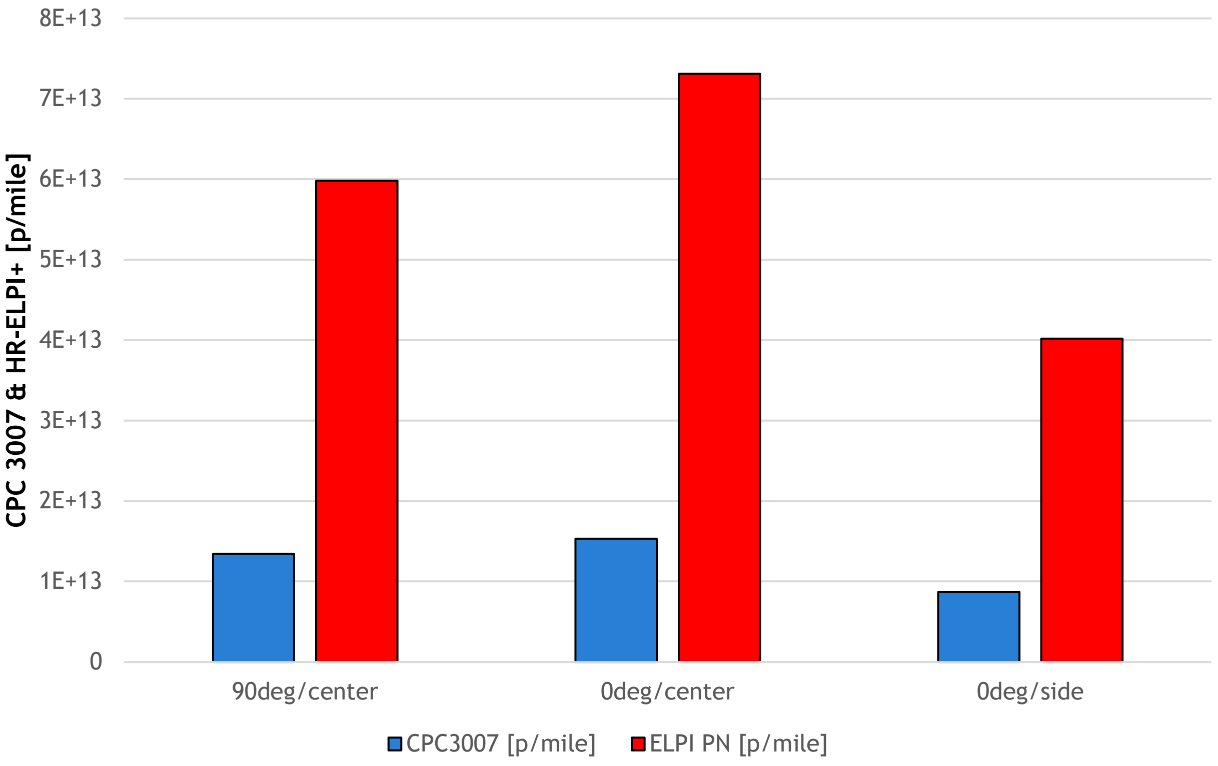
Project Development

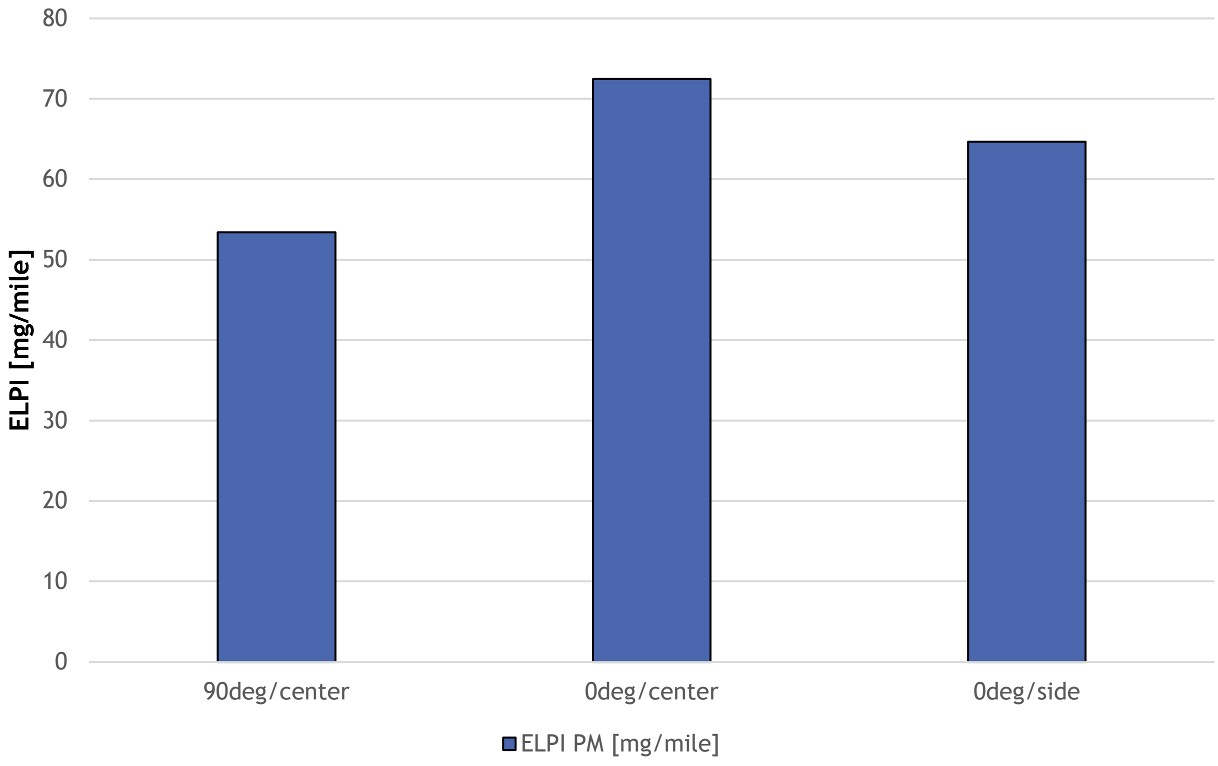
- 1st Phase:
  - Funnel system to understand PN generation mechanisms
- 2nd Phase:
  - Development of fully-enclosed sampling system and pilot testing on chassis dyno
- 3rd Phase:
  - On-road testing with fully enclosed sampling system

Preliminary tire/brake emission testing - setup

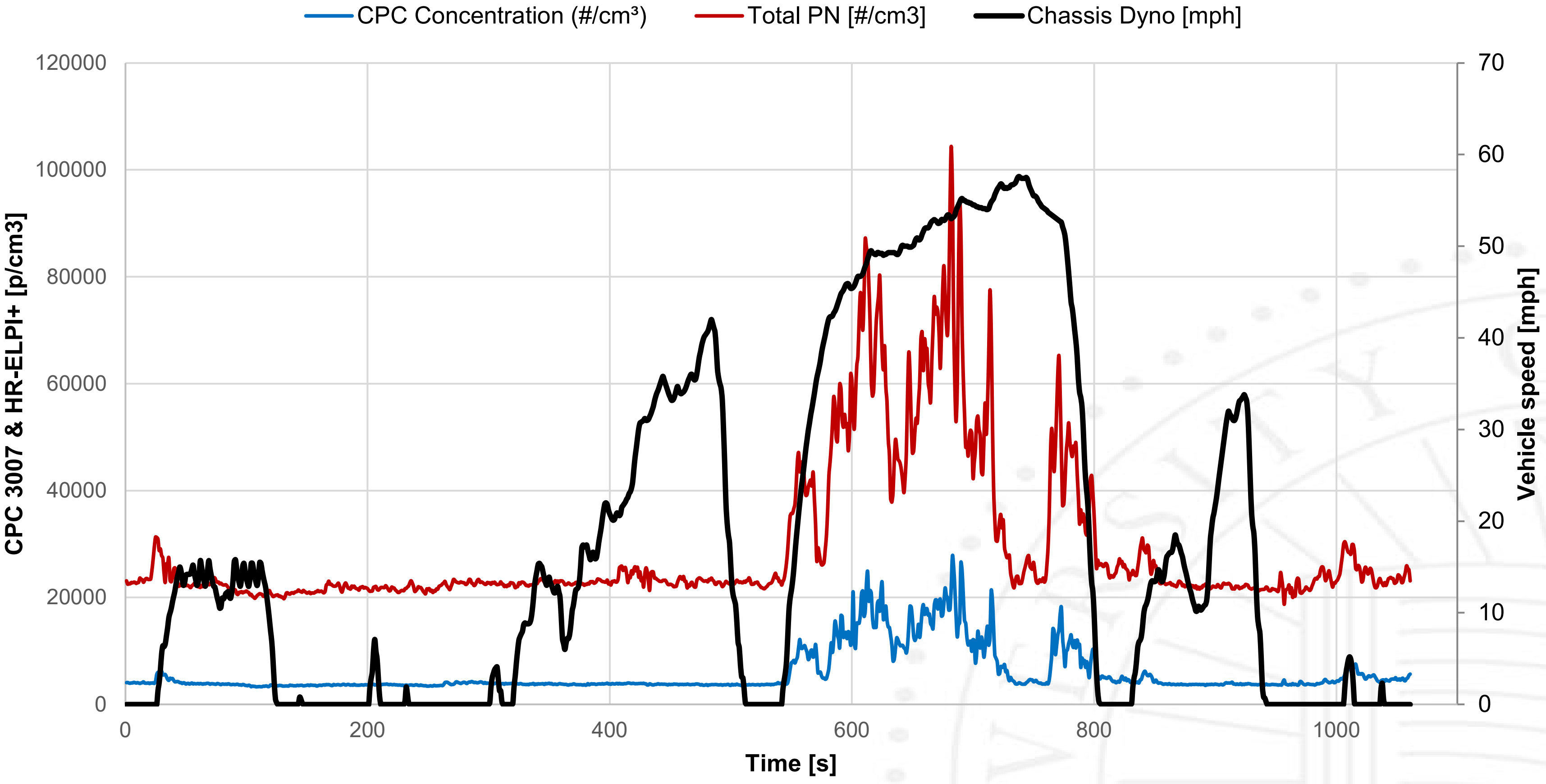
- Heated line at 50degC, to avoid potential water condensation
- Sampling points at 90deg and 0deg on the periphery of the tire → look
- Sampling point at the center and side of the tire

Aggregated emission levels per sampling point



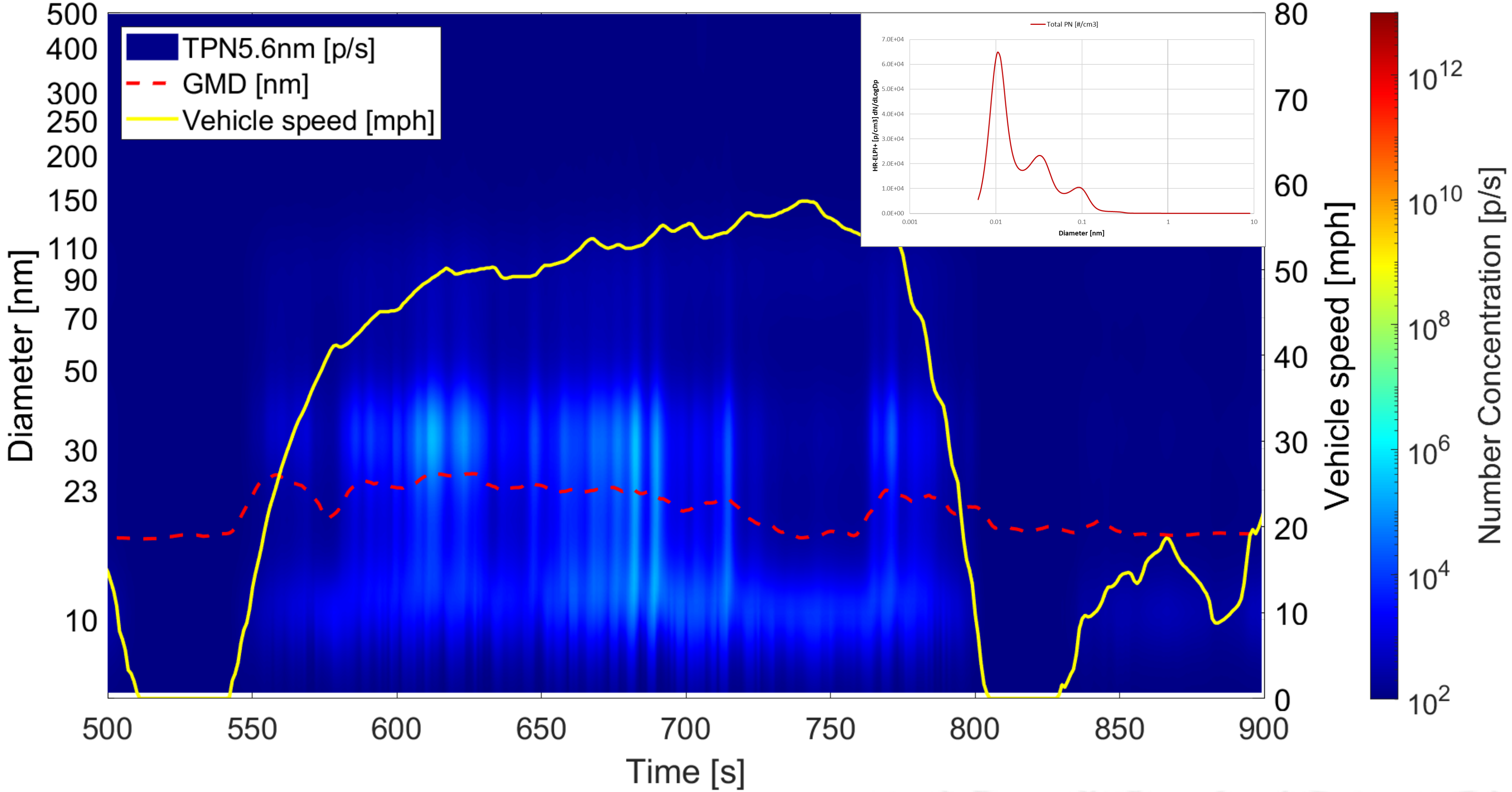


Real-time particle size distribution during the UDDS

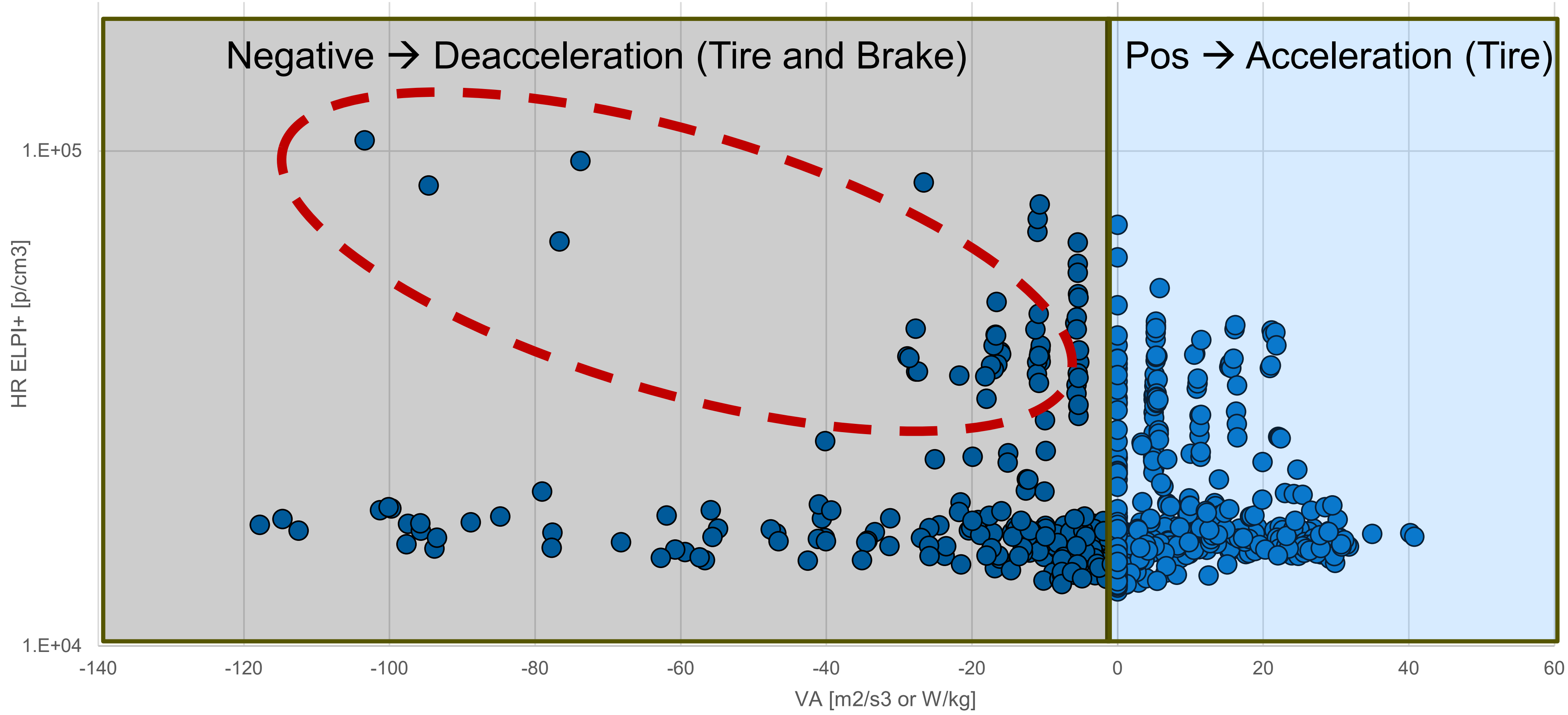


- Real-time particle concentration for CPC and ELPI at 90deg/center location
- Similar emission findings (high emission performance during 550-800s) were observed for all sampling locations
- Tire/brake temperature level seems to play a crucial role in particle emission performance

Real-time particle size distribution during the UDDS

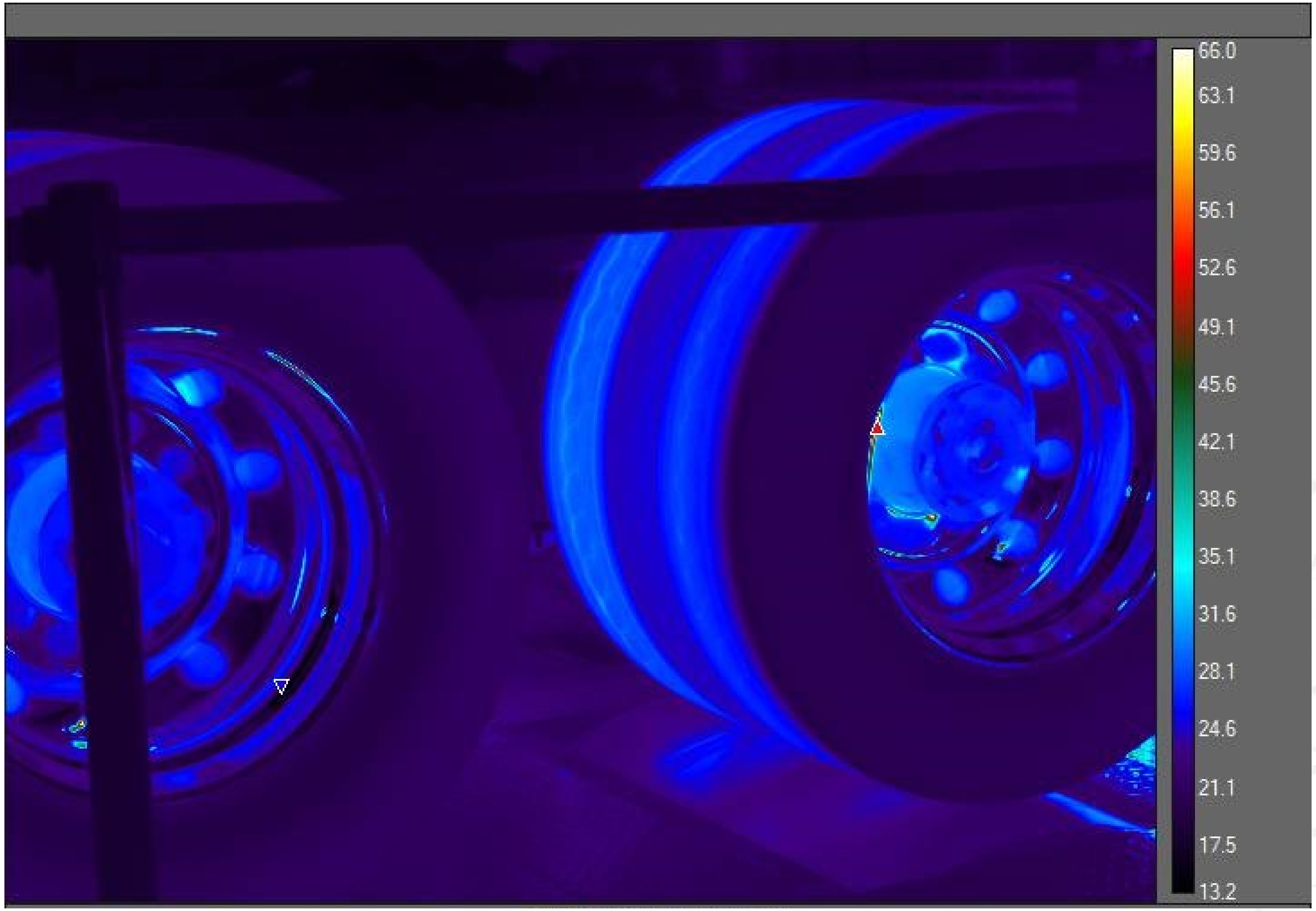


The role of driving dynamics

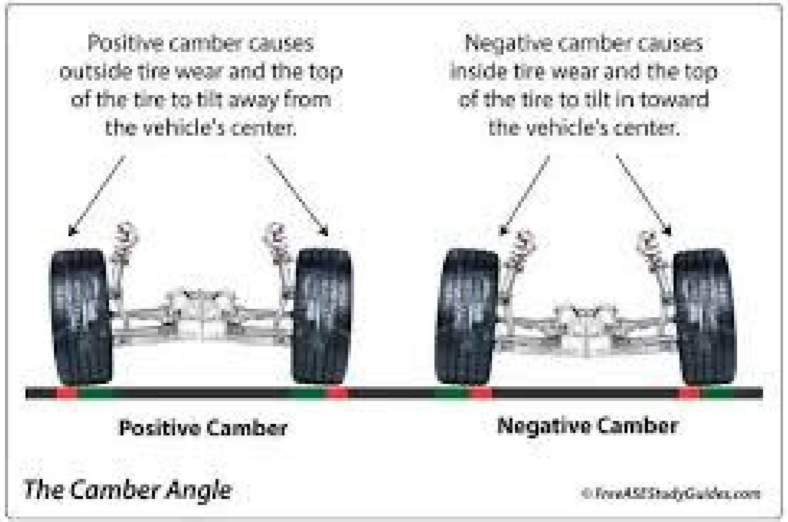


- Red circle area of interest, high emission levels during deacceleration events, potential relation with high brake disk temperature → , higher initial tire rotational speed at those points
- VA can be utilized to distinguish tire and tire + brake emissions

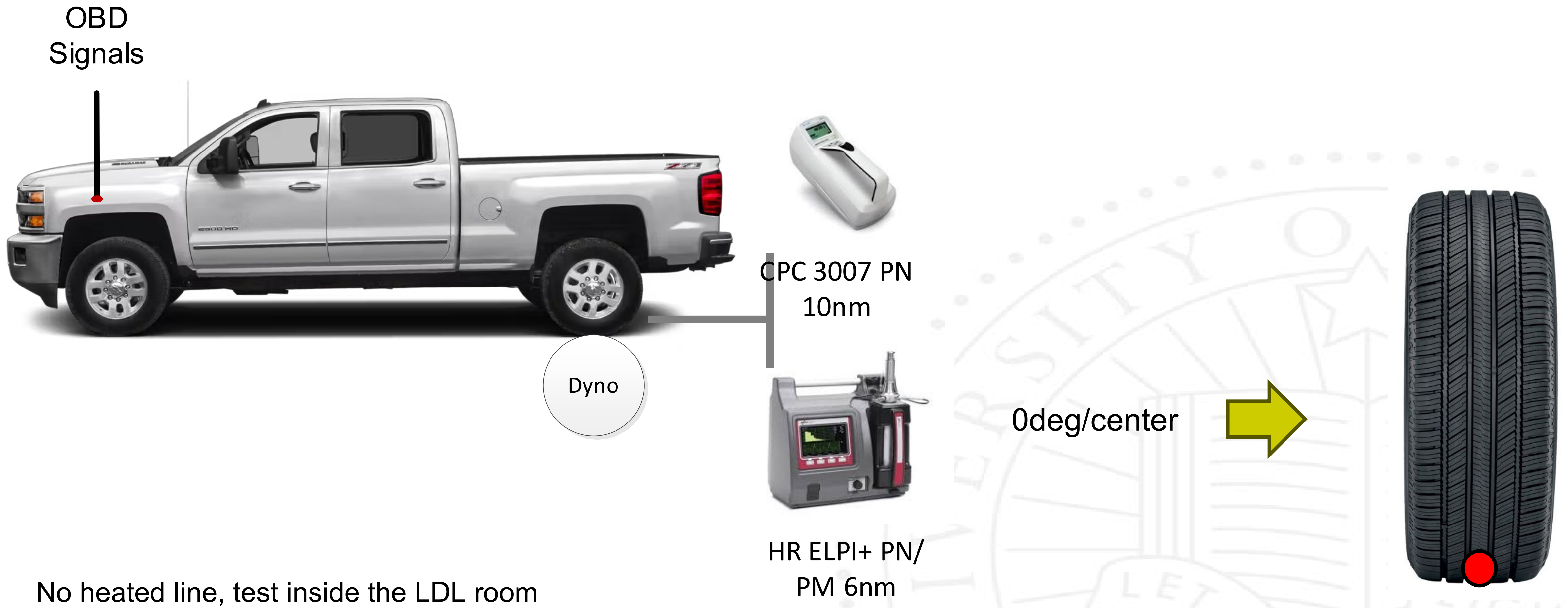
Temperature profile reading and the camber angle effect



- Preliminary temperature findings suggest that tire surface is around 27degC during cruising
- Temperature surface profile is not uniform around the tire due to camber angle → weight load may affect the camber angle and subsequently the temperature profile
- Hot spot temperature readings reached 29degC in less than 10s during deceleration phases

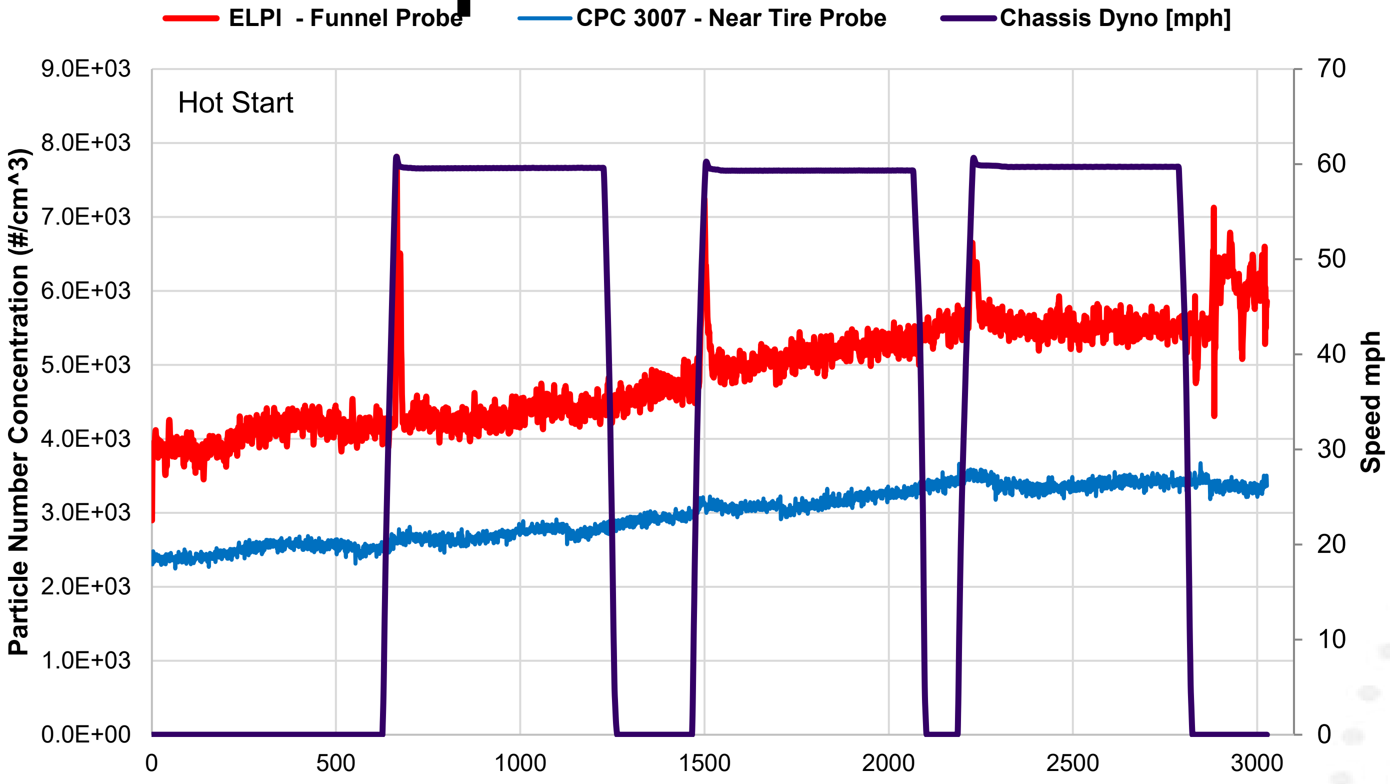


LDV Preliminary tire/brake emission testing - setup

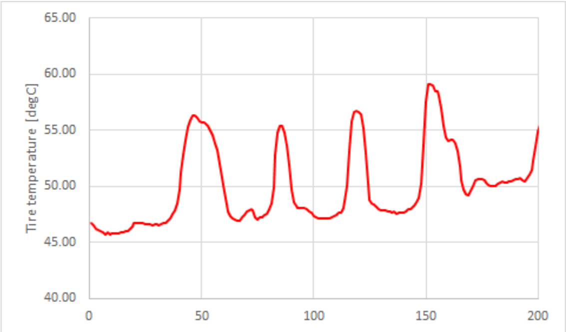


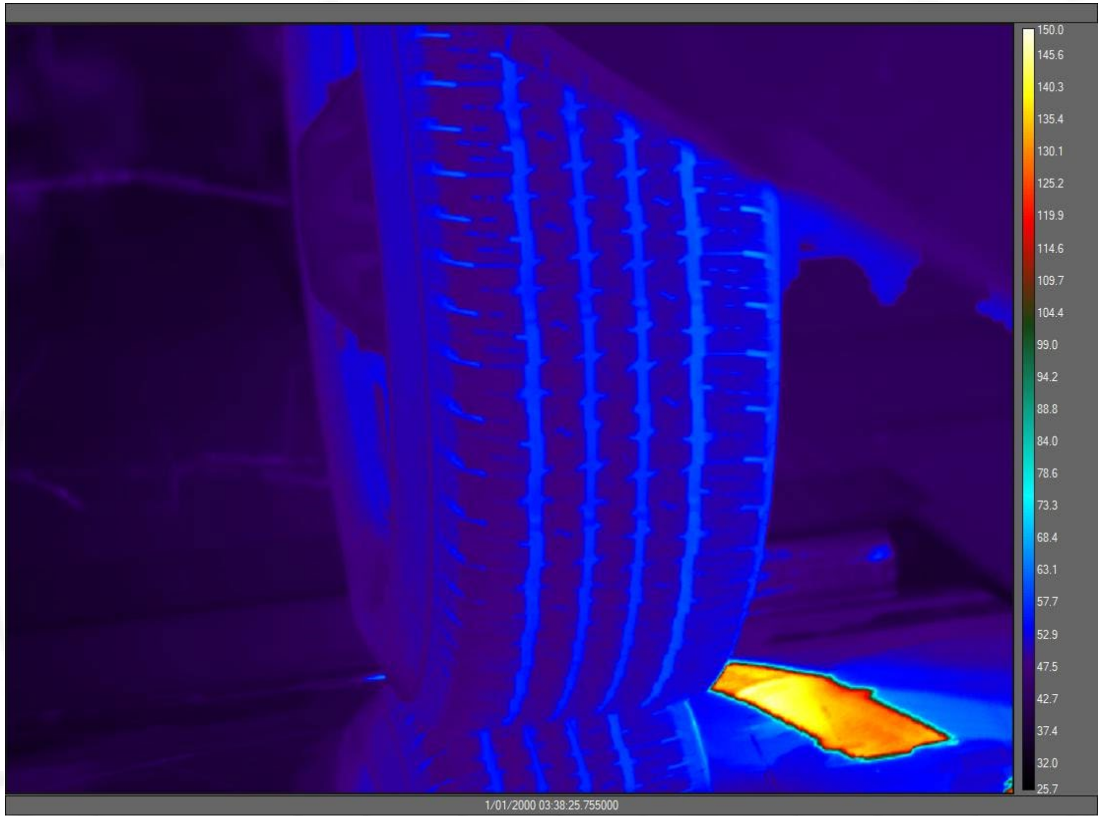
- No heated line, test inside the LDL room
- Steady-state operating points

Real-time particle number conce



- Real-time particle number concentration for CPC and ELPI at different locations
- Significant lower PN emissions compared to the HDV
- No effect of deceleration phase to PN emissions
- High ultrafine particles at the end of the test cycle (volatiles?)





Chassis-dyno brake and tire emissions

Light-duty chassis dyno measurements

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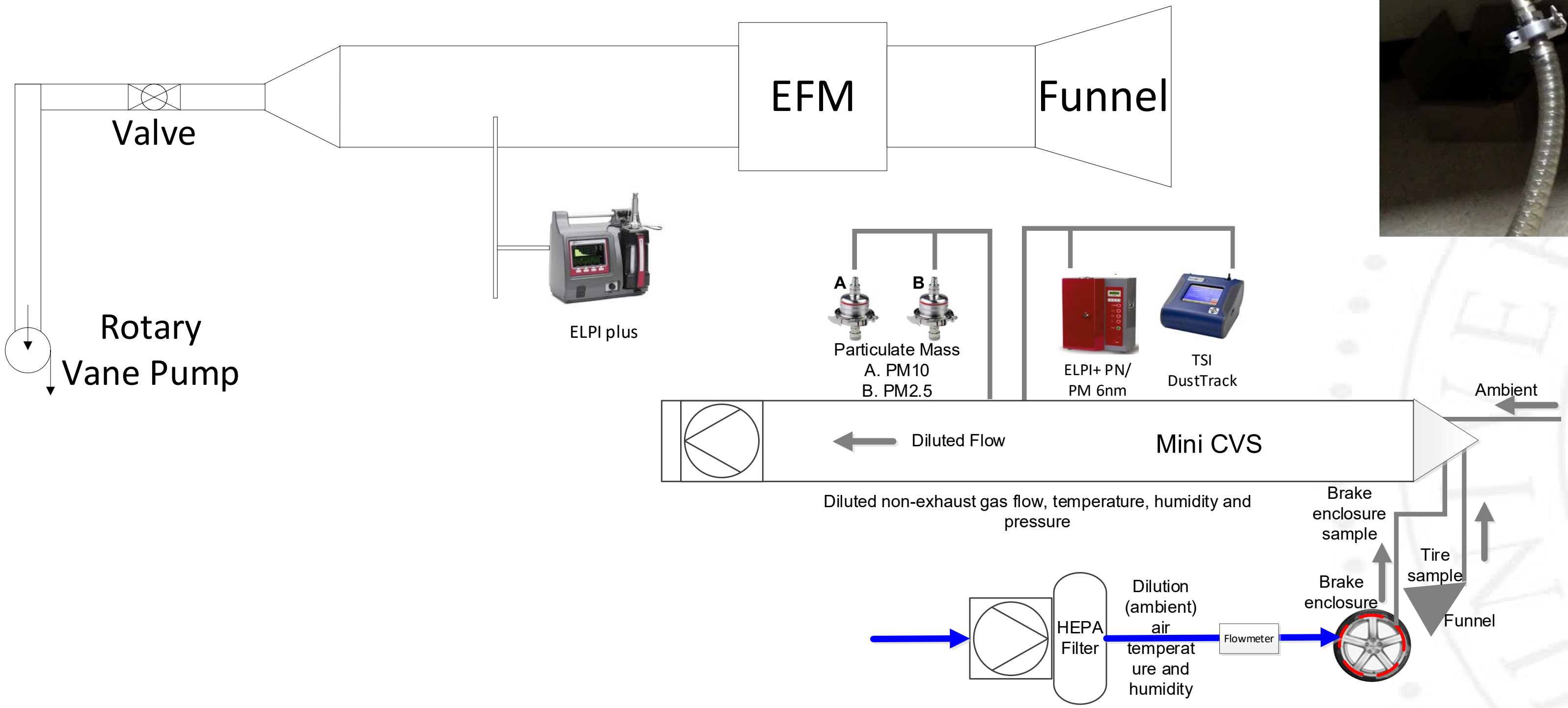
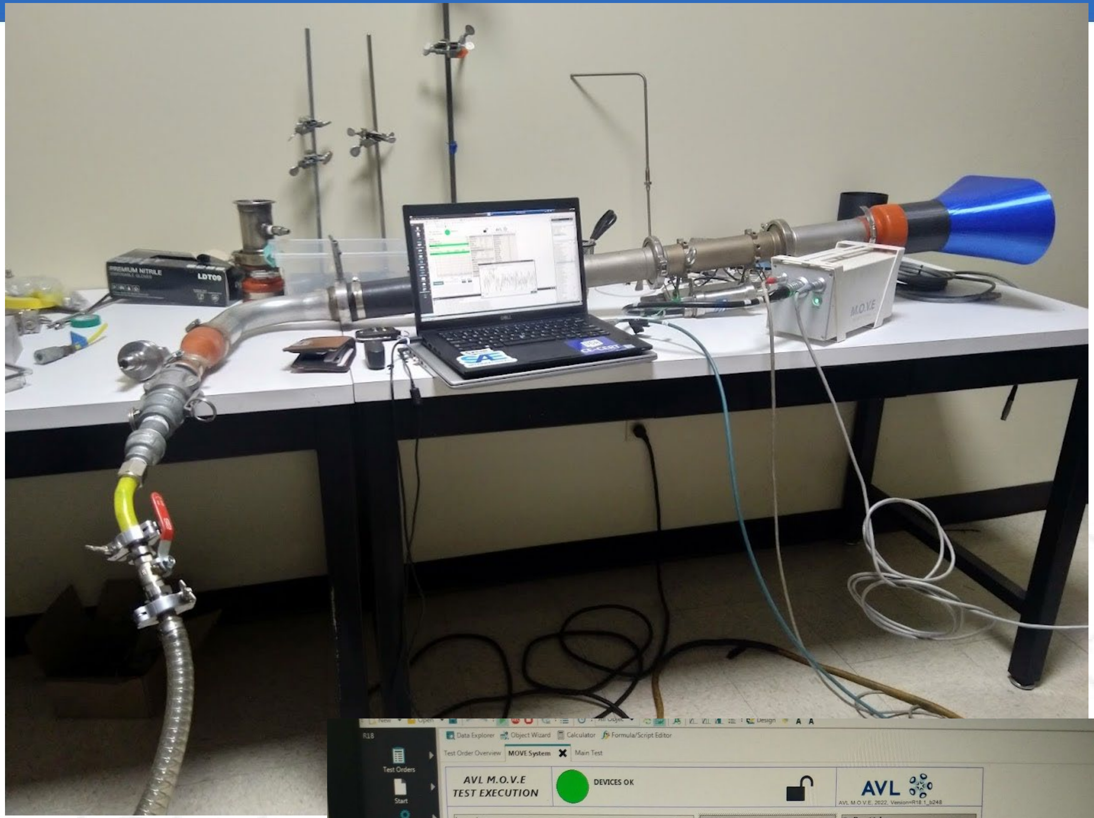
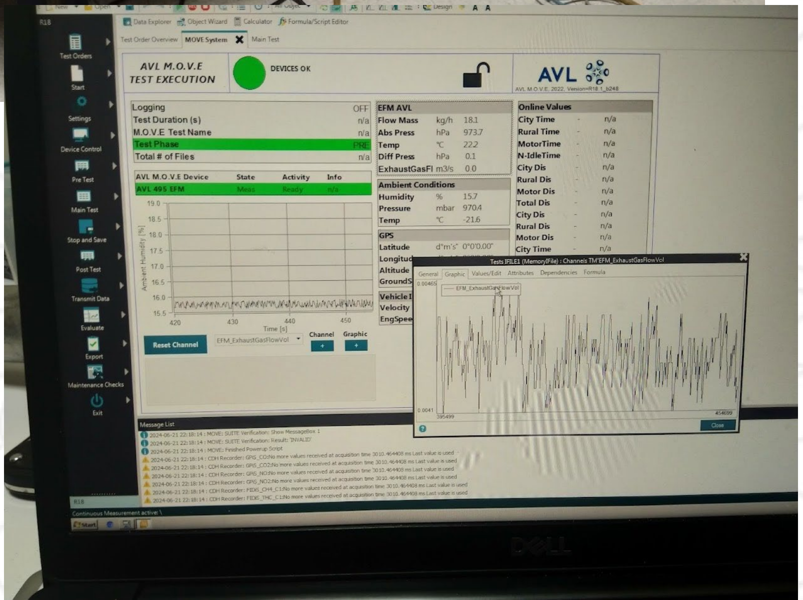
Preliminary sampling system

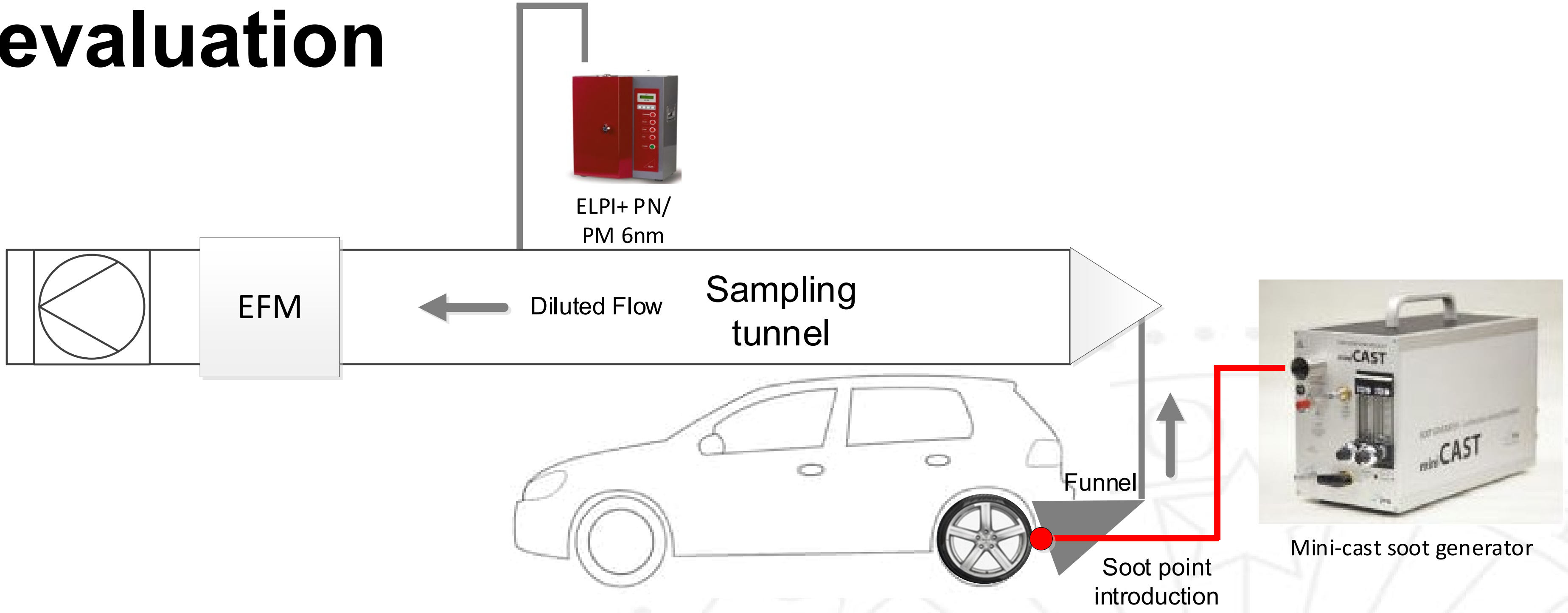
- Laboratory version of the brake and tire sampling system
- Initial evaluation operating at 0.0044 m^3/s --> 264 lpm --> 9.3 SCFM inlet flow
- Volumetric and temperature flow measurement based on the exhaust flow meter (EFM) module







Particle losses evaluation



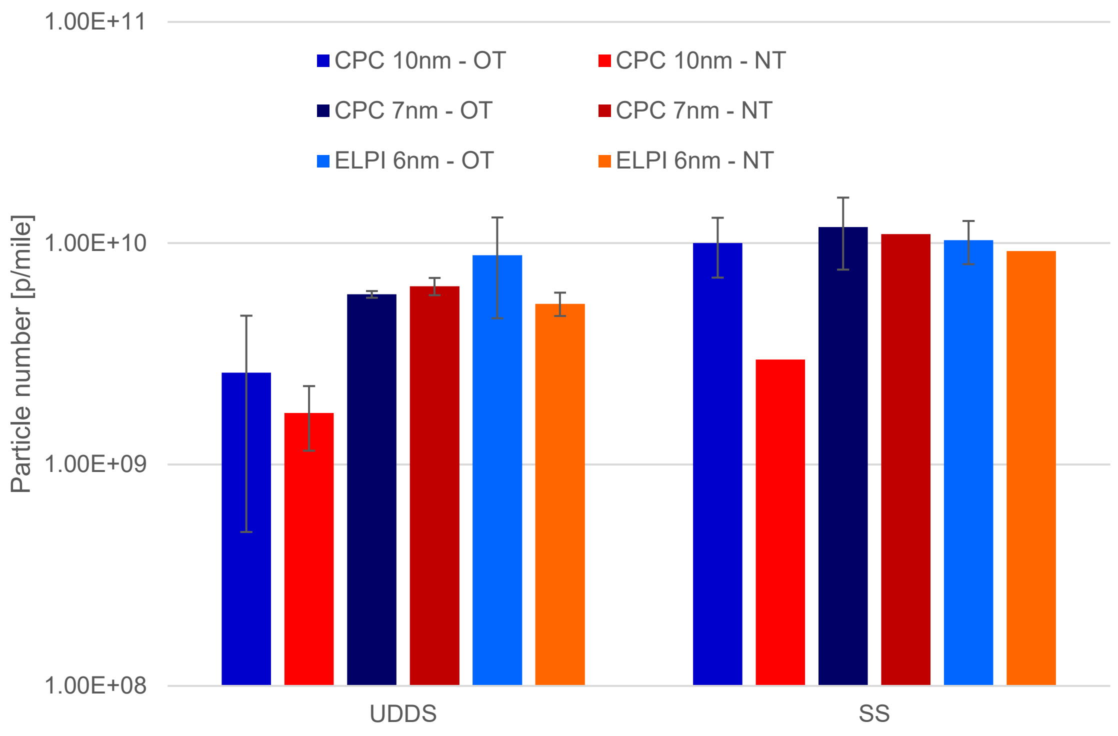
Particle losses evaluation based on mini-cast evaluation:

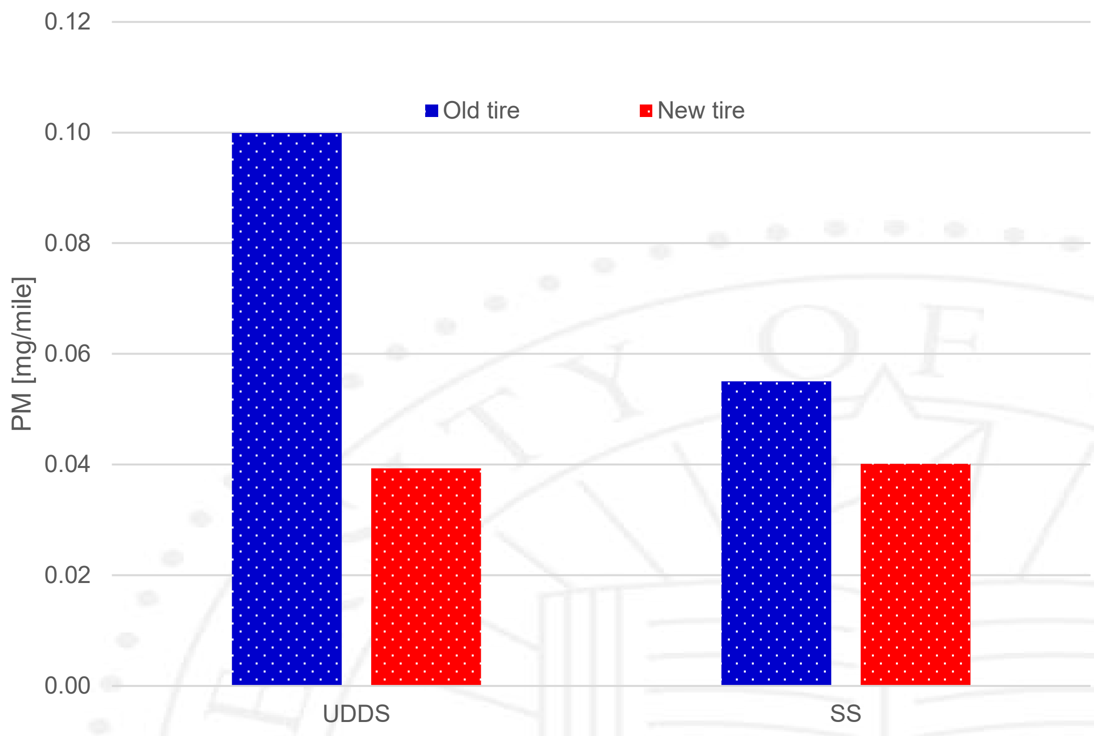
- ELPI+ utilized for PN/PM measurements at the source (soot point introduction) and the sampling point
- Evaluation under 0 mph, 30 mph and 60 mph

Aggregated emissions levels

Number	Date	Test cycle number	Sampling system	Tire condition	Test cycle	Measurement type	Tire temperature state	Vehicle	Vehicle load	CPC3007 [p/mile]	CPC3022 [p/mile]	ELPI PN [p/mile]	ELPI PM [mg/mile]
1	20-Jun	SS2		Old	Steady State	Tire	HS	Silverado	Normal				
2	21-Jun	SS1	Probe	Old	Steady State	Tire	CS	Silverado	Normal	1.56E+09	3.84E+09	2.47E+09	0.030
3	21-Jun	SS2	Probe	Old	Steady State	Tire	HS	Silverado	Normal	2.08E+11	1.92E+11	1.84E+11	0.876
4	25-Jun	SS1	Probe	Old	Steady State	Tire	CS	Leaf	Normal	3.32E+09	3.36E+09	2.76E+09	0.026
5	28-Jun	SS1	Funnel	Old	Steady State	Tire	CS	Mitsubishi	Normal	1.04E+08	1.37E+08	9.39E+07	0.001
6	28-Jun	SS2	Funnel	Old	Steady State	Tire	HS	Mitsubishi	Normal	1.43E+10	1.82E+10	1.24E+10	0.087
7	28-Jun	SS3	Funnel	Old	Steady State	Tire	HS	Mitsubishi	Normal	1.14E+10	1.29E+10	1.13E+10	0.061
8	28-Jun	SS4	Funnel	Old	Steady State	Tire	HS	Mitsubishi	Normal	6.55E+09	7.14E+09	6.46E+09	0.048
9	28-Jun	SS5	Funnel	Old	Steady State	Tire	HS	Mitsubishi	Normal	7.86E+09	9.05E+09	1.11E+10	0.024
10	2-Jul	SS1	Funnel	Old	Steady State	Tire	CS	Mitsubishi	Normal + 450 lbs	8.71E+09	1.01E+10	8.68E+09	0.076
11	2-Jul	SS2	Funnel	Old	Steady State	Tire	HS	Mitsubishi	Dyno load change + 450 lbs	9.31E+10	1.09E+11	2.07E+11	0.260
12	2-Jul	T1	Funnel	Old	UDDS	Tire	HS	Mitsubishi		4.71E+09	6.08E+09	4.58E+09	0.080
13	2-Jul	T2	Funnel	Old	UDDS	Tire	HS	Mitsubishi		4.96E+08	5.66E+09	1.31E+10	0.120
15	3-Jul	T1	Funnel	Old	UDDS	Brake	CS	Mitsubishi	Dyno load change + 450 lbs	2.33E+09	3.12E+09	4.24E+09	0.053
16	3-Jul	T2	Funnel	Old	UDDS	Brake	HS	Mitsubishi	Dyno load change + 450 lbs	7.53E+08	8.99E+09	6.24E+09	0.085
17	3-Jul	T3	Funnel	Old	UDDS	Brake	HS	Mitsubishi	Dyno load change + 450 lbs	7.73E+09	9.61E+09	7.05E+09	0.102
18	9-Jul	T1	Funnel	Old	UDDS	Brake	CS	Mitsubishi	Dyno load change + 450 lbs	7.38E+09	8.80E+09	5.58E+09	0.074
19	9-Jul	T2	Funnel	Old	60 mph/ Idle cycle	Brake	HS	Mitsubishi	Dyno load change + 450 lbs	1.39E+10	2.05E+10	1.80E+10	0.081
20	17-Jul	T1	Funnel	Old	50 mph/ Idle cycle	Brake	CS	Mitsubishi	Dyno load change + 450 lbs			2.33E+11	0.493
21	17-Jul	T2	Funnel	Old	50 mph/ Idle cycle	Brake	HS	Mitsubishi	Dyno load change + 450 lbs	8.82E+09	9.54E+09	7.87E+09	0.222
22	17-Jul	T3	Funnel	Old	50 mph/ Idle cycle	Brake	HS	Mitsubishi	Dyno load change + 450 lbs	3.29E+10	4.82E+10	3.03E+10	1.084
23	30-Jul	SS1	Funnel	New	Steady State	Tire	CS	Mitsubishi		1.37E+10	3.90E+10	3.12E+10	0.069
24	30-Jul	SS2	Funnel	New	Steady State	Tire	HS	Mitsubishi		2.98E+09	1.10E+10	9.21E+09	0.040
25	30-Jul	T1	Funnel	New	UDDS	Tire	HS	Mitsubishi	Dyno load change + 450 lbs	2.26E+09	6.96E+09	5.97E+09	0.040
26	16-Aug	T1	Funnel	New	UDDS	Tire	CS	Mitsubishi	Dyno load change + 450 lbs	2.09E+08	1.05E+09	3.16E+09	0.018
27	16-Aug	T2	Funnel	New	UDDS	Tire	HS	Mitsubishi	Dyno load change + 450 lbs	1.15E+09	5.83E+09	4.68E+09	0.039
28	16-Aug	T3	Funnel	New	WLTC	Tire	HS	Mitsubishi	Dyno load change + 450 lbs	1.30E+09	6.32E+09	5.11E+09	0.026
29	16-Aug	T4	Funnel	New	US06	Tire	HS	Mitsubishi	Dyno load change + 450 lbs	1.49E+10	7.52E+10	7.89E+10	0.133
30	16-Aug	T5	Funnel	New	US06	Tire	HS	Mitsubishi	Dyno load change + 450 lbs	3.08E+10	1.37E+11	1.44E+11	0.157

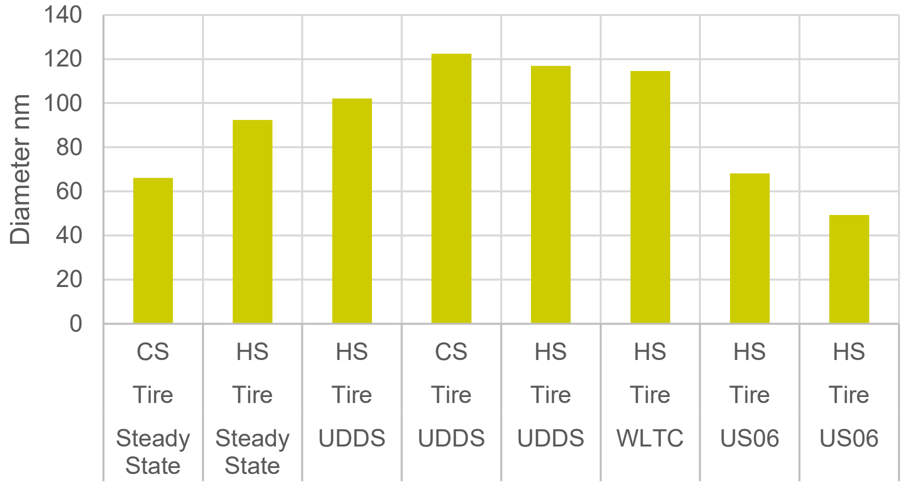
Aggregated emissions levels – Old vs New tire

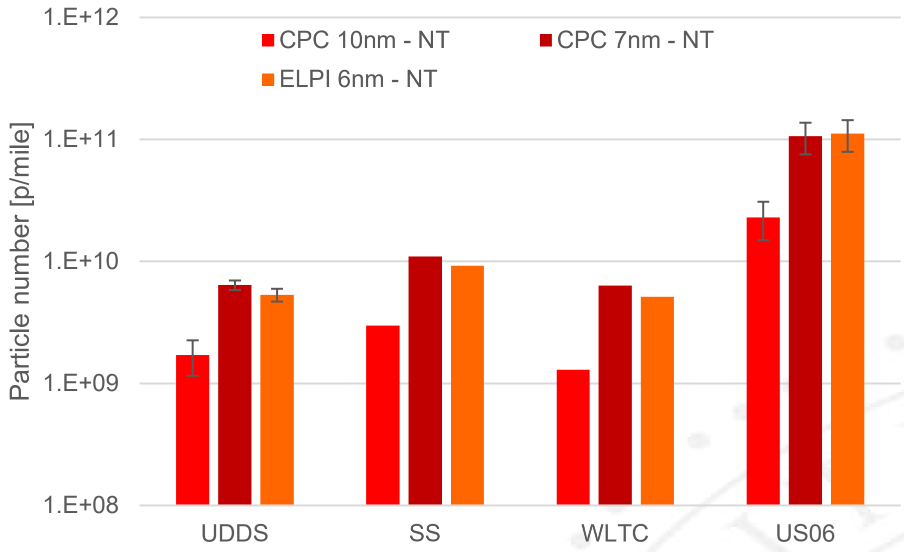




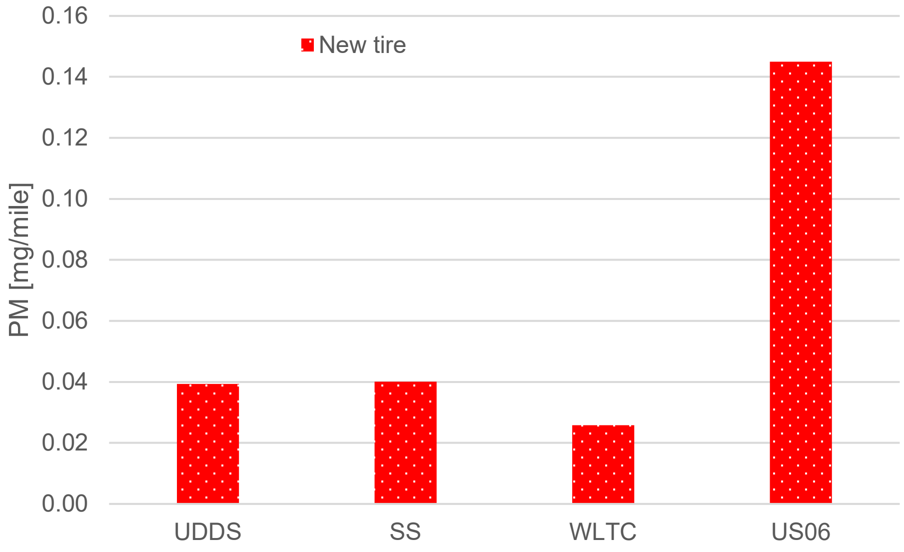
- No clear trend between old and new tire under the PN spectrum
- Higher PM emissions for the Old tire

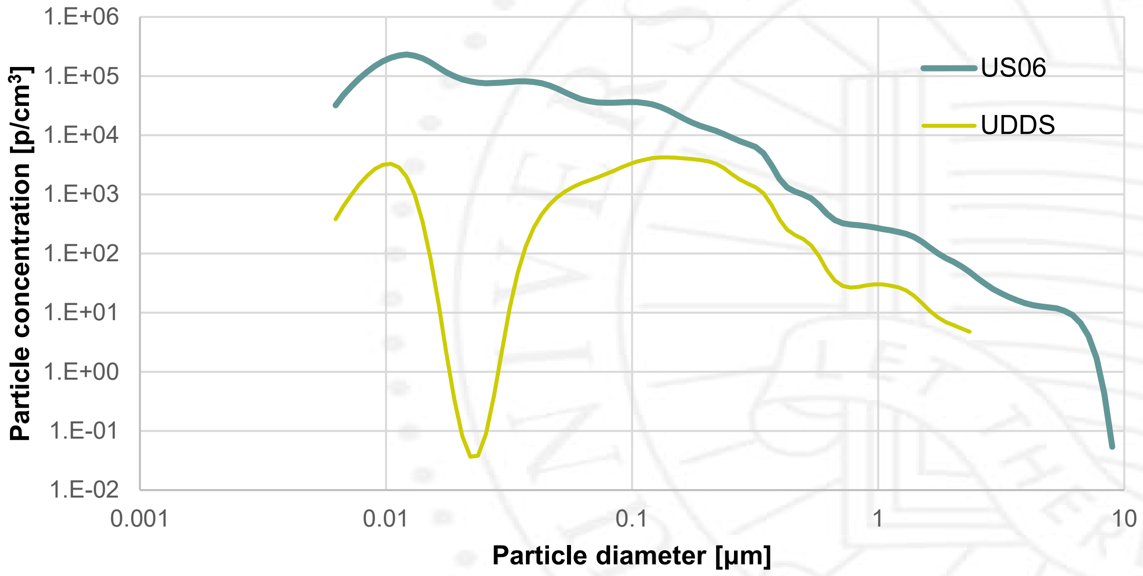
Measurement findings based on new tire



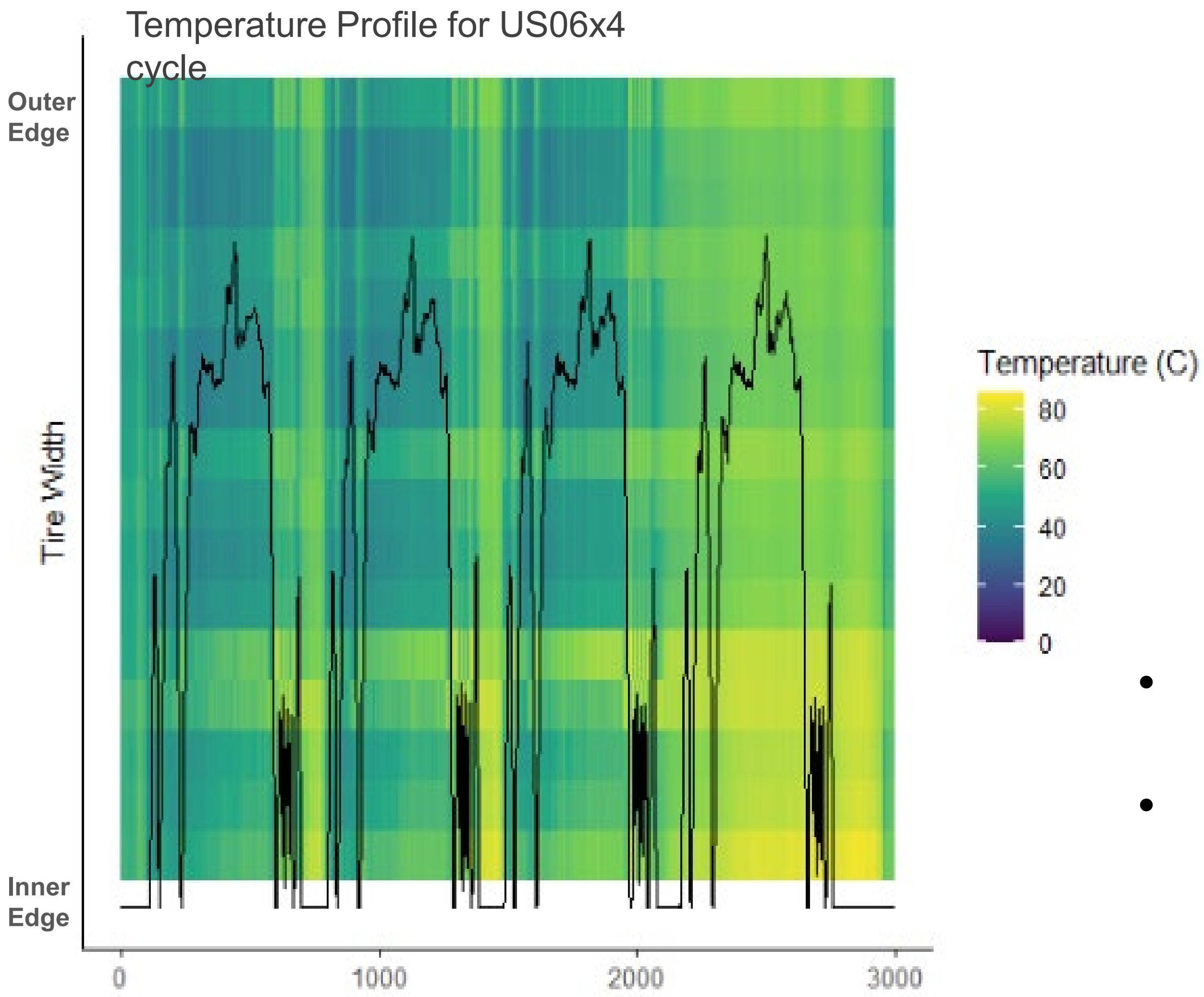


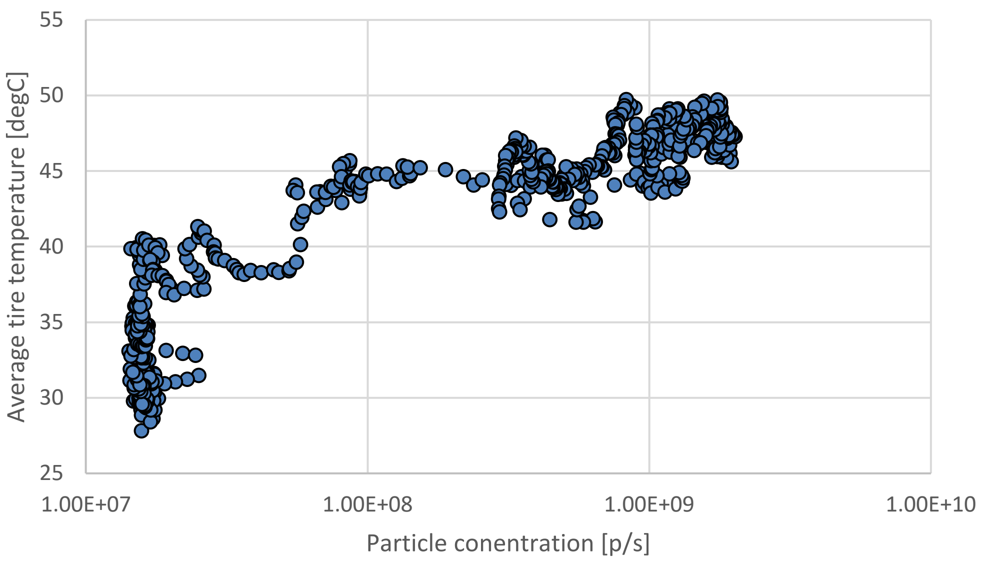
- Higher nucleation mode under US06 compared to the less aggressive UDDS
- Both high PN and PM emissions under US06





Measurement findings – effect of tire temperature





- Effect of wheel alignment on tire temperature
- 3rd dimension of braking power metrics will be required

Chassis Testing – Various Tire Pressures & Dyno Loads

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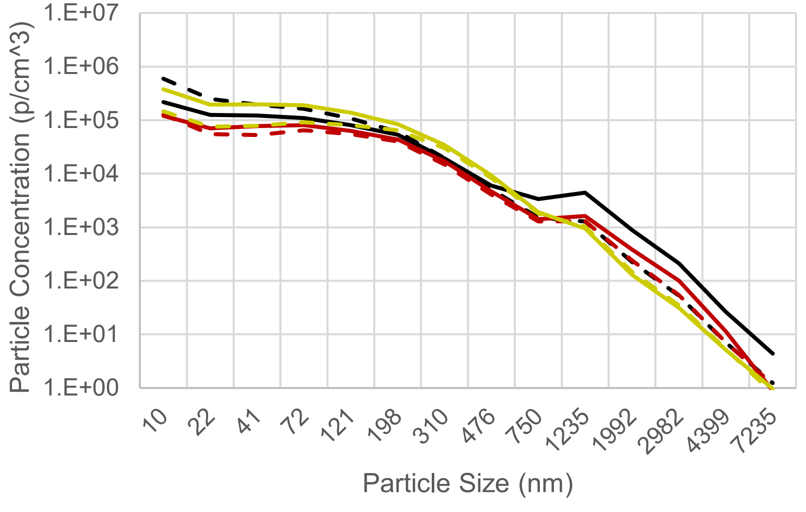
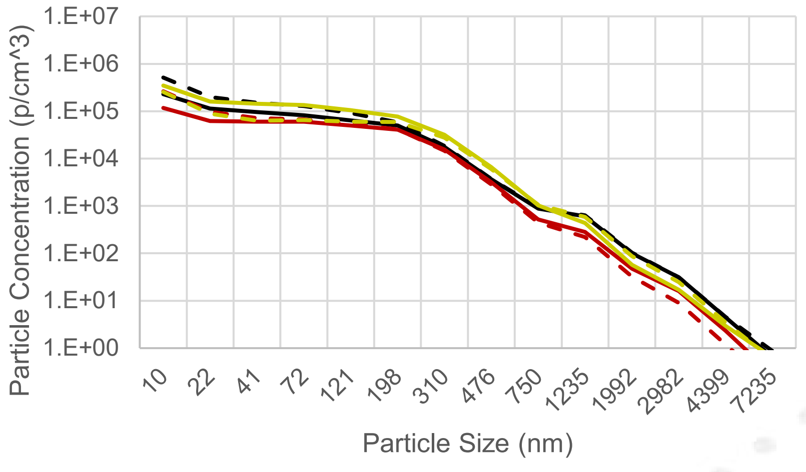
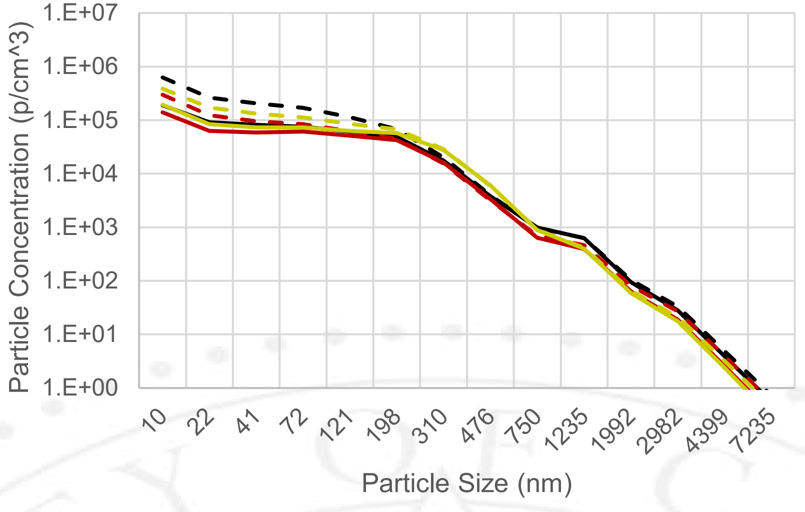
Speed <= 20mph; Temperature <= 50C



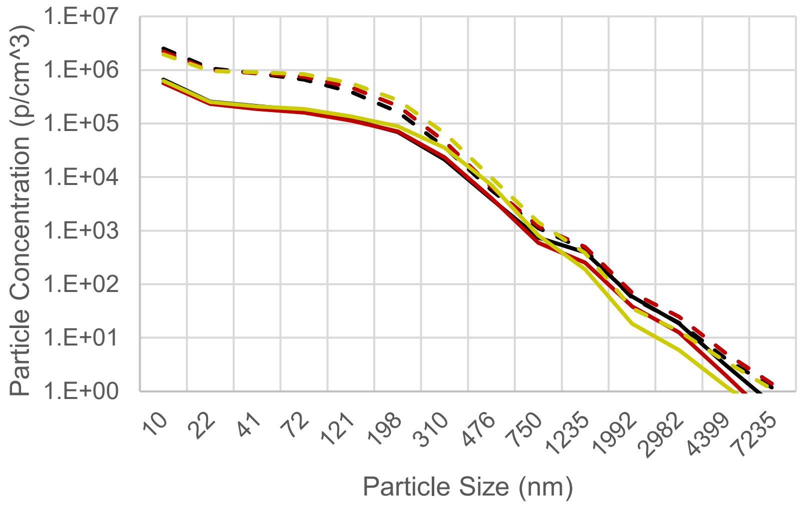
20mph < Speed <= 40mph; Temperature <= 50C



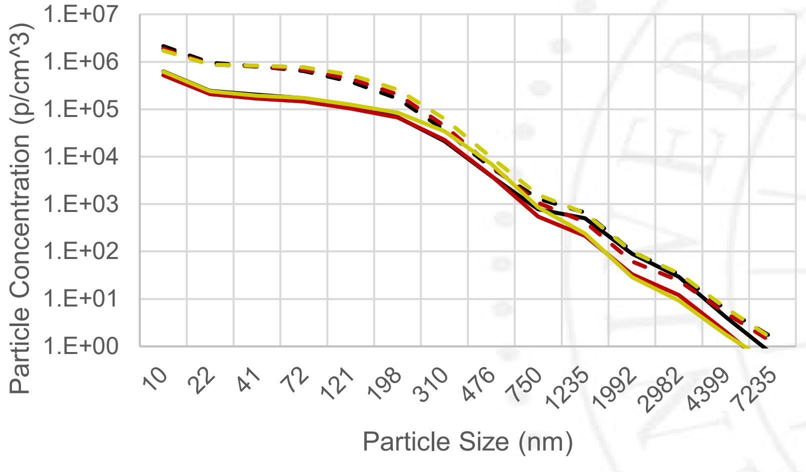
Speed > 40mph; Temperature <= 50C



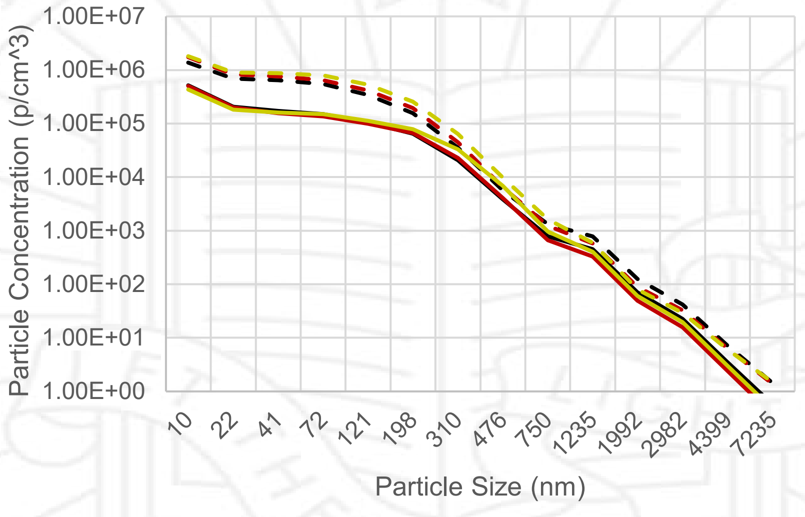
Speed <= 20mph; Temperature > 50C



20mph < Speed <= 40mph; Temperature > 50C



Speed > 40mph; Temperature > 50C



*Acceleration Events Only

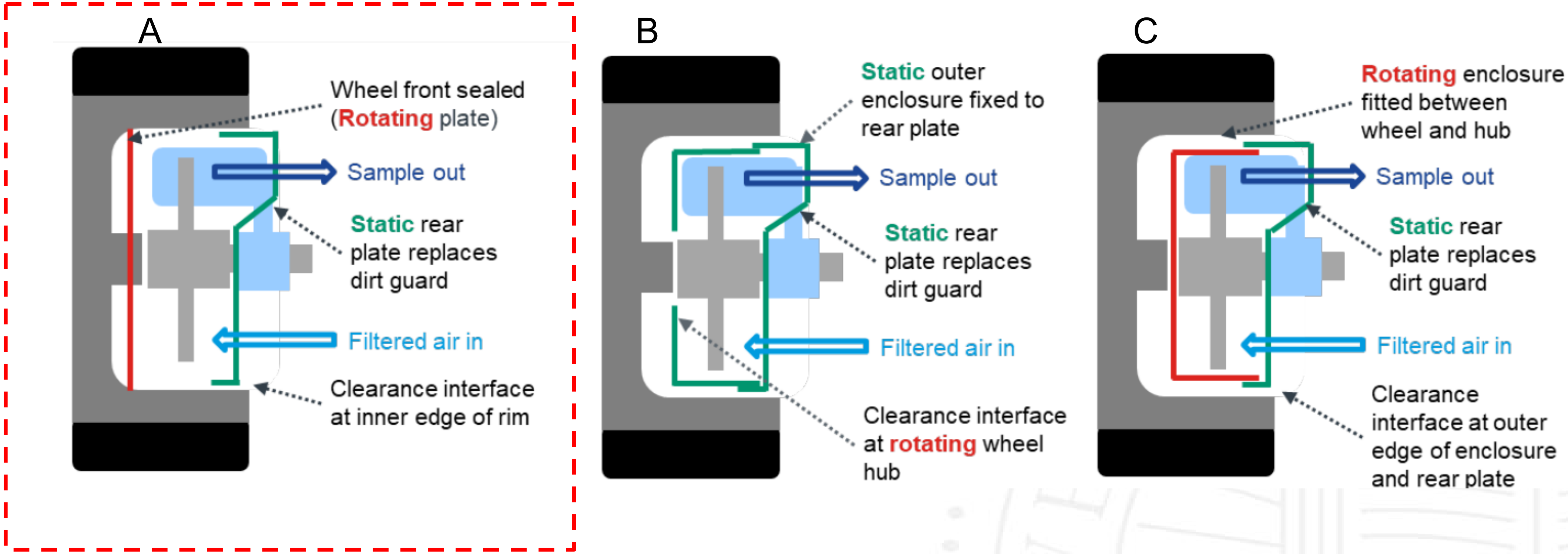
N_35psi N_44psi N_26psi H_35psi H_44psi H_26psi

N= dyno load 2750 lbs H=dyno load 3750 lbs

Final version of the brake and tire sampling system / sampling tunnel

Design approach and fabrication

UCR design approach

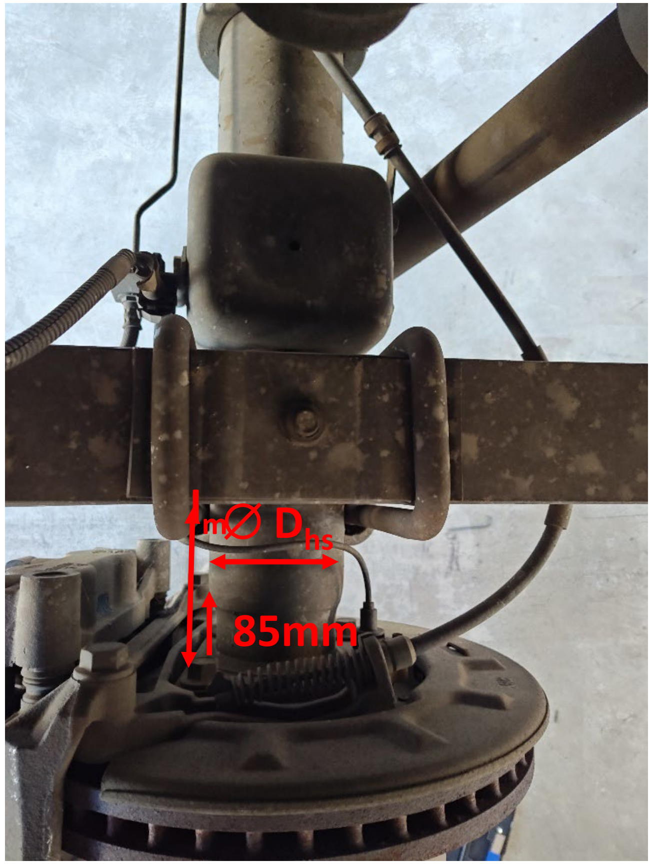


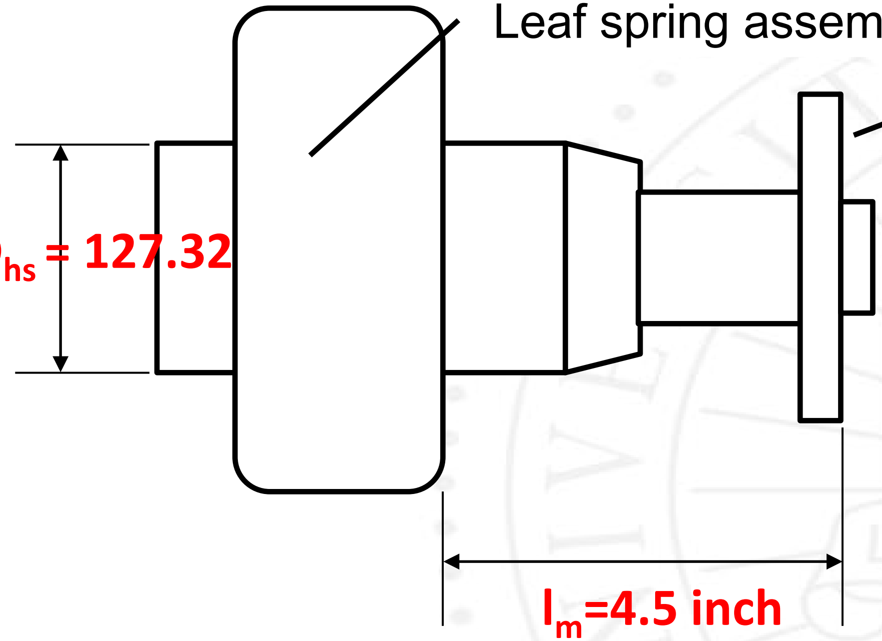
- Option A allow for a higher enclosure volume with less risk of contact between rotating and stationary parts

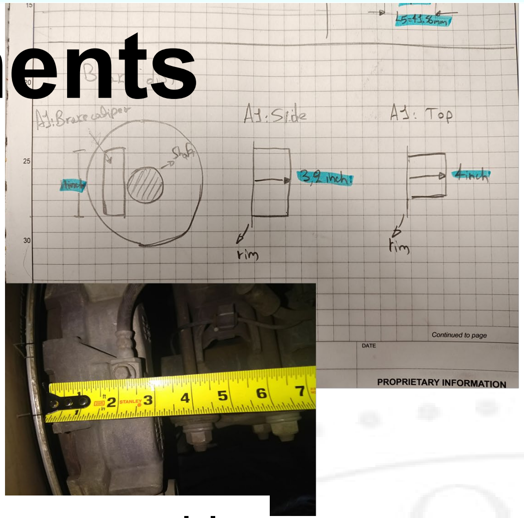
Initial steps – dimensions measurements

Spindle mounting dimensions

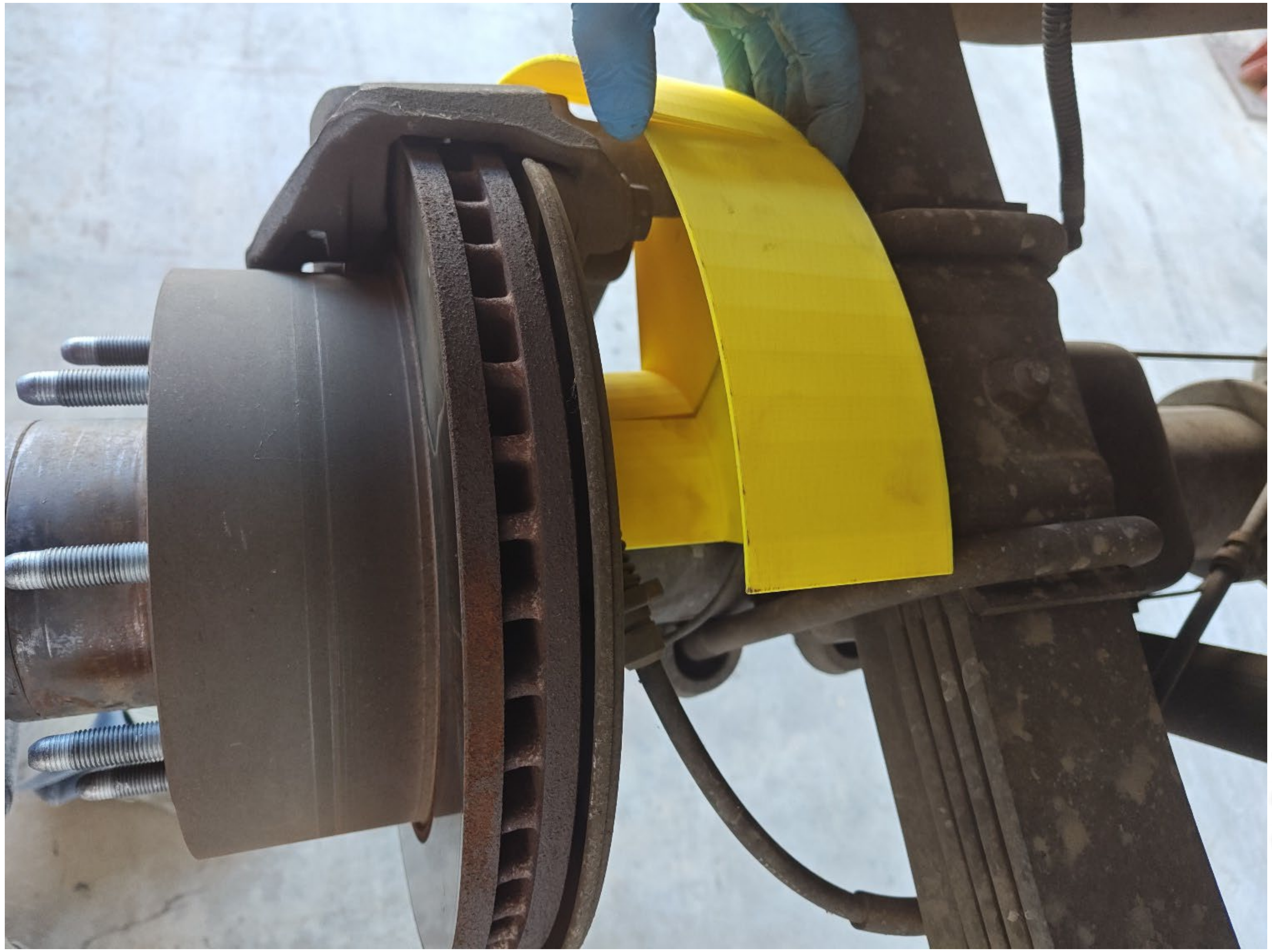
D_a = axle diameter
l_m = length from spring assembly to disc mounting face



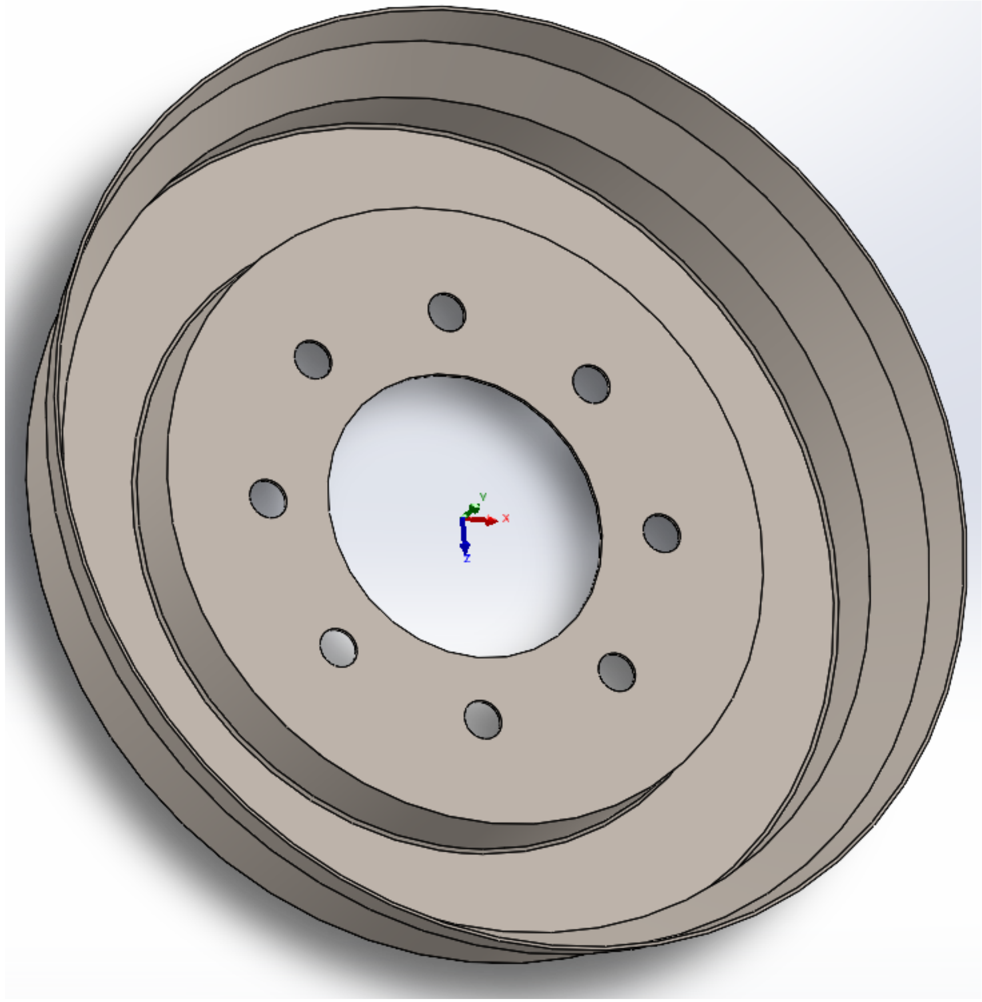


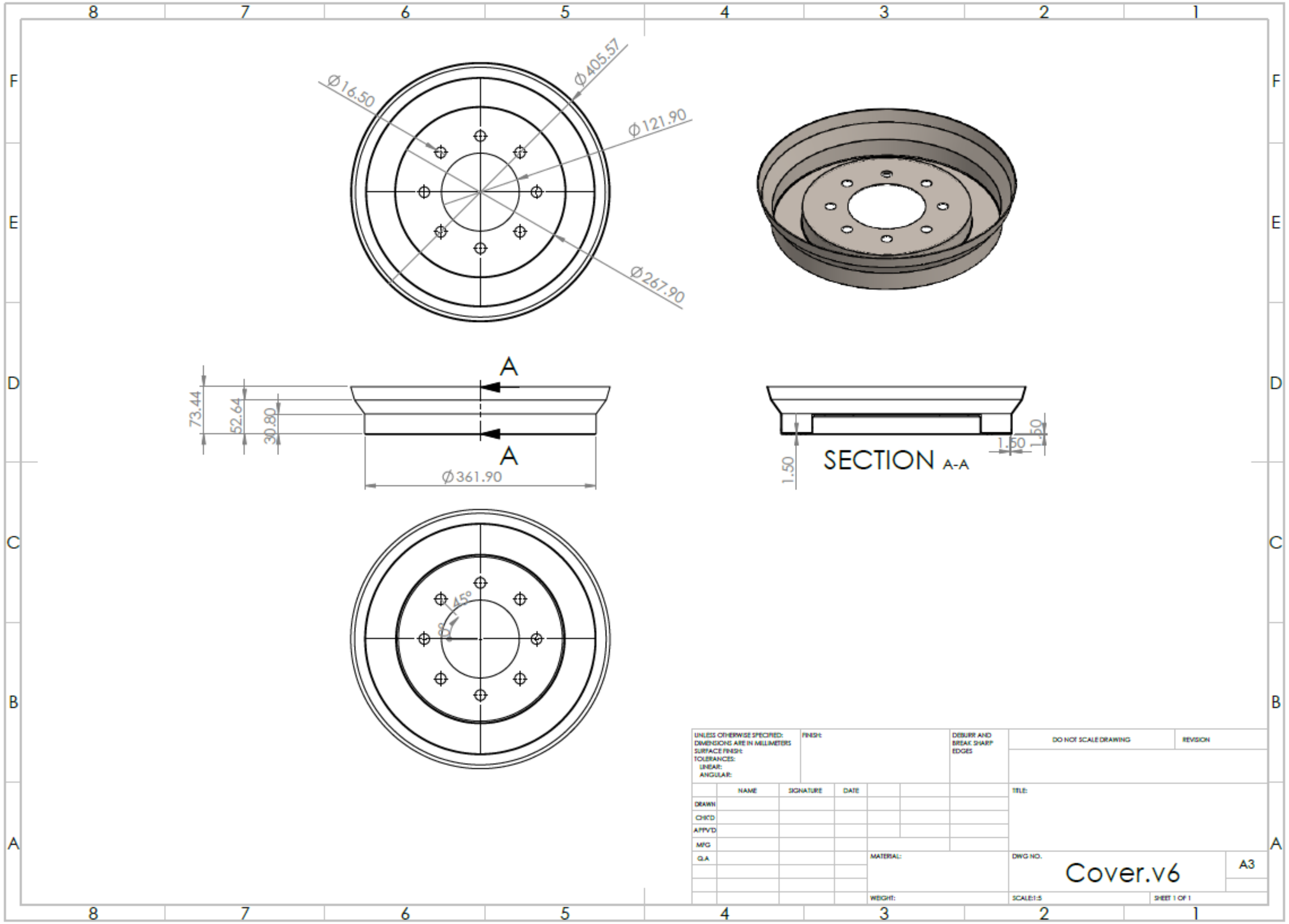


Initial steps – dimensions measurements

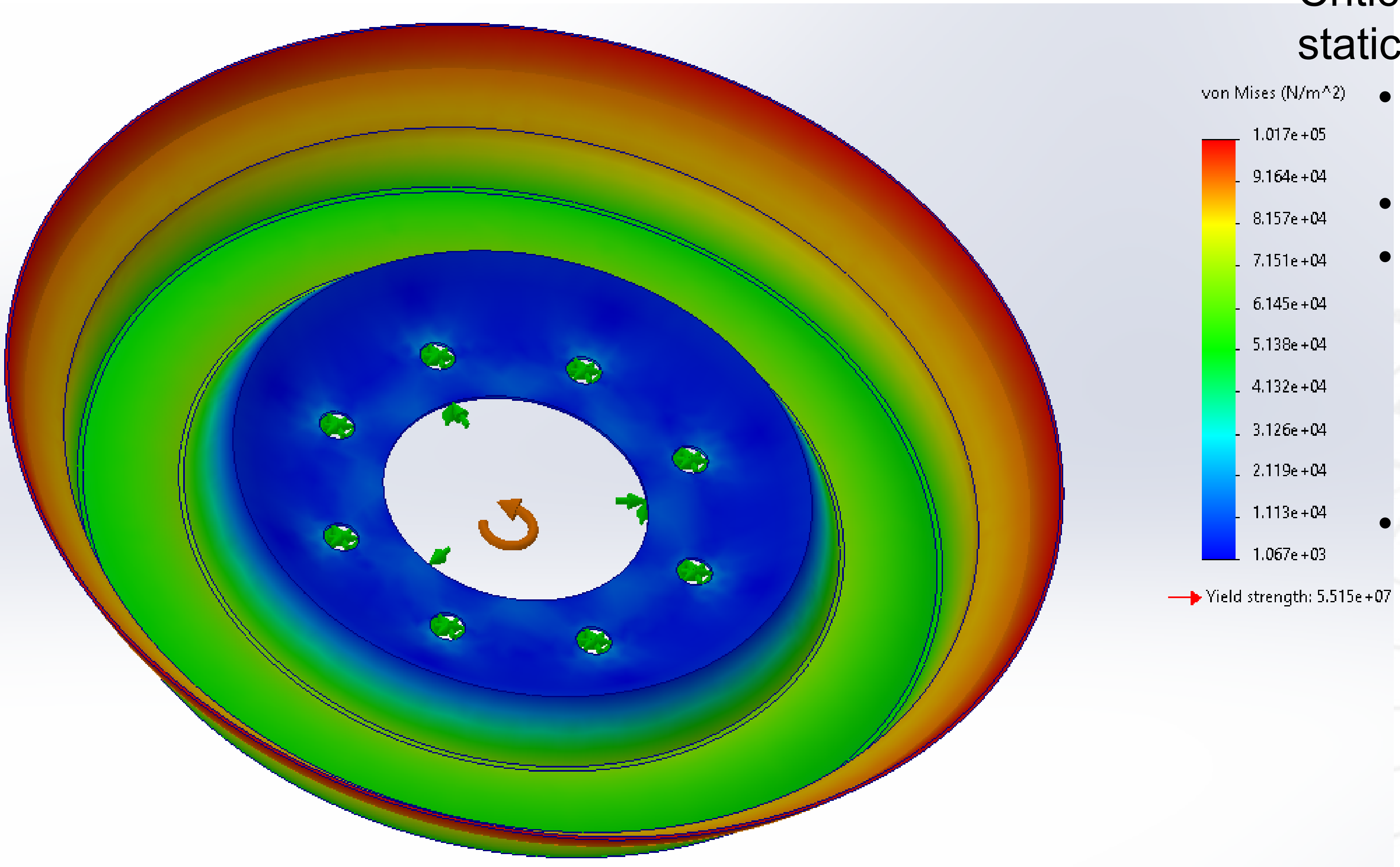


Final version of the brake sampling system – Outer plate





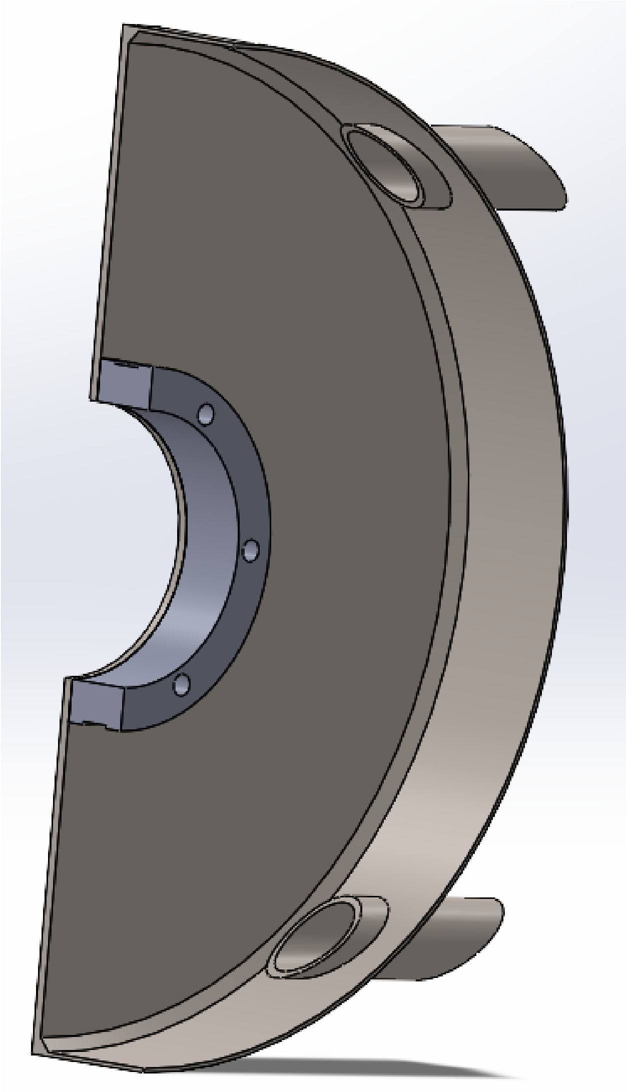
Final version of the brake sampling system - Safety

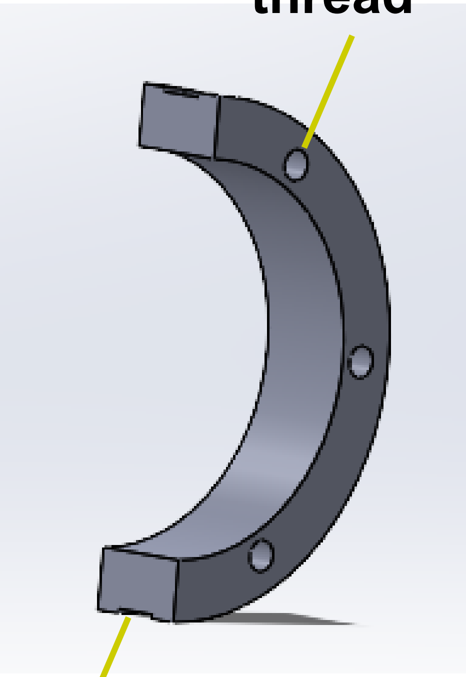


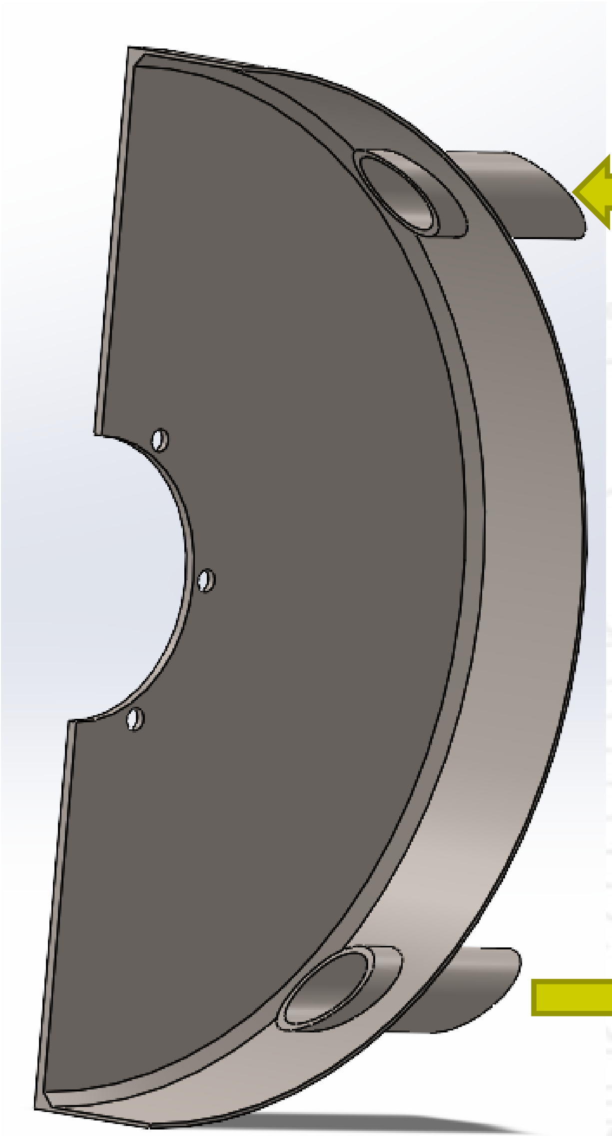
Critical components were simulated for static loading stress

- Simulation under rotational speed at 30 m/s (~60 mph)
- Von Mises stress of 101.7 kPa
- Yield strength of aluminum: Common aluminum alloys have a yield strength ranging from 30 MPa to 500 MPa (3×10^7 N/m2 to 5×10^8 N/2)
- Not high and would not cause yielding or significant deformation in 1.5 mm thick aluminum under normal conditions

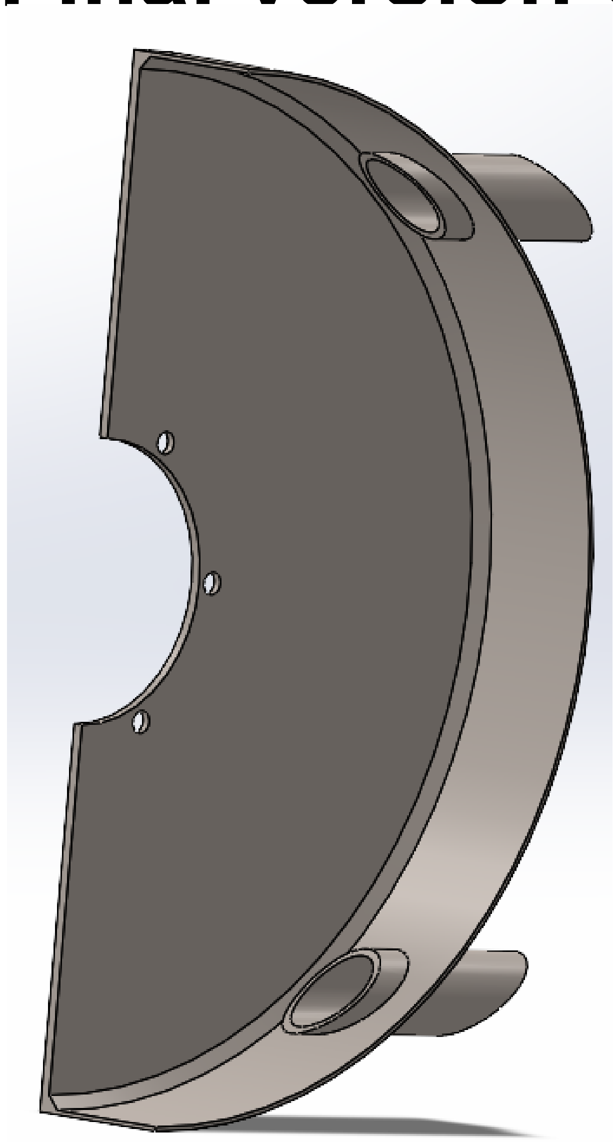
Final version of the brake sampling system – Inner plate

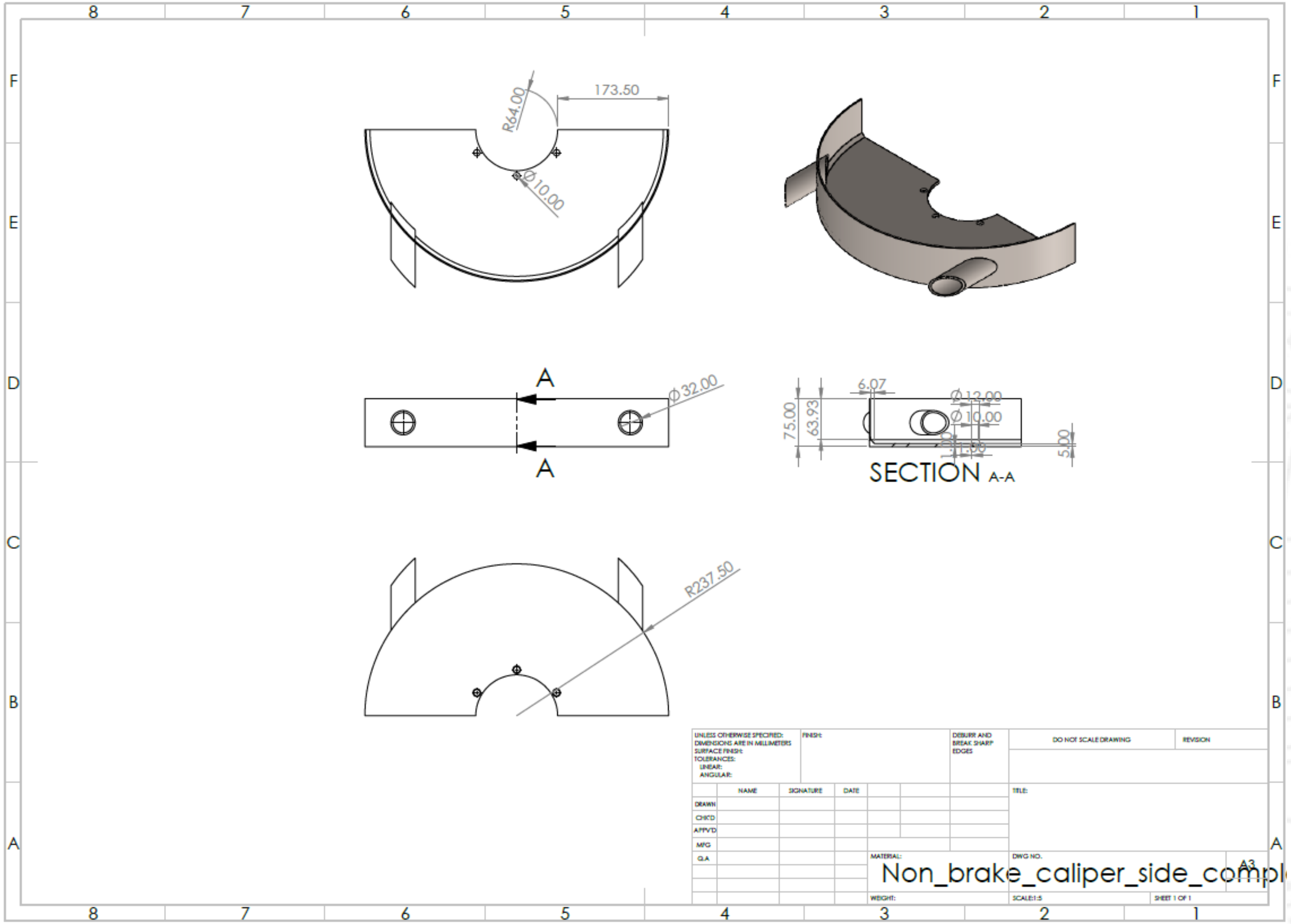




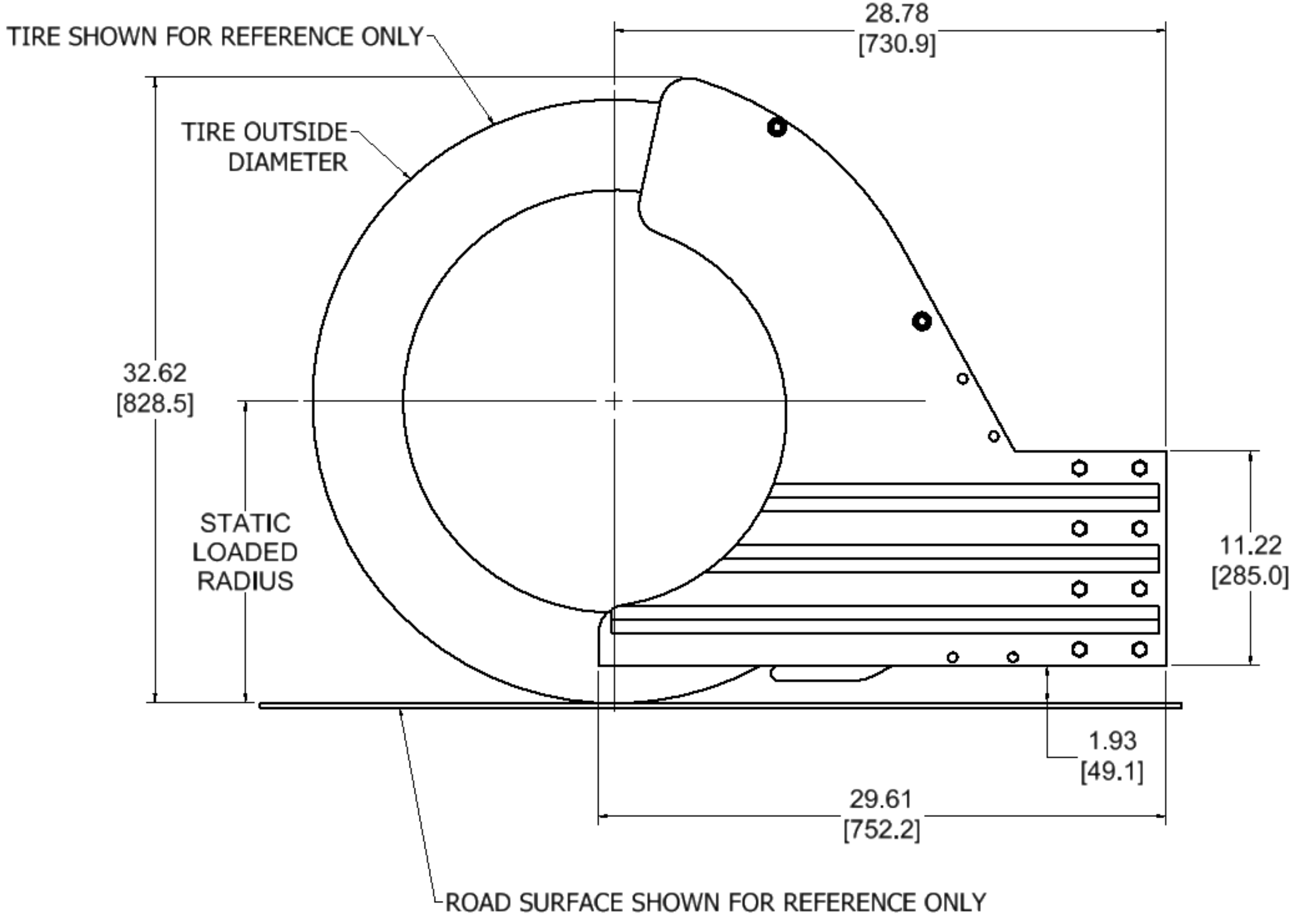


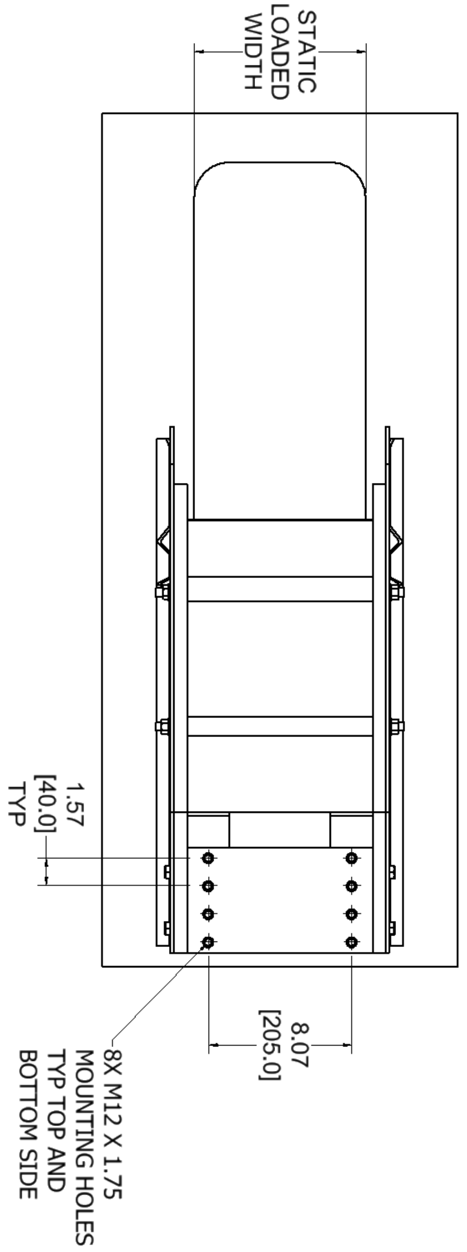
Final version of the brake sampling system – Inner plate



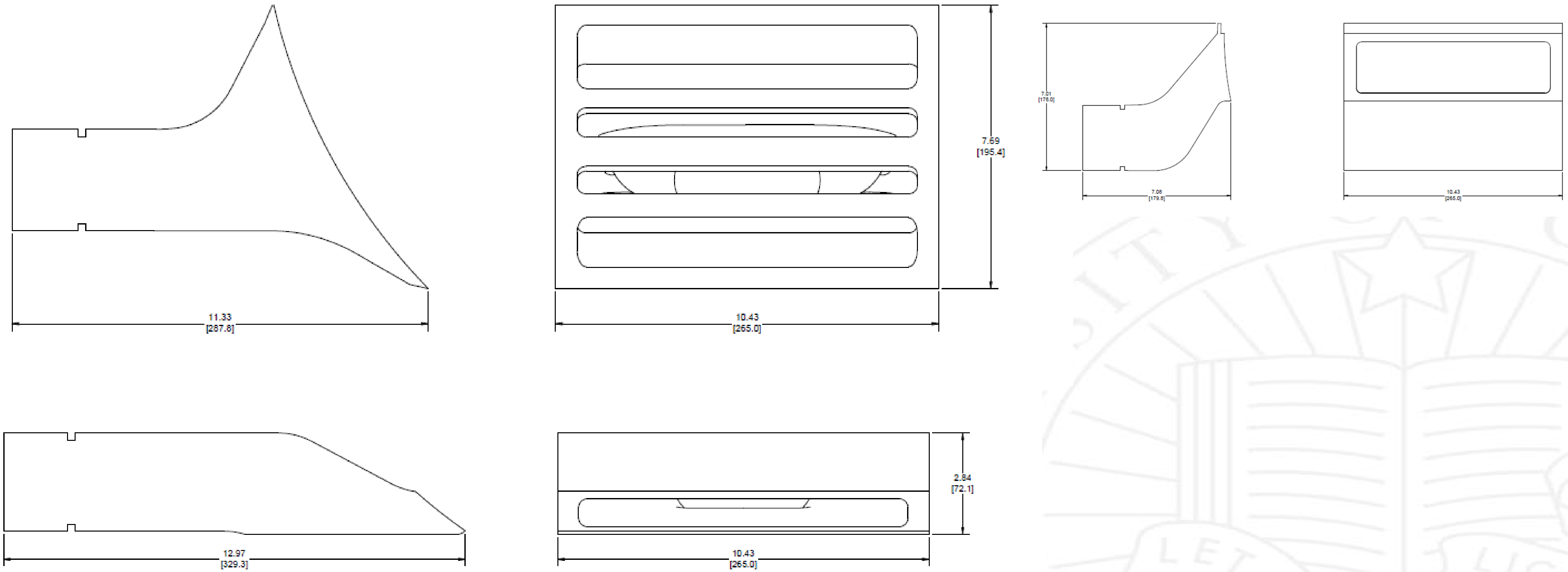


Tire sampling system – general overview

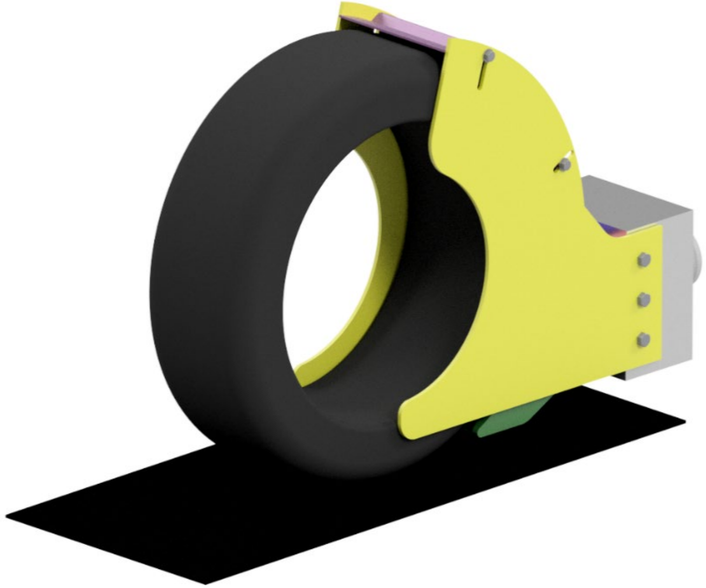


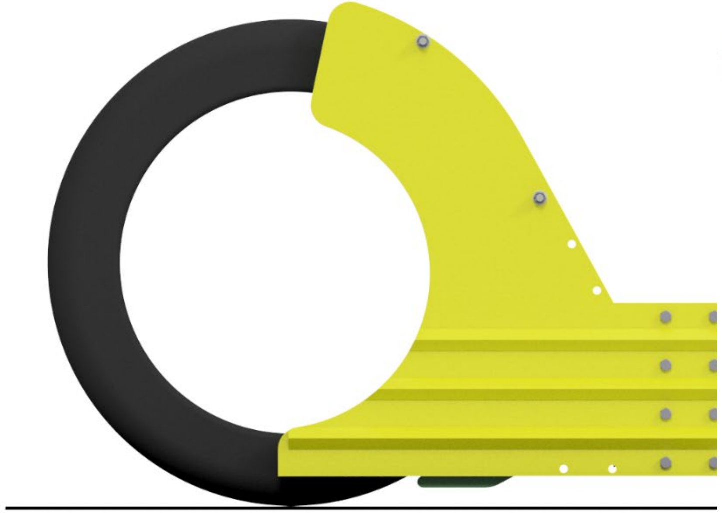


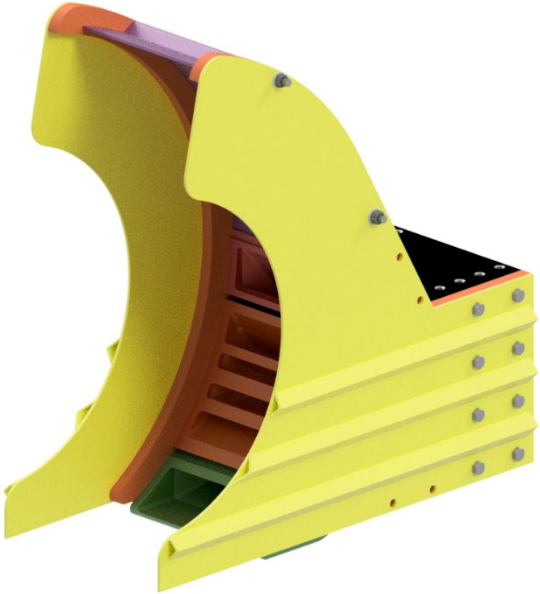
Tire sampling system – nozzle design



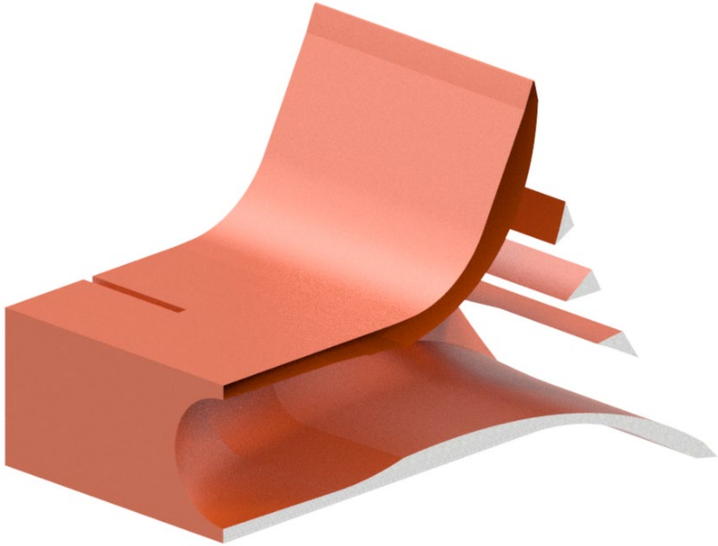
Tire sampling system – nozzle design

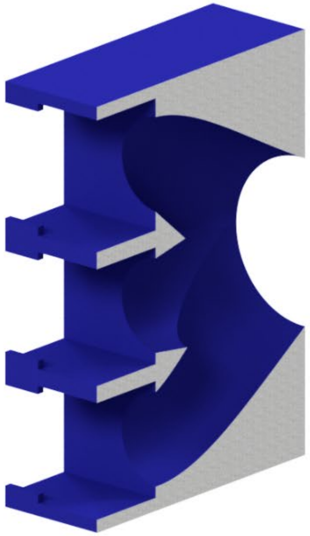


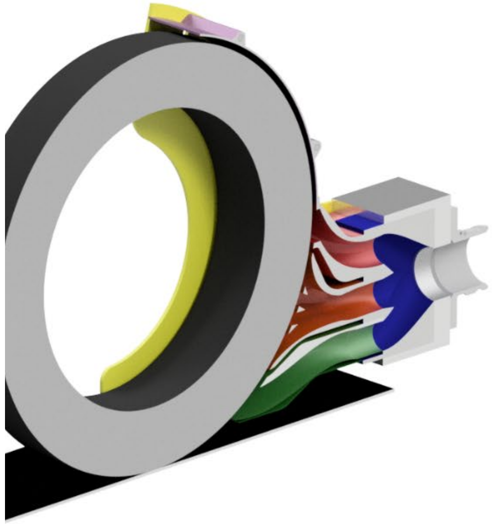




Tire sampling system – nozzle design



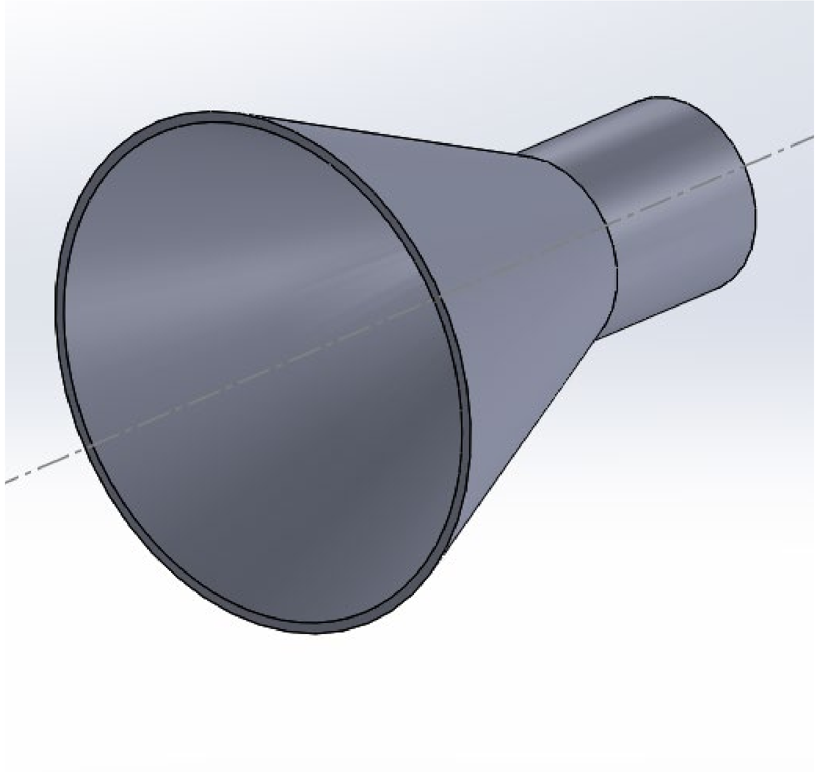


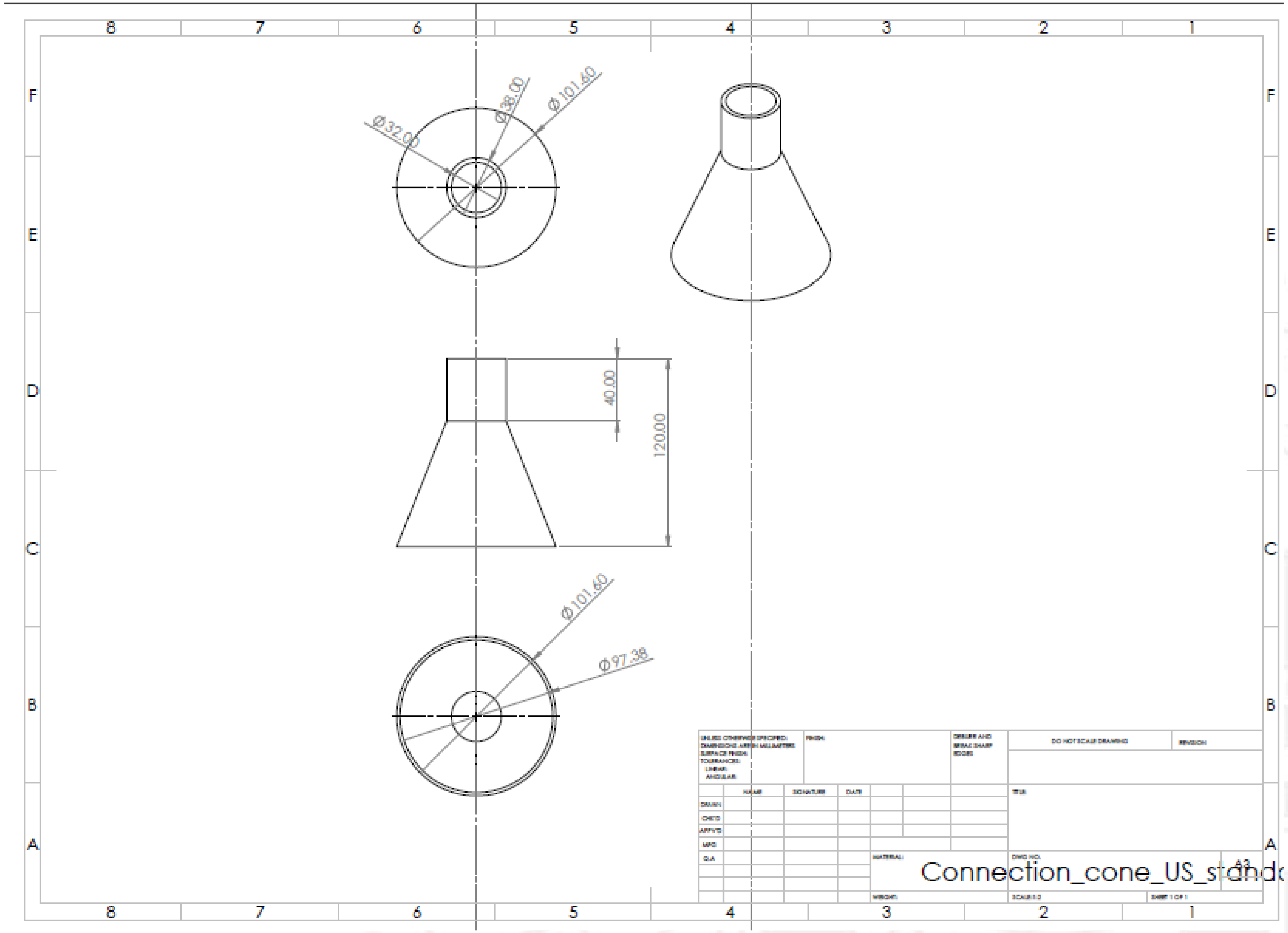


- Nozzle B

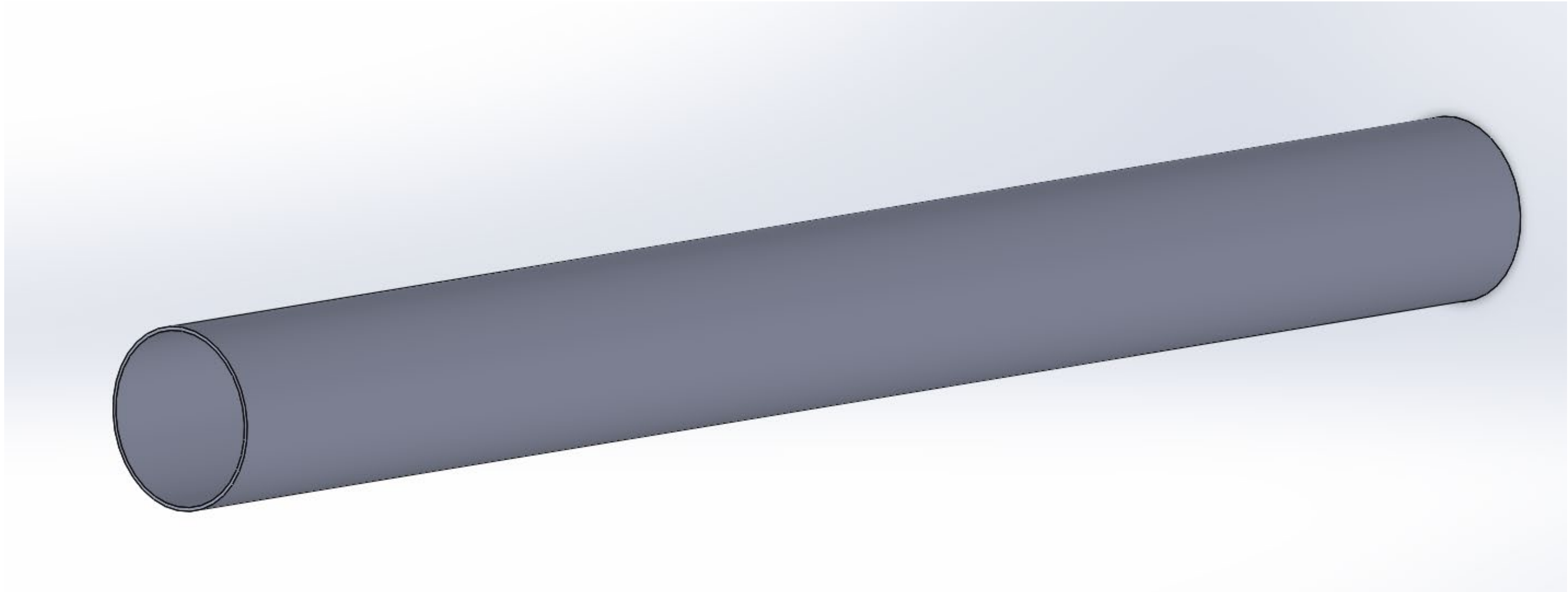
- Merging block

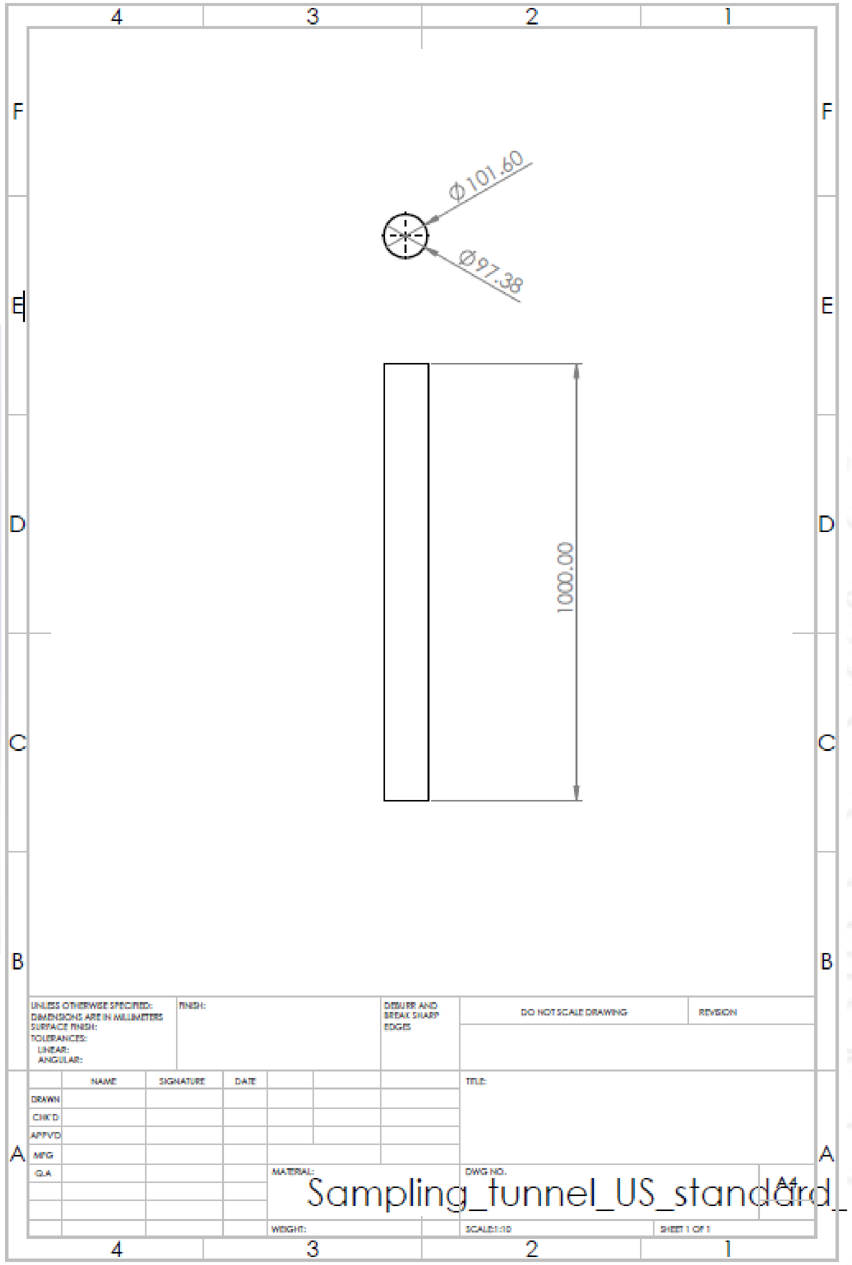
Final version of the sampling tunnel



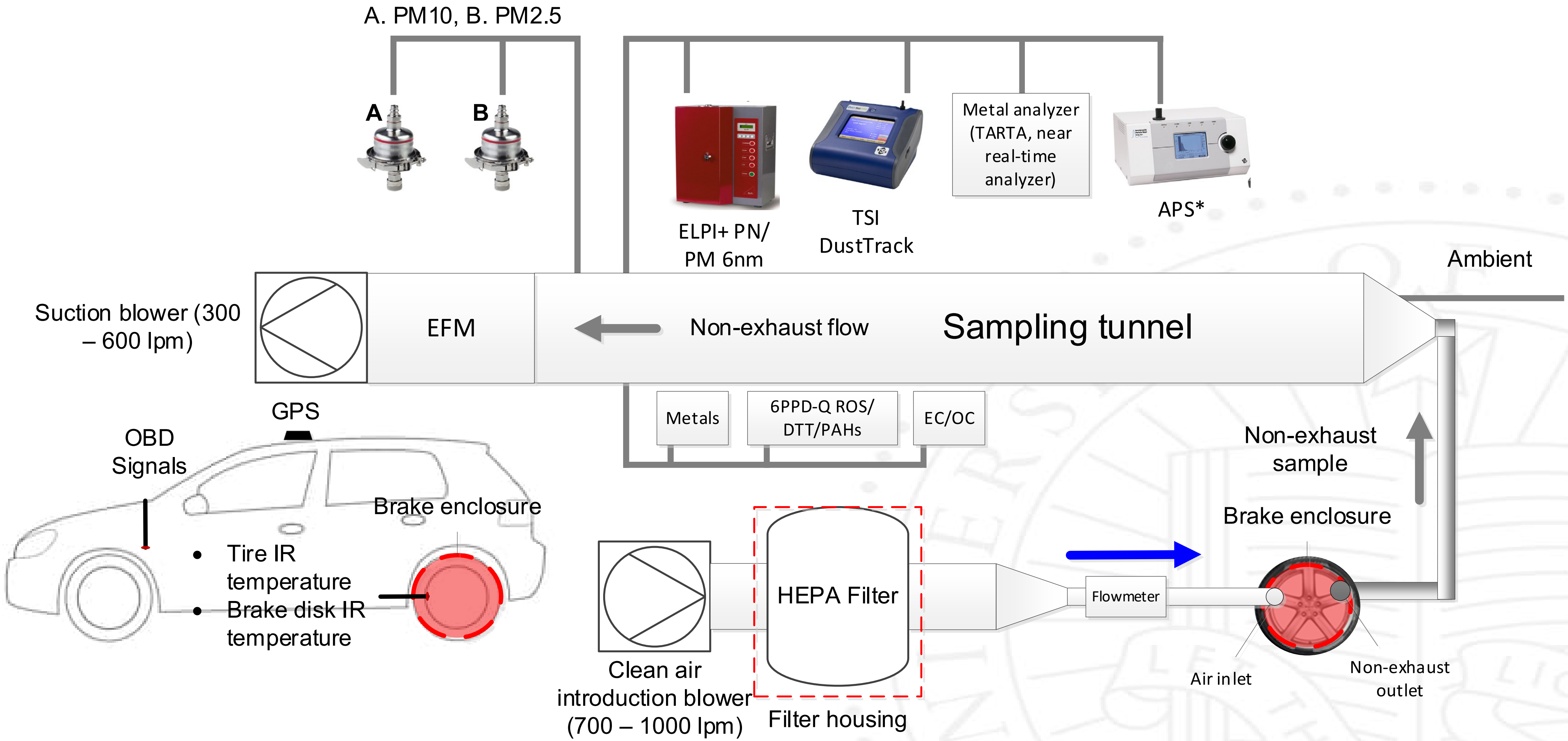


Final version of the sampling tunnel



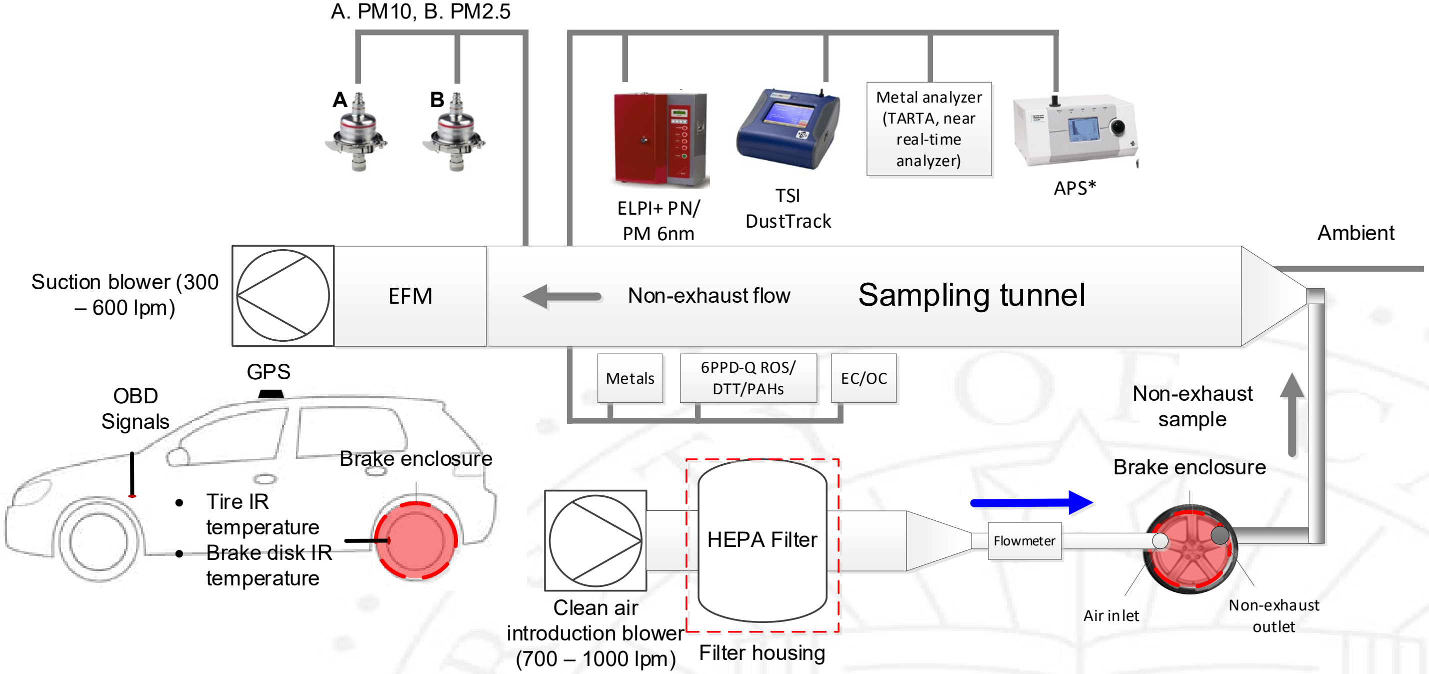


Final version of the sampling system – Brake Particles



Sampling system – brake enclosure

System layout

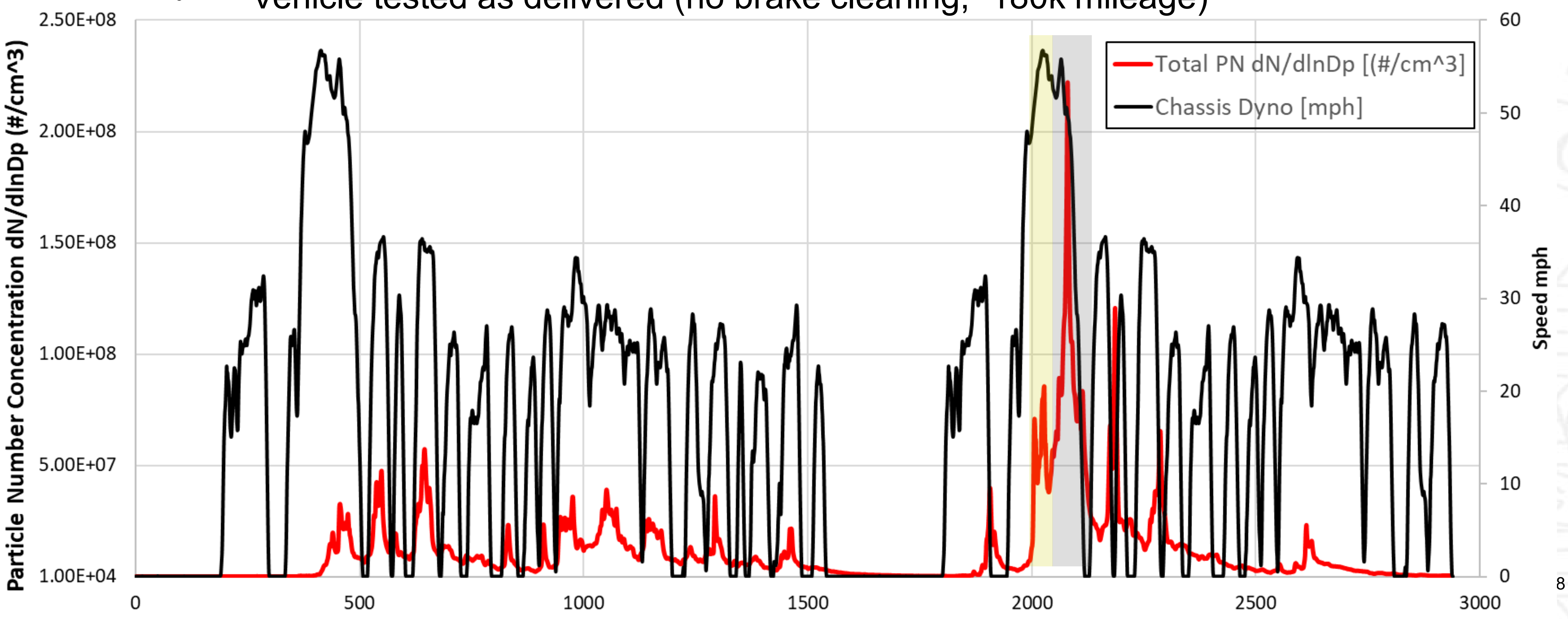


- System is under evaluation during pilot testing
  - Temperature difference between tested and non-tested wheel
  - Response time

Brake enclosure emissions

Two PN/PM generation mechanisms are existing

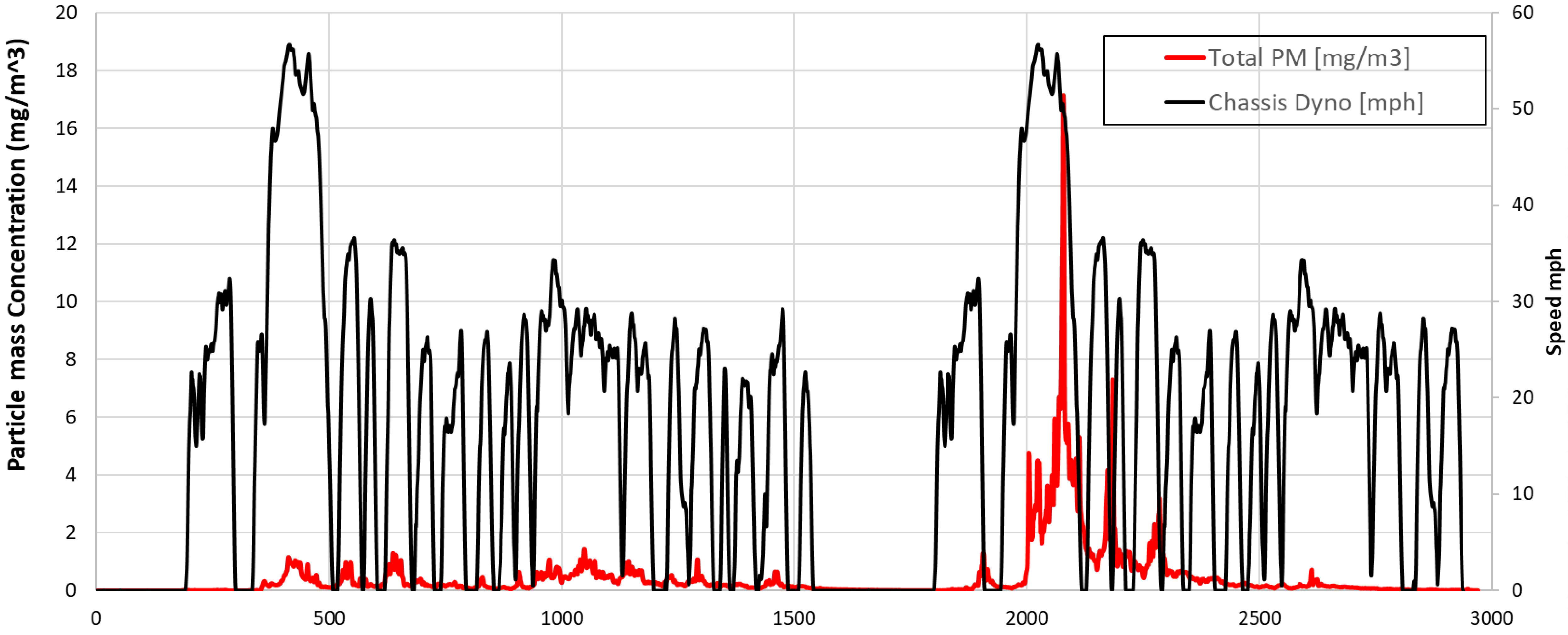
- Mixing of aged and fresh-formed particles during acceleration
- Fres-formed particles during braking
- Vehicle tested as delivered (no brake cleaning,~180k mileage)



Brake enclosure emissions

Two PN/PM generation mechanisms are existing

- High PM concentration during high-speed braking under higher temperature conditions



Sampling system

Background on brake and tire emissions and objectives

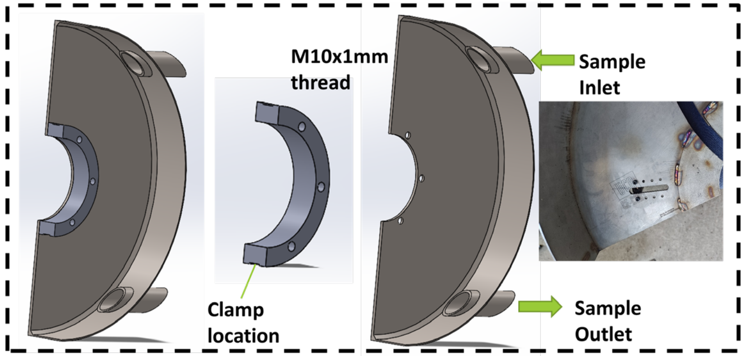
- Significant contribution of brake wear and tire wear to total particulate emission performance, enhanced by the substantial reduction of tailpipe exhaust due to advancements in combustion technologies.
- UCR developed a brake and tire sampling system to investigate the brake-wear and wheel-wear performance under different test routes, driving dynamics and different brake/tire technologies.

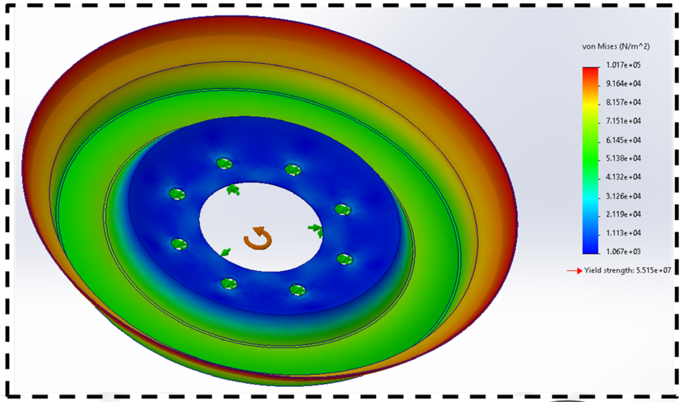
Brakes and Tire sampling methodology

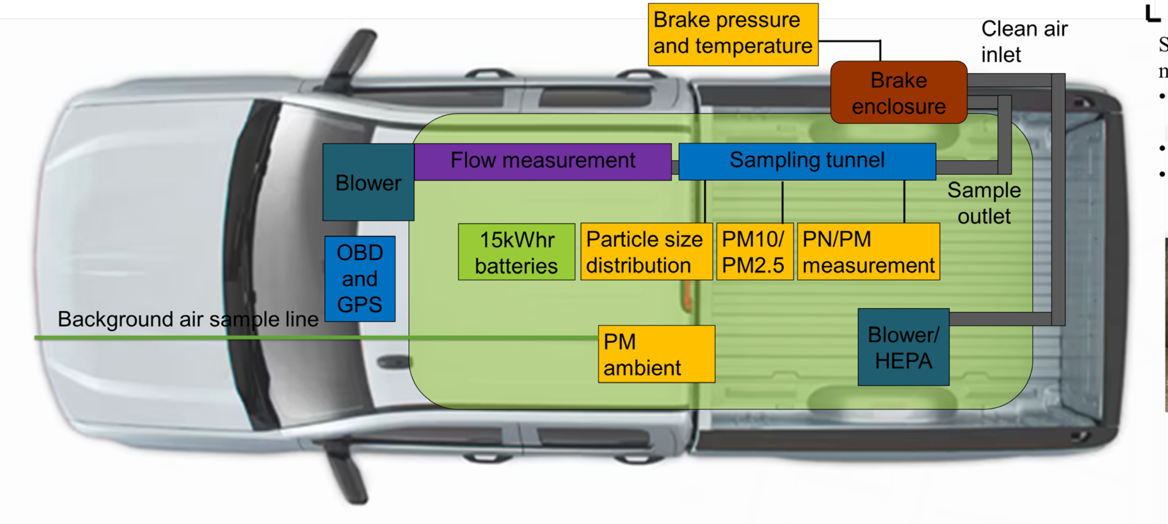
- ○ Full-enclosed brake system developed with inlet and outlet ports for clean air introduction and sampling, respectively.
- ○ Tire semi-enclosed system to cover almost half of tire size. Tire sampling system designed for 245/75R17 tires.
- ○ Sampling flows are on the order of 300-600 Lpm, and clean air introduction is in the range of 700-1000 Lpm
- ○ Brake disk temperature and brake pressure sensors are installed to characterize brake operation with brake-wear and wheel-wear performance.

Emission findings based on pilot testing

- ○ Two PN/PM generation mechanisms exist
- ○ Mixing of aged and fresh-formed particles during acceleration
- ○ Fresh-formed particles during braking
- ○ Vehicle tested as delivered (no brake cleaning,~180k mileage)
- ○ Specific tires seem to have a temperature threshold where potentially higher particle volatility and hence particle emissions are detected

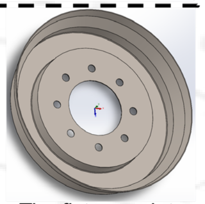




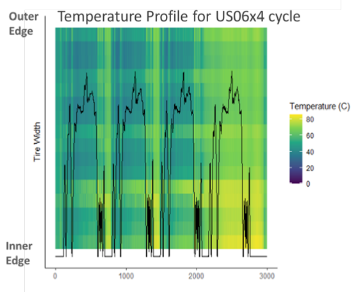


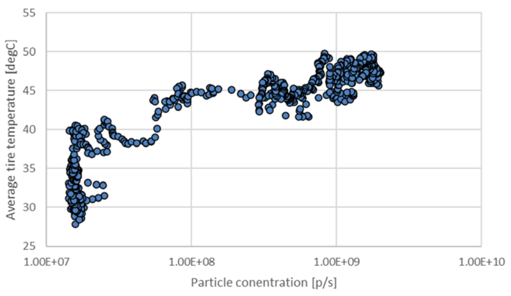
Sampling flow regulated with a blower and measured with flow meter

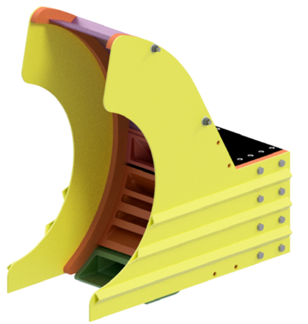
- Instrumentation for PM, PN, and size distribution, including PM10 and PM2.5 filters
- Measurement of ambient PM (background)
- Temperature infrared sensor measurement on the brake disc and tires

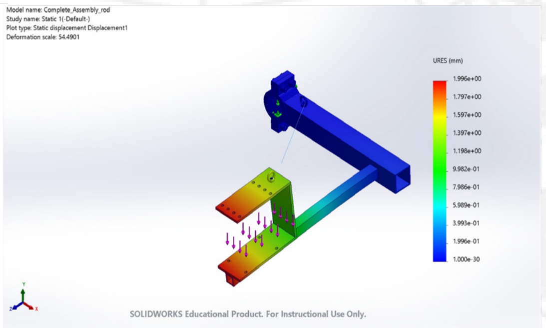


Tire fixture point









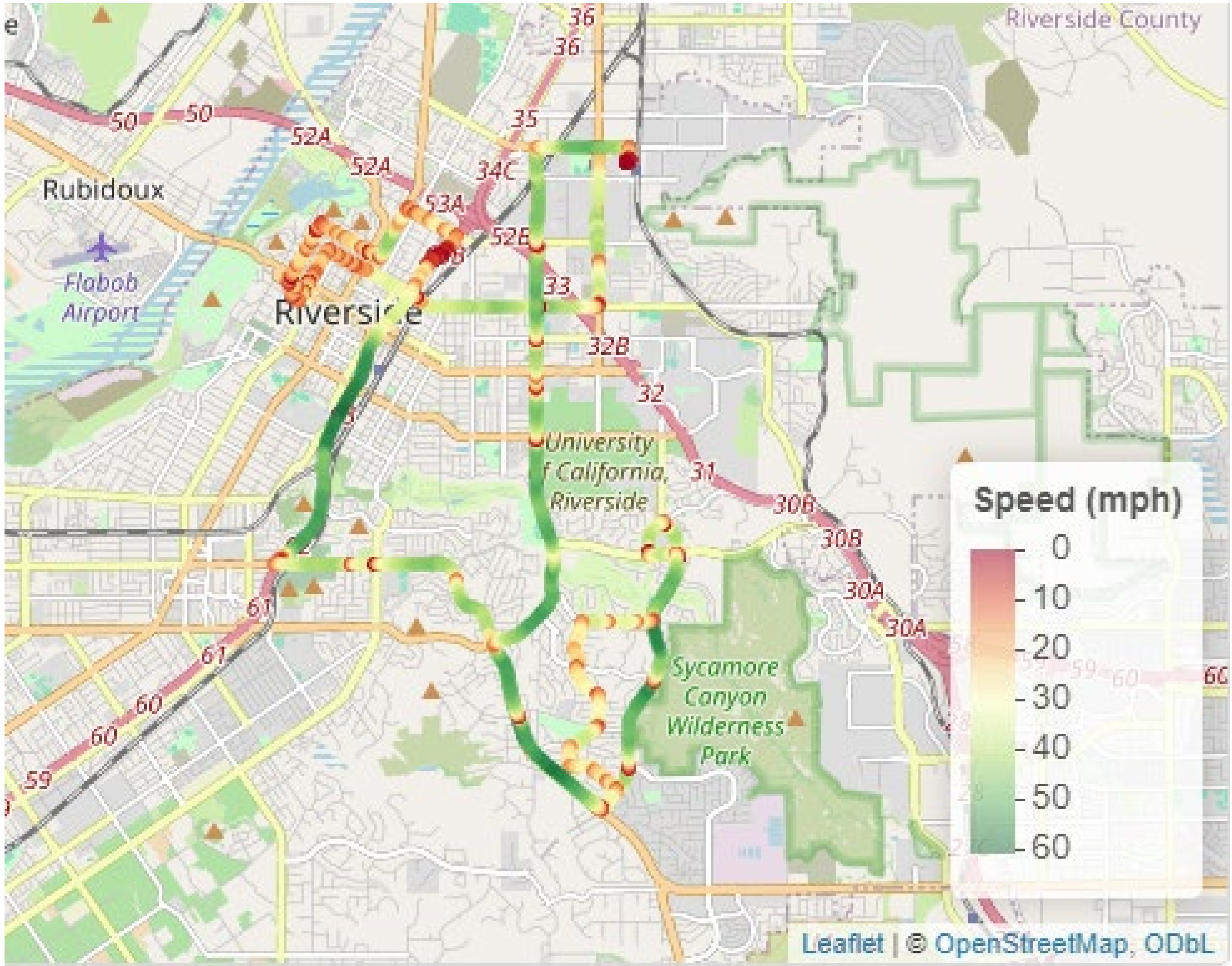
On-road brake emissions

Results

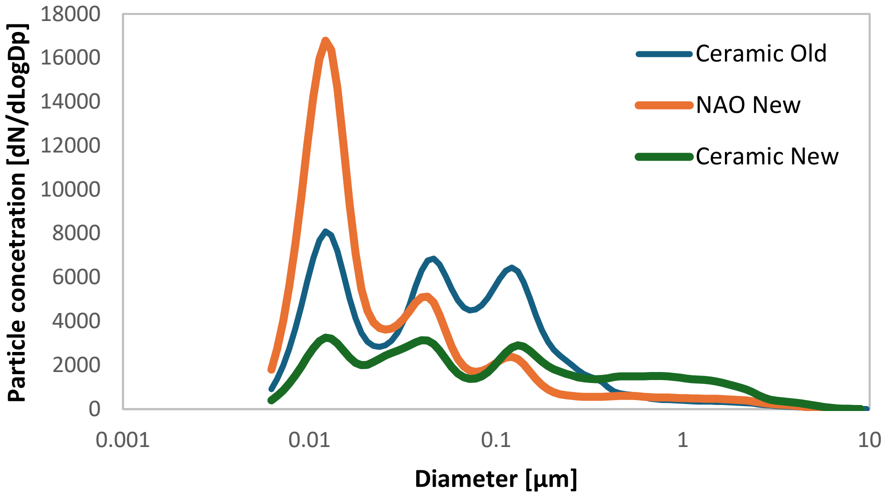
UNIVERSITY OF CALIFORNIA, RIVERSIDE

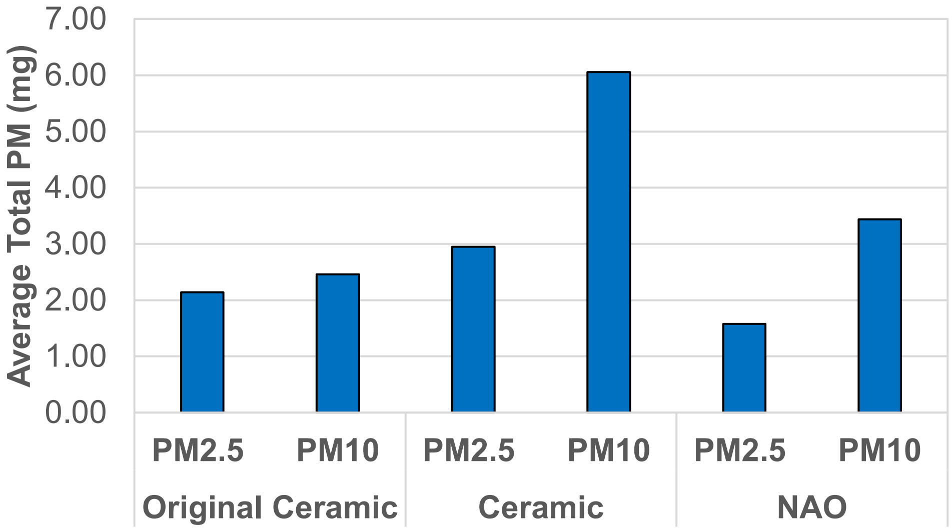
Test route

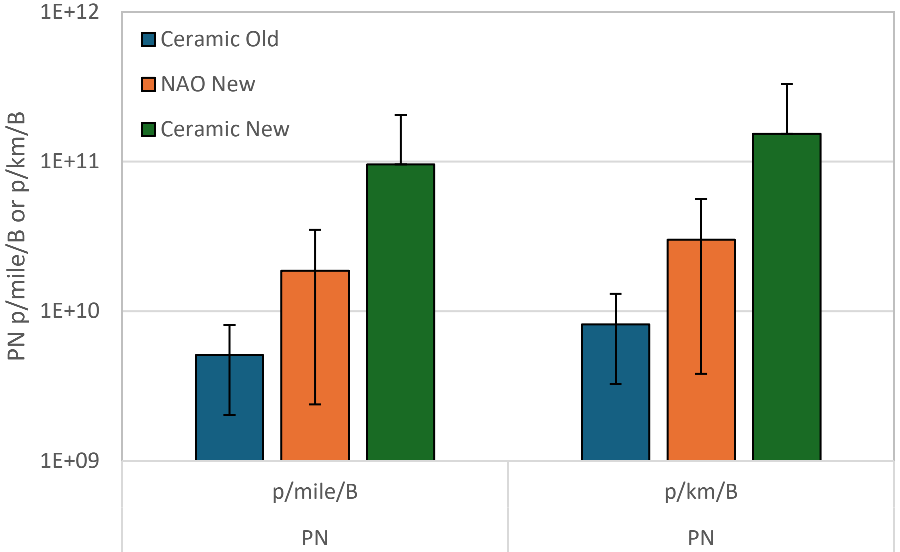
- Speed: 0-60mph
- Elevation: 254 – 468m
- Test Duration: 65 -80 minutes
- Distance: ~25miles

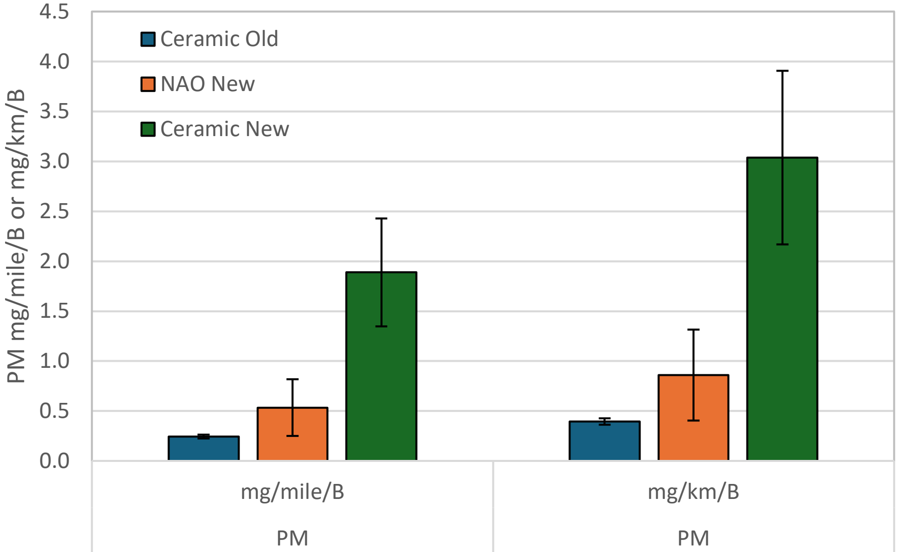


Aggregated results

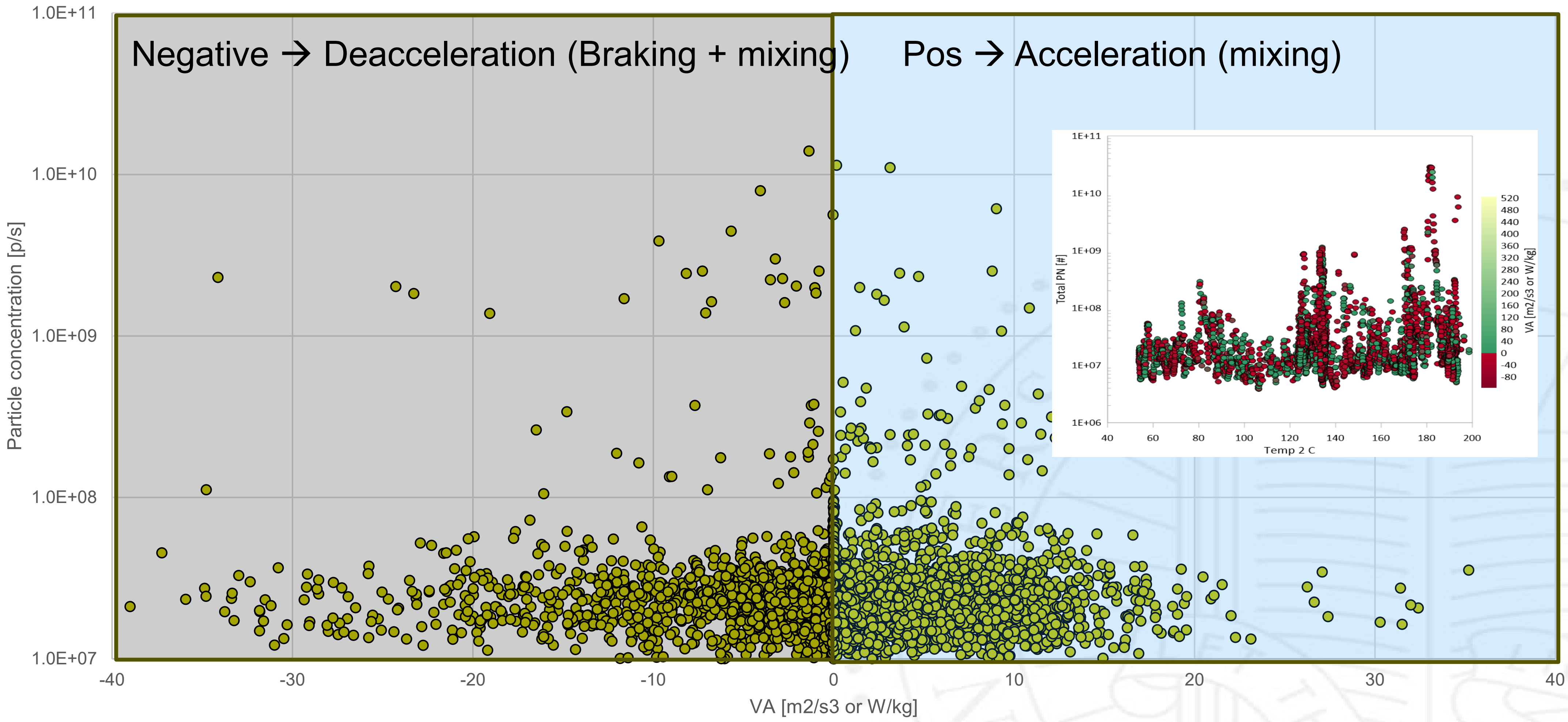








PM/PN generation mechanism



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Special Issue

Brake and Tire Non-Exhaust Emissions and Air Pollution

Guest Editor

Dr. Zisimos Toumasatos

Deadline

31 July 2025

atmosphere

IMPACT FACTOR 2.5

CITESCORE 4.6

Danke Merci Grazie Gracias

Ευχαριστώ תודה. Hvala

Dziękuję 謝謝

Thank you

감사합니다 ありがとう

اُيا Спасибо Хвала děkuji

Takk Kiitos Tänan Dank U

Mulţumesc