First results of vehicle technology effects on sub-23nm exhaust particle number emissions using the DownTo10 sampling and measurement system

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Sub-23nm PN vehicle technology effects using the DTT system

- **Introduction**
- The DTT prototype system
- Loss characterization
- Typical sampling set-up
- Correlation with production equipment
- Measurements of Euro 6 vehicles
- Real-time <23nm PN production Events
- Concluding remarks
- Further work

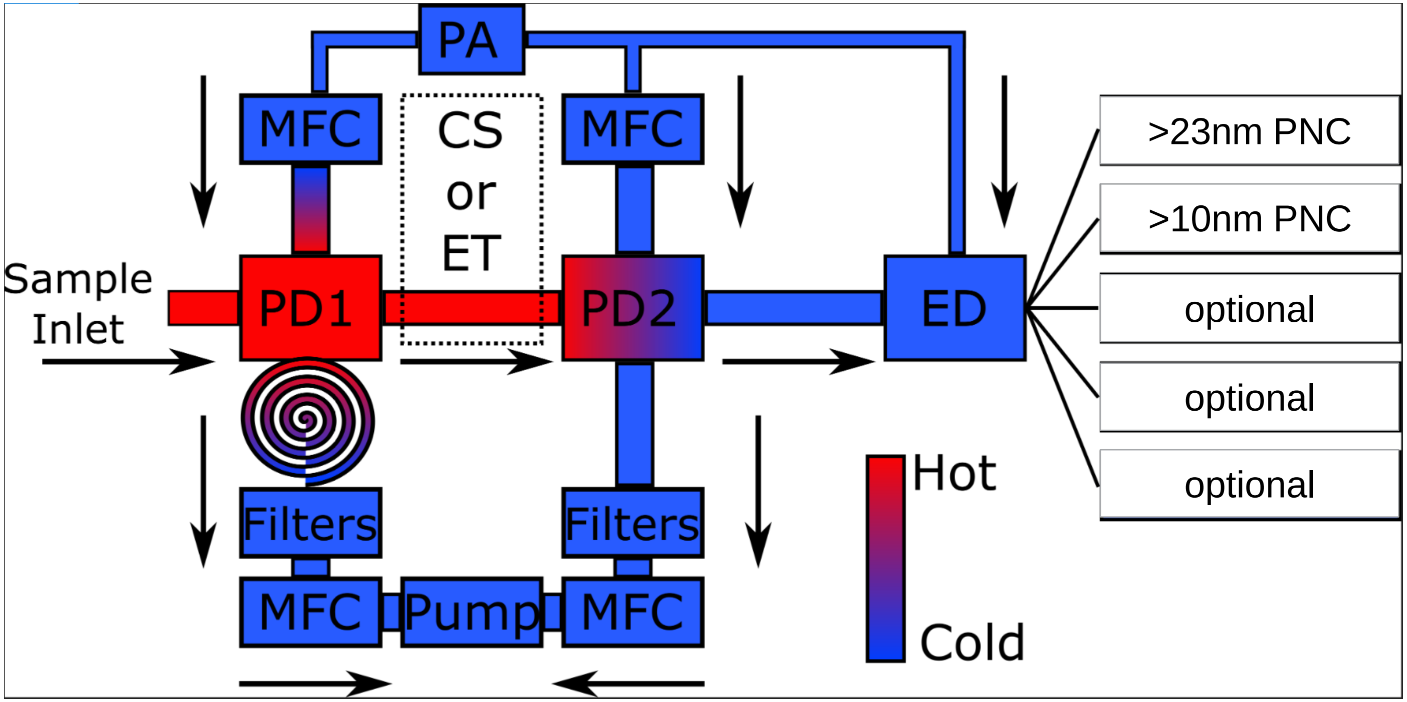
Introduction

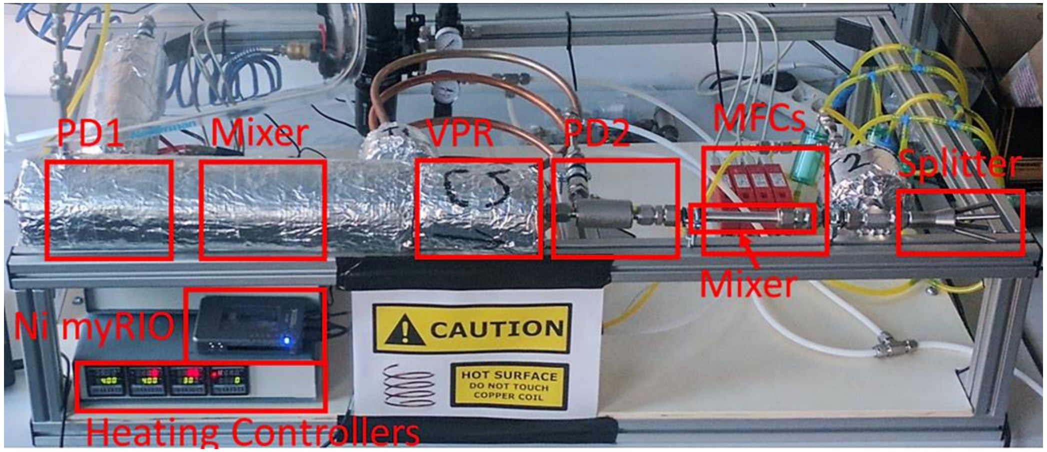
- “DownToTen” (DTT) project is one of three EU H2020 funded projects developing robust portable exhaust particle sampling system (PEPS) methodologies that will enhance the regulatory approach towards particle number (PN) emissions in the sub-23 nm region
  - New regulation to be used **if needed!**
- Focus on assessing latest generations of direct injection gasoline and diesel engines under real world conditions.
- After a rigorous selection process, DTT has identified a sub-23 nm PN sampling and measurement approach, and is testing a lab-based prototype
- This study presents preliminary results from the assessment of different vehicle technologies for <23nm PN emissions
  - using the DTT PEPS prototype in a chassis dynamometer environment, when sampling from a constant volume sampler (CVS)
- Initial assessment of the presence and magnitude of <23nm emissions will be provided

DTT Measurement System

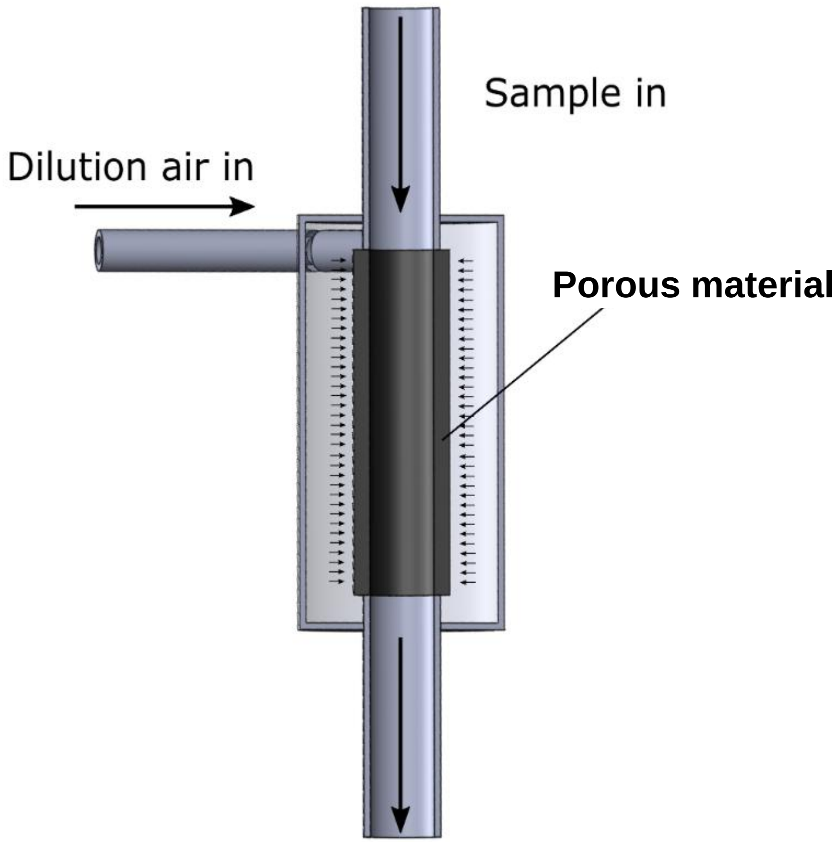
- The prototype DTT measurement system consists of two porous tube diluters (PD1, PD2) and a third, optional dilution stage for sampling high particle number concentrations. This additional dilution is supplied by an ejector diluter (ED).

- Between the two PD either an evaporation tube (ET) or catalytic stripper (CS) can be placed





Principle of Porous Tube Diluter (PD)

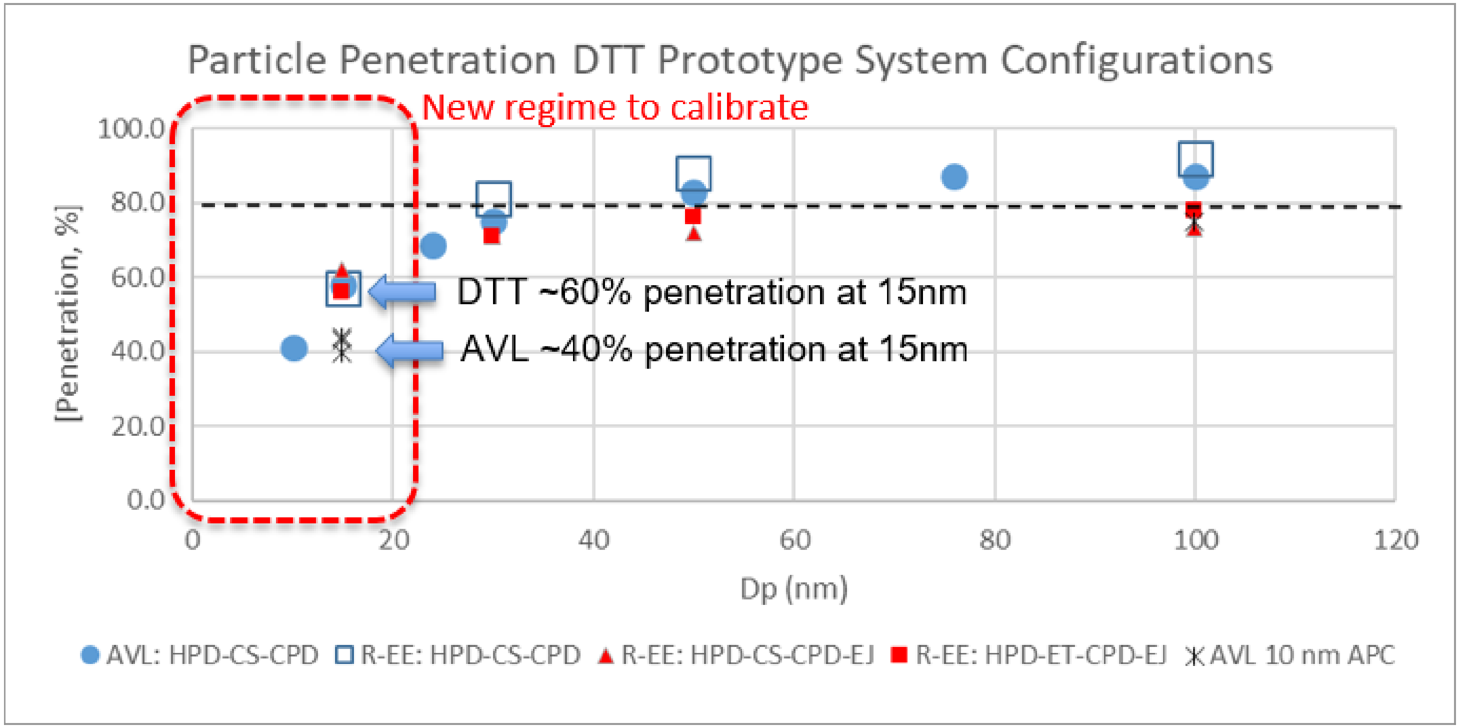


Further conditioning and measurement

- Sample enters the transport/dilution tube, which is the centre of an annulus
- Dilution air is added to the sample from the annular area, through the walls
  - The air ingress creates a protective sheath that prevents particle losses on the walls
  - Dilution air can be hot or cold
- Wall dilution also ensures good mixing of sample and diluent
- Diluter can be relatively compact

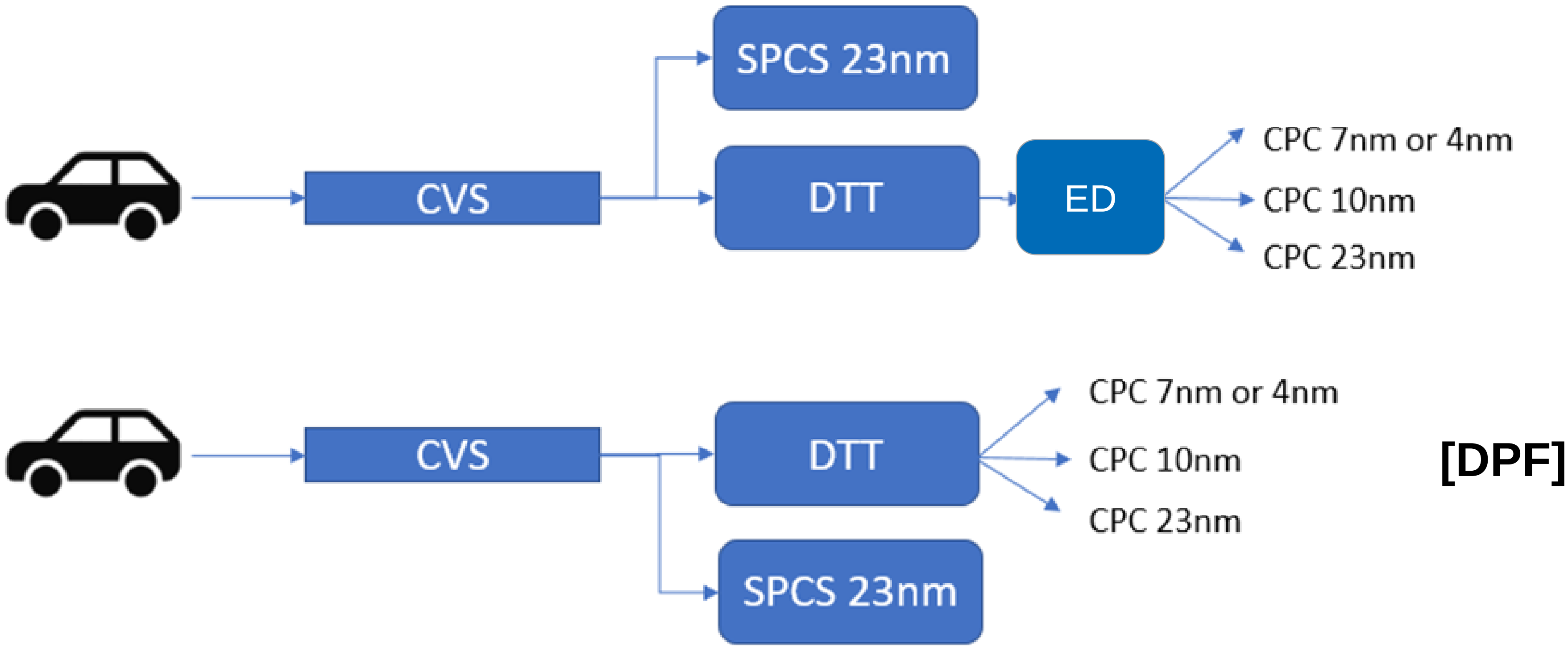
Calibration Exercises at Ricardo & AVL

- The penetration performance of the DTT prototype system when equipped with a CS as VPR is not appreciably different to that seen when an ET-based VPR is used
- The benefits of the CS in eliminating potential volatile artefacts justify its selection in preference to ET and prioritization in this study



The 20% of baseline losses are attributed to thermophoretic losses

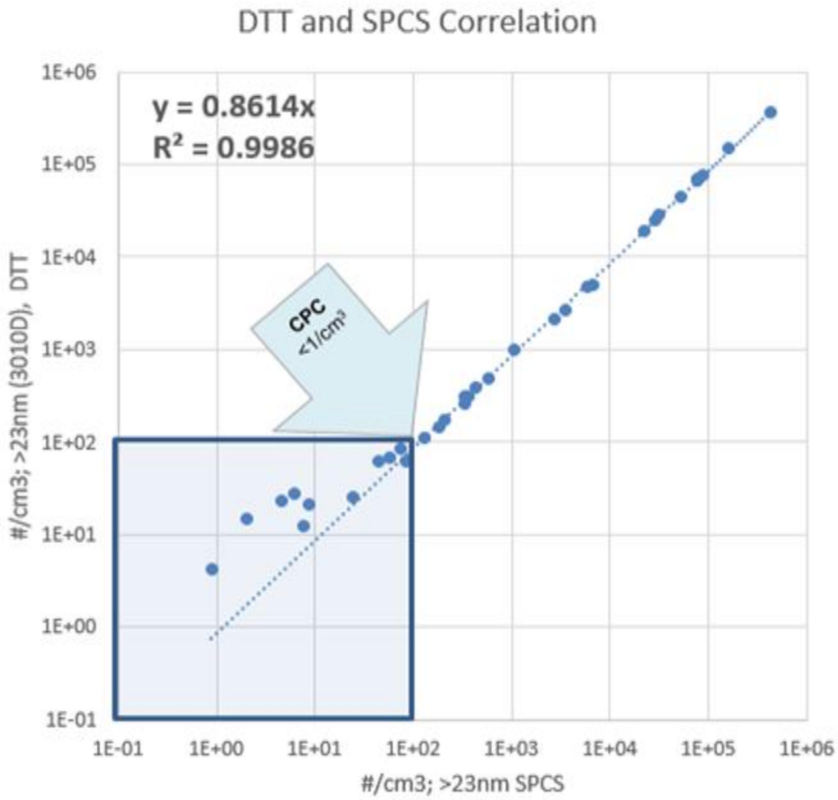
Typical Sampling Set-up



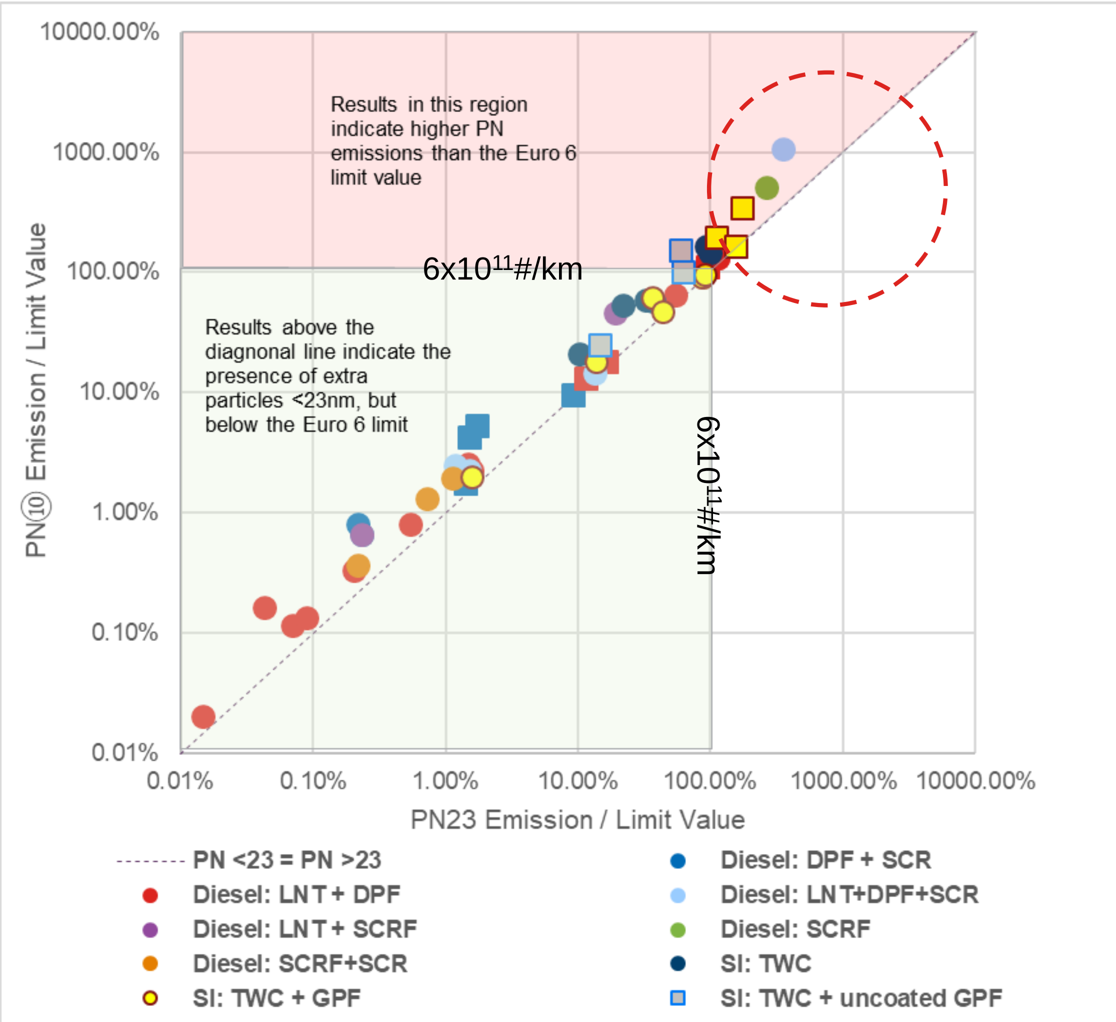
Correlation between DTT and Current Horiba Production System

- Excellent linear agreement between the DTT system and Horiba 2000SPCS above 1#/cm^3
  - Across a wide concentration range (four orders of magnitude)
- There are larger differences below this point, due to differences in dilution ratio and background particle levels in the two systems
- At >1#/cm^3, the DTT system reports ~14% lower than the commercial system
  - NOTE: data used are corrected for dilution factors, **but no PCRF correction is applied to data from either system**

Both DTT and Horiba System Measuring >23nm Particles

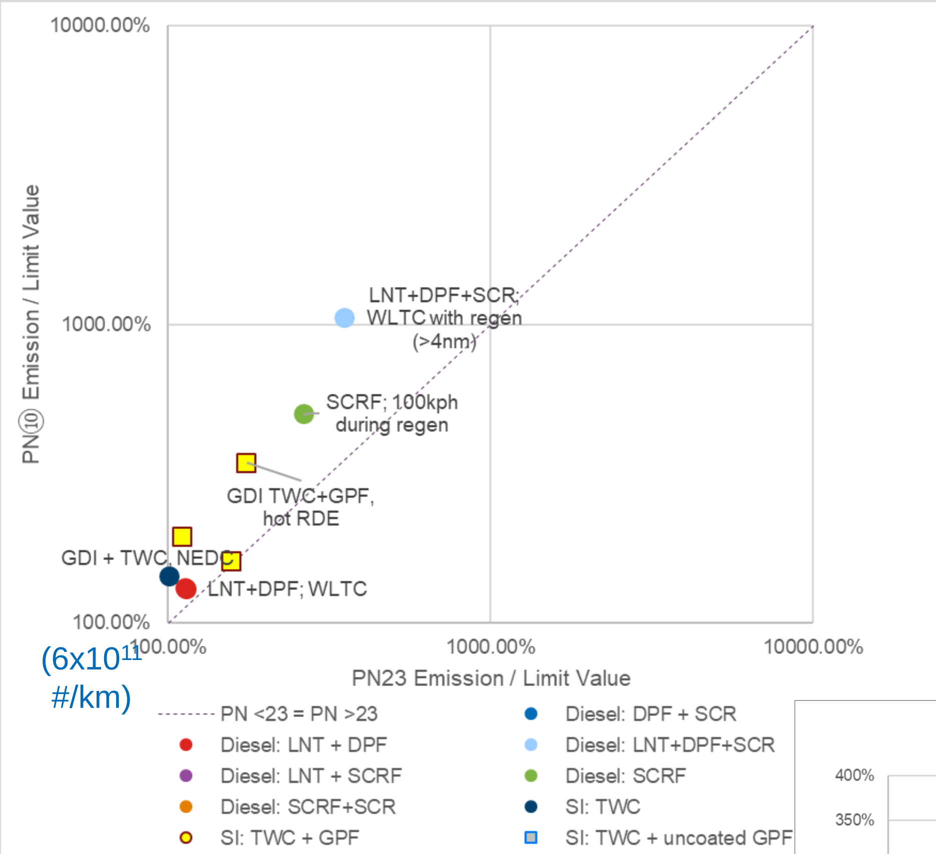


Non-volatile PN emissions from Standard Emissions Cycles

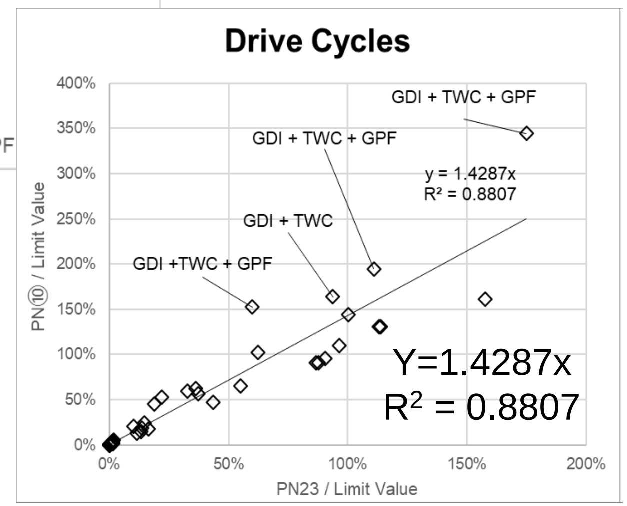


- All chassis dyno: includes US cycles, Japan cycles, NEDC, WLTC, moderate RDE and some cruises
  - Plus some fuel and climatic variations
- PN⑩ represents measurements with a particle counter that has a 50% counting efficiency at 7 or 10nm
- PN23 represents the current PN measurement approach
- Majority of tests show both PN⑩ and PN23 to be below the current European PN limit value
  - PN⑩ not corrected for <23nm losses
- ***A few results demonstrate emissions levels of PN⑩ up to ~10x the current limit value, with these tests also exceeding the limit value for the PN23 range***

Non-volatile PN emissions from Standard Emissions Cycles
Zooming in to "Exceedance Zone"

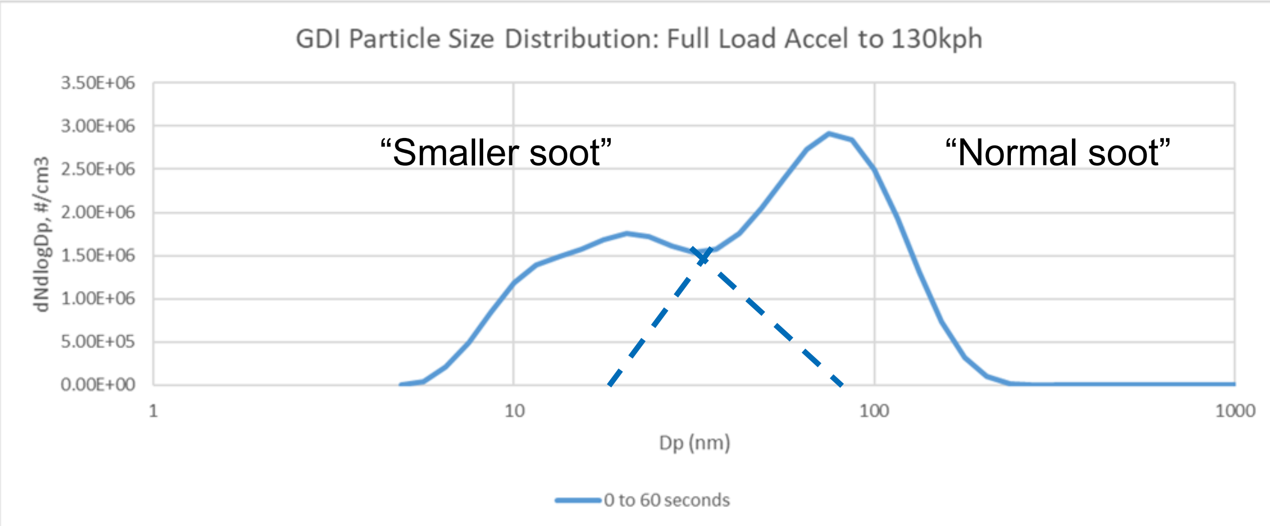


($6x10^{11}$ #/km)



- DPF regenerations show highest PN emissions in both PN23 and PN⑩ ranges
  - 10-23nm fraction increases more than >23nm range, but can be dealt with by Ki factor approach
- GDI, even with GPF, can exceed the current limit value, but not substantially
- A few non-regenerating LNT-equipped diesel results also found to be slightly above the limit
- On average, PN⑩ is ~40% higher than PN23

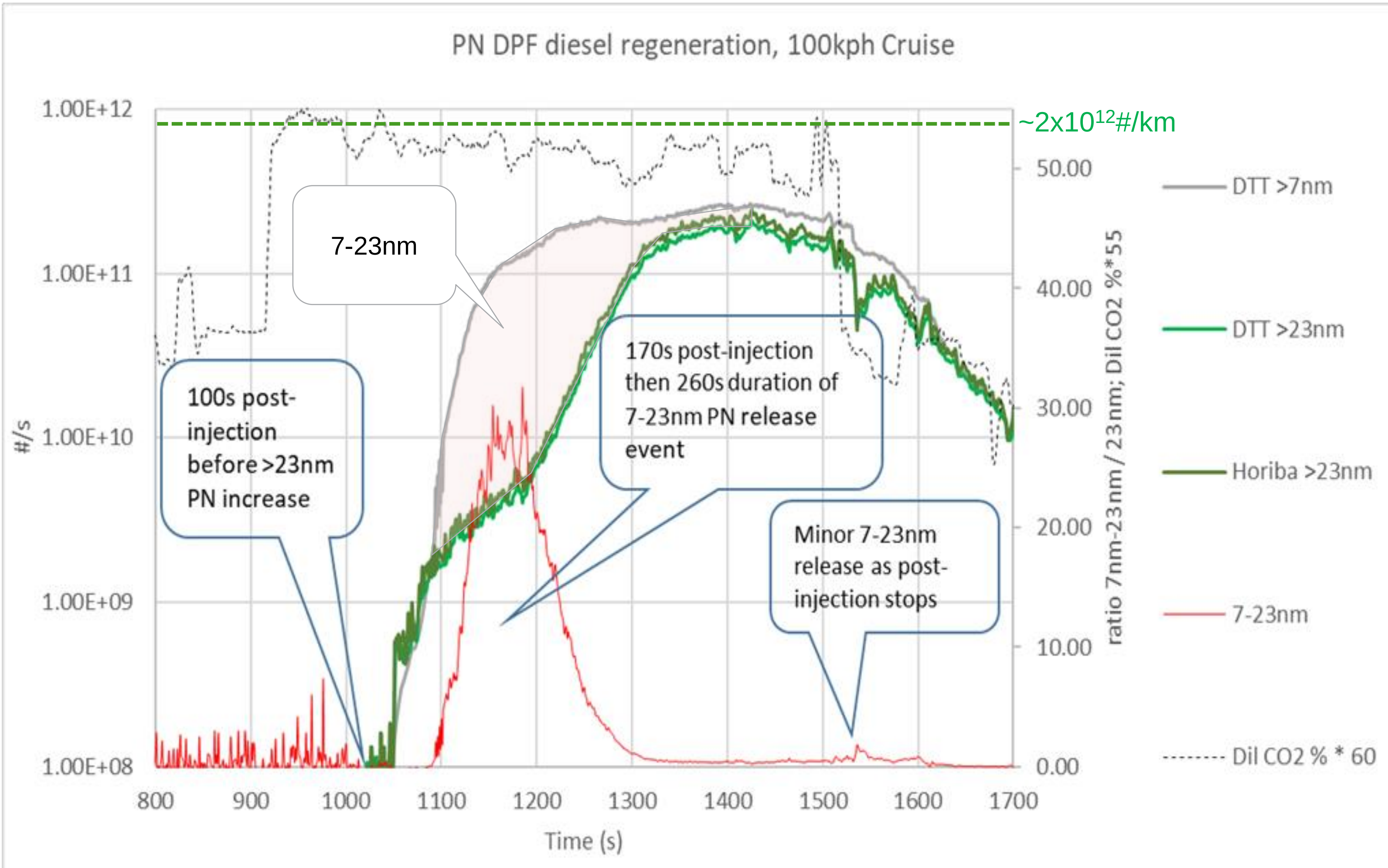
Can we make solid <23nm particles #1? Full load acceleration on lambda 1 GDI



- Hard accelerations can produce non-volatile particles in the sub-23nm range alongside a conventional soot (accumulation) mode

- There is preliminary evidence that these particles may be an additional mode of smaller soot particles

Can we make solid <23nm particles #2?
DPF active regeneration



Major <23nm particle production event

- A few minutes after post-injection starts
- Leads to <23nm emissions increase 10 to 100x those of >23nm range
  - For 2-3 minutes
- Particles are predominately <10nm in diameter (7nm d50 CPC)
- Levels and duration insufficient to influence a pass or fail result at the Euro 6c PN limit once the Ki factor is included

Concluding Remarks

- DownToTen has developed a prototype sampling system with substantially improved <23nm particle penetration compared to a production 10nm PN system
- The DTT system has a response that is highly correlated with a conventional production 23nm PN system, when both measure the current PMP size range
- Measurements of non-volatile particles from a range of vehicle technologies, aftertreatment approaches, fuels and global regulatory emissions cycles have shown:
  - That even when extending the size range down to 10nm, or just below, most emissions remain below the certification limit, even though measured levels increase by ~40% on average
  - Some technologies / aftertreatment can produce levels above the Eu 6 23nm limit value, but increases are relatively small: SI (with and without GPF), Diesel with LNT
- Some isolated engine and or aftertreatment events can produce dramatic increases in non-volatile <23nm PN, but even these do not appear to have a large influence on regulatory compliance
- It is not yet certain that a change to the regulatory size range for non-volatile particle measurement will deliver any benefit over the current PMP approach

Further work

- Functional aspects
  - Develop the prototype used in the lab to be robust in the real-world, raw-exhaust environment
- Technologies not yet explored in CVS
  - Gas engines, extreme fuels, climatic effects …
- With shift to PEMS-based system / raw exhaust in CVS facility and test cells
  - Focus on ‘extreme sources’ identified in current work
  - Validation
- Continue the parallel workstream looking at semi-volatile and secondary particles