COMPARISON OF DIFFERENT METHODS FOR THE MEASUREMEN OF EXHAUST PARTICLE NUMBER

Efthimios Zervas, Pascal Dorlhène
Renault - 1, Allée Cornuel, 91510 Lardy, France

ABSTRACT

CPC, ELPI and EEPS were used to determine the exhaust particle number of a Diesel engine on steady speeds and on NEDC, upstream and downstream DPF. In order to obtain different particle numbers, five DPFs with different porosity were used. The above three methods give quite similar particle numbers on steady speeds and on NEDC for the tests upstream DPF. Downstream DPF, EEPS reaches its limit of measurement; however, the total particle numbers obtained by this instrument are still close to the particle numbers obtained by CPC and ELPI.

INTRODUCTION

Exhaust PM measurement of Euro3 and Euro4 is based on a well adapted gravimetric method; however, another method will probably be necessary for particle mass measurements of future emission regulations. The measurement of number instead of mass is proposed for future regulations of particle emissions. In this work, Renault compares three methods measuring the exhaust particle number: Electrical Low Pressure Impactor (ELPI), Condensation Particle Counter (CPC) and Engine Exhaust Particle Sizer (EEPS) spectrometer.

EXPERIMENTAL SECTION

A 2.2L, direct injection, common rail Diesel engine was used for this work. The post-treatment line consisted of a Diesel Oxidation Catalyst (DOC, 0.5L) and a catalytic Diesel Particulate Filter (DPF, 2.5L). In order to obtain different particle numbers on the exhaust gas, five catalytic (commercial and under development) DPFs with different porosity were used. This engine is tested on dynamic engine test bench at two steady speeds of 50 and 100 Km/h, (after temperature stabilization) and on New European Driving Cycle (NEDC, cold start, simulating a vehicle of 1814 Kg inertia). Exhaust particle numbers were measured on raw gas upstream and downstream DPF. Two fuels were used for this work: with 300 and 10 ppm of sulfur.

A Fine Particle Sampler (FPS) from DEKATI was used to dilute the raw exhaust gas (x15, with N_2 at 150°C) and to avoid the back pressure due to the DPF, following by a PALLAS secondary diluter (x10, with N_2 at 20°C). Then the diluted sample was split into the three apparatus using a TSI flow splitter. This accessory is especially useful when performing instrument comparison. Exhaust particle numbers were measured with a DEKATI ELPI (7 nm to 10 µm, greased aluminum fold), a TSI CPC Model 3022A (> 7 nm) and a TSI EEPS (from 6 nm to 560 nm). Total Particle numbers are expressed in 1/Km for comparison, taking into account all stages of the ELPI and EEPS, but also taking into account only particle diameters greater than 20 nm.

RESULTS AND DISCUSSION

Comparison of particle number at steady speeds

At 50 Km/h, the total particle number upstream DPF is $1.5\text{-}6.6 \times 10^{14}$ 1/km. CPC gives slightly higher values than ELPI and EEPS. The ELPI>20nm and EEPS>20nm give respectively 20-40% and 3-5% lower particle numbers than taking into account all stages. The total particle number downstream DPF is $1.3 \times 10^{9}\text{-}9.3 \times 10^{11}$ 1/km, depending on DPF porosities. In the case of DPFs with low porosity, the three instruments determine quite different particle numbers, very close to the particle numbers measured for ambient air background tests ($8.4 \times 10^{8}\text{-}3.1 \times 10^{10}$ 1/Km). Downstream DPF, ELPI>20nm and EEPS>20nm give lower particle numbers than ELPI (28-77%) and EEPS (25-97%). This percentage is generally higher downstream than upstream DPF, indicating that downstream DPF there are proportionally much more fine particles, which are more difficult to measure due to the very low numbers and possible artefacts.

efthimios.zervas@renault.com

At 100 Km/h, the total particle number upstream DPF is $8.2x10^{13}$-$5.8x10^{14}$ 1/Km. Same tendencies, as found in the case of 50 Km/h, can be pointed out. CPC results are slightly higher than the results of ELPI and EEPS. The ELPI>20nm and EEPS>20nm give lower particle numbers than ELPI (15-50%) and EEPS (1-9%). The total particle number downstream DPF is $4.5x10^{9}$-$9.3x10^{11}$ 1/km, generally following the DPF porosity. When low-porosity DPFs are used, numbers measured by CPC, ELPI and EEPS are quite different, very close to air background tests results ($3.5x10^{8}$-$2.3x10^{10}$ 1/Km). Downstream DPF, ELPI>20nm and EEPS>20nm give lower particle numbers than ELPI (0-70%) and EEPS (14-99%).

Comparison of the total particle number on NEDC

On NEDC, the total particle number upstream DPF is 1.4-$7.5x10^{14}$ 1/km. The same tendencies as in the case of steady speeds were found. CPC gives slightly higher values than ELPI and EEPS. The ELPI>20nm and EEPS>20nm values are lower than the values of ELPI (32-57) and EEPS (9-28%). The total particle number downstream DPF is $1.9x10^{9}$-$8.7x10^{11}$ 1/km. The particle numbers measured by the three devices are quite different from each other when the low-porosity DPFs are used. These values are very close to the values of air background tests results ($1.9x10^{8}$-$2.0x10^{11}$ 1/Km). Downstream DPF, ELPI>20nm and EEPS>20nm results are lower than ELPI (0-96%) and EEPS (15-90%) measurements. This effect is generally higher than upstream DPF for the same reason as mentioned before (low particle number, possible artefact).

Comparison of the particle number versus time on the NEDC

Upstream DPF and on NEDC, the three instruments measure similar particle numbers versus time. Nevertheless, during the EUDC, EEPS signal is generally lower than the signal of the other two methods. For this reason the total particle number determined by EEPS is lower than the total particle number determined by CPC and ELPI.

Downstream DPF, only CPC and ELPI can give usable data versus time on NEDC. The particle numbers versus time of these two instruments are quite similar. EEPS signal goes down to zero most of the time. The reason is that the particle number downstream DPF is lower than the detection limits of this device, indicating that a smaller dilution ratio must be used for EEPS in the case of these measurements. Nevertheless, the total particle number determined by EEPS is similar to the particle number determined by the other two methods.

Taking all data versus time of the NEDC, there is a quite good agreement between CPC, ELPI and EEPS for the measurements performed upstream DPF. On the other hand, there is a high data scattering when the measurements are performed downstream DPF, especially in the case of EEPS.

Particle size distribution of ELPI and EEPS

In the case of steady speeds, ELPI and EEPS give quite similar median diameter for the measurements upstream DPF. EEPS has a better repeatability for this type of measurements than ELPI, due to the narrow cut size of each stage (16 channels per decade).

No big difference has been found between the particle size distributions of 50 and 100 Km/h. For both devices, the maximum number is determined at the same particle size. However, EEPS give a more “bell-type distribution” than ELPI.

CONCLUSIONS

CPC, ELPI and EEPS were used for the exhaust particle number determination of a Diesel engine. Upstream DPF, there is a quite good agreement for total particle number determined from the three instruments; however, the order CPC>ELPI>EEPS is generally observed. Downstream DPF, the particle number increases with DPF porosity. Nevertheless, an important data scattering downstream DPF and blank measurements have been observed due to the low level of particle numbers obtained. CPC and ELPI signals are quite close to each other, but EEPS signal is generally below its limit of detection. Upstream DPF, ELPI and EEPS give quite similar median diameters, although their difference in the shape of the size distribution.

efthimios.zervas@renault.com

Comparison of different methods for the measurement of exhaust particle number

Efthimios Zervas, Pascal Dorlhène

Renault

Introduction

- Particle number measurements are performed using different devices

- The performances of these devices constantly increases

- Renault compared ELPI, CPC and EEPS

Experimental Section (1)

Engine used	Common Rail Direct Injection
Fuel	Diesel
Displacement	2.2 L
Emission limits	Euro4
After-treatment device	DOC (0.5L)+DPF (2.5L)

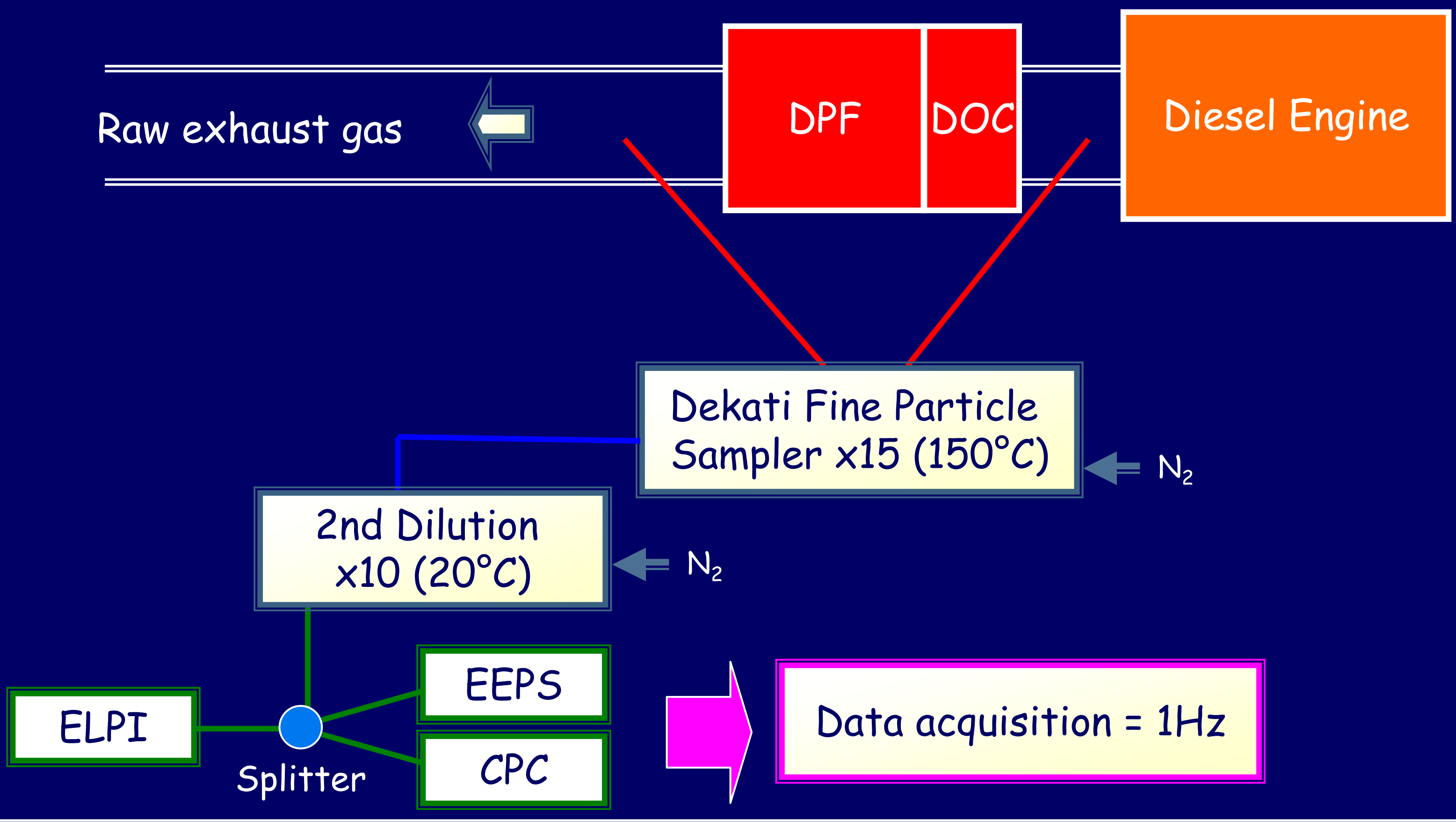
Five DPFs (commercially used and under development) with different porosity were used

Fuel with 300 and 10ppm of S

Tests on steady speeds (50 and 100 Km/h) and on the NEDC

Experimental Section (2)

Measurement of particle number



Particle number at 50 Km/h

Upstream DPF

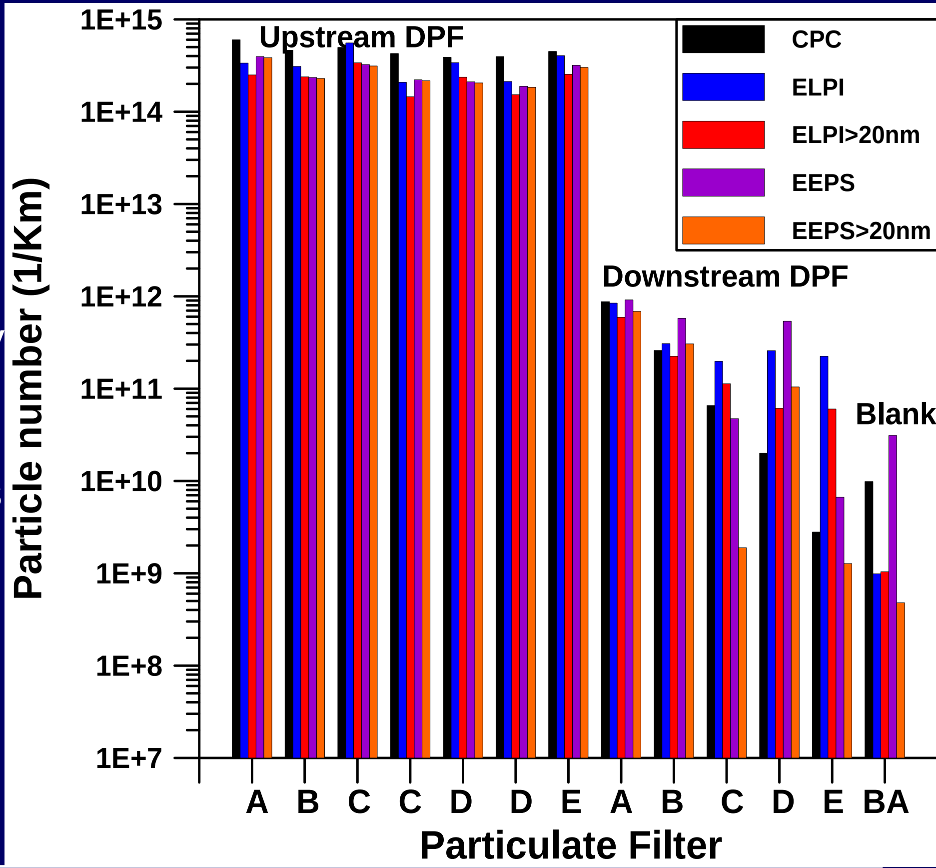
- Particle number: 1.5-6.6x10^{14} 1/km
- CPC gives higher values than ELPI/EEPS
- ELPI>20nm, EEPS>20nm give lower particle numbers than ELPI, EEPS (20-40%, 3-5%)

Downstream DPF

- Particle number: 1.3x10^{9}-9.3x10^{11} 1/km, generally increasing with the DPF porosity
- At low DPF porosity, CPC, ELPI and EEPS give quite different particle numbers, close to the blanks
- ELPI>20nm and EEPS>20nm give lower particle numbers than ELPI and EEPS (28-77%, 23-97%)

Blanks

CPC, ELPI and EEPS give a signal for air



Particle number at 100 Km/h

Upstream DPF

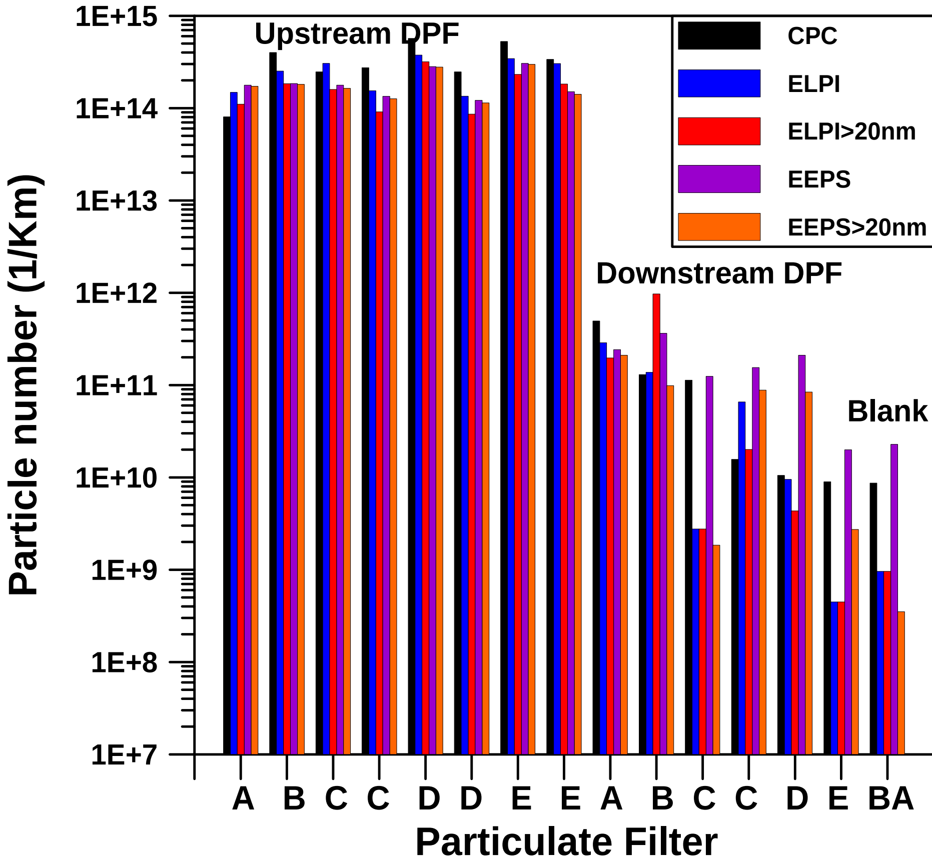
- Particle numbers: $8.2x10^{13}$-$5.8x10^{14}$ 1/km (slightly lower than 50 Km/h)
- CPC gives higher numbers than ELPI/EEPS
- ELPI>20nm, EEPS>20nm give lower particle numbers than ELPI, EEPS (15-50%, 1-9%)

Downstream DPF

- Particle numbers: $4.5x10^{8}$-$9.9x10^{11}$ 1/km (similar to 50Km/h), generally increasing with the DPF porosity
- At low DPF porosity, CPC, ELPI and EEPS give quite different particle numbers, close to the blanks
- ELPI>20nm, EEPS>20nm give lower particle numbers than ELPI, EEPS (0-70%, 14-99%)

Blanks

CPC, ELPI and EEPS give a signal for air



Particle number on the NEDC

Upstream DPF

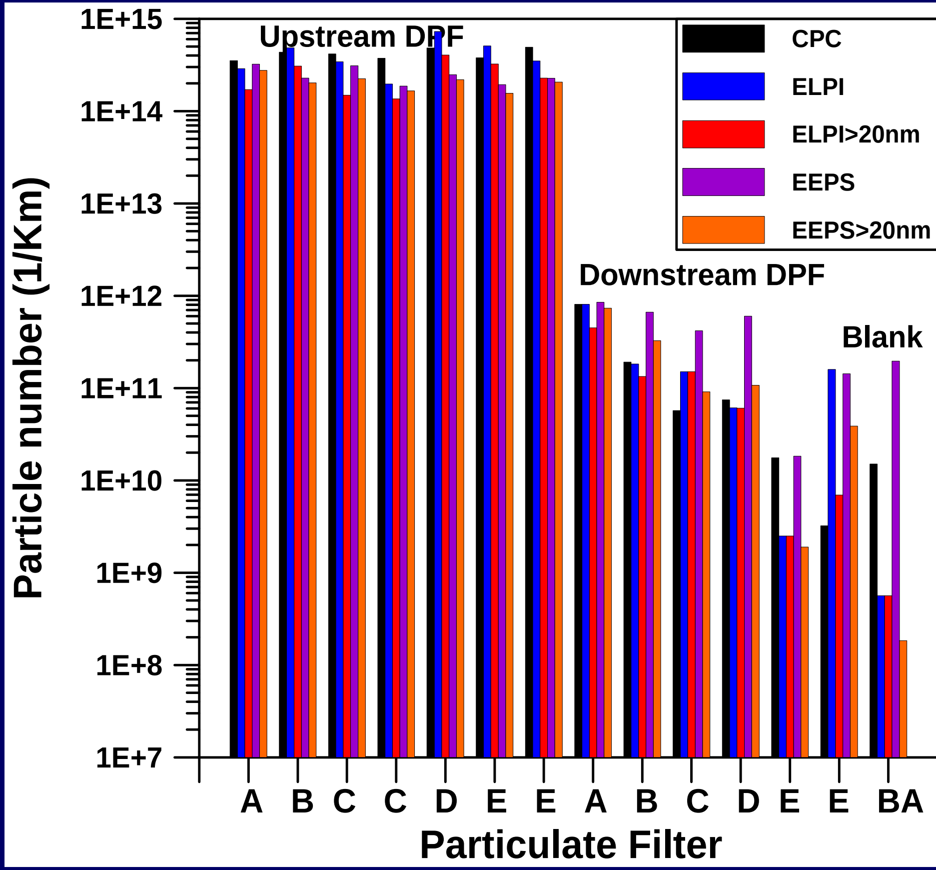
- Particle number: $1.4\text{-}7.5 \times 10^{14}$ 1/km
- CPC gives slightly higher numbers than ELPI and EEPS
- ELPI>20nm, EEPS>20nm give lower particle numbers than ELPI, EEPS (32-57, 9-28%)

Downstream DPF

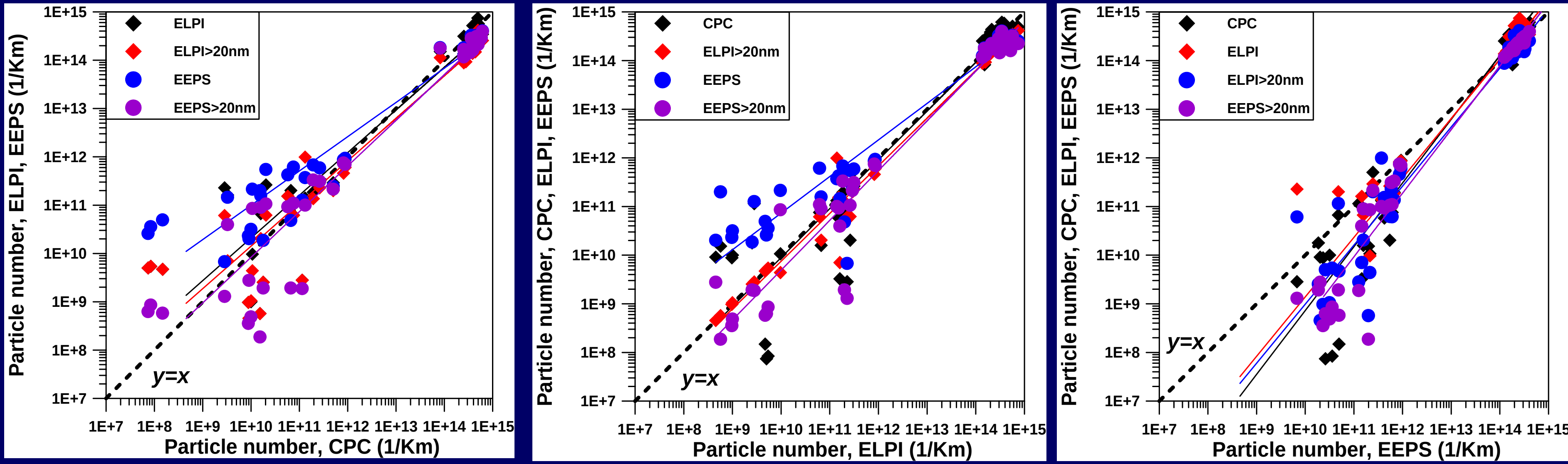
- Particle number: $1.9 \times 10^{9}\text{-}8.7 \times 10^{11}$ 1/km, generally increasing with the DPF porosity
- At low DPF porosity, CPC, ELPI and EEPS give quite different particle numbers, close to the blanks
- ELPI>20nm, EEPS>20nm give lower particle numbers than ELPI, EEPS (0-96, 15-90%)

Blanks

CPC, ELPI and EEPS give a signal for air



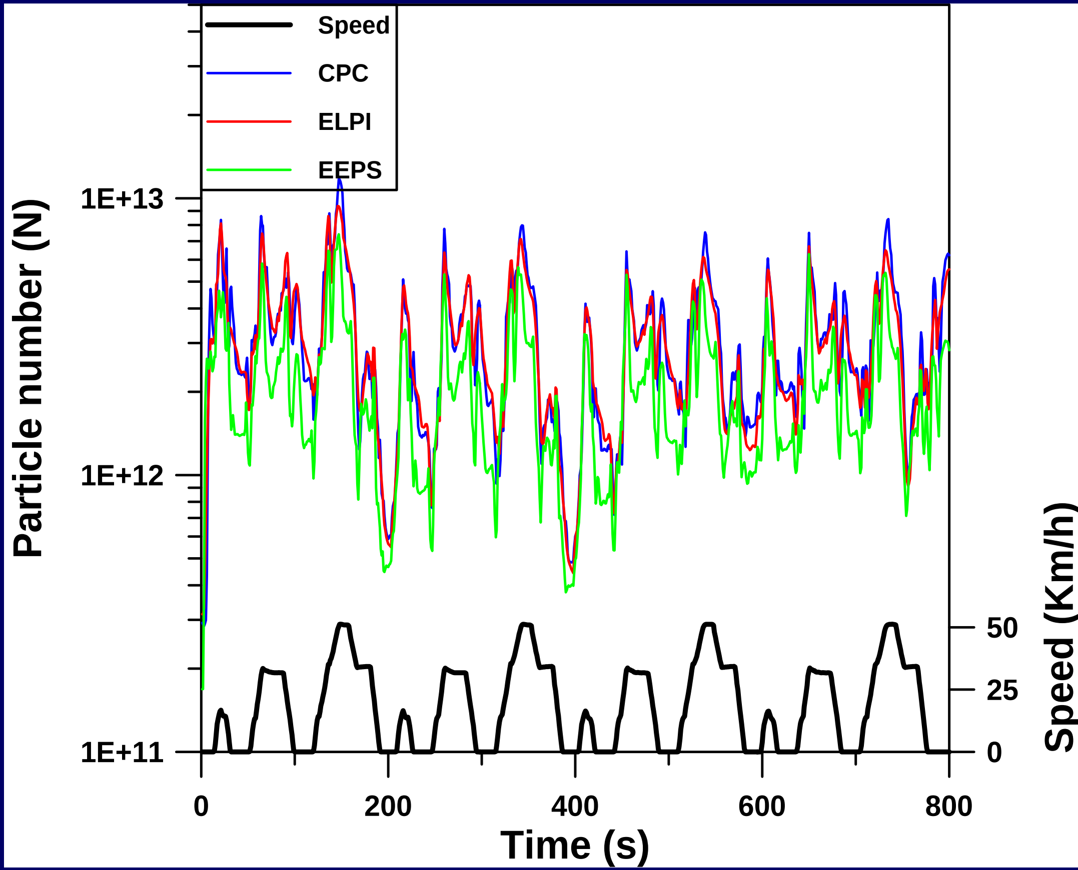
Particle number using all data of total particle number. CPC, ELPI and EEPS base



- Quite good agreement for the values upstream DPF
- Quite important dispersion for the values downstream DPF and the blanks

Comparison between CPC, ELPI and EEPS upstream DPF. ECE

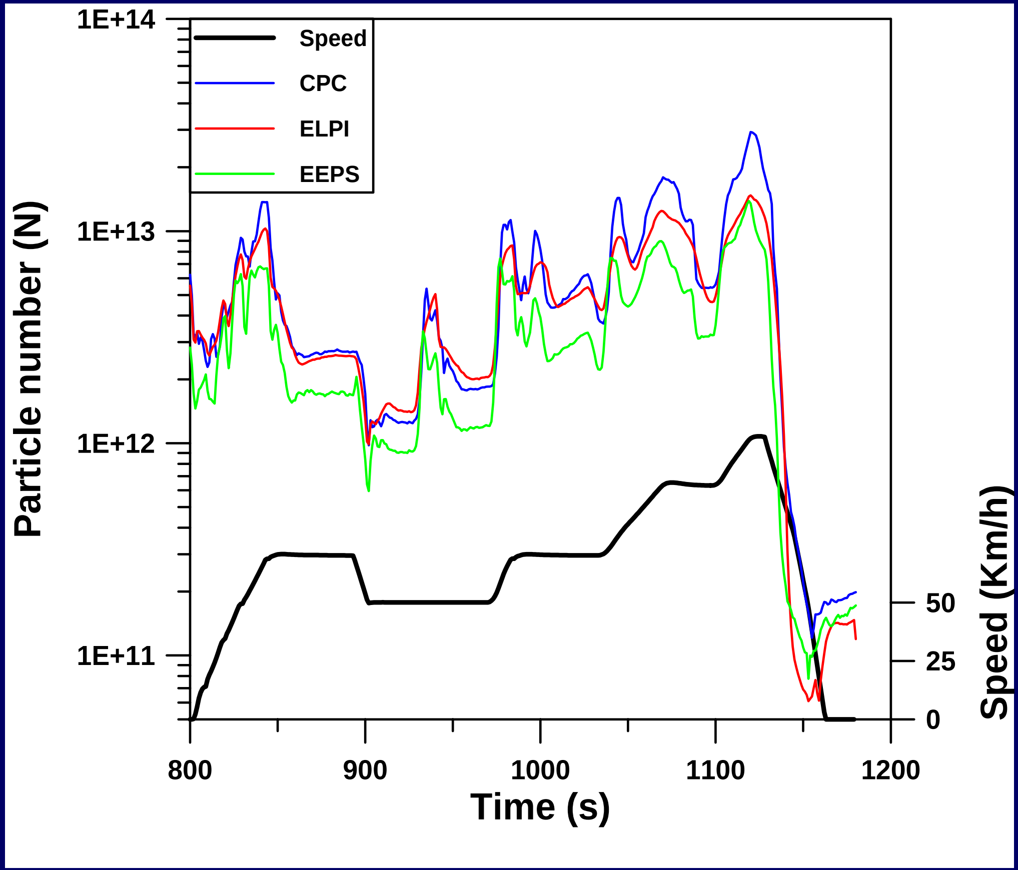
- The three devices have a similar particle number versus time curve
- Generally, the order CPC>ELPI>EEPS is observed



Comparison between CPC, ELPI and EEPS upstream DPF. EUDC

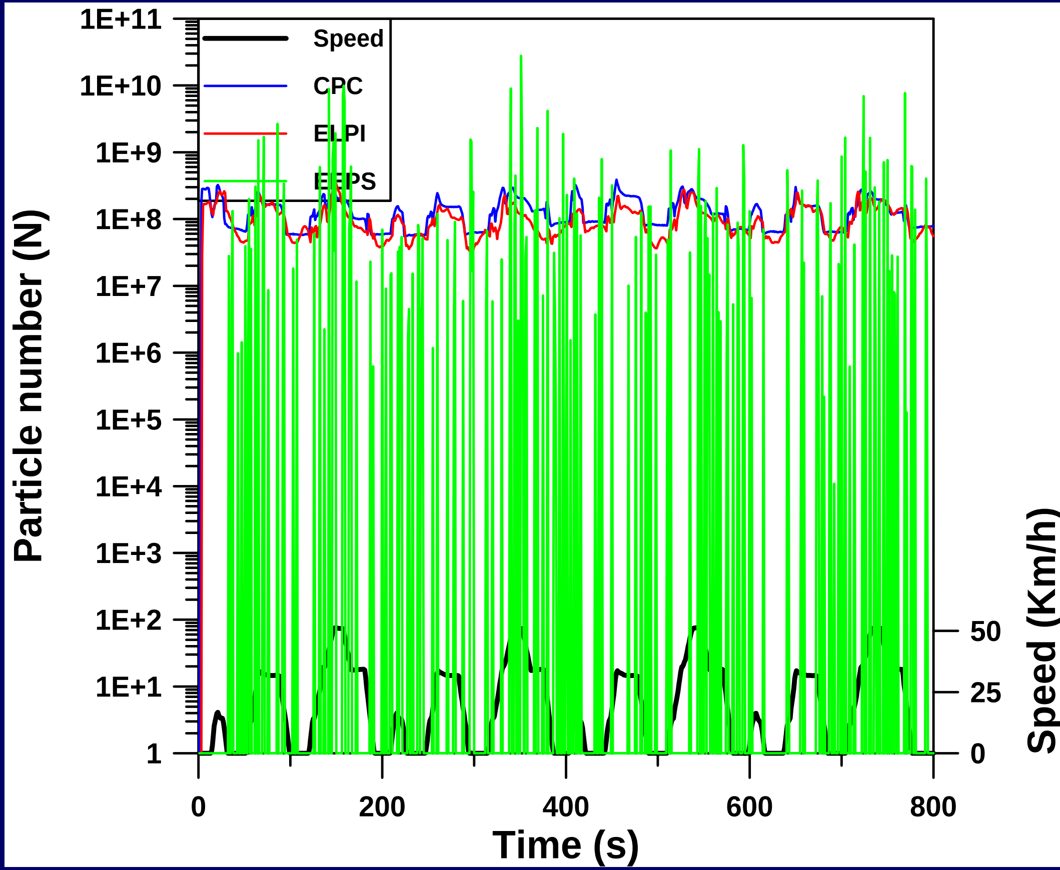
• As in the case of ECE, the three devices have a similar particle number versus time curve

• Generally, the order CPC>ELPI>EEPS is observed, but the differences are now larger



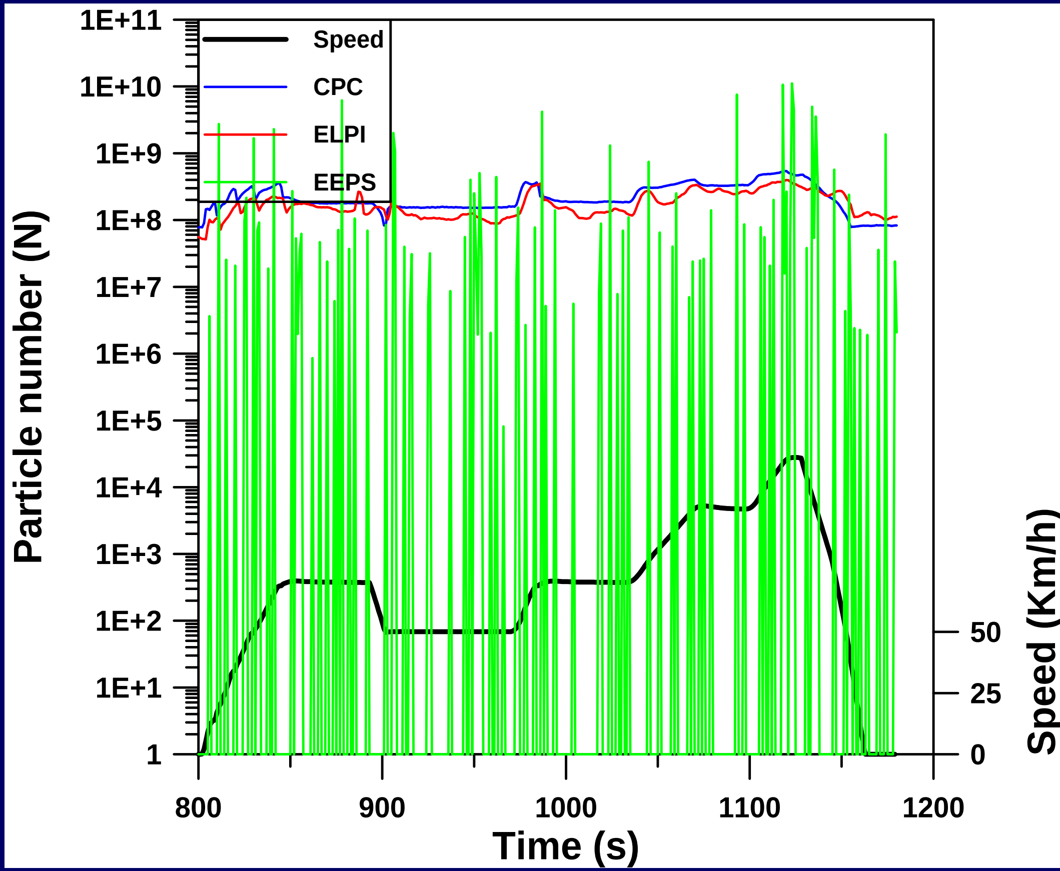
Comparison between CPC, ELPI and EEPS downstream DPF. ECE

- CPC and ELPI have a similar particle number versus time curve (ELPI is lower than CPC)
- EEPS give some values, but very often gives zero. However, EEPS total particle number is similar to the CPC and ELPI total particle number

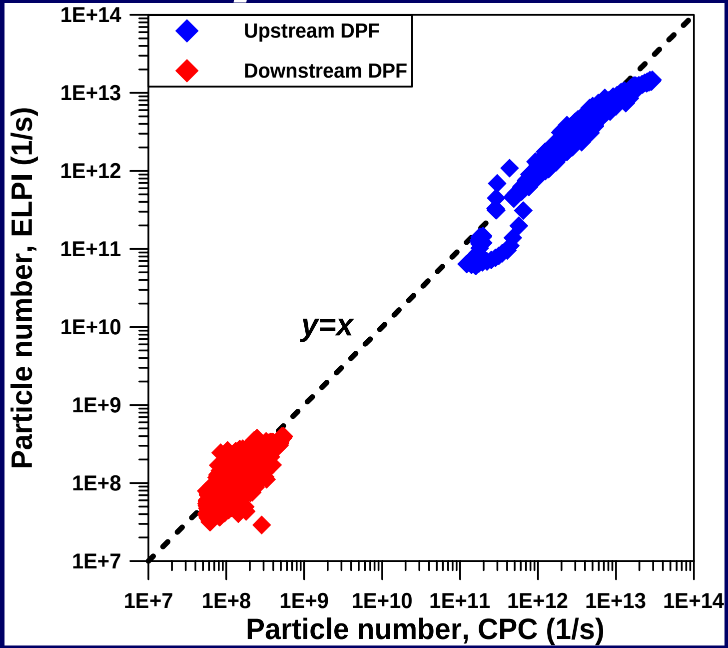


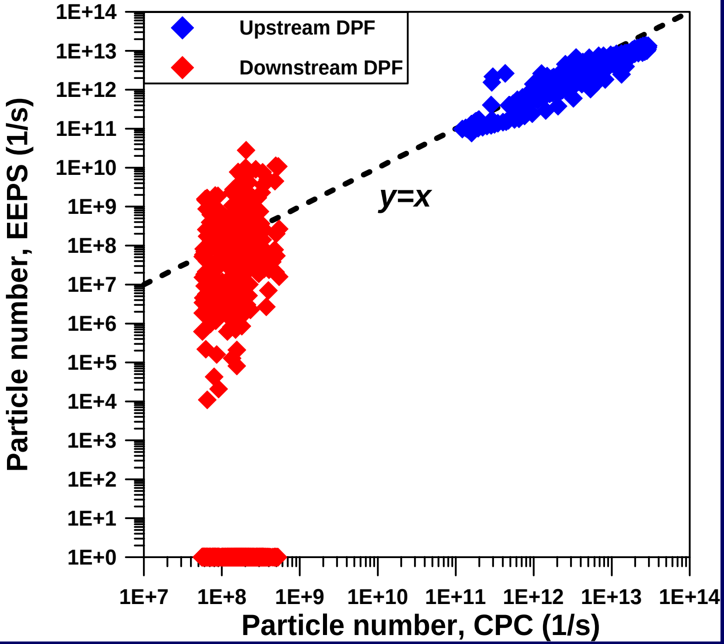
Comparison between CPC, ELPI and EEPS downstream DPF. EUDC

- CPC and ELPI have a similar particle number versus time curve (ELPI is lower than CPC)
- EEPS give some values, but very often gives zero. However, EEPS total particle number agree with the total particle number of CPC and ELPI



CPC, ELPI and EEPS upstream and downstream DPF. All NEDC points, average values of all DPFs

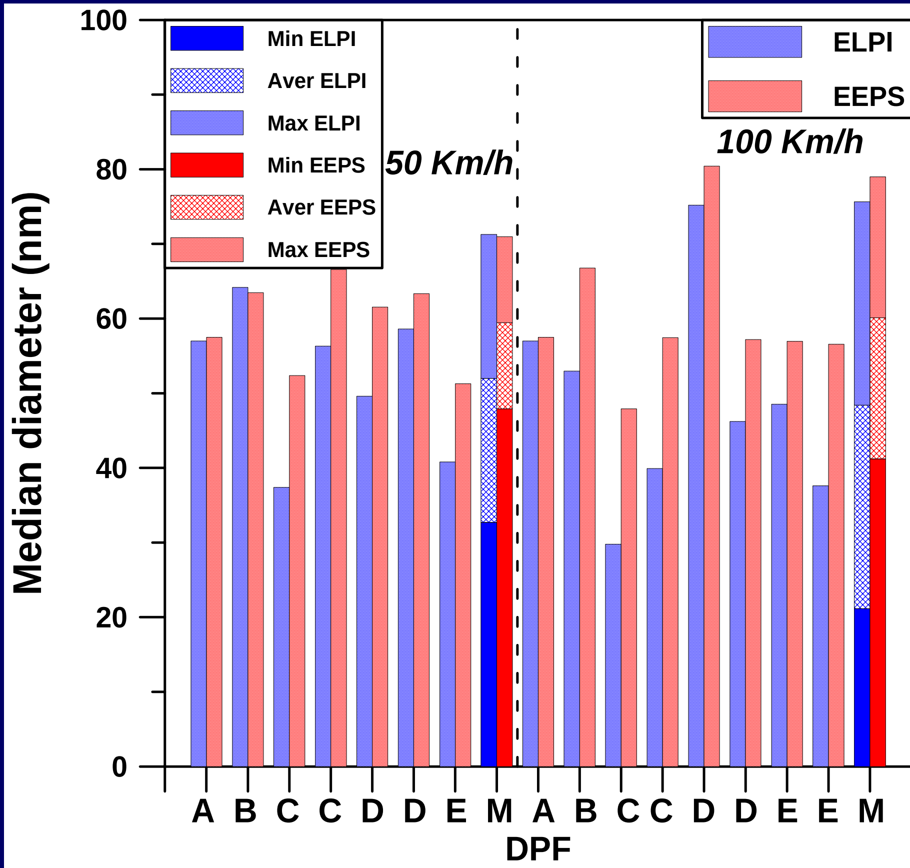




- Quite good agreement upstream DPF
- Less good agreement downstream DPF in the case of CPC/ELPI
- Very high dispersion of the CPC/EEPS data

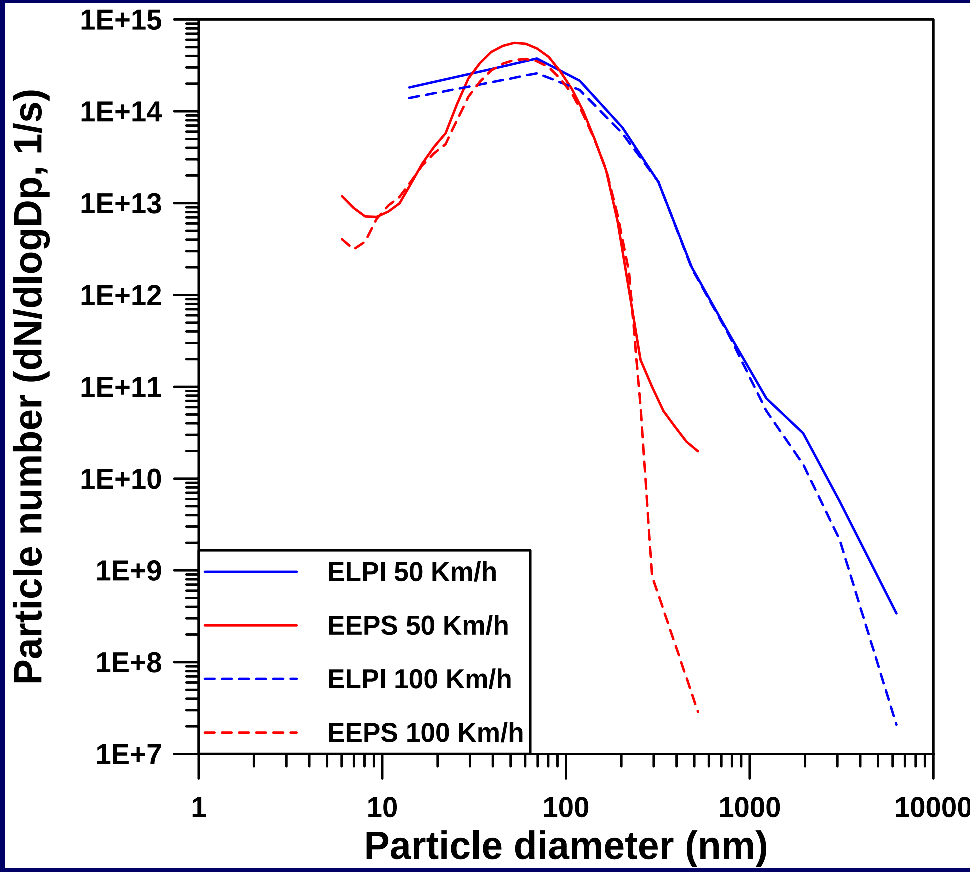
Results (11): Mean diameter (ELPI and EEPS, upstream DPF)

- The median diameter determined by ELPI and EEPS are quite close
- ELPI has larger RSD than EEPS due to the larger cut sizes of each stage
- No significant differences between 50 and 100 Km/h (but higher dispersion at 100 Km/h)



Results (13): Particle size distribution of *ELPI and EEPS (steady speeds, upstream DPF)*

- Practically, there is no difference between 50 and 100 Km/h for ELPI and EEPS
- ELPI and EEPS have a peak at the same particle diameter
- The shape is different: EEPS gives a more bell-type curve than ELPI



Conclusions

- Upstream DPF
  - CPC, ELPI and EEPS give quite similar results (steady speeds and NEDC); the order CPC>ELPI>EEPS is observed
- Downstream DPF
  - the particle number increases with DPF porosity
  - CPC, ELPI and EEPS give quite different particle numbers; ELPI and EEPS are close to blanks measurements
  - CPC and ELPI give quite similar particle behaviour versus time (CPC>ELPI)
  - EEPS reaches its limit of measurement (gives some numbers, but gives very often zero)
  - On NEDC, there is a high dispersion of the CCP/EEPS data
- Particle distribution (upstream DPF, steady speeds)
  - ELPI and EEPS give quite similar median diameters, although the shape of the size distribution is different (EEPS gives a more bell-type curve)

Thank you for your attention