WCCAP Report

Mobility Spectrometer workshop February/March 2008 in Leipzig

1. Evaluated DMPS and SMPS systems

A set of 19 DMPS/SMPS systems took part in the second EUSAAR NA3 workshop and their particle number size distributions are evaluated in this report. Since not all systems could be operated simultaneously they were split into two groups. The systems of each group participated in different particle experiments for one week (**week1** and **week2**). Information about the participating DMPS/SMPS systems is given in Tabs.1-5.

Tab.1: Information about the EUSAAR partner systems operated during week1: Beo Moussala (Beo), Finokalia (Fin), Kostice (Kos), and Montseny (Mon) that are all self-made SMPS of the Leibniz-Institute for Tropospheric Research (IfT).

	Beo	**Fin**	**Kos**	**Mon**
System	SMPS	SMPS	SMPS	SMPS
DMA	Hauke medium	Hauke medium	Hauke medium	Hauke medium
CPC	TSI-3772	TSI-3772	TSI-3775	TSI-3785
neutralizer	Krypton-85	Krypton-85	Krypton-85	Krypton-85
Flow ratio sheath : aerosol	5 : 1	5 : 1	5 : 1	5 : 1
Size range (nm)	10 - 900	10 - 900	10 - 900	10 - 900
Specific comments	--	--	--	--

Tab.2: Information about the EUSAAR IfT-TDMPS system (IfT) and systems of the German Federal Environment Agency operated during week1: Schauinsland (Schau), Hohenpeissenberg (Hpeiss) and Zugspitze (Zug). The first two are self-made IFT-SMPS.

	IfT	**Schau**	**Hpeiss**	**Zug**
System	TDMPS	SMPS	SMPS	SMPS
DMA	Hauke medium Hauke short	Hauke medium	Hauke medium	TSI long
CPC	TSI-3010 TSI-3025	TSI-3772	TSI-3772	TSI-3772
neutralizer	Krypton-85	Krypton-85	Krypton-85	Krypton-85
Flow ratio sheath : aerosol	5 : 0.5 20 : 2	5 : 1	5 : 1	5 : 1 and 4 : 1
Size range (nm)	22 - 800 3.0 - 78	10 - 900	10 - 900	10 - 550
Specific comments	--	--	--	modified TSI system

It is obvious From Tabs.1 and 2 that the EUSAAR partner systems and the ***Schau*** and ***Hpeiss*** system all built at IfT are identical with respect to their hard- and software. The ***IfT*** EUSAAR system is a Twin DMPS, i.e. that the ultra-fine and fine particle size range are measured simultaneously, and was partly operated during both weeks of the workshop.

In **week2** all devices differ in certain issues of the operation modus as can be seen in Tabs.3-5. However all DMPS systems use Hauke and all SMPS systems TSI DMAs, respectively. The ***Lund*** system is the second Twin DMPS within the workshop. Similar to the TDMPS, the ***Hel*** system is also able to measure the ultra-fine particle size range (but not simultaneously to the fine particle sizes) by using a single DMA and a sequence of a high and low flow mode.

Tab.3: Information about the DMPS systems operated during week2: Institute of Atmospheric Science and Climate Bologna (Bol), EC Joint Research System (Ispra), Norwegian Institute for Air Research (NILU) and University of Veszprem (Vesz).

Institution:	**Bol**	**Ispra**	**NILU**	**Vesz**
System	DMPS	DMPS	DMPS	DMPS
DMA	Hauke medium (modified)	Hauke medium (version 3.3)	Hauke medium	Hauke medium
CPC	TSI-3010	TSI-3010	TSI-3010	TSI-3010
neutralizer	Nickel-63	Krypton-85	Nickel-63	Nickel-63
Flow ratio sheath : aerosol	5 : 1	5 : 1	8.2 : 1	5 : 1
Size range (nm)	10 - 500	10 - 600	10 - 600	11 - 1220
Specific comments	--	--	--	--

Tab.4: Information about the SMPS systems operated during week2: University of Clermont-Ferrand (Cler), Paul-Scherrer Institute (PSI), University of Birmingham (Harw), and University of Athens (Ath).

Institution:	**Cler**	**PSI**	**Harw**	**Ath**
System	SMPS	SMPS	SMPS	SMPS
DMA	TSI long	TSI long (custom made)	TSI long	TSI long
CPC	TSI-3010	TSI-3022A	TSI-3022A	TSI-3776
neutralizer	Nickel-63	Krypton 85	Krypton 85	Krypton 85
Flow ratio sheath : aerosol	6.2 : 1	3 : 0.3	3 : 0.3	3 : 0.3
Size range (nm)	10 - 480	14 - 760	14 - 740	3 - 80 30 - 800
Specific comments	--	--	TSI inversion software	TSI inversion software

Tab.5: Information about the TDMPS systems and the DMPS system that was operated with two flow modes: IfT, University of Helsinki (Hel), and University of Lund (Lund).

Institution:	**IfT**	**Hel**	**Lund**
System	TDMPS	DMPS	TDMPS
DMA	Hauke short Hauke medium	Hauke medium	Hauke short Hauke medium
CPC	TSI-3025 TSI-3010	TSI-3772	TSI-3025 TSI-3760
neutralizer	Krypton-85	Nickel-63	Krypton-85
Flow ratio sheath : aerosol	5 : 1 20 : 2	20 : 5 4 : 1	20 : 3 6 : 0.9
Size range (nm)	22 - 800 3.0 - 78	3 - 80 30 - 800	3 - 21 21 - 850

Specific comments	--	high and low flow mode	--

A part of the **week2**-systems participated already in the workshop in November 2006 (***Bol***, ***Ispra***, ***NILU***, ***Cler***, ***Harw***, ***Hel*** and ***Lund***) whereas some systems were examined for the first time (***Vesz***, ***PSI***, ***Ath***). It should be noted that the systems operated during **week2** still measured different size intervals and with different size and time resolution, although that was identified in the analysis of the first workshop as one major drawback for an informative system inter-comparison. Thus, the determination of peak diameters and total concentration and the data inversion procedure are still influenced by those data acquisition distinctions between the systems.

For two systems (***Harw*** and ***Ath***, cf. Tab.4) a commercial TSI data acquisition and inversion software was used whereas all others apply self-made or has adopted and apply self-made inversion routines.

2. Results

2.1. Measurements

From the different lab and ambient aerosol particle measurements 5 experiments are selected for this report to present the quality of the various systems. This includes a mono-disperse particle lab experiment using 200 nm Latex particles (LATEX) and an experiment measuring the number size distribution of ambient aerosol particles (AMB) in **week1** and **week2**. In **week2**, lab generated ammonium sulphate particles (AMSU) were additionally measured in order to evaluate the system behaviour for poly-disperse aerosol particles under controlled and constant conditions. In all experiments the lab generated or ambient aerosol particles were first mixed in a chamber and subsequently distributed to each measurement system.

2.2. Presentation of the results

Mean raw and inverted particle size distributions will be shown in the following separated for the two weeks of the workshop.

The raw data size distributions are given in particle concentration (cm^{-3}) per size bin. This time they are quantitatively inter-comparable among the different systems, because they are all normalized to a sheath to aerosol flow ratio of 10 : 1. The raw distributions are shown in order to access the quality of the measurement. This check is important, because this raw distribution data is the input for the inversion routines that calculate the physical meaningful particle number size distributions in $dN/dlogd_p$. Similar to the first workshop it was still difficult to obtain a raw distribution in particle concentration per size bin for the SMPS systems controlled with the TSI software (***Harw***, ***Ath***). At least a procedure was found for the ***Ath*** system to infer the required raw data.

For the systems operated during **week2**, two different inverted number size distributions will be presented. The first is the inversion result of the respective user (USER_INV). The second are number size distributions obtained from one common inversion method applied to all systems which are labelled as “NA3”. For this common inversion method the routine developed at IfT was chosen. The transfer function of a TSI and Hauke DMA calibrated for a specific sheath to aerosol flow ratio is imbedded in this inversion routine as required for the respective system. Different flow ratios are simply taken into account by a factor that mathematically describes that deviation. No NA3 inversion could be carried out for the ***Harw*** system due to the lack of a quantitatively meaningful raw distribution as already mentioned in the paragraph before. For the user inversion of the ***Harw*** raw data the diffusion correction was switched on in the TSI software. The common NA3 inversion is at the same time the user inversion for the SMPS sytems of **week1**, i.e. only one inverted number size distribution is shown for these devices.

In principal, the size dependent detection efficiency of the CPC's that are part of the DMPS and SMPS systems was determined during the workshop in order to include this information into the common NA3 inversion. However, that led to unrealistic shapes of the number size distributions in the size range below 20 nm for several systems, most likely due to the choice of an non-appropriate parameterization formula for the CPC detection efficiency. Thus, it was abstained from including the individual CPC efficiencies for all NA3 inversions. This should not introduce significant quantitative errors since only number size distributions above 10 nm are examined where the true CPC efficiencies are quite constant and generally close to unity.

The number size distributions are presented as averages over the respective experiment periods. The raw and user inverted number size distributions are plotted exactly like they were submitted by the different users, e.g. no further smoothing was applied. In a separate sub-chapter the average particle concentration and other parameter like peak or mode diameter deduced from the size distributions are compared for the systems for **week1** and **week2**, separately.

2.3. Results week1

2.3.1. Lab experiment with mono-disperse 200 nm Latex particles

The selected experiment (RUN 4) was conducted at the 27.02.2008 from 15:00 to 15:36. All systems except the ***Mon*** system were operational during this time. The data availability of the different measurement systems concerning this lab experiment can be taken from Tab.6.

Tab.6: Measurement duration and data availability of the week1 systems for the 200 nm mono-disperse Latex experiment.

System:	**measurement time**	**raw data**	**NA3 inversion**
Beo	15:00 - 15:34	yes	yes
Fin	15:00 - 15:34	yes	yes
Kos	15:00 - 15:34	yes	yes
Mon	no data	*no*	*no*
IfT	15:01 - 15:35	yes	yes
Schau	15:02 - 15:36	yes	yes
Hpeiss	15:02 - 15:36	yes	yes
Zug	15:09 - 15:24	yes	yes

There are two main objectives that can be studied by carrying out an experiment with mono-disperse particles. The particle sizing of the mono-disperse distribution as well as the correction capability of measured multi charged particles by the respective inversion routines can be evaluated, which is done in chapter 2.3.1.2.

2.3.1.1. Averaged particle number size distributions

Mean raw and NA3 inverted particle number size distributions of each **week1** system (except ***Mon***) are shown in Fig.1 (left and right panel, respectively). Beside the nominal Latex singly charged particle peak at 200 nm, the doubly and triply charged particle peaks at about 129 and 102 nm are clearly seen in the raw distribution. The Latex particle peaks of all SMPS systems are slightly shifted to larger sizes with respect to the ***IfT*** TDMPS. Although the Latex peak diameter measured by the ***Zug*** system is in the range of the other systems, the peaks for the doubly and triply charged particles is strangely shifted to larger sizes. This is most likely the reason that these particle peaks are still strongly present after the inversion (Fig.1, right panel) whereas these particles are efficiently redistributed into the original Latex particle peak for all the other systems. By comparing raw and inverted size distributions it is obvious that the inversion slightly shifts the Latex peak to smaller diameters, so that the peak diameter difference remains. From the SMPS systems based on a HAUKE DMA (***Beo***, ***Fin***, ***Kos***, ***Schau***, ***Hpeiss***) a rather similar mono-disperse particle peak is obtained which is certainly due to their identical hardware and software setup.

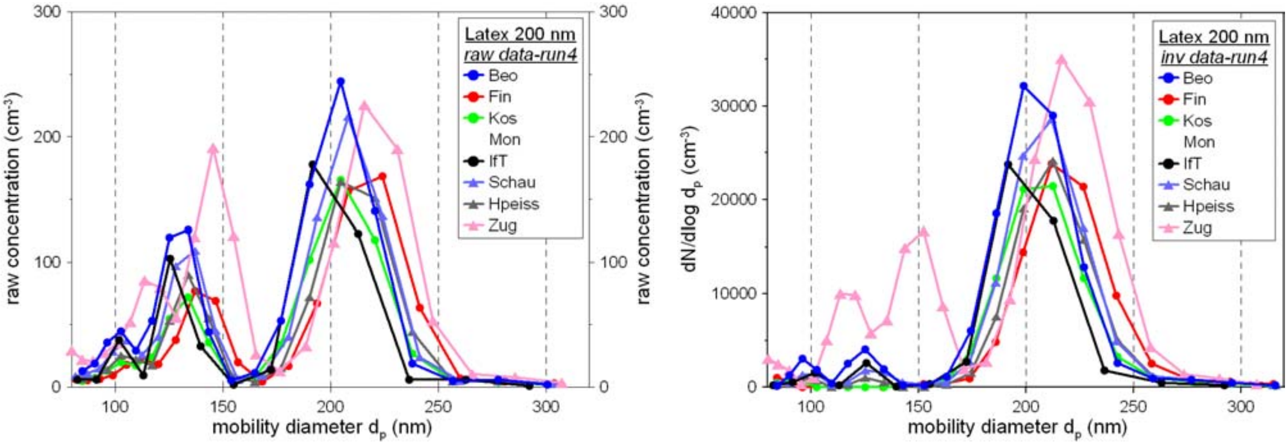

Fig.1: Raw and inverted particle size distributions (left and right panel) from the week1 systems of the 200 nm mono-disperse Latex experiment. Explanations of the different curves are given in the legends and the text.

2.3.1.2. Evaluation of the particle number size distribution and concentration measurements

From Fig.2 to Fig.4 the mean deviations of each system with respect to sizing, multi charge correction and concentration is illustrated by several bar charts.

The peak diameter in the inverted mono-disperse number size distributions range from 192 to 216 nm, which is equivalent to a maximum deviation of -4 and +8 % with respect to the nominal 200 nm Latex particle size. The Hauke DMA based SMPS uniformly overestimate the peak diameter by 6 % (Fig.2). In a subsequent test of the system it was found that an incorrect sheath flow measurement was carried out which explains the diameter shift to larger sizes.

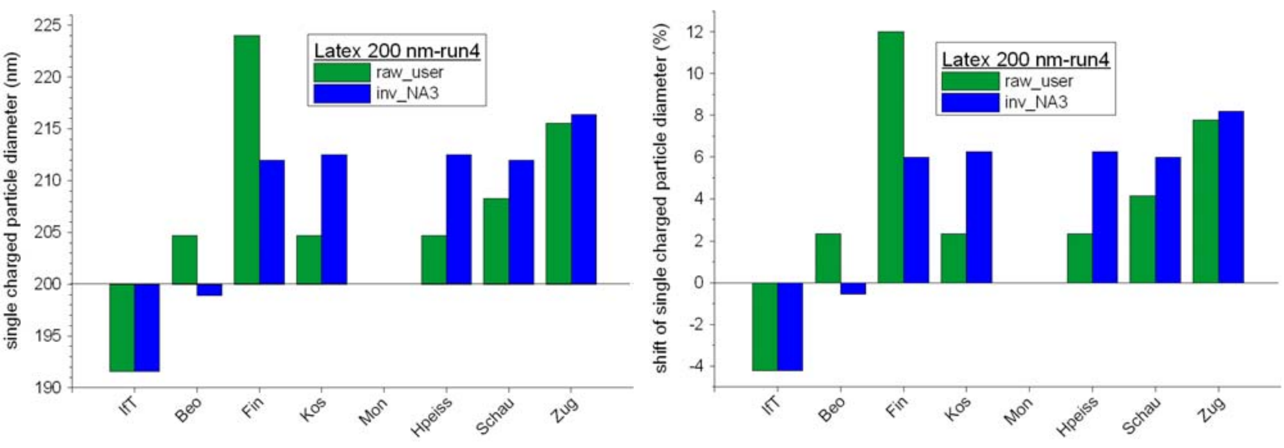

Fig.2: Measured Latex particle peak diameter of each system during week1 (left panel) and the respective relative deviation to the nominal diameter of 200 nm in % (right panel). Green and blue bars denote results from raw and NA3 inverted particle number size distributions.

Fig.3 shows the magnitude of the multi charged particle peaks related to the singly charged particle peak of raw and inverted size distributions. The comparison of raw and inverted results demonstrate the strong reduction of the multi charged particles for the TDMPS and the HAUKE DMA based SMPS due to an accurate sizing and an efficient correction implemented in the inversion. It needs to be checked why that was not achieved for the TSI DMA based system.

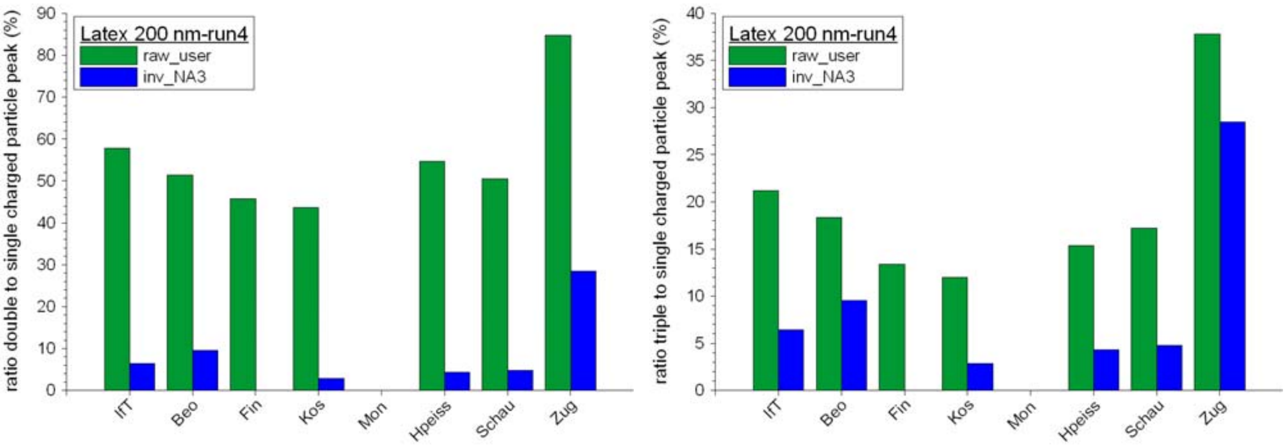

Fig.3: Magnitude of the double and triple charged peak in relation to the single charged original Latex particle peak. Green and blue bars denote results from raw and NA3 inverted particle number size distributions.

Since there was a contamination of particles smaller than 70 nm, particle concentrations were derived from the inverted number size distribution above a diameter of 80 nm (Fig.4, left panel). Due to the insufficient reduction of the multi charged particle contribution the ***Zug*** system yields a twice as high number concentration compared to the other systems. Four of five HAUKE DMA SMPS systems (***Fin***, ***Kos***, ***Schau***, ***Hpeiss***) agree better than ±15 % with the EUSAAR ***IfT*** TDMPS that was chosen here as reference, since it is the best characterized system of **week1**. A CPC derived concentration as reference could not be used due to the mentioned contamination.

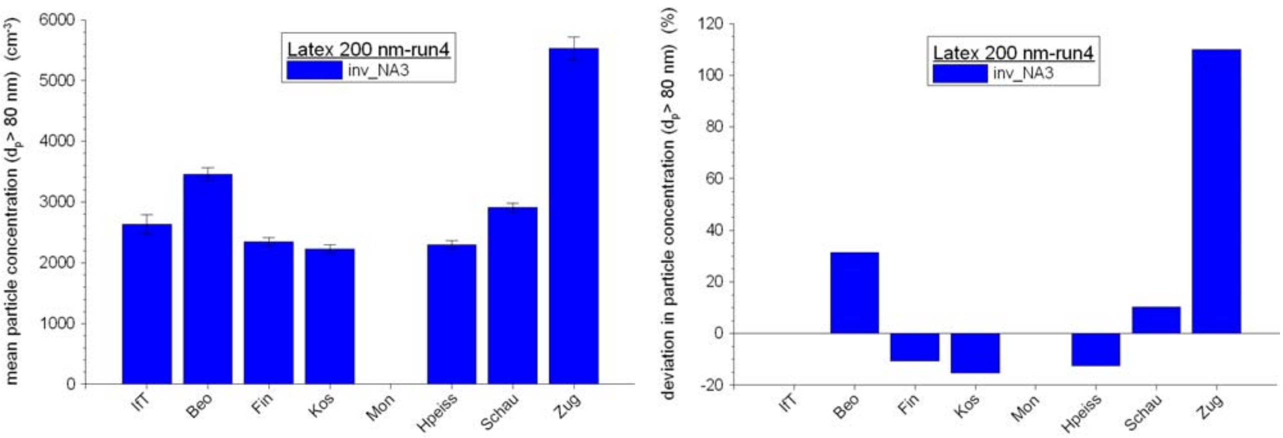

Fig.4: Left panel: Mean Latex particle concentration obtained from the NA3 inverted number size distributions for particle sizes above 80 nm. Right panel: Deviation in particle concentration of the

EUSAAR partner and German Federal Environment Agency systems in relation to the results derived from the EUSAAR IfT TDMPS.

2.3.2. Ambient aerosol particle experiment

For the presentation of results from ambient aerosol particle measurements a period is selected where all systems were operational (Run5c). This period lasted for two hours (28.02.2008 06:00 – 08:00). The data availability of the different measurement systems concerning Run5c can be taken from Tab.7.

Tab.7: Measurement duration and data availability of the week1 systems for the ambient aerosol particle experiment conducted at the 28.02.2008.

System:	measurement time	raw data	NA3 inversion
Beo	06:00 - 07:58	yes	yes
Fin	06:00 - 07:58	yes	yes
Kos	06:00 - 07:58	yes	yes
Mon	06:00 - 07:58	yes	yes
IfT	06:00 - 07:58	yes	yes
Schau	06:02 - 07:56	yes	yes
Hpeiss	06:02 - 07:56	yes	yes
Zug	06:04 - 07:58	yes	yes

All **week1** systems worked without difficulty for the whole period except the ***Mon*** system where problems with the high voltage power supply occurred so that the data points larger than a diameter of 200 nm are questionable.

The raw and inverted particle number size distributions show one maximum around 60 nm so that beside an inter-comparison with respect to concentration, the diameter position of this maximum can be compared between all systems, which is additionally done in chapter 2.3.2.2.

2.3.2.1. Averaged particle number size distributions

The mean raw and NA3 inverted particle number size distributions of each **week1** system are shown in Fig.5 (left and right panel, respectively). The raw distributions have a mono-modal shape with a mximum in the fine particle size range below 100 nm and strongly decreasing edges to smaller and larger sizes. The shapes of the raw distributions look very similar above the whole size range from 10 to 800 nm and only the distributions measured with the ***Beo*** and ***Schau*** system are systematically higher in the mode region.

The inverted number size distributions also agree well for particle diameters larger than 40 nm (agreement better than ±15 % at the mode diameter at about 50 nm). For smaller sizes the counting accuracy significantly decreases resulting in a higher discrepancy between the systems with respect to the amplitude of the distributions (agreement decreases to ± 17, ± 32 and ± 80 % at 30, 20 and 10 nm). This finding might be most likely due to different and unknown diffusional losses of small particles in the systems which needs to be further investigated. The increasing counting uncertainty additionally influences the shape of the distribution in this size range, so that 4 of the 8 systems reproduce a second maximum at smaller diameters that is larger than the primary one.

The bias of the power supply offset for the ***Mon*** system is easily seen in the inverted number size distributions (Fig.5, right panel) for particle diameters larger than 200 nm as already mentioned above.

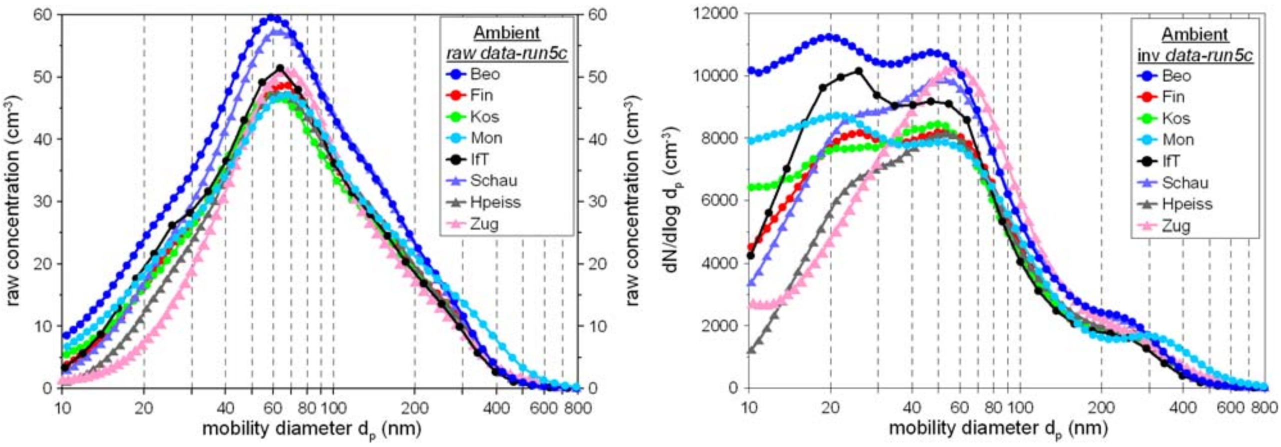

Fig.5: Raw and inverted particle size distributions (left and right panel) from the week1 systems of the ambient aerosol particle experiment. Explanations of the different curves are given in the legends and the text.

2.3.2.2. Evaluation of the particle number size distribution and concentration measurements

Fig.6 to Fig.8 provides more quantitative results with respect to the sizing and counting accuracy of the **week1** systems for the reproduction of ploy-disperse aerosol particle number size distributions.

The mode diameters inferred from the raw and inverted number size distributions are presented in Fig.6. It is obvious that the NA3 inversion shifts the mode diameter to smaller sizes relative to the raw distribution. With respect to a mode diameter averaged over all single mode diameter results, the sizing between all systems differs between -9 and +11 %. Except the ***Beo*** system, the SMPS systems that are constructed in the same way agree within ±4 %. A larger mode diameter is measured with the SMPS systems compared to the ***IfT*** TDMPS (except ***Beo***) which is again caused by the overestimation of their sheath flow setting.

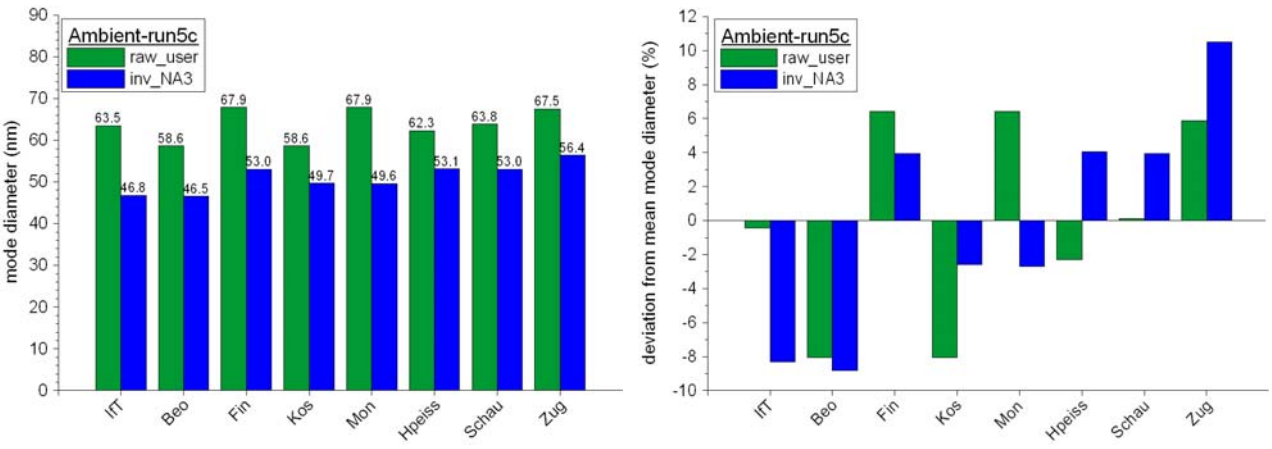

Fig.6: Measured ambient aerosol particle mode diameter of each system during week1 (left panel) and the respective relative deviation to an over-all average mode diameter in % (right panel). Green and blue bars denote results from raw and NA3 inverted particle number size distributions.

Mean number concentrations for particles diameters larger than 10 nm inferred from the inverted number size distribution of the **week1** systems are presented in the left panel of Fig.7. The dashed line denotes the mean particle concentration simultaneously measured with a CPC (TSI-3010) used as a concentration reference. The deviation to this reference is shown in the right panel of Fig.7. The ***IfT*** TDMPS measurement yields a concentration that is identical to the reference CPC reading (difference 1 %), that justifies that the concentration result of this system was used as reference for the Latex particle experiment. From the SMPS system only the ***Beo*** system overestimates (by 15 %) whereas all other systems underestimate the particle concentration. Two systems at a time under evaluate the particle concentration less than 10 % (***Mon***, ***Schau***), 20 % (***Fin***, ***Kos***) and 30 % (***Hpeiss***, ***Zug***).

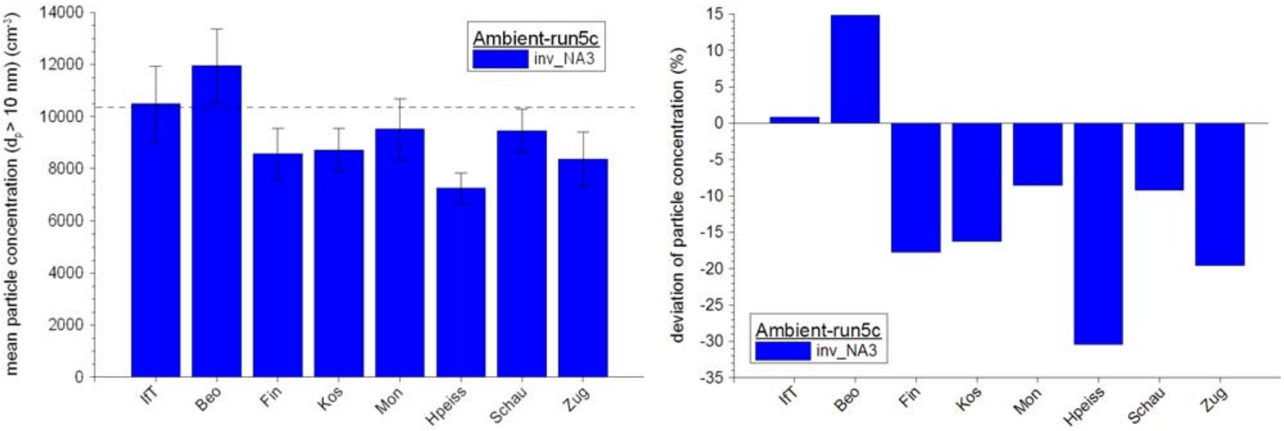

Fig.7: Left panel: Mean ambient aerosol particle concentration obtained from the NA3 inverted number size distributions of the week1 systems for particle sizes larger than 10 nm. The dashed line denotes the mean particle concentration simultaneously measured with a CPC (TSI-3010). Right panel: Deviation in particle concentration of the week1 systems in relation to the CPC result in %.

Fig.8 shows the particle concentration derived from all week1 systems for the particle diameter interval from 40 to 200 nm and the respective deviation related to the ***IfT*** TMPS. This information is helpful to evaluate to what extend the different counting efficiency at small particle diameters of the various systems is responsible for the deviations in the determination of the total particle concentration.

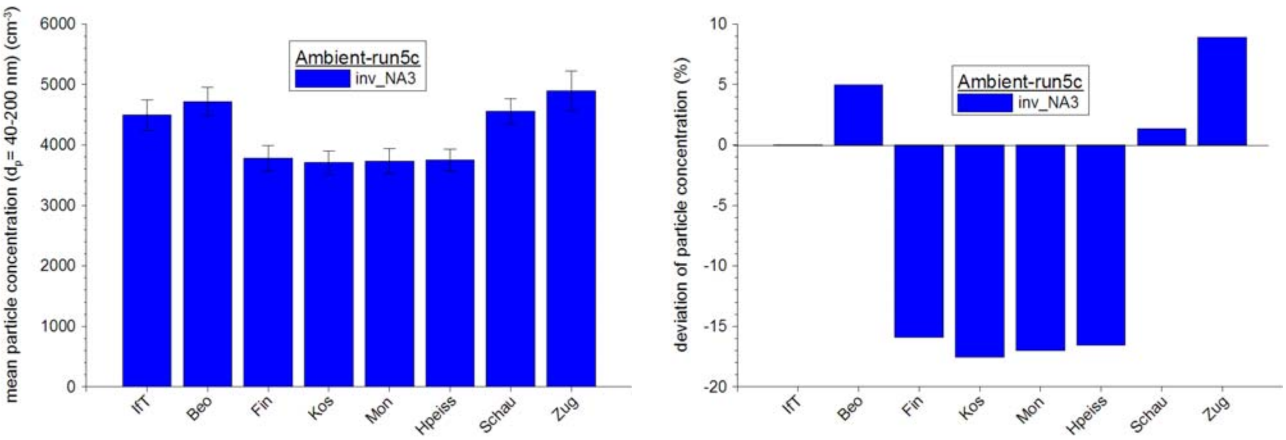

Fig.8: Left panel: Mean ambient aerosol particle concentration obtained from the NA3 inverted number size distributions of the week1 systems for a particle size range 40 - 200 nm. Right panel: Deviation in particle concentration of the week1 systems in relation to the IfT TDMPS result in %.

For this size range 4 SMPS systems (***Fin***, ***Kos***, ***Mon***, ***Hpeiss***) measure the identical concentration within the statistical uncertainty but which is about 15 % lower than the ***IfT*** TDMPS value. These findings point to an incorrect measurement of the aerosol flow for these SMPS systems. The ***Beo***, ***Schau*** and ***Zug*** system agree much closer with the ***IfT*** TDMPS overestimating the reference concentration only by about 5, 2 and 8 %.

2.4. Results week2

2.4.1. Lab experiment with mono-disperse 200 nm Latex particles

The selected 200 nm Latex particle experiment was conducted at the 07.03.2008 from 00:00 to 03:00. All systems were operational during this time. The data availability of the different measurement systems concerning this lab experiment can be taken from Tab.8.

Tab.8: Measurement duration and data availability of the week2 systems for the 200 nm mono-disperse Latex experiment.

System:	measurement period	raw data	USER inversion	NA3 inversion
Bol	00:00 - 02:59	yes	yes	yes
Ispra	00:09 - 02:55	yes	yes	yes
NILU	00:01 - 02:58	yes	yes	yes
Vesz	00:02 - 02:58	yes	yes	yes
Cler	00:00 - 02:59	yes	yes	yes
PSI	00:01 - 02:55	yes	yes	yes
Harw	00:00 - 02:59	yes, no raw concentration	yes	*no*
Ath	00:00 - 02:59	yes	yes	yes
IfT	00:02 - 02:59	yes	yes	yes
Hel	00:06 - 02:52	yes	yes	yes
Lund	00:00 - 02:59	yes	yes	yes

Again, the main objectives that can be studied by carrying out an experiment with mono-disperse particles are the particle sizing as well as the correction capability of measured multi charged particles by the respective inversion routines, which is done in chapter 2.4.1.2.

2.4.1.1. Averaged particle number size distributions

Mean raw, user and NA3 inverted particle number size distributions measured and derived from the **week2** systems are shown in Fig.9 (upper, middle and lower panel, respectively).

As already mentioned, there exists no raw data in concentration per bin for the ***Harw*** system, so that the respective raw size distribution is linked to the right axis. It is obvious that the ***Bol*** system acquired the raw data with an inappropriate size resolution, i.e. the evaluation of this system for the mono-disperse particle measurement is rather meaningless. For the ***Hel*** system only the low flow mode measurements were taken into account, since only operation mode measured the 200 nm particle peak. The double and triple charged particles peaks measured by the **week2** systems are rather similar with respect to size position and magnitude except for the ***Cler*** (shift to smaller sizes) and the ***PSI*** (twice as high raw concentration) system.

In the middle panel of Fig.9 it is seen that the user inversion of ***PSI*** is not sufficiently able to reduce the multi charged peaks although the common NA3 inversion is (Fig.8. lower panel). Moreover, the user inversion of ***Lund*** produces oscillations for the mono-disperse data set leading to negative values, which does not occur when the common NA3 inversion is applied. On the other hand, the reasonable number size distribution obtained with the NILU user inversion could not be reproduced by the common NA3 inversion.

The inverted number size distribution inferred from the ***IfT*** system is only shown in the lower panel, since user and common inversion are identical in this case. No common NA3 inversion could be carried out for the ***Harw*** system due to the lack of suitable raw data.

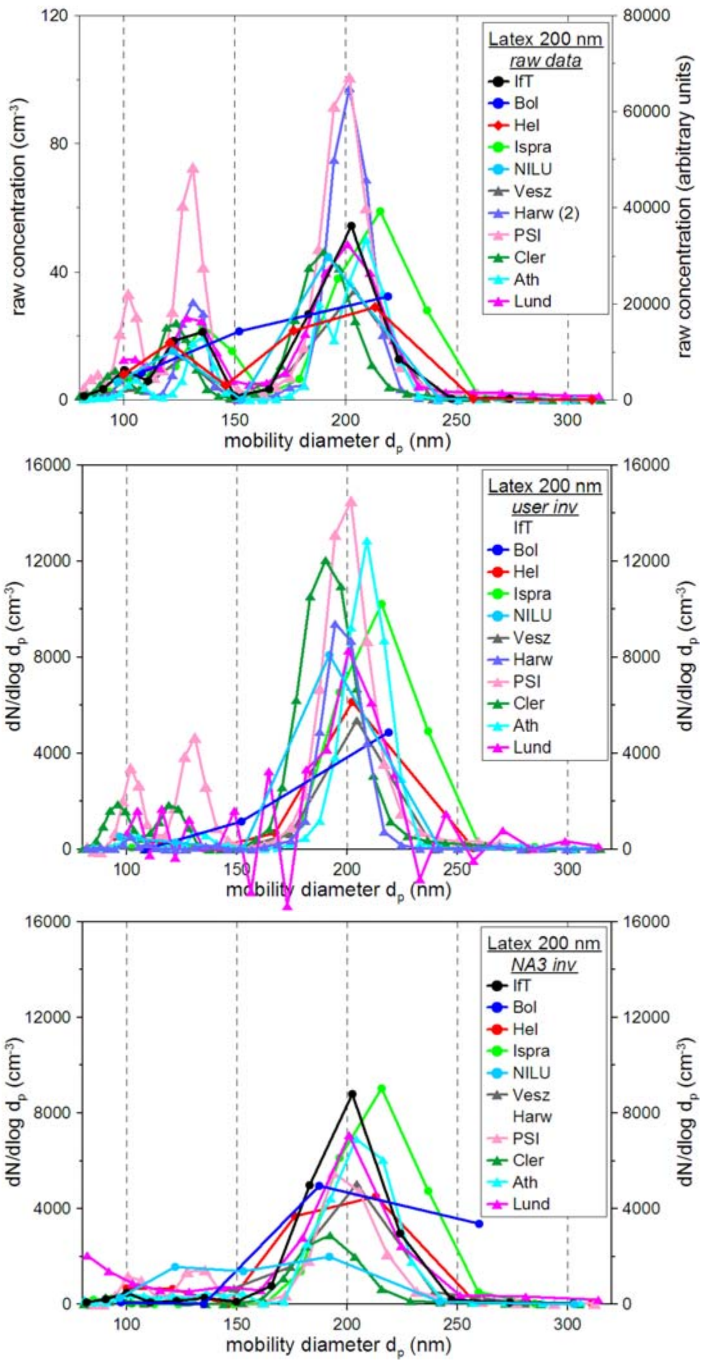

Fig.9: Mean raw, user and NA3 inverted particle number size distributions (upper, middle and lower panel, respectively) from the **week2** systems of the 200 nm mono-disperse Latex experiment. Explanations of the different curves are given in the legends and the text.

2.4.1.2. Evaluation of the particle number size distribution and concentration measurements

From Fig.10 to Fig.12 the mean deviations of each system with respect to sizing, multi charge correction and concentration is illustrated by several bar charts.

The peak diameter in the inverted mono-disperse number size distributions range from 190 to 216 nm (not taking account the low resolution ***Bol*** system), which is equivalent to a maximum deviation of -5 and +8 % with respect to the nominal 200 nm Latex particle size (cf. Fig.10). This is the same range that was already observed for the **week1** systems (cf. 2.3.1.2.) There exists no trend in the sizing deviations for the TSI-DMA based systems whereas 5 of 6 HAUKE-DMA based systems overestimate the nominal Latex particle diameter.

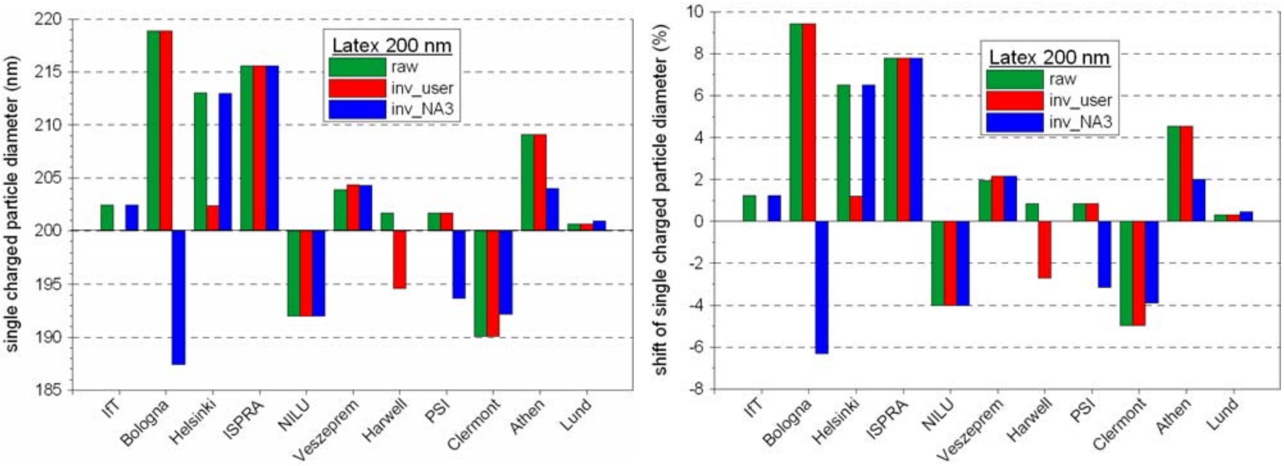

Fig.10: Measured Latex particle peak diameter of each system during week2 (left panel) and the respective relative deviation to the nominal diameter of 200 nm in % (right panel). Green, red and blue bars denote results from raw, user and the common NA3 inverted particle number size distributions.

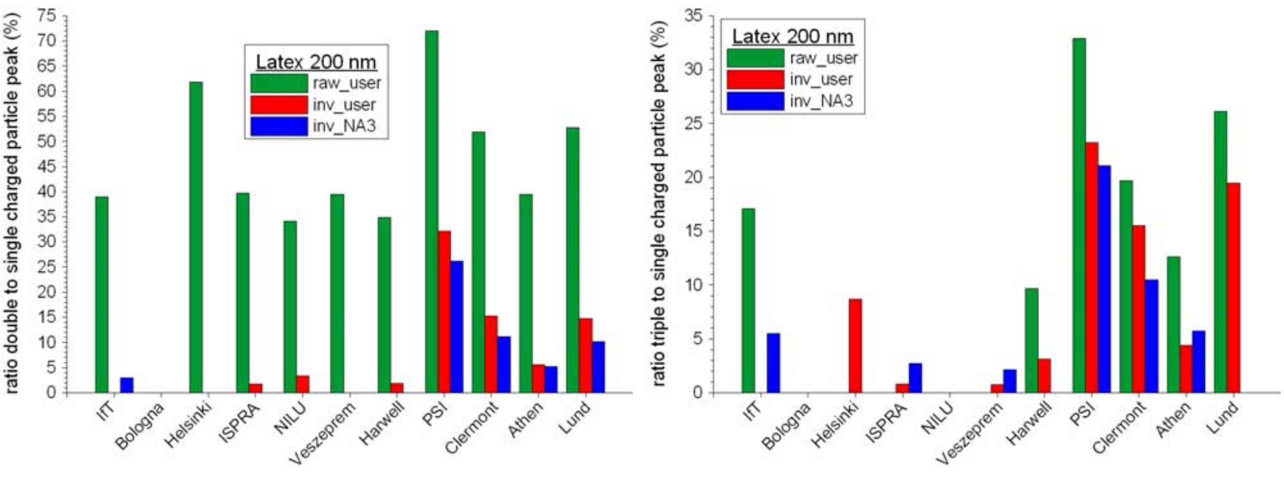

Fig.11: Magnitude of the double and triple charged peak in relation to the single charged original Latex particle peak. Green, red and blue bars denote results from raw, user and NA3 inverted particle number size distributions.

Fig.11 shows the magnitude of the multi charged particle peaks related to the singly charged particle peak of raw, user and common NA3 inverted size distributions. Similar to Fig.3, the amplitude of the double and triple charged peaks are mostly in the range of 40 to 60 % and 15 to 25 % of the single charged peak, respectively. After the inversions the multi charged peaks can not be resolved anymore for most DMPS systems (Fig.11). In general, the common NA3 inversion more efficiently reduces the multi charge particle peaks by redistributing those counts into the original Latex particle peak but the remaining amplitudes are somewhat higher than those of the **week1** systems.

As already mentioned before, there was a contamination of particles smaller than 70 nm, so that particle concentrations were derived from the inverted number size distribution above a diameter of 80 nm (Fig.12, left panel). For most systems the results from the individual and the common inversion agree satisfactorily. This is valid for ***Bol***, ***Hel***, ***Ispra***, ***Vesz***, ***Ath***. Larger discrepancies exist for ***NILU***, ***PSI***, ***Cler*** and ***Lund*** where the latter is the only one where the NA3 inversion yields higher concentrations than the user one.

In the right panel of Fig.12, the relative deviations are shown with respect to the concentration obtained from the ***IfT*** TDMPS of 826 particles cm^{-3} used as an arbitrary reference.

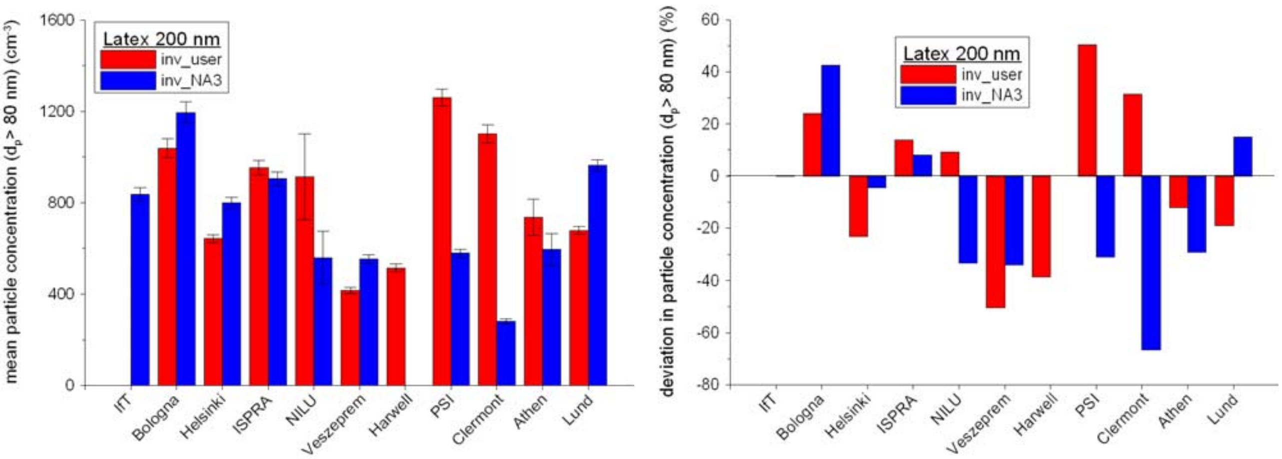

Fig.12: Left panel: Mean Latex particle concentration obtained from the individual user and the common NA3 inverted number size distributions for particle sizes above 80 nm. Right panel: Deviation in particle concentration in relation to the results derived from the IfT TDMPS.

2.4.2. Ammonium sulphate particle experiment

Tab.9: Measurement duration and data availability of the week2 systems for the AMSU lab experiment.

System:	measurement period	raw data	USER inversion	NA3 inversion
Bol	09:30 - 11:40	yes	yes	yes
Ispra	09:34 - 11:38	yes	yes	yes
NILU	09:31 - 11:35	yes	yes	yes
Vesz	09:34 - 11:31	yes	yes	yes
Cler	09:20 - 11:59	yes	yes	yes
PSI	09:23 - 11:34	yes	yes	yes
Harw	09:20 - 11:59	yes, no raw concentration	yes	*no*
Ath	09:22 - 11:59	yes	yes	yes
IfT	--	no	no	no

Hel	09:26 - 11:59	yes	yes	yes
Lund	09:20 - 11:48	yes	yes	yes

In order to evaluate the sizing and counting accuracy of the **week2** systems for a poly-disperse particle population but still under controlled, constant conditions an additional lab experiment with ammonium sulphate aerosol particles (AMSU) were carried out. This experiment took place at the 08.03.2008 from 09:20 to 12:00. The data availability of the different measurement systems concerning this lab experiment can be taken from Tab.9.

2.4.2.1. Averaged particle number size distributions

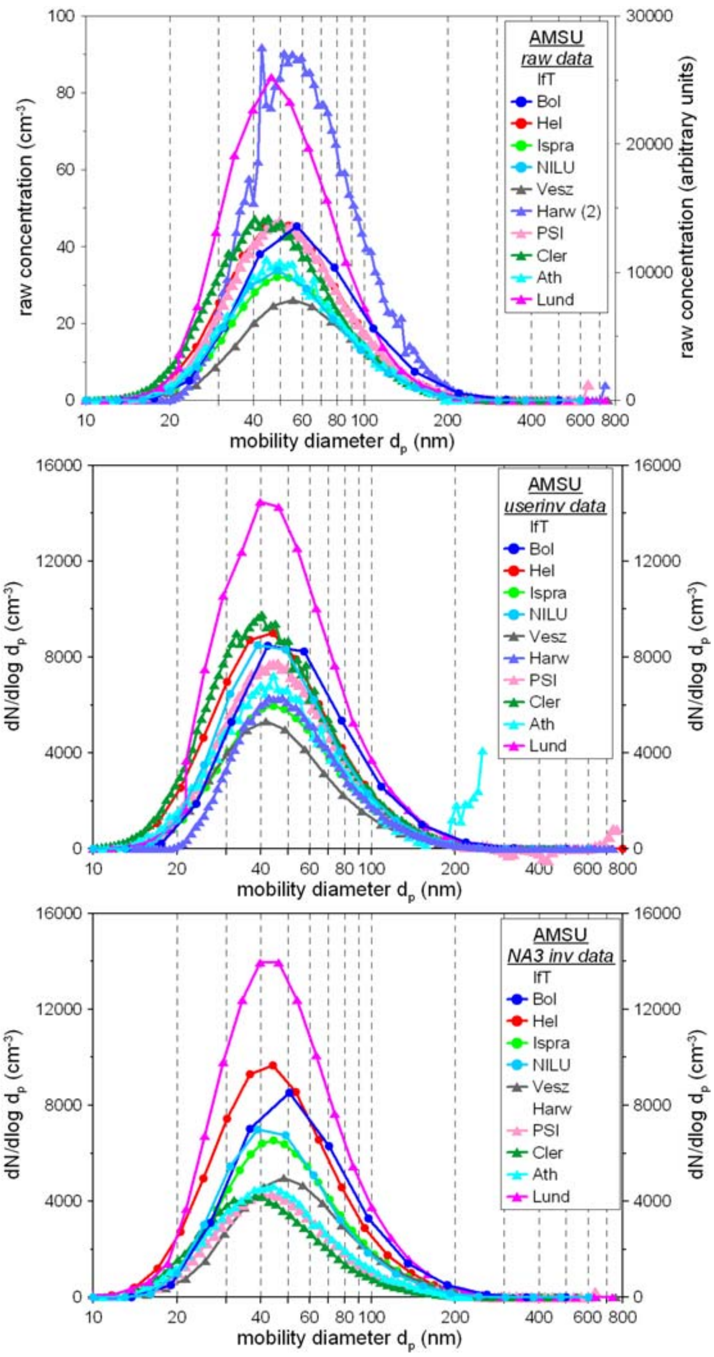

Fig.13: Mean raw, user and NA3 inverted particle number size distributions (upper, middle and lower panel, respectively) from the **week2** systems of the AMSU lab experiment. Explanations of the different curves are given in the legends and the text.

Mean raw, user and NA3 inverted particle number size distributions measured and derived from the **week2** systems are shown in Fig.13 (upper, middle and lower panel, respectively). The AMSU size distribution has one mode between 20 and 200 nm with a maximum around 50 nm. Despite this simple mono-modal shape the inverted number size distributions derived from the **week2** systems (the ***IfT*** TDMPS was not operated in this experiment) show some variation in mode diameter and number concentration, which will be further illuminated in the following section. The individual user inversions of ***Ath*** and ***PSI*** have difficulties with the reproduction of the size distribution for particle diameters larger than 200 nm (Fig.13, middle panel).

2.4.2.2. Evaluation of the particle number size distribution and concentration measurements

In Fig.14 to Fig.15 the mean deviations of each system with respect to sizing and concentration is illustrated by several bar charts.

The peak diameter of the raw and inverted size distributions are shown in the left panel of Fig.14. From all user and common NA3 inversions an average mode diameter of 44 nm was determined and used as reference to derive relative sizing deviations for each **week2** system. This is presented in the right panel of Fig.14. Compared to the Latex experiment, the relative shifts of the much smaller mode diameter is in the same range for the user inversions (< ±10 %) but larger for the common NA3 inversions. However, not all combinations of system und type of inversion show a systematic trend concerning under or overestimation with respect to sizing.

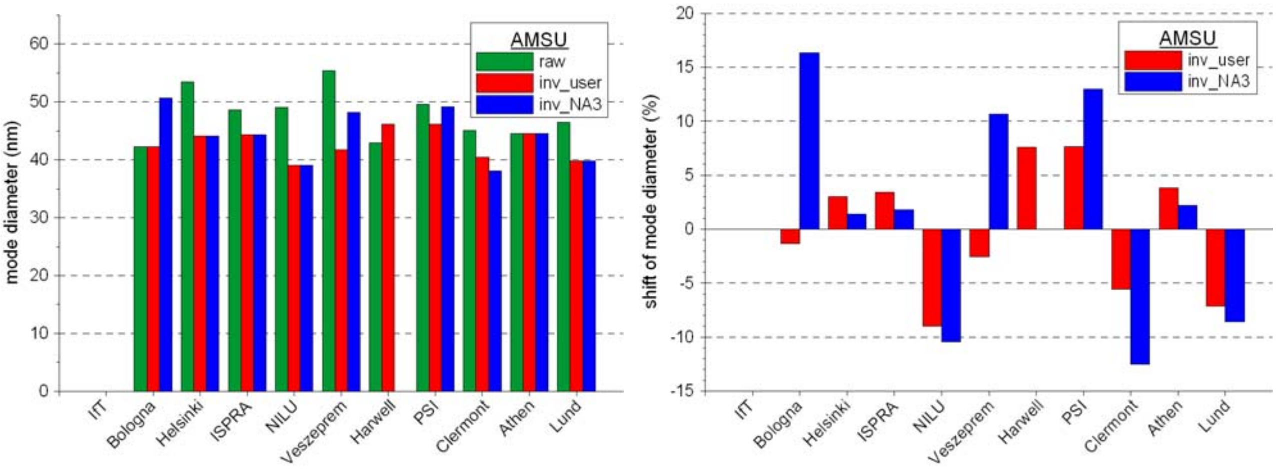

Fig.14: Measured AMSU mode diameter of each system during week2 (left panel) and the respective relative deviation to an average diameter of 44 nm in % (right panel). Green, red and blue bars denote results from raw, user and the common NA3 inverted particle number size distributions.

The particle concentrations for d_p> 10 nm inferred from the inverted number size distributions and the resulting deviation from the concentration directly measured with a CPC TSI-3010 are presented in Fig.15. In general the concentrations derived from the individual and the common NA3 inversion agree for the same system except the TSI DMA based systems where the NA3 inversion yields rather small mean values. With regard to the user inversions, 9 systems agree within ±40 %

and 5 systems agree within ±20 % with the CPC measured mean concentration. Only the Lund system needs to be regarded as an outlier due to its overestimation at about 70 %.

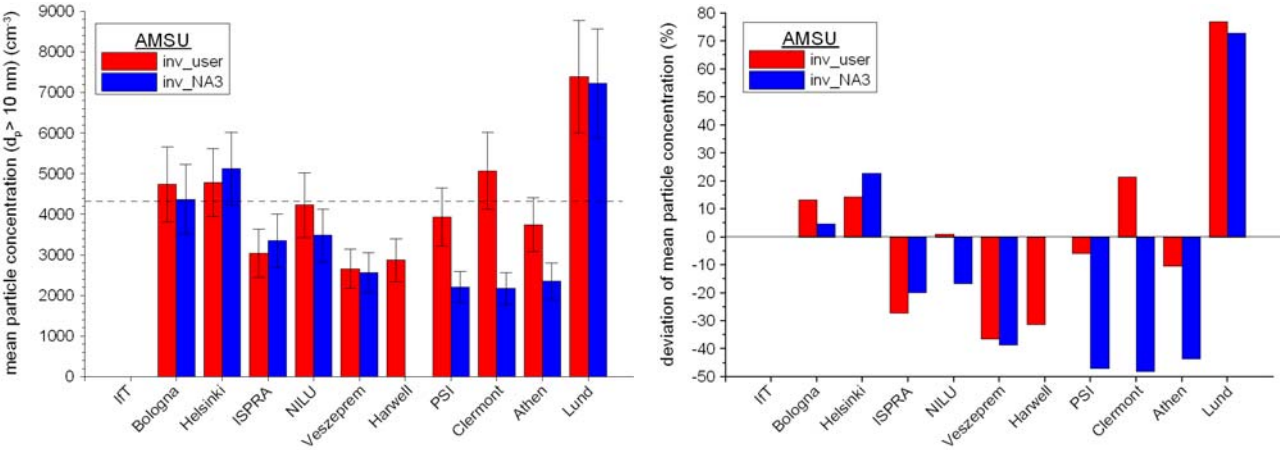

Fig.15: Left panel: Mean AMSU particle concentration obtained from the individual user and the common NA3 inverted number size distributions for particle sizes above 10 nm. Dashed line denotes particle concentration measured by a CPC TSI-3010. Right panel: Deviation in particle concentration in relation to the results derived from the CPC TSI-3010.

2.4.3. Ambient aerosol particle experiment

For the presentation of results from ambient aerosol particle measurements a period (Period 2) is selected where all systems were operated except the ***IfT*** TDMPS. This period lasted for one and a half hour (09.03.2008 13:30 – 15:00). The data availability of the different measurement systems concerning Period 2 can be taken from Tab.10.

Tab.10: Measurement duration and data availability of the week2 systems for the ambient aerosol particle experiment conducted at the 09.03.2008.

System:	measurement period	raw data	USER inversion	NA3 inversion
Bol	13:55 - 14:59	yes	yes	yes
Ispra	13:31 - 14:59	yes	yes	yes
NILU	13:31 - 14:57	yes	yes	yes
Vesz	13:36 - 14:59	yes	yes	yes
Cler	13:30 - 14:59	yes	yes	yes
PSI	13:32 - 14:59	yes	yes	yes
Harw	13:31 - 14:59	yes, no raw concentration	yes	*no*
Ath	13:33 - 14:23	yes	yes	yes
IfT	--	no	no	no
Hel	13:32 - 14:59	yes	yes	yes
Lund	13:30 - 14:59	yes	yes	yes

No difficulties were noted for all the participating **week2** systems during this experiment run. The raw and inverted particle number size distributions show a main maximum between 100 and 200 nm. The raw distribution have a smooth declining shoulder towards smaller particle sizes that is reproduced as a second maximum in some inverted number size distribution between 10 and 20 nm. Similar to the experiments discussed above an inter-comparison with respect to concentration and the diameter position of the accumulation mode maximum between all systems is presented in chapter 2.4.3.2.

2.4.3.1. Averaged particle number size distributions

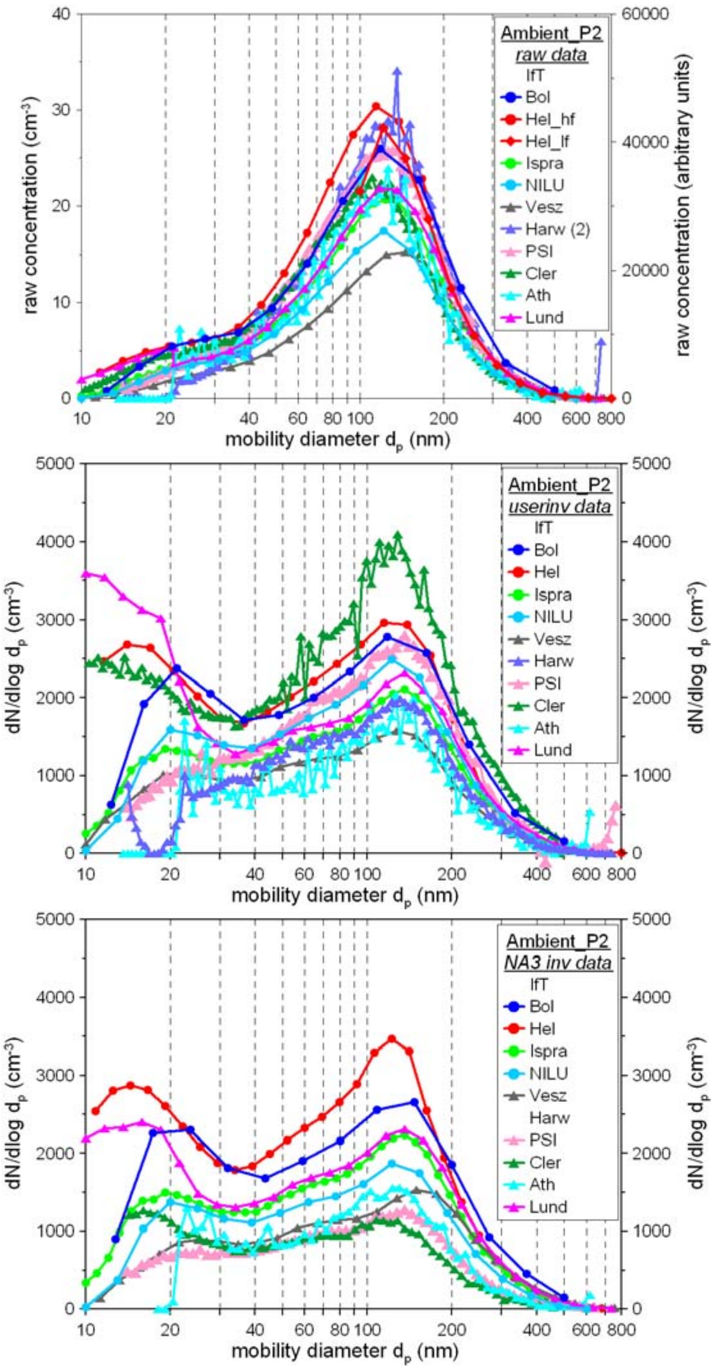

Fig.16: Raw, user and common NA3 inverted particle size distributions (upper, middle and lower panel) from the week2 systems of the ambient aerosol particle experiment. Explanations of the different curves are given in the legends and the text.

The mean raw, user and NA3 inverted particle number size distributions of the **week2** systems are shown in Fig.16 (upper, middle and lower panel, respectively). The raw distributions look quite similar and are within a difference of a factor two. It is obvious that the ***Ath*** and ***Harw*** systems are just starting counting at a diameter of 20 nm.

The inverted number size distributions agree well concerning their shapes for particle diameters larger than 40 nm, but the quantitative agreement is less satisfactory (around ±40 % at the mode diameter of about 130 nm). For sizes below 40 nm the agreement further decreases resulting in a higher discrepancy between the systems with respect to the amplitude of the distributions (variations of ± 43, ± 50 and ± 100 % at 30, 20 and 10 nm). This finding might be most likely due to different and unknown diffusional losses of small particles in the systems which was already concluded for the **week1** systems. The increasing counting uncertainty again influences the shape of the distributions in this size range, so that 6 of the 10 systems reproduce a second maximum at smaller diameters.

2.4.3.2. Evaluation of the particle number size distribution and concentration measurements

Fig.17 to Fig.19 provides more quantitative results with respect to the sizing and counting accuracy of the **week2** systems for the reproduction of the ambient aerosol particle number size distributions.

The peak diameter of the raw and inverted size distributions are shown in the left panel of Fig.17. From all user and common NA3 inversions an average mode diameter of 129 nm was determined and used as reference to derive relative sizing deviations for each **week2** system. This is presented in the right panel of Fig.14. Compared to the AMSU experiment, the relative shifts of the somewhat larger mode diameter is in the same range for the user inversions (< ±10 %) and for the common NA3 inversions (< ±15 %). This time, most combinations of system und type of inversion show the same systematic trend concerning under or overestimation with respect to sizing in comparison to the AMSU experiment.

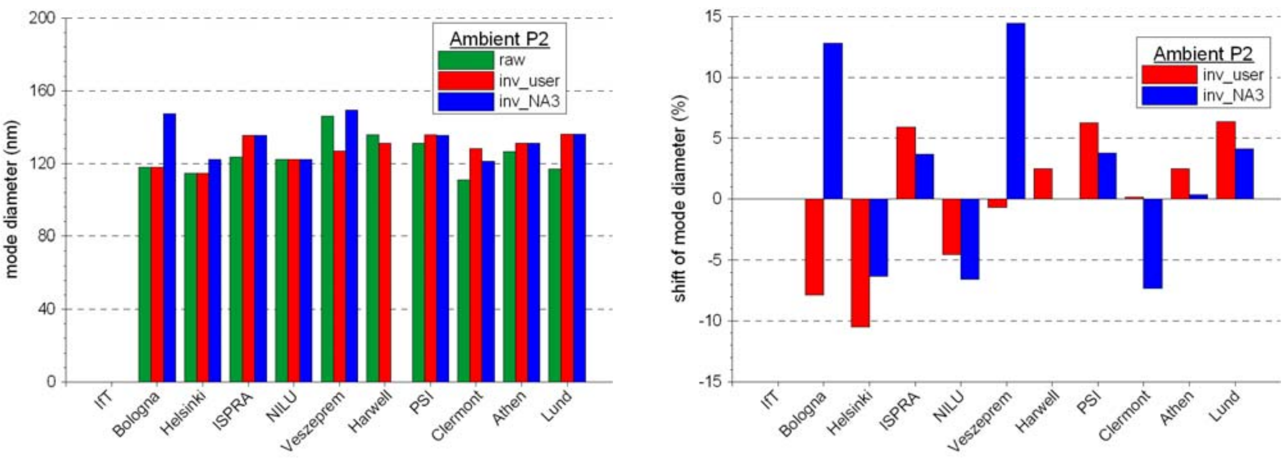

Fig.17: Measured ambient aerosol particle mode diameter of each system during week2 (left panel) and the respective relative deviation to an over-all average mode diameter in % (right panel). Green, red and blue bars denote results from raw, user and common NA3 inverted particle number size distributions.

The particle concentrations for $d_p > 10$ nm inferred from the inverted number size distributions and the resulting deviation from the concentration directly measured with a CPC TSI-3010 are presented in Fig.18. Similar to the AMSU experiment, the concentrations derived from the individual and the common NA3 inversion agree for the same system within the statistical uncertainty except for the TSI DMA based systems where the NA3 inversion yields much smaller mean values. But in contrast to the AMSU experiment, the particle concentration is substantially underestimated by most systems (9 of 10 systems). With regard to the user inversions, this time 4 systems count less particles within 20 %, 7 systems within 40 % and 3 systems count more than 40 % less particles in relation to the CPC measured mean concentration (Fig.18, right panel). The main difference between this measurement and the AMSU experiment is the presence of many small particles (diameter range between 10 and 40 nm). This leads to the hypothesis that a decreasing counting efficiency for this small particle size range is the major reason of the underestimation of the particle concentration inferred from most systems. Therefore, the particle concentration in the size range 40 to 200 nm is additionally determined for the **week2** systems (Fig.19, left panel).

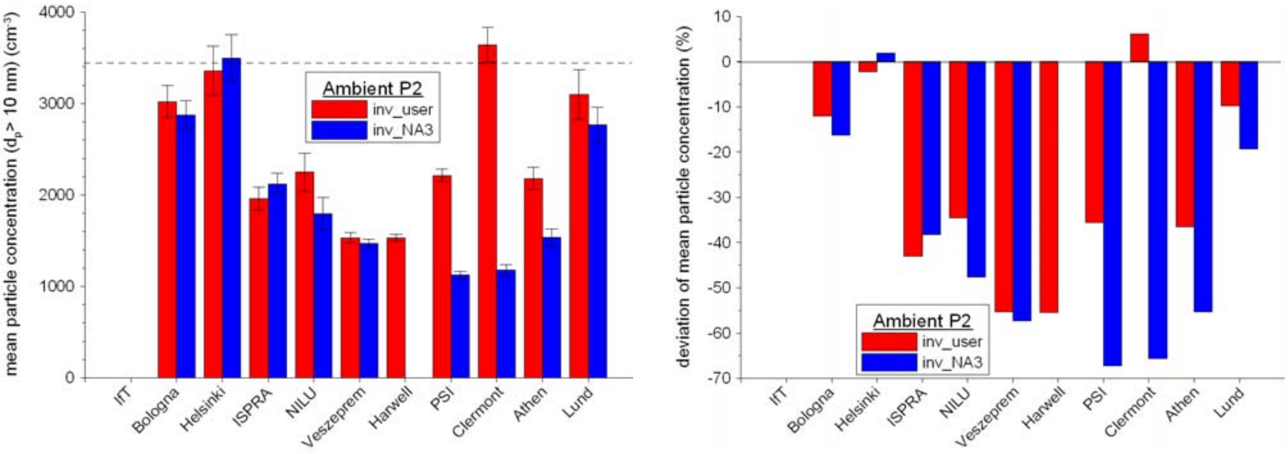

Fig.18: Left panel: Mean ambient particle concentration obtained from the individual user and the common NA3 inverted number size distributions for particle sizes above 10 nm. Dashed line denotes particle concentration measured by a CPC TSI-3010. Right panel: Deviation in particle concentration in relation to the results derived from the CPC TSI-3010.

This time the mean concentration of the ***Hel*** system is used as reference, because it showed the best agreement with the CPC result (cf. Fig.18). The deviation in number concentration measured by the other systems in relation to the Hel system is presented in the right panel of Fig.19.

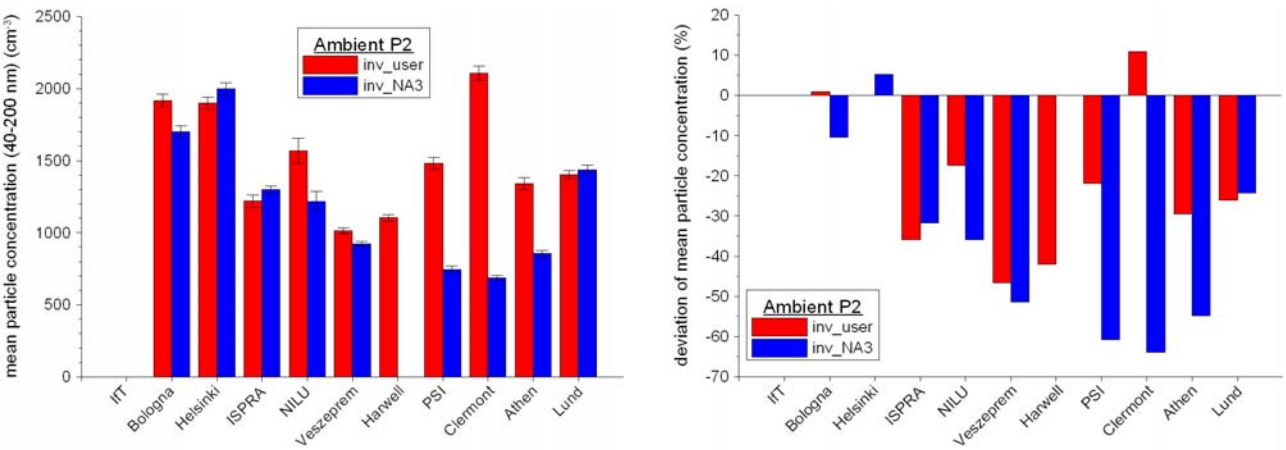

Fig.8: Left panel: Mean ambient particle concentration obtained from the individual user and the common NA3 inverted number size distributions for a particle size range of 40 - 200 nm. Right panel: Deviation in particle concentration of the week2 systems in relation to the ***Hel*** DMPS result in %.

It is obvious that still most systems reproduce lower number concentrations than the reference. However, this underestimation is less pronounced compared to Fig.18, which is an indication that this observation is indeed partly linked to a reduced counting efficiency of most **week2** systems for small particles with diameters between 10 and 40 nm. Reasons for the remaining underestimation of the particle concentration are most likely incorrect calibrated aerosol flow rates and leaks.

3. Conclusions

Shifts within ±10 % in particle size are observed during the 200 nm mono-disperse Latex particle experiments for all participating systems. These deviations are confirmed by analysing the shifts of mode diameters in poly-disperse ammonium sulphate and ambient particle experiments at smaller sizes. An even more careful sheath air calibration (better than 2 % error) carried out directly at the inlet tube and check of high voltage setting and reading could further reduce this already quite small discrepancy.

For particle diameters smaller than 20 nm, large differences are found in the shape and amplitude of the number size distributions measured by all systems. This is due to a decreasing particle counting efficiency in this size range, which could be verified by a comparison of particle concentrations derived from the systems for a particle size range of 40 – 200 nm. This might be caused by unknown diffusional losses and lead to a substantial underestimation of the measured particle concentration. This finding was more pronounced for the **week2** systems (underestimations of -55 %) and less severe for the **week1** systems (underestimations of -30 %).

The particle concentration of the less sensitive size range between 40 and 200 nm is likewise underestimated by most systems (**week2**: -45 %, **week1**: -20 %). Most likely that is caused by leaks and an incorrect aerosol flow rate calibration. These issues need more careful treatment in future measurements.

In order to achieve the information which accuracy with respect to particle sizing and counting can be achieved, the best characterized and prepared DMPS, TDMPS and SMPS systems should be inter-compared in a coming work shop.

The concept of a common NA3 inversion that is applied to all acquired raw distributions is shown to be successful in order to separate, and thus evaluate, the hardware operation of the participating systems from differences in the individual user inversions. In reverse, it would be meaningful to verify those inversions by their application to the same raw mobility distribution.