UMR
UNIVERSITY OF MISSOURI-ROLLA

Partners: UMR, MIT, Aerodyne Inc., AEDC, NASA, FAA, and HVL Assoc.

Center of Excellence for Aerospace Particulate Emissions Reduction Research

DMS500 Calibration Method for Gas Turbine Engine Sampling

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Cambridge Particle Meeting

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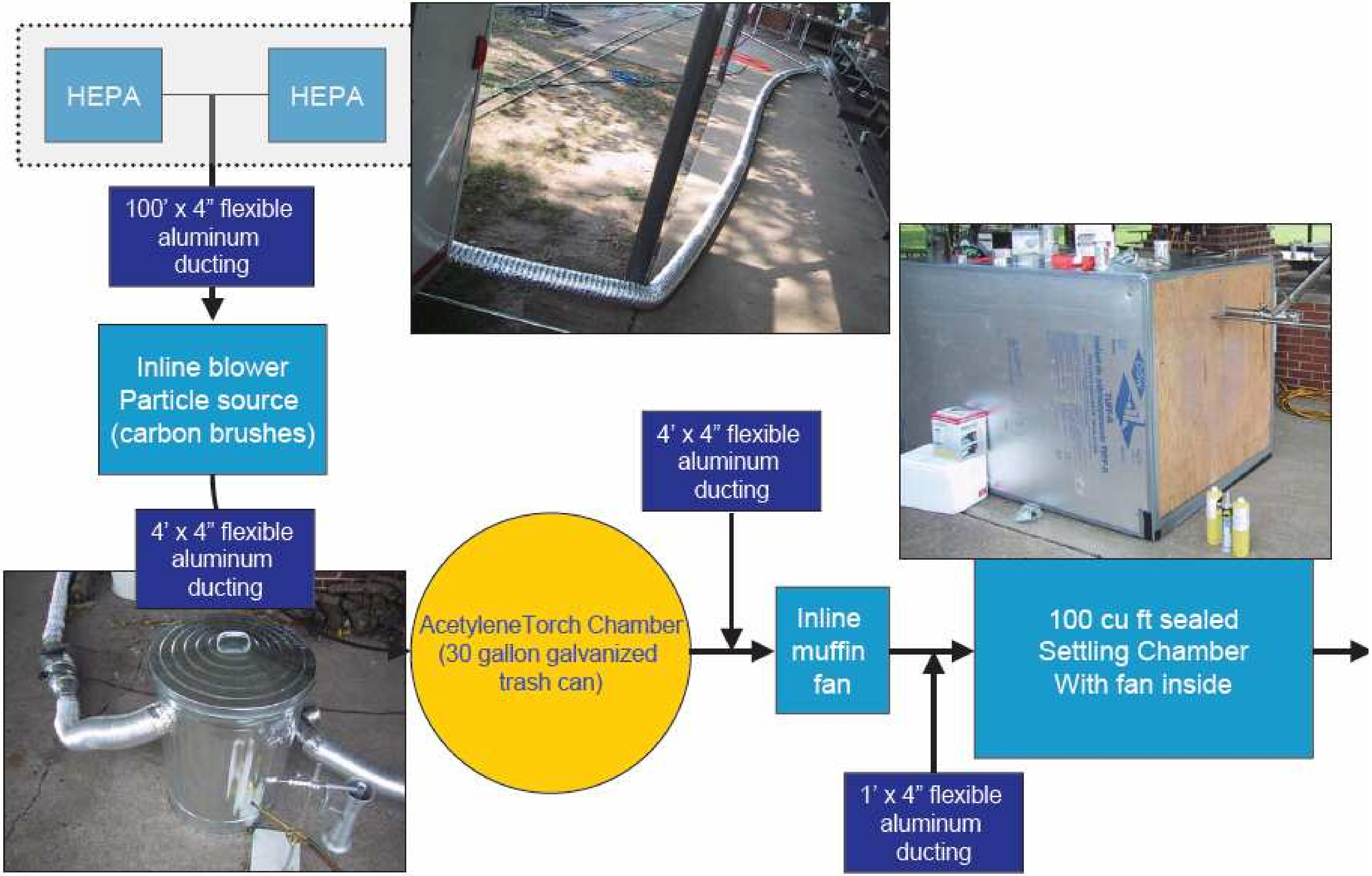
Objective

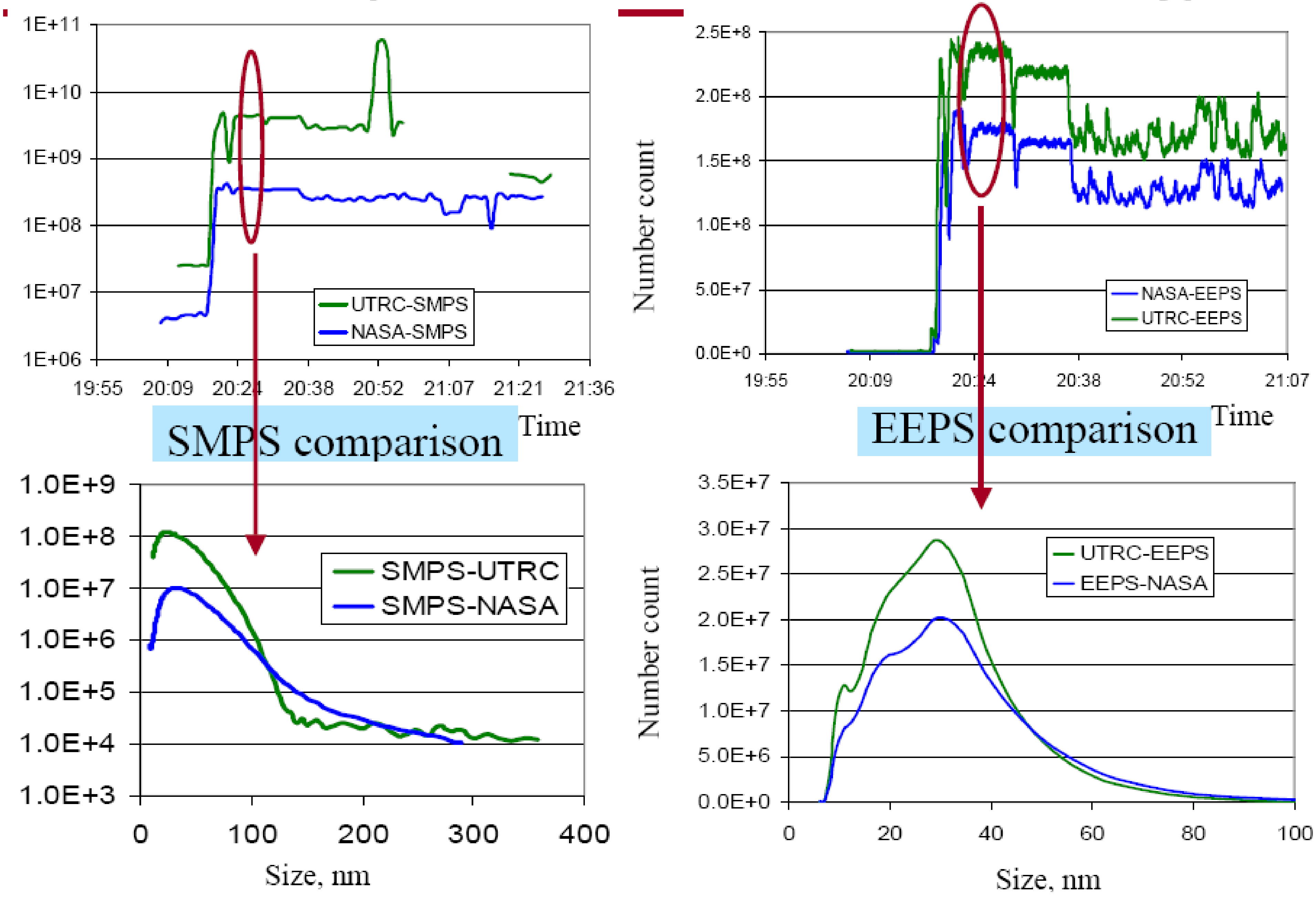
- $\{x_i, dN/dlogx_i\}$ $i=1,2,\ldots,I$
- $x'_i = Corx_i * x_i$
- $Corx = x_{PSL}/x_{instr}$
- $Corc(x_{instr}) = Conc(Ref)/Conc(Instr)$
- $dN/dlogx'_i = Corc_i * dN/dlogx_i * [\log(x_{i+1}/x_{i-1})/\log(x'_{i+1}/x'_{i-1})]$

NASA Langley Campaign

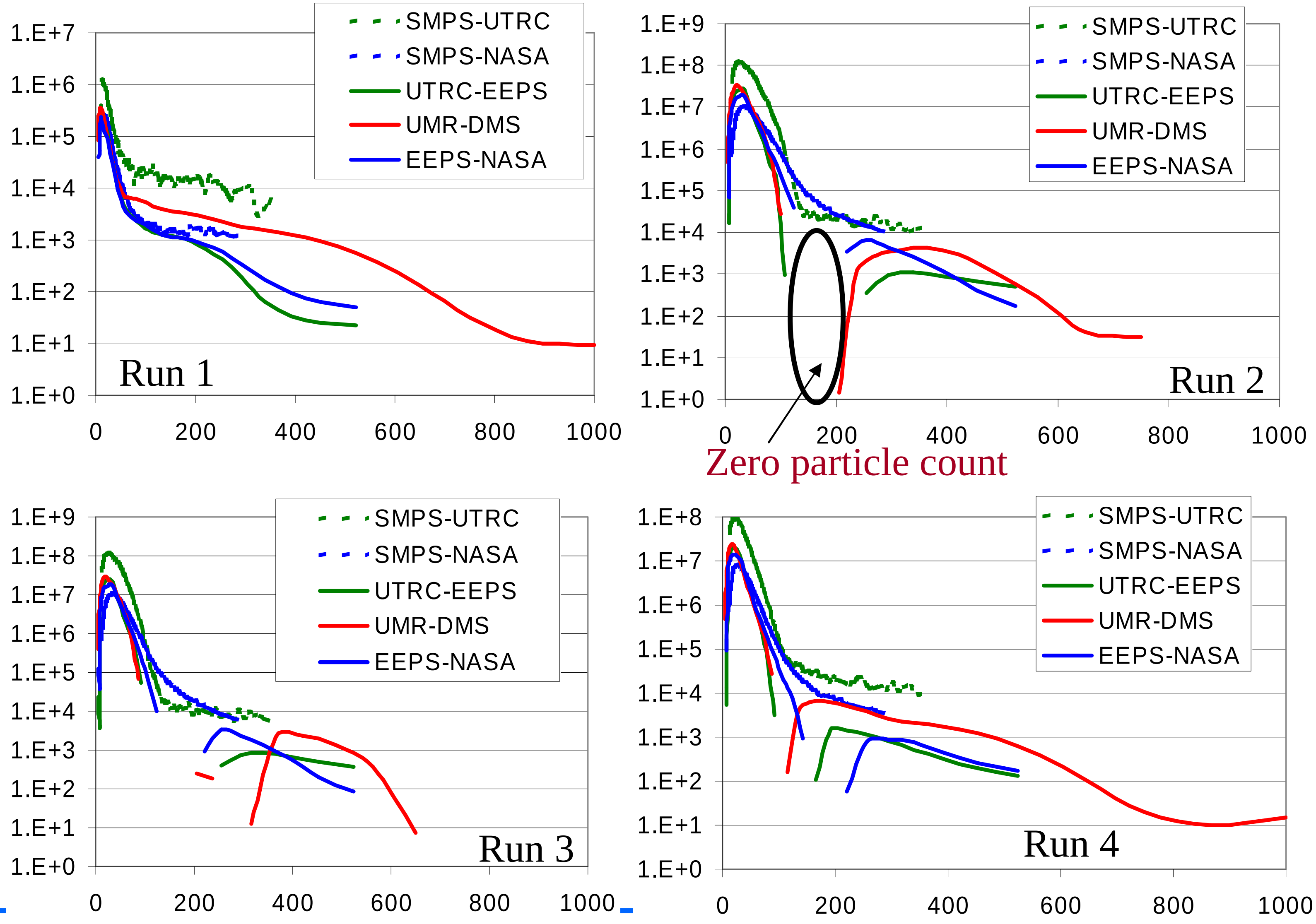
- July 2006
- Instruments
  - UMR: Two DMS500 (one)
  - NASA: SMPS, EEPS
  - UTRC: SMPS, EEPS
  - Several TSI CNC
- Objectives
  - Sample train line loss evaluation
  - Instrument Intercomparison


HEPA
HEPA
100' x 4" flexible aluminum ducting
Inline blower Particle source (carbon brushes)
4' x 4" flexible aluminum ducting
AcetyleneTorch Chamber (30 gallon galvanized trash can)
4' x 4" flexible aluminum ducting
Inline muffin fan
1' x 4" flexible aluminum ducting
100 cu ft sealed Settling Chamber With fan inside

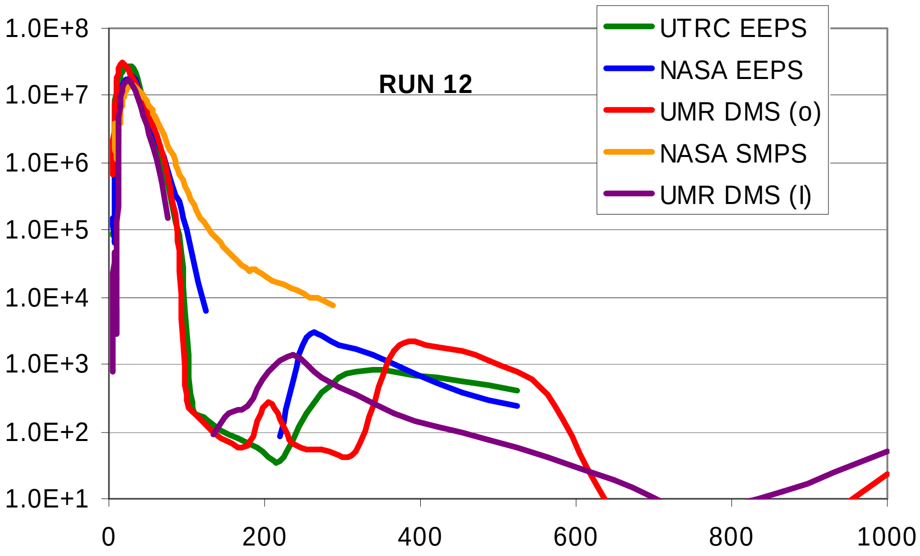
Comparison of EEPS vs. EEPS and SMPS vs. SMPS indicate discrepancies within the same instrument types

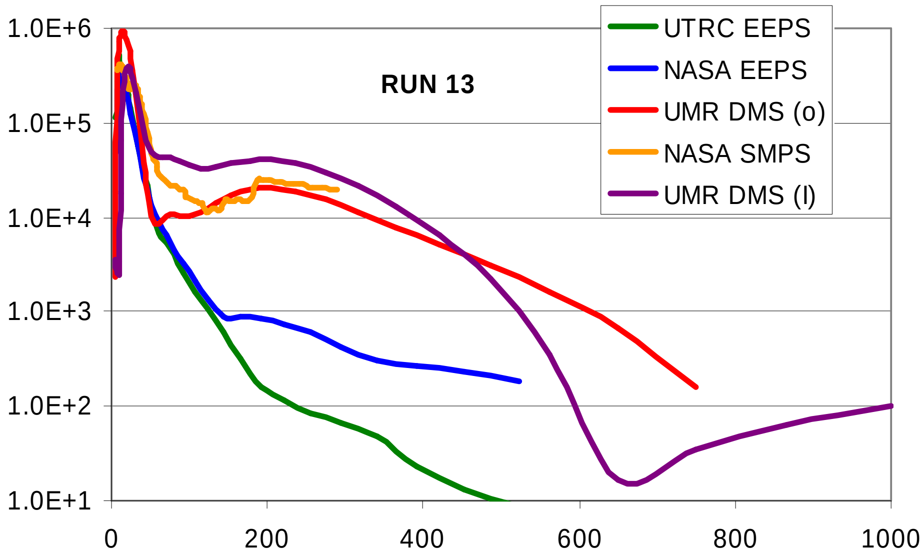


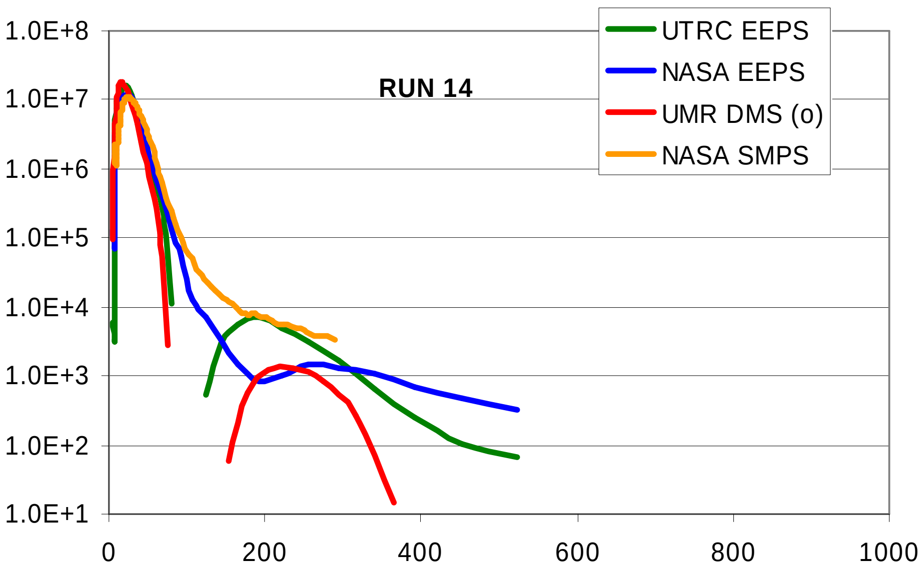
Data From 7/11/06 (Run1-4) indicate a potential issue with EEPS/DMS data at around 80-120 nm

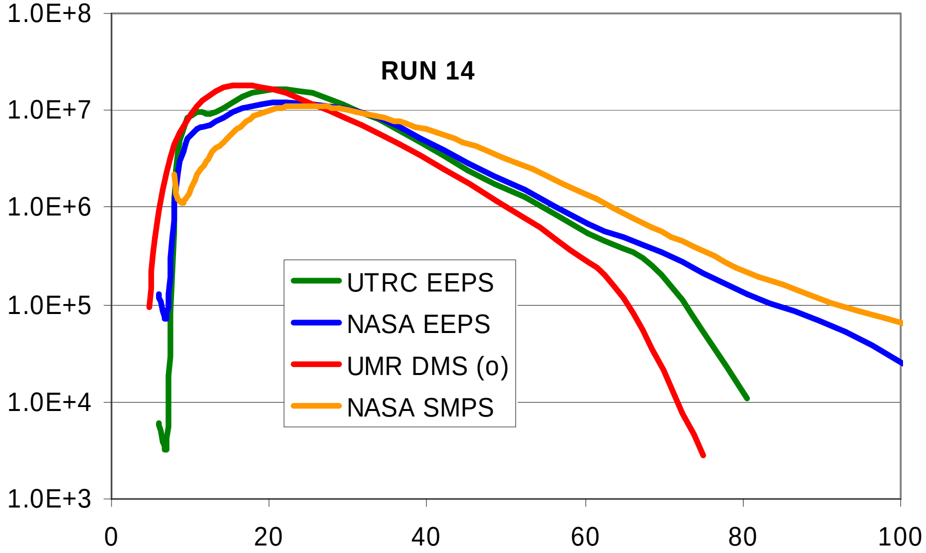


All Instruments at same location show good trends at smaller sizes but the similarity breaks at larger sizes







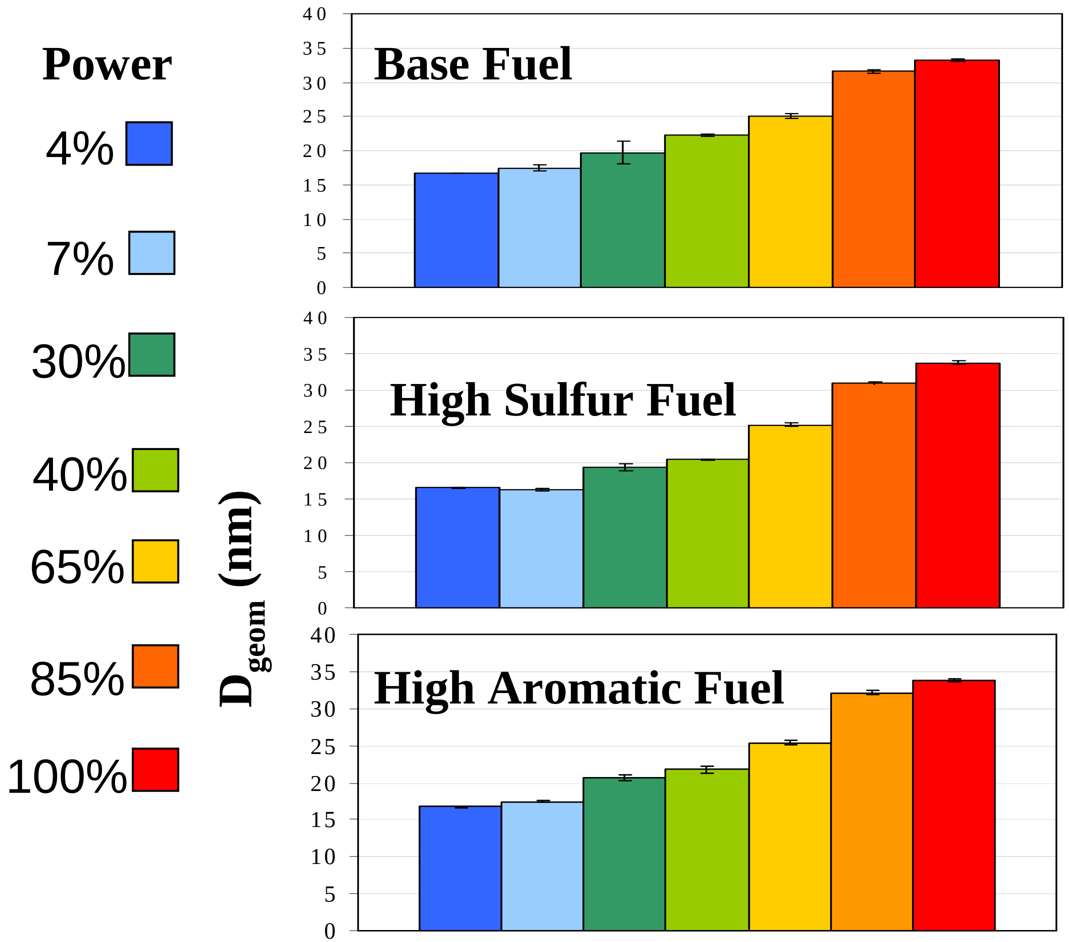


Takeaways from instrument comparison

Excellent set of data for instrument comparison

- Size distribution shows good agreement for particles smaller than 80 nm
- UTRC EEPS and one of the DMS show excellent agreement on total number of particles and distribution
- UTRC EEPS and NASA EEPS show differences of around 30% in the total counts. Size distributions also differ
- Differences between NASA and UTRC SMPS attributed to instrument setting
- With the flame on, EEPS and DMS do not perform well for large size particles. The count seem to fall off after 80 nm
  - Issue with the instrument (saturation or signal conversion)
  - Experiment with flame off did show particles in the bigger size range. Issue with flame?
- Best/Standard instruments not yet identified
- Calibration of the instruments is critical

D_{geom} vs. Power
Ploc 1m, NASA Sequences



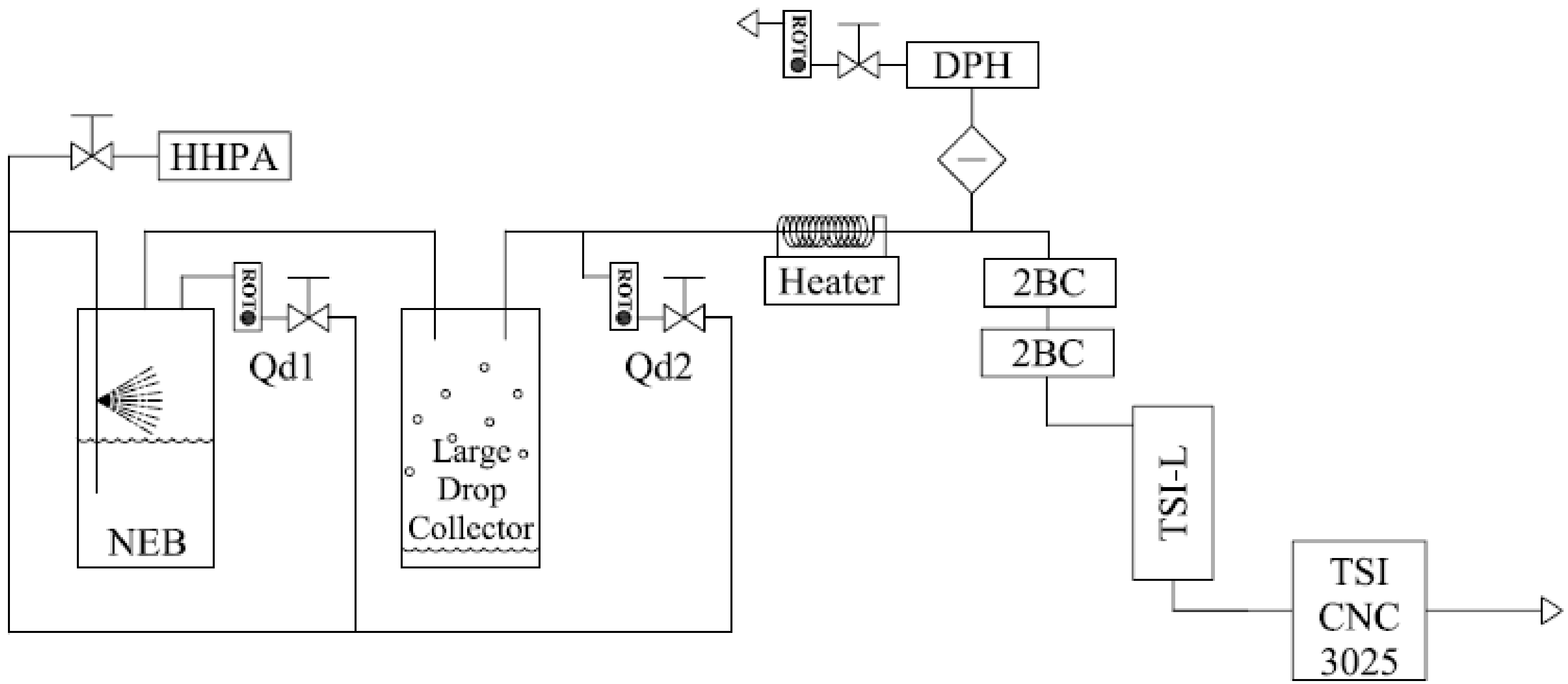
Dgeom

- Dgeom increases monotonically with power for all 3 fuels and ranges from15 ~ 34nm
- The increase for the high sulfur and high aromatic fuels is greater than that for the Base fuel by ~6-7%

Calibration Strategy

- Reference to PSL for sizing.
- Reference to TSI 3022 for concentration
- Calibrate a TSI DMA (3071) against PSL
- Use 3071 to select voltages for ZDMA
- Cut a NaCl aerosol with ZDMA and supply to DMS

Schematic1: TSI DMA Calibr



TSI DMA Calibr

Table1						
	Dp-manuf	z_psl	V	z_rk1	lnz_rk1	CorZ
Date	(nm)	(x 1e8)	(volt)	(x 1e8)		
07504	50	9.782	1066	7.503	2.015303	1.304
07504	60	6.955	1437	5.566	1.716677	1.250
07504	73	4.847	1924	4.157	1.424794	1.166
07504	90	3.324	2768	2.89	1.061257	1.150
07504	125	1.878	4730	1.691	0.52532	1.111
07503	150	1.387	6309	1.268	0.237441	1.094

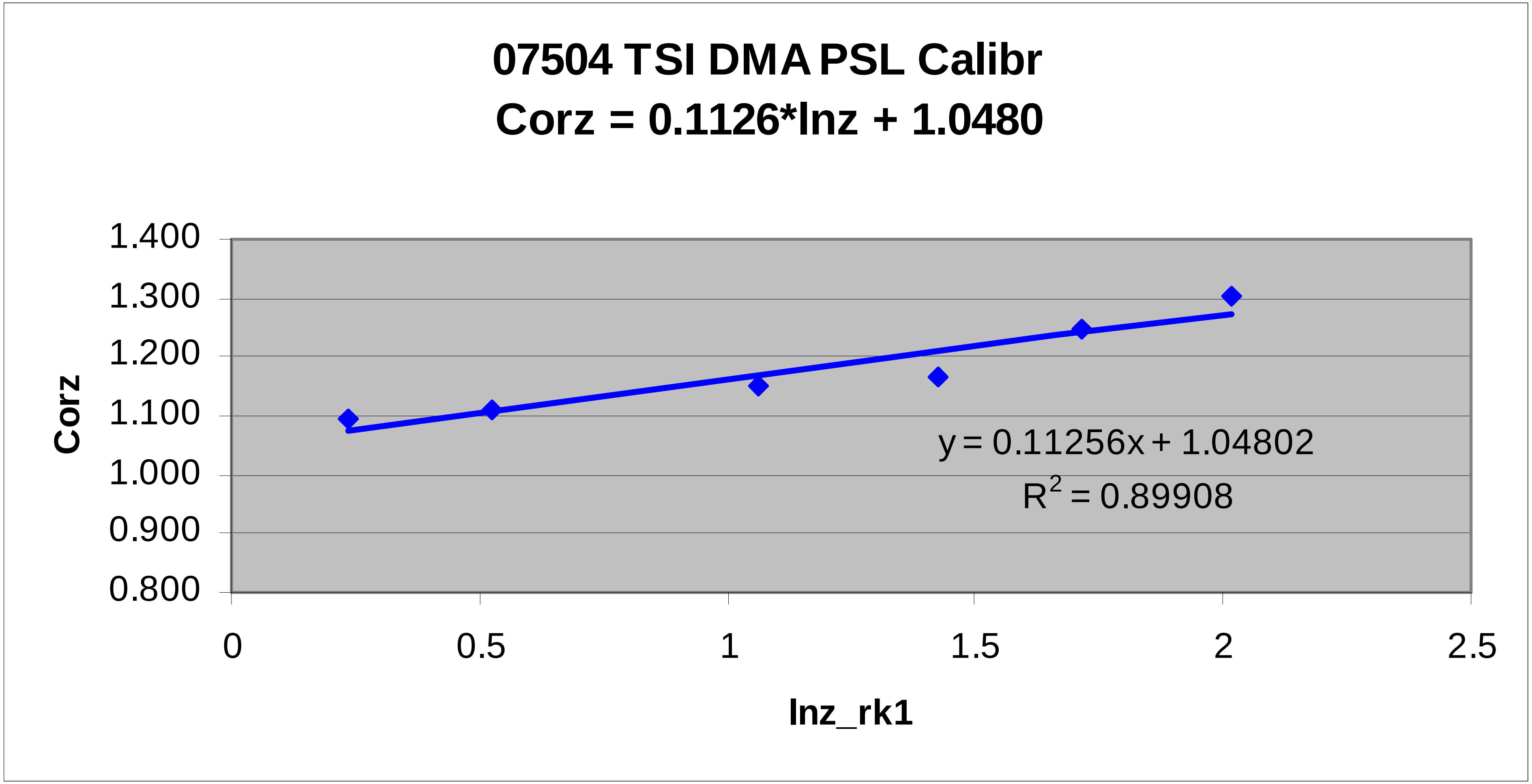
Corz = z_psl / z_rk1

Particle mobility

- $Z = \nu\ e\ C / (3\ \pi\ \mu\ x)$
-
- Z = electrical mobility
- ν = Number of charges
- e = Charge of an electron
- C = Cunningham slip correction
- μ = Viscosity of air
- x = Particle diameter

DMA mobility centroid

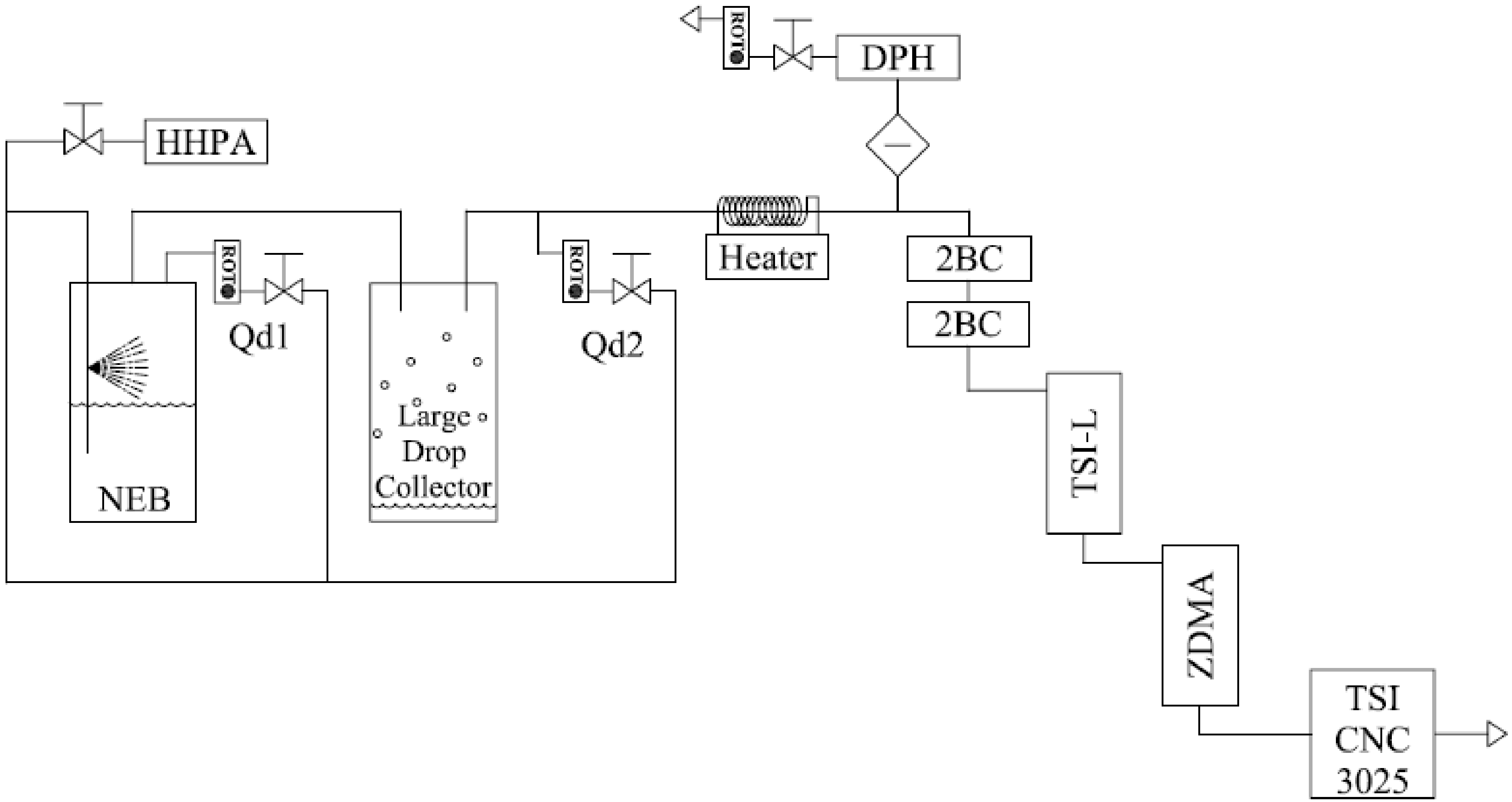
- $Z_c = (Q_{sh} + Q_e) \ln(D_2/D_1)/(4 \pi V L)$
-
- Q_{sh} = Sheath air flow rate
- Q_e = Main exhaust air flow rate
- D_2 = Inner diameter of outer cylinder
- D_1 = Outer diameter of inner rod
- V = Rod voltage
- L = Effective rod length


07504 TSI DMA PSL Calibr
Corz = 0.1126*lnz + 1.0480
1.400
1.300
1.200
1.100
1.000
0.900
0.800
Corz
y = 0.11256x + 1.04802
R2 = 0.89908
0
0.5
1
1.5
2
2.5
lnz_rk1

Uncertainties

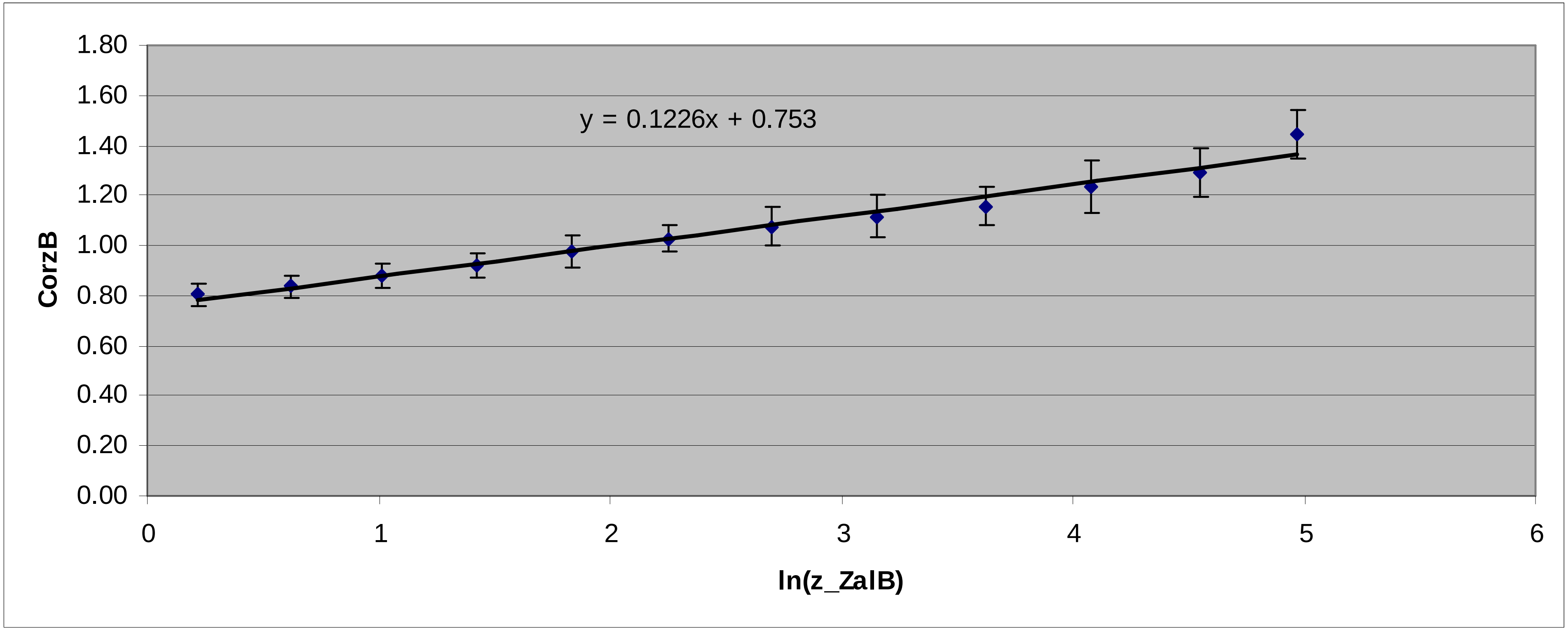
- Corz vs lnz data has a standard deviation of 0.0097.
- Corresponding uncertainties in linear fit:
  - ✓ Slope .0063
  - ✓ Intercept .0083
- Rk1 Corz = (0.1126±0.0063)lnz + (1048 ±0.0083)
- Uncertainty in calculated corrected mobility at 10nm: 3.2%.

Schematic2: TSI → ZDMA



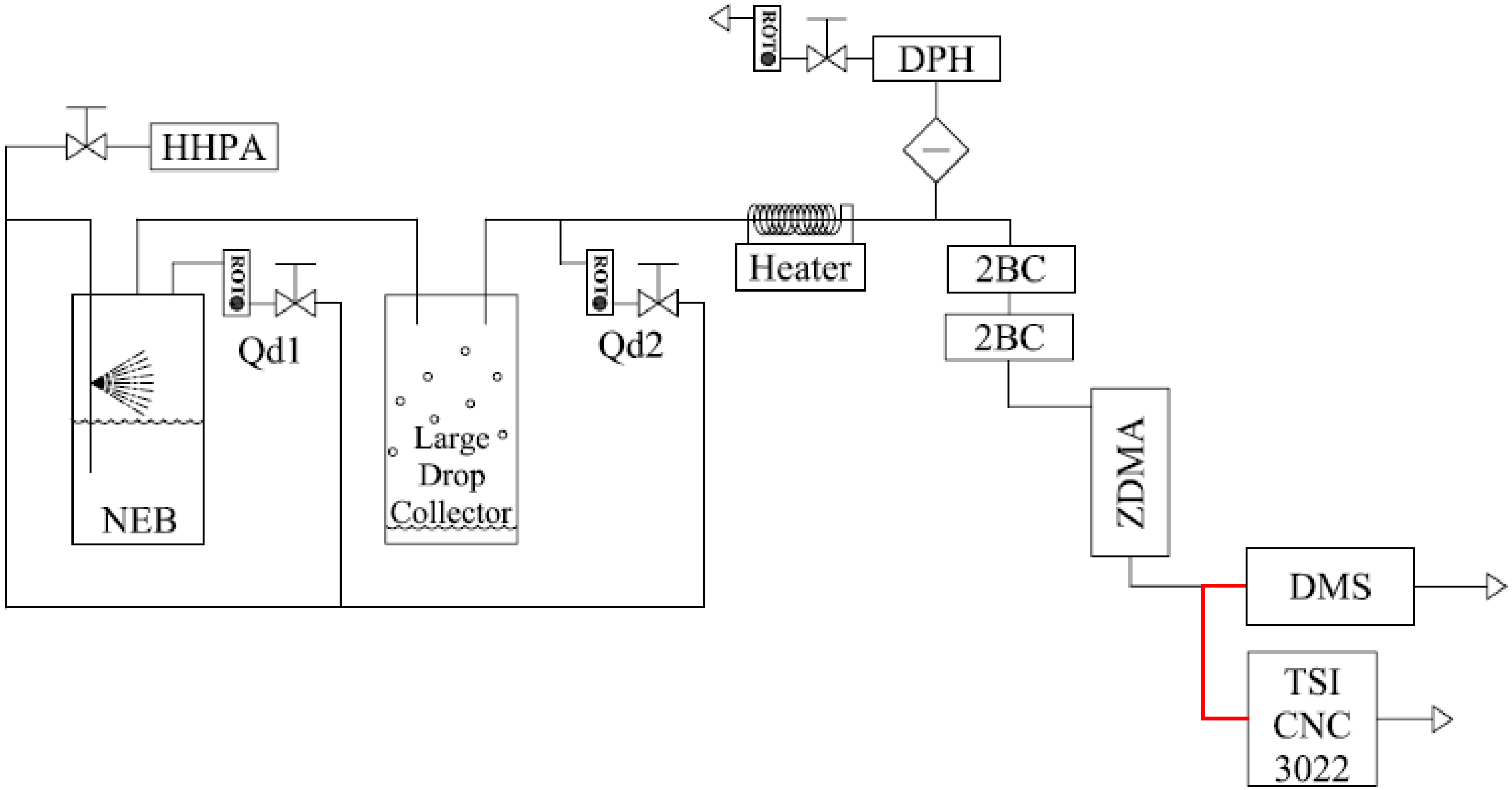
ZDMA

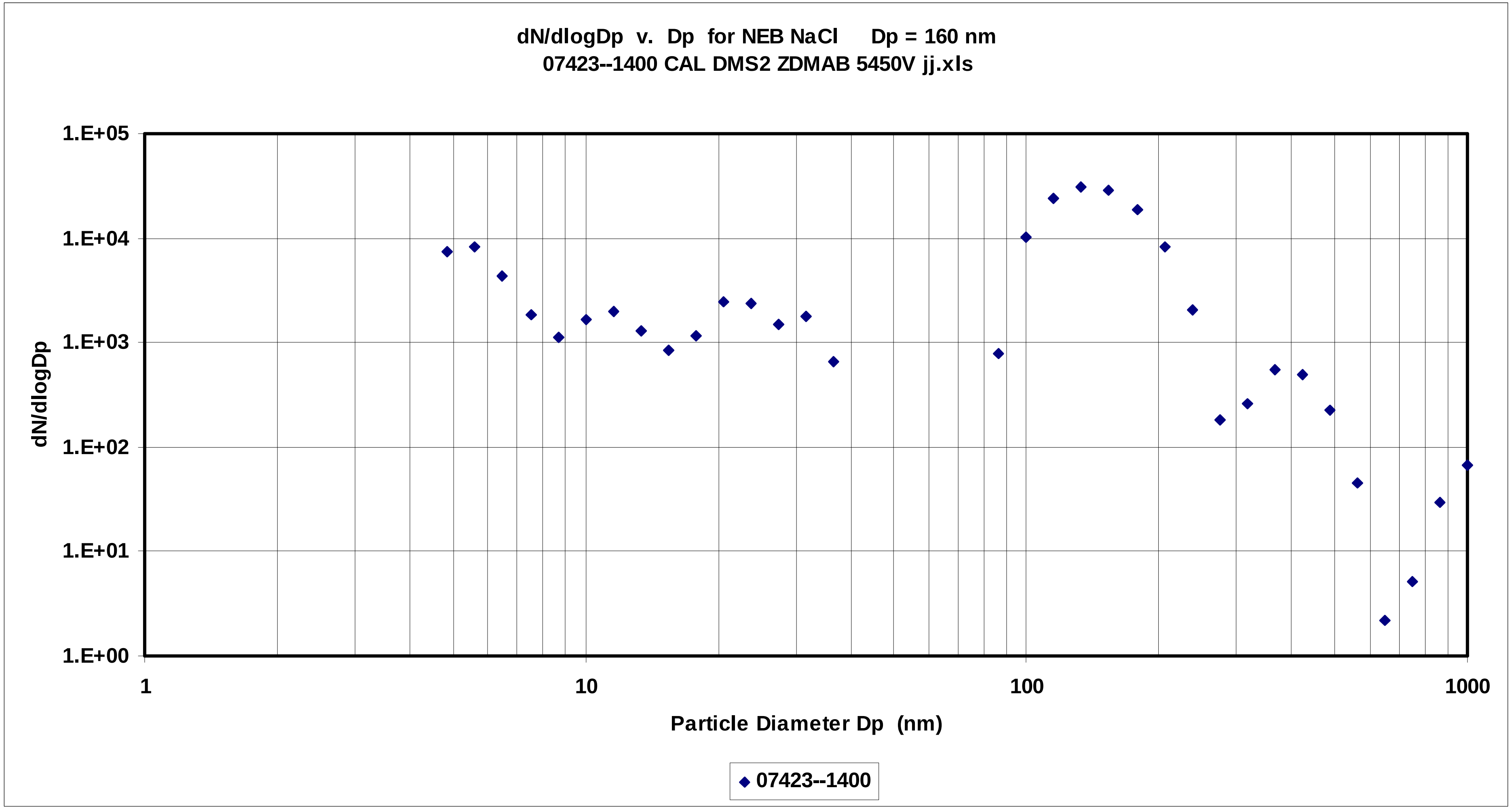
- Cylindrical geometry
- L = 0.728m
- ID outer cyl = .0889m
- OD inner cyl = .0508m

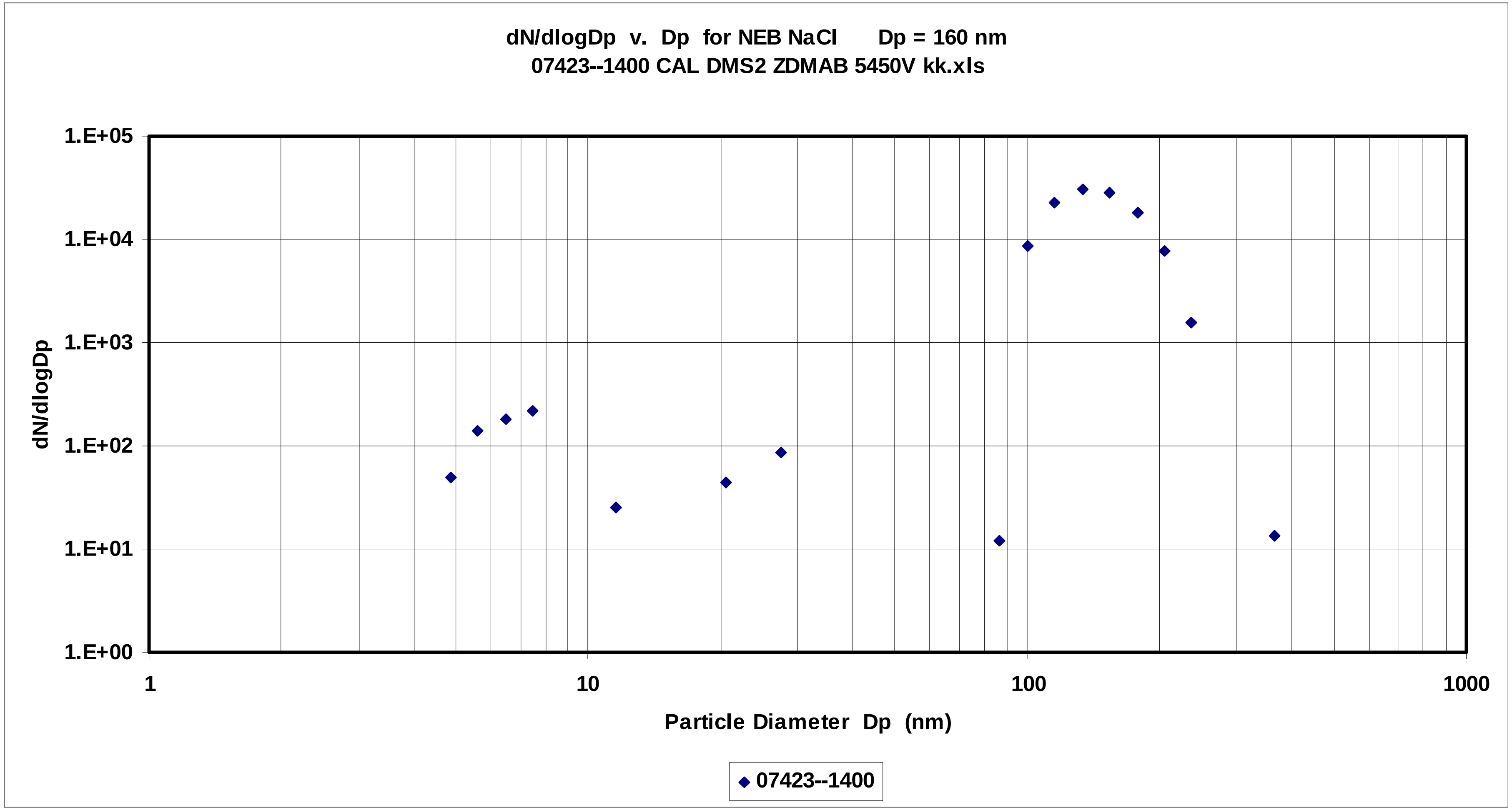


1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
CorzB
y = 0.1226x + 0.753
0
1
2
3
4
5
6
ln(z_ZalB)

Schematic3: ZDMA ➔ DMS




dN/dlogDp v. Dp for NEB NaCl Dp = 160 nm
07423--1400 CAL DMS2 ZDMAB 5450V jj.xls
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
dN/dlogDp
1
10
100
1000
Particle Diameter Dp (nm)
07423--1400


dN/dlogDp v. Dp for NEB NaCl Dp = 160 nm
07423--1400 CAL DMS2 ZDMAB 5450V kk.xls
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
dN/dlogDp
1
10
100
1000
Particle Diameter Dp (nm)
07423--1400

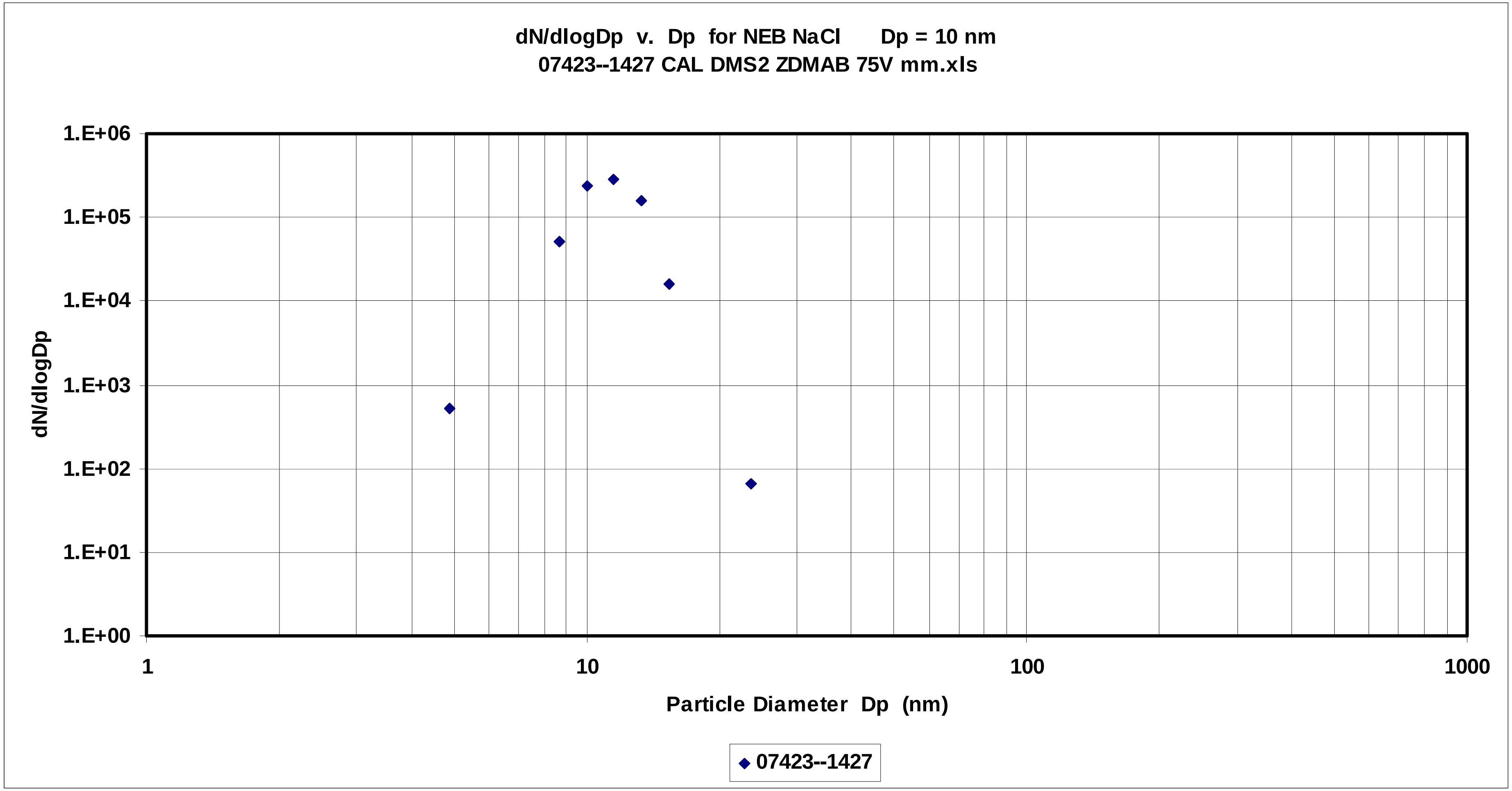
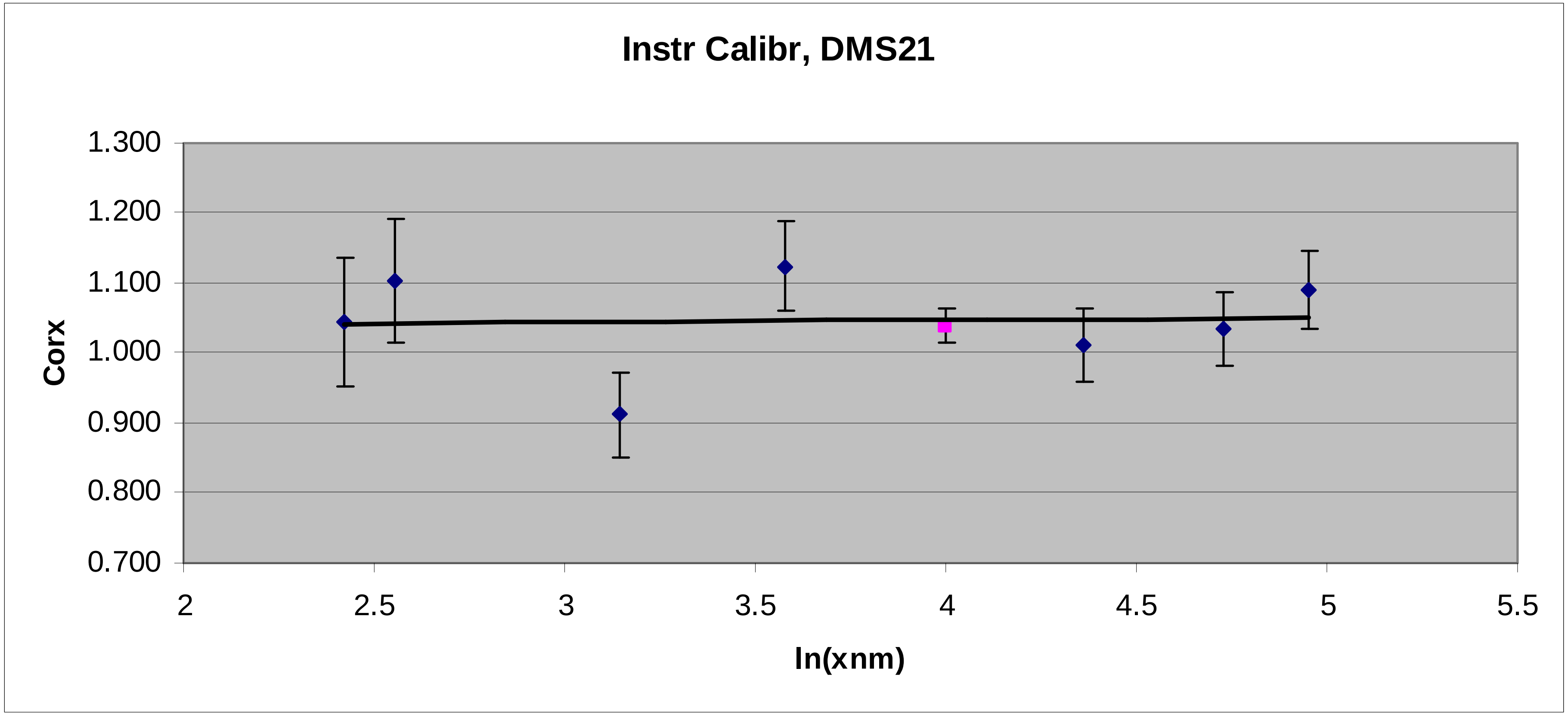

dN/dlogDp v. Dp for NEB NaCl Dp = 10 nm
07423--1427 CAL DMS2 ZDMAB 75V mm.xls
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
dN/dlogDp
1
10
100
1000
Particle Diameter Dp (nm)
07423--1427

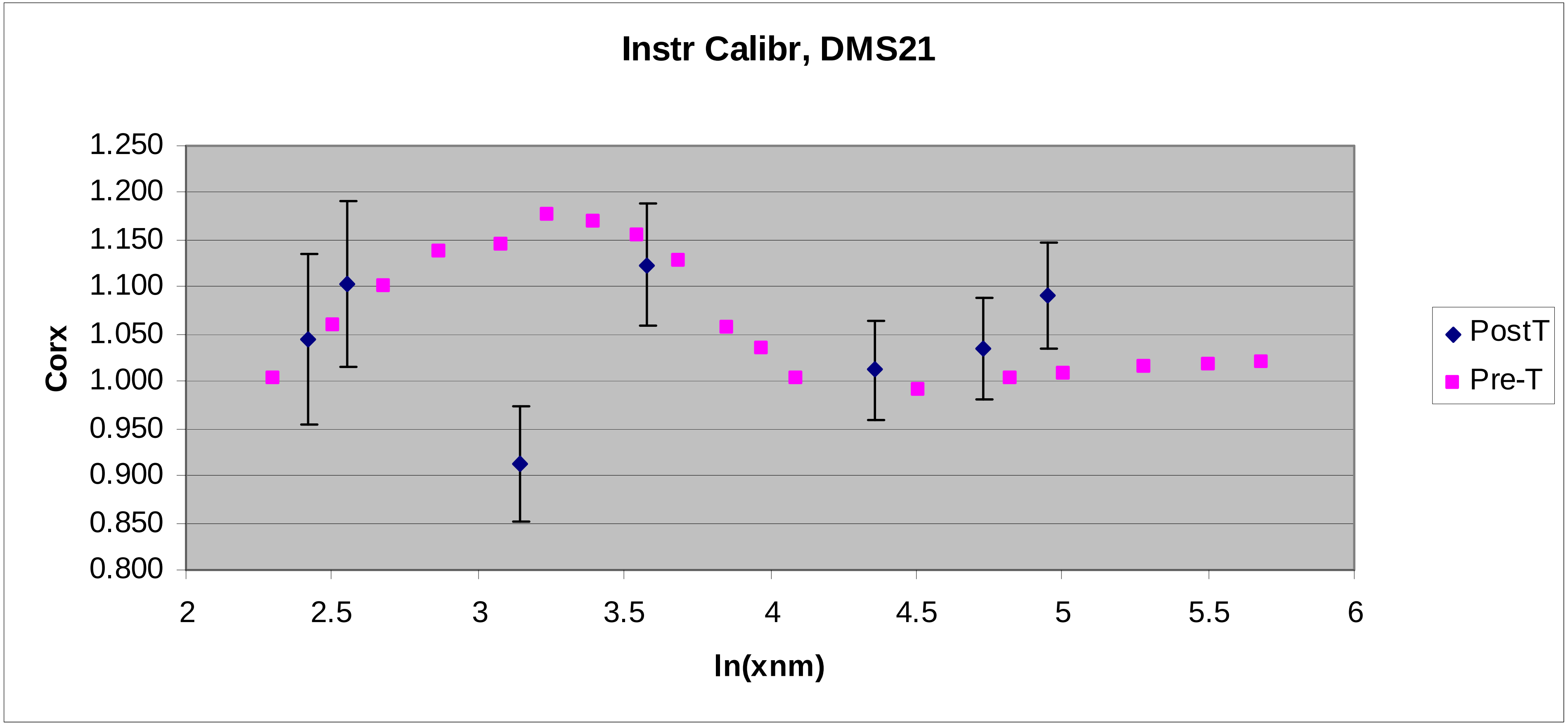
Table 2: DMS21 Calibr

Table2		fU Dp-tru				
		0.05				
V	Corr	x	TCN	Sigma	TCN	StDev
ZDMAB	z	challenge	ref 296	TCN ref	Instr	TCN-Instr
(V)		(nm)	(p/cm3)	(p/cm3)	(p/cm3)	(p/cm3)
75	150.73	11.74	74445	6169	53193	7163
105	104.34	14.18	152610	10014	105141	6229
215	47.48	21.13	8483	107	5170	1233
675	13.37	40.33	23151	729	27558	5405
2050	3.84	79.22	16291	605	23577	2589
3703	1.96	117.33	8075	364	12755	442
5450	1.26	154.33	6036	79	7361	275

x	StDev x	lnx	Corx	Corx U	CorC	CorC U
Instr	Instr					
	(nm)					
		3.25				
11.25	0.80	2.420168	1.044	0.091	1.400	0.221
12.84	0.80	2.5527261	1.104	0.088	1.451	0.128
23.15	1.00	3.1418661	0.913	0.060	1.641	0.392
35.90	1.00	3.5806371	1.124	0.064	0.840	0.167
78.31	1.00	4.3606951	1.012	0.052	0.691	0.080
113.40	1.50	4.730878	1.035	0.054	0.633	0.036
141.50	1.50	4.9523122	1.091	0.056	0.820	0.033

DMS21

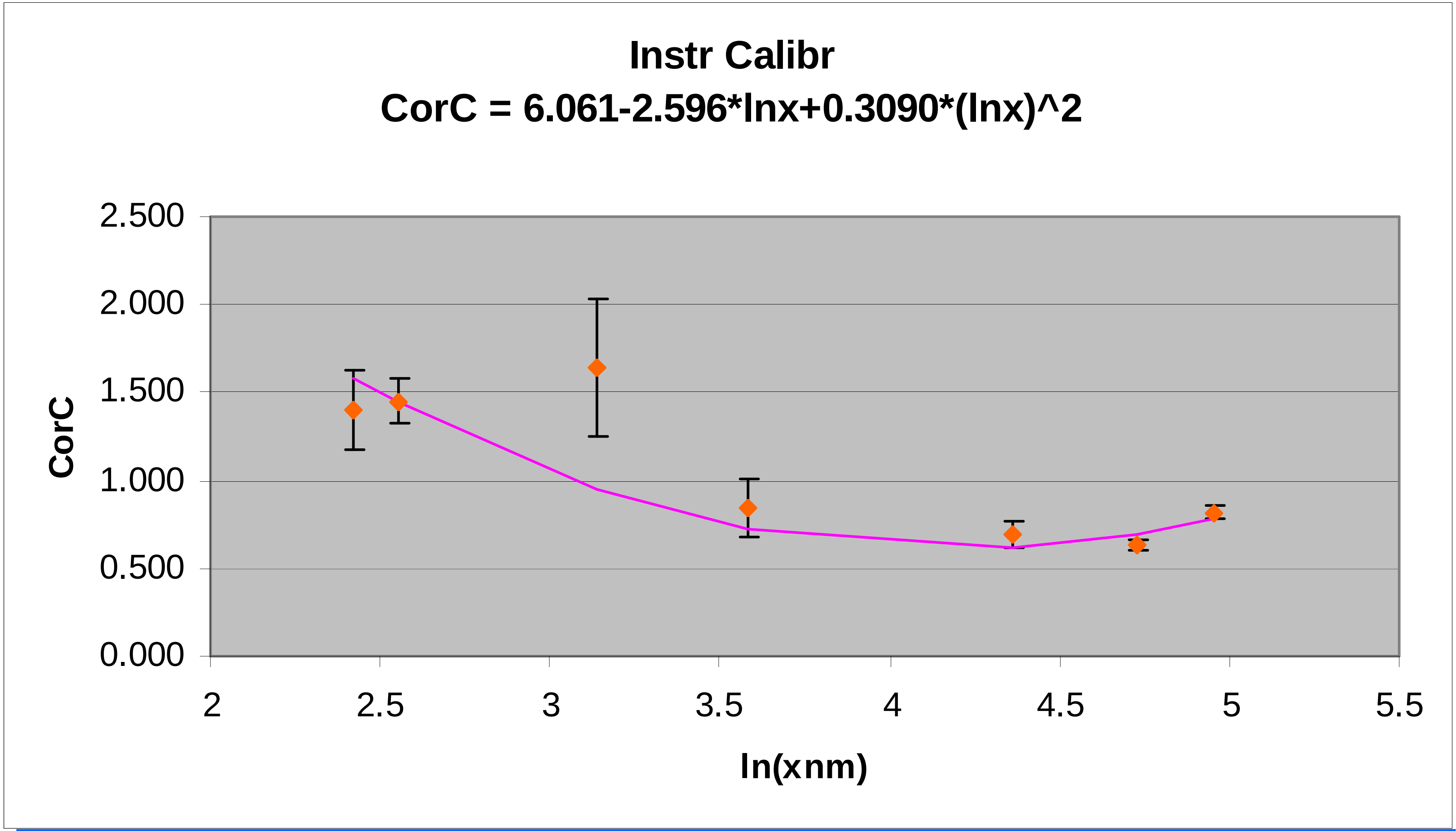

Instr Calibr, DMS21
Corx
1.300
1.200
1.100
1.000
0.900
0.800
0.700
2
2.5
3
3.5
4
4.5
5
5.5
ln(xnm)


Instr Calibr, DMS21
Corx
1.250
1.200
1.150
1.100
1.050
1.000
0.950
0.900
0.850
0.800
2
2.5
3
3.5
4
4.5
5
5.5
6
ln(xnm)
PostT
Pre-T

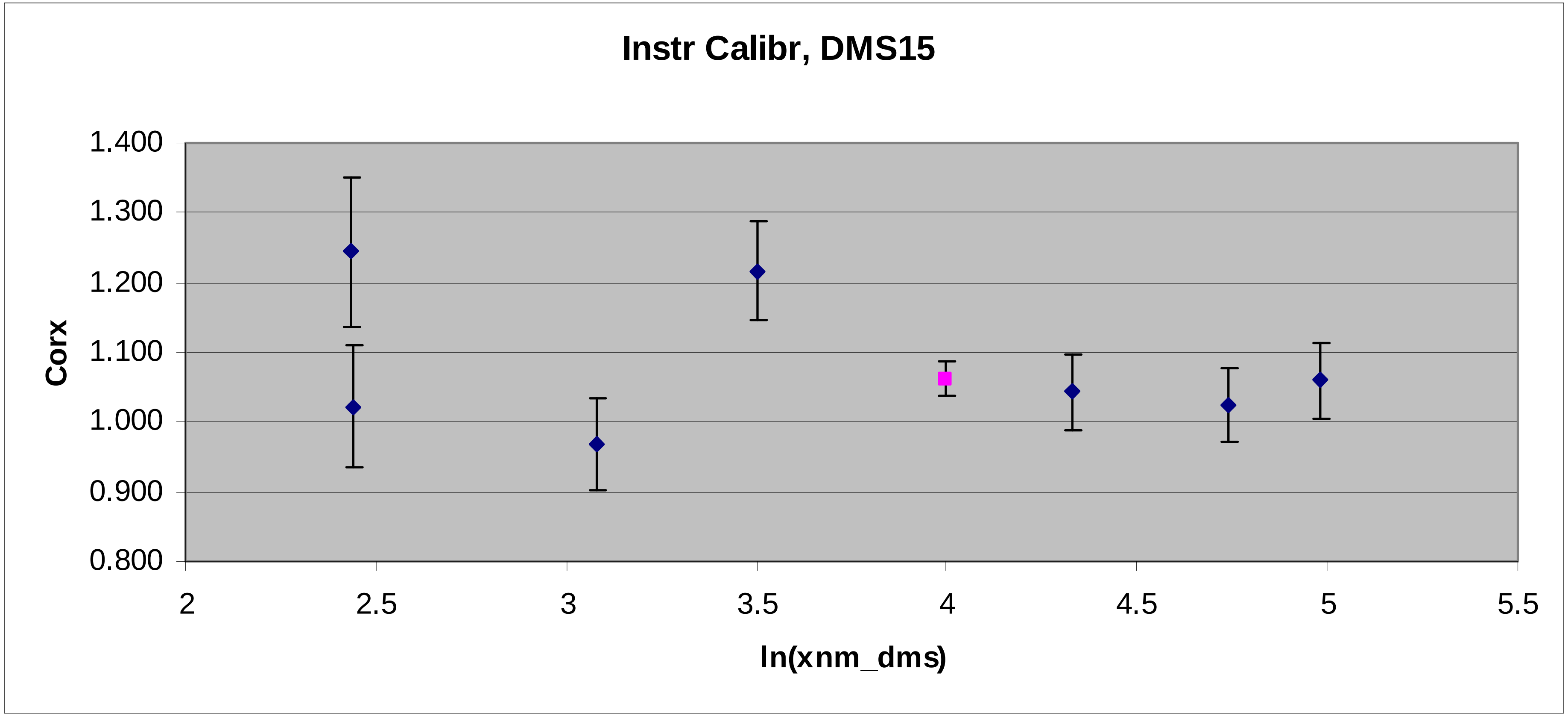
DMS21 Diameter Correction

- Corx = 8.283E-06x3 - 1.099E-03x2 + 4.119E-02x + 7.003E-01 $x \leq 60$ nm
- Corx = -8.865E-09x3 + 4.726E-06x2 - 6.351E-04x + 1.023E+00 $x > 60$ nm

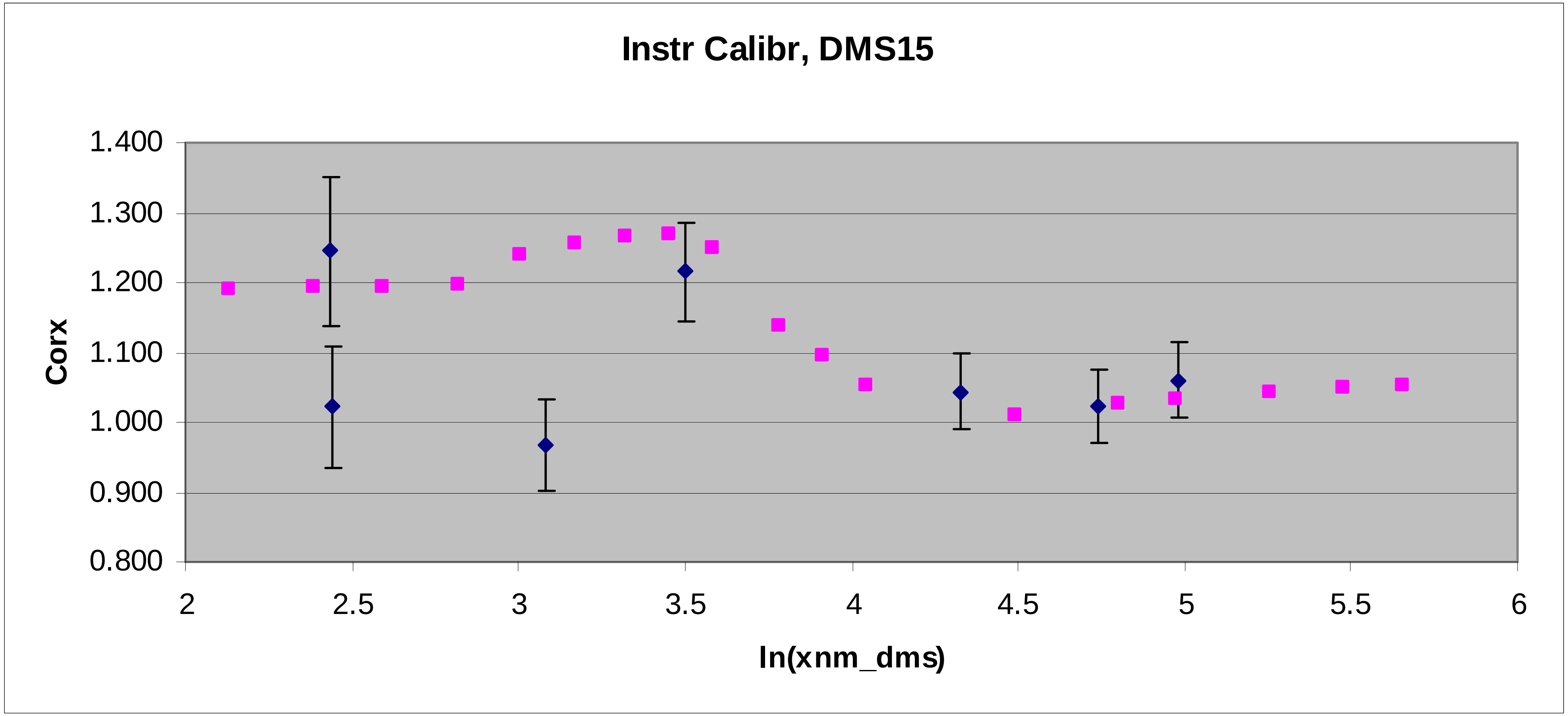
DMS21 Concentration Correction



DMS15



Instr Calibr, DMS15
1.400
1.300
1.200
1.100
1.000
0.900
0.800
Corx
2
2.5
3
3.5
4
4.5
5
5.5
ln(xnm_dms)

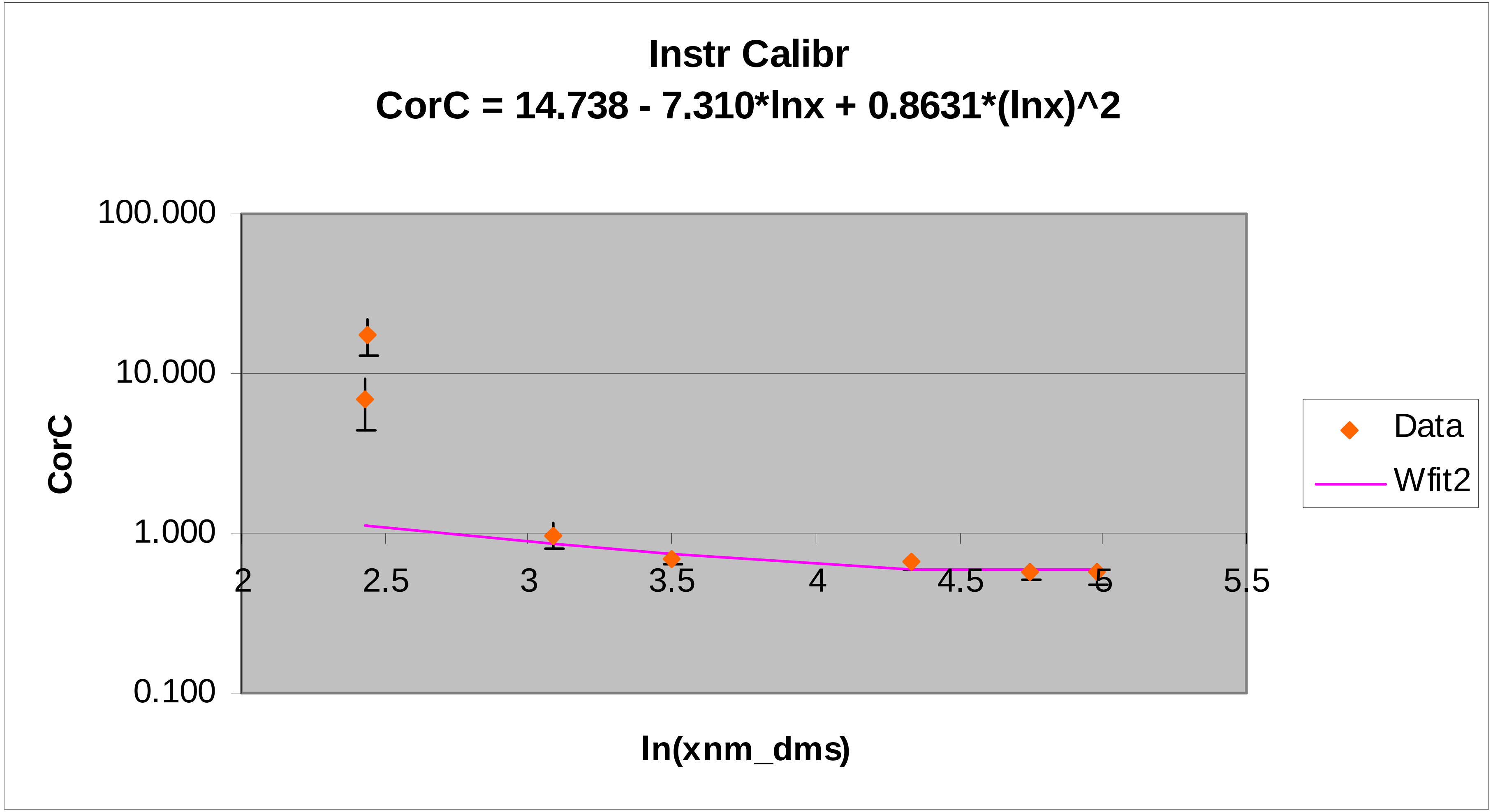


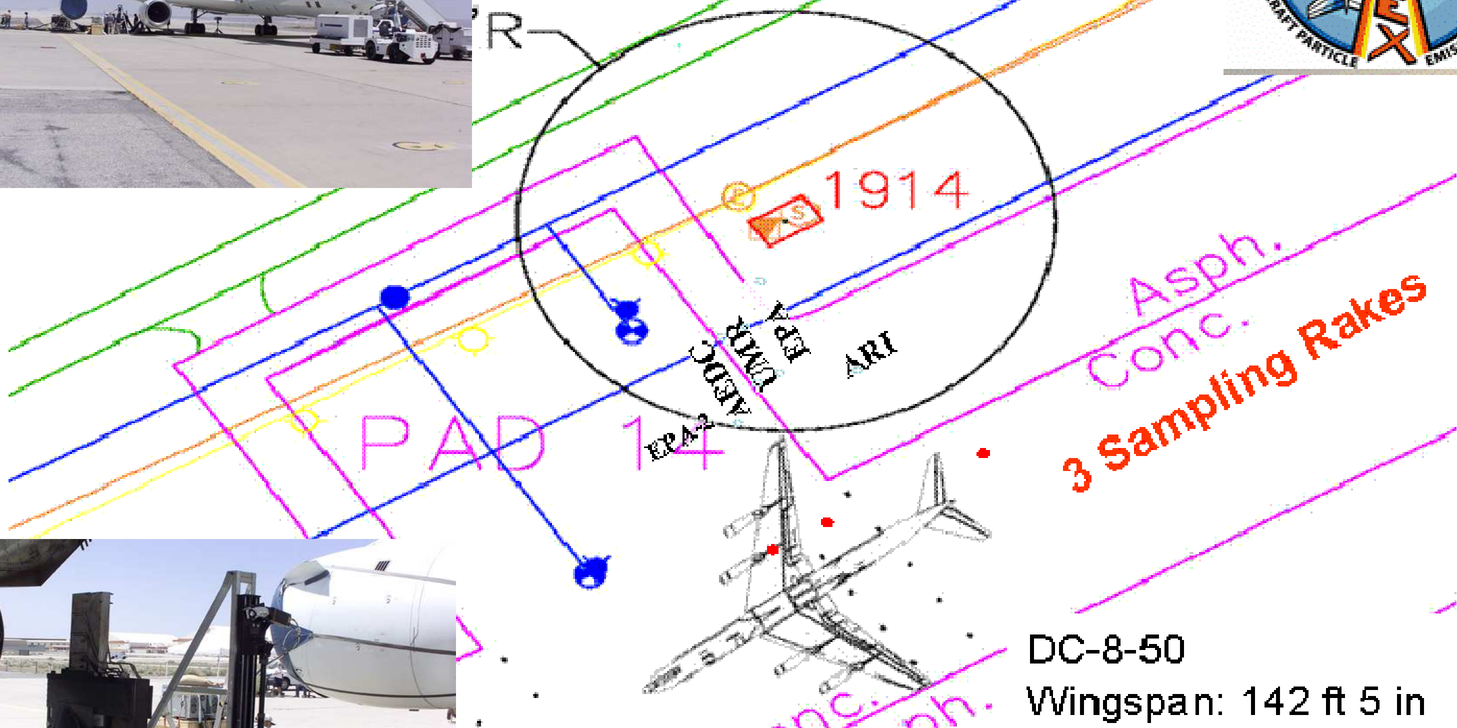
Instr Calibr, DMS15
1.400
1.300
1.200
1.100
1.000
0.900
0.800
Corx
2
2.5
3
3.5
4
4.5
5
5.5
6
ln(xnm_dms)

DMS15 Diameter Correction

- Corx = 1.673E-06x3 - 3.984E-04x2 + 1.702E-02x + 1.051E+00 x ≤ 56 nm
- Corx = -2.520E-08x3 + 1.392E-05x2 - 2.201E-03x + 1.130E+00 x > 56 nm

DMS15 Concentration Correction





DC-8-50
Wingspan: 142 ft 5 in
Length: 150 ft 6 in

Project APEX Intercomparison

DMS, SMPS, CNC comparison results

Parameter	Avg. % Difference	RMS % Difference
D_g	-5	19
D_{gM}	-7	19
TCN	15	37