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Sub 20 nm generation of soot particles using the VSP-G1 nanoparticle generator

Roeland Dijkema, MSc

Brussels, 3rd of April 2019

Agenda

Topic

1 Company

2 Introduction

3 Technology

4 Particle deposition

5 Results

6 Summary

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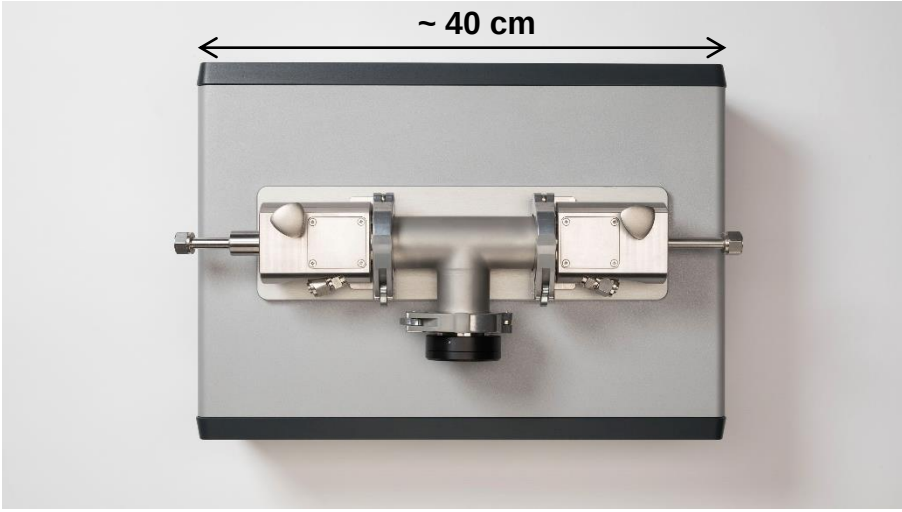
VSPARTICLE

Introduction

Philosophy

We make machines that produce nanostructured materials. Our philosophy is that these machines should be simple to operate and based on a scalable principle.

G-1



Accessories G-1

NMP-1

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VSPARTICLE timeline

Introduction

1988

Invention of spark ablation by Andreas Schmidt-Ott

2014

Start of VSPARTICLE, development of the G1

2017

3 Launching customers

Full management team covering all angles of business

2018

International expansion to research oriented markets in the Americas, Europe and Asia

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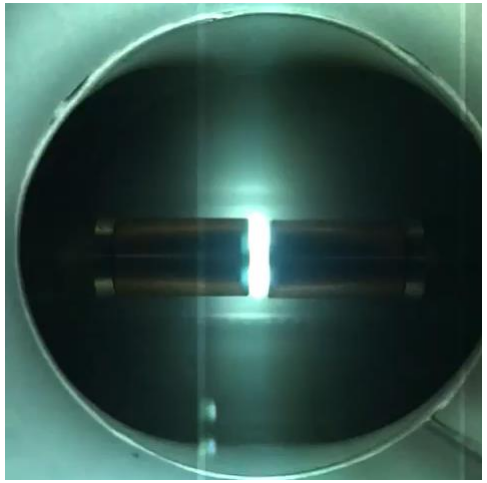
Research	1-300 Hz	~ milligrams
Industry	10.000-25.000 Hz	~ 100s milligrams

Technology

Spark ablation

- Ablation/evaporation and condensation
- Electric discharge
  - $\approx 10^4$ K, $\approx 10^{-5}$ s
- Rapid quench
  - $\approx 10^7$ K s^{-1}
- ‘Mild’ conditions
- Versatility
  - Metals
  - Carbon
  - Oxides
  - Alloys



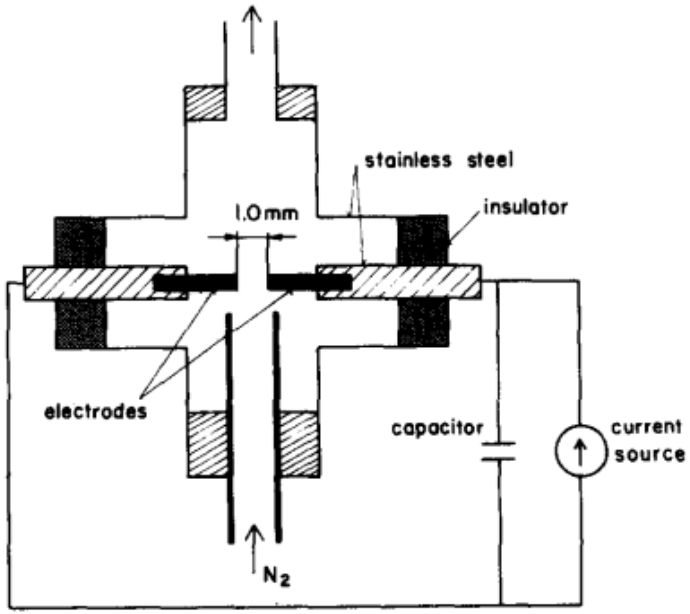


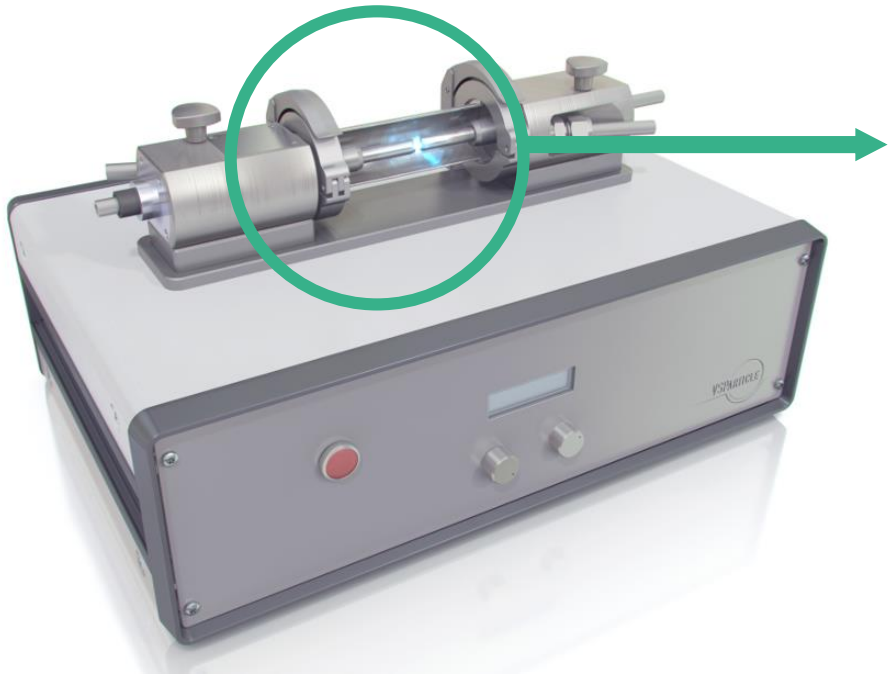
Fig. 1. Schematic of the generator.

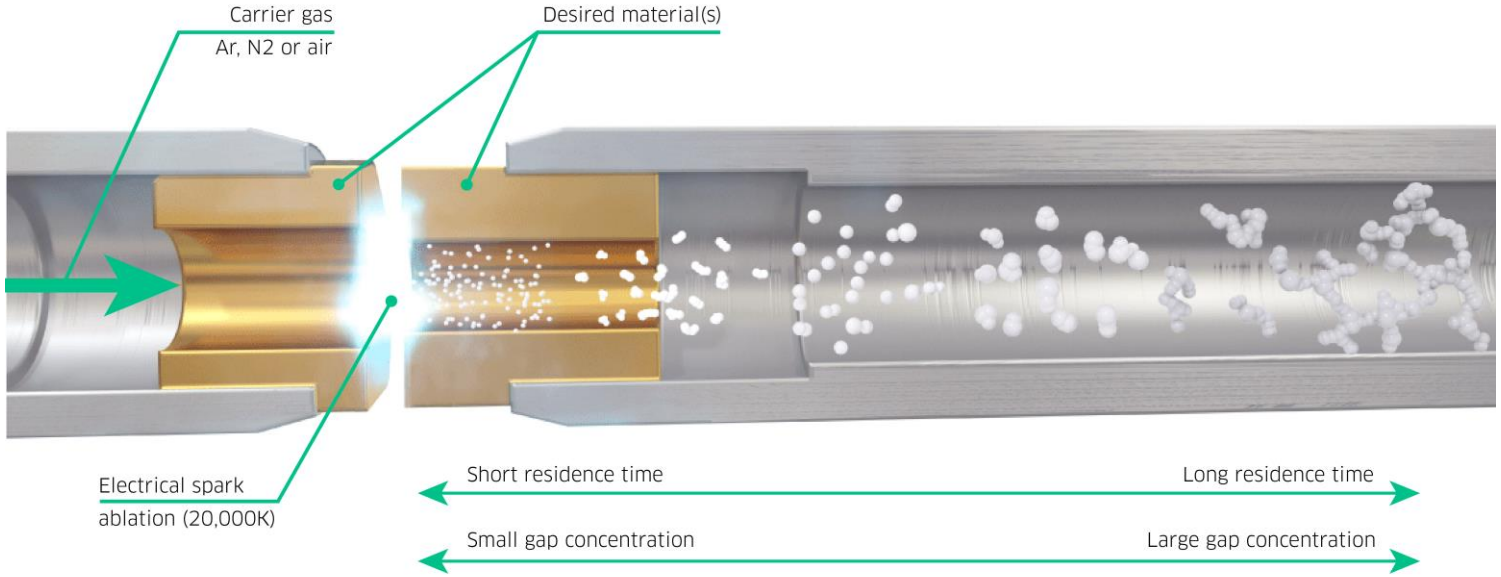
[Schwyn 1988, J. Aerosol Sci., 19 (5), p.639.]

How particle growth works in the system

Technology

Particle Production inside G1





The process takes place under atmospheric conditions

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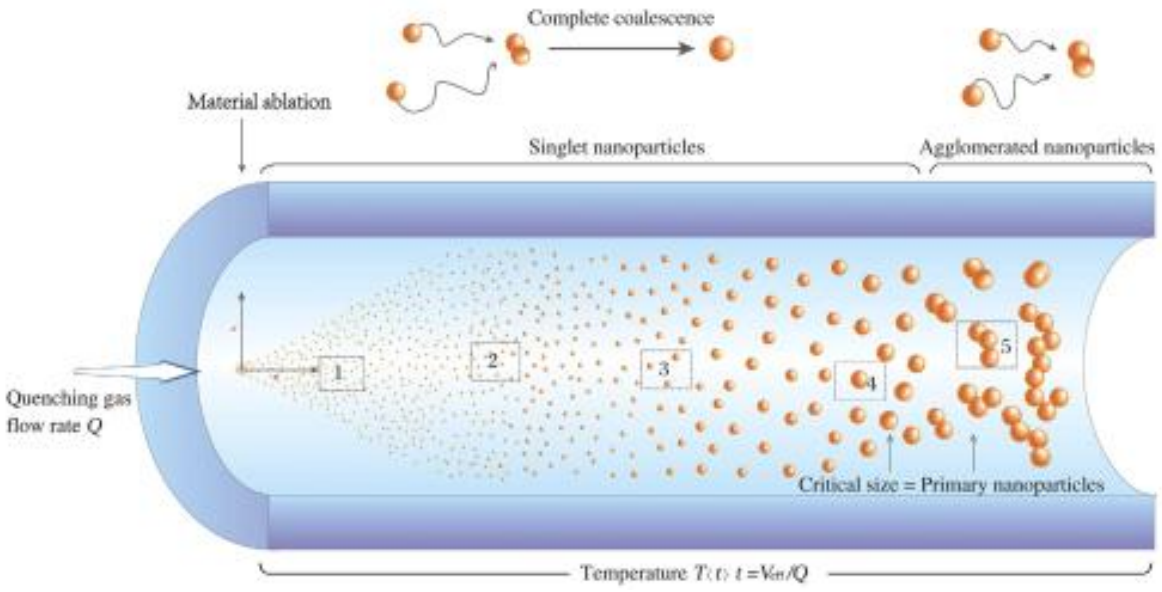
Technology

Particle formation in sparks

- Smoluchowski:

$$\frac{\mathrm{d}\,N}{\mathrm{d}\,t} = -\frac{1}{2}\beta N^2$$

$$d_p \propto N^{-\frac{1}{3}}$$



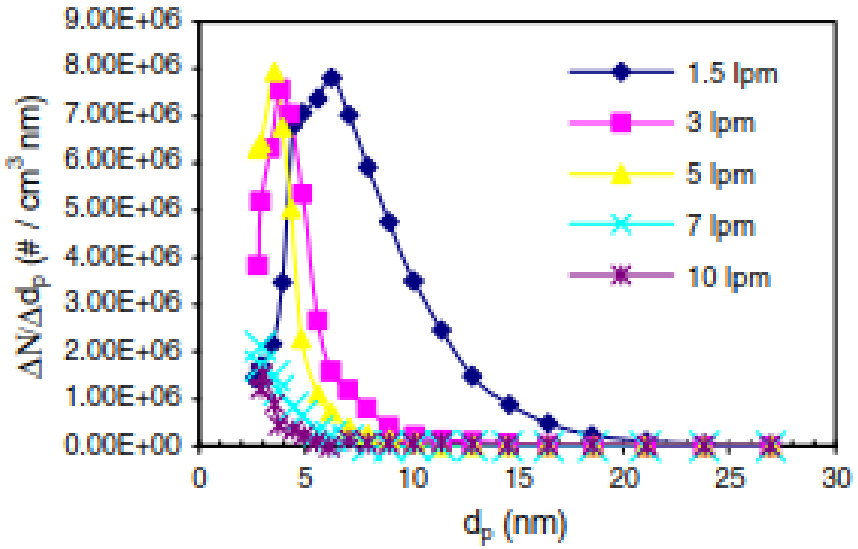
[Feng et al. 2016, J. Phys. Chem. C., 120 (1), p. 621.]
[Tabrizi et al. 2009, J. Nanopart. Res., 11 (2), p. 315]

- Controlled through voltage, current and flow

$$N_0 \propto \frac{\dot{m}}{Q} \propto \frac{U\,I}{Q}$$

$$\bar{t} = \frac{V}{Q}$$

$$d_p \propto \left(\frac{V\dot{m}}{Q^2}\right)^{\frac{1}{3}}$$



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Possibilities with G1

Technology

Materials

1 H Hydrogen 1.01																	2 He Helium 4
3 Li Lithium 6.94	4 Be Beryllium 9.01											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16	9 F Fluorine 19	10 Ne Neon 20.18
11 Na Sodium 22.99	12 Mg Magnesium 24.3											13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.1
19 K Potassium 39.95	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.87	23 V Vanadium 50.94	24 Cr Chromium 52	25 Mn Manganese 54.94	26 Fe Iron 55.84	27 Co Cobalt 58.69	28 Ni Nickel 58.93	29 Cu Copper 63.55	30 Zn Zinc 65.39	31 Ga Gallium 69.72	32 Ge Germanium 72.64	33 As Arsenic 74.92	34 Se Selenium 78.96	35 Br Bromine 79.9	36 Kr Krypton 83.8
37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium 98	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 126.9	53 I Iodine 127.6	54 Xe Xenon 131.29
55 Cs Cesium 132.91	56 Ba Barium 137.33	57-71 Lanthanoids	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium 209	85 At Astatine 210	86 Rn Radon 222
87 Fr Francium 223	88 Ra Radium 226	89-103 Actinoids	104 Rf Rutherfordi... 262	105 Db Dubnium 262	106 Sg Seaborgium 264	107 Bh Bohrium 266	108 Hs Hassium 268	109 Mt Meitnerium 272	110 Ds Darmstadtiu... 277	111 Rg Röntgium 0	112 Cn Copernicium 0	113 Nh Nihonium 0	114 Fl Flerovium 0	115 Mc Moscovium 0	116 Lv Livermorium 0	117 Ts Tennesine 0	118 Og Oganesson 0

Lanthanoids	57 La Lanthanum 138.91	58 Ce Cerium 140.12	59 Pr Praseodymi... 140.91	60 Nd Neodymium 144.24	61 Pm Promethium 145	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.5	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.97
Actinoids	89 Ac Actinium 227	90 Th Thorium 231.04	91 Pa Protactinium 232.04	92 U Uranium 237	93 Np Neptunium 238.03	94 Pu Plutonium 243	95 Am Americium 244	96 Cm Curium 247	97 Bk Berkelium 247	98 Cf Californium 251	99 Es Einsteinium 252	100 Fm Fermium 257	101 Md Mendelevium 258	102 No Nobelium 259	103 Lr Lawrencium 261

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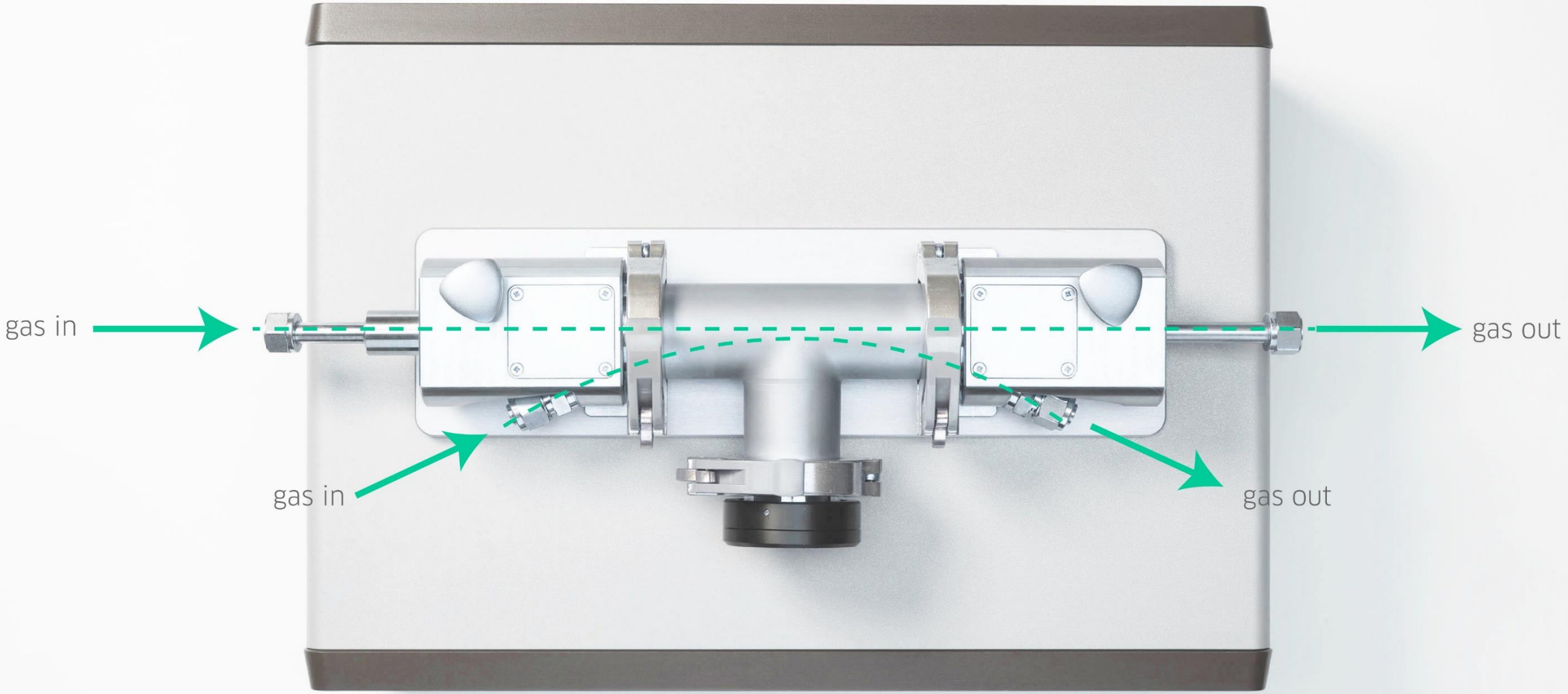
VSP-G1 design

Flexible flow configurations

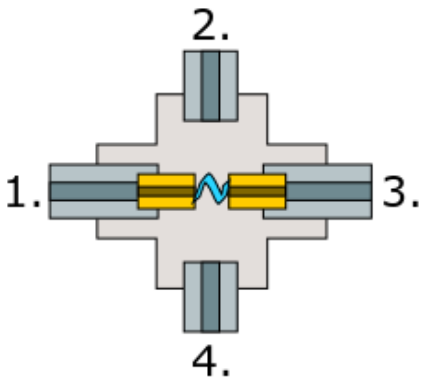


VSP-G1 design

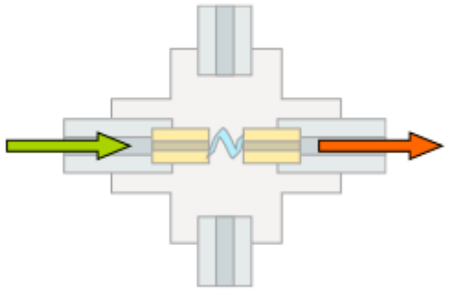
Flexible flow configurations

Results

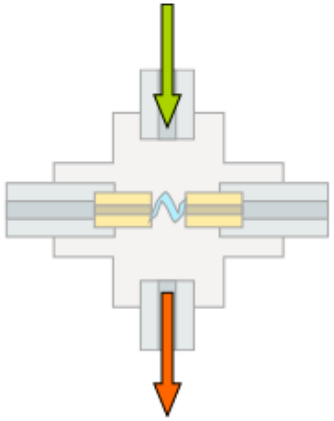
(a) A pair of hollow, silver electrodes.



(b) The spark chamber, connections are numbered from 1 to 4.



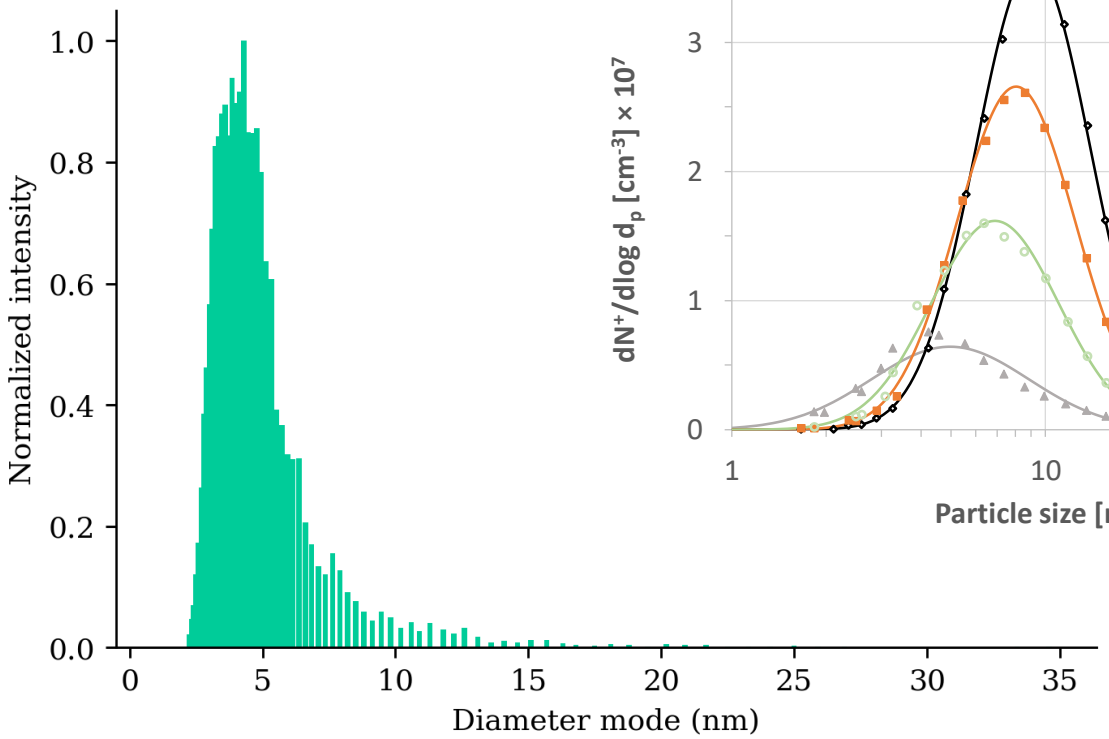
(c) Configuration 1.: Flow trough the electrodes.



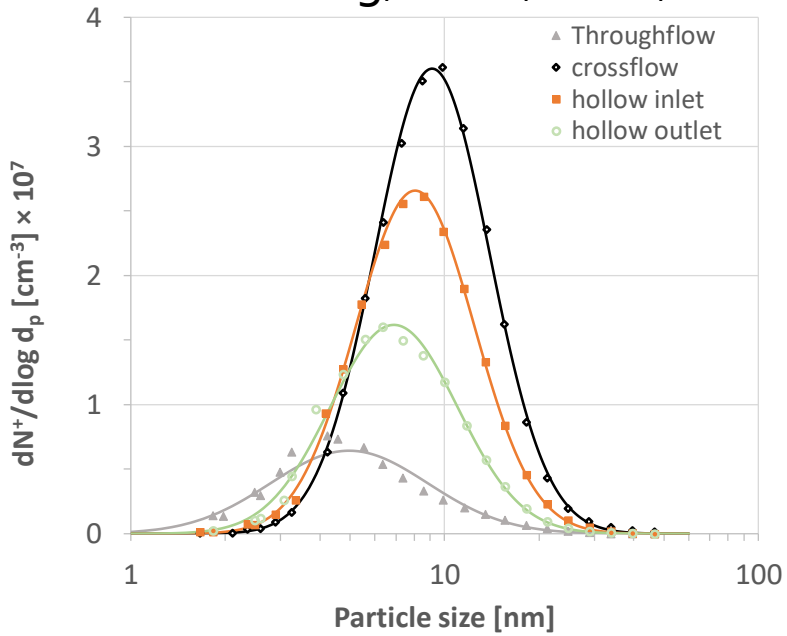
(d) Configuration 2.: The classical crossflow configuration.

VSP-G1 design

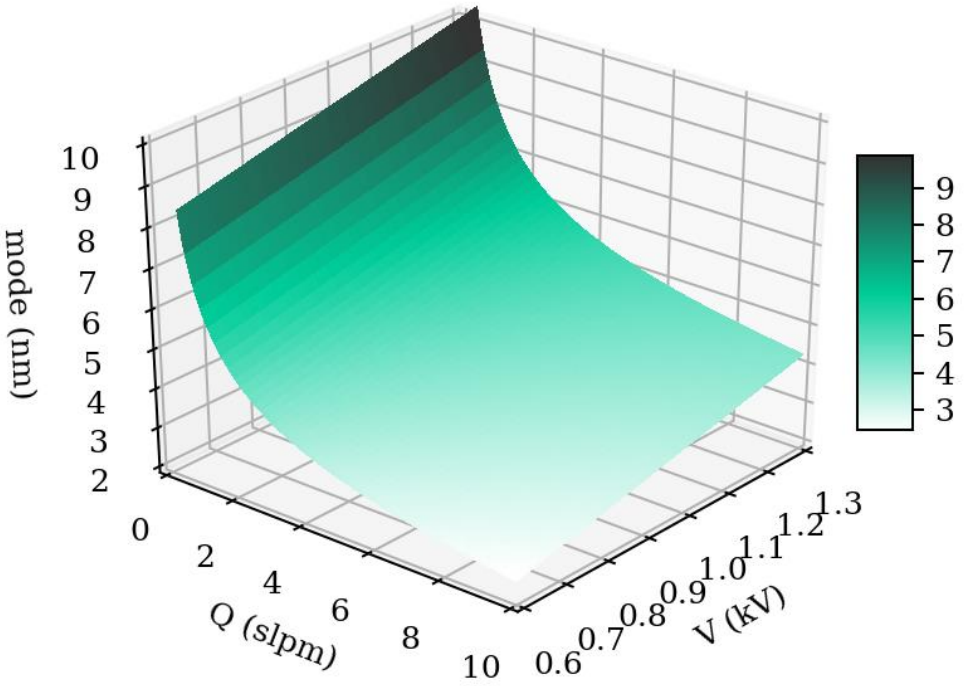
Au, Ar, Crossflow



Ag, 1.7kV, 4 mA, 4 slm



- **Tuneable size distribution**
- **Crossflow highest concentration**
- **Throughflow smallest mean diameter**



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Size-selected stability

Results

Output VSP-G1 example

Material: Copper

Carrier Gas: Argon

Flowrate: 1 L/min

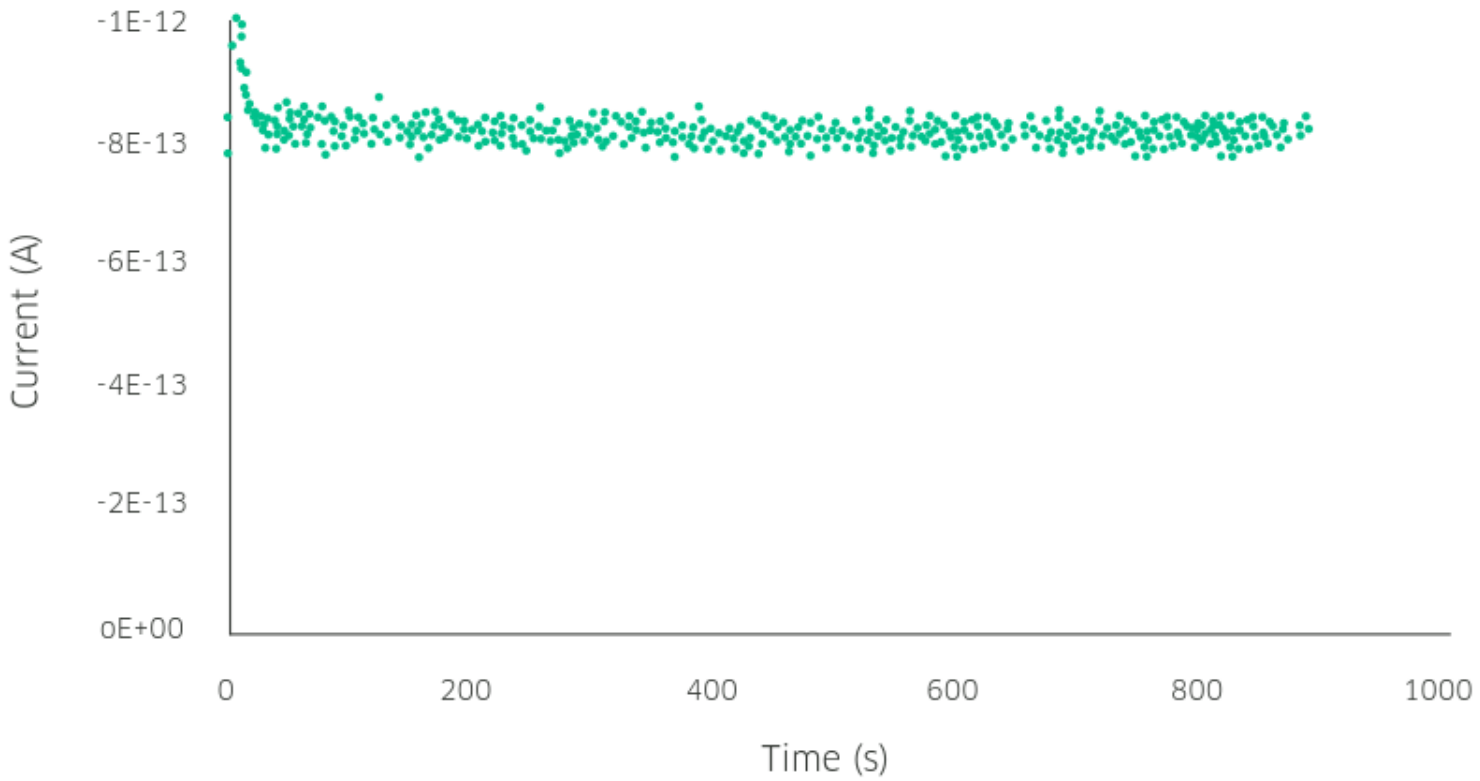
Voltage: 1.0 kV

Current: 5.0 mA

Stability of 5 nm particles

StDev: <2%

Measured with DMA (Differential Mobility Analyzer) + Electrometer & FD/C



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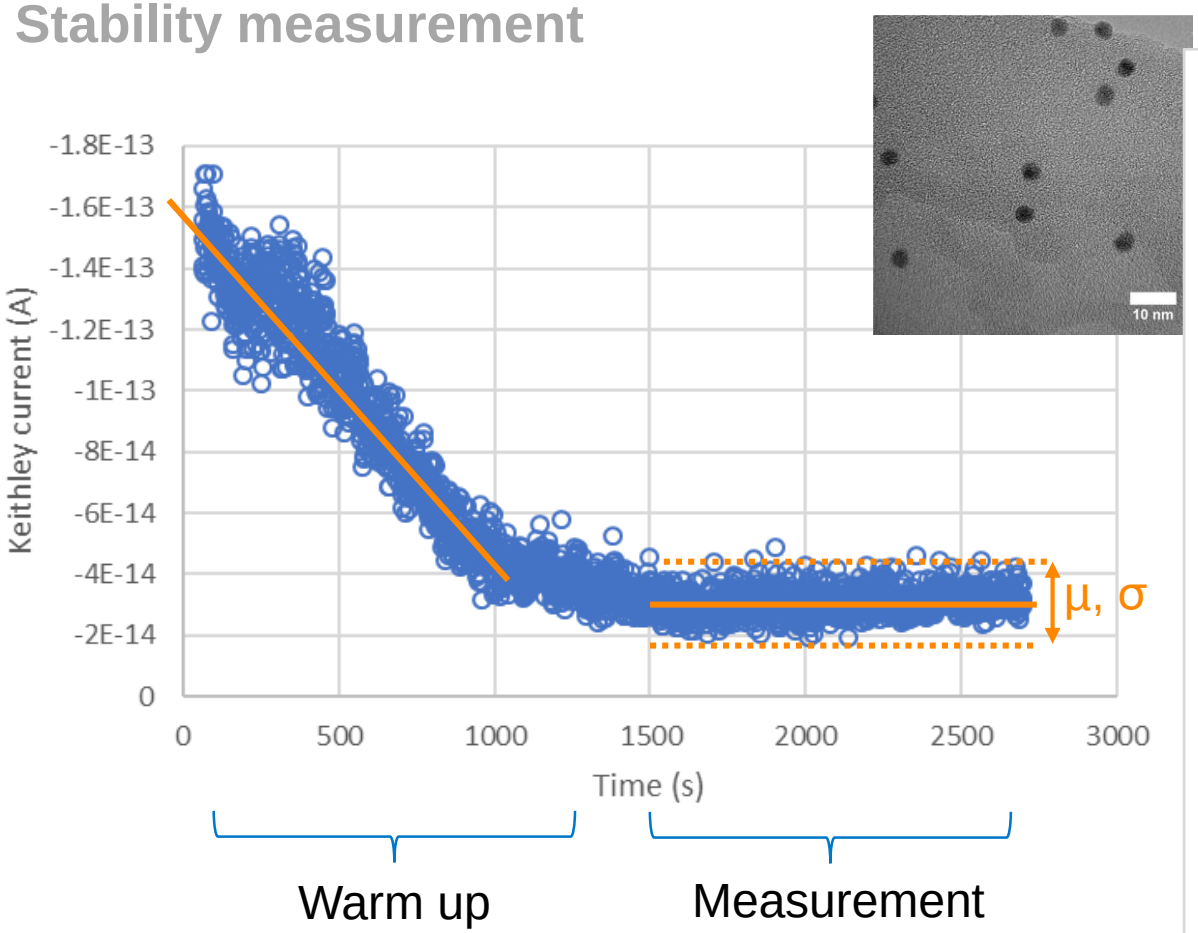
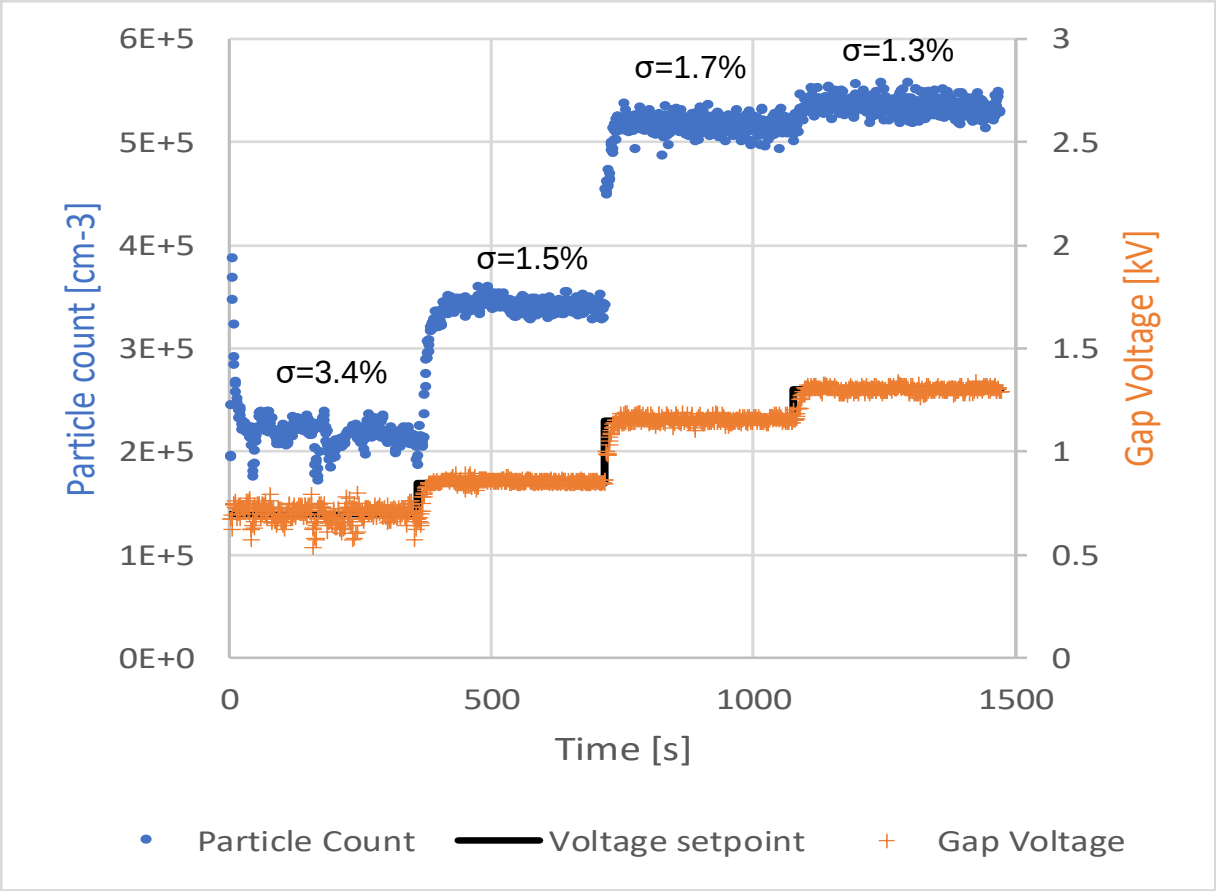
Size-selected stability measurement

Results

Stability measurement





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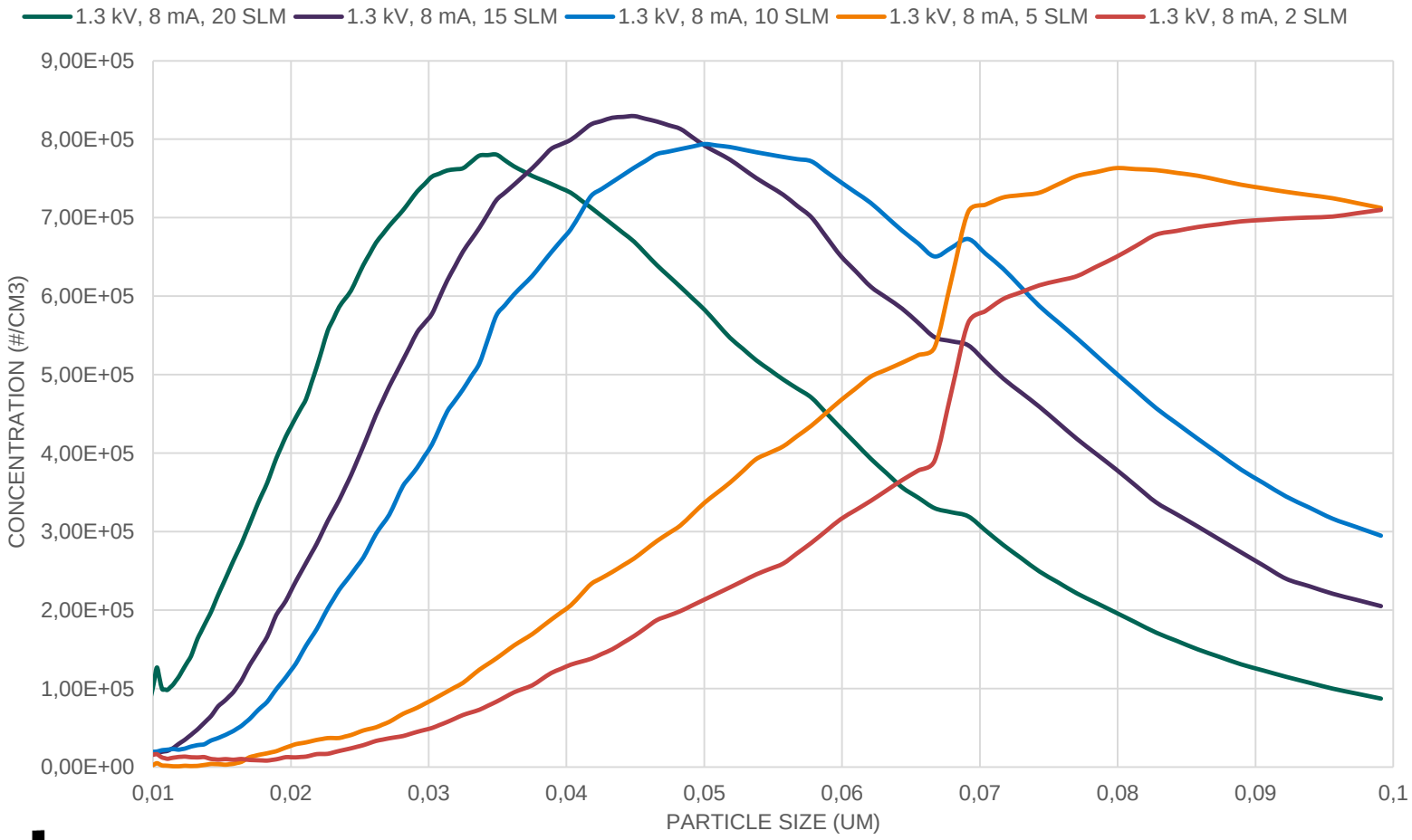
VSP-G1 emission experiments

Results

Carbon output



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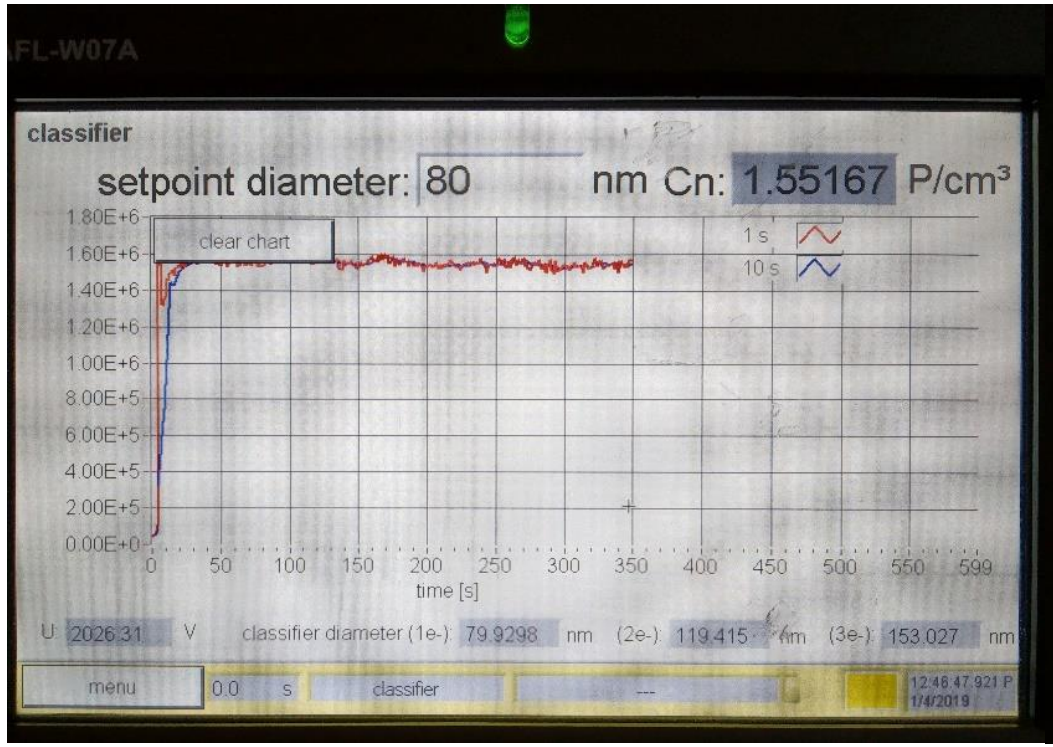
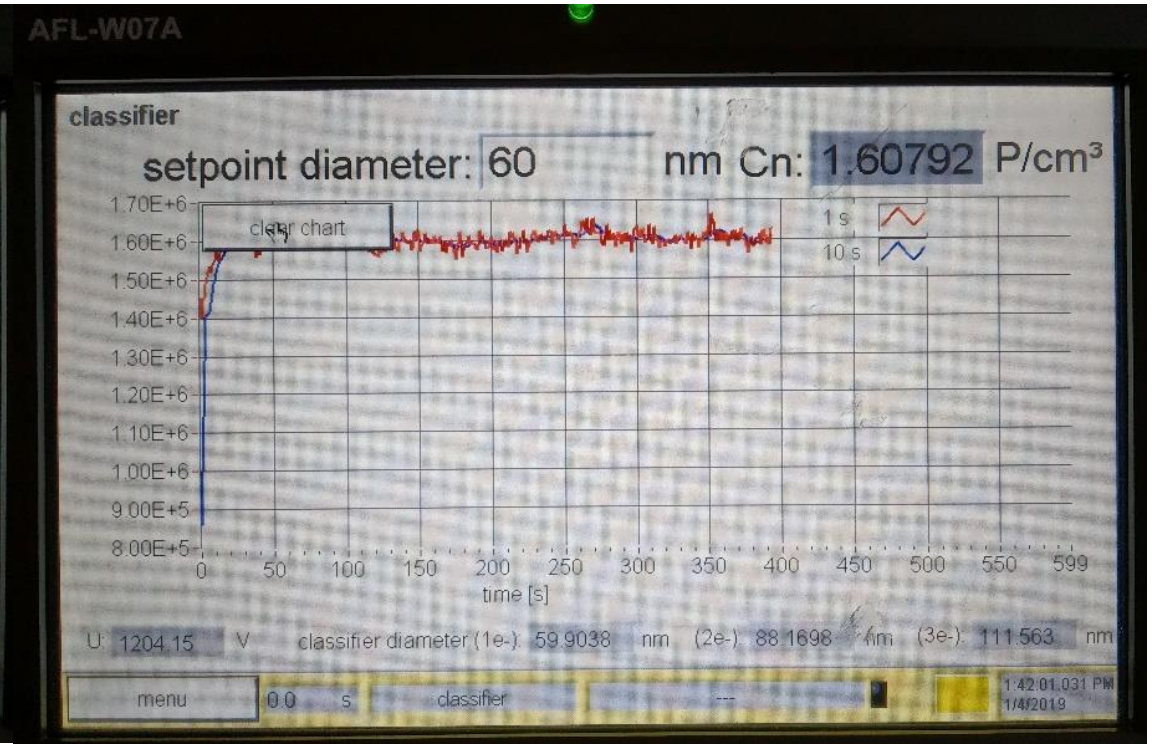
VSP-G1 emission experiments

Results

Carbon output





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Who is already using it

Some of our customers

TU Delft
Delft University of Technology

Universiteit Leiden

TU Clausthal

Universiteit van Amsterdam

UNIVERSITY OF TWENTE.

Utrecht University

MESA+
INSTITUTE FOR NANOTECHNOLOGY

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VSP-G1 Nanoparticle Generator

- R&D scale generator
- Commercially available
- Outputs an aerosol of nanoparticles
- Specifications:
  - Particle size between few atoms to 300 nm
  - Particle generation rate approx. 1 ~ 10 mg/h
  - Particle concentration 10^8 ~ 10^{11} cm^{-3}

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Thank you!

The VSPARTICLE team

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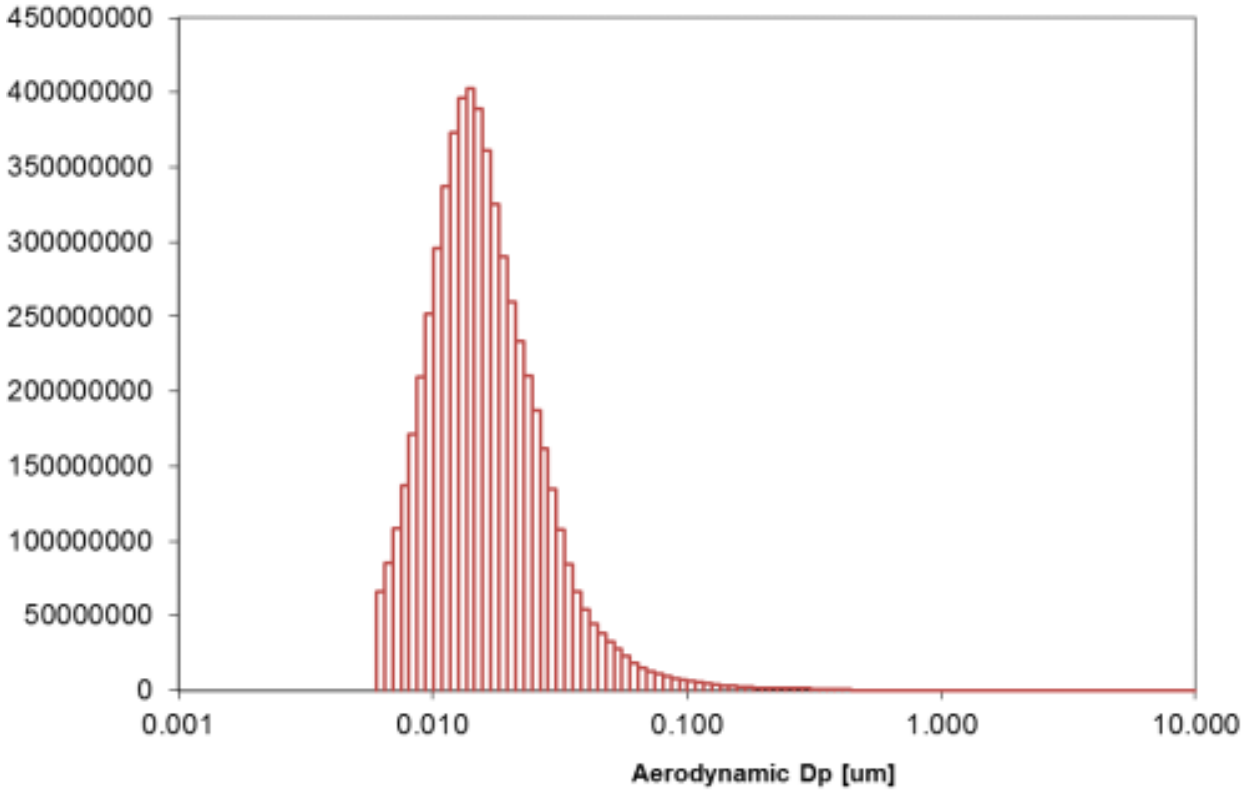
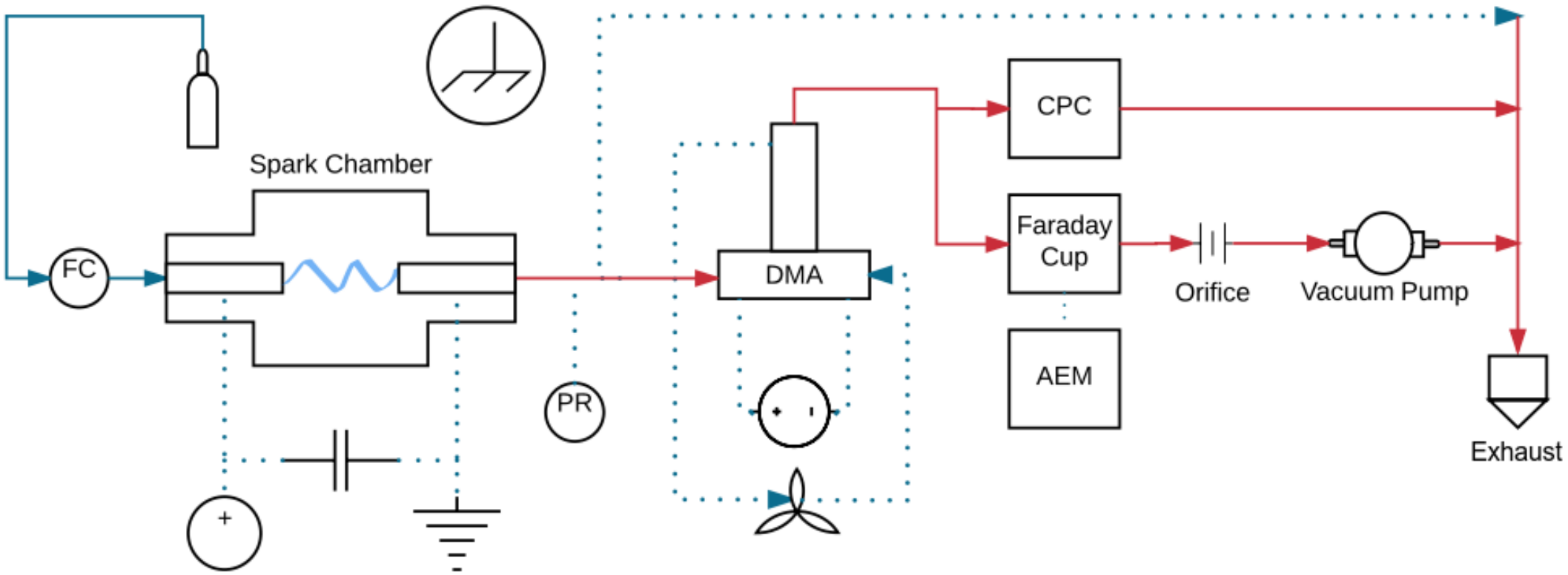
Carbon output

(Dekati Elpi+)



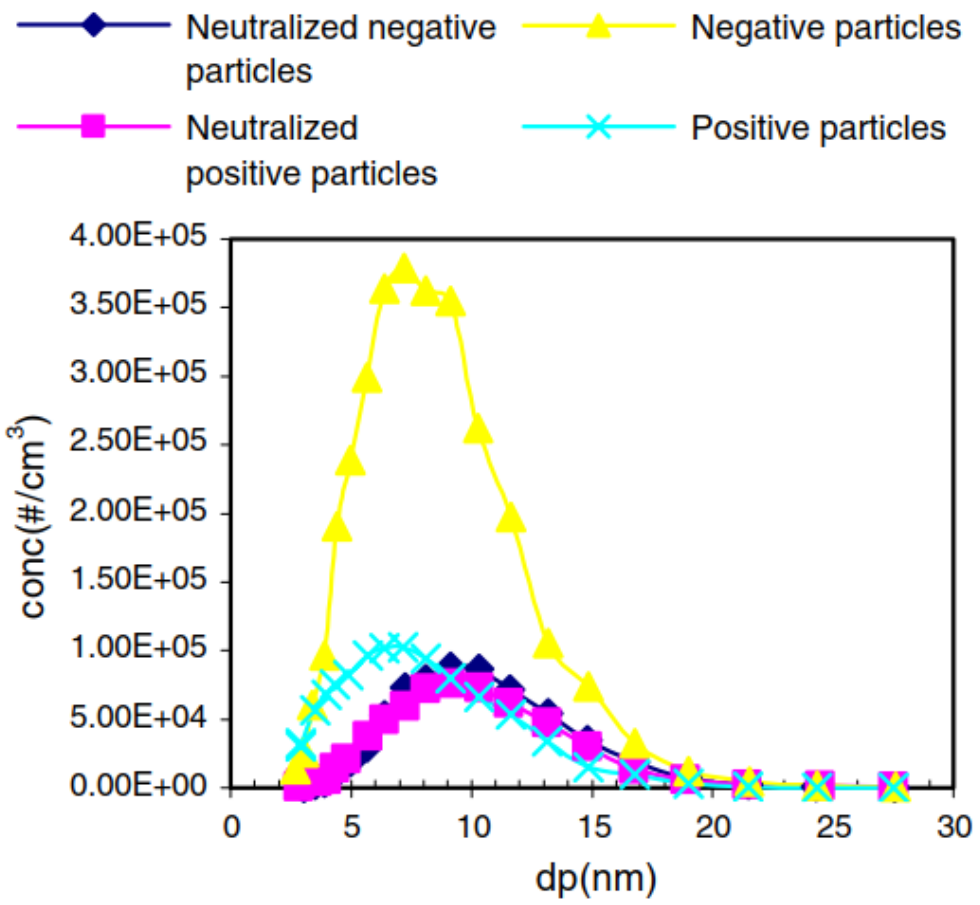
Spark ablation Setup



Self-charging

No neutralizer in setup

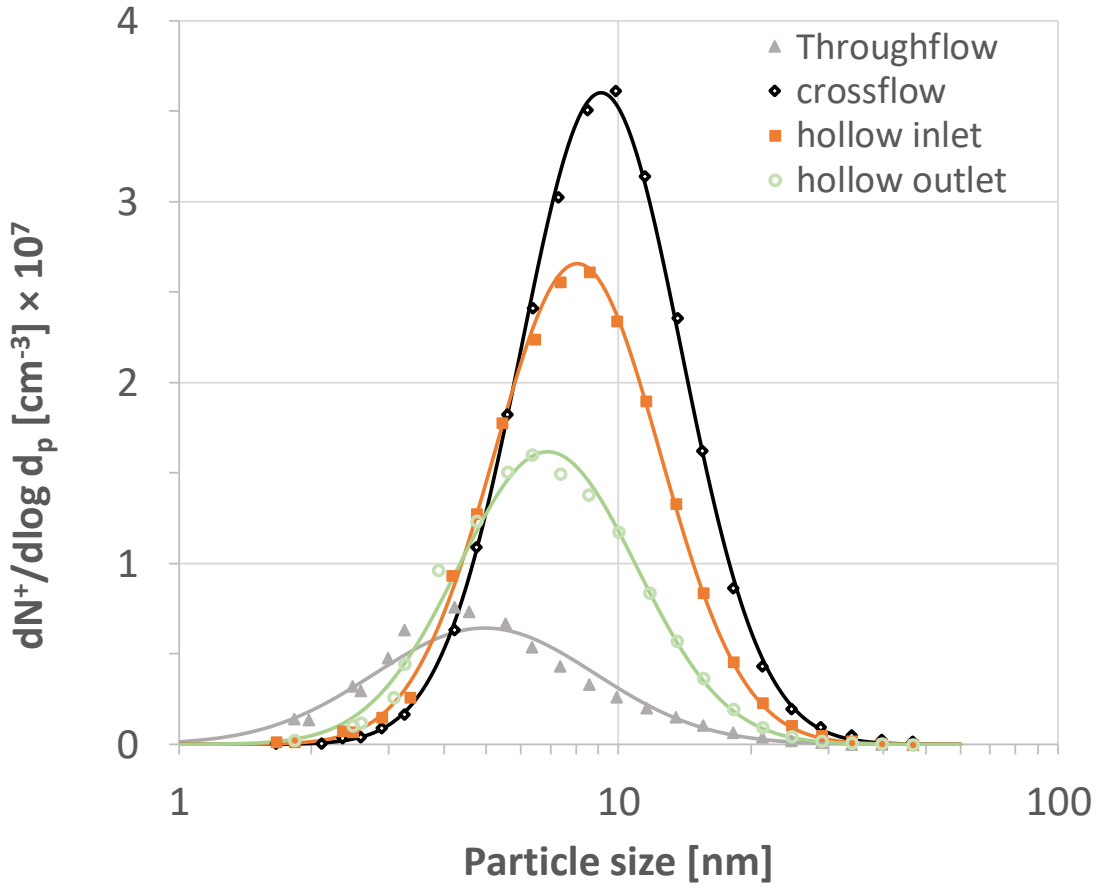
- Self-charging in plasma
- Electrostatic precipitation
- Electrostatic force towards HV Electrode
- Small particles overpresented



Tabrizi et al. 2015

Flow configuration

Influence on Size distribution

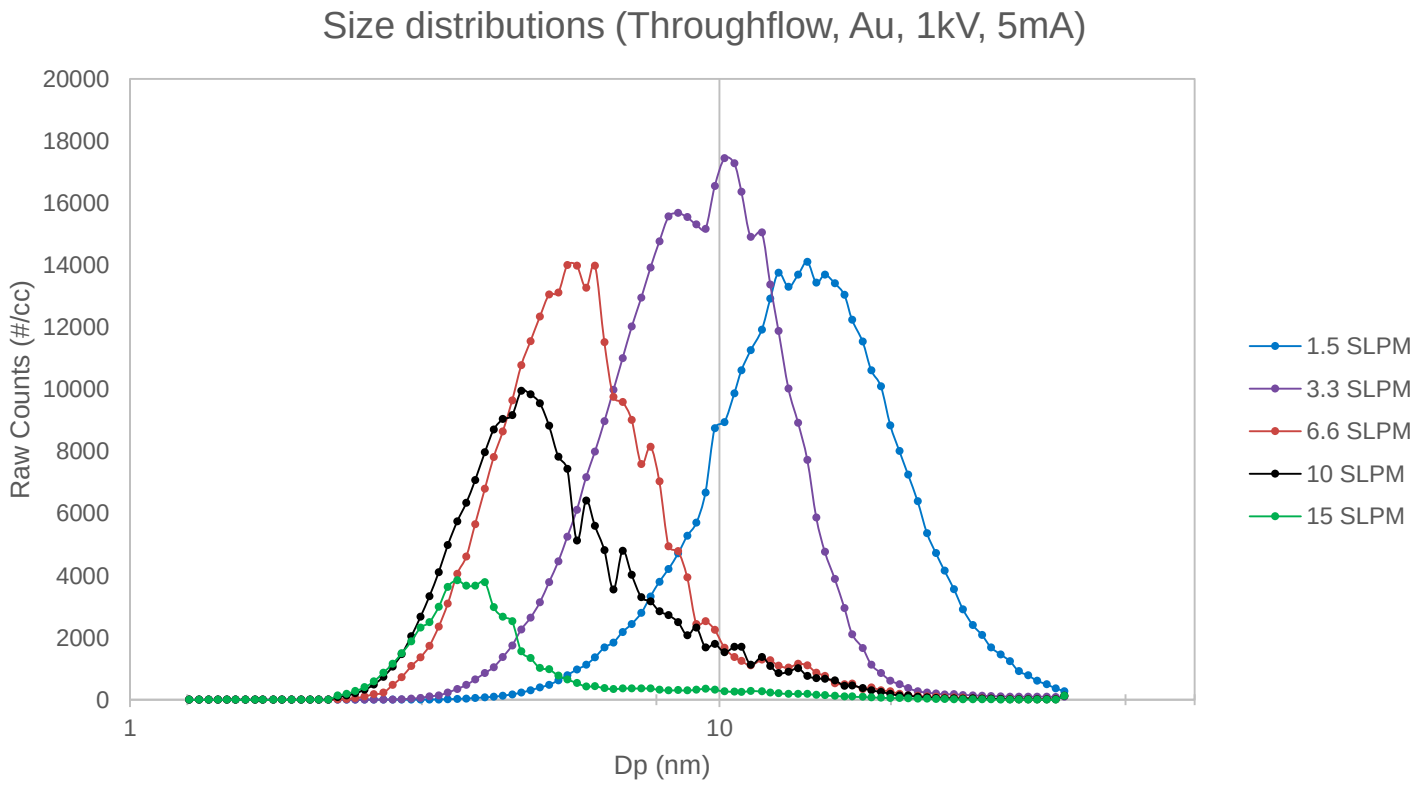


- Tuneable size distribution
- Crossflow highest concentration
- Throughflow smallest mean diameter

Ag, 1.7kV, 4 mA, 4 slm

Flowrate

Influence on size distribution



- **At highest flowrate only primary particles**
- **Dilution at higher flowrate**
- **Current, Voltage Influence**