Triboelectric charging of powder carried by an airflow

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Granular materials

- Large agglomeration of particles
- Different natures, shapes, size distributions
- Numerous applications



- Transport by pneumatic conveying widely used
- Many collisions ➡ Significant tribocharging
- Strong influence of environmental conditions

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Triboelectric effect

- Exchange of electric charges at the surfaces during a contact

Different materials

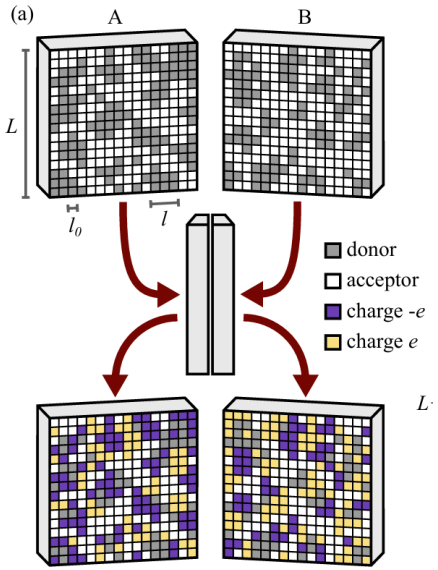
➡ Triboelectric series

+ more positive	Glass
	Mica
	Polyaamind (Nylon 6,6)
	Rock salt (NaCl)
	Wool
	Fur
	Silica
	Silk
	Aluminum
	Poly(vinyl alcohol) (PVA)
	Poly(vinyl acetate) (PVAc)
	Paper
	Cotton
	Steel
	Wood
	Amber
	Poly(methl methacrylate) (PMMA)
	Copper
	Silver
	Gold
	Poly(ethylene terephthalate)(Mylar)
	Epoxy Resin
	Natural Rubber
	Polacrylonitrile (PAN)
	Poly(vinylidene chloride) (Saran)
	Polystyrene (PS)
more negative -	Polyethylene (PE)
	Polypropylene (PP)
	Poly(vinyl chloride)(PVC)
	Polytetrafluorethylene (Teflon, PTFE)

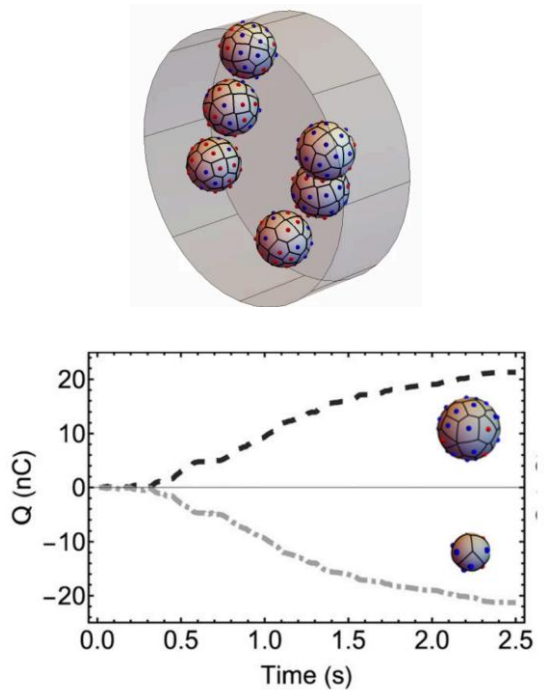
Gauntt, Sean et al., *Dynamic Modeling of Triboelectric Generators Using Lagrange's Equation, ASME,* Vol.1 (2017)

Same materials

➡ Patch model



G. Grojean et al., Physical Review Materials **7** 065601(R) (2023)



N. Preud'homme et al., Soft Matter **19**, 8911 (2023)

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Charge accumulation in granular materials

→ Lot of contacts

→ Electrostatic charges accumulation

→ Sticking

→ Intermittencies in industry

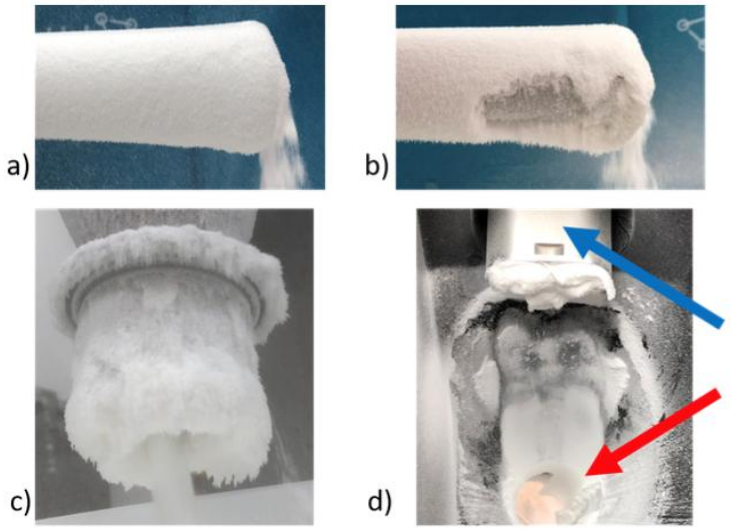

Figure 8. Representative images of electrostatic buildup of HPMC CR grades a) material accumulation on feeder barrel b) accumulated material falling off the barrel and causing a spike in the feed rate and mass flow RSD c) material accumulation at output of the hopper d) clean LIW feeder barrel (blue arrow) when placed into a hopper with material building up at hopper output instead (red arrow).

C. Allenspach, *Loss in Weight Feeding, Powder Flow and Electrostatic Evaluation for Direct Compression Hydroxypropyl Methylcellulose (HPMC) to Support Continuous Manufacturing*, Int. J. of Pharmaceutics **596**, 120259 (2021)

→ Electrostatic discharge

→ Dust explosions

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Project Codename: *Dust in the Wind*

- Collaboration between soft-matter physicists and aerodynamics engineers

@Wind Tunnel Lab ULiège

- Goal: study the triboelectric effect in granular materials carried by an airflow at different Reynolds numbers

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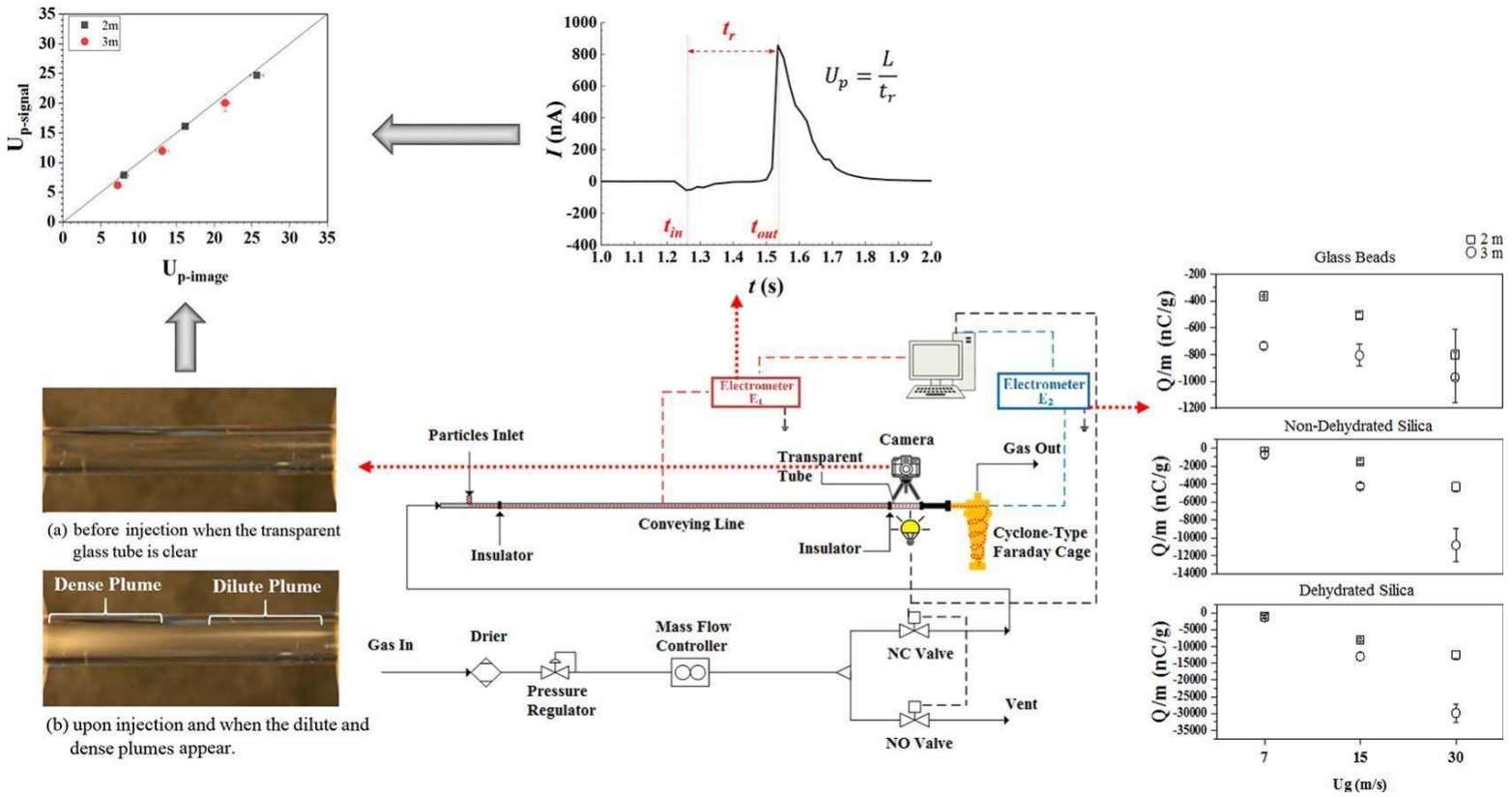
Previous works



M. I. Nimvari *et al.*, *Velocity measurement of pneumatically conveyed particles via a simple current signal technique and the influence of electrostatic charge*, Powder Technology **413**, 118018 (2023)

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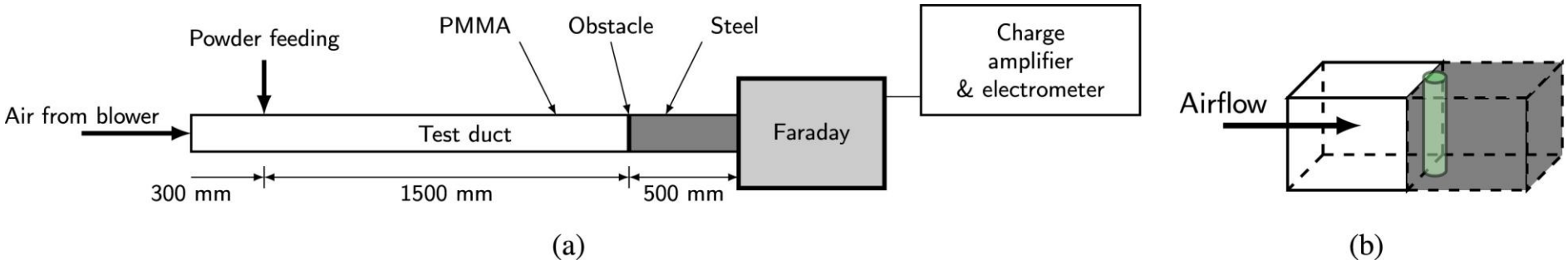
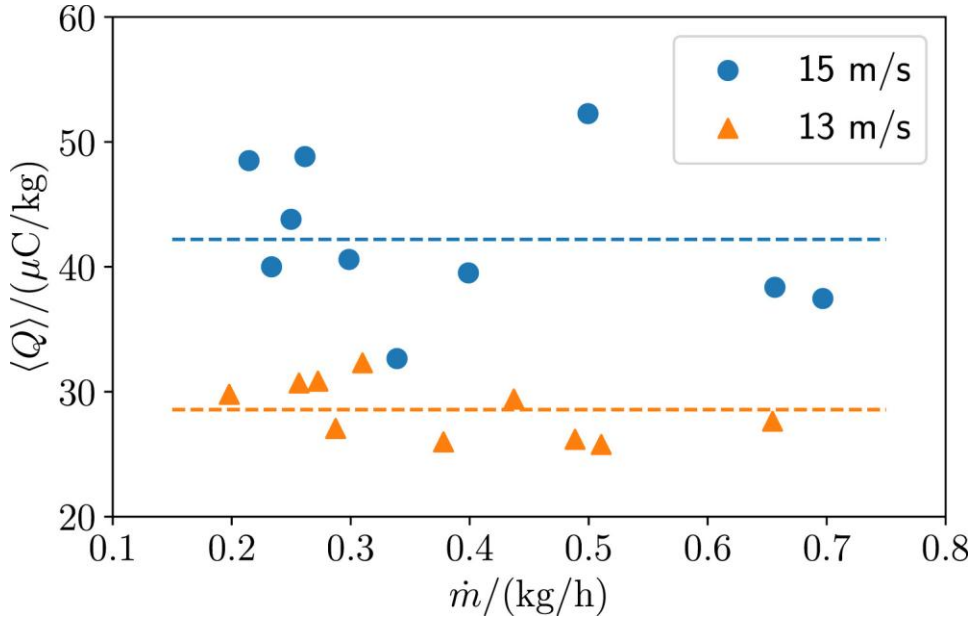
Previous works





W. Xu et al., Experimental study of humidity influence on triboelectric charging of particle-laden duct flows, Journal of Loss Prevention in the Process Industries **81**, 104970 (2023)

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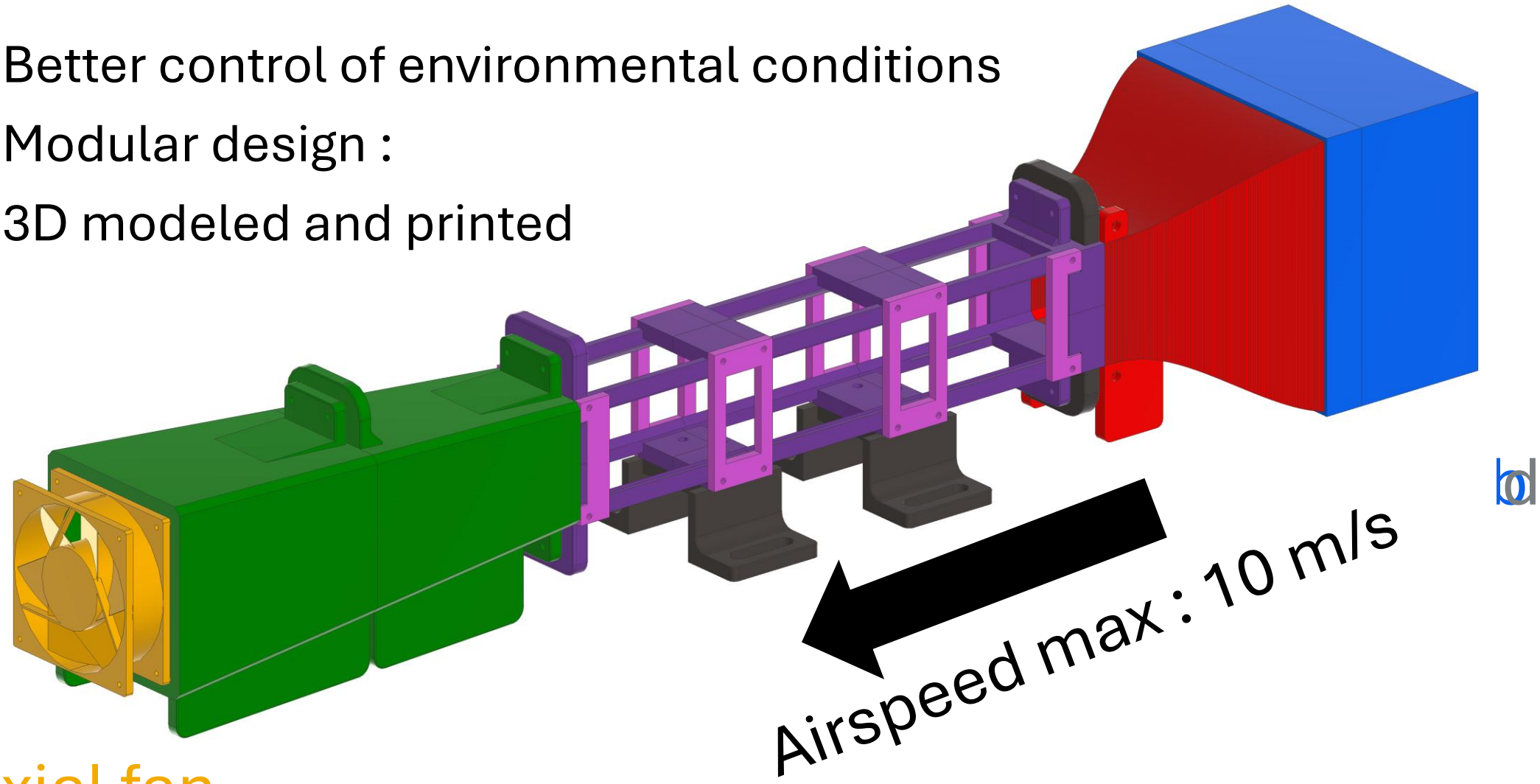
Small-scale wind tunnel

- Better control of environmental conditions
- Modular design :
- 3D modeled and printed



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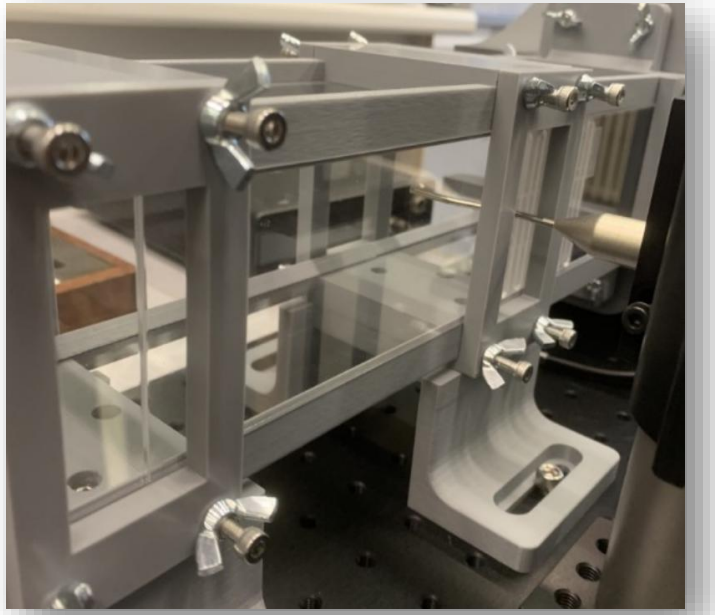
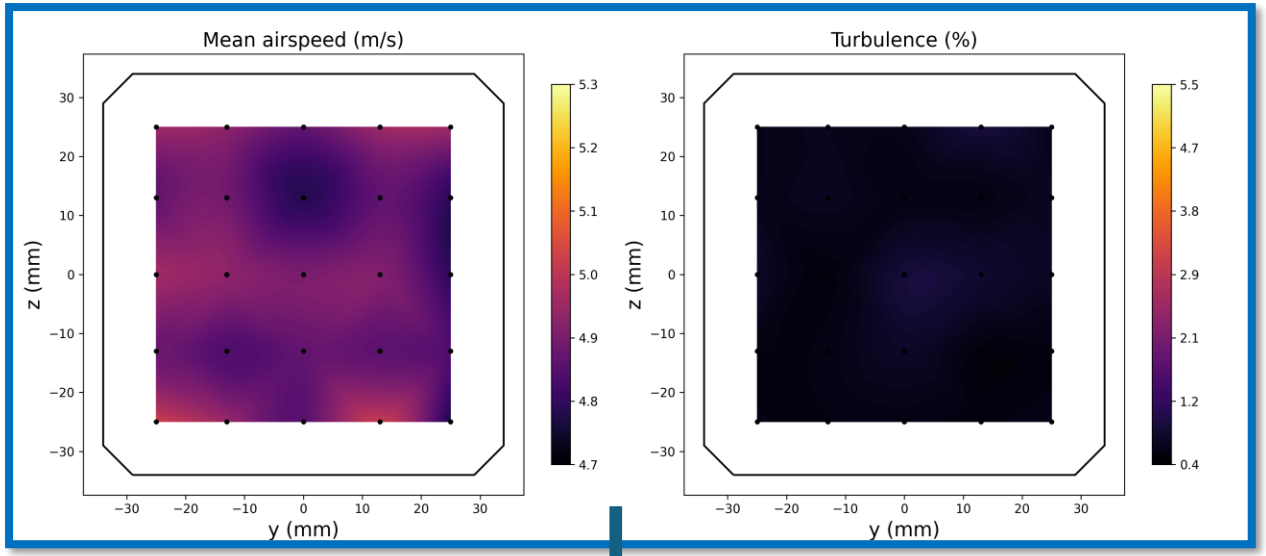
Small-scale wind tunnel

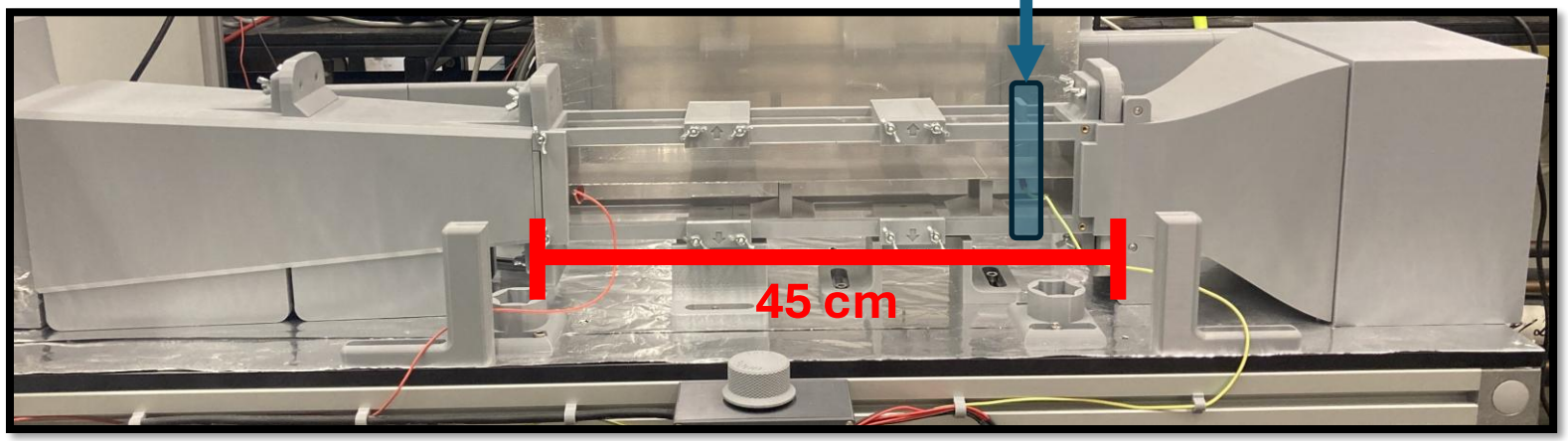
- Airflow characterisation (5 m/s):



Adjustable multi-hole pressure probe able to resolve 3-components of velocity

x = 50 mm





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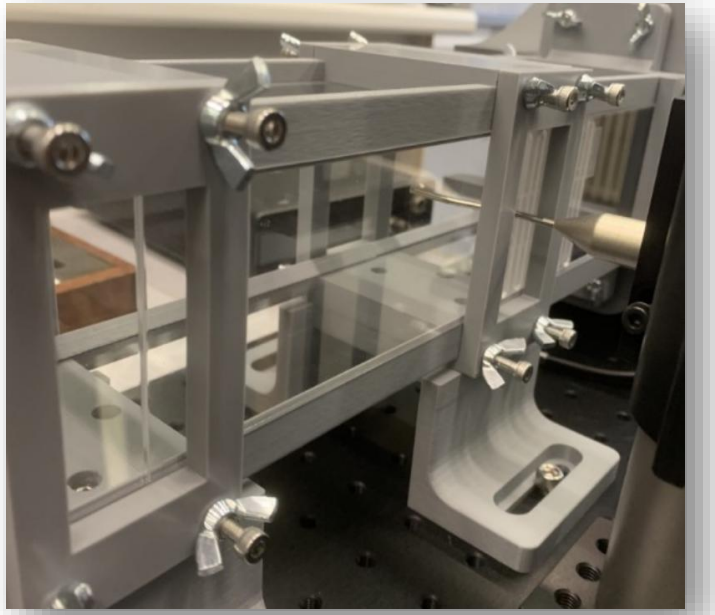
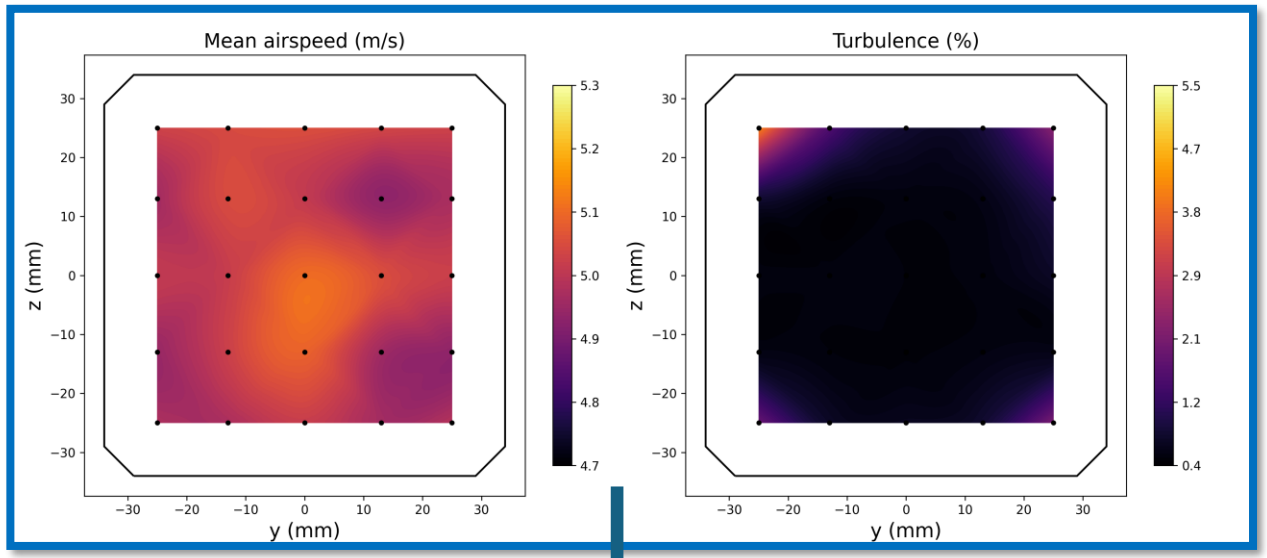
Small-scale wind tunnel

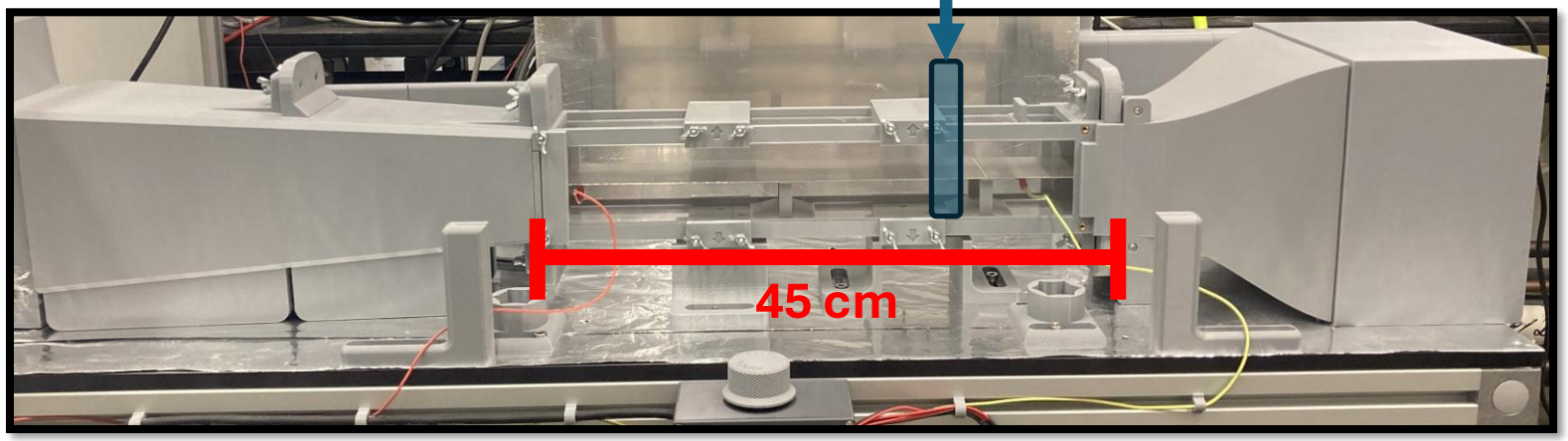
- Airflow characterisation (5 m/s):



Adjustable multi-hole pressure probe able to resolve 3-components of velocity

x = 160 mm





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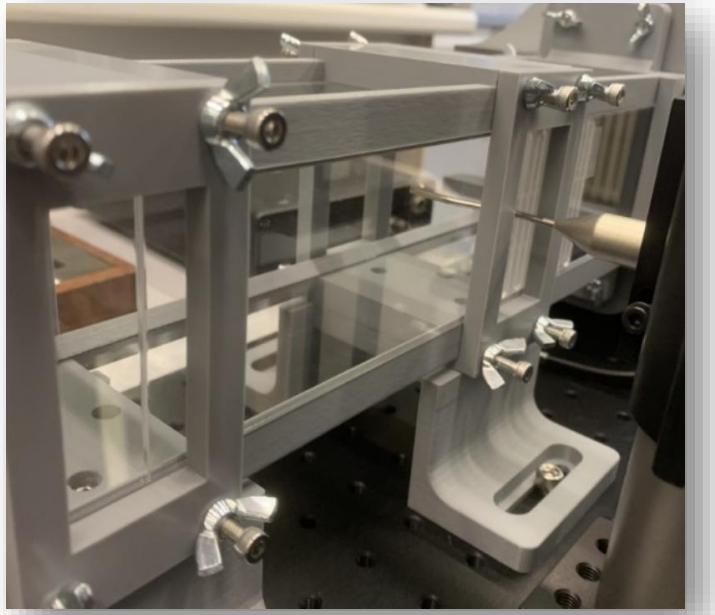
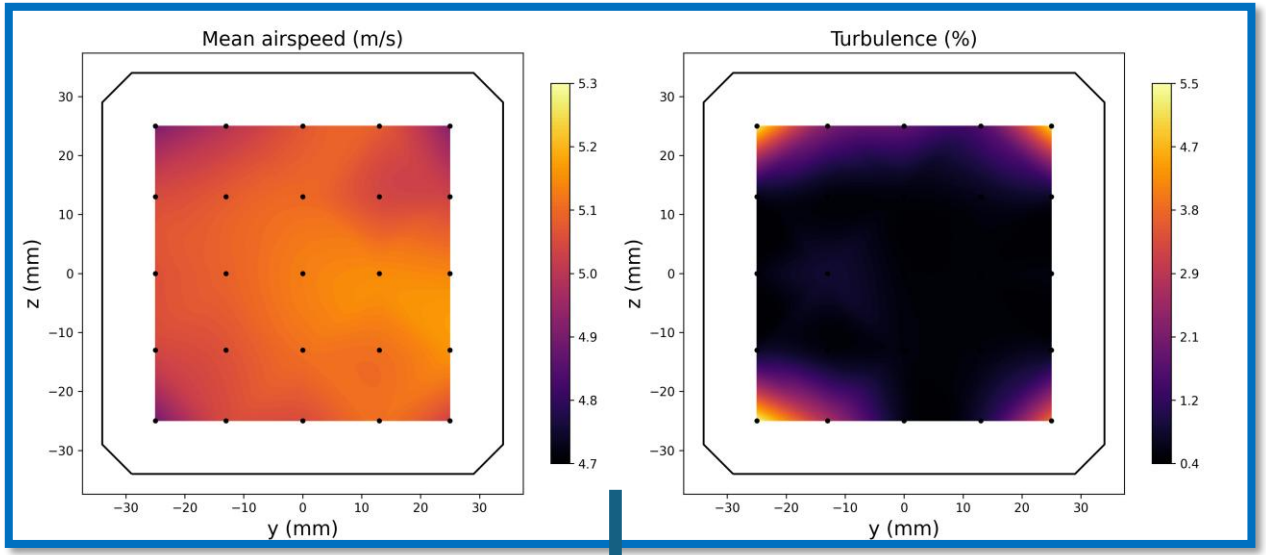
Small-scale wind tunnel

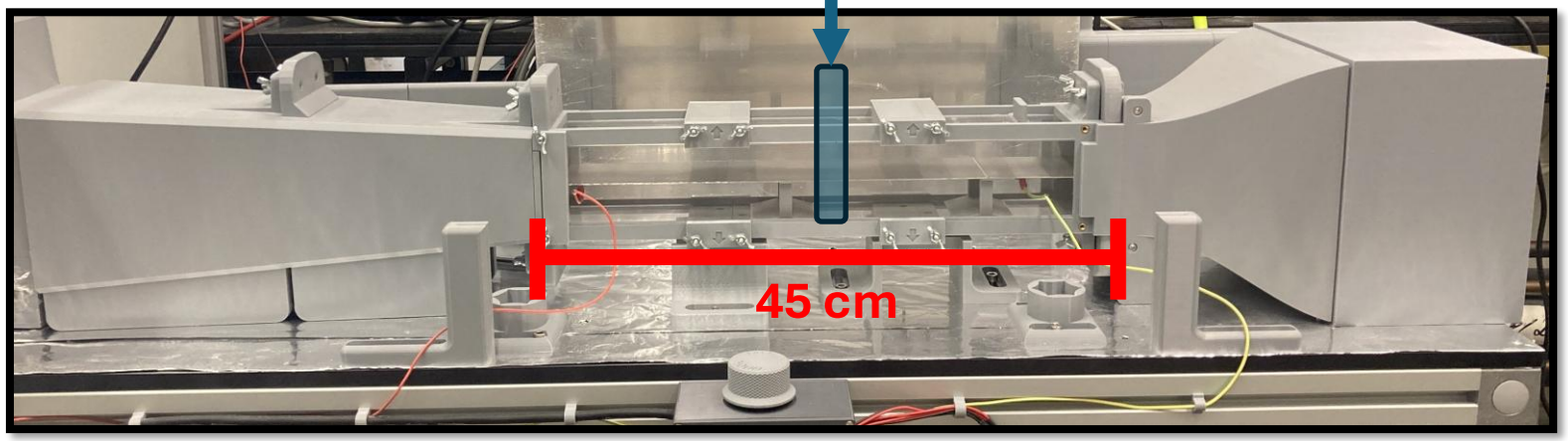
- Airflow characterisation (5 m/s):



Adjustable multi-hole pressure probe able to resolve 3-components of velocity

x = 230 mm





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Small-scale wind tunnel

- Airflow characterisation (5 m/s):

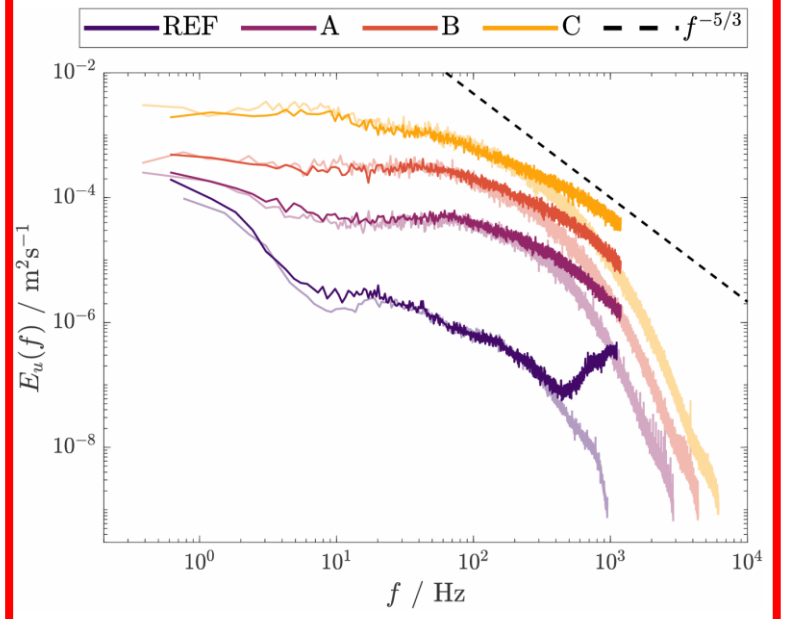


Table 3 Turbulence dissipation scales for the three analyzed cases measured at the mid-length and centerline of the test section. The reported values were derived from the hot-wire signal and the raw Cobra probe signal. For the Cobra probe, λ, η, ε, and Re_λ were evaluated using differentiation schemes of accuracies $\mathcal{O}(dx^6)$, $\mathcal{O}(dx^4)$, $\mathcal{O}(dx^4)$, and $\mathcal{O}(dx^{10})$ respectively.

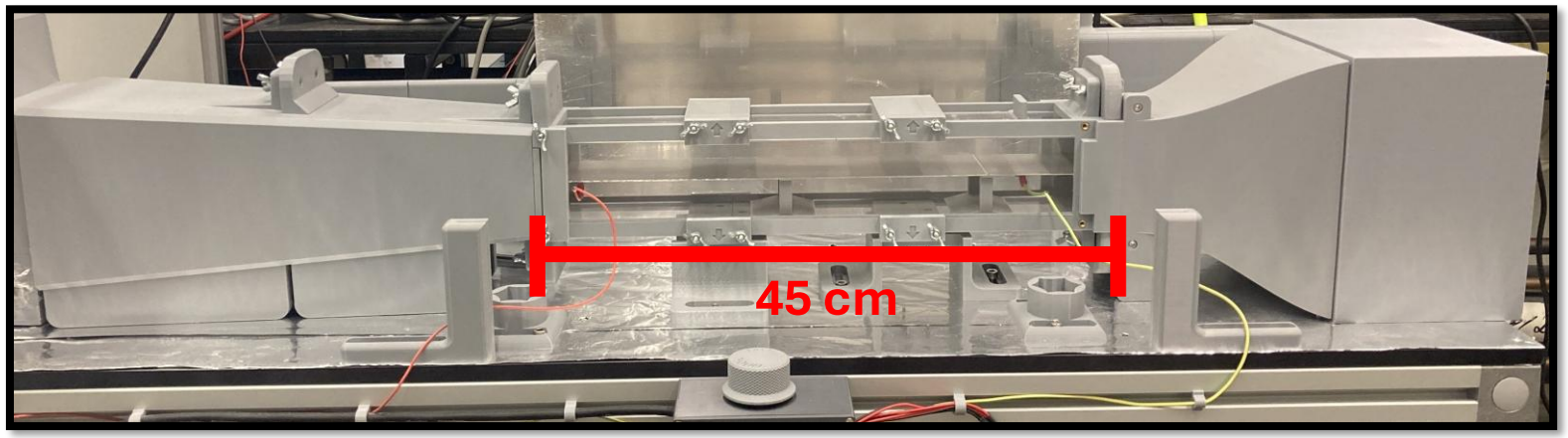
		Hot-Wire			Cobra Probe		
		A	B	C	A	B	C
λ	(mm)	3.14	3.08	3.15	3.12	3.11	3.20
η	(mm)	0.35	0.23	0.16	0.34	0.22	0.17
ε	(m^{2}s^{-3})	0.28	1.48	5.63	0.31	1.57	5.16
Re_λ	(−)	22	47	97	23	50	95

Paper submitted
(S. Dehareng et al.)

***REF, A, B, C correspond to 4 cases from lowest to highest generated freestream turbulence in the wind tunnel test section**

Turbulence analysed and compared for different cases of generated freestream turbulence:
- Hot wire
- Cobra probe

➡ Good flow homogeneity for such small-scale device



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Small-scale wind tunnel :

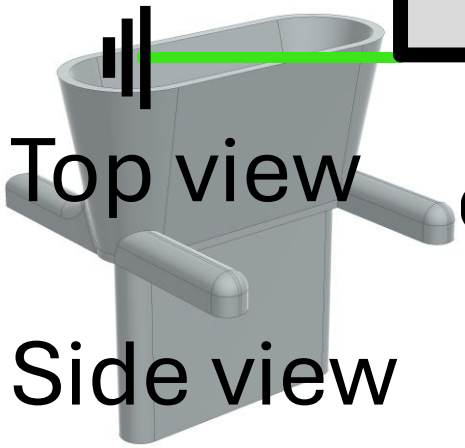
Six cameras to record the powder evolution

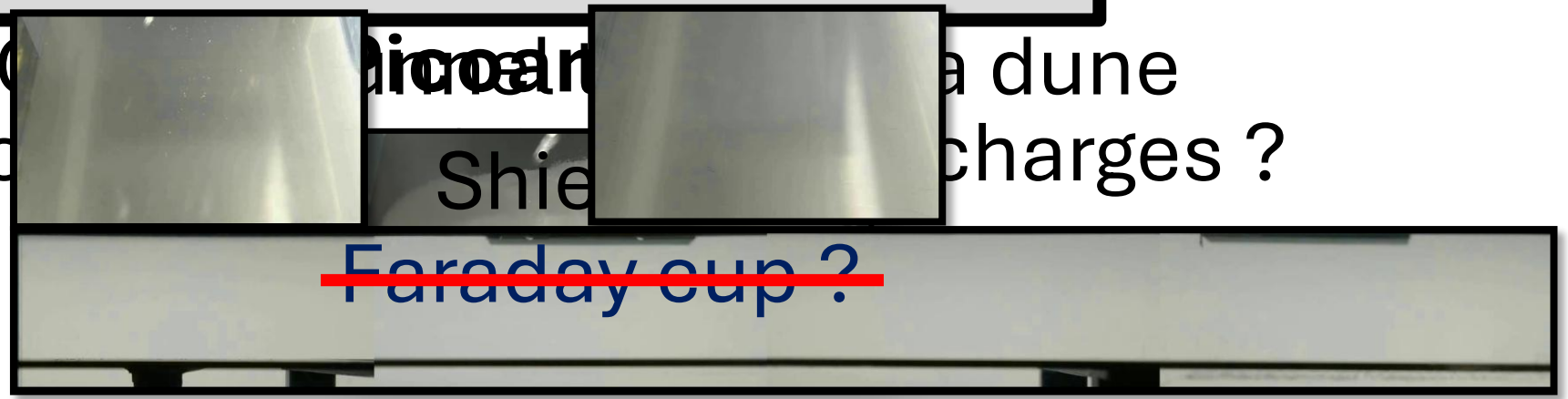
Airflow well characterised but…

Stainless-steel plates

Top view

Side view





Shie

Faraday cup ?

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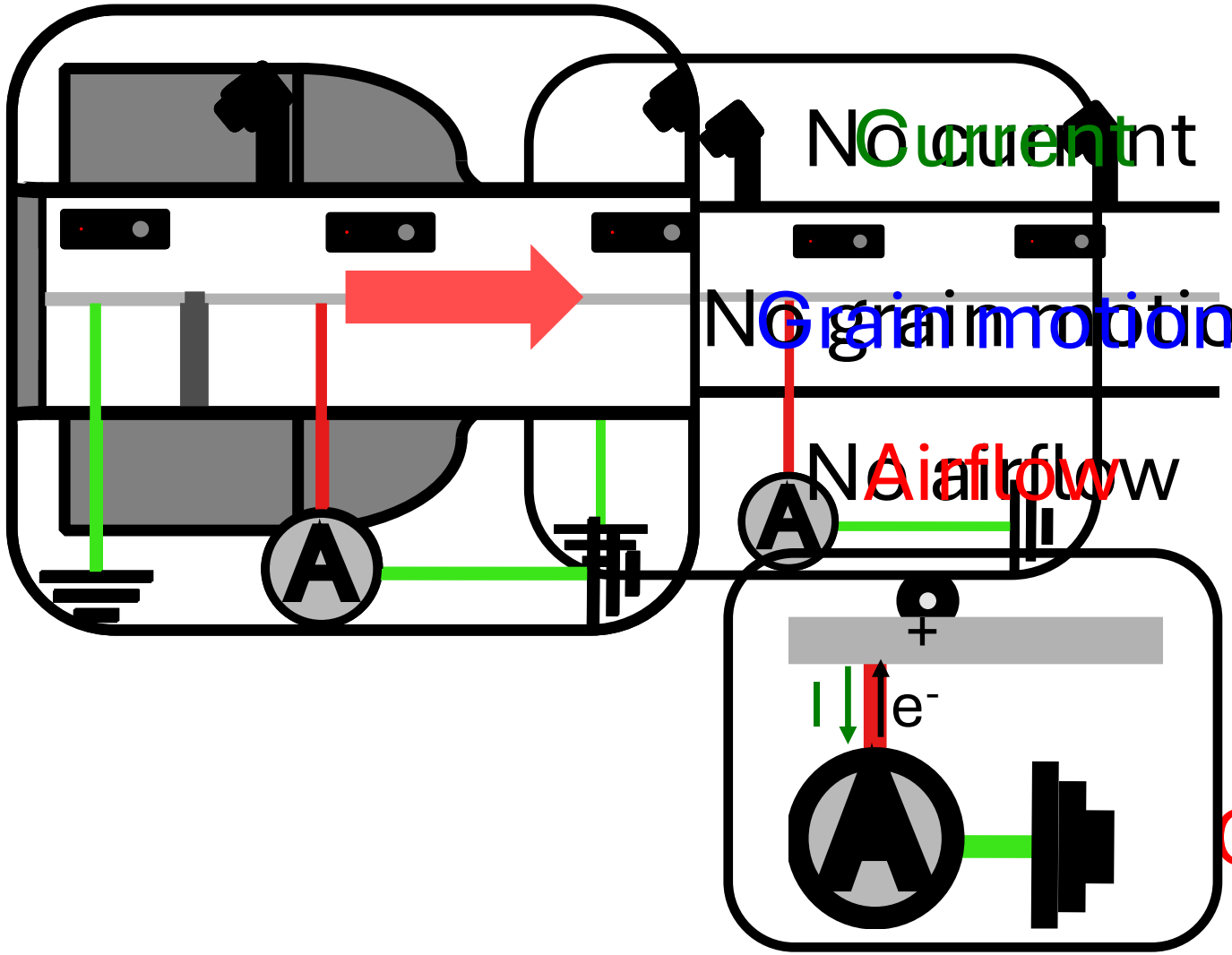
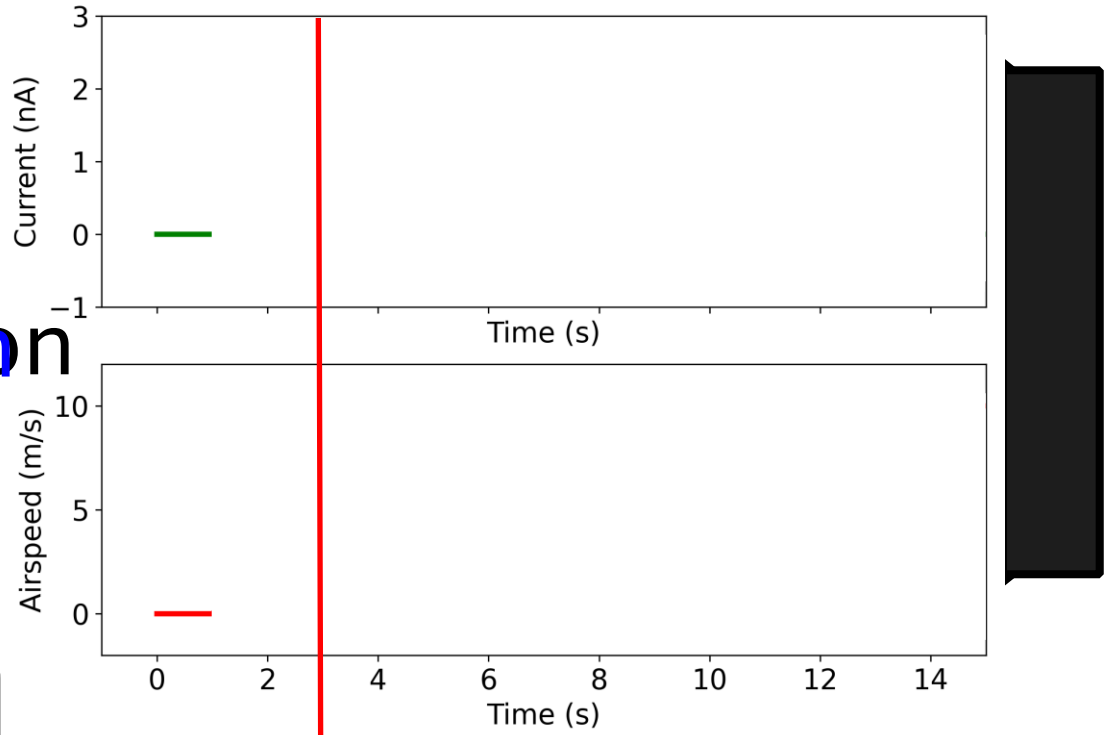
Typical experiment





Current > 0 ➡ $Q_{grain} < 0$

Critical velocity

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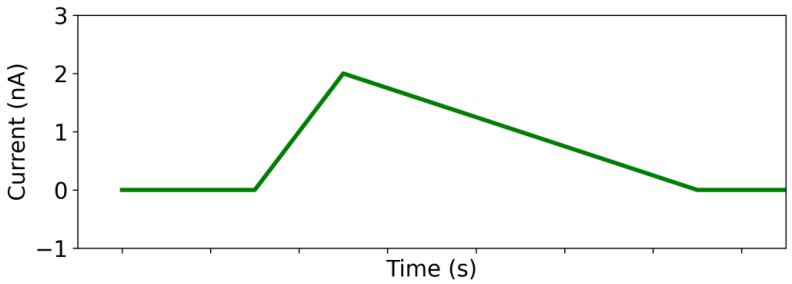
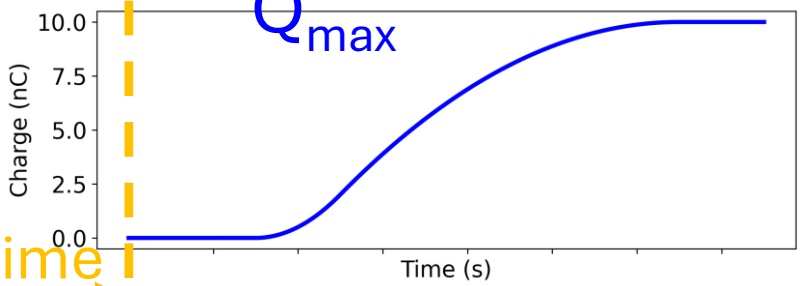
Typical experiment : analysis



Integration



Q_{max}

Characteristic Time

Charge density q_{powder} (C/kg) :

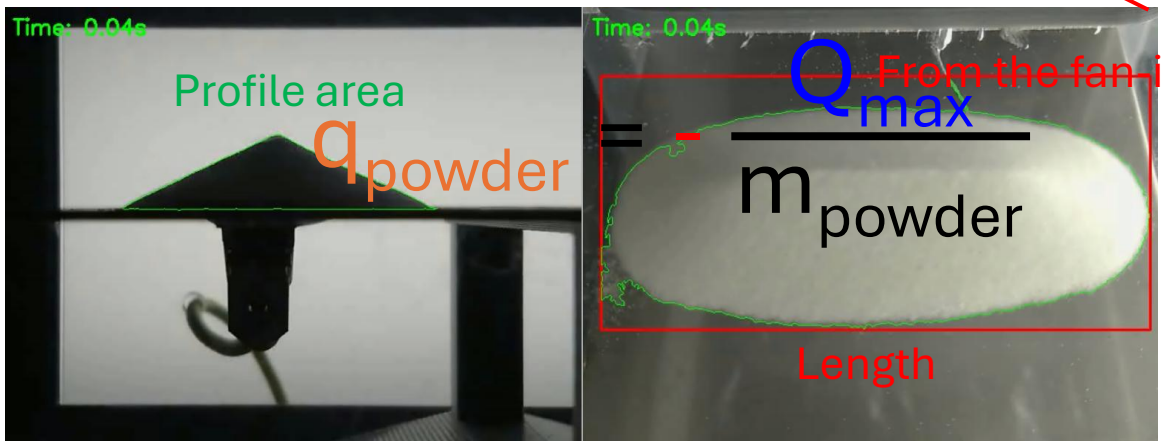
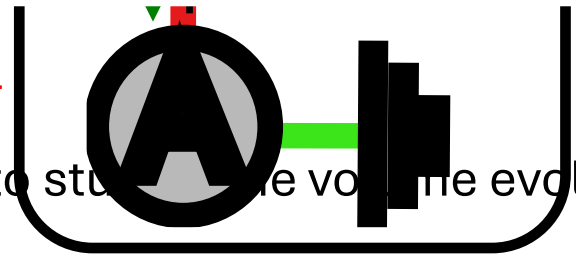


Image analysis



Possibility to study the volume evolution

Approximation :

Volume ≈ Profile area × Length

Current > 0

Charge > 0

$Q_{grain} < 0$

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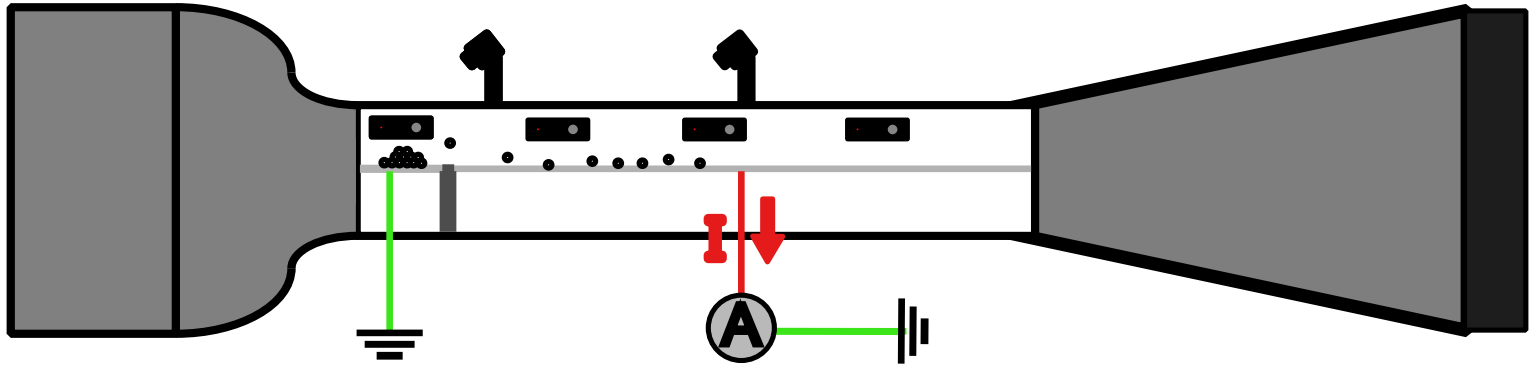
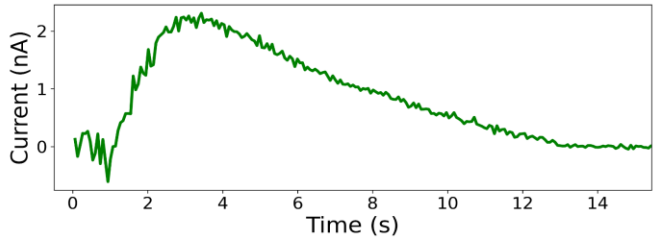
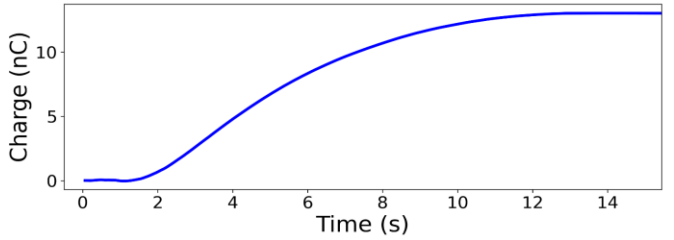
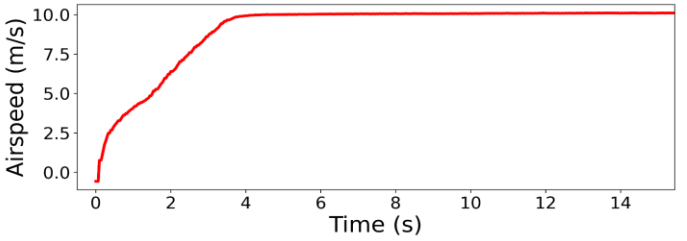
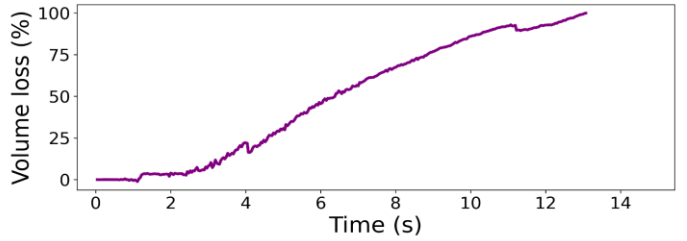
Typical experiment : example

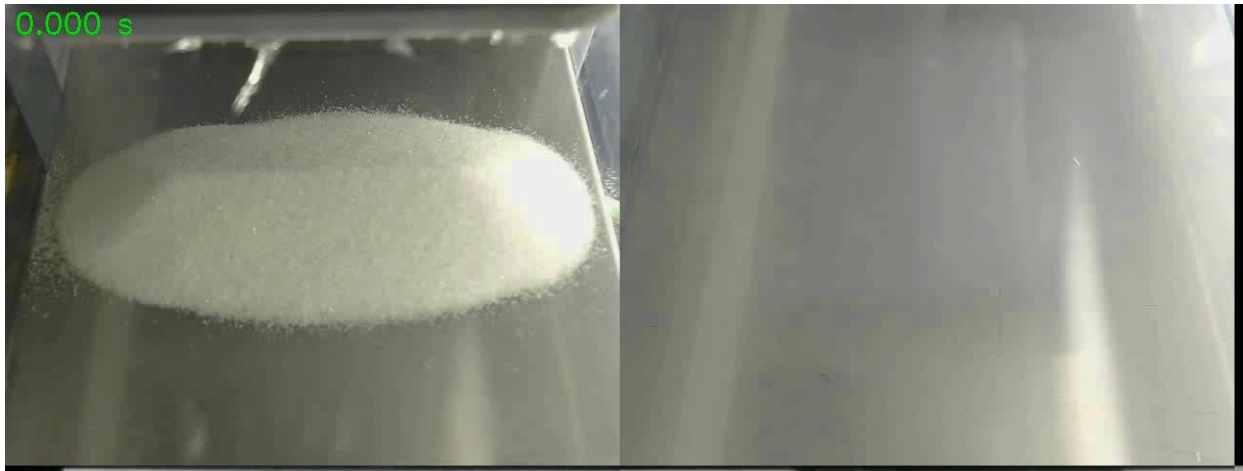






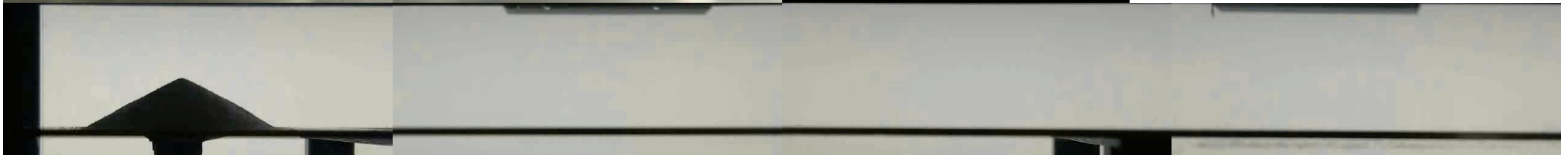






90-150 µm glass beads
Airspeed : 10 m/s
RH : 26.7 %

q_{powder} = 1.74 nC/g



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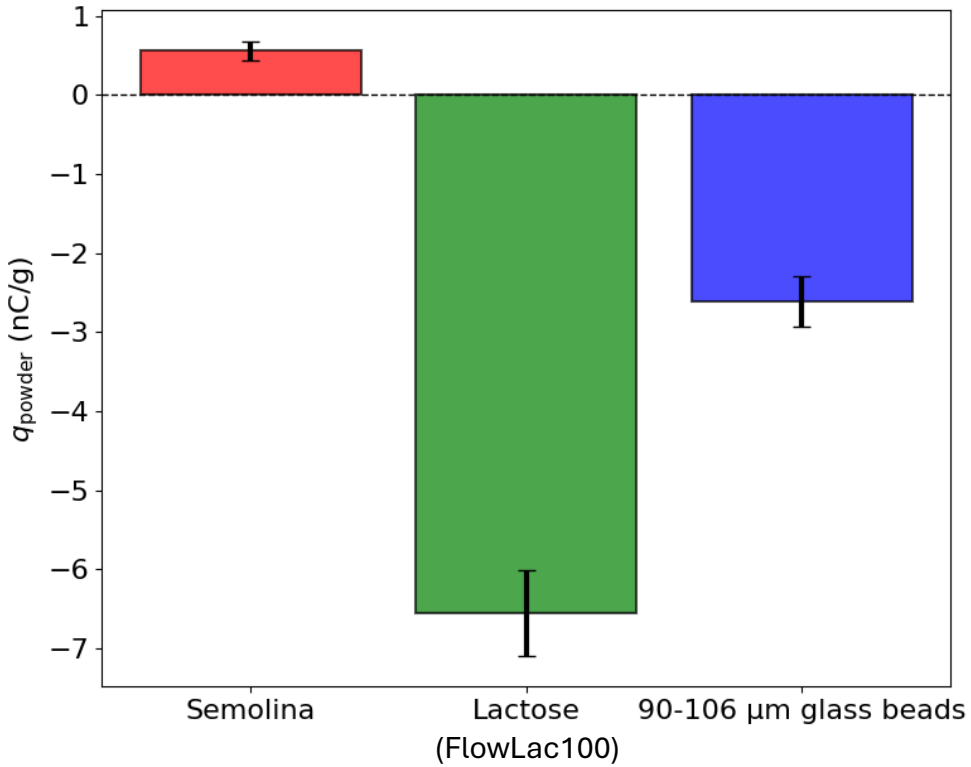
Influence of material nature

Small-scale Wind Tunnel

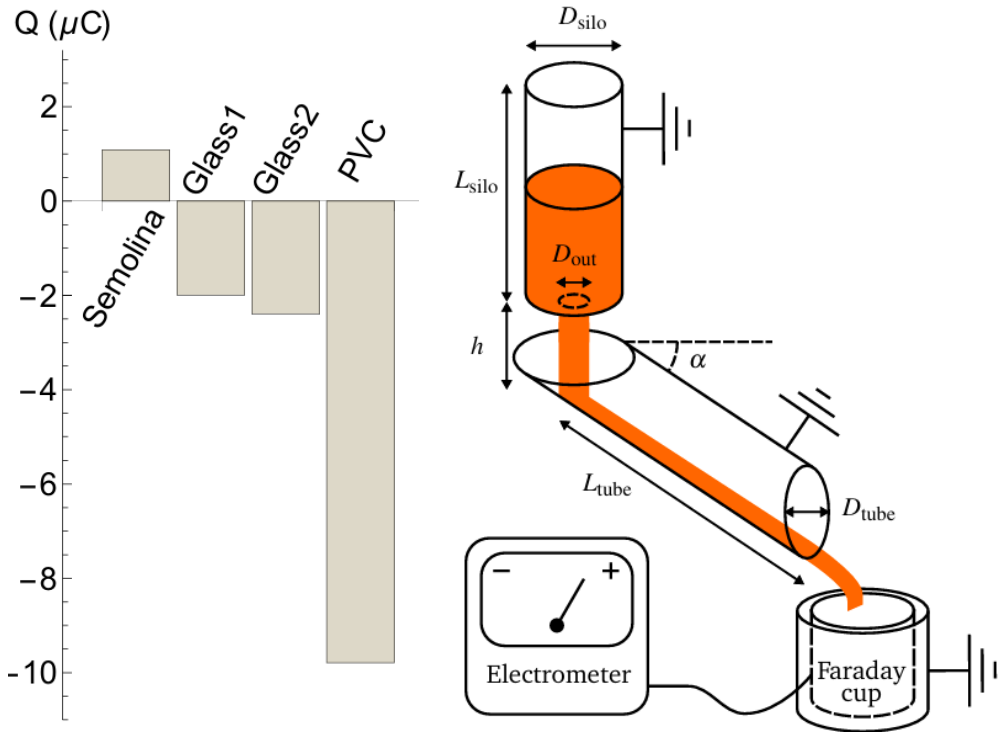
Airspeed : 10 m/s

(3 experiments per material)



➡ Triboelectric series with the plate

Inclined tube



Preud'homme et al., *Tribocharging of granular materials flowing in grounded inclined tubes*

➡ Similar trends

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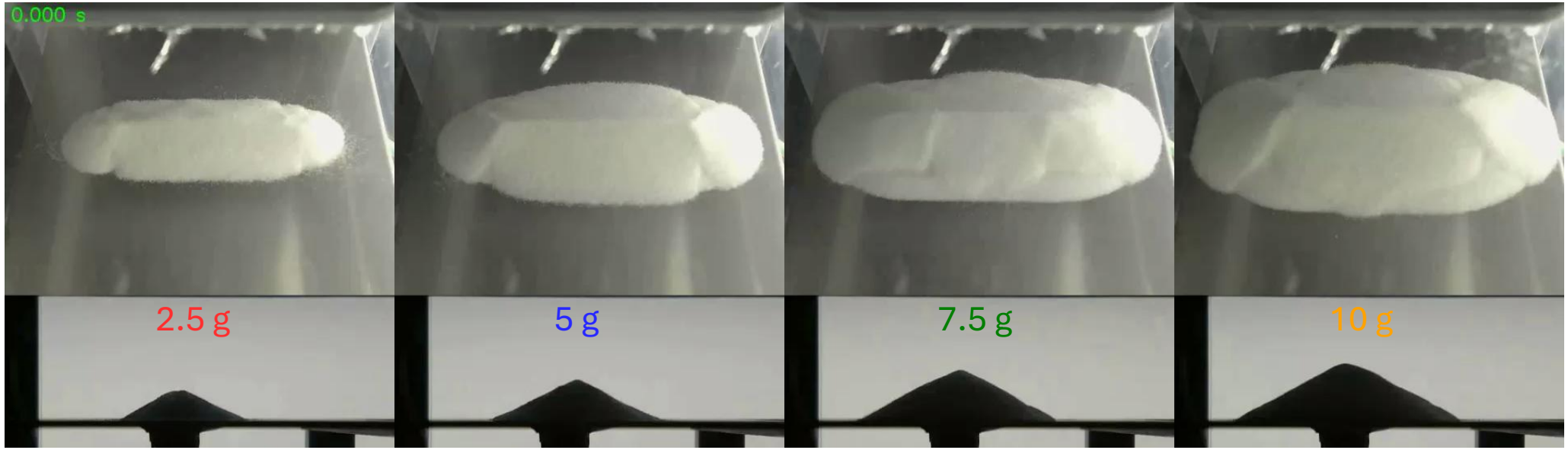
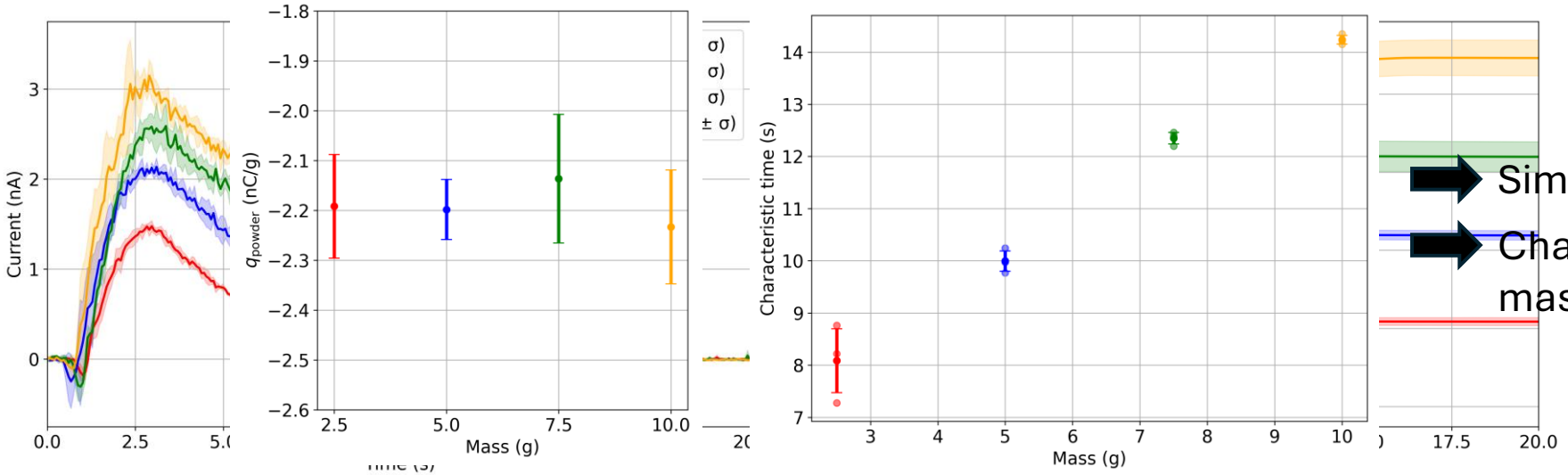
Influence of mass

90-106 µm Glass beads **Airspeed : 10 m/s** **RH: 52%**





- Highly reproducible (3 experiments)
- Similar charge density
- Characteristic time increases with mass

Mass ↗ : maximum current ↗
maximum charge ↗

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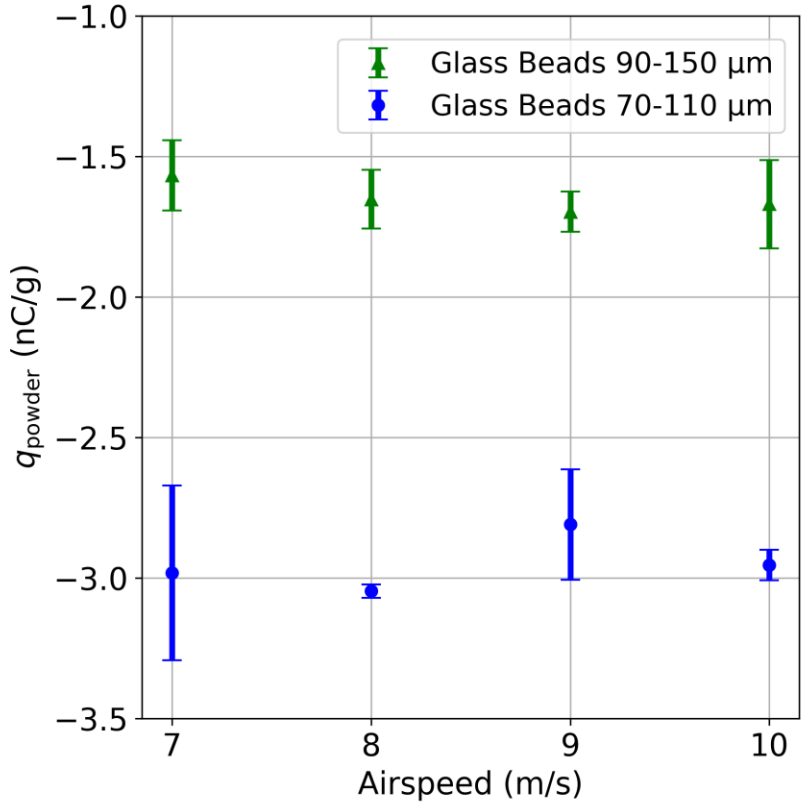
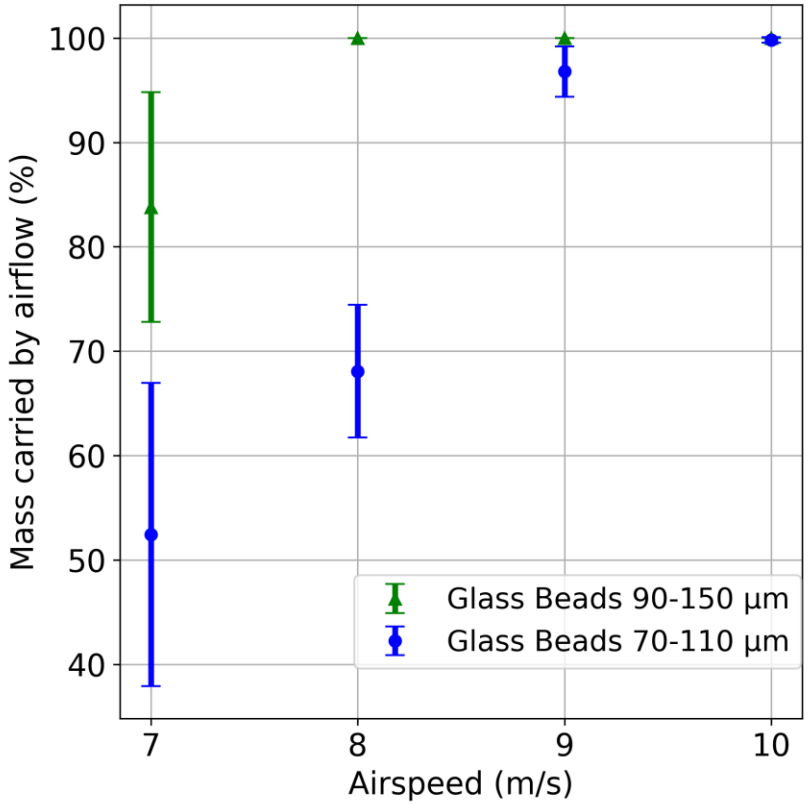
Influence of particle size and airspeed

Mass = 7.5 g **RH : 25%**





➡ Strong effect of grain size on charge density

➡ Little influence of airspeed in the laminar speed range

➡ Not all grains are carried by the flow at low airspeed

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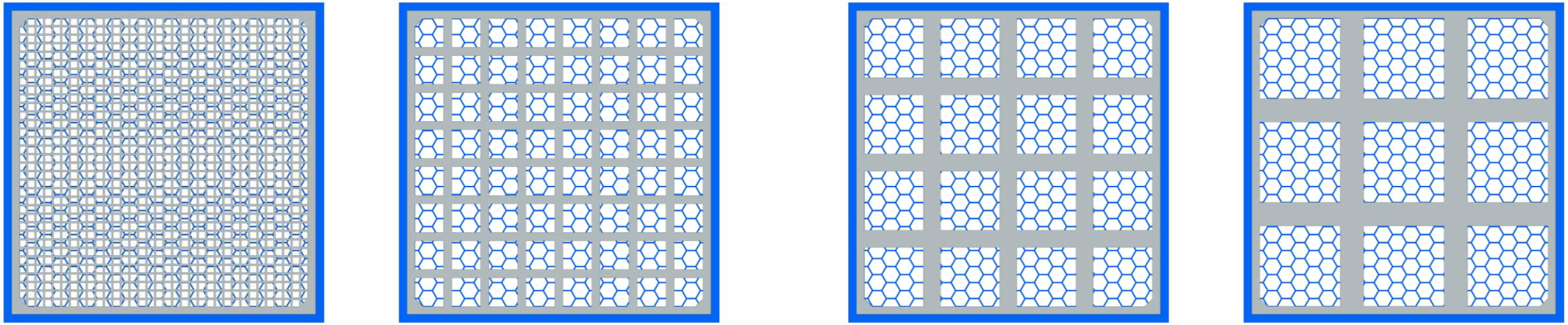
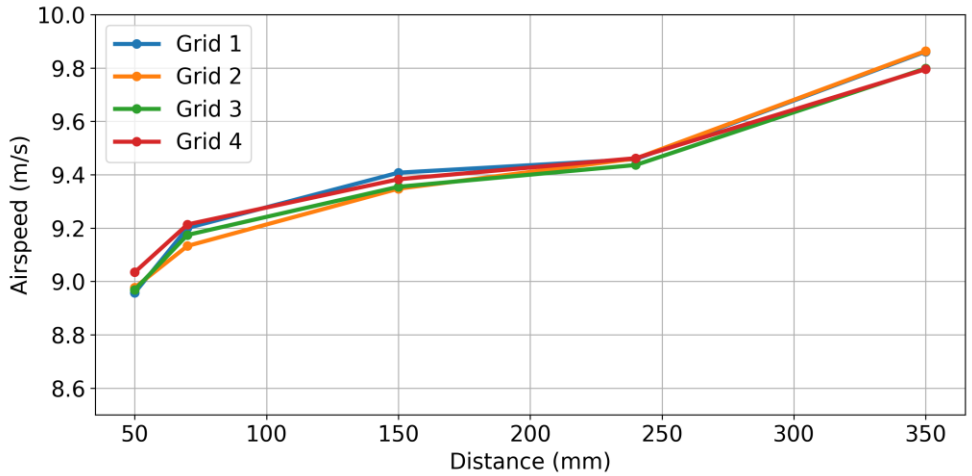
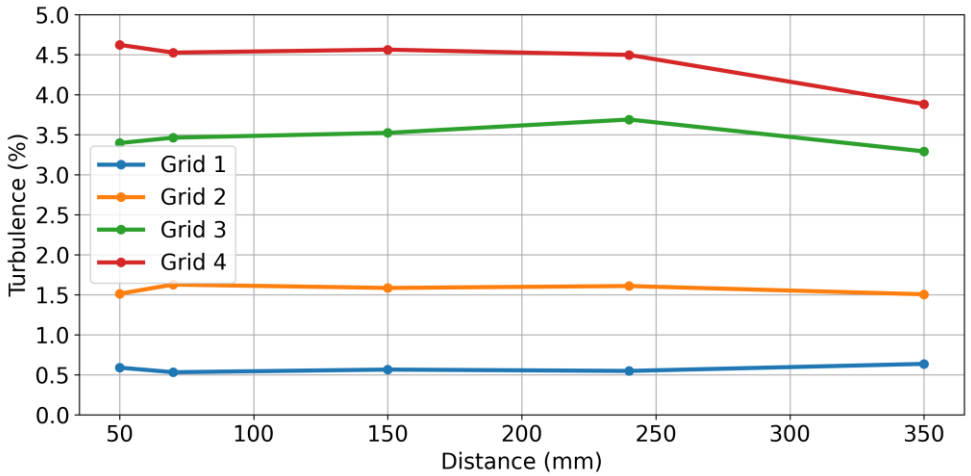
Influence of turbulence



Grid 1 Grid 2 Grid 3 Grid 4





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➡ Grids influence the turbulence, not the airspeed

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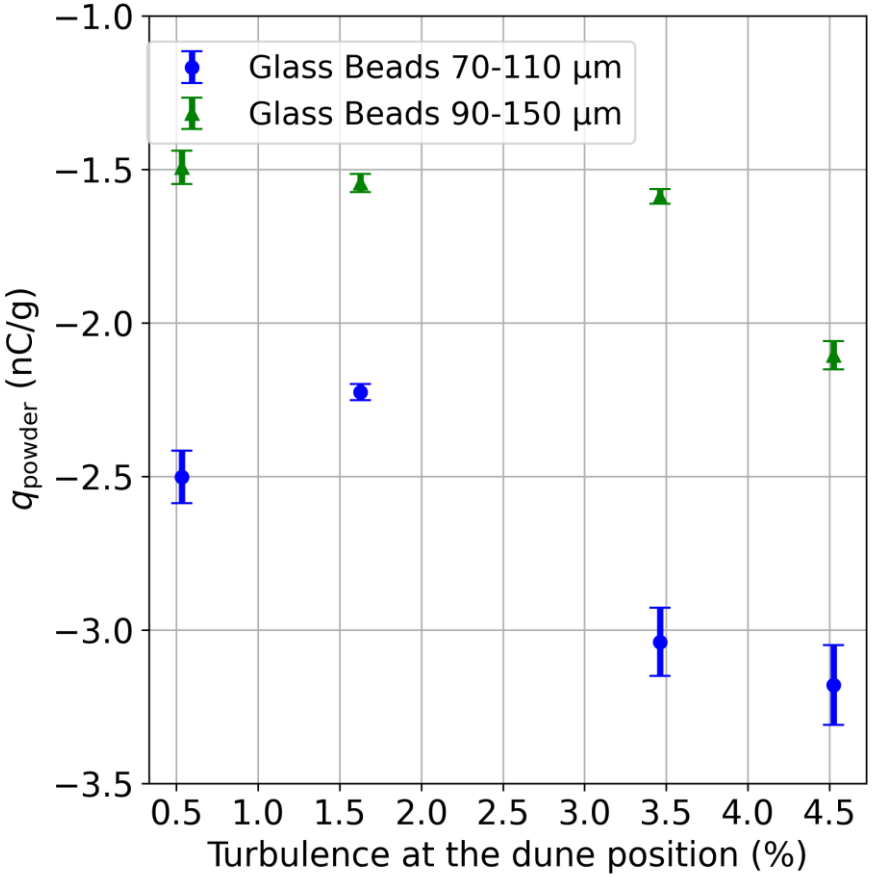
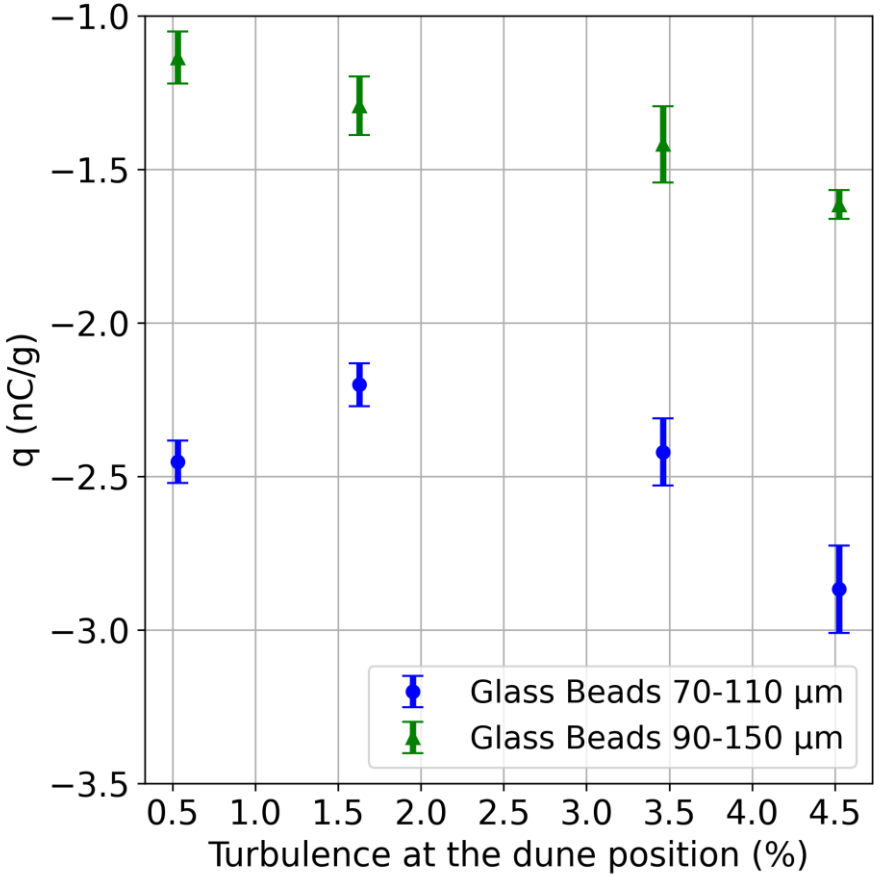
Influence of turbulence (and humidity)

RH : 27%



RH : 45%



Turbulence ↗, $|q_{powder}|$ ↗

Humidity ↗, $|q_{powder}|$ ↘

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Take home message

Turbulence significantly influence particle tribocharging

Next episode ?

Grain motion tracking with high speed camera