

Detection of charged organic grains at the surface of Titan with the DraGMet/EFIELD sensor on board Dragonfly

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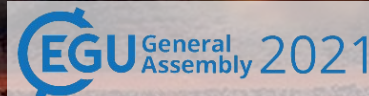
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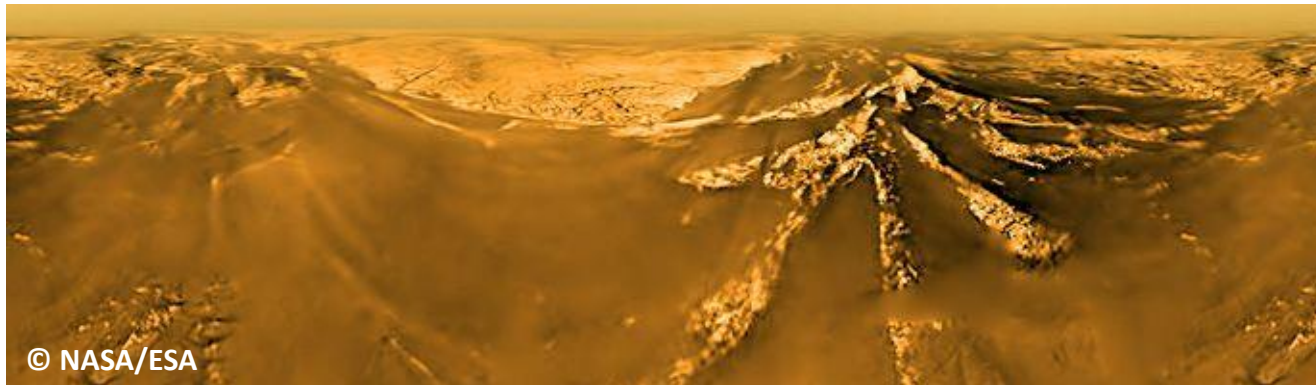
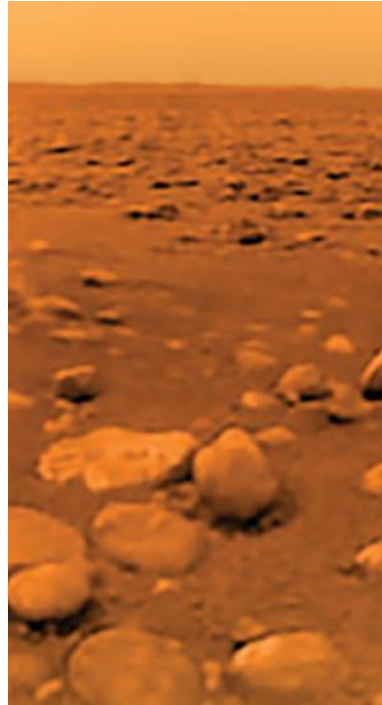
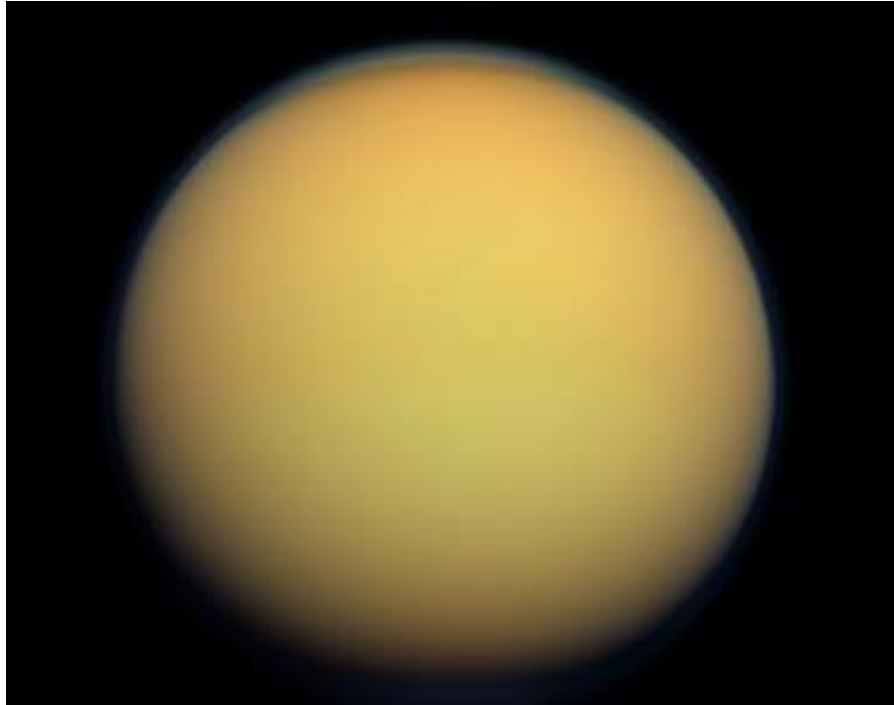
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CONTEXT

TITAN, ORGANIC GRAINS, DRAGONFLY, EFIELD

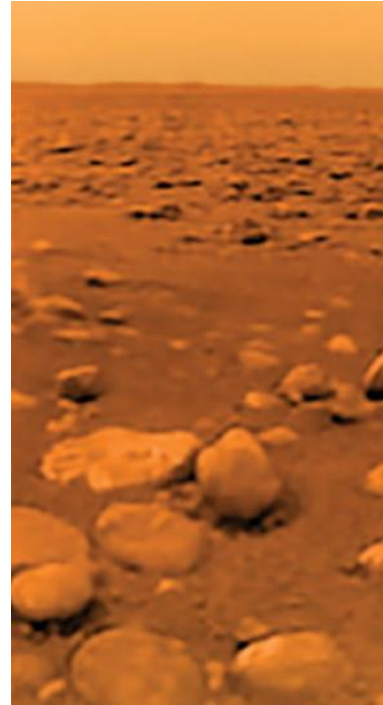
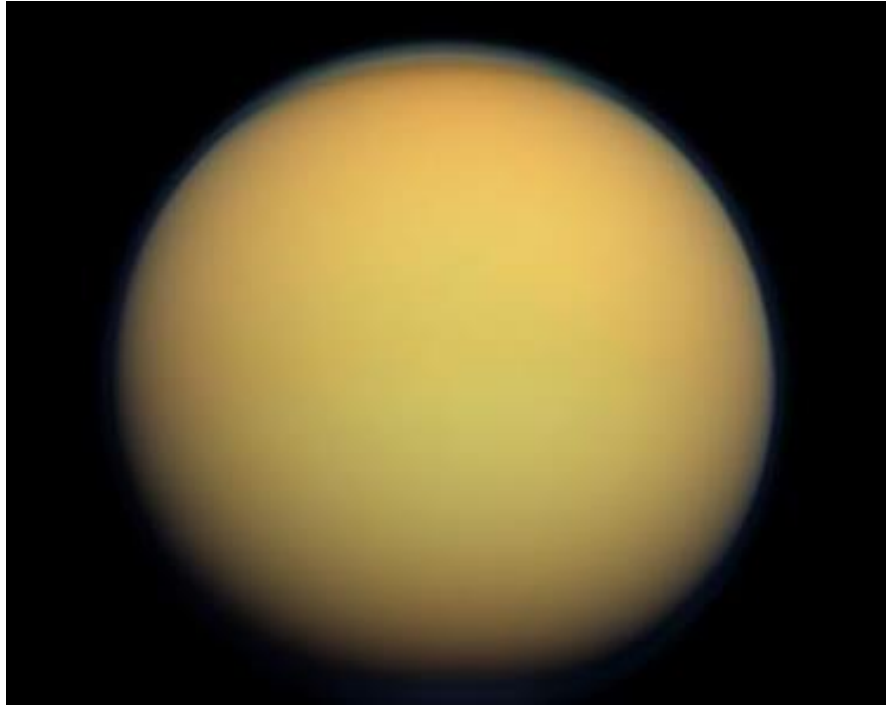
TITAN: AN EFFICIENT FACTORY OF ORGANIC PARTICLES



On Titan, Saturn's largest moon, organic particles:

- are produced in the upper atmosphere (at ~ 1200 km), by photochemistry [Waite et al, Science, 2007]
- fall through the atmosphere down to the surface, with mass flux $\approx 2 \cdot 10^{-14} \text{ kg.m}^{-2}.\text{s}^{-1}$ [Lavvas et al, PNAS, 2013]
- are likely to evolve during their fall through the atmosphere [Lavvas et al, PNAS, 2013; Chatain et al, Icarus, 2020]
- accumulate at the surface, are exposed to the local weather, maybe mix with ice and evolve into small sand grains [Janssen et al, Icarus, 2016]
- are blown by surface winds and even lead to the formation of dunes at some places [Lorenz et al, Science, 2006]

TITAN: AN EFFICIENT FACTORY OF ORGANIC PARTICLES

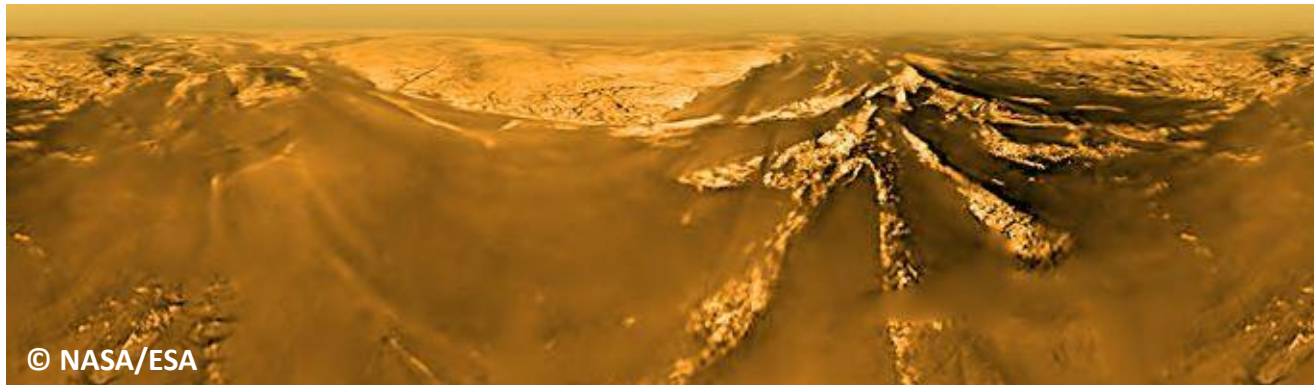


Motivations to investigate grains on Titan:

① to better understand their **formation processes, chemical composition and physical properties.**

↳ This interest is enhanced by the fact that such atmospheric production of organics likely occurred on Earth before the apparition of life [\[Arney et al, Astrobiology, 2016\]](#) .

② to better understand the **formation and evolution of Titan dune landscape.**



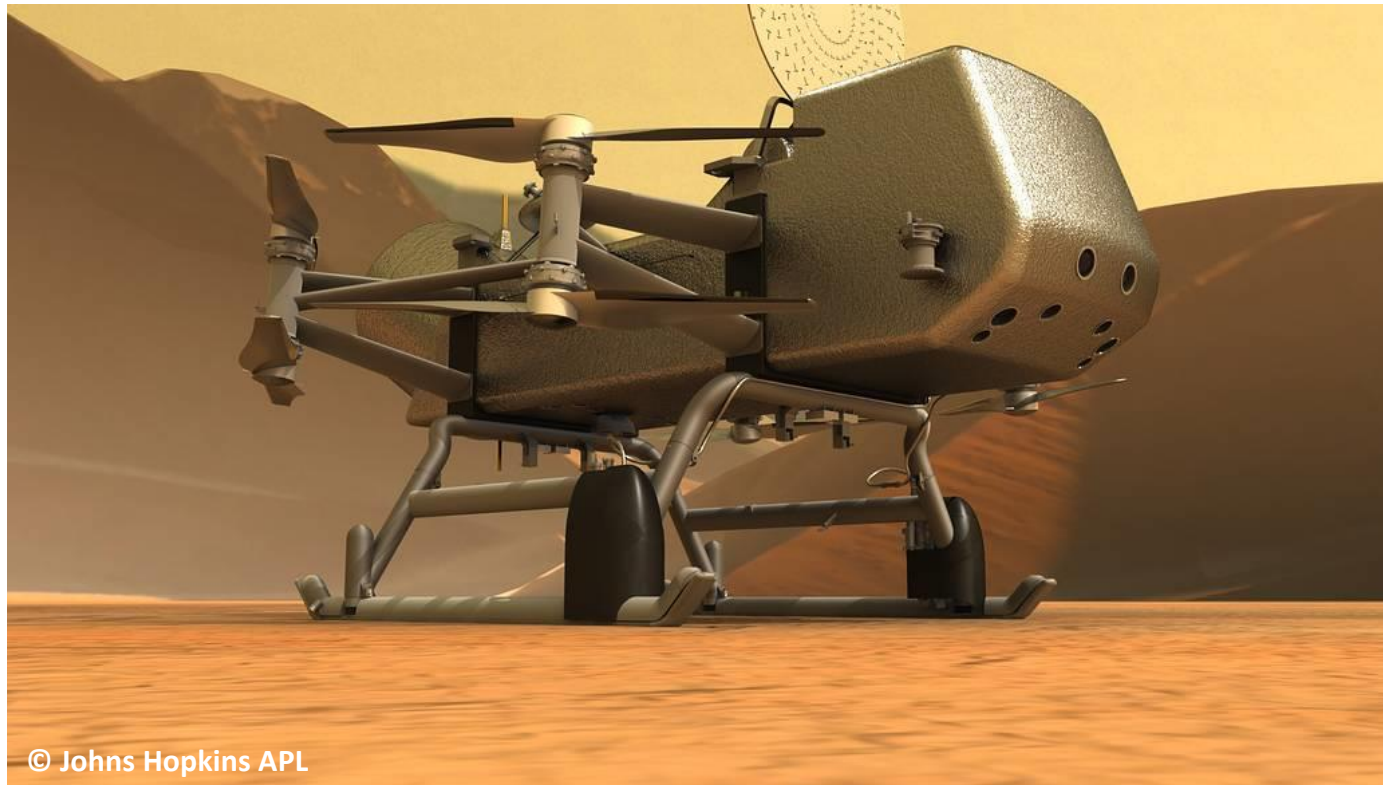
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THE DRAGONFLY MISSION



Exploration of Titan's surface at several places with an instrumented rotorcraft [\[Lorenz et al., APL TD, 2018\]](#)

Beginning of the operations planned circa 2036.



Science payload:

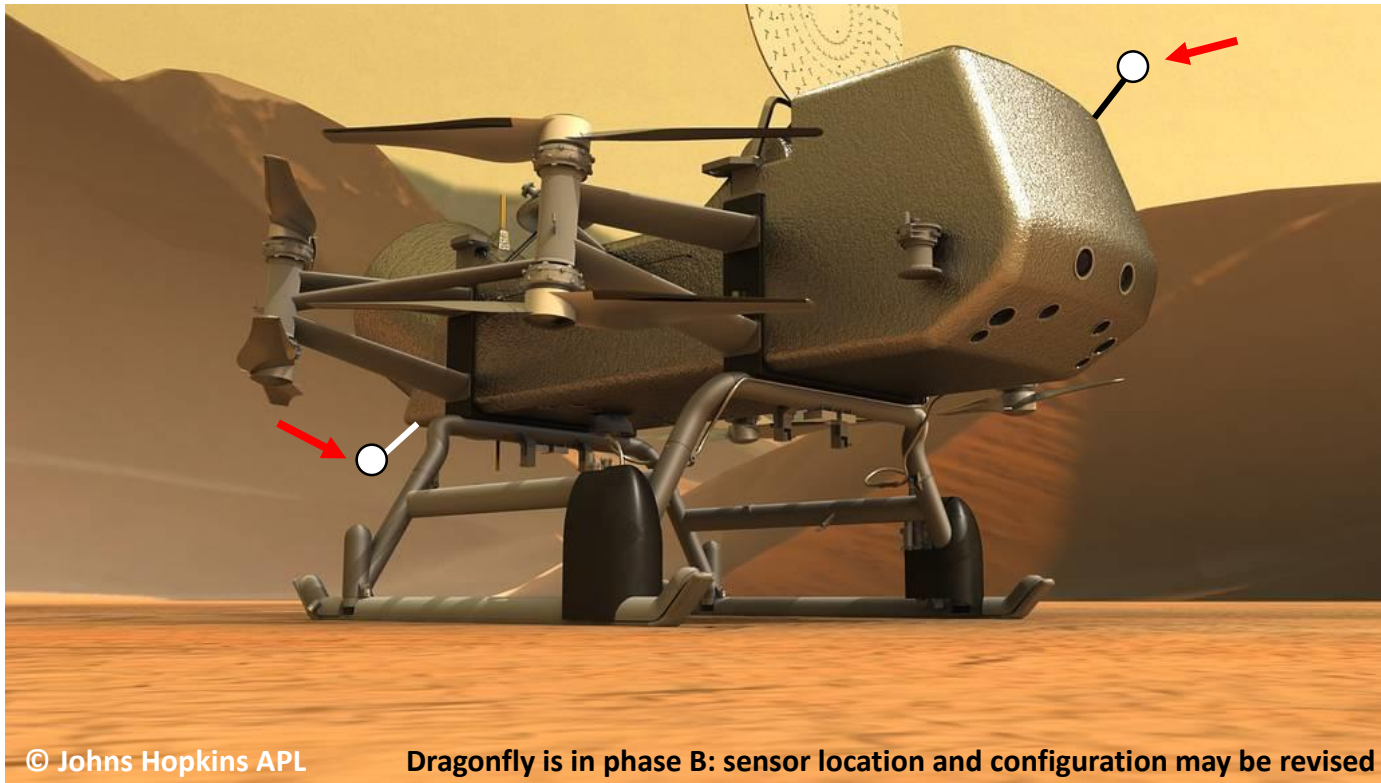
- **DraMS:** Mass Spectrometer for chemical analysis of samples of pre-biotic interest (drawn by the acquisition system DrACO).
- **DraGNS:** Gamma-ray and Neutron Spectrometer to determine the elemental composition of the ground.
- **DragonCam:** suite of cameras.
- **DraGMet:** Geophysics and Meteorology Package, to investigate the local weather, seismic activity and the **electric environment**.

THE EFIELD SENSOR



EFIELD is designed to measure the AC electric field at low frequencies (5-100 Hz) and monitor its temporal and spatial variations.

It consists of two spherical antennas (radius $R_s = 2.5$ cm), whose centers are at 20-25 cm from the lander body.



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Dragonfly is in phase B: sensor location and configuration may be revised

Scientific objectives:

- **measure Schumann Resonances:** possibly detected by the Huygens probe in 2005 (unless it was an artefact; [Lorenz and Le Gall, Icarus, 2020](#)). They would be an indication of the existence of an underground global salty ocean [[Beghin et al., Icarus, 2012](#)].

- **investigate charged organic grains blown by winds:** grains would tend to be negatively charged by friction (triboelectric effect; [Méndez-Harper et al, Nature Geoscience, 2017](#)), and induce a perturbation on the detected electric field.

objective of this work

NUMERICAL SIMULATION

**OBJECTIVE: TO SIMULATE PARTICLE TRAJECTORIES IN THE PROBE
ENVIRONMENT AND ESTIMATE THE INDUCED SIGNAL**

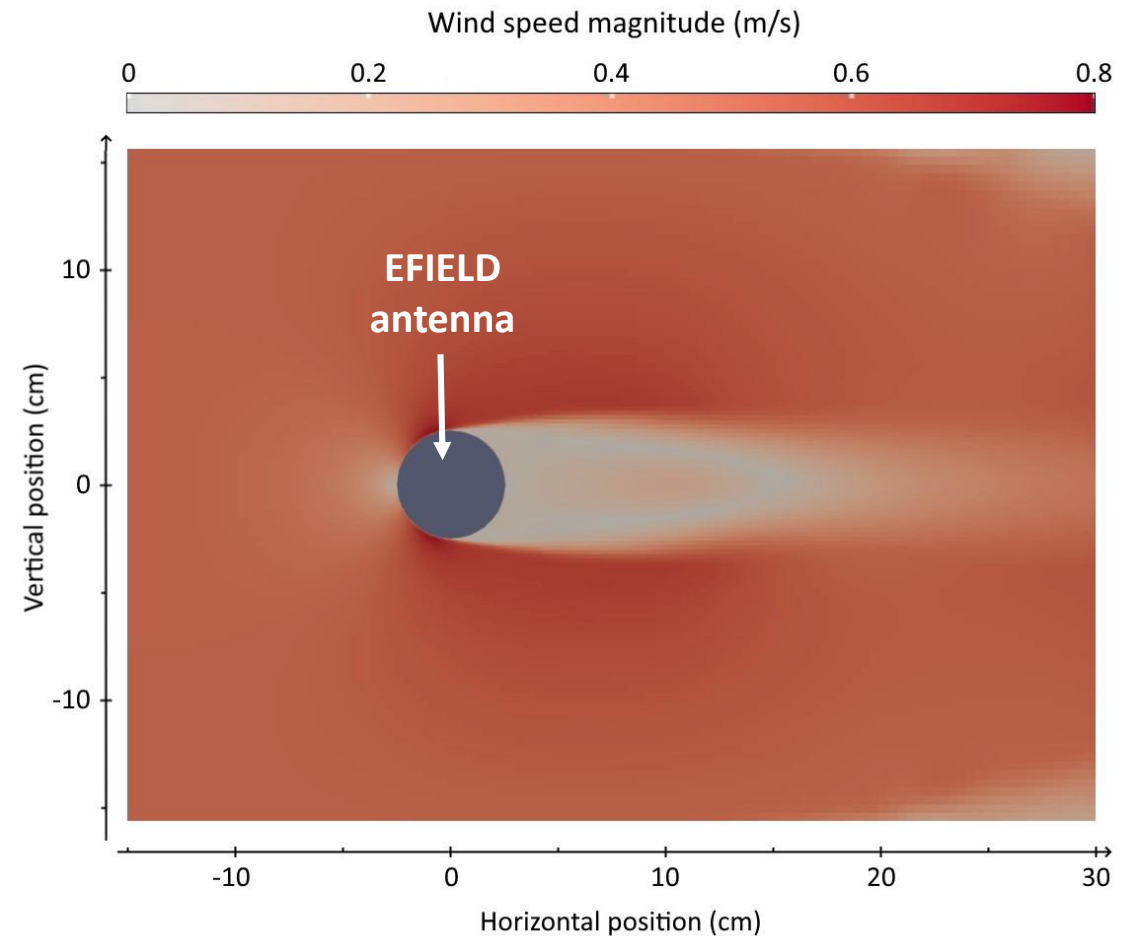
PARTICLE PROPERTIES AND WIND ENVIRONMENT

Estimation of particle properties on Titan:

- size: $r_p \approx 20$ to $600 \mu\text{m}$
- density: $\rho_p \approx 210 \text{ kg/m}^3$ (from laboratory analogues of Titan's aerosols, [Brouet et al, MNRAS, 2016](#))
- charge to mass ratio: $q_m \approx 10\text{-}100 \mu\text{C/kg}$ (from laboratory experiments, [Méndez-Harper et al, Nature Geoscience, 2017](#))

Surface wind: 0.05 to 4 m/s (usually 0.5 m/s)
[\[Lorenz, Adv. in Sp. Res., 2021\]](#)

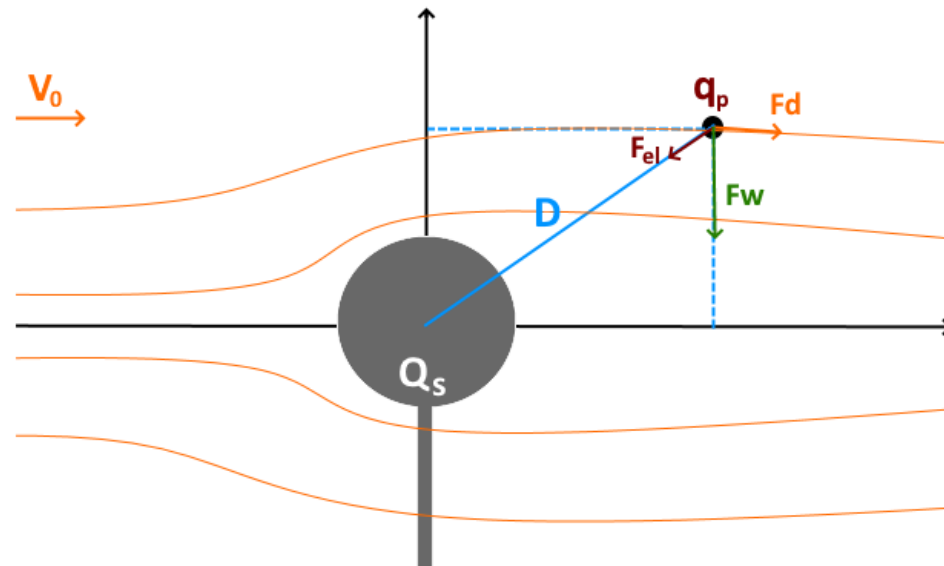
↳ turbulent flux around the spherical probe



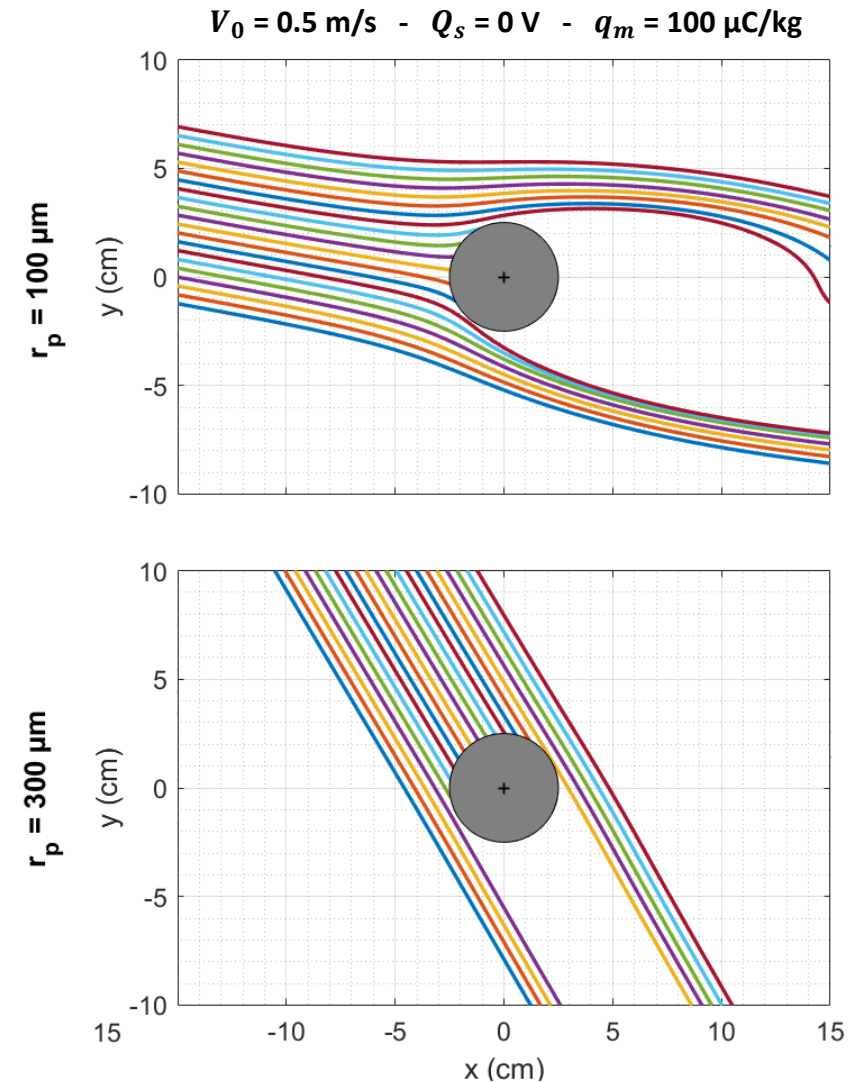
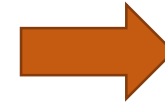
TRAJECTORY OF PARTICLES

Forces applied to the particles:

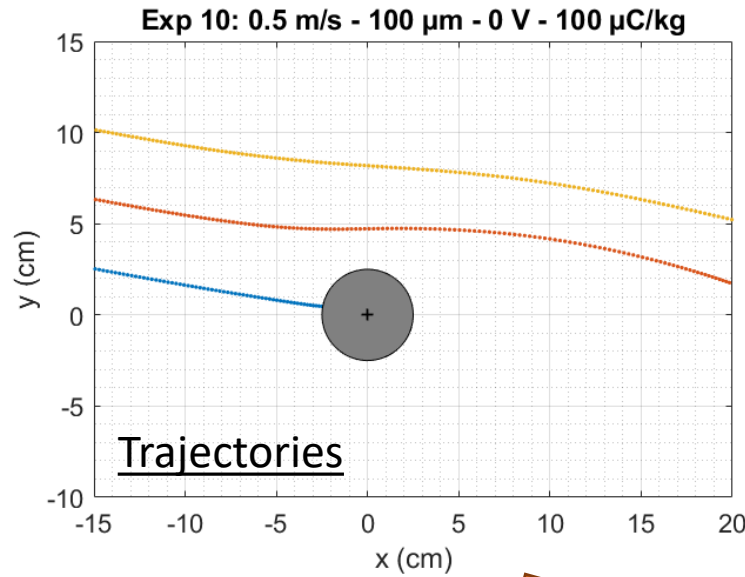
- weight (F_w)
- wind drag (F_d)
- electrical force by the metallic spherical probe, which is likely to be charged (F_{el})



particle
trajectories



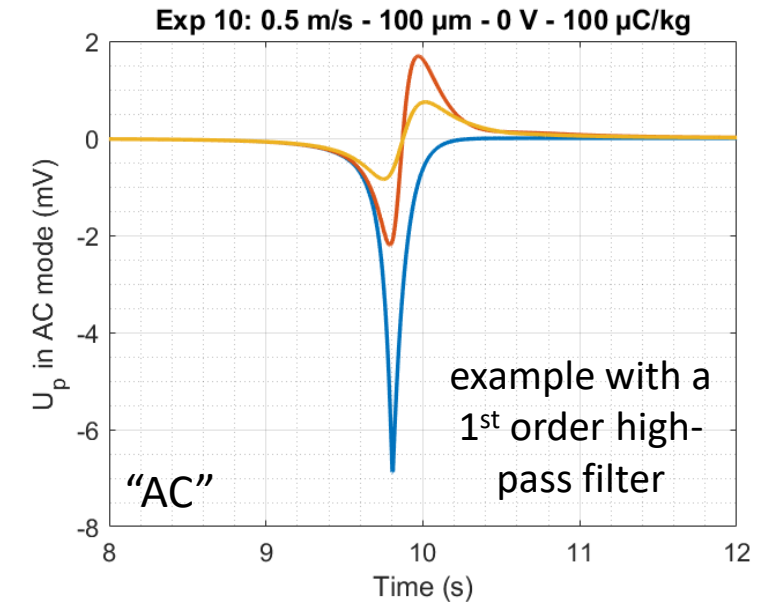
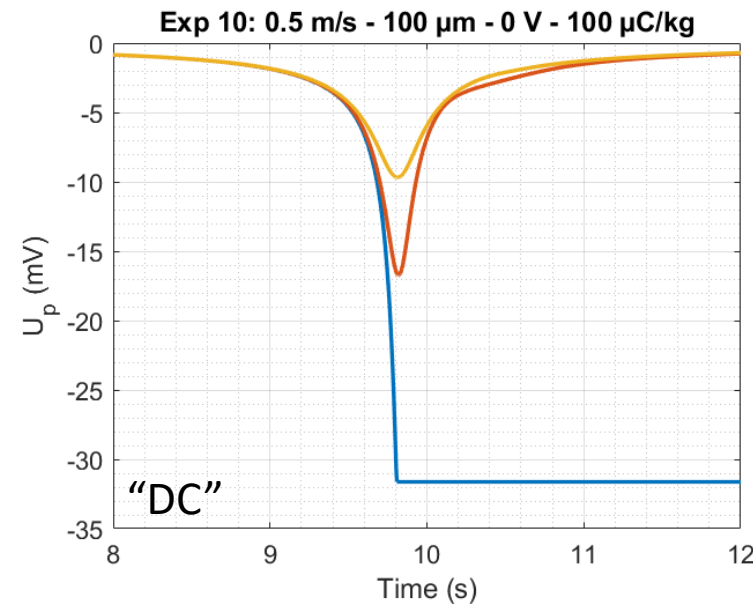
ELECTRIC POTENTIAL DUE TO A PARTICLE



Induced potential

$$U_p(t) = \frac{1}{4\pi\epsilon_0} \cdot \left(-\frac{4}{3}\pi\rho_p q_m \cdot r_p^3 \right) \cdot \frac{1}{D(t)}$$

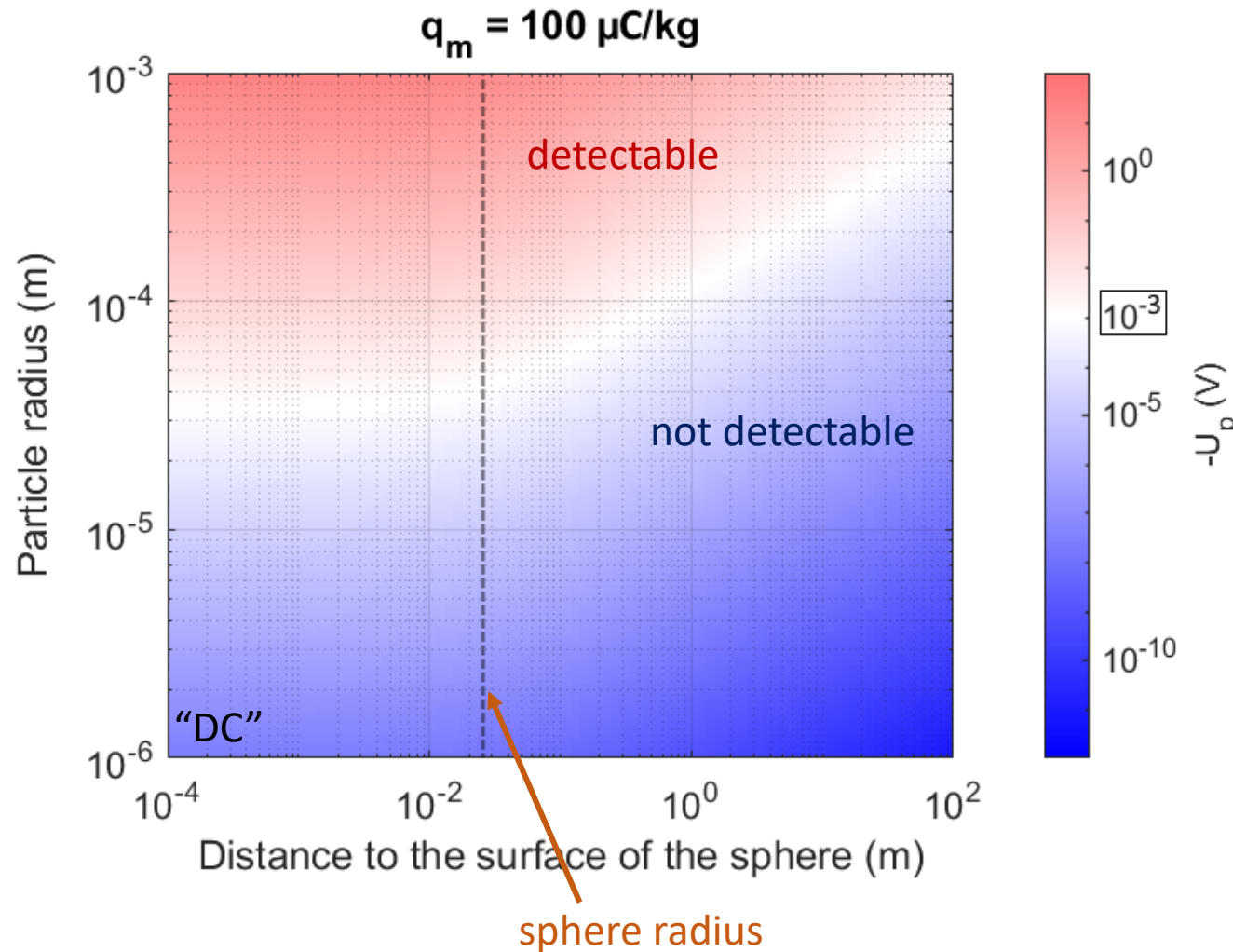
with ρ_p the particle density, q_m the particle charge/mass ratio, r_p the particle radius and D the distance to the sphere center.



filter (effect of pre-amplifier)

Related AC potential

CONCLUSION ON THE PARTICLES DETECTABLE ON TITAN



For a typical charge to mass ratio $q_m = 100 \mu\text{C/kg}$, without any gain loss from the acquisition system, and supposing a resolution limit at 1mV, the instrument would be able to detect particles:

- of $r_p = 60 \mu\text{m}$ at a distance $< 10 \text{ cm}$
- of $r_p = 100 \mu\text{m}$ at a distance $< 1 \text{ m}$

Nevertheless, the acquisition system is likely to diminish the ‘ideal’ detected voltage by a factor of 3 to 6. This could increase the particle detectable size up to a factor of 2.

MEASUREMENTS ON TITAN

WHAT WILL WE BE ABLE TO DEDUCE FROM SUCH MEASUREMENTS
ON TITAN?

THEORY

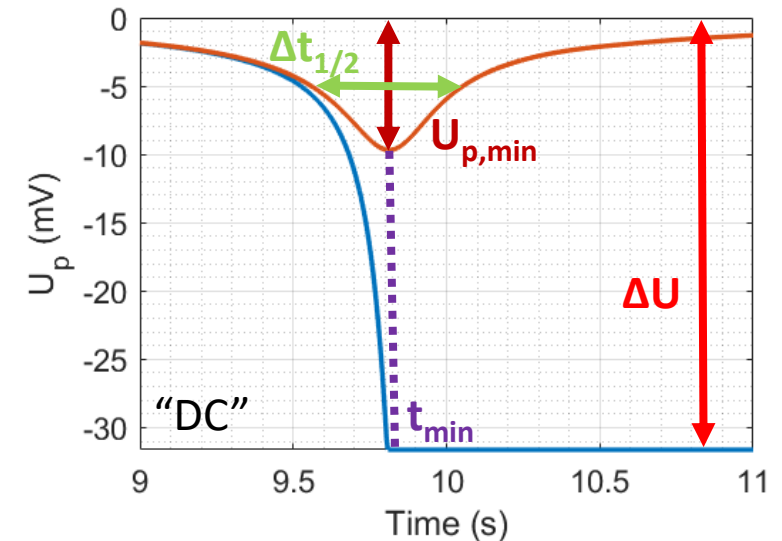
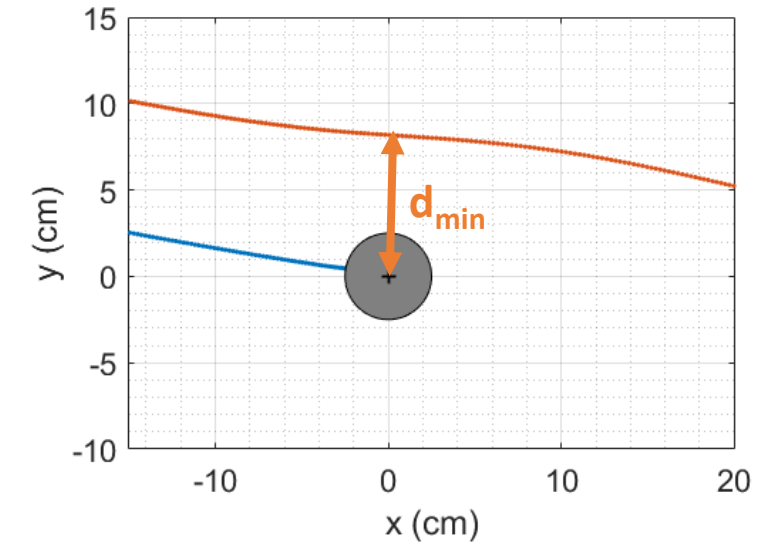
- Particle colliding with the sphere
↳ direct deduction of the particle charge : $q_p = 4\pi\epsilon_0 \cdot R_s \cdot \Delta U$
- Particle passing without collision: approximation of **constant speed v_p and linear trajectory**:

$$U_p(t) = \frac{1}{4\pi\epsilon_0} \frac{q_p/v_p}{\sqrt{(t - t_{min})^2 + (d_{min}/v_p)^2}}$$

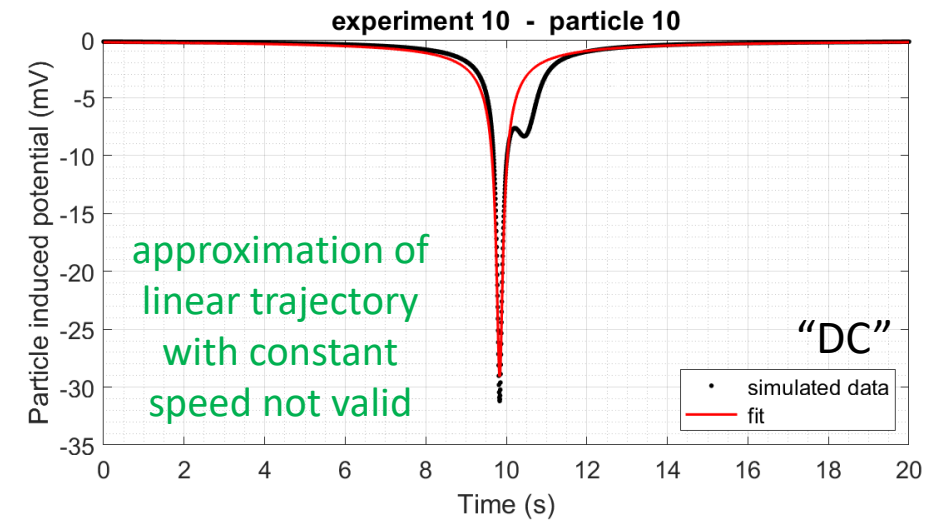
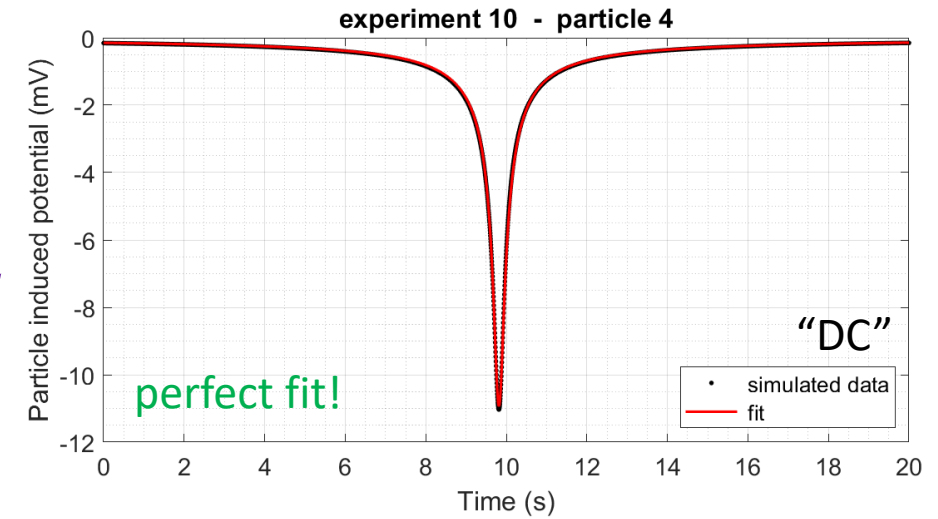
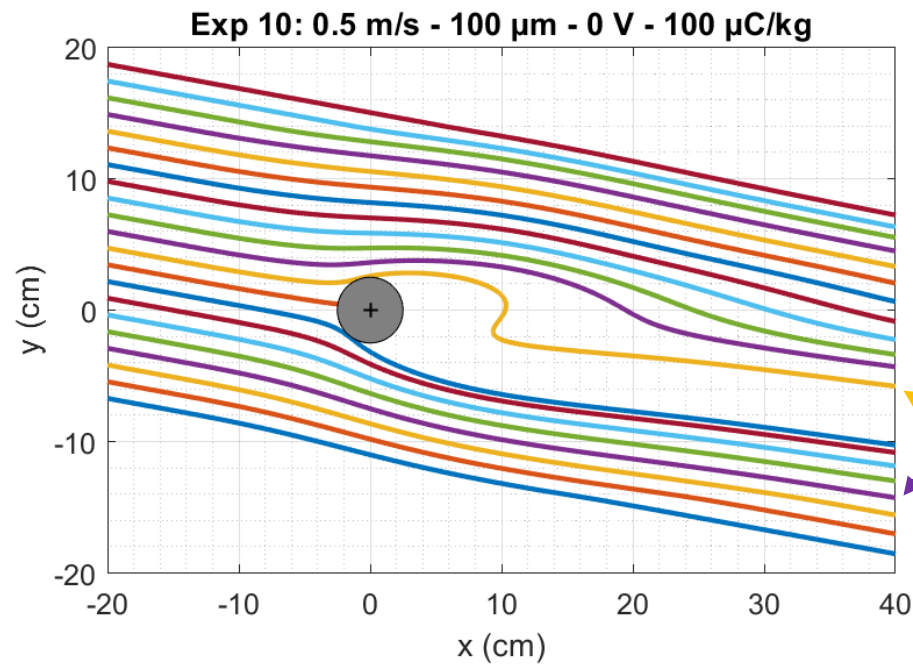
$$\text{↳ } U_{p,min} = \frac{1}{4\pi\epsilon_0} \frac{q_p}{d_{min}}$$

$$\text{↳ } \Delta t_{1/2} = 2\sqrt{3} \cdot (d_{min}/v_p)$$

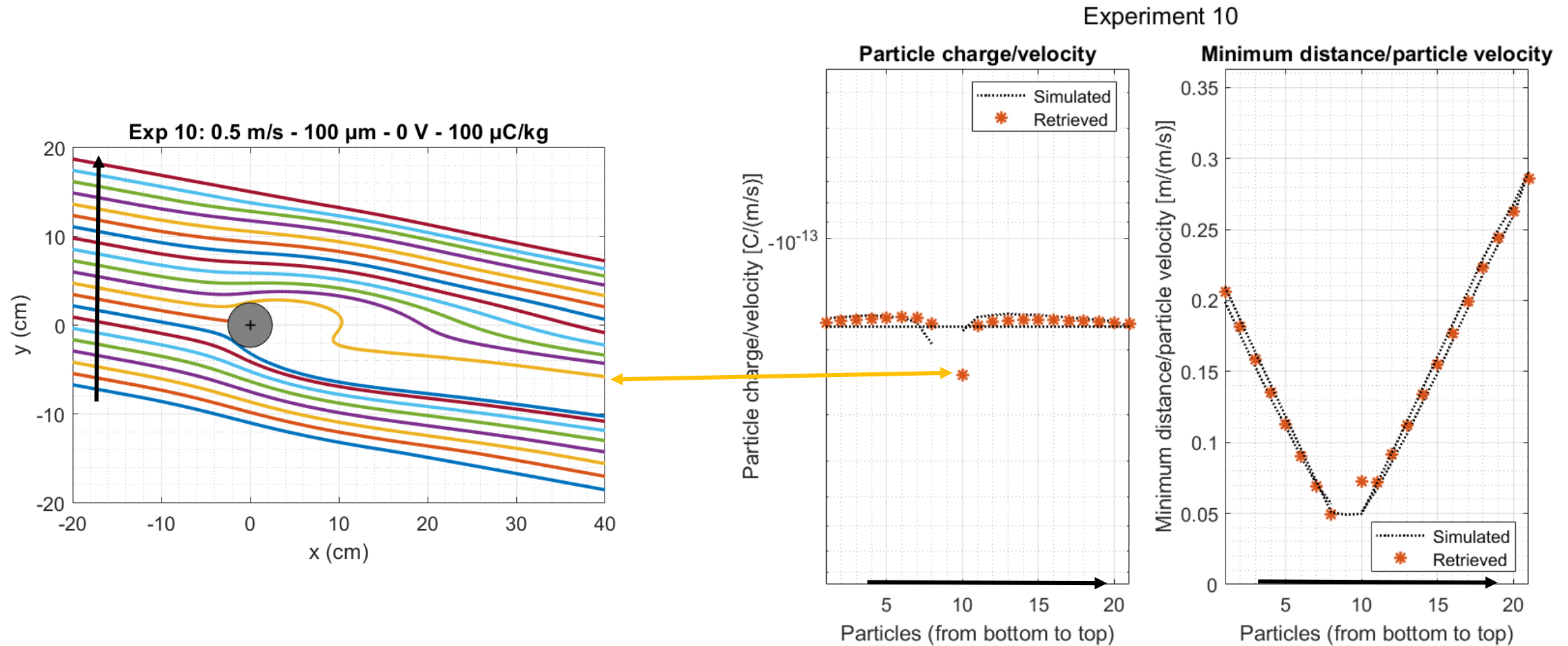
↳ the fitting of a measurement with this equation gives access to two parameters: the charge/velocity ratio of the particle (q_p/v_p), and the minimum distance to the probe/particle velocity (d_{min}/v_p).

Exp 10: 0.5 m/s - 100 μm - 0 V - 100 $\mu\text{C/kg}$ 

APPLICATION TO SIMULATED DATA



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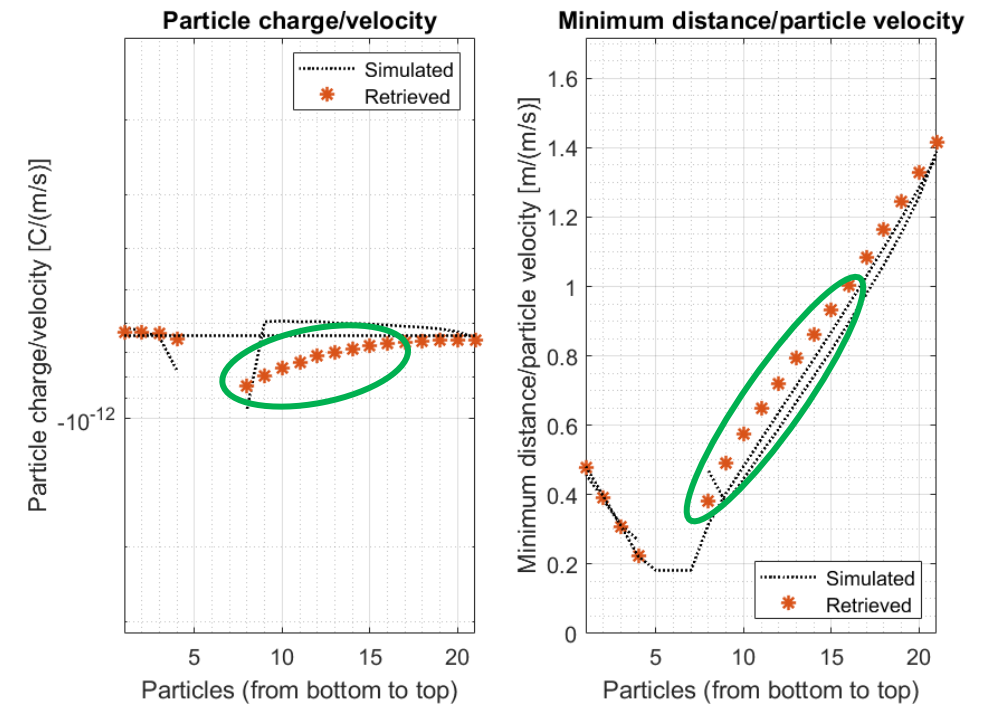
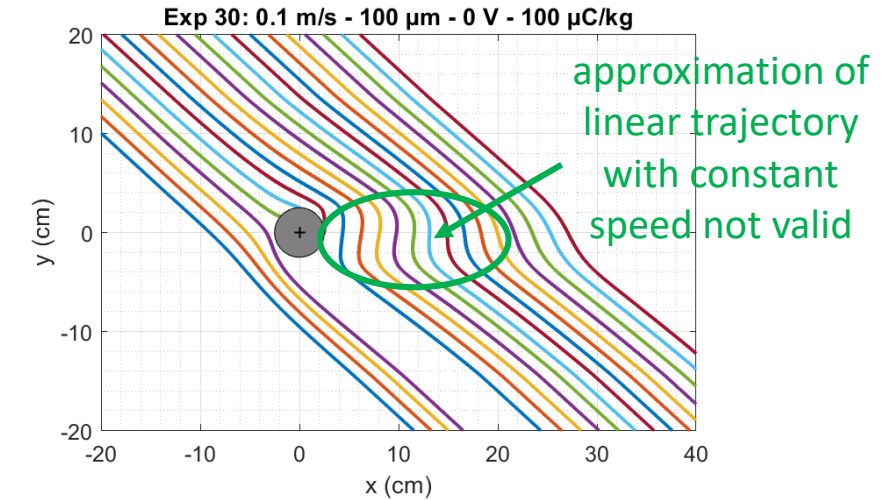
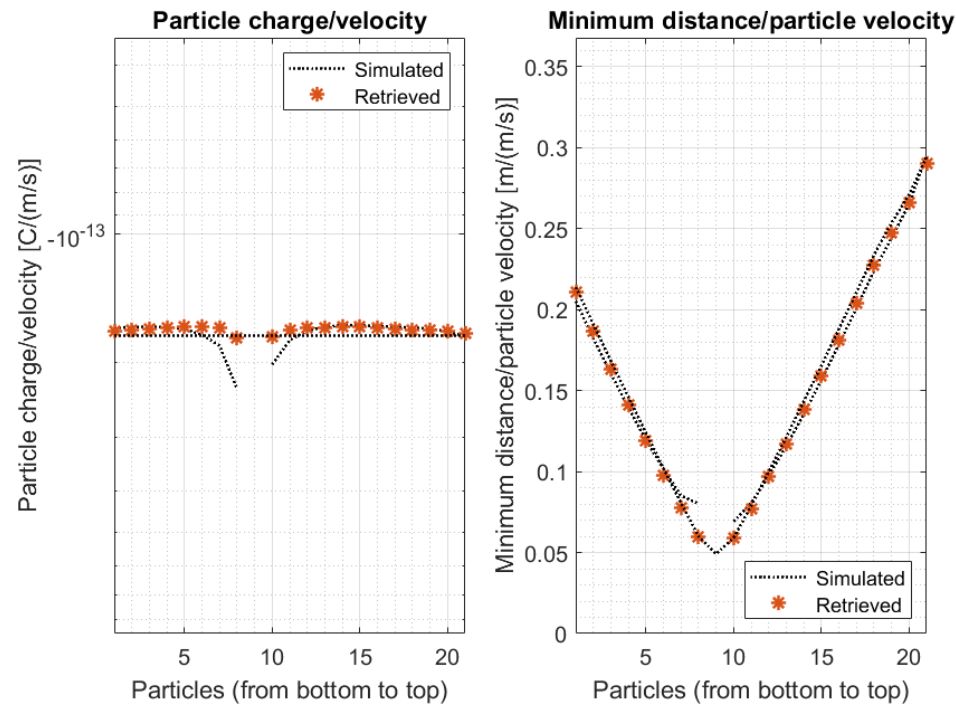
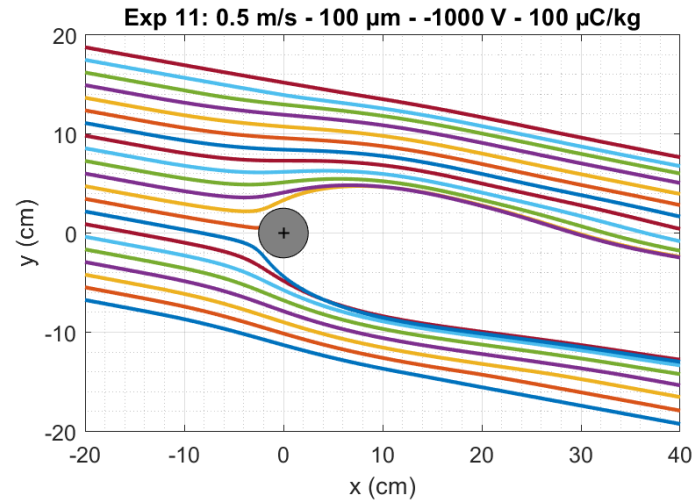


very good retrieval in general

DIFFERENT CASES

Very good retrieval with simulated data.

Approximation valid in most cases. Only small error in the fitting results in the worst cases (exp 30).



TESTS IN THE LABORATORY

TO VALIDATE THE NUMERICAL SIMULATION AND FITTING METHOD

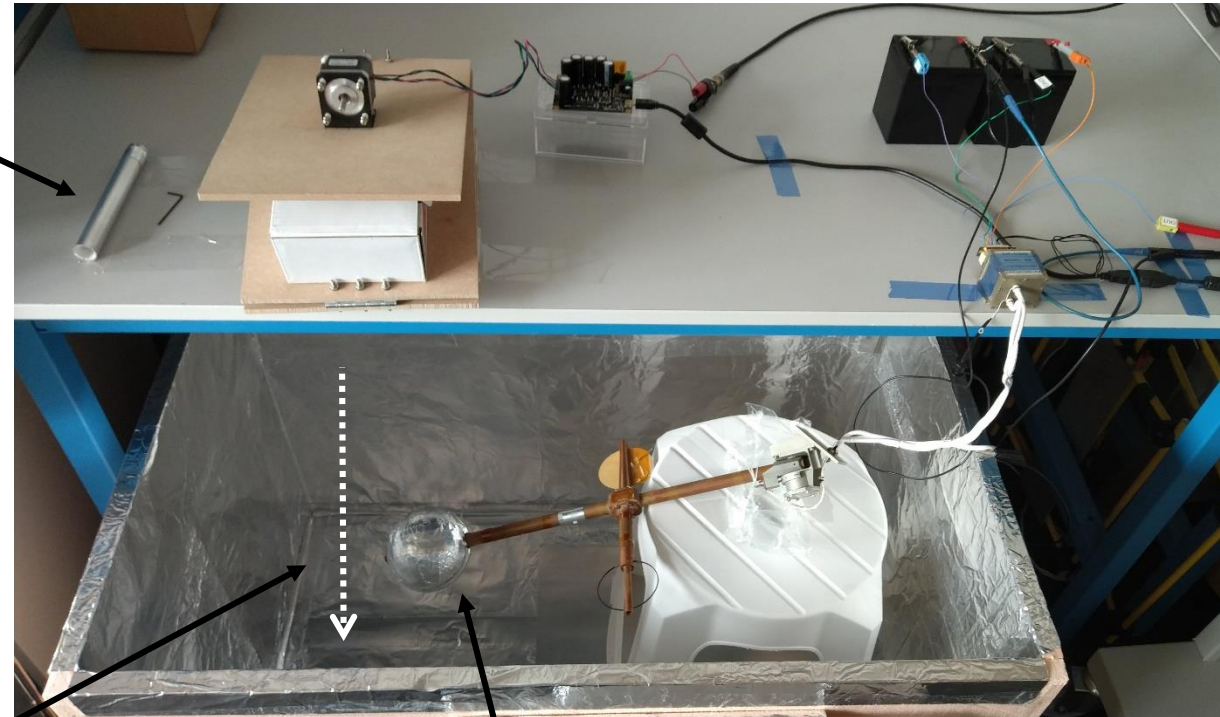
THE EXPERIMENT

① Small polystyrene balls are charged by friction in a rotating cylinder, the inside of which is coated with other small polystyrene balls.

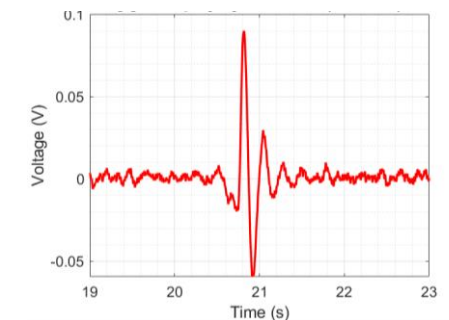
[to simulate wind on Titan, technique taken from [Méndez-Harper et al, Nature Geoscience, 2017](#)]

② Charged particles are dropped one by one to fall close to the antenna.

③ Particles are detected by the antenna (previous model of Huygens/PWA, adapted)

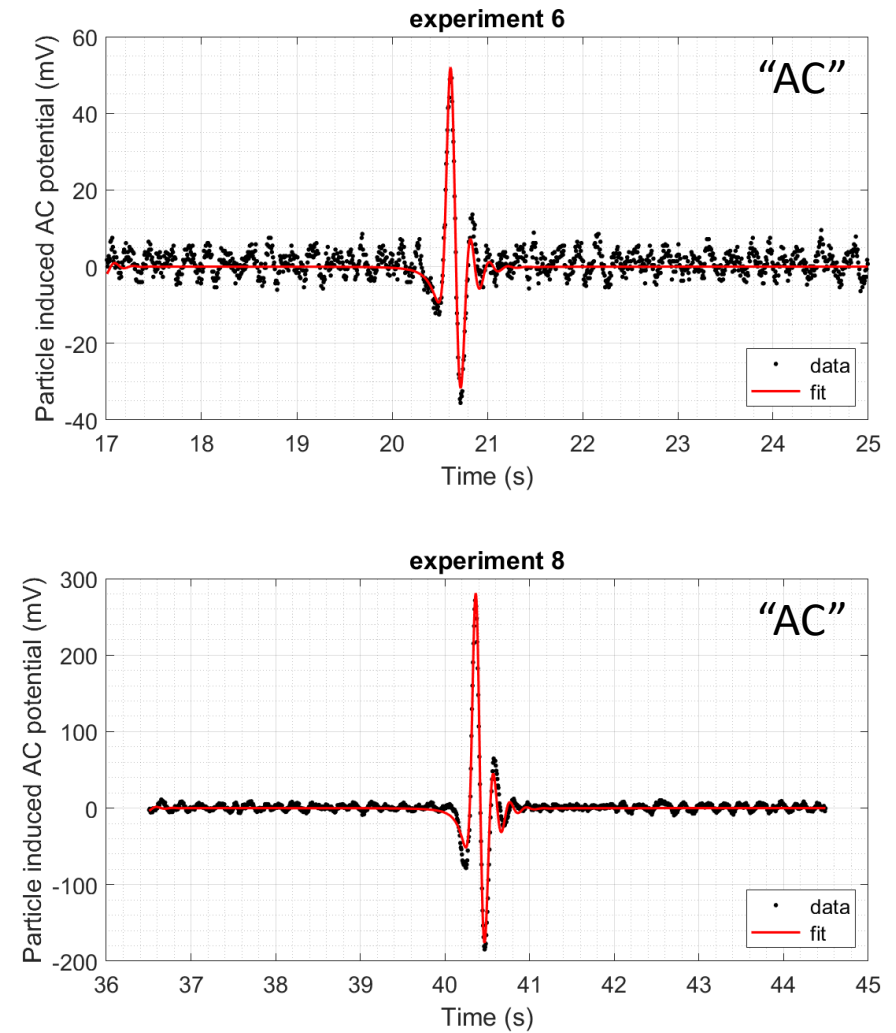
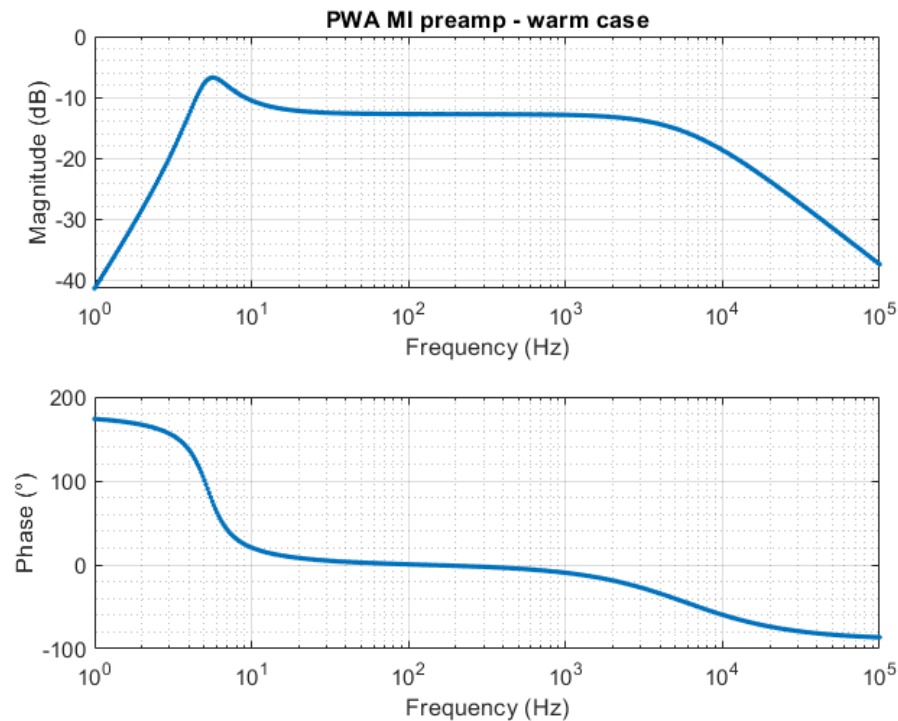


The experiment is performed in a nearly closed Faraday cage to avoid any electromagnetic disturbances.

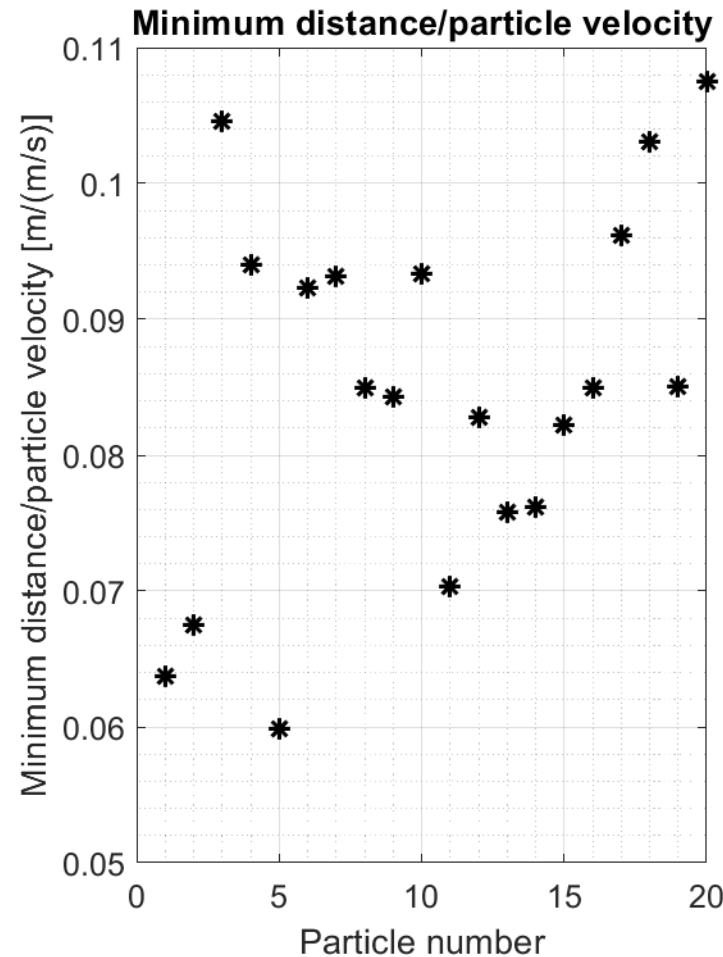
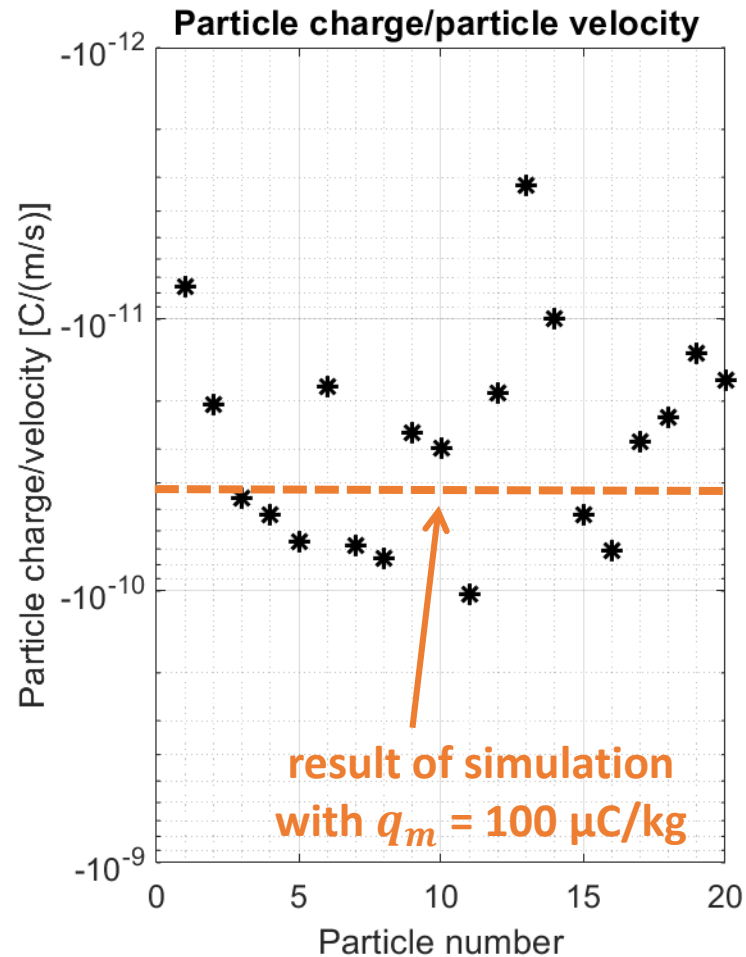


FIT OF EXPERIMENTAL DATA

We used the fitting function described in the previous section, corrected from the effect of the antenna pre-amplifier:



RESULTS OF SEVERAL EXPERIMENTS



Particles used in this test have sizes varying between 2.5 and 3.5 mm, and can be differently charged. This explains the variation observed of q_p/v_p .

We also performed a numerical simulation in the conditions of the experiment, with $r_p = 3 \text{ mm}$ and $q_m = 100 \mu\text{C/kg}$. It reproduces fairly well the observations.

SIMULATION AND EXPERIMENTAL PERSPECTIVES

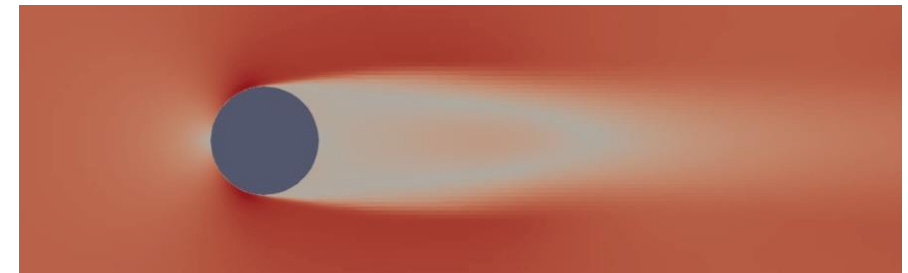
Experiments

- ① independently measure the particle charge, velocity and minimum distance to the sphere to quantitatively validate the fitting results.
- ② build a proper prototype of an EFIELD antenna (today this is only an adaptation of a previous model of Huygens/PWA), and obtain a noise level < 1 mV.
- ③ test a possible DC acquisition mode.



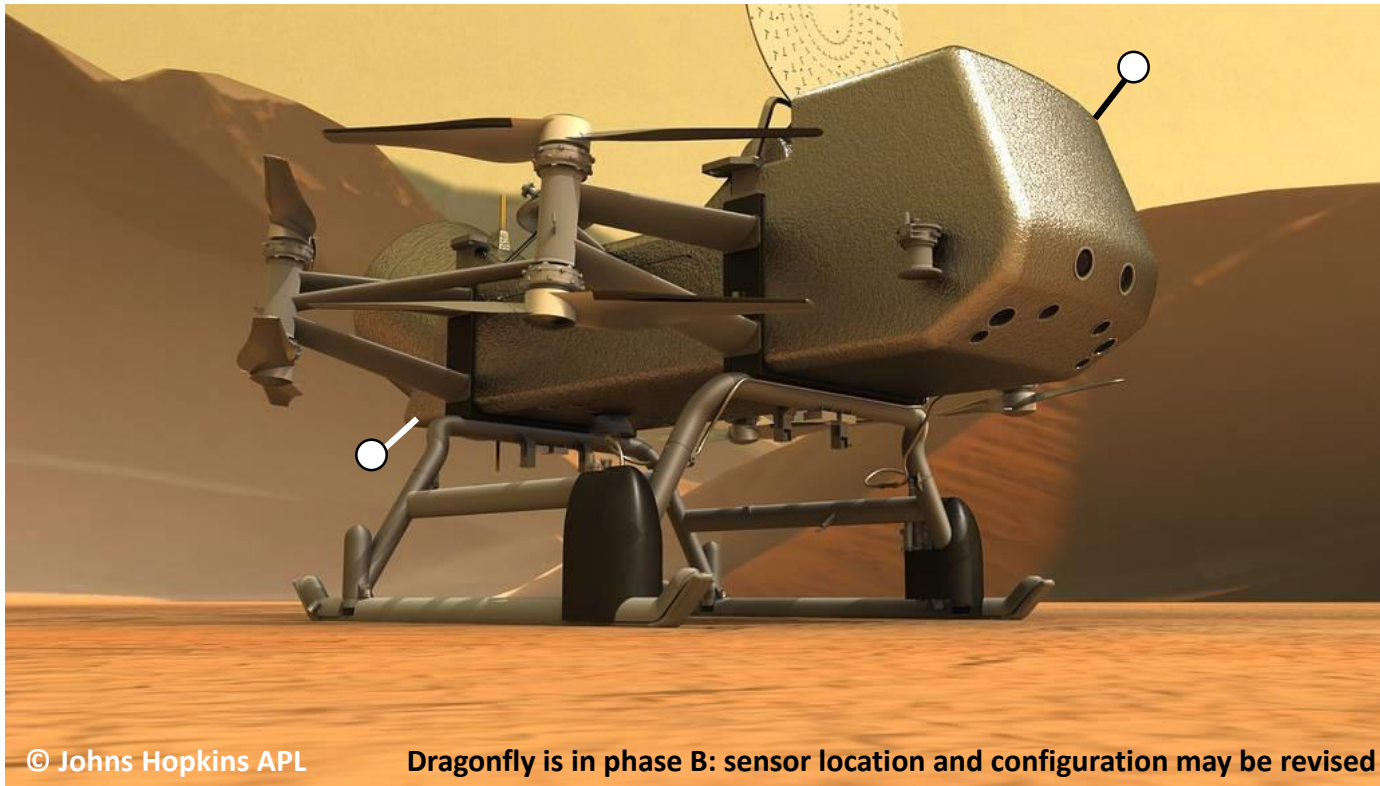
Numerical simulation

- ① add noise to the simulation to test the efficiency of the inversion.
- ② add an estimation of the error bars with a Monte Carlo approach.
- ③ investigate the effect of the lander body on the particle trajectories (wind flow + electrostatic repulsion).



CONCLUSION

The EFIELD sensor on board Dragonfly will be able to investigate charged organic grains blown by winds at the surface of Titan.



In this work we showed that:

① from the signal created by the passage of a particle it will be possible to **deduce its charge/velocity ratio (q_p/v_p)**.

↳ It will be possible to estimate the particle velocity from other instruments (wind sensor, cameras...), and therefore estimate the particle charge.

② in the case of a collision, the particle charge can be directly extracted from the DC signal (the presence of this mode on Dragonfly is currently under discussion).

③ with a noise level < 1 mV, it will be possible to **detect particles $\sim < 200 \mu\text{m}$** .

⇒ The measurement of the particle charges will help us understand the interaction between the particles and Titan surface environment (winds, saltation, friction...).