Charging Mechanisms and Orbital Dynamics of Charged Dust Grains in Particle Accelerators

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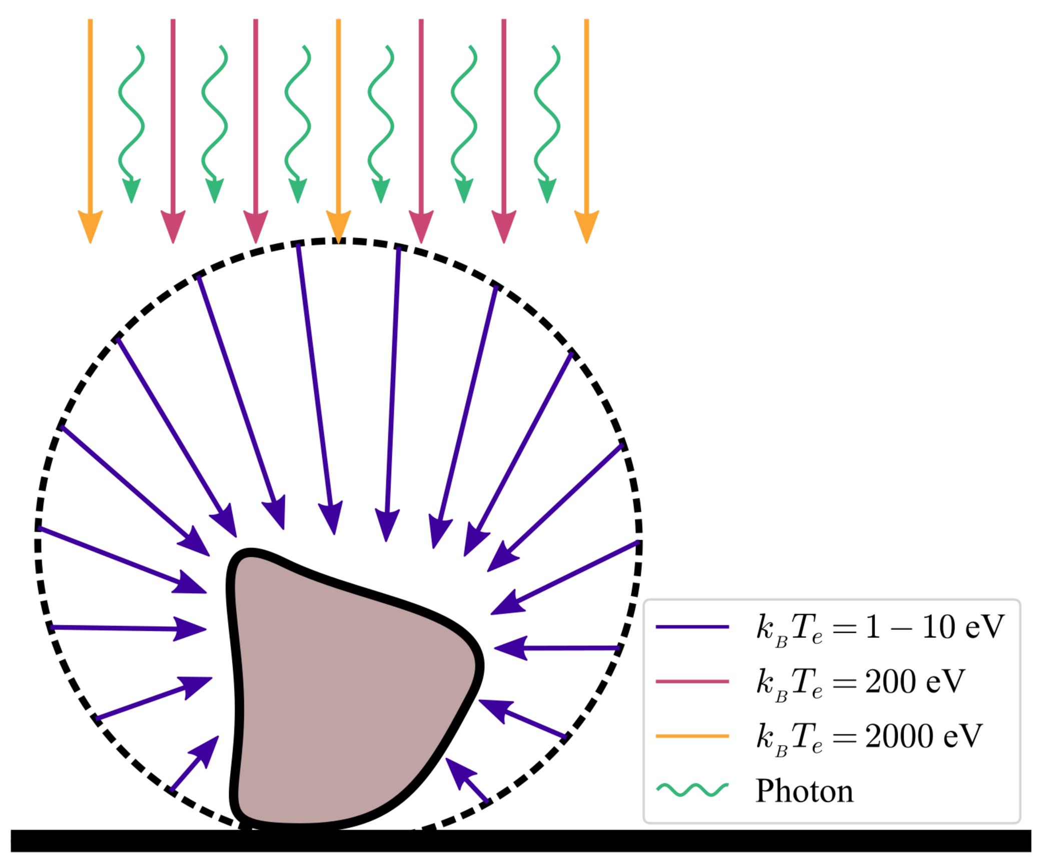
Dust in particle accelerators

Micrometer-sized dust grains are known to be the cause of several detrimental effects in particle accelerators:

- Intensity drops in electron storage rings (**TRISTAN**, **CESR**, **HERA**, **DORIS**);
- Pressure bursts in the **SuperKEKB** positron storage ring;
- Sporadic beam losses as well as magnet quenches in the **LHC**.

The presence of contaminants in the vacuum chamber of modern accelerators is unavoidable, even with careful cleaning measures. **What can explain their interaction with both p⁺ and e⁻ beams?**



Representation of a dust grain on the surface of the beam screen.

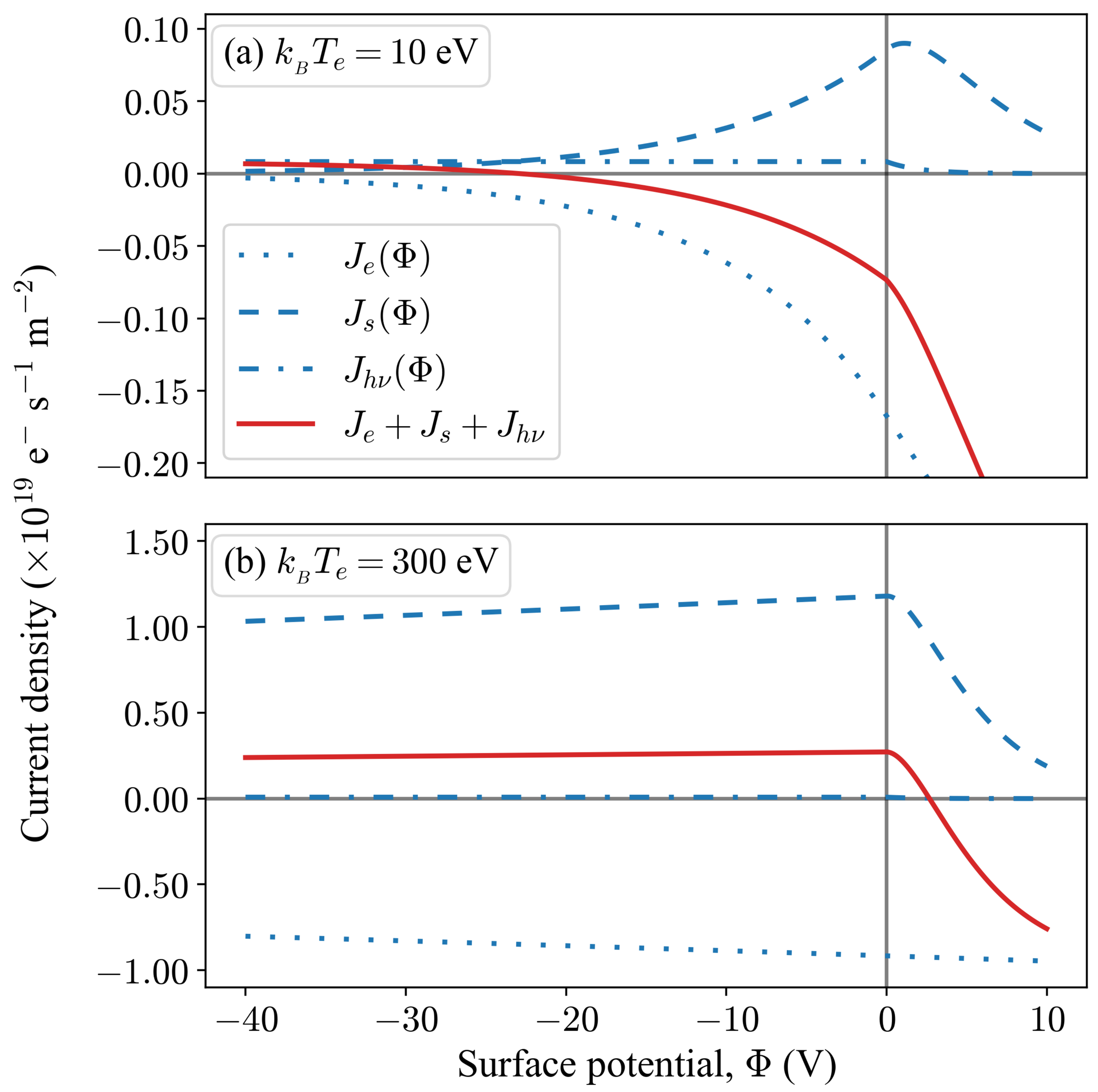
Charging Currents in the LHC

Due to the presence of **synchrotron radiation** and **electron clouds**, the main charging mechanisms are:

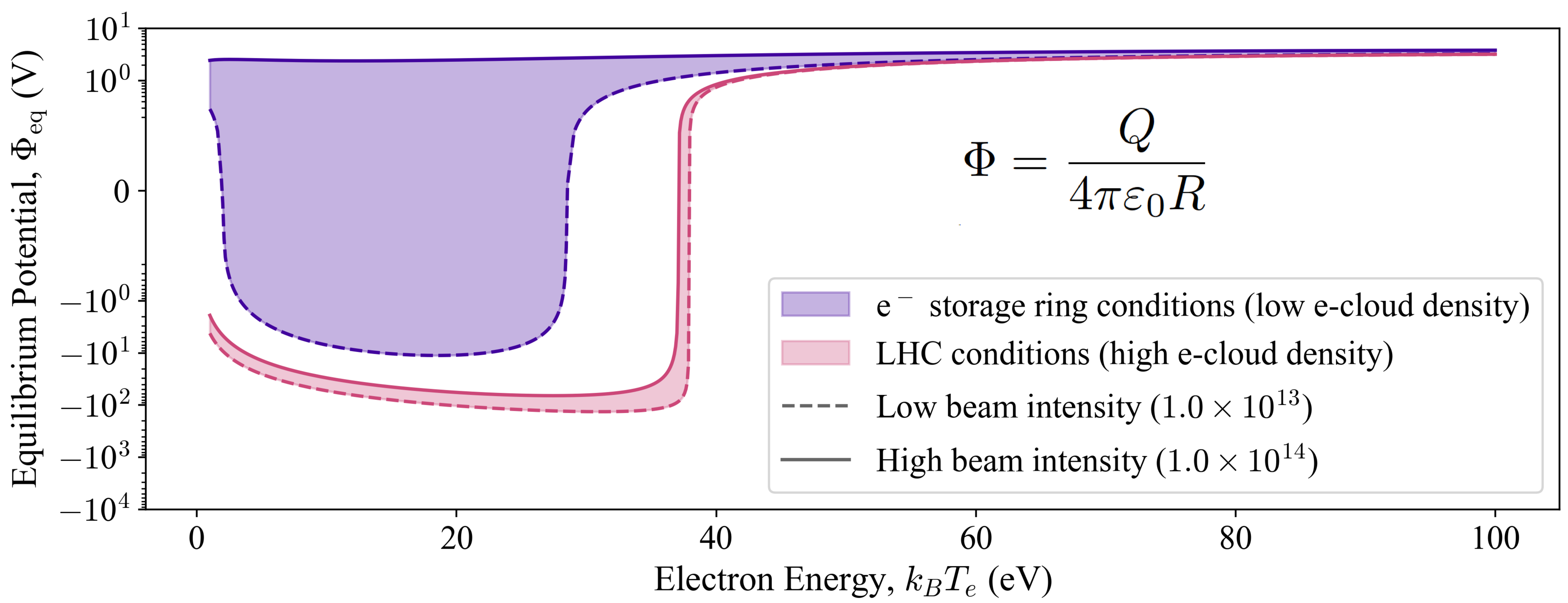
- **Electron Collection** (J_e), negative current;
- **Secondary electron emission** (J_s), positive current;
- **Photoelectric emission** ($J_{h\nu}$), positive current.

The balance between these currents dictates the **equilibrium surface potential** (net charge) of the grain.

Low energy electrons (< 10 eV) from the surrounding e-cloud contribute the most.

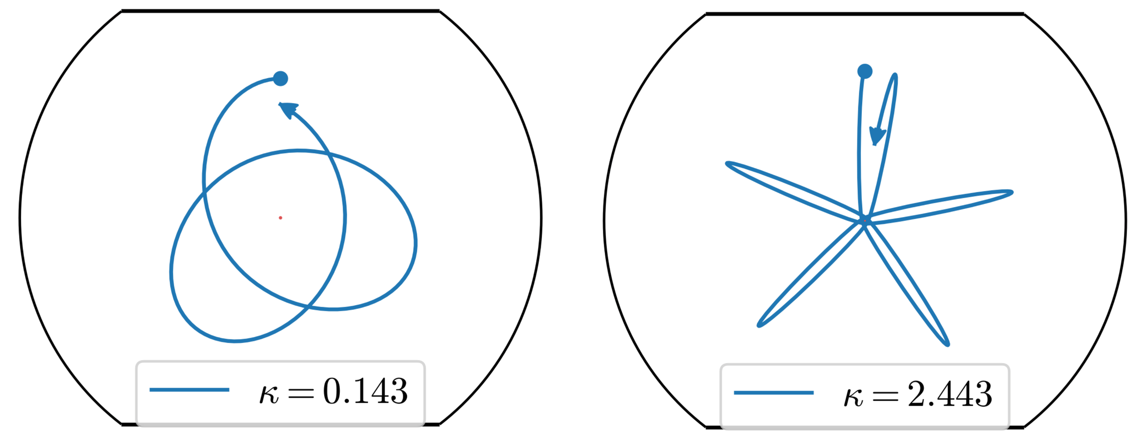


Charging currents for 10 eV or 300 eV electrons impinging on a dust grain in the LHC. The photoelectric current is the same in both cases.



Expected equilibrium potential in low and high e-cloud density conditions. The accumulated charge ends up being negative in the LHC and can be both positive or negative in e⁻ storage rings due to lower e-cloud densities.

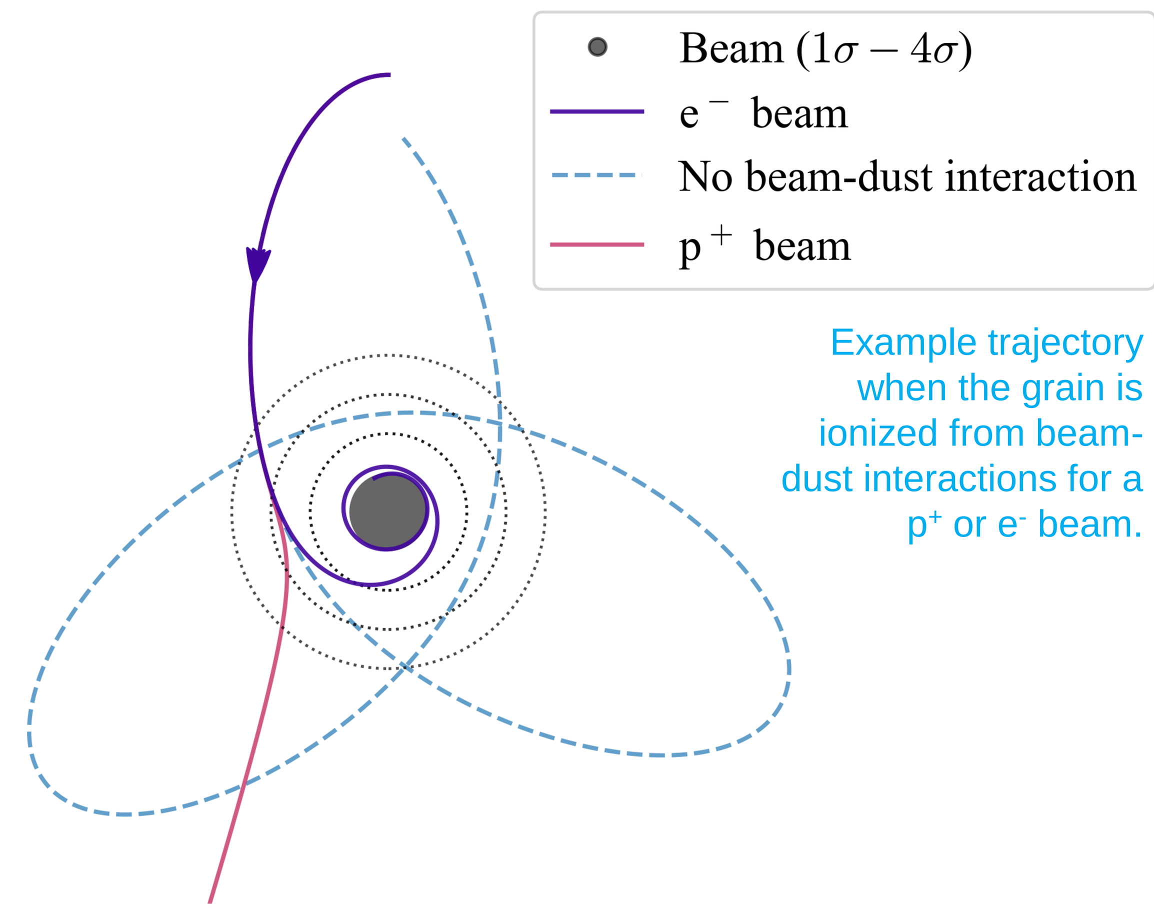
Orbits in a logarithmic potential with different shape parameters



Orbits in a logarithmic potential

Since the grain accumulates a charge opposite to the one of the beam, **bounded orbits** exist:

- A single **shape parameter (κ)** describes the shape of the orbits;
- The **radial period** can be found from the charge-to-mass ratio and the angular momentum. It dictates the time between **beam-dust interactions**;
- The grain **is ionized** (positive current) during beam-dust interactions.



Example trajectory when the grain is ionized from beam-dust interactions for a p⁺ or e⁻ beam.

The **same charging mechanisms** can be used to **explain historical observations** in the LHC and in e⁻ storage rings.

Discovery, accelerated