Workshop on Dust Charging and Beam-Dust Interaction in Particle Accelerators: *Wrap-up and questions for the discussion*

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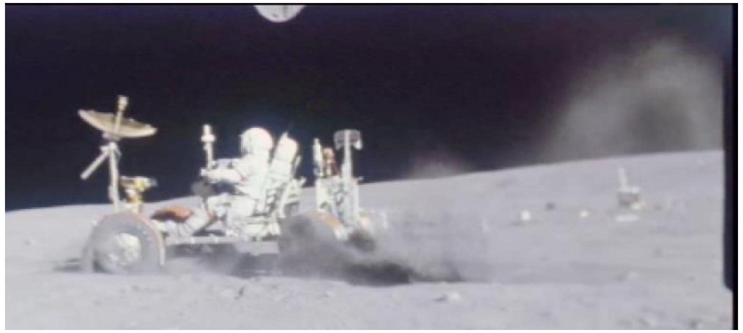
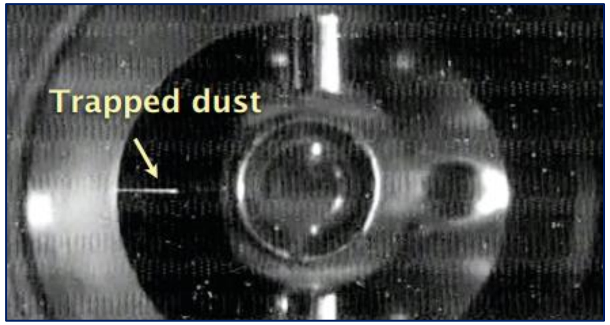
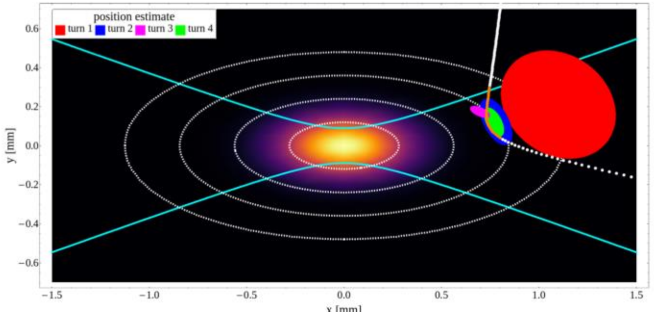
Dust is everywhere

- **Dust phenomena occur in…**
  - Space, fusion reactors, semi-conductor industry, …
  - Particle accelerators (vacuum chambers, RF cavities, kicker magnets…)
- **Dust phenomena can occur with negatively charged particle beams (electrons, anti-protons)…**
  - Dust particulates can be trapped in the beam
- **…and with positively charged particle beams (protons at LHC, positrons at SuperKEKB)**
  - Dust particulates are ionized and ejected from the beam (but can cause beam losses and lifetime degradation)

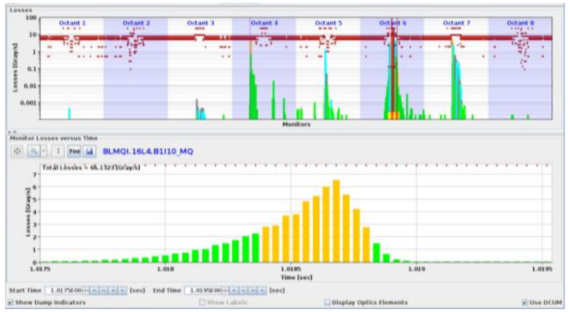




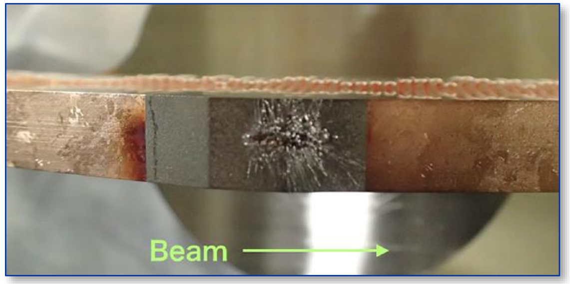


Dust is important

- **Dust-beam and plasma-beam interaction can:**
  - Induce beam losses, dump the beam, quench superconducting magnets, and cause downtime (UFOs at LHC)
  - Cause beam instabilities and limit the beam intensity (“16L2” events at LHC)
  - Damage equipment and restrict performance of an accelerator (SuperKEKB)
  - Have significant impact on machine protection and availability
  - Require to change particle type and completely exchange 6 km of vacuum system (HERA, DORIS)
  - Determine the acceptable surface treatments in an accelerator
  - Cause breakdowns and degradation of RF cavities (DESY, TRIUMF)
  - Limit the performance reach of future energy-frontier and intensity-frontier machines - if not understood and anticipated adequately (FCC-ee)

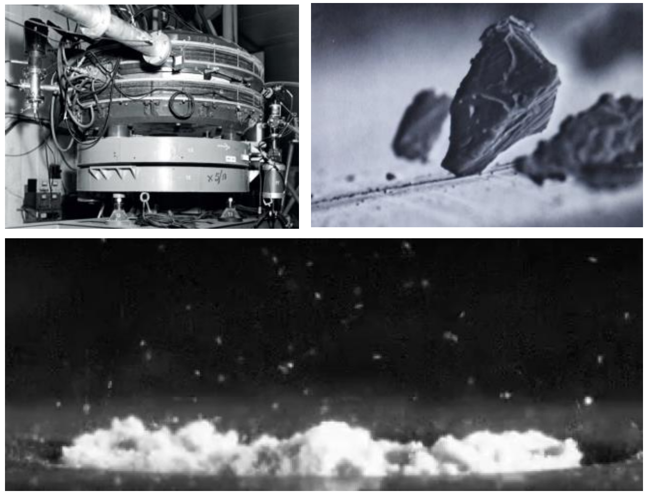
- **Dust generation has to be considered from the design phase of an accelerator and of new equipment – otherwise you might pay a high price…**





Dust is challenging

- **Understanding dust-surface, dust-beam and plasma-beam interaction is highly relevant…**
- **…and scientifically challenging**
  - “God made matter, the surface was invented by the devil” (W. Pauli)
  - Requires multi-physics approach
- **There is a lot of knowledge…**
  - Experience from past accelerators
  - Different accelerator labs
  - Space and fusion community
- **…but we have to connect the dots!**

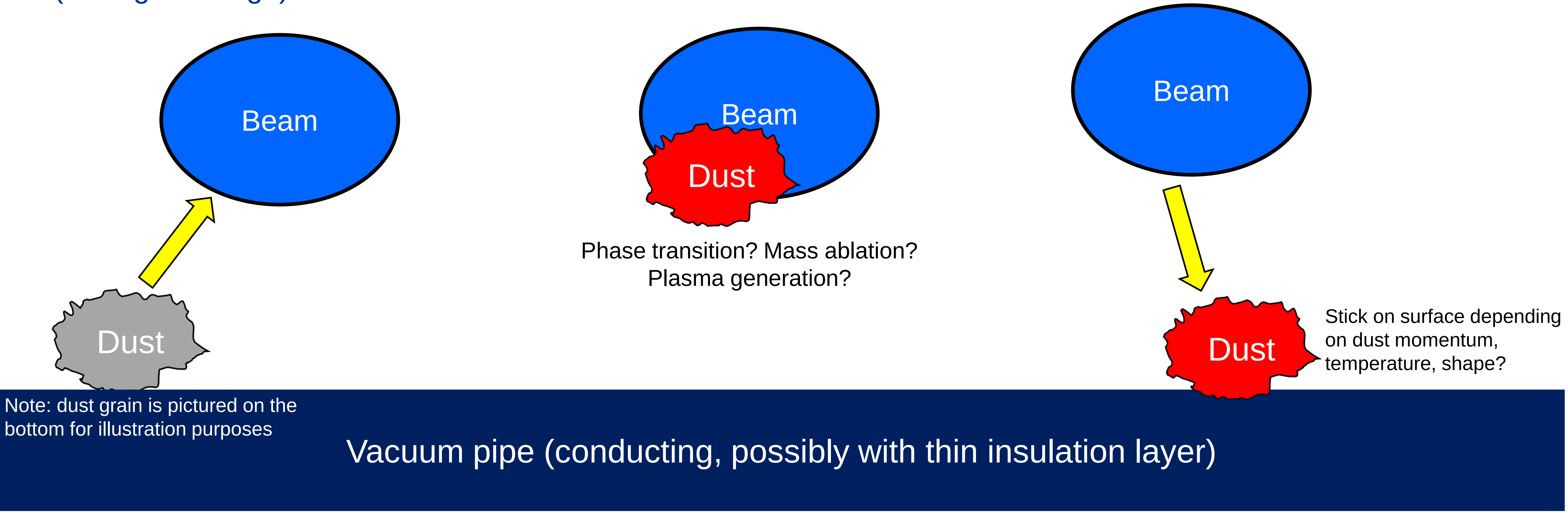


Beam-dust interaction (1/2)

1) Release from surface
(Falling? Lofting?)

2) Beam-dust interaction

3) Dust behaviour after ejection



Beam-dust interaction (2/2)

1) Release from surface

- Dust charging
  - Electron flux due to e⁻ clouds (✓)
  - Synchrotron photon flux (✓)
- Beam-induced E field ✓
- Surface conditions (contact resistance, …) and dust grain conditions (✓)
- **Full physics model/ simulation tool missing? How is a charged particulate released in view of image charges?**

2) Beam-dust (-plasma) interaction

- Solid dust particulate interacting with charged particle beam
  - Simulation codes available at CERN and good agreement with beam-loss data at LHC ✓
- Gas and plasma interacting with the charged particle beam
  - “16L2” events after evaporating solid particulates
  - Sudden Beam Losses at SuperKEKB?

3) Interaction of ejected dust particle with surface

- Temperature of the dust particle (✓)
- What happens to the dust particulates when they exit the beam?
- Can this explain UFO (de-) conditioning?
- Is there a synergy in understanding “fireball” generation at SuperKEKB?
- How is this relevant for RF cavities?

Studies: dust release and charging

Lab experiments

- Experimentally characterize dust charging and lofting of mono-layer dust or “single” dust particulates (LASP, Boulder)
  - What are the relevant parameters to be experimentally studied?
- Do we need a dedicated test stand at CERN?

Simulations

- Reproduce lab measurements with analytical or numerical calculations
- Reproduce observations at particle accelerators with numerical calculations

Beam experiments

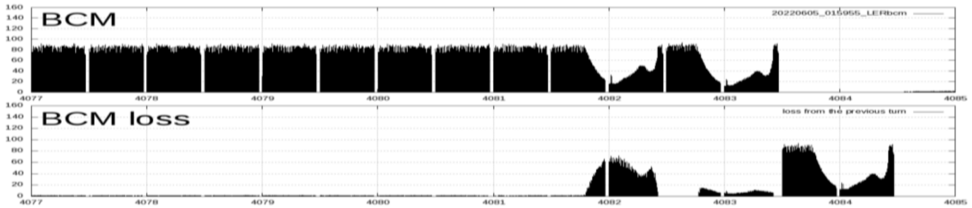
- LHC
  - Test installation of LESS-treated chamber in the LHC (including knocker)
  - Test with displaced bunches
  - Dedicated experiment at LHC (requires risk analysis)?
  - Improve UFO monitoring outside cryogenic arcs?
- CERN injectors (no storage rings…)?
- Direct (optical) measurement of dust trajectories?
- Experiments at SuperKEKB?

“Back to the future”: many impressive (lab and accelerator) experiments performed in the past…

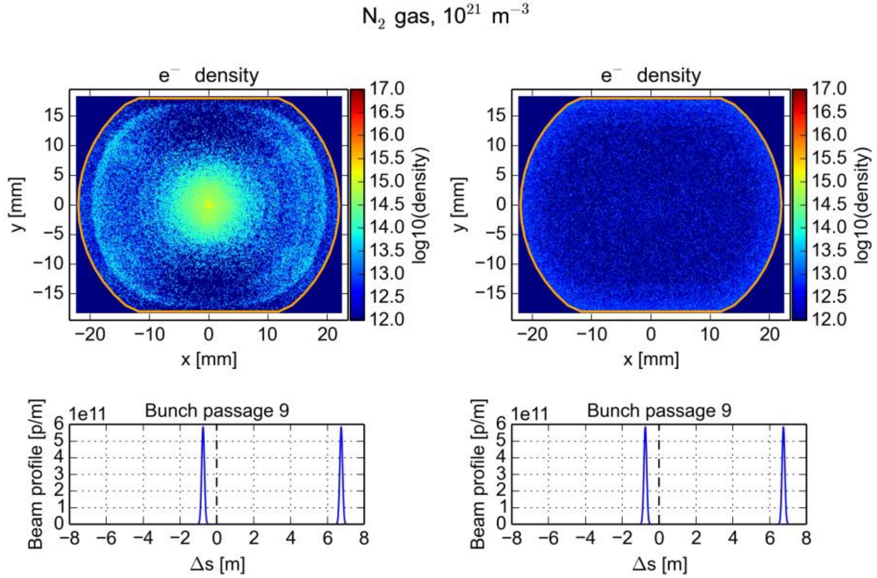
Fireball (?)

Studies: plasma-beam interaction

- **Phase transition and plasma-beam interaction**
  - How do we explain the Sudden Beam Losses at SuperKEKB?
  - What can we learn from CERN “16L2” events?
  - What are the relevant physics parameter? What simulation tool(s) do we need?
  - What can we learn from the experience of the fusion community?



- **“16L2” open questions (L. Mether)**
  - The precise release mechanism and phase transformation
  - The evolution (extent, rate of expansion) of the formed gas
  - Modelling of the electron-ion clouds and instabilities considering aspects of completely beam-dominated system (as usual for e$^-$ clouds) and more typical plasmas: missing elements are, e.g., neutral macro-particles, particle collisions...



Studies: dust migration and vacuum beam screens

- **Migration of *non-charged dust* (beam-independent) can have significant impact – and can be largely reduced with appropriate measures (where applicable): FLASH, XFEL**
- **Migration of *charged dust* in the beam has been observed at particle accelerators (e.g. Photon Factory – Advanced Ring, KEK)**
- **Dust migration in particular relevant for RF cavities (e.g. TRIUMF)**
  - Can cause degradation of cavity performances
  - Can impact especially accelerators with large RF systems: FCC-ee…
- **How can migration of charged dust be blocked or limited?**
- **Does dust migration play a role for LHC UFO deconditioning?**
- **LHC beam screens**
  - Does it make sense to newly clean (some?) beam screens before installation (or apply different installation procedures) and monitor UFO rate?
  - Can we take dust samples of beam screens before installation in the LHC for reference?
  - Can we explain the difference in the UFO rate between newly installed dipoles and quadrupoles?

Experimental studies on dust

- **Particularly interesting to learn about the experimental work on dust in the different domains: Fusion, Space Research, Accelerators**

- **Fusion research**
  - Sophisticated devices to bring a well-defined dust population into the fusion reactor, for controlled experiments to be compared with complex theoretical models

- **Space research**
  - Since decades, experiment to study various aspects of dust issues in space. This includes dust accelerators, one in operation at LASP (Boulder, University of Colorado)
  - Capable of simulating high-speed impacts of dust grains by electrostatically accelerating dust particles to cosmic speeds at several megavolts
  - Experiments to understand dust lofting with parameters similar to accelerators

- **Accelerator research**
  - Understand lofting of dust grains into the beam and understand the dynamics for dust grains in the beam
  - Experiments at SLAC for PEP2
  - A number of experiments at KEK, starting the beginning of the 90th until recently, at different machines

Thank you!

- **A great thank you to all of you…**
  - for your contributions to this workshop,
  - for the excellent presentations,
  - for the amazing discussions!
- **Looking forward to future collaborations!**

Thank you very much for your attention!

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Workshop introduction: initial questions

- How are dust particles charged in accelerators?
- How are they released from the surface?
- How does the observed conditioning work?
- Looking into the future: will beam dust interactions be limiting in future accelerators and what can we do about this?