Dust-Beam interaction in the LHC vacuum chamber

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Outline of the talk

• Background
• Dust particle dynamics
• Beam lifetime
• Future work
Introduction

in the 2008 incident some portions of the LHC beam pipe were contaminated with insulation parts, soot and metallic macro-particles

charged “dust” or macro-particles are subjected to electrical forces in the beam field and electrical image forces, plus gravity; for various reasons they could start to move, if they come close to the beam local beam losses can lead to quenches of SC magnets, but the macro-particles will also further ionize, become positively charged, and then be repelled from the beam vicinity
fibers

soot
dust particle dynamics

- Electrical beam force
- Electrical image force
- Gravity

- Charging rate due to ionization and secondary electron escape from the dust particle
\[ F_{\text{electr}} = 2N_p Q r_p c^2 \left(1 - \frac{\pi^2 + y^2}{2\sigma^2}\right) \frac{y}{AC} \]

\[ F_{\text{im}} = \frac{Q^2 r_p c^2 r}{A \left(\frac{b^2}{r} - r\right)^2} \]

\[ \text{charge rate} = \frac{16\pi^2}{3} f_{\text{rev}} N_A \frac{m_p^2 n_p c^2}{2\sigma^2} \frac{e_0 R(A)^4}{e^2} \left(\frac{\rho}{kg}\right) e^{-\frac{x^2 + y^2}{2\sigma}} \]

\( C \): circumference (26.7 km), \( A \): mass in units of proton mass, \( c \): velocity of light, \( \sigma \): rms beam size (0.3 mm), \( r_p \): proton radius, \( N_p \): number of protons (2808x1.15x10^{11})

\( R(A) \): radius of round dust particle (\( R \approx 0.1 \mu m \) for \( A \approx 10^{10} \))
particle motion in the x-y plane, inside the pipe, starting from the top; deflection by electric beam field

charging rate vs vertical position

acceleration due to el. beam force at wall vs mass
vertical acceleration at the wall due to beam force, image force, and gravity, vs the mass of singly charged dust particle, for nominal LHC beam current (solid) and 10x this current (dashed)

dust particles with masses larger than \( \sim 10^{11} \) proton masses can “fall” into the beam pipe, but the nominal beam cannot pick up any charged particles from bottom
beam lifetime

Vs vertical position (x=0, A=10^{13}) Vs proton masses (x=0, y=0.002)

\[ \frac{1}{T} = \sigma_c \frac{c}{2\pi \sigma^2} \frac{A}{C_{\text{ion}}} e^{-\frac{x^2+y^2}{2\sigma^2}} \]

\( \sigma_c \): nuclear interaction cross section of protons and dust nucleons, ~1 barn
relate lifetime with quench limit for SC magnets

$10^7$ protons /s or $\tau \sim 10^4$h

M. Brugger et al, AB-Note-2007-18
future work

• combined solution of equation of motion, charging rate and beam lifetime \{x(t), \ y(t), \ Q(t), \ T(t)\} for different A and \(x_0\)

• thermal stability of dust particles

• different dust shapes