Dust-Beam interaction in the LHC vacuum chamber

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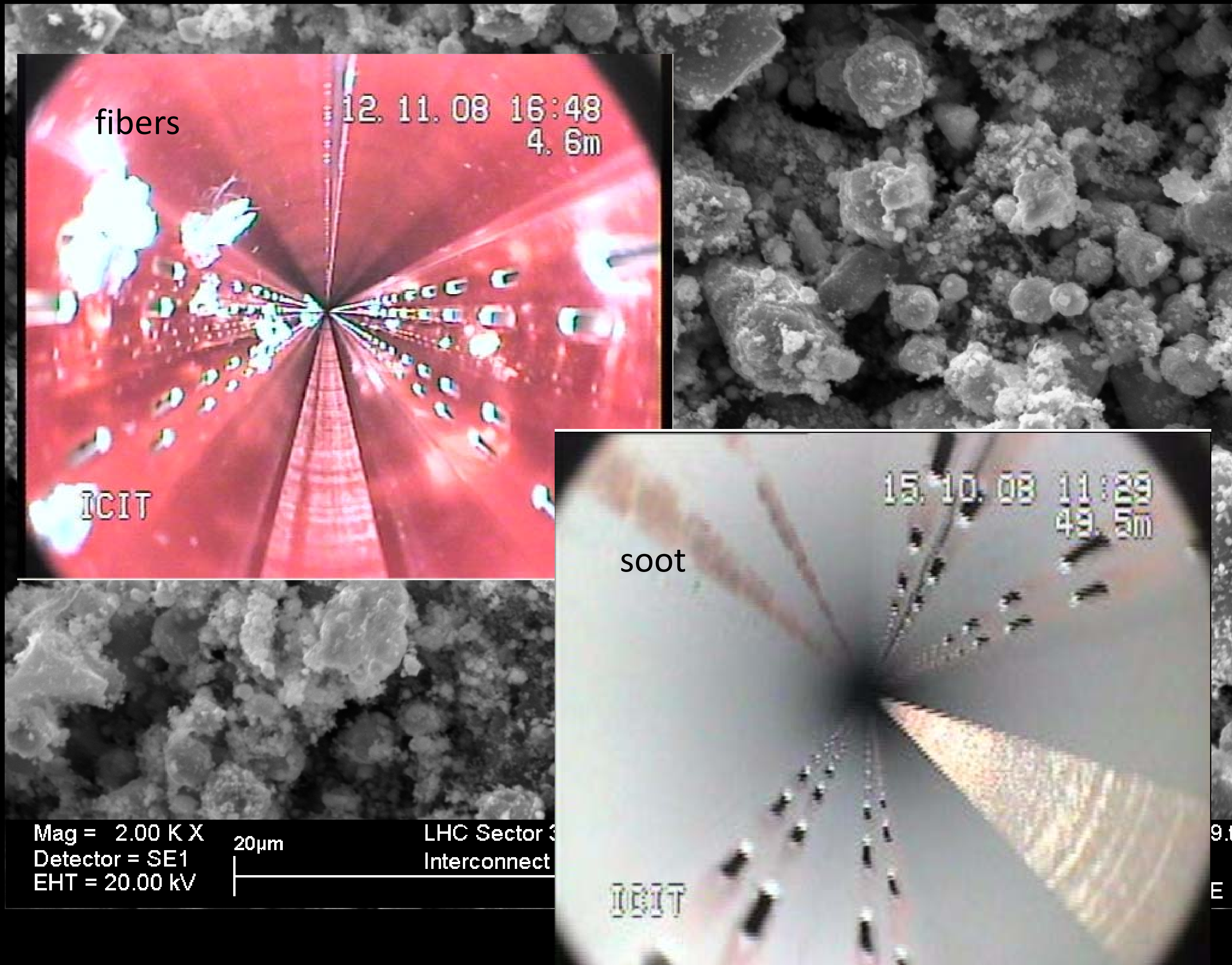
Outline of the talk

- 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
12.11.08 16:48
4.6m
ICIT
soot
15.10.08 11:29
49.5m
ICIT
Mag = 2.00 K X
Detector = SE1
EHT = 20.00 kV
20µm
LHC Sector 3
Interconnect

dust particle dynamics

- Electrical beam force
- Electrical image force
- Gravity

- Charging rate due to ionization and secondary electron escape from the dust particle

$$F_{electr} = 2\,N_p\,Q\,r_p\,c^2\,\frac{\left(1 - e^{-\frac{x^2+y^2}{2\sigma^2}}\right)}{A\,C}\,\frac{y}{r}$$

vertical component

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

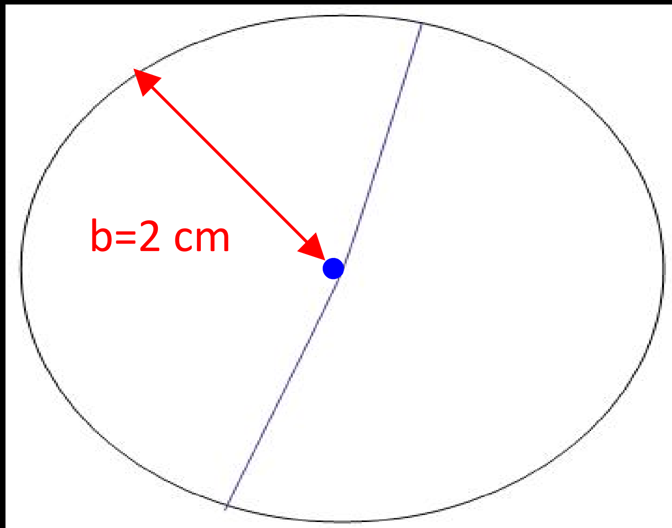
modulus

$$chargerate = \frac{16\pi^2}{3} f_{rev} N_A \frac{{m_e}^2 n_p c^2}{2\sigma^2} \frac{\varepsilon_0}{e^2} \frac{R(A)^4}{Q} \left(\frac{\rho}{kg}\right) e^{-\frac{x^2+y^2}{2\sigma}}$$

C: circumference (26.7 km), *A*: mass in units of proton mass, *c* : velocity of light, σ: rms beam size (0.3 mm), r_p: proton radius, N_p: number of protons ($2808 \times 1.15 \times 10^{11}$)
R(A): radius of round dust particle ($R \sim 0.1$ μm for $A \sim 10^{10}$)

particle motion in the x-y plane, inside the pipe, starting from the top ; deflection by electric beam field

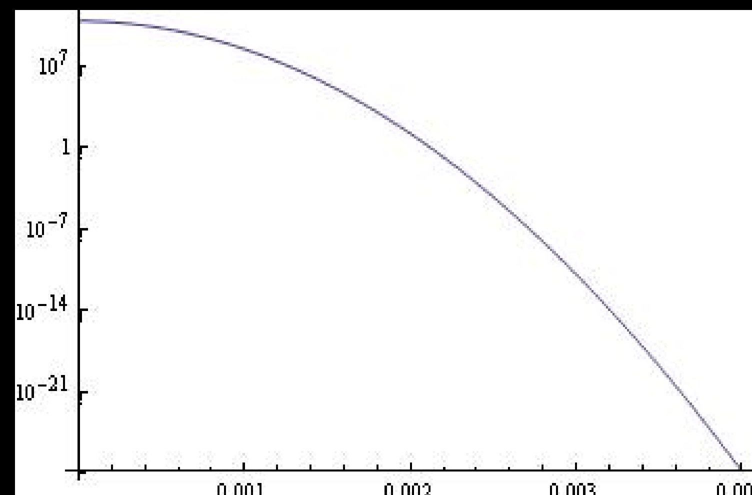
y [m]



x [m]

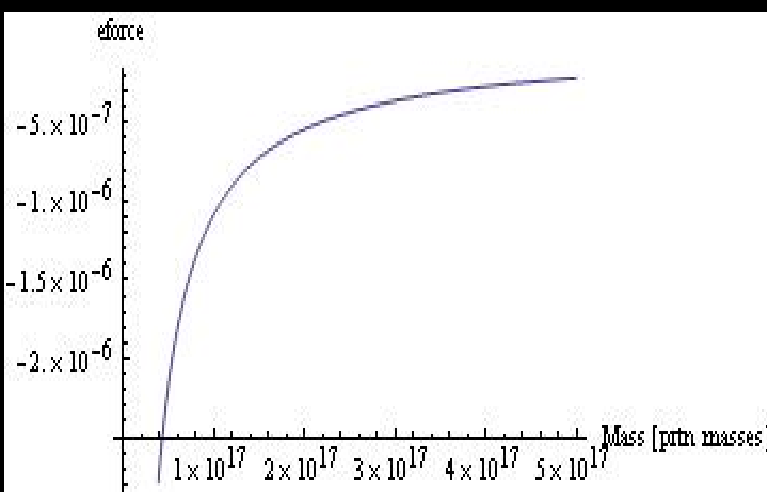
charging rate vs vertical position

dQ/dt [s^{-1}]

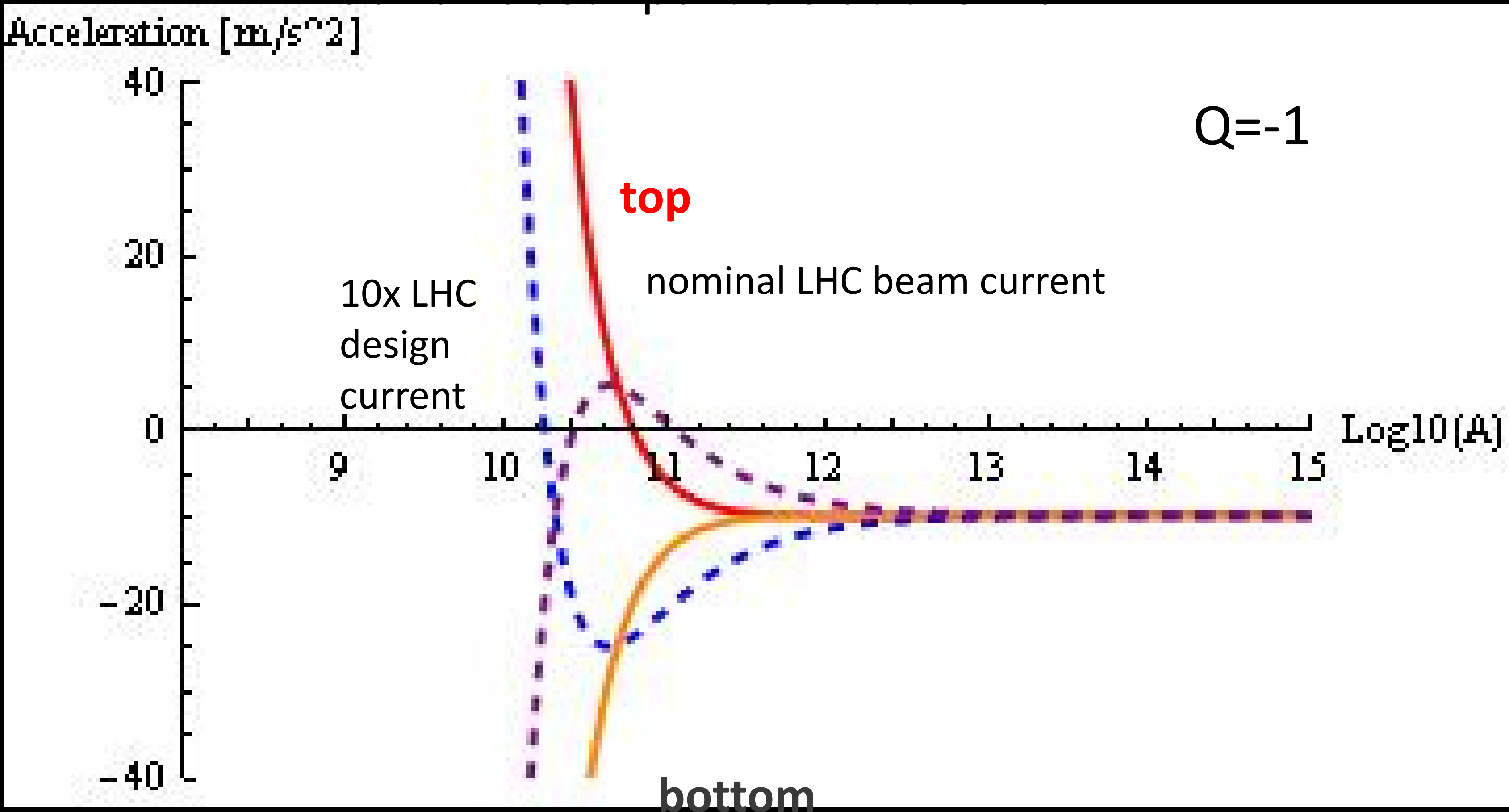


y [m]

acceleration due to el. beam force at wall vs mass



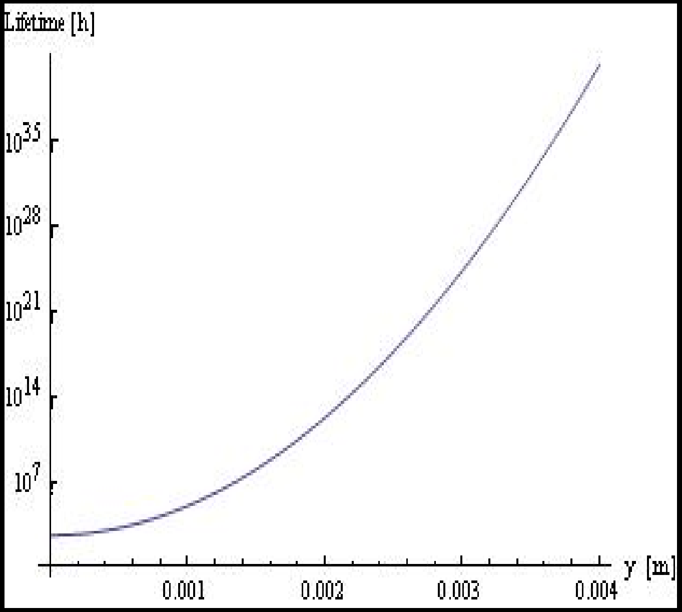
vertical acceleration at the wall due to beam force, image force, and gravity, vs the mass of singly charged dust particle, for nominal LHC beam current (solid) and 10x this current (dashed)

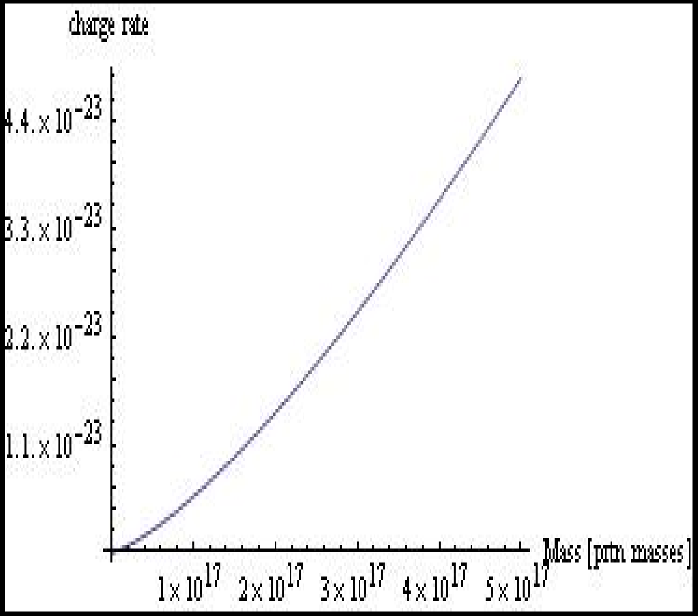


dust particles with masses larger than ~10^{11} proton masses can "fall" into the beam pipe, but the nominal beam cannot pick up any charged particles from bottom

beam lifetime

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





$$\frac{1}{T} = \sigma_c \frac{c}{2\pi\,\sigma^2\, C} \frac{A}{A_{ion}} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

σ_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