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Les Journées accélérateurs

Dynamic pressure in the LHC

Detection of ions induced by ionization of residual gas by both the proton beam and the electrons in the LHC : implications for the FCC project*

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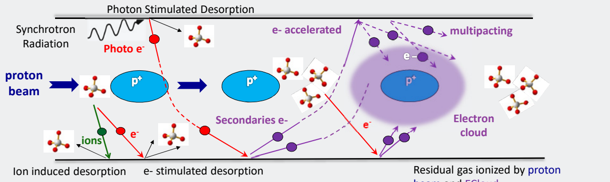
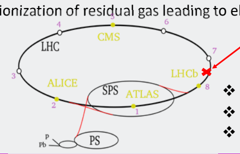
Introduction

For the FCC study, the understanding of the beam interactions with the vacuum chamber is fundamental to provide solutions to mitigate the pressure rises induced by electronic, photonic and ionic molecular desorption [1].



In-situ measurements were carried out, on the LHC Vacuum Pilot Sector [2] during the LHC RUN II, to monitor the dynamic pressure, and to collect the electrical signals due to the electron cloud and to the ions interacting with the vacuum chamber walls.

Development of DYVACS code was performed at the Linear Accelerator Laboratory (LAL) in France, in order to estimate gas density profiles taking into account electron cloud build-up (maps [3]) and ionization of residual gas leading to electron- and the ion-induced desorption.



VPS Conditions: Room temperature in a straight section

VPS station 4, "blue" beam, copper vessel, RUN II

- Positive current I_+ : copper electrode (-1000<Vbias<0).
- Electrons current I_{e-} : (K_{11} and EKD, Vbias=+9 V).
- Total Pressure : Bayard Alpert gauge.

In-situ measurements

LHC-VPS station 4, "blue" beam, copper vessel, RUN 7319

The pressure, the electron current and the positive current follow exactly the same behaviour along the time. Three major bumps are observed: Fig. 1 b)

"Proton injection" bump 1:
↗ ionization of residual gas
↗ pressure
↗ electrical currents

Energy ramp-up:
-bump 2: modifications of energy spread (depending on both the bunch length and the RF)
-bump 3: photoelectron contribution from 2.8TeV

Stable Beam
Recorded signals decrease slowly due to proton losses.

Proton-proton collisions
Signals decrease faster due to higher losses in p-p collisions.

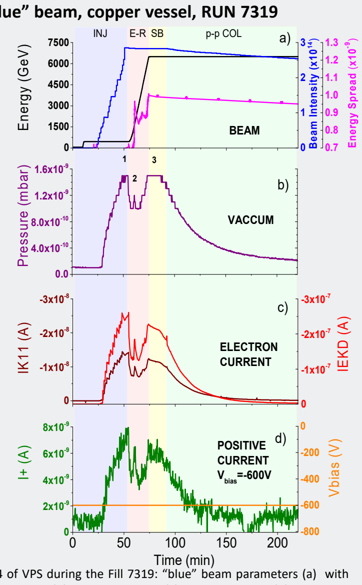


Figure 1: Measurements performed in station 4 of VPS during the Fill 7319: "blue" beam parameters (a) with the beam structure: 25ns_2556b_144bpi_20inj, pressure (b), electron current (c), positive current (d) and with a negatively biased copper electrode current $Vbias = -600\,V$

DYVACS

Analytical model of the dynamic pressure based on VASCO code

n=1D gas density — Residual gas ionization (by p beam, by EC) — thermal desorption

$$C\frac{\partial^2 n}{\partial x^2} + \eta_i\left(\sigma_{i-p}\cdot\frac{I_{beam}}{e} + \sigma_{i-e}\cdot\Gamma_e\cdot L\right)\cdot n + \eta_e\Gamma_e + \eta_{ph}\Gamma_{ph} + a\cdot q_{th,} - S\cdot n = 0$$

Molecular Diffusion — Ionic Desorption (Multi-gas model [1]) — Electronic Desorption (e^- Cloud) — Photon Desorption — Pumping Flux

For the gas j=H_2, CO_2, CO, CH_4)

$$\Gamma_{ph} = 7.017\times 10^{13}\frac{E}{r} I_{beam}\ \text{(ph/m/s)}$$

Initial electronic density:

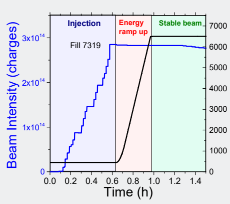
$$\rho_0 = \sum_{gas} \sigma_{gas-p}\cdot\frac{P_{gas}}{kT}\cdot I_{beam}\cdot t_T$$

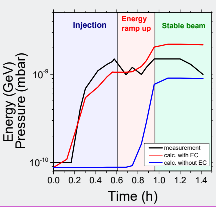
(t_T = time for one lap= 89 µs)

Electron density build-up (map method [3]):

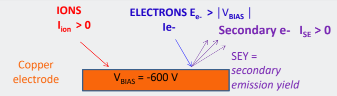
$$\rho_{m+1} = a\rho_m + b{\rho_m}^2 + c{\rho_m}^3$$

(with a=1.3 b=-1 c=0.7)





Ions or not ions?



I_+ (E, Vbias) = I_{e-} + I_{SE} + I_{ion} >0

I_{e-} : e- current collected with e- energy E > |V_{BIAS}|;
I_{SE} : positive current due to secondary electrons (SE);
I_{ion} is the positive ion current collected by the electrode.

$I_{ion} > I_{SE}$ or $I_{SE} > I_{ion}$?

Contribution of all electrons to I_+

$$I_+ (E, V_{bias}) = I_{e-} + I_{SE}$$
$$= I_{e-}[1-SEY]$$

$$SEY = \delta(E) = \delta_{max}\frac{s*\left(\frac{E}{E_{max}}\right)}{s-1+\left(\frac{E}{E_{max}}\right)^s}\ [6]$$

Depends on e- energy spectrum — Depends on SEY=f(Ee-)

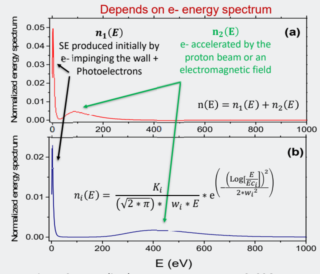


Figure 2: Normalized e- energy spectrum at 6500GeV
a) experimental measurement performed in the VPS[4]
b) calculated distribution inspired by G. Iadarola in [5]

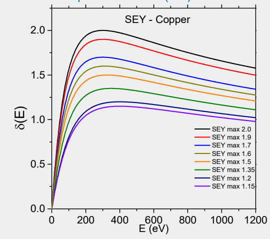


Figure 3: Calculated SEY curves for copper and for different values of the dmax and Emax parameters.

→ Calculation of I_+ as a function of V_{bias}

Calculations *vs* experimental measurements

I_+ and I_{e-} with a V_{bias} scanning (Fill 6640 Fig. 3) *(bleu squares and violet circles)* vs calculated values (color lines, Fig. 5)

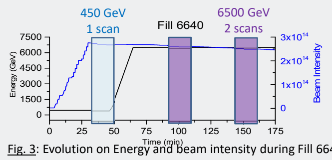


Fig. 3: Evolution on Energy and beam intensity during Fill 6640

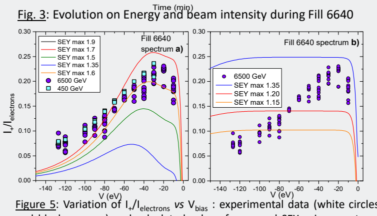


Figure 5: Variation of $I_+/I_{electrons}$ *vs* V_{bias} : experimental data (white circles and black squares) and calculated values for several SEY using spectrum (a) and (b) (color lines).

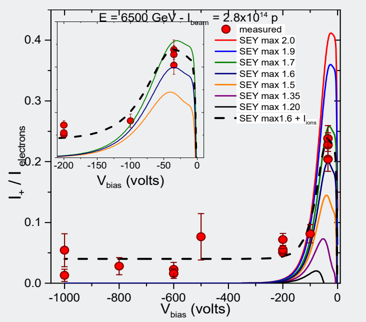


Figure 6: Variation of $I_+/I_{electrons}$ *vs* V_{bias} : experimental data (red circle) recorded during different fills and calculated values for several SEY using spectrum (a) (color lines).

- Same behaviour at 450 and 6500 GeV,
→ low contribution of photoelectrons
- Which n(E) should we consider?
→ better agreement for spectrum a)

- Below -200 V, a constant value is reached :
$I_+/I_{electrons}$ = 0.04 → IONS! SEY(copper electrode)=1.6

NUAGE code [7] gives the kick that an ion will feel when the proton beam is going through the beam pipe.
$E_{max}(CO^+)$=0.6 keV $E_{max}(H^+)$=1.6 keV

Conclusion

- Ions, created by ionization of the residual gas by the proton beam and the e-cloud, were measured during the RUN II in the VPS between IP 7 and IP 8 of LHC.
  I_+ = 4% $I_{electrons}$ & SEY(copper electrode)=1.6 & $E_{max}(CO^+)$=0.6 keV; $E_{max}(H^+)$=1.6 keV
- DYVACS seems to be in good agreement with measurements, Ecloud build-up must be considered and ionic desorption measurement should be performed and use as inputs.
- New measurement should be done during the next LHC RUN to confirm the ion current .
- WHERE DO IONS COME FROM??? This question is a crucial point that we need to answer to mitigate pressure rise during FCC-hh operation to reach beam performances that is expected.

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