POSINST simulation on Fermilab Main Injector and Recycler Ring

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Abstract

The Fermilab accelerator complex is currently undergoing an upgrade from 400kW to 700kW. This intensity could push operations into the region where electron cloud (e-cloud) generation could be observed and even cause instabilities. The POSINST simulation code was used to study how increasing beam intensities will affect electron cloud generation. Threshold simulations show how the e-cloud density depends on the beam intensity and secondary electron yield (SEY) in the Main Injector (MI) and Recycler Ring (RR).

POSINST and input parameters

POSINST simulates the build-up and dissipation of electron cloud. The electric fields are calculated in POSINST using a Particle In Cell (PIC) technique. POSINST simulates electron motions in 3D space, but calculates the electric field only for a 2D cross-section of the accelerator. POSINST treat externally applied magnetic fields as a predetermined uniform constant either parallel or perpendicular to the ideal beam trajectory, and thus can only simulate dipole or solenoidal fields. The beam parameters used in the simulations are given in table 1.

Table 1: Simulation inputs parameters

general parameters	
Beam energy [GeV]	8
Bunch Intensity [protons/bunch]	5.5e10 - 11.5e10
Total Intensity [protons]	2.71e13 - 5.41e13
ring circumference[m]	3319.419
revolution frequency [kHz]	90
Harmonic number	588
RF frequency [Mhz]	53
Total RF bucket filled	492
SEY	1.2-1.9
MI specific parameters	
σ_x [mm]	3
σ_y [mm]	3
σ_z [m]	0.3
σ_t [ns]	1
Bunch length [σ][m][ns]	10; 3; 10
Chamber major semi-axis [cm]	5.88
Chamber minor semi-axis [cm]	2.39
Dipole Field[T]	0.234
RR specific parameters	
σ_x [mm]	3.6
σ_y [mm]	1.6
σ_z [m]	0.75
σ_t [ns]	2.5
Bunch length [σ][m][ns]	4; 3; 10
Chamber major semi-axis [cm]	4.7
Chamber minor semi-axis [cm]	2.2
Dipole Field[T]	0.137

Furman-Pivi probabilistic model

The SEY curves are generated based on a set of parameters in POSINST governing the generation of backscattered electrons, rediffused electrons, and true secondary electrons. These parameters determine the shape of the SEY curve, which is scaled by an input for the peak SEY value. The POSINST electron generation parameters were obtained by fitting the Furman-Pivi probabilistic model to a real SEY measurement of steel. The SEY curves used in simulations are shown in figure 1.

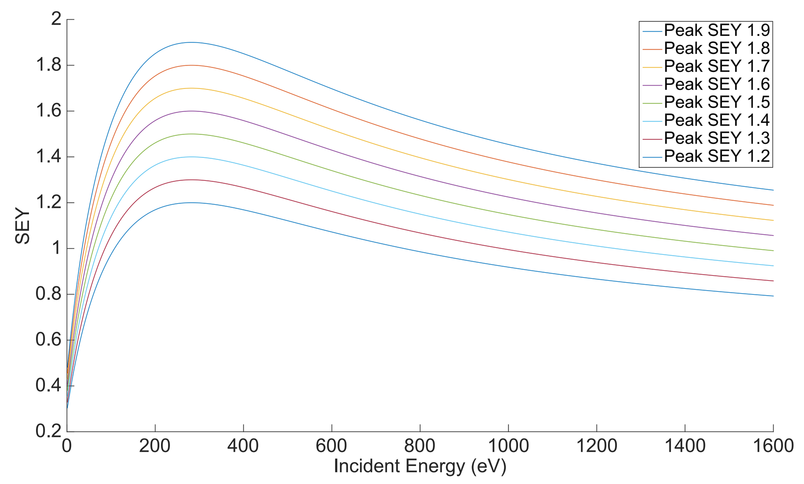

Figure 1: The SEY curves used in simulation

Threshold simulation result

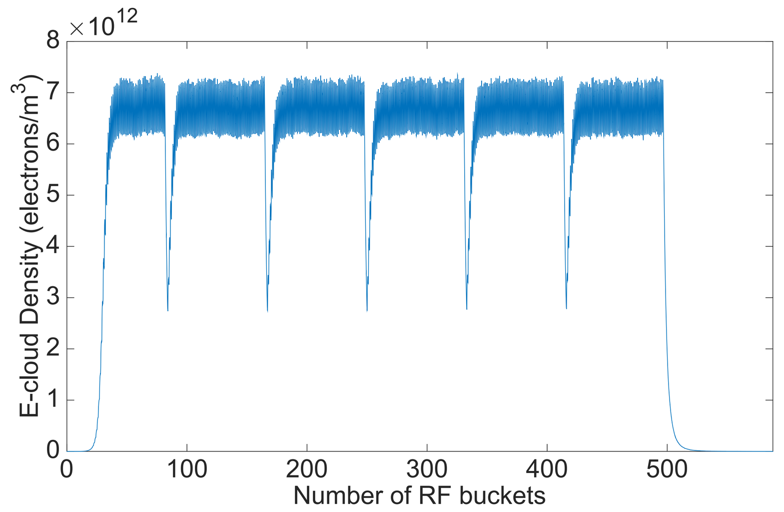

Figure 2: A typical simulation of electron cloud build up at one location in the accelerator for a time duration of one revolution period of the machine. The density of the E-cloud build up matches the filling pattern. The E-cloud builds up rapidly and then saturates. After saturation is reached, the E-cloud oscillates as bunches pass and dips as the two empty buckets between batches pass. Eventually, after the 6 filled batches pass, the E-cloud vanishes in the one batch (84 bucket) gap with no beam.

MI Simulations

Figure **??** and figure **??** show the MI threshold simulation results for the field free region and dipole region respectively.The E-cloud dips to a lower density in the field free region compared to the dipole region as the SEY and beam intensity go down. The E-cloud density reaches all the way below $10^7 electron/m^3$ in the field free region while in the dipole region the E-cloud density only reaches $10^{10} electron/m^3$. On the other hand, as the beam intensity and SEY go up, the E-cloud density reaches higher values in the field free region. For example, in the field free region, it takes less than 35×10^{12} protons for the E-cloud density to reach above $10^1 2.5 electron/m^3$ at 1.9 SEY while in the dipole region it takes over 45×10^{12} protons to get the same E-cloud density at the same SEY.

RR Simulations

Figure **??** and figure **??** show the RR threshold simulation results for the field free region and dipole region respectively. A comparison between the dipole region and the field free region shows the same trend as in MI. The E-cloud density reaches $10^7 electron/m^3$ in the field free region faster than in the MI, while on the other hand, in dipole region, the E-cloud density get down to $10^8 electron/m^3$ in RR (compare to $10^{10} electron/m^3$ in the MI). The RR dipole regions behave completely differently than the MI dipole region, It seems that because of the difference in the chamber dimensions and beam size, the E-cloud density is relatively independent of the beam intensity in the RR dipole region. The E-cloud formation is only dependent on the SEY in this region.

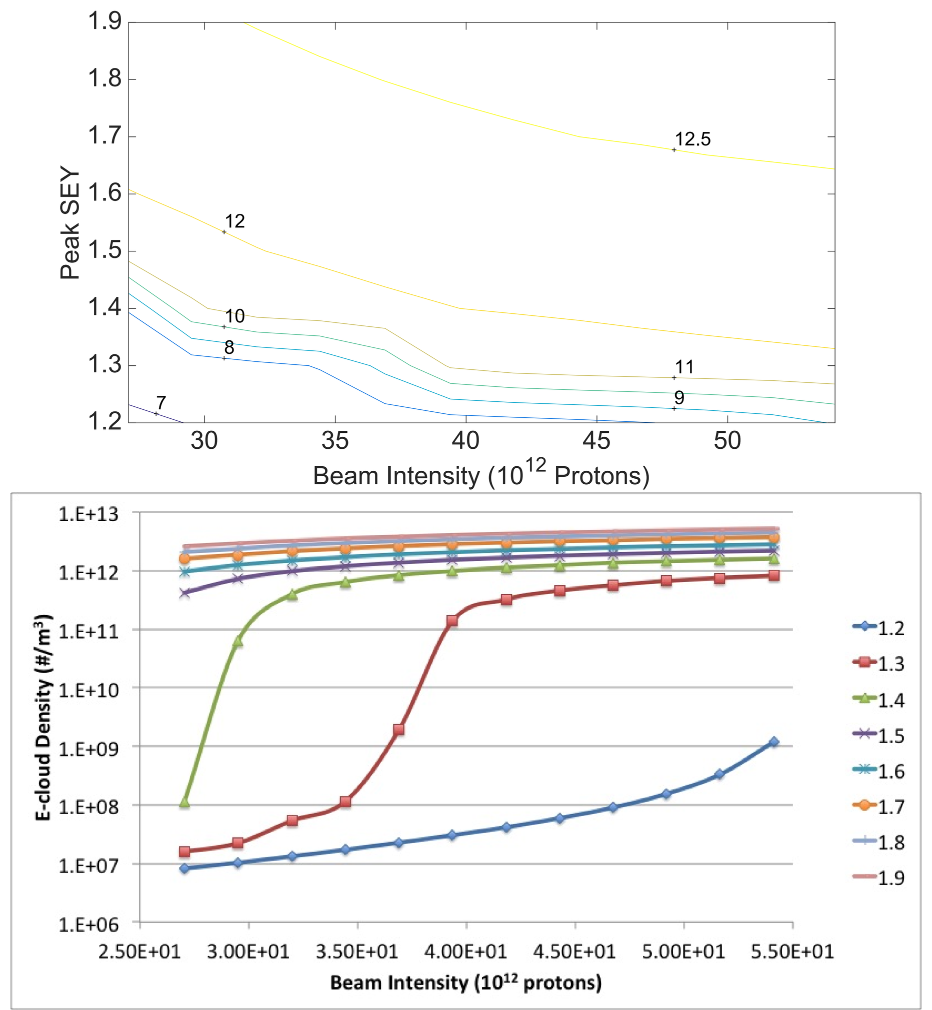

Figure 3: MI field-free region E-cloud density ($electrons/m^3$) in log scale.

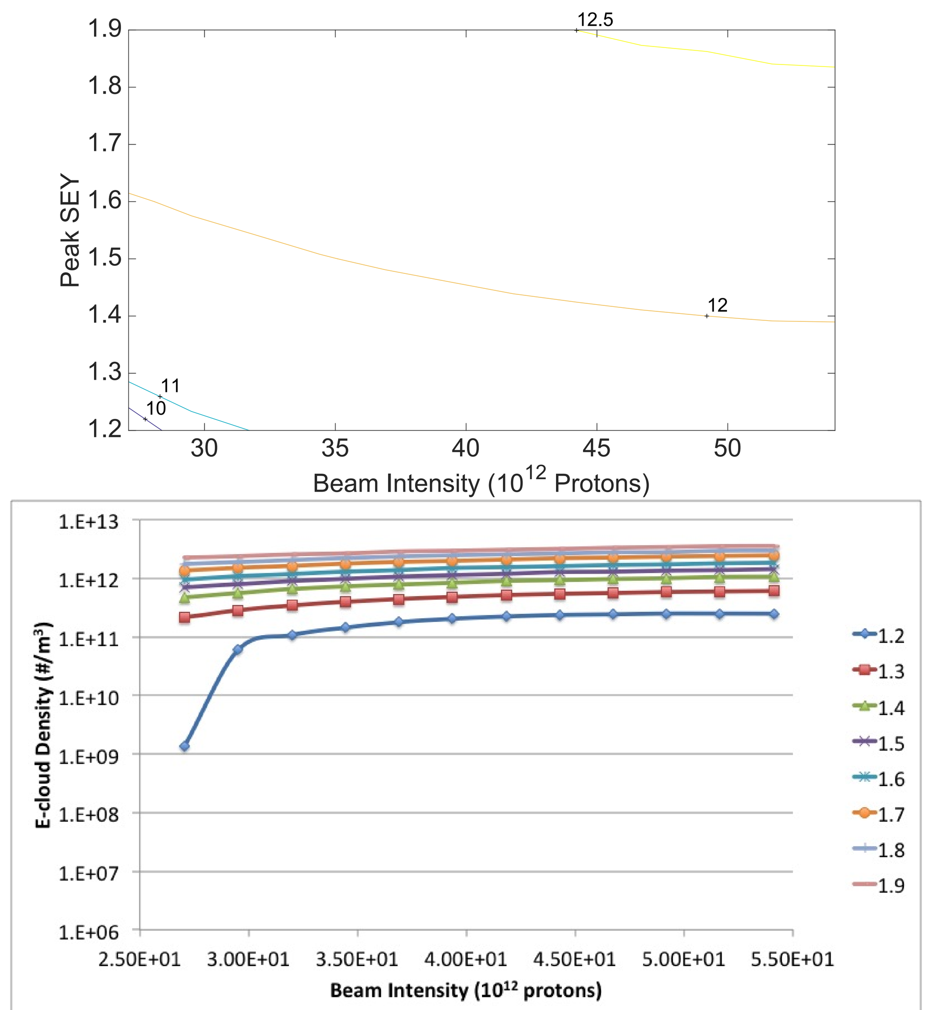

Figure 4: MI dipole region E-cloud density ($electrons/m^3$) in log scale.

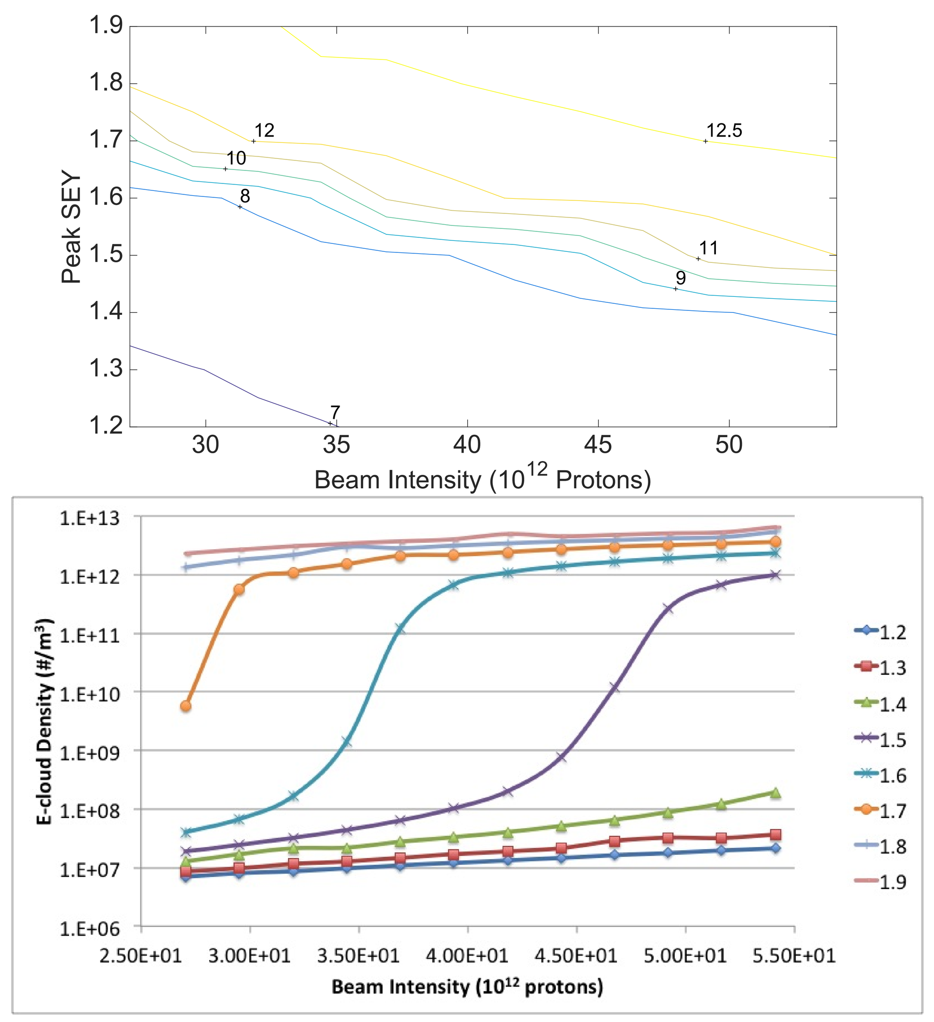

Figure 5: RR field-free region E-cloud density ($electrons/m^3$) in log scale.

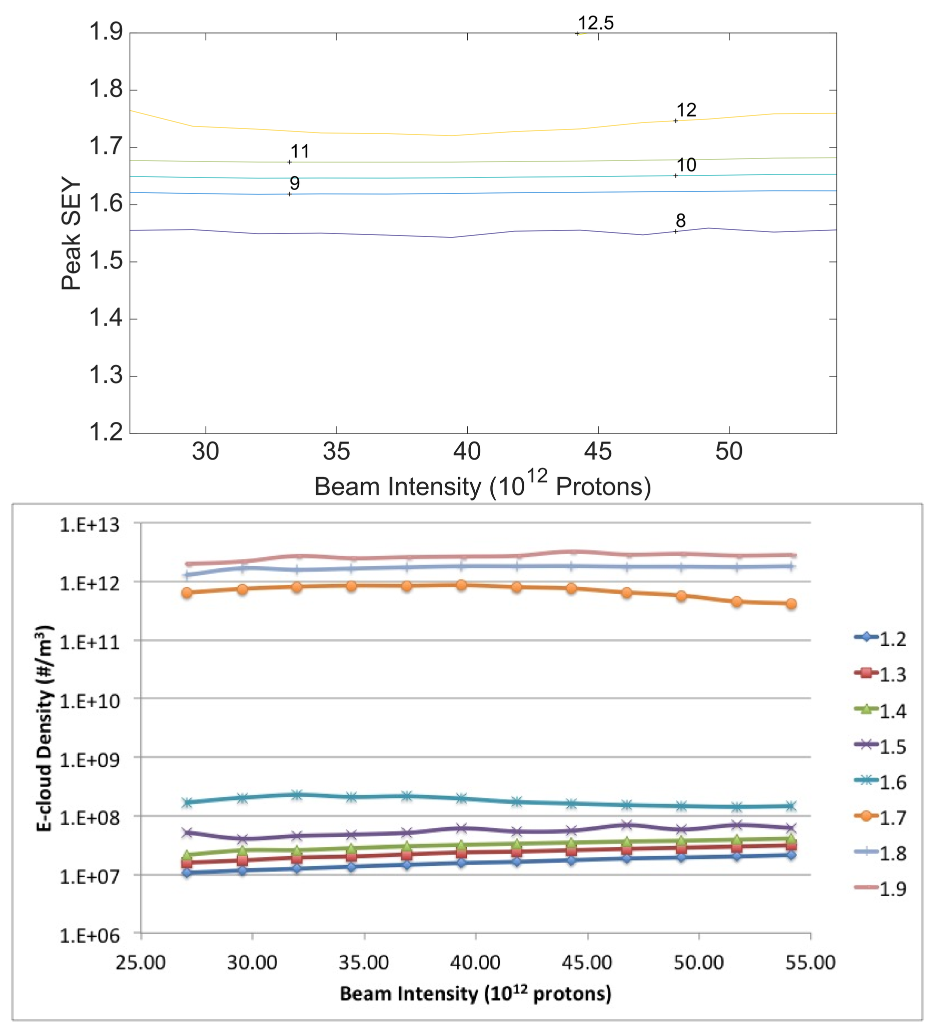

Figure 6: RR field-free region E-cloud density ($electrons/m^3$) in log scale.

FIELD FROM SECONDARY ELECTRONS

Figure 7 shows the development of the field at a specific location as the bunches pass by. This field was calculated using 5×10^{10} protons per bunch and 2.2 SEY in the dipole region. Figure 8 shows the development of E-cloud density in the same simulation. Figure 9 shows the E-cloud density at the center of the vacuum chamber. The E-cloud starts to build up after about 50 bunches have passed, the field development matches the E-cloud build up. The field reaches a maximum 10-20 buckets into the saturation region of the total electron cloud density, and then drops off. The field reaches maximum after about 120 bunches have passed, after the E-cloud density near the vacuum chamber center has leveled out.

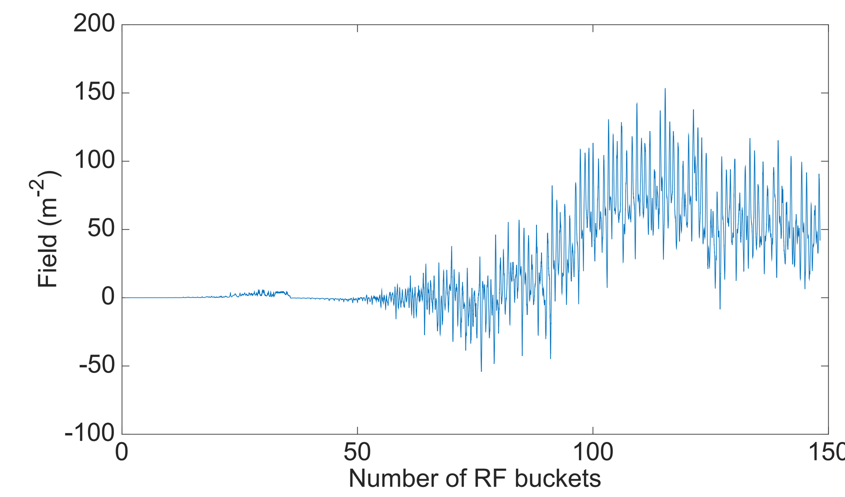

Figure 7: Field extracted from the POSINST

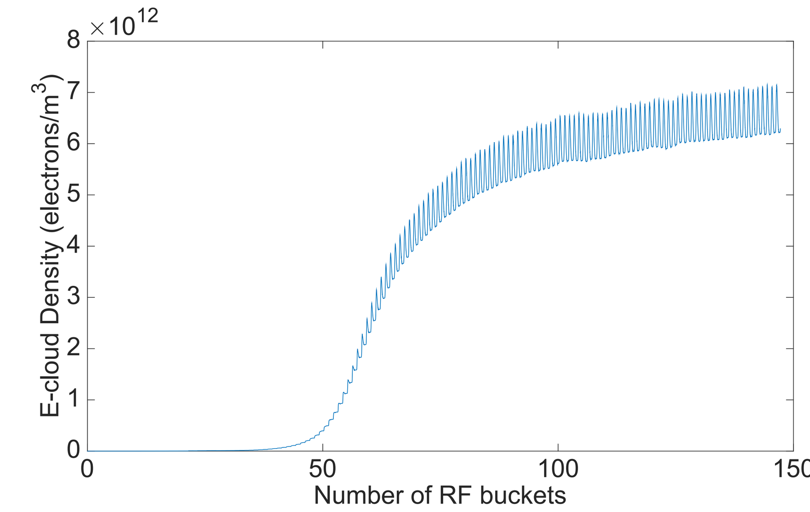

Figure 8: E-cloud density for the Field extraction simulation.

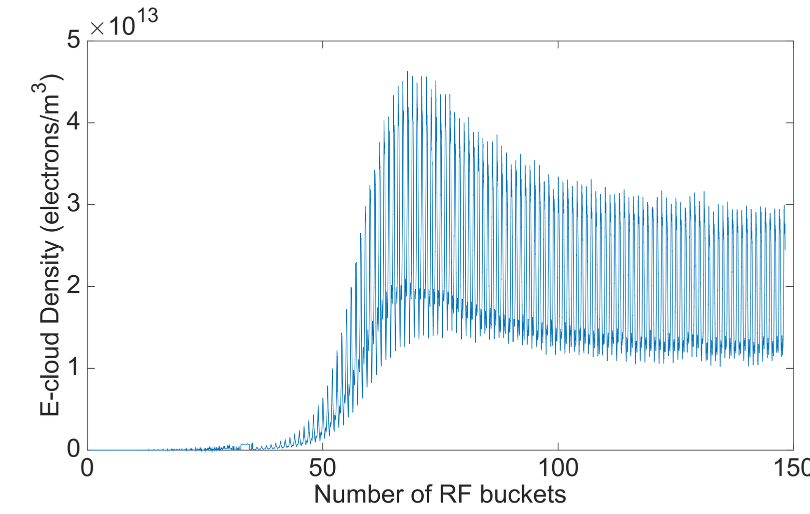

Figure 9: E-cloud density for the Field extraction simulation within a 3mm circle around the vacuum chamber center.

Conclusion

Based on the simulation results, in most cases the E-cloud generation can be greatly suppressed when the SEY of the beam pipe material is below 1.3. The only exception is in a MI dipole region, where below 1.3 SEY the E-cloud density is only suppressed by one order of magnitude. The field from the secondary electrons has been successfully extracted from the simulation. It should now be possible to calculate an effective impedance and instability growth rate due to the presence of the electron cloud using a simplified analytic model.

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