# LMCI Above and Below Transition

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- **Goal of the study: Check results previously obtained with a simple analytical model => Single-bunch interacting with both BB + SC impedances**
  - **http://cdsweb.cern.ch/record/524139/files/ps-2001-063.pdf**
  - **In the previous paper, there is also a reference to a paper by Ng in 1995 (http://lss.fnal.gov/archive/test-fn/0000/fermilab-fn-0630.pdf), discussing only BB impedance, using numerical solutions and mentioning that the intensity threshold is higher when the machine is operating below transition**

# PREDICTION

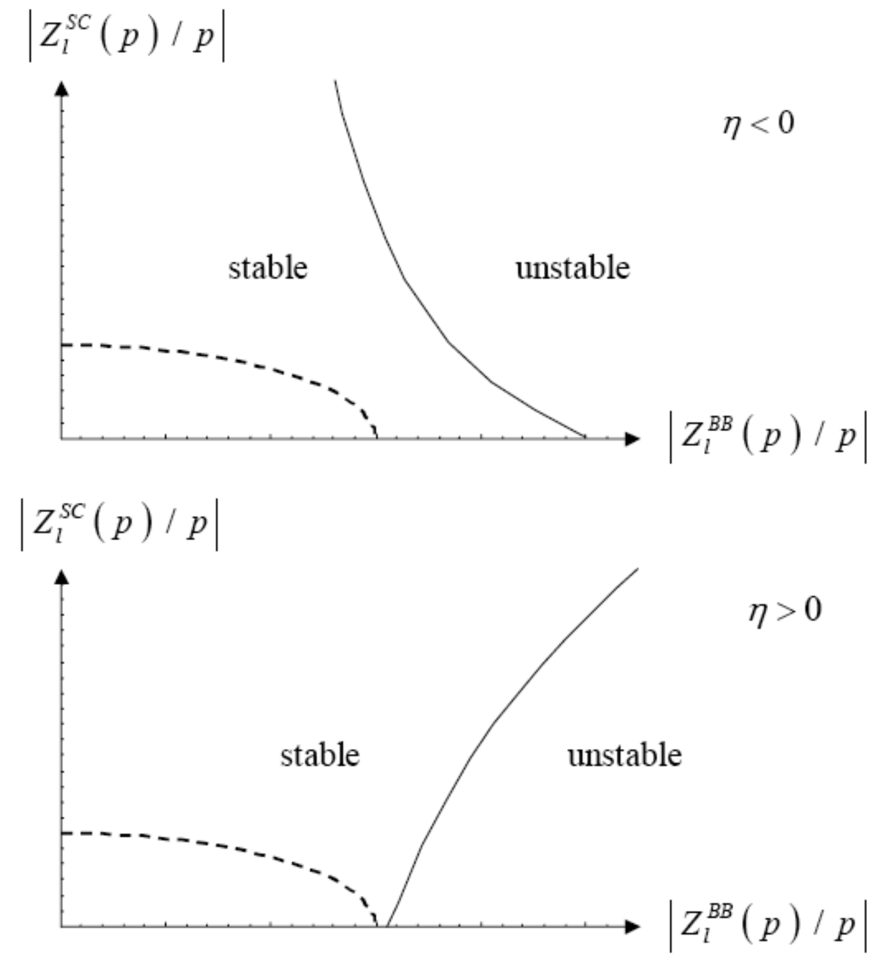


Figure 14: Stability diagram for the LMC instability below and above transition respectively for a proton bunch. The Keil-Schnell circle is represented by the dashed curve.

# HEADTAIL simulation parameters (AT) => No SC yet

| | |
|---|---|
| Flag_for_bunch_particles_(1->protons_2->positrons_3&4->ions): | 1 |
| Average_electron_cloud_density_along_the_ring_(1/m^3): | 1.e+12 |
| Number_of_particles_per_bunch: | 1e+9 |
| Horizontal_beta_function_at_the_kick_sections_[m]: | 40. |
| Vertical_beta_function_at_the_kick_sections_[m]: | 40. |
| Bunch_length_(rms_value)_[m]: | 0.21 |
| Normalized_horizontal_emittance_(rms_value)_[um]: | 3.0 |
| Normalized_vertical_emittance_(rms_value)_[um]: | 3.0 |
| Longitudinal_momentum_spread: | 0.00093 |
| Synchrotron_tune: | 0.00324 |
| Momentum_compaction_factor: | 0.00192 |
| Ring_circumference_length_[m]: | 6911. |
| Relativistic_gamma: | 27.7286 |
| Number_of_kick_sections: | 1 |
| Number_of_laps: | 30000 |
| Multiplication_factor_for_pipe_axes | 10 |
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| Longitud_extension_of_the_bunch_(+/-N*sigma_z) | 2. |
| Horizontal_tune: | 26.13 |
| Vertical_tune: | 26.18 |
| Horizontal_chromaticity_[Q'x]: | 0. |
| Vertical_chromaticity_[Q'y]: | 0. |
| Flag_for_synchrotron_motion: | 1 |
| Scale_factor_for_electrons_size: | 4 |
| Switch_for_wake_fields: | 1 |
| Switch_for_pipe_geometry_(0->round_1->flat): | 0 |
| Number_of_turns_for_the_wake: | 1 |
| Res_frequency_of_broad_band_resonator_[GHz]: | 1. |
| Transverse_quality_factor: | 1. |
| Transverse_shunt_impedance_[MOhm/m]: | 0. |
| Res_frequency_of_longitudinal_resonator_[MHz]: | 1000. |
| Longitudinal_quality_factor: | 1. |
| Longitudinal_shunt_impedance_[MOhm]: | 0.23 |
| Flag_for_the_tune_spread_(0->no_1->space_charge_2->random): | 0 |
| Flag_for_the_e-field_calc_method_(0->no_1->soft_Gauss_2->PIC): | 0 |
| Magnetic_field_(0->no_1->dipole_2->solenoid_3->combined): | 0 |
| Switch_for_initial_kick: | 0 |
| x-kick_amplitude_at_t=0_[sigmas]: | 0.0 |
| y-kick_amplitude_at_t=0_[sigmas]: | 0.0 |
| Flag_for_the_proton_space_charge: | 0 |
| Flag_for_the_sc-rotation(0->local_centroid_1->bunch_centroid): | 0 |
| Solenoid_field_[T]: | 0. |

Above Transition

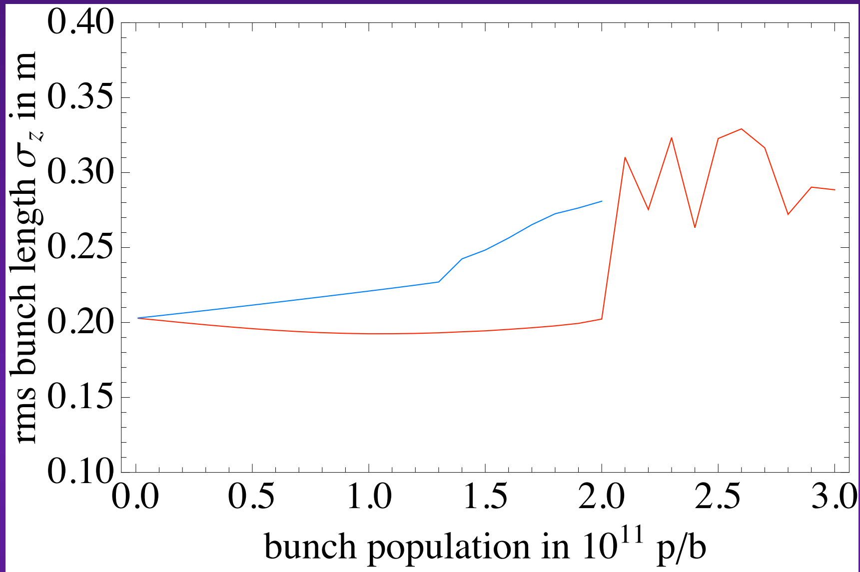
| | |
|---|---|
| Flag_for_the_sc-rotation(0->local_centroid_1->bunch_centroid): | 0 |
| Solenoid_field_[T]: | 0. |
| Switch_for_amplitude_detuning: | 0 |
| Coherent_centroid_motion_(0->off_1->on): | 1 |
| El_distrib_(1->Rect_2->Ellip_3->[1_strp]_4->[2_strp]_5->Parab): | 1 |
| Linear_coupling_switch(1->on_0->off): | 0 |
| Linear_coupling_coefficient_[1/m]: | 0.0015 |
| Average_dispersion_function_in_the_ring_[m]: | 0.0 |
| Position_of_the_stripes_[units_of_sigmax]: | 3.0 |
| Width_of_the_stripes_[units_of_sigmax]: | 0.5 |
| Kick_in_the_longitudinal_direction_[m]: | 0.001 |
| Number_of_turns_between_two_bunch_shape_acquisitions: | 10000 |
| Main_rf_voltage_[V]: | 0.6e+6 |
| Main_rf_harmonic_number: | 4620 |
| Initial_2nd_rf_voltage_[V]: | 0. |
| Final_2nd_rf_cavity_voltage_[V]: | 0.7e+6 |
| Harmonic_number_of_2nd_rf: | 18480 |
| Relative_phase_between_cavities: | 0. |
| Start_turn_for_2nd_rf_ramp: | 30000 |
| End_turn_for_2nd_rf_ramp: | 40000 |
| Sextupolar_kick_switch(1->on_0->off): | 0 |
| Sextupole_strength_[1/m^2]: | -0.254564 |
| Dispersion_at_the_sextupoles_[m]: | 2.24 |
| Switch_for_losses_(0->no_losses_1->losses): | 0 |
| Second_order_horizontal_chromaticity_(Qx''): | 0. |
| Second_order_vertical_chromaticity_(Qy''): | 0. |
| Switch_for_boundary_conditions(0->open_space_1->rect_box): | 1 |
| Switch_for_random_phase_advance(0->no_1->yes): | 0 |
| Switch_for_e-cooler(0->no_e-cooler_1->tuned_e-cooler): | 0 |
| Length_of_the_e-cooler_[m]: | 3. |
| Switch_for_the_damper: | 0 |
| Damper_x_gain: | 0.1 |
| Damper_x_noise_amplitude: | 1e-5 |
| Damper_y_gain: | 0.1 |
| Damper_y_noise_amplitude: | 1e-5 |
| Conductivity_of_the_resistive_wall_[1/Ohm/m]: | 1.e6 |
| Length_of_the_resistive_wall_[m]: | 0. |
| Switch_for_beta: | 0 |
| Switch_for_wake_table: | 0 |
| Linear_Rate_of_Change_of_Momentum_[GeV/c/sec]: | 0. |
| Second_Order_Momentum_Compaction_Factor: | 0. |

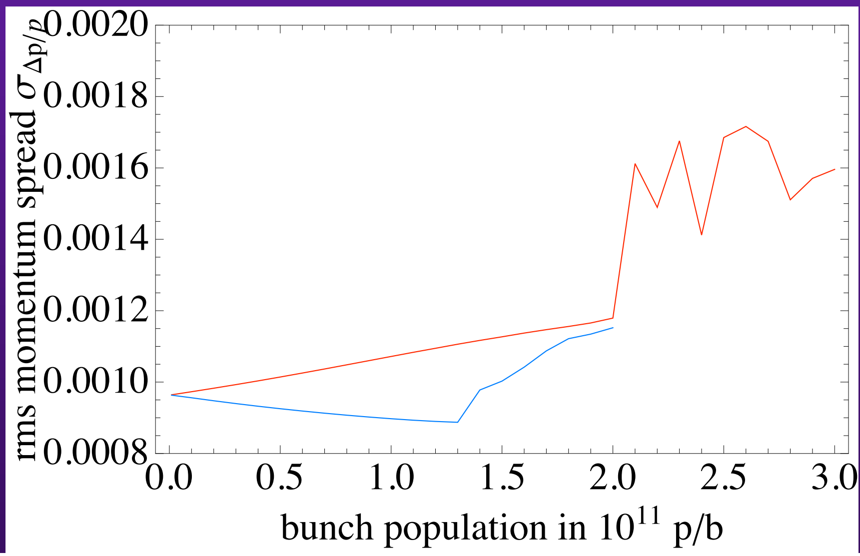
# SPS bunch interacting with a resonator impedance (Q = 1, fr = 1 GHz and $Z_l/n$ = 10 Ω), changing the transition energy to go from AT to BT

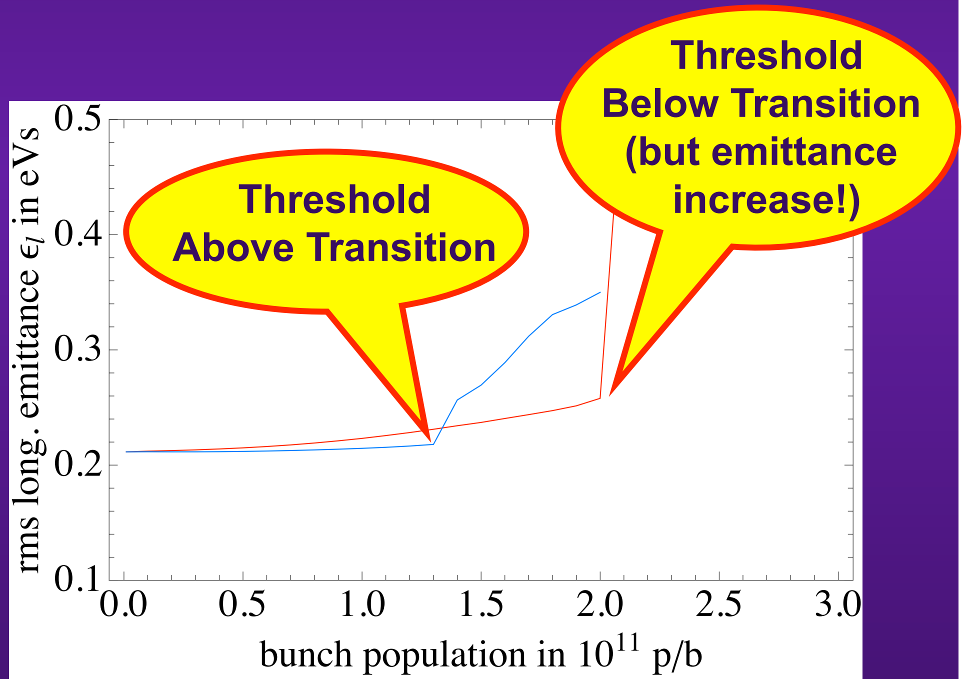
$$|\eta|_{BT} = |\eta|_{AT} = 6.2 \times 10^{-4}$$

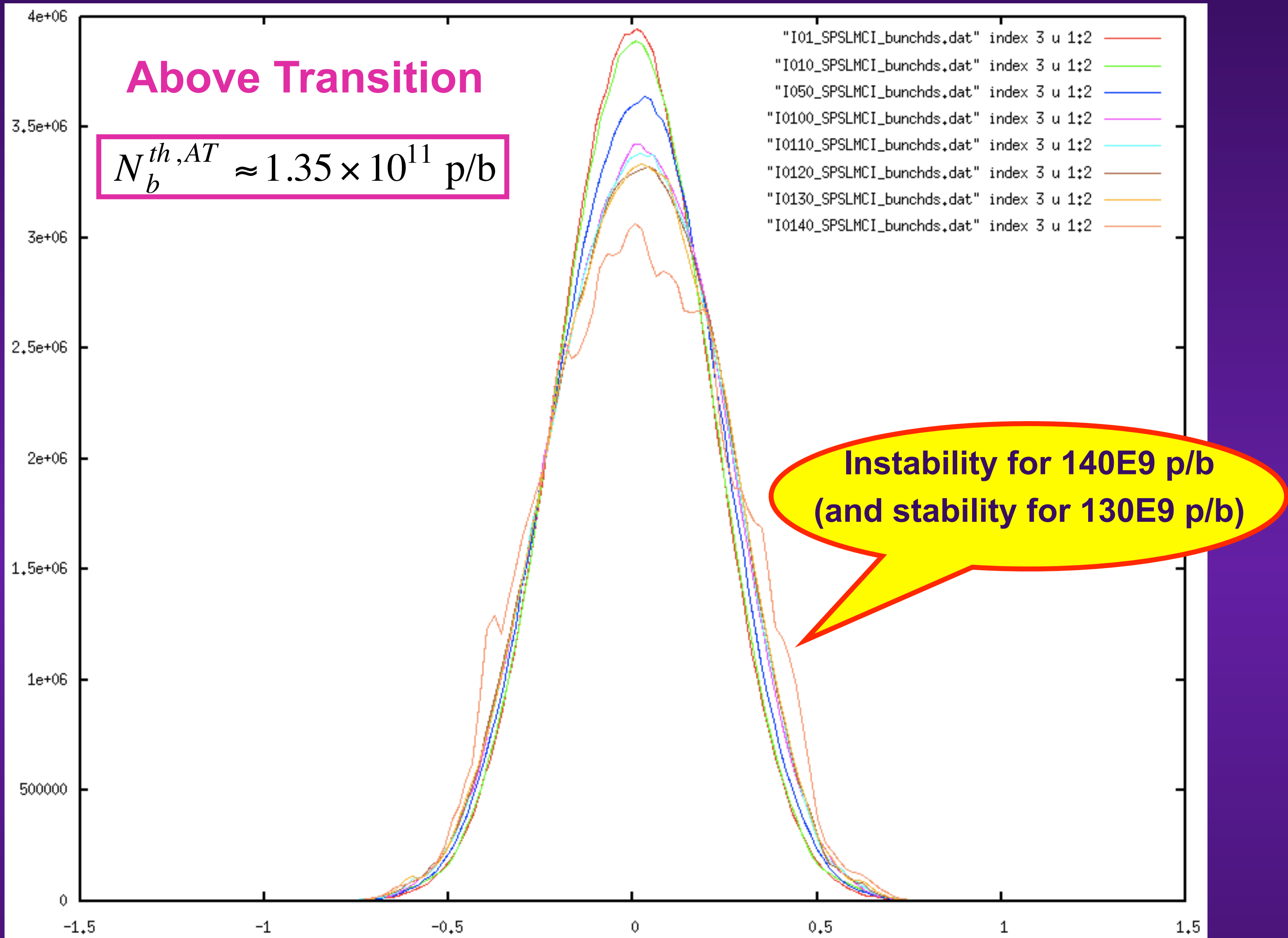
$$\alpha_{p,AT} = 0.00192$$

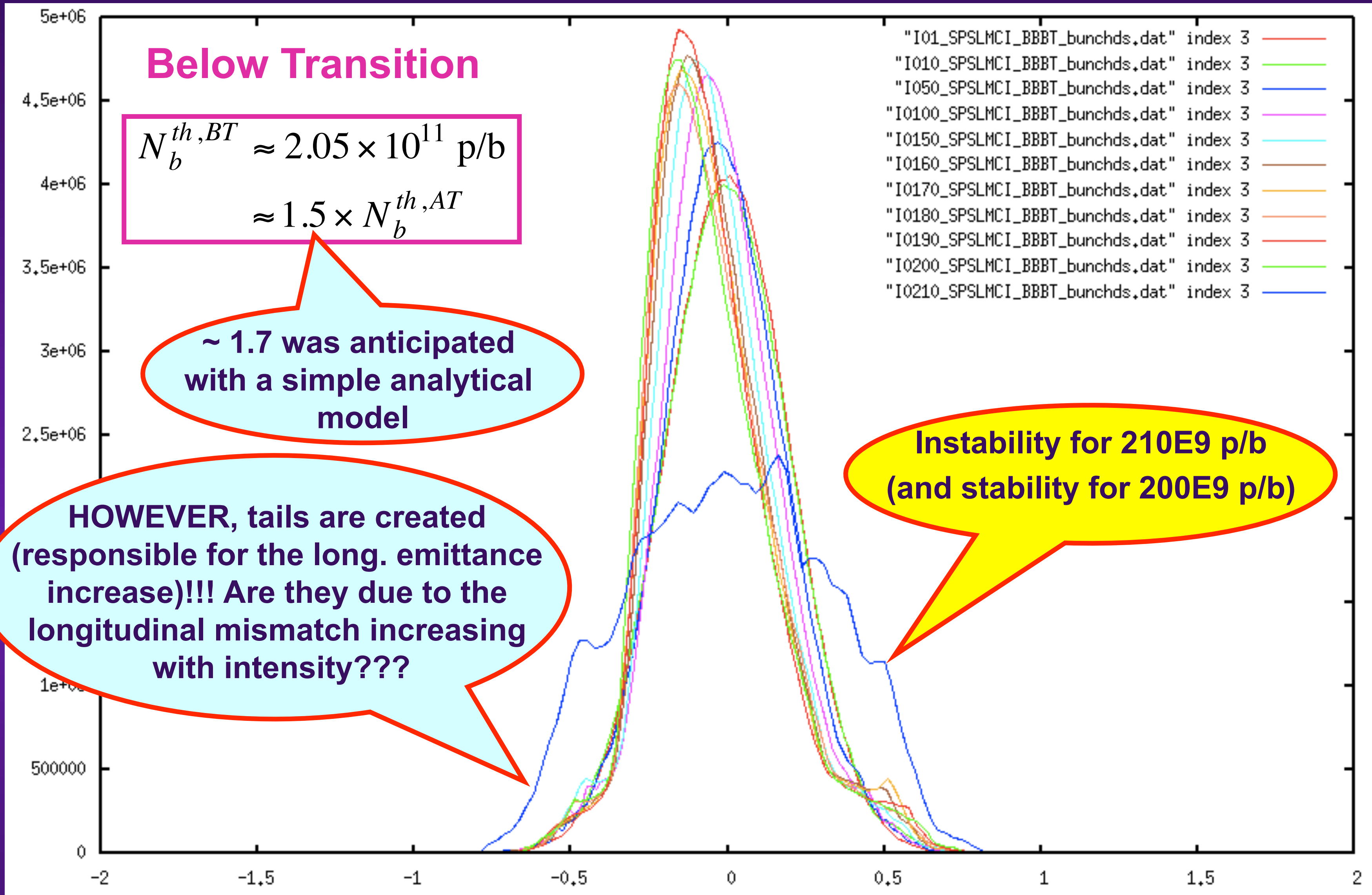
$$\alpha_{p,BT} = 0.00068$$



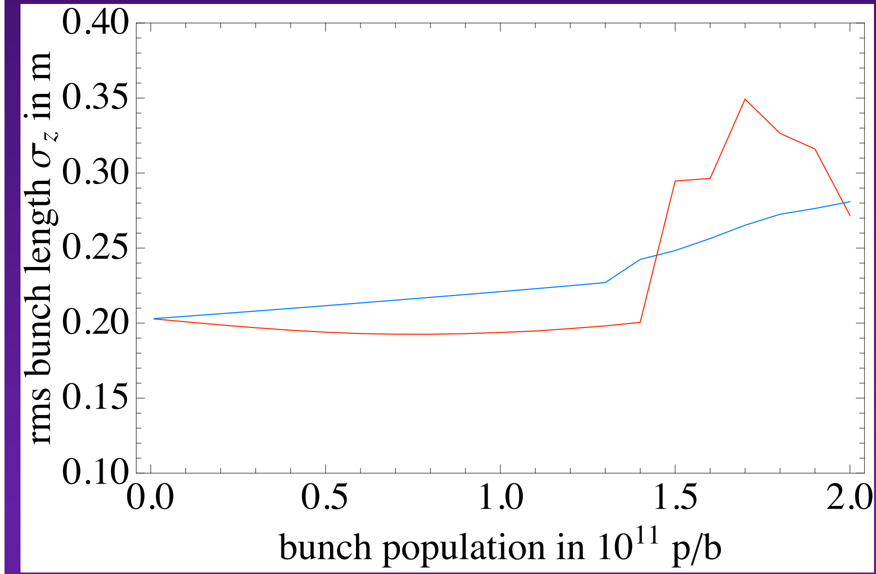




Above Transition
$N_b^{th,AT} \approx 1.35 \times 10^{11}$ p/b
Instability for 140E9 p/b
(and stability for 130E9 p/b)
"I01_SPSLMCI_bunchds.dat" index 3 u 1:2
"I010_SPSLMCI_bunchds.dat" index 3 u 1:2
"I050_SPSLMCI_bunchds.dat" index 3 u 1:2
"I0100_SPSLMCI_bunchds.dat" index 3 u 1:2
"I0110_SPSLMCI_bunchds.dat" index 3 u 1:2
"I0120_SPSLMCI_bunchds.dat" index 3 u 1:2
"I0130_SPSLMCI_bunchds.dat" index 3 u 1:2
"I0140_SPSLMCI_bunchds.dat" index 3 u 1:2
4e+06
3.5e+06
3e+06
2.5e+06
2e+06
1.5e+06
1e+06
500000
0
-1.5
-1
-0.5
0
0.5
1
1.5



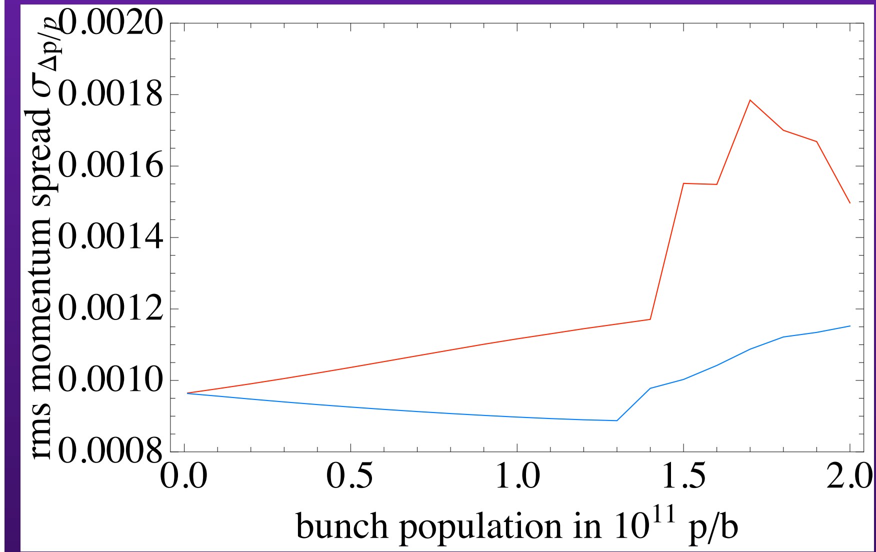

**In fact, looking at the evolution of the longitudinal distribution, it seems as if the core of the bunch is shortening but not the tails**

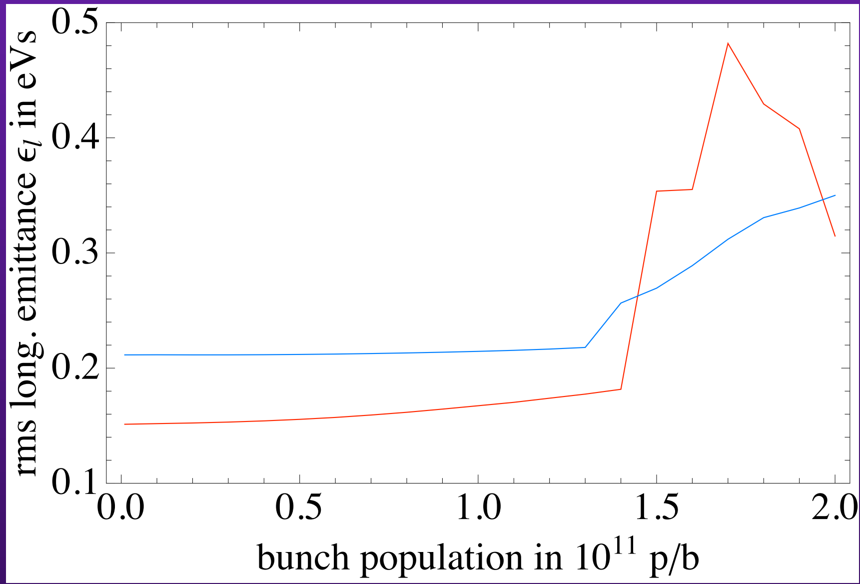
## 2nd case studied: Keep the same transition energy, bunch length and momentum spread




Value to be entered in HEADTAIL:

$$R_l = \frac{Z_l}{n} \times \frac{f_r}{f_0} = 0.23\ \mathrm{M\Omega}$$



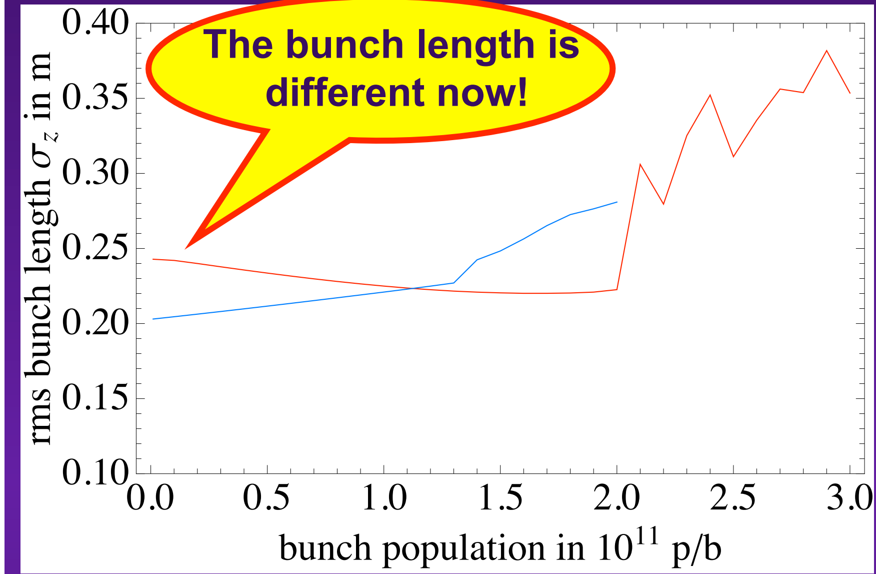



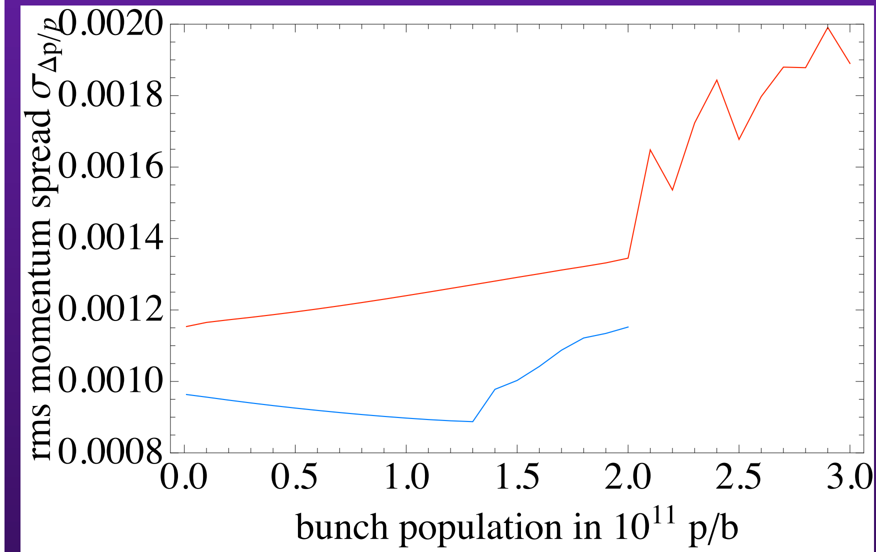
# $3^{rd}$ case studied: Keep the same transition energy but with correct momentum spread BT

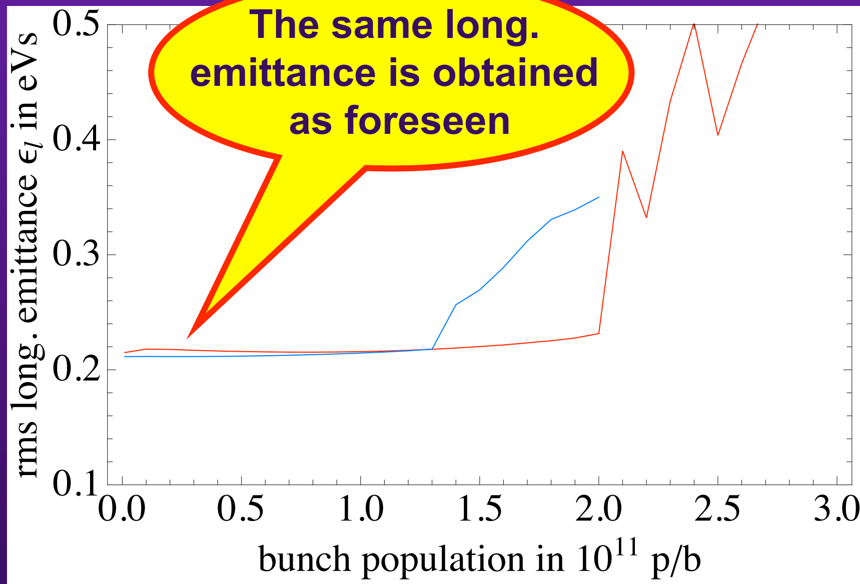
$$\left(\frac{\sigma_p}{p}\right)_{BT} = 0.00130$$

**instead of** $$\left(\frac{\sigma_p}{p}\right)_{AT} = 0.00093$$

$$\left(\frac{\sigma_p}{p}\right)_{BT} = \left(\frac{\sigma_p}{p}\right)_{AT} \times \frac{E_{t,AT}}{E_{t,BT}} \times \left(\frac{\beta_{AT}}{\beta_{BT}}\right)^2$$



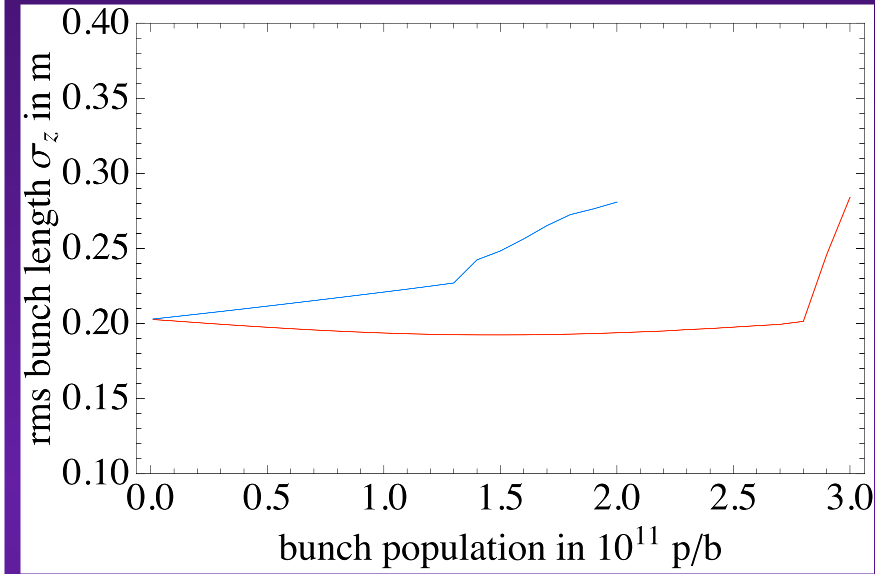
## 4th case studied: Keep the same transition energy but with correct momentum spread and bunch length BT

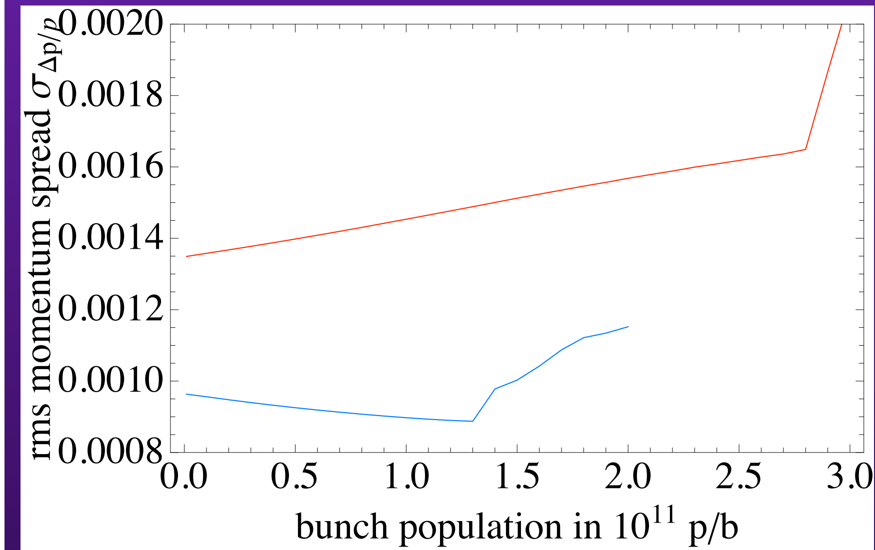
$$|\eta|_{BT} = |\eta|_{AT} = 6.2 \times 10^{-4}$$

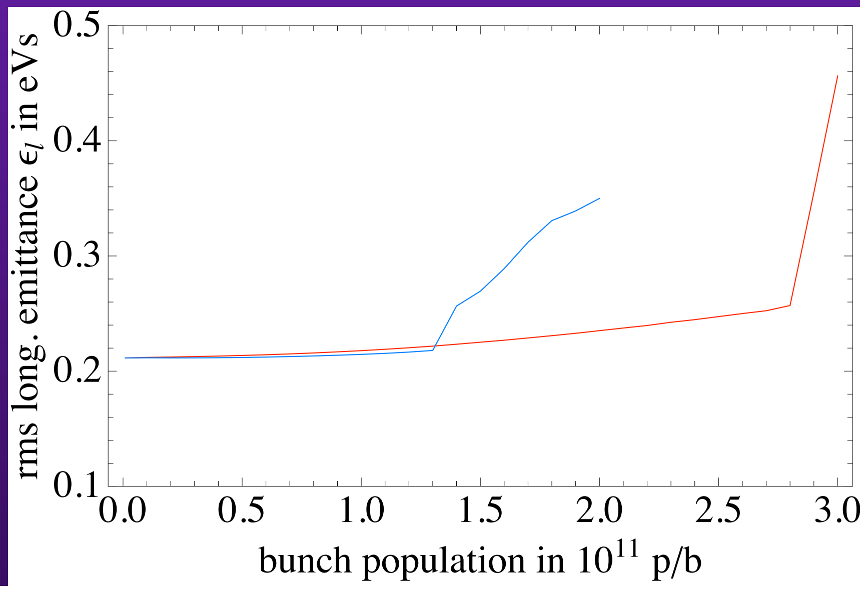
**A longitudinal re-matching is needed**

$$\omega_s = 2\,|\eta| \left( \frac{\Delta p}{p_0} \right)_{max} / \tau_b$$

$$Q_{s,BT} = Q_{s,AT} \times \frac{\left(\sigma_p / p\right)_{BT}}{\left(\sigma_p / p\right)_{AT}} = 0.00324 \times 1.4 = 0.00454$$



# CONCLUSIONS AND NEXT STEPS

- **The simulation case corresponding to the theoretical prediction is the 1st one (Case AT and BT obtained by changing the transition energy => In this case, the low-intensity bunch length, momentum spread and longitudinal emittance are the same)**

  - **The prediction of a higher intensity threshold below transition is confirmed (factor ~ 1.5 compared to ~ 1.7 estimated) assuming a BB impedance alone**

  - **Issue with the increase of the longitudinal emittance BT?**

  - **In HEADTAIL, there is a switch to have the sinusoidal (i.e. nonlinear) bucket with space charge, but no linear force with space charge => Should be implemented to continue the analysis with SC**