# NEW LONGITUDINAL BEAM DYNAMICS CODE

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## ♦ Abstract

PyLongitudinal is a new multi-particle tracking code able to simulate longitudinal beam dynamics in synchrotrons; it is written in Python by several CERN developers and currently the version 1.2.3. is available. It is a part of a project called PyHeadtail in which the idea is to create one bigger code that can be used for both longitudinal and transverse tracking. Indeed in the future there should be a merge with the transverse code. This paper presents the main features of PyLongitudinal and shows an example of its utilization for comparison of the current RF cavities in the CERN PS Booster with the new Finemet cavities from a beam stability point of view.

## ♦ The code main features

PyLongitudinal is written in the interpreted scientific language Python to avoid the use of compiled languages that, even if faster, are less intuitive and immediate; on the other hand there exist useful plugins that allow to import C and Fortran code into Python to eliminate bottlenecks.

**CODE FEATURES IN BRIEF:**

1) Different initial distributions not matched and matched with intensity effects.
2) Modularised tracking in phase space via discrete maps [1].
3) Several plot methods and saving of the beam statistics and data.
4) Beam acceleration through a momentum program.
5) Multi-section and multi-system cases.
6) Collective effects in time and frequency domain.
7) Generation of RF noise from noise spectrum.
8) Code optimisation (precalculation, h5 files, cython, beta version of tracking module parallelised).
9) Capability of merging easily with the transverse branch.
10) Easiness of utilisation thanks to an easy structure of the main_file.

## ♦ Code diagram

**Input**

- ❑ Beam properties
- ❑ Machine properties
- ❑ Number and properties of cavity sections and systems
- ❑ Loading of impedances
- ❑ Initial beam distribution

**Tracking**

```
for number_of_turns in range (1,n):
    map = induced_voltage + tracker + slicing
          + bunch_saving_data
    for i in map:
        i.track(my_beam)
```

**Output**

- ❑ Plot of particles in phase-space, of bunch length and mean position in function of time, of induced voltages, spectrum and impedances
- ❑ Saving of bunch statistics and profiles in table files

## ♦ Useful links

The code can be found on GitHub at the following address:
**https://github.com/like2000/PyHEADTAIL/tree/PYlongitudinal**
One can look at the code documentation here:
**http://like2000.github.io/PyHEADTAIL**

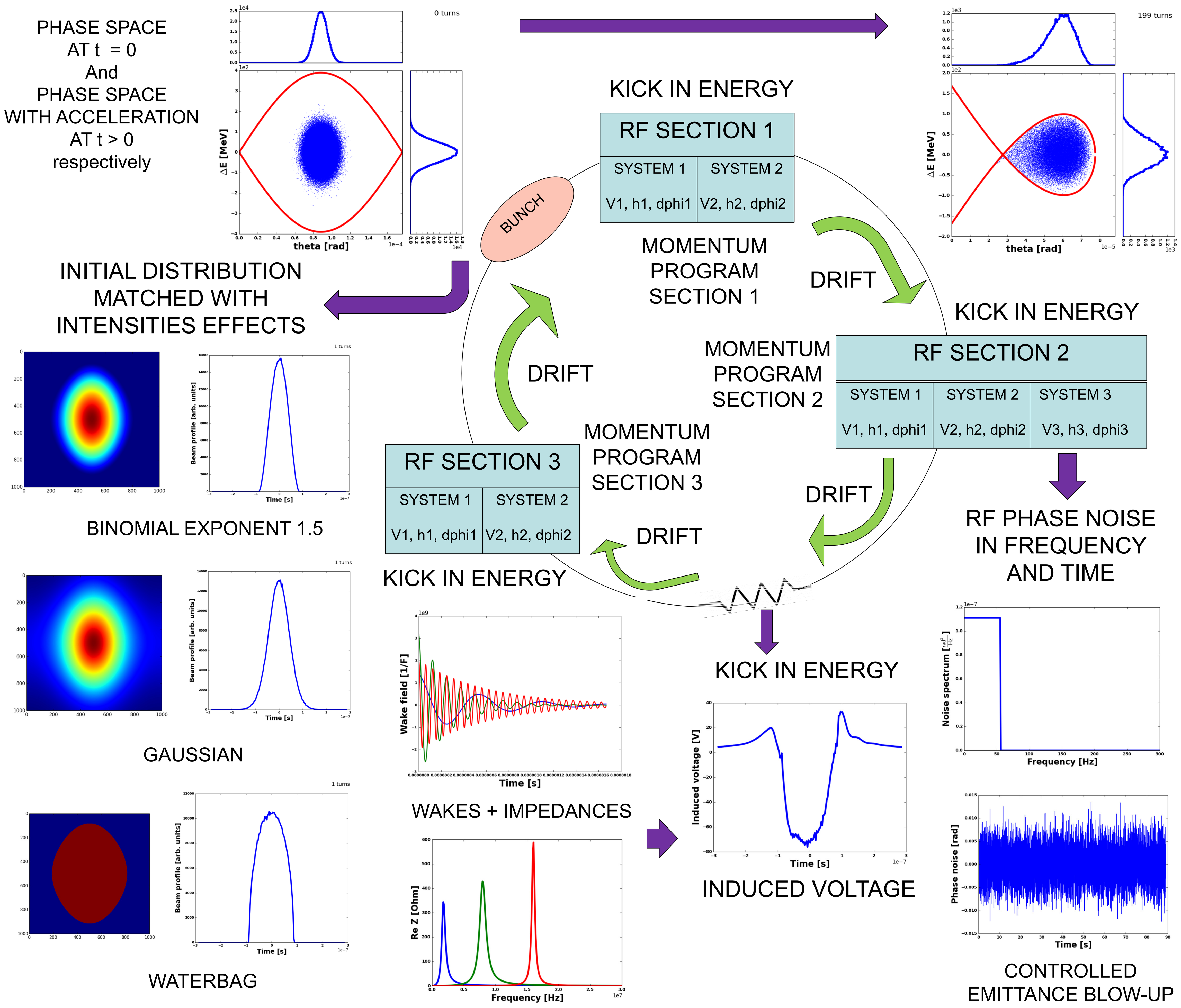
## ♦ Acknowledgements

I would like to thank, in addition to the coauthors of this paper, K. Shing Bruce Li and his ABP colleagues at CERN for having put the first seed for this project some months ago and for the numerous precious discussions held since then which have helped significantly to develop the code. I would like also to thank my CERN colleagues working for the PSB who gave me kind assistance during the acquisition of all the data required for my simulations.

## ♦ References

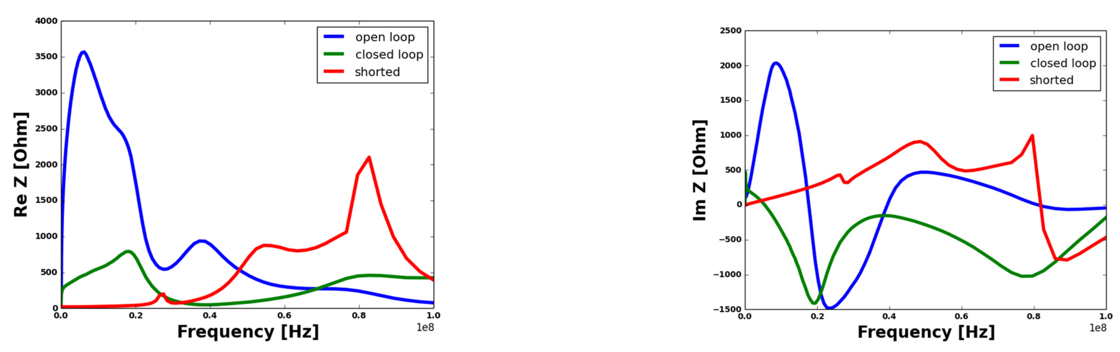
[1] J.A. MacLachlan, "Difference equations for longitudinal motion in a synchrotron", FN-529, 1989.
[2] M. Paoluzzi, C. Zannini, private communications.
[3] S. Hancock, M. Lindroos, S. Koscielniak: Longitudinal phase space tomography with space charge, , Physical review, 2000.

## ♦ Example of model adopted and code capabilities




## ♦ Effects of the new Finemet cavities in the PS Booster

- Simulations aimed at finding intensity stability thresholds at injection and extraction for the standard LHC25ns beam in presence of the new Finemet loaded wideband cavities.
- The new cavities can be used without feedback (open loop), with feedback (closed loop) or when the gap relay is activated (shorted). The relative three impedance tables have been loaded together with other tables concerning the resistive wall, kickers, ejection kicker cables and steps [2].

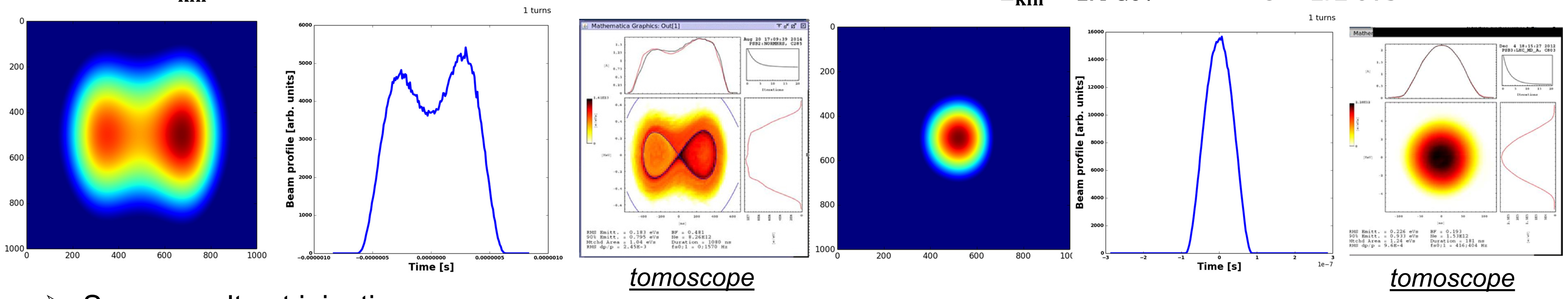



- In addition the space charge has been taken into account making use of the following formula ($Z_0$ = 377 Ω)

$$\frac{Z}{n} = \frac{g\, Z_0}{2\,\beta\,\gamma^2} = \frac{Z_0}{\beta\,\gamma^2}\left\{0.9 + \frac{1}{2}\ln\frac{\beta\,\gamma}{\beta\,\gamma(100\ \mathrm{MeV})}\right\} \qquad \text{since} \qquad g(100\ \mathrm{MeV}) = 1.8 \quad [3].$$

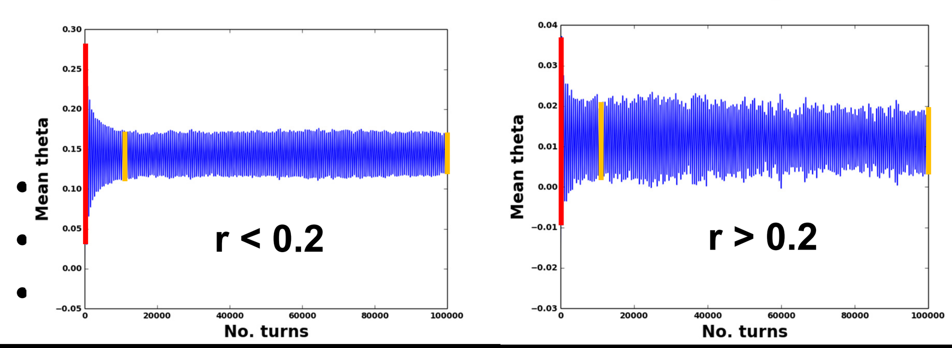
- Initial distributions matched quite well with the images given by the tomoscope at injection and extraction

$E_{kin} = 0.05$ GeV   $\varepsilon = 1.0$ eVs   $E_{kin} = 1.4$ GeV   $\varepsilon = 1.2$ eVs




*tomoscope*   *tomoscope*

- Some results at injection:
  - At injection the intensity threshold is greater than $2e^{12}$ for the three cases open loop, closed loop and shorted.
  - The current intensity used for the LHC25ns (Post-LS1) at injection is $1.9e^{12}$.
  - The ratio **r** between 2σ of the average of mean theta when the beam stabilizes (between the two orange lines) and the distance between the projections on the y axis of the first two peaks (red line) should not be over 20%: an horizontal kick of one degree in phase space has been applied to the particles to verify the presence of the Landau damping effect.




## ♦ Conclusions

A new code for longitudinal beam dynamics with high developing potential has been presented: it has a lot of features and developers and in the future these will increase in number together with a particular attention to optimisation. In addition an application of the code use to simulate the PS Booster dynamics with the new Finemet cavities has been shown.