Accelerating the World's Largest Accelerators

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CERN

At CERN – European Organization for Nuclear Research – scientists are probing the fundamental structure of the universe. Using the world's largest and most powerful particle accelerators as well the most complex and precise detectors, physicists study the fundamental particle and their interactions.

Accelerator Complex and LHC

The accelerator complex at CERN is a succession of machines that accelerate beams of particles (mainly protons) to increasingly higher energies, before injecting them into the next machine.
The Large Hadron Collider (LHC) is the last machine in this chain and can accelerate particle beams up to a record energy of 6.5 TeV. The beams are then transferred to two oppositely circulating beam pipes and finally collide inside four detectors – ALICE, ATLAS, CMS and LHCb.

The Beam Longitudinal Dynamics simulator [1] is a unique code developed at CERN to model beam motion in synchrotrons. Important upgrades of beam parameters are based on BLonD simulations. The code is modular and each simulation is composed via pipelining of multiple physics modules. The code is written in Python with C/C++ extensions for the computational kernels.
BLonD is an open-source project [2] with more than 10 contributors and numerous users. Some of the most important conclusions that have been made using BLonD can be found in the literature[3][4][5].

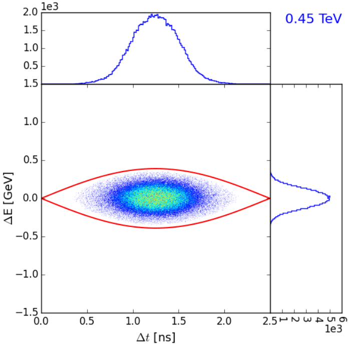
[1] http://blond.web.cerh.ch

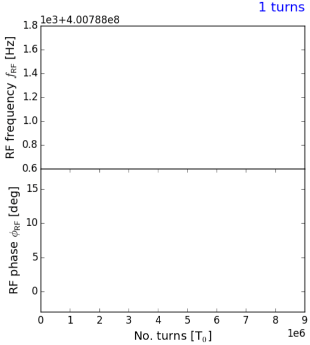
[2] https://github.com/blond-admin/BLonD

[3] Helga Timko et al. "Studies on Controlled RF Noise for the LHC". In: *54th ICFA Advanced Beam Dynamics Workshop on High-Intensity, High Brightness and High Power Hadron beams, East-Lansing, USA* (2015).

[4] Helga Timko et al. "Benchmarking the Beam Longitudinal Dynamics Code BLonD". In: *7th International Particle Accelerator Conference, Busan, Korea* (2016).

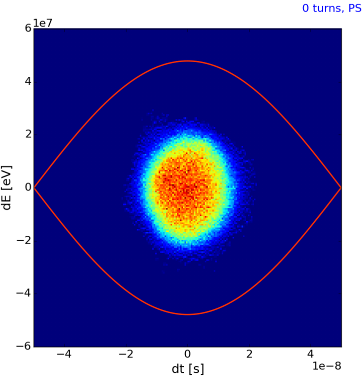
[5] Alexandre Lasheen et al. "Synchrotron frequency shift as a probe of the CERN SPS reactive impedance". In: *54th ICFA Advanced Beam Dynamics Workshop on High-Intensity, High Brightness and High Power Hadron beams, East-Lansing, USA* (2015).





LHC BLow-Up

In the LHC, maintaining a constant stability threshold requires an increase of the longitudinal emittance as the square-root of energy. This is done by RF phase noise injection that targets the bunch core. A feedback on the noise amplitude maintains a constant FWHM bunch length.

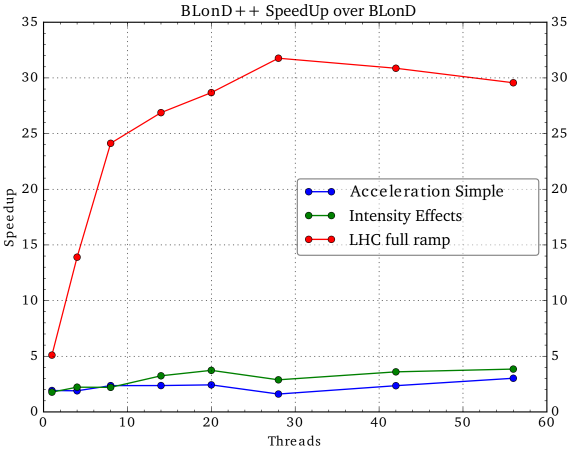


PS-to-SPS Transfer

In the PS, the LHC-type 25ns beam is created through a series of RF manipulations. After the injection of 4+2 bunches from the PSB, a triple splitting is performed and the bunches are accelerated. At flat top, each bunch is twice split in two, resulting in 72 bunches. Finally, an adiabatic bunch shortening and a bunch rotation provide bunches that are short enough to be injected into the 200 MHz buckets of the SPS.

BLonD++

BLonD++ [6] is the C++ version of BLonD. It features openMP multi-threading and auto-vectorization friendly computational kernels. BLonD++ has been proved to perform particularly faster than BLonD on time-consuming, complex simulations.



Three applications with different levels of complexity. The top Speed-Up achieved in the two less complex applications is up to 3X and 4X respectively. However, the results are different in the most complex case, demonstrating a maximum Speed-Up of 32X.

[6] https://github.com/blond-admin/BLonD-cpp

Motivation

The present CERN computing infrastructure is composed of heterogeneous general purpose CPUs (mainly Intel Xeons). The complexity of physics problems that can me modelled is restricted due to runtime limitations. A dedicated computer architecture is necessary to meet the continuously growing computational needs in the field of longitudinal beam dynamics.

Ongoing Work

Existing high-performance CERN infrastructures and software methods are being explored for their suitability to address performance and scalability issues of BLonD simulations. The interaction between different modules is investigated in detail.

Future Studies

Eventually, combinations of CPUs and accelerators, including Xeon Phis, GPUs and FPGAs, will be evaluated. Ideally, the outcome of the thesis will be a concrete proposal for an HPC system to serve the longitudinal beam dynamics studies.

Thank you all for your attention!