Accelerating the World's Largest Accelerators

International HPC Summer School on HPC Challenges in Computational Sciences, Boulder, Colorado US

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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 particles and their interactions.

Accelerator Complex and LHC

The accelerator complex at CERN is a succession of machines that accelerate beams of particles 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 into 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 of a pipeline of different physics modules. It 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 drawn using BLonD can be found in the literature[3,4,5].

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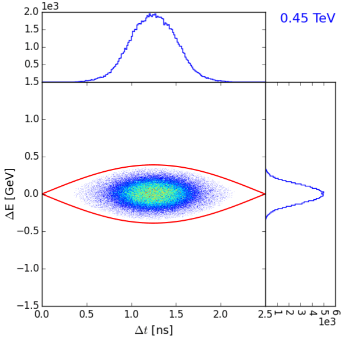
[1] http://blond.web.cerh.ch

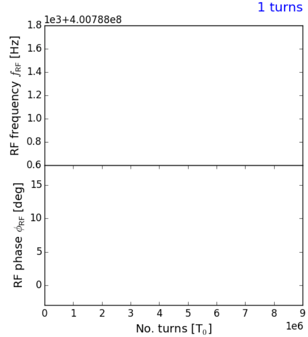
[2] https://github.com/blond-admin/BLonD

[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).

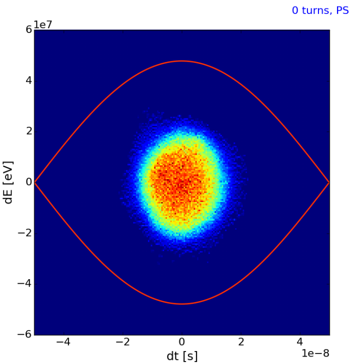
[5] Alexandre Lasheen et al. "Synchrotron frequency shift as a probe of the CERN SPS reactive impedance". In: *54th ICFA Advanced Beam Dynamics Workshop on High-Intensity, High Brightness and High Power Hadron beams, East-Lansing, USA* (2015).





LHC controlled longitudinal emittance Blow-Up

An RF noise injection targeting the bunch core maintains a constant stability threshold by increasing the emittance as the sqrt of energy. A feedback on the noise amplitude keeps constant FWHM bunch length.

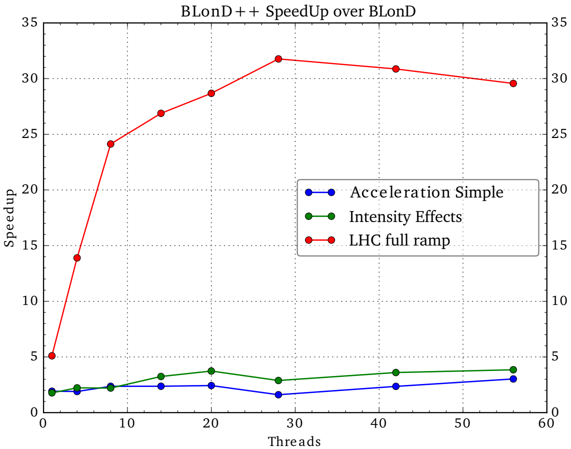


PS-to-SPS Transfer

In the PS, the LHC-type 25ns beam is created through 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.



Each line corresponds to a test-case of different complexity level. The top Speed-Up achieved in the two less complex test-cases is up to 3.0X and 3.9X respectively. However, the results are different in the most complex case, demonstrating a maximum Speed-Up of 31.8X.

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

Motivation

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

Ongoing Work

Existing high-performance CERN infrastructure 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!