High Performance Simulation of Beam-Beam and Electron Cloud Effects for LHC Upgrades Using a Self-Consistent Model

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Motivations

High Energy Collider Needs Large Luminosity for Physics Study

- The probability of event is proportional to the luminosity of colliding beams.
- Luminosity depends on:

$$L = f_b \left(\frac{4\pi\gamma_p\gamma_e}{r_p r_e} \right) (\xi_p \xi_e)(\sigma'_p \sigma'_e) \frac{e^{-\frac{d_x^2}{4\sigma_x^2}}}{\sqrt{1+\zeta^2}}$$

$$\xi_p = \frac{r_p \beta^*_p}{4\pi\gamma_p} \frac{N_e}{\sigma_e^2} \qquad \xi_e = \frac{r_e \beta^*_e}{4\pi\gamma_e} \frac{N_p}{\sigma_p^2} \qquad \zeta = \frac{\phi}{2} \frac{\sigma_s}{\sigma_x}$$

- Larger luminosity wants higher repetition rate, larger beam-beam parameters, smaller crossing angle and beam separation.
- However, beam-beam effects limit these factors and eventually luminosity.

High Performance Computer Simulation Is Needed:

❖ High Luminosity LHC upgrade Requires:

- higher bunch intensity
- smaller beta*
- smaller emittance
- larger crossing angle

-> stronger beam-beam effects

❖ E.g. Crab cavity will be a critical component in HL-LHC for crossing angle compensation.

– what are the effects of crab cavity on the colliding beams?

❖ Simulation provides an important way for risk reduction and performance optimization in hardware upgrade.

Proposed Study Plan

Beam-Beam Effects

- beam-beam interaction in the presence of noise and modulation
  - crab cavity noise effects
  - HOM in crab cavity
  - conducting wire + others
  - benchmark with MDs at LHC and SPS
- beam-beam interaction in the presence of impedance
  - crab cavity impedance
  - other machine impedance
- beam-beam interaction with electron lens compensation
  - long range + head-on
- beam-beam interaction in the presence of misaligned hollow beam
- beam-beam interaction with none-round beam
- beam-beam interaction with crab waist compensation

Electron Cloud Effects

- Electron cloud build up with 25ns bunch train in LHC
- Beam instability due to electron cloud
- e-cloud build-up and effect on beam simulated concurrently on trains of bunches
- Code benchmark

Warp-Posinst enables direct simulation of a train of 3x72 bunches

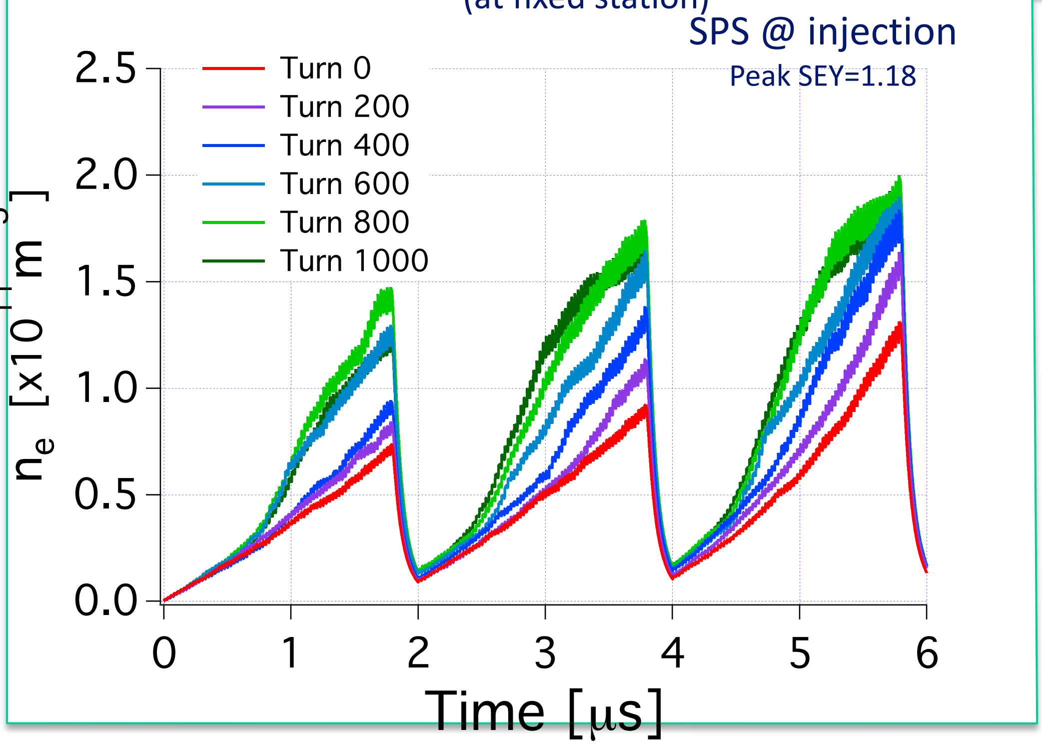
-- using 9,600 cores on Franklin CRAY supercomputer (NERSC)

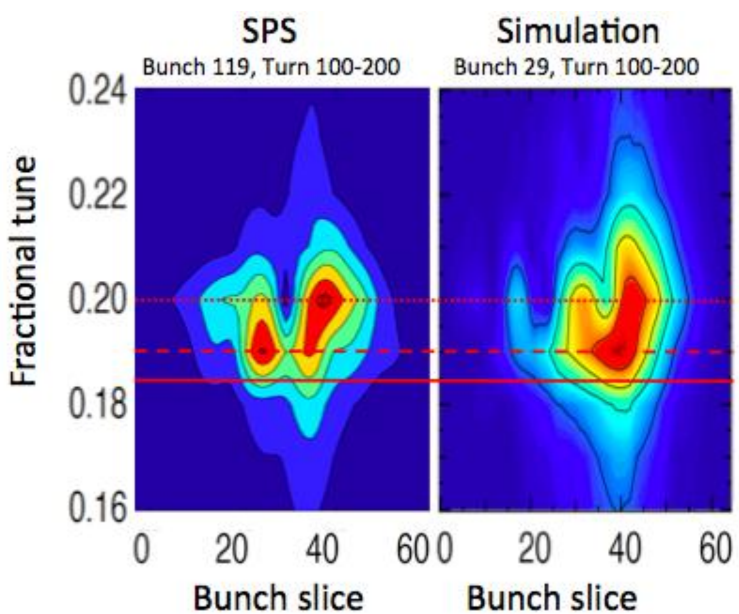
Uniquely fully self-consistent (e- buildup + effects on bunches) simulations reveal:

- large density rise up to turn 800
- multi-bunch coupling by e-cloud

Average e-cloud density history

(at fixed station)





➔ multi-physics integrated simulations are key for detailed physics understanding and high-fidelity predictions.

J.-L. Vay, et al, *IPAC12 Proc.*, (2012) TUEPPB006

Available High Performance Computing Tools

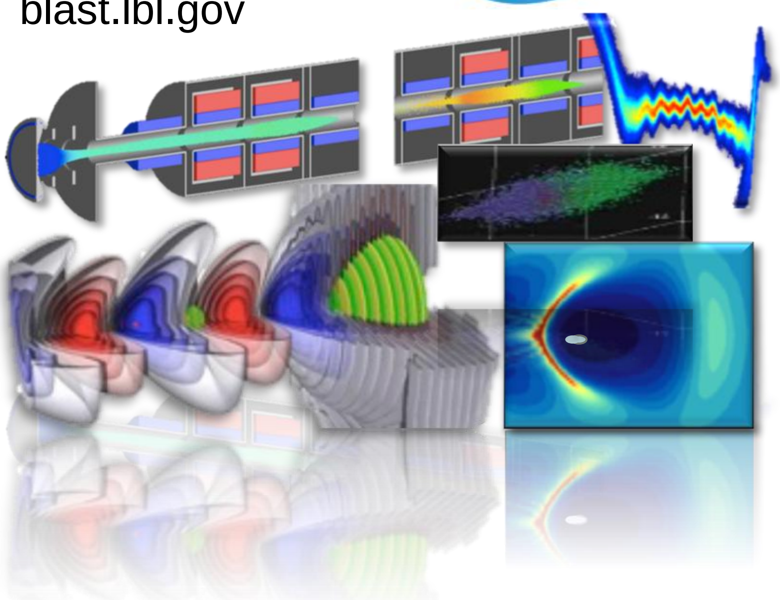
Berkeley Lab Accelerator Simulation Toolkit

blends LBNL experience in accelerators & *HPC*

BLAST

BERKELEY LAB ACCELERATOR SIMULATION TOOLKIT

blast.lbl.gov



State-of-the-art open source codes:

BEAMBEAM3D, IMPACT, POSINST, WARP.

Supporting many accelerators:

- across DOE (HEP, BES, NP, FES, DNN) and abroad (CERN, DESY, KEK, …).

Large set of physics & components:

- beams, plasmas, lasers, structures, etc *in* linacs, rings, injectors, traps, …

High-Performance Computing (HPC):

- multi-level optimizations & simulations on tens of thousands of cores

From physics studies to start-to-end self-consistent designs.

Benefits to the US Accelerator Program

- Direct contribution to the success of the LHC upgrades and future colliders
- Preservation of the expertise in accelerator colliders for future high energy physics and nuclear physics studies
- Improvement of advanced computational method on large-scale high performance supercomputers
- Test of exascale computing with real applications

Budget Request: $250k/year