Compensation of Beam-Beam effects in the Tevatron and LHC

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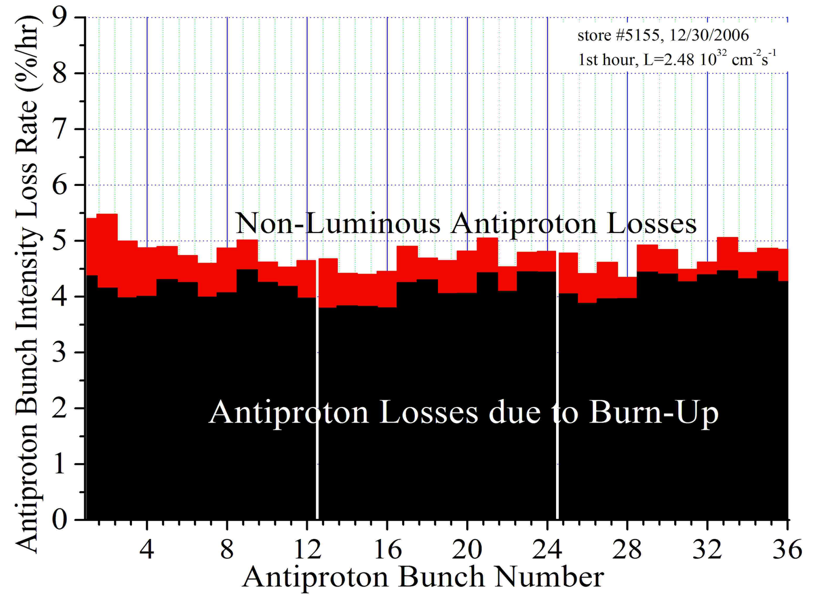
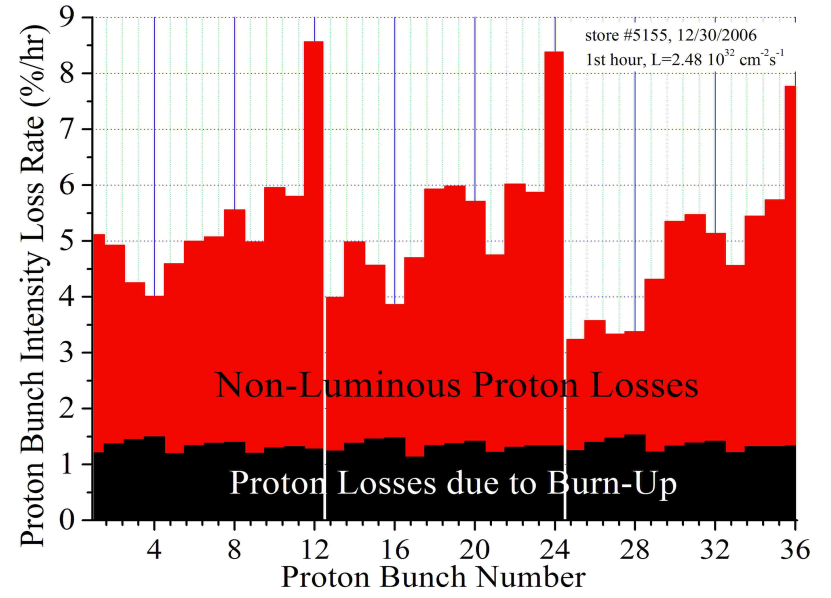
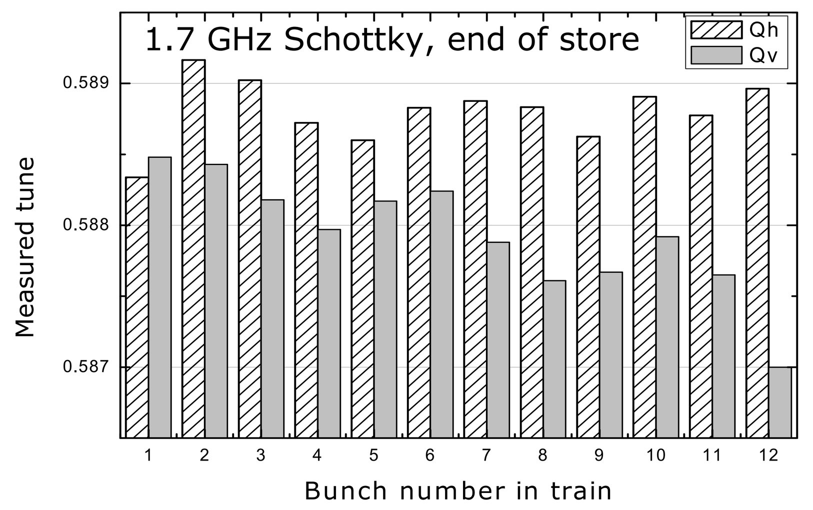
Abstract

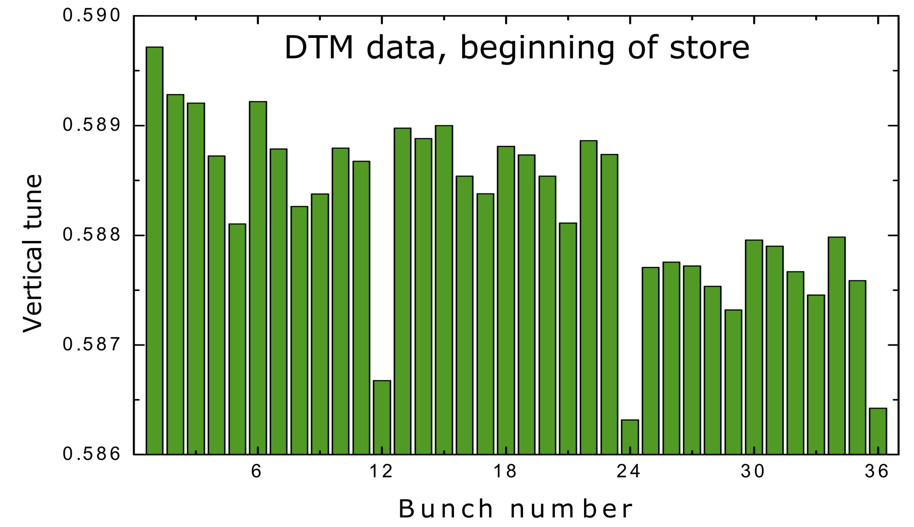
Two devices have been proposed to compensate beam-beam effects in hadron colliders: the Electron Lenses and the Wire Compensators. Initially the Tevatron Electron Lenses (TELs) were intended for compensation of long range and head-on beam-beam effects on the antiproton beam. Due to recent brightness increase of the antiproton beam, it is the proton beam now that suffers most from the beam-beam effects. We present results of beam studies with TELs, compare them with the results of computer simulations using LIFETRAC code and discuss possibilities of further improvements of the beam-beam Compensation efficiency in the Tevatron. The current carrying wires are intended to compensate long-range beam-beam effects and are being developed for the LHC. To demonstrate beam-beam compensation by wires experimentally and to test the computer models two wires were installed in RHIC. We present the results of computer simulations and compare them with experimental data.

Tevatron - why beam-beam compensation on protons





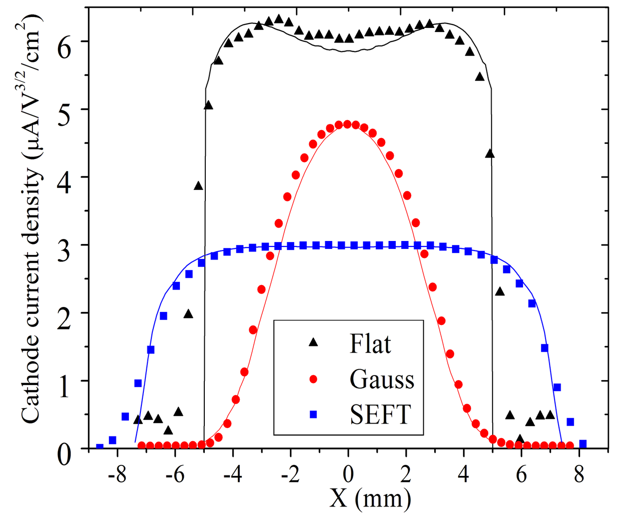


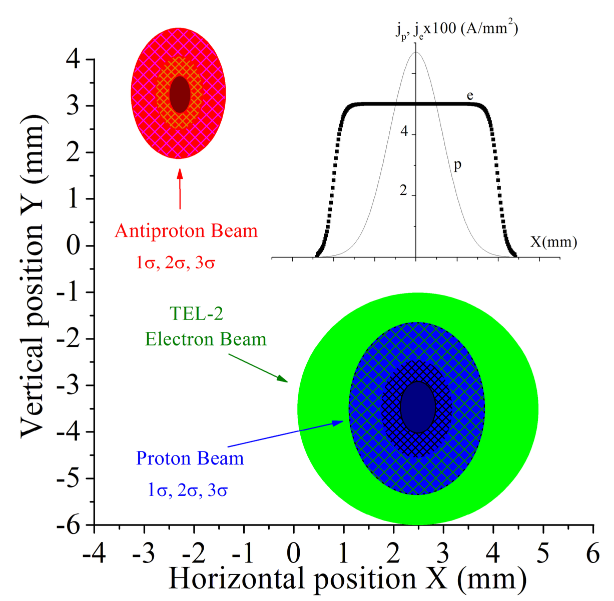


Electron lenses

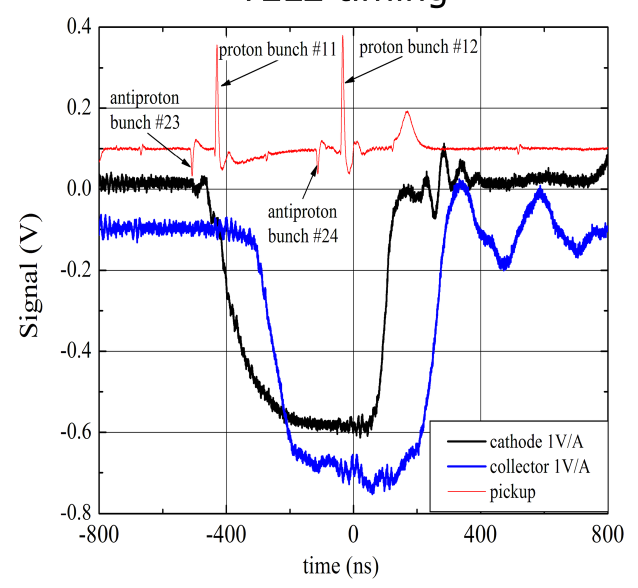
Transverse alignment of all three beams

SEFT distribution is currently used

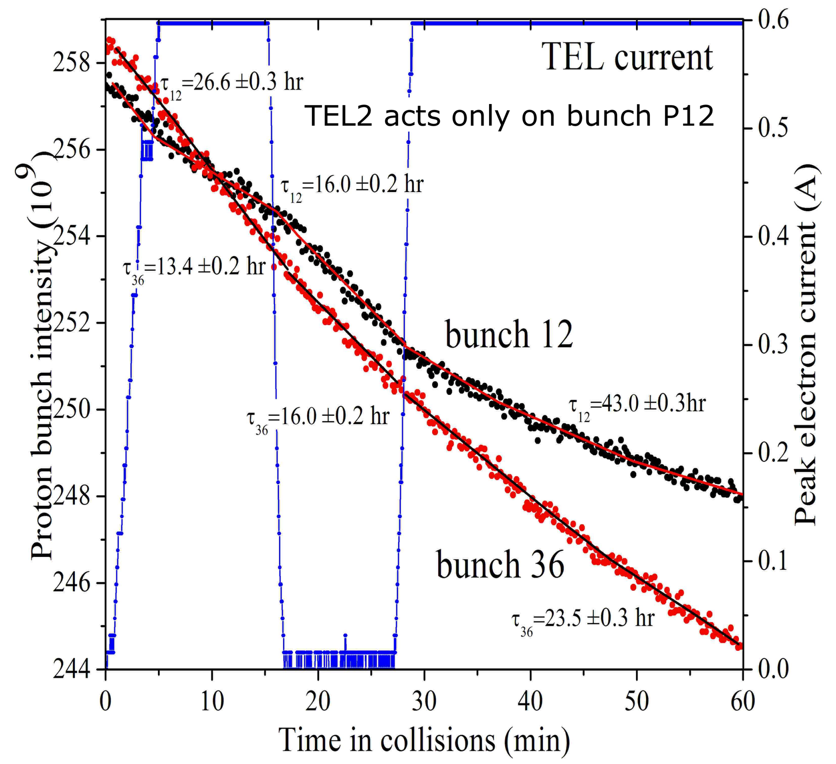


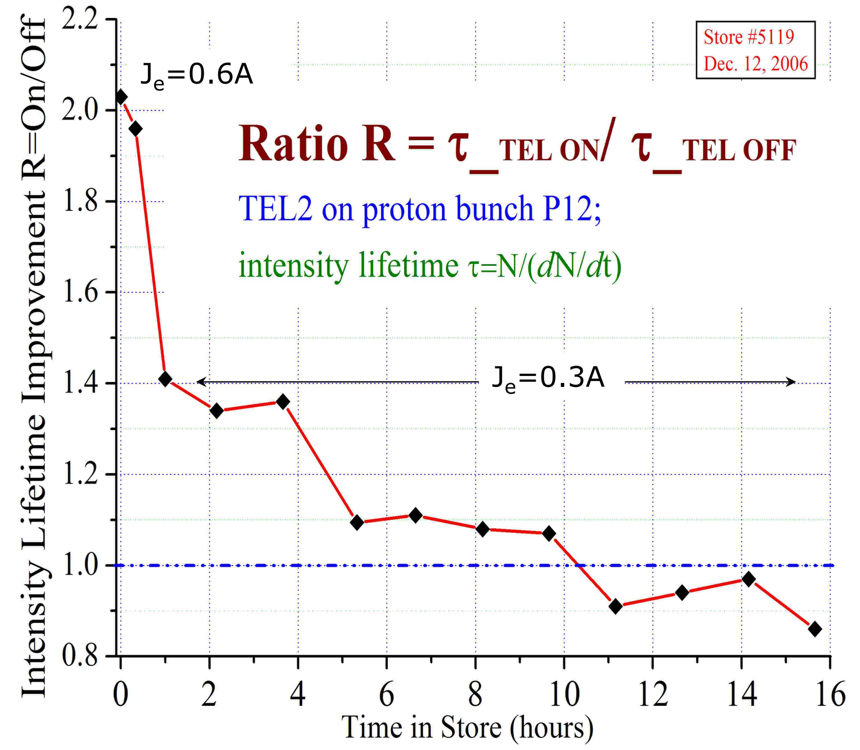


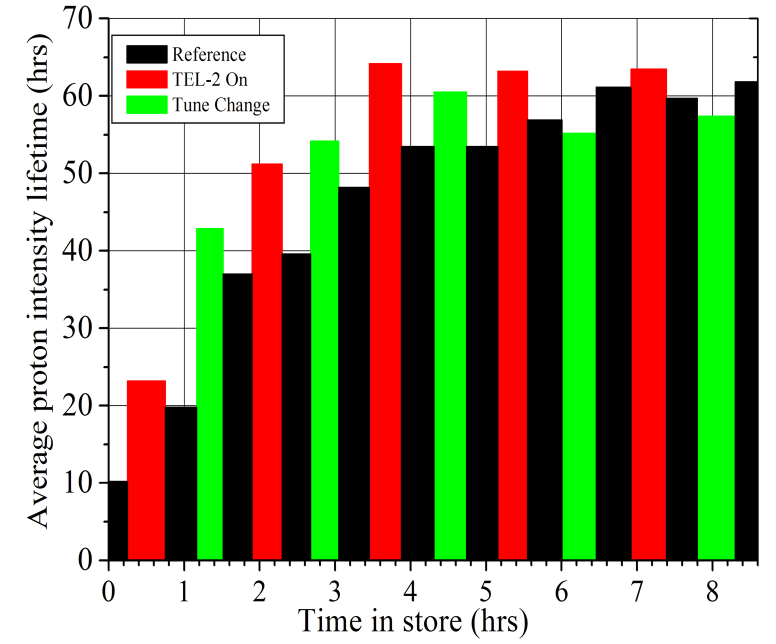
TEL2 timing

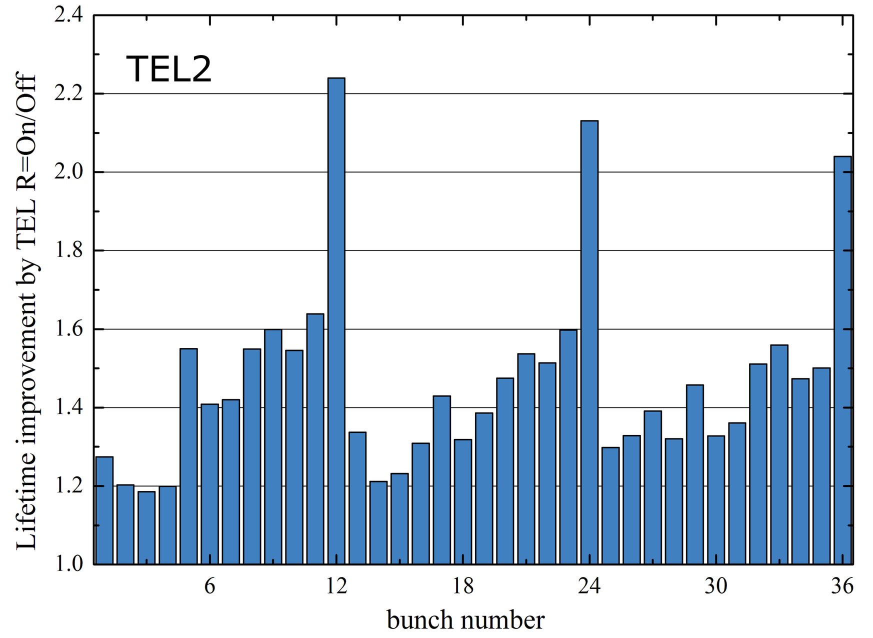


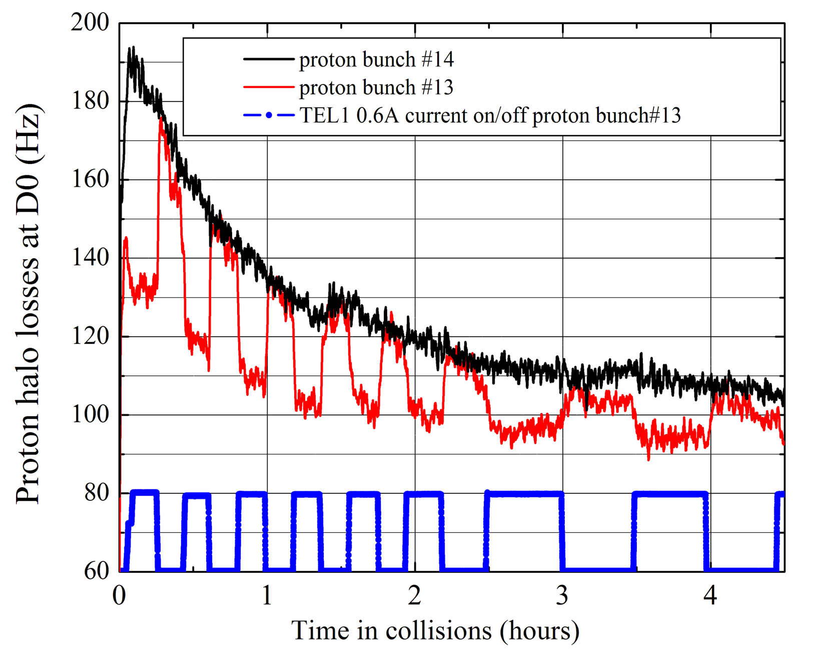
TEL1 & TEL2 beam study results

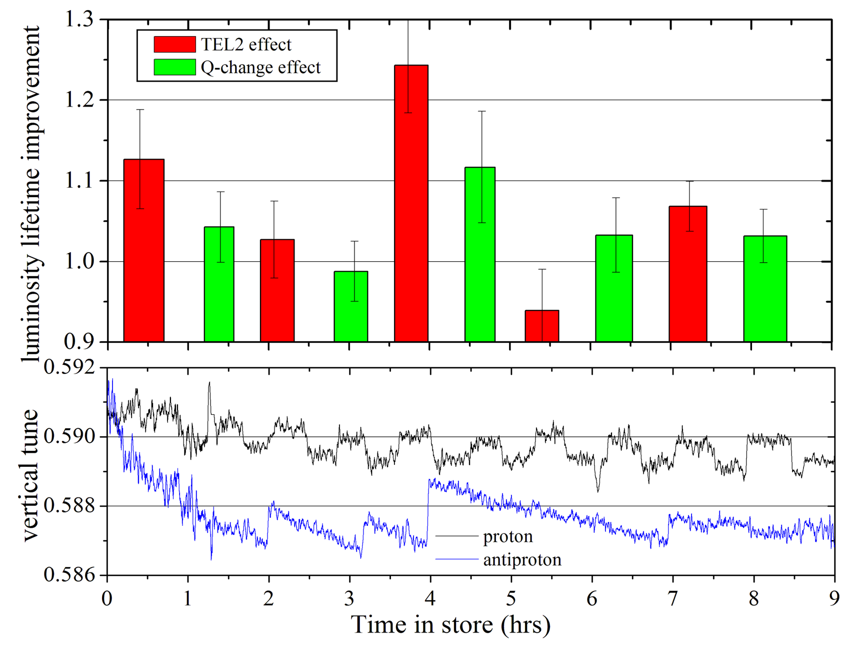










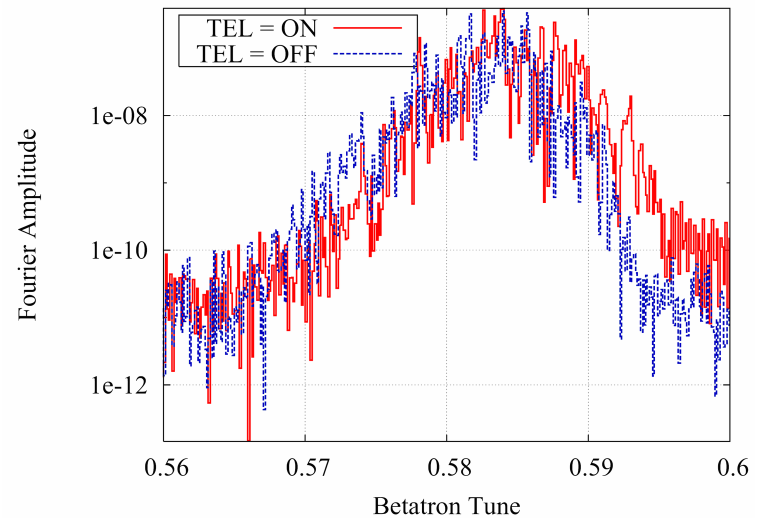


Simulations using LIFETRAC code

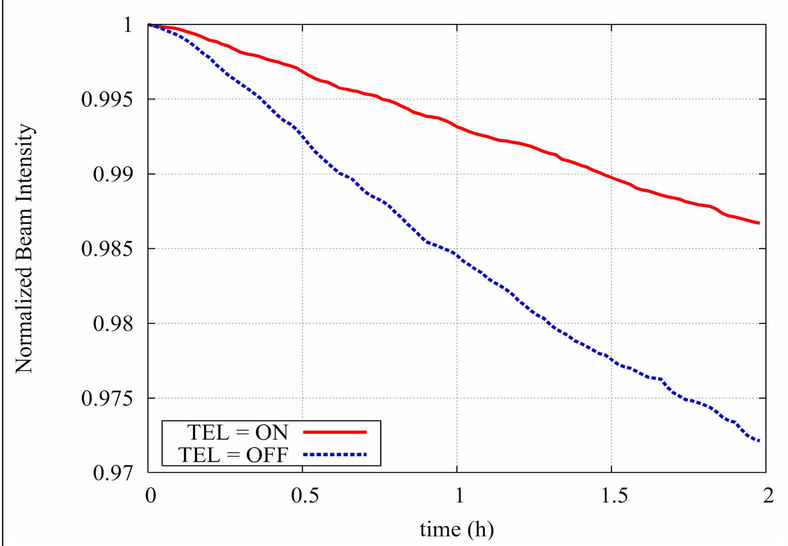
LIFETRAC is a multi-particle simulation code where a single bunch of particles is tracked through a sequence of linear maps and points of beam-beam interaction reproducing the real pattern of collisions in the Tevatron. The code makes full advantage of the current knowledge of the Tevatron optics by using measured beta-functions and helical orbits in order to compute the transfer maps for tracking particles between the IPs and to calculate the beam-beam kick.

In the simulation, the TEL was represented by a thin kick generated by the electron beam with the transverse density distribution described by the formula

$$\rho(r) = \rho_0 \left(1 + (r/r_0)^8\right)^{-1}$$



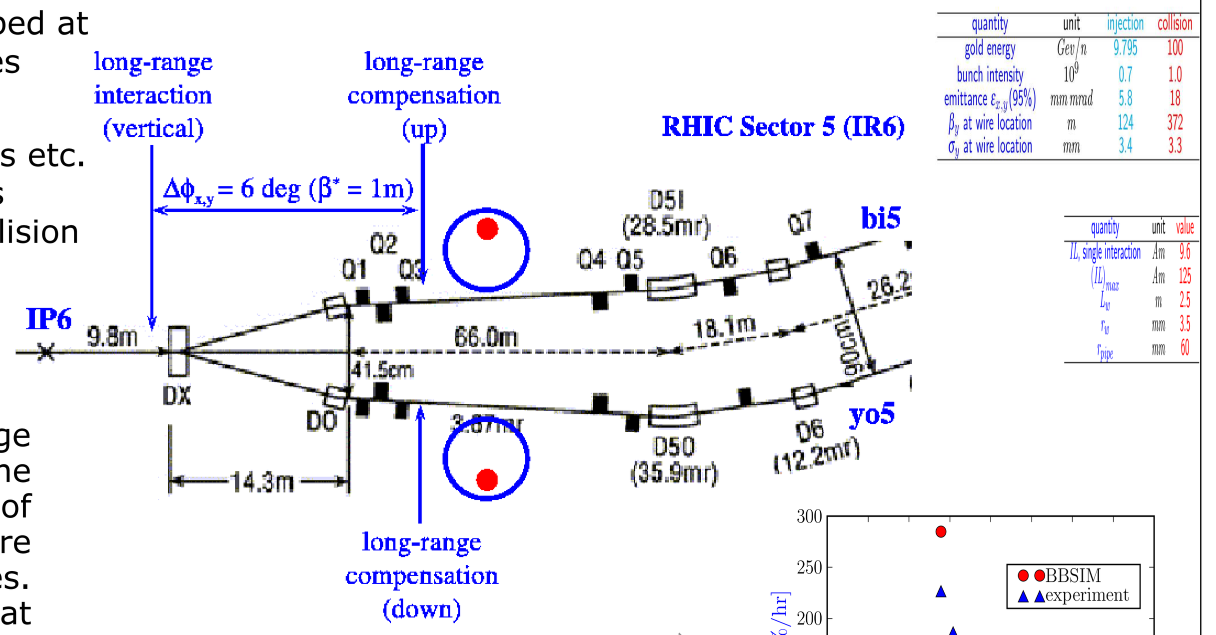
With the present computing capacity it is possible to track a bunch of 10,000 macro particles for up to 10^6 turns. With the real Tevatron revolution frequency this corresponds to roughly 2 minutes. By artificially increasing the IBS diffusion rate we are stretching this time to about 2 hours. Hence, calculating the number of particles lost from the beam during the time of simulation can be used to estimate the non-luminous beam lifetime. Although this method does not give a very accurate absolute result it is quite effective for relative comparison of various conditions.



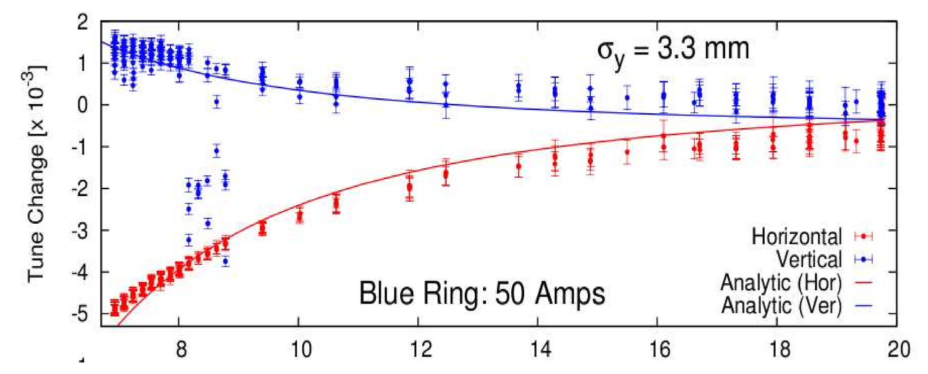
Simulations using BBSIM code

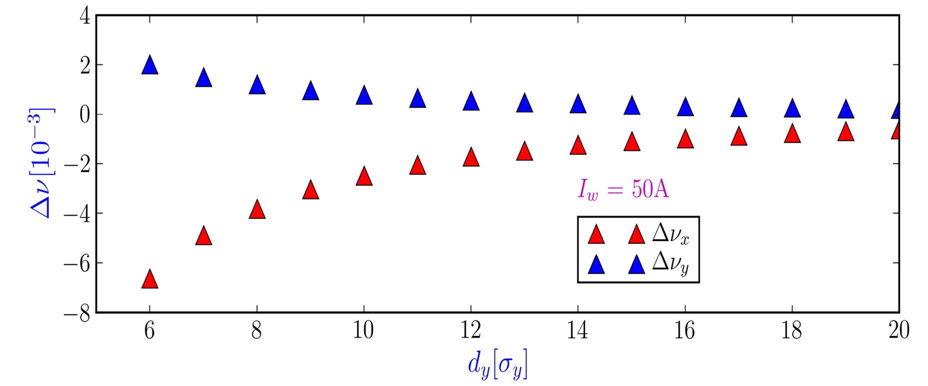
A beam-beam simulation code BBSIM has been developed at FNAL over the past few years. The following summarizes features of the package:

- 6D weak-strong model, includes synchrotron oscillations etc.
- Nonlinearities include chromaticity sextupoles, thin lens multipoles especially those in the IR quadrupoles at collision and current carrying wire.
- Head-on and Long-range interactions when present.
- Parallelization of I/O and computation.

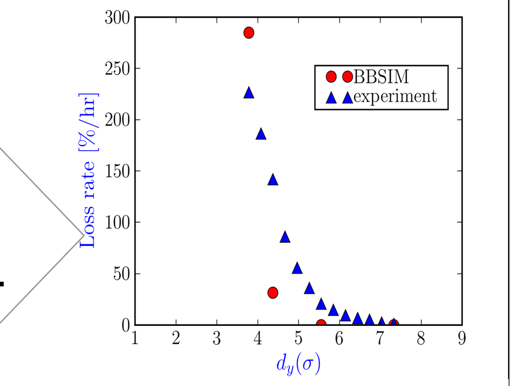


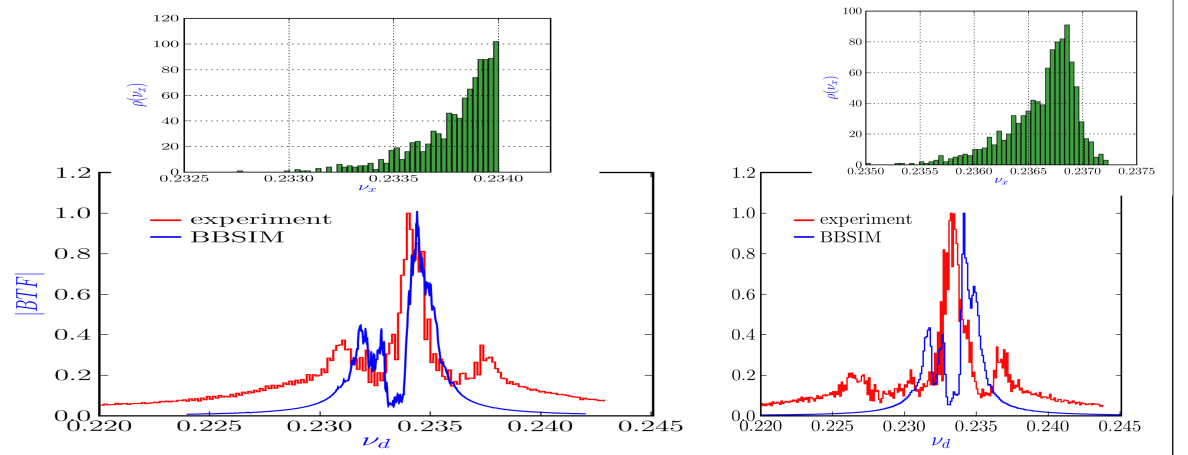
BBSIM is used to study the compensation of long range beam-beam effects by current carrying wires at the Relativistic Heavy Ion Collider. Tune shift, tune scans of diffusive aperture and beam transfer function are presented for various wire separation distances. Comparison of the loss rate from tracking with that measured by BNL is presented.





Base tune (0.230,0.216) at RHIC Au injection energy. Wire current 50A, separations 4-7σ.





Base tune (0.234,0.226) at RHIC Au collision energy. External driving force, A cos(Ω_d t) in horizontal plane. BTF: <x> as a function of exciting frequency Ω_d. IR multipoles and sextupoles are included in the model.

Summary & plans

- ✓ The 2nd Tevatron Electron Lens (vertical) ~doubled proton intensity lifetime of the bunch it was acting on
- ✓ Agreement of the experiments and LIFETRAC simulations
- ✓ The effect of the 1st Tevatron Electron Lens (horizontal) on p-lifetime varied within 20-60%
- ✓ TELs improve luminosity lifetime as well
- ✓ BBCompensation helps for ~10 hrs in HEP stores
- ❑ Will continue experimental and simulation studies → introduce in operation
- ❑ Study the effect of electron beam size on protons (lifetime, halo, Schottky) in both TELs
- ❑ Use both TELs simultaneously for BBCompensation in dc and pulsed mode
- ❑ Upgrade HV pulse generators → multi-bunch BBCompensation
- ❑ Head-on compensation with Gaussian electron beam profiles

- ✓ BBSIM Lifetime simulation agrees reasonably well with experimental results
- ❑ Introduce beam-beam effects in the BBSIM calculation
- ❑ Run simulations with realistic wire dimensions

Acknowledgements

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