Intrabeam Scattering in IOTA

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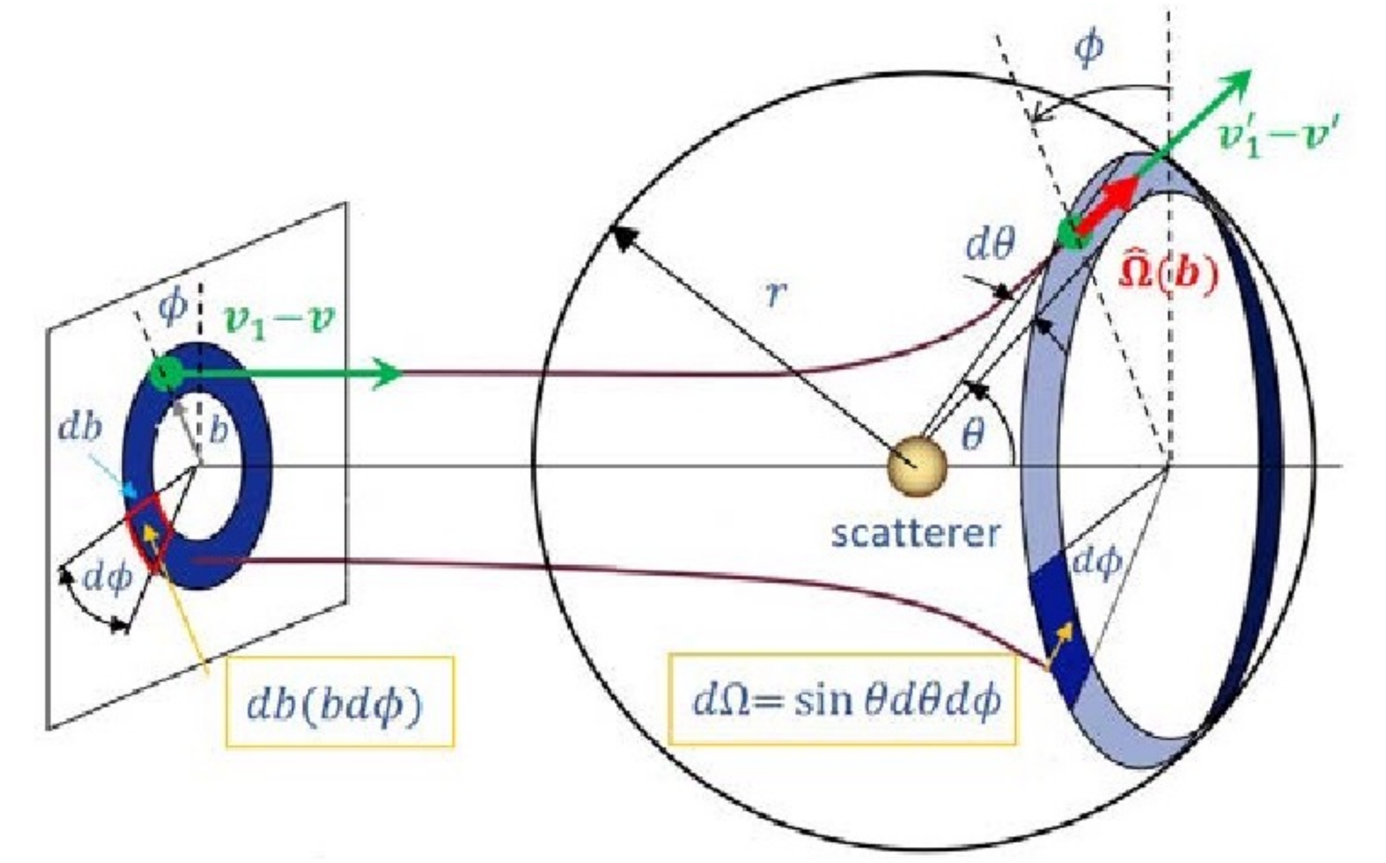


A diagram of a single instance of of an IBS collision (Picture: Intrabeam Scattering: Anatomy of the Theory, by M. Martini)

Introduction - IOTA

The Integrable Optics Test Accelerator (IOTA) ring is used as a test accelerator for advanced beam physics experiments. Originally designed for experiments with integrable optics its original functions for studying integrable optics can be turned off or reconfigured quite easy, and it is a small ring of about 40m in length, allowing it to function as a simple accelerator which can easily be dedicated to a wide range of experiments. As such, it is important to understand the beam dynamics within the accelerator. To that end, the tracking code pyORBIT is used to simulate the particles within the beam. The goal of this project was to create a module in the code that incorporates the effects of Intrabeam Scattering (IBS) into pyORBIT.

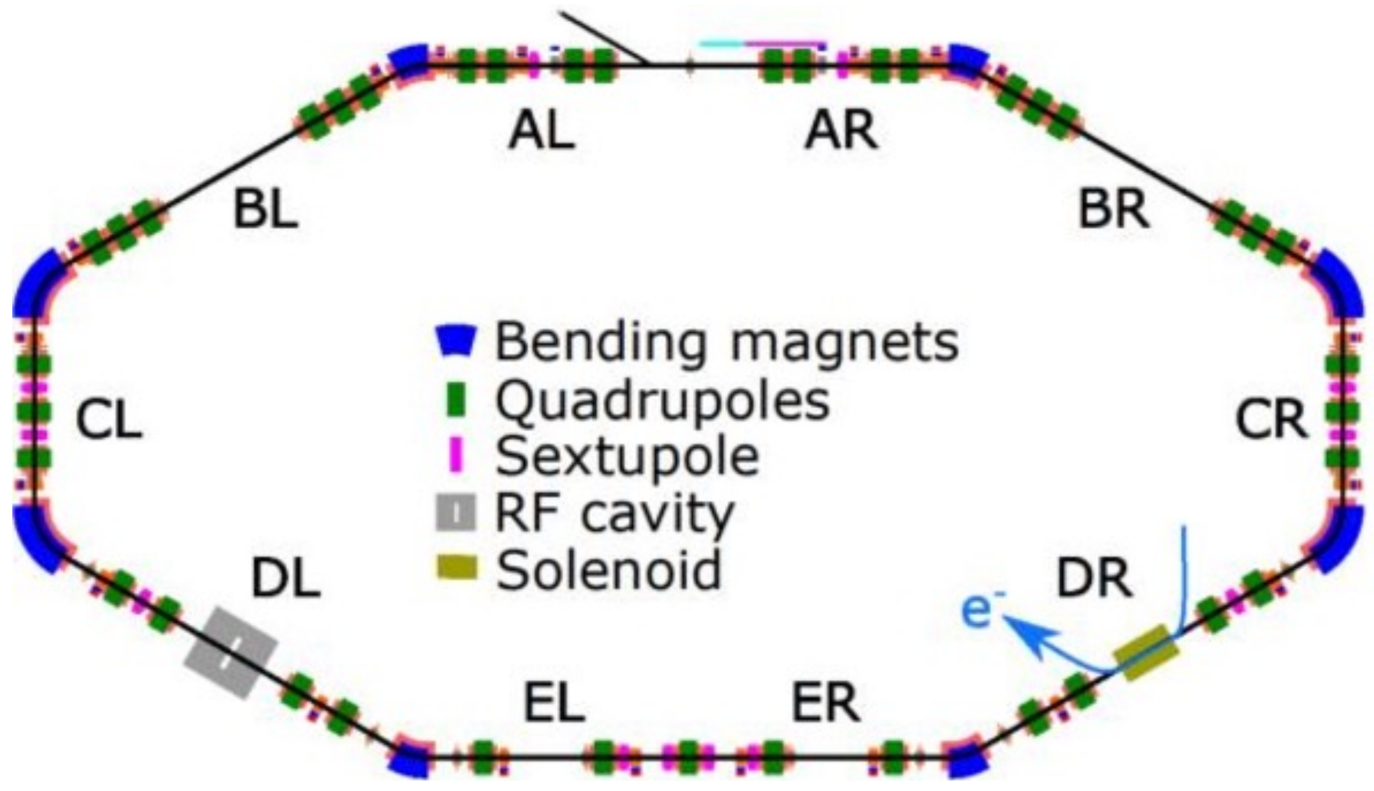


Diagram of IOTA Components (Picture: Thermionic Sources for Electron Cooling at IOTA, by M.K. Bossard, et al.)

Intra-Beam Scattering

IBS is a well-known effect in accelerator physics causing diffusion in phase space and beam spread. It, along with space charge effects, can account for a significant portion of emittance growth. Space charge effects occur due to the net effects of large quantities of charged particles near each other. IBS is the result of particles within the beam moving relative to each other. As a result of this, scattering collisions occur. As the particles collide within the beam, their positions and momenta are randomly perturbed, leading to a net effect of six-dimensional emittance growth. Due to an inverse dependency of space charge on an accelerator's γ, this effect is small for higher beam energies. IOTA has a γ of 1.0027, or a KE of 2.5 MeV, operating well below transition, and thus IBS must be considered when modelling IOTA's beam dynamics.

Intrabeam scattering
Multiple scatterings
Considers exchange of oscillation energies among all 3 directions.
All changes are assumed to be small as compared to the beam dimensions.
Diffusion in all 3 dimensions leads to a change of particle distribution. Increase and decrease of beam dimensions are possible.

Table discussing the definition of IBS (Picture: Reflections on our experiences with developing the theory of intrabeam scattering, by A. Piwinski, J. Bjorken, S. Mtingwa)

$$\frac{1}{\tau} \equiv \frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}t} = \frac{1}{\varepsilon_x}\frac{\mathrm{d}\varepsilon_x}{\mathrm{d}t} + \frac{1}{\varepsilon_y}\frac{\mathrm{d}\varepsilon_y}{\mathrm{d}t} + \frac{1}{{\sigma_p}^2}\frac{\mathrm{d}{\sigma_p}^2}{\mathrm{d}t} =$$

$$= \frac{N{r_p}^2 c L_C}{12\pi\beta^3\gamma^5\sigma_s}\int_0^L \frac{\mathrm{d}s}{L\sigma_x\sigma_y}\left[\lambda_1\Psi\left(\frac{1}{\lambda_1},\frac{1}{\lambda_2},\frac{1}{\lambda_3}\right) + \text{two cyclic permutations}\right]$$

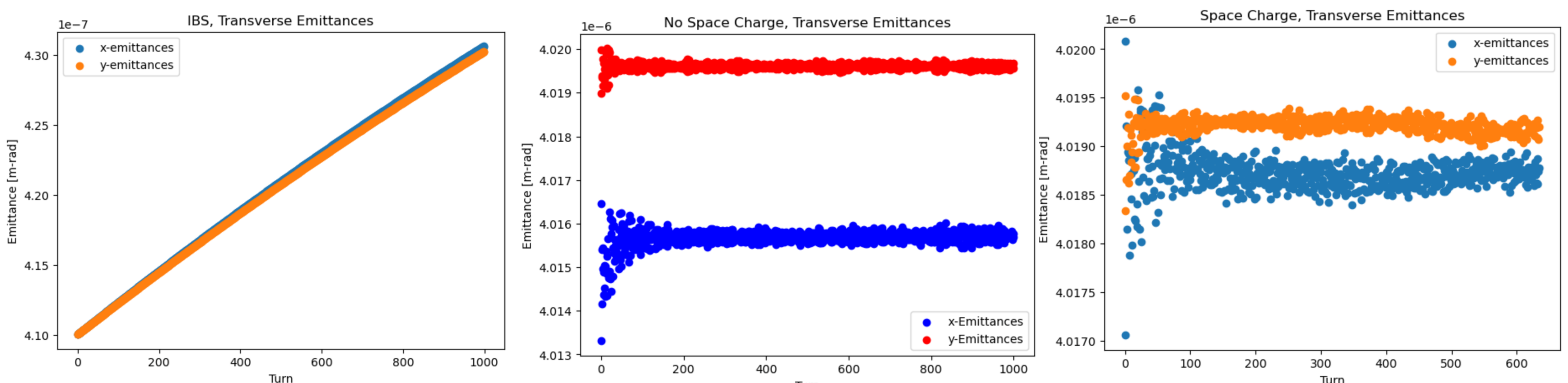
$$\Gamma = 8\pi^3\beta^3\gamma^3 M^3 c^3 \varepsilon_x\varepsilon_y\sigma_s\sigma_p .$$

Main equation for emittance growth due to IBS. In IOTA, N=9e10, initial $\varepsilon_x=\varepsilon_y$=4.10e-7, σ_p=1. 98e-3 (Picture: Intrabeam scattering formulas for fast numerical evaluation, S. Nagaitsev)

Methods and Models

The program takes as input a Methodical Accelerator Design-X (MADX) file containing the twiss parameters of the IOTA accelerator at the midpoint of each IOTA component. There are a total of 190 components along the 40 meters of accelerator, so the program can be set to either linearly interpolate or flatly extend these parameters between the components. After that, it plugs into one of three different models, each from a paper by Sergei Nagaitsev, which streamlines the Bjorken-Mtingwa model of IBS for faster numerical modelling. The slowest model approximates a beam with horizontal dispersion and uncoupled betatron oscillations, while the second slowest (~0.15x the runtime of the slow model per turn) makes the approximation of a smooth lattice, and the final model makes the assumption of zero dispersion, which is a major factor in transverse emittance growth, leading to the quickest calculations (~0.07x runtime). Each model is tested against the MADX output approximations of IBS effects for IOTA, in order to measure accuracy.

Results and Next Steps



The left graph above represents the output of the new module's transverse emittance growth due to IBS in both the x- and y-directions. The next steps are to incorporate the results of this into the code for tracking space charge in IOTA, which is represented in the middle and right graphs. These use pyORBITS particle-in-cell (PIC) code method of simulating emittances, while the IBS code currently is purely based on the mathematical model of Nagaitsev with IOTA parameters input, so the next step will be to attempt to mesh these two methods into something more cohesive. Utimately, the goal is to enable a more complete calculation of emittance growth due to both IBS and space charge, something current methods do not allow.

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