Ion Booster – Space-Charge Studies

Alex Bogacz

The Proposal Scope

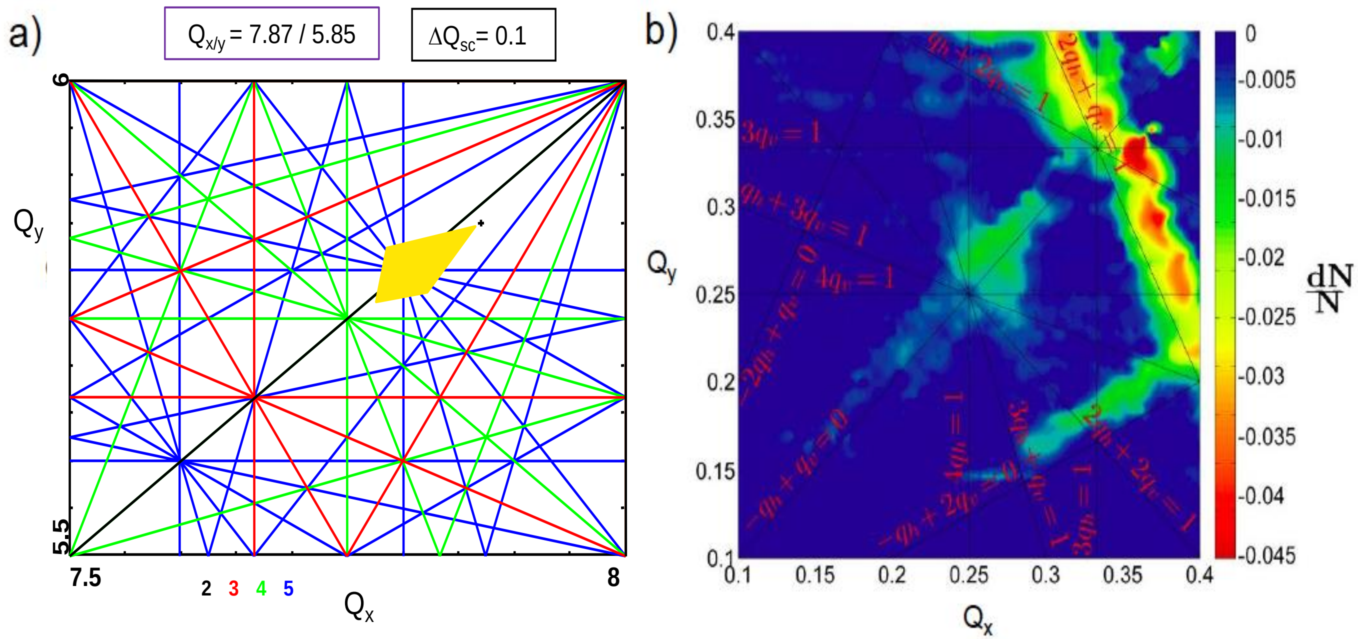
- Optimization of the Ion Booster design to operate in the **extreme space-charge** dominated regime. Mitigation of **halo formation** and beam loss through comprehensive studies of **resonance crossing** in the presence of space-charge and implementation of modern resonance **compensation techniques**.

Ion Booster Studies with Space-Charge

- We propose to study beam conditions at the injection plateau, where the effect of space-charge is considerable (e.g. Laslett tune shift greater than 0.3), and a bunched beam is stored for a long time (10^5 or more turns).
- When the machine tunes cross a stable resonance or a structure resonance it increases the transverse amplitude of particles, leading to halo formation and eventually beam loss.
- These processes will be studied numerically via multi-particle tracking (SYNERGIA) through a realistic booster lattice in the presence of magnet multipole errors (super-ferric magnet design).

Beam-Loss Tune Scan

- The goal of the simulation is to compose the so-called **beam-loss tune scan** – a fractional beam-loss as a function of the horizontal and vertical tunes – similar to the one carried out for the PS Booster at CERN.



***a)** Tune diagram for* JLEIC *booster: the sum and difference resonances and the working point.*
***b)** Normalized beam loss as a function of tunes - composed for the PS Booster*

Resonance Crossing Mitigation

- To alleviate the resulting beam loss, one can implement **third-integer resonance crossing correction** measures by creating anti-resonances via properly placed pairs of sextupoles . They would correct the stop-band width of these resonances to minimize the amplitude growth and hence beam loss.

- Simulation of the above process will ultimately provide insight into the effectiveness of the correcting scheme and will allow us to optimize the placement of the **correcting sextupoles** in the ring, as well as their strengths.

- Finally, thorough space-charge studies, outlined above, are essential to optimize the present Ion Booster design: to define the **optimum injection energy, working point tunes, maximum current**, as well as to carry out assessment of the acceptable halo and beam loss.

SYNERGIA on the JLAB Computing Platform

- SYNERGIA is installable on clusters that have software no older then 2011.
- It runs best on HPC clusters such as those used by Lattice QCD.
    - JLAB Lattice QCD 12s clusters are running CentOS 6, which is quite capable of running SYNERGIA.
    - Installing SYNERGIA on a new unfamiliar cluster with the help of responsive system administrators has been a matter of about a week, with further optimizations taking up to a month.

Balsa Terzic, ODU

- Installing SYNERGIA on a single Linux machine usually takes less than a day using the instructions on:

Edward Nissen, JLAB

https://cdcvs.fnal.gov/redmine/projects/contract-synergia2/wiki/Download_and_build_the_current_Synergia_release

SYNERGIA on the JLAB Computing Platform

- Computing requirements for a realistic space-charge simulation
- Scaling from the Fermilab Debuncher ring that has about 900 beam-line elements (similar to the JLEIC Booster)
  - That simulation takes about 1.5 seconds/turn running on 64 cores similar to those on JLAB 10q cluster with 100k macro particles.
  - One would scale time/turn linearly by number of beam-line elements times number of macro particles and inversely by number of cores up to the scaling limit.
  - One would need about 100k macro particles. On the Fermilab cluster that is similar to the 10q, one gets good scaling to 144 cores. JLab's 12s clusters have better networking hardware than the Fermilab cluster, so the scaling to larger number of cores will be even better on the JLab's cluster.

Eric Stern, Fermilab

Work Plan – Tasks & Deliverables

Q1:

- Setting up computational platform for SYNERGIA (1 month)
  - Installing SYNERGIA on a single Linux machine
  - Installing SYNERGIA on the JLAB Lattice QCD: 12s clusters.
- Study of coasting beam conditions at the injection plateau (2 × month)
  - Multi particle tracking with low space-charge ($\Delta Q = 0.1$) (10^5 turns)
  - Tracking with gradually increasing space-charge ($\Delta Q_L = 0.2, 0.3, 0.4$)

Q2:

- Simulation of bunched beam under increasing space-charge (3 × month)
  - Study of realistic injection distributions from the ion linac
  - Particle tracking in the presence of magnet multipole errors and misalignments
  - Excitation of 3-rd integer resonance line – resonance crossing simulation

Work Plan – Tasks & Deliverables

Q3:

- Studies of halo formation due to resonance crossing
  - Long term tracking (10^6 turns) with 3-rd integer res. at the injection plateau
  - FFT analysis of the tracking data
  - Envelope formalism analysis of the data
  - Normalized beam loss as a function of the horizontal and vertical tune

Q4:

- Beam-loss tune scan studies with increasing space-charge (3 × month)
  - Halo due to 3-rd integer resonance crossing (ΔQ_L = 0.2, 0.3)
  - Halo due to 2-nd integer resonance crossing (ΔQ_L = 0.25, 0.3, 0.35)
  - Effect of structure resonance on halo formation

Work Plan – Tasks & Deliverables

Q5:

- Study 3-rd-integer resonance crossing correction measures
  - Simulation of stop-band reduction with sextupoles
  - FFT analysis of the transverse amplitude distribution
  - Creating anti-resonances via pairs of sextupoles
  - Envelope analysis of the halo formation

Q6:

- Optimization of the injection scenario (3 × month)
  - Search for the optimum working point
  - Optimum length of the injection plateau
  - Realistic injection energy

Work Plan – Tasks & Deliverables

Q7:

- Study of multi-turn injection of ions (3 × month)
  - Multi particle tracking with varying number of linac pulses
  - Simulation of ion stacking at injection
  - Optimization of ion injection optics

Q8:

- Study of the transverse phase-space painting (3 × month)
  - Simulation of the horizontal phase-space painting
  - Simulation of phase-space painting in two planes (hor. and ver.)
  - Phase-space density analysis – injection efficiency