Halo collimation of fully-stripped light and heavy ions in the SIS100 *

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Introduction

The FAIR synchrotron SIS100 will be operated with high-intensity proton and ion beams [1]. The collimation system should prevent beam loss induced degradation of the vacuum, activation of the accelerator structure and magnet quenches. A conventional two-stage betatron collimation system is considered for the operation with protons and fully-stripped ions [2]. We propose to use 1 mm thick tungsten foil as the first stage – primary collimator (scatterer) and two 400 mm blocks at as the second stage – secondary collimators (absorbers).

Interaction of heavy ions with collimators

For collimation studies we are interested in angular scattering, momentum losses and fragmentation of ions in the collimator material. A charged particle passing matter experiences multiple Coulomb scattering. According to Moliere theory, the angular distribution of scattered particles is roughly Gaussian with the r.m.s. angle θ_0 (Eq.1), $B\rho$ is the magnetic rigidity and x is the foil thickness.

$$\theta_0 = \frac{0.47}{\beta\,(B\rho)\,[Tm]}\sqrt{\frac{x}{X_0}}\left[1 + 0.038\ln\left(\frac{x}{X_0}\right)\right], \quad (1)$$

here X_0 is radiation length, tabular value for tungsten is $X_0 = 3.504mm$. Moliere theory predicts a Gaussian distribution in the range $10^{-3} < x/X_0 < 100$.

Momentum loss is described by (Eq. 2) with the corrections to standard Bethe-Bloch term L_0. The δL_{shell} correction represents the motion of electrons in the matter, δL_{Bark} is proportional to Z^3 and δL_{LS} takes into account the finite radii of heavy nuclei [3].

$$-\frac{\delta p}{p} = \frac{K}{\beta^4}\frac{Z_t}{A_t}x\left[L_0 + \delta L_{shell} + \delta L_{Bark} + \delta L_{LS}\right], \quad (2)$$

here $K = 3.07 \cdot 10^{-4} GeV g^{-1} cm^2$. According to [3], the momentum straggling has a Gaussian distribution for ions heavier than $^{40}Ar^{18+}$ at SIS100 injection energy.

Cross-sections and, hence, probabilities of the inelastic nuclear interaction for light and heavy ions passing through the tungsten foil were calculated using Tripathi formula [4]. The overall probability of fragmentation for $^{238}U^{92+}$ ions in our application is 6% and lower for lighter ions.

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Simulation studies of cleaning efficiency

The simulation tool for cleaning efficiency studies uses an initial distribution of 10^5 halo particles and simulates their interaction with a collimator using implementation of models described above (Eqs. 1, 2). Then particles are tracked in the accelerator lattice with aperture limitations using MADX. After each consecutive turn, all particles are checked for impact on the primary collimator. In case of an impact, particle-material interaction is calculated.

A large portion of the halo particles is lost during the first pass through the collimation system (singlepass cleaning), however, high efficiency is gained after many turns (multipass cleaning), see Fig. .

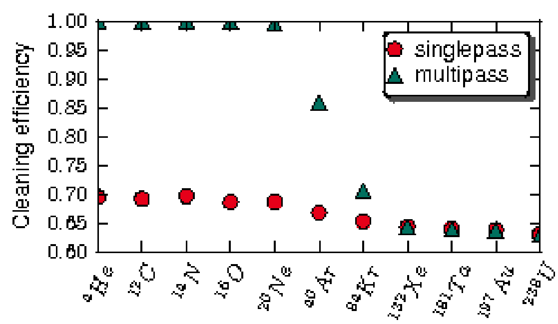

Figure 1: Cleaning efficiency at the injection energy for light and heavy ions.

The cleaning efficiency decreases with the mass number due to increasing momentum losses in the primary collimator. Strongly off-momentum heavy particles are unable to make one turn in the accelerator and are lost in the high-dispersion region of the lattice.

References

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