CERN Accelerator School: Accelerator Physics Advanced Level
Trondheim, Norway
24 August 2013

Ion Beam Collimation for the FAIR Synchrotron SIS100

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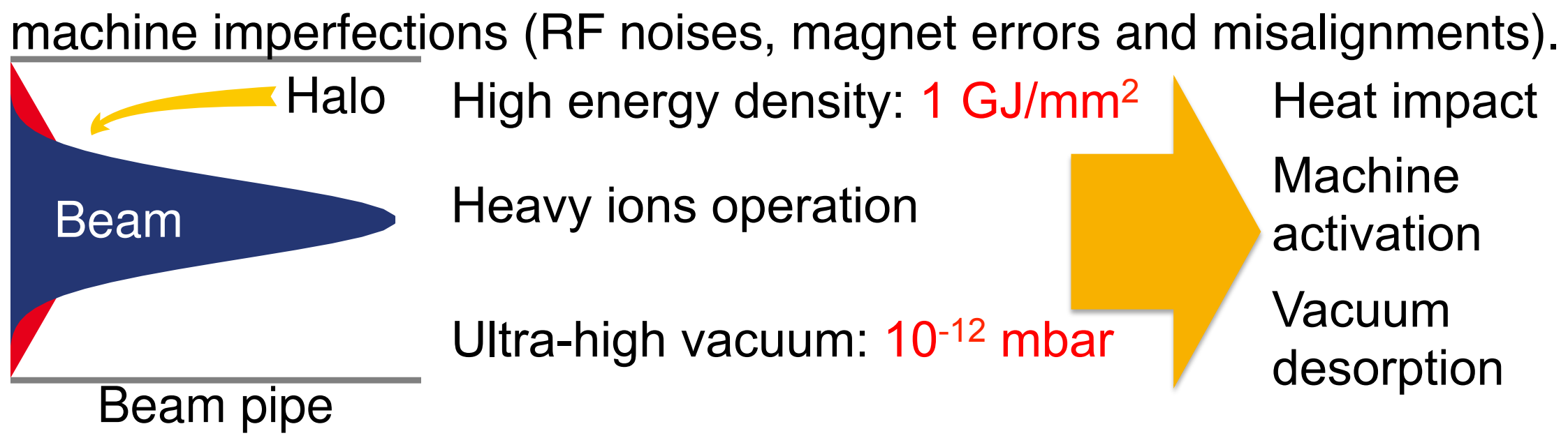
Abstract

The collimation system for the SIS 100 synchrotron has to operate with protons as well as with light and heavy fully-stripped ions ($^{2}H^{1+}$ - $^{197}Au^{79+}$). The concept and basic design features of the betatron halo collimation in SIS 100 were developed previously for proton operation. The main task of the presented work is to compare the efficiency of proton and ion beam collimation. For this purpose multi pass tracking of halo particles was performed using MAD-X including the simulation of scattering process and energy loss in the collimators using the ATIMA code. The collimation efficiency as a function of the ion species together with the detailed beam loss distribution along the ring circumference are presented.

Motivation

Beam halo is non-Gaussian tails of a beam. It occurs due to beam dynamics aspects (beam instabilities, IBS, beam mismatch) and machine imperfections (RF noises, magnet errors and misalignments).



High energy density: 1 GJ/mm^2

Heavy ions operation

Ultra-high vacuum: 10^{-12} mbar

Heat impact

Machine activation

Vacuum desorption

Halo collimation system localizes beam losses and makes machine hands-on maintainable.

Simulation of collimation efficiency

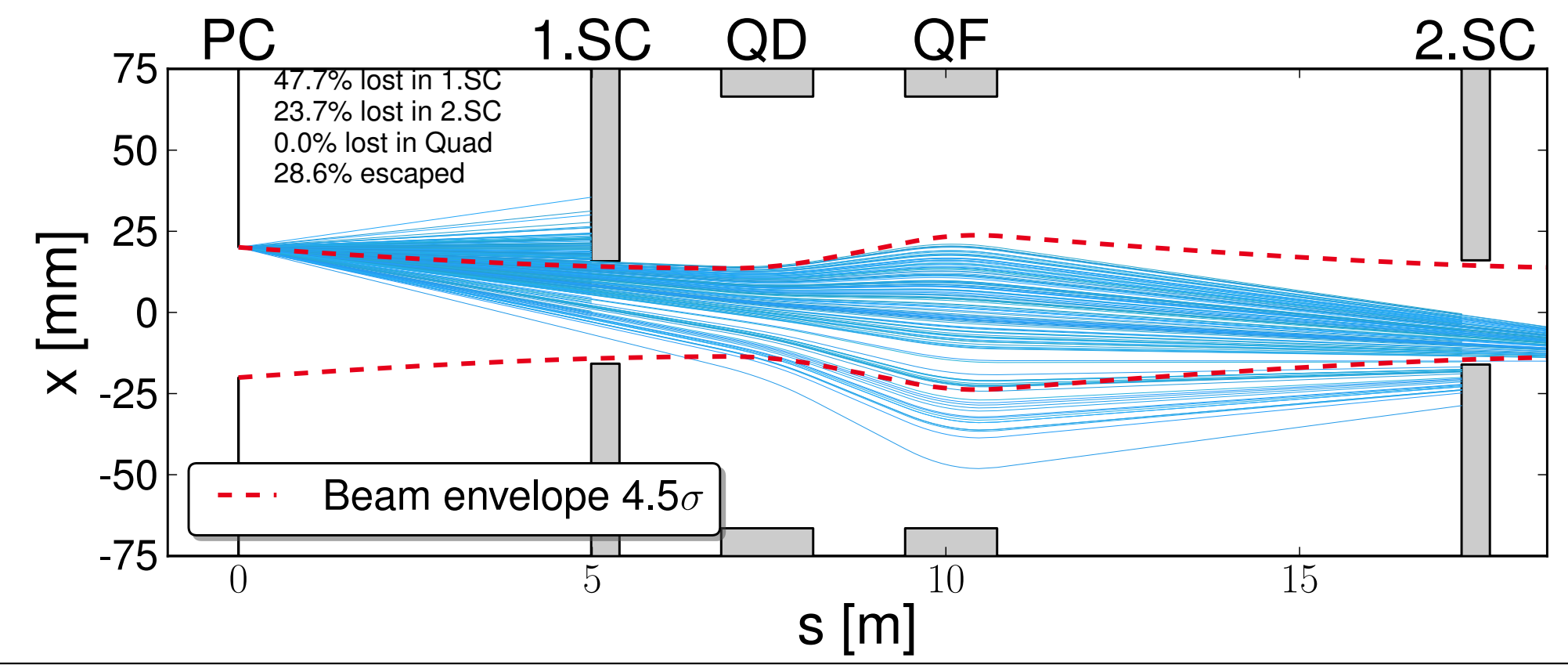
(i) Angular distribution of the ions scattered in the primary collimator is approximated as Gaussian with the r.m.s. width calculated using the Moliere theory of multiple Coulomb scattering by ATIMA code [3].

$$\boxed{\theta_{r.m.s} = \frac{13.6MeV}{\beta pc} Z\sqrt{x/X_0}\left[1+0.38\ln\left(x/X_0\right)\right]}$$

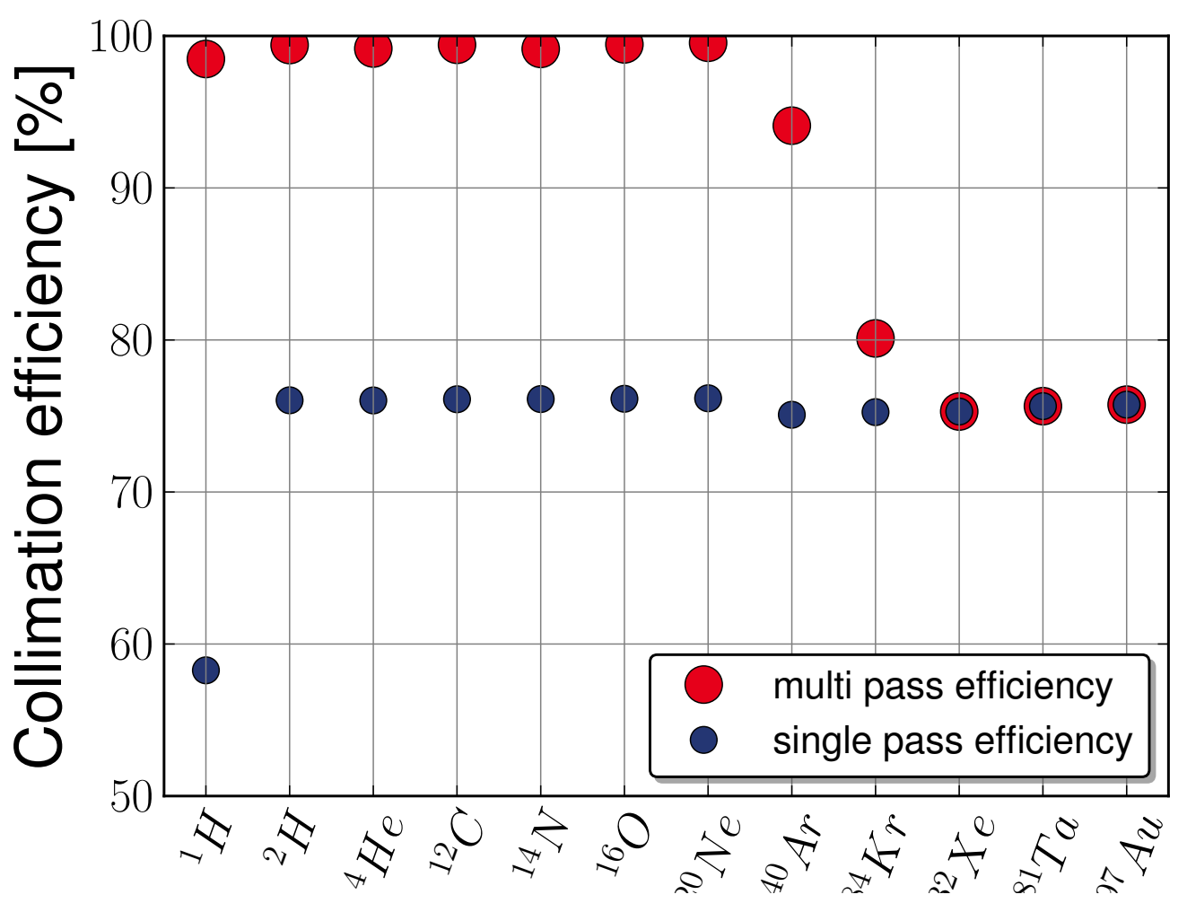
(ii) The stopping power in a material is calculated using Bethe-Bloch formula. For calculations of the stopping power of high relativistic heavy fully-stripped ions ATIMA code use Lindhard and Soerensen theory [4], which imply several corrections to standard formula L_{LS}:

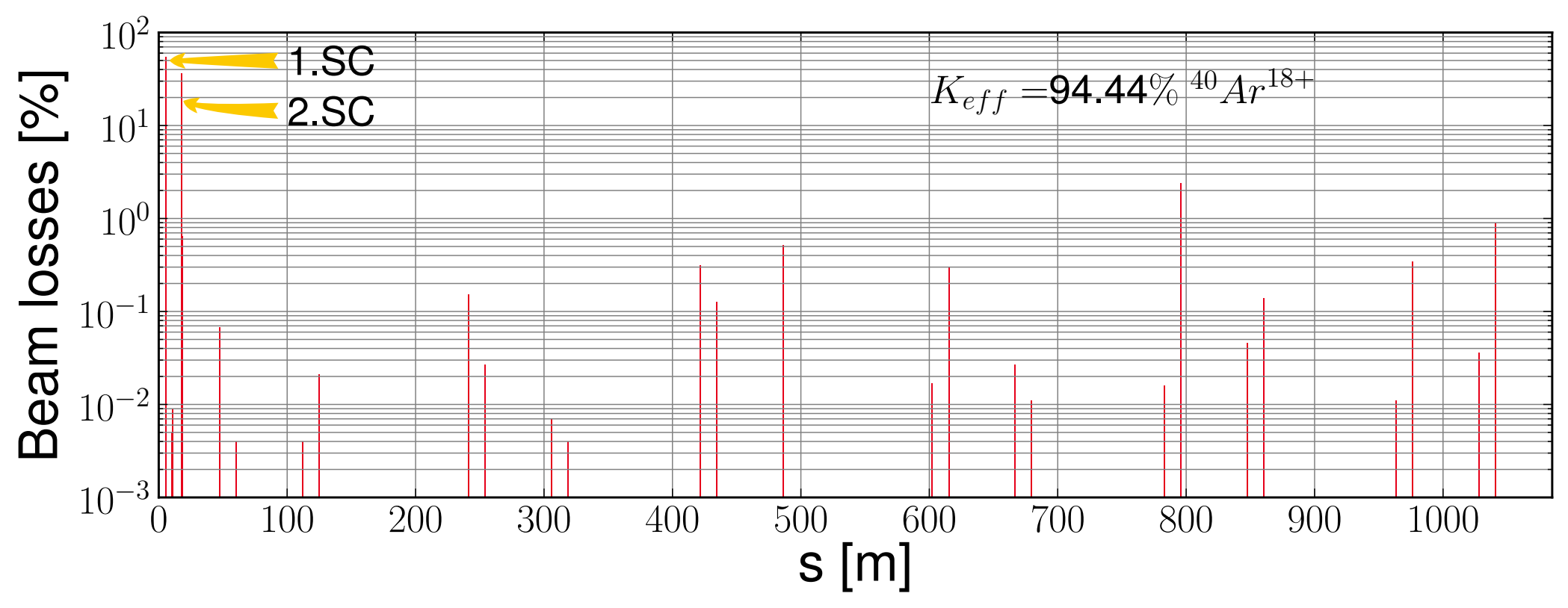
$$\boxed{-\frac{dE}{dx} = \frac{4\rho Z^2 e^4}{m_e v^2} n_e L_{LS}}$$

(iii) Tracking of halo particles in MAD-X [5] with given accelerator optics and physical aperture.



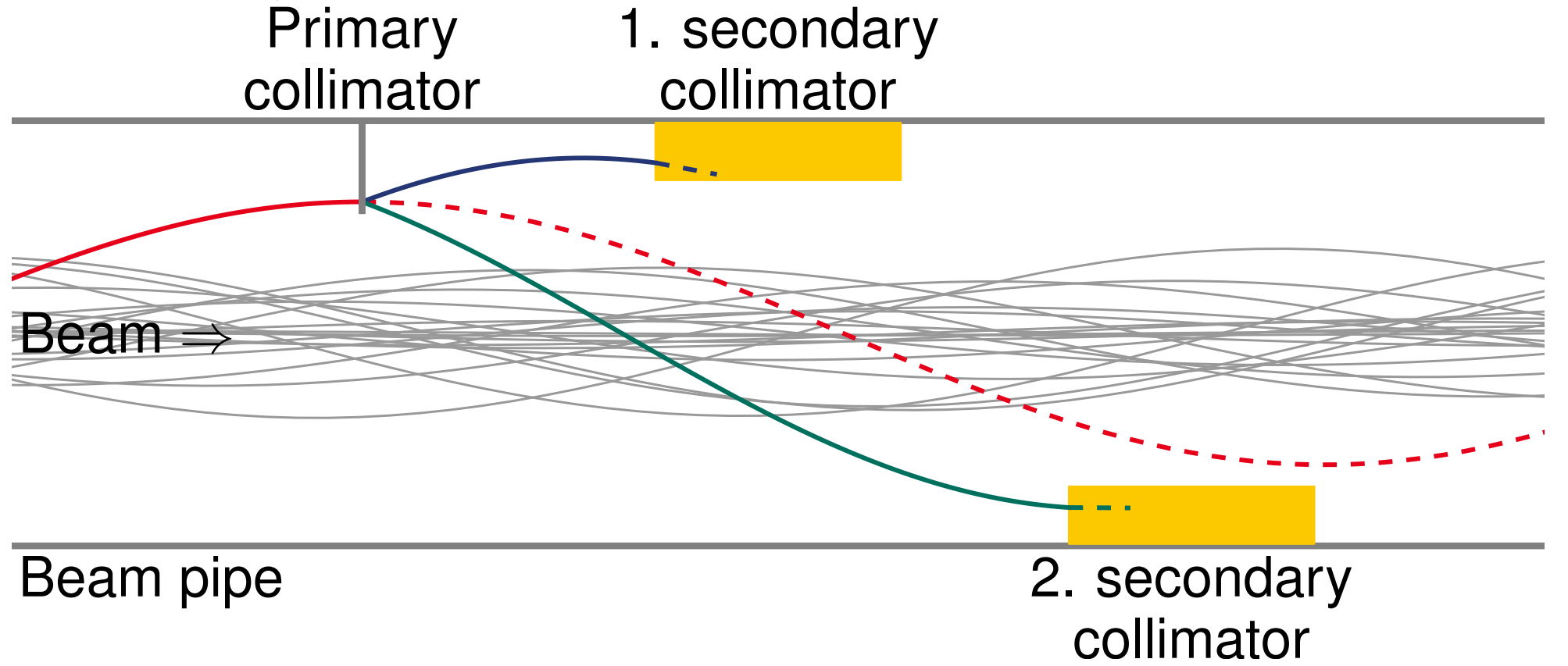
- Simulations has been performed for beams at the injection energy.
- Over 99% of light ion (up to ^{20}Ne) beam losses are located in the collimators.
- Heavy ions with bigger momentum losses in a primary collimator are lost during one turn in an accelerator.
- Beam losses outside the collimation system in SIS 100 are mainly located in cryo-collimators.
- The amount of particles taking part in an inelastic nuclear scattering is at the level of 2-4% for light ions and at the level of 4-6% for heavy ions.

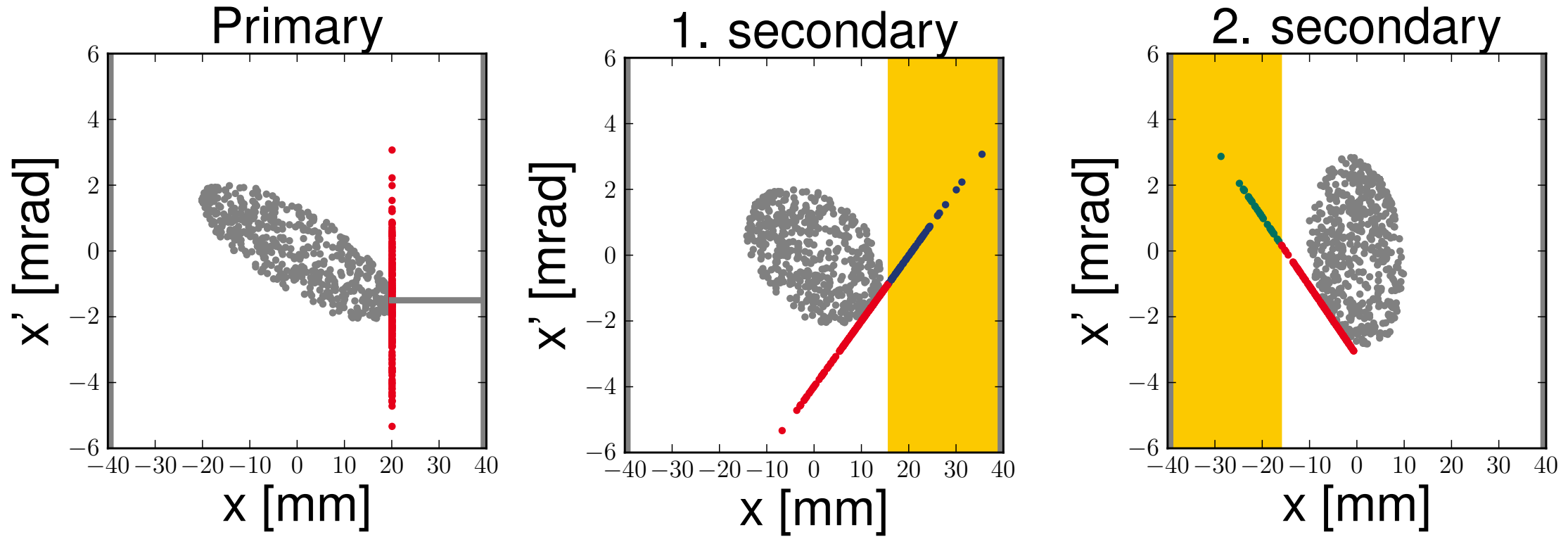




Principles of collimation

The two-stage betatron collimation system [1] consists of the primary collimator (thin foil) which scatters halo particles and the secondary collimators (bulky blocks) which absorb the scattered particles.





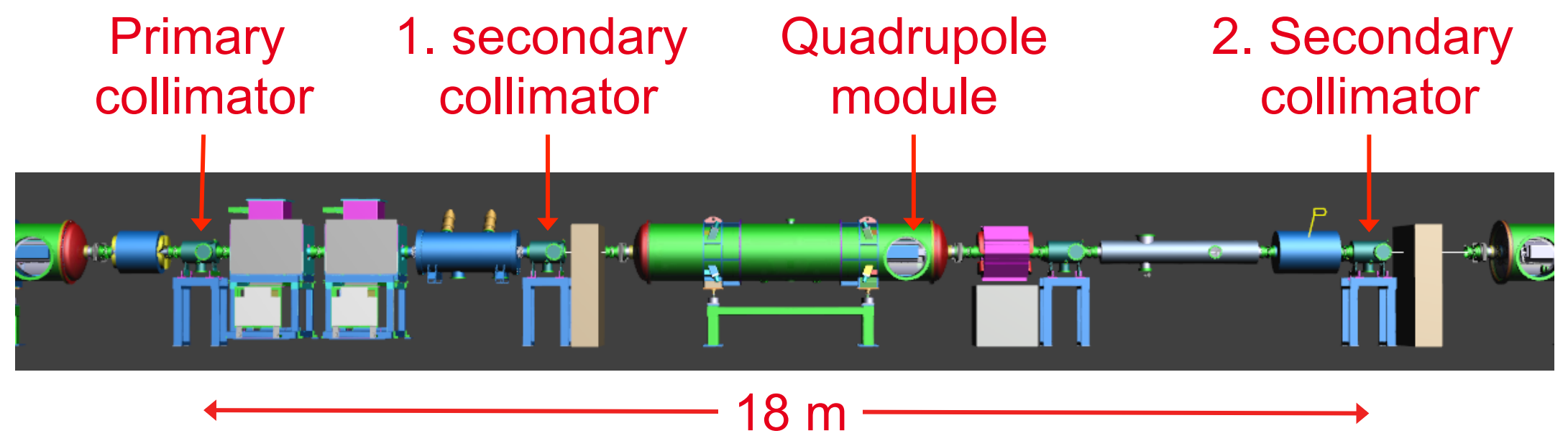
Some particles may escape collimators after single pass and be lost in the lattice or be scattered again in the collimation system.

$$\boxed{\text{Collimation efficiency} = \frac{\text{Losses in collimators}}{\text{Losses in lattice}}}$$

Collimators in SIS 100

Taking into account technical aspects of SIS 100 synchrotron [2], the following design of the collimation system has been developed:

- Collimators have a rectangular aperture with movable jaws
- The primary collimator is a 1 mm thick tungsten foil
- The secondary collimators are 40 cm long blocks

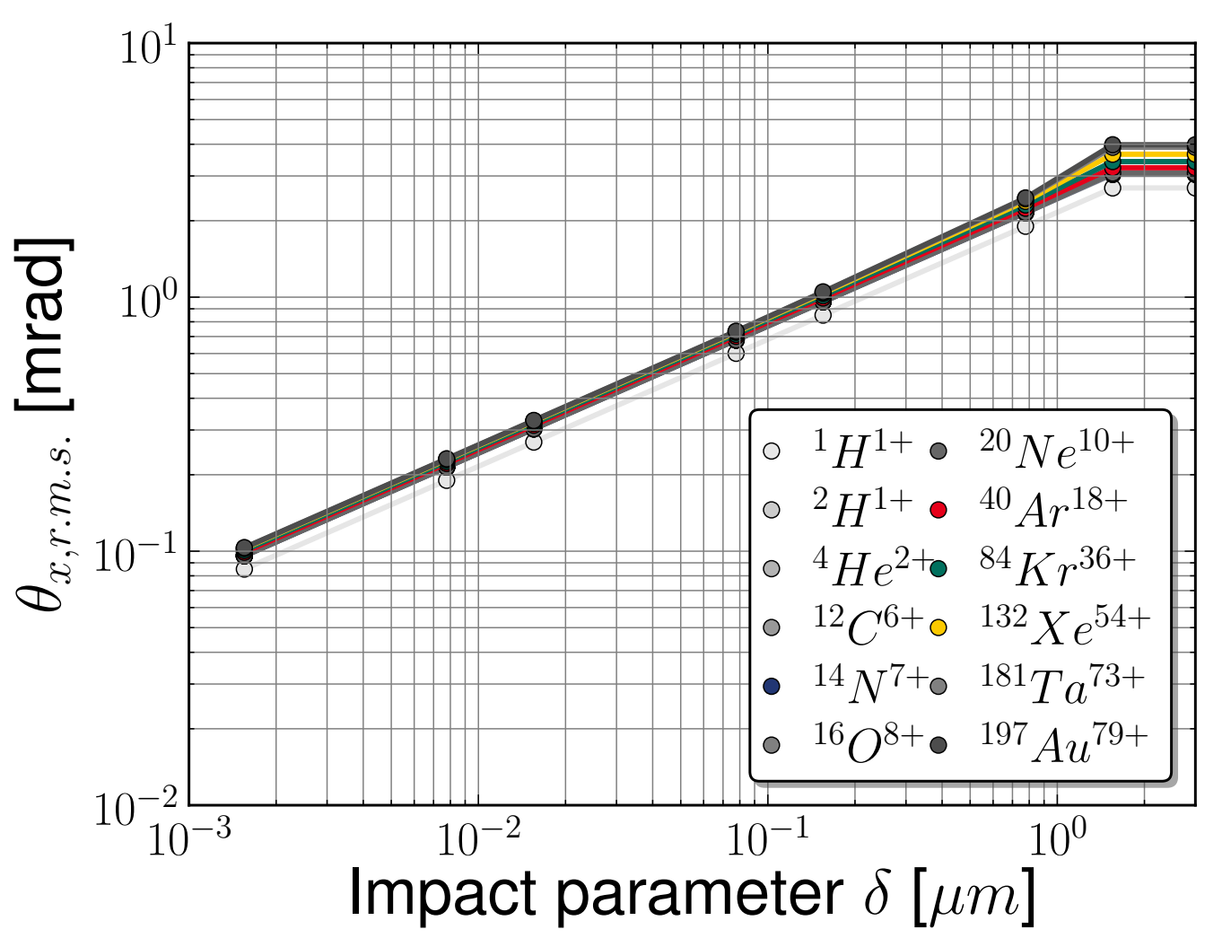


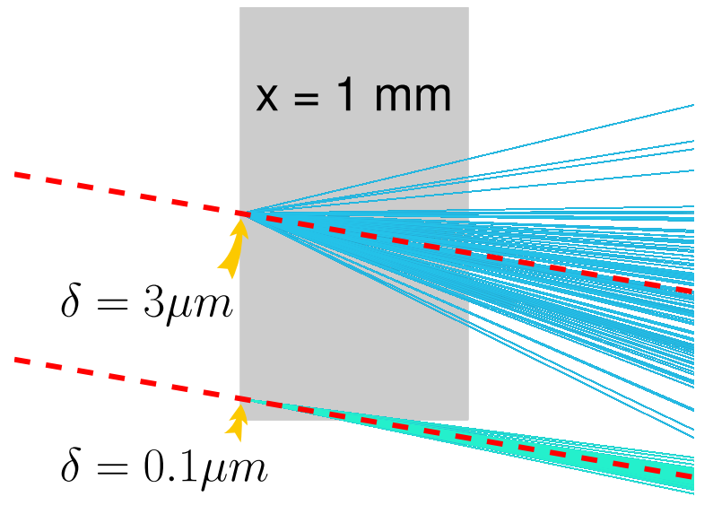
The concept of two-stage collimation is considered for protons and fully-stripped ions.

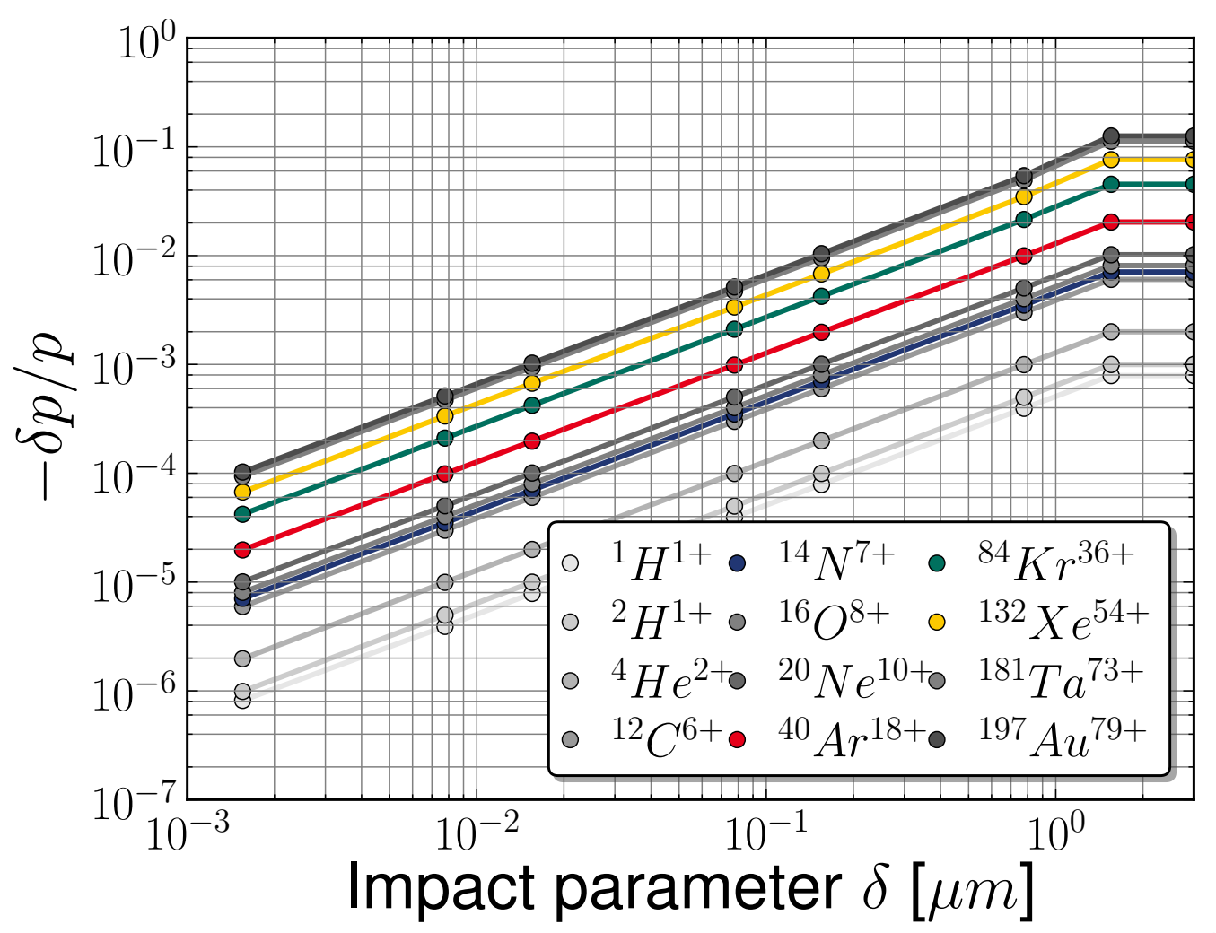
- The primary collimator were transversely placed at $4.5\sigma_{r.m.s.}$ of the beam size.
- Retraction distance (normalized difference of normalized collimators acceptance) has been chosen 0.1 based of previous investigations.

Impact parameter

- The impact parameter δ is the typical transverse offset from the edge of a primary collimator jaw for the particles impacting the collimator.
- Impact parameter is proportional to the rate of the emittance growth.
- The slope of the beam envelope at the location of the primary collimator gives different effective thickness of the foil for different impact parameter.

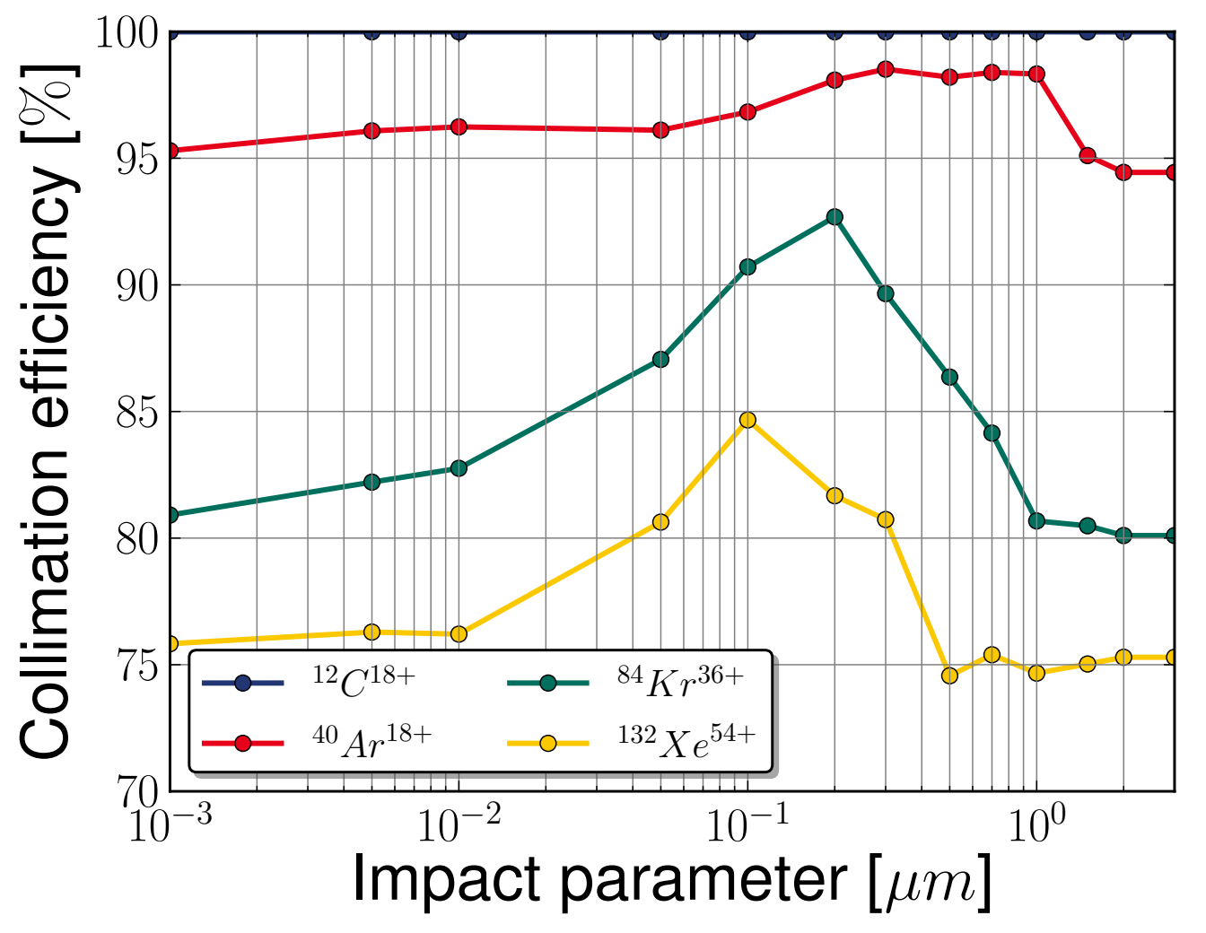


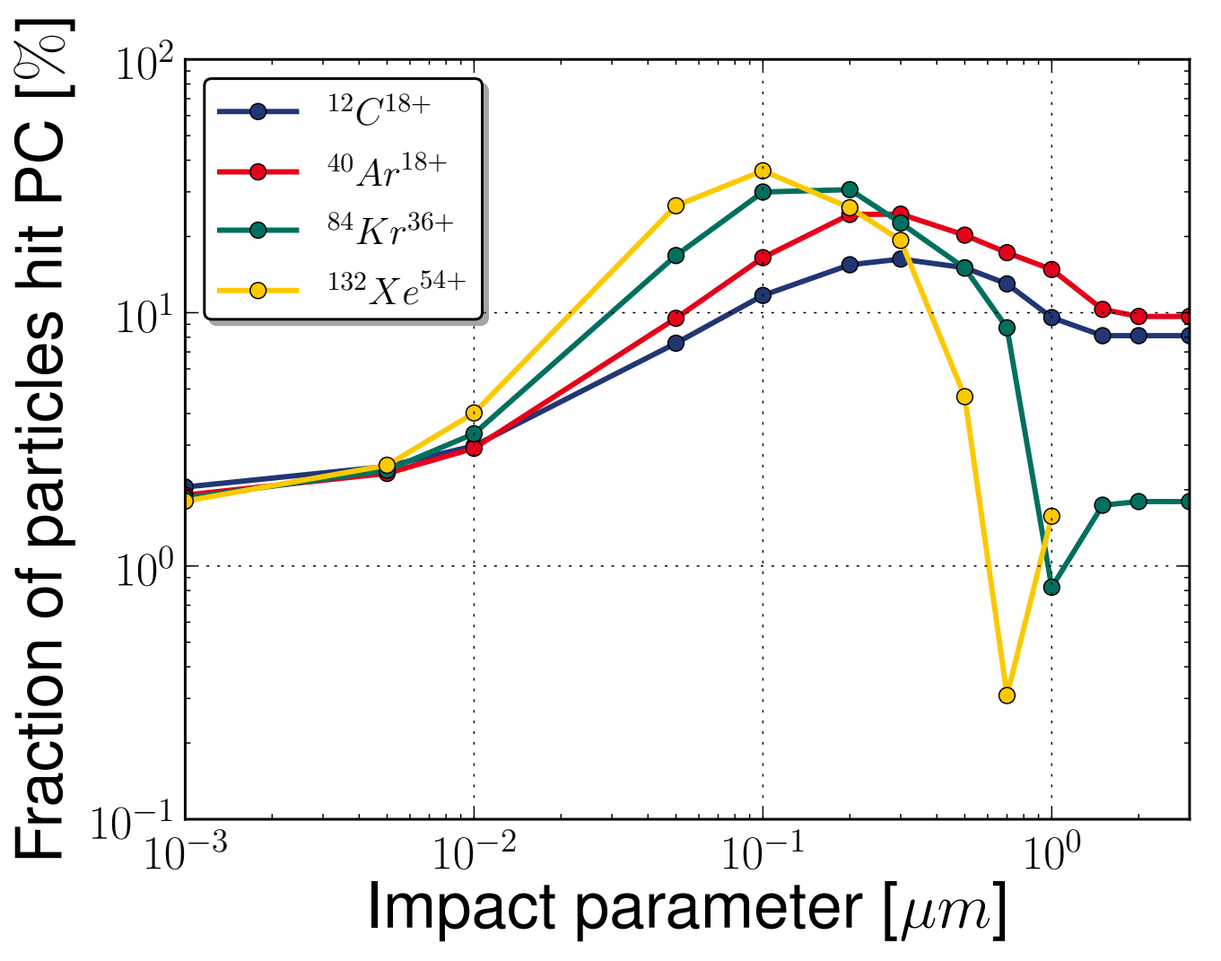




A series of simulations for initial impact parameters in the range of 10^{-3} – 3 µm has been performed:

- It was found out that after one turn less than 0.1% of ions, which was scattered with the small impact parameter, hit the primary collimator jaw with the same or smaller impact parameter for all ion species.
- The collimation efficiency of light ions (up to ^{20}Ne) has almost no dependence on impact parameter.
- Heavy ions collimation efficiency grows with the increasing impact parameter due to wider angular straggling.
- After certain value of initial impact parameter collimation efficiency decreases due to growing energy losses.

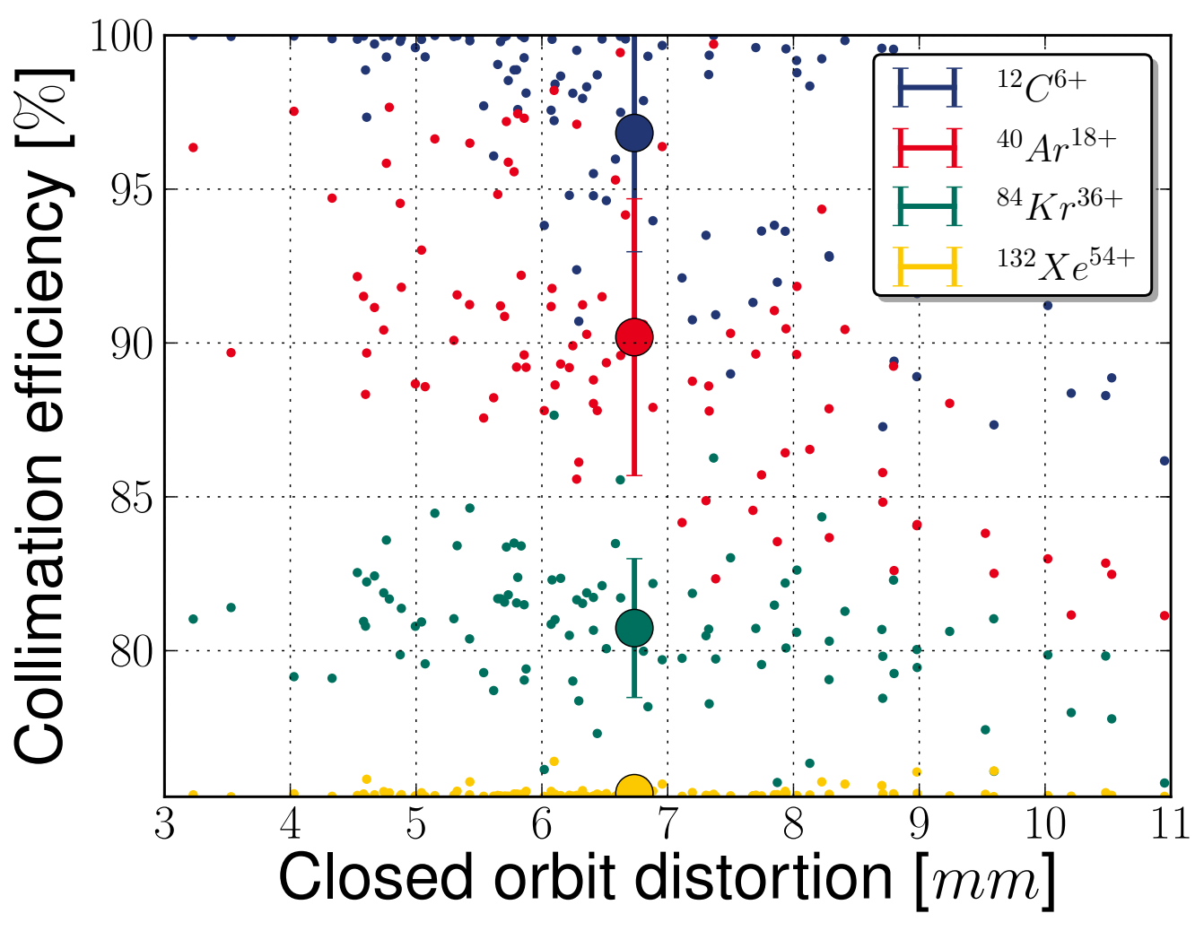


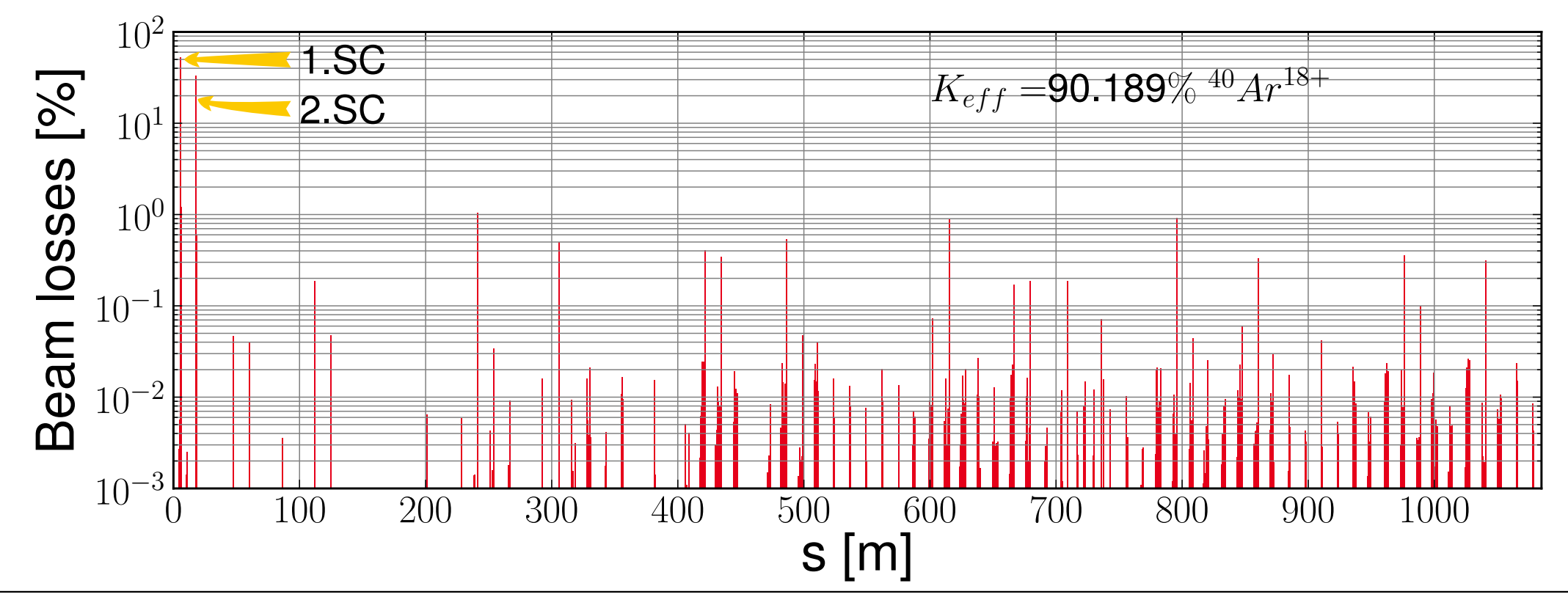


Effect of lattice errors

To estimate the influence of the lattice errors on the collimation performance the closed orbit distortion was included in the particle tracking simulations. Closed orbit distortion with r.m.s. value of 6.8 is a result of transverse positional error of magnets edges.

- Simulation has been performed for 100 different seeds of errors.
- Closed orbit distortion affects the collimation efficiency of light ions: standard deviation is 5%
- Heavy ions beams collimation is weakly dependent on closed orbit distortion.





Conclusion

It has been shown that conventional method of betatron halo collimation can be applied for fully-stripped light and heavy ions in the SIS 100 synchrotron. The main reason of higher level of ions leakage with the growing mass number is the increasing momentum losses. After certain level of momentum losses a halo particle in an accelerator could not make one turn to be scattered by the primary collimator again.

References

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This work is supported by BMBF contract 05P12RDRBM

Bundesministerium für Bildung und Forschung