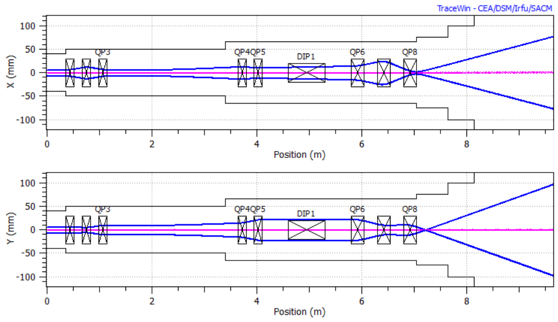

Figure 2: 3 RMS envelope along the HEBT line.

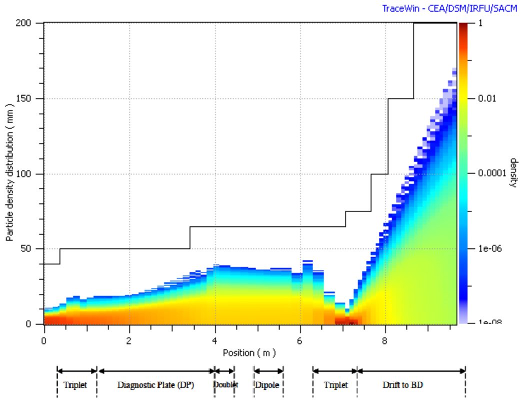

Figure 3: Particle density probability along the accelerator axis.

Studies with different input beams have shown the robustness of the HEBT line design, being able to transport properly the different beams, fulfilling the beam dump requirements in any case.

## ERROR SIMULATIONS

Previous studies have been performed for an ideal situation in which all magnetic elements are perfectly aligned and power supplies do not have any random current variation. However errors will be present in the accelerator. In this section simulations of the following errors are presented:

- magnet displacements (mm) (x and y)
- magnet rotations along the x, y and z axis
- quadrupole gradient and bending magnet field errors

The goal of the error studies is two-fold:

- To define the manufacturing tolerances of the magnets
- To evaluate the robustness of the HEBT line design as a whole with respect to manufacturing errors, quadrupole rotation or displacement. The most important goal is to obtain the proper beam conditions for the beam dump power deposition without any losses along the line. Special attention must be paid to the maximum corrector strength.

More details about the error simulations can be found elsewhere [6].

### *Static errors*

By static errors we understand time-independent (slow) errors. Some effects of these errors can be corrected, as for example those related to trajectory deviation using steerers.

In a first step of the study of static errors, the sensitivity of the HEBT to each type of error has been analyzed separately to evaluate its individual contribution. For each element of the line, the amplitude of the error is randomly generated in a uniform distribution within a given range. Afterwards, once the effect of each error type has been studied, an acceptable limit on each error is chosen, so that the effects on the trajectory deviations are about the same for all the error types. Finally, all errors within the given tolerances are combined simultaneously to verify the set of tolerances determined previously and to study the maximum beam size and overall degradation of the beam properties. In the case of beam losses or unacceptable trajectory deviations or steerer strengths, a global reduction factor would be allocated to all the errors.

After the different simulations and studies, the resulting tolerances for magnets are the following:

- Power supply tolerances for quadrupoles (dipole): ±2% (±0.1 %)
- Quadrupole (dipole) transverse displacement:±0.2 mm (3 mm)
- X-Y quadrupole (dipole) rotation: ±0.9º (±0.6º)
- Z quadrupole (dipole) rotation: ±0.3º (±0.6º)

Reasonable values are needed for steerers when all magnet errors are considered together. Small effects are observed on beam parameters. The rms and maximum values for steerer strengths and for beam position along the line are shown in Table 1. It has been found that the maximum values occur at the last triplet position.

Table 1: Summary of the effect of all combined quadrupole and dipole errors on beam position and on corrector strength

| | **x** | **y** |
|---|---|---|
| RMS orbit (mm) | 0.26 | 0.15 |
| Max orbit (mm) | 0.77 | 0.30 |
| RMS steerer strength (G.m) | 1.75 | 3.96 |
| Max steerer strength (G.m) | 6.84 | 18.39 |

Figure 4 represents the particle density probability in the presence of combined quadrupole and dipole errors, along with appropriate steerers. The whole beam remains inside the beam stay clear limit.

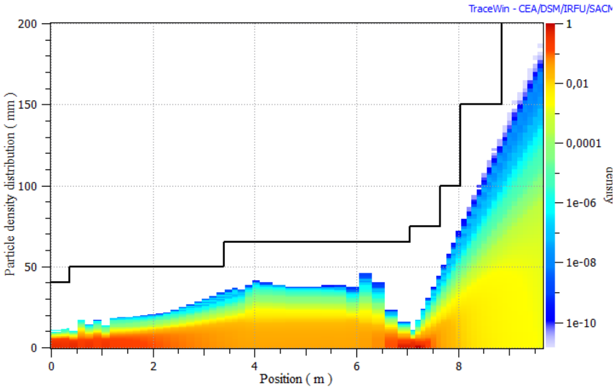

Figure 4: Particle density probability for combined quadrupole and dipole errors

### *BPM accuracy*

In addition to the errors associated to magnets, an extra source of error comes from the BPM accuracy. Its effect on the beam correction along the HEBT line has been analyzed. Dipole and quadrupole static errors have been combined with BPM accuracy errors. The main effect of the finite BPM accuracy is the increase of the orbit position deviation in both transverse directions. The rms and maximum values of the required integrated magnetic field of steerers increase linearly with the BPM accuracy.

From the results and taking into account steerer strength and trajectory position, a value of 0.1 mm has been set as a reasonable accuracy requirement for the BPMs. However, there is some uncertainty about the accuracy that can be achieved on the BPMs located in the last drift of the HEBT, due to the beam debunching and the big vacuum chamber in that region. In addition, the reduced available space there, makes it impossible to locate the BPMS in the optimum position (as far as possible from each other and the last BPM close to the beam dump entrance). Therefore, the accuracy and position of the BPMs will have a big impact on the trajectory correction, imposing stronger steerers and higher beam deviations at the beam dump entrance. Studies on this matter are ongoing.

### *Dynamic errors*

The study of dynamic errors (time-dependent, fast errors) has been performed assuming its magnitude to be a fraction of the values chosen in the static errors studied. Since dynamic errors cannot be corrected, no steerers are included in these simulations and trajectory deviation increases as the beam goes through the line, leading to maximum deviation at the input of the beam dump. Since the beam dump is quite sensitive to beam center deviations, it will be the limitative factor for dynamic errors. It has been found that dynamic errors must not exceed 2.5% of static errors. The comparison of the effect on beam trajectory of static and dynamic errors is shown in Figure 5.

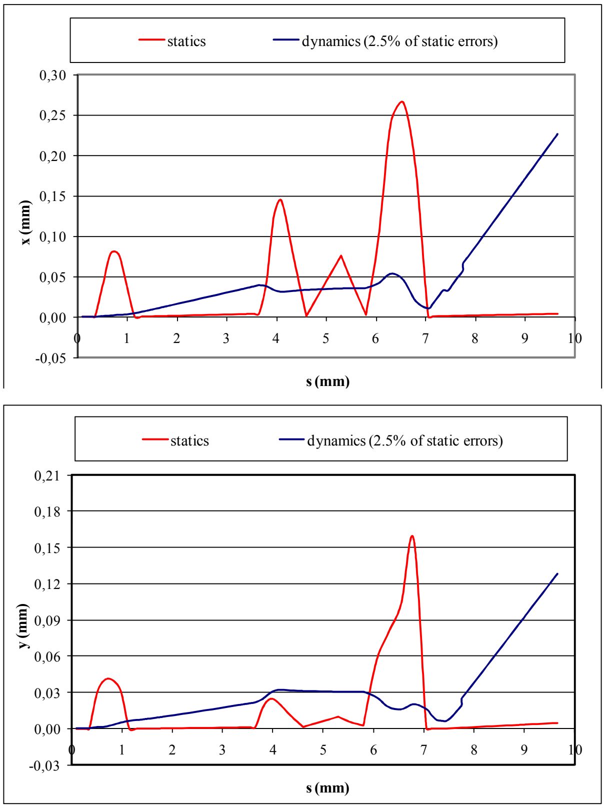

Figure 5: Comparison of the effect of static and dynamic errors on trajectory deviation

## CONCLUSION

The strong requirements imposed by the minimization of losses along the HEBT and by the beam parameters at the beam dump entrance imposes a detailed study of possible errors along the HEBT. An analysis of static and dynamic errors has been performed for the HEBT of IFMIF-EVEDA accelerator. As a result, tolerances on magnet alignment and power supply requirements have been specified. Ongoing studies include the effect of BPM accuracy and position on beam correction, the start-to-end simulations for the whole IFMIF-EVEDA accelerator and the effect of realistic magnet field maps.

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