PHASE-SPACE TRANSFORMATION FOR UNIFORM TARGET IRRADIATION AT DONES

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ABSTRACT

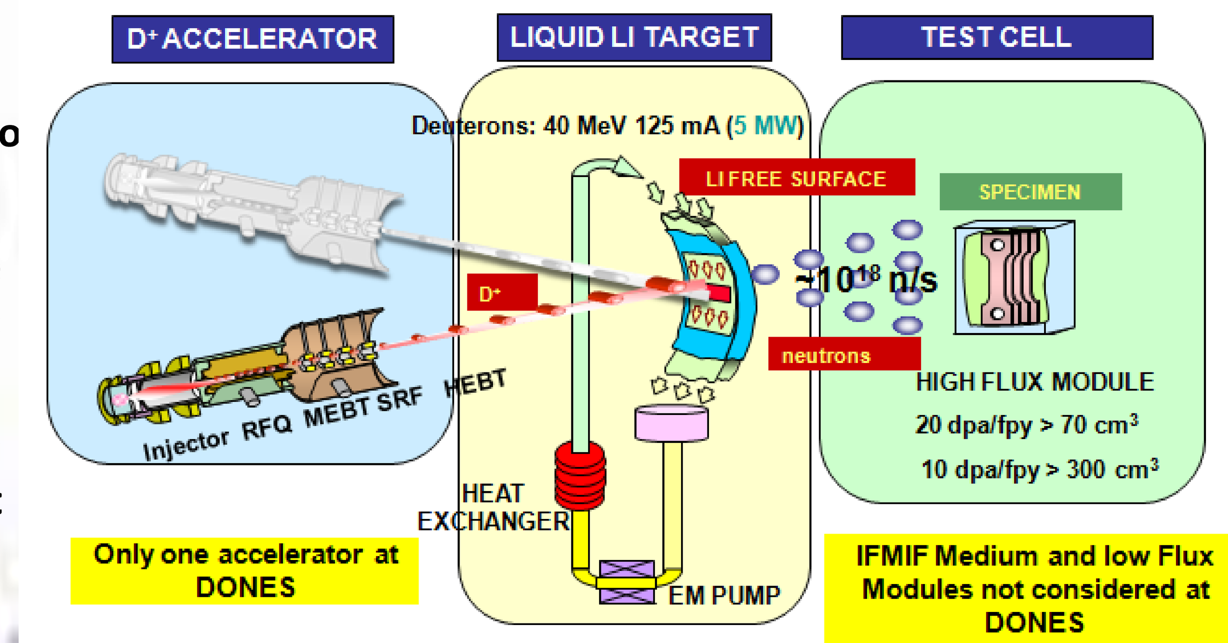
In the framework of the EU Roadmap, a DEMO Oriented Neutron Source (DONES) [1] has been proposed to provide a high neutron intense neutron source with a suitable neutron spectrum to understand the degradation of advanced materials under DEMO and future fusion plants irradiation conditions. DONES will be based on the International Fusion Materials Irradiation Facility IFMIF [2], being only one accelerator considered. The HEBT will be devoted to the transport, bending and shaping of the 40 MeV, 125 mA CW deuteron beam to the free surface of the rapidly flowing lithium target. To produce a forward peaked source of fusion-like neutrons, which stream through the target into the test cell, a rectangular uniform distribution across the flat top of the beam profile is required, being the footprint tailored in both the vertical and horizontal directions according to the target design. Different methods for beam uniformization in IFMIF accelerator has been proposed in the past [3]. Two main concerns in DONES will be the minimization of particle losses over the whole HEBT and the effect of the different shaping techniques on such strong space charge regime, especially on the beam halo modulation. A review of the different methods for the beam shaping of the high power, high space charge DONES HEBT beam will be depicted. A final solution will be proposed.

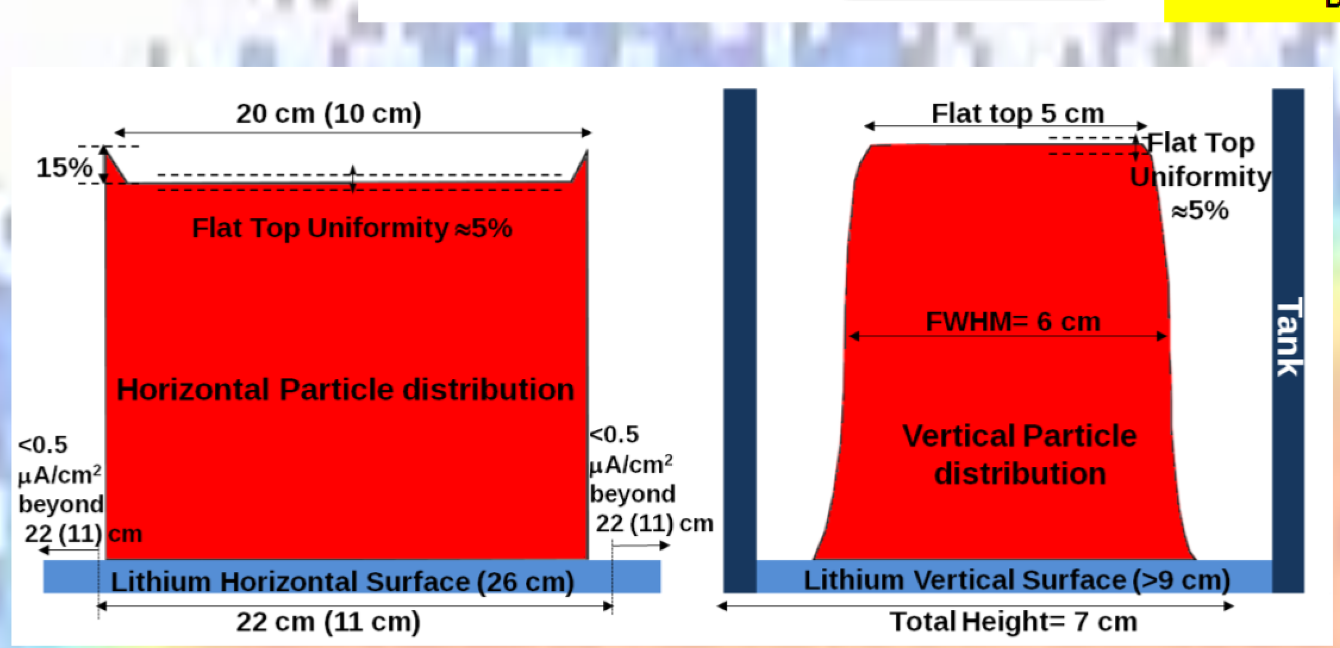
DONES

- **Early Neutron Source for DEMO materials analysis**

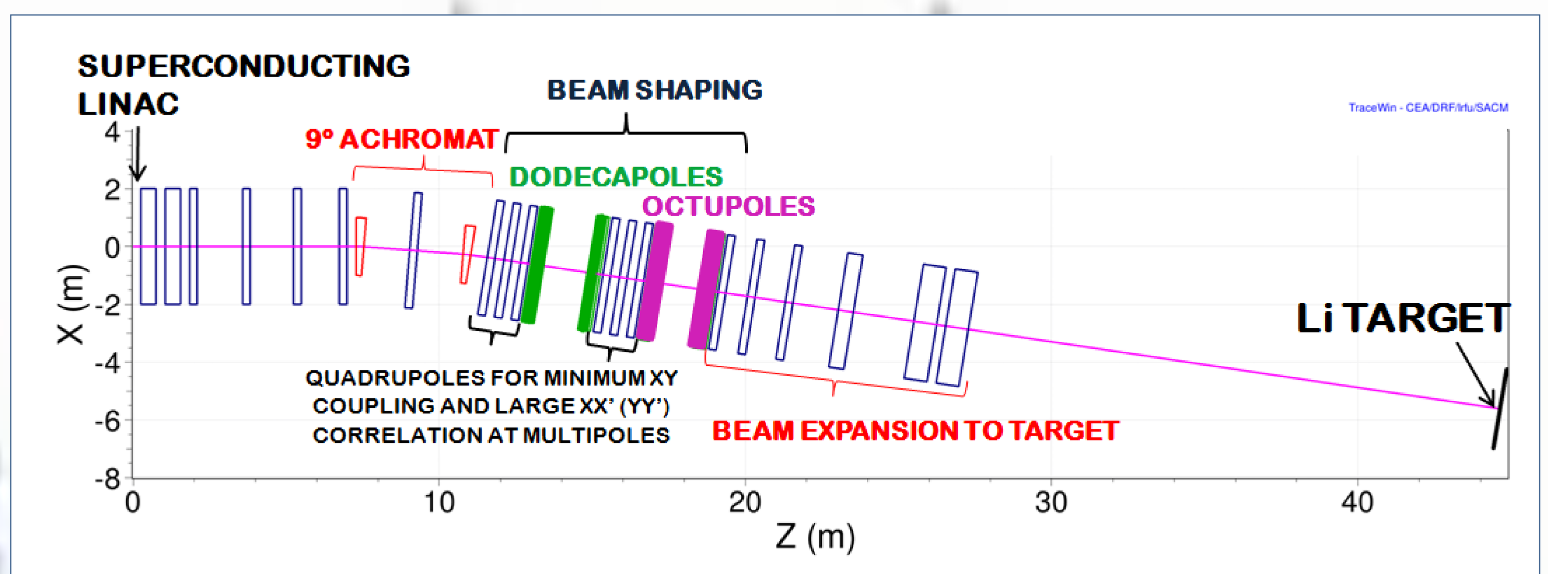
Based on a first stage of the IFMIF project: only one accelerator will be considered

- **Upgrade to a Neutron Source for Power Plant needs → IFMIF**





HEBT



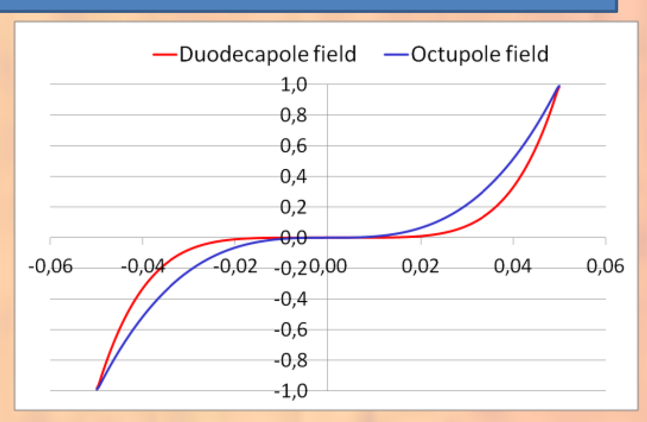
- HEBT designed to transport the beam to target with minimum losses, to shape the beam according target requirements and to allow the location of beam diagnostics
- Special attention to radioprotection issues

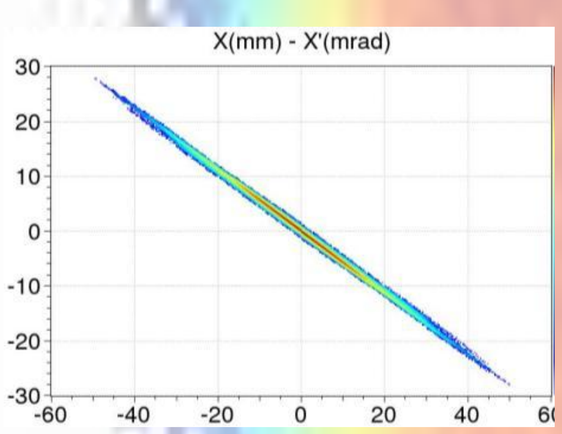
BEAM SHAPING TECHNIQUES:

- ✗ Active techniques based on pencil beam scanning→ possible disruption of the liquid Lithium by the pressure waves [6].
- ✗ "Step-like field magnets" [8] → need of a magnet prototype → impact on the DONES project timeline
- ✓ Final choice → Use of **standard high order multipoles**

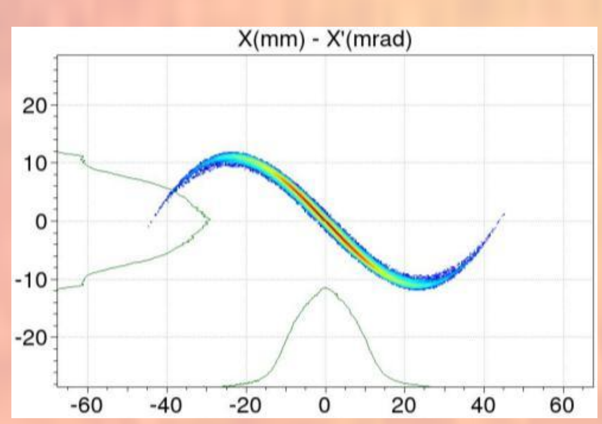
PHASE-SPACE TRANSFORMATION UNDER NON-LINEAR MULTIPOLES

- Particles located in the center of the beam distribution are unaffected
- Divergence of particles far from the center is modified → beam edges are folded into the core

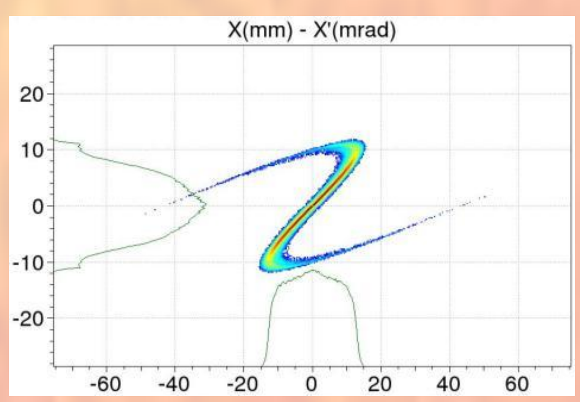




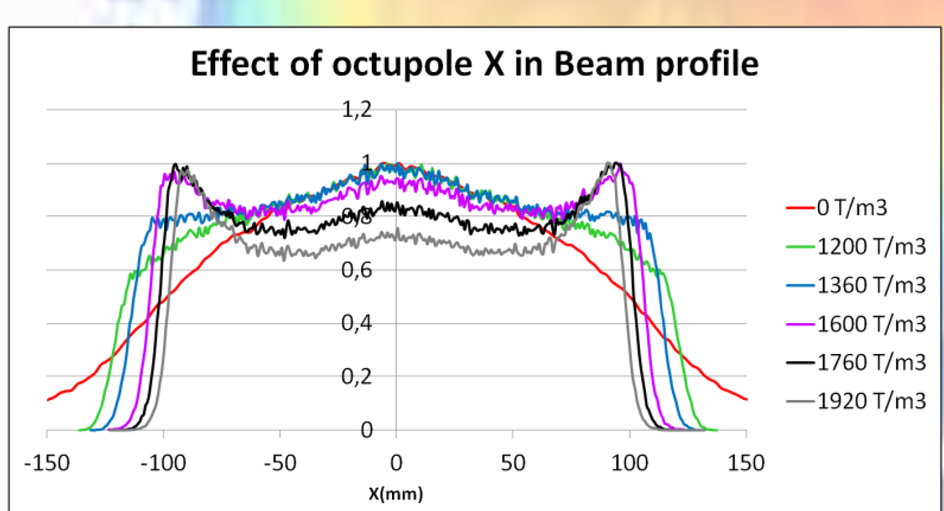
Beam at octupole entrance



Beam at octupole exit



Beam after transportation



- Weak octupoles influence only the far fringes→ modification just on distribution tails
- As octupole strength increases the central part of distribution becomes flatter
- Very strong octupoles fold particles near the core → high intensity peaks

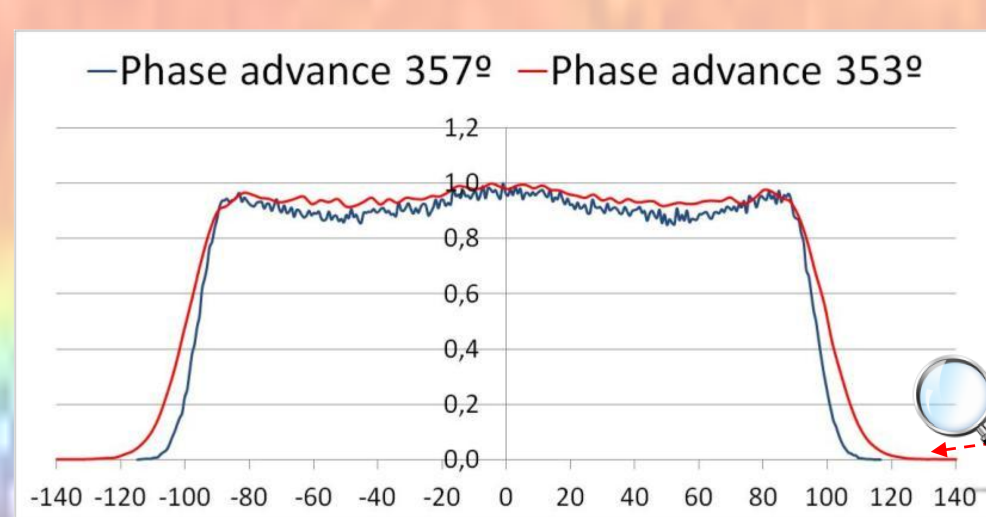
IMPACT OF PHASE ADVANCE ON BEAM SHAPING

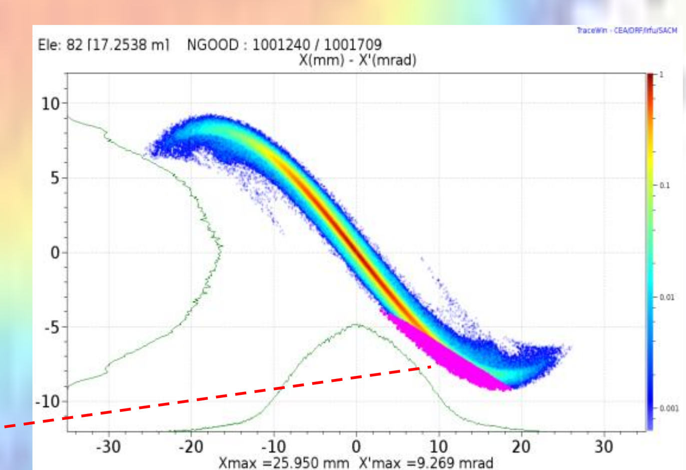
For a Gaussian beam, the octupole strength can be expressed as [11]:

$$K_8\left(\frac{1}{m^3}\right) = \frac{1}{\varepsilon\beta^2 \tan\varphi}$$

- ε emittance and β (Twiss parameter) at the octupole
- φ Betatron phase advance from the octupole to the target.

- Optical sections designed to expand the beam size at the target $\sim n\pi$
- **Phase advances** very **close to $n\pi$** would require very **strong octupoles** to obtain a flat beam.
- Solutions with **slight deviations from $n\pi$**, (±10°), would demand much **weaker octupoles** to obtain a uniform beam.
  - However, a higher contribution of particle divergence at the octupole (*xx'* transfer matrix element, M_{12}, proportional to $\sin\varphi$) → **Loss of sharpness**
- ➡ **Balance between sharp edges and weak octupoles**
- ➡ **Impact on magnet tuning** during simulations and operation



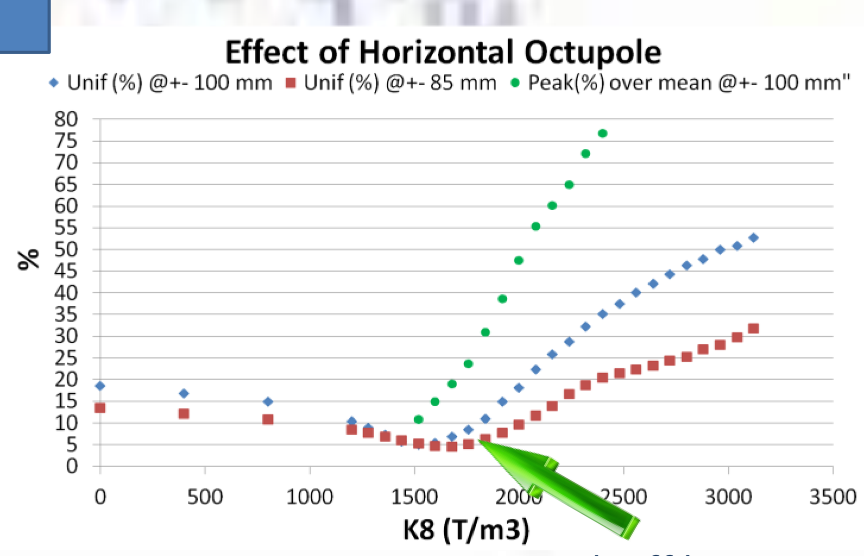


Beam just after octupole

The required octupole to get a flat beam is much weaker in the lower phase advance (1600 T/m³) than in the close to $n\pi$ configuration (2400 T/m³).

FINAL SOLUTION

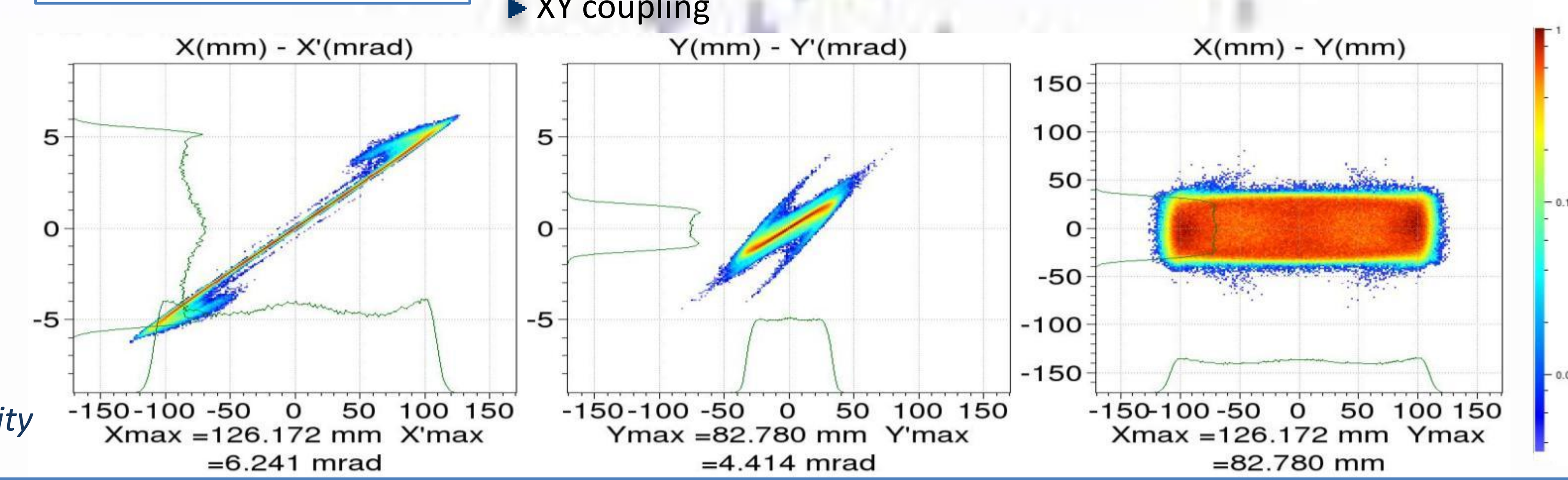
- **Octupoles** to improve the beam uniformity, limiting the tail peaks
- **Duodecapoles** to counteract the undesirable large effect of octupoles on the particles in the very far beam tail→ to limit maximum beam extension



Tradeoff between uniformity and peak edges

Octupoles & Duodecapoles

- Residual beam tail contribution from the strong space charge
- XY coupling



CONCLUSION

The application to DONES of the beam shaping method with non-linear magnets has been shown, being highlighted the strong impact of the phase advance on the optimum magnet tuning procedure.

Future simulations will include an optimization of the phase advance, minimization of x-y coupling and analysis of the 10x5 cm² beam configuration. Additionally, of particular importance are the error studies to define magnets tolerances and analysis of the space charge

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