Beam dynamics and space charge studies for the InnovaTron cyclotron*

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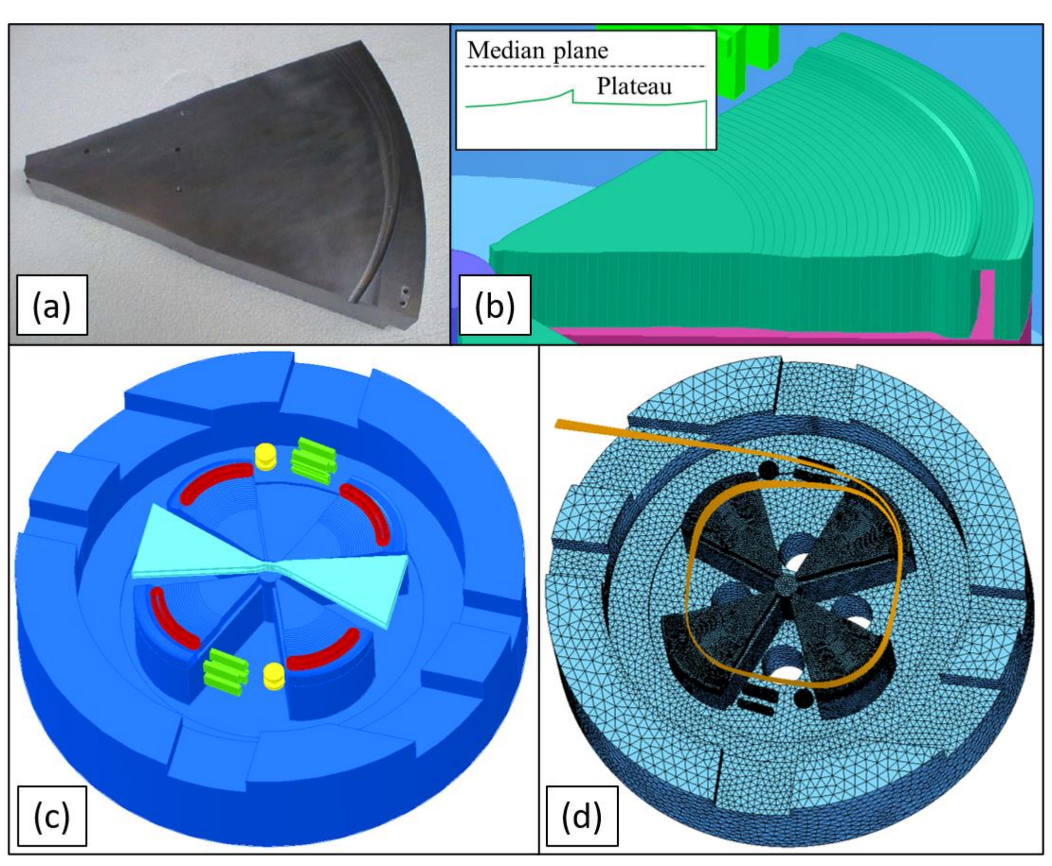
At IBA a high-intensity compact self-extracting cyclotron is being studied. There is no dedicated extraction device but instead, a special shaping of the magnetic iron and the use of harmonic coils to create large turn-separation. Proton currents up to 5 mA are aimed for. This would open new ways for large-scale production of medical radioisotopes. The cyclotron main features are presented. A major variable of the beam simulations is the space charge effect in the cyclotron center. Using the SCALA-solver of Opera3D, we attempt to find the ion source plasma meniscus and the beam phase space and current extracted from it. With these properties known, we study the bunch formation and acceleration under high space charge condition with our in-house tracking code AOC. We also discuss a new tool that automizes optimization of cyclotron settings for maximizing beam properties such as extraction efficiency.

SIMULATION STRATEGY

Our simulation approach consists in an iterative process of optimization of the cyclotron subsystems and of the full integrated design. It is based on FEM simulations and 3D beam tracking including space charge by using AOC, the IBA advanced code.
The main tasks of the InnovaTron project are:

1. optimization of magnet, extraction and central region;
2. simulations of beam extraction from an internal ion source including bunch formation in the first gap.

MAGNET

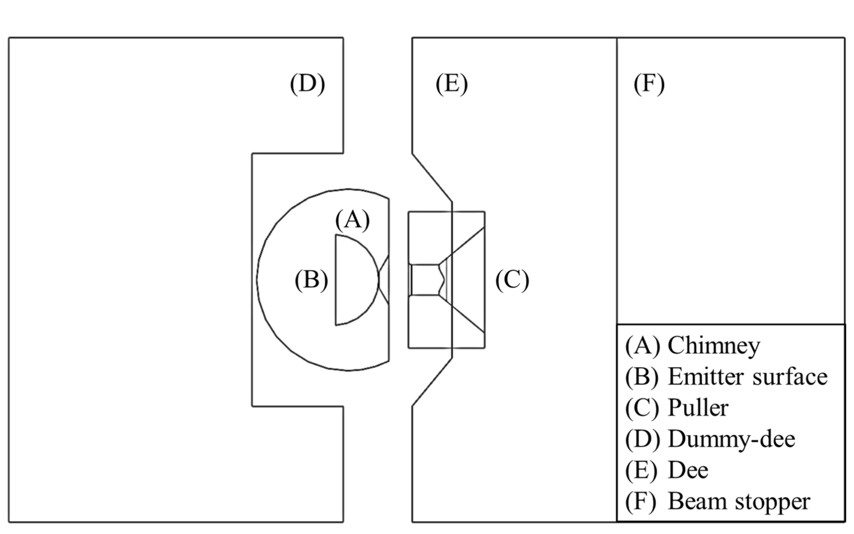


(a) Extraction groove in the prototype; (b) plateau in the improved magnet design; (c-d) FEM model of the full cyclotron

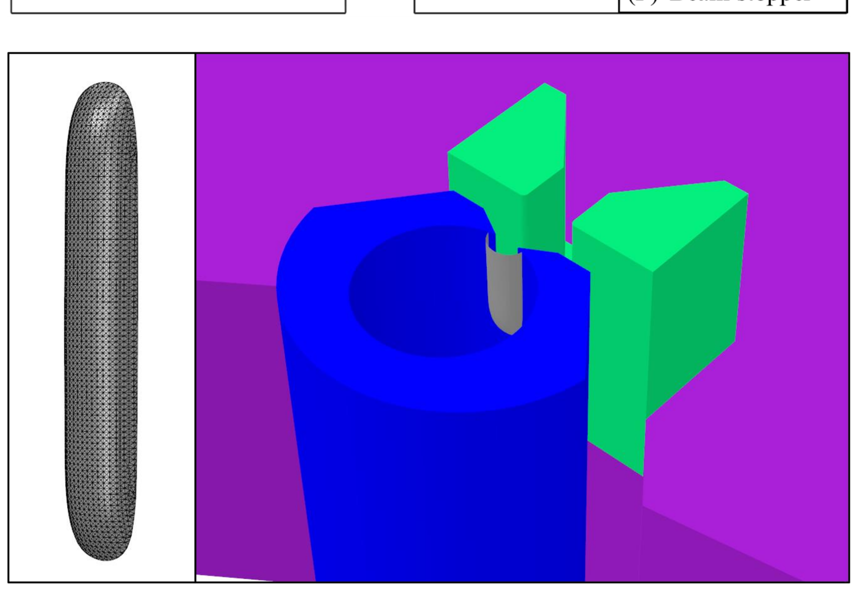
SIMULATION OF BEAM INJECTION

The following design approach has been developed to simulate the beam extraction from an internal ion source and beam dynamics in the cyclotron under space charge conditions:

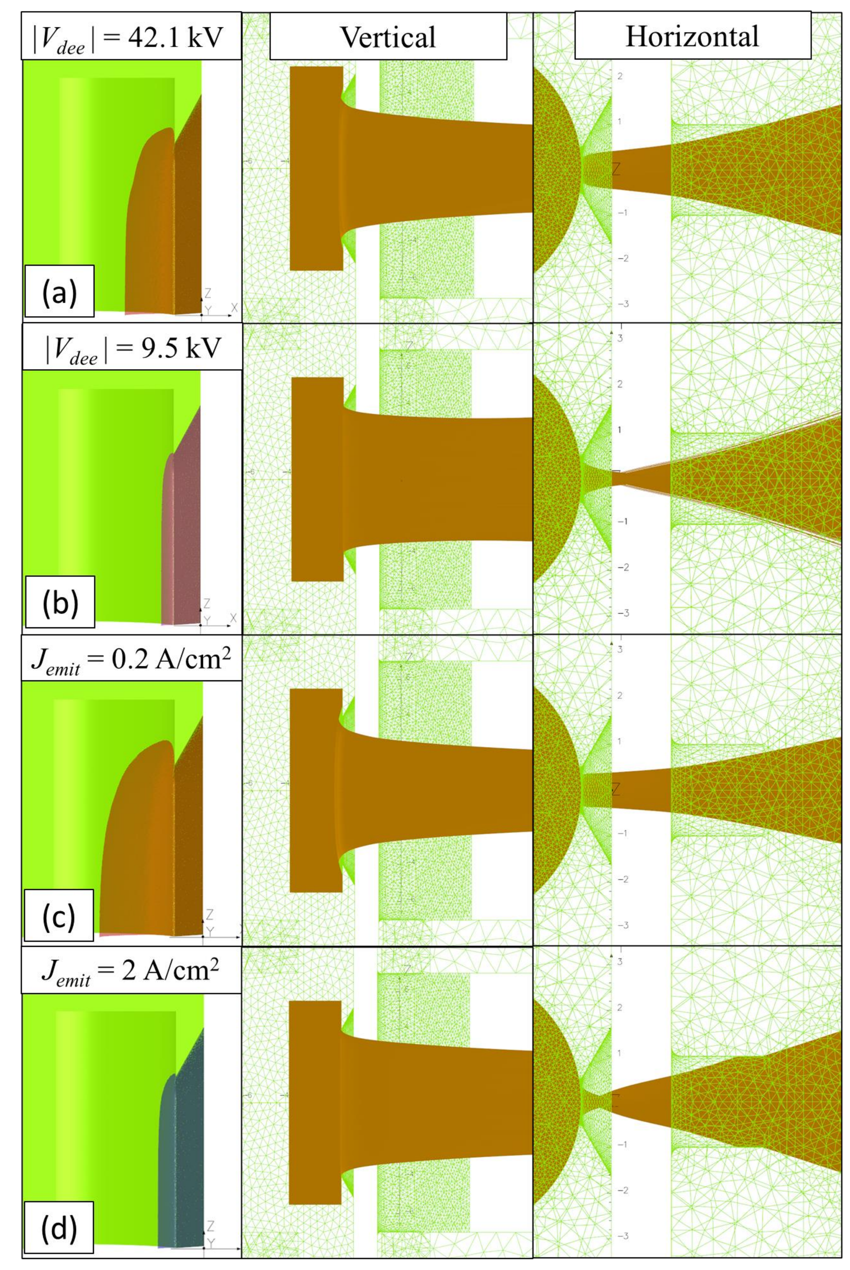
1. Solve a SCALA model of the first accelerating gap to find the meniscus shape and the beam phase space on it;
2. Fit meniscus and beam phase space and solve 3D E-field in the first gap with TOSCA putting the meniscus surface at 0 V;
3. Track the beam starting from the meniscus also simulating the bunch formation by using the space charge module of AOC.



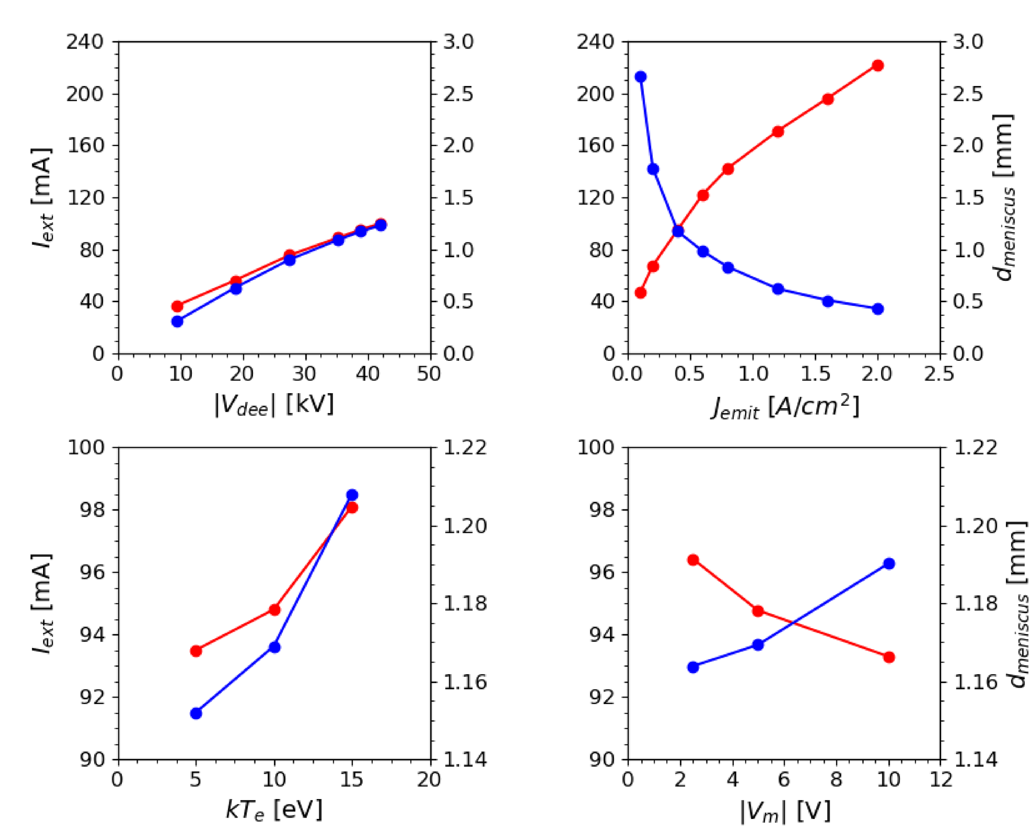
SCALA model of the first accelerating gap



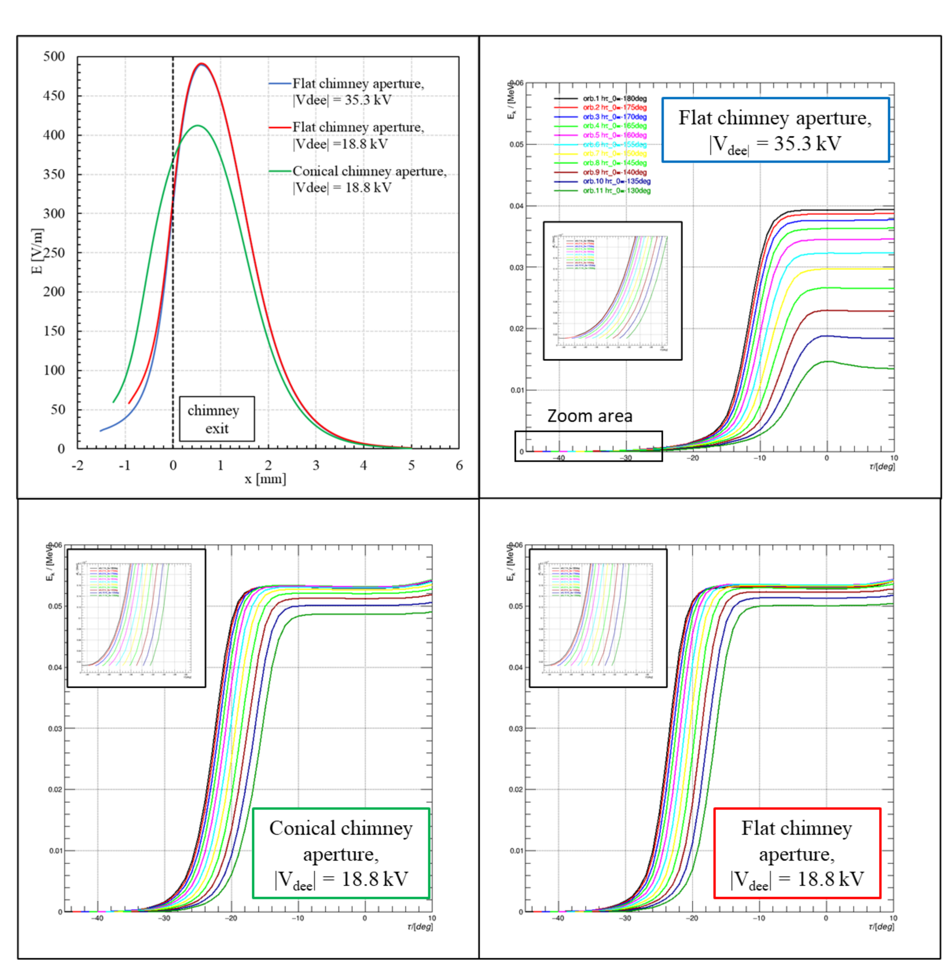
Meniscus and first gap in the TOSCA model



Plasma meniscus and extracted beam from SCALA

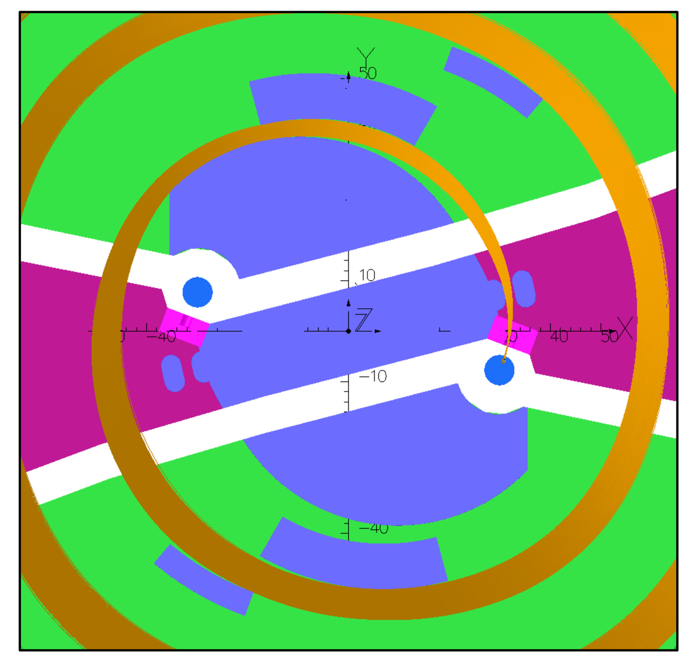


DC extracted current (in red) and meniscus position with respect to the plasma chamber aperture (in blue)

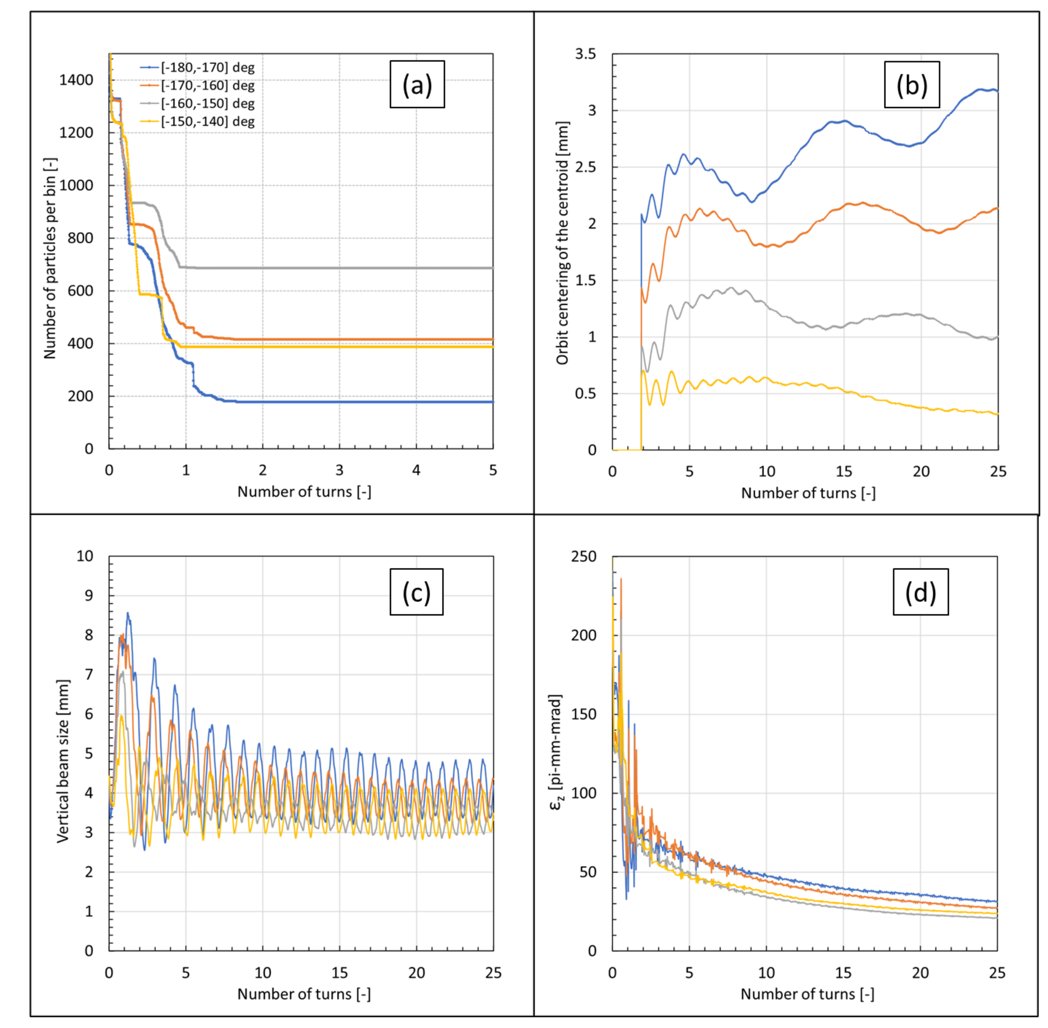


E-field and particle energy in the first gap

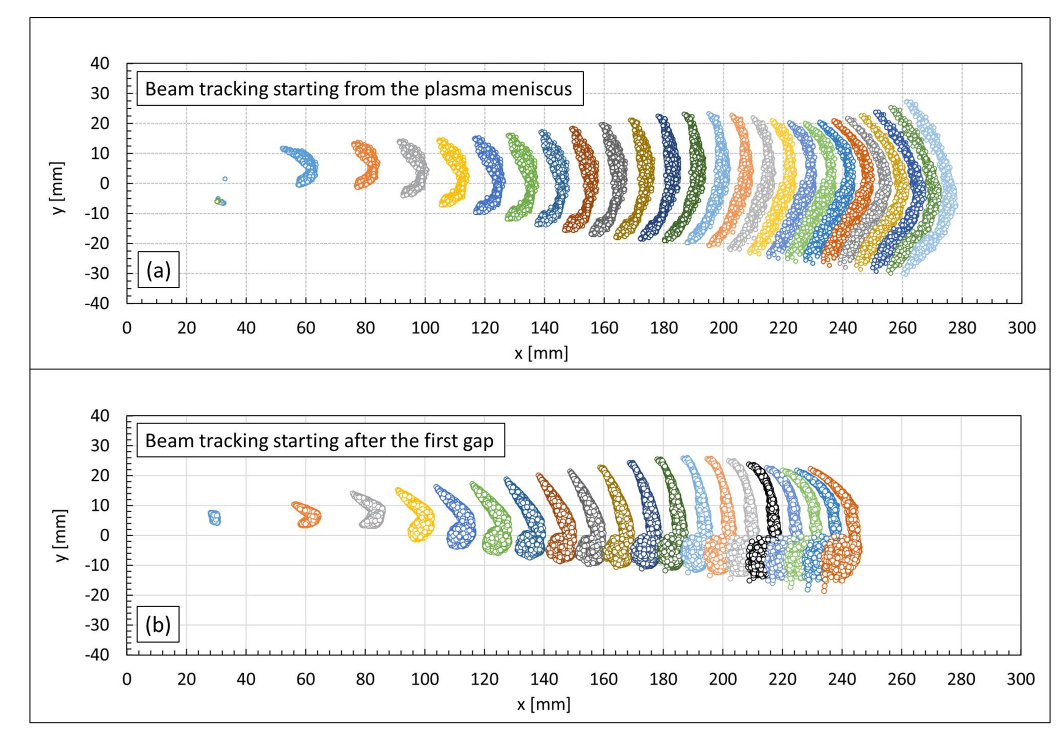
TRACKING WITH SPACE CHARGE



Optimized model of the central region



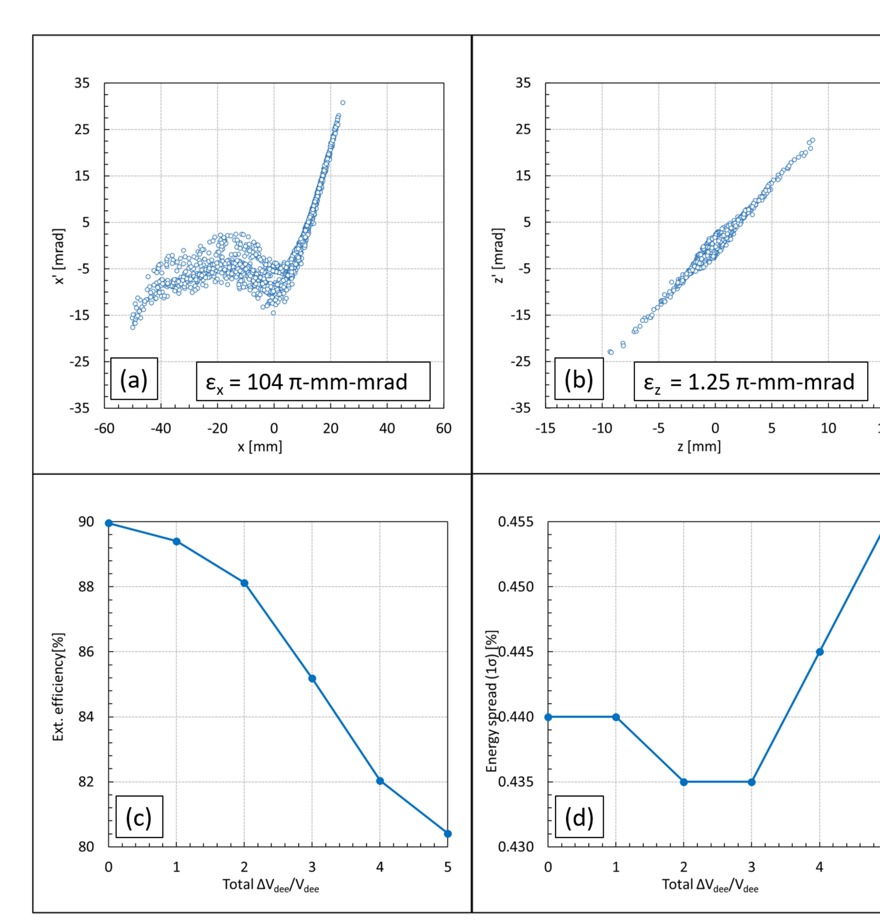
Beam rms properties in relation to starting RF-phase



XY-projection of space charge bunches for 1.7 mA and 3.2 mA

OPTIMIZATION OF CYCLOTRON SETTINGS AND EXTRACTION

Extraction efficiency [%] 1° exit port	Dee voltage 55.17 KV		Harmonic coils currents on the long poles					
			-0.35	-0.3	-0.25	-0.2	-0.15	-0.1
	Harmonic coils current on the short poles	-0.35	59.2	63.1	68.5	76.0	78.7	78.4
		-0.3	59.8	67.0	78.4	82.1	82.2	81.1
		-0.25	60.9	77.2	87.7	87.9	84.9	84.3
		-0.2	81.8	89.6	89.4	89.2	83.7	69.0
		-0.15	91.3	87.3	82.2	68.5	52.3	45.7
		-0.1	76.9	66.3	65.0	72.5	67.6	12.6



Extracted phase space and dee-voltage ripple study.

CONCLUSION

We developed new tools i) for the study of space charge beams extracted from the plasma meniscus and bunch formation in the source-puller gap and ii) for automated optimization of cyclotron settings aiming at highest extraction efficiency.
Further studies are planned, to see if the turn-separation at extraction can be improved.

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