Deflecting System Upgrade Initial Simulations for 37 MeV Cyclotron at NPI Rez

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INTRODUCTION

The goal of the work is to improve extraction efficiency of the U–120M variable energy multiparticle cyclotron, which is about 10 % for deuterons, α particles and Helium 3 ions. The extraction efficiency for protons is below 2 %.

We present simulation results of a modified extraction system concept. The change consists in replacing two electrostatic deflectors with magnetic channels providing additional radial beam focusing. Different approaches for the turn separation are evaluated. Losses along the deflector septums are minimized by an optimal shape. Calculated extraction efficiency has increased by about one order.

Actual extraction system configuration

The currently used extraction system is a modified original scheme designed in 1973 [1] and based on an electrostatic first harmonic exciter (EE) and an electrostatic compensator (EC), three electrostatic deflectors (ESD) and one magnetic channel after ESD III, see Fig. 1.

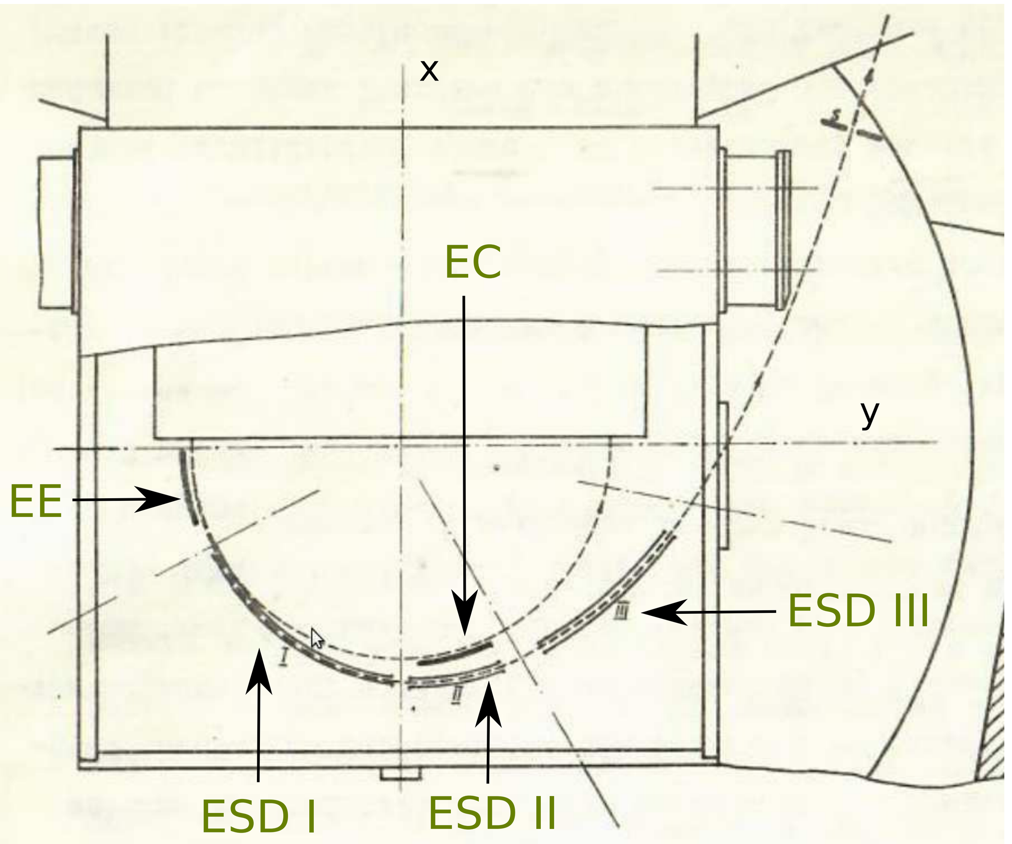

Figure 1: The original concept of the extraction system [1]

The original intention was the deflectors would also have beam focusing properties. This resulted in their complicated shape shown in Fig. 1. The low extraction efficiency is a result of combination of the deflectors complicated shape and an absence of any radial focusing force.

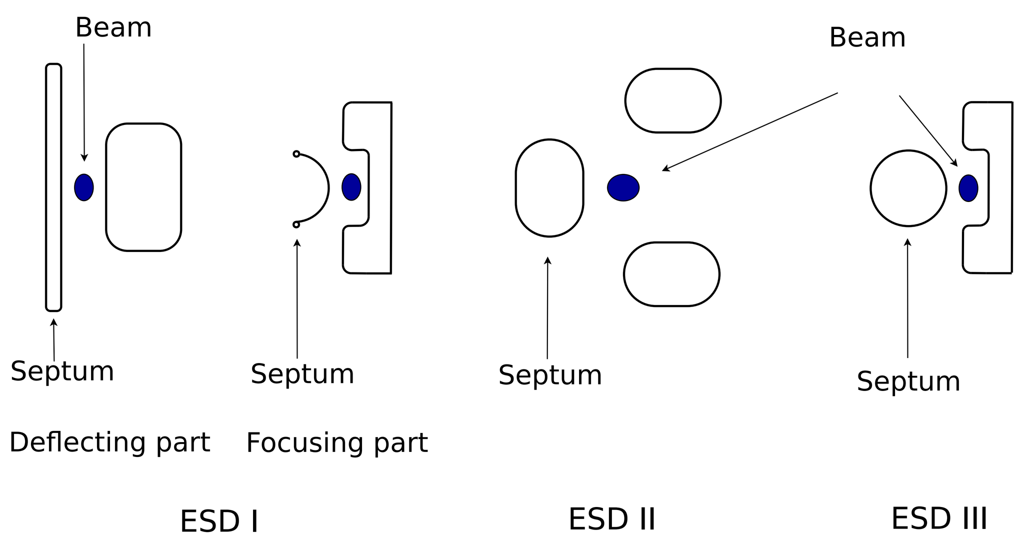

Figure 2: Non trivial profiles of the eletcrostatic deflectors. Gap width for ESD I is 5–8 mm. Gap width for ESD II is about 10 mm. Not labeled profiles belong to high voltage electrodes.

The combination of the electrostatic exciter (EE) and electrostatic compensator (EC) had extraction efficiency close to 40 %. After the compensator failure in 1980, the EE + EC first harmonic excitation system was replaced by a magnetic field bump magnet without a compensation. Then the extraction efficiency dropped to actual low values. First harmonic component of the bump coil and the first deflector ESD I are shown in figures below.

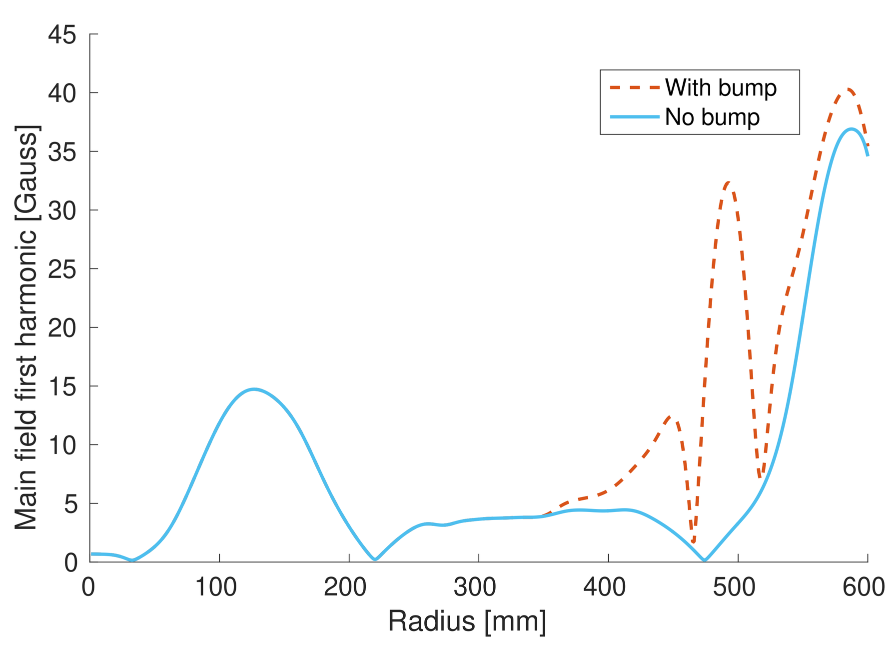

Figure 3: First harmonic field component induced by the bump coil at proton regime for 28 MeV.

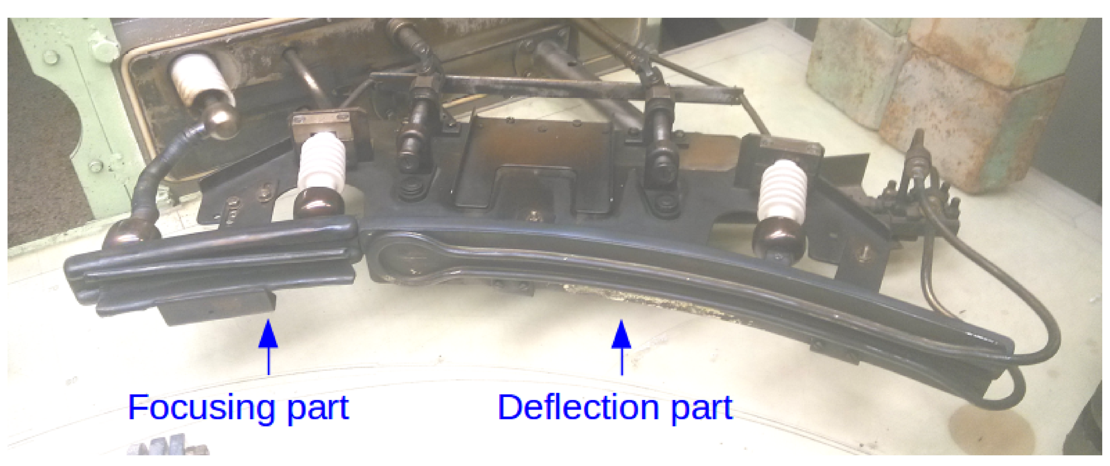

Figure 4: First electrostatic deflector ESD I is divided into deflecting and focusing part.

ACKNOWLEDGEMENTS

This work was supported by Ministry of Education, Youth and Sports under the project CANAM - LM2015056.

SIMULATIONS

Simulations were performed in Durycnm18 [2] and SNOP [3] cyclotron calculating codes for two different regimes. First simulated regime is proton with final energy 28 MeV, second regime is for $^3He^{2+}$ at 44 MeV. Three basic modifications of the extraction system were evaluated:

- Bump coil was turned off. Beam is extracted without an additional turn separation. ESD I septum thickness 0.1 mm.
- Bump coil was replaced by a short ESD 0 with septum thickness 0.14 mm. Outer harmonic coils (VC) used for a turn separation. Phase slits introduced to the cyclotron central region.
- Bump coil used for the turn separation and phase slits introduced to the central region. ESD I prolonged by 6° by its beginning shift. ESD I septum thickness 0.14 mm.

At the moment, the extraction elements are defined just by their analytical fields. Creation of 3D CAD models and implementing simulated electromagnetic fields of the elements will be done in the next step.

RESULTS

Layout of the U-120M harmonic coils is shown in Fig. 5. Inner coils (HC) for the beam centering are placed at radius 140 mm, outer coils (VC) were not intended for the extraction and are place at radius 420 mm, far from the extraction radius 510 mm. The turn separation effect from the outer coils (VC) (see Fig. 7) is beneficial only for limited number of regimes. Best results are obtained using the bump coil (Fig. 8 and Fig. 9). Without any external first harmonic, the intrinsic field first harmonic component works against the extraction process and shifts the beam center to azimuth 270°, just the opposite the deflector azimuth 114°. (Figure 1 rotated +90° with respect to coordinate system.)

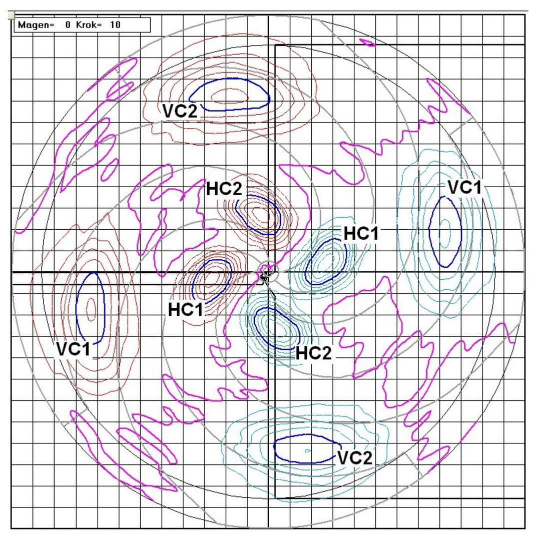

Figure 5: Inner (HC) and outer (VC) harmonic coils. VC placed at 420 mm , far from the extraction radius 510 mm. Full radius 600 mm.

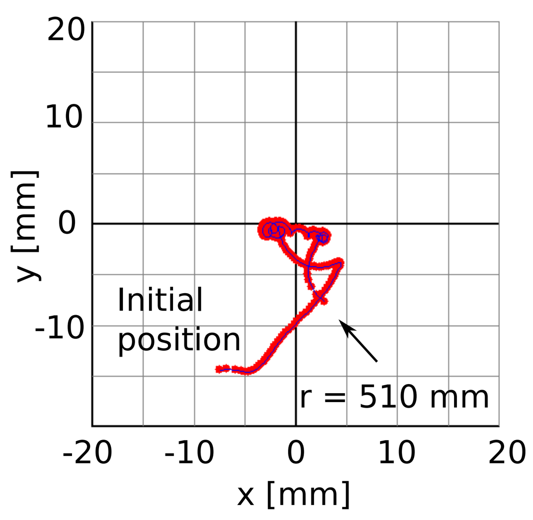

Figure 6: Cental RF phase centering. Intrinsic first harmonic present at azimuth 270°.

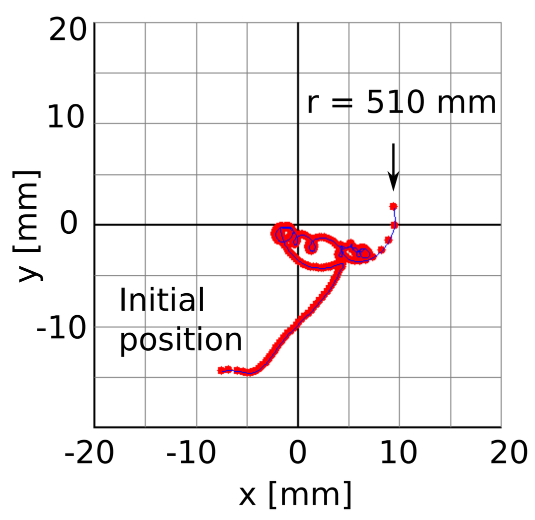

Figure 7: Turn separation using outer harmonic coils (VC). Center shifts to azimuth 70°.

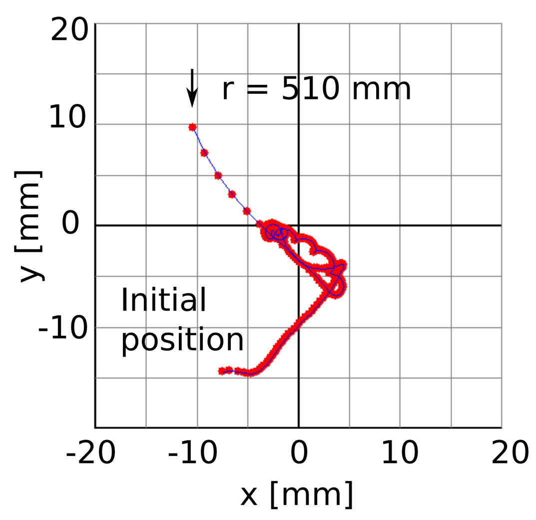

Figure 8: Turn separation using the field bump at azimuth 98°. Best results with the phase slits.

Table 1: Simulation results for analytical magnetic channels.

		p 28.0 MeV	**$^3He^{2+}$ 44.0 MeV**
RF phase beam width		30°	55°
Central RF phase		−7°	−2°
Extracted beam radial emittance		7.8 π.mm.mrad	13 π.mm.mrad
Extracted beam vertical emittance		0.9 π.mm.mrad	1.1 π.mm.mrad
Losses on septum	From initial beam	3.5 %	3.6 %
	From accelerated beam	11.8 %	7.1 %
ESD transmission ratio	From initial beam	25.8 %	47.9 %
	From accelerated beam	**88.2 %**	**92.9 %**

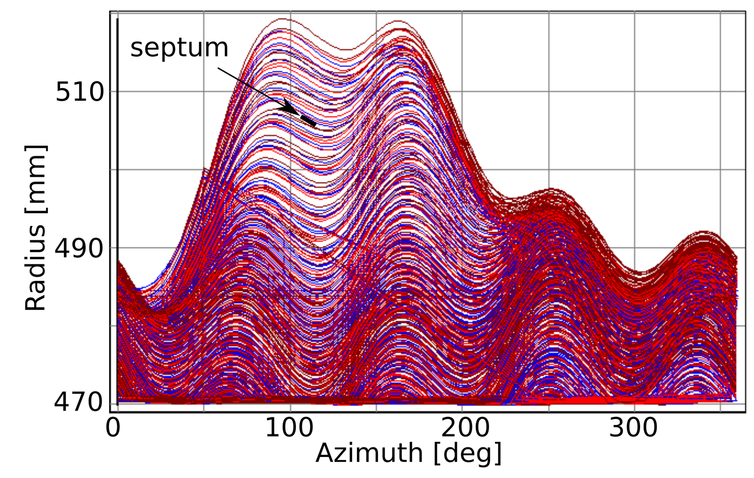

Figure 9: Turn separation at azimuth 98° using the bump coil. Preferred solution. Corresponds to Fig. 8.

ESD septum losses

Losses evaluated for an optimized septum shape. For both regimes, the same septum was inserted between turns separated by the bump coil (Fig. 8). The septum radial position and its angle was optimized separately for each regime.

An ideal septum shape, effective for most regimes, is wanted. For protons at 28 MeV, the septum losses are just at the septum beginning (see Fig. 10). For the $^3He^{2+}$ at 44 MeV, both septum ends are touching the beam and the septum position needs to be further optimized as shown in Fig. 11.

Half of the total septum loss is located at its edge. As an overheat prevention, the septum V–shape or a soft metal is considered.

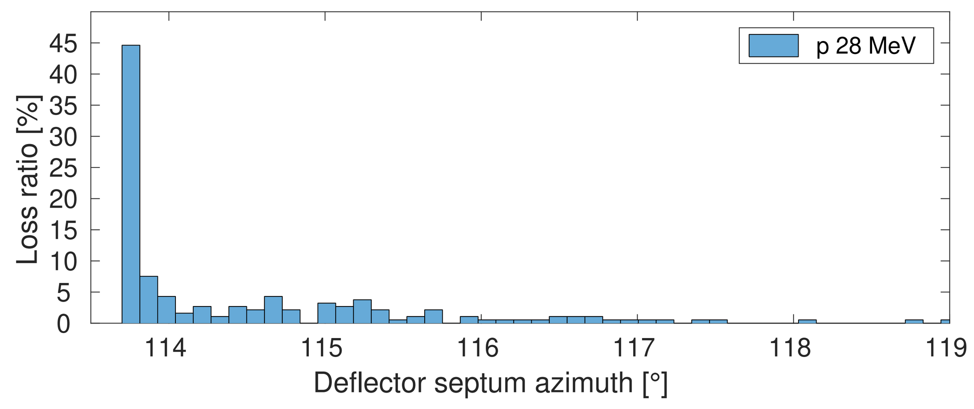

Figure 10: Regime for p 28 MeV. Detail of the septum beginning.

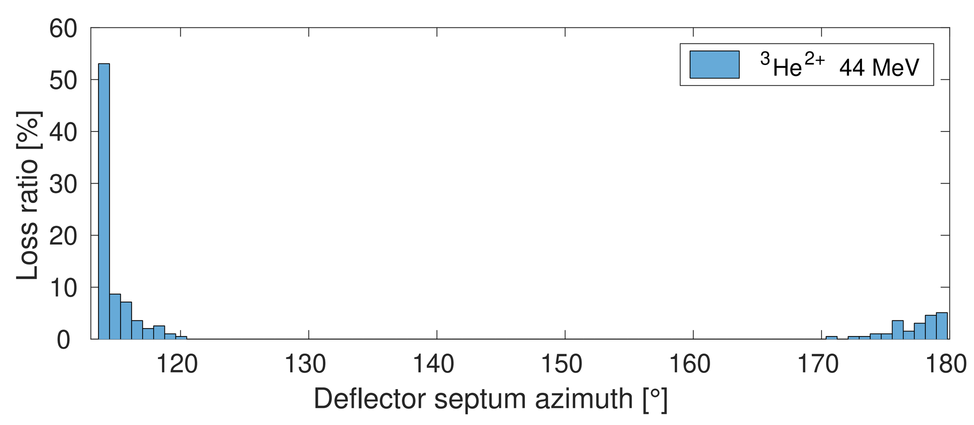

Figure 11: Regime for 3He^{2+} 44 MeV. Full septum length.

Phase slits

Introduction of the phase slits (PS) to the cyclotron central region seems to be a crucial part of the extraction system upgrade. The large reduction of the septum loss is due to the limitation of extreme RF phase values. By a proper radial position of the two simulated PS we are able to precisely limit and control the RF phase width.

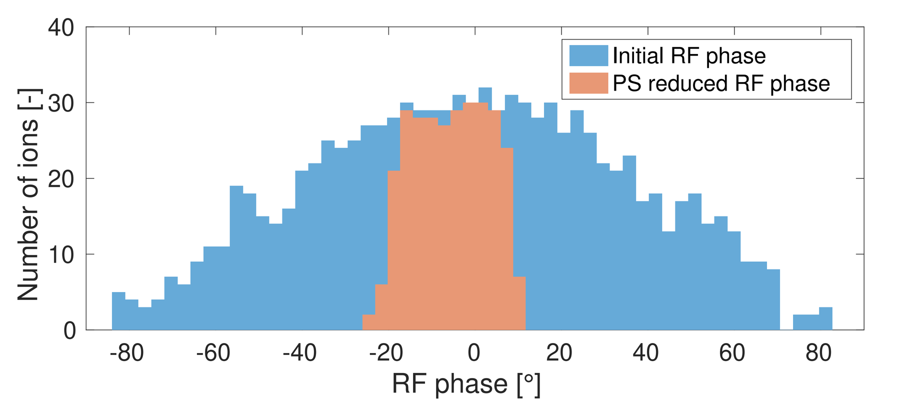

Figure 12: Reduced beam RF phase to ±15° around a center −7°.

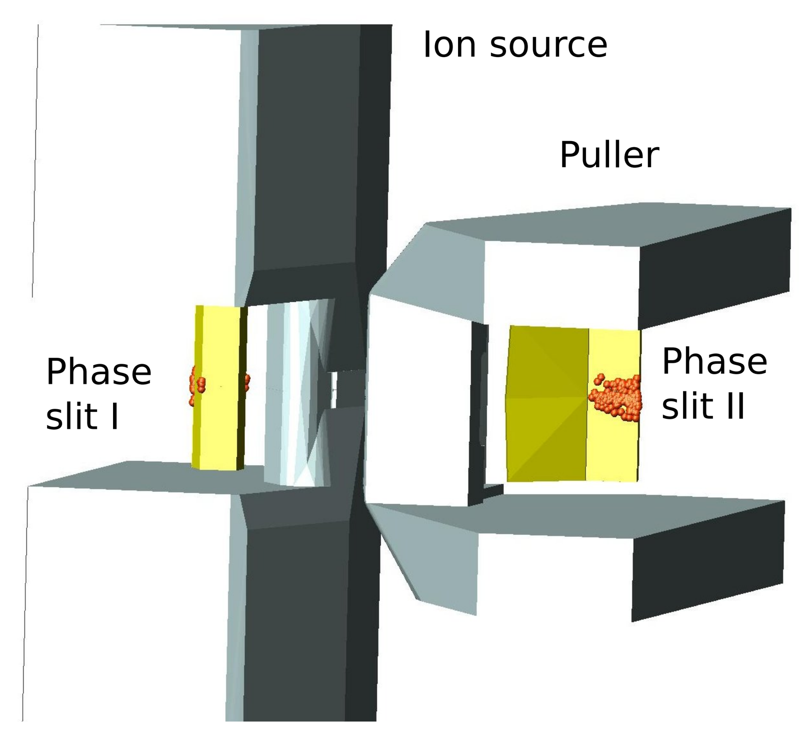

Figure 13: Loss of particles at the phase slits in central region.

CONCLUSION

We were able to increase the transmission ration of the first electrostatic deflector (ESD) by limiting the RF phase of the beam in the central region and defining a proper shape of the ESD septum. The total extracted current was significantly increased by replacing the last two ESD's with magnetic channels providing radial focus. The analytical fields of the extraction elements now used for the calculations will be replaced in the future by their simulated field. Calculating magnetic channel properties seems to be a major challenge.

References

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DOI: 10.13140/2.1.2035.9684.