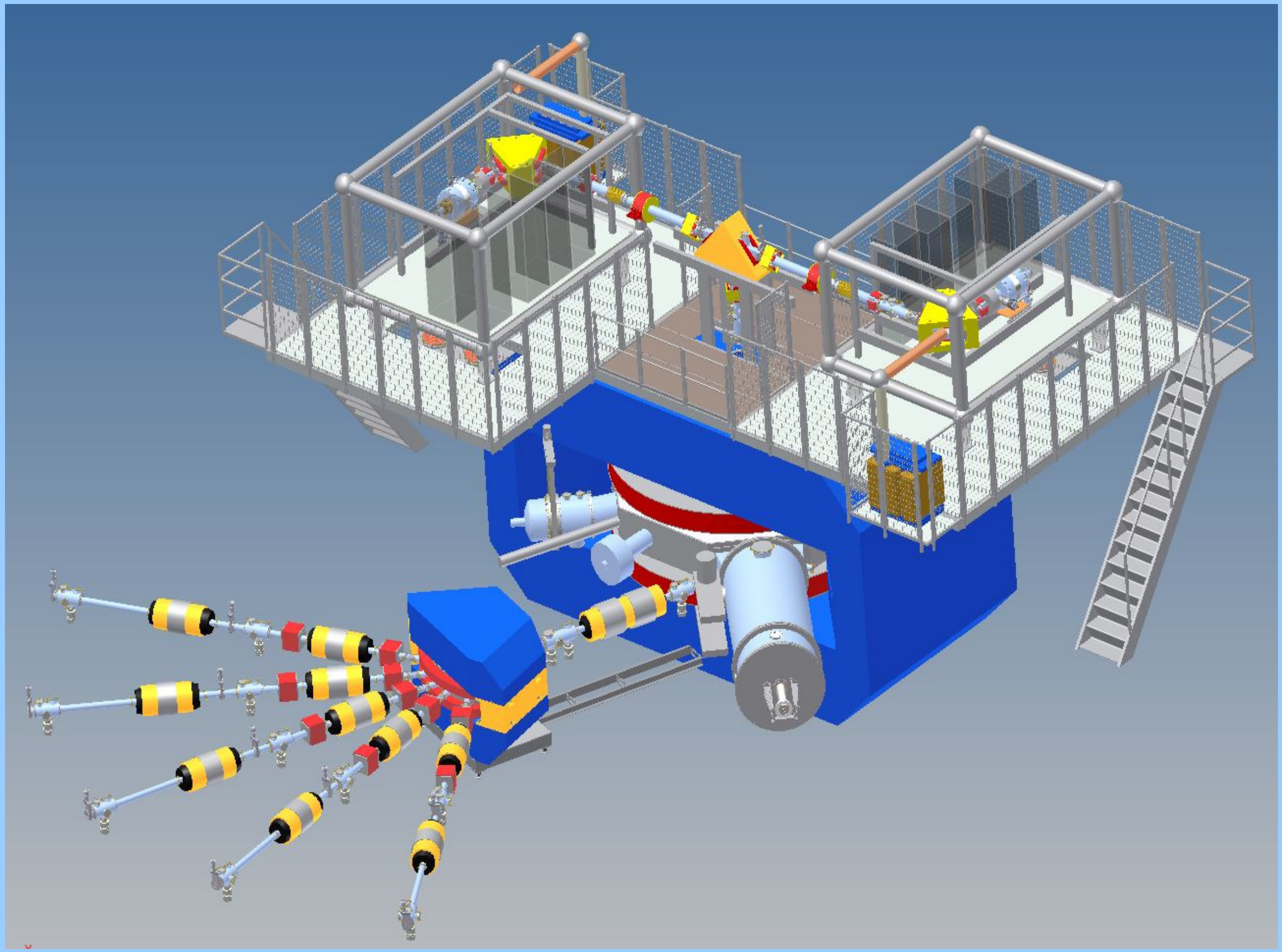
Injection and Acceleration of Intense Heavy Ion Beams in JINR New Cyclotron DC280

HIAT 2015



Abstract

At the present time the activities on creation of the new heavy-ion isochronous cyclotron **DC280** are carried out at Joint Institute for Nuclear Research.

The isochronous cyclotron DC-280 will produce accelerated beam of ions with A/Z= 4 - 7 to energy W= 4 – 8 MeV/n and intensity up to 10pmcA (for 48Ca).

The goal for DC-280 accelerator complex is more then 40% beam transfer efficiency. To achieve high-intensity ion beam, the cyclotron is equipped with high-voltage, up to 80kV, injection line and independent Flat-Top RF system.

To decrease the aperture losses at centre region the electrostatic quadruple lens will be installed between inflector and first accelerating gap. The paper presents the results of simulation of beam injection and acceleration.

U400 Cyclotron (1978)

U400 cyclotron has been in operation since 1978.

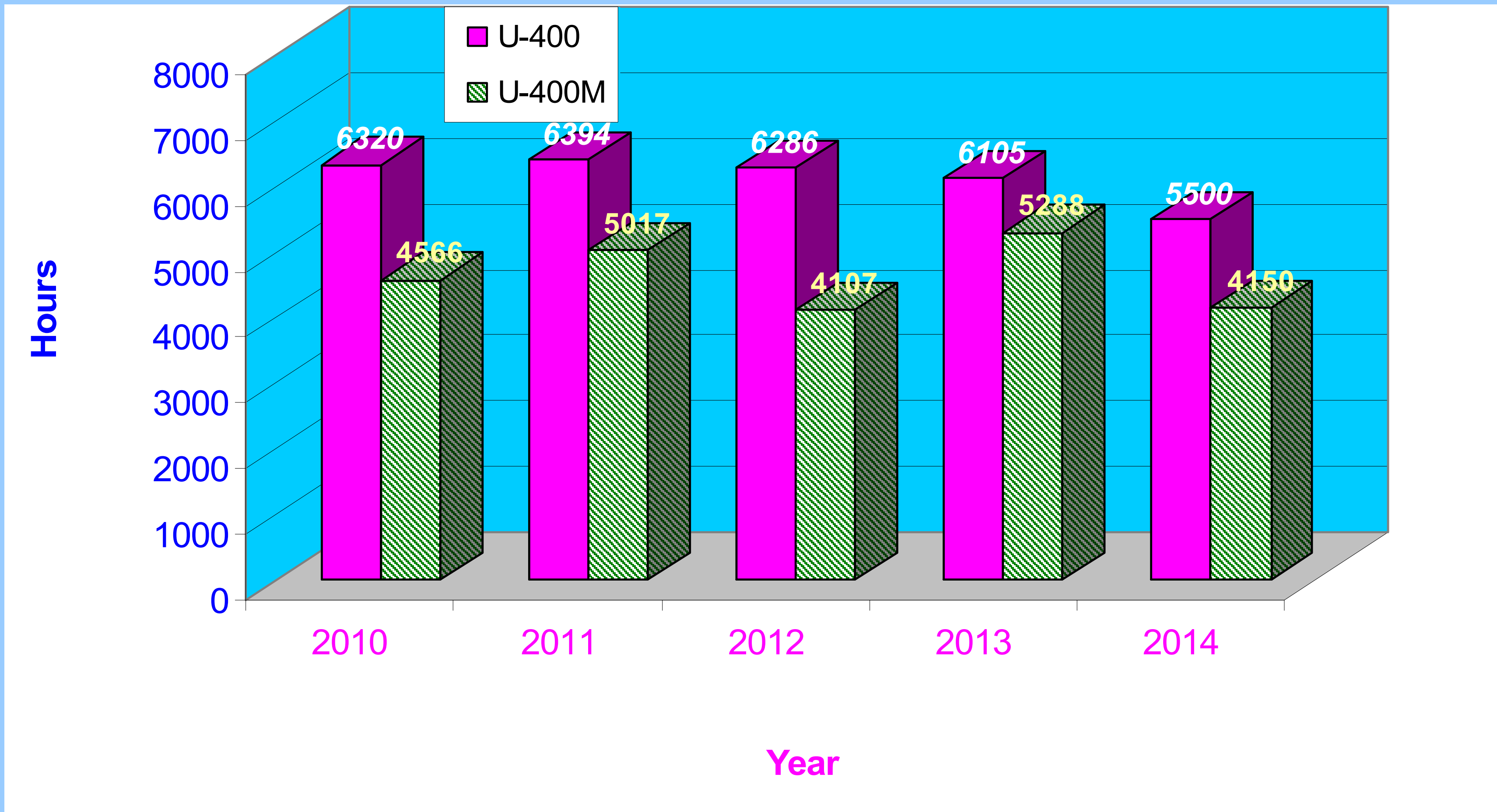
U400 is designed for production of accelerated ion beams of atomic mass in the range A=4 ÷ 209 and energy 3 ÷ 29 MeV/nuclon.

The main experiments of U400 accelerating complex are the synthesis of superheavy elements in the reactions with 48Ca ions

48Ca beam intensity on a target is about 1pmkA

http://flerovlab.jinr.ru/

U400 and U400M cyclotrons operation time



Super Heavy Element facility, Cyclotron DC280

In order to improve efficiency of the experiments it is necessary to obtain the accelerated ion beams with following parameters.

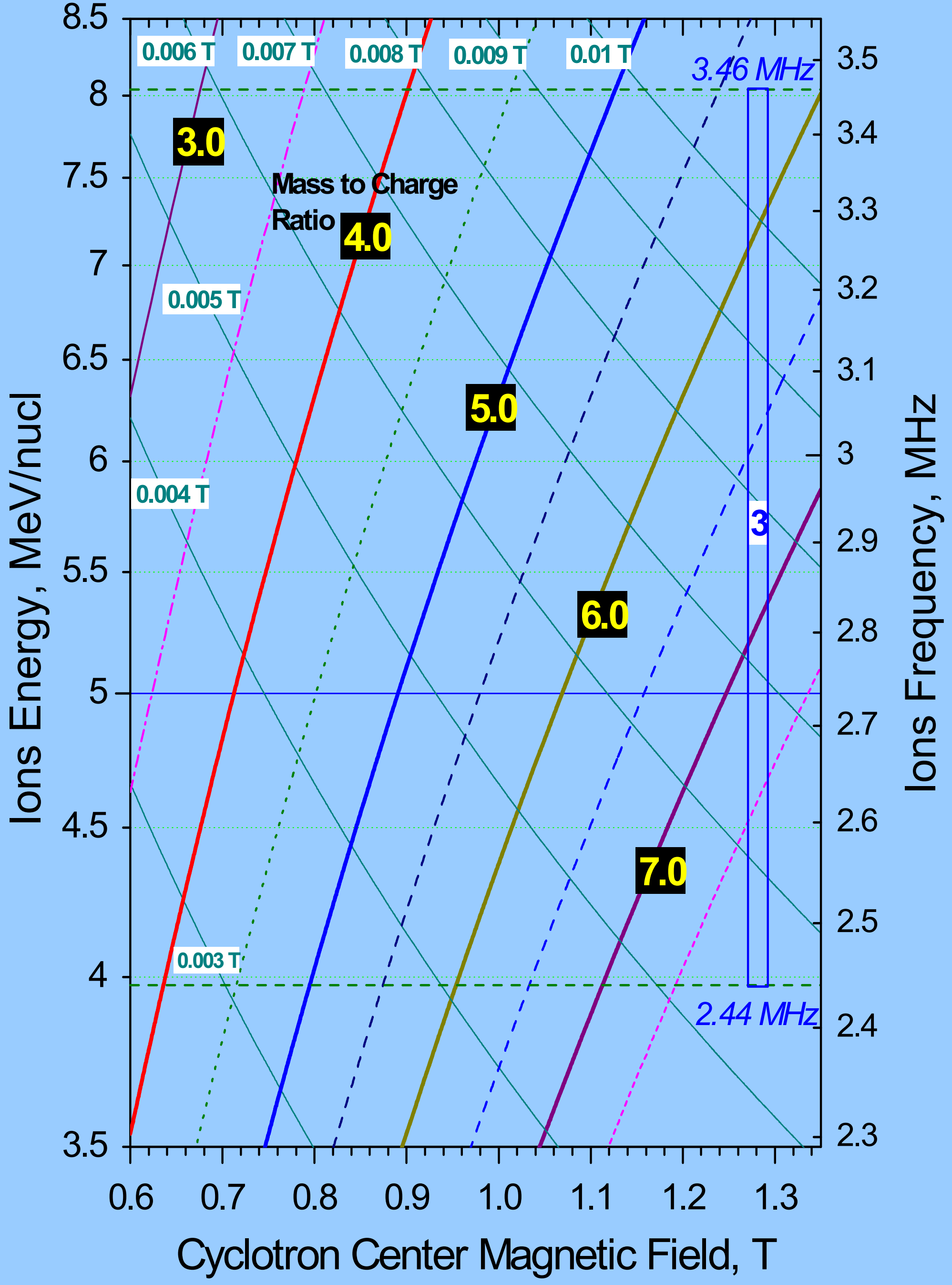
Energy	**4÷8 MeV/n**
Masses	**10÷238**
Intensity (up to A=50)	**> 10 pμA**
Beam emittance	**less 30 π mm·mrad**
Efficiency of beam transfer	**> 40%**

DC280 accelerator complex

- Synthesis and study of properties of superheavy elements.
- Search for new reactions for SHE-synthesis.
- Chemistry of new elements.

DC280 (expected) E=4÷8 MeV/A		
Ion	Ion energy, MeV/A	Output intensity, pps
^{7}Li	4	1×10^{14}
^{18}O	8	1×10^{14}
^{40}Ar	5	6×10^{13}
^{48}Ca	5	$0,6\text{-}1,2\times10^{14}$
^{54}Cr	5	2×10^{13}
^{58}Fe	5	1×10^{13}
^{124}Sn	5	2×10^{12}
^{136}Xe	5	1×10^{14}
^{238}U	7	5×10^{10}

DC280 working diagram



A/Z= 4 – 7
W = 4 - 8MeV/n

B_o = 0.6 – 1.35 T
3 harmonic RF

DC280 Main Parameters

Ion source	DECRIS-PM - 14 GHz DECRIS-SC3 - 18 GHz
Injecting beam potential	Up to 100 kV
A/Z range	4÷7
Energy	4÷8 MeV/n
Magnetic field level	0.6÷1.35 T
K factor	280
Pole diameter	4000 mm
Valley/hill gap	500/208 mm/mm
Magnet weight	1000 t
Magnet power	300 kW
Dee voltage	2x130 kV
RF power consumption	2x30 kW
Flat-top dee voltage	2x13 kV

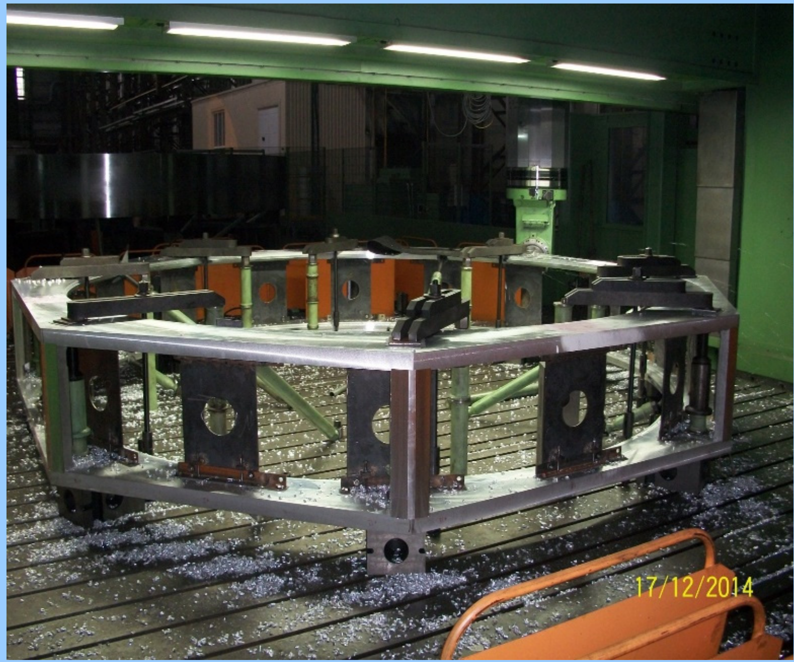
SHE factory, Building computer model

Present Status of the SHE factory building

on-line: http://inflnr.jinr.ru/dc280.html

DC280 cyclotron subsystems

DC280 main magnet



Vacuum chamber

Bending magnet

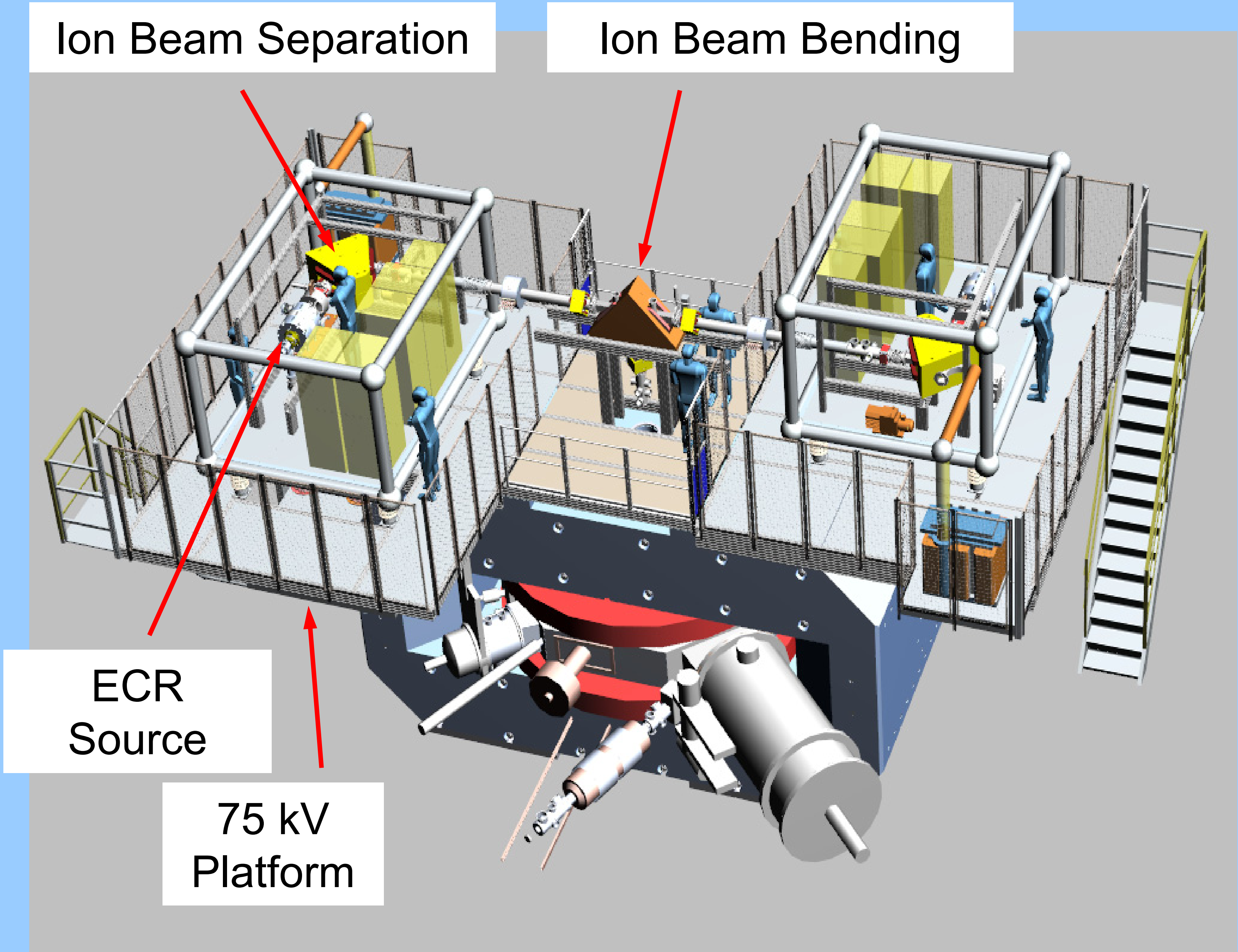
RF Amplifiers

Water cooling system

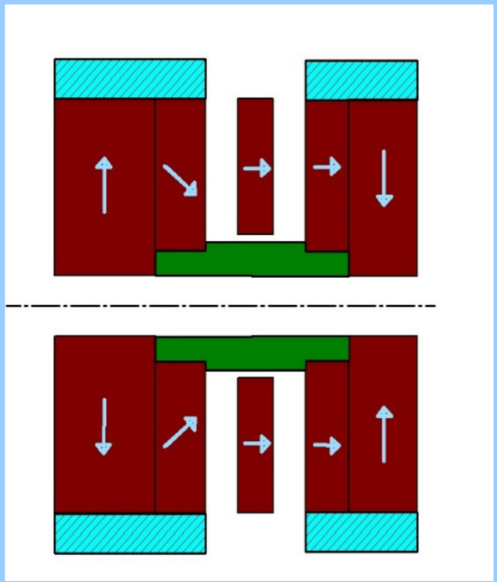
DC280 Parameters and Goals

	DC280 Parameter	Goals
1.	High voltage injection (up to 100 kV)	Decreasing space charge factor. Decreasing beam emittance.
2.	High gap between central plugs	Space for long spiral inflector and quadrupole lens
3.	Low magnetic field	Large starting radius. High turns separation. Low deflector voltage
4.	High acceleration rate with RF voltage up to 130kV	High turns separation.
5.	Flat-top system	High capture. Beam quality.

DC280 Cyclotron



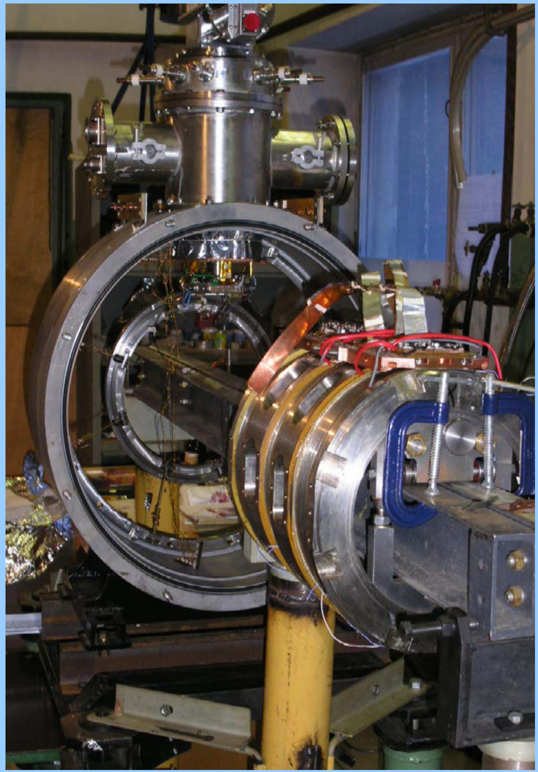
DECRIS-PM



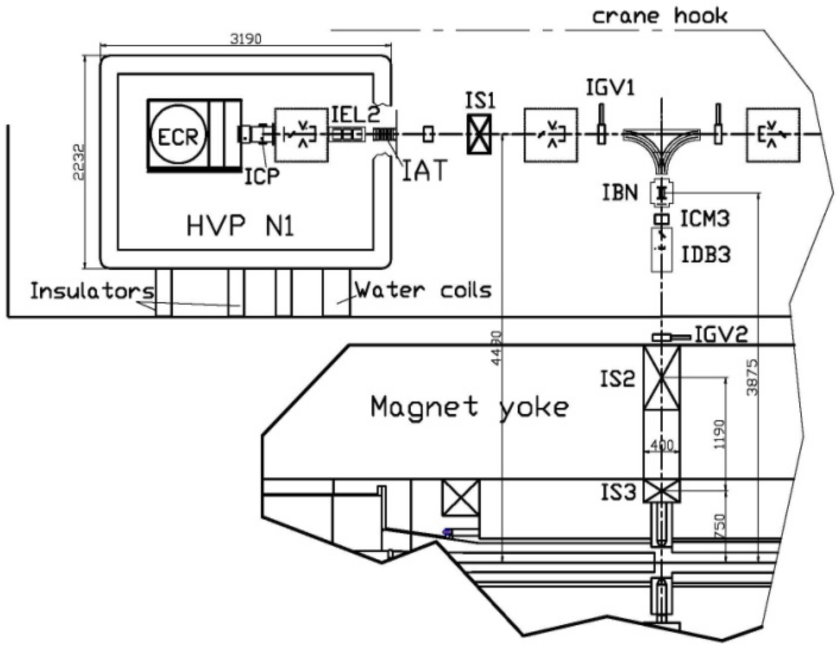
DECRIS-PM ion source with permanent magnets has to produce high intensities of ions with medium masses, from He to Kr (for example, 48Ca 7+,8+)

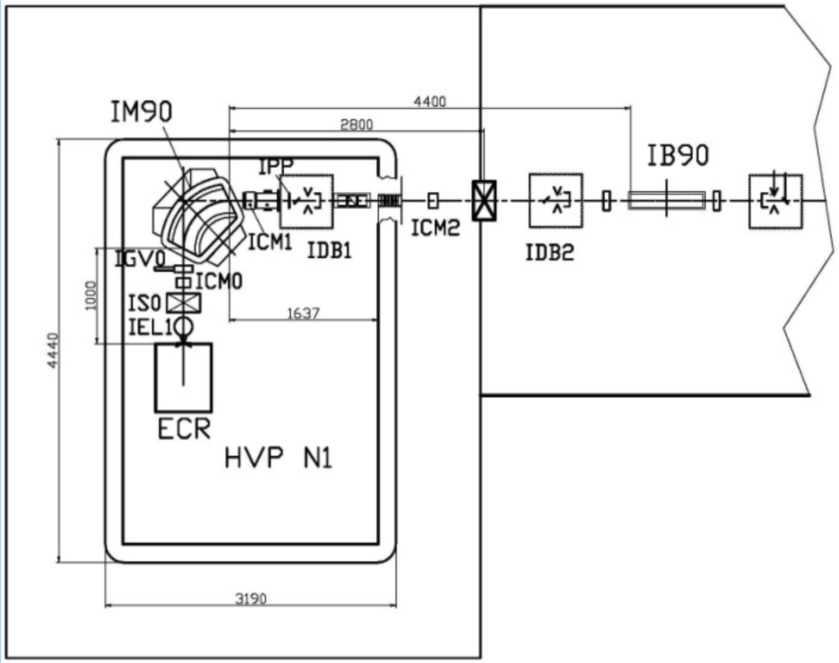
Poster session   WEPB20

DECRIS-SC



DECRIS-SC superconducting ion source has to produce the high charged heavy ions, such as 238U39+,40+.



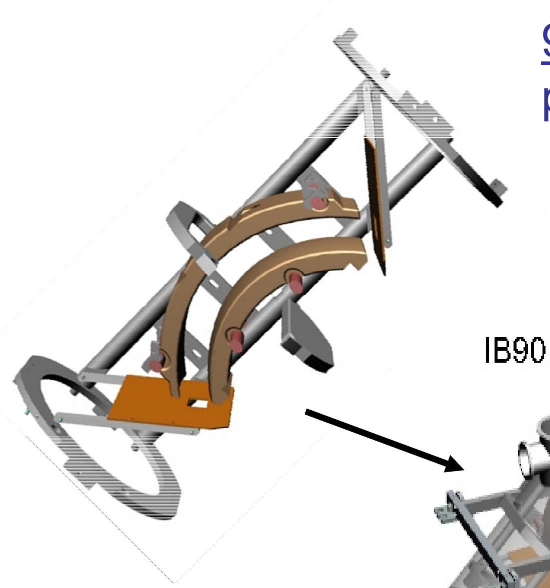


Scheme of DC280 axial injection system

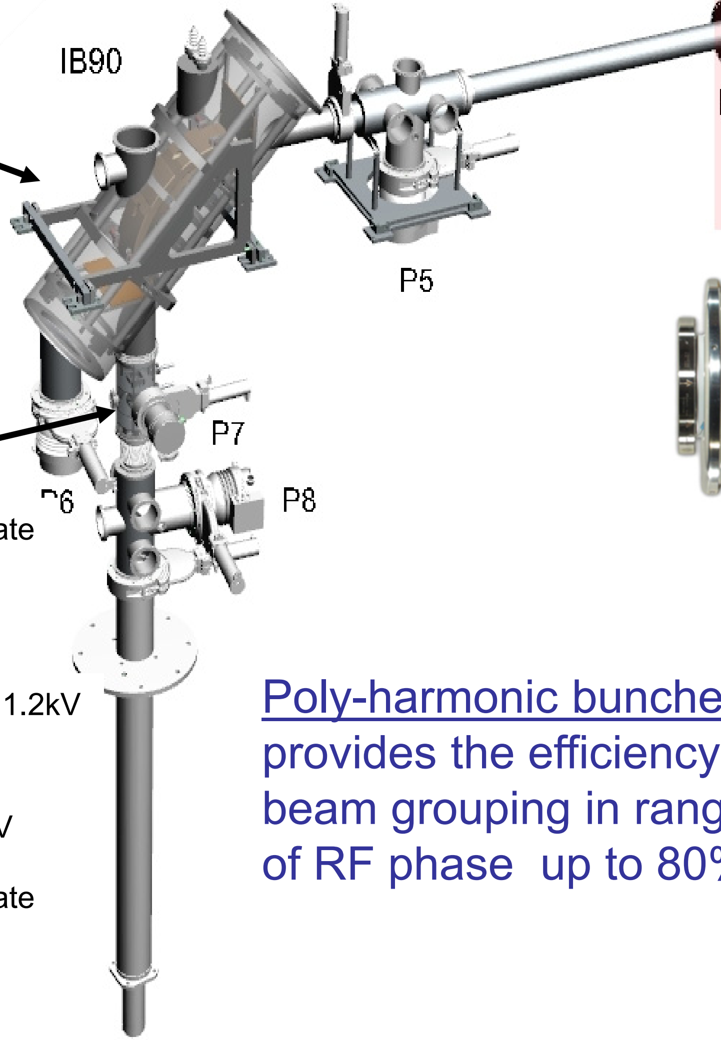
- ECR - ion sources;
- IM90 - analysing magnet;
- ICP - beam chopper;

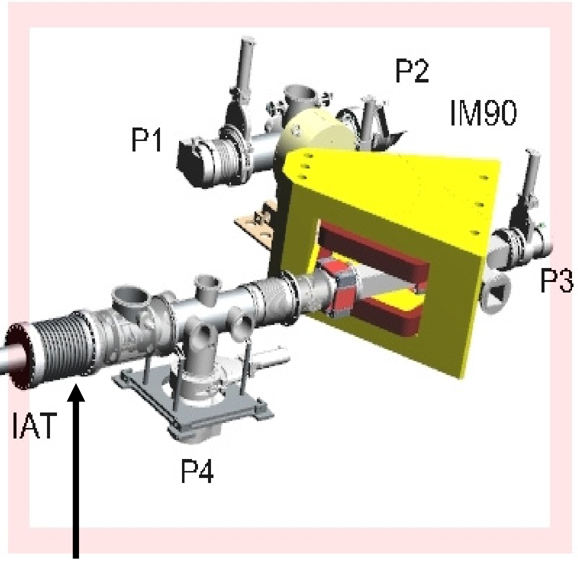
- IB90 - electrostatic bender;
- IBN - poly-harmonic buncher;

- IAT - accelerating tube;
- IEL1, IEL2 - Einzel lenses;
- IS0,IS1,IS2,IS3 - solenoids;
- ICM0÷ICM3 - steering magnets;
- IPP - pepper-pot;
- IDB1÷IDB3 - diagnostic boxes;
- IGV0, IGV1, IGV2 - vacuum gate valves.

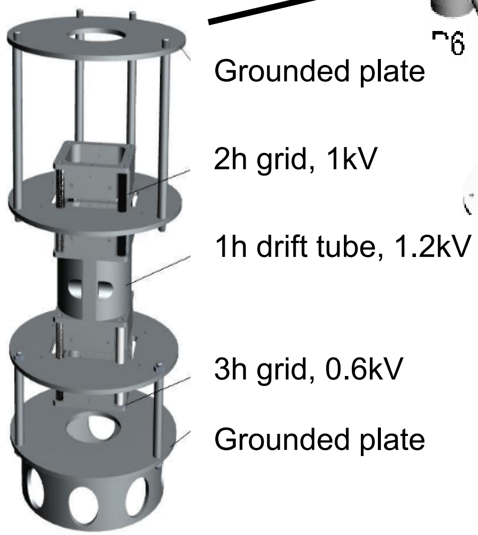


90° electrostatic bender, poster session, **MOPA14**

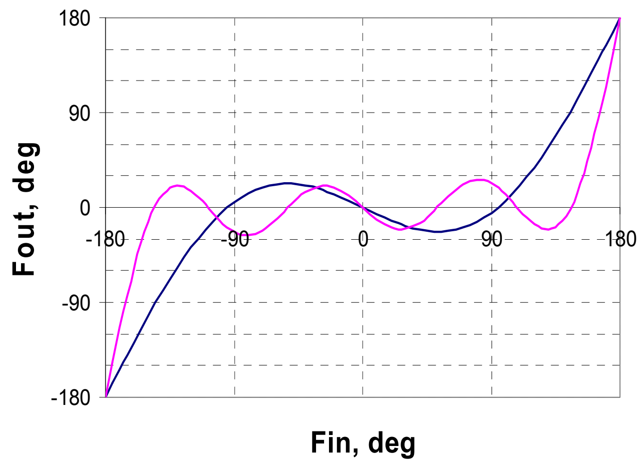




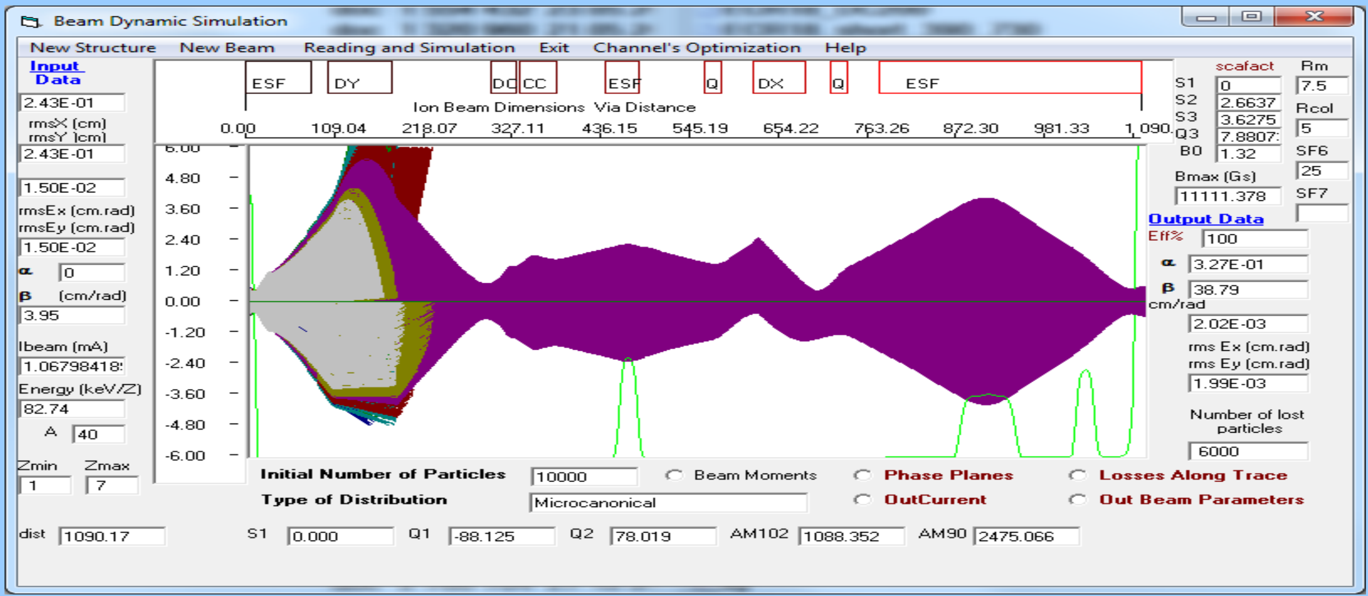
Accelerator tube
(NEC 2JA000260, Umax=75 kV)



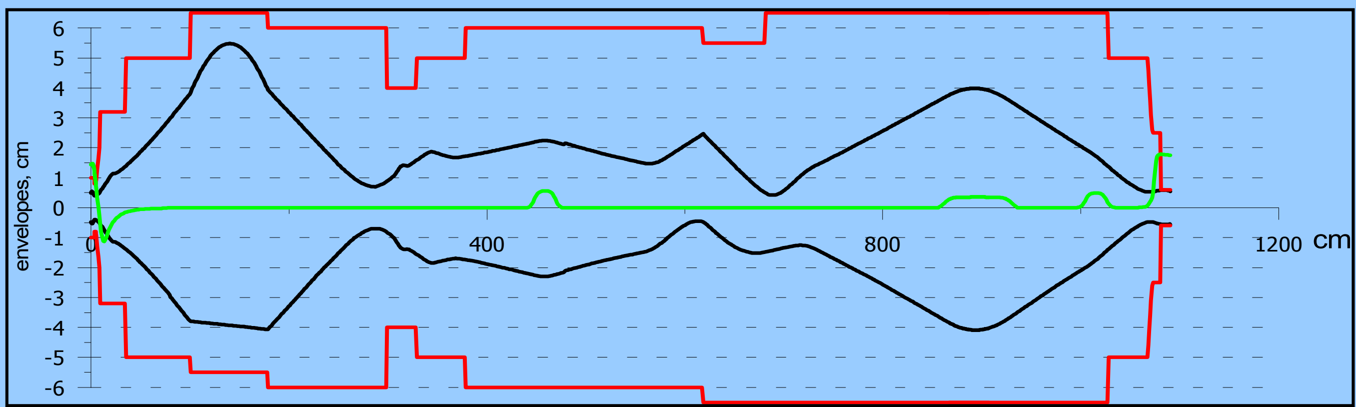
Poly-harmonic buncher provides the efficiency of beam grouping in range 20° of RF phase up to 80%



DC280 axial injection beam line calculation



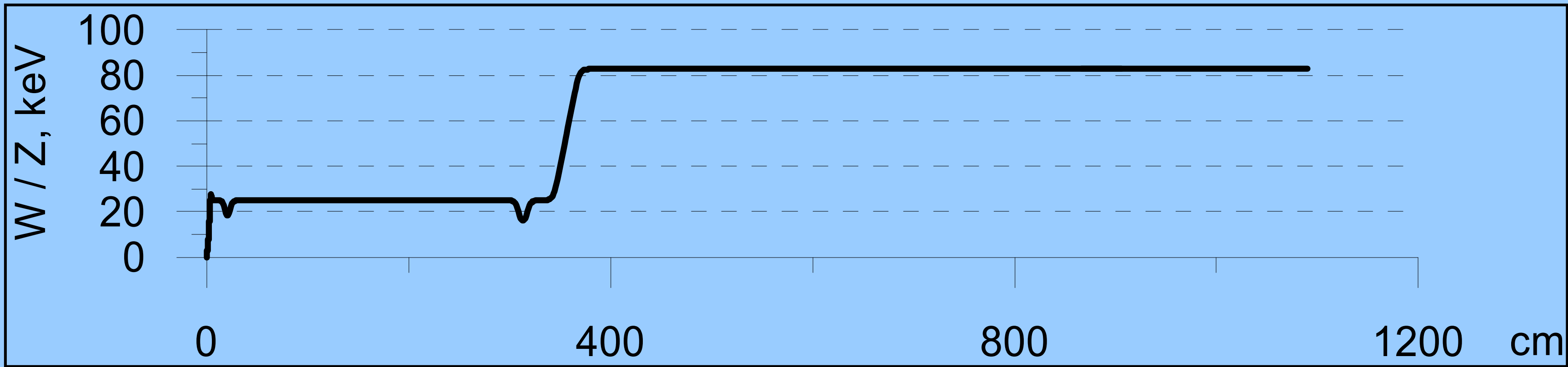
Particle trajectories



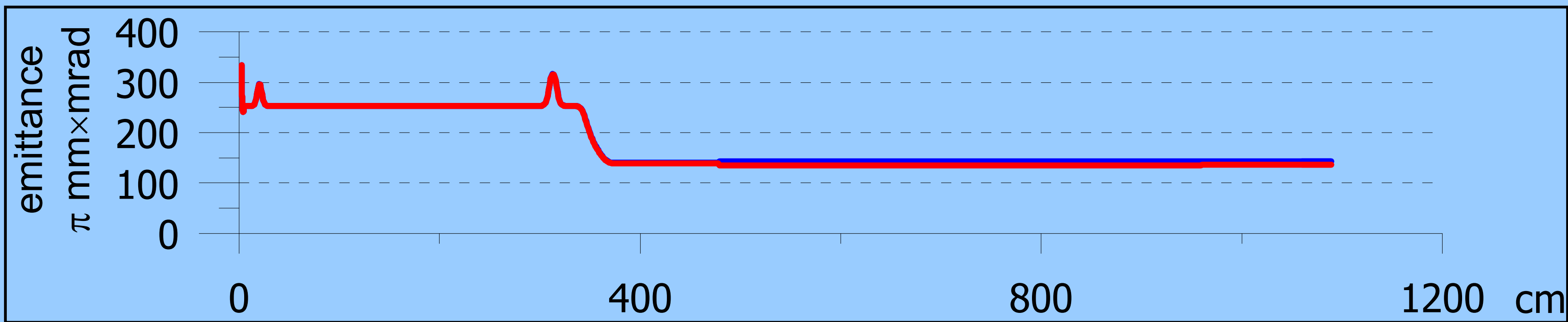
Horizontal (upper curve), vertical (lower curve) Ar^{7+} beam envelopes

Longitudinal magnetic field – green line, apertures – red line

DC280 axial injection beam line calculation

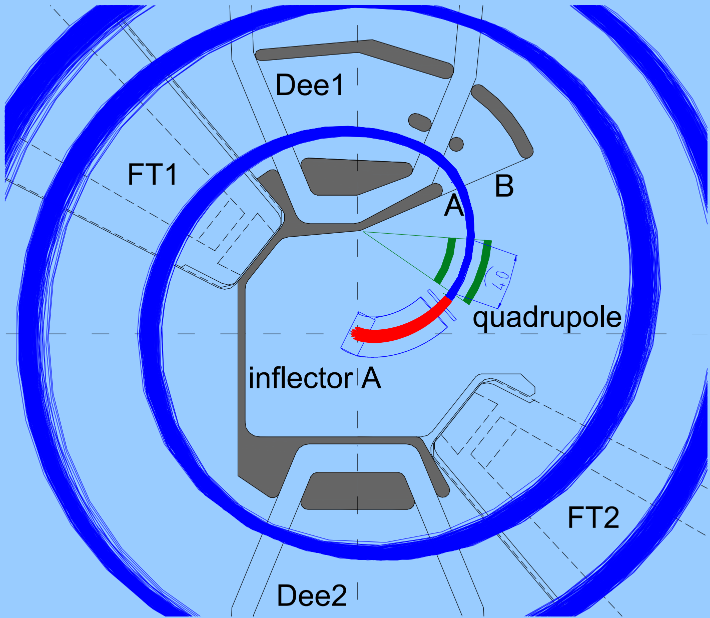


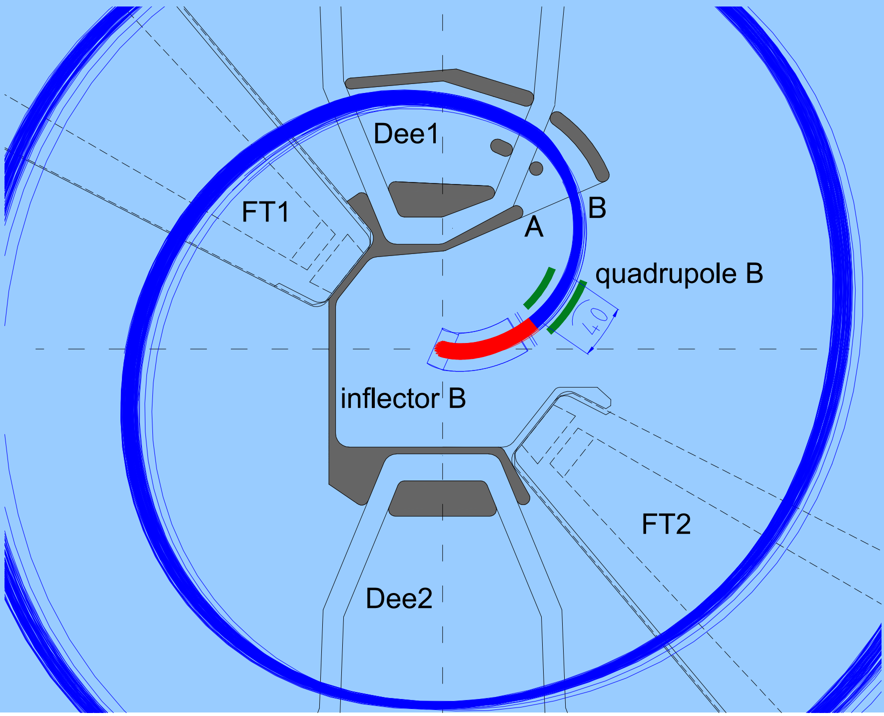
Ar^{7+} beam
kinetic energy
per unit charge

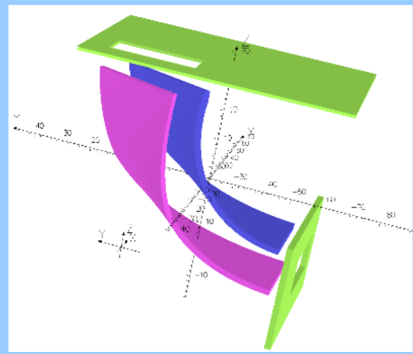


Ar^{7+} beam
emittance
(non-normalized)

DC280 Central Region



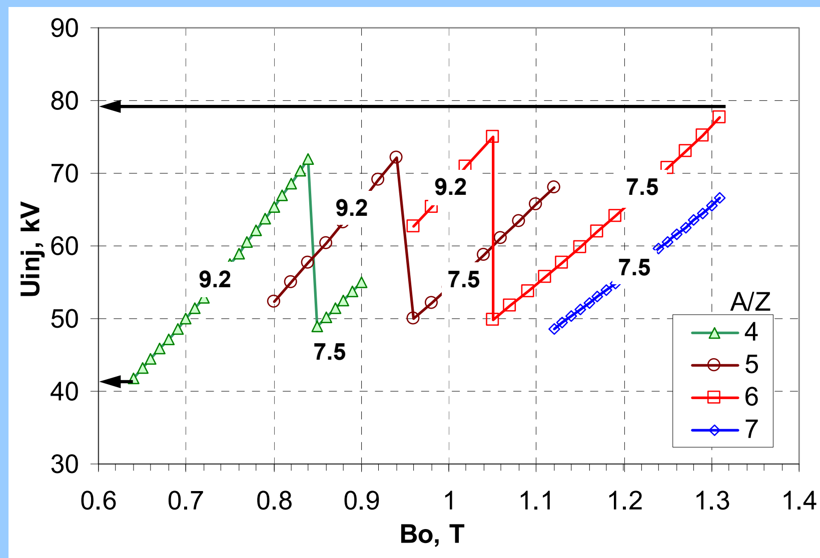




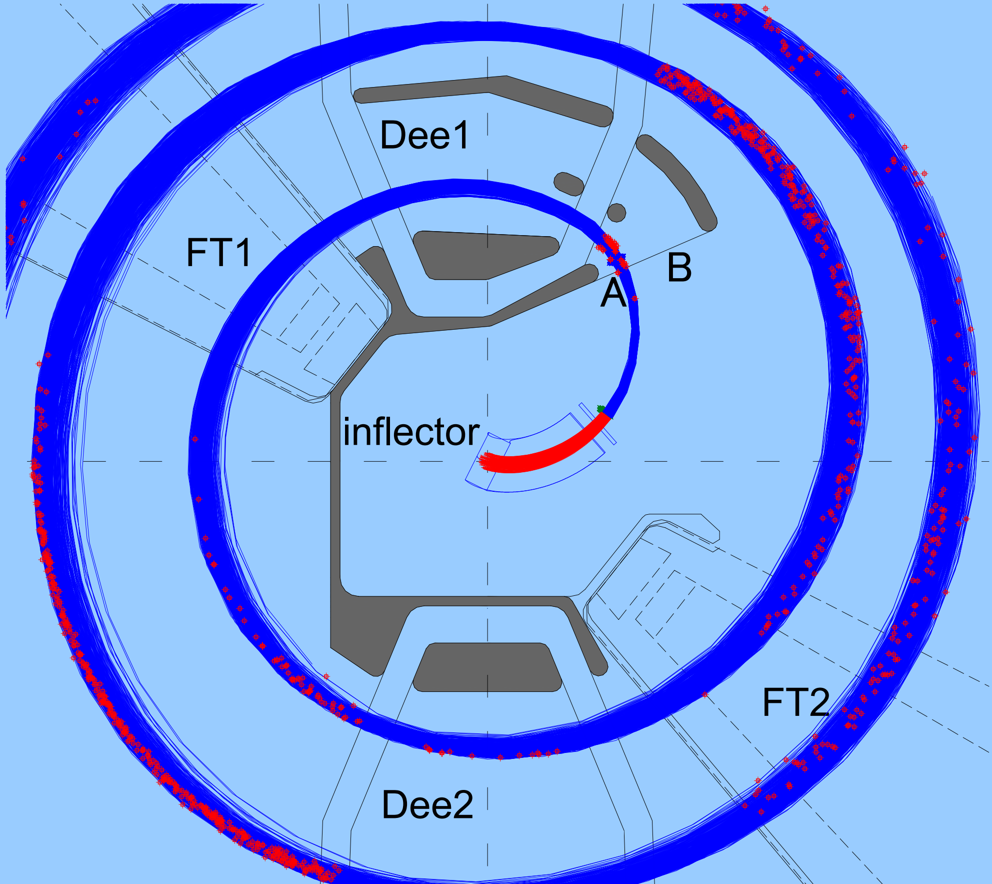
Two electrostatic spiral inflectors with Ae=6cm and Rm = 7.5cm / 9.2cm.

Inflector electrodes potential Uinf = ± 8-16kV

Double puller A&B for different starting radiuses 13.5cm and 17cm

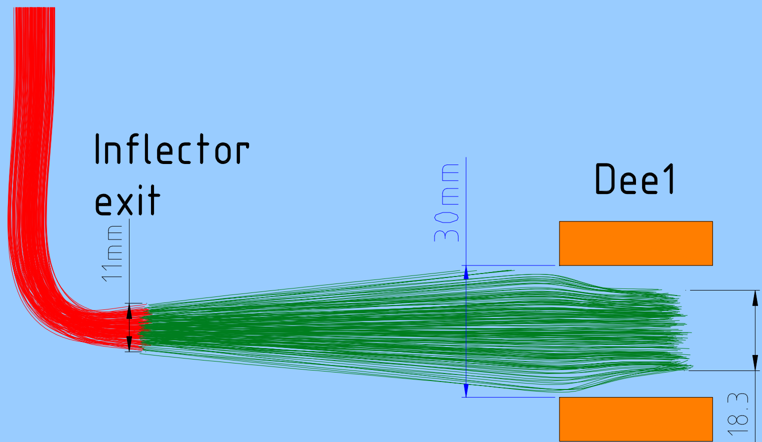


DC280 Central Region

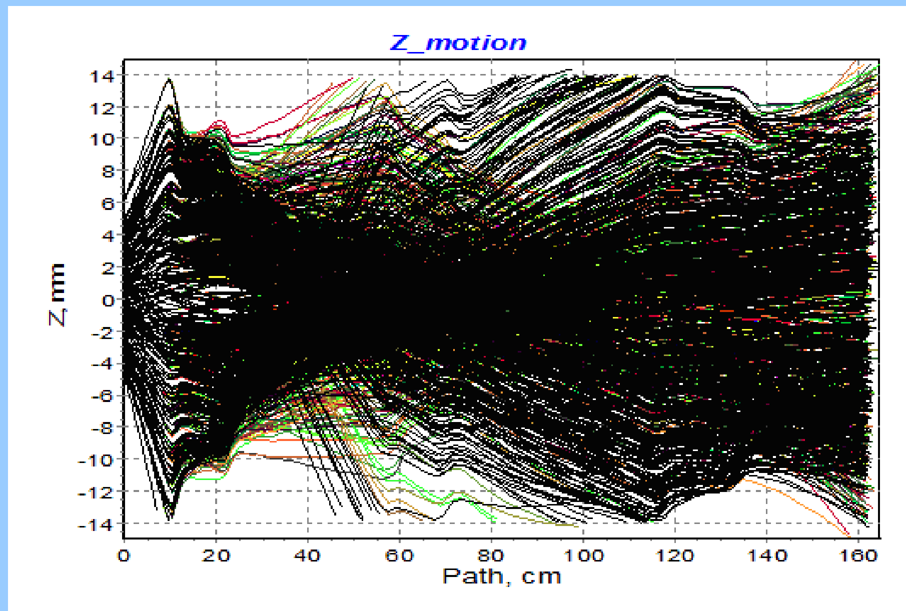


Without additional focusing the aperture losses along acceleration is about 25%.

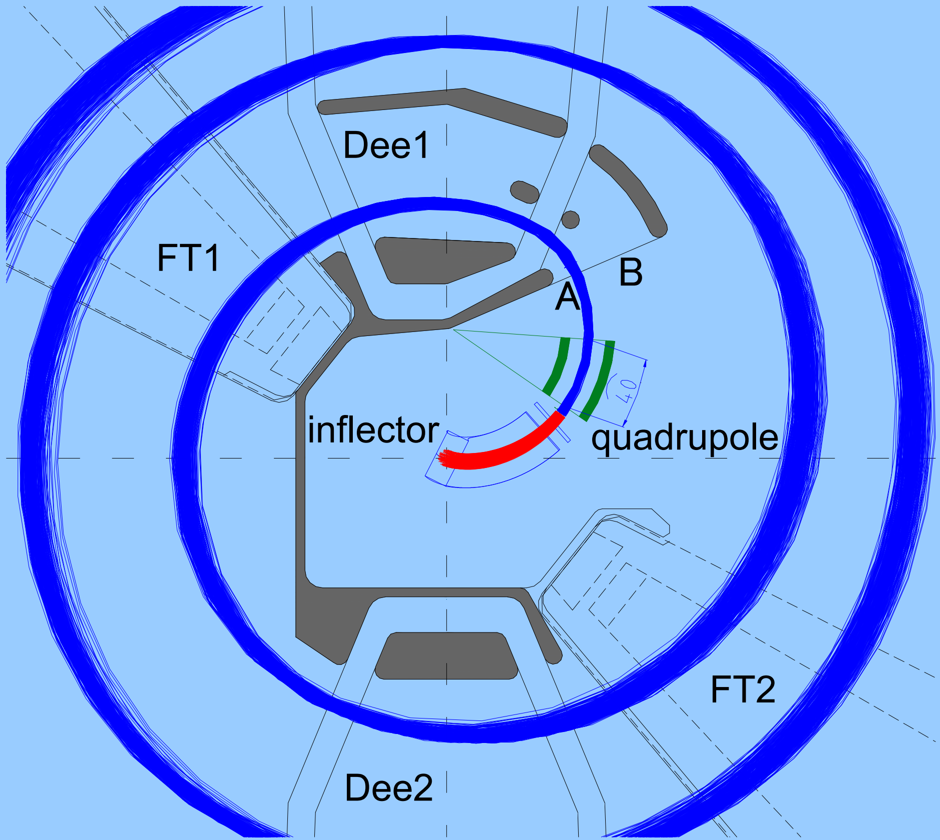
The main losses are at the first orbits.



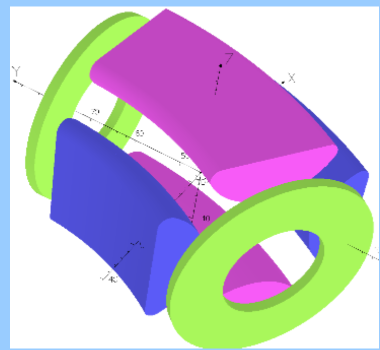
48Ca beam vertical form at first orbits

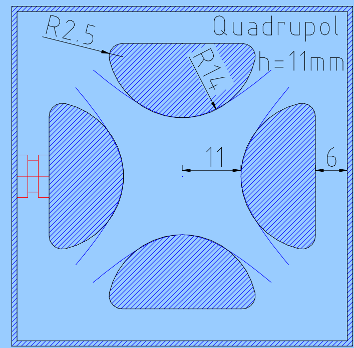


DC280 Central Region

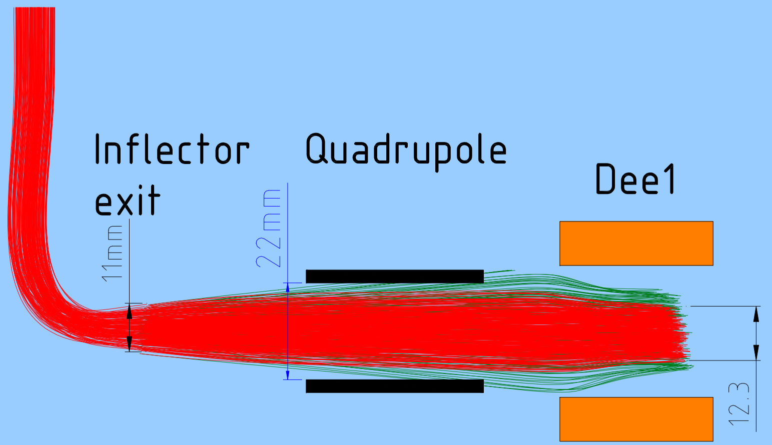


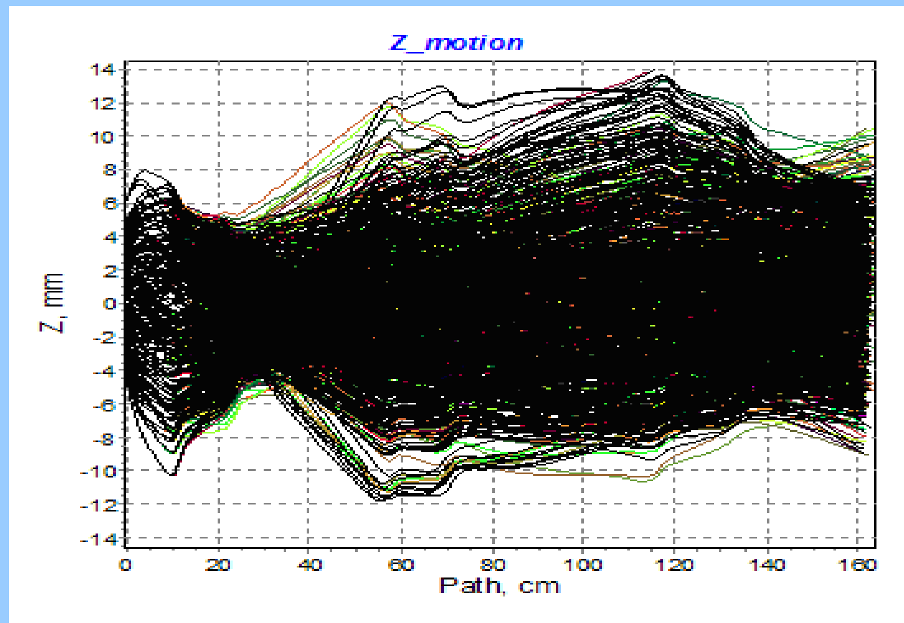
Electrostatic quadruple lens decrease <u>aperture losses from 25% to 2%.</u>





Quadrupole electrodes potential ± 3kV

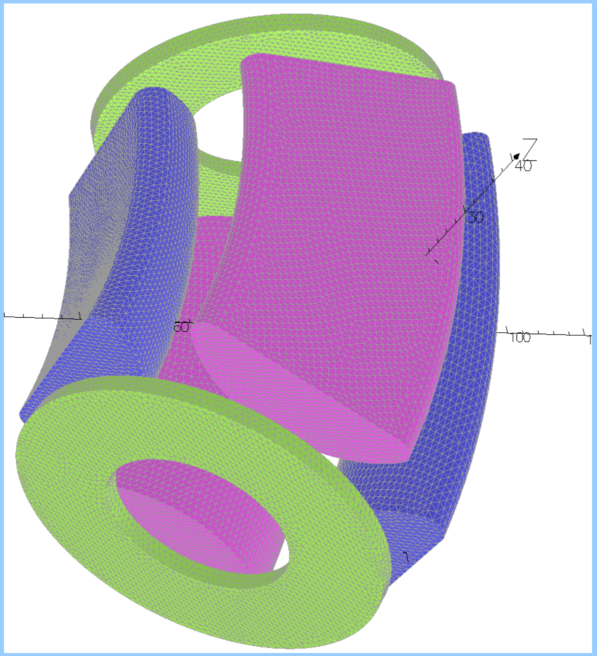




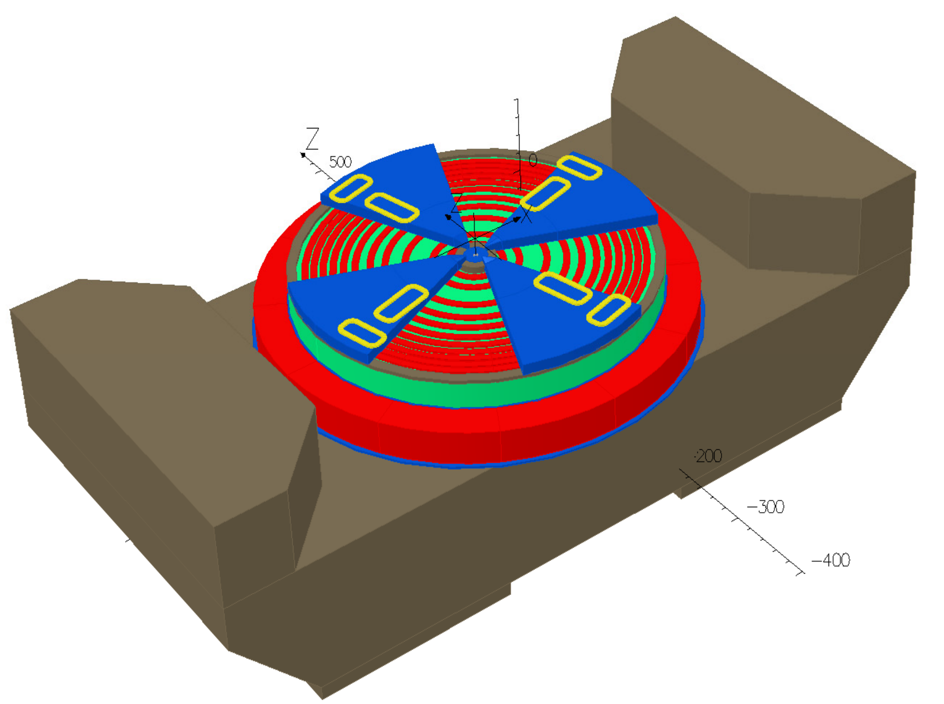
Quadrupole lense at DC280 central region

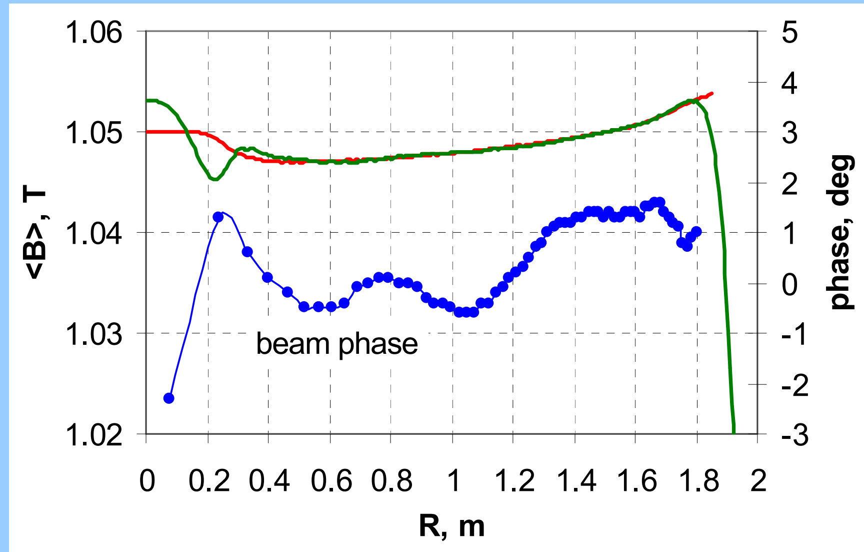
+ Decrease aperture losses
+ Increase beam efficiency
+ Permit to adjust the acceleration mode operatively

- Increase beam radial oscillation
- Complicate the central region construction

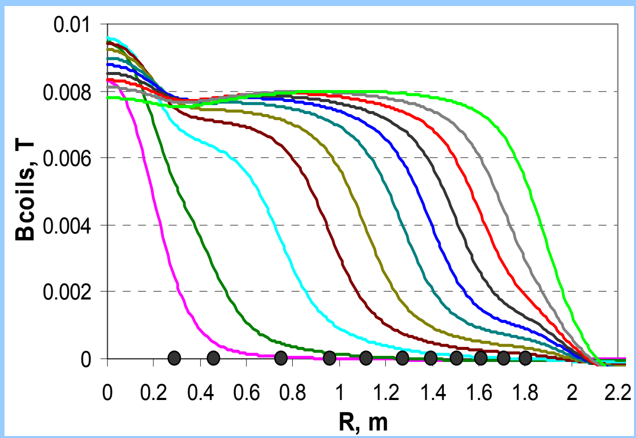


DC280 magnetic system

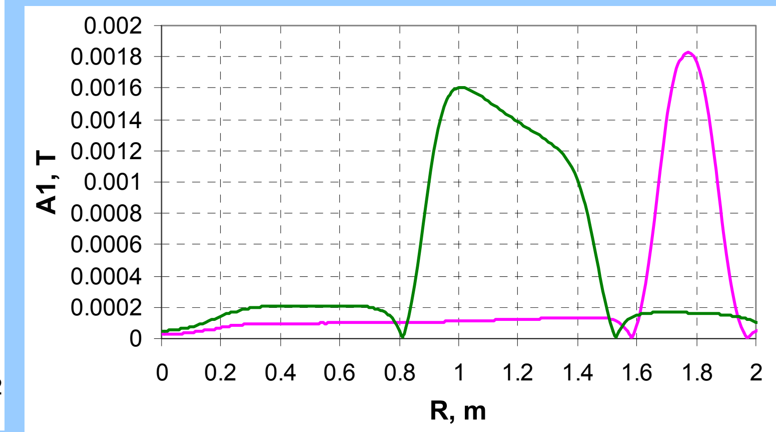




$^{48}Ca^{8+}$ beam phase along acceleration, isochronous and formed magnetic field.

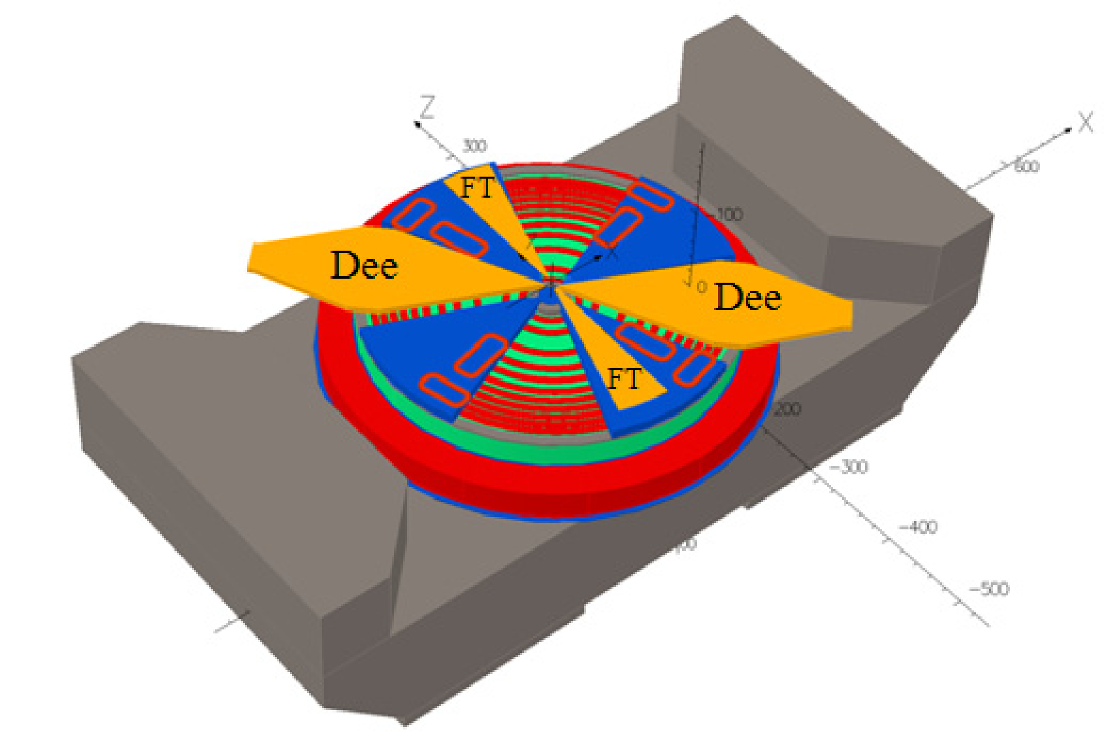


Contributions of 11 radial coils



A1- contributions of 2 pairs of azimuthal coils

Flat-Top RF system

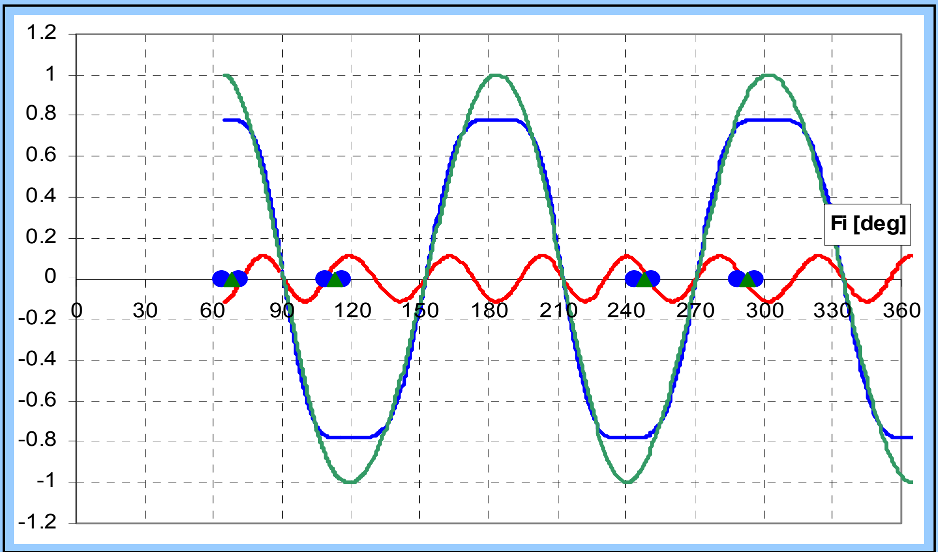


Expected advantage:

- High capture.
- Orbit separation.
- Beam quality.

Flat-Top dees:

- are placed in 208mm vertical gap between sectors
- angular size δ_{ft} = 20^{o}
- work at RF voltages $U_{ft} = 0.1U_{dee}$
- work at $h_{ft}=3h_{dee}=9$ harmonic RF



total acceleration voltage

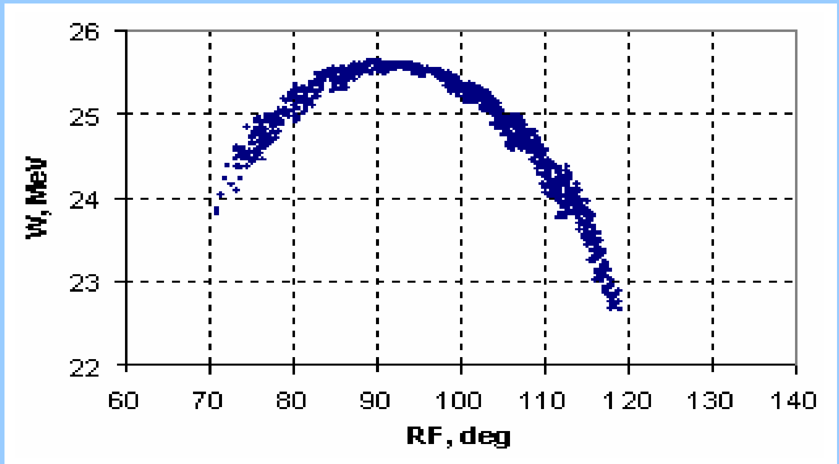
$U_{dee}Sin(\omega_{rf}\ t) + U_{ft}Sin(3\omega_{rf}\ t)$

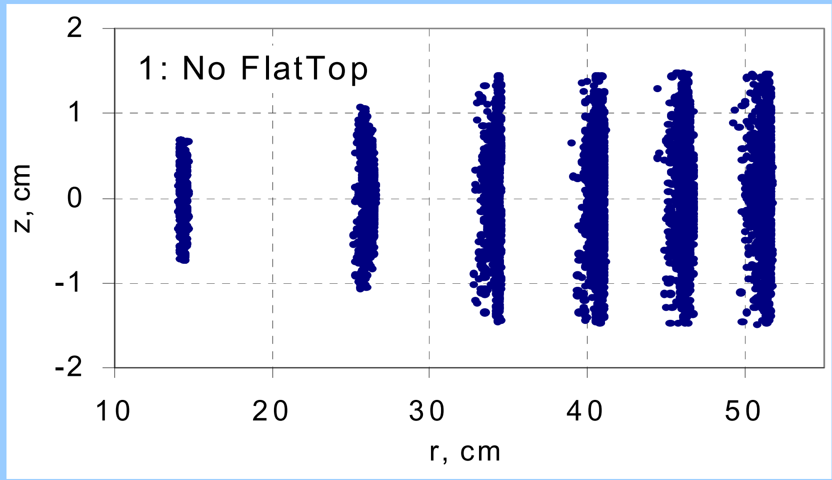
$U_{ft} \approx 0.1 \cdot U_{dee}$

DC280 centre and «Flat-Top» RF system

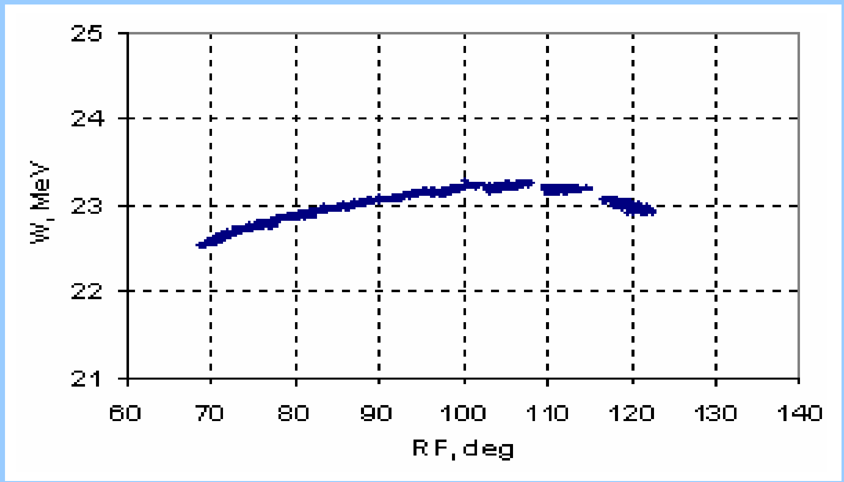
The beam energy spread at the 5-th orbit

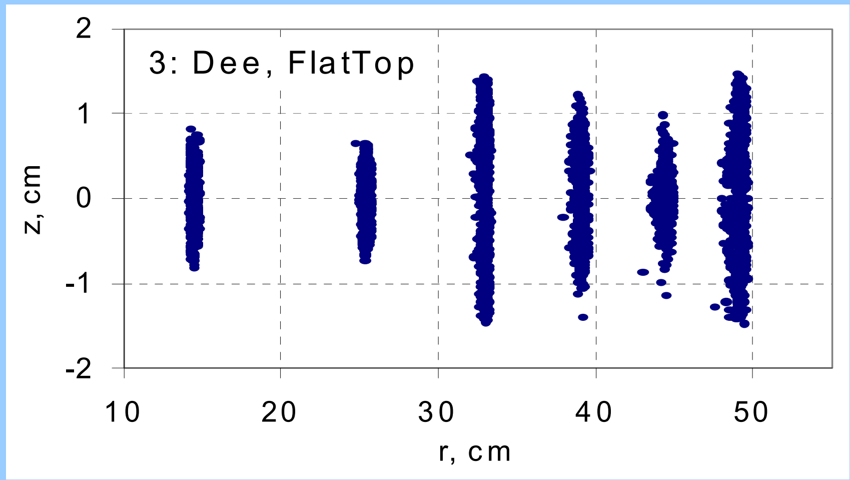
The beam transverse form for first 5-th orbits





Flat-Top is turned off



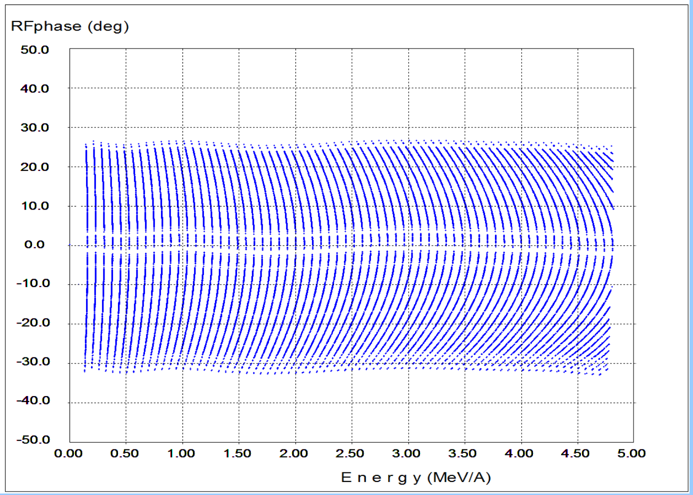


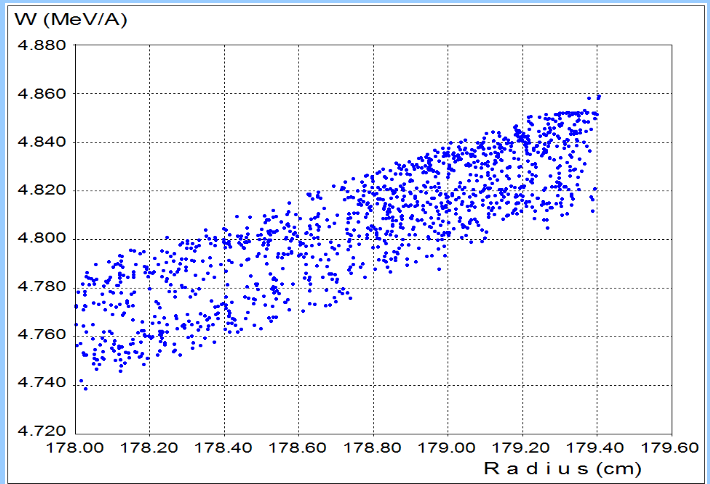
Flat-Top is turned on

DC280 Flat Top system

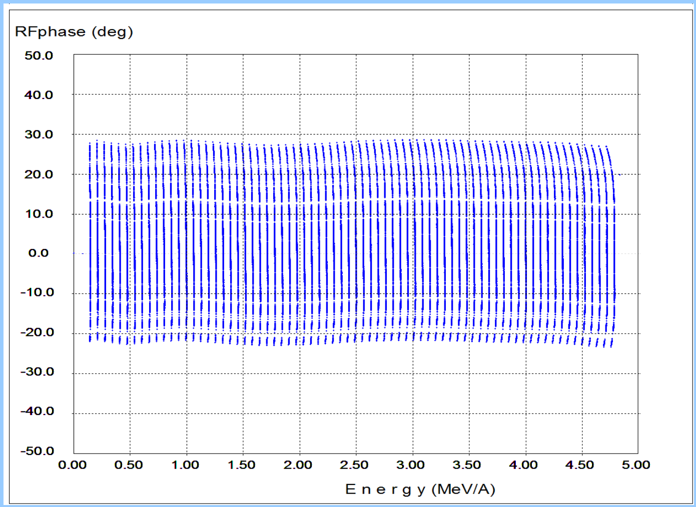
RF phase – energy position of ions along acceleration

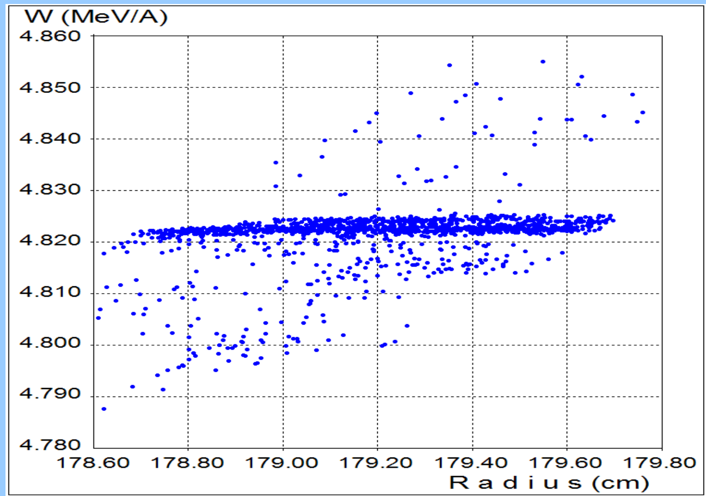
Radius – energy position of ions at the deflector entrance





Flat-Top is turned off

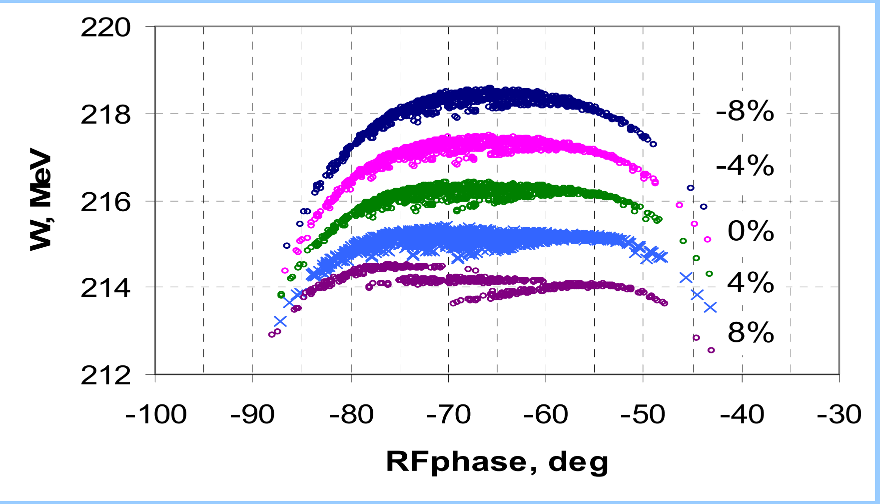




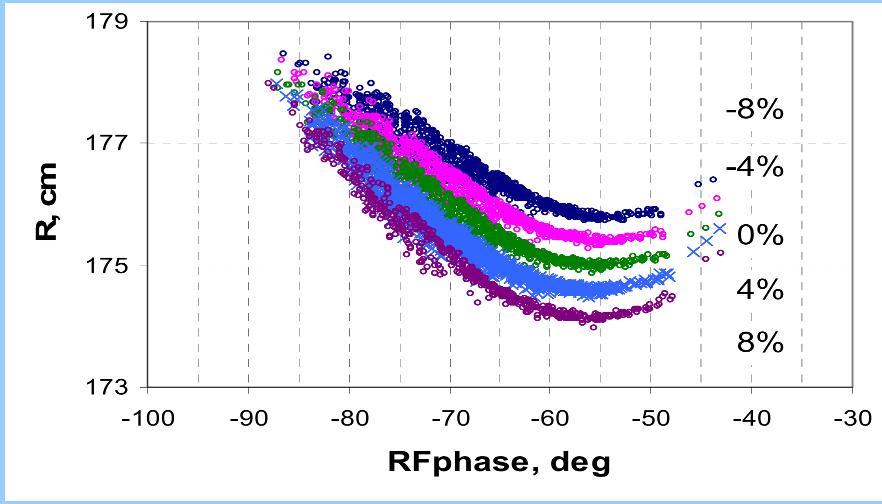
Flat-Top is turned on

Flat Top system sensitivity

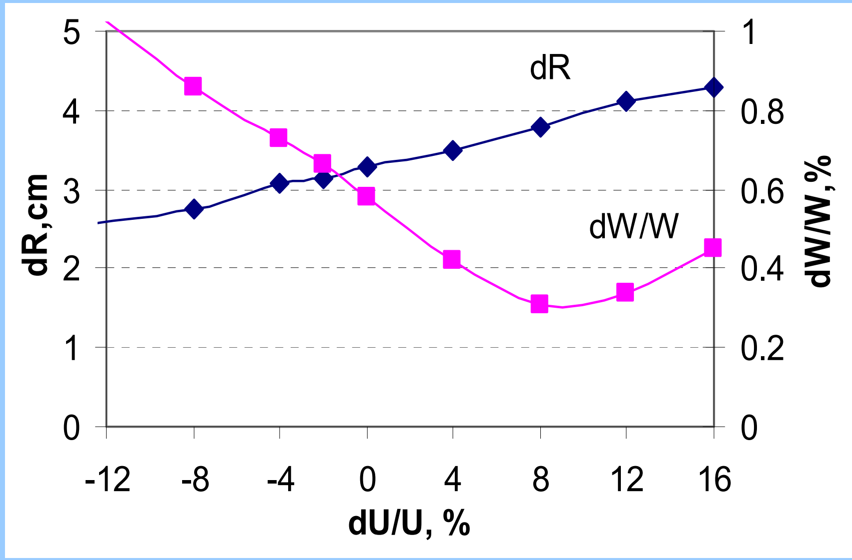
1. RF amplitude variation



$^{48}Ca^{8+}$ beam parameters at the extraction radius

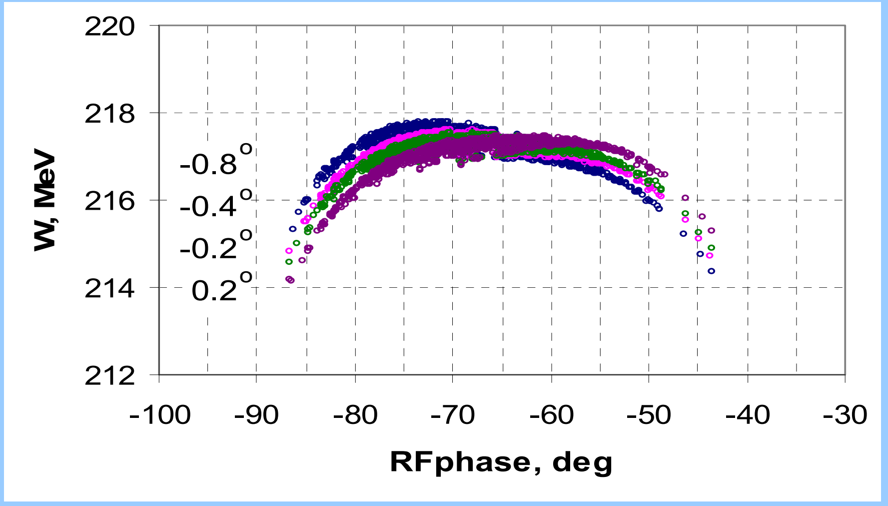


Flat-Top RF voltages $U_{ft} = 0.1U_{dee} \pm dU$



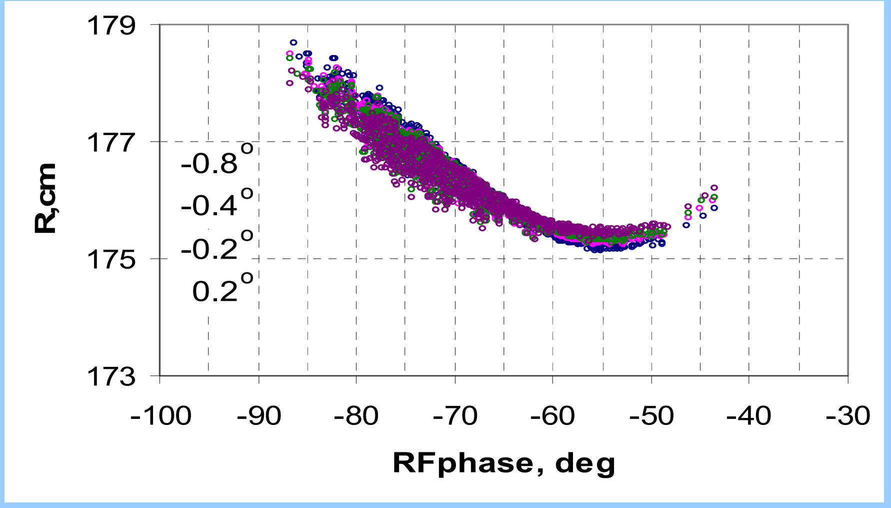
Flat Top system sensitivity

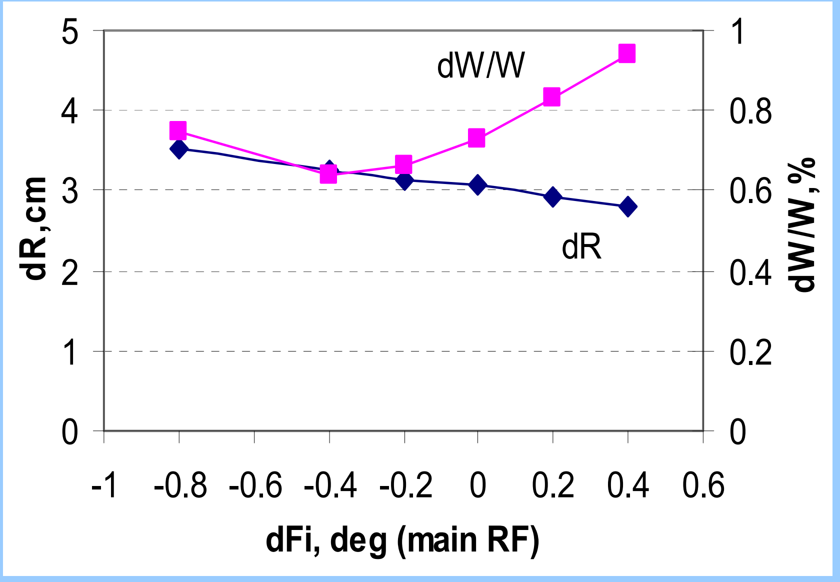
2. RF phase variation



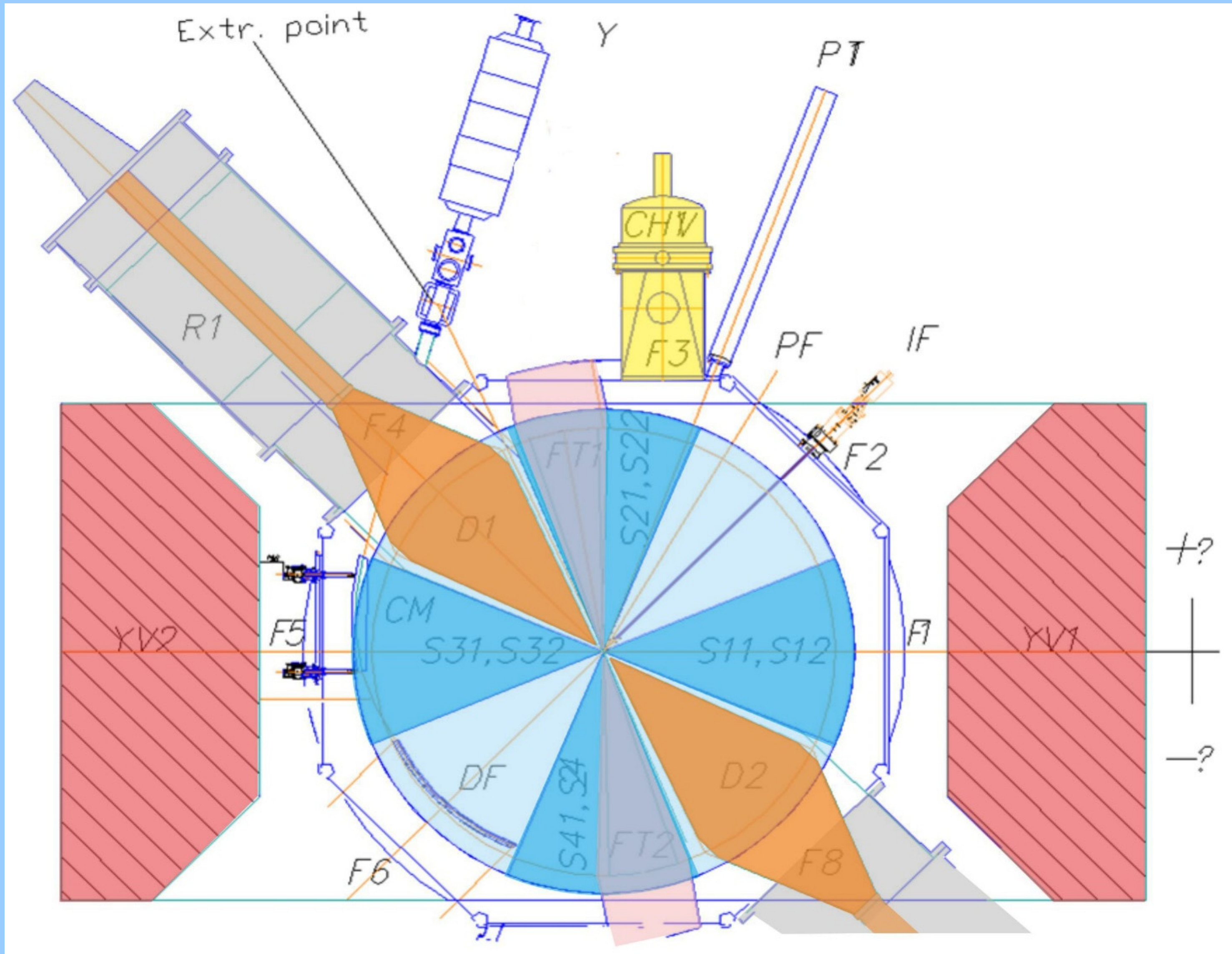
Flat-Top RF at $h_{ft}=3h_{dee}=9$ harmonic

48Ca8+ beam parameters at the extraction radius

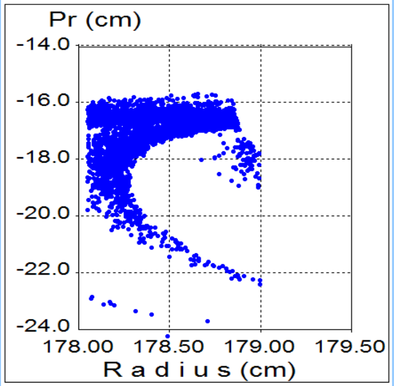


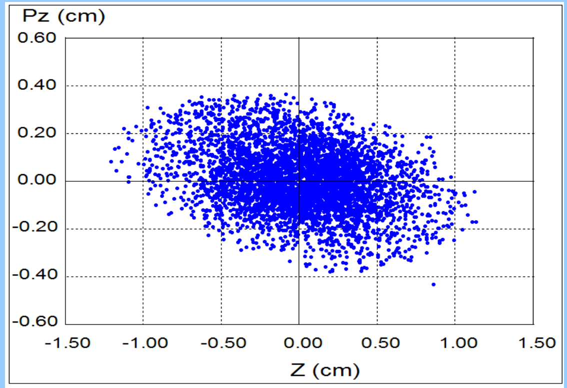


DC280 beam extraction structure

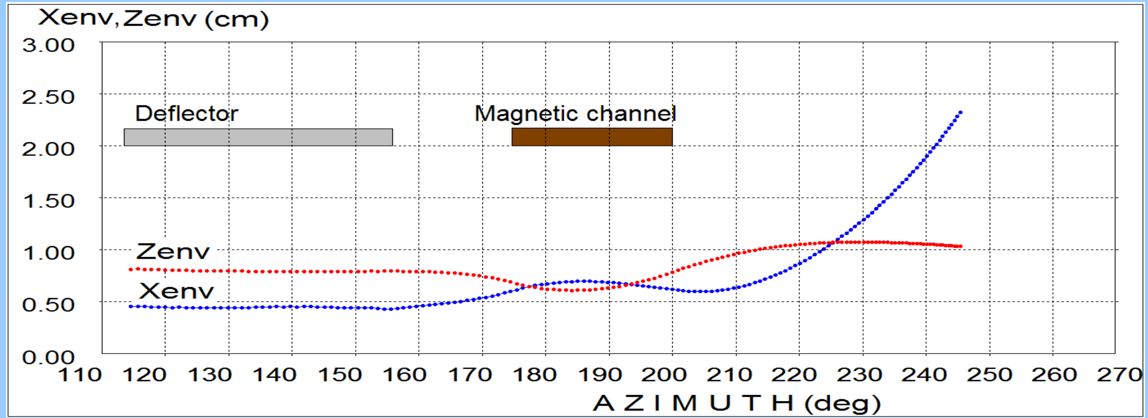


Expected efficiency of DC280 extraction system is about 70%

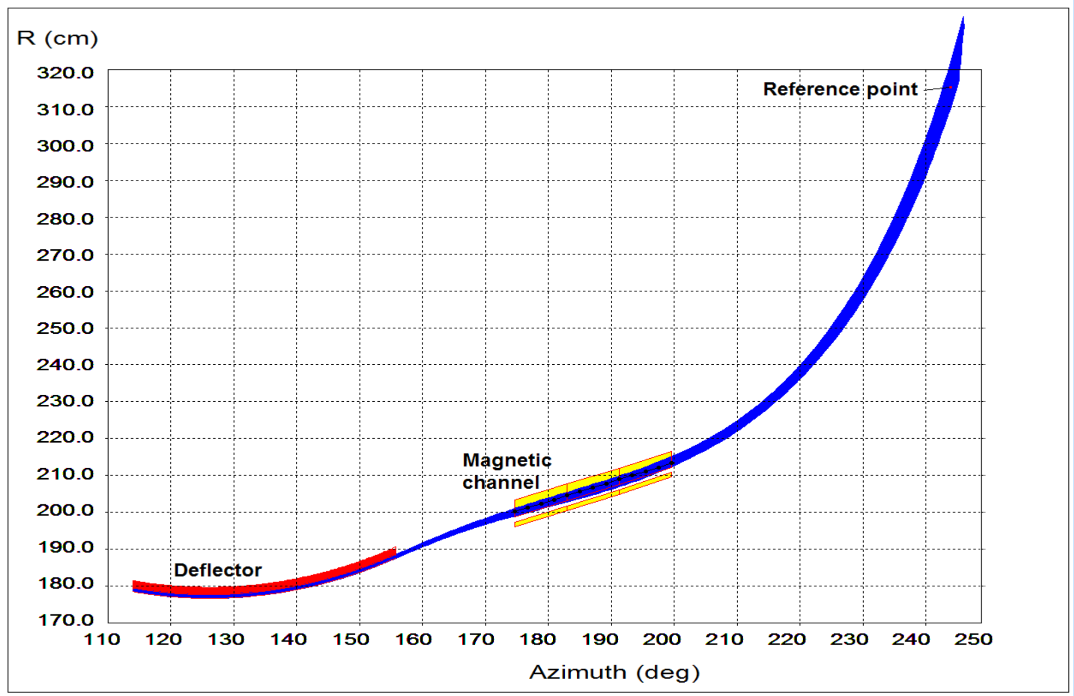


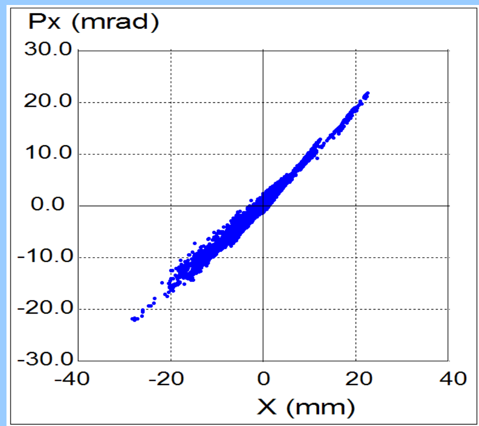


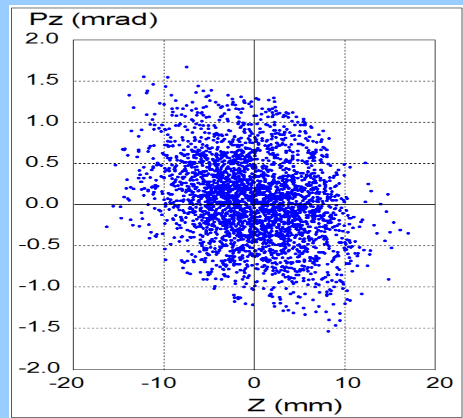
48Ca beam at deflector entrance



Changing of beam transverse envelope during extraction

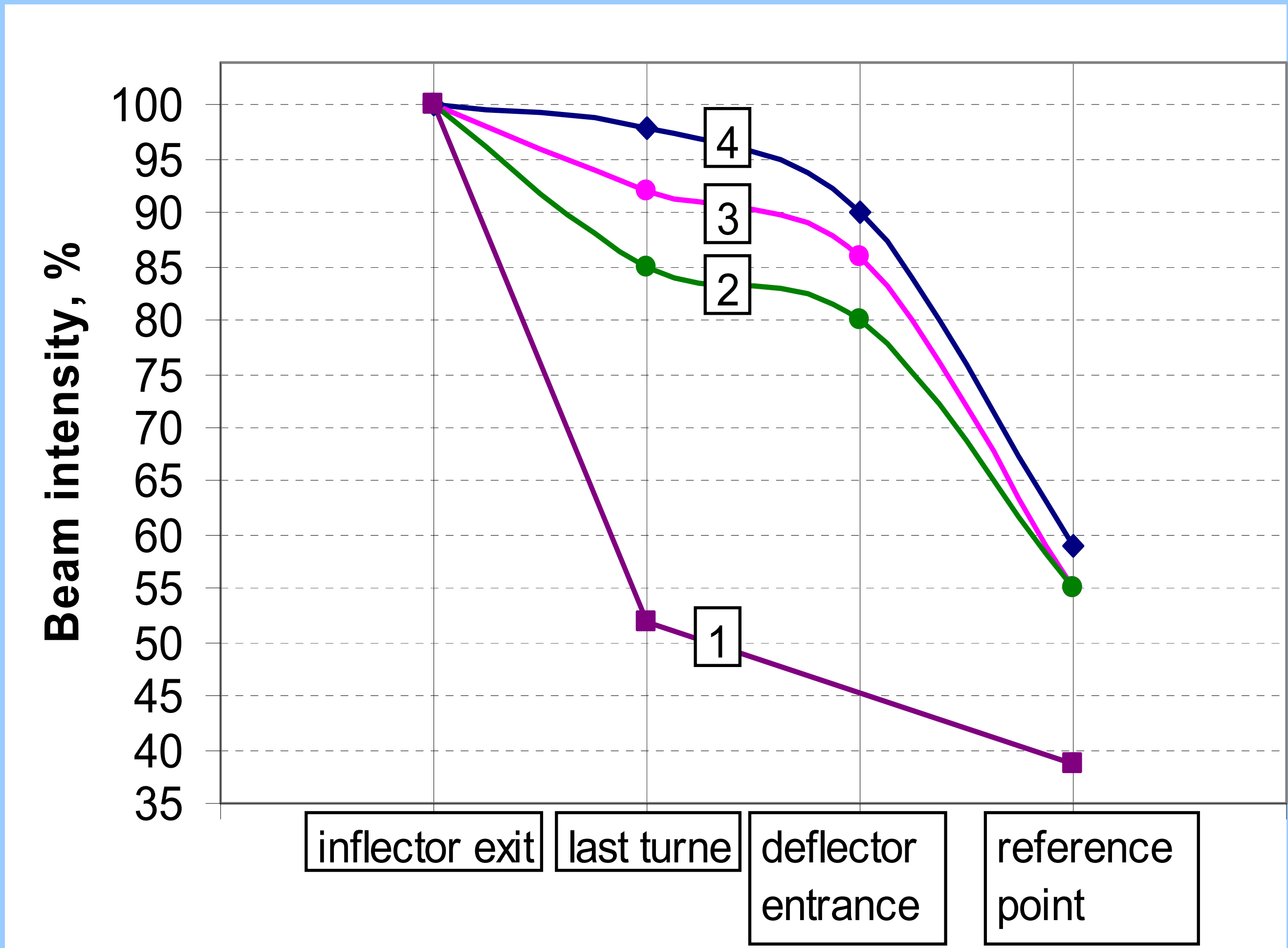






48Ca beam at reference point of beam extraction line

48Ca beam transition from inflector exit to reference point of the extracted beam line



1) Quadrupole leans is turn off

2) Quadrupole leans is turn on

3) First accelerating gap modification

4) Thin adjustment of inflector azimuthal position

Flat-Top system is turned on

48Ca beam total transition from ECR to the exit reference point

	min	max
injection beam line, buncher and capture to acceleration	70%	80%
acceleration	85%	98%
extraction	60%	70%
total transition	36%	56%
$^{48}Ca^{+8}$ beam intensity from ECR to achieve 10pmkA (80mkA) at the target	220mkA	140mkA

Thank you!