Multiple heavy ion injection into NICA Booster

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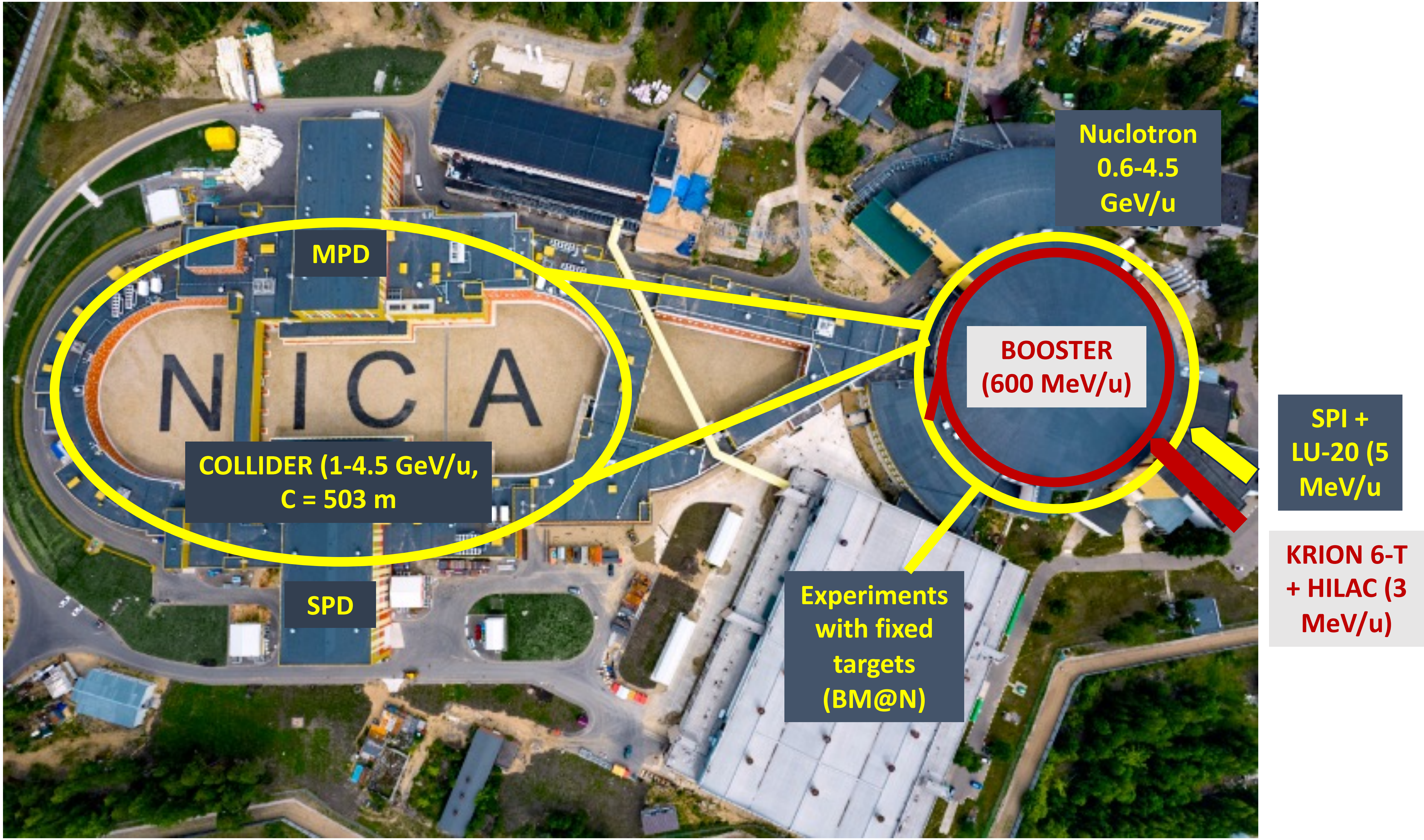
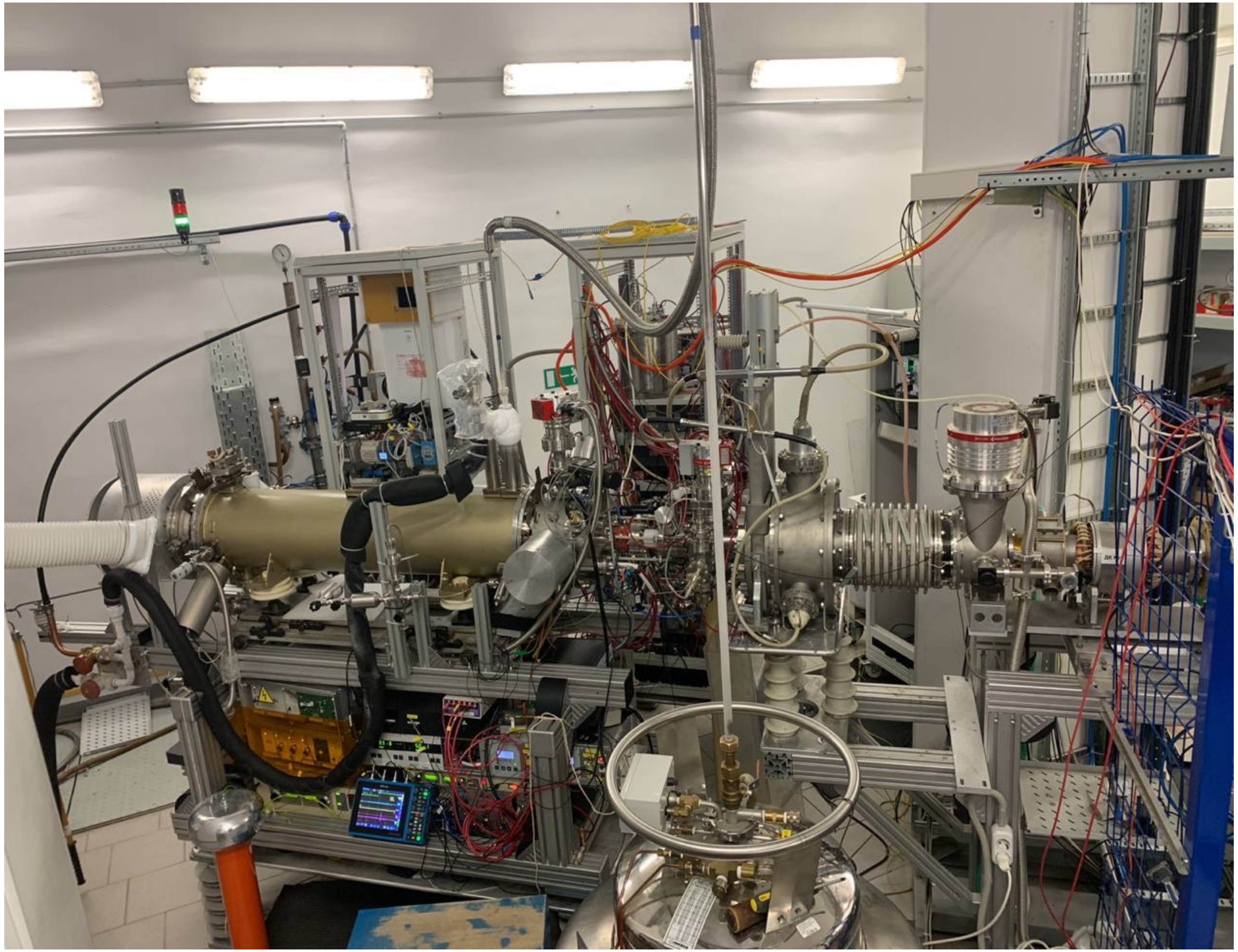
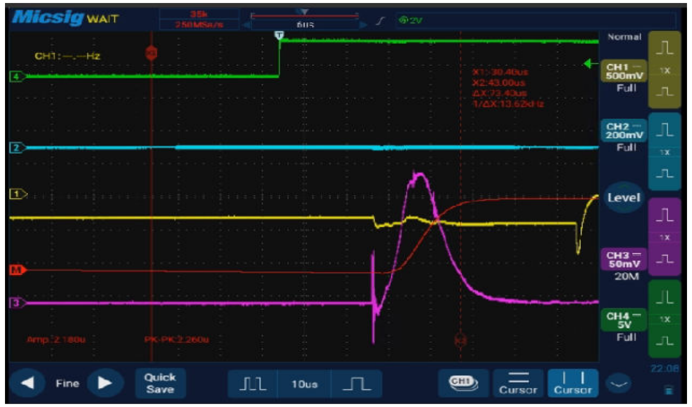
SPD
(Detector)
BM@N (Detector)
Extracted beam
Collider
MPD
(Detector)
E-cooling
Heavy Ion
Linac
Nuclotron
LU-20
Booster
NICA


NICA


NICA
MPD
COLLIDER (1-4.5 GeV/u,
C = 503 m
SPD
Nuclotron
0.6-4.5
GeV/u
BOOSTER
(600 MeV/u)
SPI +
LU-20 (5
MeV/u
KRION 6-T
+ HILAC (3
MeV/u)
Experiments
with fixed
targets
(BM@N)

KRION – 6T Electron String Ion Source

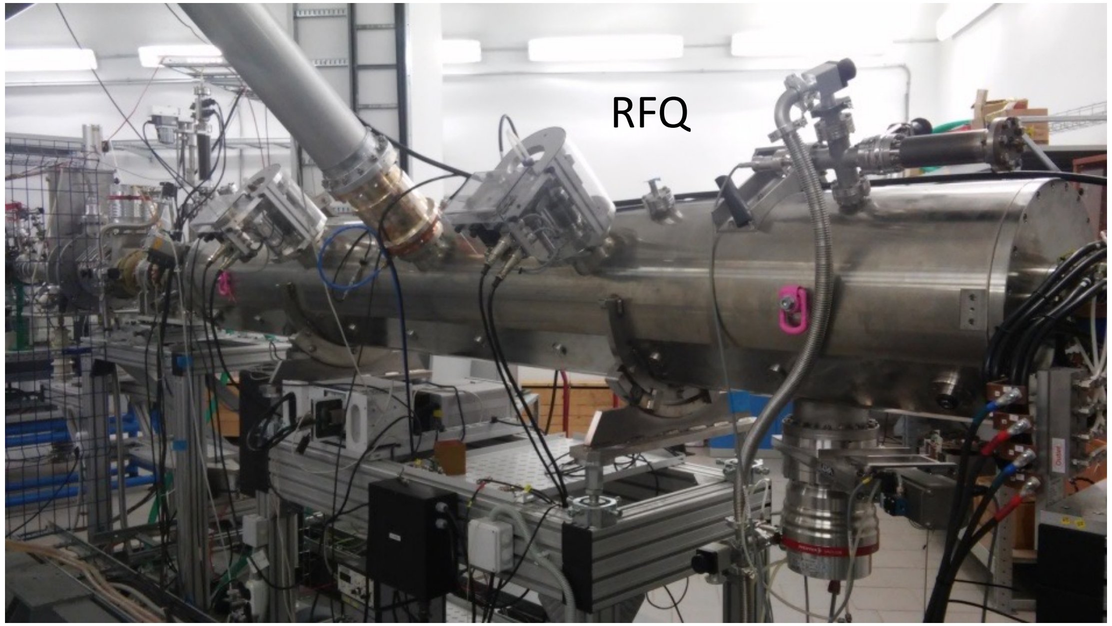


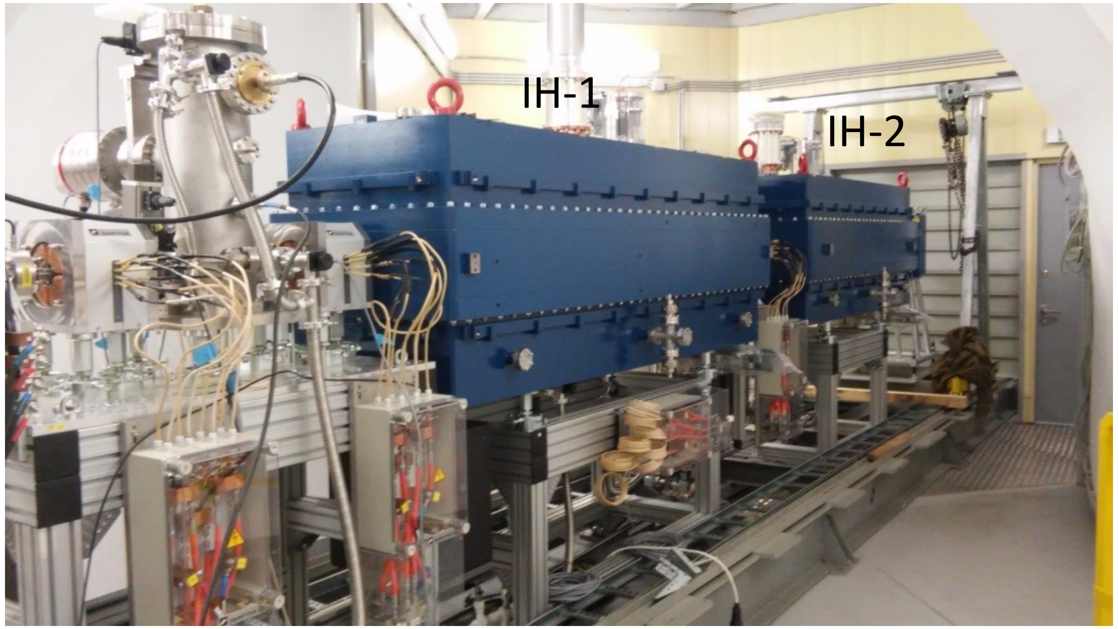


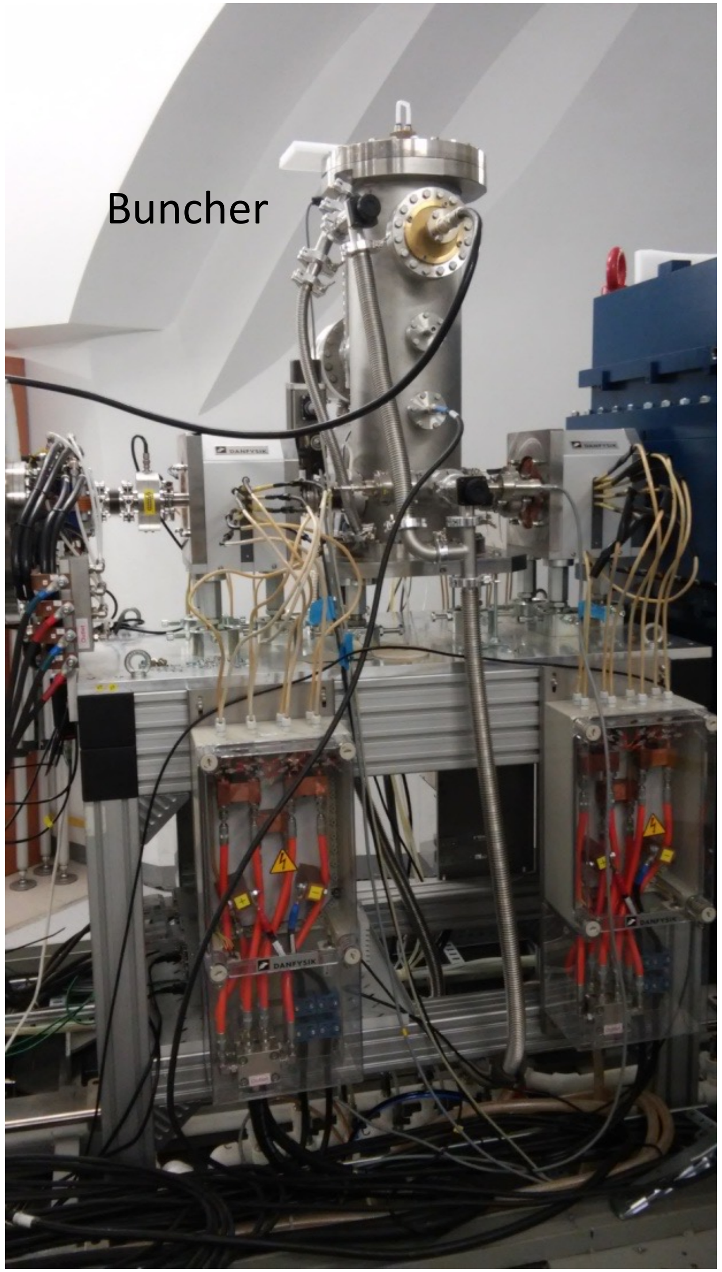
^{124}Xe Q=2,18 nК, I= 200 μA, t= 25 μs

Source type	Electron string (ESIS)
Ion type	^{124}Xe28+
Magnetic field in the trap	5T
Magnetic field at the cathode	0.25 T
Effective cathode voltage	6 kV
Cathode diameter	1.2 mm
Electron beam current	4-6 mA
Ion trap length	70 cm
Total ion charge	2.3 nC
Number of target ions at source exit	10^8

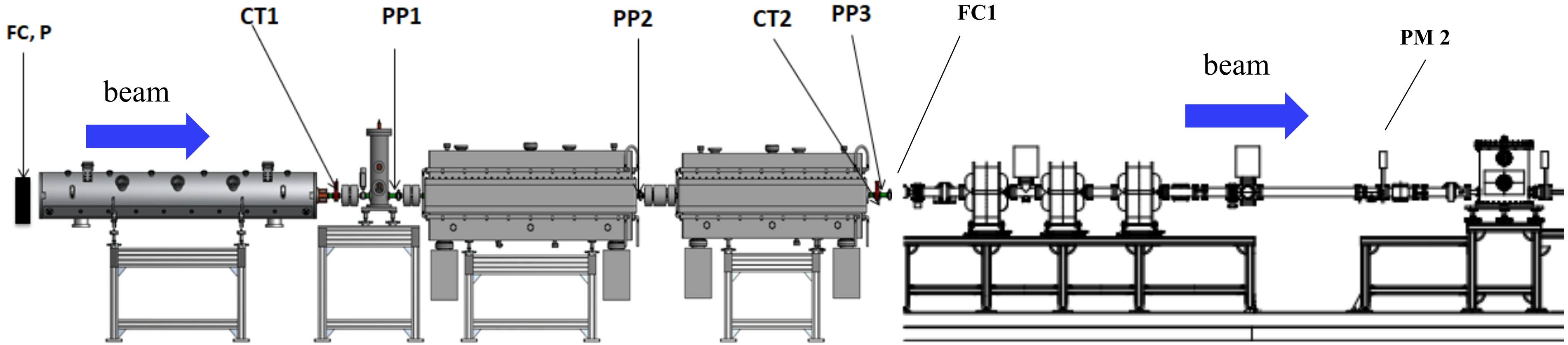
HEAVY ION LINEAR ACCELERATOR (HILAC)

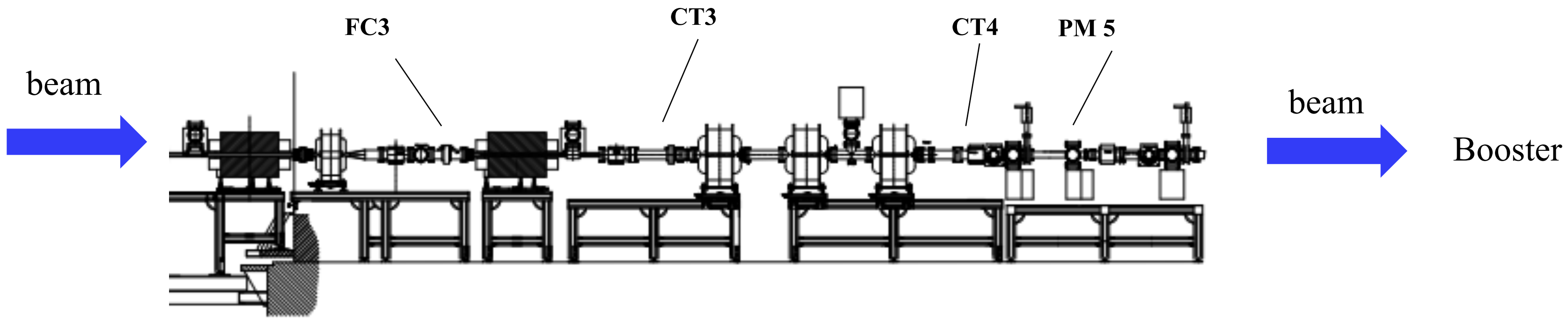






Auxillary diagnostic equipment along the injector





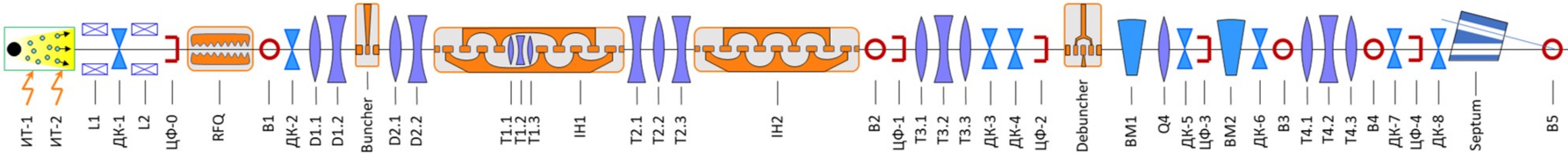
CT – Current transformer, FC – Faraday Cup, PM- Profilometer, PP- Phase Probe)фазовый датчик)

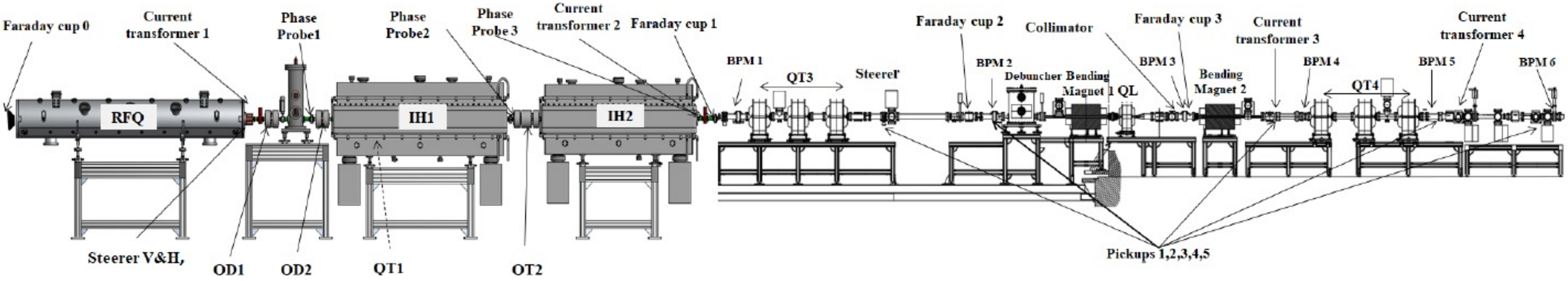
Injection line into Booster

Heavy Ion linac consists of:

- Electron String Heavy ion source (ESIS) KRION-6T, 6T conducting solenoid of 1.2m length, extraction voltage up to 25.0 kV;
- Low energy beam transport channel LEBT, E_{out} = 17 keV/n;
- Heavy ion LINAC: 4-rod RFQ is followed by two IH DTL section with the KONUS accelerating structure, accelerates ions with Charge-to-mass ratio of q/A = 6.25, E_{in} = 17 keV/n, E_{out} = 3.2 MeV/u;

-High energy beam transport channel (HILAC – BOOSTER)





Ion Source Main Parameters for the Run 4

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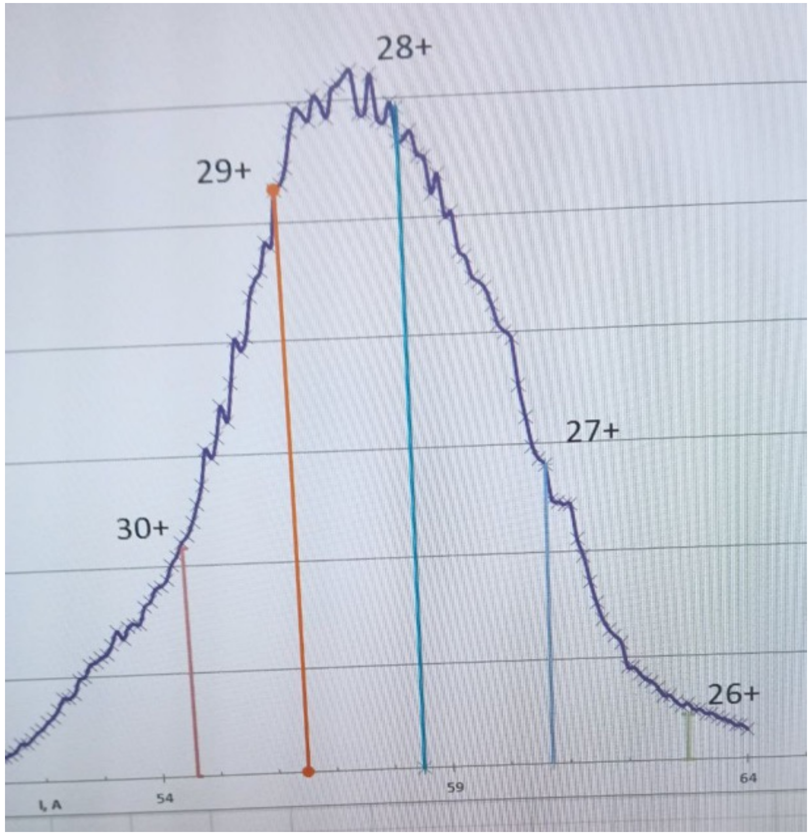
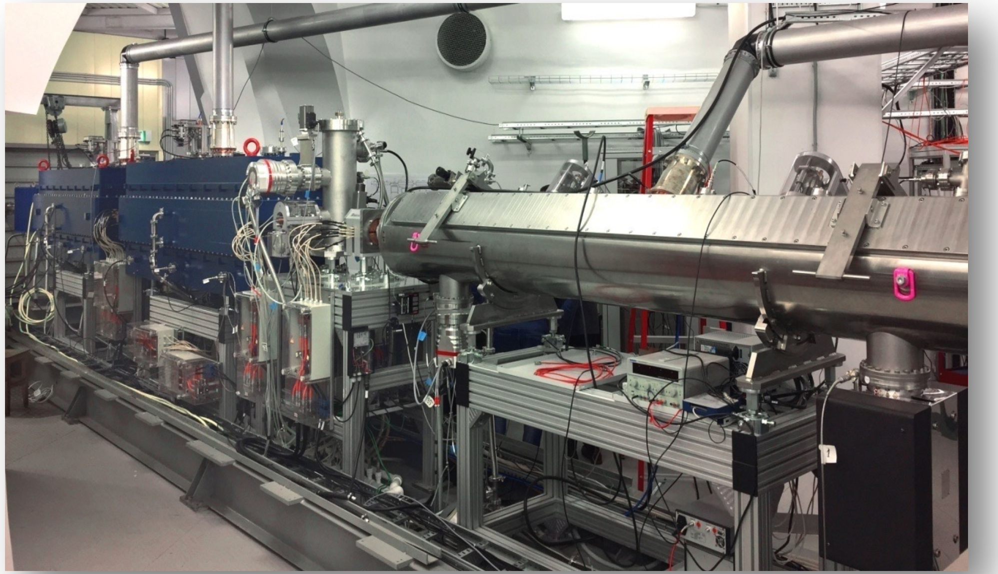
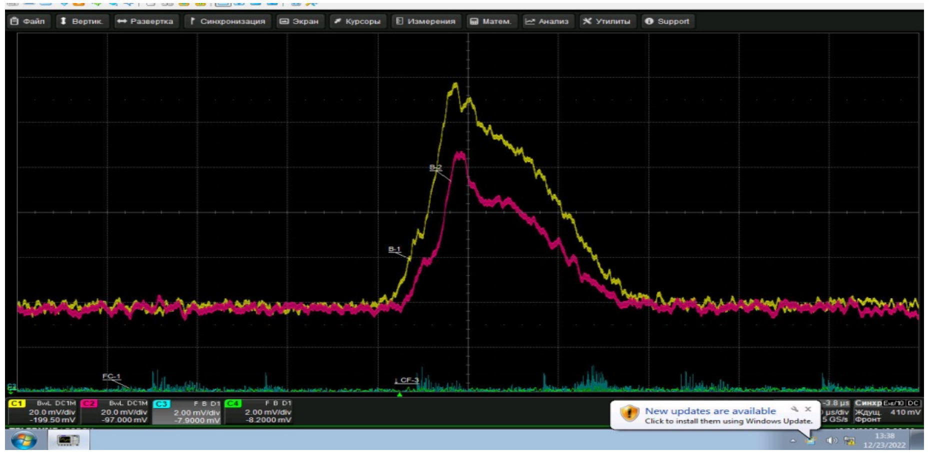


Ion composition at the linac end:
Ionization time – 18 ms;
Target charge 28+ ~20-25%
(% is close to SBSIM calculations, 23%)

Stable and safe HILAC operation with Ar^{13+} and Xe^{28+} beams





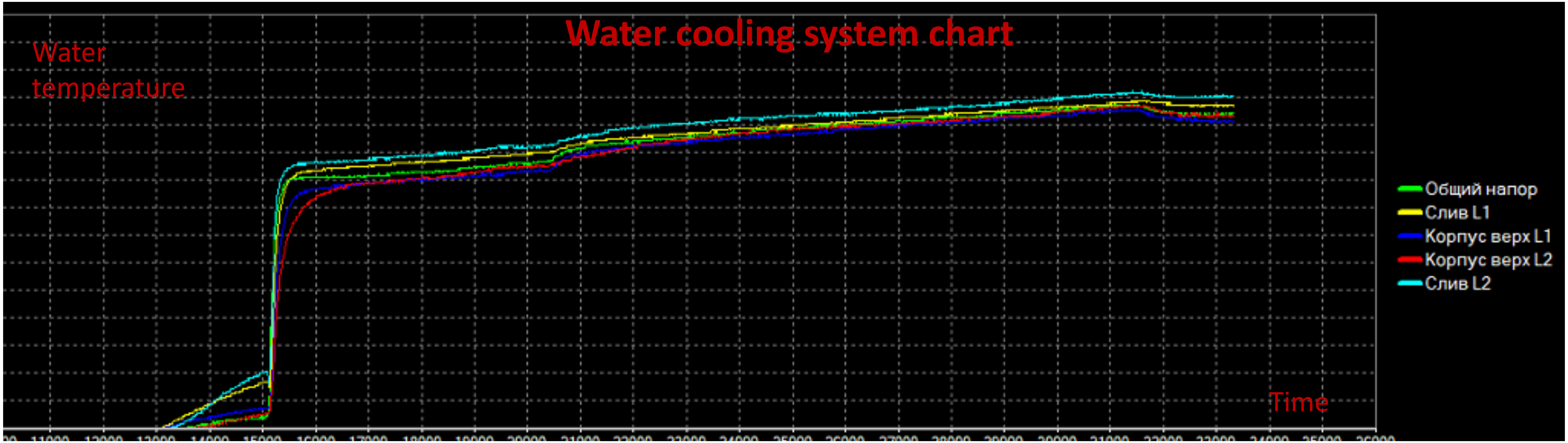
At RFQ exit I=100 μA (yellow line). At HILAC exit I=65 μA at ion pulse duration 22 μs (red line), about 70% at this pulse of target ions $^{124}Xe^{28+}$.

Number of ions accelerated in HILAC at energy 3,2 MeV/n is about 1×10^{8}.

Project HILAC intensity $^{209}Bi^{35+}$ at energy 3,2 MeV/n is about 1.8×10^{9} per pulse.

Further development

Realization of multi cycle injection and upgrade of KRION-6T

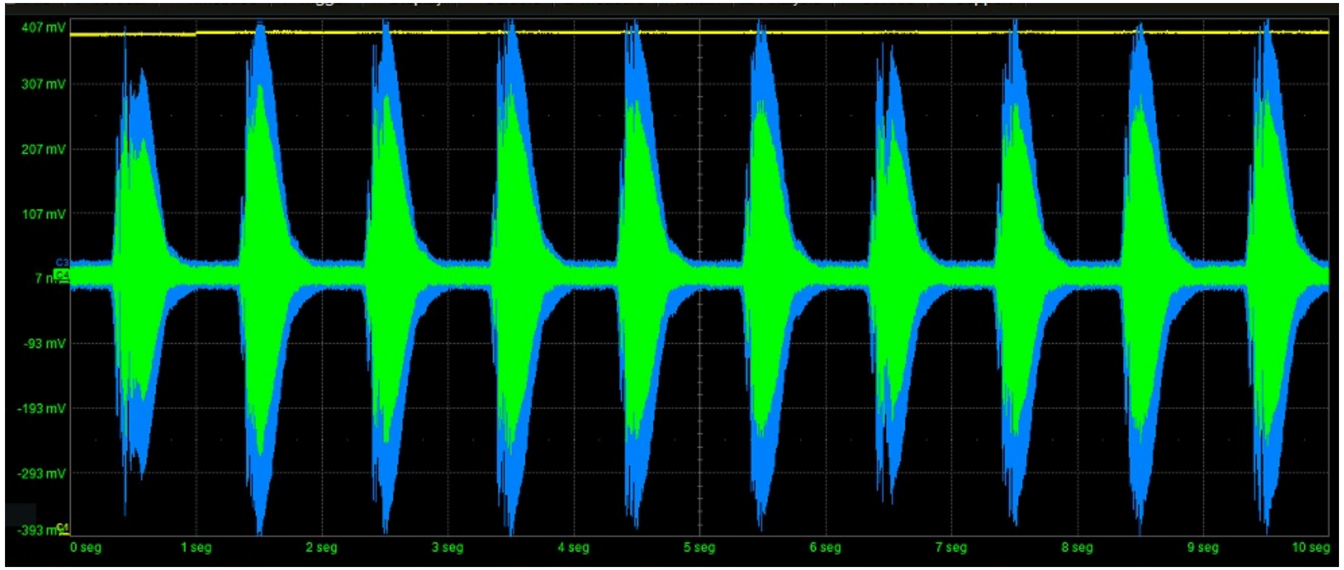


Termometr 1-Wire

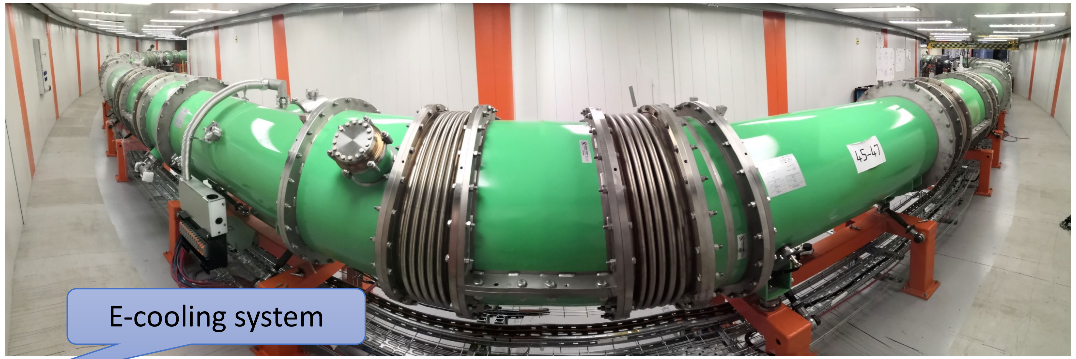
Tx = 105144: Err = 0: ID = 1: F = 04: SR = 10000ms

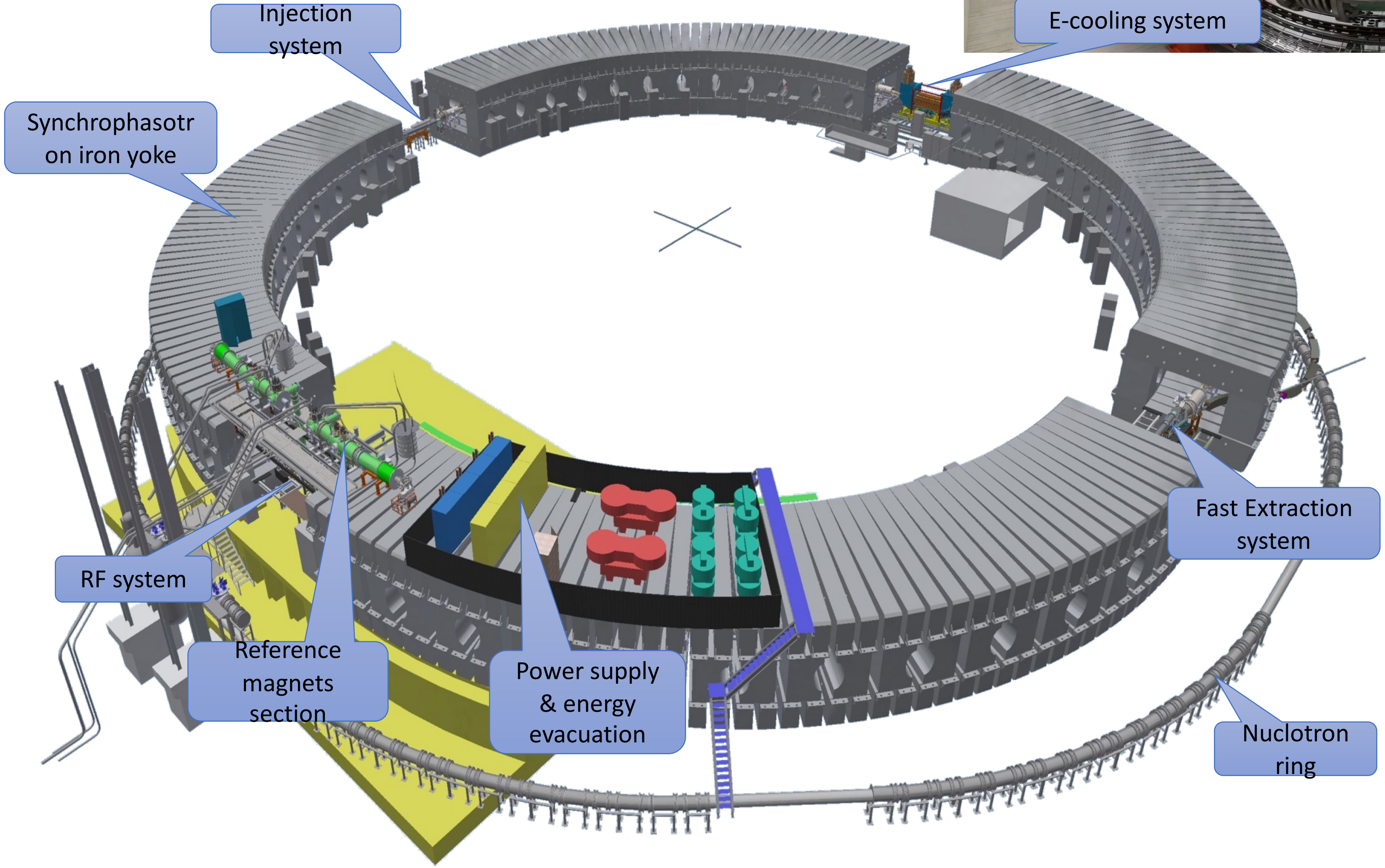
	Name	00010
0	1 - Общий напор	31,44
1	2 - Слив L1	31,75
2	3 - Корпус верх L1	31,13
3	4 - Корпус верх L2	31,38
4	5 - Слив L2	32,06
5	Статус	0
6		
7		
8		
9		

Beam signal from phase probe (10x injection)

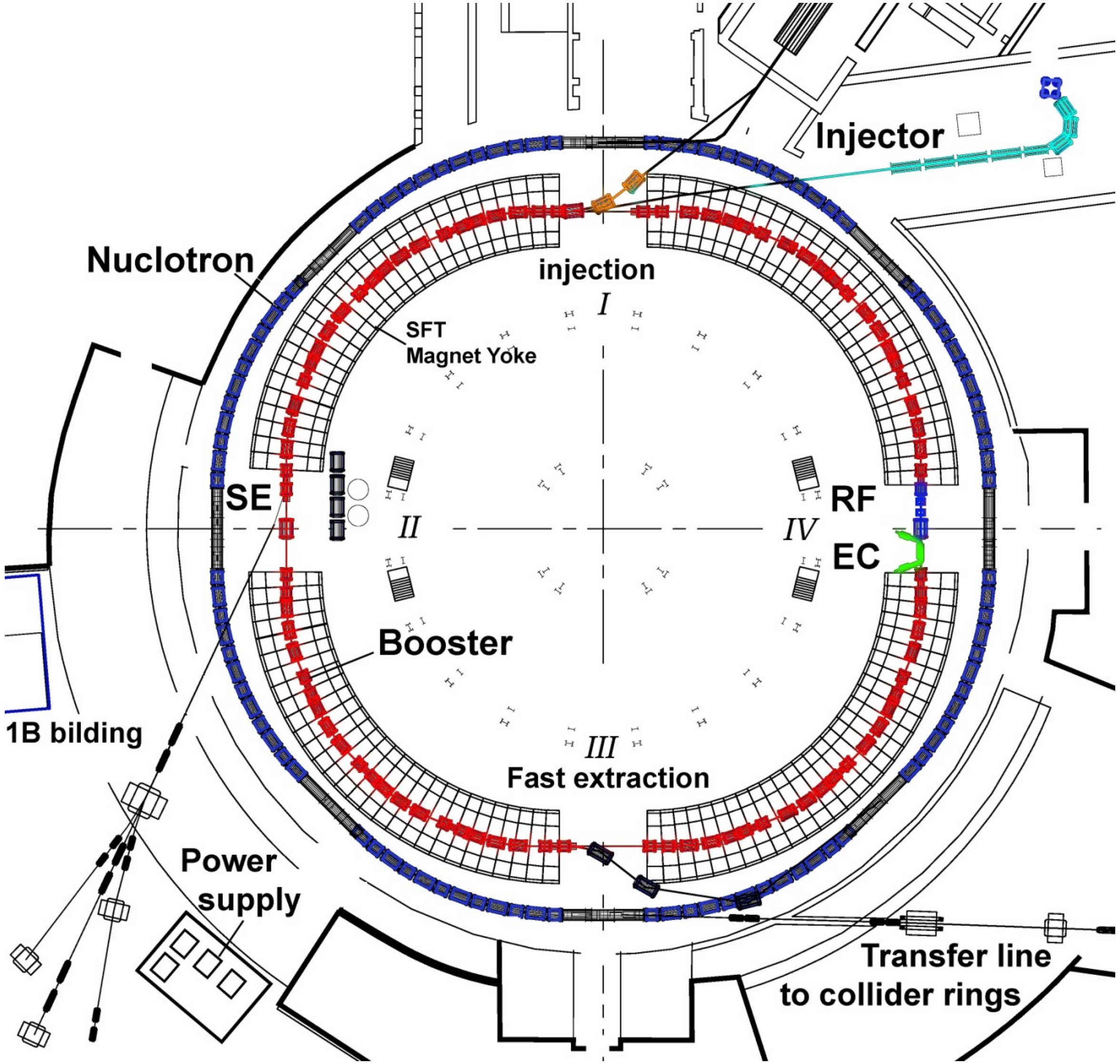


Booster ring layout



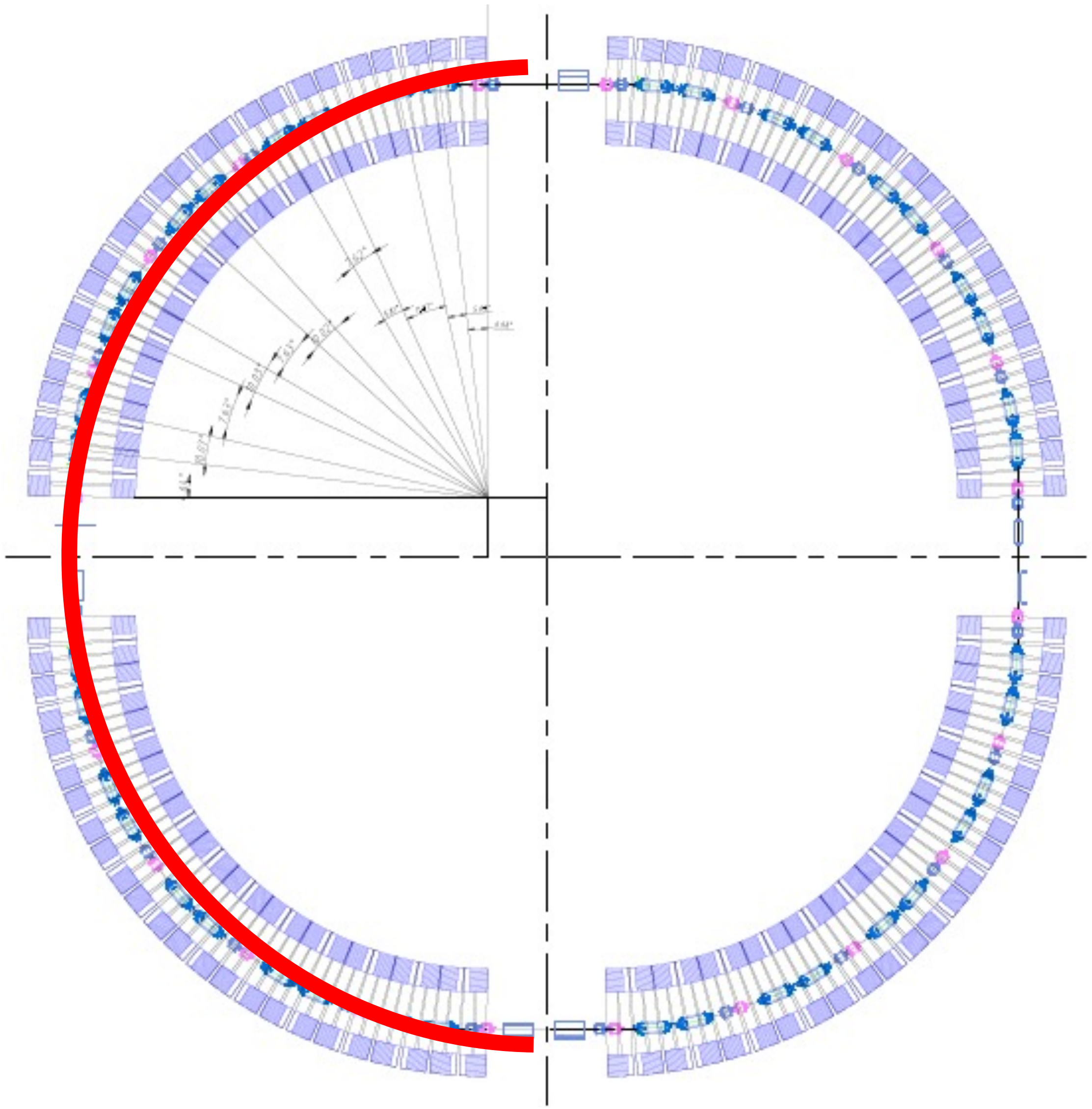


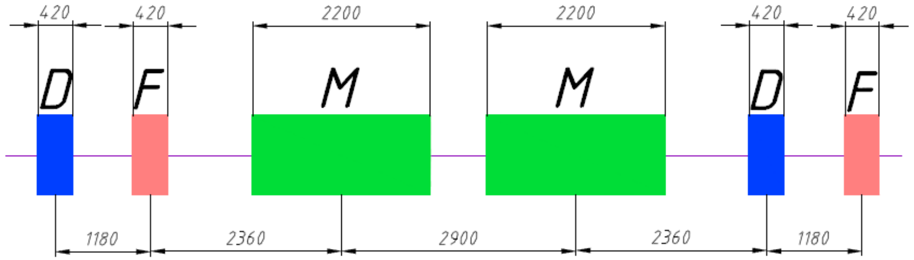
NICA Booster



	Booster
Magnetic rigidity, T/m	25
Radius, meters	211
Beam intensity, particles per pulse	2-6x10^9
Max. energy	600 MeV/u

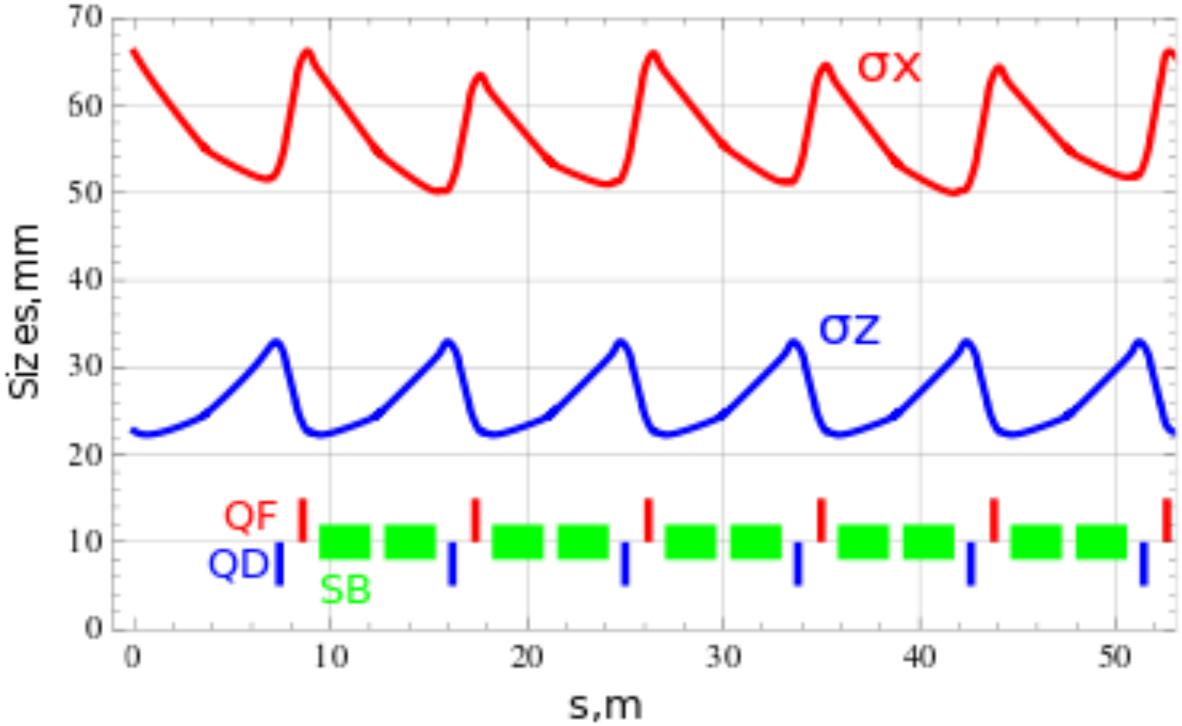
Dipoles	
Number of dipoles	40
Maximum magnetic field, T	1.8
Effective field length, m	2.2
Bending angle, deg	9.0
Curvature radius, m	14.09
Vacuum chamber, mm^2	128x64
Quadrupoles	
Number of quadrupoles	48
Field gradient, T/m	19.7/-20.3
Effective field length, m	0.4



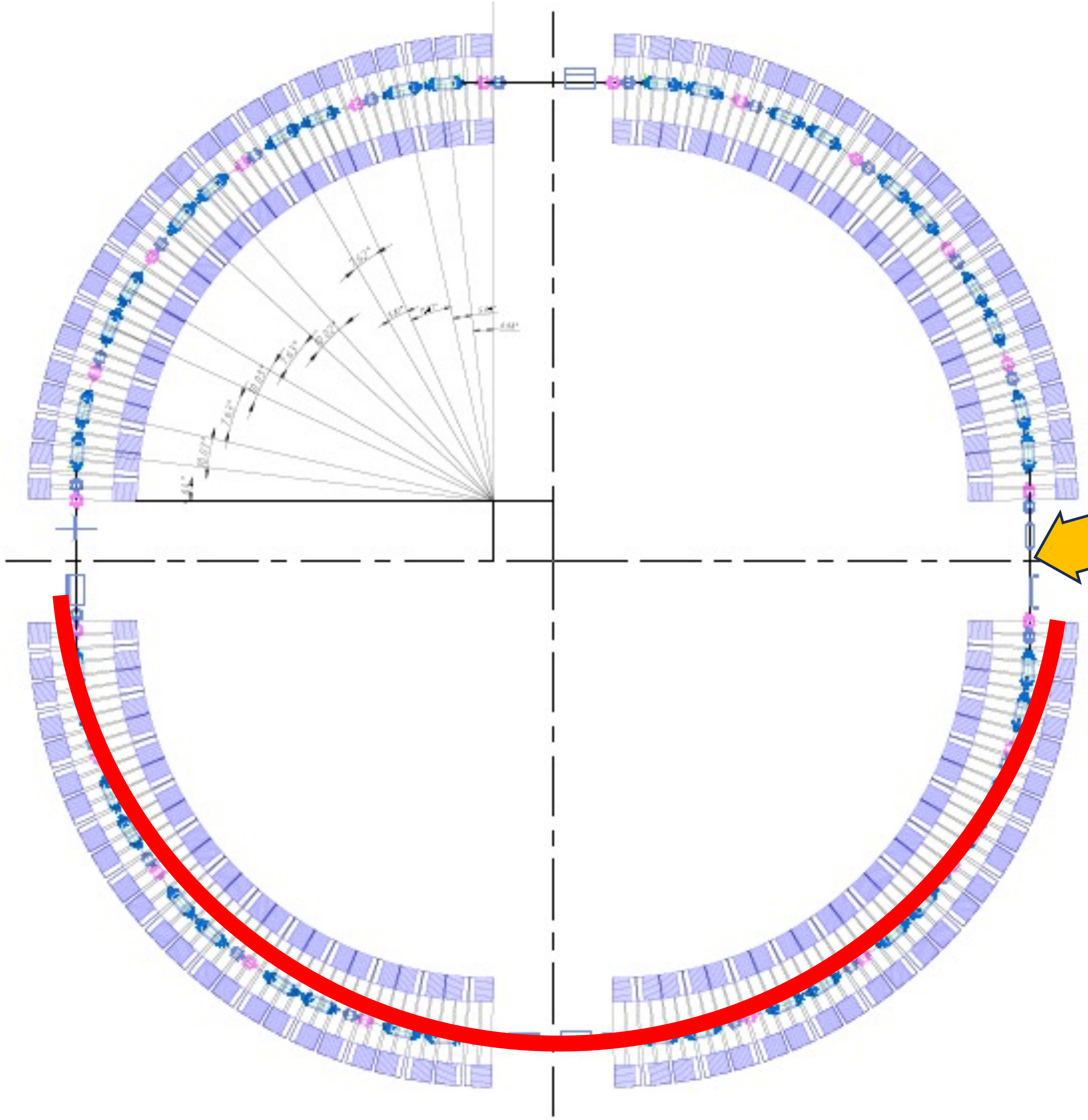


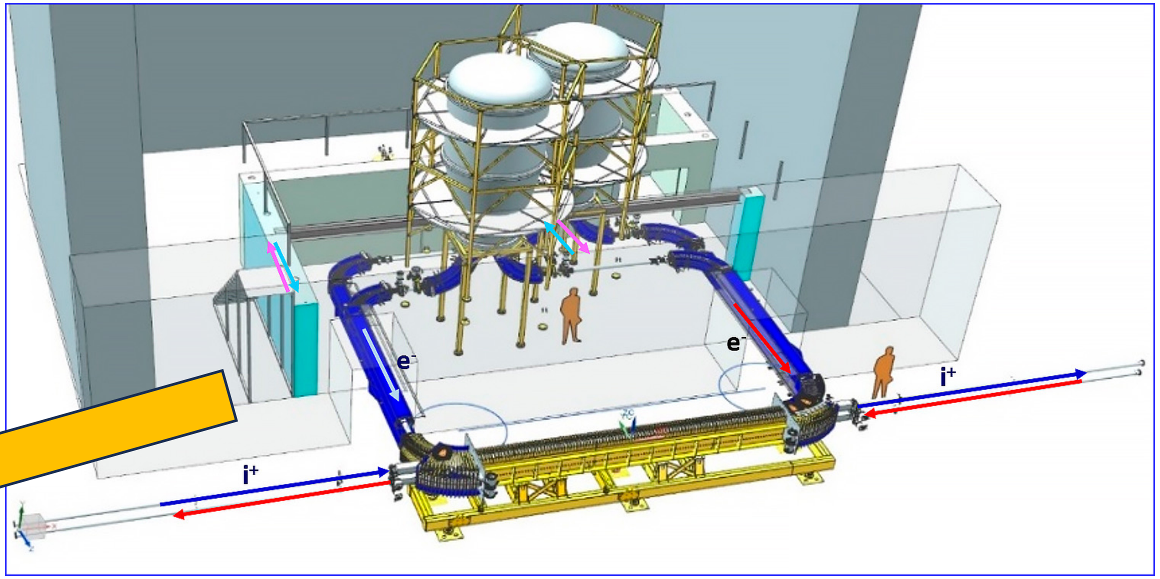
420
420
2200
2200
420
420
D
F
M
M
D
F
1180
2360
2900
2360
1180

420
420
F
D

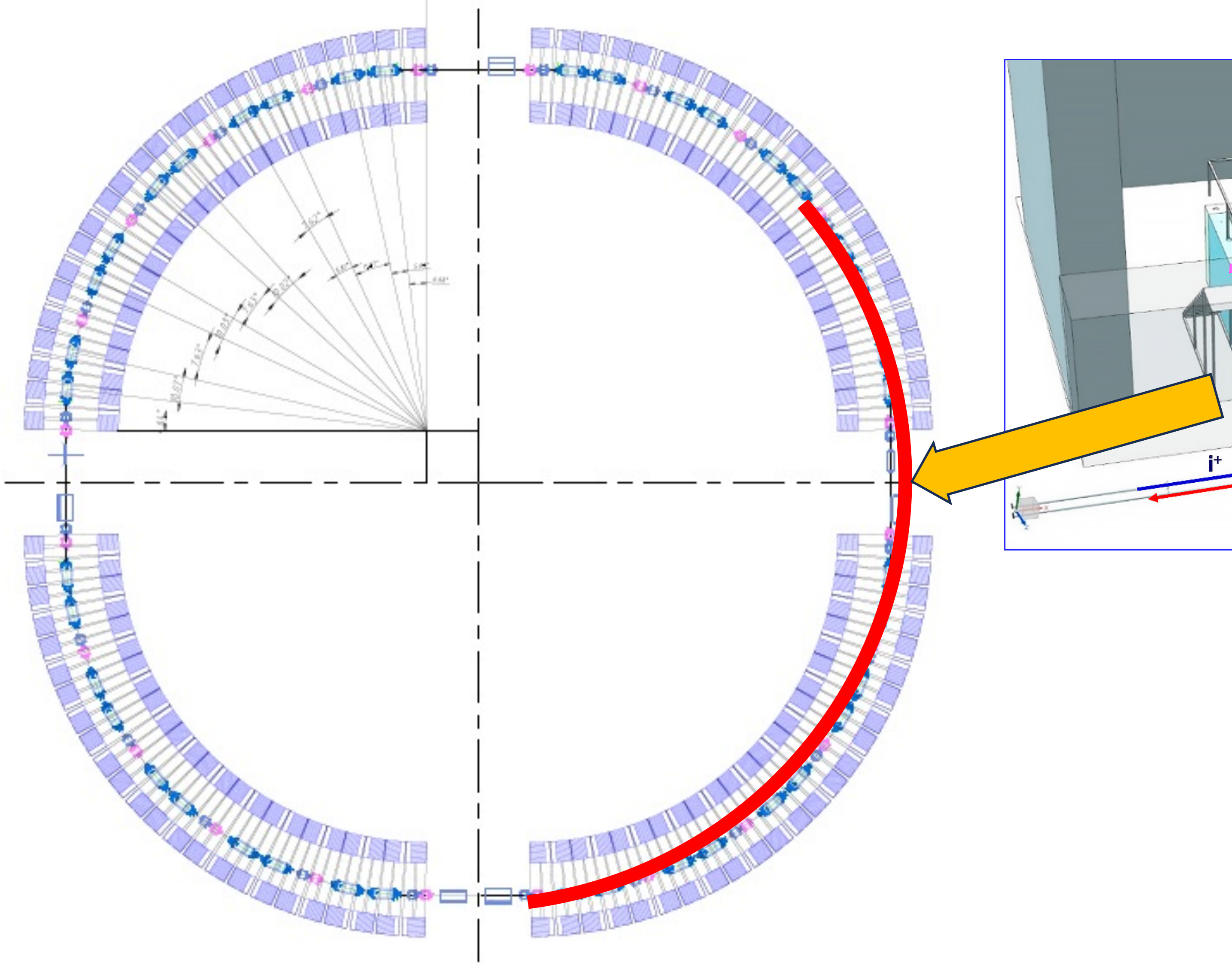


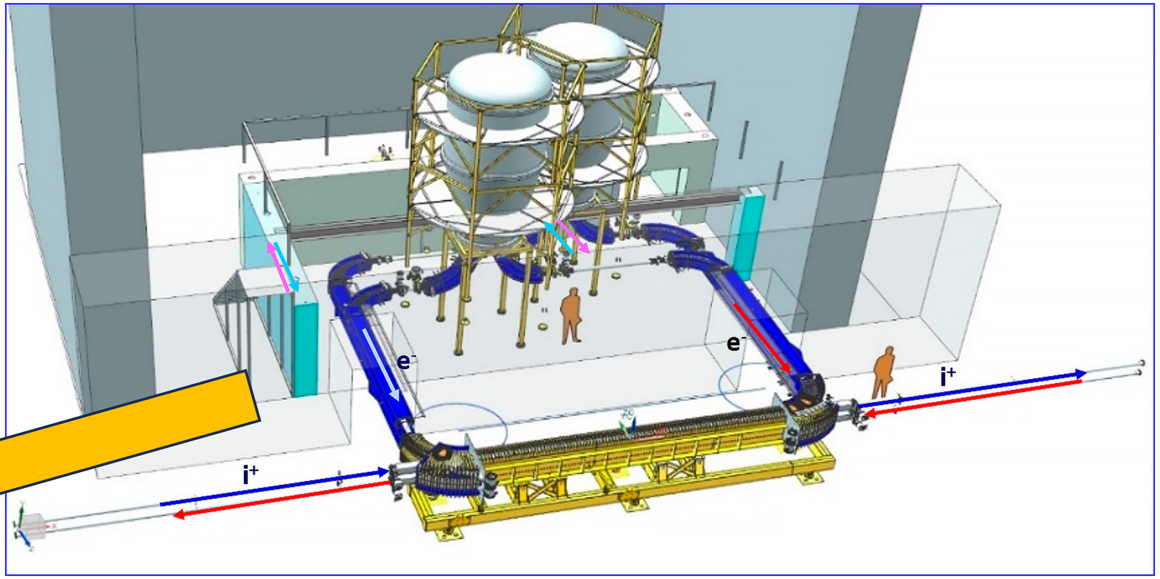
σx
σz
QF
QD
SB
Siz es,mm
s,m
0
10
20
30
40
50
60
70

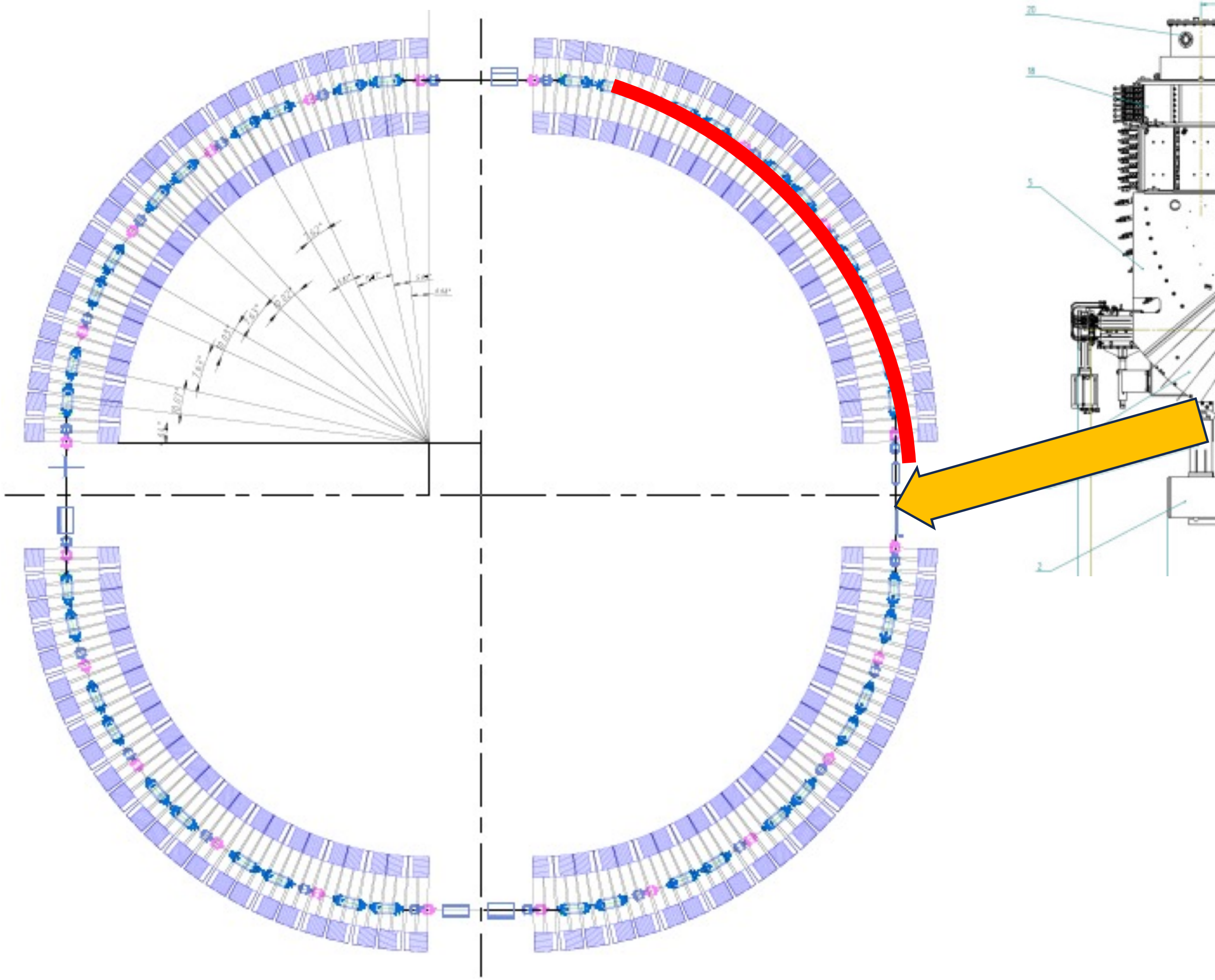


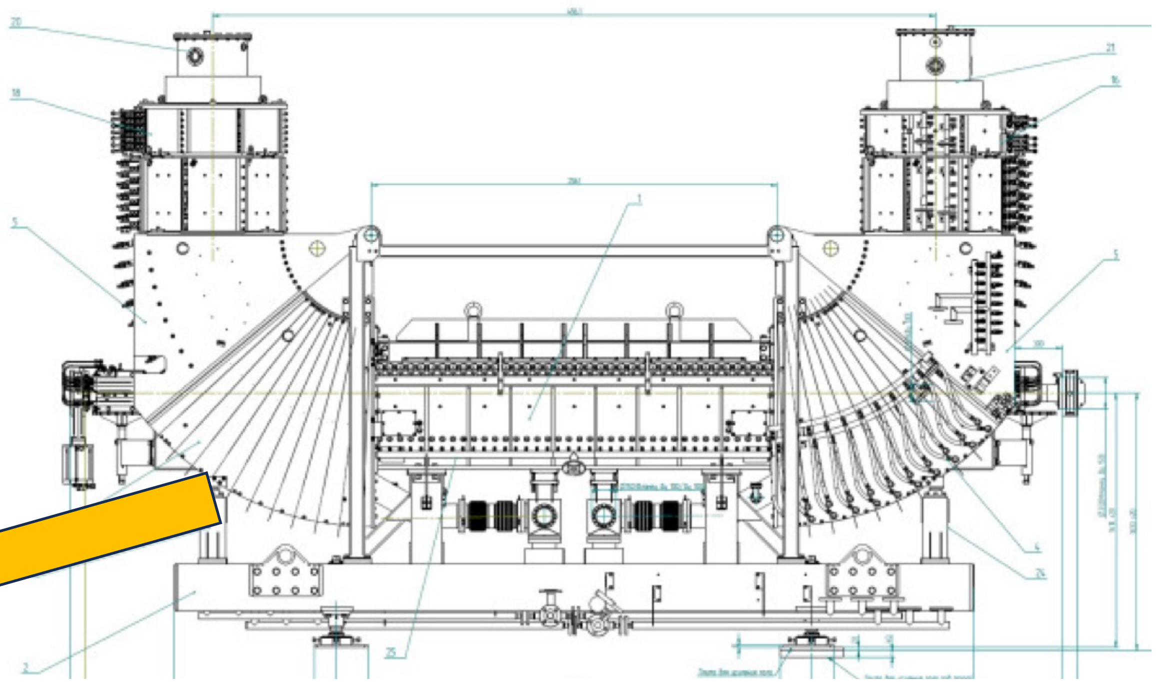


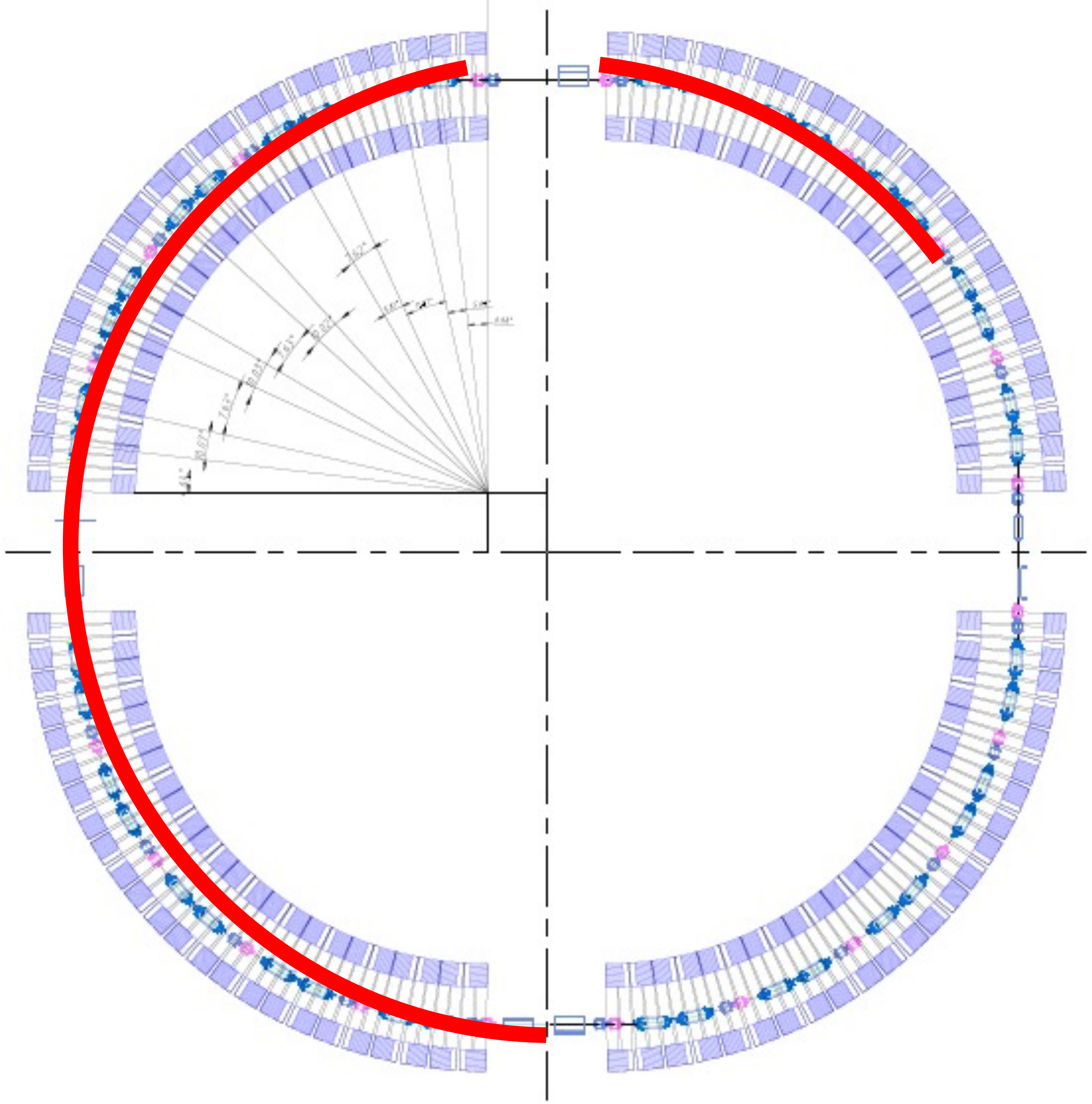
e^-
e^-
i^+
i^+



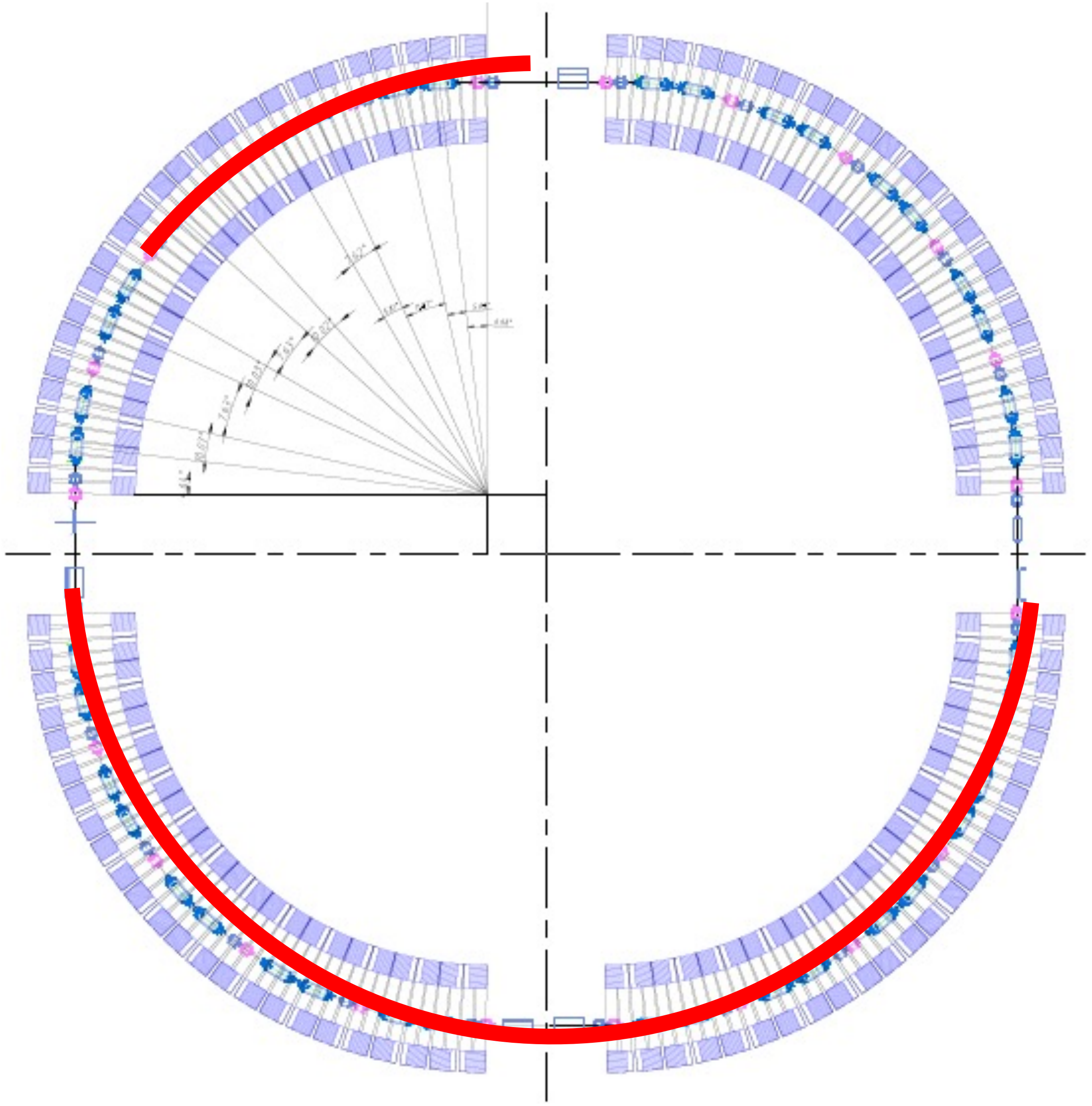

e⁻
e⁻
i⁺
i⁺







Parameter	Value
Electron energy E, keV	≤ 1
Accuracy of energy adjustment and its stability, ΔE/E	$\leq 1\cdot10^{-5}$
Beam current stability, ΔI/I	$\leq 1\cdot10^{-4}$
Electron beam loss current, δI/I	$\leq 3\cdot10^{-5}$
The strength of the ECS longitudinal magnetic field, kGs	1 – 2
Permissible inhomogeneity of the longitudinal magnetic field in the cooling area, ΔB/B	≤ 3·10-5 on the length 15 cm
Transverse temperature of electrons in the cooling section (in the particle system), eV	≤ 0.3
Correction of the ion orbit at the input and output of ECS	offset, mm ≤ 1,0 angular deviation, mrad ≤ 1,0



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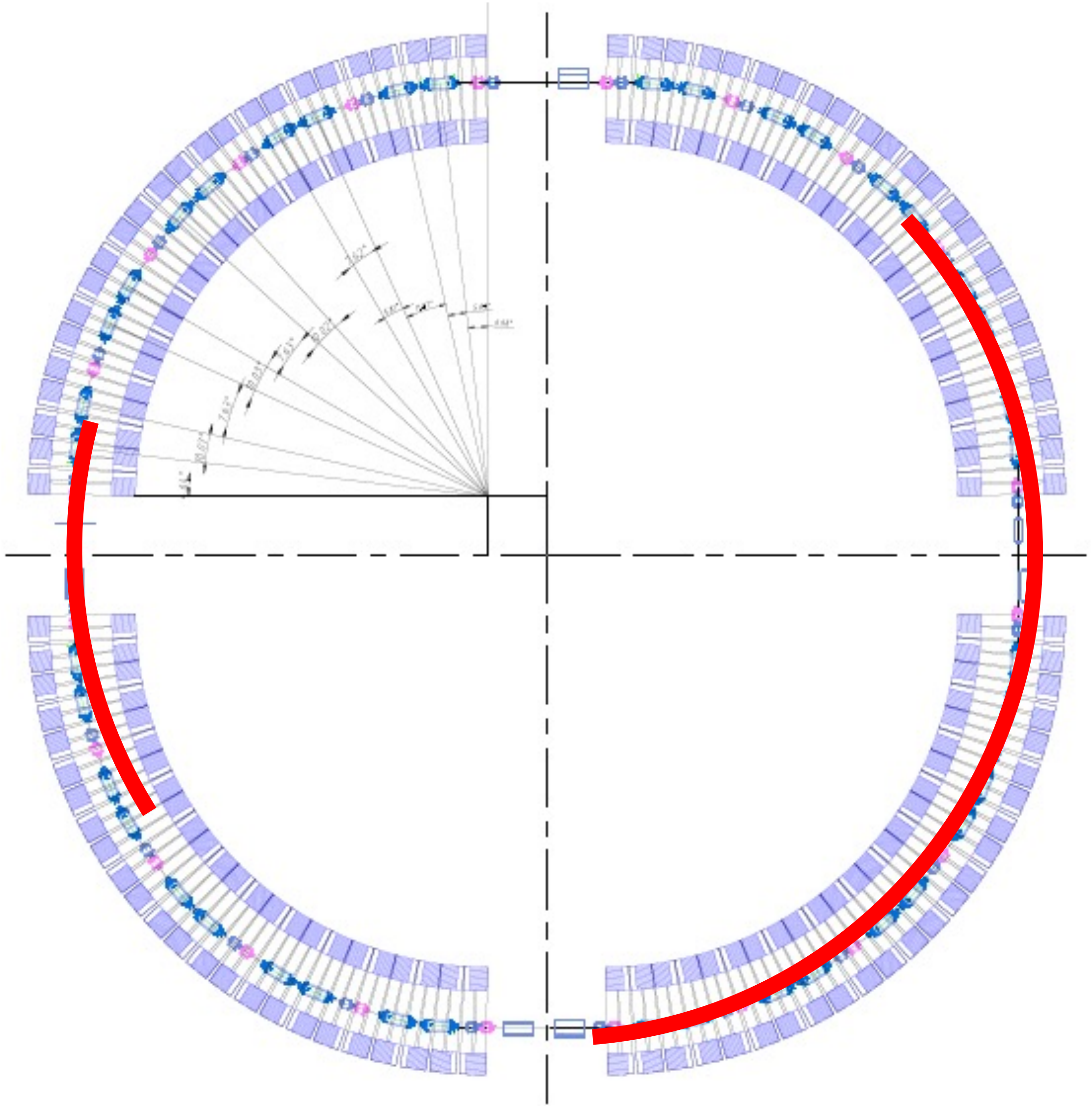

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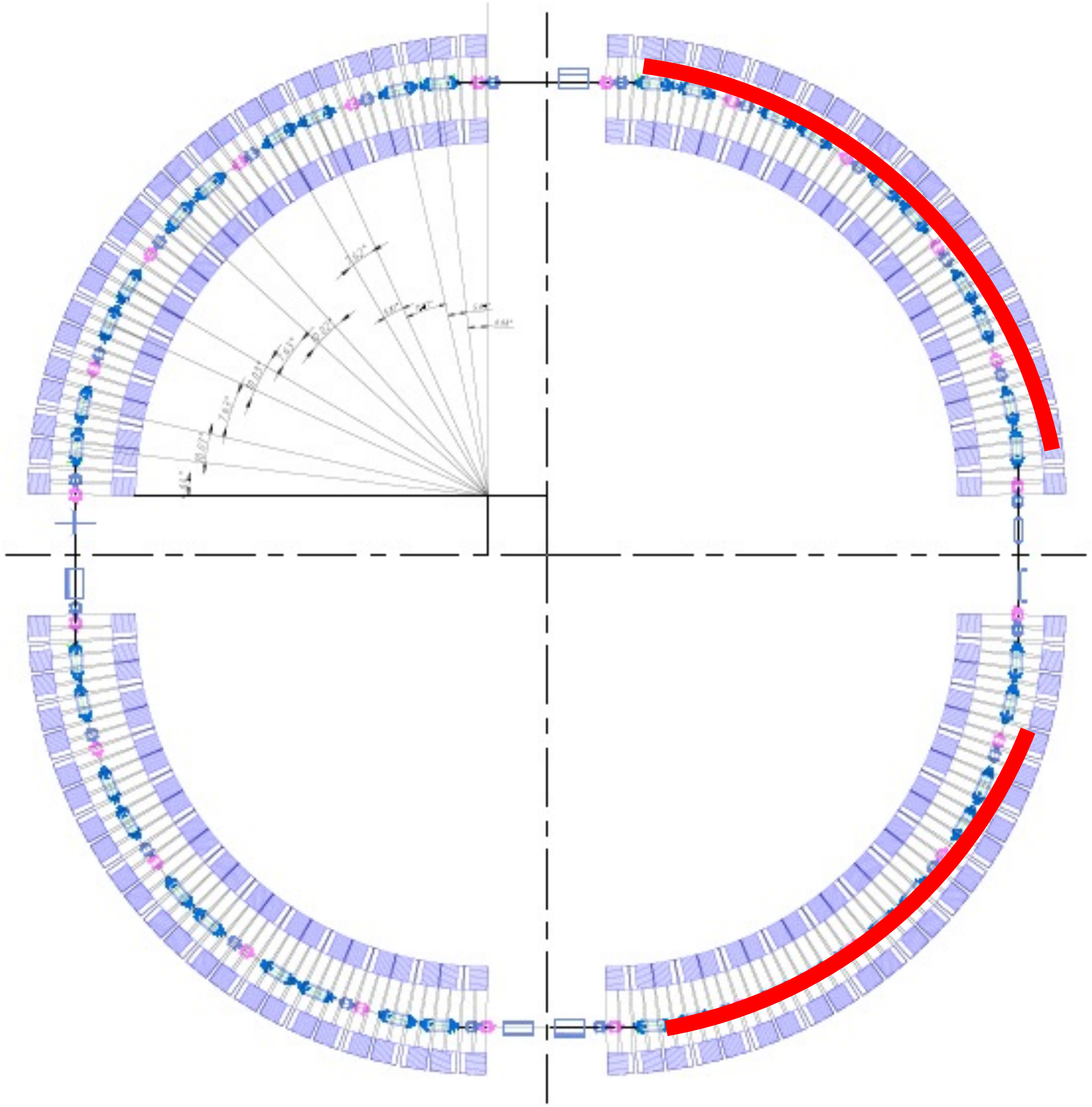

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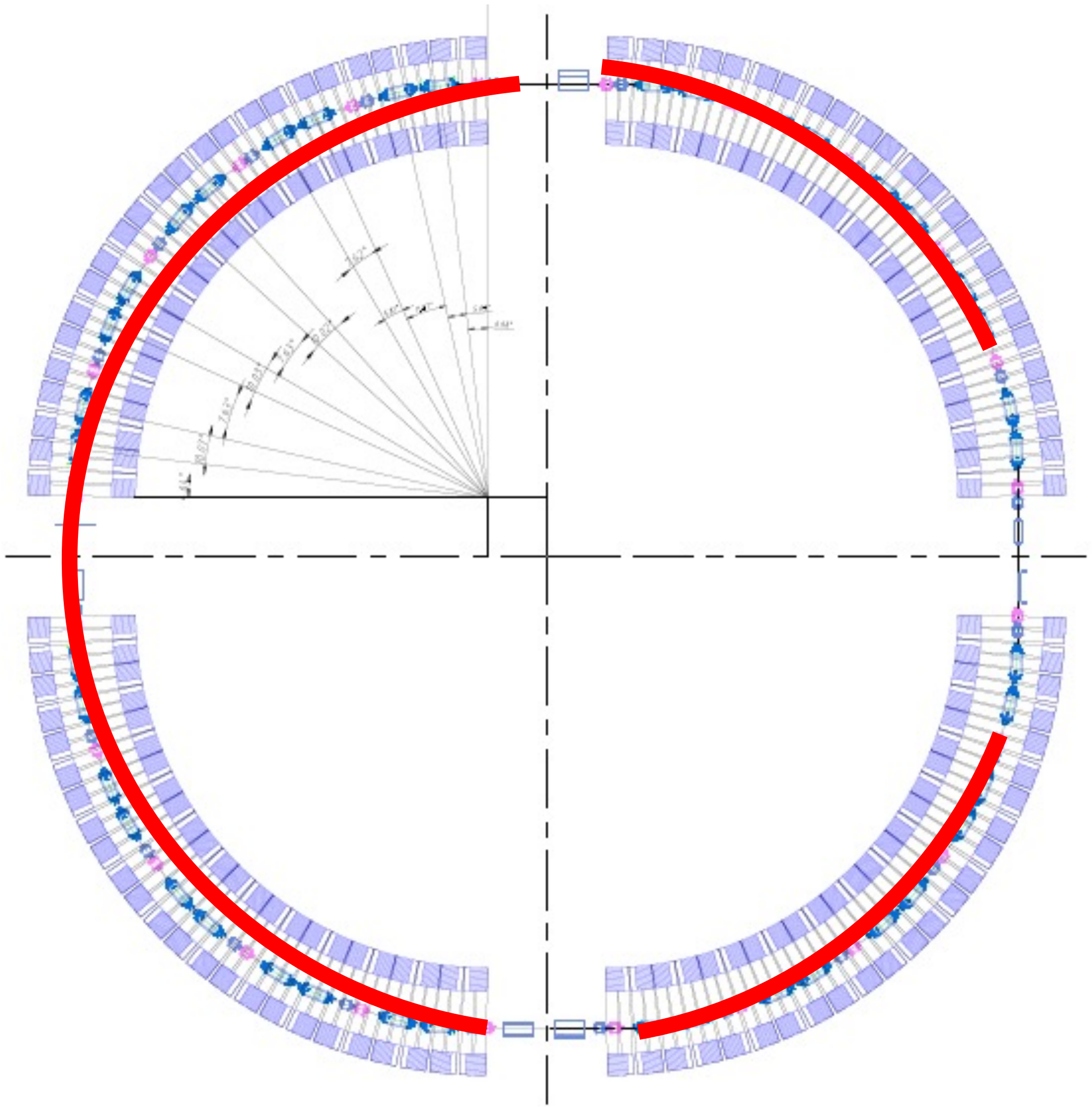
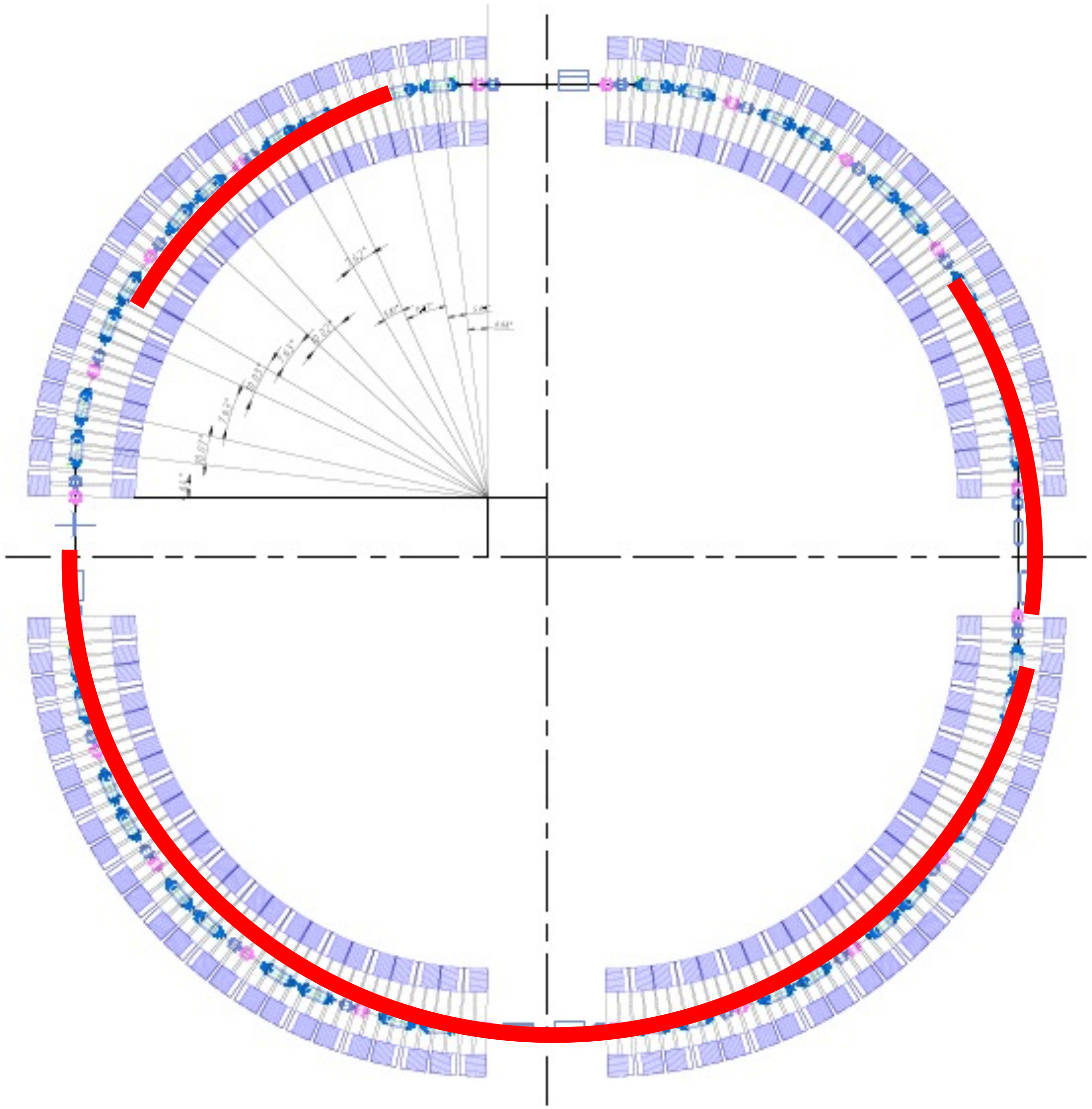
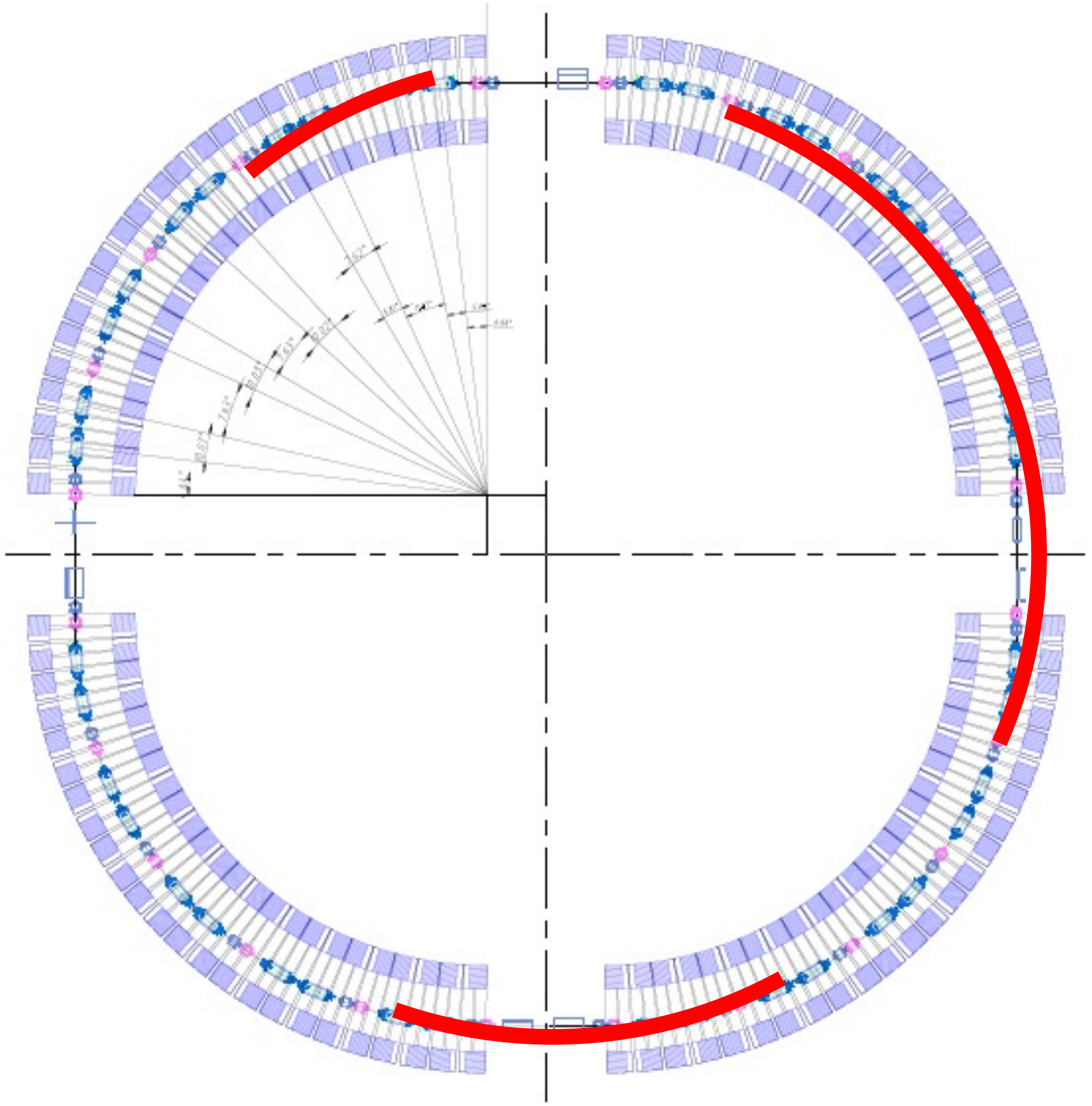
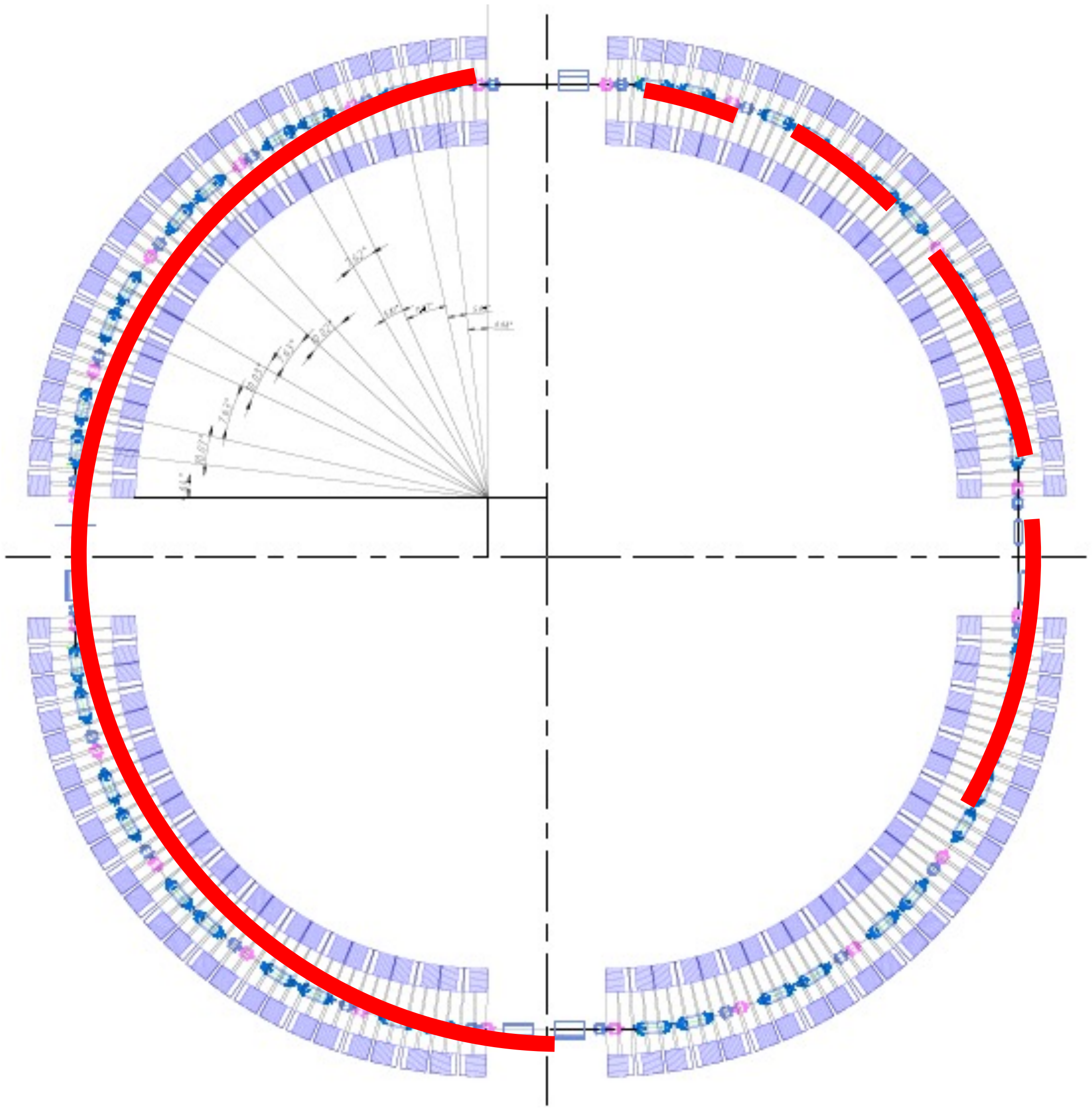
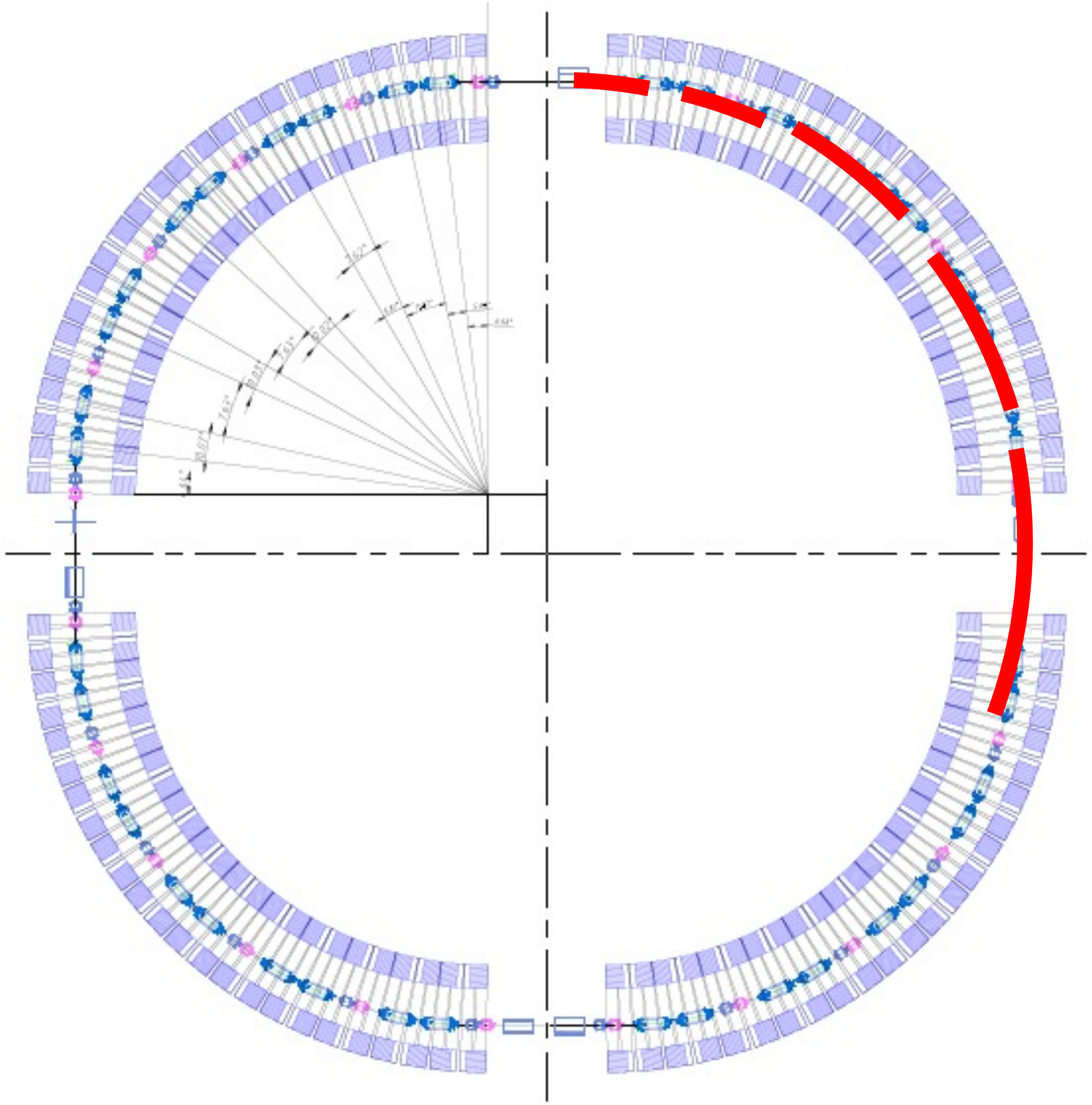
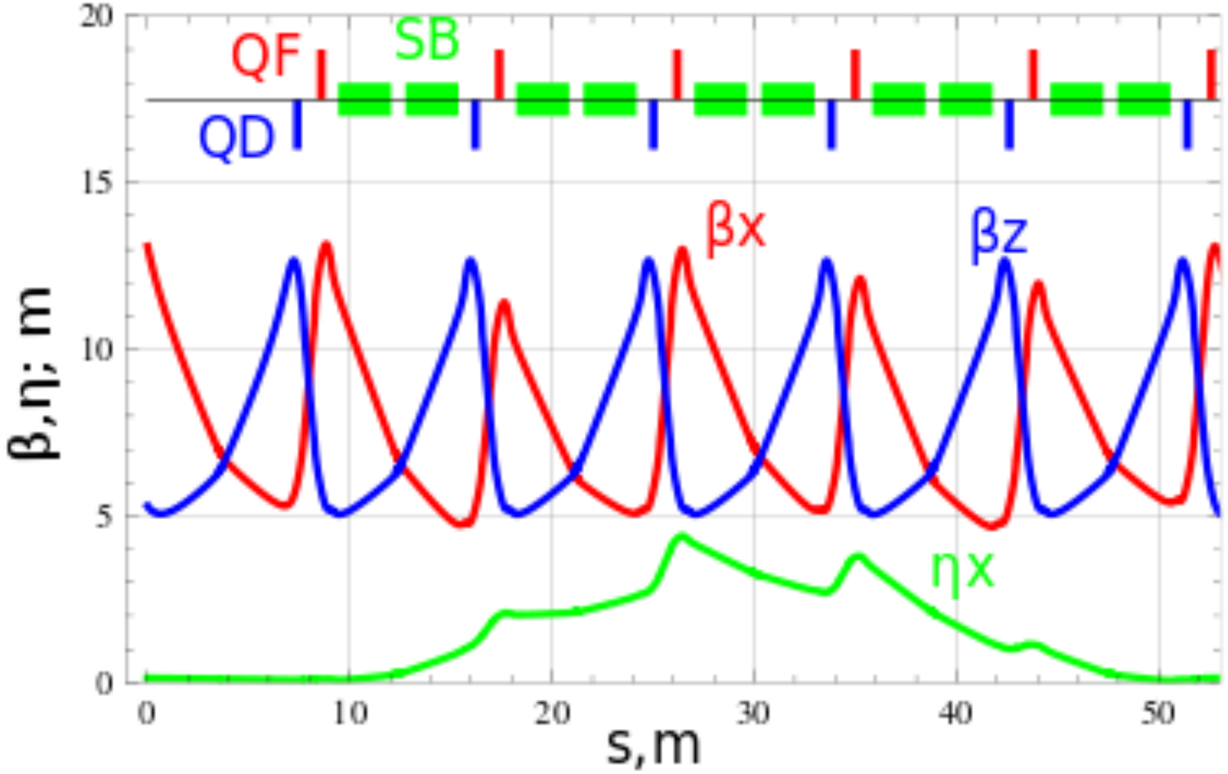






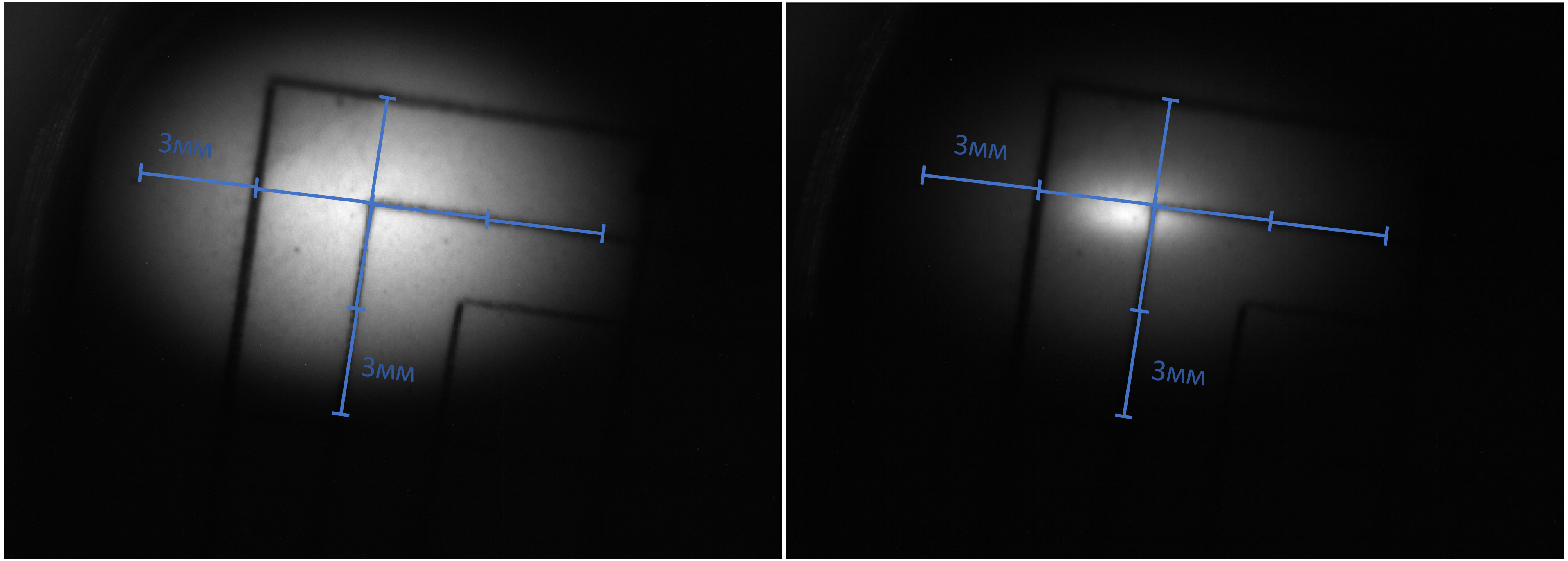






QF
SB
QD
βx
βz
ηx
β,η; m
s,m
0
5
10
15
20
0
10
20
30
40
50

Cooling of the $^{124}Xe^{28+}$ ion beam by electron beam with 50mA current at the energy of 1,830 keV

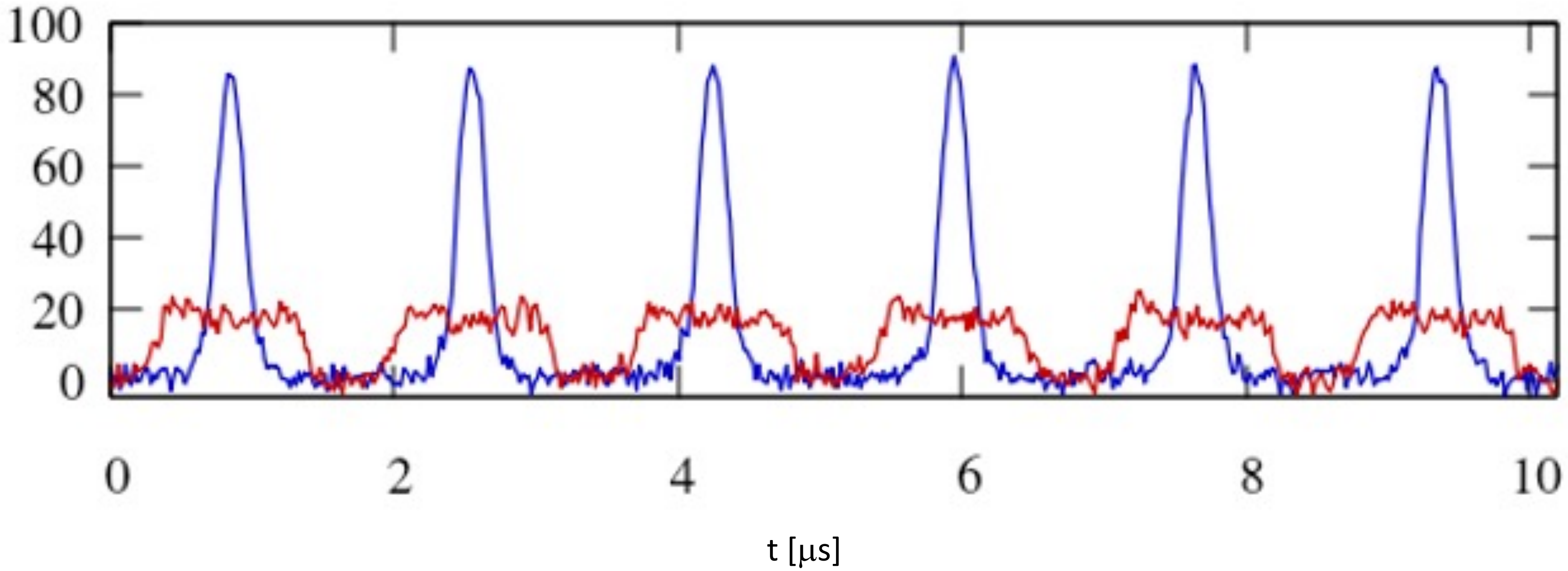


The uncooled and cooled ion beams.

При работе с пучком ионов, охлаждённых и ускоренных в Бустере, полностью «ободранных» на выходе из Бустера, доускоренных в Нуклотроне и выведенных на детектор BM@N, его *скорость счёта возросла в два раза*.

Electron Cooling in Booster

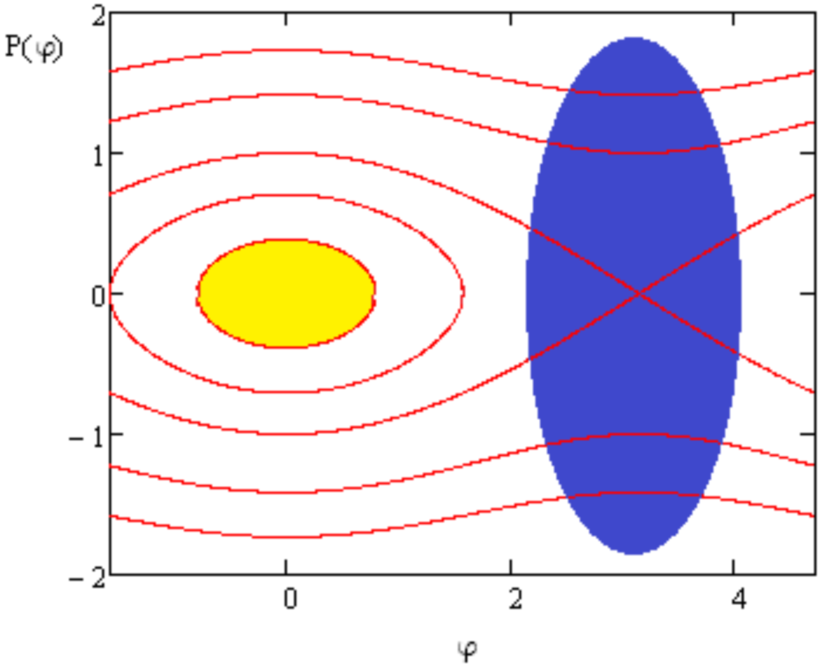
- Electron cooling was demonstrated with the RF voltage present as it is required for beam accumulation
- Measurements support the accumulation rate of about 10 Hz



Beam current dependence on time with and without electron cooling. Rf harmonic number – 5. Cooling cycle duration - 200 ms. Electron beam current 50 mA. Electron beam voltage 1.83 keV

Beam Accumulation at electron cooling

- ❑ Beam accumulation happens in the longitudinal plane at Booster injection
  - ➢ 4 μs bunch – 8 μs revolution time
- ❑ Each new injection happens after the previous one is cooled to the core
  - ➢ Expected injection rate – 10 Hz
  - ➢ 10 – 15 injections will require
  - ➢ Total cycle duration ~5 s
- ❑ The permanently present 1st RF harmonic weakly affects large amplitude particles
- ❑ For small amplitude particles the cooling force will be intentionally reduced to avoid overcooling



- ❑ To avoid anticoolig we need to match well the injection magnetic field and e-beam energy
  - ➢ It happens since for large $\Delta p/p$, dF/dt changes sign after reaching the peak

An increase of ion accumulation intensity by a factor of 5 is planned. However application of electron cooling is restricted by ion bunch space charge effects at a level of $\cdot 10^9$ ions of Bi^{35+}

CONCLUSION

The HILAC is modified for multi-injection and successfully tested (Summer 2024)

- New power supplies for solenoids are developed, installed and proved their reliability under a long-duration operation,
- New water-cooling system for lenses is ready and tested

The beam transportation channel is capable to transfer the beam of increased intensity to the Booster (Summer 2024)

The Booster Run with multi-injection is scheduled for the Winter 2024-2025

Thank you for attention!