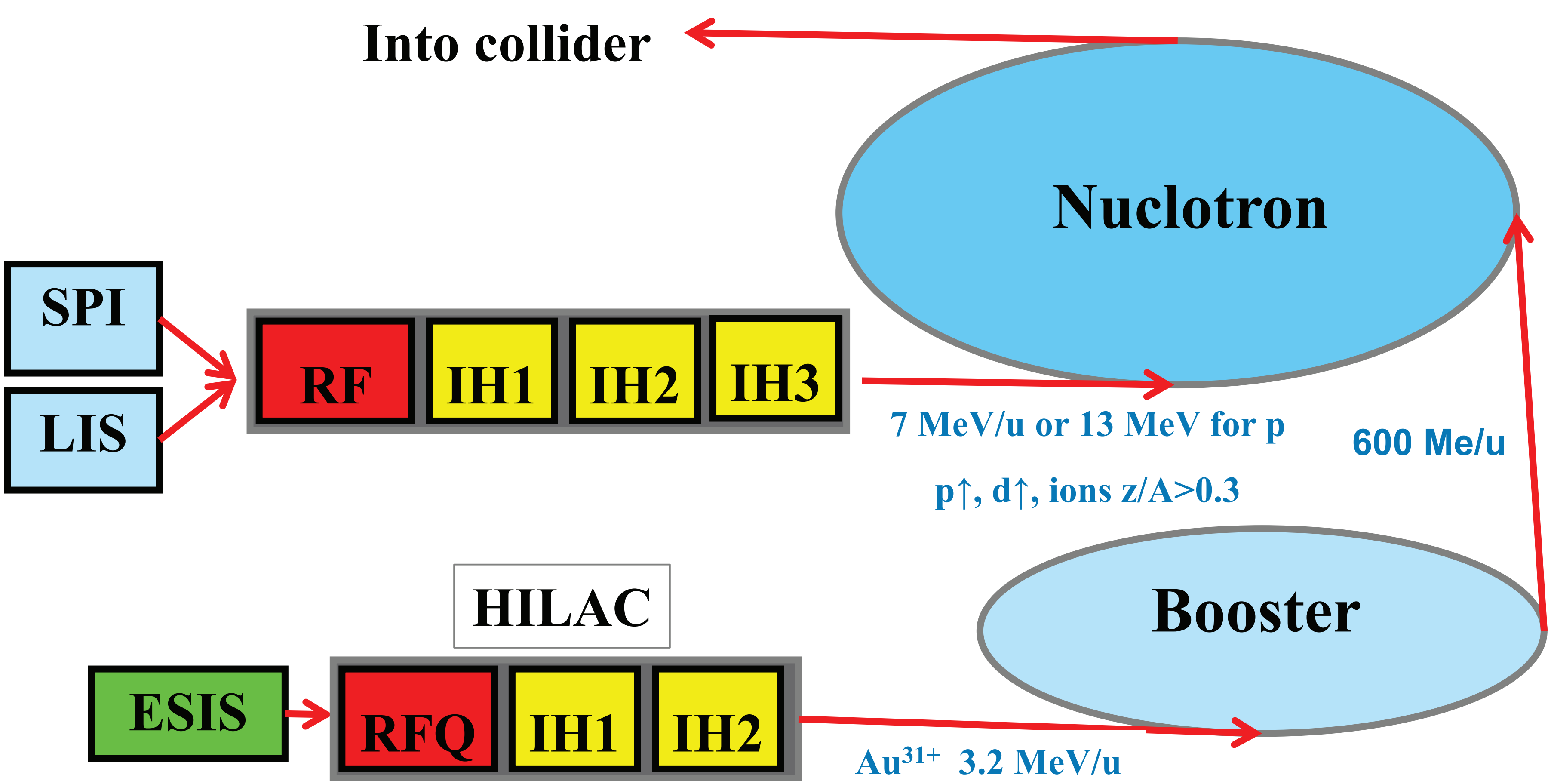
Beams formation for the injection into NICA Booster

Levterov K. on behalf of Acceleration Division

Area layout

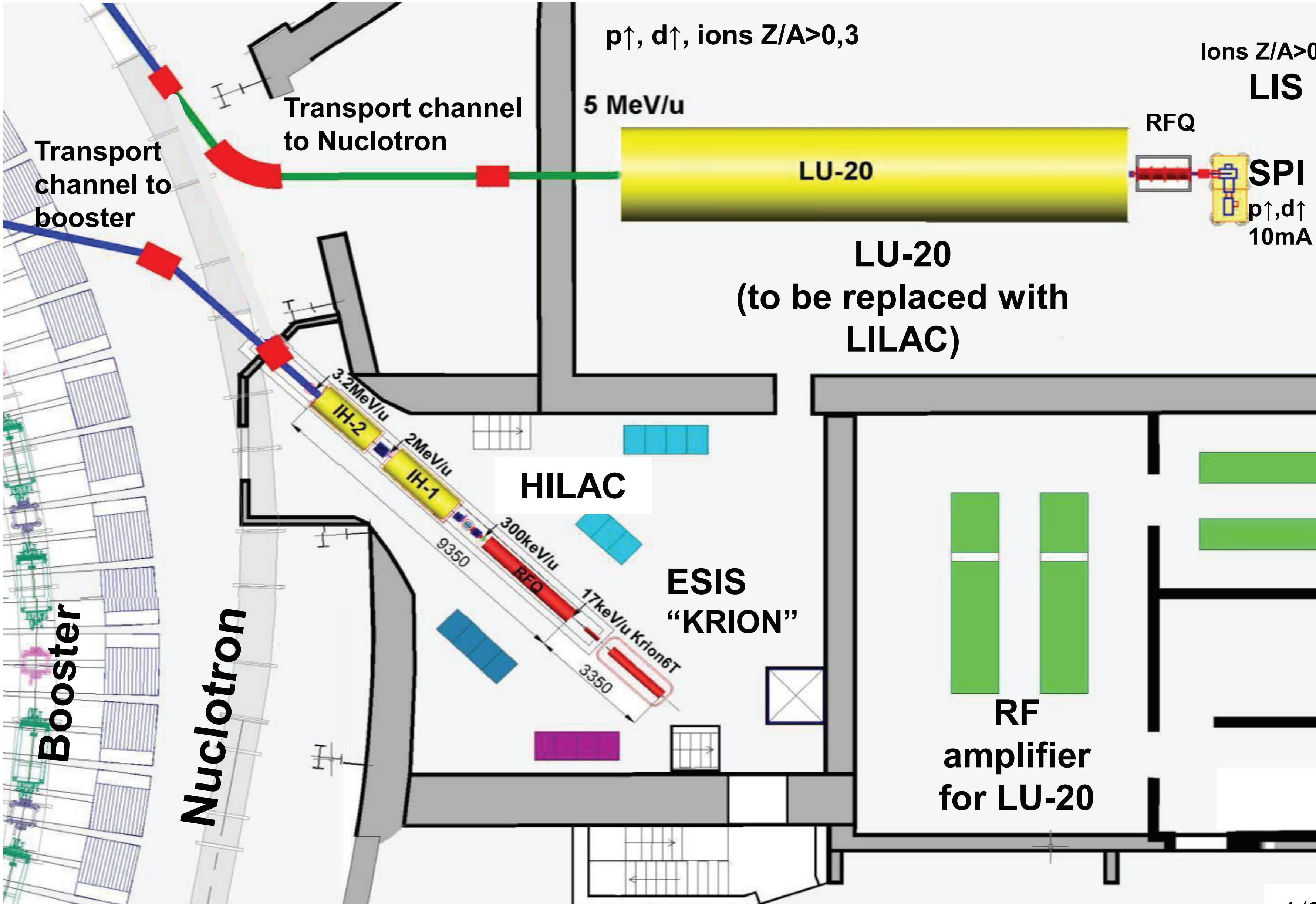

SPD
(Detector)
BM@N (Detector)
Extracted beam
Collider
MPD
(Detector)
E-cooling
Heavy Ion
Linac
Nuclotron
LILAC
Booster
NICA

HILAC & LILAC – two injectors for NICA



Beams of polarized particles p↑ и d↑ and light ions will be accelerated by LILAC (now it is LU-20), then injected into Nuclotron
Heavy ions : HILAC + Booster + Nuclotron

Injection Facility arrangement



TOPICS

- **Alvarez proton linac LU-20 as an ions injector for Nuclotron**
- **Heavy ion injector based on the KONUS IH-DTL accelerating structure**
- **Ion sources of the NICA injection facility**
- **Formation the beams of ions produced with the Laser Ion Source or plasma ion source with the cold hollow cathode for HILAC and Booster commissioning.**
- **RF beam loading and beam output energy vs RF tuning of IH2**
- **Summary.**

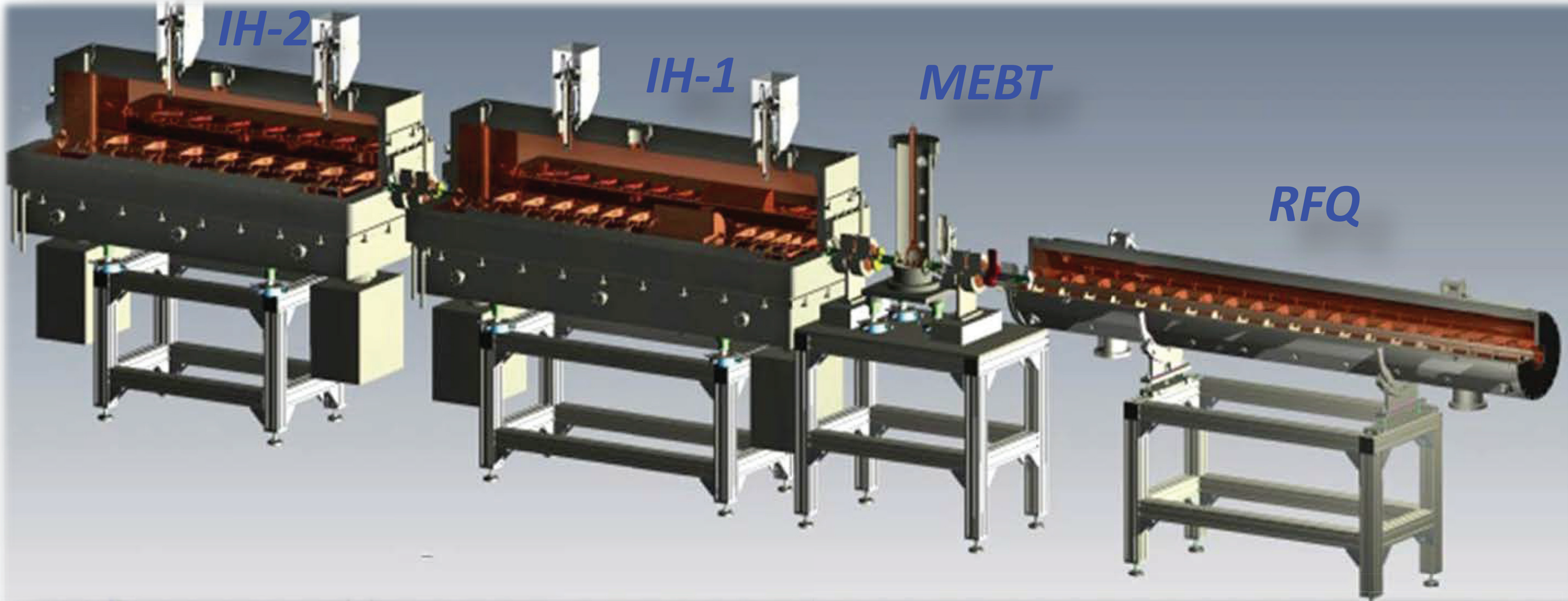
Alvarez proton linac LU-20 as an ion injector

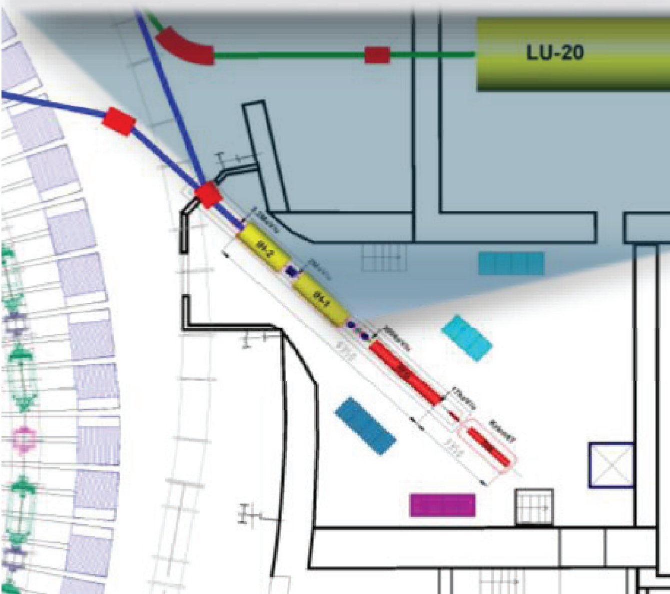
- 1974- LU-20 commissioning, 2-2.5 × 10^{11} 20 MeV protons/pulse, 4 × 10^{12} protons/pulse – record achievement
- 1971- A.M. Baldin paper "Масштабная инвариантность адронных столкновений и возможность получения пучков частиц высоких энергий при релятивистском ускорении многозарядных ионов"
- 1974 Oct - LU-20 operates in 2ββλ mode as injector of α-particles and deutrons produced by duoplasmotron ion source developed in LHEP
- 1977 - C^{6+}, N^{7+}, O^{8+}, Ne^{10+}, produced with ESIS "KRION"
- 1993 – LU-20 reconstruction; proton beam current dropped down from 40 mA to 20 mA, deutron current increased from 10 mA to 14 mA

Main features and limitations of LU-20

- Only protons were accelerated in βλ mode up to 20 MeV, the other ones species – in 2βλ up to 5 MeV/u
- A/Z≤3 due to the reasons of both maximum RF power limitation and vacuum breakdowns in RF cavity

Heavy ion linear Injector based on KONUS DTL structure
HILAC=RFQ + IH1 + IH2





A/Z 6.25	Type	Length	RF power	Output energy
RFQ	4 - rod	3.16 m	120 kW	0.3 MeV/u
MEBT	Two QD + buncher	1.4 m	3 kW (buncher)	0.3 MeV/u
IH1	DTL + QT	2.3 m	296 kW	2 MeV/u
IH2	DTL	2.1 m	278 kW	3.2 MeV/u

DTL structure IH1 + IH2

Au31+, Ein=300 keV/u   Eout=3.2 MeV/u

Accelerating structure «KONUS» (KOmbinierte NUll grad Struktur).

$\beta\lambda/2$ IH-mode, H_{110}.

Main features:

- Main acceleration along a 0° synchronous particle structure with asynchronous beam injection and a surplus in bunch energy compared to the synchronous particle.
- Transverse focusing by a quadrupole triplet or a solenoid lens.
- Longitudinal focusing by a few rebunching gaps operating at $\varphi s = -35°$

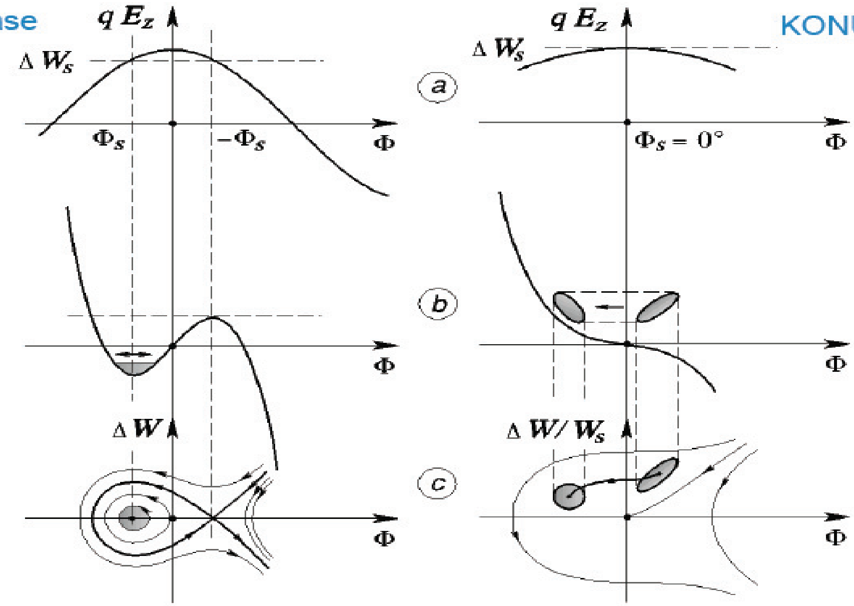
"KONUS" in the world:

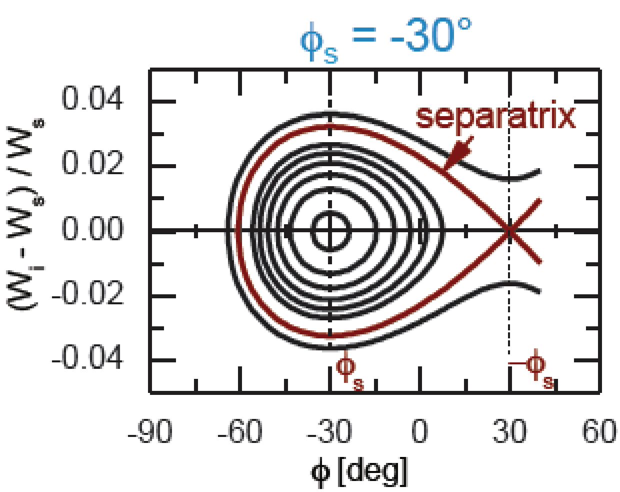
- HSI and HLI in GSI FAIR, Eout=1.4 MeV
- LINAC3- CERN, Eout=4.2 MeV
- Injector for Booster of AGS
- HIAF injector

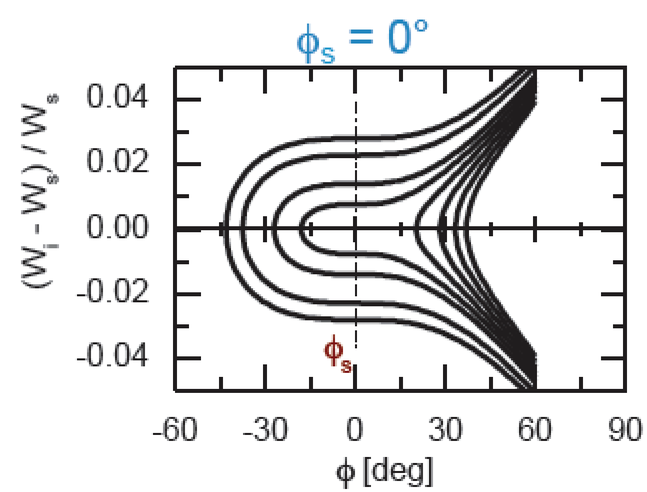
Longitudinal Motion: KONUS Versus ‘Neg. Synchr. Phase Structure‘

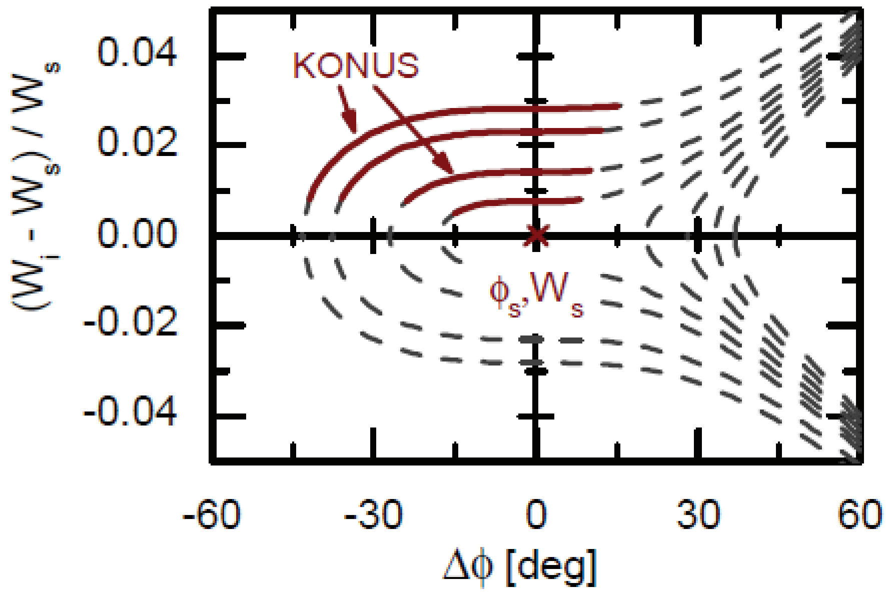
Neg. Synchr. Phase

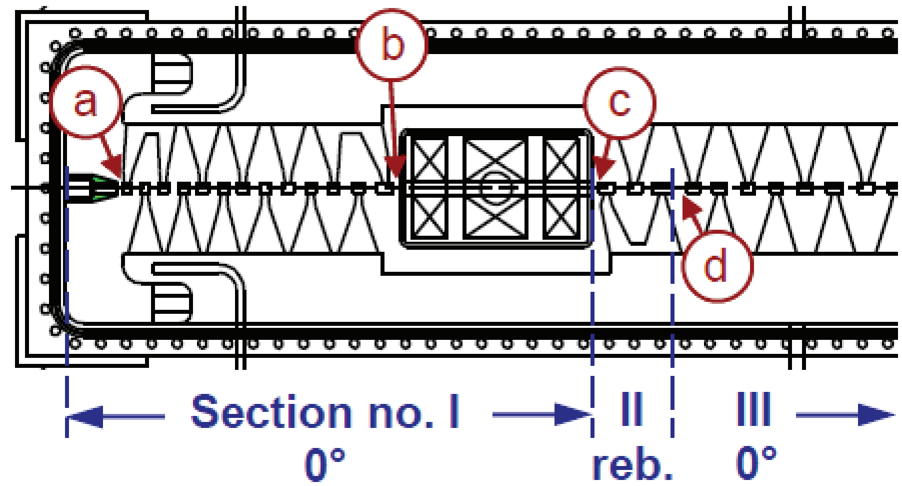
KONUS‘ – Combined 0° Structure

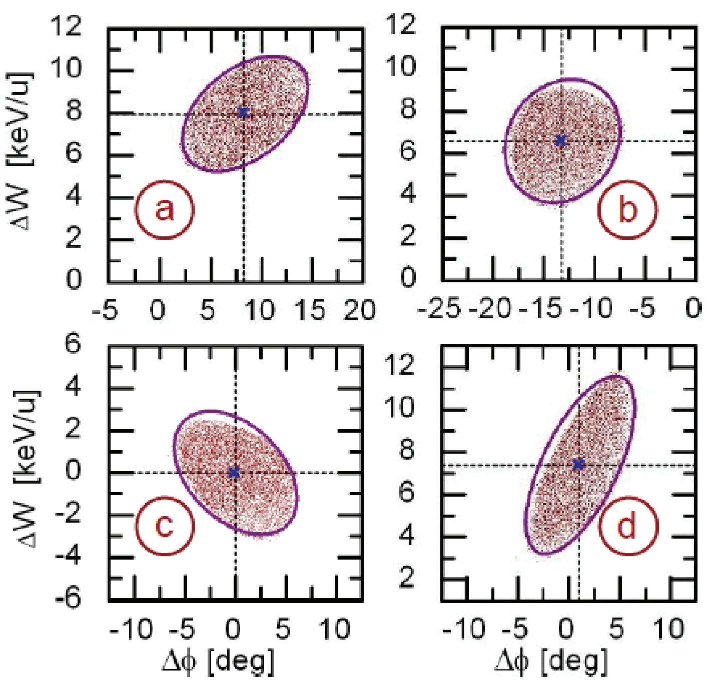


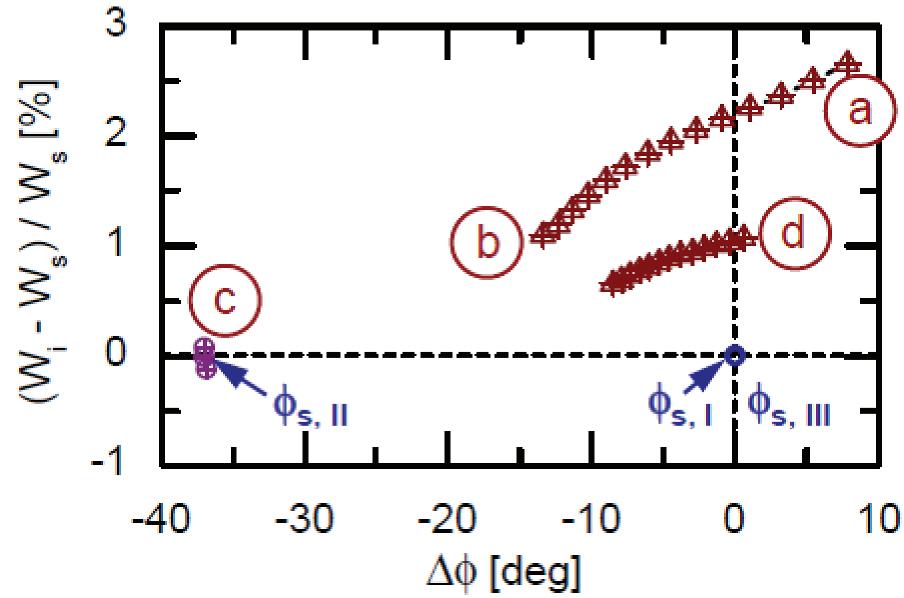





KONUS
ϕ_s, W_s
$(W_i - W_s) / W_s$
0.04
0.02
0.00
-0.02
-0.04
-60
-30
0
30
60
$\Delta\phi$ [deg]


a
b
c
d
Section no. I
II
III
0°
reb.
0°

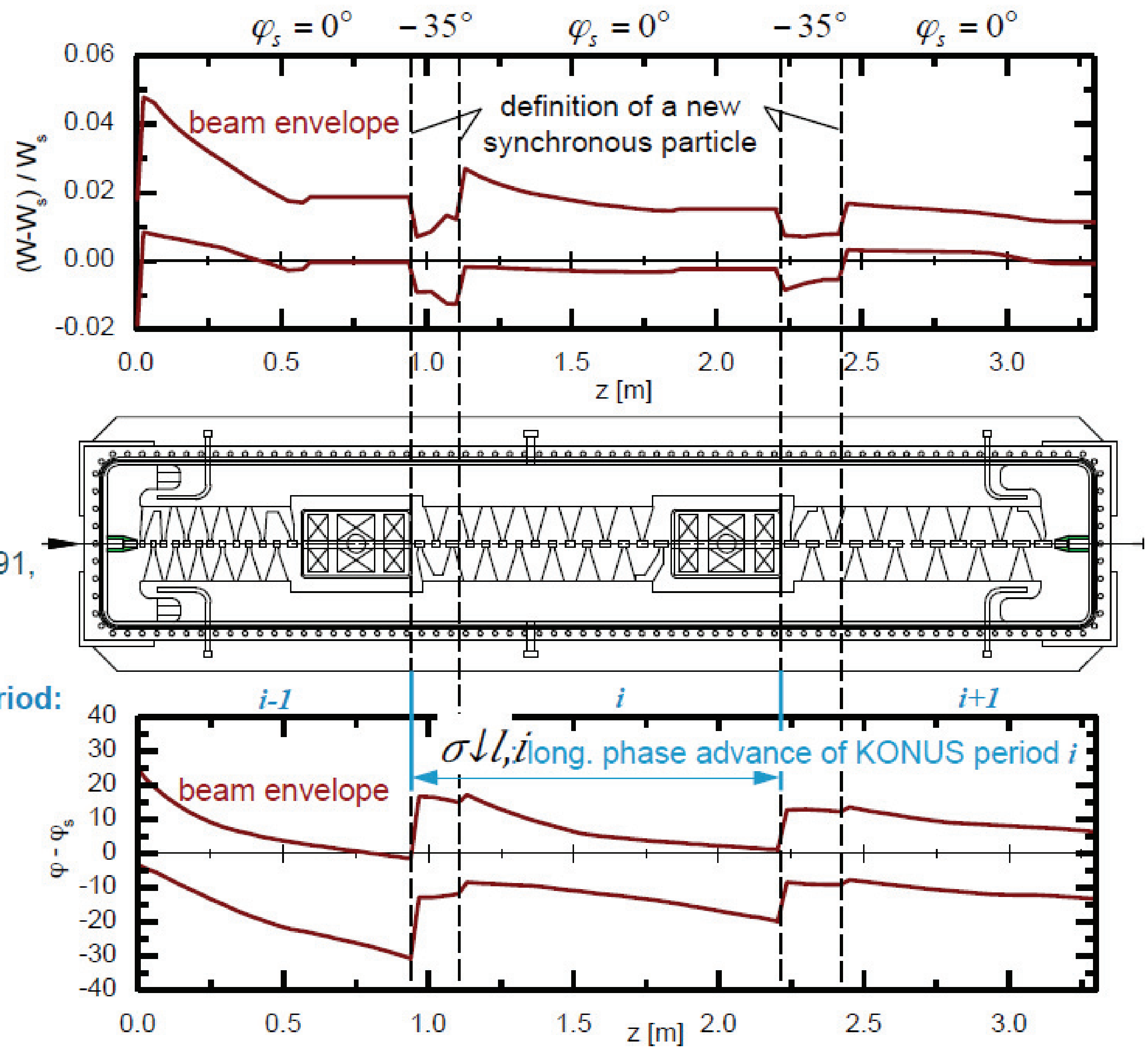

a
b
c
d
ΔW [keV/u]
$\Delta\phi$ [deg]


a
b
c
d
$\phi_{s,II}$
$\phi_{s,I}$
$\phi_{s,III}$
$(W_i - W_s) / W_s$ [%]
$\Delta\phi$ [deg]

Longitudinal KONUS Lattice Periodicity Illustrated on a Built Accelerator

IH cavity of the GSI HLI injector

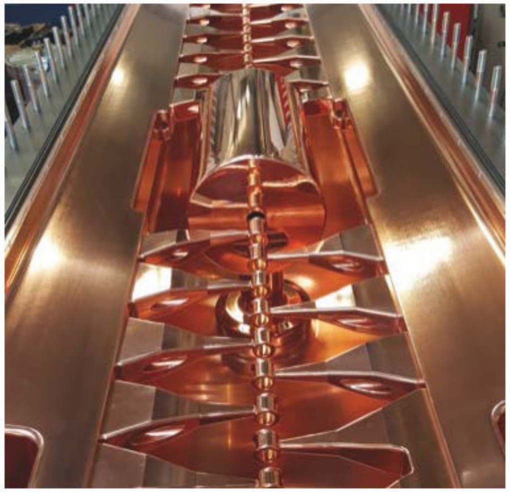
U. Ratzinger, Proc. PAC'91, San Francisco, p. 567

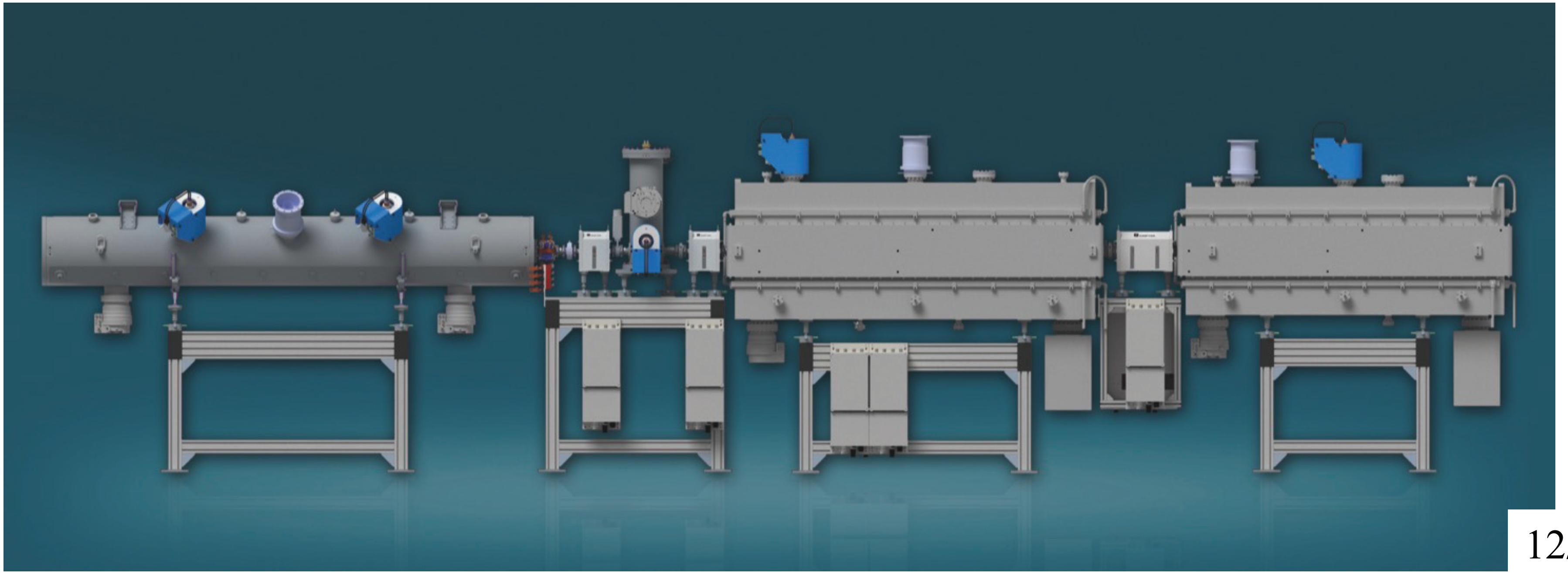


Main parameters and design features of the HILAC

	HILAC
Species	$_{197}Au^{31+}$, $_{207}Bi^{34}$
Value A/Z	≤ 6.25
Input energy	17 keV/u
Output energy	3.2 MeV/u
Beam current, mA	≤ 10
Pulse spread behind debuncher	10^{-3}
Emittance normalized, π мм мрад	0.6/0.4
Repetition rate	$\leq$ 10 Hz
Frequency, MHz	100.625
Transmission, %	98

IH1 cavity with the internal triplet inside



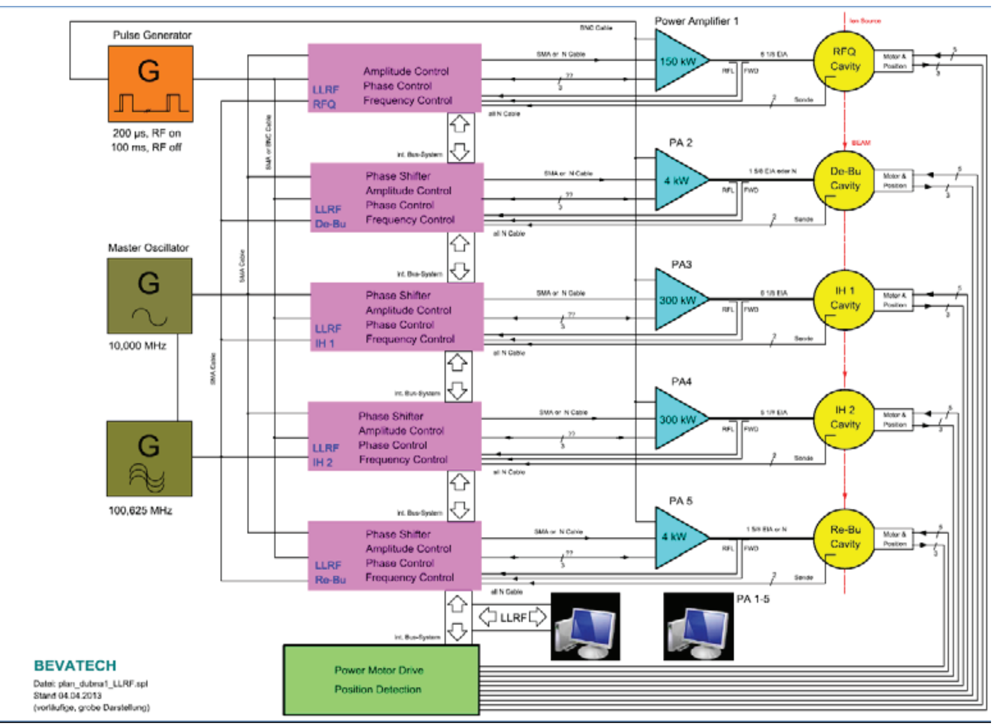


RF power supply system based on the solid state amplifiers

140 kW- RFQ, 340 kW- IH1, 340kW-IH2

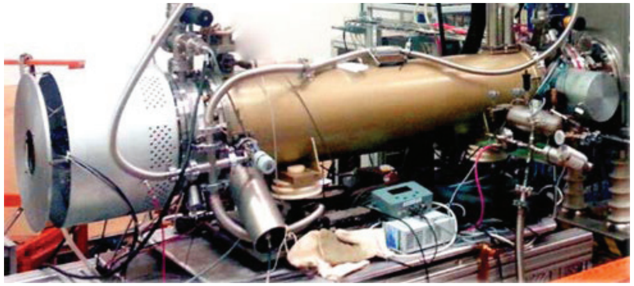
4 kW – Buncher, 4 kW - Debuncher

RF pulse duration up to 200 us

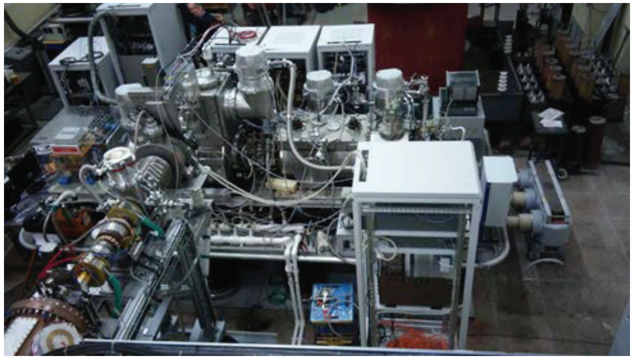


Ion sources of the NICA injection facility

- **Electron String Ion Source KRION-6T** –
  project ion source for HILAC
  heavy ion production Au^{31+}, Bi^{+Fe33}

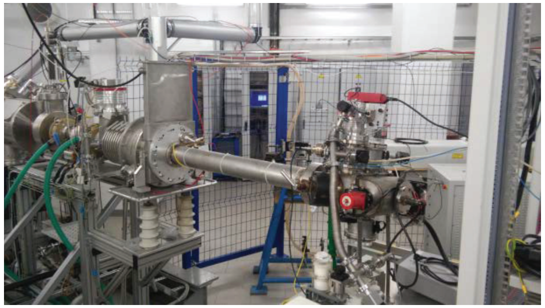


- Source of Polarized Ions **SPI**:
  project ion source for LILAC
  light ion production: p↑, d↑



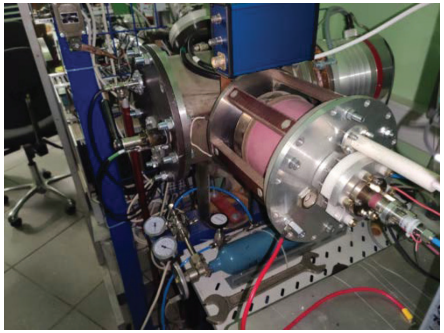
- **Laser Ion Source LIS**:

wide light ions range:
Traditional species: Li^{3+}, $^{7}Li^{3+}$, B^{4+}, C^{4+}, N^{5+}, O^{6+}, F^{7+}, Mg^{8+}, Si^{11+}
The new species: Fe



- **Helium ion source with the cold hollow cathode**

He^{1+} - for commissioning and transmission estimation

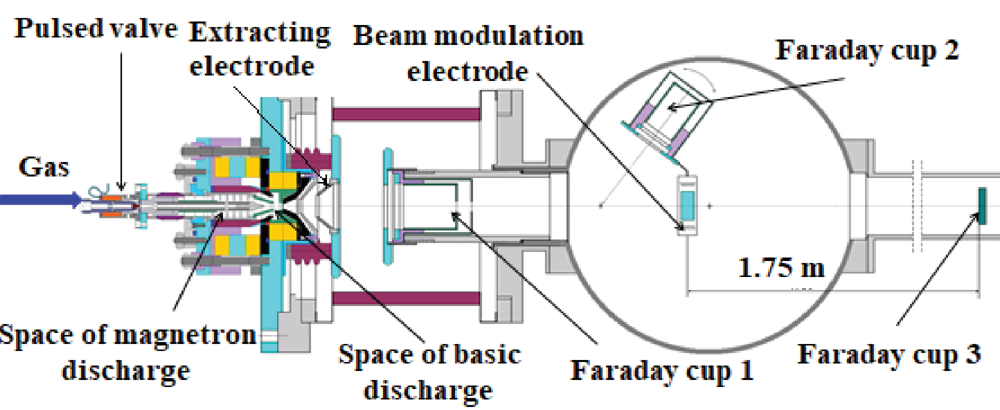


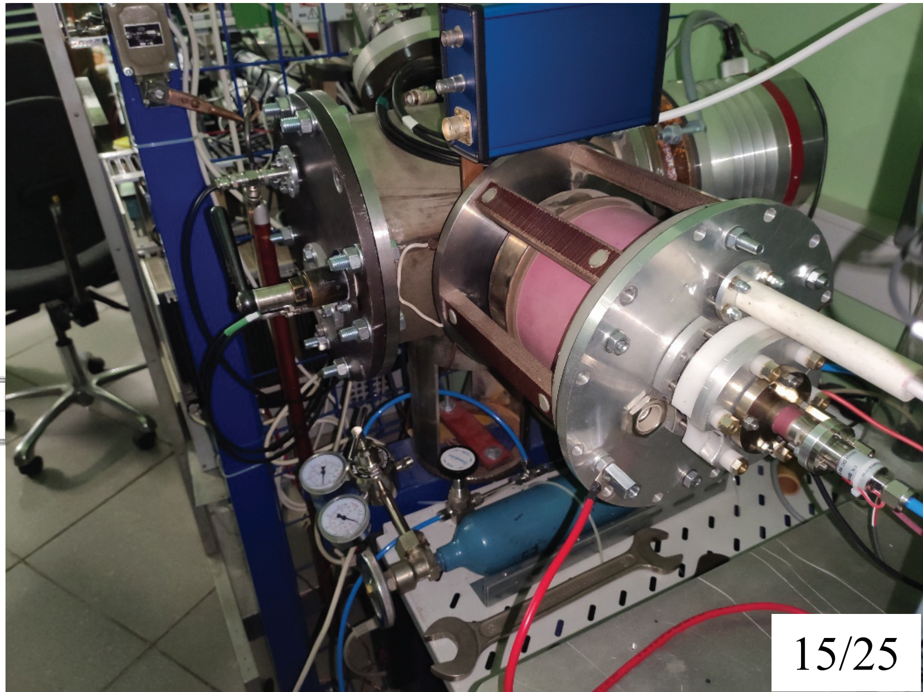
Plasma ion source with a cold magnetron hollow cathode and magnetic plasma compression

Plasma Ion Source is designed to produce the only one species He^{1+} to estimate HILAC transmission and for the Booster commissioning.

Gas system provides pulsed gas injection into space of magnetron discharge. Pulsed voltage up to 1 kV in the gaps between magnetron anode and magnetron cathode, and between magnetron cathode and anode was provided with the generator of HV pulses. Extraction voltage was supplied with the pulsed transformer and applied to the terminal whereas extraction electrode had a ground potential. Test bench for the TOF studies had three Faraday cups, beam modulation electrode and drift space ~1.8 m (see Fig. 2, 3). The total ion current was estimated with the signal from FC1and the value observed was up to 50 mA. There was the aperture 8 mm diameter in the bottom of the FC1.for the beam passing. About 25 cm behind the extracting electrode Faraday cup 2 and beam modulation electrode mounted together in one assembly could be placed manually on the beam way.

Test bench for plasma ion source



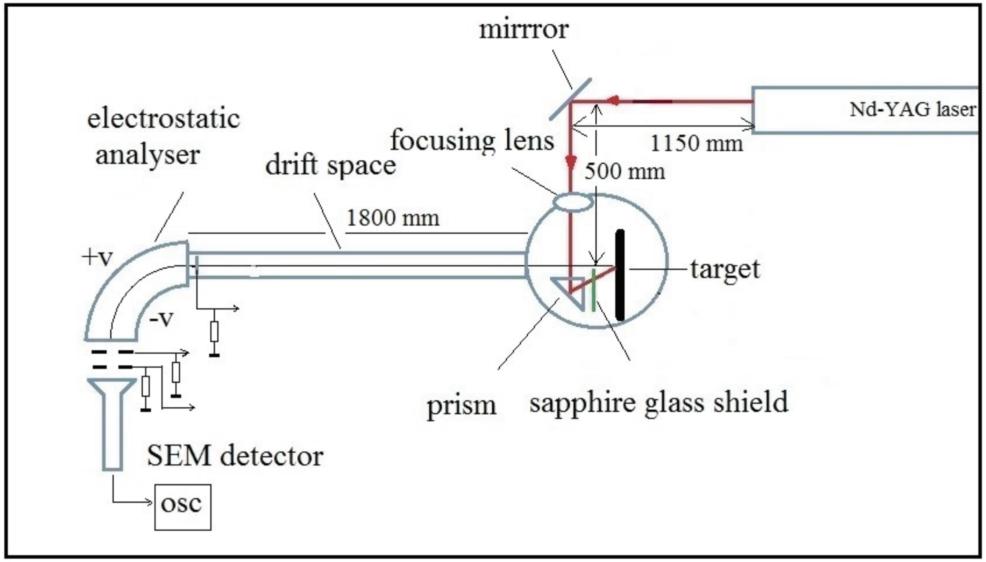


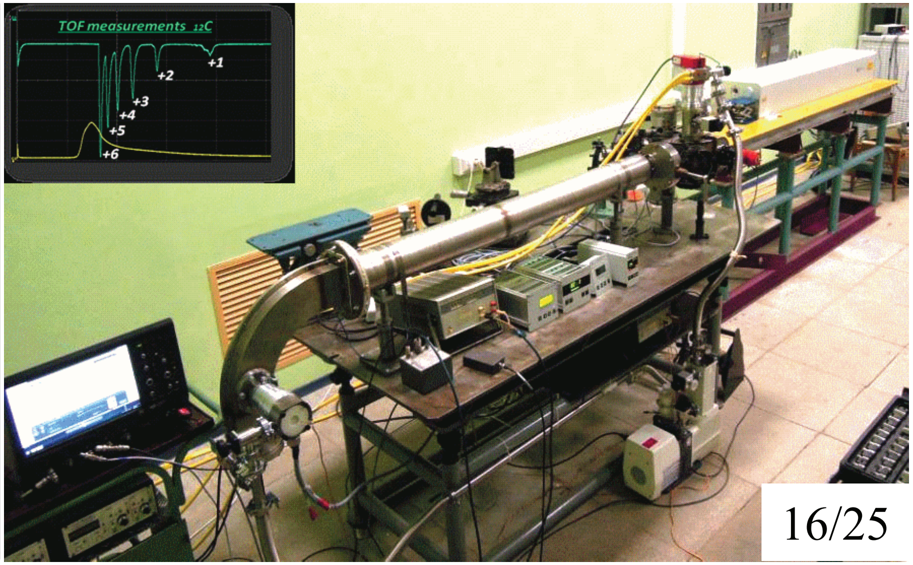
Laser ion source

Light ions with A/Z≤3: $^{6}Li^{3+}$, $^{7}Li^{3+}$, B^{4+}, C^{4+}, N^{5+}, O^{6+}, F^{7+}, Mg^{8+}, Si^{11+}. Development of the LIS is focused on the increasing of the radiation flux density on the target for the production of the ions in high charge states to provide as low A/Z ratio as possible. The previous limitation A/Z≤3 was limited by the maximum RF power and RF breakdown in cavity of proton linac LU-20. It seems reasonable to think about new sorts of heavier ions produced with Laser Ion Source that may be accelerated by HILAC in terms of "upgraded" A/Z=6.25.

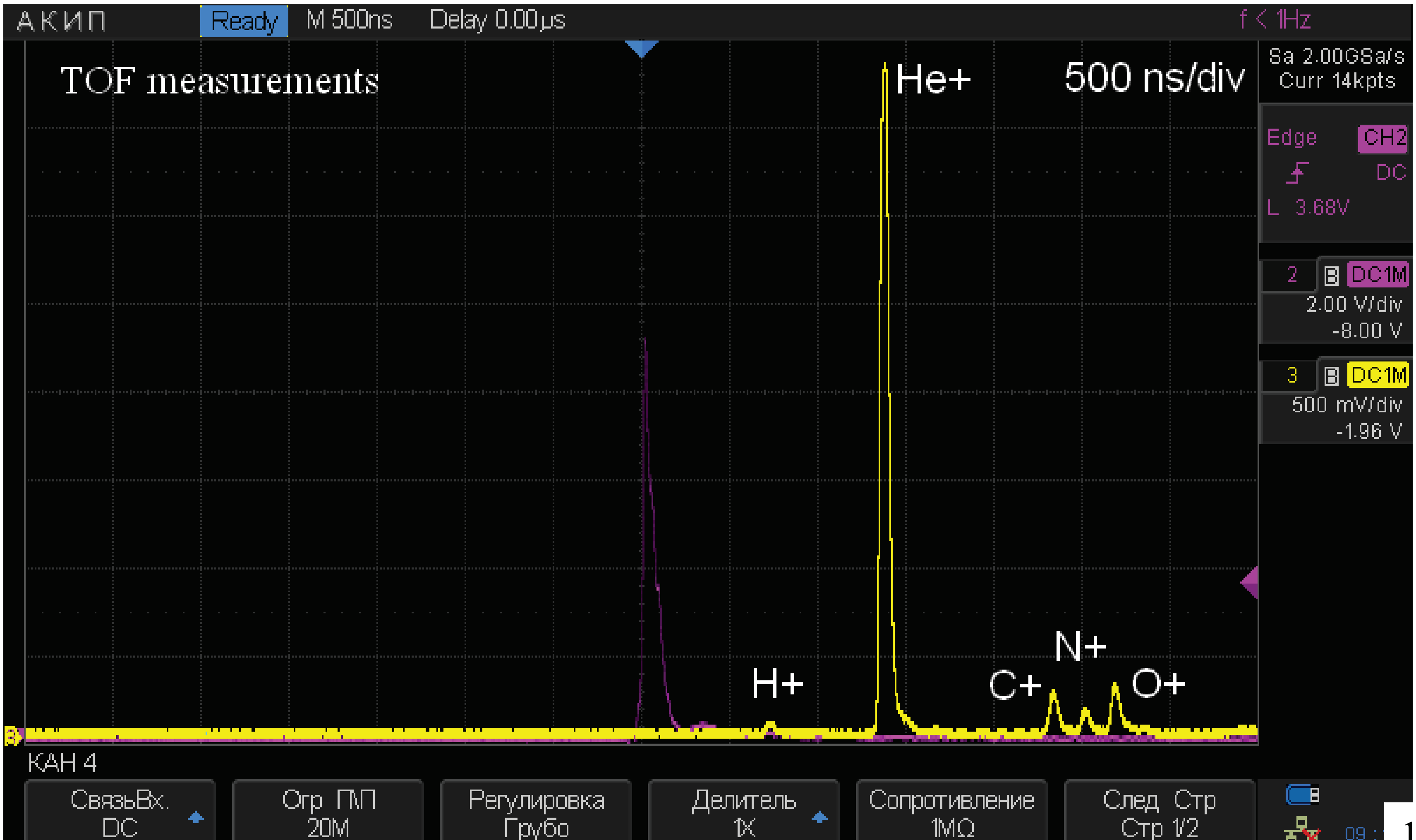
Note that HILAC was commissioned with the beams of C^{2+} ions from LIS having mass-to-charge ratio A/Z=6 close to the project one A/Z=6.25 that the ions Au^{31+} or Bi^{33+} have.

Test bench for laser plasma research



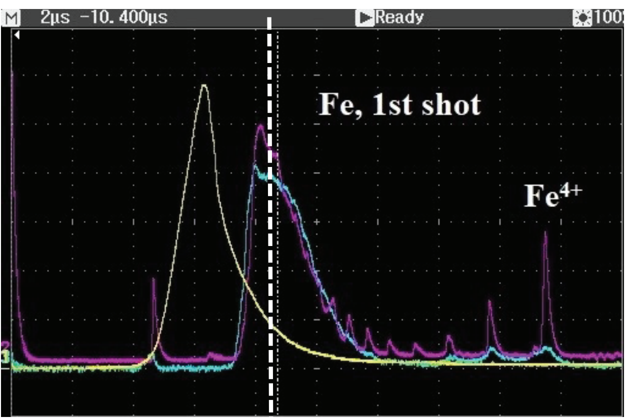


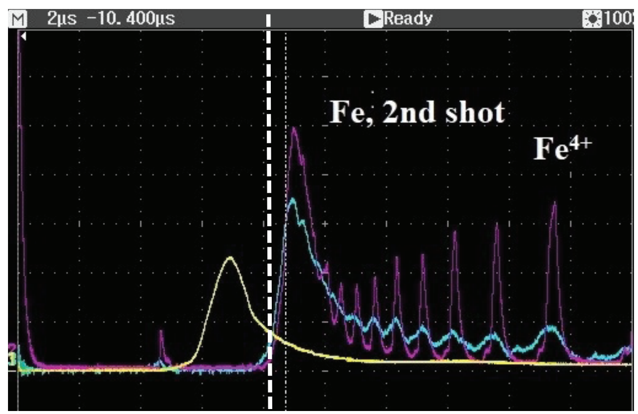
TOF spectra of He^{1+} ions produced with Helium Ion Source Yield of of He^{1+} ions~95%

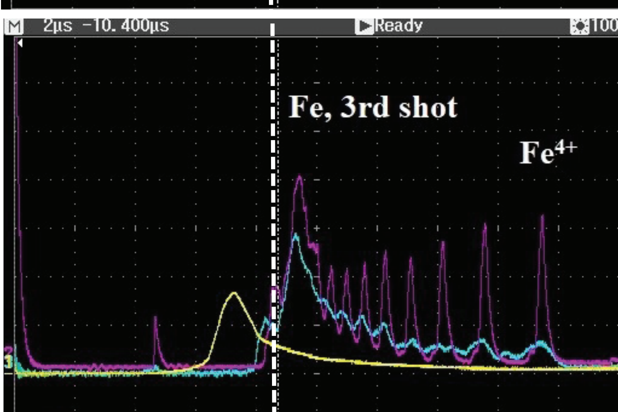


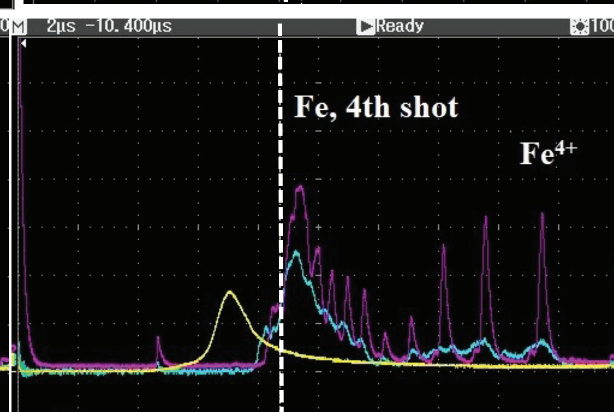
TOF spectra of ferrum ions produced with Laser Ion Source

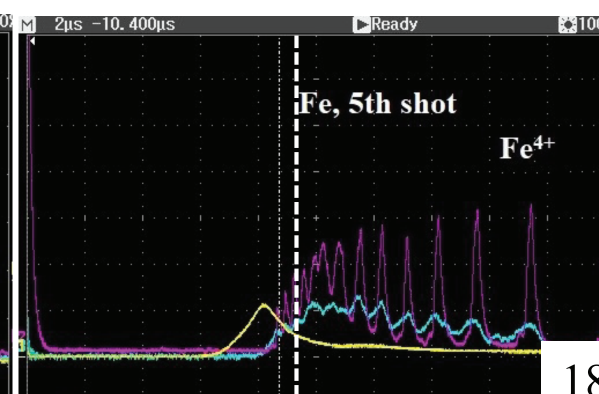
Fe ions charge states shot by shot evolution, lilac - SEM detector signals, blue - collected signal at the SEM input, yellow - collected signal at the analyzer input, white vertical line is TOF marker for Fe16+. Ionization energy for **Fe^{16+} -489 eV, Fe^{17+} -1262 eV**.





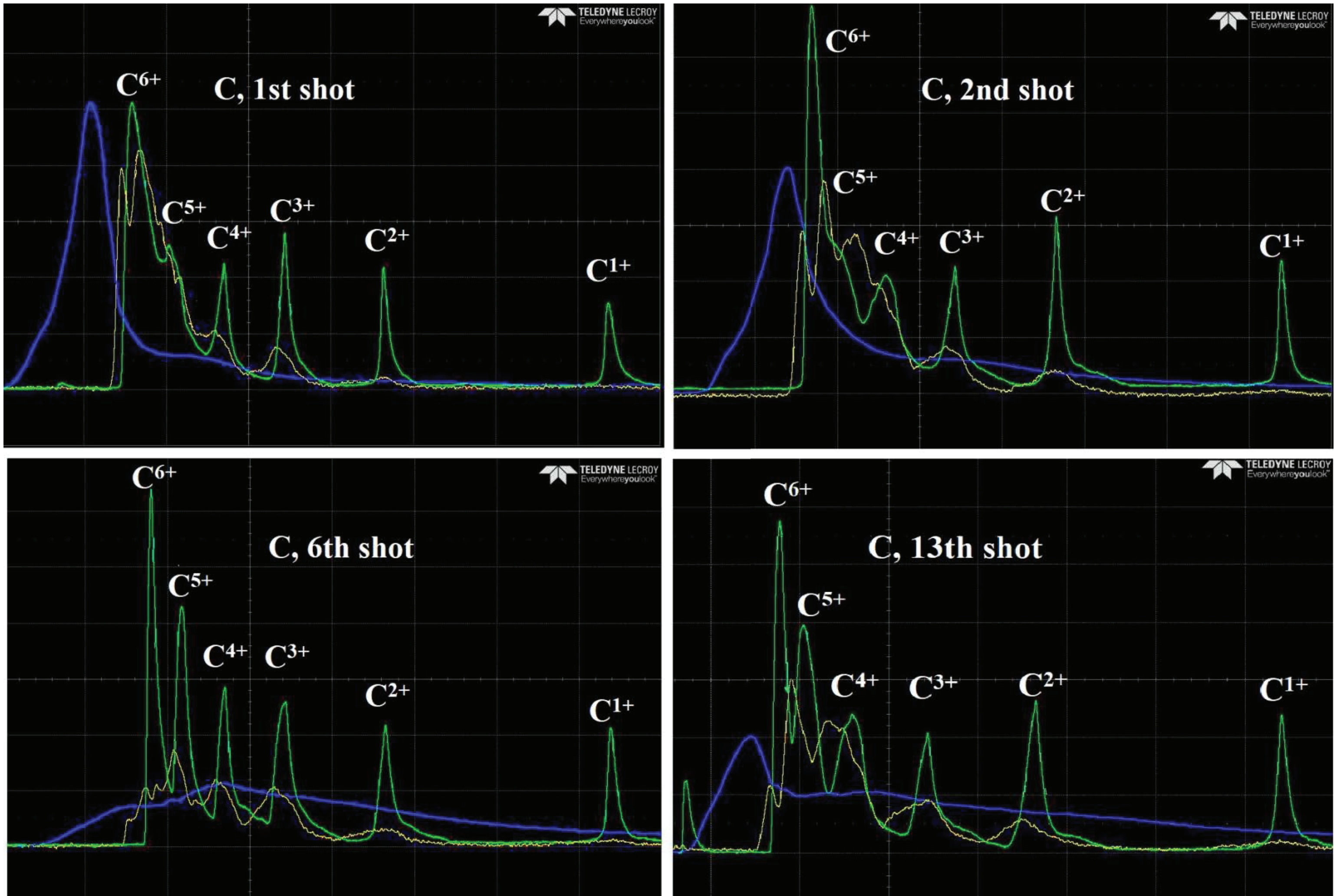






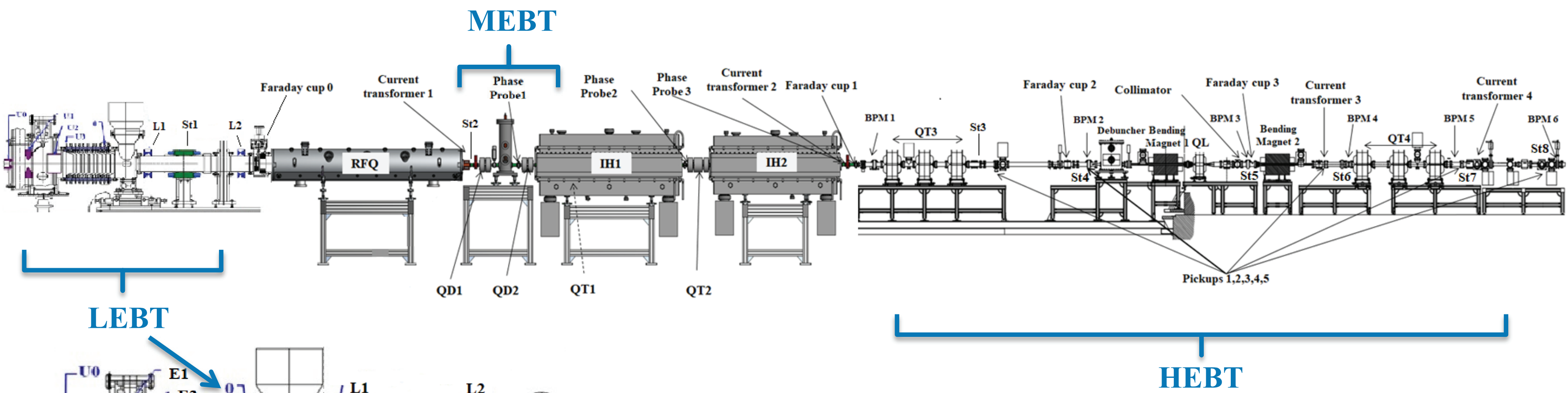
TOF spectra of carbon ions produced with Laser Ion Source

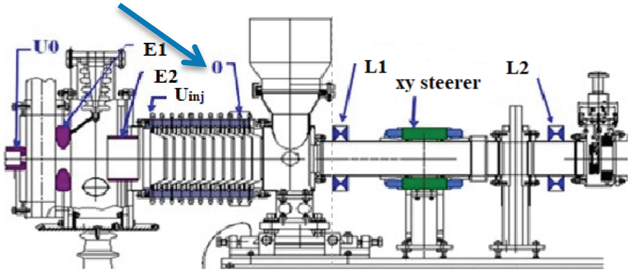
Carbon ions charge states shot by shot evolution (2us/div), green - SEM detector signals, yellow – collected signal at the SEM input, blue - collected signal at the analyzer input. Ionization energy for **C^{6+}** **490 eV**.



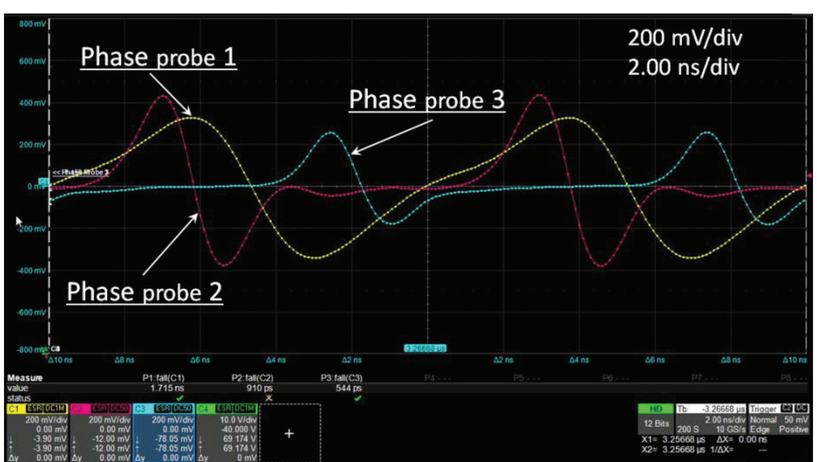
2020-2021 – assembly of the HILAC-Booster channel, He^{1+} beams accelerated with HILAC were used in the first run of NICA Booster

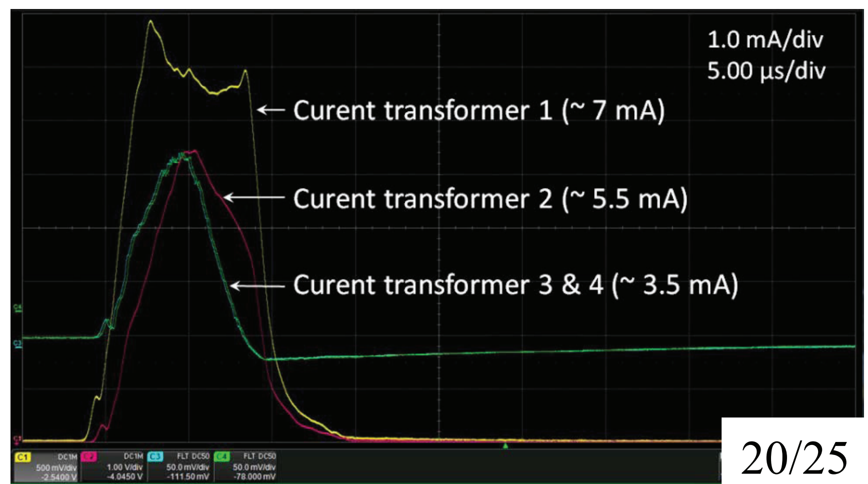
Beam diagnostic





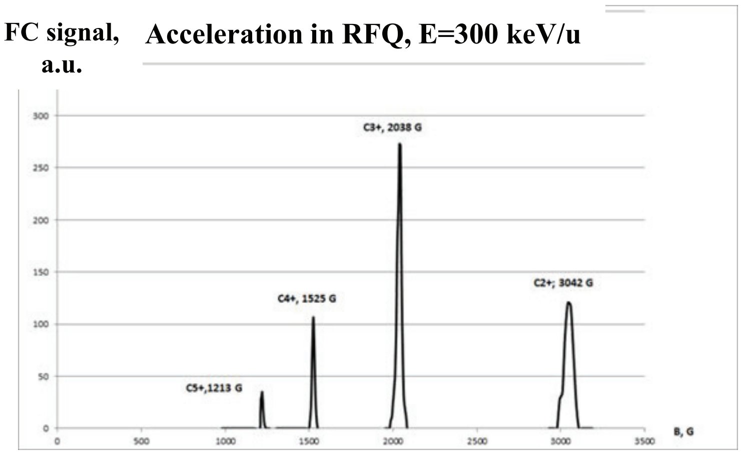
Phase probes-3, current transformers-4, shoebox pickups- 5, Faraday cups-4, beam profile monitors - 6

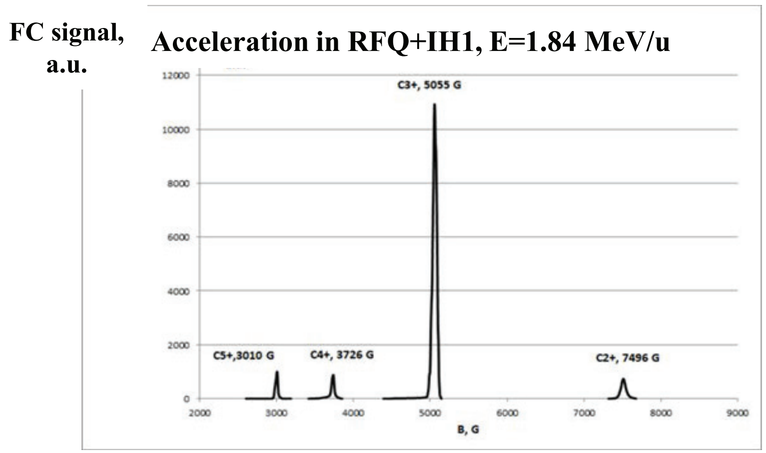


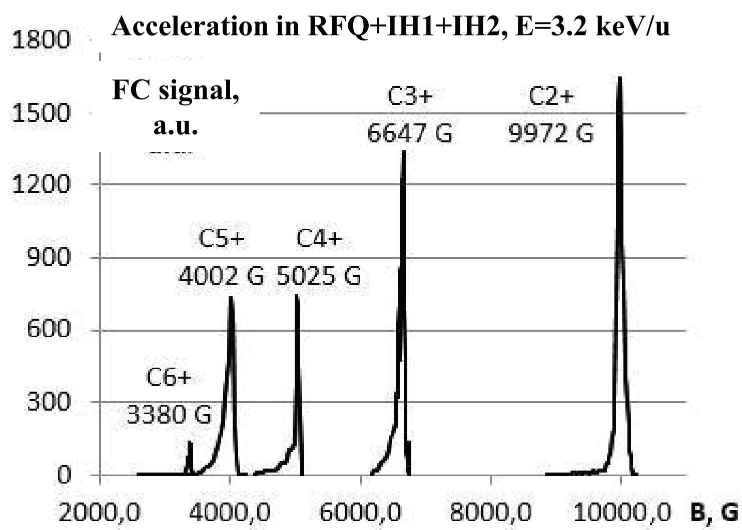


2015-2018 - HILAC assembly and commissioning

The beams of C^{2+} C^{3+} C^{4+} C^{5+} C^{6+} ions with a value A/Z=6 that is closed to the project one 6.25 from Laser Ion Source were accelerated for the HILAC commissioning. The energy of ions accelerated by each cavity step by step was measured.



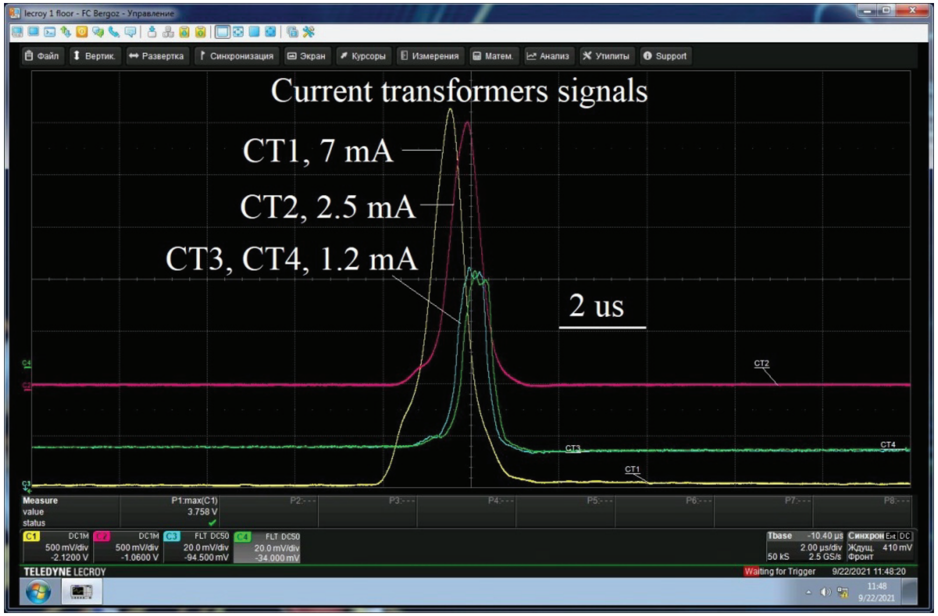


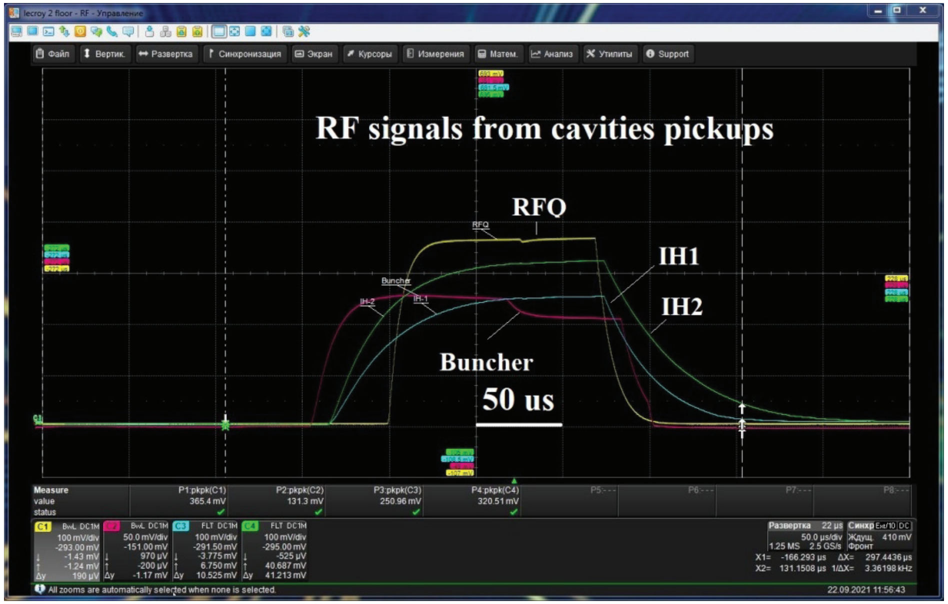


Acceleration of the Fe^{14+} ions produced with a Laser Ion Source by HILAC and injection into Booster

Fe^{14+} ions accelerated in LEBT up to 17 keV/u, ion current duration ~2 us, 7.5 mA behind RFQ, 2.5 mA – behind IH2, 1.2 mA at the injection point.

No RF beam loading was observed



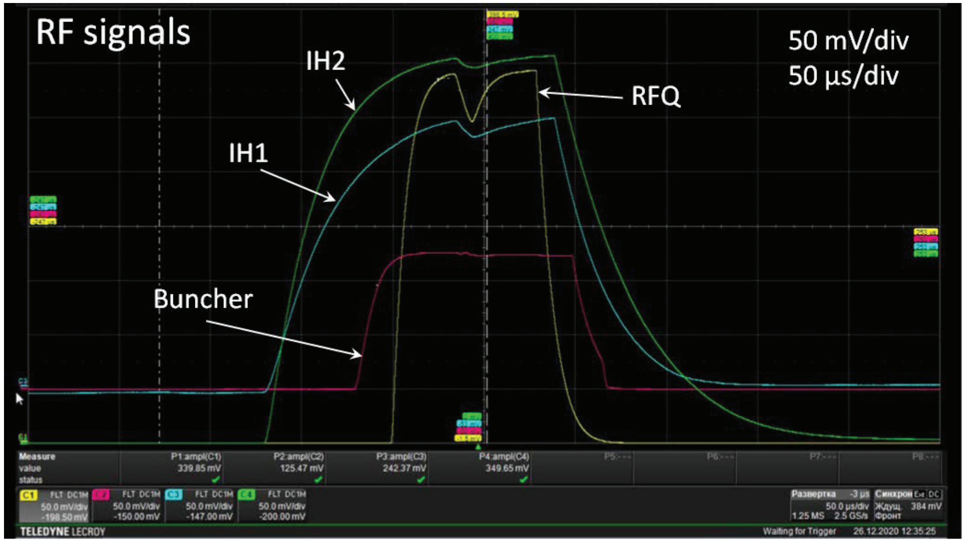


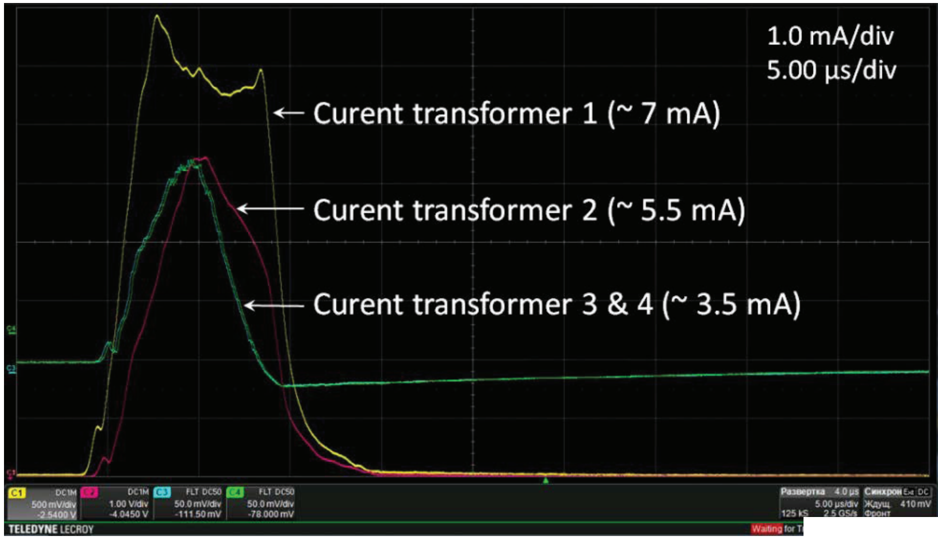
RF beam loading

Level of RF power inside each cavity was controlled by the pickups signals monitoring. The detected signals of RFQ, IH1 and IH2 pickups were observed synchronously to the beam currents presented. One can see how the part of stored field energy was eaten by the beam passing through. One can also see the reaction of the amplifier – pushing back the cavity to equilibrium level after the extra requirement of beam acceleration has gone.

RF compensation is needed evidently.

RF signals from pickups under beam loading





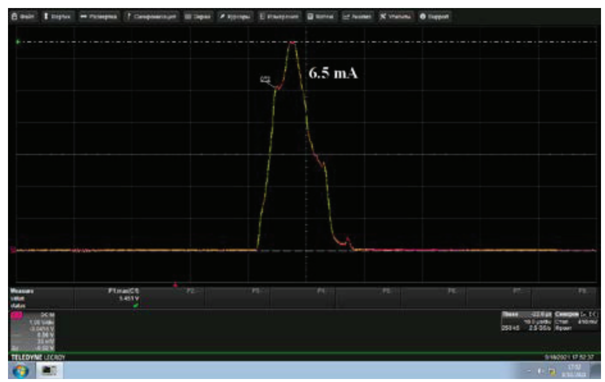
Two energy beams at the output depending on the RF phase in IH2,

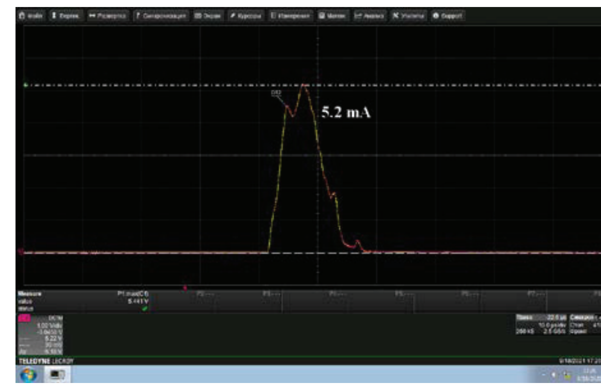
phase probe behind IH1 and Faraday cup behind first bending magnet signals

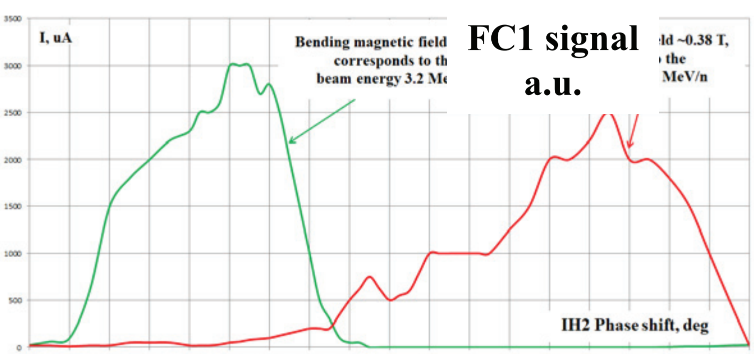
3.2 MeV/u, bunch 1.92 ns, 6mA
IH1 ON

1.84 MeV/u, bunch 2.12 ns, 6.5mA
IH1 OFF

1.84 MeV/u, bunch 2.10 ns, 5/2mA
IH1 ON







Micro bunch duration
3.2 MeV/u ~ 1.9 ns
1.82 MeV/u ~ 2.1 ns

Summary

- The linear heavy ion injector based on HILAC has been commissioned with the beams of C^{2+} ions having A/Z ratio close to the project one 6.25
- The beams of He^{1+} and Fe^{14+} have been accelerated and injected into Booster in its two first runs
- Injector should be tuned for the maximum beam transmission
- The RF system should upgraded to compensate beam RF loading
- Two beam injection energies are available
- Range of accelerated ions provided by new injector may be extended due to upgraded LIS based on Nd-YAG laser and “upgraded” ratio A/Z=6.25 available for HILAC.

Thanks