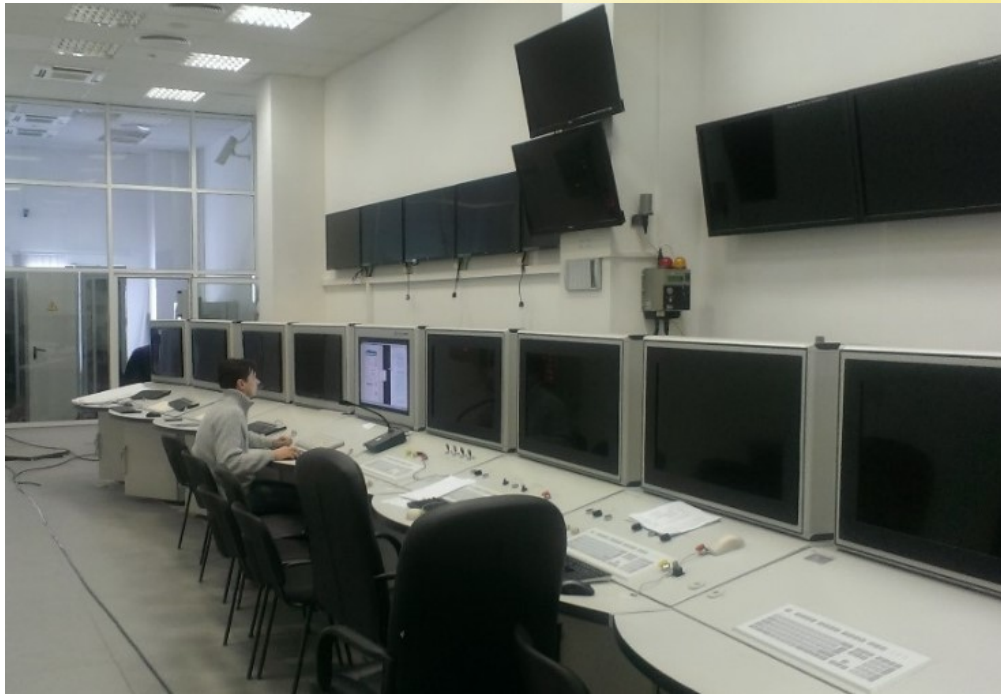
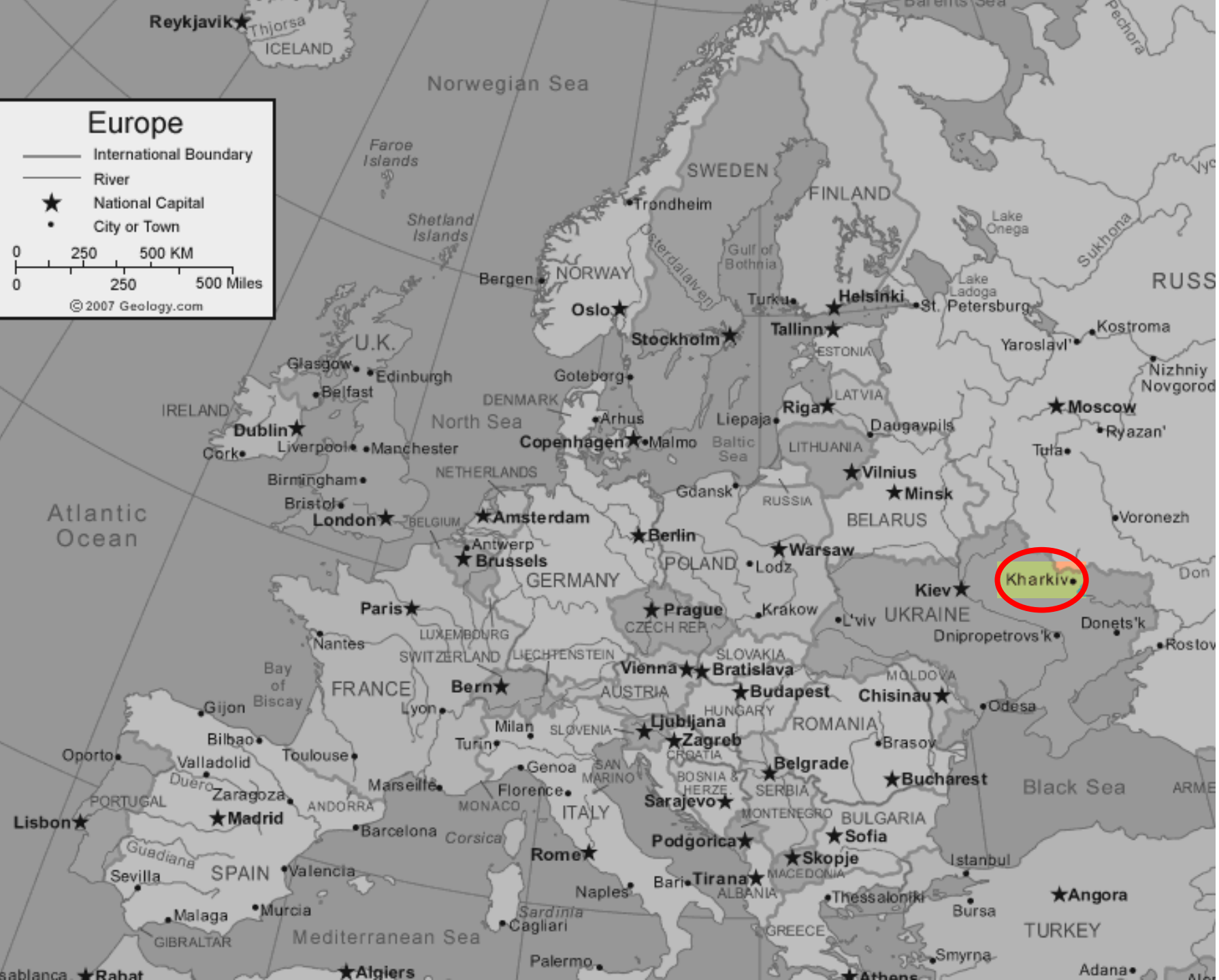
Recent achievements on accelerator operation performance during the NSC KIPT SCA neutron source physical start up

Andriy Zelinsky
on behalf of
NSC KIPT SCA Neutron Source team,
Kharkiv, Ukraine

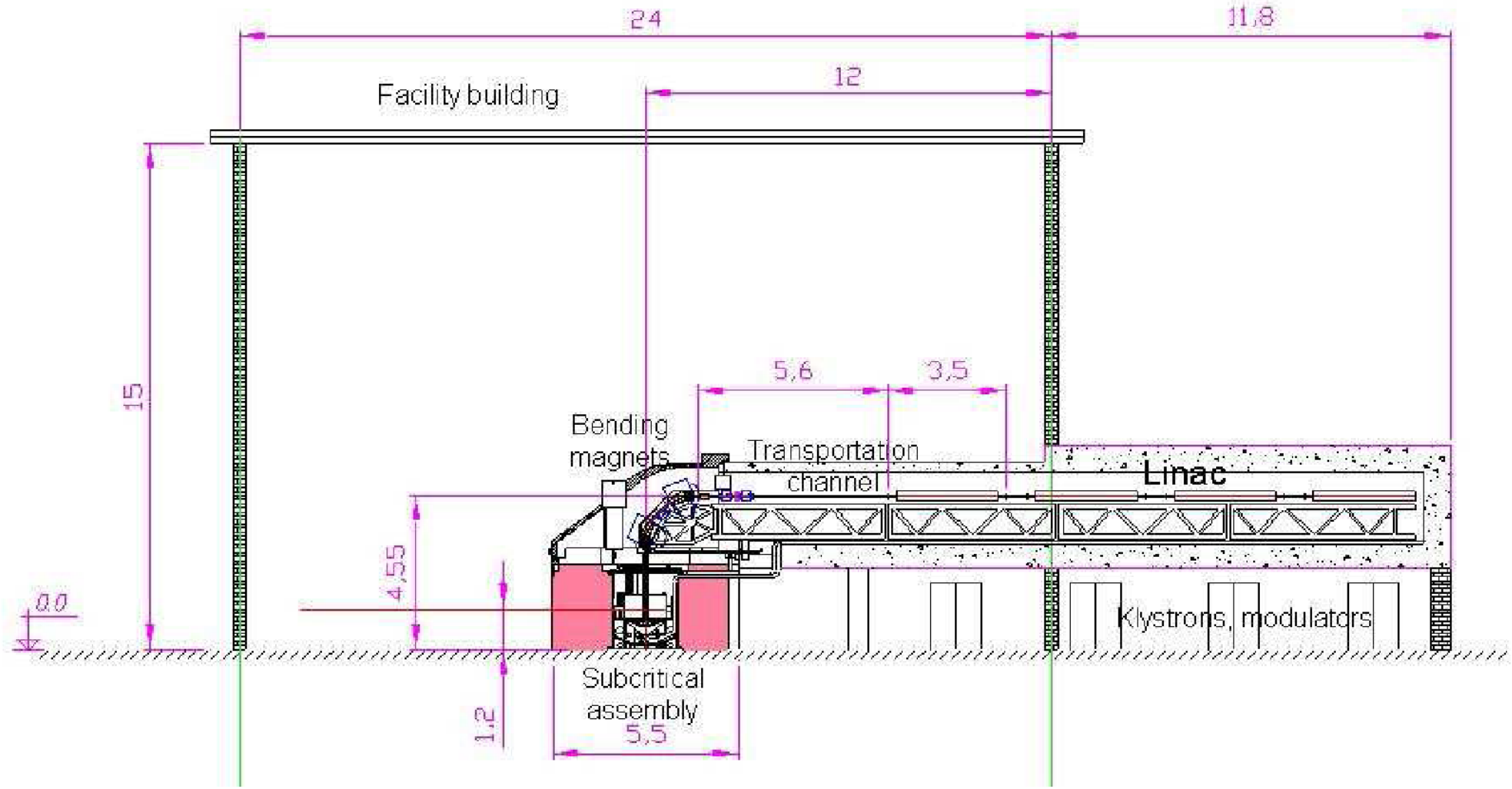


8TH MARCH, 2024

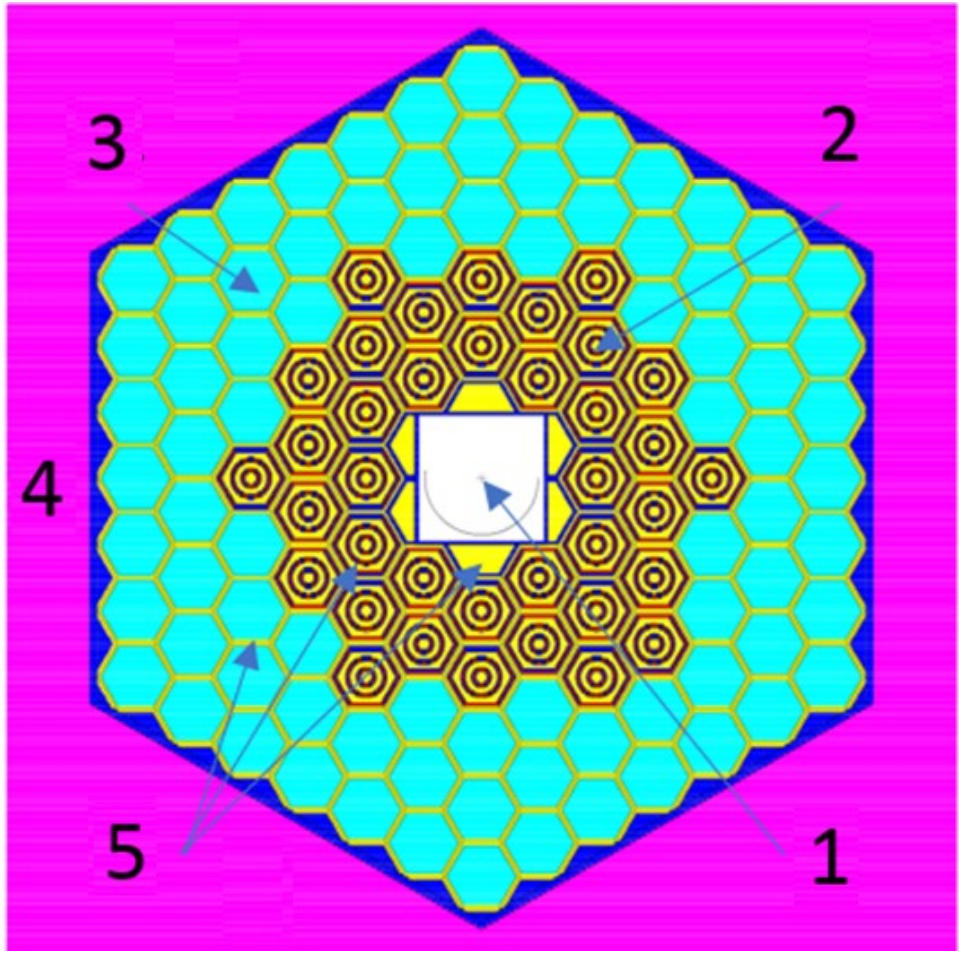

Europe
International Boundary
River
National Capital
City or Town
0 250 500 KM
0 250 500 Miles
© 2007 Geology.com
Reykjavik
Thjorsa
ICELAND
Norwegian Sea
Faroe Islands
Shetland Islands
SWEDEN
FINLAND
Trondheim
Gulf of Bothnia
Lake Onega
Lake Ladoga
Sukhona
Bergen
NORWAY
Oslo
Turku
Helsinki
St. Petersburg
Tallinn
Stockholm
ESTONIA
Kostroma
Yaroslavl'
Nizhniy Novgorod
U.K.
Glasgow
Edinburgh
Belfast
Goteborg
LATVIA
Moscow
IRELAND
DENMARK
North Sea
Arhus
Liepaja
Riga
Daugavpils
Ryazan'
Dublin
Cork
Liverpool
Manchester
Copenhagen
Malmo
Baltic Sea
LITHUANIA
Tula
Vilnius
Minsk
Birmingham
NETHERLANDS
Gdansk
RUSSIA
Bristol
London
BELGIUM
Amsterdam
BELARUS
Voronezh
Atlantic Ocean
Berlin
Antwerp
Brussels
Warsaw
POLAND
Lodz
GERMANY
Kharkiv
Kiev
Paris
Prague
Krakow
L'viv
UKRAINE
Donets'k
Dnipropetrovs'k
Rostov
Don
LUXEMBOURG
Nantes
SWITZERLAND
LIECHTENSTEIN
CZECH REP.
SLOVAKIA
Vienna
Bratislava
MOLDOVA
Bay of Biscay
FRANCE
Bern
AUSTRIA
Budapest
Chisinau
Odesa
Gijon
Lyon
HUNGARY
Ljubljana
ROMANIA
Bilbao
Milan
SLOVENIA
Zagreb
Brasov
Oporto
Valladolid
Toulouse
Turin
CROATIA
Belgrade
Genoa
SAN MARINO
Bucharest
Duero
Zaragoza
Marseille
Florence
BOSNIA & HERZE.
SERBIA
Black Sea
PORTUGAL
ANDORRA
MONACO
ITALY
Sarajevo
Madrid
Lisbon
Barcelona
Corsica
MONTENEGRO
BULGARIA
Podgorica
Sofia
Guadiana
Rome
Skopje
Istanbul
Sevilla
SPAIN
Valencia
MACEDONIA
Bari
Tirana
ALBANIA
Naples
Thessaloniki
Angora
Malaga
Murcia
Sardinia
Cagliari
Bursa
GIBRALTAR
Mediterranean Sea
GREECE
TURKEY
Smyrna
Palermo
Adana
Algiers
Rabat

SCA NEUTRON SOURCE LAYOUT

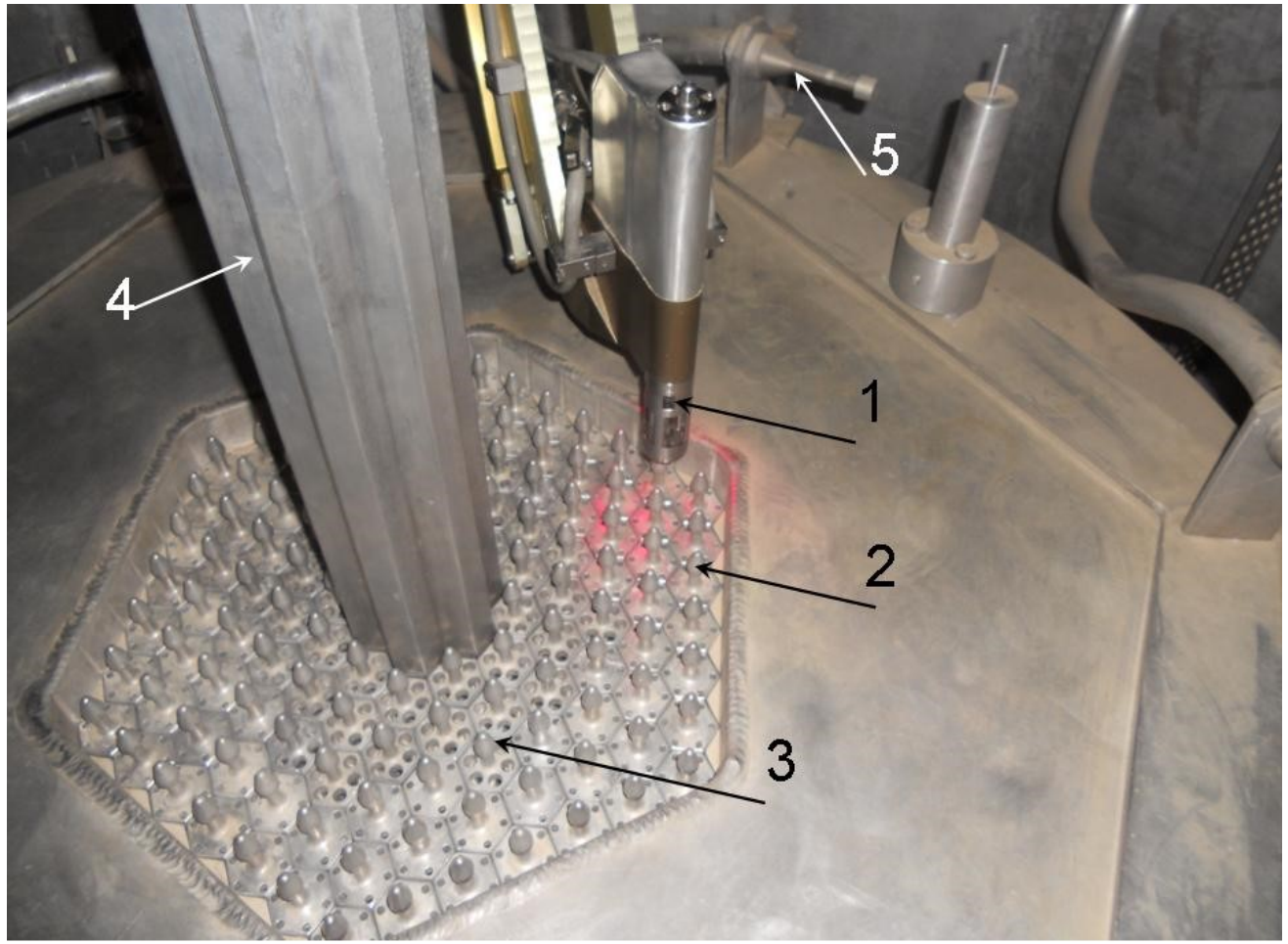
ABOUT 10^{14} neutrons/cm^2s



SCA NEUTRON SOURCE LAYOUT

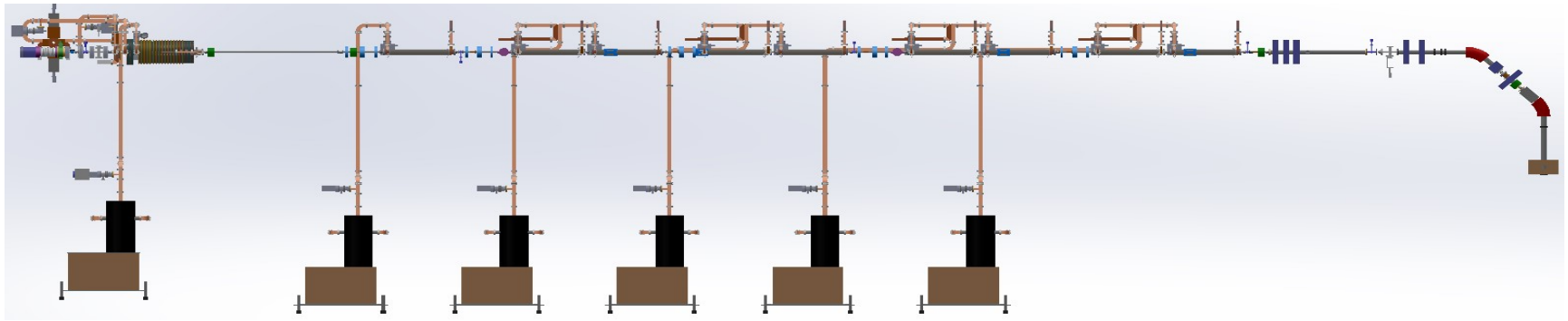


1 – neutron generating target, 2 – FAs, 3 – beryllium reflector elements,
4 – graphite reflector, 5 – cooling channels



1 – a manipulator grip; 2 – a beryllium core element; 3 – a core fuel cell; 4 – a target; 5 – a neutron sensor

ACCELERATOR LAYOUT



ACCELERATOR SPECIFICATIONS

RF frequency	2856	MHz
Beam energy	100	MeV
Beam current (operation)	0.6	A
Energy spread	3	%
Emittance(1σ)	$5x10^{-7}$	m*rad
Beam pulse duration	2.7	μc
RF pulse duration	3	μc
Repetition rate (max.)	625	Hz

SCA PHYSICAL START UP PARAMETERS:

Beam current – 0.037 mA
Repetition rate – 20 Hz
Average electron beam power is about 200 – 250 W

TIME LINE

March, 2014

April 2013 - LINAC delivery

June 2013 - Start of the LINAC installation

September 2016 - Start of a beam commissioning

May 2018 - design beam current (IHEP)

June 2018 - LLRF system put in operation

July 2018 - LINAC individual State test

December 2018 - Neutron Source integrating State test

March, 2021

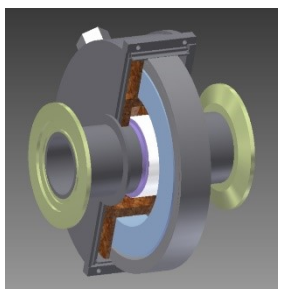
January - August 2019 - beam adjustment

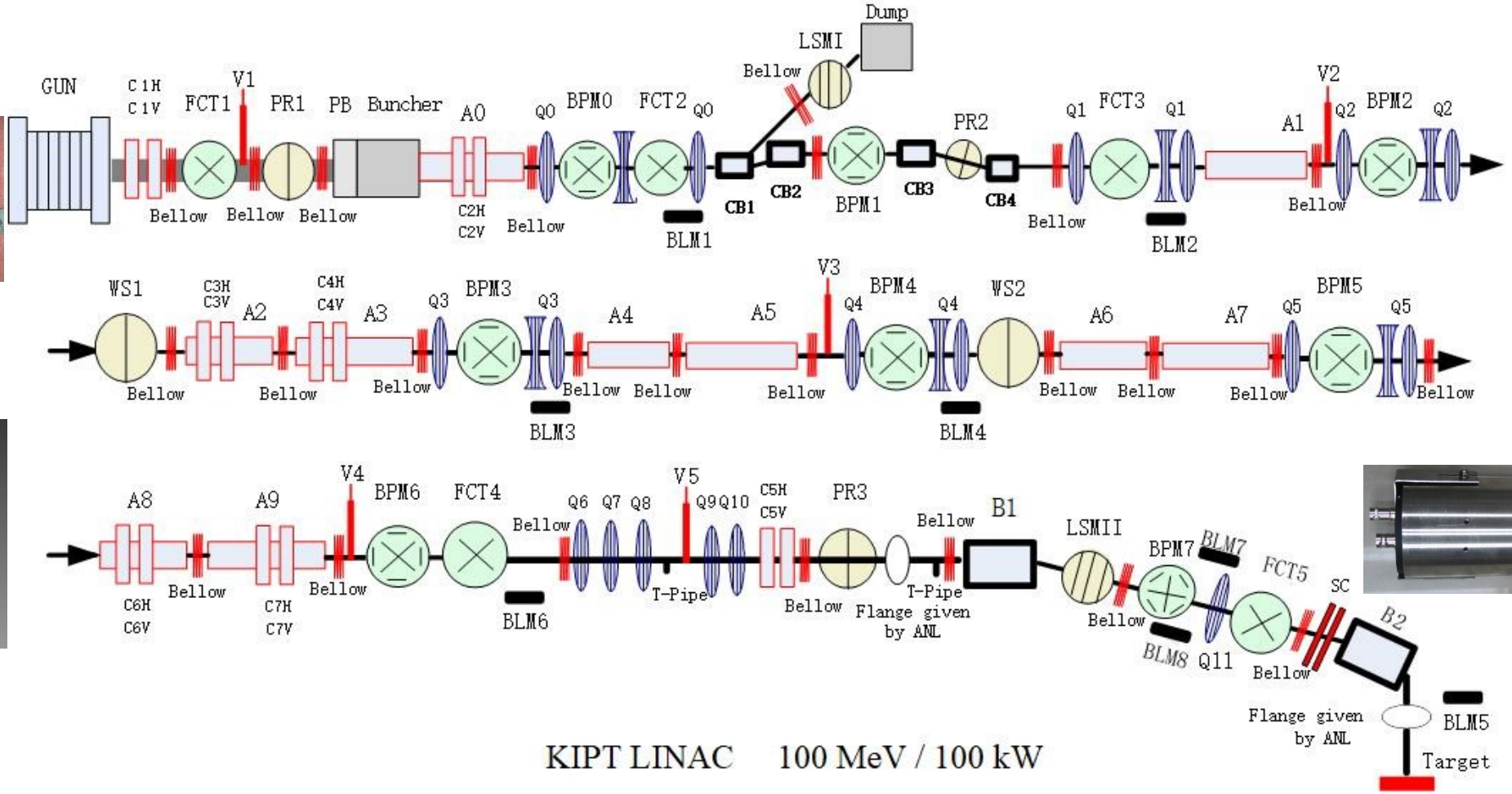
2020–2021 - Neutron Source physical start up

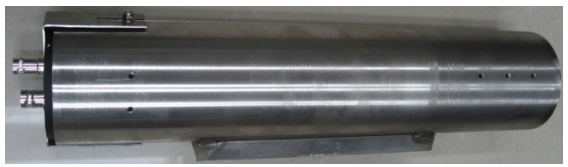
February 24, 2022 – start of the war……

March, 2022

BEAM INSTRUMENTATION LAYOUT

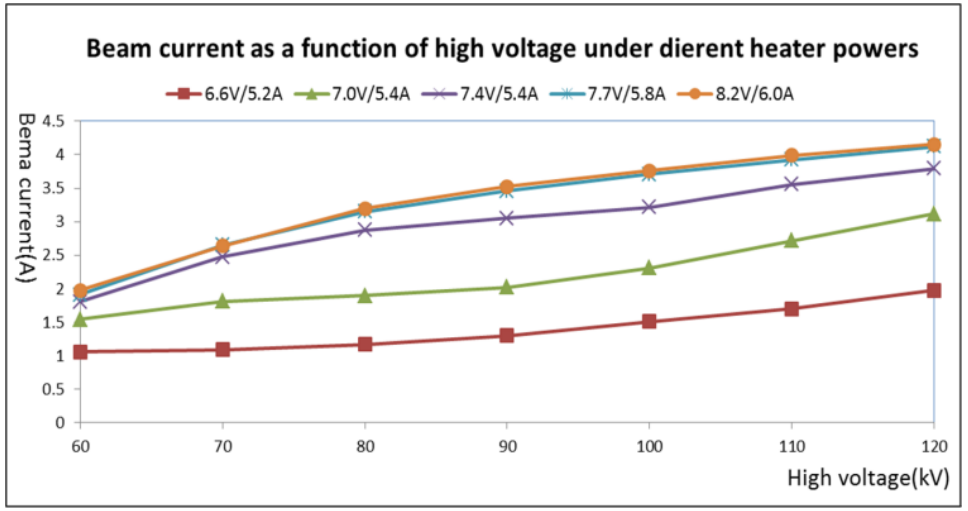


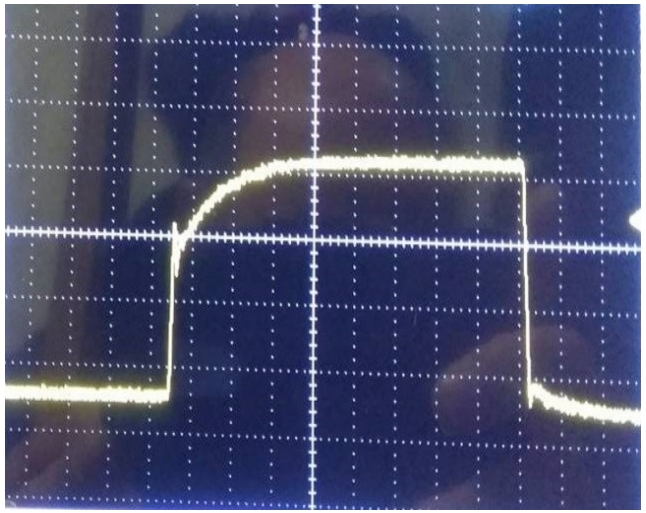


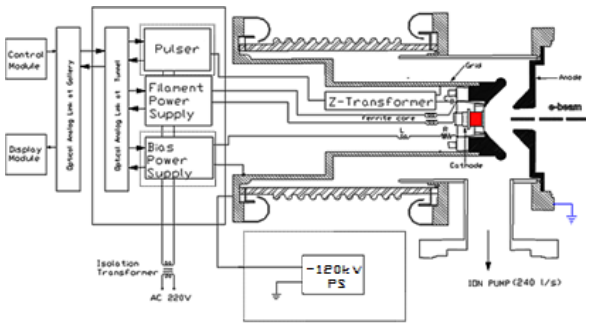


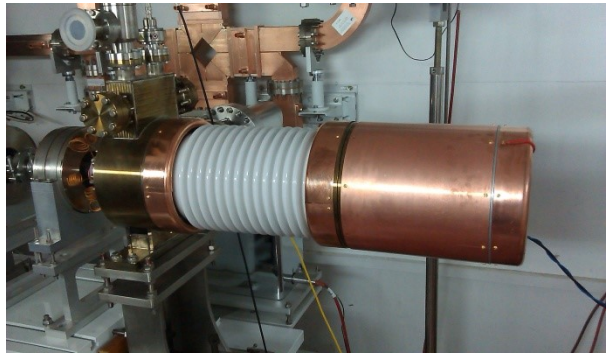
TRIODE ELECTRON GUN

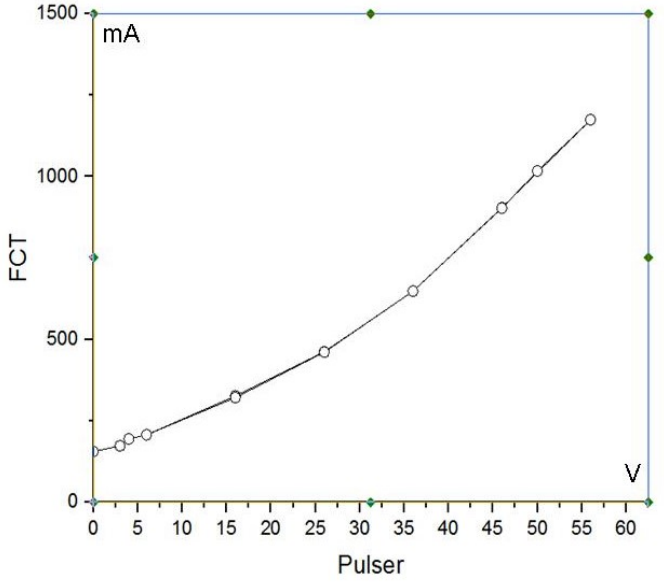
Parameters	Units	Value
Type	Triode	
Cathode (Dispenser)	EIMAC Y824	
Beam Current（Max）	A	0.2 - 2
Cathode Voltage	kV	-120
Filament Voltage	V	6.4
Filament Current	A	5.5
Grid Bias	V	7~400 (0.2A)
Pulse Voltage	V	200-600
Pulse width (FWHM)	μs	3.0











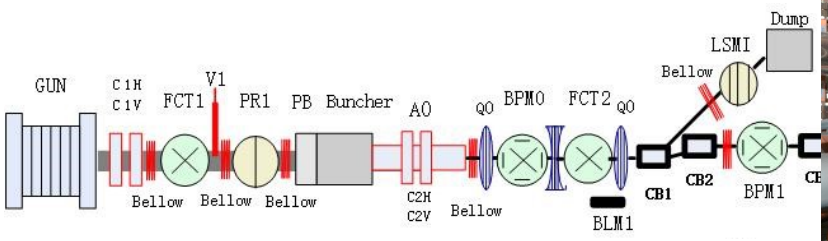
TRIODE ELECTRON GUN

EIMAC Y824

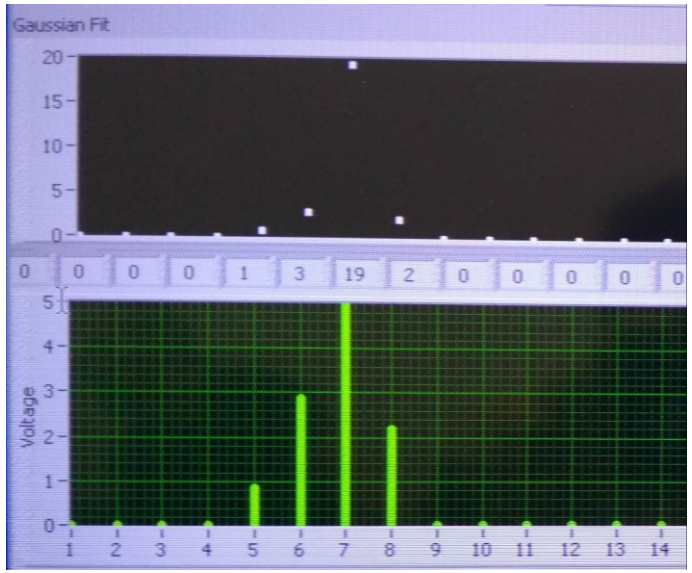
Tungsten matrix

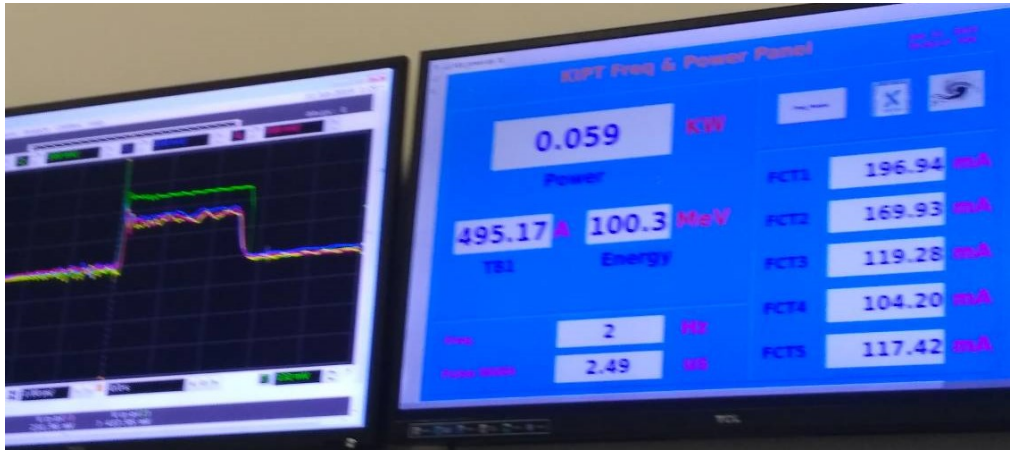
TUBE TYPE	D_{GK*} Microns	(etd) PEAK EMISSION	CATHODE AREA (cm2)	CATHODE TYPE	PERVEANCE (in uP)**	PERVEANCE PARAMETERS	HEATER****	Mu	CONFLAT SIZE
Y-824	190 - 210	15.0 a w.ec = 150 v	2	Dispenser	319.000	Eb=1360 V, Ec=20 V, ib=16 A	5.8 A w/6.3 V	175	2-3/4

OPTIMIZATION OF THE INJECTION SECTION

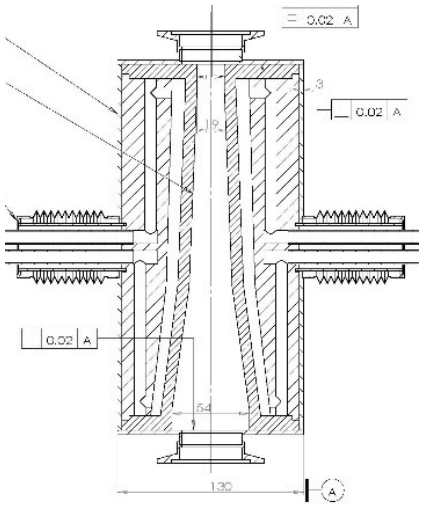


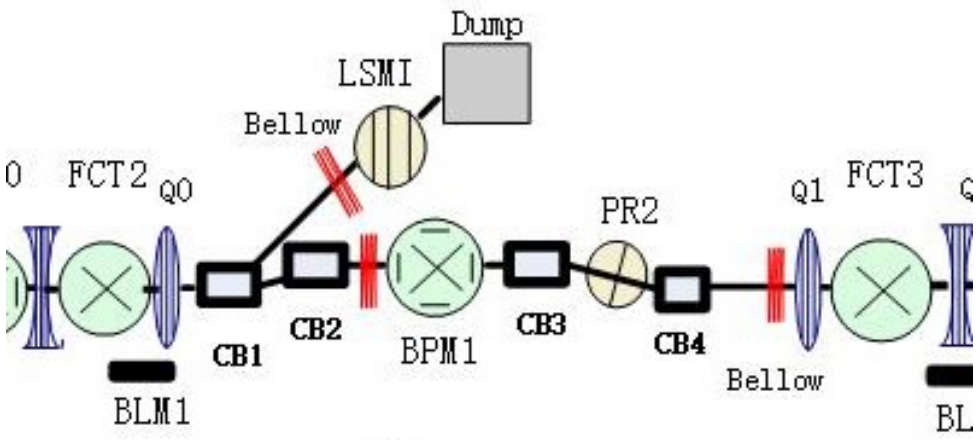
- Electron beam energy 12.5 MeV (158 A of CB1 excitation current)
- Average energy spread of about ±4 %
- The electron beam bunching and phasing was done for the different initial gun current in the range of 20-800 mA.
- The maximum efficiency of the beam injection in the A0 section of 100 mA of the gun current is about 92 %
- The average value of the injection efficiency is about 86 %

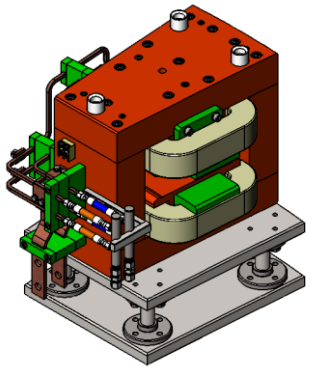


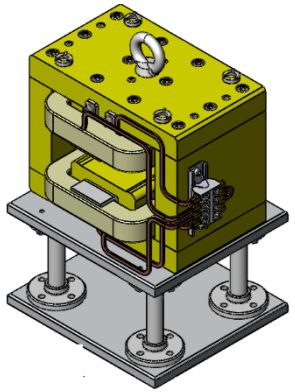


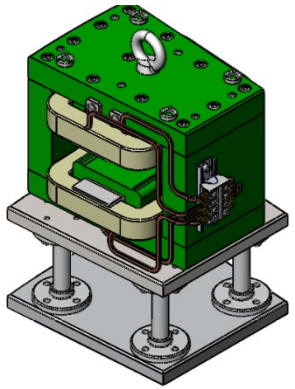
TRANSPORTATION THROUGH CHICANE

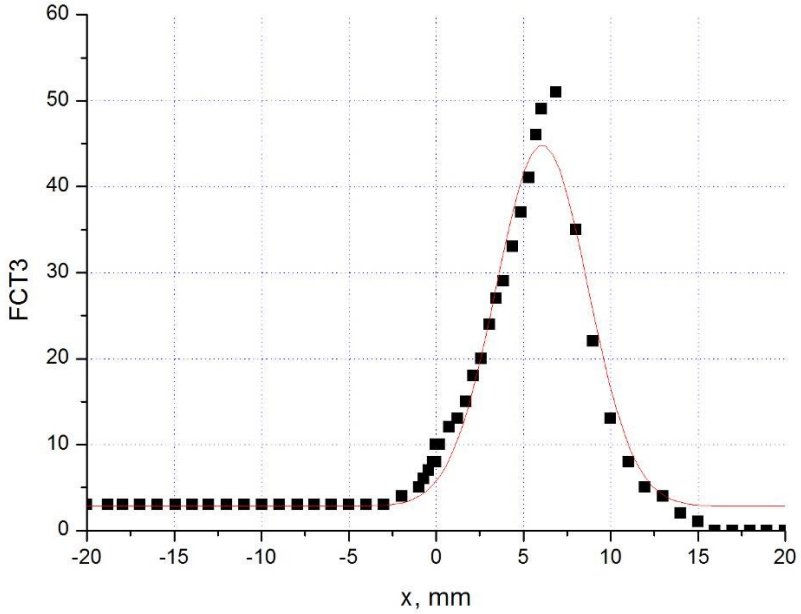


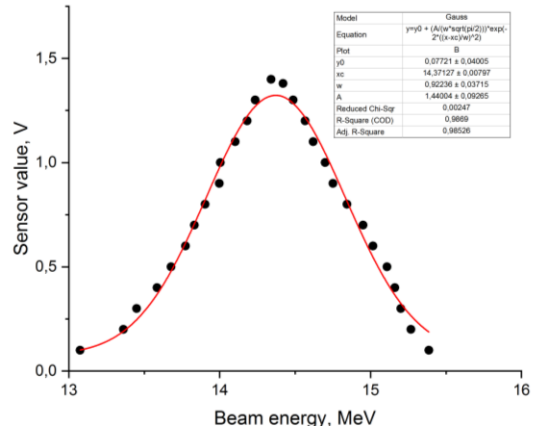






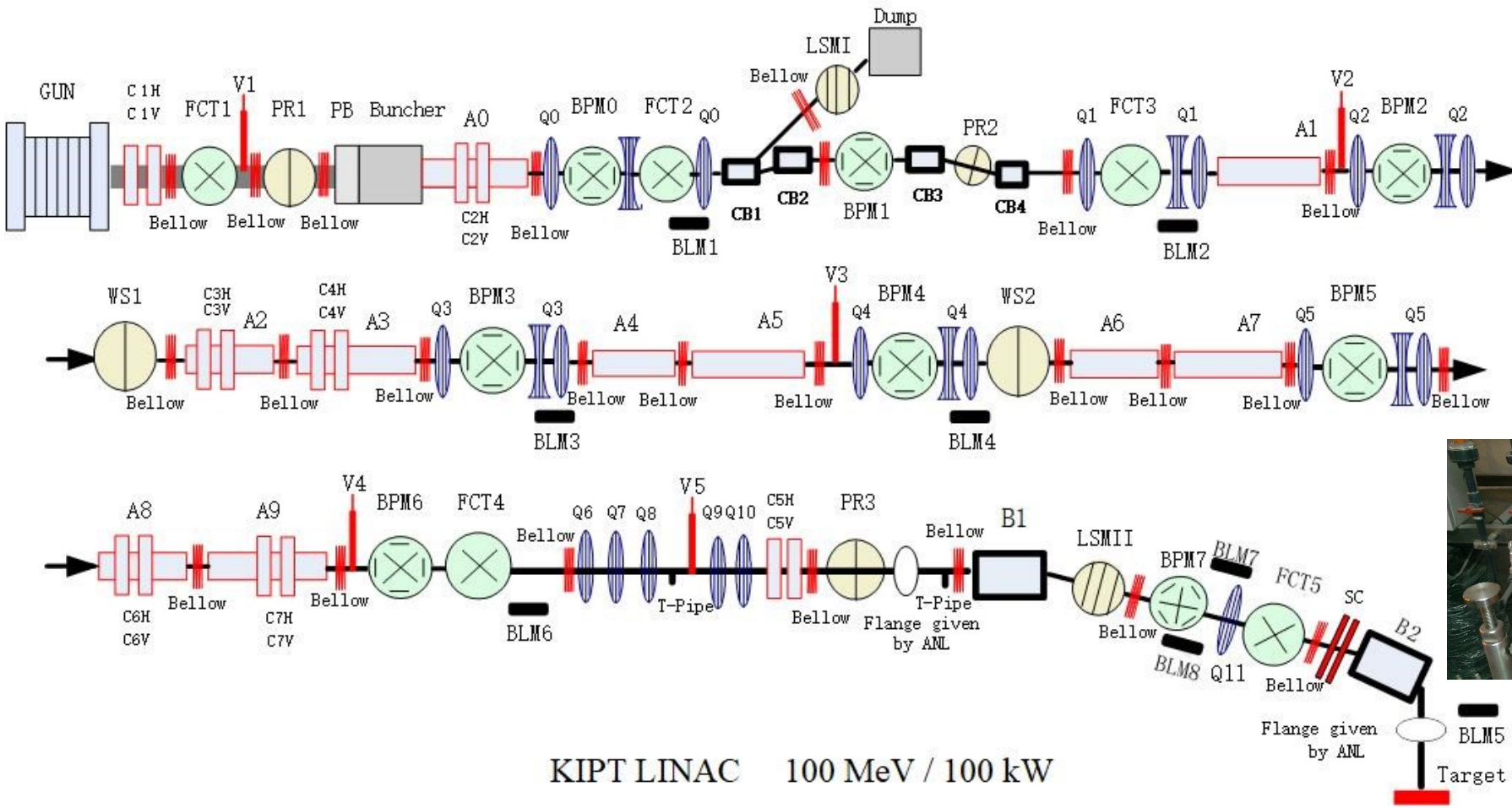


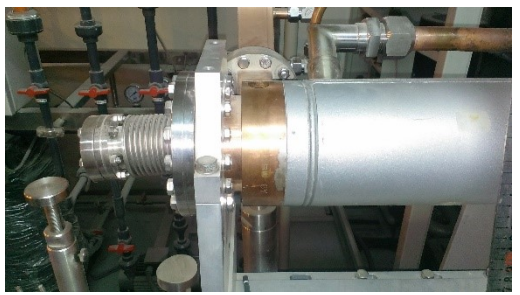




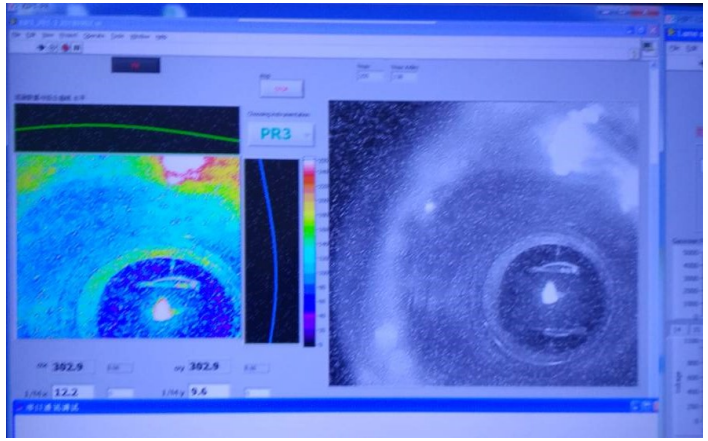
8 MARCH, 2024

BEAM TRANSPORTATION THROUGH REGULAR PART OF THE LINAC

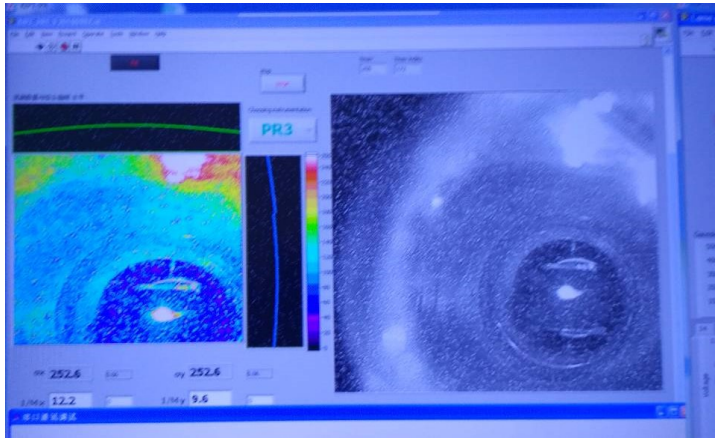




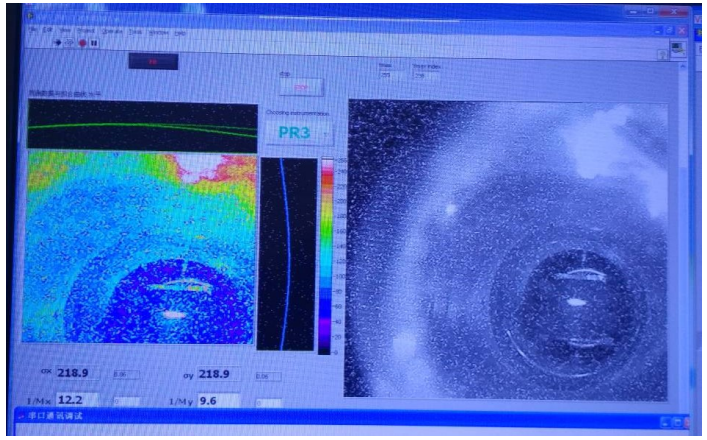
BEAM TRANSPORTATION THROUGH REGULAR PART OF THE LINAC



Electron beam position at PR3 screen with all Q6-Q10 are switched off



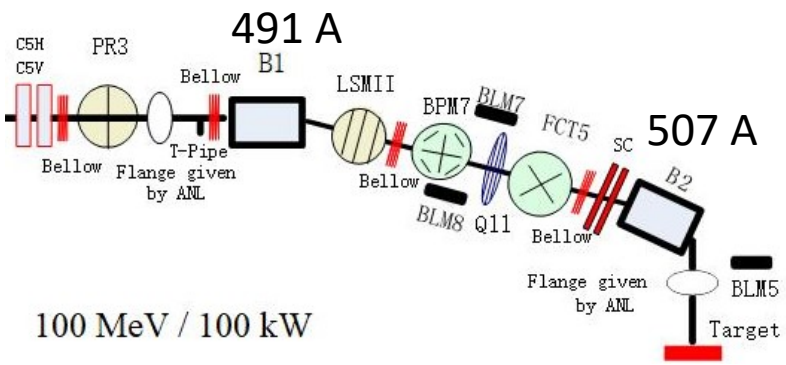
Electron beam position at PR3 screen with Q6, Q8 are switched off but Q9, Q10 are switched off

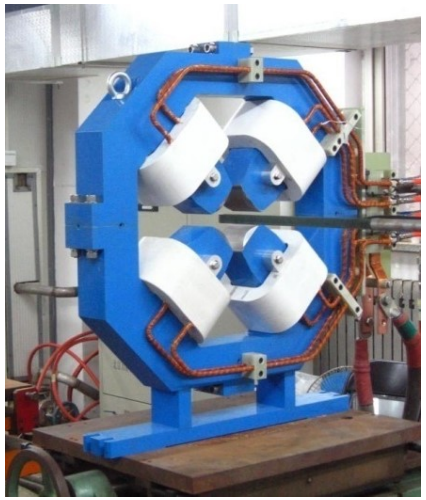


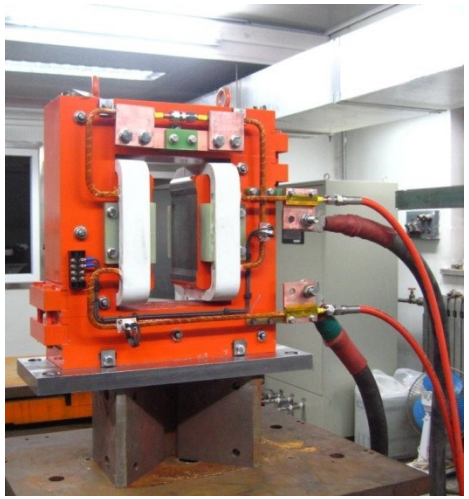
Electron beam position at PR3 screen with all Q6-Q10 are switched on

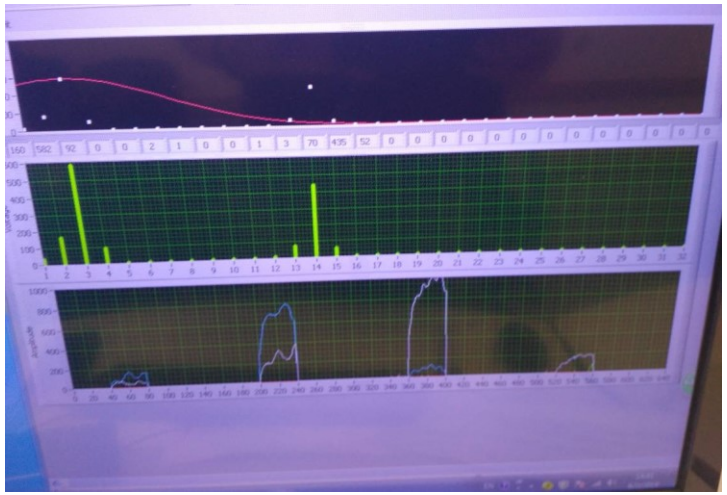
- Beam energy is 100 MeV
- Beam pulse current is 30 – 300 mA
- Maximum transportation efficiency is 99%
- Average transportation efficiency is 96%

BEAM TRANSPORTATION THROUGH TRANSPORTATION CHANNEL OF THE LINAC



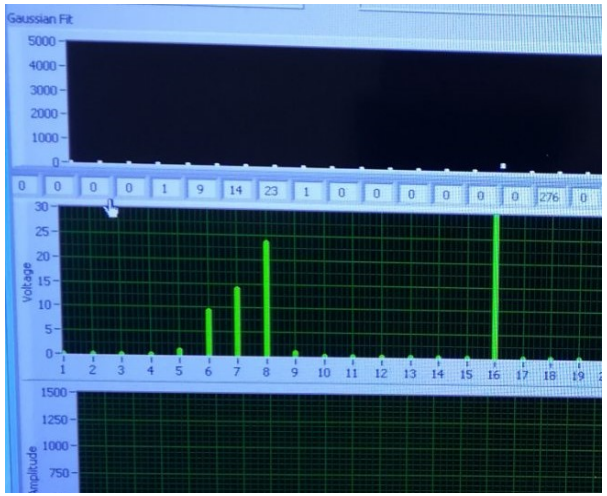


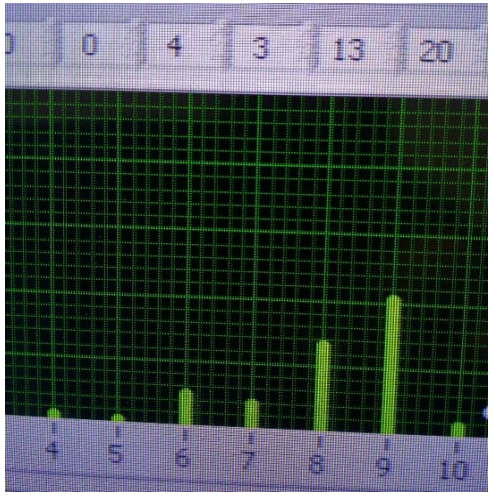


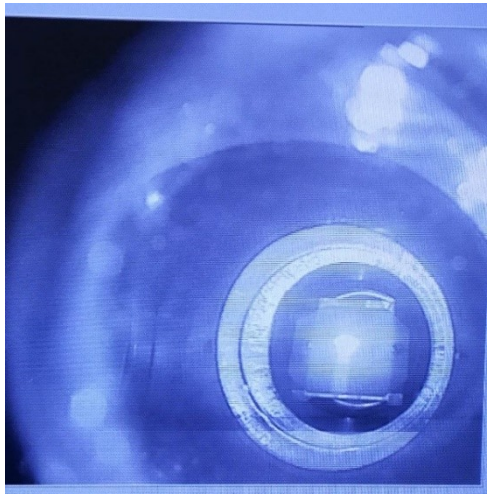


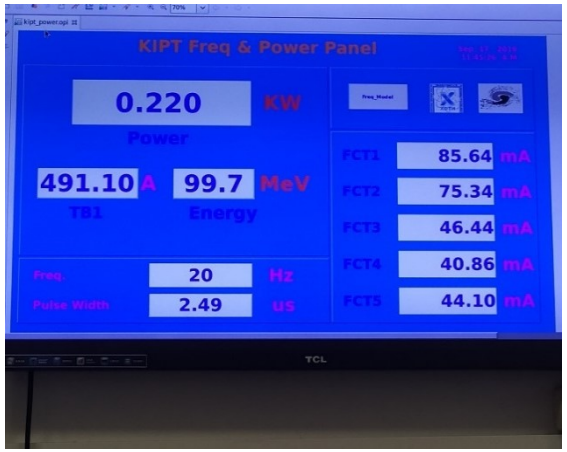
8 MARCH, 2024

STABLE MODE FOR NEUTRON SOURCE PHYSICAL START-UP

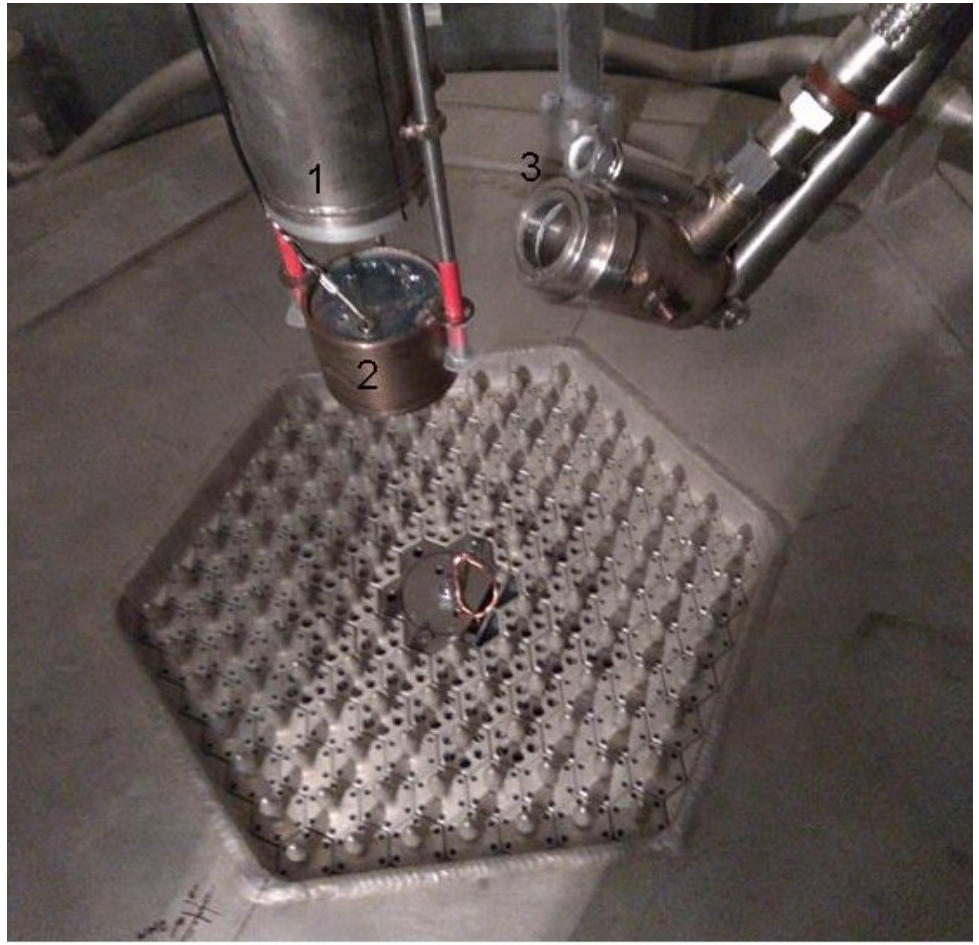


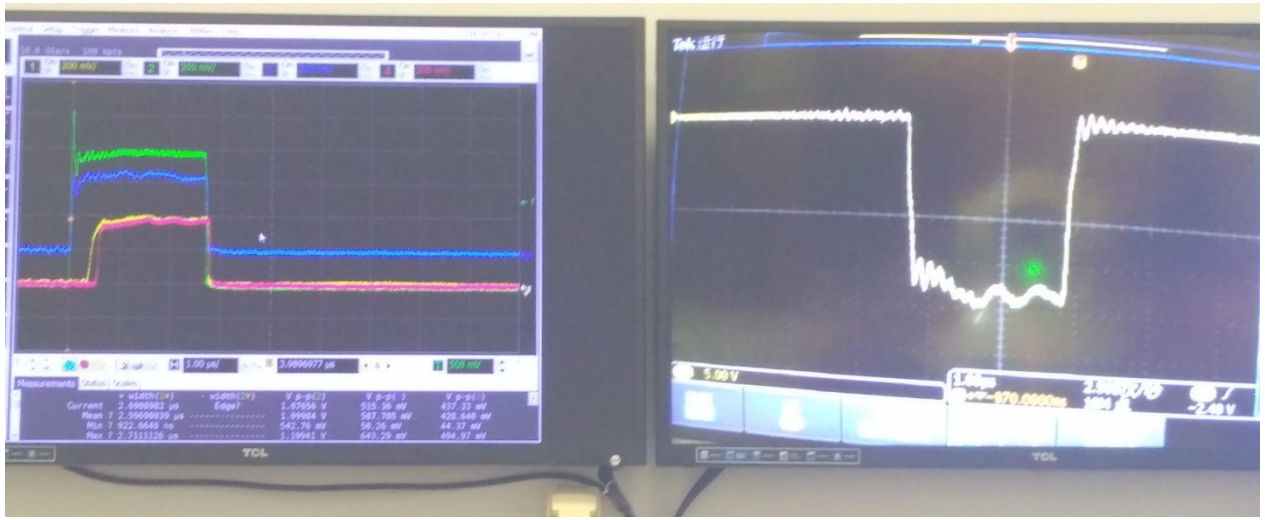






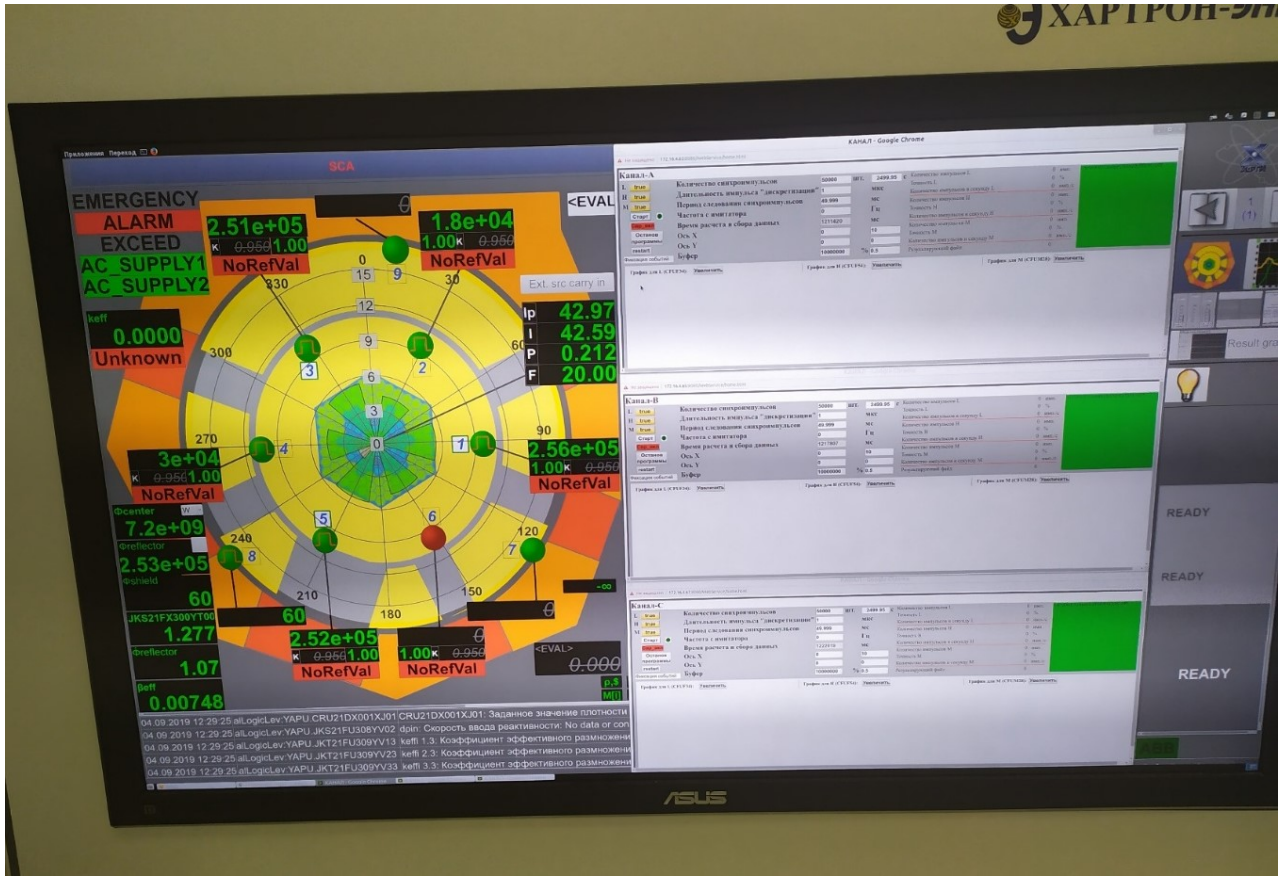
STABLE MODE FOR NEUTRON SOURCE PHYSICAL START-UP

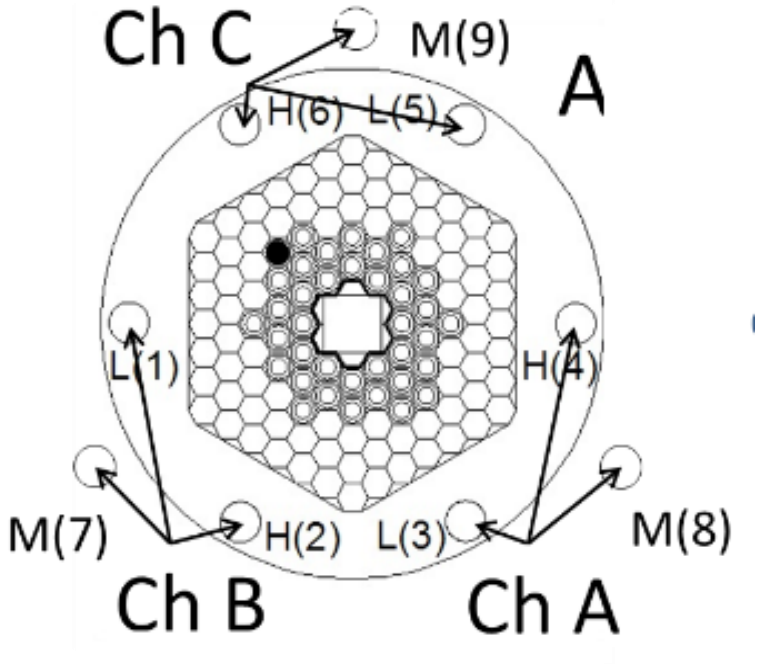


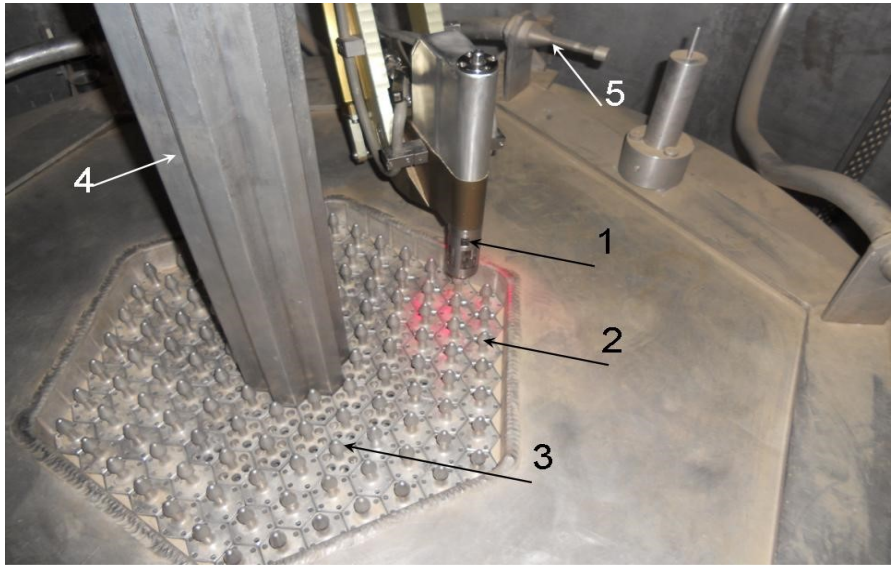


8 MARCH, 2024

NEUTRON FLUX MEASUREMENT SYSTEM

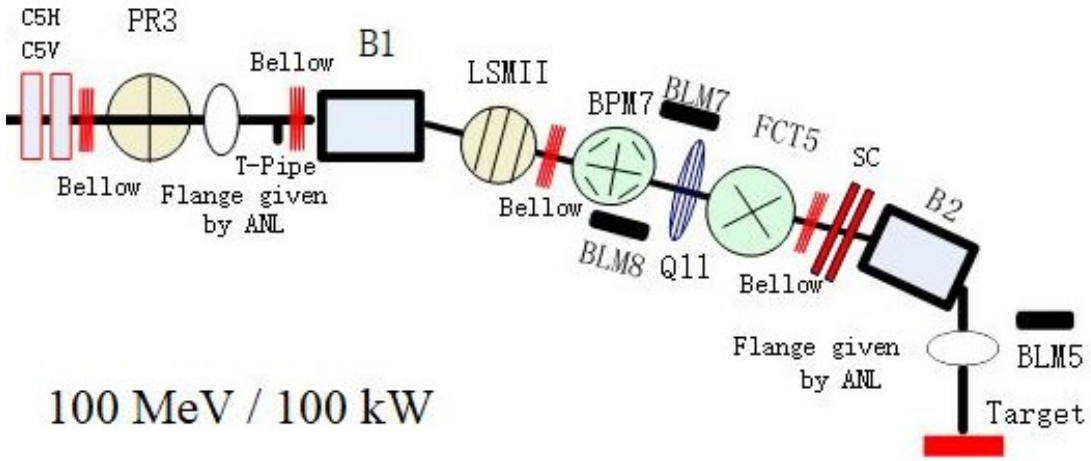


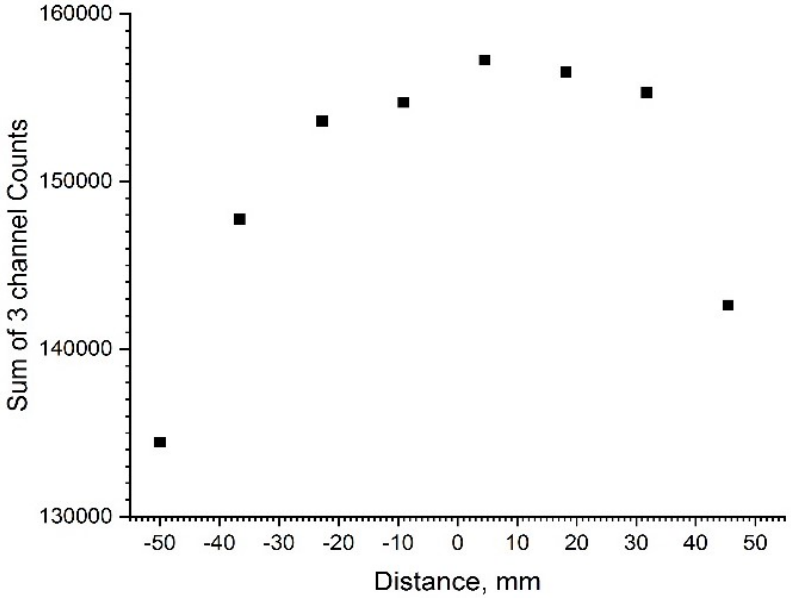


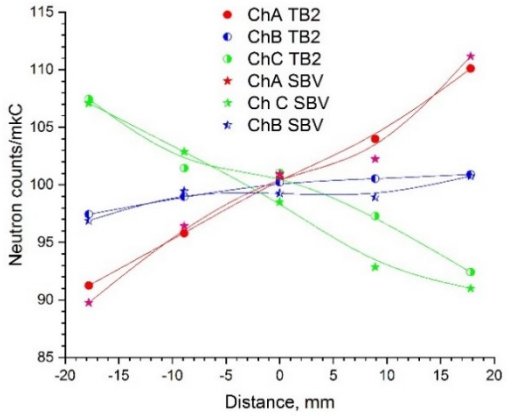


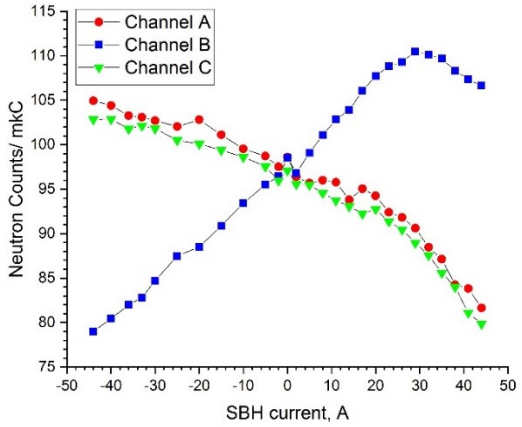
8 MARCH, 2024

NEUTRON FLUX MEASUREMENT SYSTEM



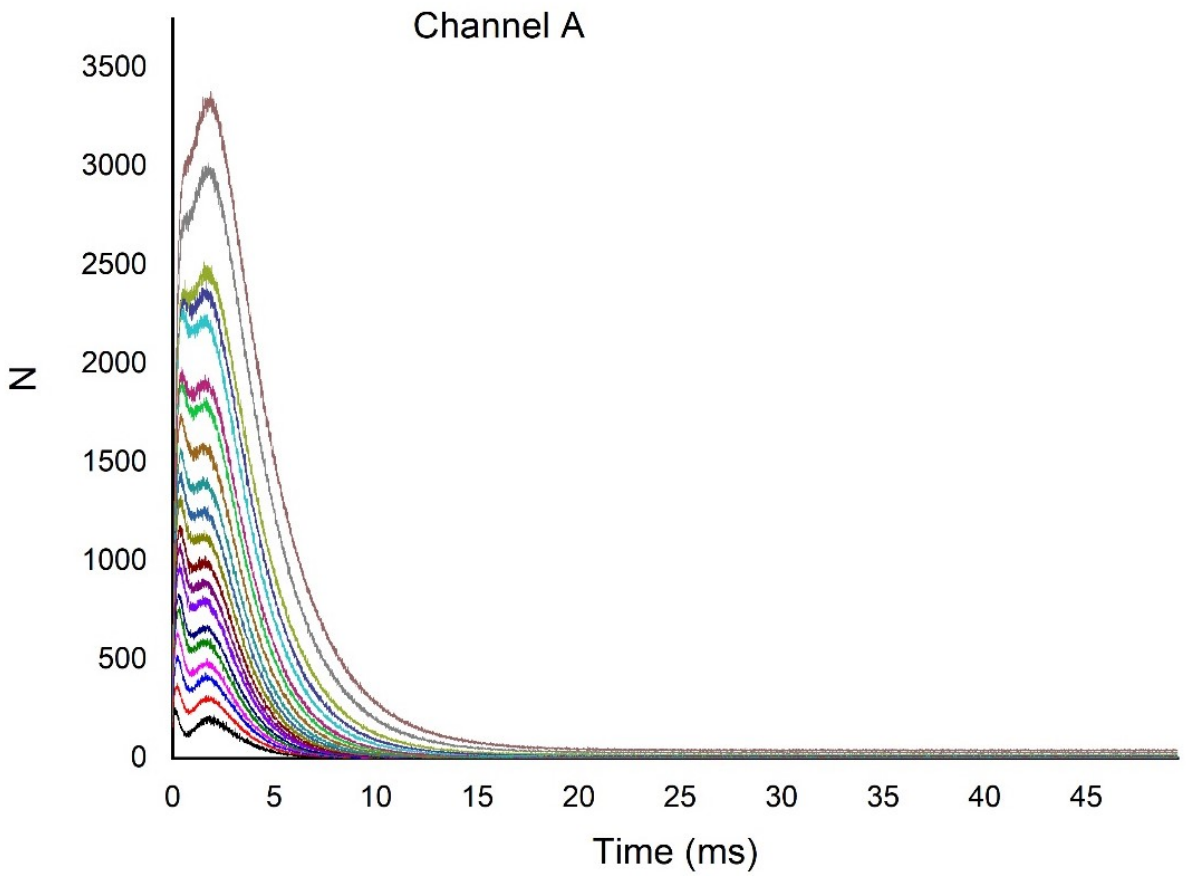


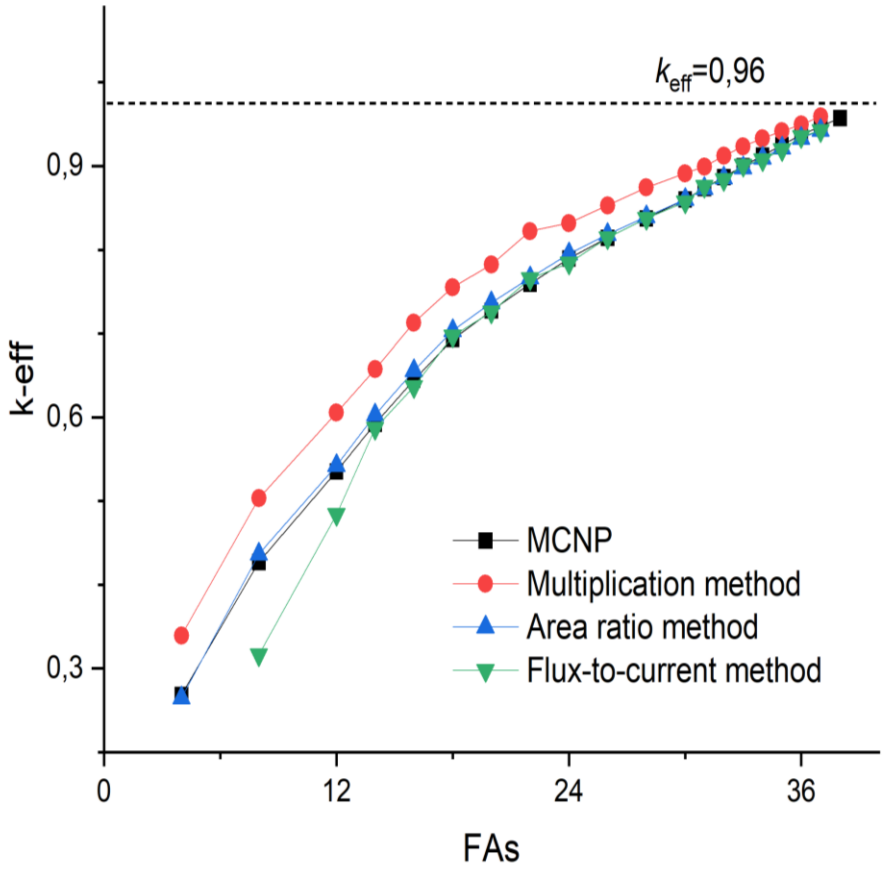




The results of neutron counts registration in dependence on B2 coil excitation current.

MAIN PHYSICAL START UP RESULTS





Pulse responses of SCA to external neutron pulse for each stage of loading measured on one of the measuring channel

Neutron flux is about 10^7 neutrons/cm^2 s and in accordance with simulations

NEXT: PILOT OPERATION UP TO DESIGN PARAMETERS

RF CONDITIONING AND OIL COOLING

ELECTRON BEAM DIAGNOSTICS AFTER THE SECOND DIPOLE BEFORE THE TARGET

PROCEDURE OF THE BEAM POWER INCREASING DURING THE ACCELERATOR TURNING

THANK YOU

Recent achievements on the Kharkiv X-ray generator facility NESTOR

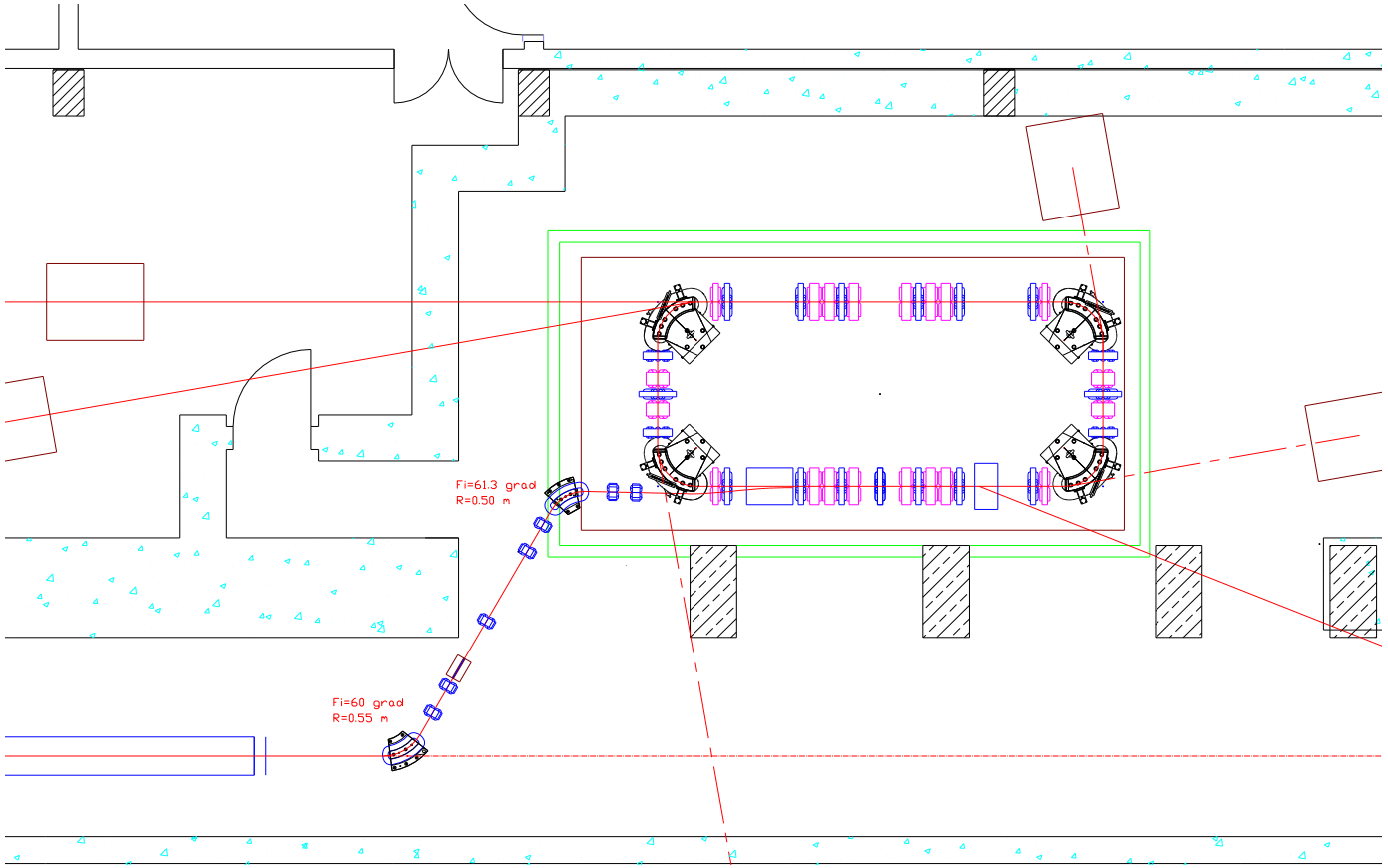
Andriy Zelinsky

on behalf of
NSC KIPT NESTOR X-ray Source team,
Kharkiv, Ukraine

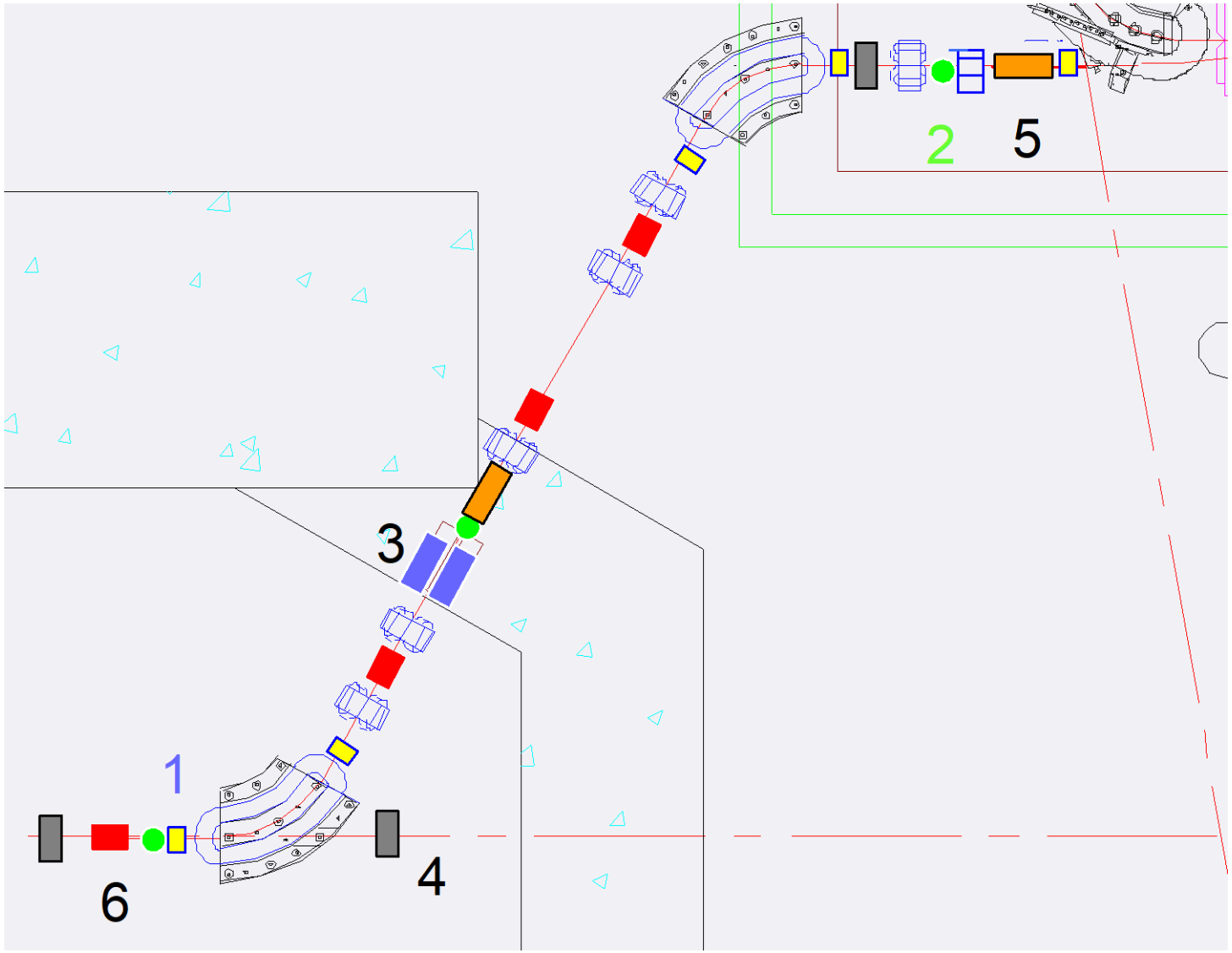
8TH MARCH, 2024

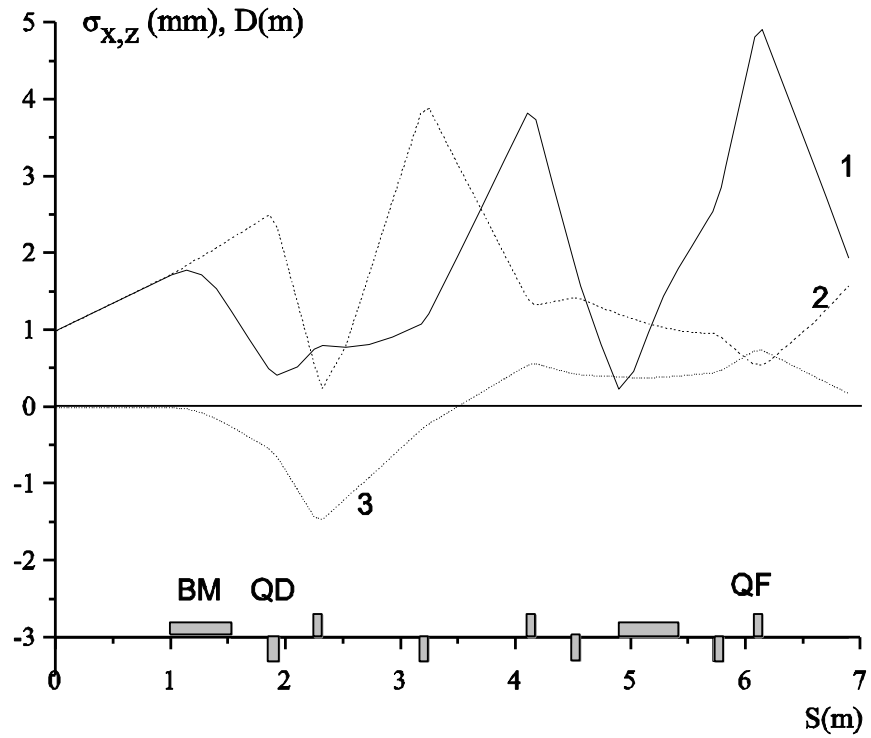
MAIN NESTOR FACILITY PARAMETERS AND LAYOUT

Storage ring circumference, m	15.418
Electron beam energy range, MeV	40-225
Betatron tunes Q_x, Q_z	3.155; 2.082
Amplitude functions β_x, β_z at IP, m	0.14; 0.12
Linear momentum compaction factor α_1	0.01-0.078
RF acceptance, %	> 5
RF frequency, MHz	700
RF voltage, MV	0.3
Harmonics number	36
Number of circulating electron bunches	2; 3; 4; 6; 9; 12; 18; 36
Electron bunch current, mA	10
Laser flash energy into optical cavity, mJ	1
Collision angle, degrees	10; 150
Scattered photon energy (Nd laser, ε_{las} = 1.16 eV), keV	6-900
Spectral brightness, phot/(s mm^2 mrad^2 0.1%BW)	5×10^{12}-5×10^{13}



INJECTION CHANNEL

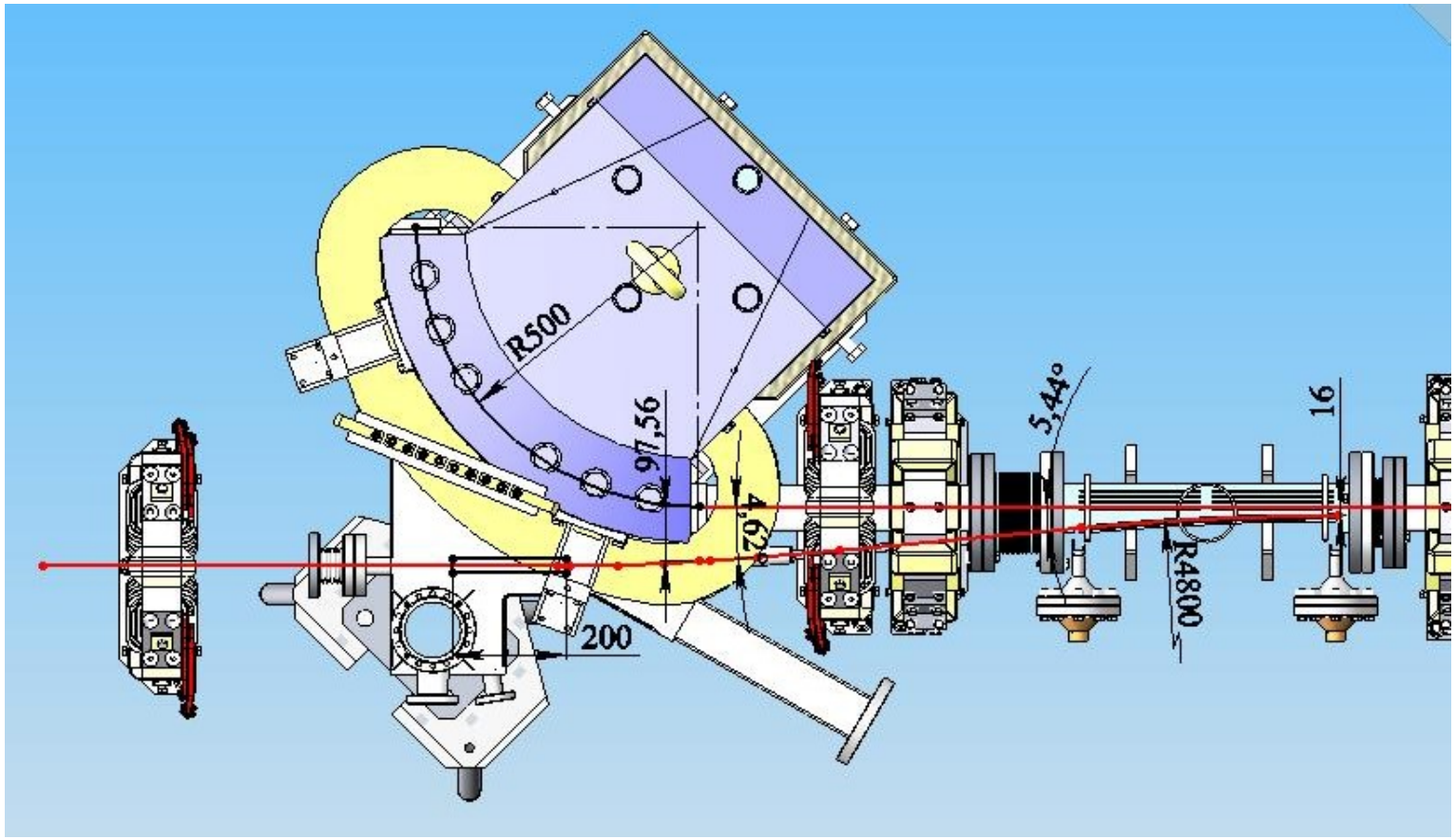


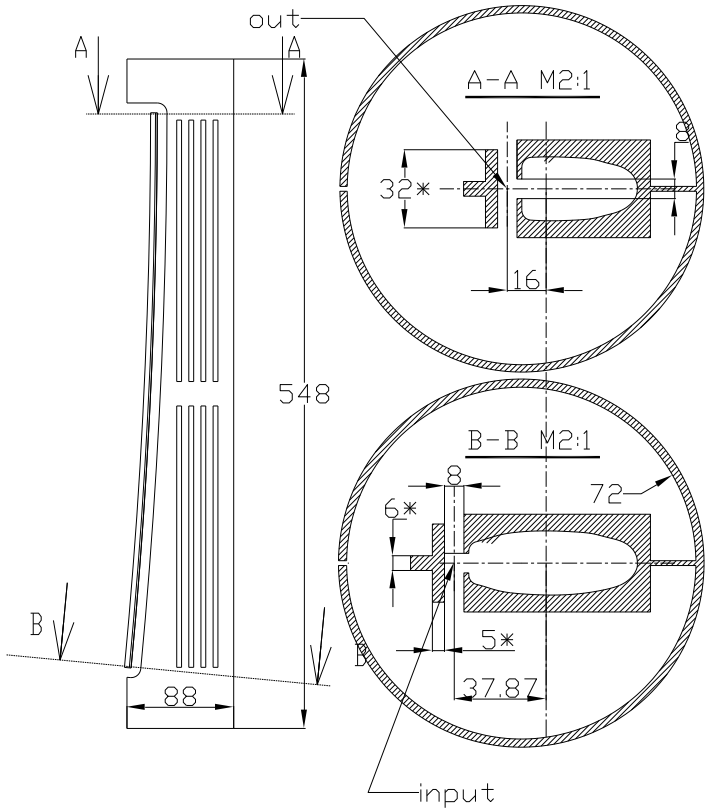


Horizontal (1) and vertical (2) beam envelopes and dispersion function (3) in the injection channel.

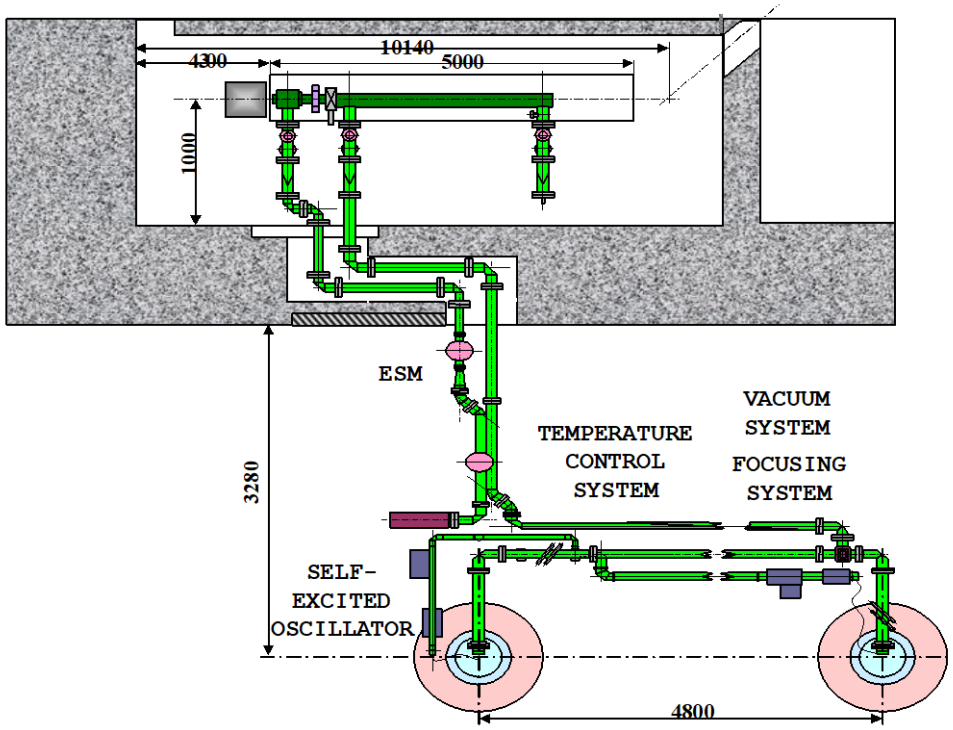
1 – bellows joint, 2 – pumping points, 3 – collimator, 4 – vacuum valve,
5 – beam position monitor, 6 – beam correctors.

INJECTION SCHEME





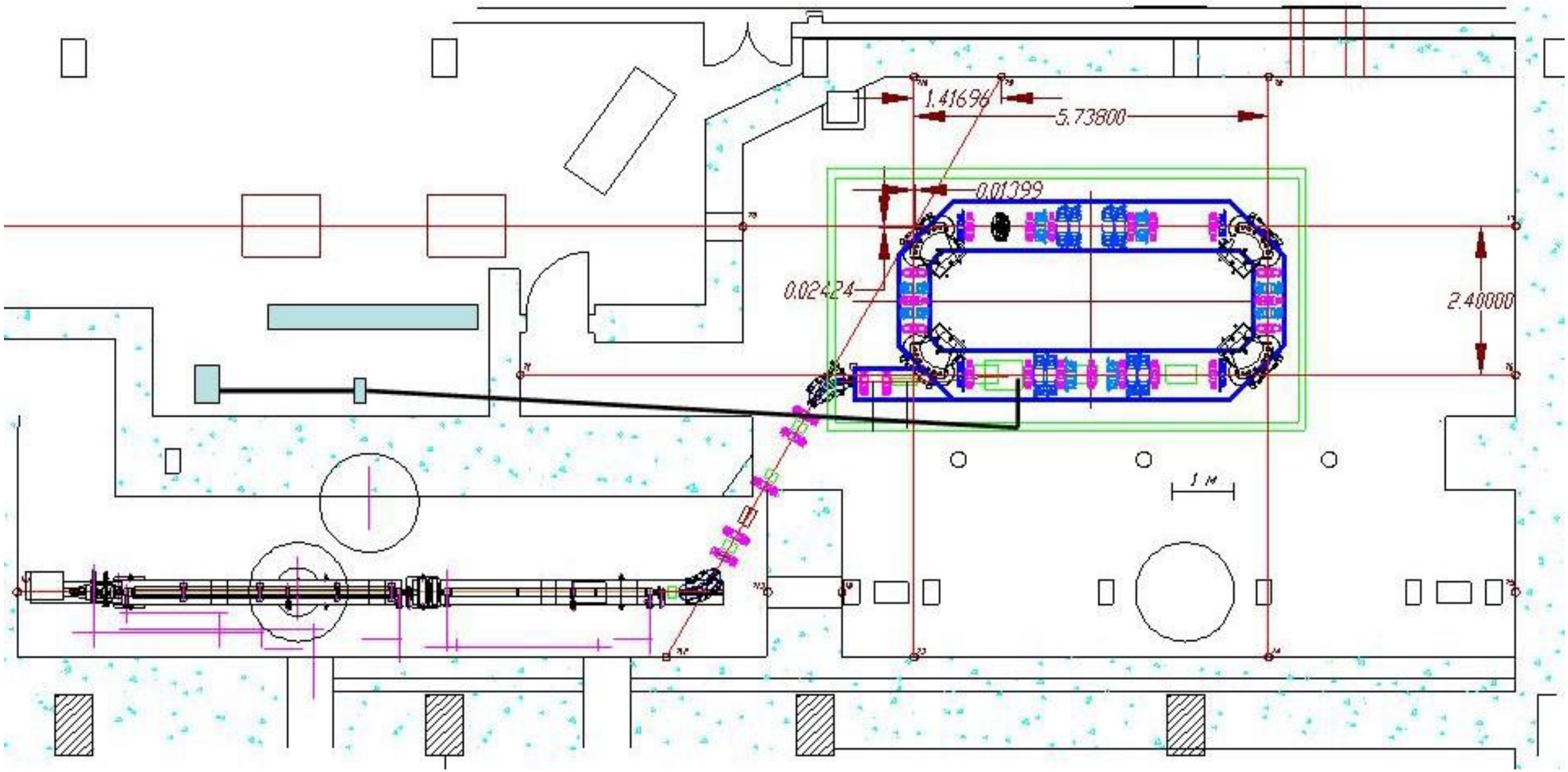
ACCELERATOR-INJECTOR



Parameter	Value
Electron beam energy, MeV	60
Emittance, m*rad	5×10^{-7}
Energy spread, %	1
Pulse charge, nC	0.5
Pulse duration, ps	10
Repetition rate, MHz	700

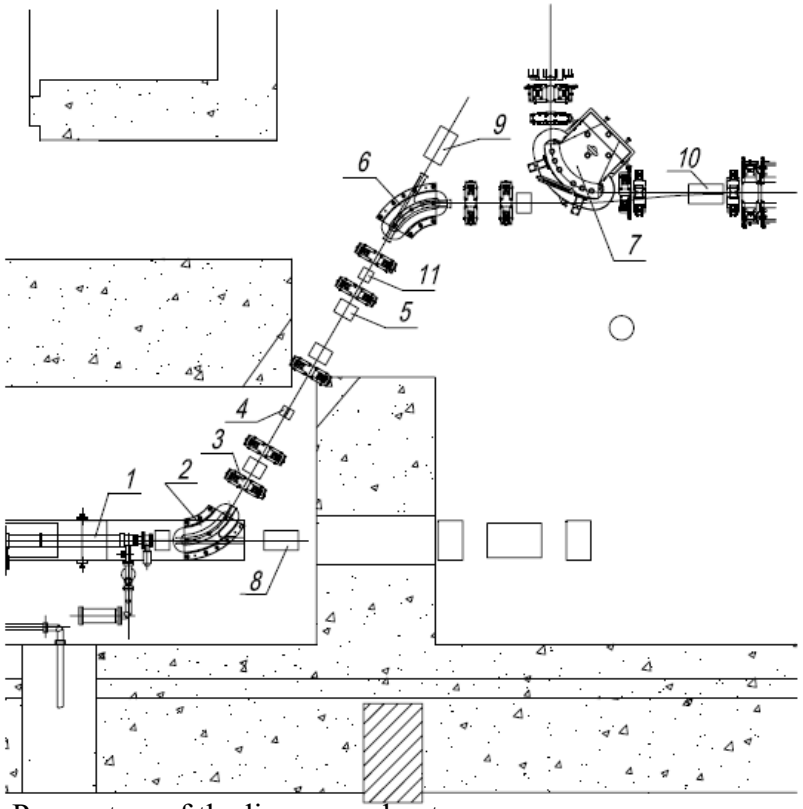
The linac-injector consists of a diode electron gun, which accelerates a beam with a current of 0.2 A to an energy of 25 keV with modulator, an injector on evanescent wave, which accelerates particles to an energy of 1 MeV and two traveling wave accelerating sections the first of which is the section“Kharkiv-85” 4,22 m long, and the second is the LU-60 section 3,22 m long with output beam energy up to 90 MeV. The accelerator operating RF frequency is 2797 MHz.

THE FIRST EXPERIMENTAL RESULTS



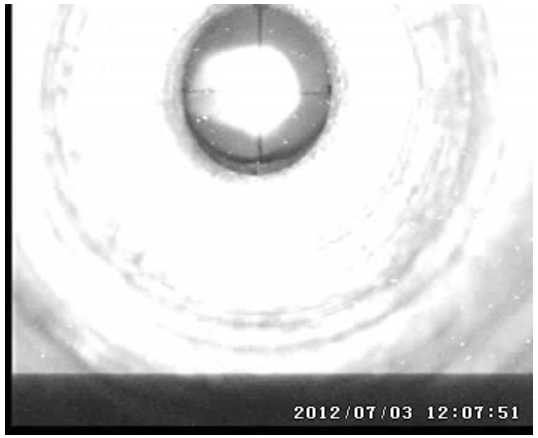
THE FIRST EXPERIMENTAL RESULTS

The output beam current of the electron gun was 140 mA.

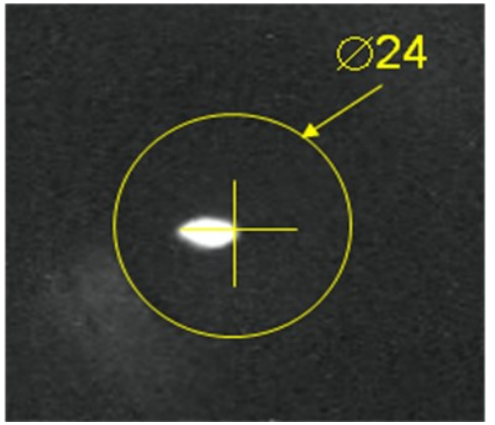


Parameters of the linear accelerator:

Energy, MeV……..60…90
RF frequency, MHz……...2797.15
Repetition rate, Hz……1…50
Pulse current, mA……...90
Pulse duration, ns……...1400
The width of the energy spectrum (steady-state), %.....1.5
Emittance (steady-state) mm mrad……...0.1.

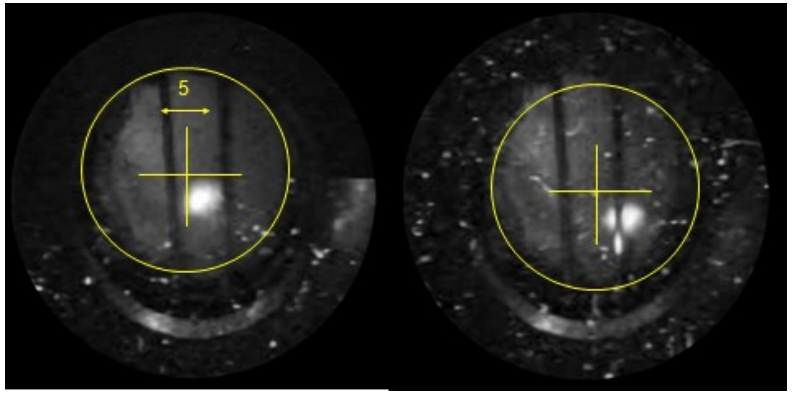


Optimized electron beam sizes at the exit of linear accelerator (RMS sizes: x-direction is about 5 mm, RMS sizes: z-direction is about 5 mm,)



Electron beam shape behind the second bending magnet of the transport channel the (9).

Electron beam current measured with current transformer detector in parallel transfer channel is about 20 mA (66% of the current at the exit of the linear accelerator).



Focused beam at the inflector point with different forces of correctors (displacement of about 5 mm).

NESTOR FACILITY MODIFICATION PLANS

Operation showed some disadvantages of this accelerator associated with used of accelerator injector hardware and long sections without additional beam focusing. In addition, the use of 2797 MHz operation frequency makes it difficult to purchase components of the RF system with such a frequency for further operation.

Thus, it became necessary to develop a new up to date injector and accelerator with commonly use operation RF frequency of 2856 MHz.

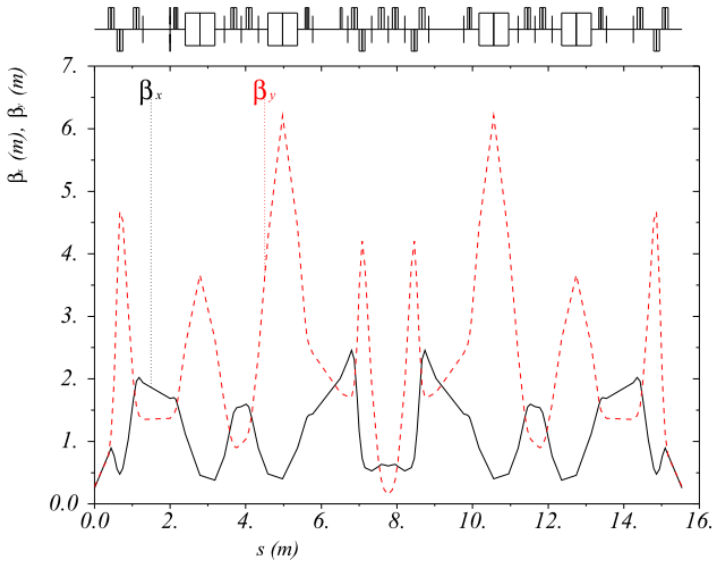
It leads to:

- New accelerator – injector with new focusing and beam instrumentation systems
- Modified storage ring lattice
- Modified RF cavity
- New laser

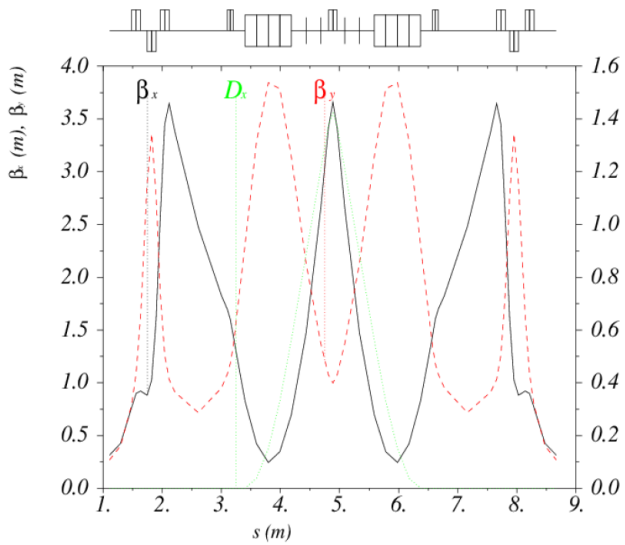
MONEY

NESTOR STORAGE RING MODIFICATION

Parameter	NESTOR	Lattice with h=37	Lattice with h=36
Ring circumference, m	15.418	15.538	15.116
Betatron frequences Q_x/Q_y	3.141/1.765	3.149/1.785	2.927/ 2.155
Momentum compaction	0.01	0.01	0.08

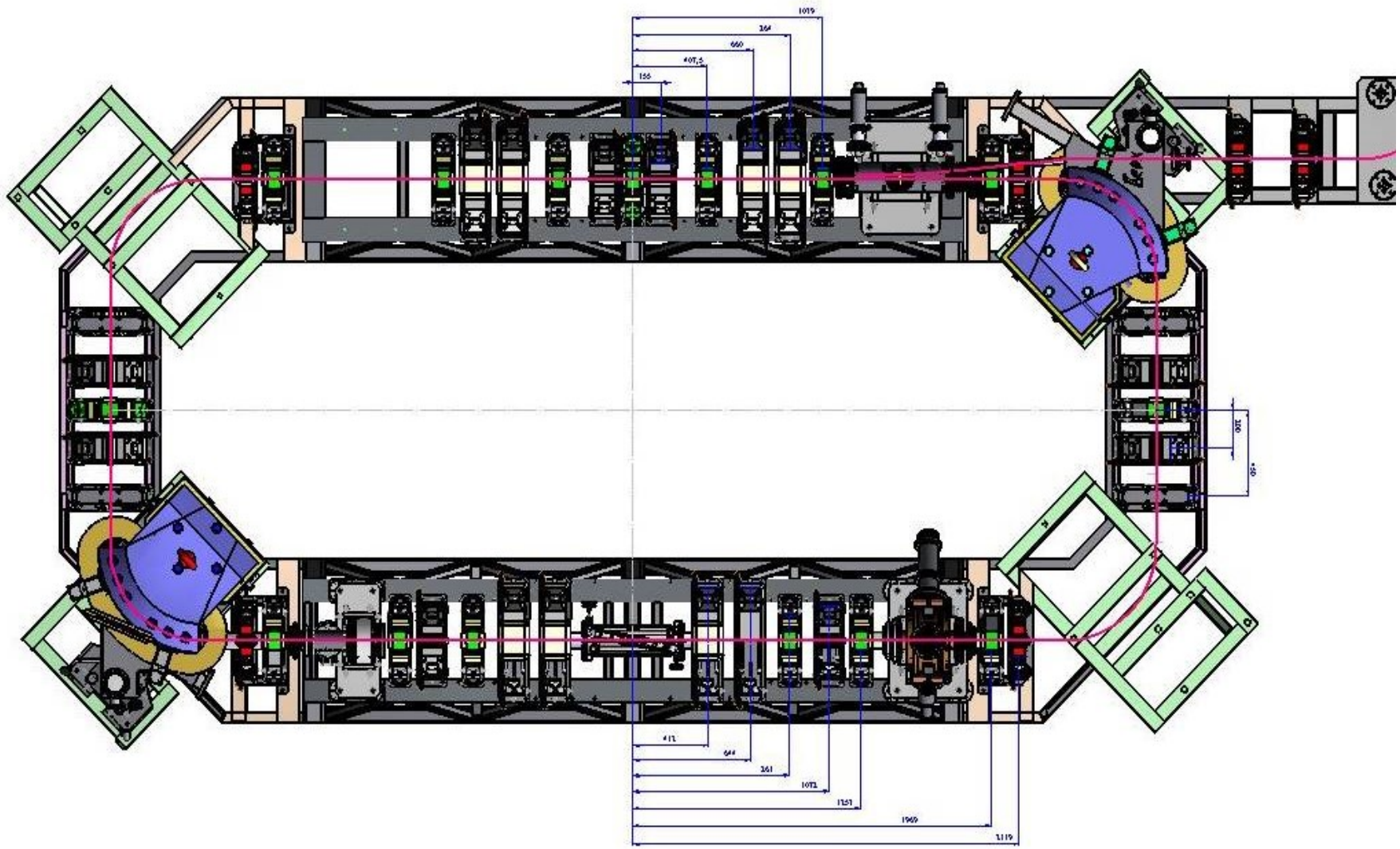


Amplitude functions at harmonics number h = 37.

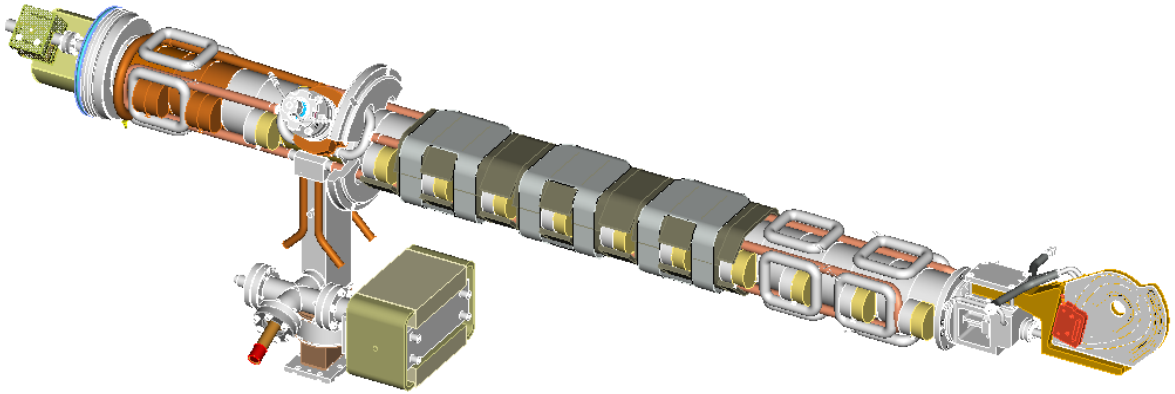


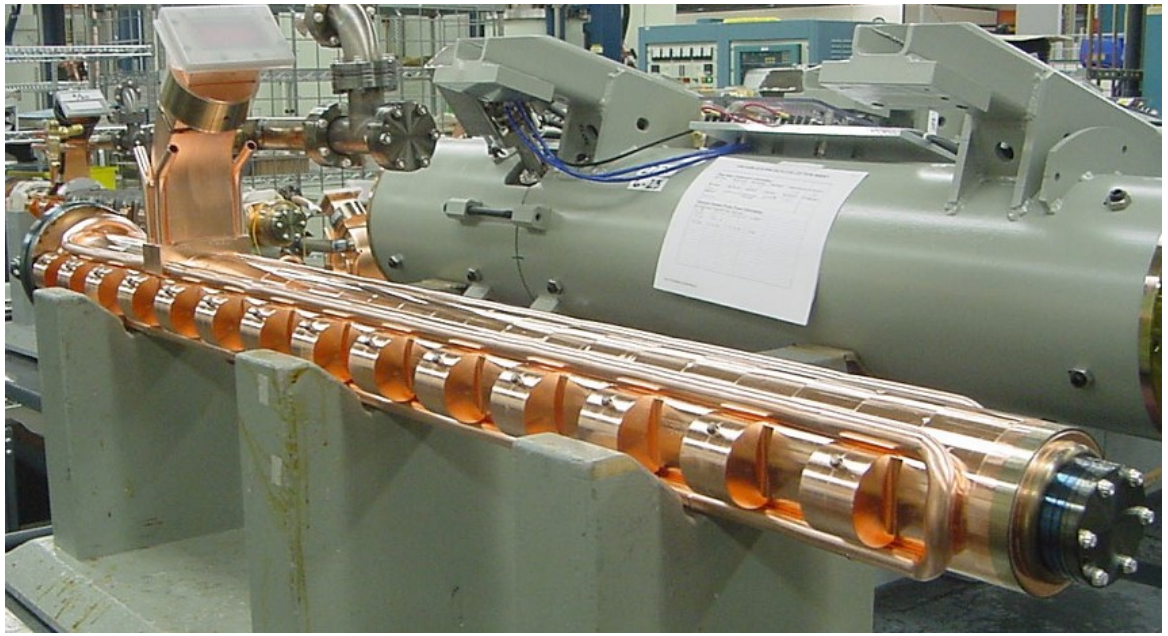
Amplitude functions of single superperiod of lattice with RF harmonics number h = 36

NESTOR STORAGE RING MODIFICATION



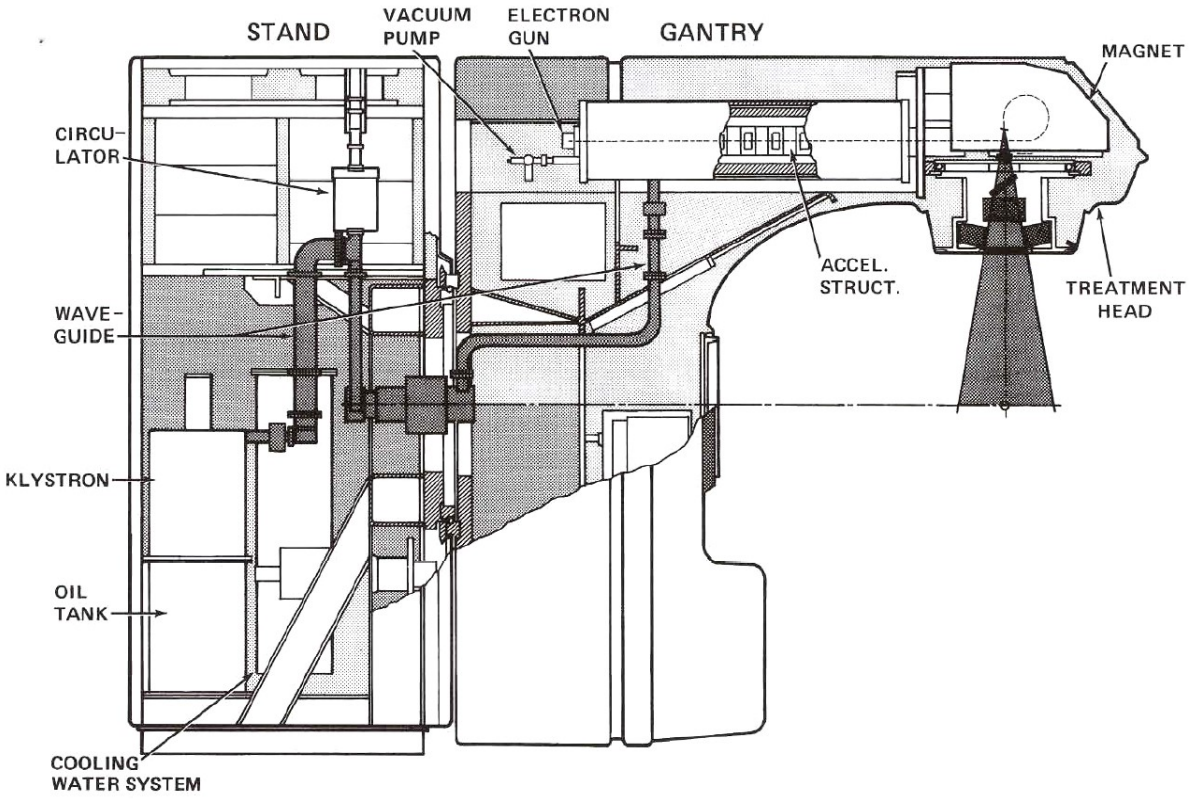
NESTOR ACCELERATOR MODIFICATION – VARIAN 2100C



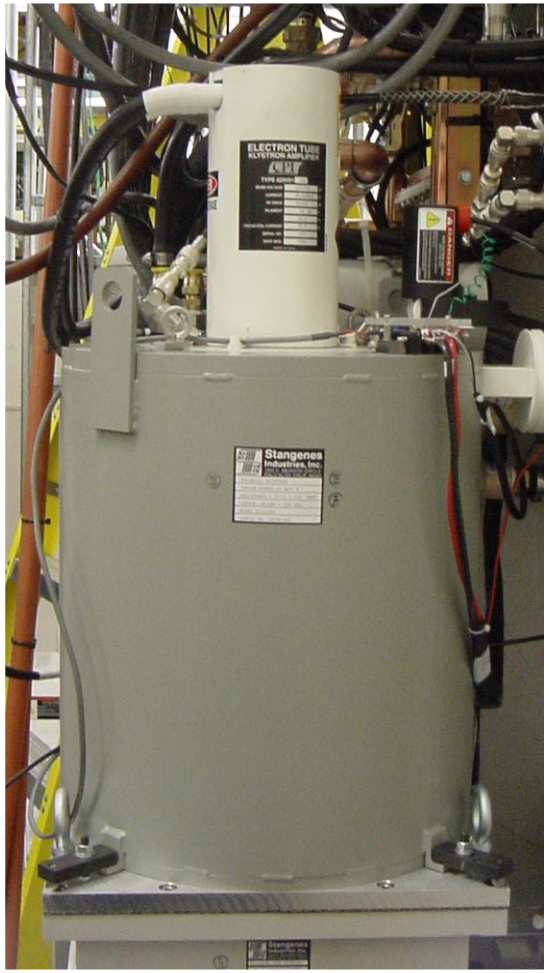


Side Coupled Standing Wave Accelerator

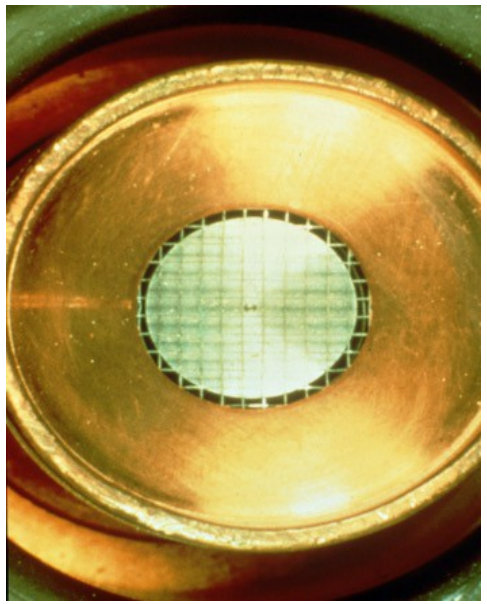
ELECTRON BEAM ENERGY: 20 – 25 MEV



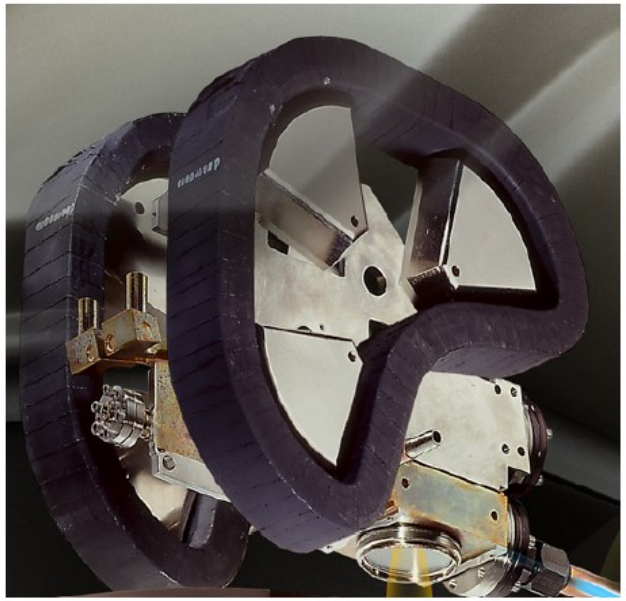
NESTOR ACCELERATOR MODIFICATION – VARIAN 2100C



Klystron-Amplifies Microwaves cleanly up to 5 Mega Watts



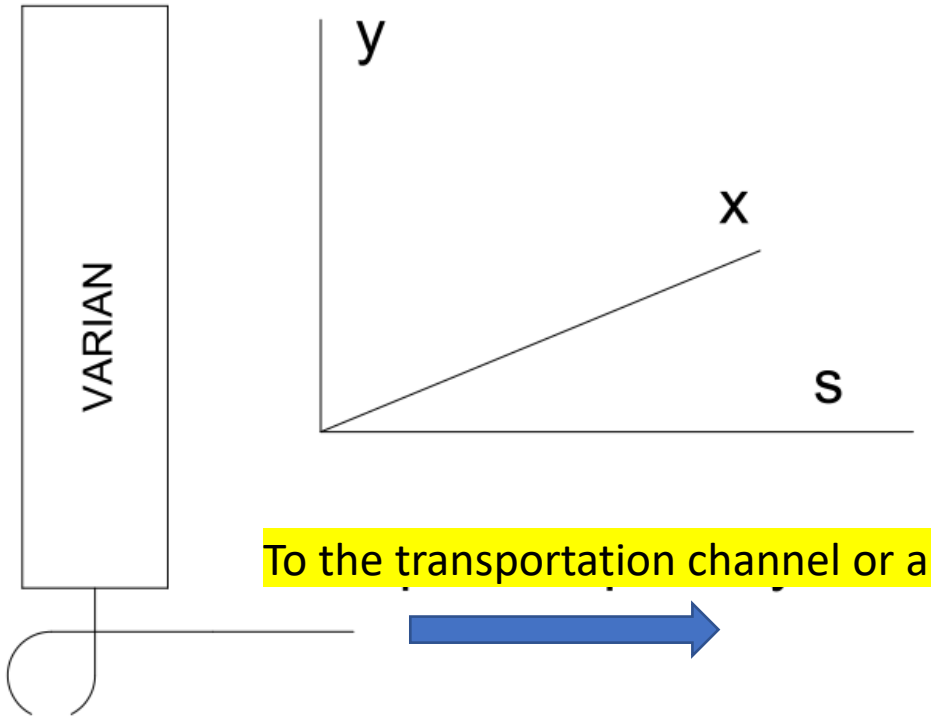
Triode electron gun

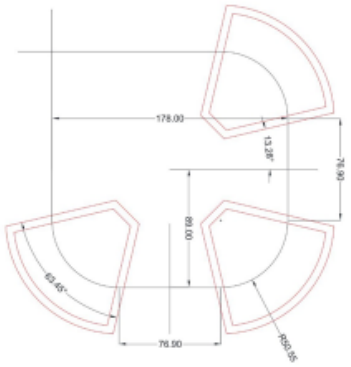


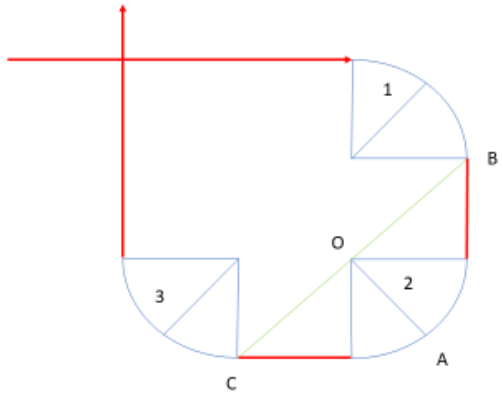
270-degree, 3-sector (pole), uniform pole gap, achromatic, bending magnet

- +/- 3% energy slits

NESTOR ACCELERATOR MODIFICATION – VARIAN 2100C



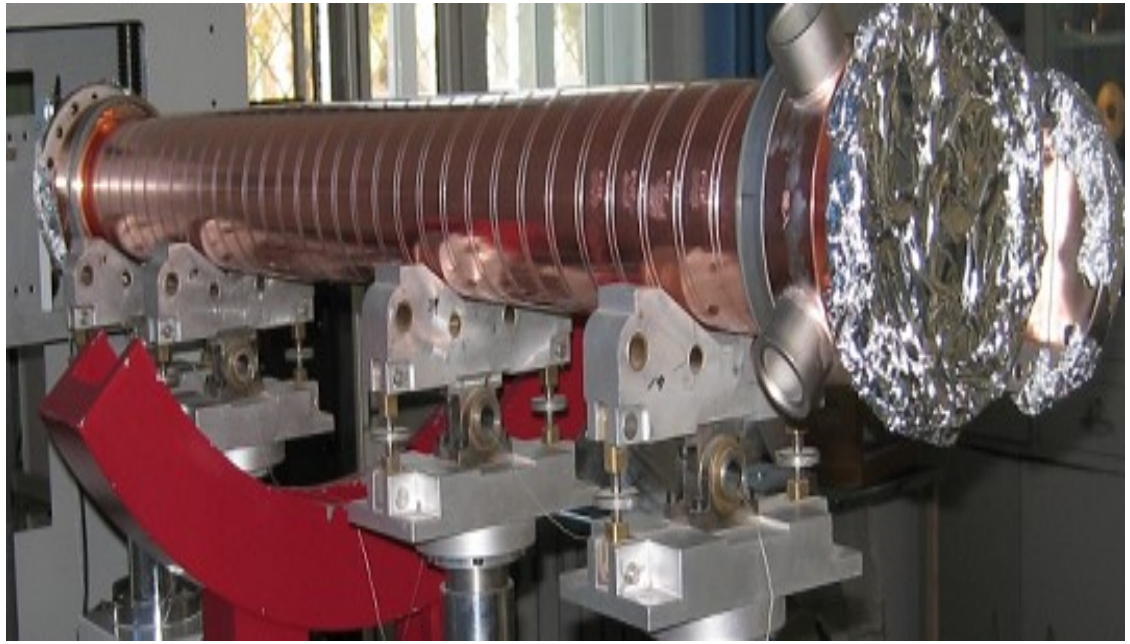




To the transportation channel or another accelerating section

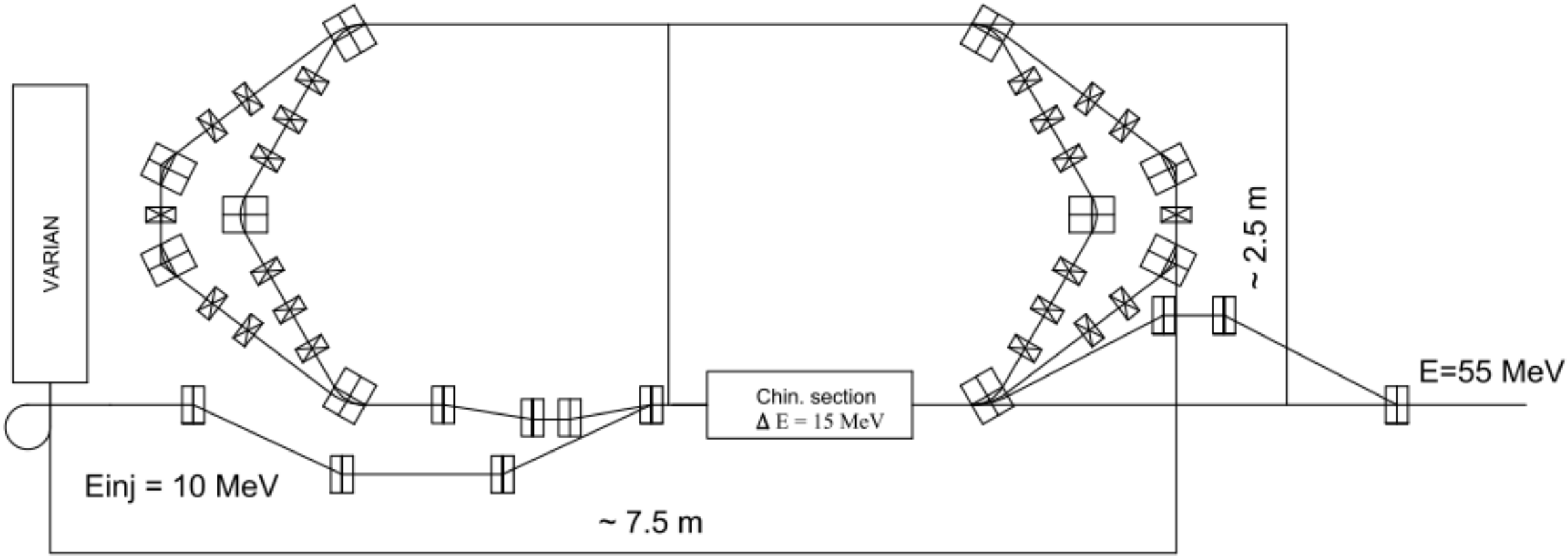
NESTOR ACCELERATOR MODIFICATION – IHEP ACCELERATING SECTION

	NSC-KIPT
Operation frequency	2856
Operation temperature	40.0 ± 0.1
Number of cells	34 regular cells/2 coupler cells
Section length	1338 (36 cells)
Phase advance per cell	2π/3 - mode
Cell length	34.989783
Disk thickness (t)	5.84
Iris diameter (2a)	27.887 - 23.726
Cavity diameter (2b)	83.968 - 82.776
Shunt impedance (r_0)	51.514 - 57.052
Q factor	13806 - 13753
Group velocity (v_g/c)	0.02473 - 0.01415
Filling time	215
Attenuation parameter	0.1406

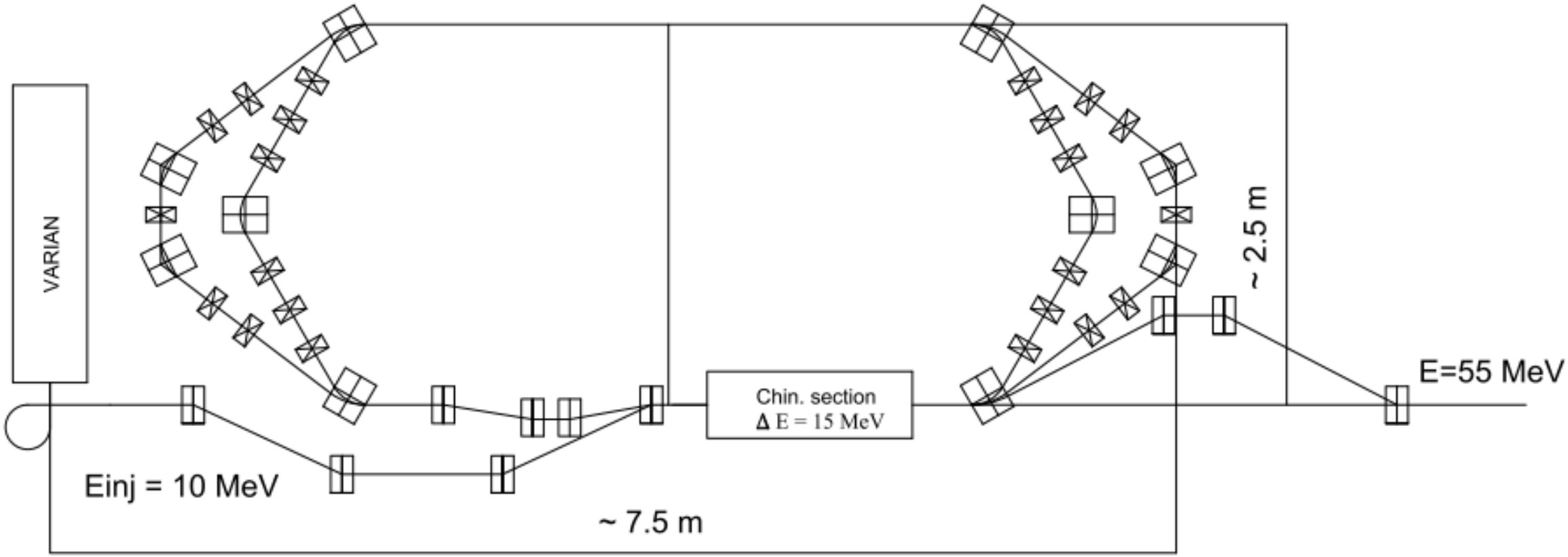


Frequency	MHz	2856
Peak beam voltage	kV	258
Peak cathode current	A	271
Peak RF output power	MW	30
Average output power	kW	56
Efficiency	%	43
Gain	dB	53
Max. Pulse repetition rate	pps	625

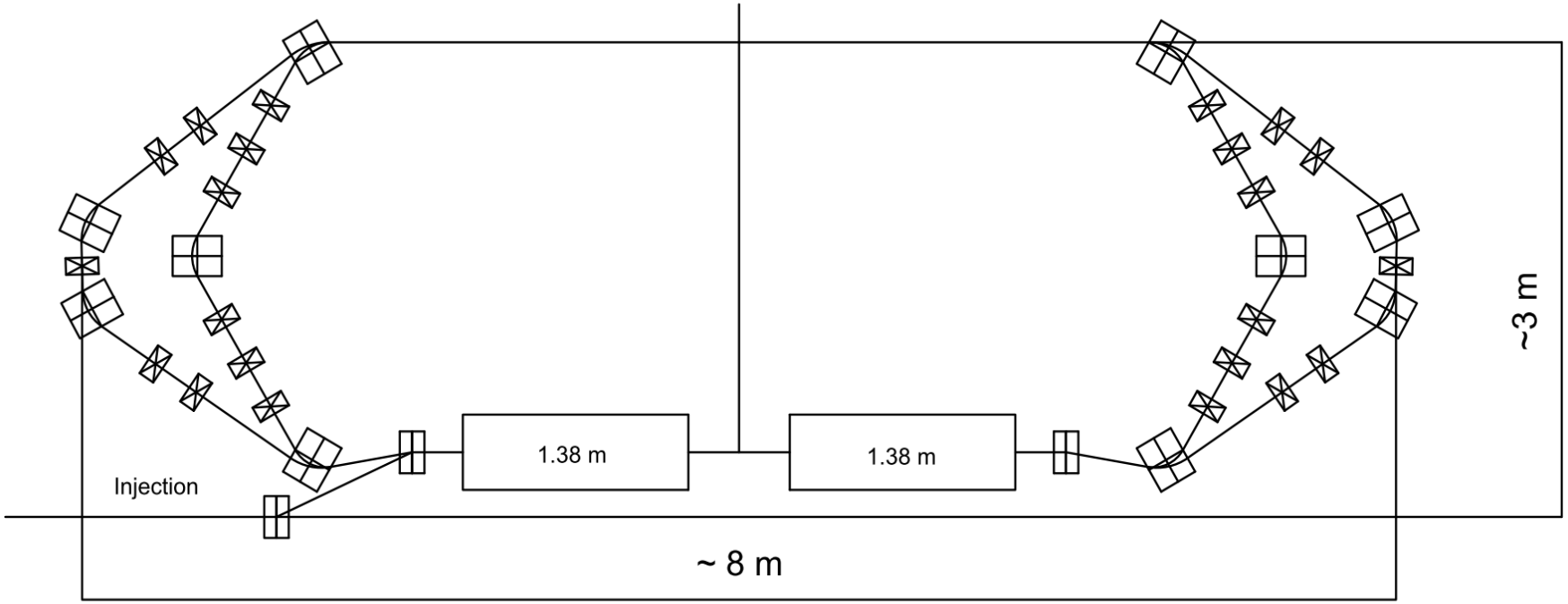
NESTOR ACCELERATOR MODIFICATION – RECICULATOR



NESTOR ACCELERATOR MODIFICATION – RECICULATOR



NESTOR ACCELERATOR MODIFICATION – RECICULATOR



THANK YOU