Accelerator technologies development at ITEP

N.N.Alexeev, V.A.Andreev, V.N.Balanutsa,
A.A.Golubev, A.A.Kolomiets, A.M.Kozodaev,
V.I.Nikolaev, Yu.A.Satov, V.A.Schegolev,
A.V.Shumshurov, A.B.Zarubin

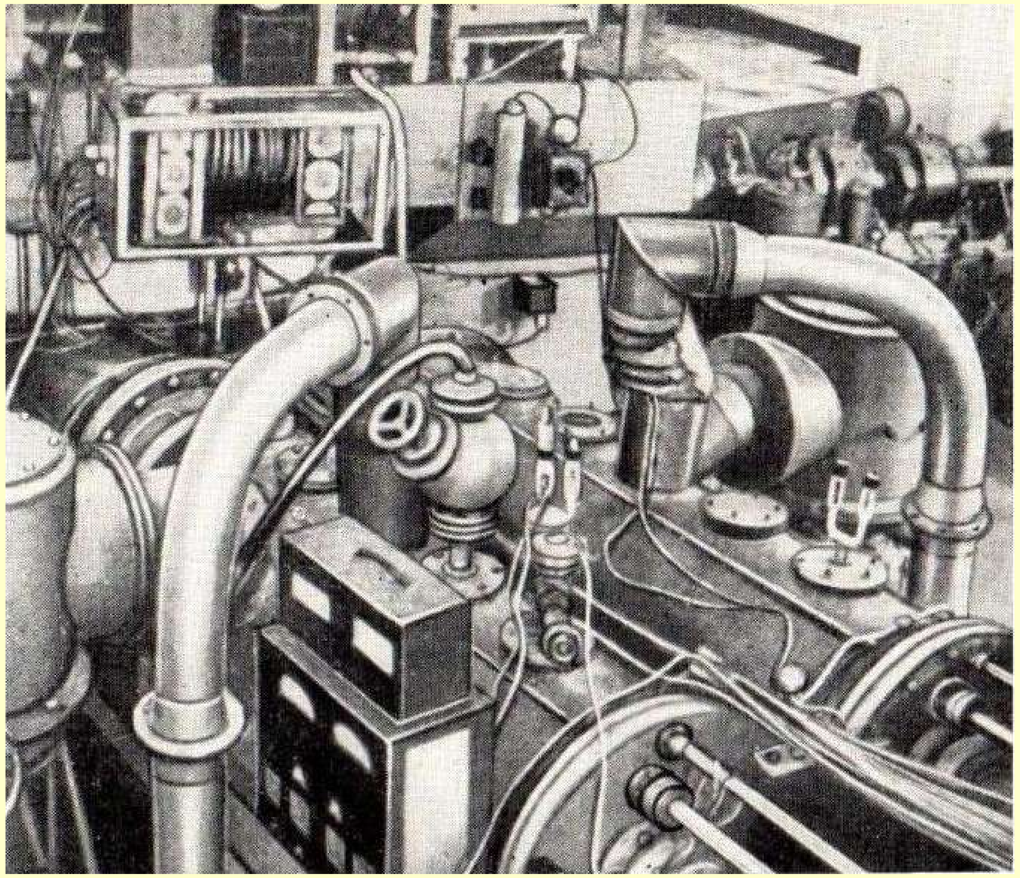
Institute for Theoretical and Experimental Physics
Moscow, Russia

RuPAC 2014

Content

First accelerator in ITEP (1948)

Layout of cyclotron



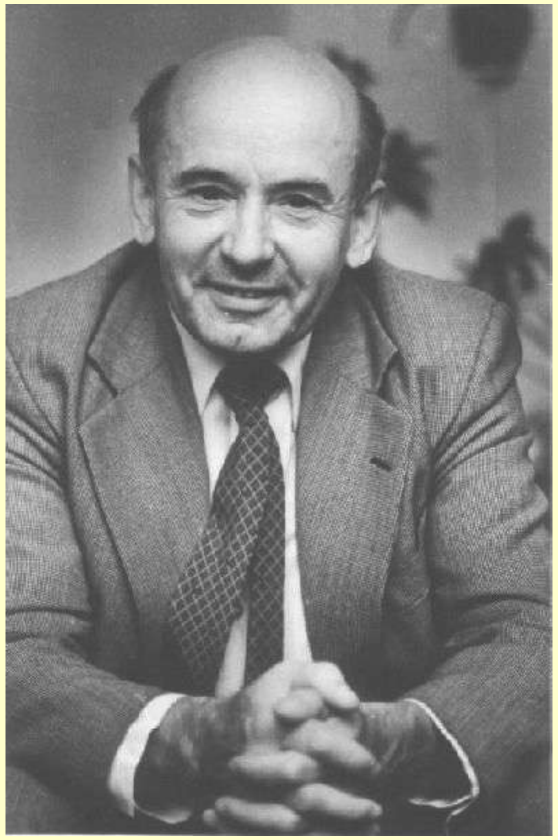
Cyclotron parameters

Weight of magnet, ton	**96.6**
Magnet diameter, m	**1.2**
Magnetic field, T	**1.6**
Accelerating frequency, MHz	**10.5**
Accelerating voltage, kV	**100**
Accelerated particles	**p, d, α**
Energy, MeV	6,2 (p) 12,5 (d) 24 (α**)**
Beam current: on target, μA extracted, μA	600 (d) 70 (d)

History of the first alternating gradient synchrotron in Russia

January 1953 -

meeting in the office of Minister (Pervuhin M.G.) of Medium machinery about new method of beam focusing using alternating gradient magnets published in Scientific American (A.A.Tyapkin memories).



Тяпкин Алексей Алексеевич, 1926-2003

Attended:M.S.Kozodaev, V.I.Veksler, M.S.Robinovich, A.A.Kolomensky, V.V.Vladimirsky, A.A.Tyapkin and others.

Recommended: to build in ITEP prototype of alternating gradient proton synchrotron for the energy of 7 GeV to verify this method and in the case of success, to build synchrotron for the energy of 50GeV.

Main administrative and scientific project managers

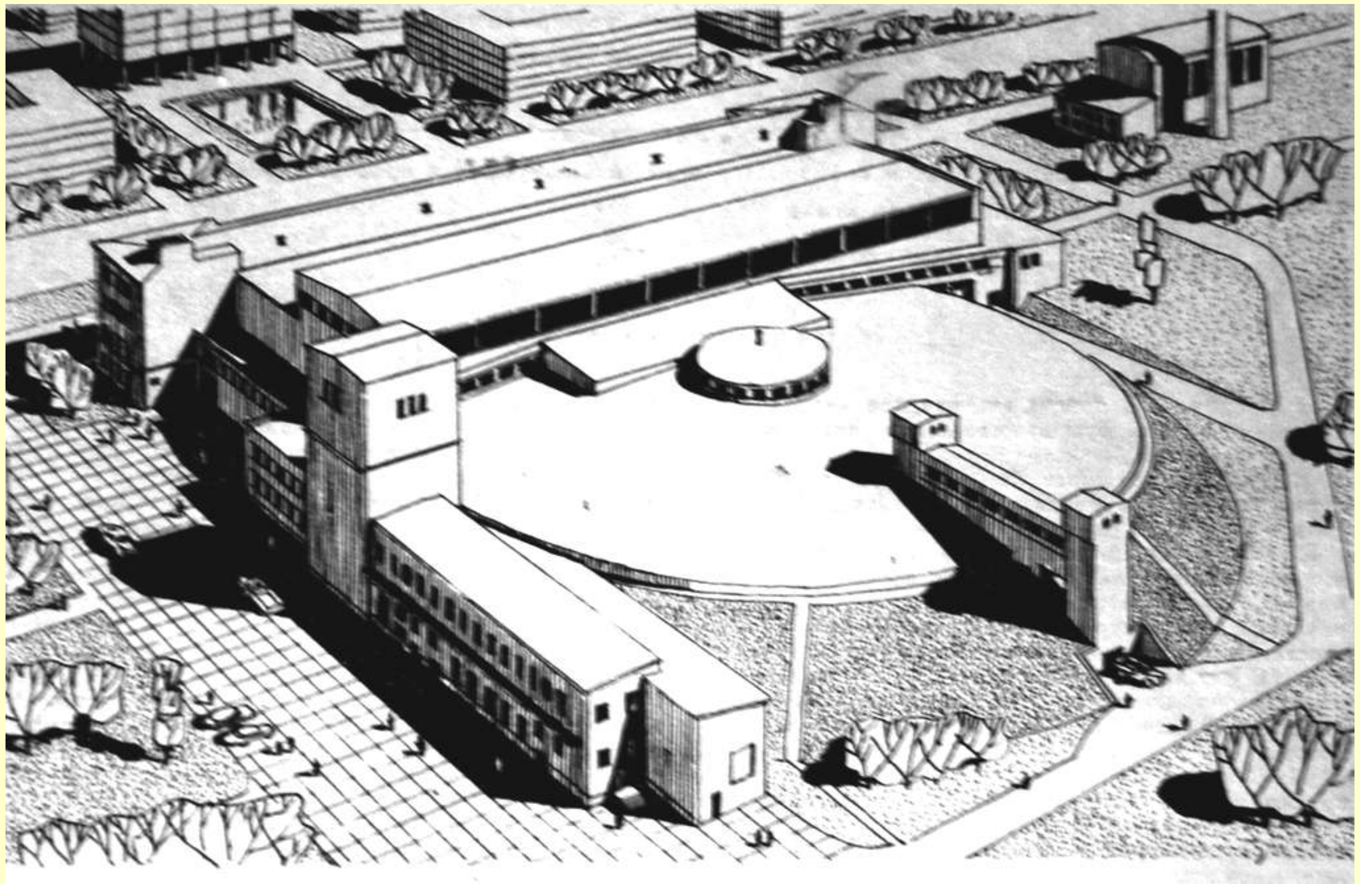
Академик
Абрам Исаакович
Алиханов

Член-корреспондент АН
Василий Васильевич
Владимирский

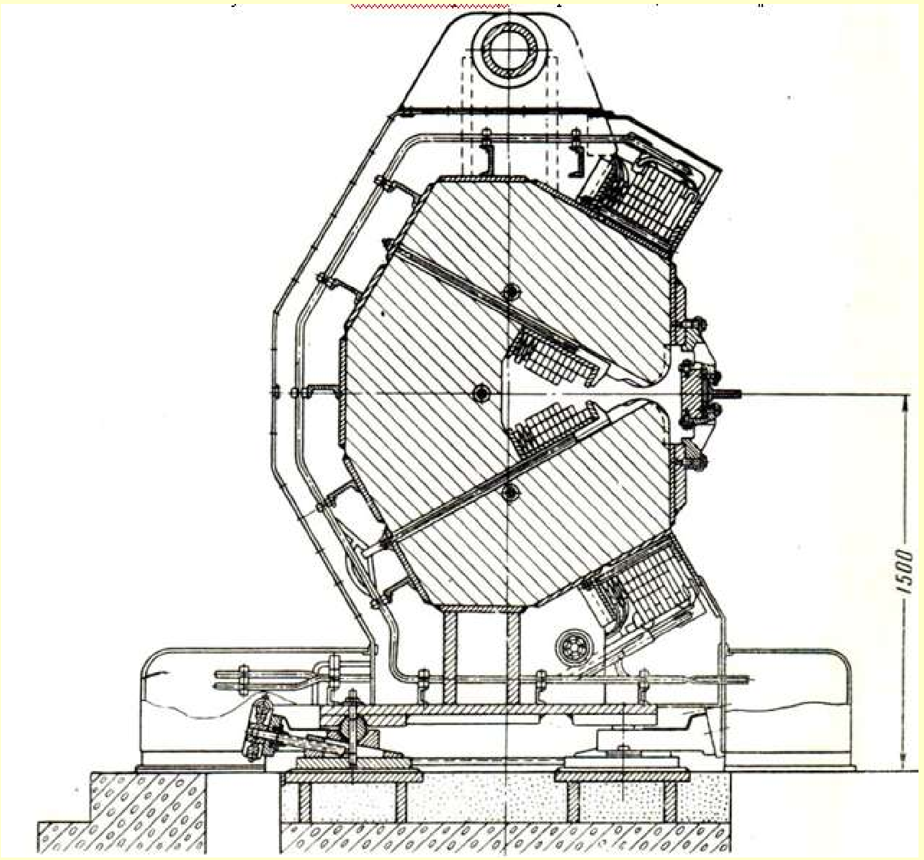
Main first participants of the project: L.L.Goldin, D.G.Koshkarev, Ju.F.Orlov, A.P.Rudik, E.K.Tarasov, V,S.Kuryshev, I.F.Kleopov, B.M.Jakovlev

Proton synchrotron U-7

Buildings of U-7 synchrotron



Magnetic C-block of U-7 lattice



1953 – start of design and construction

1961 – first acceleration of proton beam up to the energy of 7.5 GeV

Parameters of proton synchrotron U-7

Injection energy, MeV	**3,8**
Output energy, GeV	**7,0**
Beam intensity, ppp	**10^{10}**
Orbit length, m	**251,2**
No. of magnets	**98C+14X**
Straight sections, m	**0.304CC 0.417CX**
Betatron frequency	**12.75**
Transition energy, GeV	**19.2**
Field index	**460**
Dispersion function, m	**1,47**

Injector of U-7
Electrostatic generator EG-5

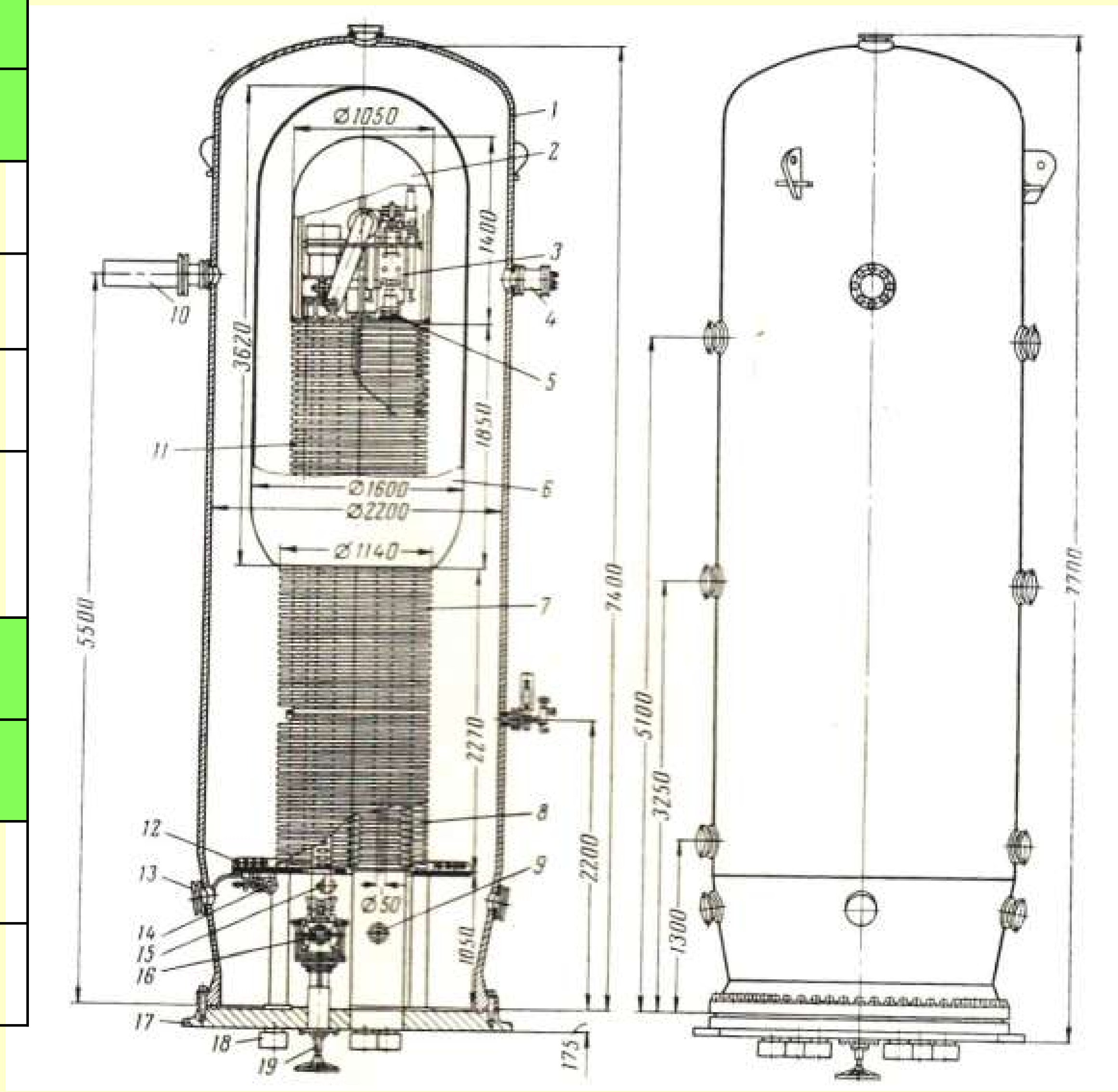
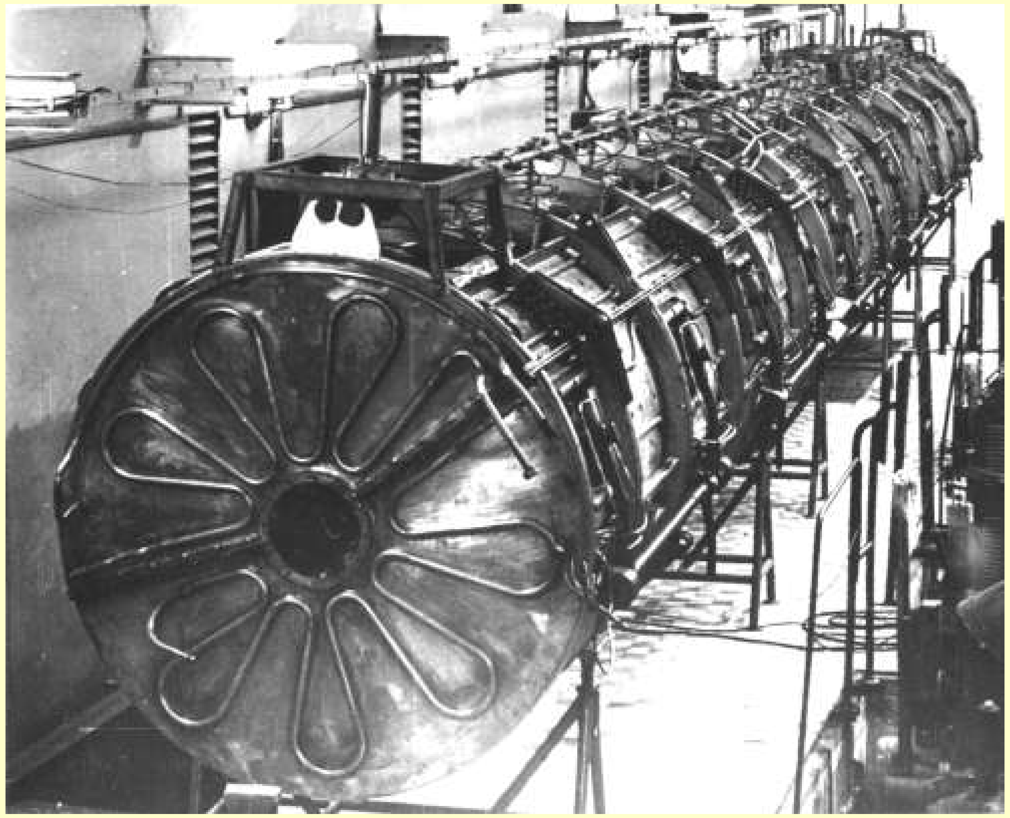


Рис. 1. Общий вид электростатического ускорителя ЭГ-5-1. 1 — котел, 2 — кондуктор, 3 — оборудование, размещенное под кондуктором, 4 — роторный вольтметр, 5 — ионный источник, 6 — промежуточный высоковольтный электрод, 7 — эквипотенциальные кольца, 8 — ускорительная трубка, 9 — электронная пушка, 10 — коронирующая стрела, 11 — изолирующая колонна, 12 — охлаждающий змеевик, 13 — смотровое окно, 14 — сельсины-исполнители, регулирующие цепи питания ионного источника, 15 — зарядная лента, 16 — нижний валик транспортера зарядов, 17 — плита котла, 18 — электрический ввод, 19 — устройство натяжения ленты

Construction of proton injector I-2

RF Resonator

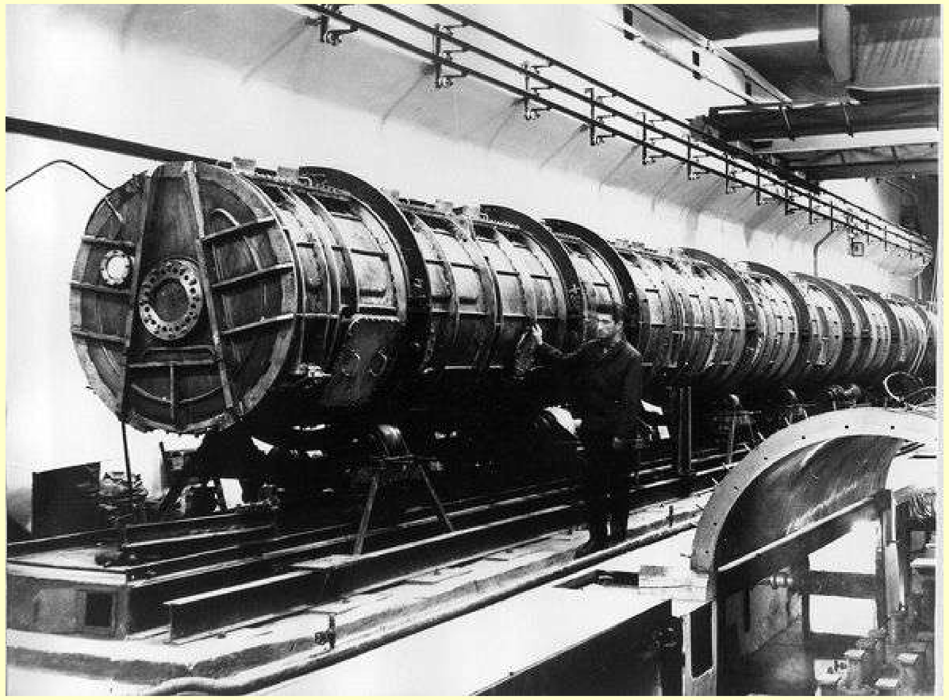


Proton linac I-2

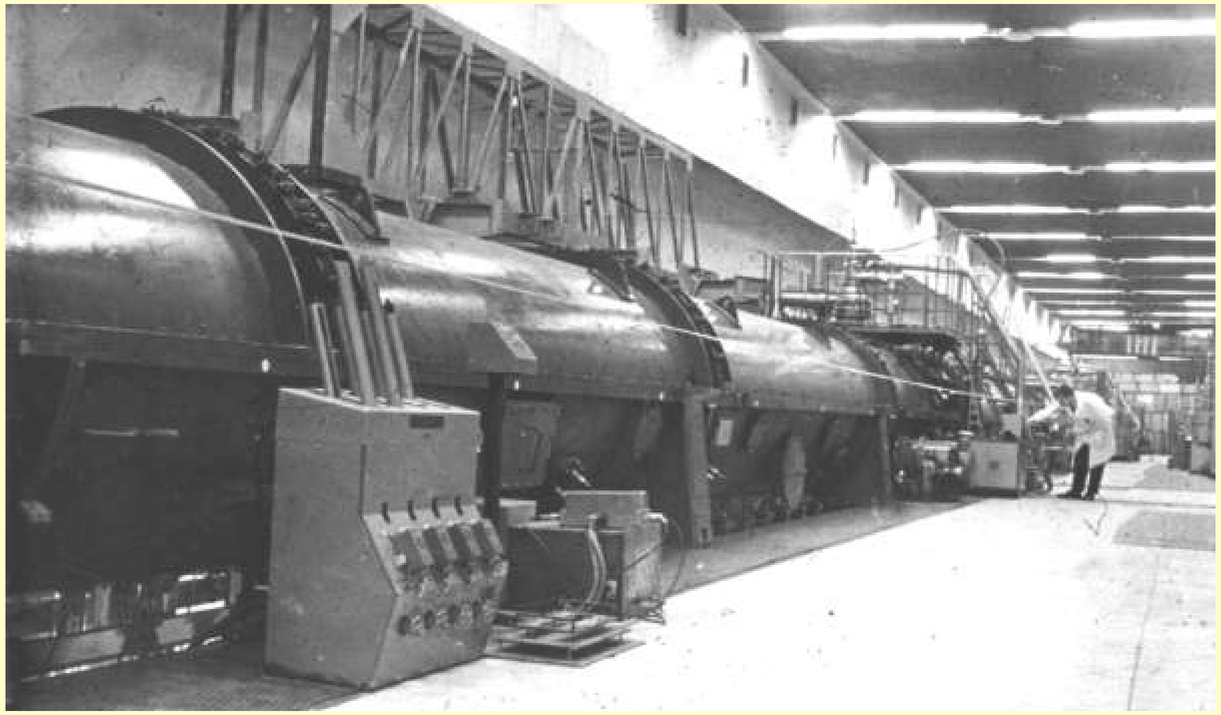
1958 – start of construction (I.M.Kapchinsky, E.N.Daniltsev, V.K.Plotnikov)
02.11.1966 – the launch of linac
11.1967 – first injection of proton beam to synchrotron U-7

Construction of proton injector I-100

RF Resonator



Proton linac I-100



1958 – start of construction (in parallel with I-2) (I.M.Kapchinsky, E.N.Daniltsev, V.K.Plotnikov, N.V.Lasarev)

27.04.1962 – establishment of IHEP as branch of ITEP

15.11.1963 – IHEP transformed into an independent Institute

28.07.1967 – the launch of linac (it was attended by: I.M.Kapchinsky, V.K.Plotnikov, V.A.Batalin, R.P.Kuibida, B.K.Kondratiev)

Awards

· **Государственная премия** за разработку, сооружение и ввод в действие линейного ускорителя протонов на энергию 100 Мэв — инжектора Серпуховского протонного синхротрона:

РТИАН- Невяжский, И.Х.,Мурин, Б.П., Поляков, Б.И., Кульман, В.Г., Басалаев, М,И.,
ИФВЭ - Ильевский, С.А.,Тишин, В. Г.,
ИТЭФ- Капчинский, И. М., Плотников, В. К., Лазарев, Н. В.,
НИИЭФА - Вахрушин, Ю. П., Солнышков, А. И.,

·· **Государственная премия** за проектирование и создание инженерного комплекса Серпуховского протонного синхротрона ИФВЭ, включающего электромагниты, вакуумную систему, системы радиоэлектроники и специальные инженерные сооружения :

ИФВЭ - Адо, Ю.М., Мяэ, Э.А,;
РТИАН - Кузьмин, В.Ф., Уваров, В.А.;
НИИЭФА - Мозалевский, И.А., Попкович, А.. Титов, В.А.
НИИ - Темкин, А.С.;
ГКАЭ СССР - Мещеряков, К.Н.
Монтажного треста - Ширяев, Ф.З.; Мальцев, С.Ф., Николаев, С.Д.,

··· **Ленинская премия** за разработку и ввод в действие протонного синхротрона ИФВЭ на энергию 70 ГэВ

ИТЭФ - Владимирский, В.В., Кошкарёв, Д.Г.,
РТИАН - Кузьмин, А. А.,
ИФВЭ - ; Логунов, А.А., Суляев, Р.М.,
НИИЭФА - Малышев, И.Ф.

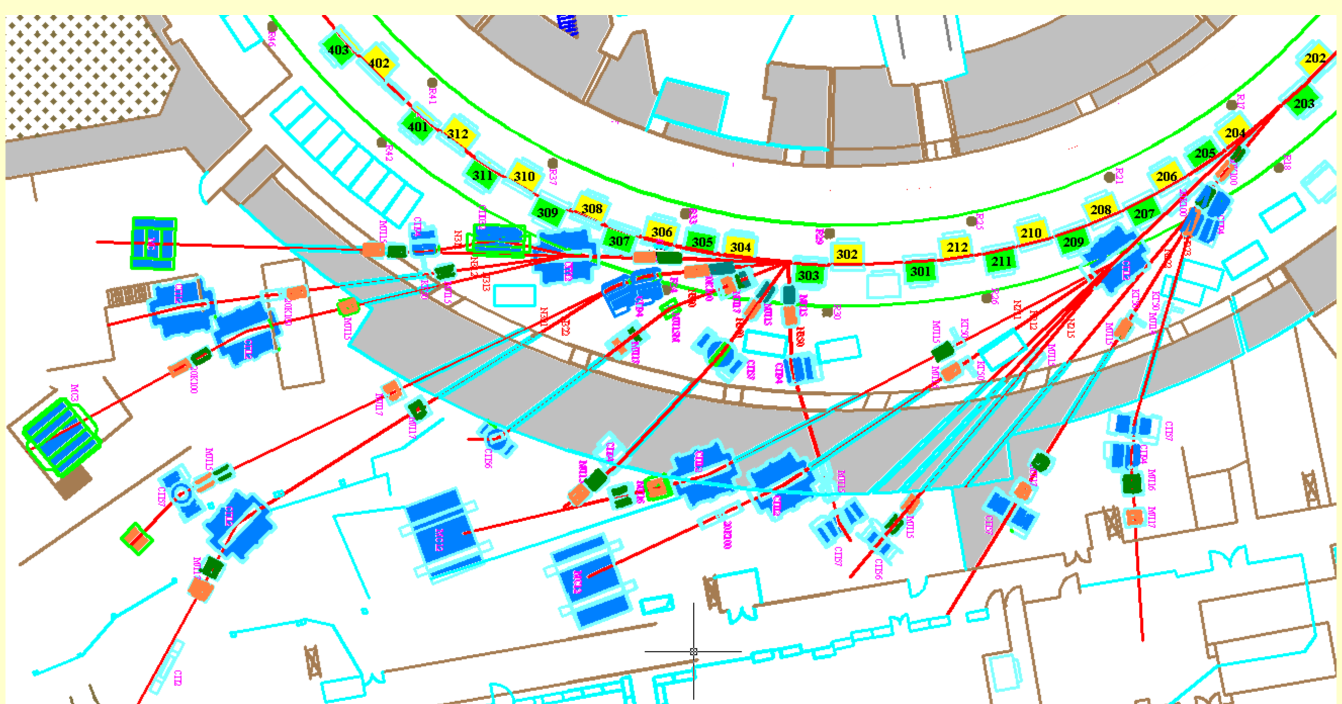
Reconstruction of U-7 to U-10 (1973)

Results of reconstruction

1. Changed lattice of Ring
2. Upgraded: accelerating system.
main power supply system,
vacuum system,
internal targets,
and others
3. Extended experimental area
4. Extended system of magnetic field correction
5. Computer control

Max. energy, GeV	**10**
Beam rigidity, T m	**34**
Orbit length, м	**251.297**
Number of magnets	**96**
Max. magnetic field, T	**1,1**
Lattice	**FODO**
Number of periods	**48**
Number of superperiods	**8**
Number of straight sections: **0,304 m** **0,450 m** **0,600 m,** **2,350 m**	 **7x8** **1x8** **2x8** **2x8**
Betatron frequency	**9,25**
Max. of amplitude function, m	**14,5**
Max. of dispersion function, m	**1,8**
Min. of , dispersion function, m	**-0,5**
Transition energy, GeV	**7,2**
Chromaticity, hor./ver.	**-5/-20**
Acceptance, hor./ver.., π mm-mrad	**80/50**
Max. beam intensity, ppp	**$1.5x10^{12}$**

Extracted beams transfer lines in BEH



Proton therapy in ITEP

The ITEP medical proton facility has been working since 1969, Energy value was regulated in the range 70-200 MeV by the time of beam ejection from the synchrotron on the ramp of magnetic cycle. One bunch from the four accelerated was used for medicine. The remaining 3 bunches were accelerated further to be used by physicists. Four treatment installations placed in three treatment rooms were used: that for stereotactic multidirectional irradiations of intracranial targets, that for eye and orbit tumors irradiations, that for urogynecological tumors, and that for general oncology.

Radiation facility for irradiation of tumors in the head-neck and pelvis in the supine position

Radiation facility for irradiation of tumors in the head-neck and in the sitting position

Up to 1988, 8000 patients has been proton treated in the world, 2500 of them in the USSR. There were 3 proton therapy facilities in Russia: in Moscow (ITEP), in Leningrad (LNPI) and in Dubna (LNP. JINR).

77% of Russia-treated patients had been irradiated in Moscow, 20% in Leningrad, and 3% in Dubna.

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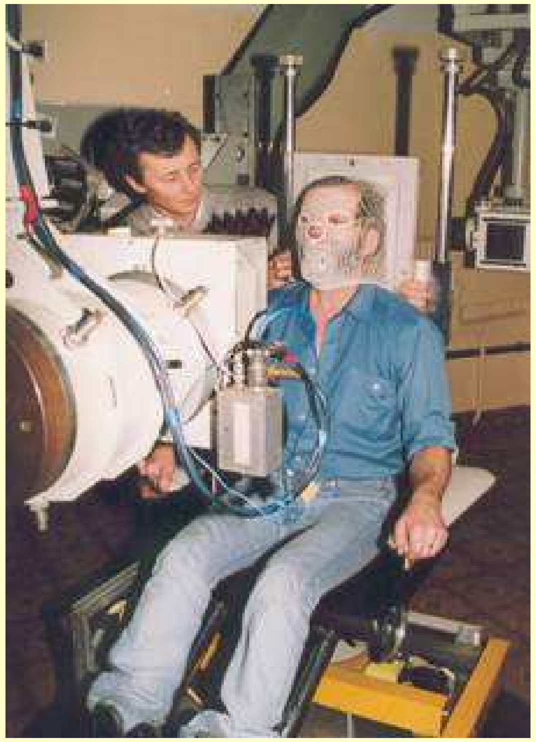

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High current linacs development

Acceleration of high current beams of proton or ions requires strong focusing of the beam at the initial stage of acceleration to compensate Coulomb forces in the beam.

This problem has been solved by V.V,Vladimirsky, I.M.Kapchinsky and V.A.Teplyakov inventing SHQF – Specially Homogenous Quadrupole Focusing (1968), renamed later Radio Frequency Quadrupole (RFQ)

1. В.Владимирский, И.М.Капчинский, В.А.Тепляков. Линейный ускоритель ионов. Авт. свид. СССР № 265312. Бюлл. ОИПОТЗ, 1970, № 10, с. 75.
2. И.М.Капчинский, А.М.Мальцев, В.А.Тепляков. О проекте линейного ускорителя протонов с пониженной энергией инжекции и с высокой интенсивностью пучка. Тр. VII Междунар. конф. по ускорит. заряж. частиц высок. энергий. Изд. АН Арм. ССР, Ереван, 1970, т. I, с. 153.

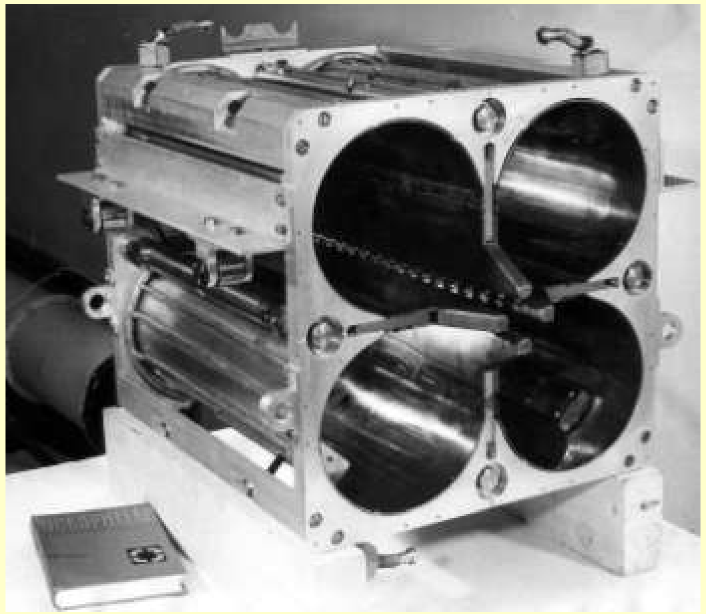
Ленинская премия (1988) - за разработку и создание линейного ускорителя ионов нового типа с фокусировкой пучка квадрупольным высокочастотным полем

ИФВЭ - Тепляков, Владимир Александрович,

ИТЭФ - Капчинский, Илья Михайлович

High current linac RFQ1 (4 vane resonator)

Inlet section

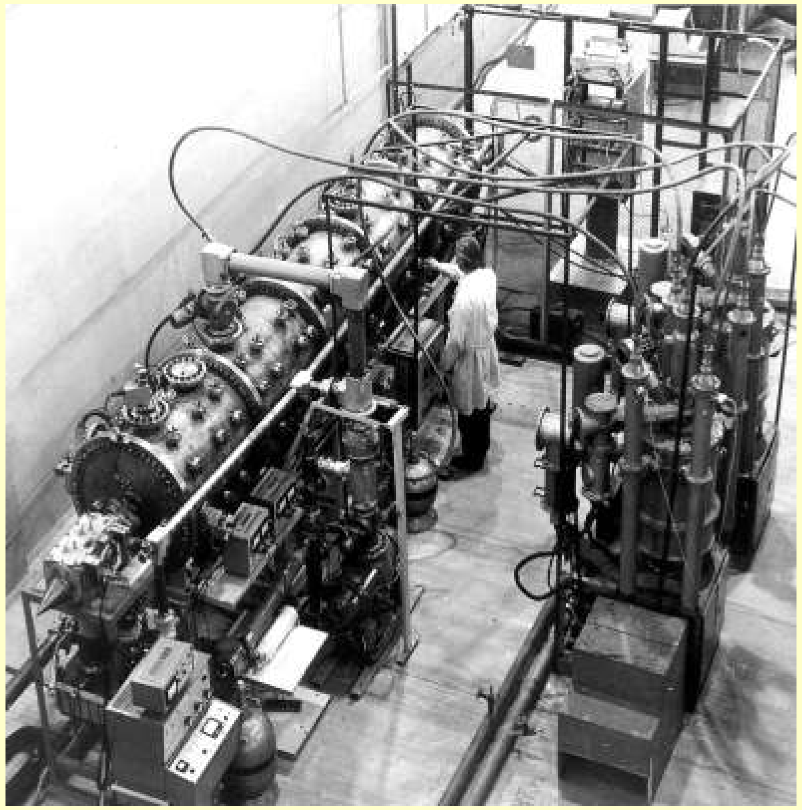


Assembled resonator and vacuum shell

Parameter of RFQ1 (1982)

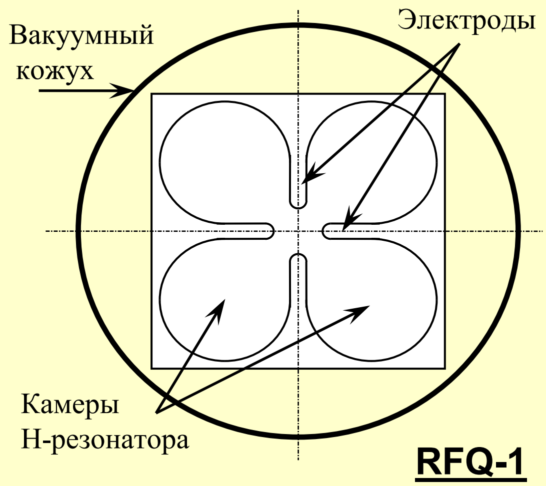
Injection energy, keV	**88**
Output energy, MeV	**3**
RF, MHz	**148.5**
Max. beam current, mA	**250**
Resonator length, m	**4.9**
Quadrant diameter, mm	**200**
Transmission at I≤100 mA, %	**~100**

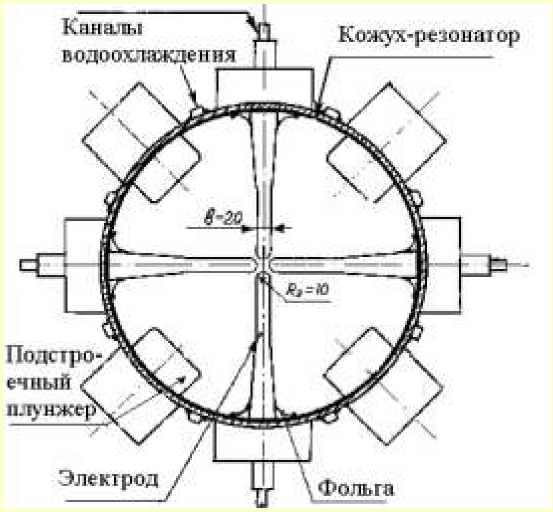
Test stand



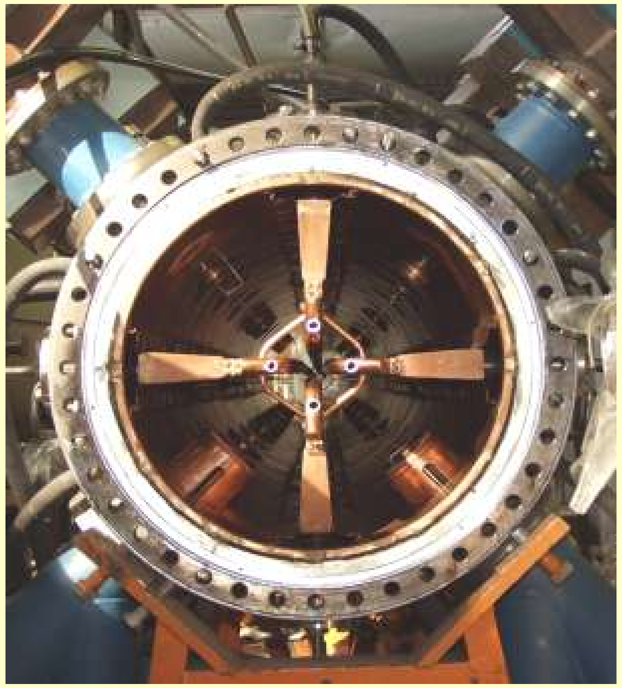
High current linac RFQ2

Cross sections of RFQ1 and RFQ2

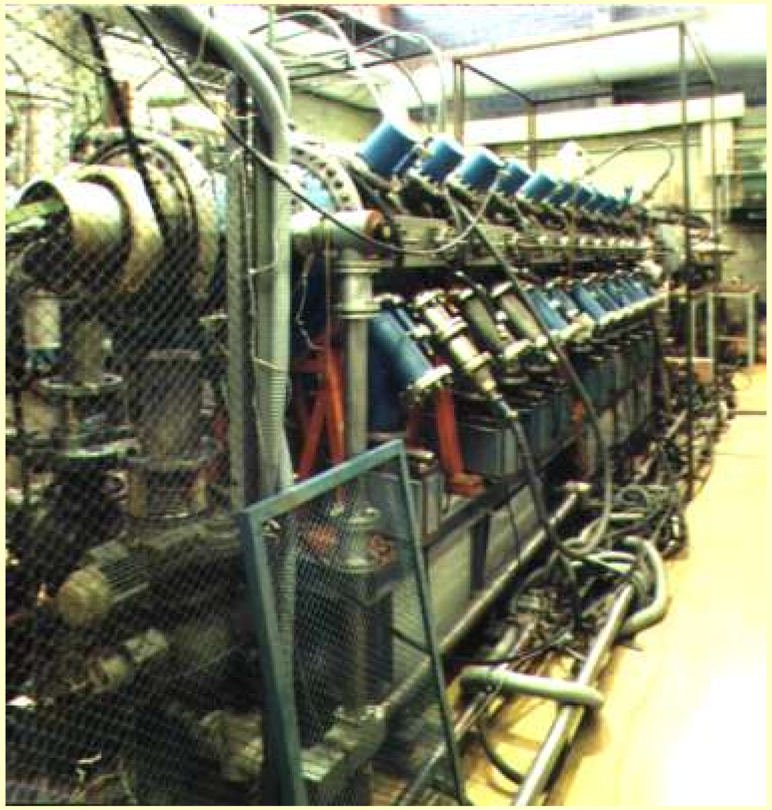




Inlet section



Test stand



Parameter of RFQ2 (1998)

Injection energy, keV	**81**
Output energy, MeV	**3**
RF, MHz	**148.5**
Resonator diameter, mm	**449**
Number of sections	**6**
Resonator length, m	**4.5**
Repetition rate, Hz	**25**
Pulsed beam current, mA	**200**
Transmission, %	**>90**
Average beam current, mA	**5**

4-Ladder RFQ (1991)

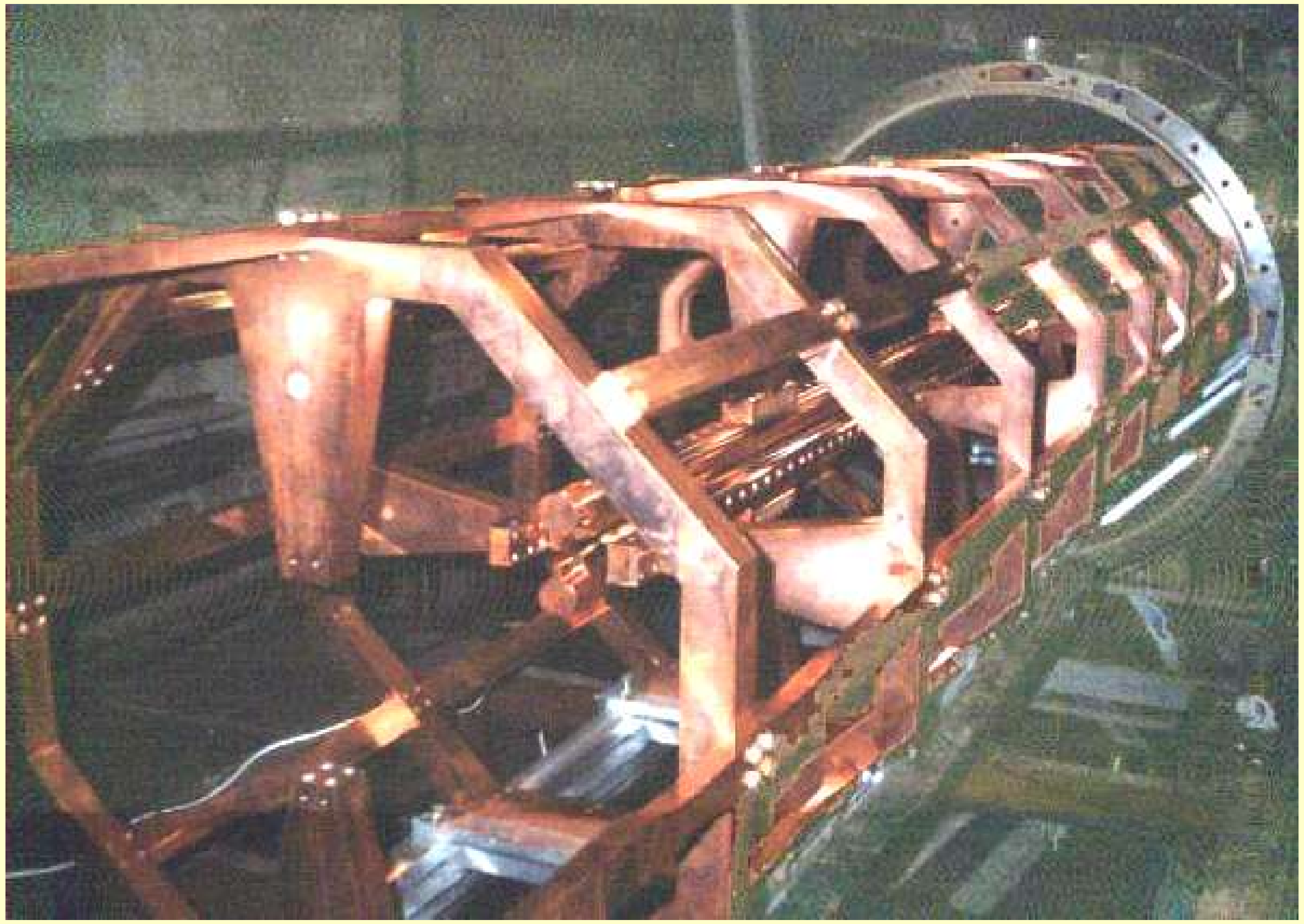
A new version of 90° – apart-stem RFQ structure, has been proposed by V.A.Andreev, hence–forth called “4-ladder ”, which combines the merits of 4-vane and 4-rod RFQ’s, has been developed in the frame-work of a collaboration between ITEP and INFN-LNL. It has good RF efficiency (quite reliable mode separation and field distribution) and maintains such merits of a 4-vane structure as simplicity of manufacture and mechanical stability

Superconducting RFQ for Positive Ion Accelerator for low-Velocity Ions (PIAVE) - injector of the SC linac ALPI at INFN-Legnaro (1999)

G. Bisoffi, V.Andreev et al., SRF 2001 Workshop,p.123

Prototype of heavy ion driver for inertial fusion (1996)

Ring-connected RFQ



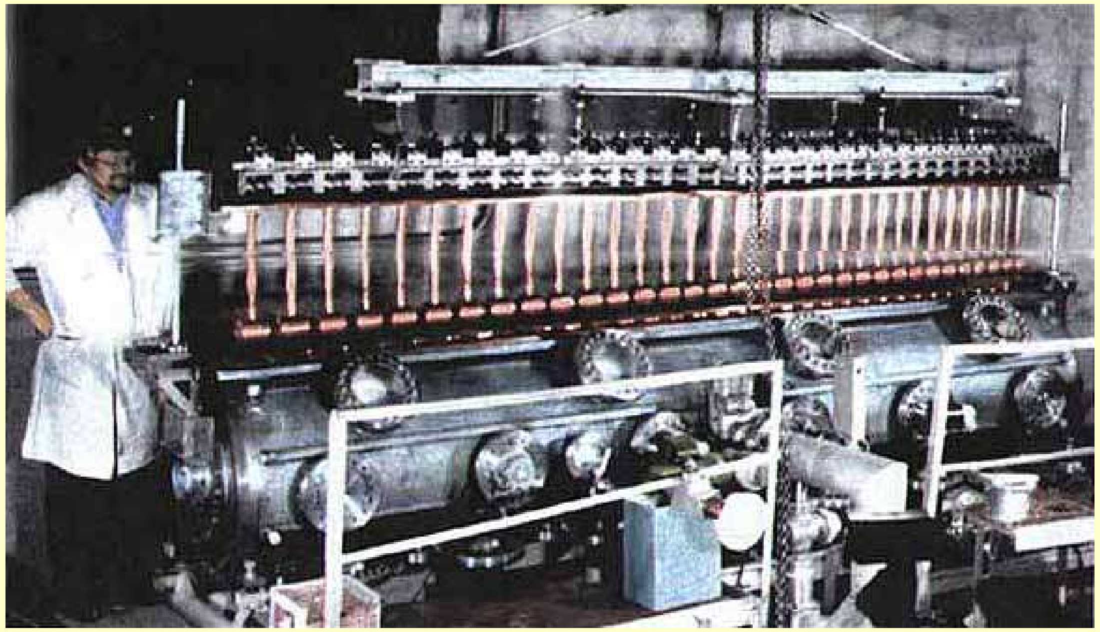
Z/A of ions	1/60
Injection energy, keV/u	1.5
Output energy, keV/u	110
RF, MHz	27
Length of resonator tank, m	12
Inner tank diameter, m	1.2
Aperture radius, mm	6.4
Shunt-impedance, MΩ m	1.49
Transmission at 15 mA, %	96
Beam pulse width, μs	400
Average beam current, μA	5

A combination of quadrupole and coaxialmodes is excited in the structure, which provides a reliable separation between operating mode and dipole ones. RFQ designed to accelerate 15 mA of U^{4+} ions from 1.5 to 110 keV/u,

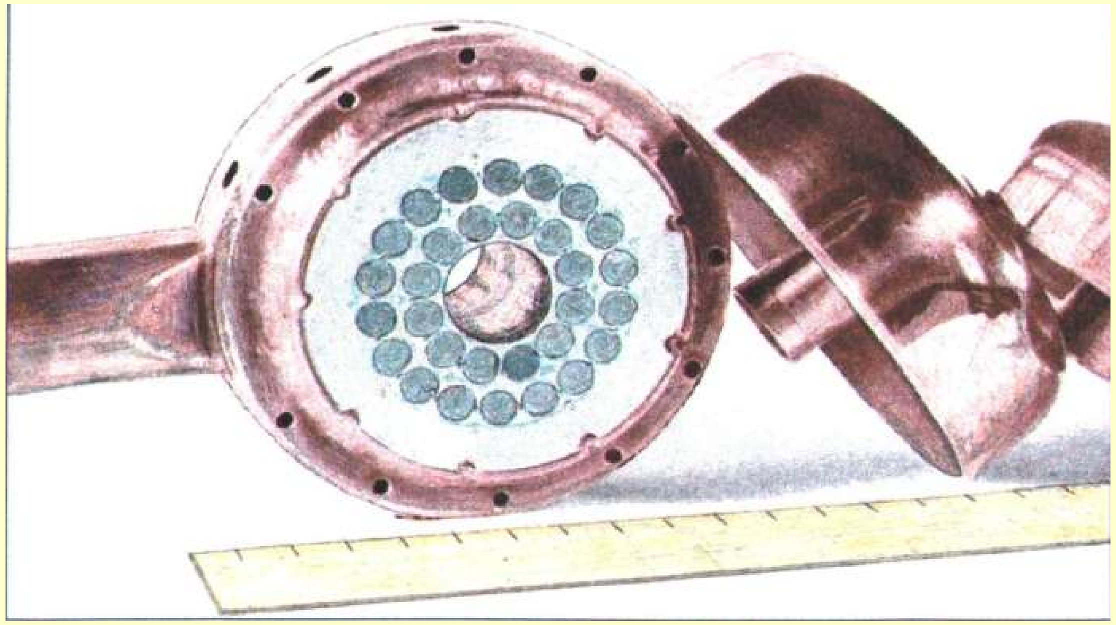
High current proton linac ISTRA-56

Parameter	RFQ	DTL1	DTL2	DTL3
Energy, MeV	0.08-3.0	3.0-10.3	10.3-36.3	36.4-56,6
RF, MHz	148.5	297		
Resonator length, m	4.5	3.9	11.7	9.2
Resonator diameter, mm	449	650	630	580
Drift tube diameter, mm	-	100	85	85
Aperture of beam line, mm	15	18	18	24
Pulsed beam current, mA	200			
Repetition rate, Hz	25			
Average beam current, μA	500			

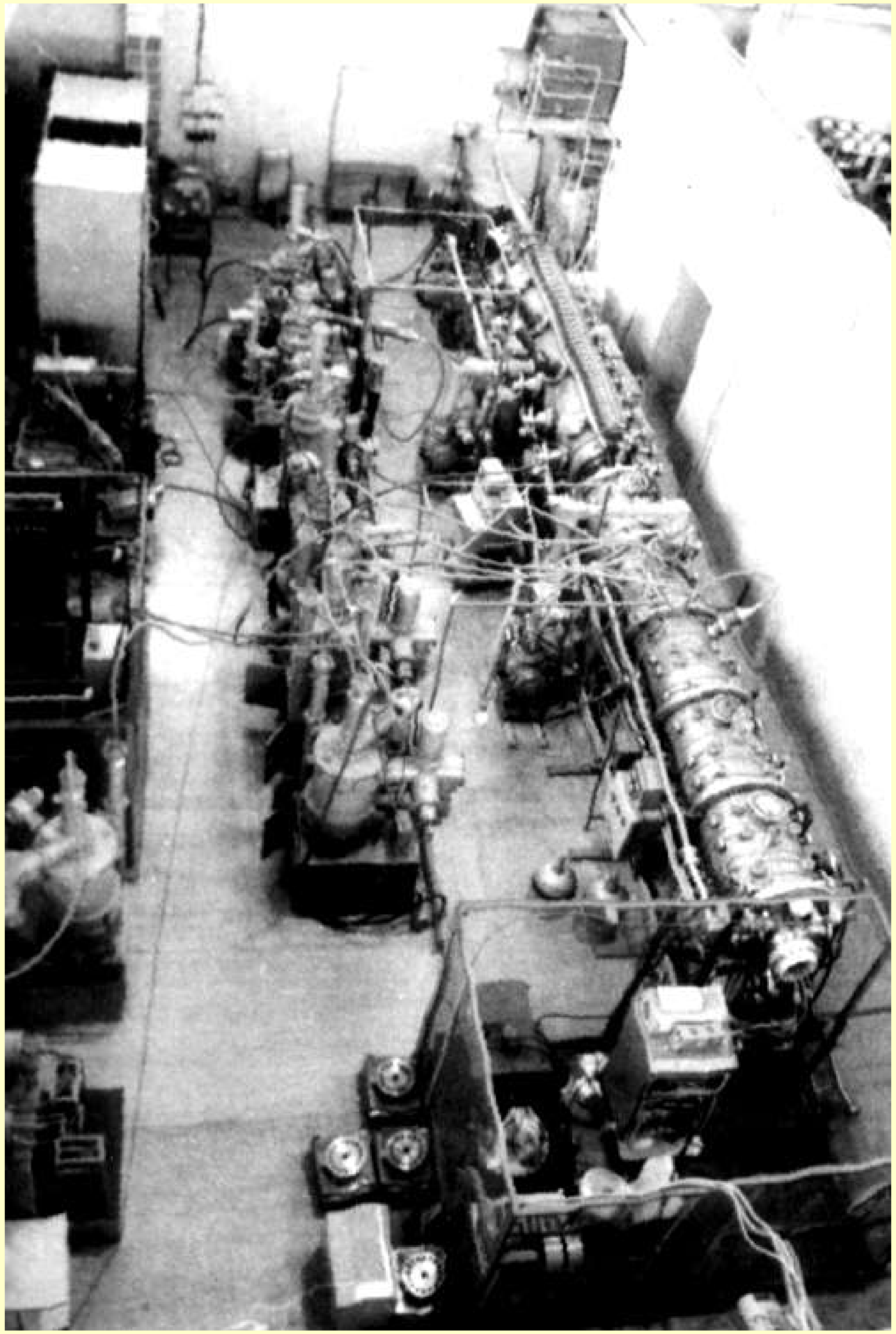
Resonator DTL1 and drift tube line



Drift tube with PMQ-lens



ISTRA-10 beam test (1989)

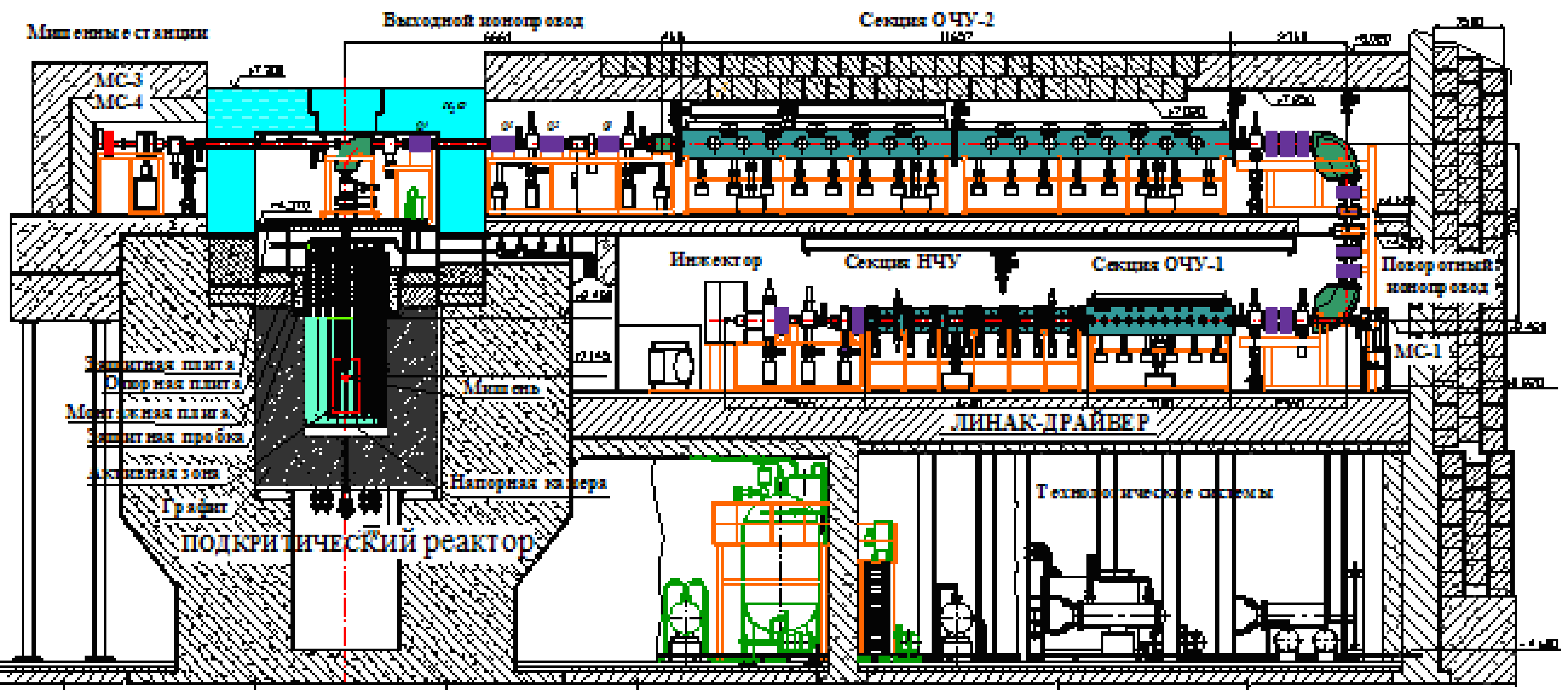


	RFQ	DTL1
Energy, MeV	0.08-3.0	3.0-10.3
RF, MHz	148.5	297
Type of wave	H_{211}	E_{010}
Resonator length, m	4.8	3.9
Resonator diameter, mm	200	650
Aperture of beam line, mm	87.7-15.4	18
RF power, MW	1.3	1.7
Max. E-field, kV/cm	247	200
Beam momentum spread, %	3.3	3.2
Pulsed beam current, mA	>100	
Repetition rate, Hz	25	

Project of Experimental ADS at ITEP

Energy, MeV	**36**
Pulsed beam current, mA	**100**
Beam pulse width, µs	**220**
Average beam current, µA	**500**

Beam power, kW	**18**
Intensity of fast neutrons, pps	**$3x10^{14}$**
Thermal neutron flux, pps	**$2x10^{12}$**
Thermal blanket power, kW	**100**



ITEP-TWAC Facility (1998-2011)

1. Motivation:

- *upgrade of proton synchrotron U-10*
- *creating an installation for experiments on physics of high energy density in matter ;*
- *development of new technologies for heavy ion beams generation, stacking and compression*

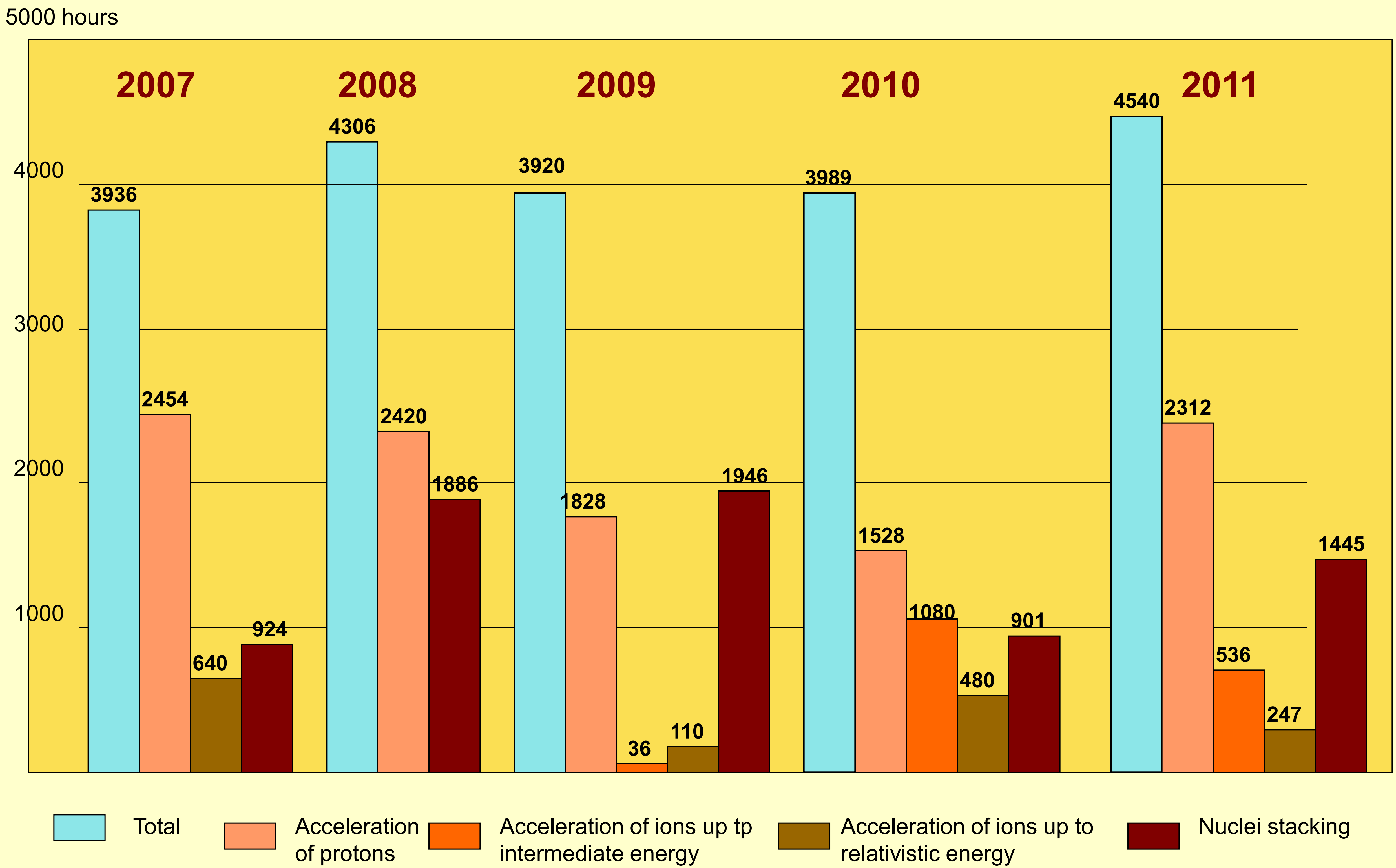
2. Realization:

- *constructed laser ion source for high charge ions generation*
- *constructed ion injector I-3 for energy 4 MV*
- *constructed RFQ part of high current ion injector I-4*
- *constructed new ion synchrotron UK for beam rigidity 13 T m;*
- *constructed system of charge exchange stacking of nuclei in U-10 Ring*

ITEP-TWAC Operation Parameters (2011)

Mode of operation	Accelerators	Beam energy, MeV/u	Regime of beam extraction
Proton acceleration	***I-2*** ***I-2/U-10***	***25*** *up to **230*** *up to **3000*** *up to **9300*** *up to **3000***	**pulse,** *10 μ/s* **medical extraction,** *200 ns*, **fast extraction,** *800 ns*, **internal target,** *1s* **slow extraction,** *0.5 s*
Ion acceleration, ***C, Al, Si, Fe, Cu, Ag***	***I-3/UK*** ***I-3/UK/U-10***	***1,5 – 400*** *up to **4000***	**fast extraction, 800 ns,** ***C*** **(***400 MeV/u, 2x10^9***),** ***Al*** **(***265 MeV/u, 2x10^8***),** ***Si*** **(***360 MeV/u, 1x10^8***),** ***Fe*** **(***230 MeV/u, 2.5x10^8***),** ***Ag*** **(***100 MeV/u, 2x10^7***),** **internal target, 1s, fast (***800 ns, 3 GeV/c***)** **slow extraction, (***0.5 s, 3 GeV/c***)** *C(4 GeV/u, 5x10^8***),** ***Al*** **(***4 GeV/u, 3x10^7***),** ***Fe*** **(***3.6 GeV/u, 2x10^7***),**
Nuclei accumulation, ***C, Al, Si, Fe***	***I-3/UK/U-10***	***200-300***	***C*** **(***300 MeV/u, 4x10^{10}***),** ***Al*** **(***265 MeV/u, 3x10^9***),** ***Si*** **(***240 MeV/u, 1x10^9***),** ***Fe*** **(***230 MeV/u, 1x10^9***),** **fast extraction with compression to** *150 ns*, **continue extraction of stacking beam**

Statistic of ITEP-TWAC operation



Project of
Multipurpose Accelerator Complex (MAC)

1. Substantiation:

- *fundamental and applied research with relativistic proton and ion beams in the energy range from 1 GeV/u up to 10 GeV for protons and 5 GeV/u for ions;*

- *applied research with proton and ion beams in the energy range from 1 MeV/u up to 1000 MeV/u in industry, biology and medicine;*

- *fundamental and technological research with high power stacked nuclei beams in the energy range of <1 GeV/u;*

- *technological research for generation, acceleration, accumulation, compression, extraction and sharp focusing of high charge state and high intensity heavy ion beams;*

- *expansion of scientific and educational activity in the areas of nuclear technologies*.

Implementation of MAC at ITEP

3. ***Practical realization*:**

- ***high current proton and ion linacs development;***
- ***extending of accelerated ions composition up to A ~ 200;***
- ***cardinal increase of intensity for accelerated ion beams in UK Ring on a base of ion injector and synchrotron upgrade;***
- ***cardinal increase of intensity for stacked nuclei beams in U-10 Ring on a base of charge exchange injection technology improvement and of using stochastic cooling of stacked beam;***
- ***expansion and development of machine experimental area;***
- ***mastering of multimode machine operation in parallel with proton and ion beams for maximal efficiency of machine operation.***

Upgrade of Injection Complex

1. **Proton injector I-2** *{24.6 MeV, ~10^{13} ppp (200mA, 10 μs), 1Hz }*

- *upgrade for : ~10^{14} ppp (200mA, 100 μs),*
- *new beam line for injection of proton beam to UK Ring*

2. **Ion injector I-3** *{A/Z=(2$\div$5), 4MV, 5mA }:*

- *upgrade to I-3M for : A/Z=(3$\div$10), ~12MV, ~10^{11} ppp (~10mA, 5 μ s),*
- *upgraded LIS with lasers L100 and L10*

3. **New high current Injector I-4 for acceleration of light ions**

- *A/Z=3, (4.8$_{RFQ}$+ 15.3$_{DTL}$)MV, ~100mA*
- *LIS with laser L20*

High current linac I-4 for light ions for ITEP-TWAC Facility

Parameters

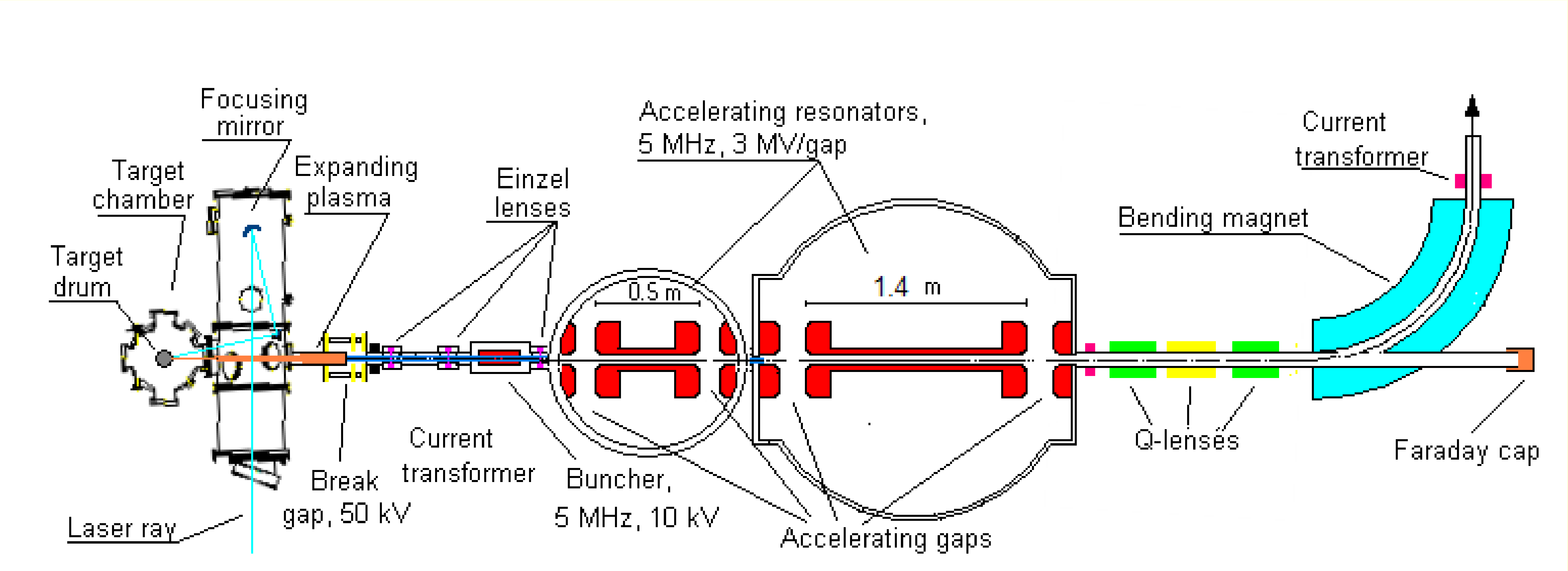
RF - (~80 MHz)
Energy - 5÷7 MeV/u
Z/A - ≤1/3
Imax - up to 100 mA

RFQ section for the energy of 1,6 MeV/u

Parameters of RFQ section

RF, MHz	81.5
Z/A	≤1/3
Energy, MeV/u	0.02/1.57
Voltage, kV	182.5
Input emittance, mm mrad	3.27*π
Output emittance, mm mrad	2.3*π
Beam current, mA	до 100
Repetition rate, Hz	до 1
Beam pulse width, μ	100
Beam energy spread, %	±1.5
Resonator length, m	6.258
Resonator diameter, m	0.564
Quality	11000

Heavy ion injector of I-3M



Accelerating ions, A/Z	3-10	Parameter	R1	R2
Injection energy, kV	50	Height, mm	2500	2970
Resonance frequency, MHz	5	Diameter, mm	1500	1985
Accelerating voltage, MV	12	Spiral diameter, mm	700	700
Trans. acceptance, $\pi\cdot$ mm mrad	1000	Spiral length, mm	1000	1500
Output momentum spread, $\Delta p/p$,%	1	Length of drift tube, mm	500	1400
Transmission factor, %	>50	Aperture, mm	70	
Quality	~6000	Width of accelerating gap, mm	250	

Upgrade of UK Ring

1. **Vacuum system**: ***improvement of vacuum to $<10^{11}$ Torr due to:***

   - replacement of vacuum chamber by thin-wall one

   - replacement of IP-vacuum pumps by IP+TSP

   - improvement of vacuum chamber baking system

   - development of NEG-technology for vacuum chamber

2. **Accelerating system**: ***increase magnet ramping rate to $4 \div 6$ T/s due to:***

   - installation of two additional accelerating stations to increase accelerating voltage up to 20 kV

3. **New main power supply system**:

   - high precision power supply of 10 kV/4 kA

4. **New slow extraction system**:

   - to Target Hall (120) and Medical Building (101a)

Acceleration of ions in upgraded UK Ring

Accelerated beam parameters with injector I-4

$A/Z \leq 3$, U_{inj} =7 MV/u, β_{inj} =0,122, F_{acc} =0.7÷10 MHz, T_{UK}=6.1 μs, p_{max}=4 GeV/c

A/Z	3(C^{4+})	2.8(Si^{10+})	2.45(Al^{11+})	2.4(C^{5+})	2.33(Si^{12+})	2 (C^{6+})
E_{max}, MeV/u	668	744	910	941	981	1229
N_{max}, p/p	$8,1x10^{11}$	$3,0x10^{11}$	$2,4x10^{11}$	$5,2x10^{11}$	$2,1x10^{11}$	$3,6x10^{11}$
N_{exp}, p/p	$3.0x10^{11}$	$1.4x10^{11}$	$1.3x10^{11}$	$1.4x10^{11}$	$1.3x10^{11}$	$2.0x10^{11}$

Accelerated beam parameters with injector I-3M

$A/Z \geq 3$, U_{inj} =(1÷ 3.5)MV/u, β_{inj} =(0.05÷0.09) , F_{acc} =0.7÷10 MHz, T_{UK}=9÷16 μs

A/Z	10(U^{24+})	9(U^{28+})	8(Au^{25+})	7(Ta^{26+})	6(Ag^{19+})	5(Ag^{22+})	4(Fe^{16+})	3(Ni^{18+})
E_{max}, MeV/u	78	95	120	154	204	283	417	668
N_{max}(T_b=5 μs)	$2x10^{10}$	$1.7x10^{10}$	$2.4x10^{10}$	$2.8x10^{10}$	$3.5x10^{10}$	$2.4x10^{10}$	$4.3x10^{10}$	$5.1x10^{10}$
N_{exp}, p/p	$6.0x10^{9}$	$5.5x10^{9}$	$6.0x10^{9}$	$6.0x10^{6}$	$8.0x10^{9}$	$7.0x10^{9}$	$9.0x10^{9}$	$8.5x10^{9}$

Upgrade of U-10 Ring

1. Improvement of vacuum up to <10^{-9} Torr:

- replacement of vacuum chamber
- creation of vacuum chamber baking system

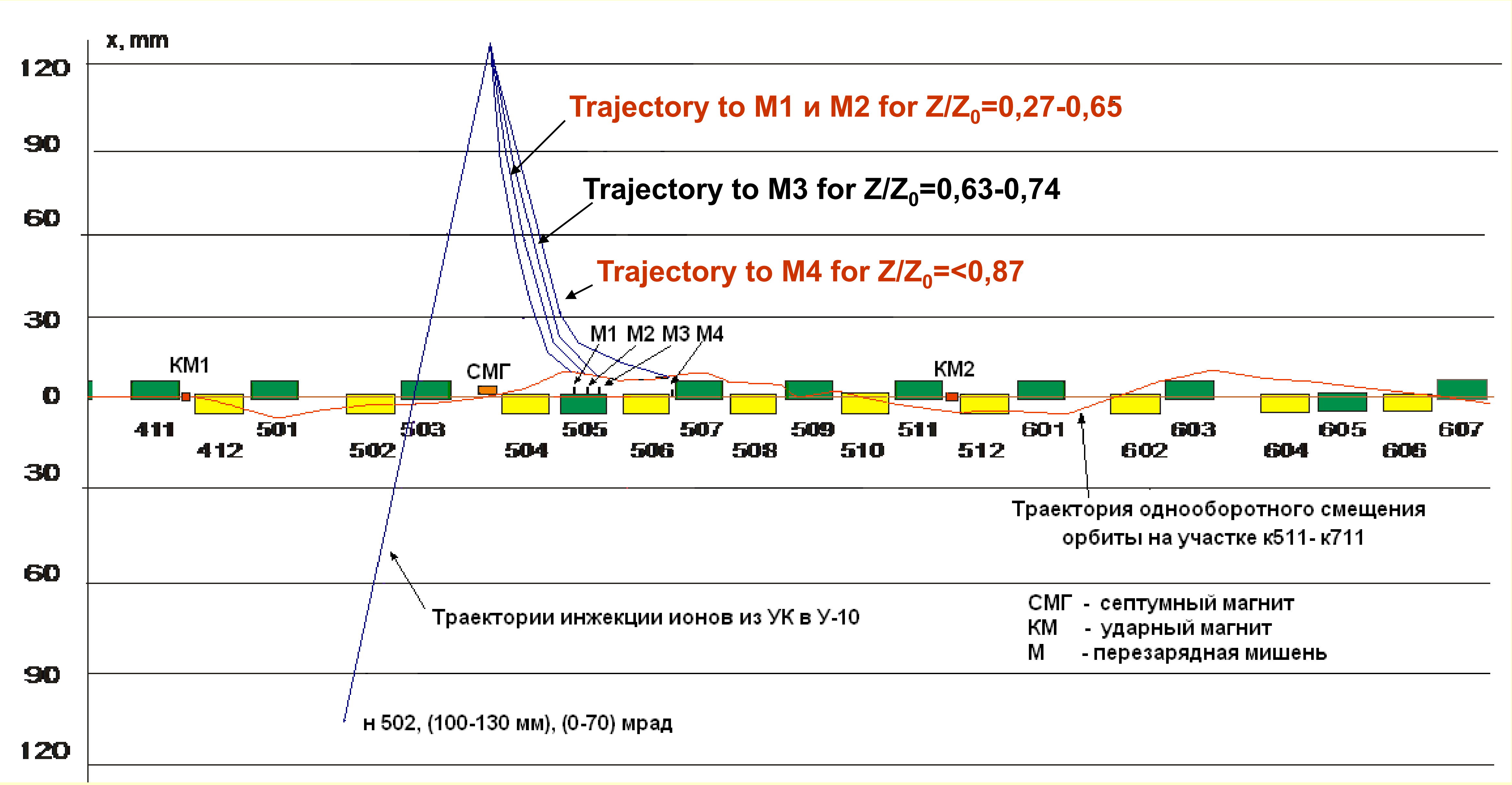
2. Improvement of charge exchange injection system:

- modification for injection of any kind of ions from UK Ring
- expanding of hor. acceptance for stacking beam up to A_x=100 π mm mrad
- mastering of dynamic filling of accumulator Ring acceptance

3. Construction of combined extraction system of 10Z GeV/c beam

- fast extracted beam_for protonography of fast processes
- slow extracted beam for nuclear research

Extended scheme of charge exchange injection



Acceleration of light ion in U-10 Ring up to relativistic energy

Parameters of injected beam

A/Z≤ 3, E_{inj} =(200÷300) MeV/u, p_{inj}=2Z GeV/c, T_{inj} =1.5 μs, h=2, F_{inj} =1.4÷1,7 MHz,

Overcharge	$_{12}C^{4+}$=>C^{6+}	$_{28}Si^{10+}$=>Si^{14+}	$_{27}Al^{11+}$=> Al^{13+}
E_{inj}, MeV/u	214	242	306
E_{max}, MeV/u	4250	4250	4060
N_{exp} with I-4, p/p	$3.0x10^{11}$	$1.4x10^{11}$	$1.3x10^{11}$
N_{exp} with I-3, p/p	$2.0x10^{11}$	$7x10^{10}$	$3x10^{10}$

Acceleration of heavy ions in U-10 Ring up to relativistic energy

Parameters of injected beam

A/Z>3,E_{inj}=(100÷250) MeV/u, p_{inj}=(2÷4)Z GeV/c, T_{inj} <2 μs, h=2, F_{inj} =1.0÷1,5 MHz

Overcharge	U^{28+}=>U^{92+} U^{28+}=>U^{90+}	Au^{25+}=>Au^{79+}	Ag^{22+}=>Ag^{47+}	Fe^{16+}=>Fe^{26+}
$E_{инж}$, MeV/u	105	121	179	242
E_{max}, MeV/u	2960	3180	3240	3800
N_{exp}, p/p	$2x10^{9}$	$4.0x10^{9}$	$6.0x10^{9}$	$8.0x10^{9}$

Upgrade of charge exchange stacking system

1. Objectives:

- *increase of injected beam intensity up to ~10^{11} for C^{6+} and ~10^{10} for Co^{27+}*
- *increase of charge exchange injection efficiency up to ~100%*
- *expansion of the Z/Z_0 range for injected ions from (0.63-0.74) to (0.27-0.87)*
- *expansion of accumulator ring acceptance up to 100 π mm mrad*
- *increase of stacked beam intensity up to >10^{13} (for C^{6+}) and >10^{12} (for Co^{27+})*
- *increase of power density for compressed beam up to the level of >10^{12} W*

2. Upgraded components

- *kickers of one turn bump system*
- *stripping targets*
- *vacuum chamber at injection trajectory*

3. New systems

- *system of dynamic expanding of accumulator acceptance at beam stacking*
- *system of stochastic cooling of stacked beam*
- *system of real time computer control of beam stacking process*

Utmost intensity of beam stacking in U-10 limited by intrabeam scattering

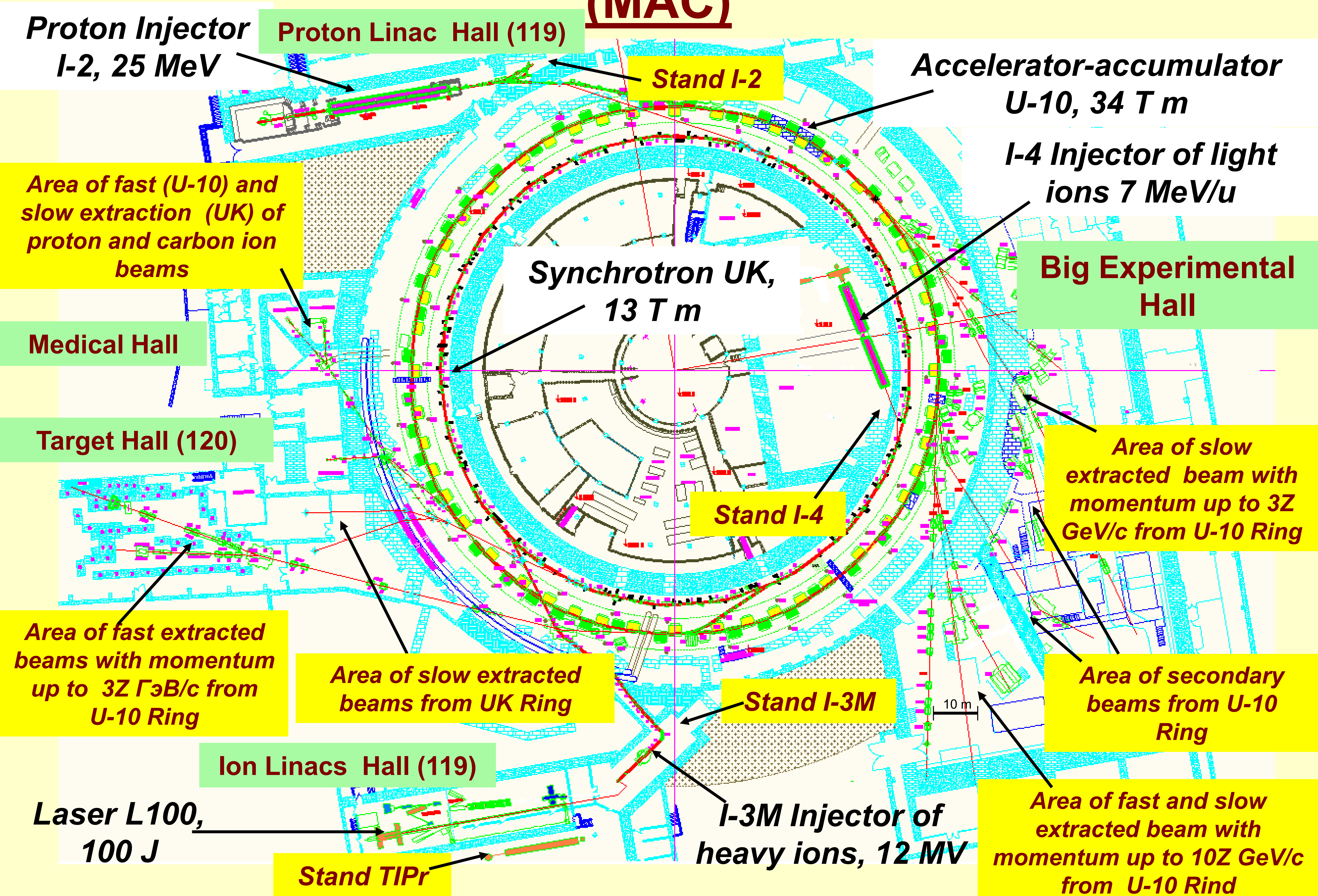
Stacking up to Coulomb limit at the injection frequency 20 Hz

Type of ion	Energy, MeV/u	N_{max}	*N·t, c* *(Δp/p)ₖ=1%*	$T_н$, c	Number of stacking cycles	Number of particles per cycle	Beam power for T=100 ns, ТВт
$_{12}C^{4+} \Rightarrow {}_{12}C^{6+}$	670	6,6·10^{13}	5·10^{14}	8	160	4·10^{11}	0.84
$_{12}C^{5+} \Rightarrow {}_{12}C^{6+}$	940	1,2·10^{14}	9·10^{14}	7,5	150	8·10^{11}	2.1
$_{27}Al^{11+} = {}_{27}Al^{13+}$	910	5,5·10^{13}	4·10^{14}	7	140	4·10^{11}	1.82
$_{59}Co^{17+} \Rightarrow {}_{59}Co^{27+}$	510	1,0·10^{13}	7·10^{13}	7	140	7·10^{10}	0.48
$_{59}Co^{25+} \Rightarrow {}_{59}Co^{27+}$	930	2,7·10^{13}	2·10^{14}	7	140	2·10^{11}	2.40

Stacking at real intensity of UK at the injection frequency 1 Hz

Type of ion	Energy, MeV/u	*N·t, c* *(Δp/p)ₖ=1%*	Number of particles per cycle	Number of stacking cycles	N_{max}	Beam power for T=100 ns, ТВт
$_{12}C^{4+} \Rightarrow {}_{12}C^{6+}$	670	5·10^{14}	3·10^{11}	41	1,2·10^{13}	0.15
$_{12}C^{5+} \Rightarrow {}_{12}C^{6+}$	940	9·10^{14}	1,4·10^{11}	80	1,1·10^{13}	0.19
$_{27}Al^{11+} = {}_{27}Al^{13+}$	910	4·10^{14}	1,3·10^{11}	55	7,1·10^{12}	0.23
$_{59}Co^{17+} \Rightarrow {}_{59}Co^{27+}$	510	7·10^{13}	9,0·10^{9}	88	7,9·10^{11}	0.04
$_{59}Co^{25+} \Rightarrow {}_{59}Co^{27+}$	930	2·10^{14}	9,0·10^{9}	150	1,4·10^{12}	0.12
$_{59}Co^{25+} \Rightarrow {}_{59}Co^{27+}$	930	2·10^{14}	9,0·10^{10}	47	4,2·10^{12}	0.37

Layout of Multipurpose Accelerator Complex (MAC)



Conclusion

1) More than sixty-year history of the development in the thematic areas of accelerator science and technology in ITEP marked a number of significant stages of elaboration and implementation of ideas and projects that helped create accelerator facility: U-7, I-2, I-100, U-70, U10, RFQ1, RFQ2, HIP1, ISTRA10, ISTRA36, TIPr, I-3, UK, ITEP-TWAC .

2) Accumulated in ITEP scientific and technical potential has allowed to create the technological base and scientific school for training of highly qualified engineers and scientists in the field of physics of charged particle beams and accelerator technology.

3) Construction of accelerator facilities at ITEP has always been focused on the development of the experimental base of the Institute, on carrying out fundamental and applied research with beams of protons and ions of intermediate energies, as well as studying and elaboration of promising technologies for generation, acceleration and accumulation of protons and heavy ions beams for accelerators and experimental facilities of future generations.

4) The proposed project of Multi-purpose Accelerator Complex created on the basis of ITEP Ring Accelerators with using of existing technological reserves will ensure continuous improvement of technical and scientific level of the research in line with the growing requirements of the physical experiment in the composition of the world's leading heavy ion complexes of intermediate energies .

5) Solid and reliable foundation for the creation in the ITEP experimental area on the basis of the upgraded ITEP accelerator complex is in demand in various fields of fundamental and applied research and the perspective of effective use of accelerated beams of protons and ions generated in a wide range of operating parameters.