THE NEW SOURCE OF POLARIZED IONS FOR THE JINR ACCELERATOR COMPLEX

(status of the project, July 2010)

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Studies of the structure of light nuclei including the deuteron and features of strong interactions using beams of **polarized deuterons** accelerated at the **Synchrophasotron** - weak-focusing **10 GeV** proton synchrotron have been started at the **Laboratory of High Energies (LHE, JINR)** since the middle of the **80s**

Since 2003 these studies have been continued at the NUCLOTRON - a strong focusing superconducting 6AGeV heavy ion synchrotron that was put into operation in 1993

The basic problem of the new machine in comparison with the Synchrophasotron is one-turn injection

The NUCLOTRON injection time is limited to about 8.36 μs whereas it was about 200 μs for the old accelerator

That's why the construction of a new high intencity polarized ion source is considered as a very important high priority task

The new flagship JINR project in the domain

of high energy nuclear physics, NICA (NUCLOTRON-based Ion Collider fAcility), aimed at the study of phase transitions in strongly interacting nuclear matter at the highest possible baryon density, was started in 2006

The NICA program consists of several subprojects

The first one is the project NUCLOTRON-M, where the new polarized ion source is included in

The realization of the project was started in 2008 and

is supposed to be completed in 2011

Physics with polarized light ion beams is considered as an important

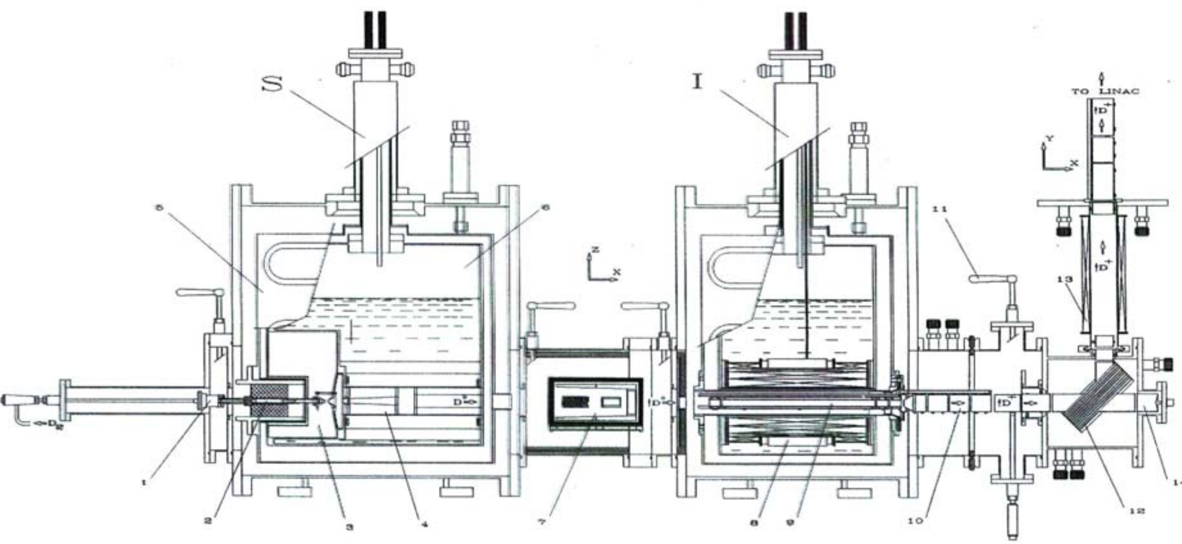
part of the NICA collider program **also**

The expected luminosity is planned at the level of (10^{30} -10^{31}) $cm^{-2} \cdot s^{-1}$

The source of polarized deuterons used up to now (0.4 mA ↑D^+ cryogenic source POLARIS) cannot provide some of the key parameters of the beams necessary for the NUCLOTRON/NICA facility

$\uparrow D^{+}$ CRYOGENIC SOURCE POLARIS

POLARIZED DEUTERON SOURCE POLARIS



S – polarized atomic source, I – Penning ionizer

1 – electromagnetic gas valve, 2 – dissociator, 3 – nozzle chamber
4 – SC sextupole magnet, 5 – nitrogen shield, 6 – helium cryostat
7 – RF cell, 8 – SC solenoid, 9 – electron optics, 10 – ion optics
11 – vacuum gate, 12 – electrostatic mirror, 13 – solenoid of the spin-precessor, 14 – Faraday cup

Cryogenic source POLARIS was used long time at the synchrophasotron to produce polarized deuteron beam

This setup was designed at the end of 1970-ies

An atomic beam forming process is required to pump a large mass of injected gas. There was no developed turbopump technology that time yet. It was decided to apply cryocondensation of deuterium molecules on cooled surfaces

The source consists of two LHe cryostats:

a pulsed atomic beam stage with two superconducting sextupole magnets,

- the Penning plasma ionizer with high field SC solenoid

The energy of the deuteron beam at the output of the source is about 3 keV, the current: 0.3-0.4 mA

The vector and tensor polarizations are:

Pz ~ $^{+}$/-0.54

Pzz ~ $^{+}$/- 0.76

- Further development of the polarization program at NUCLOTRON/NICA facility supposes the substantial increasing of intensity of source of the polarized particles

- As the first step the increase of intensity of the accelerated polarized D^+ beam is supposed

- The important fact is depolarization resonances are absent in the total energy range of the NUCLOTRON-M but only for the deuteron beam

The Source of Polarized Ions Proect for JINR Accelerator Complex (SPI-project) assumes the development of the universal high-intensity Source of Polarized Deuterons &Protons using charge-exchange ionizer

Nearly resonant charge-exchange reactions for production of polarized protons & deuterons are

$H^0\uparrow + D^+ \Rightarrow \mathbf{H^+}\uparrow + D^0$

$D^0\uparrow + H^+ \Rightarrow \mathbf{D^+}\uparrow + H^0$ $\sigma \sim 5\ 10^{-15}\ cm^2$

- The design output current of the SPI will be up to 10 mA for $\uparrow D^+$ ($\uparrow H^+$)
- The D^+ polarization will be up to 90% of the maximal vector (±1) & tensor (+1,-2) polarization

The SPI-project is based on the equipment which was supplied within the framework of the Agreement between JINR & IUCF(Bloomington, USA)

The project will be realized in close cooperation with INR of RAS (Moscow, Russia)

- The main purpose of the SPI-project is to increase the intensity of the accelerated polarized beams at the JINR Accelerator Complex up to

10^{10} d/pulse

The SPI-project includes the following stages:

- development of the high-intensity Source of Polarized Ions
- complete tests of the SPI
- modification of the linac pre-accelerator platform & power station
- improvement of the pre-accelerator tube vacuum using the turbomolecular pumping
- adaptation of the existing remote control system (console of linac) of the SPI under the high voltage
- mounting of the SPI and equipment at the pre-accelerator platform, linac runs with polarized beams and polarization measurements at the linac output

- The most labour-consuming and expensive work is development of the **Source of Polarized Ions** based on the equipment of **Cooler Injector Polarized IOn Source (CIPIOS)** developed at Indiana University Cyclotron Facility (IUCF, USA) in cooperation with the INR of RAS (Moscow) in 1999

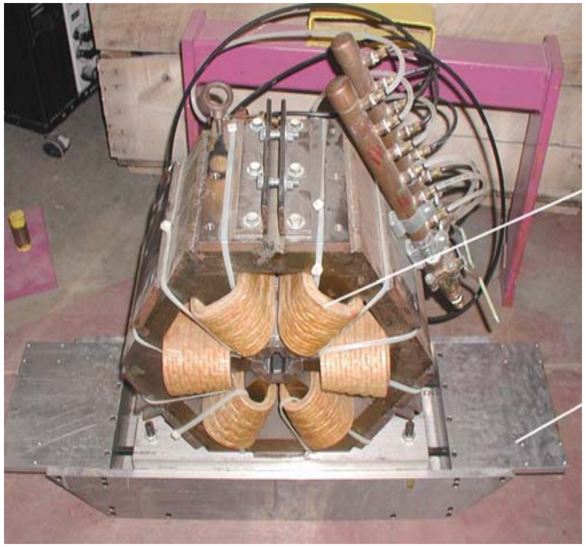
Acknowledgements

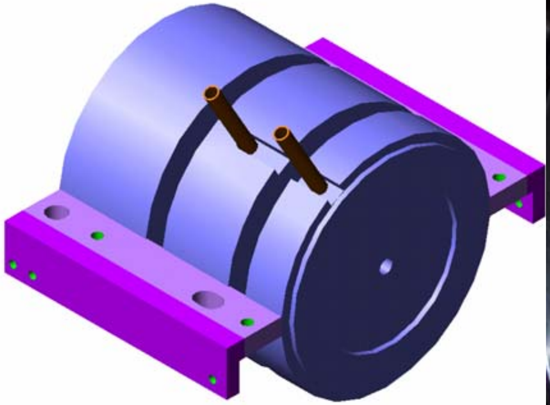
- The big work on transfer of the CIPIOS equipment from IUCF in Dubna has been done by

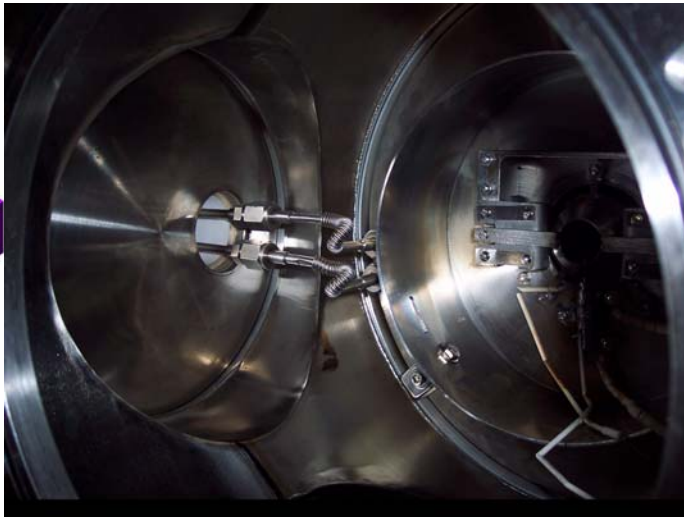
V.P. Derenchuk

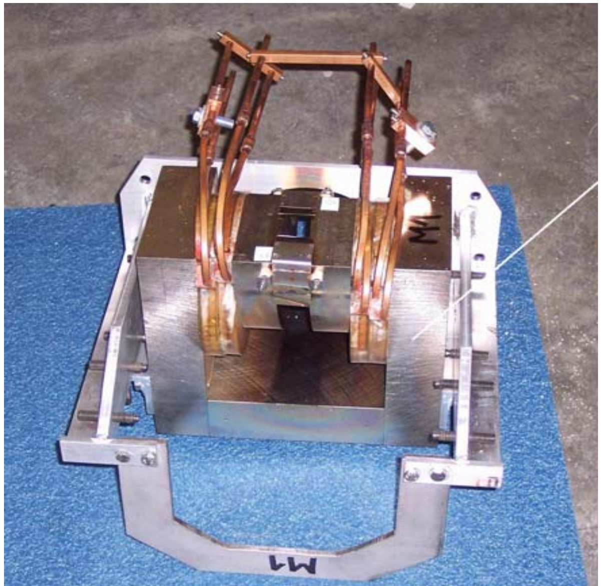
Indiana University Cyclotron Facility, USA

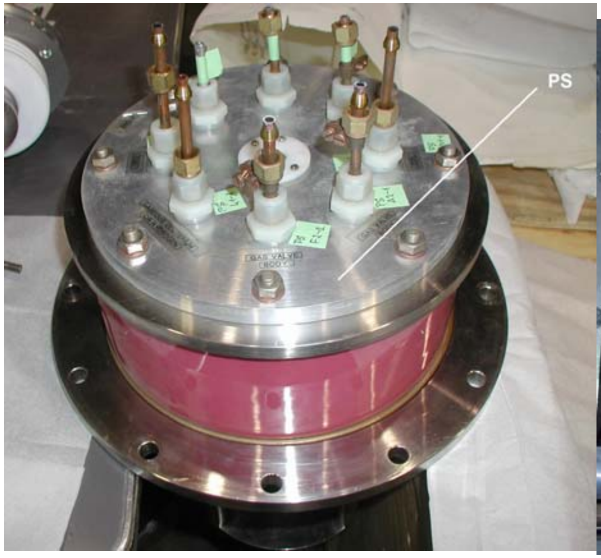
Some CIPIOS parts delivered to LHEP-JINR from IUCF

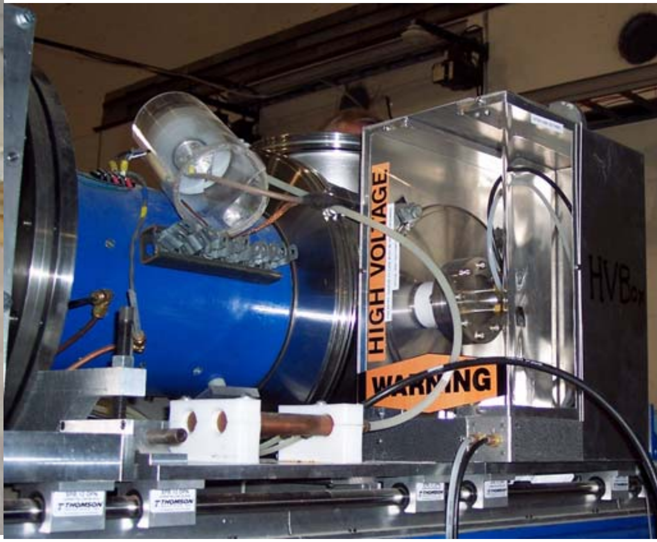












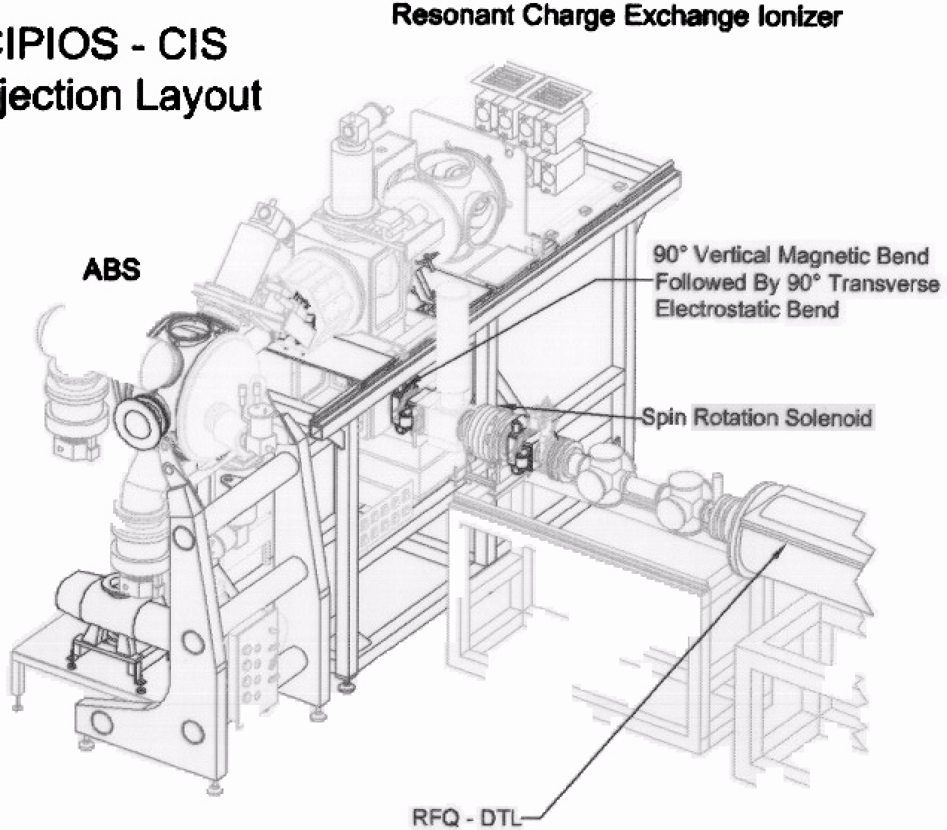
- **CIPIOS includes**
  - source of the polarized atoms using the permanent sextupole magnets (B= 1.4 T) for focusing and electron spin separation
  - radio frequency transitions units of nuclear polarization
  - resonant charge-exchange ionizer (the polarized ions are formed at resonant charge-exchange of the polarized atoms and unpolarized ions in plasma)
  - special spin orientation system at the output of **CIPIOS** in vertical position

Note:

CIPIOS was intended for high-intensity negative polarized and unpolarized beams production

Cooler Injector Polarized IOn Source (CIPIOS)

CIPIOS - CIS
Injection Layout



Beam Properties

- Pulsed @ 1Hz to 4Hz
- 25 keV Beam Energy
- Polarized H^- or D^-
- Nominal polarization ≥ 80%
- ≈ 1.5 mA (peak) from source
- ≥ 25 mA (peak) unpolarized available

Characteristics of the source of negative polarized ions IUCF (CIPIOS):

- peak current of polarized ion beam H^- (D^-) - 1.8 (2) mA
- peak current of polarized ion beam H^- (D^-) - 40 (30) mA
- polarization H^- - 80-85%
- polarization D^-:

Type of polarization	Pz nominal	Pz measured	Pzz nominal	Pzz measured я
vector (+)	+1	0.909(31)	+1	0.891 (13)
vector (-)	-1	-0.684 (30)	+1	0.695 (14)
tensor(+)	0	0.003 (32)	+1	0.875 (13)
tensor (-)	0	0.020 (33)	-2	-1.591 (13)

- normalized emittance H^- (D^-) - 1.2 π mm mrad
- pulse duration – up to 500 microsec. @ 1-4 Hz from source
- energy of polarized ion beam - 25 keV

INR source of polarized protons

- It is known that at INR the source of polarized protons with the charge-exchange plasma ionizer and the polarized atom storage in the ionization volume has been developed

Characteristics of polarized H^+ (H^-) ion beam of the INR source

H^+

Without polarized atom storage

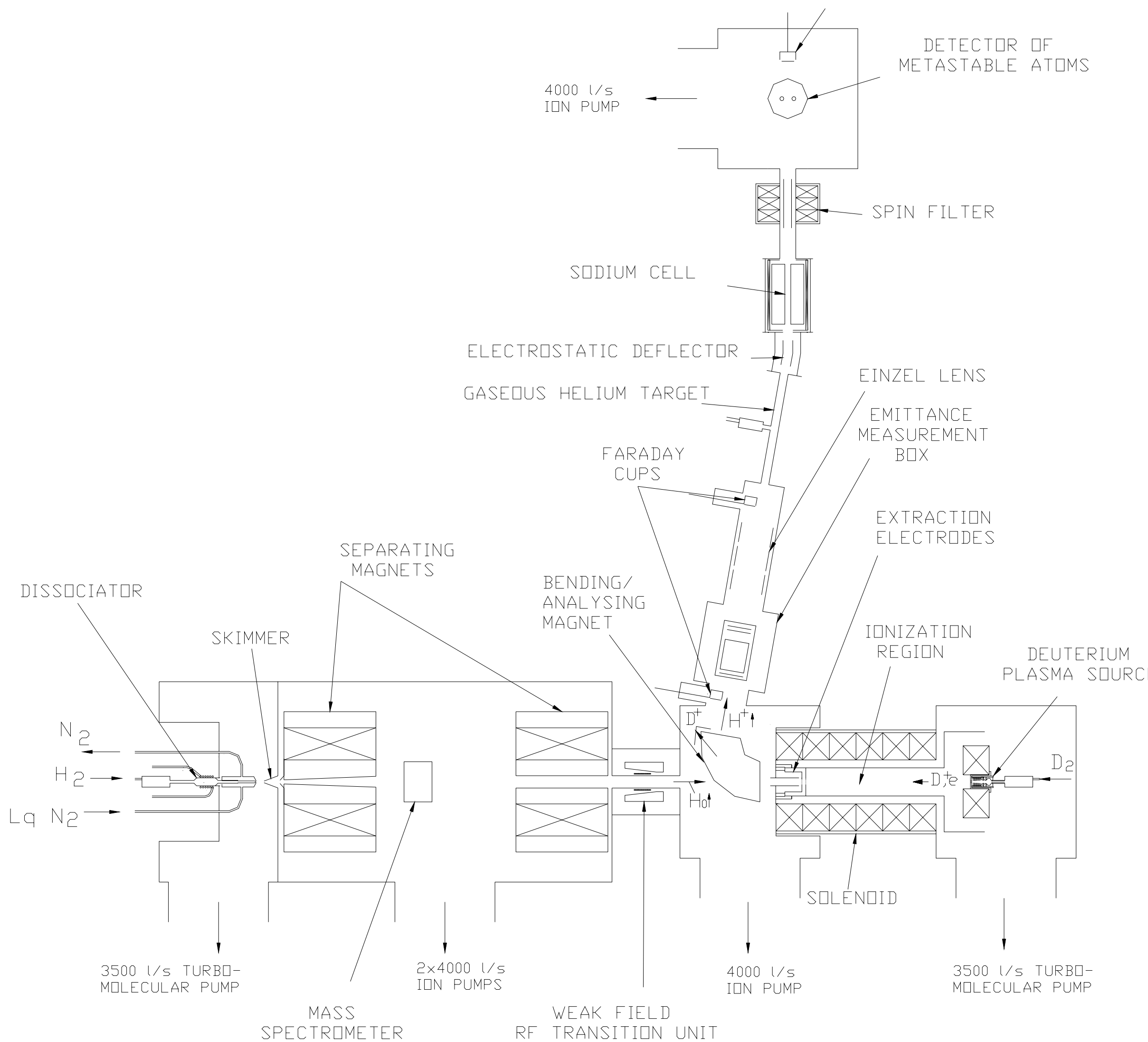
Intensity	**6 mA**
Polarization	85%

With polarized atom storage

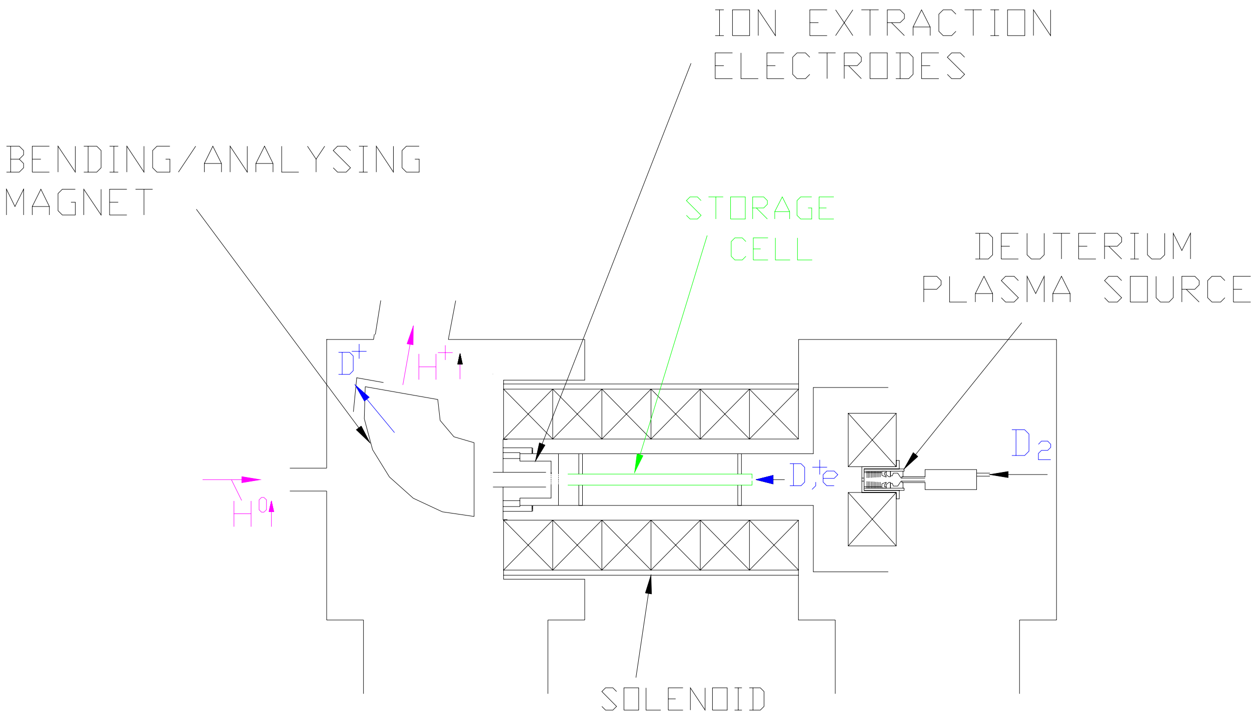
Intensity	**11mA**
Polarization	80%

H^-

Intensity	**4 mA**
Polarization	90%

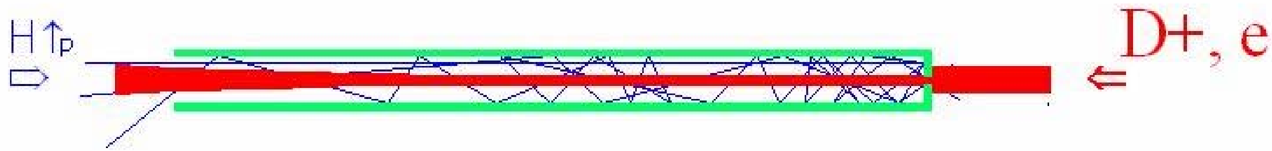


Schematic layout of the polarized proton source
with nearly resonant charge—exchange plasma ionizer



Schematic diagram
of nearly resonant charge-exchange plasma ionizer
with a storage cell

INR source with a storage cell



- **Density of polarized hydrogen atoms in an ionization region of a polarized ion source can be increased in comparison with free polarized atomic hydrogen beam by using of a storage cell**

- **This was tested at INR:**
  11 mA H^{+} beam has been obtained with 80 % polarization

The ionizer with storage of polarized atoms for the SPI allows

- increase intensity of the polarized ion beam,
- reduce emittance of the polarized beam
- considerably reduce H_2^+ ion current which is difficult to be separated from polarized D^+ due to similar mass of the ions.

- At the moment the specificity of the NUCLOTRON is that one-turn injection is used and this machine allows one to accelerate only positive ions

- Therefore it is expedient to use the source of positive polarized deuterium ions

Note:

The highest intensity of the beam is reached for positive polarized ion sources with charge-exchange plasma ionizer and the storage cell

SPI-project assumes to convert the charge-exchange ionizer of **CIPIOS** into the ionizer using storage of polarized deuterium atoms and production of **positive polarized deuterons** by resonance charge-exchange in the hydrogen plasma

The transferred equipment of a source **CIPIOS** is not fully completed

That is why the development and manufacturing of missing modules and parts of the new SPI is required

Mainly it concerns missing elements of the **A**tomic **B**eam **S**ource (**ABS**)

In addition acquisition of the missing equipment and devices for the source is also necessary

- vacuum chamber of the ABS and sextupole magnets
- dissociator
- channel of the atomic deuterium (hydrogen) beam cooling
- fast pulse valve of molecular deuterium (hydrogen) injection into the dissociator bulb
- the power supply of the pulse gas valve
- high-frequency pulse generator (pulse power up to 5 kW, 50 MHz)
- modulator of the high-frequency generator (maximum voltage up to 4.5 kV and a pulse current up to 2 A)

should be development

For optimization of the atomic beam intensity it is necessary

- to measure the **atomic beam density** in the pulse mode using the time-of-flight mass-spectrometer
- to measure the **atomic beam velocity distribution**
- to compute the **optimum location** of the permanent sextupoles

The designing and manufacture of **ABS** parts, optimization of the intensity of the atomic beam, and functional tests of the RF cells of the nuclear polarization of deuterium (hydrogen) atoms will be performed at **INR of RAS (Moscow)**

Source POLARIS (JINR)

Transition	I	Pz	Pz^2 I	Pzz	Pzz^2 I
M (1 → 4)	1/2	-2/3	2/9	0	0
M (3 → 6)	1/2	2/3	2/9	0	0
M (2 → 6)	1/2	1/3	1/18	1	1/2
M (3 → 5)	1/2	1/3	1/18	-1	1/2

SPI (JINR)

Transition	I	Pz	Pz^2 I	Pzz	Pzz^2 I
M (1 → 4) M (3 → 5)	1/3	0	0	-2	4/3
M (1 → 4) M (2 → 6)	1/3	0	0	1	1/3
M (2 → 6) M (1 → 4)	1/3	-1	1/3	1	1/3
M (3 → 5) M (2 → 6)	1/3	1	1/3	1	1/3

The **RF-transition units** will be checked and tuned with a sextupole electromagnet as an analyzing device

The purpose is to get atomic **D** beam with the pulse density of **$2.5 \cdot 10^{10}$** at/cm^3 at the distance of **150** cm from the cooling channel outlet and the most probable velocity of **$1.5 \cdot 10^5$** cm/s

The work which is carried out at JINR includes

- assembly and tests of the charge-exchange plasma ionizer, including the storage cell in the ionization volume
- transportation of hydrogen plasma with the flow of unpolarized protons up to 100 mA through the storage cell
- optimization of the ion-optical system up to 25 keV and transport of the high-current deuteron beam
- long-term tests of the SPI with the storage cell in the ionizer
- polarimetry of the accelerated beam at the output of linac

It is necessary to develop control system components for primary analysis & data acquisition and for fiber optic system of data transmission

Status of the SPI - project

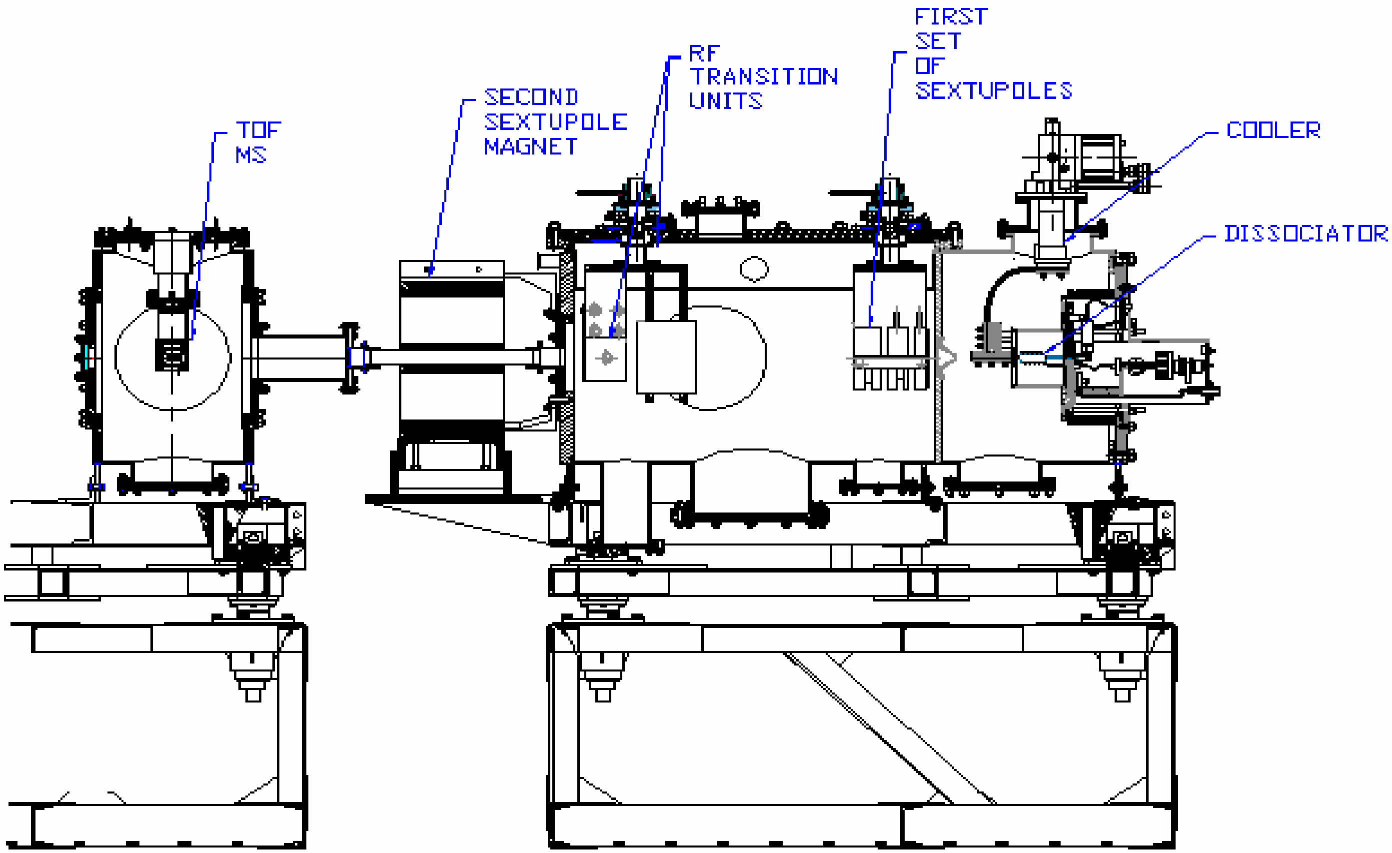
Intensive work on preparation of the source for tests is carried out at INR

Special attention during the tests will be focussed at the problems of the atomic beam formation process and study of the RF-transitions efficiency under nuclear polarization of the atomic deuterium beam

The beginning of tests of ABS is planned by the end of 2010

The testbench for the charge-exchange ionizer is under preparation at JINR

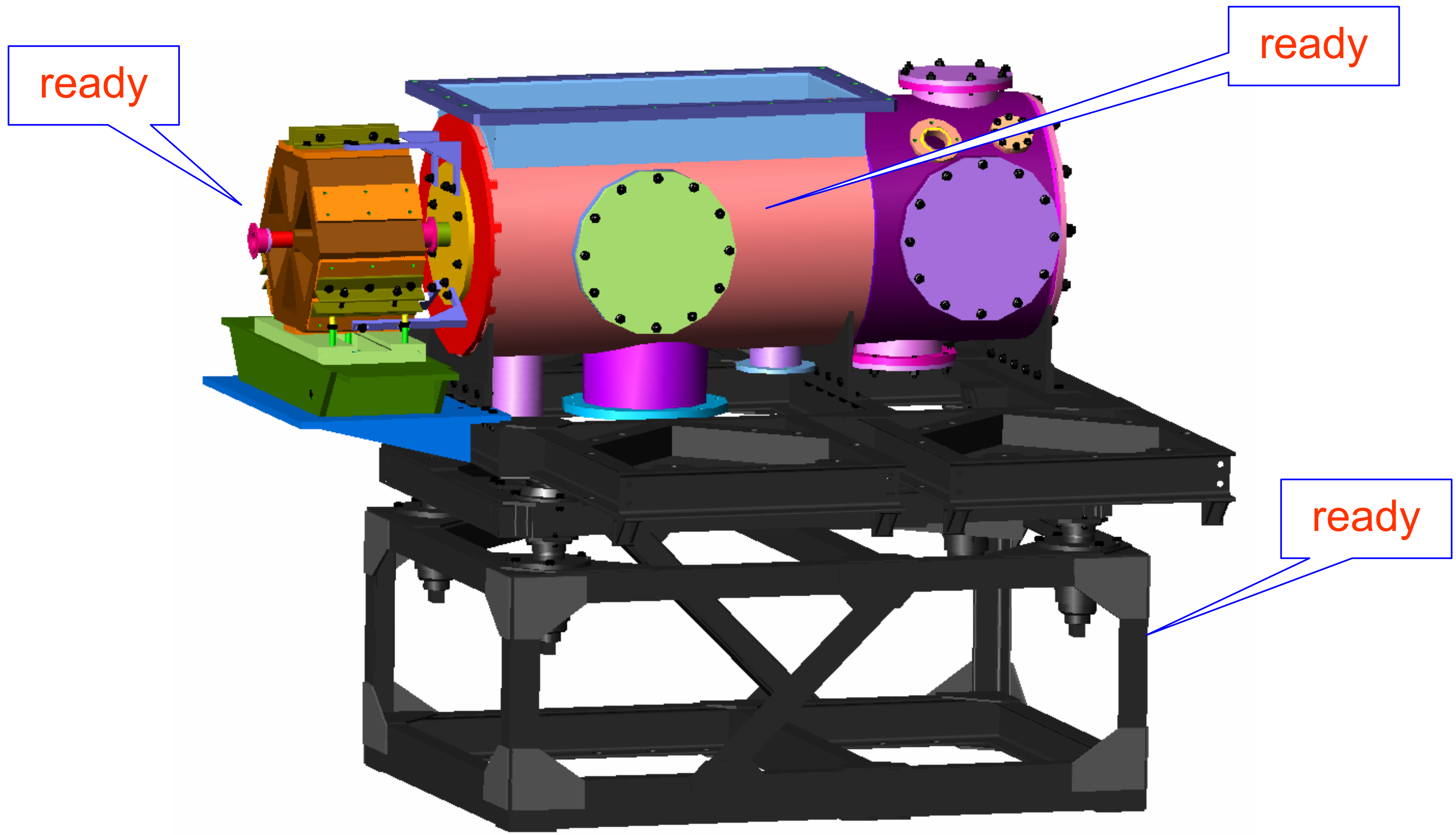
Atomic Beam Source general view



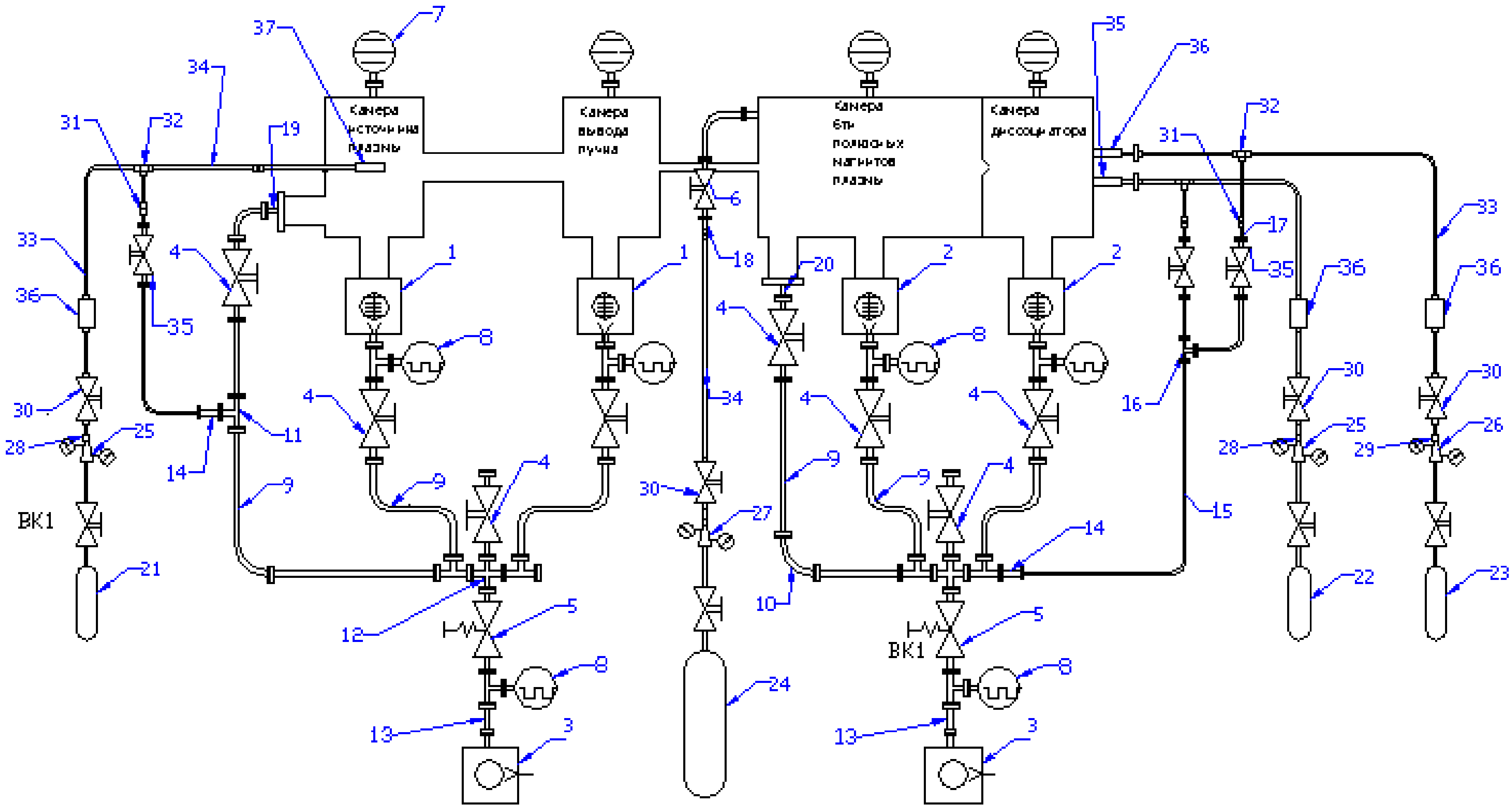
Pulsed dissociator (INR-type), nozzle cooling to 70 K, set of permanent magnet sextupoles and electromagnet sextupole (CIPIOS), WF and SF RF transitions units

Expected intensity of polarized deuteron beam is $1.5 \cdot 10^{17} sec^{-1}$ (3 ms pulse), polarized hydrogen beam - $2 \cdot 10^{17} sec^{-1}$

Atomic Beam Source setup general view



Vacuum pumping system of the SPI



- Pump, **Turbo-V 3K-T**, **2300** l/s H_2 , **2400** l/s He - 2 item
- Pump, **Turbo-V 2K-G**, **1600** l/s N_2 - 2 item
- Fore pump **Dry scroll pump type TriScroll 600 Inverter**, **30**m³/h - 2 item

equipment is already purchased

Cryocooler, **Single Stage Cryodyne Refrigeration System, Model 350** will provide 40 watts of heat lift at 77K

equipment is already purchased

Pressure measurement system, **MaxiGauge TPG256A controller for 6 gauges**

equipment is already purchased

- **Total price of equipment ~ 136 K€**

Atomic Beam Source setup general view

Dissociator & Sextupole magnets vacuum chamber

Mass spectrometer vacuum chamber

Leak detector ТИ-14

Pump Turbo-V 3K-T 2300 l/s H_2

5L D_2 & O_2 cylinders

Atomic Beam Source setup front view

Dissociator

RF-generator of dissociator

Atomic Beam Source setup front view

Deuterium & Oxygen pulse fast valves

Current leads

Dissociator flange with the removed RF-generator

RF power inputs

Atomic Beam Source dissociator chamber

Cryoterminal

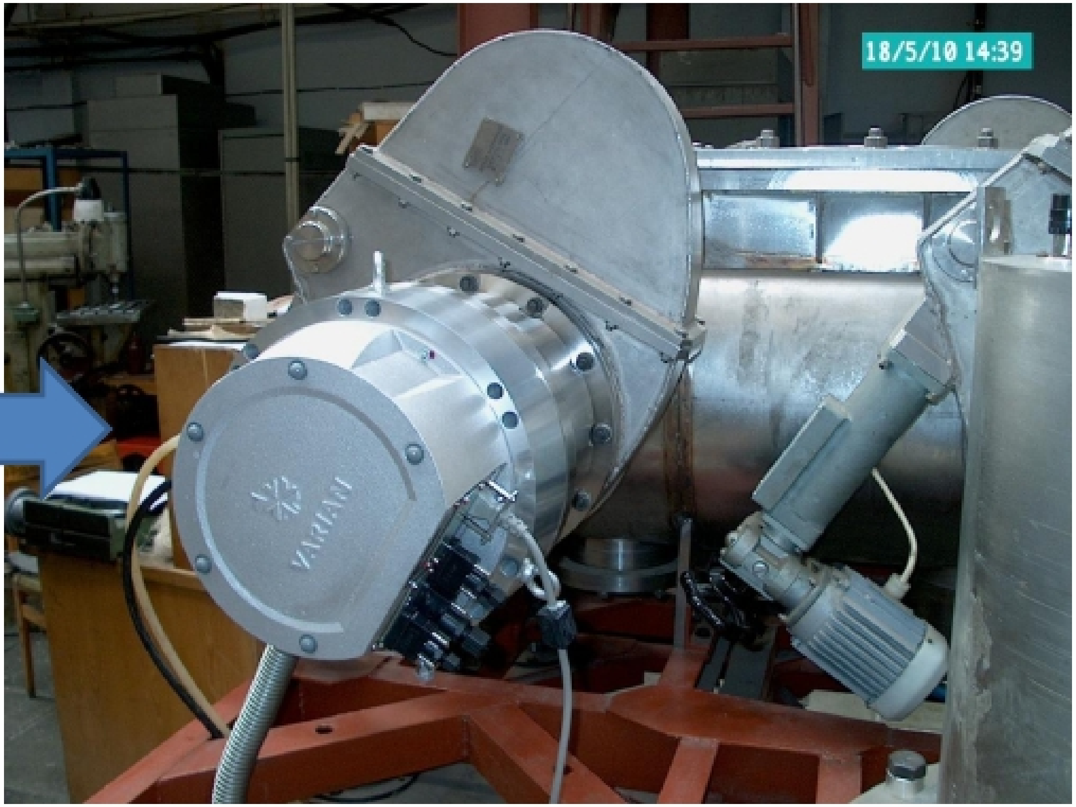
Dissociator chamber

Atomic Beam Source

Permanent sextupole assembly & RF-cells adjustment mechanism

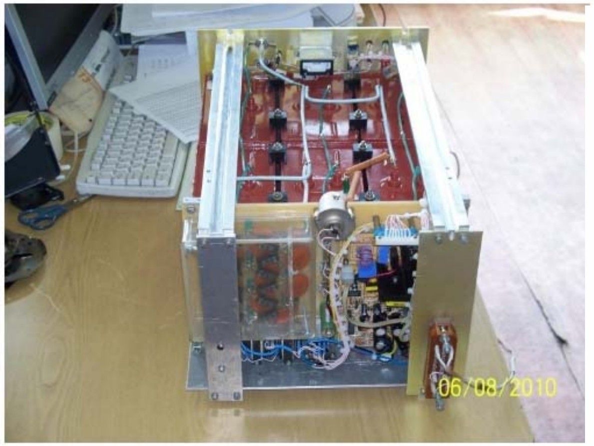
Atomic Beam Source setup view

Turbo-V 3K-T
pump
tests



Some electronic devices of Atomic Beam Source

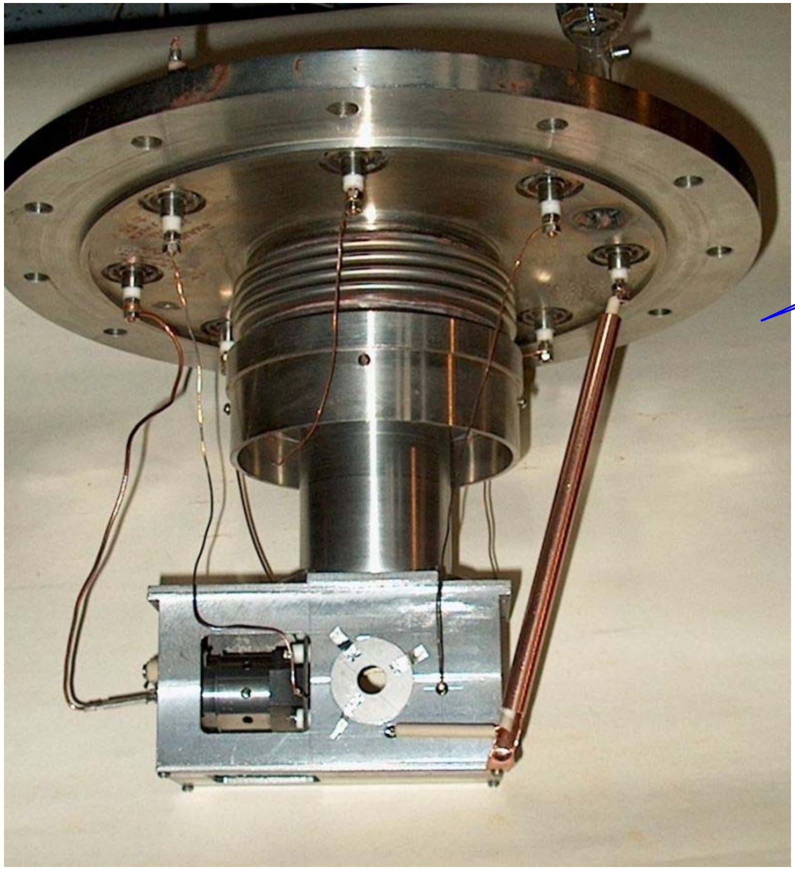
High Voltage modulator of RF-generator (rear view)



Pulse valve power supply

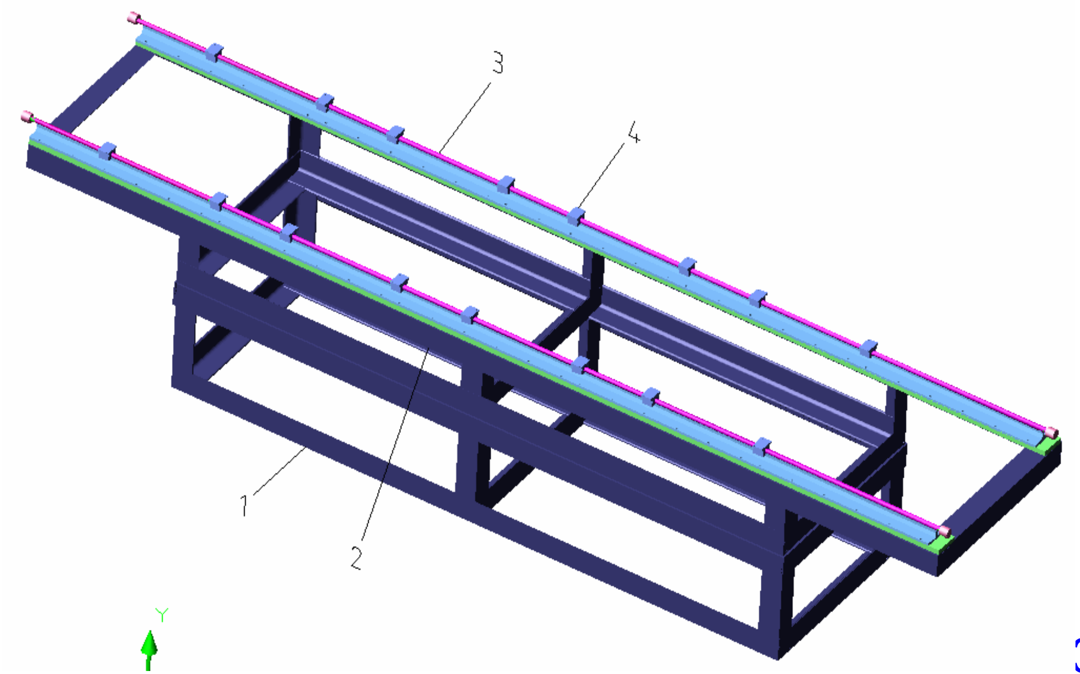
High Voltage modulator of RF-generator (manufacturing process)

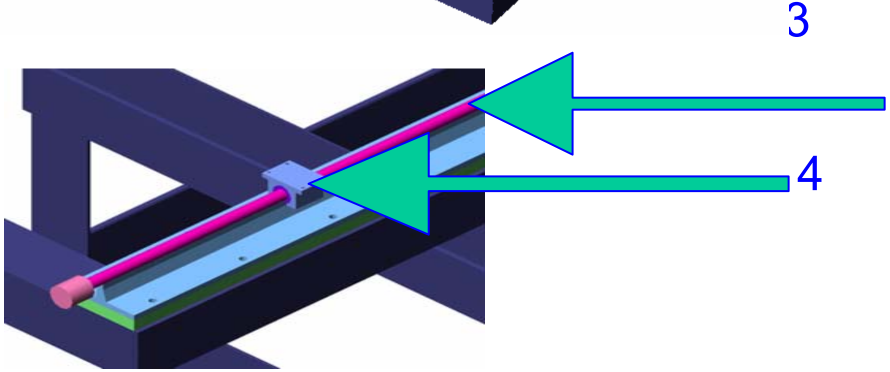
Time-of-flight mass-spectrometer with cross-beam ionizer



ready

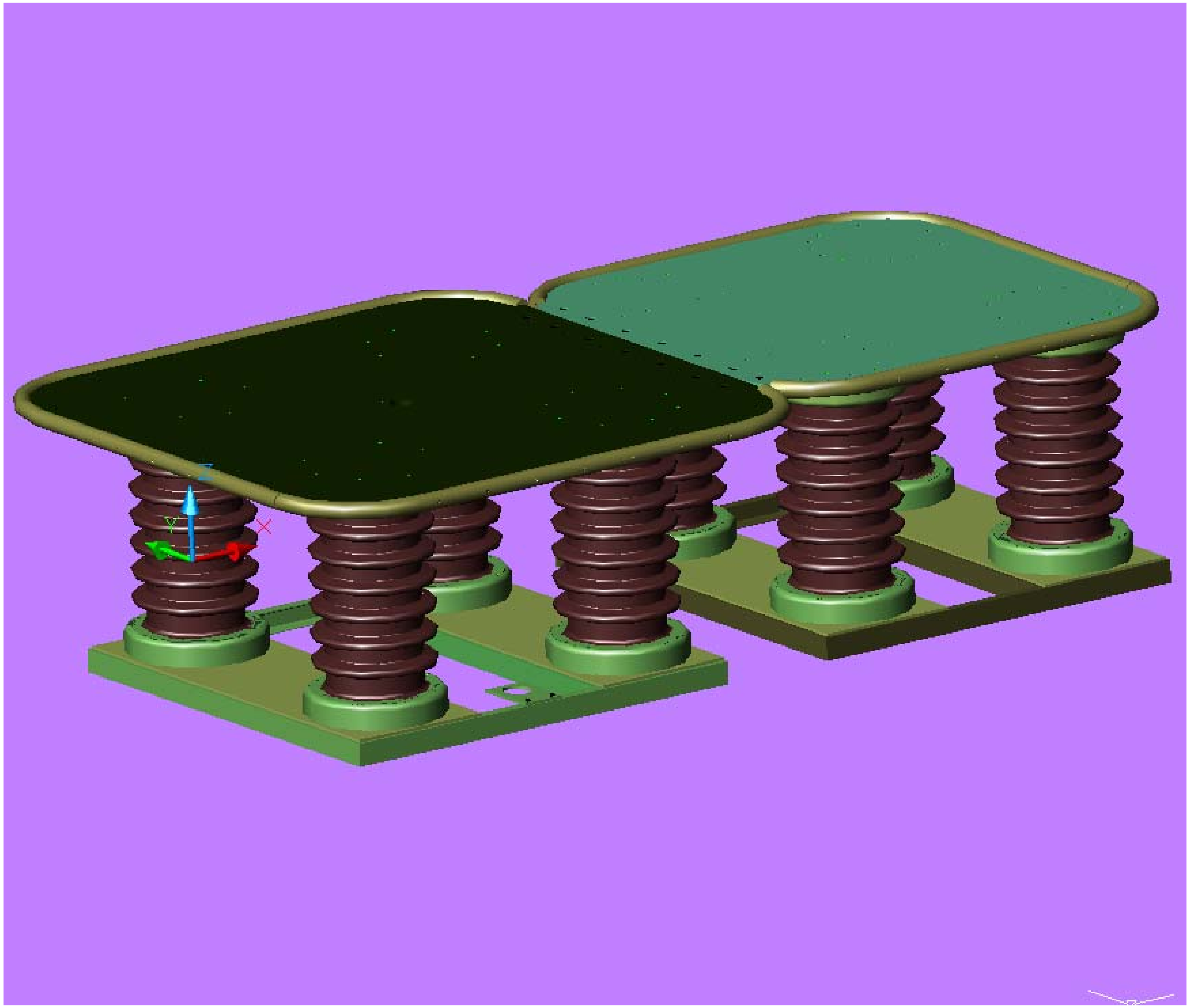
SPI supporting frame



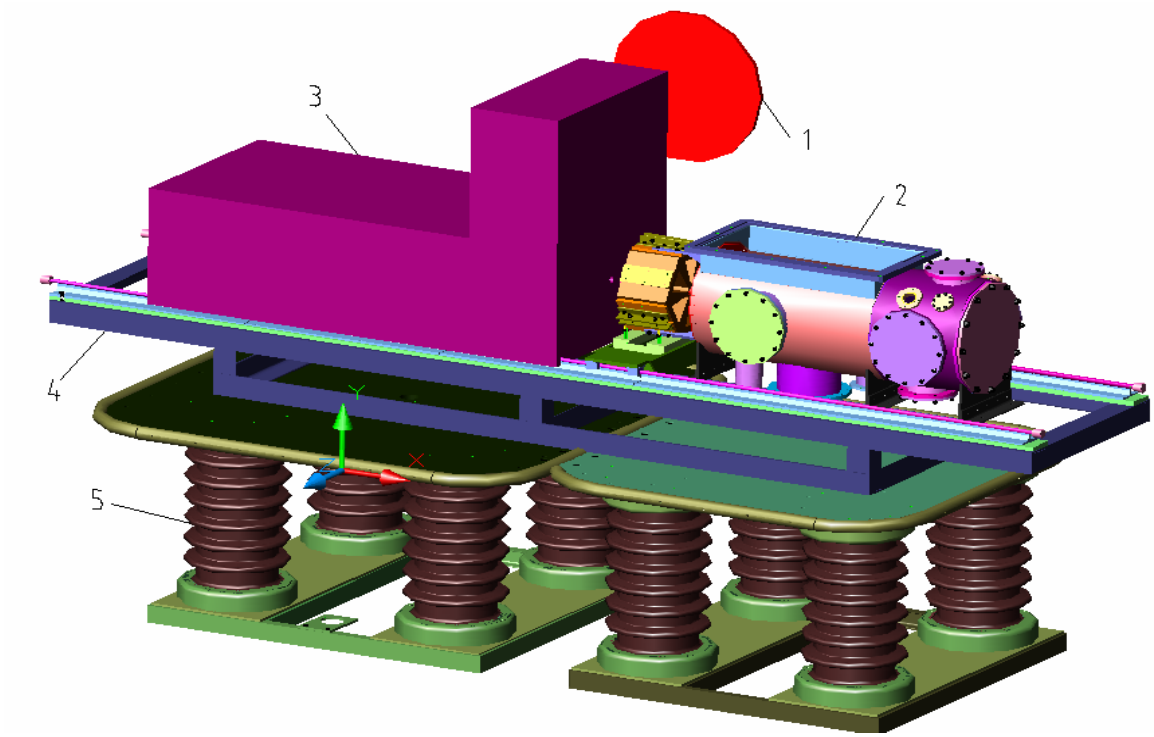


1. lower section, 2. upper section, 3. guide rods , 4. sliding bearings

High-voltage terminal at the linac (Lu-20)
(possible variant of improvement)

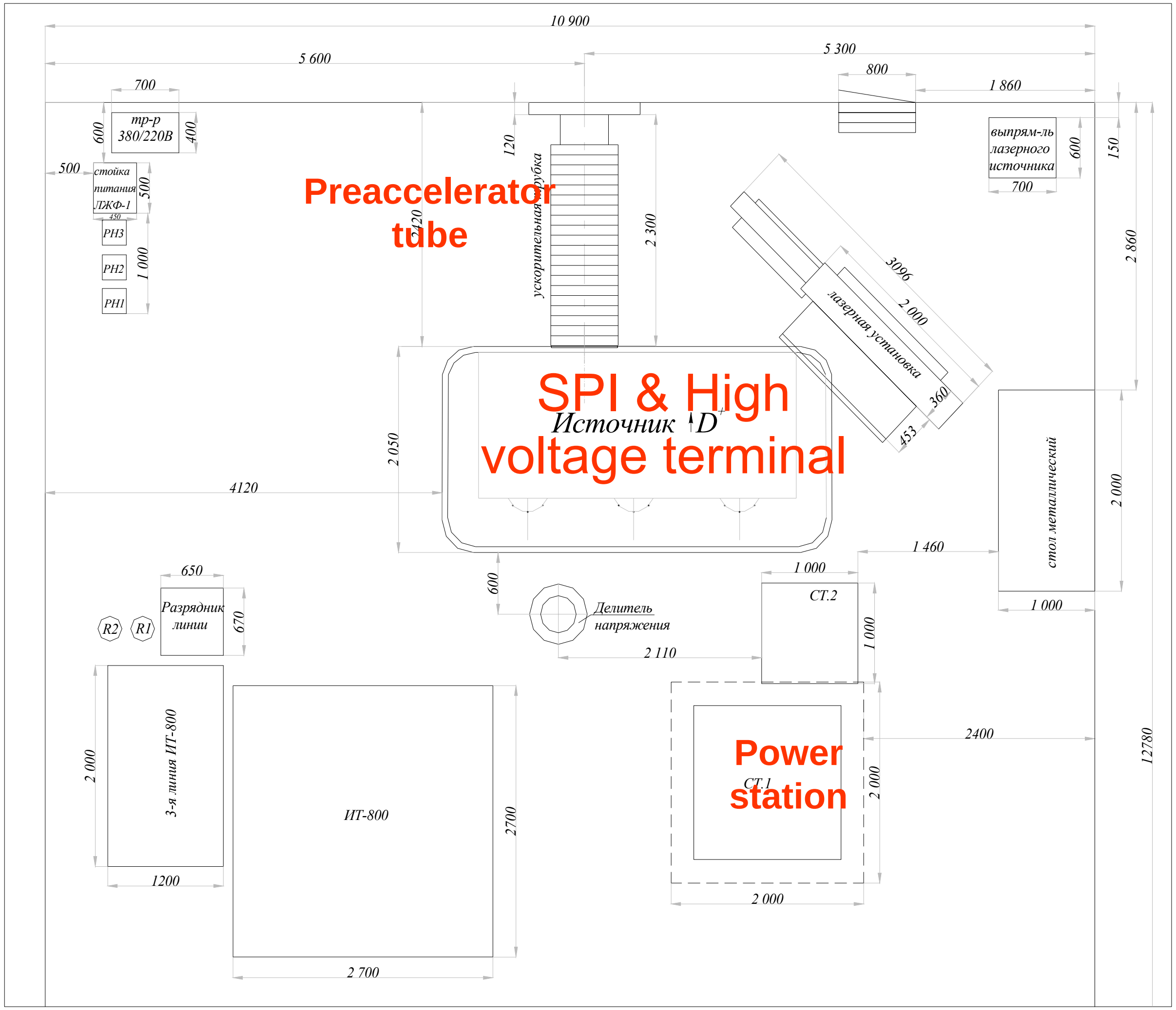


SPI high-voltage terminal at the linac (Lu-20)
(possible variant of improvement)



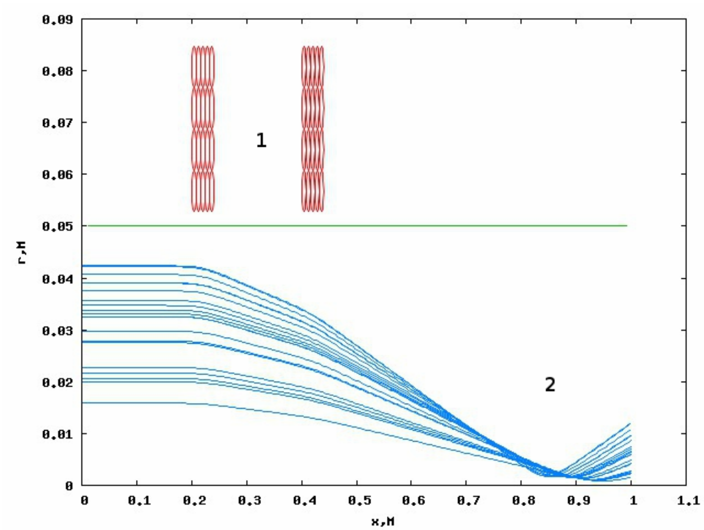
1. flange of the accelerating tube, 2. source of polarized atoms place, 3. charge exchange ionizer place, 4. SPI supporting frame, 5. linac high-voltage terminal

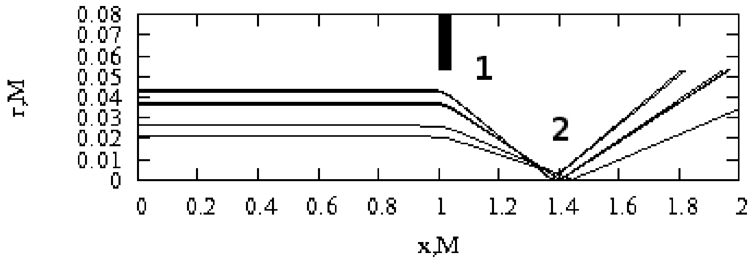
Plan of SPI placing at linac hall



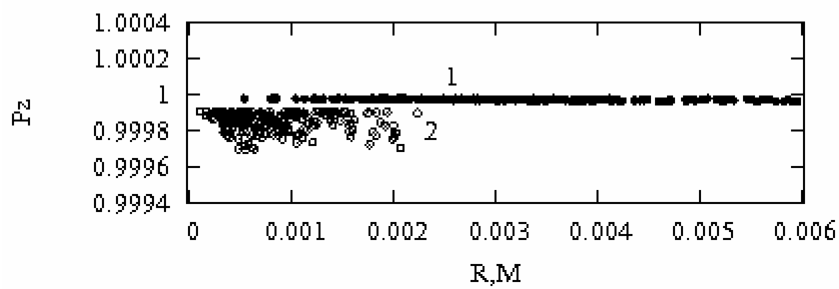
To prevent distortion of the spin orientation of the deuterons beam under the influence of short-focus lens at the input of linac is proposed to use dual short-focus lens, consisting of two coils with a opposite current direction

Optimization of the spin orientation of polarized D^{+} at the input of linac



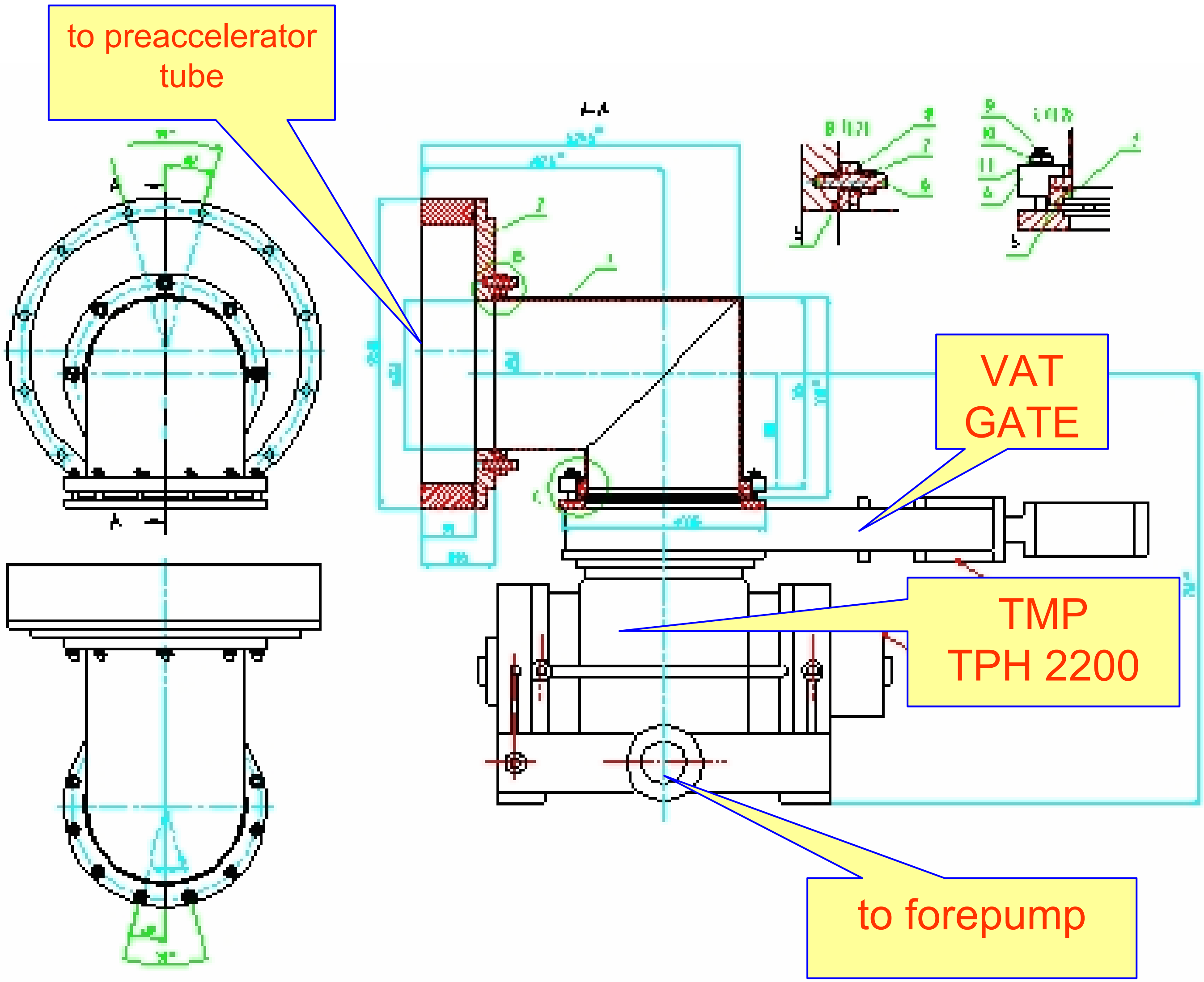


- Calculated trajectories of deuterons. 1. Windings of the lens, 2. Particle trajectories



- The vertical projection of the deutron spin as a function of the radius after passing through two lenses. : 1. The current in the lens 50 kA, 2. 100 kA

Turbomolecular pumping of the linac preaccelerator tube



Thank you