NICA Absolute Polarimeter

N.V. Dunin, V.V. Fimushkin, M.V. Kulikov, R.A. Kuzyakin,
Yu.V. Prokofichev, A.M. Shumkov (JINR, Dubna)

Absolute Polarimeter (APol) with the internal polarized atomic hydrogen/deuterium jet target is being built to measure absolute value and signs of proton or neutron polarization beams in NICA collider.

APol general view

Main tasks for APol

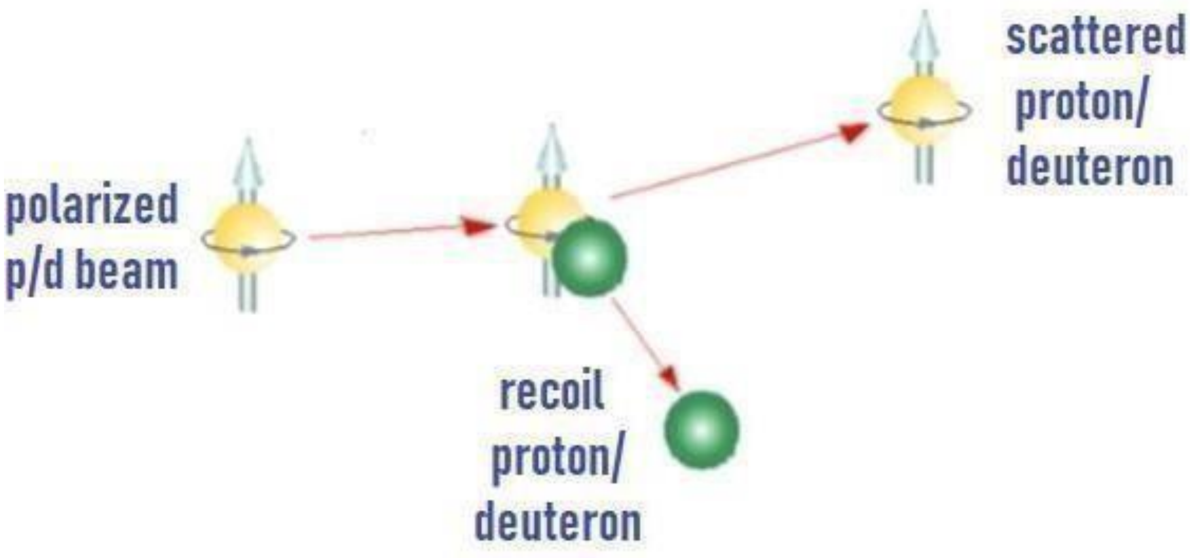
Absolute Polarimeter will allow to

- Perform measurements of beam polarization in NICA facility

- identify the noise impact on polarization of any NICA equipment

- monitoring the degree of beam polarization during operation of the Collider

Polarimetric reaction and polarization measurement basics



A_N (analyzing power) range: **20% .. 8%**

beam energy range: **3..11 GeV**

recoil particle energy: **200 MeV**

recoil particle registration angle (in lab system): **75°**

Measured beam polarization: $$P_{\text{beam}} = -\frac{\varepsilon_{\text{beam}}}{\varepsilon_{\text{jet}}} P_{\text{jet}} = -\frac{\varepsilon_{\text{beam}}}{A_N}$$

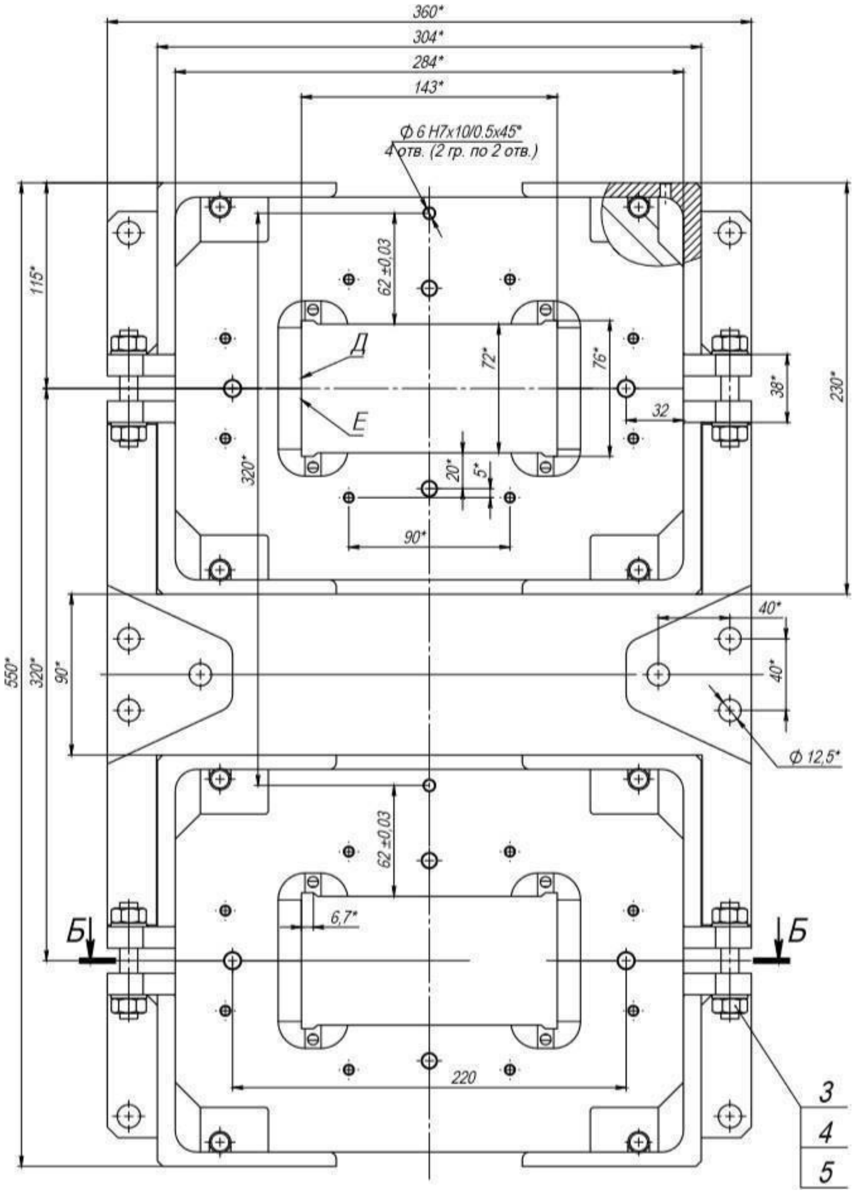
where $A_N = \varepsilon_{\text{jet}} / P_{\text{jet}}$ - analyzing power of the polarimetric reaction

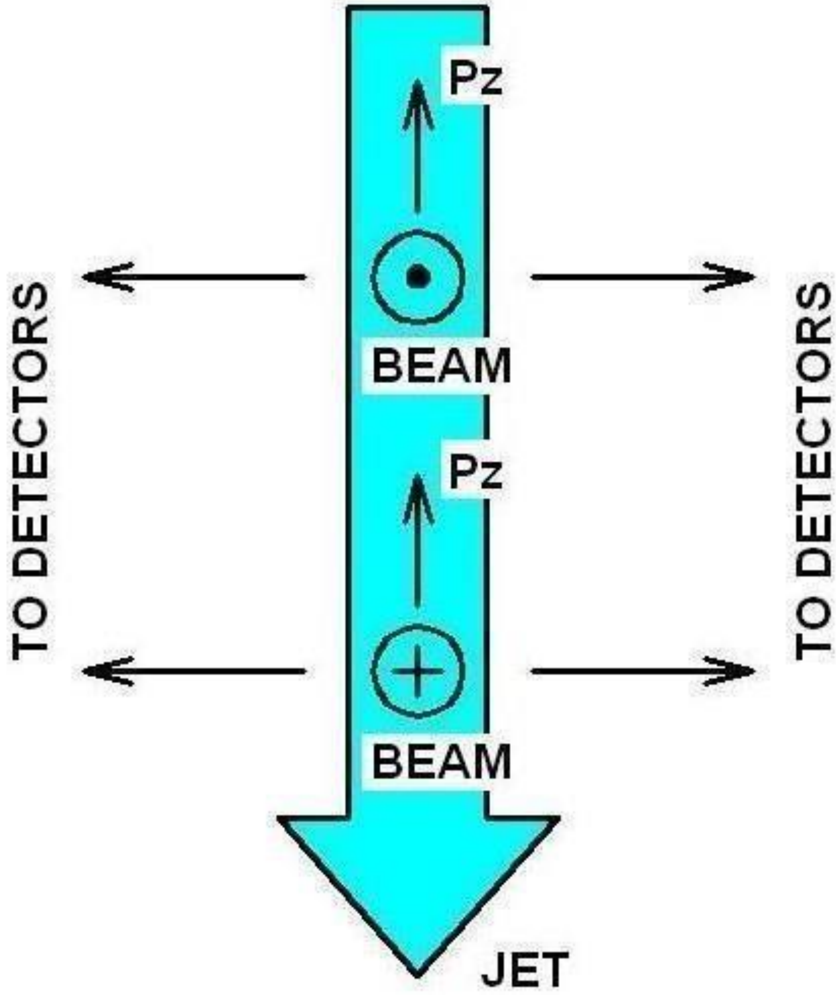
$$\varepsilon \equiv \frac{N_{left} - N_{right}}{N_{left} + N_{right}}$$ - acceptance

Actual geometry requirements

Section of NICA dipole magnet of collider

Two lines of beam (acceleration and transportation) is located one under another at 32cm distance. Beams crossing will be just in two places, in MPD and SPD area





Estimation time of APoL measurements for proton-proton elastic scattering

Rate of event acquisition: $N = \Delta\sigma \cdot L \cdot \Delta\psi$,where

$\Delta\sigma$ – scattering cross-section into direction of registration,

$\Delta\psi$(=0.016) – acceptance ,L – luminosityInturn:

$L = N_{bunch} \cdot n_{bunch} \cdot F \cdot t_{jet}$,

where

N_{bunch}(=10^{12}) – number of protons/deuterons per bunch (for NICA)

n_{bunch}(=22) – number of bunches (for NICA)

F(=$3 \cdot 10^8$ m*s^{-1}/503m=$6 \cdot 10^5$ s^{-1}) - frequency of crossing the jet

(for RHIC it is 3.8/0.5=**7.6 times smaller**)

t_{jet} (=10^{12} atom/cm^2) – target thickness of the jet,

and numerically:

$$L = 10^{12} \cdot 22 \cdot 6 \cdot 10^5 \cdot 10^{12} = 1.3 \cdot 10^{31}\ s^{-1} \cdot cm^{-2} = 1.3 \cdot 10^4\ s^{-1} \cdot mb^{-1}$$

Details of the estimations show what factors effect on the measurement time

Number of events needed to measure A_N with an accuracy of 5%: $N_A=(0.05\cdot A_N)^{-2}$

Time needed to measure A_N with an accuracy of 5%: $T=N_A/N$.

If we put numbers in the table we see:

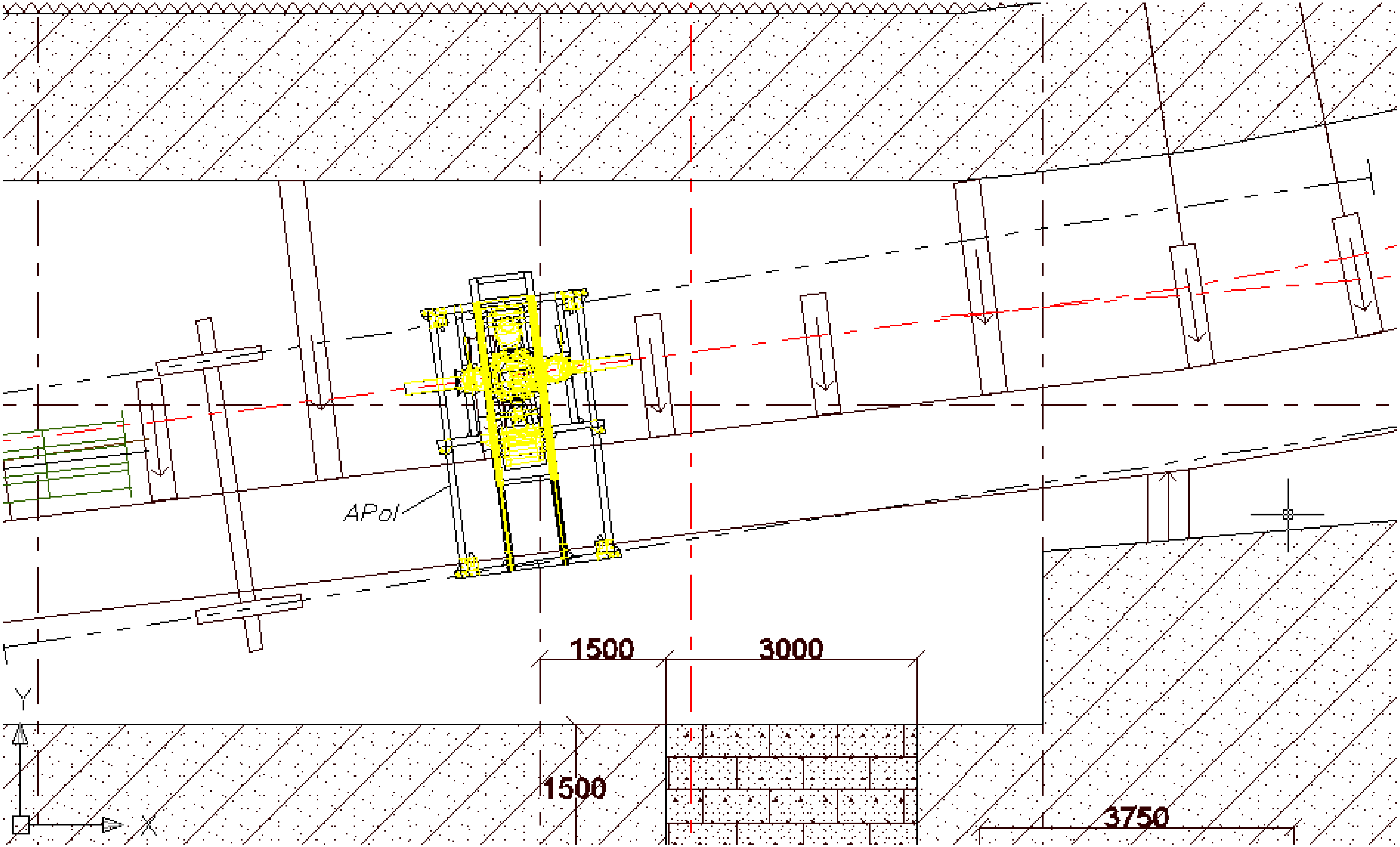
Energy of the beam, GeV	Scattering cross-section, mb	Analizing power	Number of events needed for δA_N=5%	Time of measurement
3	3.08	0.195	10500	18 seconds
7	2.29	0.107	35000	73 seconds
11	1.84	0.077	67500	182 seconds

Data for cross-sections and analyzing powers are taken from NIMA **211** (1983) 239-261.

Using provided data for cross sections, power analyzing and consider statistical errors we can get following measurement time estimate.

Proposed placement of the APol setup at NICA collider

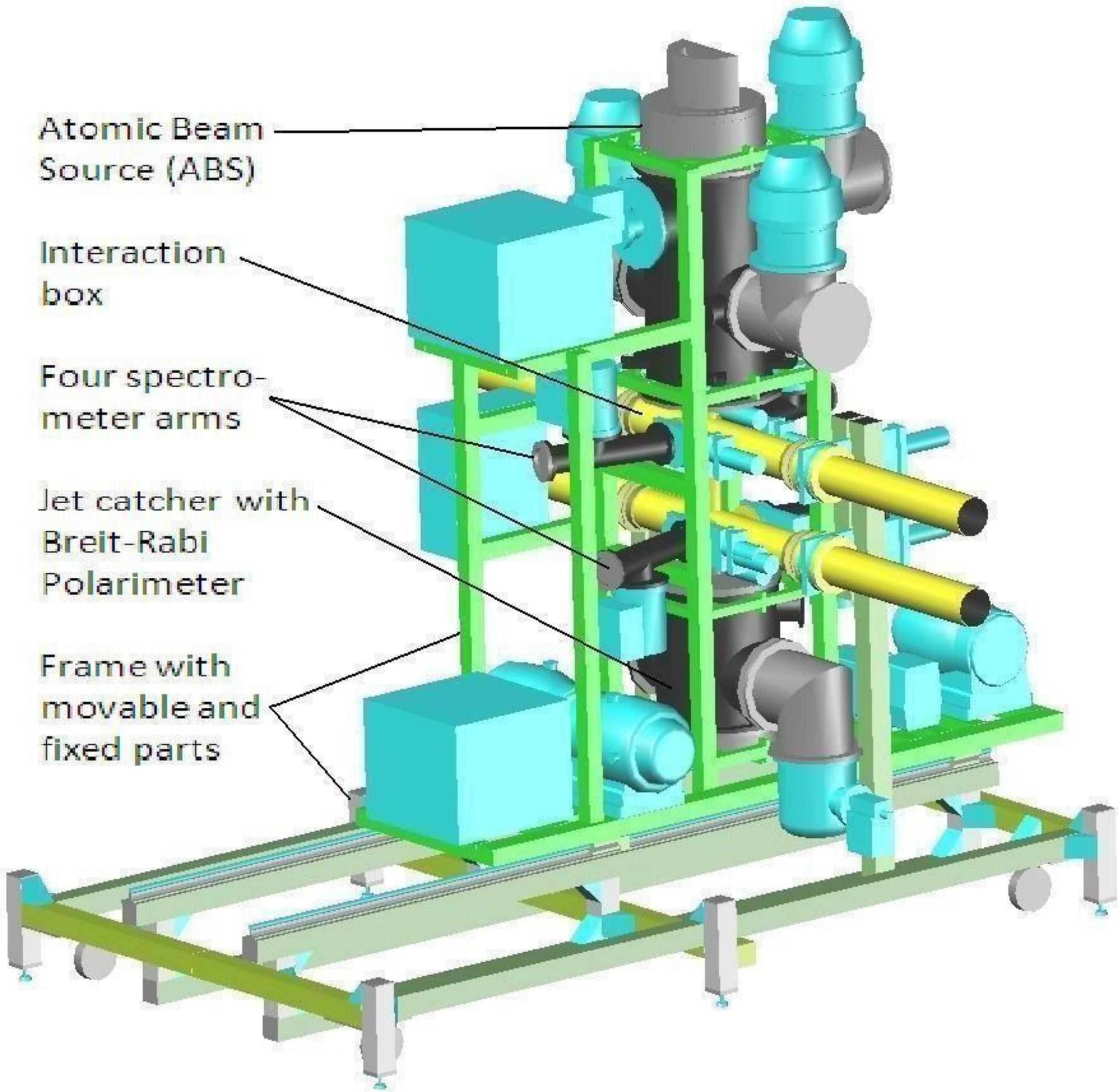
60 cm along the beam is needed for APol placement. It is better to install it in the “warm” gap to avoid impact of cryogenic equipment.



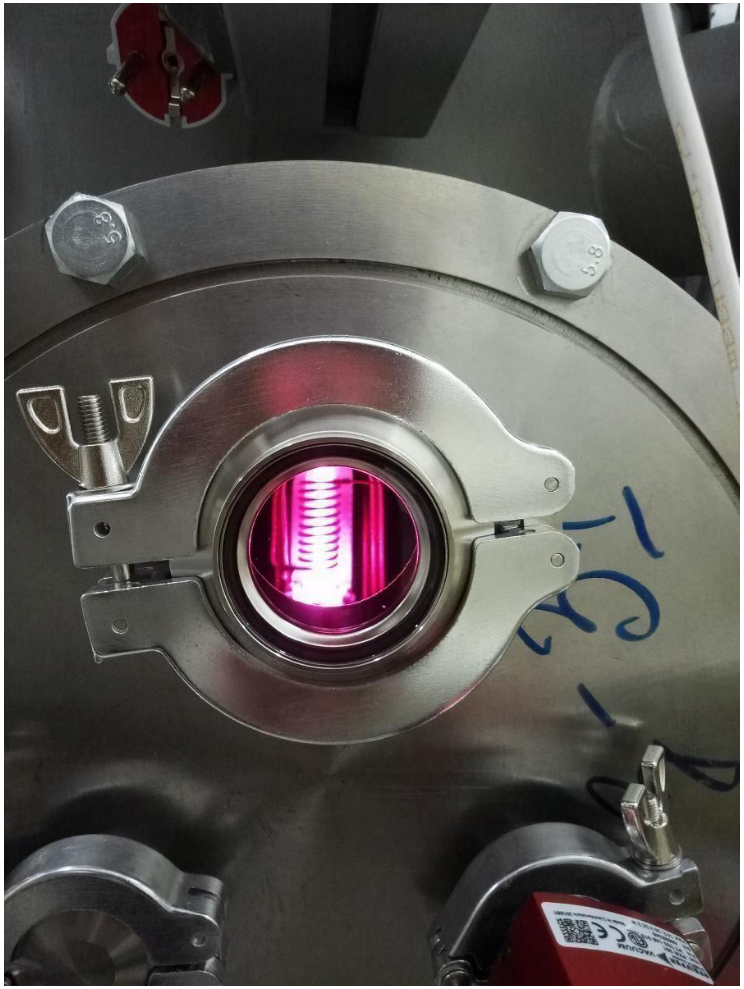
Main subunits of APol

APol consists of:

- Atomic Beam Source (ABS)
- Interaction box
- Four spectro-meter arms
- Jet catcher with Breit-Rabi Polarimeter
- Frame with movable and fixed parts

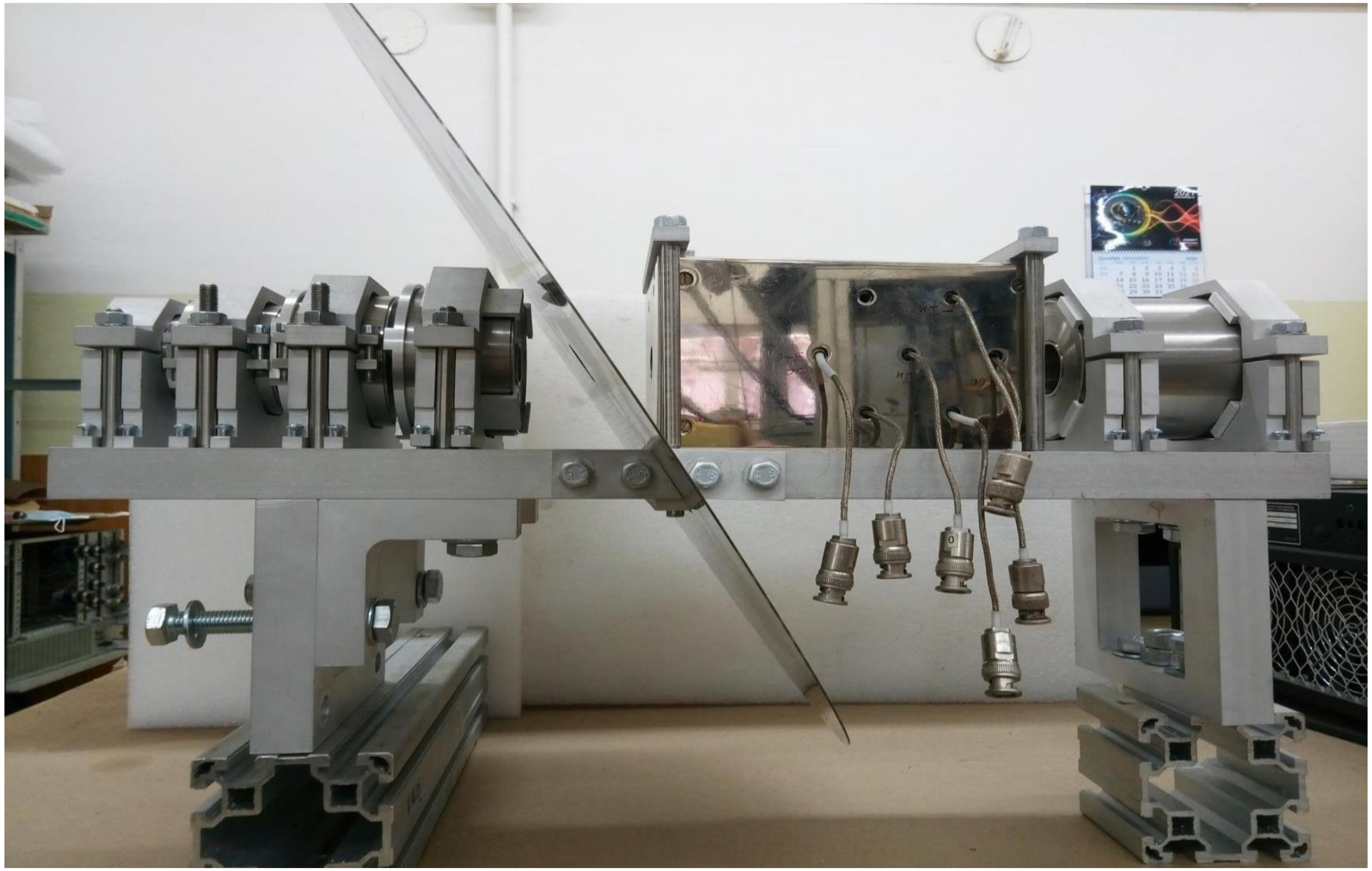


APol dissociator



Pyrex glass pipe on the left called a “Dissociator”. High frequency inductor wound around it. Inductor powered by 280 watts with 13 MHz frequency. This induces a HF discharge that makes a dissociation of molecules.

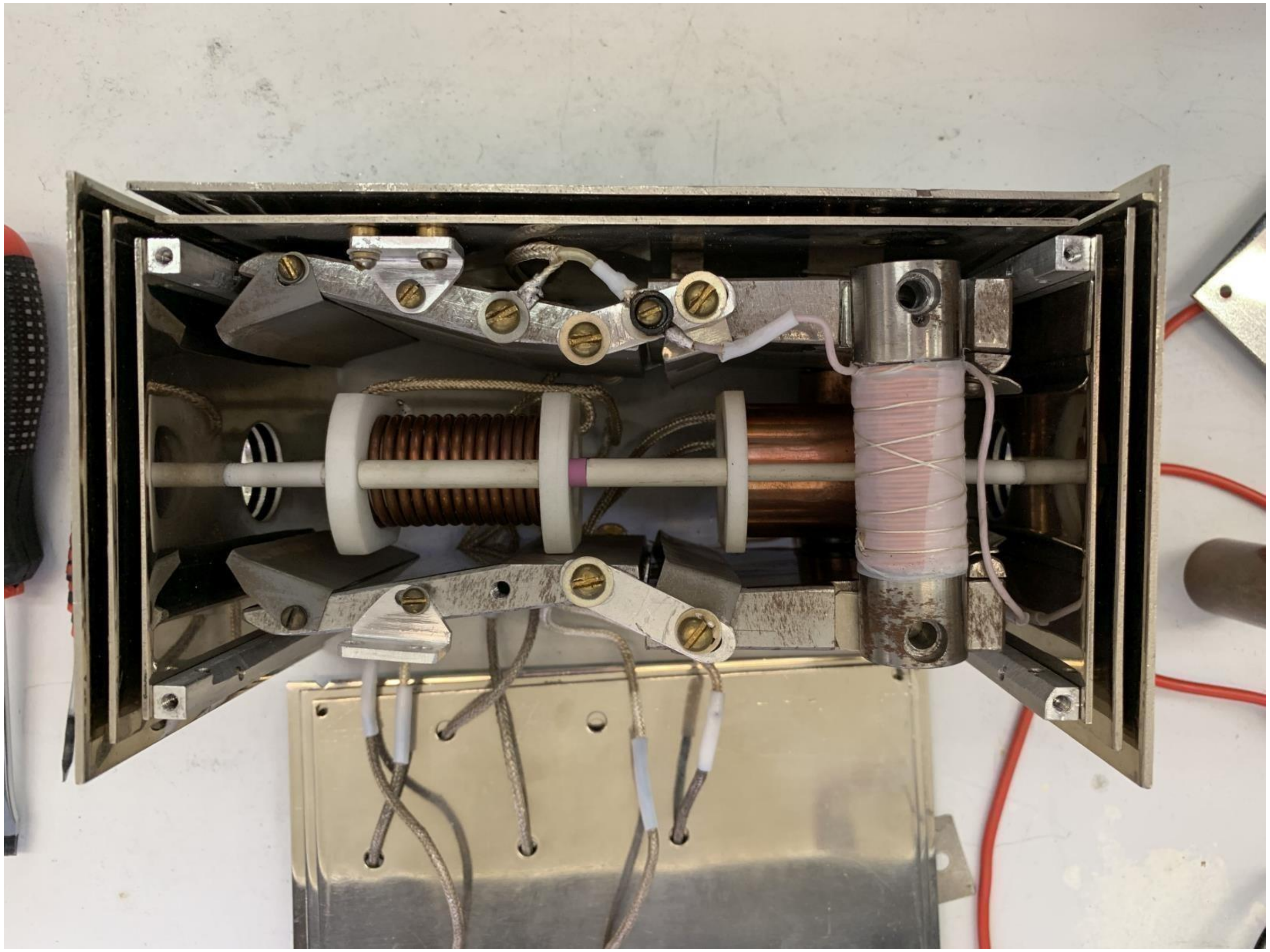
APol permanent (Nd-Fe-B) sextupole magnet structure



This device designed to separate atoms from a beam by their electron and nuclear spins. It consists of:

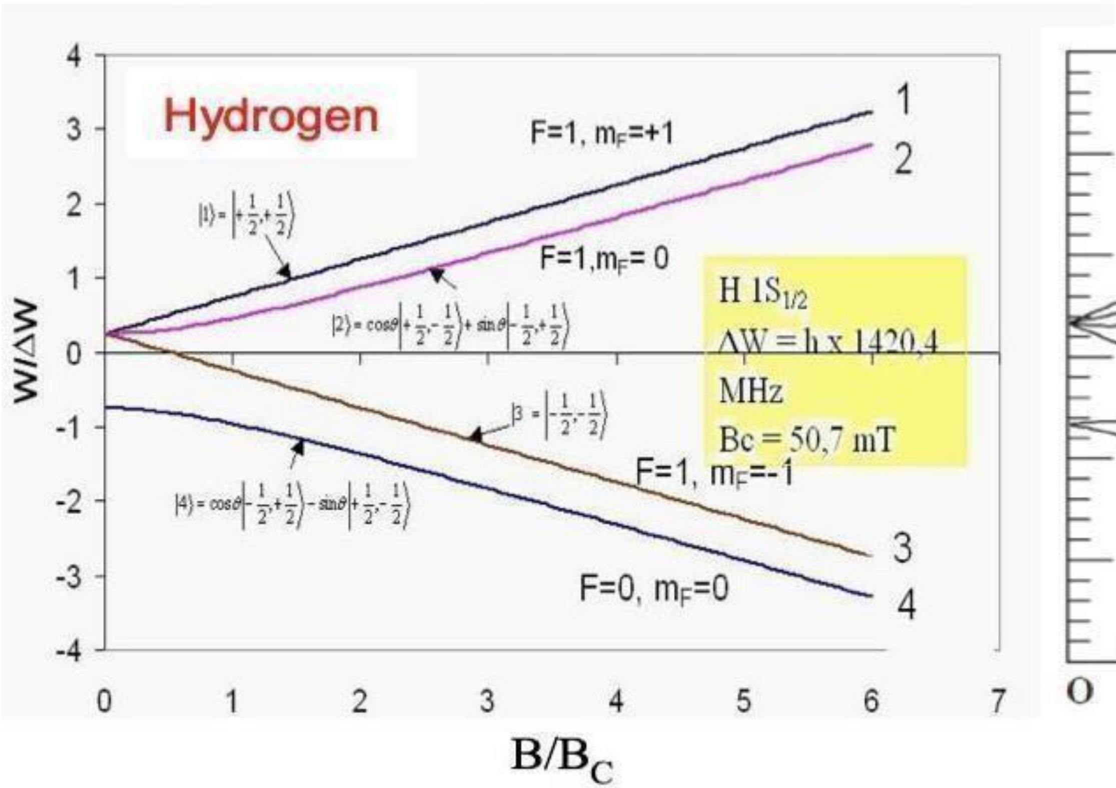
1) Set of the <u>5 sextupole magnets</u>(Neodymium-Ferrum-Bor).
2) Nuclear polarization cell (between 4^{th} and 5^{th} magnets). The max. magnetic field is 1.7 Tesla on the inner structure.

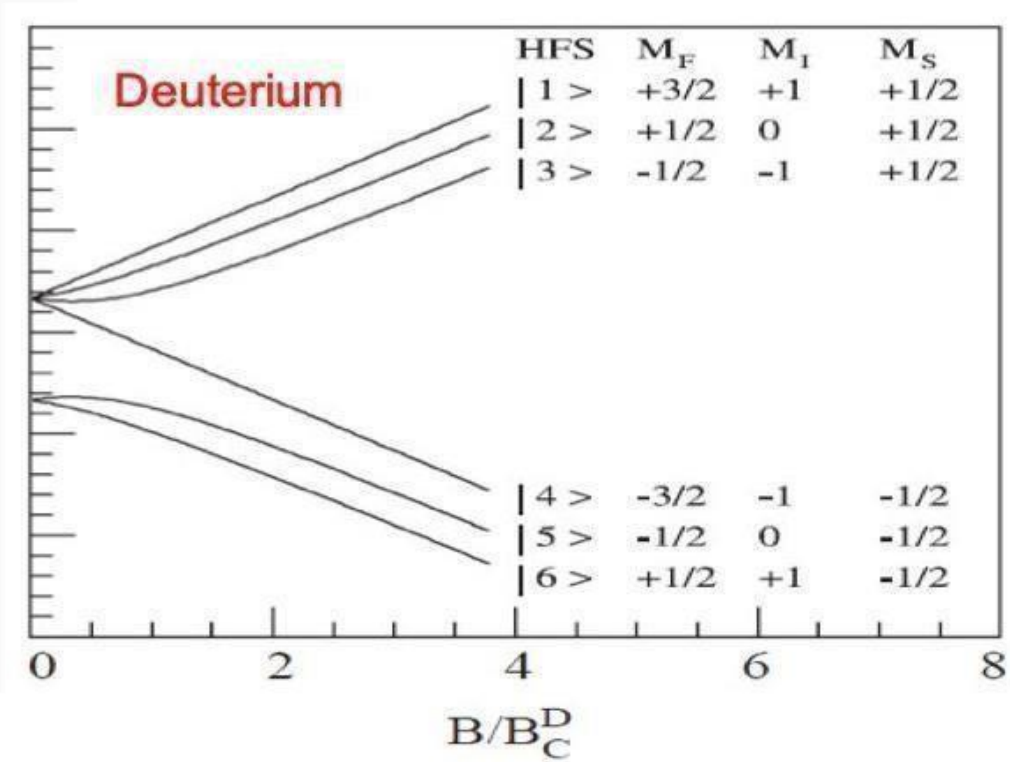
APol medium field transition cell for deuterium atoms



Medium field transition (MFT) cell is need to obtain maximal polarization of atoms. To achieve this **nuclear spins should be co-directed to their electronic spins.**

Energy diagrams of hfs of hydrogen & deuterium atoms in ground state



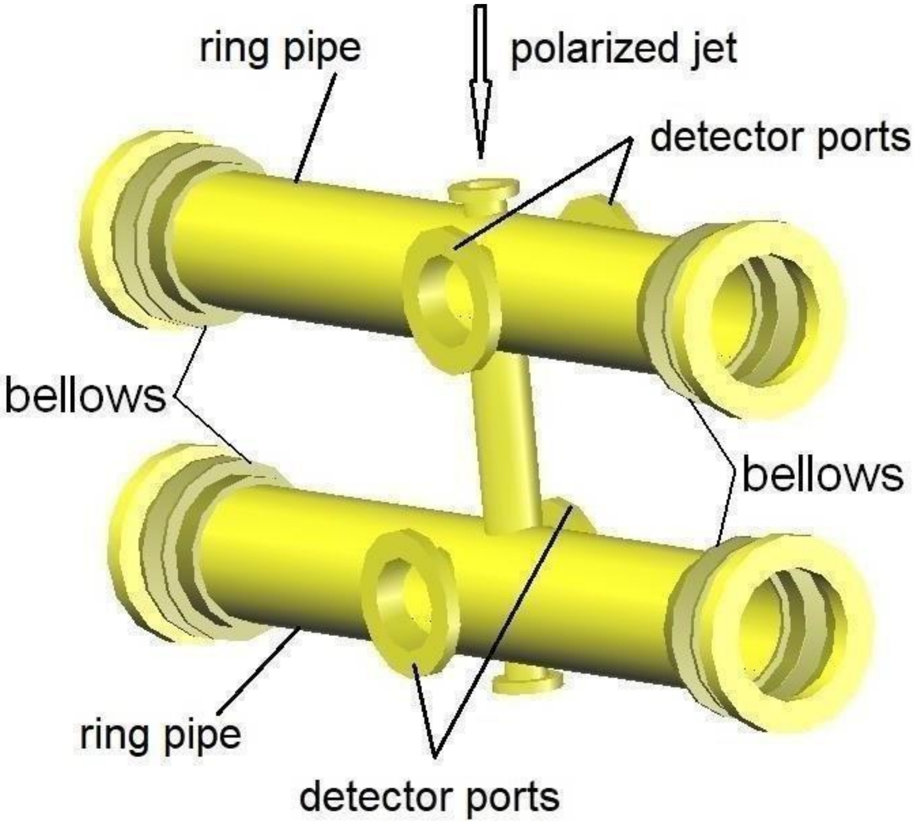


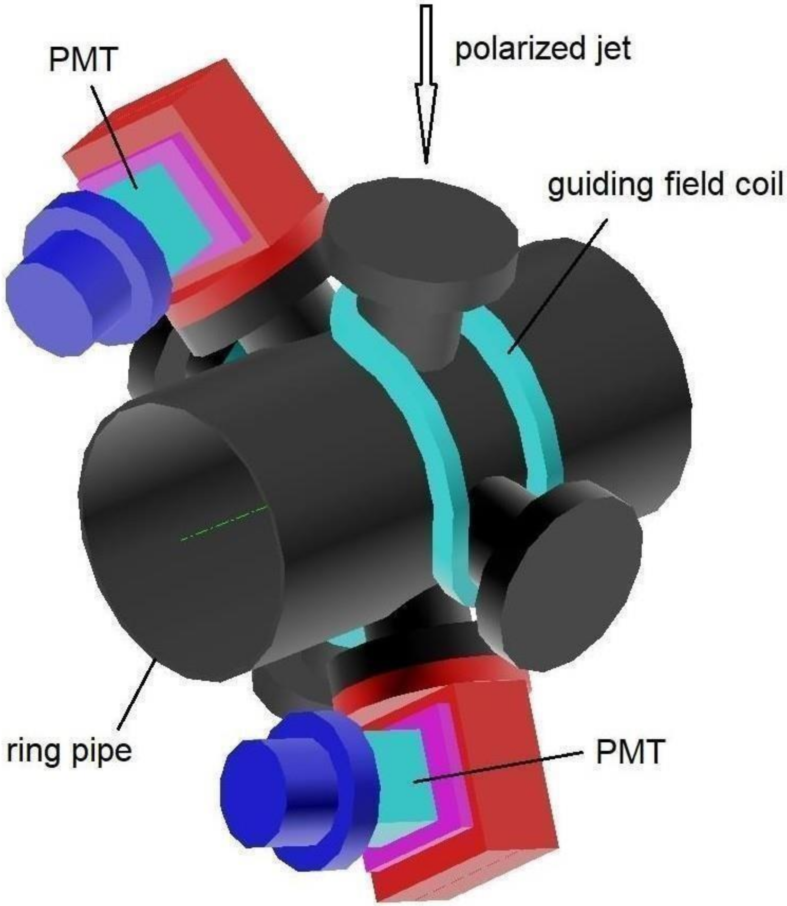
Hydrogen	Final State	Pz
MFT 2->3	1	+1
Deuterium	Final State	Pz
MFT 3->4 + SFT 2->6	1	+1

To obtain polarization in APol we will use following MFT and SFD for Hydrogen and Deuterium.

APol interaction box

1 **2**





1 – version for horizontal reaction plane

2 – version for 45° reaction plane (PMT – Photo Multiplier Tube)

Main operational parameters of APol:

- **steady operation mode**
- throughput of H_2/D_2

  Q = **1 torr·l/**s = **3.4·10^{19} molecule/s** = **6.8·10^{19} atom/s**
- nozzle temperature T_N=**80°K**
- speed of nozzle outflow (=speed of sound):

  for hydrogen - $c_H=(k_B T/m_H)^{0.5}$ = **1 km/s**

  for deuterium – $c_D=(k_B T/m_D)^{0.5}$ = **0.75 km/s**
- Mach number in atomic beam M=**2.9**
- most probable velocity for atomic beam velocity distribution:

  for hydrogen – **1940 m/s**

  for deuterium – **1370 m/s**
- beam temperature (=width of veloiity distribution) T=**23°K**
- pole tip magnetic field of Nd-Fe-B sextupole magnets B_0=**1.5T**
- atomic beam intensity in the interaction region – **10^{17} atom/s**
- expected target thickness of the atomic beam in the box – **10^{12}atom/cm^2**

Vacuum conditions:

- differencial vacuum pumping system is used
- vacuum in dissociator chamber (the 1st stage): $5*10^{-4}$ mbar
- vacuum in beam forming chamber (the 2nd stage): $5*10^{-6}$ mbar
- vacuum in nuclear polarizing region chamber (the 3d stage): $1*10^{-6}$ mbar
- **expected vacuum in interaction box: $1*10^{-10}$ mbar**

Operational requirements:

Electric power: 15 kW, single and three phase, 220 V, 50 Hz

Cooling water: 2 m^3/h, 3 atm

Pressurized air: 5,5 atm

Occupied area: 6.5 m^2 (3.5m x 2m)

Part of Apol parameters that we need to control and monitor

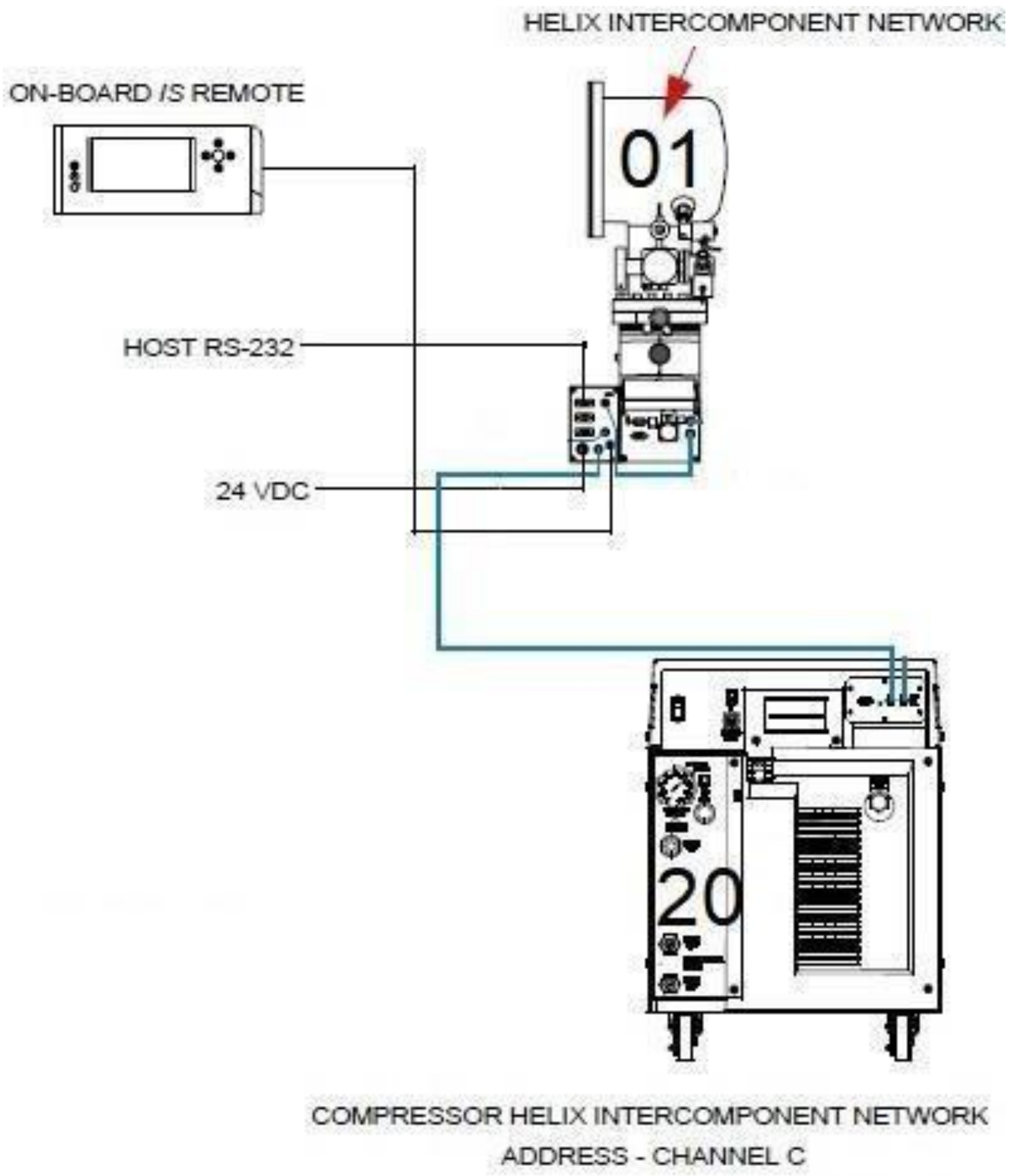
Parameters for monitoring

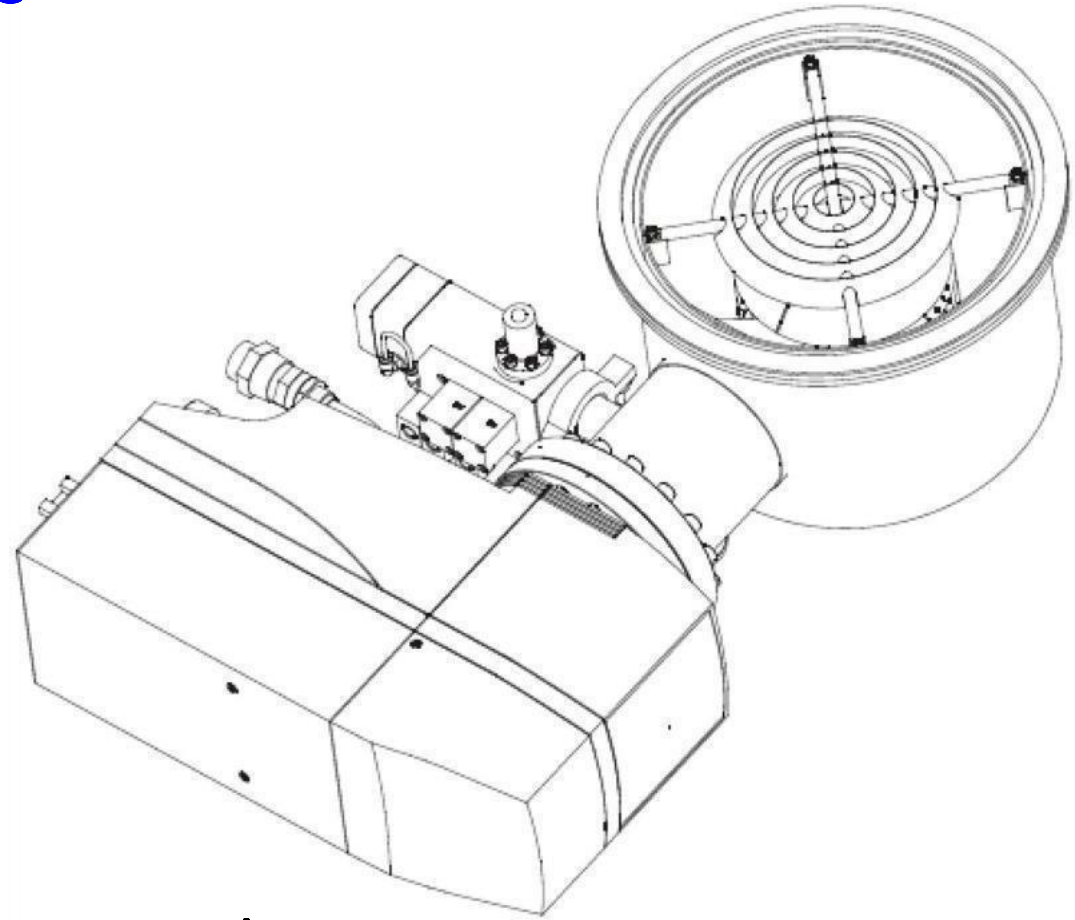
- **Cooling loop** that contains water(**10 sensors**)
- Compressor **water flow rate**
- Compressor **supply/return pressure**
- Cryosystem **First and Second stages temperatures (K)**
- Valves (Exaust, Purge, Rough)
- PMT **impulses count**

Parameters for control

- **Cryopump** states (**ON,OFF**)
- **Compressor** states(**ON,OFF**)
- **Regeneration** process for cryosystem (**Start,Abort,Shutdown**)
- Valves (Exaust, Purge, Rough)

Brooks Cryosystem diagram for APoL





Problem overview:

Remote control monitoring required through PC software. Need future integration with SCADA.

Request and response codes

Full regeneration start:

2450 3031 4E31 600D (HEX)

$P01N1` (ASCII)

Compressor ON:

2450 3230 4131 540D (HEX)

$P20A1T (ASCII)

Get supply pressure:

2450 3230 4F3F 310D (HEX)

$P20O?1 (ASCII) ,

A message packet for the On-Board IS Controller.

It is composed of:

- A starting flag character: $ for ASCII (24 hex)
- P and a cryopump or compressor address, when communicating with a cryopump or compressor on the network
- (examples: P00=cryopump #0; P20 = compressor #0) Or N when communicating directly to the Controller
- Message dependent Data Field Characters
- Message Checksum Character
- An ASCII carriage return (CR) code (0D hex)

CRC calculation for Brooks Cryosystem

Checksum calculation algorithm

1) Sum all bytes from an array of ASCII characters to each other

2) logically multiply the sum from step 1 by the mask **11,000,000** (192 in decimal)

3) divide the number from step 2 by mask **100 00 00** (64 in DEC)

4) The resulting number from step 1 **XOR** the number from step 3

5) Result from step 4 logically multiply (**AND**) by mask **111 111** in HEX (63 DEC)

6) **48 (DEC)** + result from step 5 = CRC

Check sum calculation (C#)

```
private void button1_Click(object sender, EventArgs e)
{
    var a = Convert.ToInt32(textBox2.Text, 16);
    var b = Convert.ToInt32(textBox3.Text, 16);
    var c = Convert.ToInt32(textBox5.Text, 16);
    var d = Convert.ToInt32(textBox4.Text, 16);
    var f = Convert.ToInt32(textBox11.Text, 16);
    var s = Convert.ToInt32(textBox12.Text, 16);
    var ss = Convert.ToInt32(textBox13.Text, 16);
    //  var f = Convert.ToInt32(textBox11.Text, 16);
    var result = a + b + c + d + f + s + ss;
    // textBox1.Text = (Convert.ToString(result, 2).PadLeft(8, '0'));
    //   0b11111111 ^ 0b100= 0b11110111
    int h = 192; //maska
    int z = 63;  //maska
    int mask76d_bin = result & h;
    textBox6.Text = (Convert.ToString(mask76d_bin, 2).PadLeft(8, '0'));
    int realmask= mask76d_bin / 64;
    textBox7.Text = (Convert.ToString(realmask, 2).PadLeft(8, '0'));
    int xor_result = realmask ^ result;
    textBox8.Text = (Convert.ToString(xor_result, 2).PadLeft(8, '0'));
    int maskd5d0 = xor_result & z;
    textBox9.Text = (Convert.ToString(maskd5d0, 2).PadLeft(8, '0'));
    int addend0 = 48 + maskd5d0;
    textBox10.Text = (Convert.ToString(addend0, 2).PadLeft(8, '0'));
    //hex representation of checksum
    string shex = Convert.ToString(addend0, 16);
    textBox1.Text = shex;
}
```

LabVIEW control software for cryopump system

Features:

- Direct control for cryopump and/or compressor

(2 types of regeneration,

supply/return pressure monitoring , water flowrate

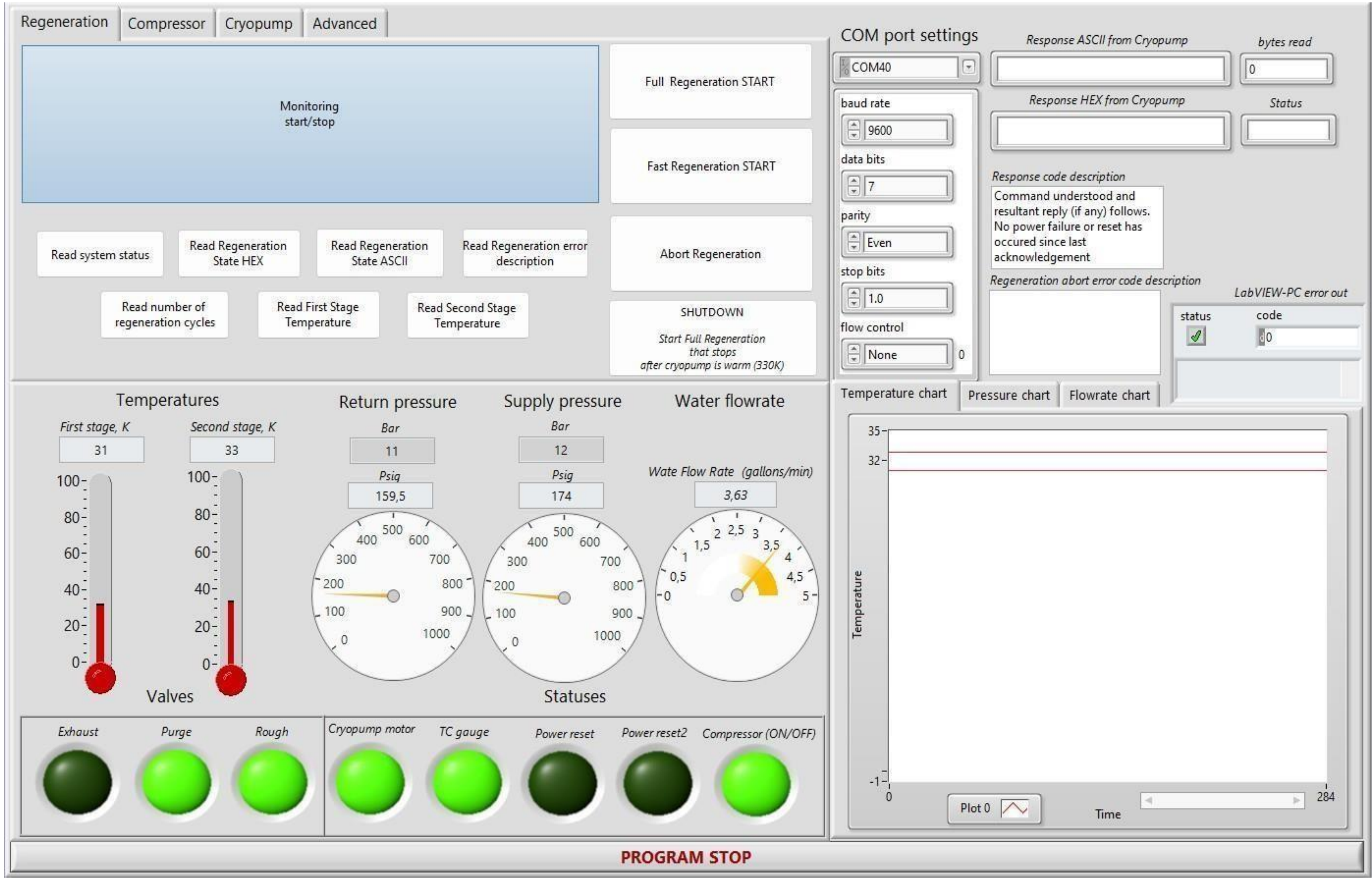
- Valves status and control

(Purge, Exaust, Rough)

- Event driven
- First and second

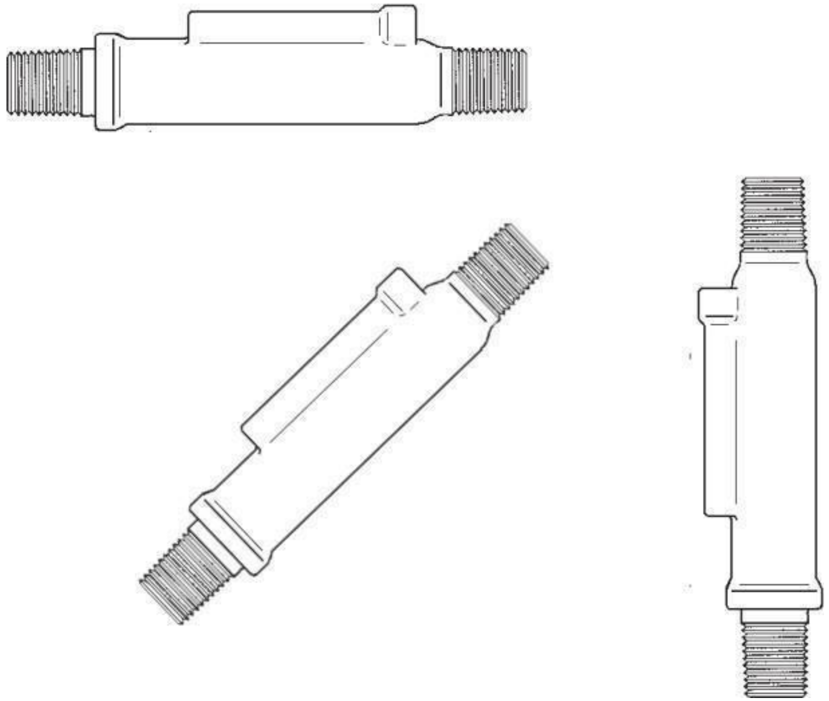
stage temperatures

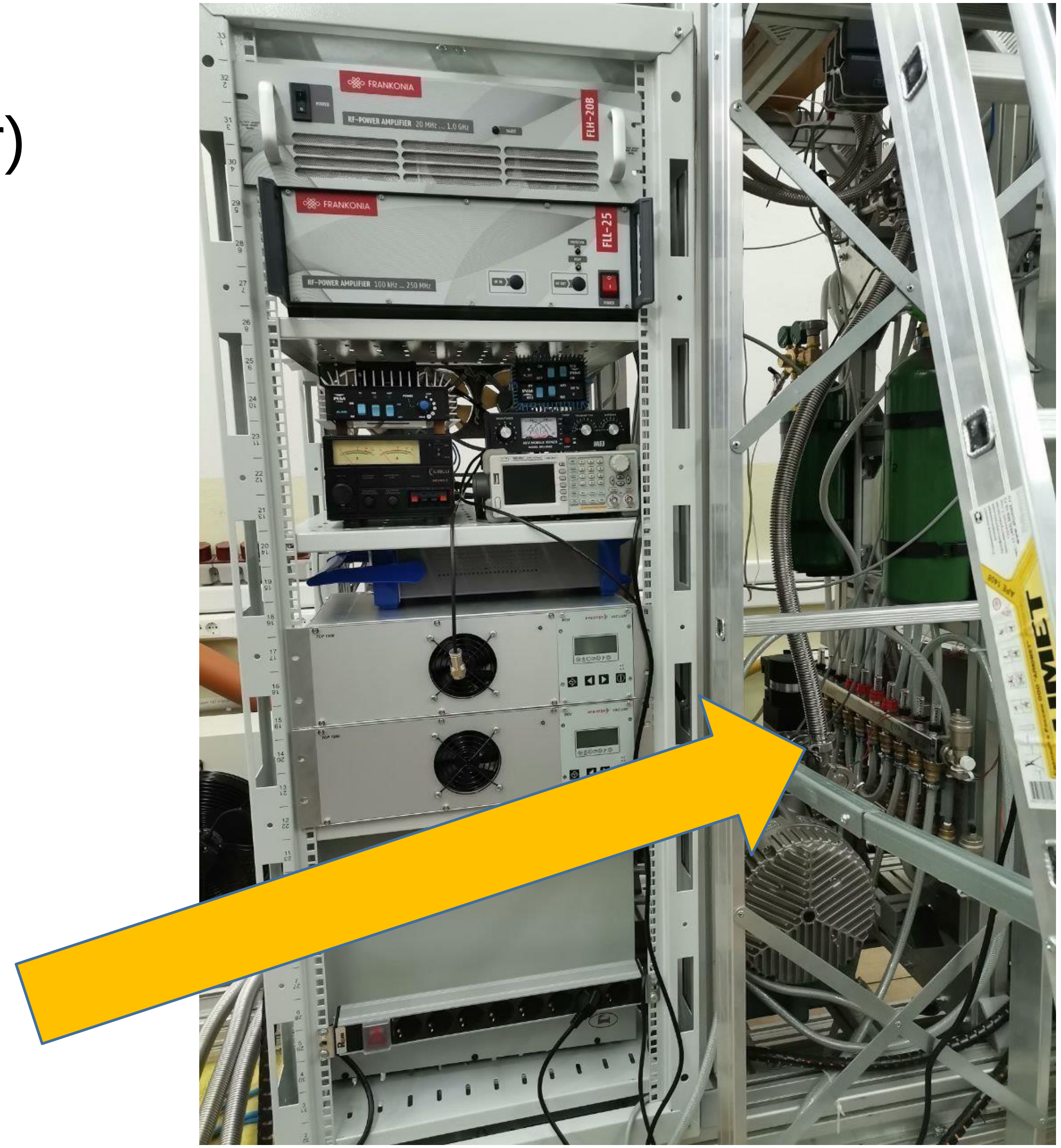
User interface



10 channels water monitoring for APol

Coolant loop monitoring (water)

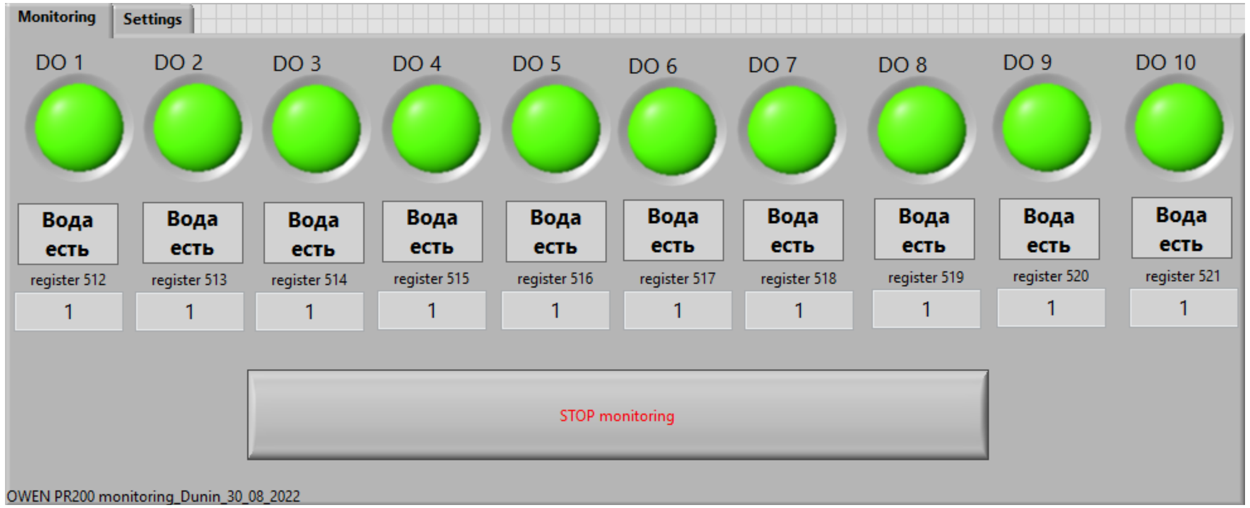


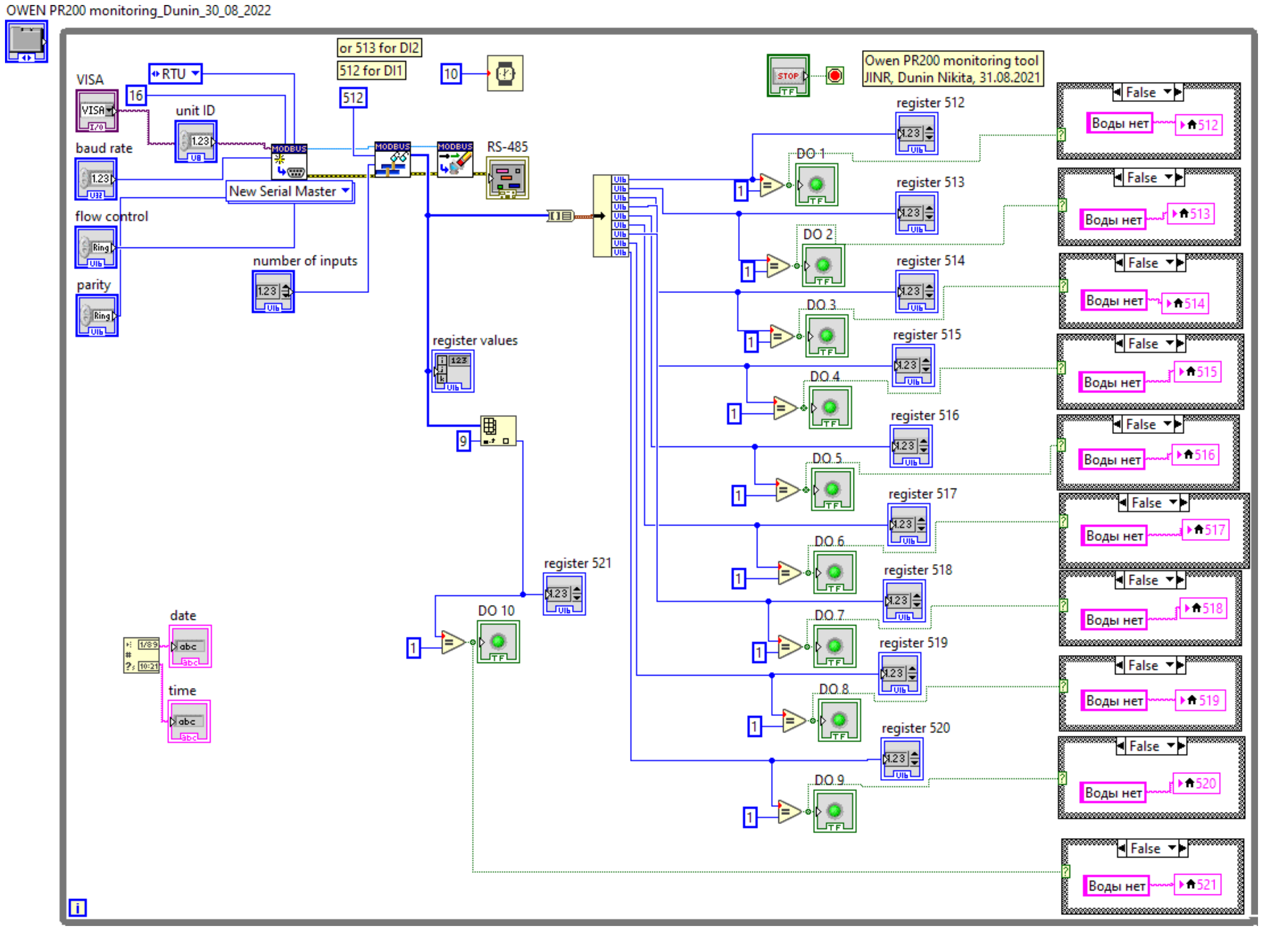


Dwyer P2 flow switches
(8 DI, 2 AI -voltage)

10 channels water monitoring for APol

Features:





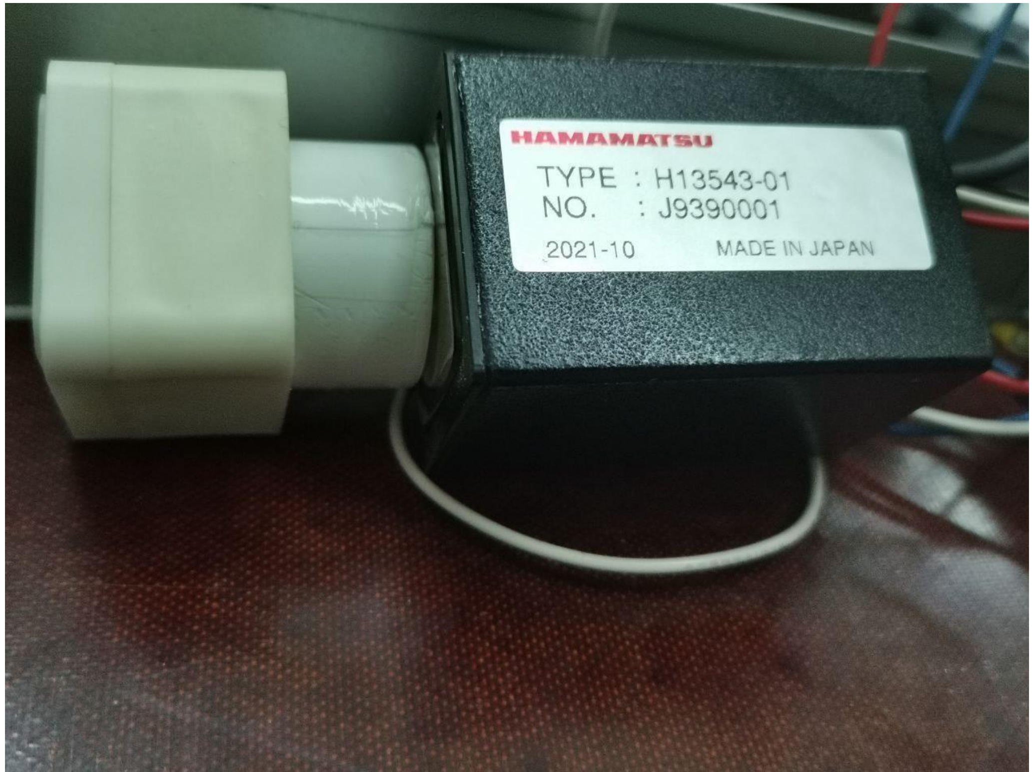
- Modbus protocol implementation
- Possibility to control different electrical loads with Owen PR200 PLC

Detector setup based on PMT with BGO scintillator

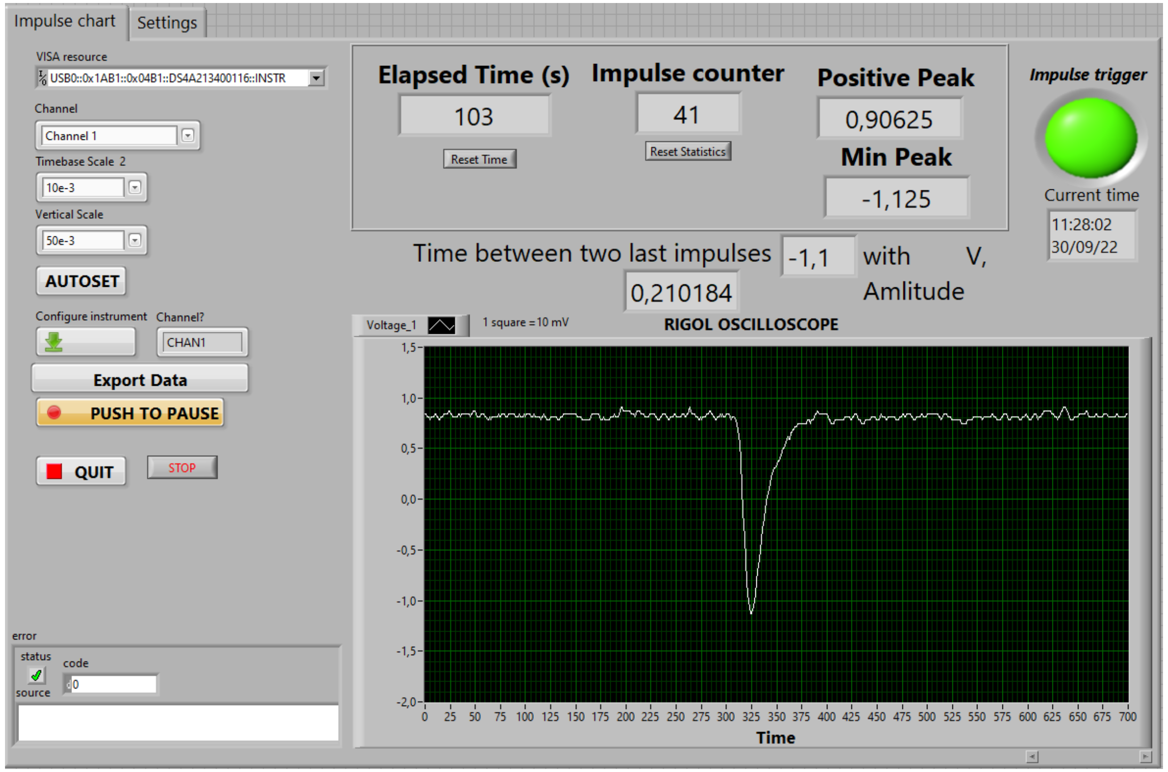
Dimensions of BGO crystal is 20*20*40

.Power supply – 5 V.

Internal high-voltage power supply circuit

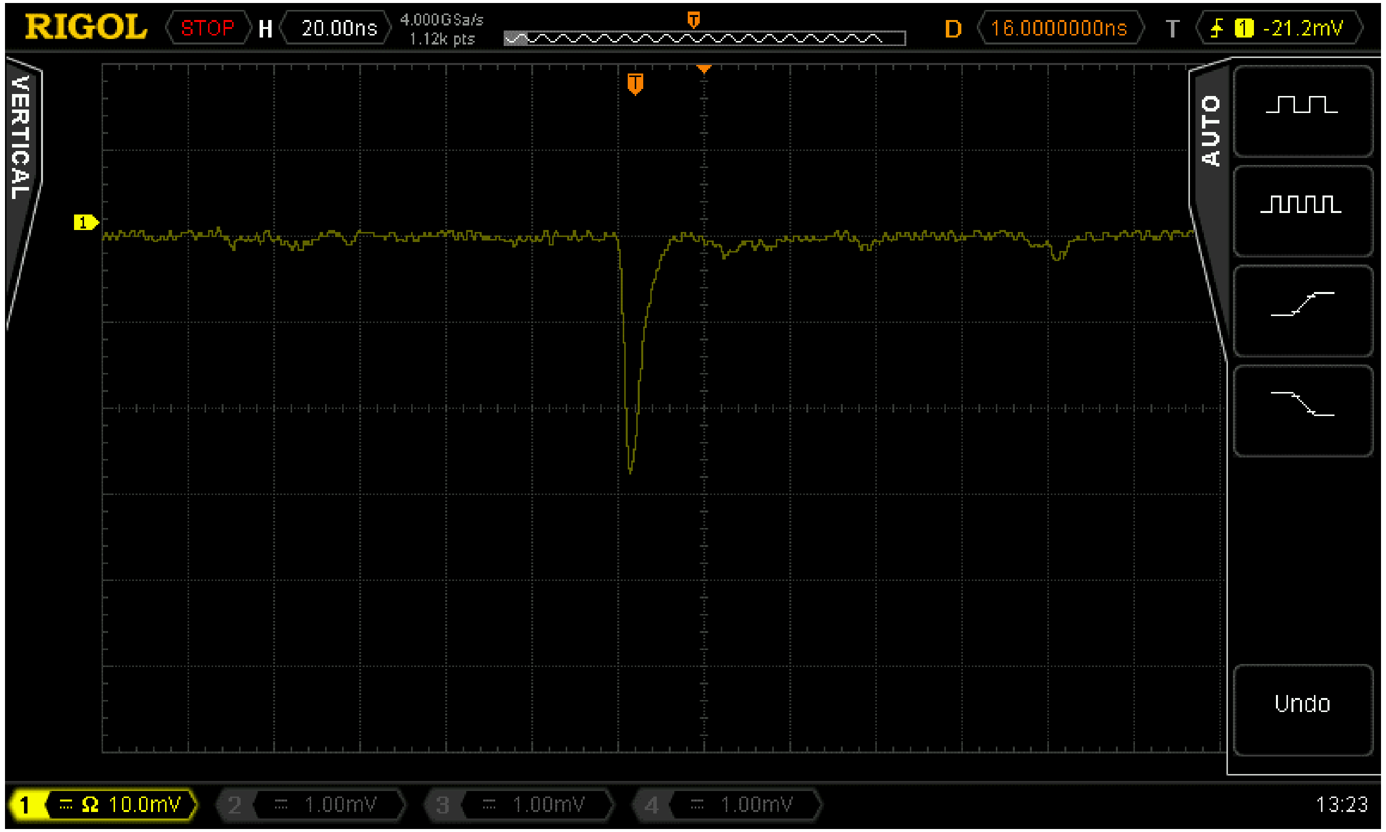


LV User interface for RIGOL DS4024



Single photoelectron mode

Amplitude 30 mV, length 15 ns, noise 2 mV



To measure single photoelectron mode we cover photocathode with a black cloth.

BGO cosmic shower

Amplitude 150 mV, length 1000 ns, noise 10 mV

BGO response characteristic (Bismuth germanade) same as plastic scintil.

BGO cosmic shower (Low voltage)

Amplitude 250 mV, length 500 ns, Noise 12mV

Amplitude 160 mV, length 600 ns, Noise 15 mV

Conclusions

Purchased Equipment – 95%
Instruments and electronic equipment – 90%
Setup Control Software – 30%
DAQ Software – 50%

- Testing of vacuum equipment has been completely carried out.
- Magnet system measurements and analysis have been carried out (Values are close to optimum).
- Preliminary tests of Dissociator and Atomic Beam Source performance have been carried out. (Atomic hydrogen beam intensity is about $7 \cdot 10^{16}$ atom/s, degree of dissociation is 80%)

Coordination of the location of the polarimeter in the ring is required

Final design of the interaction region is an open question up to now

Nearest plans

For the APol main tasks, it is sufficient to measure the vector polarization for polarized protons and deuterons

In near future, it is planned to install a magnetic system with subsequent measurements of the polarized atomic beam density using the mass spectrometer Prisma Pro©

Thank you for your attention!