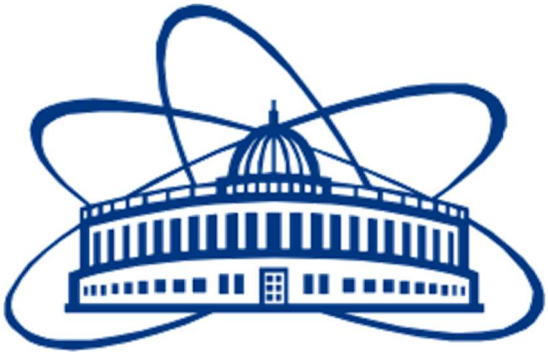

JOINT INSTITUTE FOR NUCLEAR RESEARCH

Flerov Laboratory of Nuclear Reactions

FINAL REPORT ON THE

SUMMER STUDENT PROGRAM

Construction of gas mixing system for Time Projection Chamber (TCP) with Residual Gas Analyzer (RGA) PrismaPlus Pfeiffer Vacuum

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Abstract

Inseparable part of any physical experiment are detectors, devices and sophisticated equipment like advanced mechanical and complex electronic construction. Without those things, no experiment can be done. Almost always, before the main experiment, every scientist spend a lot of time for designing, constructing and test experimental setup. In many fields of science, a design of a new devices and systems are determined by realization of future ideas which can lead to discoveries and novel results.

This document describes construction of gas mixing system for Time Projection Chamber (TCP) with continuous control of gas composition by using Residual Gas Analyzer. For preparing mixture of gases were used 4-channel flow meter conjugate with pressure stabilizer. Gas composition control system is based on PrismaPlus Pfeiffer Vacuum. A special test setup, containing vacuum chamber, turbo molecular pump and set valves, pipes and gauges was prepared.

As a result, it manage to achieve fully-working system, which can be used in many applications based of TCP.

1. Introduction.

- ## Time Projection Chamber

In physics, a time projection chamber (TPC) is a type of particle detector that uses a combination of electric fields and magnetic fields together with a sensitive volume of gas or liquid to perform a three-dimensional reconstruction of a particle trajectory or interaction.

The original design

The original TPC was invented by David R. Nygren, an American physicist, at Lawrence Berkeley Laboratory in the late 1970s.[1] Its first major application was in the PEP-4 detector, which studied 29 GeV electron–positron collisions at the PEP storage ring at SLAC.

A time projection chamber consists of a gas-filled detection volume in an electric field with a position-sensitive electron collection system. The original design (and the one most commonly used) is a cylindrical chamber with multi-wire proportional chambers (MWPC) as endplates. Along its length, the chamber is divided into halves by means of a central high-voltage electrode disc, which establishes an electric field between the center and the end plates. Furthermore, a magnetic field is often applied along the length of the cylinder, parallel to the electric field, in order to minimize the diffusion of the electrons coming from the ionization of the gas. On passing through the detector gas, a particle will produce primary ionization along its track. The z coordinate (along the cylinder axis) is determined by measuring the drift time from the ionization event to the MWPC at the end. This is done using the usual technique of a drift chamber. The MWPC at the end is arranged with the anode wires in the azimuthal direction, θ, which provides information on the radial coordinate, r. To obtain the azimuthal direction, each cathode plane is divided into strips along the radial direction.

In recent years other means of position-sensitive electron amplification and detection have become more widely used, especially in conjunction with the increased application of time projection chambers in nuclear physics. These usually combine a segmented anode plate with either just a Frisch grid or an active electron-multiplication element like a gas electron multiplier. These newer TPCs also depart from the traditional geometry of a cylinder with an axial field in favour of a flat geometry or a cylinder with a radial field.

Earlier researchers in particle physics also usually made use of a more simplified box-shaped geometry arranged directly above or below the beam line, such as in the CERN NA49 and NA35 experiments.

The Liquid Argon Time Projection Chamber (LArTPC)

In 1977, Carlo Rubbia devised a liquid-argon time projection chamber, or LArTPC. The LArTPC operates under many of the same principles as Nygren's initial TPC design, but uses liquid argon as a sensitive medium instead of gas.

Detector design and properties

Liquid argon is advantageous as a sensitive medium for several reasons. The fact that argon is a noble element and therefore has a vanishing electronegativity means that electrons produced by ionizing radiation will not be absorbed as they drift toward the detector readout. Argon also scintillates when an energetic charged particle passes by, releasing a number of scintillation photons that is proportional to the energy deposited in the argon by the passing particle. Liquid argon is also relatively inexpensive, making large-scale projects economically feasible. However, one of the primary motivations for using liquid argon as a sensitive medium is its density. Liquid argon is around one thousand times denser than the gas used in Nygren's TPC design, which increases the likelihood of a particle interacting in a detector by a factor of around one thousand. This feature is particularly useful in neutrino physics, where neutrino–nucleon interaction cross sections are small.

The body of a typical LArTPC is formed of three parts. On one side of the detector is a high-voltage cathode plane, used to establish a drift electric field across the TPC. Although the exact electric potential at which this is set is dependent on the detector geometry, this high-voltage cathode typically produces a drift field of 500 V/cm across the detector.

On the side opposite of the cathode plane is a set of anode wire planes set at potentials much higher (less negative) than that of the cathode. Each plane is separated from its neighbors by a small gap, usually on the order of 1 cm. A plane consists of many parallel conducting wires spaced by a few millimeters, and the angle at which the wires are oriented relative to the vertical varies from plane to plane. Together, these planes read out signals from the drift electrons. For a detector with N anode wire planes, the inner $N - 1$ planes are called induction planes. These are set at lower (more negative) potentials than the outer plane, allowing drift electrons to pass through them, inducing signals that are used for event reconstruction. The outer plane is called the collection plane because the drift electrons are collected on these wires, producing additional signals. Having multiple planes with different wire orientations permits two-dimensional event reconstruction, while the third dimension is found from electron drift times.

The third part is a field cage between the cathode and anode. This field cage maintains a uniform electric field between the cathode and the anode, so that drift electron trajectories deviate as little as possible from the shortest path between the point of ionization and the anode plane. This is intended to prevent distortion of particle trajectory during event reconstruction.

A light-collection system often accompanies the basic LArTPC as a means of extracting more information from an event by scintillation light.It can also play an important role in triggering, because it collects scintillation light only nanoseconds after the particle passes through the detector. This is comparatively (on the order of 1000 times) shorter than the time taken by the freed electrons to drift to the wire planes, so it is often sufficient to demarcate the collection time of scintillation photons as a trigger time (t0) for an event. With this trigger time, one can then find electron drift times, which enables three-dimensional reconstruction of an event. While such systems are not the only means by which a LArTPC

can identify a trigger time, they are necessary for studying phenomena like supernovae and proton decay, where the particles undergoing decay or interaction are not produced in a human-made accelerator and the timing of a beam of particles is therefore not known. Photomultiplier tubes, light guides, and silicon photomultipliers are examples of instruments used to collect this light. These are typically positioned just outside the drift volume.

Signal readout

In a typical LArTPC, each wire in each anode plane is part of an RC circuit, with the wire itself located between the resistor and capacitor. The other end of the resistor is wired to a bias voltage, and the other end of the capacitor is wired to the front-end electronics. The front-end electronics amplify and digitize the current in the circuit. This amplified and digitized current as a function of time is the "signal" that is passed to the event reconstruction.

For a given anode plane wire, the signal produced will have a specific form that depends on whether the wire is located in an induction plane or in a collection plane. As a drift electron moves toward a wire in an induction plane, it induces a current in the wire, producing a "bump" in output current. As the electron moves away from a wire, it induces a current in the opposite direction, producing an output "bump" of the opposite sign as the first. The result is a bipolar signal. In contrast, signals for a collection plane wire are unipolar, since electrons do not pass by the wire but are instead "collected" by it. For both of these geometries, a larger signal amplitude implies that more drift electrons either passed by the wire (for induction planes) or were collected by it (for the collection plane).

The signal readout of all of the wires in a given anode plane can be organized into a 2D picture of a particle interaction. Such a picture is a projection of the 3D particle interaction onto a 2D plane whose normal vector is parallel to the wires in the specified anode plane. The 2D projections corresponding to each of the anode planes are combined to fully reconstruct the 3D interaction.

A diagram of LArTPC design and basic operating principles is shown on Fig. 1.

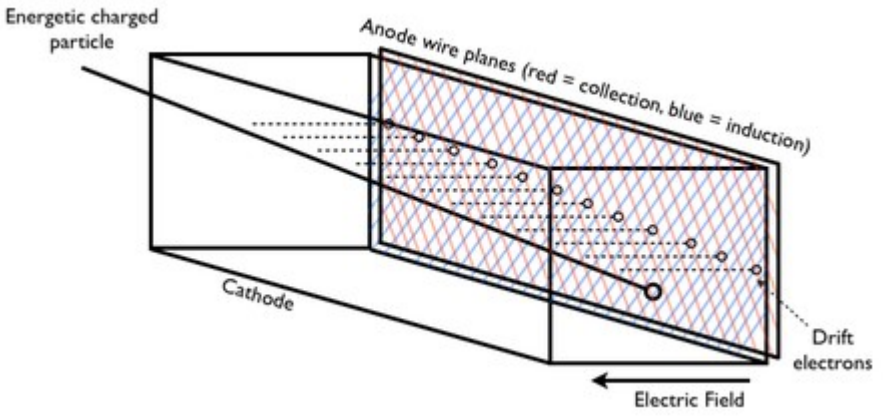


Fig. 1. Diagram of LArTPC design and basic operating principles

- **Residual Gas Analyzer- PrismaPlus Pfeiffer Vacuum**

RGA is a small and usually rugged mass spectrometer, typically designed for process control and contamination monitoring in vacuum systems. Utilizing quadrupole technology, there exists two implementations, utilizing either an open ion source (OIS) or a closed ion source (CIS). RGAs may be found in high vacuum applications such as research chambers, surface science setups, accelerators, scanning microscopes, etc. RGAs are used in most cases to monitor the quality of the vacuum and easily detect minute traces of impurities in the low-pressure gas environment. These impurities can be measured down to 10^{-15} Torr levels, possessing sub-ppm detectability in the absence of background interferences.

RGAs would also be used as sensitive in-situ leak detectors commonly using helium, isopropyl alcohol or other tracer molecules. With vacuum systems pumped down to lower than 10^{-5} . Torr—checking of the integrity of the vacuum seals and the quality of the vacuum—air leaks, virtual leaks and other contaminants at low levels may be detected before a process is initiated.

Open ion source

OIS is the most widely available type of RGA. Residual Gas Analyzers measure pressure by sensing the weight of each atom as they pass through the quadrupole. Cylindrical and axially symmetrical,[1] this kind of ionizer has been around since the early 1950s. The OIS type is usually mounted directly to the vacuum chamber, exposing the filament wire and anode wire cage to the surrounding vacuum chamber, allowing all molecules in the vacuum chamber to move easily through the ion source.

With a maximum operating pressure of 10^{-4} Torr and a minimum detectable partial pressure as low as 10^{-14} Torr when used in tandem with an electron multiplier.

OIS RGAs measure residual gas levels without affecting the gas composition of their vacuum environment, though there are two main performance limitations. First, outgassing of water from the chamber, H_2 from the OIS electrodes and most varieties of 300-series stainless steel used in the surrounding vacuum chamber due to the high temperatures of the hot-cathode source (> 1300 °C). Secondly Electron Stimulated Desorption (ESD) is noted by peaks observed at 12, 16, 19 and 35 u rather than by electron-impact ionization of gaseous species, with the effects similar to outgassing effects. This is frequently counteracted by gold-plating the ionizer which in turn reduces the adsorption of many gases. Using platinum-clad molybdenum ionizers is an alternative.

Closed ion source

With applications requiring measurement of pressures between 10^{-6} and 10^{-5} Torr, the problem of ambient and process gases can be significantly reduced by replacing the OIS configuration with a CIS sampling system. Such an ionizer sits on top of the quadrupole mass filter and consists of a short, gas-tight tube with two openings for the entrance of electrons and exit of ions. The ions are formed close to a single extraction plate and exit the ionizer. Electrically insulated alumina rings seal the tube and the biased electrodes from the rest of the quadrupole mass assembly. The ions are produced by electron impact directly at the process pressure. Such design has been applied to gas chromatography mass spectrometry instruments before adaption by quadrupole gas analyzers.

The CIS anode may be viewed as a high conductance tube connected directly to the process chamber. The pressure in the ionization area is virtually the same as the rest of the chamber. Thus the CIS ionizer produces ions by electron impact directly at the process pressure whilst the rest of the mass analyzer is kept under high vacuum. Such direct sampling provides good sensitivity and fast response times.

PrismaPlus is mass spectrometer is designed to partial pressure analysis at pressure < 10^{-4} mbar, but to not overload device, the pressure is limited to less than 10^{-5} mbar. Typical applications are measurments, monitoring and process control functions in vacuum systems. On Fig. 2. are shown scheme of quadrupole, active zone of analyzer and main part containing electronic system.

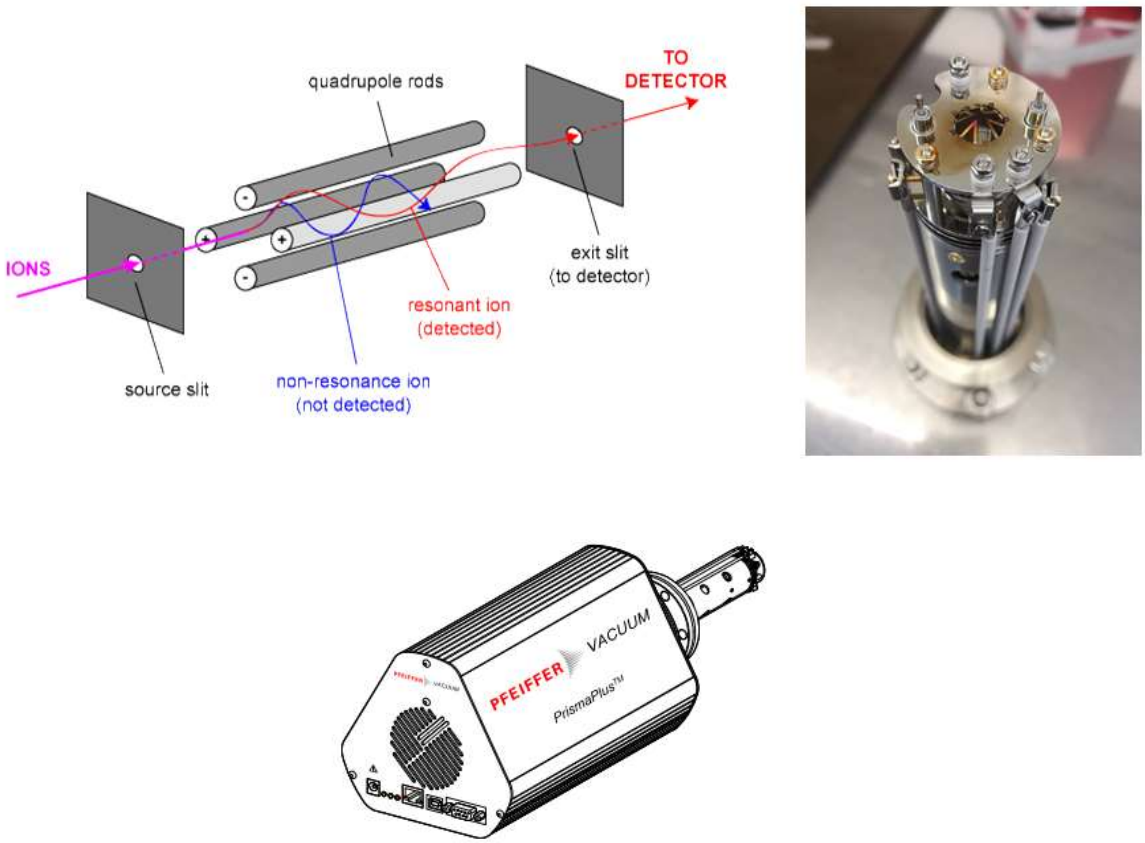


Fig 2. Scheme of quadrupole, active zone of analyzer and main part containing electronic system.

The mass spectrometer system comprises of the following components shown on Fig. 3.

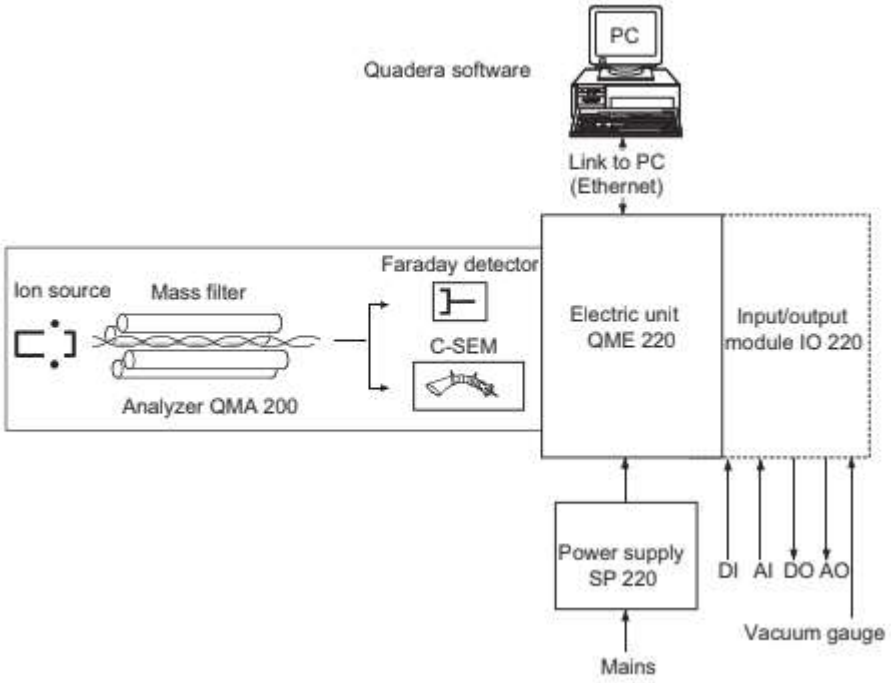


Fig. 3. Components of mass spectrometr

- **OTPC as special type of TPC**

Optical Time Projection Chamber (OTPC) is a unique device, designed and constructed at Faculty of Physics of University of Warsaw (Poland) by a team led by prof. dr hab. Wojciech Dominik. The project of developing a special detector to study the 2p radioactivity was born in a conversation with prof. Wojciech Dominik on December 14, 2002. The main idea of combining optical readout with a time projection chamber was adopted early in 2003. First images of alpha particles, by a CCD sensor, were taken in 2004. The first prototype of the full OTPC system was tested with the beam of 12C at the Warsaw Cyclotron in March 2006. More information about OTPC can be found in [1].

The first serious test of the OTPC was performed at FLNR lab at JINR Dubna in June 2006. By fragmentation of 20Ne beam at 50 MeV/u various beta delayed proton and alpha emitters were produced. Selected ions were separated and identified in flight by the ACCULINNA separator. We were implanting them into the OTPC and waiting to see their decay with emission of charged particles. The counting gas was a mixture of 49% He + 49% Ar + 1% N2 + 1% CH4 at atmospheric pressure. Results of this experiment are mentioned in [2].

Principle of operation is that an ion to be studied is stopped in the active volume, filled with a gas mixture and homogenous electric field; the ion and charged particles emitted in its decay ionize the gas; ionization electrons drift towards amplification section with a constant velocity; in the final stage of the charge amplification light is emitted which is recorded by means of a CCD camera and a photomultiplier tube (PMT); the signal from the PMT is sampled by a digital oscilloscope yielding the total light intensity as a function of time; combination of this information with the CCD image allows to reconstruct the particle's track in three dimensions; a special gating electrode is used to reduce the sensitivity of the chamber when the heavy ions are implanted. Scheme of OTPC is shown on Fig. 4. First versions of the OTPC used wire-mesh electrodes in the amplification zone, later replaced by the GEM foils (Fig. 5).

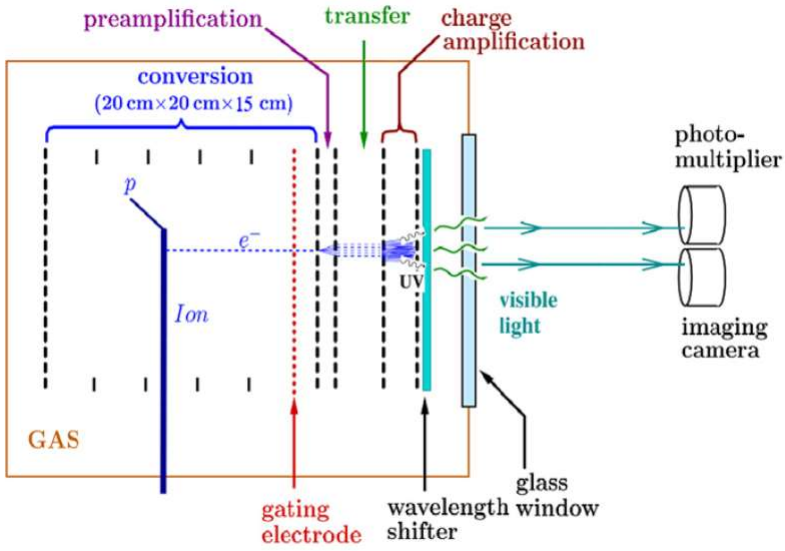


Figure 4. Schematic view of the OTPC detector[1].

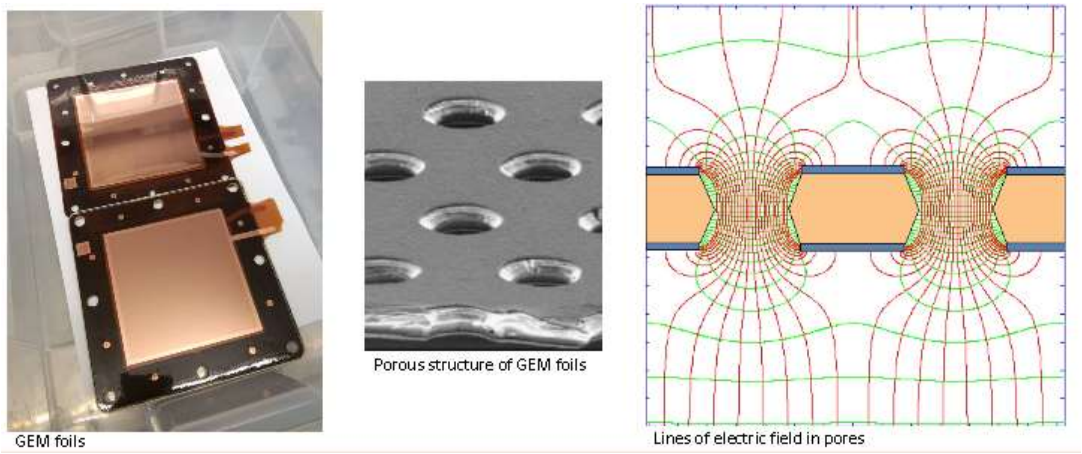


Fig. 5. GEM foils.

[1] Miernik et al., Nucl. Instr. Methods A 581 (2007) 194

2. Construction of gas mixing system.

One of main part of constructed setup is four channel flow meter and pressurizer developed by BETA-ERG company from Warsaw, Poland. System communicate with PC through RS-485 standard protocol. To avoid incompatibility with PC without this type of port, special RS-485/USB converter was used. Flow meter, pressure stabilizer and signal converter are presented on Fig. 6.

Because of lack special wires, almost all of them were made in addition.

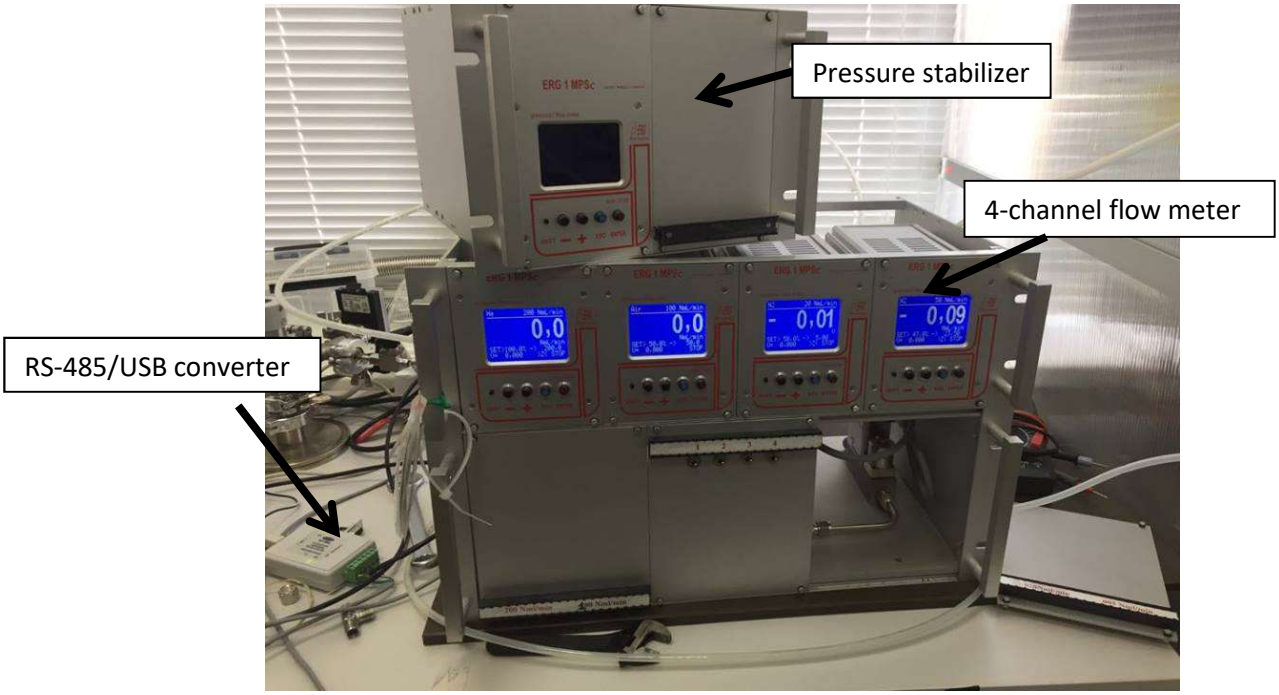


Fig. 6. Four channel flow meter with pressurizer.

Control of gas mixing system can be done via MONITOR software. Every channel of flow meter is manage by stand-alone controller. Any controller has unique Mod Bus (MB) address, and can be recognized as individual device. Thanks to RS-485 standard and advanced software, set of controller can work in Master/Slave mode. Controller for pressure stabilizer is identical as controllers used for flow meters, also MONITOR software has implemented packages to communicate and manage pressurizer. Main interface of MONITOR software is presented on Fig. 7.

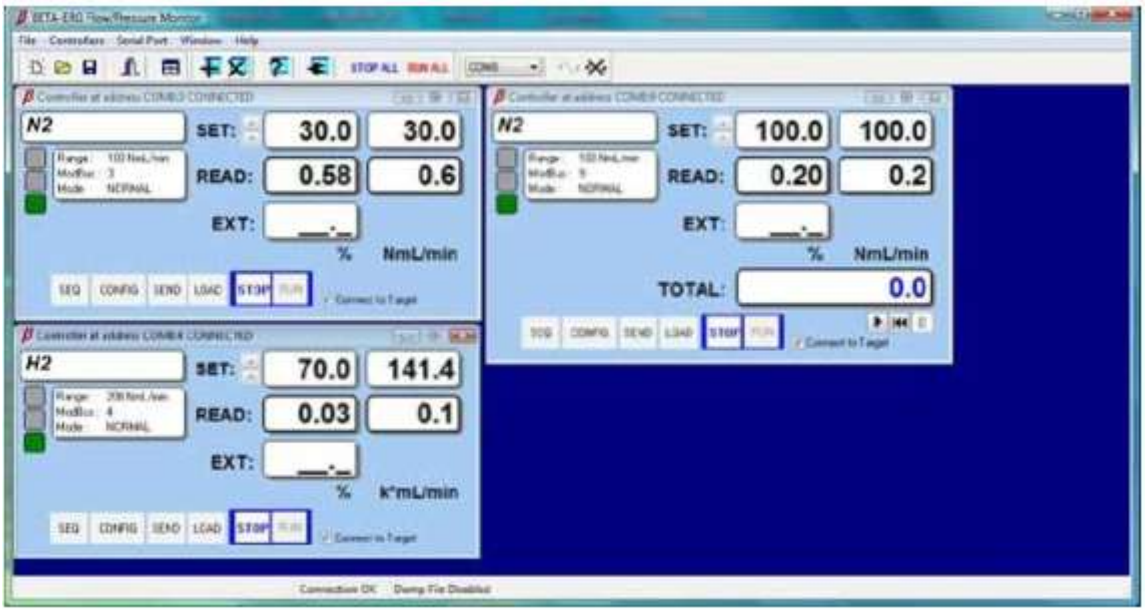


Fig. 7. Interface of MONITOR software.

Software can automatically scan constructed network of devices, find compatible controllers and add them to current configuration. As result, special frames are created, each is correspond to each controller. An example fram is presented on Fig. 8.

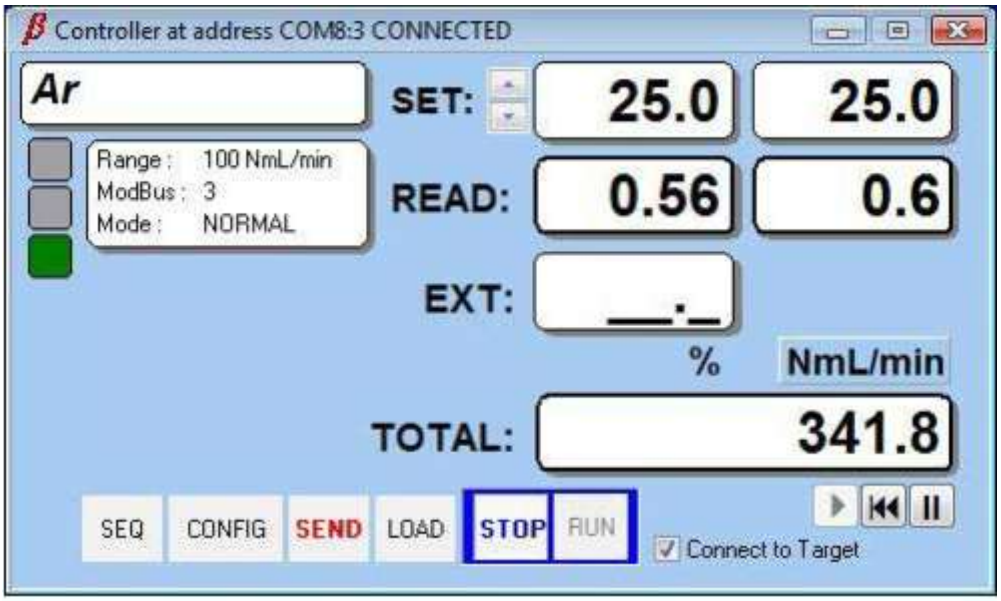


Fig. 8. Example frame of flow meter controller.

Using this software, many useful feature can be done. With SEQ, complex macros of sequential changes of parameters can be done in simple way. Using CONFIG, change of parameters like type of gas, scale of flow, conversion factor and operation mode can be arbitrarily set. Button SEND and LOAD can send applied setting to controller, and get configuration previously set manually on controller. With STOP and RUN, initiation and shut of flow can be done immediately.

Software has option to save and load configured work space, it's very useful when experimental setup is constructed in advance.

To check and monitor composition of gas mixture, a lot of measures where done using PrismaPlus RGA. Few of them, are presented in further part of the document.

Figure 9 presents that before injection , the level of nitrogen is the highest. After injection argon, its level is the highest.

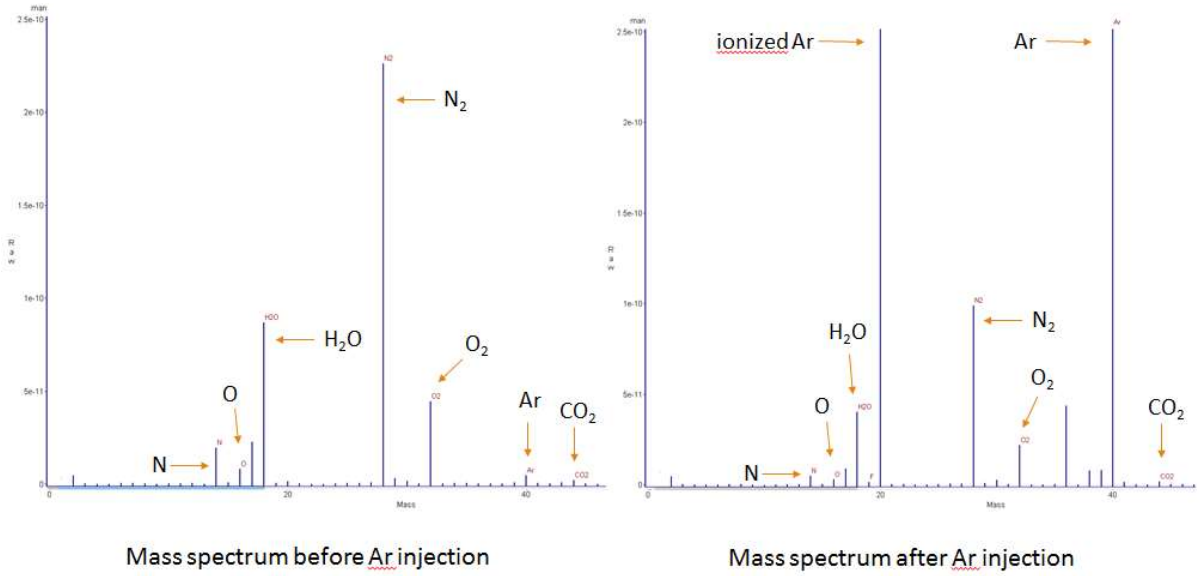


Fig. 9. Change amount of nitrogen and argon after injection argon measured by RGA.

In Figure 10 a vacuum setup is presented.

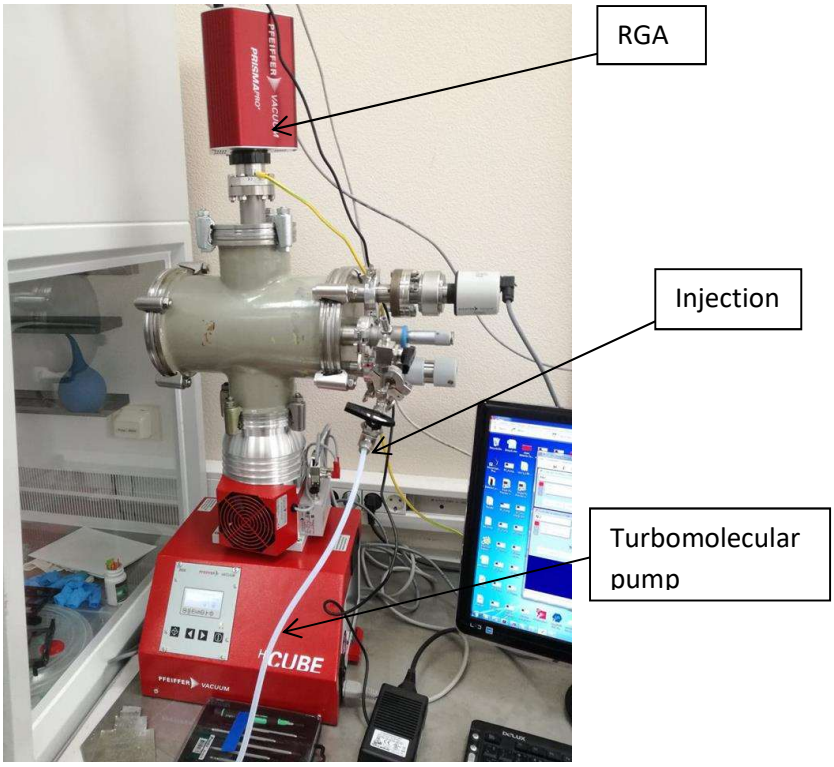


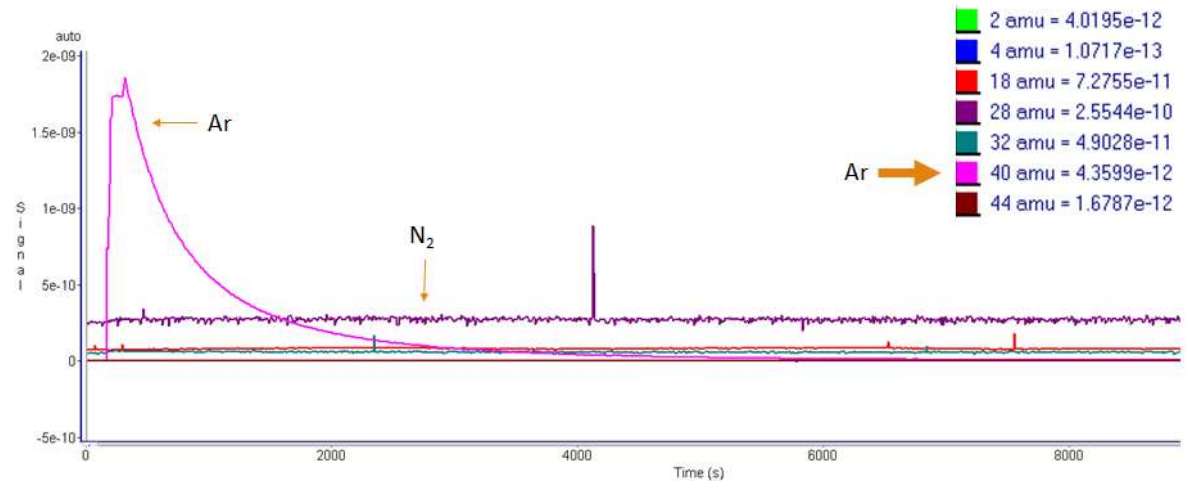
Figure 10. Vacuum setup.

In this setup, we can obtain a pressure in order 10^{-6} mbar. As it is shown on figure 11.

Figure 11. Low pressure which mean good level of vacuum.

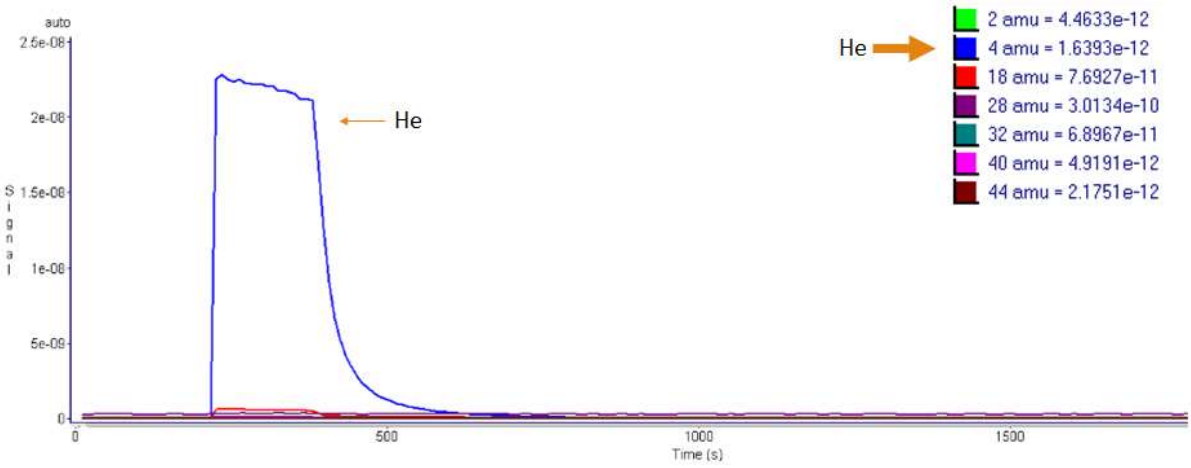
3. Test experiments

Firstly, I inject argon to the setup. The amount of argon is raised and falls after few seconds. Level of nitrogen and other gases is the same.

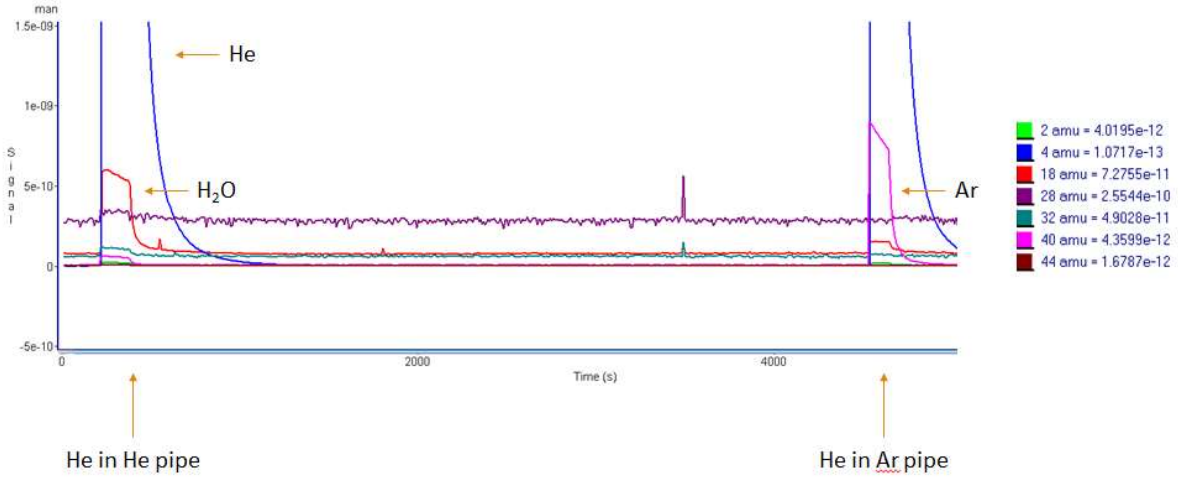


Graph 1. Time spectrum after Ar injection.

On Graph 2, for about 250 seconds amount of helium is on the same, high level, and after 250 seconds falls.

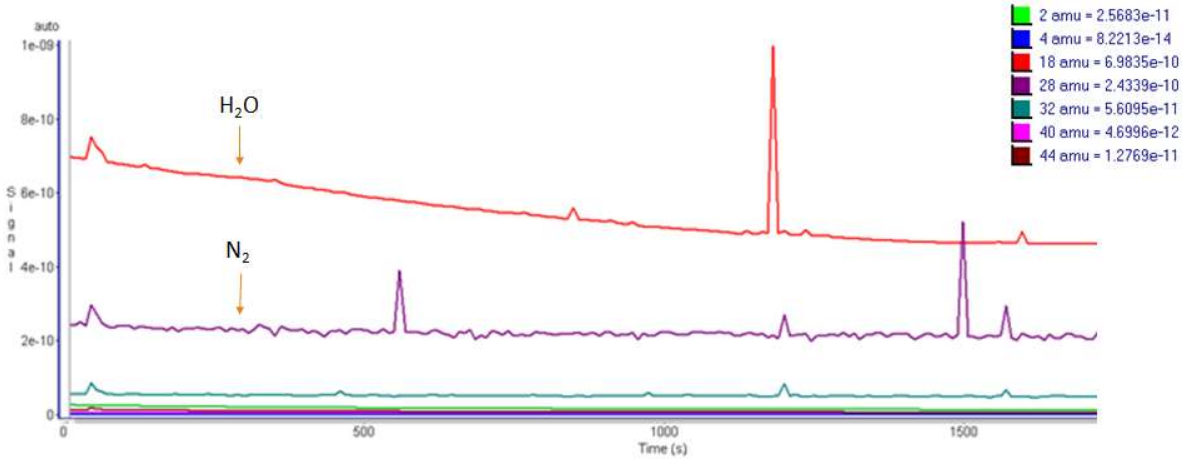


Graph 2. Time spectrum after He injection.



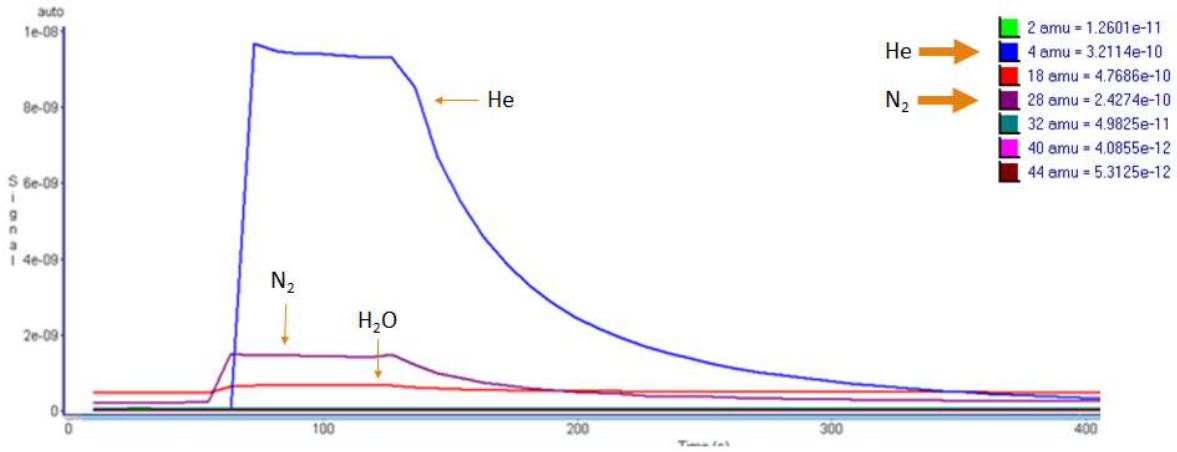
Graph 3. Time spectrum after He injection using pipe contaminated with Ar (zoom).

A test measurement on Graph 4 shows that in setup there is nitrogen and H_20 which mean that vacuum is not good.



Graph 4. Time spectrum of measurement of gas composition with recent construct of vacuum system.

Test measurement on Graph 1, shows that height of signal is proportional to amount of gas in the mixture, and after about 250 seconds falls.



Graph 5. Test of gas mixing system to check contribution of selected gases to the gas mixture. Gas mixture of 95% He_2 and 5% of N_2 has been prepared using BETA-ERG mixing system.

4. Conclusions

Main goal of my stay in JINR during Summer Student Program was to design, build and test system for preparing and control mix of gases.

Application for this setup is to obtain optimal conditions of ionizing medium used in TPC. It manage to achieve fully working mixing gas system based on 4-channel flow meter and pressure stabilizer. Another advantage of this system is continuous measurement of gas composition by using residual gas analyzer.

To prepare this system and make test, I needed to learn enormous amount of knowledge and experience. To construct vacuum system I spend many time for consultations about technical aspects of equipment and state-of-art in vacuum systems. As result, I've gained a lot of experience and practical skill necessary to work with low pressure constructions. Another field of science which I get to know was computer science and electronics. Knowledge of protocols, standards of communications, networks, different types of hardware and software and many other things is even more than useful during construction of this type of projects. In other side, without gained experience with soldering, preparing electric and pneumatic connection, assembling this kind of system is impossible. Usually every piece of system can be bought or ordered, but using knowledge and practical skills, preparation of simple parts is much faster and certain.

During Summer Student Program, I've gained exceptional experience and skills, which are very valuable and priceless in my future studies.

I hope that system will be useful for next experiments and applications.

5. Acknowledgments

In that place I want to heartily thank to my supervisor dr Grzegorz Kamiński from Flerov Laboratory of Nuclear Reactions for the introduction into the world of exotic nuclei and showing all advantages of work in the nuclear physics laboratory.

I would also sincerely thank to Joint Institute for Nuclear Research for the possibility of participating in Summer Student Program, which is not only important scientific experience, but also open minding adventure and opportunity to get to know Russian culture. I will mention very well in the beautiful Dubna surrounding.

In the end I wish to thank all of people that I met during my practice – other students and workers of JINR for interesting discussions, experience they shared with me and unforgettable time that I spend here.

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