He3-He4 Dilution Refrigerators,

Results, Traditions,
Dzhelepov Lab. of Nuclear Problems
JINR, Dubna
50-ty years anniversary

USOV Yury, **3.10.2016**
Montenegro, Budva, Becici

London, Clarke and Mendoza - proposed a continuously working Refrigerator based on the principle of Dilution of He3 in He4. Phys. Rev. 128 (1962), 1992.

1). Neganov B.S., Borisov N.S. and Liburg M.Yu. “Zh. Exp. Teor. Fiz.” 50 (1966) 1445.

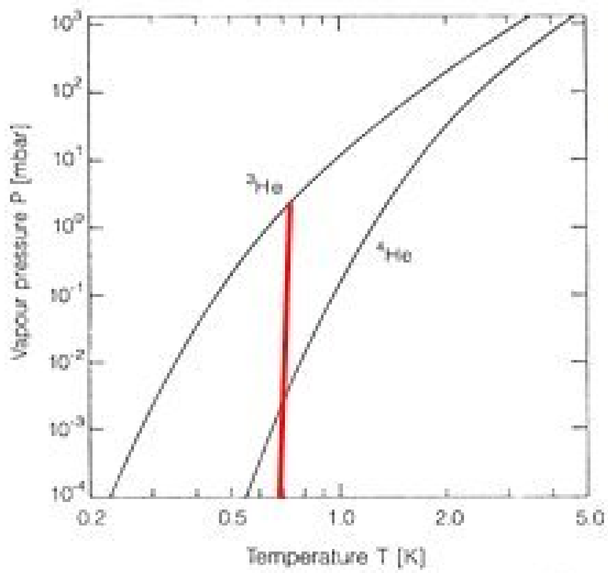
T min. = 0.05 K

2). Hall H.E., Ford P.J. and Thomson K. “Cryogenic”, 6, (1966) 80.

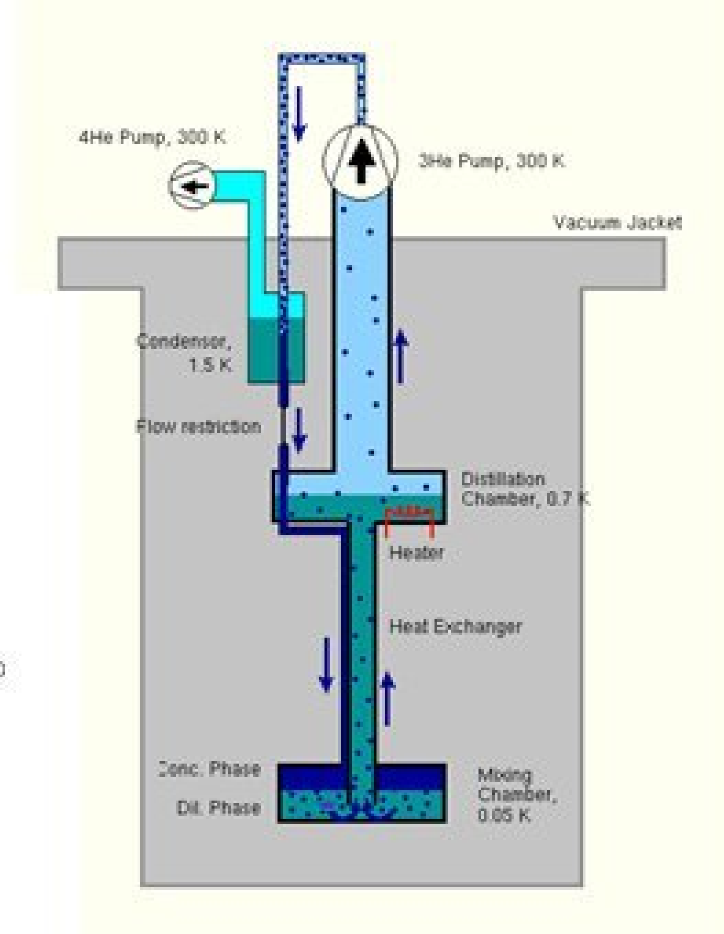
T min. = 0.2 K

3) P. Das, R. de Bryan Outboter and K.W.Taconis, LT 9, 1965, pp. 1253-1255.

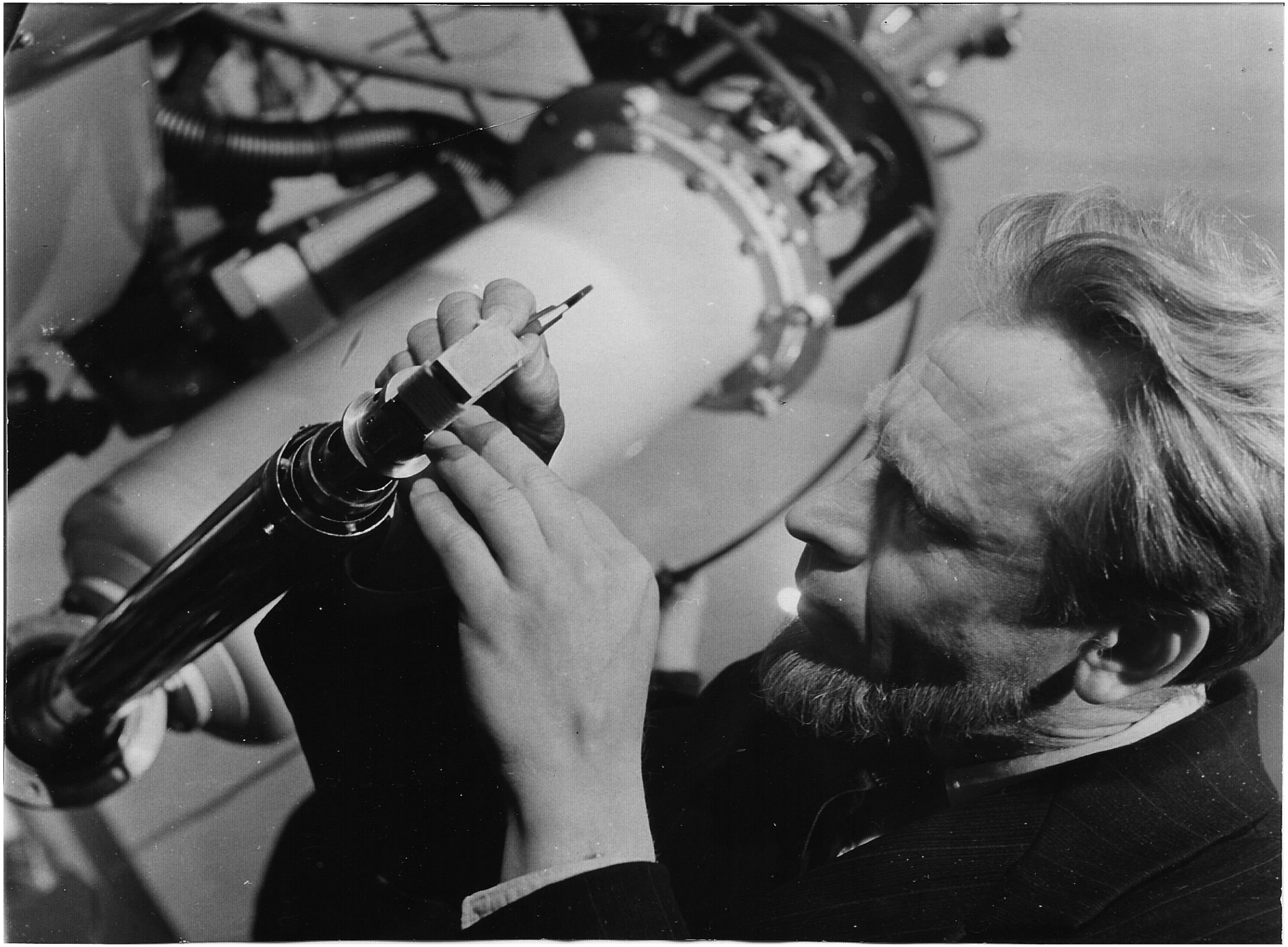
T min. = 0.22 K



Vapour pressures of liquid ^{3}He and liquid ^{4}He

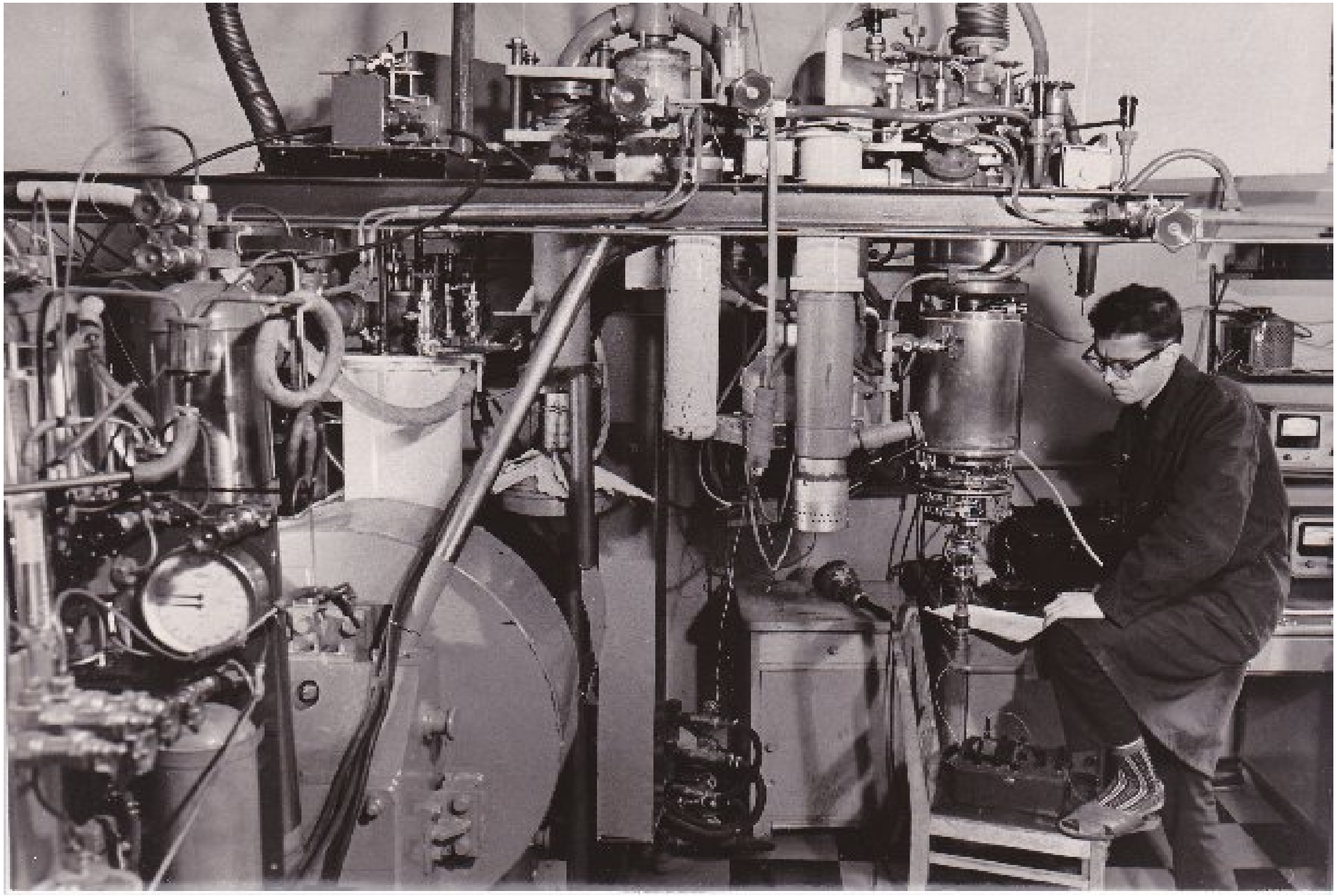


1. 3Helium absorbs energy when it dissolved into diluted phase
2. $Q = n * [H_d(T) — H_c(T)] \approx 82nT^2$
   Heat Q absorbed by n moles 3Helium
3. Distillation in the «Still» at 0.7K



B.S.Neganov during tuning of 1K Dynamic Polarized target (app.1965).

LMN target development started at Dubna in 1964 when Chamberlain supplied the exact prescription for the crystal production. The TARGET prepared by Luschikov, Neganov, Parfenov and Taran (Sov.Phys. JETP 22, 1966, 285) was first used pp-scattering at 660 MeV at the Dubna-Synchrocyclotron.



(1966) A combine setup including a 1K dynamic polarized target and a dilution refrigerator where an ultra low temperature 5 mK was reached.

An ultra low part of the cryostat of the dilution refrigerator

Experience with Polarized Dynamic Targets and achieving Very Low Stationare Temperatures in 1966 at JINR by B.S.Neganov, N.S.Borisov and M.Yu.Liburg and another group gave rise to the IDEA of using a radically new cooling technique based on dissolving 3He in 4He, to create a Frozen Spin Polarized Target. In fact, three facilities of this type had been developed which are used until now in experiments at the beams of IHEP-Protvino, PNPI-Gatchina and Charles University-Prague. The short history of the development of such proton and deuteron targets at the JINR is given.

The principle of operation of a frozen spin target is based on long nuclear spin relaxation time at low temperatures (≈ 50 mK) and moderate magnetic fields (≥ 0.3 T). After the polarization build-up with the Dynamic Nuclear Polarization process, the microwave power is turned off and the polarization is "frozen in". Then a magnetic field is lowered till about 0.3 T, so the spin relaxation time can be many days at about 50 mK.

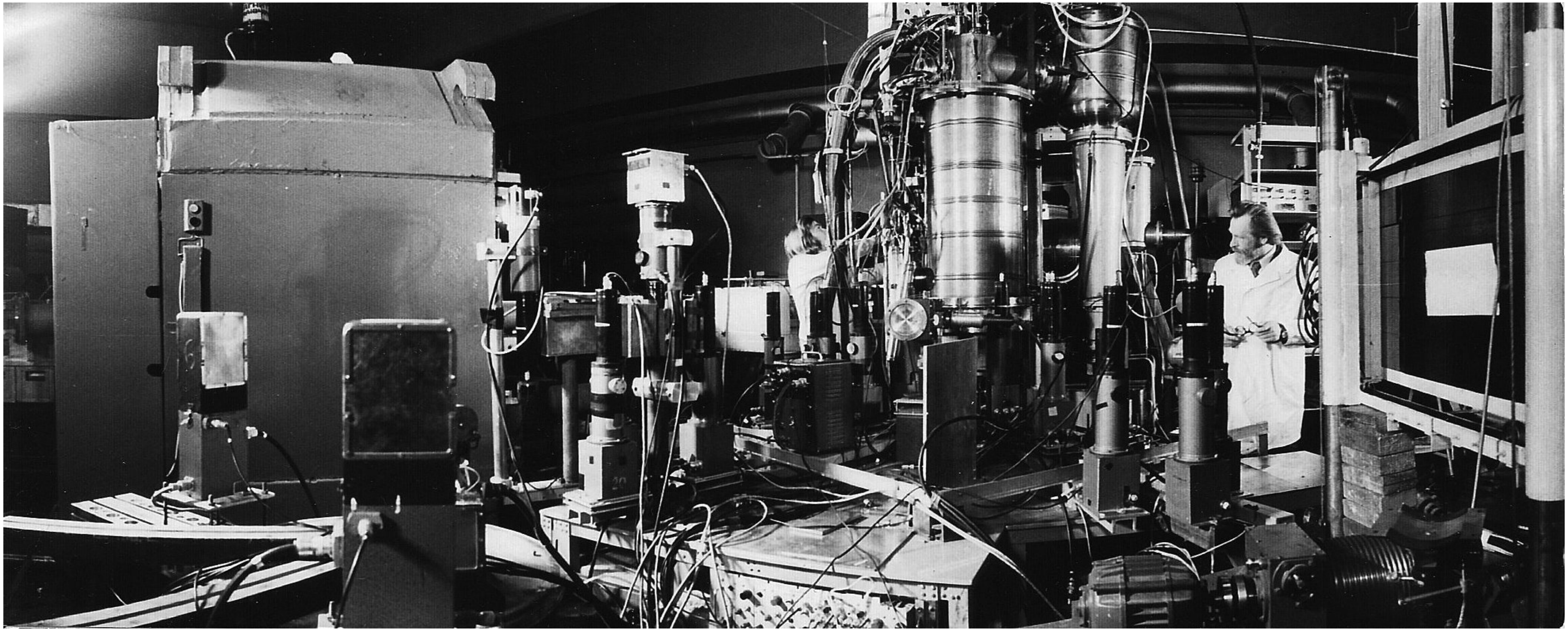
The first Frozen Polarized Target (1975)

during Tests Preparation

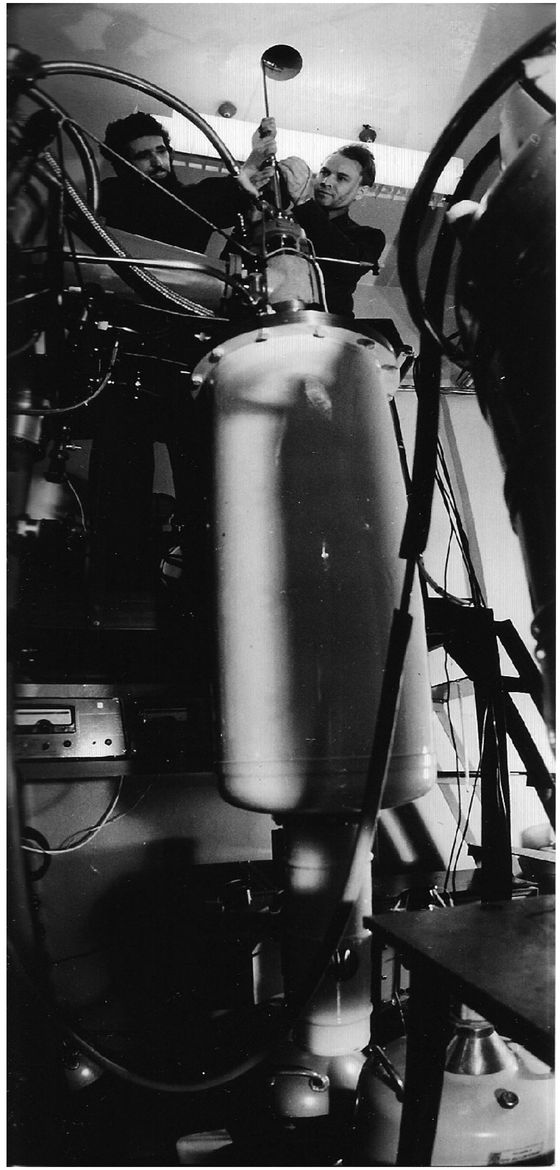
(B. Neganov and N. Borisov)

In 1975 at the Laboratory of Nuclear Problems JINR the experiments at the Phasotron of LNP on measurement of a polarization parameter in the elastic *pp*-scattering were begun with a knewly made frozen spin proton target PT. This target is working at Gatchina until now.

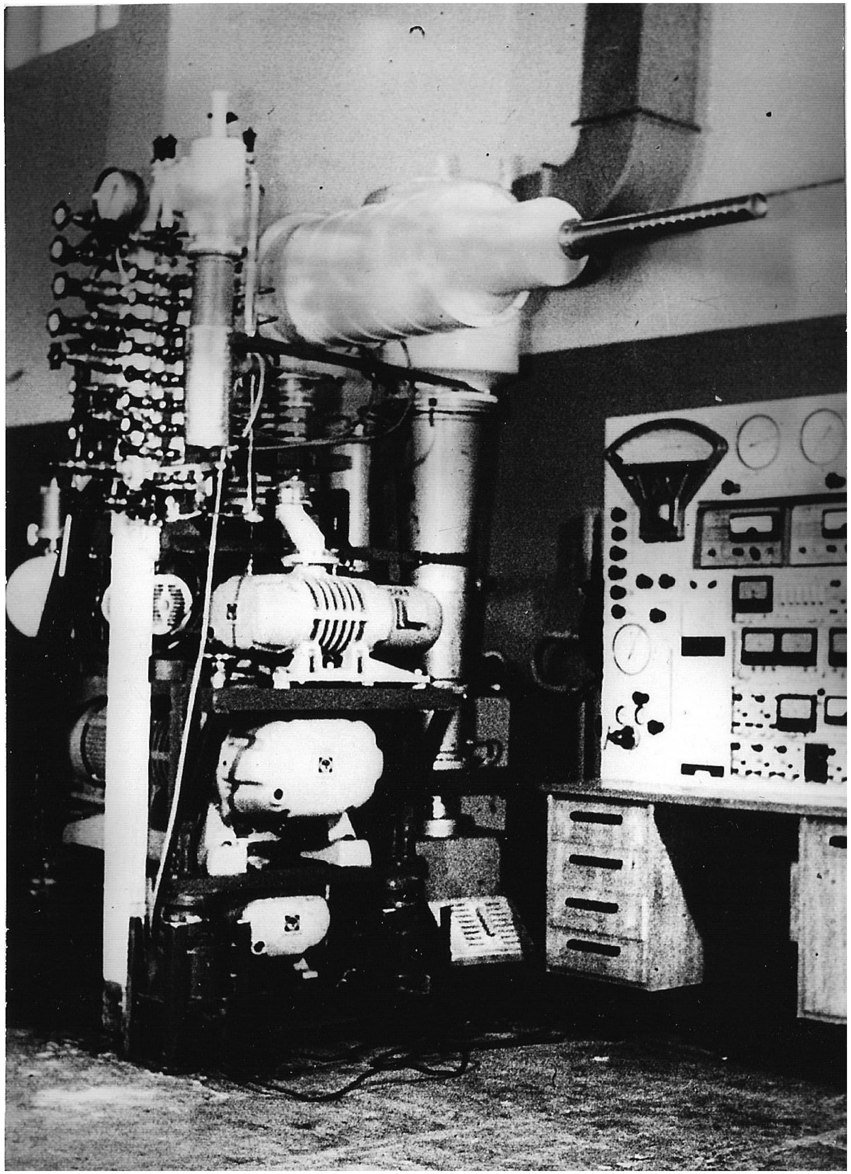
The Low temperature unit of the first Frozen Polarized Target
and Insert for loading Target Material.



B.S.Neganov during experiment “πp” at the LNP Phasotron (1975)



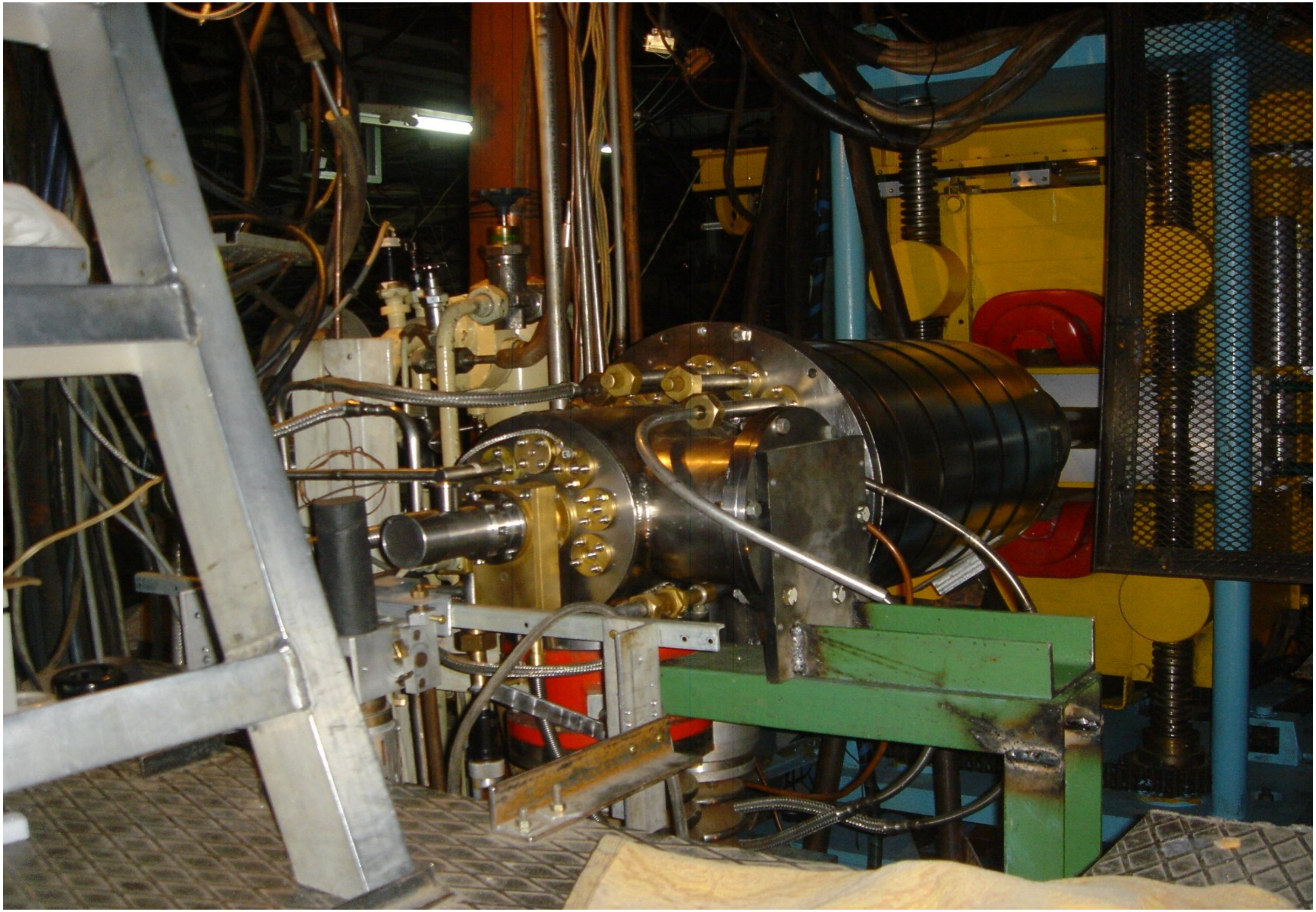
Setup for research with short-lived Isotopes (1977)



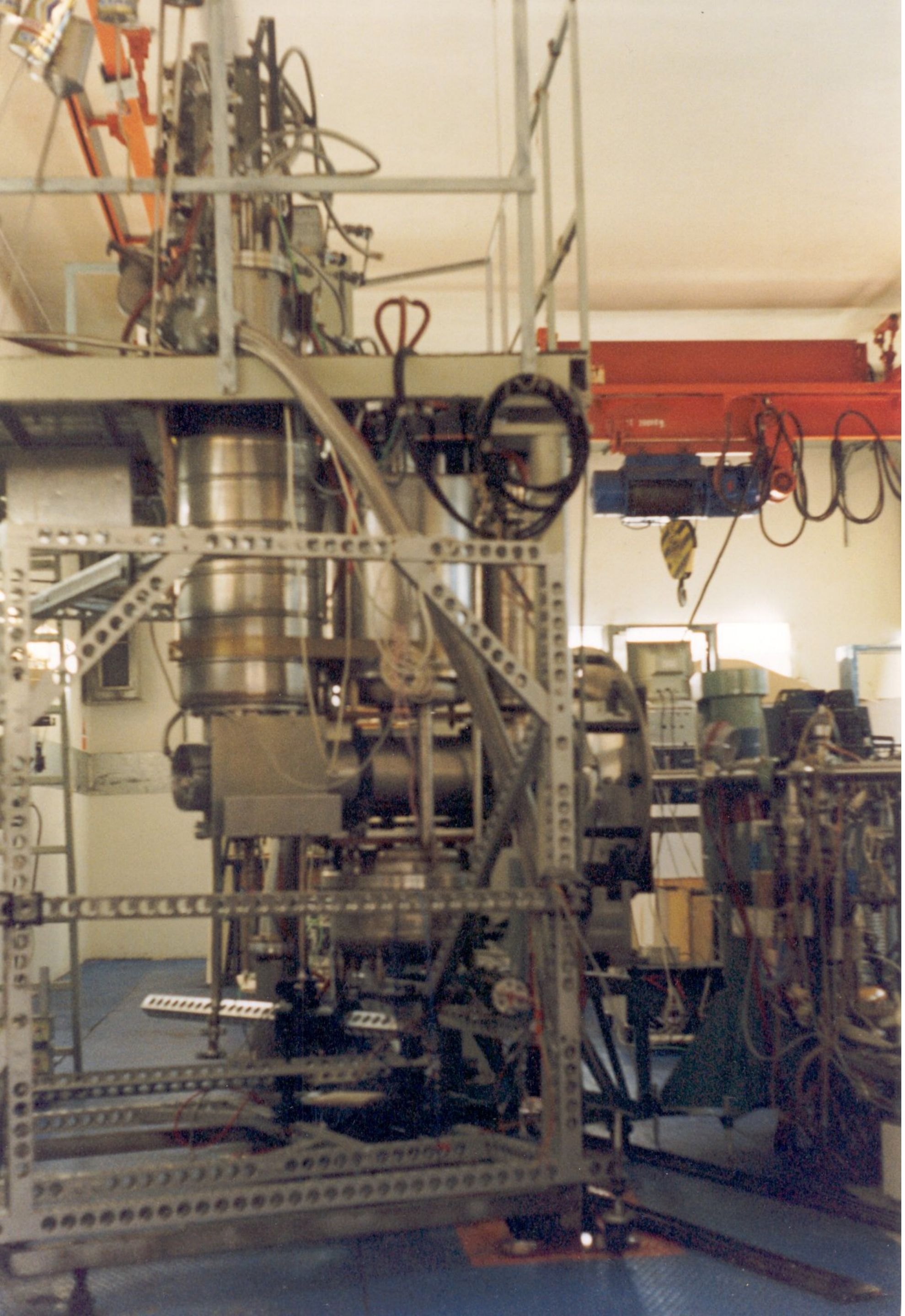
Second FPT before transportation

to IHEP (Protvino) – 1978

The next Target with length 20 cm and 60 cm^3 in volume, which has been used for experiments with 40 GeV π^- mesons and 70 GeV protons at the accelerator of the Institute of High Energy Physics in Protvino since 1978. Lot of articles (over 40) were published since 1976 using these two targets. In 1988 this frozen target was upgradet to deuteron mode.

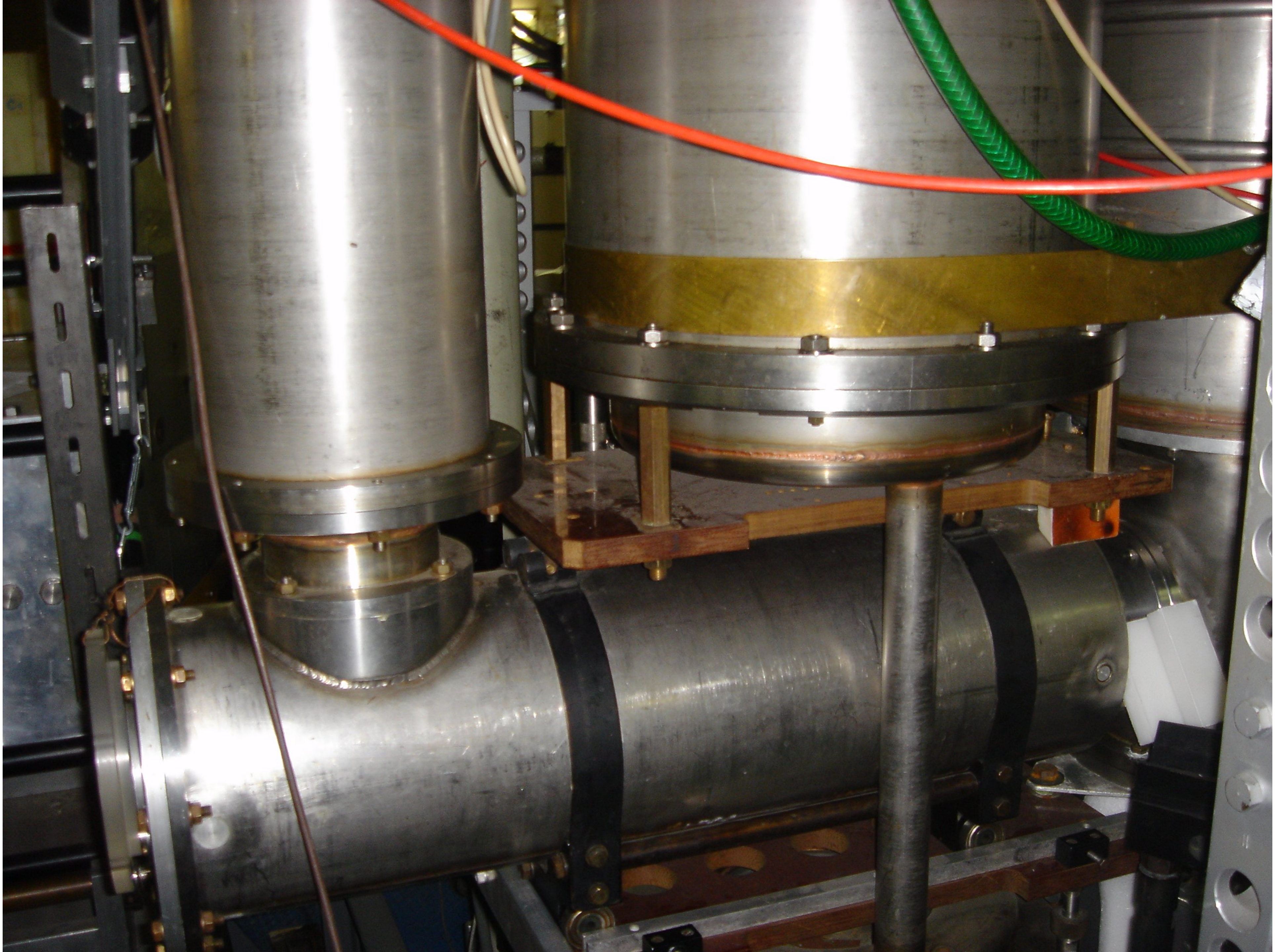


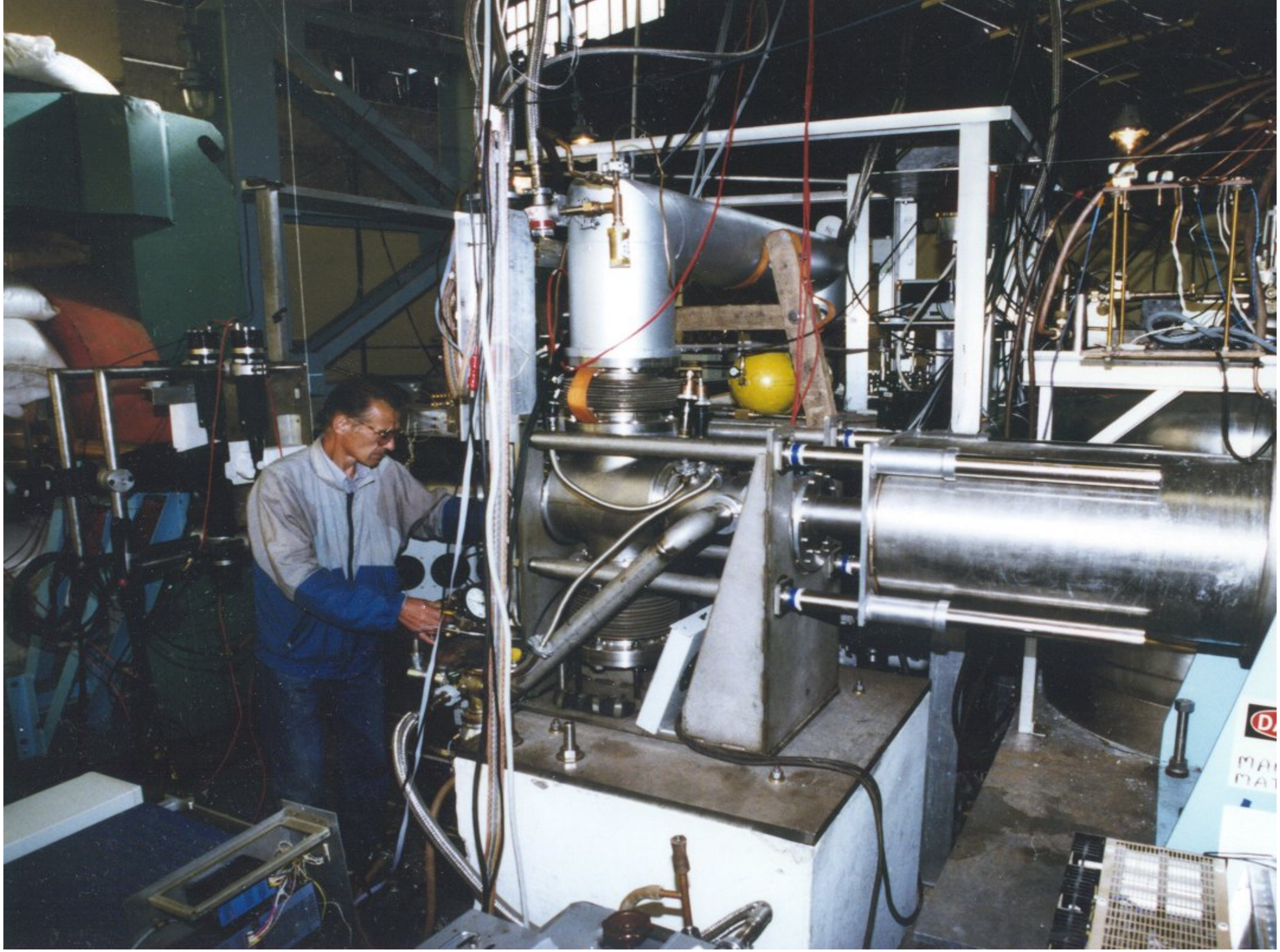
Протонная поляризованная “замороженная” мишень для вторичных пучков частиц высокой энергии.



In 1994 we have developed the new target 20 cm³ in volume, intendet for polarization parameters studies in *np*-scattering using 15 MeV polarized neutron beam produced by the Van de Graaf accelerator of the Charles University, Prague. This target is a complex including a stationary Cryostat with a dilution refrigerator, a movable magnetic system providing a “warm” field and consist of a superconducting dipole magnet with a large aperture, and electronic equipment for providing a dynamic polarization and NMR-signal detection [6]. The further development of this target is under is under preparation for deuteron polarization for next experiment. The purpose of this project is to study three-nucleon interactions using 14-16 MeV polarized neutron beam in conjunction with polarized deutron target.

N.S.Borisov, V.N.Matafonov, A.B.Neganov, Yu.A.Plis, O.N.Shchevelev, Yu.A.Usov, I.Jansky, M.Rotter, B.Sedlak, I.Wilhelm, G.M.Gurevich, A.A.Lukhanin, J.Jelinek, A.Srnka, L.Skrbek. Target with a frozen nuclear polarization for experiments at low energies. NIM A 345, (1994) 421-428. In Proc. of the 11th Int. Symposium on High Energy Spin Physics, pp.545-550, Bloomington, 1994.



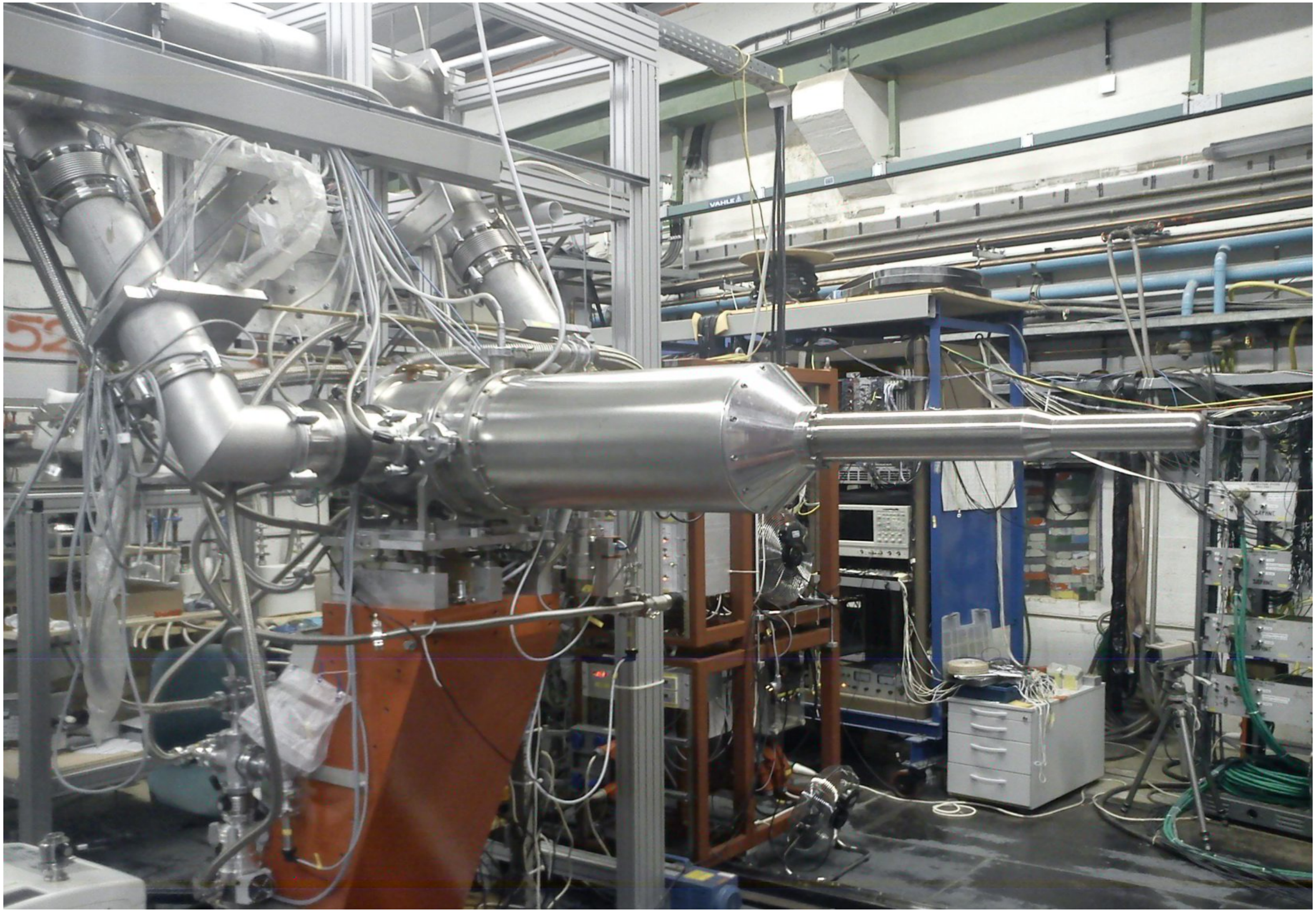


The last development is the reconstruction of the Saclay-Argonne frozen spin proton polarized target which was built for and used initially in experiments at FermiLab. A new quality was given to the target during this reconstraction-transportability from one experimental area to another. All the major parts of the target assembly dieposed closely to the beam line are mounted on two separate decks,which can be moved as blocks in and out of the beam, and also between various accelerators.

This project was supported by INTAS grants in 1993 and 1995.

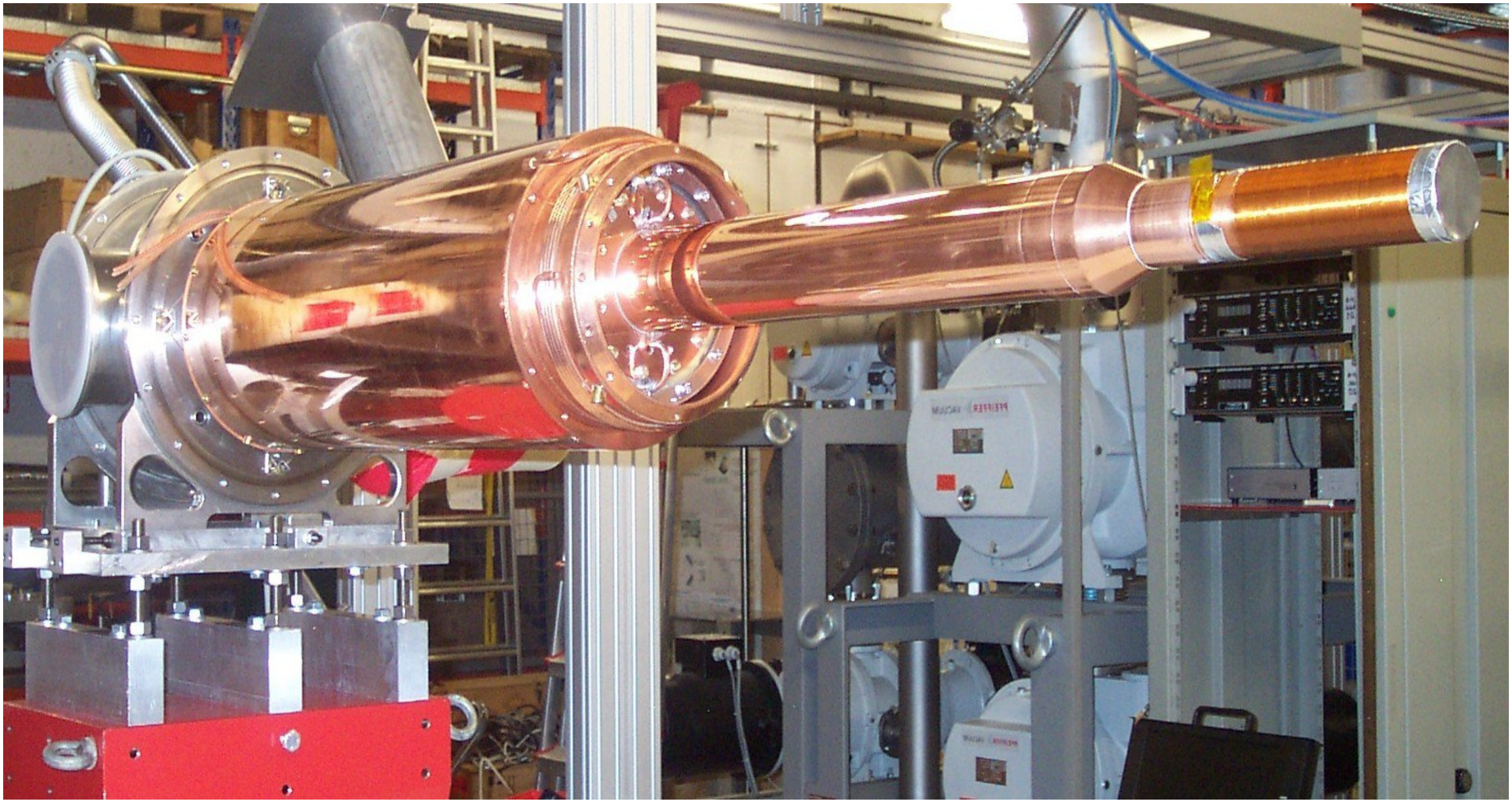
Frozen Polarizet Target at MAMI C (Mainz).

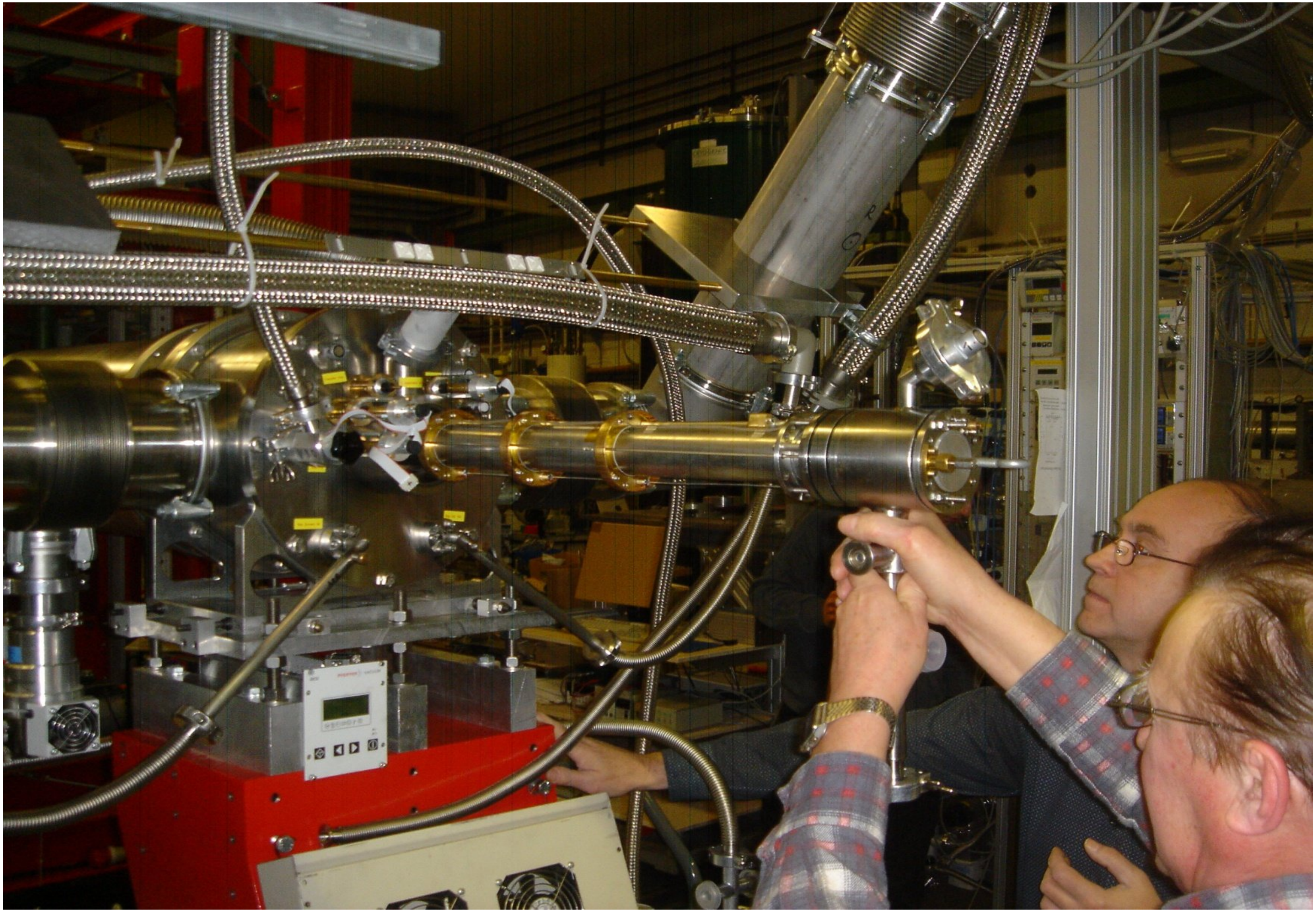
Cryostat of the Frozen spin target



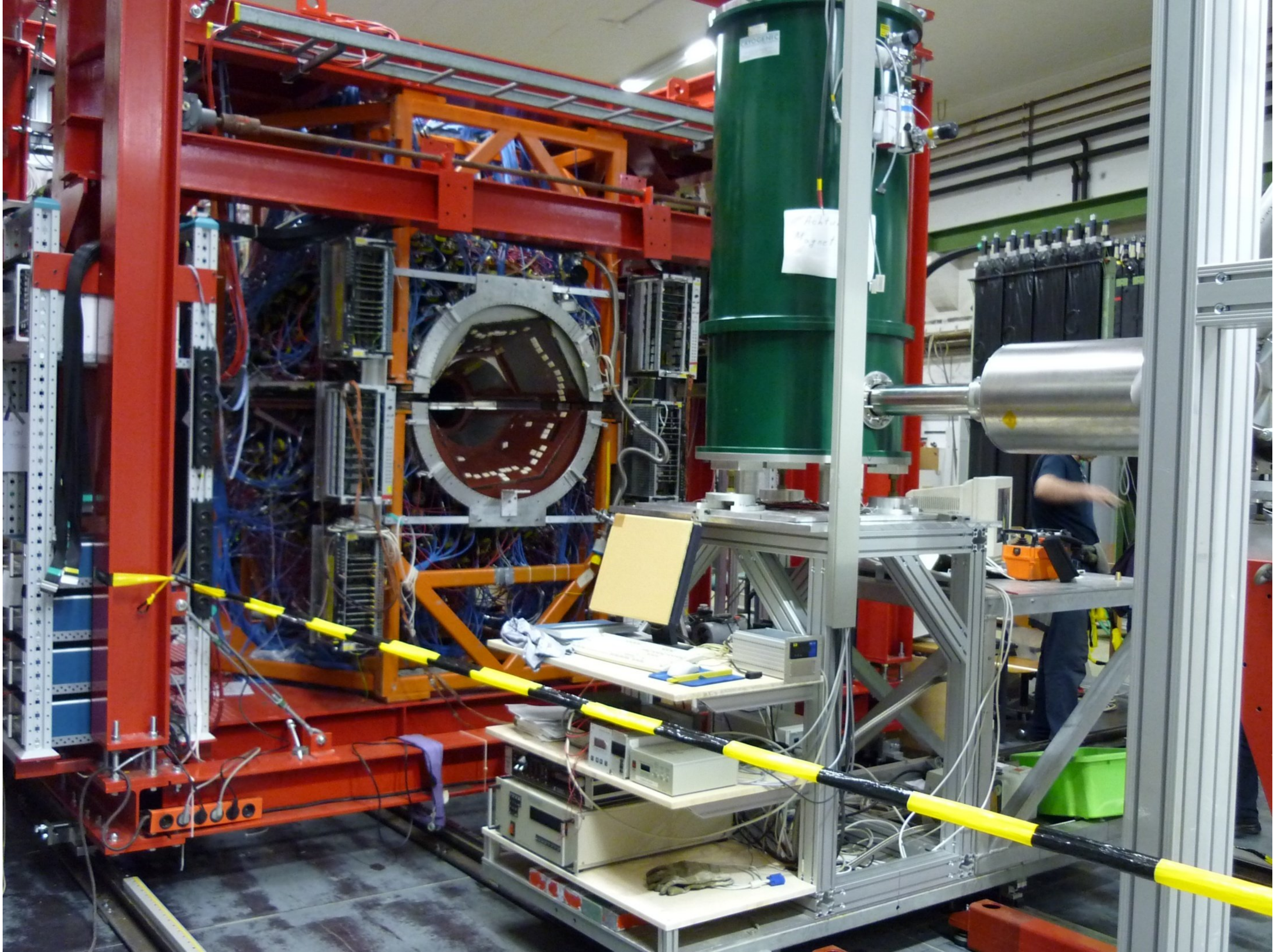
Internal longitudinal Holding coil

(solenoid coil manufactured of 0.227-μm multifilamental NbTi cable and consisting of four layers, each having 600 turns wound around a 0.3-mm thick copper holder, T ≈ 1.5 K)





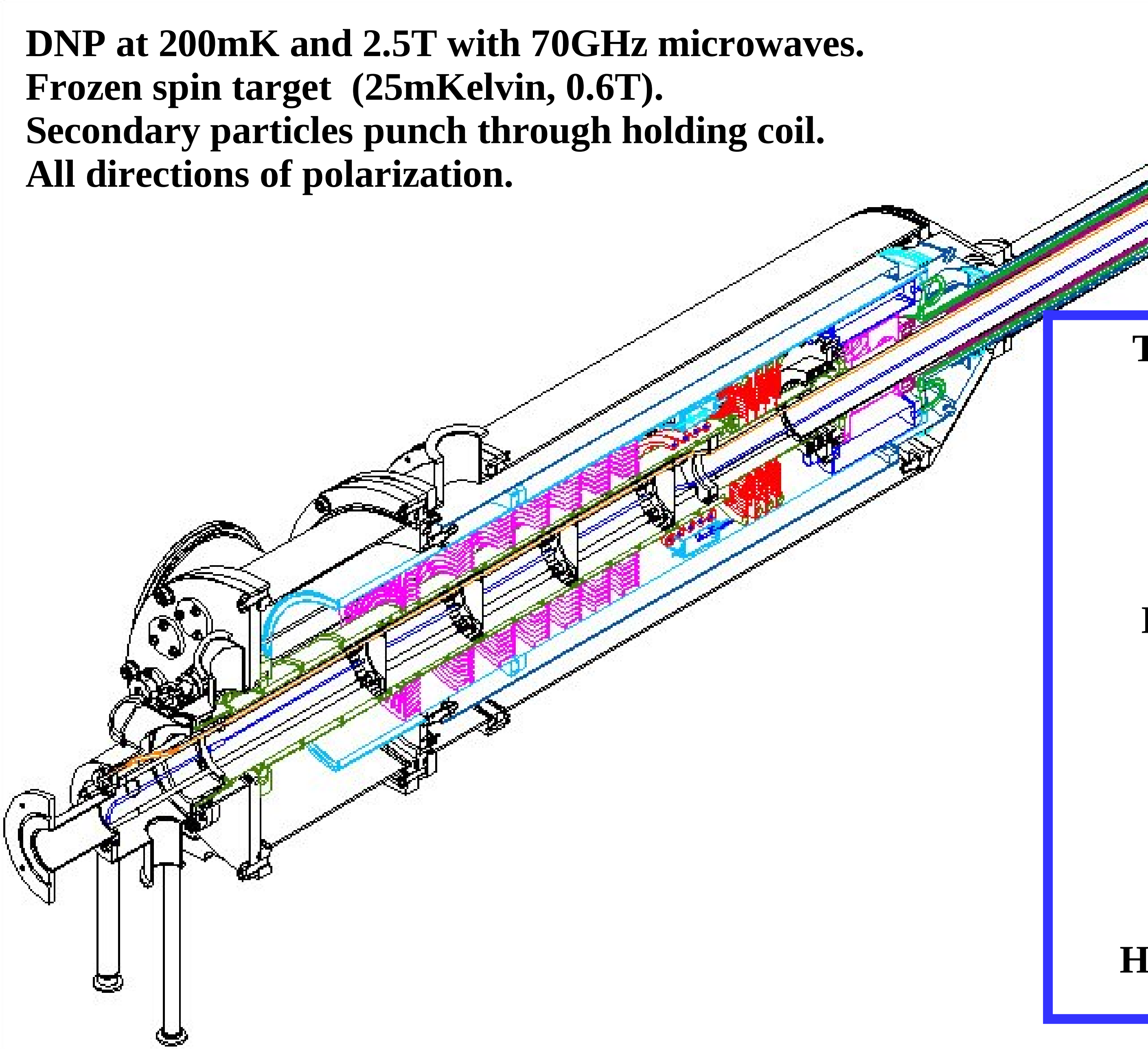
Loading target material during Run at MAMI C



Polarizing magnet

Magnet Technology

DNP at 200mK and 2.5T with 70GHz microwaves.
Frozen spin target (25mKelvin, 0.6T).
Secondary particles punch through holding coil.
All directions of polarization.



Transverse (Saddle coil)

and

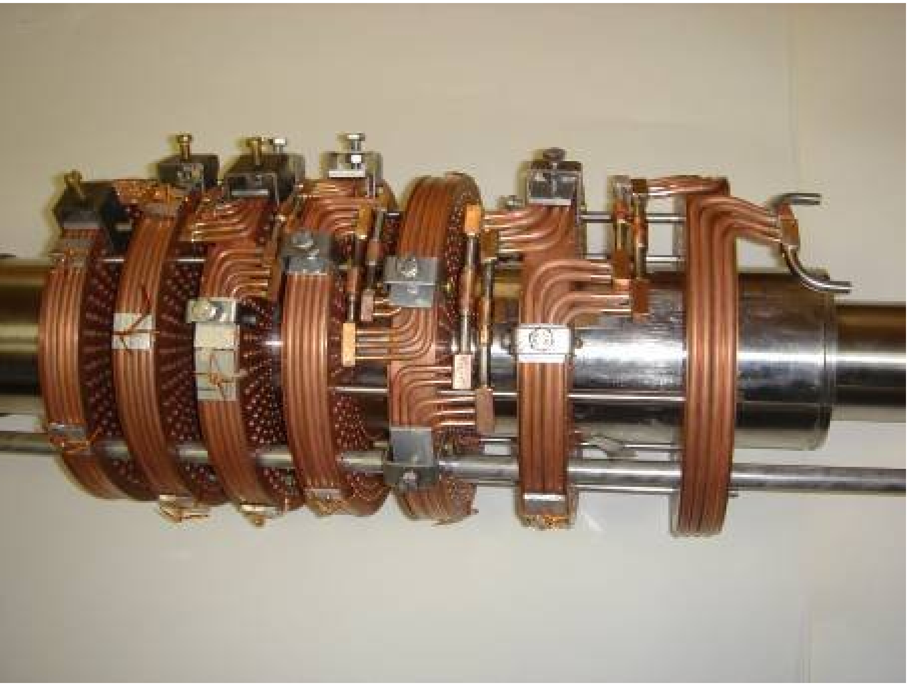
Longitudinal (Solenoid)

Internal

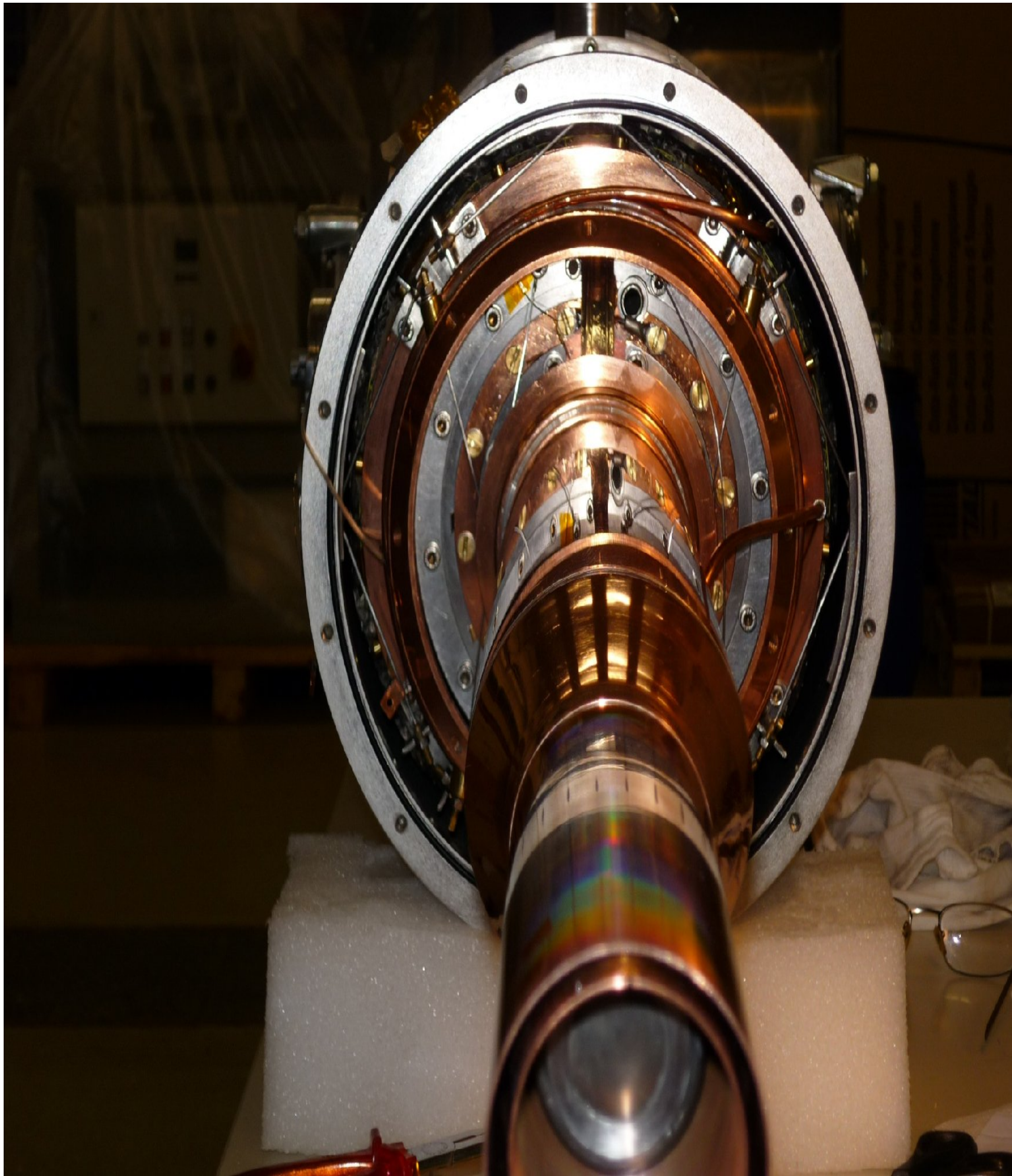
Holding Field (1.2K, 0.6T)

Impressions from the technical realisation

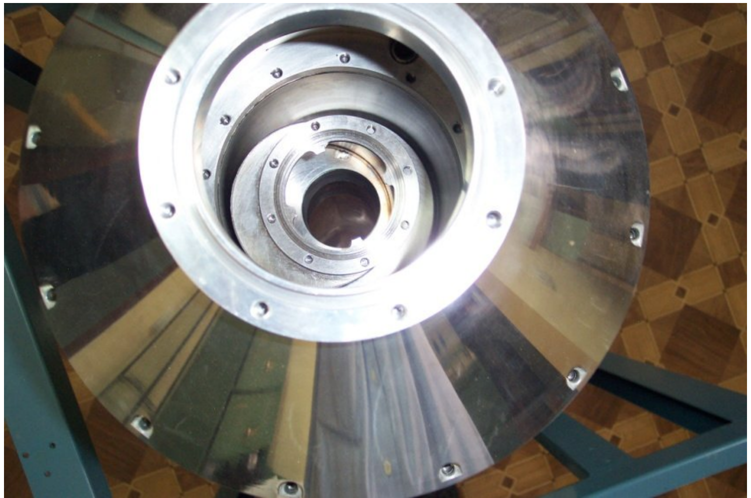
High temperature heat exchanger



Alignment thermal radiation shields



Alignment still and evaporator

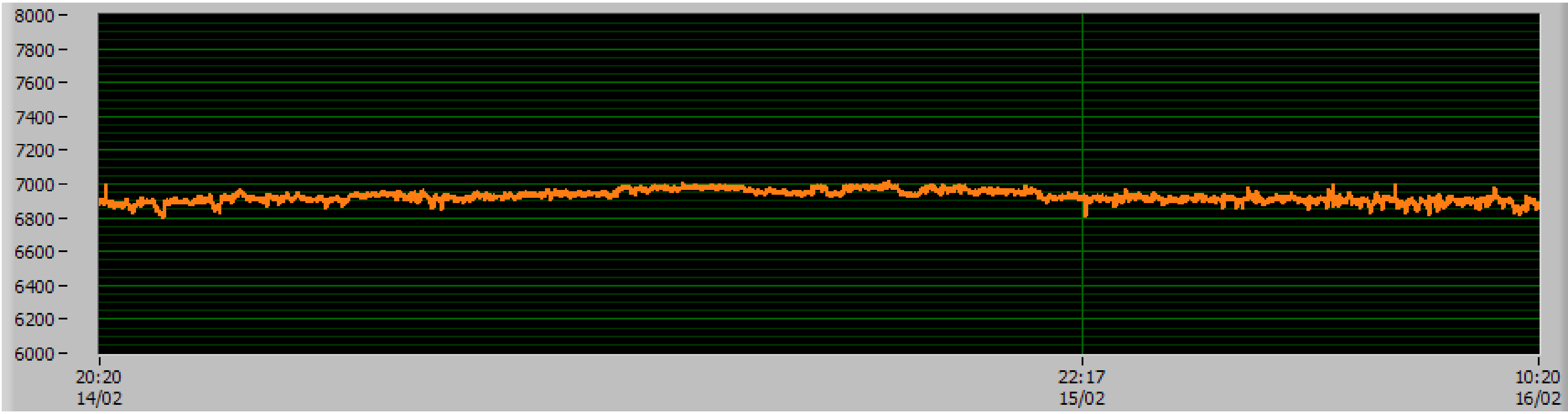


Cryostat Performance

T=24mK

T=27mK

T=29mK

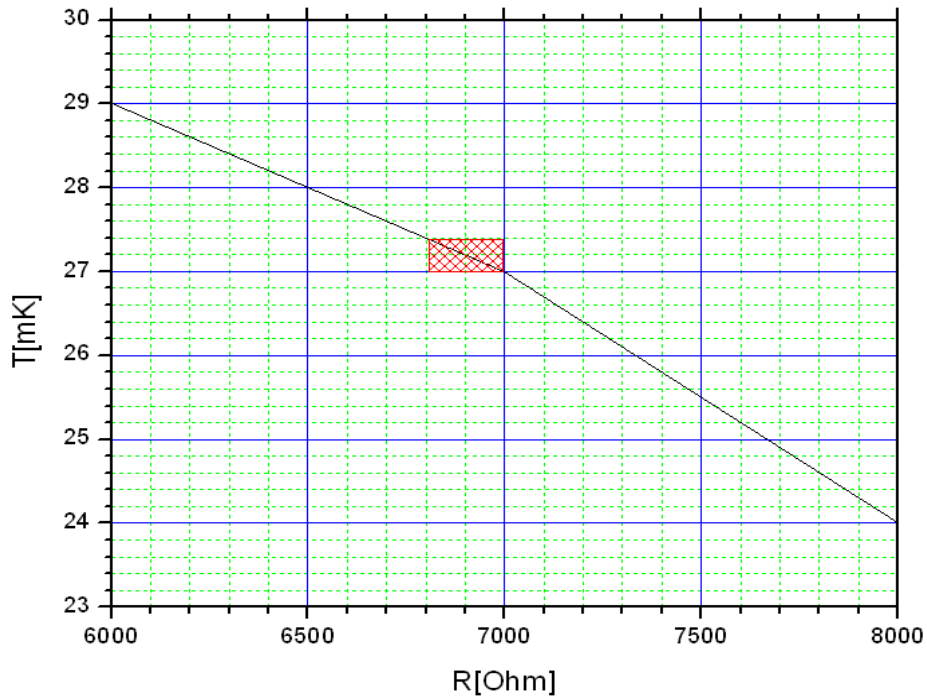


Δt=40h

Temperature stability:

ΔT ~ +- 0.2mKelvin (one day)

(typical one week measurement period).



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The New Frozen Spin Target at MAMI[1, 2]

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Abstract—The new frozen spin polarized target for experiments at the polarized beam of the real photon facility A2 of the MAMI accelerator is described. The A2-collaboration at the Mainz Microtron MAMI is measuring photon absorption cross section using circularly and linearly polarized photons up to the energy of 1.5 GeV. The photons are produced in the 'Bremsstrahlungs' process. In the years 2005/2006 the Crystal Ball detector with its unique capability to cope with multi photon final states was set up in Mainz. Since 2010 the experimental apparatus has been completed by a polarized target. The horizontal dilution refrigerator of the Frozen-Spin Target has been constructed and is operated in close cooperation with the Joint Institute for Nuclear Research in Dubna, Russia. The system offers the opportunity to provide longitudinally and transversely polarized protons and deuteron. In this paper the operation experience of this new Frozen-Spin Target and first results from the runs in 2010 and 2011 are presented.

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1. THE 'CRYSTAL BALL AT MAMI'

1.1. The MAMI Accelerator

The MAMI accelerator (see Fig. 1) with its source of polarized electrons, based on the photoeffect on a strained GaAs crystal, routinely delivers polarized beams with a maximum energy of 1608 MeV. We typically have a degree of polarization of about 85%. Details about the new machine type can be found in reference [1].

1.2. The A2 Real Photon Facility

The A2 Real Photon Facility is one of the three major experiments using the electron beam from the MAMI accelerator, see Fig. 2.

The experiments A1 and A4 use the direct electron beam, while in A2 the electron beam is converted in a beam of photons in the "Bremsstrahlungs' process.

The electrons are used to produce a secondary beam of real photons in the 'Bremsstrahlungs'—process. The energy of these photons is detected in the Glasgow–Mainz tagging-system [2].

The resulting photons can be circularly polarized, with the application of a polarized electron beam, or linearly polarized, in the case of a crystalline radiator. The degree of polarization achieved is dependent on the energy of the incident photon beam E_0 and the energy range of interest, but currently peaks at ~75% for linear polarization and ~85% for circular polarization.

The Glasgow Photon Tagger (see Fig. 3) provides energy tagging of the photons by detecting the post-radiating electrons and can determine the photon energy with a resolution of 2 to 4 MeV depending on the incident beam energy, with a single-counter time resolution of 0.117 ns. Each counter can operate reliably to a rate of ~1 MHz, giving a photon flux of 2.5×10^5 photons per MeV. Photons can be tagged in the momentum range from 4.7 to 93.0% of E_0.

1.3. The Crystal Ball Detector Setup

The central detector system consists of the Crystal Ball calorimeter combined with a barrel of scintillation counters for particle identification and two coaxial multiwire proportional counters for charged particle tracking. This central system provides position, energy and timing information for both charged and neutral particles in the region between 21° and 159° in the polar angle and over almost the full azimuthal range.

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[1] This work was supported by the 'Deutsche Forschungsgemeinschaft' (SFB 443), DFG-RFBR (Grant No. 09-0291330), the European Community-Research Infrastructure Activity under the FP6 'Structuring the European Research Area' program (Hadron Physics, contract number RII3-CT-2004-506078).

[2] The article is published in the original.

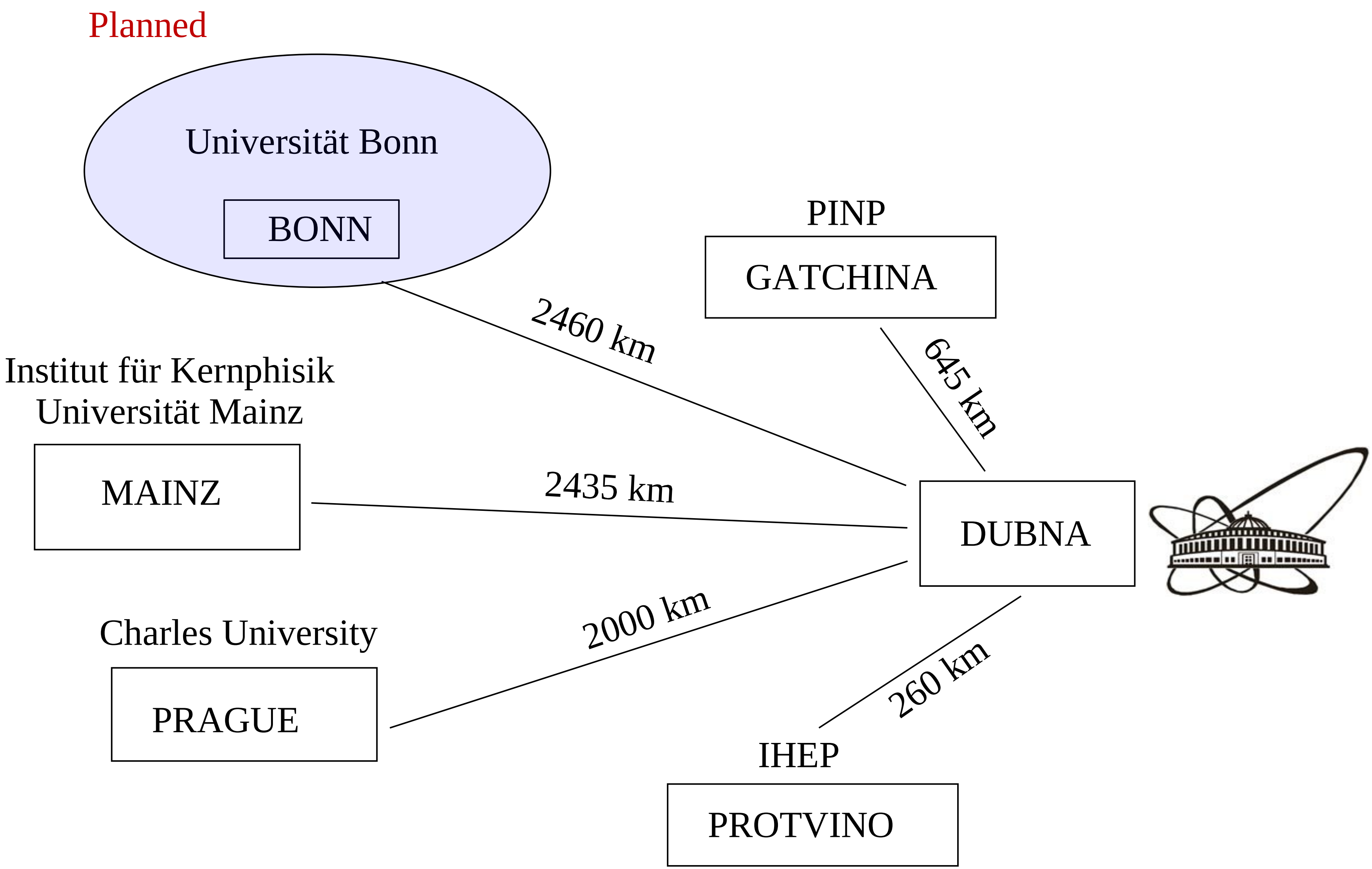
Table: Parameters of the frozen polarized targets JINR

Year of the first publ.	Volume (cm3)	Material	Magnetic field (Tesla) dynamic/ frozen mode	Accelerator (place)	Maximum polarization (%)	Tmin (mK)
1976	15	C3H6(OH)2 1,2-propanediol with Cr(V)	2.69/2.69	Dubna,Gatchina (in use)	P± = 98 ± 2	36
1980	60	C3H6(OH)2 with Cr(V)	2.06/0.45	Protvino (in use)	P± = 87 ±3	20
1985	60	(CD2OD)2 deuterated ethanediol with Cr(V)	2.06/0.45	Protvino (in use)	P± = 37 ±3	
1994	20	C3H6(OH)2 with Cr(V)	2.7/0.37	Prague (in use)	P+ = 93 ± 3 P_ =98 ±2	20
1995	140	C3H6(OH)2 with Cr(V)	2.7/2.7	Dubna (in use)	P+ = 84 ± 3 P_ = 91 ±3	50
2013	10	P /D	2.5/0.5	Mainz	84/75.2	25
from 2015	10	New	Cryostat	Bonn		25-30

27.04.1928-19.08.2012

Professor Boris NEGANOV passed away on 19 August 2012.

The map of JINR's frozen polarized target activities



THANK YOU !