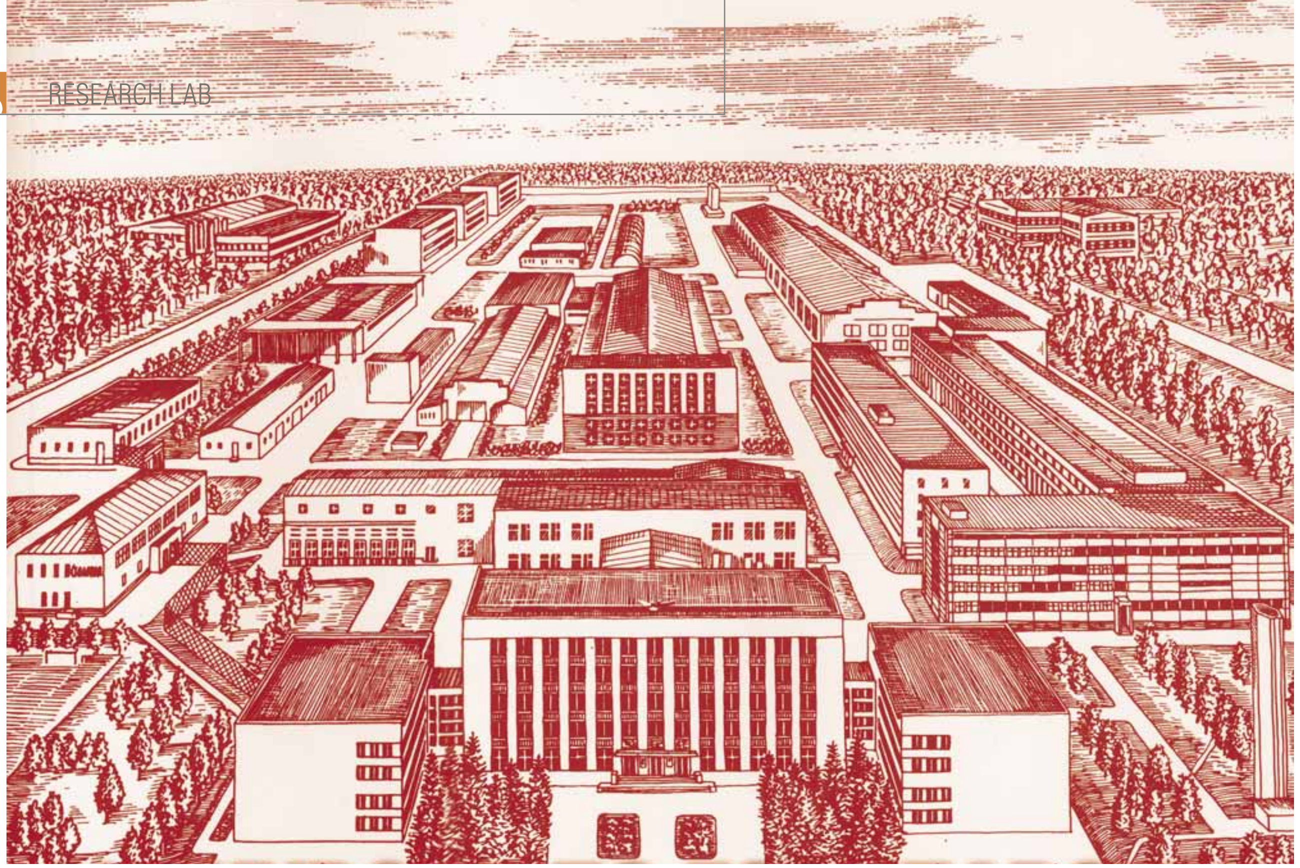


EXCURSION IN THE "STATE" OF THE INSTITUTE OF NUCLEAR PHYSICS: where particles are born

A SERIES OF ARTICLES

The issue of the matter-divisibility limits dates back to the 5th century B.C. In antiquity, in addition to a discrete pattern of the world known as *atomism*, the belief in infinite divisibility of matter was also fairly popular. Even Democritus, the founder of atomism, believed that *atoms* — indivisible, eternal, and invariable particles — consist of smaller elements, which have practically no size at all. Antique disputes about these unclear objects, however, were purely speculative.

The result of experimental investigations of the structure of matter at the end of the 19th century was the discovery of the atomic nucleus and elementary particles. A new vision of particles was proposed by Paul Dirac, who developed a theory aimed at describing electron motion in late 1920s. The theory revealed the fundamental symmetry of matter and antimatter and predicted the existence of an "antielectron" having the mass of an electron but oppositely charged. Indeed, such a particle — *positron* — was discovered two years layer.

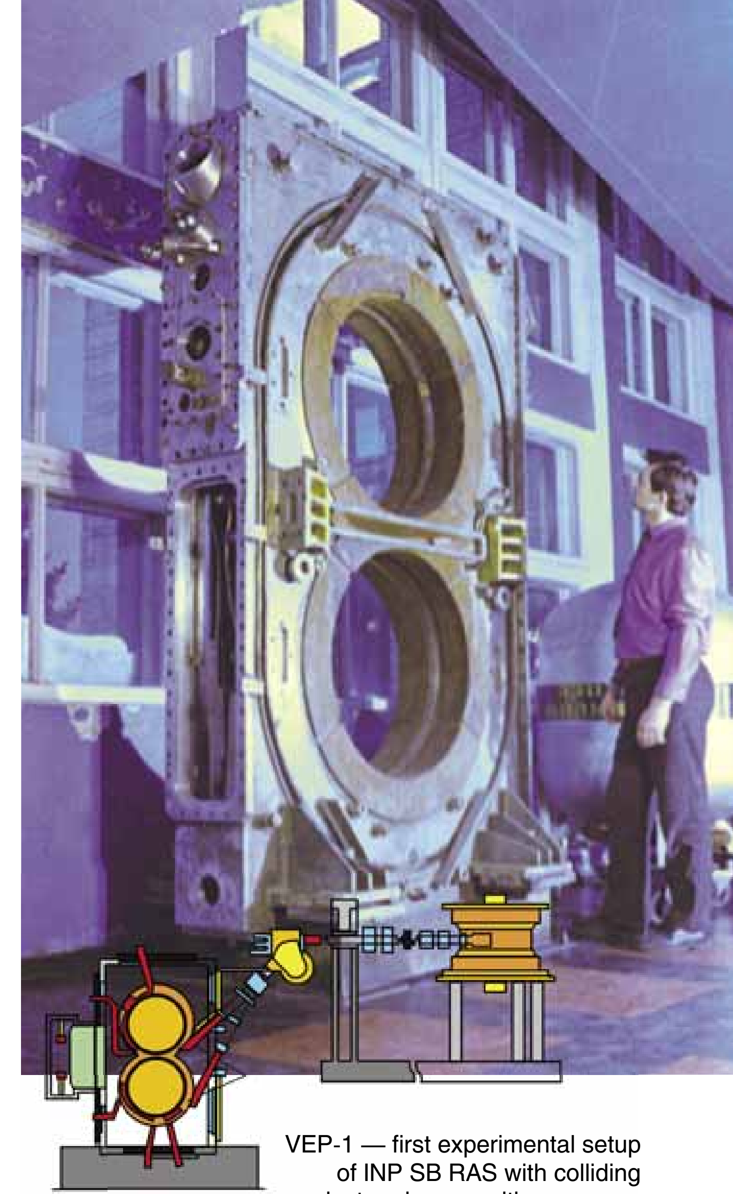
When it became clear that the entire matter observed consists of atoms, and the latter consist, in turn, of neutrons, protons, and electrons, physicists almost believed that they finally managed to find the ultimate "bricks" of the universe — infinitely small and indivisible units of matter.

A principally new stage of research into subatomic phenomena, however, started in early 1930s. Improvement of experimental techniques and development of new instruments for the detection of elementary particles allowed discovering new kinds of the latter. Thus, 6 elementary particles have been known by 1935, 18 by 1955, and more than 100 by now. In this situation, the use of the term "elementary" as applied to these particles is merely a tribute to tradition.

As a result, the problem of matter divisibility is solved today in an absolutely unforeseen manner. It turned out that two high-energy particles during their collision break into fragments whose sizes, unexpectedly, are not smaller than those of the primary particles. New particles emerge owing to the kinetic energy involved in the collision process. The only method of further division of particles is their collision with the use of high energy. Thus, we can divide the matter again and again without obtaining smaller fragments: new particles merely arise from the energy used.

Thus, elementary particles are divisible and indivisible at the same time. This seems to be paradoxical as long as we keep to the idea of "building bricks." Yet, this contradiction is reconciled if particles are considered as certain dynamic "essentials" or, more correctly, as processes utilizing a certain amount of energy contained in their mass. During a collision of two particles, their energy is redistributed and forms a new set of "essentials." If the kinetic energy of the collision is sufficiently high, the new set can include additional particles that were not present in the initial set.

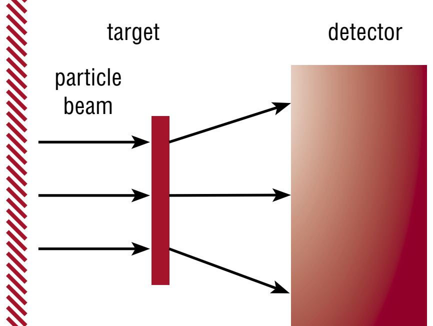
The main method used currently to study the properties of elementary particles is based on their high-energy collisions; that is why this part of physics is also called the *high-energy physics*. A high level of the kinetic energy of particles is obtained in huge setups reaching several miles in circumference — *accelerators* — where particles are accelerated to velocities close to the velocity of light.



VEP-1 — first experimental setup of INP SB RAS with colliding electron beams with an energy of 2x160 MeV

What does a child do if he wants to learn what a toy consists of? First he tries to take it to pieces by hand. If he fails, he employs almost scientific methods: the object of the study is accelerated by hand and thrown onto a wall. The result of this test can be fragments, which are then inspected with the help of eyes, hands, and the tongue. If no fragments are formed, the test is repeated with a higher energy of acceleration — until the goal is achieved. Accelerators on out-going beams operate in a similar manner

Layout of the experiment in elementary-particle physics



The next stage in obtaining "fragments" of elementary particles offered ***accelerators on opposing (colliding) beams****. You can imagine two children with identical toys thrown toward each other. In the case of success, there will obviously be a greater number of fragments, but the accuracy in this test should be much higher than in the previous one. One of the first such accelerators was created in 1964 under the supervision of G.I. Budker, the first Director of the Institute of Nuclear Physics SB RAS*

If particles are considered to be elementary, how can their collision result in fragmentation? It is not merely identical particles but a particle (electron) and its antiparticle (positron) that collide in electron-positron accelerators. Annihilation can give birth to new structures, and it is the latter that produce fragments to be examined. The higher the energy of colliding particles, the heavier particles emerge in the experiment

Yury A. ROGOVSKY, post-graduate student, chief laboratory assistant:

Relativistic machine

Facilities with colliding beams are now the main sources of information in the elementary-particle and high-energy physics. The energy of particles interacting in such colliders continuously increases: from 250 MeV in the first electron storage ring VEP-1 (INP SB RAS) to 2x7 TeV in the proton-proton Large Hadron Collider currently under construction at the European Center of Nuclear Research (CERN).

INP has extensive experience in creating electron-positron storage rings with high luminosity. The VEPP-2M booster ring with an energy of particle generation ranging from 0.36 to 1.4 GeV was in successful service here in 1972—2000. The process of radiation self-polarization of beams was observed on VEPP-2M for the first time in the world, and the method of precision measurement of the electron energy, now successfully used elsewhere to measure the masses of elementary particles, was put into practice. During the years of its existence, the facility has been modernized several times, and there were several generations of detectors of elementary particles.

__COLLIDER__ — accelerator with opposing (colliding) beams of charged particles

__ELECTRON-VOLT__ (eV) — unit of energy popular in high-energy physics.
__1 eV__ – energy acquired by an electron passing through a potential of 1 V; it approximately corresponds to 10,000°C;
__MeV__ (mega-electron-volt) — million of eV; __GeV__ (giga-electron-volt) — billion of eV;
__TeV__ (tera-electron-volt) — million of millions of eV

__LUMINOSITY__ — important parameter of the accelerator characterizing the number of particle collisions at the point of the collision of beams in a cross section per unit time. The greater the number of collisions, the higher the chance that something interesting will emerge

__COOLING of the beam__ — decrease in the velocities of elementary particles in the beam reference system. In other words, it is not sufficient to speed up particles, it is necessary that they pass in a compact group and do not scatter

In 1999, the INP administration decided to significantly upgrade VEPP-2M to increase luminosity and maximum reachable energy up to 2 GeV. The new project was entitled VEPP-2000, where 2000 indicates the number of MeV to be obtained rather than the millennium as many people think. A natural question arises: Why do we need an accelerator with such a comparatively small energy, whereas machines with a power almost thousand-fold greater are already available? The answer is simple: when you need to drive a nail, you do not take a hand sledge — it is more convenient to use a small hammer.

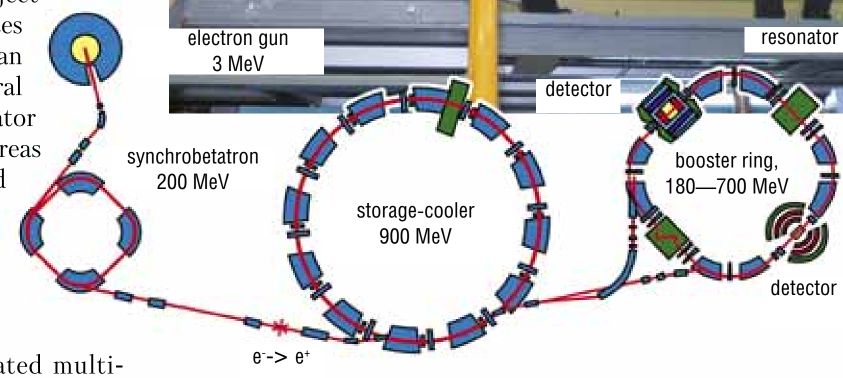
All modern accelerators are sophisticated multi-component systems, which can be considered by using an example of the VEPP-2000 machine.

First, it includes an *electron gun*, which is a source of electrons. Then there follows a *synchrobetatron*, where the electron energy increases from 30 to 250 MeV. In the storage *cooler BEP*, the particles obtained previously are accumulated, and their energy further increases to 900 MeV. Finally, there follows the main booster ring of VEPP-2000 with a perimeter of 24 m, where charged particles move along closed circular trajectories, as in all cyclic accelerators.

A charged particle in the magnetic field is known to move along a circular trajectory; therefore, the main closed orbit in the accelerator is generated by *dipole magnets* with a vertical magnetic field. The accelerator size is normally limited by the available space, and this is the reason why rather strong magnets have to be used. Thus, to reach a design beam energy of 1 GeV, the magnetic field strength should be 24 kGs, which exceeds the natural magnetic field of the Earth by a factor of more than 30 thousand!

In straight-line segments, the beam is controlled by magnets with a special configuration of the magnetic field — the so-called quadrupole lenses. The name of these magnets was due to their influence on the beam. Like a conventional optical lens diffracts the light beam, these magnets can focus or defocus the beam of particles flying though them.

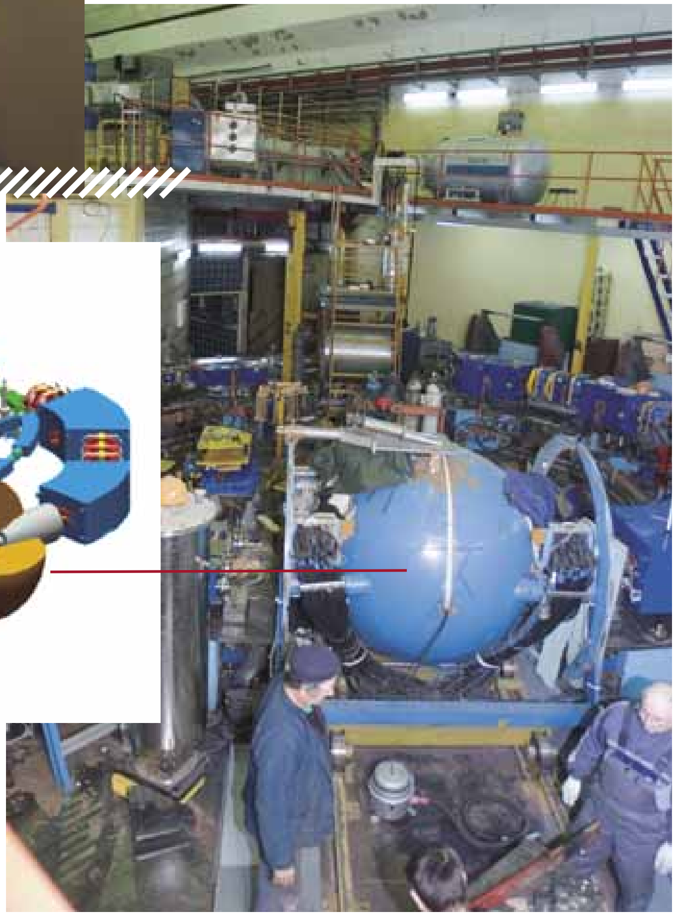
An essential element of the accelerator is a *resonator*. This is a device where the beam is accelerated by an electric field, because it is known that a charged particle moves with acceleration in a longitudinal electric field. The resonator

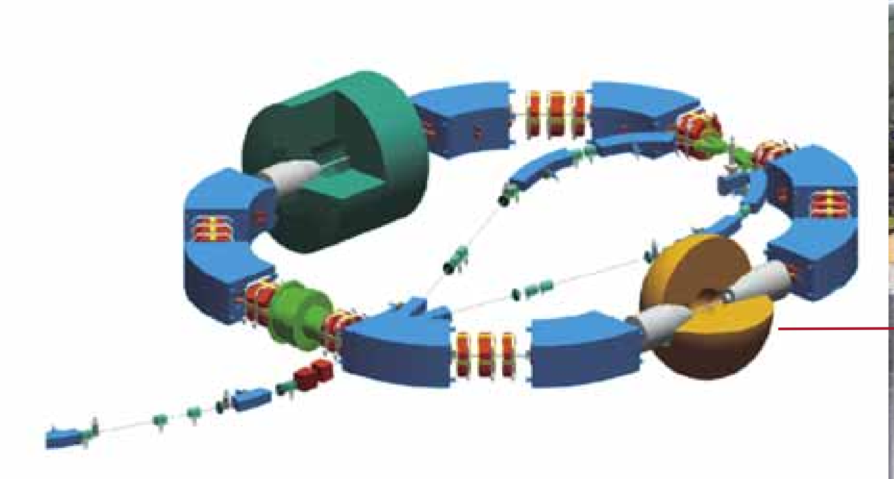


VEPP-2M complex operated within the range of energies from 0.4 to 1.4 GeV. The maximum luminosity reached was 5x10^{30} cm^{-2}xsec^{-1} with an energy of 510 MeV

BEP — storage ring of electrons/positrons for energies up to 900 MeV

Museum exhibit of INP — pivotal magnet of the VEPP-2M accelerator





Detector of elementary particles (SND) in the experimental gap of the newly created VEPP-2000 booster ring

resembles a closed cylinder with an electric field reaching the maximum strength at the point where the beam passes and at the time it passes. Passing through the resonator in each round, the beam is accelerated by energy imparted in small portions; after a large number of rounds, it is accelerated to a velocity fairly close to the velocity of light.

Collisions of the electron and positron beams that can give birth to a new particle occur at two diametrically opposite points surrounded by advanced *detectors of elementary particles.*

A specific feature of VEPP-2000 is the use of novel optical devices for reaching a high design luminosity of 1032 cm-2 x sec-1. The optical scheme of the accelerator implements the concept of circular beams proposed at INP in 1989. The method is based on the disposal of betatron coupling resonances in transverse motion, which affect the dynamics of circulating beams, owing to the generation of an additional integral of motion — the longitudinal component of the angular momentum. This scheme will be implemented in practice by using superconducting solenoids for focusing the beams at their "meeting point." VEPP-2000 will be the first facility in the world with this type of optical instrumentation

Superconducting solenoids operate at a very low temperature; therefore, each unit of a solenoid has a buffer volume of 200 liters for storage of liquid helium (its temperature is 4 °K or — 269 °C)

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