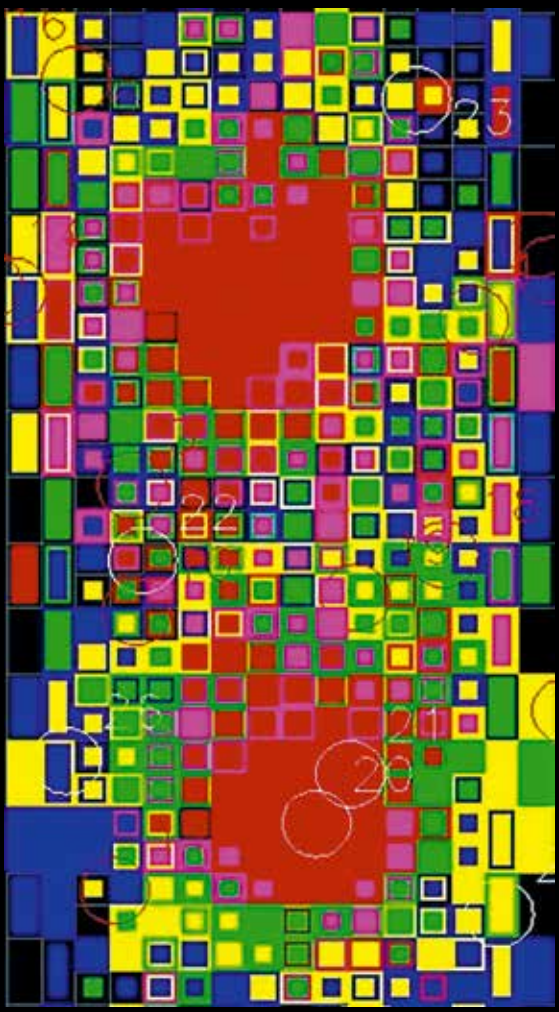
BUDKER INSTITUTE OF NUCLEAR PHYSICS
SIBERIAN BRANCH OF RUSSIAN ACADEMY OF SCIENCE
NOVOSIBIRSK



ELECTRON-POSITRON COLLIDER

# SUPER C-TAU FACTORY

NEW POSSIBILITIES
NEW TECHNOLOGIES
NEW PHYSICS

# THINKING LIKE A MARTIAN

We are used to perceiving the world around us as it is: the grass is green; the wind fans one's face; the sunlight heats. We almost never think why the reality around us is as it is. Nobel laureate in physics Richard Feynman believed that to see the picture of the world as a whole and to understand the laws of nature, we needed to look at things as if we were seeing them for the first time, for example, to think like a Martian. According to the scientist, such an approach – of a being that knows nothing about the world around – is the basis of scientific thinking, and this primordial curiosity will enable us to understand the arrangement of the perfectly beautiful mosaic created by nature.

One of the areas of knowledge shedding light on the structure of the world is the physics of elementary particles, and the Standard Model has become the pinnacle of its development. This theory has combined the strong, the electromagnetic, and the weak interactions of particles and withstood numerous experimental verifications. Its latest triumphant confirmation was the discovery of the Higgs boson in experiments at the Large Hadron Collider.

The main objective of the physics of elementary particles, cosmology, and astrophysics is to study our universe and search for answers to the fundamental questions about its origin, components, and the laws that govern it. The process of learning how the universe works will never stop, the research methods constantly changing and improving.

The search for new physics means hunting for supposed deviations from the Standard Model and is conducted in various ways, including neutrino experiments, attempts to detect dark matter, and investigation into the nature of cosmic rays. However, most of our knowledge in the field of elementary particle physics comes from collider experiments.

# SUPER C-TAU FACTORY

## THE SUPER C-TAU FACTORY IS A COLLIDER WHERE ELECTRON AND POSITRON BEAMS MEET.

Their collisions will result in annihilation, mutual disappearance, and creation of new particles. Study of their properties allows us to understand the structure of matter at the micro level and to confirm the predictions of the Standard Model in more detail. However, the main objective of the physics of elementary particles is detection of phenomena that are beyond this model. The most important characteristics of colliders are the particle collision energy and luminosity, a quantity that defines the number of particle productions per unit time.

## SUPER C-TAU FACTORY:

**Why "C"? Because the collider is designed to study charm quarks.**

**Why "Tau"? Because it will enable the study of tau leptons, the heaviest of the known leptons, whose properties have been explored the least.**

**Why "Factory"? A particle factory is a special class of colliders with record luminosity.**

**Why "Super"? Because its luminosity exceeds that of the colliders working in this energy range by a hundred times.**

## THE ACCELERATION COMPLEX OF THE SUPER C-TAU FACTORY INCLUDES THE FOLLOWING:

### Injector of positrons and electrons

The injector is to produce and store enough particles to generate colliding beams. We at Budker Institute of Nuclear Physics SB RAS (BINP SB RAS) have already launched a new injection complex for the operating colliders. It will become the basis for the injection complex of the Super C-Tau Factory.

### Linear Accelerator

Electron and positron beams are accelerated in it before they enter the ring of the collider.

### Collider

It is one or two rings, in which particle beams fly towards each other and collide at the intersection point. There is a special detector to register their collision.

### Detector

Equipment that registers particles produced and measures their parameters.

The Crab Waist technology of beam-beam collision will yield a record luminosity, a hundred times higher than that in other accelerators in this energy range. Together with the longitudinal polarization of electrons, this will ensure a qualitatively new level of experimentation.

**CREATION OF THE SUPER C-TAU FACTORY WITH ENERGY 2 E = 2–5 GEV, RECORD LUMINOSITY, AND LONGITUDINAL POLARIZATION OF BEAMS ENABLES ACQUISITION OF QUALITATIVELY NEW INFORMATION AND WILL PROVIDE RUSSIA'S PRIORITY IN THE FOLLOWING FIELDS**

- **PHYSICS AND TECHNOLOGY OF ELECTRON-POSITRON COLLIDERS OF ULTRA-HIGH LUMINOSITY**
- **METHODS OF PARTICLE DETECTION**
- **PHYSICS OF CHARMONIUM AND OF CHARMONIUM-LIKE STATES**
- **SPECTROSCOPY OF STATES FROM LIGHT QUARKS**
- **PHYSICS OF D MESONS AND CHARMED BARYONS**
- **PHYSICS OF TAU LEPTONS**

# GEOGRAPHY OF COLLIDERS

**DO YOU KNOW THE NUMBER OF COLLIDERS IN THE WORLD? CURRENTLY, THERE ARE SEVEN COLLIDERS, AND TWO OF THEM ARE LOCATED IN NOVOSIBIRSK, AT BUDKER INSTITUTE OF NUCLEAR PHYSICS.**

Seven, is it a lot or few? At first glance, it seems enough; no need for more colliders. However, each of the colliders turns out to have its own «zone of responsibility». These zones are defined by two factors: the collision energy and the luminosity.

During the past decade, the previous generation of particle factories (the phi-factory DAFNE with the detector KLOE (Italy), the B factories at KEKB with the detector Belle (Japan) and at PEPII with the detector BaBar (USA), and the C-Tau Factory at BEPC II with the detector BES III (China)) has yielded a lot of outstanding results. The next generation of such installations includes the Super B Factory SuperKEKB, which is being launched in Japan.

The Super C-Tau Factory will enable much more accurate and detailed investigation into processes with charm quarks and tau leptons than it is possible at the currently operating C-Tau Factory at BEPC II (China). The point is that **the Novosibirsk collider will collect statistics of events of interest 100 times faster.** This enormous amount of data will let us study practically all the states with quarks of the first two generations (u, d, s, and c quarks), and search for «exotic» states. In addition, such a flow of information will enable research on fundamentally new phenomena, such as CP violation in the system of charmed hadrons and in decays of tau leptons, as well as lepton number violation.

.

# GEOGRAPHY OF COLLIDERS

EUROPE

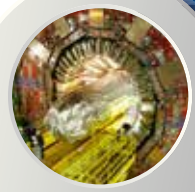
LHC (CERN)

USA

PEPII with BaBar detector (USA)

RUSSIA

VEPP-4M and VEPP2000 (Novosibirsk, Russia)



CHINA

C-Tau Factory at BEPC II with BES III detector (Beijing, China)

ITALY

phi-factory DAFNE with KLOE detector (Frascati, Italy)

JAPAN

B factory at KEKB with Belle detector (Tsukuba, Japan)

**THE LARGE HADRON COLLIDER AT CERN** (CERN IS THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH), **WHERE PROTON-PROTON COLLISIONS ARE STUDIED AT THE ENERGY OF 13 TEV. THIS IS THE HIGHEST ENERGY ACHIEVED IN LABORATORY CONDITIONS.**

Experiments are also carried out in colliders in Frascati (Italy), Novosibirsk (Russia), Beijing (China), and Tsukuba (Japan), where collisions of electrons with their anti-particles, positrons, are studied. Although the collision energy is less than that in the Large Hadron Collider, the high luminosity of these facilities makes it possible to explore rare processes within the framework of the Standard Model and beyond it, which cannot be done in experiments at CERN.

# SUPER C-TAU FACTORY AND NEW PHYSICS

On the one hand, the Standard Model for physicists is like the multiplication table for the schoolchildren. It has been tested and is reliable. On the other hand, some facts (for example, astrophysical observations) give room for doubt. Does this theory fully describe the physical picture of the world? We all know that 5×4 = 20, but imagine that this equality can be violated, albeit very rarely! Of course, everyone will want to make sure of this. So is with the Standard Model – the physicists want to understand whether it is absolutely correct. In physics, the criterion of truth is the experiment, so scientists conduct ultra-accurate measurements and try to detect deviations from the predictions of the Standard Model.

## THE SEARCH FOR NEW PHYSICS IS CONDUCTED IN MANY AREAS:

- EXPERIMENTS AT HADRON AND ELECTRON-POSITRON COLLIDERS;
- EXPERIMENTS WITH HIGH-INTENSITY ACCELERATION SOURCES OF SECONDARY PARTICLES (KAONS, MUONS, AND NEUTRINOS);
- EXPERIMENTS WITH REACTOR NEUTRINOS; SEARCH FOR DARK MATTER, DOUBLE BETA DECAY, AND PROTON DECAY;
- DETECTION OF COSMIC PARTICLES;
- LAND-BASED AND SPACE-BASED ASTROPHYSICAL OBSERVATIONS

All these experiments produce results, and phenomena beyond the Standard Model have already been discovered, each of them being a mystery, a challenge for the modern science. For example, why does the experimental value of the anomalous magnetic moment of the muon noticeably exceed the theoretical prediction? How can the existence of neutrino oscillations be explained? There are global questions to the modern structure of the universe: why is it made up mainly of matter, antimatter being practically absent? What is the nature of dark matter and dark energy?

**THE GOAL OF THE SUPER C-TAU FACTORY PROJECT IS THE CREATION OF A UNIQUE FACILITY TO ADDRESS A NUMBER OF PROBLEMS IN FUNDAMENTAL PHYSICS: SEARCH FOR CP-VIOLATION EFFECTS IN DECAYS OF CHARMED PARTICLES, SEARCH FOR NEW PHYSICS IN RARE DECAYS OF CHARMED PARTICLES OR IN THOSE PROHIBITED BY THE STANDARD MODEL, VERIFICATION OF THE STANDARD MODEL IN DECAYS OF TAU LEPTONS, SEARCH FOR AND EXPLORATION OF A COMPLETELY NEW FORM OF MATTER, GLUEBALLS AND HYBRID PARTICLES. THESE PROBLEMS CAN BE SOLVED AT NO OTHER INSTALLATIONS.**

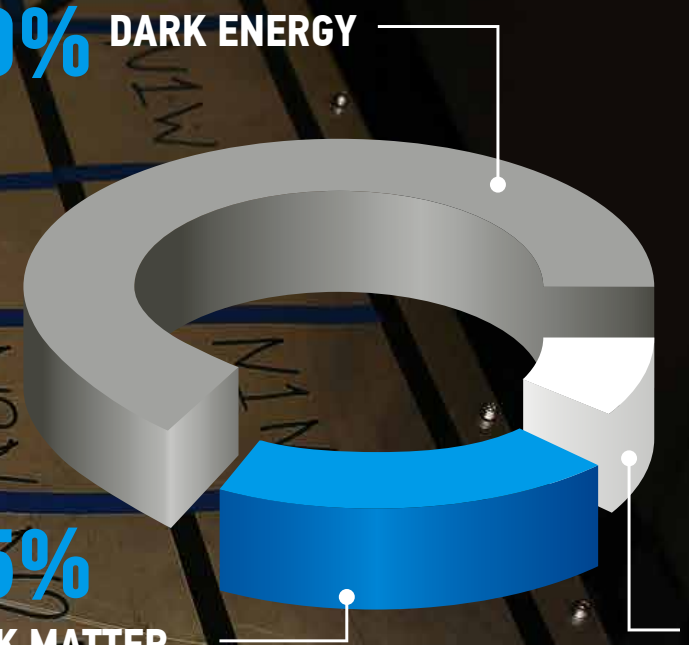
# EVOLUTION OF THE UNIVERSE

Lev Landau said once that cosmology is often mistaken. The methods of cosmological observations have changed since then, and now they can yield quantitative answers to many questions, for example, about the matter the universe consists of. The familiar form of matter, the baryon one, which can be seen, touched, broken, or bent, turned out to be only 5% of the mass of the universe! The remaining 95% is dark matter (25%) and dark energy (70%). Scientists are sure that these forms of matter exist, but they still do not know their nature.

Attempts to directly register dark matter using underground detectors are conducted massively. However, the nature of dark matter can be understood only with the help of colliders, through studying the production and decays of the particles of which it consists.

One of the candidates for dark matter is supersymmetric particles, but the chances of finding them in experiments at the Large Hadron Collider are minimal. The possible range of dark matter particle masses cannot be determined so far. Those can be heavy particles, production of which requires colliders of even higher energies, or quite light ones, for example, sterile neutrinos or axions, which can be detected in the Super C-Tau Factory.

# ENERGY DISTRIBUTION IN THE UNIVERSE

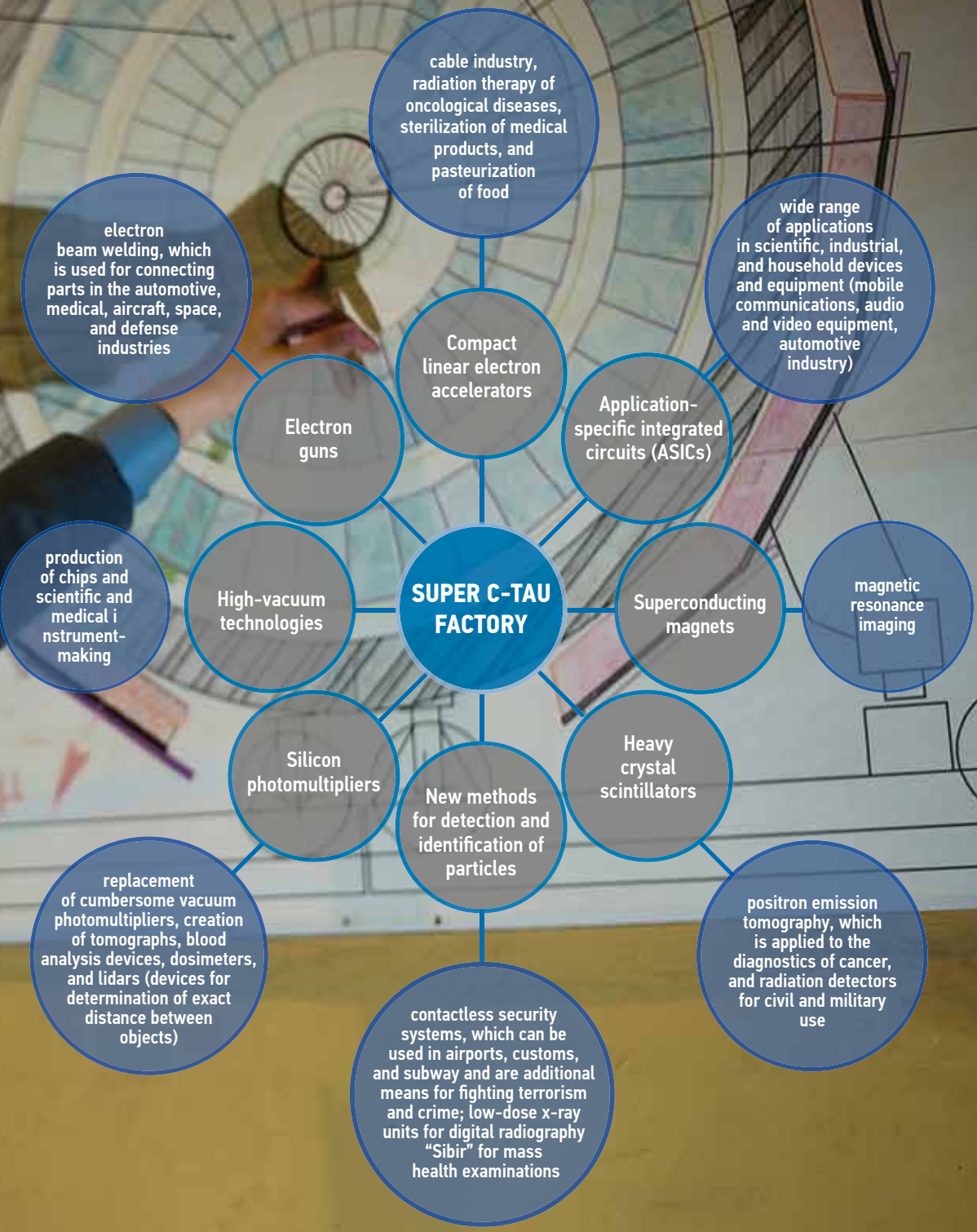


# LEAP INTO THE DAY AFTER TOMORROW

Ordinary morning. You wake up, check you e-mail, browse news feeds in social networks, warm up your breakfast in the microwave, wash up, and head to work. Throughout the day, you use technologies and do it unconsciously so that you do not even notice them. However, they have appeared quite recently, and each of them has its own story. For example, without colliders, neither microwaves nor the worldwide Internet network would exist. Major scientific projects are always a leap into the day after tomorrow; they bring the future closer and allow the next generation of technologies to be used today.

It was the development of accelerators and detectors that gave the world unique opportunities: technologies for cancer therapy, synchrotron radiation (a powerful tool for multidisciplinary research), and much more. For example, the developments by BINP SB RAS for colliding beams have enabled creation of a line of unique electron guns, which are now used at many enterprises of Russia.

## TECHNOLOGIES THE SUPER C-TAU FACTORY WILL BOOST:



# CRADLE FOR THE COLLIDER

**THE ENGLISH LAWN IS PERFECT. THE TRADITION OF LAWN CARE HAS BEEN EVOLVING FOR HUNDREDS OF YEARS; ONE GARDENER PASSED IT TO ANOTHER. GERMAN BREWERIES HONED THE SKILL OF MIXING HOP AND MALT FOR YEARS. WE IN NOVOSIBIRSK ALSO HAVE OUR OWN TRADITION; WE HAVE BEEN CREATING COLLIDERS FOR ALMOST 60 YEARS. HERE ARE JUST A FEW FACTS ABOUT THE SCIENTIFIC SCHOOL OF BINP SB RAS:**

- One of the first two colliders in the world has been built at BINP SB RAS.
- Since 1964 to the present time, at least one collider has been kept working at BINP SB RAS.
- BINP SB RAS participates in all Russian and international megaprojects involving colliders.
- At present, BINP SB RAS conducts experiments at two colliders (VEPP-4M and VEPP-2000) and uses three up-to-date detectors (KEDR, SND, and CMD-3).
- Members of BINP SB RAS have made the decisive contribution to the justification of the Crab Waist scheme for beam collision.
- It is the BINP SB RAS colliders and accelerators where
  - multiple production of hadrons has been detected for the first time in the world;
  - the method of resonant depolarization for exact measurement of beam energy in an accelerator has been proposed and implemented;
  - the hadron production cross section in the low-energy region has been measured with the world's best accuracy;
  - the masses of a whole series of particles have been measured with record accuracy;
  - the photon splitting process has been measured for the first time in the world.

# BIG DATA

## THE SUPER C-TAU FACTORY WILL PRODUCE UP TO 500 THOUSAND EVENTS PER SECOND, AND EACH EVENT IS TO BE DETECTED AND STORED.

One event of the detector of the Super C-Tau Factory «weighs» about 30 kB, which results in a data flow of 120 Gbps, or 1.24 PB ($10^{15}$ bytes) in 24 hours! For comparison: one hour of video in the FullHD standard takes 36 GB. That is, in 1 hour the complex will create data “equal” to 1500 hours of FullHD video, watching which would take two months. The ALICE detector of the well-known Large Hadron Collider produces a data stream about 50 times smaller than that expected at the Super C-Tau Factory.

Analysis of this information is a real challenge for IT professionals, since one has to find the few events of interest among trillions of others. The Data Processing Center of the Super C-Tau Factory will combine more than ten thousand hard drives, thousands of solid-state storage devices, and tens of thousands of processors to receive and analyze events from the detector. The performance of the supercomputer cluster of the detector of the Super C-Tau Factory will be ten times higher than the total performance of all supercomputers currently operating in Novosibirsk.

Implementation of high-energy physics megaprojects, as a rule, leads to development of technologies for production of high-performance computers and organization of high capacity communication networks for processing of scientific data. For example, in 1989 at CERN a web server, web browser, web page, and the concept of hypertext were invented; the World Wide Web originated. Somewhat later, the idea of distributed processing of data from the detectors of the Large Hadron Collider, more commonly known as GRID, was suggested and implemented there.

Subsequently, high-performance computing systems and broadband communication lines began to be used in solving scientific problems beyond the high-energy physics, for example, in biology (for study of genomes), in medicine (for development of new drugs), and in geology (for modeling processes occurring within the Earth).

# THE DESIGN DEPARTMENT AND EXPERIMENTAL WORKSHOP OF BINP SB RAS

## A GOOD SCIENTIFIC IDEA IS PRICELESS, BUT IT IS ALWAYS JUST THE BEGINNING.

To realize it, titanic work of a whole collective is required, and not every idea reaches its "hardware" implementation, which requires reciprocal ideas from engineers, programmers, designers, and workers of the highest qualification. At Budker Institute of Nuclear Physics, the «idea-project-product» chain is always realized completely. The point is that from the day of the foundation of the Institute, the members of the Institute not only generated scientific ideas and experiments, but also created installations and equipment by their own. The Institute has a full team of specialists who can turn scientists' dreams into reality and make the ideas «work». It is, first of all, due to our own design department and experimental workshop.

## THE DESIGN DEPARTMENT INCLUDES:

- 100 members, 40 of whom are leading design engineers and 5 are candidates of science.
- Up-to-date computer and software equipment, including 60 workplaces of the 3D design solution Solid Edge + Teamcenter (Siemens, Germany).

As a rule, the design department is simultaneously working on 15 to 20 large projects and a whole series of smaller tasks.

The following can be an example:

- the vacuum and cryogenic equipment for the world's largest European X-ray free-electron laser XFEL (DESY, Germany),
- the test bench for accelerating a 1.5 A H- beam and the C2U injector for the ambitious project on controlled thermonuclear fusion in cooperation with Tri Alpha Energy, USA,
- the RF stations and the electron cooling unit for the Russian collider NICA (JINR, Russia),
- the conceptual design of the ring for ions and antiprotons, Collector Ring, for the accelerator complex FAIR (GSI, Germany),
- a range of works on the upper and equatorial port plugs for the unprecedentedly complex project of the first commercial thermonuclear reactor ITER (France).

## BINP EXPERIMENTAL WORKSHOP

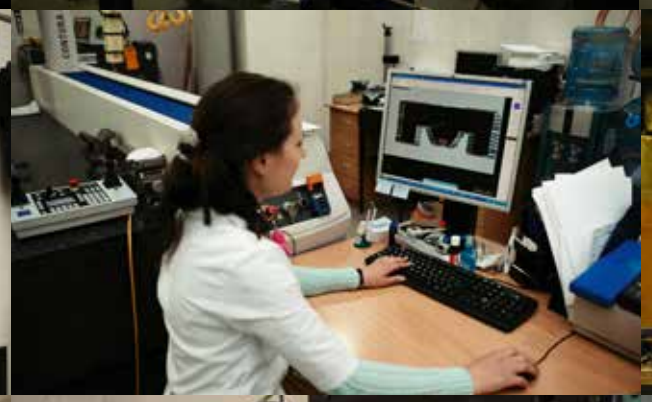
The workshop was created on April 17, 1979. It began with small mechanical and radio workshops, and now it is the largest unit in the structure of the Institute. The workshop comprises about a hundred technological divisions, specialized workshops and bays, located on three production sites, with a total area of about 60 000 $m^2$. There are about 700 staff members, more than 400 units of machines and large technological equipment. BINP SB RAS is the only institute of the Russian Academy of Sciences that has such a large production subdivision.

The primary objective of the experimental workshop is the production of unique scientific and technical equipment for BINP SB RAS and other scientific centers in Russia and in the world. All this equipment is designed and constructed at our Institute, and most of the plants and devices manufactured are unique.

The BINP experimental workshop fulfills contracts for scientific centers and projects of Russia, Europe, Asia, and America: HZB (Germany), CERN (Switzerland), DESY (Germany), BNL (USA), PSI (Switzerland), DIAMOND (England), CLS (Canada), ALBA (Spain), ESRF (France), KEK (Japan), XFEL (Germany), NICA (Russia), ITER (France), FAIR (Germany), and many others.









# IS THIS DANGEROUS?

**IT MAY BE THE MOST COMMON QUESTION ABOUT COLLIDERS.**
**THE ANSWER IS NO!**

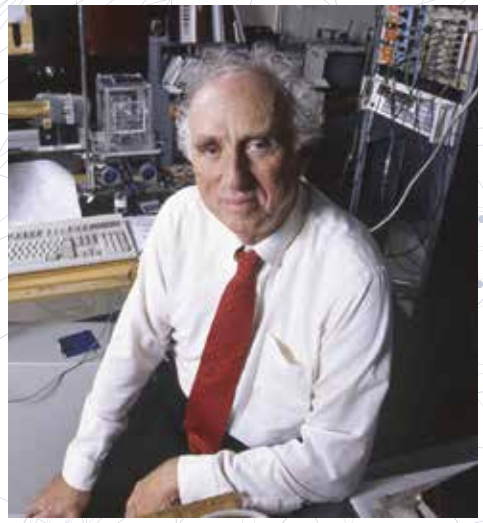
• The project of the engineering infrastructure of the Super C-Tau Factory was developed in accordance with the current requirements of fire, electrical, and radiation safety.

• The project of the Super C-Tau Factory is environmentally friendly and does not entail any environmental risks because the installation is not a source of hazardous chemical and biological contaminants. The accelerator ring, which is a source of radiation, is located far underground, and only special personnel is allowed to the radiation-dangerous premises. Once the accelerator is turned off, there is no induced radiation in the tunnel, which means that people can be there without threat to their health.

• During operation, the collider poses no threat to the environment since it is located underground at a depth of 13 to 18 meters and is serviced by specialists with the appropriate form of access.

# EXPERT OPINION

## NOBEL LAUREATE MARTIN PERL:



"The Super C-Tau factory will produce $10^{10}$ tau leptons pairs, much larger than the existing tau lepton data sets. This $10^{10}$ data set is also much larger than the future data sets that might be produced in the existing electron-positron colliders or in other proposed colliders such as Super-B factories... In the fifty year history of development, building and operation of electron-positron colliders, many laboratories have made contributions to inventions, basic theoretical understanding, and practical accelerator technology. However the two leading laboratories are the Budker Institute of Nuclear Physics and my institution, the SLAC National Accelerator Laboratory. The construction and operation of the Super Tau Facility will continue the leadership of Budker Institute of Nuclear Physics".

## KEK DIRECTOR GENERAL ATSUTO SUZUKI:

"This physics program will be complementary to the program at SuperKEKB, the next generation B meson factory being constructed at KEK, and will play an essential role to elucidate effects of new physics in the flavor decays. Also, I would like to point out that the technology for this facility has many common items with the one for SuperKEKB, and therefore, joint R&D program between BINP and KEK will be very helpful for both of us".



## THE PROJECT WAS APPROVED BY THE INTERNATIONAL AND EUROPEAN COMMITTEES FOR FUTURE ACCELERATORS.

## THE MEMORANDUM OF INTENT FOR THE JOINT CREATION OF THE SUPER C-TAU FACTORY WERE SIGNED BY THE FOLLOWING LABORATORIES:

- KEK (Japan),
- LNF/INFN (Italy),
- John Adams Institute (England),
- Joint Institute for Nuclear Research (Dubna, Russia),
- Institute for Nuclear Problems of BSU (Minsk, Belarus).

## THE FOLLOWING ORGANIZATIONS EXPRESSED THEIR INTENTION TO JOIN THE MEGAPROJECT:

Kurchatov Institute, the SLAC laboratory (USA), CERN, and other Russian and foreign centers of the USA, France, Poland, Italy, and China, which have large experience in creating equipment and conducting research on the elementary particle physics. Nine Russian institutes expressed willingness to cooperate (PINP, ITEP, INR RAS, etc.).

Currently, joint work on solving the principal questions in the creation of the Super C-Tau Factory is actively under way.

# GENEVA, TSUKUBA, AND NOVOSIBIRSK. THREE COLLIDERS AND ONE PROJECT

The international interest in the Novosibirsk project is due to the mutual complementarity of the research program of the Super C-Tau Factory, the Belle II experiment at the electron-positron super-collider SuperKEKB (Japan), and the LHCb experiment at the Large Hadron Collider. These three installations can be considered as a single international megaproject, being implemented in the three countries and united by a single physical task of search for new physics in the heavy quark sector. CERN and KEK have already signed agreements on cooperation with BINP SB RAS.

It is expected that experts of the PANDA collaboration (FAIR) will also participate in the work on the detector of Super C-Tau Factory. In addition, to implement the Super C-Tau Factory project it is necessary to use the experience gained at the PEP-II (USA) and DAFNE (Italy) facilities. Experts of these laboratories will take part, for example, in the creation of the feedback systems and low-impedance vacuum chambers.

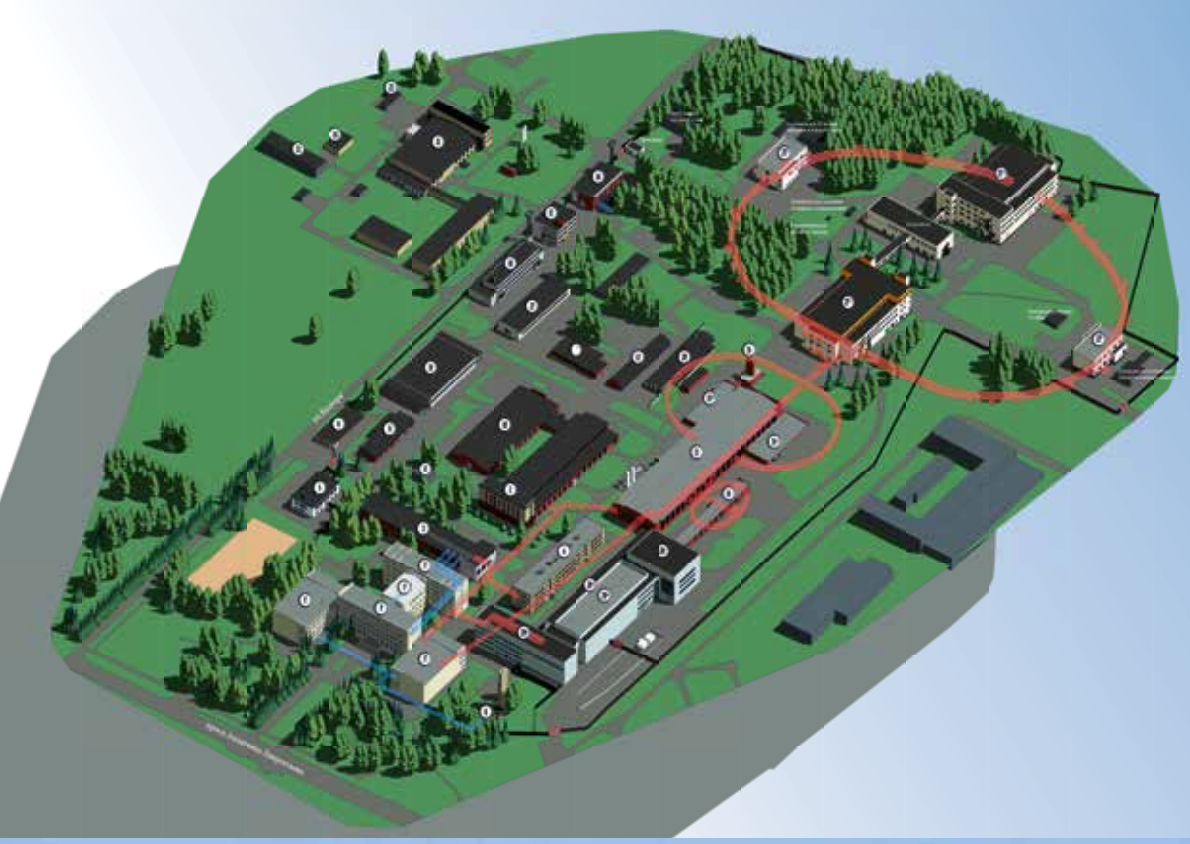
Thus, specialists from Russia, Italy, UK, Japan, Germany, USA, Israel, Slovenia, Poland, and other countries will participate in the project of the Super C-Tau Factory.

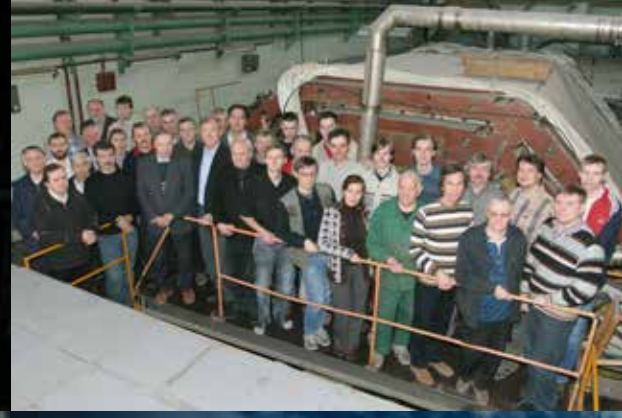
# FACTORY OF OPPORTUNITIES

It is planned that in addition to the foreign scientific organizations, leading Russian institutes and universities will actively participate in the international collaboration of the Super C-Tau Factory project. Those include, first of all, the NSU and NSTU, as well as the MSU, MEPI, MIPT, and St. Petersburg State University. Involving students already at early stages reveals talents much faster and facilitates bringing up highly qualified specialists in various fields.

The implementation of the Super C-Tau Factory project will add to development of the infrastructure of the region: modern buildings and a hotel will be built, and additional jobs will appear. Akademgorodok of Novosibirsk and the region as a whole will take on a new lease of life. Due to the grandiosity of the project, the consequences of its realization will be comparable to the effect of the founding of the Novosibirsk Science Center.

The creation of such a large installation will ensure the leadership of Russia in the field of basic research for the next 15 to 20 years. The proximity of the research institutes of the Siberian Branch of the RAS, of the leading educational centers, and of the Novosibirsk Technopark will contribute to the creation of an effective cluster based on the Super C-Tau Factory and aimed at the development of complex research in the field of fundamental and applied science, rapid practical application of new scientific ideas, and development of innovative economy of the region and the country as a whole.






On the first cover:
Cosmic particle shower detected in the calorimeter of the Spherical Neutral Detector (SND).

Photos in booklet presented by
Svetlana Erygina,
Maksim Kuzin,
SB RAS archive and open sourses

ЗОЛОТОЙ ТИРАЖ
типография