ELEMENTARY PARTICLE PHYSIVS ACTIVITY AT THE BUDKER INSTITUTE OF NUCLEAR PHYSICS

A.Skrinsky
BINP, Novosibirsk

Institute of Nuclear Physics was organized in 1958 on the base of Professor Budker Laboratory of the Institute of Atomic Energy, Moscow. And till his early passing away in 1977, Professor G.I.(A.M.)Budker was Director of our Institute.

Practically, from the very beginning, elementary particle (high energy) physics, based on novel accelerator ideas and approaches, and fusion/plasma physics, were the main directions of our basic research. At the same time, a serious attention was paid all the time to by-product application; we always try to keep strong scientific, technical and personal integrity of our basic and applied activity.

From the very beginning, the elementary particle physics was focused on the development and active use of colliding beams.

The first installation (the first for us and the "parallel-in-time" to the Princeton-Stanford one) was the electron-electron collider VEP-1 (Figure 1).

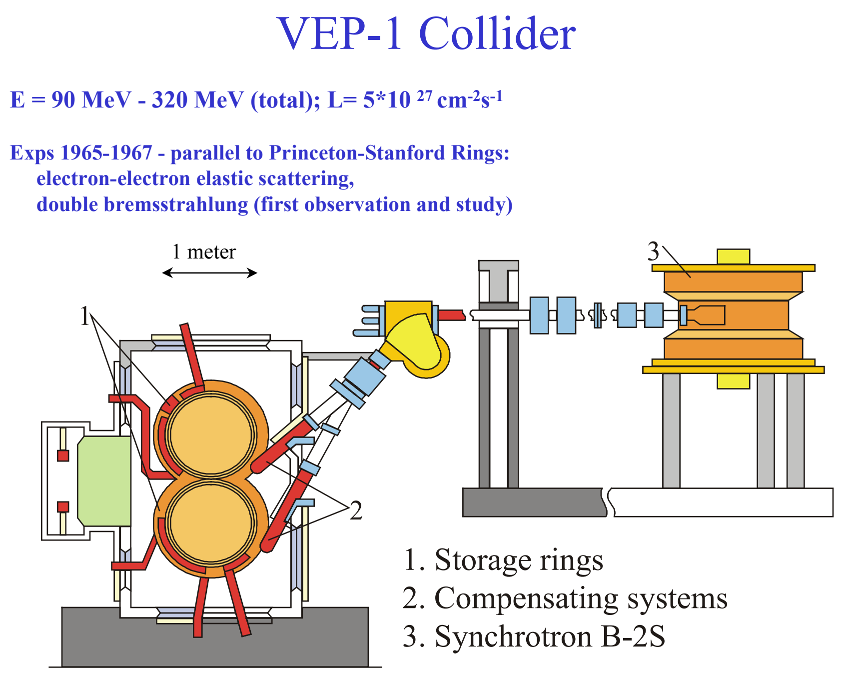

Figure 1.

The main achievement for these both installations was the practical proof of possibility carry out non-trivial experiments at colliding beams (let us not forget, that for years the 1956 proposals of D.Kerst and G.O'Neill were considered by most of specialists as absolutely impractical).

But we understood (at least, starting from 1959, many years prior the VEP-1 operation) much more reach could be electron-positron colliders, which in annihilation produce "all" particles with the mass in reach. And in 1967 the first in the world experimental results in electron-positron annihilation were obtained at our VEPP-2 collider (Figure 2).

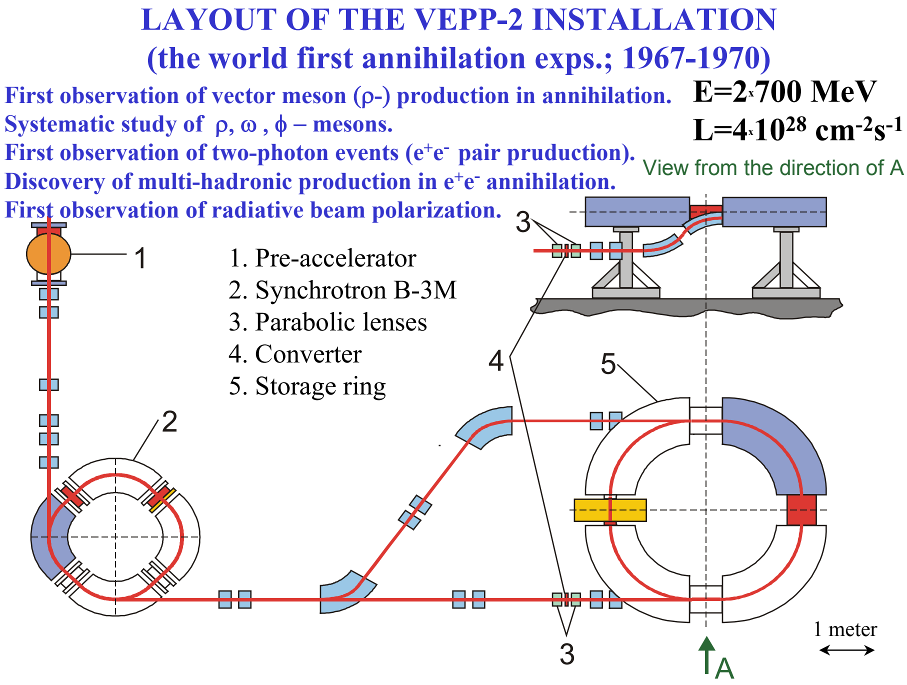

Figure 2.

In 1970 we decided to replace the VEPP-2 by a new electron-positron collider for the same energy range up to 1.4 GeV total, but with 100 times higher luminosity (the "pre-Factory"), - the VEPP 2M collider (Figure 3).

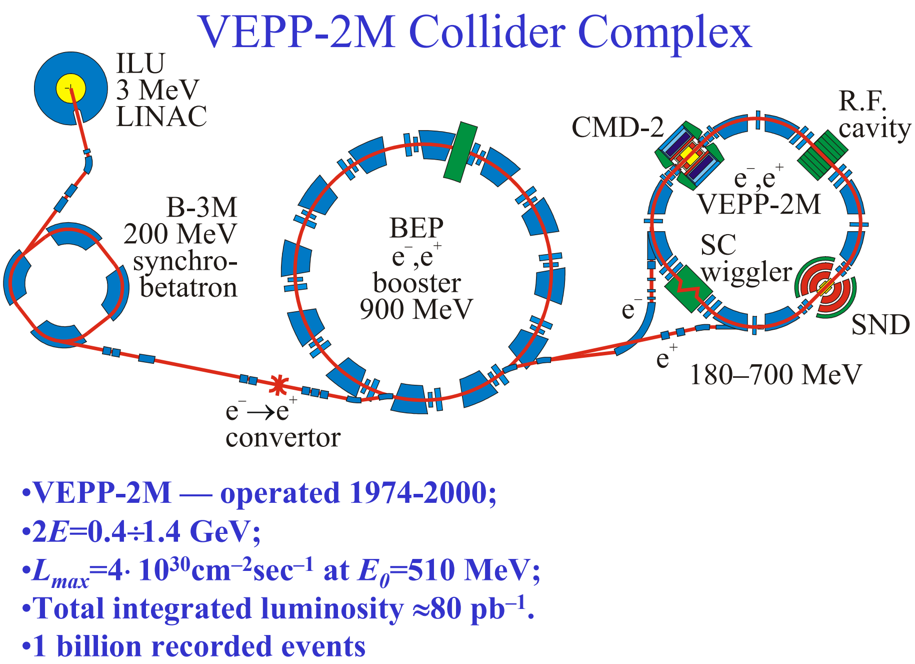

Figure 3.

And up to the year 2000 this collider (with continuous upgrading, especially in detector systems) for 25 years was the main supplier of basic information on processes in annihilation channel.

Especially important were the results on very high precision hadron production, important for evaluation of hadron contribution in to muon (g-2). The current evaluation of the relative error in hadron contribution of VEPP-2M energy range is 0.6%. The dominating fraction of the contribution (pion pair production) is presented at Figure 4.

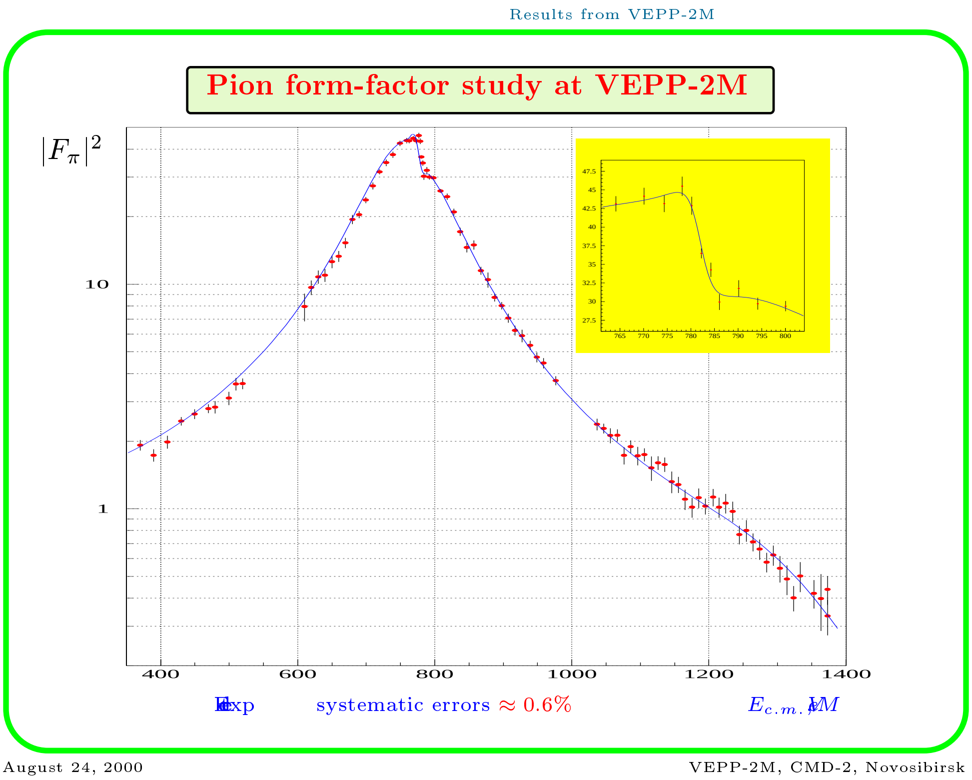

Figure 4. Charged pion form-factor in VEPP-2M energy range.

In VEPP-2M experiments several very interesting phenomena were found; one example is presented at Figure 5. At the right part of the Figure, the upper border of the shaded region shows the expectations with well established mesons, only. The fit of experimental data demonstrates that 2 additional ω-type mesons are required.

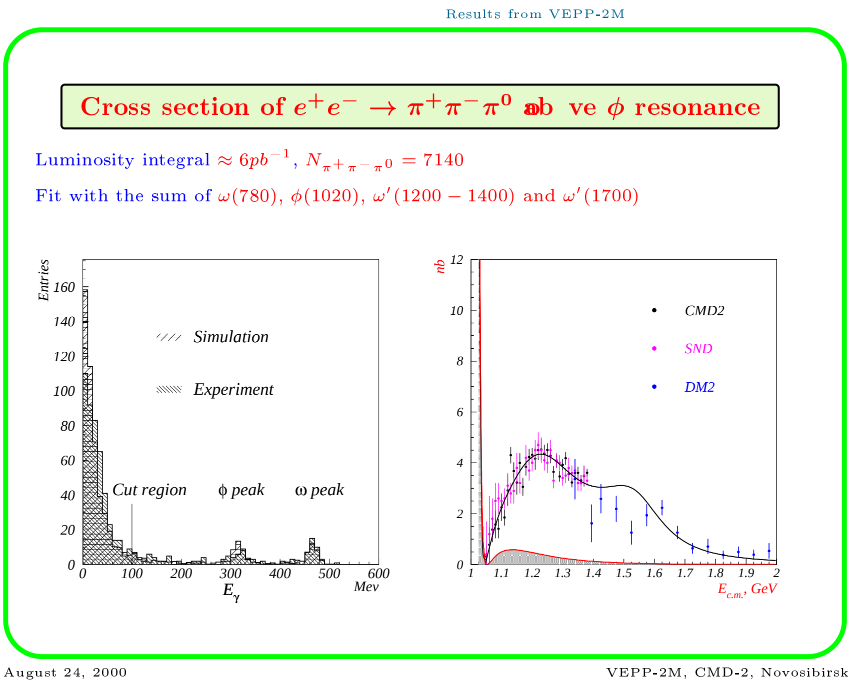

Figure 5.Electron-positron annihilation in to 3 pions above φ meson.

We came to the conclusion that unambiguous interpretation of this and other phenomena requires much cleaner and precise data for somewhat higher energies (the existing data between 1.4 GeV and Ψ region are very poor). And we decided to replace the veteran VEPP-2M with a new VEPP-2000 collider with energy up to 2 GeV total and luminosity up to $1 \cdot 10^{32}\,cm^{-2}s^{-1}$ (Table, Figure 6). The fast construction of this modest collider would not only clarify hadronic phenomena, but give us invaluable experience in "round beam" option of the reaching extremely high luminosity, using, in particular, solenoids for final focus in interaction regions. Now, the construction of VEPP-2000 collider is well under way.

	VEPP-2M Em=700 MeV	VEPP-2000 Em=1000 MeV	
E (MeV)	**510**	**510**	**900**
Π (cm)	**1788**	**2438.8**	
I^+, I^- (mA)	**40**	**34**	**200**
$\varepsilon \cdot 10^5$ (cm·rad)	**3**	**0.5**	**1.6**
β_x (cm) β_z (cm)	**40** **5**	**6.3** **6.3**	
ξ_x ξ_z	**0.016** **0.050**	**0.075** **0.075**	**0.075** **0.075**
L ($cm^{-2} \cdot s^{-1}$)	**$3 \cdot 10^{30}$**	**$1 \cdot 10^{31}$**	**$1 \cdot 10^{32}$**

Table. Main parameters of VEPP-2M and VEPP-2000.

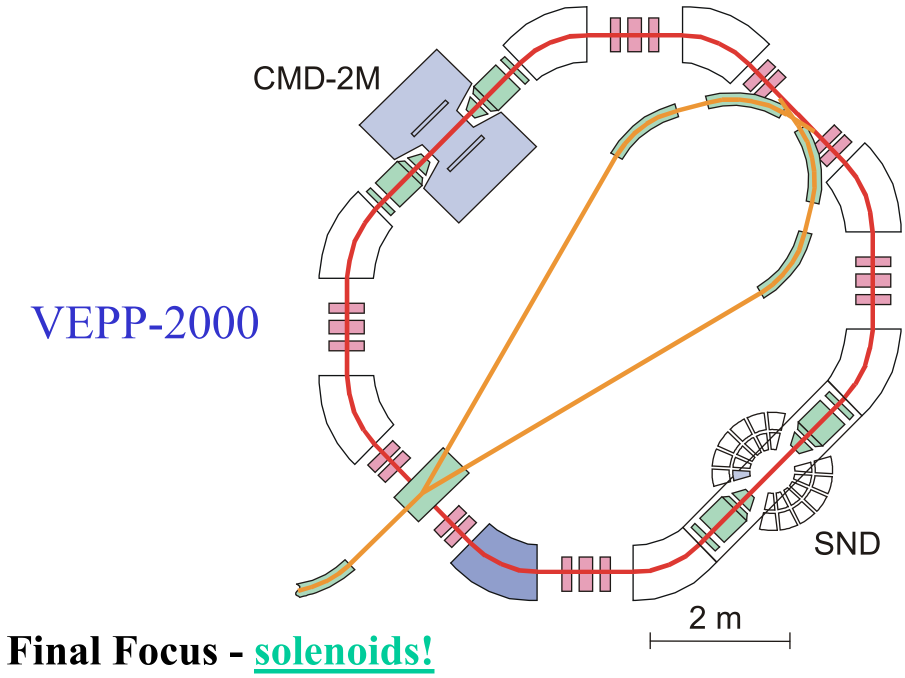

Figure 6. The schematic view of the future VEPP-2000 collider.

I want to remind, the "Round Beams" option implies several important issues.

a). Equal - and small! - beta values at Interaction Region:

$$\beta_x = \beta_z = \beta_0 \ ;$$

.b). Equal horizontal and vertical emittances, excited via quantum fluctuations independently up to the level, required for desired luminosity

$$\varepsilon_x = \varepsilon_z \ ;$$

.c). Equal betatron tunes with "zero" coupling ("no" tunes splitting):

$$Q_x = Q_z \ ;$$

d). Small positive (for e^+e^-) non-integer tune fraction {Q};

e). Low (tunable) synchrotron frequency Q_s

Items a), b) and c) lead to the conservation of angular momentum in transversal motion, thus converting this motion to "one-dimensional" one, with less beam-beam resonances, which can cause beam blow-up and/or degrade its lifetime.

Items d) and e) proved in computer simulations to be useful in rising the maximal beam-beam tune shift ξ_{max}, which does not damage luminosity. We hope to raise this value, at least, up to 0.1, in comparing with 0.05 - the best achieved up to now for flat beams.

The additional useful effect arises due to the simple fact, that beam-beam tune shift for given counting bunch density is 2 times lower for round beams than for smaller dimension of flat beam.

Before to switch to VEPP-4M collider now in operation, I wish to remind the successful proposition, development and effective use in our Institute of high precision mass measurements by resonant depolarization of transversally polarized electrons and positrons.

POLARIZED BEAMS IN STORAGE RINGS FOR HIGH PRECISION MEASUREMENT OF PARTICLE MASSES (RADIATIVE DEPOLARIZATION)

Colliders: VEPP-2M, VEPP-4 (+ LEP for Z^0). Detectors: OLYA, NED, KMD, MD-1

Mesons	Masses, MeV		Year	accur. impr.	prspcts keV
	Particle Data Group	Experimental data			
K^- K^+	493.657±0.020 493.84±0.13	493.670±0.029	1979	5	det.
K^0	497.670±0.13	497.742±0.085 497.661±0.033	1985 1987	4	det.
ω	782.4±0.2	781.78±0.10	1983	2	3
Φ	1019.70±0.24	1019.52±0.13	1975 1978	2	3
Ψ	3097.1±0.9	3096.93±0.09	1980 1981	10	10
Ψ′	3685.3±1.2	3686.00±0.10	1980 1981	10	15
ϒ	9456.2±9.5	9460.57±0.12	1982 1984 1986	**80**	10
ϒ	10016±10	10023±0.5	1984	20	
ϒ′	10347±10	10355.3±0.5	1984	20	
e^+,e^-	(g–2) comparison: $\Delta\mu'/\mu_0 \le 1\cdot 10^{-11}$		1987		

As a result: 10^{-5} precision mass scale from 1 GeV/c^2 to 100 GeV/c^2.

Figure 7. (The last column presents our evaluation of technically feasible ultimate precision of mass measurements by the resonant depolarization method)

The VEPP-4M collider (Figure 8) is almost new machine; especially, very advanced is the detector KEDR (Figures 9). The immediate aim for experiments started is to measure total hadron cross-section in electron-positron annihilation with the precision, acceptable for muon g-2 interpretation and for definition of α_{em} at high energies, and to improve substantially the precision of tau-lepton mass knowledge.

Electron-Positron Collider VEPP-4M
(up to 11 GeV total energy)

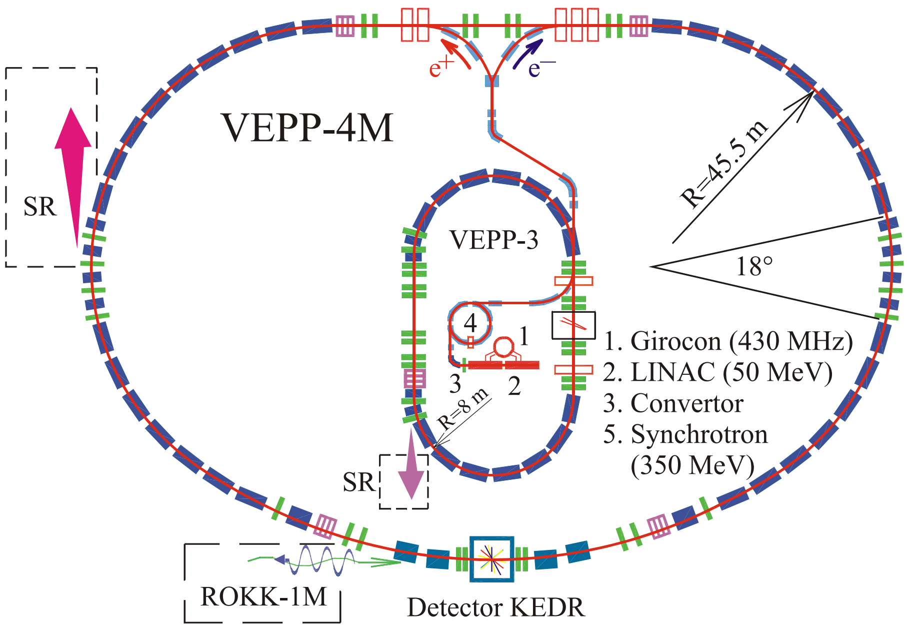

Figure 8.

Detector KEDR

1 – Beam pipe
2 – Vertex detector
3 – Drift chamber
4 – Aerogel threshold counters
5 – ToF counters
6 – **30 Tons LKr calorimeter**
7 – Superconducting coil
8 – Yoke
9 – Muon chambers
10 – CsI calorimeter
11 – Compensating solenoid
12 -- Quadrupole

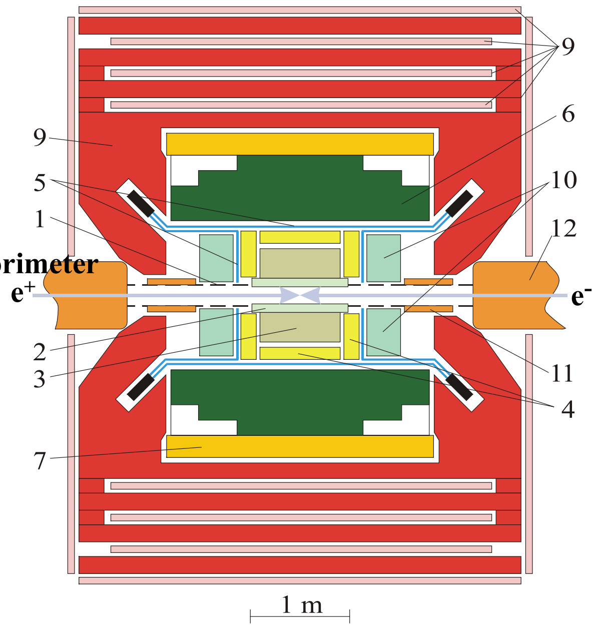

Figure 9. “KEDR” – the central detector of VEPP-4M collider.

The next and long-term goal is the study of hadron physics in two-photon channel. For this aim, the VEPP-4M interaction region is arranged as high resolution two-arm spectrometer for remaining electrons and positrons (Figure 10).

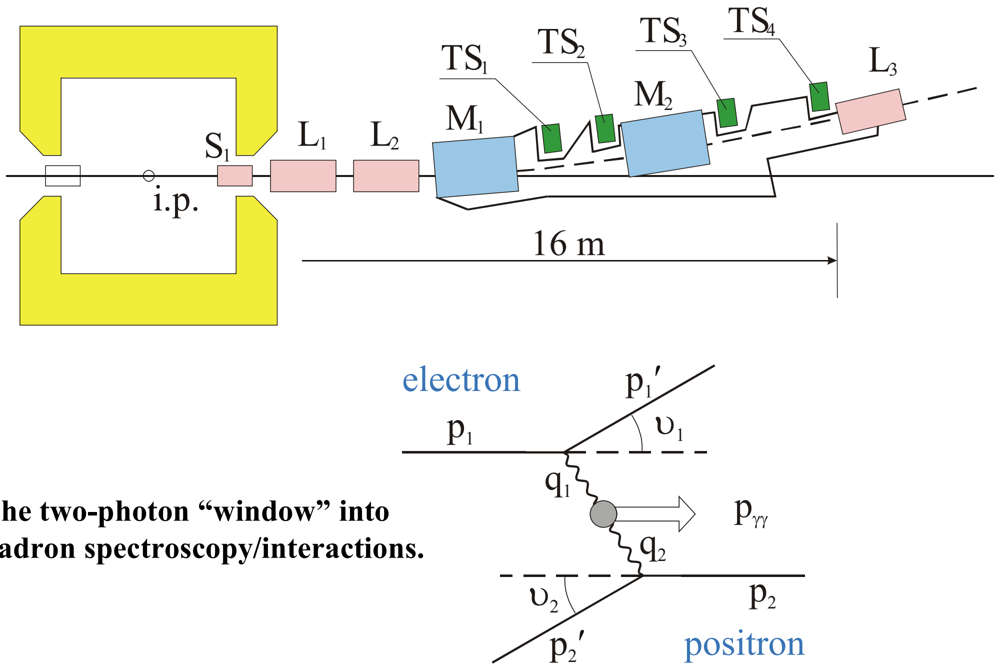

Figure 10.

The mass resolution for two-photon event was evaluated experimentally using laser backward Compton scattering and is order of magnitude better than in all previous experiments (Figure 11), while the efficiency of such double tagging is not worth than 30%.

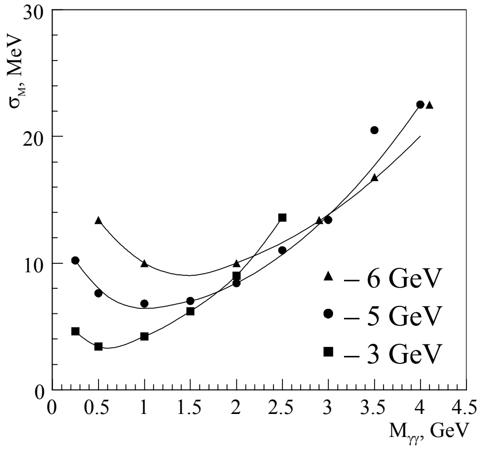

Figure 11.

Even the modest financial requirements of current operation and upgrading of the existing colliders in the Institute are not fully covered by the nowadays State support. But our participation in design and construction of “high scale” and “high technology” installations and equipment for research centers abroad (international and national), and also selling our technological and medical equipment (also mostly abroad) give us possibility – albeit very slowly! – step-by-step to design and construct new complex which we call VEPP-5
(Figure 12).

VEPP-5 SCHEMATIC LAYOUT

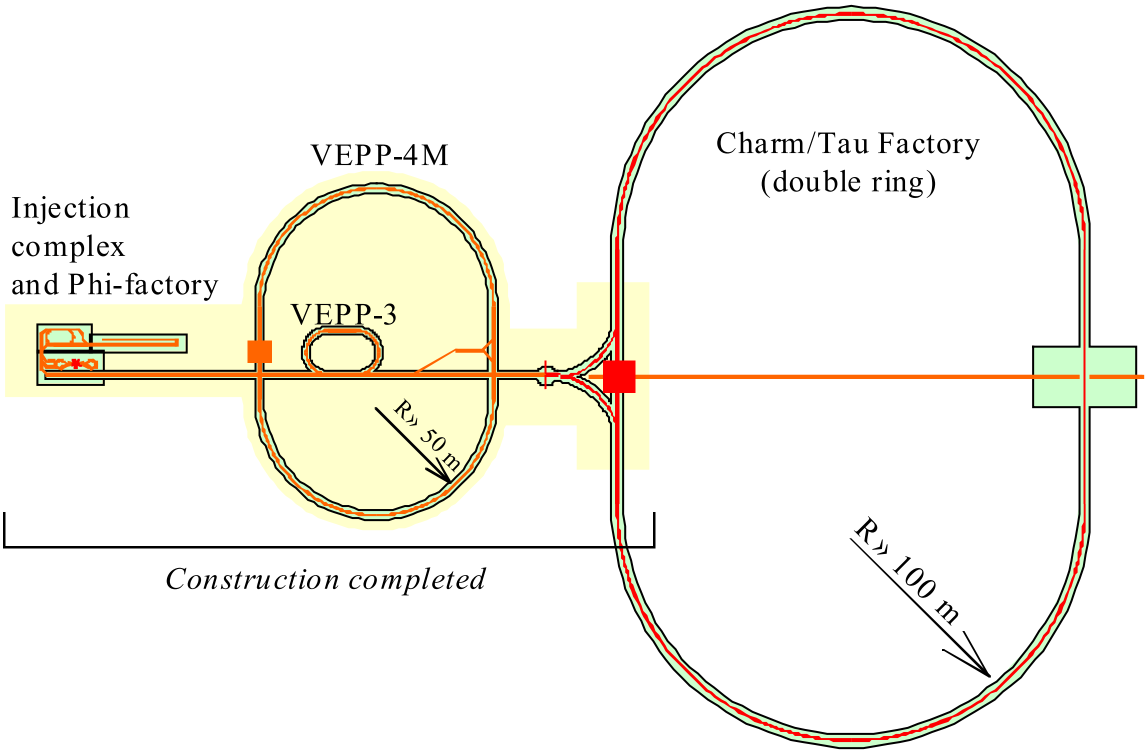

Figure 12.

The main goal of the project is Charm/Tau Factory (total energy up to 5 GeV), which (if successful) would have extraordinary good and useful potential:
high luminosity regime – “Round Beams”:

L_{max} up to $1\cdot10^{34}$ $cm^{-2}sec^{-1}$;

longitudinally polarized collisions (with independent arbitrary helicities):

L up to $1\cdot10^{33}$ $cm^{-2}sec^{-1}$;

high “effective” monochromaticity:

for dM_{event}=50 keV, L$\geq 1\cdot10^{32}$ $cm^{-2}sec^{-1}$.

The First part of the project – the Injector complex – is nearing the completion. It will provide up to 10^{10} positrons and electrons per second at 510 MeV, properly bunched and cooled to very low emittances – for to supply VEPP-4M in operation, VEPP-2000 under construction and future Charm/Tau Factory.

The above mentioned use of transversally polarized particles (electrons and positrons, first of all) for high precision mass determination, invention and theoretical proof of possibility to have stable longitudinal polarization in storage rings at interaction region, and many other “polarization developments” were (and are!) an important fraction of our activity (and our achievements).

Now I will tell about our contribution to the directions in high energy physics development, which did not became, in practice, fractions of our “in-house” program. And the first one is the line of LINEAR COLLIDERS.
We (at Novosibirsk) started to search for approach to reach hundreds of GeV (center-of mass) in electron-positron collisions still in 1960s. Immediately we understood: because of SR, the only way is linear collider.
(And the first sketch of single-pass-collider at SLAC was drawn at that time. Albeit, such option is not the way to really high energy – because of arcs.)
(Linear collider approach as replacement for storage rings based collider was considered for the electron-electron experiments at «low» 3 GeV energies by M. Tigner, 1965.)
The first INP presentation of LinCol approach as the way to reach hundreds of GeV in e–e+ was at International Seminar on High Energy Physics Prospects, Morges, 1971. In 1978, April, at the Budker’s Memorial International Seminar at Novosibirsk we, for the first time, presented a self-consistent physics project – VLEPP, which included:
- single bunch high efficiency energy extraction;
- transversal single bunch instability and its curing by bunch energy gradient (BNS damping);
- achievability of 100 MeV/m acceleration gradients;
- beamstrahlung as one of the major problems– and the flat beams as the way to cure the problem;
- beam-beam single pass instability limit.
In 1988 the Branch of our Institute was arranged at Protvino, under V.Balakin leadership, for VLEPP R&D and construction – to arrange full use of well developed for the Protvino UNK project powerful construction facilities!
Of course, now the VLEPP project is stopped because of well known economical reasons in Russia.

Much was done and much is progress in the Protvino Branch – as part of international activity , with the hope – to be “full right partners” in realization of the future Global Linear Collider Project.

Now, about our Muon-Muon Collider activity. Again, still in 1960s, we understood, that the reasonably long muon life-time (growing relativistically), and ionization cooling of muon beams give possibility to reach in muon colliders the energies even higher than for electrons and positrons, and acceptable luminosity (1969, 1971, 1980, 1981, 1995, 1998,…).
Now, it is subject of efforts for many laboratories in the World (with our – minor – participation).
Moreover, in “the same stream”, we proposed afterwards to use ionizationally cooled and accelerated muon beams as very efficient source of muon and electron neutrino (1980), – the direction, which became now so popular.

Yet another very important fraction of our activity is the invention, experimental and theoretical development of Electron Cooling method. It took 35 years (after initial proposal) the method not only to become routinely used in many labs, but to take the central place of many very modern and very advanced projects (RIKEN, GSI, BNL-RHIC, …).

As I told already, we participate actively in activities of many laboratories in the World. And the highest scale of collaboration is in the Particle and Nuclear Physics projects. The incomplete list of collaborations is as following:

CERN (LHC machine, ATLAS, LHCb, CERN-GranSasso)
SLAC (separation magnets for PEP-II, BaBar data analysis, heavy liquid metal targetry for NLC)
KEK (BELLE data taking and analysis, …)
FNAL (Lithium liquid metal lenses and rods, …)
DESY
GSI (Ion Buncher, eFragment Collider, Electron Coolers)
BNL (RHIC luminosity upgrade via Electron Cooling, g-2 experiment,…)
BATES Lab (Longitudinally Polarized Electron Ring upgrade, High Luminosity Longitudinally Polarized ep Collider via Electron Cooling)
Uppsala U. (data taking with jointly developed CsI Detector)
IMF, Lanzhou (Electron Coolers)
(+ RIKEN, Juelich, ORNL,…)
(in bold are our higher scale partners in Particle and Nuclear Physics).

As an example, at Figure 12 were presented, so called, Addenda, which specify our work for LHC machine project.

CERN - Budker INP COLLABORATION Novosibirsk 2001

	PARTICIPATION IN LHC MACHINE PROJECT	PERIOD	TOTAL PRICE (kCHF)
A1	MANUFACTURE AND DELIVERY OF DIPOLE AND QUADRUPOLE MAGNETS FOR LHC TRANSFER LINES.	1996–2000	26 340
A2	MEASUREMENTS OF PHOTODESORPTION COEFFICIENTS FOR PROTOTYPES OF LHS VACUUM CHAMBERS.	1996–1997	250
A3	MEASUREMENTS OF DISTIBUTIONS OF PHOTON REFLECTION AND PHOTOEMISSION FOR PROTOTYPES OF LHC VACUUM SYSTEM.	1998–2000	500
A4	PERFORMANCE OF DESIGN WORK WITHIN THE FRAME OF LHC PROJECT.	1998–2000	255
A5	PERFORMANCE OF R&D AND DELIVERY OF EQUIPMENT FOR LHC.	1998–2000	2 000
A6	MANUFACTURE AND DELIVERY OF BUS-WAYS FOR LHC DIPOLE CIRCUITS.	2000–2001	1 168
A7	MANUFACTURE AND DELIVERY OF SUPERCOND. BUS-BAR SETS FOR LHC.	2000–2004	22 472
A8	MANUFACTURE AND DELIVERY OF SUPPORT JACKS FOR LHC MAGNETS.	2000–2001	605
A9	MANUFACTURE AND DELIVERY OF VACUUM SYSTEM COMPONENTS FOR LHC TRANSFER LINES.	2000–2002	1 695
A10	MEASUREMENTS OF PHOTOSTIMULATED DESORPTION FOR NON-EVAPORATABLE GETTER (NEG) COATED SURFACES.	2000–2002	250
A11	MEASUREMENTS OF PHOTOSTIMULATED DESORPTION FOR PROTOTYPES OF LHC VACUUM CHAMBERS.	2000–2002	250
A13	MANUFACTURE AND DELIVERY OF THE COMPONENTS FOR THE LHC ARC VACUUM INTERCONNECTS.	2000–2004	7 011
A14	MANUFACTURE AND DELIVERY OF SHORT STRAIGHT SECTION COLD MASS BUS-BARS SETS.	2000–2002	8 992

72 MCHF

Total value should reach 95 MCHF + 9 MCHF for CERN-GranSasso line.

Figure 12.

Now, the Addendum No1 is completed: all 360 dipoles and 180 quads – 4 000 Tons of magnet and vacuum equipment for LHC – were finally designed at INP, fabricated, measured and transferred from Novosibirsk to CERN for 5 000 kilometers! According to the time schedule and specs. The first magnet arrived to CERN in 1999, the last one – 15/06/2001.