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THE MAJOR ACCELERATOR PROJECTS IN CHINA

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Introduction

I am much pleased to have this opportunity to present the major accelerator projects in China before such an illustrious audience. I hope through my description you can get some idea about our development of science and technology in general and the emphasis in basic research and status of accelerator development in particular.

The development of accelerators in China began only after the founding of PRC in 1949. Some of the major milestones are as follows: a Van de Graaff of 2.3 MV in 1959, a 25 MeV betatron in 1963, an 1.2m cyclotron and an electron linear accelerator of 30 MeV together with its 14 MW high power klystron in 1964, a 10 MeV proton linac in 1982, etc. All these accelerators, totalling over sixty including some imported ones, are low energy accelerators. However, they have served their purpose as research tools in nuclear physics as well as made important contributions to our development of science and technology.And, at the same time, laid the foundation for further development into the realm of higher energies.

To satisfy the need of modernization of science and technology in China, some medium and high energy accelerators had been proposed and are now under construction. In the following, I am going to describe three major ones as listed in Table 1, from the points of rationale, general layout, main design features and present staus respectively.

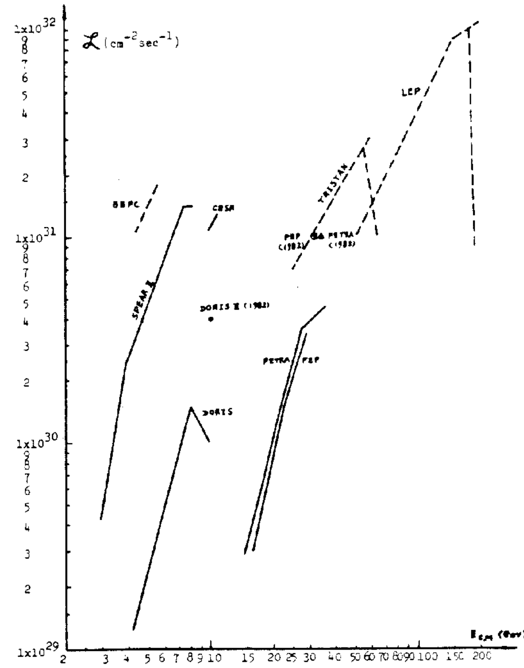

Fig. 1. Luminosity vs center-of-mass energy for some $e^{\pm}$ colliders

Table 1. General Aspects of the Three Major Accelerator Projects in China

Project	Location	Institute	Energy	Purpose
Beijing Electron Positron Collider (BEPC)	Beijing	Institute of High Energy Physics (IHEP)	2.2/2.8 GeV	Particle Physics, sychrotron radiation, high energy nuclear physics
Lanzhou Heavy Ion Research Facility (HIRFL)	Lanzhou	Institute of Mordern Physics (IMP)	100---5 MeV/A	heavy-ion nuclear physics, atomic, molecular and solid state physics
Hefei Synchrotron Radiation Laboratory (HESYRL)	Hefei	University of Science and Technology of China (USTC)	800MeV	sychrotron radiation, medium energy nuclear physics

Beijing Electron Positron Collider[1] (BEPC)

Rationale

The original plan of China's first high energy accelerator was a 50 GeV proton synchrotron. However, during the readjustment of our national economy, it was realized that developing high energy physics along the route of proton synchrotron with increasing higher energies is not consistent with our economy. So we switched over to the $e^{\pm}$ collider to take advantage of the fact that relatively high available energy can be obtained with only modest investment.

The $e^{\pm}$ collider has the short-comings of fixed particle reactions and limited working energy range that limit the kinds of experiments can be performed. However, the limited working energy range of the collider has its beneficial effect to us in the sense that collider of higher energy can not cover that of lower energy in its usefulness because of the sharp drop-off of luminosity. As can be seen from Fig.1, although BEPC is quite modest in energy, its luminosity still allows it to do useful physics, such as charmed meson and τ heavy lepton physics, charmed baryon physics, etc.

Another justification of the BEPC project is that it can be used parasitically or dedicatedly as a synchrotron radiation light source. Because of the difference in beam energies between BEPC and HESYRO, photon critical energies can differ by as much as a factor of 12 for the same magnetic field, so they will complement each other in many fields of applications.

Finally, the injector linac of BEPC can also be used for stationary target experiments in high energy nuclear physics. So BEPC facility will actually serve a triple purpose.

General Layout

The general layout of BEPC is as shown in Fig. 2. It consists of four major systems, i.e., injector, storage ring, detector and a data processing center not shown in the figure. The injector is a linac that provides positron or electron beam of 1.1/1.4 GeV for half energy injection to the storage ring. It consists of 3 parts, i.e., a 30 Mev pre-injector to shape the beam to narrow bunches, a 340 MeV electron linac with a retractable tungsten target at its end, followed by pulsed focussing field, accelerating section and R.F. separator for positron production, and a 1.1/1.4 GeV $e^{\pm}$ LINAC FOR FINAL ACCELERATION. This injector, totalled 220 m in length, is a conventional constant gradient, $2\pi/3$ mode linac except that a pulse compression scheme, called Energy Doubler, to enhance the peak power at the expense of pulse width is employed which can effectively double the klystron (Fig. 3) peak power input to the accelerator structure.

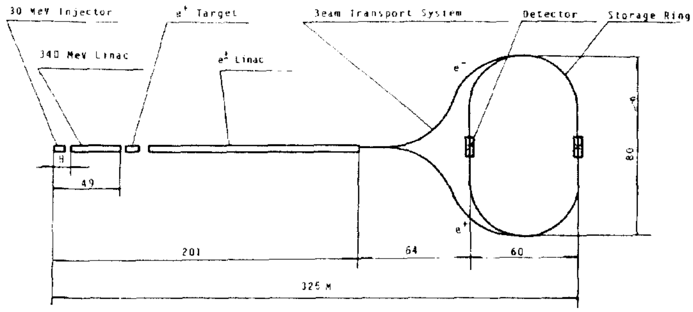

Fig.2. General Layout of BEPC

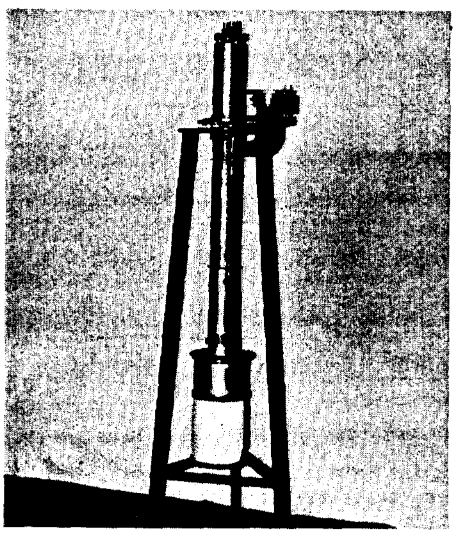

Fig.3. Klystron to be used in BEPC injector linac

The storage ring is designed with a luminosity, $\mathcal{L} = 1.7 \times 10^{31}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ at 2.8 GeV under the assumptions of 0.04 maximum beam-beam tune shift with 66 ma circulating currents and a vertical beta function at the interaction point, $\beta_y^* = 10$ cm. A minibeta mode of operation, with $\mathcal{L} = 4 \times 10^{31}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ at $\beta_y^* = 4.2$ cm can also be realized in this ring by removing the compensating coils. It is of race-track shape with 2 long straight sections and 2 arcs totalling 238.4 m in circumference. There are two experimental areas with 5 m long interaction regions at the middle of the long straight sections. R.F. cavities are located at either side of the interaction region. At the middle of the arcs, there are two straight sections of 5 m long for the $e^{\pm}$ injection and feed-back systems. Four wiggler magnets are located at the missing bending magnet locations around the ring to keep the emittance constant so that luminosity varies as energy squared can be realized.

About lattice option, a seperated function FODO lattice consisting of low-beta-insertions, dispersion suppressors, regular cells, and symmetry sections has been adopted as shown in Fig.4. There are 40 dipoles and 60 regular quadru-poles. The typical beam aperture in the regular arc is 58 mm vertical 120mm horizontal.

For the detector, we adopt a general purpose magnetic spectrometer at one of the interaction region as a first step. The main components of this detector are drift chambers, time of flight counter, shower counter, muon identifier, a conventional solenoid magnet, etc. This spectrometer is designed to have good charged particle identification, good spatial and momentum resolution, good spatial and energy resolution for low energy photons and good detection efficiency.

For data processing, a VAX 11/780 is used as on-line computer for data acquisition and data analysis while a more powerful off-line computer system will be used for data analysis in the data processing center with an estimated data rate of about 10^7 per year.

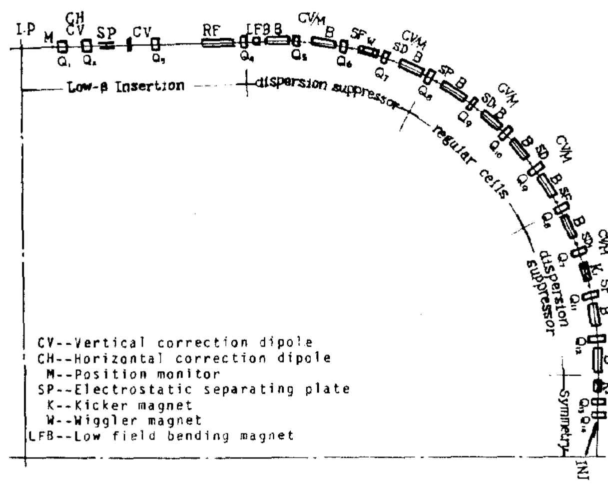

Fig.4. Schematic diagram of BEPC lattice in a quadrant

Main Design Features

As can be understood, the potential of BEPC to make contribution to physics with the above mentioned detector depends critically on the realization of the designed goal of luminosity. So, much emphasis has been laid in this respect.

To postpone the occurrence of aperture limitation, a relatively large aperture in consistent with our budget allocation, has been adopted. To alleviate the fast head-tail instability at injection, the averaged value of beta function and the beta function at the place where R.F. cavities are located are kept as low as practical, lower R.F. frequency of 200 MHZ is chosen, smoother vacuum chamber is emphasized and smaller number of R.F. cavities are preferred, so that the current instablility threshold can be reasonable large. If in spite of these measures the fas head-tail effect still turns out to be the limitation, means to increase the injection energy have also been considered, such as to improve the klystron output or to adopt the recirculation scheme. The phase shift between the neighouring insertions is also chosen to be just above a multiple of a half integer, since there is theoretical and experimental evidences that higher luminosity could be obtained in this way.

For synchrotron radiation application in the parasitic mode of operation, the figure of merit[2] F characterizing the lattice structure is 0.36. However, in the dedicated mode of operation, by adjusting the quadrupole excitation so that the tunes of the storage ring become $Q_{x,y} = 7.25$ instead of $Q_x = 6.28$ and $Q_y = 7.12$ for collider operation, one can obtain a F value of 0.11 which is quite satisfactory for a general purpose light source.

Present Status

The plan of BEPC project is to finish the construction in about five years after approval. For the present, preliminary design has been finished and the detailed design is under way. Pre-fabrication work has also been started since mid 1982. Models of various detectors are in the process of testing, on-line and off-line high energy physics computer program library is being established, and a 2.5 ns, 1a electron gun has been completed.

The pre-injector linac, a sector of storage ring vacuum system and some prototype magnets will be operating within this year, and civil engineering construction is expected to start early next year.

Lanzhou Heavy Ion Research Facility[3] (HIRFL)

Rationale

Heavy ion reactions provide the possibility of studying the collision process of two complex nuclei, the complete fusion reactions, new nuclides far from the beta stability curve, etc. These studies will greatly enrich our understanding of the nuclear structure and reaction mechanism. Besides, it has been found in late years that heavy ion beams have applications in many fields beside nuclear physics, such as atomic physics, molecular physics, solid state physics, material science, radiotherapy, radiography, etc. Perhaps this explains why there are impressive activities throughout the world in the design and construction of low and medium energy accelerators for heavy ion research and why HIRFL came into being.

Among the various types of accerlator, such as tandem, linac and cyclotron, and their various combinations suitable for heavy ion work, cascade cyclotron scheme has been adopted for HIRFL. This is because the injector cyclotron, an existing facility, is readily available for isochronous conversion and the main cyclotron, a separated sector type, is well known for its convenience of injection and extraction as well as its flexibility in operation.

General Layout

The general layout of HIRFL is shown in Fig. 5. It is composed of 2 cyclotrons in cascede. The injector is a sector focusing cyclotron (SFC), of 1.7 m dismeter and 3 sectors, with energy constant K=69, which gives ion energies of 8.5 MeV/A for C and 0.5 MeV/A for Xe. After extraction, the ion beam passes through a beam transport system consisting of 5 bending magnets, 31 quadrupoles, 2 R.F. bunchers and a foil stripper, totalling about 60 m in length. This system simultaneously performs the functions of achromatic beam transportion, phase space matching and increasing the charge states of accelerated ions.

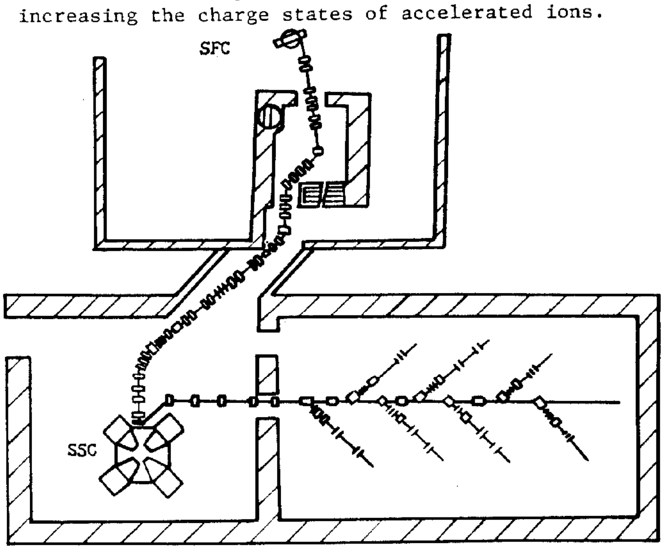

Fig.5. General layout of HIRFL

Then, the ion beam is injected into the main accelerator, a separated sector cyclotron (SSC) with K=450, which gives ion energies of 100 MeV/A for C and 5 MeV/A for Xe. This SSC (see Fig. 6) consists of four 52° sector magnets, each weights about 500T, 2 R.F. cavities symmetrically placed in two opposite valleys to supply accelerating voltage of 100-250 KV, and a integrated vacuum chamber about 90 m^3 volume to accomodate the pole tips, coils, cavities and injection and extraction elements and maitaining a vacuum of $10^{-7}\tau$ at the beam orbit plane. The SSC will be operated at 16 KG with 1 m average injection radius and 3.21 m average extraction radius. The expected performance of the system is: ion beam intensity 10^{11} -10^{12} PPS, beam emittance <10 mmmr, energy spread $\sim 10^{-2}$ -10^{-3}.

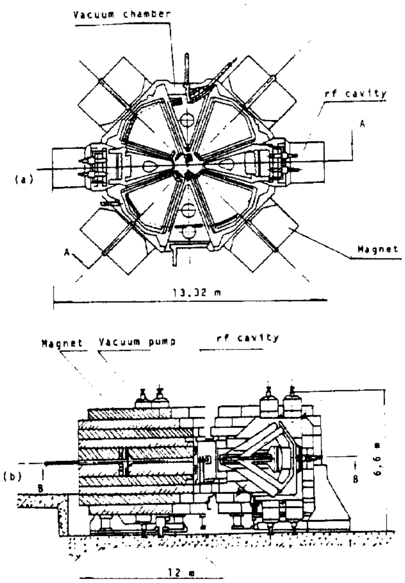

Fig.6. Construction of HIRFL main accelerator, SSC

After being extracted from the SSC, the accelerated ion beam is transported to a hall with several experimental stations where on-line isotope separater and helium jet, ionization chamber, heavy ion TOF spectrometer and scattering chamber are located.

Main Design Features

The cascade-cyclotron scheme adopted by HIRFL design has many advantages. Among them the injector SFC which can accelerate Ar up to 4.19 MeV/A gives relatively high energy output and thus can be used independently to provide light heavy-ion beams for experimental use. In between the two cyclotrons, one can use stripping foil to increase the charge state of the ions in order to achieve more efficient accelera- tion in the main accelerator.

In the main cyclotron, SSC, the injection radius has been chosen so large that the injection elements can be conveniently arranged. For the injection and extraction of different ions with different energies, the design ensures only a minimum amount of repositioning of the injection and extraction elements, such as electrostatic deflectors and septum magnets,would be required. For the benefit of phase compression of the ion beam during acceleration, the R.F. voltage should increase with radius, so a 1/2 λ R.F. cavity is adopted. The accelerating voltage is chosen reasonably high in order to reduce the number of turns required during acceleration so as to minimizing beam loss due to change of charge state.

For the vacuum system,a monolithic structure is adopted for the vacuum chamber. The advantage of this design is to leave plenty of room for the installation of beam injection system at the central region of the accelerator at the expense of increasing gas load for pumping system.

Present Status

The HIRFL project was approved in 1976 and civil engineering construction started in 1978. By now, R and D work, such as 1/4 scale sector magnet model, its power supplies and measuring devices, various types of R.F. cavity models, magnetic material studies, etc.

have all been finished, the detailed design is also near completion.

The first 52° sector magnet of SSC(fig.7) and its power supply have been delivered, and the other sectors will be ready by 1984. The vacuum chamber and R.F. system will be installed in 1985 and the converted SFC will be operating by the same year. In 1986, beam transport, vacuum and R.F. system will be adjusted separately while tune-up of the whole facility will be carried out in 1987.

Fig.7. The first sector magnet of SSC, HIRFL

Hefei Synchrotron Radiation Facility[4]

Rationale

The importance of synchrotron radiation light source is evidenced by the fact that by now there are 21 storage rings and synchrotrons being used for synchrotron radiation research and about 19 dedicated sources are under construction or being proposed.

The diversity of the applications of synchrotron radiation, from basic research to applied and developmental research,is obviously very attractive for our modernization programme and therefore a group of physicists and engineers at the University of Science and Technology of China(USTC) has started to build a dedicated storage ring which will be run by the Hefei Synchrotron Radiation Laboratory(HESYRL) when completed.

The energy of the storage ring was chosen as 800 MeV with 1.2 Tesla magnetic field. The reason for this choice is two-fold. Firstly, the synchrotron radiation produced has a broad spectrum covering VUV and soft X-ray, with most radiation concentrated at 20-50 Å where a wide field of promising research work can be done. Secondly, Higher energy machine will be more complicated and expensive for USTC to build while the Touschek lifetime might be too short for lower energy machine.

General Layout

The HESYRL facility consists mainly of a 800 MeV storage ring and a 200 MeV electron linac, as shown in Fig.8.

The linac injector consists of 9 sections of 3 meter long constant impedance $2\pi/3$ mode accelerating structure driven by 5 high power klystrons. It has a total length of 35.5 m and can provide a pulsed current of 50 ma at pulse width of 0.2-1 μs.

Electrons produced by the linac, passing through a beam transport system about 60 m in length, are injected into the storage ring until more than 300 ma circulating current is accumulated. This takes about 2 min and the storage ring is then ramped slowly in 3 min to an operating energy of 800 MeV, at which the beam emits synchrotron radiation with a lifetime about 8 hrs. After that, the whole process is repeated.

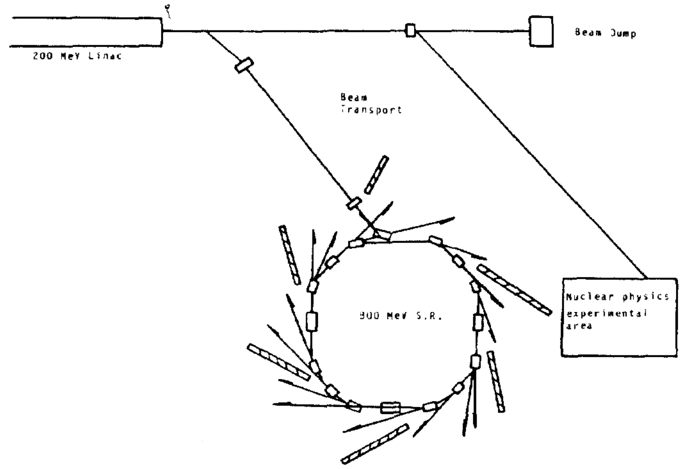

Fig. 8. General layout of HESYRL facility

The storage ring,as shown in Fig.9, consists of 12 bending magnets at 1.2 T and with a bending radius of 2.22 m. There are four 3.2 m straight sections to accomodate the injection elements, R.F. cavity, wiggler magnets and undulater. The circumference of the S.R. is 66.13 m. Since the stored beam life time is about 8 hrs, the linac electron beam will be sent through another beam transport system to a nuclear physics experimental station during this period.

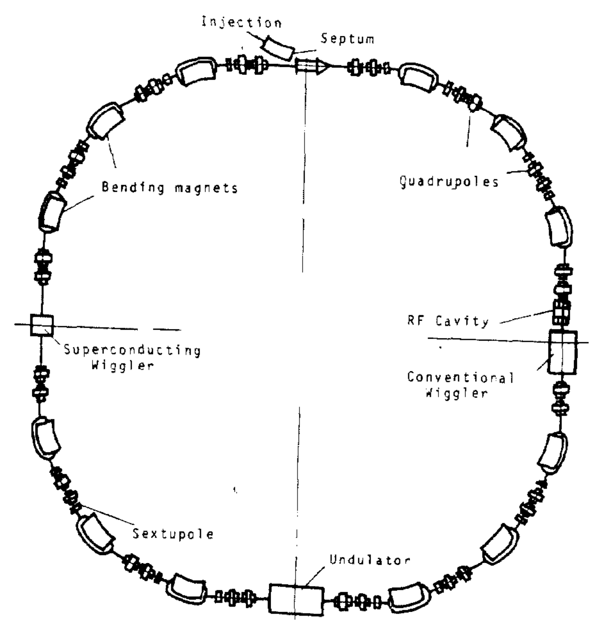

Fig.9. Schematic diagram of HESYRL storage ring lattice

Main Design Features

There are 15 optical beam channels from the conventional and superconducting wiggler magnet, undulator and from every bending magnets. They are further split to a total of 40 experimental stations distributed around the storage ring and grouped into 6 experimental areas, namely 3 for physics-chemistry, 1 for biology, 1 for radiation metrology and 1 for lithography.

From the regular bending magnets, the critical wavelength of the synchrotron radiation is 24 Å while the maximum photon flux is 1.6×10^{14} photon/sec. 1%.mr. When a 5T superconducting wiggler is installed, critical wave-length of 5.8 Å can be reached and the range of wave-length coverage is significantly extended.

In the design of the storage ring lattice emphasis was placed on the flexibility of operation to suit different experimental needs. By adjusting the excitation currents of the ring quadrupoles four different configurations can be realized, i.e. general purpose light source(GPLS), high brightness light source(HBLS), high flux light source(HFLS) and short pulse light source(SPLS) respectively, differentiated mainly by the source cross-sectional area and bunch length. The first one, GPLS, is expected to be adopted most regularly because it brings about a moderately small beam size and longer beam lifetime which suits the need of most experiments. HBLS has an extremely small beam size while HFLS has a relatively large beam size in order to hold more current, and SPLS utilizes bunches of very short length to produce short light pules of the order of 10^{-11} sec..

Present Status

The acclerator laboratory at the USTC took the responsibility for the project proposal and design in 1978. All essential R and D work related to this project have been finished, such as a 30 MeV electron linac section, prototype bending and quadrupole magnet, a vacuum chamber section with distributed ion pump(Fig. 10), a prototype kicker magnet with its pulsed power supply etc.

HESYRL is now in the process of land requisition and it is estimated that around 5 years is needed to complete the project.

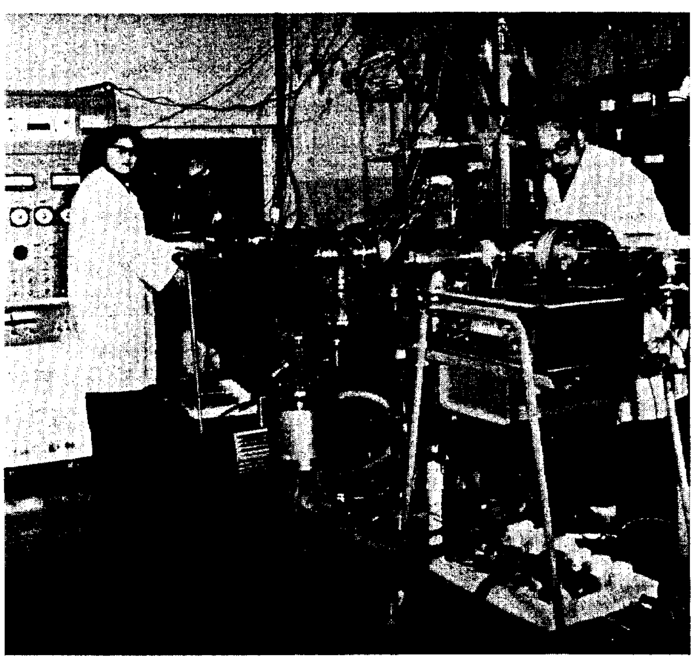

Fig.10. HESYRL vacuum chamber model with distributed ion-pump

Acknowledgment

During the design and execution of the above mentioned projects we have been generously helped by the staff of many world renowned accelerator laboratories in supplying information and providing expert advices. I would like to take this opportunity to express our sincere appreciation.

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