THE GERMAN 40-GeV PROTON-SYNCHROTRON

Karlsruhe Study Group

presented by
W. Heinz

A study group of the Kernforschungszentrum at Karlsruhe, Germany, has been engaged for some time in the design of a German high energy proton accelerator. The project was initiated and directed by the late Prof. A. Schoch. In these days the proposal [1] was completed and some of you already have got it right in time for this conference. Together with other national projects [2][3] we have heard of here, this accelerator will contribute to form a larger basis for high energy physics. The maximum energy of the proposed machine is 40 GeV, the designed intensity 10^{12} protons/s in the extracted beam, the repetition rate of the accelerating cycle 1/s up to 2/s. With the slower cycle a flat top of up to 0.4 s is included. The mean radius of the machine is 150 m.

The energy is higher than that of the CERN PS and the Brookhaven AGS to profit by the increased fluxes and higher secondary momenta of the produced particles. The intensity is comparable with conventional accelerators and was chosen to avoid troubles with space charge effects and induced radio-activity. To arrive at a project not too expensive in both, technical and financial respect, it is more favourable to raise the energy rather than the intensity. Later on an improved injector would allow to raise the intensity, too. For intensity improvement (up to a factor of 10) without altering the main synchrotron the injection energy has to be increased (by a factor of 2.5).

The design of this accelerator is based on the fact that the costs for buildings, magnets, power supplies etc. have an increasing tendency, whereas the aids and appliances of electronic control and regulation are getting more and more effective and cheap. A design was chosen that allows reducing the size of the magnets by reducing the necessary magnet aperture and simultaneously improving the performance of the machine. This is obtained by realizing two ideas.

First, beam monitoring and correction during acceleration are used to reduce closed orbit displacements due to misalignments of the magnets, magnetic field errors etc. (similar to the 10/20 GeV Cornell Electron Synchrotron)[4]. There remain only the stabilizing oscillation of the particles due to the finite emittance, momentum spread and space charge of the beam and other unavoidable exciting mechanisms, e.g. gas scattering. The vacuum chamber has only to admit these inherent oscillations around the designed equilibrium orbit. The aperture of the magnets and hence the total stored energy can be kept small. The weight of the magnets and the exciting magnet power are reduced. The ring tunnel is simple and without special foundation (Fig. 1).

Secondly, a booster synchrotron is used to raise the injection energy for getting a simple main synchrotron. The injection energy is 2 GeV so that the particles have nearly the velocity of light ($\beta = 0.95$). The frequency swing of the revolution and RF frequency is only 5 %. Space charge limits and the magnetic field at injection are raised, betatron oscillation amplitudes are smaller. The magnet aperture can thus be further reduced, the outer dimensions of the vacuum chamber being 4 x 8 cm^2. The total weight of the magnet is 1,660 t, compared with 3400 t of CERN. Fig.2 gives an impression of the sizes of our magnet (solid line) and the CERN magnet (dotted line). The savings of magnet power due to a smaller aperture are used to get a faster cycle at equivalent power level. We have the following cycle: 0.3 s rise - 0.4 s flat top - 0.3 s fall. That means a duty factor of 40 %. Without flat top or at lowered energy the cycle can be faster (up to 2/s). The peak power is 31 MW, the average total dissipation 2,5 MW.

The lattice of the main synchrotron consists of 64 unit cells with 2 focusing and 2 defocusing C-shaped combined function magnets per unit, and 8 long straight sections with 2 quadrupoles each. The beam observation stations and correcting elements are located within the FOFODODO-structure of the unit cells, the accelerating cavities in 4 of the long straight sections with 3 cavities per section. The other 4 long straight sections are used for injection fast and slow ejection and internal targeting. Fig. 3 shows the lay-out of the main synchrotron including the injector system (linac and booster synchrotron) and the two experimental halls (one for the internal target, the other for the extracted beam). We have considered several possible injection schemes: Linac, fast and slow cycling, and multiple booster synchrotrons. We propose a multiple ring booster, because it is slow cycling and space charge limits are not so serious. It consists of 3 rings. For their radii r_B the relation $3\ r_B = r_M$ (r_M radius of the main synchrotron) is valid. The 3 pulses of the single synchrotrons then fill the main ring. The magnets of the booster ring are common and excited simultaneously. The magnet units are manageable (maximum weight 9 t, maximum field 5.6 kG). Their exist detailed studies by the CERN group [5] for a 4-ring booster.

The dependance of costs on n in the region n = 3, n being the number of rings, is very flat. However, costs and complexity decrease with decreasing n, n = 1 being the least expensive version. A single ring booster would have the radius of the main synchrotron The two synchrotrons can be located concentric in the main ring tunnel saving extra costs for a second tunnel. A serious problem arises with remanent and magnetic stray fields in the common tunn However, further investigations may show that the single ring version is more advantageous than the proposed 3-ring booster.

Table 1 gives the main parameters of the proposed accelerator. Th figures there may help the characterise it and give some more deta The last figures of this list are of special interest. They illust the economic gain of our scheme compared with other existing or planned machines. The total weight of the magnet including the booster is 2,360 t. The end energy divided by this weight is a measure of the economy of the magnet.

Accelerating scheme: Linac (30 MeV)
Booster synchrotron (2 GeV)
Main synchrotron (40 GeV)

Main ring:

Maximum kinetic energy	40 GeV
Injection energy	2 GeV
Circulating current	$1{,}25 \cdot 10^{12}$ protons/s
Intensity of the extracted beam	10^{12} protons/s
Repetition rate at end energy	1/s
Maximum repetition rate	2/s
Structure of the period	$FO_1FO_2DO_1DO_2$
Number of periods	64
Length of period	13,25 m
Number of long straight sections	8
Number of betatron oscillations per turn	14,25
Accelerating cycle: rise time	0,3 s
flat top	up to 0,4 s
fall time	0,3 s
Mean radius	150 m
Magnetic radius	100 m
Maximum field at equilibrium orbit	1,36 T
Injection field at equilibrium orbit	0,093 T
Magnet aperture	4 x 8 cm^2
Number of magnet units	4 x 64
Length of unit	2,45 m
Weight of magnet unit	6,5 t
Length of long straight section	11,78 m
Total weight of the magnets	1.660 t
Total stored energy	4 MJ
Peak magnet power	31 MW
Average total dissipation	2,5 MW
Revolution frequency	0,302 ...0,319 MHz
Accelerating frequency	29,0 ...30,6 MHz
Average energy gain per turn	420 keV
Harmonic number	96
Number of accelerating gaps	12
Frequency swing	1 : 1,06

Booster synchrotron:

Type: 3-ring-synchrotron with separated function magnets

Maximum kinetic energy	2 GeV
Maximum repetition rate	2/s
Structure of the period	$O_1BO_2Q_FO_2Q_DO_2Q_FO_2BO_1$
Number of periods	30
Number of betatron oscillations per turn	5,25
Mean radius	50 m
Magnetic radius	16,6 m
Maximum field at equilibrium orbit	0,56 T
Injection field at equilibrium orbit	0,048 T
Magnet aperture	7 x 14 cm^2
Number of magnet units	5 x 30
Total weight of the magnets	973 t
Weight of magnet units:	
bending magnet B	9 t
long quadrupole Q_D	6 t
short quadrupole Q_F	3 t
Total stored energy	1,5 MJ
Peak magnet power	9,0 MW
Average total dissipation	1,3 MW
Revolution frequency	0,236 ...0,905 MHz
Accelerating frequency	7,55 ...29,0 MHz
Average energy gain per turn	12 keV
Harmonic number	32
Frequency swing	1 : 3,84
Number of accelerating gaps / ring	2

Costs:

Accelerator	65 MDM
Buildings	56 MDM
Total	121 MDM

Planned running-in 1972

Economy of magnet:

CERN PS 28 GeV	8,24 MeV/t
Brookhaven AGS 33 GeV	8,25 MeV/t
France 23/ 45 GeV	10,2 MeV/t
Europe 300 GeV	10,0 MeV/t
USA 200 GeV	10,5 MeV/t
Germany 40 GeV	16,9 MeV/t

References:

1) Vorschlag zum Bau eines 40 GeV Protonensynchrotrons, Kernforschungszentrum Karlsruhe, Institut für Experimentelle Kernphysik, Juli 1967

2) R. Levy-Mandel, A 23/45-GeV Proton Synchrotron Sixth International Conference on High Energy Accelerators, Cambridge, Mass. (1967)

3) S. Suwa, The Japanese 40-GeV Proton Synchrotron Project, Sixth International Conference on High Energy Accelerators, Cambridge, Mass. (1967)

4) R.R. Wilson, The 10 to 20 GeV Cornell Electron Synchrotron, CS - 33 (1967)

5) CERN staff, MPS, private communications

F. T. Cole (NAL): Would you comment on your choice of combined function in the main ring and separated function in the booster?

W. Heinz: The combined function system was chosen for the main ring as it gives better access to the vacuum system. The separated function design of the booster synchrotron will allow for a future improvement program of increased intensity and higher energy.

E. D. Courant (Brookhaven): My question is also addressed to Dr. Levy-Mandel and Dr. Suwa who also have presented plans for accelerators in the range of 40 GeV and 10^{12} protons per sec. As this current will be below what will be available from the AGS and CPS after completion of their improvement programs, and as the energy is only a little higher, do you believe that these accelerators will still be useful from the point of view of doing physics?

W. Heinz: Intensity is not the only factor in improving experiments. The smaller emittance obtainable by using a booster synchrotron could be equally important. Also, a future intensity improvement program is also possible with this accelerator.

R. Levy-Mandel: I showed a table comparing particle fluxes from our proposed accelerator with those from the AGS and CPS after the intensity improvement. It was shown that these fluxes were very favorable and I would also point out that it is possible to obtain beams of Σ's etc. with longer path lengths for experiments when one goes to 45 GeV. It is true that in the future one must aim for higher intensities of up to 10^{13} protons per sec.

F. Amman (Frascati): Was the choice of the slow cycling booster as against a fast cycling one dictated by economics or reliability?

W. Heinz: As the main synchrotron is relatively fast cycling, the choice of a slow cycling booster was determined by cost.

H. G. Hereward (CERN): Could you explain why you wish to change the Q in the booster and by how much?

W. Heinz: We do not now know if we need to change the Q for higher intensities but we may need to change the Q to optimize the working point of the machine.

V. Dzhelepov (Dubna): As the CPS and the AGS are already working, and the Serpukhov accelerator is now starting, does it not make sense to design 40 GeV machines only if they have a very much higher intensity? Also it is difficult to understand the justification for building three of these machines in the world.

W. Heinz: At the present time there is a shortage of machine time available for experiments and even another accelerator of the same performance would be interesting.

G. K. Greene (Brookhaven): One of the things we have learned during the last few years is that as we raise the energy of accelerators we can also raise the intensity. The research programs at CERN and Brookhaven I think have demonstrated how important such an intensity increase can be. I agree with Dr. Dzhelepov and I would plead that, as we push the energy up and we know how to push the intensity up, we do it.

TUNNEL CROSS SECTION

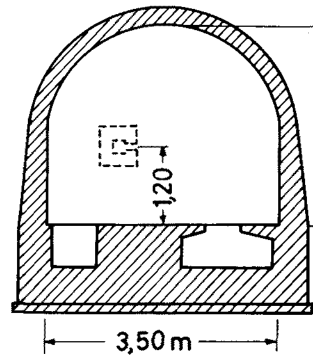

Fig. 1: Cross section of the ring tunnel

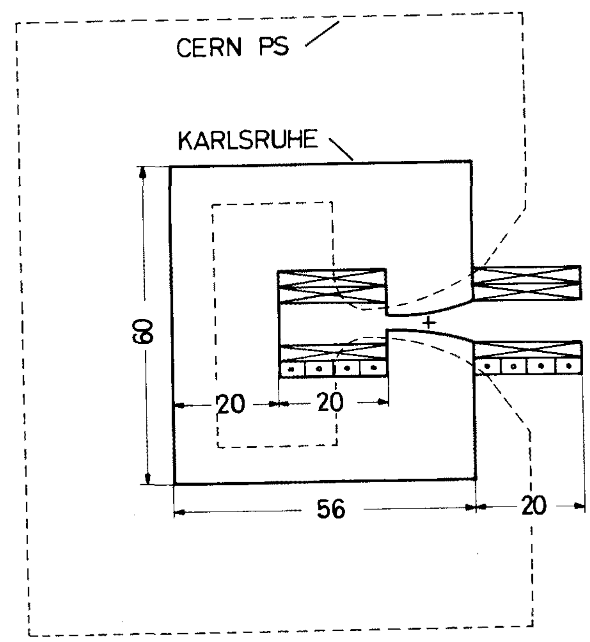

Fig. 2: Cross section of the magnet of the main synchrotron (solid line) compared with that of the magnet of the CERN-PS(dotted line)

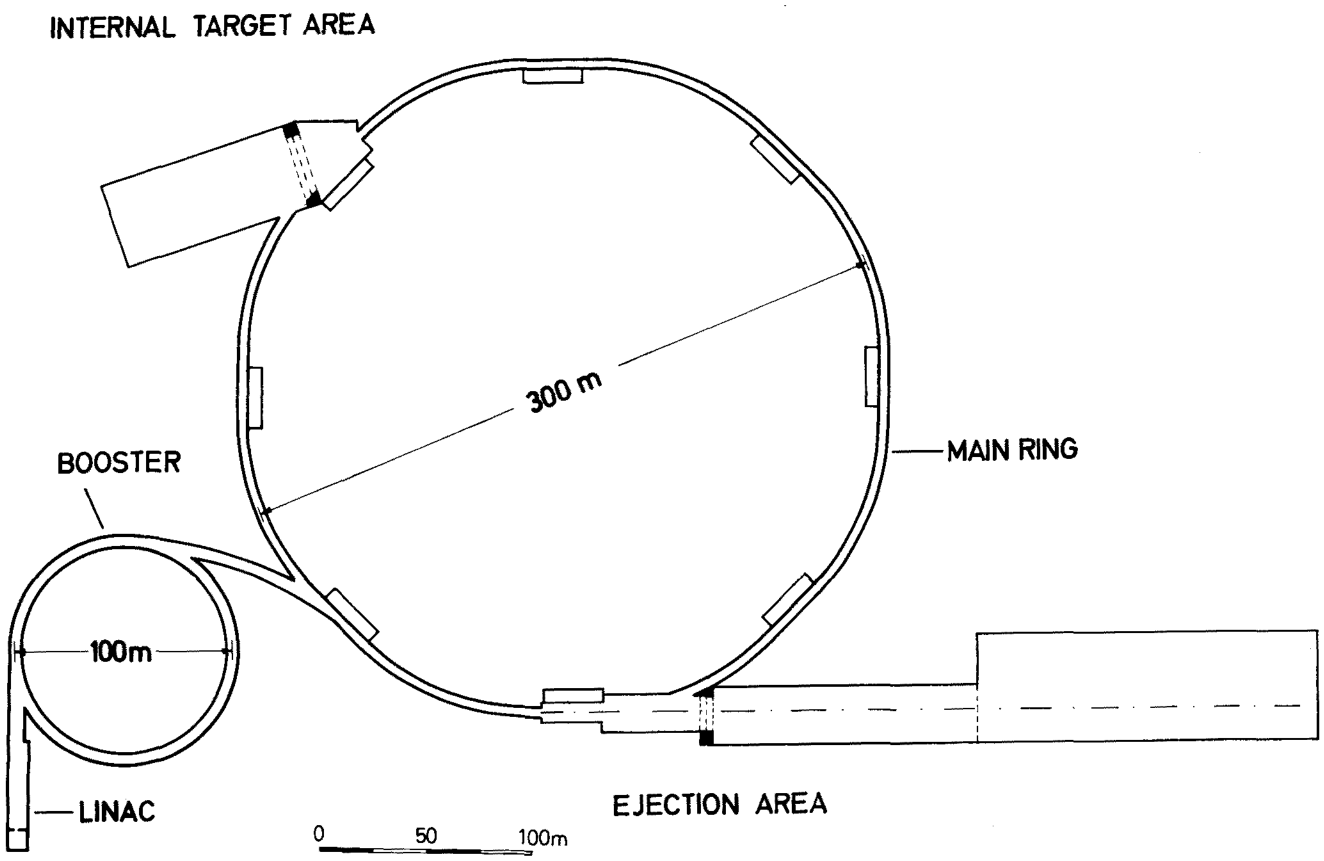

Fig. 3: Planned lay-out of the accelerator.