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Design Considerations and Expectations of a Very Large Hadron Collider *

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The ELOISATRON Project is a proton-proton collider at very high energy and very large luminosity. The main goal is to determine the ultimate performance that is possible to achieve with reasonable extrapolation of the present accelerator technology. A complete study and design of the collider requires that several steps of investigations are undertaken. We count five of such steps as outlined below.

The performance limitation of a large hadron collider is determined by the superconducting magnet technology, and by the beam dynamics, both which may lead to a very large circumference of the collider. The first step of the investigation deals indeed with these two most outstanding issues of the project: the large size of the collider, which beyond a certain limit may be unmanageable for a variety of technical and economical considerations, and the strength of the superconducting magnets which needs to be achieved and demonstrated. These two issues are of course related to each other since beam momentum p, bending radius ρ and magnetic field B are bound together by the well-known relation

$$B\,(\text{Tesla})\ \rho\,(\text{meter}) \ = \ 3.3356\, p\,(\text{GeV/c}) \qquad (1)$$

After these three major parameters, beam energy, magnetic field and the size of the collider, have been selected, the ELOISATRON Project will have to deal with another group of considerations during the second step of the study. They include: optimal design of the collider layout and, in particular, the design of the interaction region. The ELOISATRON is conceived as a classical circular collider. It is unfortunate that its size is required mostly to carry the proton beams around, circulating in opposite directions, so that they may collide in few, relatively short regions where the collider detectors are located and the experimental program is carried out. The design of the interaction region will interface with the overall collider outline at one end, and with the detector occupancy on the other. Requirements may be very stringent, especially concerning the collider luminosity which is the main parameter used by the users to evaluate the performance. For instance, the following criterion may be adopted. The reference design of the SSC, the large USA proton-proton collider now discontinued, called for a luminosity of 10^{33} cm^{-2} s^{-1} at the beam energy of 20 TeV. It is estimated that the required luminosity scales quadratically with the beam energy to compensate for the loss of the cross-section of the special events that one wants to detect. Thus, we may require the following behavior of the luminosity L with the beam energy E

$$L \ = \ (\,10^{33}\,\text{cm}^{-2}\,\text{s}^{-1}\,)\ (\,E\,/\,20\,\text{TeV}\,)^2 \qquad (2)$$

On top of this, it is also desirable that a large size project like the ELOISATRON has the conceptually demonstrated capability of increasing in a second phase the performance of the collider by

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an order of magnitude beyond the values derived from Eq. (2).

The total proton-proton cross-section remains essentially unchanged with the beam energy. This has the consequence to increase the number of total events, most of them undesired, that appear in a single beam-beam crossing. To cope with this one requires a design of the interaction region and of the colliding beam configuration such to reduce the total number of events per crossing, and the development of collider detectors that are capable to absorb the number of events appearing in a single crossing at very high rate.

Since the collider is circular and the proton trajectories are bent, because of the large energy values involved, protons will radiate energy away by interacting electromagnetically with the vacuum, the same way electrons do in circular electron colliders. Thus the motion and the dynamics of the proton beam at large energies is definitively affected by the synchrotron radiation, and this is to be taken into account in the design of the collider and in the evaluation of its performance. Fortunately, it seems that the effects of the synchrotron radiation have positive consequences for the enhancement of the collider performance.

The next step of the study deals with more specific and detailed design of essential systems, that, though may look peripheral to the collider design proper, are nevertheless crucial, since they may set ultimate limitations and consequences. In particular, one has to deal with considerations of the injector system, which alone may take the dimensions of the CERN Large Hadron Collider project, the RF system which is required for the beam acceleration and storage over long periods of time, and of the vacuum system which interfaces with the cryogenics built in the superconducting magnets and with the effects of the synchrotron radiation.

The fourth step of the study includes topics and considerations of more intellectually sophisticated nature. The analysis becomes more delicate, but very essential. The ELOISATRON is clearly a very expensive project, and it is important that a high confidence in the design and in the expectation of the collider performance is maintained. We deal here with beam parameters that need to be demonstrated that can indeed be sustained over long periods of time, since in colliding mode the collider will have to perform stably and continuously over a period of time at least one day long. Thus, it is crucial to prove well in advance the stability of the motion of a single proton as well as of all the beam together. In particular we have to deal with the issue of beam emittance preservation under a variety of conditions and effects, like beam manipulation during beam transfer and acceleration, and motion under the effects of magnet imperfections. Also, we should understand the limitations caused to the individual bunches stability, and how to avoid bunch-to-bunch instabilities, especially because of the beam interaction with the large rf system. Finally, we need an understanding and a strategy on how to cope with the short and long-term effects of the beam-beam interactions.

Finally, the fifth and last step of the design deals with considerations about the management of a project of such large size. The financial cost is of course an issue of paramount importance; it can be sustained only with a truly international collaboration. This, of course has deep implications and ramifications of social and political nature. The procurement of the superconducting magnets and of other collider components, for instance, the injector, is also crucial, and one needs to learn how to interface with industries all around the world. Furthermore, the construction, assembly and operation of the facility requires front-end knowledge of the methods for handling and managing the project.

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The study of proton colliders at very large energies has been done in different occasions at several times and several locations. We can certainly rely and draw experience from existing operating hadron colliders at Fermilab and in CERN, and from projects like the SSC and the LHC that have been designed in details. Beyond the SSC energy of 20 TeV, the ELOISATRON Project has evolved through a sequence of Workshops that were held in Erice during the many past years. More recently, after the discontinuity of the SSC project, explorations of very large proton colliders with beam energy in the range of several tens of TeV are emerging again in USA, like RLHC and PIPETRON. It is obvious that these projects can also be identified with the ELOISATRON Project, since they all share the same motivations and goals. It is clear that the ELOISATRON Project represents the ultimate circular hadron collider, which needs to be defined, well beyond the LHC and the SSC.

The pioneering work in the field was done during the summer of 1984 at Snowmass, Colorado, when a hadron collider dominated by the synchrotron radiation effects [1,2] was investigated. It was determined already at that time that these effects are significant and beneficial at the beam energy of 40 TeV, but also that they have very limited consequences at the energy of 20 TeV, when the beam performance is essentially determined by the properties of the injector. The major difference between then and now is that at that time a bending field of 6.5 Tesla was assumed, the value of the SSC project. Today this may sound a conservative figure, since higher field may be soon reached and will be more beneficial to the overall collider performance.

It is easily agreed that the synchrotron radiation dominated collider would represent truly the ultimate hadron collider at the highest energy and luminosity. Looking back with the wisdom of the after, if the SSC should today be proposed again for construction, very likely one would consider a higher field, for instance 13 Tesla to take advantage of the effects of the synchrotron radiation. This would either reduce the size, and thus maybe cost, by a factor of two, or conversely double the beam energy to 40 TeV for the same original size.

References

[1] A. G. Ruggiero, "Synchrotron Radiation Effects in a Very Large Hadron Collider", Proceedings of the 1984 Snowmass Workshop, page 451.

[2] R. R. Wilson, "Proton Cooling by Radiation". Proceedings of the Workshop on Producing High Luminosity High Energy Proton-Antiproton Collisions, page 155. March 1978. Berkeley, California.