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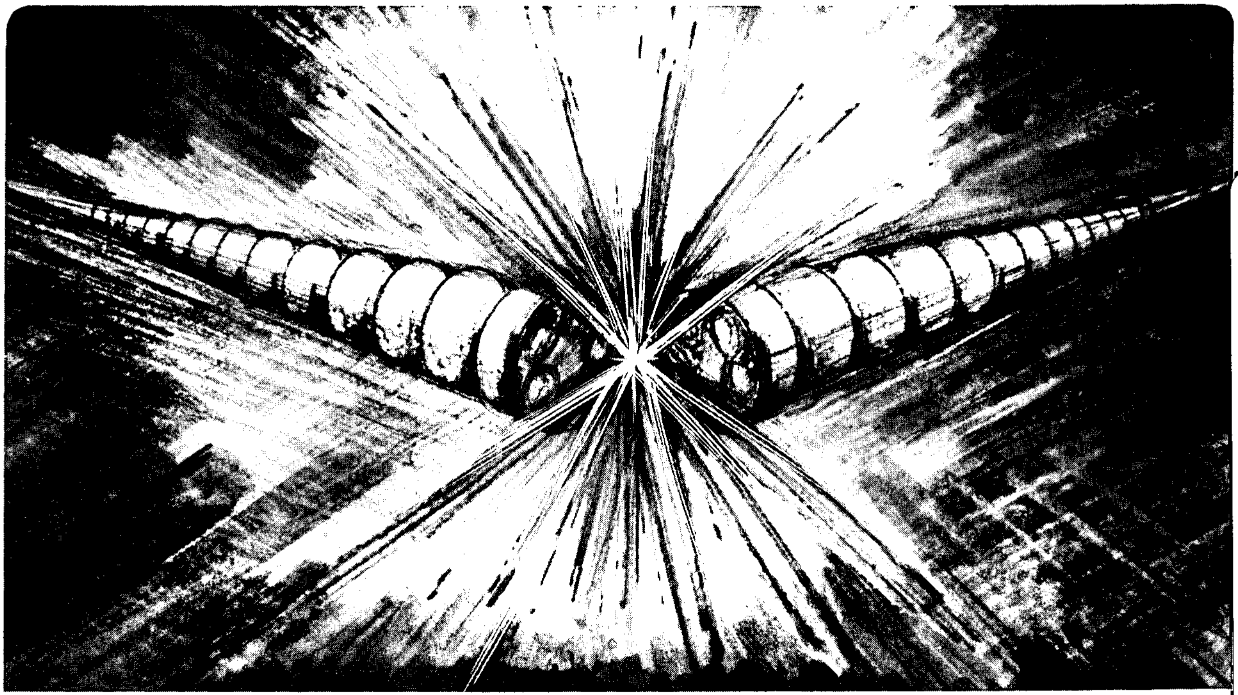

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ENERGY AND LUMINOSITY LIMITS OF HADRON SUPERCOLLIDERS

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ABSTRACT:

Extending the frontiers of experimental high energy physics in a manner that maximizes discovery potential requires the building accelerators of ever higher particle energies and luminosities. Both hadron and e^+e^- colliders have been proposed for this role. Based on a self-consistent computational model, this paper explores the features of hadron supercolliders beyond the SSC. The application of the presently available accelerator technologies embodied in the designs of the LHC and SSC to an ELOISATRON operating at 100 TeV per beam would yield a collider with a luminosity of 10^{34} cm^{-2} s^{-1}. Even higher energies and luminosities are clearly possible. The paper concludes with an examination of the ultimate potential of synchrotron–based colliders to explore PeV energies.

I. GENERAL CONSIDERATIONS

The continuing search for understanding the nature of mass and the dynamical principles underlying the physical universe has led particle physicists to explore phenomena at the energy frontier particle interactions. The modern tools for the experimental explorations are colliders with ever higher beam energies and ever higher luminosities. Fig. 1 illustrates the performance trends for present and future hadron colliders. What are the energy dependences of the physics and technology that determine these trends?

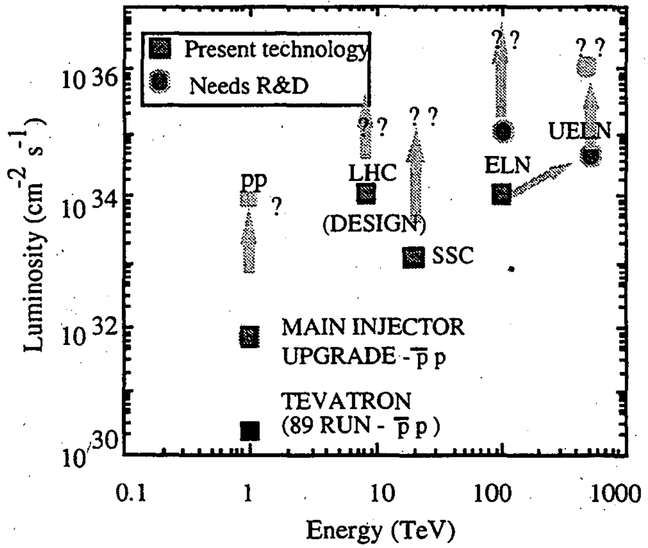

Figure 1. Luminosity goals of present and future hadron colliders

For simplicity, assume that both beams have bunches of equal population, N_B with a spacing S_B. In terms of the normalized emittance, ε_n, the relativistic factor γ and the β-function at the interaction point, β^*, the luminosity is

$$\mathcal{L} = \frac{N_B^2\, c\, \gamma}{4\pi\, \varepsilon_n\, \beta^*\, S_B} = \frac{1}{e\, r_p}\left(\frac{N_B\, r_p}{4\pi\, \varepsilon_n}\right)\left(\frac{\gamma\, I}{\beta^*}\right) \equiv \frac{1}{e\, r_p}\,\xi\left(\frac{\gamma\, I}{\beta^*}\right). \tag{1}$$

In eq. (1) I is the average current; r_p is the classical proton radius; ξ is the tune shift. The luminosity rises naturally with increasing beam energy at the "price" of increased practical difficulties in machine design. The difficulties of increasing the luminosity faster than linearly with energy are associated with increasing the beam current.

In analyzing the energy and luminosity limits of supercolliders one looks to choose N, S_B, β^*, and ε_n as a function of energy, E, subject to the following design constraints: 1) Detector limitations – electronics cycling and event resolution; 2) Beam physics – tune shifts, beam lifetimes, emittance growth; 3) Accelerator technology – magnets, fault modes handling of synchrotron radiation, beamline impedance, radiation damage of components.

II. SYNOPSIS OF SELECTED CONSTRAINTS

Constraints deriving from the interaction region reflect problems of event resolution and challenges of detector survival. For adequate event reconstruction, one ideally chooses the current per bunch and the bunch spacing so that the mean number of events per crossing, $\langle n \rangle$, is sufficiently low that the luminous region contains fewer than 1 event/cm. $\langle n \rangle$ depends on E via the inelastic cross-section, σ_{inel}:

$$\langle n \rangle = \frac{\mathcal{L}\, \sigma_{inel}\, S_B}{c} \tag{2}$$

Furthermore, cycling of the data acquisition electronics requires ≥10 ns between crossings. In a general sense the difficulties of dealing with the radiation from the collision point are most simply expressed by the power in charged particle debris (per side); namely,

$$P_{debris} = 350\ \mathrm{W}\left(\frac{\mathcal{L}}{10^{33}}\right)\left(\frac{\sigma_{inel}}{90\ \mathrm{mb}}\right)\left(\frac{E}{20\ \mathrm{TeV}}\right). \tag{3}$$

The fundamental beam-beam effect that limits luminosity is the tune shift due to the space charge of the colliding beams. Although tune shifts as high as 0.06 have been measured in e^+e^- colliders, the experience with hadron beams at the CERN S$\bar{p}$pS and at the Tevatron indicates that

A parameter exploration with ELOSCALE indicates an approach to construct a 100 TeV proton supercollider with a luminosity $>10^{34}$ cm^{-2} s^{-1} (ELN-34) at P_{sync} =5 W/m by using the same technologies that are being realized for the LHC. Raising P_{sync} to 20 W/m yields 10^{35} cm^{-2}s^{-1} (ELN-35). Parameters for both of these cases are given in Table 4. The variation of the luminosity of ELN with P_{sync} and operating energy are shown in Fig. 2. Fig. 3 displays two examples of cost and operational sensitivities such as those dependent on B_{dipole}.

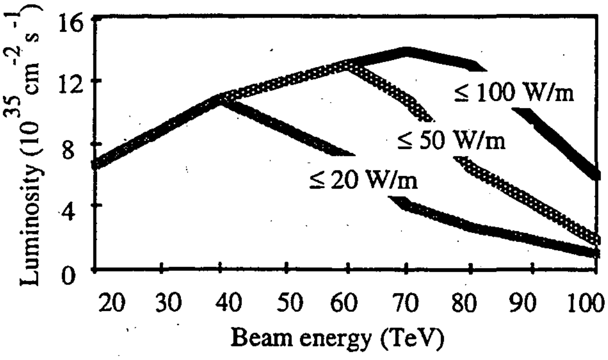

Figure 2. The luminosity ELN as a function of beam energy for radiation loads from 20 – 100 W/m.

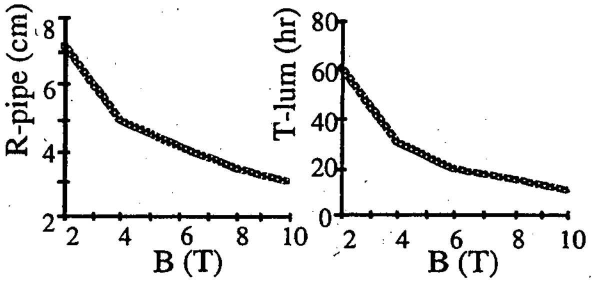

Figure 3. Variation of dipole aperture and luminosity lifetime with B_{dipole} for ELN35.

IV. ULTIMATE SUPERCOLLIDER

For the long term, ELOSCALE studies suggest the ultimate potential of conventional storage ring technology in the exploration of the high energy frontier of elementary particle physics. If the vacuum chamber of the storage ring operates at room temperature, then one could construct a hadron collider with a center of mass energy of 1 PeV and a luminosity $> 10^{36}$ cm^{-2} s^{-1}. With a circumference twenty times SSC's and consuming ≈ 2 GW of mains power, this proton synchrotron may well be the ultimate supercollider.

As the survival of detector components is doubtful at such a high luminosity, a more probable scenario for UELN is to keep the luminosity at 10^{34} cm^{-2} s^{-1}. In that case all of the technical sub-systems are much closer to the present state of technology. In particular the vacuum sub-system should be fairly close in character to that of the ELN. The walls could be kept at 150 °K to limit the power to the compressors to 500 MW. Table 5 compares the high and "low" luminosity options.

Table 5. Two possible sets of characteristics of an Ultimate ELOISATRON (UELN)

Center of mass energy	1 PeV	
Circumference (km)	1500	1015
B_{dipole} (T)	8	13.5
Beam energy	500 TeV	
Beam current (mA)	800	10
Mains power (GW)	2	0.5
$\langle P_{sync} \rangle$ (W/m)	1400	55
Interaction regions (IR)	2	2
Limiting technology	IR survival	Management
Tune shift per IR	0.01	0.006
Luminosity (cm^{-2} s^{-1})	$\approx 10^{36}$	10^{34}

V. CONCLUSIONS

A systematic parameter search with the ELOSCALE code shows that conventional proton synchrotrons are a suitable technology for hadron supercolliders with an energy and luminosity much higher than those of the SSC. In particular, an ELOISATRON operating at 100 TeV per beam with a luminosity $>10^{34}$ cm^{-2}s^{-1} (ELN-34) could be constructed by using technologies now available. Assuming moderate advances in accelerator technology during its design cycle, one could expect to operate ELN at luminosities $\approx 10^{35}$ cm^{-2}s^{-1} at 100 TeV/beam (ELN-35). Such a hadron supercollider based on conventional technology would have the physics reach and discovery potential at least as great as a 10 TeV $e^{+}-e^{-}$ linear collider, for which no reasonable design concept now exists. With further advances in a few key technologies, a PeV collider based upon conventional proton synchrotron approaches would be technologically possible.

If existing technologies are extended into new regimes (e.g., given practical, high T_c superconductors suitable for magnet windings), one could extend the luminosity at 100 TeV/beam to $\sim 10^{36}$ cm^{-2} s^{-1}. Such a supercollider would contain ≈500,000 bunches with associated beam crossing rates approaching 1 GHz yielding several tens of collisions per crossing. As detectors are unlikely to accommodate or even survive extremely high luminosities, a more fruitful upgrade of a 100 TeV class collider would be a 70% energy increase in the existing tunnel (2ELN in Table 4).

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References:

[1] SSC Site-specific Conceptual Design Report, 1990
[2] W. A. Barletta, "Maximizing The Luminosity Of Hadron Supercolliders At 10 - 100 Tev", in Supercolliders and Superdetectors, W. Barletta and H. Leutz, ed. World Scientific, 1993

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