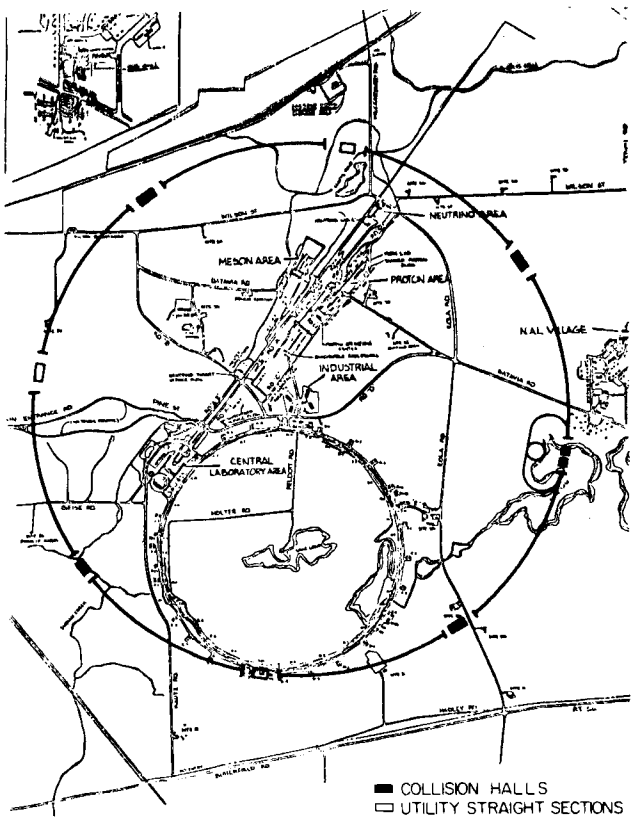
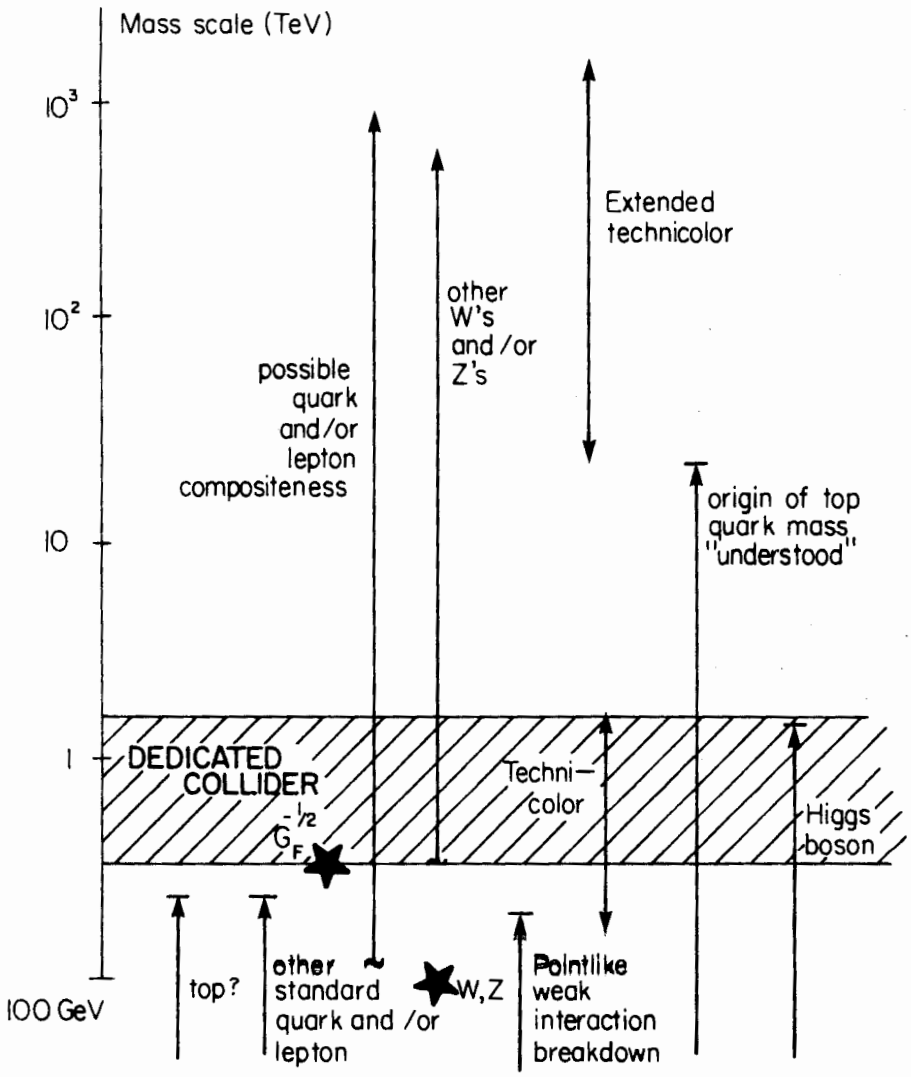
THE FERMILAB DEDICATED COLLIDER

A short article in last month's **Fermilab Report** announced that Fermilab is proposing to the HEPAP Subpanel on Long Range Planning that we build a Dedicated Collider on the Fermilab site. The purpose of this article is to review the proposal in more detail.

The Dedicated Collider (DC) is a $\bar{p}p$ collider operating at a center-of-mass energy of 4 to 5 TeV with four interaction halls and a luminosity of more than 10^{31} cm^{-2} sec^{-1}. Included is a 10-GeV electron ring with two interaction regions to intersect the 2 to 2.5 TeV proton ring for ep collisions. Construction could begin in October 1985 with the ring complete and cold by April 1989. The accompanying sketch illustrates the proposed ring siting.



Layout of the Dedicated Collider on the Fermilab site.



Energy landmarks.

The Dedicated Collider ring fits gracefully within the present Fermilab site and can make use of the Tevatron as an injector for both protons and antiprotons. It also makes use of existing Fermilab superconducting-magnet and refrigeration-system technology to provide a rapid and economical way to more than double the maximum U.S. and, indeed, world hadron collider energy. This very high energy, good luminosity, and large available running time will increase the potential physics productivity of the U.S. program by orders of magnitude. The ep option is competitive with any existing or planned ep facility and it could be upgraded to a 40 GeV×2 TeV collider which would be unique in the world.

The Dedicated Collider is designed to have a total of six experimental areas, four major experimental areas for $p\bar{p}$ collisions and two for ep collisions. Further, the Tevatron fixed-target program will no longer share the accelerator with the TeV I collider and can therefore operate at full efficiency. The $p\bar{p}$ luminosity is in excess of $10^{31}cm^{-2}sec^{-1}$ and the ep luminosity is $6\times10^{31}cm^{-2}sec^{-1}$. The first stage of this project can be chosen to emphasize either the ep option or the $p\bar{p}$ option, depending upon the scientific priorities perceived to exist at the time of decision (approximately 1986). No matter which option is chosen, it will be Laboratory policy that the fixed-target Tevatron II physics program will not be compromised either in support or in operation by the construction program for the Dedicated Collider.

Decoupling the Collider physics from TeV II results in a substantial gain in productivity for the fixed-target program. This will increase utilization by considerably more than a factor of two by the elimination of end effects in switching between programs. More importantly, experiments will be permitted longer dwell times in beam lines, a process that is well know to increase greatly the productivity of this kind of research.

Physics

The high energy and good luminosity of the DC suffices to address the physics issues in this 500 to 1000 GeV effective-mass domain. This is exemplified by the table at the top of the next page which shows the attainable mass scale for many hypothetical particles. Theoretical high-energy physics is at an impasse after a decade of remarkable progress. An impressive representation of theorists have publicly pleaded for experimental illumination, especially in the effective mass range well "beyond the W." There is now a proliferation of speculations as to how to extend the standard model. The graph on page 7 illustrates this and emphasizes the 1-TeV mass range as particularly rich in candidates for refining our view of the physical world. In the context of world physics, we note the attention being given to the effective-mass region near 100 GeV by LEP and SLC in e^+e^- collisions, by the CERN collider in $p\bar{p}$ collisions, and possibly HERA in ep collisions. There is much to be learned in this energy domain, but it seems clear that by the end of the decade there will be an urgent need to look well beyond that mass scale.

Mass limits attainable in the DC for production of 100 events at $\int dtL = 10^{38} cm^{-2}$. The two columns correspond to different assumed parton distribution functions. The "gluon-poor" distributions are those of Owens, Reya, and Duke. The "gluon-rich" distributions are those of Baier et al. (as used at the 1982 Snowmass study).

Particle	Mass limit GeV/c^2 "Gluon-poor"	Mass limit GeV/c^2 "Gluon-rich"
Standard model:		
Higgs scalar	135-220	170-340
Heavy fermion	320	395
Jet pair mass	>700	>1000
New gauge bosons:		
W' or Z'	1200	1200
Supersymmetric partners:		
squark	215	300
gluino	400	500
Techniparticles:		
octet	345	500
sextet	330	500
triplet	260	340
Higgs-like scalars:		
P	640	1400
P_0^8	400	960
Compositeness (hadron jets):		
LH scale	3000	2200
RH scale	2500	1800

The Tevatron I collider provides the first step in this exploration. In reaching the mass range 200-400 GeV, TeV I will provide a major stimulus to go further. The DC covers the 500 to 1000 GeV range. This mass range, while only a factor 2-3 above TeV I, may well be an especially rich one. It is very arguable that this is the natural mass scale needed to understand the "Higgs sector" of electroweak physics.

No one has yet built an ep colliding-beam facility. Electron-proton collisions, which have yielded so much insight into hadron structure in the past, have no less promise for the future. Even setting aside production of new states in ep collisions, the study of "conventional" phenomena such as QCD jets or weak-interaction form factors should be especially fruitful. ep collisions share many of the features of simplicity possessed by

e^+e^- collisions, as well as having some of the richness and higher energy of the phenomena seen in hadron-hadron colliders. If the $p\bar{p}$ phenomena differ in any essential way from e^+e^- collider phenomena, then it is important to have means of interpolating between the extremes. ep collisions provide that interpolation.

Energy

The bulk of the proposal addresses the design and physics of a 4 TeV collider (2 TeV against 2 TeV), but there do exist options which give us considerable confidence that we can actually achieve close to 5 TeV at little or no cost increase. These include increased magnet "packing," higher magnetic field, and larger radius.

The Colliders

In order to attain the design luminosity of $(1\text{-}4)\times10^{31}$ $cm^{-2}sec^{-1}$, the $p\bar{p}$ collider stores 44 bunches each of protons and antiprotons (10^{11}/bunch) with electrostatic deflectors used to separate the bunches between collision points. The TeV I system of $\bar{p}$ accumulation is used, with injection into the DC at E0 at 1 TeV. The ep collider has 80% beam polarization with spin rotators to provide longitudinally polarized beam at the collision points. The electron ring is of appropriate energy to serve as injector into a Stage II 40-GeV electron ring concentric with the DC ring.

Costs

The project is being proposed in the most conservative way, following Saver experience in great detail. In this way, the costs must be overestimated, since experience usually results in improvement. Fermilab has ten years of experience in superconducting-magnet R&D. This engenders a sharp discrimination between changes that may require extensive R&D and those that may be undertaken with confidence. The construction cost is $362M for the $\bar{p}p$ option, with an incremental cost of $60M to acquire ep physics. Alternatively, we estimate a cost of $396M for the ep option, with an incremental cost of $25M for adding $\bar{p}p$ physics. To this should be added approximately $10M in PE&D and R&D costs. The choice of ep vs $\bar{p}p$ as first priority need not be made until 1986. Although detectors have not been considered in any detail, a plausible allocation for detector costs is $120M for the $p\bar{p}$ option and $50M for the ep option.

Schedule and Manpower

Crucial dates are the following:

August 1983	Refined conceptual design and request for FY85 construction funding at the level of $10M.

July 1984	Final design after review by DOE for FY86 budget cycle. Completion of all R&D essential to achieving the design.
October 1984	Beginning of procurement of long lead-time items, tooling, and so forth. Begin A&E work, some site preparation.
October 1985	Beginning of assembly of magnets, refrigeration. Begin civil construction.
April 1989	Cooldown of entire ring and beginning of commissioning.
September 1989	Physics.

Allocation of manpower to this task will largely come from people now involved in Saver, TeV I, and TeV II construction activities. Meticulous attention has been paid to giving the Tevatron program enough support to be able to operate and improve the Saver, beam lines, and TeV I reliability and intensity. The Laboratory manpower growth is minimal (~5%), but there will be problems of matching skills between what we have and what we need.

Conclusion

The 1981 Subpanel on Long Range Planning chaired by George Trilling, recommended "a start by the mid 1980's on a new high-energy construction project...". Examples of such a new facility cited in that report are "an electron-proton collider or a less-expensive high-luminosity ($L \sim 10^{33} cm^{-2} sec^{-1}$) hadron-hadron collider built in the ISABELLE tunnel; a second proton collider ring at Fermilab dedicated to $p\bar{p}$, pp, and/or ep collisions, an e^+e^- collider using superconducting cavities (as proposed for CESR II), or a combination of smaller facilities, one of which might be a major non-accelerator facility."

The Fermilab Dedicated Collider provides an excellent, practical solution to this perceived need for a new facility. But most important, it will produce the first-class science that is required by the rapid evolution of the field. By 1989, there will be great pressure to explore physics at multi-TeV energies beyond TeV I.

The basic philosophy underlying the design is to minimize research and development and capitalize on the large and successful Fermilab R&D programs of the past several years. In this way, the Dedicated Collider can be built rapidly, using designs and estimates of costs and schedules based on actual experience.

Finally we note that the Dedicated Collider is an evolution of the Fermilab Site Filler which has been part of the Laboratory's long-range planning since 1972. In 1974, Robert Wilson wrote in **Scientific American** (**230**, 72, 1974):

"The largest superconducting ring we could build within our present boundaries would have a circumference of about 10 miles. If the facility were designed as an intersecting-storage-ring system, it might enable us to reach collision energies of several million GeV. If the experiments we are now capable of doing do not yield the knowledge we desire, or, what is more likely, if the new knowledge makes it irresistible to discover what happens at very much higher energies, we are confident those energies can be achieved at our laboratory on the Illinois plain."