WORKSHOP ON FUTURE ISR PHYSICS

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The Fermilab Collider Project*

by

J. Cronin
University of Chicago
and Fermilab

* Written from Notes taken during J. Cronin's talk
Copies available upon request from Ch. Redman, CERN/ISR
1. **Introduction**

The purpose of this note is to convey the flavour of the discussions which took place during the Aspen summer study, which extended over three weeks in June-July, 1977. Under discussion were five main items:

(i) Collision geometries and in particular low-$\beta$

(ii) Use of pp systems

(iii) The Fermilab main ring as a storage ring

(iv) Detectors

(v) Experimental areas

One should also mention an unauthorized activity which was to think about e-p.

The Fermilab Collider project, referred to as the Tevatron project, is based on the doubler, which, as a 1 TeV accelerator, can be used as a collider with the present main ring operated at 250 GeV. One thus also obtains 1 TeV in the center-of-mass system.

The coming year is of crucial importance. The final choices should be made. One can foresee several important developments which can be itemized as follows:

(i) Meet the necessary quality with the Doubler magnets

(ii) Conduct storage studies and low-$\beta$ studies on the main ring

(iii) Design experimental areas(s). The fact that the machine is near ground level is of course an important asset

(iv) Design studies for the detector and start some prototype work. It is understood that Fermilab will manage the construction of the big detector. Nevertheless collaboration with university groups willing to engage at some risk is encouraged.

2. **The Key Parameters of Colliding Beam Possibilities at Fermilab**

The first option corresponds to pp collisions (Doubler and main ring). As previously mentioned, the main ring would work at 250 GeV (DC) while the superconducting Doubler will work at 1000 GeV. The center-of-mass energy is therefore $\sqrt{s} = 1000$ GeV. The effective luminosity is $L = 4 \times 10^{30}$ cm$^{-2}$ sec$^{-1}$. The second option corresponds to pp collisions. This can be considered in the present main ring and in the Doubler ring.
In the main ring used as a p\bar{p} collider one could run at 250 GeV, thus reaching $\sqrt{s} = 500$ GeV. The foreseen luminosity, using present components and the small electron cooling ring under construction, would be $L \approx 3 \times 10^{28}$ cm$^{-2}$ sec$^{-1}$.

In the Doubler ring, one would run at 1000 GeV. This would give $\sqrt{s} = 2000$ GeV with an expected luminosity which should eventually be larger than $10^{30}$ cm$^{-2}$ sec$^{-1}$. This latter option is very interesting as a long term prospect.

At present, the convenient way to assess the merit of $\sqrt{s}$ and $L$ is to consider W production. This is done in Figure 1 which gives the number of events per hour for W$^+$ production assuming an efficient luminosity 10 times lower than the nominal one. Production cross-sections for the W are those calculated in the standard parton model.

The pp Collider project offers therefore a good fighting chance to find the W, as it is expected in the framework of present gauge theories.

3. The Physics Programme

Considered here is the physics programme based on the pp Collider project. The total cross-section at $\sqrt{s} = 1000$ GeV is expected to be $\sigma_{\text{tot}} \approx 100$ mb. The expected luminosity is $5 \times 10^{30}$. This corresponds to $5 \times 10^5$ interaction/sec.

While W,(Z) search is of course the important goal in the physics programme, there are many other topics of great interest.

Search for W,(Z) is part of what can be called "Wide Angle Physics". The detectors which one can contemplate have actually great similarities to those used for e$^+$e$^-$ colliding beam experiments. As part of wide angle physics one should also mention the study of high $p_T$ phenomena, and jet studies. As an illustration of what to expect, Figure 2 gives the calculated production rate for jets as a function of the jet transverse momentum, assuming that the $p_T^8$ behaviour continues and that the $p_T^{14}$ behaviour, expected from Quantum Chromodynamics, eventually appears as $p_T$ increases much beyond 10 GeV.
Figure 1: W production rate for the three possible options
Figure 2: Expected production rates for jets
events/hour per GeV in a 2π solid angle
Next to the Wide Angle programme one may consider the exploitation of cosmic ray hints which lead to expect "unconventional" large cross-section phenomena as the incident energy increases beyond $10^5$ GeV. This corresponds to $\sqrt{s} = 430$ GeV, well below the collider energy. One may expect events with unusually large multiplicities, showing a new penetrating component in the hadronic showers or events with an unusual character (with practically no neutrals). Finally, one should not forget "small angle physics" corresponding to the now classical aspects of hadronic interactions. This is something worth exploring in the new energy domain thus opened. The at most 50 m available in the interaction region may bring strong limitations. Nevertheless one may hope to overcome it with ingenuity.

4. The Main Ring as a Storage Ring

At present the mean pressure value around the pipe is $5 \times 10^{-8}$ torr. This provides the main limitation for the beam lifetime. The lifetime for a 200 GeV beam (at $2 \times 10^{13}$) is of the order of 2 hours. The luminosity lifetime (beam blow up) is of the order of 0.5 hours. Figure 3.b) gives the beam size as a function of time (it is directly related to the luminosity lifetime) at 100 and 200 GeV. It does not scale as $p^2$ as it most simply should. The transverse growth rate is larger than what can be expected from beam gas scattering. The longitudinal growth rate is rapid (from 2 nsec to 5 nsec in a time of the order of 100 sec). The intensity lifetime is given in Fig. 3.a).

Background measurements have been made using 4 1-foot counters set around the vacuum pipe. The registered rate corresponds mostly to minimum ionizing particles. For $2 \times 10^{13}$ stored protons one gets typically $1.2 \times 10^6$/sec in a single counter (of the order of $2 \times 10^5$/sec over the 4 counters). One expects over the entire surface a background rate of about $4 \times 10^6$/sec. The background is mainly proportional to the beam intensity. It also contains a small term proportional to the time derivative of the intensity, which is negligible.

Improvements in vacuum should help. Without any rebuild one may expect to reach $10^{-8}$ torr.

Low-β tests should take place in the spring of 1978. One expects adverse effects on the stored beam lifetime and it is expected that new correction elements will be required to restore the beam lifetime.

At present the main ring studies are encouraging and results look fine. Nevertheless the project needs the superconducting Doubler ring for which some technical difficulties remain.
5. **Schedule for the Superconducting Ring**

According to present plans it should be completed in 3 years (October, 1980). However this estimate is very sensitive to funding. The first sextant should be installed in the main ring tunnel in one year (October, 1978).

If everything goes on schedule one should be able to operate the collider by the end of 1981. There is of course an adverse set of priorities according to which, within the US programme, Fermilab should concentrate on a fixed target machine (the Doubler as a 1 TeV accelerator). It is clear however that when both rings are working, the motivation for colliding the protons will be overwhelming!

The calculation of the luminosity to be then expected assumes $2 \times 10^{13}$ protons in each ring; head on collisions, an emittance $\Sigma = 13\pi/p$ mm-mrad; $\beta^*_E = 10$ m at 1000 GeV (for the Doubler) and $\beta^*_M = 5$ m at 250 GeV (for the present main ring). Achieving such $\beta^*$'s requires the construction of special quadrupoles. The resulting (initial) luminosity is $6.6 \times 10^{30}$ cm$^{-2}$ s$^{-1}$. This is obtained assuming no stacking.

The average luminosity is calculated assuming a main ring beam life scaled to 250 GeV (when now measured at 200 GeV); a transverse bunch spreading scaled to 250 GeV (when now measured at 200 GeV); a main ring refill every 15 minutes (the filling time being of 36 sec). The energy doubler performances are assumed to be 10 times better (the filling time is in this case 6 minutes). The resulting average luminosity, relevant for physics, is $4 \times 10^{30}$ cm$^{-2}$ s$^{-1}$.

The general set-up is shown in Figure 4.a). The protons in the doubler circulate clockwise while the protons in the main ring circulate counterclockwise. This corresponds to the use of a reverse injection which is presently under construction.

The location of the doubler ring and the present main ring in the tunnel is shown in Figure 4.b). Figure 4.c) gives the parameters for an intersection. This results in a change of the respective location of the two rings which in between B and C (Figure 4.a) would be as shown in Figure 4.d).

Figure 4.e) gives the spatial arrangement of the intersecting region with different possible choices for the main parameters (field and length).
Figure 3.a) : Beam intensity lifetime
Figure 3.b) : Transverse growth of the beam
Figure 4.a: Stacked protons rotation in the main ring (counter clockwise) and in the Doubler (clockwise). The two beams would intersect in B and C.
Figure 4.b) : The Doubler set-up in the present tunnel
Figure 4.c) : Parameters of the intersection
Figure 4.d) : Main Ring and Doubler (up) location in between the two adjacent intersection zones (B and C)
Figure 4.e: Intersection region and different choices for the field parameters

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Figure 5.a) : The detector (along the beams)
The scale is in meters
Figure 5.b): The detector (perpendicular to the beam)
It is 8 m wide and 10 m high
The available experimental zone would correspond typically to $10^0 < \theta^* < 172^0$, or to a rapidity interval $\Delta y \approx 6.3$ (asymmetric beam energies).

A sketch of the detector being presently discussed is shown in Figures 5.a) and 5.b).

Most recent references on the Fermilab Collider project are as follows:

1) Fermilab TeV Program, Superconducting Magnet Ring, 1977

2) Report of 1977 Aspen Summer Study on $pp$ and $\bar{p}p$ Collisions (available December 1, 1977)