SOME COMMENTS ON SUPERHIGH ENERGY ANTIPROTON-PROTON COLLIDERS

David B. Cline
Fermilab, Batavia, Ill. and Univ. Wisconsin, Madison, Wisconsin, USA

ABSTRACT

We discuss the possible construction of very high energy p̄p colliders. These machines will profit from high luminosity and will likely require a new generation of high intensity antiproton sources. We outline one such possible source here.

Antiproton-proton colliders are under construction at CERN and Fermilab. These specific machines were first suggested in order to discover the intermediate vector boson[1,2]. In that case it was shown that a luminosity of $\sim 10^{30}$ cm^{-2} sec^{-1} provides an adequate event rate, if suitable detectors are employed[1]. This goal has been incorporated as a design criterion for the two machines being constructed[3,4,5]. If higher energy p̄p colliders are to be constructed the design luminosity must be set by either physics goals or by the inherent limitations in the luminosity that can be achieved in such machines. This limitation may arise from beam-beam interaction or from the total intensity of the antiproton source. In this note we will present a discussion of these contraints[*].

Consider first the expected cross sections for high energy pointlike reactions

$$\sigma^{W}_{pt} \simeq \frac{4\pi\alpha^2}{3s} \simeq \left(\frac{87}{s}\right) \text{nb GeV}^2$$

for weak-electromagnetic cross-section. For strong cross sections

$$\sigma^{s}_{pt} \simeq \left(\frac{\alpha_s}{\alpha}\right)^2 \left(\frac{87}{s}\right) \text{nb GeV}^2$$

the magnitude of these cross sections for various values of s are given in Table 1. The luminosity of a p̄p machine required to produce one event per day is also given in Table 1. Note that for the high energy reactions the cross section has dropped by a large factor and requires high luminosity to give adequate rate. Note also that the strong processes are still observable at $s \simeq 100$ TeV^2 if machines of luminosity $\sim 10^{33}$ cm^{-2} sec^{-1} are available. On the other hand e^+e^- machines with luminosity less than 10^{33} cm^{-2} sec^{-1} would not provide adequate event rate for energies above 300 GeV.

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* These considerations were carried out with J. Ellis.

Table 1

s $(GeV)^2$	Cross section (cm^2)	L_{min}(1 event/day) $(cm^{-2}\ sec^{-1})$
$(30)^2$	$\sigma^W \sim 8.7 \times 10^{-35}$	10^{30}
	$\sigma^S \sim 2 \times 10^{-32}$	10^{28}
$(300)^2$	$\sigma^W \sim 8.7 \times 10^{-37}$	10^{32}
	$\sigma^S \sim 2 \times 10^{-34}$	10^{30}
$(1000)^2$	$\sigma^W \sim 8.7 \times 10^{-38}$	10^{33}
	$\sigma^S \sim 2 \times 10^{-35}$	10^{31}
$(10{,}000)^2$	$\sigma^W \sim 8.7 \times 10^{-40}$	10^{35}
	$\sigma^S \sim 2 \times 10^{-37}$	10^{33}

The cross section for some processes will grow with energy due to QCD effects. An example of this is the production of W and W^+ Higgs boson as shown in Figure 1. The event rate for various reactions for antiproton-proton colliders with $L \sim 10^{32}\ cm^{-2}\ sec^{-1}$ and $\sqrt{s}$ = 40 TeV are given in Table 2. Very large rates of single W and W pair production are obtained. At these energies the W/Z production almost become "hadronic" like in rapidity as shown in Figure 2 (calculations made by Frank Paige after the meeting).

There is an obvious moral to all this - high energy $\bar{p}p$ machines will easily reproduce the production of W/Z etc. with modest luminosity but need high luminosity to reach into new areas of very high momentum transfer pointlike collisions where new physics may be "hiding".

Table 2

Event rates for $\bar{p}p$ collisions at 40 TeV • event/day
with $L \simeq 10^{32}\ cm^{-2}\ sec^{-1}$

Process	Rate	Remarks
$\bar{p}p \to W^{\pm} + X$	$\sim 1.6 \times 10^6$	
$\bar{p}p \to Z^0 + X$	$\sim 4 \times 10^5$	
$\bar{p}p \to W^{\pm}$ + Higgs boson	∼ 1-1,000	($M_H \sim$ 15-500 GeV)
$\bar{p}p \to W^+ + W^- + X$	∼ 1,000	
$\bar{p}p \to \ell + \bar{\ell} + X$	∼ 1-10	Probe lepton structure ($M_{Jet+Jet} \sim$ 10 TeV)
$\bar{p}p \to$ Jet + Jet + X	∼ 1-10	Probe quark structure ($M_{Jet+Jet} \sim$ 10 TeV)
$\bar{p}p \to$ heavy quark + $\bar{Q}$ + X ↳ $W + Q^1$	∼ 1-10	Super-massive fermions ($M_Q \sim$ 500 GeV)

The general scheme for antiproton-proton colliders is shown in Figure 3. The luminosity for an antiproton-proton collider is given by

$$L = \frac{N_{\bar{p}} (f\gamma) (\Delta\nu)_{max}}{r_p \, \beta^*}$$

where β^* is the β at the interaction point, $N_{\bar{p}}$ are the total number of antiprotons and $(\Delta\nu)_{max}$ is the maximum tune shift due to beam-beam interaction, r_p is the classical proton radius. The tune shift is given by

$$(\Delta\nu)_{max} = \frac{r_p N_{\bar{p}}}{n_b E}$$

where n_b is the number of bunches in the machine and E is the invariant emittance of the beam.

Table 3 shows a comparison of the various values of these parameters for the three antiproton-proton colliders. In order to obtain a high luminosity the total number of antiprotons must be much larger than for presently planned machines[3,4,5]. This implies the development of a superhigh intensity antiproton source.

Table 3

Comparison of machines

γ	$(f\gamma)$	β^* (m)	$(\Delta\nu)_{max}$	L (cm^{-2} sec^{-1})	$N_{\bar{p}}$
2.7×10^2 (SPS p̄p collider)	1.3×10^7	1.5	2×10^{-3}	10^{30}	6×10^{11}
10^3 (Tevatron p̄p collider)	5×10^7	1.5	2×10^{-3}	4×10^{30}	5×10^{11}
2×10^4 (20 TeV p̄p collider)	10^8	2	5×10^{-3}	10^{32}	5×10^{12}

In order to produce a very high intensity antiproton source it is necessary to consider the yield of antiprotons from a target

$$\frac{N_{\bar{p}}}{N_p} = \frac{1}{\sigma_0} E \frac{d^3\sigma}{dp^3} (p\Delta p) \ \Delta\Omega \ (\varepsilon_1)(\varepsilon_2)$$

where

ε_1 = factor for absorption in target

ε_2 = target efficiency.

For the case

$$E\,\frac{d^3\sigma}{dp^3} \sim 1\ \text{mb/GeV}^2;\ \frac{\Delta p}{p} = \pm 2\%\ ,$$

and for the case of

$$\varepsilon_x \sim \varepsilon_y \sim 100\ \text{mm mr storage ring}\ ,$$

we find

$$\frac{N_{\bar{p}}}{N_p} = 9 \times 10^{-6}\ .$$

The number of antiprotons per day is

$$\Sigma N_{\bar{p}}/\text{day} \sim 5 \times 10^{12}\ .$$

One possible antiproton collector scheme is shown in Figure 4. Two storage rings are used, one to "precool" the antiprotons and one to store and "freeze" the antiprotons phase space. We have assumed the possibility of fast stochastic Betatron cooling and deceleration in the precooler ring. A similar scheme has been worked out for the Fermilab $\bar{p}p$ machine but employs a much smaller aperture for the precooler[5]. The cooling and beam manipulation angles are shown schematically in Figure 5. This shows the various beam gymnastics in the two rings. The possibility of fast Betatron stochastic cooling depends on the development of very large bandwidth amplifiers and pickup systems with reduced noise.

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REFERENCES

1) C. Rubbia, P. McIntyre and D. Cline, "Producing massive neutral intermediate vector bosons with existing accelerators", Proceedings of the International Neutrino Conference, Aachen 1976, H. Faissner, H. Reithler and P. Zerwas, editors, p. 683. See also proposal P-492 Fermilab (1976).

2) D. Cline, P. McIntyre, F. Mills and C. Rubbia, "Collecting antiprotons in the Fermilab booster and very high $\bar{p}p$ collisions", Fermilab TM689 (1976). See also D. Cline, "Possibility for antiproton-proton colliding beams at Fermilab", CERN $\bar{p}p$ Note 08, May, 1977. E. Gray et al., "Phase space cooling and $\bar{p}p$ colliding beams at Fermilab", 1977 Accelerator Conference Proceedings.

3) Design of a proton-antiproton colliding beam facility, CERN/PS/AA 78-3.

4) Proceedings of the Joint Fermilab - LBL Workshop on high luminosity $\bar{p}p$ storage rings, F. Cole, editor Fermilab (1978).

5) B. Brown et al., "The Fermilab high intensity antiproton source", FNAL Report (unpublished-for the ANL, FNAL, INP, LBL, U-WI design group).

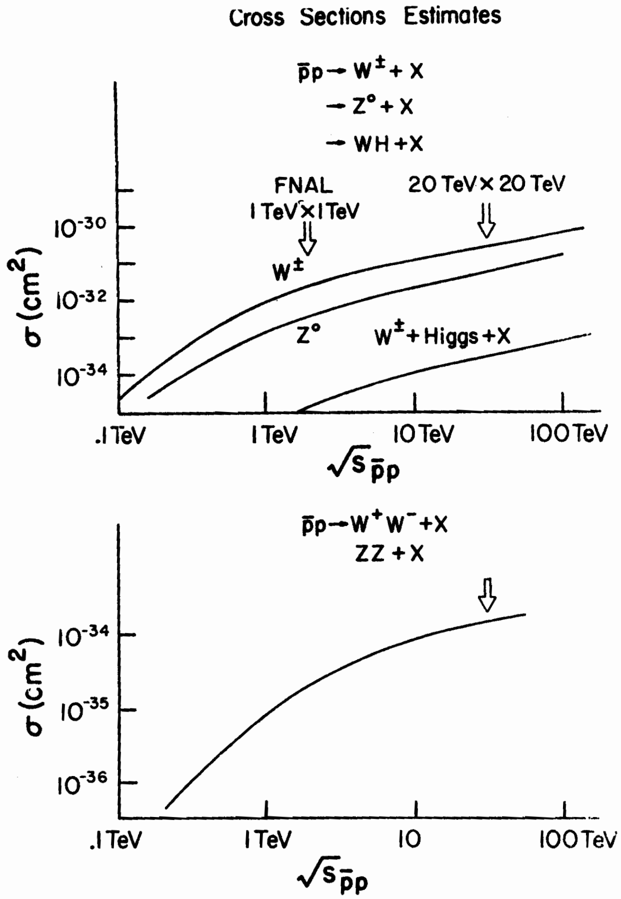
Cross Sections Estimates
p̄p → W± + X
→ Z° + X
→ WH + X
FNAL
1 TeV × 1 TeV
20 TeV × 20 TeV
W±
Z°
W± + Higgs + X
σ (cm²)
10-30
10-32
10-34
.1 TeV
1 TeV
10 TeV
100 TeV
√s p̄p
p̄p → W+W- + X
ZZ + X
10-34
10-35
10-36
.1 TeV
1 TeV
10
100 TeV
√s p̄p

Fig. 1

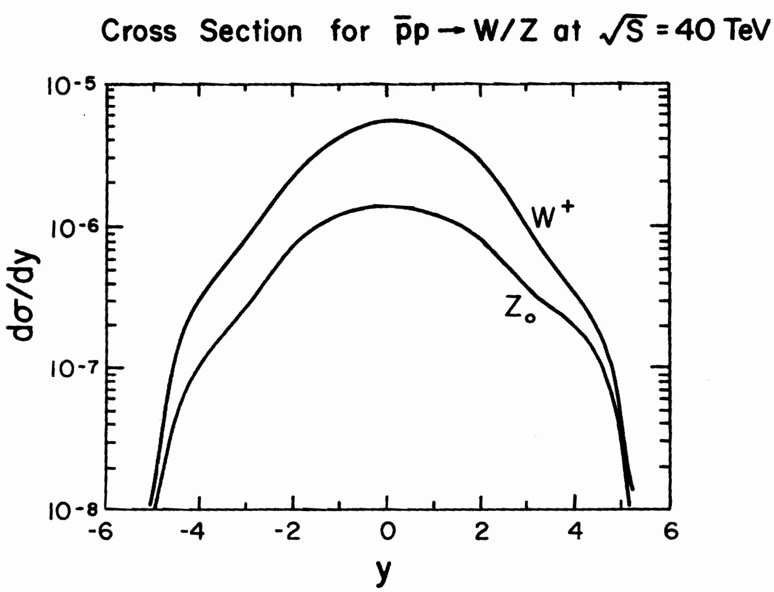
Cross Section for p̄p → W/Z at √S = 40 TeV
dσ/dy
10-5
10-6
10-7
10-8
W+
Zo
-6
-4
-2
0
2
4
6
y

Fig. 2

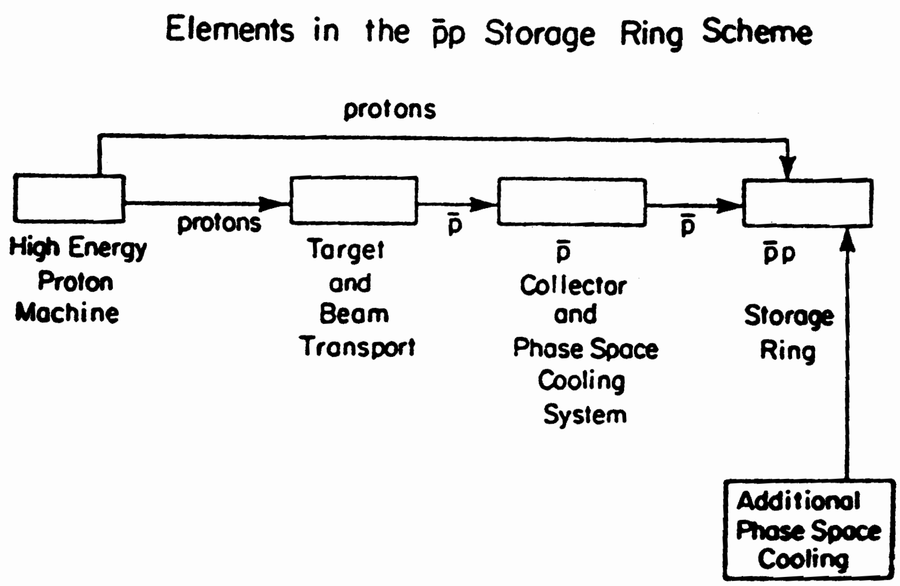
Elements in the $\bar{p}p$ Storage Ring Scheme
protons
protons
$\bar{p}$
$\bar{p}$
High Energy Proton Machine
Target and Beam Transport
$\bar{p}$ Collector and Phase Space Cooling System
$\bar{p}p$ Storage Ring
Additional Phase Space Cooling

Fig. 3

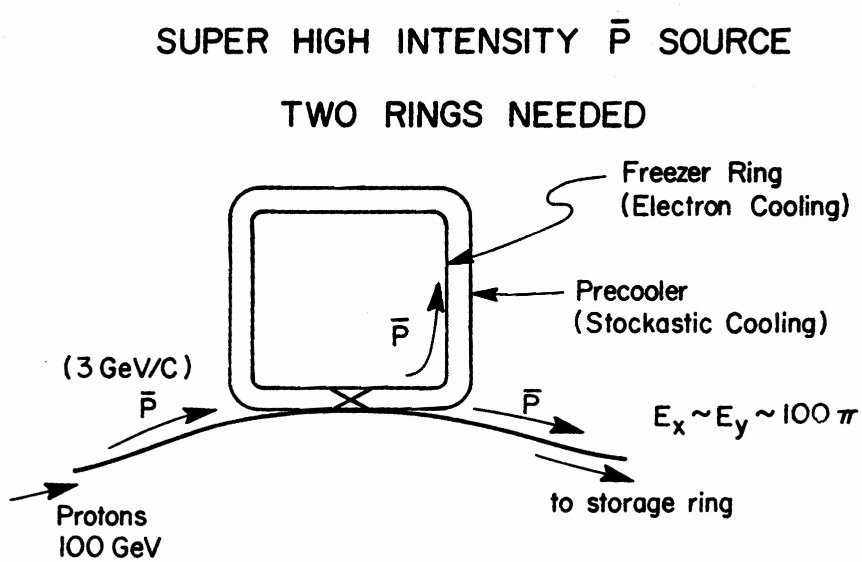
SUPER HIGH INTENSITY $\bar{P}$ SOURCE
TWO RINGS NEEDED
Freezer Ring (Electron Cooling)
Precooler (Stockastic Cooling)
$\bar{P}$
(3 GeV/C)
$\bar{P}$
$\bar{P}$
$E_x \sim E_y \sim 100\,\pi$
to storage ring
Protons 100 GeV

Fig. 4

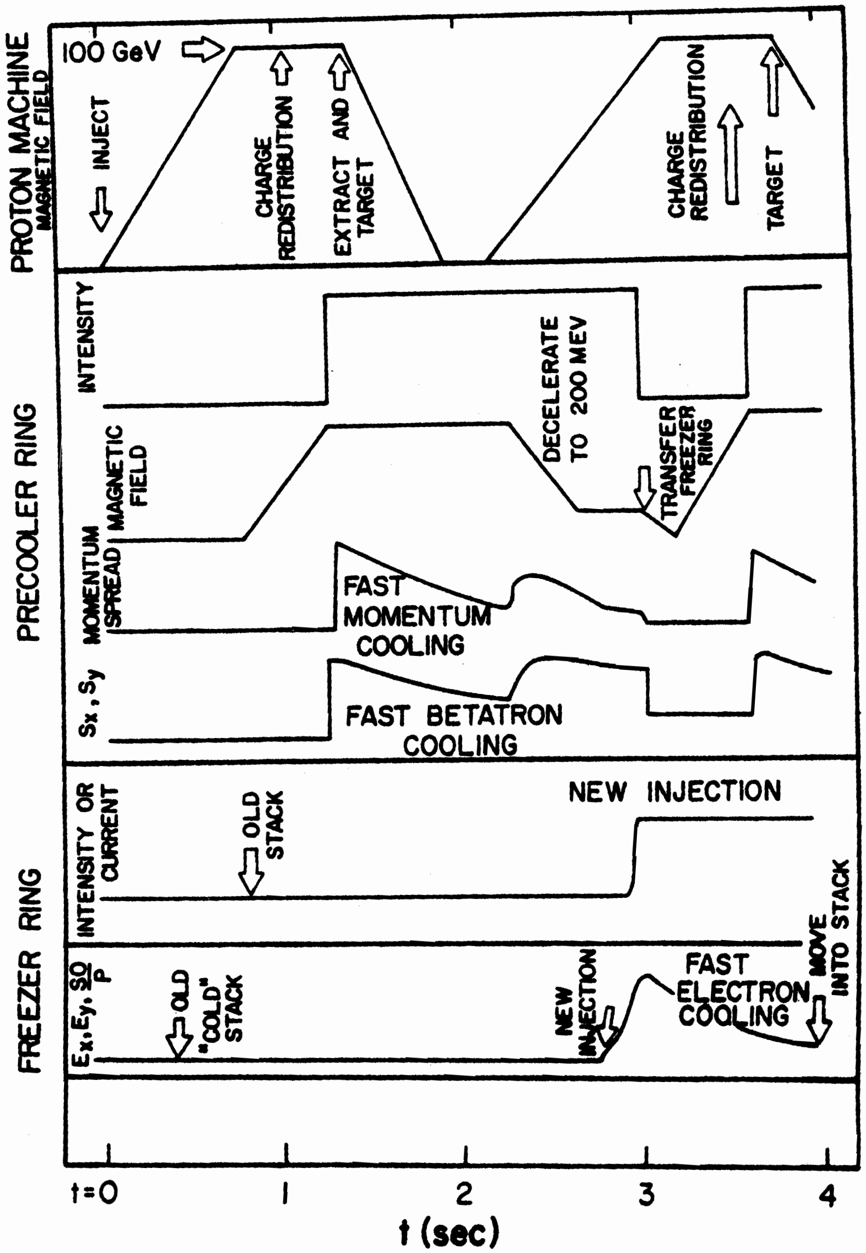
PROTON MACHINE
MAGNETIC FIELD
100 GeV
INJECT
CHARGE REDISTRIBUTION
EXTRACT AND TARGET
CHARGE REDISTRIBUTION
TARGET
PRECOOLER RING
INTENSITY
MAGNETIC FIELD
DECELERATE TO 200 MEV
TRANSFER FREEZER RING
MOMENTUM SPREAD
FAST MOMENTUM COOLING
Sx , Sy
FAST BETATRON COOLING
FREEZER RING
INTENSITY OR CURRENT
OLD STACK
NEW INJECTION
Ex, Ey, δp/p
OLD "COLD" STACK
NEW INJECTION
FAST ELECTRON COOLING
MOVE INTO STACK
t=0
1
2
3
4
t (sec)

Fig. 5