Update of One Scheme for Collecting and Cooling Antiprotons at Fermilab

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Three significant factors have changed since proposal 492 was submitted to Fermilab. (1) The proposal as such was rejected — thus another approach to obtaining a cooling ring must be undertaken at Fermilab. (2) New data on electron cooling indicate the cooling times are very short. (3) Recent pp lepton pair scattering experiments have indicated very small antiquark distributions consistent with antineutrino data thus making the p̅p option even more important since the antiparton distributions in the proton may be even smaller than presently estimated. In addition the p̅p option may allow the possibility of reaching the weak interaction unitarity limit. These three factors affect the p̅p colliding beam physics at Fermilab and are addressed in sections (a), (b) and (c) of this note.

(a) A scheme for obtaining a modest cooling ring at Fermilab, carrying out cooling studies and early p̅p physics.

The schemes are as follows

a. Install PPA machine near booster and linac. Replace vacuum chamber with stainless — use existing quadrupoles — high vacuum system. Install electron and stochastic cooling devices. Convert to strong focus $Q \sim 4$, $\gamma_T \sim 4$.

*(This work has been carried out in conjunction with P. McIntryre and C. Rubbia of Harvard University.)
b. Study cooling using proton beams from linac and booster.

c. Collect modest $\bar{p}$ yield from external target and booster or main ring extracted beam - produce $\bar{p}'s$ from booster or main ring beam. Use transfer line between booster and main ring that is to be built for reversing the main ring. (Fig. 1)

d. Cool $\bar{p}'s$ and reinject into booster - accelerate wrong direction in booster - inject in main ring. (Fig. 1)

e. Carry out studies of colliding $\bar{p}$ - p in main ring - simultaneous acceleration etc.

f. Some modest physics experiments with $\sqrt{s} > 400$ GeV, $L > 10^{26}$ cm$^{-2}$ sec$^{-1}$?

g. If 4 GeV/c injection into the main ring is possible the scheme would change a little as shown in Fig. 2. In this scheme the cooling ring and transfer lines are put together with nearly all existing components - it is the most modest possible scheme, in my opinion.

(b) The impact of new data on Electron Cooling.

The new measurements show that cooling times of 50 ms are possible. This opens the possibility of a new scheme for $\bar{p}$ collection - collect small $\Delta p/p$ in a rapid cycling mode - the PPA machine would be ideal since it ran at 20 CPS. An alternate possibility is the use of the booster for collection and deacceleration of the small $\Delta p/p$ bite.

The scheme consists of the following steps

1. Inject $\bar{p}'s$ into the PPA ring at $\sim 4$ GeV/c with a small momentum bite ($\Delta p/p \sim \text{few} \times 10^{-3}$). (or inject $\bar{p}'s$ into the booster at 8 GeV/c).
2. Deaccelerate to 300-400 MeV/c within the range of the PPA cavity - drift tube system not needed here - and electron cool. (Deaccelerate in the booster to 200 MeV)

3. Back up the ramp with the cooled beam - the beam is either put in parking orbit near the edge of the aperture or transferred to another ring (or stored in another ring at low momentum).

4. If the cooling time is 50 ms the PPA or Booster might be run at 10 CPS.

5. Rough estimates give the following yield assuming
   a. $10^6 \overline{p}/(\Delta p/p \sim 3 \times 10^{-3})$ collected.
   b. PPA at 10 CPS.
   c. 1000 sec.

we get $\sim 10^{10} \overline{p}$. (In the case of the booster a larger yield is expected). In 10 sec we get $10^8 \overline{p}$ which can be injected into the main ring, accelerated, and extracted to give 500 GeV/c $\overline{p}$'s into the "external antiproton beam area". If the cooling continues for $10^4$ sec and for $5 \times 10^{10}$ protons in a main ring bunch the $\overline{p}p$ luminosity is $\sim 10^{29}$ cm$^{-2}$ sec$^{-1}$.

Work needs to be carried out on the following questions

1. What maximum $\Delta p/p$ will the existing PPA R.F. system contain? (or the Booster)

2. What improvements are needed to the systems to obtain a larger $\Delta p/p$ bite?

3. Can the cooled $\overline{p}$ beam be parked for $10^3$ - $10^4$ sec in the presence of $10^4$ - $10^5$ new injections (colliding beam option)? (In the case of the booster a storage-cooling ring is necessary due to the booster vacuum)
4. If the answer to 3 is no, can the cooled beam be parked and stored for $10^1 - 10^3$ new injections so that the antiproton acceleration and extraction scheme can be carried out?

5. Can we build a very modest, very small aperture storage ring concentric to the PPA to store the cooled $\bar{p}$'s; collecting at 4 GeV/c and accelerate to 8 - 9 GeV/c if necessary (as shown in Fig. 1)? (Same question for the booster)

The use of the booster offers a simpler solution to the beam transport and "brute force" $\bar{p}$ cooling problem since the booster is a rapid cycling machine. (See Fig. 3 for the scheme). Other advantages are the collection at 8 GeV/c $\bar{p}$ momentum and the large booster aperture. The most severe disadvantage is the poor booster vacuum which necessitates the addition of a modest storage ring to electron cool and store the $\bar{p}$'s. The simplest scheme is to install a D.C. storage ring in the booster tunnel operating at 200 Mev (as shown in Fig. 3). The same device can be used to inject $10^8$ $\bar{p}$'s into the main ring in the normal direction and thus convert the main accelerator to 500 GeV/c antiproton accelerator (Fig. 4).

(c) **Reaching the Unitarity Limit with $\bar{p}p$ machines.**

Suppose the $W^+$ or $Z^0$ do not exist! The weak interaction unitarity limit is still the most interesting energy to study weak interactions. The C.M. energy is $\sim 600$ GeV. There are 4 ways to reach and study the unitarity limit
Each process is uniquely associated with an experimental technique, i.e. (1) requires high energy neutrino beams, (2) requires colliding $e^+e^-$ rings of extremely high energy and so forth.

I believe it can be proven that process (3) is unique to $\bar{p}p$ machines and (4) to $pp$ machines - but that (4) is swamped by strong interaction background. Figures (5, 6) show the relative $\bar{u}u$ luminosity for the $\bar{p}p$ and $pp$ colliding beam devices in parton models. In order to reach the luminosity needed to study the unitarity limit we use three factors $^{1,2}$

$$\sigma_{\bar{u}u} \text{ (Unitarity limit)} = 10^{-33} \text{ cm}^2$$
$$\langle m^2/S \rangle = \langle \tau \rangle$$
$$L_{\bar{u}u}^{\text{eff}} \text{ from Fig. 5}$$

The "effective" cross section at the unitarity limit is

$$\sigma_{\bar{u}u} \text{ (Unitarity limit)} = \sigma_{\bar{u}u} \cdot L_{\bar{u}u}^{\text{eff}} \langle \tau \rangle$$

$$m_{\bar{u}u} = 600 \text{ GeV}$$

$$\sigma_{\bar{v}N} + \bar{u} + X = \sigma_{\bar{v}u} \cdot L_{\bar{v}u}^{\text{eff}} \langle \tau \rangle$$

$$m_{\bar{v}u} = 600 \text{ GeV}$$

Table 1 shows the required $\sqrt{S}$ and $L$ needed to obtain 10 events/hr at the unitarity limit.
Table 1 also shows that $1 \text{ TeV} < 1 \text{ TeV}$ $\bar{p}p$ rings can reach the unitarity limit with modest luminosity and favorable "signal/noise" ratios. For $\nu + N$ scattering the situation is better but 300 TeV accelerators are required. The $p\bar{p}$ option is very unfavorable because with modest machine energies ($1 \text{ TeV}$) extremely high luminosity is required and the resulting signal to noise is very small. It appears that $p\bar{p}$ colliding beam machines are the only practical hope to reach the weak interaction unitarity limit.

References

1. J. D. Bjorken, talk given at the Very Big Accelerator Meeting.
2. Finjord and Ravndal preprint.
<table>
<thead>
<tr>
<th>Process</th>
<th>Single Beam Energy</th>
<th>$\sqrt{s}_{uu}$</th>
<th>$L (cm^{-2}sec^{-1})$</th>
<th>(Signal/noise)*</th>
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<tbody>
<tr>
<td>$\nu + N \rightarrow \mu N^+$</td>
<td>180 TeV</td>
<td>.600 TeV</td>
<td>$3 \times 10^{33}$</td>
<td>$\infty$</td>
</tr>
<tr>
<td>$p + p \rightarrow \mu$</td>
<td>(3 - 5) TeV</td>
<td>.6 TeV</td>
<td>$3 \times 10^{31}$</td>
<td>0.1</td>
</tr>
<tr>
<td>$\bar{p} + p \rightarrow \mu$</td>
<td>1 TeV</td>
<td>.6 TeV</td>
<td>$3 \times 10^{33}$</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>$p + p \rightarrow \mu$</td>
<td>1 TeV</td>
<td>.6 TeV</td>
<td>$3 \times 10^{30}$</td>
<td>1</td>
</tr>
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</table>

*Estimated from relative effective luminosities in Fig. 5
Injected into MR
(8–9) GeV/c

Fig. 1
Fig. 2

Injected into MR
4 GeV/c
-366-

Fig. 3

Production target

Rapid cycling $\bar{p}$ collector and decelerate

Cooling-storage Ring

Injection and Extraction from collector and cooler (at 200 MeV)
\( p \) production target

\( p \) (Hot)

\( p \) (cold)

Rapid cycling \( p \) collector and decelerate Cooling-storage Ring

(Reverse Booster)

Injection and Extraction from collector and cooler (at 200 MeV)

(Extract \( p \) to) (External Areas)

\( p \) Accelerator

Fig. 4
\[ \sqrt{\tau} = \frac{\text{ENERGY IN PARTON-ANTI PARTON COLLISION}}{\text{TOTAL ENERGY AVAILABLE}} \]

Fig. 5

Bjorken

\( \nu_\mu + u \)

\( \bar{u}u \)

\( \nu + \text{Hadron Collision} \)

\( \bar{p} + p \text{ Collision} \)

\( p + p \text{ Collision} \)
Fig. 6

\[ \frac{s^2 d^2 \sigma}{d \phi^2} \]

- Finjord & Ravndal

- Legend:
  - \( pp^+ \mu^- + \bar{X} \)
  - \( \bar{p} p^+ \mu^- + \bar{X} \)

- Axes:
  - \( \tau \)
  - \( 10^{-6} \) to \( 10^{-1} \)