PS/AA/BA/EJ/afm

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AA LONG TERM NOTE No 28

PROPOSAL FOR A SUBSTANTIAL IMPROVEMENT OF CERN $p\bar{p}$ COMPLEX

A NEW ANTIPROTON COLLECTOR (AC)

This note outlines the research and development needed for a more luminous $\bar{p}$-source and, if these were successful, their incorporation into a new ANTIPROTON COLLECTOR (AC) to be inserted between the $\bar{p}$-production target and the present Antiproton Accumulator (AA).

1. Introduction

The design goal of the CERN $p\bar{p}$ complex is a peak luminosity of 10^{30} $(\mathrm{cm}^{-2}.\mathrm{s}^{-1})$.To-date we have achieved $> 5.5 \times 10^{28}$ $(\mathrm{cm}^{-2}.\mathrm{s}^{-1})$ a factor eighteen away from the goal. The complexity of the operation of three accelerators in series plus their various transfer lines accounts for almost a factor of two out of the eighteen. The rest, a factor of about ten can simply be attributed to missing antiprotons either in the accumulator (AA) or the collider (SPS).

Theoretical studies during this last year indicate that although one might gain perhaps a further factor of two in the accumulation of antiprotons in the AA without major technological changes to the machine, the factor of ten is not within our grasp. However, as a result of these studies, a way, at least in theory, to collect many more antiprotons and subsequently cool them quickly, became evident.

In practice, some technical advances outlined below are needed. These fall into roughly two separate branches of technology; the first, related to collecting more antiprotons per bombarding proton on a target, has to do with developing extremely strong pulsed magnetic lenses. The second, has to do with cooling the much larger flux of antiprotons so produced, and consists essentially of extending the bandwidth of our present cooling equipment well into the many gigahertz range of

If these developments prove to be successful, they could be incorporated into a new $\bar{p}$-collecting and fast-cooling ring placed upstream of a modified AA.

Indeed, it is not possible to obtain the same result by modifying the AA only. This new collector ring would be on roughly the same scale of the present AA but with magnets and vacuum chambers specially designed to accept an antiproton beam with four times the momentum spread of those captured in the AA. The new machine would also accept antiprotons which diverge twice as much as those in the AA, in both the vertical and horizontal planes. Altogether a factor of up to sixteen in antiproton flux may therefore be contemplated. This could result, after allowing for some inefficiencies, in at least a factor of ten in accumulation rate over and above the present value.

Today, the chances of detecting a Z_0 are rated at about one every few months of collider operation. With the possibility of increasing the accumulation rate of $\bar{p}$'s by a factor of ten and with subsequent improvement in exploiting more $\bar{p}$'s for longer coasting times in the SPS, it should be possible to increase the rated chances of detecting a Z_0 to one every week.

2. Technological developments for a high flux antiproton source

The new $\bar{p}$ collector is designed to receive 10^8 antiprotons per PS cycle within a transverse acceptance of 200π mm.mrad and a momentum spread of 6%. This goal can be achieved if special technologies are developed in the domain of targets and magnetic lenses of high gradient and of microwave systems operating in the 2-4 GHz frequency range for the stochastic cooling systems.

2.1. More antiprotons per bombarding proton on target

As is often the case, the improvement by more than one order of magnitude in the number of antiprotons implies the introduction of novel features, based on advanced technology.

The first one is a better match between the phase space produced by the target and the acceptance of the transfer channel and the AC.

This is achieved by a pulsed target.

Pulsed target

For a long and thin target, the production diagram in the phase space looks like a "butterfly". This figure is poorly matched to the acceptance ellipse of a transfer channel. The purpose of the current pulsed in or around the target is to redistribute the particles in such a way that they fill the acceptance ellipse more uniformly. Three configurations (at least !) can be envisaged :

i) The current flows in the heart of the target. Particles are well confined but limitations come from proton de-focusing and antiproton re-absorption.

ii) The current flows in a sheath around the target. This sheath may be a thin conducting layer or the skin depth of a copper target. Very high fields can be reached and focusing occurs outside the target in a low absorption material.

iii) The current flows in a graphite or lithium shell. The focusing is quasi-linear.

The target is usually made of copper about 10 cm in length. Its diameter is of the order of 2 or 3 mm or less and the current intensities needed are about one to two hundred kiloampères in pulses of length 10 to 20 µs. The pulses occur every 2.4 seconds.

The second feature concerns the focusing elements both before and after the target, which should be as strong as possible.

Indeed, for a given acceptance of the AC, the smaller the proton spot on the target, the larger the angle of the cone of p's which is collected. Similarly, a very strong lens after the target limits the physical aperture of the transport system to the AC to a conventional one for CERN machines. Conceptually, very strong lenses can be obtained simply by driving a large pulse current through a conducting medium, either a solid with low atomic number, to limit the absorption of the antiprotons, or a plasma.

In such devices, which are focusing in all planes, the magnetic field raises linearly from zero at the centre to the maximum field on the outer radius.

Lithium or plasma lenses

The material of the lens must absorb the antiprotons as little as possible. This is the reason for the choice of lithium for solid lenses. A plasma is the limit case where absorption is negligible. In both cases, the current starts flowing in the outer skin of the conductor.

2.2. "Cooling" of the beam

The beam produced by the target and collected by the focusing system over a very large phase space volume (large transverse dimensions and momentum spread) must be cooled by at least one order of magnitude in each of the three dimensions during the time of one PS cycle (2.3 s). The cycle is divided into two phases; betatron (transverse) cooling occurs in the first phase and is followed by momentum coooling, the cooling times being slightly in excess of one second for each phase.

2.2.1. Betatron (transverse cooling)

The cooling time τ for optimum gain of the system is given by :

$$\tau = \frac{2N}{W} (M + U).$$

where N = total number of particles to be cooled,
W = bandwidth of the system,
M = mixing factor,
U = noise to signal (power) ratio for the amplifier.

Clearly to obtain the minimum cooling time the bandwidth must increase proportionally to the number of particles N, while the mixing factor M should be as small (close to 1) as possible and so should be U, which depends on the temperature of the system. In order to achieve the goal of cooling ten times more particles, the bandwidth of the system must be extended to 1 or 2 GHz.

Pick-ups and kickers

The pick-ups are designed to balance Schottky signal (M) and thermal noise power (U) almost equally at the beginning of the betatron cooling. They consist of 100 sets of pairs of directional couplers of 75Ω characteristic impedance. This type of coupler is chosen for its high sensitivity. It is made of a plate whose length is tuned to a quarter of the mid wavelength (2.5 mc at 3 GHz). Its width is smaller than half the minimum wavelength (3.75 cm at 4 GHz) in order to avoid resonances. The signals from each coupler in a given position (top, bottom, right or left) are added in a combiner board using strip lines and printed circuit technology. After combination, the signals coming from opposite rows of couplers are added or subtracted in a hybrid circuit and then amplified in a low noise solid state amplifier.

The betatron system presents a pecularity. Due to the large transverse dimensions of the beam, the gap between the electrodes of a particular pair is larger than half the cut-off wavelength and wave guide modes can propagate. The response of the system under such conditions is being studied. This situation exists at the beginning of the cooling only because the inter-electrode gaps are continuously adjusted to fit the beam size as the cooling proceeds. Thus every 2.4 seconds, the cycle time, the gaps open and close in much the same style as the shutters of the AA precooling system. The control of the electrodes is made by servo-mechanisms of the type used for the AA shutters.

The kickers have the same structure as the pick-ups, also open and close each cycle, but do not require any cryogenic cooling.

Low noise preamplifiers

The number of pick-up stations is not sufficient to ensure a good Schottky to thermal noise power ratio at room temperature. This limitation is simply due to the space available in the machine. The terminating resistors of each coupler have to be cooled down to 40 K (noise temperature) and the characteristics of the best solid state amplifiers (Gallium arsenide field effect transistors, in short Ga As FET) have to be extended into our frequency range (2-4 GHz). The development is essentially in the design of input and output circuits and perhaps also in the efficient cooling of the transistor itself.

Power amplifiers

At microwave frequencies, power amplifiers with a sufficiently broad bandwidth are the so-called traveling wave tubes. In spite of all the efforts made in the design to limit the required output power, several kilowatts between 2 and 4 GHz are absolutely necessary. All the kickers need not be driven with the same tube but typical characteristics would be 1 kW maximum power and a good linearity up to 300 W. Tubes whose performances approach our requirements have been built in United States and in France for telecommunications. It seems that the technical problems can be solved but the cost of these devices is likely to be very high. For instance, a tube built in the USA having 1.5 kW output over a bandwidth of 2 GHz costs 80 kSF and its power supply 500 kSF. We would need 20 of them. The total cost would be 1 600 kSF for the tubes and 10 000 kSF for the power supplies ! Needless to say we shall try to buy the power supplies from competitive suppliers by specifying them ourselves.

2.2.2. Momentum cooling and very high frequency filters

For momentum cooling, the filter method is used. The essential part of the filter is a transmission line which presents notches every 1.5 MHz the revolution frequency. The tolerance on the deviation of the notch centre with respect to its ideal position is about 10^{-5}. The line can work in the reflection mode with one end short circuited, its length is then one half the machine circumference (90 m), or in the transmission mode in which case its length is the whole circumference (180 m). At very high frequencies and room temperature, the attenuation and dispersion of the signal are adversely affected by the skin effect. For this reason, a superconducting cable is under study in the USA at Fermilab; it consists of a coaxial line whose inner conductor is niobium and outer conductor is lead.The cable is wound on a spool and immersed in liquid helium; it works in the transmission mode with rather good characteristics.

Other solutions can be investigated. The delay might be provided by optical or acoustic systems. The notch structure may also be built in a purely electronic way with synthesizers and mixers.

However it is done, development work is urgently needed on these devices.

3. Brief description of the p-collector

A detailed description of the preliminary ideas for a new $\bar{p}$-collector is given in the AA Long Term Development Note 26. The layout is outlined in the accompanying figure.

It consists essentially of a racetrack of bending and focusing magnets with a total circumference of 188 metres for a nominal momentum of 3.5 GeV/c. The two long straight sections are designed to be dispersion free and will contain all the cooling devices as well as being the injection and ejection regions. The pick-ups are in one long straight section and the kickers are in the other. Communication between pick-ups and kickers is by the most direct path across the diameter of the semicircle followed by the beam. The dimensions and strengths of the magnets and lenses are similar to the shorter bending magnets and narrow lenses of the AA. The beam optics is chosen to give the optimum phase advance between cooling devices. The frequency dispersion is both suitable for adequate unscrambling of signal information for the stochastic cooling process as well as being small enough to ensure rapid bunch compression, with a radiofrequency cavity, of the five antiproton bunches each having a momentum spread of 6%.

This bunch rotation is the first step in reducing the momentum spread to about 1.5%. It needs an RF cavity capable of supplying a few hundred keV per turn at around 9 MHz. Antiprotons with a transverse emittance of 200π mm.rad are injected into the five RF buckets set up by the cavity and the one sixth reduction in momentum spread occurs in less than 100 mseconds.

Next the fast betatron or transverse cooling systems are, literally, set into motion and reduce the emittances in both planes down to a few π mm.mradians. Calculations indicate that, with the developments outlined above, this can be achieved in one second. Finally, in the 1.3 seconds remaining of the 1.4 second cycle time before the next burst of $\bar{p}$'s arrive, the wideband fast momentum cooling system is switched on to attain the final momentum spread of around one per mil.

The $\bar{p}$'s are then rebunched and ejected from the AC and transferred to the AA where they are stochastically decelerated and cooled into the stack core. The much increased flux of $\bar{p}$'s arriving at the AA can only be handled by also increasing its bandwidth, presently 250 MHz for the existing stack-tail system, into the gigahertz range.

The antiprotons spend only a few seconds in the collector so that requirements on vacuum are much reduced from that of the AA where bake-outs and ultra-high vacuum technology had to be used. Hopefully this should have repercussions in making the engineering of the cooling devices, and indeed the whole vacuum chambers of the collector, considerably cheaper.

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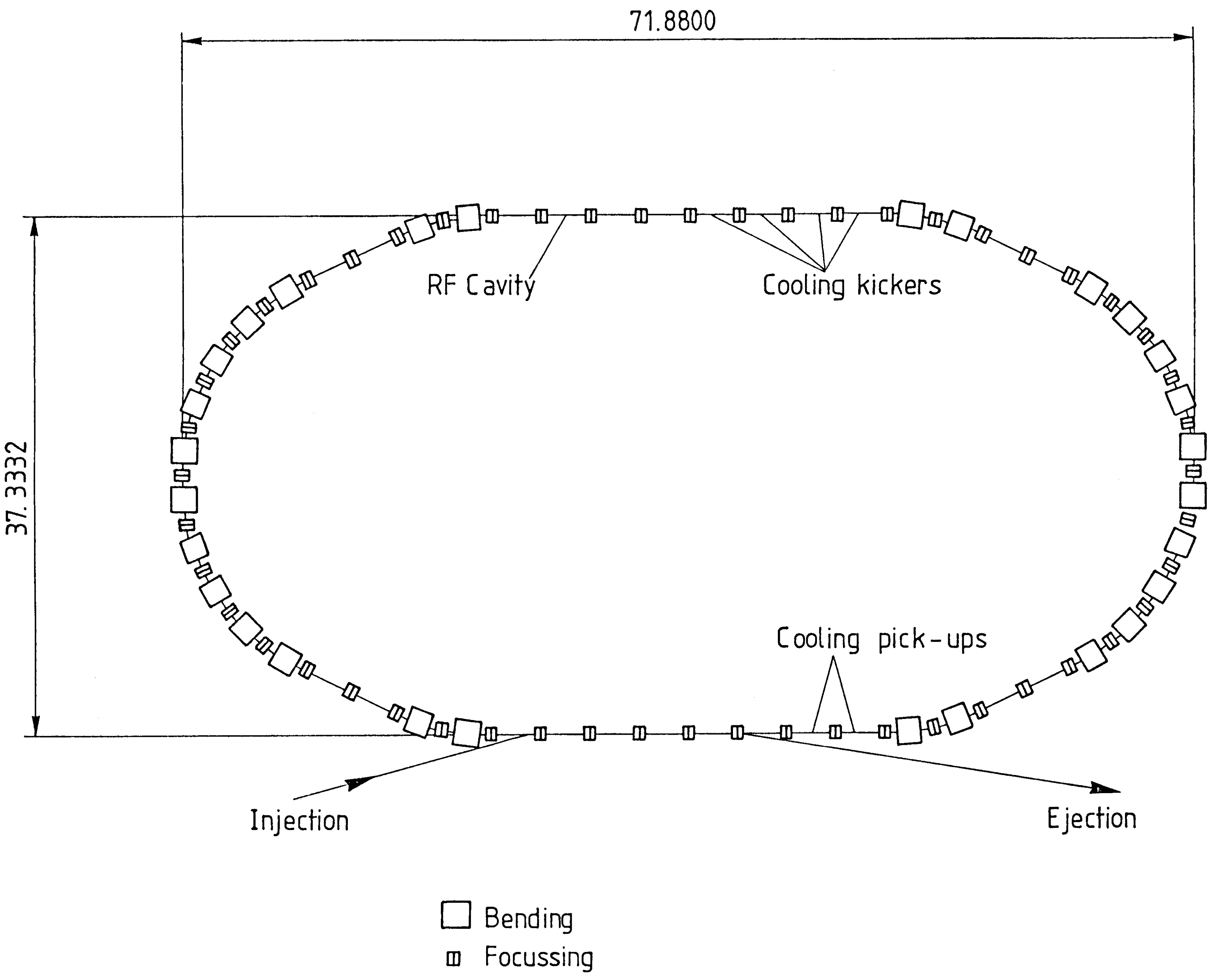
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RF Cavity
Cooling kickers
Cooling pick-ups
Injection
Ejection
Bending
Focussing

PS/AA/BA/ma
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CORRELATION LIST OF ADVANCED TECHNOLOGY NEEDED FOR THE ANTIPROTON COLLECTOR

	Item	Fields in which this technology has already been developed or may be of interest
	Lithium lens	
	Pulse generator (500 kA - 1 MA, 1 ms)	
1.	Transformer (ratio of the number of turns ∿ 24/1) in radiation environment	Electrotechnical engineering
2.	Pulsed power supply (50 kA, 1 ms)	Power supplies; high magnetic field
3.	Lithium technology	Medicine. Nuclear reactors
4.	High pressure test equipment for lithium container (∿ 5000 bars every 2 s)	Fabrication of synthetic crystals
	Plasma lens	
5.	Pulse generator (1 MA, ≤ 5 μs)	Electrotechnical engineering
6.	Technology	Fusion research. Special weapons. Fast switches for deflectors and laser triggers
	High frequency equipment (1-4 GHz)	
7.	Low noise preamplifiers cooled at cryogenic temperatures	Radioastronomy. Semi-conductors. Gallium Arsenide technology
8.	Broadband power amplifiers	Traveling wave tubes applied to telecommunications and counter measures
9.	Pick-up/kicker structures	Coupling systems used in microwave engineering
10.	Combiner/splitter board	Strip lines with fast wave propagation
11.	Periodic filter	Superconducting coaxial cables. Liquid helium transmission lines. Optical or acoustic delay lines. Frequency synthesizers.