

**LEAR AND SUPERLEAR FOR AN INTERMEDIATE  
ENERGY ANTIPROTON PHYSICS PROGRAMME**

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ABSTRACT

The future intermediate energy antiproton physics programme to be discussed by the SPSLC meeting foreseen in Cogne in September 1992, requires the study of new facilities. To fulfill the physics demands, both a modification of the Lear machine in the PS South Hall and the installation of a new Superconducting Storage Ring in the PS East Hall, are considered. This report presents the actual status of the study.

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# Lear and SuperLear for an Intermediate Energy Antiproton Physics Programme

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**Abstract.** The future intermediate energy antiproton physics programme to be discussed by the SPSLC meeting foreseen in Cogne in September 1992, requires the study of new facilities. To fulfill the physics demands, both a modification of the Lear machine in the PS South Hall and the installation of a new Superconducting Storage Ring in the PS East Hall, are considered. This report presents the actual status of the study.

## 1. Introduction

In earlier studies [1, 2], SuperLear was conceived as a compact multipurpose ring with a wide energy range (1.5 to 15 GeV/c), high intensity ( $10^{12} \bar{p}$ ) and maximum possible luminosity. The injection of antiprotons was foreseen at fixed momentum, 3.5 GeV/c, directly from the Antiproton Accumulator. No final choice of the location was made, but installation in a new or an existing hall, the ISR service building 181, the PS-West or East Hall was contemplated.

An important objective of these studies was to determine the luminosity and resolution limits. For operation with internal jet targets, these limits turned out to be satisfactory for the future users. However, the luminosity and bunch length obtainable in proton-antiproton collisions appeared to be inadequate to permit the desired broad programme of bottomonium fine spectroscopy.

As a consequence, the PSCC at its special meeting in Cogne in September 1990 recommended to concentrate on the physics that can be done in internal target mode and to attribute low priority to the collider option. At this meeting, three prime domains of interest were identified which concern both Lear and SuperLear.

- Antihydrogen physics, needing ultra-low energy beams from Lear or from a dedicated facility to feed Penning traps (and  $e^+$  from another specialized facility).
- Direct CP-violation tests via the  $\Lambda\bar{\Lambda}$ -channel. They call for operation with a jet target and a high-intensity circulating beam at about 1.65 GeV/c.
- Charm physics, (charmonium, charmed exotic mesons, and charmed baryons), requiring antiprotons at momenta ranging from 3 to 12 GeV/c and optionally from 2 to 15 GeV/c.

The first of these items will be discussed during a meeting, scheduled to take place at Garching in mid 1992. The two others concern the present workshop and will be treated in this report.

In line with the recommendations of the Cogne meeting, the following topics have been reconsidered in close collaboration with the potential users:

- Modification of Lear for the  $\Lambda\bar{\Lambda}$ -experiment (the possibility to do this experiment in SuperLear is less attractive since the detector set-up is compatible with Lear low-energy physics).
- Performance of SuperLear with internal targets.
- Extracted beams from SuperLear.
- A collider option of SuperLear to be implemented at a much later stage.

These topics will be discussed in the rest of this paper with emphasis on the updates made in the conceptual design of SuperLear to meet the new physics requirements.

## 2. Modifications of Lear for the $\Lambda\bar{\Lambda}$ -CP-experiment

We assume that the experiment [3] will use an internal hydrogen target with a "state of the art" density of  $10^{14}$  protons/cm<sup>2</sup>. To reach a satisfactory luminosity, a beam of  $3 \times 10^{11}$  circulating antiprotons then is needed (see §4). At the present injection momentum of 0.6 GeV/c, space-charge effects limit the intensity to a few  $10^{10}$ . To overcome this bottleneck the transfer from the PS to LEAR has to be done at the highest momentum which can be used without too much modification of the hardware. The critical components are:

- the ejection kicker and septum of the PS,
- some elements of the PS-Lear transfer line,
- the Lear injection system.

First results indicate that a transfer momentum of about 1.2 GeV/c could reasonably be implemented.

In addition to the energy upgrading a multibatch injection scheme -based on the transfer via the PS and the stacking in Lear of several pulses from the AA- has probably to be used to fill more than  $10^{11}$  antiprotons into Lear. This scheme can then also be used for "topping up", i.e. adding antiprotons at regular intervals so that the luminosity never drops significantly during a run.

The layout of the detector region is being studied in collaboration with the user team. The possible installation of the (existing!) low-beta quadrupoles leaves no space for "close-by" compensation of the effect of the detector solenoid. The possibility to use a "self-compensated solenoid" (with opposite field direction in the up- and downstream part) is under study.

In summary: it appears that the proposed  $\Lambda\bar{\Lambda}$ -experiment can be performed in Lear after a reasonable amount of modifications. Other scenarios, including the operation of SuperLear at 1.6 GeV/c look less attractive to us and to the users.

It should be mentioned that the higher injection energy seems to be incompatible with extraction at momenta above a few hundred MeV/c. Thus the very low-energy operation could be preserved but the higher momenta in Lear would be exclusively devoted to internal target operation.

## 3. Choices for SuperLear

The requirements established during the Cogne meeting and in later discussions call for a very compact 12-15 GeV/c ring. With superconducting magnets such a machine can be built with a circumference of 125 m - 160 m (PS/5, PS/4). A ring of this size can just about fit into the PS East Hall; an effort has therefore been made in our recent studies to find a design which meets this objective.

Antiprotons can then be supplied via the PS, where they can be accelerated (or decelerated) to the operating energy required in SuperLear. To supply antiprotons to the East Hall a new fast ejection from the PS is needed -probably using existing kickers, and a septum to be installed in SS84- together with a new transfer line from the PS to the East area (Fig. 1). For testing the machine, low-energy protons can be sent to SuperLear via the existing PS extraction facility.

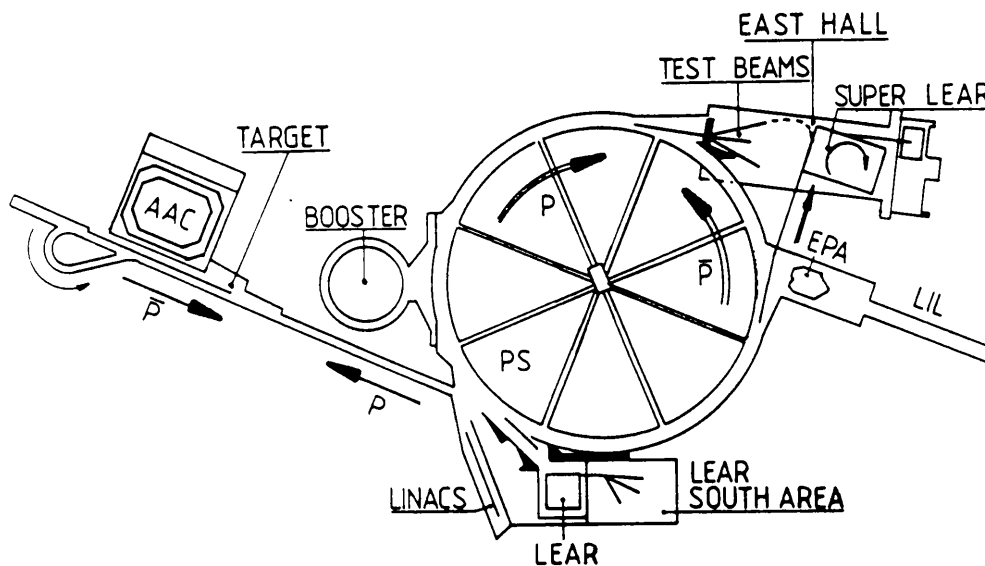


Fig. 1. SuperLear general layout

The use of an existing, well-equipped hall to house the machine and its experimental area reduces the cost very significantly. A pleasant consequence of the transfer via the PS is that SuperLear can then become a fixed (but adjustable) energy storage ring. This avoids the persistent-current problem, which plagues superconducting machines with energy ramping. It also opens the possibility of topping up of the intensity, which is very attractive for operation with internal targets.

The price to pay is the high-injection energy in SuperLear with the necessity to use stronger septum and kicker, and the danger of inducing quenching of the superconductors due to beam losses.

The layout of the ring in the hall is subject to a number of restrictions: an important constraint is given by the test beams installed in the upper part of the East Hall. It is very desirable to leave these beams intact, even if one could envisage moving part of the tests into the North Area and/or to a test area with 600 MeV electron beams to be created at EPA. Other boundary conditions are given by the orientation of the transfer lines PS-SuperLear (for antiprotons and for test protons), by the extraction line from SuperLear, by the space required for the experiments at the machine and in the external area, and by the infrastructure of the hall (crane limits, etc.). For the 125 m circumference machine a satisfactory solution seems at hand. For the bigger machines it will be more difficult to preserve all the present test beams.

#### 4. Availability of antiprotons and performance limitations

To work out performance limitations we assume a flux of  $10^7$  antiprotons/sec. This corresponds to the present capability of AAC when 3 cycles per PS supercycle are used for  $\bar{p}$ -

production [4]. This mode of operation is compatible with most of the anticipated future PS programmes.

To estimate the intensity of the extracted beams, the above flux has to be multiplied by the overall efficiency, which for high energy in Lear is of the order of 50%. We can thus expect mean extracted fluxes of several  $10^6$ , and perhaps  $10^7$  antiprotons/sec with some improvement.

The upper limit for the performance in the internal target and collider mode can be derived in a similar way: with the hypothesis that all antiprotons are consumed in the  $p\bar{p}$  interactions, for which we take a total "loss" cross section ( $\sigma_t$ ) of 100 mb, we obtain the "consumption-limited" luminosity as

$$L = \left( \frac{1}{\sigma_t} \right) \left( \frac{dN}{dt} \right) = 10^{32} \text{ cm}^{-2}\text{s}^{-1}$$

Our design aim is to reach this luminosity limit. It will be shown in section 9 below, that this is difficult, if not impossible, in the collider mode. However, with an internal target a luminosity close to the above limit seems to be within reach.

In fact the luminosity is determined by the target density ( $\rho d$ ), the particle revolution frequency ( $f_0$ ) and the number ( $N$ ) of circulating antiprotons as

$$L = \rho d f_0 N$$

Thus we have to match  $\rho d$  and  $N$  to reach the "consumption limit" of  $10^{32} \text{ cm}^{-2}\text{s}^{-1}$ . We take  $N = 5 \times 10^{11}$  (about 14 h of accumulation at  $10^7/\text{s}$ ) as a reasonable intensity. Then the optimum target thickness is  $10^{14}$  protons/cm<sup>2</sup> which is within reach of present target technology. If denser targets can be provided, the optimum luminosity can be obtained with lower intensity beams. More details are given in Table 1 where also data for Lear are included.

Table 1 - Target thickness and luminosity for various conditions

| Machine   | $p$<br>(GeV/c)         | $f_0$<br>(MHz) | $N$                                      | $\rho d$<br>(p/cm <sup>2</sup> )           | $L$<br>(cm <sup>-2</sup> s <sup>-1</sup> ) |
|-----------|------------------------|----------------|------------------------------------------|--------------------------------------------|--------------------------------------------|
| Lear      | Jetset <sup>1)</sup>   | 2              | $3 \times 10^{10}$                       | $5 \times 10^{12}$                         | $5 \times 10^{29}$                         |
|           | $\Lambda\bar{\Lambda}$ | 1.65           | $1 \times 10^{11}$<br>$5 \times 10^{11}$ | $2.5 \times 10^{14}$<br>$5 \times 10^{13}$ | $8 \times 10^{31}$                         |
| SuperLear | 125 m                  | 3 - 12         | $1 \times 10^{12}$<br>$3 \times 10^{11}$ | $4 \times 10^{13}$<br>$1.4 \times 10^{14}$ | $1 \times 10^{32}$                         |
|           | 157 m                  | 3 - 12         | $1 \times 10^{12}$<br>$3 \times 10^{11}$ | $5 \times 10^{13}$<br>$1.8 \times 10^{14}$ | $1 \times 10^{32}$                         |

1) present situation, not limited by antiproton production,  $N$  limited at injection,  $\rho d$  by present gas jet.

At this stage we have to examine the beam emittances resulting from the equilibrium between heating at the target and stochastic cooling. With zero dispersion ( $D \rightarrow 0$ ) and small

$\beta$ -functions ( $\beta_{h,v} < 2$  m) at the target (see section below) we have small beam size and small emittance heating ( $d\epsilon/dt$ ) where the latter is given by:

$$\frac{d\epsilon_{4rms}}{dt} = 8\pi \left( \frac{15}{p v / c} \right)^2 \frac{\rho d m_p}{l_{rad}} f_0 \beta_{h,v}, \text{ where } p \text{ is in MeV / c and } \epsilon_{4rms} = \frac{\pi(4\sigma)^2}{\beta}$$

Here  $m_p$  ( $1.67 \times 10^{-24}$  g) is the proton mass,  $l_{rad}$  (63 g/cm<sup>2</sup> for hydrogen) the radiation length and  $f_0$  ( $\cong 2$  MHz) the revolution frequency.

The equilibrium with an emittance cooling time constant ( $\tau$ ) can then be estimated using

$$\epsilon_{eq,4rms} = \tau \left( \frac{d\epsilon_{4rms}}{dt} \right)$$

Some results are compiled in Table 2 where a target thickness of  $10^{14}$  protons/cm<sup>2</sup> and a cooling time constant of 1 h (see section 6 below) are assumed.

We can thus expect emittances of the order of a few mm-mrad, provided that fast enough cooling times can be reached. In these conditions operation at the luminosity limit with targets of about  $10^{14}$  protons/cm<sup>2</sup> looks quite feasible.

Table 2 - Equilibrium emittance with a target thickness of  $10^{14}$  protons/cm<sup>2</sup> an emittance cooling time constant of 1 h, and a beta function of 2 m.

| Beam momentum<br>(GeV/c) | Equilibrium emittance ( $4\sigma$ )<br>( $\pi$ mm-mrad) |
|--------------------------|---------------------------------------------------------|
| 2                        | 21                                                      |
| 3.5                      | 6                                                       |
| 5                        | 3                                                       |
| 12                       | 0.4                                                     |

## 5. Lattices

### 5.1. General features

Following up on earlier work[1, 2], new versions of a compact high-luminosity storage ring have been designed with a different emphasis on the number of internal targets and/or extracted beams. An overview of three examples is given in Table 3.

Table 3 - Overview of different machines considered

| Lattice<br>(SuperLear) | Circumference<br>(m) | Internal targets | Extraction              | Shape          |
|------------------------|----------------------|------------------|-------------------------|----------------|
| 44                     | 125                  | 2<br>or<br>1     | no<br>yes <sup>1)</sup> | racetrack      |
| 51                     | 157                  | 2                | yes                     | long racetrack |
| 205                    | 157                  | 2                | yes                     | "pear shaped"  |

1) In SuperLear 44 the changeover from two targets to one target plus ejection and vice versa needs installation/removal of septa.

In addition to the boundary conditions discussed before, the following features were kept in all versions of the lattice:

- one or two sections for internal targets and/or one section for slow extraction serving two (or three) external beam lines,
- changeover from target to extraction mode with a modification of the optics but without the need to relocate elements. This condition is not met in SuperLear 44, where the transition from two targets to one target plus extraction requires the installation of septa,
- adjustable transition energy, favouring strong stochastic cooling;
- the possibility to have zero dispersion and small  $\beta$ -functions ( $\beta_h \cong \beta_v \cong 1.5$  m) at the target locations,
- the option for a collider mode to be implemented at a later stage; this mode will, however, need a major re-shuffling of elements.

These points will be discussed in more detail below.

## 5.2 Lattice SuperLear 44

The layout of a ring with 125 m circumference, called SuperLear 44, is sketched in Fig. 2. The extraction septum (SMH) in straight section ST 21 can be replaced by a second target if desired. In operation with (one or two) internal targets, the sections ST 21 and ST 41 have small beta values and zero dispersion. We require that these properties as well as the tunes  $Q_h$  and  $Q_v$  remain unchanged when transition energy is tuned to different values.

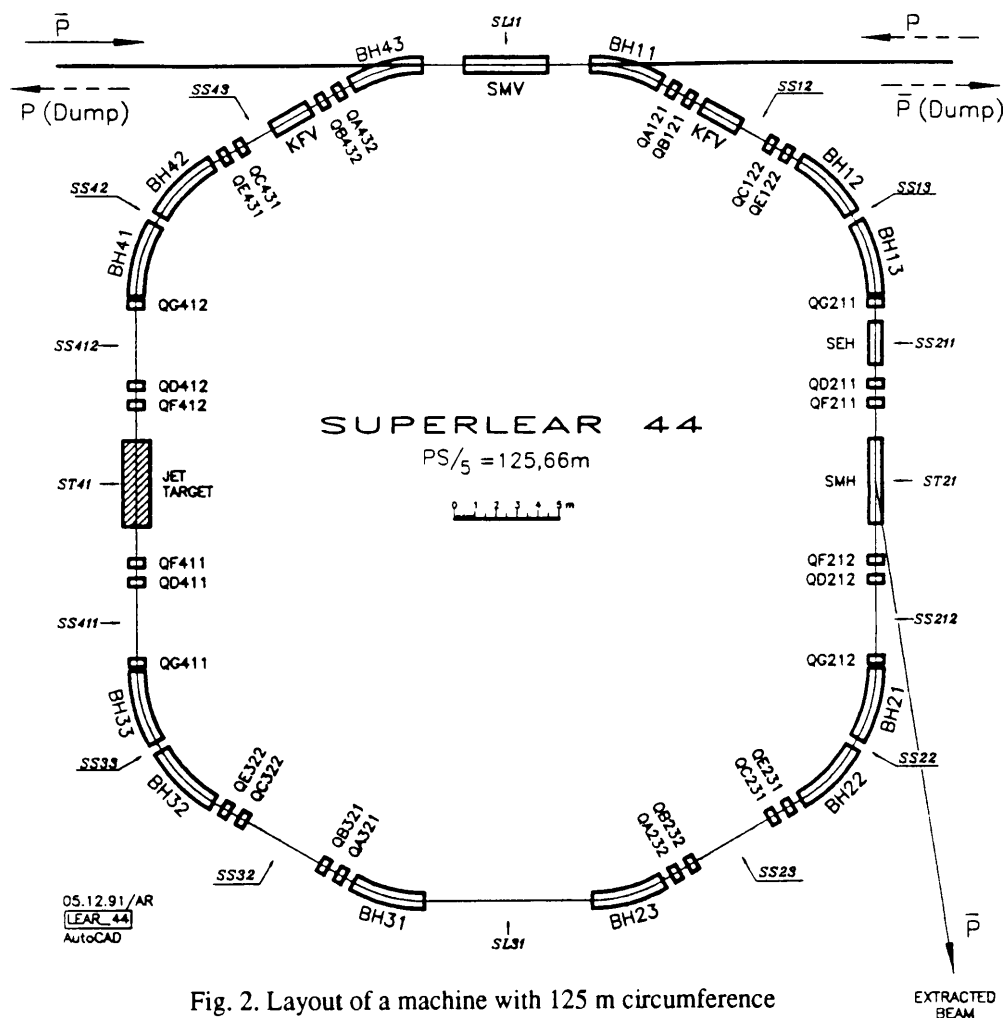


Fig. 2. Layout of a machine with 125 m circumference

The adjustment of  $\gamma_{tr}$  is obtained by tuning the quadrupoles, predominantly those labelled QC and QE and, to a lesser extent, the others (QA, QB, QG, QF). The objective is to create a "local dispersion bump" in the magnets adjacent to the section SL 11, such that the change in

$$\gamma_{tr}^{-2} = \frac{1}{2\pi R} \int_0^{2\pi R} \frac{D}{\rho} ds$$

is large and the  $Q$ -changes:

$$\Delta Q = \frac{1}{2\pi} \int_0^{2\pi R} \left( \frac{1}{\beta} - \frac{1}{\beta_0} \right) ds \cong \frac{1}{4\pi} \int_0^{2\pi R} \Delta k \beta ds$$

remain negligible.

The variation of some lattice properties with transition energy -again for the example of SuperLear 44- is summarized in Table 4. One notes that the beta functions are quite sensitive to the value of  $\gamma_{tr}$ , especially if the  $Q$ -values are fixed. If we accept somewhat different working points at different energies, then  $\gamma_{tr}$ -adjustment with beta functions not exceeding 30 m should be attainable.

Table 4 - Variation of lattice functions in SuperLear 44 as function of transition energy. The working point is close to  $Q_h \cong 3.8$ ,  $Q_v \cong 2.4$ ,  $D = 0$  and the  $\beta$ -functions are small in the target sections in all cases.

| Transition energy<br>$\gamma_{tr}$ | $\alpha = 1/\gamma_{tr}^2$ | Dispersion in SL 11<br>(m) | Maximum $\beta_h$<br>(m) | Maximum $\beta_v$<br>(m) |
|------------------------------------|----------------------------|----------------------------|--------------------------|--------------------------|
| 3.5i                               | -0.08                      | -8.2                       | 33                       | 30                       |
| 4.5i                               | -0.05                      | -6.0                       | 22                       | 31                       |
| $\infty$                           | 0.0                        | -2.9                       | 17                       | 35                       |
| 4.5                                | 0.05                       | 0.2                        | 34                       | 36                       |
| 3.5                                | 0.08                       | 2.3                        | 26                       | 36                       |
| 2.5                                | 0.16                       | 7.0                        | 15                       | 37                       |

For ultra-slow extraction, a different optical setting summarised Table 5 is used (see §8.3 below). Beam cooling is less important during extraction. Therefore we do not plan to use  $\gamma_{tr}$ -tuning in these working conditions.

Table 5 - Lattice properties for ultra-slow extraction in lattice SL 44

|                         |                     |              |
|-------------------------|---------------------|--------------|
| Horizontal tune         | $Q_h$               | $\cong 3.65$ |
| Vertical tune           | $Q_v$               | $\cong 2.6$  |
| Transition energy       | $\gamma_{tr}$       | $\cong 13$   |
| Maximum horizontal beta | $\beta_{h,max}$ [m] | 15           |
| Maximum vertical beta   | $\beta_{v,max}$ [m] | 33           |
| Dispersion in ST 21     | D(ST 21) [m]        | 1.5          |
| Dispersion in SL 11     | D(SL 11) [m]        | -0.4         |



### 5.3 Alternatives

The principle of  $\gamma_{tr}$ -tuning discussed above can be retained for the lattice variants. The longer racetrack, SuperLear 51, has been obtained by inserting  $\pi$ -straight sections into the centre of ST 21 and ST 41 of the lattice SuperLear 44 (Fig. 3). This larger machine offers several advantages which stem from the more ample straight-section space. The septa for extraction can remain installed when the ring is used with two internal targets, and more room is available for stochastic cooling and a beam cleaning system.

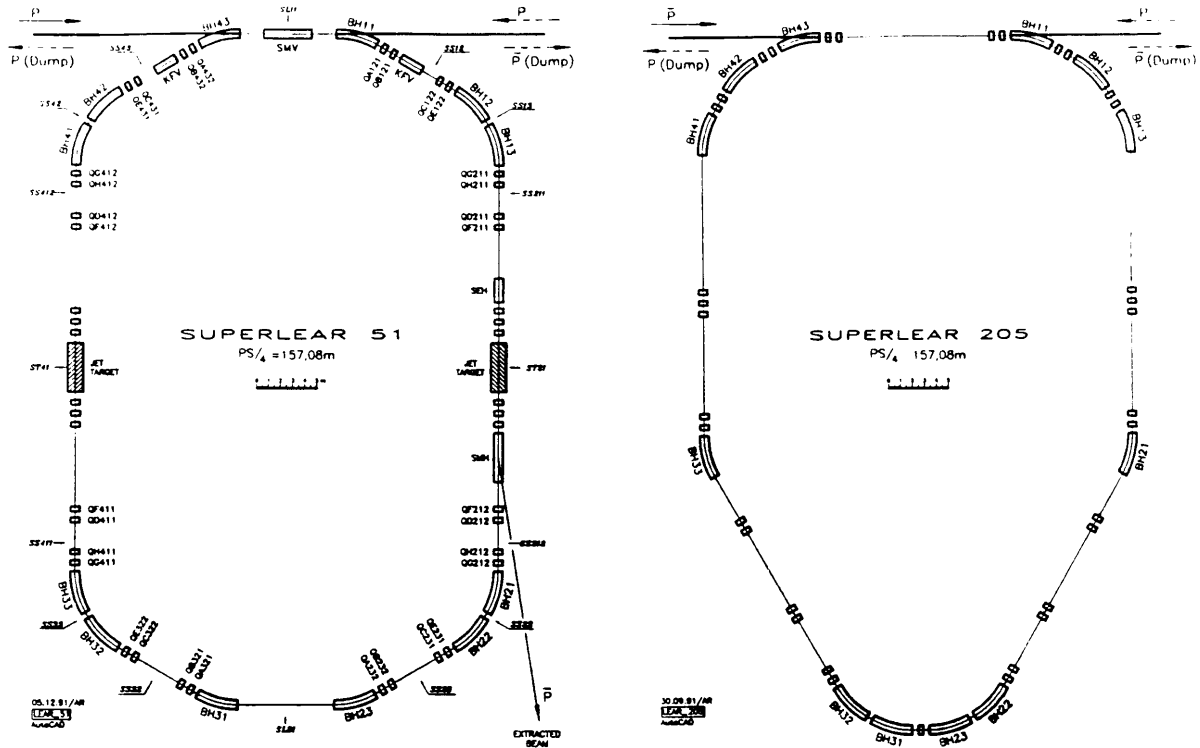


Figure 3. Layout of machines with 157 m circumference

The price to pay for these advantages: four extra quadrupole doublets and greater difficulty to house the ring in the East Hall respecting the crane limits, leaving the possibilities for "easy" injection and ejection lines and preserving sufficient space for test beams in the upper part of the hall.

It is because of these difficulties that the pear-shaped geometry, SuperLear 205 (Fig. 3), was considered, where the straight sections are ideally oriented for injection and ejection. However, due to the (less regular) shape, it is more difficult to find satisfactory optics. More work is necessary to finalize these studies.

## 6. Stochastic cooling

Phase-space cooling is needed to compensate the beam heating due to multiple scattering on internal targets. We assume an ACOL-type stochastic cooling system with several distinct bands and an effective overall bandwidth ( $W$ ) as high as 10 GHz, capable to work in the full

energy range of the machine. In this way we can hope to obtain acceptable cooling time constants even for  $N = 10^{12}$  circulating antiprotons. In fact to estimate the cooling time we use

$$\tau = \frac{10N}{W}$$

where the numerical factor 10 is chosen to fit data from AAC. Thus we can expect  $\tau = 10^3$  s for energies where a good optimization is possible and  $\tau = 1$  h in more difficult situations.

We assume that the cooling path cuts diagonally across the ring with the pick-ups in SS 412 and the kickers in SS 212. Compared to the beam path (half the ring circumference) this short-cut leads to a gain of about 80 ns, which leaves sufficient room for the delays in the coaxial guides and the amplifiers.

To assure good mixing between kicker and pick-up, a relatively large dispersion of the corresponding time of flight

$$\frac{\Delta T}{T} = \eta_{k,p} \left( \frac{\Delta p}{p} \right)$$

is required where  $\eta_{k,p}$  is the "local off-momentum function" kicker to pick-up. For a regular lattice with the same optical properties all around the ring  $\eta_{k,p}$  is half the  $\eta$ -function of the full ring ( $\eta = |\gamma_{tr}^{-2} - \gamma^{-2}|$ ). Good mixing is then guaranteed at frequencies

$$f > \frac{f_0}{2\eta_{k,p}(\Delta p/p)}$$

It is desirable to satisfy this condition for the upper bands and, if possible, for the full frequency range (from, say, 1 GHz onwards). With the revolution frequency ( $f_0$ ) of about 2 MHz and a typical momentum width ( $2\sigma$ ) of  $2 \times 10^{-3}$  this calls for  $\eta_{k,p}$ -values of at least 0.1 to satisfy these conditions from 5 GHz onwards.

On the other hand, small mixing between observation and correction (pick-up to kicker) is essential for efficient stochastic cooling. At the expense of doubling the number of quadrupole families, it is possible to make the corresponding local  $\eta$ -function different from that of the kicker to pick-up path and to adjust it close to zero. We then arrive at a "mixed lattice" which consists of two half-rings with different local values of transition energy. In this way the "mixing dilemma" of stochastic cooling is circumvented. To avoid unwanted mixing even for momentum spreads of say  $4 \times 10^{-3}$ , the local  $\eta$ -function must be smaller than 0.02, thus calling for a virtually isochronous half-ring where transition is adjusted close to the working energy.

In many situations, for instance, during commissioning or setting-up, simplicity of the optics may be more important than extreme cooling. In these situations, one can of course work with a uniform  $\eta$  of, say, 0.05 all around the ring.

For transverse (vertical and horizontal) cooling we adopt the usual method with position pick-ups at locations where the  $\beta$ -functions are large. We require that at the typical working points, the betatron phase advance between sections SS 412 (PU) and SS 212 (kicker) does not deviate by more than  $30^\circ$  from the ideal values of  $90^\circ$  modulo  $180^\circ$ , such that  $\tau^{-1} \propto \sin^2 \psi = 0.7$  instead of 1.

For longitudinal cooling we adopt the filter method for the lower frequency range where the Schottky bands are separated. At higher frequencies we can perhaps use a method based on the time of flight between pick-ups in SS 411 and SS 412, which are about 15 m apart

from each other. If desired, we can also adopt the "Palmer" method with a pick-up in SS 32 where the dispersion is large. The condition of isochronism, discussed above, has then to be compromised.

The pick-ups and kickers for all three systems ( $h$ ,  $v$  and  $p$ ) have to work efficiently in the required range  $v = 0.9c-0.96c-1c$  of beam velocities ( $p = 2.0-3.5-15$  GeV/c). Ideally, each system has its own dedicated pick-ups and kickers thus permitting independent optimization. The units will be installed in tanks of about 2 m length, similar to those used in the AAC. Thus, in the larger machines, there will be three pick-up and three kicker tanks installed in sections SS 411/SS 211 and SS 412/SS 212. In the smaller versions like SuperLear 44, where space is very limited, the horizontal, vertical and sum signals from the same array of plates have to be used. We foresee to have the pick-up plates mechanically adjustable to fit the beam size for different working conditions. In contrast to AAC, relatively slow movement is sufficient to follow the cooling of the beam with time constants of tens of minutes and/or to re-optimize for different energy.

Clearly, more detailed design work is needed but we believe that the concept outlined above will permit us to attain the required cooling strength entirely with stochastic cooling. An exception is the collider mode where very strong bunching is needed. Then with  $10^{12}$  circulating antiprotons, electron cooling (with electron energies in the range of 0.5 to 6 MeV) has to be used. This necessitates new developments.

## 7. Superconducting magnets

### 7.1 Aperture

In our studies the same aperture as that of the HERA magnets has been taken ( $\phi_{ic} = 75$  mm coil-to-coil and  $\phi_{ivc} = 65$  mm inside the vacuum chamber) with the aim to simplify the adaptation of the HERA design.

The required acceptances of the machine are:

$$\Delta p/p = \pm 3.5 \times 10^{-3}$$

$$A_h = 30\pi \text{ mm}\cdot\text{mrad}$$

$$A_v = 30\pi \text{ mm}\cdot\text{mrad}$$

and the corrected peak-to-peak closed orbit distortion is smaller than 5 mm.

This imposes the following constraints to the lattice functions:

$$\hat{\beta}_x \leq 30 \text{ m} \quad \text{at } D = 0$$

$$\beta_x \leq 15 \text{ m} \quad \text{at } \hat{D} = 6 \text{ m}$$

$$\hat{\beta}_z \leq 30 \text{ m}$$

These conditions seem reasonable, even if our preliminary lattices so far do not meet all the limits in the full range of transition energies considered.

### 7.2 Dipole typical specifications

We take:

$$\text{Magnetic field} \quad \hat{B} = 6 \text{ T (at } cp = 12 \text{ GeV, } B\rho = 40 \text{ Tm)}$$

$$\text{Bending radius} \quad \rho = 6.7 \text{ m}$$

$$\text{Bending angle} \quad \theta = 30^\circ (15^\circ)$$

$$\text{Magnetic length} \quad \ell = 3.5 \text{ m (1.75 m)}$$

|         |                                |
|---------|--------------------------------|
| Sagitta | $s = 22.8 \text{ cm (5.7 cm)}$ |
| Number  | 12 (24)                        |

Several techniques are possible:

- For a  $30^\circ \cos\theta$  magnet the HERA technique looks promising [5]. The possibility to use existing HERA tools is being investigated. The construction and testing of a prototype would provide precious information especially on curvature effects which are special to our case.
- Another technique has been looked at, based on the experience gained at INP-Novosibirsk in the design of a  $\phi$ -factory and in the development of compact synchrotron light sources [6].

Based on straight units of 1.75 m, such magnets look feasible and easy to build even if they lead to larger magnets, needing more superconducting material and higher stored energy.

- Finally the superferric technique developed at the Texas Accelerator Center (TAC) and applied to curved magnets for synchrotron light projects has been proposed [7].

This technique looks, a priori, well adapted to SuperLear.

Novosibirsk-type and superferric magnet imply strong compensation coils to correct for saturation effects. Prototypes are necessary to measure the behavior of such magnets in the energy range of SuperLear before a choice can be made.

### 7.3 Quadrupole specifications

We take:

|                     |                                    |
|---------------------|------------------------------------|
| Gradient            | $\hat{G} = 80 \text{ Tm}^{-1}$     |
| Normalized gradient | $k = 2 \text{ m}^{-2}$             |
| Magnetic length     | $\ell = 0.4 \text{ m}$             |
| Number              | 28 to 44, depending on the lattice |

These quadrupoles have to be grouped in 7 or 11 families with 4 elements per family to fulfill the lattice requirements.

The design and the tools of the HERA quadrupoles can be used in principle, the main difference being the length of the quadrupole [5]. Nevertheless, HERA uses large conductors for the superconducting coils -perhaps not well adapted to the large number of families necessary in our case.

Novosibirsk is developing "many-turn" quadrupoles which look more suitable for SuperLear. In addition the superferric technique can also be used for the quadrupoles [7]. Again the construction and testing of prototypes seem necessary to make the final choice.

### 7.4 Correcting elements (dipoles, sextupoles or multipoles)

Even if the correcting elements can be incorporated as additional coils in the main elements, it looks, a priori, easier to envisage separated multipoles fitting well with the SuperLear layout.

This question has not yet been studied in detail.

## 8. Injection and extraction

In this chapter we compile some parameters of the injected and extracted beams, the figures have to be reviewed at a later stage.

### 8.1 Incoming beam

Parameters of a batch with  $N_{\bar{p}} \leq 4 \times 10^{11}$  (40% of an AA stack) are summarised in Table 6.

Table 6 - Properties of the incoming beam

|         | p<br>(GeV/c) | $A_p$<br>(eVs) | $\Delta t$<br>total<br>(ns) | $\Delta P/P$<br>$10^{-3}$<br>( $2\sigma_p$ ) | $\epsilon_H$<br>$\pi \times \text{mm} \cdot \text{mrad}$<br>( $2\sigma_{\text{def}}$ ) | $\epsilon_V$<br>$\pi \times \text{mm} \cdot \text{mrad}$<br>( $2\sigma_{\text{def}}$ ) |
|---------|--------------|----------------|-----------------------------|----------------------------------------------|----------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| AA exit | 3.5          | 1              | -                           | -                                            | 3                                                                                      | 2.5                                                                                    |
| PS exit | 3.5          | 1              | 100                         | 2.5*                                         | 3                                                                                      | 2.5                                                                                    |
|         | 12           | 1.3            | 100 (82)                    | 0.7 (0.86)                                   | 1.2                                                                                    | 1                                                                                      |

\* This value does not fit into the acceptance of the injection channel; therefore, at low energies the number of particles injected has to be lower so that the extraction bucket from the AAC can be  $< 1$  eVs.

### 8.2 Injection in SuperLear

The injection is done in the vertical plane where good use of the machine acceptances (vertical betatron motion from septum to kicker) can be made. The transverse matching for the different energies is achieved by the quadrupoles in the transfer line. The PS rf voltage and harmonic number can be matched to those of SuperLear.

Table 7- Rf parameters at injection

|                               | $V_{\text{rf}}$<br>(kV) | $\Delta P/P$<br>$10^{-3}$<br>( $2\sigma_p$ ) | $t_t$<br>$4\sigma_t$<br>(ns) | $A_p$<br>(eVs) |
|-------------------------------|-------------------------|----------------------------------------------|------------------------------|----------------|
| Circulating beam<br>debunched |                         | 0.7                                          |                              | 6.95           |
|                               | bunched h = 1           | 7.1                                          |                              | 6.95           |
|                               | h = 2                   | 3.55                                         | 190                          | 6.95           |
| Incoming beam<br>h = 2        | 3.55                    | 0.86*                                        | 82*                          | 1.3            |

\* Typical values for the smallest machine:  $L = 125.6$  m,  $T_{\text{rev}} = 420$  ns at 12 GeV/c leading to rise and fall time for the kicker of about 79 ns, which is the limit technically feasible with the PS.

### 8.3 Extraction

The ultra-slow extraction pioneered at Lear would be used in SuperLear. The particles are removed from the stack by rf noise and transported into a resonance by a diffusion process.

A third-integer resonance is used ( $Q_x = \text{Integer} \pm 1/3$ ) with adjustment of phase and amplitude by sextupoles. The particles are extracted by a thin electrostatic septum followed by a thicker magnetic septum.

The alignment of the separatrices can be done by a careful choice of the dispersion, chromaticity and resonance parameters, as done in Lear. This gives additional constraints for the lattice design.

The spill rate can be adjusted in the range of  $10^5$  to  $10^7$   $\bar{p}$ /s with a total of  $3 \times 10^{11}$  per cycle.

## 9. Collider option

In the light of the new lattices this option has been briefly reconsidered because of the interest for some potential users. The luminosity limits given by the beam-beam interaction ( $\Delta Q_{bb} \leq 0.003$ ) and by the single beam space-charge effects ( $\Delta Q_{sc} \leq 0.01$ ) have been extensively discussed in previous reports [2].

In our present lattice design, short bunches can be obtained more easily with a given rf voltage by using the possibility to operate the machine close to transition (very small  $\eta$ -value). A necessary condition to have "reasonable" rf voltage is to reduce  $\Delta p/p$  ( $\sigma_p = 10^{-3}$ ) by a strong longitudinal cooling. The high luminosity imposes a strong transverse cooling ( $\sigma_x \sim \sigma_z \sim 1$  mm). Stochastic cooling is not feasible because of the high particle density in the bucket.

For these reasons, a high-current and high-energy electron cooling is a necessity; this needs a new technology to be developed (at 12 GeV/c the electron energy is 6 MeV).

Table 8 summarizes the optimum bunch length and luminosity for  $N_p = N_{\bar{p}} = 10^{12}$  and the rf voltage needed assuming  $\gamma_{tr} = 3i$ .

Table 8 - Maximum luminosity and minimum bunch length for  $N_p = N_{\bar{p}} = 10^{12}$ ,  $\sigma_p = 10^{-3}$ , and  $\beta^*_{x,z} = \sigma_L$ . Values in brackets correspond to the optimum obtainable if the rf voltage is limited to 250 kV.

| CP<br>(GeV) | $\sigma_L = \beta^*$<br>(m) | L<br>( $10^{30} \text{ cm}^{-2}\text{s}^{-1}$ ) | $V_{rf}$<br>(kV) |
|-------------|-----------------------------|-------------------------------------------------|------------------|
| 1           | 4.0                         | 0.1                                             | 20               |
| 3           | 0.75                        | 2                                               | 80               |
| 5           | 0.25                        | 10                                              | 250              |
| 7           | 0.15 (0.28)                 | 25 (15)                                         | 450 (250)        |
| 10          | 0.05 (0.30)                 | 100 (18)                                        |                  |

The luminosity values are obtained by using a single ring with one bunch per beam and an equal number  $N$  of  $\bar{p}$  and  $p$ :

$$L = \frac{N^2 f_0}{A} \quad (\text{luminosity per crossing})$$

where  $A = \pi 2\sigma_x 2\sigma_z$  is the effective crossing area..

At low energy,  $cp < 5$  GeV, the maximum theoretical luminosity and the minimum bunch length can be improved by using a double ring, operating with crossing angle in the multibunch mode. But the gain remains too limited to envisage such a solution.

## 10. Conclusion and acknowledgements

The standard technology part of the machine is well under study and a conceptual design will be ready for Cogne 92. A number of machine physicists of PS Division and many of our colleagues working on the antiproton machines have been of great help and will be more involved in the future, as will be the hardware specialists.

The magnet studies are the most critical item and care is necessary to arrive at reasonable specifications. The CERN specialists in superconducting magnets and cryogenics have priorities completely incompatible with our present studies. But we have been fortunate to benefit from the decisive contributions of H. Kaiser from DESY, P. Vobly from INP-Novosibirsk and P. McIntyre from Texas Accelerator Center, on the feasibility of curved superconducting magnets for SuperLear. Several interesting ways to build such magnets are open, but before any final choice it appears necessary to build and measure prototypes. Collaborations have to be set up with these institutes and with industry for this purpose. The preparation of prototypes has to start now if the first physics runs with SuperLear are wanted in 1997.

No major difficulties have been identified for the rest of the design. A 3 to 12 GeV/c machine in the East Hall, working with internal targets and extracted beams, looks feasible.

In the collider mode the performances are limited by space-charge effects, and a new layout of the machine is necessary which needs a long shutdown. It has therefore to be considered as a long-term option. The  $\Lambda\bar{\Lambda}$  CP-experiment appears to be feasible in the modified Lear machine and thus decoupled from SuperLear.

Studies are in progress and a more detailed report will be prepared for later.

## 11. References

- [1] Gianfelice E., Lefèvre P. and Möhl D. 1985 *Proc. of the 3rd Lear Workshop on Physics with Antiprotons at Lear in the ACOL Era 83, Tignes* (U. Gastaldi et al. Editors: Editions Frontières)
- [2] Giannini R., Lefèvre P. and Möhl D. 1987 *Proc. of the 4rd Lear Workshop on Physics at Lear with Low-Energy Antiprotons, Villars-sur-Ollon* (C. Angler et al. Editors: Harwood Academic Publishers)
- [3] Hamann N. 1991 *Experimental Approach to CP Violation in Hyperon Decay* (This workshop)
- [4] Maury S. 1991 *Status of the Antiproton Source* (This workshop)
- [5] Kaiser H. 1991 *The Hera Superconducting Dipole and its Extrapolation to Smaller Rings* (This workshop)
- [6] Vobly P. 1991 *Superconductive Magnets for SuperLear* (This workshop)
- [7] McIntyre P. 1991 *Superferric SuperLear* (This workshop)