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SuperLEAR, Conceptual Machine Design

R. Giannini, P. Lefèvre, D. Möhl

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Abstract

Following the Workshop on "Physics at SuperLEAR", which was held in Zürich in October, 1991, a conceptual design was worked out for a 3.5-12 GeV/c antiproton cooling ring optimised for operation with an internal target and an extracted beam. This paper summarises the main features and discusses the expected performances.

1. INTRODUCTION

Since about 1985, several groups have expressed their interest [1, 2] for an antiproton ring with beam momenta in the range of 2 to 15 GeV/c. It was quickly realised [3], that the request for very high luminosity and high resolution can best be met in a compact cooling ring with superconducting magnets, which was since referred to as SuperLEAR, S-LEAR or SL (for Superconducting Low-Energy Antiproton Ring).

During the years the emphasis evolved from a collider and internal target machine to a facility where priority is put on a high-quality extracted beam in addition to the internal target. In October 1991, a workshop held at the Physics Institute of the University of Zürich gathered about 120 participants to discuss the case for such a facility [2]. It was then suggested to update the machine design according to the orientation which had evolved during the meeting, and with sufficient detail to permit reliable performance and cost estimates.

This study was carried out by a small nucleus group with brief but precious help from many machine experts. The design worked out includes several new features:

- a very compact storage ring (to favour high luminosity) with curved superconducting magnets as already envisaged in the earlier studies,
- installation in the existing PS East Hall,
- a special injection mode, which permits "topping-up", i.e. adding antiprotons rather than dumping the beam prior to each new injection,
- injection close to the energy of operation (to avoid ramping of the magnets),
- a bending and focusing structure which is isochronous (revolution time independent of momentum) for half of the ring and strongly unisochronous for the other half. This solves the mixing problem and allows for advanced stochastic cooling.

- a LEAR-type, ultra-slow extraction system with special optics to minimise losses on the septum, thus permitting high-quality spills with a duration of several hours.

It is the aim of the present contribution to highlight the new design and the resultant performances.

2. ASSUMPTIONS, CHOICES AND IMPLEMENTATION

The requirements confirmed during the Zurich meeting call for a nominal momentum range of 3.5-12 GeV/c with the possibility to decelerate down to 2 GeV/c, where a reduced performance is accepted. Using 6 tesla bending magnets such a machine can be built with a circumference of about 160 m (PS/4). A ring of this size can just fit into the PS-East Hall; an effort has therefore been made to find a design that meets this objective. The use of an existing well-equipped hall to house the machine and its experimental area reduces the cost very significantly.

Antiprotons can then be transferred via the PS, where they are accelerated or decelerated to the energy required in SuperLEAR. To supply this beam to the East Hall, we propose a new fast ejection from the PS [4] using existing kickers, a new septum to be installed in SS84 and a new transfer line [5] PS to East area (Figure 1). Protons to test S-LEAR can be sent via the present PS ejection line to the East Hall [6]. The experiment(s) with the extracted beam can be installed in the downstream annex (CERN Building 156) of the hall.

Figure 1. Proposed implementation of SuperLEAR on the CERN site.

Figure 2. Layout of the egg-shaped "ring" SL 225.

Figure 3. PROPOSED LAYOUT of SUPERLEAR.
in the PS EAST HALL.

An attractive 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 is critical in superconducting machines with energy ramping. It also opens the possibility of topping-up of the intensity, which permits efficient use of the antiprotons and optimum luminosity with internal targets. The price to pay is the high injection energy in SuperLEAR with the necessity to use a stronger septum and kicker [7].

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 Area. It is desirable to leave these beams intact, even if one could envisage to move part of the tests into the North Hall 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 a separate one for test protons), by the extraction line from SuperLEAR [8], by the space required for the internal and the external detector and by the infrastructure of the hall (crane limits, etc.). The egg-shaped "ring" SL 225 (Figure 2) solves these problems in a satisfactory manner. The machine circumference of 157 m leaves sufficient space for injection-ejection, stochastic cooling, diagnostics, as well as for beam cleaning and emergency dumping systems [9] to protect the superconducting magnets. One 6m long section with appropriate optical properties is reserved for the internal target and the associated detector.

The proposed implementation is shown in Figure 3. A floor space of about 80 m² for the experiments with the external beam is available in the Hall annex (CERN Building 156). Additional space in the same building can be useful to install control and equipment rooms. The ring is entirely on the concrete foundations of the Hall. It surpasses the present shielding wall in one place and the area accessible by the two existing cranes in two places. The walls can relatively easily be displaced to enclose the machine, and part of the new shielding can be set up outside of the hall. The essential components, in particular the internal and the external detector, are in reach of the overhead cranes. Mobile charge lifts can be used to install machine equipment outside the crane limits.

The test beams can remain practically unchanged.

3. AVAILABILITY OF ANTIPROTONS AND PERFORMANCE LIMITATIONS

To work out performance limitations we assume a flux of 10^7 antiprotons/s. This corresponds to the present capability of AAC when 3 (out of 6) cycles per PS supercycle are used for $\bar{p}$ -production [10]. 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/s with high duty factor.

The upper limit for the performance in internal target 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 (σ_t) of 100 mb, we obtain the "consumption-limited" luminosity as

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

Our aim is a design with an *average* luminosity close to this limit. The peak luminosity which can be obtained for shorter periods is higher, but then the AA will be emptied as the consumption exceeds the production.

With an internal target, the luminosity is determined by the target density (ρd), the particle revolution frequency (f_0) and the number (N) of circulating antiprotons as

$$L = \rho d f_0 N \quad (2)$$

Thus we have to match ρd and N to reach the "consumption limit". It is obvious from Equation (2) that this is possible (or easier) with large f_0 , i.e. in a small ring. Two limiting cases (10^{11} or 10^{12} circulating antiprotons both in a machine of 157 m circumference) are compiled in Tables 1 and 2, where the corresponding matched target densities and the concurrent beam properties are included. The beam sizes and emittances result from the equilibrium between heating mechanisms like small angle scattering at the target, intrabeam scattering, interaction with the residual gas, diffusion on high-order betatron resonances and beam instabilities on the one side and stochastic beam cooling on the other hand.

A computer code, based on Piwinski's theory including the variation of the optical functions around the ring [11], is available to analyse intrabeam scattering. This turns out to be the limiting effect in the "thin target high-intensity" cases. In the other extreme case, scattering on the target can determine the resolution limits. A vacuum pressure of less than a few times 10^{-10} torr is required such that scattering on the residual gas remains negligible.

It is desirable to have zero dispersion ($D \rightarrow 0$) and small β -functions ($\beta_{h,v} < 2$ m) at the target. This leads to small beam size and small emittance heating ($d\epsilon/dt$), where the latter is given by:

$$\frac{d\epsilon_{2rms}}{dt} = 2 \left(\frac{15 \text{ MeV} / c}{p v / c} \right)^2 \frac{\rho d m_p}{l_{rad}} f_0 \beta_{h,v} \quad [\pi \text{ m} \cdot \text{rad} / \text{s}] \quad (3)$$

Here $\epsilon_{2rms} = (2\sigma)^2 / \beta_{h,v}$ is the "2 σ emittance" (containing 86% beam for a Gaussian), p (MeV/c) is the beam momentum, m_p (1.67×10^{-24} g) is the proton mass, l_{rad} (63 g/cm² for hydrogen) is the radiation length and f_0 (≈ 1.9 MHz) is the particle-revolution frequency in the storage ring.

The equilibrium with an emittance cooling time constant (τ) can then be estimated using

$$\epsilon_{eq,2rms} = \tau \left(\frac{d\epsilon_{2rms}}{dt} \right) \quad (4)$$

In Tables 1 and 2, cooling-time constants of 15 min (see Section 5 below) have been assumed to determine the equilibria. We conclude from the tables

that, in this case, emittances of the order of a few mm·mrad, i.e. rms beam sizes of the order of the millimeter, with a divergence of less than 1 mrad at the target and a momentum spread of 10^{-4} can be reached, in spite of the heating mechanisms discussed.

Table 1
Circulating beam quality, high intensity case

Intensity	$1 \times 10^{12} \bar{p}$	
Luminosity with internal target	$1 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$	
Matched target thickness	$5 \times 10^{13} \text{ protons/cm}^2$	
Consumption	$1 \times 10^7 \bar{p}$ per sec.	
Topping up (10%)	$1 \times 10^{11} \bar{p}$ every 3 h	
Stochastic cool. time const.	15 minutes	
Beam properties:		
Momentum	3.5 GeV/c	12.0 GeV/c
Maximum emittance (86%)	$3.8\pi \text{ mm}\cdot\text{mrad}$	$2.0\pi \text{ mm}\cdot\text{mrad}$
rms momentum spread	0.6×10^{-3}	0.4×10^{-3}
rms beam size (at $\beta = 2 \text{ m}$)	1.4 mm	1.0 mm
rms beam divergence (at $\beta = 2 \text{ m}$)	0.7 mrad	0.5 mrad

Table 2
Circulating beam quality, low-intensity case

Intensity	$1 \times 10^{11} \bar{p}$	
Luminosity with internal target	$1 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$	
Matched target thickness	$5 \times 10^{14} \text{ protons/cm}^2$	
Consumption	$1 \times 10^7 \bar{p}$ per sec.	
Topping up (30%)	$3 \times 10^{10} \bar{p}$ every 1 h	
Stochastic cool. time const.	15.0 minutes	
Beam properties:		
Momentum	3.5 GeV/c	12.0 GeV/c
Maximum emittance (86%)	$1.8\pi \text{ mm}\cdot\text{mrad}$	$0.75\pi \text{ mm}\cdot\text{mrad}$
rms momentum spread	0.35×10^{-3}	0.25×10^{-3}
rms beam size (at $\beta = 2 \text{ m}$)	0.9 mm	0.6 mm
rms beam divergence (at $\beta = 2 \text{ m}$)	0.4 mrad	0.3 mrad

Two extreme beam intensities are assumed in the examples. A reasonable choice is probably $N = 5 \times 10^{11}$ (about 14 h of accumulation at $10^7/\text{s}$) requiring the optimum target thickness of $10^{14} \text{ protons/cm}^2$. This is in reach of the present technology (see examples given in Table 3), if the distance to be traversed by the cluster jet is not too large. If denser targets

can be provided, then the optimum luminosity can be obtained with lower intensity beams, which would ease the operation of the ring.

A storage ring with normal conducting (1.8 T) magnets would be about 3 times larger and thus need a correspondingly denser target or larger intensity.

Table 3
Target thickness and luminosity for some internal target machines

Machine	p (GeV/c)	f_0 (MHz)	N	ρd (p/cm ²)	L (cm ⁻² s ⁻¹)
LEAR Jet Set ¹⁾	2	3.5	3×10^{10}	5×10^{12}	5×10^{29}
SPS UA6	300	0.04	3×10^{11}	2×10^{14}	1×10^{30}
FNAL E760 ²⁾	3-9	0.6	1.5×10^{11}	1×10^{14}	1×10^{31}
SuperLEAR proposed	3.5-12	1.9	5×10^{11}	1×10^{14}	1×10^{32}

1) Present situation, not limited by antiproton production, N limited at injection and ρd by present gas jet.

2) Jet target in antiproton accumulator, design values (see J. Peoples, Proc. 2nd LEAR Workshop, Villars 1987).

It has been noted that all estimates up to now are based on the present performance of the $\bar{p}$ source. With a major improvement programme it might be possible to gain perhaps a factor of 5 in the $\bar{p}$ production rate. Such a programme would have to include:

- further upgrading of the PS beam for $\bar{p}$ production,
- new targetting techniques,
- advanced stochastic cooling in the AC and the AA,
- perhaps the complete rebuilding of the AA.

This could considerably add to the cost of SuperLEAR. Also, to profit from the higher flux, which would in principle permit a luminosity of up to 10^{33} cm⁻²s⁻¹, very dense targets with 10^{15} p/cm² or very bright circulating beams with intensities in excess of 10^{12} $\bar{p}$ are required. Upgrading of the source has therefore not been further considered.

4. LATTICE

New versions [12] of a compact lattice have been designed with emphasis on high-luminosity internal target operation and a high-quality extracted

beam. Our choice is for the structure, called SL 225, sketched in Figure 2 above.

In addition to the boundary conditions discussed before, the following requirements are met:

- adjustable transition energy, favouring strong stochastic cooling;
- the possibility to have zero dispersion and small β -functions ($\beta_h \approx \beta_v \approx 1.5$ m) at the target locations;
- a section with good optical properties for the implementation of the ultra-slow extraction;
- changeover from target to extraction mode without the need to relocate elements;
- an anticlockwise proton (and a clockwise antiproton) injection system, which can serve as emergency ejection for antiprotons (and for test protons, respectively);
- a long section appropriate for beam cleaning using a system of collimators, scrapers and absorbers to protect the magnet (and the internal detector) from lost beam [9].

Figure 4. An example of the lattice functions. The plots starts in the centre of Section SS 8 (see Figure 2) and goes to SS 4 (half around the ring).

The lattice functions (Figure 4) have a basic superperiod of 1 and an approximate periodicity of 6. The adjustment of γ_{tr} is obtained by tuning the quadrupoles, predominantly those in straight sections 1 and 7 (Figure 2). The objective is to create a "local dispersion bump" in the 4 magnets BH 81-82-11-12, such that the change of

$$\gamma_{tr}^{-2} = \frac{1}{2\pi R} \int_0^{2\pi R} \frac{D}{\rho} ds \quad (5)$$

is large and the Q -changes:

$$\Delta Q = \frac{1}{2\pi} \int_0^{2\pi R} \left(\frac{1}{\beta} - \frac{1}{\beta_0} \right) ds \approx \frac{1}{4\pi} \int_0^{2\pi R} \Delta k \beta ds \quad (6)$$

remain negligible. We require in addition that the small beta values and zero dispersion at the internal target do not change when transition energy is tuned to different values. To this end the quadrupoles are grouped in a relatively large number of families (7-10).

Table 4
Conditions imposed simultaneously on the maximum lattice functions

	Dispersion function (m)	Maximum β_h (m)	Maximum β_v (m)
Location of maximum dispersion	6	15	30
Location of maximum horizontal β	0	30	30

Some variation of the lattice functions in other places is permitted, but the maxima should not exceed the values given in Table 4, so that with $\Phi = 65$ mm beam aperture (see Section 7) and an allowance of 5 mm total for closed orbit errors [13], the acceptances are $A_h \approx A_v = 30\pi$ mm·mrad, $\Delta p/p = \pm 3.5\%$, independent of the value of γ_{tr} .

5. STOCHASTIC COOLING

Strong phase-space cooling is needed to compensate the beam heating due to multiple scattering on the internal target and the other heating mechanisms discussed above. Some cooling is also desirable during the ultra-slow extraction to control the vertical emittance and the momentum distribution.

We assume an ACOL-type of stochastic cooling system with several distinct bands and an effective overall bandwidth (W) as high as 8 GHz. 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

$$\tau = \frac{8N}{W} \quad (7)$$

where the numerical factor 8 is chosen to fit data from AAC. Thus we can expect $\tau = 10^3$ s for energies where a good optimisation is possible and $\tau = 1$ h in more difficult situations.

The cooling path takes a short-cut diagonally across the ring with the pick-ups in straight section 6 where the dispersion function and its derivative are zero or small. Compared to the beam path (half of the ring circumference) this short-cut leads to a gain of at least 150 ns, which leaves sufficient room for the delays in the coaxial guides and the amplifiers. A supplementary pick-up for additional longitudinal cooling can be located in section 6 where the dispersion is large. The kickers in section 2 (Figure 2) are all at small D and D' .

Emphasis in the lattice design as discussed above has been put on the requirement to provide optical conditions which favour stochastic cooling. Schematically, the ring consists of two parts: the isochronous part pick-up to kicker, where ideally particles have the same flight time, independent of energy, and the half-ring kicker to pick-up where the dispersion of the flight time is large. This arrangement solves the "mixing dilemma" of stochastic cooling as it assures the absence of particle mixing between observation and correction and efficient mixing after correction.

The dispersion of the travelling time kicker to pick-up may be expressed by:

$$\frac{\Delta T}{T} = \eta_{k,p} \left(\frac{\Delta p}{p} \right) \quad (8)$$

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

$$f > \frac{f_0}{2\eta_{k,p}(\Delta p/p)} \quad (9)$$

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 1.9 MHz and a typical momentum width (2σ) of 2×10^{-3} this calls for $\eta_{k,p}$ -values of at least 0.1. These are obtained by tuning the transition energy (γ_{tr}) of the lower half-ring to an imaginary value of about 3.5i.

Small mixing between observation and correction (pick-up to kicker) is obtained by tuning the transition energy of the other half of the ring. To avoid the unwanted mixing even for momentum spreads of, say, 3.5×10^{-3} , the corresponding off-momentum function ($\eta_{p,k}$) must be smaller than 0.02, thus calling for a virtually isochronous half-ring where transition is adjusted close to the working energy. We then arrive at a "mixed lattice", which consists of two half-rings with different local values of transition energy.

The price to pay is the large number of quadrupole families and the need to have different optical settings at different 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 η 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 β -functions are large. We require that at the typical working points, the betatron phase advance between sections SD 62 (PU) and SD 22 (kicker) does not deviate by more than 25° ($\tau \propto \sin^2 \psi = 0.8$ instead of 1) from the ideal values of 90° modulo 180° . The same requirement holds for the other pick-up and kicker locations SD 63 - SD 23.

For longitudinal cooling we adopt the filter method for the lower frequency range where the Schottky bands are separated. At higher frequencies we can use a method based on the time of flight between pick-ups in SD 62 and SD 63, which are about 16 m apart from each other. If desired, we can also adopt the "Palmer" method which is based on the detection of the radial displacement with momentum and thus requires the pick-up where dispersion is large. This condition is fulfilled in section SD 53, but the condition of isochronism, discussed above, can then not be met simultaneously for all three cooling paths (cf. Figure 2).

The pick-ups and kickers for all three systems (h, v and p) have to work efficiently in the required range $v/c = (0.9)-0.96-0.998$ of beam velocities ($p = (2.0)-3.5-15$ GeV/c). Slotted "Faltin-type" pick-ups and kickers can be used, which have been working very reliably in the AAC. An interesting alternative consists in the "printed-circuit" structures recently developed at Fermilab [14]. To be compatible with a vacuum of 10^{-10} torr, the Teflon support would have to be replaced by a substrate which gives less outgasing.

To cope with the relatively large range of beam velocities, the signals from several short (about 20 cm long) sections must be combined in parallel, so that the phase slip between beam and wave remains small. The lengths of the guides from these sections to the combiner have to be readjusted for each different beam velocity. This is current practice in LEAR where the beam velocities change over an even larger range.

Ideally, each of the three cooling systems has its own dedicated pick-ups and kickers thus permitting independent optimisation. However, if desired, the sum and difference signals from the same array of plates can be used. The units will be installed in tanks, about 2.1 m in length, similar to those used in ACOL. There will be three pick-up and at least two kicker tanks, as indicated in Figure 2.

We foresee to have the pick-ups mechanically adjustable to fit the beam size for different working conditions. In contrast to the AC, a relatively slow

movement with time constants of tens of minutes is sufficient to follow the cooling of the beam and/or to re-optimize for different energy.

Some development work is needed but we believe that the concept outlined above will permit us to attain the required cooling strength entirely with stochastic cooling.

6. INJECTION AND EXTRACTION

6.1. Injection

Parameters of a batch with $N\bar{p} \leq 4 \times 10^{11}$ (40% of an AA stack) at the exit of the AA and the PS are summarised in Table 5.

Table 5 - Properties of the incoming beam

	Momentum p (GeV/c)	Bunch area A_p (eVs)	Bunch length Δt total (ns)	Momentum spread $\Delta p/p$ 2σ (10^{-3})	Transverse emittances ϵ_h ϵ_v $(2\sigma)^2/\beta$ (mm·mrad)	
AA exit	3.5	1	80	2	3	2.5
PS exit	3.5 12	1 1.3	120 60	1.6 1.25	3 1.2	2.5 1

The injection is done in the vertical plane with septum and kicker in the same long straight section.

This layout avoids traversing of superconducting elements with the injected beam. It simplifies the design of the cryostats and the protection against injection losses. However, a powerful septum and kicker are necessary as the distance between these elements is limited.

An alternative version of the lattice, called SL 226 (Figure 5), has been prepared, where the kicker is in the small straight section in front of the bending magnet BH 21 and the injected beam passes through the quadrupole doublet QF 13, QD 13 before arriving at the kicker.

In both lattices (SL 225 and SL 226) the transverse matching for the different energies is achieved by the quadrupoles in the transfer line. The rf voltage and the harmonic number of SuperLEAR can be matched to those of the PS to have bunch to bucket transfer.

A limitation occurs around PS transition energy where it is impossible to extract the PS beam with $2\sigma_p < 2 \times 10^{-3}$ as required by the acceptance of the extraction channel. The forbidden zone is for momenta between about 5.5 and 5.8 GeV/c. To overcome this difficulty, slow ramping of SuperLEAR over a small energy range can be used as it is foreseen for energy scanning in internal target operation.

Figure 5. The alternative layout SL 226

A change of transition energy in the PS has also been envisaged but this has the inconvenience of changing the optical conditions, in particular the phase advance between the ejection kicker and septum.

6.2. Extraction

The ultra-slow extraction pioneered at LEAR would be used in SuperLEAR [16]. The particles are removed from the stack and transported into a resonance by a diffusion process induced by rf noise. To this end, the chromaticity of the betatron tune ($\xi = [(dQ/Q)/(dp/p)]$) is set to a value of about 0.6 by means of sextupole lenses.

A third-integer resonance ($Q_h = 11/3$) is used with adjustment of phase and amplitude which is also done by sextupoles. The particles are extracted by a thin electrostatic septum followed by a thicker magnetic septum. Extraction from this compact machine for momenta as high as 12 GeV/c requires strong elements. The electrostatic septum is composed of two units with a length of ≈ 1 m each, and the magnetic septum consists of five 1 m long units, two of them under vacuum and three outside of the vacuum chamber.

To minimise losses on the septum, the alignment of the separatrices can be done by a careful choice of the dispersion, chromaticity and resonance excitation, as done in LEAR.

By controlling the strength of the noise, the spill rate can be adjusted in the range of 10^5 to $10^7 \bar{p}/s$ with a total of 3×10^{11} per cycle.

Beam cooling is less important during extraction. Therefore, we plan to use a simpler optics with fixed transition energy in these working conditions. Lattice properties for the extraction working point are summarised in Table 6.

Table 6
Lattice properties for ultra-slow extraction

Horizontal tune	Q_h	≈ 3.65
Vertical tune	Q_v	≈ 3.7
Transition energy	γ_{tr}	≈ 13
Max. horizontal beta	$\beta_{h,max}$	15 m
Max. vertical beta	$\beta_{v,max}$	30 m
Dispersion at magnetic septum	D_s	1.5 m

7. SUPERCONDUCTING MAGNETS

7.1. Dipoles

The main characteristics of the dipole magnets are summarised in Table 7. The inner coil diameter of 75 mm is equal to that of the HERA magnets [17]. In our case, this would permit a beam aperture of about 65 mm. Due to the large sagitta, a curved design is chosen to make good use of the aperture. For a $\cos\theta$ magnet the HERA technique looks promising [17]. The possibility to use existing HERA tools has been investigated. The

construction and testing of a prototype would provide precious information especially on curvature effects which are special to our case [17, 18].

Table 7
Characteristics of the superconducting dipoles

Number	$N_m = 16$
Magnetic field	$\hat{B} = 6 \text{ T}$
Bending angle	$\theta = 22^\circ 5$
Bending radius	$\rho = 6.67 \text{ m}$
Corresponding momentum	$p = 12 \text{ GeV}/c$
Magnetic length	$\ell = 2.62 \text{ m}$
Sagitta	$s = 128 \text{ mm}$
Inner coil diameter	$d = 75 \text{ mm}$

7.2. Quadrupoles

There are 30 "main quadrupoles" and 8 smaller "inter-bending quadrupoles", the latter spaced between two adjacent bending magnets (Figure 2). To save space, both sets of quadrupoles are superconducting. Again the inner coil aperture is the same as for HERA. Thus the design and the tools of the HERA lenses can be used in principle, the main difference being the length of the quadrupole [1.7]. Nevertheless, HERA uses large conductors for the superconducting coils - not well adapted to the large number of families necessary in our case. Perhaps "many-turn" quadrupoles would be more suitable for SuperLEAR.

Table 8
Characteristics of the superconducting quadrupoles

	Main quadrupoles	Auxiliary quadrupoles (between bending magnets)
Number	$N_Q = 30$	$N_q = 8$
Gradient	$\hat{G} = 80 \text{ Tm}^{-1}$	$\hat{G} = 40 \text{ Tm}^{-1}$
Normalized gradient	$k = 2 \text{ m}^{-2}$	$k \leq 1 \text{ m}^{-2}$
Magnetic length	$\ell = 0.4 \text{ m}$	$\ell \leq 0.3 \text{ m}$

8. CONCLUSION AND ACKNOWLEDGEMENTS

A 3.5 to 12 GeV/c cooling ring to be installed in the East Hall has been studied in some detail to arrive at realistic performance estimates. With the present accumulation rate of the antiproton source, a luminosity of

$10^{32} \text{ cm}^{-2}\text{s}^{-1}$ in internal target mode and extracted fluxes of up to $10^7 \bar{p}/\text{s}$ can be expected. The cooled beam has a momentum resolution of a few 10^{-4} and a typical rms size and divergence of 1 mm and 0.5 mrad at the internal target. The test beams presently installed in the upper part of the hall could co-exist.

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The contacts with the potential users have been very helpful, interesting and pleasant.

9. REFERENCES

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