CE /

CERN-PS 92-37/AR

SW9227

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

9

[redacted]

CERN/PS 92-37 (AR)

SUPERLEAR

Presented by P. Lefèvre
PS Division, CERN, CH-1211 Geneva 23

SUMMARY

A possible future low-energy antiproton programme at CERN will be discussed at a special meeting of the experimental Committee (SPSLC) in September 1992.
In this contribution to the *Journées d'études SATURNE* an overview of the machine aspects is presented. It concerns the future of LEAR after 1993 and a new superconducting storage ring for momenta up to 12 GeV/c: SuperLEAR.

Contribution to the
Sixièmes Journées d'Etudes SATURNE
Le Mont Sainte-Odile, France
May 18-22, 1992

Geneva, Switzerland
May 1992

SUPERLEAR

Presented by P. Lefèvre
PS Division, CERN, CH-1211 Geneva 23

Summary

A possible future low-energy antiproton programme at CERN will be discussed at a special meeting of the experimental Committee (SPSLC) in September 1992.
In this contribution to the *Journées d'études SATURNE* an overview of the machine aspects is presented. It concerns the future of LEAR after 1993 and a new superconducting storage ring for momenta up to 12 GeV/c: SuperLEAR.

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 acceptable 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, the former committee for PS and SC experiments, 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.

- **Anti-hydrogen physics**, needing ultra-low energy beams from LEAR or from a dedicated facility to feed Penning traps (and e^+ from another specialised 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 Munich in mid-1992. The two others have been discussed in a workshop held at Zurich in October 1991 [3].

One important result of this meeting from the machine point of view was to give very low priority to the collider option and to present strong arguments in favour of an external beam facility.

A special meeting of the SPSLC, the new committee which discusses the SPS and LEAR experiments, will be organised at Cogne in September 92 to make recommendations on the future of the CERN low-energy antiproton programme.

Both, modifications of LEAR and the feasibility study of a new facility (SuperLEAR) will be presented to provide input to the potential users preparing letters of intent.

All the aspects of this physics programme and its facilities will be presented during the second biennial Conference on Low-Energy Antiproton Physics (LEAP'92) at Courmayeur, 14-19 September 1992.

2. MODIFICATIONS OF LEAR

2.1 *Ultra-Low Energies*

An important improvement is being done on the electron cooling device. A new collector has been installed and a new gun is in preparation with independent adjustments of the electron intensity and energy. The aim is to have 3×10^9 cold antiprotons decelerated to 60 MeV/c to be fast extracted and degraded for capture in Penning Traps.

2.2 *Cp-Violation Study Through $\Lambda\bar{\Lambda}$ Decay*

A proposal has been presented and favourably received during the March session of the SPSLC [4].

The experiment will use an internal hydrogen target with a "state of the art" density of 10^{14} protons/cm^2. To reach a satisfactory luminosity ($\mathcal{L} \geq 5\times10^{31}$), a beam of more than 1.5×10^{11} circulating antiprotons is needed (see point 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 (mainly the LEAR injection system.)

First results indicate that a transfer momentum of about 1 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.

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.

3. CHOICES FOR SUPERLEAR

A very compact ring with superconducting magnets, a circumference of 157.08 m (PS/4) for circulating beams of momenta in the range of 3.5 GeV/c to 12 GeV/c has been proposed. The option for lower momentum (2 GeV/c) with reduced performances will be kept.

The principle of installing two large experimental facilities at SuperLEAR has been adopted

- an internal jet target and its associated detector for precision measurements of charmonium, and the search for exotic resonances **formed** in $p\bar{p}$ annihilation,
- an extraction system to bring the beam on an external target and the associated general purpose detector for charm and light quark spectroscopy and the search for resonances **produced** in $p\bar{p}$-annihilation.

Such a machine can just fit into the existing PS East Hall. 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 - 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.

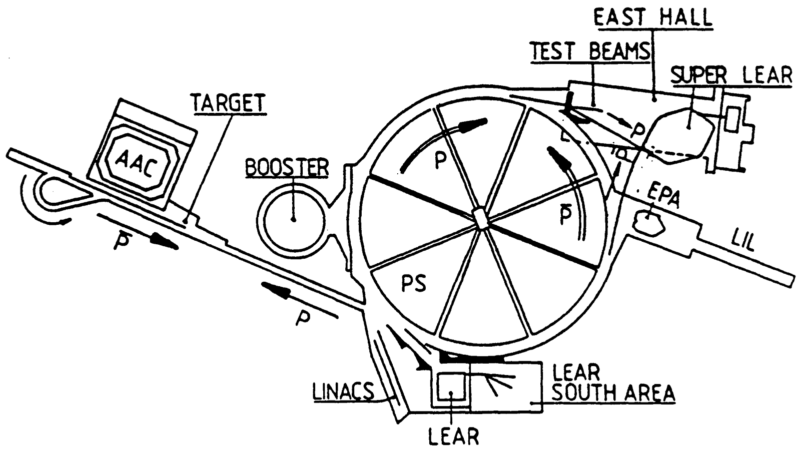

Fig. 1. SuperLEAR general layout

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. The test area will only be slightly reduced to permit installation of SuperLEAR. 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.

4. AVAILABILITY OF ANTIPROTONS AND PERFORMANCE LIMITATIONS

To work out performance limitations we assume an input 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 (S. Maury[3]). 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 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

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

Our design aim is to reach this luminosity limit. This is difficult, if not impossible, in the collider mode. 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 (ρd), 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 ρd and N to reach the "consumption limit" of 10^{32} cm^{-2}s^{-1}. We take $N = 5 \times 10^{11}$ (about 14 h of accumulation at 10^7/s) as a reasonable intensity. Then the optimum target thickness is 10^{14} protons/cm^2 which is within reach of present target technology [4]. 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 (GeV/c)	f_0 (MHz)	N	ρd (p/cm^2)	L (cm^{-2}s^{-1})
LEAR Jetset1)	2	3.45	3×10^{10}	5×10^{12}	5×10^{29}
$\Lambda\bar{\Lambda}$	1.65	3.3	$\geq 1.5 \times 10^{11}$	10^{14}	$\geq 8 \times 10^{31}$
SuperLEAR 157 m	3.5 - 12	1.84 - 1.9	1×10^{12} 5×10^{11}	5×10^{13} 10^{14}	1×10^{32}

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

The beam emittances result from the equilibrium between heating at the target, intrabeam scattering, blowup on resonances, instabilities on one side, and stochastic cooling on the other hand. The estimated beam qualities expected on the target are indicated in Table 2.

Table 2 - Beam qualities (2σ definitions) on the target for $\beta_{x,z} \sim 2$ m

$\varepsilon_{x,z}$	1 to 2.5 μm
$2\sigma_{x,z}$	1.5 to 2 mm
$2\sigma_p$	0.6 to 0.7×10^{-3}

5. LATTICE SL 225

5.1 A large number of lattices have been worked out, following the evolution of physics requests. The choice has been made for SL 225 with 16 bending magnets of 22°5 each and 38 quadrupoles grouped in several families.

This lattice satisfies the following constraints:

- Acceptances $A_x = 30$ μm
  $A_z = 30$ μm
  $dP/P = \pm 3.5 \times 10^{-3}$

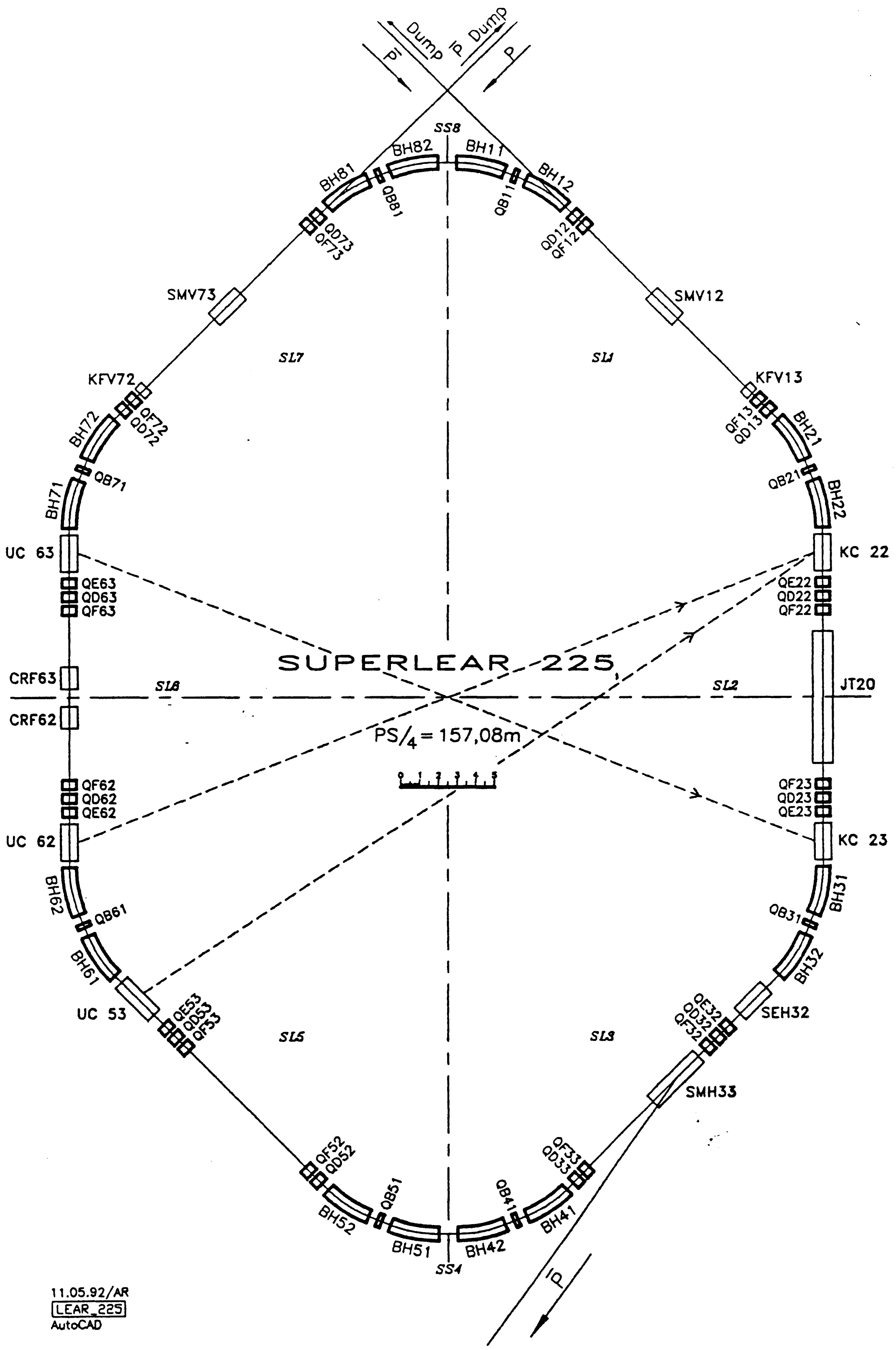

Fig. 2 - Layout of SL 225 with 157 m circumferemce

- Two long straight sections with an orientation and a length which are favourable for direct injection of $\bar{p}$ and p,
- One large section for the jet target detector with zero dispersion and low betas (≤2 m) at the target position,
- One long section to provide an extracted beam in the direction of the East Hall extension for a relatively large experimental area.

The working points are ajustable around $Q_x \sim 3.6$ and $Q_z \sim 3.5$, and the chromaticities are corrected to zero in target operation and positive value ($\xi_x \sim 0.5$) in extraction mode.

5.2 *Stochastic Cooling*

Phase-space cooling is needed to compensate the beam heating due to multiple scattering on the 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.

The main effort on the lattice has been to provide favourable optical conditions for a very strong stochastic cooling system. The top half-machine is isochronous between pickup and kicker in order to permit large bandwidth without mixing of the particles between observation and correction.

The isochronism corresponds to $\eta = 0$ for half the machine with the change of revolution frequency with momentum:

$$\eta = \frac{df/f}{dP/P} = \frac{1}{\gamma^2} - \frac{1}{\gamma_{TR}^2}$$

Thus the transition energy γ_{TR} has to be adjusted at each energy to have $\gamma_{tr} = \gamma$. This effect is obtained by a *local dispersion bump* making a large change in γ_{tr} with negligible Q changes.

The other half of the machine has a fixed imaginary transition $\gamma_{tr} = 3.5i$ to have a large η function producing a good mixing between kicker and pickup, as desired for the cooling.

6. INJECTION AND EXTRACTION

In this chapter we compile some preliminary parameters of the injected and extracted beams.

6.1 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 (GeV/c)	A_p (eVs)	Δt total (ns)	$\Delta P/P$ 10^{-3} $(2\sigma_p)$	ε_H $\pi \times$ mm·mrad $(2\sigma_{def})$	ε_V
AA exit	3.5	1	-	-	3	2.5
PS exit	3.5 12	1 1.3	120 60	1.25 1.6	3 1.2	2.5 1

6.2 Injection in SuperLEAR

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

Some limitations occur around PS transition energy where to extract the PS beam with $2\sigma_p < 2\times10^{-3}$ as determined by SuperLEAR acceptance, a forbidden zone has to be accepted with momenta between 5.5 and 5.8 GeV/c. Methods are under study to overcome this difficulty (γ_{tr} changes in the PS or ramping over a small energy range is SuperLEAR).

6.3 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 = Integer ±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 3×10^{11} per cycle.

7. SUPERCONDUCTING MAGNETS

7.1 Dipole typical specifications

We take:

Magnetic field	$\hat{B}$	=	6 T (at $cp = 12$ GeV, $B\rho = 40$ Tm)
Bending radius	ρ	=	6.67 m
Bending angle	θ	=	22°5
Magnetic length	ℓ	=	2.62 m
Sagitta	s	=	12.8 cm
Number			16

For a 22°5 cosθ magnet the HERA technique looks promising (H. Kaiser [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.

7.3 Quadrupole specifications

We take:

Gradient	$\hat{G}$	=	80 Tm^{-1} (at CP = 12 GeV, $B\rho$ 40 TM)	
Normalized gradient	k	=	2 m^{-2}	$k << 1\ \mathrm{m}^2$
Magnetic length	ℓ	=	0.5 m	$\ell << 0.3$ m
Number			30	8

These quadrupoles have to be grouped in several families 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 [3]. However, HERA uses large conductors for the superconducting coils - which are not well adapted to the large number of families necessary in our case.

Perhaps "many-turn" quadrupoles will be more suitable for SuperLear. Again the construction and testing of prototypes seem necessary to make the final choice.

7.4 Correcting elements (dipoles, sextupoles or multipoles)

This is still under study. A priori it looks simple to have separated correcting elements. For chromaticity correction we are looking into the possibility to incorporate sextupolar windings into the quadrupoles to save space and to keep the maximum dynamical acceptance.

8. CONCLUSION AND ACKNOWLEDGEMENTS

The standard technology part of the machine is well under study and a feasability study will be ready for Cogne 92.

The magnet studies are the most critical item and care has to be taken 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, on the feasibility of curved superconducting magnets for SuperLEAR. Several interesting ways to build such magnets have been pointed out, but before any final choice it appears necessary to build and measure prototypes. Collaborations have to be set up with other institutes and with industry for this purpose. The preparation of prototypes has to start immediately after Cogne if the first physics runs with SuperLEAR are wanted in 1997.

No major difficulties have been identified for the rest of the design. A 3.5 to 12 GeV/c machine in the East Hall, working with internal targets and extracted beams, looks feasible.

The $\Lambda\bar{\Lambda}$ CP-experiment appears to be possible in the modified LEAR machine and thus discoupled from SuperLEAR. LEAR can also easily serve as source of ultra-low-energy antiprotons for an anti-hydrogen programme.

Studies are in progress and a more detailed report will be prepared in 1992.

The machine aspects of this work have been elaborated by a Working Group for future PS antiproton programme with major contributions from R. Giannini, D. Möhl, D. Vandeplassche and G. Cesari.

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.

They are all thanked.

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] Amsler C., Urner D.Editors, 1992, *Physics at SuperLEAR: Proc. of the SuperLEAR Workshop held at the University of Zurich*, 9-12 October 1991

[4] Hamann N. et al., 1992, *CP-Violation in Hyperon Decays: The Case* $\bar{p}p \to \bar{\Lambda}\Lambda \to \bar{p}\pi^+ p\pi^-$ CERN SPSLC 92-19