1 HISTORY - Low Energy Antiproton Ring

1977
- During the Antiproton Accumulation studies as an intense source of cooled $\bar{p}$ for the CERN high energy $p\bar{p}$ collider in SPS, the idea put forward to add to the AA a facility for experiments with low energy $\bar{p}$ was received with enthusiastic support from many members of the CERN physics community.
  - PROTVINO - 10th Int. Conf. on High Energy Accelerators,

1978
- Investigation of physics possibilities and machine aspects.

January 1979
- Conceptual study of a facility for low energy antiproton experiments,
- CERN - KfK (Karlsruhe) Workshop on physics with cooled low energy antiprotons

May 1979
- Presentation to PSCC (Proton Synchrotron and Synchro-cyclotron Committee).

May 1980
- Design study of a facility for experiments with Low Energy Antiprotons (LEAR).

July 1982
- $\bar{p}$ in LEAR - Extracted : April 1983.

July 1983
- $\bar{p}$ pre-run for physics (Delay due to SPS collider and ISR priorities).

October-December 1983
- $\bar{p}$ physics run at 600 MeV/c and 300 MeV/c.

2 PHYSICS INTERESTS

There are many different physics aspects in the 17 already approved experiments.
A common interest in the LEAR physics experiments is the following:

WORK ON STRONG INTERACTIONS HOPING TO LEARN SOMETHING MORE ABOUT THE QUARK-GLUON DYNAMICS IN THE LOW ENERGY REGION.

For the purpose of experiments one had to simplify the very complex system of $p\bar{p}$ possible reactions [by switching off the inelastic scattering ($\pi$ production) below 800 MeV/c or even the Charge Exchange Channel below 100 MeV/c], and work in a region where the annihilation process dominates.
These physics had limits which were imposed by the modest quality of the low energy $\bar{p}$ beams produced by conventional methods:
- large beam dimensions (large target volume and complexity of detectors)
- large $\Delta p/p$  

- large $x$ contamination,
- duty cycle of primary beam.

In conclusion, very poor beam at low energies.

LEAR has improved the situation from the point of view of $\bar{p}$ intensity and density by factors of $10^3$ to $10^7$ (fig. 1), and therefore led the way to new fields such as,
- scattering experiments (transmission targets): the unexplored region below 300 MeV/c, or badly seen regions because of beam quality (300 MeV/c - 2 GeV/c).
- Stop experiments: permitting to switch off the losses in the degraders by starting degradation below 300 MeV/c (negligible hadron interactions in the degrader), and to obtain very small stop volumes.

In general LEAR provides a precise experimental tool which:
. opens the domain of low energy quark dynamics (chemistry of quarks by carrying experiments connected to baryonium, gluonium, etc.),
. using nuclear targets it allows to tackle the nuclear physics aspects in a completely new fashion,
. permits many exciting applications to future options due to the further improvements on statistical precision and energy resolution ($\Delta p/p$):
  internal targets, $H^0\bar{p}$ co-rotating beams (protonium formation in flight), $p\bar{p}$ collider and ultra low energy domain (down to 20 MeV/c !).

3 SUMMARY SPECIFICATIONS (fig. 2)

| $\bar{p}$ | 3.5 GeV/c |
| LEAR |
| AA |
| PS |
| .6 GeV/c | 1.5 GeV/c |
| 175 MeV |
| LINAC 1 |
| .3 GeV/c |
| H$^-$ | 50 MeV |
| 2 GeV/c |
| 1983 |
| .3 |
| .2 GeV/c |
| .1 GeV/c |

-------- lowest possible energy in LEAR
Main aspects of the already approved stretcher mode:

AA – PS transfers, nominal values:

\[ 10^9 \bar{p}[3 \times 10^8 \text{ to } 3 \times 10^9] \text{ every } 10^3 \text{ sec } [30' \text{ to } 1 \text{ h}] \]

LEAR extraction \( 10^6 \bar{p}/s \) [\( 10^4 \text{ to } 10^5 \bar{p}/s \)]

Duty cycle < 90% (necessary cooling time)

\( \Delta p/p < 10^{-3} \) beam diameter < 1 cm

This mode includes some "provisions" for later options

\[ [10^{11} \bar{p} \text{ in the LEAR machine}] \]

Experimental area:

- 17 experiments approved
- 16 experiments installed – 250 physicists – 52 institutions
- 6 separate areas – 3 fed simultaneously (2 splitters)

4 CHOICE OF PARAMETERS (Table 1)

The present operation mode is: 12 h (8 h) AA stacking and 12 h (16 h) transfer to LEAR.

A 24 h/day operation mode will be in operation in 1984.

AA batches of \( 10^9 \bar{p} (3 \times 10^9) \) are unstacked in \( A_s = 0.5 \text{ eVs} \) (0.2 eVs) buckets (limited by minimum possible voltage in the RF system). Such a batch is necessarily taken in the tail of the stack (lower density region) which is partially cooled: expected emittances

\[ E_H < 1.5 \text{ (mm.mrad)} \]

\[ E_V < 1 \text{ (mm.mrad)} \]

- A new scheme (missing bucket with high harmonic number) is in preparation:

\[ A_s = 0.05 \text{ eVs} \]

- to obtain \( 10^9 \bar{p} \) from the well-cooled dense part of the stack.

4.1 RF

RF Capture on \( h=10 \) (instead of the normal \( h=20 \)) harmonic number for deceleration in the PS, down to 0.6 GeV/c. The constraint is minimum possible RF frequency on the PS cavities (2.56 MHz) with a voltage of \( V_{RF} = 120 \text{ KV} \), which fixes the PS-transfer energy with reasonable acceptances for PS extraction, transfer and LEAR injection.

\( A_x = 40 \text{ (mm.mrad)} \)

\( A_y = 20 \text{ (mm.mrad)} \)

\( A_s = 0.8 \text{ eVs} : \Delta p/p < 5 \times 10^{-3} \) (new magnetic septum in PS SS26, full aperture kicker in PS SS28 have been installed)
4.2 Transfer PS - LEAR for p

A separate 50 m tunnel has been built equipped with a quasi periodic transfer line and matching section (difficult dispersion matching due to the high dispersion function in LEAR SS and opposite bending angle in the line).

Vertical difference - PS = 1.26 m  
LEAR = 1.66 m (option for p̅p detector !)

4.3 p and p̅

- Transfer LINAC 1 - LEAR (different energy and polarity), needed for OPTIONS, authorised from the beginning for machine and experimental tests. This transfer line includes a 244° loop with unity matrices in x and z planes and dispersion free at the end.

4.4 LEAR external constraints (fig. 3)

Existing South hall  
Shielding inside the hall (possible roof for p̅p option)  
Large experimental area (South hall extension)  
Orientation of SS to permit 200 m decay line for (p̅p)⁰ option

( Dimension PS/8 = AA/2  
C = 2π x 12.5 m = 78.5 m  
(SQUARE Machine with 4 long SS 8 m (total)  

SS1 INJECTION - EXTRACTION  
Magnetic septum Injection/Extraction 155 mrad - 52 mrad  
(fixed - coil outside vacuum) l = .9 m  e = 9 mm  
22000 AT  
Full Aperture kicker INJECTION 2 x 10 mrad  
rise/fall time 100 ns-flat top 700 ns  
Electrostatic septum EXTRACTION e = 0.1 mm  l = .7 m  
6 mrad  E = 8 mV/m (1 cm gap)  
2nd Magnetic septum EXTRACTION 26 mrad  
l = .4 m  e = 30 mm  
30000 AT.

SS2 - Option:

low beta insertion (4 additional quadrupoles - 1985):
JET TARGET or
p-p̅ collider detectors.
SS3 - Approved option (1986). Electron cooling system
   Modified ICE Gun (Vacuum - HV Generator)
   for cooling below injection energy, useful for
   - JET TARGET, high luminosity (compensates multiple Coulomb scattering in the
     target),
   - increasing the beam's lifetime for pp, p̅H− options,
   - making additional cooling for very low energies.
SS4 - 2 RF cavities 2 x 9 kV (10 kV) (one installed)
   wide range ferrites 0.4 to 4 MHz

For RF capture, two modes of operation in LEAR:
   - Debunching + Adiabatic capture,
   - Bunch to bucket capture (in operation since September 1983) to save longitudinal
     emittance
   (13 - 14 kV to capture Aν = 0.5 evs
   ( 7 - 8 kV to capture Aν = 0.25 evs
   - 3rd air resonant cavity possible for pp collider (very short bunches) on high RF
     harmonic.
   - Also installed in SS4:
     - 2nd INJ H'p (charge exchange)
     2 fast dipoles and a 1 thin carbon target (< 10 μ) for stripping
     2nd injection line (in preparation).
     - FAST EXTRACTION full aperture kicker (1 module) reduced acceptance channel

Note: Ultra high vacuum:

10^{-11} to 2.10^{-12} Torr

Very important for low energy scattering and H− stripping.
All elements bakeable in situ 300° C (350° C), 24 h (40 h total temperature cycle).
Turbo molecular + sputter Ion + Ti sublimation pumps.

5 LEAR LATTICE (fig. 3, 4)

Symmetric 4 period lattice, separated functions BODFOFDOB
- 4 bending magnets 6.55 m, 90°, B = 1.6 T
  . Yoke inside circumference (2 x 6 bloks), to permit:
    injection-extraction lines, neutral lines, n targets (OPTION!)
  . Additional longitudinal gap between blocs to install this n target (increase of
    vertical gap of extreme bloc and small long gap, needed to preserve orbits in the
    magnet).
  . Vertical aperture ± 27 mm (minimise θz at magnet entrance)
- 8 focusing doublets
  16 Quadrupoles 0.5 m G = 12 T/m
  [k ≈ 1.8 m⁻² at 2 GeV/c, B₀ = 6.67 Tm]
  horizontal dimension reduced to limit the angle of INJ/EX Lines:
  Horizontal aperture ± 75 mm (minimise θₓ at the middle of F quad.)

- Very strong focusing machine:
  Qₓ = 2.3 Qᵧ = 2.7 (ADJUSTABLE FOR OPTIONS)
  phase advance Δφₓ ~ 250°/period
  betatron wavelength 30 m (PS ~ 100 m, SPS ~ 600 m)

- Very high γ TRANSITION (even more imaginary)
  γ TR = - (14.5)² to - (6.3)²

  large |η| to favour mixing in the stochastic cooling process

\[
\frac{df}{f} = -\eta \frac{dp}{p}, \quad \eta = \frac{1}{\gamma^2} - \frac{1}{\gamma \gamma TR}
\]

  small dispersion (Dₓ) function in magnets (≈ 0 to save acceptance), adjustable to
  zero in short straight section for H⁻⁻⁻⁻ co-rotating option (p and H⁻⁻⁻⁻ travel together
  for ~ 1 m despite of their small mass difference)

  γ ≪ γ TR. No negative mass effects (longitudinal instabilities and intra-beam
  scattering for very short bunches and very small Δp/p (need High RF and Strong
  Cooling for options)

  combination of "large" dispersion Dₓ in SS, small α = \frac{1}{\gamma TR} and large |η|,

  makes the transverse gymnastics of coasting beams easier and favours the
  ultra slow extraction process.

- Chromaticity correction:
  24 sextupoles (20 normal and 4 skew)

\[\bar{R} = 2 \text{ m}^{-3}, \quad \Delta \eta = \frac{\Delta Q}{Q} \Delta p/p = \pm 3\]

The sextupoles are also used for excitation of 3rd order extraction stopband 3Qₓ = 7 and
compensation of other 3rd order resonances.

Special care has been taken to evaluate the natural chromaticity of LEAR (small machine:
dispersion function not negligible as compared to bending radius, correct evaluation of
magnet fringing fields).
A comparison of large programs (AGS, SYNH, TRANSPORT, PATRICIA) and analytical approaches gives an estimate of $\xi_x = -1.29$ and $\xi_z = -2.76$ which agree with the measurements.

Special small programs for LEAR have been written:

- Mini AGS TWISS
- COMFORT (developed with SLAC),
permitting the modelling of ON-LINE correcting programs for chromaticity, extraction resonance and orbit corrections.

- Orbit correction (reduces the orbit from 20 mm to less than 5 mm)
  - horizontally: 8 backleg winding - 6 dipoles
  - vertically: 6 dipoles
makes also bumps for ejection trajectories.

6 WORKING POINT AND RESONANCES (fig. 5, 6)

<table>
<thead>
<tr>
<th>STRETCHER mode</th>
<th>OPTIONS (INT target, H⁻⁻⁻⁻⁻)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_x = 2.3$</td>
<td>$- 3.2$</td>
</tr>
<tr>
<td>$Q_z = 2.7$</td>
<td>$- 2.7$</td>
</tr>
<tr>
<td>$E_x = 0.6$ for extraction</td>
<td>$E_x = 0$</td>
</tr>
<tr>
<td>$E_z = 0$</td>
<td></td>
</tr>
</tbody>
</table>

The machine has shown sensitivity to the 4th and 5th resonances and therefore a jump of the working point had to be made:

- $Q_x = 2.3$ to $Q_x = 2.325$
- $Q_z = 2.73$ to $Q_z = 2.74$

from $E_x = E_z = 0$ to $E_x = 0.6$, $E_z = 0$

INJ. Accel./Decel. to Extraction

7 STOCHASTIC COOLING (fig. 7)

1st Stage - "simple" ICE type cooling system
At .6 GeV/c and .3 GeV/c for:
- initial pre-cooling after injection (permits adiabatic emittances increase during deceleration),
- transverse cooling before and during extraction (dense extracted beam),
- small longitudinal cooling during extraction (to preserve shaped distribution in p).
longitudinal cooling (filter method) 20 - 220 MHz (150 - 400 MHz, in preparation).
- Pu 1 (2) 0.5 m
- Corrector 2 (1) 16 gaps

transverse cooling 250 - 750 MHz
- Pu horizontal 2 x 2 m in bending magnet
- Pu vertical 1 x 2 m in quad and SS
- space problems: long transverse Pu are needed for a good signal/noise ratio
- short corrector 0.1 m
2nd path for high energy (2 GeV/c), needed to have shortest signal path at each energy to avoid particle mixing between Pu and corrector (more important for transverse cooling).

performances for ~ 10^9 p or \( \bar{p} \)
reduction of 3 to 5 (transv. emitt. and \( \Delta p/p \)) in 2' to 4'

2nd Stage. A further development of the stochastic cooling is anticipated.
- to compensate multiple scattering on residual gas and diffusion on resonances
- to have highly monochromatic and dense beams at low energy, in combination with electron-post cooling.
A new system will be studied to obtain shorter cooling times by using the improvements on the other machine systems and perhaps at ultra low energies, travelling wave Pu (to improve signal to noise ratio), and at high energies, movable Pu.

8 ULTRA SLOW EXTRACTION

* Resonant 3rd order extraction (classical)
  3 \( Q_x = 7 \) excited (Amplitude and Phase) by a set of sextupoles

A bump is created by local dipoles and extraction elements are a thin electrostatic septum (position angle adjustable) and two magnetic septa (fix for bake-out problems) (fig. 8)

* Ultra slow - A conventional slow extraction consists in changing the distance between resonance \( (Q_x = 7/3) \) and beam tune \( (Q_x = 2.31) \), for all particles (small changes of \( Q_x \) with quadrupoles or small dB/dt on the field flat top for a given \( E_x \))

This method is inadequate for long spills (10^3 sec) because the ripple of the different elements lead to strong spill modulations (poor duty factor).

(10^6 p/s represents one particle every 1 to 5 turns, mean value !)
The new approach is based on the fact that a noise signal (bandwidth \( \Delta f \)) around an harmonic \( h \) of revolution frequency \( f = h \cdot \text{frev} \) causes diffusion of the particles into the resonance (with careful machine adjustment)

\[
\frac{\Delta \varphi}{Q} = \xi_x \quad \frac{\Delta p}{\eta} = \frac{\xi_x}{\eta} \cdot \frac{\Delta f}{f}
\]

The diffusion process strongly reduces the ripple effect because, during the random walk of particles the distribution does not behave as a rigid body but tends to fill up any void, reducing the discontinuities in the diffusion distribution, i.e. in the spill rate (fig. 9).

Noise (\( f \approx 15 \) to \( 20 \) MHz, \( \Delta f < 200 \) kHz) is sent through an RF gap (actually gaps of the longitudinal cooling kicker).

The power of the noise is chosen to minimise the ripple: 10 to 20 W, i.e. 60 \( \mu \)W/Hz for the 180 kHz standard bandwidth.

A previous shaping of the distribution (through the same noise channel) is used to make the spill more constant during the \( 10^3 \) sec. (\( \Delta f = 60 \) kHz - 0.5 W - 10 sec).

The spill rate is adjusted by the speed of the frequency sweep

\[
\frac{\Delta f}{\Delta t} = \frac{\Delta f_{\text{beam}}}{10^6 \text{ Hz}} = 60 \text{ Hz/ms}
\]

By carefully adjusting the \( \xi_x \) and phase/amplitude of the 7th harmonic of sextupoles, one can make coincide on the instable separatrix the trajectories of particles belonging to different transverse emittances (fig. 10).

\[
\xi_x = 0.6 \quad \lambda 7 = 8\text{ m}^{-1} \quad \psi 7 \approx 30^\circ \quad \text{(from mid SS1)}
\]

Results:

Spill of 15', 30', 1 hour have been achieved (fig. 11) with
- good reproducibility,
- 50% constant spill,
- dense extracted beams (not yet well measured, but better than specified)

the qualities of extracted beam are, in theory:

\[
\xi_x = 0 + \text{ripple effect}
\]

\[
\xi_z = \xi_x \quad \text{(emittance of circulating beam)}
\]

\[
\Delta p = (\xi_x)^{1/2} + \text{ripple (importance of transverse cooling)}
\]
The estimated values are summarized in Table 1.

A 50 Hz and 100 Hz structure on the beam due to error in power supplies of the transverse elements has been seen, limiting the duty factor; this point will be improved in 1984.

Experimental areas

This beam has been correctly split into three different areas simultaneously (fig. 12) and experiments on the six different areas have received 300 MeV/c for some hours; the schedule foreseen is as follows:

10 days at 600 MeV/c in November 1983
10 days at 300 MeV/c in December 1983,

and in 1984, additional energies of 200, 300, 600 and 1500 MeV/c are expected.
REFERENCES


2) G. Plass (editor) : Design study of a facility for experiments with low energy antiprotons, CERN/PS/DL/80-7, 1980

3) W. Hardt, P. Lefèvre, D. Möhl, G. Plass : The Lear project, Proceedings of the 5th European Symposium on nucleon antinucleon interactions, Bressanone (Italy) published by Cleup - Padova 1980


5) P. Lefèvre : Construction of the LEAR facility : status report, presented at the workshop on physics at LEAR with cooled low energy antiprotons Erice (Silicy) May 9-12, 1982

6) M. Bouthéon (editor) : LEAR running in news 1 to 9 1982/83


8) M. Bouthéon : Proposition de l'éjection rapide d'antiprotons en section droite 26, PS/OP Note 80-12

9) R. Garoby : PS Machine development notes-PS/RF Note 83-4

10) D.J. Simon : A possible scheme to transfer 50 MeV H+ ions (and protons) from the old PS linac to LEAR, PS/MU/BL Note 79-10 (LEAR Note 79) March 79

11) D.J. Simon (editor) : LEAR running-in news N°5 (First tests of the loop), July 1982

12) E. Gianfelice, R. Giannini, J. Jaeger : Methods of closed orbit correction in LEAR with unequally spaced pick ups and correctors, CERN/PS/LEA 83-1

13) D. Möhl : Phase space cooling techniques and their combinations in LEAR, presented at the workshop on physics at LEAR with cooled low energy antiprotons Erice (Silicy) 9-12/5/1982

14) S. van der Meer : Stochastic extraction - A low version of resonant, CERN/PS/AA 78-6

15) W. Hardt : Slow extraction from LEAR, Proceedings of the joint CERN-KFK workshop on physics with cooled low energy antiprotons, KFK 2826, 1979


17) R. Cappi, R. Giannini, W. Hardt : Ultraslow extraction, status report, presented at the workshop on physics at LEAR with cooled low energy antiprotons - Erice (Silicy) 9-16/5/1982

18) W. Hardt : Ultraslow extraction out of LEAR (transverse aspects), CERN/PS/DL/LEAR Note 81-6

19) R. Giannini : Beam envelope in LEAR at third order resonant extraction,CERN/PS/CD Note 81-4

20) R. Giannini : Ultraslow extraction out of LEAR - comparison of measurements with theory and proposal for the future, PS/LEA Note 83-3

21) R. Giannini et al. : Low energy antiprotons at the CERN PS, presented at the 12th International Conference on high-energy accelerators, FERMILAB NATIONAL ACCELERATOR LAb., August 11-16, 1983
### Table 1

**LEAR basic parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Momentum (kinetic energy) range</td>
<td>0.1 - 2 GeV/c (5.3 MeV - 1.3 GeV)</td>
</tr>
<tr>
<td>Injection momentum (kinetic energy)</td>
<td>0.6 GeV/c (175.4 MeV)</td>
</tr>
<tr>
<td>Circumference</td>
<td>78.54 m (= 2π x 12.5 m)</td>
</tr>
<tr>
<td>Typical cycle</td>
<td>10^6 p/s injected every 10^3 s</td>
</tr>
<tr>
<td>Typical extracted beam</td>
<td>≈ 900 s</td>
</tr>
<tr>
<td>Typical spill length</td>
<td>4 of 8 m length each</td>
</tr>
<tr>
<td>Long straight sections</td>
<td>8 of 1 m length each</td>
</tr>
<tr>
<td>(between quadrupoles and Bending Magnet)</td>
<td>4, 6.55 m, B = 1.6 T</td>
</tr>
<tr>
<td>Bending magnets, No, arc length, field at 2 GeV/c</td>
<td>16, 0.5 m, k = 1.8 m^-2 (g = 12 T/m)</td>
</tr>
<tr>
<td>Quadrupoles, No, magnetic length, max gradient at 2 GeV/c</td>
<td>4 superperiods, separated function</td>
</tr>
<tr>
<td>Focusing structure</td>
<td>BoDFOFDoB</td>
</tr>
<tr>
<td>Betatron wavenumbers and momentum compaction (stretcher mode)</td>
<td>Q_H = 2.3, Q_V = 2.7</td>
</tr>
<tr>
<td>Aperture limitation</td>
<td>α = γL^2 = -4.8 x 10^-5</td>
</tr>
<tr>
<td>Acceptances (stretcher mode)</td>
<td>a_H = ±70 mm, a_V = ± 29 mm</td>
</tr>
<tr>
<td>Vacuum system, design pressure (N_2 - equivalent)</td>
<td>1.6 × 10^-11 to 1.6 × 10^-12 Torr</td>
</tr>
<tr>
<td>Bake out temperature, bake out and pump down time</td>
<td>300°C, ≈ 40 h</td>
</tr>
<tr>
<td>RF - system frequency range (h = 1)</td>
<td>0.4 - 3.5 MHz</td>
</tr>
<tr>
<td>Peak voltage per turn (stretcher mode)</td>
<td>12 kV</td>
</tr>
<tr>
<td>PS beam bunch properties at transfer (h = 10 in PS), area, total bunch length</td>
<td>A = 0.5 eVs, t_b = 250-300 ns</td>
</tr>
<tr>
<td>Acceptance of transfer system</td>
<td>E_H = 40 x 10^-6 rad m, E_V = 20 x 10^-6 rad m</td>
</tr>
<tr>
<td>Assumed AA beam properties at 3.5 GeV/c (unstacking of 10^3 p)</td>
<td>ΔE/Δp = ± 1.1 %</td>
</tr>
<tr>
<td></td>
<td>E_H = 400 x 10^-6 rad m</td>
</tr>
<tr>
<td></td>
<td>E_V = 200 x 10^-6 rad m</td>
</tr>
<tr>
<td></td>
<td>ΔE/Δp = ± 5 x 10^-3</td>
</tr>
<tr>
<td></td>
<td>E_H = 3π x 10^-6 rad m</td>
</tr>
<tr>
<td></td>
<td>E_V = 1.5π x 10^-6 rad m</td>
</tr>
<tr>
<td></td>
<td>A = 0.5 eVs (at h = 1 in AA)</td>
</tr>
</tbody>
</table>
Table 2

Estimated emittances of the external beam
(In units of $10^{-3}$ radm for $E_H$, $E_V$ and in units of $10^{-3}$ for $\Delta p/p$)

<table>
<thead>
<tr>
<th>Internal beam</th>
<th>$E_H$</th>
<th>$E_V$</th>
<th>$\Delta p/p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>As injected into LEAR (0.6 GeV/c)</td>
<td>30</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>Decelerated to 0.2 GeV/c w/o cooling</td>
<td>90</td>
<td>45</td>
<td>9</td>
</tr>
<tr>
<td>Accelerated to 1.5 GeV/c w/o cooling</td>
<td>12</td>
<td>6</td>
<td>1.2</td>
</tr>
<tr>
<td>Stochastic cooling at 0.6 GeV/c -emittances at 0.6 GeV/c</td>
<td>7</td>
<td>3.5</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>0.2 GeV/c</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>1.5 GeV/c</td>
<td>2.8</td>
<td>1.4</td>
</tr>
<tr>
<td>Additional electron cooling at 0.2 GeV/c</td>
<td>$\sim 1$</td>
<td>$\sim 2$</td>
<td>$\sim 0.1$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>External beam</th>
<th>$\Delta p/p$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>beam is too large to be ejected</td>
</tr>
<tr>
<td></td>
<td>1.7</td>
</tr>
</tbody>
</table>

Note: 95% emittances to get 2σ emittances divided by 1.5
Fig. 4

Fig. 5 Systematic resonances of order 1 to 4 for lattice with four superperiods.
Momentum Cooling at 609 MeV/c (6 min.)

\[ f_{\text{rev}} = 2.078 \text{ MHz} \]
\[ f = 30 f_{\text{rev}} \]

0.36 mA \( \times 10^6 \) \( \frac{\Delta f}{f} = 3.3 \times 10^{-3} \rightarrow 1.3 \times 10^{-3} \)

No loss \( \frac{\Delta p}{p} = \frac{1}{\gamma} \frac{\Delta f}{f} \) \( \gamma = -0.7 \)

Horizontal Cooling of \( \bar{p} \) at 609 MeV/c (5 min.)

\( (n-q)f_{\text{rev}} \) \( n f_{\text{rev}} \) \( (n+q)f_{\text{rev}} \)

\( Q_x = 2 + q \)
\( h = 108 \)
\( f_{\text{rev}} = 2.078 \text{ MHz} \)

height of Side bands = \( \alpha_{\beta} \sqrt{N} \leq \sqrt{N} \epsilon \text{Ex} \)

Fig. 6

Fig. 7
ORBIT AT EXTRACTION OUT OF LEAR

\[ A_1 = 8 \text{/m} \quad \varphi_1 = 30^\circ \]

-100
-90
-80
-70
-60
-50
-40
-30

X (mm)

EXTRACTED ORBIT

MAGNETIC SEPTUM

ORBIT THREE TURNS BEFORE EXTRACTION

L = 0 IS IN THE MIDDLE OF SS1

L (m)

Fig. 8
\( \bar{p} \) extraction 30' at 609 MeV/c

Fig. 11
First results of beam tuning in the Lear experimental area

Beam profiles downstream of first splitter magnet
MWPC's displays  50MeV protons

Splitter magnet 1

\[ B = 0 \quad \text{deflected beam} \quad B \neq 0 \quad \text{non deflected beam} \]

H plane (2mm/bin)
V plane (6mm/bin)

Beam spot size measured at experimental focus S1 (PS 183)

Fig. 12