PERSPECTIVES OF ION COOLING RINGS

D. Möhl
CERN, CH-1211 Geneva 23, Switzerland

1. Introduction

Phase space cooling of proton and antiproton beams has led to spectacular results. Examples are:

- the accumulation of 5 x 10^{11} antiprotons from batches of 3 x 10^6
- the preparation of sharply collimated beams of 10^7 to 10^8 circulating particles with emittances of the order of 1 π mm.mrad and a momentum spread of a few times 10^{-4}
- the extraction of high quality low energy antiproton beams with a flux of up to 10^6 $\bar{p}$/s
- the non destructive observation of as few as 50 circulating particles by reducing their spread in revolution frequency to 10^{-5}
- the increase of the lifetime of stored beams by a factor of 50.

At CERN, these new techniques have made an ambitious programme of antiproton physics possible covering a range of centre of mass energies from almost rest to 600 GeV/c. On the high energy side, this programme culminated in the observation of the intermediate vector bosons predicted by the unifying electro-weak theory. At low energies, cooling and deceleration of antiprotons have opened the door to high resolution studies of the nucleus-, antinucleus forces, and quark-antiquark interactions, and to the determination of elementary properties of the antiproton with unprecedented precision.

In the light of these achievements, it is natural to consider the application of similar techniques to other rare particles like heavy-ions and/or polarized beams. The use of electron cooling in this context was in fact suggested already some time ago by the Novosibirsk group. Followed by the very encouraging results of the cooling experiments (Table 1) and the successful operation of antiproton rings (Table 2), their work has led to a number of proposals for light and heavy ion coolers which will be reviewed in this paper.

Table 1

Cooling experiments and experimental cooling rings

Machine /place	Machine circum-ference (m)	Type of cooling	Energy of experiment (MeV)	First cooling tests
NAP-M/Novo-sibirsk	47	Electron Stochastic	5-65 65	1974 1981
ISR/Cern	960	Stochastic	26000	1975
ICE/Cern	72	Stochastic Electron	1000-1400 45	1977 1978
Experimental cooling ring/ Fermilab	135	Electron Stochastic	200 200	1980 1980
TARN/ INS-Tokyo	33	Stochastic	7	1982

Table 2: Antiproton cooler rings

Machine	Place	Circumference (m)	Energy (GeV)	First operation
Accumulator AA	CERN	156	2.8	1980
Intersecting storage rings ISR *	CERN	960	25-30 2.8-5.0	1981** 1983***
Low energy ring LEAR	CERN	78	0.005-1.3	1982
Fermilab $\bar{p}$ source:	FNAL			
debuncher		505	8.0	1986
accumulator		474	7.9	1986
Antiproton collector ACOL	CERN	182	2.8	1987

* The ISR was dismantled in 1984.
** Proton antiproton colliding beams with stochastic cooling of the circulating antiproton beam.
*** Charmonium physics with internal target in conjunction with stochastic cooling of the circulating $\bar{p}$ beam.

2. Typical features of proposed ion coolers

In 1980, R. Pollock et al. proposed adding a cooling ring to the Indiana Cyclotron. This proposal was followed by at least eight other ion cooler ring projects (see tables 3 to 5). Three are now (October 1986) in an advanced stage of construction.

Although these projects cover a wide range both in physics goals and parameter space, a few common features can be discerned: a typical cooler ring (Figs 1 and 2) is a storage ring of 50 to 150 m circumference with:

- two or several relatively long straight sections to include beam cooling devices and apparatus for physics with the circulating beam;
- different families of straight sections or variable optics to adapt to the requirements of different experiments
- ultra-high vacuum, a low frequency RF system with large frequency swing, densely packed straight sections ...
- electron cooling (in all) and provision for stochastic cooling (in most of the projects)
- internal targets in conjunction with phase-space cooling for high resolution studies
- different modes of operation of the same machine (storage ring, accelerator, recirculator, accumulator, duty-cycle stretcher, post-stripper, co-moving or colliding beams)
- different types of stored particles.

The physics goals of the proposed coolers are to a large extent complementary. All projects call for new accelerator techniques. Some of these were tested already in the cooling experiments and used in the antiproton coolers (Table 2), others cover completely new ground as will become clear in the following.

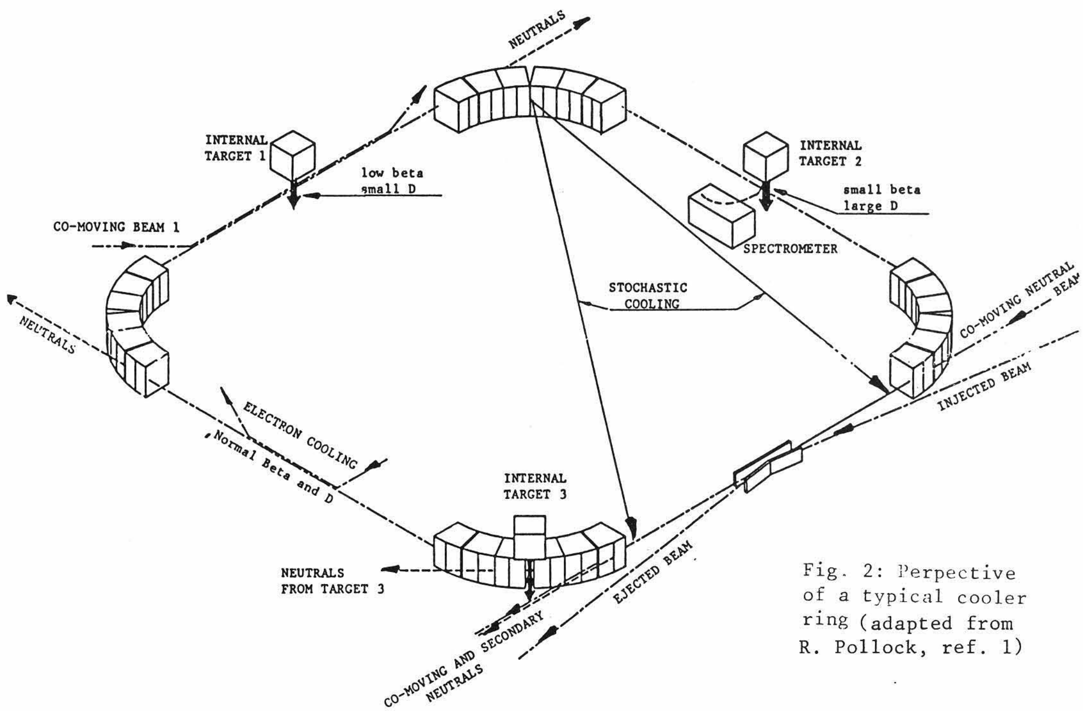

Fig. 2: Perpective of a typical cooler ring (adapted from R. Pollock, ref. 1)

Table 3: Light and heavy ion cooler ring projects

Place		Acronym	Injector	Status
Aarhus,	Denmark	ASTRID	Tandem	project (constr.)
Bloomington,	USA	IUCF-COOLER	Cyclotron	constr.
Darmstadt,	Germany	ESR	Linac	project (constr.)
Heidelberg,	Germany	HSR	Tandem	project (constr.)
Jülich,	Germany	COSY	Cyclotron	project
Osaka,	Japan	?	Cyclotron	project
Stockholm,	Sweden	CRYORING	EBIS source+RFQ	project (constr.)
Tokyo,	Japan	TARN II	Cyclotron	constr.
Upsalla,	Sweden	CELSIUS	Cyclotron	constr.

Table 4: Main parameters of cooler ring projects

Machine	circumference (m)	No. and total length of long straight sections	Energy range for protons
Aarhus	34	4, 13 m	-150 MeV
Bloomington	87	6, 25 m	-500 MeV
Darmstadt	103	2, 20 m	-2.1 GeV
Heildelberg	35	4, 14 m	25-100 MeV
Jülich	160	2, 35 m*	20-1500 MeV
Stockholm	49	6, 18 m	0.4-20 MeV
Tokyo	76	6, 20 m	-1.3 GeV
Upsalla	82	4, 20 m	50-1200 MeV

* Subdivided by quadrupoles

Table 5: Lattice parameters of proposed coolers

Machine	"B.RHO" (T.m) max	Working* point Q h	Q v	γ tr	Beta and dispersion functions* Maximum β h,v (m)		Minimum β h,v (m)		Max. D (m)	Min. D (m)	Ref.
Aar.	1.8	2.3	2.8	5.6	6.4	10	1.2	0.2	2.2 4.4	0.2 0	A
Blo.	3.7	4.1	5.1	4.8	51	56	0.1	0.3	4	0	B
Dar.	9.5	2.3	2.4	2.6	35	40	2.0	1.5	6	0	C
Hei.	1.5	2.2	1.3	3.1	17	8.5	0.2	2.4	1.6	0	D
Jul.	7.7	3.2	3.1	1.5	26	32	2.3	2.1	16	-7.4	E
Sto.	0.65	3.3	1.8	4.2	8.1	9.5	2.3	2.6	2	1.5	F
Tok.	6.8	1.8	1.2	3.0	30	26	1.8	3	4.6	0	G
Ups.	6.3	1.7	1.8	2.4	24	18	1.2	1.3	10	-1.3	H

* Many projects foresee several different working conditions; Q values and beta functions are given here for what the present author considers to be the typical cooling mode.

The information contained in tables 3 and 5 has been extracted from material supplied by the following persons:

A: S. Möller, 25.11.1986; B: D. Friesel, 14.10.1985; C: B. Franzke, 6.12.1985; D: E. Jaeschke and E. Steffen, 25.6.1985; E: S. Martin, 12.12.1985; F: B. Rensfeldt, 3.9.1986; G: A. Noda, 22.6.1984; H: H. Herr, 18.2.1985.

The author apologizes for possible errors of interpretation and for not having included later updates.

3. Basic objectives

New possibilities opened up with cooling rings (in general) include:

i) the accumulation of rare particles to overcome source limitations (AA, FNAL source, ESR)

ii) the provision of high quality extracted beams (LEAR, ESR)

iii) high resolution experiments with circulating beam and internal target (virtually all proposals)

iv) high resolution experiments with the internal beam and a co-moving ion or laser beam (option of LEAR, ASTRID) or with colliding beams (option of LEAR)

v) long time beam storage for special experiments at low energy.

vi) accelerator research.

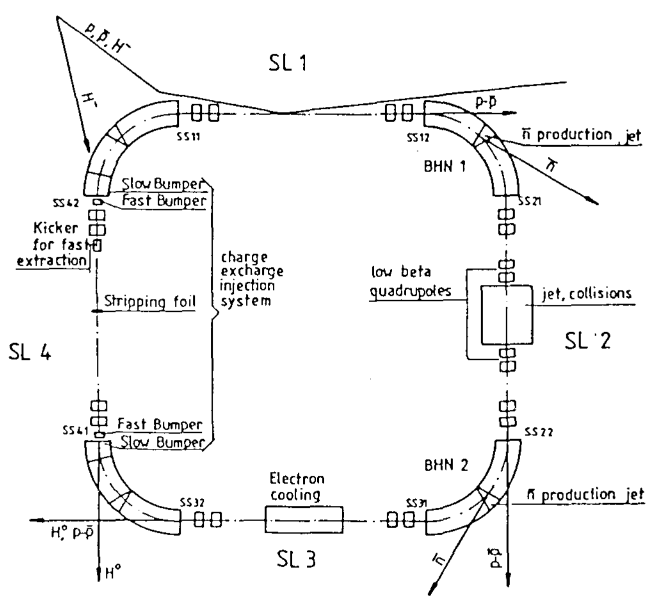

Fig. 2 : Provisions in the layout of LEAR for physics with the circulating beam. Protons can be injected clockwise for machine tests or anti-clockwise (charge exchange injection of H^-) for p-p̄ collisions to be observed in SL2. Alternatively a gas jet target and related detectors can be installed in SL2. Space for other jet targets is reserved in the centre gaps of magnets 1 and 2 to produce neutrals (e.g. n̄). Negative hydrogen can be injected to co-rotate with antiprotons. A large number of "exit tubes" for neutrals is foreseen.

Other specialities of the storage ring are: the almost continuous or adjustable (coasting or bunched) structure of the circulating and slowly ejected beam and the possibility of scanning the energy in fine steps by "offsetting" the equilibrium energy of the cooling system.

These and other benefits have to be balanced against a number of intensity and density limitations proper to a storage ring as will be discussed next.

4. Fundamental limitations

Important density and intensity limitations are:

1) the stacking limit (number of turns continuously injectable <"1000")

2) transverse space-charge detuning (Laslett limit)

3) longitudinal self-bunching instability (Keil-Schnell limit)

4) beam blow-up due to intra-beam scattering (Piwinski limit)

5) beam blow-up and loss due to Coulomb scattering on the residual gas or an internal target

6) blow-up and loss due to diffusion caused by high order betatron resonances, and/or ripple of the storage ring fields, etc.

7) particle loss due to charge exchange with the rest gas or pick-up of cooling electrons

A few words of explanation have to suffice here. Concerning the stacking limit: present day techniques do not manage to inject beam in a continuous fashion into a storage ring for more than several hundred turns or may be a thousand. The world record belongs to the TARN Group here who - by a combination of transverse and longitudinal stacking - manage to inject up to 500 turns. The limiting factor is the acceptance. Even if the incoming beam has zero phase-space, the circulating beam will eventually fill the acceptance due to various kinds of "inefficiencies". Examples are the need to displace the beam by a fraction of the septum thickness from turn to turn or the blow-up occurring in a stripping foil.

Accumulation with phase-space cooling does not escape from this rule as long as cooling times (many milliseconds for present electron coolers, seconds for stochastic cooling) are much longer than a turn (≈ 1 μs) and even considerably longer than the injection time. In short, the storage ring is better adapted to a pulsed input beam (EBIS-source, normal linac, synchrotron) than to a continuous injector like a tandem or a cyclotron.

The intensity - or more precisely: beam density - limitations 2), 3) and 4) above become increasingly restrictive, with decreasing energy (e.g. like $\beta^{-2}\gamma^{-1}$) and with increasing ion charge (typically like q^2/A). Details depend on the exact set of parameters but frequently self-bunching or intra-beam scattering become most limiting. Unfortunately, only computer codes are available to assess this latter effect in general. For the limitations 2) and 3), simple analytical rules of thumb exist (the Laslett formula with a tolerable "storage ring tune shift" of, say, ΔQ = 0.01 for 1), and the Keil-Schnell formula for 2)).

The slow beam blow-up 5) and 6) can be alleviated by fast cooling. With linear emittance increase ($\dot{E}$ = const) and a cooling rate $1/\tau = -(1/E)(dE/dt)$ equilibrium emittances are :

$$E_{eq} = \tau \dot{E}$$

Small E_{eq} is only reached in the presence of a good vacuum and a relatively thin internal target, so that blow-up $\dot{E}$ is small. In a similar way, intra-beam scattering can be balanced, provided growth is not too fast. Blow-up due to the effects 2) and 3) is (usually) too violent to be tamed by cooling; conditions below the threshold of these effects are essential.

In table 6, we give an example of beam parameters as imposed by these limitations for a "hypothetical model cooler" (LEAR lattice!). These numbers should be taken with great care. They hopefully ilustrate trends but the exact values depend rather critically on the detailed parameters of the storage ring.

Table 6

Intensity limits for a "hypothetical model cooler"

Energy	Limiting particle number and internal target thickness for			
	protons		Uranium 92+	
MeV/u	N	$\rho d(g/cm^2)$	N	$\rho d(g/cm^2)$
5	10^8	$5x10^{-11}$	10^7	$2x10^{-10}$
50	$3x10^9$	$2x10^{-9}$	10^8	$5x10^{-7}$
500	$3x10^{10}$	$5x10^{-9}$	10^9	$2x10^{-8}$

These numbers are meant to illustrate trends. Exact values depend critically on a number of storage ring- and cooling system parameters. A "small beam": ($E_H \approx E_V$ =1 π mm.mrad, $\Delta p/p$ = $4x10^{-4}$) is assumed. For a "large beam" ($E_H \approx E_V \approx$ 50 π mm.mrad, $\Delta p/p$ = 1.5 x 10^{-3}), these intensity limits are more favourable by a factor of about 10. Intra-beam scattering and matched target thickness are worked out, assuming a cooling time constant for protons (Uranium 92+) of 1 s (30 ms) at 5 and 50 MeV/u and 100 s (3 s) at 500 MeV/u. For a d = 1 cm thick target of atomic mass A, the number density is: n (atoms/cm^3) = 6.3 x 10^{23} .ρd/A (g/cm^2).

5. Cooling methods

The two cooling methods tested with protons (and protons and Alpha particles at TARN) seem well suited for heavier ions. Cooling by electrons uses - as you know - an electron beam which travels together with the ions over part of the storage (Fig. 3). The electrons absorb transverse and longitudinal energy deviation of the ions by Coulomb interaction. Viewed in the "electron rest frame" moving with the electrons, ions are "stopped" similarly to the slowing down of particles in matter by virtue of their energy loss to the atomic electrons. A simple estimate of the cooling time can be made using the binary collision model in which the ion interacts only with one electron at a time. This permits the scaling of the results from protons to ions, noting that the energy transfer per collision and hence the cooling rate scale like

$$1/\tau \ \alpha \ q^2/A$$

(a weak logarithmic dependence on q due to the different range of impact parameters is neglected here). This suggests fast cooling for highly charged ions. However, these ions can more easily pick up cooling electrons and get lost from the storage ring, owing to the change of their charge state. In fact, the recombination rate due to electron capture scales approximately like

$$1/\tau_r \ \alpha \ q^2$$

For protons, typical cooling and recombination times are τ = 50 ms to 10 s, τ_r = 10^5 s to 10^6 s both strongly dependent on proton and electron beam parameters. In table 7, these time constants are scaled to heavier ions. One concludes that electron cooling of heavy ions seems feasible with at worst a few percent recombination loss per cooling time. However, if one wants to apply cooling for long periods, one will have to reduce the electron current, which of course also reduces the cooling strength.

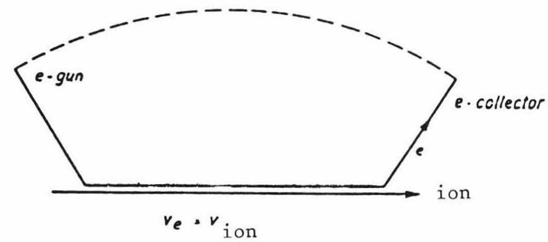

Fig. 3: The principle of electron cooling: electrons travel together with antiprotons over part of the storage ring at the ion velocity and absorb transverse oscillation energy and momentum deviation by Coulomb interaction.

Table 7

Scaling of electron cooling time and recombination time for three different ion species singly or fully stripped. Normalization such that for protons: cooling time τ = 1s recombination time τ_r = 10^5 s.

Particle to be cooled			Cooling time	Recombination time	τ_r/τ
Ion type	mass No. A	charge state q	τ (s)	τ_r (s)	( )
p	1	1	1	10^5	10^5
Ne	20	1	20	10^3	5 x 10^3
		10	0.20	580	2.9x 10^3
U	238	1	238	10^5	4.2x 10^2
		92	0.025	4	1.6x 10^2

Stochastic cooling uses an electronic feedback system as indicated in Fig. 4 to correct the momentum deviation and the betatron oscillations of each individual particle. A set of pick-up electrodes senses the error of a particle; the signal is amplified in a high-gain wide-band amplifier and applied on a corrector down-stream in the storage ring. Accepting a fair amount of simplification, cooling may be viewed as the competition between two effects. The action of a test particle upon itself via the cooling system and the perturbing action of the other particles on the test particle ("incoherent heating effect"). Owing to the finite bandwidth (W) of the cooling system, the correction signal of a particle will be present during a time T_s = 1/2W, where T_s is the response time of the system. All particles passing during this time interval will influence the test particle. To minimize their heating effect, it is important to have large bandwidth and a small number of particles.

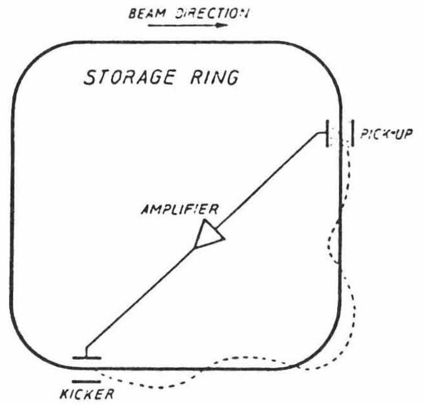

Fig. 4: The principle of (horizontal) stochastic cooling. The pick-up measures horizontal position; the kicker corrects angular deviation. They are spaced by a multiple plus one quarter of the betatron wavelength. A position error at the pick-up transforms into an error of angle at the kicker. This angular error is corrected.

These qualitative considerations may help to understand the cooling-rate expression, which can be written as

$$1/\tau = (W/N)\cdot\text{"const"}$$

In the best of all cases, "const" = 1. For practical systems "const" ≈ 1/10 at the start of cooling with a tendency to decrease as the beam shrinks. In our simple model, the cooling rate is independent of the ion properties. More elaborate models indicate a greater ease in bringing "const" closer to 1 for highly charged ions.

Present day systems work with cooling times of 1 s for 10^7 particles or 1 day for 10^{12}. A factor of 10 will be gained in the near future by pushing the bandwidth into the gigahertz region. This imposes, however, other severe constraints (e.g. the choice of the transition energy and the cooling system power) on the storage ring design. A discussion is beyond the scope of this introduction. All we want to retain here is that fast stochastic cooling is restricted to relatively small intensity beams.

Comparing the two cooling methods, one notes a certain complementarity: electron cooling works best for beams which are already cool: the transfer of energy is most efficient when ion and electron cross each other slowly. Stochastic cooling works best for a large beam which induces strong error signals on the pick-up. The two can then be combined for strong "core cooling" by electrons and "halo cleaning" by the stochastic method. The latter can be emphasized using special pick-up electrodes which mainly look at the (few!) particles in the halo.

6. Characteristics of the internal target mode

Experiments at low and medium energy using a beam impinging on an external target are frequently severely limited by Coulomb interaction with the target material. Either a thin target is chosen and then most beam passes without producing the desired reactions. Or, the target is thick and then interaction spot and energy are smeared out due to multiple scattering and straggling. The situation is more favourable when the target is placed inside the storage ring: ideally all non-interacting particles are then recycled and pass some 10^6 times per second. Thus a thin target can be used efficiently.

Coulomb interaction also occurs in the internal target. The pile-up of small angle scattering and straggling leads to beam heating which can be compensated by a strong enough cooling system. Beam losses still occur due to large angle scattering such that the particle hits the chamber, before the cooling system can react. This, (as well as the multiple scattering) can be alleviated by a special arrangement of the focusing system to produced a "low beta" i.e. a very strong beam focus at the target so that large angular deviations can be accepted. This leads at the same time to a small beam spot on the target as desired for many applications.

The competition between wanted and unwanted interactions is illustrated in Fig. 5, where the cross-sections for the desired strong interaction as well as for loss by multiple and by single scattering are sketched for protons.

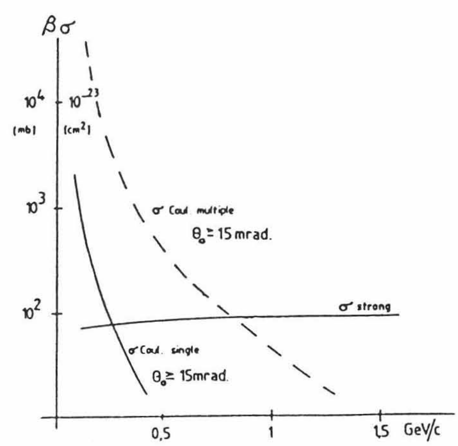

Fig. 5: Interaction of protons with an internal hydrogen target. Normalized cross section β.σ (schematic) for particle loss due to strong interactions and due to multiple scattering and single scattering, with an angle larger than the acceptance at the target (15 mrad with low beta in LEAR). Multiple scattering here means the pile-up of small angle deflections during a large number of revolutions. A cooling system of sufficient strength counteracts this pile-up. Losses due to multiple scattering are then avoided.

The high cooling power of electron cooling is well suited to keep the core of the beam in shape. Particles scattered to larger angles (inside the acceptance) can be restored by the stochastic halo cleaning system as discussed above. As to the target itself: hydrogen cluster jet targets with a density of 10^{13}-10^{15} atoms/cm^2 (≈ 10^{-10}-10^{-8} g/cm^2) are more or less standard and solid fiber, whisker or dust targets intercepting a small fraction of the beam have been contemplated. In any practical design, the target thickness, cooler optics, refilling cycle, cooling strength and vacuum pressure have to be carefully matched. With N (≈ 10^{10}) circulating particles, a revolution frequency f (≈ 1 MHz) and a target thickness ρd (= 10^{15} atoms/cm^2) the luminosity is

$$L = N\rho d f \qquad (\approx 10^{31}\ \text{cm}^{-2}\ \text{s}^{-1})$$

With a cross-section σ for beam loss (σ ≈ $10^{-25}/\beta$ cm^2 assuming protons), the beam lifetime is

$$\tau = N/(L\sigma) \qquad (= 10^4.\beta\ \text{(s)}).$$

Hence a relatively dense target and high beam intensity seem desirable. But both parameters are constrained by the beam density limitations and the cooling strength required to guarantee small emittances as discussed in section 3 above.

Due to the stacking limit (illustrated in Fig. 6), the highest improvement with an internal target is possible in the situation of a pulsed source of rare particles where ideally all particles can be stored and used. In connection with a "DC-source", the stored beam has a flux which is higher than the source current by the number of turns injectable. The cooled equilibrium beam may (or may not) be smaller than the injected beam. A less spectacular but still a respectable gain is then obtainable, compared to a thin external target. As an additional bonus of the cooler, the beam produced between injections can profitably be used for other applications.

Other specific advantages are the possibility of using a (clean!) polarized internal target (polarized H° jet), of observing the recoil of target atoms, of tagging reaction products, and of working without windows in the primary beam. There is also the relative ease of momentum fine-scanning.

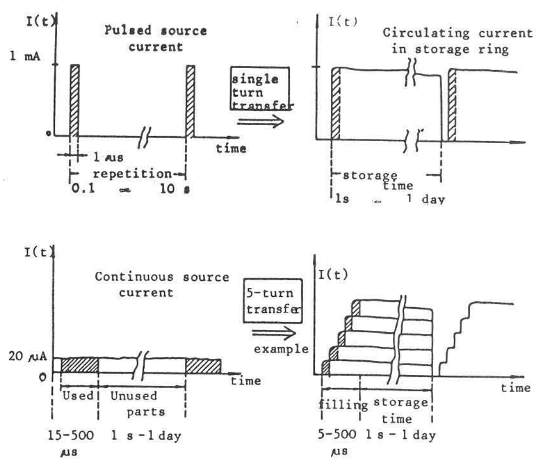

Fig. 6: Filling of a storage ring from a pulsed and a DC-source.

7. Co-moving and colliding beams

Co-moving beams seem well suited for high precision studies at small-centre of mass energy as the "beam" and the "target" move together with small and well controllable energy difference. Also: the target is free of electrons and other contaminants. The cooled beam is dense and "recycles" efficiently through the target. Reaction products leave the target with a c.m. velocity comparable to the beam velocity.

Different schemes are conceivable: ions with the same charge to momentum ratio can co-rotate in the same magnetic guide field. To have the same velocity, the charge to mass ratio q/A has to be equal in addition to q/p. Ions of a slightly different q/A can still be forced to rotate at the same velocity provided that the storage ring can hold the corresponding momentum spread. In this situation, the two beams overlap efficiently only in low dispersion sections where the orbit separation with momentum is small. An example is the co- rotating beam of antiprotons and negative hydrogen as proposed for LEAR.

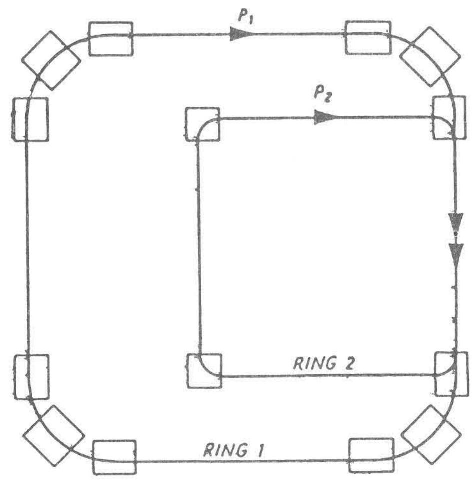

Fig. 7: Schematic view of a double ring scheme for co-moving ions of different momentum (from D. Möhl et al., N.I.M. 202, p. 142) (1982).

Alternatively, neutral beams (e.g. H°) can co-move over a straight part of the storage ring circumference and charged particles of a sufficiently different q/A can be brought to co-move over a field free section in much the same way as the cooling electrons (the two ring scheme in Fig. 7 gives an example).

To date all these schemes have received less study than the internal target mode. One of the difficulties is that the target beam suffers from much the same intensity limitations as the main beam. Densities obtainable are much lower than in a cluster jet. Hence, luminosity is a problem unless reactions with a cross-section of, say, 10^{-20}-10^{-22} cm^2 are to be studied.

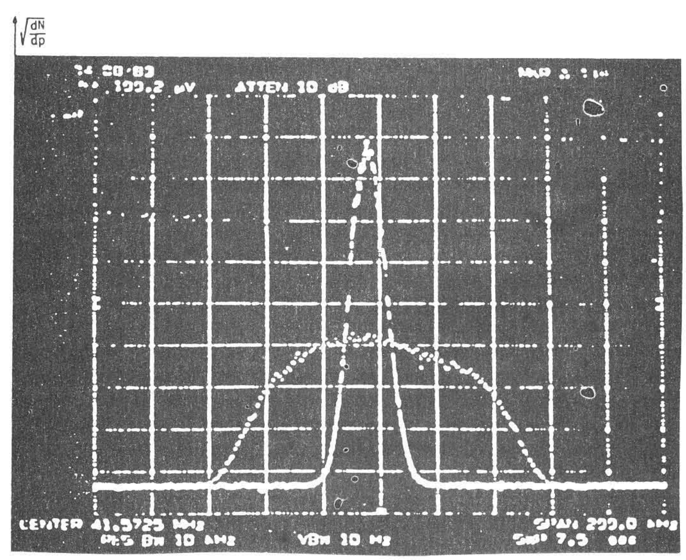

Fig.8 : Momentum cooling at 600 MeV/c in LEAR. Particles density $\sqrt{dN/dp}$ versus momentum. During 3 minutes of cooling $\Delta p/p$ of $\approx$ 3 x 10^9 particles is reduced by a factor 4.

8. Perspectives and conclusions

- The great interest in ion cooler rings is manifested by a large number of projects all over the world. At least four of the proposed rings should come into operation within the next two years.

- These cooler rings will open new possibilities for atomic-, nuclear- and particle physics and innovate interesting concepts in accelerator technology.

- Storage rings are plagued by various types of intensity limitations. The advantages of a cooler seem most pronounced in situations where one can trade intensity for resolution.

- The gain with cooling rings is obvious in connection with pulsed sources of rare particles. Cyclotrons produce dense beams with an almost perfect time structure so that it seems hard to do better. Yet: using ultra-thin internal targets (fiber, gas-jet, co-moving or colliding beams), new possibilities are to be expected with "post-cooling" of a cyclotron beam.

- The physics of electron cooling and frozen beams -as pioneered in Novosibirsk - has been rich in itself and will continue to produce surprises.

- The cooling rings to come will soon produce results surpassing by far the original scope of phase-space cooling.

9. Short bibliography

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12. G.I. Budker et al, CERN report 77-08, 1977.

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15. R. Pollock et al., Proposal for an advanced light ion facility, Indiana University, Dec. 1980 and subsequent work, see in ref. 1 to 4 above.

Density limitations are discussed in papers by:

16. H. Herr, ref. 3 and 4 above, and by

17. I. Hoffmann, in ref. 3 above, as well as: I. Hoffmann and R. Meyer-Prüssner, Intensity limitations of cooled heavy ion beams, GSI Darmstadt report GSI 85-19.

18. H.O. Meyer, in ref. 2 and 4 above.

Co-moving beams are discussed by:

19. G. Budker et al., ref. 12 above.

20. U. Gastaldi et al., e.g. at the LEAR Workshops, see under ref. 14 above.

Note added in proof.

During the conference, I learnt of four more cooling rings planned in the USA: "HISTRAP", a 2 Tesla meter heavy ion storage ring with a circumference of about 47 meters (similar to ASTRID and CRYORING) studied at Oak Ridge National Laboratory, and three storage rings with parameters similar to the Darmstadt ESR, planned at Lawrence Berkeley Laboratory, Brookhaven National Laboratory and Oak Ridge respectively.

The Osaka ring (now specified as a 8 Tesla meter race-track with 125 m circumference and a lattice similar to COSY) has become an authorized project (at least its phase 1 which foresees operation as a "recirculator").

Finally, COSY, upgraded to 11 Tesla meter rigidity and 183 m circumference, seems now to be authorized for construction. The number of accepted proposals known to me is therefore nine (all listed in table 3) and at least four more coolers are being studied.