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INCREASING THE PROTON INTENSITY OF PS AND SPS

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Abstract

Recently, a series of meetings were organised with PS and SPS participants, to discuss the possibilities of increasing the proton intensity on the SPS targets (with particular emphasis to CNGS) as well as ISOLDE and nTOF. Increasing the brilliance of the LHC beam, as required for ultimate LHC performance, was also discussed.
Several schemes were proposed, as a staged approach, i.e. starting from the most simple and cheap, though difficult, to the more advanced and expensive. After comparing the advantages and disadvantages of the various methods, three basic schemes were retained as candidates for further investigations and as good / necessary starting points for further improvements.
Chapter 1 is devoted to PSB and PS issues and contains essentially a description of the three selected schemes.
Chapter 2 deals with limitations in the SPS.
Chapter 3 is a synthesis of basic conclusions.
In the Appendix, a work-plan is presented for PSB and PS theoretical and experimental studies with a time estimate for preliminary results.

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1. PSB and PS issues

Introduction

The PS and the SPS are faced with a challenge: is it possible to increase the CNGS proton flux by a factor 2 or 3?

The present nominal proton intensity foreseen on the CNGS target [1] is 4.8 10^{13} protons per SPS cycle of 6 s duration. In case of dedicated operation this corresponds to a proton flux of • . = 0.8 10^{13} p/s on the target.

To obtain such a record intensity in the SPS, each accelerator of the SPS injector chain (LINAC2, PSB, PS) must also run very close to its maximum performance, in terms of intensity, emittance vs acceptance, and collective effects like e.g. space charge tune shift, etc.

In this chain, unfortunately, there is not a single limitation. For example, if LINAC2 and PSB were replaced with a 2.2 GeV Superconducting Proton Linac (SPL) [2], limitations of the PS and SPS would still dominate. Finally, the overall global performance, that is a gain of a factor 2 or 3, would not be so spectacular and certainly not proportional to the investment.

This obliges us to search for multiple small gains of 10-20% here and there, by optimising beam transfers and collective effects, minimising losses, etc. and eventually trying to imagine new improved operations.

Recently, meetings were organised with PS and SPS participants, to discuss the possibilities of increasing the proton intensity on the SPS targets (with particular emphasis to CNGS) as well as ISOLDE and nTOF. Increasing the brilliance of the LHC beam, as required for ultimate LHC performance, was also discussed. Many schemes were proposed as a staged approach, i.e. starting from the most simple and cheapest, though already difficult, to the more advanced and expensive. The schemes were essentially focused on PSB and PS improvements, obviously a necessary condition for high intensity acceleration in the SPS.

Comparing advantages and disadvantages of the various methods, three basic schemes (so-called 1.1, 1.2 and 2.1) were chosen as best candidates for further investigations and as starting points for further improvements.

They are described in the following paragraphs.

1.1 *Scheme 1.1*: Double batch filling of the PS

The issue is not how to produce a high intensity beam from the PSB. As this can be done with a double batch filling, which is a relatively easy operation. The main problem is how to accelerate in the PS an intensity about twice as high as the present performance, keeping a good beam quality, i.e. low emittance blow-up and small losses.

This is the most important chapter as it concerns the high intensity limits in the PS machine which is an issue common to any other scheme (the SPS has also the same kind of problems).

Three processes are critical for losses: injection, transition and extraction.

1.1.1 Injection

Assuming a PS horizontal and vertical acceptance of $A_x = 60$ μm and $A_y = 20$ μm [3] then the incoming beam from the PSB at 1.4 GeV must have physical emittances at

2σ smaller than ε_x = 22 μm and ε_y = 9 μm (the value of the horizontal emittance takes also dispersion effects into account), to keep losses smaller than ~1%. To accelerate such a beam in the PS with negligible transverse blow-up, the incoherent self-field space charge detuning has to be smaller than 0.3, imposing an intensity limit of the PSB bunches to $N_b < 0.6\ 10^{13}$ p/bunch. The other beam parameters are given in Table 1 below.

k_b (= h)	N_b [10^{13}p/b]	ε_x [μm, 2σ]	ε_y [μm, 2σ]	ε_l [eVs, 2σ]	τ_b [ns]
8	0.6	22	9	1.3	180

Table 1. Beam parameters at 1.4 GeV injection to obtain 4.8 10^{13} p/pulse in the PS machine (k_b is the number of bunches, h is the harmonic number, N_b is the intensity per bunch, ε_x, ε_y and ε_l are the hor., vert. and long. emittances, τ_b is the total bunch length).

This performance could be achieved if a double batch injection, similar to the one currently used for the LHC beam, is applied. In this operation each of the four PSB rings accelerates a single bunch. By injecting 2 x 4 bunches into the PS at h = 8, a total intensity of 4.8 10^{13} p/pulse will be produced, corresponding to a gain of 1.5 in intensity. However, this intensity increase will not yield an equivalent gain on the total p flux, as the double batch operation will lengthen the PS and the SPS cycles by 1.2 seconds. The effective gain $G = \phi / \phi_0$, could be 1.34 at best.

1.1.2 Transition

To minimise the losses at transition and avoid beam break up instabilities, the longitudinal emittance should be larger than ε_l = 2.2 eVs [4,5]. The present PSB machine can produce bunches of ε_l = 1.3 eVs with a total bunch length τ_b = 180 ns, compatible with kicker rise times. By combining controlled longitudinal blow-up with flat bunch generation [6,7] the space charge detuning could be reduced to less than 0.25 in both planes. The complementary longitudinal blow-up from 1.3 to 2.2 eVs can be done in the PS at the end of the injection flat-top.

1.1.3 Extraction

The peculiarity of this extraction and the fact that solutions to this problem are almost completely independent of the previous considerations demands a special chapter, so-called *Scheme 1.2*, shown later.

1.1.4 Others issues

1) Transverse and longitudinal emittance degradations and losses can also occur during the acceleration if collective effects are not mastered.

2) Transverse coupled bunch and single bunch head-tail instabilities should be cured using x-y coupling, chromaticity control, octupoles and possibly with a transverse feedback system (under construction for the LHC beam).

3) Longitudinal coupled bunch instabilities would certainly require a new powerful multi-mode feedback system.

4) At 14 GeV/c, before the extraction from the PS, an RF gymnastic of debunching-rebunching at 200 MHz is presently performed to help the SPS RF capture. At high intensity, this operation will be very unstable because it is very sensitive to beam loading

(due to the low RF voltage) and prone to microwave instability (due to the low momentum spread of the debunched beam). A new procedure has been proposed [8] which contemplates a 'partial debunching' by lengthening the bunches with a non-adiabatic bunch rotation at high voltage and a 200 MHz modulation obtained by a series of high voltage SC RF cavities to be installed somewhere in the PS to SPS transfer line TT2-TT10. A total voltage of 60 MV, but negligible power, over a total length of ~10 m, should provide the required beam modulation. Eliminating the 200 MHz capture in the PS would allow removal of many of the present 200 MHz cavities, decreasing the impedance of the machine. This proposal and other possible solutions are under study.

1.2. *Scheme 1.2* : a new 5-turn Continuous Transfer (CT)

The SPS circumference is 11 times the PS circumference. To minimise the SPS filling time by using only two PS cycles, a 5-turn extraction is currently used. This operation consists in cutting the horizontal phase space occupied by the beam into five slices of about the same area (emittance) using an electrostatic septum. The five slices are fast extracted one after the other (continuously), filling about one half (5/11) of the SPS in a single PS shot. The other half is filled with a second shot on a following cycle of the PS, 1.2 s later. This slicing procedure also allows a reduction of the transverse beam emittance in order to inject into the SPS acceptance of A_x = 3 μm and A_y = 2 μm. The high emittances of the high intensity beam, and the intrinsic non-uniform slicing result in an overall transfer efficiency of only 80 %. Even worse, half of the losses are localised on the PS electrostatic septum, rendering this equipment prone to failure and difficult to repair.

A novel system has been proposed [9], which foresees a transverse plane 'adiabatic capture' of the beam into the four islands of a 4^{th}-order resonance generated with sextupoles and octupoles. Present simulations indicate this method as promising, and theoretical and experimental work is in progress. The potential advantages of this method are smaller losses, small emittances and better matching, i.e. better PS-SPS transfer efficiencies. Moreover, at this stage of the studies, the hardware modifications appear to be relatively modest.

Combining *schemes 1.1 and 1.2* the total improvement gain on the proton flux should be 1.5.

1.3. *Scheme 2.1*: A new H^- 120 MeV Linac

One of the main bottlenecks, the first that the beam sees in passing through the accelerator chain, is the space charge detuning at the injection of the PSB. At present, for high intensity (or density) beams, this value is about 0.5, a very high and limiting value.

For a given intensity, emittance and bunch shape, the space charge detuning is inversely proportional to $\beta\gamma^2$. Increasing the Linac energy from the present 50 to 120 MeV, the net gain on the space charge detuning is 70% [10]. Moreover, by relaxing the space charge limitations it becomes possible to take full advantage of an H^- injection. Today, with protons, transverse emittance and intensity are strongly linked, that is one cannot adjust the intensity without changing the emittance or vice-versa.

Replacing protons with H^-, an extensive use of non-Liouvillian 'painting techniques' (the injection time is a few hundred turns) will allow independent changes in intensity and emittance. This is a very important improvement, not only for obtaining high intensity CNGS beams but also for LHC beams, ISOLDE, etc. Moreover it is a solid method to get the high beam brilliance, not yet fully achieved with the conventional method, requested for the LHC ultimate luminosity of 2.5 10^{34} $cm^{-2}s^{-1}$. In addition, a longitudinal painting will permit to remove the present longitudinal blow-up and bunchflattening gymnastics. A higher injection energy could help to shorten the PSB cycle in view of a possible faster PSB repetition rate.

It should be noted, however, that H^- injection will most likely preclude all ion operations in the PSB. This should be acceptable since direct injection from LEIR into the PS is foreseen for LHC ion operation.

Concerning the CNGS beam, this new LINAC would double the performance of the PSB but would not, of course, eliminate the intensity limitations in the PS (or SPS). Consequently the double-batch injection would no longer be necessary and the PS filling time would be reduced by 1.2 s. The total gain (*scheme 1.1 + 1.2 + 2.1*) in proton flux would be 1.8.

1.4. Other schemes

Other schemes (actually improvements to the basic ones) or combinations of schemes were also considered (see Table 2, at Page 12). Some are listed below without going into the details.

a. *Scheme 1.2a* : Running the PSB at twice its rate i.e. one pulse every 0.6 s. instead of 1.2 s [11].
This may require important hardware modifications. A degradation of the present beam quality is probable, except if using an H^- 120 MeV LINAC. The net gain would be moderate (~10%) for CNGS and high (~ x 2) for ISOLDE.

b. *Scheme 1.3* : Extracting from the PS at 26 GeV/c instead of 14 GeV/c.
The advantage is the injection into the SPS above transition, which would reduce some losses in the SPS. The disadvantages are a 1.2s longer cycle (filling time) and a CT extraction hardware (essentially ES31) which is presently limited to 14 GeV/c. A study is under way to explore the possibility of compensating these 1.2s by changing the PSB magnetic cycle [12].

c. A 3-turn CT
would permit a triple injection into the SPS, which gives a higher intensity but also implies a longer filling time and higher losses due to larger emittances. The beam dynamics of a new 3-turn CT is much more complicated and the scheme probably unfeasible.

d. *Scheme 3.1*: Making use of a 2.2 GeV SPL,
as already mentioned, could theoretically" provide a gain of a factor ~ 4. However, it seems absolutely unrealistic to envisage such a high intensity in the PS and SPS due to the extreme collective effects.

2. SPS issues

Introduction

Looking at the different scenarios retained for the PS it is clear that the SPS will have to accelerate up to 8 10^{13} p/cycle. The maximum intensity accelerated up to now is 4.8 10^{13} p/cycle. This record intensity was limited by several factors:

- The intensity in the PS
- The emittance of the PS beam at these intensities.

- Heating of contacts in damping loops of the 200 MHz standing wave cavities.
- Limitations in the feedback of the 350 MHz super conducting cavities.

These limitations will disappear : the 200 MHz and 350 MHz cavities that were used for lepton acceleration have been removed from the SPS. Also the emittance should no longer be a problem since the scenarios proposed by the PS aim specifically at reducing the emittance for the proposed intensities so that the beam will fit the SPS aperture. The question is now to discover where the new intensity limitations in the SPS will be.

2.1 Single Bunch Limitations

Assuming the beam is injected in two batches, the intensity per bunch for a total intensity of $8\ 10^{13}$ p/cycle is $1.9\ 10^{10}$ p/b. (For three batch injection this would rise to $2.1\ 10^{10}$ p/b). This is well below the bunch intensity of $1.6\ 10^{11}$ p/b that was accelerated during the collider period. It is also half the bunch intensity where we start to observe problems with the electron cloud ($4\ 10^{10}$ p/b) when working with the LHC beam with 25 ns bunch spacing. Simulations will have to be performed to check the threshold for 5 ns bunch spacing but we expect no problems here.

There remains the question of loss of Landau damping at high energy due to the broadband impedance. This will be dealt with later.

2.2 Local Density

In order to get an idea of beam loading and instantaneous RF power, it is good to look at the intensity on a time scale of 1 μsec - the cavity rise-time is typically of the order of 600 ns. The local density for high intensity beam would then be $4\ 10^{12}$ / μsec, corresponding to a RF beam current varying between I_{RF} = 0.8 A at bunch length τ_b = 4 ns and 1.2 A for τ_b = 1ns. The nominal LHC beam will have similar local density, and feed forward and feedback loops are being designed to cope with this kind of beam loading, typically 1100 kV induced per cavity. However, these loops are for the moment being built to handle a frequency swing corresponding to acceleration from 26 GeV/c to 450 GeV/c. Extension down to an injection energy of 14 GeV/c will complicate matters since the beam loading impedance depends on the RF-frequency. The RF power required depends on the beam current and the voltage necessary to provide the bucket area at the acceleration rates foreseen. The maximum power available per travelling-wave cavity is 1 MW when pulsed. The power needed simply to provide the energy gain/turn is 570 kW/cavity. Major limitations are found in the front porch - for these intensities the maximum emittance allowed is 0.4 eVs. See Figs. 1 and 2. As the energy increases, the emittance can slowly increase to ~ 1 eVs at 300 GeV/c and 1.5 eVs at 390 GeV/c. This can help significantly with instabilities, see later. Power requirements scale approximately with emittance squared and since all elements in the RF power chain, amplifier, feeder-line and coupler, are at their limits, longitudinal emittance conservation becomes a dominant issue.

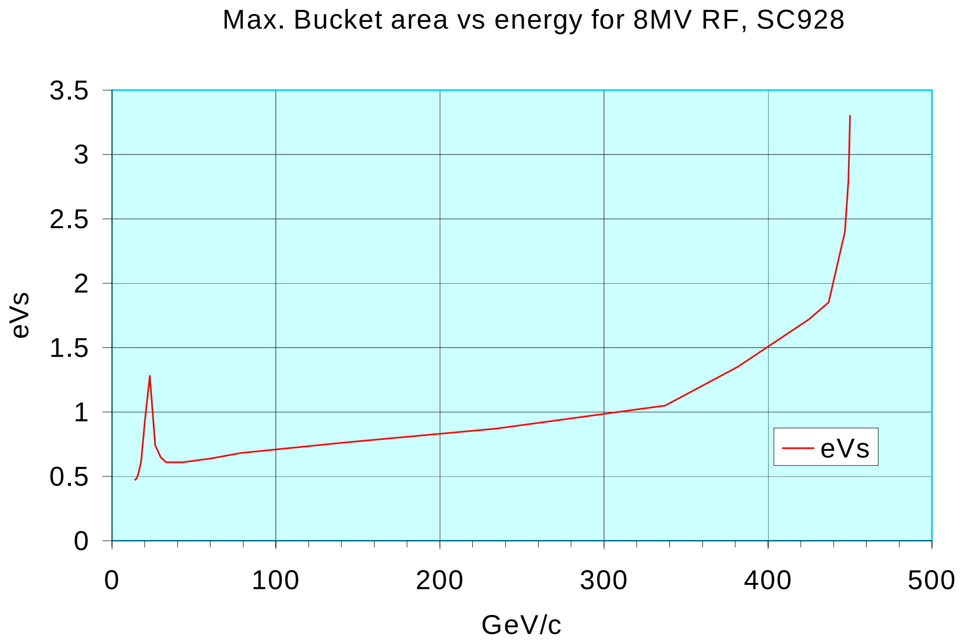

Fig. 1. Maximum bucket area vs energy for 8 MV RF. 14 - 450 GeV/c fixed target cycle

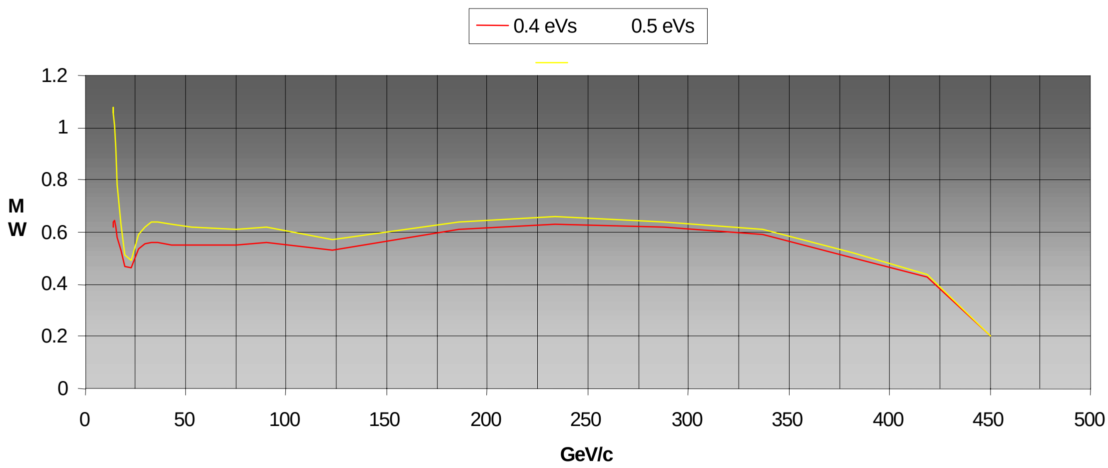

Fig. 2. Power / cavity as a function of energy for emittances 0.4 eVs and 0.5 eVs. RF current 1.1A.

2.3 Total intensity

A total intensity of 8 10^{13} protons distributed over the whole SPS ring is 50% higher than the maximum ever achieved and twice as high as the ultimate LHC current. One of the problems with high total currents is the resistive wall instability. The damper will already be upgraded for the LHC beam, its bandwidth being extended to 20 MHz. While this covers all modes for the LHC beam, 25 ns bunch spacing, we would need 100 MHz for the CNGS beam, 5 ns spacing. However in addition we can use the full aperture of the machine in combination with octupoles (for the LHC we have to stabilise a beam with much smaller transverse dimensions.) In particular this would be necessary for higher bunch modes such as quadrupole, sextupole etc. Multi-bunch longitudinal instabilities are also a worry - they are covered below.

2.4 Front porch and Transition

High intensity beams always give a few percent losses, both in the front porch and at transition, even after carefully optimising all the machine parameters. The front porch losses are very dependent on the injected transverse beam dimensions. At transition this is less true. The losses increase rapidly with intensity reaching ~ 5% at 4.5 10^{13} even when optimised, see Fig. 3. For the moment it is not known how much loss we will have with 50% more beam. Once the PS is able to give the increased intensity, we will have to study this problem. However, the losses during the front porch and at transition will certainly not be zero, and there will always be a longitudinal blow up through transition, typically by a factor 2, which is very demanding of the RF power. For these reasons the SPS is strongly in favour of a continuous transfer at 26 GeV/c, instead of 14 GeV/c, in order to avoid crossing transition energy in the SPS.

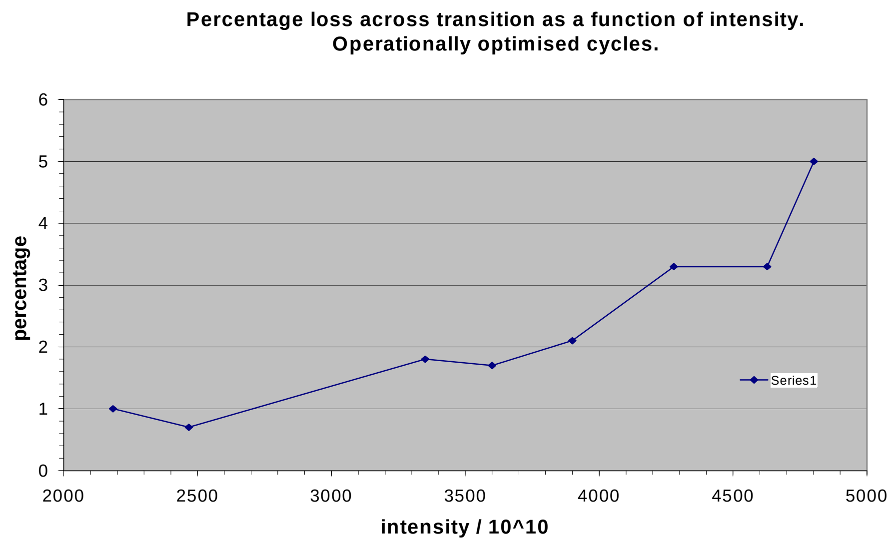

Fig. 3. Percentage beam loss at transition as a function of intensity after optimisation of transition crossing.

2.5 High energy - instability thresholds

High intensity beams become increasingly unstable with energy. This can be seen in Fig. 4 where the instability threshold for narrow-band impedances is plotted as a function of time in the cycle [13]. Note that for each bunch length the resonator frequency giving the lowest threshold impedance is assumed.

The cycle taken is the present 26 to 450 GeV/c LHC cycle. The fixed target cycle is faster but the overall behaviour is similar. At low energies, effects due to η are important while at high energy, the curves are dominated by the energy change and the thresholds drop dramatically. Not only are coupled bunch instabilities more likely due to the narrow-band impedance, there is also a possibility of losing Landau damping due to the coherent frequency shift from the broad-band impedance - the threshold value for the broadband impedance, Im(Z/n), drops to < 20 Ω at top energy for an emittance of 0.5 eVs and a bunch current of 0.15 mA.

As stated previously the available power allows some longitudinal emittance increase as the energy increases and unlike the SPS for LHC beam, there is no strong limitation on energy spread at extraction. If the emittance is increased as ~ $E^{1/2}$ to 1 eVs then the dotted threshold curve is obtained. (Similar behaviour is observed for the broadband impedance). Ways of producing a controlled emittance increase are being examined. The 800 MHz Landau damping system is also available - the problems of operating this system under high beam-loading conditions are under study.

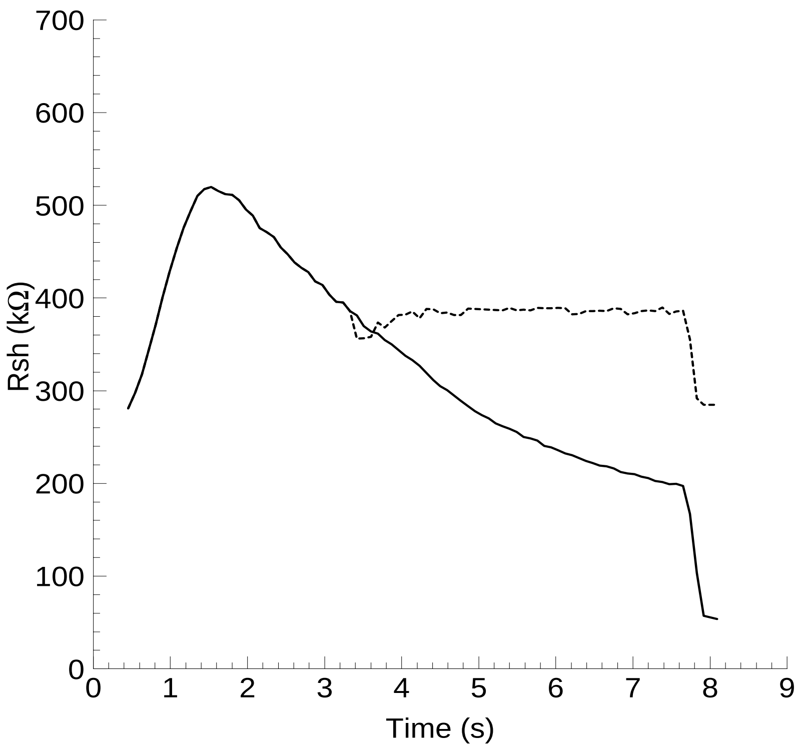

Fig. 4. Instability threshold for narrow-band impedance for a longitudinal emittance of 0.5 eVs. CNGS beam current 0.7 A.

2.6 Change in transition energy

If we can inject at 26 GeV/c then an additional advantage might be obtained by working with a lower transition energy. The injection voltage matching becomes easier; for example with γ_{tr} = 19.6, then for an emittance of 0.4 eVs, τ_b = 4ns, the matching voltage increases from 800 kV to 2 MV. Instability thresholds are improved due to the η change though this is partially offset by the lowering of available bucket area. However for γ_{tr} = 19.6 there would be a net gain of 25 %. Difficulties that would have to be solved are a reduced aperture (but transverse emittances are smaller) and injection matching adjustment.

2.7 Bunch to Bucket Transfer

It is an experimental fact that a coasting beam of a few 10^{12} p/cycle is longitudinally unstable in the SPS and suffers a huge momentum blow-up. For that reason adiabatic capture is out of the question for high intensities, and a bunch into bucket transfer is applied. The de-bunching and recapture in 200 MHz in the PS is a delicate process and longitudinal instabilities are observed during the de-bunching For that reason the PS has proposed to make a “quasi” uniform distribution with very long bunches using bunch rotation, followed by immediate ejection. A strong 200 MHz cavity in TT10 would then create a momentum modulation, which would give a bunched beam after something like 40 SPS turns (cf. point 1.1.4). The questions are how stable the beam will be during these 40 turns, and how do we capture the beam. One can imagine injecting the uniform PS beam directly in the 200 MHz bucket of the SPS. This could give a faster 200 MHz structure and hence controllable beam but would lead to an emittance blow-up that we would like to avoid for the reasons mentioned above. This last point can be experimentally tested this year. The bunching process with momentum modulation in TT10 can be studied with simulation.

2.8 Studies for the SPS

It seems that while there is no hard limit stopping us from going to 8 10^{13} p/cycle there are a large number of grey areas where experimental studies must be made. This is particularly true this year because of the campaign to lower the SPS machine impedance, 98% completed this shutdown, and which will give us a different machine.

Below is a list of studies that were proposed by the SPS Study Working Group (SSWG) we will have to do this year:

- Recover from the long shut-down, the "big bang"; recover the machine aperture from before the shut down.
- Study the effect of the impedance reduction on instability thresholds etc.
- Study controlled longitudinal blow up.
- High intensity through transition.
- Uniform beam to bucket transfer.
- Blow up over 40 turns
- Simulation with TT10 momentum modulation, effect of finite speed of RF switch.

It must be emphasised that in order to carry out these studies, the PS must be able to give the high intensity proton beam in parallel with the moderate intensity physics beam. This means finding a way to operate the continuous transfer in a pulse to pulse mode.

3. Summary and Conclusion

a. A summary list of the various schemes is shown in Table 2 below.

b. A gain of a factor 1.5 on the proton flux seems attainable though difficult, using scheme 1.1 (double batch) and 1.2 (new 5-turn CT), with a moderate cost, i.e. some MCHF (almost depending on 200 MHz SC cavities). These schemes are good starting points to explore the various limitations.

c. A gain of a factor 1.8 appears as a maximum overall gain using scheme 2.1, i.e. a new H^- 120 MeV Linac (cost range ~70 MCHF).
LHC, ISOLDE, nTOF, etc. would also benefit.
The 120 MeV linac could be the first stage of a 2.2 GeV SPL.
It could be placed in the PS South Hall.
It requires a more detailed design.

d. A gain of a factor 3 is unrealistic, even with an SPL (some hundred MCHF).
PS and SPS collective effects are the essential limitations.

A work-plan proposal for studies concerning Schemes 1.1, 1.2 and 2.1 is presented in the Appendix.

#	Denomination	N sps [10^{13}p/p]	POT flux ϕ [10^{13}p/s]	Gain = ϕ / 0.8	Cost (ord. of mag.) [MCHF]	Remarks
0	present nominal scheme	4.8	4.8 / 6 = 0.8	1	0	Already difficult
1.1	**=0 + double batch PS inj.**	**7.7**	**7.7 / 7.2 = 1.07**	**1.34** (1.42)	**1**	**Higher N_{sps} but longer cycle** (cost without 200MHz SC cav.)
1.1 a	1.1 + PSB @ 0.6s	7.7	7.7 / 6.6 = 1.17	1.46 (1.51)	3	Important HW modifications (?) Improvements to ISOLDE
1.2	**1.1 + new5-turnCT**	**8.6**	**8.6 / 7.2 = 1.19**	**1.49** (1.58)	**2**	**Better transfer efficiency (lower losses)**
1.2 a	1.2 + PSB @ 0.6s	8.6	8.6 / 6.6 = 1.30	1.63 (1.68)	4	Best of group 1
1.3	1.2 + 26GeV/c	8.6	8.6 / 8.4 = 1.02	1.28	3	No transition in SPS CT @ 26GeV/c ?
1.3 a	1.3 + displaced & shortened PSB cycle	8.6	8.6 / 7.2 = 1.2	1.5	3	Very interesting
2.1	**1.2 + a new H^- 120MeV Linac**	**8.6**	**8.6 / 6 = 1.43**	**1.79** (1.79)	**70**	**Improvements also for LHC, ISOLDE,…**
3.1	SPL at 2.2GeV + new 5-turnCT at 14GeV/c	23	23 / 6 = 3.83	4.79	300	Extremely high coll. effects =>UNREALISTIC

Table 2. A list of various schemes (the arrows indicate the "selected schemes"). They are listed in 3 groups 1.n, 2.n and 3.n, where 1, 2 and 3 are the number of digits in the cost figure. "Nsps" is the p intensity / pulse in the SPS. "POT flux" is the proton on target flux, i.e. Nsps / SPS cycle duration with cycle duration = 4.8s + time between two PS extractions (actually the varying parameter). "Gain" is the ratio of POT flux / present nominal flux and in brackets the value for the "interleaved mode"[1]. "Cost" is a very approximate cost evaluation (order of magnitude).

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APPENDIX

A work-plan proposal for PSB and PS studies concerning *Schemes 1.1 , 1.2 and 2.1*

The following work-plan is a list of main items to be studied in order to estimate the feasibility of each scheme.
Approximate time scales are suggested to obtain some preliminary results.

Scheme 1.1 **(double batch / high intensity)**

They are essentially experimental studies, i.e. MD's.

- PSB: obtain 2.4 10^{13}ppp (= 6 10^{12} p/ring) with the following emittances: ε_{x2}=22 μm, ε_{y2}=9 μm, ε_{l}=1.3 eVs, τ_b ~180 ns (using ctrl. long. b.u. and eventually flat bunches).
  Preliminary results in June 01.

- <u>PSB-PS matching</u>
  This study is being done for LHC
  Preliminary results in June 01

- <u>Head-tail resistive wall instability (higher modes)</u>
  theoretically this instability should be cured by x-y coupling (as in LHC beam). If not, the new Transverse Feedback have to be used.
  Preliminary results in June 01

- <u>Transverse emittance conservation at $\Delta Q > 0.3$</u>
  to minimize the emittances at extraction, emittance conservation is an issue. Some ~30% could be acceptable at the beginning.
  A ΔQ~0.3 should produce a b.u. of ~30% on a parabolic bunch.
  Flat bunches from PSB will certainly help in reducing space charge effects.
  Reducing the flat-bottom length could be envisaged by modifying the PSB cycle timing .
  Working point optimization is mandatory.
  Preliminary results before summer 2001

- <u>Resonance compensation</u>
  It is also a way of reducing emittance blow-up at 1.4 GeV.
  It is a long and tedious study.
  Preliminary results in 2002

- <u>8 =>16 bunch splitting</u>
  It is probably necessary for a better transition crossing (reduces the beam size because of smaller dp/p).
  Doing this gymnastic with 5 10^{13}ppp and in presence of strong beam loading is an issue.
  Preliminary results before September 01.

- <u>Acceptance measurements and optimisation</u>
  PSB-PS transfer line and PS acceptance are key points for machine performance at high intensity.
  They should eventually be re-measured (they should be 60 and 20 μm in x and y) and possibly improved.
  Are PFW's reducing dynamic aperture?
  For this we need some new tools: a turning bump (software) and an xx'-yy' measurement system *(also needed for new CT studies, see later).*
  Preliminary results before end 2001.

- <u>Beam Loading</u>
  It is probably a big problem but it has to be solved to accelerate the beam.
  It can lead to RF hardware implementations / modifications *(i.e.: time, money and manpower problems).*
  Indications before summer.

PS acceleration

- <u>Transition crossing</u>
  Orbit distortions at triplets and doublets reduce acceptance and induce losses for large (intense) beams.
  Closed orbit corrections at this energy are limited.
  Preliminary results before summer.

- <u>BBU instability.</u>
  We know from nTOF beam that a single bunch of 6 10^{12}p can cross transition safely if ε_l >2.2 eVs (on h=8). Scaling for CNGS indicates that 16 bunches of 3 10^{12}p and 1.2 eVs should also be stable, if there is no coupling between bunches. This has to be proved.
  Preliminary results before October.

- <u>Revisit γ_t jump.</u>
  If the problems at transition persist, then the entire scheme of • $_t$ jump (triplets and doublets) should be revisited.

- <u>Long. coupled bunch instabilities</u>
  One of the most difficult problems to solve.
  Mode number identification (mode number analyser to be built?).
  An "all mode n" feedback has probably to be built also.
  Impedance identification / measurements / reduction.
  Hardware implementations have to be conceived, implying money, manpower and time availability.
  Indications before end 2001.

- <u>Working point (Q_x,Q_y,ξ_x, ξ_y) adjustements</u>
  Precise control of w.p. and in particular of the chromaticity, is mandatory for high intensity beams.
  The present PFW control (software) should be improved.
  Indications before end 2001.

PS high energy

- Debunching & 200 MHz rebunching.
  Test stability of the present operation.
  Test feasibility of the new 'debunching', i.e. bunch lengthening by bunch rotation, extraction and measurent of the effects in the SPS.
  Set up a PS-SPS study group to analyse and recommend solutions and consequences (6 months).
  Indications in 2001

- e-cloud effects on 200 MHz bunches
  This possibility is already under study with simulations and experiments with and for the LHC beam.
  Preliminary results before summer

Remarks:
The PS team will try to prepare a 'medium' intensity beam, i.e. 3-4 10^{13} ppp in PPM to allow parasitic MD's in the SPS machine before the end of the year.

Scheme 1.2 **: a new 5-turn CT**

Preliminary remarks:

- the new 5-turn CT is an improvement not only of scheme 1.1 but of any other scheme (including the present nominal one).
- The studies on the new 5-turn CT are decoupled from the studies on high intensity described above. They can proceed almost in parallel with little interference.

Present Status

- An idealized model has been studied and a simulation program has given first encouraging results.
- A more realistic model is being implemented in the simulation, in particular to study the sensitivity to tune variations and other machine non-linearities.
- The experimental implementation requires a special instrumentation, under construction, for xx’-yy’ measurements.
  Preliminary results before summer.

- If and when the feasibility of the transverse adiabatic capture will be experimentally proven (hopefully before the end of 2001) then
- The implementation of the optical modifications (minor?) for a new 5-turn CT could be studied and finalized *(feasibility study in 2002).*
  Indications in 2001

Remarks:
A new 5-turn CT at 26 GeV/c and a new 3-turn CT, using a combination of a 3rd and a 6th order resonance, are also under theoretical study.

Scheme 2.1 : a new H^- 120 MeV Linac

Questions, problems and (some) answers:

- Which performance can the PSB aim for ?
- How good is this linac for the PSB ?
- Upgrading of PSB injection line to 60% higher momentum.
- Design of a H^- injection with painting in 6D phase space.
- Revisit resonance compensation.
- Beam loading on RF cavities.
- etc.
-

  => study group with Linac & PSB experts to define the required linac beam characteristics etc., with the constraint that this machine could become an SPL front-end
  Goal: provide specifications.
  Duration: 3 months.

- Detailed linac design, including siting.
  => linac design team, with outside collaborators involved in the SPL (CEA, IN2P3, Legnaro,…)
  Goal 1: design report with siting.
  Goal 2: cost analysis, based on the potential "in kind" contributions by other institutions.
  Duration: 12 months