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Potential for neutrino and radioactive beam physics of the foreseen upgrades of the CERN accelerators

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1. Introduction

The integrated luminosity in the LHC experiments will directly depend upon the reliability and the level of performance of the injectors (Linac2, PSB, PS, SPS). The working group on "Proton Accelerators for the Future" which is in charge of elaborating a baseline scenario for the upgrade of these accelerators [1] in close collaboration with the group looking after "Physics Opportunities with Future Proton Accelerators" [2] has published its views for maximizing the LHC performance in a first document [3]. The present report updates the information concerning the proposed future accelerators and highlights their interest for a possible neutrino facility at CERN as well as for a next generation ISOL-type radioactive ion beam facility ("EURISOL" [4]).

2. Proposed upgrades of the LHC injectors

Beyond the mandatory consolidation required for reliable operation, the existing injectors have to be progressively replaced by higher performance accelerators to improve the intensity and brightness of the beam delivered to the LHC. The proposed machines and their interconnections are sketched in figure 1.

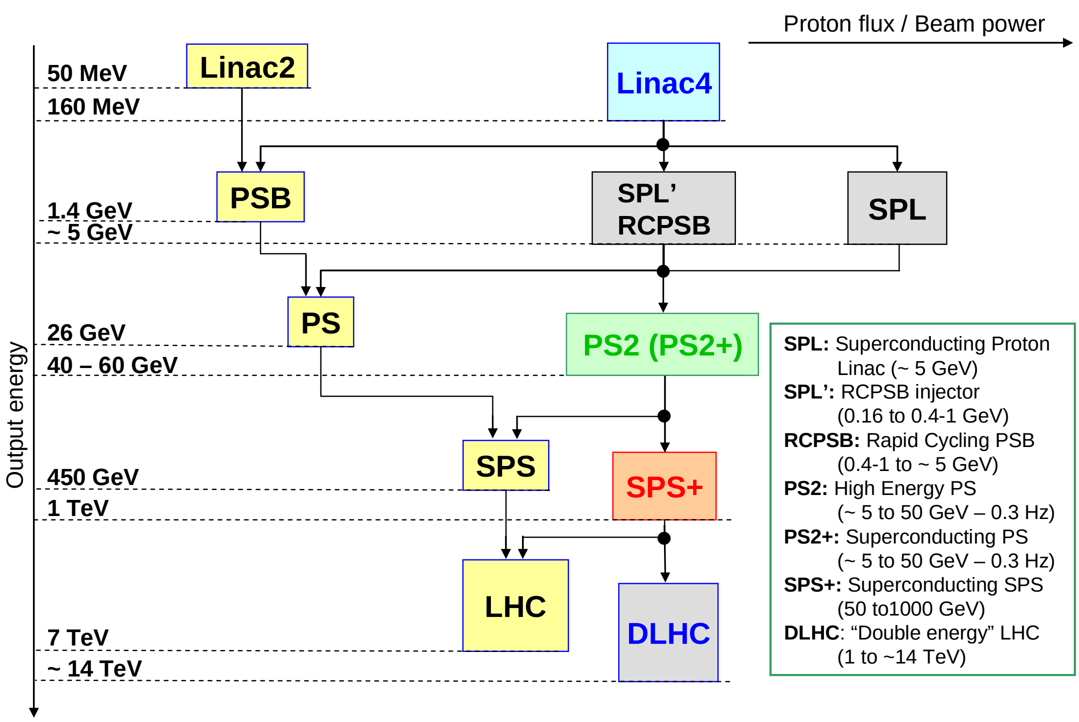

Figure 1: Evolution of the CERN proton accelerators complex

Linac4

Injection in the PSB is a well identified bottle-neck for the generation of the type of high brightness beams required for LHC, because of space charge effects at 50 MeV. The favored solution to increase the brightness up to the ultimate level and help cover the needs of the future LHC luminosity upgrades is to build a new Linac ("Linac4") injecting protons at 160 MeV, thus halving space charge in the PSB. It will also result in a reduction of the LHC filling time and an increased reliability. The main characteristics of Linac4 are summarized in table 1.

Table 1: Linac4 beam characteristics

Type of ion	H-	
Kinetic energy	160	MeV
Pulsing rate	up to 50[1]	Hz
Pulse length (max.)	$\leq$ 0.4	ms
Current during the pulse	40	mA
Chopping factor	60-70	%

[1] As injector for the PSB, the cycling rate of Linac4 will be limited to less than 2 Hz.

PS2 (or PS2+)

After the PSB, the SPS is the next bottle-neck for high brightness beams in the cascade of LHC injectors. Preliminary studies show that significant improvements can be expected from increasing the injection energy (40-60 GeV). It is therefore proposed to build a new 50 GeV synchrotron called "PS2" that will replace the 40 years old PS. This machine is nowadays at the same time the oldest designed and the most flexible in the CERN complex, adapting the beam characteristics to the needs of multiple users. Substantial benefits can be expected from using today's knowledge in accelerators and optimizing for the present and future needs of CERN. The main characteristics of the PS2 synchrotron are given in table 2. As an option within the same circumference, the use of fast cycling superconducting magnets would allow to reduce the electrical consumption and to reach an even higher energy ("PS2+").

Table 2: Main characteristics of PS2

Maximum beam energy (kinetic)	50	GeV
Injection energy (kinetic)	~ 4	GeV
Mean radius	200	m
Bending radius	94.4	m
Maximum bending field (B)	1.8	T
Maximum dB/dt	1.5	T/s
Cycling period	3.6	s
Number of bunches for LHC per pulse [25 ns bunch spacing]	144	
Maximum intensity per bunch[1] for LHC [$\varepsilon_{H,V}$ (rms - normalised)= 3 π.mm.mrad]	3.4×10^{11}	p/bunch

[1] 25 ns time interval between bunches, with an optimum injector (e.g. the SPL)

Because it has twice the PS circumference, the effect of space charge is twice larger in PS2. Therefore, the injection energy has to be higher than 3.5 GeV to make it possible to prepare 25 ns-spaced LHC bunches with twice the ultimate brightness or 12.5 ns-spaced bunches with the ultimate brightness. As an intermediate solution, the PS could be used as an injector, but the performance of PS2 (PS2+) would be limited.

SPL (or SPL' & RCPSB)

The characteristics of the injector of PS2 will strongly depend upon the other uses of its beam. For a neutrino factory, a beam power of 4 MW is necessary and the beam energy may have to be increased up to ~ 5 GeV. For a beta-beam facility, the beam energy could be of 3.5 GeV, but the beam power would have to be brought up to 4 MW for the generation of a ν super-beam and 5 MW for a next generation ISOL-type radioactive ion beam facility. In case such a high beam power is needed, a superconducting proton linac ("SPL") coupled with storage ring(s) is a very attractive solution. The main parameters of the SPL are shown in table 3.

Table 3: Main characteristics of the SPL

Type of ion	H-	
Kinetic energy	≥ 3.5	GeV
Beam power	4–5	MW
Pulsing rate	50	Hz
Pulse length (max.)	≤ 0.7	ms
Current during the pulse	40	mA
Chopping factor	60-70	%

If a multi-MW beam power is not necessary, the SPL should be compared to an alternative solution based on a medium energy linac ("SPL'") followed by a Rapid Cycling Synchrotron ("RCPSB").

SPS+

The present SPS has been built 30 years ago and it is limited to 450 GeV. A new synchrotron using fast cycling superconducting magnets, aiming at a minimum impedance budget and located in the SPS tunnel ("SPS+") could have better characteristics and be able to accelerate up to 1 TeV. This would ease operation of the collider and open new possibilities for increasing luminosity using bunches of larger transverse emittances. Moreover, an injector at 1 TeV or more would be absolutely necessary for a future higher energy LHC (e.g. "DLHC"). In any case, experience with commissioning and running-in will help better estimate the interest of increasing the LHC injection energy to 1 TeV.

3. Implementation stages and benefits

The implementation of the proposed upgrades is foreseen in four stages, summarized in table 4, together with their main benefits for the various users.

In the first stage, Linac4 is built, which will simplify operation of the PS complex for LHC, secure the delivery to the SPS of bunches with the ultimate characteristics and help investigate the SPS capability to handle very high brightness beams.

In the second stage, the PS is replaced by PS2 (or PS2+), which should make the SPS able to reliably deliver the ultimate type of beam to the LHC. The mean beam power of approximately 150 kW available at 50 GeV from PS2 can be of interest for physics experiments looking for muon or rare kaon decays. However, as long as no new injector is built for PS2, the PS will have to be used and the performance of PS2 will be limited.

Therefore the third stage should be ideally authorized as soon as possible after the second one. As mentioned in section 2, the preferred solution will be strongly influenced by the presence of other users than PS2 or PS2+. In case a neutrino facility or a next generation ISOL-type radioactive ion beam facility is foreseen, the SPL is a very attractive solution. The maximum beam quality achievable with the SPS will then be available for the LHC.

In the fourth stage, the SPS+ could be built for the benefit of the LHC and its potential higher energy successor, e.g. the DLHC.

Table 4: Implementation stages and benefits

	STAGE	1	2	3	4
	DESCRIPTION (***new accelerator***)	***Linac4*** PSB PS SPS	***Linac4*** PSB ***PS2 or PS2+*** (& PS) SPS	***Linac4*** ***SPL*** ***PS2 or PS2+*** SPS	***Linac4*** ***SPL*** ***PS2 or PS2+*** ***SPS+***
INTEREST FOR	Performance of LHC injectors (SLHC)	+ Ultimate beam from PS	++ Ultimate beam from SPS	++ Maximum SPS performance	+++ Highest performance LHC injector
	Higher energy LHC	-	-	-	+++
	β beam	-	-	++ (γ ~100)	++ (γ ~200) [2]
	ν Factory	-	-	+++ (~ 5 GeV prod. beam[1])	+++ (~ 5 GeV prod. beam[1])
	k, μ	-	~ 150 kW beam at ~50 GeV	~ 200 kW beam at ~50 GeV	~ 200 kW beam at ~50 GeV
	EURISOL	-	-	+++ (5 MW at a few GeV[1])	+++ (5 MW at a few GeV[1])

[1] Full beam power alternatively for ν factory or an ISOL RIB facility if the SPL is built for 5 MW; simultaneously if the SPL is built for 10 MW.

[2] Reduced synergy between super-beam and β beam because of the different ν energies.

4. Conclusion

CERN has traditionally encouraged the use of its accelerator complex by all kind of physics experiments, using beam over all the available energy range. The upgrades proposed to get the maximum benefits from the LHC represent also a unique opportunity to re-enforce this tradition and provide Europe with a world-class facility for neutrinos and possibly nuclear physics (EURISOL) during the next decade.

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References

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[3] *Preliminary accelerator plans for maximizing the integrated LHC luminosity, M. Benedikt, R. Garoby, F. Ruggiero, R. Ostojic, W. Scandale, E. Shaposhnikova, J. Wenninger,* http://paf.web.cern.ch/paf/Documentation/PAFviews.pdf

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