Technical Design Report

Executive summary

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Abstract

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The LIU-PSB project can be broken up into two major upgrade programs: the upgrade of the injection line and injection period for injection of 160 MeV H- ions from Linac4, and the upgrade of the PSB rings, extraction and transfer line for 2 GeV operation. Table xx shows the main upgrade items, along with risks and time lines.

Activity	Baseline or Option	Description	Risk if not done	Time (m)	Can Start	Work status
Magnets	Baseline	Modification/replacement of magnets for 160 MeV injection and 2 GeV operation	some magnets are currently urgent consolidation items; no Linac4 connection, no 2 GeV upgrade	4 to 5	extended EYTS	design and procurement in progress
LL RF	Baseline	Full renovation of the LL RF	old system obsolete and inappropriate for Linac4 and new HL RF	for new HL RF: 7 for L4: 1.5	extended EYTS; TFB modifications planned by the end of 2014	partly completed
HL RF	Baseline	Replacement of the C02 and C04 system by new wideband cavities and renovation of the C16 system	old system obsolete and will not work with Linac4 intensities and 2 GeV; baseline is new RF system	10.5	LS2	prototype installation being tested
Power converters L4 injection	Baseline	New power converters for 160 MeV H- injection	no Linac4 connection		extended EYTS	design and procurement in progress
Power converters ring, extraction & TL	Baseline	Modification/replacement of power converters for 2 GeV operation	no 2 GeV; some items were also consolidation items (reliability issue); the present MPS would need consolidation if continue to		LS2	design and procurement in progress

			run			
Beam instrumentation	Baseline	Improved instrumentation for measurement of high brightness beams and for 160 MeV H- injection	commissioning with Linac4 impossible; quality of emittance diagnostics insufficient	9	extended EYTS	design phase
Beam intercepting devices	Baseline	New main dump and new injection dumps for H- injection	no Linac4 connection		extended EYTS	main dump completed, injection dumps design phase
Linac4 injection	Baseline	Rebuild injection line and injection period for H- injection	no Linac4 connection	9 + 1.5 cool down	extended EYTS	integration phase
2 GeV extraction and transfer	Baseline	Upgrade extraction and transfer hardware from 1.4 GeV to 2.0 GeV operation	no 2 GeV upgrade	7	LS2 (to be checked if some equipment could be installed before in an EYTS…)	design phase
Vacuum	Baseline	Vacuum system for the new injection period, other vacuum work as imposed by the hardware upgrade	no Linac4 connection		extended EYTS	
Electrical Systems	Baseline	Upgrade of the electrical distribution for increased power need (2 GeV operation and increased cooling needs)	inappropriate for increased power needs		in parallel with MPS building construction; can some items from the renovation be done during an EYTS?	
Cooling and Ventilation	Baseline	Full refurbishment of the PSB cooling plant in order to satisfy the needs of 2 GeV operation	obsolete system and inappropriate for new needs		in parallel with MPS building construction; otherwise LS2	
Installation, Transport and Handling	Baseline	Consolidation of handling equipment and adaptation of equipment for installations in	Equipment not ready, delays		LS1	partially completed

		the frame of the energy upgrade				
Civil Engineering	Baseline	New building for the new MPS, various work in the PSB ring to create space for cables	no 2 GeV upgrade	not shutdown dependent		new building design in progress
Interlock Systems	Baseline	New interlocks for operation with Linac4	no Linac4 connection	extended EYTS		
Control	Baseline	Controls needs driven by the other activities	New equipment cannot be controlled	extended EYTS		

2.2 Outlook/concluding remarks

The two main parts of the upgrade (modification of the injection and energy upgrade) are scheduled to be implemented simultaneously during LS2, while it should be noted that all equipment required for Linac4 connection is planned to be available already in 2016. All design choices have been made, with the final decision on the HL RF pending. Preparation, design and procurement are in progress in essentially all areas. Many items are partially consolidation items, i.e. some work on the equipment would need to be done independently of the injection and energy upgrade. This has been detailed in [hanke].

[hanke]: K. Hanke et al, PS Booster Energy Upgrade Feasibility Study - First Report, https://edms.cern.ch/document/1082646/3

3 LIU-PS - 1 -2 pages

3.1 Scope of the LIU-PS upgrade: scope of the machine upgrade: The work that needs to be accomplished to deliver the specified beam parameters at the entrance of the LHC (baseline and options). So what is to be done, how and when? Risks? Status?

Activity	Baseline or Option	Description	Risk if not done	Time (m)	Can Start	Work status
Beam Instrumentation		Renovation of BWS (including turn-by-turn). New plus faster BLMs. New injection SEMGRID. New IPM				
Magnets		New vertical correctors and new normal/skew quadrupoles				
Transverse damper		New power amplifiers				
Longitudinal damper		Finemet cavity to damp longitudinal coupled bunch instabilities.				
Radiation shielding		Increase of radiation shielding on top of extr. Septum and rte Goward				
Power converters		Low energy quadrupoles, orbit correctors, skew quadrupoles/sextupoles. New Power converters for 40-80 MHz cavities				
Beam dumps		New beam dumps				
2 GeV injection		New injection septum. New injection extra kicker. New injection magnet bumper. Appropriate new power converters and new instrumentation for the injection septum included in "Instrumentation" and "Power converters".				
RF-HP		10 MHz System renovation baseline, upgrade of feedback amplifiers.				
RF-LL		New 1-turn delay feedbacks, 10 MHz and 40MHz/80 MHz cavities.				
RF-LL		Replace existing beam control by fully digital beam control.				
Vacuum		New vacuum chambers. New electron cloud monitors. Activities for other groups				

3.2 Outlook/concluding remarks

4 LIU-SPS

Activity	Baseline or Option	Description	Risk if not done	Time (m)	Can Start	Work status
Machine interlocks	Baseline	Replace relays with standard PLC based solution.	Poor reliability; maintenance costs; need to maintain obsolete system	6	LS1	Finished
800 MHz upgrade	Baseline	Install digital control and new 1-turn low-level feedback and feed-forward for amplitude and phase stability. Consolidation of power system. Doubling of available power to match 200 MHz upgrade	Instabilities, impedance and poor beam quality; difficult controlled emittance blowup; longer LHC filling time; resources and reliability risk with obsolete low-level.	12	LS1	Finished
LSS1 vacuum sectorisation	Baseline	Add sector valves around TIDVG and MKP/D to reduce dose, protect equipment and reduce pump- times	Risk of venting and damage to sensitive/very radioactive equipment. Increased radiation dose to personnel	6	LS1	Finished
Scraper improvement	Baseline	Construction of additional spares and local shielding improvement	Reduced LHC performance, with losses from beam tails	0	n/a	Active: assembly
Beam Instrumentation	Baseline	Upgrade MOPOS electronics; new wire scanners; upgrade BGI, BSRT, IMM and Head-Tail monitors	Poor beam size measurement; insufficient resolution, no bunch-by-bunch; extra cost, resources and reliability risk with obsolete systems	24 (total)	LS1	Active: cabling, design, prototypes
Transverse damper upgrade	Baseline	Dedicated pickups; digital low-level control; 200 MHz local oscillator; cable consolidation.	Larger emittances; extra cost; resources and reliability risk with obsolete system, no damping for ions	9	LS1	Finished
Arc vacuum sectorisation	Baseline	Reduce length of arc sectors by factor 2; reduce pumping times; preserve better ecloud scrubbing	Longer scrubbing times for ecloud; longer recovery from vacuum interventions	6	LS2	Active: cabling
Upgrade TIDVG	Baseline	Upgrade TIDVG core to accept future LHC beams	TIDVG damage for intense LHC beams; long (months) recovery time	3	LS2	Active: design
Reduce kicker impedance	Baseline	Addition of transition pieces in MKD; serigraphy of MKQ	Intensity limitation with high duty cycle beams (scrubbing)	3	2015/16	Active: MKD

ZS improvements	Baseline	More pumping; reduce impedance; improve ion traps and anode circuit	Sparking; limit FT beams; longer switch to LHC cycle	3	2015/16	Active: design
200 MHz low level upgrade	Baseline	Upgrade drivers, cavity controllers, HV power supplies, CV and power couplers; digital low-level control	Poor beam control; instability; poor LHC performance; extra cost, resources and reliability risk with obsolete system	6	2016/17	Active: design
Extraction protection upgrade	Baseline	Replacement of TSPG4/6 by upgraded versions with better robustness and protection of MSE	Damage of TPSG or MSE in event of miss-steered beam at extraction	3	LS2	To start
200 MHz power upgrade	Baseline	Rearrange to 6 RF cavities with 2 additional 1.4 MW power plants. Reduce impedance by 15%, double RF voltage to increase RF current.	25 ns bunch intensity limited at about 1.3e11 p+; longer bunches to LHC; beam losses in SPS and LHC	12	LS2	Active: building, tendering, design
TI2/TI8 protection devices	Baseline	Upgrade TCDIs for robustness and protection; new locations in TI2/TI8.	Damage to TCDI or TI2/8 magnets in case of steering error; higher LHC injection losses.	3	LS2	Active: design
New wide band feedback system	Option	Intra-bunch damping system to damp instabilities from TMCI or ECI.	Longer scrubbing times for ecloud; increased need for aC coating; lower instability thresholds	3	LS2	Active: prototype
New external high energy beam dump	Baseline	New dump system outside SPS ring, using existing fast extraction and new switching series of magnets.	Increased TIDVG activation; TIDVG damage; longer setting up times; reduced LHC availability.	6-18	LS2	Active: design
Upgrade MSE septa converters	Option	Replace MSE/T converters with high stability versions	Longer LHC setting up time for injection; LHC injection loss	6	LS2	Active: study
aC coating of vacuum chambers	Baseline	Coat all SPS main magnets and chambers to supress electron cloud. Coat chamber inside magnet, in BHA5	25 ns intensity limitation; poor beam quality; long conditioning times; higher beam losses; larger emittance	18	LS2	Active: prototype
100 ns rise time kickers for ions	Baseline	Upgrade MKP PFLs, new in-vacuum septum, dump and instrumentation	Lower luminosity in LHC for Pb ions	6	LS2	Active: design

4.1 Outlook/concluding remarks

5 LIU-IONS 1 -2 pages

5.1 Scope of the LIU-IONS upgrade: scope of the machine upgrade: The work that needs to be accomplished to deliver the specified beam parameters at the entrance of the LHC (baseline and options). So what is to be done, how and when? Risks? Status?

Activity	Baseline or Option	Description	Risk if not done	Time (m)	Can Start	Work status
10 Hz	Baseline	Allow injection into LEIR every 100 ms	Lower intensity in LEIR	18	2016	Study started
LBS	Baseline	New spectrometer line after connection of Linac4 to PSB	No energy measurement ofLinac3 beam	18	LS2	Study started
LEBT	Baseline	Rematched optics in Low Energy Beam Transport, between source & RFQ	Lower intensity in LINAC3/LEIR	18	2017	Study started
Oven Test stand	Baseline	Additional lead oven to study the dynamics of the existing one	Low knowledge of oven behaviour	6	2015	Active: design
Source test stand	Option	Alternate source for machine experiments, independent of operational one; can be used as spare in case of emergency	No spare source, no training of supervisors			Not started
LEIR Dump	Baseline	Allowing to safely and cleanly dump the ion beam when not desired by PS or LHC.	Vacuum degradation in LEIR and PS	18	LS2	Study started
100 ns rise time kickers (see SPS)	Baseline	Upgrade MKP PFLs, new in-vacuum septum, dump and instrumentation	~23% less peak luminosity in LHC for Pb ions	6	LS2	Active: design
SPS Momentum slip Stacking	Baseline	RF gymnastics to merge trains PS trains in the SPS, effectively decreasing the bunch spacing from 100 ns to 50 ns.	~43% less peak luminosity in LHC for Pb ions	6	LS2	Active: design
SPS damper	Baseline	Upgrade transverse damper for ion injection in SPS	Larger ion emittances		2015	Active: prototype

5.2 Outlook/concluding remarks

In order to reach the required performance level – 7 times the design peak luminosity for Pb-Pb collisions level – the intensity limitation currently experienced in LEIR has to be overcome. This can only be achieved with an extensive study programme, including not only simulations but especially machine developments with beam.

6 Costing/scheduling/outlook 1 -2 pages

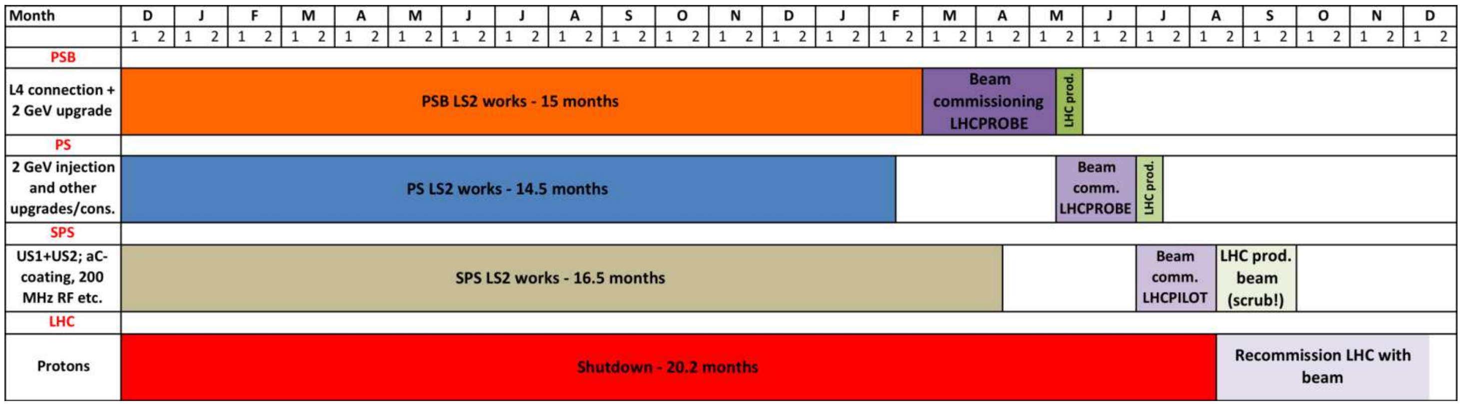
6.1 Costing

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Grand Total MCHF
LIU-MNG						55	764	1,668	2,000	2,000	2,000	2,000	1,000	**11,487**
LIU-PSB	138	313	340	955	1,711	4,195	6,351	13,827	21,694	11,863	4,165	396	0	**65,948**
LIU-PS				245	461	3,429	3,246	4,814	4,936	3,297	1,795	240	75	**22,538**
LIU-SPS				504	2,126	3,450	5,856	8,712	13,583	18,308	15,085	9,168	1,075	**77,867**
LIU-ION							50	400	500	2,100	2,300	2,000	0	**7,350**
LIU Project Grand Total	138	313	340	1704	4298	11129	16267	29421	42713	37568	25345	13804	2150	**185,190**

Scheduling

For implementing all LIU upgrades during LS2**:** 20.5 months to produce LHC Pilot and 22 months to produce run2 LHC beam type (prior LS2).

The schedule needs to be reduced by (at least) 3.5 months and work is on-going to identify installation which could be anticipated to run 2 winter stops and shutdowns.



6.2 Outlook

Extensive MDs will be required to benefit from the injectors' upgrades and reach the expected beam characteristics Þ LIU has to be completed ~one LS before the HL-LHC upgrades are implemented in the collider (LIU during LS2 if HL-LHC is during LS3)

Acknowledgement (Section style)

We wish to thank A. N. Colleague for enlightening comments on the present topic.

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Appendix A: Title of appendix (Appendix heading 1 style)

A.1 Appendix heading 2 (Appendix heading 2 style)

While the title of the appendix is styled as a section heading, please remember to use 'Section', 'Subsection', etc. styles for the headings (rather than the numbered styles), adding the Appendix number and tab yourself.

A.1.1 Appendix heading 3 (Appendix heading 3 style)

The appendices are otherwise formatted just like the main body of the contribution.

A.1.1.1 Appendix heading 4 (Appendix heading 4 style)