Commissioning of the PSB with Linac4

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Booster Re-commissioning: Phases

re-commissioning of the PSB with the 160 MeV H- beam from Linac4

two stages:

1.) re-commissioning to nominal performance, i.e. produce beams with parameters as with the present Linac2

2.) commissioning to ultimate performance, making full profit of Linac4 to generate PSB beams with brilliance and intensities exceeding the ones possible with Linac2

tasks:

- commissioning strategies and preparation work

- scheduling of the commissioning

- commissioning phase

task 1: development of commissioning strategies and other preparation work

- commissioning strategies:
  - identify milestones, and anticipate for each milestone possible difficulties together with strategies and procedures to overcome them
  - deduce from this the definition of hardware (e.g. beam diagnostics) and applications needed to ensure efficient commissioning
  - to be completed by end 2009 in order to give input for hardware choices; at this stage the time needed to achieve the milestones will be estimated

- develop detailed scenarios for the production of the different beams and establish operational procedures

- coordination of all Booster related aspects
  - follow up and provide input for design, design choices and hardware upgrades related to the transfer of the beam from Linac4 to the PSB (e.g. identify needs for consolidation of hw in the existing part of the transfer line)

    example: consolidation of the BHZ (and other) power supplies
  - strategy for the characterization of the beam during its transfer to the PSB

    example: diagnostics for the dump line, upgrade of LBE/LBS lines

- consolidation and upgrade of the Booster and its beam lines (e.g. improved or additional instrumentation)
  examples:
  - upgrade of the Booster orbit measurement with new read-out electronics to allow (at least for some pick-ups) turn-by-turn measurement
  - renovation of the multipole power supplies (has started)

- identify and schedule modifications that can be advanced to shutdowns before 2012/13 (to reduce the work load during the 2012/13 shutdown as far as possible)
  examples: removal of the ion distributor, installation of new bump magnets, consolidation of distributor electronics in 2007/08

- functional specifications for the operational interfaces (application programs) that will be needed for the Linac4-PSB complex in the Linac4 era
  example: first Linac4 applications are being worked on during the 2008/09 shutdown, e.g. SEM grid application

- schedule machine studies (MDs) to explore operational scenarios in the Linac4 era
  example: single batch transfer of LHC beams to the PS

• at end of Linac4 commissioning/beginning of PSB commissioning nominal performance

condition:
- hardware installation completed and hardware tested
- Linac commissioning completed up to LBE/LBS measurement lines

first rough list of milestones, together with first ideas on critical systems and procedures:

1.) verification of the beam in the LBE/LBS emittance and spectrometer measurement lines, including energy and energy spread (LBS)
(should be completed within the Linac commissioning)
2.) if necessary re-match of the line upstream of LBE/LBS and/or BI line
→ critical instrumentation: transverse phase space
3.) transfer of the beam to the PSB injection region

- during PSB re-commissioning to nominal performance

condition:
- synchronization PSB/Linac4 chopper
- synchronization of the rf systems of the 4 PSB rings (new digital low-level rf control system)

1.) transfer low intensity beam through the injection region; proper steering with view screen in foil position; measurement of foil efficiency and foil heating
→ critical items: beam position; foil temperature; interlock required to work in case of foil degradation or damage

2.) establish injection and circulating beam
→ critical items: pick-ups with varying integration time (for measurement of bump closure); possibly additional trim power supplies for some QDEs

3.) increase intensity, setting up of chopping during distributor rise time
→ critical items: beam loss measurement, interlocks, foil position for safe operation

4.) beam capture
→ injection and first capture on ramp or flat bottom?
- slow capture to improve adiabaticity and to reduce losses to acceptable level
- adjust energy spread of injected beam
→ critical issues: no fundamental difficulties expected (similar to present operation)

Commissioning Strategy & Preparation

- during commissioning to ultimate performance

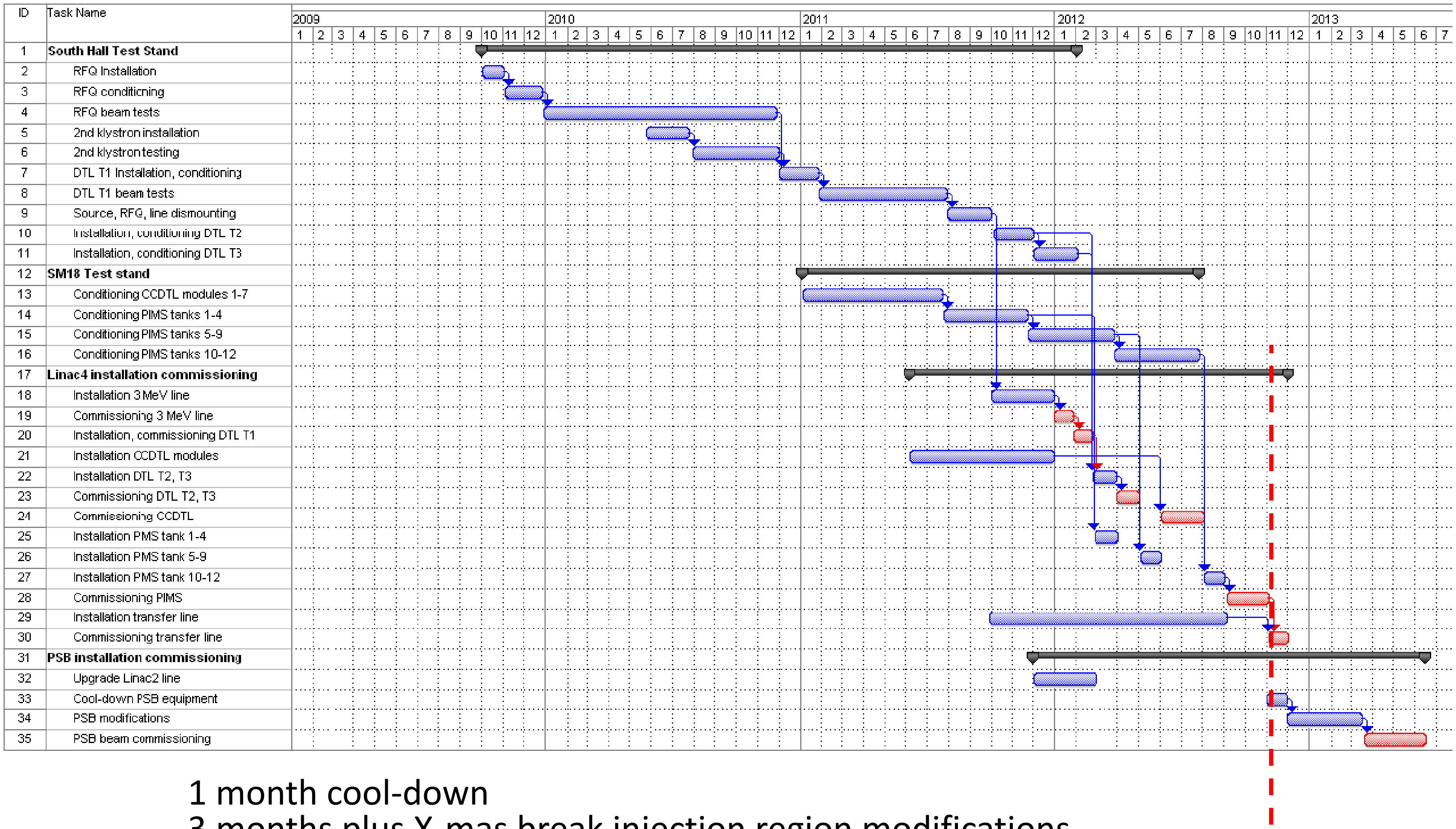
  condition:
  - synchronization of PSB RF with energy modulation in the PIMS

1.) setting up of longitudinal painting
  1.1) setting up of energy ramping and verifications in the measurement lines
    → critical instrumentation: LBS (spectrometer) line
  1.2) setting up of chopping for longitudinal painting
    → critical system: control of chopping and energy modulation
    → first painting on flat bottom or ramp?
  1.3) setting-up of PSB RF capture for longitudinal painting

2.) increase of intensity and/or beam brilliance by iteratively
  - increasing the number of injected turns
  - fine adjustments (e.g. dynamic working point) to optimize performance and to minimize beam loss (might already be required from the beginning for high-intensity beams)
  - verification that losses stay at acceptable level

3.) setting up of single-batch PSB to PS transfer for nominal 25ns LHC beams
  - longitudinal gymnastics in the PSB
  - transfer and gymnastics in the PS (fast blow-up and/or bunch rotation to limit duration with very large direct space charge tune shifts)

task 2: scheduling of the commissioning



1 month cool-down
3 months plus X-mas break injection region modifications
3 months Booster commissioning

Linac2 stop

Scheduling: Nominal Performance

inside the 3 months Booster commissioning:
(no detailed planning for the moment but first rough time estimate for the different steps)

1.) characterization in the LBE/LBS lines : <1 week (should be part of linac commissioning)
2.) if re-matching required: 1 weeks in total with 1.)
3.) transfer to injection region, steering etc: 1 week
4.) setting up of low intensity beam on the stripper foil: 2 weeks
5.) establish injection and circulating beam: 2 weeks
6.) increase intensity, setting up of chopping during distributor rise time: 2 weeks
7.) beam capture: 1 week
8.) setting up of all user beams: 3 weeks for the first beams, the total time to set up all beams will be longer (setting up continues as function of the accelerator schedule)

Σ = 12 weeks

- 3 months Booster commissioning estimated tight but sufficient
- followed by 2 weeks for PS and 2 weeks for SPS according to our experience (for PS and SPS the beams are identical during phase 1)

24h operator shifts, can assume 2 physicist/engineer shifts (early and late – night shifts if running late).

scheduling for commissioning to ultimate performance is less critical, since it can be carried out in parallel to operations

- first setting-up of longitudinal painting is expected to take about 6 weeks (2 weeks for energy ramping, 2 weeks for chopping and 2 weeks for capture)
- increase of intensity and setting-up of single-batch transfer to the LHC will be an iterative process and last for about the whole run

task 3: commissioning

beams to be delivered from the PSB in the first stage ("nominal performance"):

- deliver all operational beams from the PSB with Linac4 with the same characteristics that they have presently with Linac2 (in the moment when Linac2 is permanently stopped)

machine sectors:

- commissioning of the Booster injection line, the H- injection scheme, the Booster rings and the beam lines at extraction (BE, BT, BTP up to PS injection point, BTM, BTY up to ISOLDE targets)

LHC-type beams

user	**description**	**h**	**rings**	**intensity per ring**	**emittance r.m.s.** x [π mm mrad] (n.) y [π mm mrad] (n.) z [eVs] at extr.	**dp/p** [10^{-3}]	**bunch length at extraction** total, [ns]	**energy** [GeV]
LHC25A LHC25B	25ns LHC beam	1	1,2,3,4 3+4	nom: 1.6E12 (optional 1/10, 1/5, 1/3,1/2*, 2/3)	2.5 2.5 1.3	2.0	180	1.4
LHC75A LHC75B	75ns LHC beam	1	1,2,3,4 3+4	0.8-5.4E11	2.5 2.5 0.9	2.0	150	1.4
LHCPILOT	early LHC beam	1	3	0.5E10	2.5 2.5 0.3	1.0	85	1.4 GeV
LHCPROBE	early LHC beam	1	3	0.5-2.0E10	<1 <1 0.2	1.0	75	1.4 GeV
LHCINDIV	single bunch physics beam	1	1-4	2.0-12E10	2.5 2.5 0.3	1.0	80	1.4 GeV

* LHC50

other physics beams

user	**description**	**h**	**rings**	**intensity per ring**	**emittance r.m.s.** x [π mm mrad] (n.) y [π mm mrad] (n.) z [eVs] at extr.	**dp/p** [10^{-3}]	**bunch length at extraction** total, [ns]	**energy** [GeV]
SFTPRO	SPS fixed target	2	1,2,3,4	3.5E12	6.0-8.0 5.0-6.0 1.6	2.7	180	1.4
CNGS	CNGS beam	2	1,2,3,4	0.6-8.0E12	varying varying 1.6	2.7	180	1.4
EASTA	PS East Hall	1	3	2.0-3.0E11	1.0 1.0 1.1	2.0	150	1.4
EASTB	PS East Hall	1	2,3	1.0E11	3.0 1.0 1.1	2.0	150	1.4
EASTC	PS East Hall	1	3	4.5E11	3.0 1.0 1.1	2.0	150	1.4
AD	AD	1	1,2,3,4	4.0E12	7.0-8.0 6.0 1.7	2.2	190	1.4
NORMHRS NORMGPS	ISOLDE HRS and GPS	1	1,2,3,4	1E13	<15.0 <9.0 2.3	2.7	230	1.0/1.4
STAGISO	ISOLDE staggered beam	1	2,3,4	depending on user	<5.0 <4.0 <1.6	<2.0	230	1.0/1.4
TOF	nTOF beam	1	1,2,3,4	9.0E12	~20 ~10 2.1	2.9	230	1.4

beams to be delivered from the PSB in the second stage
("ultimate performance")

the aim of this second phase of PSB commissioning with Linac4 is to make full use of the increased injection energy and the new injection scheme

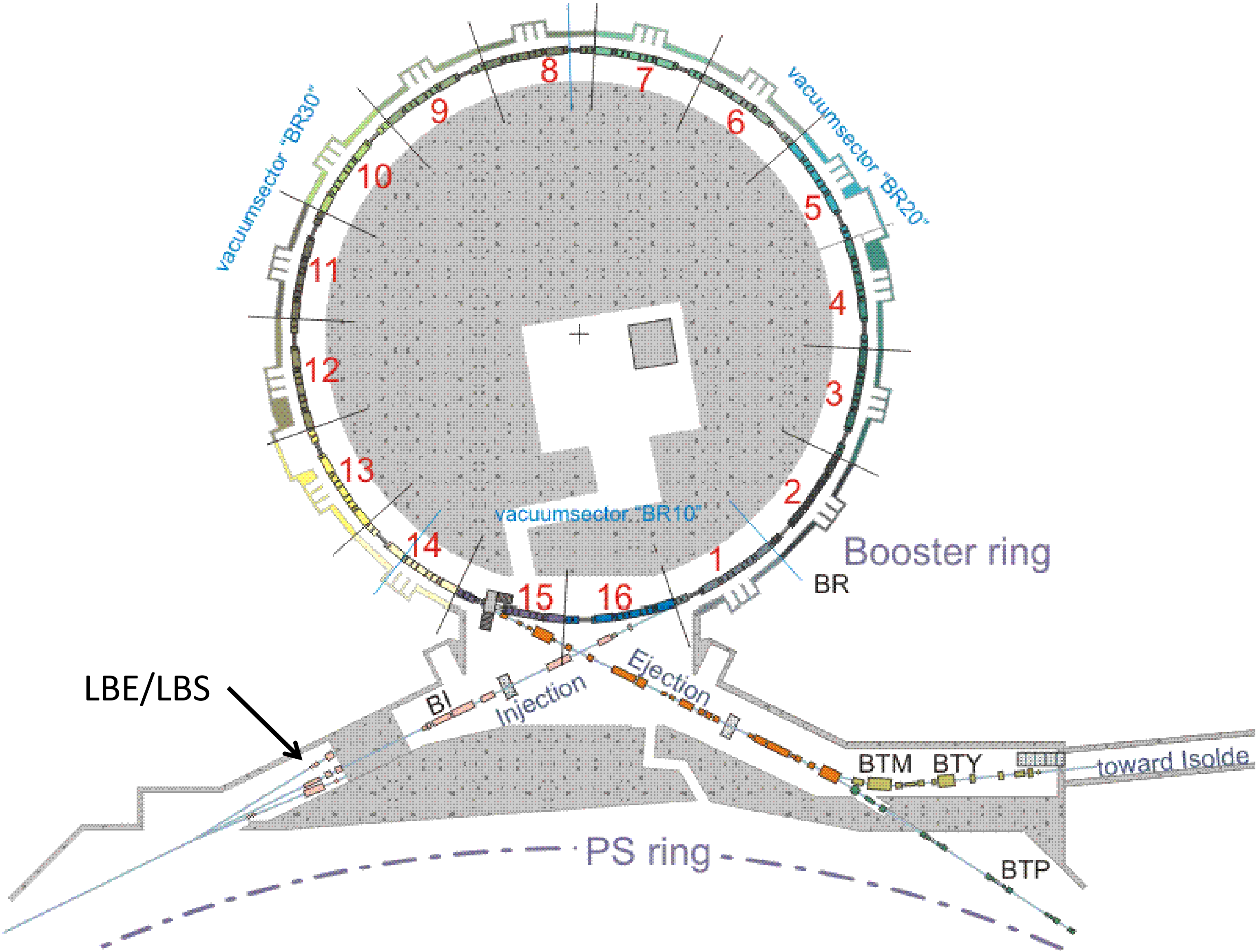
this stage comprises the setting up of the proposed active longitudinal painting scheme and aims at producing the following beams beyond the present possibilities with Linac2:

- nominal 25ns LHC beam with single transfer between the PSB and the PS
  - intensity per PSB ring has to be doubled to 3.25E12 protons while keeping the normalized transverse emittance within ε (r.m.s.) = 2.5 μm
- improvements for the PS and ISOLDE
  - increased injection energy and new injection principles allow generating beams with higher intensities and/or smaller emittances also for other users than LHC
  - PS high intensity operation: emittances tailored to needs of PS to reduce losses and (slightly) higher intensity
  - ISOLDE: increased intensity possible

Machine Sectors

- PSB includes the Booster rings as well as the Booster injection line (BI) and the beam lines at extraction (BE, BT up to PS injection, BTP, BTM, BTY up to ISOLDE targets)
- assume that this work package is in charge of commissioning these lines
- assume that this work package is not in charge of commissioning the transfer line from Linac4 to the PSB (new transfer line, LT, LTB).
- assume that Linac4 beam is available on schedule and within specifications at the location of the LBE/LBS measurement lines

Machine Sectors



- camera to monitor the foil and foil temperature; foil holder design such that one position is occupied by a view screen
- SEM grids in Booster rings: the first idea to have SEM grids next to each stripper foil was dropped due to space constraints. However two SEM grids (horizontal and vertical) per Booster ring at a convenient position appear very useful to monitor the matching. Multi-turn acquisition (~16 turns) and ppm operation required.
- monitoring of the H^0 and H^- dump: it has been proposed to segment the dump in 2 parts for H^0 and H^- and to measure the dump current separately for each part via a resistance. This would allow to detect foil degradation through a relative comparison (no absolute measurement). A monitor (view screen) should be glued on each of the two parts for a 2D profile of the dumped beam.
- bump closure: modify the PSB orbit measurement system; replace old normalizer modules by new electronics providing digital data with variable integration time. This would enable turn-by-turn orbit measurement
- large-band pick-up: it should be considered to add a large-band pick-up (up to 1.5 GHz) for transverse measurements in the Booster. A large-band pick-up for longitudinal measurements is available.

Safety Aspects

It is in the scope of this work package to ensure that safety regulations are met, as it is the case during operation of all accelerators. The main risks are electrical risks and radiation protection issues.

We will ensure that operational procedures for the operation of the PSB with Linac4 will be set up and respected. This includes the procedures for “patrouilles”, the procedures for giving access, and operation modes.

Another issue is the activation of accelerator components by beam loss. Here, the appropriate measures to minimize activation must be put in place (interlocks triggered by BLMs). In case hands-on maintenance is required, the appropriate cool-down time is to be determined by SC/RP.

Electrical equipment must be protected as well as possible (power/magnets work packages); In case work needs to be done on electrical equipment, the usual procedures for “condemnation” and “consignation” will be applied.

Definition of alarms (in case of beam loss etc.) that will have to be transmitted to the CCC in order for appropriate action to be taken.

Machine Protection and Interlocks

The Booster commissioning working group is looking into the specifications for interlocks to be used for machine protection.

example: rapid source stop in case of e.g. distributor failure or foil degradation

- detailed list of requirements in preparation

The Booster commissioning Working Group involves representatives of several work packages. It meets presently about every 4-6 weeks. The frequency of the meetings will be increased as the commissioning phase approaches. The minutes and action lists of the working group meetings can be found at

https://twiki.cern.ch/twiki/bin/SPL/BoosterCommissioningWorkingGroupMeetings

mandate of the working group:

- follow up of hardware and software issues related to the upgrade of the Booster and its injection line in order to ensure that the machine is operational when commissioning starts
  - examples: consolidation of the Booster orbit measurement (start 08/09 shutdown), removal of ion distributor, improved diagnostics (e.g. matching monitors in the rings), …
- decide and report commissioning procedure; this includes the sequence of events, and some fine planning
- give input for the general schedule, make sure that it is realistic and coherent; draft a detailed commissioning schedule, to be compatible which the overall project schedule
- characterization of beams from Linac4 during transfer to the PSB (dump line, measurement lines); specifications of the diagnostics for the beam line between the end of PIMS and Linac dump
- provide specifications for applications from an operations point of view

intermediate milestones:

- first report on commissioning strategies by the end of 2009 (to allow taking into account some conclusions for hardware design of equipment)
- reports on the design of particular hardware not covered by other work packages:
  - report on the upgrade of the LBE-LBS lines: mid 2009
  - report on the dump line: mid 2009
- report on the Booster commissioning procedures
- detailed schedules (~1 year before start of the commissioning)
- minutes of the Booster Commissioning Working Group addressing detailed technical issues

The work package “Booster Commissioning to nominal performance” has a budget of 100 kCHF, which have been preliminarily allocated to be spent to 50% during 2012 and to 50% during 2013. As there is no hardware involved in this work package, the budget will be used for travel (to invite experts during the commissioning phase, or for CERN staff to visit labs which operate facilities with H- injection). The budget can also be used to cover last-minute items which turn out to be needed for operation and are not available, e.g. additional OASIS channels, computers and the like.

The work package “Booster commissioning to ultimate performance” has also a budget of 100 kCHF.

The manpower allocated for Booster commissioning (to nominal performance) in the Operations Group is presently 0.65 FTE, split between two physicists at 40% respectively 25% (plus one fellow).
Integrated over 5 years this yields 3.25 M.YEARS

There is additional manpower in terms of "second-job" activities of Booster operators, who do application programming for the PS complex machines including Linac4. It is assumed that the involvement of Booster operators (7 technical engineers) will increase as the commissioning comes closer, reaching 100% during the commissioning phase itself (to be confirmed by the operations group)

The manpower allocated for commissioning to ultimate performance is 0.85 M.YEARS (spread out over 5 years), plus an additional request of 1 M.YEAR shortly before and during commissioning.

It will be envisaged to involve students and visitors.

Hands-on experience made at other laboratories having already implemented H^- charge exchange injection is very relevant for PSB recommissioning with Linac4. To profit from this experience we plan to visits of CERN staff at laboratories operating an H^- and to invite outside experts for the commissioning phase.

A significant part of the allocated budget is needed to cover travel expenses associated with collaborations with external institutions.

Present Status

The Booster commissioning working group has started to work officially on 22 November 2007, with informal discussions taking part already beforehand. The minutes and action lists of the working group are available via the Linac4 web page.