LIU hardware and beam commissioning: strategy

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on behalf of the LIU Beam Commissioning Working Group

Acknowledgements: D. Jacquet for the Injector Settings Management Working Group

Chamonix 2018 Workshop, 29 January – 1 February, 2018
Pre-LS2 LHC injector complex and beams

NON-LHC facilities:
ISOLDE: the radioactive ion beam facility
East Area: secondary beam lines fed by PS protons on 2 targets
nTOF: pulsed neutron source
AD/ELENA: low energy antiprotons
AWAKE: proton driven plasma wake field acceleration
HiRadMat: high intensity /brightness to material test facility
North Area: secondary beam lines fed by SPS protons/ions on 3 targets. Multiturn extraction (MTE) beam.
# Pre-LS2 LHC injector complex and beams - protons

<table>
<thead>
<tr>
<th>$p^+$ beam/facility</th>
<th>machine</th>
<th>comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISOLDE</td>
<td>PSB</td>
<td>$I &gt; 3.2 \times 10^{13}$ in 4 rings; critical: losses and steering in extraction region and to ISOLDE targets</td>
</tr>
<tr>
<td><strong>MTE for North Area</strong></td>
<td>PSB, PS, SPS</td>
<td>$I_{SPS} \leq 4 \times 10^{13}$; $h=2$ in PSB; critical: $\varepsilon_V$&lt;br&gt;Low intensity MTE required for alignment in PS and SPS and aperture measurements</td>
</tr>
<tr>
<td>LHC</td>
<td>PSB, PS, SPS</td>
<td>~ 15 variants; critical: $\varepsilon$, tails, losses; extractable to LHC, SPS&lt;br&gt;COAST,... Probe beam not commissioning beam in injectors</td>
</tr>
<tr>
<td>nTOF</td>
<td>PSB, PS</td>
<td>$I_{PSB} 8 \times 10^{12}$ from 1 PSB ring; or $3 \times 10^{12}$ in parasitic operation</td>
</tr>
<tr>
<td>East</td>
<td>PSB, PS</td>
<td>$6 \times 10^{11}$ from 1 PSB ring</td>
</tr>
<tr>
<td>AD</td>
<td>PSB, PS</td>
<td>$4.5 \times 10^{12}$ from 4 rings</td>
</tr>
<tr>
<td>HiRadMat</td>
<td>SPS</td>
<td>Operation of facility with high intensity LHC beam. critical: $\varepsilon$,&lt;br&gt;High precision experiments</td>
</tr>
<tr>
<td>AWAKE</td>
<td>PSB, PS, SPS</td>
<td>$I_{SPS} \sim 3 \times 10^{11}$; $4 \sigma_t &lt; 1$ ns, synchronised to AWAKE laser</td>
</tr>
</tbody>
</table>

**RED** = required at commissioning stage
Pre-LS2 LHC injector complex and beams

- Commissioning of all operational $p^+$ beam flavors in injector complex: 8 weeks (relying on settings of previous run and not including LN2)
  - LHCPROBE beam no injector commissioning beam
  - Injector commissioning: cannot be done with LHC beams only, FT beams required

- Single and multi-bunch ion beams for LHC and SPS fixed target commissioned parasitically to $p^+$ operation, day shifts: > 8 weeks

### 2018 schedule

<table>
<thead>
<tr>
<th>Wk</th>
<th>Mo</th>
<th>Tu</th>
<th>We</th>
<th>Th</th>
<th>Fr</th>
<th>Sa</th>
<th>Su</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>22</td>
<td>DSO test LN2</td>
<td>DSO test TT2</td>
<td>FSO test LN2</td>
<td>Close PSB, PS, TT2</td>
<td>HW tests, Cold Checkout &amp; Re-commissioning with beam</td>
<td>Technical Stop (YETS)</td>
</tr>
<tr>
<td>5</td>
<td>29</td>
<td>START LHC</td>
<td>DSO test PSB, PS</td>
<td>Beam to PSB</td>
<td>Close SPS</td>
<td>Beam to PSB</td>
<td>Beam to PSB</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>DSO test LN4</td>
<td>DSO test TT2</td>
<td>Close SPS</td>
<td>DSO test TT2/T12</td>
<td>Beam to PSB</td>
<td>Beam to SPS</td>
</tr>
<tr>
<td>7</td>
<td>13</td>
<td>DSO test PSB, PS</td>
<td>START LN4 RR</td>
<td>Beam to PSB</td>
<td>DSO test PSB - NA</td>
<td>Beam to PSB</td>
<td>Beam to PSB</td>
</tr>
<tr>
<td>8</td>
<td>20</td>
<td>START LN4 RR</td>
<td>Beam to PSB</td>
<td>Close ISOLODE</td>
<td>Beam to PSB</td>
<td>Beam to PSB</td>
<td>Beam to PSB</td>
</tr>
<tr>
<td>9</td>
<td>23</td>
<td>Beam to AD</td>
<td>Beam to AD</td>
<td>Beam to AD</td>
<td>Beam to AD</td>
<td>Beam to AD</td>
<td>Beam to AD</td>
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<tr>
<td>10</td>
<td>24</td>
<td>Beam to PSB</td>
<td>Beam to PSB</td>
<td>Beam to PSB</td>
<td>Beam to PSB</td>
<td>Beam to PSB</td>
<td>Beam to PSB</td>
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<tr>
<td>11</td>
<td>25</td>
<td>Beam to LEIR</td>
<td>Beam to LEIR</td>
<td>Beam to LEIR</td>
<td>Beam to LEIR</td>
<td>Beam to LEIR</td>
<td>Beam to LEIR</td>
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<td>12</td>
<td>26</td>
<td>Beam to LEIR</td>
<td>Beam to LEIR</td>
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<td>13</td>
<td>27</td>
<td>Beam to LEIR</td>
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<td>14</td>
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<td>Beam to LEIR</td>
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<td>15</td>
<td>29</td>
<td>Beam to LEIR</td>
<td>Beam to LEIR</td>
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<td>16</td>
<td>30</td>
<td>Beam to LEIR</td>
<td>Beam to LEIR</td>
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</tbody>
</table>

LHC high intensity available
LIU goals in a nutshell

- **LIU beam parameters**

<table>
<thead>
<tr>
<th>Protons</th>
<th>Bunch length</th>
<th>Bunch intensity</th>
<th>Normalized emittance</th>
<th>Number of bunches</th>
</tr>
</thead>
<tbody>
<tr>
<td>HL 25 ns</td>
<td>1.65 ns</td>
<td>$2.3 \times 10^{11}$</td>
<td>2.1 (\mu m)</td>
<td>288</td>
</tr>
<tr>
<td>BCMS LIU</td>
<td>1.65 ns</td>
<td>$2 \times 10^{11}$</td>
<td>1.3 (\mu m)</td>
<td>$288 = 6 \times 48$</td>
</tr>
</tbody>
</table>

- **Pb\(^{82}\) and slip stacking**

<table>
<thead>
<tr>
<th>Bunch intensity (Pb/b)</th>
<th>Normalized emittance</th>
<th>Number of bunches</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.9 \times 10^8$</td>
<td>1.5 (\mu m)</td>
<td>$14 \times 4$</td>
</tr>
</tbody>
</table>

- **Fixed target beams:** *restore the pre-LS2 performance*
## Summary of main hardware upgrades for LIU

<table>
<thead>
<tr>
<th>Machine</th>
<th>Hardware upgrades*</th>
</tr>
</thead>
<tbody>
<tr>
<td>LINACs</td>
<td>LINAC4 = 160 MeV normal conducting H⁻ LINAC</td>
</tr>
<tr>
<td>LEIR</td>
<td>new transfer line beam position monitors, beam dump, new orbit system</td>
</tr>
</tbody>
</table>
| PSB     | • new H⁻ injection system at 160 MeV  
          | • new beam instrumentation  
          | • 2 GeV extraction energy → new main power supply  
          | • new RF system  
          | • upgraded transfer lines and extraction system |
| PS      | • new 2 GeV injection system  
          | • new beam instrumentation  
          | • new internal dumps  
          | • RF upgrade for reliability/maintainability and beam stability |
| SPS     | • 200 MHz power upgrade and new LLRF  
          | • new beam dump and protection devices  
          | • AC coating and impedance reduction, aperture consolidation  
          | • new beam instrumentation |

* Details of upgrades in machine specific talks of this session.
Rough timeline of post-LS2 beam commissioning

- **The first year of Run 3 (2021) will have to be fully devoted to**
  - The recovery of the pre-LS2 beams (protons) with LIU equipment, both for LHC and FT physics
  - The production of the Pb ion beams to the full LIU performance with slip stacking in SPS for the 2021 ion run

- **2022 should be devoted to accelerating 2e11 p/b injected in the SPS**
  - Already injected in 2017 with 70% of the target bunch intensity, brightness and train length
  - Still marginally stable in the PS and affected by instabilities in the SPS

- **Further intensity steps (additional 15% and 10%) to be made in 2023 and 2024**
  - These steps are unprecedented and will require dedicated scrubbing runs in the SPS and fine transverse and longitudinal optimisations
  - While high intensity is being commissioned, corrective actions compatible with YETS could be applied, if needed.

**2020-21**

- Commissioning of pre-LS2 beams with Linac4 and installed LIU equipment + commissioning of the LIU performance Pb ion beams with slip stacking in SPS

**2022**

- Commissioning of 1.8 $10^{11}$ p/b with the desired brightness and loss budgets out of SPS

**2023**

- Commissioning of 2.1 $10^{11}$ p/b up to SPS extraction and tests of higher intensity at least up to the SPS injection

**2024**

- Commissioning of 2.3 $10^{11}$ p/b up to SPS extraction with the desired brightness and loss budgets
LIU commissioning program - what needs to be done?

- **Integrate new hardware**
  - New operational scenarios, higher level parameters
  - Define/prepare software, cover all interfaces (interlocks, timing, settings generation,...)
  - Define test procedures

- **Tools**
  - Next generation settings management in injectors: model based settings generation and correction
  - New timing system approach

- **Ensure readiness of plans and procedures for commissioning**

- **Establish teams and responsibilities**

- **Organize, execute, analyze dry runs/reliability runs/hardware commissioning, beam commissioning to deliver beam parameters according to predefined time line**
How will we do it?

→ LIU Beam Commissioning Working Group (BCWG)

First meeting 19 October 2017

https://indico.cern.ch/category/9633/

• A la LHC commissioning

• Members from operations, beam dynamics, equipment groups and controls

• Collaboration across all machines
  • To establish common strategy on how to commission beams
  • To ease preparing interfaces between machines (beams, equipment, signals)
  • Towards common philosophy on how to operate CERN's accelerators
    − Review current operational methods
    − Majority of lower energy machines does not rely on model based settings generation and correction
    − LHC ideas to injectors and develop them further

• Core team for strategy and separate teams for specific tasks
  • E.g. injector settings management working group
How will we do it? - BCWG in 2018

<table>
<thead>
<tr>
<th>2018 Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Formalize beam commissioning</strong> with 2018 start-up</td>
</tr>
<tr>
<td>• Add beam commissioning to re-commissioning check lists</td>
</tr>
<tr>
<td>• Establish planning and time allocation of tests</td>
</tr>
<tr>
<td>• Review approach and procedures afterwards</td>
</tr>
<tr>
<td>• Take reference measurements</td>
</tr>
</tbody>
</table>

LEIR will already have all LIU upgrades

**This will serve as template for after LS2**

**Tools:**

• Launch injector **settings management** working group

• Establish prioritized list of tools to be prepared/upgraded for after LS2 per machine; define resources and deadlines

• Develop further **online beam parameter (and performance) analysis and tracking**

• Prepare list of methods/algorithms to test during 2018 run

**How to commission main new LIU systems** in the different machines?

• Define beams, entry conditions, infrastructure, test procedures, tools

• Include new systems in beam commissioning check lists
Ongoing activities (1)

- **Online beam commissioning check list and planning tool**
  - To define checks with procedures, track progress and plan the hardware and beam commissioning period

Example:
Check lists 2017 in the SPS
Ongoing activities (1)

- **Online beam commissioning check list and planning tool**
  - To define checks with procedures, track progress and plan the hardware and beam commissioning period

Example:
Check lists 2017 in the SPS
Ongoing activities (1)

- **Online beam commissioning check list and planning tool**

<table>
<thead>
<tr>
<th>Initial Aperture Scan</th>
<th>100%</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Orbit</th>
<th>83%</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Orbit</th>
<th>Time in BPMS for first turn FT</th>
<th>Time in BPMS for LHC</th>
<th>Good signal on max number BPMS</th>
<th>Kick response for gain</th>
<th>Beam based alignment, 2 optics</th>
<th>Beam dump pattern check</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit</td>
<td>✅</td>
<td>✅</td>
<td>✅</td>
<td>✅</td>
<td>✅</td>
<td>✅</td>
</tr>
</tbody>
</table>
Ongoing activities (1)

- **Online beam commissioning tool**
  - beam based alignment, 2 optics

- calibrate BPMs
- make sure that the gates are set correctly for FT on the first island
- do short kick response with single kicks 90 deg apart, check whether all BPMs follow. Compare the oscillation in difference what you should expect (pink line on YASP display e.g. in H: Last predicted H correction DIFFERENCE to DV Ref)
- SFT 5000 ms
- LHC25ns: at flattop

prepare data directory in sps/steering directory: e.g. alignment2017

**The actual correction:**
- Take multiple acquisitions. Save the average in File>Save/Read data files... (not only on the multiple acquisition window)
- start Yasp with configuration: 'double optics setup'
- under "Machine Specials": choose "Multiple Twiss Selection"
- choose the optics for beam 1 and beam 2: do not forget to press "load" afterwards
- under "Machine Specials": choose multiple Twiss data. open the files for the different beams
- under "status control": go to "scaling": scale e.g. QE2 BPMs H and V by 1.2466 (even though the ks of H and V are not completely the same)
- check whether the old alignment from the year before does not create closed bumps with the new corrections.
- Check also log book entry of Tuesday 15th of March 2016 afternoon shift.
History of orbit tested for beam based alignment, 2 optics.

**VKAIN 13:53**

Quadrupoles moved:

H: QF.32410 (0.37 mm) QF.51010 (-0.59 mm)
V: QD.20710 (0.48 mm) QD.30110 (0.55 mm)

FT beam RMS improvement:

H: 2.45 mm -> 1.78 mm
V: 2.77 mm -> 1.93 mm

LHC beam RMS improvement:

H: 3.5 mm -> 2.2 mm
V: 2.9 mm -> 1.7 mm
Ongoing activities (2) – LINAC4 and PSB injection system

• LINAC4 commissioned to 160 MeV with H⁻ on main dump
  • RF hardware and software commissioning still ongoing
  • Reliably achieved current: 23 mA peak (goal: 40 mA)
  • Emittance, energy, energy spread within specification
  • Availability of 90.6% of beam on dump achieved

• Highlight 2017: Half sector test (10/2016-4/2017) – test ½ PSB injection chicane of one ring in LINAC4 transfer line:
  • Understand and learn to operate PSB injection equipment
  • Stripping foil test stand: evaluation of lifetime and foil changing mechanism and foil diagnostics
  • Stripping efficiency > 99%

• Next milestones for LN4 operation:
  • Prepare LN4 for PSB injection; transition to operation to be completed
    – Debuncher cavity, RF feedforward to be commissioned
    – Improve beam quality out of LN4: current, pulse shape
    – Address operational issues: flexible operation with RF feedforward, interlocking
  • Finish remaining software tools: emittance measurement,…
    – Responsibility of software for source control to be clarified.
Ongoing activities (3)

• LIU hardware already installed/ being commissioned:
  • LEIR: new transfer line BPMs
  • PSB: main dump installed, turn-by-turn trajectory, Finemet cavity reliability run, prototype wirescanner, new amplifiers for transverse feedback,…
  • PS: most RF upgrades in place, new beam gas ionization profile monitor, wire scanner
  • SPS: first AC coated magnets and impedance reduction, new fast beam current intensity monitor, extraction kicker impedance reduction

• Upgraded operational methods:
  • LEIR model based operation for ring and transfer lines
  • Optics checks as part of standard start-up for PSB and PS: kick response, k-modulation
  • Combined 4 ring PSB 2 PS steering algorithm
  • Higher level tune and chromaticity parameters and correction tools for the PS
  • 2 x 40 MHz for bunch rotation in PS to reduce capture losses at SPS injection point
  • Improved tune function commissioning for high intensity LHC cycles with new tools from power controls and transverse damper in SPS
  • …
Ongoing activities (4)

Injector settings management working group

Chairperson: D. Jacquet

• 3 main objectives
  • Model based generation and high level parameters for low energy machines
  • Homogenization of controls across accelerators
  • Collaboration to define next generation settings management for injectors
    – Specific requirements for ppm machines: e.g. super settings,…

• All CERN machines participate
  • And (almost) all machines agree to change

• 2 day workshop 10-11 January 2018
  • Concrete short term and longer term tasks decided
  • Manpower identified, but not committed
### BCWG during LS2

**2019**
- Extend hardware commissioning check lists for LIU equipment, including special tests
- **Define LS2 dry runs and HWC, including planning of tests with shutdown coordination**
- Implement new settings management, optics, methods
- Further work on commissioning procedures

**2020**
- Finalize tools
- Establish the detailed **commissioning plan for LHC and FT beams***
  "Rough" commissioning with LHC beam only, detailed setting up needs LHC AND FT beams
- Coordinate/execute LS2 dry runs, HWC and check-out
- **Follow-up on beam commissioning** progress

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*The LIU beam commissioning will cover the commissioning of all injector beam types. Certain commissioning methods require FT beams. The same manpower is involved.*
Long Shutdown 2

Master Schedule of the Long Shutdown 2 (2019-2020)
Key dates LS2

- **First proton beam**
  - LHCProbe beam to the LHC: 4 March 2021
  - First beam to the SPS 18/1/2021. 6 weeks of stand alone commissioning
  - First beam to the PS 23/11/2020. 6 weeks of stand alone commissioning
  - First beam to the PSB 14/9/2020. 2.5 months of stand alone commissioning
  - LINAC4: beam to LBE mid 2019, beam re-commissioning start: 6/4/2020

- **Hardware commissioning and check-out:**
  - Several months of hardware commissioning and check-out by operations team foreseen in schedule per machine after individual system tests by equipment owners.

- **We will add**
  - Final date for delivery of FESA APIs
  - Required availability for controls, timing,…
  - Dry runs during shutdown period
  - Fixed target beam and ion key dates

- **Commissioning plan for post-LS2 still to be defined.**
  - First extrapolations from present experience: Time allocated in schedule provides sufficient margin, provided appropriate testing before beam
Risks for schedule

• LIU beams in LIU machines will be new territory

Risks for schedule:

• The LIU ion run in 2021 means an additional complication
  • Commission slip stacking
  • Deliver HL-LHC ion parameters

• LIU equipment and beam production schemes:
  • Hardware installation: time, manpower, budget allocated
  • Operation: requirements for software being finalised in 2018/LS2

• To deliver the software for LIU in time need
  • Support from the equipment groups for collaboration and readiness of FESA layer
  • Support from CO
  • …enough available manpower in OP (/ABP)
  • deadlines and manpower requirements are being prepared
    - 2018 goal for BCWG
Conclusions

- LIU equipment is either in construction, partly installed or some of it already commissioned.

- The LIU beam commissioning working group (BCWG) is preparing the next phase with the goal:
  - to efficiently commission the new injector chain
  - to use standardized procedures across machines

- Leveraging from the experience of LHC commissioning, BCWG will cover:
  - Operational methods and beam dynamics
  - Tools
  - Testing procedures, planning and definition of deliverables
  - Establishing and deploying the teams

- BCWG is preparing a roadmap to achieve the LIU goals: detailed breakdown and milestones due at the end of this year.
  - Commissioning of fixed target beams is part of LIU commissioning to be added
  - Software requirements and manpower allocation to be addressed with high priority
THANK YOU FOR YOUR ATTENTION!

LHC Injectors Upgrade
Experience from start-up after LS1

• Example of the PSB after LS1: new digital LLRF, upgraded beam instrumentation, mainly controls changes

Setup with beam

• First beam in the machine rapidly
  • Monday 2nd June first beam injected into the Bl line around lunchtime
    • First beam (1 turn; 40E10) injected in R3, lost after 5 ms
    • In the afternoon small intensity accelerated in all 4 rings
    • Tuesday optimising injection, debugging instrumentation, RF setting-up
    • Wednesday ejection to the new dump

• First beam sent to the PS 17th June (3 days earlier than in planning)

• 2.5 months after first beam, we were still not at nominal performance (ISOGPS 2600E10ppp; should be ~3200E10ppp).

Re-commissioning work group 16/4/2015