Setting the scene

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R. Scrivens, E. Shaposhnikova
Outline

- LIU project aims
- LIU project lifecycle: LS2 project organisation
- Motivation and objectives of the LIU Workshop
Aims of the LHC Injectors Upgrade project

- **Performance:**
  - **Deliver beam parameters** at LHC injection matching the requested HL-LHC target for protons and heavy ions.
  - Define and deploy means to overcome performance limitations in all injectors.

Proton beam properties @LHC injection

<table>
<thead>
<tr>
<th></th>
<th>( N_b \times 10^{11} \text{ p/b} )</th>
<th>( \varepsilon_{x,y} \text{ (( \mu \mathbf{m} ))} )</th>
<th>Bunch/batch spacing</th>
<th>Bunches</th>
</tr>
</thead>
<tbody>
<tr>
<td>HL-LHC target</td>
<td>2.3</td>
<td>2.1</td>
<td>25 ns / 200 ns</td>
<td>4x72b per injection</td>
</tr>
</tbody>
</table>

Pb ion beam properties @LHC injection

<table>
<thead>
<tr>
<th></th>
<th>( N_b \times 10^8 \text{ ions/b} )</th>
<th>( \varepsilon_{x,y} \text{ (( \mu \mathbf{m} ))} )</th>
<th>Bunch/batch spacing</th>
<th>Bunches</th>
</tr>
</thead>
<tbody>
<tr>
<td>HL-LHC target</td>
<td>1.9</td>
<td>1.5</td>
<td>50 ns / 100 ns</td>
<td>7x8b per injection</td>
</tr>
</tbody>
</table>

- **Sustainability/availability:**
  - Ensure and improve injectors’ availability/reliability for the HL-LHC operation by identifying and upgrading sensitive/ageing equipment, improve radioprotection and services (in synergy with CONS)

LIU Workshop, 13-15 February 2019

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Goals of the LHC Injectors Upgrade project

- Main RF system (200 MHz) upgrade
- Longitudinal impedance reduction & partial a-C coating
- New beam dump and protection devices
- Acceleration of H⁻ to 160 MeV
  - Nominal 40 mA within 0.4 μm, Run 3 target 25 mA within 0.3 μm
- 2 GeV injection
  - New RF equipment including broad-band feedback
- 160 MeV H⁻ charge exchange injection
- Acceleration to 2 GeV with new main power supply and new RF systems
LIU Project timeline

Many activities performed, some completed, and partial equipment installation already done prior to LS2 (recommendation of CSR2015)

Run 2 (past):
- Beam studies;
- Equipment specification, design, prototyping, procurement, testing, installation and commissioning;
- Cabling / decabling;
- Surface work (CE, racks);
- Linac4 commissioning

LS2: readiness of remaining equipment, installation of LIU equipment in all injectors (incl. of the Linac4 to PSB connection), LBE run.

Run 3: Recovery of pre-LS2 beams
+ LIU beam commissioning through the injectors (HL-LHC ions for end 2021)
LIU project lifecycle: entered into a new phase

During LIU project lifecycle: organisational changes performed to follow the project phases.

End 2018: LIU management brainstorming sessions to adapt the project structure to the LS2 phase.
LIU organisation in LS2: 3 pillars

LIU-LS2 Machine
Technical coordination

Mandate (adapted to the specificities of each machine):

- Equipment Readiness for Installation, NCs
- Progress in installation, issues, impacts on others, mitigations—including analyses of issues coming from non LIU equipment impacting LIU planning/performance/priority
- Overall equipment integration
- IST preparatory stage, issues, mitigations
- Progress in machine HW and Beam comm. preparation and execution
- Beam performance related issues
- Completion/updating of documentation (General Safety, ECR, procedures for IST, HW, Beam commissioning ...)
- Launch and steer Ad-Hoc meeting series to promptly address issues
LIU organisation in LS2: 3 pillars

Mandate:

• Ensure overall commissioning coordination between injectors chains
• Ensure readiness of plans/procedures for commissioning
• Ensure readiness of tools
• Establish sub-working groups / teams
• Organise, analyse beam commissioning
• LIU beam commissioning objectives from post LS2 until end of 2021:
  Recover the pre-LS2 LHC beam type parameters, including beams required for LIU setting-up, and delivering of HL-LHC ions for 2021 operation.

The LIU-CCC mandate will be reviewed (in the course of 2021, pending commissioning progress) and remaining activities will be merged into a single body, together with other on-going activities (e.g. beam dynamics) to ensure the overall approved Beams Performance milestones.

The LIU-CCC will report directly to the LIU project and IEFC / LMC.
LIU organisation in LS2: 3 pillars

Mandate:
• Coordinate the beam dynamics studies at the interface between the machines of the injector complex for both protons and ions
• Define priorities for machine and simulation studies to ensure the LIU goals and prepare the accelerator complex to deliver the beams requested by physics users
• Promptly evaluate the potential consequences of the evolution of the LIU program during LS2 (installation schedule, non-conformities) on the LIU parameter list
• Analyse beam performance with respect to the present and future requirements and, if needed, define machine upgrades and mitigation strategies for remaining limitations
LIU executive committee: view across the machines

Mandate:

- Follow-up overall LIU work progress (equipment readiness, LS2 execution, beam performance, HW and BC preparation and execution)
- Review LIU TC machine recommendations for final rational decision throughout injectors
- Ensure planning, budget, resources
- Address general safety matters and documentation
- As needed, include the review per equipment group (former ‘LIU and group management meeting’)
- Report to ATS director and as needed to related committees (IEFC, LMC, LIU/HL-LHC executive committee, LS2C)
## LIU organisation in LS2

### LS2 Committee

<table>
<thead>
<tr>
<th>LS2 Injectors Shutdown Planning Coordination</th>
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<tbody>
<tr>
<td>Linac4/Linac3/LEIR/PS Complex Shutdown Planning coordination</td>
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<tr>
<th>SPS Shutdown Planning coordination</th>
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<tbody>
<tr>
<td>LIU SPS LS2 Tech. Coordination</td>
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<tr>
<td>LIU SPS BD Working group</td>
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<tr>
<th>LIU Executive committee</th>
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<tbody>
<tr>
<td>LIU Commissioning Coordination</td>
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<tr>
<td>LIU Beam Dynamics Coordination</td>
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<table>
<thead>
<tr>
<th>Linac4 LS2 Tech. Coordination</th>
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<td>Linac4 Commissioning Working group</td>
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<table>
<thead>
<tr>
<th>Linac3 – LEIR LS2 Tech. Coordination</th>
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<td>Linac3 – LEIR Commissioning Working Group</td>
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<table>
<thead>
<tr>
<th>LIU PSB LS2 Tech. Coordination</th>
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<td>LIU PSB Commissioning Working Group</td>
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<table>
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<tr>
<th>LIU PS LS2 Tech. Coordination</th>
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<td>LIU PS Commissioning Working Group</td>
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<tr>
<td>LIU SPS Commissioning Working Group</td>
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</table>
LIU organisation in LS2

1. Weight on these 3 pillars will rapidly change as LS2 progresses.

2. Very close collaboration and reactivity from the 3 Teams leaders (Joint Team Leaders - JTL), for each machine.
LIU organisation in LS2

- LIU Beam Dynamics Coordination (+Machine BD WG)
- LIU Commissioning Coordination (+Machine WG)
- LIU-LS2 Machine Technical coordination

Post LS2 - successful pre-LS2 beam recovery

Injectors Beam Performance Coordination
LIU workshop: in LS2 and towards run3 and beyond

Three pillars addressed into three sessions:

- **Beam Dynamics and performance reach – Giovanni and Heiko**
  - Comprehensive status of the current reach, of the simulation tools needed for the restart and on the focus on critical path studies;
  - Comprehensive plan over 2019-2021 with priorities, milestones and timelines

- **LS2 system readiness and work execution – Julie and Brennan**
  - LIU work progress and readiness for beam during LS2 – mitigations
  - Identify systems which have been postponed to post LS2 (post LIU), together with spare situation, and remaining de-cabling campaign

- **Commissioning preparation and execution phases – Verena and Alex**
  - Strategy endorsed by all machines
  - List of milestones and timelines
  - Is the commissioning time adequate? What are the chronological priorities to ensure the LIU baseline targets?
Outlook

- 8 years old project: many important milestones, achievements, allowing the project to enter into LS2 with a robust preparation, readiness stage and strategy
- Into LS2: critical phase, in which the project will evolve quickly from installation, to testing, commissioning and operational beam delivery
- Important to follow these phase evolution very closely to deliver our objectives and quickly react - as needed
- During this workshop, we will mainly address the critical points, mitigations and set the path for pre-LS2 beam recovery and LIU beam parameters ramp-up, including HL-LHC Pb ions beam
- Mid-longer term view, in terms of post LIU ‘heritage’

Much still ahead of us! One indicator: 2019 LIU budget allocation
Much still ahead of us: 2019 is peak spending year

Additional measures in place to assist the BC holders to follow their spending evolution

LIU Cumulative Budget

LIU Annual Budget

<table>
<thead>
<tr>
<th>Budget by Machine</th>
<th>Charged 2018</th>
<th>Budget 2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIU-IONS</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>LIU-PSB</td>
<td>13.1</td>
<td>10.9</td>
</tr>
<tr>
<td>LIU-PS</td>
<td>3.6</td>
<td>5.7</td>
</tr>
<tr>
<td>LIU-SPS</td>
<td>11.2</td>
<td>25.5</td>
</tr>
<tr>
<td>Total</td>
<td><strong>28.1</strong></td>
<td><strong>42.4</strong></td>
</tr>
</tbody>
</table>
LIU proton beam parameters target

- **Linac4-PSB connection**
  → Reduced space charge, double PSB brightness

- **PS upgrade**
  → 2 GeV injection + large longitudinal emittance transfer from PSB
  → RF feedbacks to suppress longitudinal instabilities and reduce transient beam loading

- **SPS upgrade**
  → 200 MHz RF power upgrade and new LLRF
  → Q20, scrubbing + partial (staged) SPS aC coating
  → New beam dump & transfer line collimators
  → Longitudinal impedance reduction (flange shielding and HOM reduction)
LIU Pb ion beam parameters target

Baseline LIU Pb ion parameters compliant with HL-LHC request

- Single bunch parameters at SPS extraction match requested ones when including additional losses in SPS due to slip stacking
- **Number of bunches** only achievable with momentum slip stacking in the SPS, depending on full deployment of new LLRF capabilities for the 200 MHz RF system
- Slip stacking tests in 2018
  + 20 mm radial displacement didn’t lead to BCT losses → Enough space to move only one beam during slip stacking
  - Longitudinal instabilities observed on 300 GeV plateau → Stabilisation techniques available (i.e. 800 MHz, longitudinal emittance blow up), but will need to be studied in simulations (LS2) and then tested + commissioned

<table>
<thead>
<tr>
<th>N (x 10^8 ions/b)</th>
<th>ε (µm)</th>
<th># of bunches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achieved (100 ns)</td>
<td>2.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Achieved (75 ns)</td>
<td>2.3</td>
<td>1.5</td>
</tr>
<tr>
<td>HL-LHC target (50 ns)</td>
<td>1.9</td>
<td>1.5</td>
</tr>
</tbody>
</table>
LIU Beam Dynamics session

- Wrap-up LIU beam performance reach - baseline and mitigation scenarios for both protons and ions – much achievements reached, what’s next?
- Present the sensitivity of HL-LHC integrated performance reach to variations in LIU delivered parameters
- Summarise conclusions from run 2 MD and operation in 2018, in context of LIU parameters and performance
- List beam performance related activities in 2019-2020 (LS2) (data analysis, simulations, code development …)
- List LIU beam measurements needed during run3
- Define milestones with timeline

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LIU-LS2 system readiness and shutdown execution session

- List RFI dates for LIU equipment in the context of machine installation planning
- Identify critical delivery path items (or already late) and discuss mitigation
- Review readiness prospects for selected highest risk/impact systems (incl. some IST)
- List known NCs or variation from specified equipment performance, and impact
- Present status of related general safety documentation and identify outstanding items
- Present risk analysis of LIU installation planning with mitigation (with agreed methodology)
- List hardware related improvements postponed to post LS2 and performance impact
- List of any items needing upgrade that were missed from LIU
- Overview of spares for start-up
LIU activities on the critical path

- LIU PSB Upgrade
- Consolidation of the TT2 Power Converters
- 200MHz RF Upgrade
- Beam Dump Upgrade
- Linac4 Connection
- New Emittance Measurement Line LBE
- Linac 3 Shutdown
- Linac 4 Beam Commissioning
- LHC PROBE Beam

Timeline:
- OCT 2018
- NOV 2018
- DEC 2018
- JAN 2019
- FEB 2019
- MAR 2019
- APR 2019
- MAY 2019
- JUN 2019
- JUL 2019
- AUG 2019
- SEP 2019
- OCT 2019
- NOV 2019
- DEC 2019
- JAN 2020
- FEB 2020
- MAR 2020
LIU-LS2 system readiness and shutdown execution session

- Still major workload on important and critical path items left during LS2
- Critical path items to be listed and analysed further
  - RF systems
  - Beam intercepting devices
  - B269 (CONS TT2 EPC)
- What have we pushed to post LIU?
LIU commissioning session

- Activity organisation and responsibilities
- Review IST, requirements and identify potential risks with mitigations, in context of LS2 and restart planning
- HW commissioning: status of plans, requirements (services, signals, controls, applications, procedures, check-lists...), risks, mitigations, resource conflicts
- Beam commissioning: timeline, milestones, documentation for beam permit, pre-LS2 beam performance recovery and LIU beam commissioning plans, requirements (settings management, on-line monitoring, tools, applications)
- Set the path to improve operational methods – where needed- with longer term strategy
Analyse the duration of each of the commissioning phases