LHC Injectors Upgrade Workshop

Montreux, 13-15 February 2019
Performance and reliability with ions from Linac3 to PS

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Outline

• Highlights from 2018
• Performance overview from Source to PS
• Source/Linac3
• LEIR
  o Preparation to the LHC run
  o Performance during the LHC run
• PS
• Summary
Highlights from 2018

End of 2017 YETS
Source change of main insulators
Source commissioning
Linac3 commissioning
17th: Ions in TL + LEIR
25th: Ions to PS
18th: NOMINAL 3+6 (75 ns) to PS
23rd: Birth of optimizers in LEIR
27th: NOMINAL at LIU (8.8e10c)
New GSI stripper foils tested
Source solenoid incident
Start of LHC run
9th: Intensity record 10.88e10c
End of LHC run
Overview from Source to PS

- LEIR capture & ramp are the most important losses.
- Otherwise above 90%.
Overview from Source to PS

- LEIR extracted intensity linear with Linac3 current.
- $30 \text{ uA} \rightarrow \text{LEIR “comfortably” at LIU performance with 10% margin.}$
- PS 75 ns +40% above LIU target
Source + Linac3 at LIU target!

- Source solenoid incident
- Oven refills
- RF faults

30uA required for LEIR - LIU

Foil ($Pb^{29+} \rightarrow Pb^{54+}$)
Source performance

Good performance thanks to:
1. 24/24h support (normally on working hours only outside the LHC run).
2. Only fresh Pb was used through the year: faster recovery after refill (8-9 hours).
3. 25 yo Thomson RF generator replaced with Sairem before start of operation

GHOST: two modules tested to improve source stability.
• Source HT extraction voltage optimization
• Automatic ramping of the oven power at source restart after an oven refill
• Development of additional modules planned in LS2.
Linac3 performance

Joint efforts together with LEIR team to:

1. Identify tolerances on RF parameters (in synergy with LLRF upgrade needs).
2. Find optimal RF settings to improve LEIR injection performance.

Example: tank 1 phase scan

Example: Schottky observation from LEIR

LS2: refining simulations models based on these measurements
Linac3: a closer look to the foils

- Intensity delivered to LEIR strongly dependent on foil stripping efficiency ($Pb^{29+} \rightarrow Pb^{54+}$).
- New GSI-produced stripping foils procured and tested:
  - Thoroughly characterized during dedicated MDs
  - Better reproducible characteristics with respect to previous foils.

![Energy spread](chart1)

![Energy mean](chart2)

![Pb54+ production](chart3)
Linac3: a closer look to the foils

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Monitoring foil performance:
- ITFS + Schottky + transfer line BPMs: now possible to carefully monitor it!
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**Example of foil performance monitoring**

- Mean/Std energy shift
- Ramping rate shift
- Higher charge states production

Old foil | New foil
Linac3: RF consolidation

Present situation:

- Several faults with long downtime due to RF-related failures: 3% of LHC Ion run.
- LLRF mostly analogue system dating to 70’s concepts with 90’s additions.
- No LLRF internal remote diagnostics.
- Large fluctuations in acquisition channels (amplitude should be stable at 0.1%, acquisition fluctuates by 0.3%).
- Ramping/Debunching LLRF have obsolete components.

Consolidation (as planned for LS2):

- Replacement of SS amplifiers for buncher, debuncher and ramping cavities (in sync with LLRF).
- Maintenance of RF amplifiers foreseen for RFQ, IH-DTL Tanks 1,2,3 with new LLRF monitoring.
- RFQ and Tank1 high power SS (post-LS2), in procurement phase (only one system budgeted in consolidation).
- Agreed with TE-EPC to request post-LS2 consolidation for power converter (Tanks 2,3).

Expected improvements:

- Acquisition accuracy compatible with required stability.
- More reliability of the system.
- Better LLRF diagnostics: identify long term drifts (including phase).
LEIR performance in 2018

• Improvement in performance reach:
  - Maximization of momentum acceptance.
  - Orbit correction during all the cycle.
  - Orbit bump in SS4 to minimize vacuum pressure.
  - RF capture with voltage amplitude/frequency modulation.
  - Tune bump towards 2.75 during capture.
  - Optimizer tools to improve injected pulse energy distribution.
  - Optimizer tools to improve injection efficiency.
  - Tune ripple elimination.
  - Cooler optimization with “cooling maps”
  - Momentum correction during accumulation (radial loop-like).

• Improvements in performance stability:
  - Cure of ETL.BHN10 temperature drifts
  - Injection optimizers+equalizer+aut
  - Performance monitoring tools

Details in LIU-Ions Beam Performance 22/01/2019!
LEIR performance in 2018

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- Improvements in performance stability:
  1. Identified source of drifts with temperature
  2. Optimized injection optimizers+equalizer+autopilot
  3. Introduction of performance monitoring tools
  4. Suppression of impedance source
1. Source of drift with temperature

- LEIR injection reproducibility highly affected by temperature variations.
- Mainly first injection affected -> -10%/degree reduction in injection efficiency!
- New injection line BPMs helped for source identification: ETL.BHN10

Dependence on temperature due to large current transient: cured with new current function.
2. Optimizers

- First application in 2018.
- Essential tool for OP to maintain LEIR machine performance.
- Concept applied as well at level of the source and in the SPS.

Further development followed up in a dedicated forum.
2. Optimizers + Equalizer

- Injection trajectory “equalized” against PS stray fields (on average in a super-cycle).
  1. Observe position at ETL BPM + injection efficiency in LEIR.
  2. Correct with ETL.BHN10
2. Optimizers + Equalizer + Autopilot

- Cycle-by-cycle compensation of the PS stray fields with automatized scripts.
- Further development/strategies followed up in LS2
3. Performance monitoring tools


- Helpful tool for OP support
- Performance tracking and statistics
4. Impedance source suppression

- ABP+BI joint effort identified the source of strong V instability (ER.UQFHV41, unused BTF pickup).
- It was a potential limitation with high intensity or very cooled beams (MD).
- Impedance removed by termination matching: instability suppressed.
LEIR performance during LHC ion run

Timeframe of data analysis:
- LHC Ion run for LEIR started on 4/11 and ended on 3/12.
- NOMINAL h2+4 (100 ns) and NOMINAL h3+6 (75 ns) analysed.

Analysis done accounting for Linac3 performance following 2 criteria:
- Average current $\geq 30\mu$A
- Minimum pulse current $\geq 20\mu$A

Two LHC scenarios:
- Full LHC run (setup + luminosity production)
- Only LHC luminosity production
NOMINAL  $h = 2+4$ (100 ns)

- Statistical analysis on extracted intensity: full LHC run

<table>
<thead>
<tr>
<th>100 ns</th>
<th>Mean $/10^{10}c$</th>
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</tr>
</thead>
<tbody>
<tr>
<td>LHC run</td>
<td>9.1</td>
<td>9.6</td>
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Performance of NOMINAL $h = 2+4 / \text{Linac3} \geq 30.0 \mu A$
NOMINAL $h = 2+4$ (100 ns)

- Statistical analysis on extracted intensity: LHC lumi production

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Performance of NOMINAL $h = 2+4$ / Linac3 $\geq 30.0 \mu A$ / Lumi production
NOMINAL $h = 3+6$ (75 ns)

- Statistical analysis on extracted intensity: full LHC run

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Performance of NOMINAL $h = 3+6$ / Linac3 $\geq$ 30.0 $\mu$A

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CERN
NOMINAL \( h = 3+6 \) (75 ns)

- Statistical analysis on extracted intensity: LHC lumi production

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Performance of NOMINAL \( h = 3+6 \) / Linac3 >= 30.0 \(\mu\)A / Lumi production

New WR Btrain calibration lost
LEIR efficiency

- Injection efficiency ~ 50% on average
• Injection efficiency \( \sim 50\% \) on average
• Transmission efficiency \( > 90\% \) on average.
LEIR efficiency

- Injection efficiency ~ 50% on average
- Transmission efficiency > 90% on average.
- Capture efficiency: 80% → 95% (ceiling at $11\times10^{10}$?)
  - Main players: IBS + SC → simulation efforts in LS2 to improve understanding.
Pros:

• Simple RF manipulation scheme in PS
• 40% above LIU intensity target for the PS (67% of LIU target on total intensity in LHC compared to 58% for 100 ns case).

Observations:

• Satellites when handling 20 MHz to 80 MHz: between buckets in SPS
• Microwave instability at transition: > 1GHz, input for longitudinal impedance model.
Summary

• 2018: another year of record performance!
• Source and Linac3 steadily delivered 30uA during LHC ion run.
• LIU targets achieved and exceeded in LEIR and PS:
  • +10% intensity margin in LEIR
  • +40% bunch intensity in PS for 75 ns
• Several sources of performance drift identified both in Linac3 (e.g. foils, RF settings) and LEIR (e.g. temperature drifts on BHN10).
• Source of faults between Linac3 and LEIR understood and identified for consolidation (if not already planned, e.g. LLRF).
• LEIR machine better understood year by year, both in operation (e.g. injection efficiency) and intensity limitations (SC+IBS).
• Largely profited of new instrumentation (ring BPM electronics, transfer line BPMs and SEM fast electronics, new Schottky electronics) and new tools for OP to increase machine reproducibility.
• LS2: prepare restart and progress on simulations (injection, cooling, SC, …)
Thanks for your attention!