CERN

LHC Injectors Upgrade

LHC Injectors Upgrade Workshop

Montreux, 13-15 February 2019

LHC Injectors Upgrade

Performance and reliability with ions from Linac3 to PS

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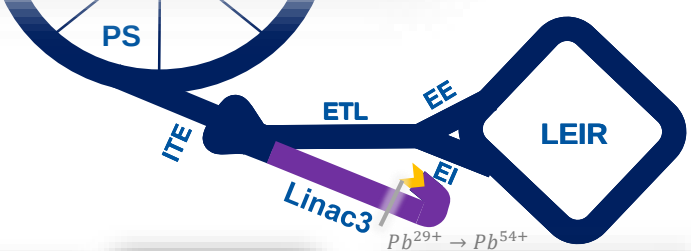
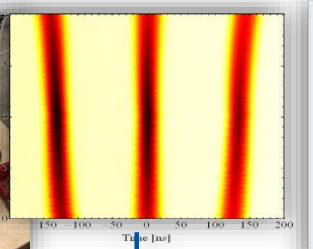
Acknowledgements: R.Alemany Fernandez, S.Albright, M.E.Angoletta, H.Bartosik, G.Baud, A.Beaumont, G.Bellodi, S.Bertolo, M.Bozzolan, J.Cenede, S.Cettour, D.Cotte, H.Damerau, F.Di Lorenzo, A.Dworak, A.Frassier, C.Gagliardi, D.Gamba, R.Gorbonosov, S.Hirlander, A.Huschauer, M.Jaussi, V.Kain, G.Kotzian, T.Kovener, D.Kuchler, A.Lasheen, A.Latina, T.Levens, E.Mahner, E.Manosperti, O.Marqversen, M.C.Mastrostefano, A.Michet, D.Moreno Garcia, D.Nicosia, M.O'Neil, E.Ozturk, G.Piccinini, A.Poscia, S.Ramberger, J.Resta Lopez, A.Saa Hernandez, E.Said, R.Scrivens, L.Soby, G.Tranquille, D.Valuch, B.Veglia, F.Wenander, M.Zampetakis, P.Zisopoulos, and PS/SPS OP teams.

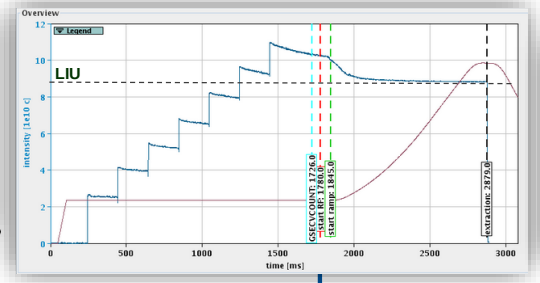
Outline

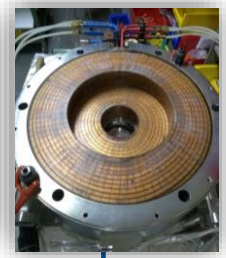
- Highlights from 2018
- Performance overview from Source to PS
- Source/Linac3
- LEIR
  - Preparation to the LHC run
  - Performance during the LHC run
- PS
- Summary

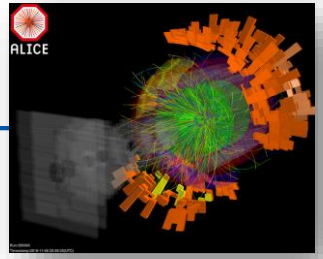
Highlights from 2018











Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec

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)

6th: 2016 performance reached.

Source extraction system repair against breakdowns

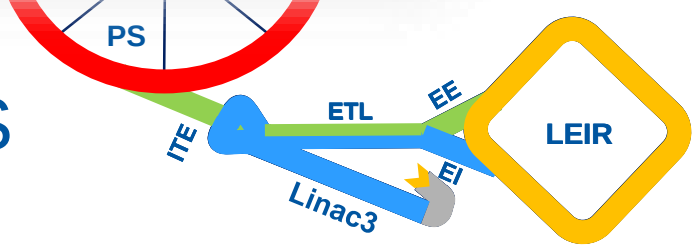
New GSI stripper foils tested

Source solenoid incident

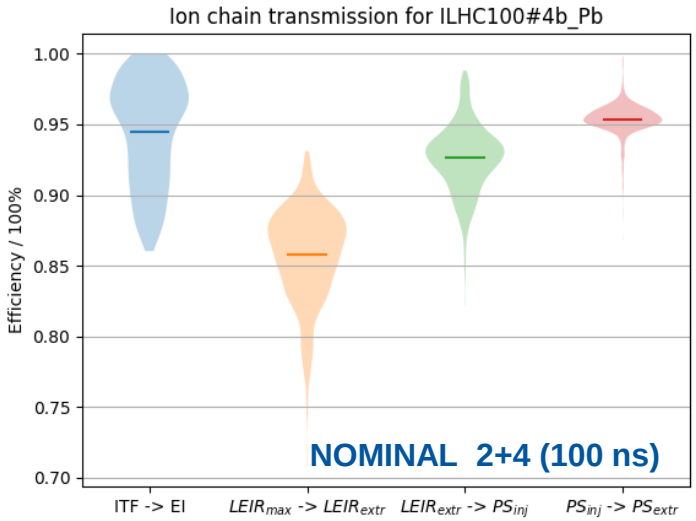
Start of LHC run
9th: Intensity record 10.88e10c

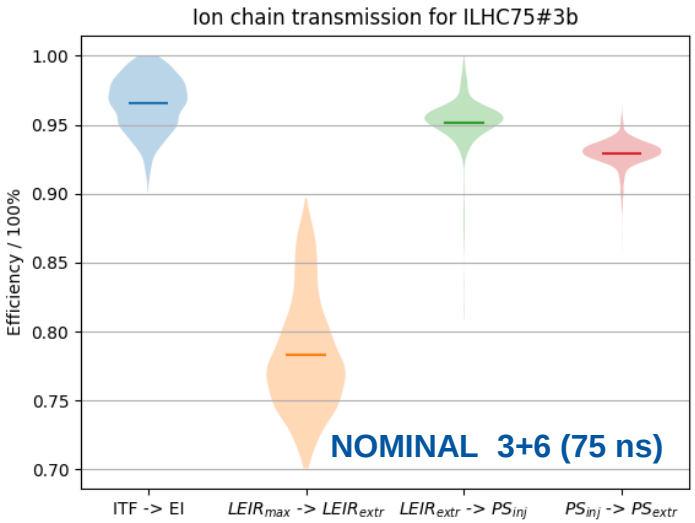
End of LHC run

Overview from Source to PS



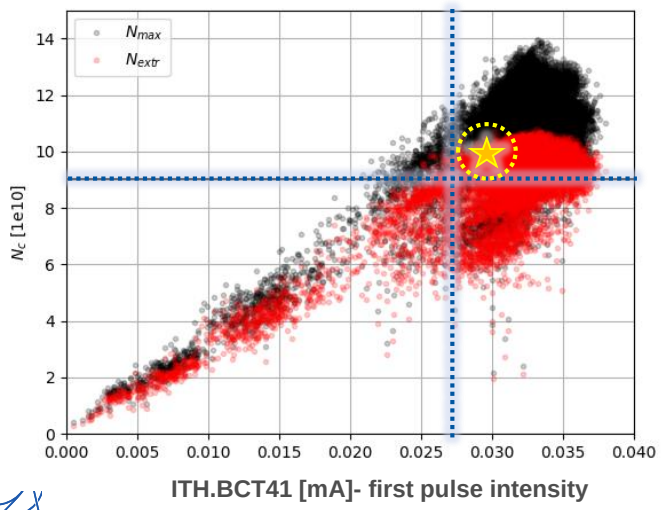
- LEIR capture & ramp are the most important losses.
- Otherwise above 90%.

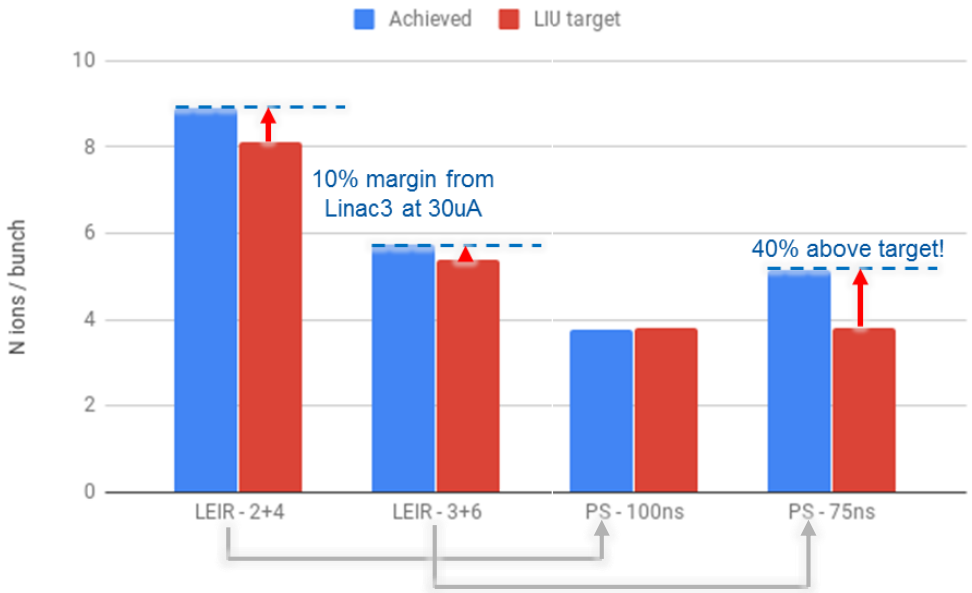




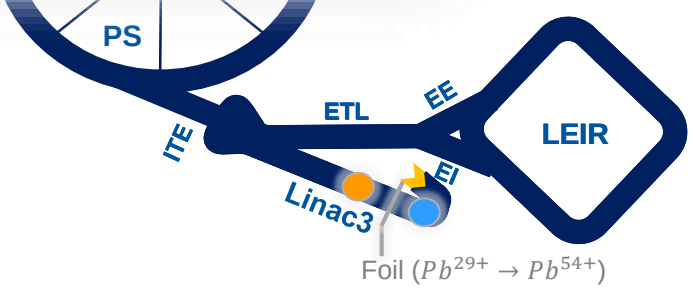
Overview from Source to PS

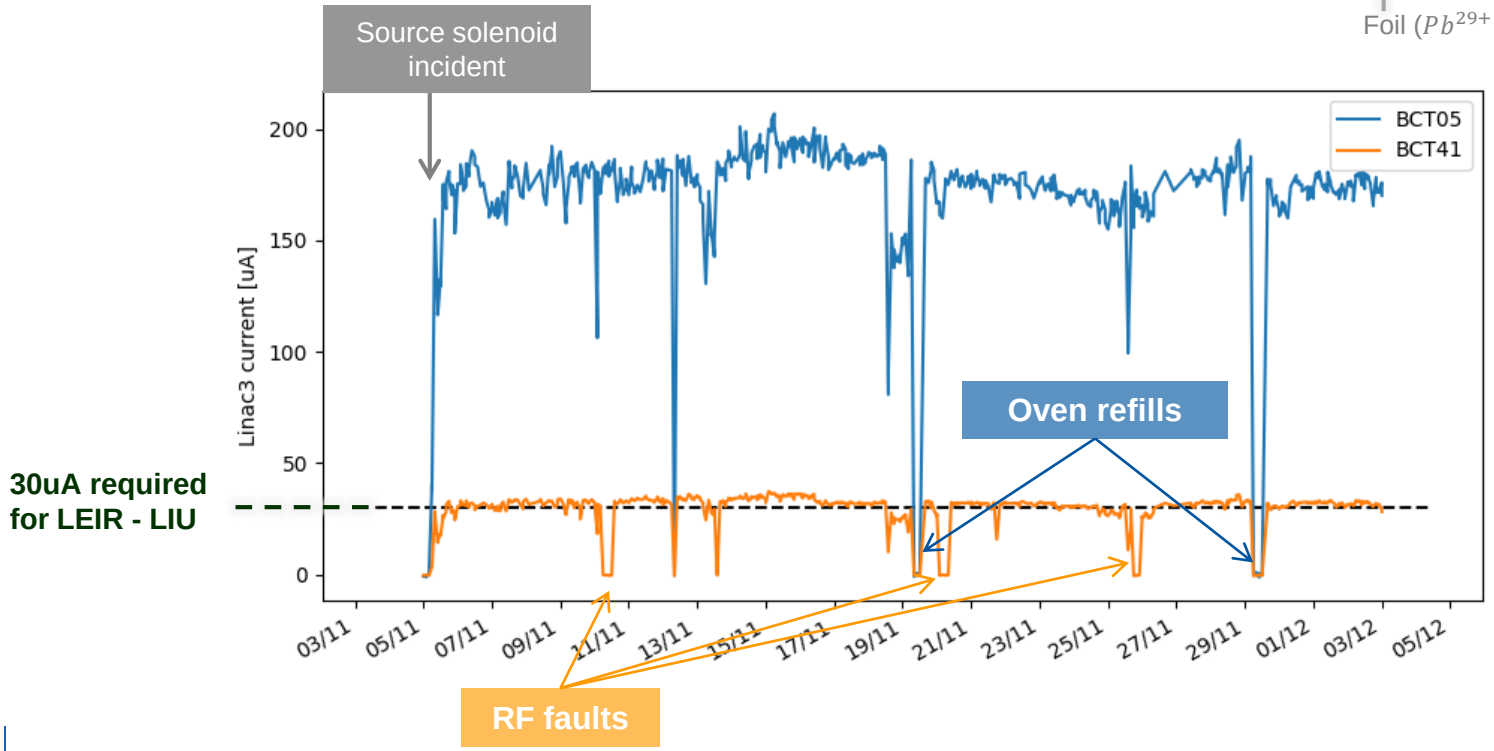
- LEIR extracted intensity linear with Linac3 current.
- 30 uA → LEIR “comfortably” at LIU performance with 10% margin.
- PS 75 ns +40% above LIU target





Source + Linac3 at LIU target!





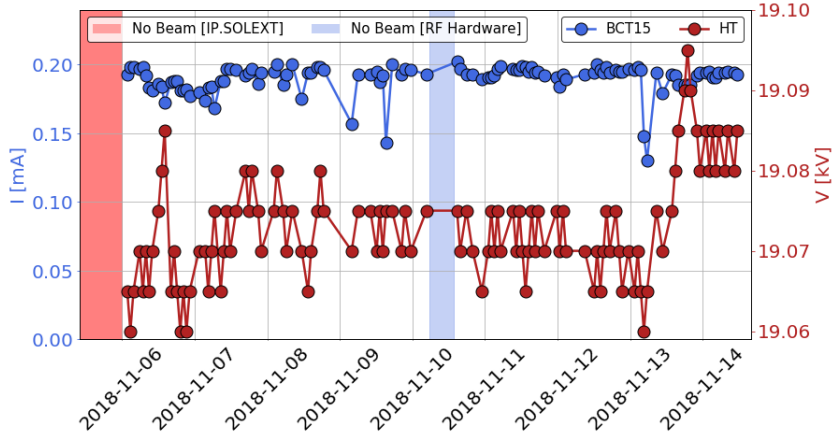
Source performance

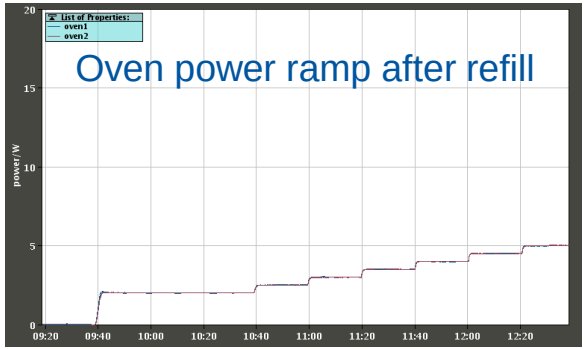
Good performance thanks to:

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.



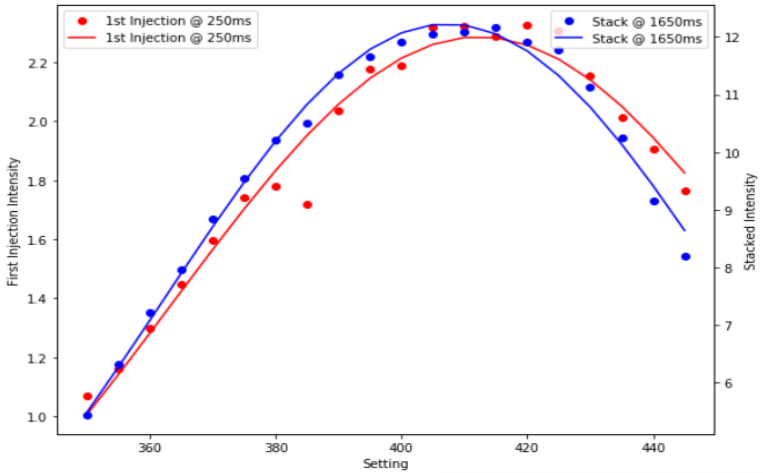


Linac3 performance

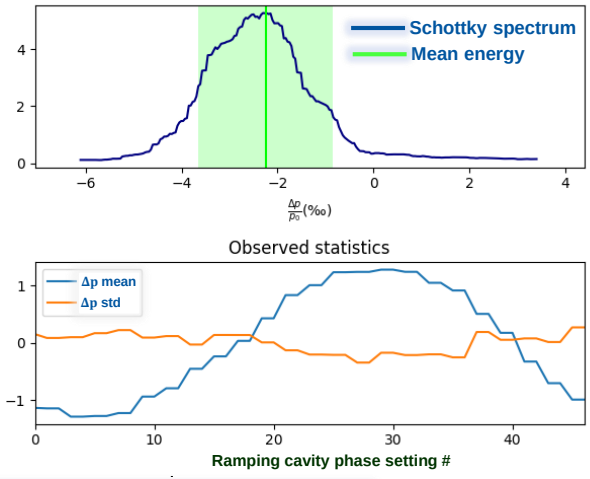
Joint efforts together with LEIR team to:

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



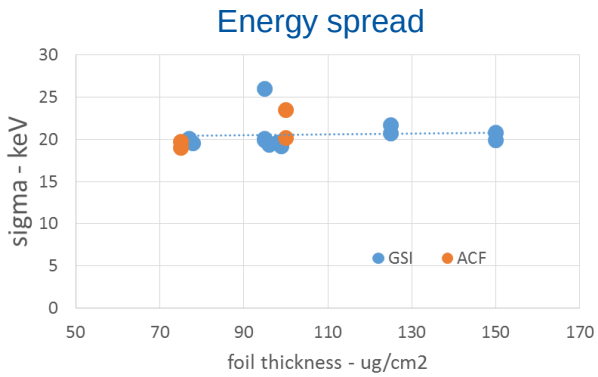
Example: Schottky observation from LEIR

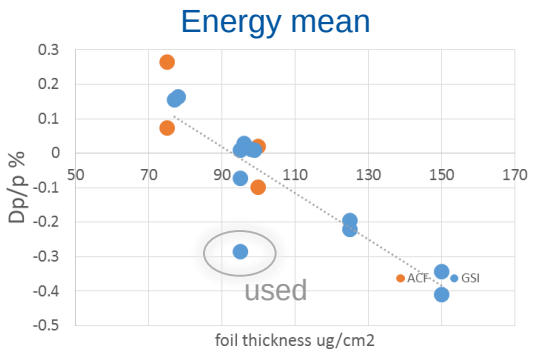


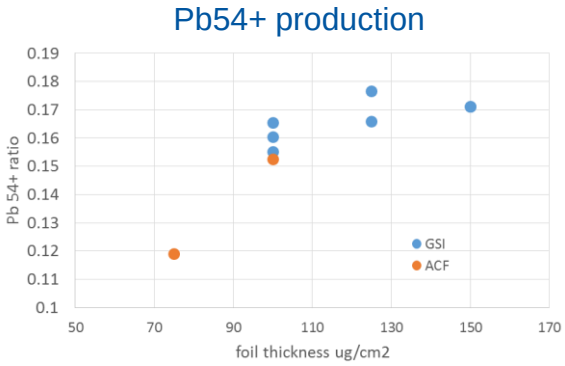
LS2: refining simulations models based on these measurements

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.







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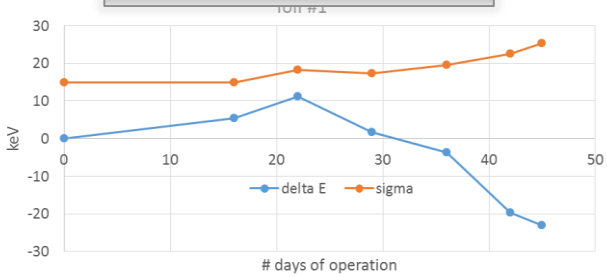
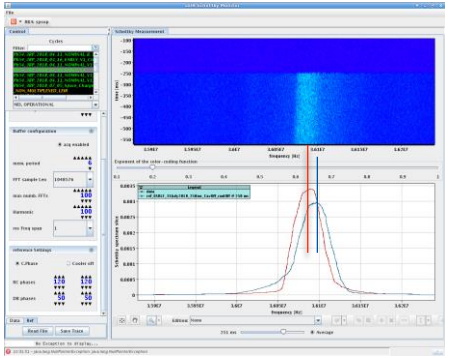
Monitoring foil performance:

- ITFS + Schottky + transfer line BPMs: now possible to carefully monitor it!

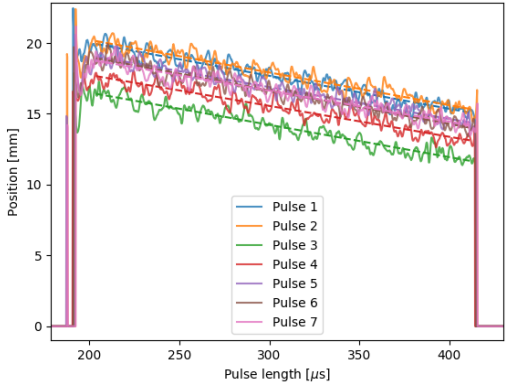
ITFS spectro-line



Schottky spectrum



BPMs



Linac3: a closer look to the foils

- Intensity
- New GS
  - Tho
  - Bet

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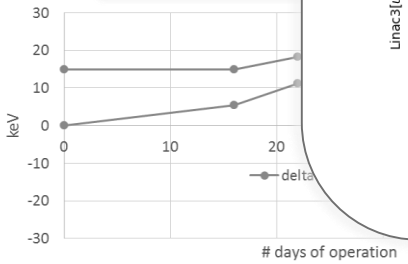
us foils.

Monitoring foil

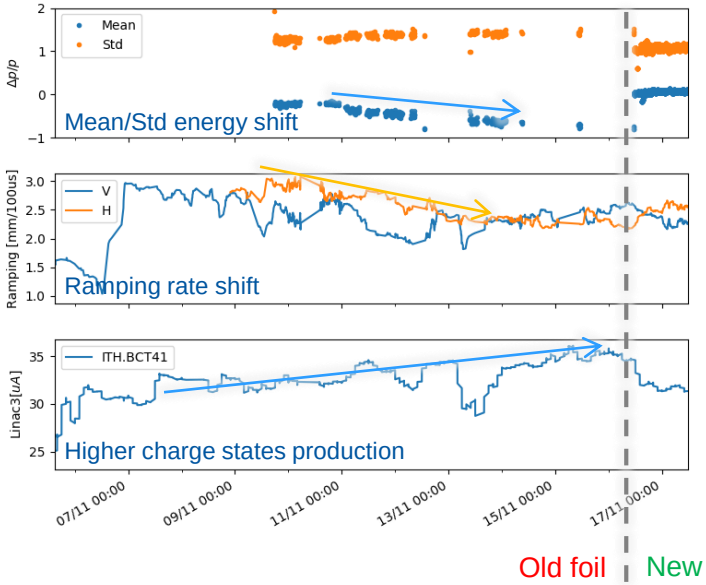
- ITFS + Sch

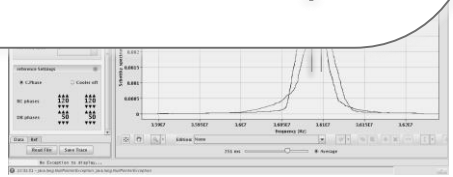
monitor it!

ITFS spe



Example of foil performance monitoring





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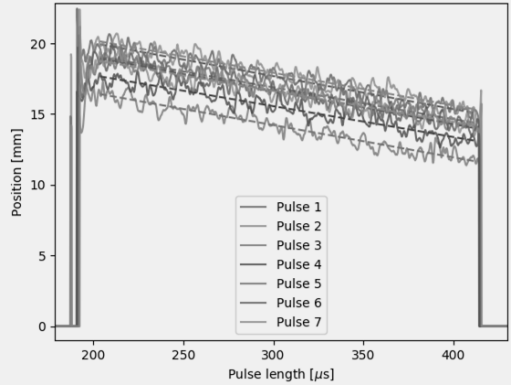


Linac3: RF consolidation

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).

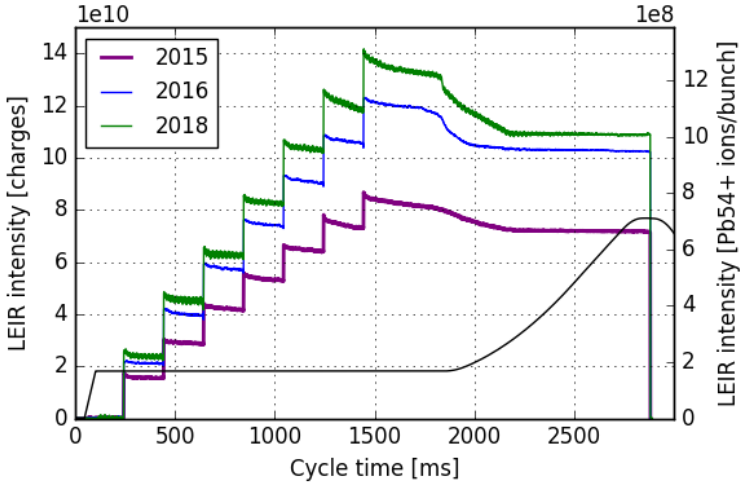
LEIR performance in 2018

- 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).

2016

2017

2018



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

LEIR performance in 2018

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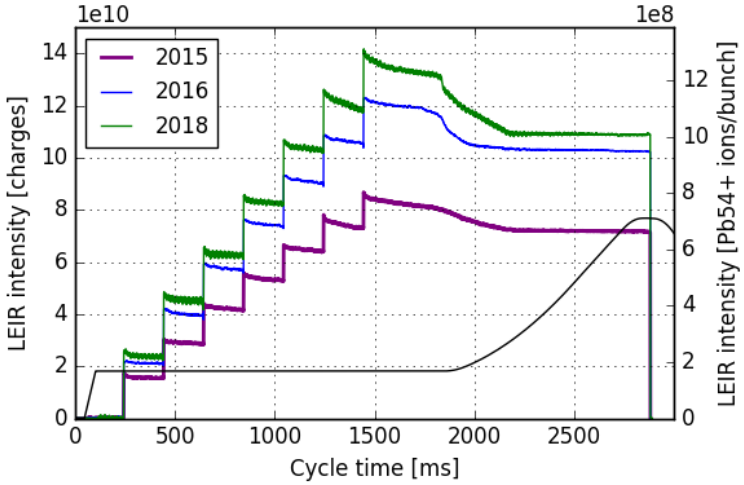
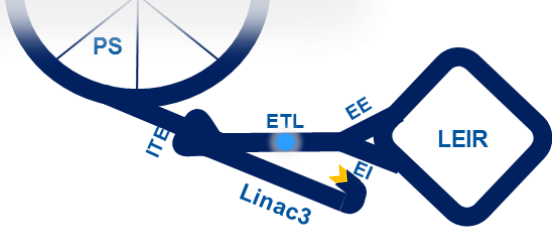
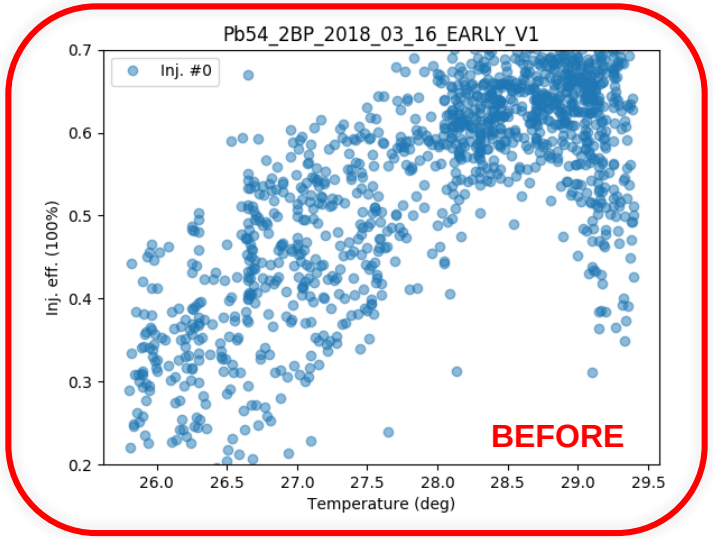


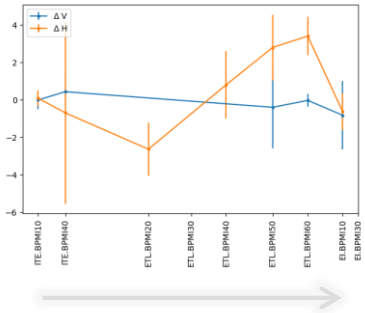
- Improvements in performance stability:
  1. Identified source of drifts with temperature
  2. Optimized injection optimizers+equalizer+autopilot
  3. Introduction of performance monitoring tools
  4. Suppression of impedance source

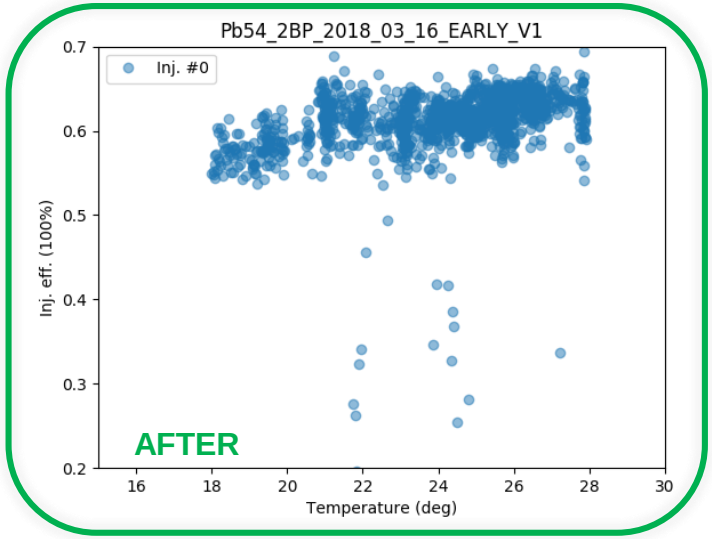
1. Source of drift with temperature



- 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

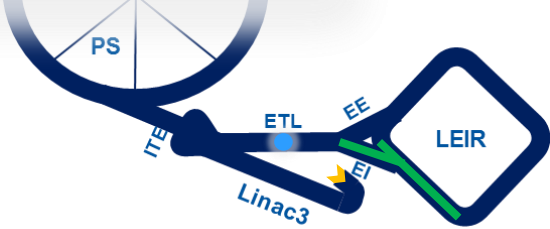






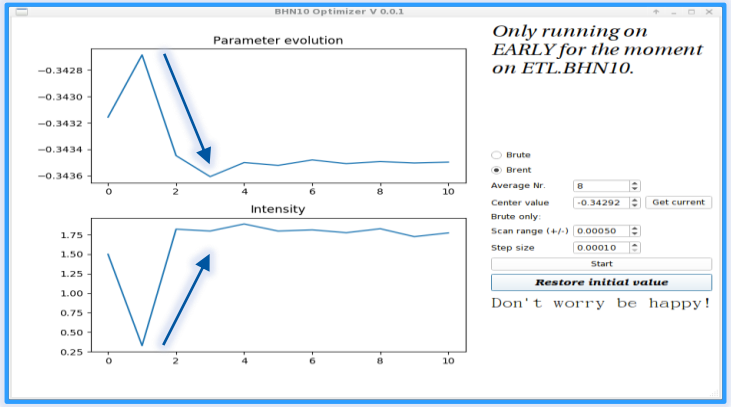
- Dependence on temperature due to large current transient: cured with new current function.

2. Optimizers

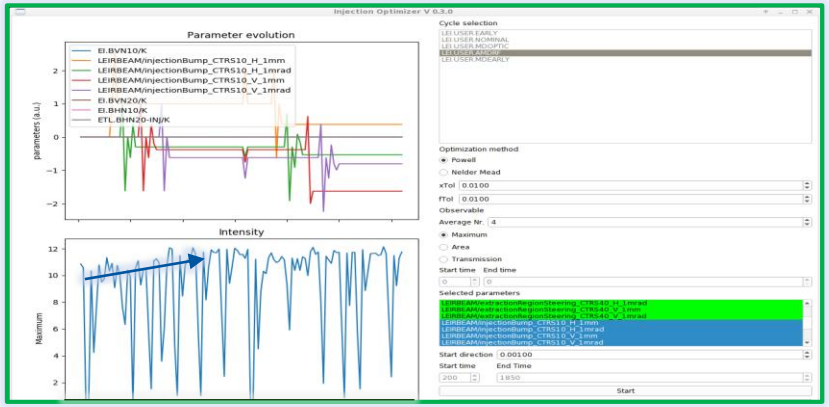


- First application in 2018.
- Essential tool for OP to maintain LEIR machine performance.
- Concept applied as well at level of the source and in the SPS.

Example of single parameter optimization

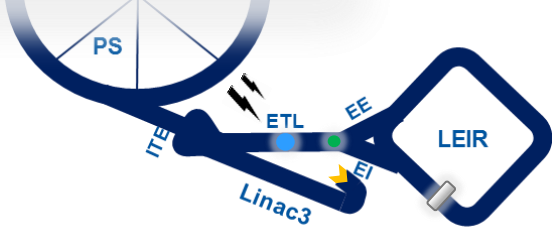


Example of a multi parameter optimization

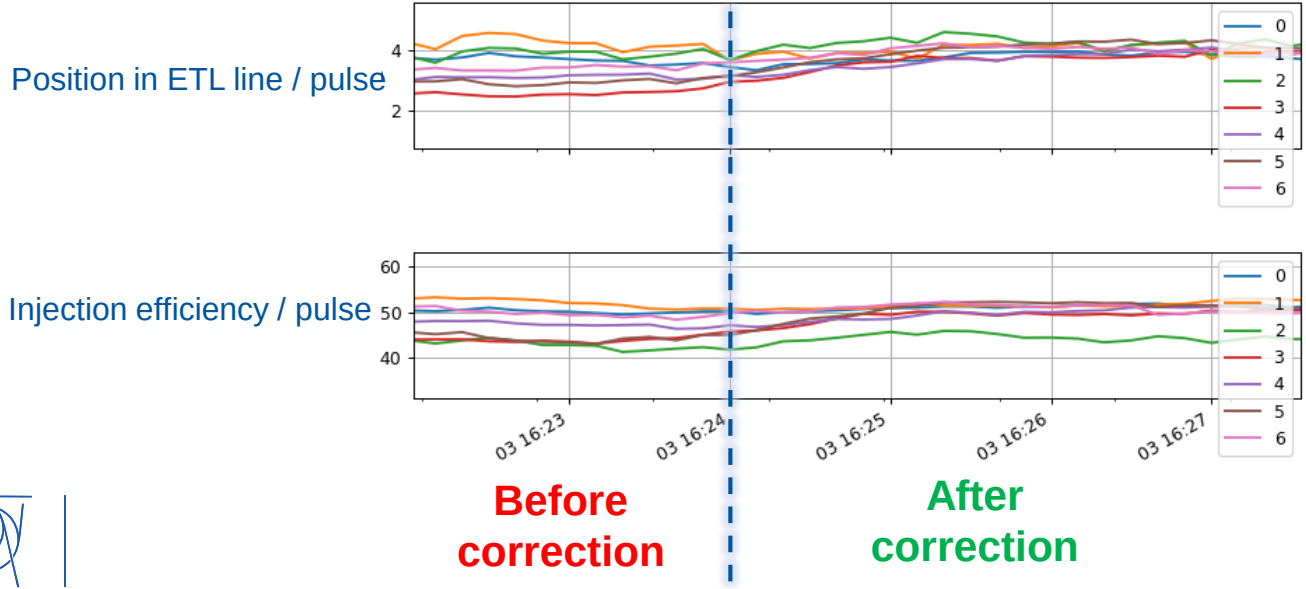


Further development followed up in a dedicated forum.

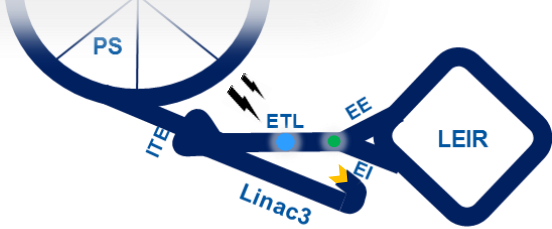
2. Optimizers + Equalizer



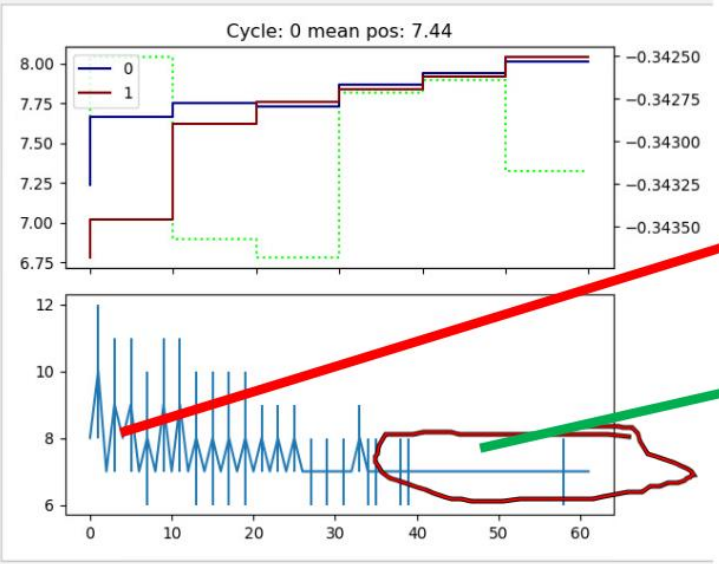
- Injection trajectory “equalized” against PS stray fields (n average in a super-cycle).
  1. Observe position at ETL BPM + injection efficiency in LEIR.
  2. Correct with ETL.BHN10

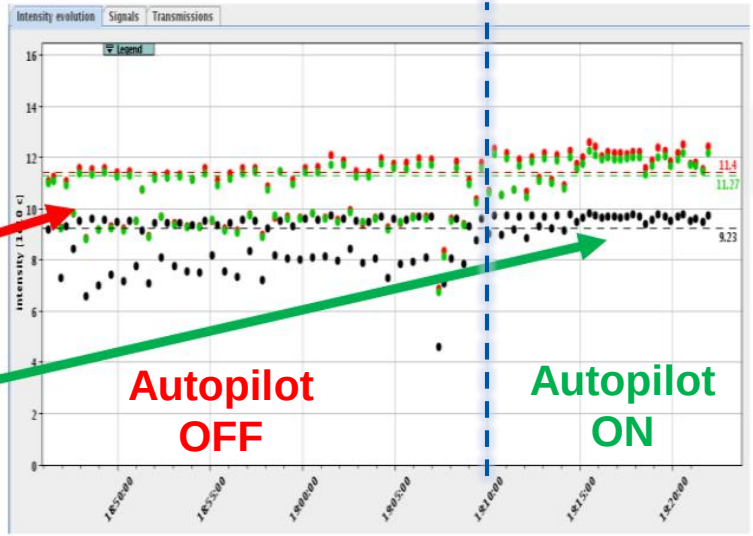


2. Optimizers + Equalizer + Autopilot



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

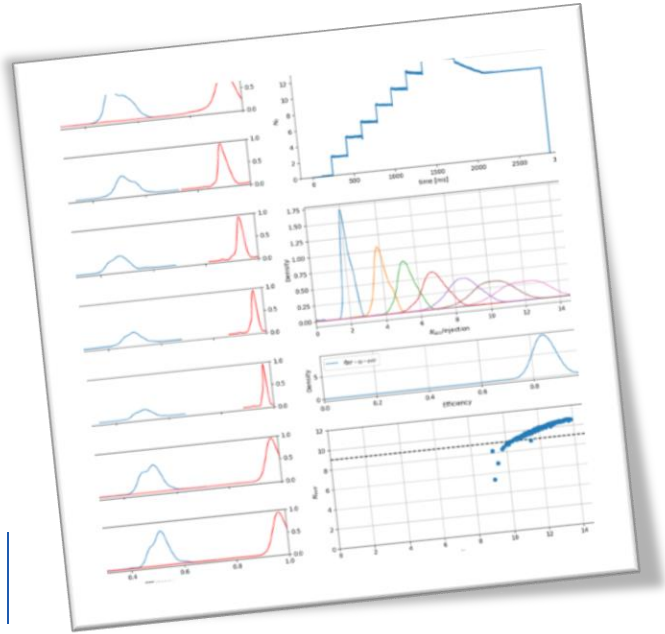


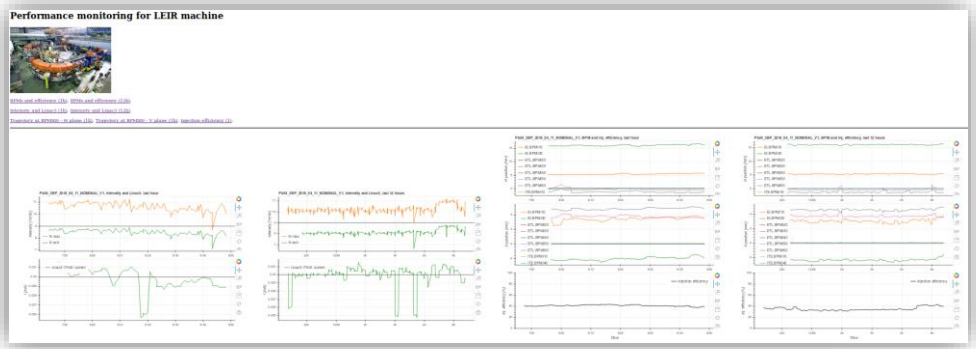


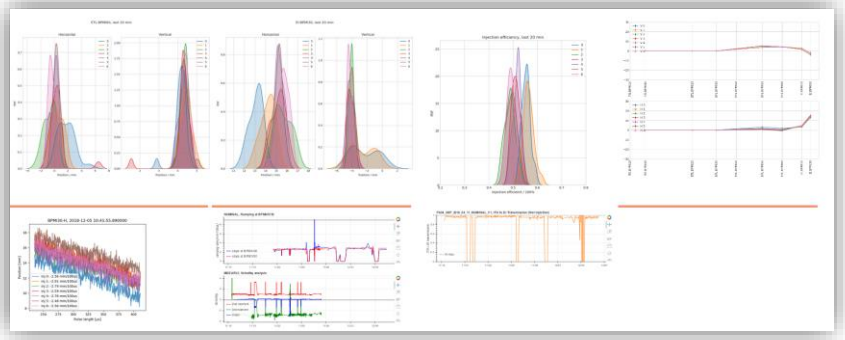
3. Performance monitoring tools

Monitoring website to identify source of performance loss on https://info-leir.web.cern.ch/info-leir/main.htm

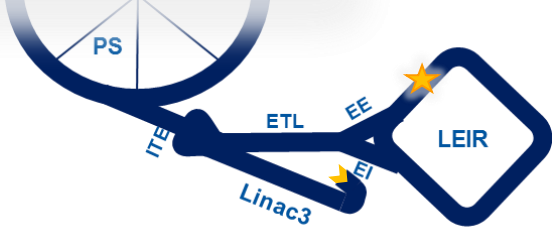
- Helpful tool for OP support
- Performance tracking and statistics



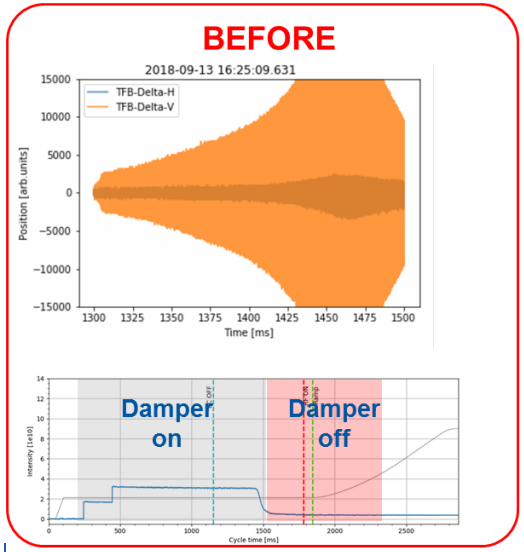




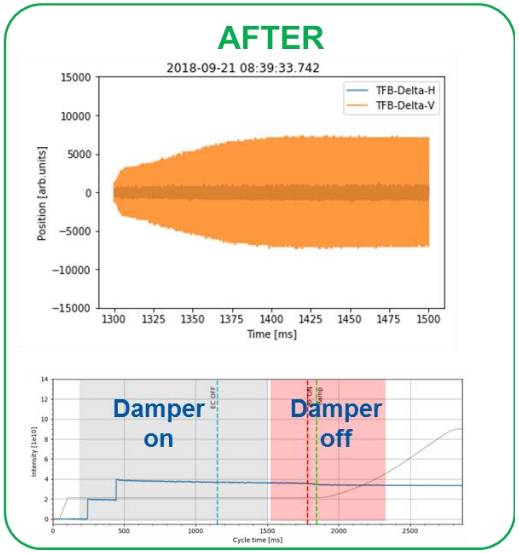
4. Impedance source suppression



- 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.



matching terminations of BTF pickup



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 ≥ 30uA
- Minimum pulse current ≥ 20uA

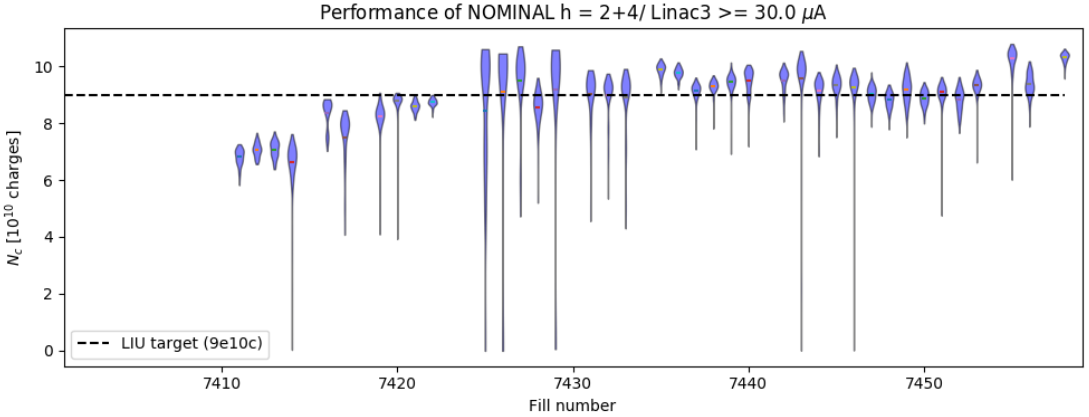
Two LHC scenarios:

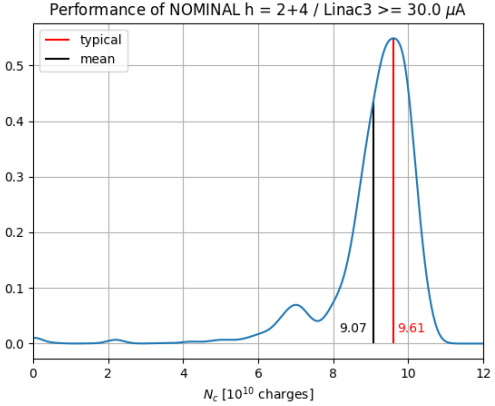
- Full LHC run (setup + luminosity production)
- Only LHC luminosity production

NOMINAL h = 2+4 (100 ns)

- **Statistical analysis on extracted intensity:** full LHC run

100 ns	**Mean** $/10^{10}$**c**	**Typical**$/10^{10}$**c**	**LIU**$/10^{10}$**c**
LHC run	**9.1**	**9.6**	**8.8**

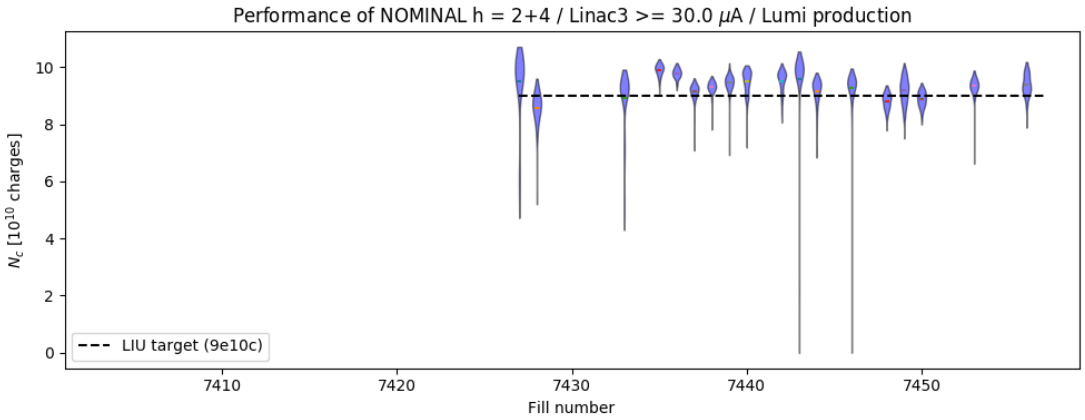


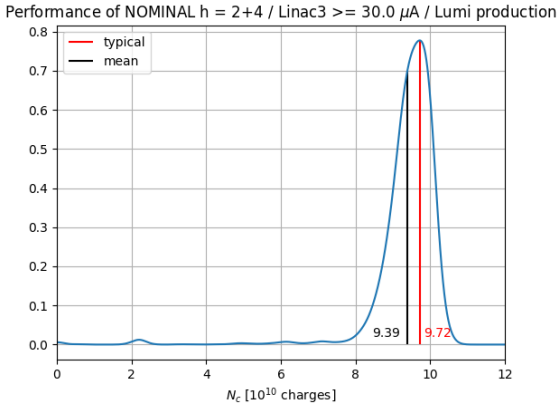


NOMINAL h = 2+4 (100 ns)

- **Statistical analysis on extracted intensity:** LHC lumi production

100 ns	Mean $/10^{10}$c	Typical$/10^{10}$c	LIU$/10^{10}$c
LHC run	**9.1**	**9.6**	**8.8**
LHC lumi	**9.4**	**9.7**	

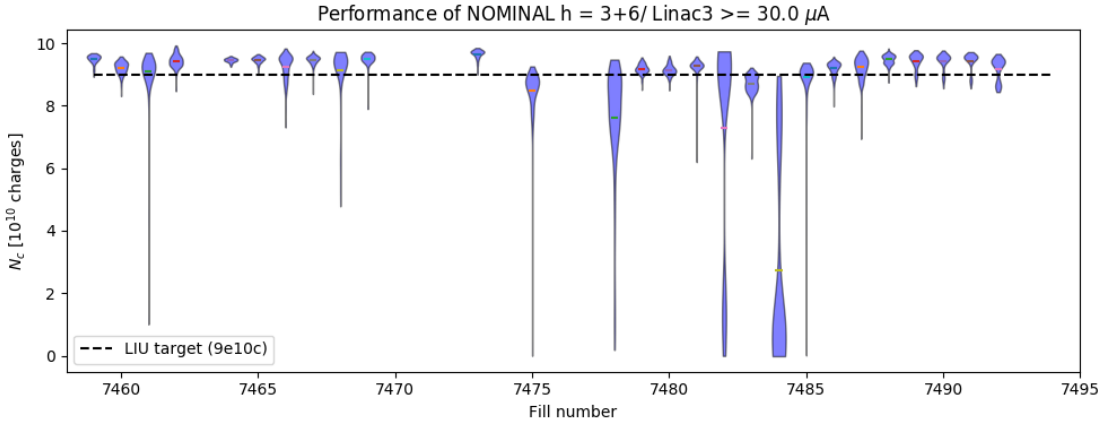


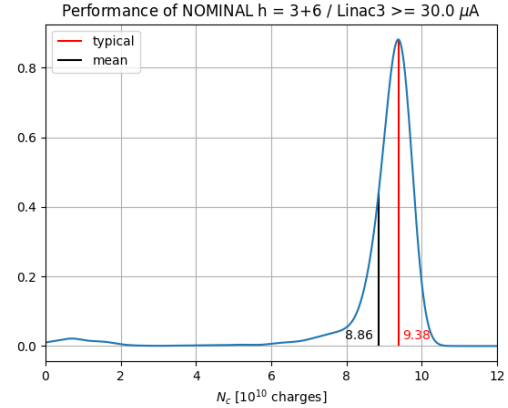


NOMINAL h = 3+6 (75 ns)

- **Statistical analysis on extracted intensity:** full LHC run

75 ns	Mean $/10^{10}$c	Typical$/10^{10}$c	LIU$/10^{10}$c
LHC run	**8.9**	**9.4**	**8.8**

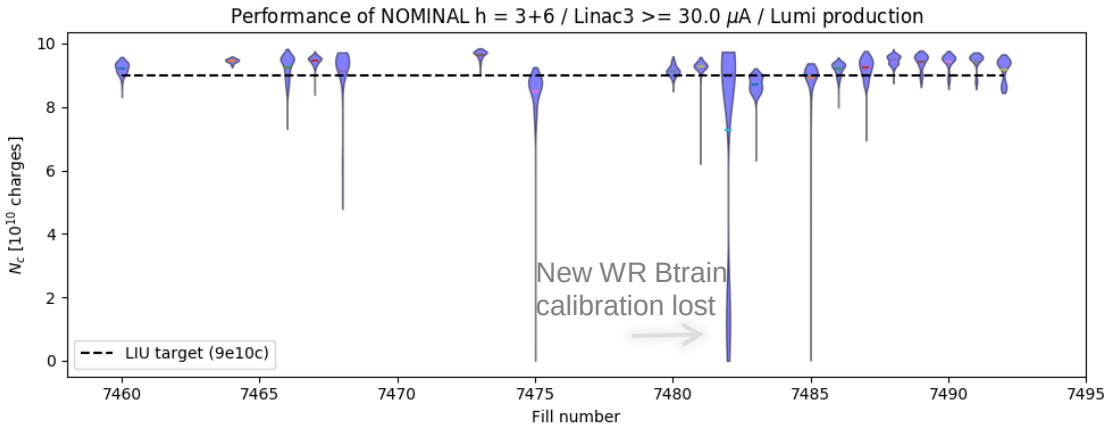


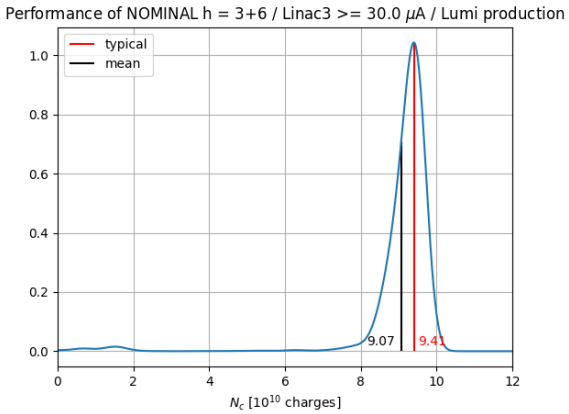


NOMINAL h = 3+6 (75 ns)

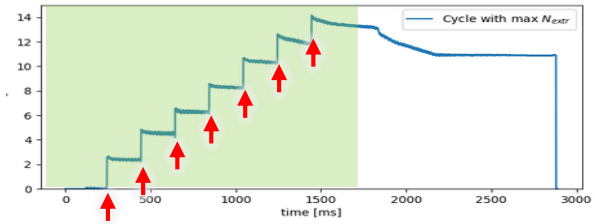
- **Statistical analysis on extracted intensity:** LHC lumi production

75 ns	Mean $/10^{10}$c	Typical$/10^{10}$c	LIU$/10^{10}$c
LHC run	8.9	9.4	8.8
LHC lumi	9.1	9.4	

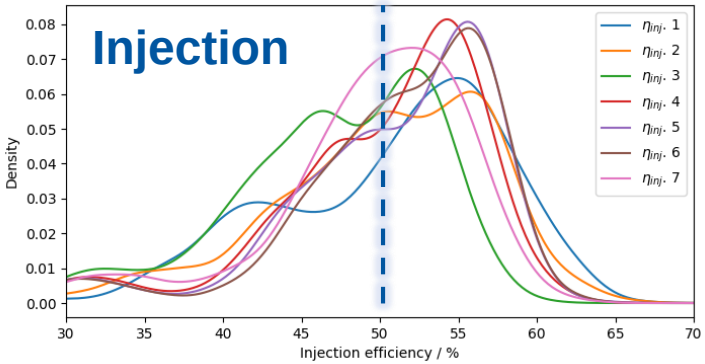




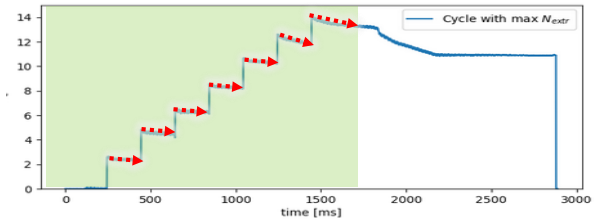
LEIR efficiency



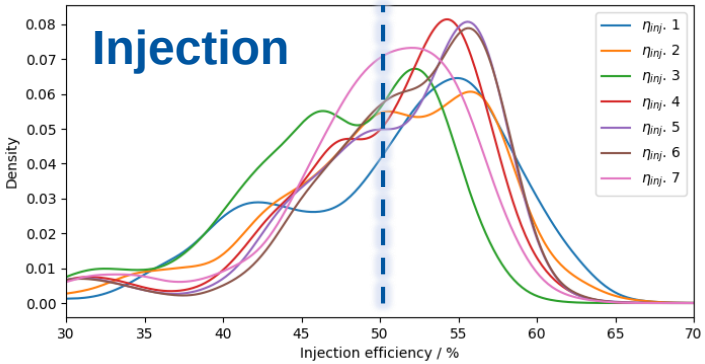
- Injection efficiency ~ 50% on average

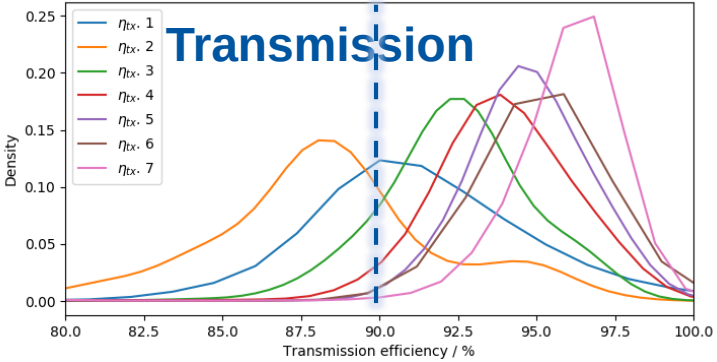


LEIR efficiency

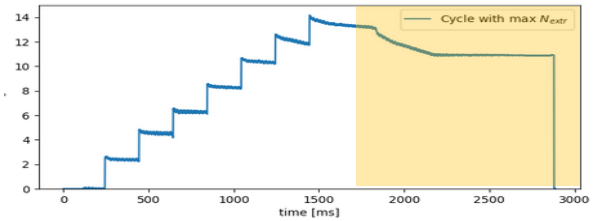


- Injection efficiency ~ 50% on average
- Transmission efficiency > 90% on average.

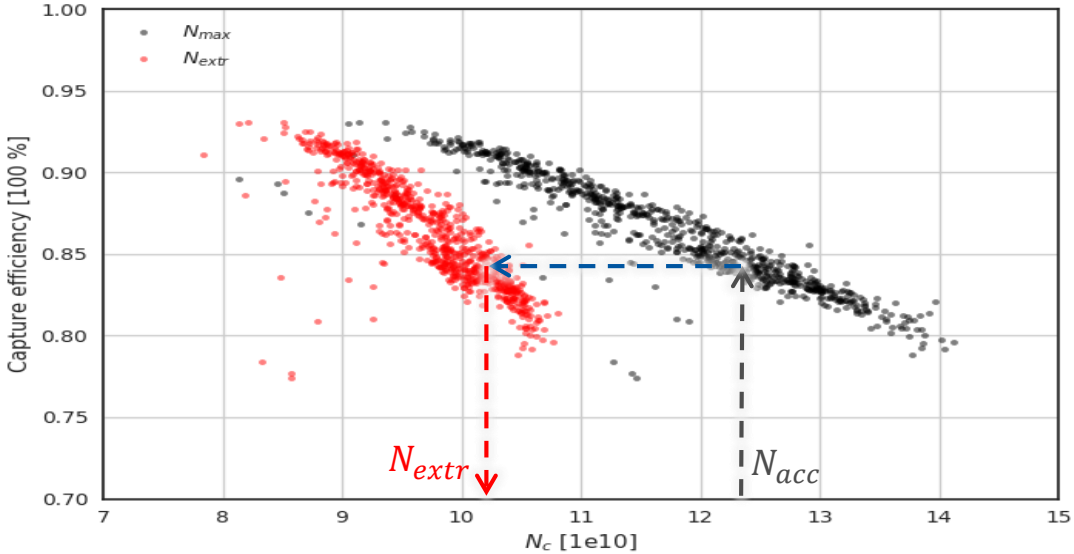


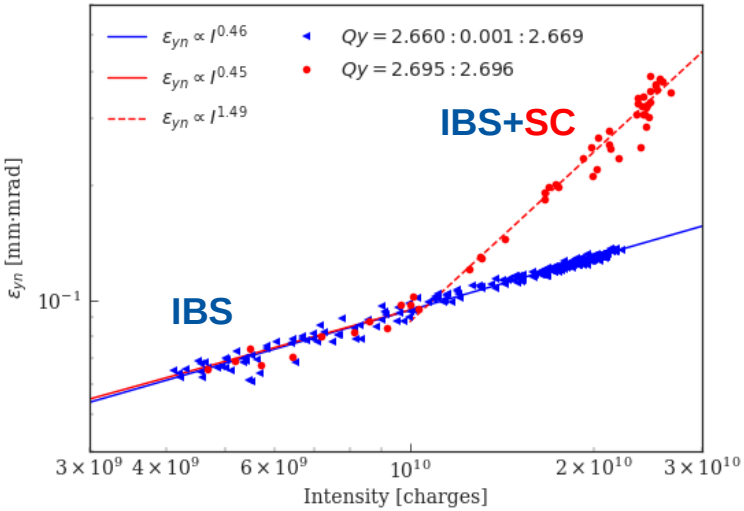


LEIR efficiency



- Injection efficiency ~ 50% on average
- Transmission efficiency > 90% on average.
- Capture efficiency: 80% → 95% (ceiling at 11e10c?)
  - Main players: IBS + SC → simulation efforts in LS2 to improve understanding.





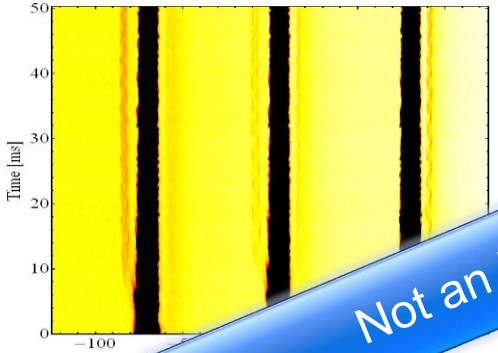
75 ns bunch spacing in the PS

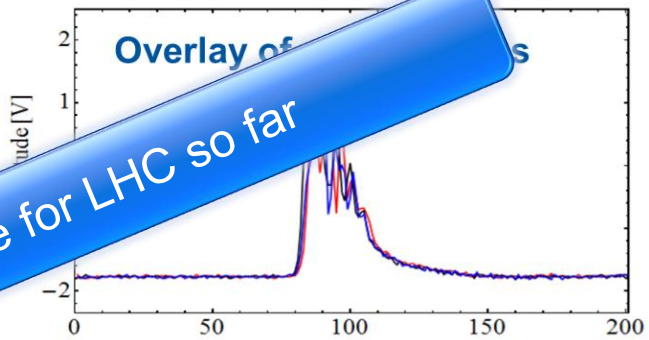
Pros:

- 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.





Not an issue for LHC so far

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!