LHC Injectors Upgrade

LEIR performance in 2018

HIRLAENDER S.

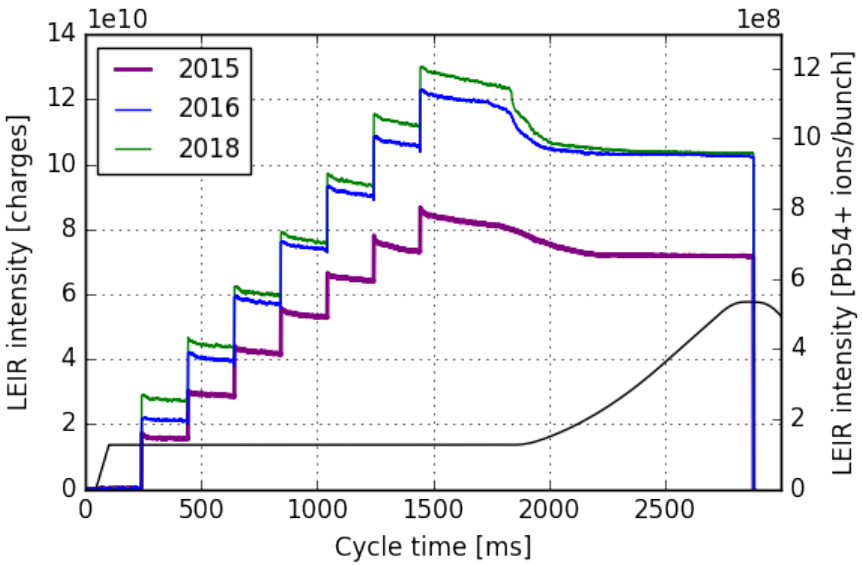
ALBRIGHT S., ALEMANY FERNANDEZ R., ANGOLETTA M. E., BARTOSIK H., BAUD G., BELLODI G.,BIANCACCI N., BOZZOLAN M., CORNELIS K., HUSCHAUER A., JAUSSI, M., KAIN V., KUCHLER D.,LEVENS T., LOURO-AVLES D., MAHNER E., MARKVERSEN O., NICOSIA D., SAA HERNANDEZ A., SCHENK M.,SCRIVENS R., SOBY L.

CERN

What will be shown?

- RECAP: Performance for LIU beam parameters
- Reliability - deliver steadfast intensity:
  - The new Schottky system
  - Optimization/Recovery tools
  - Reduce the temperature drifts of ETL.BHN10
- Status of the BPM system
- Resonance/Instability:
  - Identification of the KQFHV31 as the cause of a vertical instability
  - Sextupole settings for resonance compensation
- Summary/next steps

Review 2015/2016/2017/2018- so far – LEIR



- 2015 (Lead)
  - Outstanding thanks to improved LEIR performance
- 2016 (Lead)
  - Increased thanks to improvements in source + Linac3,
  - **LIU-ion beam parameters met**
- 2017 (Xenon)
  - MDs mainly to prepare for Lead 2018
  - Xenon source more stable than lead source
- 2018 (LEAD)
  - **LIU-ion beam parameters accomplished**

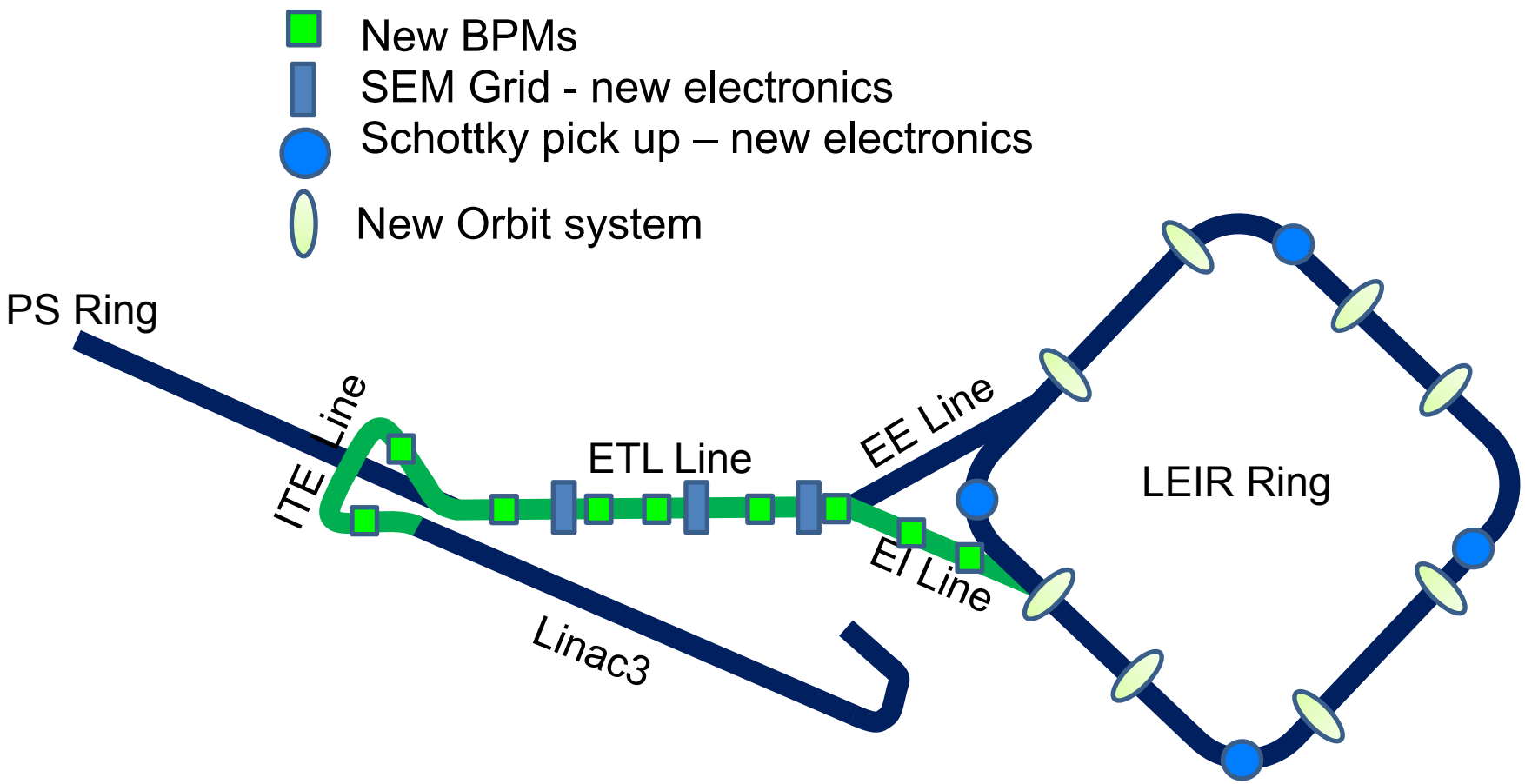
The focus is maintaining this performance reliably

The challenges

1. **Regularly deliver the required high beam intensity**
   - Improvement of monitoring of beam parameters from Linac3/ Transferline/Ring (e.g. Transferline BPMs, Schottky-system)
   - Make LEIR performance less sensitive - recover faster the optimal machine settings/beam parameters (e.g. due to changes, degradation and drifts)

2. **Gain intensity margin in LEIR to avoid operating at performance limit**
   - Optimization of sextupole settings
   - Faster ramping to
     - Minimize low energy IBS losses
     - Free space for more injections

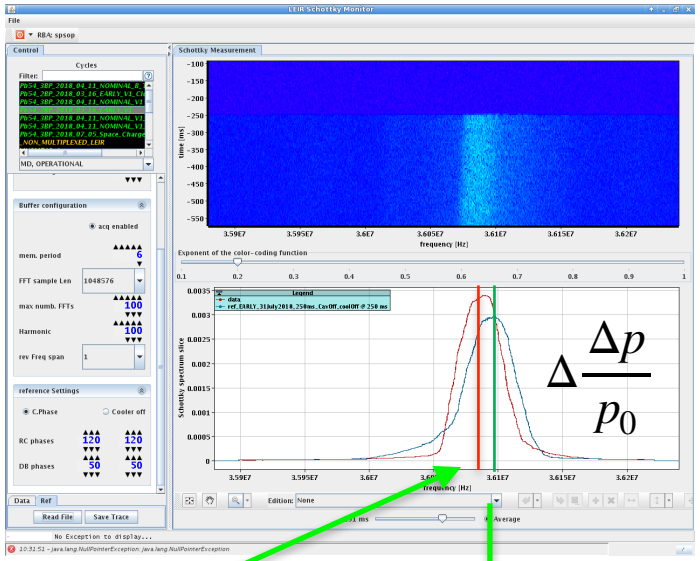
Additional/upgraded beam instrumentation 2018

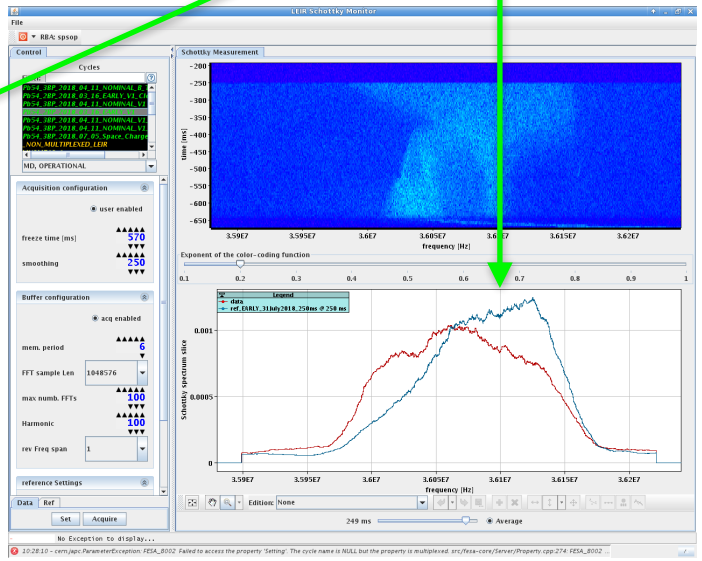


Schematic representation

The new Schottky system

- **New Schottky system in 2018**
  - Based on electronics from ELENA
  - Standard integration in controls environment
  - Allows online and continuous advanced Schottky diagnosis
  - GUI - operational since end of June
- **Schottky system – non destructive**
- **Essential tool to identify energy drifts from Linac3**
  - An energy mismatch w.r.t. reference is shown on the right - <u>leads to considerable changes</u>



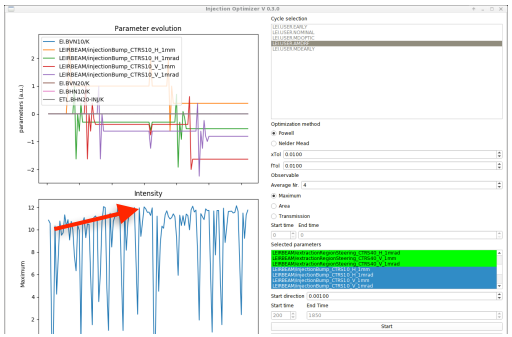


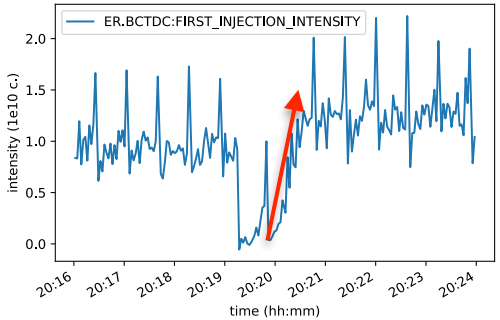
Automatic multi-parameter optimizations

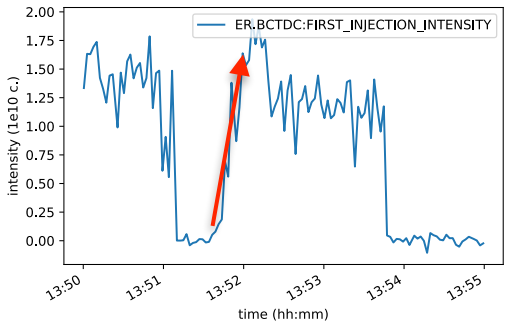
- Blind optimizers in LEIR are used on a daily basis to improve the performance/ injection process
- Easy to use, very reliable
- Overall injection efficiency/performance increased significantly
- New Algorithms with memory are currently tested with first success - instantaneous recovery (deep Q reinforcement learning - pictures below)

Recover performance automatically

Example of a multi parameter scan of the injection line





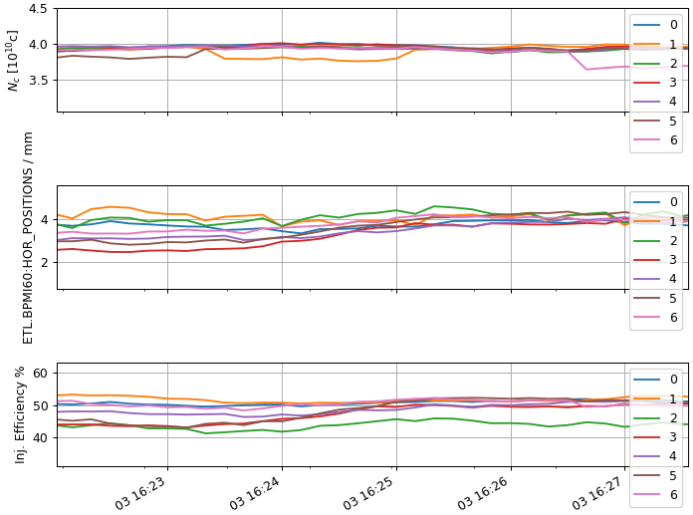


After 50 min. training

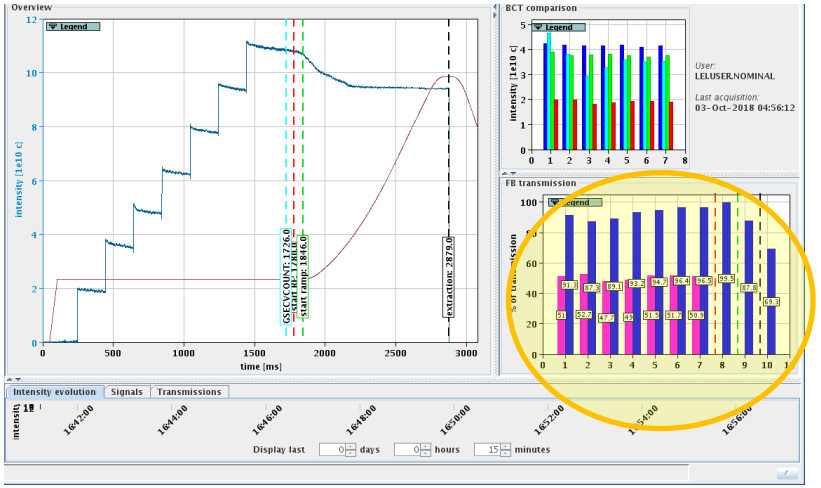
BHN10 multi injection function optimization

- **ETL.BPMI60 horizontal trajectory available and accurate.**
- **Allows to compute the BHN10 kick correction/pulse.**
- **Once the first injection is optimized (machine learning approach), deterministic corrections are applied for the following pulses to equalize their trajectory (and injection efficiency).**

Correction

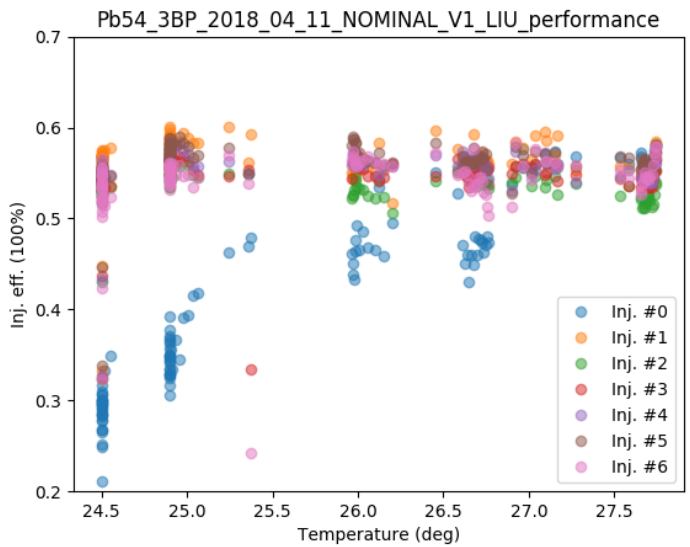


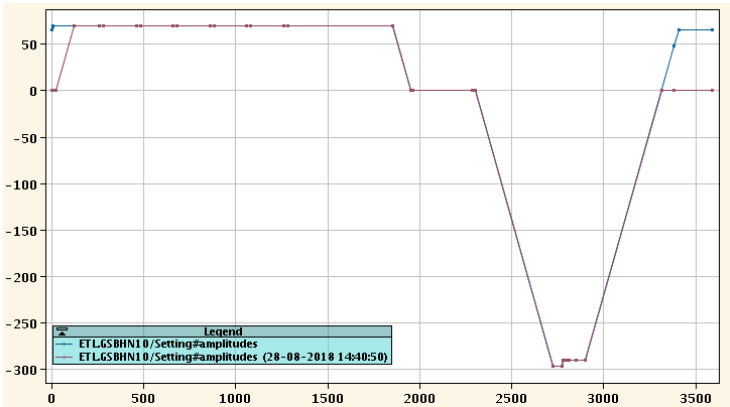
Equalized efficiencies



ETL-BHN10 drift with temperature

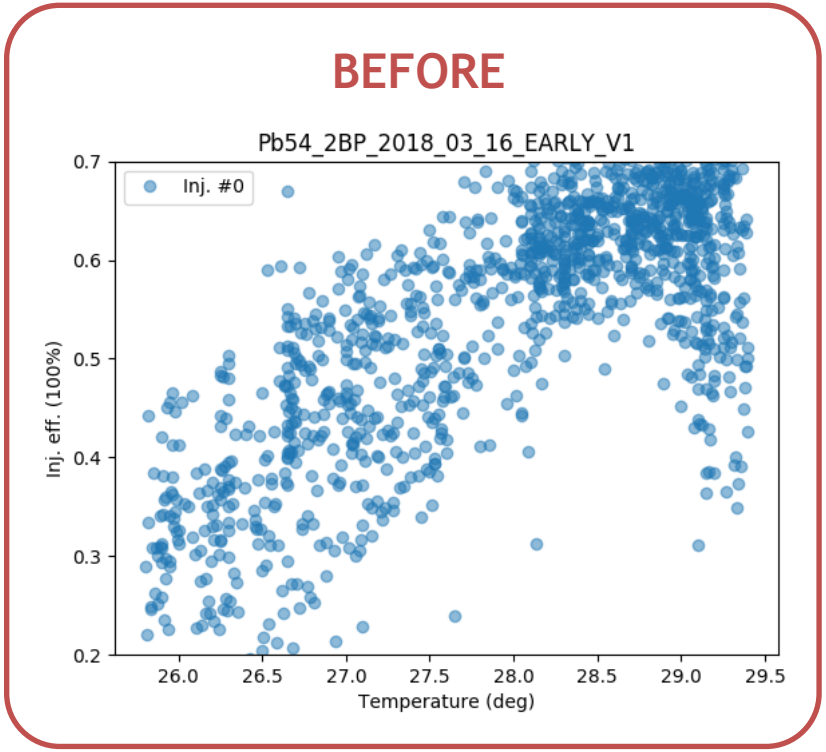
- **LEIR injection reproducibility highly affected by temperature variations.**
- **Mainly first injection affected-> -10%/degree reduction in injection efficiency!**

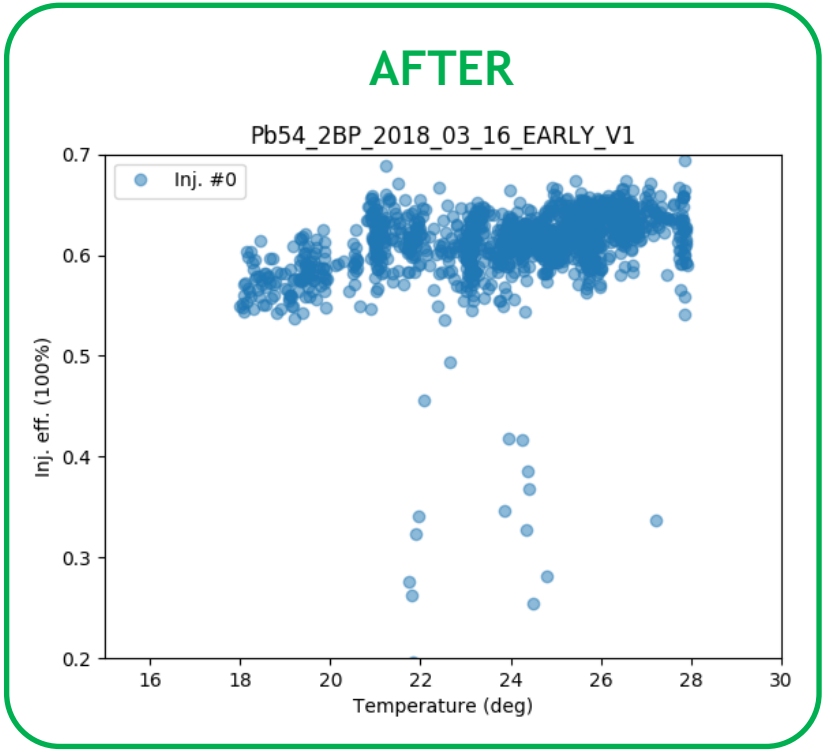




- **New ETL.BHN10 function implemented to avoid large current overshoot in the function:kept 65A current at beginning/end of the cycle.**

New BHN10 function



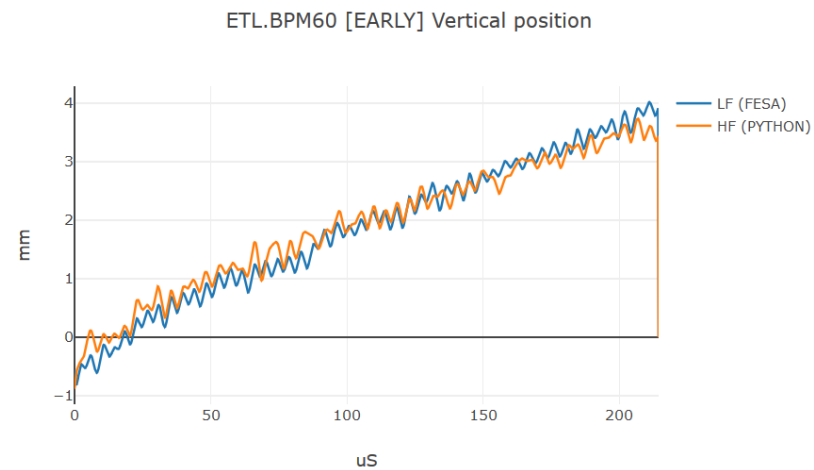


- **Dependence on temperature significantly reduced!**
- **Visible impact on daily operation**

New BPMs system

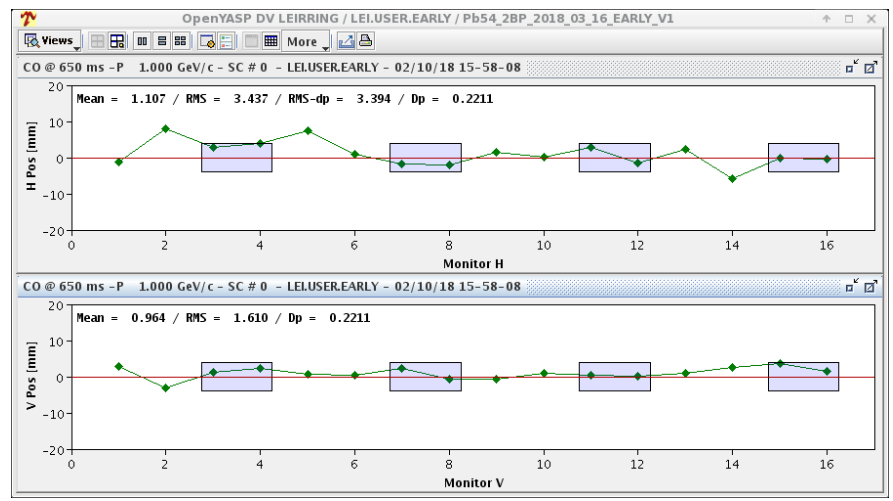
Injection BPMs:

- Positions in LSA Optics and being imported to YASP.
- Test of 101MHz and comparison with a secondary free BPM shows excellent agreement (see plot on right).
- 101MHz enabled amplifiers moved to other injection BPM in ITS2 – tests ongoing this week.
- LIU BI follow up meeting planned the end of October.



Ring

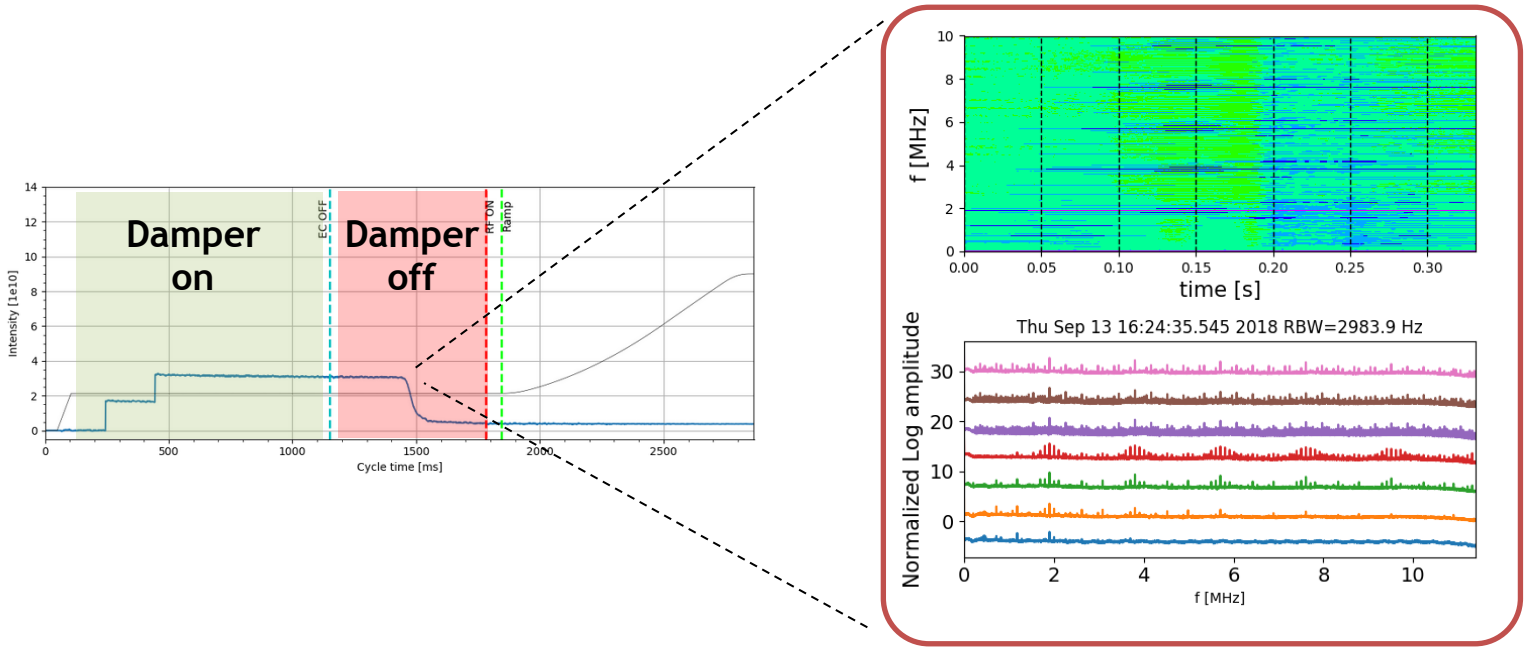
- Installed and commissioning started in 2017 with Xe
  - Orbit - Operational, and used with YASP.
  - Trajectory – Software delivered by BI. OP application almost ready, testing starting in the next week.
  - First turn – Signal interpretation ongoing. Electron suppression on pick ups installed. FESA class position calculation to be implemented and further testing foreseen.



LEIR vertical instability

- **Until TS2, LEIR could not be operated without transverse feedback due to a fast vertical instability peaked at 1.9 MHz, not predicted by the impedance model.**

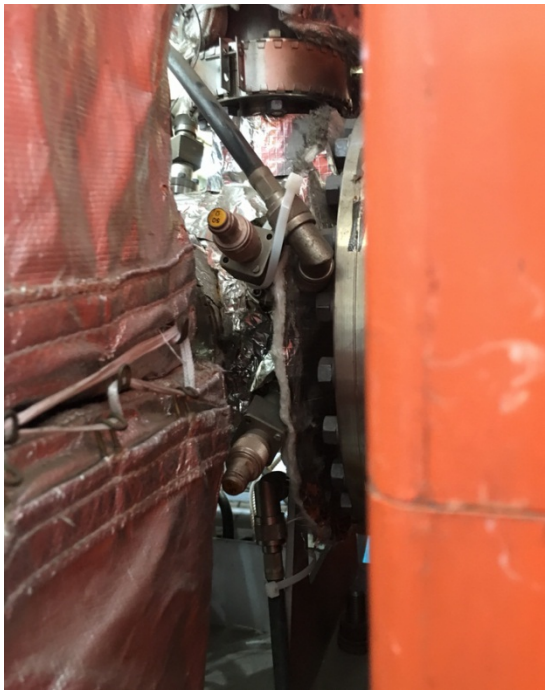
- **A detailed study of the instability imprinting in the transverse beam spectrum was performed in 2018 using the V Schottky system.**

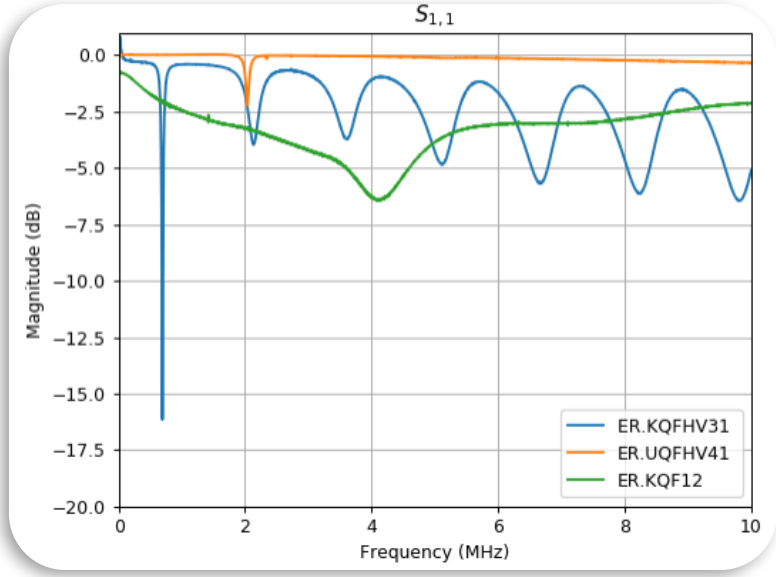


- **Instability pattern-> not properly terminated cables of stripline pickups/ kickers!**

Source identification

- **RF measurements were done in reflection on the devices' cables to try and identify the source.**
- **Repetitive pattern similar to the beam instability found for KQFHV31**

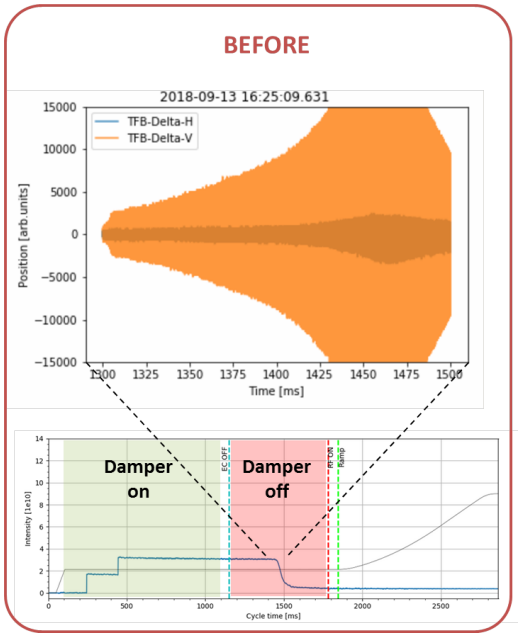


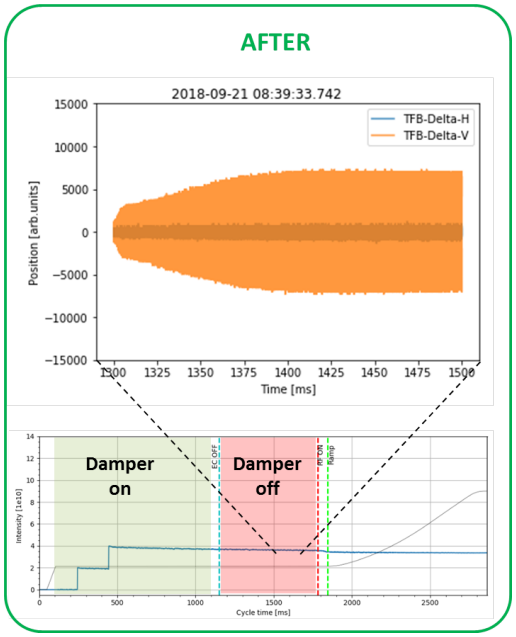


- **Foreseen: reconnect and repeat measurements**

LEIR V instability after TS2

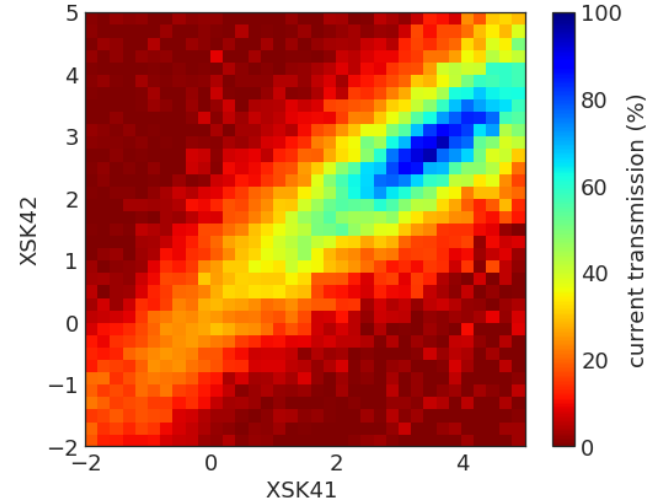
- **The beam survives without vertical damper: still activity but much lower growth rate.**
- **Even the NOMINAL can survive without vertical damper.**
- **Damper still helpful/necessary e.g. in MD cycles with small H/V emittances.**

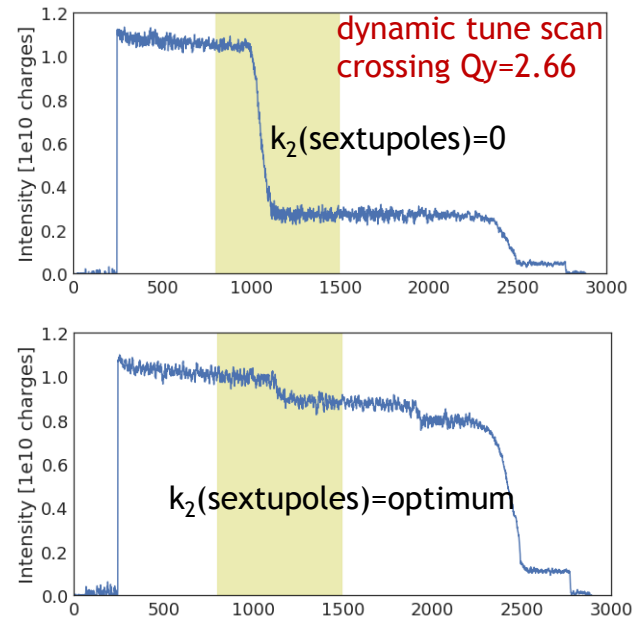




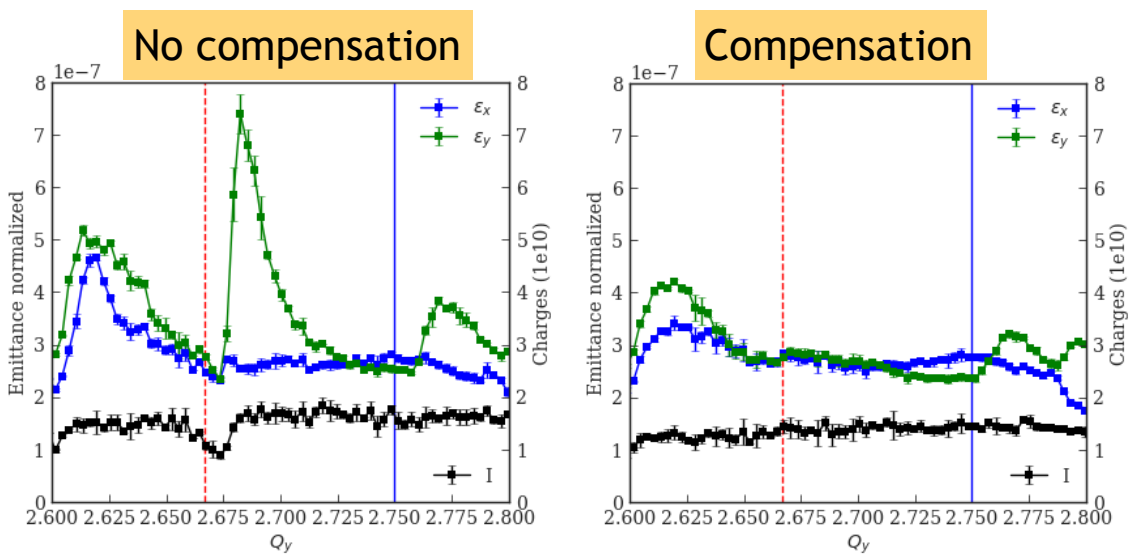
Resonance compensation

- **Compensation of resonance at Qy = 2.66 with skew sextupoles up to 90%:**
- **For low and high intensity beams**
- **During injection plateau and during ramping (optimum settings at higher sextupole current --> source of resonances excitation is ramped as well)**





Measurements of losses and emittances as a function of Qy:



Summary - next steps

- **Focus: maintain performance reliability**
  - Schottky is operational: Momentum distribution can be compared to references - drifts are immediately visible and can be corrected
  - Injection BPMs used improve stability
  - The performance (due to drifts) is recovered quickly with optimizers
  - The ETL.BHN10 temperature drift has been significantly reduced
- **Instabilities/resonances**
  - The source of a vertical instability was identified and mitigated - KQFHV31
  - Qy = 2.66 resonance non space charge driven — can be compensated
- **Next steps:**
  - Stray field compensation/ETL.BHN10
  - Improvement of the fast ramping cycle with 8 injections
  - BPM System: First turn/turn by turn measurements at an operational level
  - Operational fast optimizers

LHC Injectors Upgrade

THANK YOU FOR YOUR TIME!