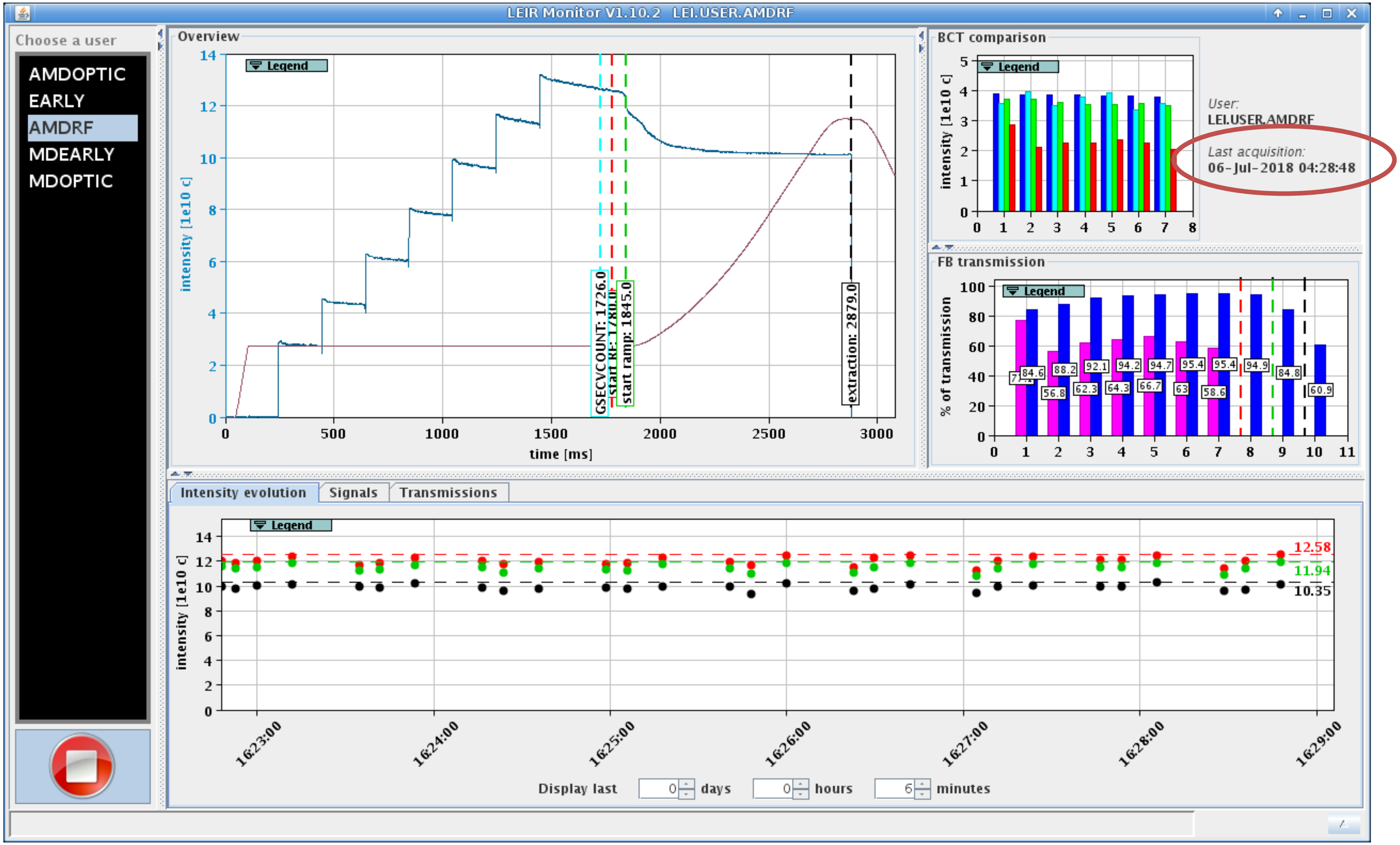
Intensity record in LEIR

N.Biancacci

Acknowledgements: R.Alemany, H.Bartosik, G.Bellodi, G.Baud, M.Bozzolan, K.Cornelis, A.Frassier, S.Hirlaender, V.Kain, A.Latina, D.Moreno, D.Nicosia, A.Saa Hernandez, R.Scrivens, G.Tranquille.

10.35e10c reached!

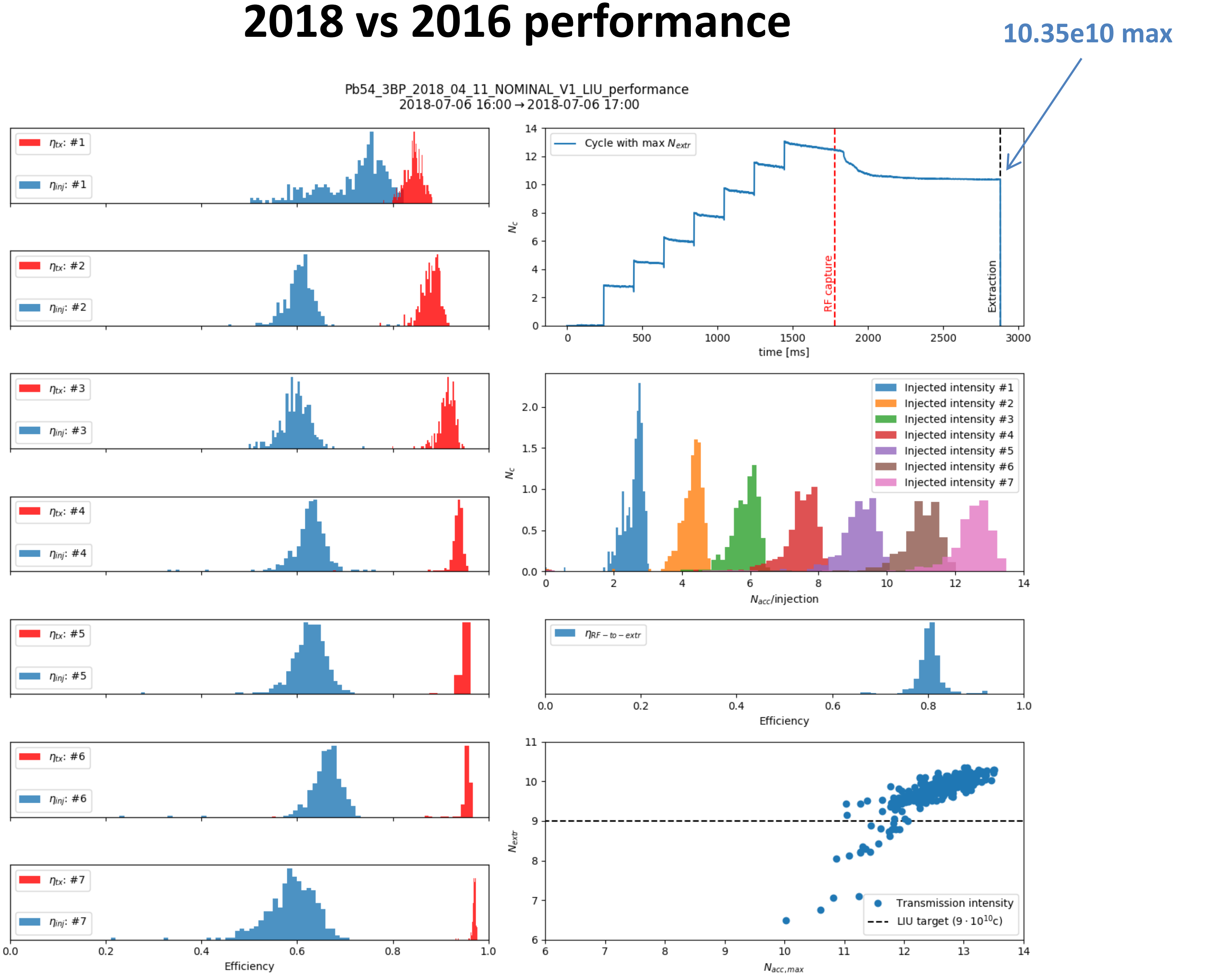


See also 20th FOM meeting, 10/07/2018

Outline

- 2018 vs 2016 performance
- Steps to LIU achievement
- Reproducibility issues: present understanding and open questions.
- Summary and next steps

2018 vs 2016 performance



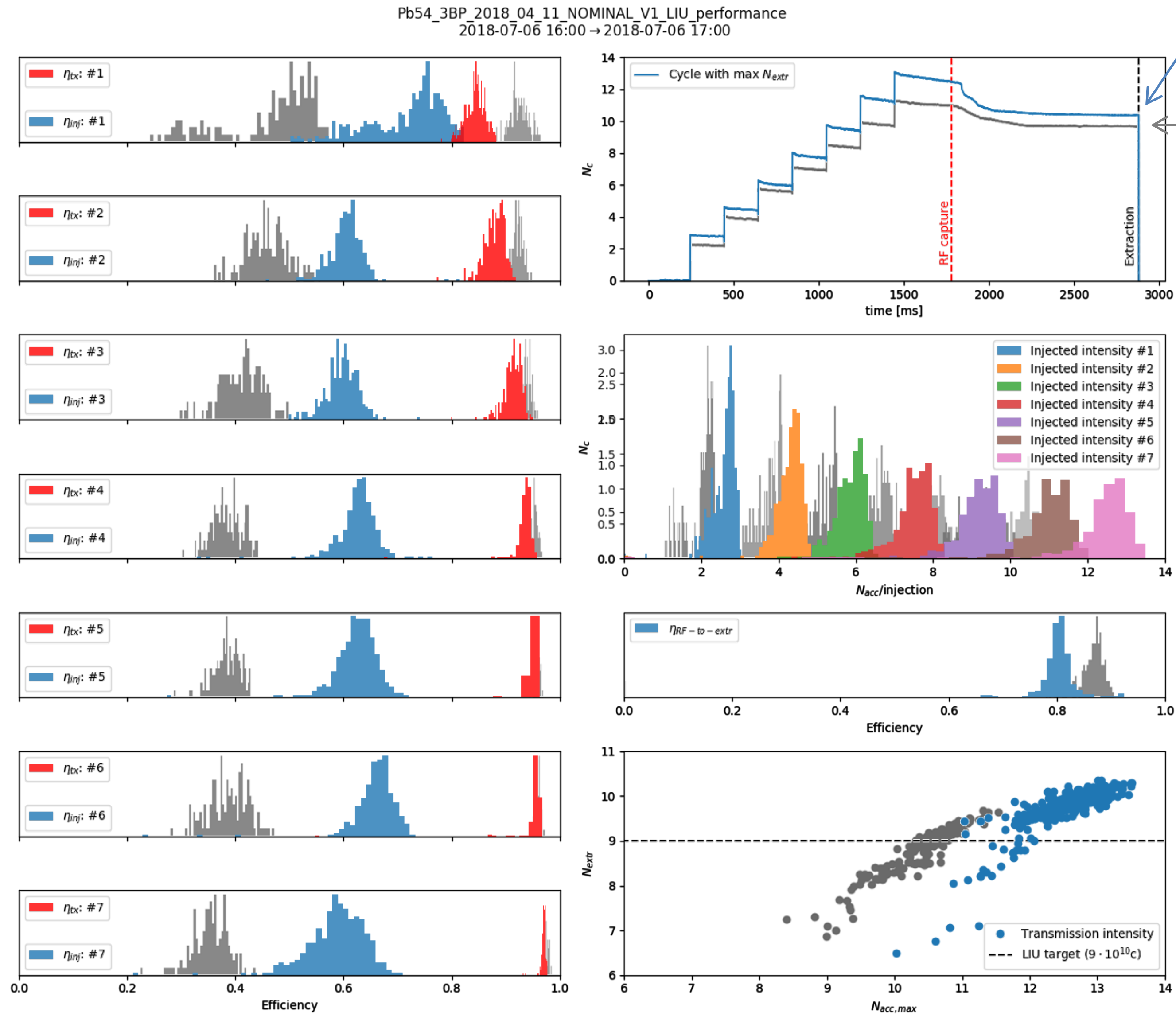
- NOMINAL cycle statistics as at the first high intensity record on 2018/07/06.

2018 vs 2016 performance

01/12/2016
Best
performance

10.35e10 max

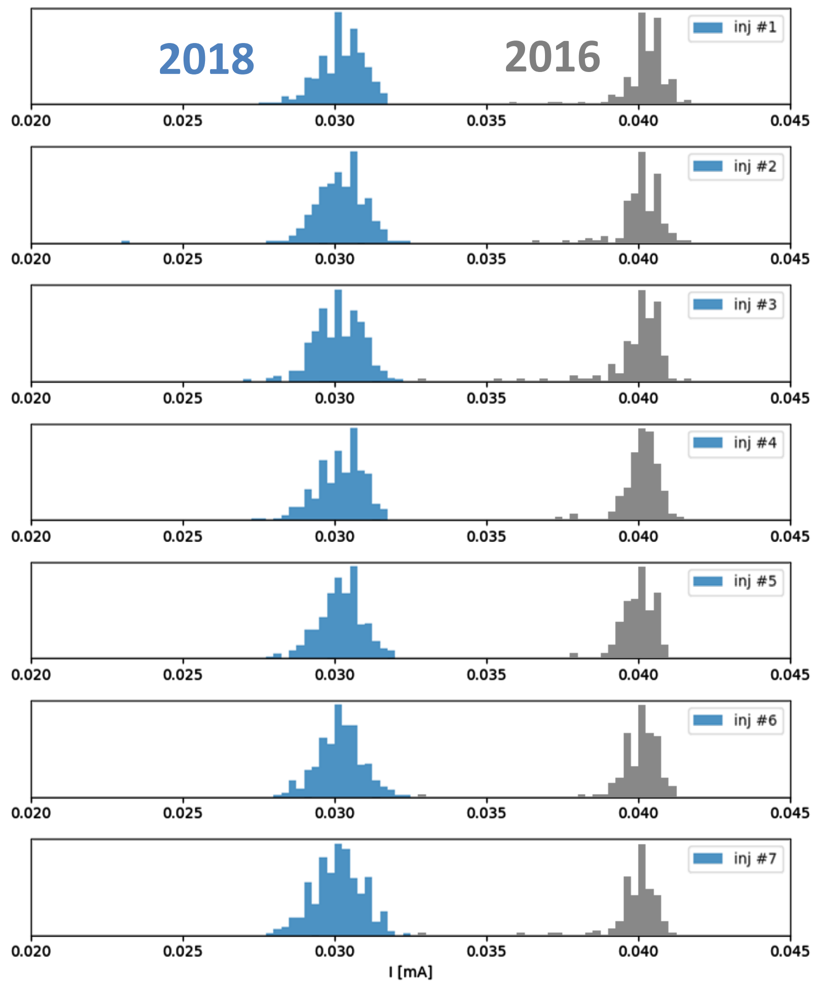
10.22e10 max
(cut in LDB)



- >20% higher injection efficiency than 2016 -> Met LIU target!
- Worse transmission through RF capture (90% in 2016)

2018 vs 2016 performance

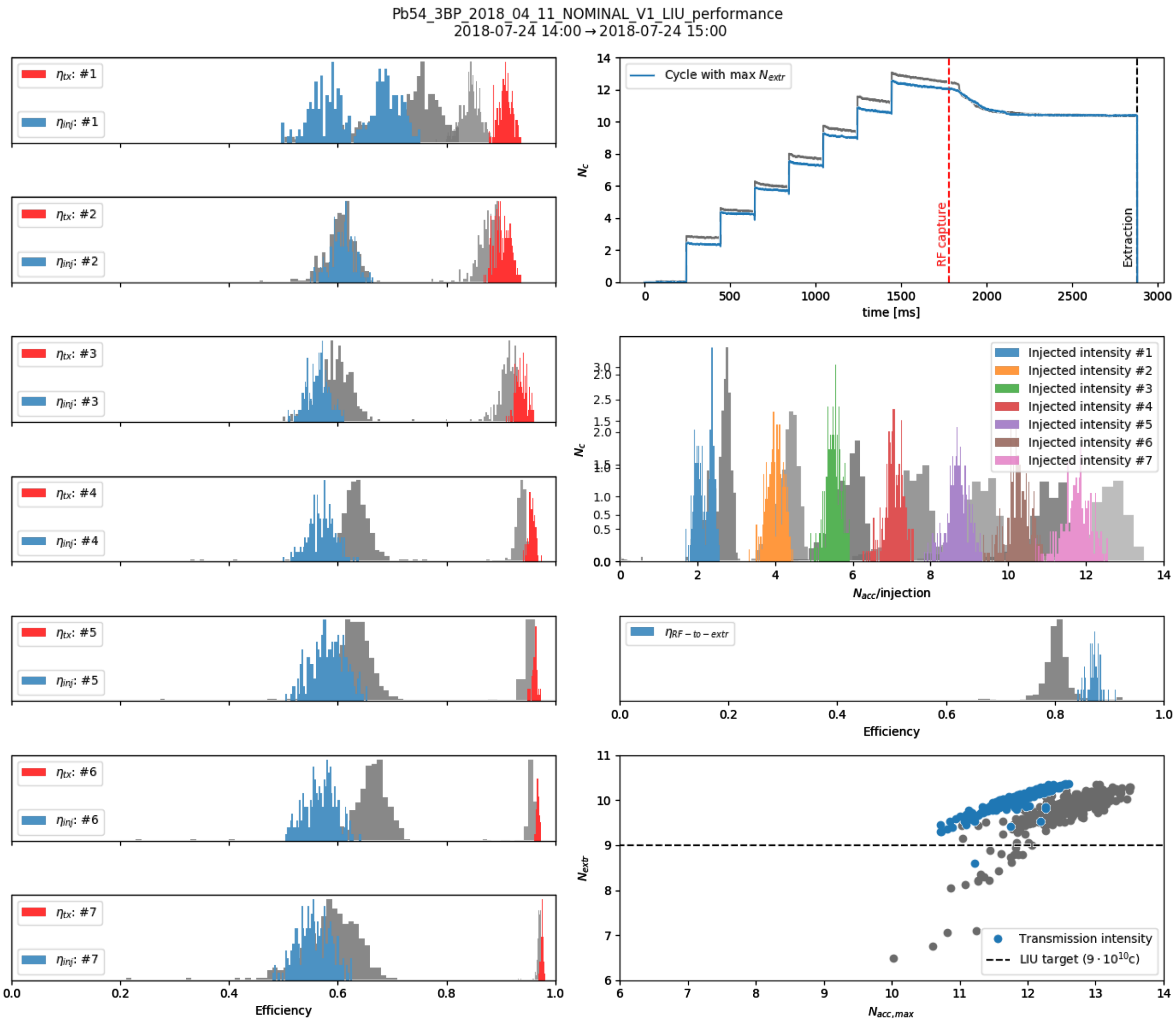
Linac3 current at ITH.BCT41



- Record achieved despite the lower Linac 3 current (30uA vs 40uA)
- Further optimization (orbit during RF capture) brought us to a new record ->

2018 vs 2016 performance

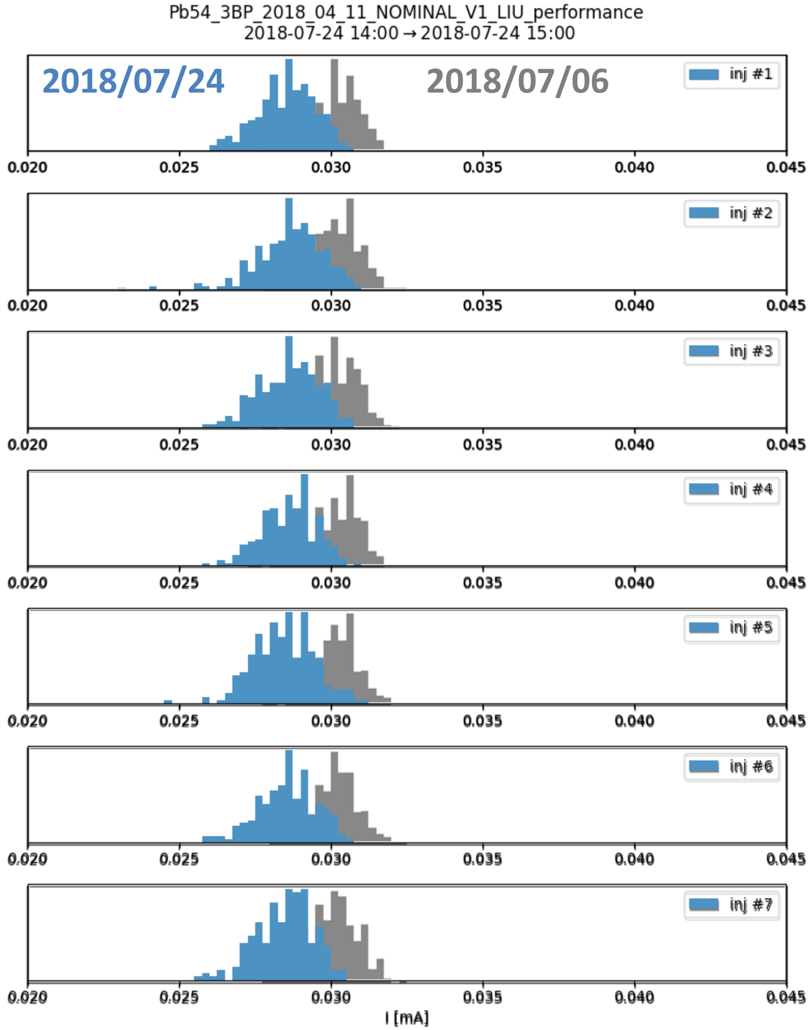
06/07/2018
First record



- New record achieved on 2018/07/24!
- Re-met LIU intensity with 90% transmission through RF capture (as in 2016) and…

2018 vs 2016 performance

Linac3 current at ITH.BCT41



- New record achieved on 2018/07/24!
- Re-met LIU intensity with 90% transmission through RF capture (as in 2016) and…
- … 27uA mean Linac3 current.

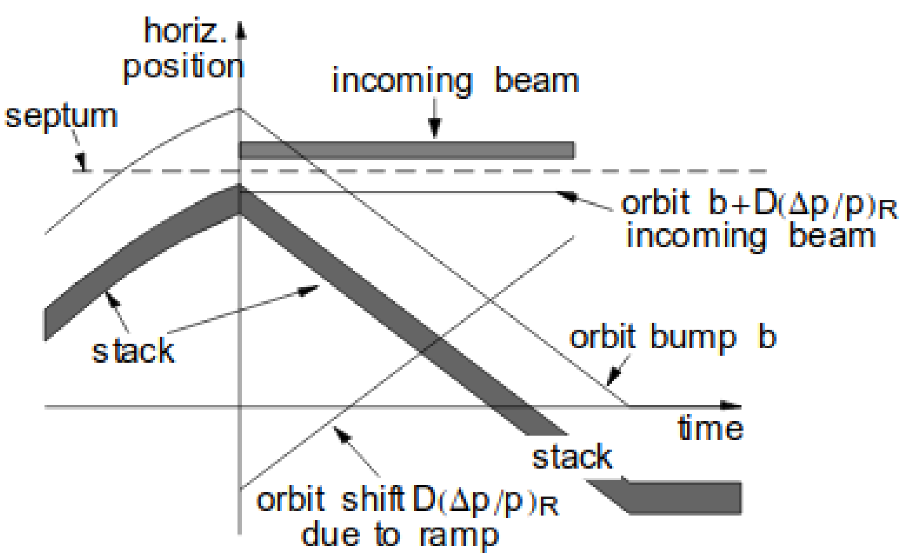
Steps for LIU intensity achievement

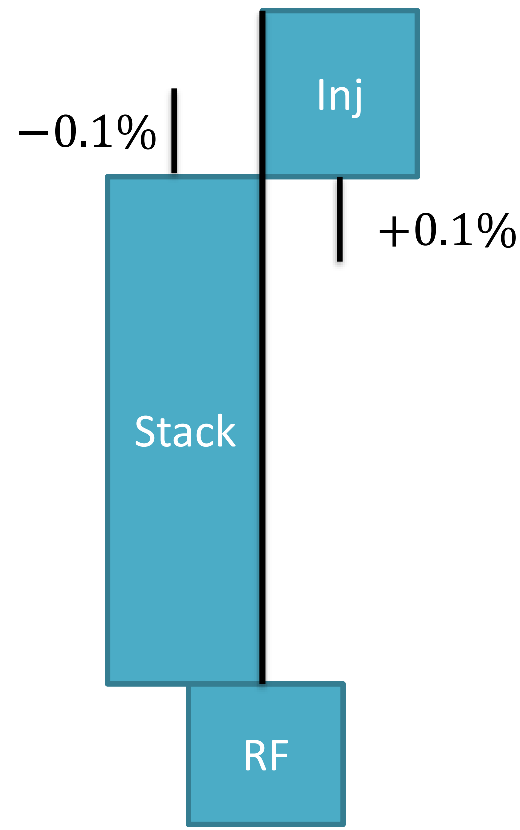
1. Maximization of momentum acceptance.
2. Orbit correction during all the cycle.
3. Injection bump/ injection trajectory optimization.
4. Tune ripple elimination.
5. Tune bump towards 2.75 during capture.
6. Orbit in the cooler optimization for best distribution.
7. Momentum correction during accumulation (radial loop -like).
8. Orbit bump in SS4 to minimize vacuum pressure.
9. Injected pulse energy distribution optimization.
10. RF capture with voltage amplitude/frequency modulation.

1. Maximization of momentum acceptance.

$$\bar{x}_{co} = x_{co} + D_x \frac{\Delta E}{E} = x_{co} - \frac{D_x}{\eta}\frac{\Delta f_r}{f_r}$$

- Due to LEIR injection scheme, large injection bump accommodates the energy ramped LINAC3 pulse (+/-0.2%)
- Stacked (mono-energetic) beam needs to be lowered in energy as it would be scraped if in the same momentum of the injected beam.
- Achieved by energy dragging with electron cooler.
- Closed orbit errors need to be corrected as well, on momentum, to avoid additional losses.





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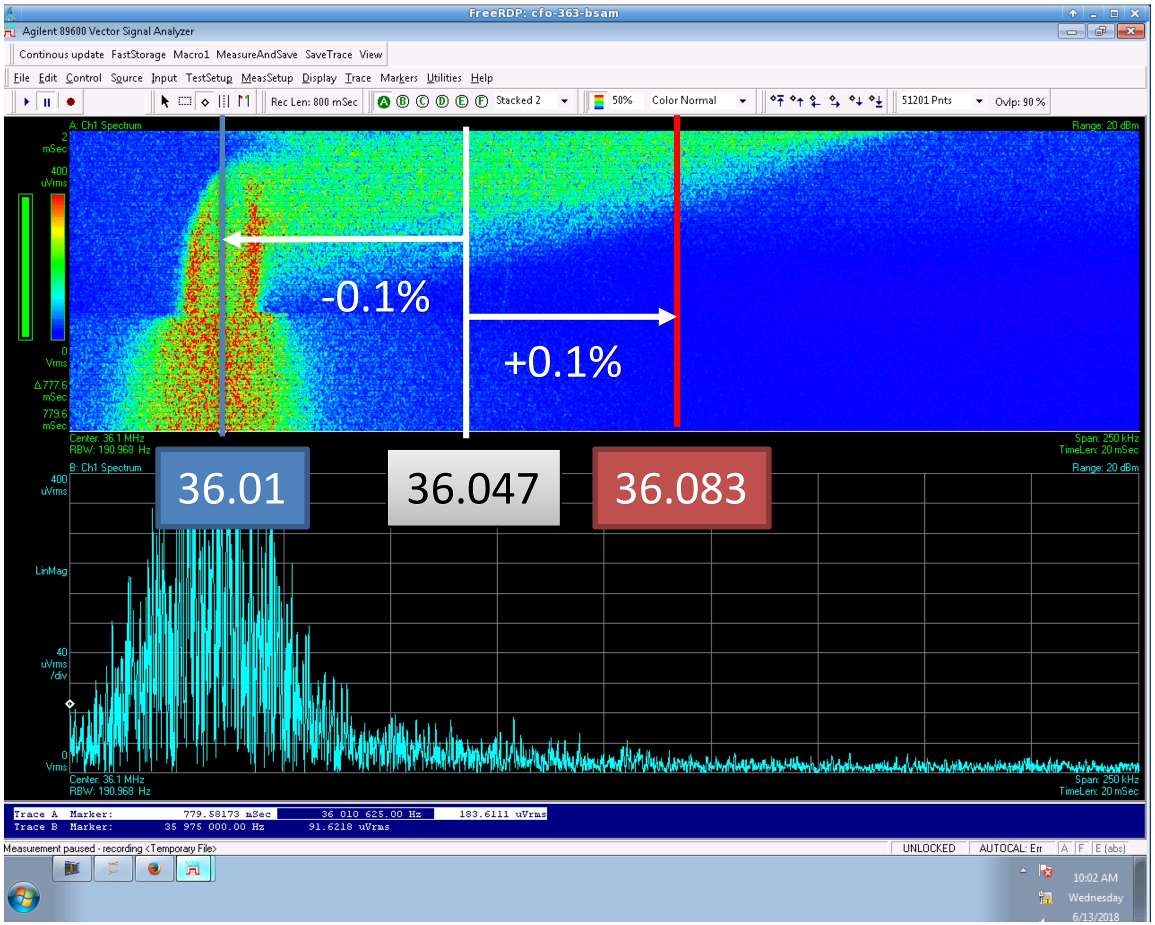

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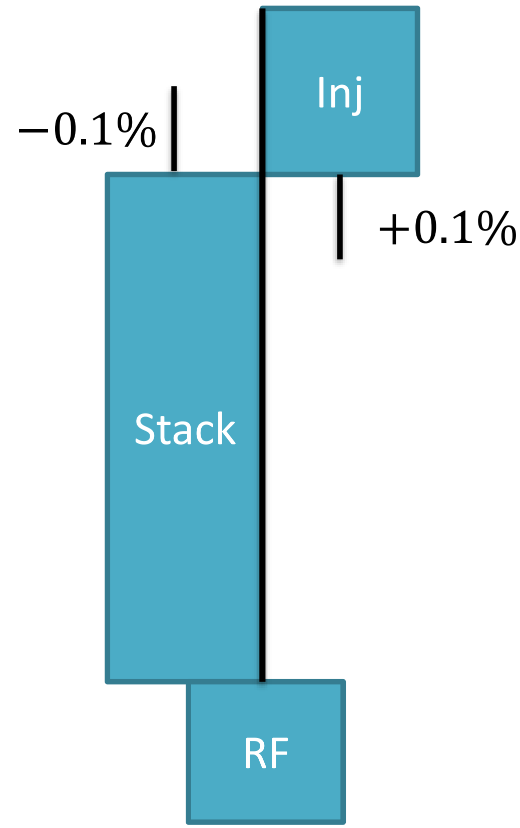
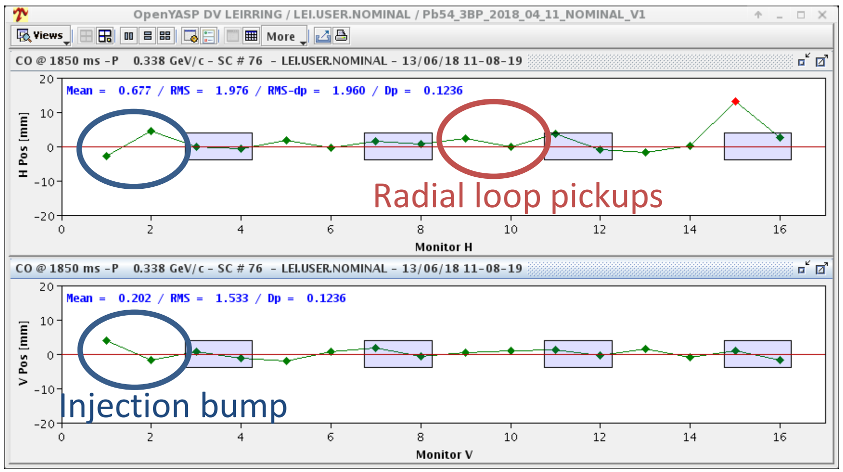
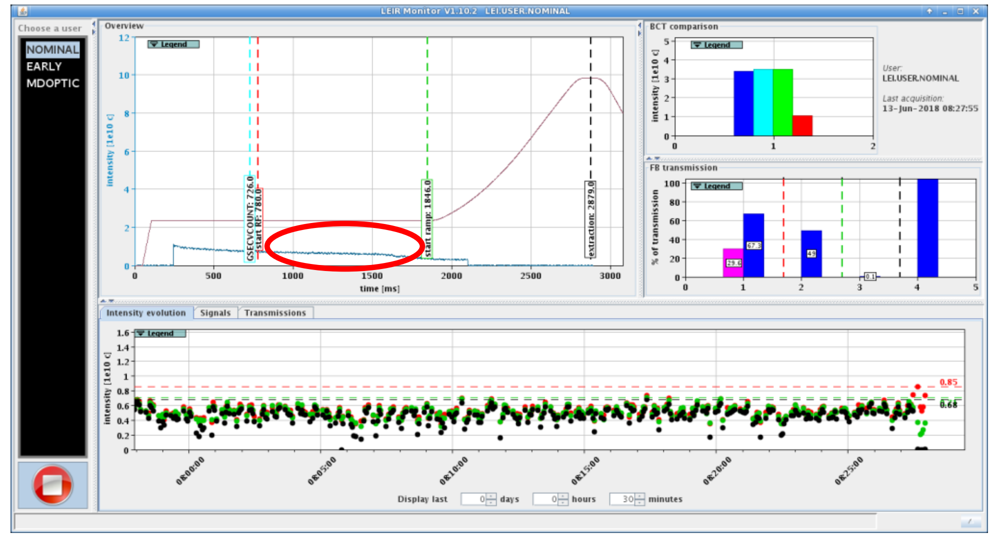


2. Orbit correction during all the cycle



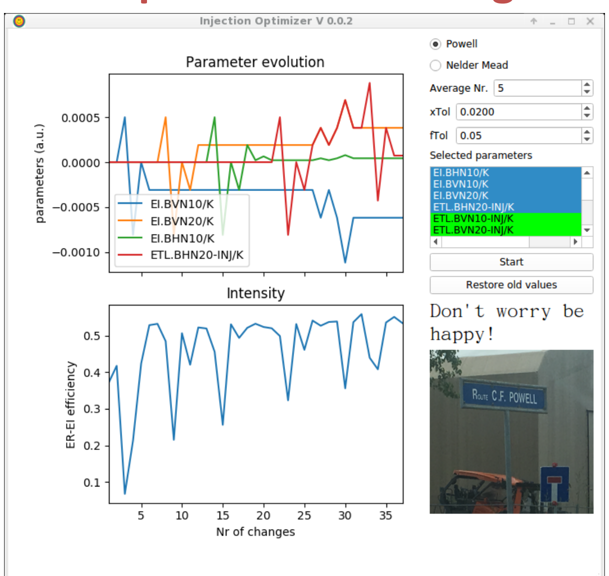


- Need to split flat bottom correction to be able to inject and to correct without depending on injection bump.
- Bare correction done to flatten beam at radial loop pickups.
- Btrain corrected to be on momentum at the frequency expected by RF.

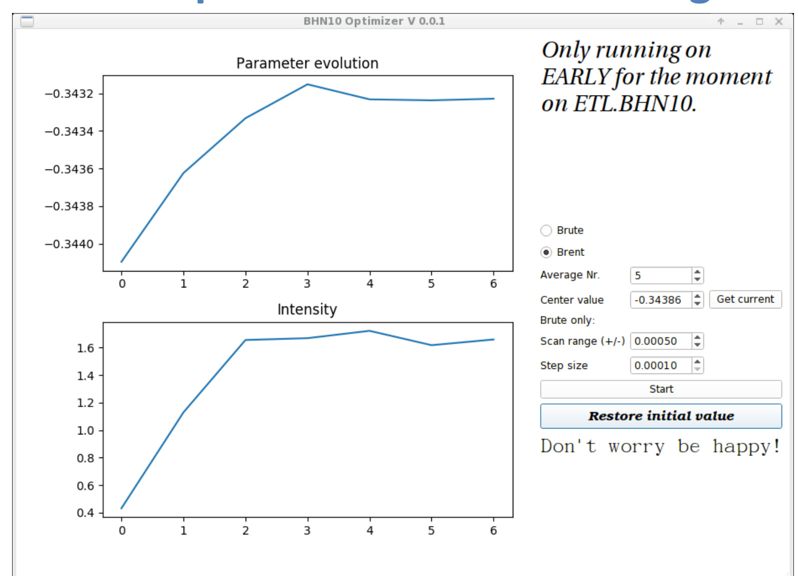
3. Injection bump/ injection trajectory optimization

- Optimizers routinely applied in order to recover optimal injection settings.
- Main knobs are:
  - the injection bump in the LEIR ring
  - Correctors in the ETL/EI line
- Fast convergence subject to stable Linac3 current and number of cycles.

Example: EI line steering



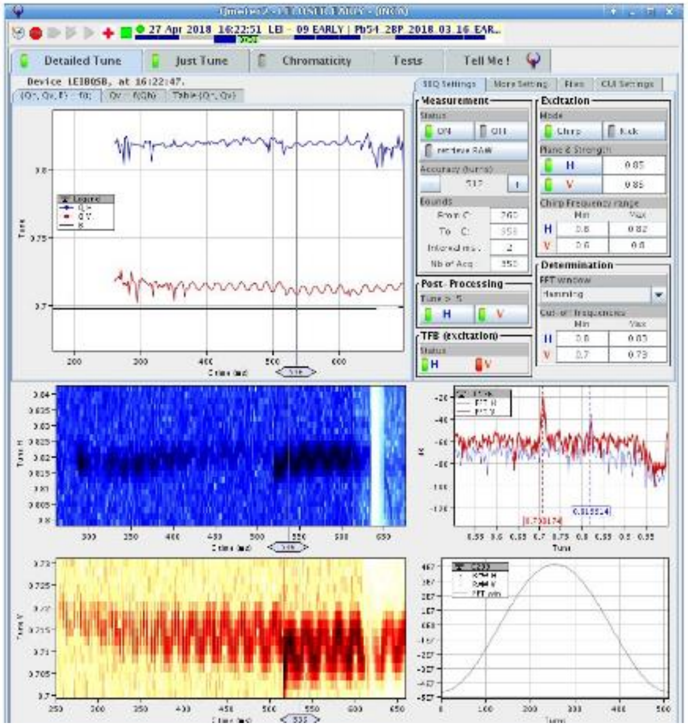
Example: ETL corrector steering



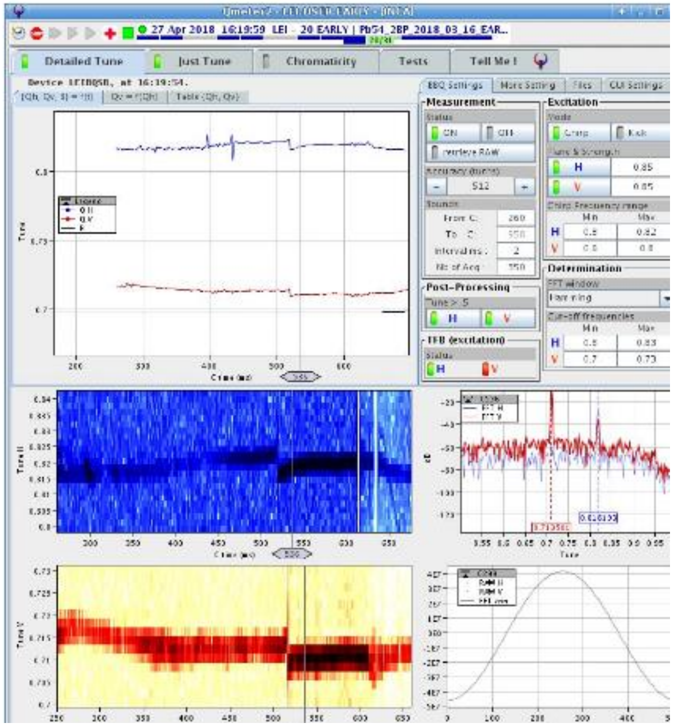
4. Tune ripple elimination

- See also D.Moreno in MSWG #10 on 27 Jul 2018.
- Tune ripple induced by feed down effect on sextupole windings XFW01 (not actually used in LEIR, but enabled..)

XFW01 ON



XFW01 OFF



D.Moreno et al.

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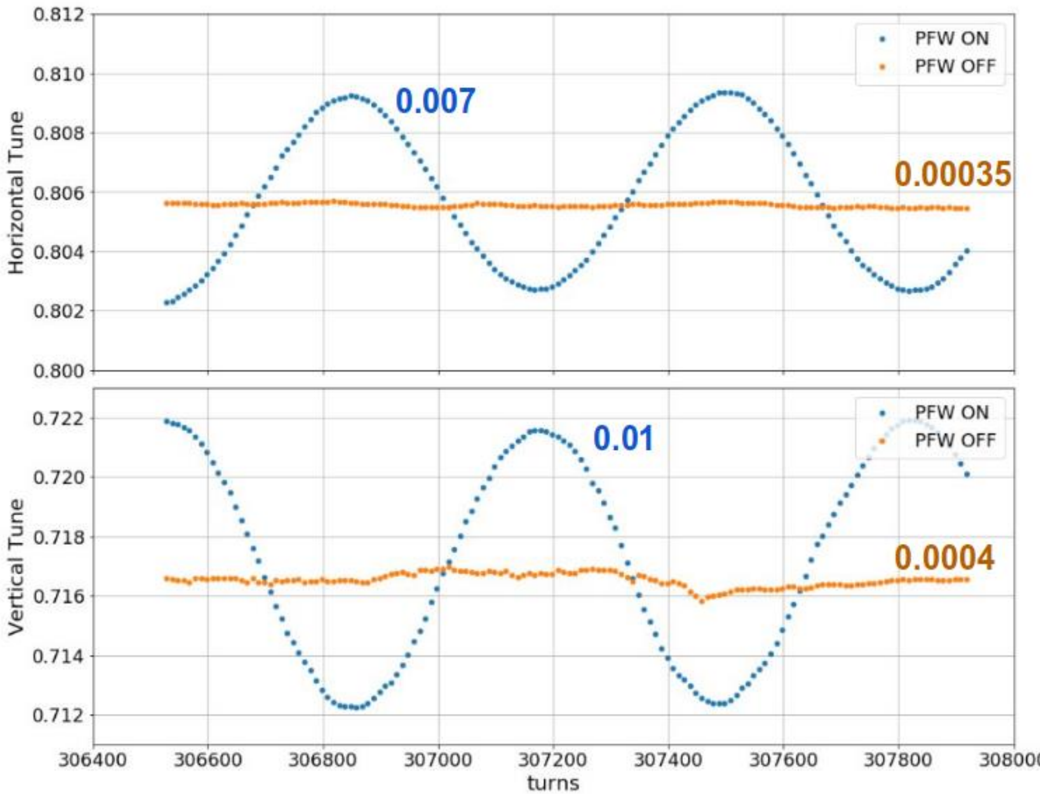
- Disabling the correctors, the tune ripple is suppressed



D.Moreno et al.

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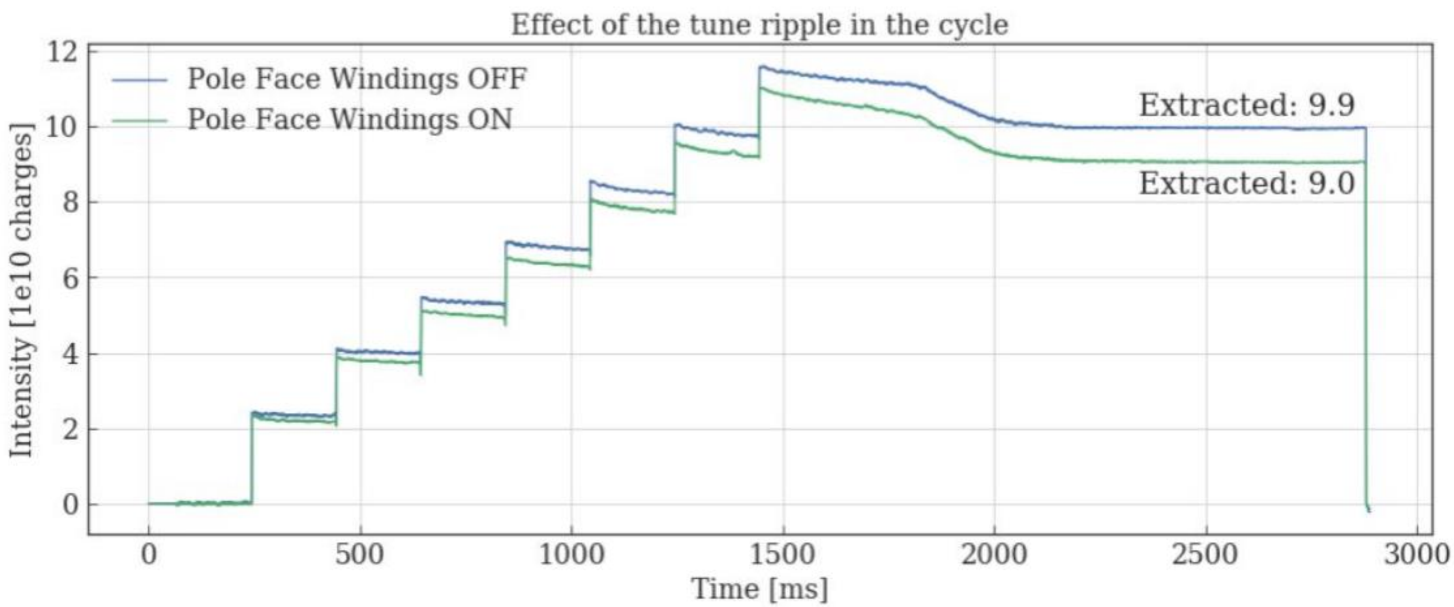
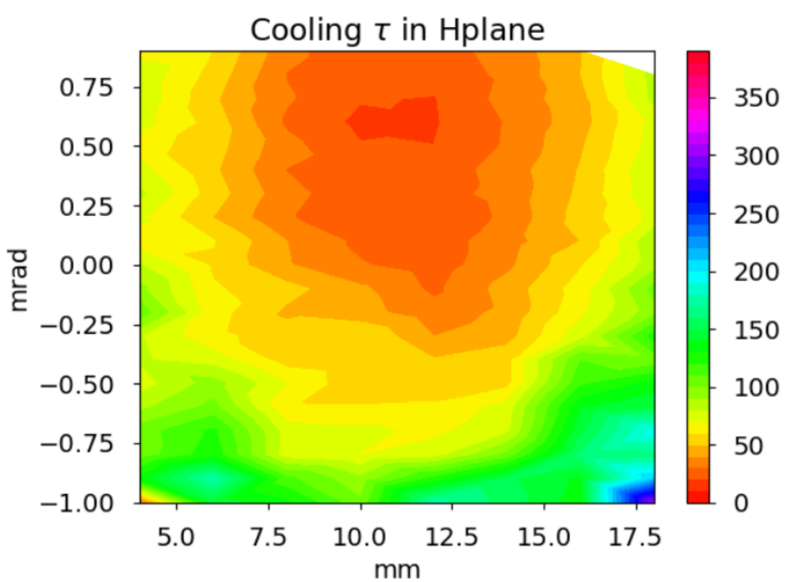
- Tune ripple induced by feed down effect on sextupole windings XFW01 (not actually used in LEIR, but enabled..)
- Disabling the correctors, the tune ripple is suppressed.
- Clearly affecting lifetime of injected beam (pushing particles into dangerous resonances).

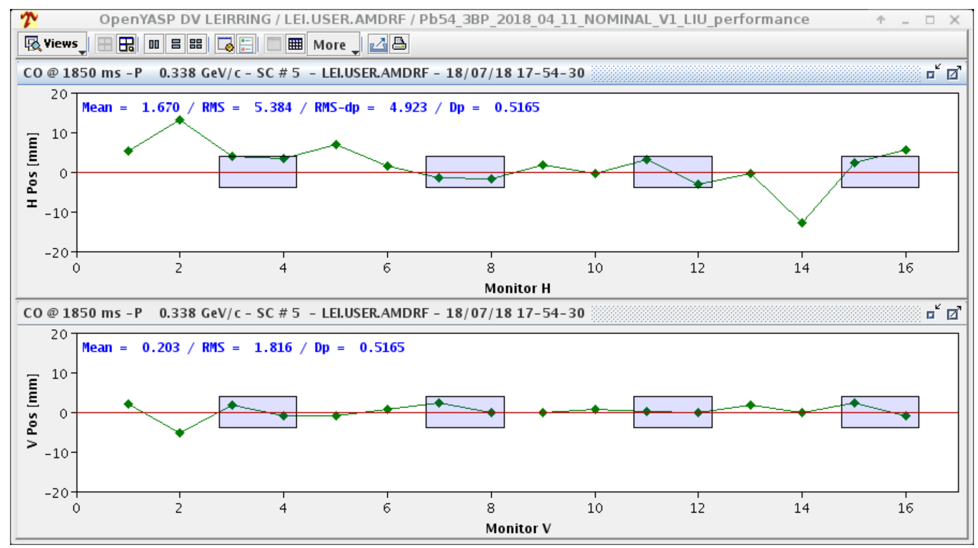


D.Moreno et al.

5. Orbit in the cooler optimization for best distribution

- Cooling maps in H/V produced by A.Saa Hernandez et al. (to be presented)
- Island of strong H cooling confirmed.
- Optimal bump settings are not necessarily the “coolest” ones:
  - Small beam size -> ok for aperture, may lead to poor lifetime or instabilities.





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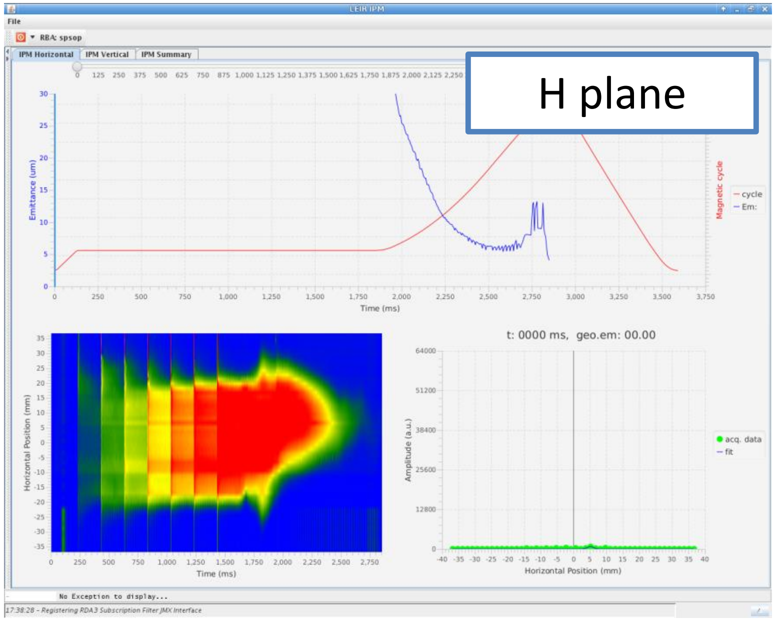
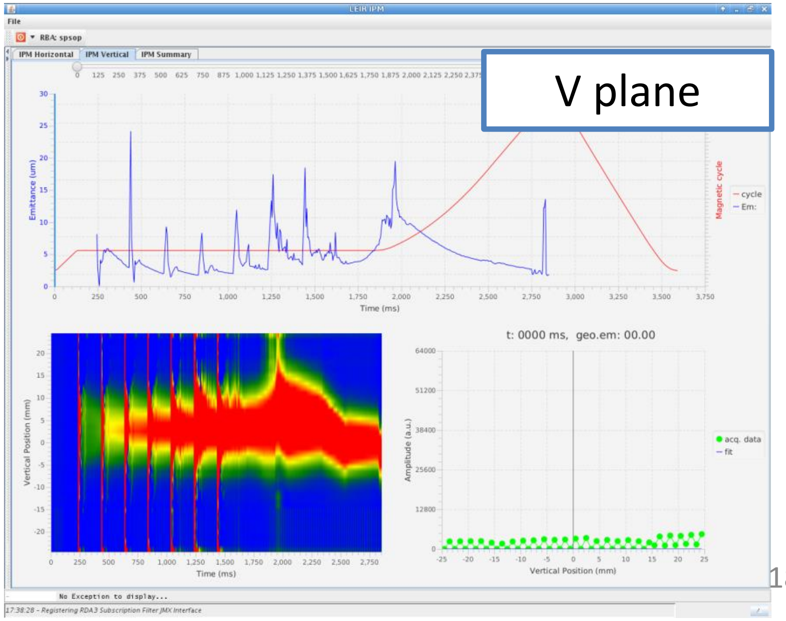
- Island of strong H cooling confirmed.
- Optimal bump settings are not necessarily the "coolest" ones:
  - Small beam size -> ok for aperture, may lead to poor lifetime or instabilities.
- Operational settings for accumulation:
  - Fast cooling in V (due to tighter aperture): straight bump through the cooler.
  - Weak cooling in H (larger aperture): achieved with non-zero angle in cooler bump.

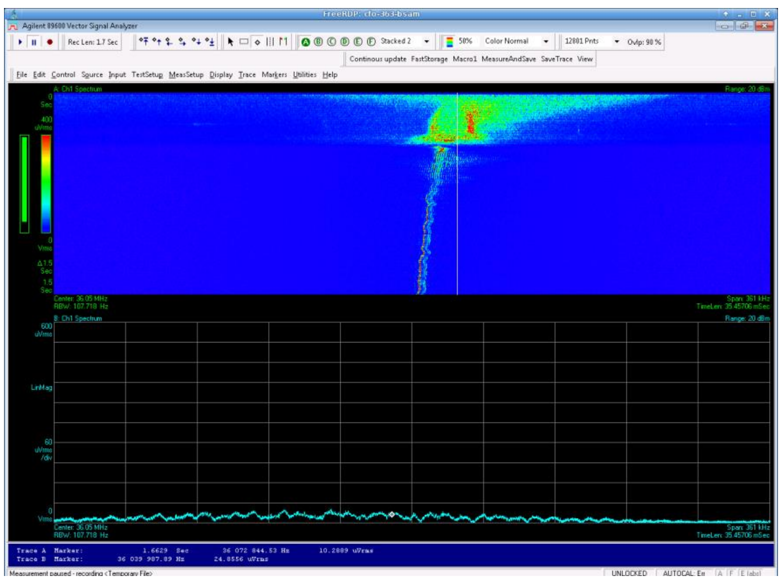




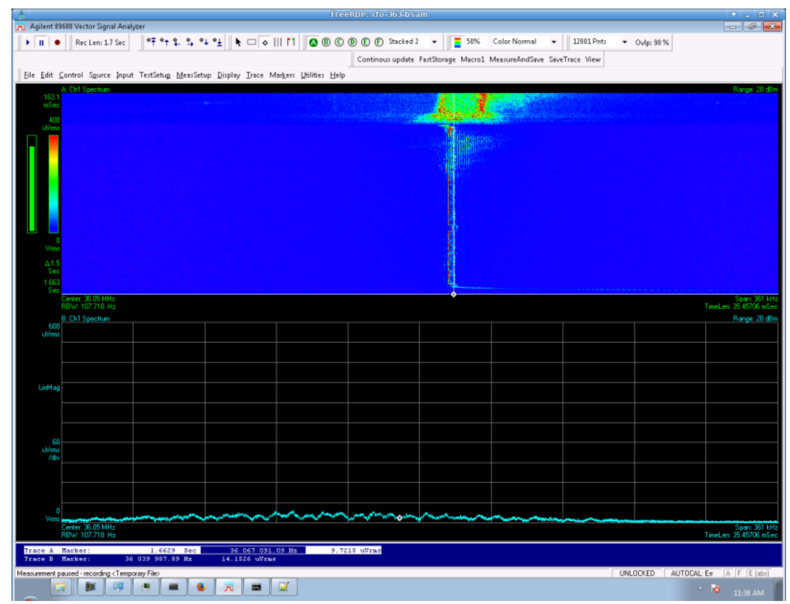
6. Momentum correction during accumulation (radial loop -like)

- Effect of Bfield drift can be seen removing radial loop (RL) after early capture.
- RL changes frev to ensure no orbit drifts
- Cannot be used in accumulation phase: no bunch structure at RL pickups.

Radial loop ON

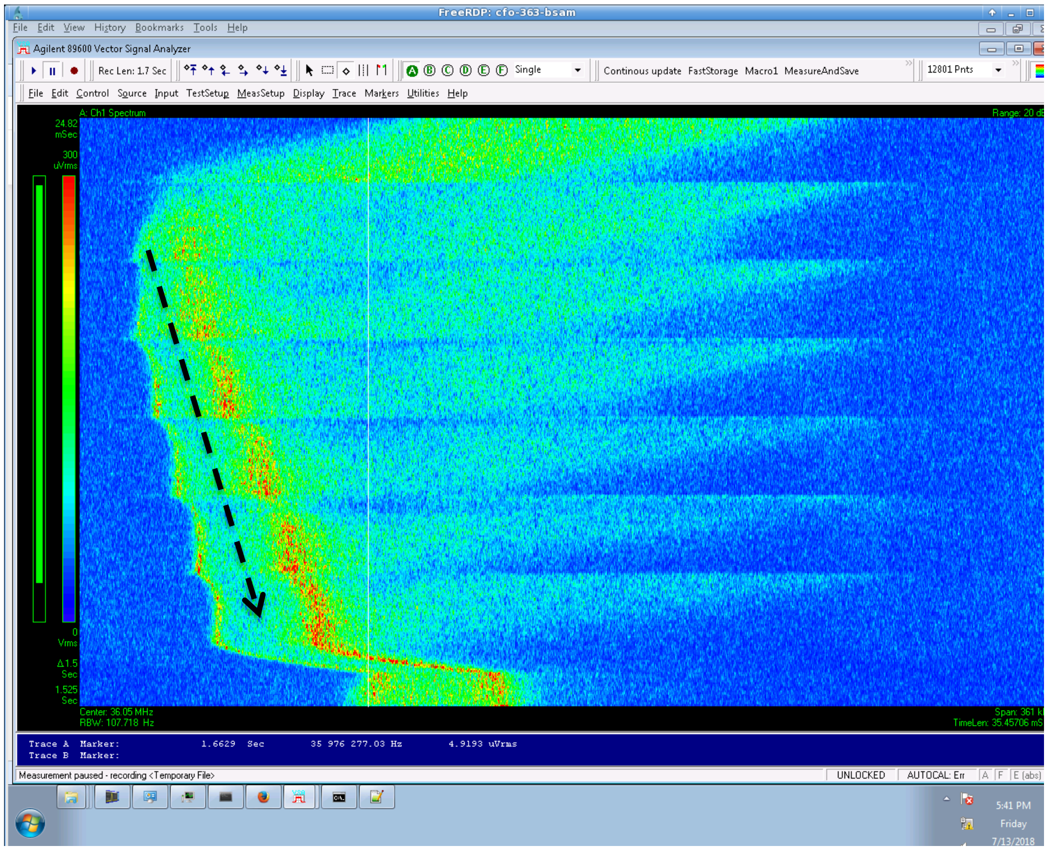


Radial loop OFF



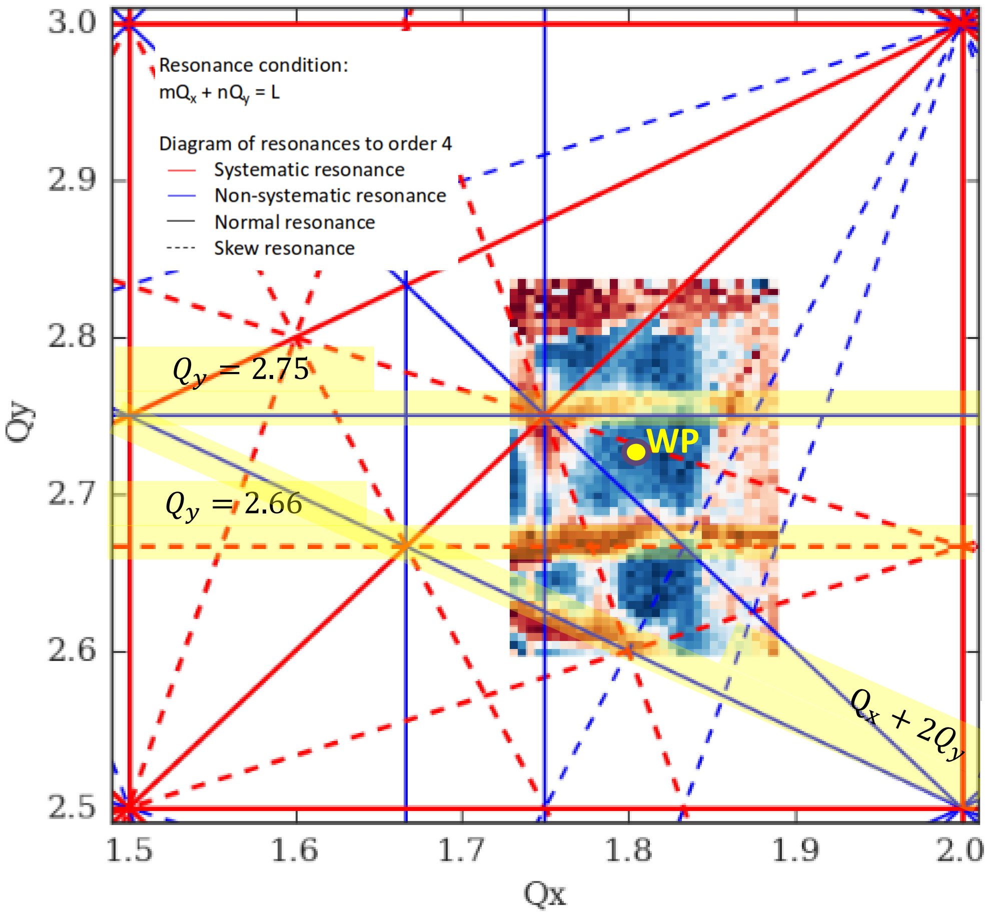
A.Saa Hernandez, D.Moreno

6. Momentum correction during accumulation (radial loop -like)



- Momentum increased in accumulation to compensate Bfield drift.
- So far we give the same order of frev correction needed as if the RL were on…

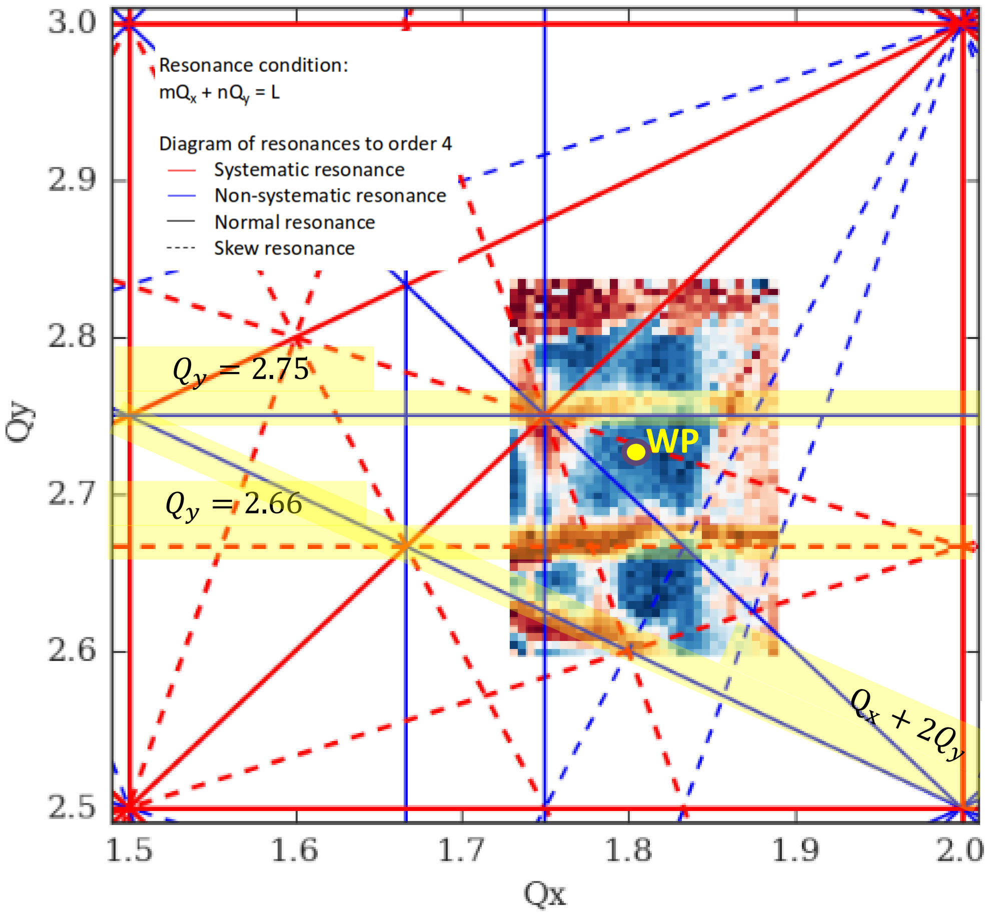
7 .Tune bump towards 2.75 during capture

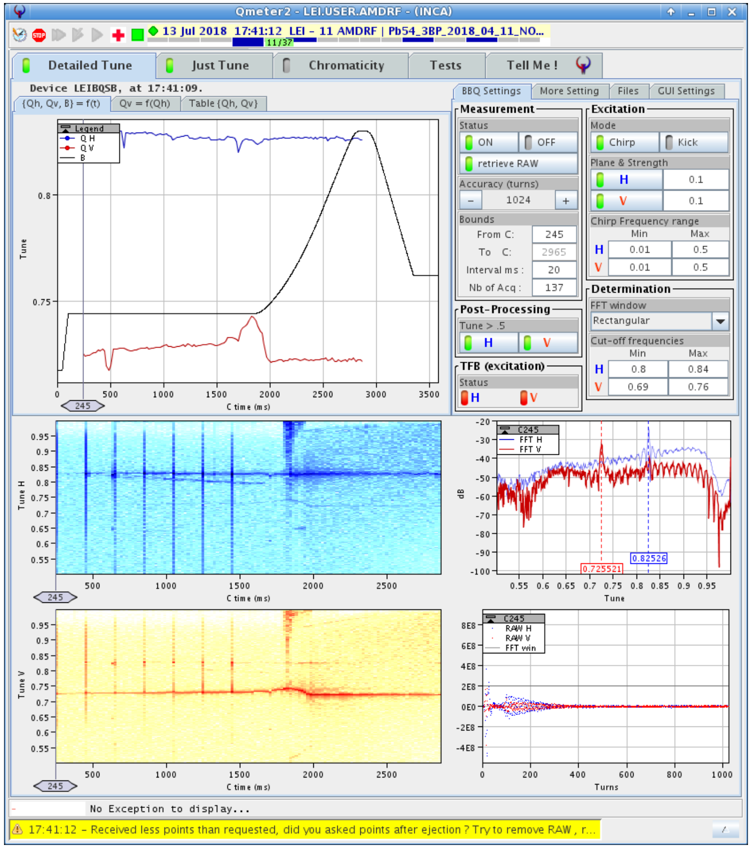


A.Saa Hernandez

- Main resonances in LEIR at 2.75 and 2.66.
- Large tune spread at high intensity before end of cooling and during capture.

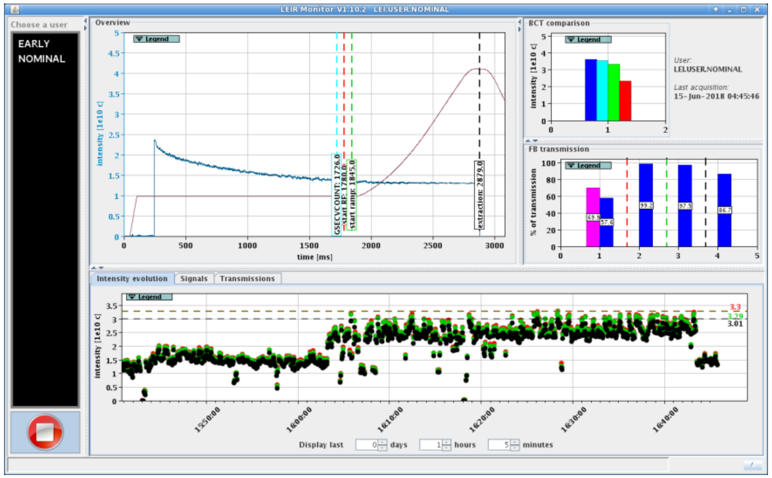
7 .Tune bump towards 2.75 during capture

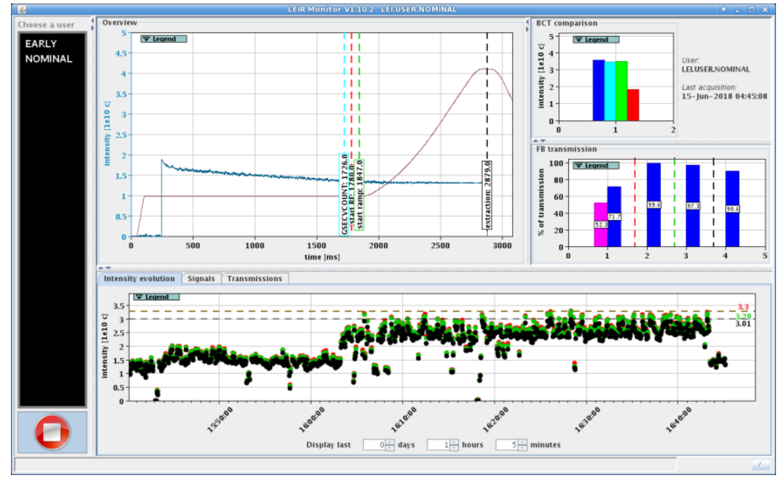


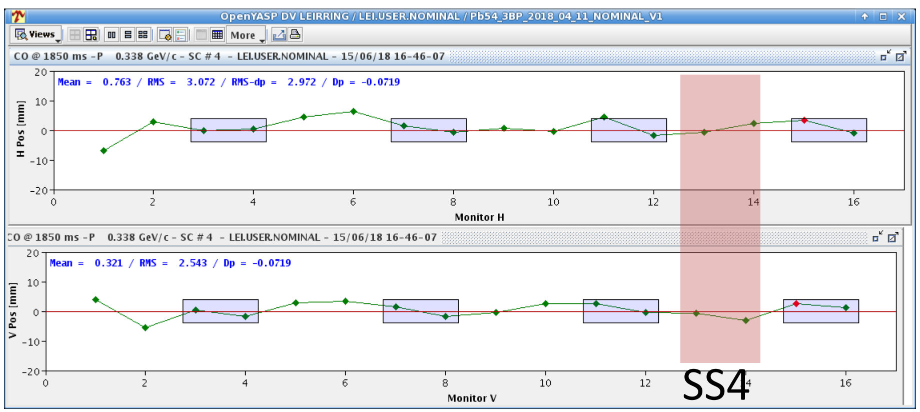


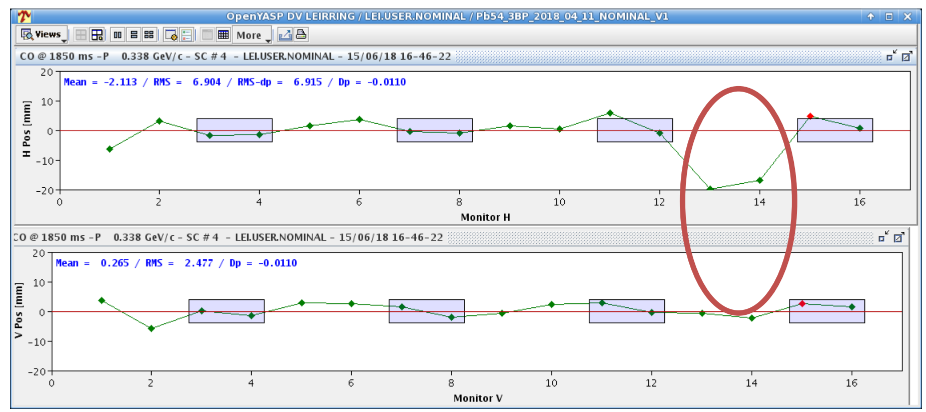
- Main resonances in LEIR at 2.75 and 2.66.
- Large tune spread at high intensity before end of cooling and during capture.
- “More space” if approaching the 2.75 from the bottom during capture.
- Improvement in operation, to be further studied w.r.t. space charge effects.

8. Orbit bump in SS4 to minimize vacuum pressure





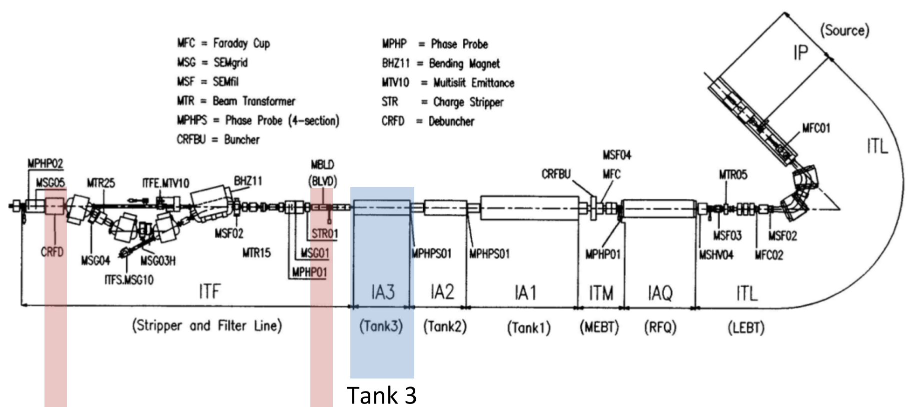




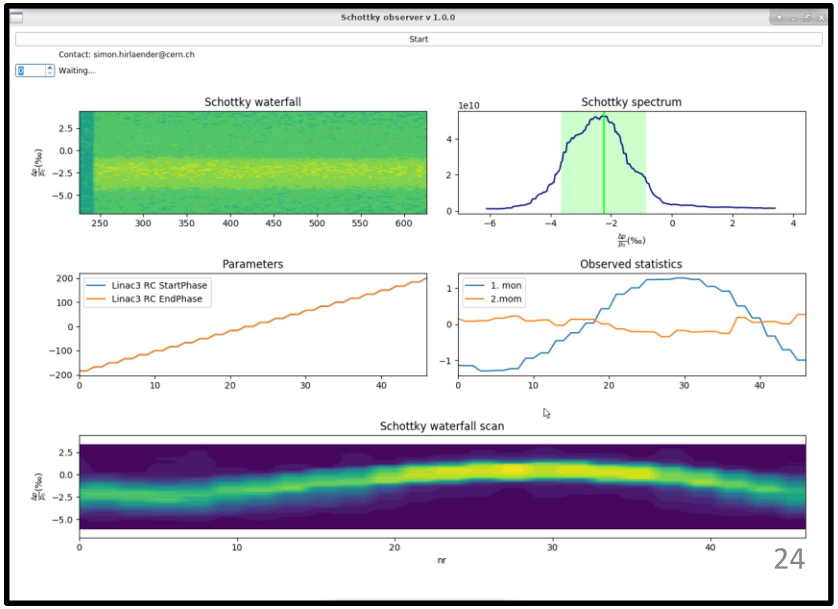
- Lifetime poor if no bump in SS4.
- Improved with orbit bump (many shapes did the job).
- Reason to be studies in detail.

9. Injected pulse energy distribution optimization

- Injection efficiency depends also on the beam energy distribution coming from Linac3.
- Mean energy offset or large energy tails are eventually lost if out of acceptance.
- Currently being optimized with help of Linac3 team looking at:
  - Tank 3 output energy (defines LEIR mean energy)
  - Ramping/Debunching cavities settings (define energy spread along pulse)

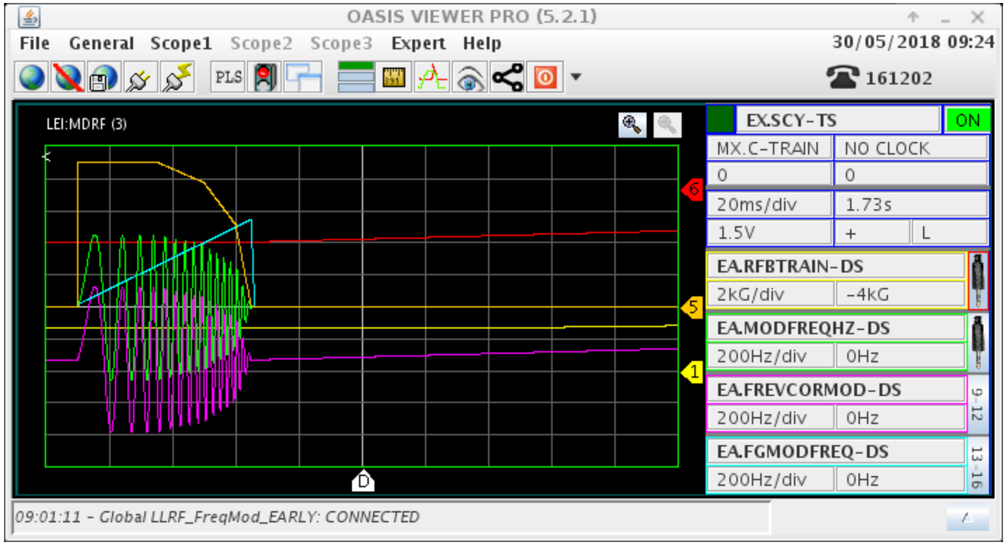


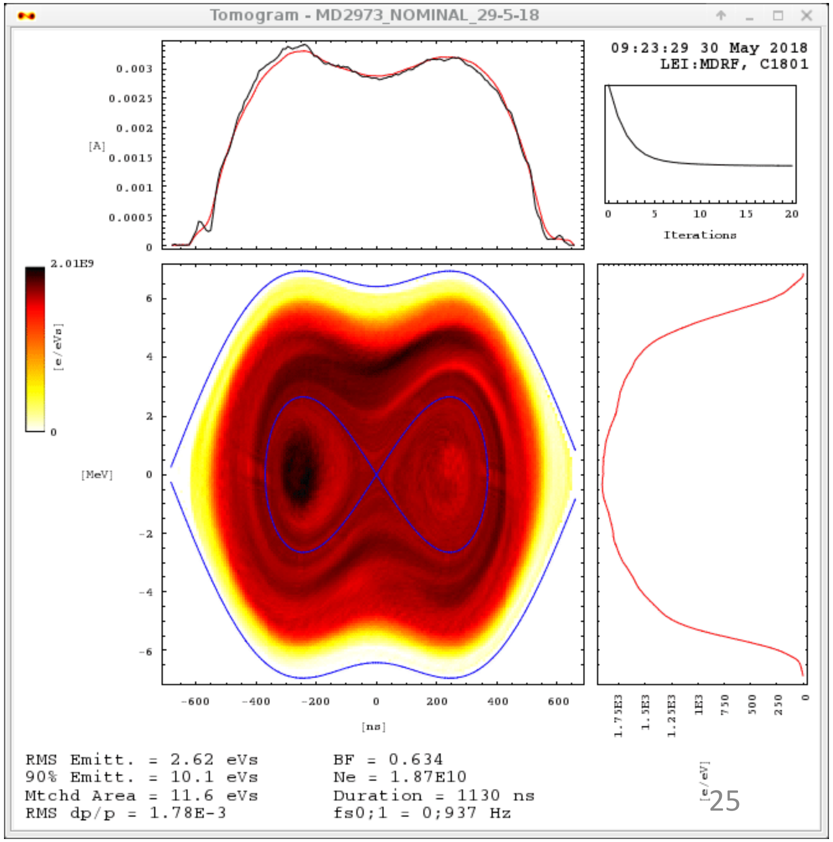
Example of ramping cavity phase scan in LEIR



10. RF capture with voltage amplitude/frequency modulation

- Currently operated in h = 2+4 for NOMINAL beam.
- RF capture losses improved with voltage amplitude and frequency modulation.
- Limit to ~10eVs emittance.

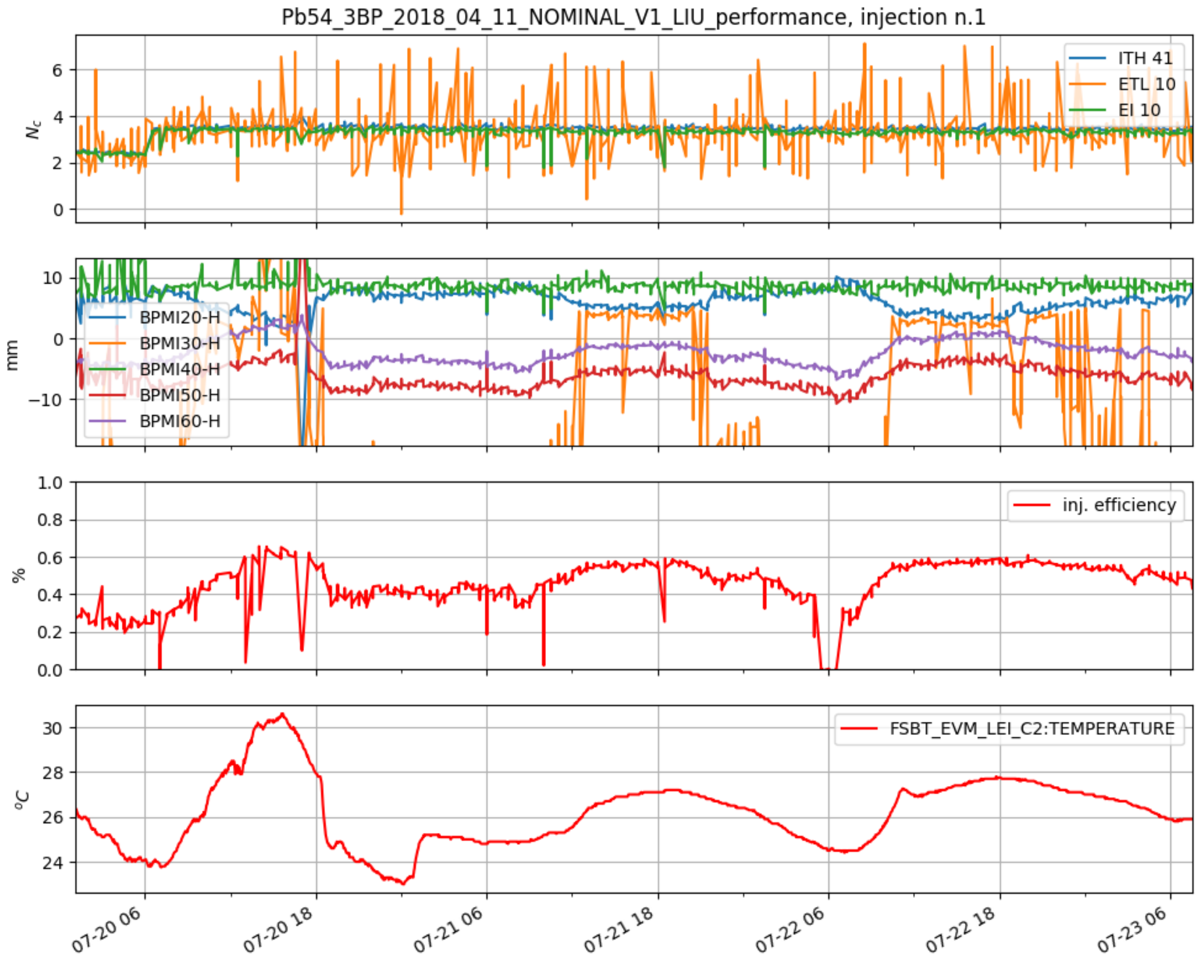




Reproducibility issues: present understanding and open questions

- NOMINAL cycle reached LIU target of 9e10 and more.
- Acquisition of margins is essential for safe operation at target performance.
- Daily experience shows large fluctuation in extracted intensity.
- Root causes being investigated:
    1. ETL line correctors fluctuations
    2. Linac3 current fluctuations
    3. Change in injected momentum energy distribution (not treated here)
    4. Stray fields (not treated here)

#2: ETL correctors current drift with temperature



- Day/night temperature change affecting ETL trajectory.
- First injection efficiency is mainly affected: can be worse as -40%!

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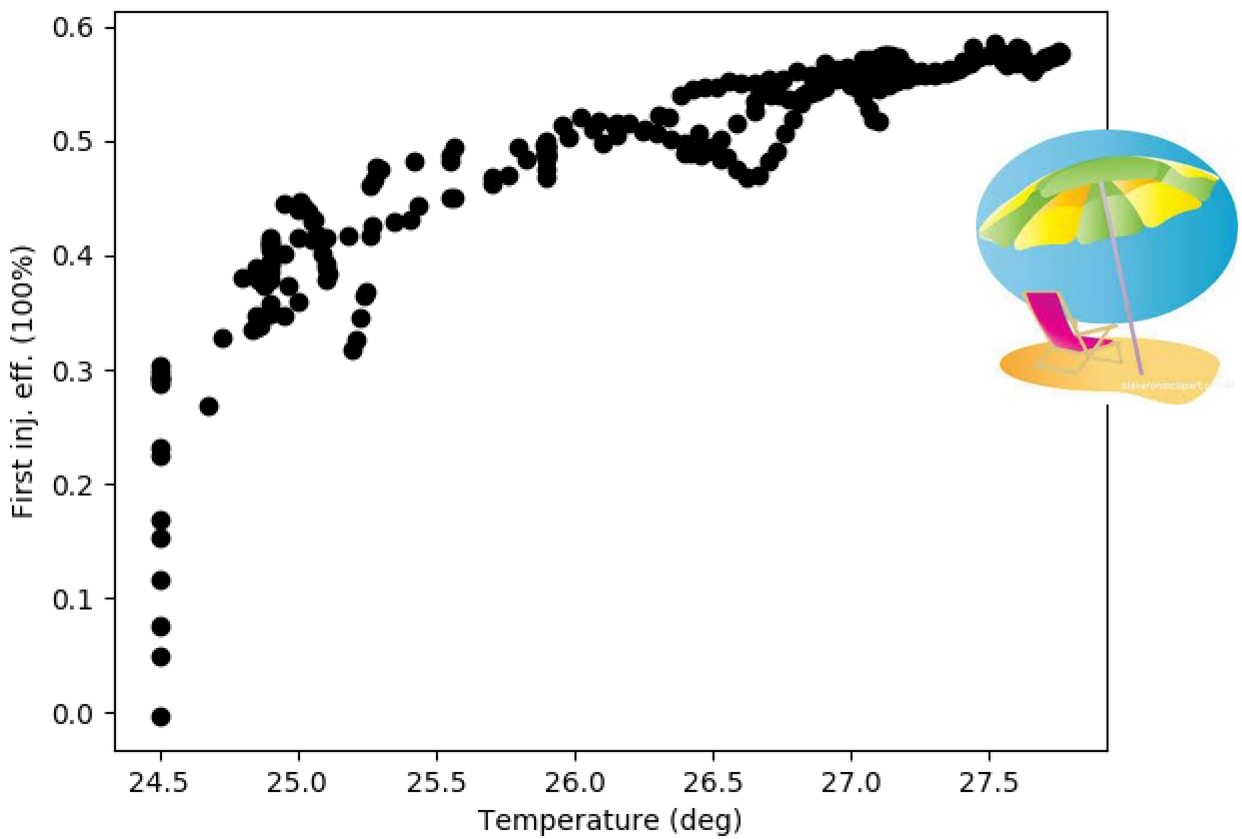
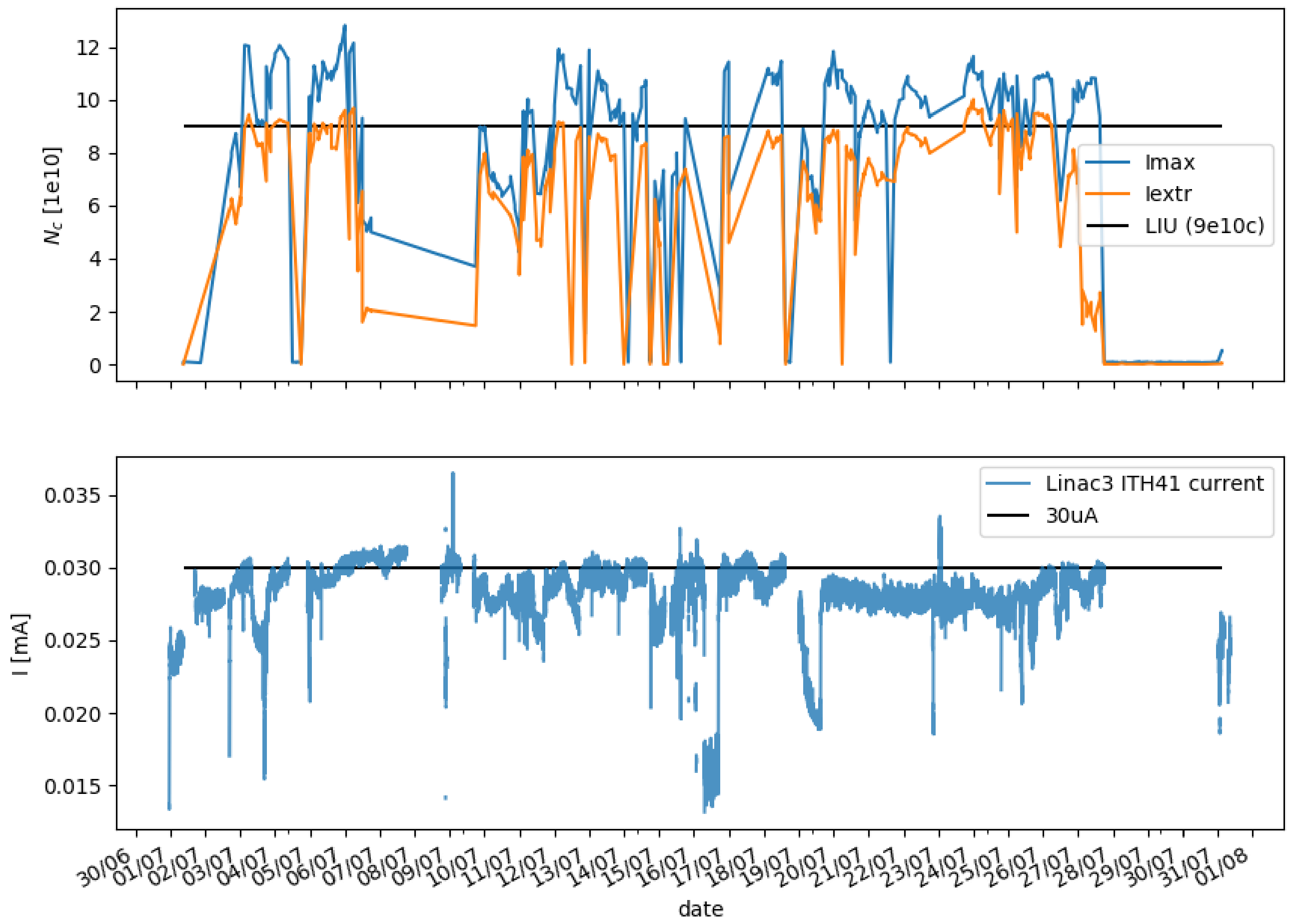


- Strong correlation with temperature: the hotter the better! ☺
- Corrector source under investigation.

#2: Linac3 current



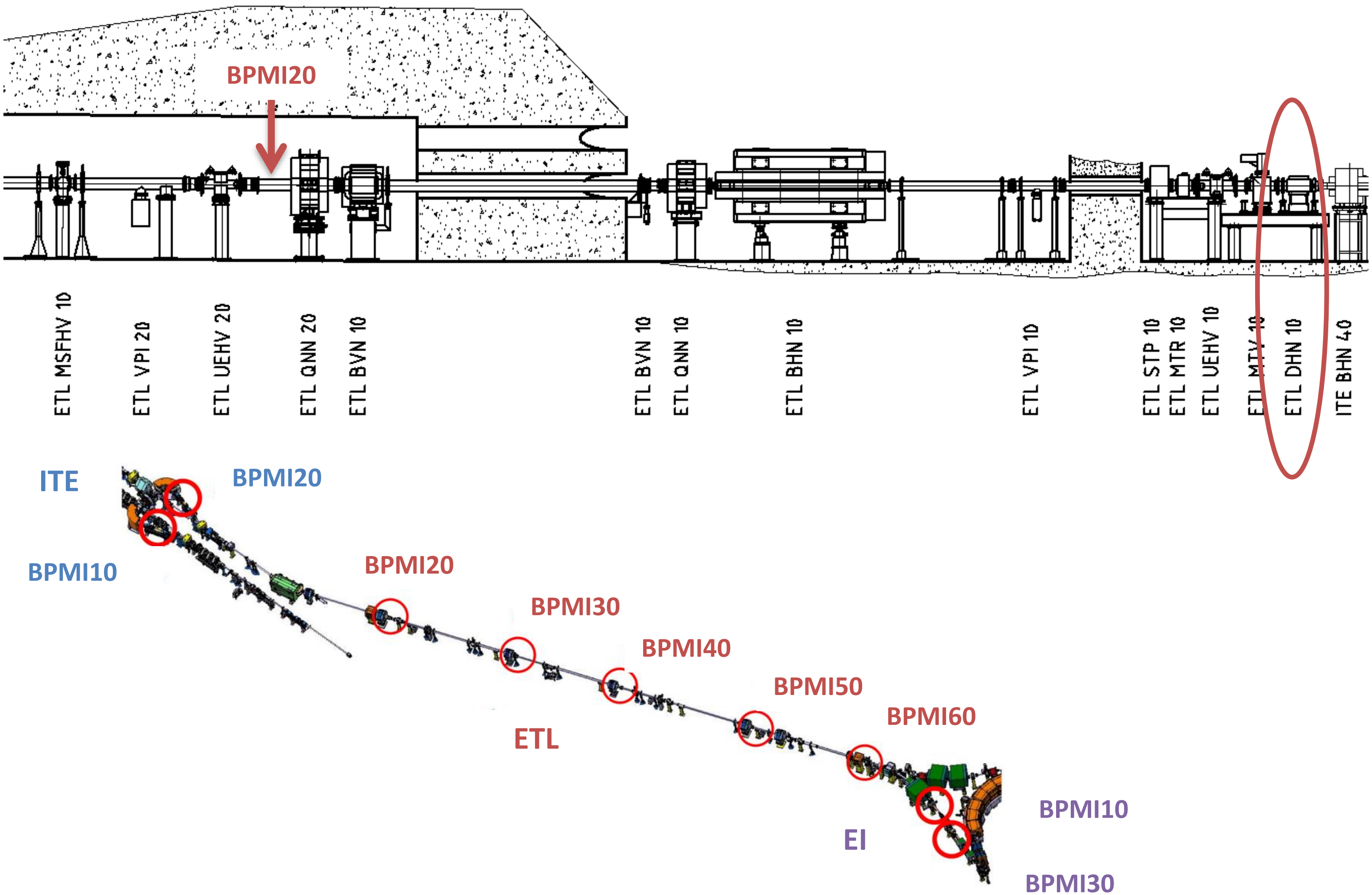
- Linac3 current down-drifts are 1:1 reflected in LEIR extracted intensity.
- LEIR optimized for LIU target with 27uA average but little margins against fluctuations.

Summary and next steps

- LEIR has reached 10.35e10c extracted with an average injected current of 27uA from Linac3
- High performance, w.r.t 2016, is mainly due to the better injection efficiency (>20% higher)
- Injection efficiency is a result of maximized machine momentum acceptance and orbit correction from/to the injection point.
- Linac3 settings (Tank3, Ramping/Debunching cavity) are crucial for good injection perfomance.
- Transmission is a result of orbit optimization through cooler and SS4, tune and momentum optimization.

- Reproducibility represents now the major challenge.
- Different sources (temperature fluctuation, source current, etc..) are being identified and ranked in terms of impact to performance reached.

Spares slides


BPMI20
ETL MSFHV 10
ETL VPI 20
ETL UEHV 20
ETL QNN 20
ETL BVN 10
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ETL QNN 10
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ETL VPI 10
ETL STP 10
ETL MTR 10
ETL UEHV 10
ETL MTV 10
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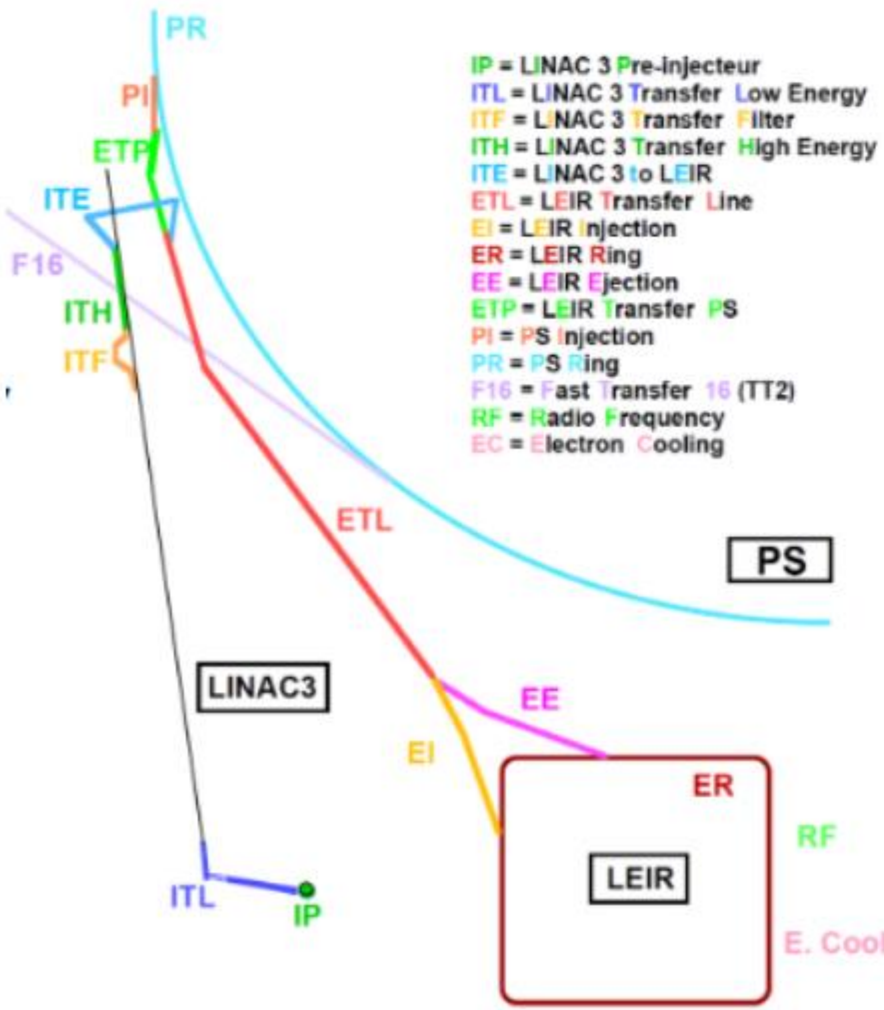
PR
PI
ETP
ITE
F16
ITH
ITF
IP = LINAC 3 Pre-injecteur
ITL = LINAC 3 Transfer Low Energy
ITF = LINAC 3 Transfer Filter
ITH = LINAC 3 Transfer High Energy
ITE = LINAC 3 to LEIR
ETL = LEIR Transfer Line
EI = LEIR Injection
ER = LEIR Ring
EE = LEIR Ejection
ETP = LEIR Transfer PS
PI = PS Injection
PR = PS Ring
F16 = Fast Transfer 16 (TT2)
RF = Radio Frequency
EC = Electron Cooling
ETL
PS
LINAC3
EE
EI
ER
RF
LEIR
ITL
IP
E. Cool