LEIR e-cooler operational experience and needs

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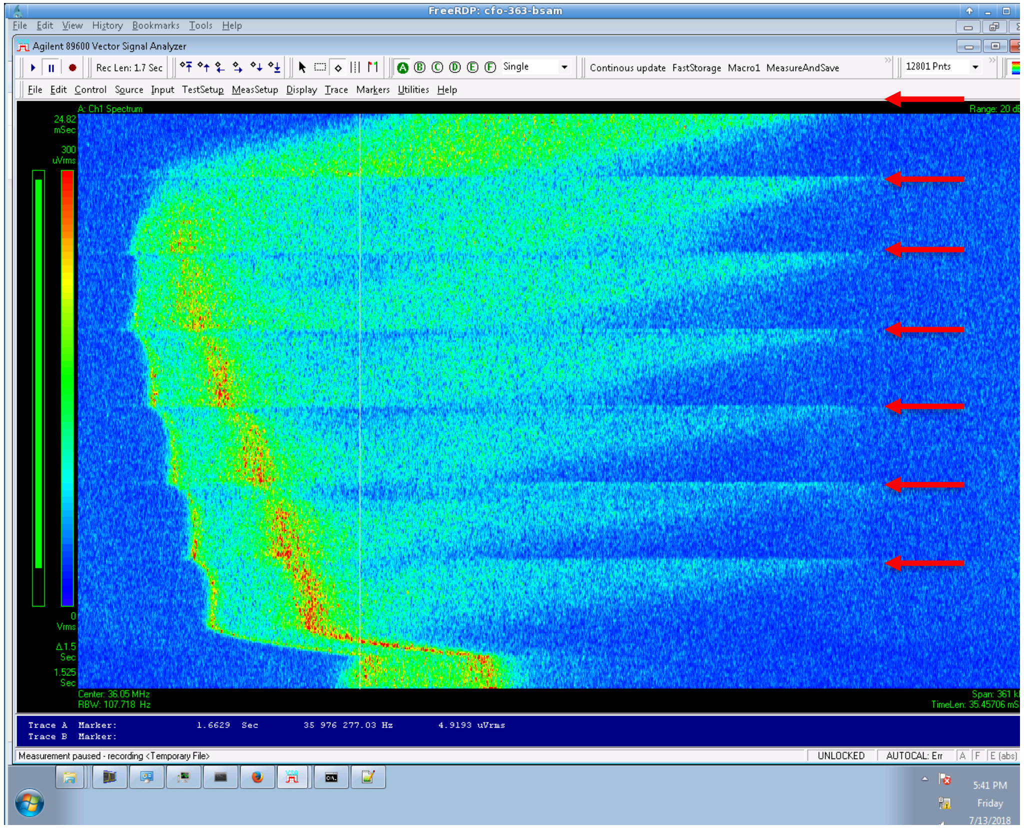
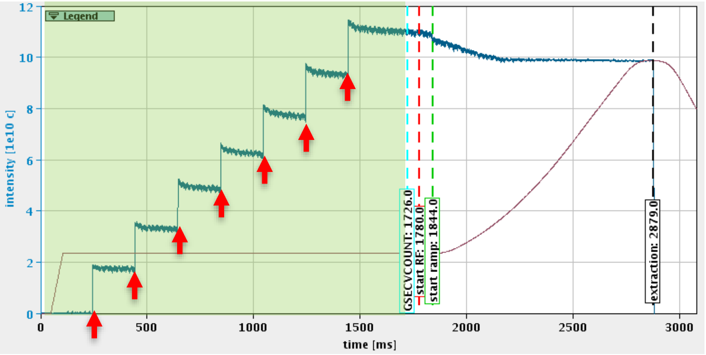
Introduction

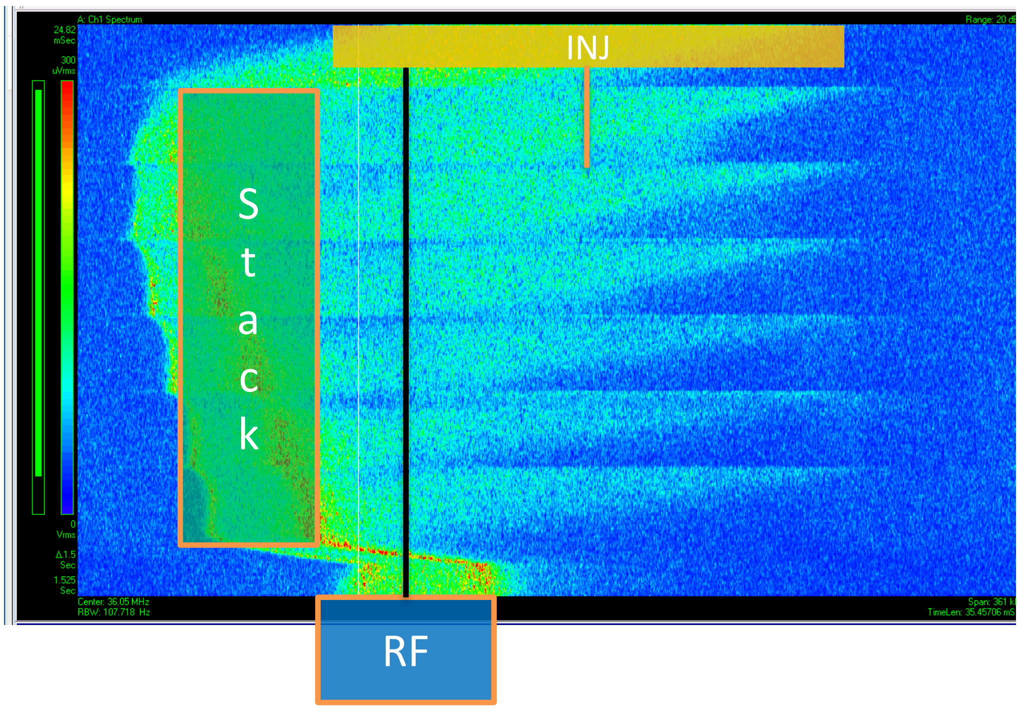
- LEIR injection process is based on multiple injections of Linac3 pulses: stacking in momentum and transverse phase space.

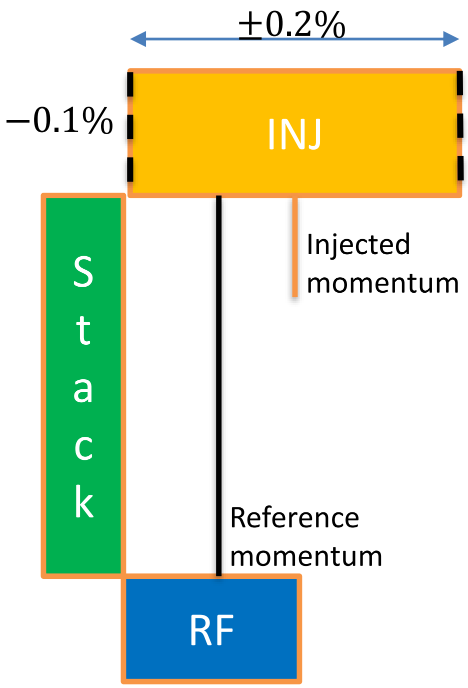




Introduction

- LEIR injection process is based on multiple injections of Linac3 pulses: stacking in momentum and transverse phase space.
- Electron cooler vital device to:
  - Drag the injected beam into a stacking position.
  - Cool down longitudinal and transverse phase spaces of multiple injections.
  - Drag beam back for RF capture.





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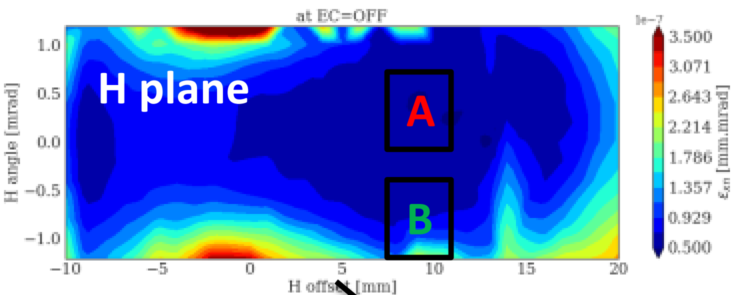
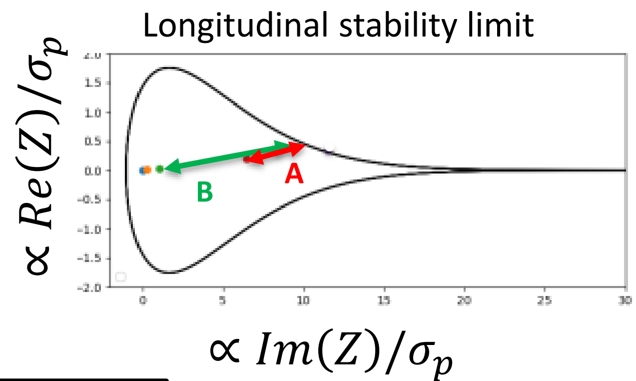
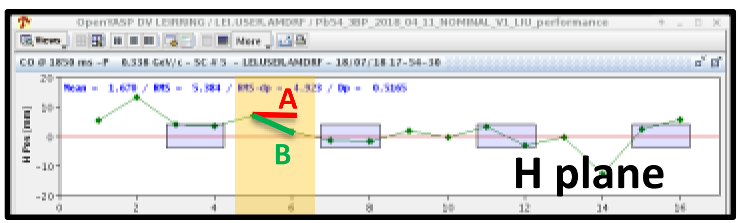
- Parameters *touched* in operation:
  - E-beam current:
    - Depends on grid/gun/cathode voltages)
    - Typical value: 200/300mA
  - E-beam relative velocity to the ion beam:
    - Depends on gun voltage
    - Typical relative velocity: -0.1/-0.2%
  - Ion beam overlap to the E-beam (orbit bump):
    - see next slide

Operational experience (1/5)

- E-beam mainly defines:
  - Stacked beam off-momentum orbit (limited by aperture limitations)
  - Final ion beam profile (limited by instabilities): strongly dependent on ion-electron relative trajectory (cooling maps).





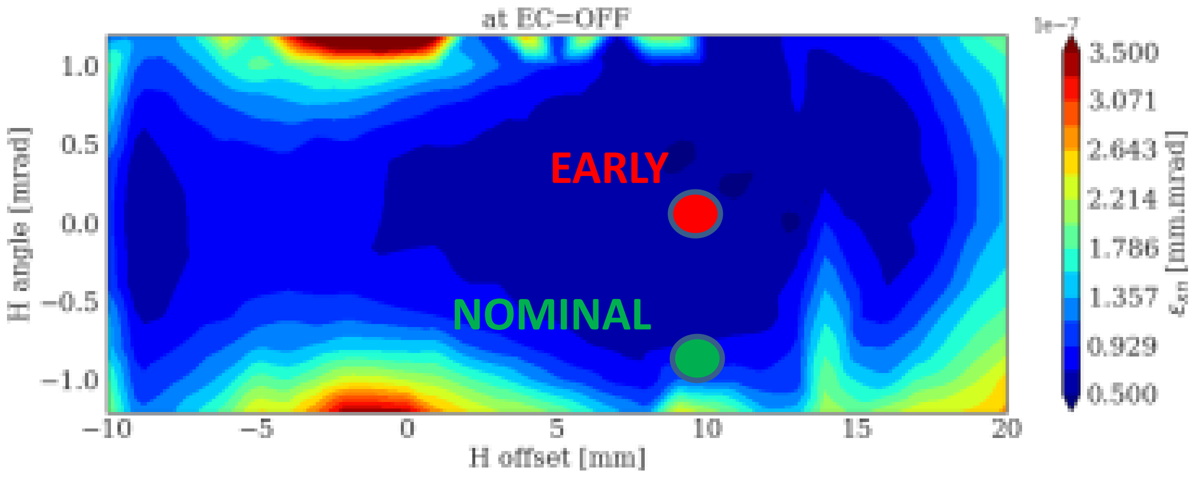


A: close to boundary

B: more margin!

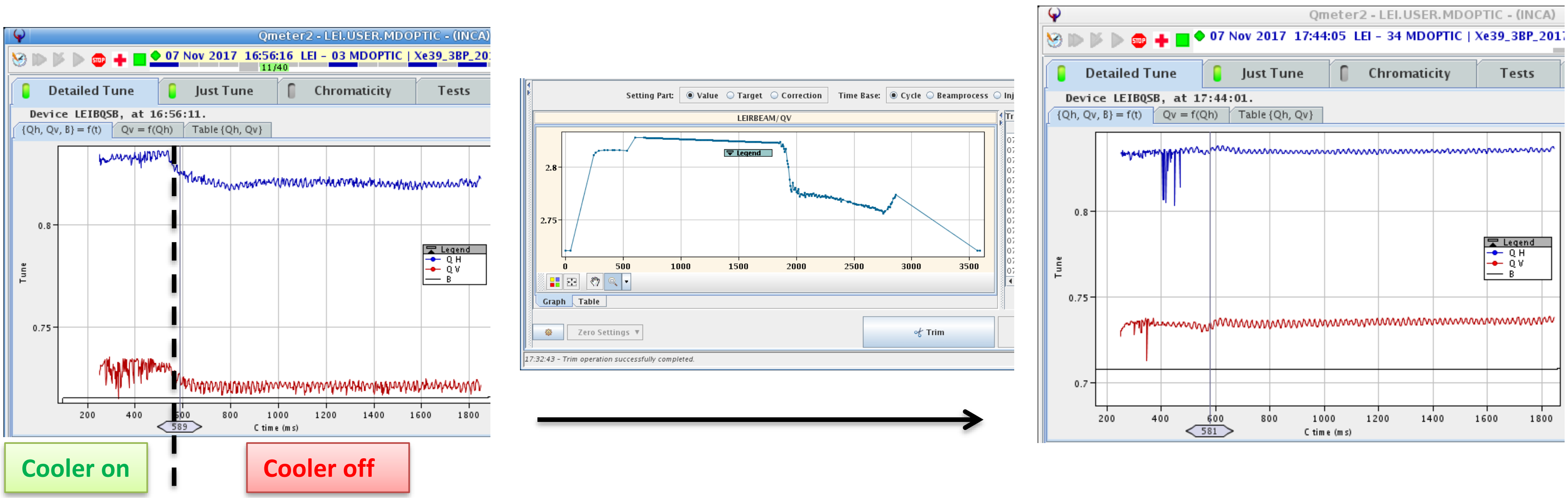
Operational experience (2/5)

- EARLY settings (1 injection, 2.4s cycle):
  - 200 mA*
  - Flat bump (fastest cooling)
- NOMINAL (7 injections, 3.6s cycle):
  - 300 mA
  - H angle to allow larger H beam size (slower cooling, but more stable)



Operational experience (3/5)

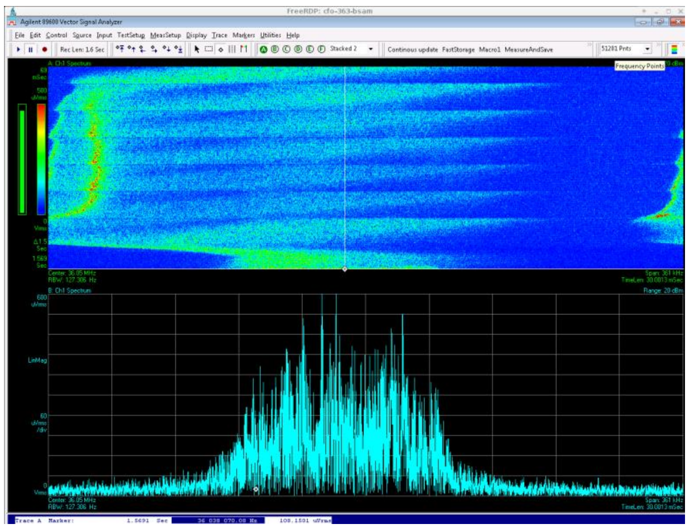
Electron beam tune shift:

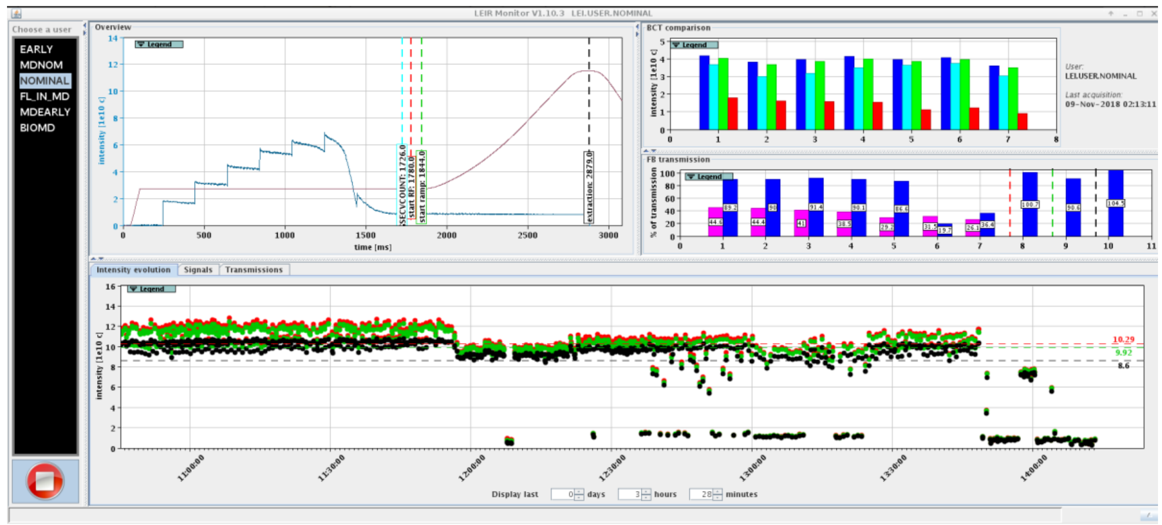


- Dependent on electron beam density, size, ion intensity.
- Compensated empirically (with Qmeter app)

Operational experience (4/5)

- Intensity dependent corrections:
    - Missing injection -> change in final ion velocity (lower)
    - Lower Linac3 intensity injected -> change in final ion velocity (lower)

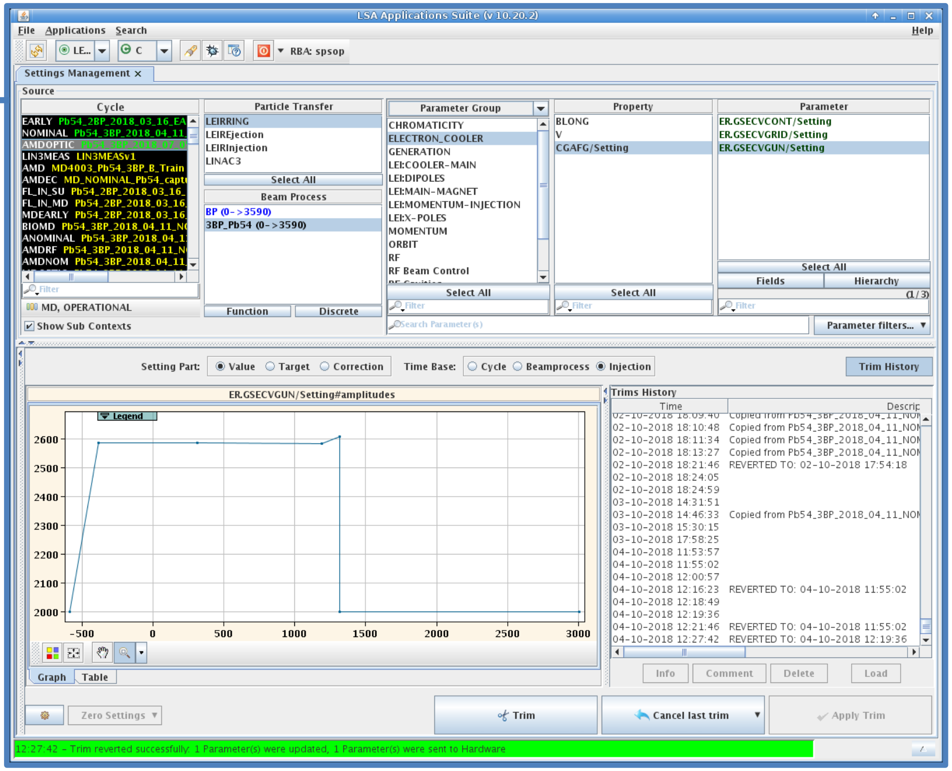




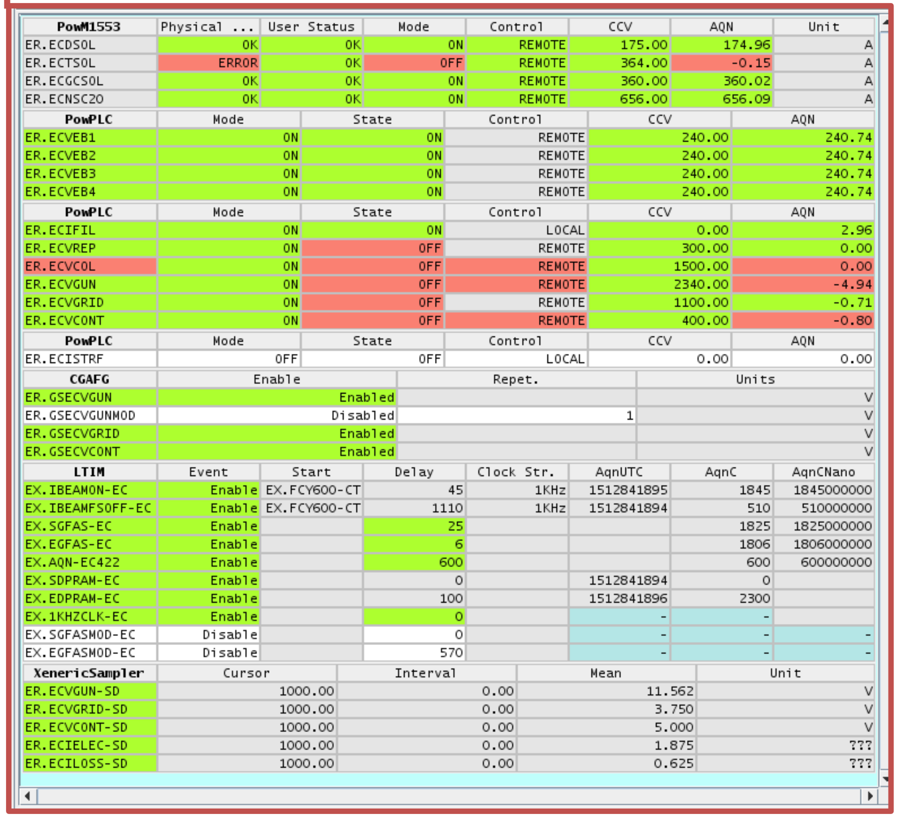
Corrected by modification on gun voltage function but reason not yet fully clear.

Operational experience (5/5)

Voltages parameters in LSA



Others in working set



PowM1553	Physical ...	User Status	Mode	Control	CCV	AQN	Unit
ER.ECDSOL	OK	OK	ON	REMOTE	175.00	174.96	A
ER.ECTSOL	ERROR	OK	OFF	REMOTE	364.00	-0.15	A
ER.ECGCSOL	OK	OK	ON	REMOTE	360.00	360.02	A
ER.ECNSC20	OK	OK	ON	REMOTE	656.00	656.09	A

PowPLC	Mode	State	Control	CCV	AQN
ER.ECVEB1	ON	ON	REMOTE	240.00	240.74
ER.ECVEB2	ON	ON	REMOTE	240.00	240.74
ER.ECVEB3	ON	ON	REMOTE	240.00	240.74
ER.ECVEB4	ON	ON	REMOTE	240.00	240.74

PowPLC	Mode	State	Control	CCV	AQN
ER.ECIFIL	ON	ON	LOCAL	0.00	2.96
ER.ECVREP	ON	OFF	REMOTE	300.00	0.00
ER.ECVCOL	ON	OFF	REMOTE	1500.00	0.00
ER.ECVGUN	ON	OFF	REMOTE	2340.00	-4.94
ER.ECVGRID	ON	OFF	REMOTE	1100.00	-0.71
ER.ECVCONT	ON	OFF	REMOTE	400.00	-0.80

PowPLC	Mode	State	Control	CCV	AQN
ER.ECISTRF	OFF	OFF	LOCAL	0.00	0.00

CGAFG	Enable	Repet.	Units
ER.GSECVGUN	Enabled		V
ER.GSECVGUNMOD	Disabled	1	V
ER.GSECVGRID	Enabled		V
ER.GSECVCONT	Enabled		V

LTIM	Event	Start	Delay	Clock Str.	AqnUTC	AqnC	AqnCNano
EX.IBEAMON-EC	Enable	EX.FCY600-CT	45	1KHz	1512841895	1845	1845000000
EX.IBEAMFSOFF-EC	Enable	EX.FCY600-CT	1110	1KHz	1512841894	510	510000000
EX.SGFAS-EC	Enable		25			1825	1825000000
EX.EGFAS-EC	Enable		6			1806	1806000000
EX.AQN-EC422	Enable		600			600	600000000
EX.SDPRAM-EC	Enable		0		1512841894	0	
EX.EDPRAM-EC	Enable		100		1512841896	2300	
EX.1KHZCLK-EC	Enable		0		-	-	
EX.SGFASMOD-EC	Disable		0		-	-	-
EX.EGFASMOD-EC	Disable		570		-	-	-

XenericSampler	Cursor	Interval	Mean	Unit
ER.ECVGUN-SD	1000.00	0.00	11.562	V
ER.ECVGRID-SD	1000.00	0.00	3.750	V
ER.ECVCONT-SD	1000.00	0.00	5.000	V
ER.ECIELEC-SD	1000.00	0.00	1.875	???
ER.ECILOSS-SD	1000.00	0.00	0.625	???

- Not always easy to master and synchronize (e.g. EX.IBEAMFSOFF fast switch).
- Some knobs need to account delays w.r.t. cycle time.

Operational needs (1/3)

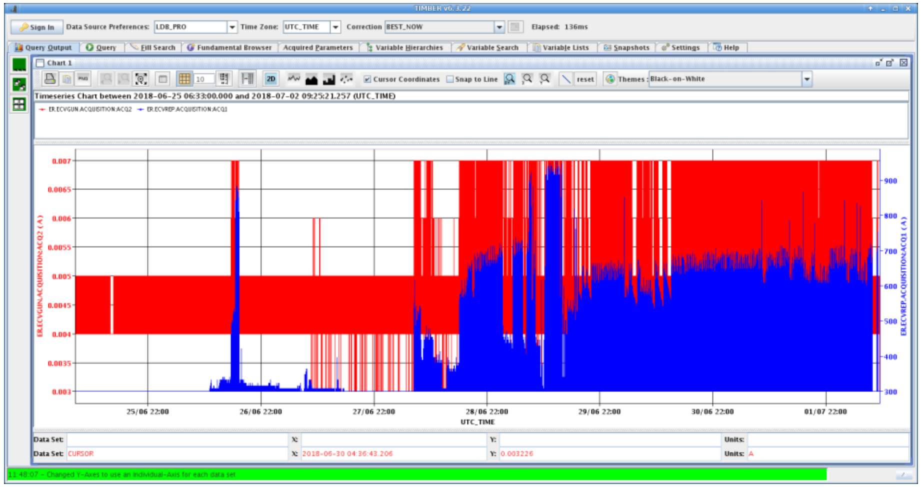
- Higher level parameters needed:
  - Offset velocity w.r.t. ion beam:
    - Set up directly velocity offset (makerule to gun/grid/cathod voltages) getting input from BRho.
    - Set as a function in LSA.
  - Cooling current:
    - Allow for direct input: automatic conversion to voltage needed.
  - Ions-electron position:
    - Cooling maps are useful but time consuming (few hours each scan)
    - E-beam current modulation would allow for direct e-beam measurement from BPMs -> ideally before injection!
  - Unify scattered settings management (LSA, working set): can we learn from AD?

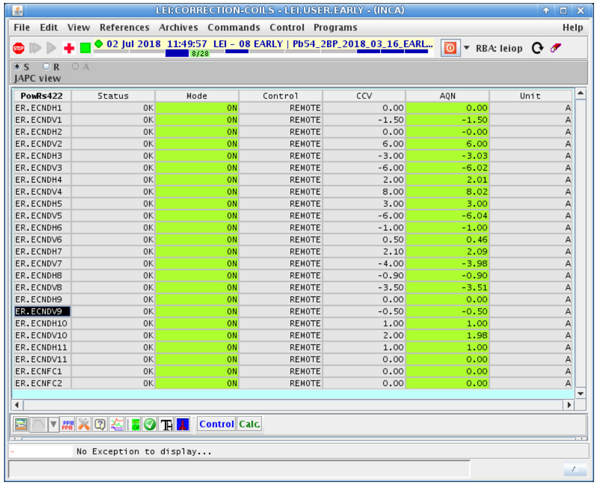
- E-cooler optics modeling:
  - Virtual parameters: LEIRBEAM/DX_EC and LEIRBEAM/BeCool: they both correct the tune. No documentation about the value exists, one of them is not even in a well define parameter group, but just hidden inside the ~NONE parameter. What are those values coming from? Are they theoretical, or coming from measurements?
  - needs to verify how effective is the present coupling compensation scheme (e.g. effect of QSK, orbit w/ and w/o compensation, …).
  - will profit from turn by turn measurements.

Operational needs (2/3)

- Setting management:
  - E-cooler settings management needs improvement: do we have the correct default values at generation level for all the parameters? How many parameters are non-multiplexed?
  - Corrector settings: could need tuning, but this is an expert action (in principle), however is up to operations to keep settings consistent between cycles. If those settings are really non-ppm they should be moved to a non-multiplexed cycle.

From elogbook 02/07/2018 11:42: *We found losses on the repeller electrode which changes the regulation of Vgun. How these losses occurred we do not know as identical settings on other cycles did not produce the same situation.* ***Are the machine orbit correctors close to the e-cooler affecting the electron beam trajectory****? The current in ER.ECNDV9 was changed from 0.5 A to -0.5A and this cured the problem. The new value of ER.ECNDV9 has been copied onto all the cycles)*





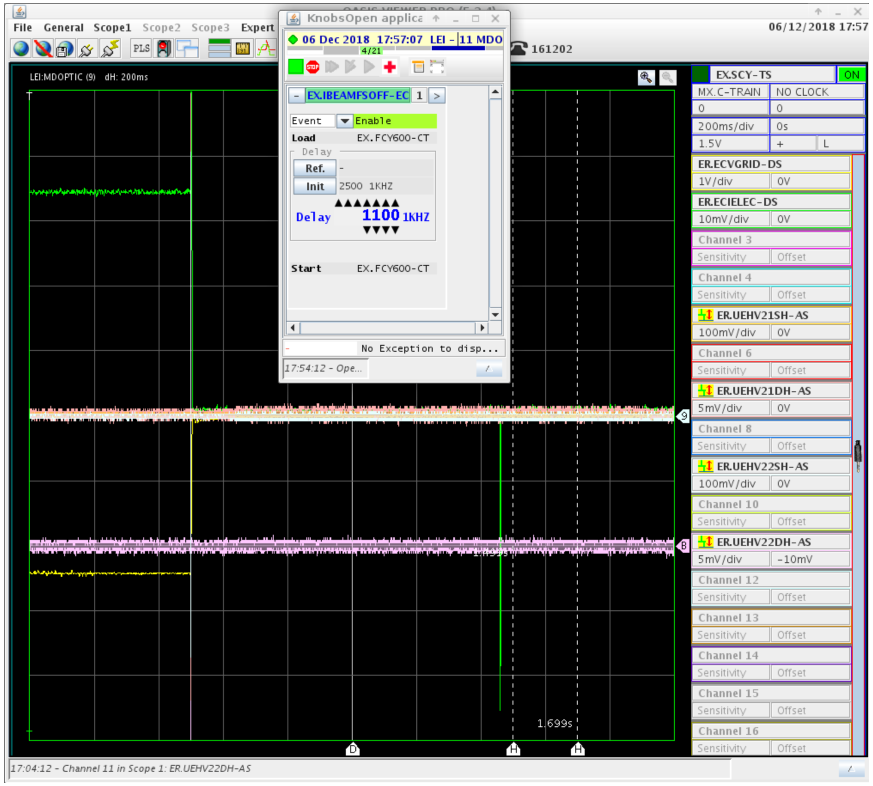
PowRs422	Status	Mode	Control	CCV	AQN	Unit
ER.ECNDH1	OK	ON	REMOTE	0.00	0.00	A
ER.ECNDV1	OK	ON	REMOTE	-1.50	-1.50	A
ER.ECNDH2	OK	ON	REMOTE	0.00	-0.00	A
ER.ECNDV2	OK	ON	REMOTE	6.00	6.00	A
ER.ECNDH3	OK	ON	REMOTE	-3.00	-3.03	A
ER.ECNDV3	OK	ON	REMOTE	-6.00	-6.02	A
ER.ECNDH4	OK	ON	REMOTE	2.00	2.01	A
ER.ECNDV4	OK	ON	REMOTE	8.00	8.02	A
ER.ECNDH5	OK	ON	REMOTE	3.00	3.00	A
ER.ECNDV5	OK	ON	REMOTE	-6.00	-6.04	A
ER.ECNDH6	OK	ON	REMOTE	-1.00	-1.00	A
ER.ECNDV6	OK	ON	REMOTE	0.50	0.46	A
ER.ECNDH7	OK	ON	REMOTE	2.10	2.09	A
ER.ECNDV7	OK	ON	REMOTE	-4.00	-3.98	A
ER.ECNDH8	OK	ON	REMOTE	-0.90	-0.90	A
ER.ECNDV8	OK	ON	REMOTE	-3.50	-3.51	A
ER.ECNDH9	OK	ON	REMOTE	0.00	0.00	A
ER.ECNDV9	OK	ON	REMOTE	-0.50	-0.50	A
ER.ECNDH10	OK	ON	REMOTE	1.00	1.00	A
ER.ECNDV10	OK	ON	REMOTE	2.00	1.98	A
ER.ECNDH11	OK	ON	REMOTE	1.00	1.00	A
ER.ECNDV11	OK	ON	REMOTE	0.00	0.00	A
ER.ECNFC1	OK	ON	REMOTE	0.00	0.00	A
ER.ECNFC2	OK	ON	REMOTE	0.00	0.00	A

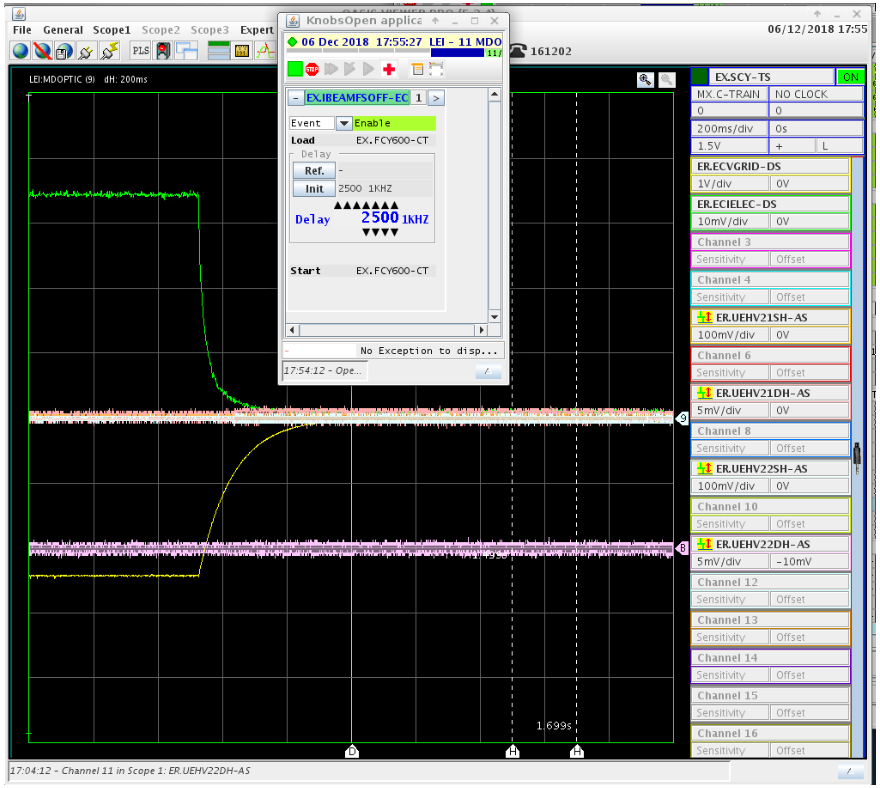
Operational needs (3/3)

- Improvement of diagnostics:
  - Online e-beam current measurements: E-current monitoring via inspector or the expert e-cooler view application is not reliable or easy to understand since there is a delay w.r.t. played cycle, all the cycles are shown together, and sampling rate is too low producing sometimes fictitious data. Monitoring per cycle is needed. Inspector might not be the best solution since latency problems.
  - Collector and repeller currents: important diagnostics observables (show the current collected at the collector and the voltage delivered by the repeller). They should always be constant, if oscillating there is a problem. Today we do not have those signals monitored online, but we have to go to timber. Improving the online monitoring of these parameters could help spotting e-cooler problems faster.
  - Online e-beam position: important to monitor relative e-beam / ion position reproducibility and cycle by cycle variation or long term drifts.
- Long term view:
  - Tuning if conditions change: model based re-inforced learning algorithms can help to retune.
  - Cooling maps, and other response maps are a by product of the learned model.
  - Algorithms can be trained on simulations first (see RF-track 2.0 development)
- Training
  - Shutdown lecture on the electron cooler operation for OPs and supervisors (planned).

Additional slides

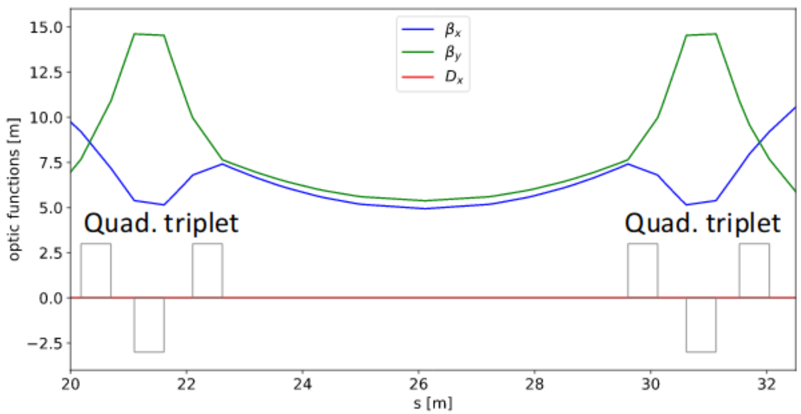
Unusual knobs





Cooler optics modeling

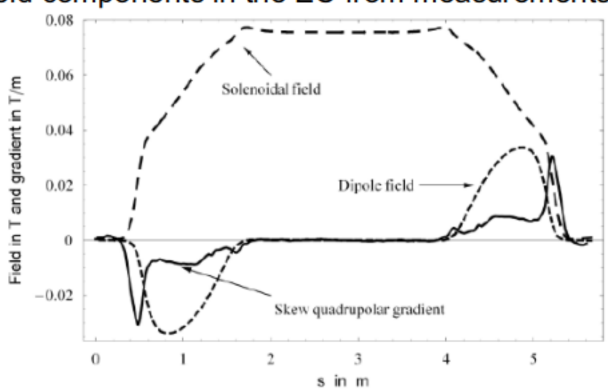
Step 3: Implement Electron Cooler



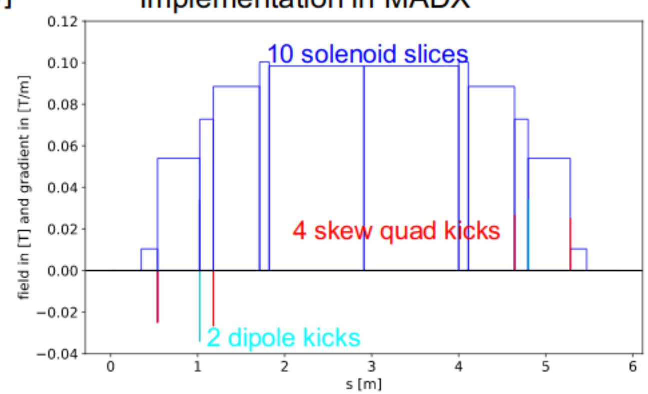
Up to know: simplest lattice model

- Quad. triplets focus β_x and β_y in straight sections
- Electron Cooler and compensating elements treated as drifts

Field components in the EC from measurements [1]



Implementation in MADX

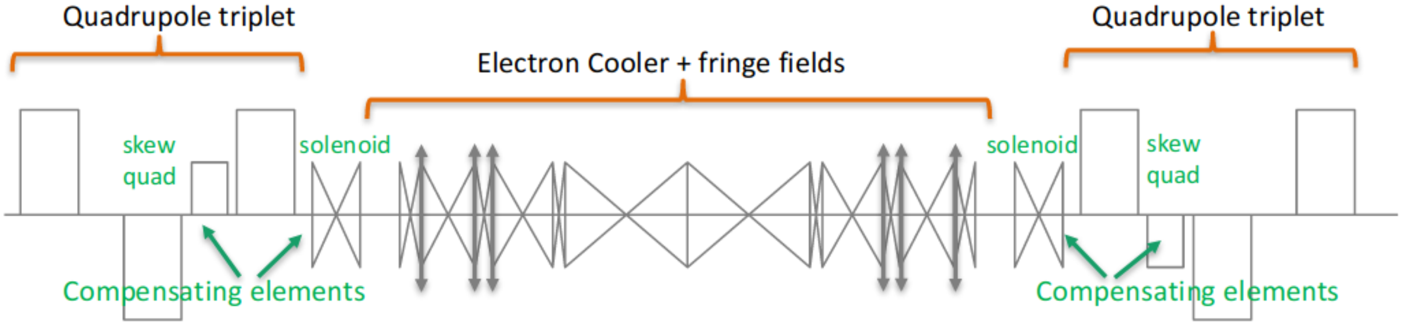


[1] C. Carli, P. Belochitskii, M. Chanel, J. Pasternak, *LEIR Lattice*, Proc. EPAC 2006

Cooler optics modeling

Step 3: Implement Electron Cooler

Include EC and compensation elements in the lattice:



Apply procedure by J. Pasternak to match iteratively :

- coupling compensation
  - Goals: zero-orbit at markers in straight sections + coupling terms from Rmatrix = 0
  - Optimization variables: strengths of compensating element and strengths of all vertical and horizontal correctors

- re-match "normal" lattice parameters
  - Goals: tunes, chromaticities and optics at EC (betas and dispersion)
  - Optimization Variables: 5 quadrupole families, 2 sextupole families and dkDT20, dkFT23 (corrector windings)