



Automatic Beam Tuning

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EMIS 2012

Beam Tuning

Physical layout



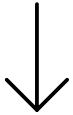
Model (simplified)

Difficult to include misalignments, ion-source, ion traps, etc.



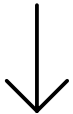
Definition of "Good Beam" (inc. constraints)

Can be very complex



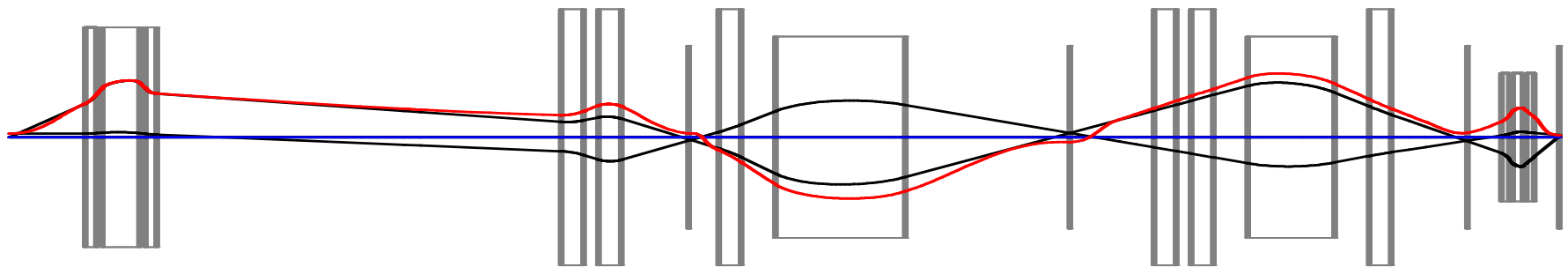
Non-linear Optimiser

Requires realistic starting point



Hand tuning

To account for geometry errors, imprecise beam definition, etc.



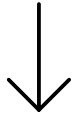
Beam Tuning

Physical layout



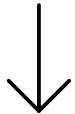
Definition of "Good Beam" (faraday cup)

Very simple



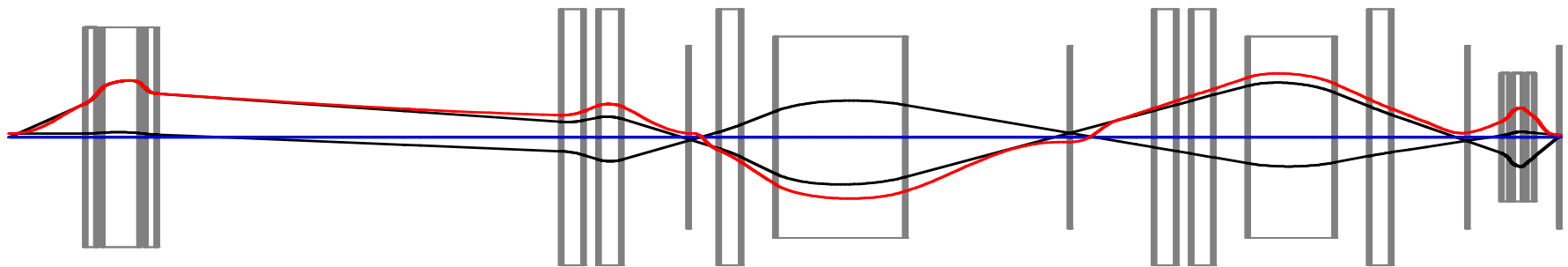
Non-linear Optimiser

Realistic starting point: use previous tune



(Hand Tuning not needed)

Imperfections already accounted for



Choice of Optimiser

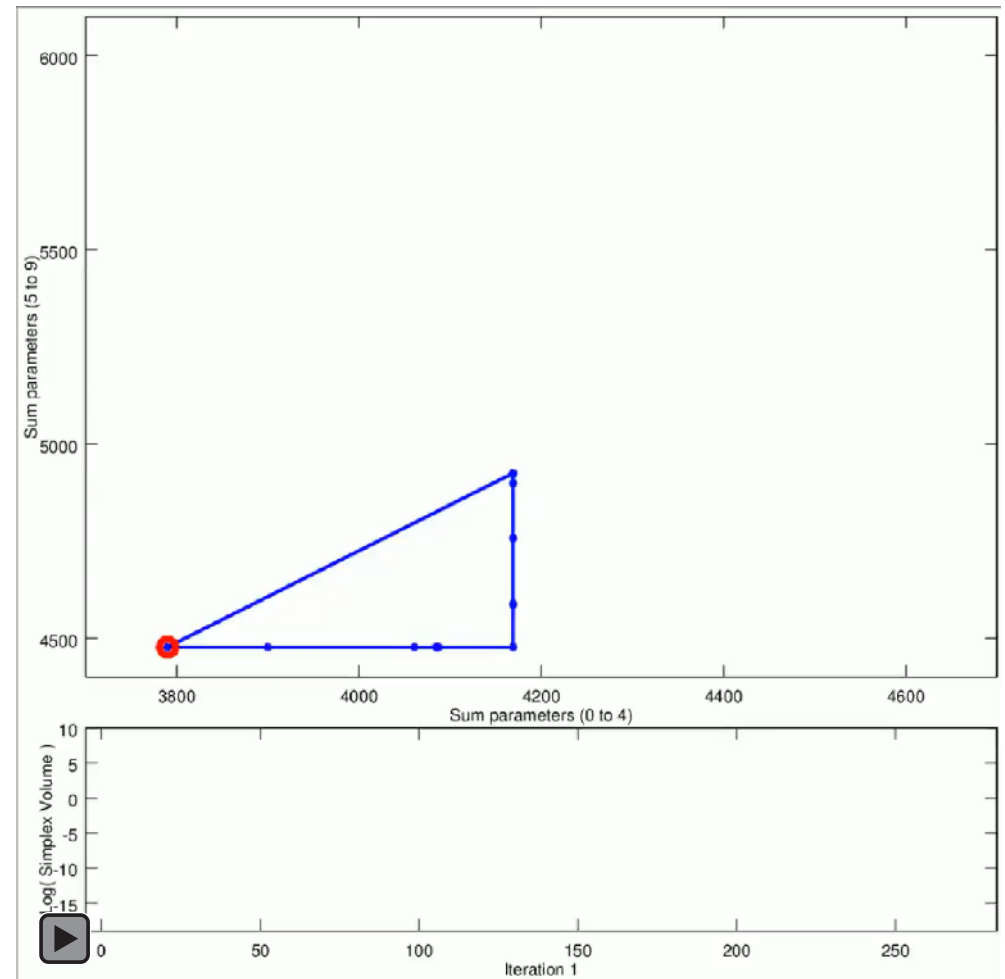
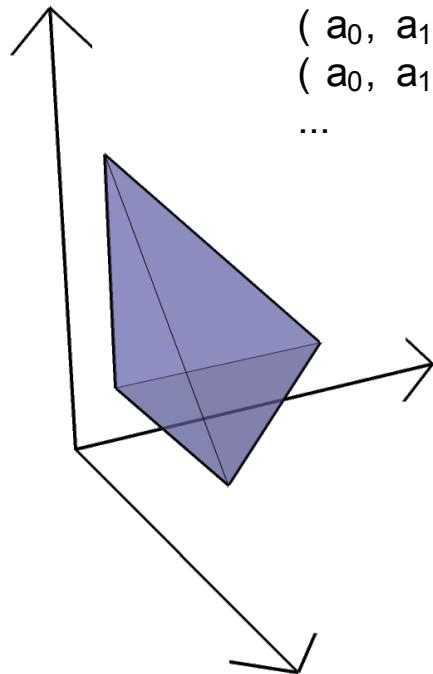
Nelder-Mead simplex algorithm

n independent parameters $(a_0, a_1, a_2, a_3 \dots)$

user-defined step size for each parameter $(\delta a_0, \delta a_1, \delta a_2, \delta a_3 \dots)$

n -dimensional tetrahedron

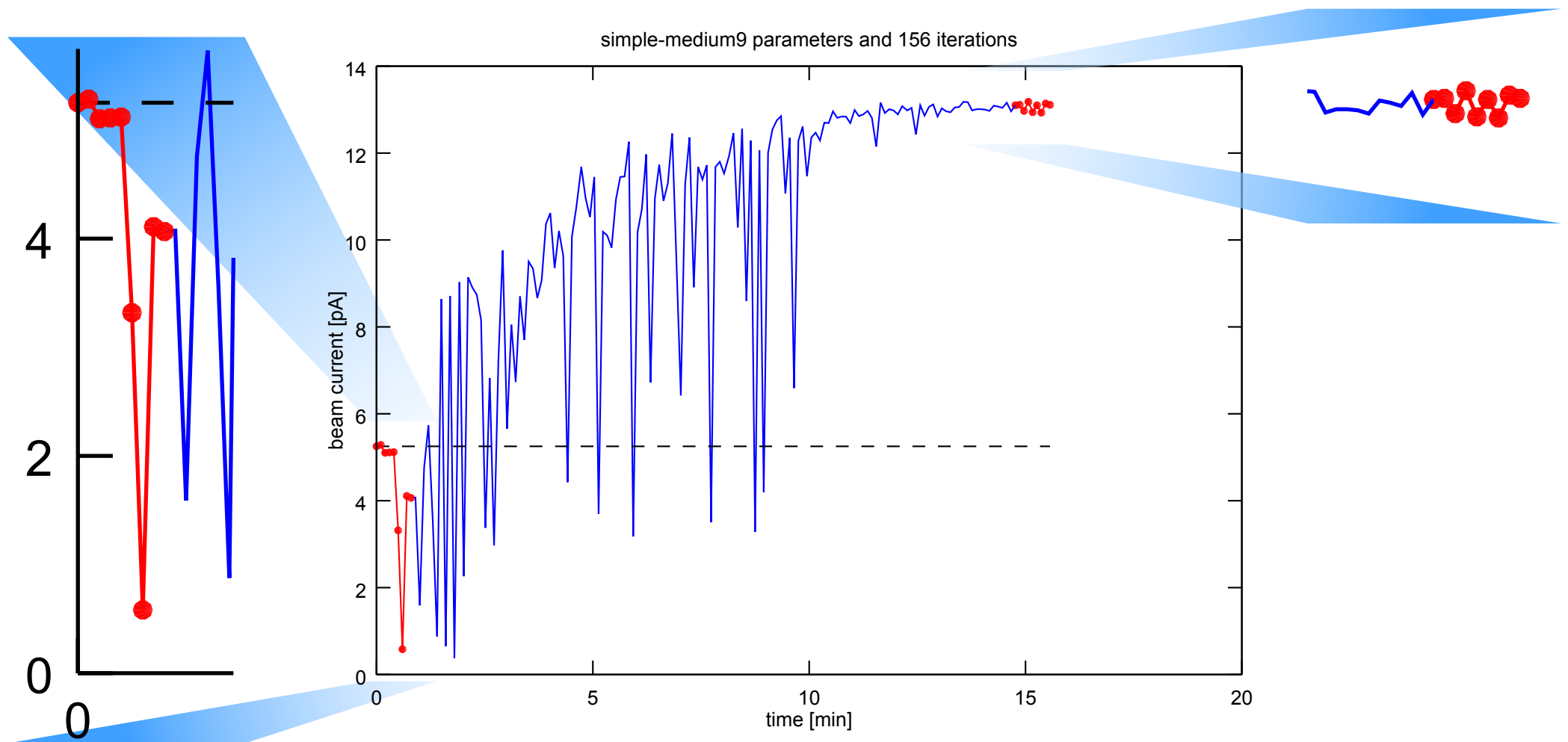
$n+1$ vertices $(a_0, a_1, a_2, a_3 \dots)$
 $(a_0 + \delta a_0, a_1, a_2, a_3 \dots)$
 $(a_0, a_1 + \delta a_1, a_2, a_3 \dots)$
 $(a_0, a_1, a_2 + \delta a_2, a_3 \dots)$
...



Results: short beamline

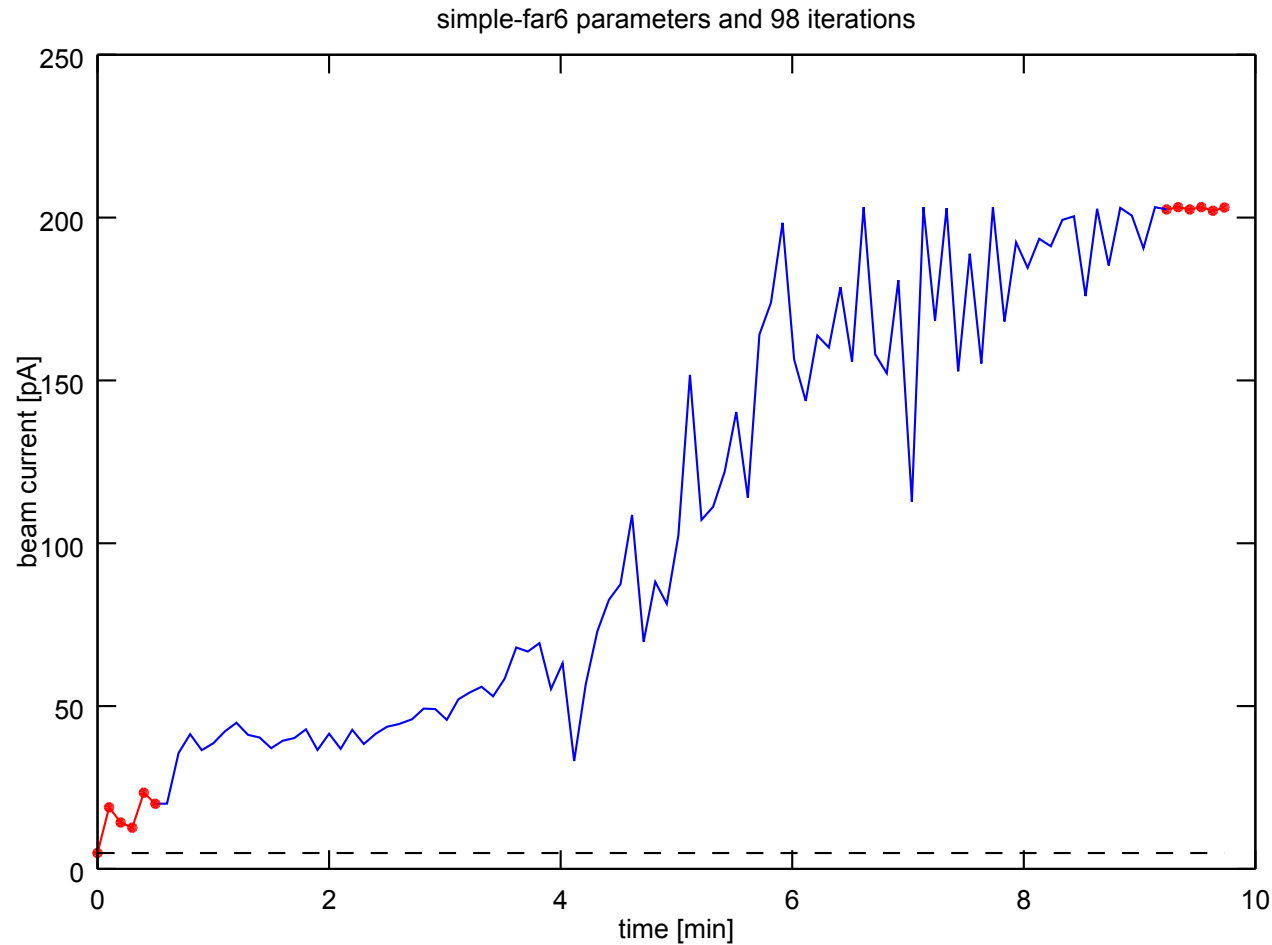
Short beamline (4 quads, 4 steerers, 1 octupole)

Starting point near to optimum tune



Results: short beamline

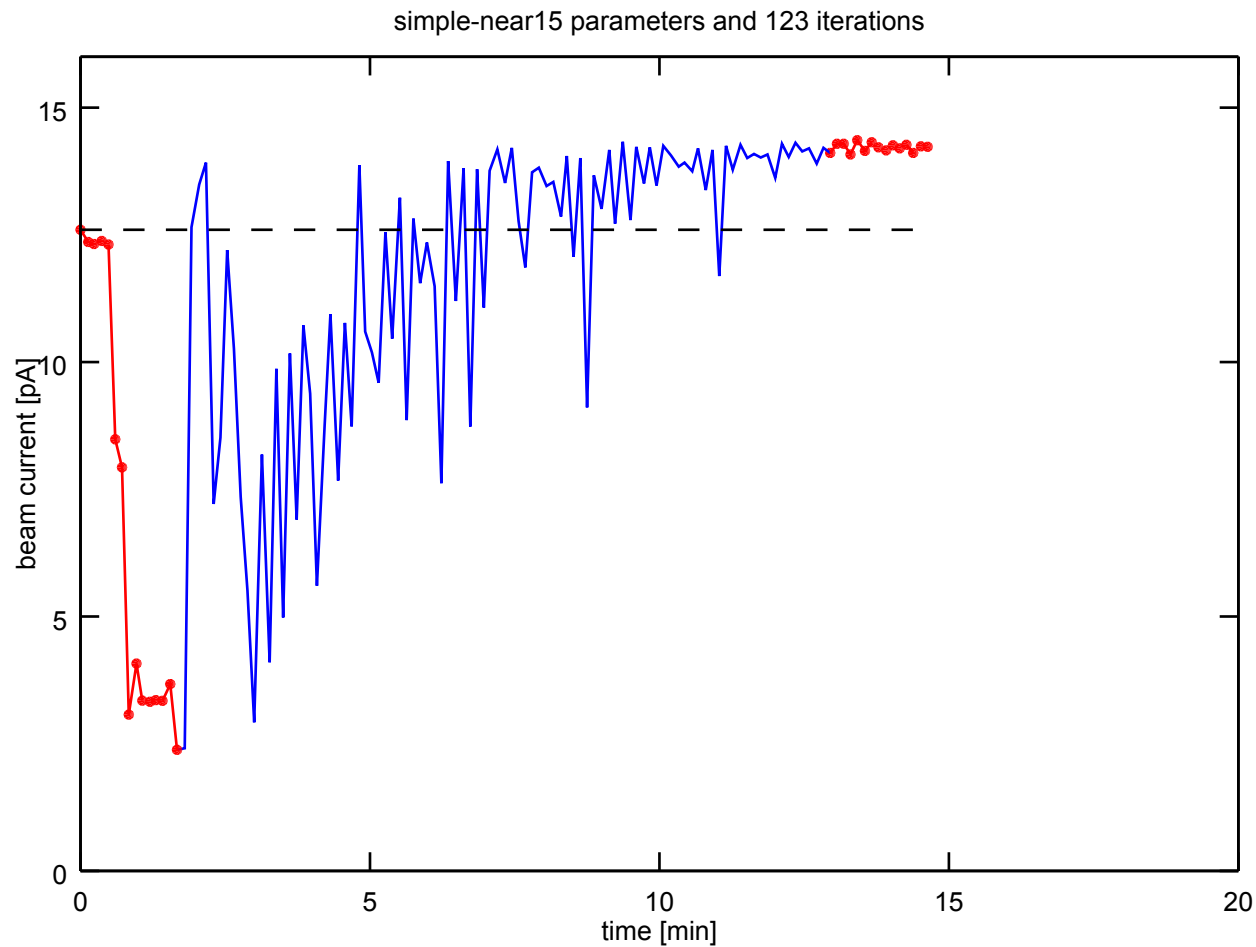
Starting point far from optimum tune
42x gain in transport



Results: short beamline

Starting point near to optimum tune

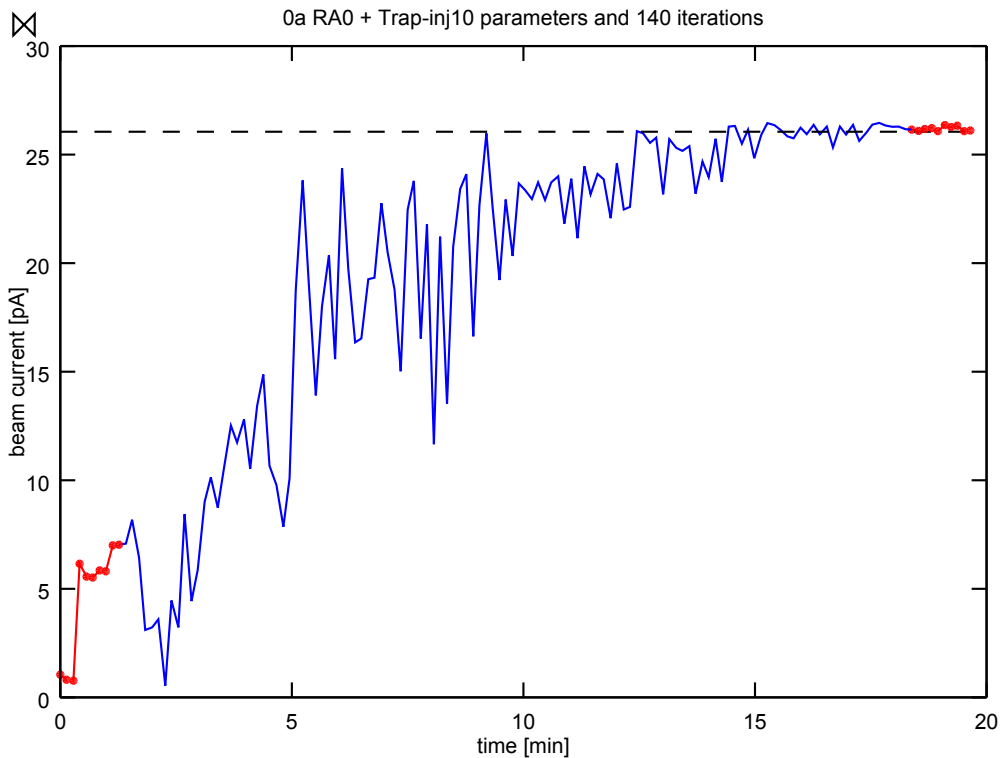
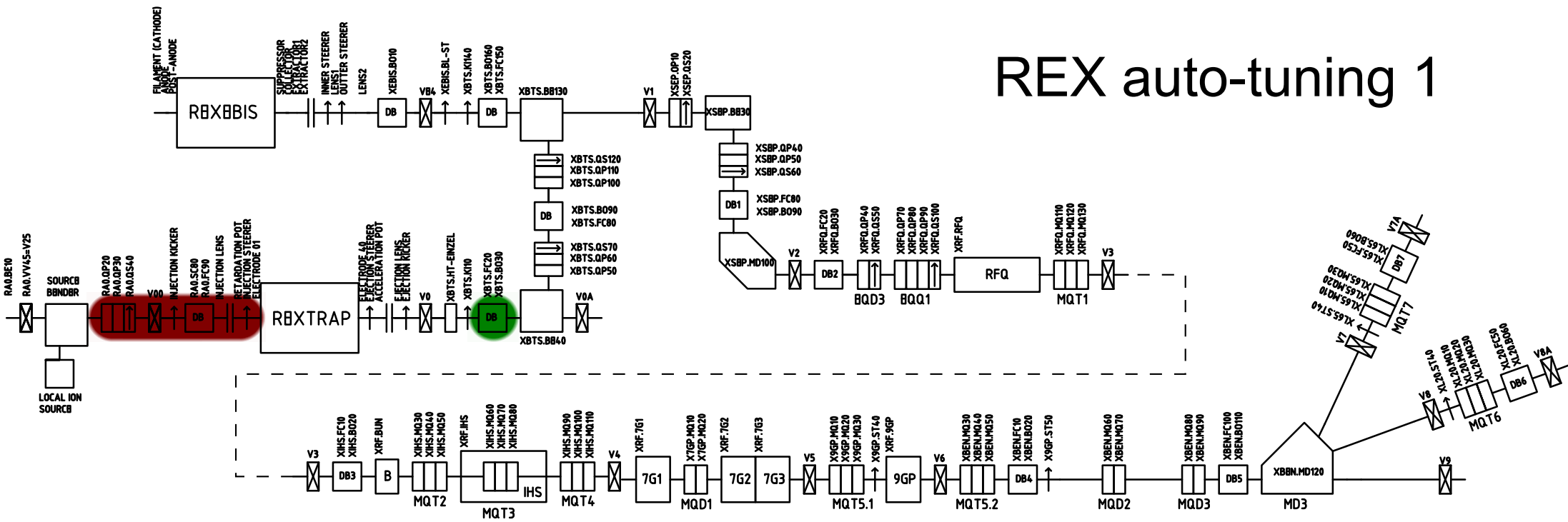
13% gain in transport





Higher Dimensions

REX auto-tuning 1



Trap injection:

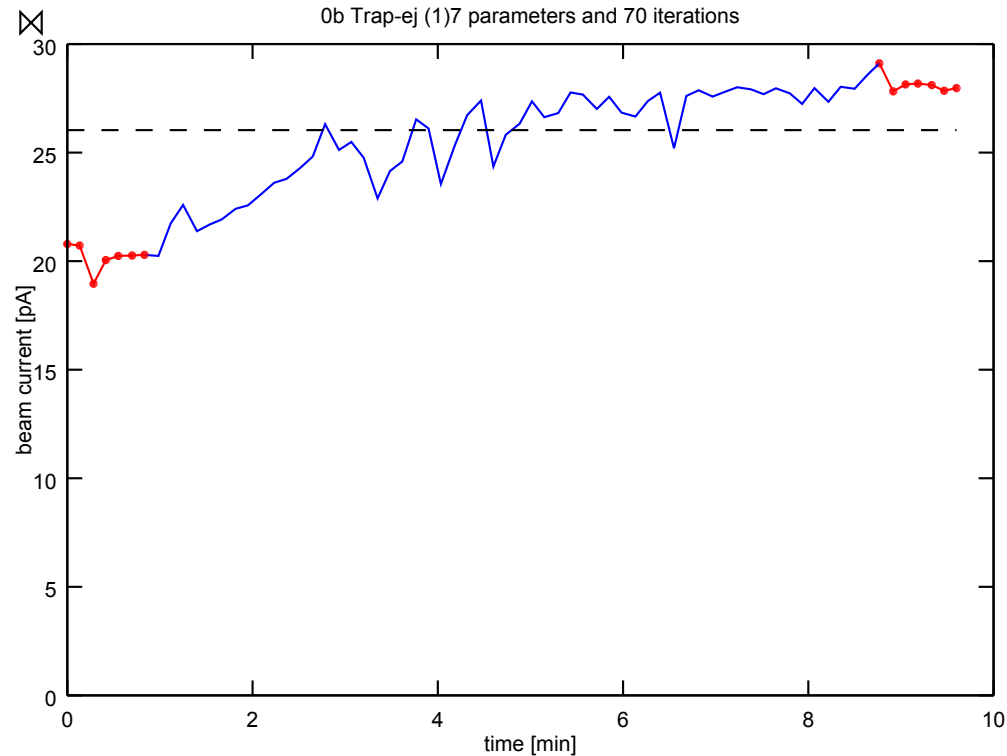
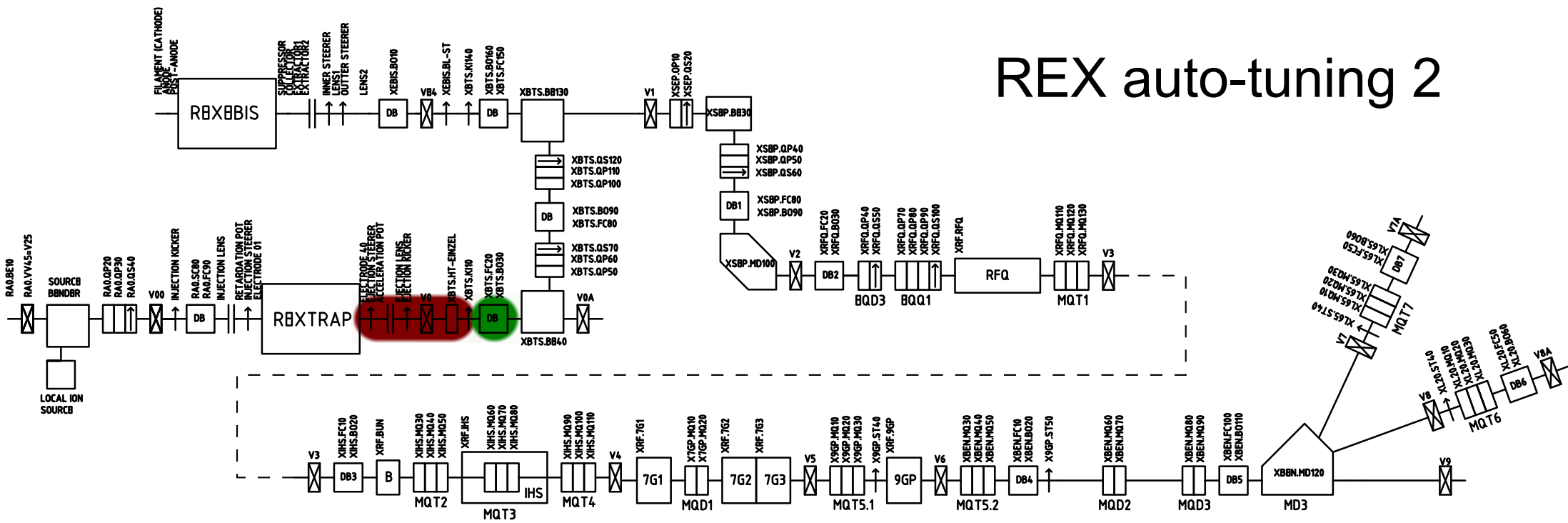
10 parameters

140 iterations

Gain 25x W.R.T de-tuned start

Gain +0.2% W.R.T nominal

REX auto-tuning 2



Trap ejection (1):

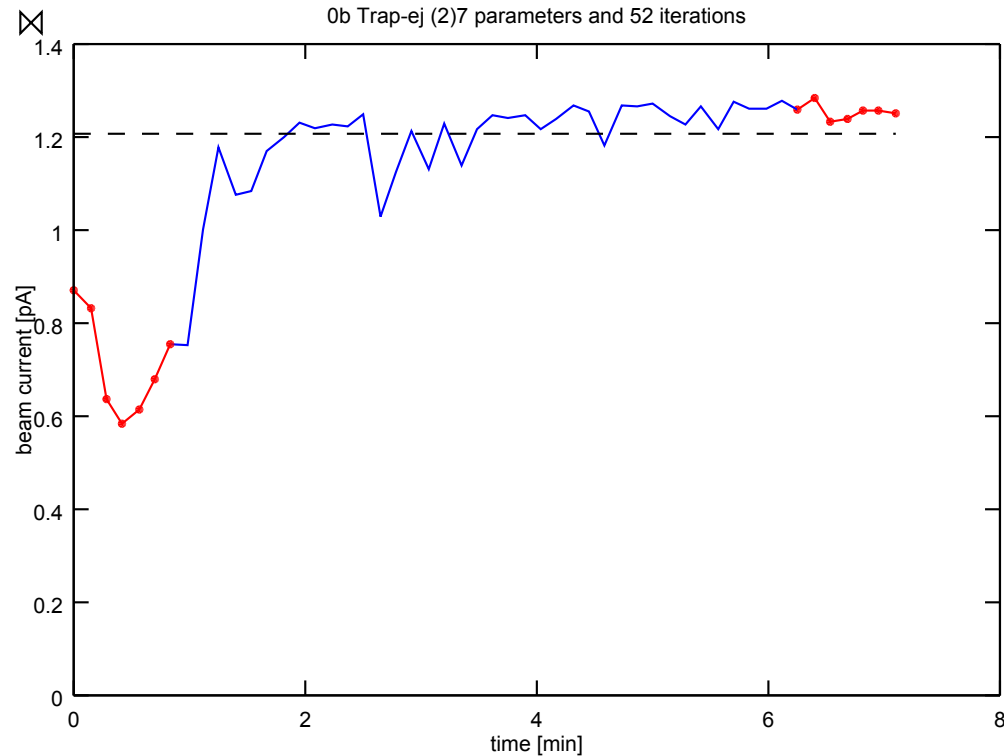
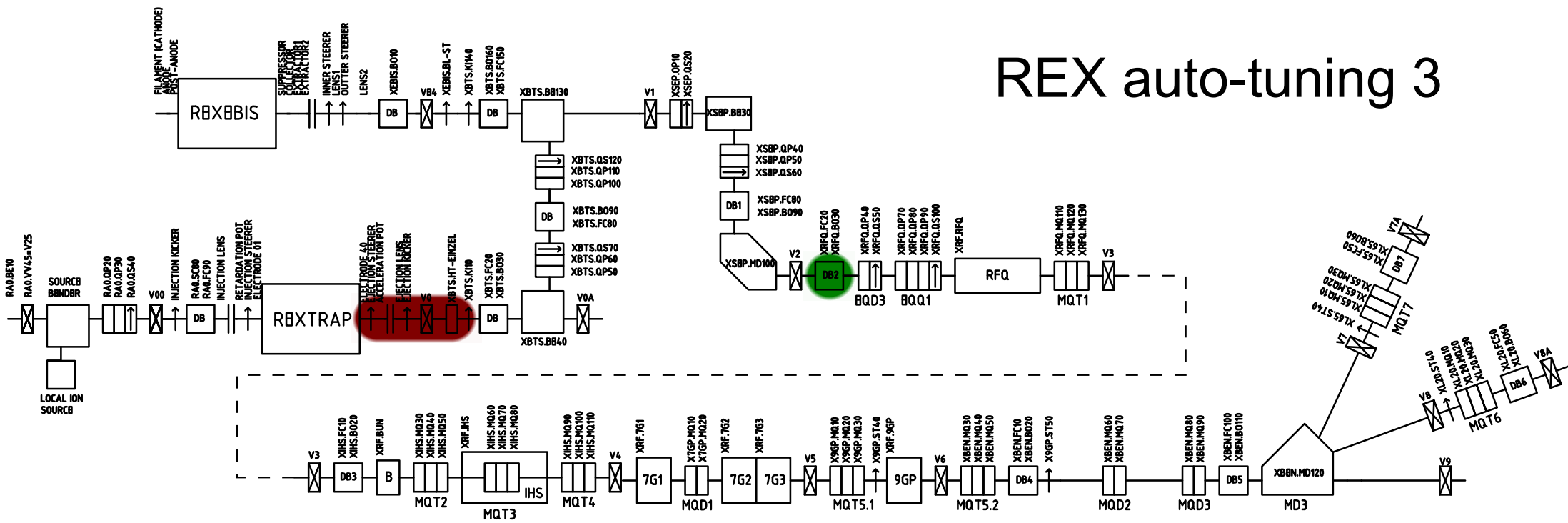
7 parameters

70 iterations

Gain +35% W.R.T de-tuned start

Gain +7.4% W.R.T nominal

REX auto-tuning 3



Trap ejection (2):

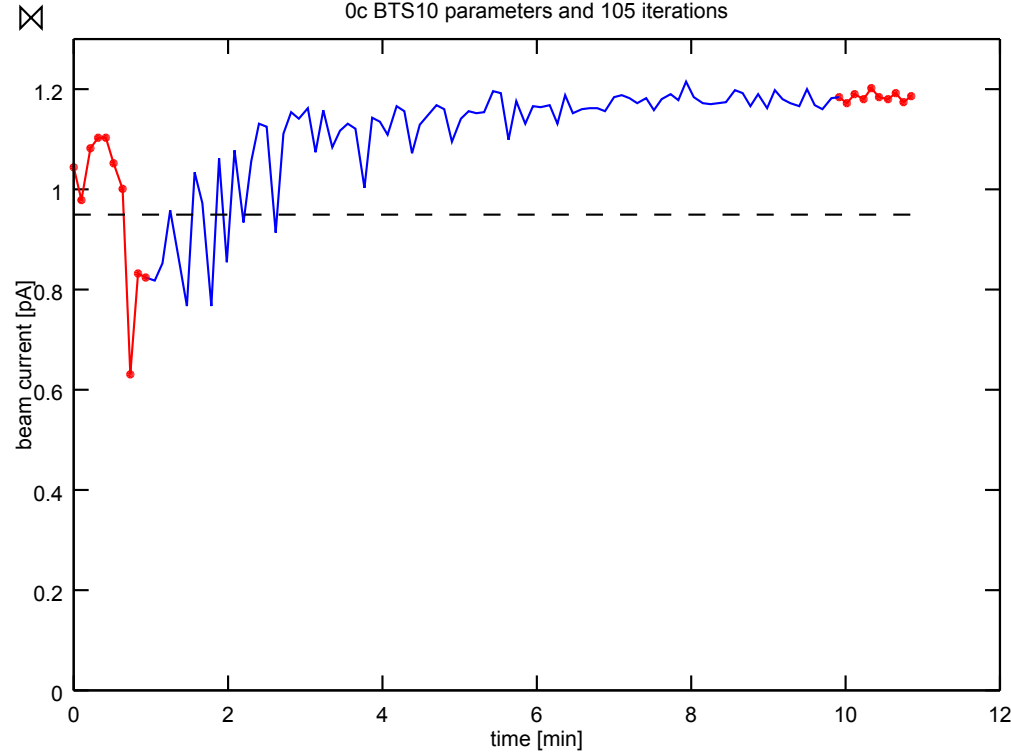
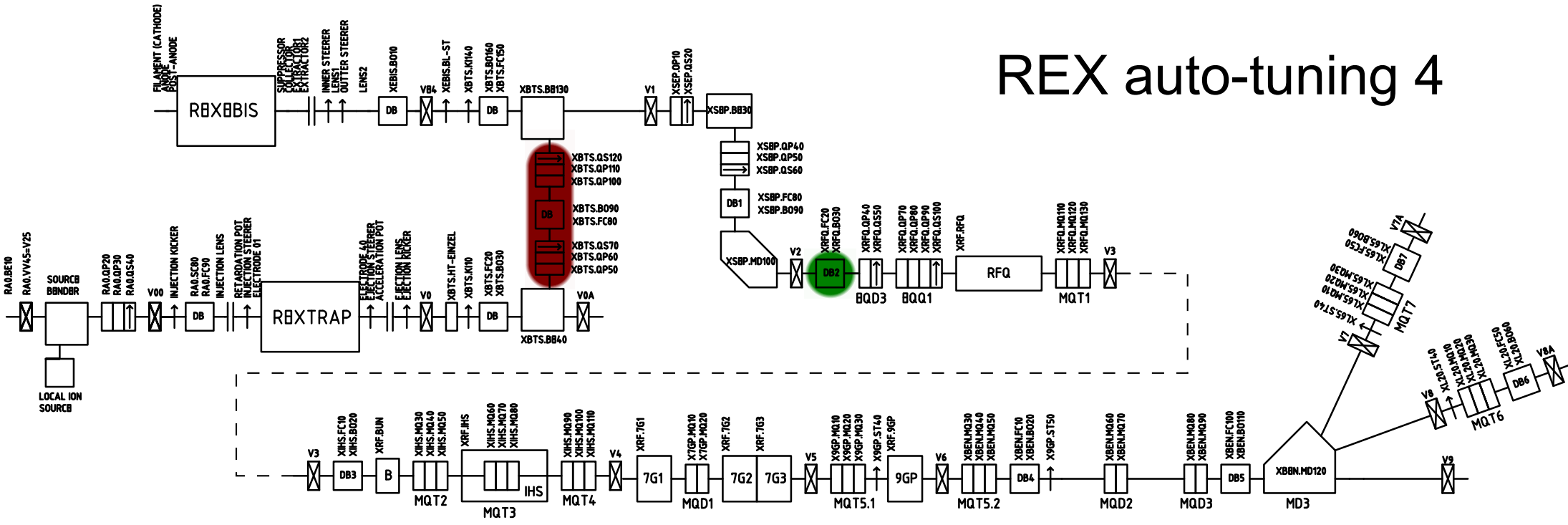
7 parameters

70 iterations

Gain +44% W.R.T de-tuned start

Gain +3.6% W.R.T nominal

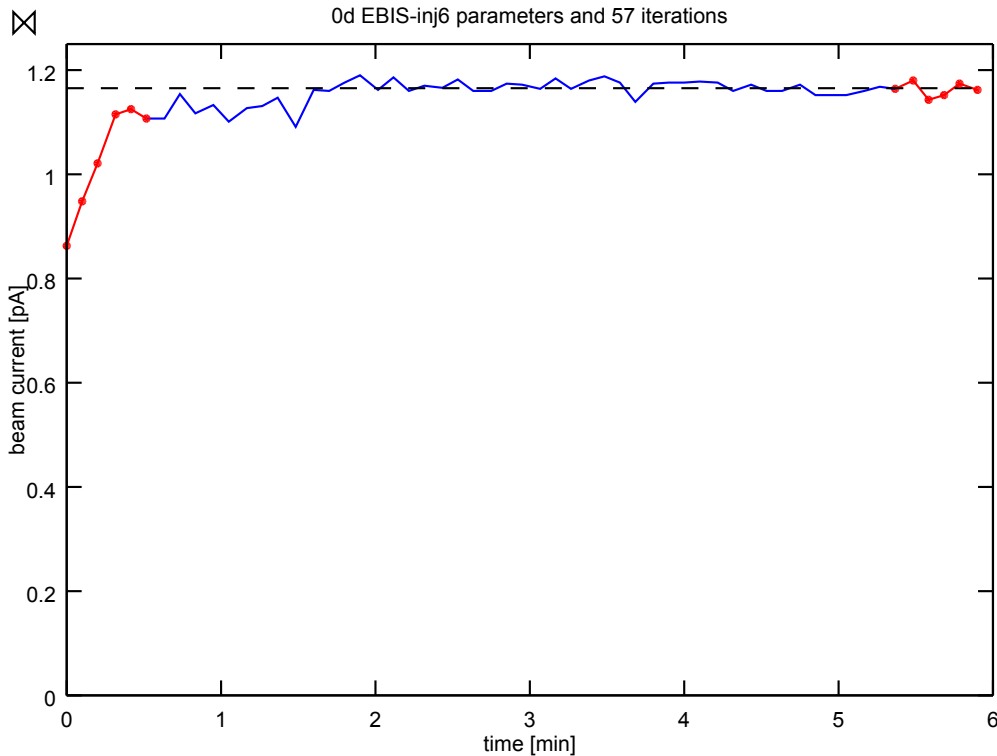
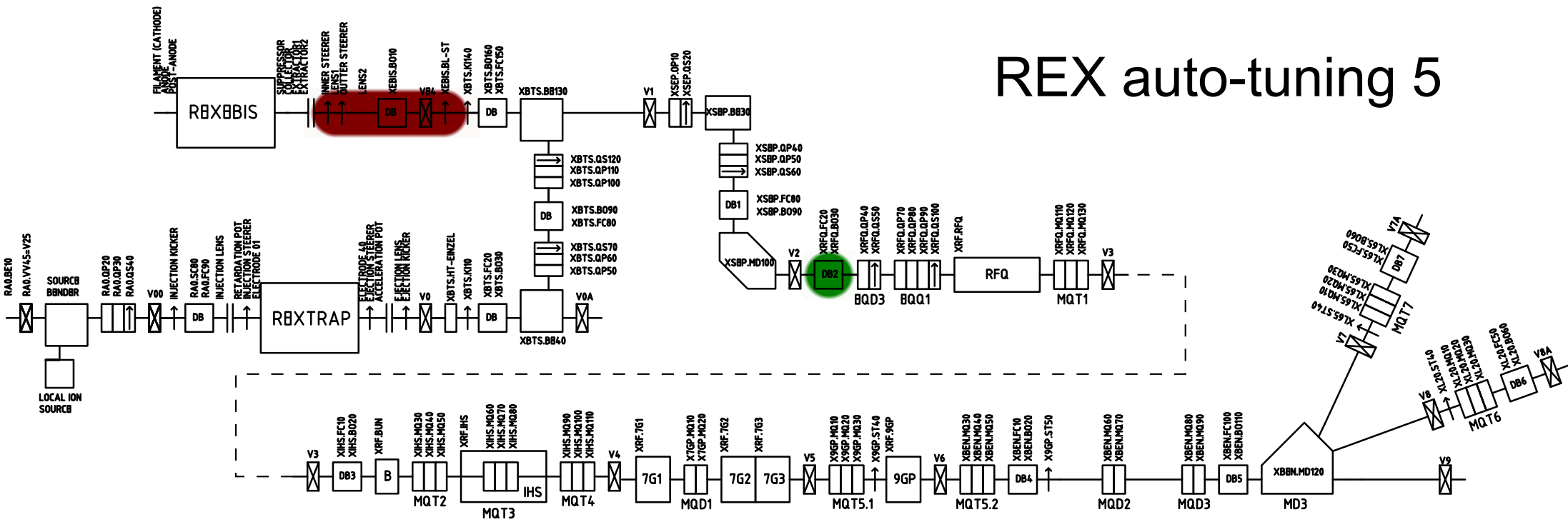
REX auto-tuning 4



Beam-Transport Section:

- 10 parameters
- 105 iterations
- Gain +14% W.R.T de-tuned start
- Gain +25% W.R.T nominal

REX auto-tuning 5



EBIS injection:

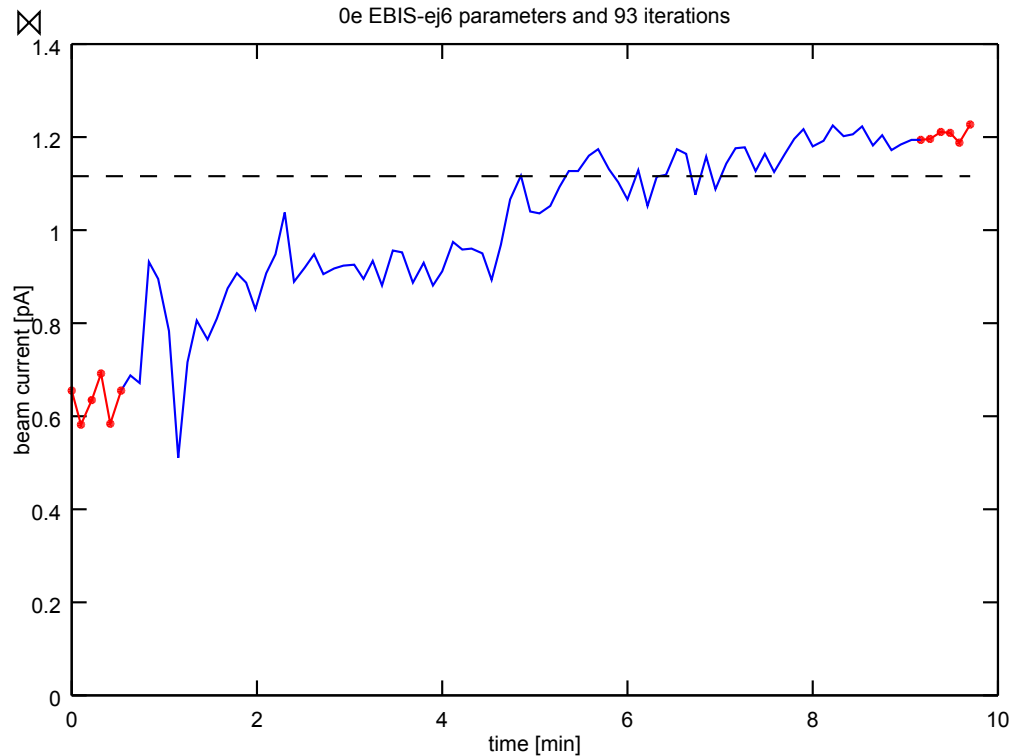
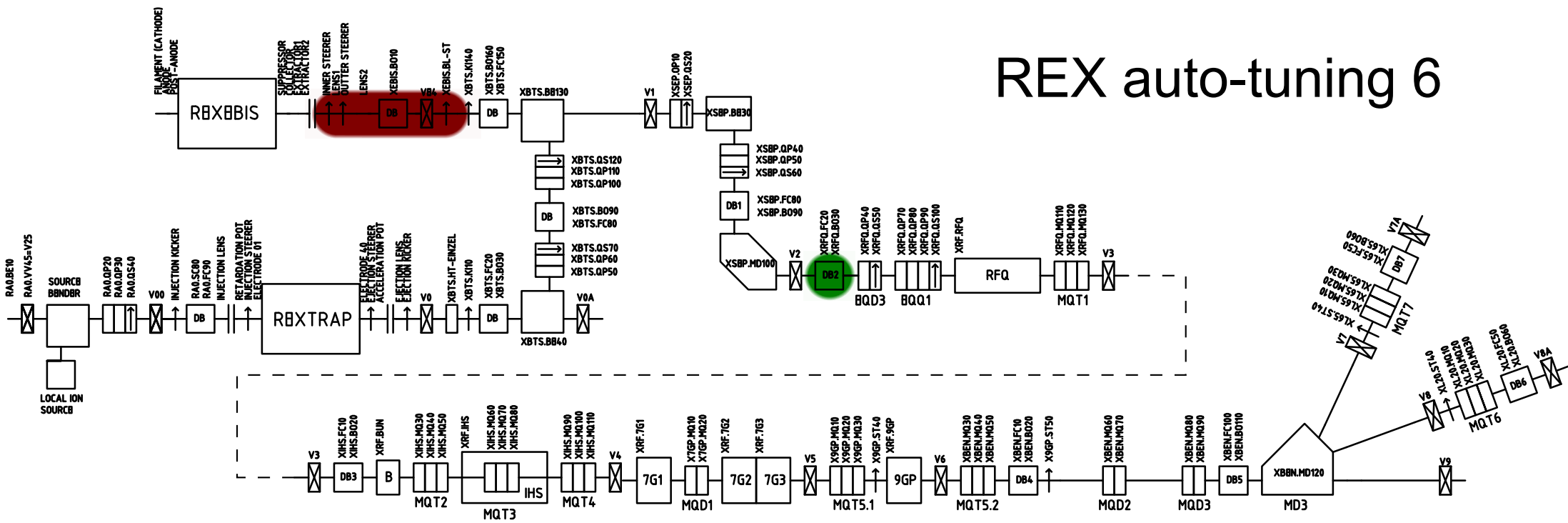
6 parameters

57 iterations

Gain +35% W.R.T de-tuned start

Gain -0.3% W.R.T nominal

REX auto-tuning 6



EBIS ejection:

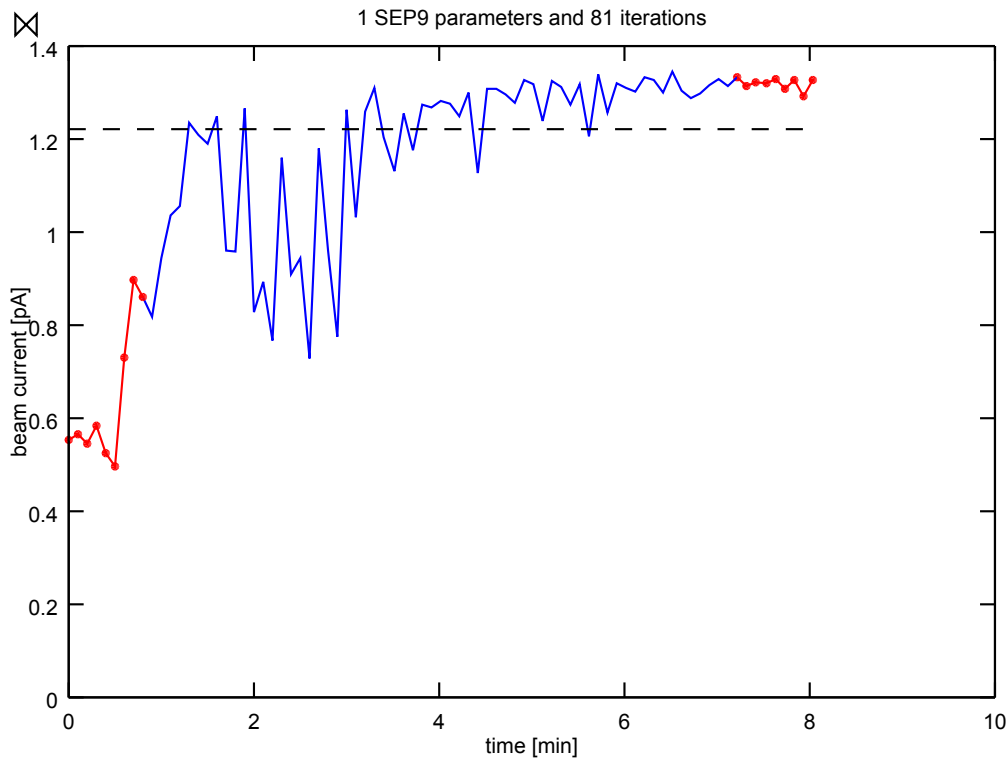
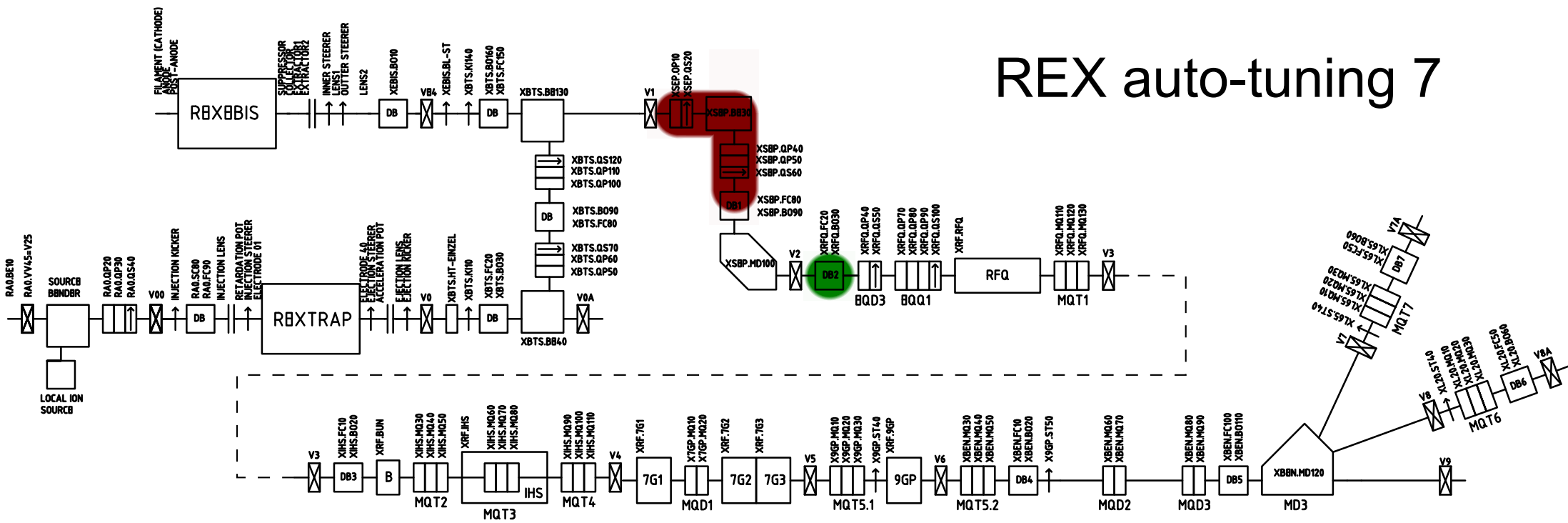
6 parameters

93 iterations

Gain +87% W.R.T de-tuned start

Gain +10% W.R.T nominal

REX auto-tuning 7



Separator Section:

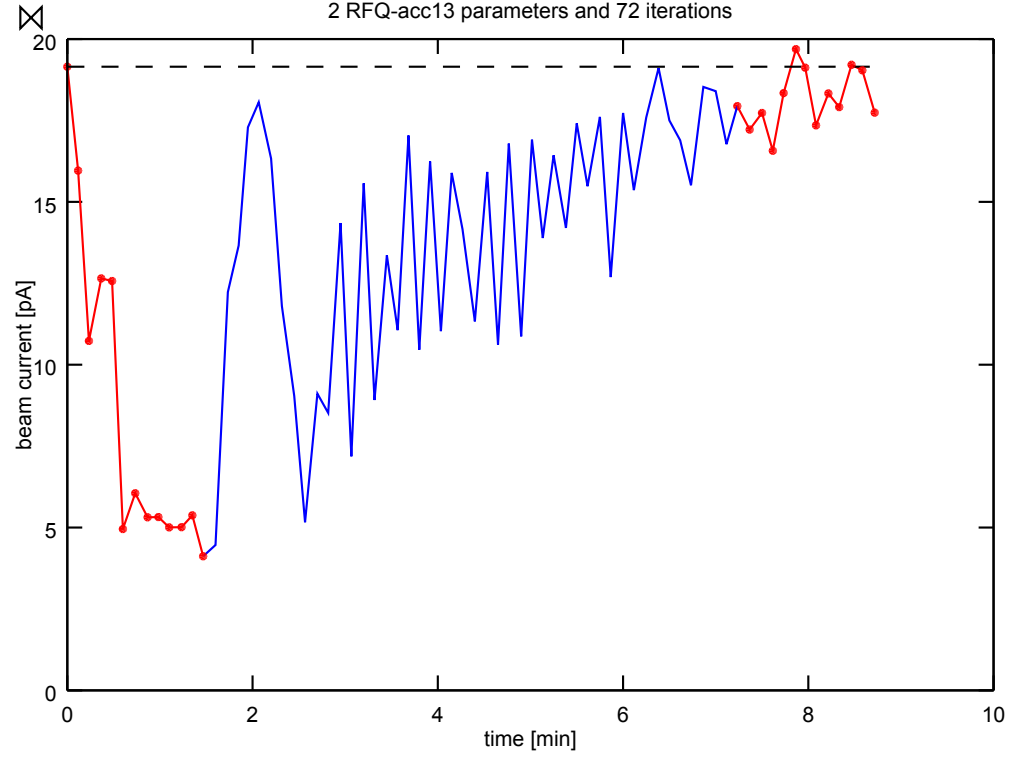
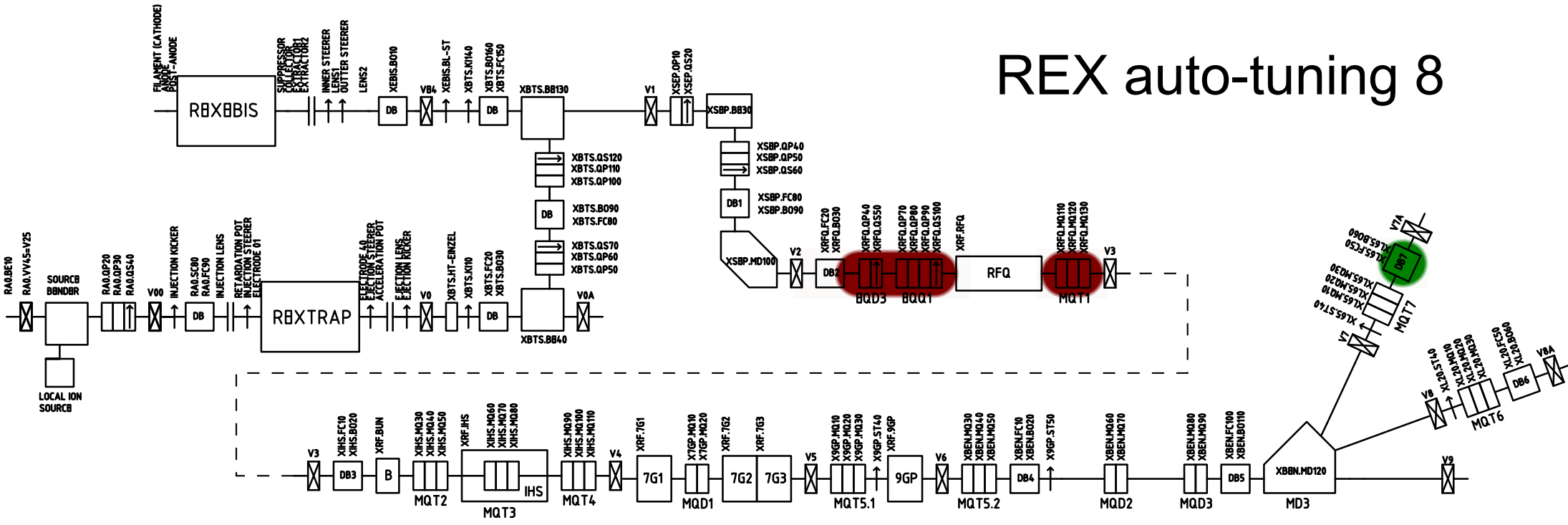
9 parameters

81 iterations

Gain +140% W.R.T de-tuned start

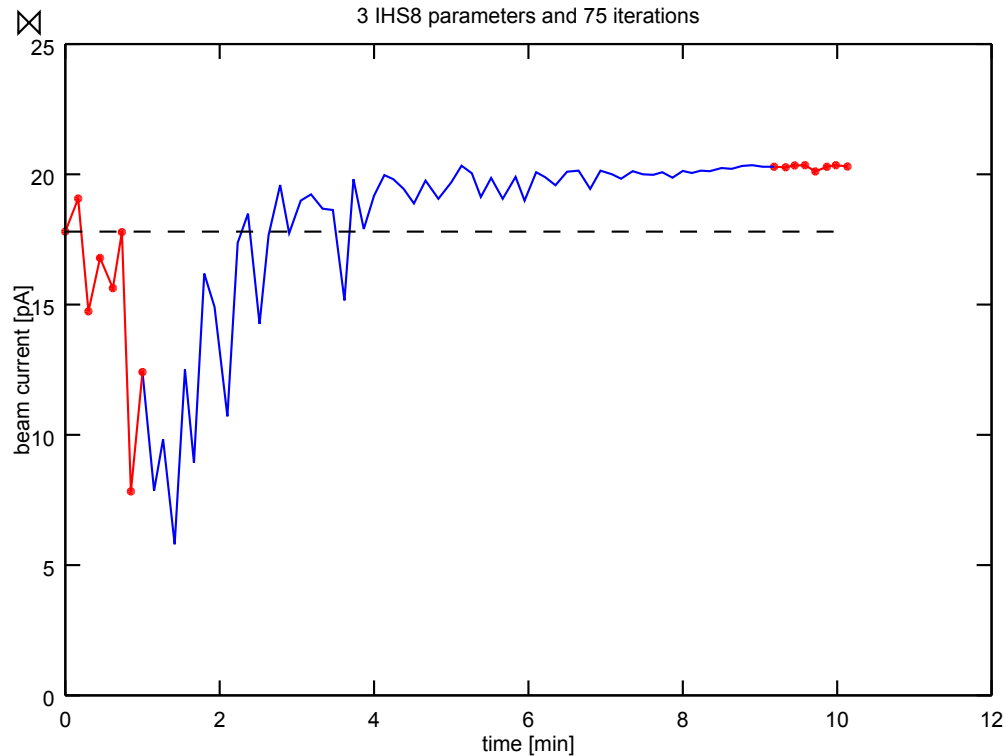
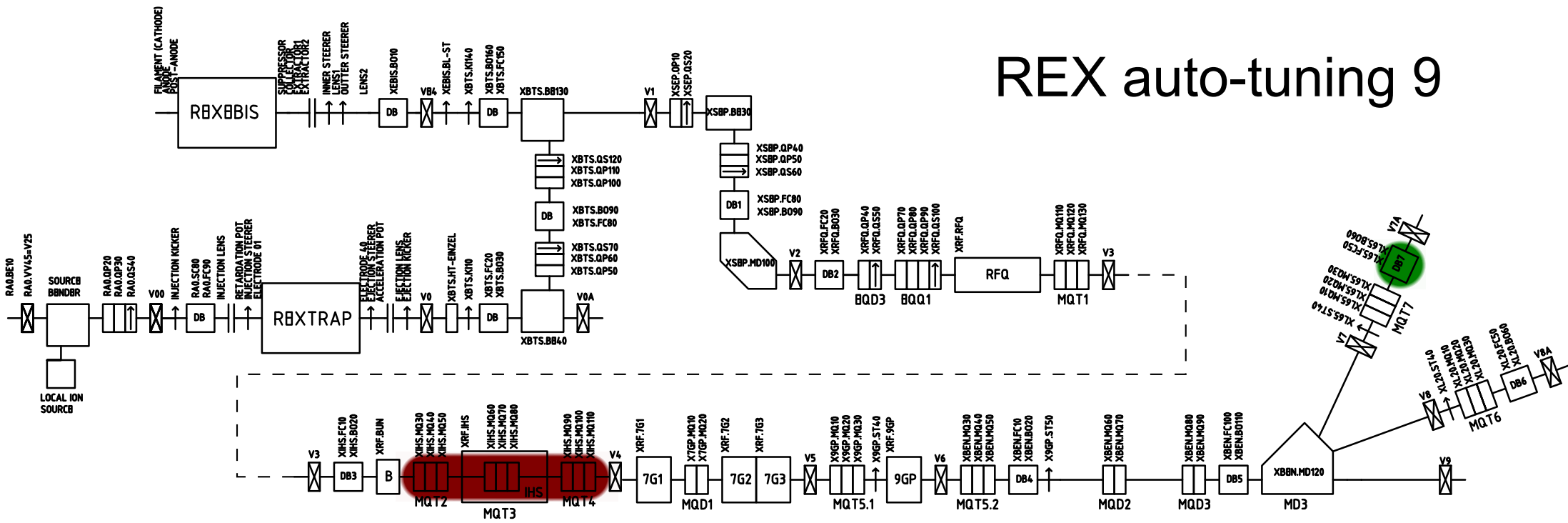
Gain +8.7% W.R.T nominal

REX auto-tuning 8



RFQ:
 13 parameters
 72 iterations
 Gain -7% W.R.T nominal

REX auto-tuning 9



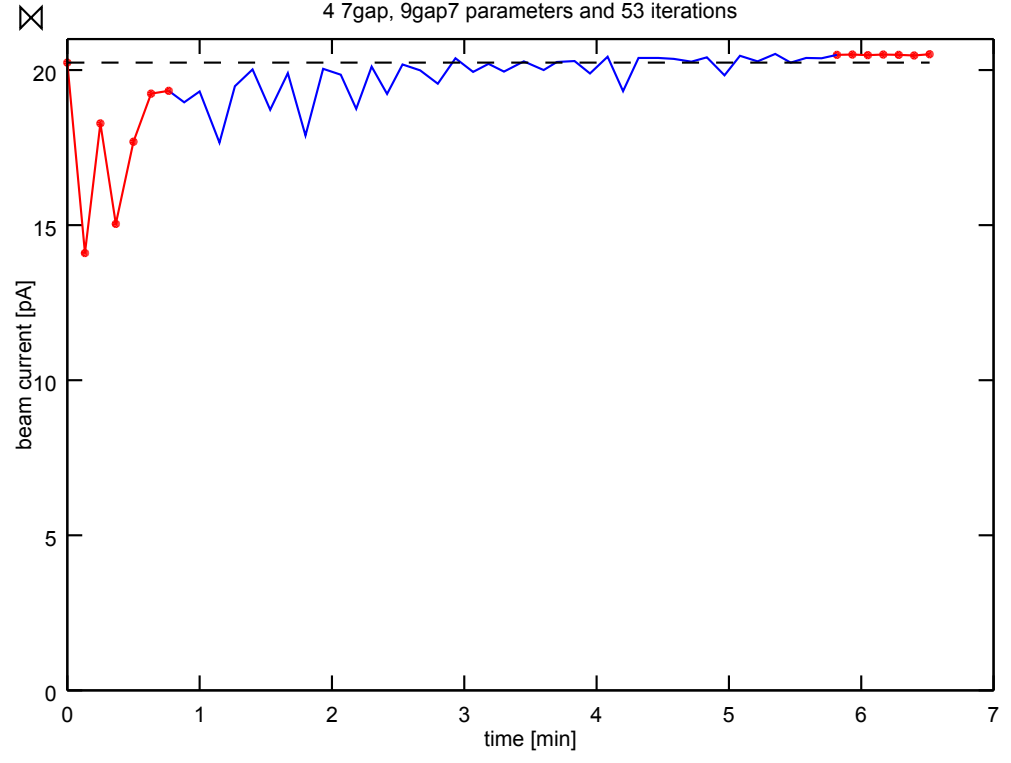
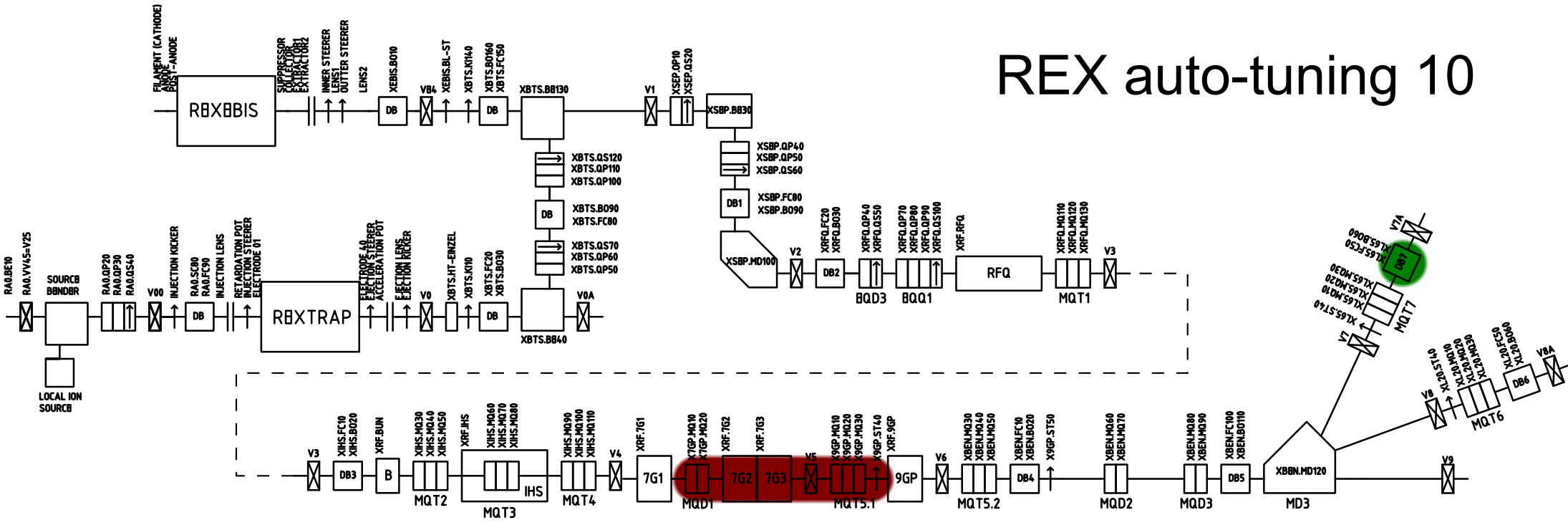
"IH" section:

8 parameters

75 iterations

Gain +14% W.R.T nominal

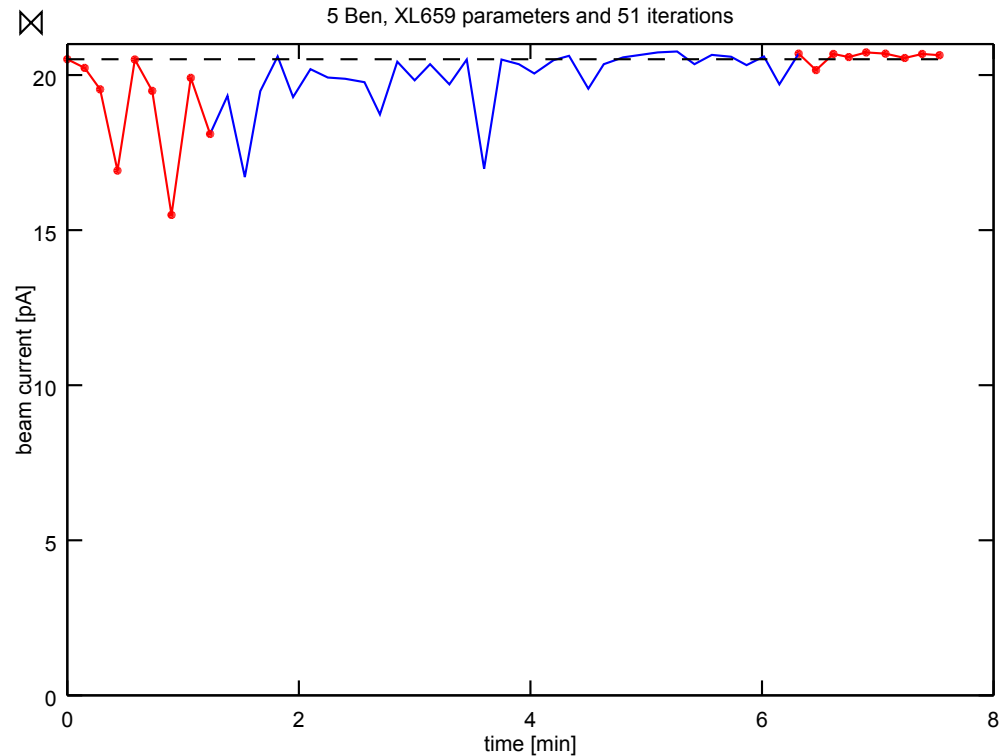
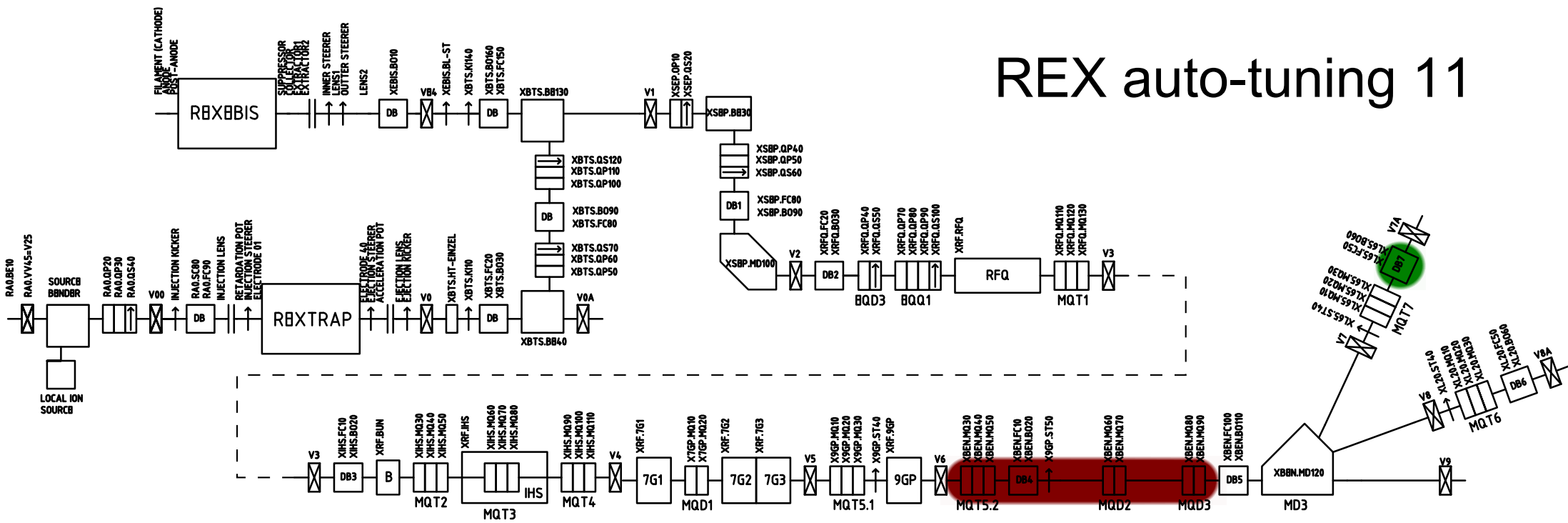
REX auto-tuning 10



"7-gap" and 9-gap sections:

- 7 parameters
- 53 iterations
- Gain +1.3% W.R.T nominal

REX auto-tuning 11



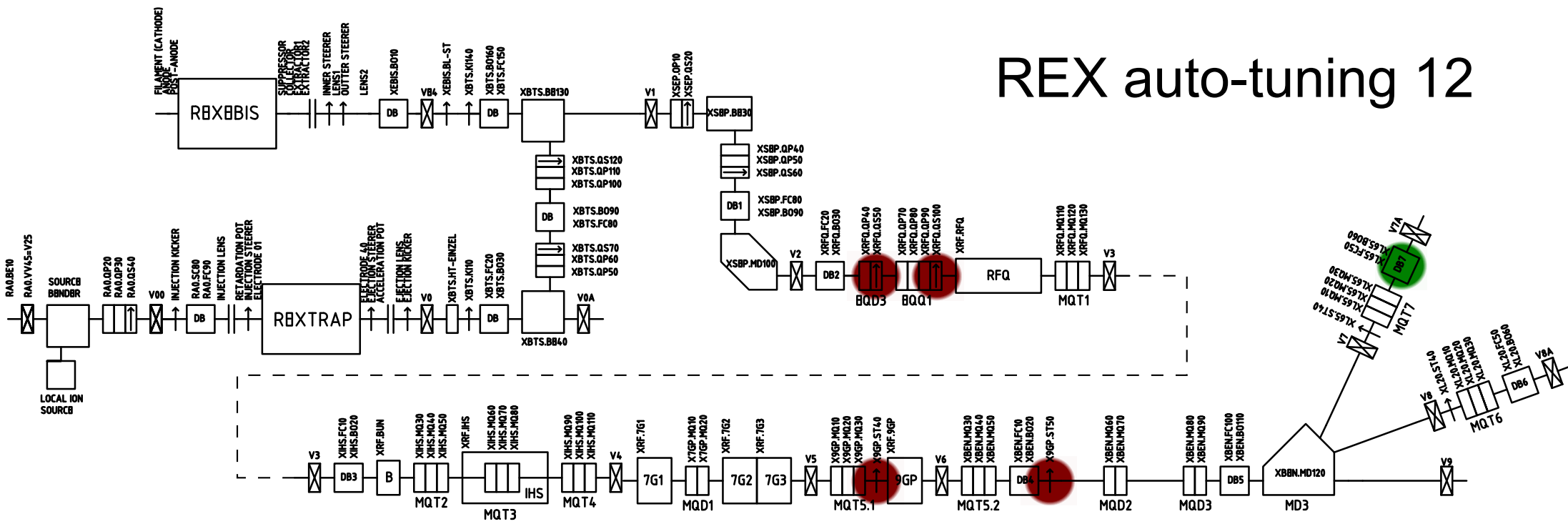
"7-gap" and 9-gap sections:

9 parameters

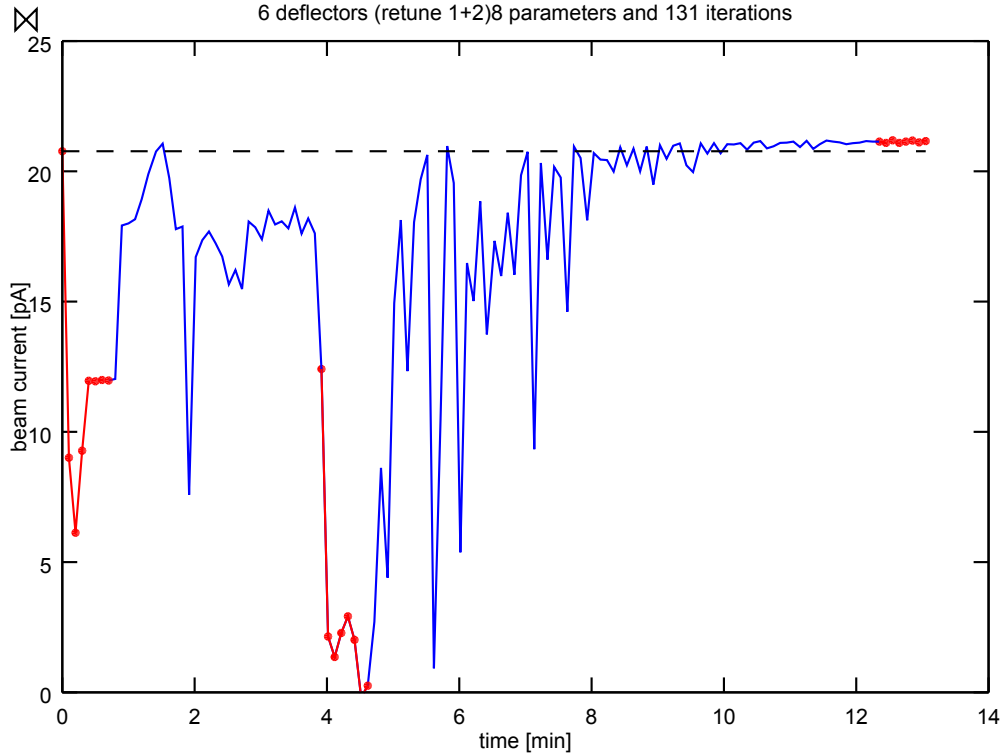
51 iterations

Gain +0.6% W.R.T nominal

REX auto-tuning 12



6 deflectors (retune 1+2)8 parameters and 131 iterations



Fine-tuning of Deflectors:

8 parameters

131 iterations

Gain +1.9% W.R.T nominal

Multi-Phase Tuning

100 parameters tuned in 12 phases: Injection and extraction for 2 ion-traps
LEBT
Linac optics

Total 980 iterations over 117 minutes

Strictly no human intervention beyond loading pre-defined configurations

97% increase in beam transmission WRT nominal parameters
(392x increase in beam transmission WRT de-tuned parameters)

Final linac transmission 88% (manual tuning 85% - 87% typical best)

Parameters **not** auto-tuned : trapping potentials / electron beam / RF



Conclusions

Results of Auto-Tuner

Much of the beam-tuning task is rote and may be automated

Automated tuning is robust even with complex beam-lines

Almost any parameter can be auto-tuned

Optimisation is purely statistical : no model is required

Auto-tuning may be set to run complex sequences at antisocial hours

Process is much faster than a human operator

Result can be similar to an experienced human operator

Caveats

Auto-tuning does not replace skilled human operators

A "sensible" starting point must be provided

A scripted tuning sequence must be written for each beamline

Not all parameters can be auto-tuned (eg. cathode-heating)

Future

Robust termination condition which can distinguish instrument noise from
real beam variations

Intelligent restarts if convergence fails

Pre-scripted tuning sequences for major beamlines

Rigorous comparison with human operators

Reliability testing

A user-friendly sequencer

Sophisticated tune quantifiers (eg. narrow beam at separator focii)



Auto-tuning can save physics time

Improved use of skilled personnel

-- thanks to --

Emiliano Piselli