

# Automatic Beam Tuning

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Barcelona 2014

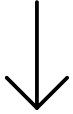
# Beam Tuning

Physical layout



Model (simplified)

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



Definition of "Good Beam" (inc. constraints)

Can be very complex



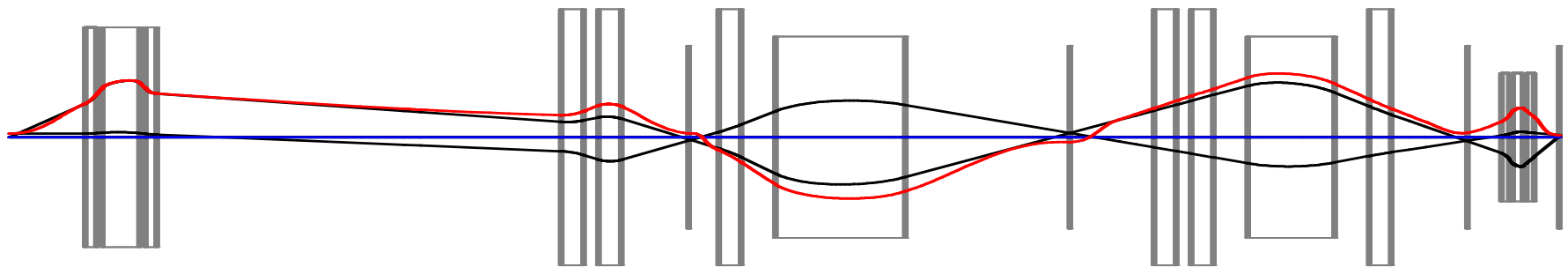
Non-linear Optimiser

Requires realistic starting point



Hand tuning

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



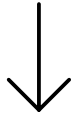
# Beam Tuning

Physical layout



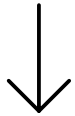
Definition of "Good Beam" (faraday cup)

Very simple



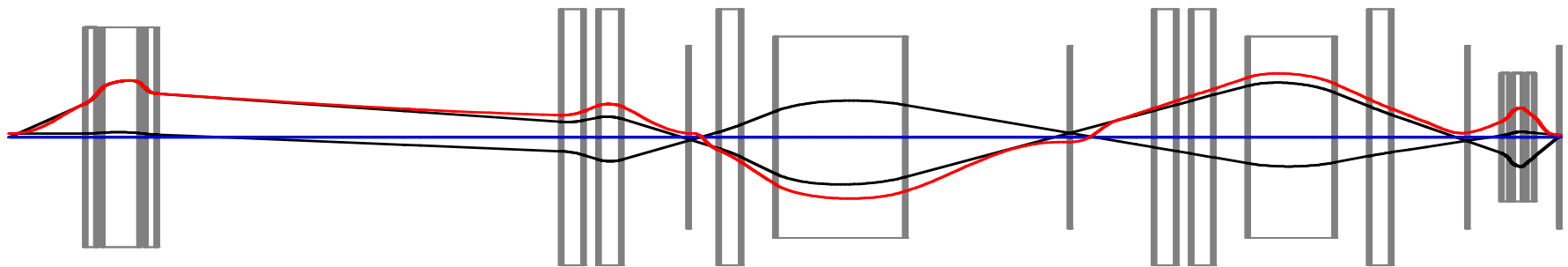
Non-linear Optimiser

Realistic starting point: use previous tune



(Hand Tuning not needed)

Imperfections already accounted for



# Choice of Optimiser

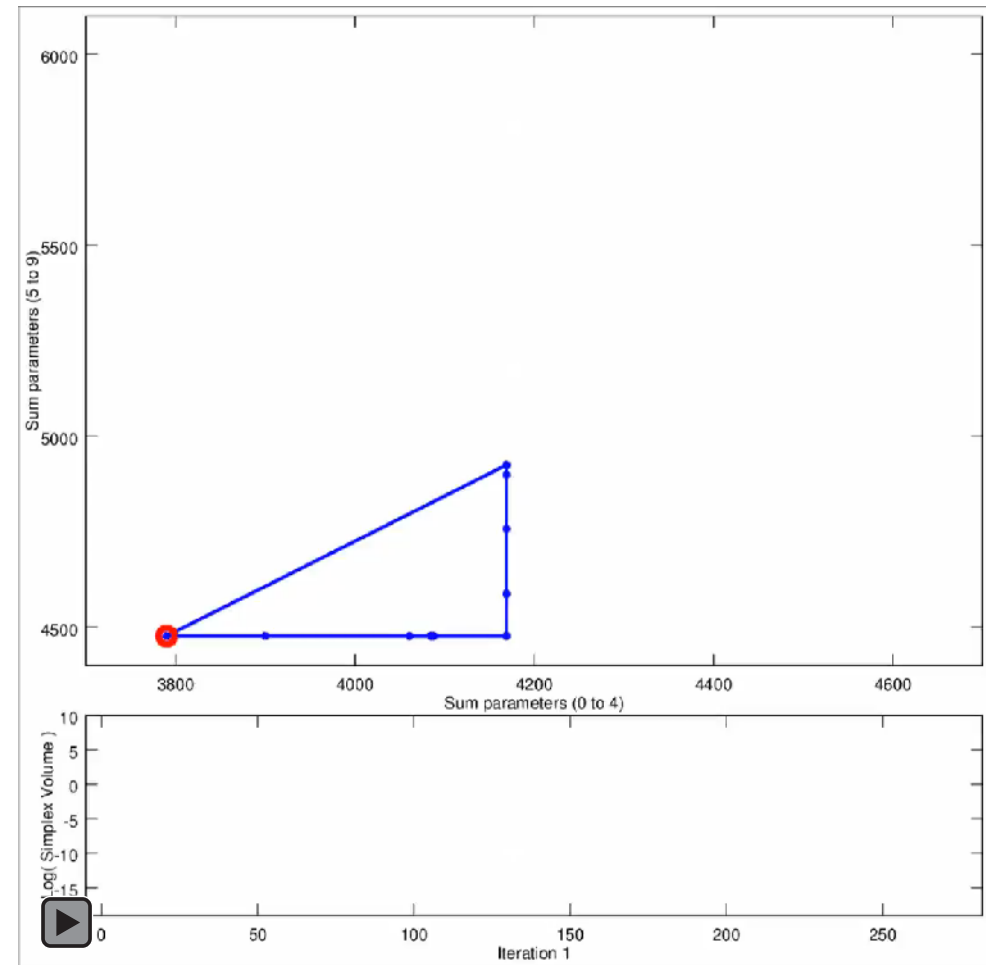
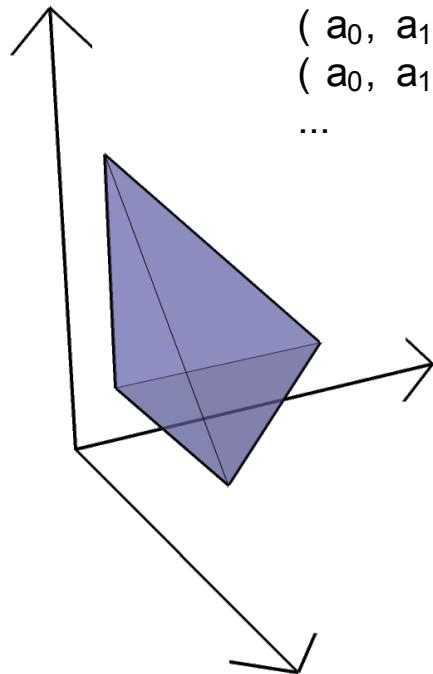
## Nelder-Mead simplex algorithm

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

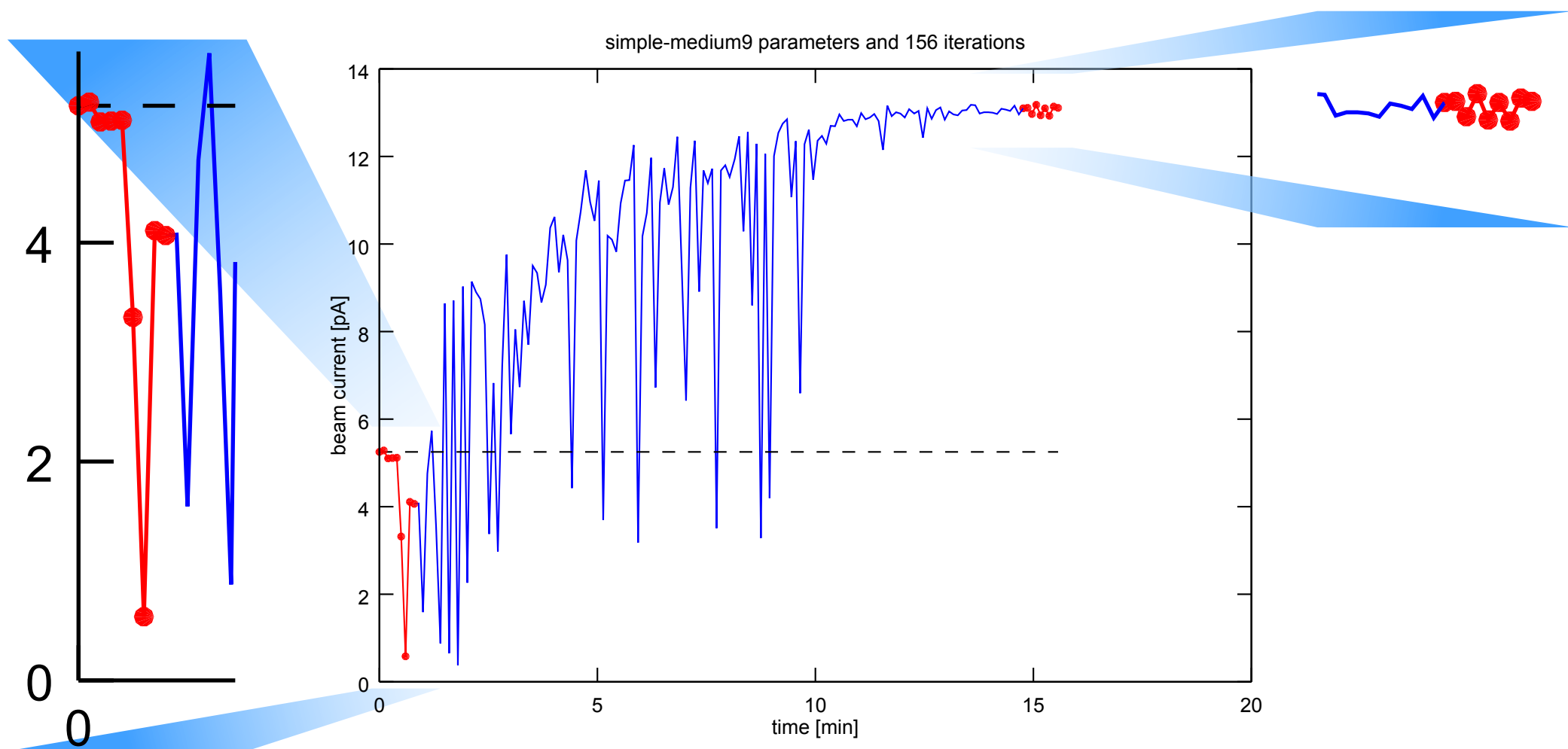




# Results: short beamline

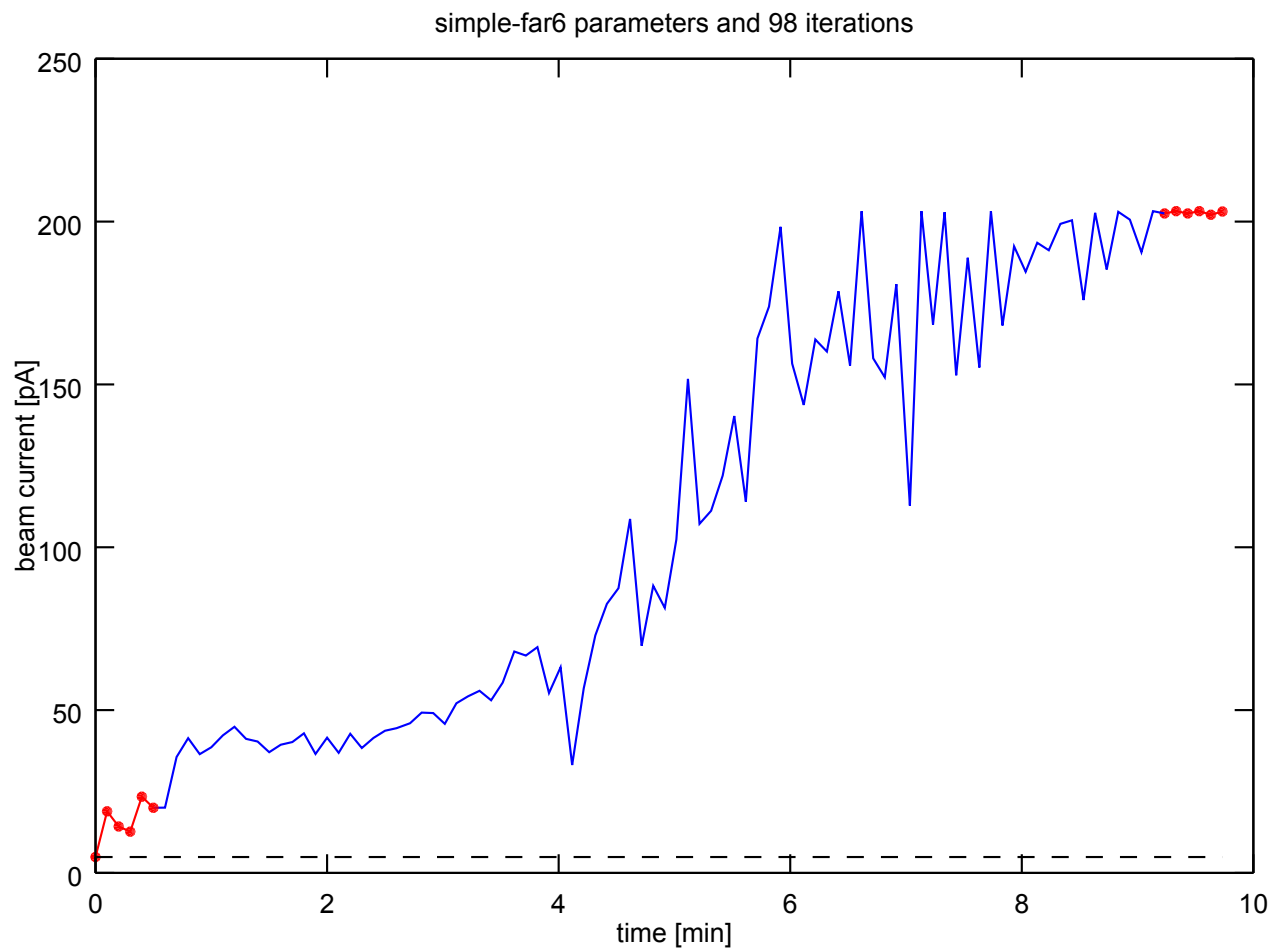
Short beamline (4 quads, 4 steerers, 1 octupole)

Starting point near to optimum tune



# Results: short beamline

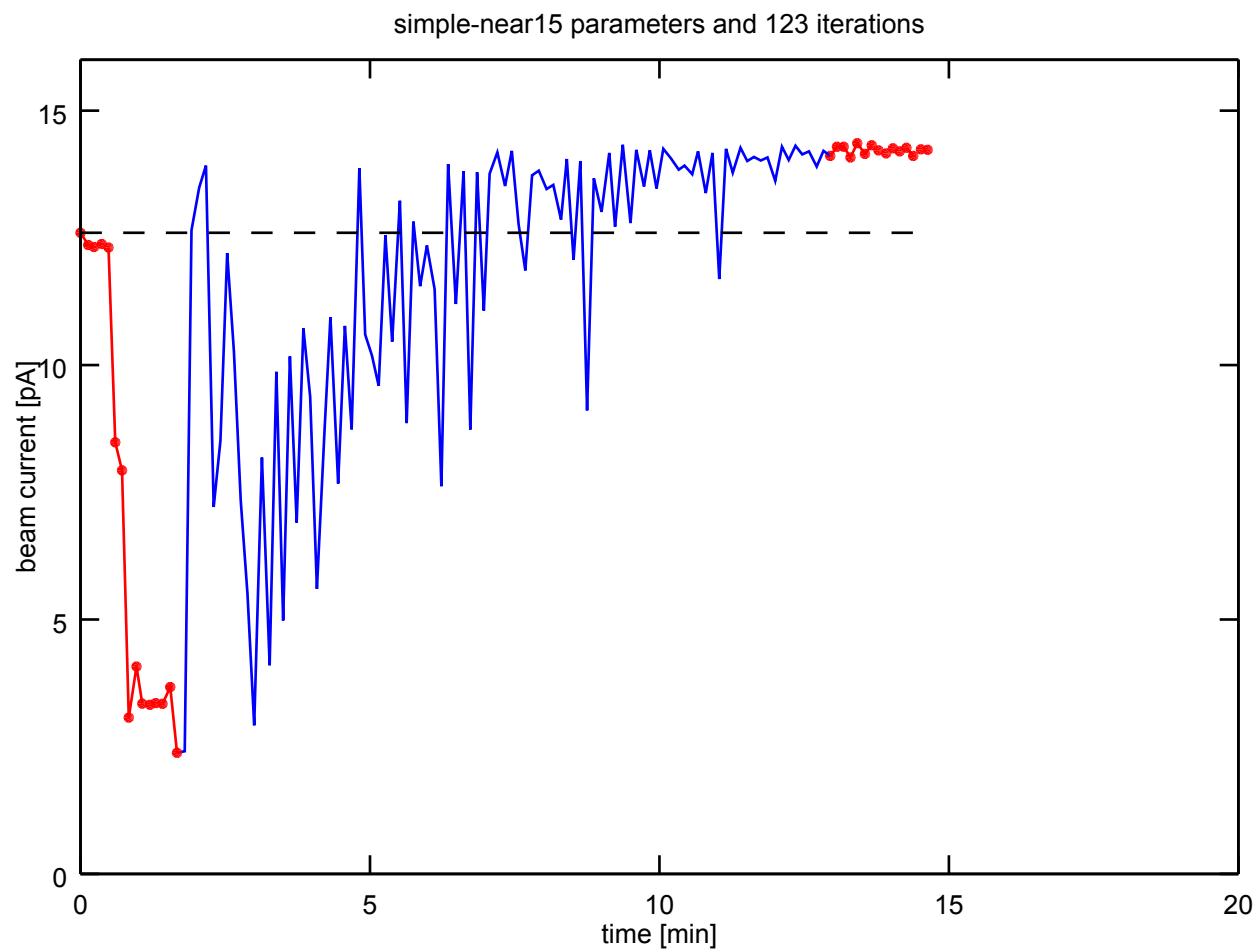
Starting point far from optimum tune  
42x gain in transport



# Results: short beamline

Starting point near to optimum tune

13% gain in transport

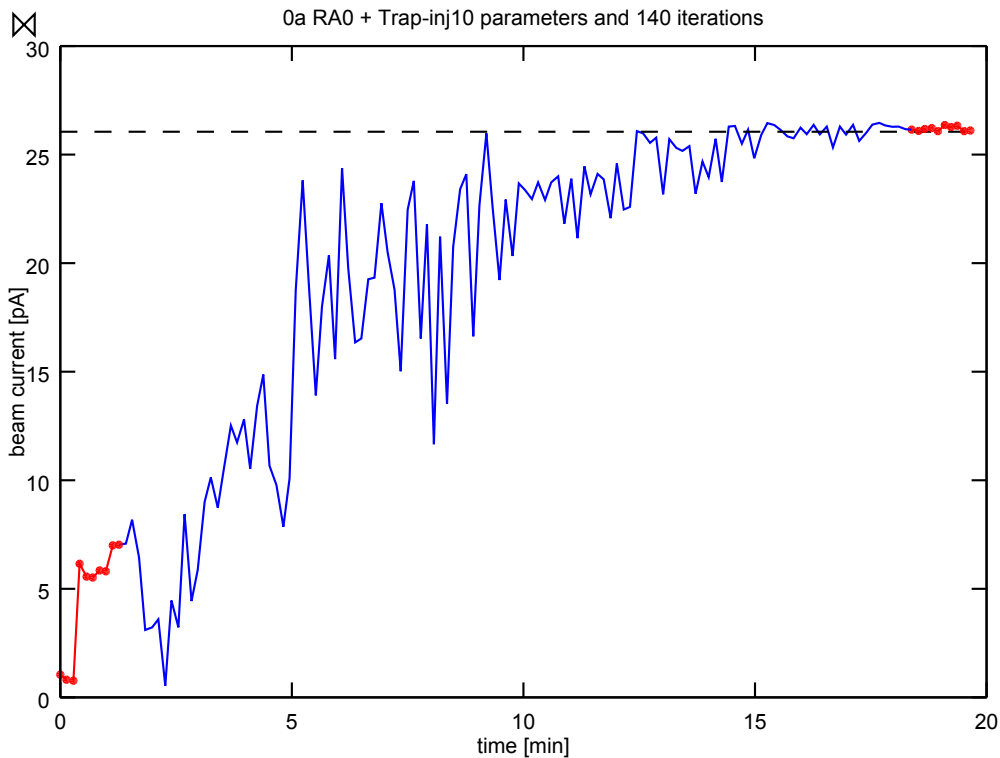
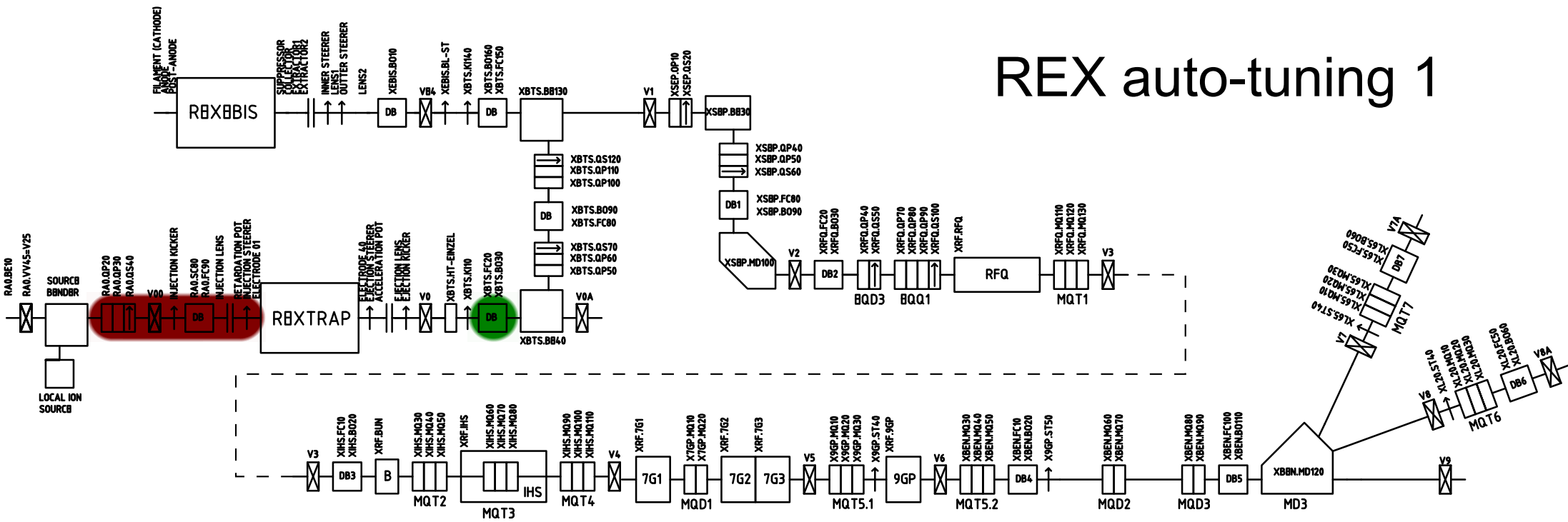




Higher Dimensions



# REX auto-tuning 1



## Trap injection:

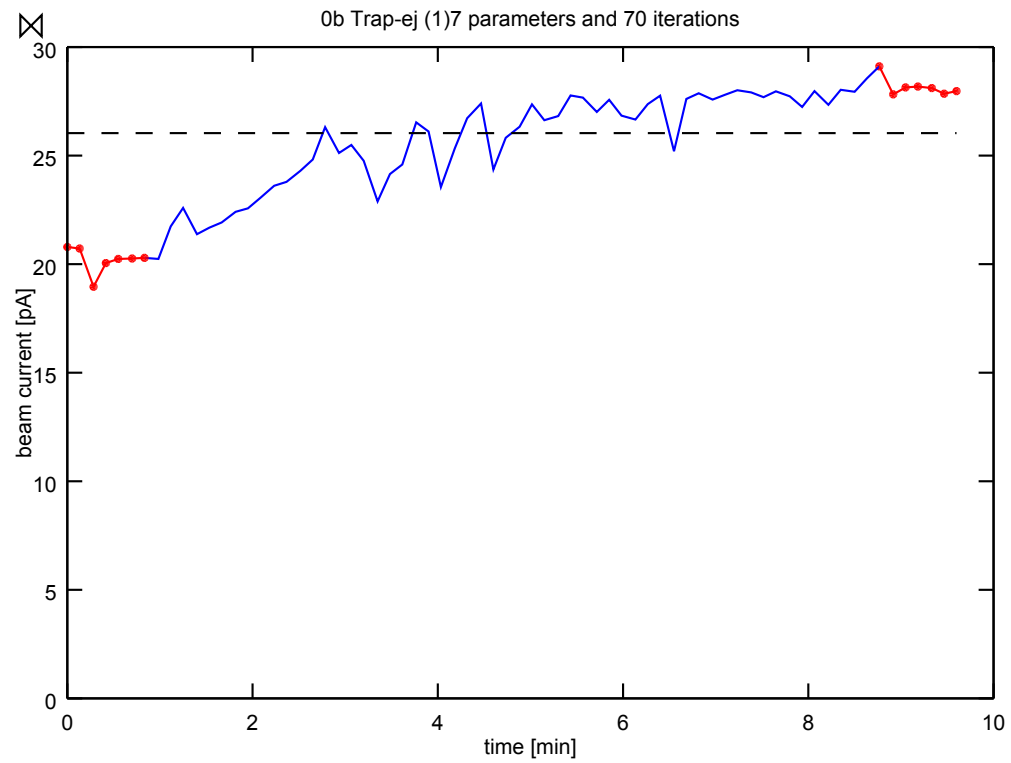
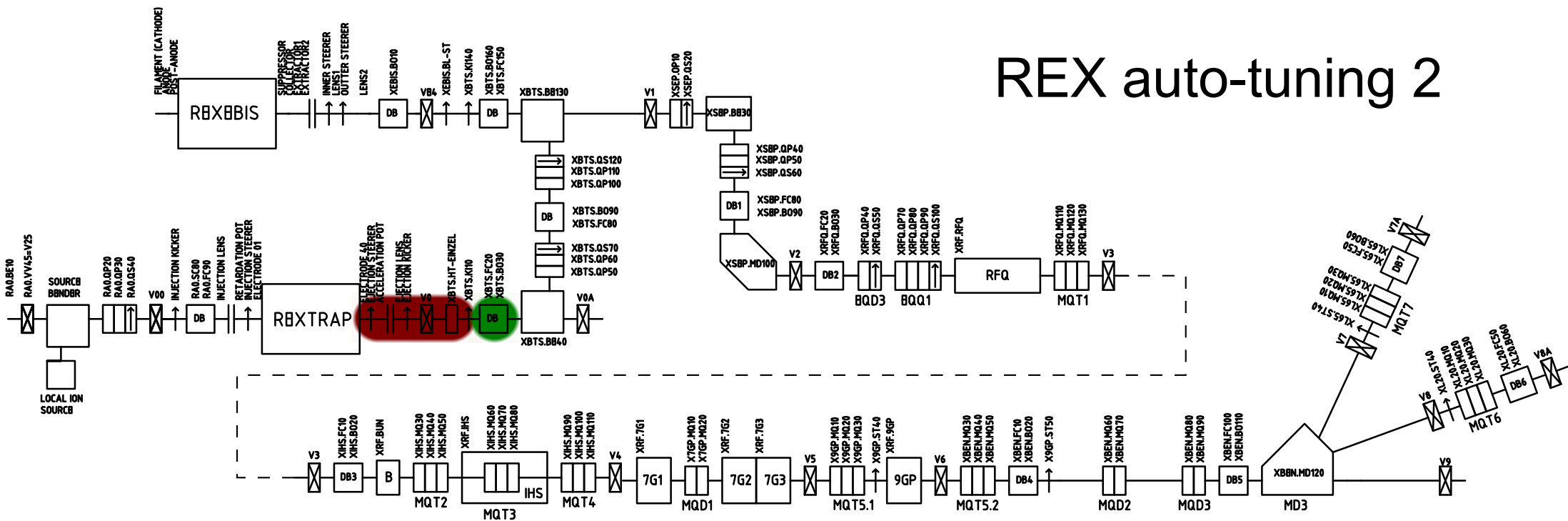
10 parameters

140 iterations

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

Gain +0.2% W.R.T nominal

# REX auto-tuning 2



## Trap ejection (1):

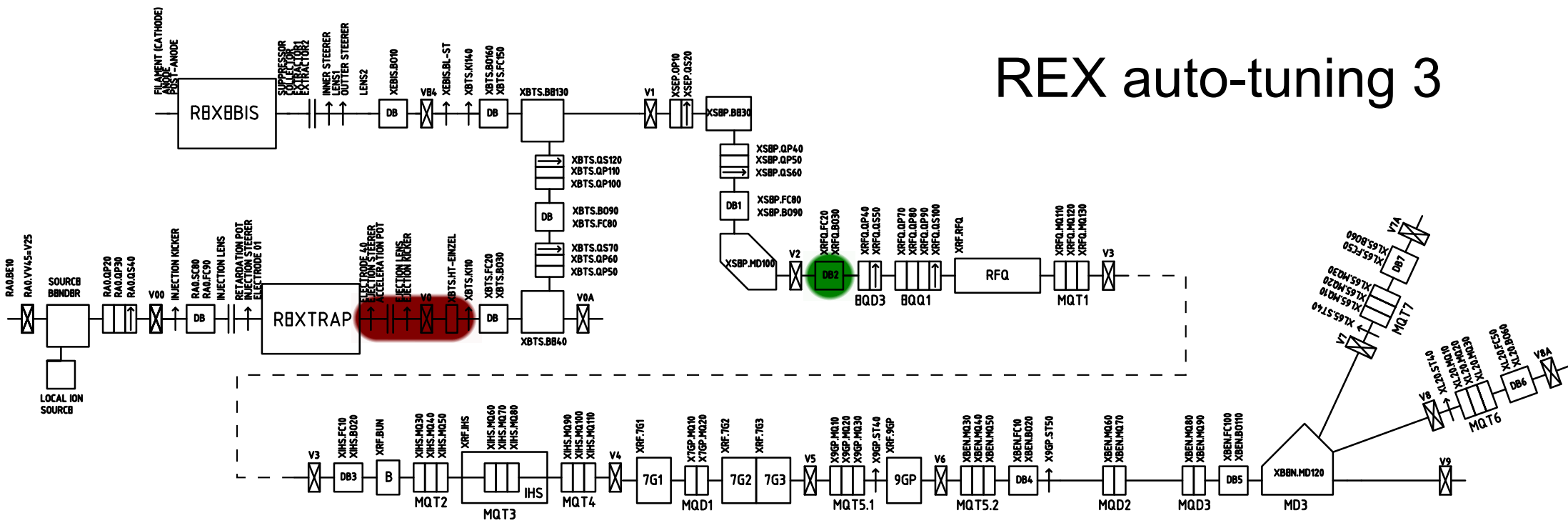
7 parameters

70 iterations

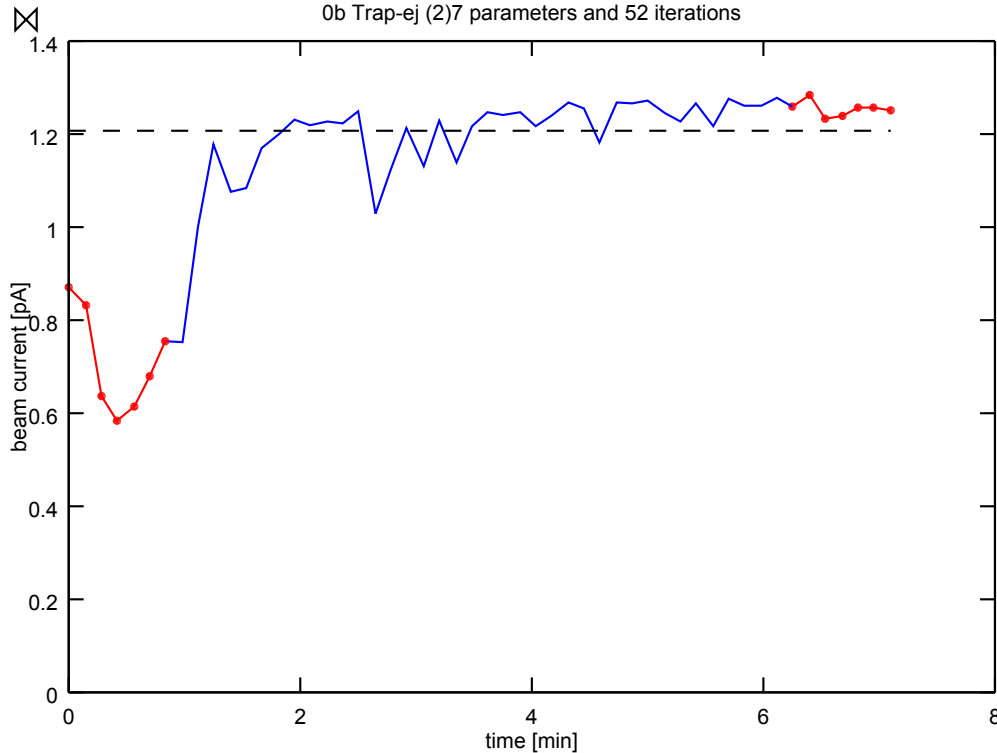
Gain +35% W.R.T de-tuned start

Gain +7.4% W.R.T nominal

# REX auto-tuning 3



Ob Trap-ej (2)7 parameters and 52 iterations



## Trap ejection (2):

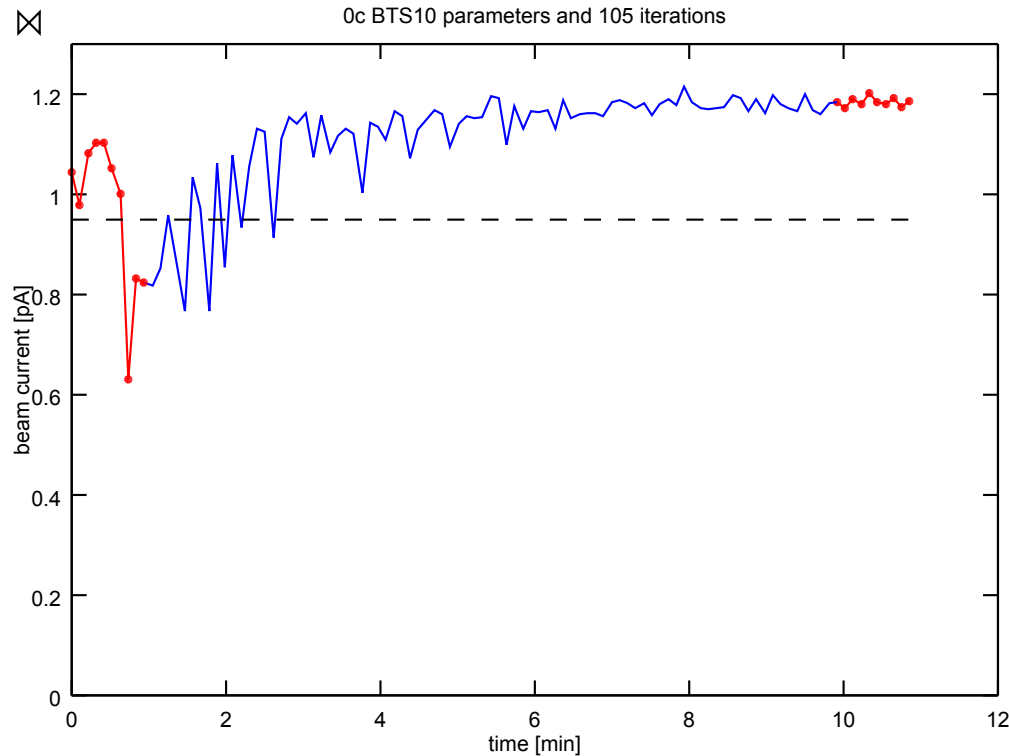
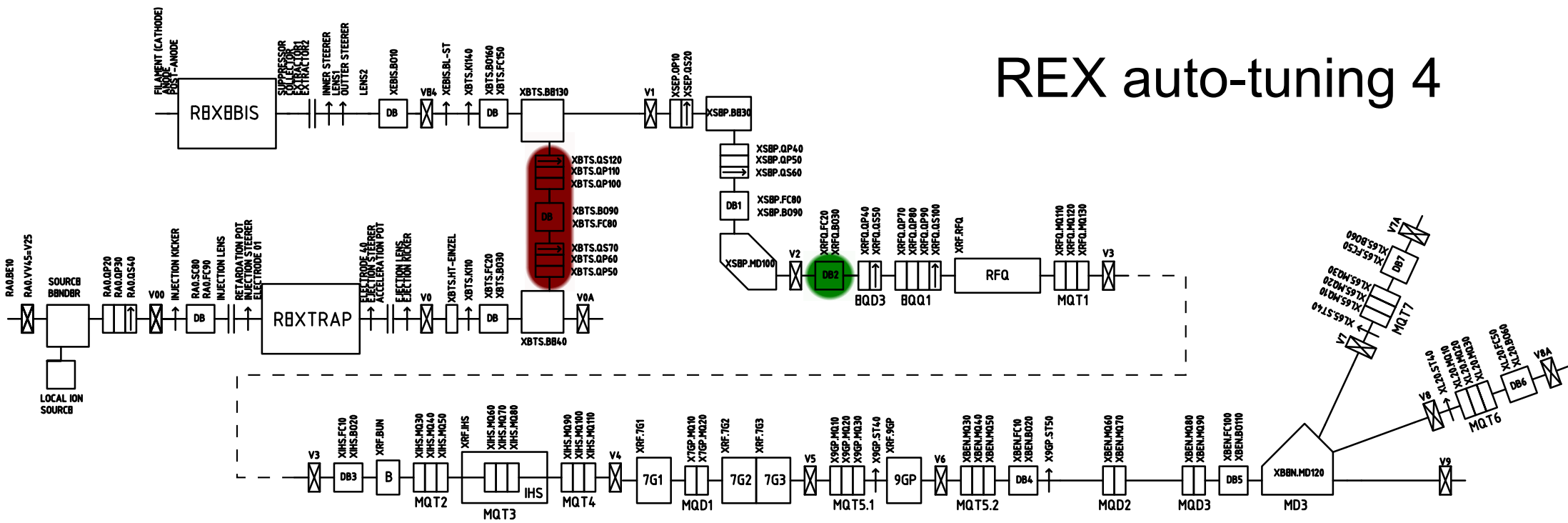
7 parameters

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

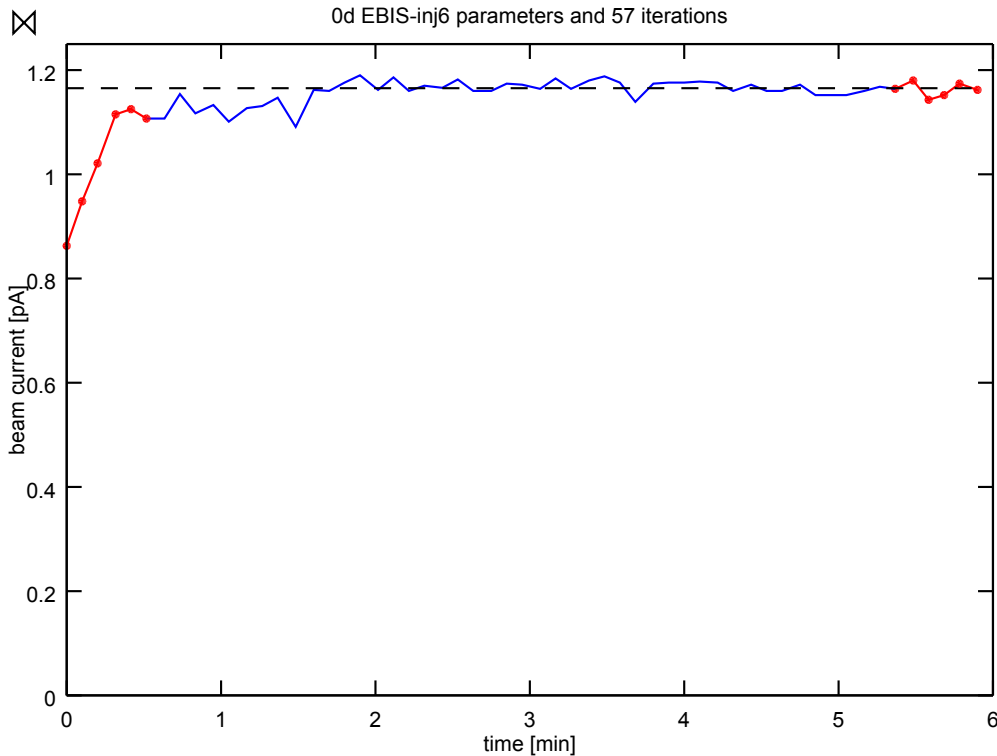
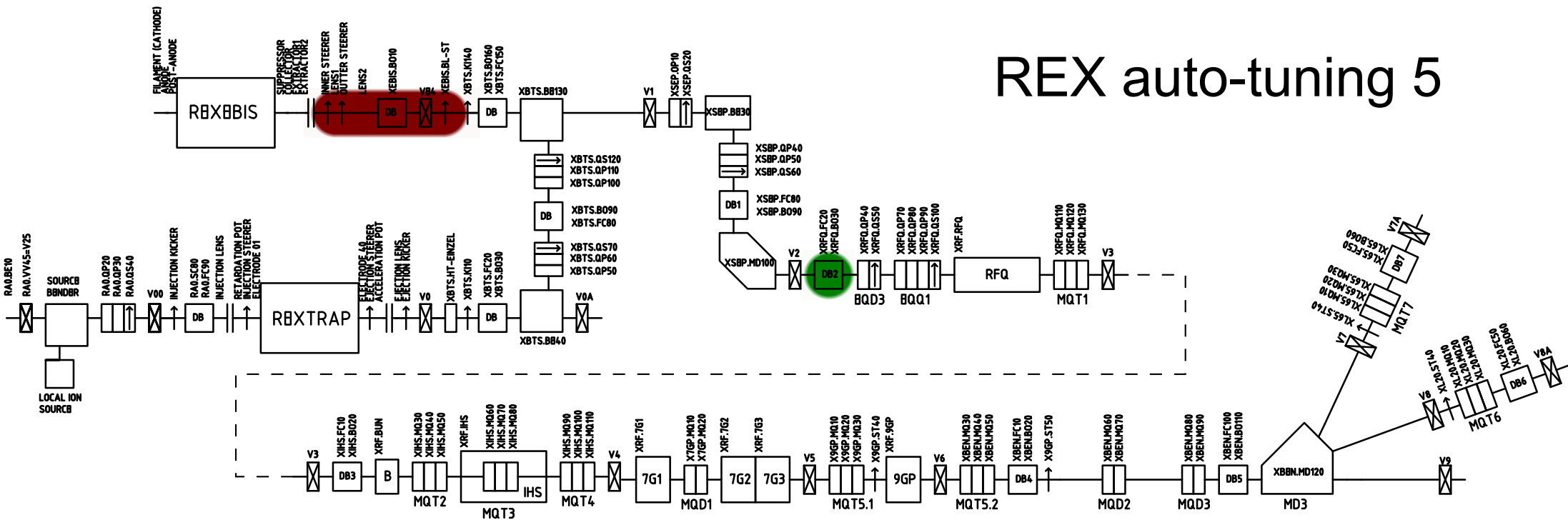
105 iterations

Gain +14% W.R.T de-tuned start

Gain +25% W.R.T nominal



# REX auto-tuning 5



## EBIS injection:

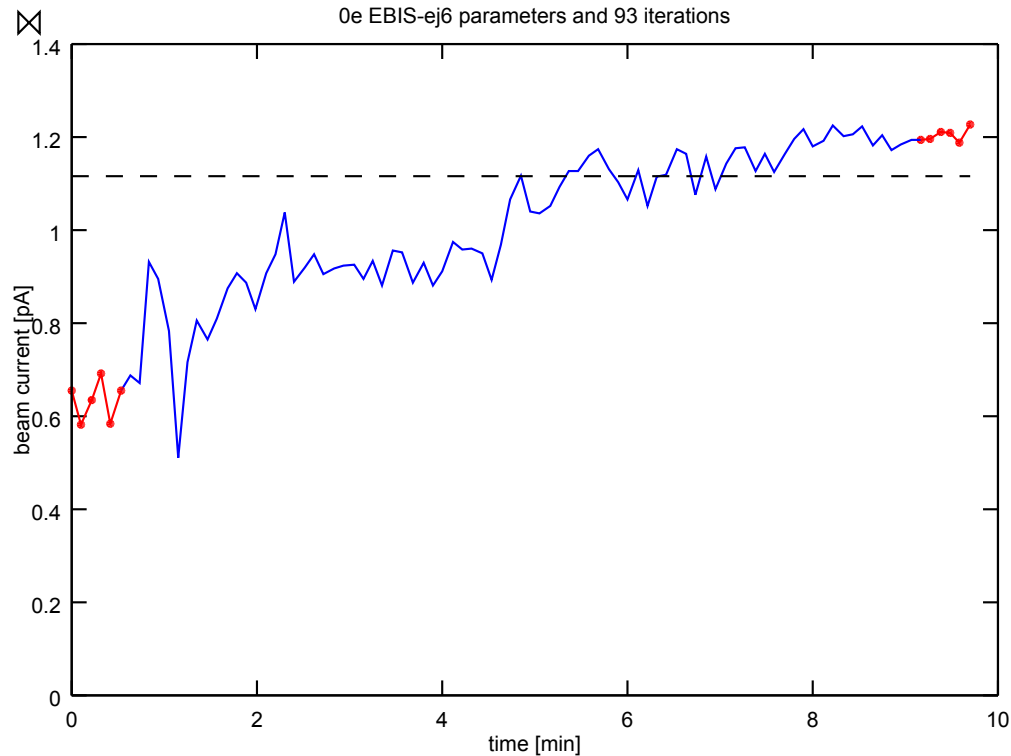
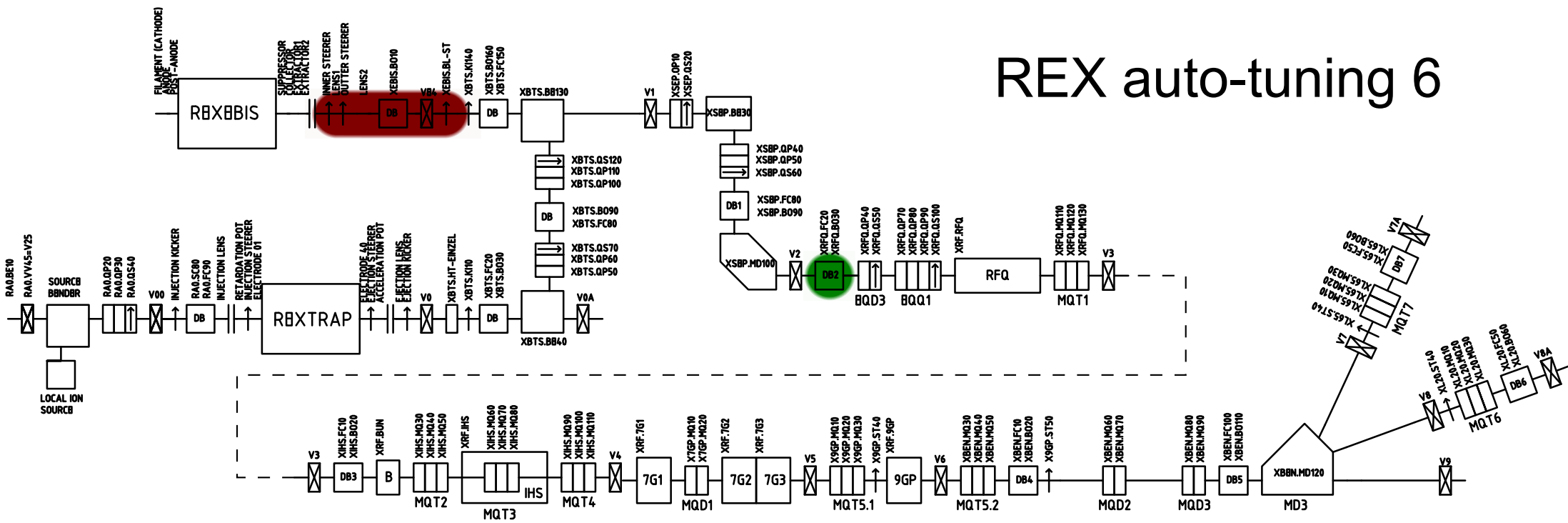
6 parameters

57 iterations

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

Gain -0.3% W.R.T nominal

# REX auto-tuning 6



## EBIS ejection:

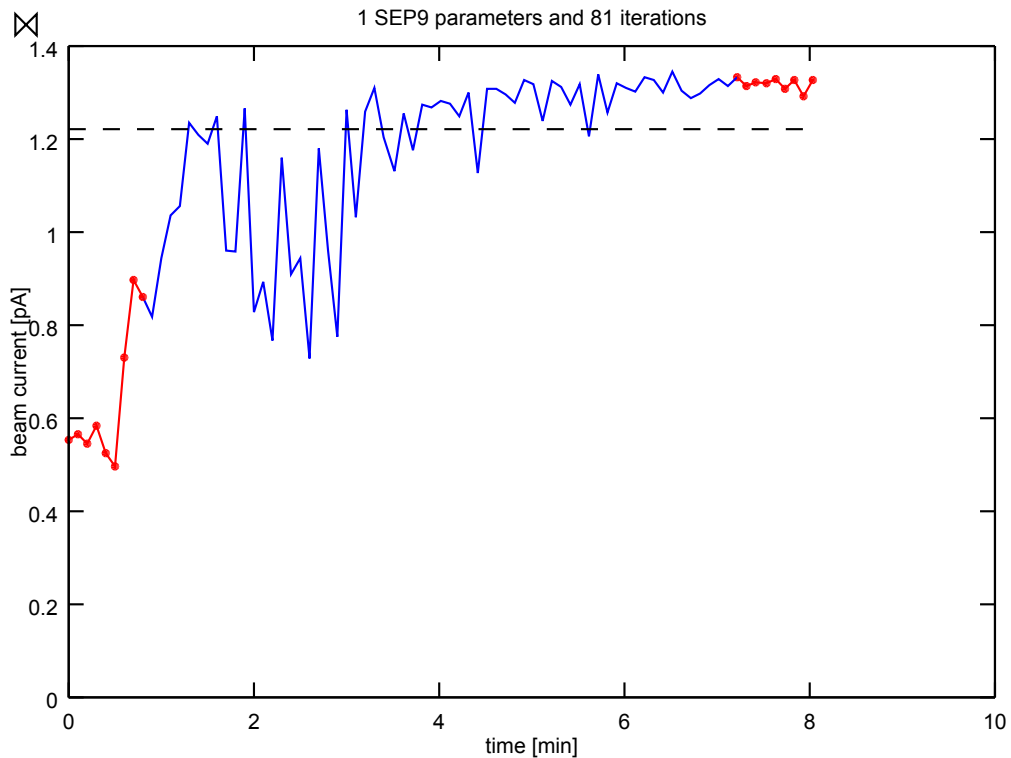
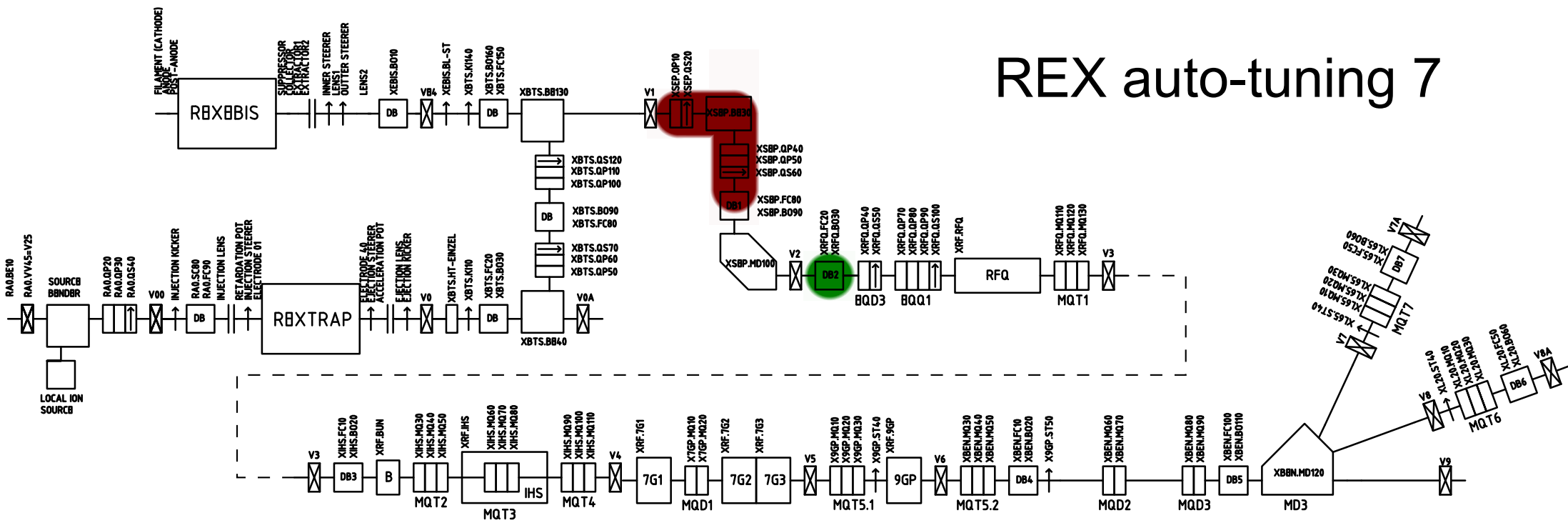
6 parameters

93 iterations

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

Gain +10% W.R.T nominal

# REX auto-tuning 7



## Separator Section:

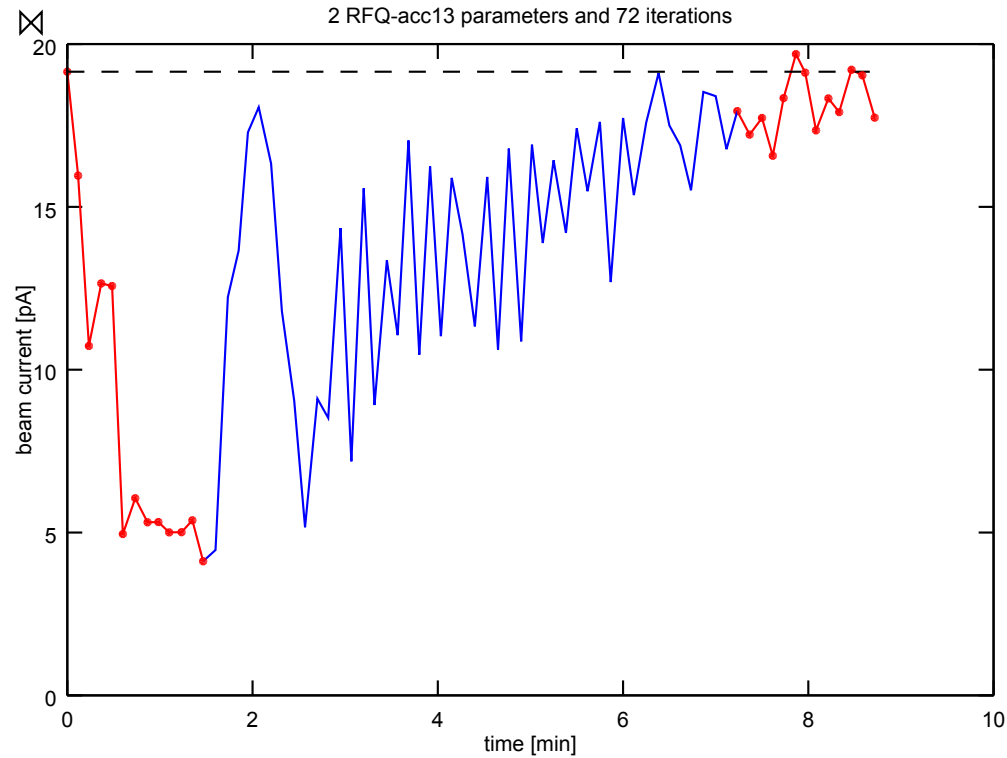
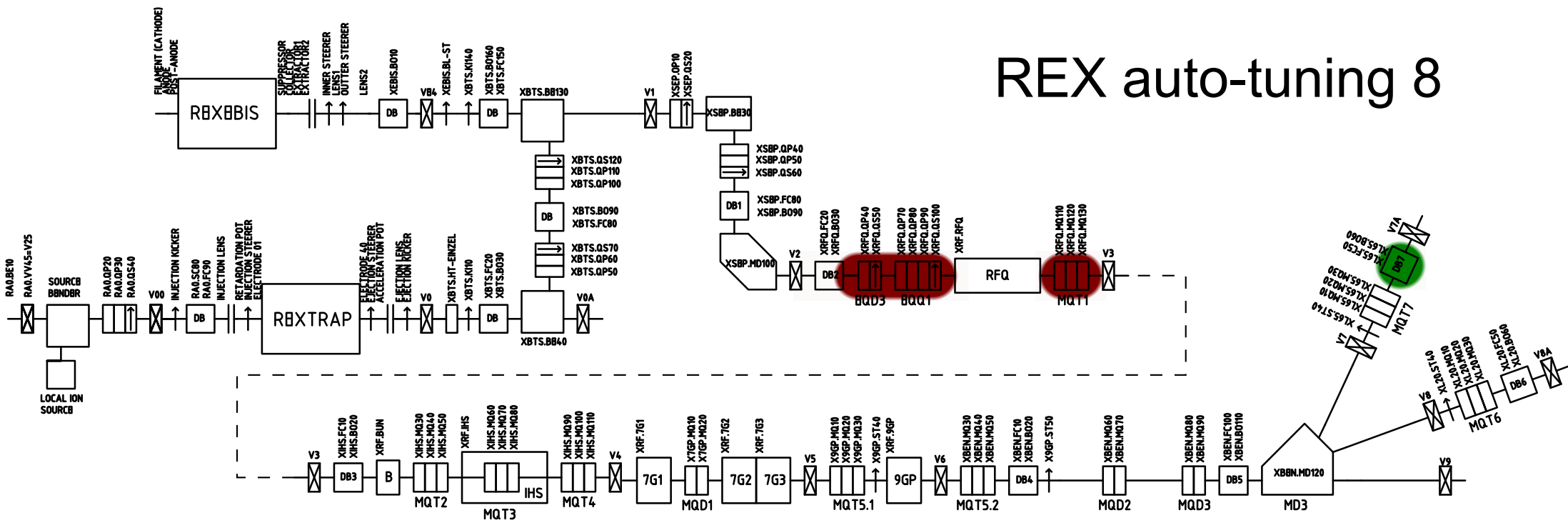
9 parameters

81 iterations

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

Gain +8.7% W.R.T nominal

# REX auto-tuning 8



**RFQ:**

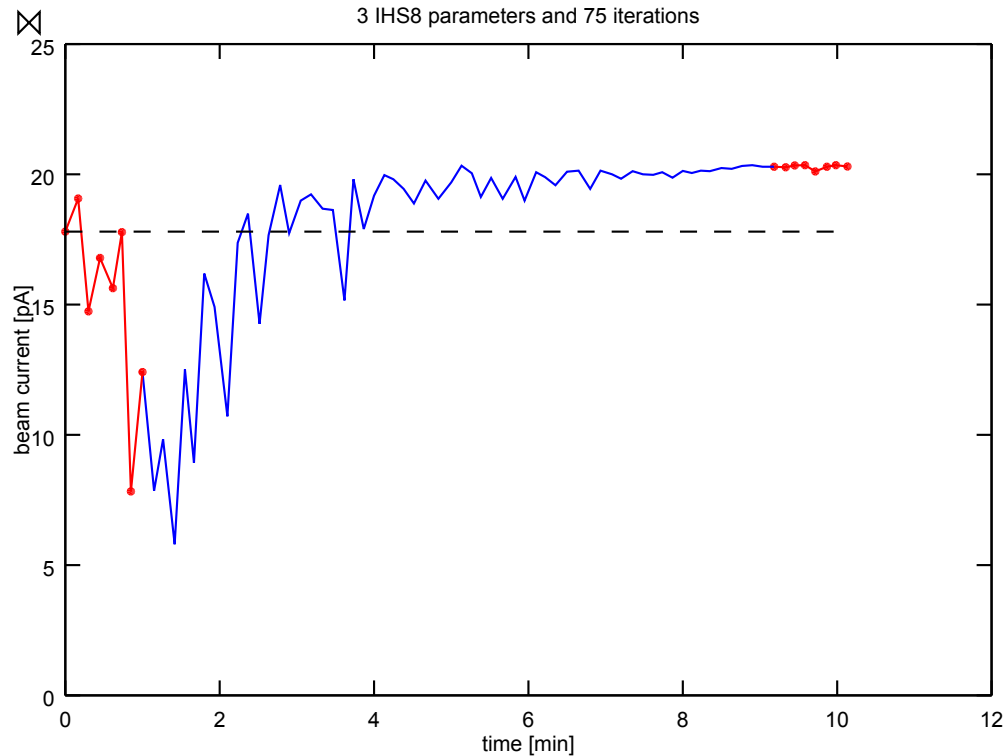
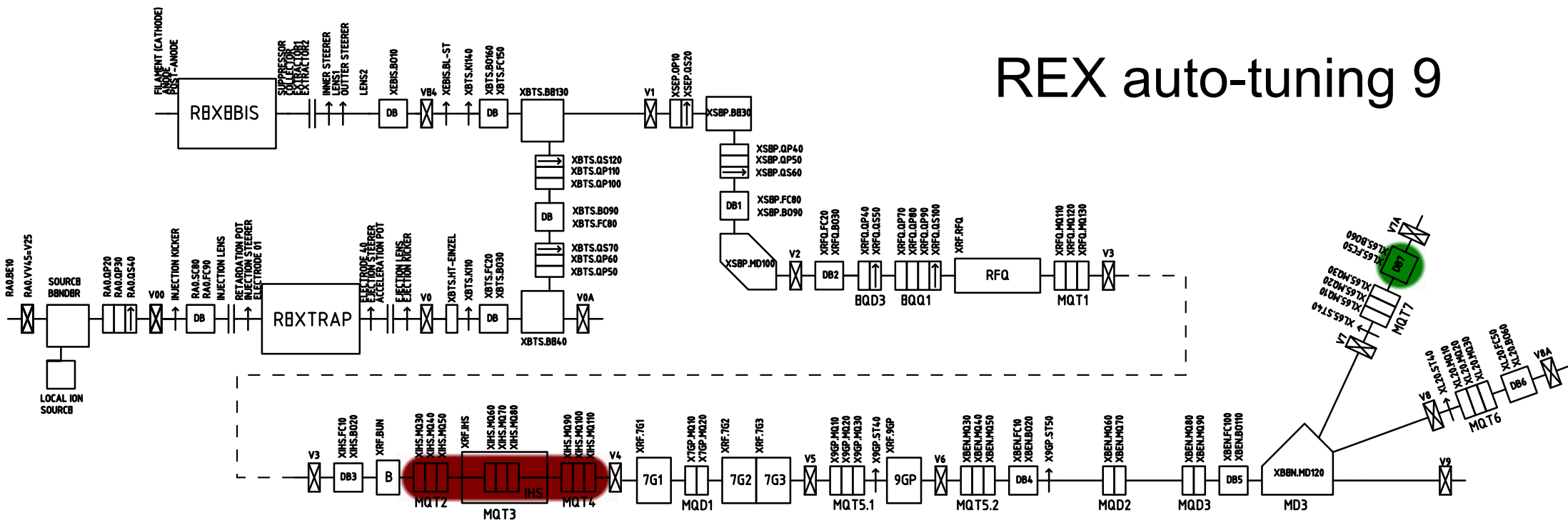
13 parameters

72 iterations

Gain -7% W.R.T nominal



# REX auto-tuning 9



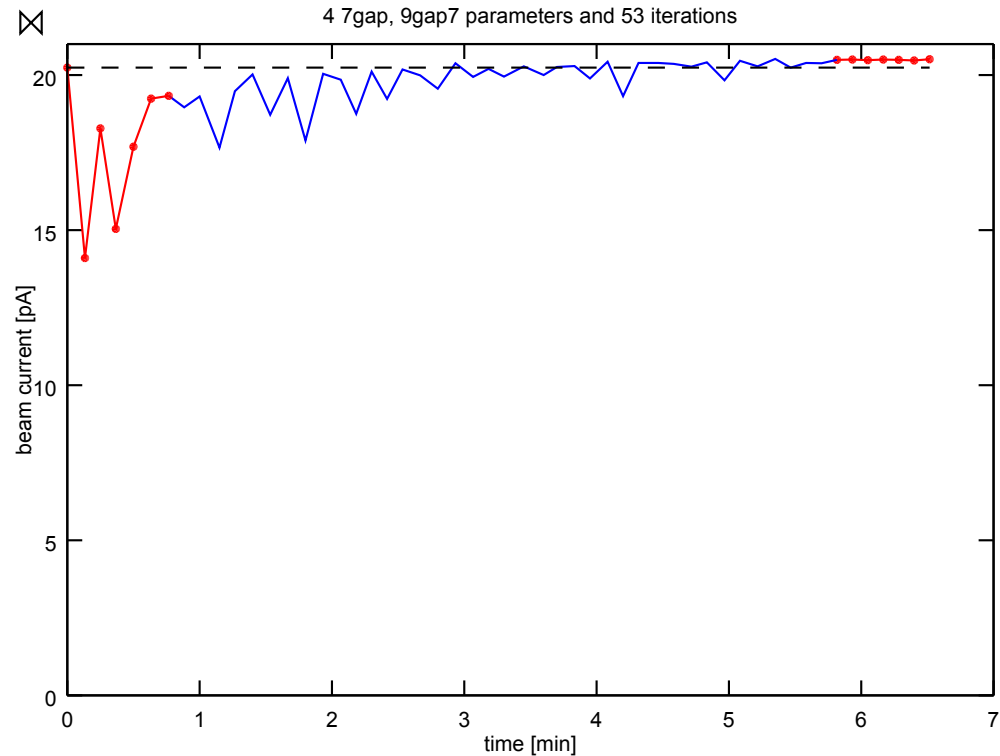
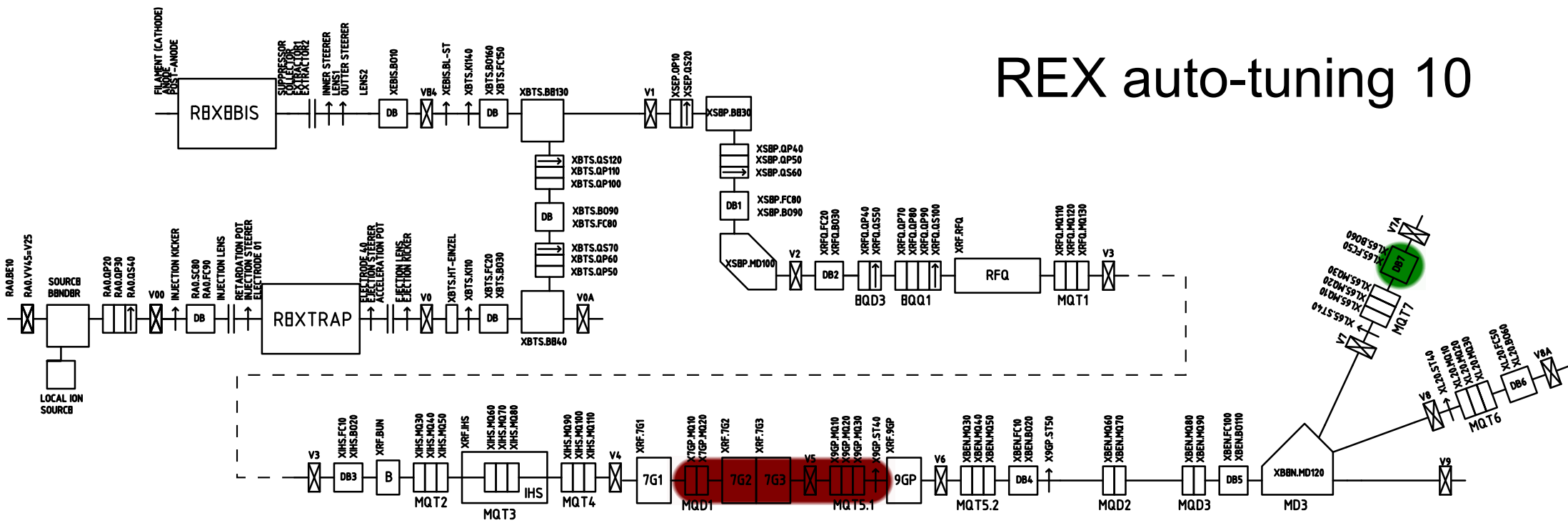
**"IH" section:**

8 parameters

75 iterations

Gain +14% W.R.T nominal

# REX auto-tuning 10



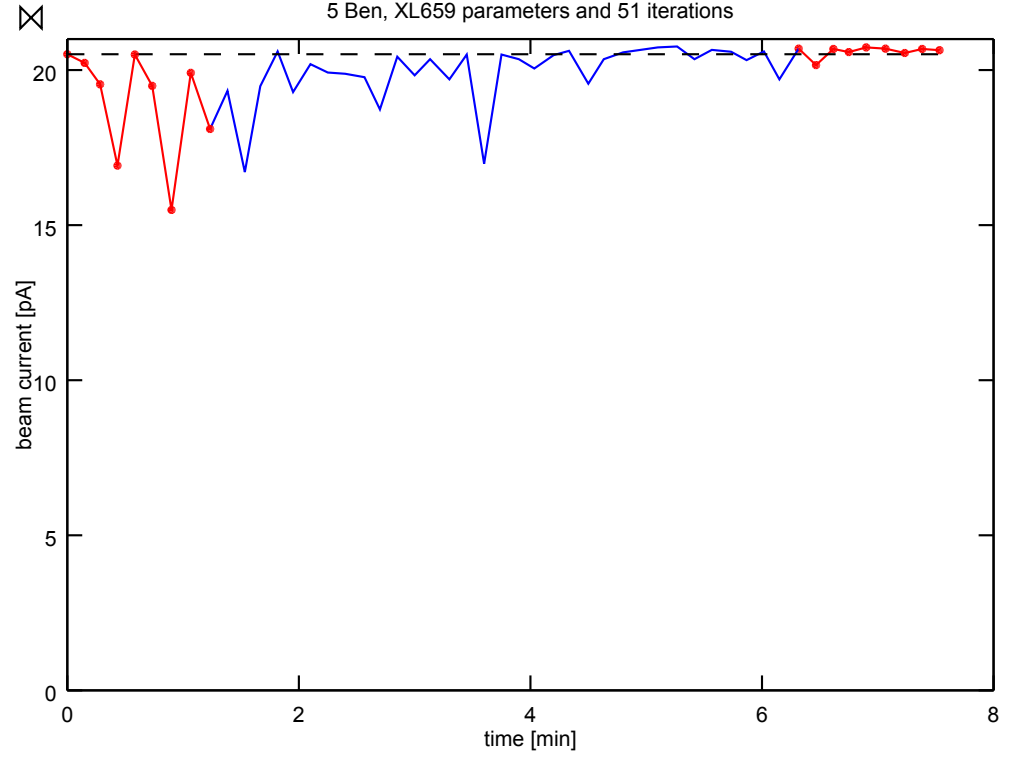
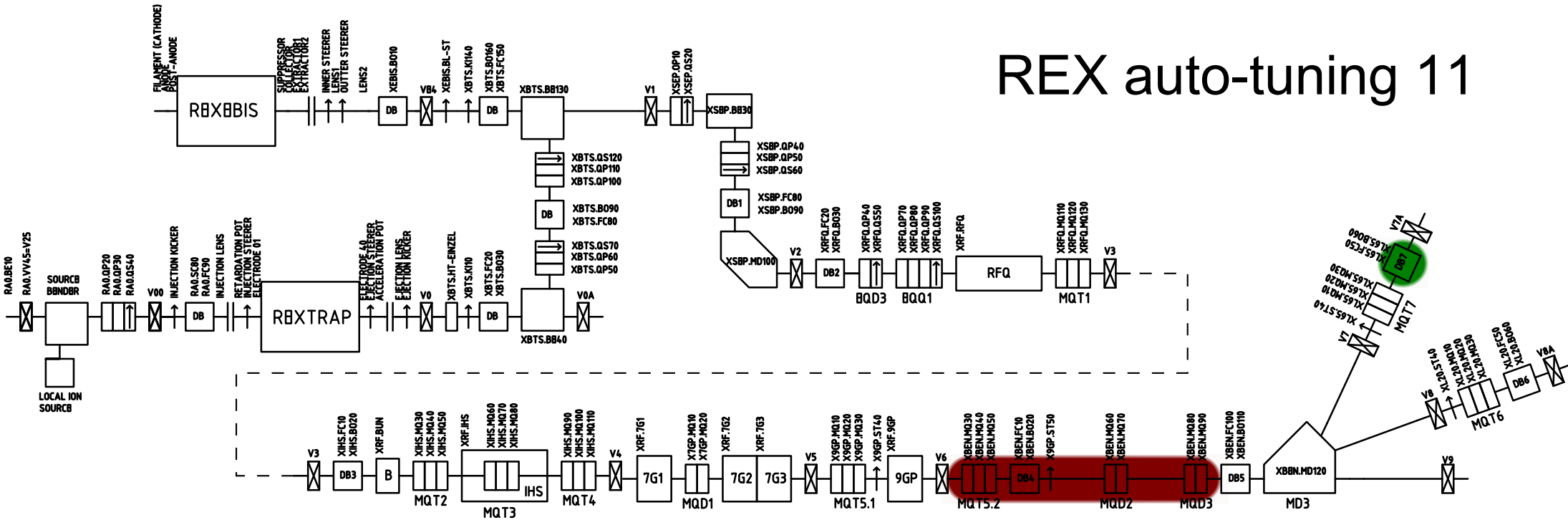
**"7-gap" and 9-gap sections:**

7 parameters

53 iterations

Gain +1.3% W.R.T nominal

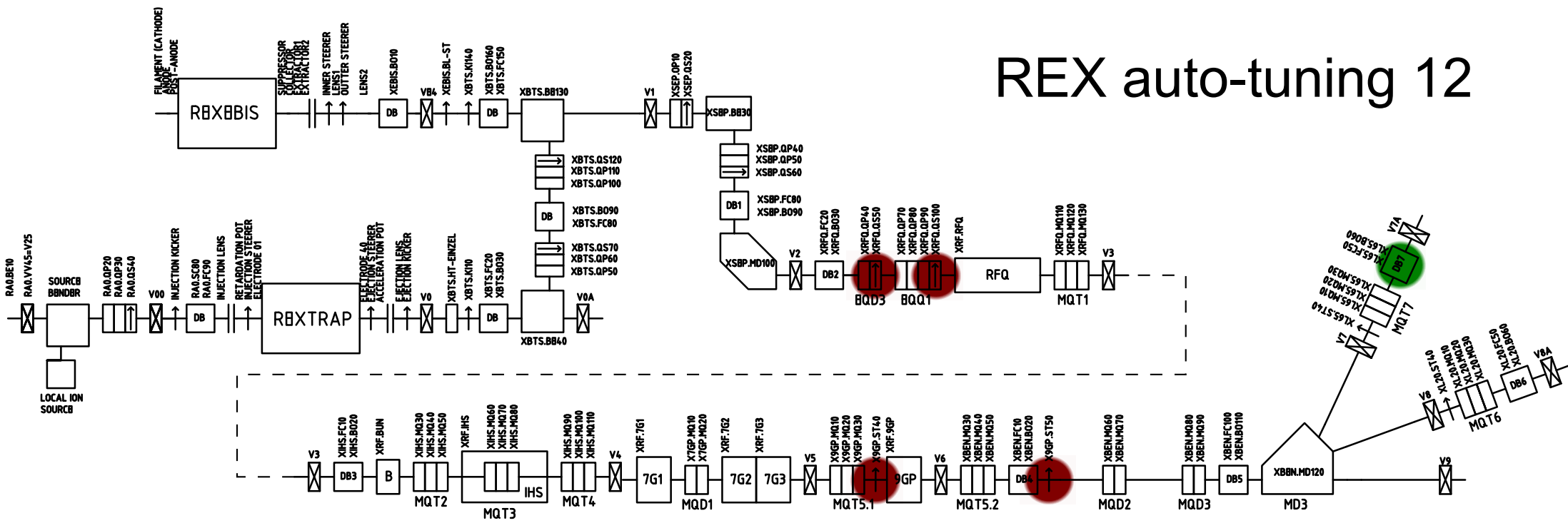
# REX auto-tuning 11



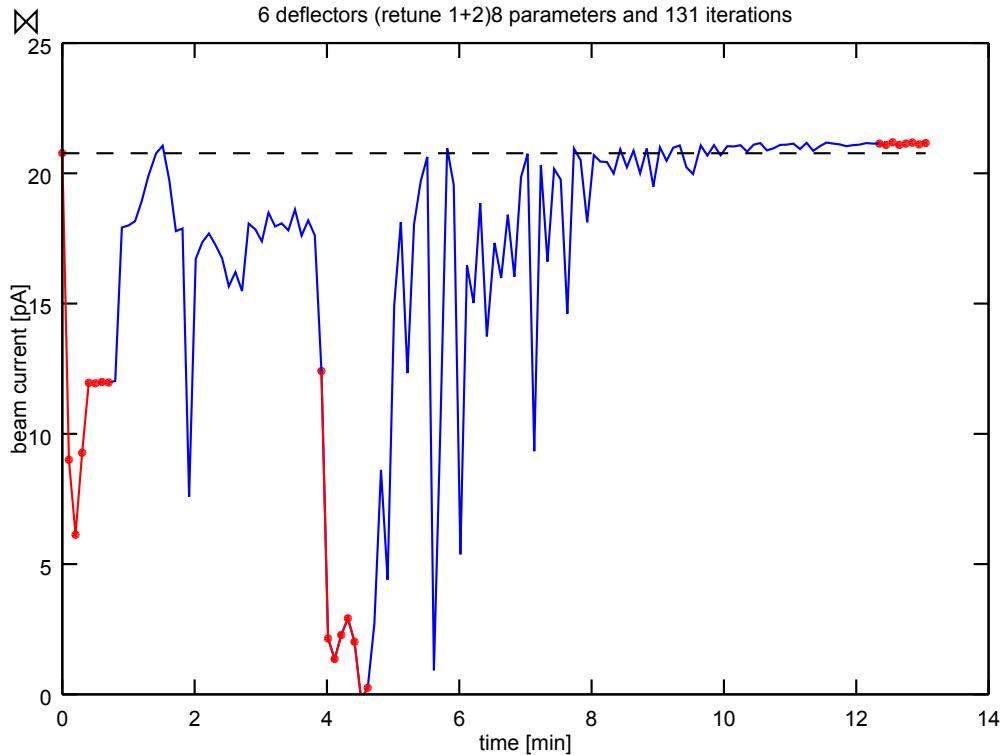
**"7-gap" and 9-gap sections:**

- 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



The background of the slide features a close-up, slightly blurred view of the complex, metallic components of a particle accelerator, showing various pipes, flanges, and structural elements.

# 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)

A close-up photograph of a metal mesh structure, likely a filter or a component of a machine. The mesh consists of circular openings arranged in a grid, with radial spokes extending from the center of each opening to the outer edge. The metal has a dark, slightly reflective finish. The word "Development" is overlaid in the center in a white, sans-serif font.

Development

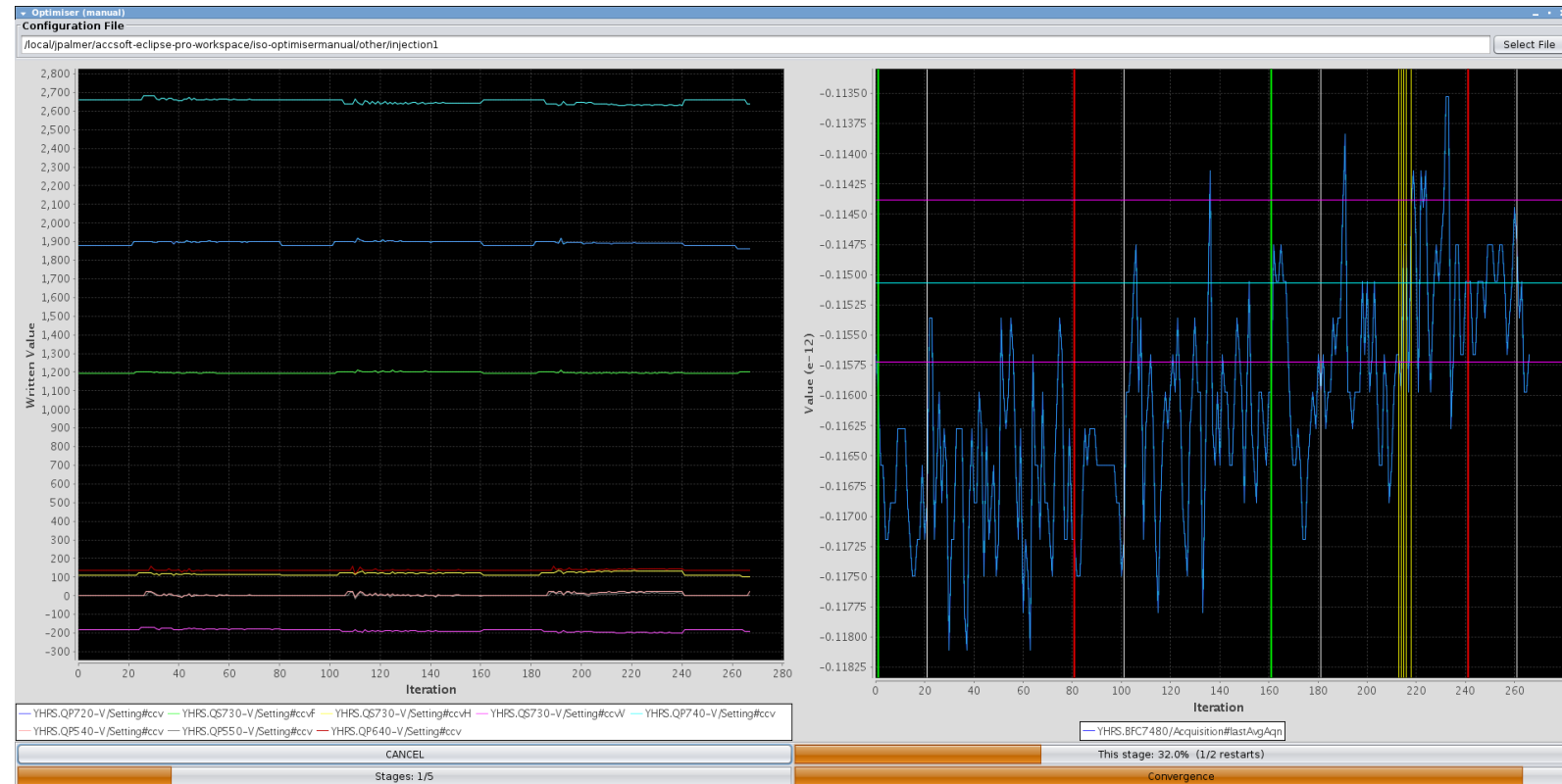
# Development

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

Intelligent restarts if convergence fails

Rigorous comparison with human operators

Reliability testing





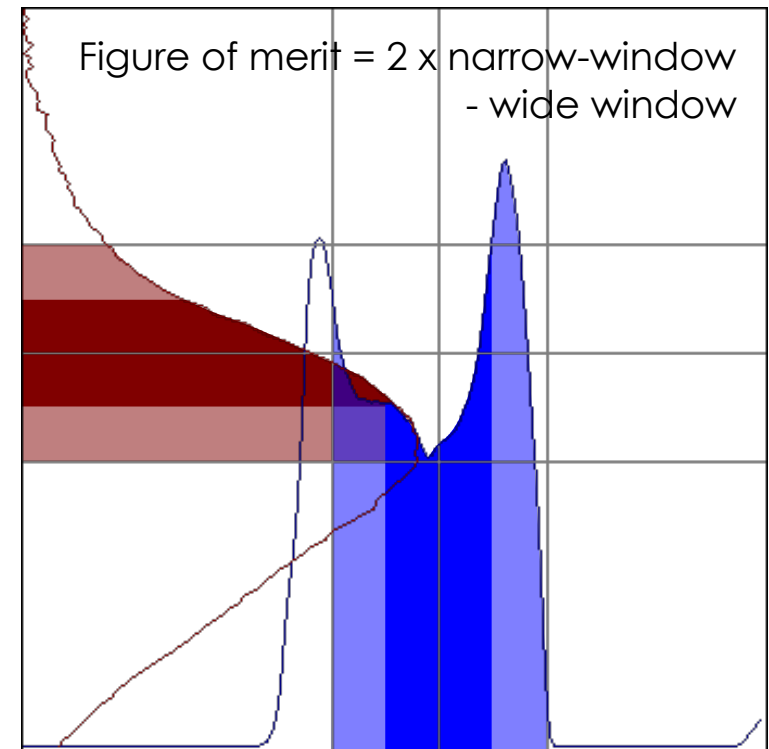
# Development

A user-friendly sequencer

Pre-scripted tuning sequences for major beamlines

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

SOURCE	DESTINATION
GPS	Tapestation
HRS	LA1
	LA2
	RA0
	COLLAPS
	CRIS
	etc...
Tune separator	
Tune beamline	



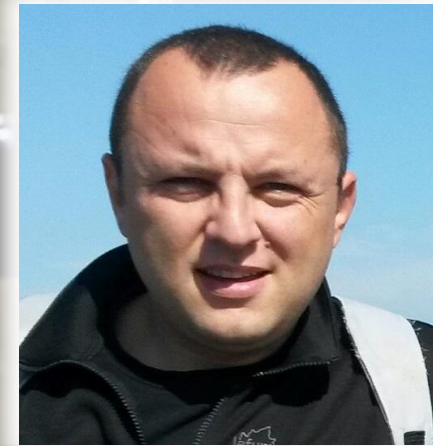
Auto-tuning can save physics time

Improved use of skilled personnel

-- thanks to --



Jake Palmer



Emiliano Piselli