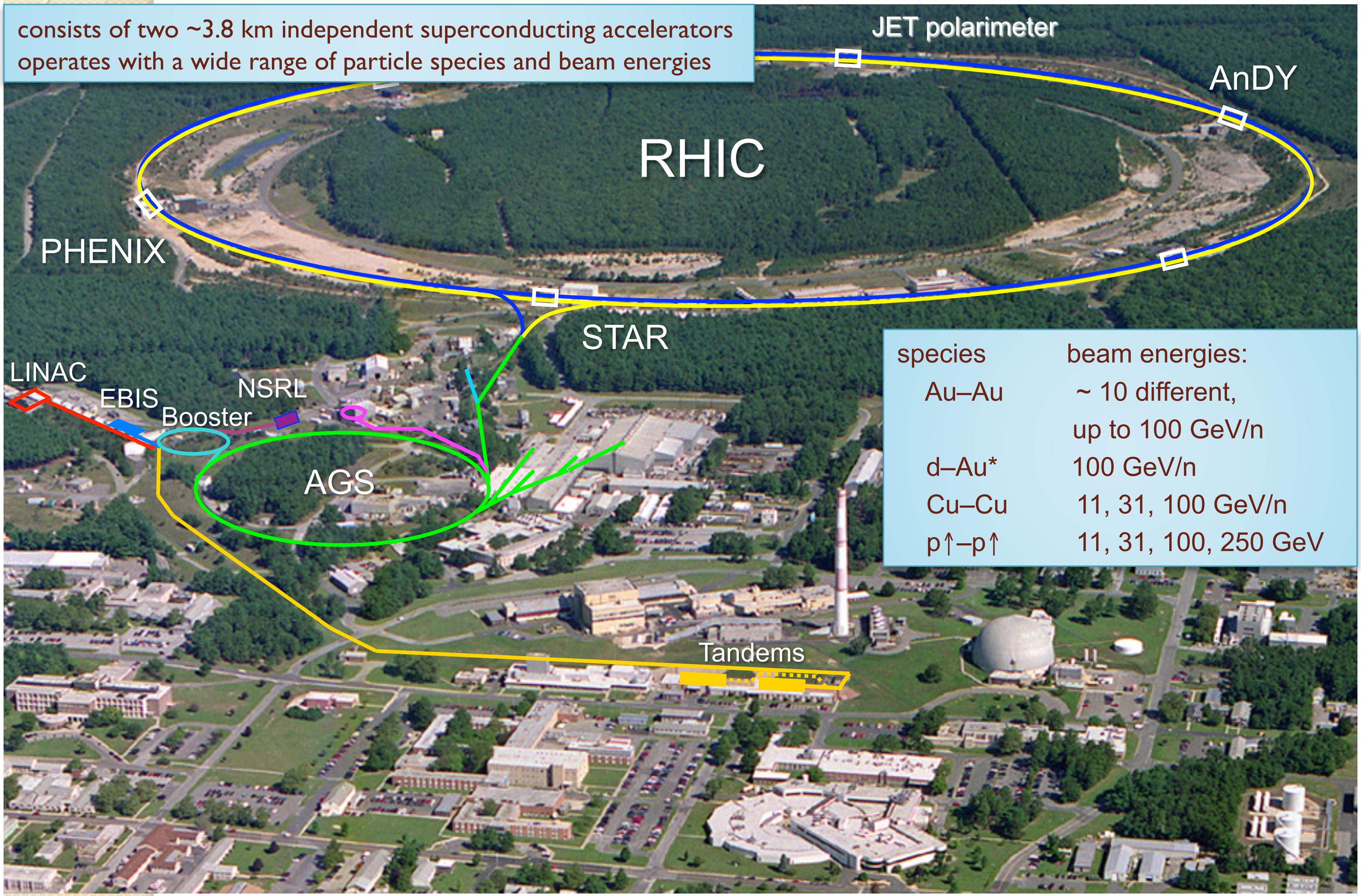
RHIC online modeling and experience with feedbacks

G. Robert-Demolaize, A. Marusic, M. Minty

OUTLINE

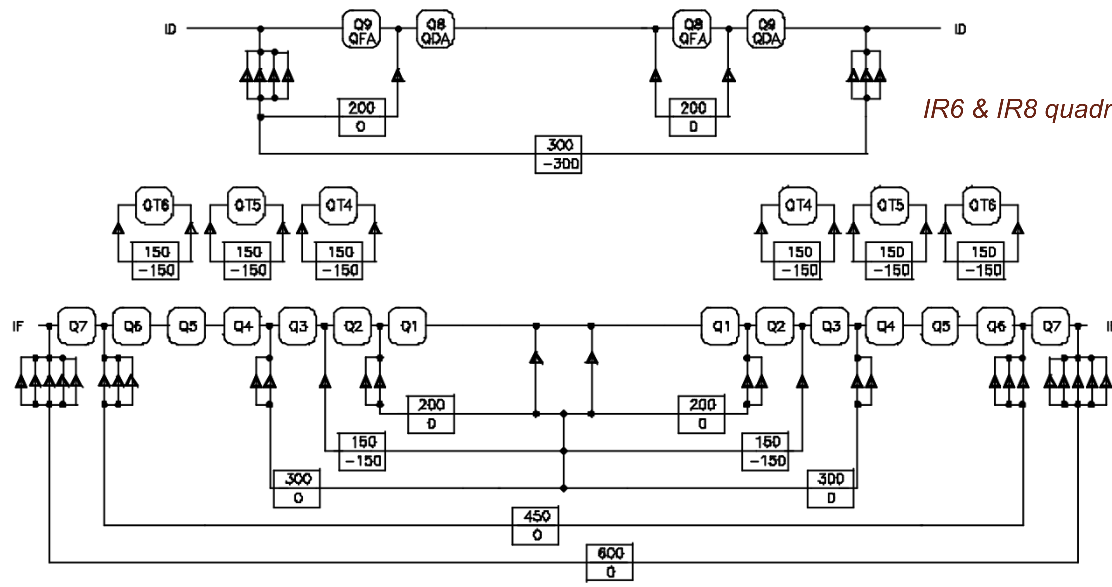
consists of two ~3.8 km independent superconducting accelerators
operates with a wide range of particle species and beam energies



species	beam energies:
Au–Au	~ 10 different, up to 100 GeV/n
d–Au*	100 GeV/n
Cu–Cu	11, 31, 100 GeV/n
p↑–p↑	11, 31, 100, 250 GeV

- RHIC lattice originally designed in MAD-8/MAD-X environment, created as a line of thick-lens elements. Each ring (Blue and Yellow) has its own lattice file.

- A separate strength file for each ring is generated by taking into account the IR quadrupole wiring scheme:



IR6 & IR8 quadrupole wiring scheme

=> the common parameter is the power supply current: need transfer functions to obtain the gradient K_i for each quadrupole.

- Specific macros are used for each IR to rematch the local β^* to its target value. Each macro is then ran iteratively to create a database of IR settings for each desired β^* and working point.

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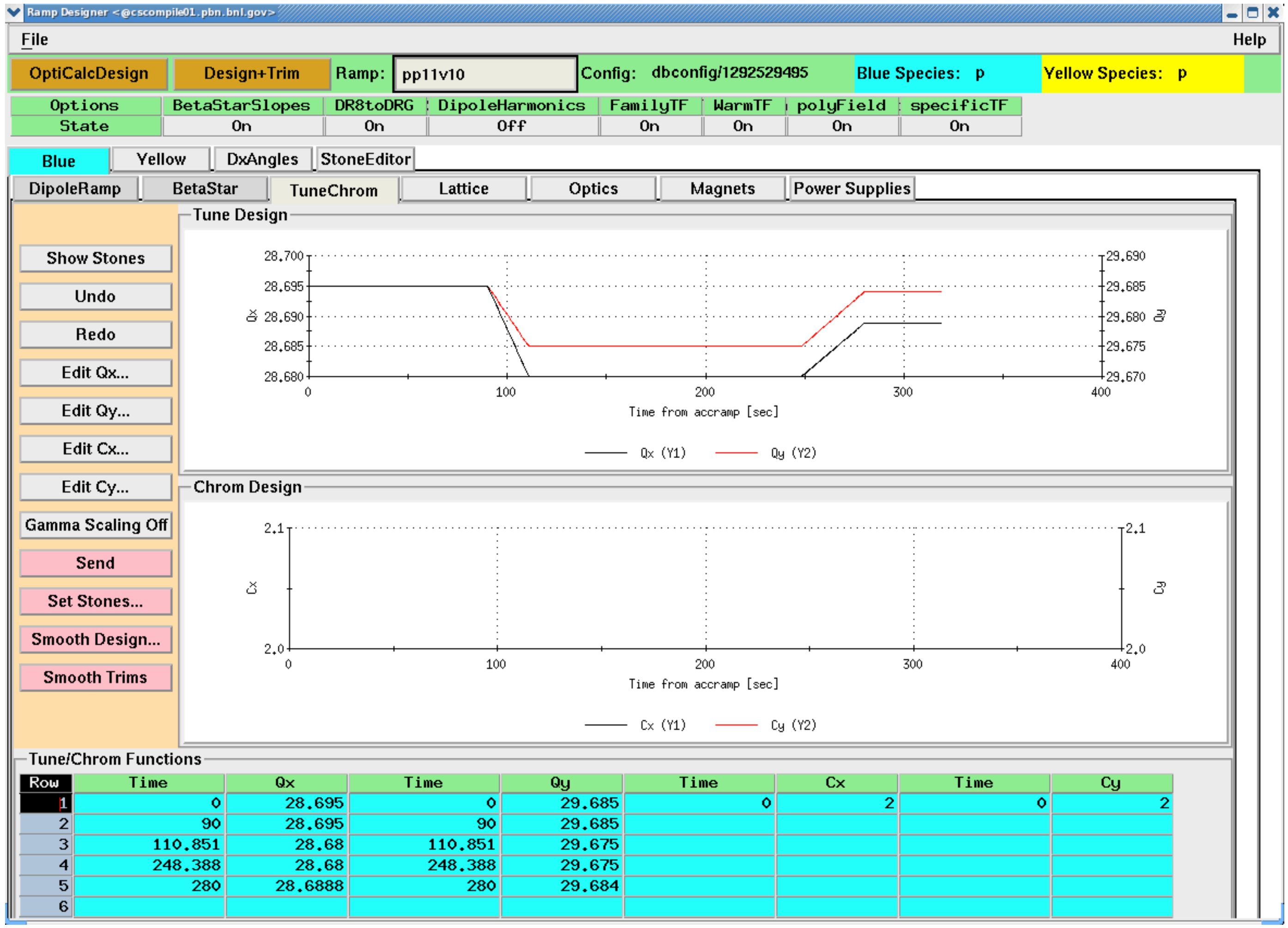
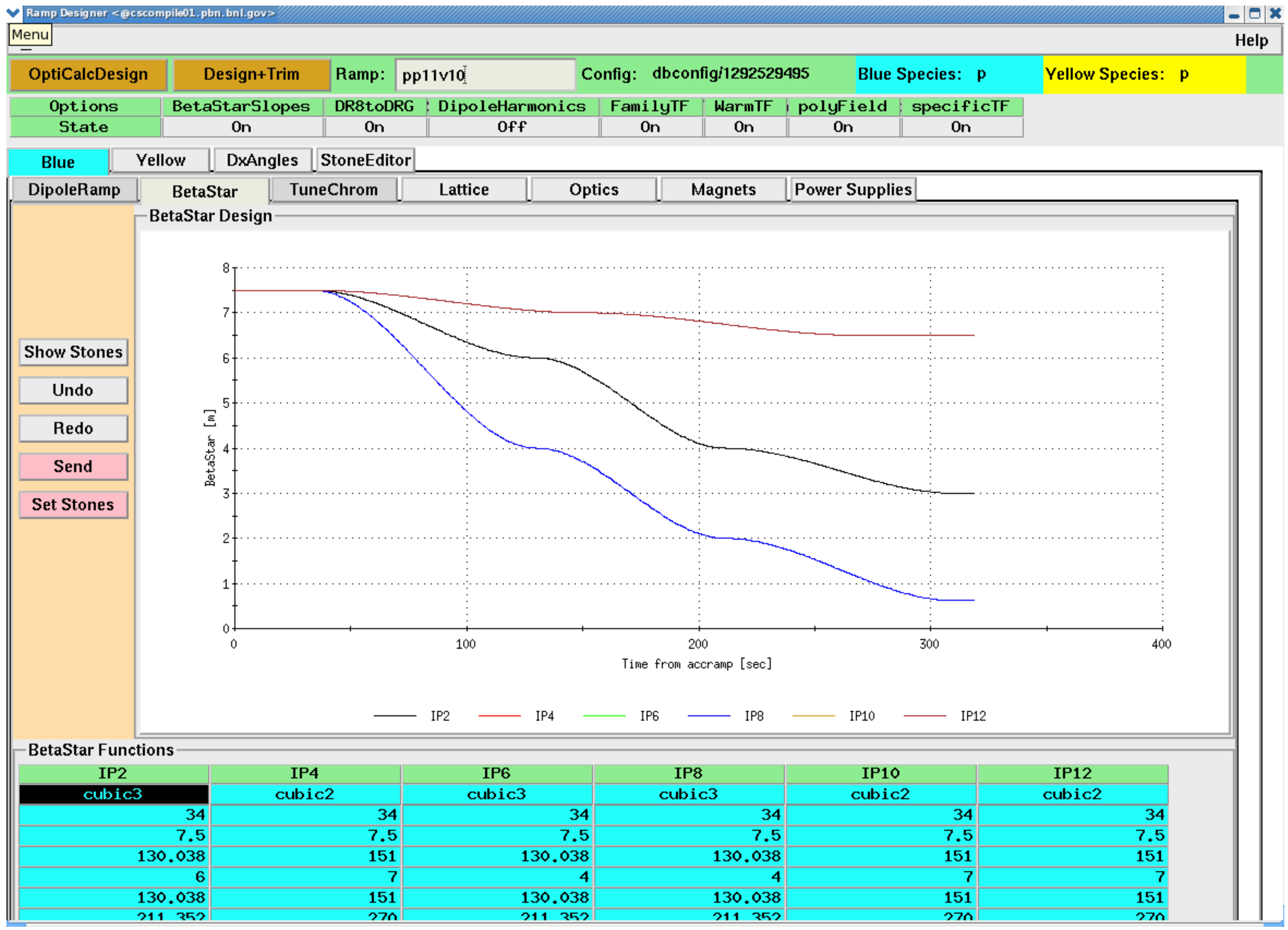


- RampDesigner is the software used to complement the MAD model in creating the energy ramp for each Run.



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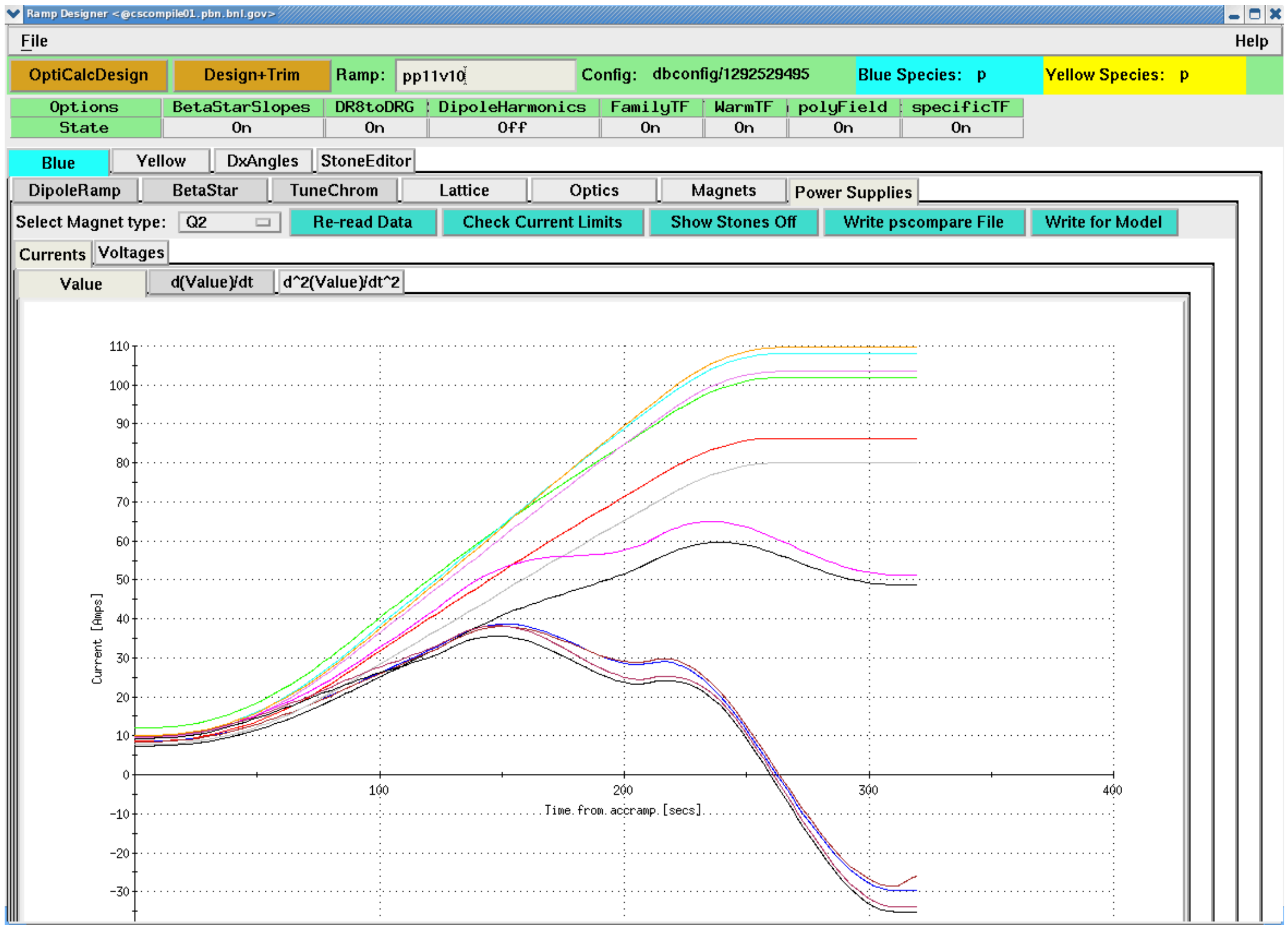

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- RHIC energy ramps are based on StepStones, i.e. checkpoint along the ramp in magnet currents: this allows for smooth β^* squeeze and/or tune swings (if needed).

- To operate with RampDesigner, one needs a computation server: RampManager.

- RampManager loads the StepStone input files and the database of measured magnetic transfer functions to always ensure the conversion between magnet current and magnet gradient; the sorting into magnet families is also done on this server.

- In addition to RampManager, there is a 2nd server dedicated to optics calculations and tune/chromaticity matching: OptiCalc, made of two separate engines:
  - lattice optics, based on one-turn map eigenvectors and eigenvalues calculations;
  - tune and chromaticity corrections, based on a measured response matrix.

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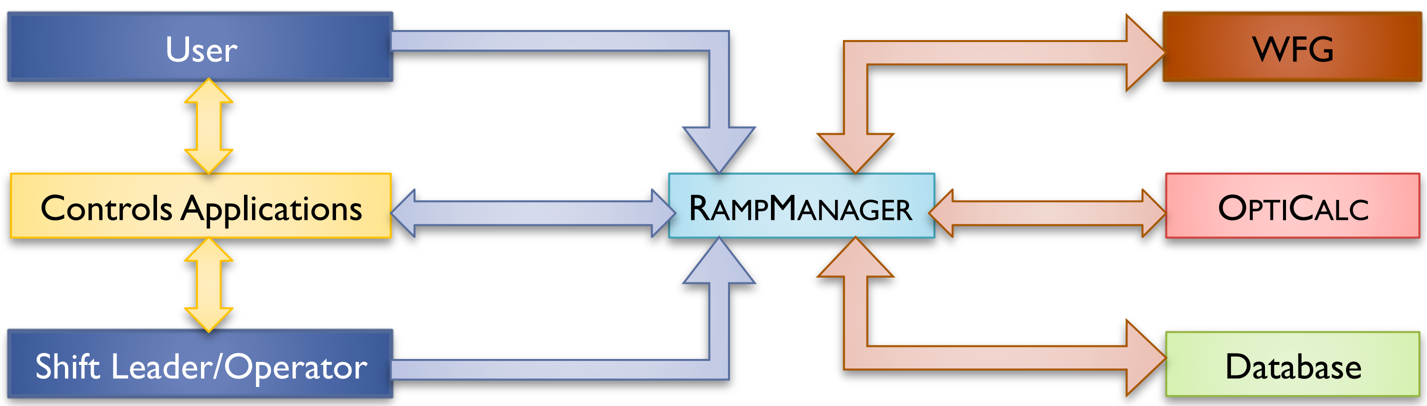
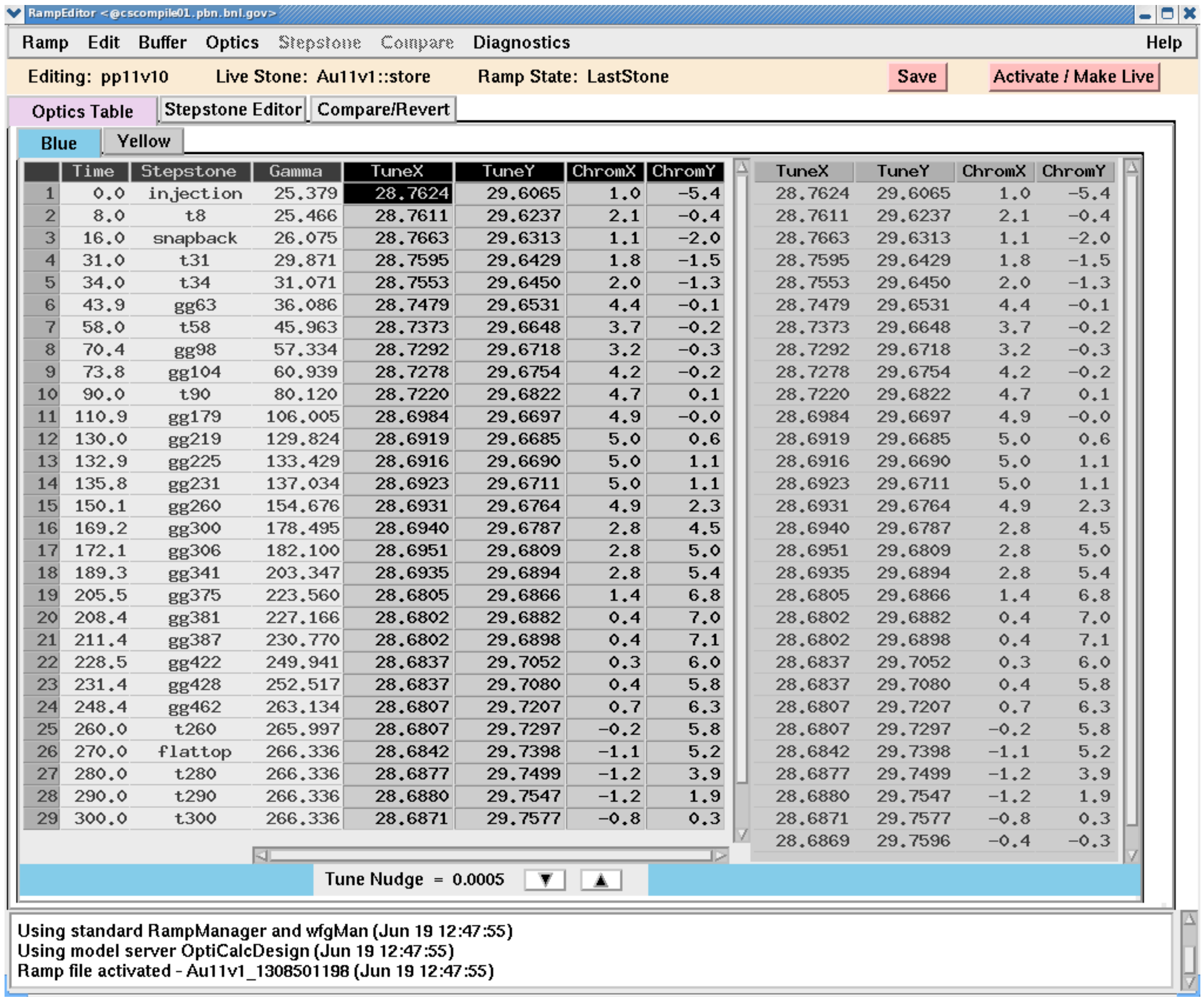
- Schematically:



- Among the controls software, one was designed to provide a GUI to OPTICALC: RAMPEDITOR:



	Time	Stepstone	Gamma	TuneX	TuneY	ChromX	ChromY
1	0.0	injection	25.379	28.7624	29.6065	1.0	-5.4
2	8.0	t8	25.466	28.7611	29.6237	2.1	-0.4
3	16.0	snapback	26.075	28.7663	29.6313	1.1	-2.0
4	31.0	t31	29.871	28.7595	29.6429	1.8	-1.5
5	34.0	t34	31.071	28.7553	29.6450	2.0	-1.3
6	43.9	gg63	36.086	28.7479	29.6531	4.4	-0.1
7	58.0	t58	45.963	28.7373	29.6648	3.7	-0.2
8	70.4	gg98	57.334	28.7292	29.6718	3.2	-0.3
9	73.8	gg104	60.939	28.7278	29.6754	4.2	-0.2
10	90.0	t90	80.120	28.7220	29.6822	4.7	0.1
11	110.9	gg179	106.005	28.6984	29.6697	4.9	-0.0
12	130.0	gg219	129.824	28.6919	29.6685	5.0	0.6
13	132.9	gg225	133.429	28.6916	29.6690	5.0	1.1
14	135.8	gg231	137.034	28.6923	29.6711	5.0	1.1
15	150.1	gg260	154.676	28.6931	29.6764	4.9	2.3
16	169.2	gg300	178.495	28.6940	29.6787	2.8	4.5
17	172.1	gg306	182.100	28.6951	29.6809	2.8	5.0
18	189.3	gg341	203.347	28.6935	29.6894	2.8	5.4
19	205.5	gg375	223.560	28.6805	29.6866	1.4	6.8
20	208.4	gg381	227.166	28.6802	29.6882	0.4	7.0
21	211.4	gg387	230.770	28.6802	29.6898	0.4	7.1
22	228.5	gg422	249.941	28.6837	29.7052	0.3	6.0
23	231.4	gg428	252.517	28.6837	29.7080	0.4	5.8
24	248.4	gg462	263.134	28.6807	29.7207	0.7	6.3
25	260.0	t260	265.997	28.6807	29.7297	-0.2	5.8
26	270.0	flattop	266.336	28.6842	29.7398	-1.1	5.2
27	280.0	t280	266.336	28.6877	29.7499	-1.2	3.9
28	290.0	t290	266.336	28.6880	29.7547	-1.2	1.9
29	300.0	t300	266.336	28.6871	29.7577	-0.8	0.3

TuneX	TuneY	ChromX	ChromY
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28.7479	29.6531	4.4	-0.1
28.7373	29.6648	3.7	-0.2
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28.6916	29.6690	5.0	1.1
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28.6935	29.6894	2.8	5.4
28.6805	29.6866	1.4	6.8
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28.6842	29.7398	-1.1	5.2
28.6877	29.7499	-1.2	3.9
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28.6869	29.7596	-0.4	-0.3

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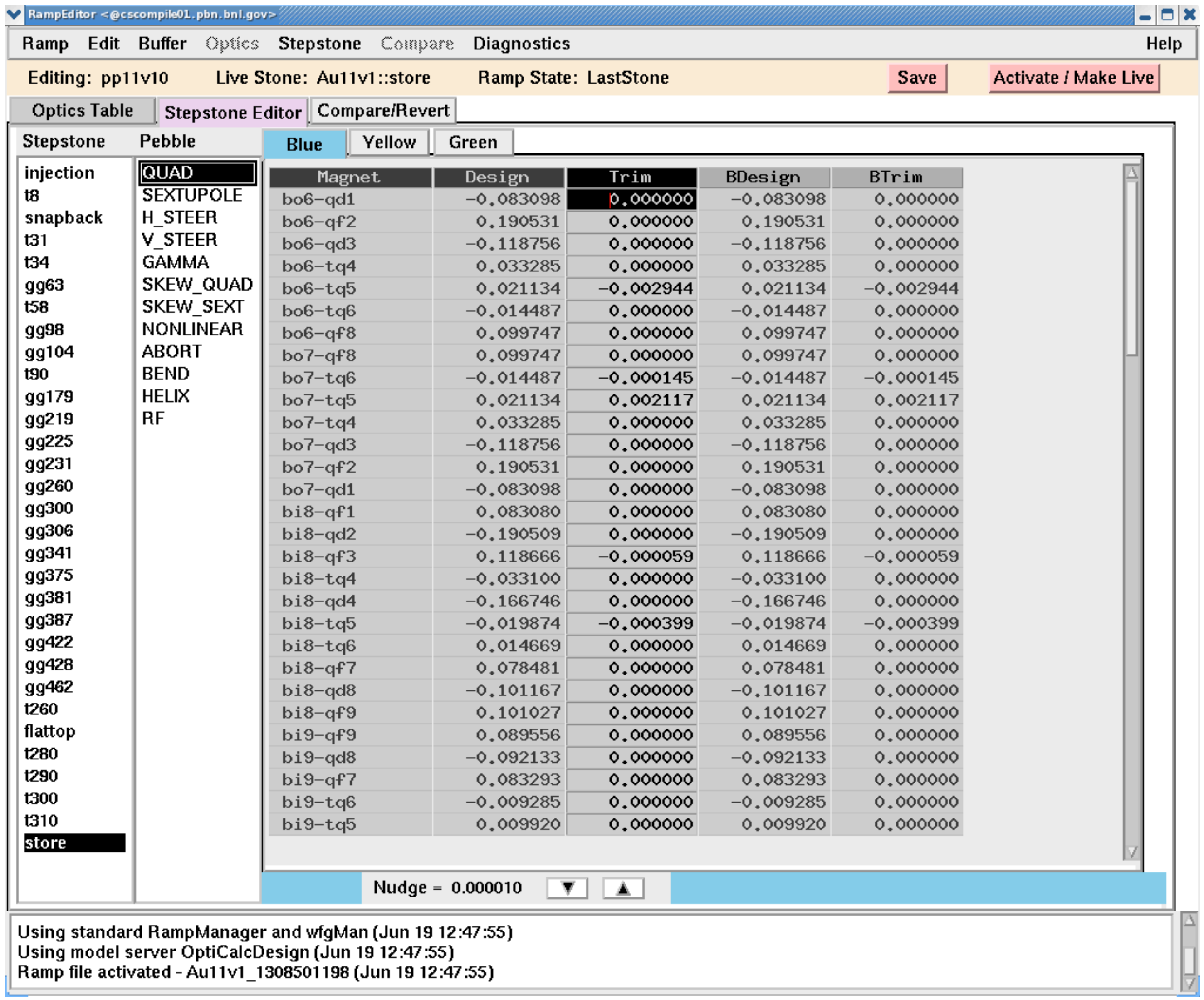

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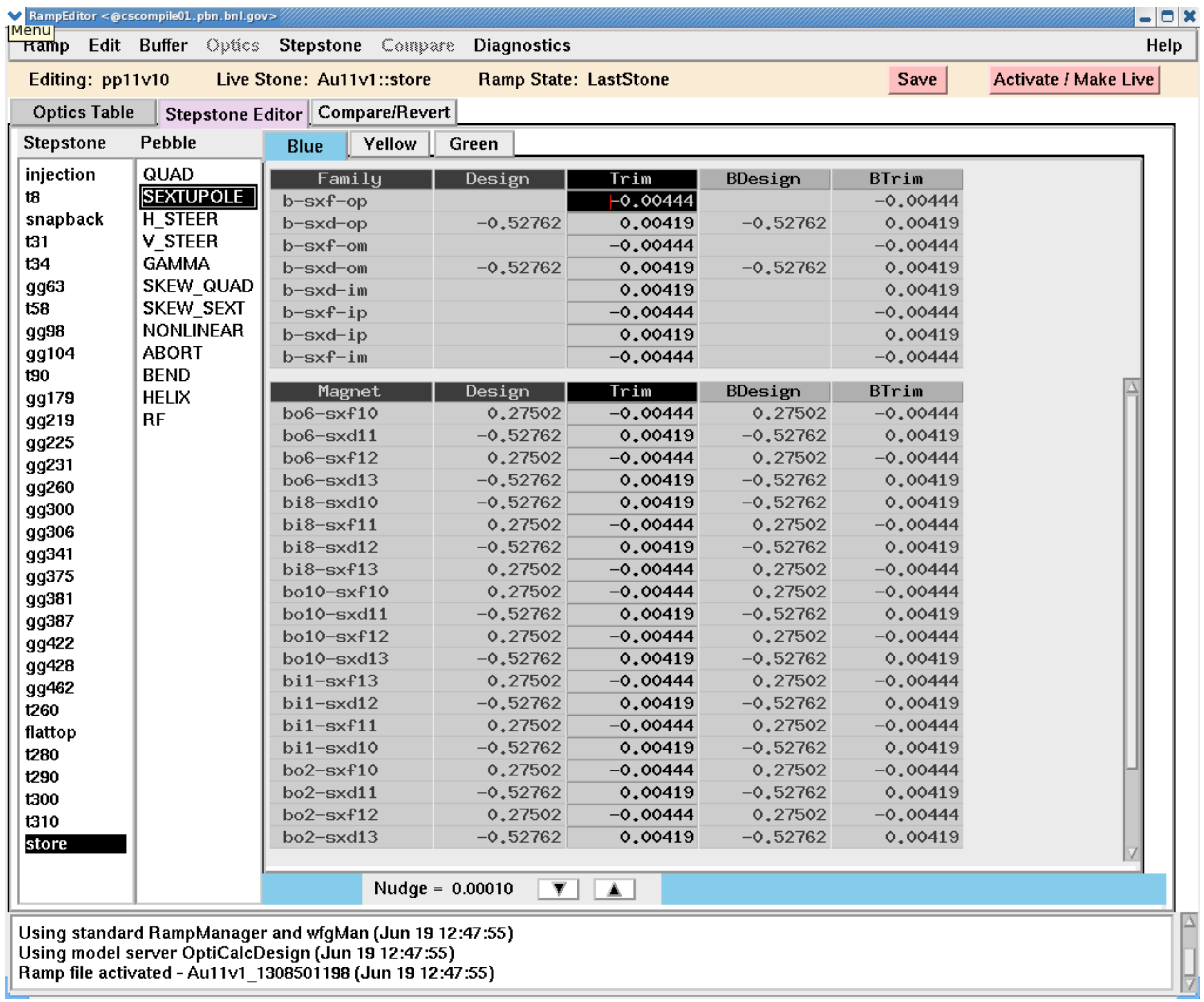
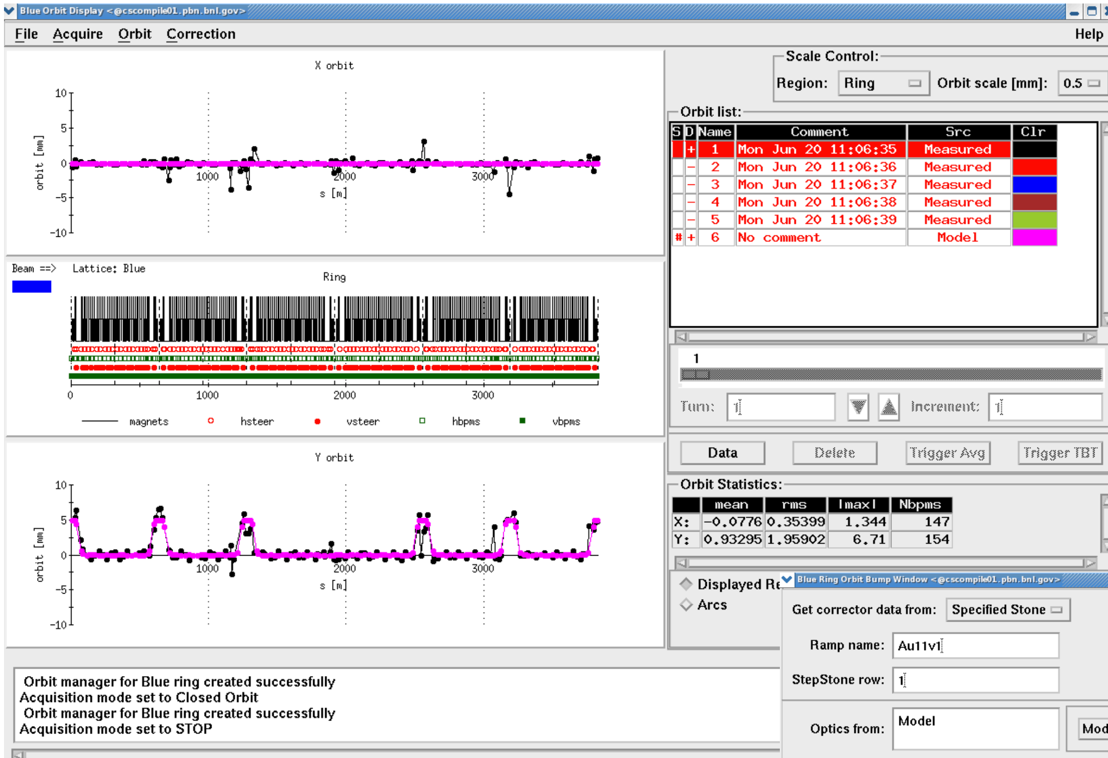


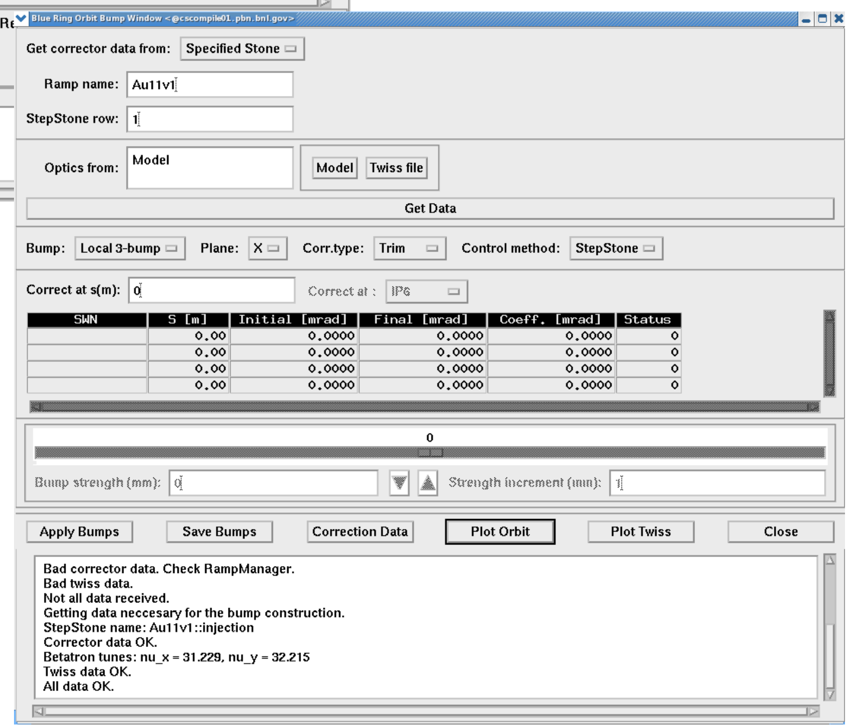
- Among the controls software, one was designed to provide a GUI to OPTICALC: RAMPEDITOR: allows changing the machine parameters with either a global knob (tune/chrom), a family knob (sextupole and up) or changing individual magnets.

- Each magnet strength (gradient) is split into two parts: DESIGN and TRIM. DESIGN is the target optics and tune/chromaticity parameters as expected from MAD and RAMPDESIGNER work, while TRIM is the correction one needs to apply to effectively get those design settings in the machine.

- For closed orbit modeling, a separate library was created, ORBITCALC. It is handled independently by a specific GUI: RHICORBITDISPLAY. OPTICALC does not contain any orbit information, but can control the steering magnets.



RhicOrbitDisplay main window



RhicOrbitDisplay local correction window

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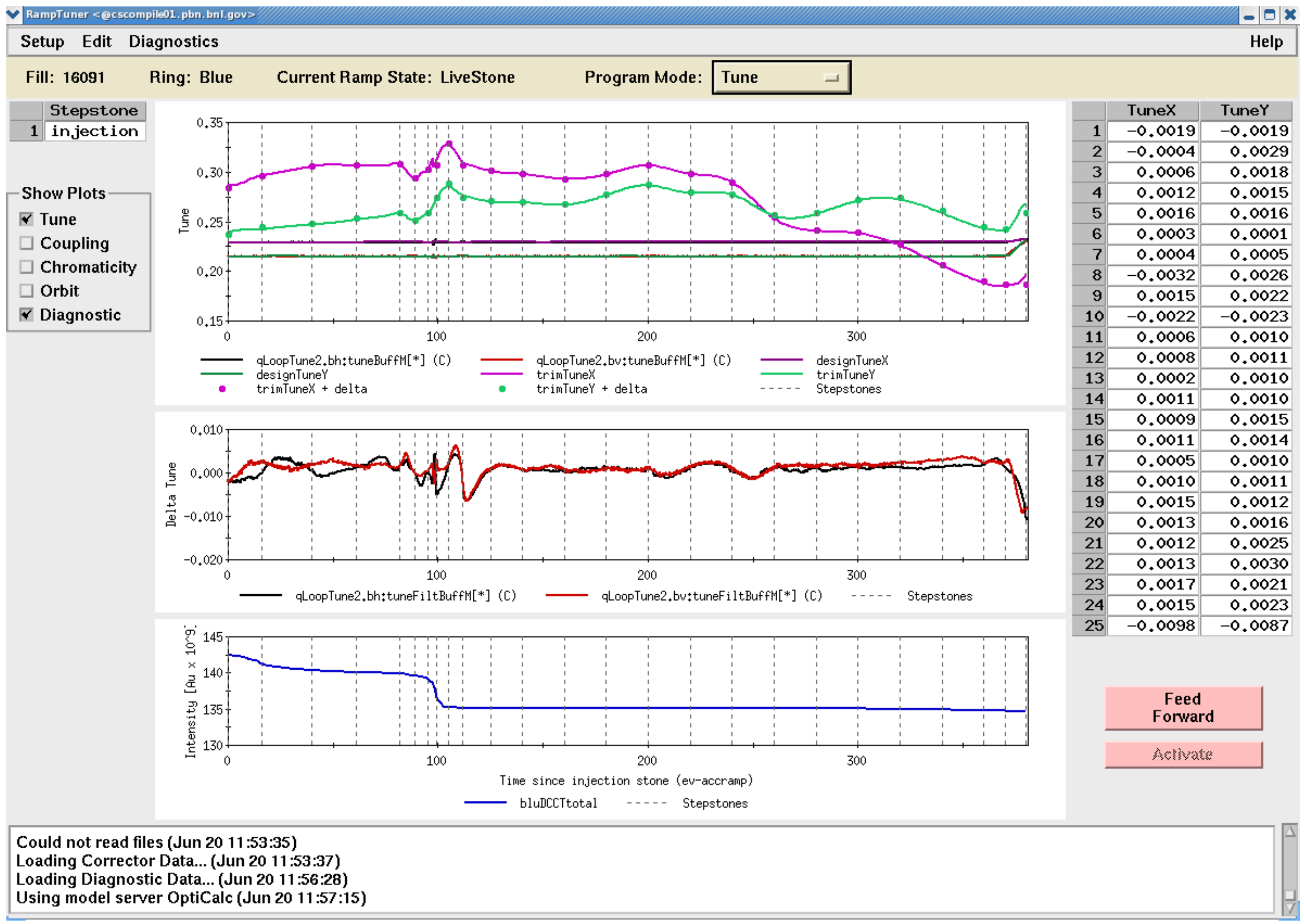
- Once the energy ramp and its target orbit (incl. separation bumps) have been designed, one only needs a selected number of StepsStones to control the beam along that ramp. ANCHORED StepStones mark the settings that are definitely required at the considered time along the ramp; between those, the online model applies a POLYNOMIAL INTERPOLATION to get the corresponding magnet strengths

  => one of the key components to the feedback systems!!

- Feedback systems: as of RHIC Run10, all four feedbacks (tune, coupling, orbit, chromaticity) can be used simultaneously during ramp development.

- RAMPTUNER is the interface between OPTICALC and feedback/feed-forward system:



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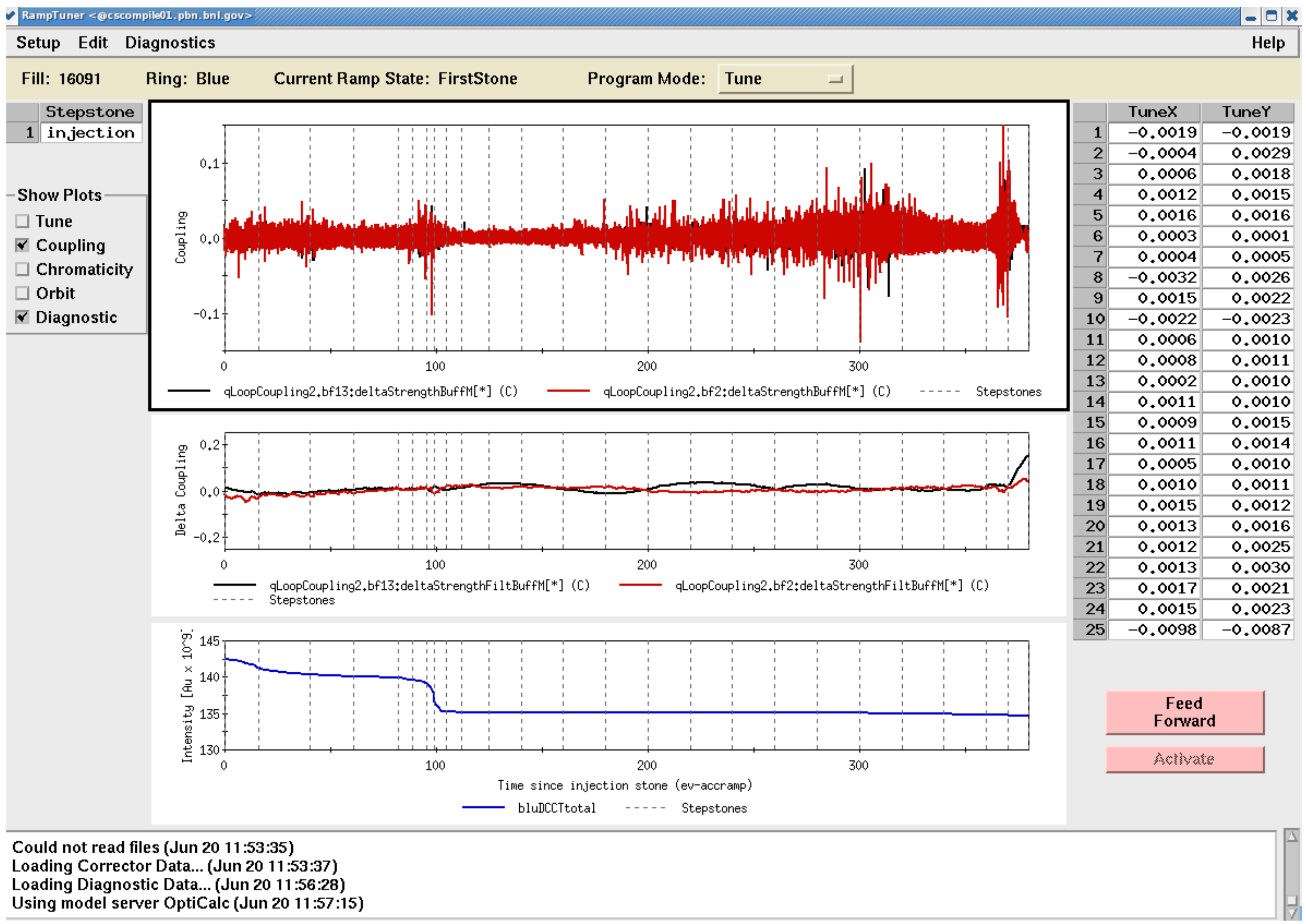

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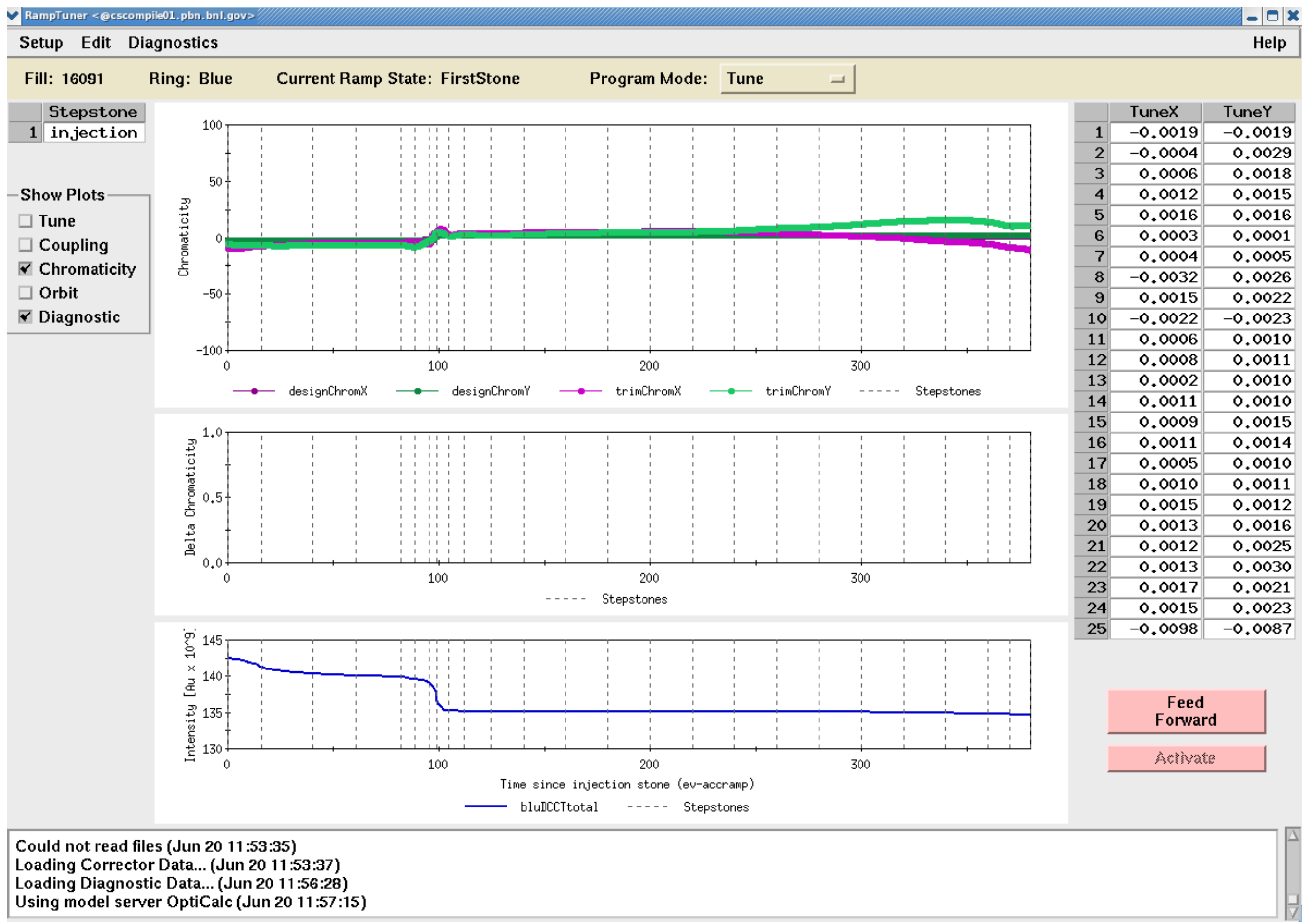

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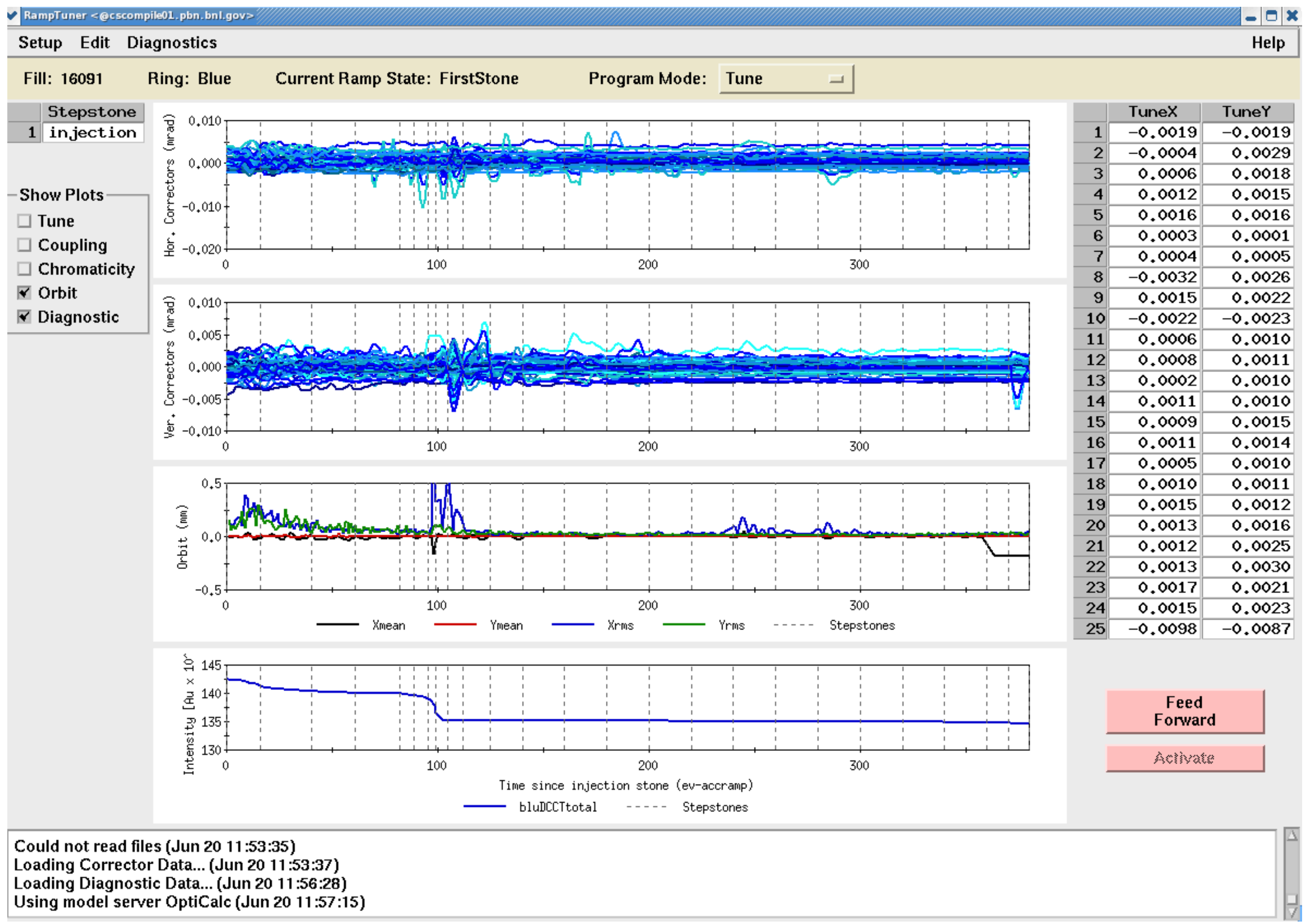
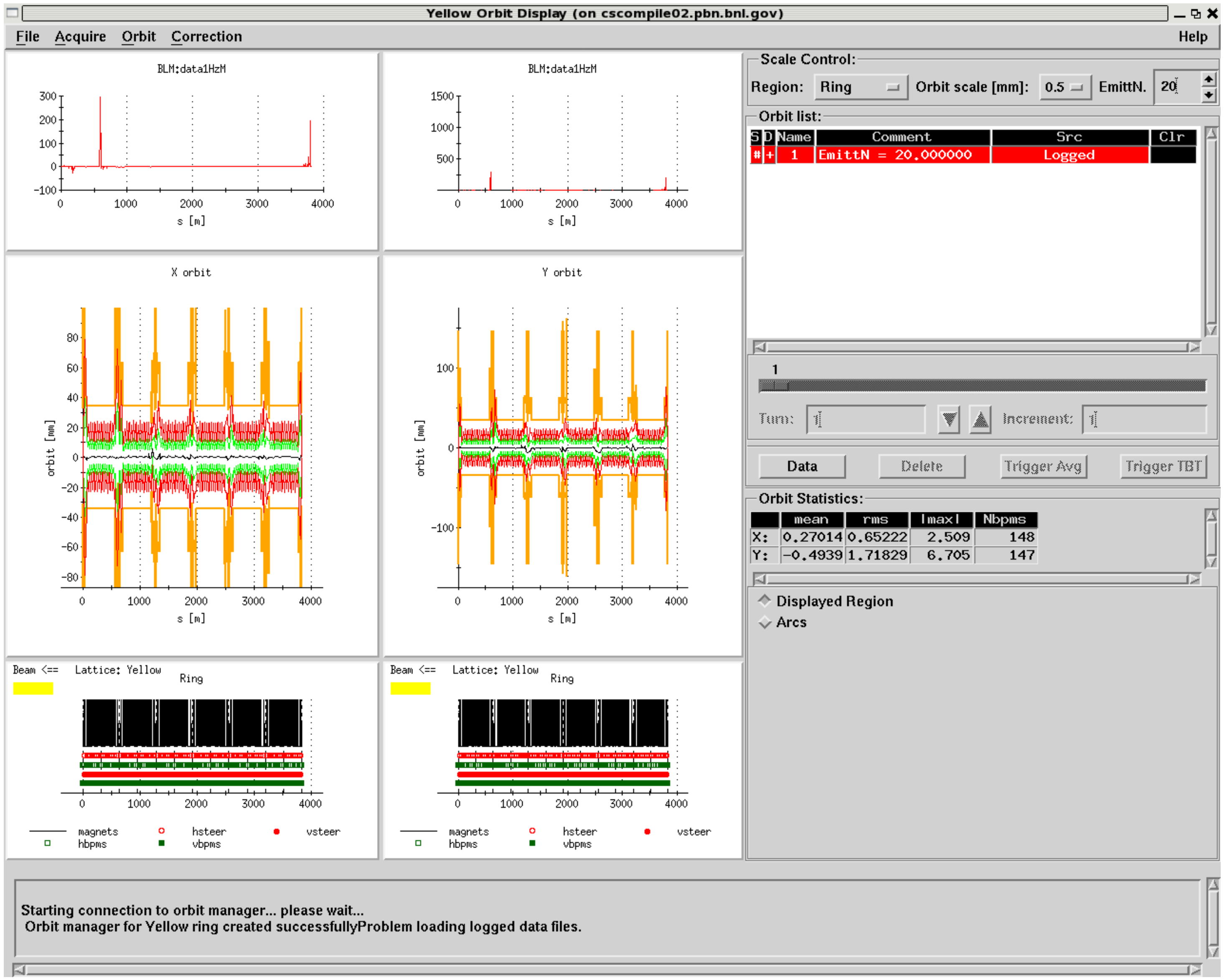


- <u>Use of online model as a diagnostics tool:</u> RHICBEAMENVELOPE application, designed to provide access to all data relevant to the analysis of longitudinal beam loss patterns



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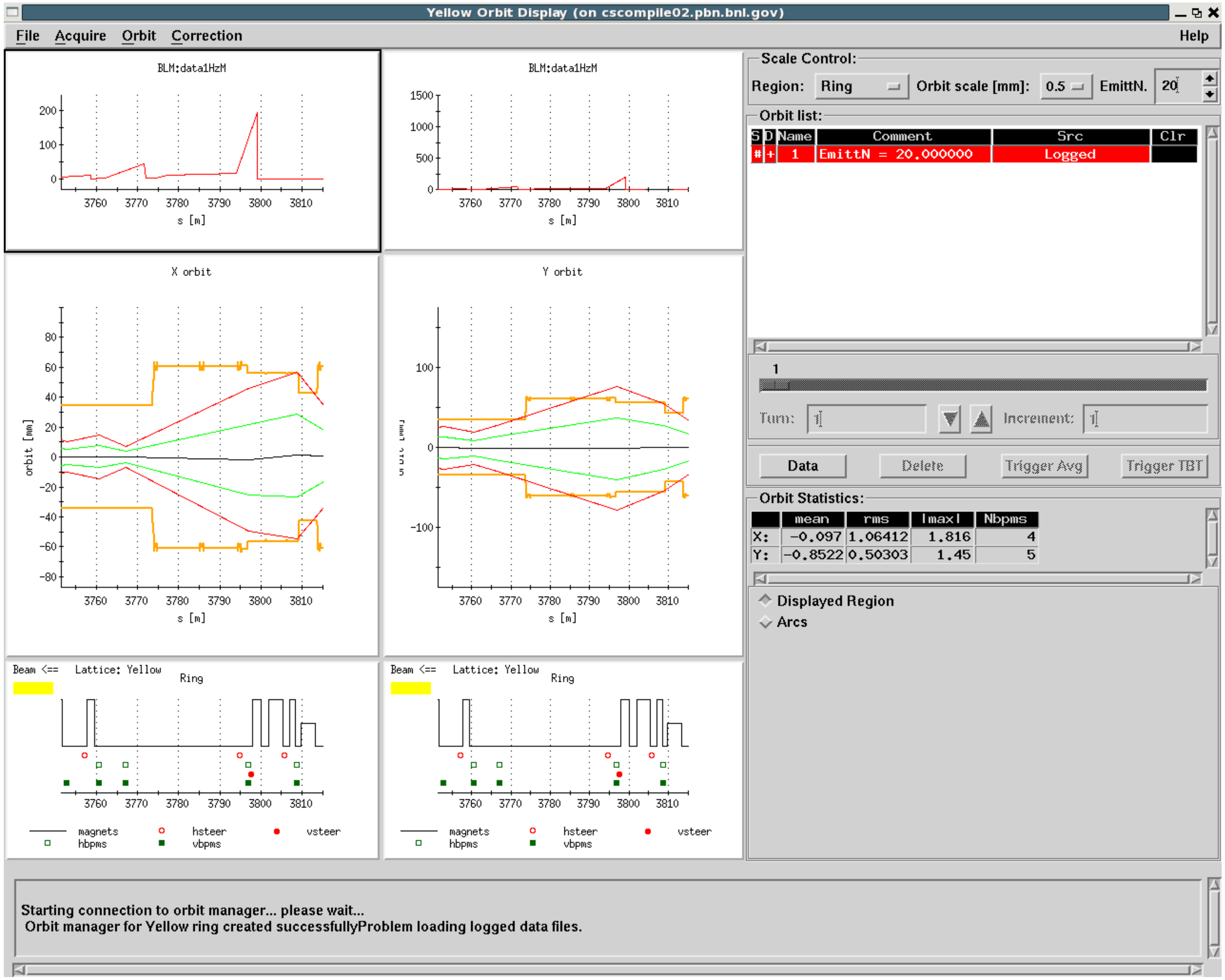

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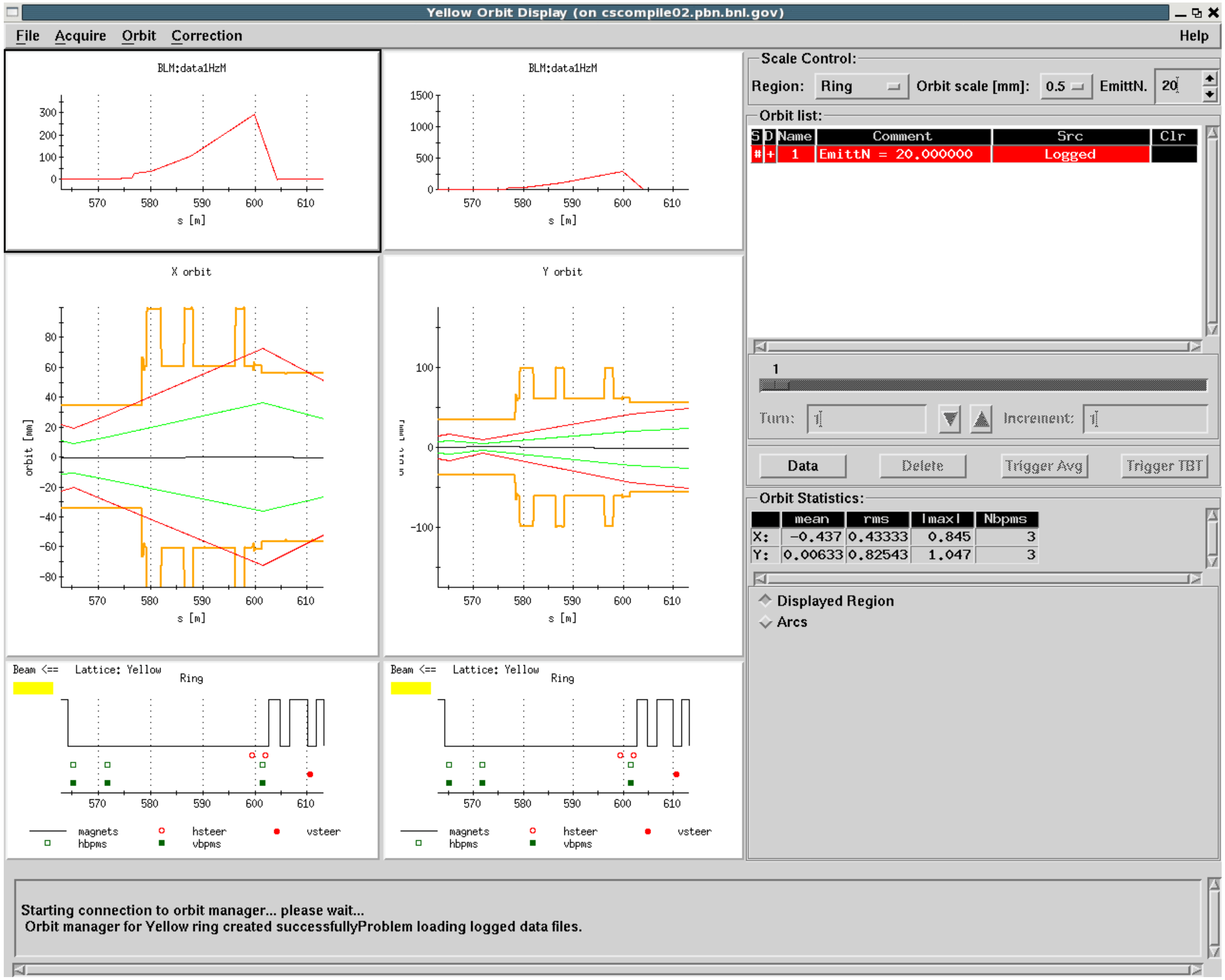
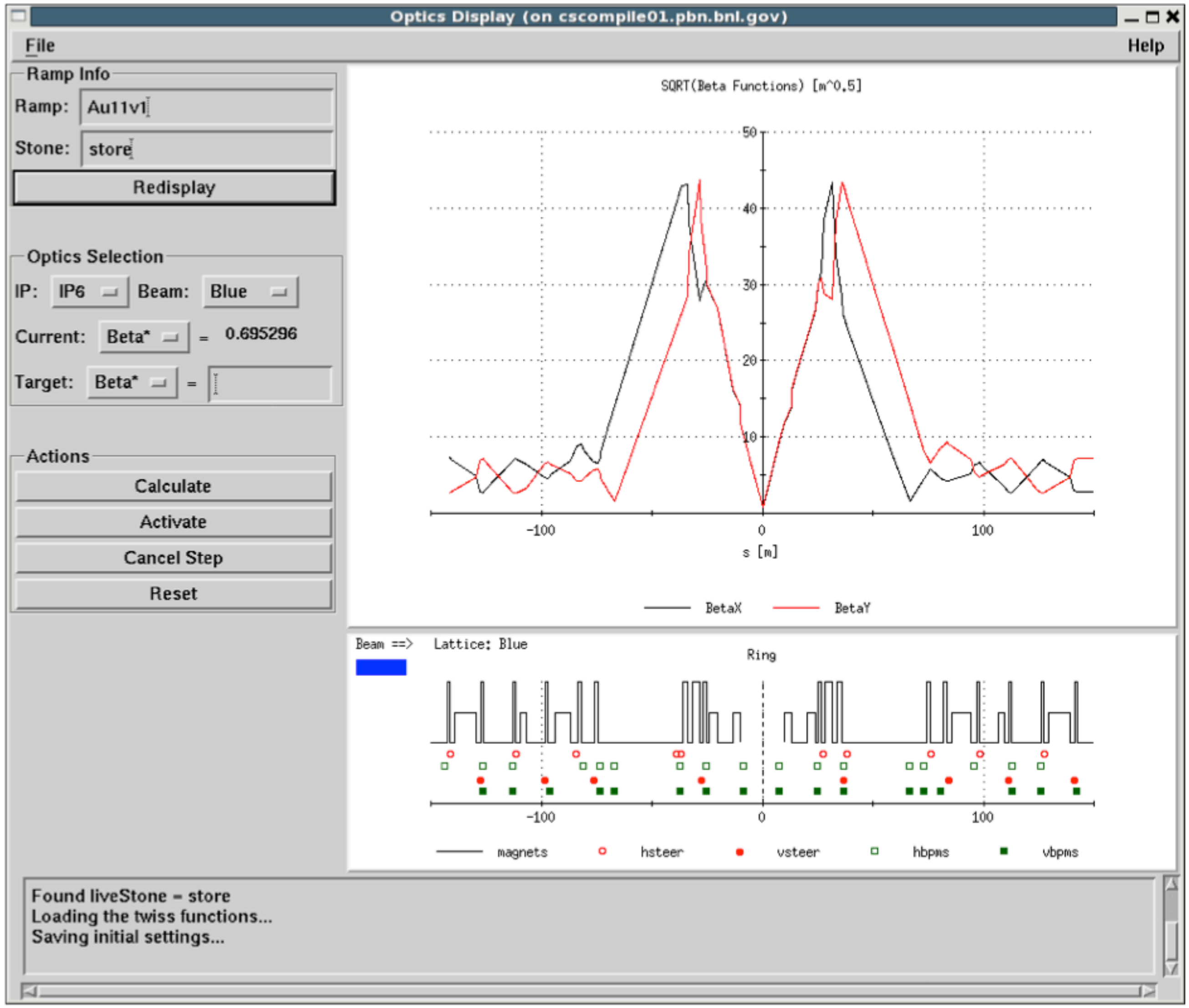
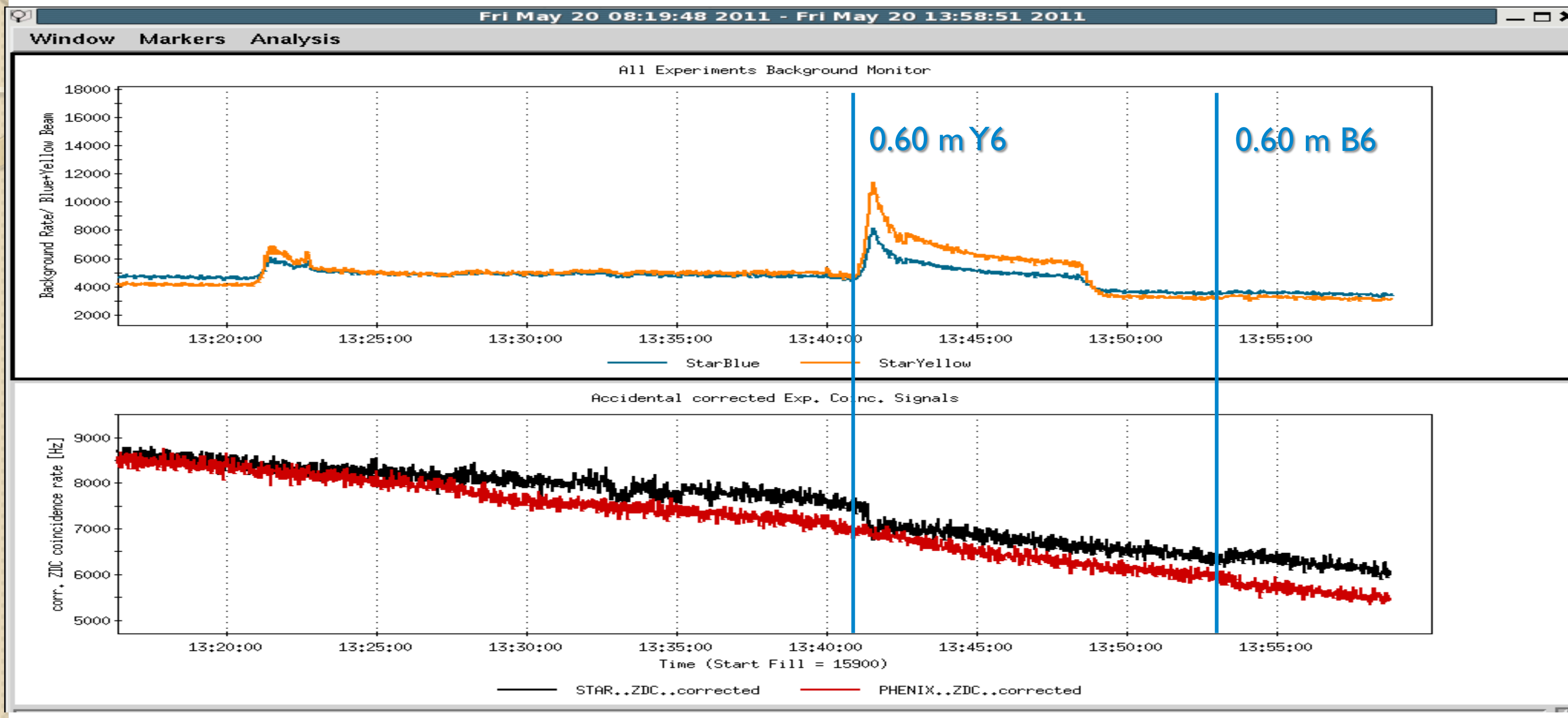


- <u>Use of online model as a beam experiment tool:</u> RHICBETASTAR application, designed to rematch a given IR to achieve a new target β^* value, in the context of Au runs with stochatic cooling (smaller emittance => larger available aperture => room for further squeeze)



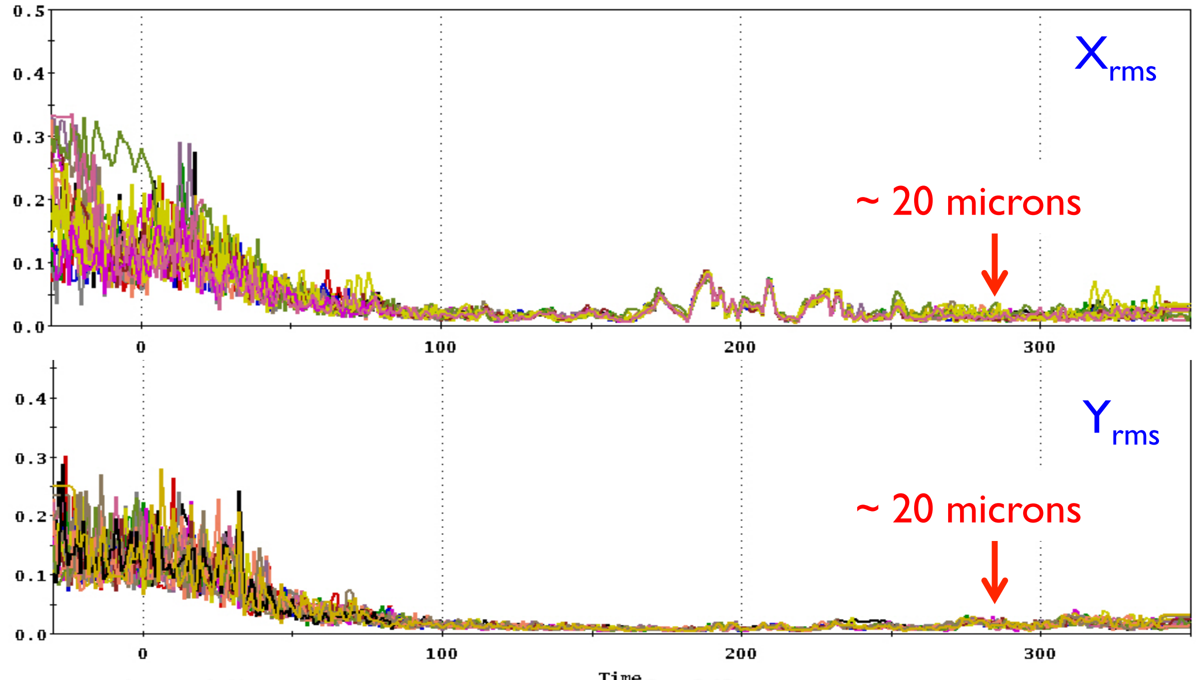
(still under commissioning)

- Use of online model as a beam experiment tool: RHICBETASTAR application, designed to rematch a given IR to achieve a new target β^* value, in the context of Au runs with stochatic cooling (smaller emittance => larger available aperture => room for greater squeeze)

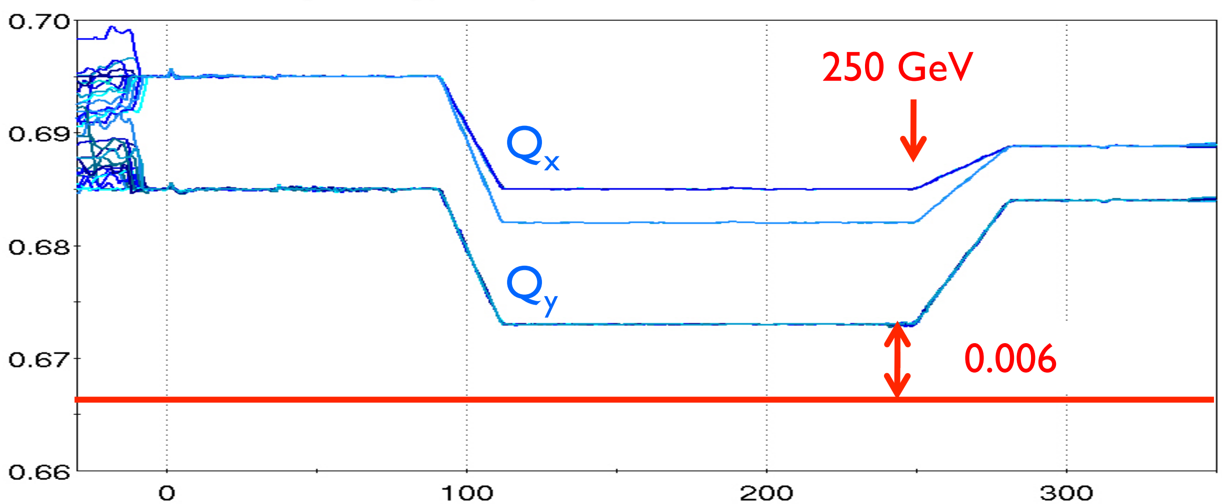


- Preliminary results; actually lead to checklist of system requirements (chromaticity control + use of tune/orbit feedback) and further offline studies of a similar knob using MAD-X algorithm module to calculate ΔK_i for IR quadrupoles rematching with boundary conditions (*still being analyzed*).

- <u>Feedback in the context of proton preservation and avoidance of spin resonance:</u>

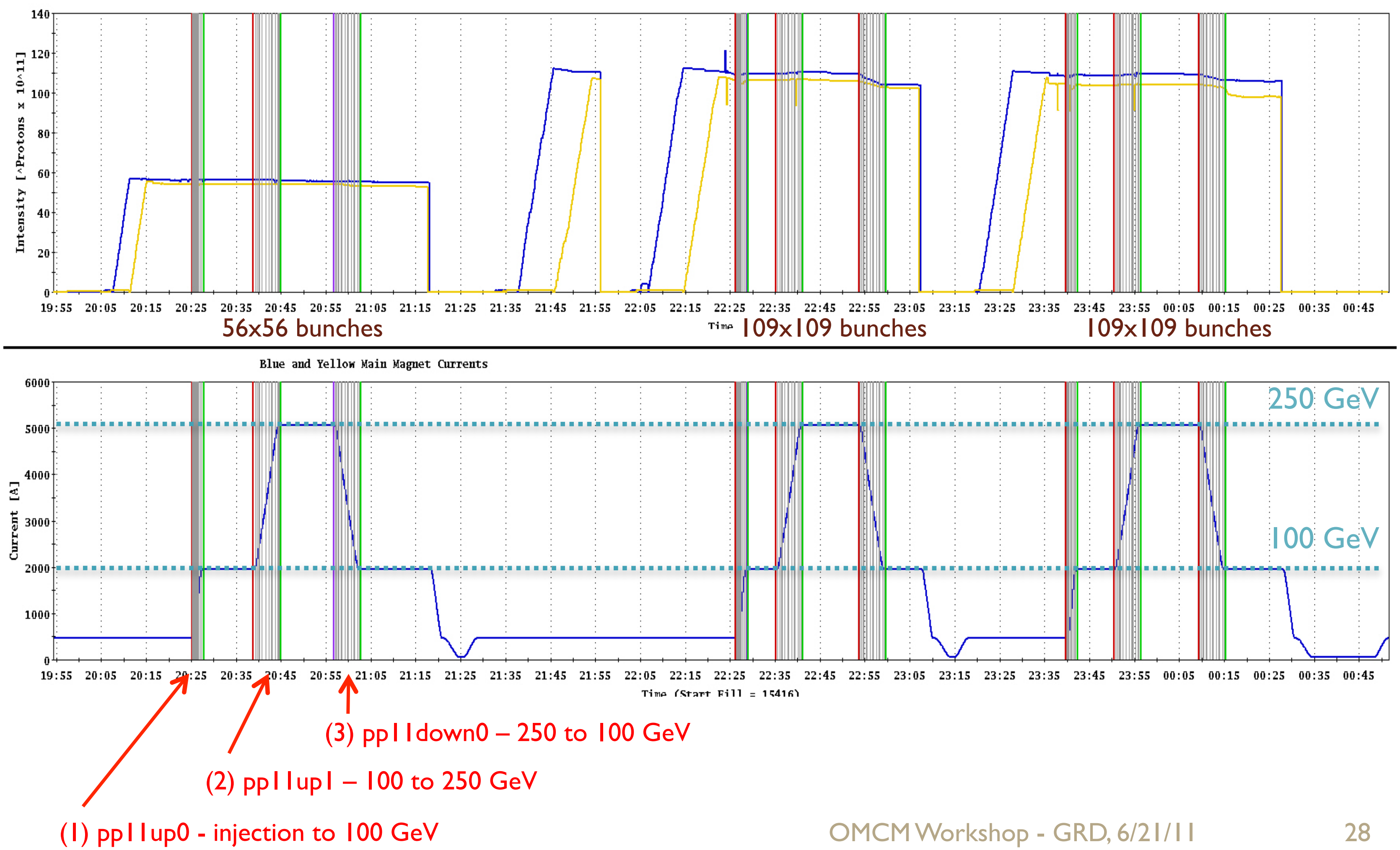


Precision beam control enabling energy ramps near Q=2/3

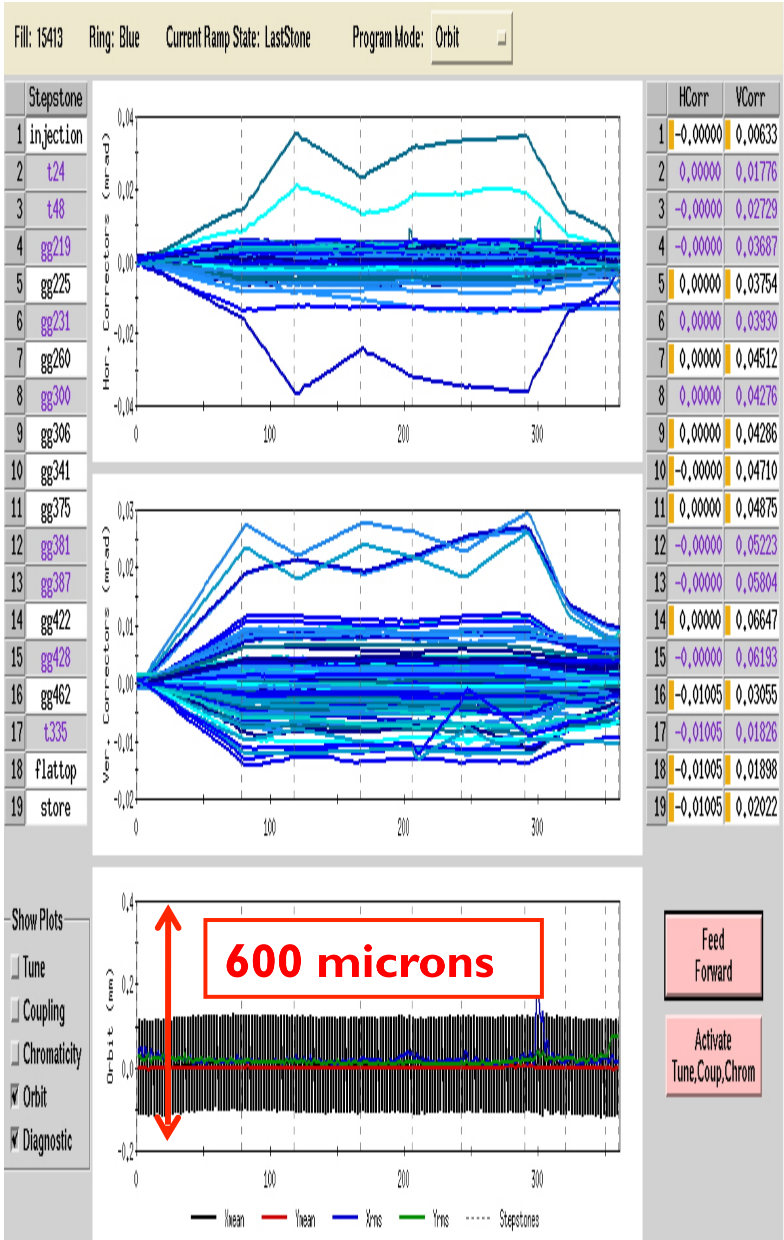


- Feedback in the context of beam polarization measurement at 250GeV: measured via H-jet to be 46%; data acquired at 100 GeV before and after the energy ramp to 250 GeV using a CNI polarimeter show 11% polarization loss per ramp – assuming identical loss during acceleration and deceleration: from previous runs at 100 GeV, that would imply a store polarization of 56%

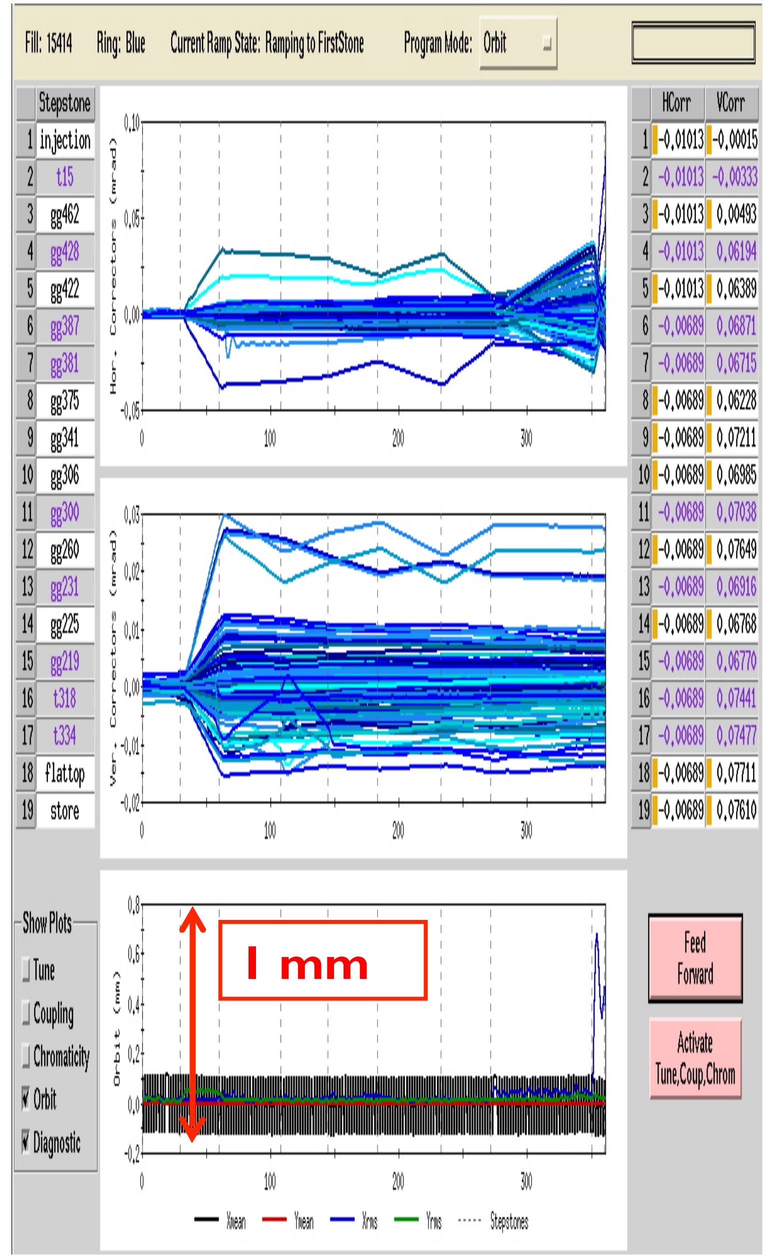
  => setup and 3 up & down ramps in 2 shifts, all executed with simultaneous orbit, tune, coupling and chromaticity feedback



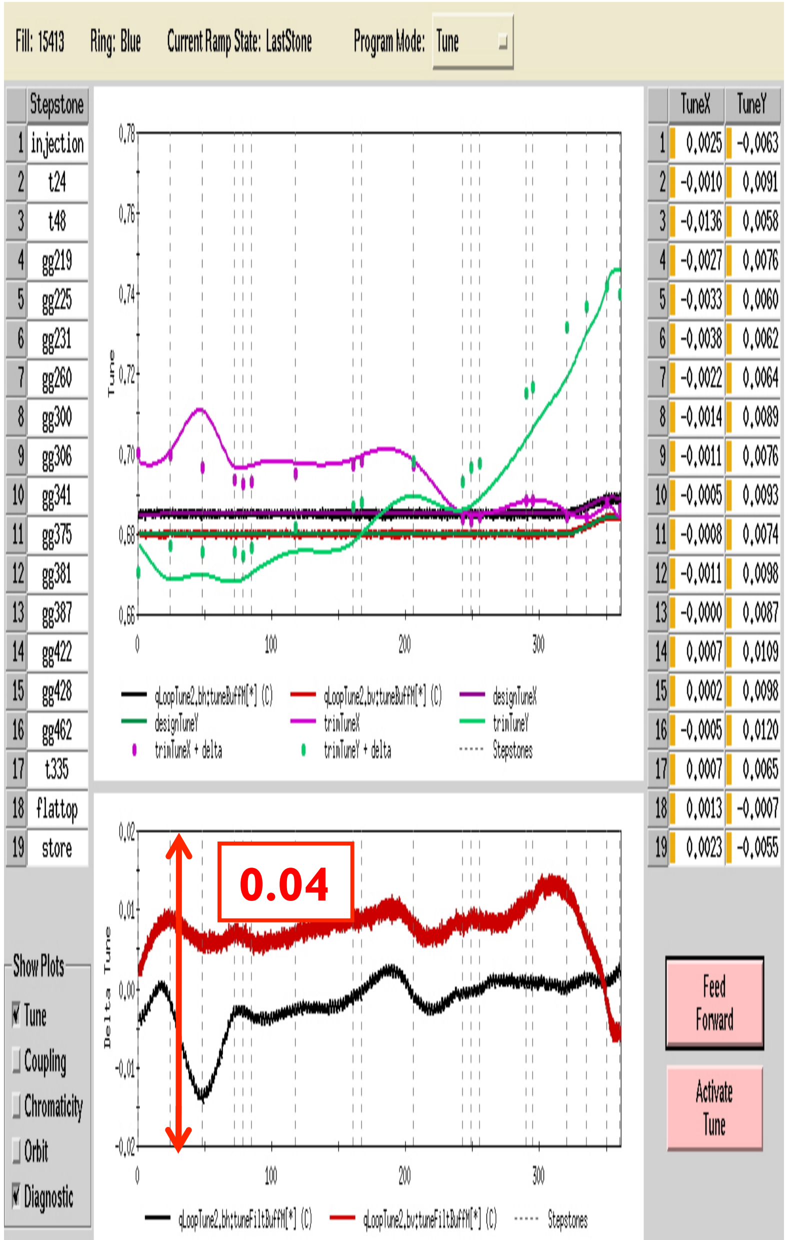
BLUE RING feed-forward ORBIT of pp11up1



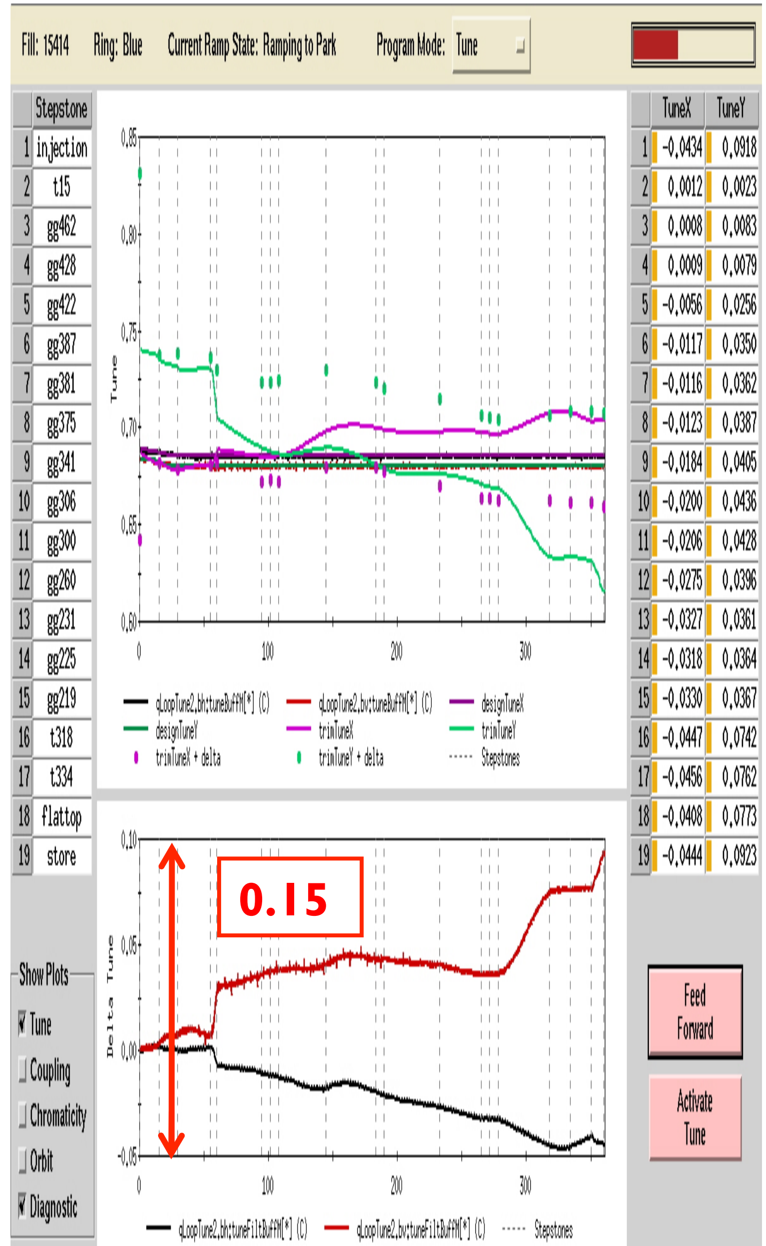
BLUE RING feed-forward ORBIT in pp11down0



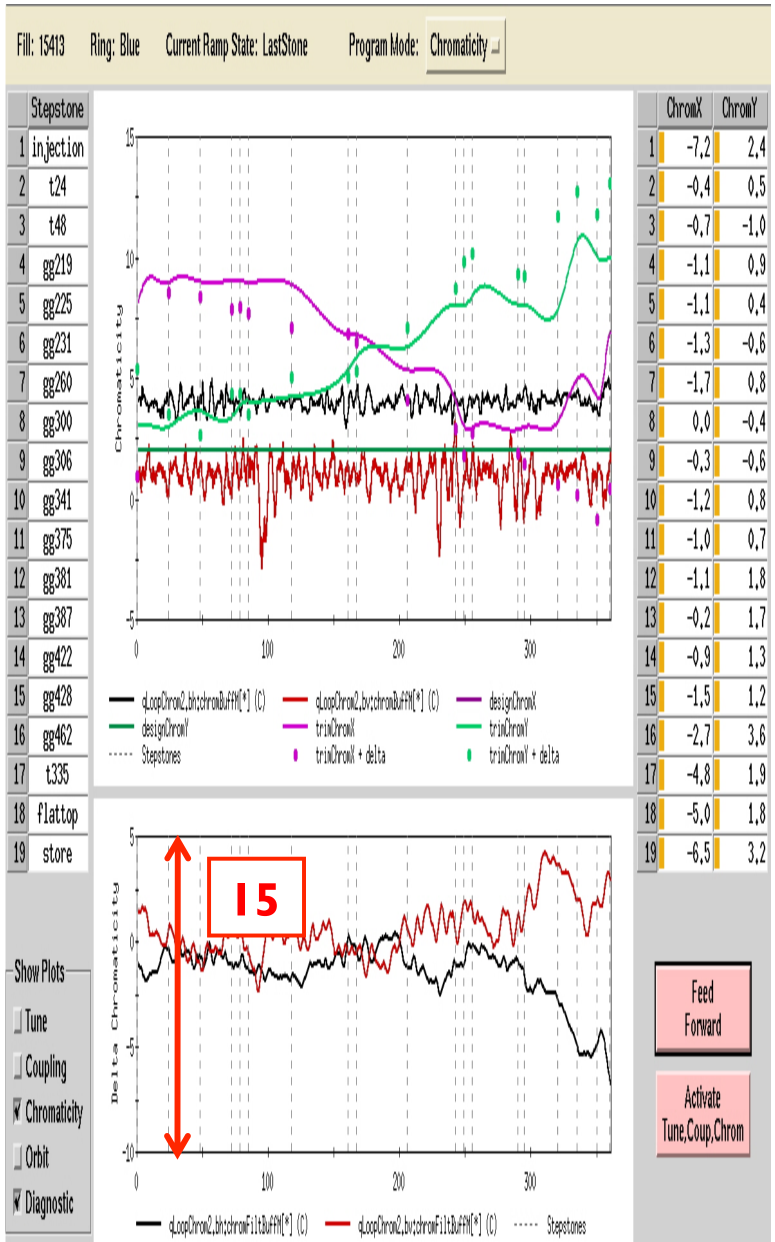
BLUE RING feed-forward TUNES of pp11up1



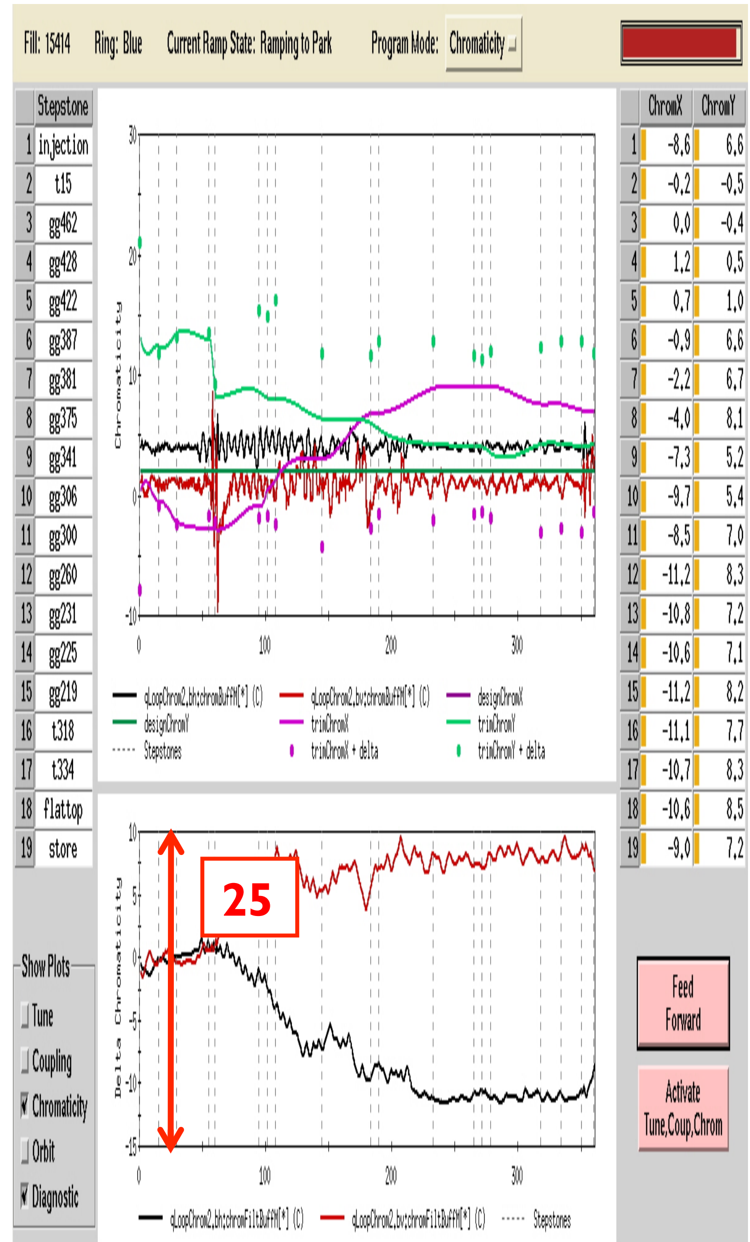
BLUE RING feed-forward TUNES in pp11down0



BLUE RING feed-forward CHROM of pp11up1



BLUE RING feed-forward CHROM in pp11down0



- The RHIC Online Model is made of a lattice and energy ramp design used as inputs to two computation servers, RAMPMANAGER and OPTICALC, each with their own dedicated purpose.

- In the past, the RHIC energy ramp was based entirely on StepStones to allow for orbit and tune control and beta* squeeze schemes evolving throughout the energy ramp. RAMPMANAGER/ OPTICALC have evolved over the Runs to provide an interface with multiple feedback loops now used routinely at RHIC to accelerate, squeeze and steer the beams into collisions and for periodic orbit control during normal physics stores.

- Ramp commissioning as well as dedicated accelerator physics experiments profit from these enhanced capabilities:
  - shorter ramp development period (shifts instead of days), instant benefit to STAR and PHENIX experiments in term of integrated luminosity;
  - controlling the beam properties using the 4 feedback systems while dynamically squeezing β^* in any given IR (interest in both squeeze and un-squeeze);
  - data easily accessible for the development of diagnostic and analysis tools (e.g. RHICORBITDISPLAY, RHICBEAMENVELOPE, LOPTICS for optics measurement and correction).

- Future work with OPTICALC: looking into the possibility of using some of MAD capabilities as part of the matching modules, study of the b2 field component in dipoles for low energy runs, develop methods for non-linear correction (Q'' and Q''' mainly).