Beta* leverage during RHIC AuAu Run14

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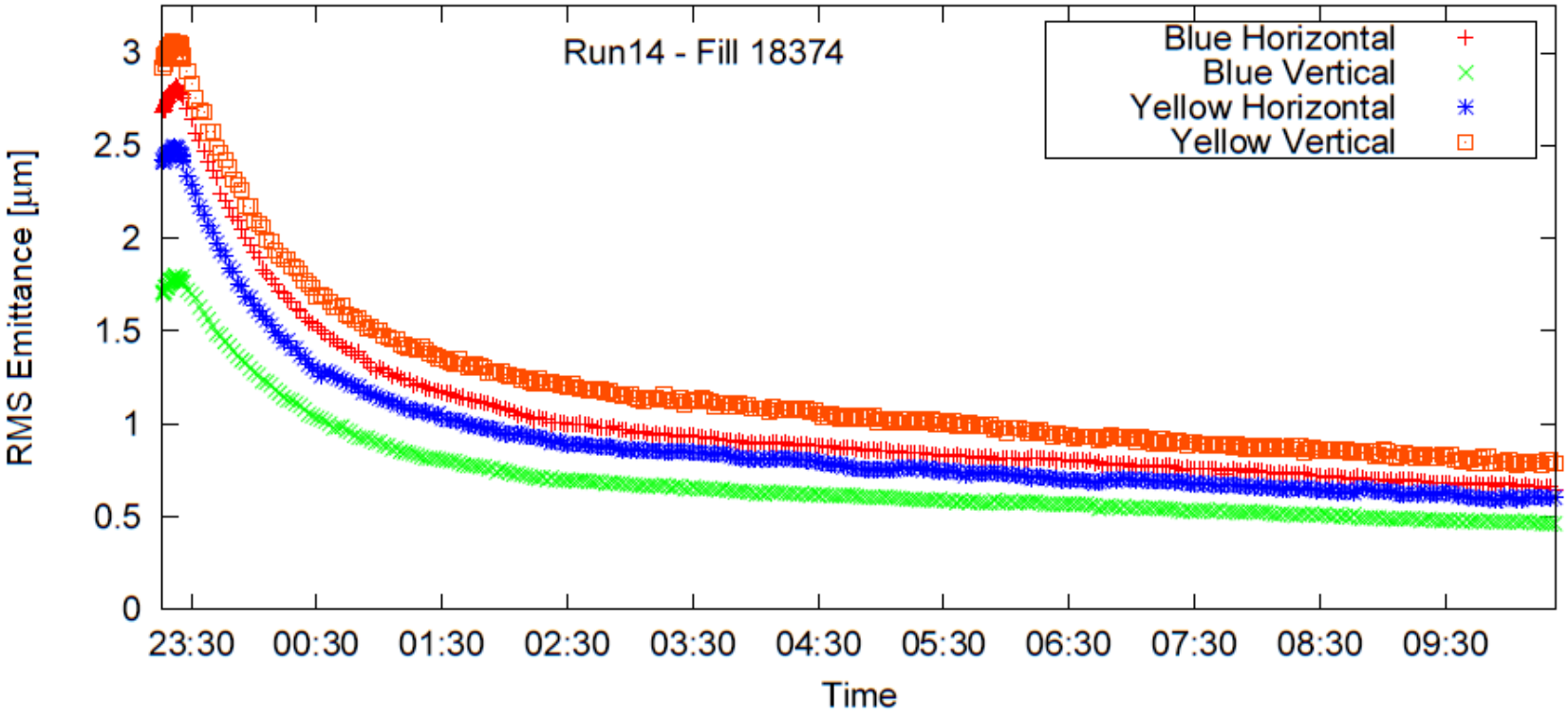
- RHIC Stochastic Cooling (SC) is operational for heavy ions lattices since Run11; upgrades over the past 3 years improved the system reliability and efficiency so that longer store lengths could be achieved:

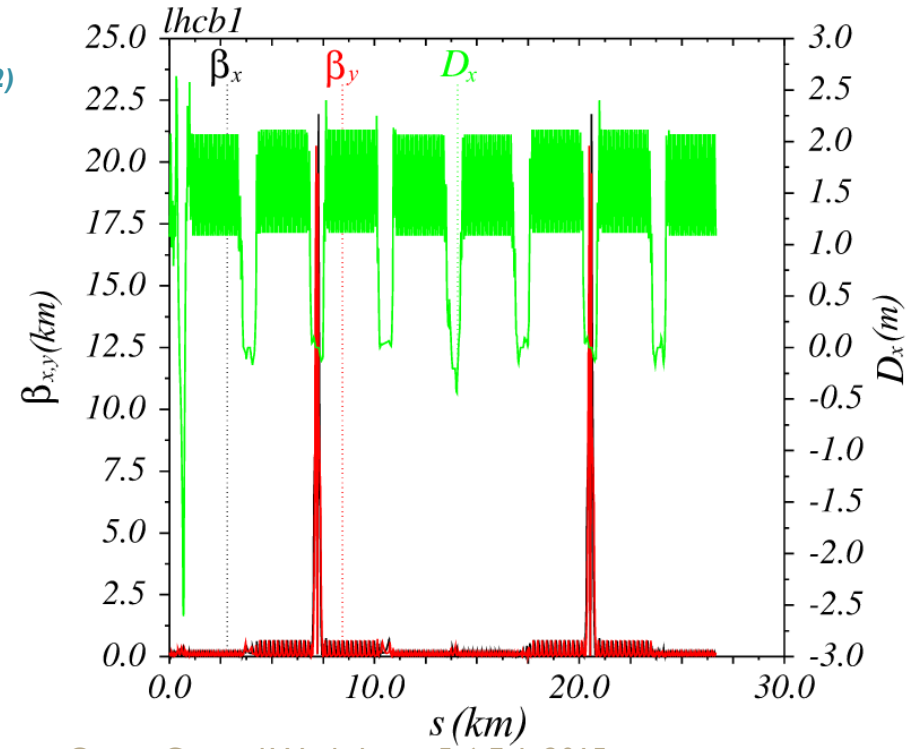


- SC provides enough additional transverse aperture in the IR triplets to try and squeeze β^* in the STAR and PHENIX experimental insertions for integrated luminosity leveling!

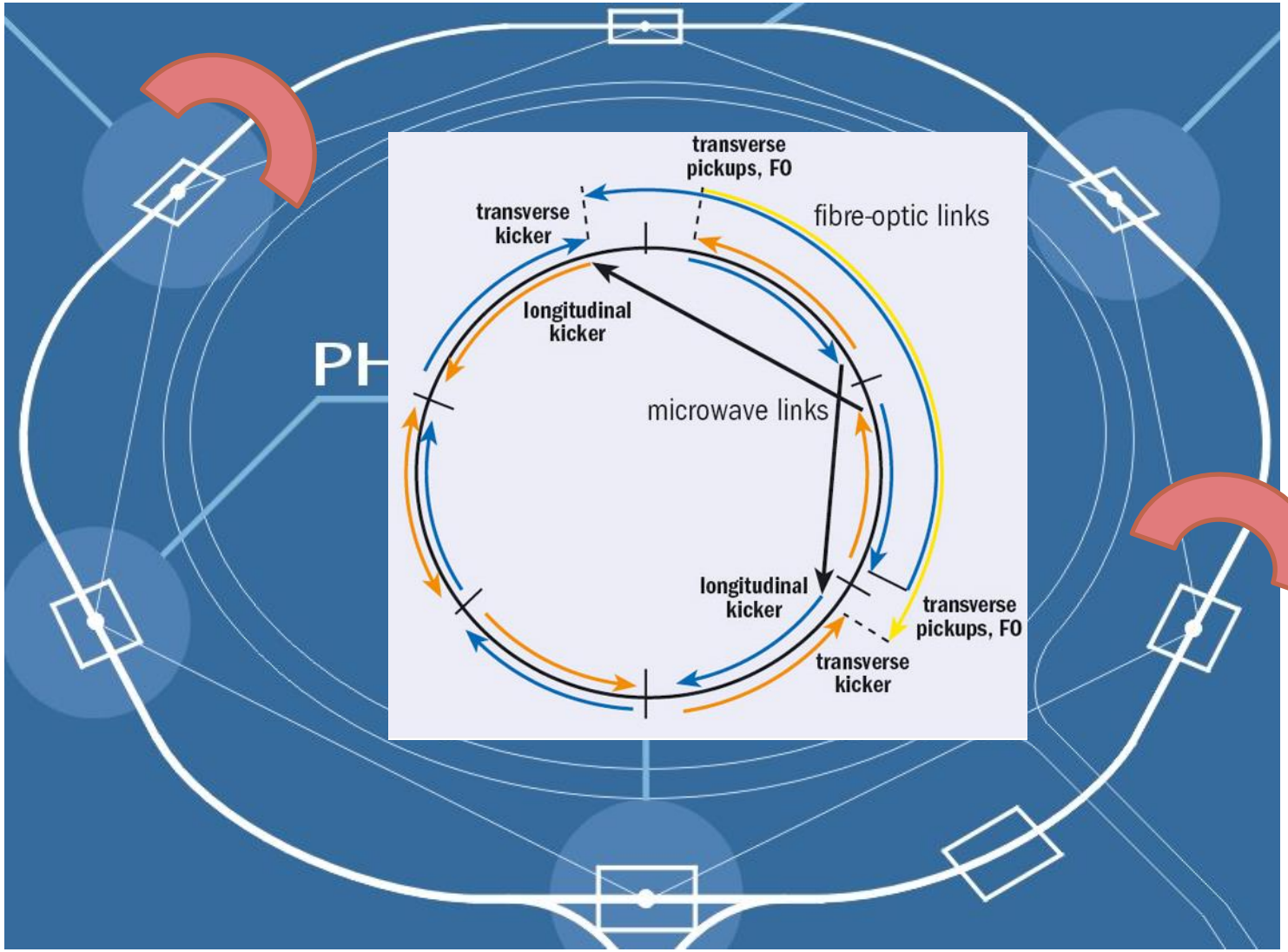
- Since Run12, RHIC uses a non-IBS suppression lattice for Heavy Ions runs that leaves little room in the IR shunt supplies to try and squeeze either STAR and PHENIX β^* by any significant amount => study the feasibility of CERN's Achromatic Telescopic Scheme (ATS) in RHIC

- Principle:
  - use the insertions around the targeted IR's to launch and cancel a β-beating wave in both planes that would have its waist at the IP;
  - requires $\Delta\mu(cell)$ close to 90 for increased chromatic correction efficiency of sextupoles at constant strength ($\Delta\beta_{max}$ reached at each sextupole location).

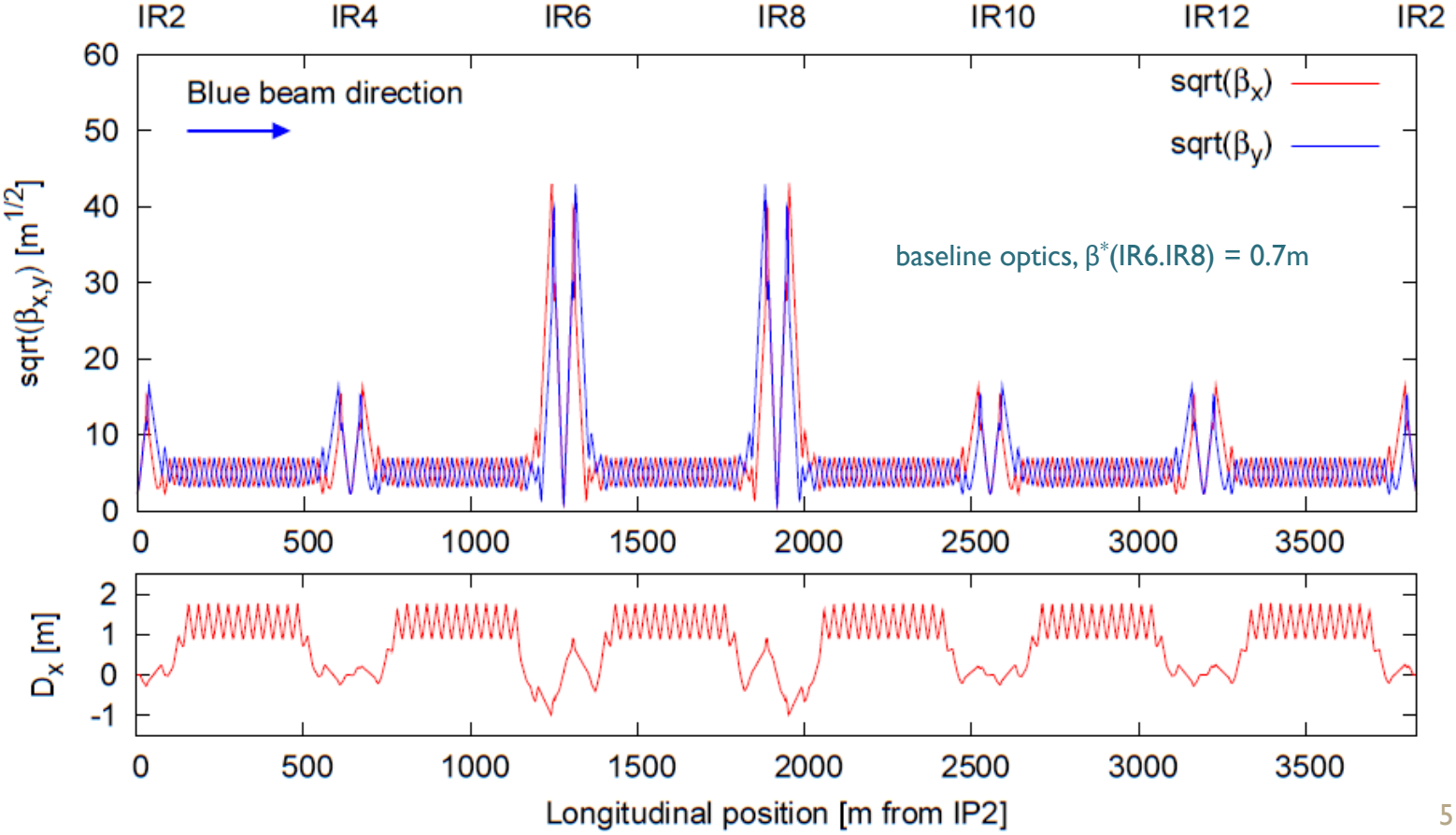
(Source: S. Fartoukh, PhysRevSTAB.16.111002)



- Matching section:



- Theoretical design: use the IR's around the targeted experimental insertion to launch and close a β-beat wave to allow reducing β^* further with little to no change to the chromatic functions. ATS requires a 90° FODO lattice and phase advance of $k(\pi/2)$ between the targeted IP and both focusing and defocusing sextupole families for the ideal chromaticity correction scheme. However, the RHIC lattice was designed with the STAR and PHENIX IR's downstream of one another. For the ATS scheme implementation, this adds another phase advance constraint for the β-beat wave to be effective at both IP's at the same time. For Run14, the Uranium-Uranium lattice from Run12 was taken as a baseline: it offered the best performance in terms of dynamic aperture and integrated luminosity for RHIC high energy A-A runs.



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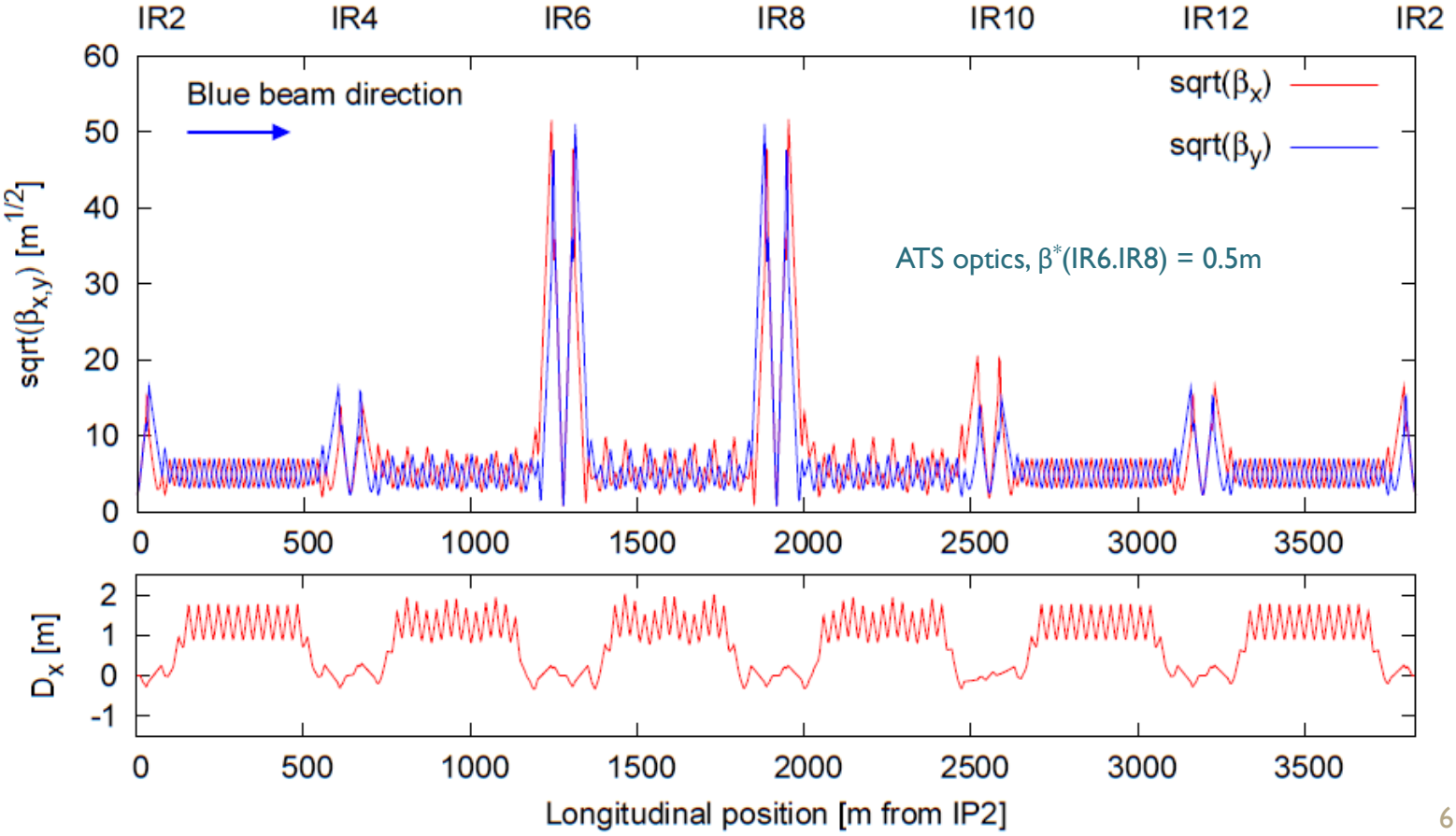
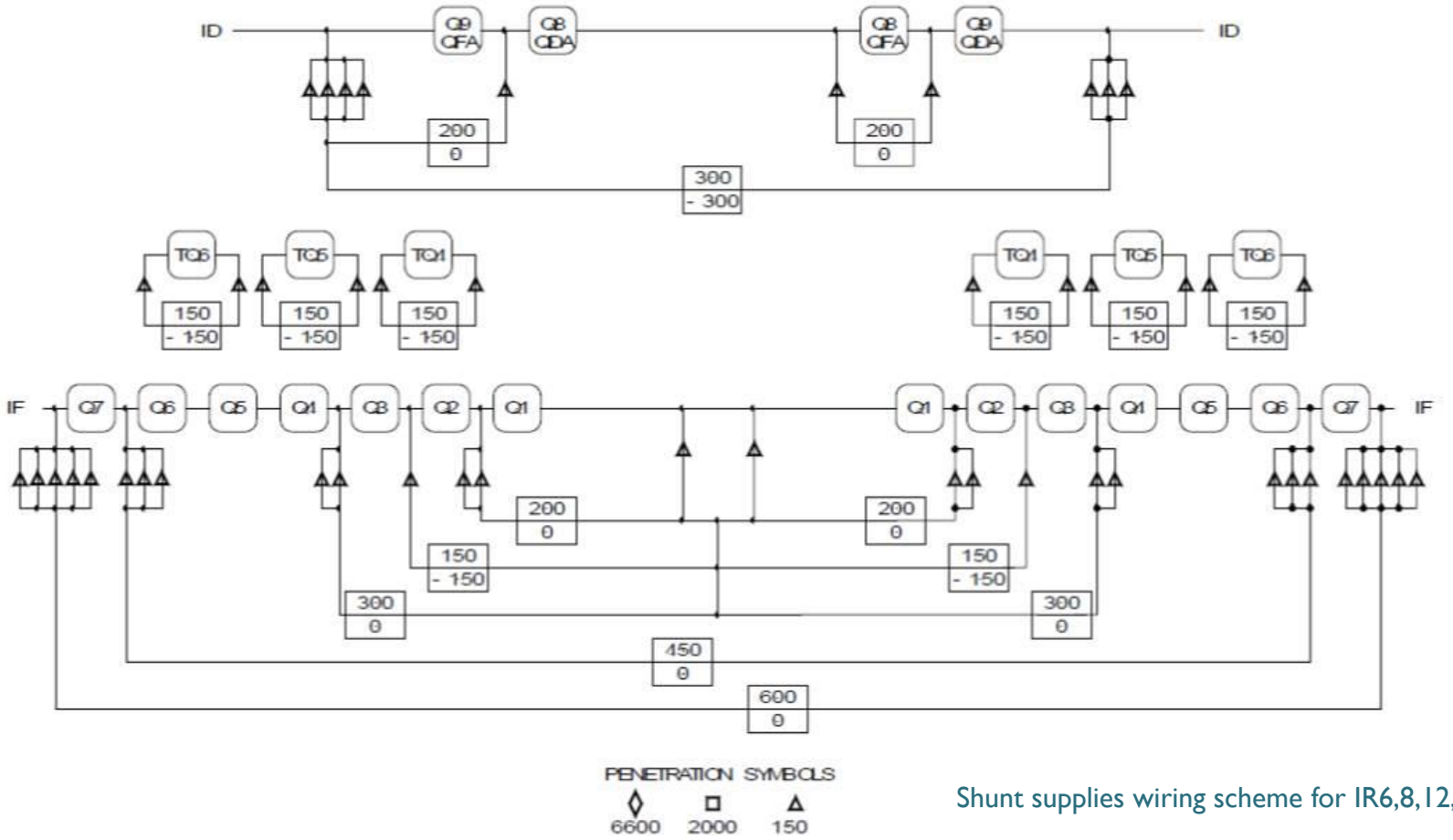


- Machine constraints: contrary to the LHC (one PS per quadrupole), RHIC features a nested wiring scheme which puts additional constraints into the MAD-X matching algorithm.



Shunt supplies wiring scheme for IR6,8,12,2

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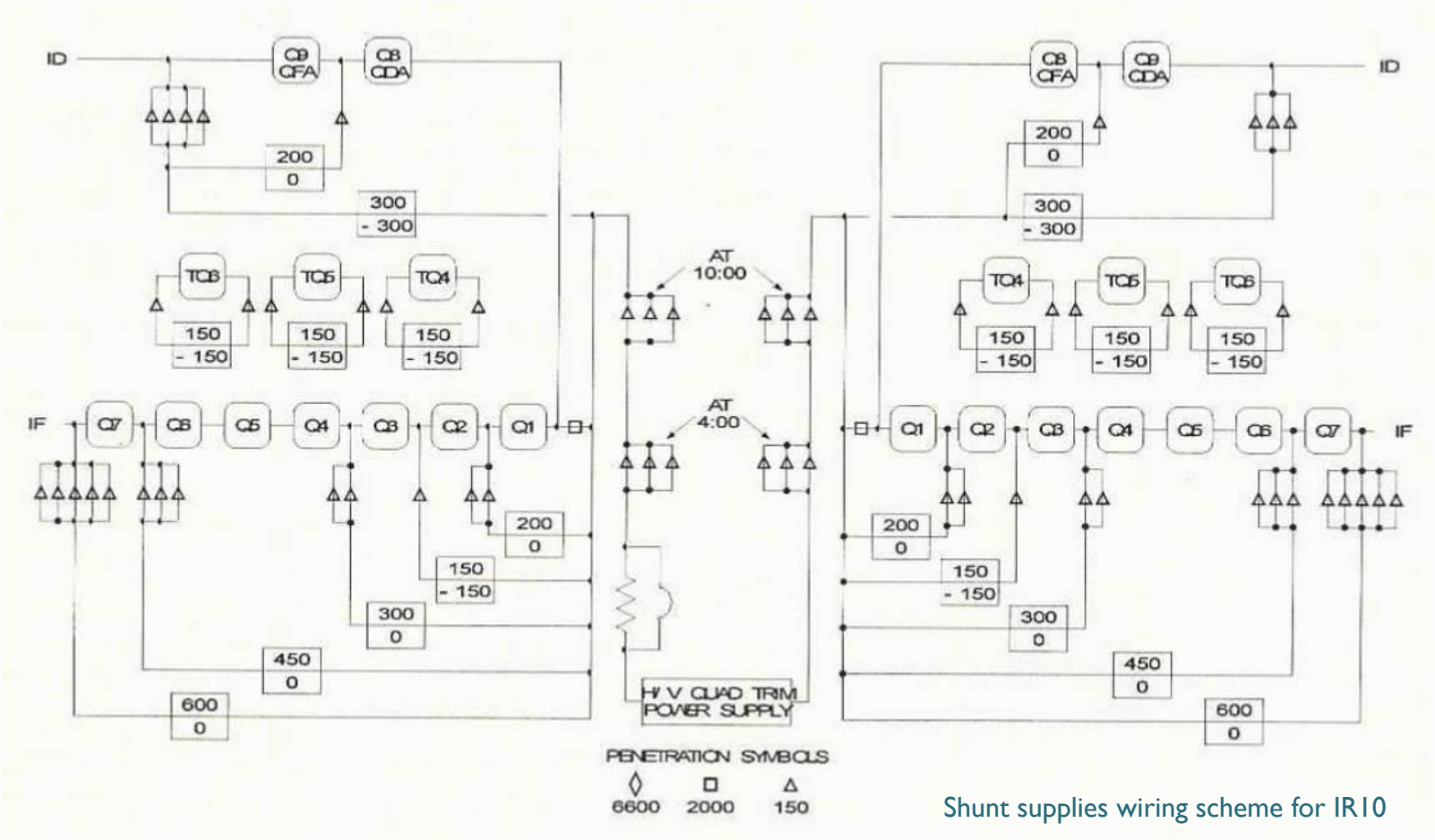
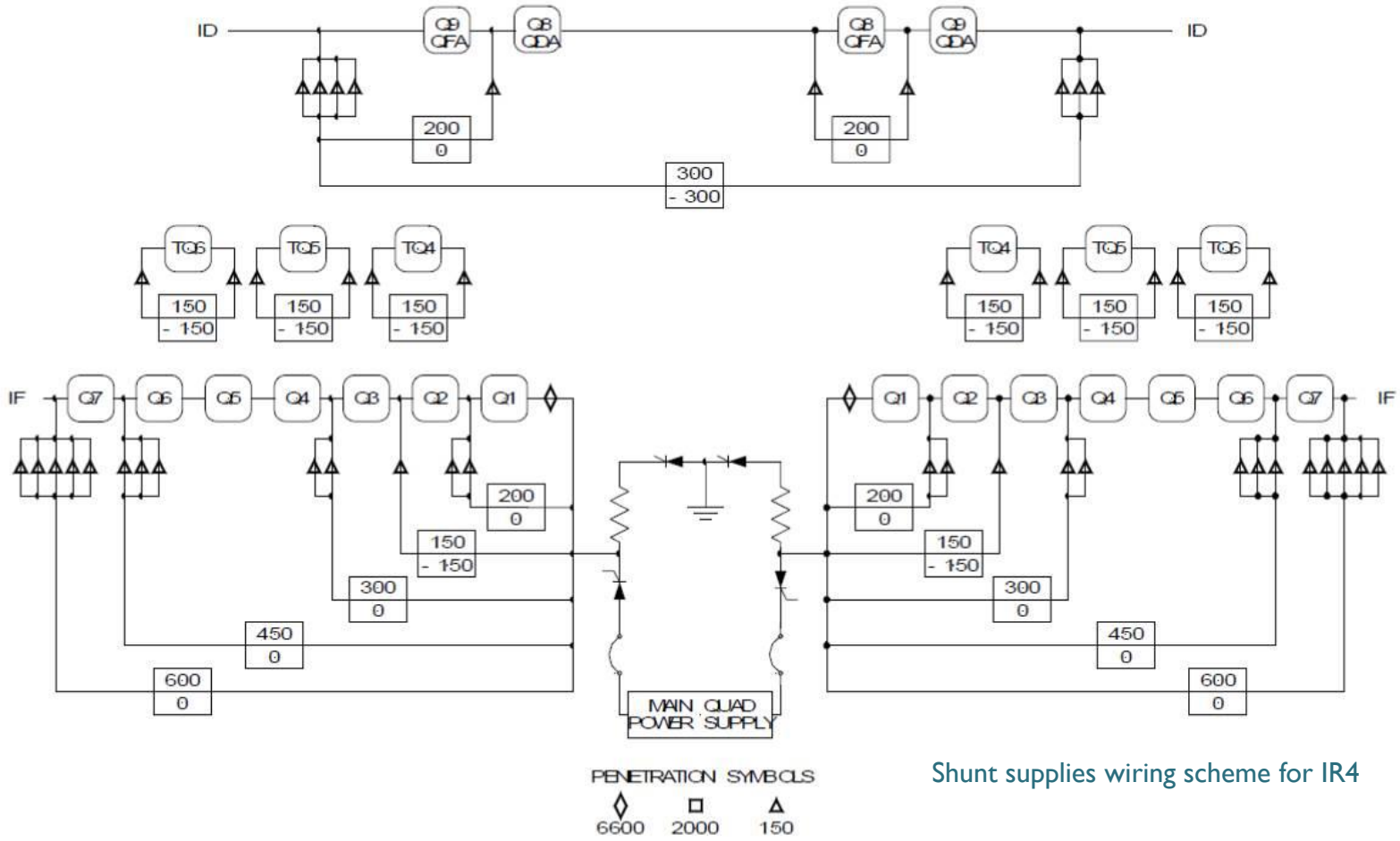


Shunt supplies wiring scheme for IR10

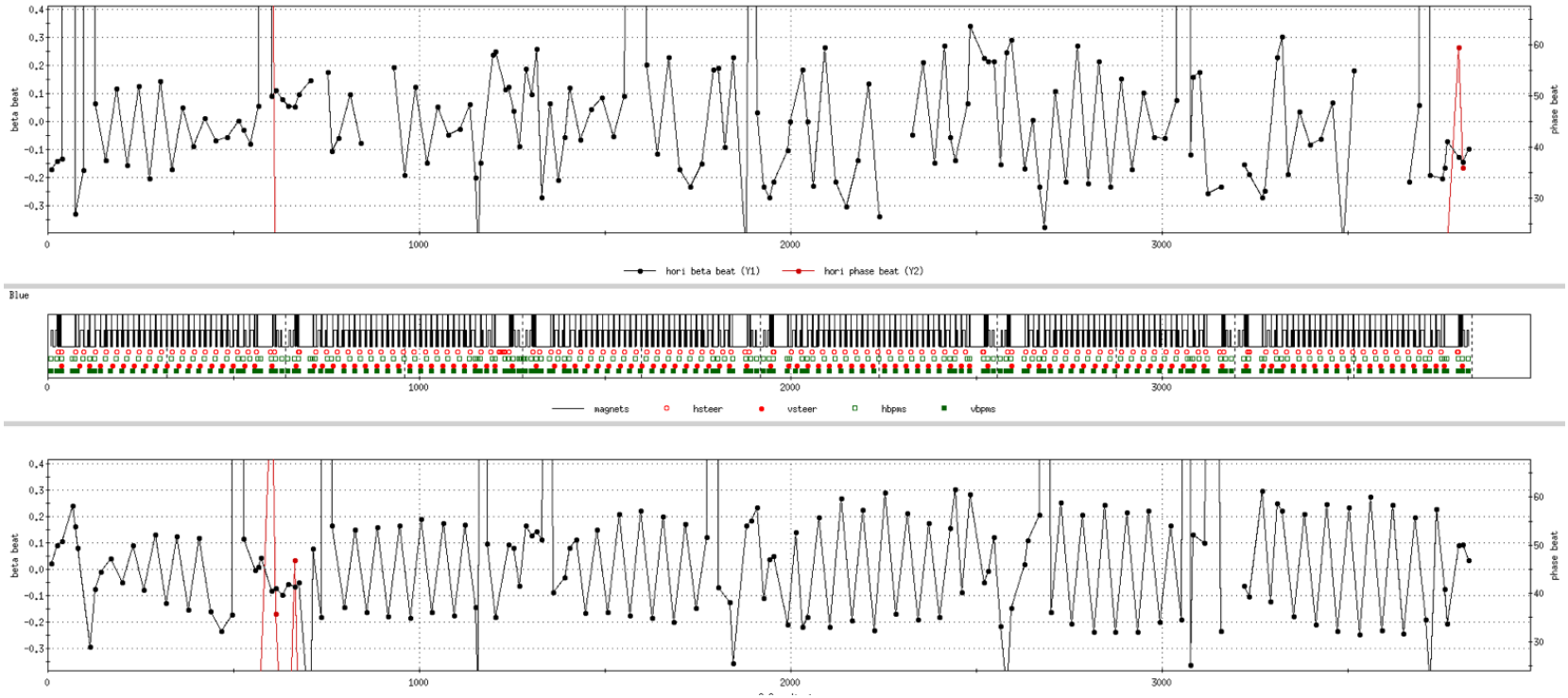
- Machine constraints: contrary to the LHC (one PS per quadrupole), RHIC features a nested wiring scheme which puts additional constraints into the MAD-X matching algorithm.



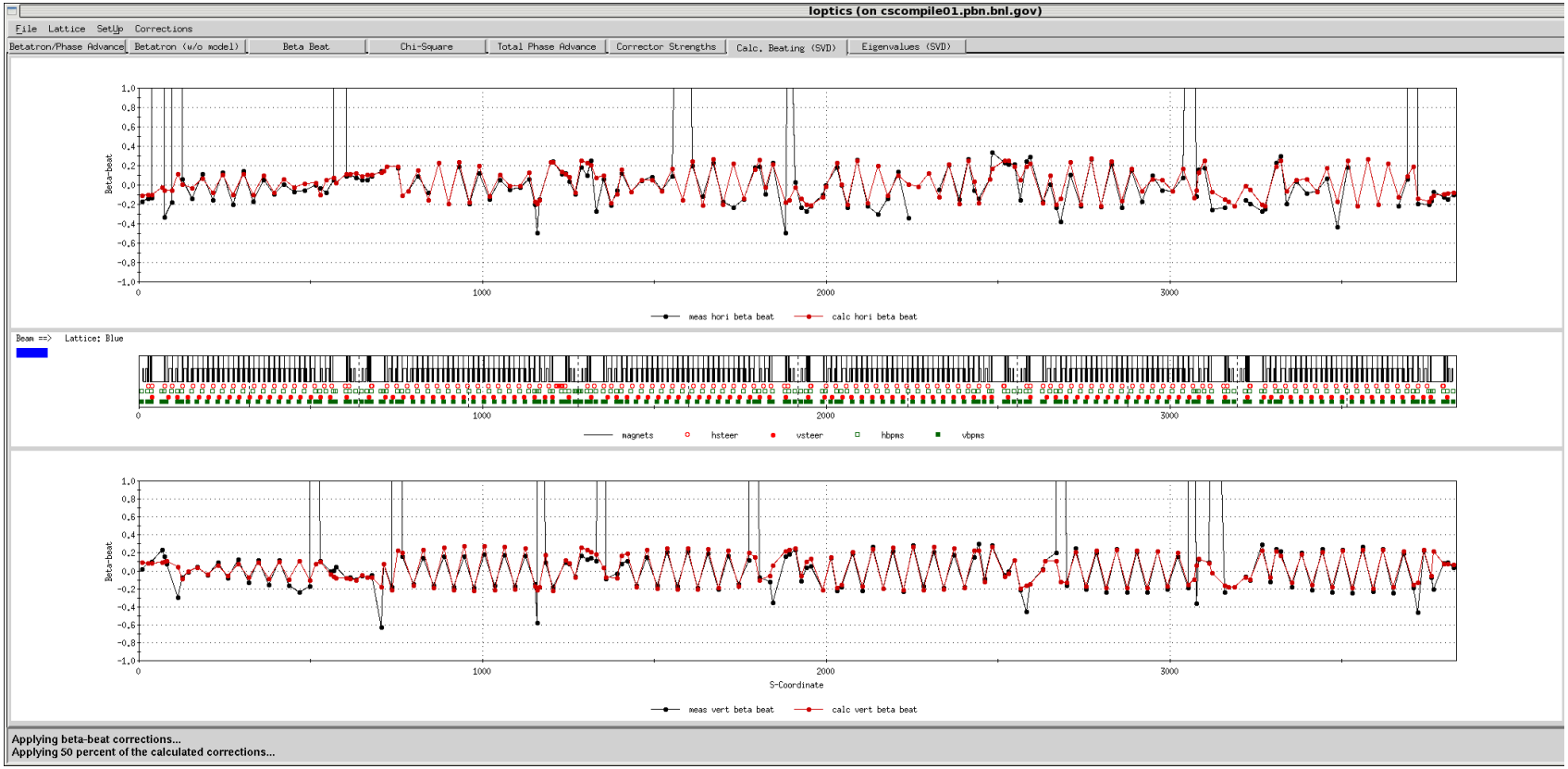
Shunt supplies wiring scheme for IR4

- Machine constraints: contrary to the LHC (one PS per quadrupole), RHIC features a nested wiring scheme which puts additional constraints into the MAD-X matching algorithm.

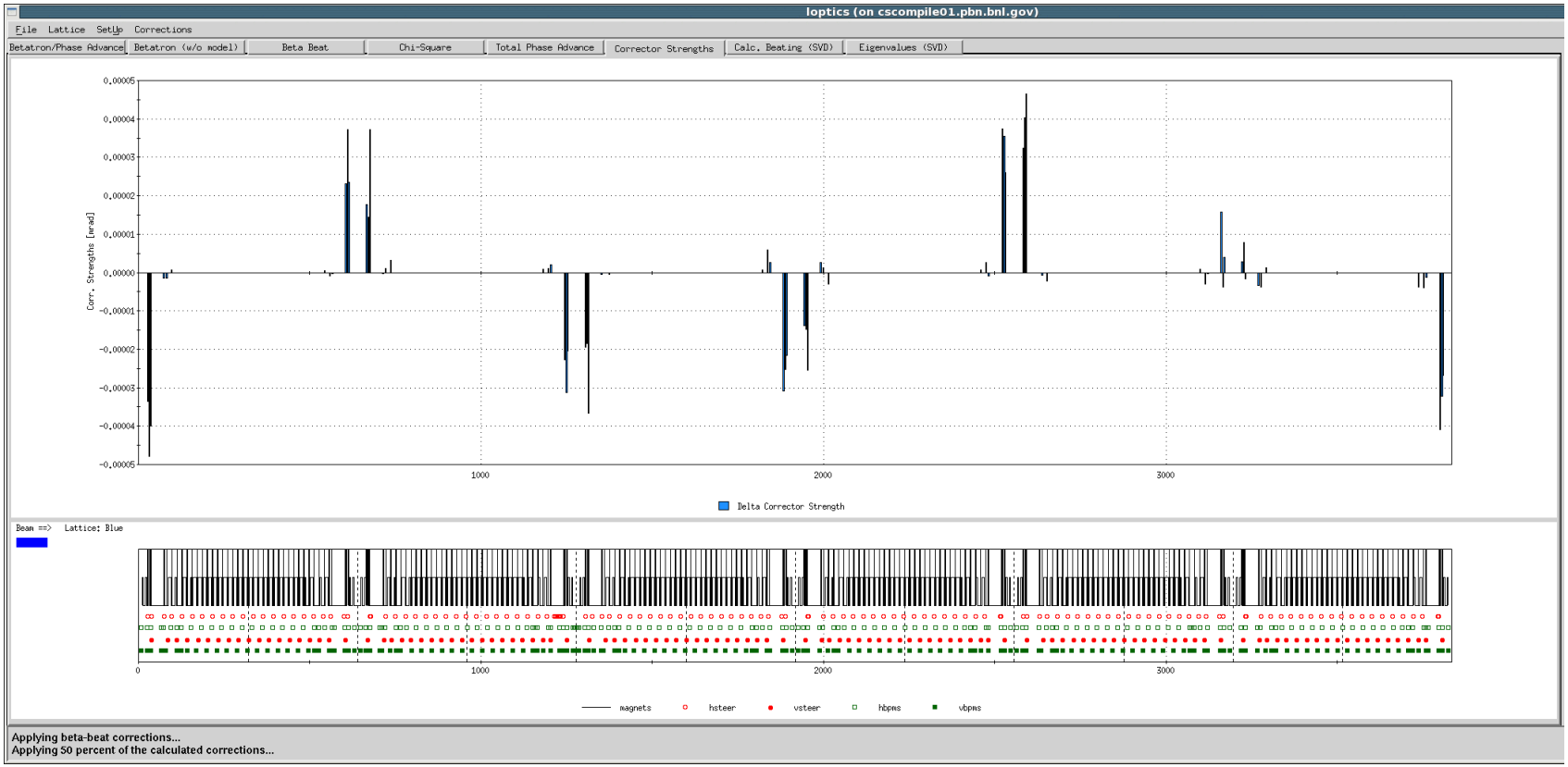
- The required quadrupole strengths for the RHIC ATS scheme are calculated based on an initial design with β^*(STAR,PHENIX) = 0.7m and perfect, unperturbed optics. Implementing these new optics would therefore require rounds of optics corrections: measurements from turn-by-turn orbit data show a 20-30% β-beat perturbation for the Au14-s0 optics



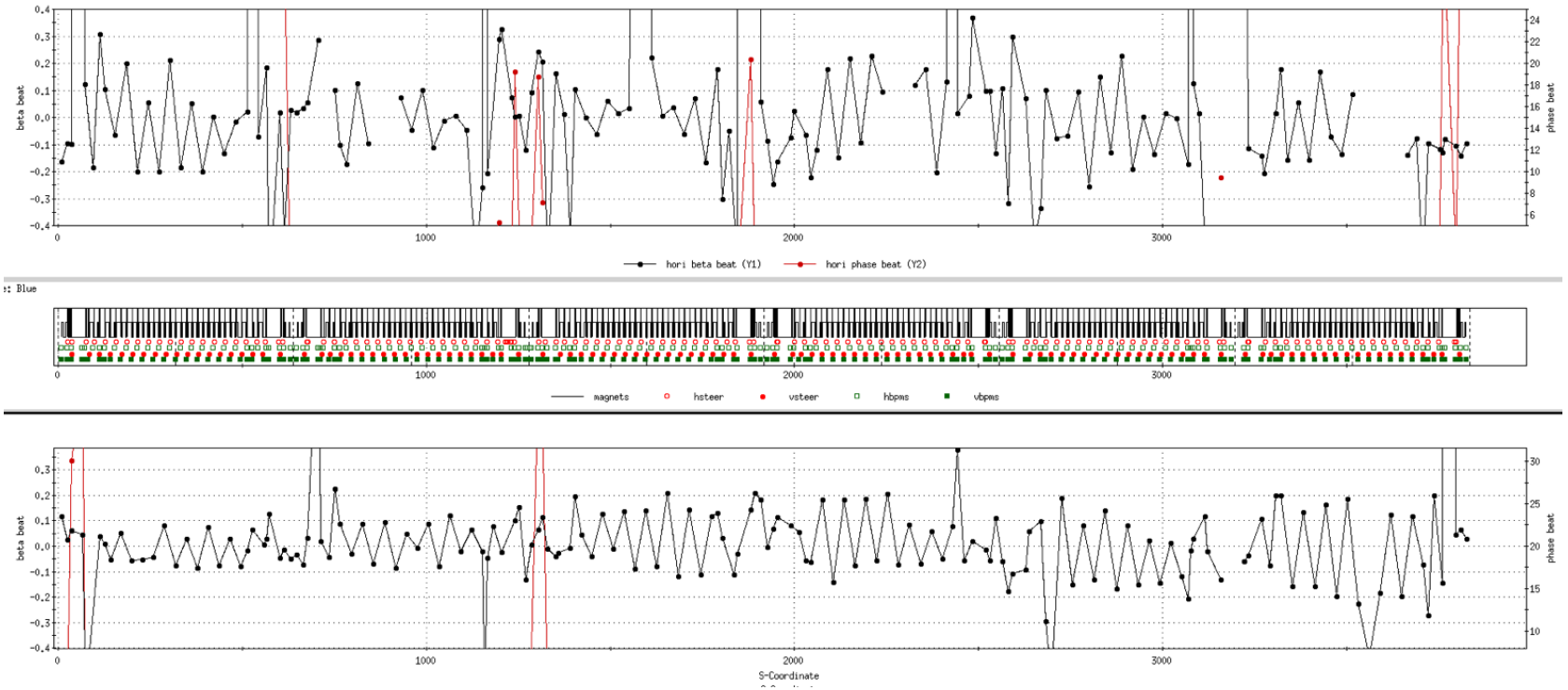
- Comparing predicted (red) and measured (black) beta-beating:



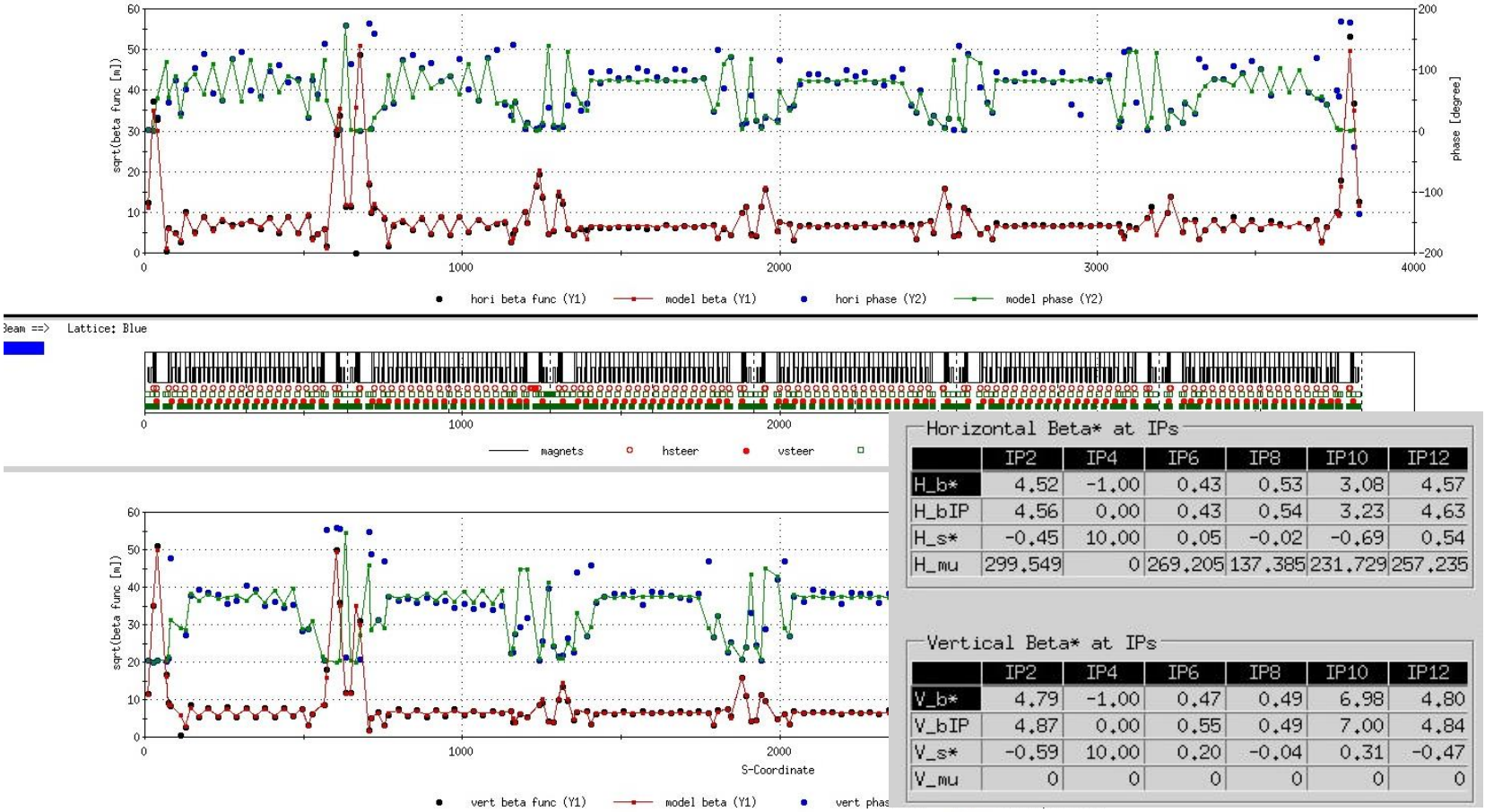
- Calculated corrector strengths for the 72 selected quadrupoles (Q1-3,TQ4-6 for all IR's):



- Beta-beating before and after corrections (for $\beta^* = 70$ cm):



- Timeline:
  - first APEX attempt: Fill #18126
    - established the storage ramp for telescope beta squeezing to 0.6m β*
    - 1st time 100% online β-beat correction with loptics
  - first time reaching 50cm in Blue for Fill #18128
  - first time with 50cm in Yellow for Fill #18239



Horizontal Beta* at IPs

	IP2	IP4	IP6	IP8	IP10	IP12
H_b*	4.52	-1.00	0.43	0.53	3.08	4.57
H_bIP	4.56	0.00	0.43	0.54	3.23	4.63
H_s*	-0.45	10.00	0.05	-0.02	-0.69	0.54
H_mu	299.549	0	269.205	137.385	231.729	257.235

Vertical Beta* at IPs

	IP2	IP4	IP6	IP8	IP10	IP12
V_b*	4.79	-1.00	0.47	0.49	6.98	4.80
V_bIP	4.87	0.00	0.55	0.49	7.00	4.84
V_s*	-0.59	10.00	0.20	-0.04	0.31	-0.47
V_mu	0	0	0	0	0	0

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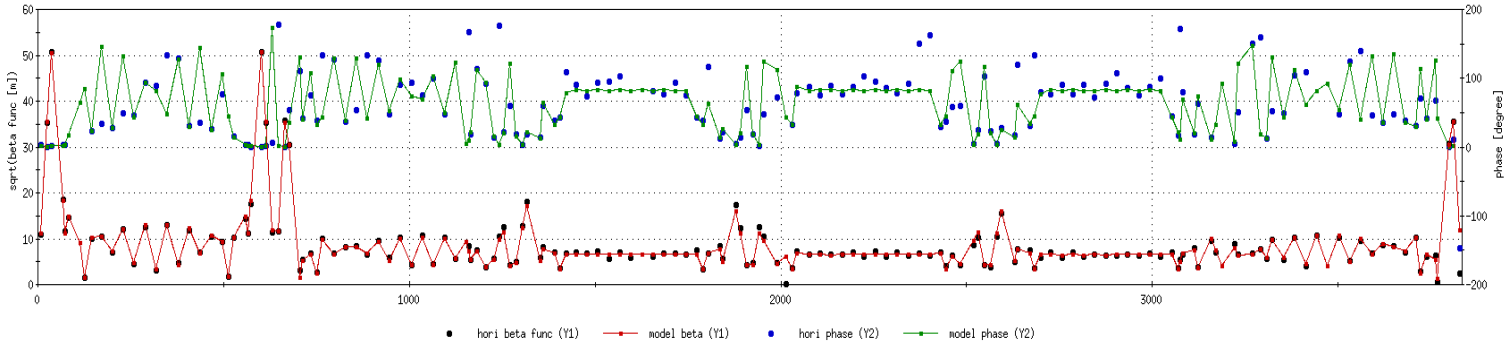
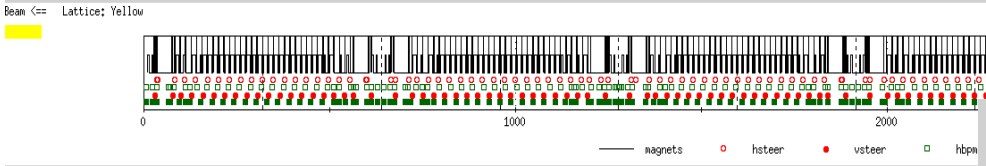
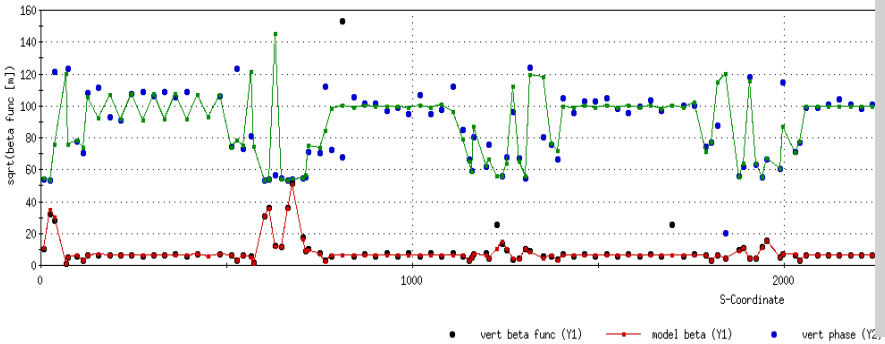






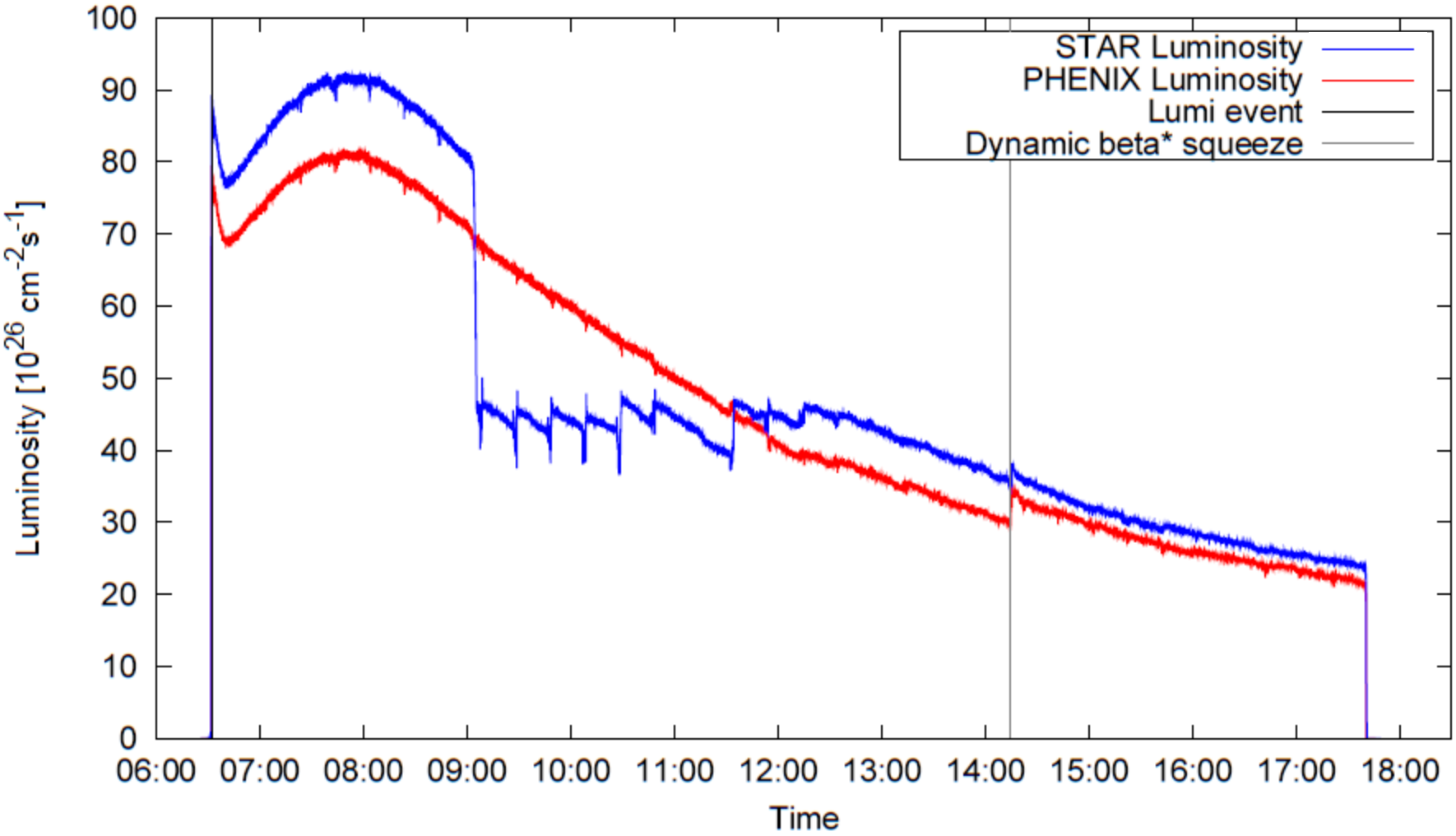
Horizontal Beta* at IPs

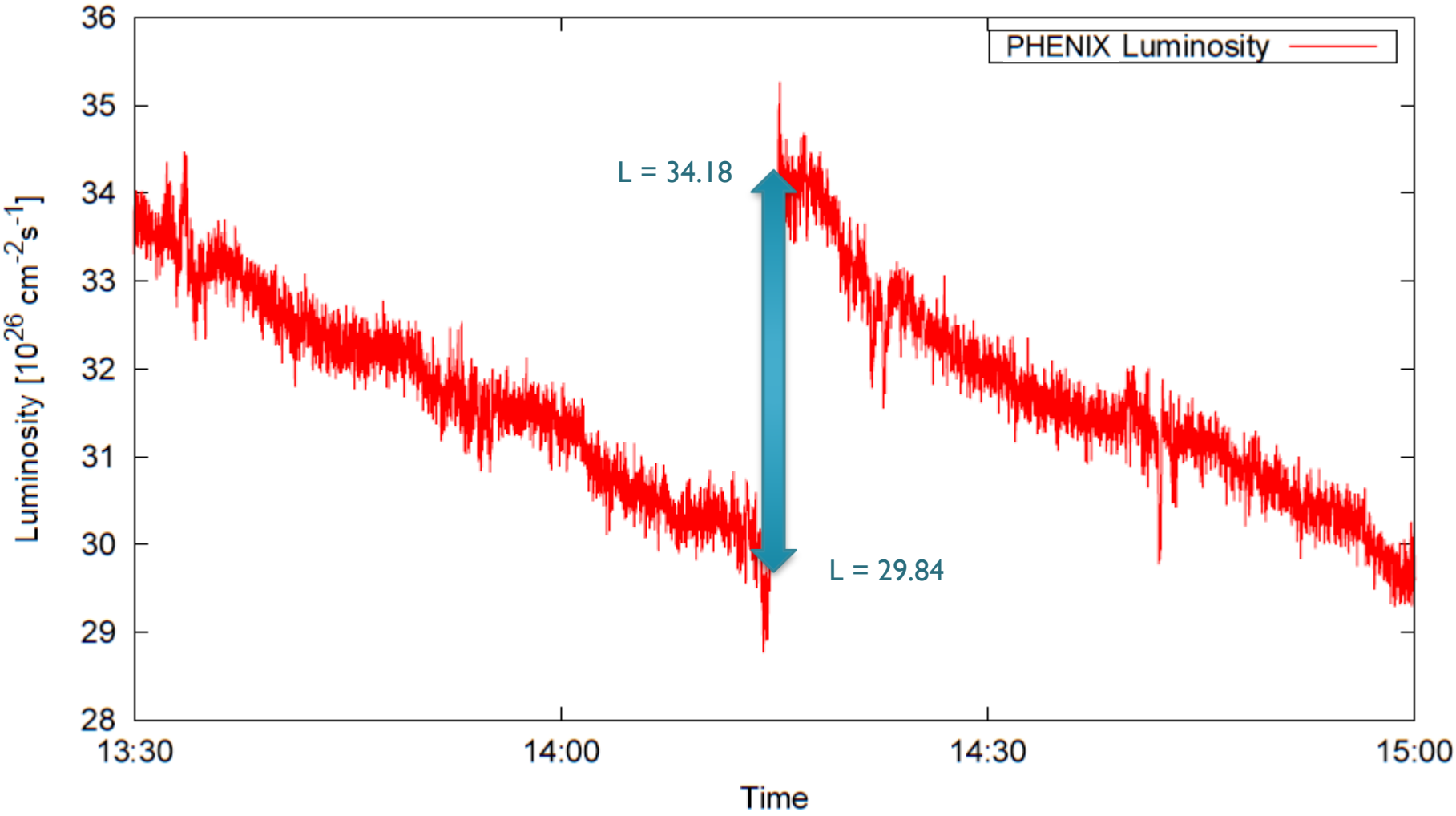
	IP2	IP4	IP6	IP8	IP10	IP12
H_b*	5.98	12.07	0.50	0.49	3.98	4.12
H_bIP	6.00	13.19	0.52	0.54	3.98	4.12
H_s*	-0.29	-3.67	0.10	-0.15	-0.19	-0.11
H_mu	239.591	235.286	55.555	157.394	162.894	41.484

Vertical Beta* at IPs

	IP2	IP4	IP6	IP8	IP10	IP12
V_b*	4.67	7.45	0.59	0.47	6.49	4.92
V_bIP	4.67	7.94	0.60	0.48	6.55	4.93
V_s*	0.17	-1.91	0.07	0.06	-0.61	-0.20
V_mu	188.5	344.3	313.6	47.7	217.6	170.0

- Luminosity as a function of time during one of the stores featuring dynamic β* squeeze:





- Measured luminosity (ZDC) gain: $\Delta = 14.54\%$
- Predicted: $(\text{hourglass}/\beta)_{ATS}/(\text{hourglass}/\beta)_{classic} = 14.47\%$ (using APEX optics measurements and assuming stable bunch length).

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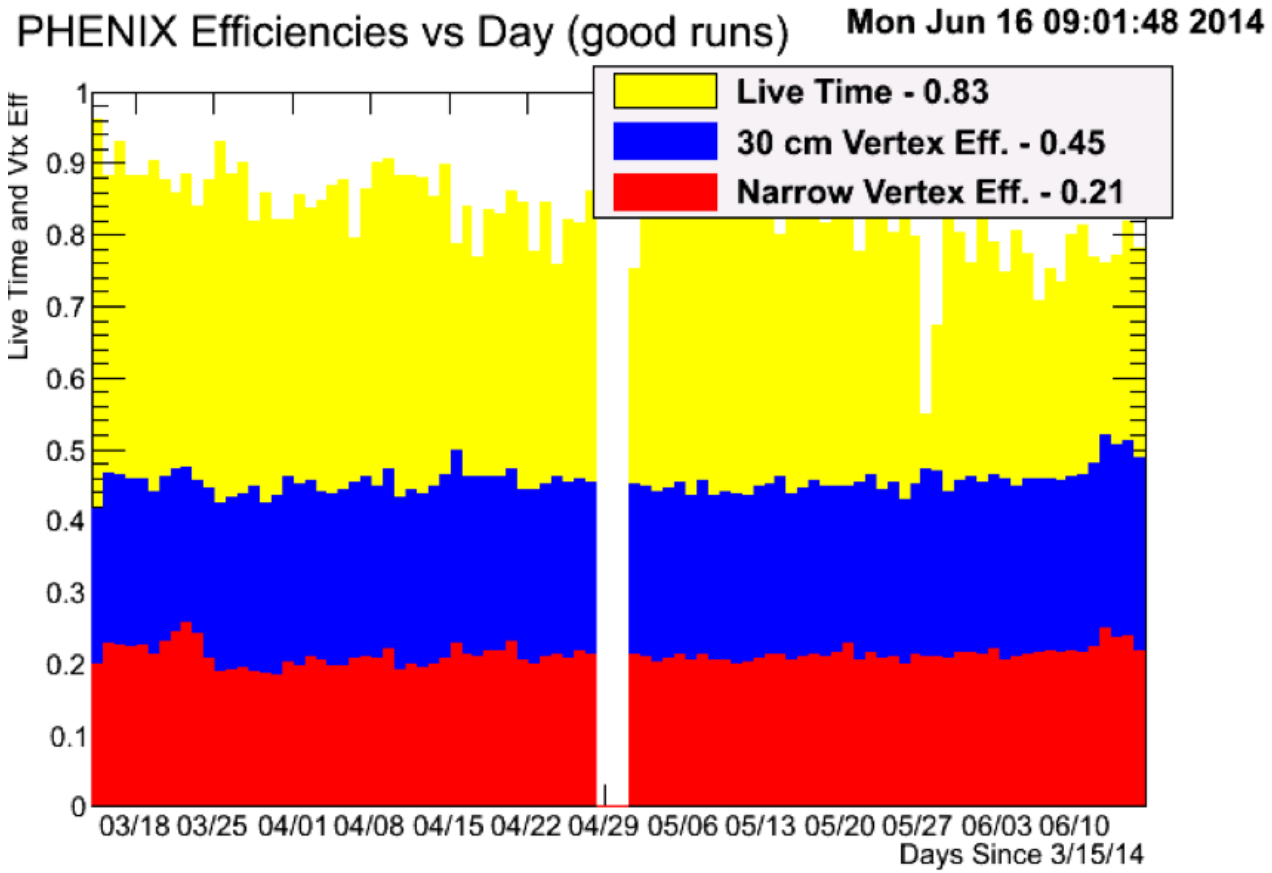
- End-of-store experiment:
  - with a 12x12 test ramp (APEX) = Fill #18272
  - with a full 111x111 = failed (LISA used Au14-s0 to re-optimize), Fill #18261
  - with a full 111x111 = successful, Fill #18320 (both Blue and Yellow)

- **THOR (Telescopic Hi-lumi Optics for RHIC) declared operational on 6/12/2014!**

- Complications during commissioning:
  - need to commission each individual stone separately: APEX was the ideal place to do so;
  - chromaticity control: prefire protection bumps and their large orbit offsets in the corresponding arcs pushed our knobs to a whole different realm (about -60 units in Yellow…) => should be less of a problem with the new masks!

CONCLUSION

- From Run14 operations:
  - successful implementation of the concept of ATS optics: achieved the requested β* in both STAR and PHENIX experiments;
  - resulting change in luminosity also follows predictions from design;
  - for future A-A runs, the next step is leveling luminosities for the entire length of a store.



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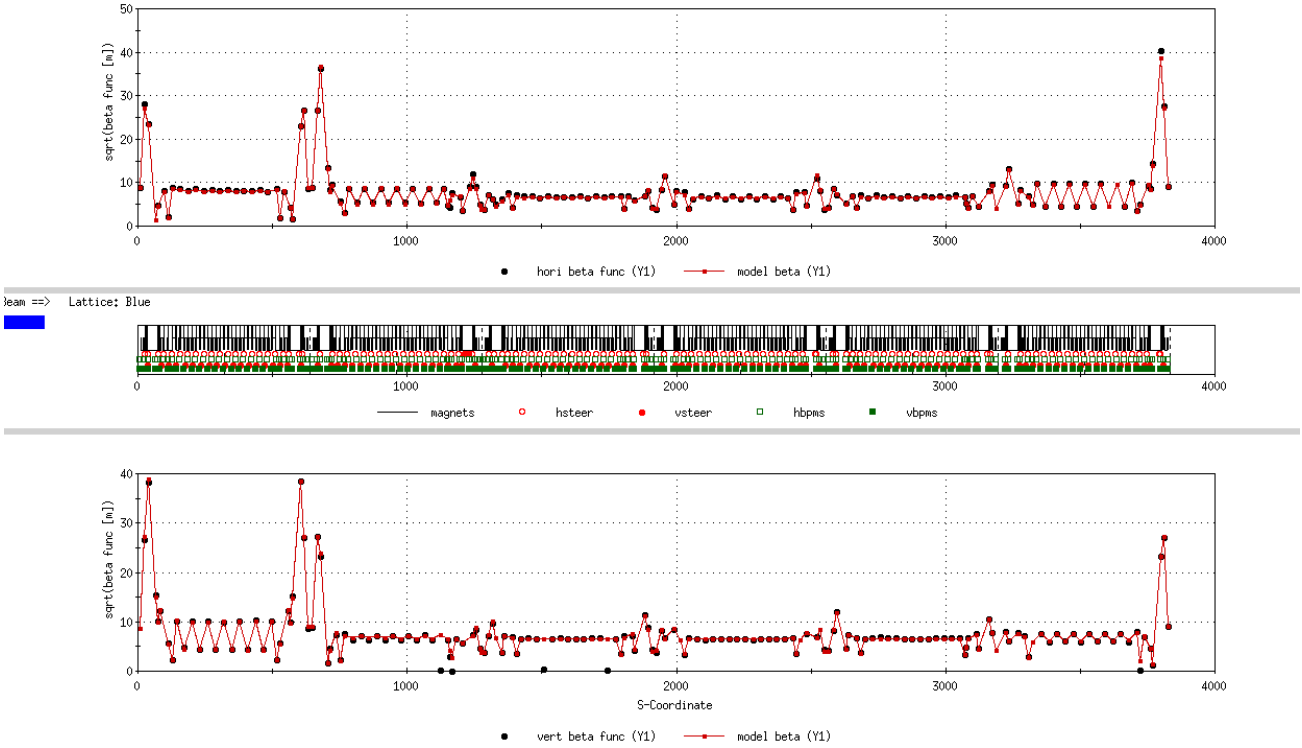
- Run15 applications:
  - based on initial design by S. White, RHIC Run15 for polarized protons features a lattice that satisfies all theoretical requirements for "full" ATS implementation;
  - redesigned the whole RHIC ramp construction system to allow for additional lattice constraints related to operations with the electron lens compensation scheme: first linear optics measurements show great agreement with design values.



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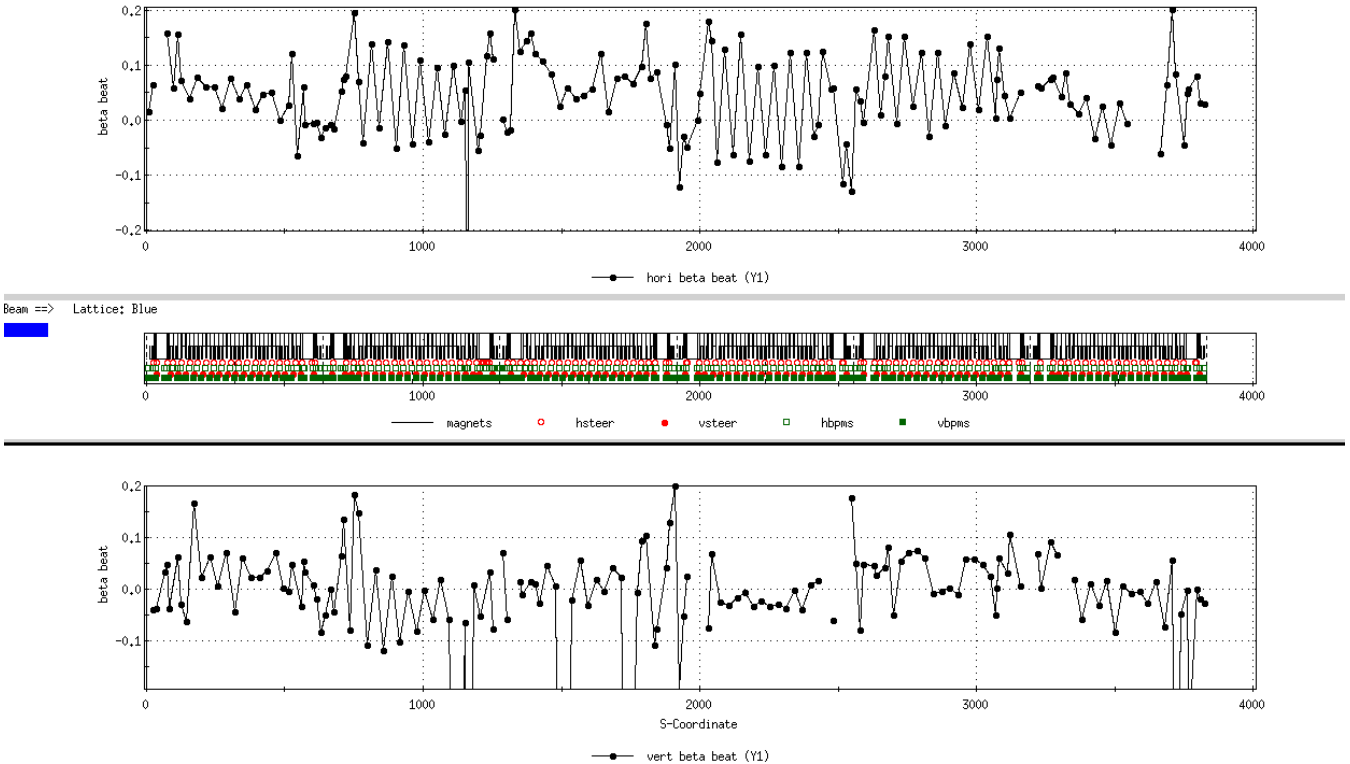

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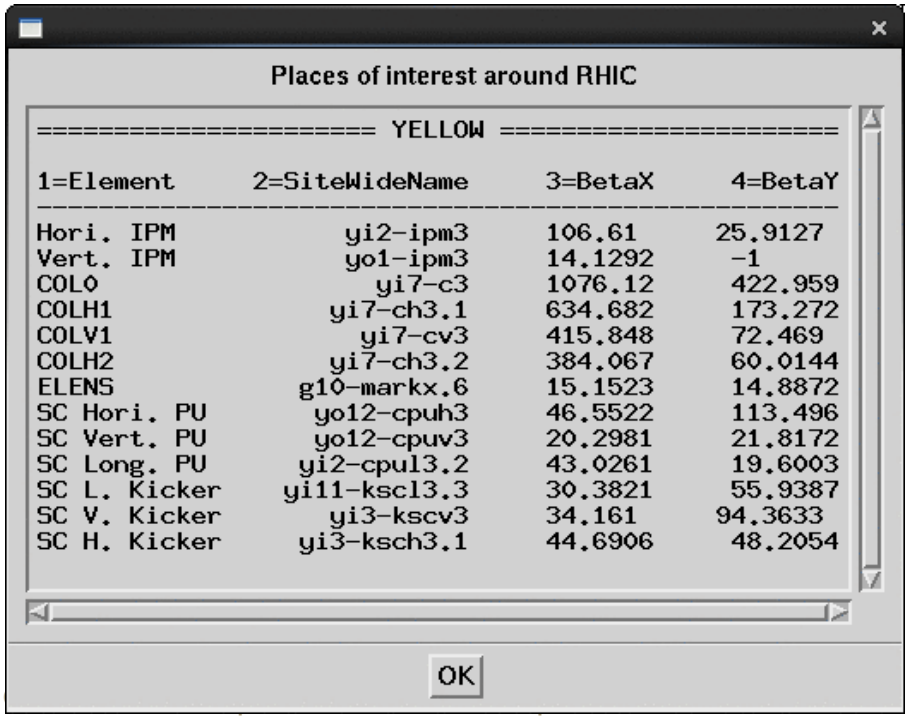

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- Additional features to be tested:
  - RHIC Run15: repeat chromaticity measurements, incl. non-linear terms, to assess the quality of the ATS lattice design;
  - test a new chromaticity knob that uses 24 families (instead of the current 2), to allow for specific corrections in the ATS matching section;
  - prepare a lattice comparable to pp-Run15 but dedicated to A-A runs: check power supply limits, take SC system requirements into account.