High Luminosity LHC

Difference between SLHC3.1b and HLLHCV1.0 (for DA)

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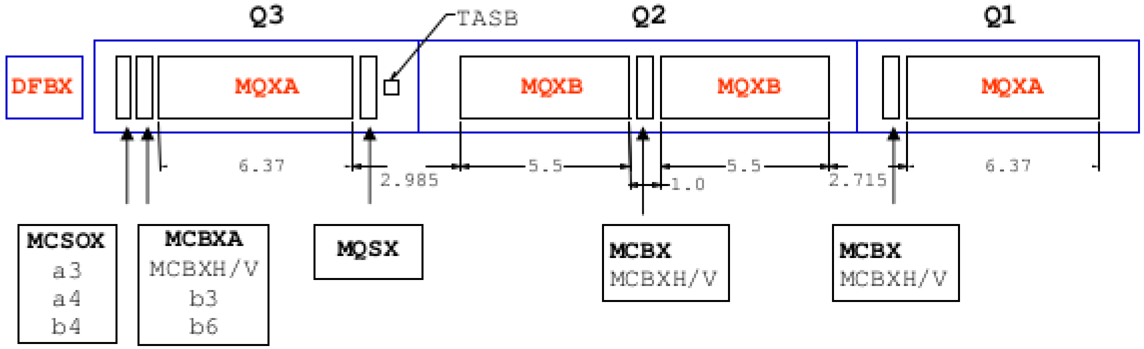
SLHCV3.1b – HLLHCV1.0

- Differences related to the triplet layout relevant for DA of HLLHCV1.0 w.r.t. SLHCV3.1b:a
  - Larger betamax (7%) due to: smaller gradient and Q1-Q3 split (50cm additional drift). Therefore:
  - Larger driving terms and main sextupole strengths.
  - Different positions of the quadrupole connection sides w.r.t the IP.
  - Different phase advance between IP1 and IP5.
  - Different position of the correctors.

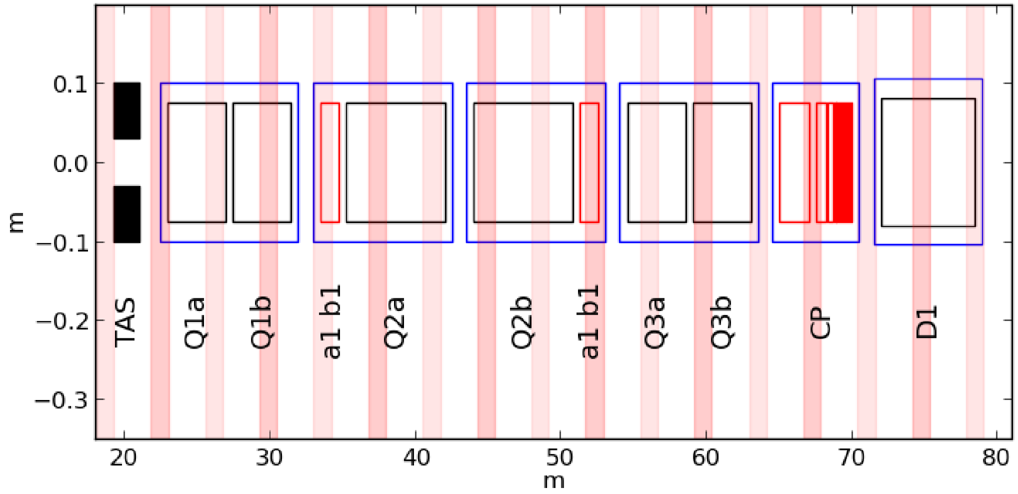
DA studies overview

- First DA studies showed a drop of D of about 1 sigma.
- Review of the tools showed no significant defects.
- Review of the impact of the orientation showed a larger impact of the systematic a4, a6 and a smaller impact of the systematic b3, b5. However the present field qualities are dominated by random components.
- Under study: potential improvements by different choice of the phase advance between IP1 and IP5.

HL-LHC V1.0 layout



LHC nominal layout



HLLHC V1.0 layout

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Triplet layout and orientations

- SLCHCV3.1b:

a) IP |Q1= |Q2a= |Q2b= |Q3=

- HLLHCV1.0:

a) IP =Q1a||Q1b= =Q2a| |Q2b= =Q3a||Q3b=

b) IP |Q1a=|Q1b= |Q2a= |Q2b= |Q3a=|Q3b=

c) IP =Q1a||Q1b= |Q2a= =Q2b| =Q3a||Q3b=

Left side mirror symmetric. = lead end side; | non lead end side;

3.1b: side cancellation between Q1-Q3 and Q2

1.0a: local cancellation between quads, preferred orientation from hardware integration

1.0b: Mimic closely 3.1b

1.0c: reverses Q2 to better cancel Q1b with Q2a

Other options tested but not exhaustively.

Correction Strategy

- Strategy to set the correctors' strength (see S. Fartoukh, LHC Project Note 349): minimisation of driving terms.

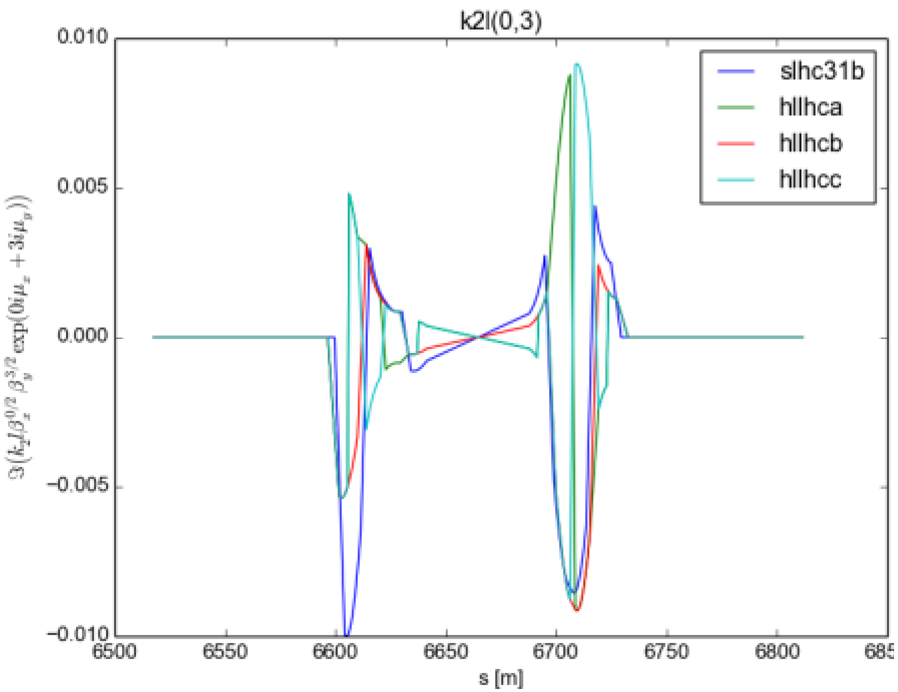
$$\begin{cases} c\,(b_n;p,q) \;\equiv\; \int_{\mathrm{IR_{left}}} ds\, K_{n-1}(s)\, \beta_x^{p/2}\, \beta_y^{q/2} + (-1)^n \int_{\mathrm{IR_{right}}} ds\, K_{n-1}(s)\, \beta_x^{p/2}\, \beta_y^{q/2} & , q\,\text{even} \\ c\,(a_n;p,q) \;\equiv\; \int_{\mathrm{IR_{left}}} ds\, K_{n-1}^{(s)}(s)\, \beta_x^{p/2}\, \beta_y^{q/2} + (-1)^n \int_{\mathrm{IR_{right}}} ds\, K_{n-1}^{(s)}(s)\, \beta_x^{p/2}\, \beta_y^{q/2} & , q\,\text{odd}\,, \end{cases}$$

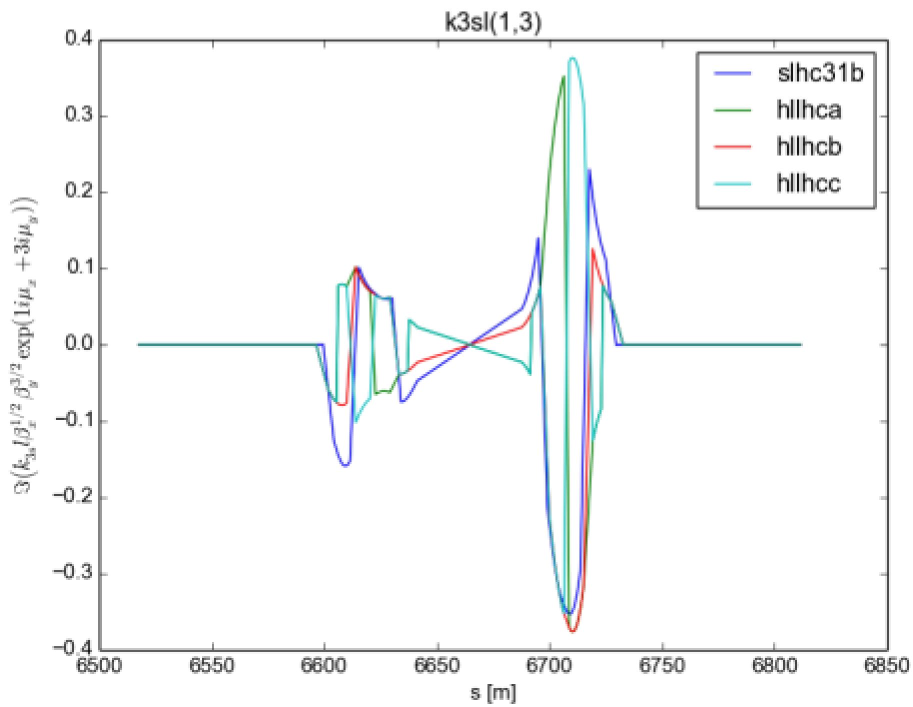
- Selection of the driving terms to be corrected:
  - b3: c(1, 2) and c(2, 1); a3: c(0, 3) and c(3, 0)
  - b4: c(4, 0) and c(0, 4); a4: c(3, 1) and c(1, 3)
  - b6: c(0, 6) and c(6, 0); a5: c(0, 5) and c(5, 0)
  - b5: c(5, 0) and c(0, 5); a6: c(5, 1) and c(1, 5)

The choice of the resonances is based on the proximity to the working point

Feed down effects are not included in the correction strategy, but effect from systematic errors is minimised.

Triplet harmonic driving terms





Errors modulate by large variation of the beta functions.

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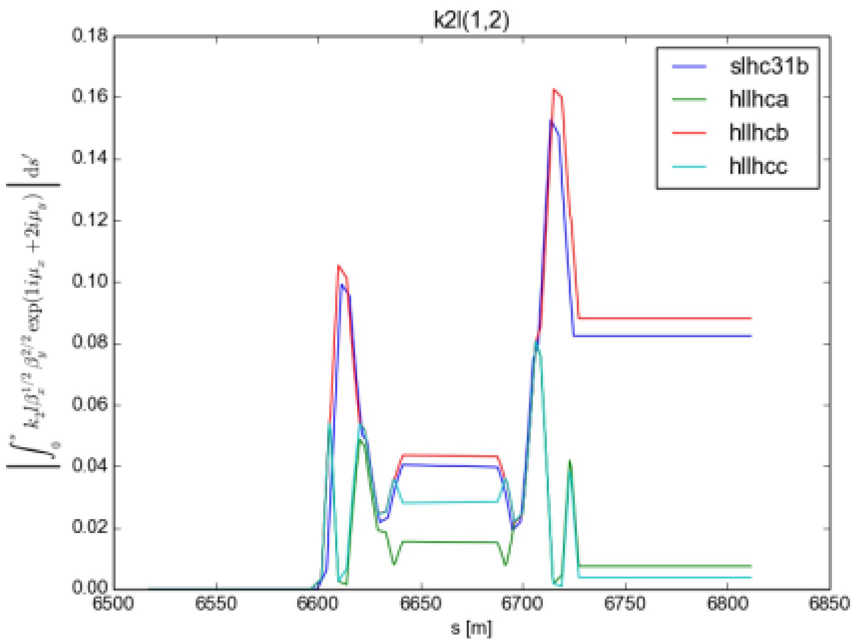
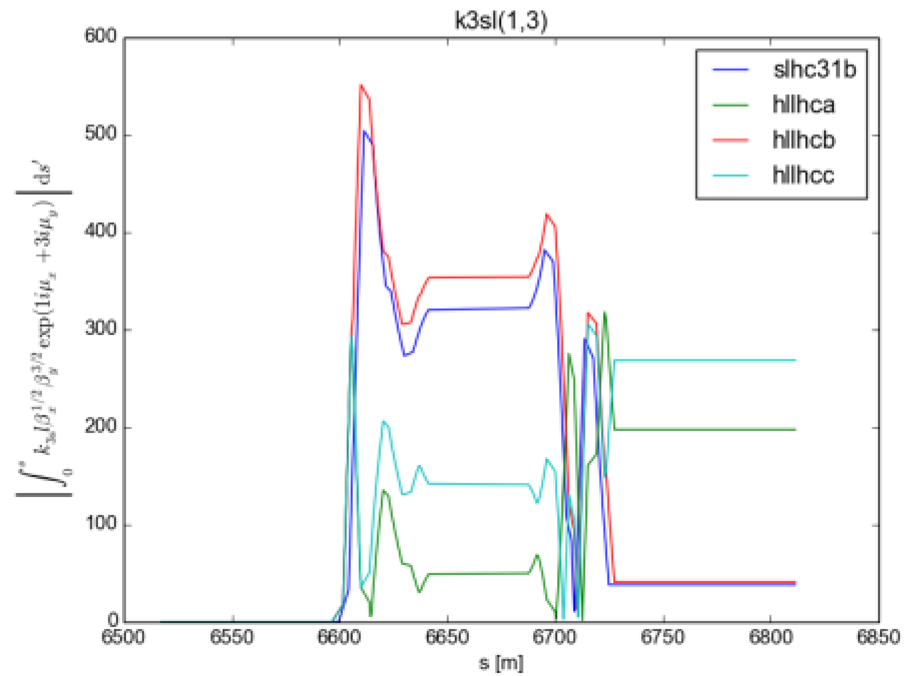
Integrated driving terms





3.1b like orientation always worse at the IP, but left-right cancellation occurs for odd skew components.

Tracking tools

- Model: For each magnet class $b_S = b_M + \frac{b_U \xi_U}{1.5}$and for each magnet $b = b_S + \xi_R b_R$ where b stands for all $b_n = B_n/B_N$ and $a_n = A_n/B_N$ and $\xi_U$and $\xi_R$are normal distributed random variables cut at 1.5σ and 3σ.
- Error tables: set of M,U,S values for all multipoles and for inj. and collision energy at a given reference radius as seen from the current lead end (e.g. Rr_MQXCD, b3M).
- Macros and scripts: Depending on global flags ON_(AB)(SR) assign errors to individual magnets taking into account the magnet orientation.

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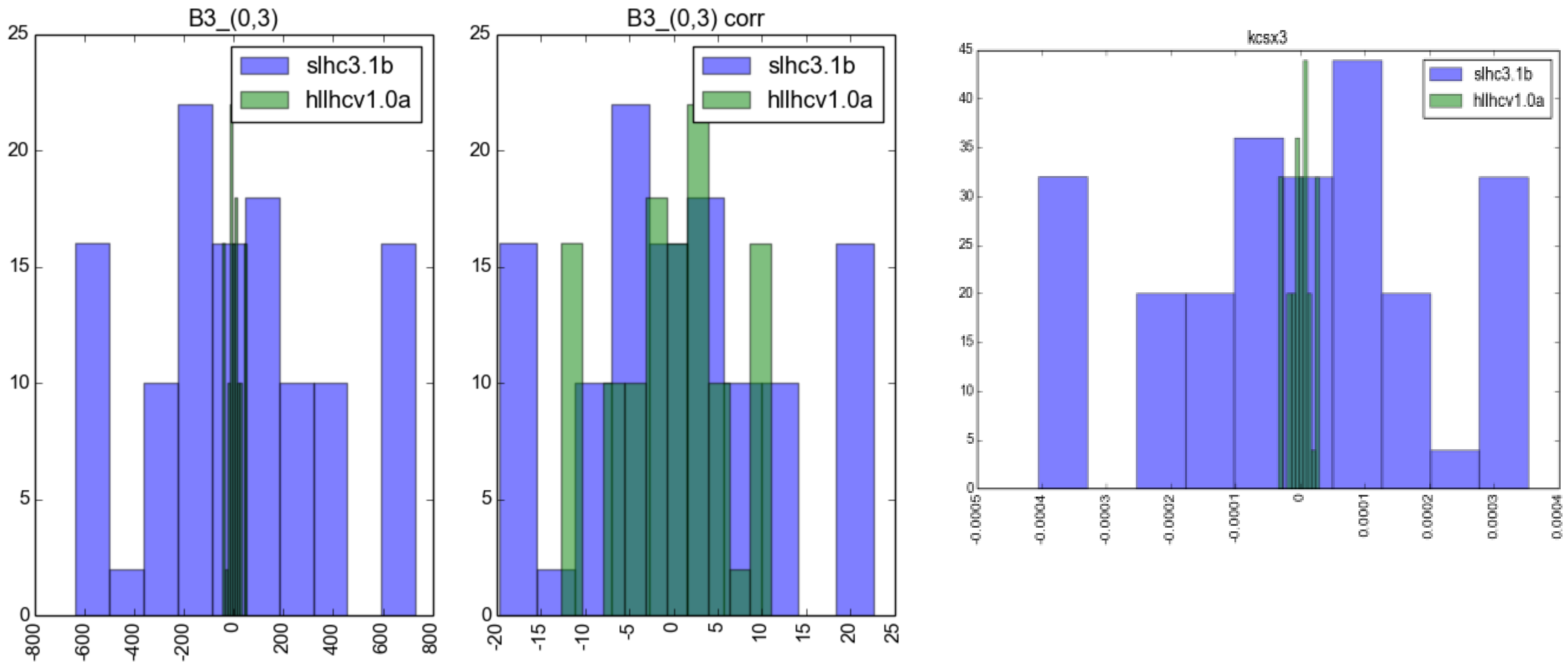
Target 65 MQX error table

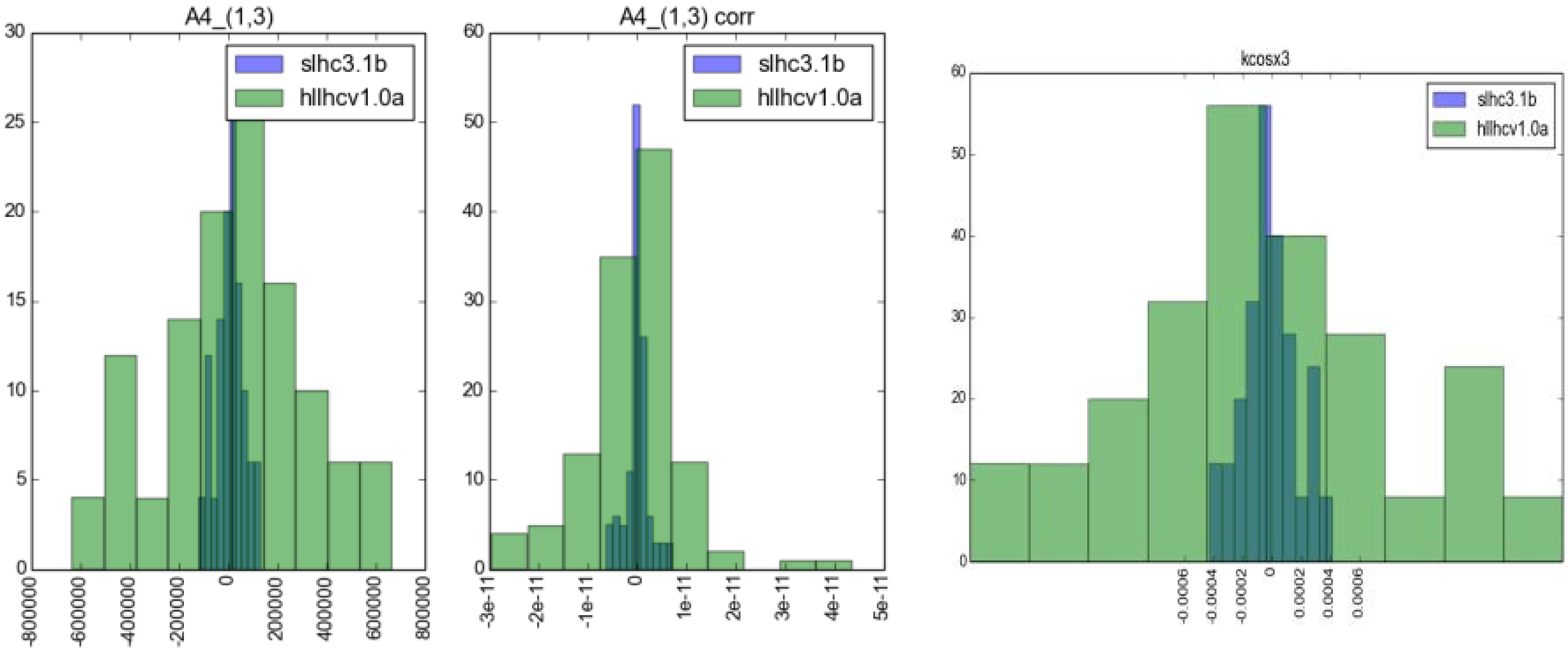
```
b1M  0.0000 ; b1U  0.0000 ; b1R  0.0000 ;   a1M  0.0000 ; a1U  0.0000 ; a1R  0.0000 ;
b2M  0.0000 ; b2U  0.0000 ; b2R  0.0000 ;   a2M  0.0000 ; a2U  0.0000 ; a2R  0.0000 ;
b3M  0.0000 ; b3U  0.8200 ; b3R  0.8200 ;   a3M  0.0000 ; a3U  0.8000 ; a3R  0.8000 ;
b4M  0.0000 ; b4U  0.5700 ; b4R  0.5700 ;   a4M  0.0000 ; a4U  0.6500 ; a4R  0.6500 ;
b5M  0.0000 ; b5U  0.0840 ; b5R  0.0840 ;   a5M  0.0000 ; a5U  0.0860 ; a5R  0.0860 ;
b6M  0.8000 ; b6U  0.5500 ; b6R  0.5500 ;   a6M  0.0000 ; a6U  0.1550 ; a6R  0.0620 ;
b7M  0.0000 ; b7U  0.0950 ; b7R  0.0950 ;   a7M  0.0000 ; a7U  0.1520 ; a7R  0.0950 ;
b8M  0.0000 ; b8U  0.0650 ; b8R  0.0650 ;   a8M  0.0000 ; a8U  0.0880 ; a8R  0.0550 ;
b9M  0.0000 ; b9U  0.0350 ; b9R  0.0350 ;   a9M  0.0000 ; a9U  0.0640 ; a9R  0.0400 ;
b10M 0.0750 ; b10U 0.1000 ; b10R 0.1000 ;   a10M 0.0000 ; a10U 0.0400 ; a10R 0.0320 ;
b11M 0.0000 ; b11U 0.0208 ; b11R 0.0208 ;   a11M 0.0000 ; a11U 0.0260 ; a11R 0.0208 ;
b12M 0.0000 ; b12U 0.0144 ; b12R 0.0144 ;   a12M 0.0000 ; a12U 0.0140 ; a12R 0.0140 ;
b13M 0.0000 ; b13U 0.0072 ; b13R 0.0072 ;   a13M 0.0000 ; a13U 0.0100 ; a13R 0.0100 ;
b14M-0.0200 ; b14U 0.0115 ; b14R 0.0115 ;   a14M 0.0000 ; a14U 0.0050 ; a14R 0.0050 ;
b15M 0.0000 ; b15U 0.0000 ; b15R 0.0000 ;   a15M 0.0000 ; a15U 0.0000 ; a15R 0.0000 ;
```

Driving term and corrector strength



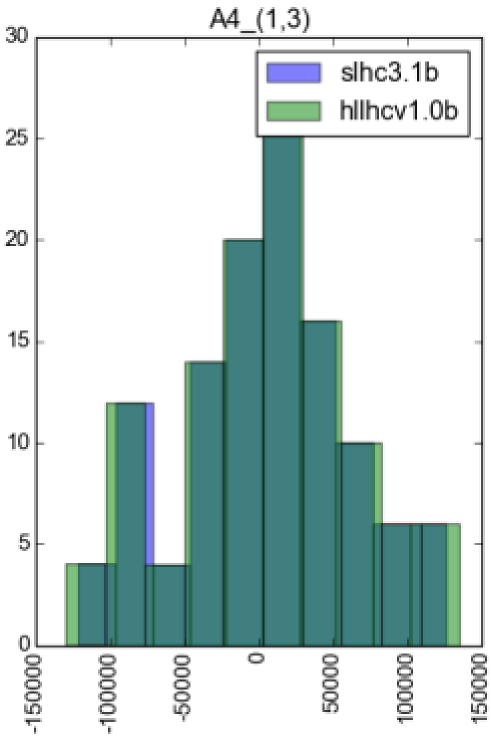
Example when random are off: 3.1b worse than 1.0a

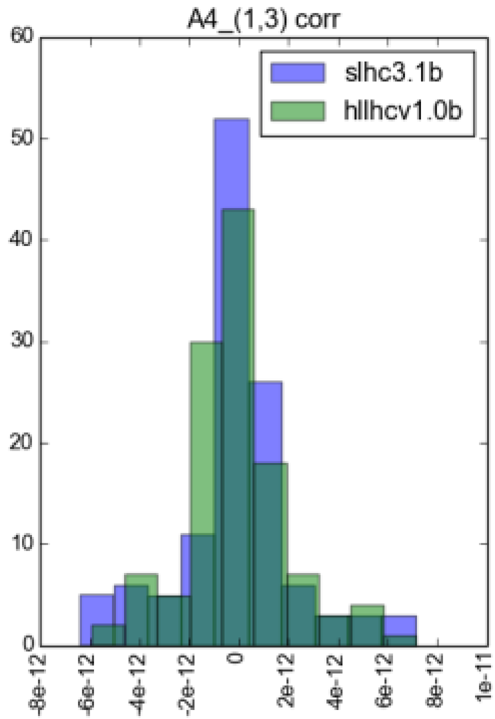
Driving term and corrector strength

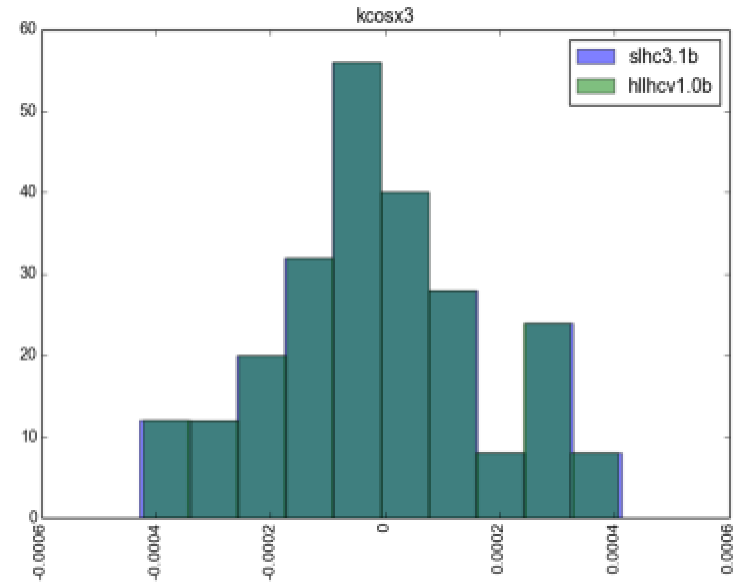


Example when random are off: 1.0a worse than 3.1b

Driving term and corrector strength







Example when random are off: 1.0b very similar to 3.1b.

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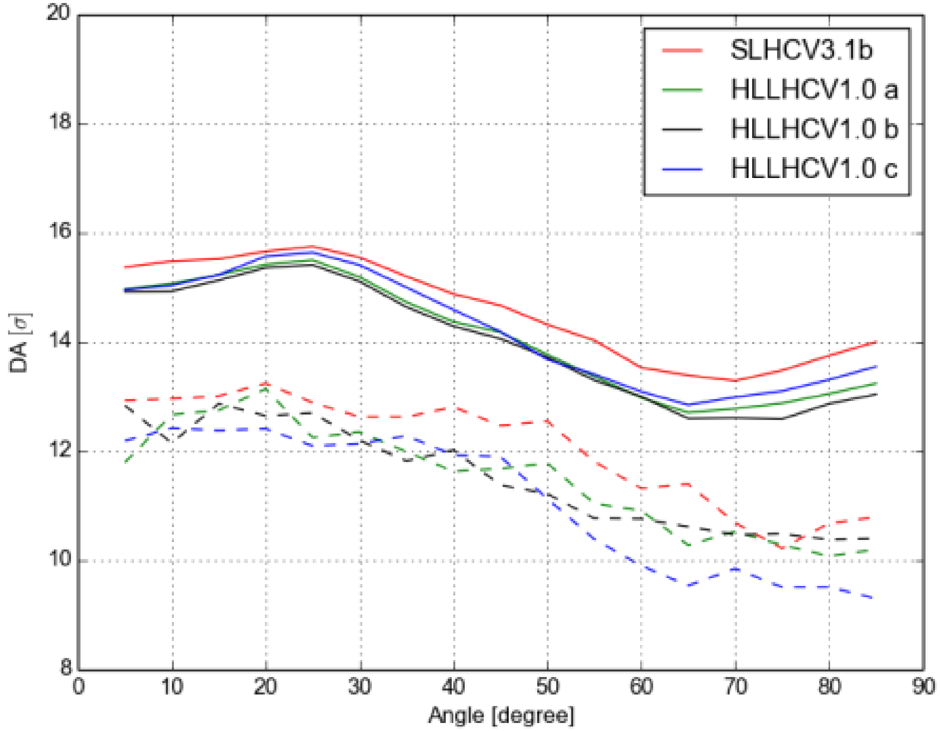
Tracking results



- 1.0 optics have the same beta* of 3.1b slightly different IP1-IP5 phase advances and slightly higher beta function.
- Using target 65 error table optimized for 3.1b: not obvious choice of reorientation.