Trying to reduce corrector strength and residual orbit by profiting of the alignment system capabilities.

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112th HiLumi WP2 Meeting – 05/12/2017

Outline

- Overview of present orbit correction scenario
- Plans toward a realistic orbit correction strategy
- Old knobs and new knobs
  - Profit of the versatile alignment system
- New orbit correction budgets
  - Reduced number of correctors
- Questions being investigated
- Summary

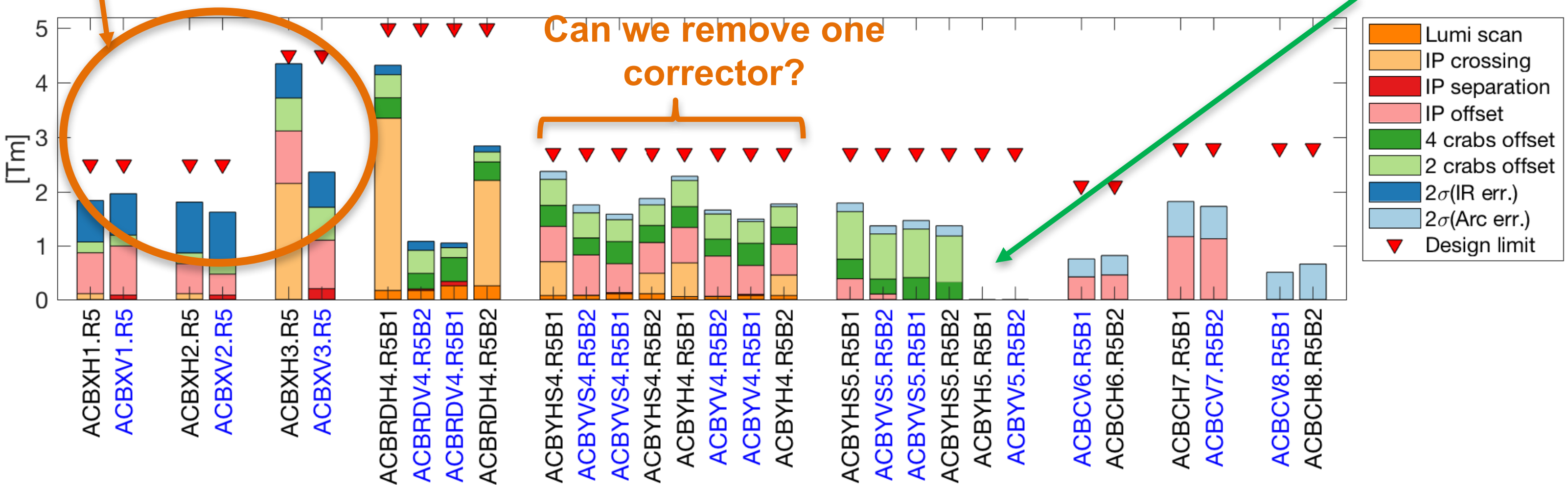
Optics under consideration

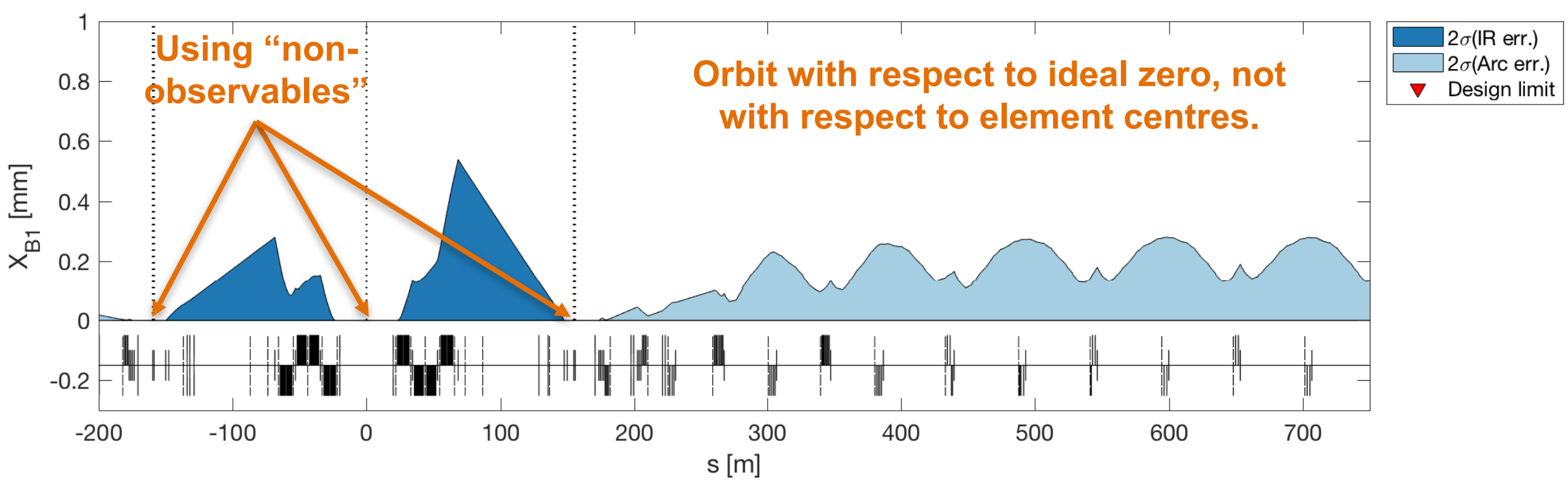
- Optics (slhc/opt_150_150_150_150_thin.madx)
  - E = 7 TeV; σ_E = 1.08e-4; ε_N = 2.5 µm
  - on_x1=295; on_x5=295; (note that 250 is nominal.)
  - on_x8=0; on_x2=0;
  - on_lhcb=0; on_alice=0;
  - on_sep1=2;on_sep2=0;on_sep5=2;on_sep8=0;
  - Considering only IP5
- Errors:
  - All square distributions
    - (i.e. if ±0.5 mm, then sigma = 0.5/sqrt(3) = 0.2887 mm)
  - Quadrupoles
    - ±0.5mm DX/DY, ±10mm DS, ±0.002 DKR1, ±1 mrad DPSI.
  - Dipoles
    - ±10mm DS, ±0.002 DKR0, ±0.5 mrad DPSI.

Where we are

Budget taken for orbit correction

To simplify analysis avoided using third corrector on Q5





Where we are: knobs

It is in the "other" plane, so they should not sum up.

It controls sloop between two pairs of CC:
- Can we get rid of it?

Circuit	Cros. [±295 μrad]	Sep. [±0.75 mm]	Off. [±2 mm]	4 crab off. [±0.25 mm]	2 crab off. [±0.5 mm]	Lumi scan. [±0.1 mm]	Sum	Budget
MCBX1	0.11	0.08	1.05	0	0.2	0	1.44	2.5
MCBX2	0.11	0.08	0.57	0	0.2	0	0.96	2.5
MCBX3	2.15	0.20	0.99	0	0.6	0	3.94	4.5
MCBRD4	3.18	0.10	0	0.44	0.42	0.25	4.39	5
MCBY4	0.64	0.02	0.74	0.41	0.46	0.07	2.34	2.7
MCBYS4	0.64	0.02	0.74	0.41	0.46	0.11	2.38	2.7
MCBY5	0	0	0	0	0	0	0	2.7
MCBYS5	0	0	0.39	0.42	0.89	0	1.7	2.7
MCBC6	0	0	0.47	0	0	0	0.47	2.1
MCBC7	0	0	1.17	0	0	0	1.17	2.8
MCBC8	0	0	0	0	0	0	0	2.8
MCBC9	0	0	0	0	0	0	0	2.8
MCB10	0	0	0	0	0	0	0	1.895

Means orbit at crab cavities

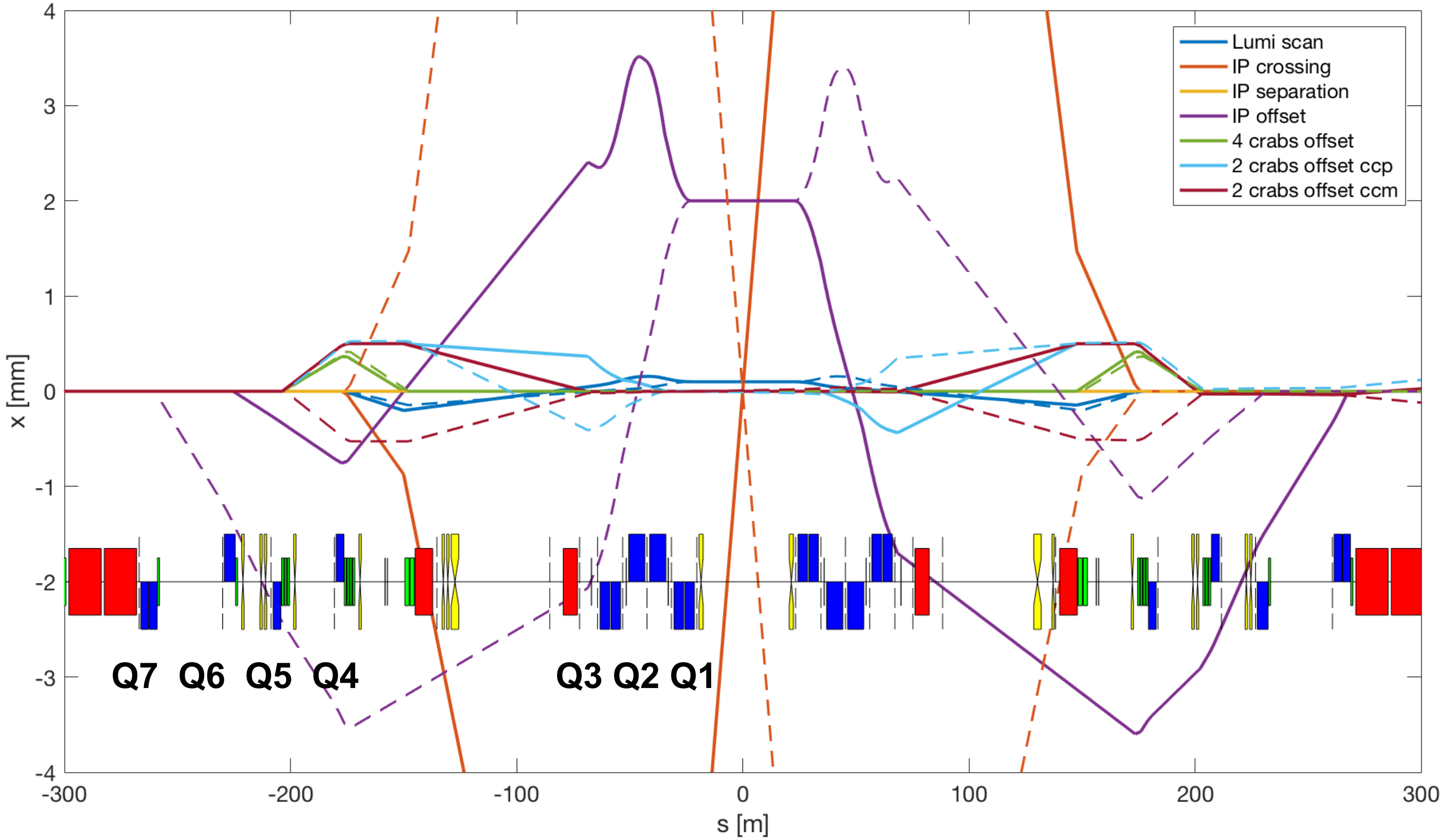
Require flexible bellows at CC -> more impedance

Quite some strength/orbit

- Enough? Necessary?
- The CC pairs (one per beam, per side) can be transversely moved independently.

Where we are: knob effect on orbit

- Solid is B1, dashed is B2



Plans

1. Use movers during a technical stop
   - implement IP offset, but still have a residual alignment error of (0.5 mm or better if possible)
   - less corrector in Q1-Q4, more in Q5-Q7, gain in aperture in Q1-Q4

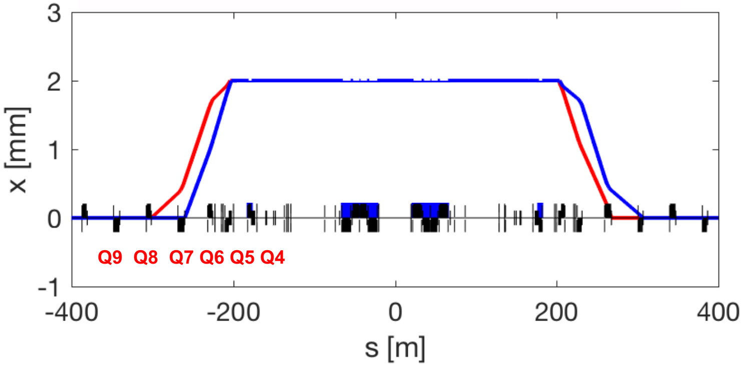
2. Use movers during beam commissioning
   - see if a procedure exists (e.g. k-modulation at injection to calibrate magnetic center with BPM center) to reduce the residual alignment errors to 0 mm with beam observations
   - estimate the reduction of orbit corrector strengths 0.5, 0.0

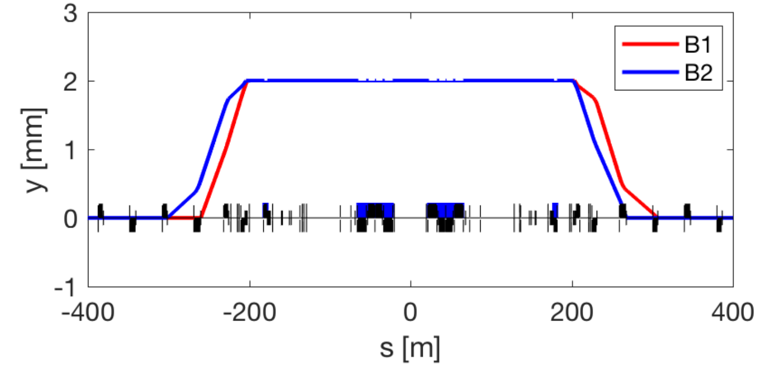
3. Residual orbit at the crab cavities
   - How much we are confident of the orbit at the crab cavities?
   - That is how much do we have to move the beam to center the cavity or move the cavity (if possible) to center the beam.

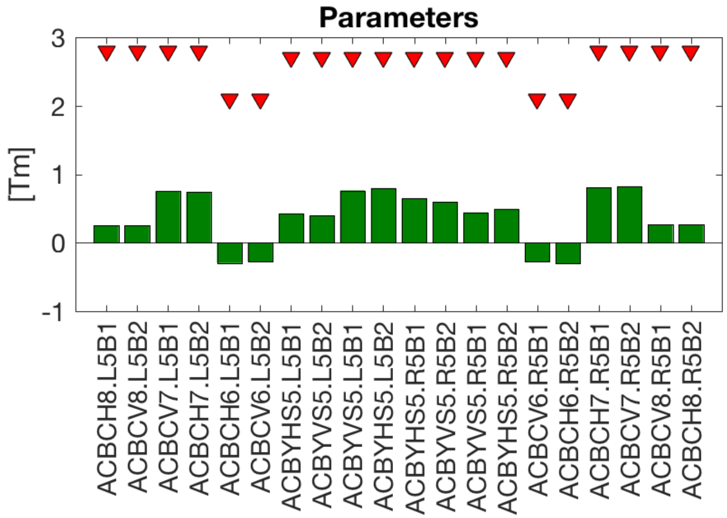
4. How to do a good a crossing angle BPM (BI specification, K-modulation vs beta-error)

Getting rid of offset knob – far-medium

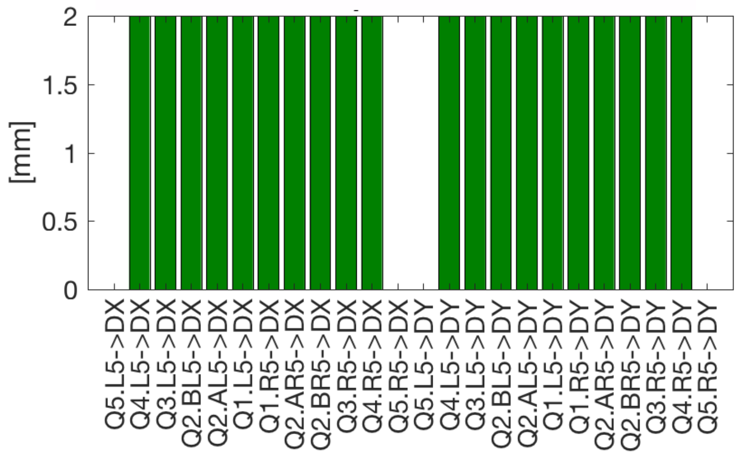
Orbit bump from Q10 to Q5







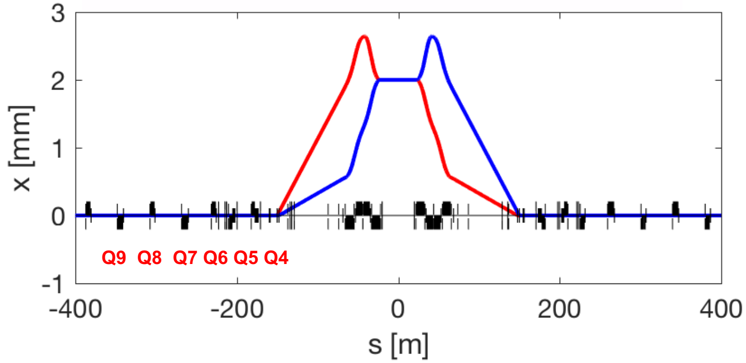
Moving of 2 mm all elements from Q4.L to Q4.R:



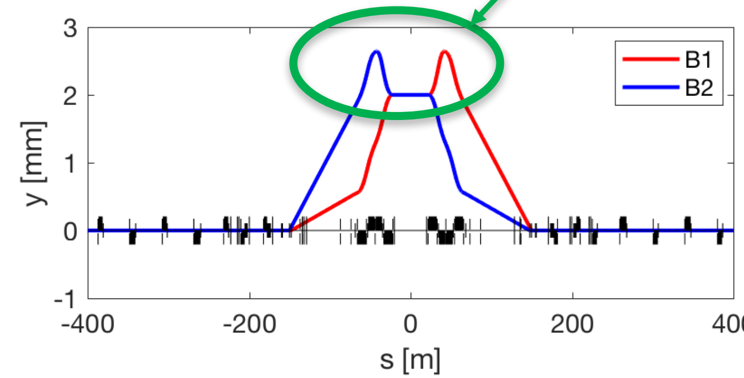
NOTE: Orbit w.r.t. quad offset

Getting rid of offset knob – nearV2

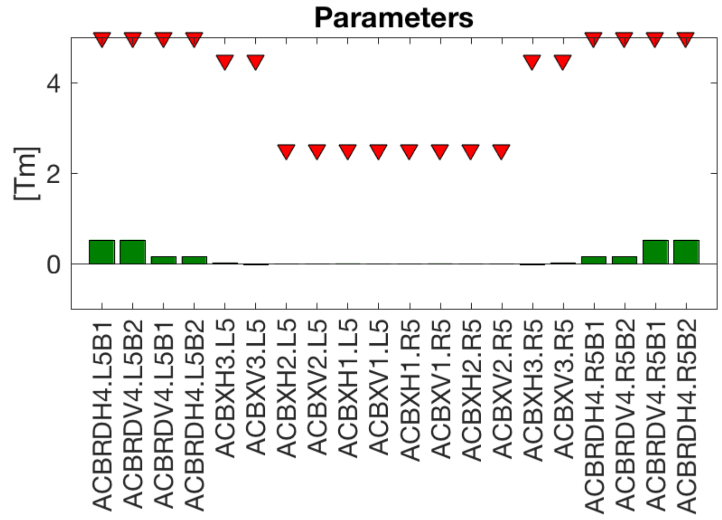
Orbit closed on D2



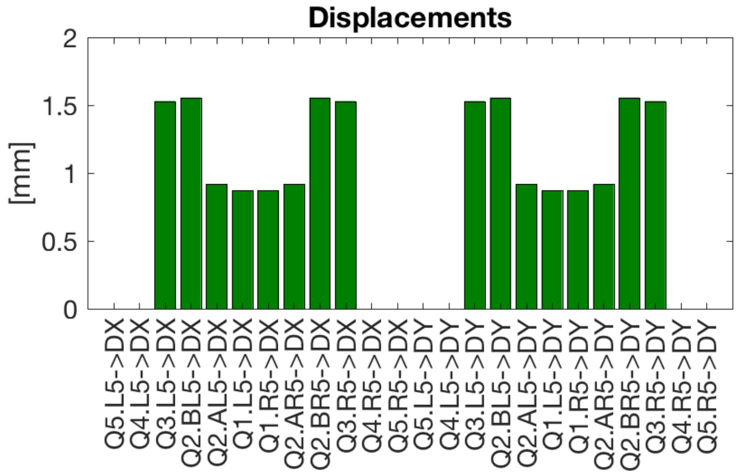
Loss of aperture



< 0.6 Tm ACBRD;
not using RCBX



Moving of ~1 mm the triplet



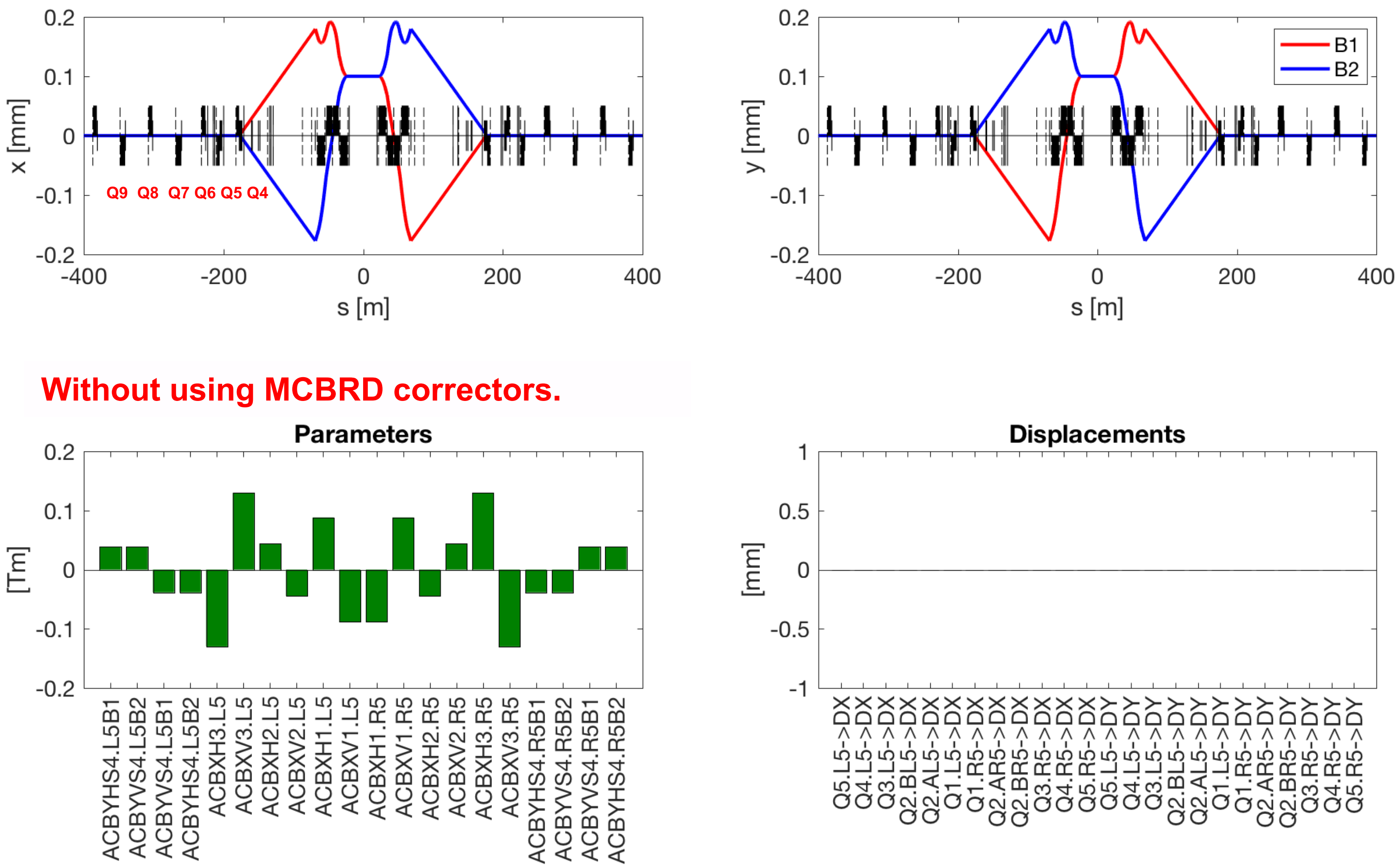
Getting rid of offset knob: resume

- Far-Long/Med: Q1-Q4 of 2 mm
- NearV2: about 1.5 mm on Q3+Q2B, 1 mm Q2A+Q1

Circuit	Off. [±2 mm]			Sum			Budget
	Baseline	Far-Med	nearV2	Baseline	Far-Med	nearV2	
MCBX1	1.05	0	0	1.44	0.39	0.39	2.5
MCBX2	0.57	0	0	0.96	0.39	0.39	2.5
MCBX3	0.99	0	0.02	3.94	2.95	2.97	4.5
MCBRD4	0	0	0.53	4.39	4.39	4.92	5
MCBY4	0.74	0	0	2.34	1.6	1.6	2.7
MCBYS4	0.74	0	0	2.38	1.64	1.64	2.7
MCBY5	0	0	0	0	0	0	2.7
MCBYS5	0.39	0.80	0	1.7	2.11	1.31	2.7
MCBC6	0.47	0.31	0	0.47	0.31	0	2.1
MCBC7	1.17	0.82	0	1.17	0.82	0	2.8
MCBC8	0	0.27	0	0	0.27	0	2.8
MCBC9	0	0	0	0	0	0	2.8
MCB10	0	0	0	0	0	0	1.895

↑ Interesting one

Improving lumi-scan knob

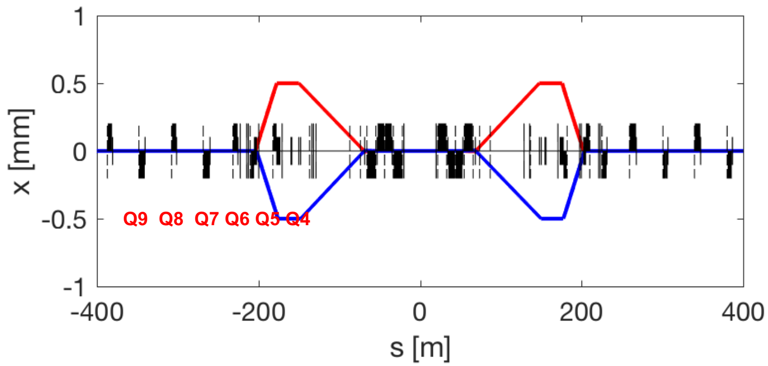


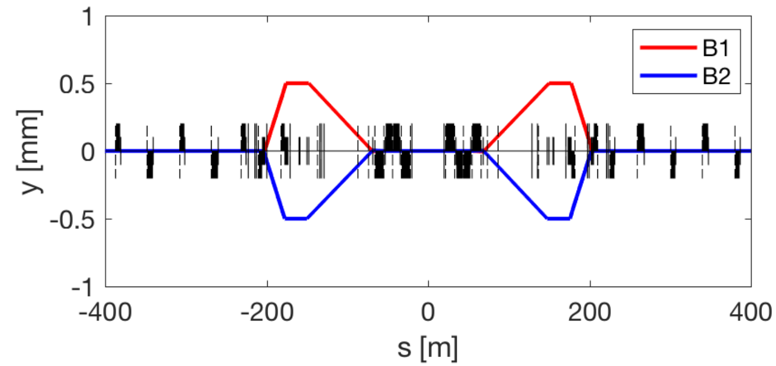
Improving lumi-scan knob: resume

- Note that both versions introduce a small orbit at crab cavities (< 0.1mm)

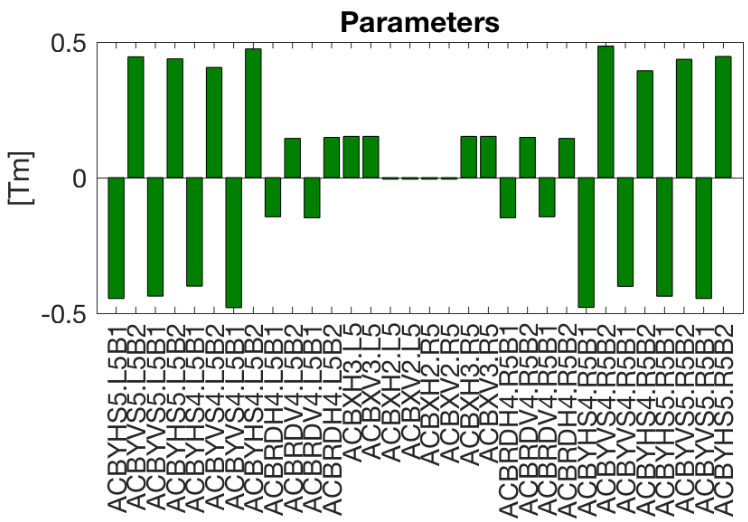
Circuit	Lumi scan. [±0.1 mm]		Sum		Budget
	Baseline	New	Baseline	New	
MCBX1	0	0.09	1.44	1.53	2.5
MCBX2	0	0.05	0.96	1.01	2.5
MCBX3	0	0.13	3.94	4.07	4.5
MCBRD4	0.25	0	4.39	4.14	5
MCBY4	0.07	0	2.34	2.27	2.7
MCBYS4	0.11	0.04	2.38	2.31	2.7
MCBY5	0	0	0	0	2.7
MCBYS5	0	0	1.7	1.7	2.7
MCBC6	0	0	0.47	0.47	2.1
MCBC7	0	0	1.17	1.17	2.8
MCBC8	0	0	0	0	2.8
MCBC9	0	0	0	0	2.8
MCB10	0	0	0	0	1.895

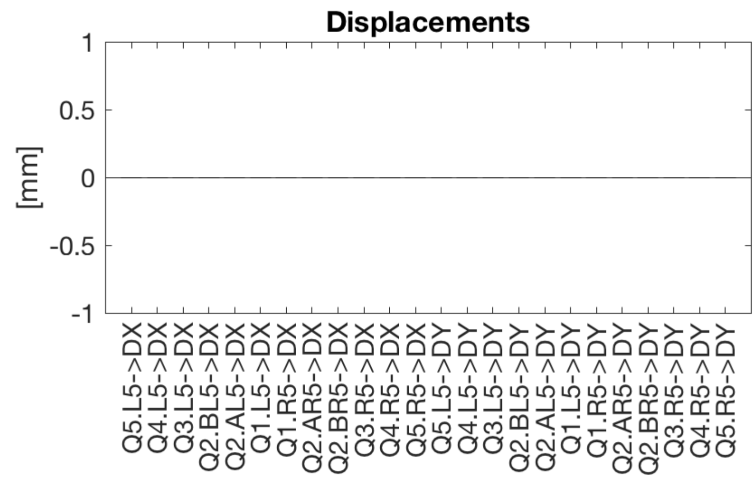
Simple beam separation at CC





Without using MCBRD correctors.





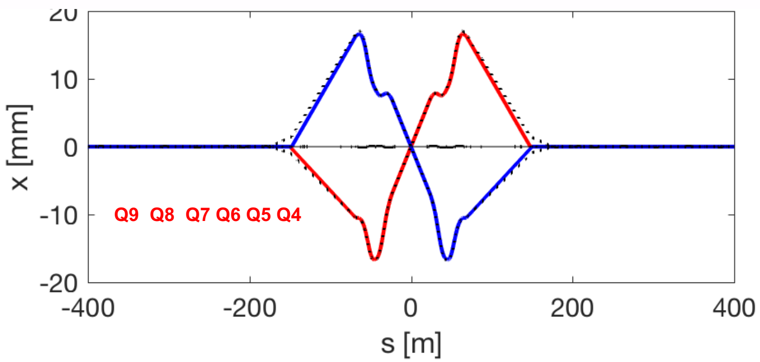
New CC adjustment knob

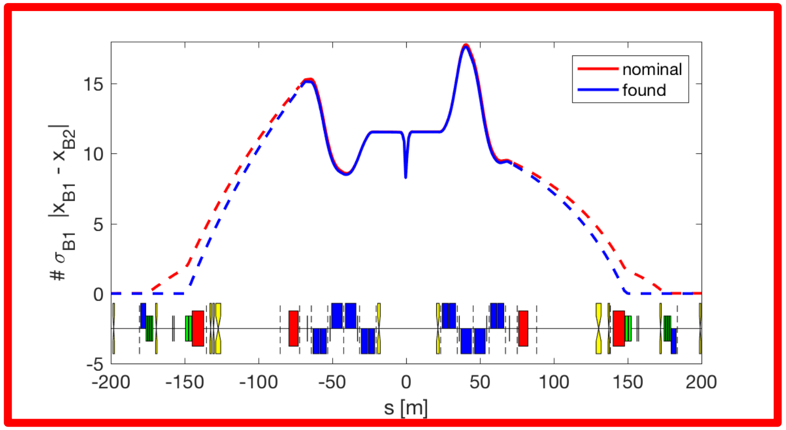
- It only allows to “separate” the beams at CC.
  - One should rely on rigid translation of both cryomodules.

Circuit	CC adjustment			Sum		Budget
	4 cc off. [±0.25 mm]	2 cc off. [±0.5 mm]	New 2 CC separation [1 mm]	Baseline	New	
MCBX1	0	0.2	0	1.44	1.24	2.5
MCBX2	0	0.2	0.01	0.96	0.77	2.5
MCBX3	0	0.6	0.15	3.94	3.49	4.5
MCBRD4	0.44	0.42	0.15	4.39	3.68	5
MCBY4	0.41	0.46	0	2.34	1.47	2.7
MCBYS4	0.41	0.46	0.48	2.38	1.99	2.7
MCBY5	0	0	0	0	0	2.7
MCBYS5	0.42	0.89	0.45	1.7	0.84	2.7
MCBC6	0	0	0	0.47	0.47	2.1
MCBC7	0	0	0	1.17	1.17	2.8
MCBC8	0	0	0	0	0	2.8
MCBC9	0	0	0	0	0	2.8
MCB10	0	0	0	0	0	1.895

Improving crossing knob – No Q4

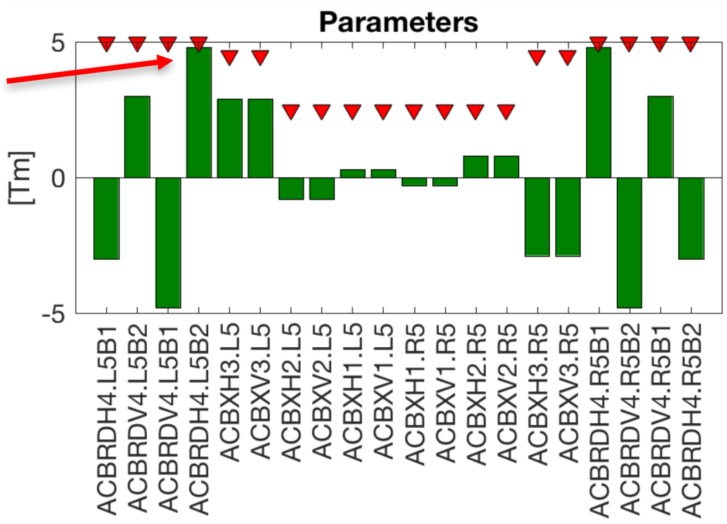
Orbit closed on D2 -> NO orbit at crab cavities



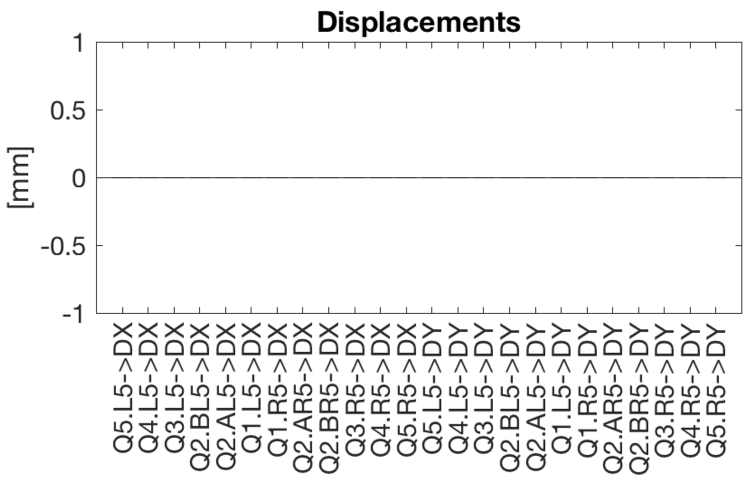


Using most of the strength on MCBRDs!

4.8 Tm at 7 TeV

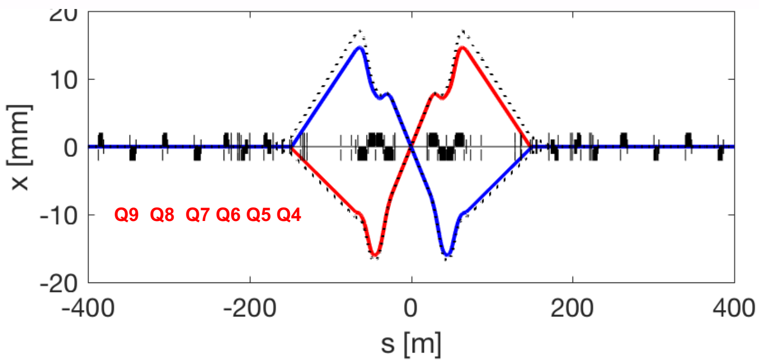


Not using quads

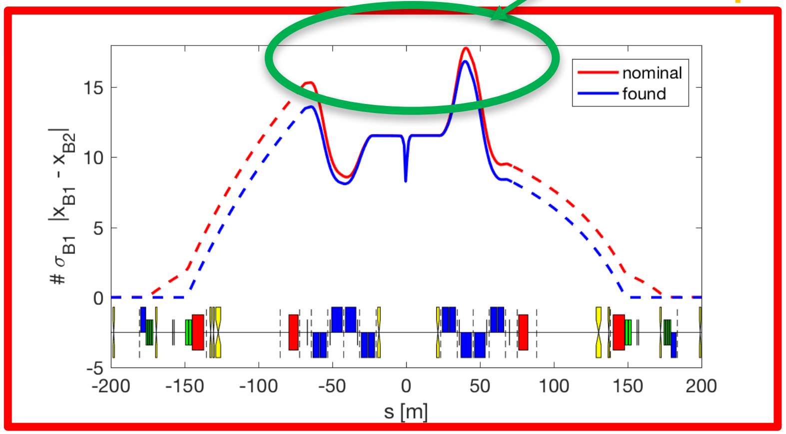


Improving crossing knob – No Q4 + quads

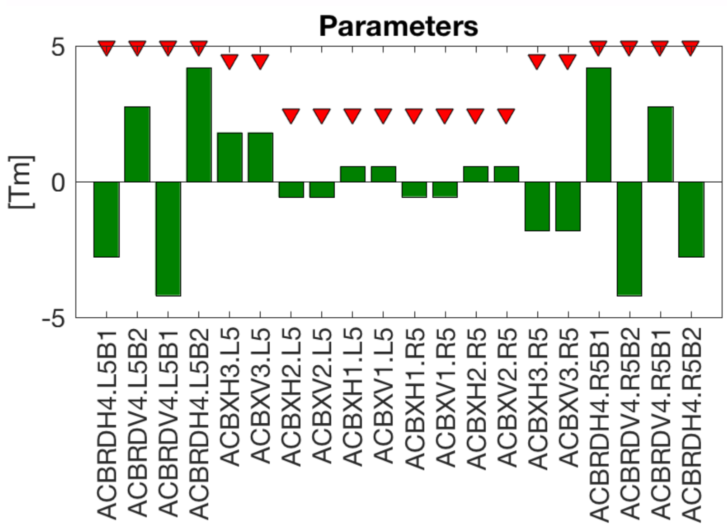
Orbit closed on D2 -> NO orbit at crab cavities



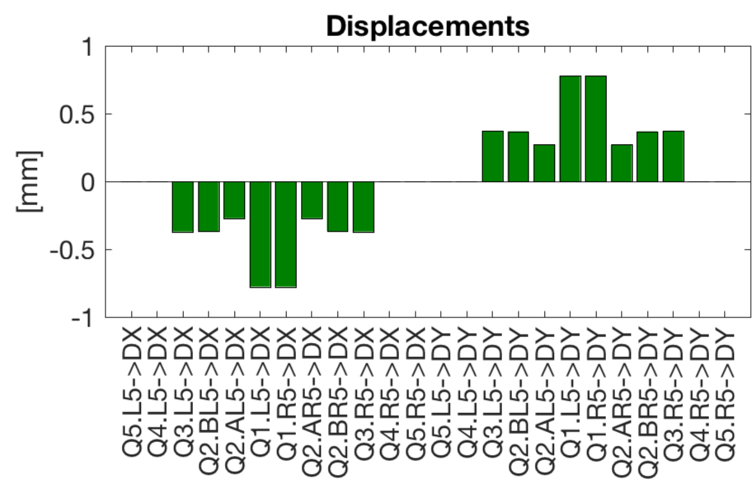
Loss of aperture



Using most of the strenght on MCBRDs!



Displacing the triplets



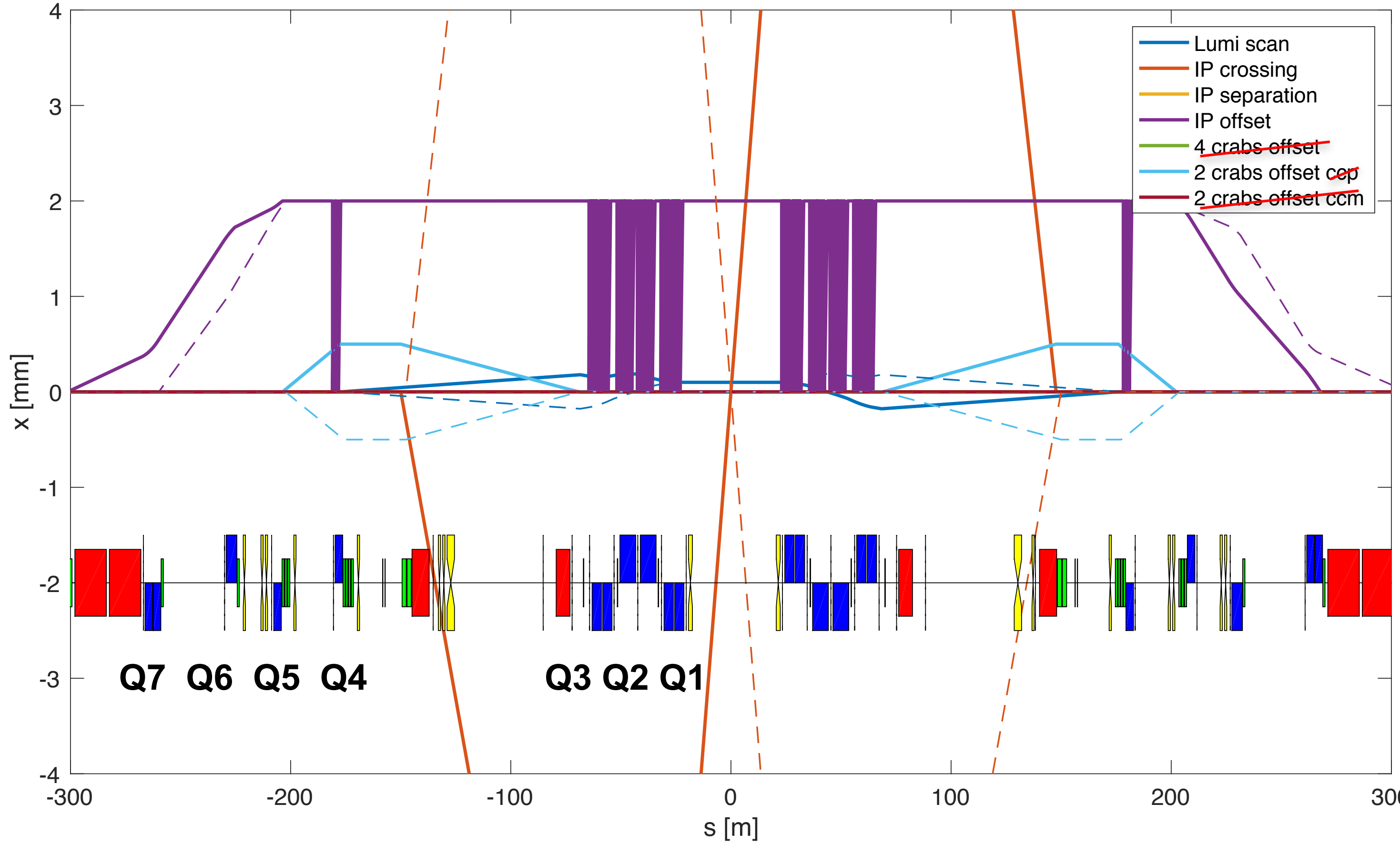
All “new” knobs together

It is in the “other” plane, so they should not sum up.

Circuit	Cros. [±295 µrad]	Sep. [±0.75 mm]	Off. (far med) [±2 mm]	2 crab separation [1 mm]	Lumi scan. [±0.1 mm]	Sum (baseline)	Sum New	Budget
MCBX1	0.29	0.08	0	0	0.09	1.44	0.38	2.5
MCBX2	0.8	0.08	0	0.01	0.05	0.96	0.86	2.5
MCBX3	2.9	0.20	0	0.15	0.13	3.94	3.18	4.5
MCBRD4	4.8	0.10	0	0.15	0	4.39	4.95	5
MCBY4	0	0.02	0	0	0	2.34	0	2.7
MCBYS4	0	0.02	0	0.48	0.04	2.38	0.52	2.7
MCBY5	0	0	0	0	0	0	0	2.7
MCBYS5	0	0	0.80	0.45	0	1.7	1.25	2.7
MCBC6	0	0	0.31	0	0	0.47	0.31	2.1
MCBC7	0	0	0.82	0	0	1.17	0.82	2.8
MCBC8	0	0	0.27	0	0	0	0.27	2.8
MCBC9	0	0	0	0	0	0	0	2.8
MCB10	0	0	0	0	0	0	0	1.895

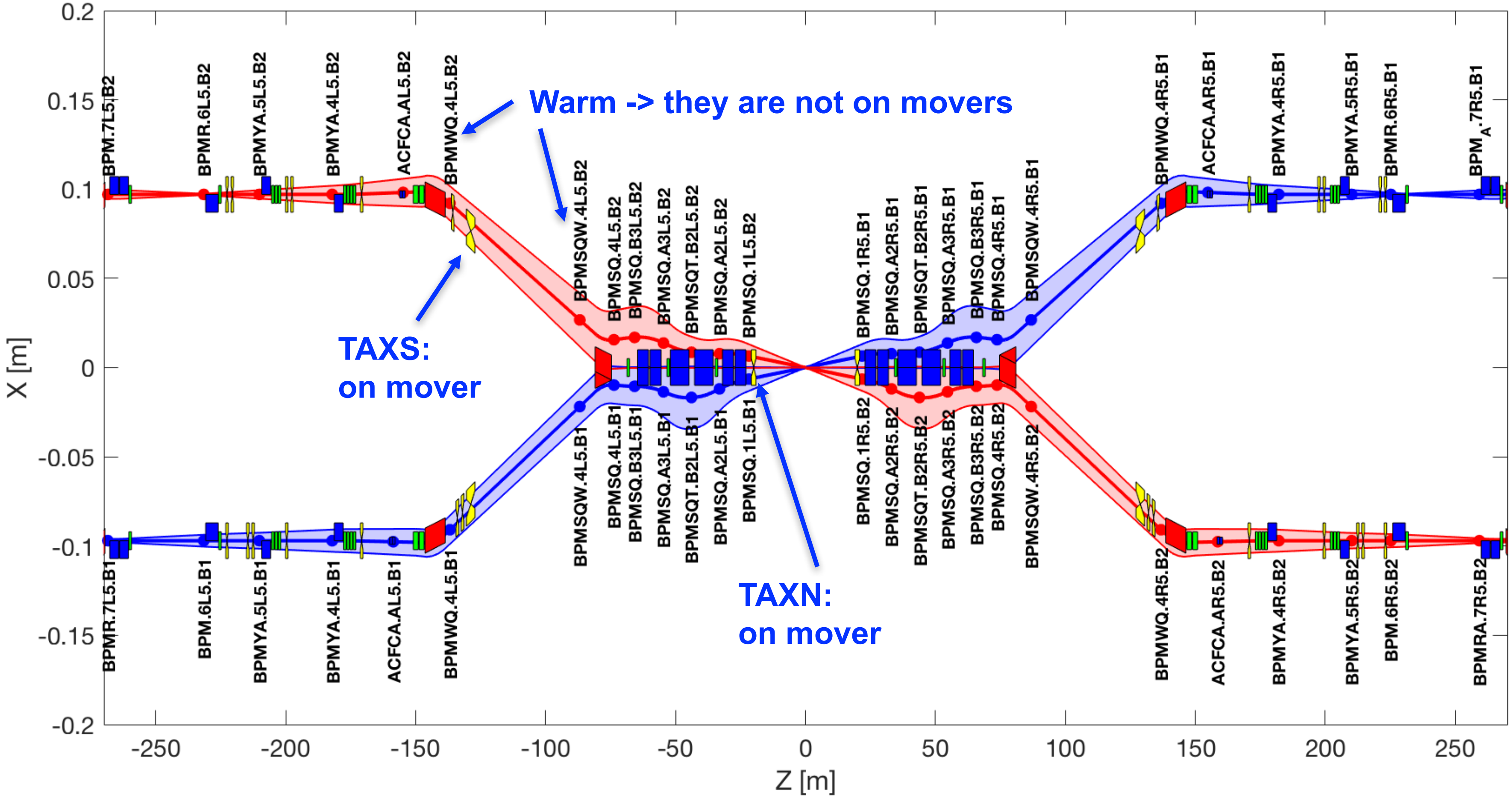
New knobs: orbit effects

- Solid is B1, dashed is B2



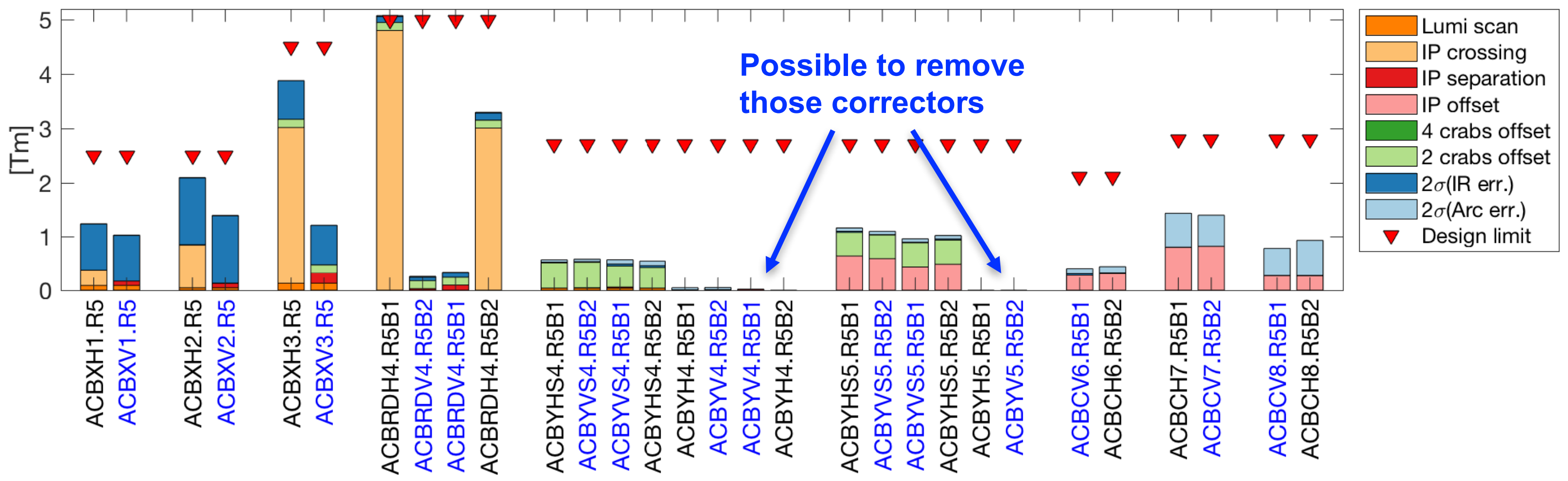
Where are the BPMs?

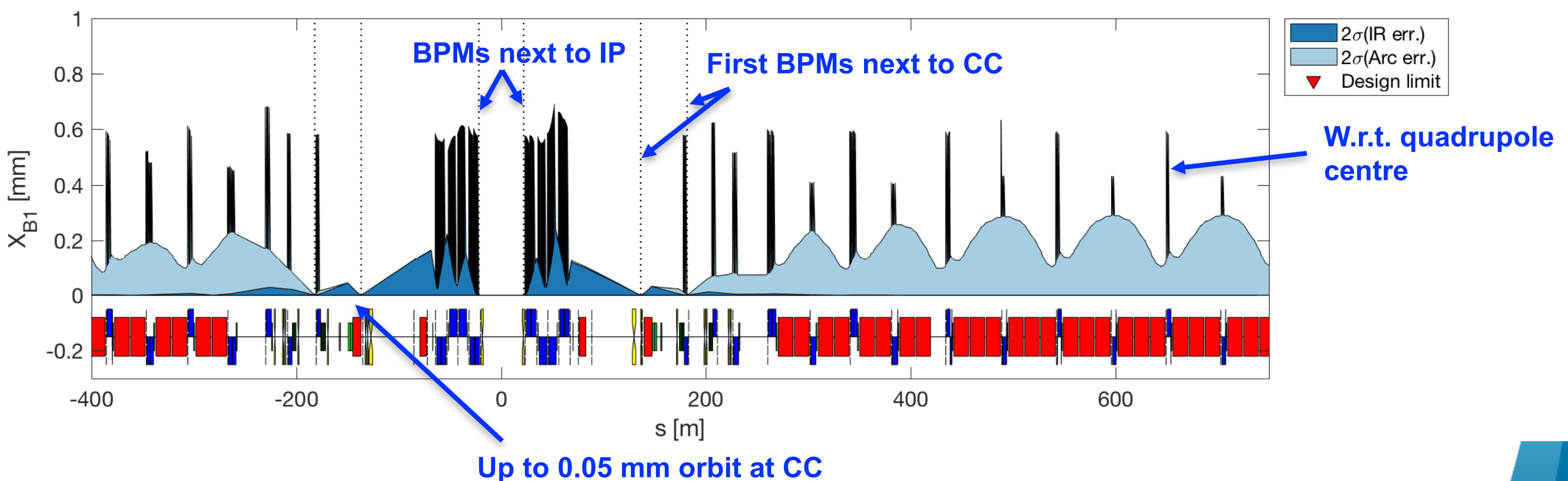
Baseline crossing orbit (taking into account of Survey) with 6σ beam size (taking into account beta and dispersion)



Warning: using only BPMs one cannot be sure of the orbit in crab cavities

New orbit correction





Resumé: required budget correctors

- Values in Tm at 7 TeV.

Circuit	IR err. [2*std]	Arc err. [2*std]	Lumi scan. [±0.1 mm]	Cros. [±295 µrad]	Sep. [±0.75 mm]	IP Off. [±2 mm] ***	sum	budget
ACBX1	0.86	0.01	0.09	0.3	0.08	0	1.25	2.50
ACBX2	1.26	0.01	0.04	0.8	0.08	0	2.1	2.50
ACBX3	0.73	0	0.13	2.88	0.2	0	3.74	4.50
ACBRD4	0.13	0.02	0	4.8	0.1	0	4.93	5.00
ACBY4	0.01	0.04	0	0	0.02	0	0.06	2.70
ACBYS4	0.04	0.08	0.04	0	0.02	0	0.15	2.70
ACBY5	0	0	0	0	0	0	0	2.70
ACBYS5	0.02	0.06	0	0	0	0.8	0.86	2.70
ACBC6	0.03	0.11	0	0	0	0.31	0.42	2.10
ACBC7	0	0.63	0	0	0	0.82	1.45	2.80
ACBC8	0.01	0.66	0	0	0	0.27	0.93	2.80
ACBC9	0	0.59	0	0	0	0	0.59	2.80
ACB10	0	0.65	0	0	0	0	0.65	1.90
ACB11	0	0.58	0	0	0	0	0.58	1.90
ACB12	0	0.62	0	0	0.02	0	0.64	1.90
ACB13	0	0.62	0	0	0	0	0.62	1.90
ACB14	0	0.62	0	0	0	0	0.62	1.90
ACB15	0	0.62	0	0	0	0	0.62	1.90

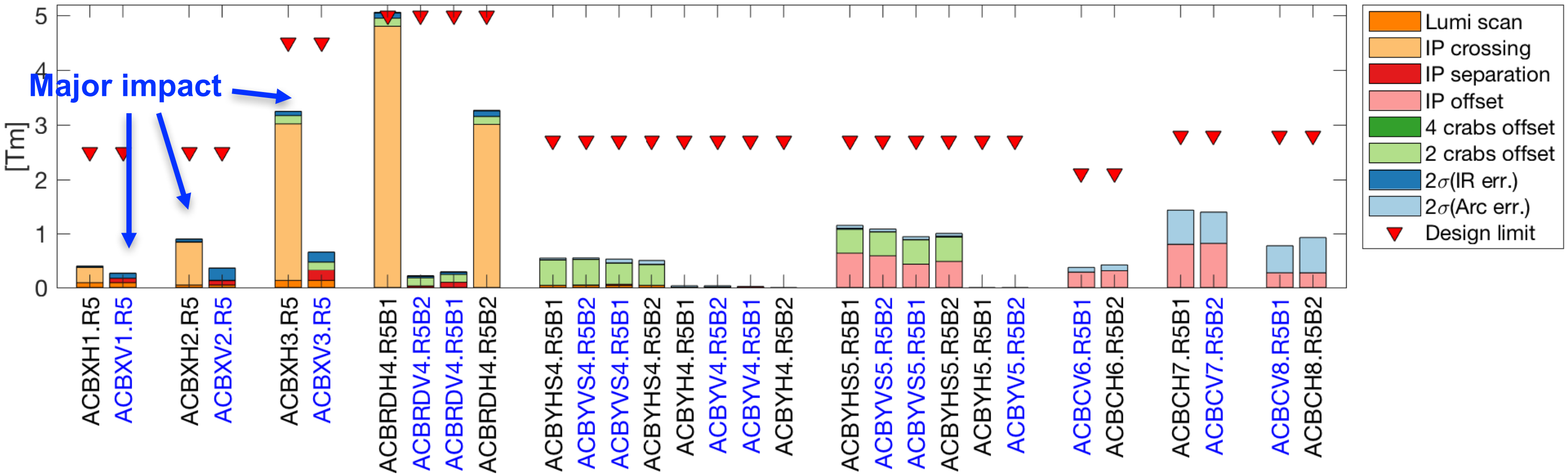
*** **It requires to translate Q1-Q4 of 2 mm in the direction of the required offset.**

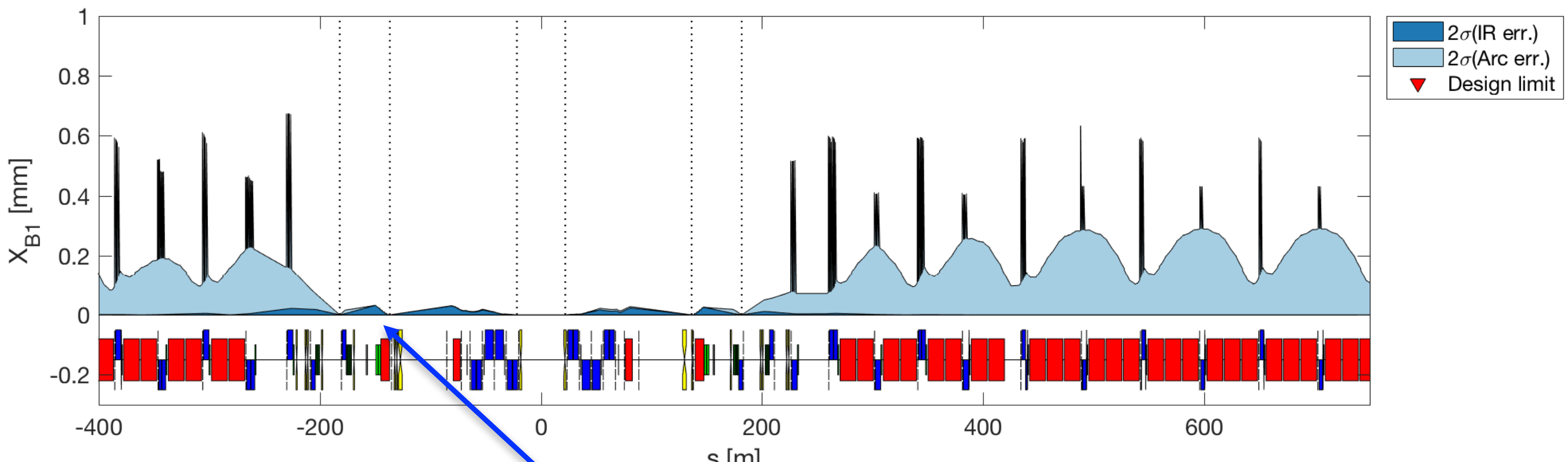
Resumé: aperture loss/orbit [mm]

Circuit	IR err. [2*std]	Arc err. [2*std]	Lumi scan. [±0.1 mm]	Cros. [±295 µrad]	Sep. [±0.75 mm]	IP Off. [±2 mm] ***	sum
TAXS	0	0	0.1	5.89	0.75	0	5.99
MQXFA.[AB]1	0.61	0	0.12	11.02	0.91	0	11.75
MQXFB.[AB]2	0.69	0	0.19	16.68	1.2	0	17.56
MQXFA.[AB]3	0.66	0.01	0.16	16.66	0.82	0	17.48
MBXF	0.16	0.01	0.17	14.9	0.47	0	15.23
TAXN	0.02	0	0.08	3.89	0.16	0	3.99
MBRD	0.03	0	0.06	1.71	0.1	0	1.8
MCBRD	0.04	0	0.05	0.29	0.06	0	0.38
MCBY[HV].[AB]?4	0.01	0.02	0.01	0	0	0	0.03
MQY.4	0	0.58	0	0	0	0	0.58
TCLMB.5	0.02	0.05	0	0	0	0	0.05
MCBY[HV].[AB]?5	0.02	0.07	0	0	0	0	0.07
MQY.5	0.02	0.62	0	0	0	1.96	2.58
TCLMC.6	0.03	0.14	0	0	0	1.79	1.93
MCBC[HV].6	0.03	0.17	0	0	0	1.74	1.91
MQML.6	0.03	0.69	0	0	0	1.76	2.45
MCBC[HV].7	0.01	0.22	0	0	0	0.55	0.77
MQM.[AB]7	0.01	0.61	0	0	0	0.57	1.18
MCBC[HV].8	0.01	0.23	0	0	0	0	0.23
MQML.8	0.01	0.61	0	0	0	0.06	0.67
MCBC[HV].9	0	0.19	0	0	0	0	0.19
MQMC.9	0	0.59	0	0	0	0	0.59
MQM.9	0	0.6	0	0	0	0	0.60
MCB[HV].10	0	0.26	0	0	0	0	0.26
MQML.10	0	0.59	0	0	0	0	0.59

*** It requires to translate Q1-Q4 of 2 mm in the direction of the required offset.

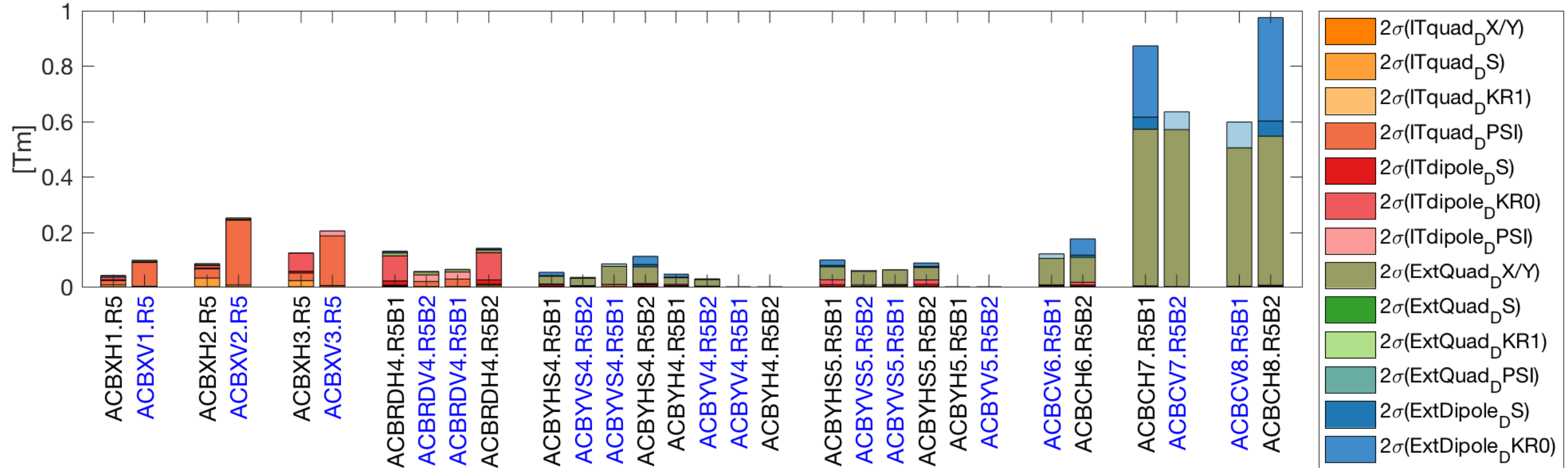
New orbit correction (no Q1-5 DX/DY)

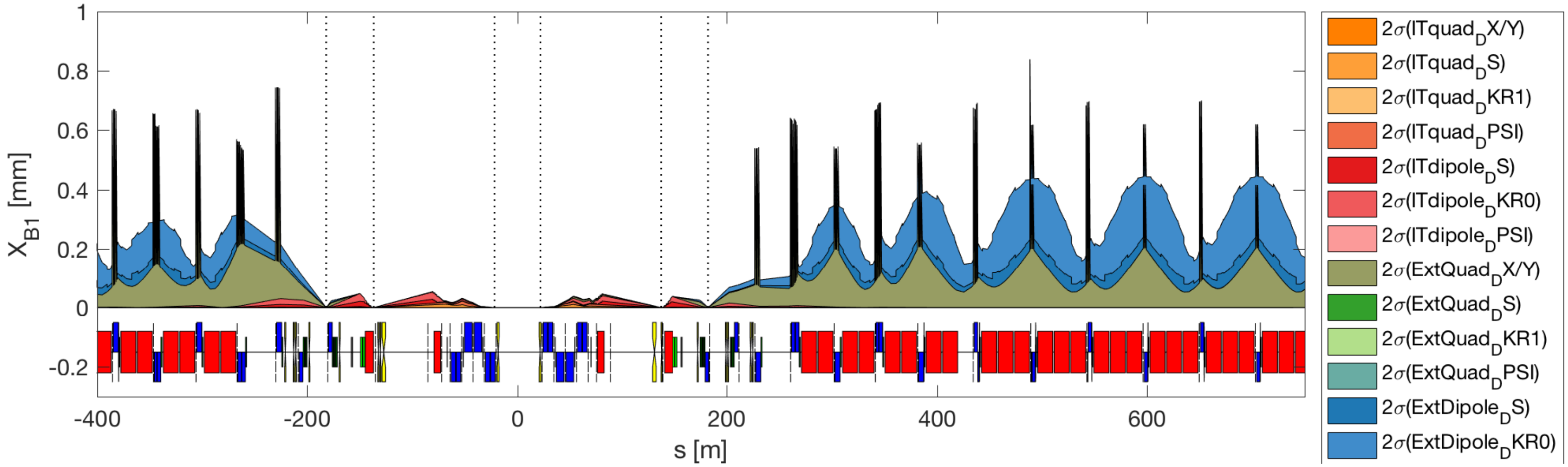




Still up to ~0.04 mm orbit at CC

New orbit correction (no Q1-5 DX/DY) - split





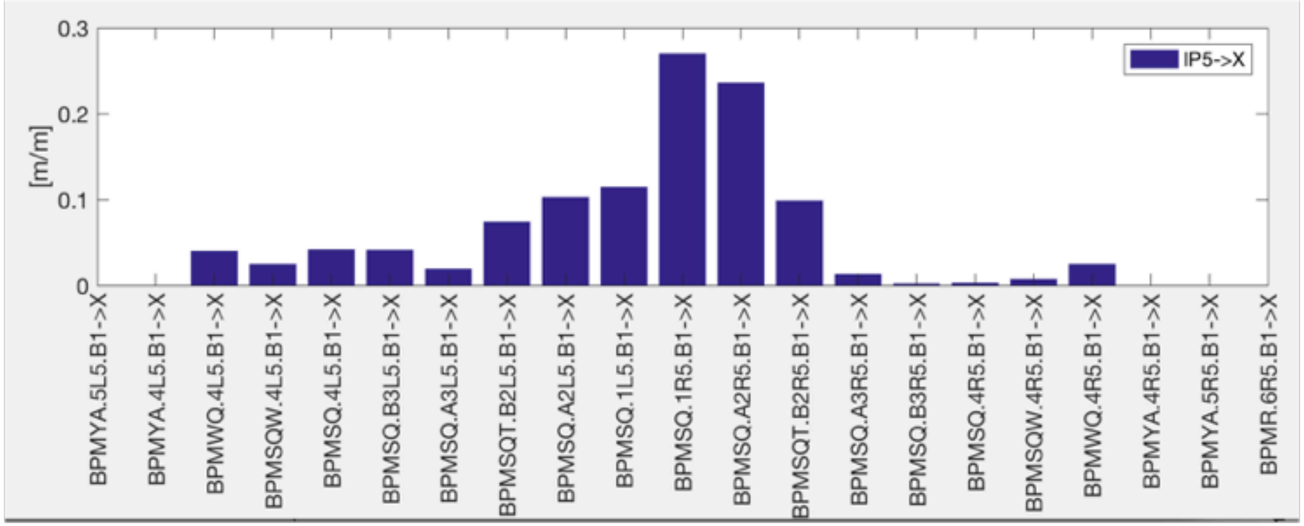
Open question: how to align quads?

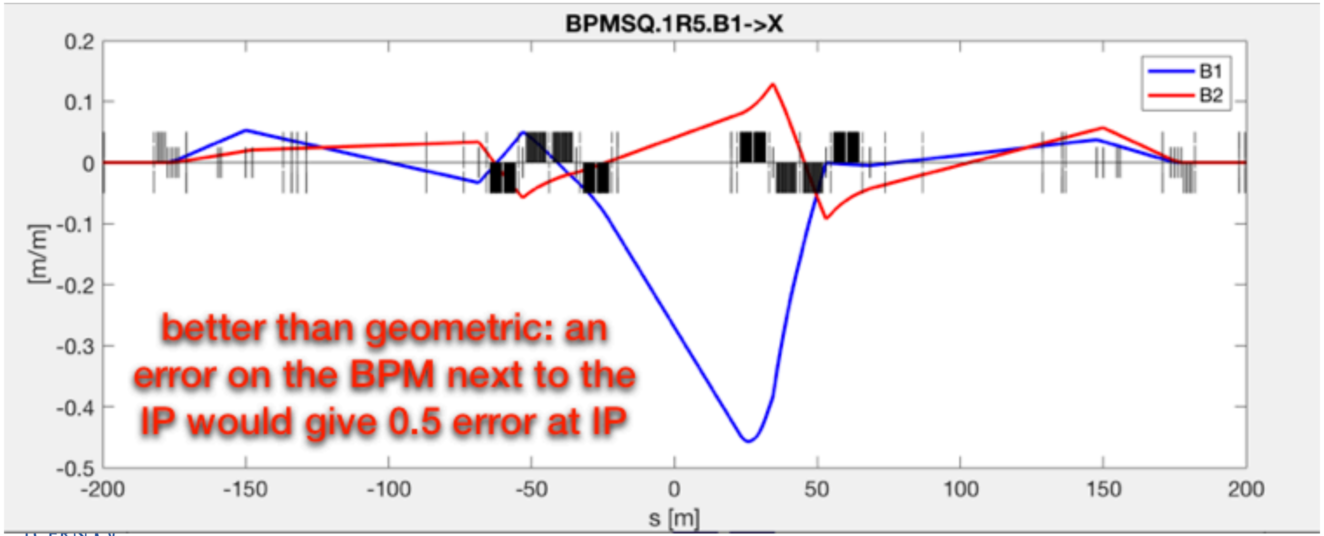
- Possible procedure:

1. Identify centre of quads.
   a. Perform k-modulation on each single quad.
      - Look at closed orbit perturbation.
   b. Modify orbit with corrector at best phase advance until no effect by k-modulation.
      - Identify centre of quadrupole as “zero orbit” on the attached BPM.
2. Back to initial orbit.
   a. Measure orbit response by quadrupole offset.
   b. Measure orbit response of correctors.
3. Find best quadrupole movement that minimises orbit and correctors strength.
4. …

Open question: impact of BPM noise

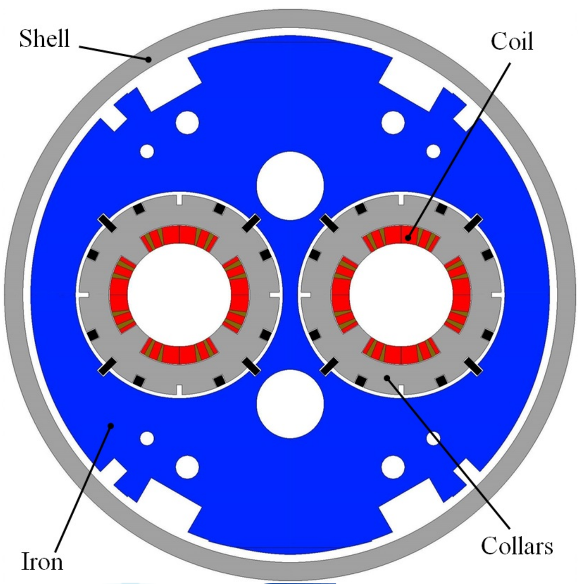
- Noise/offset on one BPM can induce an IP orbit shift.



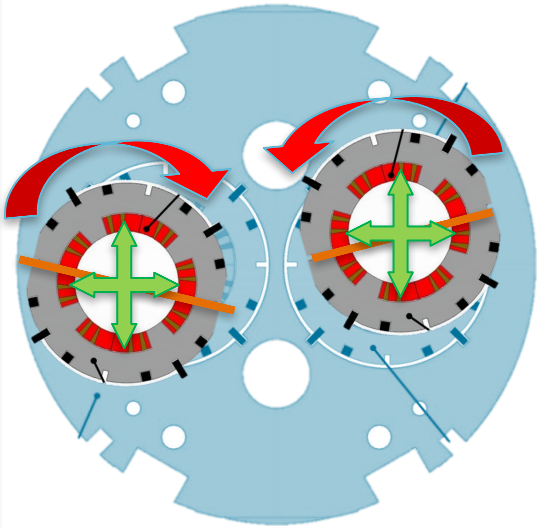


Additional remark: transverse errors

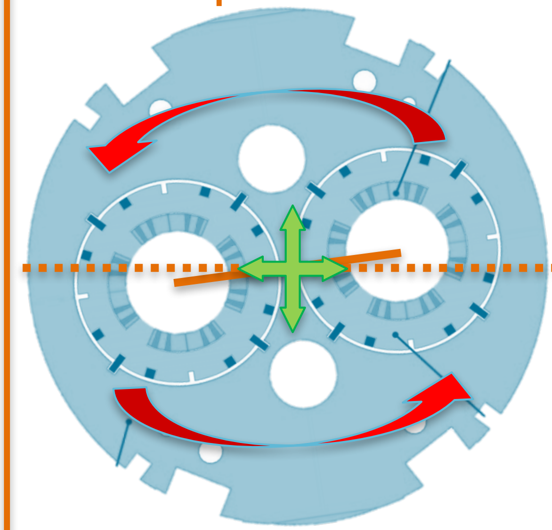
- **Not all quads are independent.**
  - **e.g. if you move Q1A, you also move Q1B…**
- **The two apertures are not independent…**
- ***For the time being we consider everything independent.***



At the moment we are considering this case as the most generic one



1 mrad roll over 194/2 mm aperture separation, means +- 0.1 mm correlated vertical displacement!



Summary

- The offset knob can be implemented profiting of the alignment system
- The crossing knob can be closed on D2
  - But minimum margin on MCBRD
- We could remove 2 correctors on Q4 and Q5
  - Strong assumption that CC can be easily moved, possibly during commissioning with beam
- Alignment of the quadrupoles with beam could be beneficial for aperture optimisation
  - A procedure needs to be properly implemented and verified (MD?)
- The impact of BPM noise/error on the orbit correction procedure needs to be assessed
  - Strongly depends on type of error, and orbit correction strategy
  - Need to profit of LHC experience
- Are all misalignment assumptions correct?

Plans

1. Use movers during a technical stop
   - implement IP offset, but still have a residual alignment error of (0.5 mm or better if possible)
   - less corrector in Q1-Q4, more in Q5-Q7, gain in aperture in Q1-Q4

   OK

2. Use movers during beam commissioning
   - see if a procedure exists to reduce the residual alignment errors to 0 mm with beam observations
   - estimate the reduction of orbit corrector strengths 0.5, 0.0

   TO DO!

   OK

3. Residual orbit at the crab cavities
   - How much we are confident of the orbit at the crab cavities?
   - That is how much do we have to move the beam to center the cavity or move the cavity (if possible) to center the beam.

   To follow up

4. How to do a good a crossing angle BPM (BI specification, K-modulation vs beta-error)

   To follow up

Backup

Are all imperfections correctly treated by a linear approximation?

- In section where strong non-linearities are present (e.g. nominal sextupoles), the linear approximation **might not be correct**!
- In case of a pure linear lattice (only quadrupoles and bends):

Imperfection	Linear?	Explanation
Quad. incoming orbit (x_e)	yes	In first approximation one can write the orbit kick (Δx') as: $$\Delta x' = (x_e + x_0 + \Delta x_Q) k_{Q_0} (1 + \Delta k_Q / k_{Q_0})$$ $$\approx x_0 k_{Q_0} + x_e k_{Q_0} + \Delta x_Q k_{Q_0} + x_0 k_{Q_0} \Delta k_Q / k_{Q_0}$$
Quad. misalignment (Δx_Q)	yes	
Quad. field error ($\Delta k_Q / k_{Q0}$)	ni	
Quad. roll	ni	Similar to field error (depends on x_0) + coupling.
Bend. roll (θ)	Yes (small θ)	$$\Delta x' = \Delta x'_0 \left[-\sin(\theta) + \Delta k_B / k_{B_0}\right]$$ $$\Delta y' = \Delta x'_0 \sin(\theta)$$
Bend. field error ($\Delta k_B / k_{B0}$)	yes	
Longitudinal misalignments	ni	Linear for bends, similar to field error for quads.

- Working hypothesis:
  - All **non-linear elements** (e.g. arc sextupoles) are **turned off** in the model.
  - We are looking for a solution in proximity of the ideal orbit. Non-linear and second order effects are supposed to be small.

Treatment of errors

- Before
  - Always orbit with respect to ideal orbit (x/y = 0)
- After
  - Considering that if you move a quadrupole, then the “zero” aperture loss is when the beam is off-centre with respect to the ideal orbit…. i.e. it should pass in the middle of the quadrupole…

Simplified treatment of the problem (last year)

- In first approximation the problem is linear and two are the main equations:
  - Orbit variation along the a beamline (**Δx**) is linear with respect to misalignments/errors (**Δe**)
  - And with respect to correctors strengths (**Δc**)
  - The linear coefficients form the matrices $\mathbf{RM_e}$ and $\mathbf{RM_c}$

$$\overrightarrow{\Delta x} = \mathbf{RM_e}\,\overrightarrow{\Delta e} \qquad\qquad \overrightarrow{\Delta x} = \mathbf{RM_c}\,\overrightarrow{\Delta c}$$

- The response matrices can be measured/extracted by exciting the MAD-X model and measuring the response on the relevant optics parameters.
- One is interested only to correct some key* locations. E.g. in case of misalignments:
  - Zero orbit variation at the boundaries of the line (to be "transparent" to the ideal machine)
  - No variation of position and crossing angle at the IP
  - No orbit excursion at the crab cavity location.
- The problem is simplified to the following equation:

$$\overrightarrow{\Delta c} = -\mathrm{pinv}(\mathbf{RM_c^*})\mathbf{RM_e^*}\,\overrightarrow{\Delta e} = \mathbf{RM_{tot}}\,\overrightarrow{\Delta e}$$

  - Where the * matrices are a subset of the measured matrices $\mathbf{RM_e}$ and $\mathbf{RM_c}$ keeping only the important rows.
- The residual orbit at other locations is simply:

$$\overrightarrow{\Delta x} = \mathbf{RM_c}\,\mathbf{RM_{tot}}\,\overrightarrow{\Delta e} + \mathbf{RM_e}\,\overrightarrow{\Delta e}$$

Treatment of the problem small improvements

- In first approximation the problem is linear and two are the main equations:
  - Orbit variation along the a beamline (**Δx**) is linear with respect to misalignments/errors (**Δe**)
  - And with respect to correctors strengths (**Δc**)
  - The linear coefficients form the matrices **RM_e** and **RM_c**

RM_o is sort of an Identity matrix

New RM_e matrix

$$\overrightarrow{\Delta x} = \mathbf{RM_e}\,\overrightarrow{\Delta e} - \mathbf{RM_o}\overrightarrow{\Delta e} = [\mathbf{RM_e} - \mathbf{RM_o}]\overrightarrow{\Delta e} \qquad \overrightarrow{\Delta x} = \mathbf{RM_c}\,\overrightarrow{\Delta c}$$

- The response matrices can be measured/extracted by exciting the MAD-X model and measuring the response on the relevant optics parameters.
- One is interested only to correct some key* locations. E.g. in case of misalignments:
  - Zero orbit variation at the boundaries of the line (to be "transparent" to the ideal machine)
  - No variation of position and crossing angle at the IP
  - No orbit excursion at the crab cavity location.

Use only nearby BPMs

- The problem is simplified to the following equation:

$$\overrightarrow{\Delta c} = -\mathrm{pinv}(\mathbf{RM_c^*})\mathbf{RM_e^*}\,\overrightarrow{\Delta e} = \mathbf{RM_{tot}}\,\overrightarrow{\Delta e}$$

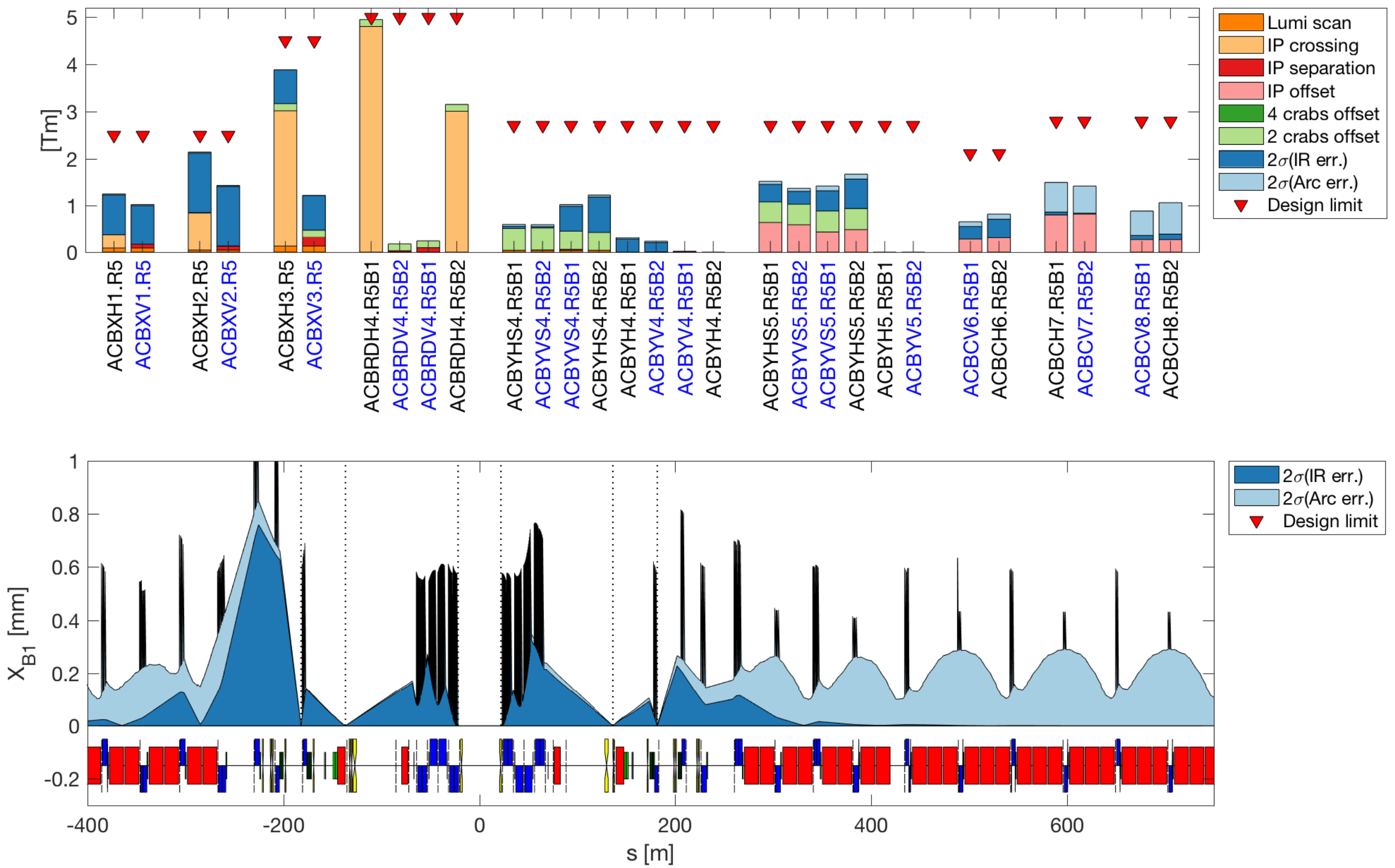
  - Where the * matrices are a subset of the measured matrices **RM_e** and **RM_c** keeping only the important rows.
- The residual orbit at other locations is simply:

$$\overrightarrow{\Delta x} = \mathbf{RM_c}\,\mathbf{RM_{tot}}\,\overrightarrow{\Delta e} + \mathbf{RM_e}\,\overrightarrow{\Delta e}$$

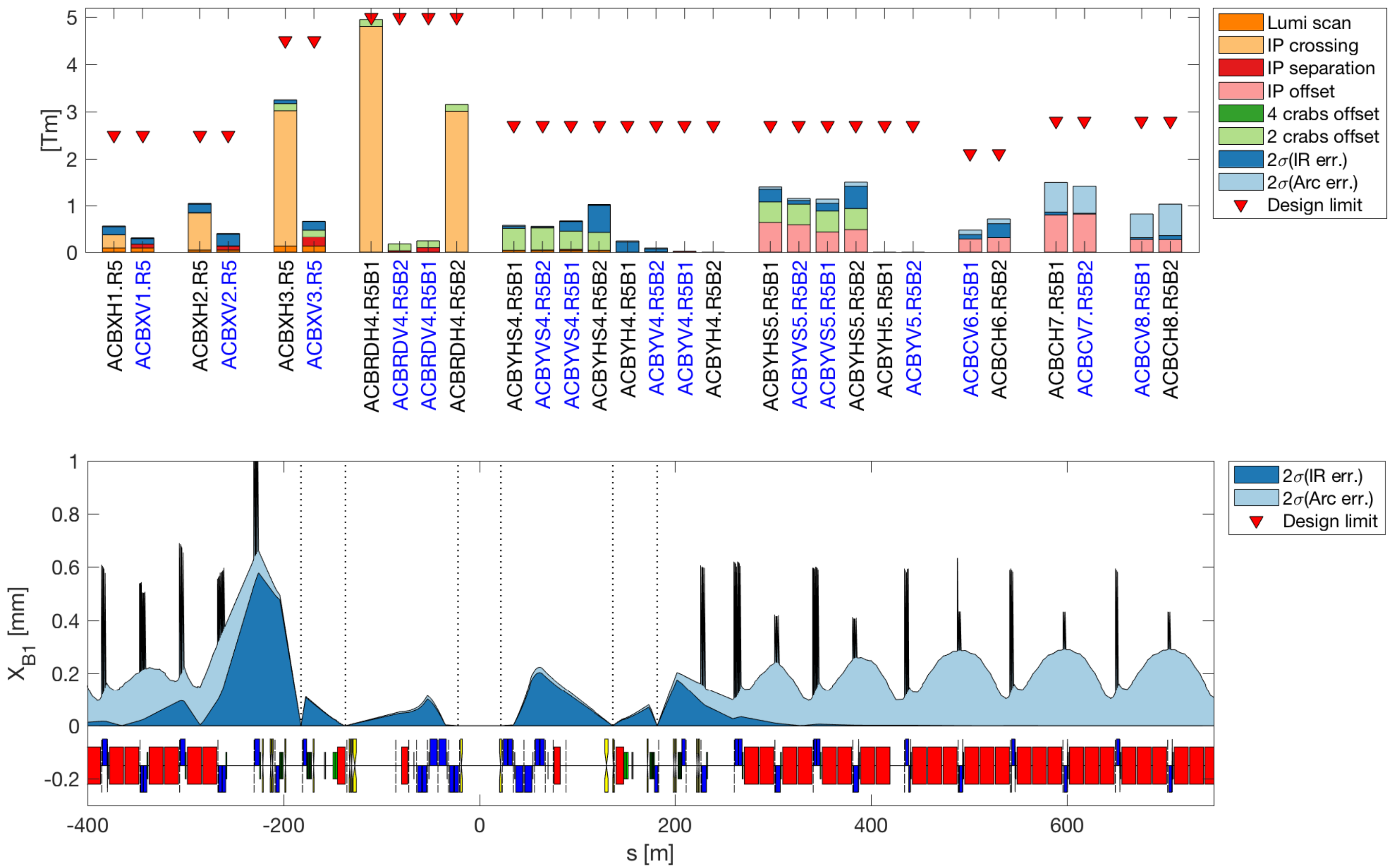
New orbit correction (no ACBRD)

- Same as before, but trying to remove orbit correction from MCBRD correctors.

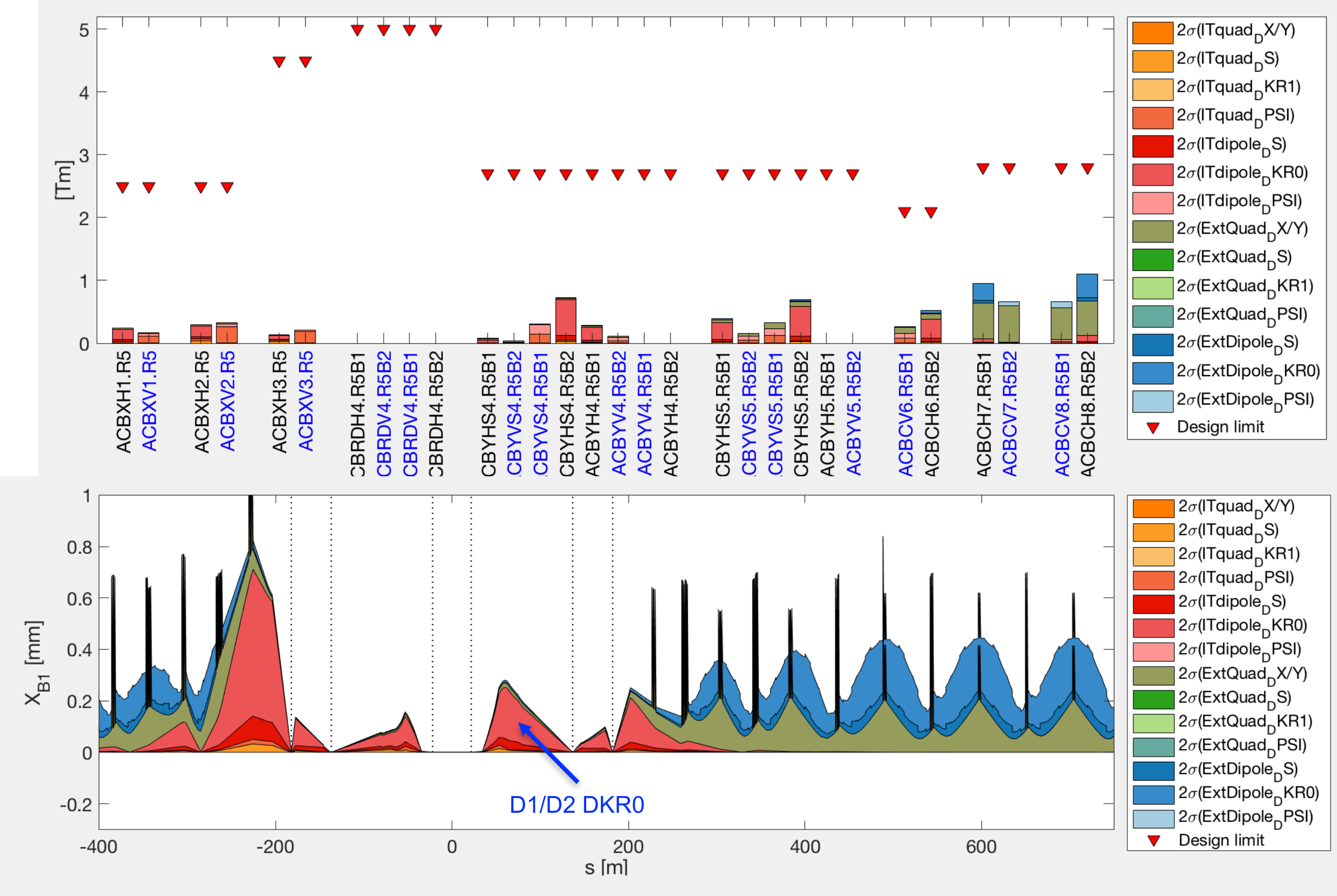
New orbit correction (no ACBRD)



New orbit correction (no ACBRD; no Q1-5 DX/DY)



New orbit correction (no ACBRD; no Q1-5 DX/DY)

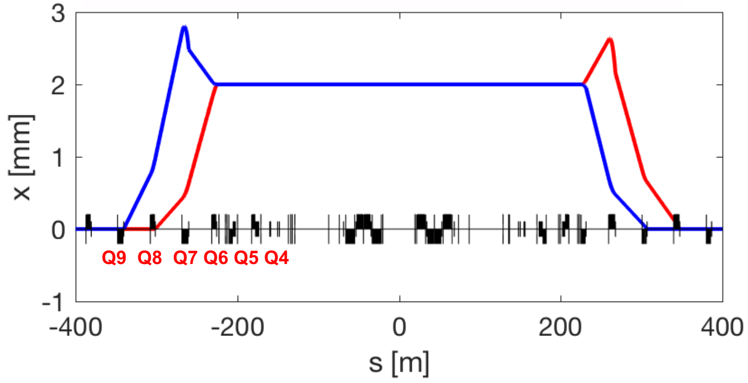


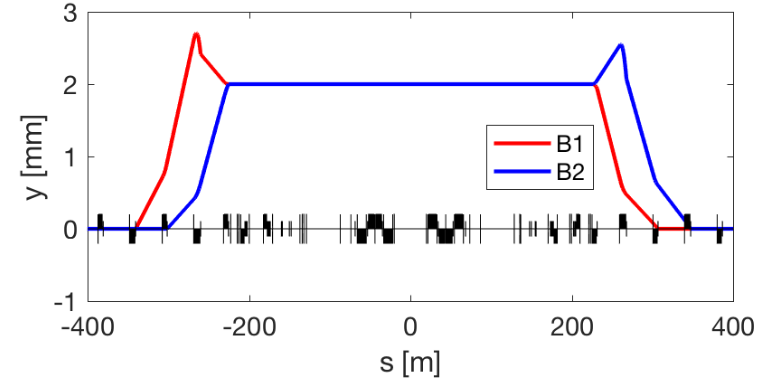
CC alignment knobs

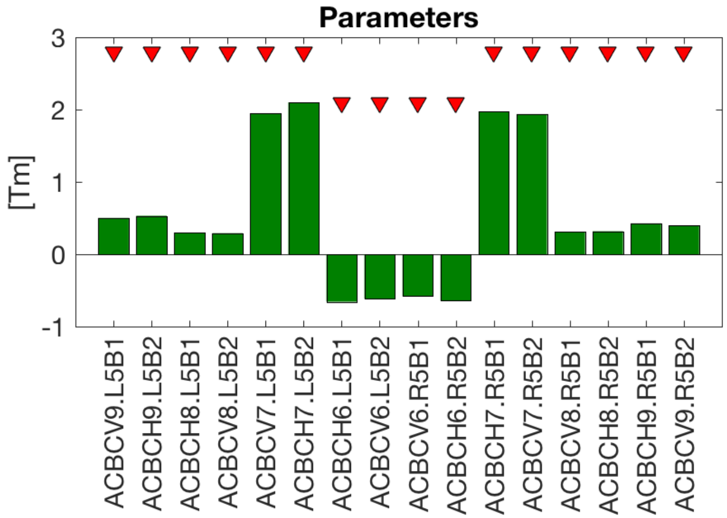
- Assumptions from Miriam's paper:
  - residual orbit of ±0.5 mm can be tolerated in the crab cavities
    - https://indico.cern.ch/event/307357/ (2014)
    - https://indico.cern.ch/event/323860/ (2014)
  - crab cavities represent very sensitive BPMs and one can assume that the orbit displacement at the location of the crab cavities would be known within 0.01–0.1 mm [R. Calaga – private com]
- Additional investigations by Riccardo (24/11/2016):
  - crabbing plane to max ±1mm per cavity, or up to ±2mm for transients of few ms. ±3mm if off.
- Additional question: how precise one can measure the orbit? In both planes? With/without RF?
- In the baseline only one pair of CC per beam per side. The two pairs are in two independent cryomodules that can be moved independently.

Getting rid of offset knob – far-short

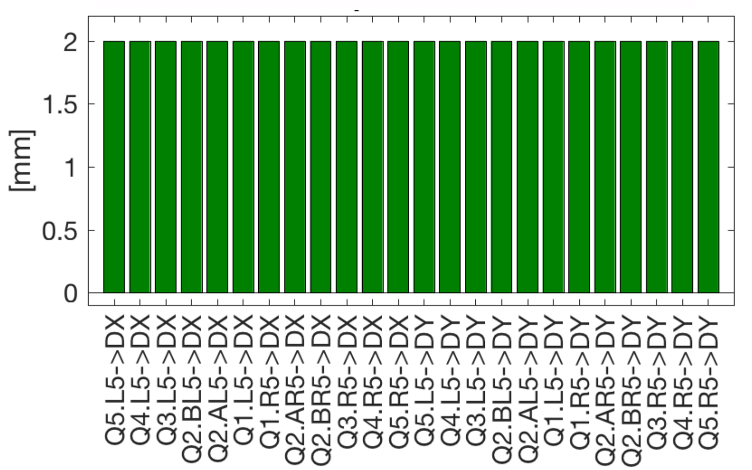
Orbit bump from Q9 to Q6





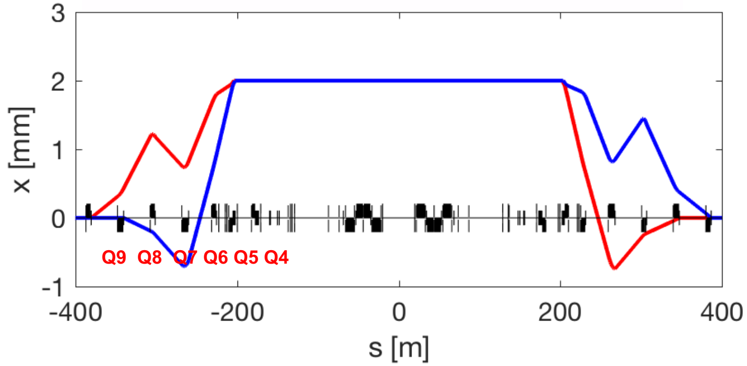


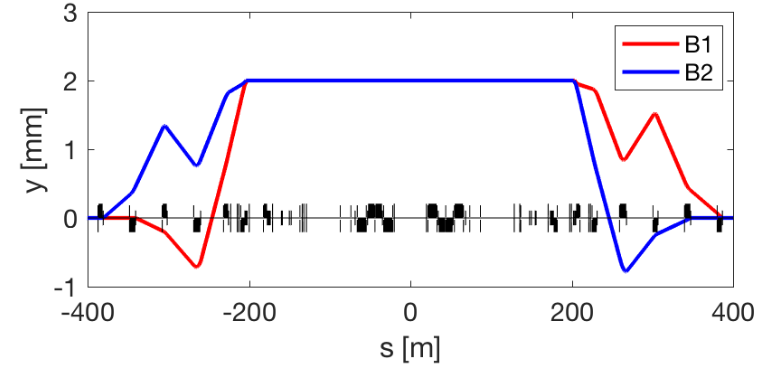
Moving of 2 mm all elements from Q5.L to Q5.R:

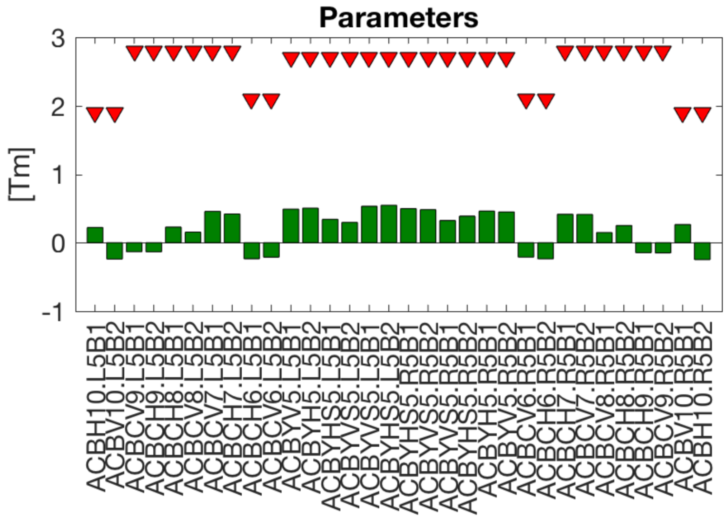


Getting rid of offset knob – far-long

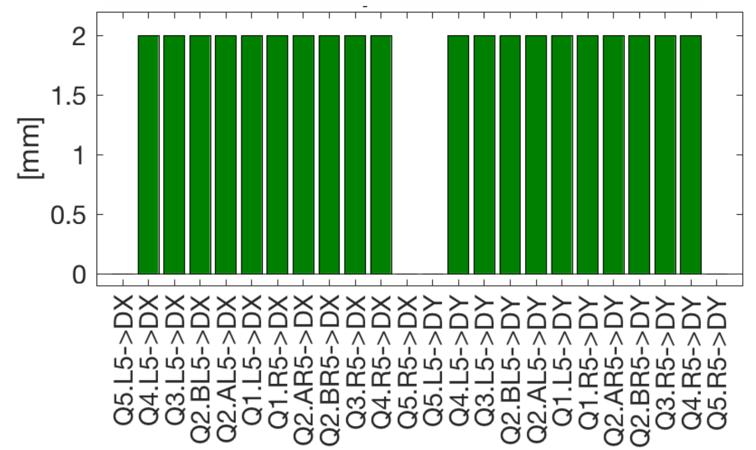
Orbit bump from Q10 to Q5





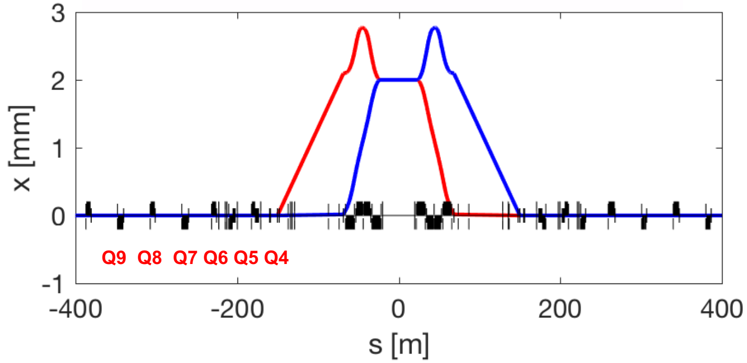


Moving of 2 mm all elements from Q4.L to Q4.R:

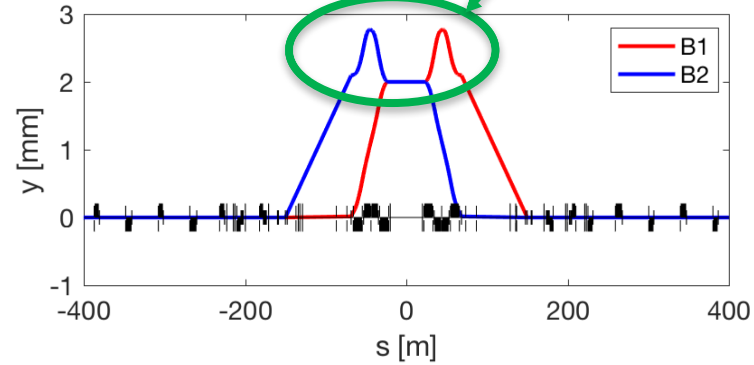


Getting rid of offset knob – nearV1

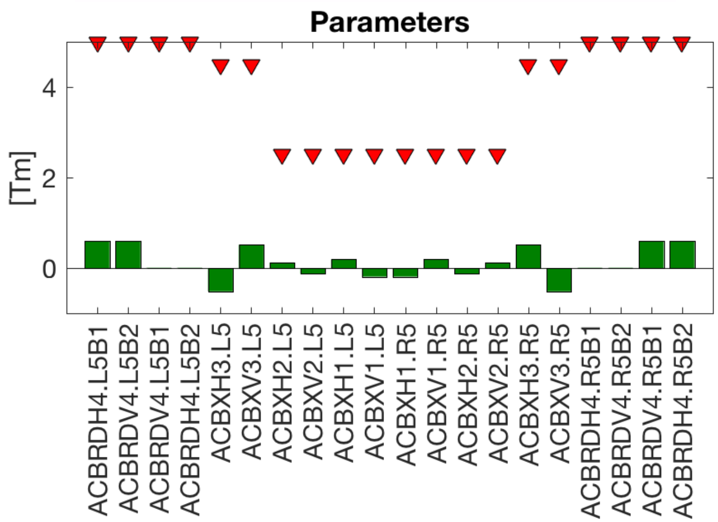
Orbit closed on D2



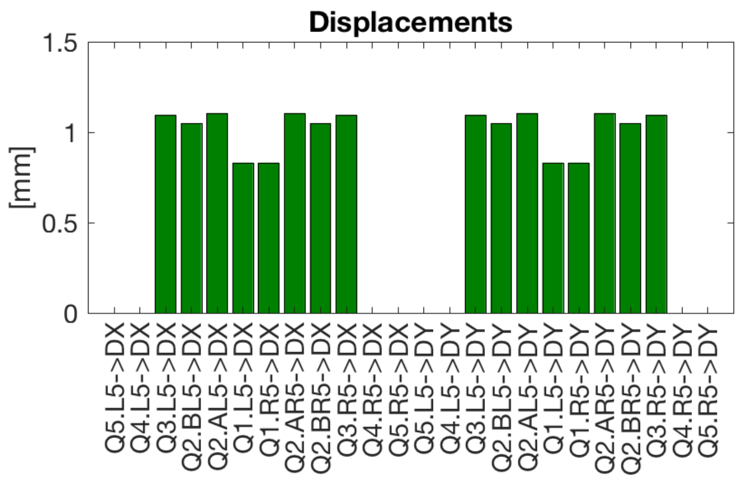
Loss of aperture



< 0.6 Tm per corrector.

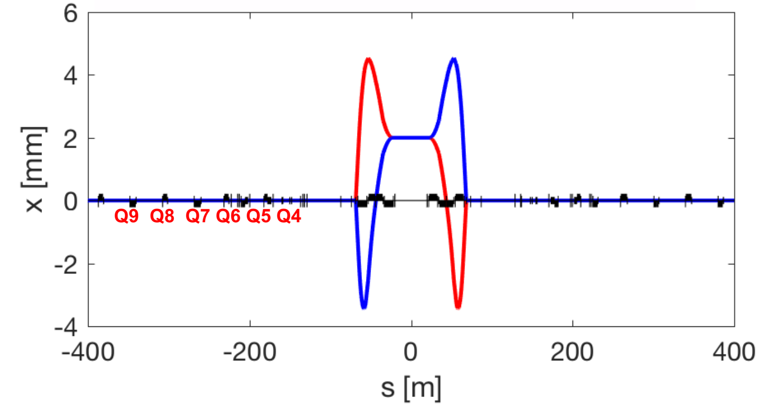


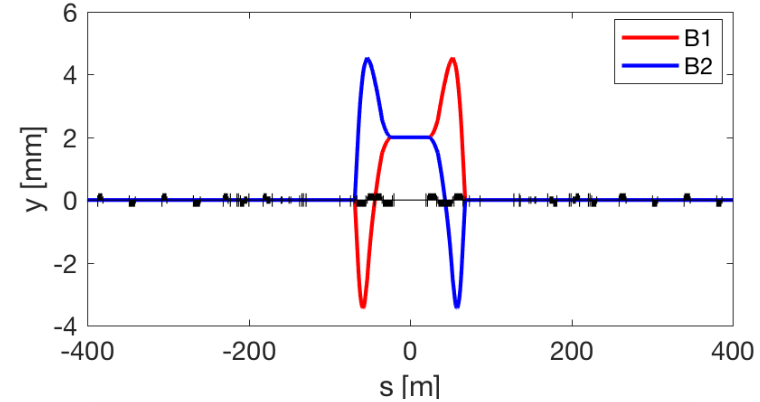
Moving of ~1 mm the triplet



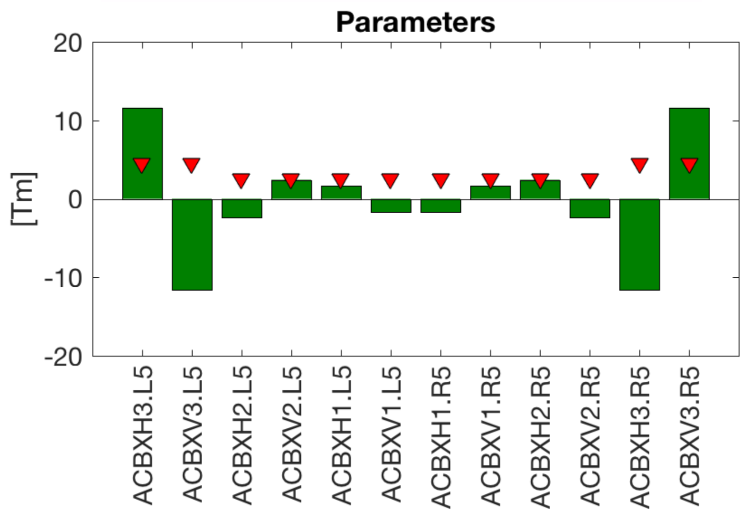
Getting rid of offset knob – extreme

Orbit closed on Q3

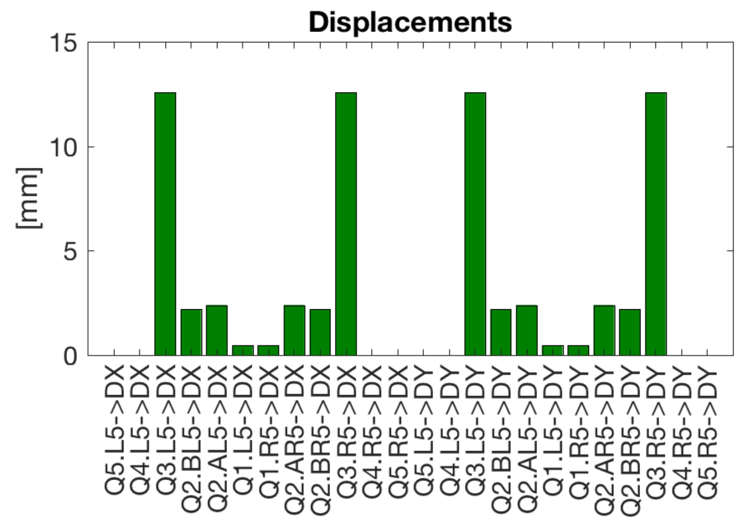




> 10 Tm.



Movements >10 mm



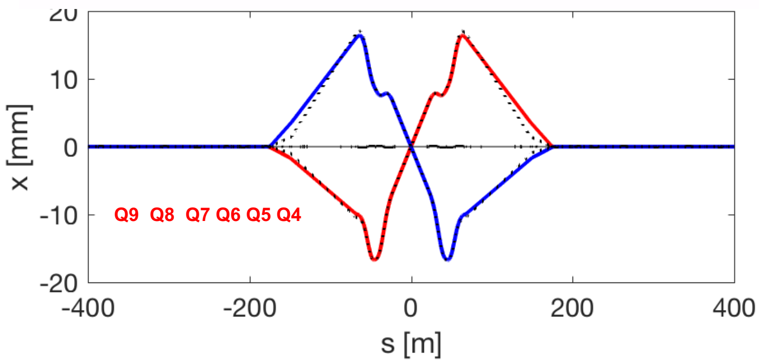
Getting rid of offset knob: resume

- Far-Long/Med: Q1-Q4 of 2 mm
- NearV2: about 1.5 mm on Q3+Q2B, 1 mm Q2A+Q1

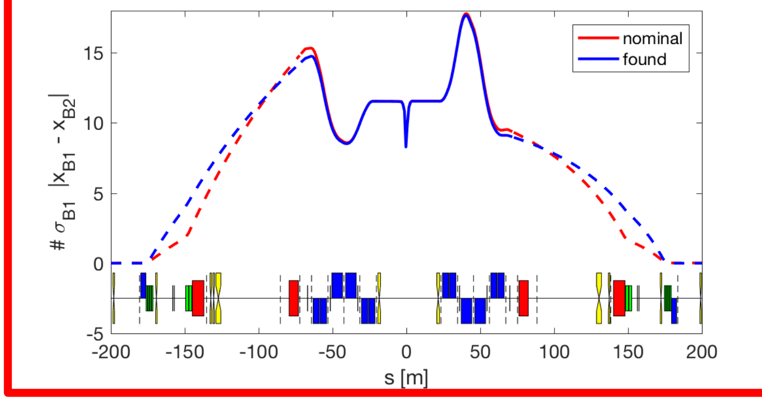
Circuit	Off. [±2 mm]				Sum				Budget
	Baseline	Far-Long	Far-Med	nearV2	Baseline	Far-long	Far-Med	nearV2	
MCBX1	1.05	0	0	0	1.44	0.39	0.39	0.39	2.5
MCBX2	0.57	0	0	0	0.96	0.39	0.39	0.39	2.5
MCBX3	0.99	0	0	0.02	3.94	2.95	2.95	2.97	4.5
MCBRD4	0	0	0	0.53	4.39	4.39	4.39	4.92	5
MCBY4	0.74	0	0	0	2.34	1.6	1.6	1.6	2.7
MCBYS4	0.74	0	0	0	2.38	1.64	1.64	1.64	2.7
MCBY5	0	0.51	0	0	0	0.51	0	0	2.7
MCBYS5	0.39	0.55	0.80	0	1.7	1.86	2.11	1.31	2.7
MCBC6	0.47	0.24	0.31	0	0.47	0.24	0.31	0	2.1
MCBC7	1.17	0.46	0.82	0	1.17	0.46	0.82	0	2.8
MCBC8	0	0.23	0.27	0	0	0.23	0.27	0	2.8
MCBC9	0	0.13	0	0	0	0.13	0	0	2.8
MCB10	0	0.27	0	0	0	0.27	0	0	1.895

Improving crossing knob -- default

Orbit closed on Q4 -> orbit at crab cavities



(here not as optimised as the baseline)



Not using quads