Crab Cavity Knobs

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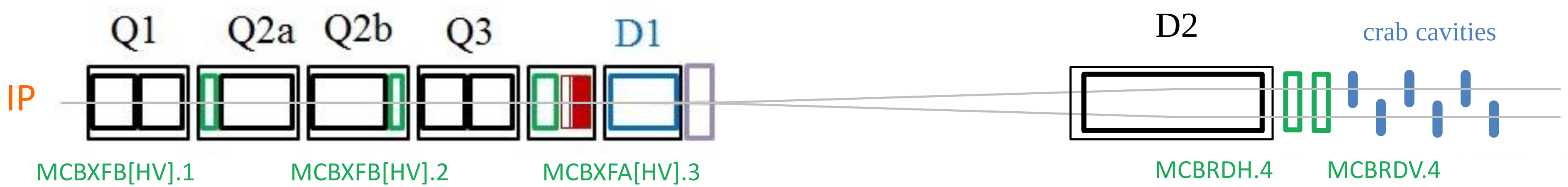
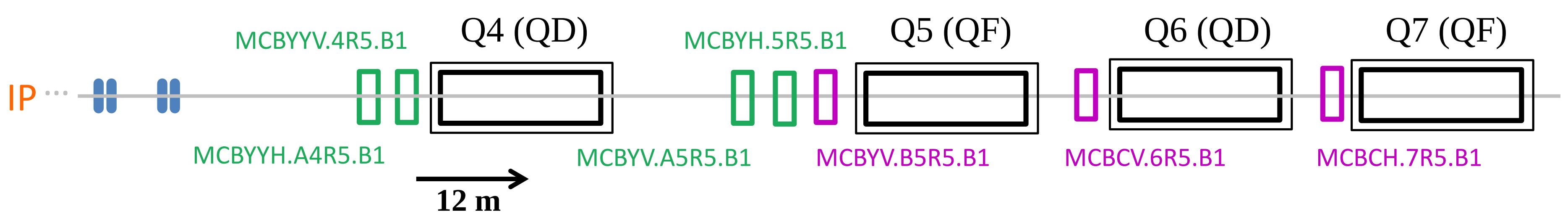
for details see: Crossing scheme and orbit correction in IR1/5 for HL-LHC

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Correctors in IR1/5, layout HLLHCV1.1





Correctors in IR1/5, layout HLLHCV1.1

	corrector strength [Tm]						
	round optics: $\beta^* = 0.15/0.15$ m, xing = ± 295 μm, separation = ± 0.75 mm						
	MCBX1	**MCBX2**	**MCBX3**	**MCBRD**	**MCBYY4**	**MCBY5**	**MCBC6/7**
x-scheme	0.12	0.05	1.81	2.88	1.30	0.00	0.00
offset	0.34	0.34	0.72	0.09	0.09	0.00	0.00
IT error	0.92	1.40	0.78	0.04	0.00	0.00	0.0
crab	0.44	0.00	0.65	1.16	2.15	1.56	0.00
lumi	0.00	0.00	0.00	0.27	0.20	0.00	0.00
arc	0.00	0.00	0.00	0.00	0.70	0.70	0.70/0.84
sum	1.82	1.79	3.96	4.44	4.44	2.26	0.70/0.84
margin %	27.2	28.4	12.0	1.3	1.3	16.3	75.0/70.0
max	2.50	2.50	4.50	4.50	4.50	2.70	2.80/2.80

The crab cavity knobs contribute almost as much as the x-scheme -> we are right at the limit with the corrector strength!!!

Correctors in IR1/5, layout HLLHCV1.1

	corrector strength [Tm]						
	flat optics: $\beta^* = 0.30/0.075$ m, xing = ± 275 μm, separation = ± 0.75 mm						
	MCBX1	**MCBX2**	**MCBX3**	**MCBRD**	**MCBYY4**	**MCBY5**	**MCBC6/7**
x-scheme	0.12	0.05	1.69	2.68	1.21	0.00	0.00
offset	0.34	0.34	0.72	0.09	0.09	0.00	0.00
IT error	0.92	1.40	0.78	0.04	0.00	0.00	0.0
crab	0.44	0.00	0.65	1.16	2.15	1.56	0.00
lumi	0.00	0.00	0.00	0.27	0.20	0.00	0.00
arc	0.00	0.00	0.00	0.00	0.70	0.70	0.70/0.84
sum	1.82	1.79	3.84	4.24	4.35	2.26	0.70/0.84
margin %	27.2	28.4	14.6	5.7	3.3	16.30	75.0/70.0
max	2.50	2.50	4.50	4.50	4.50	2.70	2.80/2.80

… only slightly better situation for flat optics

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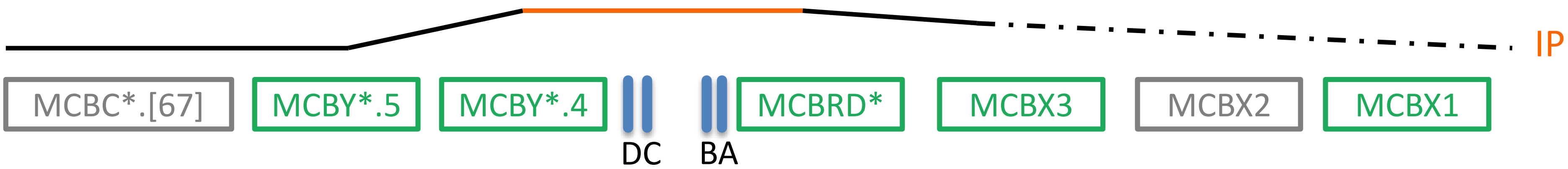
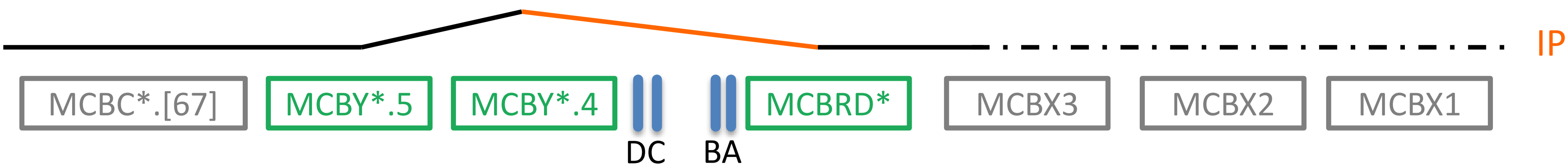
What we can do: crab cavity knobs

We can control 2 points in the crab cavity area, but not 4.

Shift knob: range = +/- 0.5 mm, knobs, ccp: x_{b1}(crab)= x_{b2}(crab), ccm: x_{b1}(crab)=-x_{b2}(crab)



Slope knob (ccs): +/- 0.25 mm



<table>
<tr><th></th><th colspan="5">corrector strength [Tm]</th></tr>
<tr><th>knob</th><th>MCBX1</th><th>MCBX3</th><th>MCBRD</th><th>MCBYY4</th><th>MCBY5</th></tr>
<tr><td>ccp</td><td>0.37</td><td>0.40</td><td>0.31</td><td rowspan="2">0.42</td><td rowspan="2">0.43</td></tr>
<tr><td>ccm</td><td>0.00</td><td>0.14</td><td>0.14</td></tr>
<tr><td>ccs</td><td>0.00</td><td>0.00</td><td>0.52</td><td>0.95</td><td>0.44</td></tr>
<tr><td>sum</td><td>0.37</td><td>0.54</td><td>0.97</td><td>1.79</td><td>1.30</td></tr>
</table>

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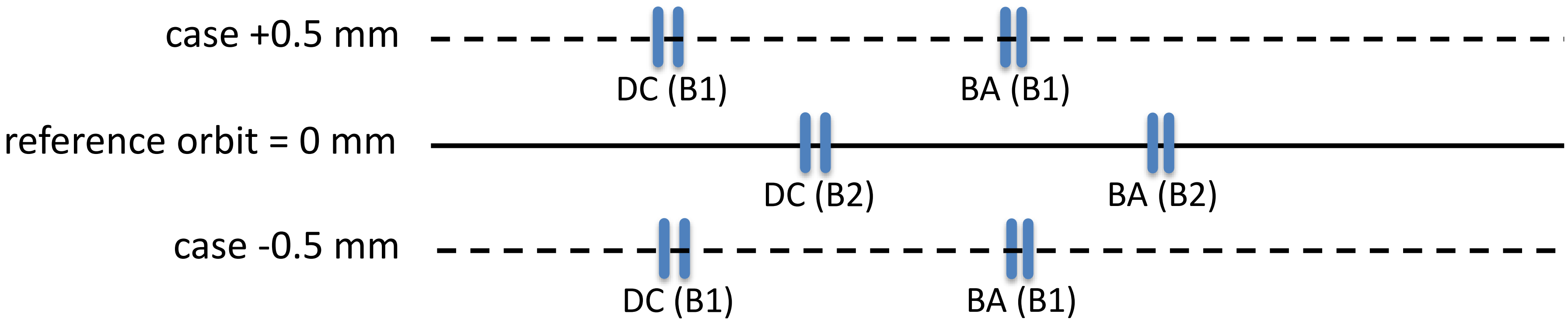
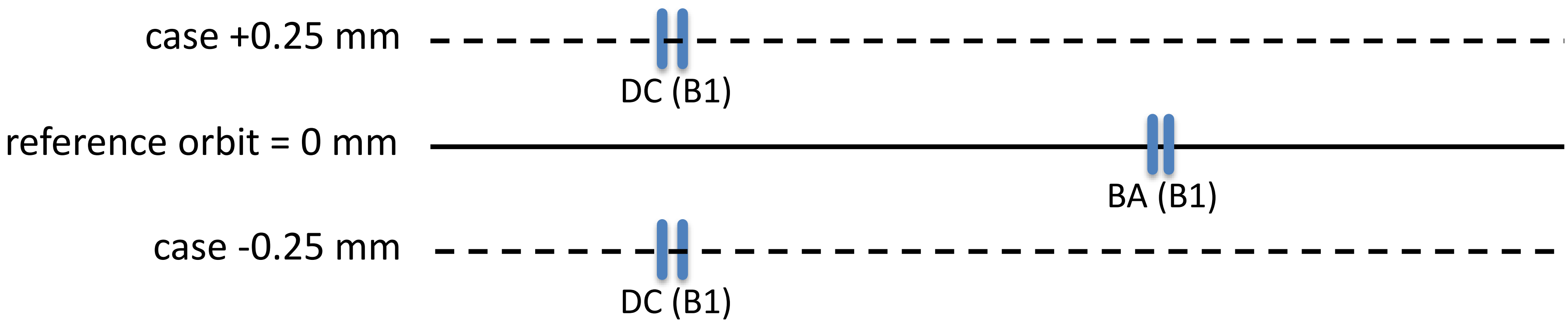
Crab cavity knobs - range

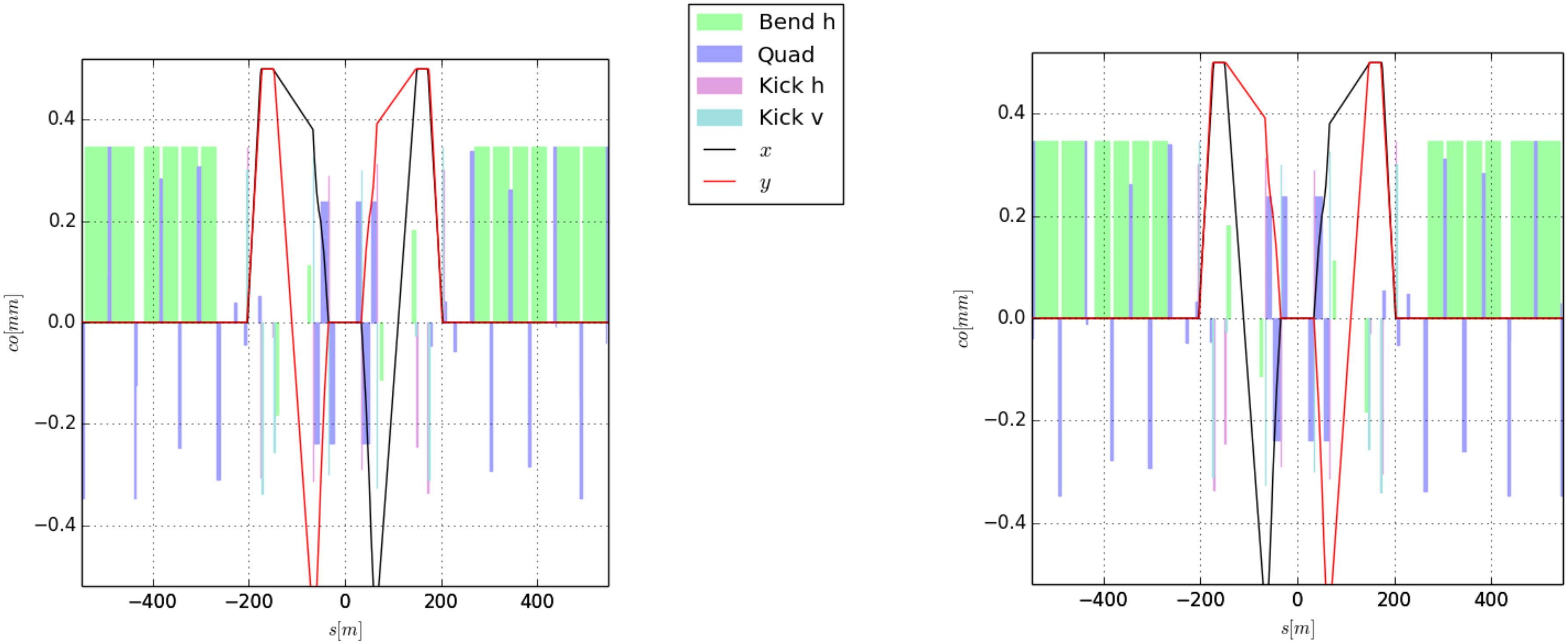
shift knob



slope knob



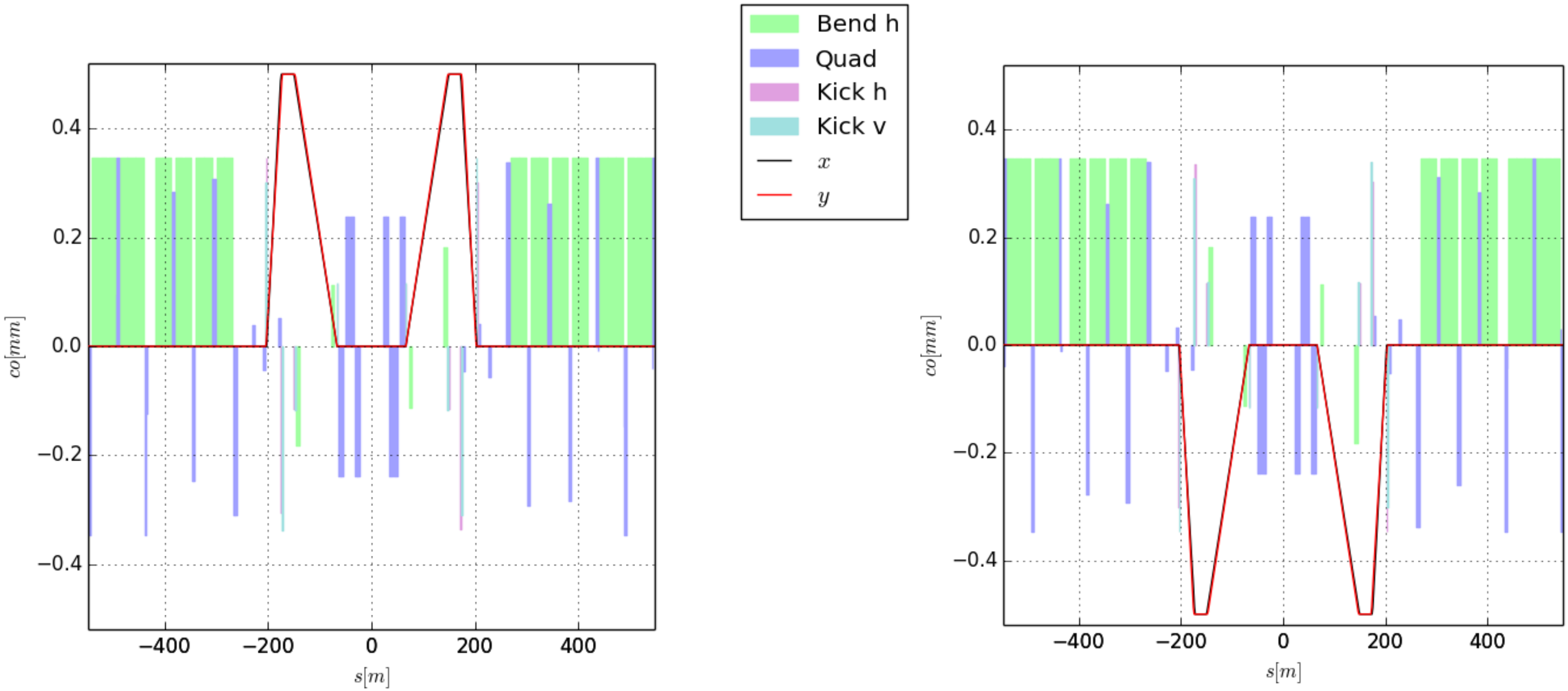
Crab cavity knobs - ccp



IR5, beam 1

IR5, beam 2

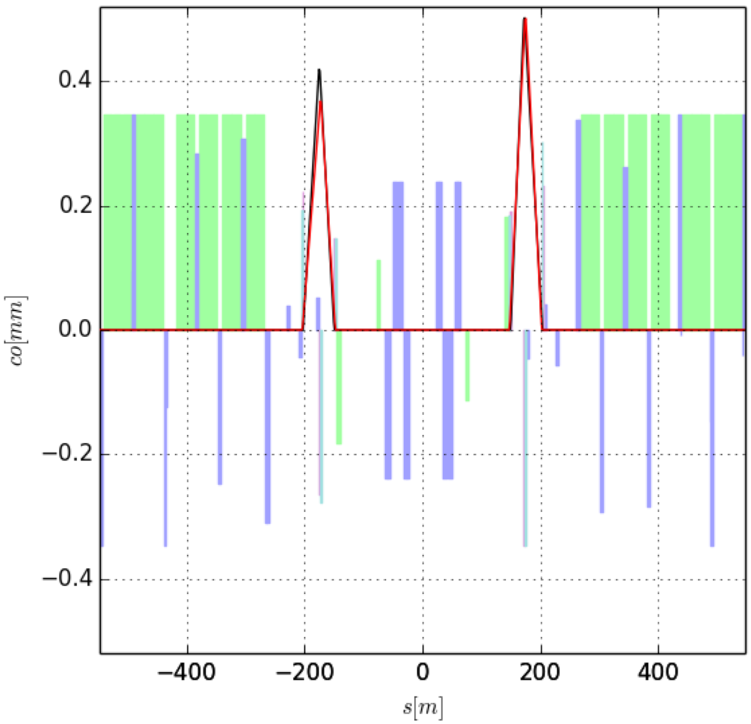
Crab cavity knobs - ccm



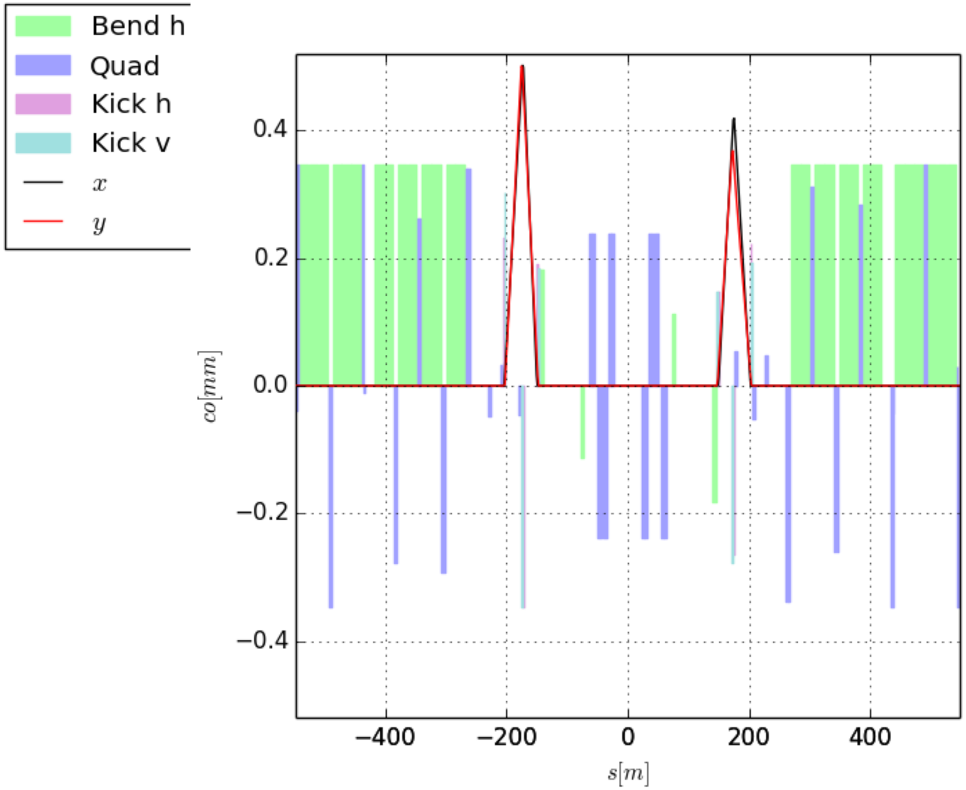
IR5, beam 1

IR5, beam 2

Crab cavity knobs - ccs



IR5, beam 1



IR5, beam 2

Alignment tolerances

Note: what counts is the orbit deviation from the electrical center of the crab cavities (not the mechanical)!

What we know:

1. tolerable orbit in crab cavities:
    a. if crab crossing active: +/- 1.0 mm from electrical center
    b. if crab crossing not active: +/-2.0 mm from electrical center
    c. if crab crossing not active and less current: >+/-2.0 mm (e.g. VdM could be up to +/-2.5 mm)
2. Alignment of crab cavities:
   The mechanical center of the crab cavities can be aligned within +/-0.5 mm. This includes the initial misalignment and the alignment which might occur between alignment campaigns **(what is the interval assumed?)**. The alignment error is independent of if the crab cavities are in the same cryomodule or not!
2. The difference between the electrical and mechanical center is not known yet. (It is expected to be small (below the +/-0.5mm), but requires data from cavities fabricated to define a better estimate)
3. Using the crab cavities as BPMs, the orbit can be determined within +/-0.1 mm at the location of the crab cavities

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Alignment tolerances

Note: what counts is the orbit deviation from the electrical center of the crab cavities (not the mechanical)!

What we can conclude in respect of the orbit budget:

1. operational margin = tolerable orbit deviation at location of crab cavities in case of active crab crossing and after subtraction of alignment errors:

   +/- 1 mm–[+/-0.5 mm (align. error of mech. center)]–[+/-d_{me} mm (align. error of electrical-mech. center)]

   = +/-(0.5-d_{me}) mm

2. the position of the electrical center with respect to the beam at the crab cavities (neglecting the information of nearby BPMs) is known within:

   +/-0.1 mm (precision of crab cavities as BPMs)

Open questions:

1. knowledge of alignment error between electrical and mechanical center
2. are the beam-based alignment knobs still useful to compensate alignment errors? (note that they can only adjust two points in the cc section, but we have 4 cavities)?
3. orbit corrector strength has to be reevaluated once we know all alignment errors (see also next slide)

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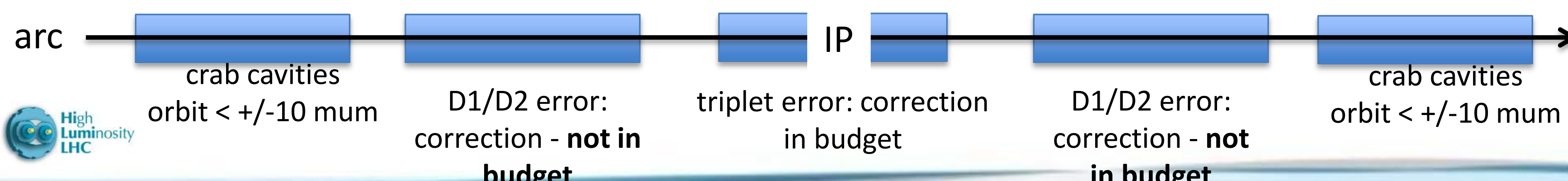
Scenario with using BPMs in IR region

Scenario/budget using the BPMs in the IT and crab cavity region:

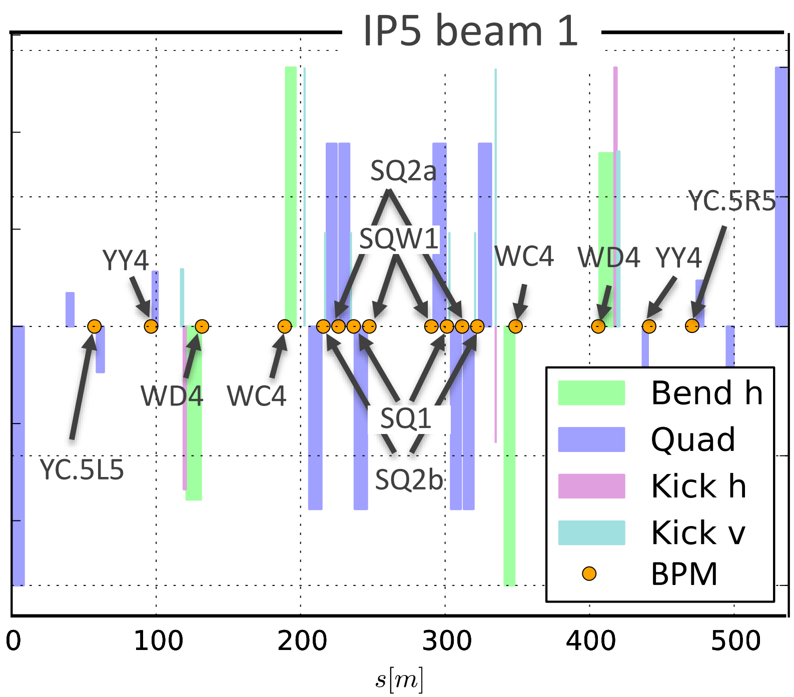
Assuming a 1-2 mum BPM precision, the orbit at the location of the crab cavities could be known even more precisely, let's say <+/- 10 mum (see the sketch on the following slide):

a. [+/-0.5 mm] – [+/-d_{me}] – [+/- 10 mum] would be left for the adjustment of the crossing scheme (**note:** the alignment error d_{me} between electrical and mechanical center is not known)
b. orbit corrector budget – contributions not taken into account/to be confirmed:
   - The orbit correctors in the DS/arc need to have sufficient strength to correct the orbit to <+/-10 mum in the crab cavity section **(still to be verified)**
   - The orbit deviation caused by errors in the IT are already included in the budget, leaving only the uncertainty of the D1/D2 transfer function to be compensated (either by D1/D2 currents or nearby orbit corrector)
   - -> beam based alignment of cc knobs could be used for D1/D2 error correction, but the range needed should be considerably smaller

=> we might have even margin in the corrector strength, if there are not any bad surprises by the alignment error between electrical and mechanical center (hopefully the error is much smaller than +/-0.5 mm) and the D1/D2 transfer function error!



BPM layout



Optimization of BPM position to increase the knowledge of the orbit in the crab region:

- Add a BPM in between D2 and crab
- Exchange the position of the BPM at Q4

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