HL-LHCV1.4

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TCC meeting 20/9/2018

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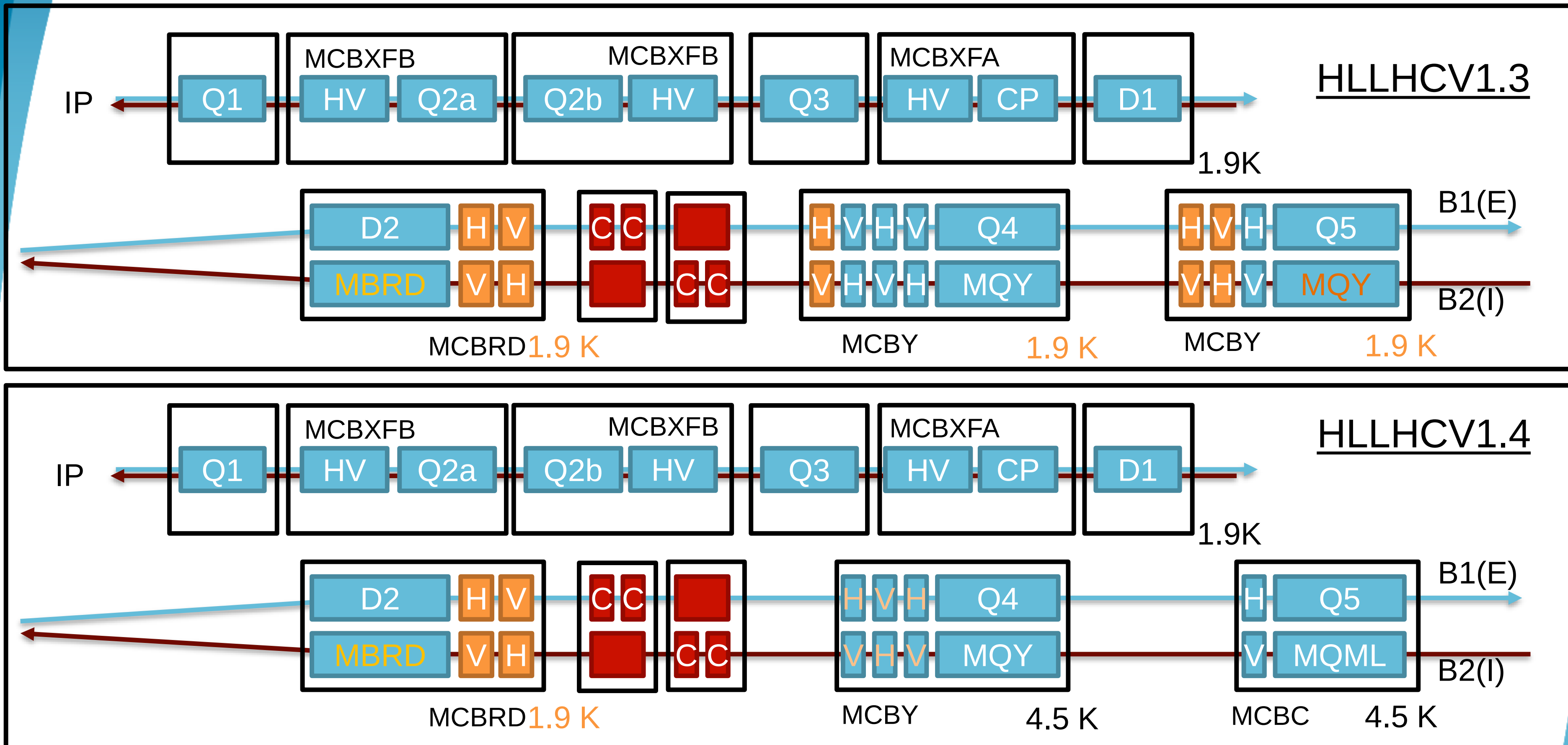
- Summary of the changes
- Orbit corrector budget and non conformities
- IR4 Optics update (instrumentation and e-lens)
- IR6 Optics update (TCDQ gap)
- Crossing plane choice timeline

Layout main changes



Changes with respect to the baseline:

- Q4: reusing existing cold mass (3 correctors instead of 4), no need of 1.9 K.
- Q5: reusing existing Q5 cold mass (1 corrector instead of 3), no need of 1.9 K.
- <u>Full deployment of remote alignment system to be used with safe beam</u>.

Chamonix 2018

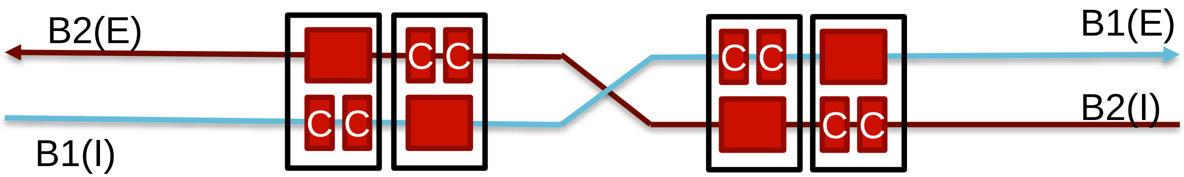
Summary of changes HLLHC1.3 → 1.4

Main layout changes:

- 4 crab cavities/IP/beam/side no longer possible:
- Q4, 4xMCBY+MQY 1.9 K → 3xMCBY+MQY 4.5 K
- Q5 3xMCBY+MQY 1.9 K → 1xMCBC+MQML 4.5 K
- Remote alignment system:
  - machine can be realigned during beam commissioning for IP shift and orbit flattening
  - Reduced use of orbit correctors and increase aperture
- Other changes:
  - Q4 – Q5 new positions from cryogenic request
  - New corrector package strengths and lengths
  - LS2 approved changes: MBH, TCLD, MQW, TDIS, TANB

- <u>Other changes are being addressed by integration/hardware teams:</u>
  - will be included when drawings will be released for the next optics version

Point 1/5: Crabbing angle



7 TeV Optics	Q7 [T/m]	Crab angle [μrad]
HLLHCV1.3	200	380
HLLHCV1.4	200	375
HLLHCV1.4	214	388

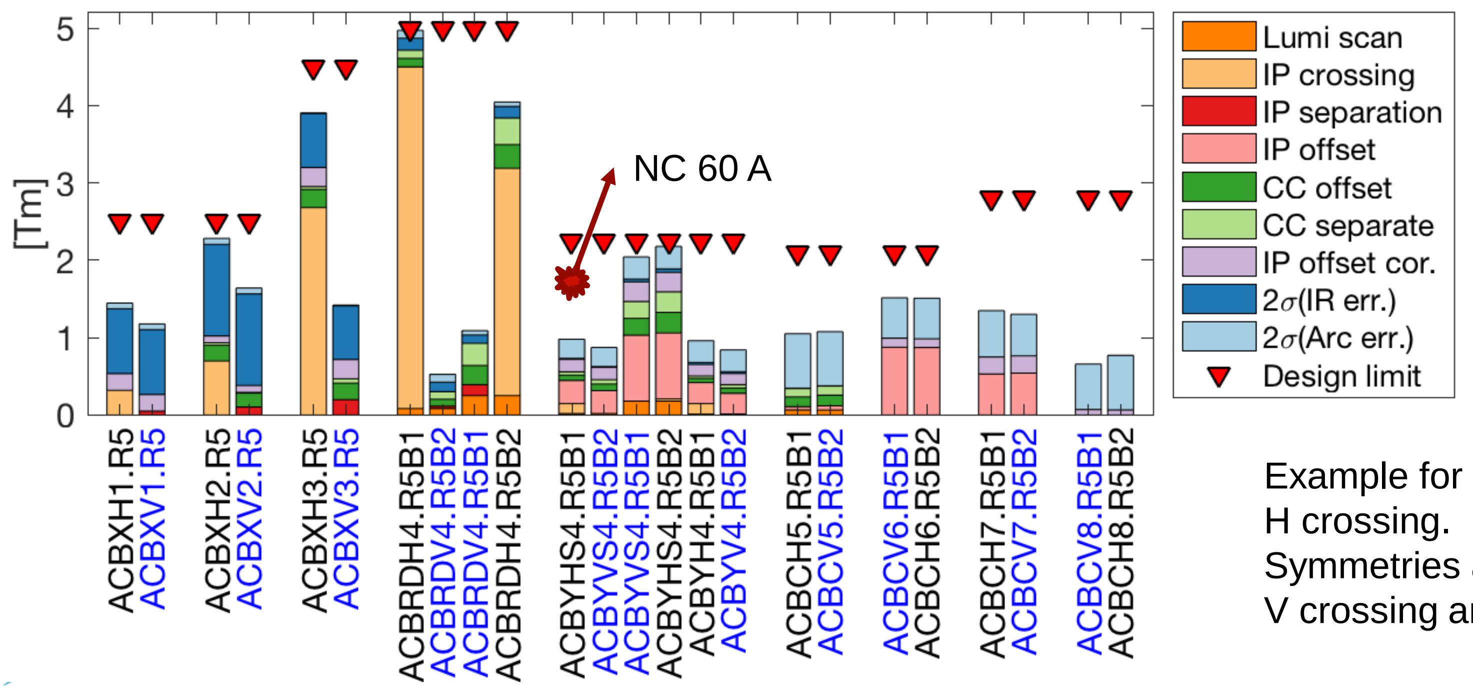
- 5 μrad lost due to Q4-Q5 displacement from HL1.3 to HL1.4.
- Higher than nominal Q7 current allows to increase crabbing angle, which would be usable for 7 TeV scenario (at least in Run IV) if Q7 would reach ultimate current. Need test of Q7 to ultimate current to validate this possibility.
- Further improvements (few % level) are possible by optimizing optics and CC ordering in the layout depending on the crossing plane. Is this conceivable from the HW and integration point of view?

Summary of strengths with remote alignment

Knobs and correction for:

- ±295 µrad crossing angle in H/V plane (H in the figure)
- ±0.75 mm separation in V/H plane (V in the figure)
- ±2 mm IP offset with correctors + Q1-Q4 displaced by 2 mm
- ±0.1 mm IP movement independent for B1/B2 for luminosity scan
- 2 σ correction of ±0.5 mm residual quad. misalignment and ±0.5 mrad dipole tilt.
- Short range orbit adjustments (±0.2 mm CC adjustment, ±0.5 mm IP shift with orbit correctors)

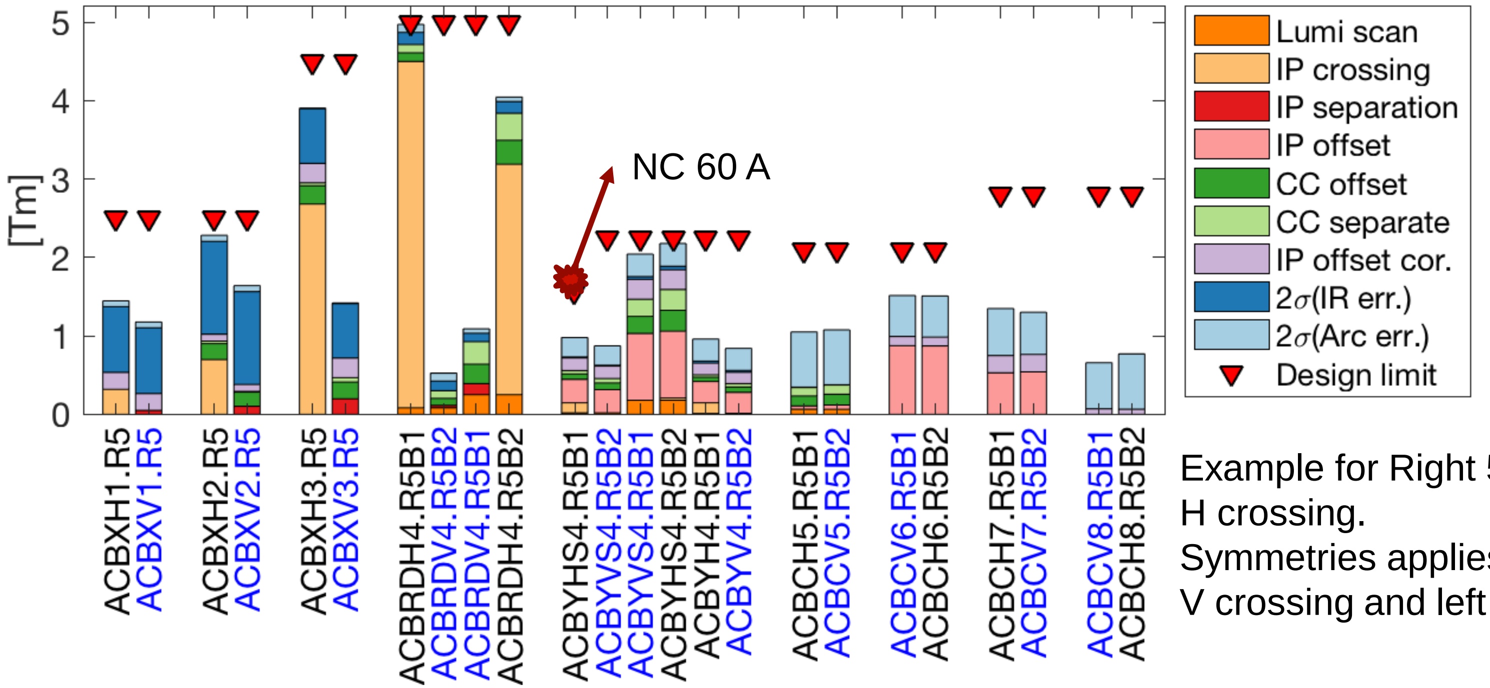
Remote alignment for IP shift and orbit corrector minimization during beam commissioning.



Example for Right 5 with H crossing.
Symmetries applies for V crossing and left side.

Non Conform MCBY

- Non-conformities evaluated by M. Giovannozzi in the context of the previous layout.
- Non conform magnet MCBYHS4.R5B1 (MCBYHS4.L5B1 in LHC) can be also compensated by MCBYH4.R5B1.
- 4 other MCBYs out 38 are not conform (one aperture limited to 20 - 50 A for possible internal short)



Example for Right 5 with H crossing.
Symmetries applies for V crossing and left side.

<u>An explanation on the origin of the NC and long term outlook for the series is mandatory to establish a robust strategy.</u>

Apertures estimates

	Round	Flat
TAXS	16.3	14.0
Q1	17.4	15.9
Q23	<u>13.1</u>	<u>12.7</u>
D1	13.9	13.0
TAXN	18.0	14.0
D2	19.5	15.0
CRABS	28.3	20.1
Q4 Mask	19.3	13.6
Q5 Mask	21.0	14.9
Q6 Mask	26.5	18.9

Aperture in σ at 2.5 μm/γ at 7 TeV

Round β^*=15 cm, θ_c= ± 250 μrad (10.5 σ);
Flat β^*=7.5/18-30 cm, θ_c= ± 245 μrad (11.3-13.5 σ);

Tolerances:
Mechanical: beam screen shape tolerances, ground motion and fiducialization margins (being reviewed)
Beam: optics and orbit errors
Offset: IP shift 2 mm using remote alignment
Target: 11.9 σ (round), 11.4 – 11.7 σ (flat)

Design Principle: triplet should always be the aperture bottleneck.

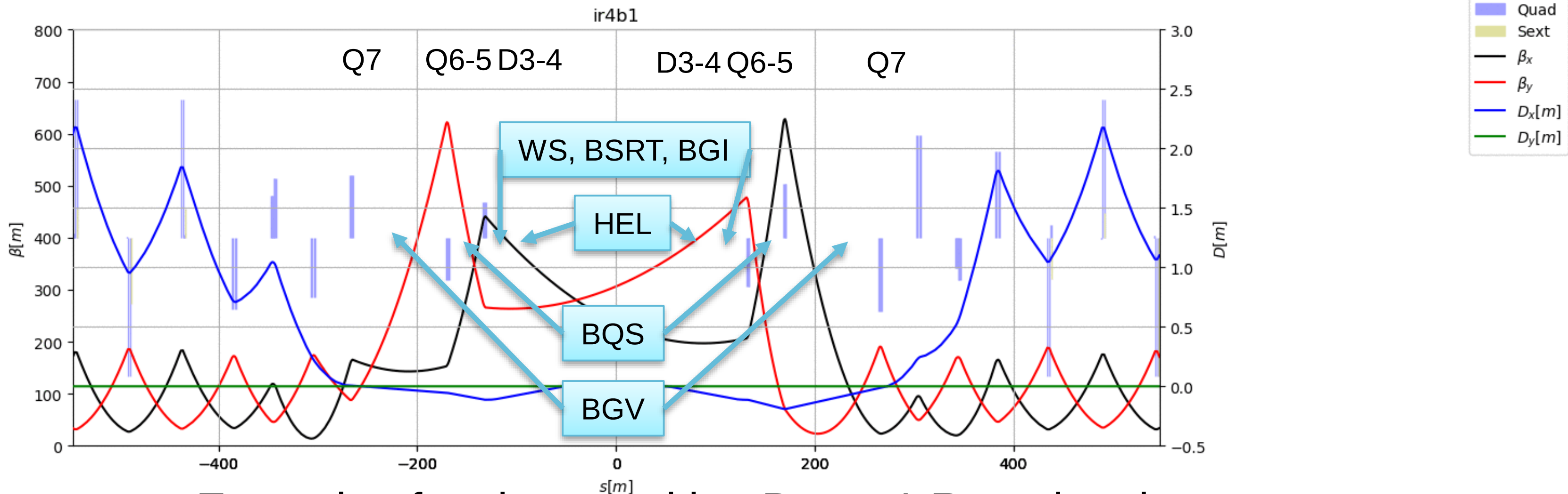
<u>Respected principle and sufficient aperture margins for round and flat thanks to the remote alignment.</u>

<u>WP8 could evaluate if a reduction of few mm of TAXN aperture gives measurable improvements in the energy depositions.</u>

Point 4: optics requests from BI

Follow-up from several WP2-WP13 meetings:

- The proposed optics can be used from injection to flattop without optics transition (provided no ATS during the ramp). Further improvements still possible but deemed not necessary at this stage.
- Increase the minimum beta at the BSRT above 200 m while keeping the beta at HEL bigger than 250 m.
- Optics solution compatible with requirements for main instruments (BSRT, WS, BGV) being evaluated by WP13.
- Minor changes for the ADT from previous version. WP4 validation needed anyway?
- E-lens aperture compatible with 50 mm diameter.

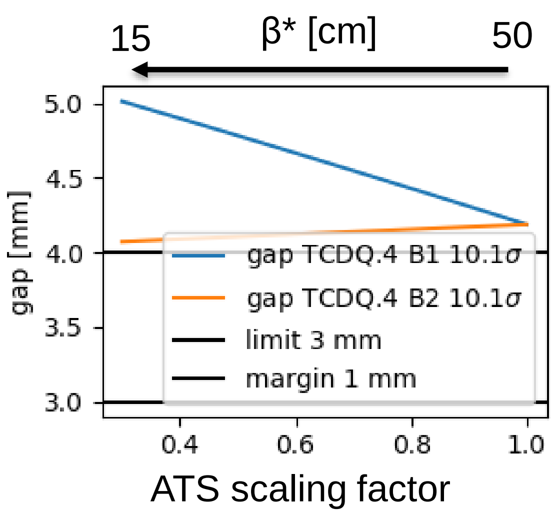


Example of optics transition Beam 1 Round optics

Point 6: Proposal for TCDQ gap margin

TCDQ gaps	Old [mm]	New [mm]	
Min real gap	3	3	Based on present FLUKA and ANSYS studies at 2.2 10^{11}. Lower for lower ppb?
Interlock	1.2	0.8-0.5	Based on studies with DOROS TCSP
Position accuracy, β-beat	0.3	0.3	
Dispersion δ =2e-4	0.4	0.1	Using realistic D_x=0.5 m instead of 2 m
Total margin	1.9	0.9-1.2	1.1 needed for WP2 running scenarios

BETS:fixed gap at flat top in mm corresponding to the setting at the end of the squeeze.



Round squeeze

Operational scenario TCDQ settings:

- Beam 1: $\beta_{x,TCDQ}$ increases during the squeeze
  - 5 mm: from 12.3σ →10.1 σ:
- Beam 2: $\beta_{x,TCDQ}$ decreases during the squeeze
  - 4.1 mm: from 9.6 σ → 10.1 σ.
- For flat optics Beam 2 β increases during the squeeze instead and gap >4.2 mm.
- 9.6 σ feasible but not ideal. TCDQ leveling (MD3 S. Fartoukh) and/or ATS during the ramp can increase this value.

A gap of 4.1 mm is needed to validate the optics.

Point 6: Q5 Current

Q5.L6 campaign, LMC 21/3/2018, A. Verweij

MQY	Current [A]	Gradient [T/m]
Nominal	3610	160
Ultimate	3900	173
SS Limit 1.9K	5800	257
Quench	4000	177
Stable operation	3950	175

Test for Q5.R6 as well proposed during end-of-run test.

[1] (Nominal gradient + 1%)+50 A using LSA

	HLLHCV1.4 @ 7TeV (with MS in Q10)			Operational current[1]	
	Round β*=15/15 cm	FlatCC β*=7.5/18 cm	Flat β*=7.5/30 cm	7 TeV [A]	7.5 TeV [A]
Q5.L6 [T/m]	163/165	160/167	148/171	3755/3928	4025/4205
Q5.R6 [T/m]	159/151	160/150	161/147	3708/3476	3977/3727

- Few T/m reduction w.r.t HLLHCV1.3 in particular for Q5.R6.
- Possible to operate at 7 TeV (at least Run IV) without 1.9K upgrade.
- Possible to operate at 7.5 TeV (from Run V) without 1.9K upgrade of Q5.R6 if PC tests are successful.

Point 6: optics, aperture, crossing plane

	Round	FlatCC	Flat
β* Xing/Sep [cm]	15/15	18/7.5	30/7.5
Xing angle [μrad]	±250	±240	±245
MKD-TCT [°] IP5	30	22	25
Protected H Ap. [σ] IP1/5	11.2/11.9	11.2/11.4	11.2/11.7
Protected V[1)] Ap. [σ] IP1/5	11.2/11.2	11.2/11.2	11.2/11.2
Crossing plane IP5	V or H	H	H
Aperture Xing plane [σ]	13.1	14.2	15.6
Aperture Sep plane [σ]	16.5	12.7	12.7

1) assuming different settings for TCTH and TCTV, which is under study (R. Bruce)

Enough aperture with free choice of crossing plane for round optics.

- Present baseline is V-plane in IP5 based on maximizing the round optics margins.
- Need to get input for the forward physics program from the experiments.
- Potential of a flat optics with crab cavities requires more studies.
- What is the time scale for the finalization of the crab cavity layout?

Conclusion

- HLLHCV1.4 implements:
  - New matching section layout reusing Q4, Q5 thanks to remote alignment.
  - Improved Point 4 optics for BI and e-lens.
  - Further reduction of Q5.R6 to avoid 1.9 K upgrade at 7.5 TeV.
  - Compatible with non conform MCBY in Point 5 (but need to understand the origin also for the other MCBYs).

Optimization:

  - Crab angle increase for 7 TeV operations if Q7 can reach ultimate current. To be added at the end-of-run tests?
  - Further improvements if layout optimized different in Point 1 and 5. Feasible?
  - TAXN aperture could be reduced by few mm. Is it worth for energy deposition?

- Operational scenario relies on TCDQ gap margin of 1.1 mm.
- Point 4 Optics needs further checks from WP13 and WP4.
- Crossing plane finalization needs a timeline.

Backup

MQW

DCUM	Old slots	Old Circuit	New slots	New Circuit
19870.8	MQWA.A5L7	RQ5.LR7	MQWA.A5L7	RQ5.LR7
19867.0	MQWA.B5L7	RQ5.LR7	MQWA.B5L7	RQ5.LR7
19863.2	MQWB.5L7	RQT5.L7	MQWA.C5L7	RQ5.LR7
19859.4	MQWA.C5L7	RQ5.LR7	MQWA.D5L7	RQ5.LR7
19855.6	MQWA.D5L7	RQ5.LR7	MQWA.E5L7	RQ5.LR7
19851.8	MQWA.E5L7	RQ5.LR7	removed	removed
20117.5	MQWA.A5R7	RQ5.LR7	MQWA.A5R7	RQ5.LR7
20121.3	MQWA.B5R7	RQ5.LR7	MQWA.B5R7	RQ5.LR7
20125.1	MQWB.5R7	RQT5.R7	MQWA.C5R7	RQ5.LR7
20128.9	MQWA.C5R7	RQ5.LR7	MQWA.D5R7	RQ5.LR7
20132.7	MQWA.D5R7	RQ5.LR7	MQWA.E5R7	RQ5.LR7
20136.5	MQWA.E5R7	RQ5.LR7	removed	removed

Radiation Shielding Installation and Possible Optics Change for the MBW and MQW Magnets in IR 3 and 7 of the LHC. Second phase LS2 LS3 and HL-LHC. LHC-MW-EC-0002 v.1.1

Injection optics from R. Bruce, from a branch of HL-LHCV1.3.

Corrector package

Magnet name		Integrated field at R_{ref}=50 mm [T m]		Magnet coil length [mm]		Magnet length [1] [mm]		Magnetic [3] length [mm]	
		Base line	New value	Base Line [2]	New value	Baseline	New Value	TDR	New Value
Skew quadrupole	MCQSXF	1.000	0.700	728	528	814	614	807	462
Normal sextupole	MCSXF	0.063	0.095	132	192	194	254	111	171
Skew sextupole	MCSSXF	0.063	0.095	132	192	194	254	111	171
Normal octupole	MCOXF	0.046	0.069	119,6	169,6	183	233	87	151
Skew octupole	MCOSXF	0.046	0.069	119,6	169,6	183	233	87	151
Normal decapole	MCDXF	0.025	0.037	118,6	168,6	183	233	95	138
Skew decapole	MCDSXF	0.025	0.037	118,6	168,6	183	233	95	138
Normal dodecapole	MCTXF	0.086	0.086	490	490	575	575	430	465
Skew dodecapole	MCTSXF	0.017	0.017	135	135	200	200	89	92

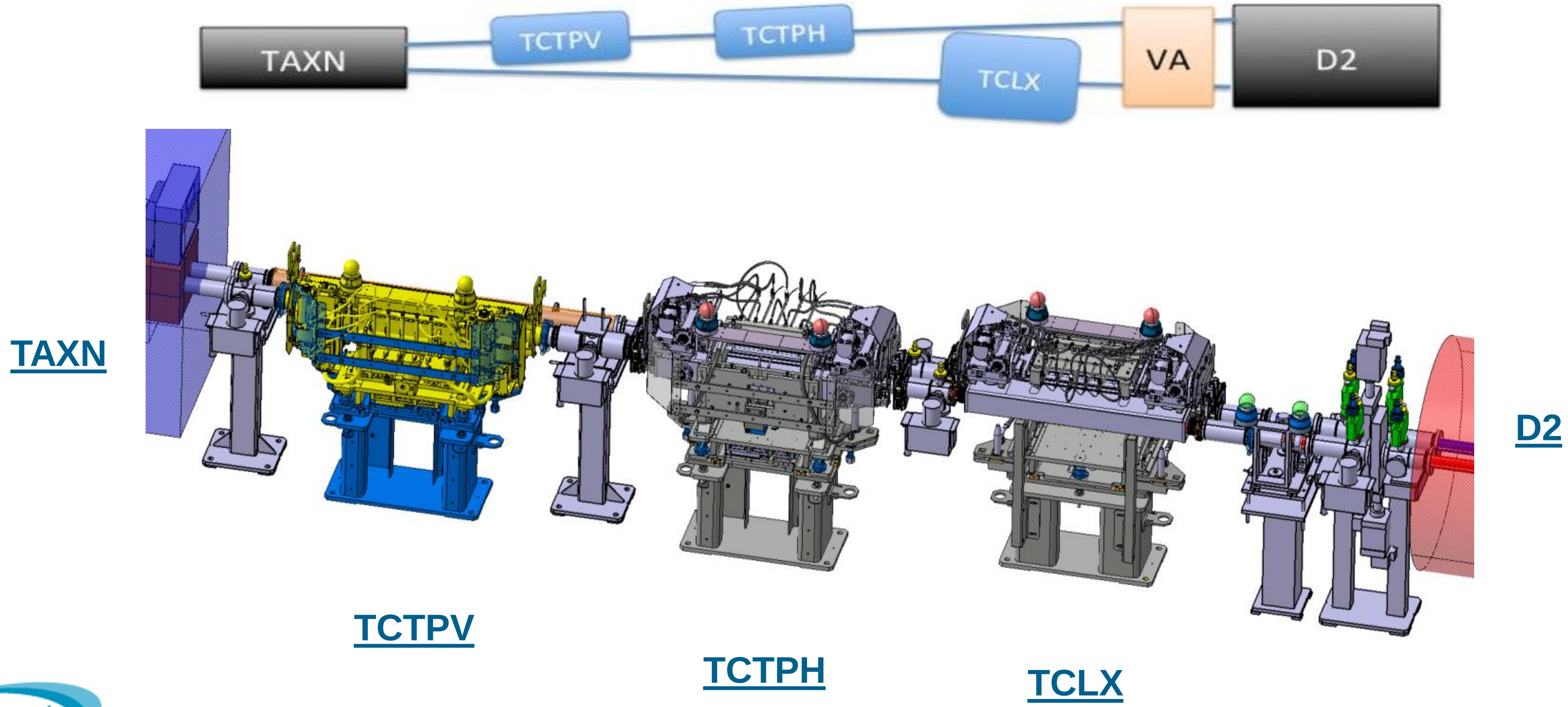
Source: https://edms.cern.ch/document/1963788/1.0 HL-LHC ECR: WP3 CHANGE OF QUADRUPOLE, SEXTUPOLE, OCTUPOLE AND DECAPOLE CORRECTORS INTEGRATED FIELD

[1]: not the magnetic length; [2] values differ slightly from TDR;

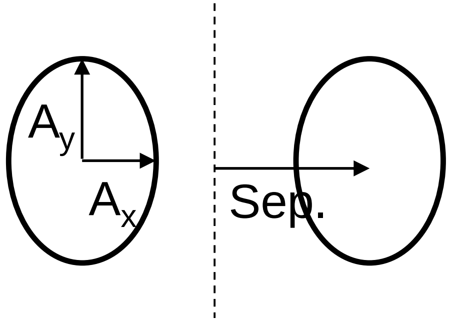
TCLX – TCPH issues in HLLHC

- Beam size in between TAXN – D2 is much larger than LHC due to lower β* and D2 closer to the triplet, beam separation smaller than LHC because D1 – D2 distance is shorter.
- TCLX needs thicker internal jaw to provide dose protection to D2

-> Larger stroke in less space.



TCL-TCT Aperture specifications



Offset (X,Y)	Baseline		Remote alignment		
Ground Motion + Fiduc.	~2 mm		~0.5 mm		
Orbit Error + crab adj.	2.5 mm		2.5 mm		
Collimator stroke	15 σ + 10 % (β-beat)		15 σ + 10 % (β-beat)		
Protected aperture	12 σ + 10 % (β-beat)		12 σ + 10 % (β-beat)		
2 mm IP shift	With orbit correctors		With re-alignment		
Round 15 cm	**A_x [mm]**	**A_y [mm]**	**A_x [mm]**	**A_y [mm]**	**Sep. [mm]**
TCLX	36.4	27.9	31.9	26.1	86.0-87.5
VTCLX	28.0	36.4	26.1	31.9	86.0-87.5
TCTPH	28.5	37.1	26.5	32.7	83.4-84.9
VTCTPH	37.0	28.1	32.5	26.4	83.4-84.9
TCTPV	28.9	38.0	26.9	33.7	80.4-81.9
VTCTPV	38.1	28.7	33.7	26.9	80.4-81.9
Flat 7.5/18 cm	**A_x [mm]**	**A_y [mm]**	**A_x [mm]**	**A_y [mm]**	**Sep. [mm]**
TCLX	42.8	33.8	38.3	32.0	86.0-87.5
VTCLX	33.9	42.9	32.1	38.4	86.0-87.5
TCTPH	34.2	43.5	32.3	39.1	83.4-84.9
VTCPTH	43.3	34.0	38.8	32.2	83.4-84.9
TCTPV	34.5	44.3	32.6	39.9	80.4-81.9
VTCTPV	44.2	34.5	39.8	32.5	80.4-81.9

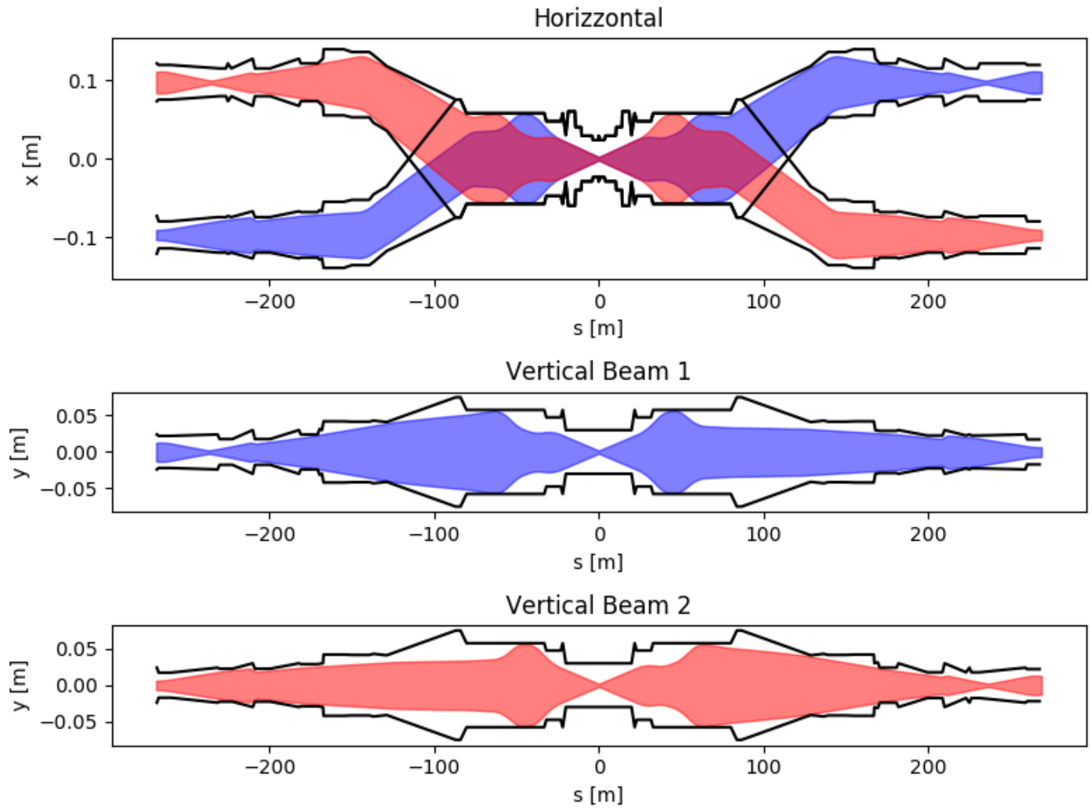
Aperture for vacuum layout

WP12 asked beam envelope without mechanical, alignment and fiducialization tolerances to specify vacuum apertures.
The request inverts the typical work flow because mechanical, alignment and fiducialization are not finalized.

Recipe given:

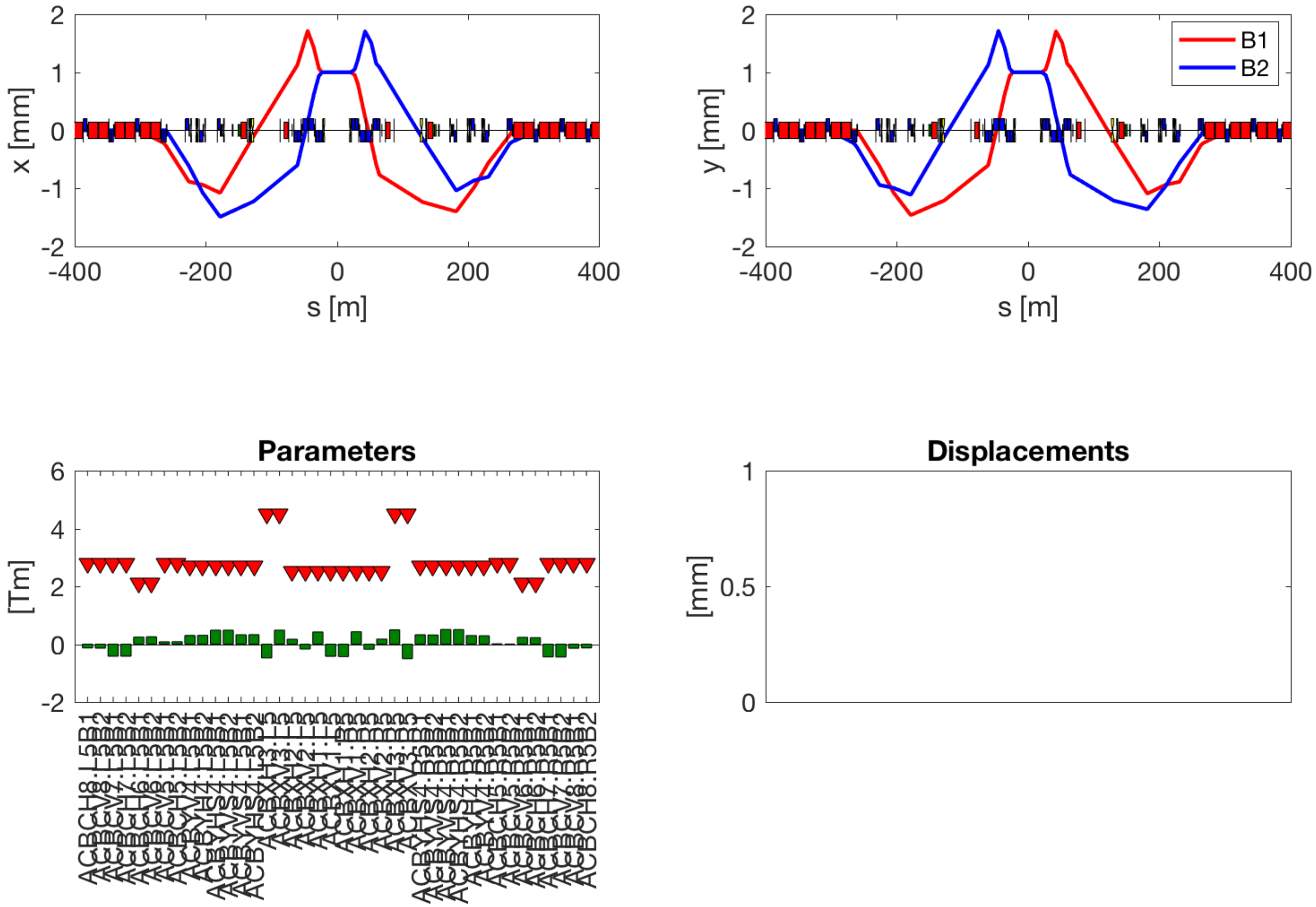
Beam stay clear =
$1.1\ n_\sigma\ \sigma_{nominal} + 2\ \text{mm}$
where:
n_σ = 13.25 up to D1
n_σ = 15 TAXN-Q5
n_σ = 20 sigma Q6 to Q7.

In addition, new vacuum aperture should always have larger margins than those found in the triplet.
Table available here.



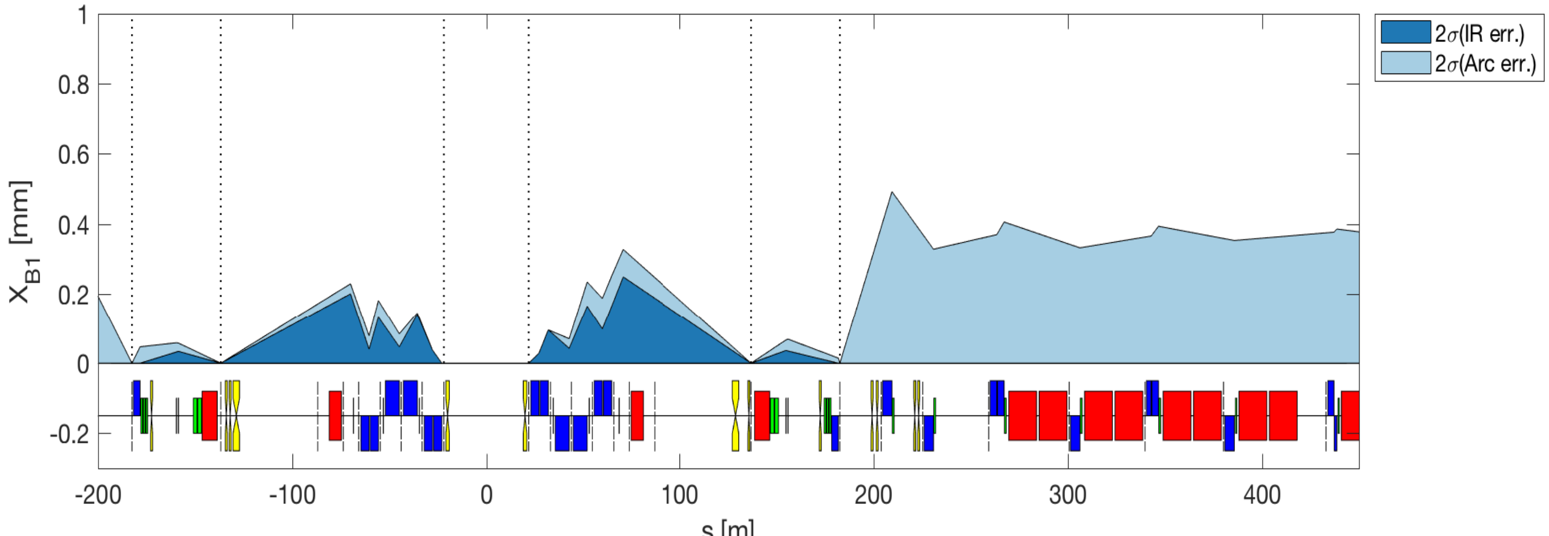
Consistent with present hardware and avoid additional aperture bottleneck.

IP offset with correctors only (up to Q8) (+1mm)



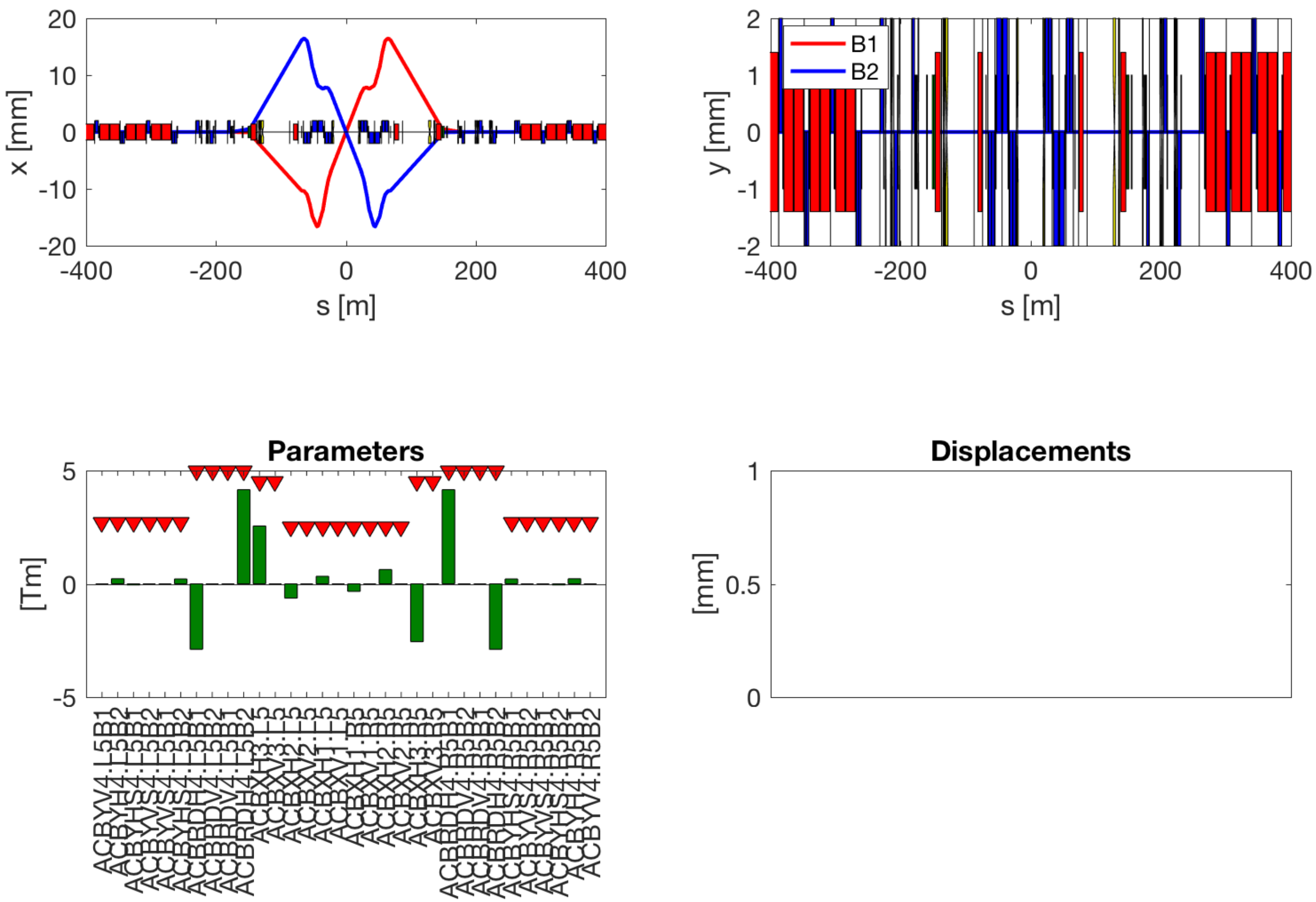
Orbit corrected as usual at relevant BPMs

- 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.~~
      - Presently considering only DX/DY on quadrupoles. Normally DS/DKR1/DPSI has minor impact.
      - To be repeated with "nominal" crossing condition.
  - Dipoles
    - ±10mm DS, ±0.002 DKR0, ±0.5 mrad DPSI.

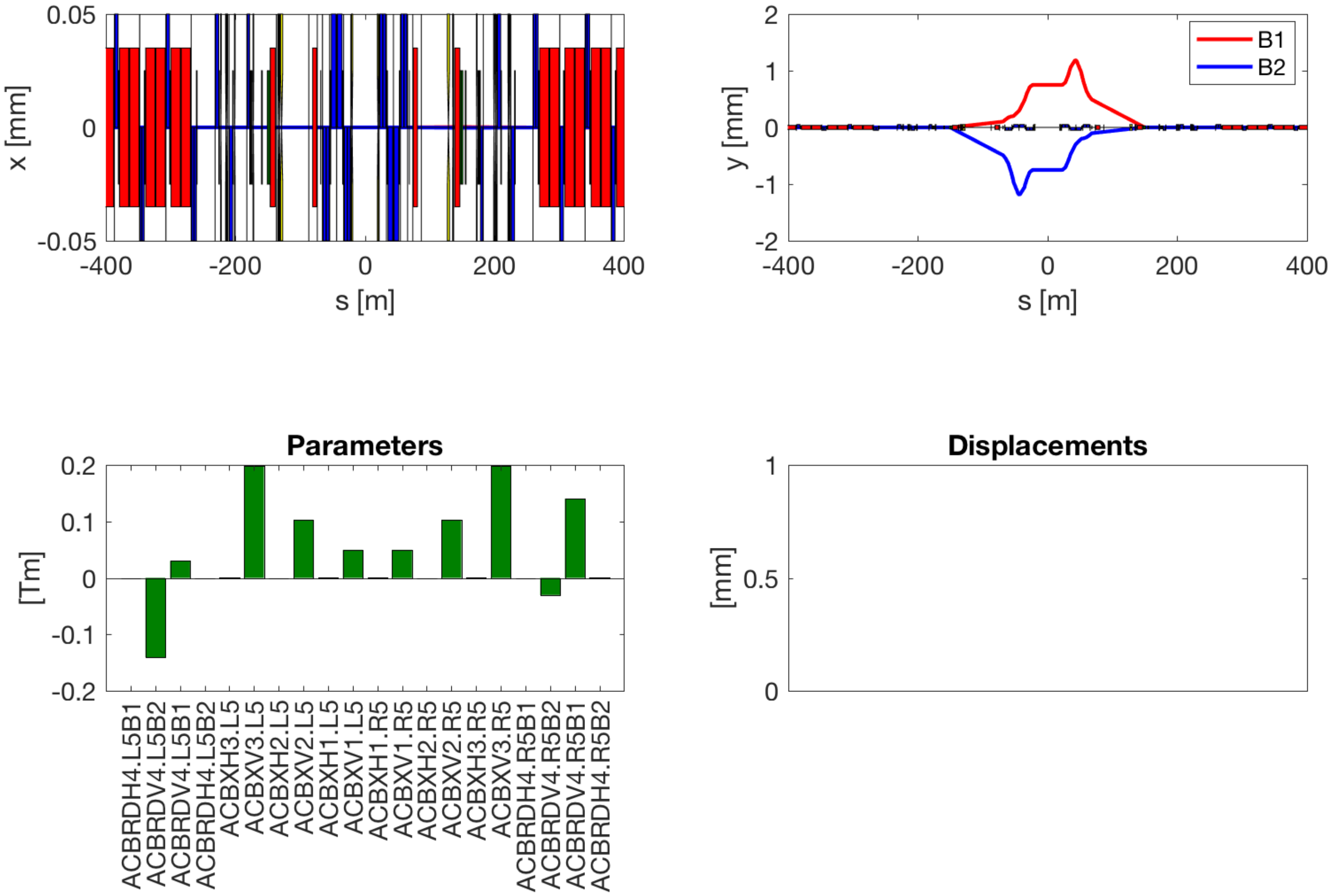


Do not include BPM errors, but to be compared with 2 mm budget in aperture calculations.

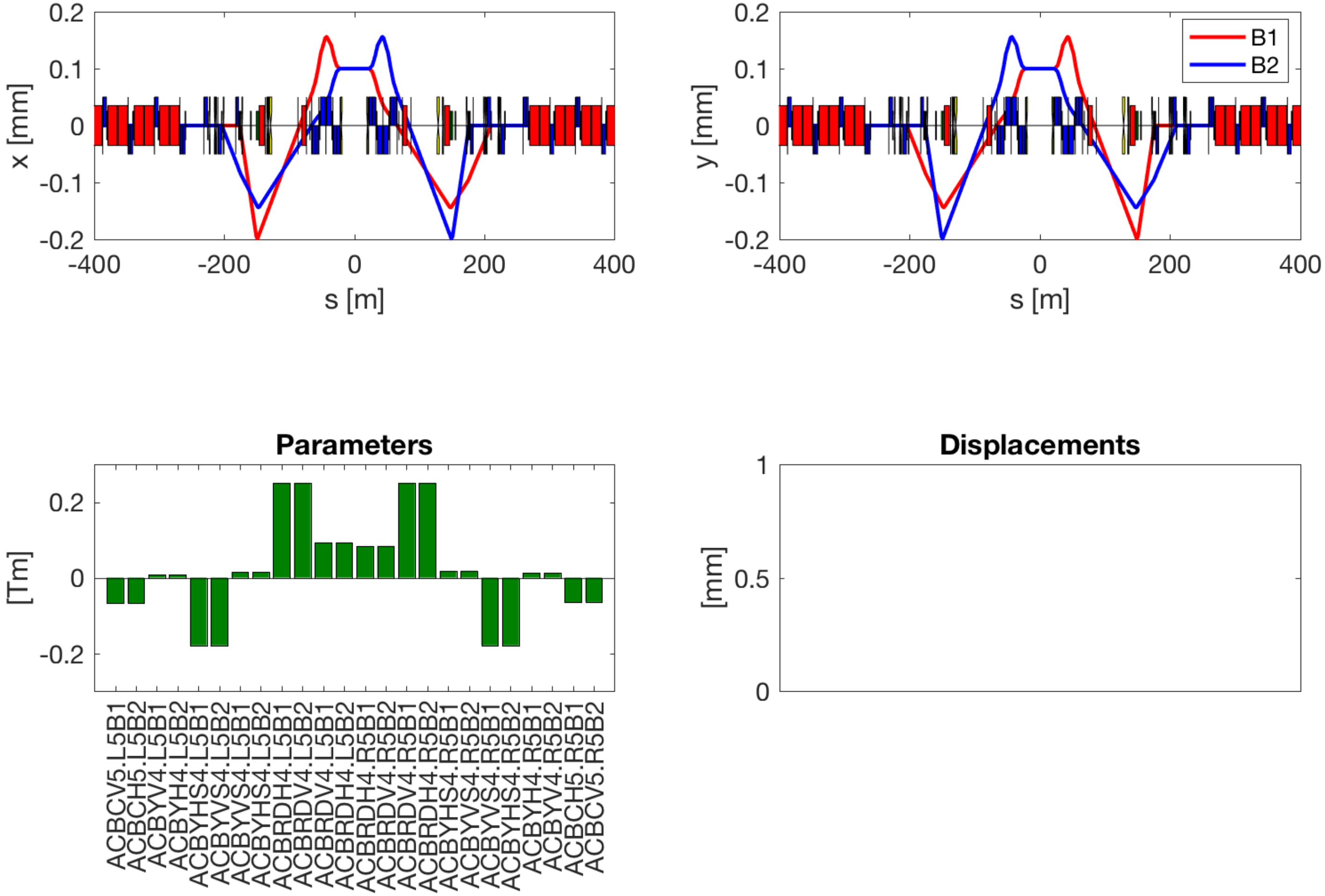
IP crossing (+-295 urad)



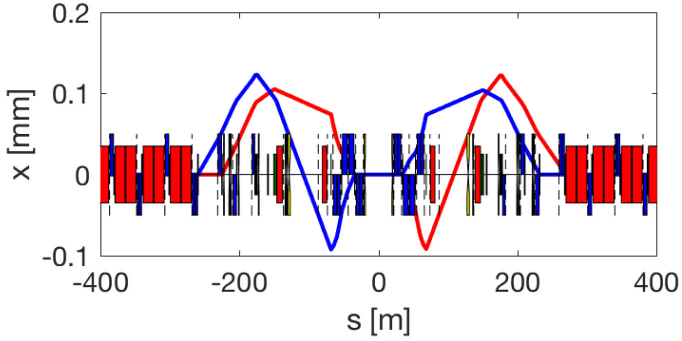
IP separation (+- 0.75 mm)

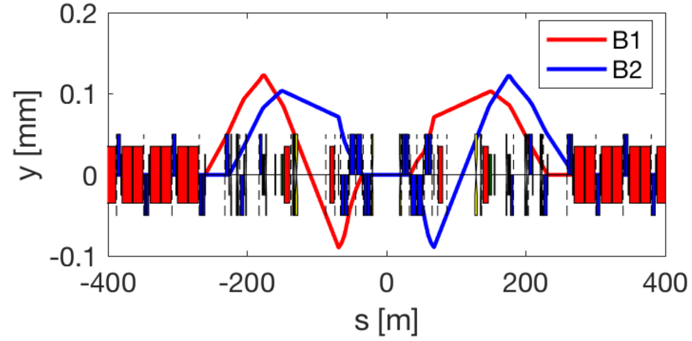


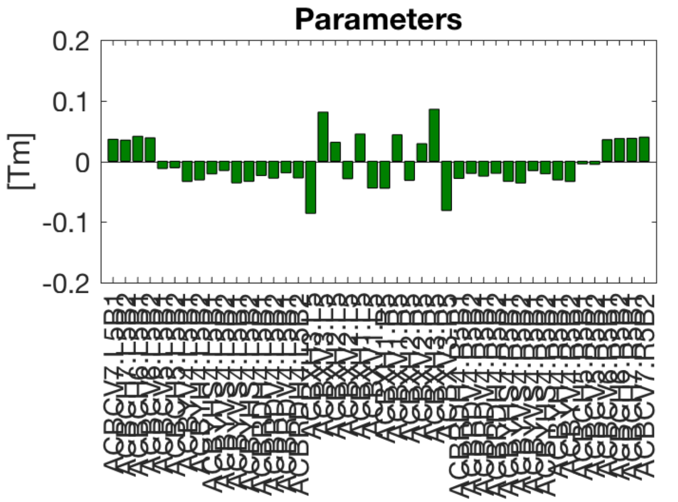
Lumiscan (+- 100 um)

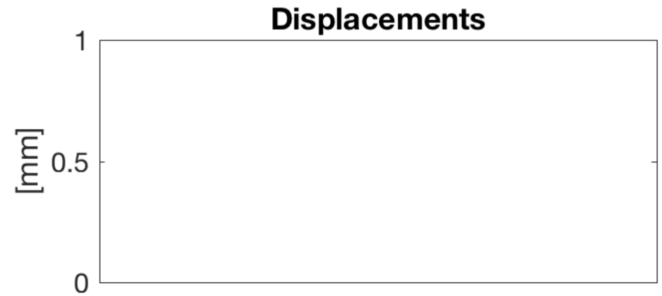


CC offset (100 um)

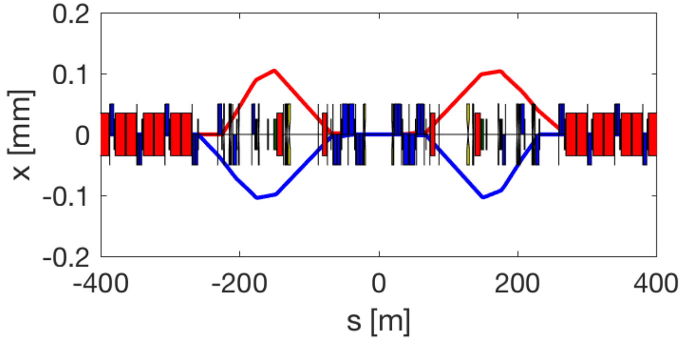


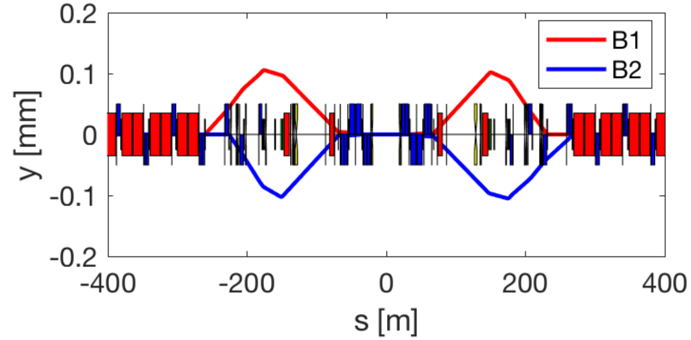


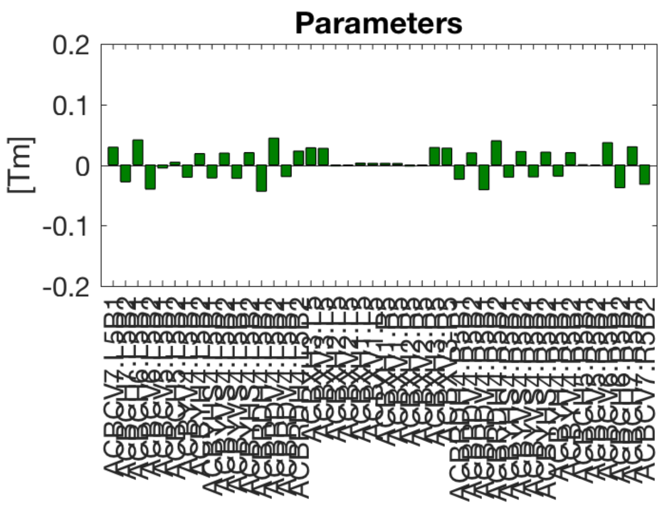


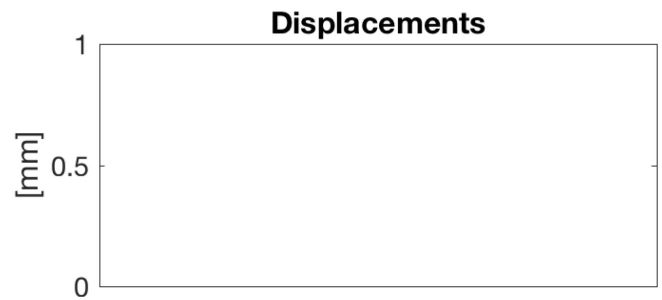


CC separation (+- 100 um)

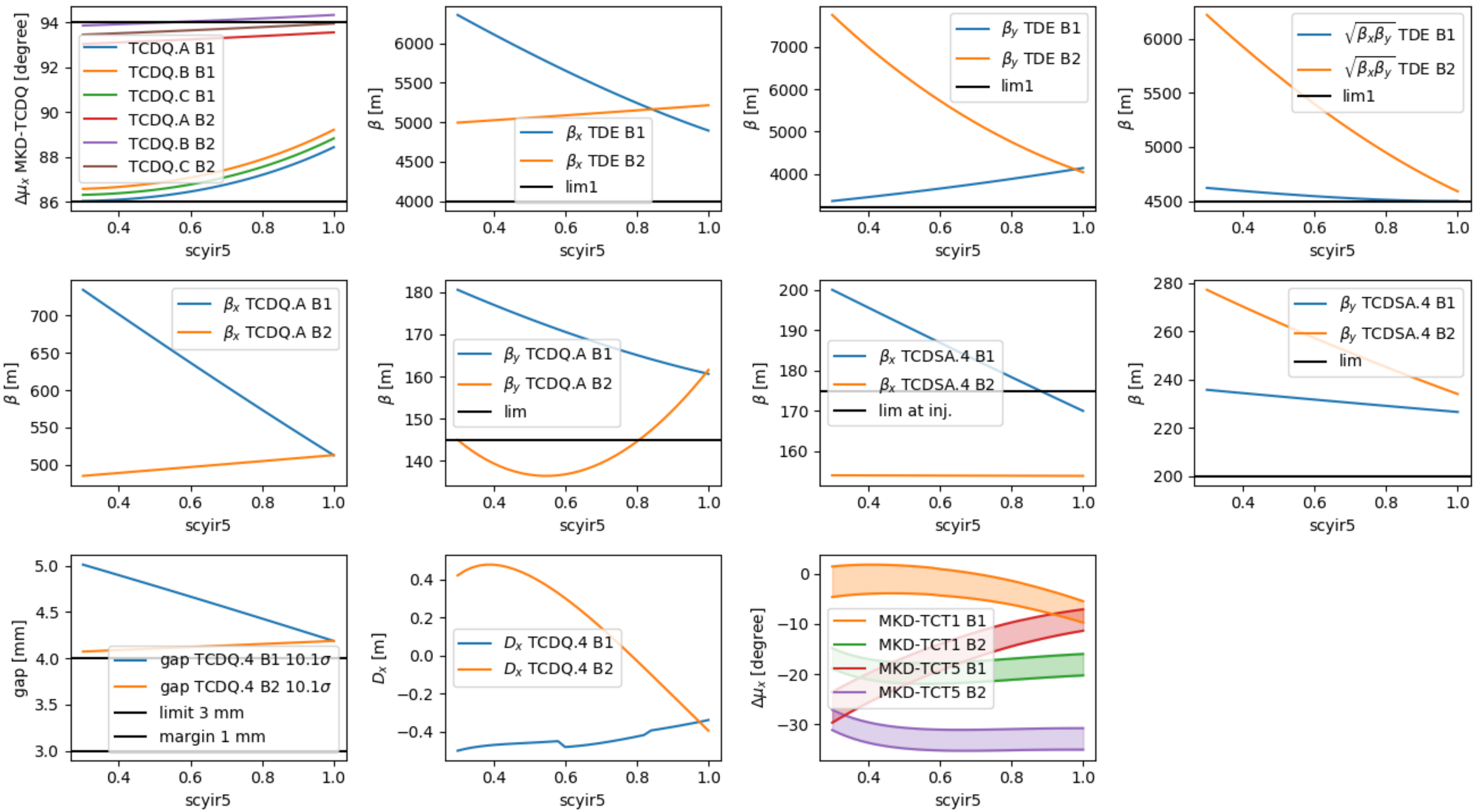








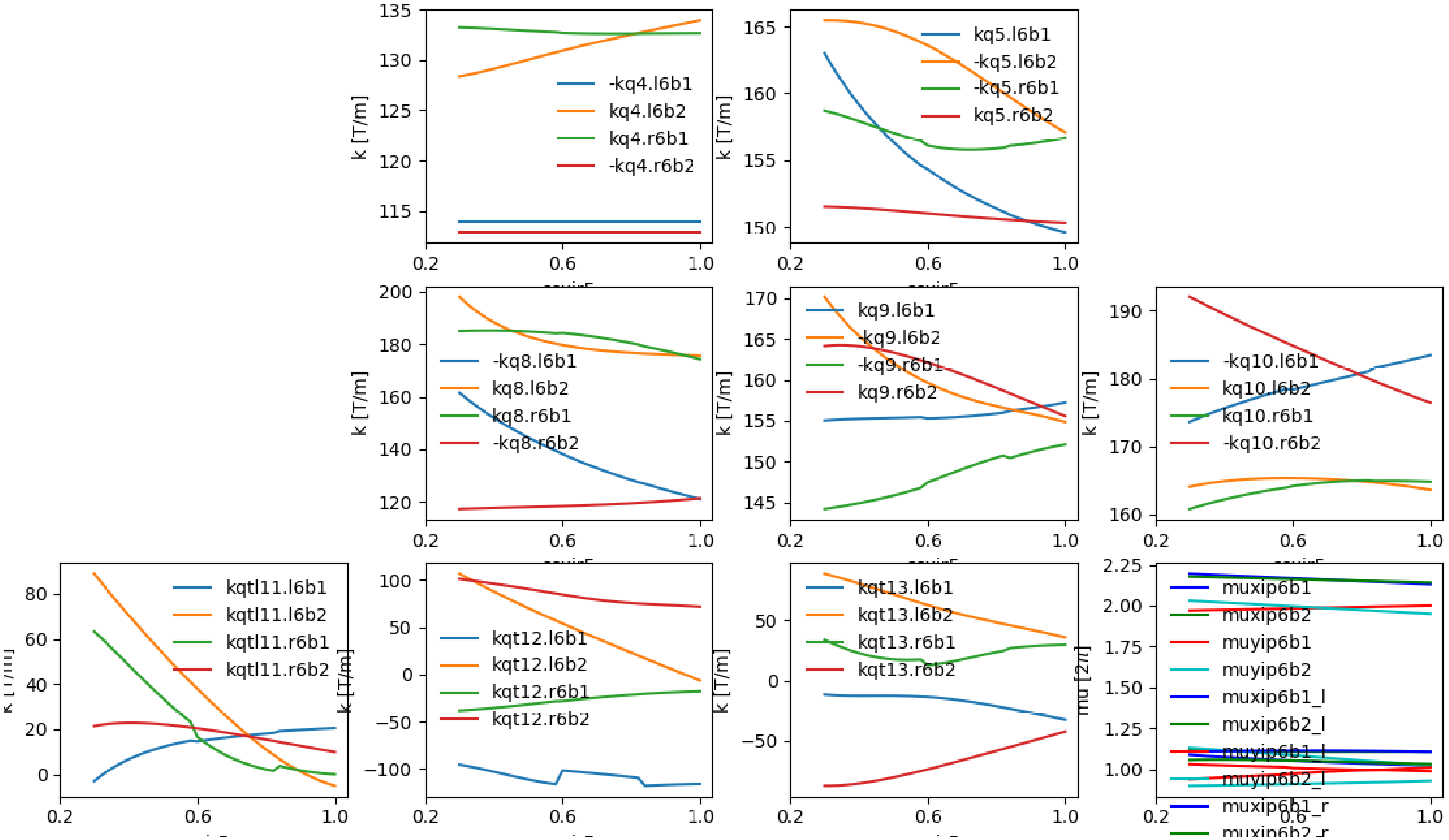
Point 6: Round Optics



TCDQ settings:

- Beam1: 5 mm: from 12.3σ →10.1 σ: β increases during the squeeze
- Beam2: 3.9 mm: from 9.6 σ → 10.1 σ. β decreases during the squeeze

Point 6: Round Optics



TCDQ settings:

- Beam1: 5 mm: from 12.3σ →10.1 σ: β increases during the squeeze
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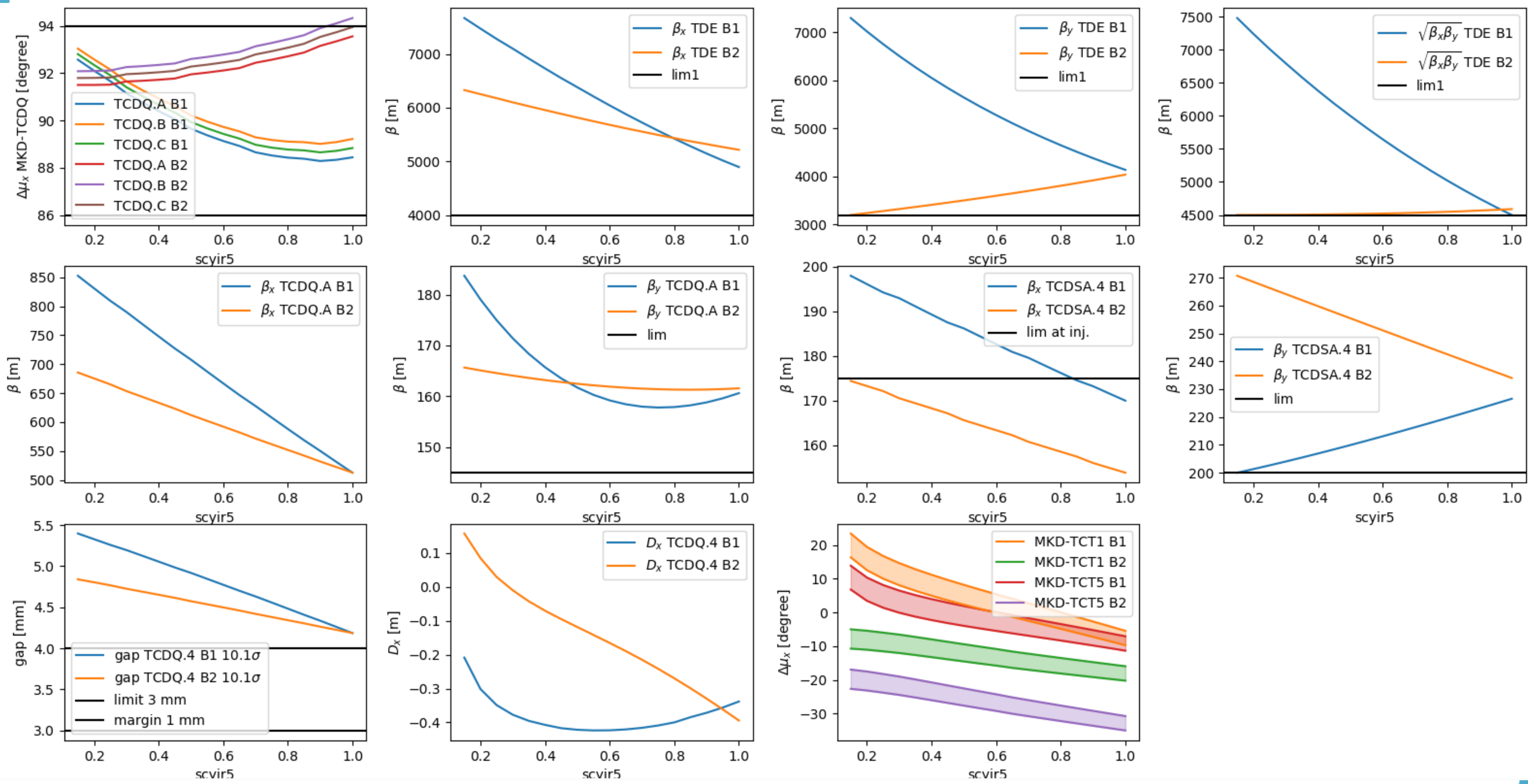
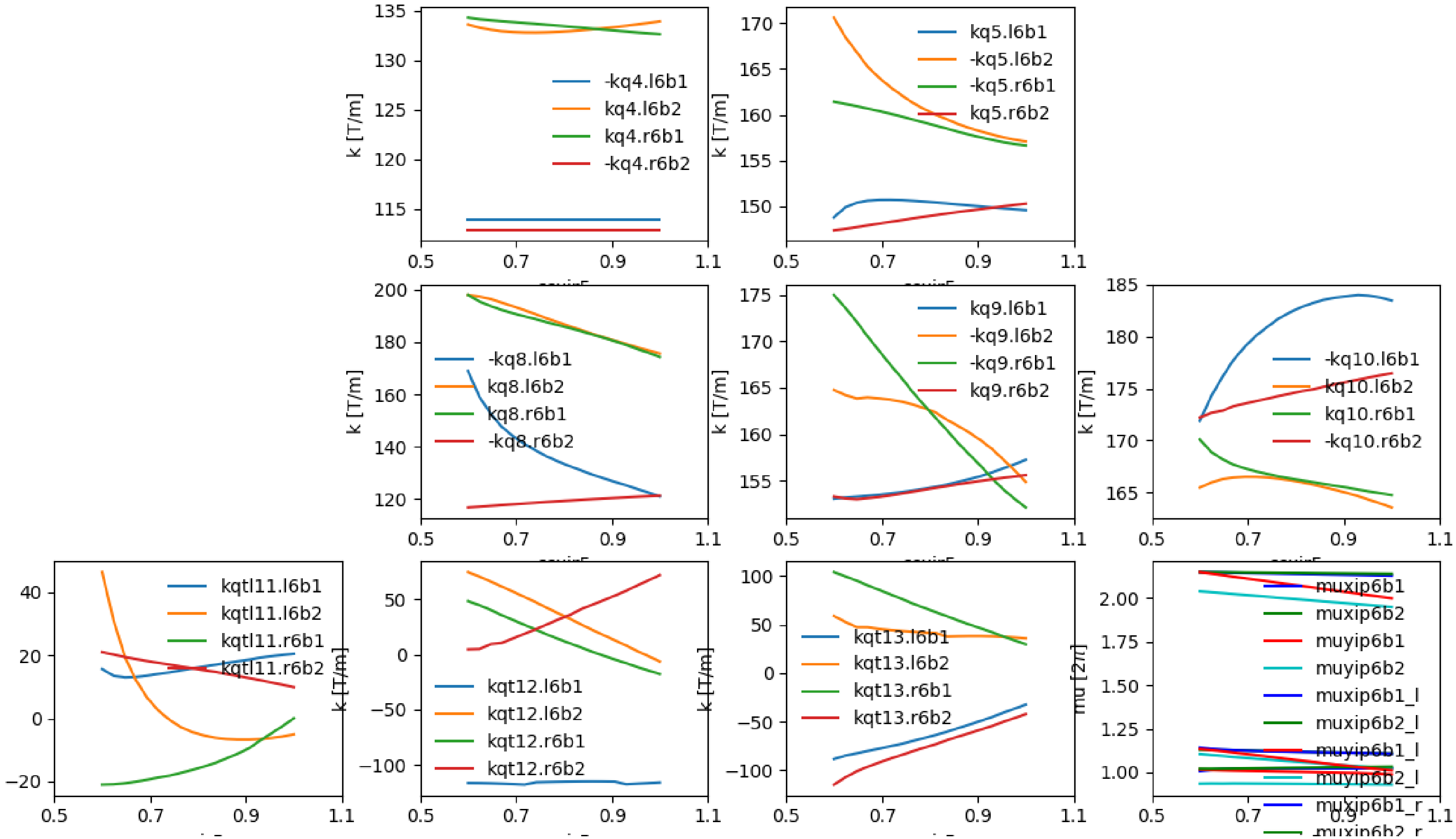
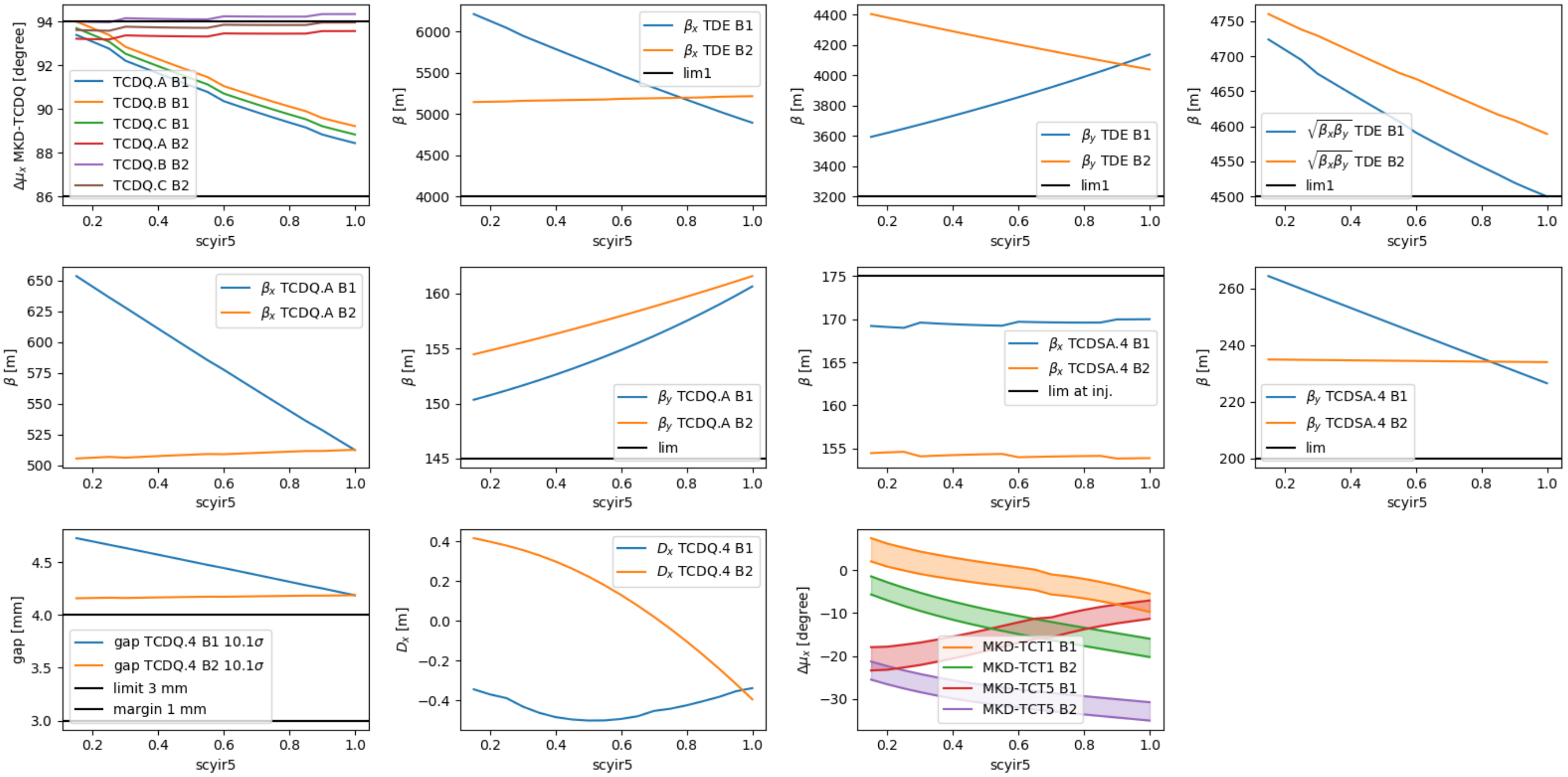
Point 6: Flat (7.5/30 cm)



Point 6: Flat (7.5/30 cm)



Point 6: FlatCC (7.5/18 cm)



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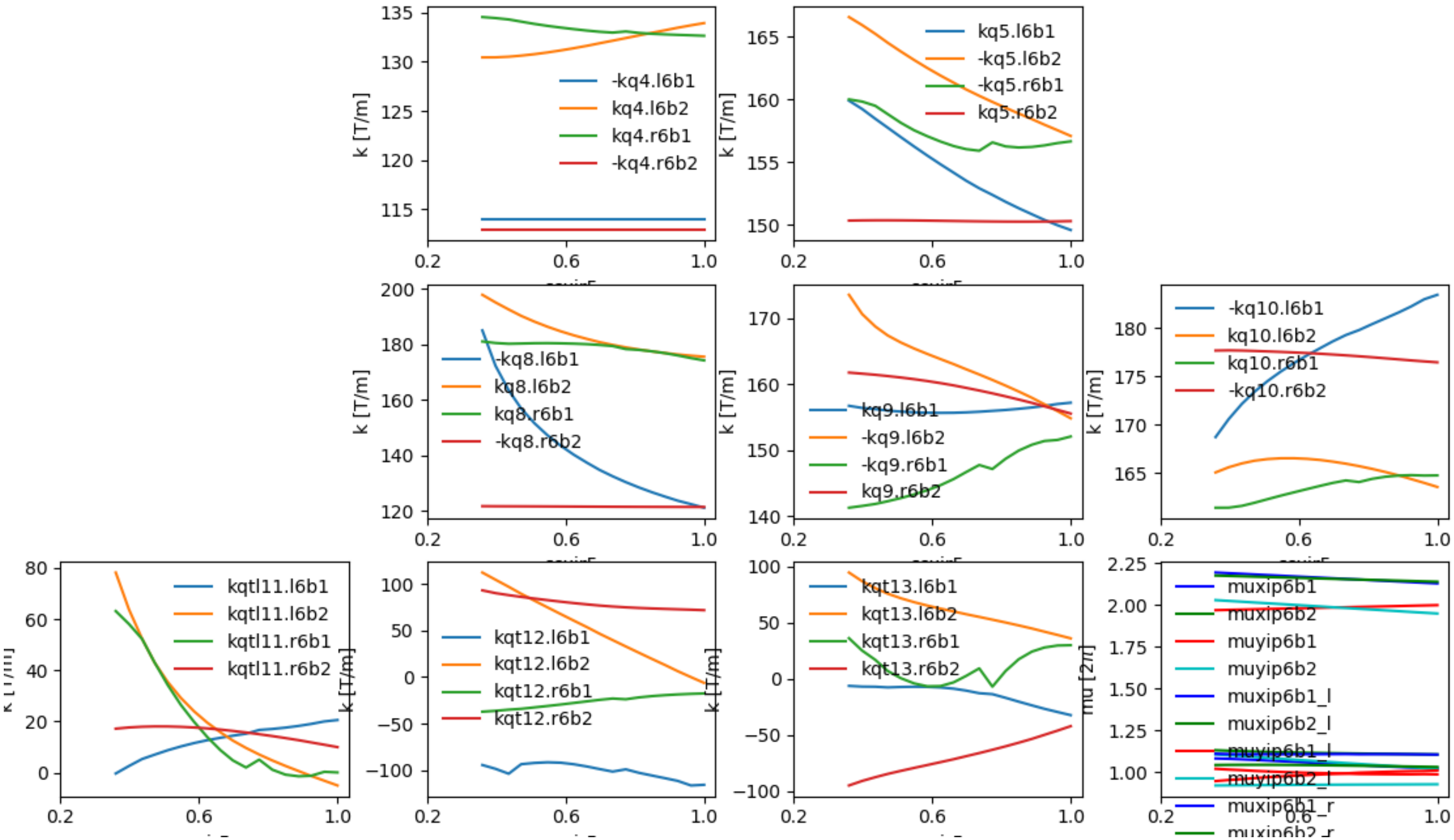
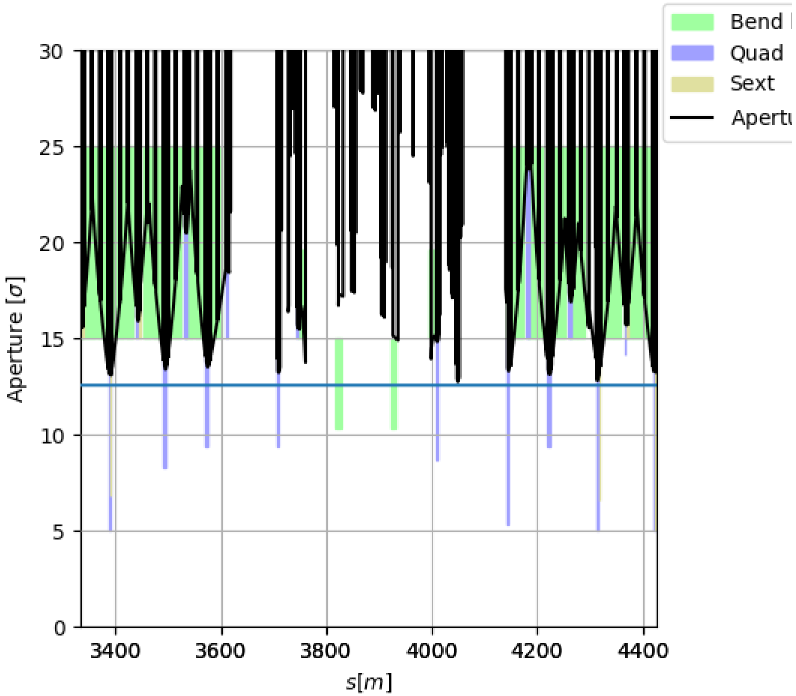
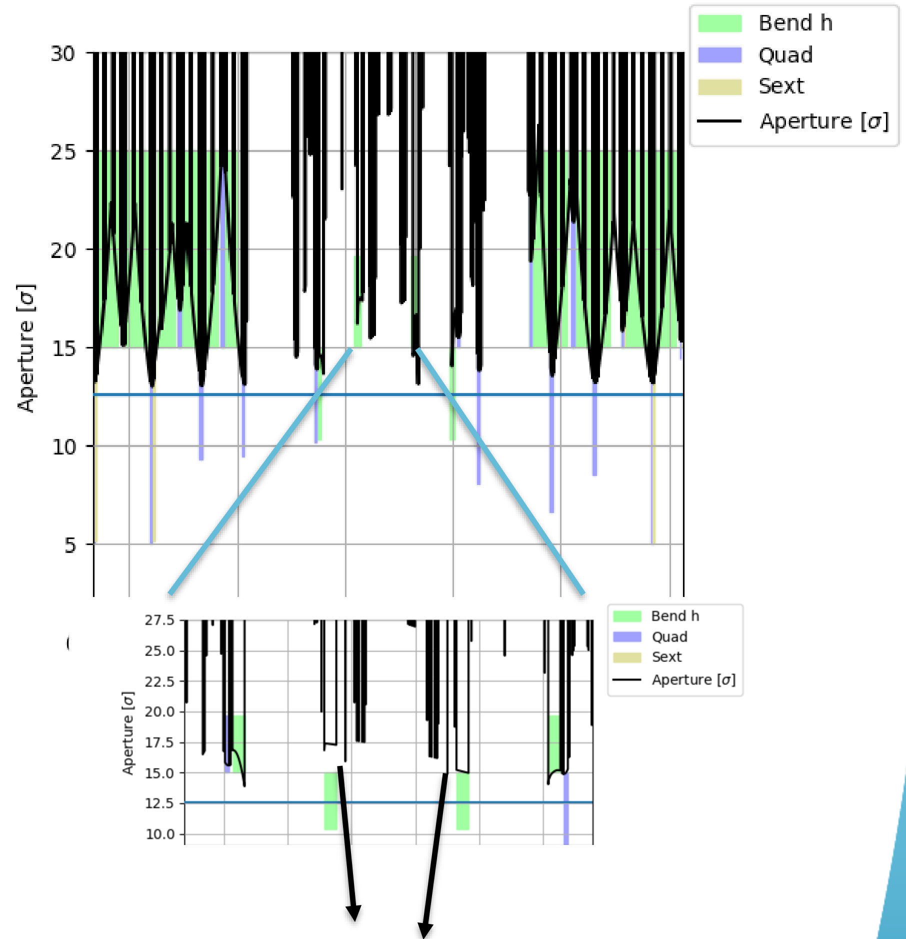


New IR4 Injection Optics





Aperture at injection above the target of 12.6 σ using HL-LHC aperture tolerances.

<u>E-Lens Diameter of 50 mm would still fit.</u>

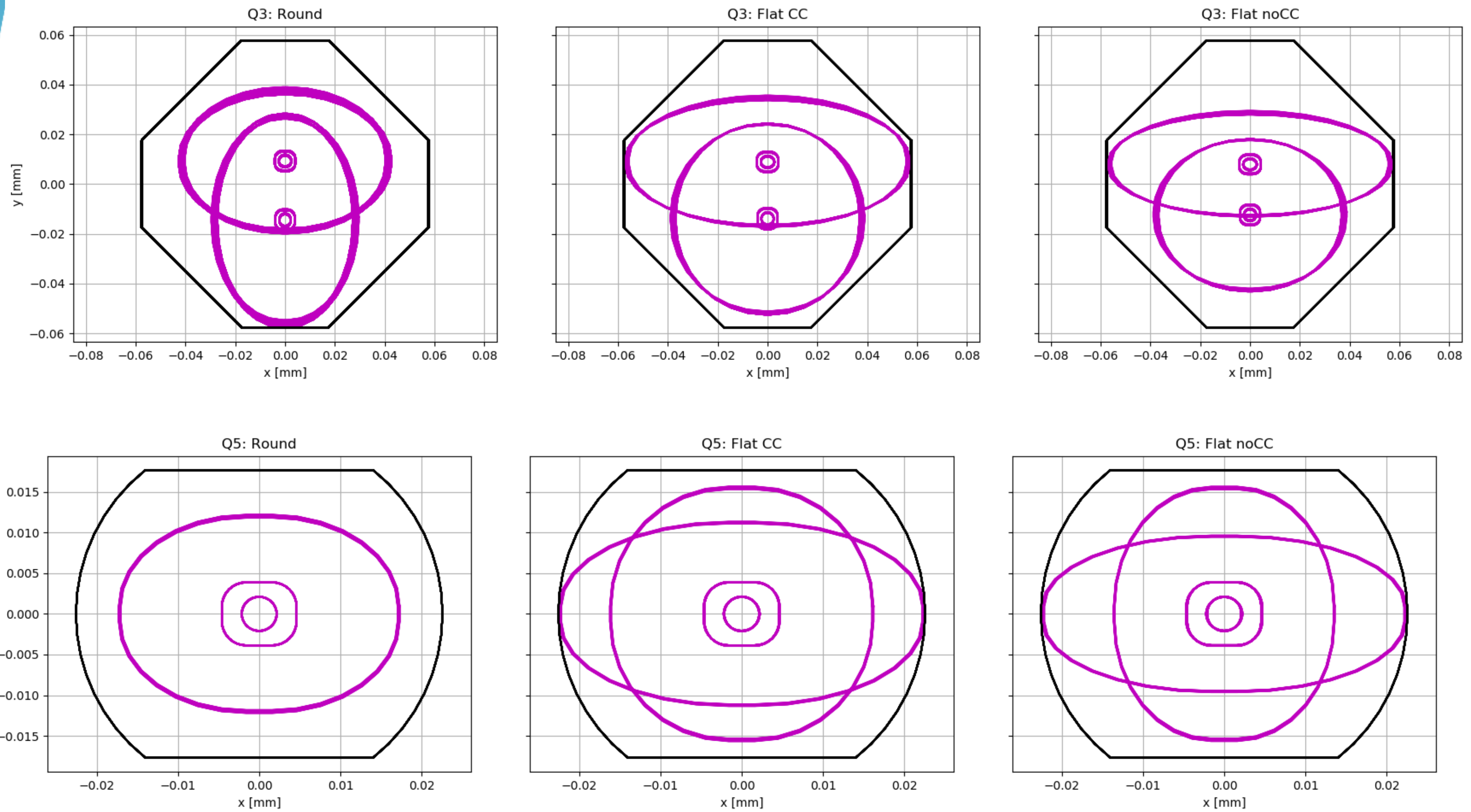
Non Conform MCBY

- Non-conformities evaluated by M. Giovannozzi in the context of the previous layout.
- Non conform magnet MCBYHS4.R5B1 can be also compensated by MCBYH4.R5B1 (which has 30 A left).
- Non conformity can be accepted if MCBYHS4.R5B1 does not degrade to much further.
- 4 other MCBYs are not conform

RCBYH4.R8B1 Possible internal short	1051795	Limited to 50 A with 0.67 A/s and I_delta is changed to minus 50 % of I_PNO. Increased to 60 A with I_delta=-30 A as of HWC 2016/7, upon e-mail Massimo dd 7/12/2016.
RCBYHS4.L5B1 Possible internal short	1053709	Limited to 50 A with 0.67 A/s and I_delta is changed to minus 50 % of I_PNO.Increased to 60 A with I_delta=0 A as of HWC 2016/7, upon e-mail Massimo dd 7/12/2016.
RCBYHS5.R8B1 Possible internal short	1063839	Limited to 20 A with 0.6 A/s in 2013. I_PNO is set to 40 A with dI/dt=0.3 A/s for HWC 2014/15 with I_delta=0 A. Increased to 50 A with I_delta=0 A as of HWC 2016/7, upon e-mail Massimo dd 7/12/2016.
RCBYV5.L4B2 Possible internal short	1049055	Limited to 50 A with 0.67 A/s and I_delta is changed to minus 50 % of I_PNO. Increased to 60 A with I_delta=0 A as of HWC 2016/7, upon e-mail Massimo dd 7/12/2016.
RCBYVS4.R8B1 Possible internal short	no NC	Commissioned during HWC 2014/5 to 72 A with I_delta=0 A. I_delta reduced to -36 A as of HWC 2016/7.

An explanation on the origin of the NC and long term outlook for the series is mandatory to establish a robust strategy.

Apertures



Q3: Round
Q3: Flat CC
Q3: Flat noCC
Q5: Round
Q5: Flat CC
Q5: Flat noCC
y [mm]
x [mm]