Layout update in IR1/5

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Thanks to S. Fartoukh, P. Fessia, C. Garion, C. Magnier, H. Prin, E. Todesco, B. Vasquez De Prada

Introduction and outline

- Layout changes

- Optics changes

- Aperture

- Next activities

- Summary

Layout: V1.1 -> V1.2 in IR1 and IR5

Changes	by
Triplet gradient reduction. New length, position; D1 position changed by 2.35 m towards the arc.	WP3, WP15
TAXS moved towards the IP by 0.33 m (better integration)	WP2, WP8, WP15
D1/D2 integrated strength from 33.4 Tm to 35 Tm (reduced CC voltage) resulting in TAXN-D2-CRAB rigid shift (0.18 m towards the arc)	WP2
no D2/Q4 mask, more space between TCTs/TCLs	WP10, WP15
MCBRD – MCBYY length (1.5 m -> 1.8 m) for larger integrated strength	WP3, WP2, WP15
D2, Q4 and Q5 orbit corrector orientations	WP2, WP15
Q4-Q5 position re-optimized (reduced CC voltage)	WP2
Minor changes of all interconnection lengths	WP15

Changes implemented in optics files. TODO:
- BPM position to be iterated with Blanca
- TCL.6 (maybe even the TCTs) to be iterated with Collimation team
- Renamed TCT.5 in TCT.6 (S. Chemli)
- Wire space reservation (WP2)

Optics V1.1 -> V1.2

- Increase pre-squeeze β* 44 cm -> 48 cm (due to lower triplet gradient)

- Increased peak β at constant β* by 5% (due to lower triplet gradient)

- Typical ATS squeeze, injection, VDM updated

- Provided alignment optics for BPM calibration

- Offset knobs ± 2mm introduced due to recent requests from Experiments

- Lumi scan knobs in the shadow of this knob with ~100 µm range

- TODO:
  - $\beta_{x,y}$ in Q4 tunability range
  - IR8 ATS with β*< 3 m and IP longitudinal shift for LHCb new requests
  - IR4 optics optimization for instrumentation and e-lens (received only generic optics specifications)
  - IR6 optics optimization (no feedback yet LBDS constraints)
  - Include D1/D2 transfer function correction if powered in series (not likely to happen)
  - Exotic optics: no ATS (no IP phase constraint), ATS2 (suboptimal arc matching) to increase Q4 $\beta_{x,y}$ tunability range at the cost of chromatic correction and/or arc aperture.

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Squeezed optics

- β* pre-squeeze: 44 cm -> 48 cm

- Crab cavity: 12 MV needed for 590 μrad

- New squeeze transitions needed for flat optics to have β*= 40 cm in the crossing plane.

- Optics provided:

β*	15 cm	7.5 cm/30 cm	20 cm	10 cm/40 cm
Crossing angle	± 295 μrad	± 245 μrad	± 255 μrad	± 210 μrad
	12.5 σ	14.5 σ	12.5 σ	14.5 σ
Separation	± 2 mm	± 0.75 mm	± 2 mm	± 0.75 mm

Aperture margins

1. Layout and optics define nominal orbit and beam sizes.

2. Geometry of the vacuum system (e.g. beam screens inner dimensions with tolerances).

3. Operational tolerances on beam size are added to the actual beam size.

4. Alignment and fiducialization tolerances are subtracted from available aperture.

5. The difference in units of beam sigma is calculated and compared with the aperture protected by the collimation systems
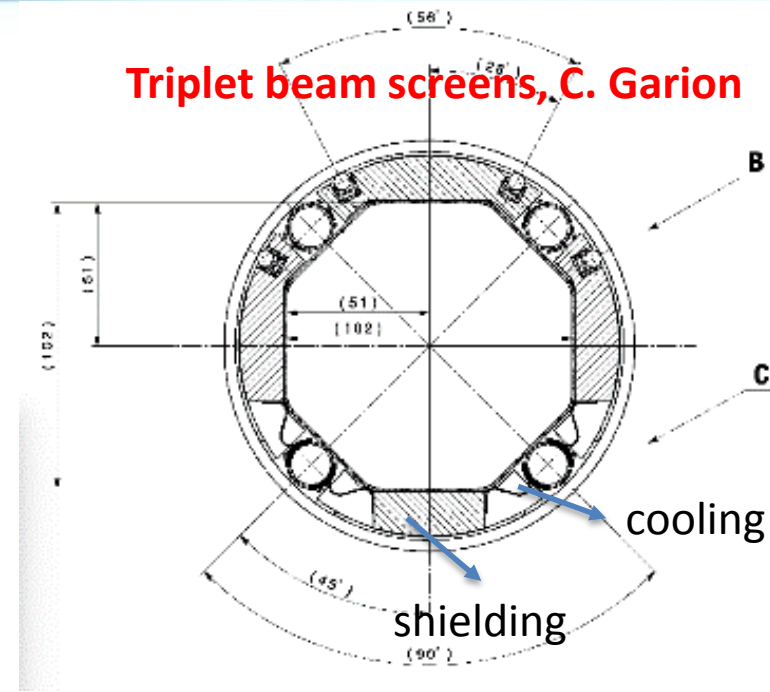
Aperture triplet region

Octagonal beam screens for triplets/D1 with tungsten shielding have been designed.

Expected straightness: 0.5 mm

Shape tolerance: ± 1 mm (C. Garion 12/06/2015), to be confirmed by the prototype.

The possibility of reducing the tungsten layer thanks to alternating crossing planes (**F. Cerutti, S. Fartoukh**) should be checked.

cooling

shielding

| Element	H or V gap [mm]	45° gap [mm]
Q1	102-1.5	102-1.5
Q2-Q3-CP	122-1.5	114-1.5
D1	122-1.5	114-1.5

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Aperture D2-Q4-Q5

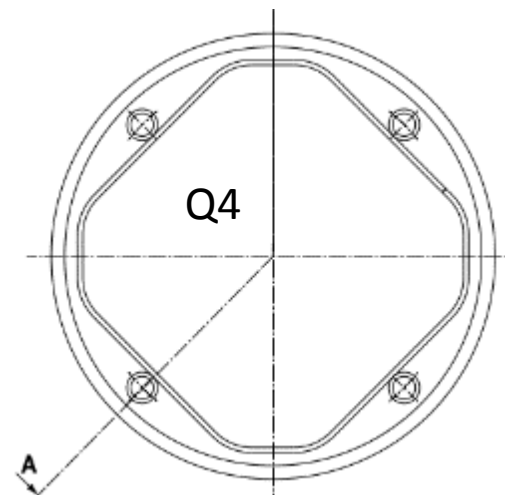New D2-Q4 octagonal beam screens have been designed, **no tolerances given, yet**.

Q5 beam screens (RectEllipse) oriented for collision optics aperture optimizations.

Same triplet tolerances removed from the mechanical dimensions.

Element	H or V gap [mm]	45° gap [mm]
MBRD	87.0-1.5	78.0-1.5
MQYY	78.5-1.5	63.8-1.5
Q5	57.8, 48.0	

D2
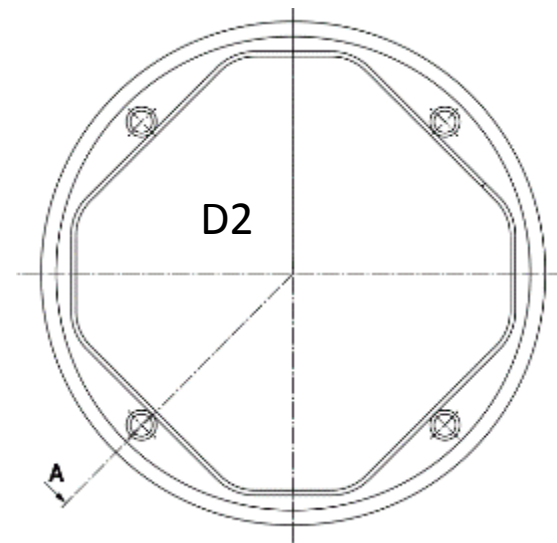
C. Garion, no tolerances included

Q4

Orbit corrector knobs

- IP crossing, separation, offset (**x:** ±295 µrad, **, s:** ±0.75 mm, **o:** ±2.0 mm)
- beam based alignment of crab cavities: **ccp**, **ccm** (shift): ±0.5 mm, **ccs** (slope): ±0.25 mm
- IT alignment and transfer function errors (**err**): ±0.5 mm transverse, ±10 mm longitudinal, ±2x10^{-3} relative gradient error, ±2x10^{-3} D2 relative field error.
- orbit correction from the arc (to confirmed): **arc** 0.7 Tm;
- **lumi** scan knobs (single beam IP shift for 100µm)

name	x-scheme [Tm]			cc alignment [Tm]			err [Tm]	arc [Tm]	lumi [Tm]	summary [Tm]		
	x	s	o	ccp	ccm	ccs	err	arc	lumi	tot	max	margin [%]
MCBX1	0.14	0.11	1.16	0.19	0	0	0.92	0	0	2.42	2.5	**3.30**
MCBX2	0.07	0.05	0.79	0.19	0	0	1.40	0	0	2.17	2.5	**1.53**
MCBX3	2.11	0.2	0.94	0.45	0.15	0	0.78	0	0	4.43	4.5	**1.45**
MCBRD4	2.97	0.09								60	4.5	**-2.89**
MCBYY4	1.49	0.04								74	4.5	**-5.39**
MCBY5	0	0	1.35	0.40	0.40	0.35	0	0	0	2.46	2.7	8.9
MCBY5	0	0	0	0	0	0	0	0.7	0	0.7	2.7	26
MCBC6	0	0	0.46	0	0	0	0	0.7	0	0.46	2.8	83.4
MCBC7	0	0	1.40	0	0	0	0	0.7	0	1.40	2.8	50

- Studying re-sharing forces with new crossing and separation scenarios
- MCBRD/YY length increase 1.6 m -> 1.8 m needed

Beam tolerances and collimation protection

Beam tolerances have been re-defined by:

- Taking into account LHC Run I successful experience

- Adding safety margins based on possible unknowns.

For collimation:

- magnet protected by TCT: ≥ **12 σ**

- magnet not protect by TCT: **18 σ[2]** or possibly less, pending dedicated studies (R. Bruce) .

Beam Tolerance	LHC DR Inj./Coll.	HL-LHC Inj./Coll.
Emittance [μm] (normalization only)	3.75/3.75	3.5/3.5
β-beating [%]	20/20	10/20
Orbit error [mm]	4/3	4/2
Spurious Disp. [%]	27.3/27.3	14/10
$\Delta p/p$ [10^{-4}]	15/8.6	6/2
Target aperture [σ]	8.4/8.4	**9[1]**/**12** (**18[2]**)

R. Bruce et al., CERN-ACC-2014-0044

Minimum aperture not protected by TCT in collision and aperture targets at injection should be confirmed by WP5[2] and WP14[1].

Aperture vs optics for baseline

	Round 15 cm	Round 20 cm	Flat 7.5 cm	Flat 10 cm
	[σ]	[σ]	[σ]	[σ]
TAXS	**9.9**	12.1	**9.6**	**11.3**
MQXFA.[AB]1	13.2	16	12.3	14.2
MQXFB.[AB]2	**9.4**	**11.7**	**9.7**	**11.2**
MQXFA.[AB]3	**9.5**	**11.8**	**10**	**11.6**
MBXF	**10.7**	13.1	**10.6**	12.3
TAXN	**11.6**	13.8	**9.5**	**11.0**
MBRD	13.1	15.3	**11.1**	12.8
MCBRD	16	18.7	13.7	15.4
MCBYY	15.4	17.9	13.4	15.5
MQYY	16.3	18.9	13.9	16.1
TCLMB.5	20.3	23.5	14.5	16.8
MCBY[HV].5	20.6	23.9	15	17.3
MQY.5	21.4	24.7	15.3	17.7
TCLMC.6	21.2	24.6	15	17.4
MCBC[HV].6	24.7	28.5	**17.4**	20.1
MQML.6	21.8	25.2	**15.7**	18.1

Aperture includes worst case scenarios for all knobs (IP crossing, separation, offset, crab cavity offset) assuming linear addition
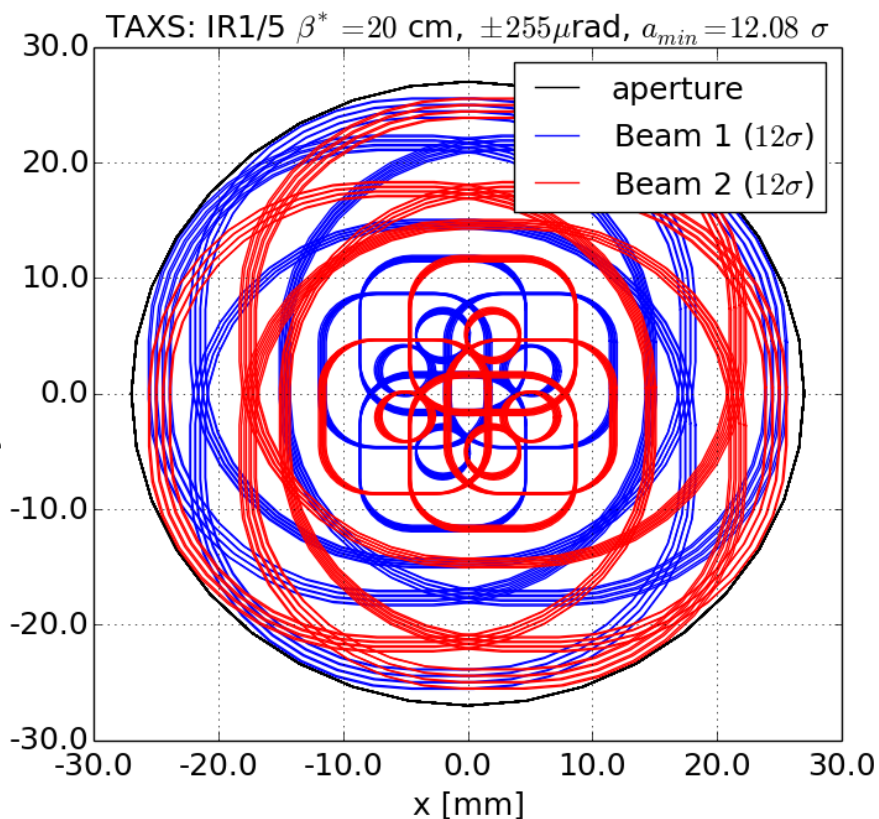
Aperture in the triplets can be recovered by:
- reducing crossing angle (round optics) and separation (flat optics) if one assumes that β* levelling is feasible
- reducing beam screen/cold bore tolerances, shielding thickness (see US-LARP presentation)
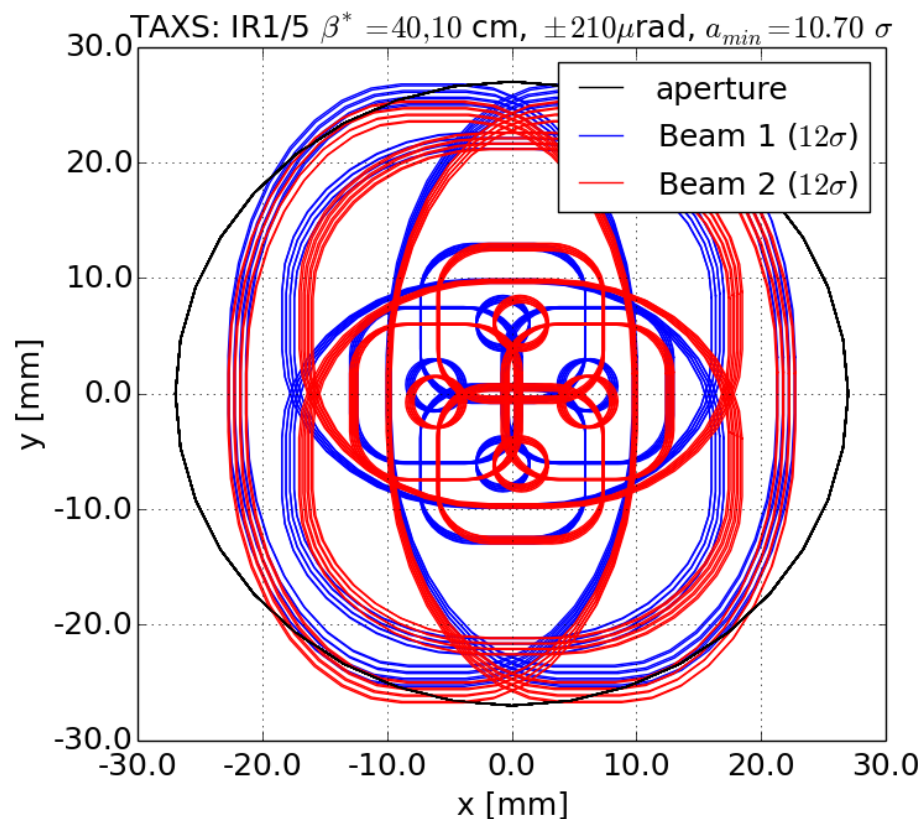
This allows:
- more aperture in the triplet at constant β* or
- more performance if matching section keeps present margins.

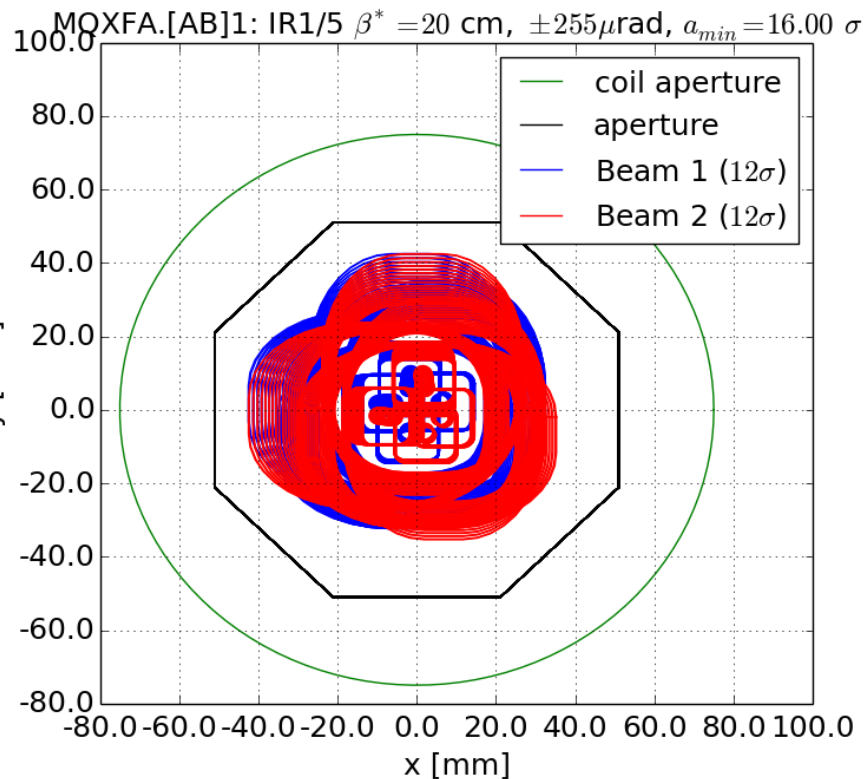G - HL-LHC TC Meeting

TAXS

Round

Flat

TAXS: IR1/5 $\beta^* = 20$ cm, $\pm 255 \mu$rad, $a_{min} = 12.08$ σ

TAXS: IR1/5 $\beta^* = 40,10$ cm, $\pm 210 \mu$rad, $a_{min} = 10.70$ σ

Legend: aperture — Beam 1 (12σ) — Beam 2 (12σ)

TAXS aperture needs to be increased to 60 mm

Q1

Round

Flat

MOXFA.[AB]1: IR1/5 $\beta^* = 20$ cm, $\pm 255\mu$rad, $a_{min} = 16.00\ \sigma$

MOXFA.[AB]1: IR1/5 $\beta^* = 40,10$ cm, $\pm 210\mu$rad, $a_{min} = 14.26\ \sigma$

Q1 OK

Q2

Round

Flat

MOXFB.[AB]2: IR1/5 $\beta^* = 20$ cm, $\pm 255\mu$rad, $a_{min} = 11.66\ \sigma$

MOXFB.[AB]2: IR1/5 $\beta^* = 40, 10$ cm, $\pm 210\mu$rad, $a_{min} = 11.25\ \sigma$

Legend:
- coil aperture
- aperture
- Beam 1 (12σ)
- Beam 2 (12σ)
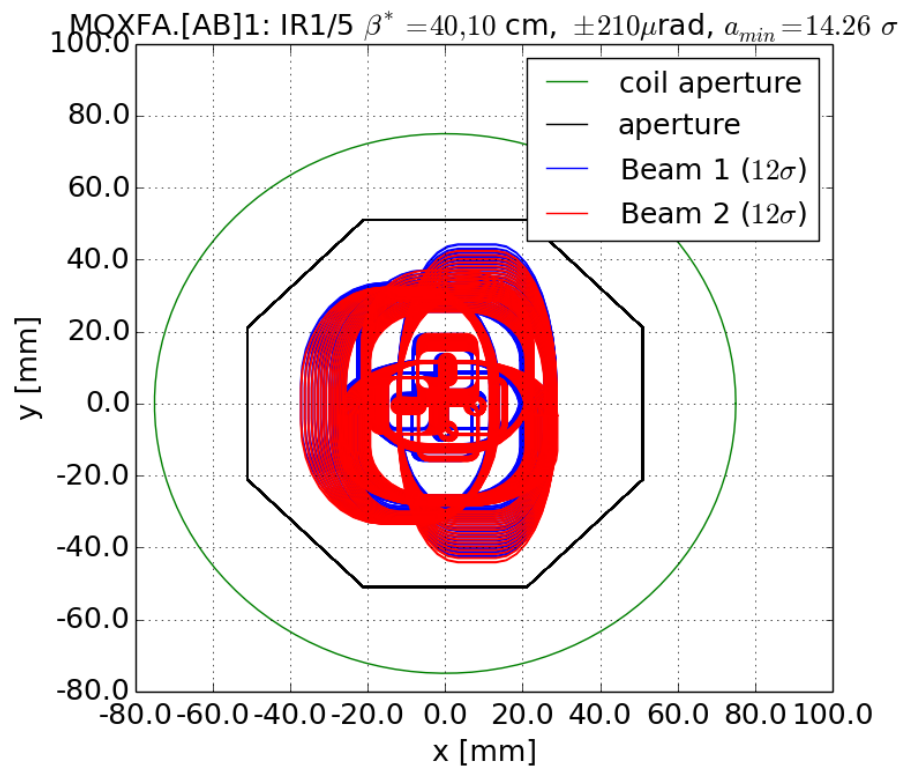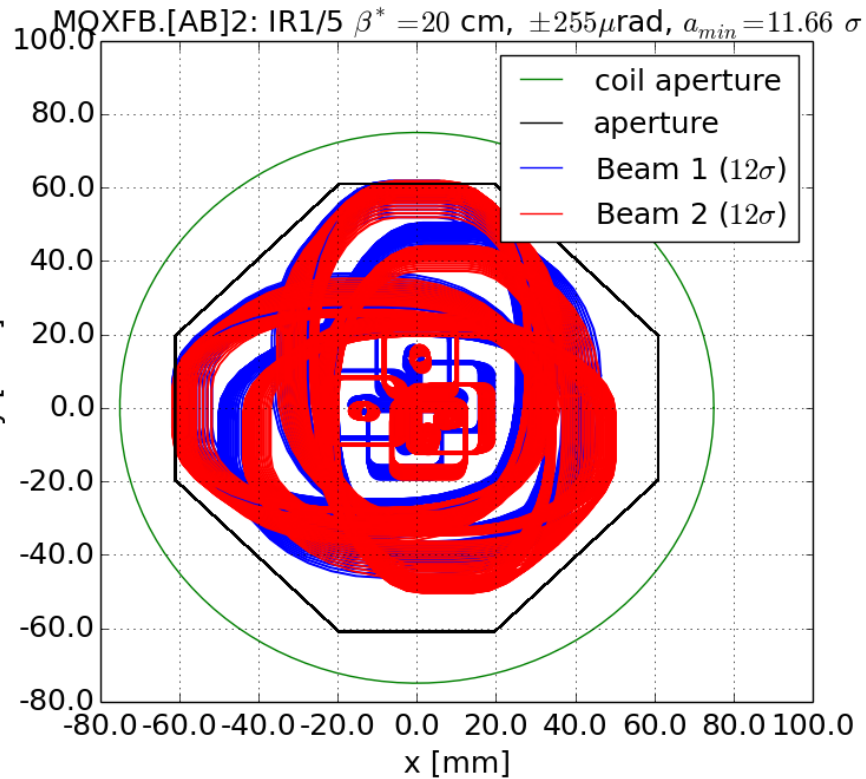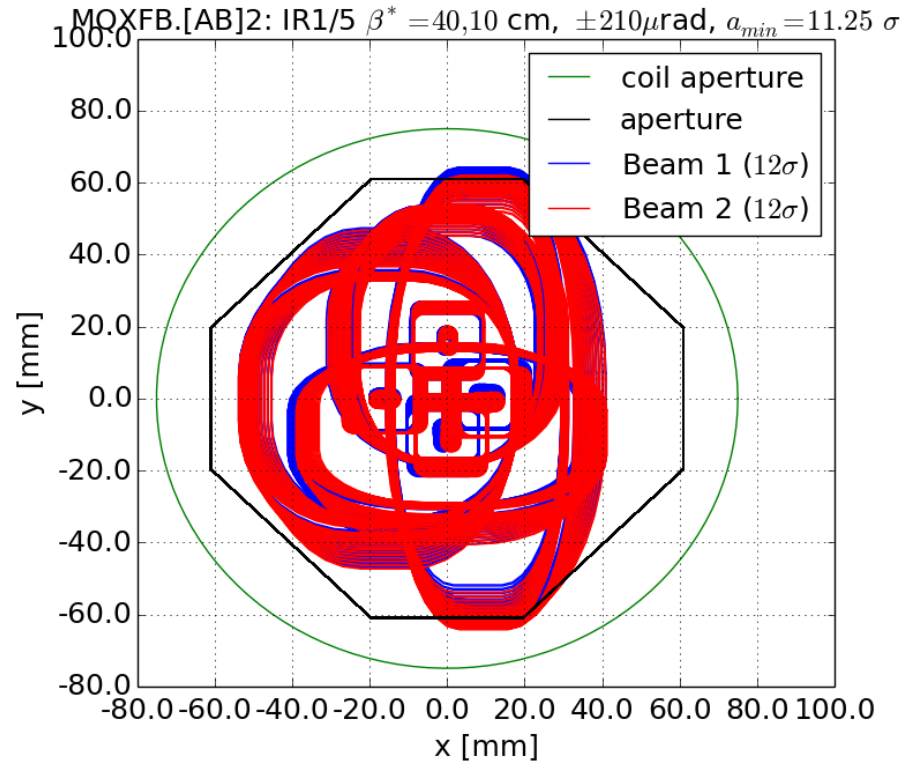
Q2 not OK, but options to improve it available

TAXN

Round **Flat**

Left

IR1/5 $\beta^* = 20$ cm, ± 255 μrad: TAXN.4L, $a_{min} = 13.91$ σ

IR1/5 $\beta^* = 40,10$ cm, ± 210 μrad: TAXN.4R, $a_{min} = 11.41$ σ

Right

IR1/5 $\beta^* = 20$ cm, ± 255 μrad: TAXN.4R, $a_{min} = 13.77$ σ

IR1/5 $\beta^* = 40,10$ cm, ± 210 μrad: TAXN.4R, $a_{min} = 11.41$ σ
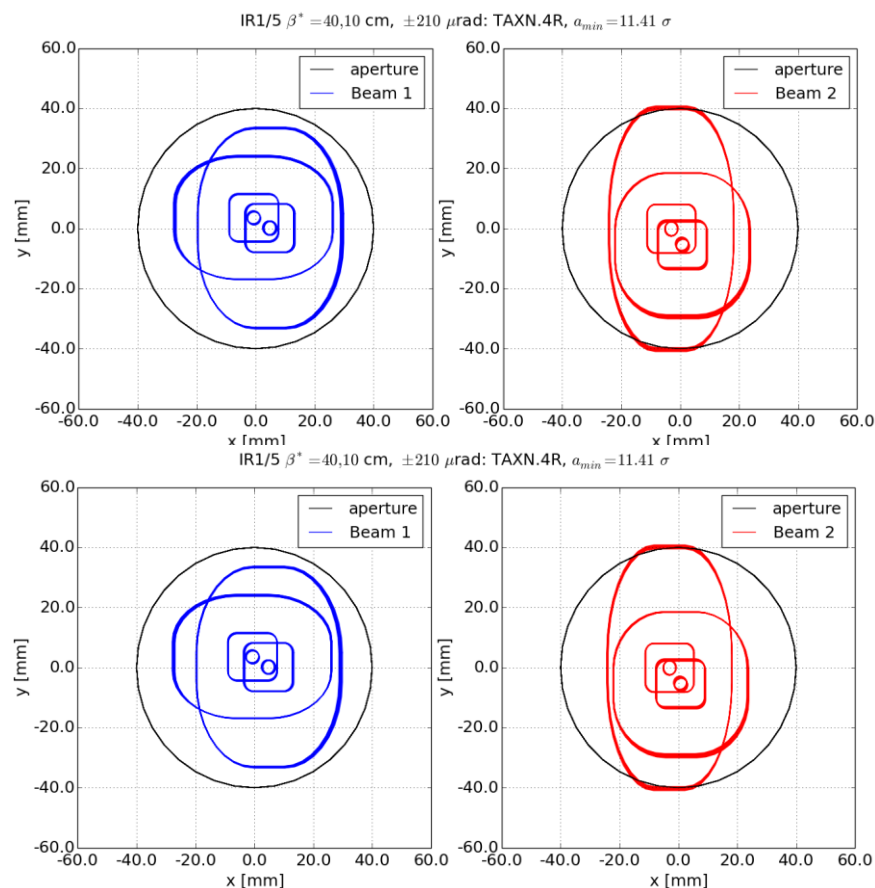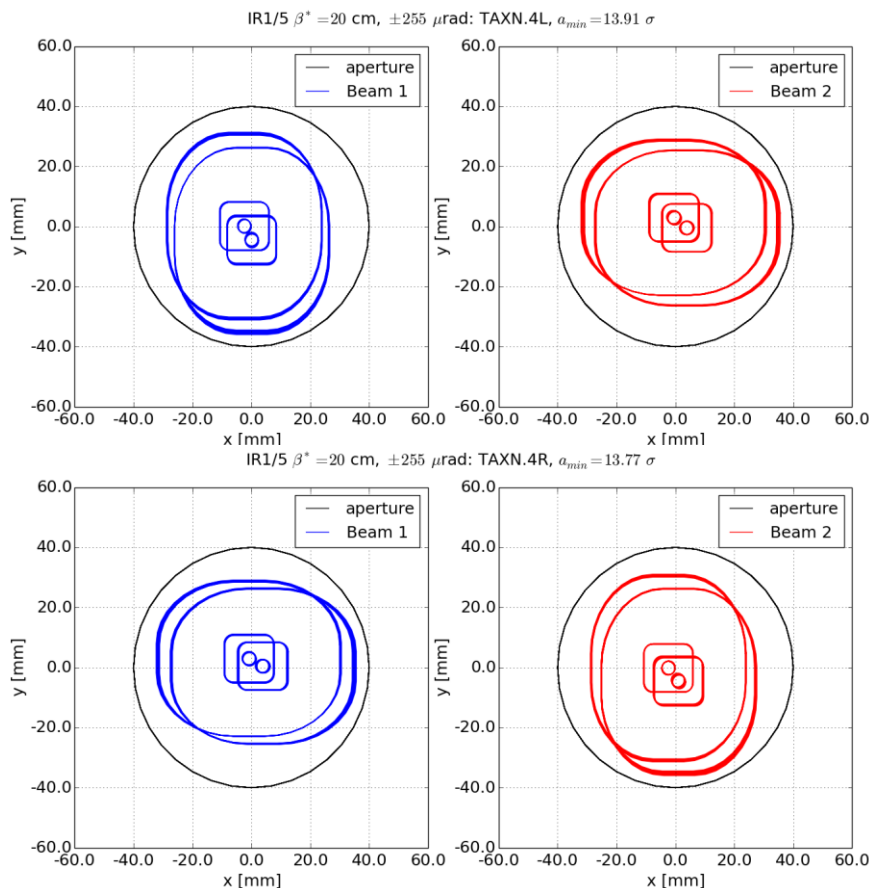
Aperture to be increased: 80mm to 85mm

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Q4 options

	Coil aperture	Beam[1] aperture	H,V[2] full gaps	Round 15 cm	Round 20 cm	Flat 7.5 cm	Flat 10 cm
	[mm]		[mm]	[σ]	[σ]	[σ]	[σ]
MCBYY	90	Octagon	73.8,73.8	15.4	17.9	13.4	15.5
MQYY	90	Octagon	73.8,73.8	16.3	18.9	13.9	16.1
MCBYY	80	Octagon	63.8,63.8	11.6	13.5	10.1	11.7
MQYY	80	Octagon	63.8,63.8	12.3	14.2	10.5	12.1
MCBY	70	RectEllipse	57.8,48	11.8	13.7	8.4	9.8
MQY	70	RectEllipse	57.8,48	13	15.1	9.2	10.6

- **We exclude the option MQY for robust flat optics operations.**
- **MQYY at 80 mm is not sufficient to provide enough flexibility**:
  - Any improvement in triplet aperture would be useless if Q4 aperture is degraded.
  - If Q4 needs to be pushed towards D2 more aperture is needed (about 0.7 σ).
  - In case of operation at 6.5 TeV.
  - The use of a Rectellipse beam screen can help recovering aperture, but only in specific cases: freezing optics constraints or crossing plane.

Impact of energy deposition needs to be re-evaluated in case of reduction of coil aperture
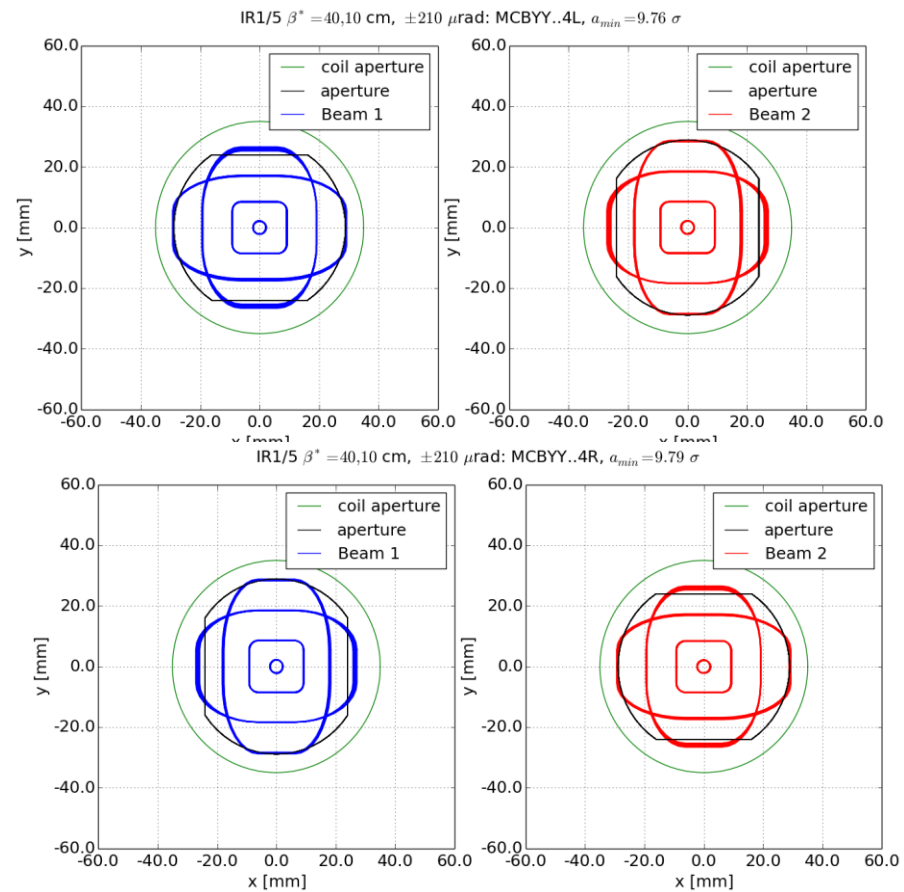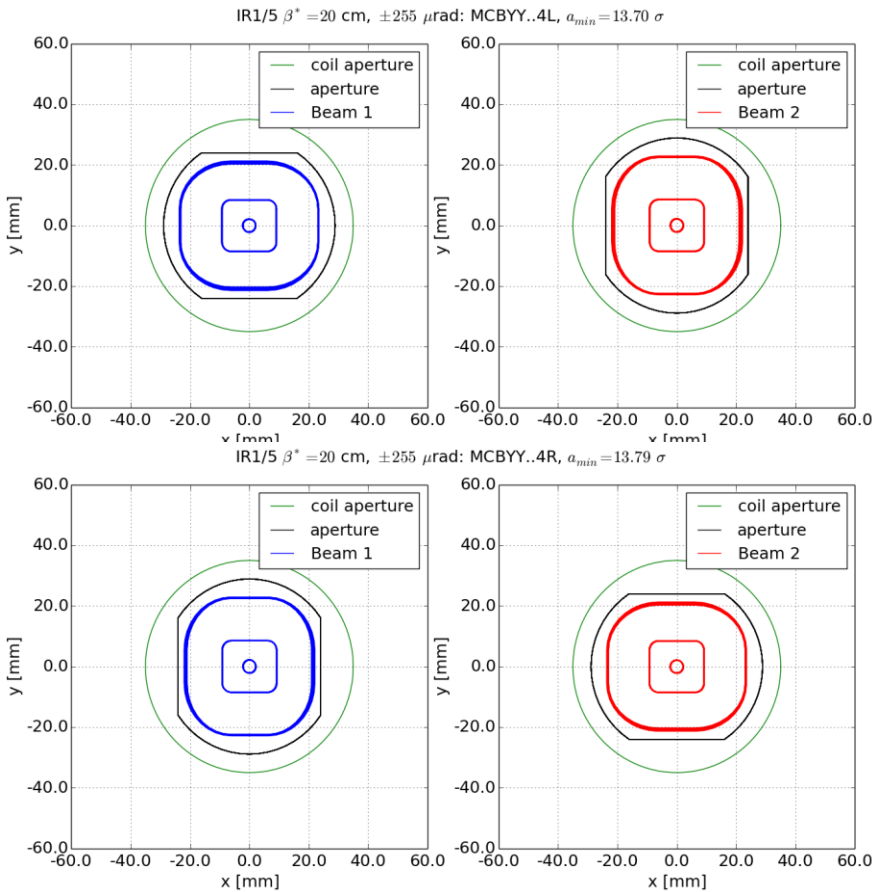
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Q4: MQY with 70 mm coils
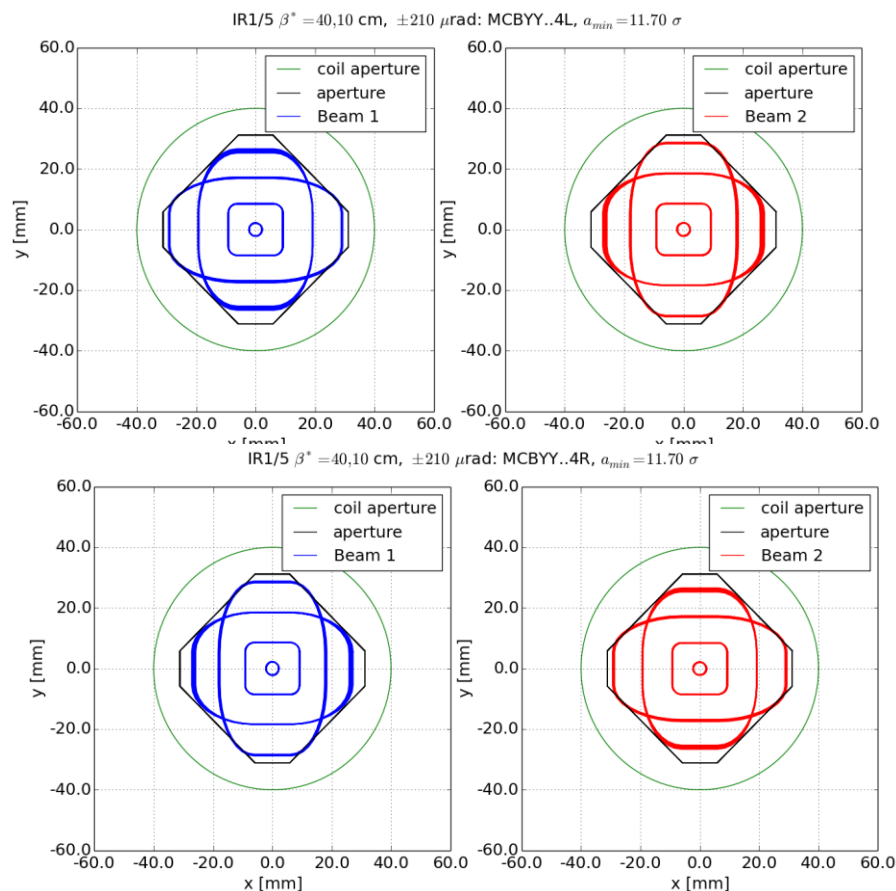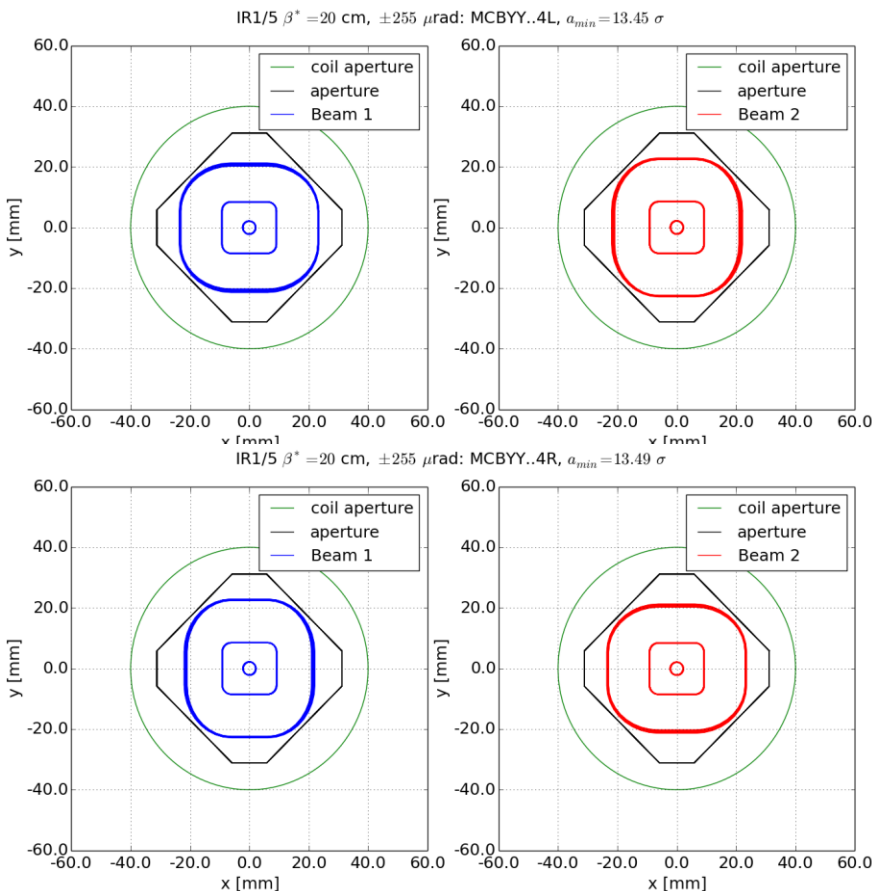
Round

Flat

Q4 with MQY not ok

Q4: MQYY with 80 mm coils

Round

Flat

Left

Right

MQYY with 80mm coil not OK. RectEllipse option can help only for special cases.

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Q4: MQYY with 90 mm coils

Round

Flat

Left

IR1/5 $\beta^* = 20$ cm, ± 255 μrad: MCBYY..4L, $a_{min} = 17.88$ σ

IR1/5 $\beta^* = 40,10$ cm, ± 210 μrad: MCBYY..4L, $a_{min} = 15.55$ σ

Right

IR1/5 $\beta^* = 20$ cm, ± 255 μrad: MCBYY..4R, $a_{min} = 17.92$ σ

IR1/5 $\beta^* = 40,10$ cm, ± 210 μrad: MCBYY..4R, $a_{min} = 15.55$ σ

Q4 with MQYY: OK

Q5 options

	Coil aperture	Beam[1] aperture	H,V[2] full gaps	Round 15 cm	Round 20 cm	Flat 7.5 cm	Flat 10 cm
	[mm]		[mm]	[σ]	[σ]	[σ]	[σ]
TCLMB.5	70	RectEllipse	57.8,48	20.6	23.9	15.0	17.8
MCBY[HV].5	70	RectEllipse	57.8,48	21.4	24.7	15.3	18.4
MQY.5	70	RectEllipse	57.8,48	21.2	24.6	15.0	17.6
TCLMB.5	56	RectEllipse	45.1,35.3	14.0	16.2	10.0	11.6
MCBC[HV].5	56	RectEllipse	45.1,35.3	13.8	16.0	10.1	11.7
MQML.5	56	RectEllipse	45.1,35.3	14.4	16.6	10.3	11.9

The RectEllipse shapes are oriented in opposite way w.r.t the LHC for both MQY and MQML options.

- **The choice of a new MQYY option for Q4 allows to re-use the MQY for Q5 including, which provides the two additional orbit correctors that are needed in Q5.**
- **The MQY aperture is also needed for the present alignment optics at injection (not shown in the table).**
- **The MQY aperture may avoid the need of a TCT protecting Q5.**

MQYY for Q5 in Q7+ optics

An additional Q7 and 2xMQYY in Q5 per side allow a substantial reduction of crab cavity voltage.
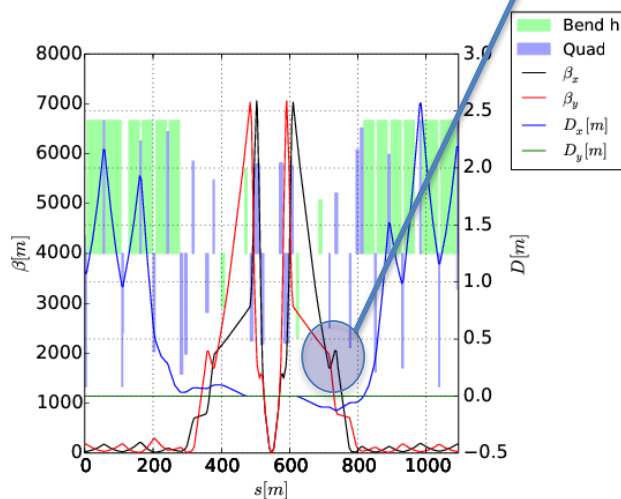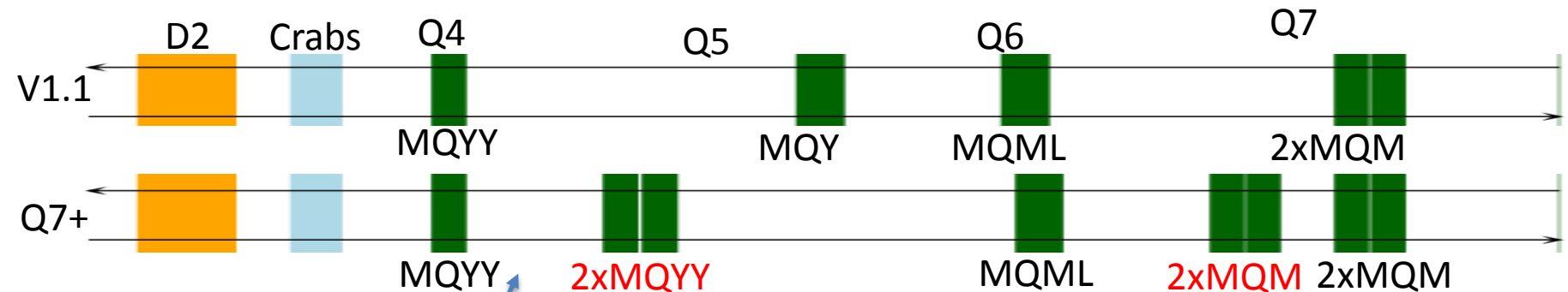
	V1.1	Q7+
Crab voltage for 295 µrad	12 MV	8.8 MV

Voltage reach based on 90 mm aperture without offset at the IP.

Ref: B. Dalena et al., Task 2.2, 24/10/2014

Without the additional Q7, it is difficult to make use of the large aperture margin provided by a MQYY in Q5. This option is therefore dropped.

Next activities

Layout re-validation (Q4-Q5 position)	WP15, WP2
Wire space reservation	WP2
Review energy deposition	WP10
Confirm ground motion and fiducialization assumptions	Survey, WP3, WP8
Validation minimum protected aperture (collimation, injection, dump)	WP5, WP14
Validation aperture TAXS and TAXN with Experiments	WP8
Beam screen tolerances	WP12
Validation of dump (IR6), injection (IR2, IR8) optics constraints	WP14
Specification of optics constraints for IR4	All requestors
Validation requirements orbit correction from the arc	WP2/OP

Summary

- New layout and optics increased β* value for the squeeze and pre-squeeze optics.

- Critical revision of aperture, taking into account all constraints learnt from Run I experience.

- Orbit correctors margins re-evaluated taking into account all known requests: additional strength needed (increased magnetic length). In addition, revision of the strength sharing on-going.

- Q4 aperture: option of re-using MQY excluded. The current baseline is kept (90 mm), pending evaluation of benefits (magnet side) of slight aperture reduction (e.g., down to 85 mm).

- Q5 aperture: critical review of aperture indicates the benefits of re-using the MQY (present Q4). This choice provides naturally also the needed two additional orbit correctors.

Back-up

Offset knob – 2mm
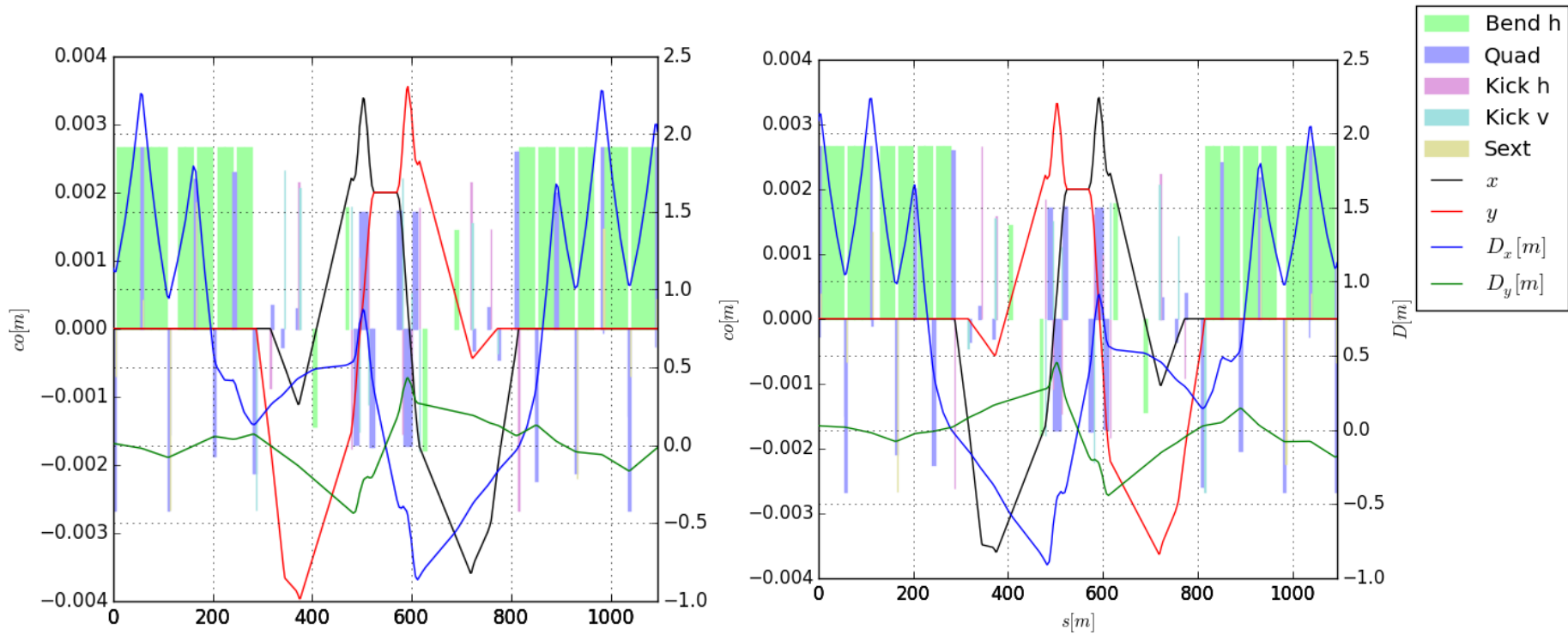
Orbit corrector knobs - 1.5 m, 3T

- IP crossing, separation, offset (**x:** ±295 μrad, **, s:** ±2.0 mm, **o:** ±2.0 mm)
- beam based alignment of crab cavities: **ccp**, **ccm** (shift): ±0.5 mm, **ccs** (slope): ±0.25 mm
- IT alignment and transfer function errors (**err**): ±0.5 mm transverse, ±10 mm longitudinal, ±2x10^{-3} relative gradient error, ±2x10^{-3} D2 relative field error.
- orbit correction from the arc (to confirmed): **arc** 0.7 Tm;
- **lumi** scan knobs (single beam IP shift for 100μm)

name	x-scheme [Tm]			cc alignment [Tm]			err [Tm]	arc [Tm]	lumi [Tm]	summary [Tm]		
	x	s	o	ccp	ccm	ccs	err	arc	lumi	tot	max	margin [%]
MCBX1	0.14	0.29	1.22	0.19	0	0	0.92	0	0	2.63	2.5	-5.2
MCBX2	0.07	0.14	0.55	0.19	0	0	1.4	0	0	2.54	2.5	-1.42
MCBX3	2.11	0.54	0.94	0.45	0.15	0	0.78	0	0	4.43	4.5	1.45
MCBRD4	2.97	0.24	0	0.28	0.15	0.52	0.08	0.35	0.27	4.53	4.5	-0.63
MCBYY4	1.49	0.12	1.12	0.42	0.42	0.92	0	0.35	0.2	4.81	4.5	-6.98
MCBYS5	0	0	1.35	0.4	0.4	0.44	0	0	0	2.46	2.7	8.9
MCBY5	0	0	0.47	0	0	0	0	0	0	0.47	2.8	83.31
MCBC6	0	0	1.4	0	0	0	0	0	0	1.4	2.8	50
MCBC7	0.14	0.29	1.22	0.19	0	0	0.92	0	0	2.63	2.5	-5.2

Orbit corrector knobs – 1.8 m

- IP crossing, separation, offset (**x:** ±295 µrad, **, s:** ±0.75 mm, **o:** ±2.0 mm)
- beam based alignment of crab cavities: **ccp**, **ccm** (shift): ±0.5 mm, **ccs** (slope): ±0.25 mm
- IT alignment and transfer function errors (**err**): ±0.5 mm transverse, ±10 mm longitudinal, ±2x10^{-3} relative gradient error, ±2x10^{-3} D2 relative field error.
- orbit correction from the arc (to confirmed): **arc** 0.7 Tm;
- **lumi** scan knobs (single beam IP shift for 100µm)

name	x-scheme [Tm]			cc alignment [Tm]			err [Tm]	arc [Tm]	lumi [Tm]	summary [Tm]		
	x	s	o	ccp	ccm	ccs	err	arc	lumi	tot	max	margin [%]
MCBX1	0.19	0.28	0.88	0.19	0	0	0.92	0	0	2.27	2.5	9.04
MCBX2	0.09	0.14	0.14	0.19	0	0	1.4	0	0	1.9	2.5	24.06
MCBX3	2.29	0.54	0.41	0.45	0.15	0	0.78	0	0	4.08	4.5	9.37
MCBRD4	3.55	0.28	0	0.28	0.15	0.52	0.08	0	0.27	4.76	5.4	11.91
MCBYY4	1.07	0.08	2.1	0.42	0.42	0.92	0	0.7	0.2	4.96	5.4	8.24
MCBYS5	0	0	1.23	0.4	0.4	0.44	0	0	0	2.34	2.7	13.51
MCBY5	0	0	0.0	0	0	0	0	0.7	0	1.26	2.8	83.31
MCBC6	0	0	1.26	0	0	0	0	0	0	1.26	2.8	55.17
MCBC7	0	0	1.4	0	0	0	0	0	0	1.4	2.8	50

Effect of the knobs

	Coil aperture	Beam[1] aperture	H,V[2] full gaps	Sep. knob	Crossing Knob	Crab shift knob	Crab slope knob	Offset knob
	[mm]		[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
TAXS	54	Circle	54, 54	0.8	6.1	0.0	0.0	2.0
MQXFA.[AB]1	150	Octagon	102, 102	0.8	11.2	0.0	0.0	2.4
MQXFB.[AB]2	150	Octagon	122, 122	1.2	16.7	0.2	0.0	3.6
MQXFA.[AB]3	150	Octagon	122, 122	0.8	16.6	0.4	0.0	2.8
MBXF	150	Octagon	122, 122	0.5	15.5	0.5	0.0	2.4
TAXN	n/a	Circle	80, 80	0.2	5.5	0.9	0.0	3.0
MBRD	105	Octagon	87, 87	0.1	3.3	1.0	0.0	3.3
MCBRD	105	Octagon	87, 87	0.1	1.7	1.0	0.1	3.4
MCBYY	90	Octagon	73.8,73.8	0.0	0.1	1.0	0.5	4.0
MQYY	90	Octagon	73.8,73.8	0.0	0.0	1.0	0.5	3.9
TCLMB.5		RectEllipse	57.8, 48	0.0	0.0	0.4	0.2	3.7
MCBY[HV].5	70	RectEllipse	57.8, 48	0.0	0.0	0.0	0.0	3.6
MQY.5	70	RectEllipse	57.8, 48	0.0	0.0	0.2	0.1	3.5
TCLMC.6	56	RectEllipse	45.1,35.3	0.0	0.0	0.0	0.0	2.3
MCBC[HV].6	56	RectEllipse	45.1,35.3	0.0	0.0	0.0	0.0	2.1
MQML.6	56	RectEllipse	45.1,35.3	0.0	0.0	0.0	0.0	2.1

[1]Either Beam screen or beam pipe;
[2] Rectellipse types are exchanges the H,V orientation depending on the polarity

MG - HL-LHC TC Meeting

Effect of the knobs – 1.8 m

	Coil aperture	Beam[1] aperture	H,V[2]full gaps	Sep. knob	Crossing Knob	Crab shift knob	Crab slope knob	Offset knob
	[mm]		[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
TAXS	54	Circle	54, 54	0.8	6.1	0.0	0.0	2.0
MQXFA.[AB]1	150	Octagon	102, 102	0.8	11.2	0.0	0.0	2.5
MQXFB.[AB]2	150	Octagon	122, 122	1.2	16.7	0.2	0.0	3.4
MQXFA.[AB]3	150	Octagon	122, 122	0.8	16.6	0.4	0.0	2.6
MBXF	150	Octagon	122, 122	0.5	15.5	0.5	0.0	1.7
TAXN	n/a	Circle	80, 80	0.2	5.5	0.9	0.0	3.1
MBRD	105	Octagon	87, 87	0.1	3.3	1.0	0.0	3.4
MCBRD	105	Octagon	87, 87	0.1	1.7	1.0	0.1	3.7
MCBYY	90	Octagon	73.8,73.8	0.0	0.1	1.0	0.5	4.3
MQYY	90	Octagon	73.8,73.8	0.0	0.0	1.0	0.5	4.2
TCLMB.5		RectEllipse	57.8, 48	0.0	0.0	0.3	0.1	3.7
MCBY[HV].5	70	RectEllipse	57.8, 48	0.0	0.0	0.0	0.0	3.6
MQY.5	70	RectEllipse	57.8, 48	0.0	0.0	0.1	0.1	3.5
TCLMC.6	56	RectEllipse	45.1,35.3	0.0	0.0	0.0	0.0	2.3
MCBC[HV].6	56	RectEllipse	45.1,35.3	0.0	0.0	0.0	0.0	2.1
MQML.6	56	RectEllipse	45.1,35.3	0.0	0.0	0.0	0.0	2.1

[1]Either Beam screen or beam pipe;
[2] Rectellipse types are exchanges the H,V orientation depending on the polarity

Alignment optics
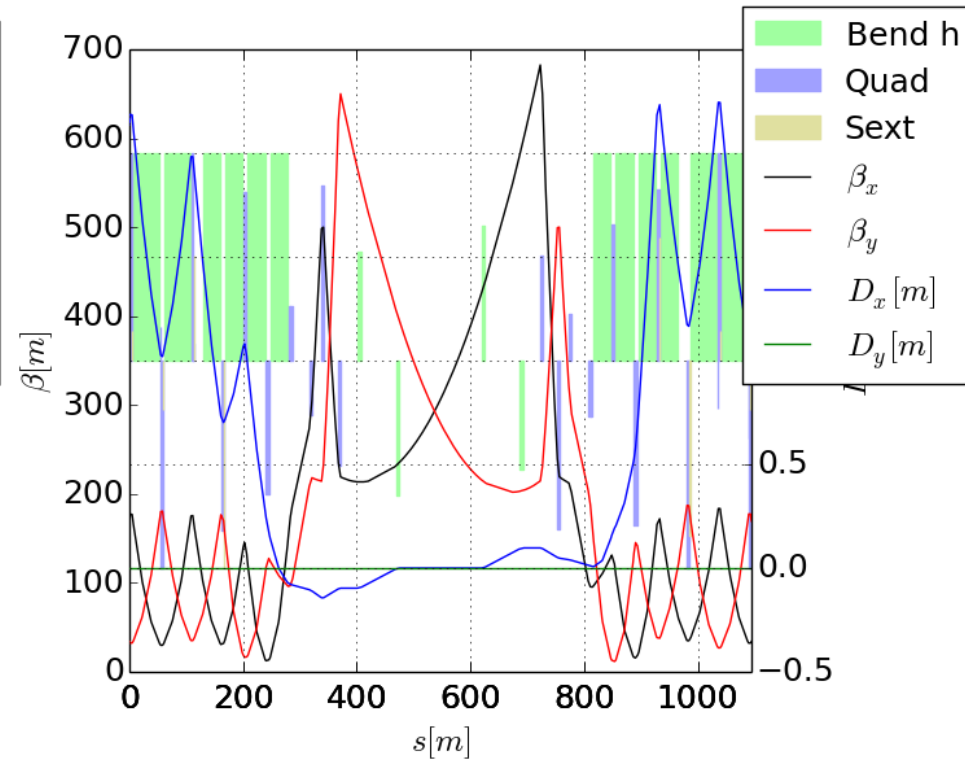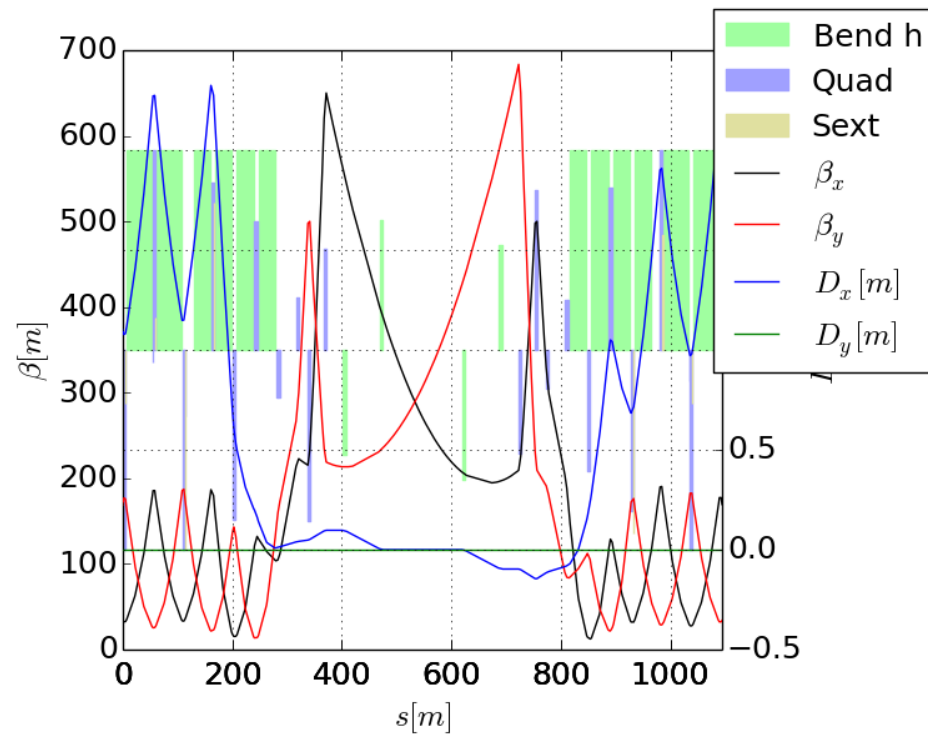
Optics to align BPMs in the triplet at injection.

Compatible with injection strength, but aperture not exceptional in the arcs.