IR4 Optics for HL-LHC

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Thanks to S. Fartoukh, A. Rossi, A. Mereghetti.

Meeting 6/3/2018

IR4 Optics development for HL

SLHCV3.0 – HLLHC1.2:

- Twiss parameter at IP and phase advance adjusted for ATS

LHC:

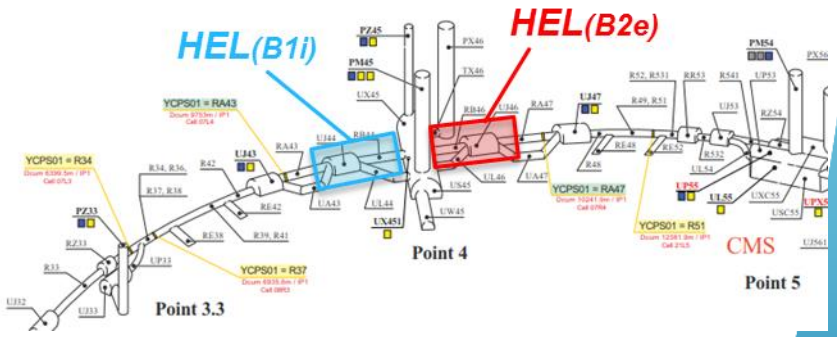
- new IR4 optics developed by S. Fartoukh in 2015 to enhance beta for instrumentation.

HLLHCV1.3:

- Proposal for enhancement β functions (also during the ramp, 67th WP2 meeting 26/4/2016) but no action pending e-lens specification finalization.
- IR4 modified for phase optimization for MKD-TCT phase advance.

HLLHCV1.x: E-lens final specifications:

Spec	Value
β [m]	220±40
|D| [m]	< 0.5
|Orbit| [mm]	±2
Solenoid [T]	5
Bends [Tm]	~ 2·2.5·sin(15°)·0.15 =0.2
Bends kick [μrad]	130 @ 450 GeV



BI Requirements

Device/ instrument	Position (from IP4) and constraints	Phase advance	Beta/beam size	Injection/flattop optics
BGI	~ -63m (B1)	N/A	as large as possible	*
BGI for HL	one on each side – opposite beam from BSRT. (BGI B1 on L, BGI B2 on R)	N/A	as large as possible	*
BGV now	~ -220m (B2)	N/A	as large as possible	*
BGV for HL	1 on B2. Baseline location for HL between Q6 and Q7. Could also consider Q5 to Q6 but more crowded.	N/A	as large as possible circular beam	constant beam size throughout the cycle would be an advantage
BSRT – BSRI	~ ±59m	90° from crabs and -180°from IP in IP1/5	as large as possible	*
E/O BPM	Where phase advance (Q5-Q6 easier to integrate)	90° from crabs and -180°from IP in IP1/5		-
HEL	~ -40m (B1), +40m (B2)	N/A	as large as possible circular beam	constant beam size throughout the cycle would be an advantage
Schottky BPM BQSV & BQSH	~ 115.3, 174.1m (B1) ~ 114, 176m (B2)	N/A	as large as possible	Orbit must be in the centre throughout the cycle*
Tune BPM BQL	~ 138, 149, 172.7m (B1) ~ -175, -116.8m (B2)	N/A	as large as possible	*
WS	~ ±85m	N/A	as large as possible	*

* change in beta between injection and flattop (if not too large) should be ok, to be evaluated depending on proposed optics. Beta must then be measured throughout the full cycle.

A. Rossi, 31/1/2018

IR4 Beams sizes

*squeezed optics not optimized in IR4

β_{xB1}/β_{yB1} β_{xB2}/β_{yB2}[m]	Pos.	LHC Run I	LHC 2015-16	LHC 2017	HLLHC <=V1.3 (inj*)
e-lens	D3	271/ 94/224/228	280/250/283/206	287/220/278/272	232/212/281/263
BSRT/I	D3	178/191/128/332	204/317/201/327	205/287/190/356	136/270/191/365
BGI	D3-4	314/ 96/273/213	316/242/321/188	324/214/318/259	279/208/321/245
WS	D3-4	165/288/124/405	195/368/189/411	193/340/178/414	130/320/178/435
BQSH	Q5-7	469/129/406/198	483/126/419/171	459/129/421/247	426/ 92/425/226
BQSV	Q5-7	169/388/138/459	198/418/151/372	194/393/130/543	142/371/130/491
BPLH1	Q5-7	434/175/416/229	455/173/415/195	443/169/416/283	400/135/420/256
BPLH2	Q5-7	448/126/399/166	460/123/460/182	431/128/433/152	403/ 89/431/165
BPLV	Q5-7	216/386/139/474	245/384/191/493	239/365/180/470	193/337/180/500
BQLV2	Q5-7	-/-/138/440	-/-/151/358	-/-/130/519	-/-/129/470
BPLX	Q5-7	304/279/297/323	331/278/302/268	323/266/294/394	277/234/296/356

Type	Elem Beam 1	Elem Beam 2	Type	Elem Beam 1	Elem Beam 2
BSRT	MU.A5R4.B1	MU.A5L4.B2	BPLH1	BPLH.A6R4.B1	BPLH.6R4.B2
BGI	BGIH.5L4.B1	BGIH.5R4.B2	BPLH2	BPLH.7R4.B1	BPLH.A7L4.B2
WS	BWS.5R4.B1	BWS.5L4.B2	BPLV1	BPLV.B6R4.B1	BPLV.B5L4.B2
BQSH	BQSH.7R4.B1	BQSH.5R4.B2	BPLV2	None	BPLV.7R4.B2
BQSV	BQSV.5R4.B1	BQSV.7R4.B2	BPLX	BPLX.H6R4.B1	BPLX.D6R4.B2

Options for HLLHCV1.x

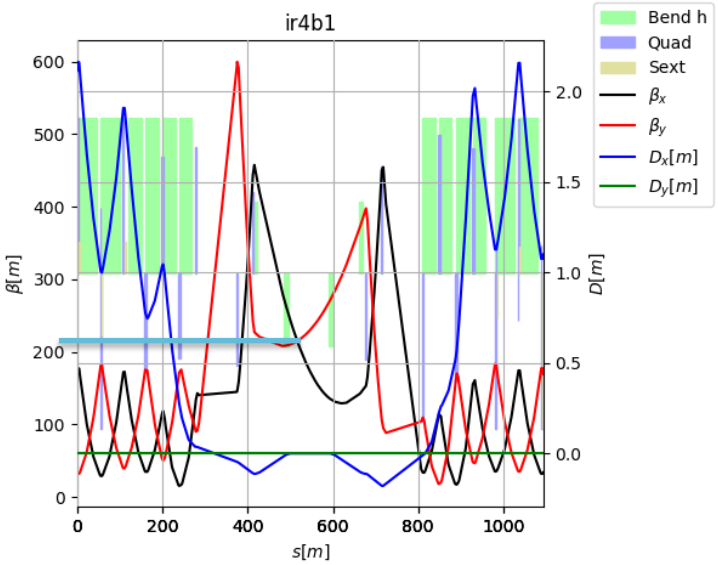
1. Improvements with no optics changes during the ramp (constrained by aperture at injection).
2. With optics transition during the ramp (constrained by phase advance and ATS squeeze):
   A. Round beam as large as possible at e-lens only (Beam 1 left, Beam 2 right)
   B. Round beam left – right as large as possible (proposed by S. Fartoukh, 27/11/2018)

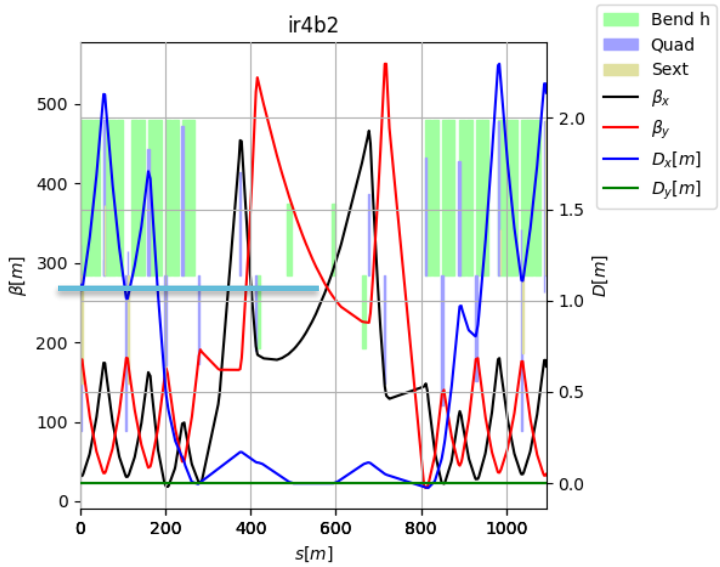
Performing optics transition during the ramp opens:

- Needs optics measurement along the ramp and calibrations
- Similar overhead for optics correction of starting ATS squeeze during the ramp.

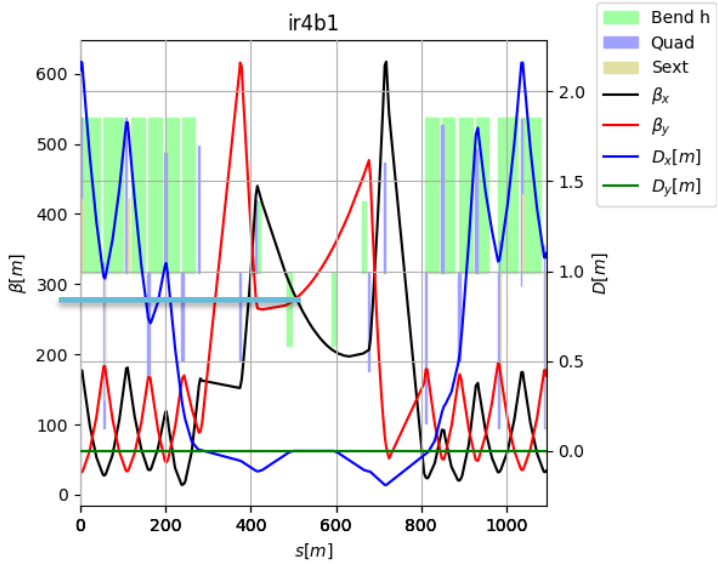
New IR4: No Optics changes during ramp

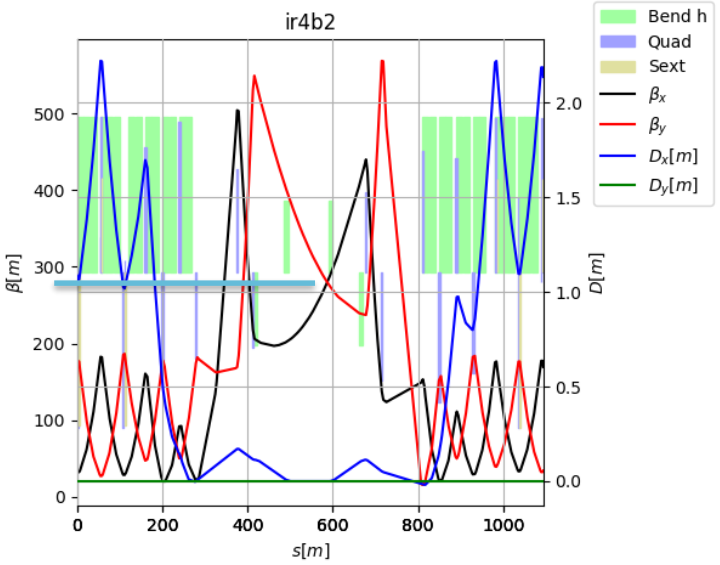
HL1.3





HL1.x





Increased beta and rounded in B1, more round in B2

New IR4: No Optics changes

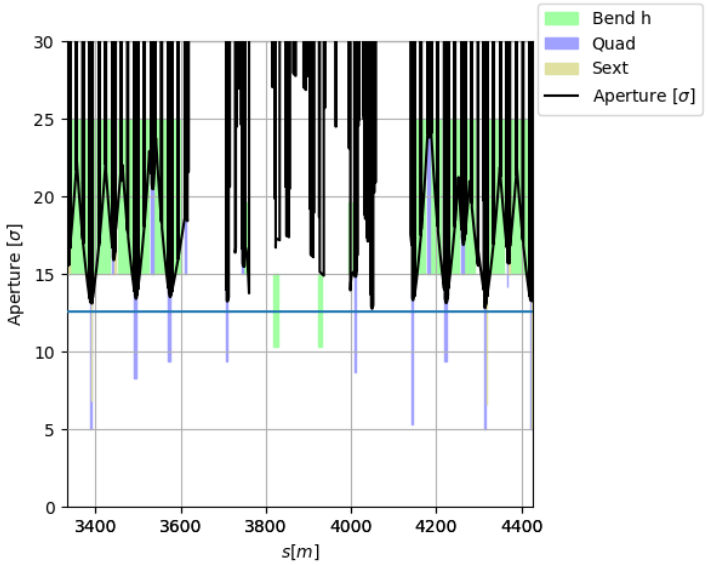
β_{xB1}/β_{yB1} β_{xB2}/β_{yB2}[m]	Pos.	HLLHC <=V1.3 (inj.)	HLLHC 1.x Inj	LHC 1.X Round 15cm
e-lens	D3	232/212/281/263	280/280/280/280	280/280/280/280
BSRT/I	D3	136/270/191/365	206/351/206/384	206/351/206/384
BGI	D3-4	279/208/321/245	314/270/314/262	314/270/314/262
WS	D3-4	130/320/178/435	197/402/197/453	197/402/197/453
BQSH	Q5-7	426/ 92/425/226	577/ 58/405/240	515/109/405/240
BQSV	Q5-7	142/371/130/491	201/451/124/506	201/451/ 76/559
BPLH1	Q5-7	400/135/420/256	543/117/396/270	481/165/387/276
BPLH2	Q5-7	403/ 89/431/165	543/ 51/479/168	492/104/432/230
BPLV	Q5-7	193/337/180/500	260/389/201/517	251/405/201/517
BQLV2	Q5-7	-/-/129/470	-/-/124/483	-/-/ 73/530
BPLX	Q5-7	277/234/296/356	375/246/280/371	346/283/251/397

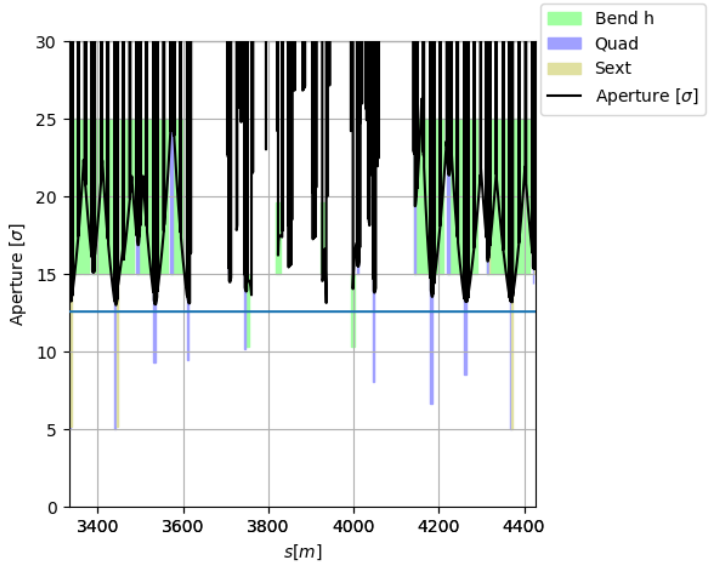
Flat 30/7.5 cm and 18/7.5 cm optics are also possible.

No MS10-14F families should be possible although they are a bit harder.

HiLumi HL-LHC PROJECT

New IR4: No Optics changes



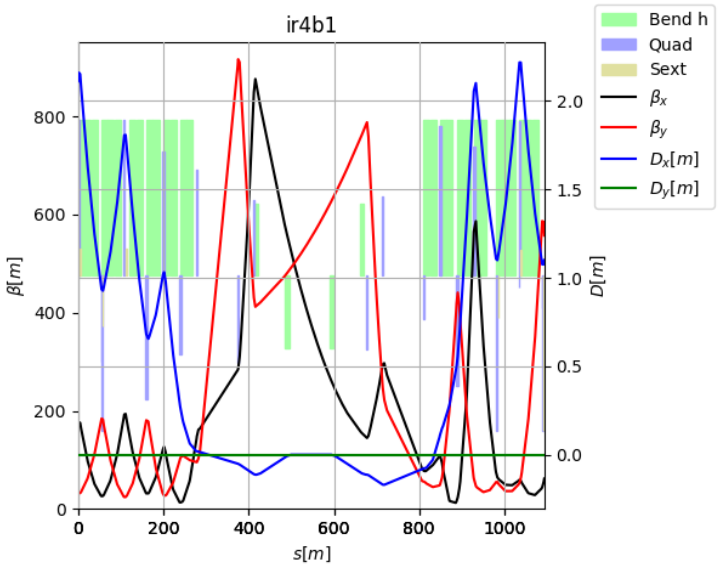


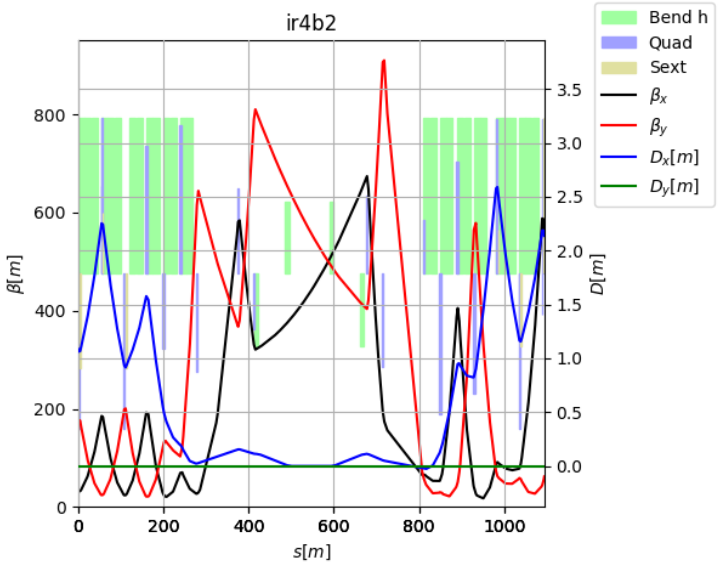
Aperture at injection above the target of 12.6 σ using HL-LHC aperture tolerances..

New IR4: Optics changed during the ramp

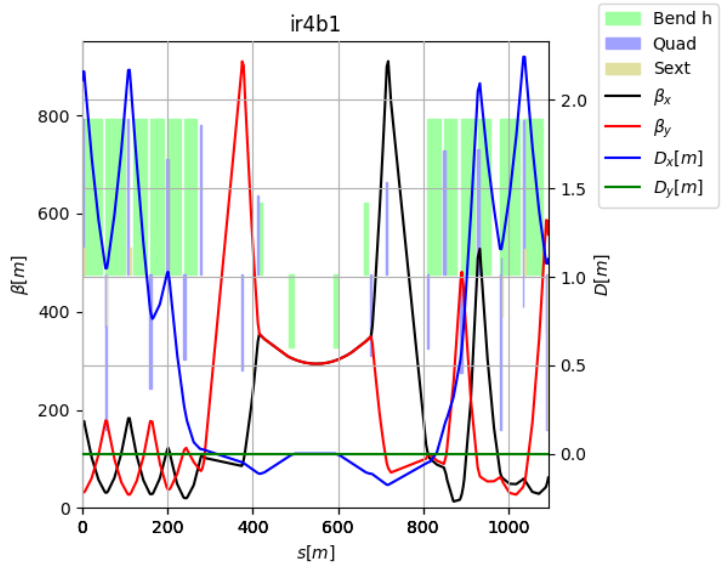
Round 15 cm Flat top

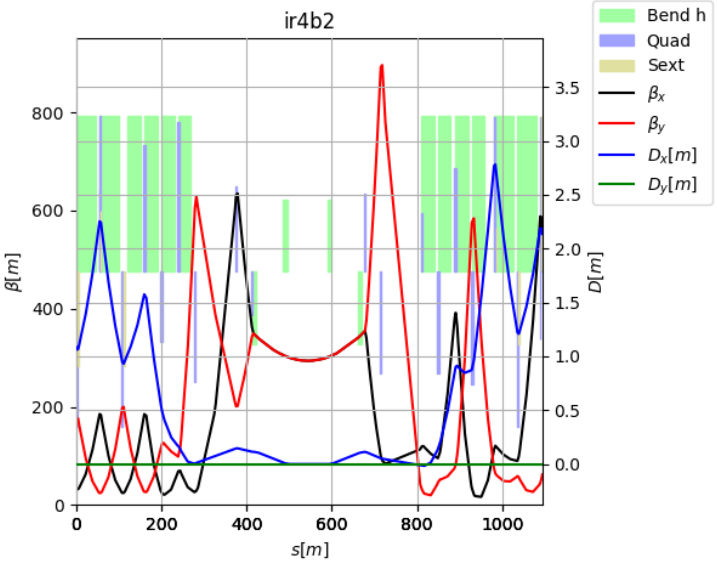
Option:
Largest and round beta at e-lens only





Option:
Large and round beta everywhere





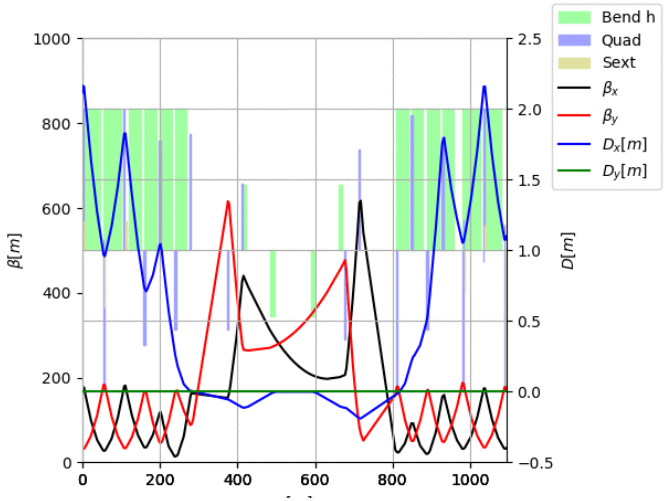
New IR4: Optics changed during the ramp

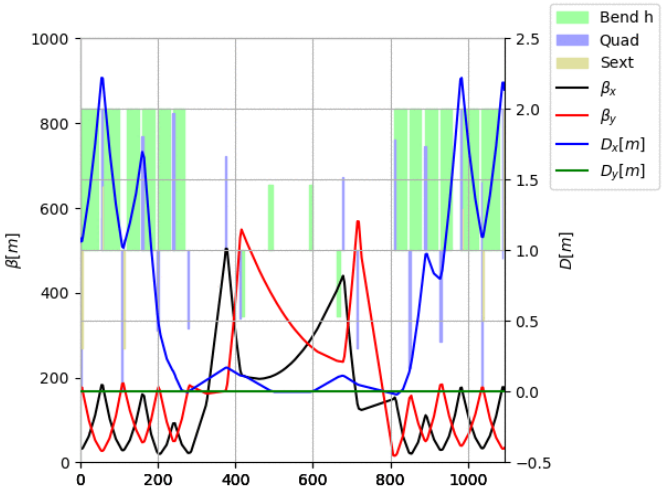
β_{xB1}/β_{yB1} β_{xB2}/β_{yB2}[m]	Pos.	HLLHC No ramp	HLLHC Ramp elens max	LHC Ramp all round
e-lens	D3	280/280/280/280	500/500/500/500	300/300/300/300
BSRT/I	D3	206/351/206/384	265/624/386/634	300/300/300/300
BGI	D3-4	314/270/314/262	587/472/541/470	309/309/309/309
WS	D3-4	197/402/197/453	195/695/350/710	317/317/317/317
BQSH	Q5-7	577/ 58/405/240	284/211/638/417	864/ 76/341/341
BQSV	Q5-7	201/451/124/506	157/757/161/831	337/337/ 86/811
BPLH1	Q5-7	543/117/396/270	270/303/602/453	809/116/316/409
BPLH2	Q5-7	543/ 51/479/168	272/201/554/374	826/ 72/601/209
BPLV	Q5-7	260/389/201/517	164/678/328/777	425/295/338/338
BQLV2	Q5-7	-/-/124/483	-/-/156/801	-/-/ 84/780
BPLX	Q5-7	375/246/280/371	208/489/418/609	584/203/217/572

With optics transition during the ramp one can aim at substantially increase beta at the instrumentation.

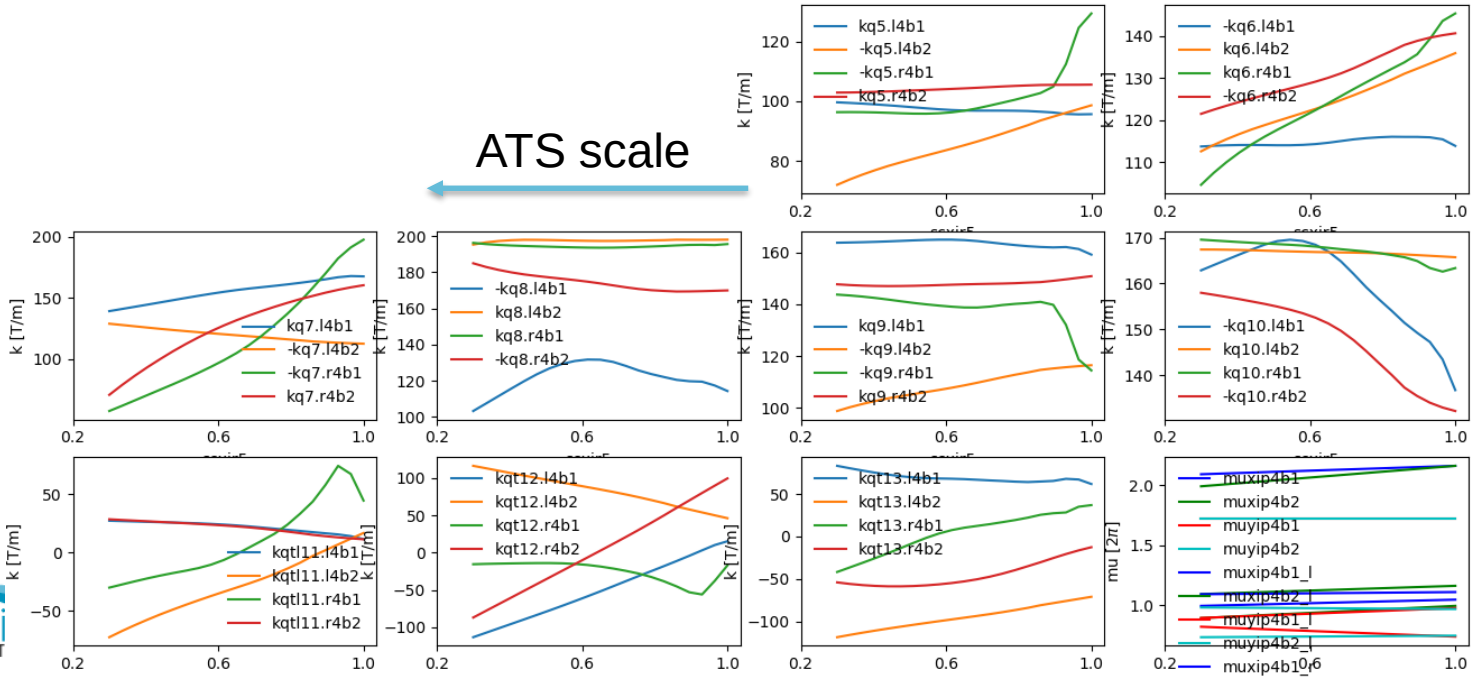
Values for 15 cm round, flats and MS10-14F may have smaller values since they are harder to optimize.

New IR4: Optics changed during the ramp





ATS scale



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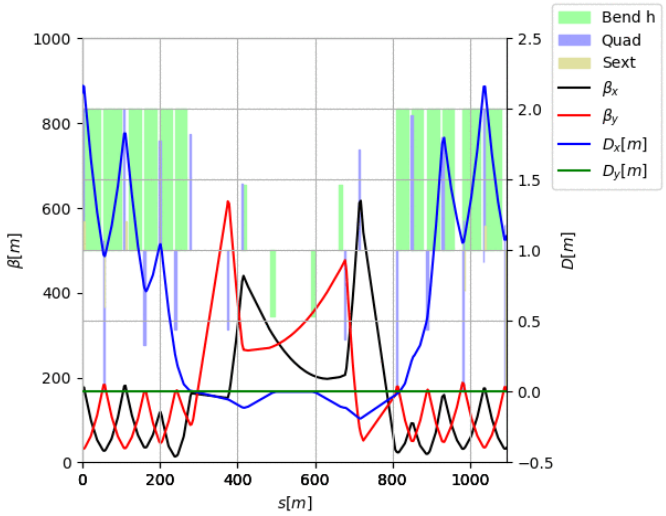
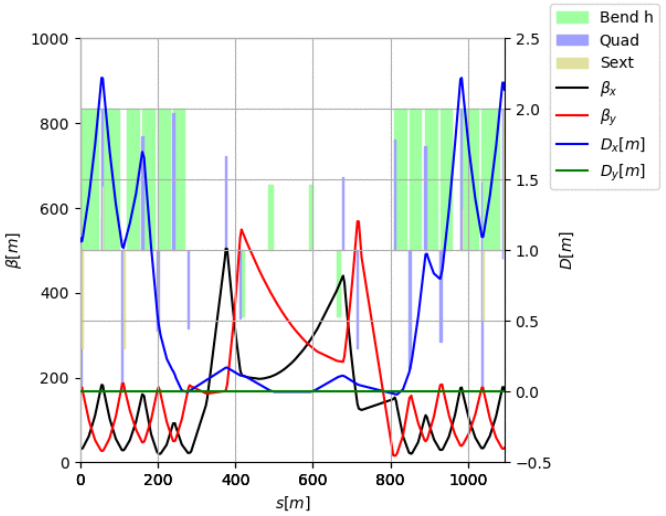
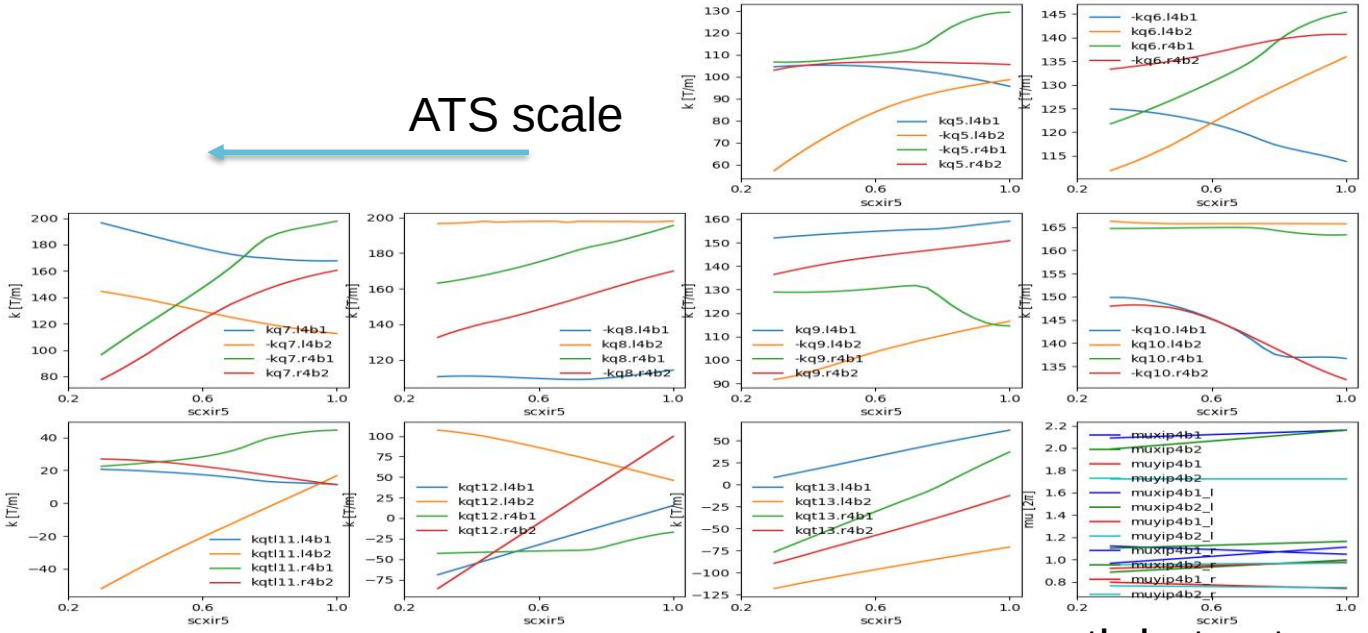




ATS scale



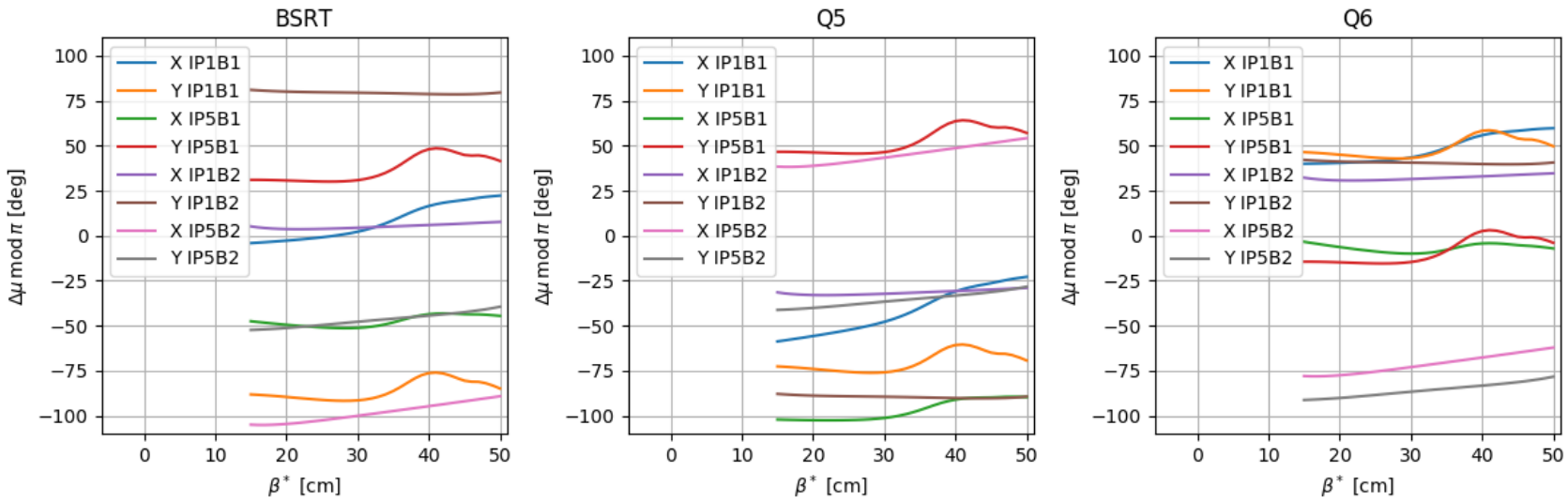
smooth but not acceptable

Phase Advance constraints

Phase advance constraints from IP1/5 to IP4 cannot be resolved today because:

- MS 10 Option has impact on μ_y ARC45
- Lifetime studies depending on $\Delta\mu_{x/y}$ IP1-IP5 can further constraint the phase.
- MKD-TCT constraints μ_x in almost all the ring
- During ATS $\Delta\mu_x$ IP4 to IP1/5 changes during ATS squeeze

Best bet: 2 location space by π/2 (as the ADT) to be at least sensitive in one instrument



HLLHCV1.3 round squeeze

Phase Advance constraints

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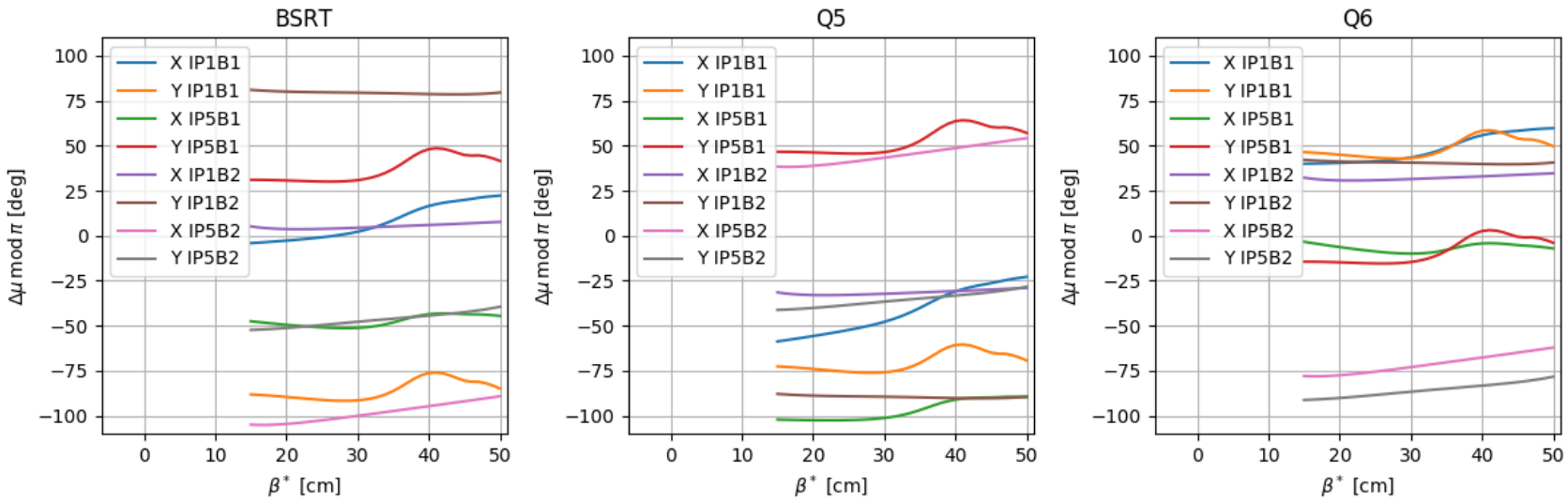
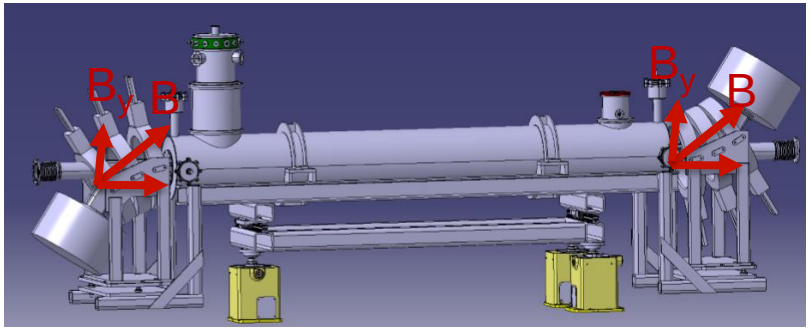


Example round optics HL1.3

Orbit in IR4 with e-lens



Bent solenoids introduce a non negligible dipolar horizontal kick in particular at injection:

- 2·2.5 T·15 cm·sin(15°) ~ 0.2 Tm ~ 130 µrad@450GeV [specs from D. Perini, real field integral to be evaluated]

Since no close orbit corrector (closer is 80 – 100 m away)

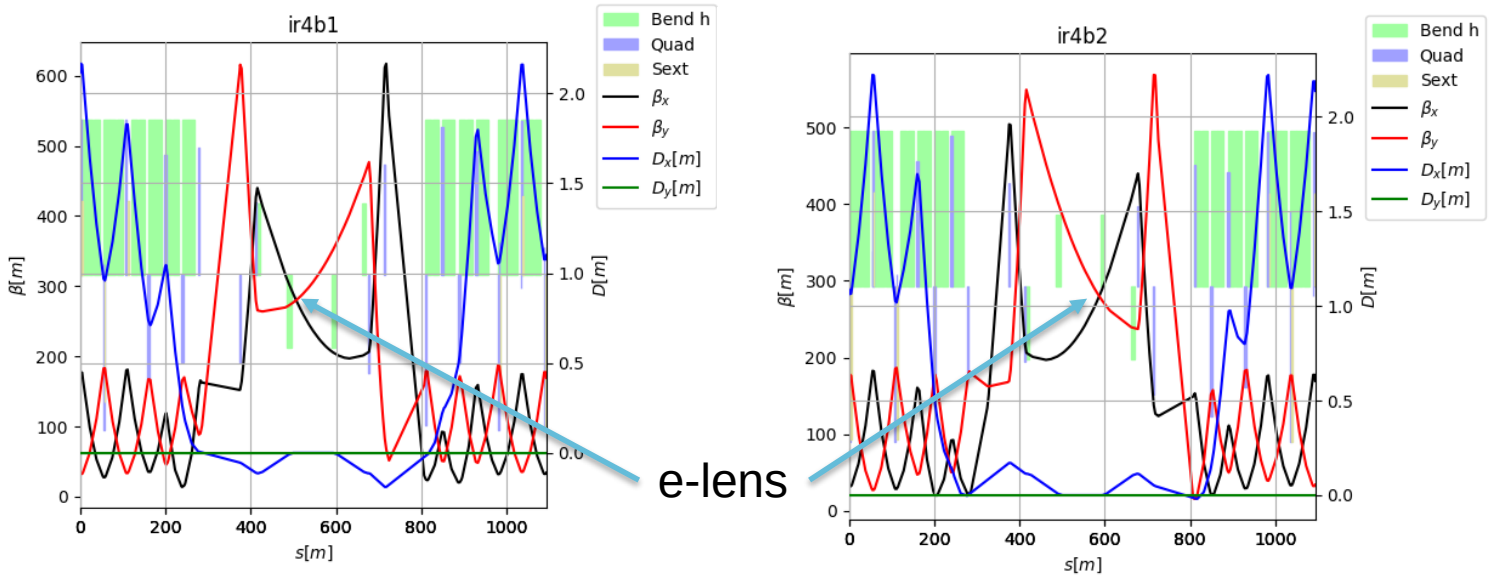
- Absorb orbit change with a local orbit corrector
- If not possible at least one can us D3-D4 (as last resort…)

Small aperture structure

- W. Hofle asked for an aperture restriction to fit a small aperture structure (High-BW pickup).

Best location for round structure as close as possible to the e-lens:

- β_x and β_y ~280 m at injection
- Beam size (12.6 σ + tol.) ~20 mm (radius) instead of 26 mm (e.g. in ADT)



Conclusion

- HL-LHCV1.3 IR4 good starting point for e-lens and instrumentation optimizations
- Can be improved by taking advantage of the injected aperture.
- Can be further improved by performing optics transitions at cost of additional complexity that needs to be evaluated.
- Phase advance constraints are difficult to meet and can conflict with aperture and lifetime optimizations.
- Orbit effects of e-lens needs to be addressed.
- Close to e-lens one can reduce the aperture.

Back-up

Aperture at injection - 2017

Aperture measurements: Injection

- **Summary** of the measurements performed **at injection:**

Date	B1H [σ]	B1V [σ]	B2H [σ]	B2V [σ]
7/05/2017	Q6R2 13.1-13.3	Q4L6 12.2-12.4	Q6L8 12.0-12.5	Q4R6 12.8-13.0
2016	MBCR.4R8 12.5-13.0	Q6L4 12.0-12.5	TCDQM.4L6 12.5-13.0	Q4R6 12.5-13.0

- At injection **apertures are similar to the ones in 2016.**
- **Bottlenecks** found at **different locations.**

N. Catalan, 29/5/2017, collimation meeting
https://indico.cern.ch/event/642139/