Present and future of IR4 Optics

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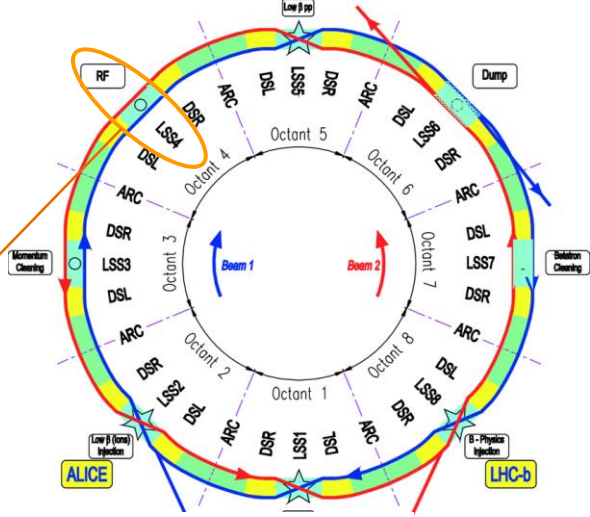
Thanks to F. Roncarolo

Point 4 Region

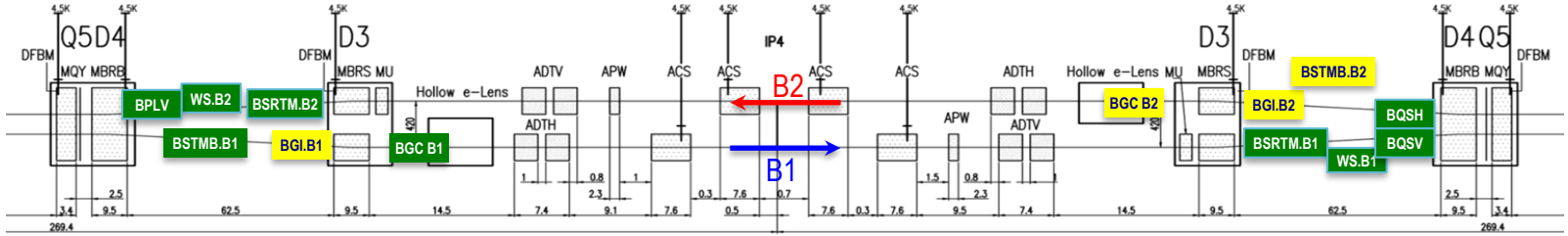
LSS4 contains the main RF and most of the special instruments. In addition, ADT BPMs are hosted in the DS.
E-lens is not expected in Run 4.

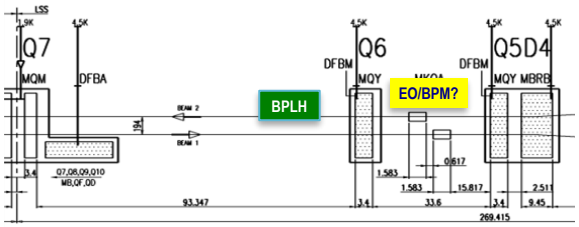


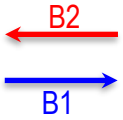
Existing

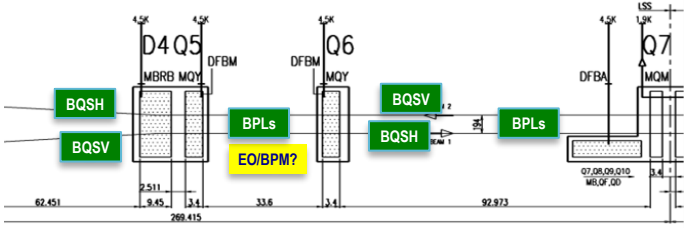
New for HL

RF INSERTION





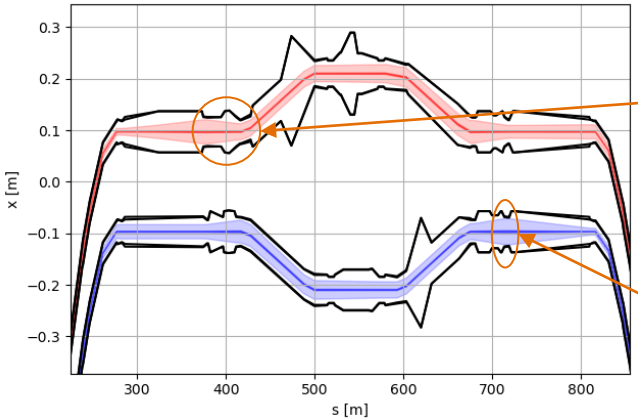


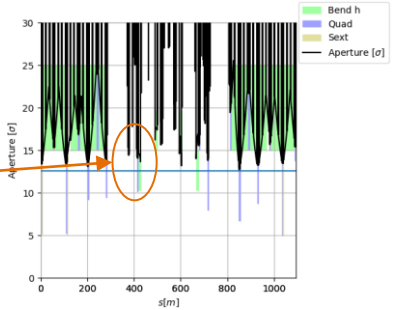


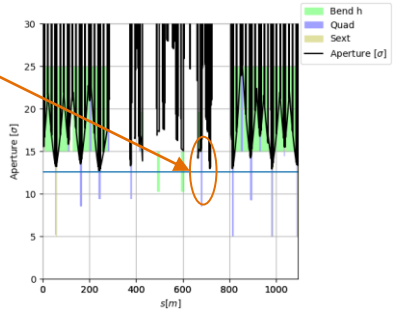
IR4 Optics: injection

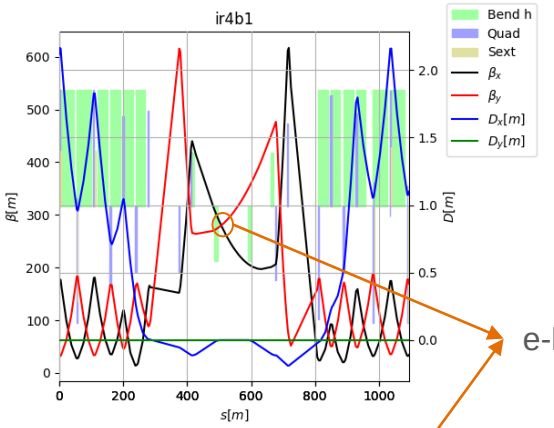
The optics unit IR4 goes from Q13L and Q13R and contains 36 individually powered quadrupoles.

At injection energy, IR4 optics is severely constrained (as any other LHC insertions) by aperture constraints.

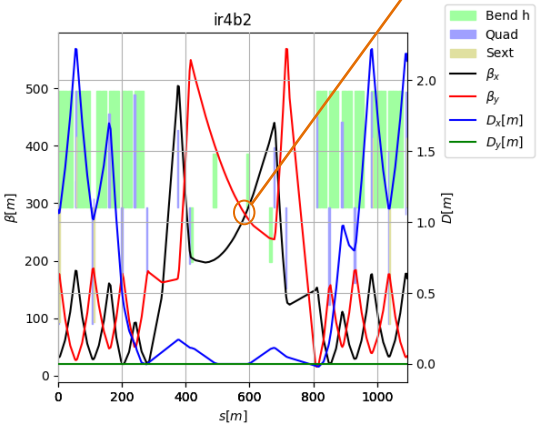








e-lens



IR4 Optics: Run 3 to Run 4

Still, some flexibility exists, and it was used in 2018 to build the HL-LHC version optimized for e-lens.

Elements	Pos.	LHC Run III β_{xB1} β_{yB1} β_{xB2} β_{yB2}[m]	HL-LHC V1.6/MD β_{xB1} β_{yB1} β_{xB2} β_{yB2}[m]
e-lens	D3	287 220 280 271	280 280 280 280
BSRT/I	D3	205 287 197 358	206 351 206 384
BGI	D3-4	324 214 314 258	314 270 311 263
BWS	D3-4	193 340 185 418	197 402 197 453

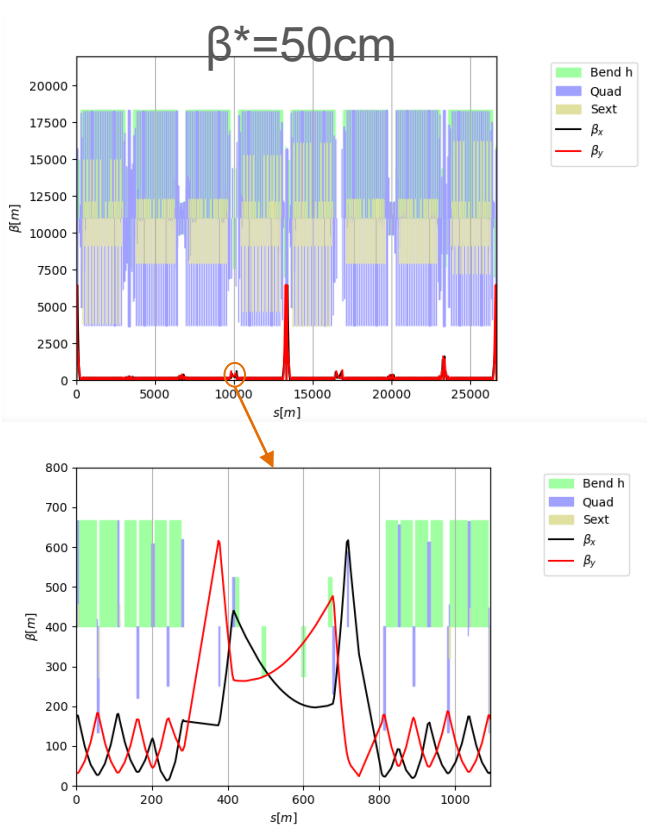
IR4 Optics: flat top constraints

Going to flat top the injection constraints disappear and the optics flexibility is used

- to build the ATS scheme
- keep optics conditions at IP unchanged from injection to end of levelling

There is still additional optics flexibility. Currently, is used to control the long-range phase advance constraints, in combinations with the MQTs in the arcs.

However, could also be used to further optimize the optics, in particular, if we allow changes of optics conditions at the IP.

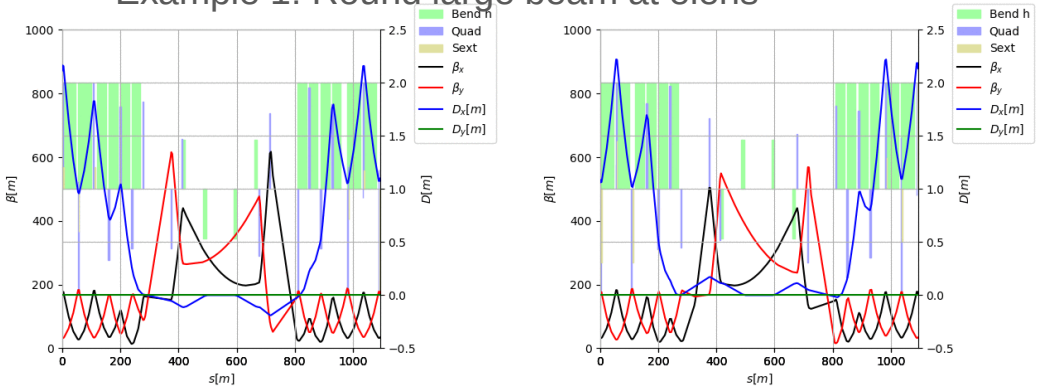


IR4 Optics: future directions

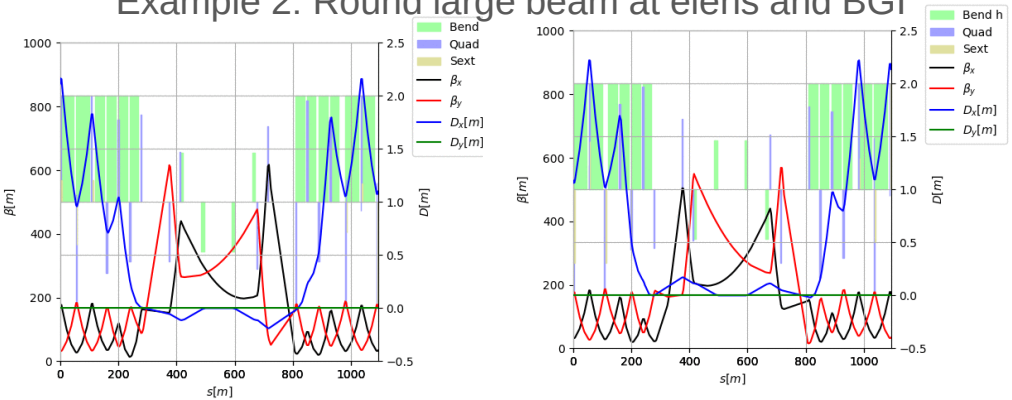
Few example of transitions were studied in 2018 to evaluate potential gains.

Here, a transition in LSS4 is also combined with an ATS squeeze, but one has to apply them separately.

Example 1: Round large beam at elens



Example 2: Round large beam at elens and BGI



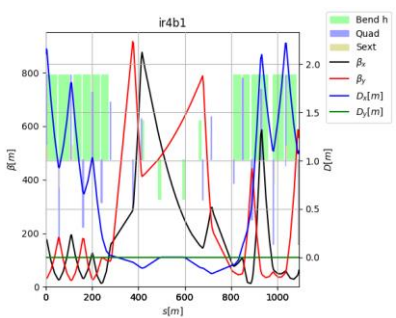
IR4 Optics: future directions

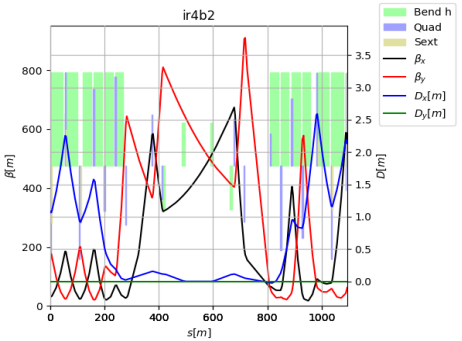
Few example of transitions were studied in 2018 to evaluate potential gains.

Here, a transition in LSS4 is also combined with an ATS squeeze, but one has to apply them separately.

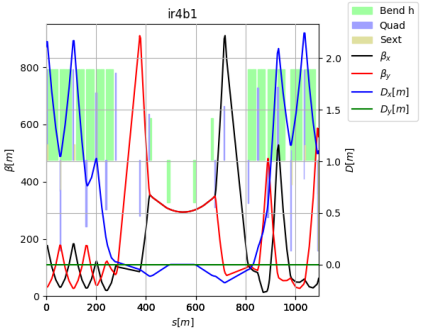
The two examples show that it is easier to optimize one side of two planes rather than the two sides of two planes.

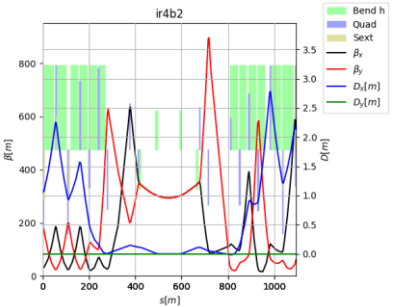
Example 1: Round large beam at elens





Example 2: Round large beam at elens and BGI





IR4 Optics: future directions

These examples show potential improvements.

However, the optics solutions are just a proof of concept and needs to be incorporated in a new operational cycle, which may degrade some figures.

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

The cost of going in this direction is

Build a new optics cycles for round and flat optics. Study in detail implications of changing optics in LSS4: needs of recalibration, optics measurements, ADT kickers in principle ok.
An MD with pilots has been carried out already!

IR4 Optics MD

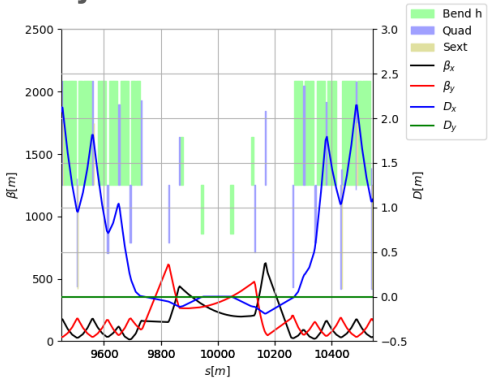
IR4 optics for HL was studied and optimized for BI around 2019.

At that time, it was decided not to use the aperture flexibility at high energy to increase beta* for the baseline.

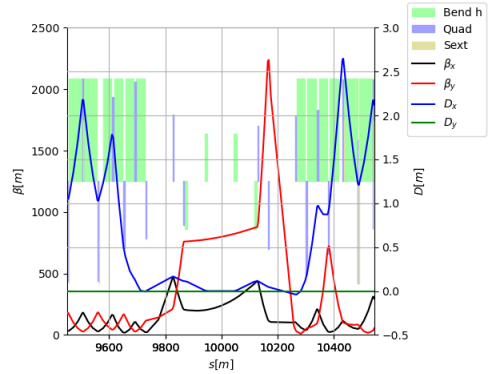
Still, the option is not excluded in general and the interest for BGI, coronograph, etc.. is very high.

For the MD studies, we proposed to try to increase the beta function during a segment in the squeeze.

Inj. nominal



Proof of principle optics for machine studies



Conclusion

HL-LHC IR4 optics was optimized in Run 4 based on:

- Largest round beam at e-lens
- No optics change from injection to end of levelling as a conservative approach.

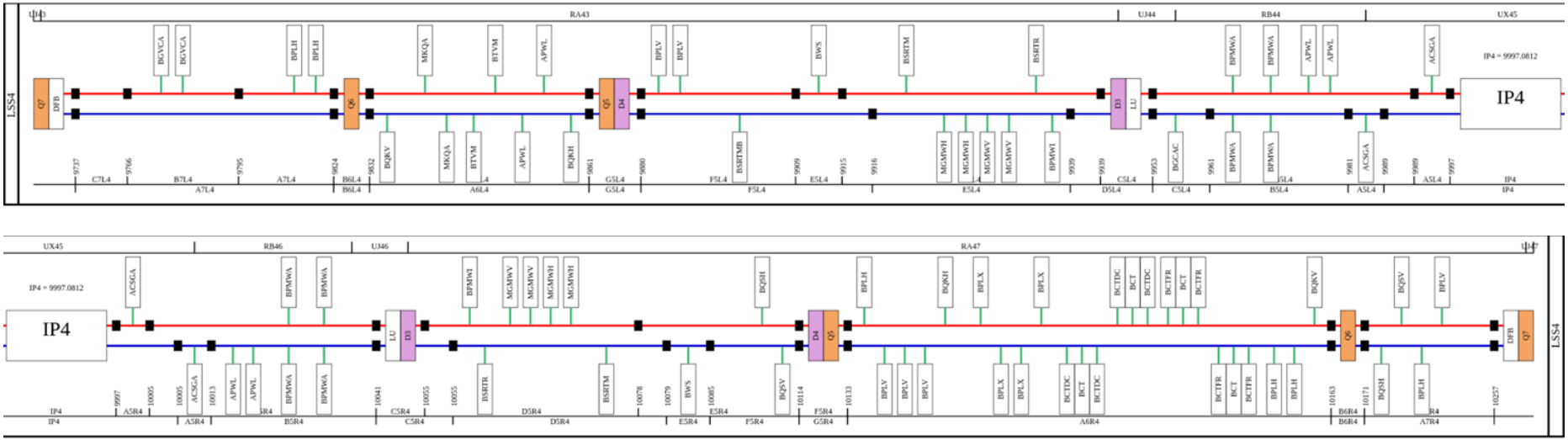
E-lens will not be likely present in Run 4, we can then displace optics flexibility towards instruments.

LHC operations is getting more and more experienced with optics transitions, we can re-evaluate the options of also changing optics IR4 optics during the ramp.

This opens a new window of optimization opportunities that could be exploited at the cost of optics development time: studies and MD time to certain extent.

Back-up

Synoptic



https://accelerator-synoptics.web.cern.ch/?machine=LHC&version=EYETS%202024-2025&region=LSS4

Requirements on optics

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 BPL	~ 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.

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

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)