# HL-LHC optics updates

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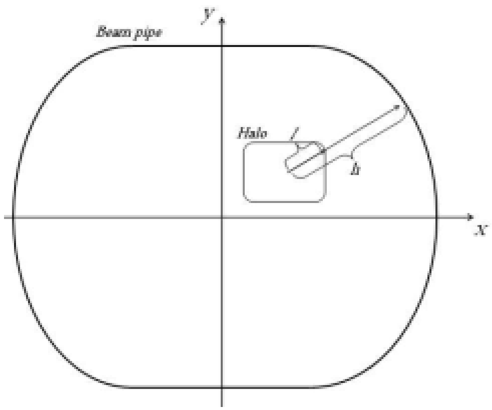
Acknowledgment C. Garion

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.

# Review aperture at injection




New settings for aperture margin evaluation. In the LHC design report the $n_1$ (aperture of the primary collimators) values were used assuming in given aspect ratio of the halo.

Recently we adopted directly the minimum protect aperture in sigma. New parameters and tolerance for aperture calculation have been established (R. Bruce)

| Aperture margins | Orbit [mm] | β-beat | δ $10^{-4}$ | Sp. $D_{x,y}$ [%] | Emit n. [μm] | Halo (ref,h,v,rad) [σ] | Target [σ] |
|---|---|---|---|---|---|---|---|
| n1 inj. | 4+0 | 20% | 15 | 27.3 | 3.75 | 6, 7.3, 7.3, 8.4 | 7, 6.7 |
| HL-LHC inj. | 2+2 | 10% | 4 | 14 | 3.5 | 6, 6, 6, 6 | 9? |
| n1 coll. | 3 | 20% | 8.6 | 27.3 | 3.75 | 6, 7.3, 7.3, 8.4 | 7, 6.7 |
| HL-LHC coll. | 2 | 20% | 2 | 10 | 3.5 | 6, 6, 6, 6 | 12 |

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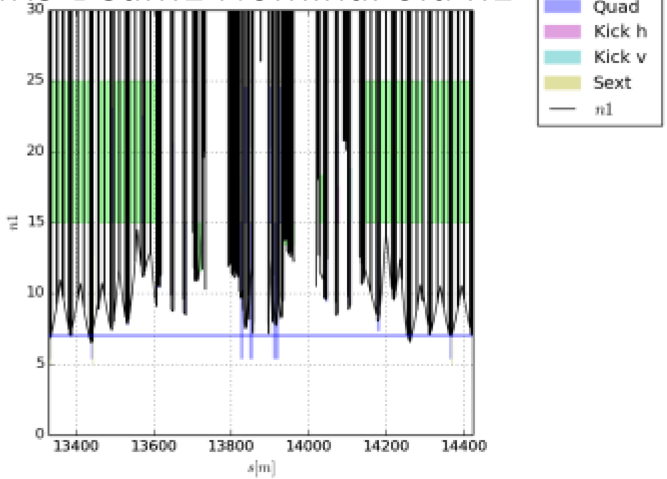
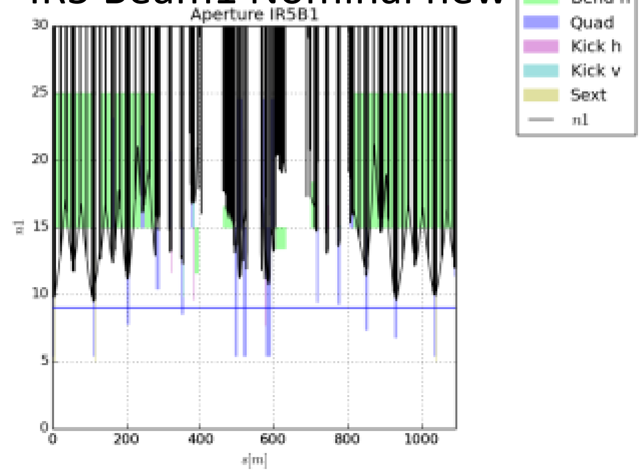
# Examples aperture at injection

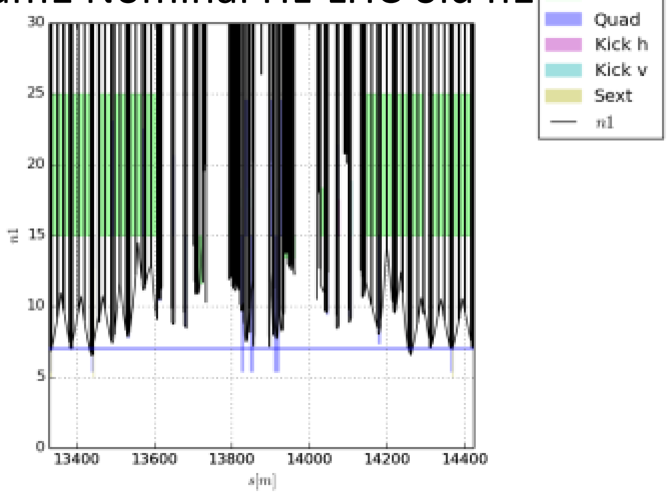
IR5 Beam1 Nominal old n1



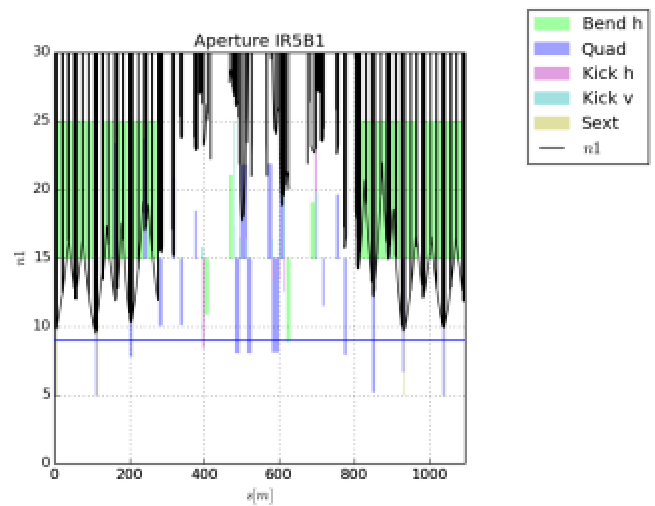

IR5 Beam1 Nominal new




IR5 Beam1 Nominal HL-LHC old n1

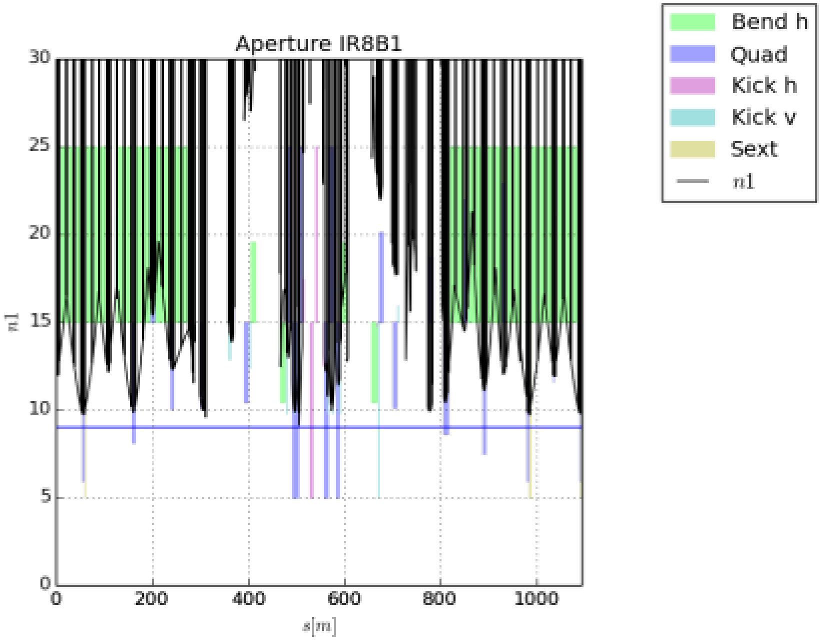


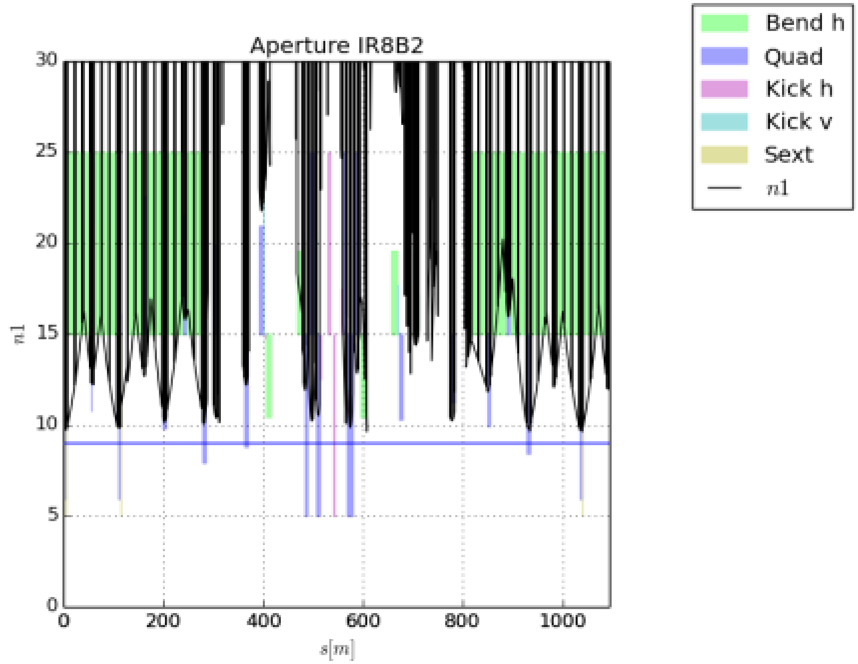

IR5 Beam1 Nominal HL-LHC new



# Examples aperture at injection

IR8 Beam1 for 2015 and future HL optics

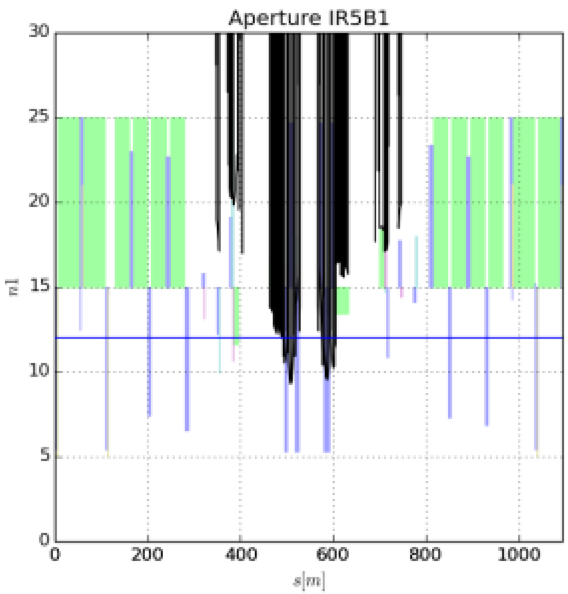


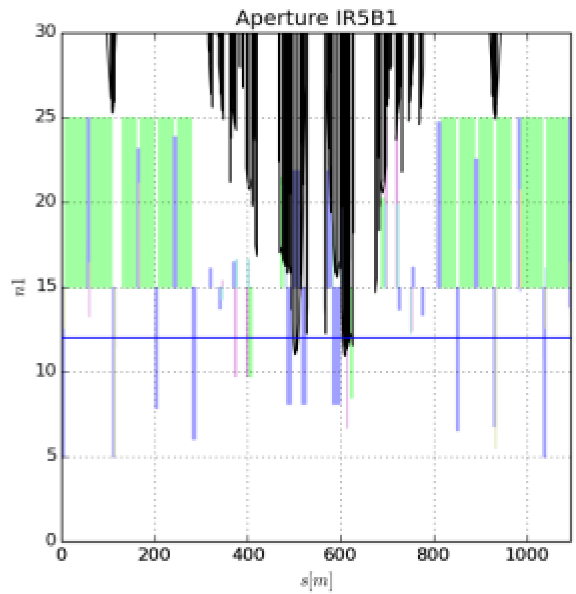

New method predicts bottleneck in IR8 at injection.

# Examples aperture in collision

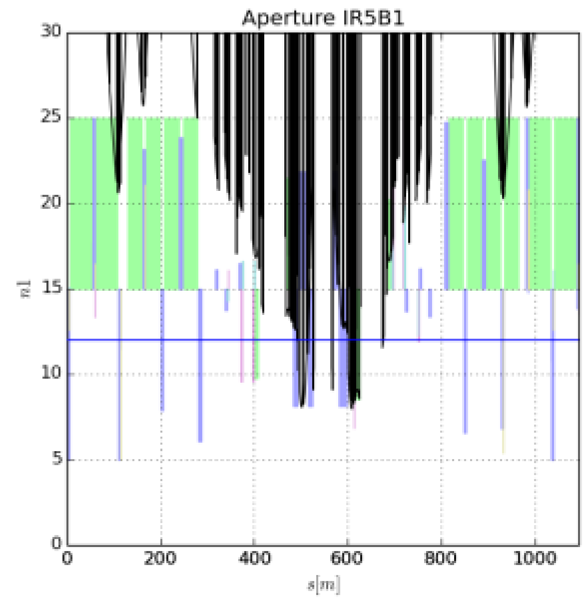
LHC 2015 (β*=40 cm, ± 145 μrad) with HL-LHC criteria




HL-LHCV1.1 (β*= 15 cm)




HL-LHCV1.1 (β*= 10 cm)




Aperture plots are available on cern.ch/lhcoptics

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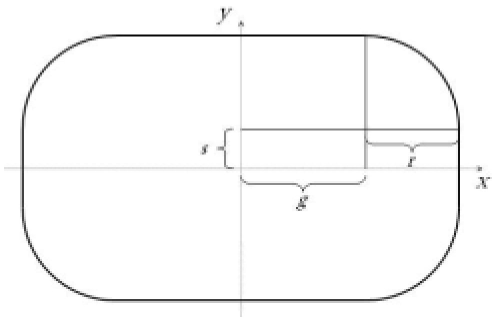
# Review TAS aperture at injection

| TAS [mm] | Diam. | r tol | g tol | s tol |
|---|---|---|---|---|
| LHC | 34 | 1 | <=0.2 | <=0.2 |
| Phase I | 50 | 2 | 0.5 | 0.5 |
| SLHCV3.x-HLLHCV1.0 | 60 | 2 | 0.5 | 0.5 |
| HLLHCV1.1 | 54 | 2 | 0.5 | 0.5 |




Mechanical tolerance definitions.

TAS apertures redefined for HL-LHCV1.1 upon request of the experiments to protect the beam experimental beam pipes. Concrete failure scenarios are not been identified yet.

# • Dependence on offset injection aperture

| offset [mm] in xing-plane | inj | | inj15 | |
|---|---|---|---|---|
| | minimum n1 over IR1/5 | | | |
| | TAS | MQX | TAS | MQX |
| -2 | 14.79 | 15.96 | 20.35 | 23.84 |
| -1 | 15.99 | 16.82 | 21.99 | 25.10 |
| 0 | 17.18 | 17.69 | 23.64 | 26.36 |
| 1 | 16.00 | 17.05 | 22.00 | 25.5 |
| 2 | 14.8 | 16.17 | 20.36 | 24.22 |

| offset [mm] in separation-plane | inj | | inj15 | |
|---|---|---|---|---|
| | minimum n1 over IR1/5 | | | |
| | TAS | MQX | TAS | MQX |
| -2 | 15.99 | 17.67 | 22.56 | 26.36 |
| -1 | 16.63 | 17.68 | 23.23 | 26.36 |
| 0 | 17.18 | 17.69 | 23.64 | 26.36 |
| 1 | 16.62 | 17.69 | 23.22 | 26.35 |
| 2 | 15.97 | 17.69 | 22.53 | 26.35 |

**note:** the aperture (n1) is increased by a positive offset in IR5 and negative offset in IR1

TAS aperture, bottleneck at injection, however well above protected aperture.

M. Fitterer

- Dependence on offset collision aperture

| offset [mm] in xing-plane | round | | sround | | flat | | sflat | | presqueeze | |
|---|---|---|---|---|---|---|---|---|---|---|
| | minimum n1 over IR1/5 | | | | | | | | | |
| | TAS | MQX | TAS | MQX | TAS | MQX | TAS | MQX | TAS | MQX |
| -2 | 10.77 | 10.09 | 7.88 | 7.30 | 10.58 | 10.95 | 8.23 | 8.89 | 18.69 | 17.42 |
| -1 | 11.55 | 10.58 | 8.51 | 7.71 | 10.89 | 10.97 | 8.54 | 8.93 | 20.00 | 18.29 |
| 0 | 12.28 | 11.04 | 9.09 | 8.07 | 11.07 | 10.93 | 8.78 | 8.89 | 21.28 | 19.13 |
| 1 | 11.49 | 10.79 | 8.43 | 7.91 | 10.81 | 10.88 | 8.47 | 8.83 | 19.96 | 18.60 |
| 2 | 10.69 | 10.22 | 7.77 | 7.42 | 10.48 | 10.84 | 8.13 | 8.77 | 18.64 | 17.67 |

**note:** the aperture (n1) is increased by a positive offset in IR5 and negative offset in IR1

| offset [mm] in separation-plane | round | | sround | | flat | | sflat | | presqueeze | |
|---|---|---|---|---|---|---|---|---|---|---|
| | minimum n1 over IR1/5 | | | | | | | | | |
| | TAS | MQX | TAS | MQX | TAS | MQX | TAS | MQX | TAS | MQX |
| -2 | 11.8 | 11.06 | 8.79 | 8.07 | 9.94 | 10.14 | 7.81 | 8.21 | 20.45 | 19.19 |
| -1 | 12.14 | 11.11 | 9.02 | 8.15 | 10.53 | 10.56 | 8.32 | 8.58 | 21 | 19.17 |
| 0 | 12.28 | 11.04 | 9.09 | 8.07 | 11.07 | 10.93 | 8.78 | 8.89 | 21.28 | 19.13 |
| 1 | 12.09 | 10.97 | 8.95 | 7.99 | 10.47 | 10.5 | 8.27 | 8.51 | 21 | 19.09 |
| 2 | 11.68 | 10.91 | 8.65 | 7.91 | 9.88 | 10.07 | 7.75 | 8.14 | 20.4 | 19.05 |

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TAS aperture (54 mm) may become aperture bottleneck for IP offset and extreme flat optics. (M. Fitterer)

# New layout TAN – D2 area

- In HLLHCV1.1, D1-D2 need to provide 33.8 Tm (1449 μrad) to provide 194mm separation in 66.941 m.
- D1, D2 are specified for 35T/m (1499 μrad) corresponding to a minimum distance of 64.710 m.
- If minimum distance is used, separations at TCT and TCL will be reduced by about 0.5-1mm (50 μrad x distance from D2 center) with respect to HLLHCV1.1.

- New BPM, TCT, TCL, TAN longitudinal positions will be specified by Paolo in the coming days.
- New optics may results in β in the area, to be reviewed when L* will be fixed.
- After optics is found, TAN apertures and separations can be defined.

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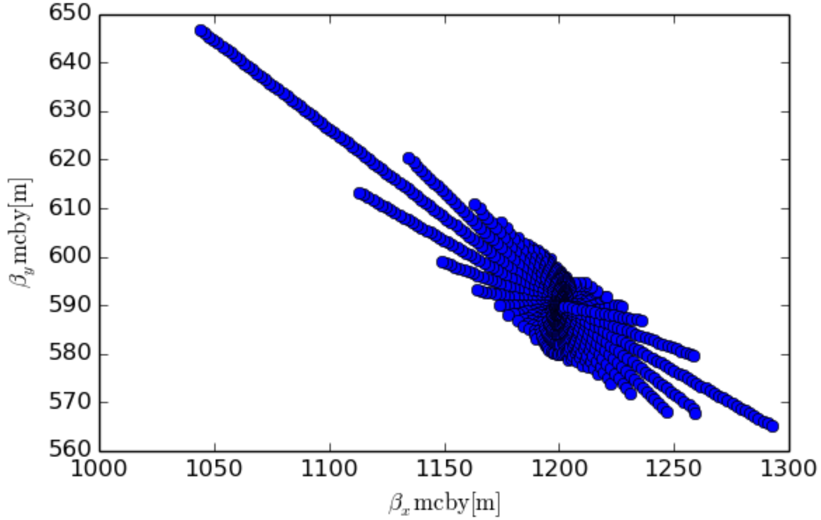
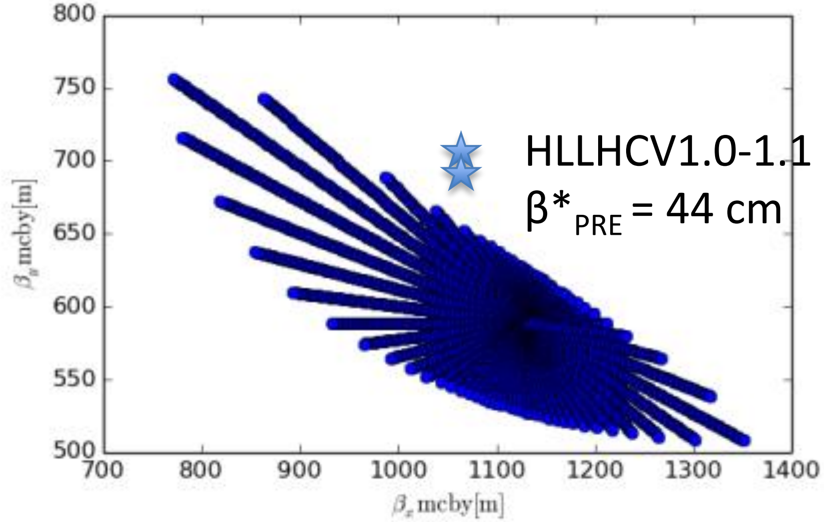
# Tunability in D2-Q4 area

L*=24 m, $\beta^*_{PRE}$ =48 cm




L*=23 m, $\beta^*_{PRE}$ = 48 cm




Beam size in the TAN-D2 region depends on the final optics (optimized for aperture or crab cavity voltage).
Beam size should not change dramatically in the following layout.

# New D2 and Q4 Beam screens

D2 and Q4 beams screen shapes were roughly estimated by R. De Maria and L. Esposito for completing HLLHCV1.1 models. They were reviewed by C. Garion (new)

| [mm] | MBRD 1.1 | MBRD new | MQYY 1.1 | MQYY draft | MQYY draft | MBX LHC | MQXF 1.1 |
|---|---|---|---|---|---|---|---|
| Coil ID | 105 | 105 | 90 | 90 | 90 | 80 | 150 |
| Cold Bore OD | 102 | 101 | … | 86 | 86 | 78 | 147 |
| C.B. thickness | 2 | 4(3?) | … | 2.6 | 2.6 | 2 | 5 |
| B.S. shape | oct. | oct. | rectell. | oct. | rectell. | rectell. | oct. |
| Cooling tubes | 5 | 6 | 5 | 6 | 6 | … | … |
| B.S. thickness | 1 | 1 | 1 | 1 | 1 | … | 2->1 |
| B.S. inner H/V gap | 89.2 | 85(87?) | 64, 74 | 72.8 | 63.8, 75.8 | 57.6, 67.4 | 118 |
| B.S. inner 45° gap | 84 | 76(78?) | n/a | 63.8 | n/a | n/a | 118 |

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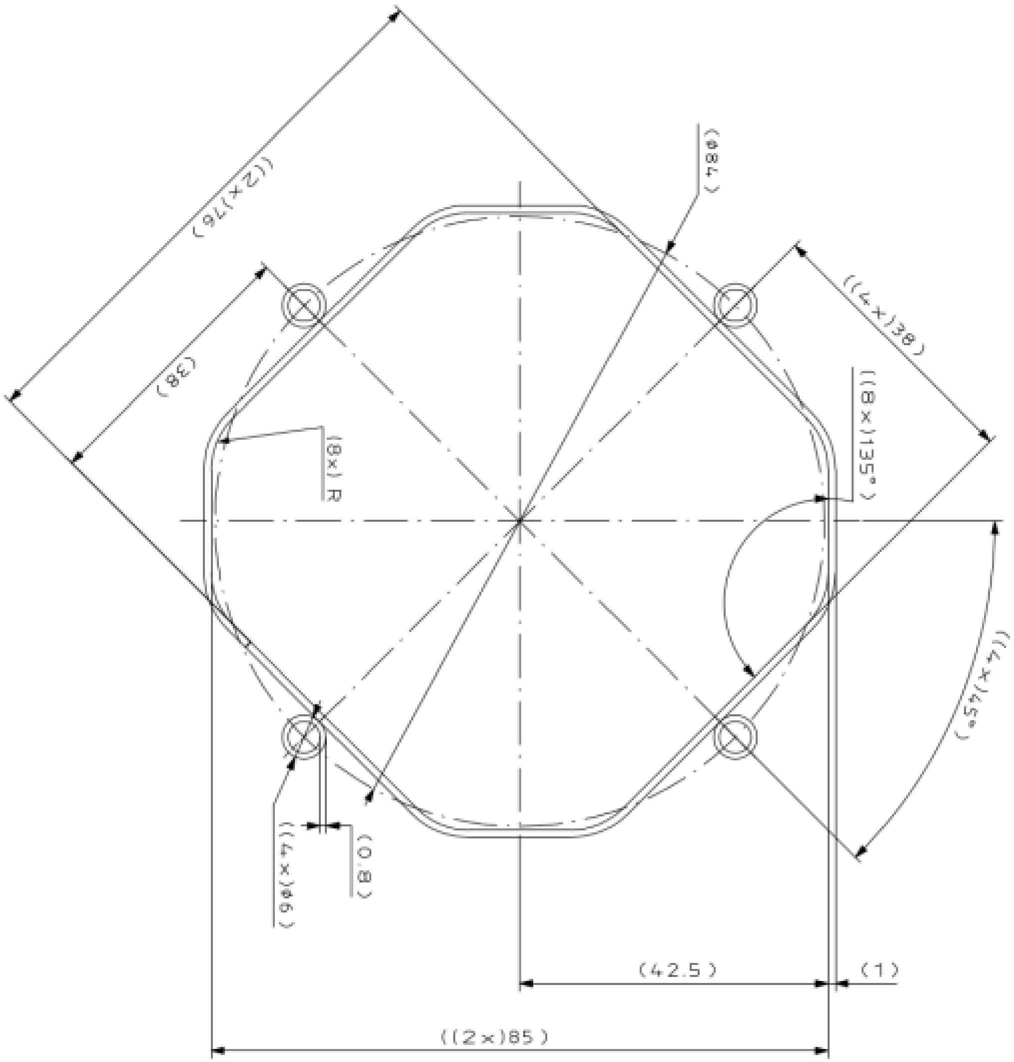
# New D2 Beam Screen




Similar design proposed for Q4 with scaled parameter, to be reviewed.

C. Garion

# • Comparison old/new D2 BS using HLV1.1 lattice

M. Fitterer

| optics | minimum protected aperture over IR1/5 for MBRD | |
|---|---|---|
| | old (σ) | new(σ) |
| round | 19.15 | 16.31 |
| sround | 15.34 | 13.43 |
| flat | 14.43 | 13.62 |
| sflat | 11.79 | 11.12 |
| presqueeze | 32.93 | 28.93 |
| inj | 25.82 | 22.79 |
| inj15 | 30.94 | 29.0 |

Lost of up to 20% in sigma for with new beam screen.

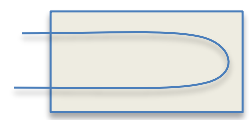
12 σ protected by TCT5 otherwise protected aperture can be up to 20 σ (R. Bruce).

If 3mm CB thickness is feasible, it would be beneficial to restore margins.

Aperture to be reviewed for the next layout and optics iteration.

# Magnet orientations

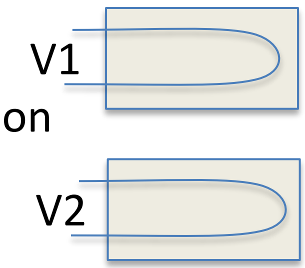
Connection end side



Return side

- Field quality is given by looking at the magnet from the connection end side.
- For twin aperture magnets V1 is the aperture on the left and V2 is the aperture on the right.
- Magnetic measurements assume positive x pointing to the right.
- Accelerator codes assume positive x pointing to the left for a particle entering in the aperture and rotating clockwise.
- Example: focusing quadrupole $k_1>0$ for accelerators and $B_2<0$ for magnetic measurements.

Connection end side

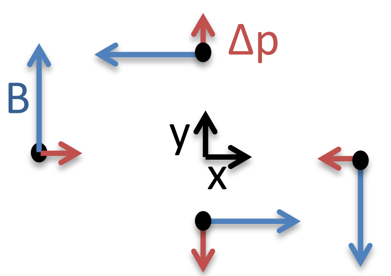



Return side

V1 -> outer channel
V2 -> inner channel

Magnetic measurements

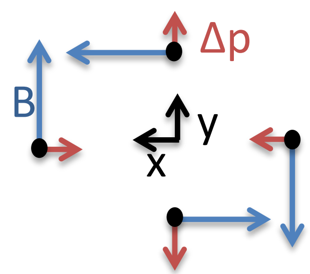
$B_y+i\,B_x= B_2\,(x+iy)/R_0$




$B_2<0$

Accelerator codes

$\Delta p_x- i\,\Delta p_y=- k_1\,(x+iy)$




$k_1>0$

y rotation, change of convention, change b2->b4, flip x direction ($y_{FAC}$):

All types: even $B_n$, odd $A_n$ change signs
Bend: even $b_n$, odd $a_n$ change signs
Quad: odd $b_n$, even $a_n$ change signs

# Magnetic Imperfection statistics

| Magnet TYPE systematic error | |
|---|---|
| Single Aperture | Double Aperture |
| $\xi_{nU\_TYPE} = b_{nU\_TYPE} Gauss_T(1.5)/1.5$ | |
| $b_{nS\_TYPE} = b_{nM\_TYPE} + \xi_{nU\_TYPE}$ | $b_{nS\_TYPE\_V1} = b_{nM\_TYPE\_V1} + \xi_{nU\_TYPE}$<br>$b_{nS\_TYPE\_V2} = b_{nM\_TYPE\_V2} + \gamma_{FAC}\, \xi_{nU\_TYPE}$ |
| **Individual Magnet error** | |
| Single Aperture | Double Aperture |
| $\xi_{nR\_MAG} = b_{nR\_MAG} Gauss_T(3.0)$ | $\xi_{nR\_MAG\_V1} = b_{nR\_MAG} Gauss_T(3.0)$<br>$\xi_{nR\_MAG\_V2} = b_{nR\_MAG} Gauss_T(3.0)$ |
| $b_{n\_MAG} = b_{nS\_TYPE} + \xi_{nR\_MAG}$ | $b_{n\_MAG\_V1} = b_{nS\_TYPE\_V1} + \xi_{nR\_MAG\_V1}$<br>$b_{n\_MAG\_V2} = b_{nS\_TYPE\_V1} + \xi_{nR\_MAG\_V2}$ |

Systematic error are correlated between apertures

Random error are not correlated between apertures

Error tables for statistical assignments assume <u>accelerator sign</u> conventions.

Error tables for measured errors assume <u>magnetic measurement sign</u> conventions.

Need to know from Ezio if the convention for the latest error table: sign convention, V1 or V2 (e.g. One table obtained for D2 and $b_{nM\_TYPE\_V2} = \gamma_{FAC} * b_{nM\_TYPE\_V1}$).

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# Corrector's imperfections

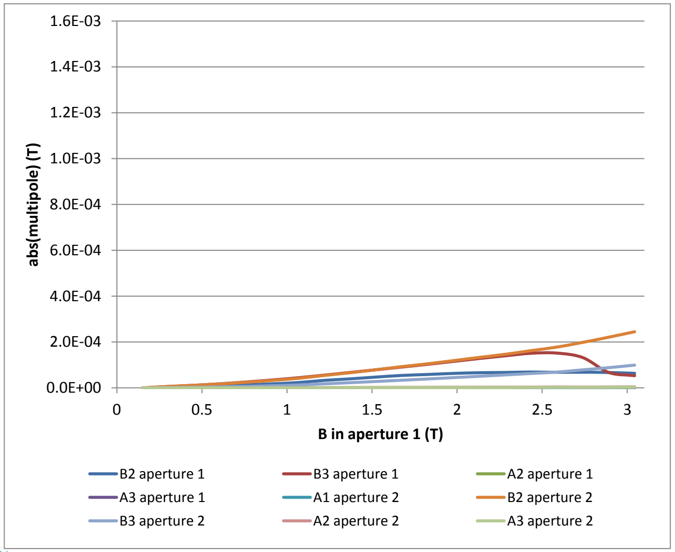
Orbit correctors are almost always weakly powered because they are set of perfectly  machine

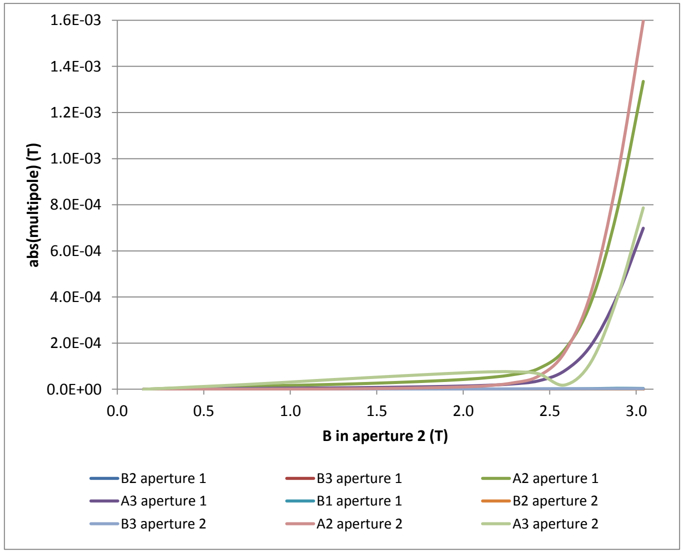
Error routing input absolute errors scaled with energy for different worst case scenarios (peak powering, asymmetric powering).

Input needed $B_n$, $A_n$ in mTm at a given reference radius (e.g. 2/3 of the aperture) for aperture V1 and V2 with the explicit signs and  sign convention annotation.

Error routines will provide the necessary conversions.

E.g. MCBRD for different powering scenarios, J. Rysti 25/2/2015 WP3 meeting

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# Triplet Orientations in V1.0 and V1.1

| | | B1 enters | B2 enters | B4 enters |
|---|---|---|---|---|
| Right | Q1a | Connection | Connection | Return |
| | Q1b | Return | Return | Connection |
| | Q2a | Connection | Connection | Return |
| | Q2b | Return | Return | Connection |
| | Q3a | Connection | Connection | Return |
| | Q3b | Return | Return | Connection |
| | D1 | Return | Return | Connection |
| Left | Q1a | Return | Return | Connection |
| | Q1b | Connection | Connection | Return |
| | Q2a | Return | Return | Connection |
| | Q2b | Connection | Connection | Return |
| | Q3a | Return | Return | Connection |
| | Q3b | Connection | Connection | Return |
| | D1 | Connection | Connection | Return |

= connection end side
| return end side
{} Cryostat

IP {=Q1a| |Q1b=} {=MCBX|=Q2a|} {|Q2b=|MCBX=} {=Q3a|| Q3b=} {|MCBY=} {|D1=}

→ Beam 1

# Matching section magnet orientations in V1.0 and V1.1

| | | | B1 enters | B2 enters | B4 enters |
|---|---|---|---|---|---|
| Right IR1 IR5 | D2 | MBRD | Return V2 | Return V1 | Connection V1 |
| | D2 c | MCBRD | Return V2 | Return V1 | Connection V1 |
| | Q4 c | MCBYY | Return V2 | Return V1 | Connection V1 |
| | Q4 | MQYY | Return V2 | Return V1 | Connection V1 |
| | Q5 c | MCBY (3x) | Return V2 | Return V1 | Connection V1 |
| | Q5 | MQY | Return V2 | Return V1 | Connection V1 |
| Left IR1 IR5 | D2 | MBRD | Connection V1 | Connection V2 | Return V2 |
| | D2 c | MCBRD | Connection V1 | Connection V2 | Return V2 |
| | Q4 c | MCBYY | Connection V1 | Connection V2 | Return V2 |
| | Q4 | MQYY | Connection V1 | Connection V2 | Return V2 |
| | Q5 c | MCBY (3x) | Connection V1 | Connection V2 | Return V2 |
| | Q5 | MQY | Connection V1 | Connection V2 | Return V2 |
| | Q6 | MQM (1.9K) | Connection V1 | Connection V2 | Return V2 |

Present orientations are going to be reviewed including Q6 by Paolo since 4.5K jumpers needs to stay in the higher part of the tunnel, while 1.9K is the opposite.

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# Error routines and mask for Beam2

New macro_errors rewritten to handle Beam2 and Beam 4 without changing in individual error routines.

New mask created taking into account beam-beam features, but no plan of thorough testing.

New masks files and routines under testing.

# Optics List

| | Insertions | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Optics** | **IR1 ==IR5** | **IR5==IR1** | **IR2** | **IR8** | **IR4** | **IR6** | **IR3** | **IR7** |
| **Injection** | β*=6 m, inj. | β*=6 m, inj. | β*=10 m, inj. | β*=10 m, inj. | | | | |
| **End of Ramp** | β*=6 m | β*=6 m | | β*=10 m | inj. | inj. | | |
| **Pre-squeeze 3** | β*=3 m | β*=3 m | β*=10 m | β*=3 m | | | | |
| **Pre-squeeze** | β*=44 cm | β*=44 cm | | | | | | |
| **Collision Round** | $\beta^*_{ATS}$=15 cm | $\beta^*_{ATS}$=15 cm | β*=10 m, ATS(3x,3x) | β*=3 m, ATS(3x,3x) | ATS(3x,3x) | ATS(3x,3x) | inj. | inj. |
| **Collision Ions** | β*=44 cm | β*=44 cm | β*=50 cm | β*=50 cm | | | | |
| **Injection VDM** | β*=15 m | β*=15 m | β*=10 m, inj. | β*=10 m, inj. | inj. | inj. | | |
| **Collision VDM** | β*=30 m | β*=30 m | β*=30 m | β*=30 m | | | | |
| **Collision Flat** | $\beta^*_{ATS}$=7.5/30 cm | $\beta^*_{ATS}$=30/7.5 cm | β*=10 m, ATS(6x,1.5x) | β*=3 m, ATS(6x,1.5x) | ATS(1.5x,6x) | ATS(1.5x,6x) | | |
| **Collision FlatHV** | $\beta^*_{ATS}$=30/7.5 cm | $\beta^*_{ATS}$=7.5/30 cm | β*=10 m, ATS(1.5x,6x) | β*=3 m, ATS(1.5x,6x) | ATS(6x,1.5x) | ATS(6x,1.5x) | | |
| **Collision sRound** | $\beta^*_{ATS}$=10 cm | $\beta^*_{ATS}$=10 cm | β*=10 m, ATS(4.4x,4.4x) | β*=3m, ATS(4.4x,4.4x) | ATS(4.4x,4.4x) | ATS(4.4x,4.4x) | inj. | inj. |
| **Collision sFlat** | $\beta^*_{ATS}$=5/20 cm | $\beta^*_{ATS}$=20/5 cm | β*=10 m, ATS(9x,2.2x) | β*=3 m, ATS(2.2x,9x) | ATS(9x,2.2x) | ATS(9x,2.2x) | | |
| **Collision sFlatHV** | $\beta^*_{ATS}$=20/5 cm | $\beta^*_{ATS}$=5/20 cm | β*=10 m, ATS(2.2x,9x) | β*=3 m, ATS(9x,2.2x) | ATS(2.2x,9x) | ATS(2.2x,9x) | | |

In red transition and final steps to do or verify/redo for the next layout.

Input: new ATS factors as a function of β* in IR1/IR5.

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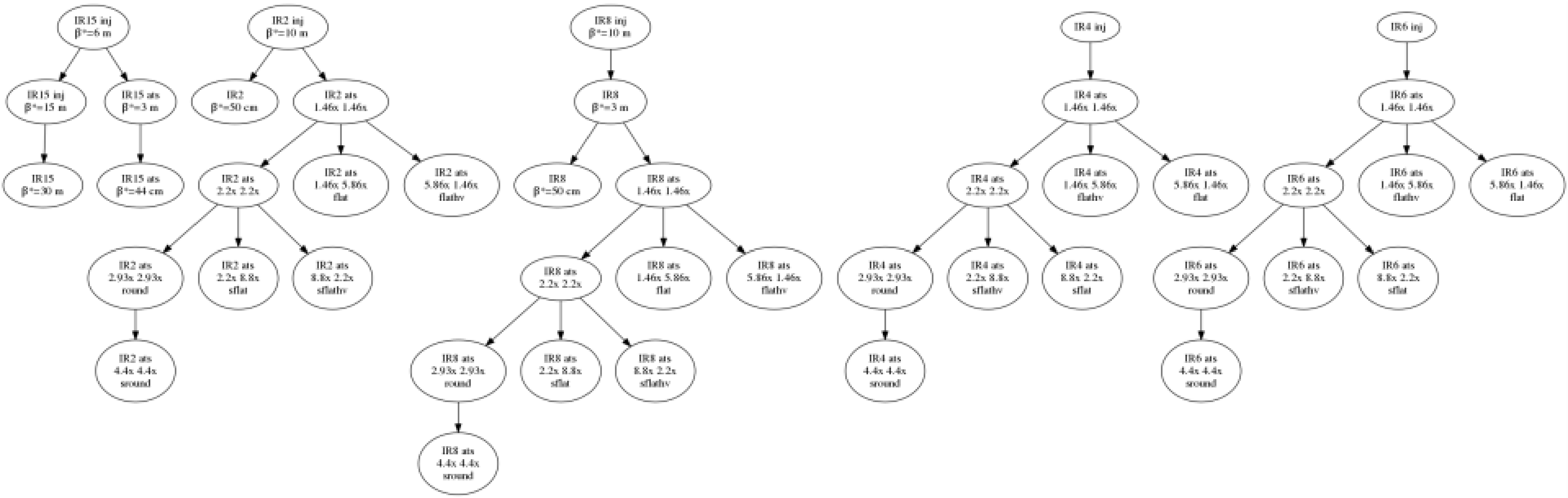
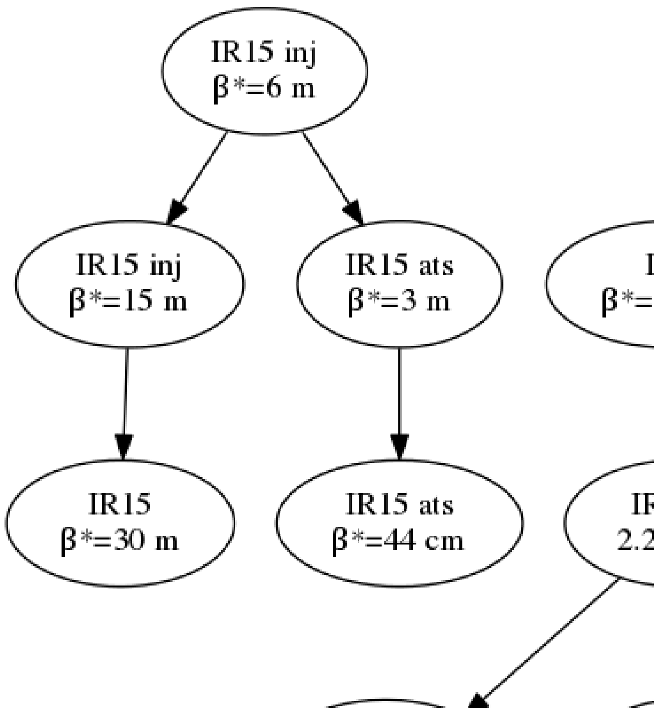
# Optics connections

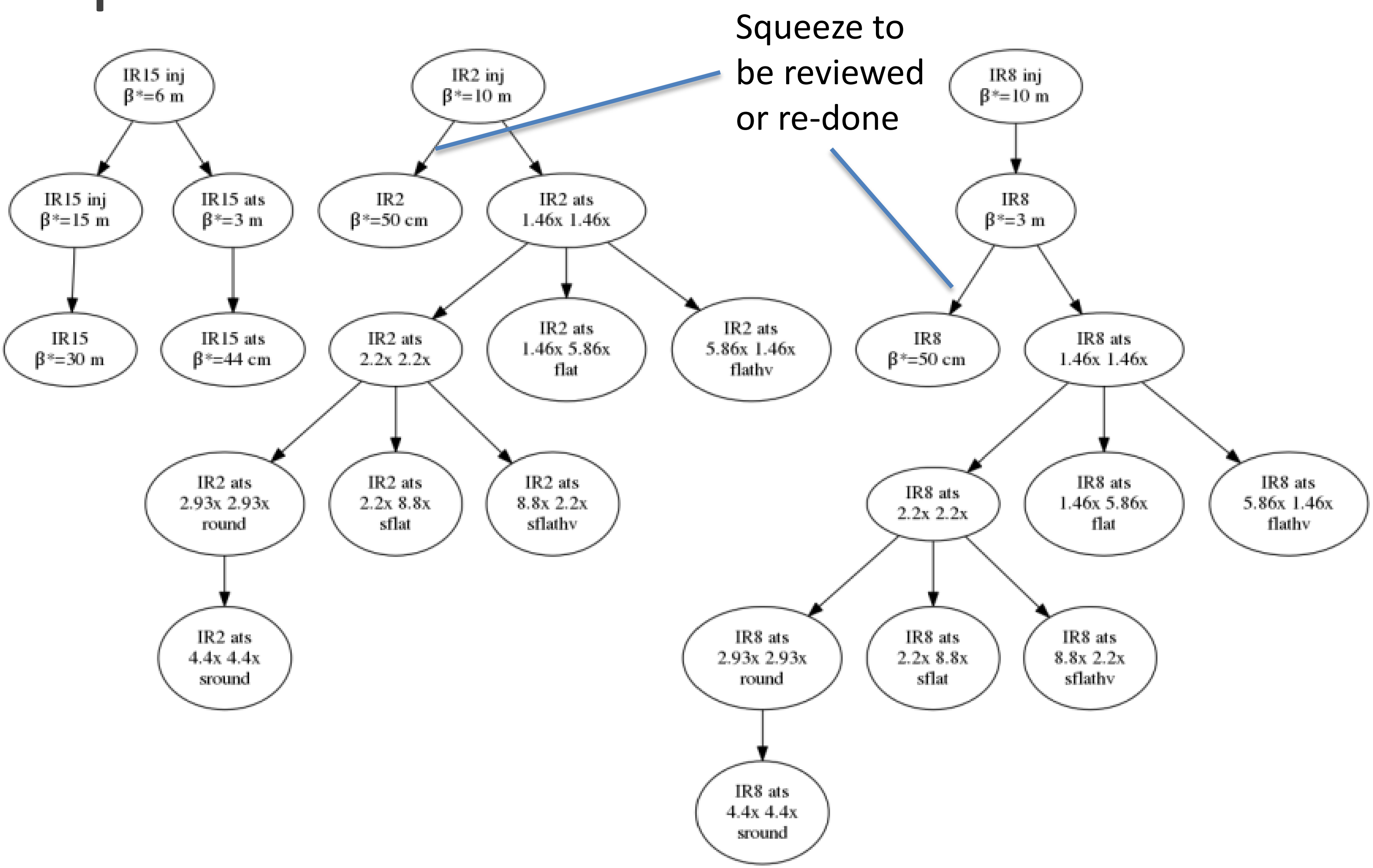


# Optics connections




Squeeze in IR1 and IR5 needs to be redone due to the new layout.

# Optics connections

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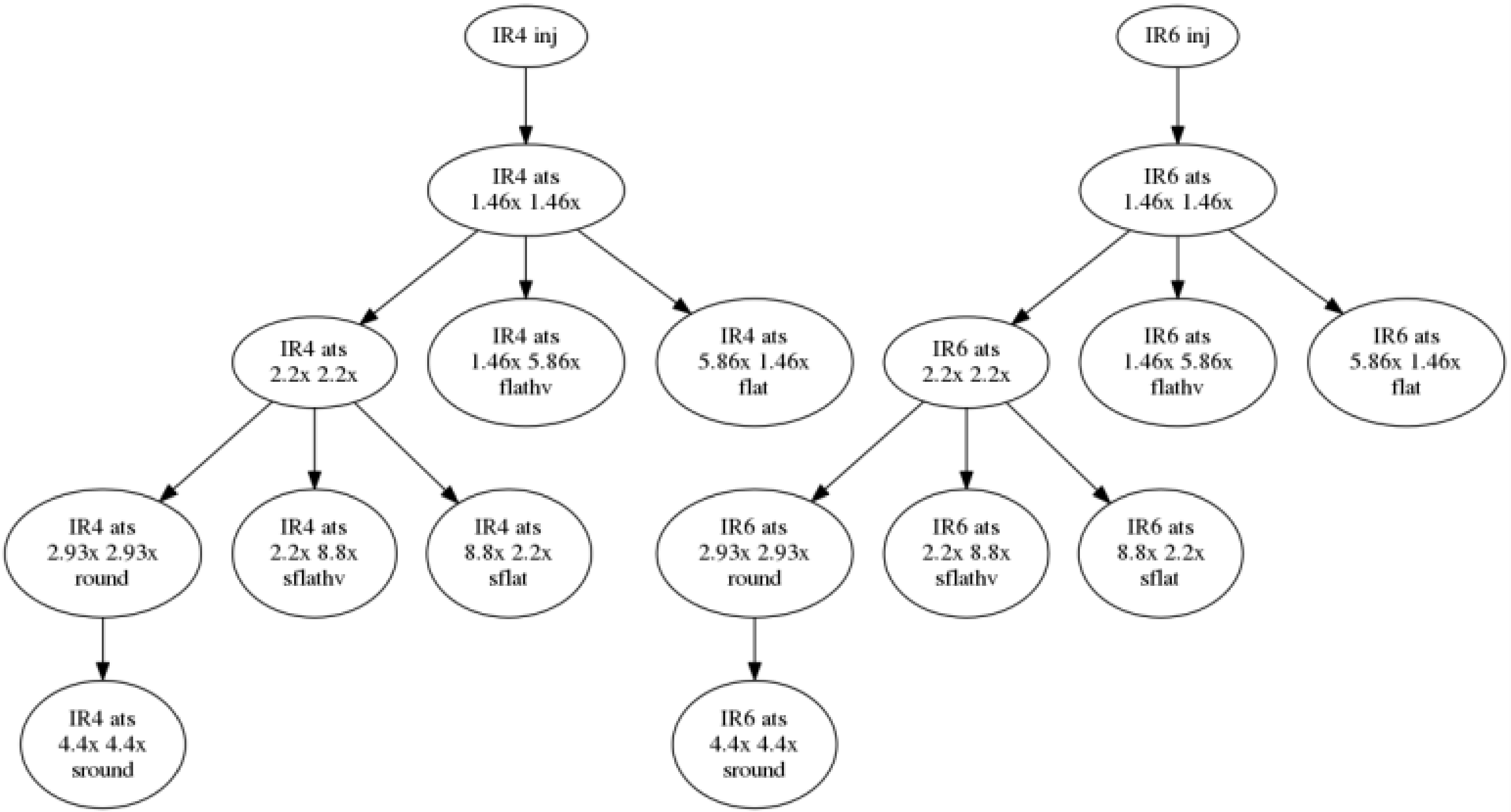
# Optics connections




IR6 Squeeze needs revision due to:

- change of layout (doubling Q5)
- possible issues of damaging of collimators in case of failure scenario if product of Beta functions too small

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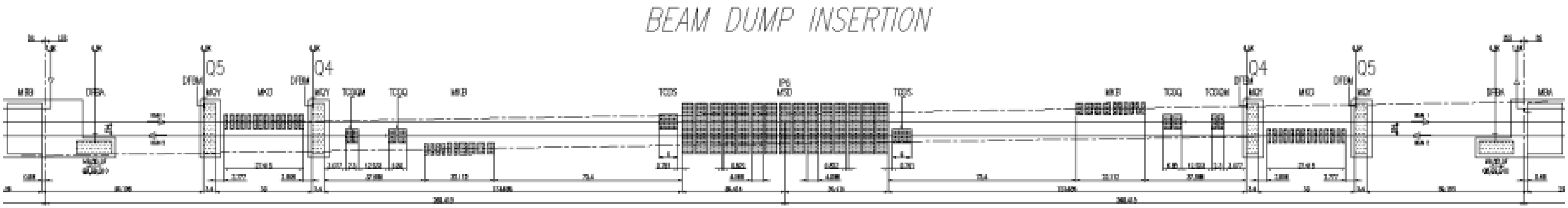
# IR6 Layout

Different squeeze sequences are needed depending on the final β* for CMS.

IR6 optics is very rigid due to position of the quadrupoles and internal phase advances.




Since the beginning the ATS optics had stronger Q5:

- SLHCV3.0, SLHCV3.01: double MQY
- SLHC3.1b, HLLHCV1.0: MQYL
- HLLHCV1.1: Double MQY

Basic needs taken into account: MKD – Septum phase advance , beam size at dumps. However optics are not validated for collimator settings and failure scenarios (WP5 - WP14):

- beta functions at collimators do vary during the squeeze
- phase advance between MKD TCT are not optimal optimized.

# IR6 Optics and Squeeze

Basic needs taken into account:

- MKD – Septum phase advance
- Beam size at dumps.

However optics and squeeze are not fully validated (WP5, WP14):

- phase advance between MKD and TCT are neither optimal nor optimized and impact TCDQ – TCT retraction.
- Failure scenarios with ATS in the arc
- β-functions at TCDQ, TCDS, TDE do vary during the squeeze.
- Warnings issued for low $\beta_y$ TCDQAR6.B1- TCDQAL6.B2 in sflathv and flat resp. large and large $\beta_y$ in flathv, sflathv (J. Uythoven 10/4/2014).
- Safe recommendation: all collimator should have beam area not smaller than 90% of nominal values (J. Uythoven 10/2014)

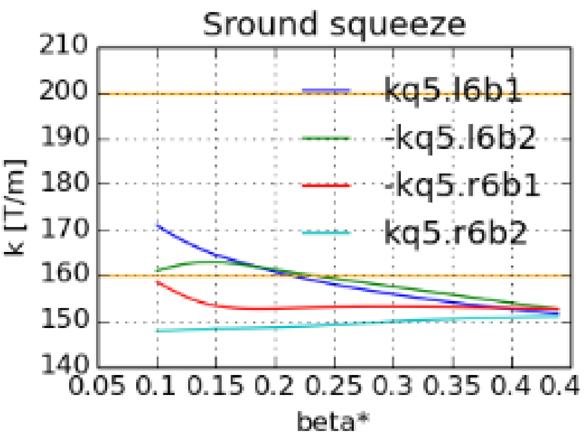
| optics | $\beta_x$ IP6 | $\beta_y$ IP6 | $\mu_x$ tcsg → mkd_h5l6b1 | $\beta_x$ dump | $\beta_y$ dump |
|---|---|---|---|---|---|
| inj b1 | 187.3 | 168.1 | 94.8 | 5012 | 3955 |
| inj b2 | 187.7 | 178.4 | 94.8 | 5052 | 3698 |
| round b1 | 324.3 | 188.2 | 90 | 8172 | 4463 |
| round b2 | 248.8 | 176.7 | 90 | 6123 | 3698 |
| flat b1 | 212.2 | 156.3 | 90 | 5067 | 4643 |
| flat b1 | 217.6 | 238.5 | 90 | 5238 | 4286 |
| flathv b1 | 298.1 | 236.3 | 90 | 7466 | 4446 |
| flathv b2 | 272.8 | 205.9 | 90 | 6784 | 3717 |
| sround b1 | 241.2 | 185 | 90 | 5900 | 3955 |
| sround b2 | 252.5 | 167.2 | 90 | 6224 | 3725 |
| sflat b1 | 236.9 | 190.6 | 90 | 5778 | 6771 |
| sflat b2 | 248.7 | 237.1 | 90 | 6120 | 3728 |
| sflathv b1 | 314 | 176.8 | 90 | 7895 | 3956 |
| sflathv b2 | 277.7 | 216.9 | 90 | 6918 | 3722 |

KQ4.L6B1 and KQ4.R6B2 have nominal strength.

R. De Maria (CERN, Geneva) HLLHCV1.0 HL-LHC WP14, 2013/07/09 11 / 13

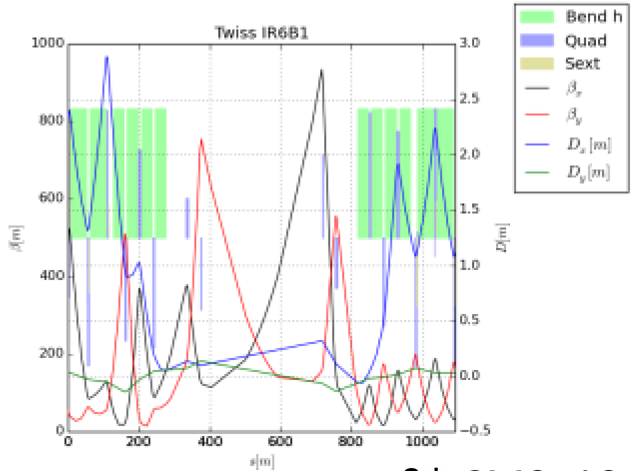
# IR6 Optics and Q5 Squeeze assuming the exiting MQY

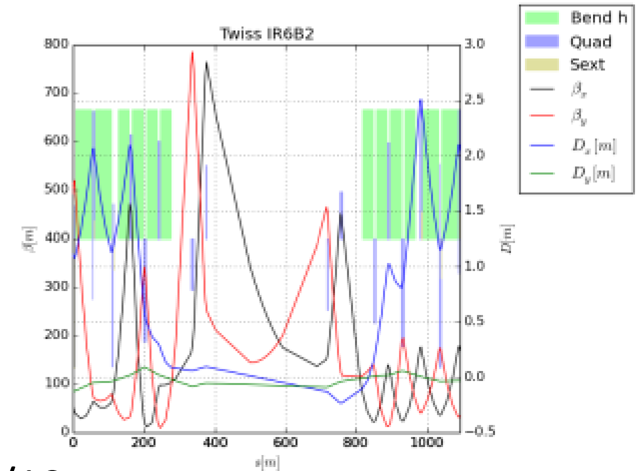
Squeeze of Q5 to reach final optics.



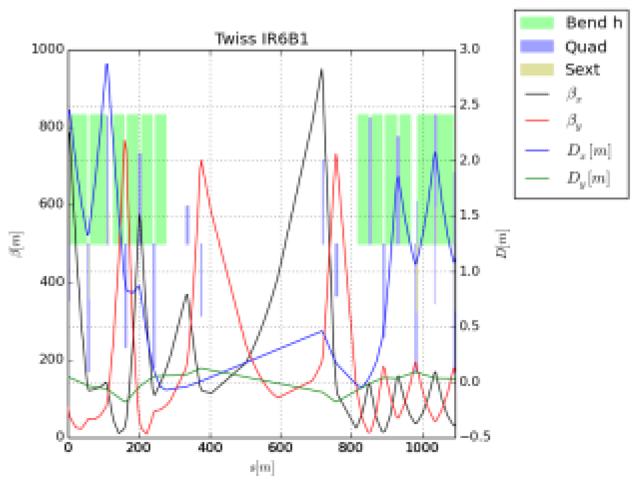

A similar squeeze has been develop and tested with pilot beam in the LHC. S. Fartoukh et al. ATS MD notes I-II-III.

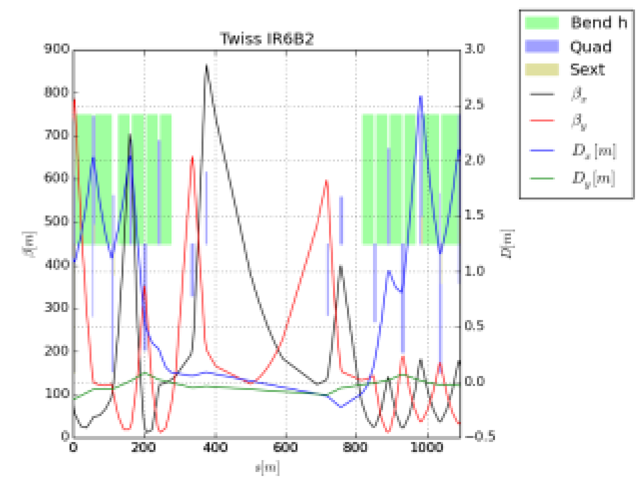
β* CMS: 15cm/15cm




β* CMS: 10cm/10cm

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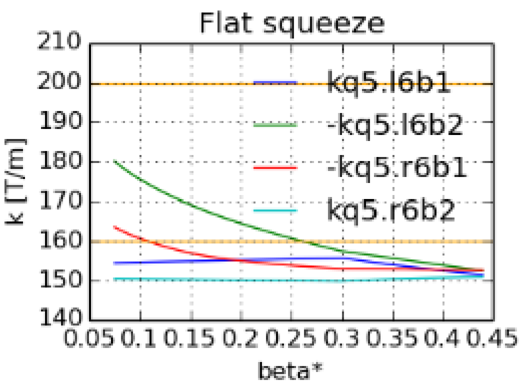
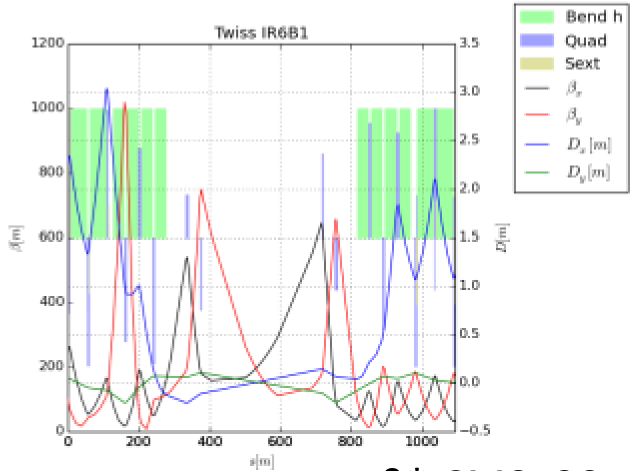
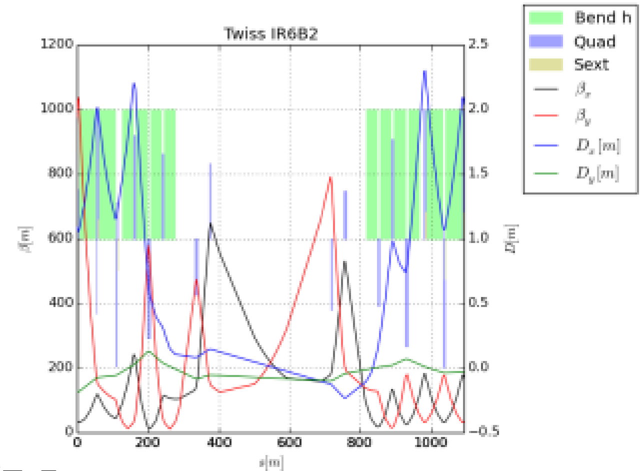
# IR6 Optics and Q5 Squeeze assuming the exiting MQY

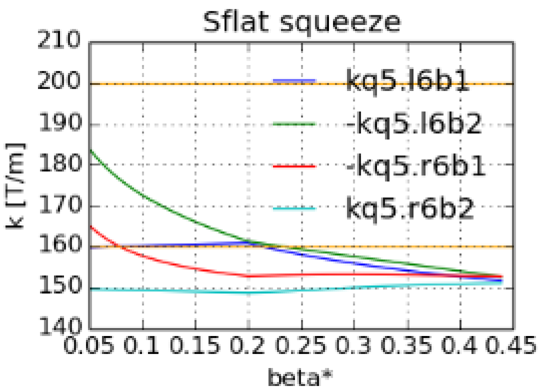


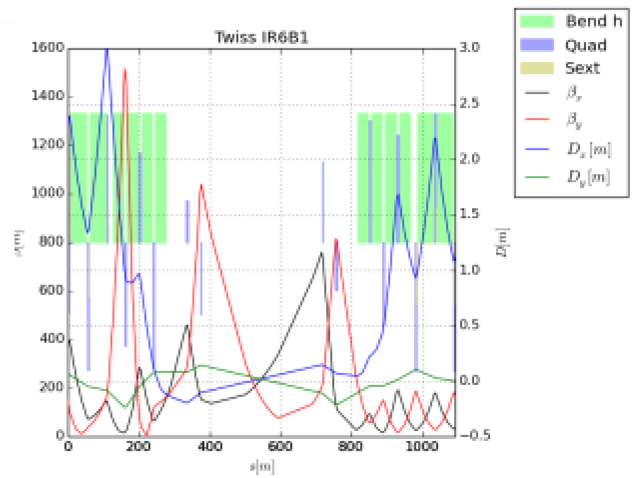

β* CMS: 30cm/7.5cm

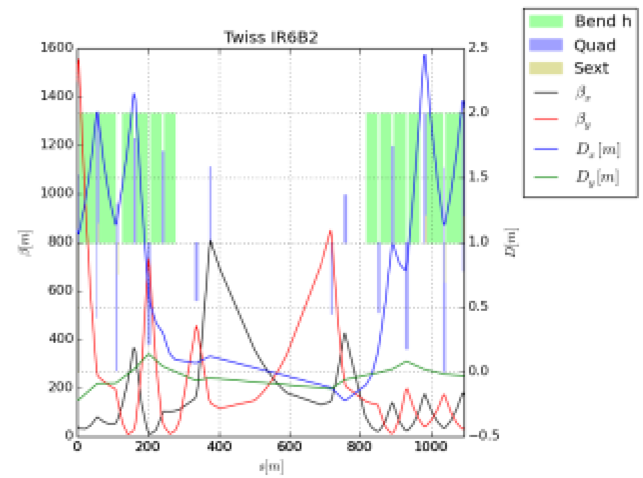



β* CMS: 20cm/7.5cm

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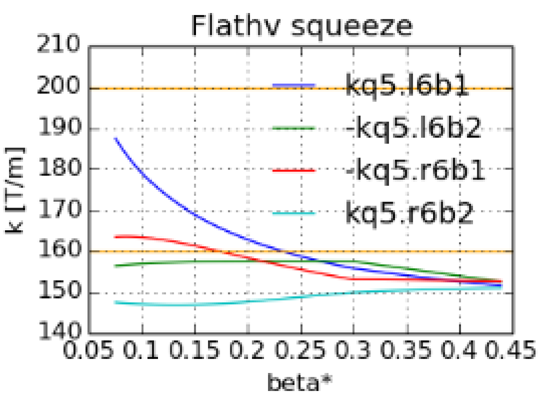
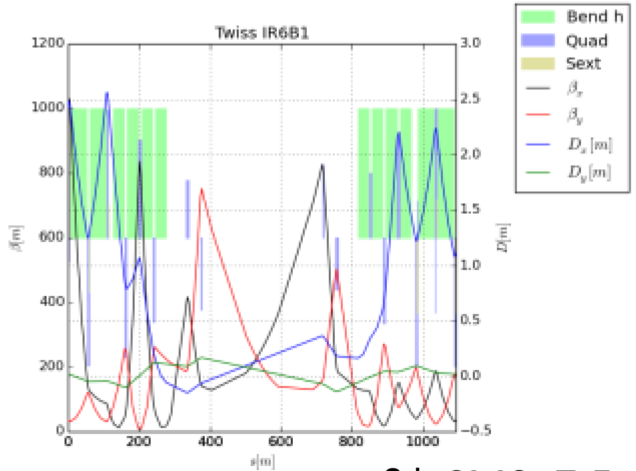
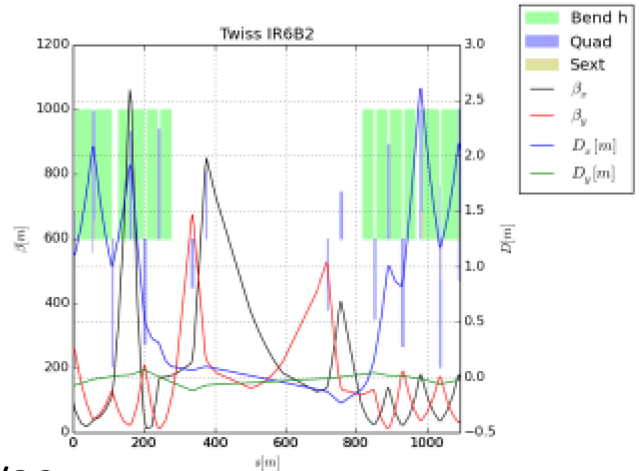
# IR6 Optics and Q5 Squeeze assuming the exiting MQY

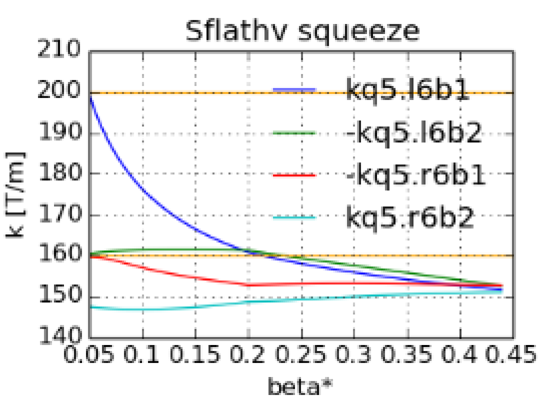
β* CMS: 7.5cm/30cm

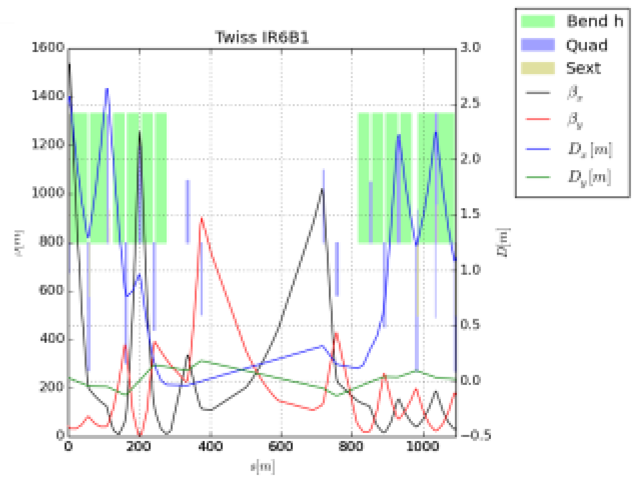


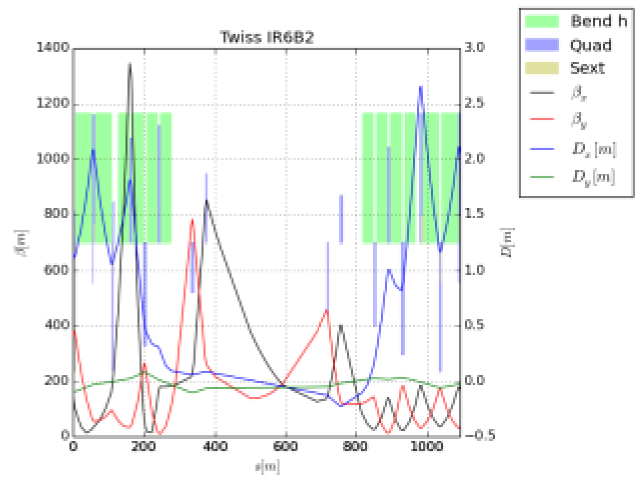




β* CMS: 7.5cm/30cm

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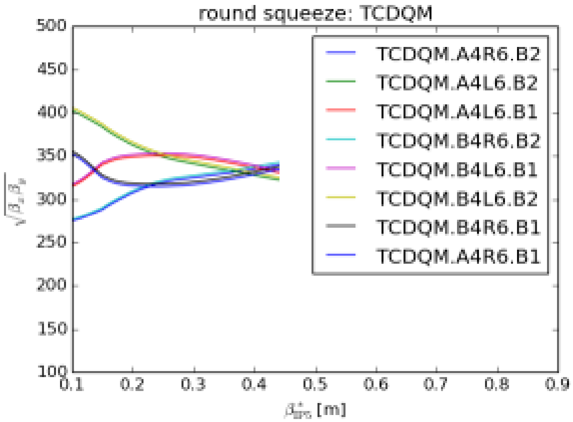
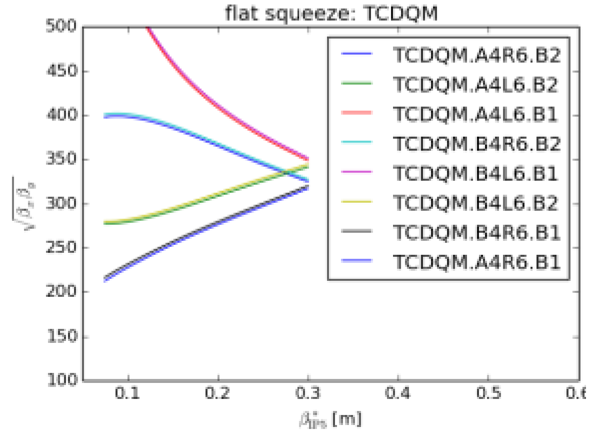
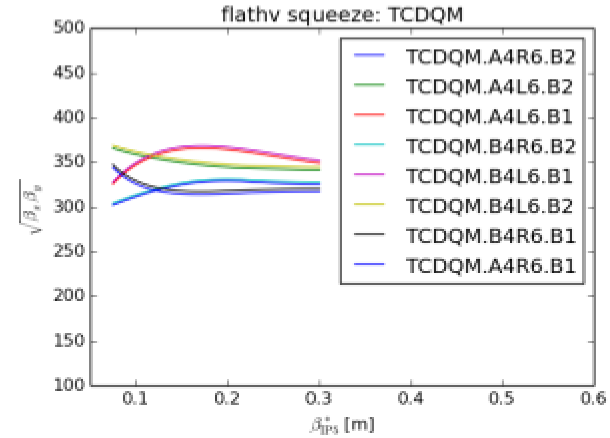
# Evolution of beta during IR6 squeeze

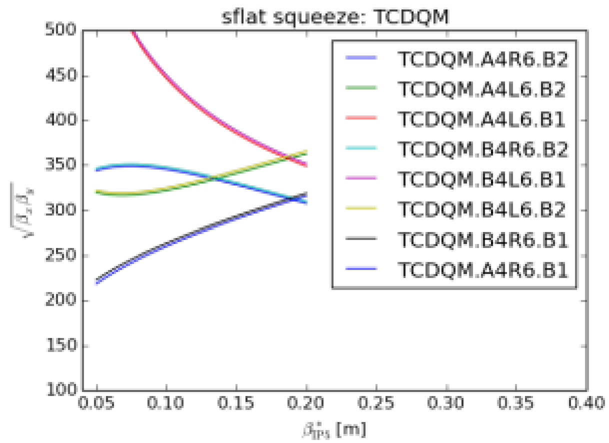


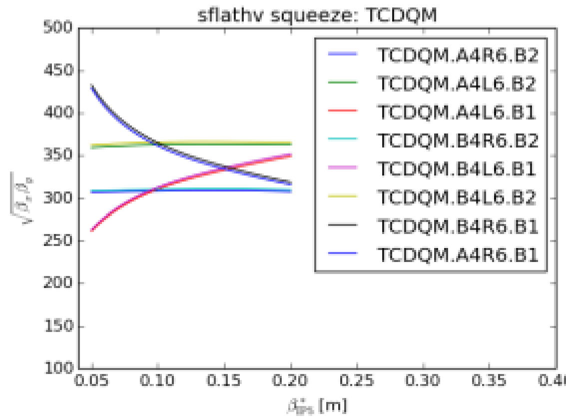



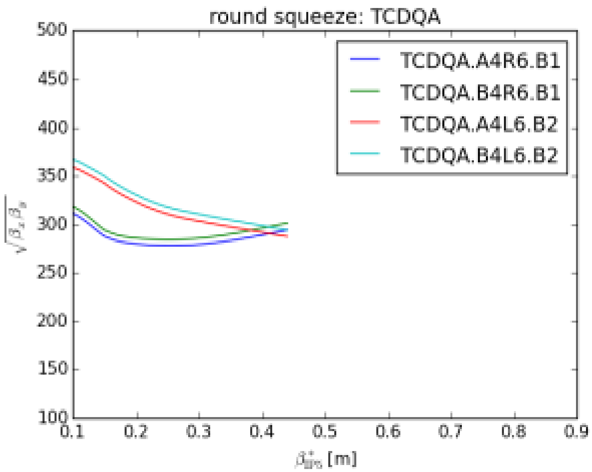

Flat and sflat squeeze problematic for TCDQM.[AB]R6.B2

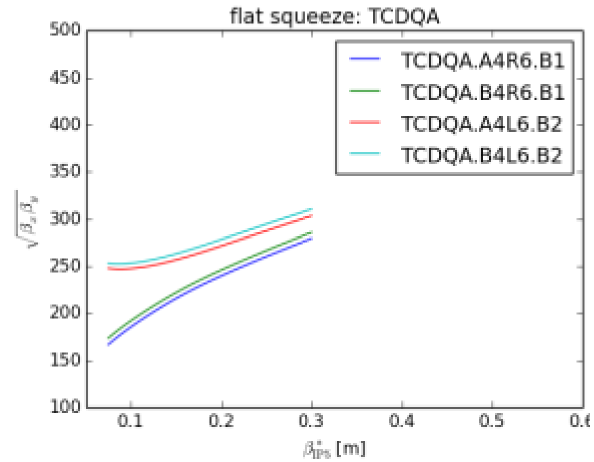
Sflat HV problematic for TCDQM.[AB]L6.B1

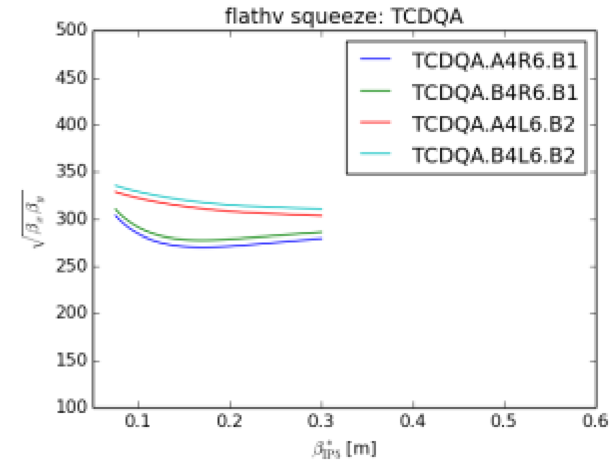


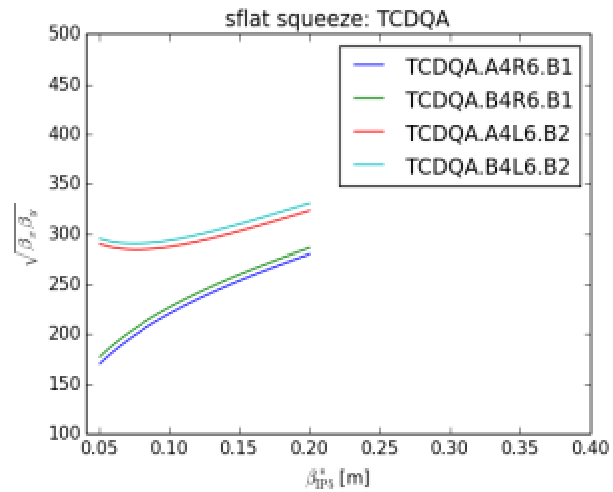
# Evolution of beta during IR6 squeeze

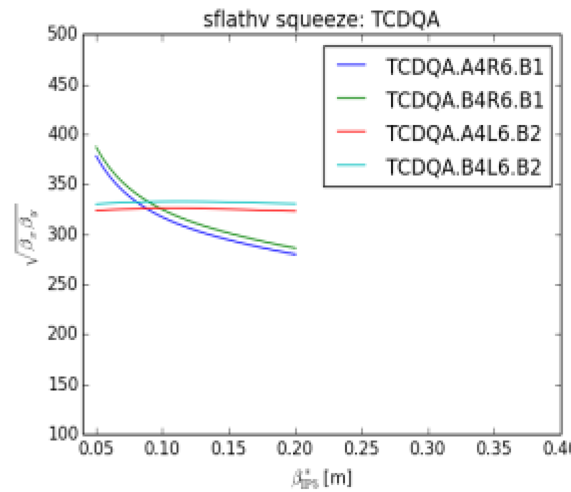


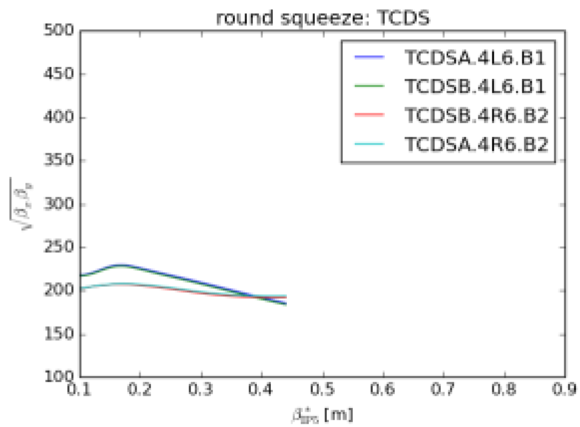



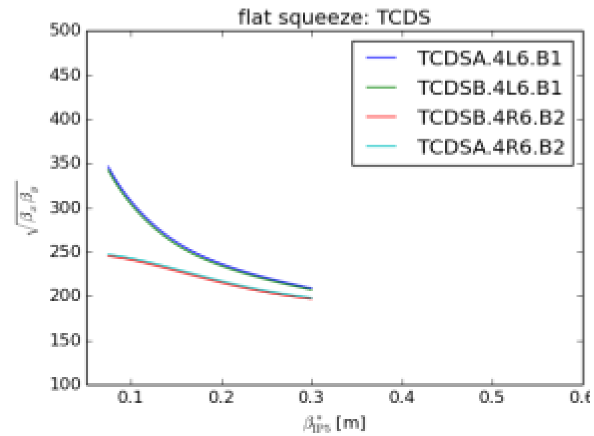

Flat and s flat squeeze problematic for TCDQA.[AB]R6.B1

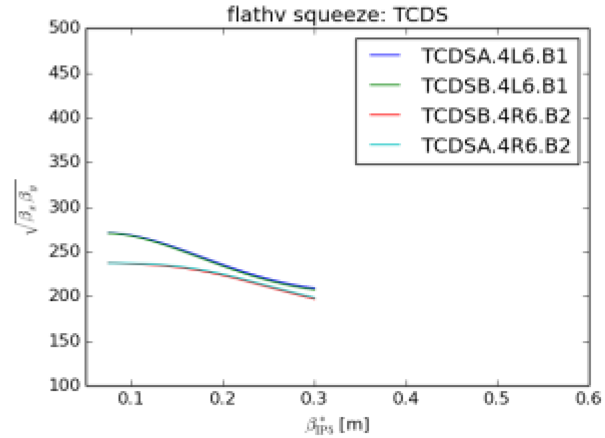


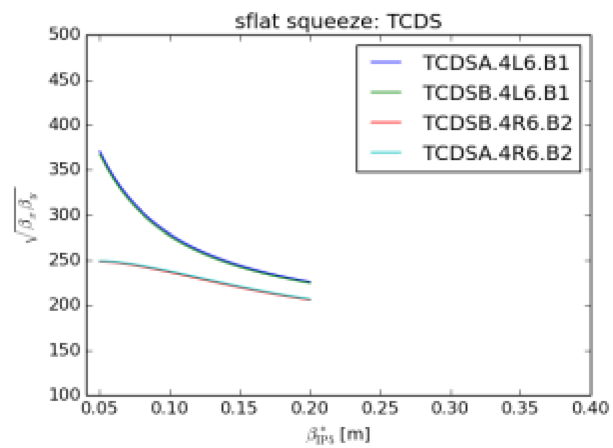
# Evolution of beta during IR6 squeeze

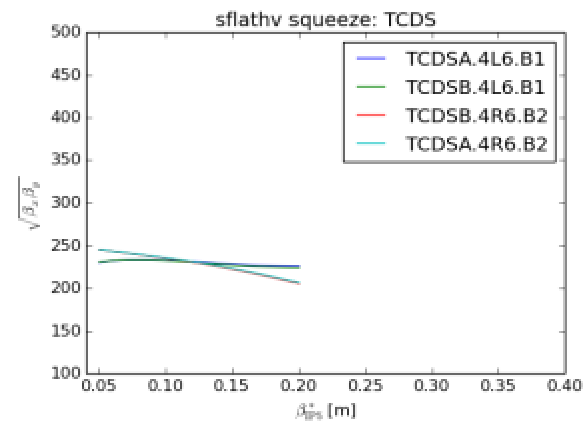


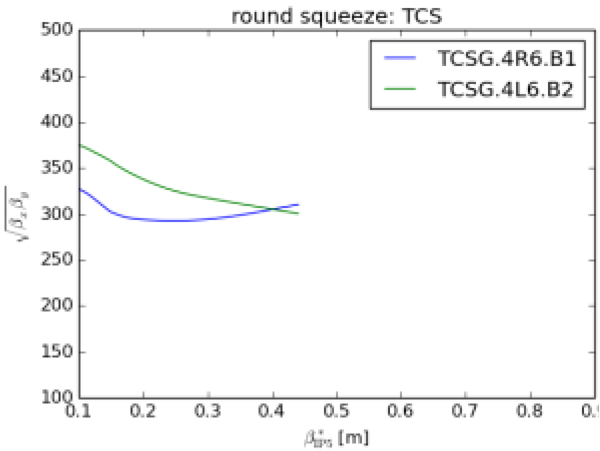



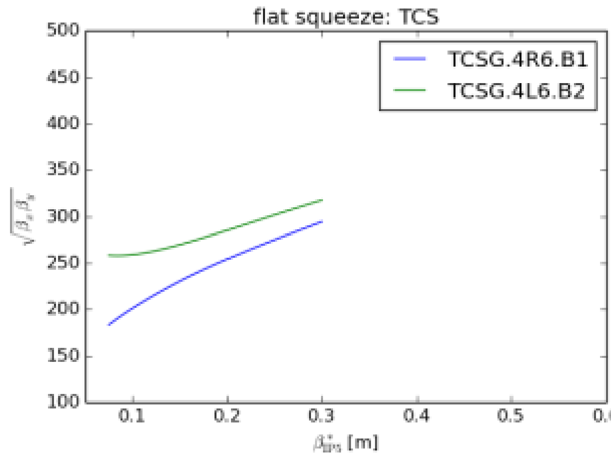

No problem for TCDS

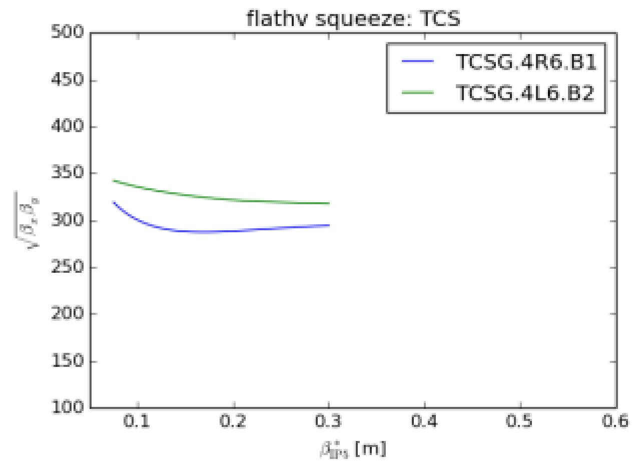


# Evolution of beta during IR6 squeeze




Flat and s flat squeeze problematic for
TCSG.4L6.B2