SLHCV3.1b: HL-LHC optics overview

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CERN, Geneva

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Introduction

SLHCV3.1b contains a realistic, nearly complete, usable optics model for an HL-LHC scenario using 150T/m triplets Based on SLHCV3.0 and ATS_V6.503. [1]
It is not final since it still depends on some working assumptions:

- interconnect lengths between magnets,
- lengths and types of triplet correctors,
- installation and relocation of several matching quadrupoles,

and misses some parts

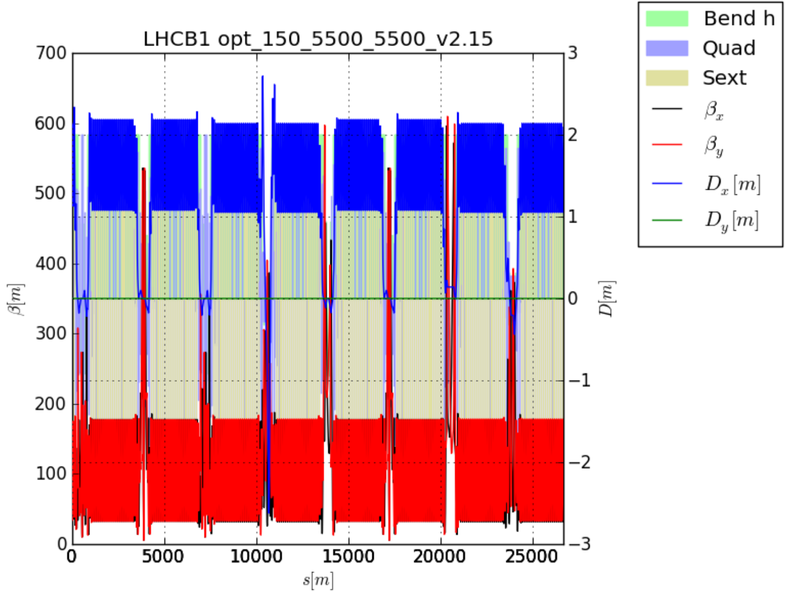
- optics transitions,

and some optimizations

- phase advance optimization for IR2/8/4/6,
- control of Q",
- position of triplet BPMS,
- IP1-IP5 phase advance (or maybe working point).

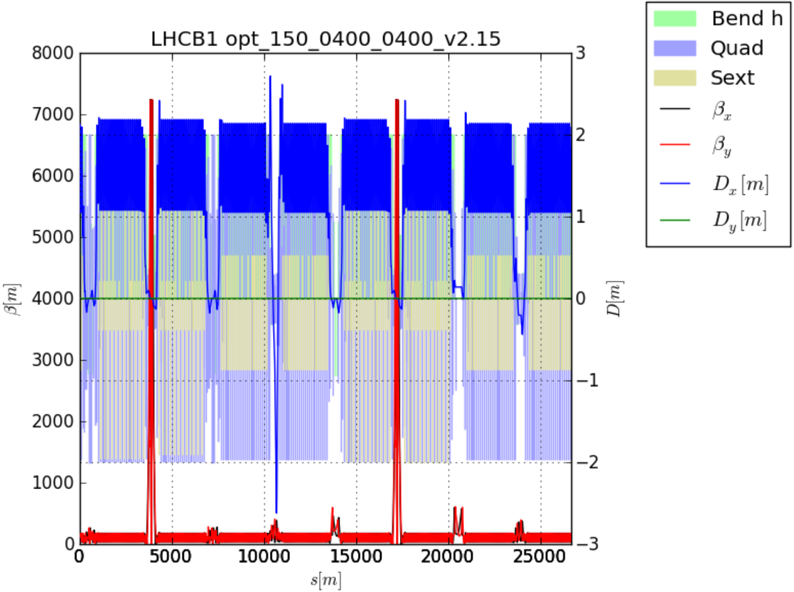
[1] SLHC Project Report 49, 50, 53, 55, ATS Note 2011 33, 60, 132 and reference therein.

LHC B1

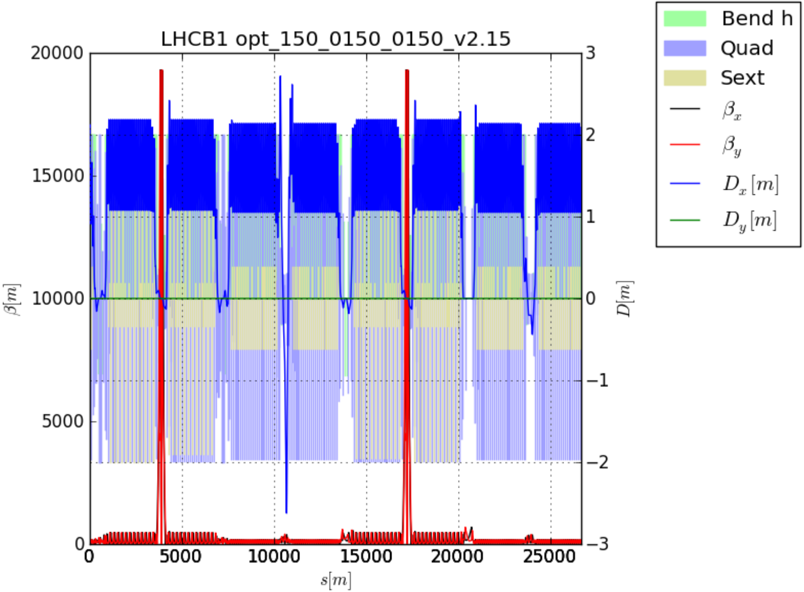


LHCB1 opt_150_5500_5500_v2.15
700
600
500
400
300
200
100
0
0
5000
10000
15000
20000
25000
$s[m]$
$\beta[m]$
3
2
1
0
−1
−2
−3
$D[m]$
Bend h
Quad
Sext
β_x
β_y
$D_x[m]$
$D_y[m]$

LHC B1

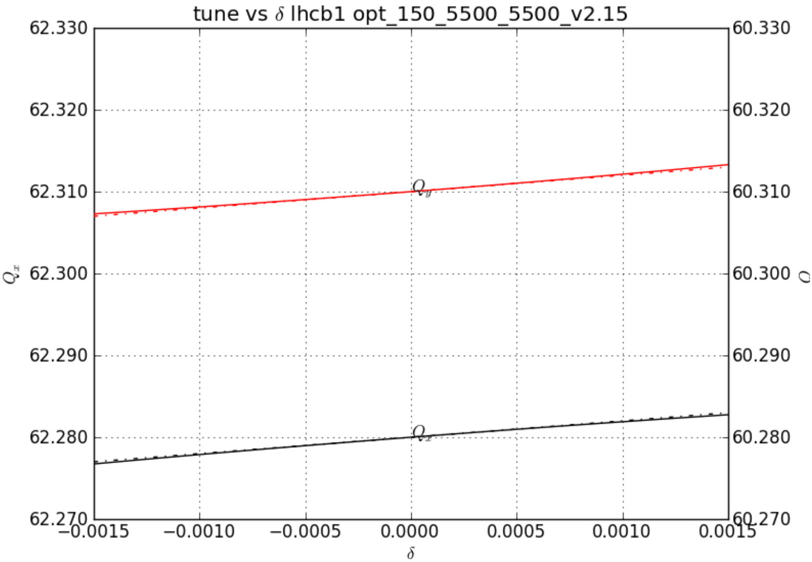

LHCB1 opt_150_0400_0400_v2.15
$\beta[m]$
$D[m]$
$s[m]$
Bend h
Quad
Sext
β_x
β_y
$D_x[m]$
$D_y[m]$
0
1000
2000
3000
4000
5000
6000
7000
8000
5000
10000
15000
20000
25000
3
2
1
0
−1
−2
−3

LHC B1

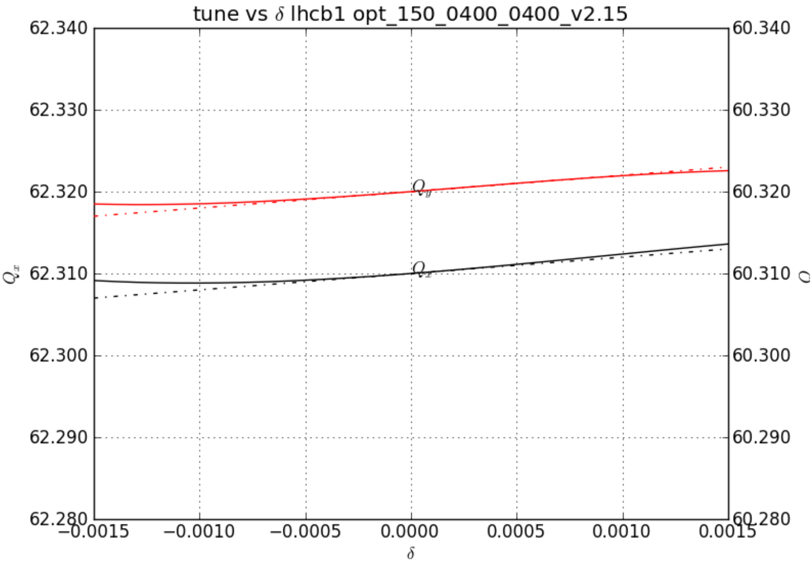


LHCB1 opt_150_0150_0150_v2.15
20000
15000
10000
5000
0
3
2
1
0
−1
−2
−3
0
5000
10000
15000
20000
25000
$s[m]$
$\beta[m]$
$D[m]$
Bend h
Quad
Sext
β_x
β_y
$D_x[m]$
$D_y[m]$

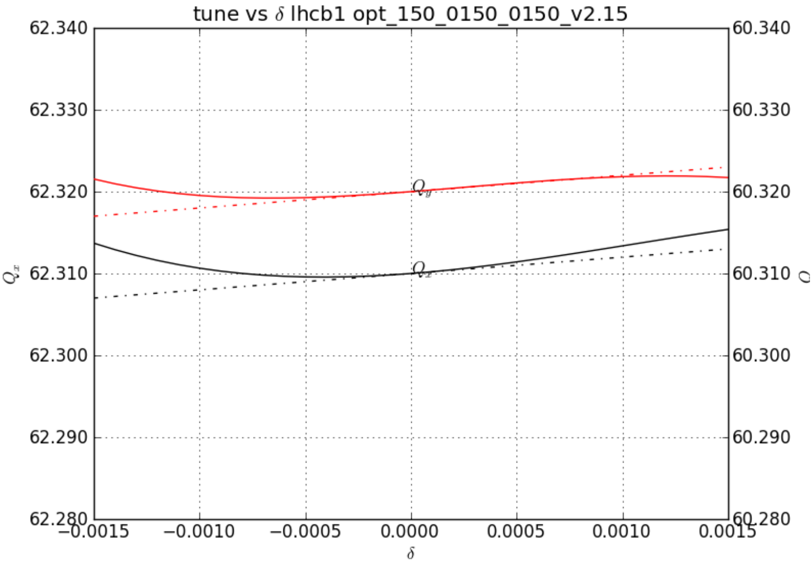
Tune vs delta



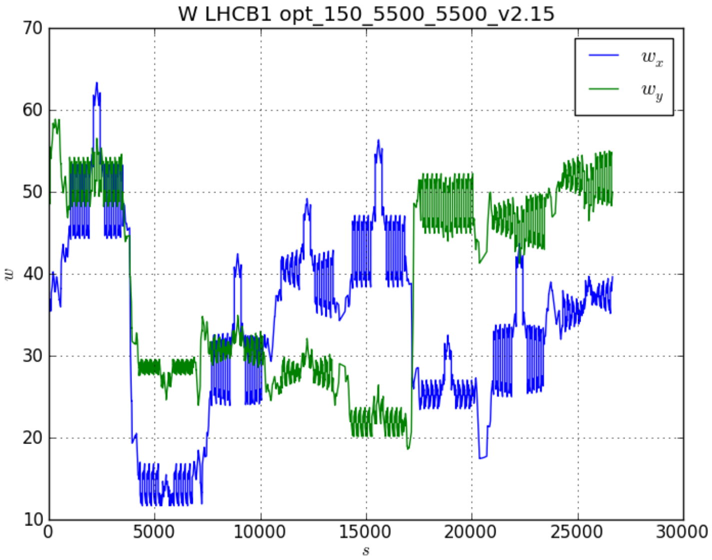
Tune vs delta



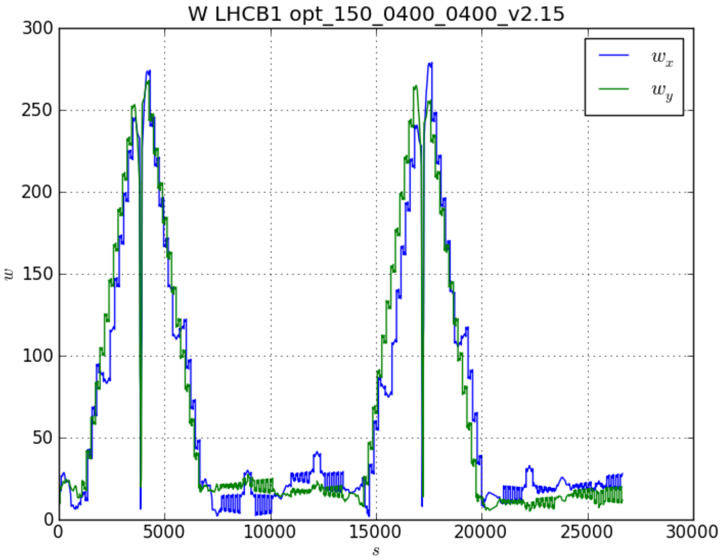
Tune vs delta



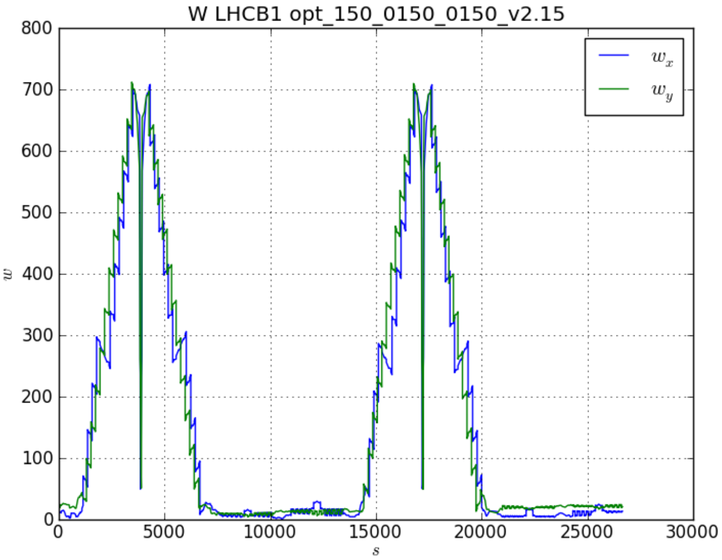
W functions: $W\delta = |\Delta\beta/\beta_0 + i(\Delta\alpha_0 - \alpha\Delta\beta_0/\beta_0)|$



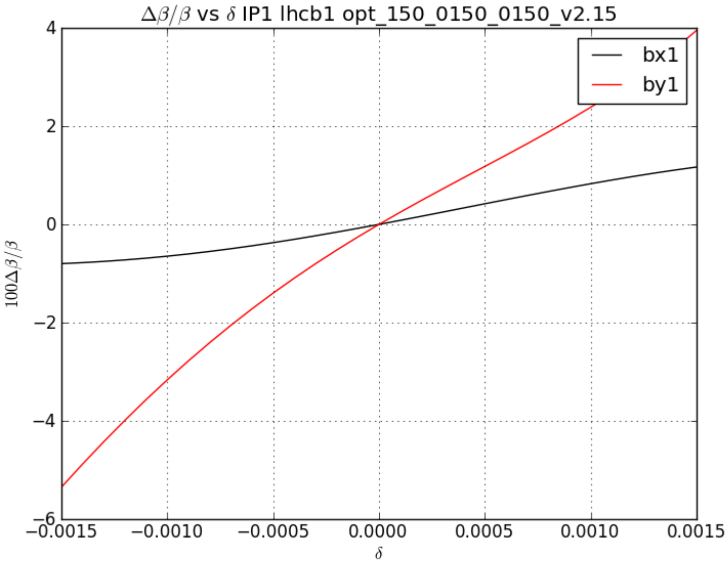
W functions: $W\delta = |\Delta\beta/\beta_0 + i(\Delta\alpha_0 - \alpha\Delta\beta_0/\beta_0)|$



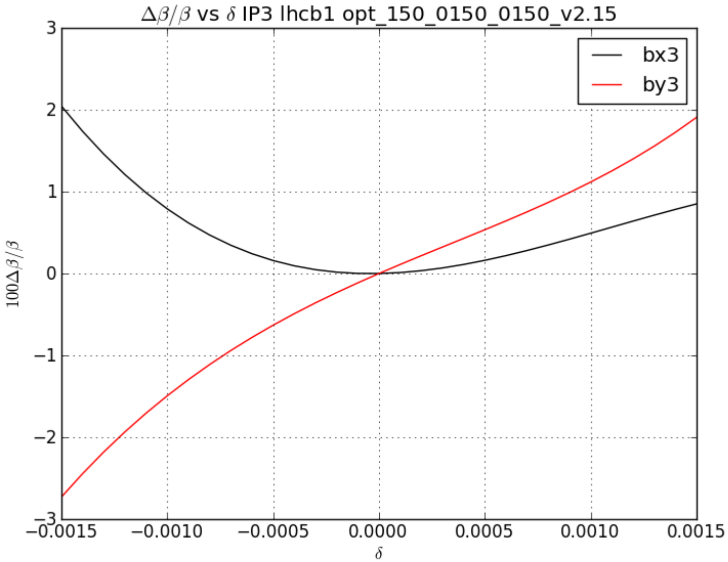
W functions: $W\delta = |\Delta\beta/\beta_0 + i(\Delta\alpha_0 - \alpha\Delta\beta_0/\beta_0)|$



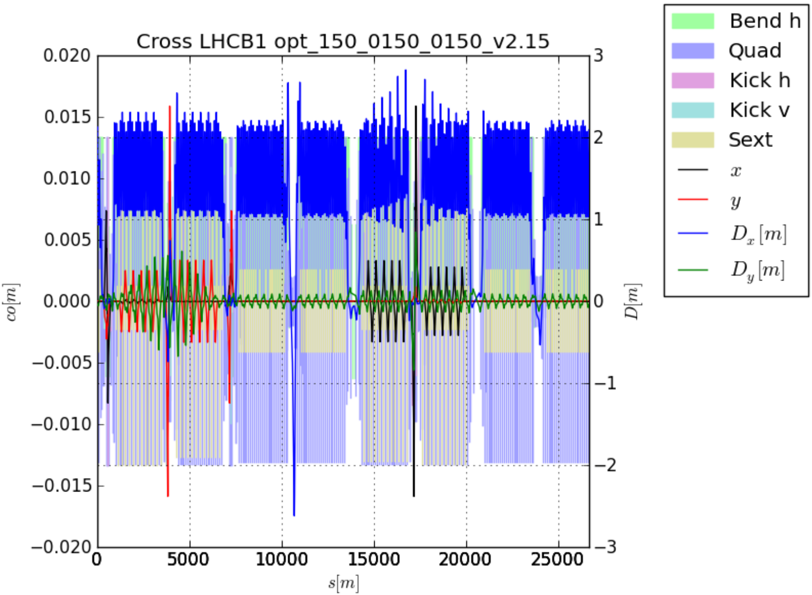
Non linear beta beating



Non linear beta beating



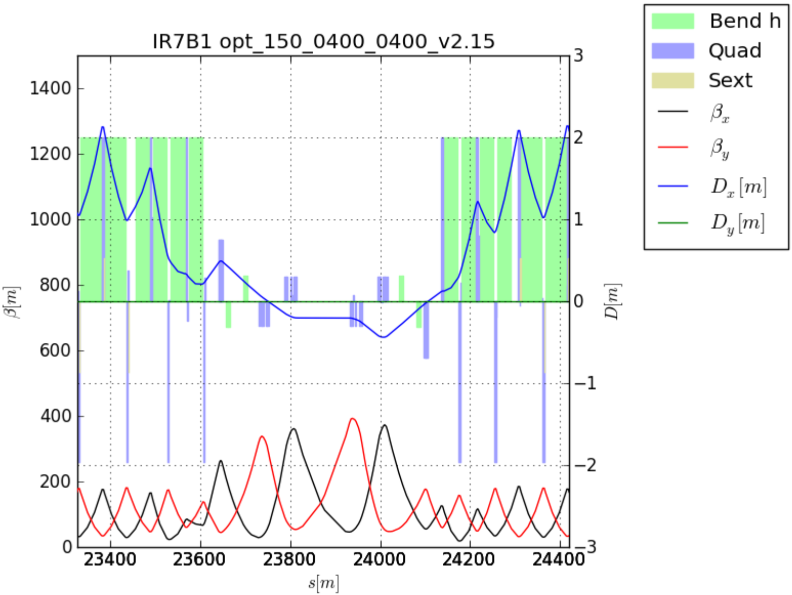
LHC Spurious dispersion



Tour

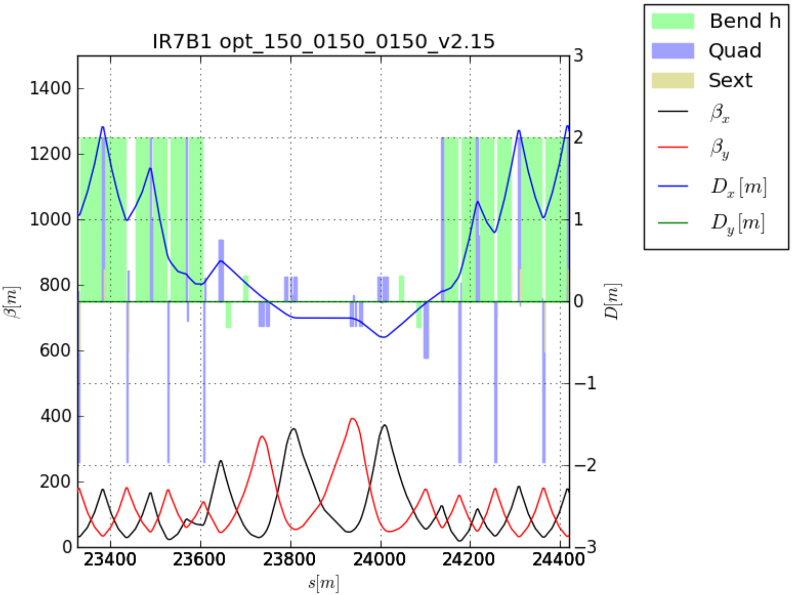
- Effort to keep beta function unnecessarily large, magnet strengths not too close to lower limit, minimum changes with respect to nominal.
- For IR2 and IR8 phase advances probably not yet optimal.
- For IR4 Beta at the IP preserved as much as possible, to be checked for the damper and other instruments.
- IR3 and IR7 identical just rematched for the new arcs.

IR7 B1

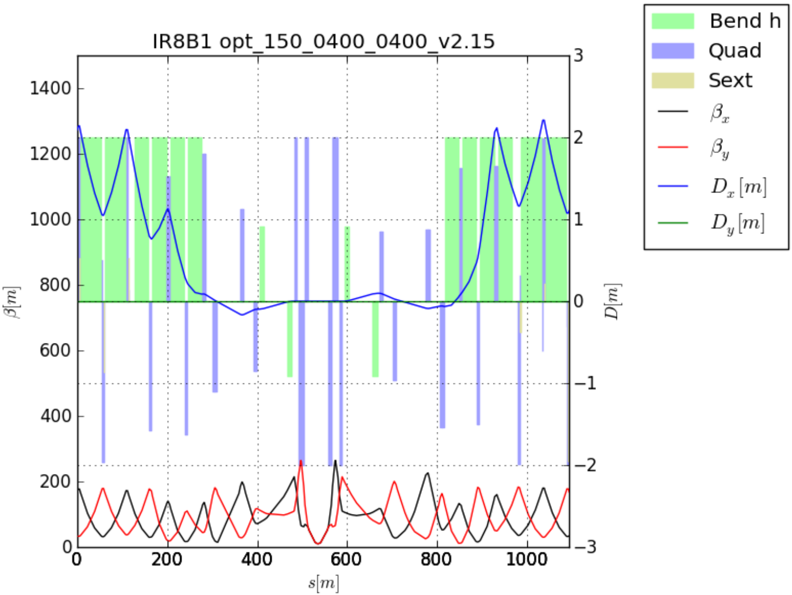


IR7B1 opt_150_0400_0400_v2.15
1400
1200
1000
800
600
400
200
0
3
2
1
0
−1
−2
−3
23400
23600
23800
24000
24200
24400
$s[m]$
$\beta[m]$
$D[m]$
Bend h
Quad
Sext
β_x
β_y
$D_x[m]$
$D_y[m]$

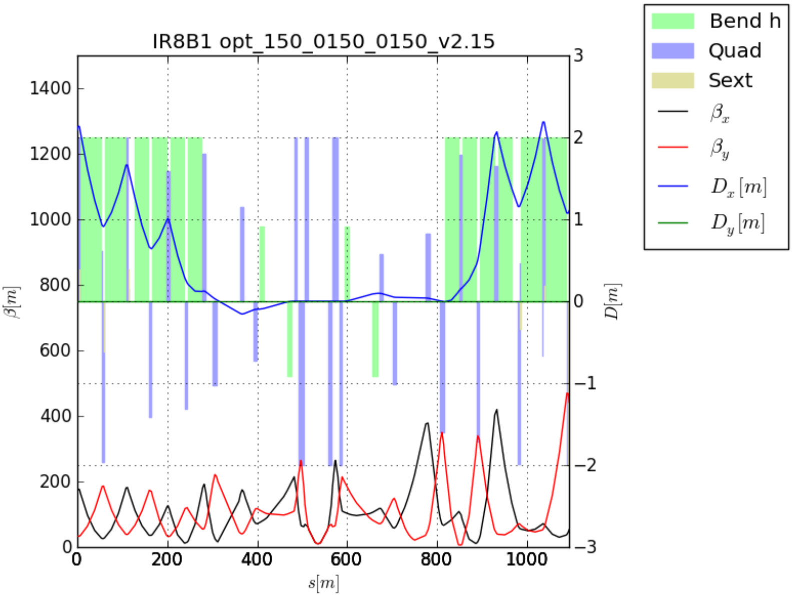
IR7 B1


IR7B1 opt_150_0150_0150_v2.15
1400
1200
1000
800
600
400
200
0
3
2
1
0
−1
−2
−3
23400
23600
23800
24000
24200
24400
$\beta[m]$
$D[m]$
$s[m]$
Bend h
Quad
Sext
β_x
β_y
$D_x[m]$
$D_y[m]$

IR8 B1

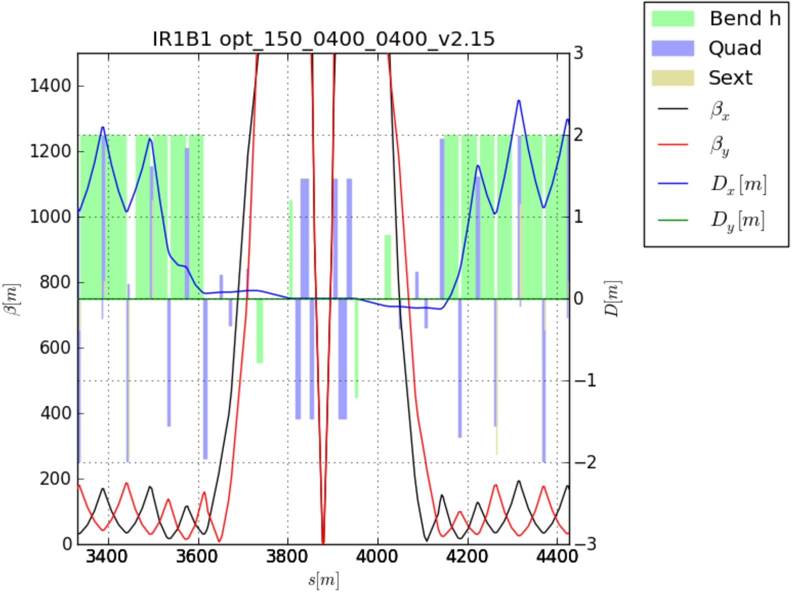

IR8B1 opt_150_0400_0400_v2.15
1400
1200
1000
800
600
400
200
0
0
200
400
600
800
1000
3
2
1
0
−1
−2
−3
$\beta[m]$
$D[m]$
$s[m]$
Bend h
Quad
Sext
β_x
β_y
$D_x\,[m]$
$D_y\,[m]$

IR8 B1



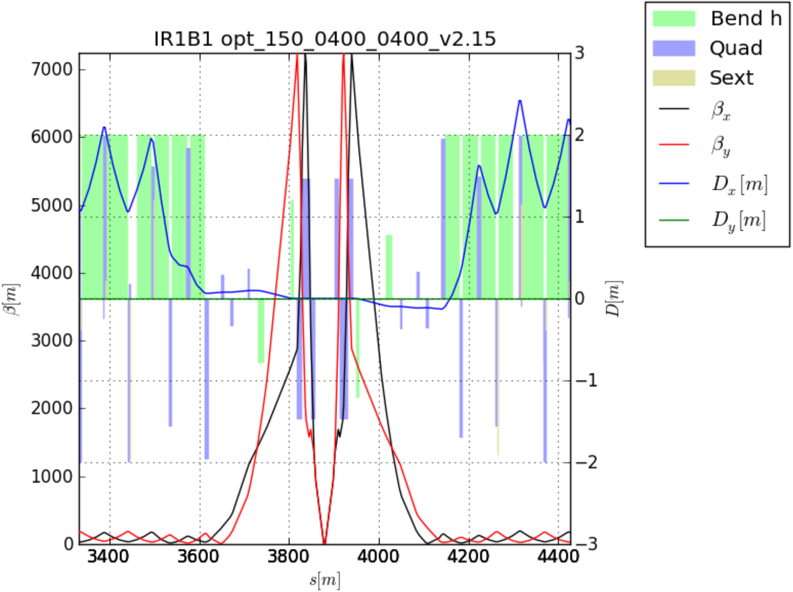
IR8B1 opt_150_0150_0150_v2.15
β[m]
D[m]
s[m]
0
200
400
600
800
1000
1200
1400
3
2
1
0
−1
−2
−3
Bend h
Quad
Sext
β_x
β_y
$D_x\,[m]$
$D_y\,[m]$

IR1 B1



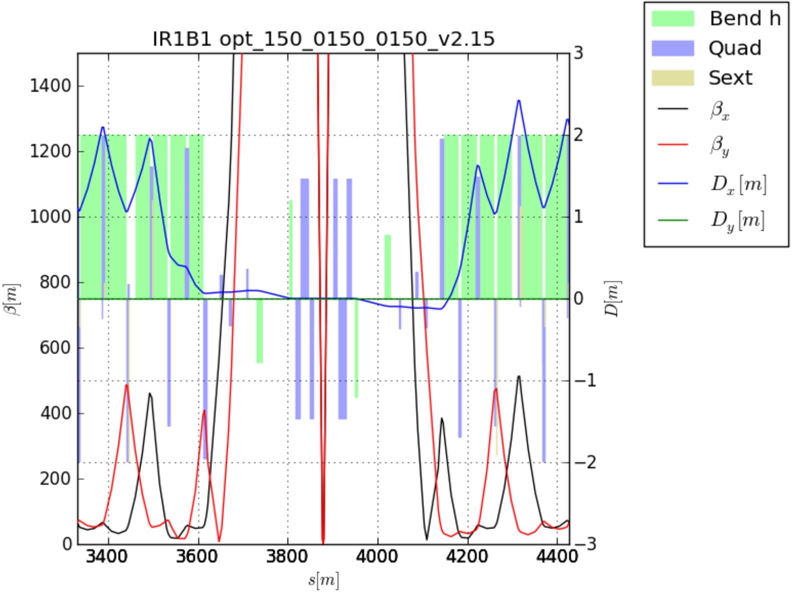
IR1B1 opt_150_0400_0400_v2.15
1400
1200
1000
800
600
400
200
0
3400
3600
3800
4000
4200
4400
3
2
1
0
−1
−2
−3
$\beta[m]$
$D[m]$
$s[m]$
Bend h
Quad
Sext
β_x
β_y
$D_x[m]$
$D_y[m]$

IR1 B1



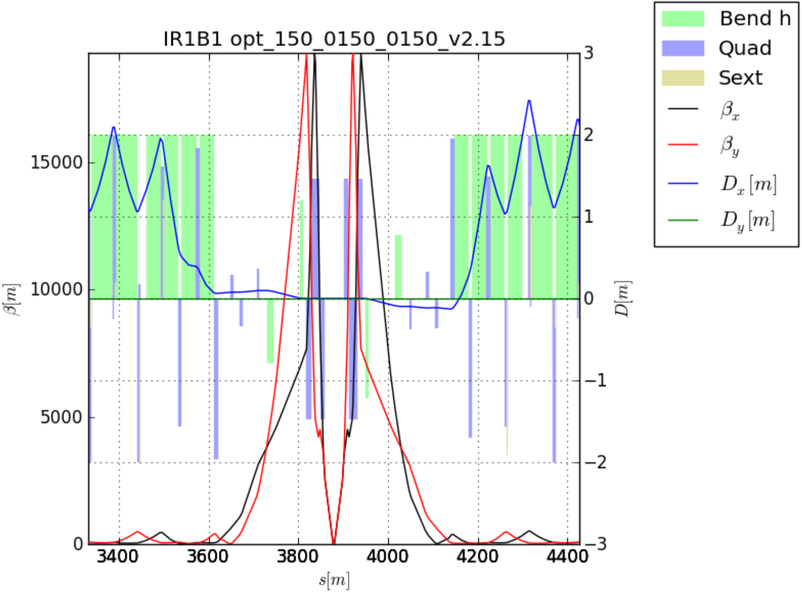
IR1B1 opt_150_0400_0400_v2.15
7000
6000
5000
4000
3000
2000
1000
0
3400
3600
3800
4000
4200
4400
3
2
1
0
−1
−2
−3
$\beta[m]$
$s[m]$
$D[m]$
Bend h
Quad
Sext
β_x
β_y
$D_x[m]$
$D_y[m]$

IR1 B1



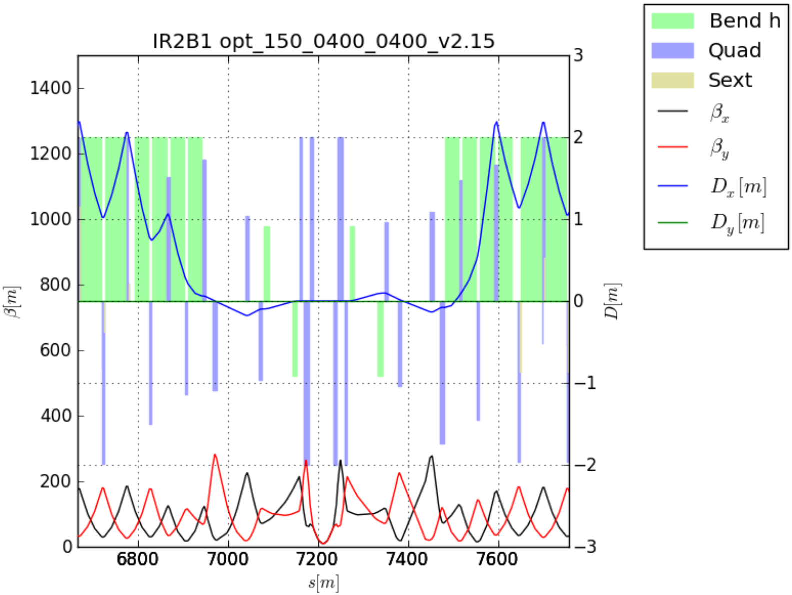
IR1B1 opt_150_0150_0150_v2.15
1400
1200
1000
800
600
400
200
0
3400
3600
3800
4000
4200
4400
3
2
1
0
−1
−2
−3
$\beta[m]$
$s[m]$
$D[m]$
Bend h
Quad
Sext
β_x
β_y
$D_x[m]$
$D_y[m]$

IR1 B1



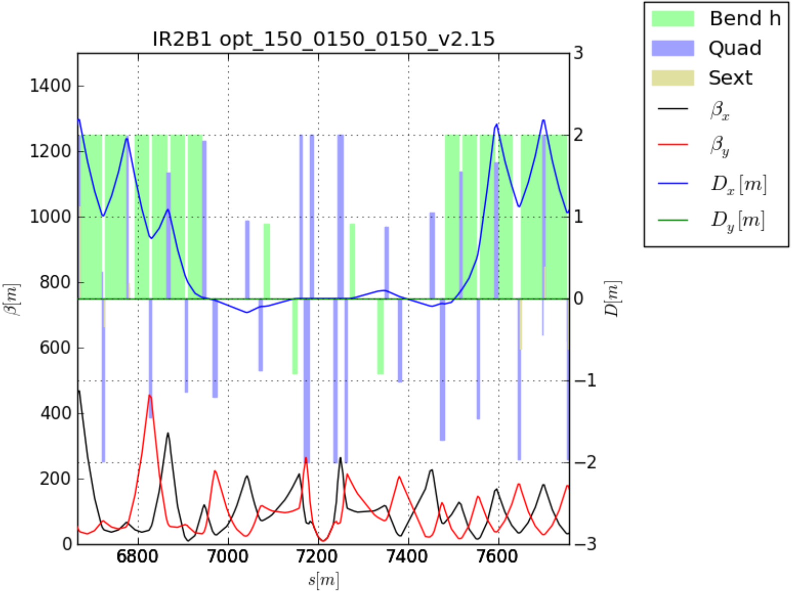
IR1B1 opt_150_0150_0150_v2.15
Bend h
Quad
Sext
β_x
β_y
$D_x[m]$
$D_y[m]$
$\beta[m]$
$D[m]$
$s[m]$
0
5000
10000
15000
3400
3600
3800
4000
4200
4400
−3
−2
−1
0
1
2
3

IR2 B1



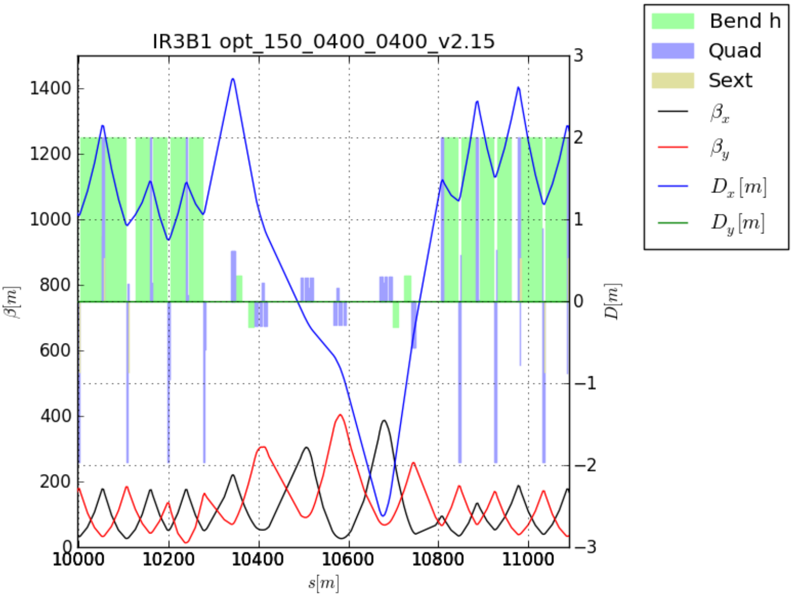
IR2B1 opt_150_0400_0400_v2.15
Bend h
Quad
Sext
β_x
β_y
$D_x [m]$
$D_y [m]$
$\beta[m]$
$D[m]$
$s[m]$
0
200
400
600
800
1000
1200
1400
6800
7000
7200
7400
7600
3
2
1
0
−1
−2
−3

IR2 B1



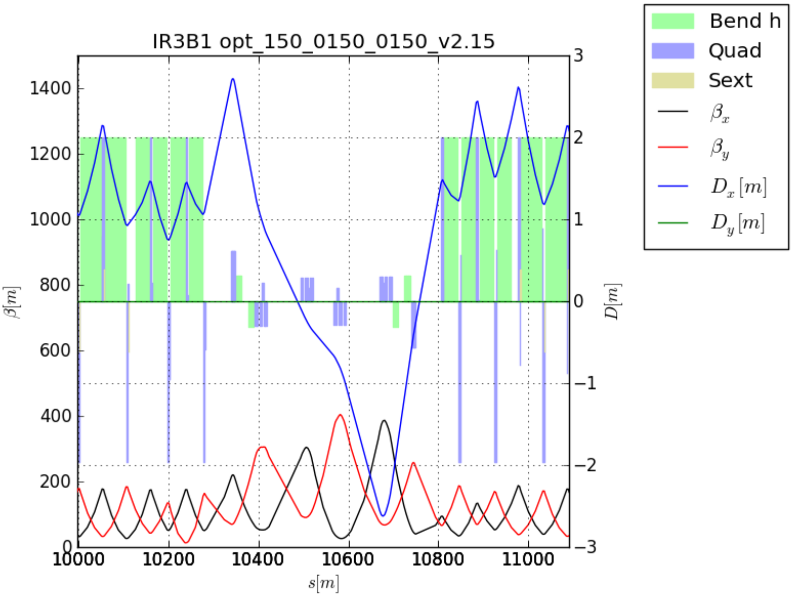
IR2B1 opt_150_0150_0150_v2.15
Bend h
Quad
Sext
β_x
β_y
$D_x[m]$
$D_y[m]$
$\beta[m]$
$D[m]$
$s[m]$
1400
1200
1000
800
600
400
200
0
6800
7000
7200
7400
7600
3
2
1
0
−1
−2
−3

IR3 B1



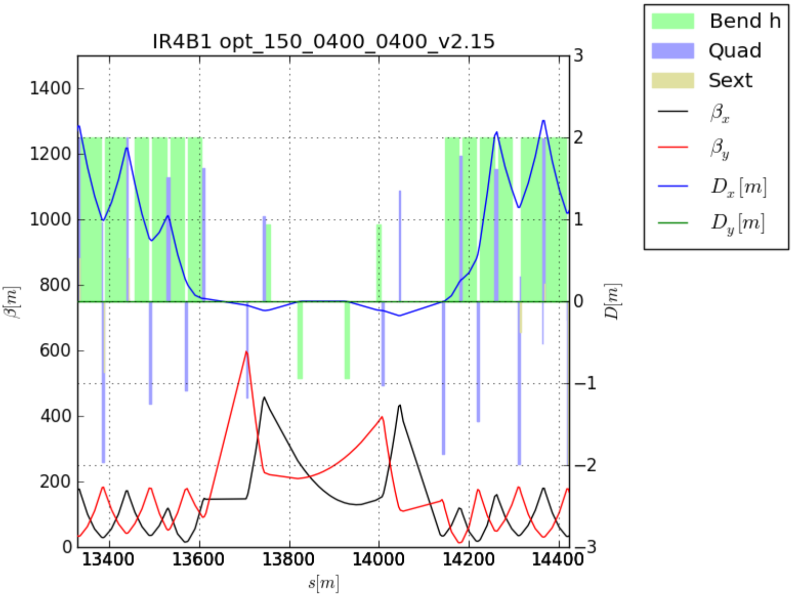
IR3B1 opt_150_0400_0400_v2.15
Bend h
Quad
Sext
β_x
β_y
$D_x[m]$
$D_y[m]$
$\beta[m]$
$D[m]$
$s[m]$
0
200
400
600
800
1000
1200
1400
10000
10200
10400
10600
10800
11000
−3
−2
−1
0
1
2
3

IR3 B1



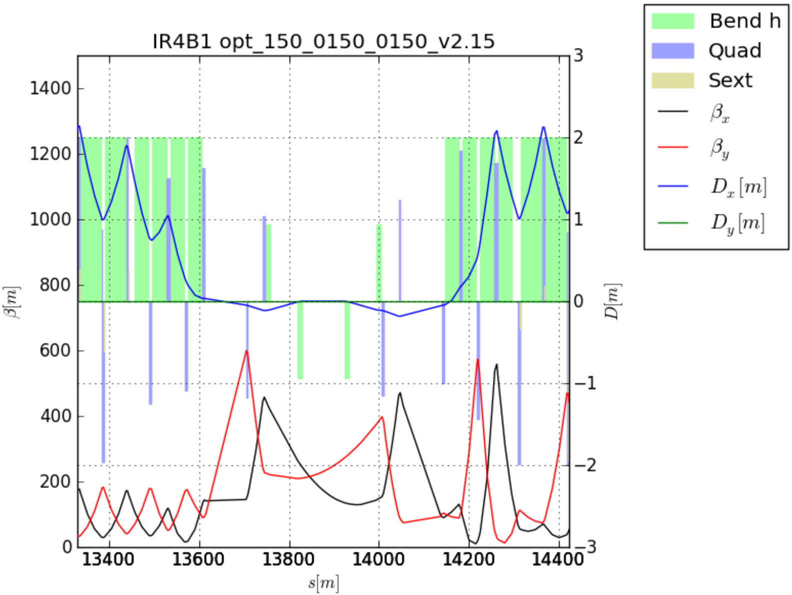
IR3B1 opt_150_0150_0150_v2.15
Bend h
Quad
Sext
β_x
β_y
$D_x[m]$
$D_y[m]$
$\beta[m]$
$D[m]$
$s[m]$
1400
1200
1000
800
600
400
200
0
10000
10200
10400
10600
10800
11000
3
2
1
0
−1
−2
−3

IR4 B1



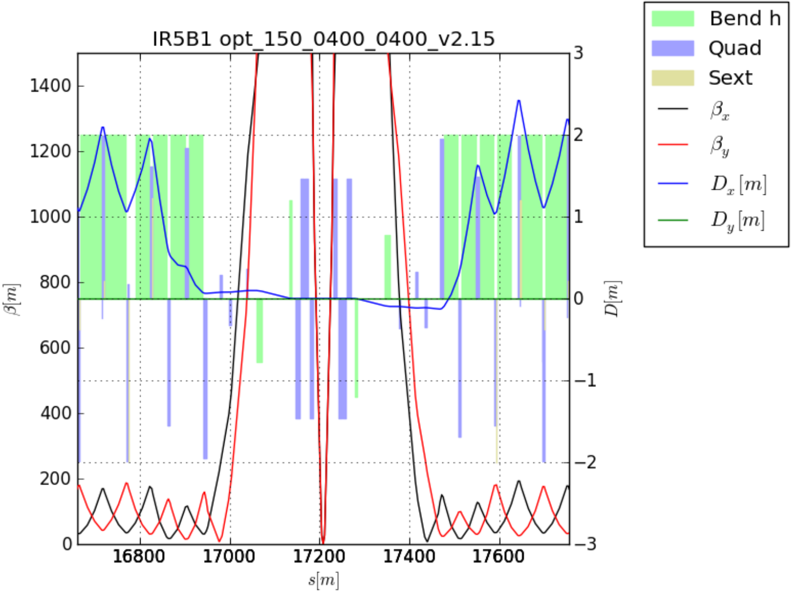
IR4B1 opt_150_0400_0400_v2.15
1400
1200
1000
800
600
400
200
0
3
2
1
0
−1
−2
−3
$\beta[m]$
$D[m]$
13400
13600
13800
14000
14200
14400
$s[m]$
Bend h
Quad
Sext
β_x
β_y
$D_x[m]$
$D_y[m]$

IR4 B1



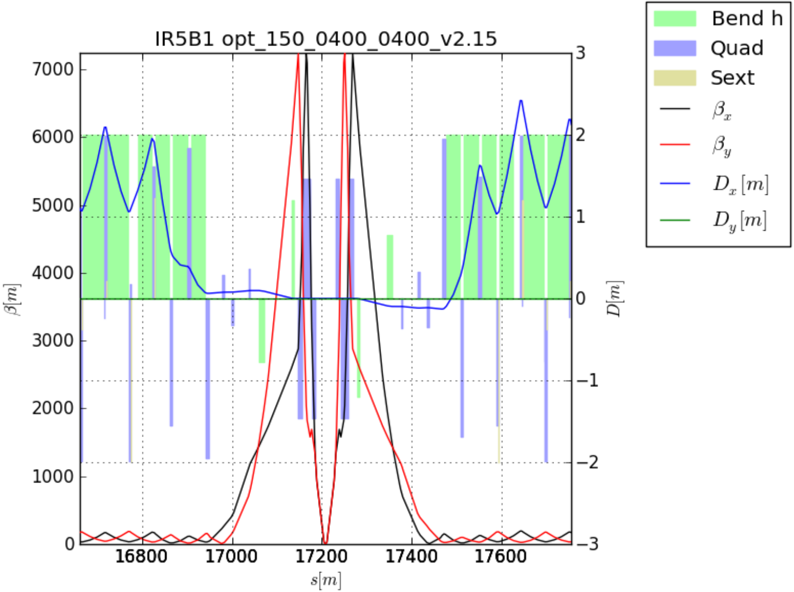
IR4B1 opt_150_0150_0150_v2.15
1400
1200
1000
800
600
400
200
0
3
2
1
0
−1
−2
−3
13400
13600
13800
14000
14200
14400
$\beta[m]$
$D[m]$
$s[m]$
Bend h
Quad
Sext
β_x
β_y
$D_x[m]$
$D_y[m]$

IR5 B1

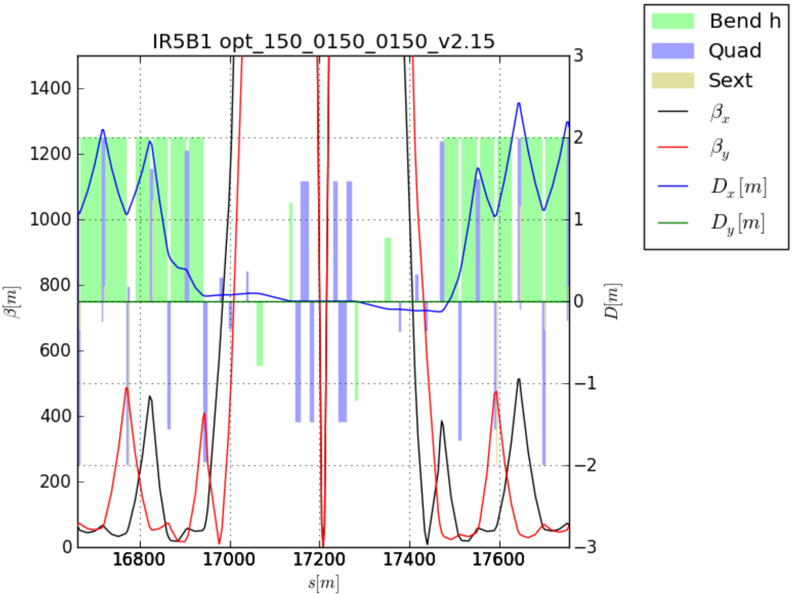


IR5B1 opt_150_0400_0400_v2.15
1400
1200
1000
800
600
400
200
0
16800
17000
17200
17400
17600
$s[m]$
$\beta[m]$
3
2
1
0
−1
−2
−3
$D[m]$
Bend h
Quad
Sext
β_x
β_y
$D_x[m]$
$D_y[m]$

IR5 B1

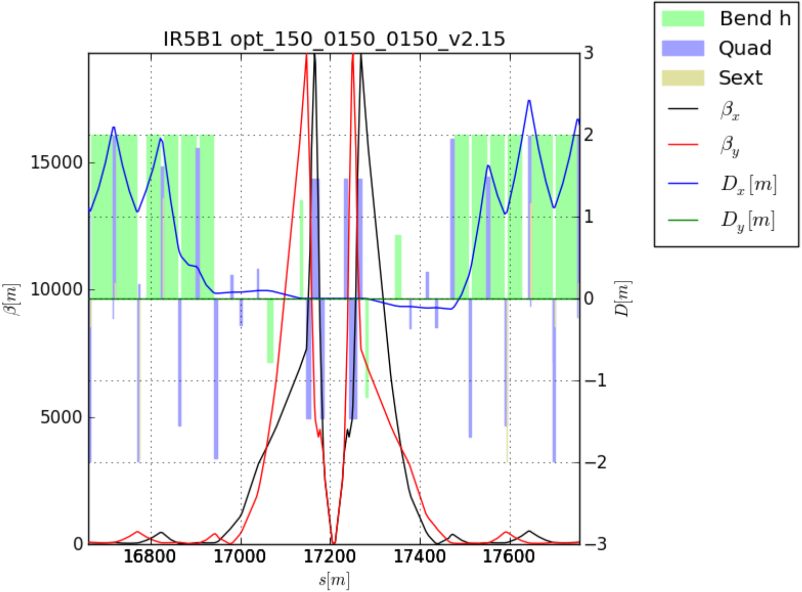

IR5B1 opt_150_0400_0400_v2.15
7000
6000
5000
4000
3000
2000
1000
0
$\beta[m]$
16800
17000
17200
17400
17600
$s[m]$
3
2
1
0
−1
−2
−3
$D[m]$
Bend h
Quad
Sext
β_x
β_y
$D_x[m]$
$D_y[m]$

IR5 B1



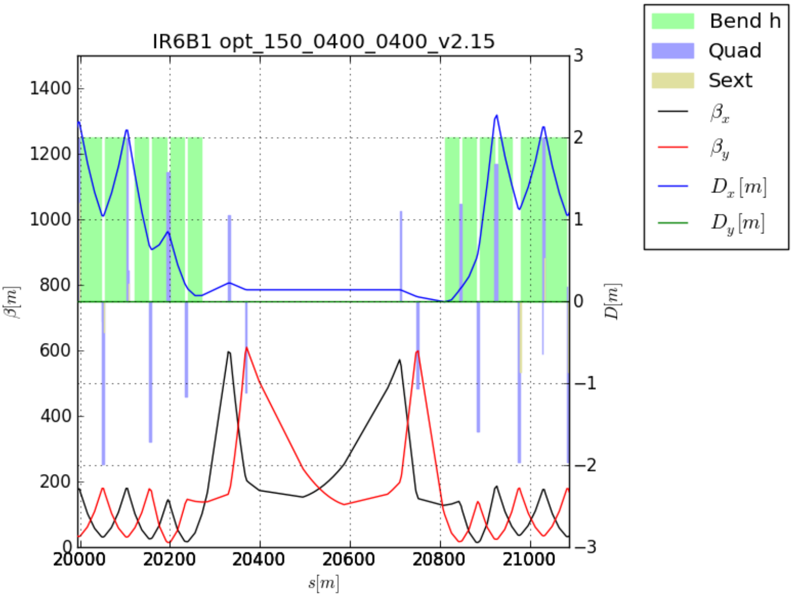
IR5B1 opt_150_0150_0150_v2.15
Bend h
Quad
Sext
β_x
β_y
$D_x[m]$
$D_y[m]$
$\beta[m]$
$D[m]$
$s[m]$
0
200
400
600
800
1000
1200
1400
16800
17000
17200
17400
17600
3
2
1
0
−1
−2
−3

IR5 B1

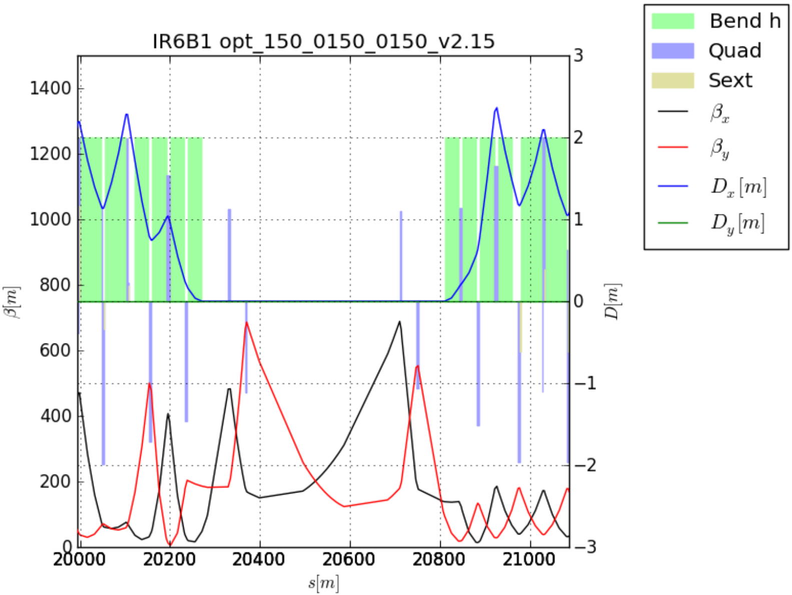


IR5B1 opt_150_0150_0150_v2.15
15000
10000
5000
0
3
2
1
0
−1
−2
−3
16800
17000
17200
17400
17600
$s[m]$
$\beta[m]$
$D[m]$
Bend h
Quad
Sext
β_x
β_y
$D_x[m]$
$D_y[m]$

IR6 B1


IR6B1 opt_150_0400_0400_v2.15
Bend h
Quad
Sext
β_x
β_y
$D_x[m]$
$D_y[m]$
$\beta[m]$
$D[m]$
$s[m]$
1400
1200
1000
800
600
400
200
0
20000
20200
20400
20600
20800
21000
3
2
1
0
−1
−2
−3

IR6 B1



IR6B1 opt_150_0150_0150_v2.15
Bend h
Quad
Sext
β_x
β_y
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
1400
1200
1000
800
600
400
200
0
20000
20200
20400
20600
20800
21000
3
2
1
0
−1
−2
−3

IR6 dump system features

name	dpxb1	dpxb2	dxb1	dxb2	bxb1 dump	bxb2 dump	byb1 dump	byb2 dump	dmuxb1 kick	dmuxb2 kick
	murad	murad	m	m	m	m	m	m	2pi	2pi
inj	0	-256	0.14	0.186	5012	5052	3955	3698	0.2631	0.2633
1111	0	-256	0.14	0.186	5012	5052	3955	3698	0.2631	0.2633
3333	0	0	0	0	5455	5867	4241	3699	0.25	0.25
4444	0	0	0	0	5743	6134	3955	3698	0.25	0.25
8228	0	0	0	0	5581	5820	6115	3698	0.25	0.25
5115	0	0	0	0	5012	5052	4063	3699	0.25	0.25
2882	0	0	0	0	7456	6818	3955	3698	0.25	0.25
1551	0	0	0	0	7244	6758	3974	3828	0.25	0.25

```
bxb1  bxb2  byb1  byb2: beta function at the dump
dxb1  dxb2 dpxb1 dpxb2: dispersion and angular dispersion at IP6
dmuxb1 dmuxb2:  phase advance between TCSG.4[RL]6 and MKD.H5[LR]6
```

Without injection constraints optics can be optimized for the dump system.
It is possible to attempt to improve inj and 1111.

Repository: names and specs

name	$\beta^*_\times$ [m]	$\beta^*_\parallel$ [m]	$\theta_\times/2$ [μrad]	$\Delta_\parallel/2$ [mm]	$\times$ planes IP1/IP5
opt_150_11000_11000	11.0	11.0	170	2	v/h, adj.
opt_150_5500_5500	5.5	5.5	245	2	v/h, adj.
opt_150_2000_2000	2.0	2.0	80	2	v/h, adj.
opt_150_0400_0400	0.40	0.40	180	0.75	v/h, adj.
opt_150_0150_0150	0.15	0.15	295	0.75	v/h, adj.
opt_150_0100_0100	0.10	0.10	360	0.75	v/h, adj.
opt_150_0075_0300	0.30	0.75	275	0.75	v/h, fixed
opt_150_0050_0200	0.20	0.05	335	0.75	v/h, fixed
opt_150_0075_0300hv	0.30	0.75	275	0.75	h/v, fixed
opt_150_0050_0200hv	0.20	0.05	335	0.75	h/v, fixed

with their thin version.

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Repository: names and specs

name	$\beta^*_\times$ [m]	$\beta^*_\parallel$ [m]	$\theta_\times/2$ [μrad]	$\Delta_\parallel/2$ [mm]	$\times$ planes IP1/IP5
opt_150_11000_11000	11.0	11.0	170	2	v/h, adj.
opt_150_5500_5500	5.5	5.5	245	2	v/h, adj.
opt_150_2000_2000	2.0	2.0	80	2	v/h, adj.
opt_150_0400_0400	0.40	0.40	180	0.75	v/h, adj.
opt_150_0150_0150	0.15	0.15	295	0.75	v/h, adj.
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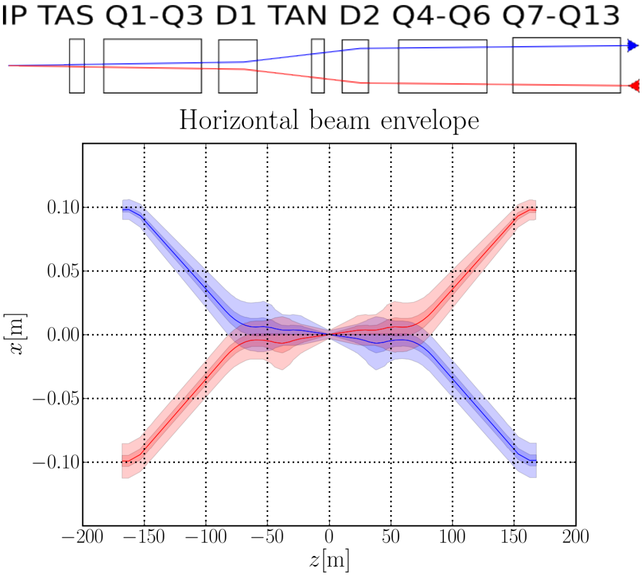
LHC IR layout



Layout changes

IR1 and IR5 triplet area ($l_{\mathrm{Q1}} = l_{\mathrm{Q3}}$, $l_{\mathrm{Q2a}} = l_{\mathrm{Q2b}}$):

```
IP 22.54 {.46 | Q1   | .46} .36 .12 BPM .24
         {.36 | MCBXDa | .46 | Q2a    |.46 } .24 BPM .12 .36
         {.46 | Q2b    | .46 | MCBXDb |.36 } .24 BPM .12 .36
         {.46 | Q3     | .46 } .24 BPM .12 .36
         {.18 .18 |MCBXC   |.18  .20 .115|MQSX3   |.115
          .20 .075|MCOSSX3 |.075 .20 .075|MCSTX3  |.075
          .20 .075|MCDTSX3 |.075 .25}
```

D1: single sc. dipole; TAN and TCT: nominal length
D2: larger aperture 2-in-1, moved towards the IP by 15m
Crab cavities: 3 staggered modules per side per IP per beam
Q4: larger aperture 2-in-1
Q5: long MQY type moved towards the arc by 11m
Q10: added MS circuit and replaced MCBC
IR6: new long MQY type Q5

Layout parameters

```
l.MQXL       :=      7.6850000000 ;
l.MQX        :=      6.5770000000 ;
dq1q2a       :=      3.5600000000 ;
dq2aq2b      :=      1.9150000000 ;
dq2bq3       :=      3.5600000000 ;
deltaposD2   :=    -15.0000000000 ;
deltaposQ4   :=      0.0000000000 ;
deltaposQ5   :=     11.0000000000 ;
deltaposQ6   :=      0.0000000000 ;
```

Lengths in m.

Repository: names and specs

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opt_150_0400_0400	0.40	0.40	180	0.75	v/h, adj.
opt_150_0150_0150	0.15	0.15	295	0.75	v/h, adj.
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opt_150_0050_0200	0.20	0.05	335	0.75	v/h, fixed
opt_150_0075_0300hv	0.30	0.75	275	0.75	h/v, fixed
opt_150_0050_0200hv	0.20	0.05	335	0.75	h/v, fixed

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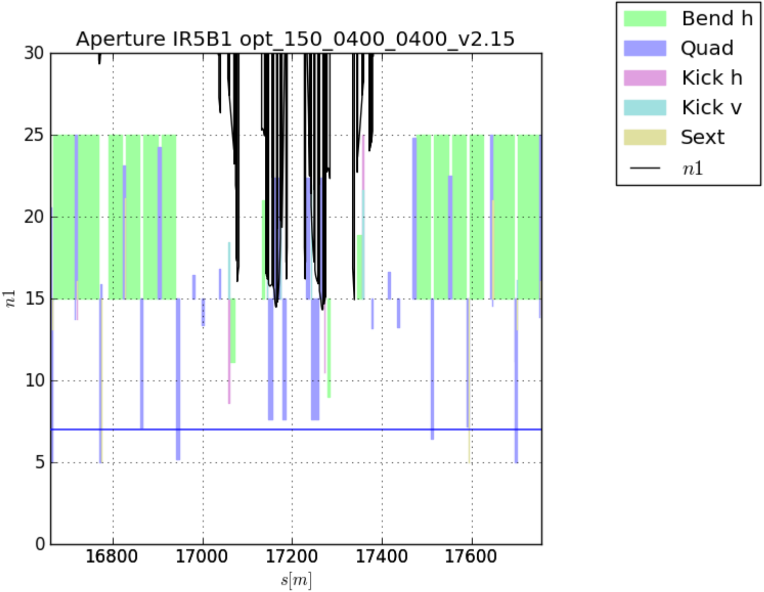
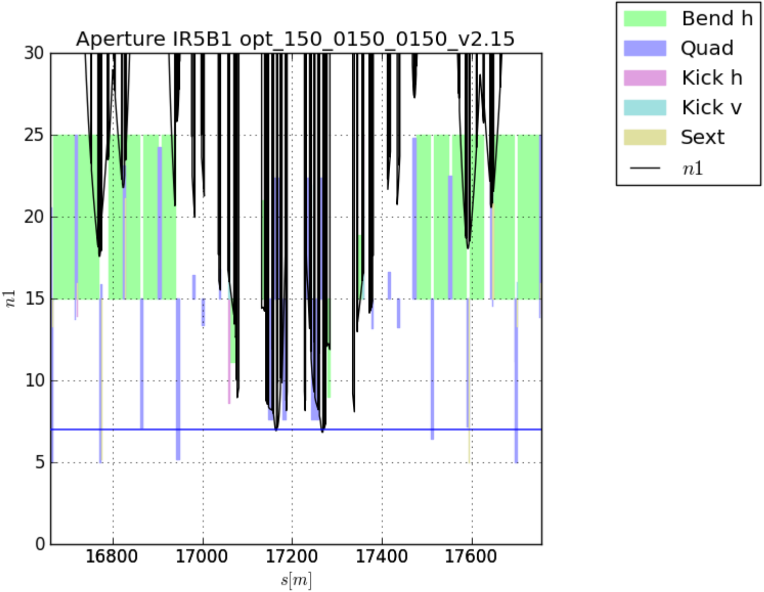
IR5 squeeze



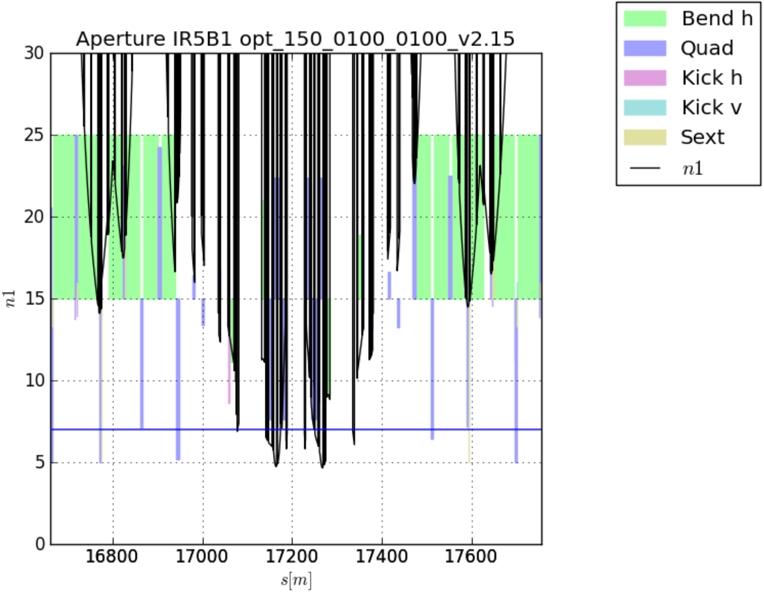
Aperture IR5B1 opt_150_0400_0400_v2.15
30
25
20
15
10
5
0
$n1$
16800
17000
17200
17400
17600
$s[m]$
Bend h
Quad
Kick h
Kick v
Sext
$n1$

IR5 squeeze



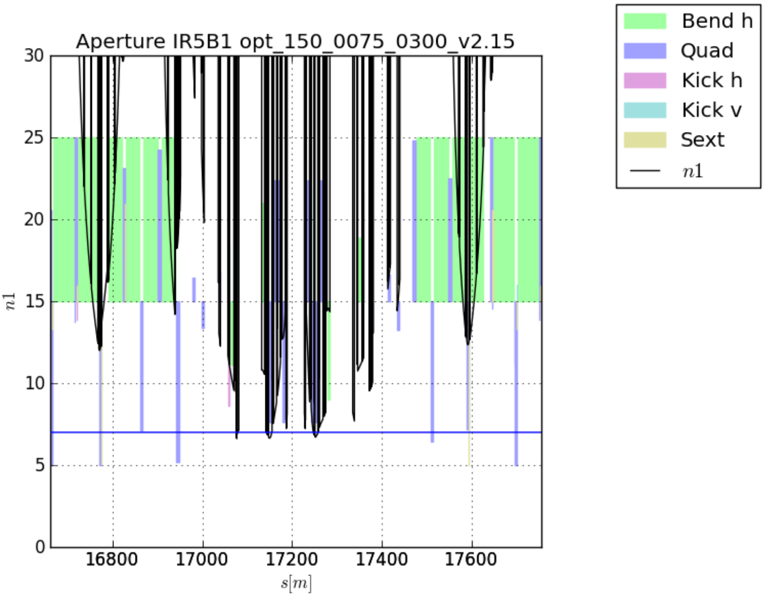
Aperture IR5B1 opt_150_0150_0150_v2.15
30
25
20
15
10
5
0
$n1$
16800
17000
17200
17400
17600
$s[m]$
Bend h
Quad
Kick h
Kick v
Sext
$n1$

IR5 squeeze

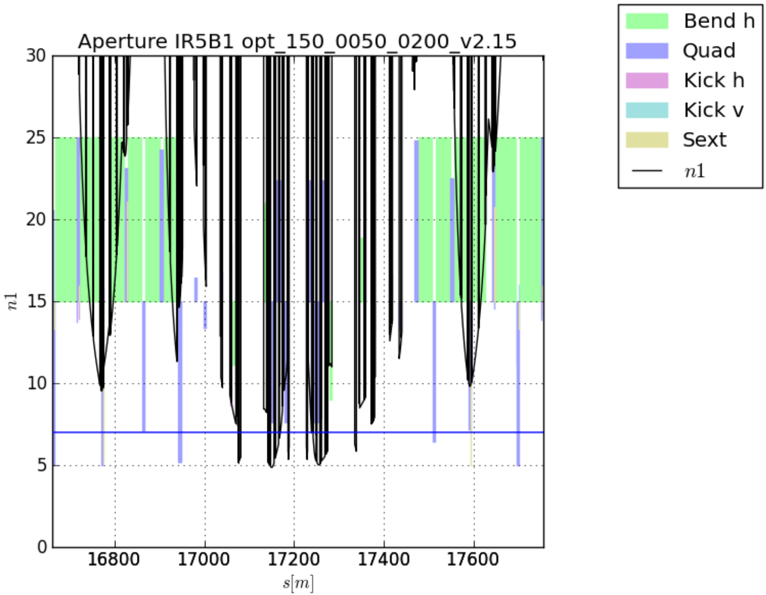


Aperture IR5B1 opt_150_0100_0100_v2.15
30
25
20
15
10
5
0
$n1$
16800
17000
17200
17400
17600
$s[m]$
Bend h
Quad
Kick h
Kick v
Sext
$n1$

IR5 squeeze


Aperture IR5B1 opt_150_0075_0300_v2.15
30
25
20
15
10
5
0
n1
16800
17000
17200
17400
17600
s[m]
Bend h
Quad
Kick h
Kick v
Sext
n1

IR5 squeeze


Aperture IR5B1 opt_150_0050_0200_v2.15
30
25
20
15
10
5
0
16800
17000
17200
17400
17600
$s[m]$
$n1$
Bend h
Quad
Kick h
Kick v
Sext
$n1$

Aperture model

Based on PhaseI.

- MQX and MC_X: octagon scaled by the triplet aperture ($a_{\rm mqx} = 140$mm)
- D1: round $r = a_{\rm mqx}/2 + 7$mm
- TAS: round $r = 30$mm
- BPMs: round $r = a_{\rm mqx}/2$
- TAN: ellipse $a, b = 41, 37$mm
- D2 and MCBYY: rectellipse $g, r = (37, 42)$mm for 106mm coil aperture
- Q4: rectellipse $g, r = (30, 35)$mm for 90mm coil aperture
- BPMs D2, Q4, Q5: round $r = 41, 37.5, 30$mm

Repository: names and specs

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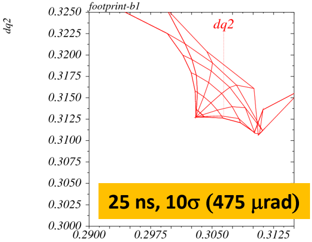
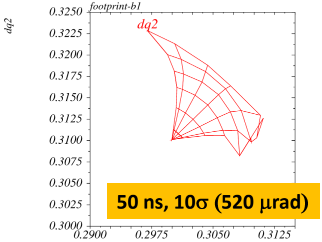
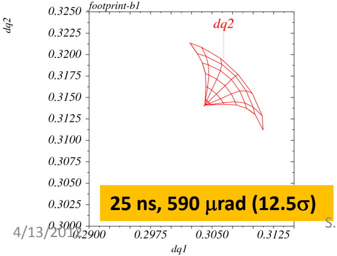
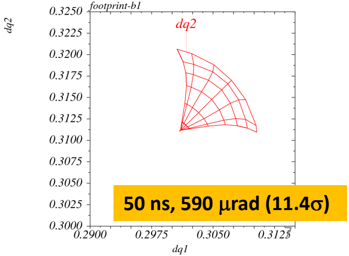
Why a priori 590 μrad Xangle and not the "canonical" 10σ ?

→ **Tune footprint at 6σ** with **21 LR's per IP side (longer IT)**, HO at IP1 and IP5, β*=15 cm and **beam parameters (higher bunch charge)** given in the previous table

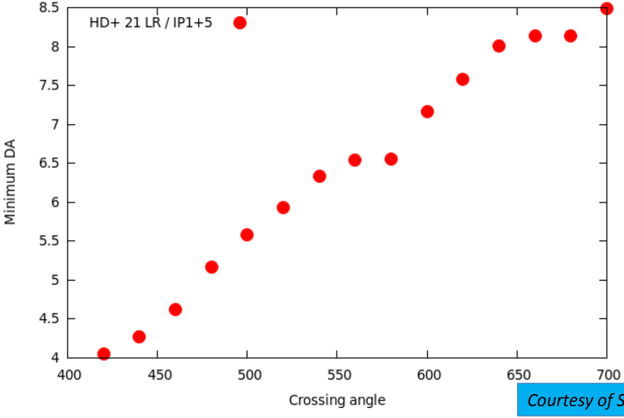






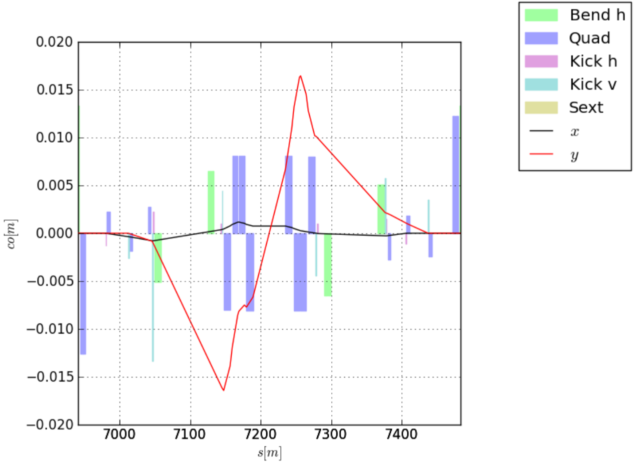


→ 100'000 turns DA simulation results vs Xangle confirming the "pathological tune footprint" (25 ns beam parameters, β^*=15 cm, only sextupoles, LR and HO, no crab-crossing no field imperfection)



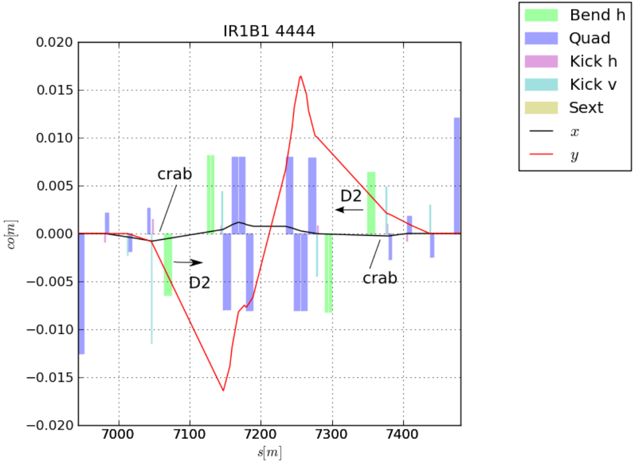
Courtesy of S. White (USLARP)

Present crossing scheme



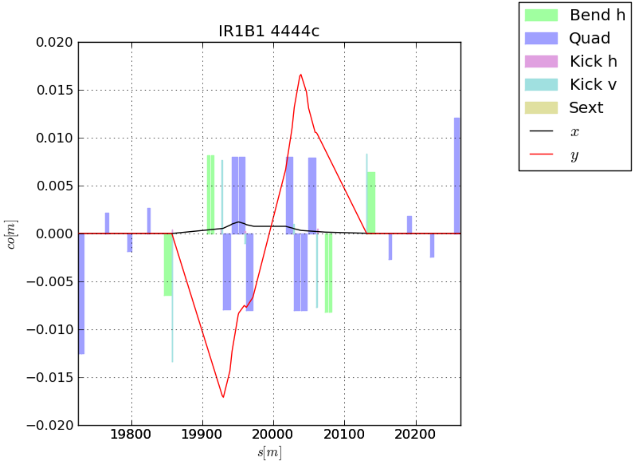
- In collision:
  - $\beta^* = 15$cm, crossing angle $580\,\mu$rad, separation 1.5mm
- The close orbit excursion at the cavity is:
  - $3.35\,\mathrm{mm}$ for 10σ crossing angle

Present crossing scheme



- In collision:
  - $\beta^* = 15$cm, crossing angle $580\,\mu\text{rad}$, separation 1.5mm
- The close orbit excursion at the cavity is:
  - $3.35\,\text{mm}$ for 10σ crossing angle

New crossing scheme



- No orbit displacement at the crab cavity location nor in D2 and Q4.
- The corrector in D2 can be placed in the non-IP side to save strength and gain some aperture for horizontal crossing
- Additional aperture margin in D2 and Q4 as side effect.

Crab layout

```
--B1> |D2|.4|MCH|.4|MCV| 1.8 <C> 2.6 <C> 2.6 <C>     5.3 |MC|Q4|
<B2-- |D2|.4|MCH|.4|MCV| 3.1     <C> 2.6 <C> 2.6 <C> 4.0 |MC|Q4|
```

```
l.D2=10
l.MCBH/V=1.5
```

Total voltage for the 3 modules for 590μrad: 11.7MV and 10.7MV.

Optics (Task 2.2)

- Latest estimate for the **crab-voltage** at 15 cm β^*:

  - **9 MV** (3 mod.) is fine but if Θ_c=460 μrad (9-10σ) is OK at half-current (L=5E34)??

  → detailed studies needed to determine the settings Θ_c (N_b) and $V_{crab}(\Theta_c)$ @L=5E34

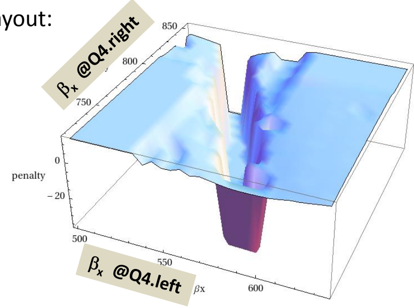
  - **Then clear limitation showing up for lower β^* e.g. 10 cm!**

- Develop **new ATS pre-squeezed optics and/or layout** to push the beta's at the crabs (Q4) on both IR sides

  - not possible with the present matching section layout:

  … the two IR sides are anti-correlated optics anti-symmetry) and **the width of the matching valley is 10% only, i.e. 5% on V_{crab}**

  … work ongoing to improve the situation by modifying the matching section pushing the idea of a **stronger Q7, and replacing Q5 & Q6 by 2 doublets**



Optics match-ability as a function of the β's at the crab-cavities), courtesy B. Dalena (CEA)

Single bore orbit corrector strengths

MCBX[2] type orbit correctors in the non-IP side for Q1, Q2, Q3. Function: orbit correction due to misalignments and crossing scheme

Strength orbit correction: $x_{tol} g_{\mathrm{triplet}} l_{\mathrm{triplet}} = 0.6\,\mathrm{Tm} \rightarrow 25\,\mu\mathrm{rad}$

Strength for crossing scheme (50% safety margin):

Element	Plane	crossing		separation	
		kick[μrad]	field [Tm]	kick[μrad]	field [Tm]
nominal-like round β^*					
MCBX.3	H&V	49*1.5 =73	1.7	11*2	0.51
closed round β^*					
MCBX.1	H&V	17*1.5 =25	0.6	5*2	0.23
MCBX.3 [3]	H&V	140*1.5 =210	4.9	10*2	0.46

[2]nominal: 3.3T, 1.5Tm

[3]may be partially absorbed by D1

2-in-1 orbit corrector strength

MCBY type (but wider aperture) either in the IP side of D2 to save vertical aperture or in the non-IP side to save strength and aperture for positive crossing angle.

Strength for crossing scheme (50% safety margin):

Element	Plane	crossing		separation	
		kick[μrad]	field [Tm]	kick[μrad]	field [Tm]
nominal-like round β^*					
MCBYY.4	H&V	126*1.5=189	4.4	22*2	1.0
MCBY.5	H or V	32*1.5 = 48	1.1	10*2	0.46
MCBC.6 [4]	H or V	35*1.5 = 53	1.2	12*2	0.28
closed round β^*					
MCBYY.4 [5]	H&V	244*1.5 =366	8.5	8*2	0.37

[4] Nominal 2.5T, 2.27 Tm

[5] may be partially absorbed by D2

MCBX and MCBYY strengths

name	acbx1	acbx3	acbyy
opt_150_11000_11000	18.18	45.61	98.03
opt_150_2000_2000	5.62	21.27	47.80
opt_150_5500_5500	17.57	65.54	143.68
opt_150_0400_0400	6.62	49.73	109.97
opt_150_0150_0150	6.62	81.50	180.23
opt_150_0100_0100	6.62	99.46	219.95
opt_150_0075_0300	6.62	75.98	168.01
opt_150_0050_0200	6.62	92.55	204.67
opt_150_0075_0300hv	6.62	75.98	168.01
opt_150_0050_0200hv	6.62	92.55	204.67
max nominal values	64	64	97
reserve for orbit correction	25	25	n/a

Maximum values per family in μrad.

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opt_150_0150_0150	0.15	0.15	295	0.75	v/h, adj.
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opt_150_0075_0300hv	0.30	0.75	275	0.75	h/v, fixed
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Directory listing

/afs/cern.ch/eng/lhc/optics/SLHCV3.1b

```
aperture                    opt_11000_11000.madx
beambeam                    opt_5500_5500.madx
errors                      opt_2000_2000.madx
toolkit                     opt_0400_0400.madx
iroptics                    opt_0150_0150.madx
tables                      opt_0100_0100.madx
readme                      opt_0075_0300.madx
slhc_sequence.madx          opt_0050_0200.madx
slhc_removeinstall.madx     opt_0075_0300hv.madx
crab_install.madx           opt_0050_0200hv.madx
job_sample.madx             opt_11000_11000thin.madx
job_makeoptics.madx         opt_5500_5500thin.madx
job_makethin.madx           opt_2000_2000thin.madx
                            opt_0400_0400thin.madx
                            opt_0150_0150thin.madx
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                            opt_0050_0200thin.madx
                            opt_0075_0300hvthin.madx
```