# SLHC V3: selected topics

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# Introduction

The HL-LHC (formerly SLHC) effort attemps to increase the peak lumoninosity of the LHC with some hardware changes.
There are many parameters that can be tweaked together with new equipment to increase the luminosity (e.g.):

$$L = L_{\mathrm{ho}} F_{\mathrm{geo}} F_{\mathrm{hr}}$$

$$\frac{2\beta_x^*}{\sigma_z d_{\mathrm{s}}} > F_{\mathrm{geo}} < 1 \qquad F_{\mathrm{hr}} << 1 \text{ for } \beta^* < \sigma_z$$

The following will focus only on the problems and possibilities for reducing $\beta^*$.

# Introduction

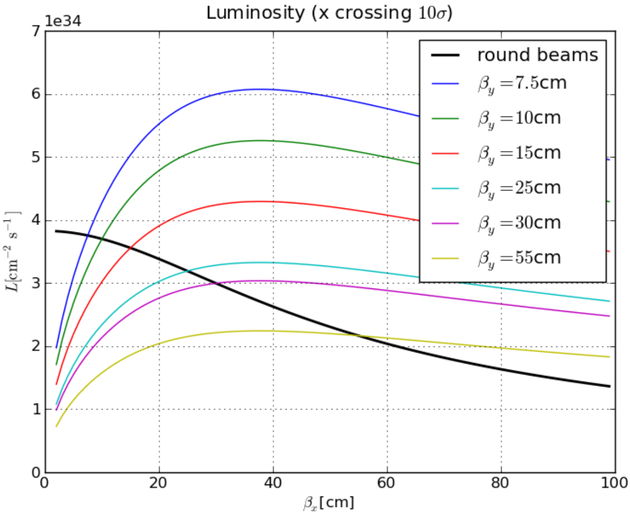
The HL-LHC (formerly SLHC) effort attemps to increase the peak lumoninosity of the LHC with some hardware changes.
There are many parameters that can be tweaked together with new equipment to increase the luminosity (e.g.):

$$L = \frac{N_b^2 n_b f_{\mathrm{rev}}}{4\pi\epsilon\sqrt{\beta_x^*\beta_y^*}} \frac{1}{\sqrt{1+\left(\frac{\sigma_z d_{\mathrm{s}}}{2\beta_x^*}\right)^2}} F_{\mathrm{hr}}$$

$$\frac{2\beta_x^*}{\sigma_z d_{\mathrm{s}}} > F_{\mathrm{geo}} < 1 \qquad F_{\mathrm{hr}} << 1 \text{ for } \beta^* < \sigma_z$$

The following will focus only on the problems and possibilities for reducing $\beta^*$.

# Example




$N_b = 1.7 \cdot 10^{11}$, $n_b = 2808$. $\sigma_z = 7.55$cm, $d_\mathrm{s} = 10$, $\epsilon_n = 3.5$ mm mrad

# Motivation

Phase I upgrade (corresponding to the layout SLHCv2) showed that:

- $\beta^*$ can be reduced only to $30$ cm with no margin

- the main limitations is the chromatic aberrations and strength of the matching section quadrupoles

- the luminosity gain coming from $\beta^*$ is $37\%$

SLHCv3 aims at overcoming those limitations using a new strategy to construct a collision optics. At this stage we proved that:

- the LHC layout is compatible with the new scheme excluding:
  - new larger aperture triplet and Q4-Q5 D1-2 TAS and new TAN in IR1 and IR5,
  - new MQY type Q5 in IR6,
  - possibly an additional MS per family and/or a recommissioning of the MS at 600A (see future studies at the end)

- the performance in terms of DA (excluding beam beam and the new elements) are barely acceptable of extreme cases ($\beta^* = 7.5, 30$cm where the luminosity gain is a factor 2.5)

# New scheme

The new squeezing strategy involves the following steps:

- IR1 and IR5 are squeezed to 60cm round beam in the usual way.
- The squeeze continues keeping the strength of the IR1-5 and the arcs constant and using the neighbor insertions (8-2, 4-6) quads to continue the squeeze at constant phase advance.

As a consequence there will be a betabeat in the neighbor arcs (strong arcs: 8-1 1-2 4-5 5-6).

If:

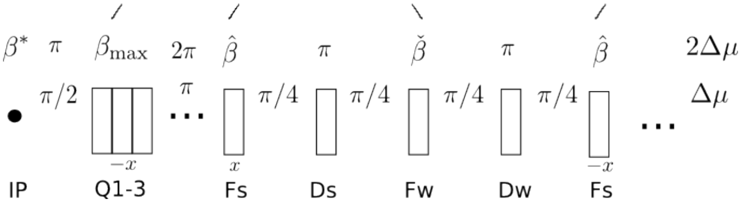
- the strong arcs phase advance is $\pi/2$,
- the phase advance from the IP and the first MS of one F and D family (strong families) is $\pi/2$ equivalent to $\pi$ in the triplet,
- the strong MS are used to compensate the off momentum beta beat of the triplet at $\beta^* = 60$cm or $\beta_{\max} = 5.5$km.

Then:

- each MS of one family (*strong*) will experience a peak of the beta function proportional to the $1/\beta^*$ and to $\beta_{\max}$ in the triplet.
- each MS creates a off momentum beta beta perturbation that adds coherently and cancel exactly the perturbation from the triplet for any $\beta_x^*, \beta_y^*$ at any stage of the squeeze.
- with a closed orbit peak at the strong sextupole, it is possible to create a dispersion perturbation that can compensate the spurious dispersion.

# New scheme

Beta beat rotate with twice the phase advance.



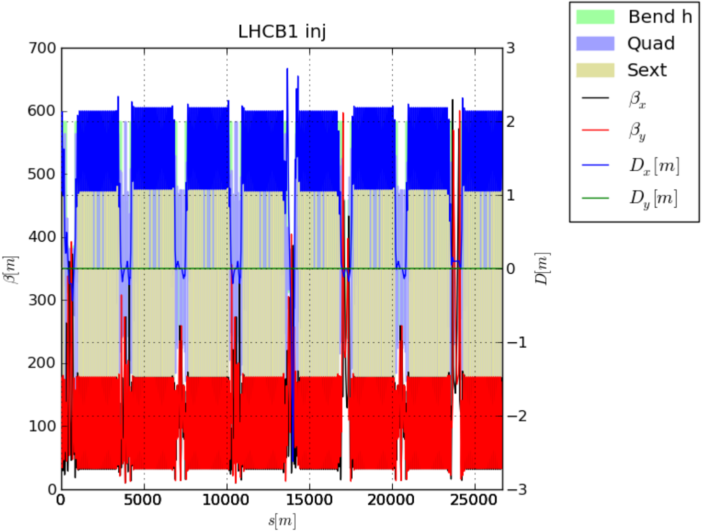

$\hat{\beta}$: high beta peak: nominal + perturbation
$\check{\beta}$: low beta peak: nominal - perturbation
Fs,Ds: Strong focusing, defocusing sextupole location
Fw,Dw: Weak focusing, defocusing sextupole location

# Optics

| Name | IP1 | | | IP5 | | |
|---|---|---|---|---|---|---|
| | $\beta^*_x$ [m] | $\beta^*_y$ [m] | X plane | $\beta^*_x$ [m] | $\beta^*_y$ [m] | X plane |
| inj | 14 | 14 | H or V | 14 | 14 | V or H |
| 1111 | 0.60 | 0.60 | H or V | 0.60 | 0.60 | V or H |
| 2222 | 0.30 | 0.30 | H or V | 0.30 | 0.30 | V or H |
| 2828 | 0.30 | 0.075 | H | 0.30 | 0.075 | H |
| 2882 | 0.30 | 0.075 | H | 0.075 | 0.30 | V |
| 8228 | 0.075 | 0.30 | V | 0.30 | 0.075 | H |
| 8282 | 0.075 | 0.30 | V | 0.075 | 0.30 | V |

Inj: integer tune split reduced to 2, 4 arcs at $\pi/2$;
1111: pre-squeezed optics IR15 constant from now on, using PhaseI elements;
others: squeeze using IR8, IR2, IR4, IR6, numbers refers to the $\beta^*$ reduction factor.

# LHC Squeeze



LHCB1 inj
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
0
100
200
300
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10000
15000
20000
25000
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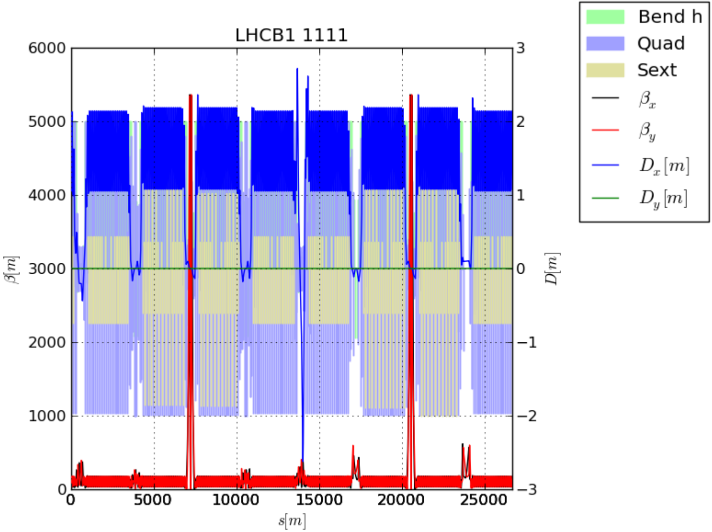
−1
−2
−3

# LHC Squeeze


LHCB1 1111
6000
5000
4000
3000
2000
1000
0
$\beta[m]$
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5000
10000
15000
20000
25000
$s[m]$
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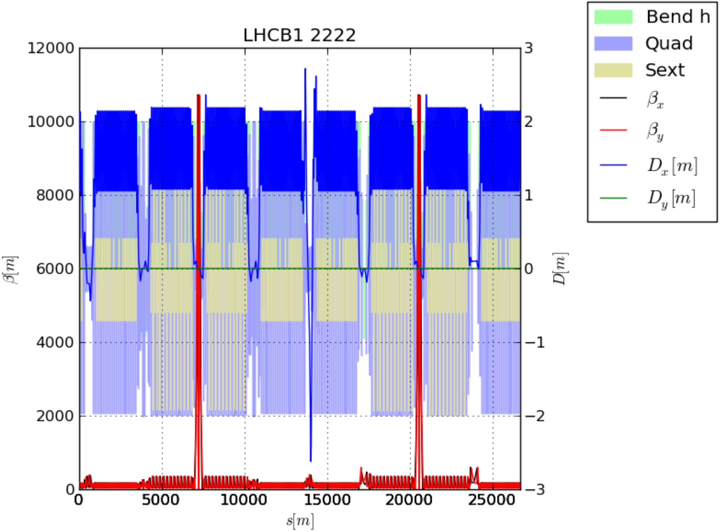
2
1
0
−1
−2
−3
$D[m]$
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$

# LHC Squeeze



LHCB1 2222
12000
10000
8000
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2000
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5000
10000
15000
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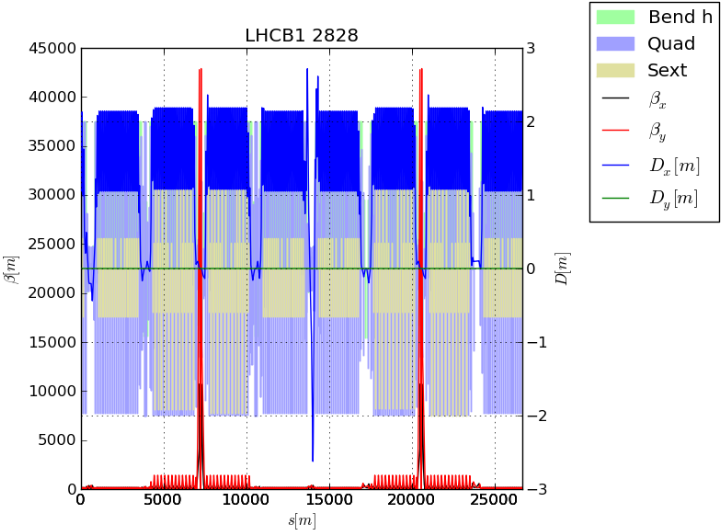
$\beta[m]$
$D[m]$
$s[m]$
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$

# LHC Squeeze


LHCB1 2828
45000
40000
35000
30000
25000
20000
15000
10000
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5000
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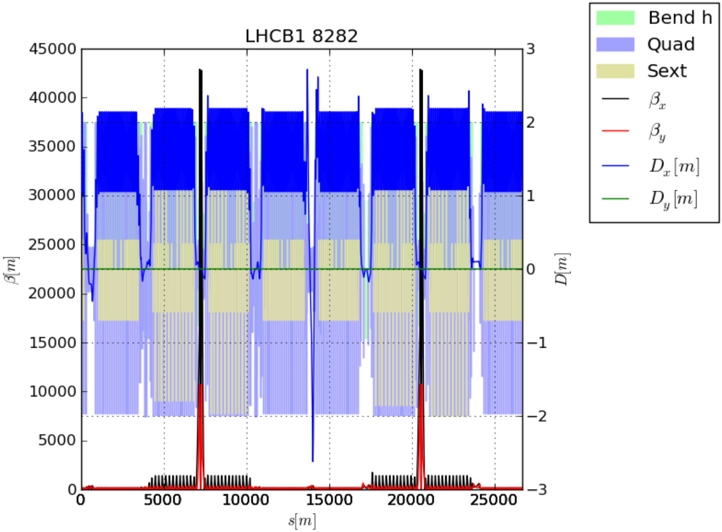
15000
20000
25000
$s[m]$
$\beta[m]$
3
2
1
0
−1
−2
−3
$D[m]$
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$

# LHC Squeeze



LHCB1 8282
45000
40000
35000
30000
25000
20000
15000
10000
5000
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$\beta[m]$
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5000
10000
15000
20000
25000
$s[m]$
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−1
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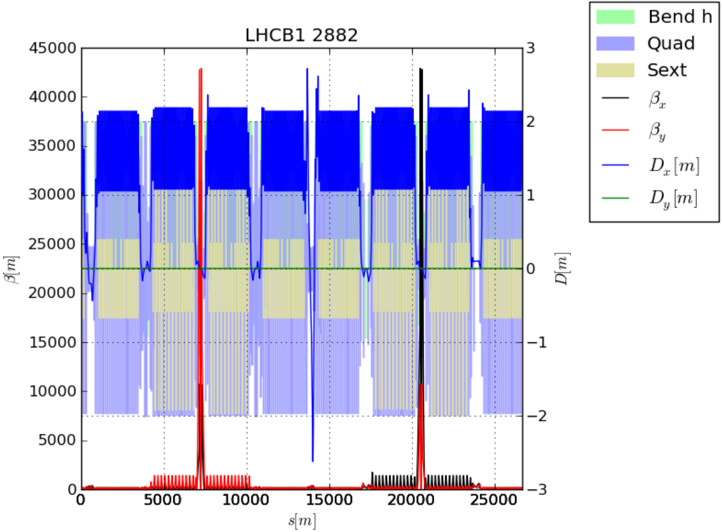
−3
$D[m]$
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$

# LHC Squeeze


LHCB1 2882
45000
40000
35000
30000
25000
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15000
10000
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$\beta[m]$
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$s[m]$
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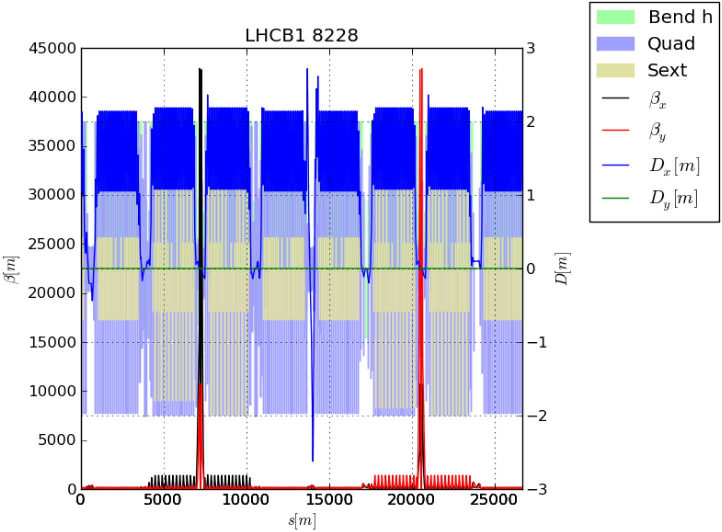
$D[m]$
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$

# LHC Squeeze



LHCB1 8228
45000
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35000
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15000
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5000
10000
15000
20000
25000
s[m]
β[m]
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2
1
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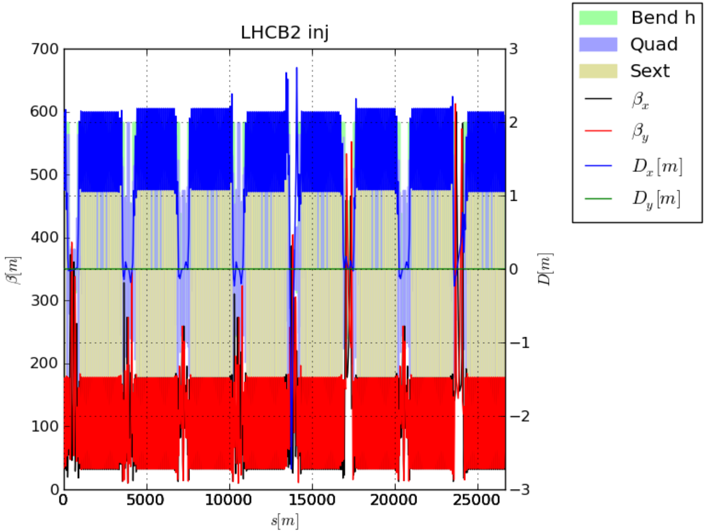
−1
−2
−3
D[m]
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$

# LHC Squeeze



LHCB2 inj
700
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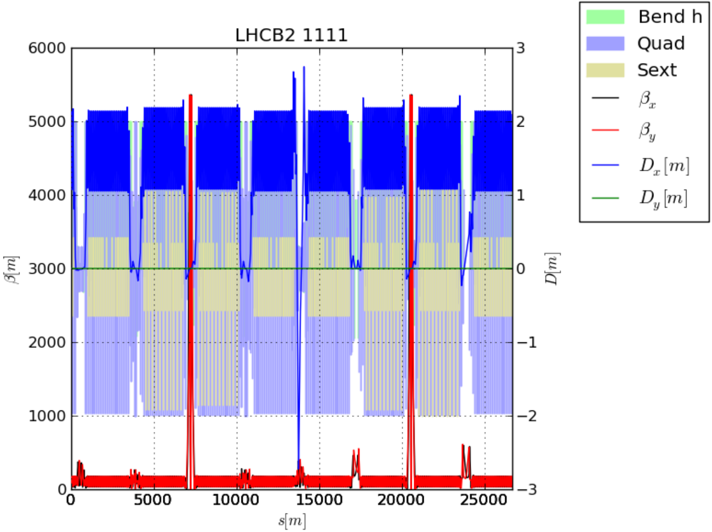
$\beta[m]$
$D[m]$
$s[m]$
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$

# LHC Squeeze



LHCB2 1111
6000
5000
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3000
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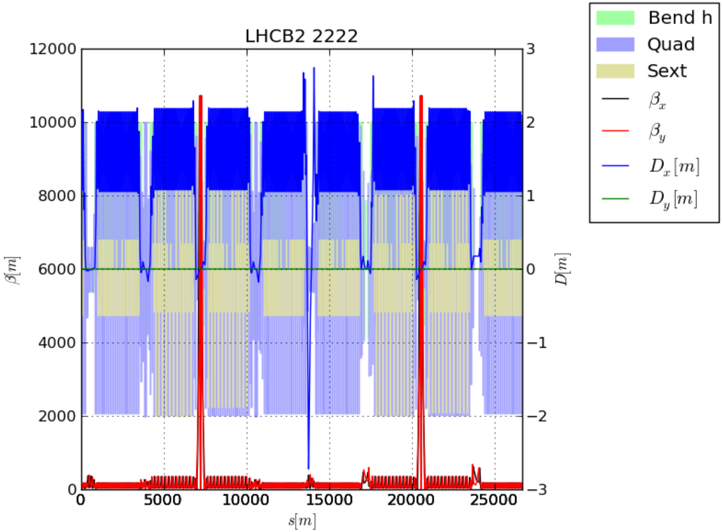
$\beta[m]$
$s[m]$
$D[m]$
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$

# LHC Squeeze



LHCB2 2222
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$s[m]$
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Bend h
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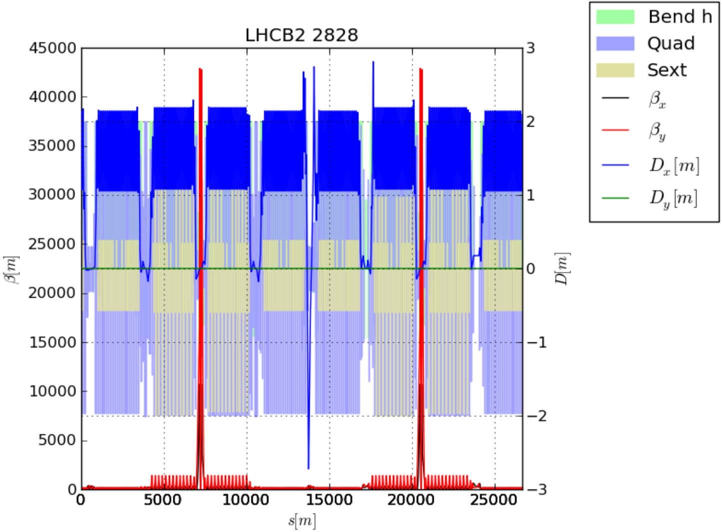
Sext
$\beta_x$
$\beta_y$
$D_x[m]$
$D_y[m]$

# LHC Squeeze


LHCB2 2828
45000
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$\beta[m]$
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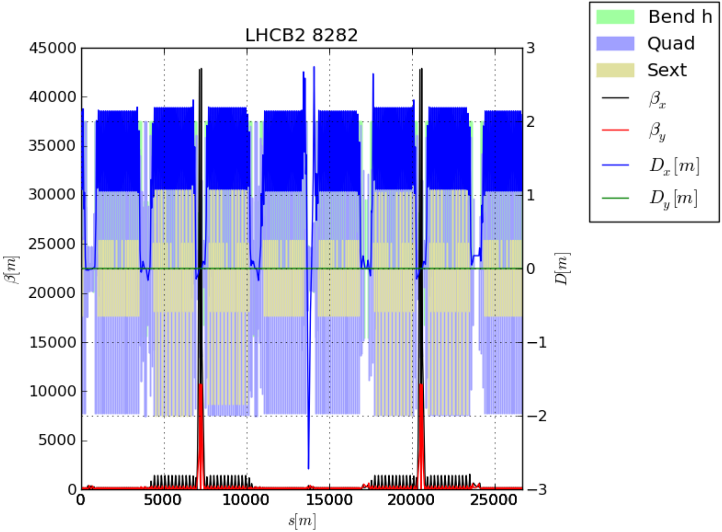
$D[m]$
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$

# LHC Squeeze



LHCB2 8282
Bend h
Quad
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$\beta_x$
$\beta_y$
$D_x[m]$
$D_y[m]$
$\beta[m]$
$D[m]$
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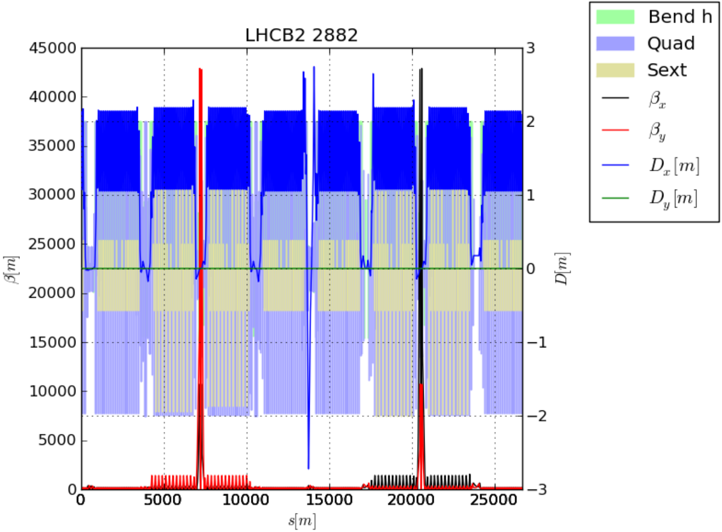
# LHC Squeeze



LHCB2 2882
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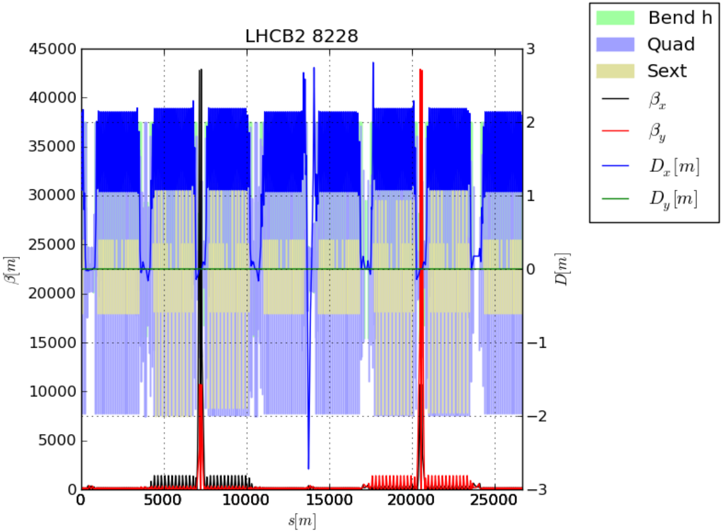
$D[m]$
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x[m]$
$D_y[m]$

# LHC Squeeze



LHCB2 8228
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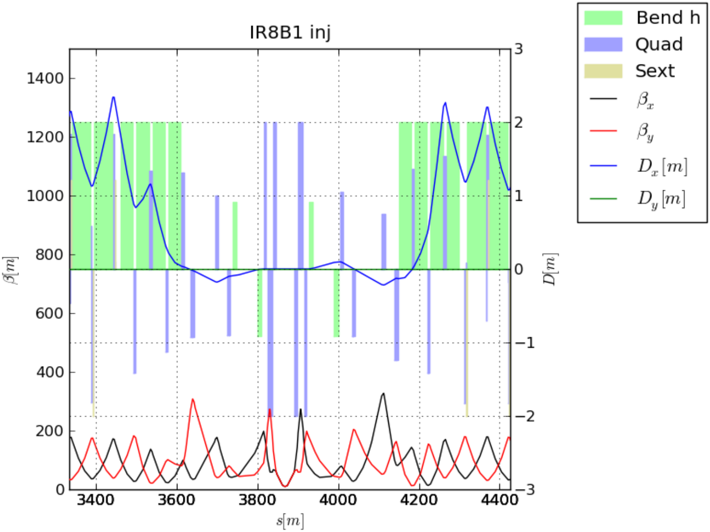
$s[m]$
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$

# IR8 Squeeze



IR8B1 inj
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x[m]$
$D_y[m]$
$\beta[m]$
$D[m]$
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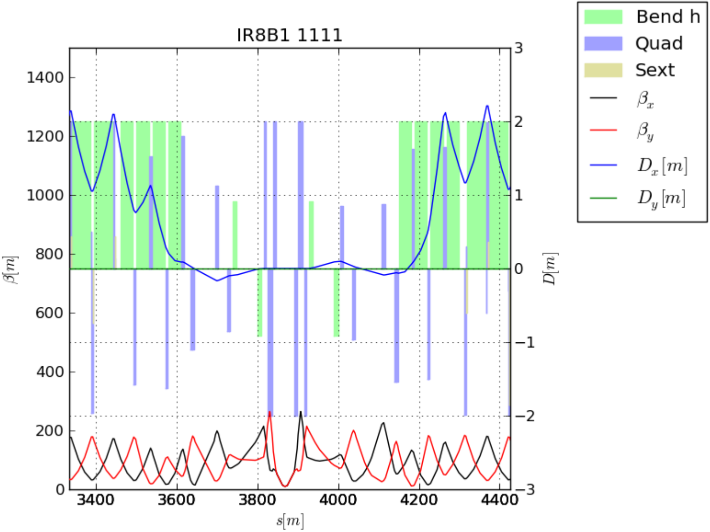
# IR8 Squeeze



IR8B1 1111
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$\beta_x$
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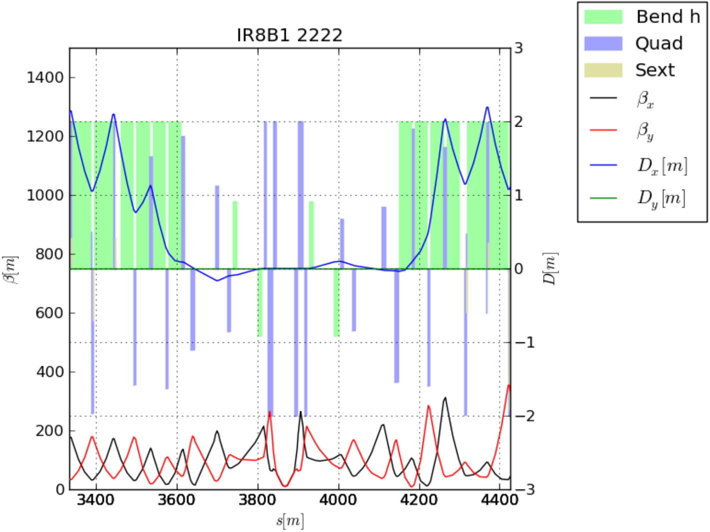
$D_x\,[m]$
$D_y\,[m]$

# IR8 Squeeze



IR8B1 2222
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$s[m]$
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$D[m]$
Bend h
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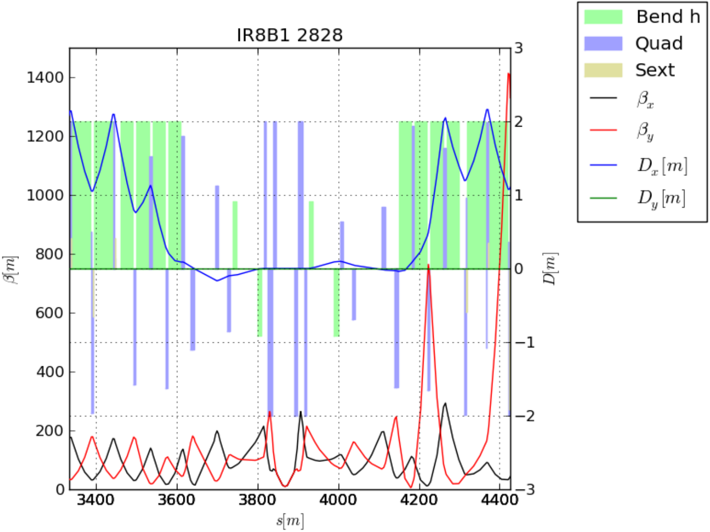
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$

# IR8 Squeeze



IR8B1 2828
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$D[m]$
Bend h
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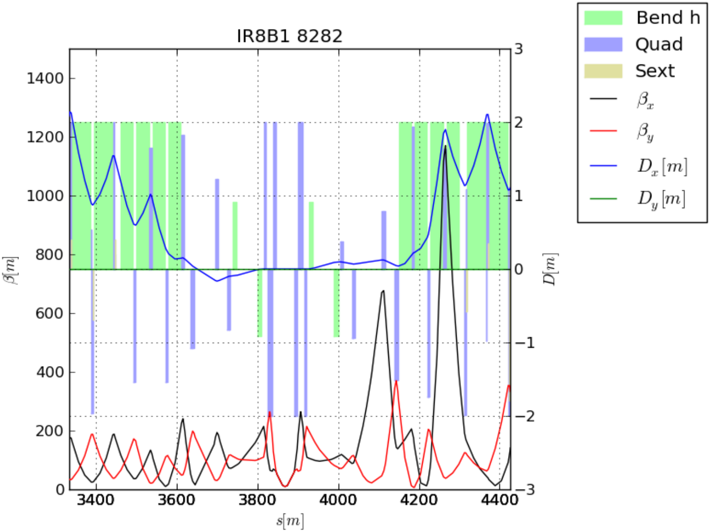
$\beta_x$
$\beta_y$
$D_x[m]$
$D_y[m]$

# IR8 Squeeze



IR8B1 8282
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$D[m]$
Bend h
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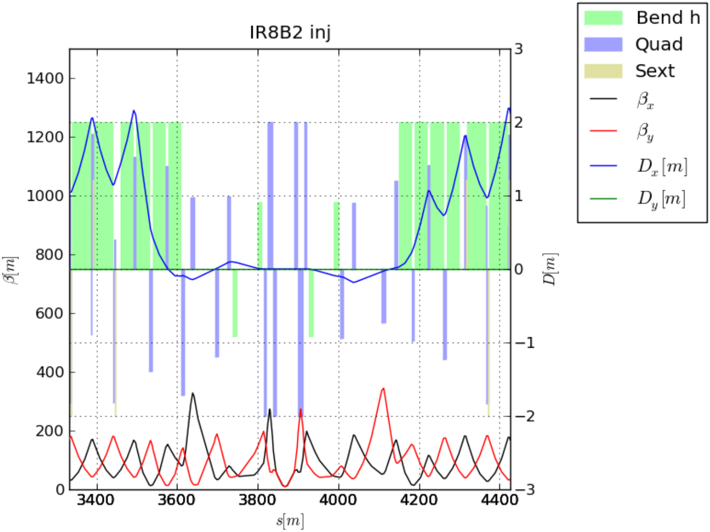
$\beta_y$
$D_x[m]$
$D_y[m]$

# IR8 Squeeze


IR8B2 inj
Bend h
Quad
Sext
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$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
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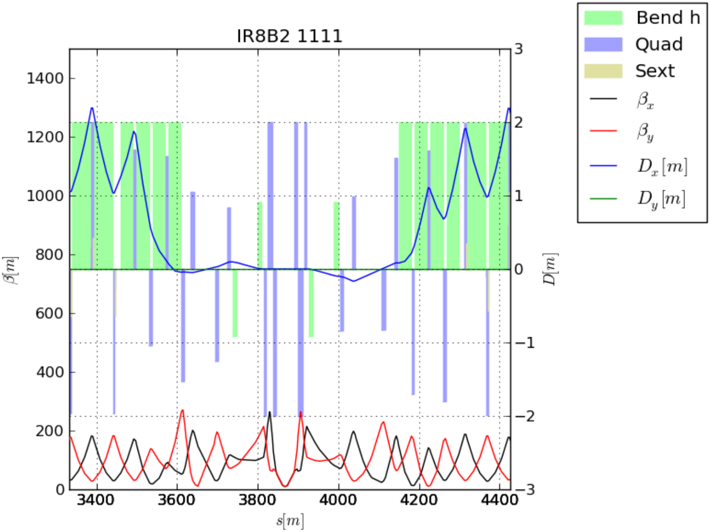
# IR8 Squeeze



IR8B2 1111
Bend h
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Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
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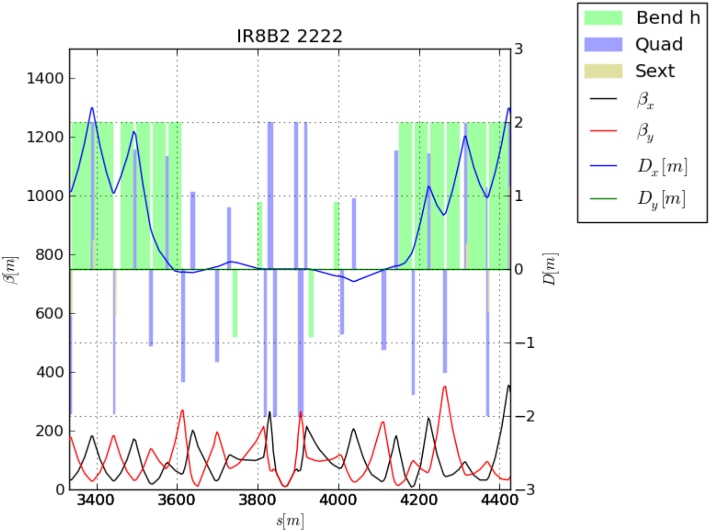
# IR8 Squeeze



IR8B2 2222
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
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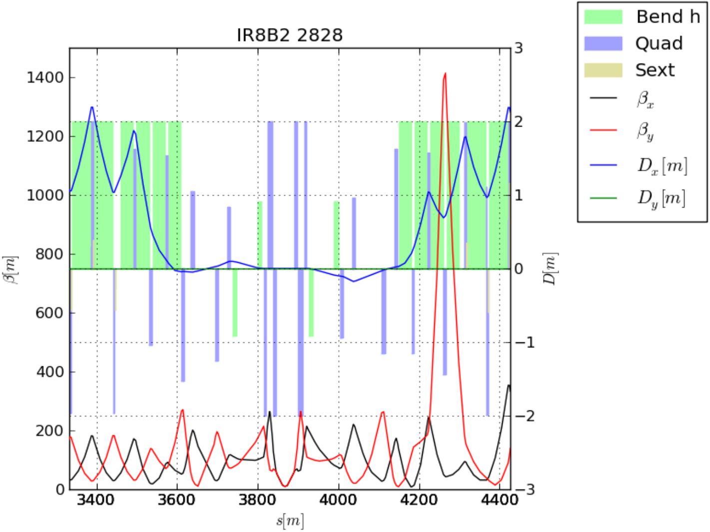
# IR8 Squeeze



IR8B2 2828
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
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−1
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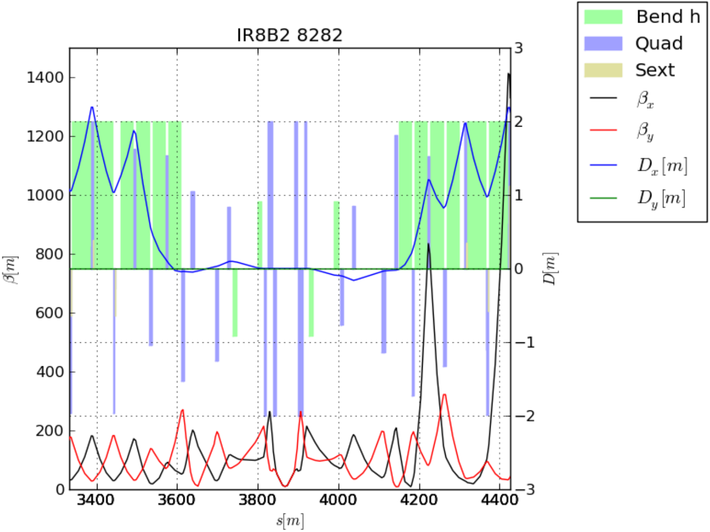
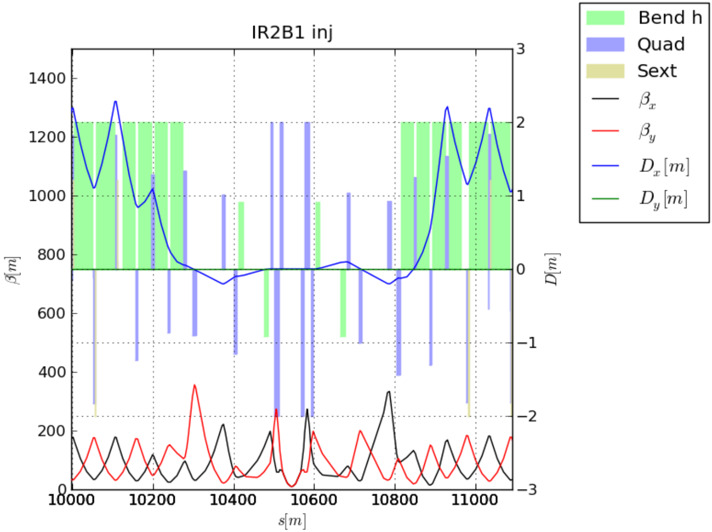
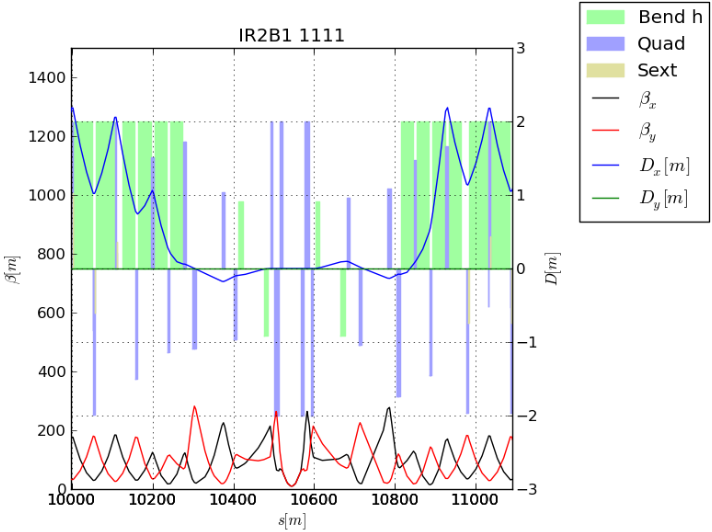
# IR8 Squeeze



# IR2 Squeeze

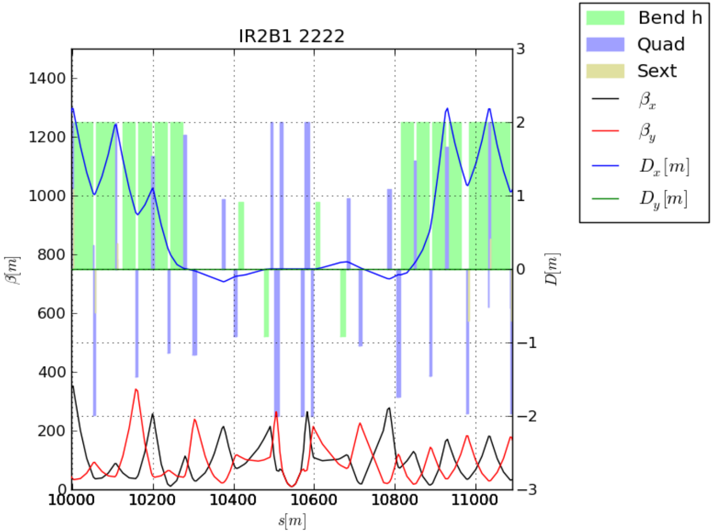

IR2B1 inj
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x[m]$
$D_y[m]$
$\beta[m]$
$D[m]$
$s[m]$
0
200
400
600
800
1000
1200
1400
10000
10200
10400
10600
10800
11000
3
2
1
0
−1
−2
−3

# IR2 Squeeze



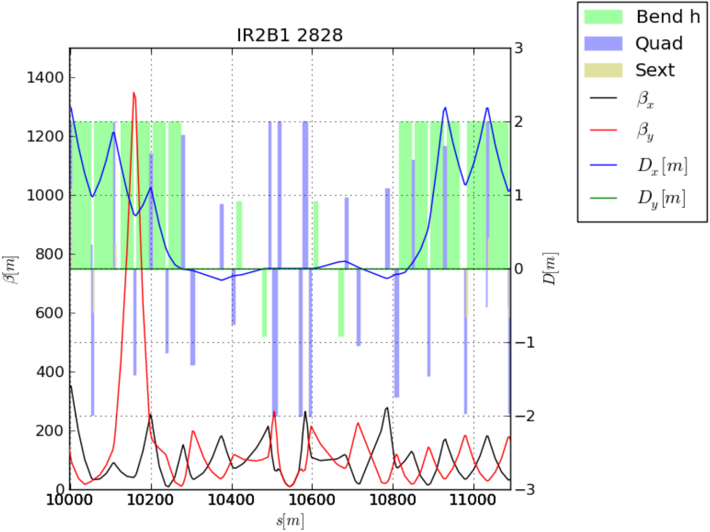
IR2B1 1111
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
0
200
400
600
800
1000
1200
1400
10000
10200
10400
10600
10800
11000
3
2
1
0
−1
−2
−3

# IR2 Squeeze

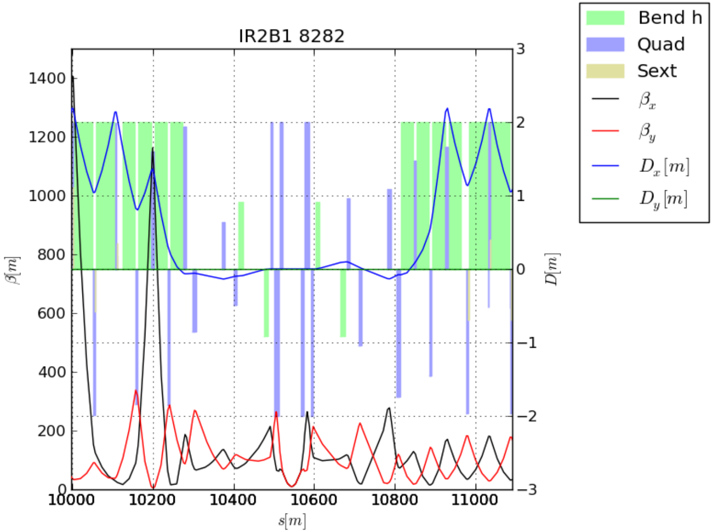


IR2B1 2222
1400
1200
1000
800
600
400
200
0
$\beta[m]$
3
2
1
0
−1
−2
−3
$D[m]$
10000
10200
10400
10600
10800
11000
$s[m]$
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$

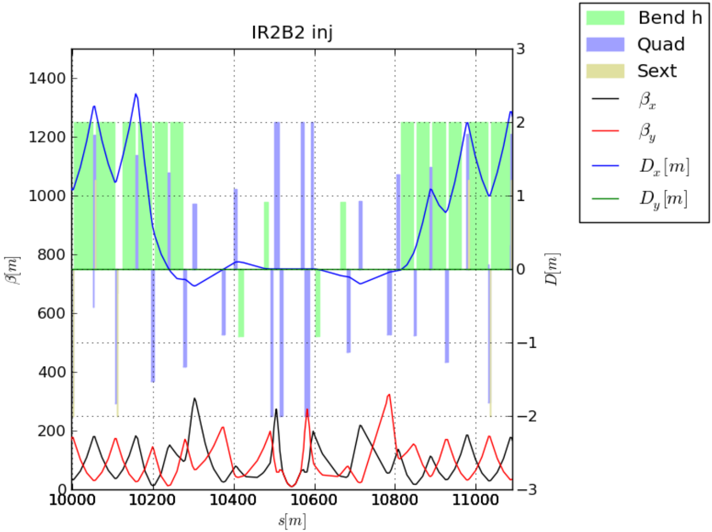
# IR2 Squeeze


IR2B1 2828
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x [m]$
$D_y [m]$
$\beta[m]$
$D[m]$
$s[m]$
1400
1200
1000
800
600
400
200
0
3
2
1
0
−1
−2
−3
10000
10200
10400
10600
10800
11000

# IR2 Squeeze

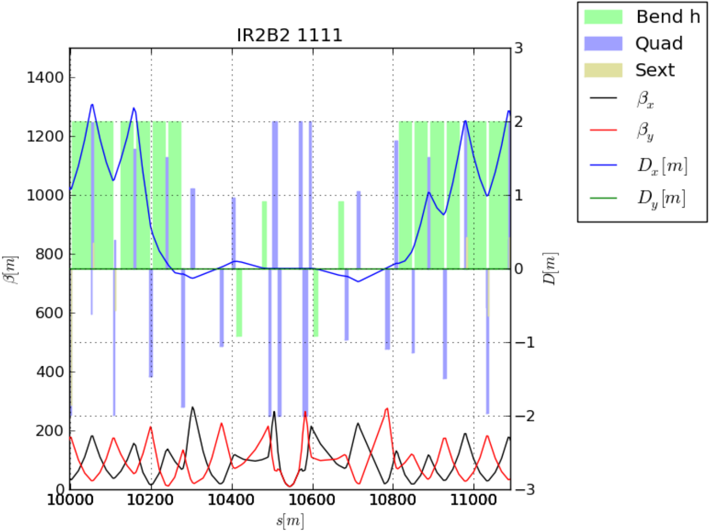

IR2B1 8282
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
0
200
400
600
800
1000
1200
1400
10000
10200
10400
10600
10800
11000
3
2
1
0
−1
−2
−3

# IR2 Squeeze

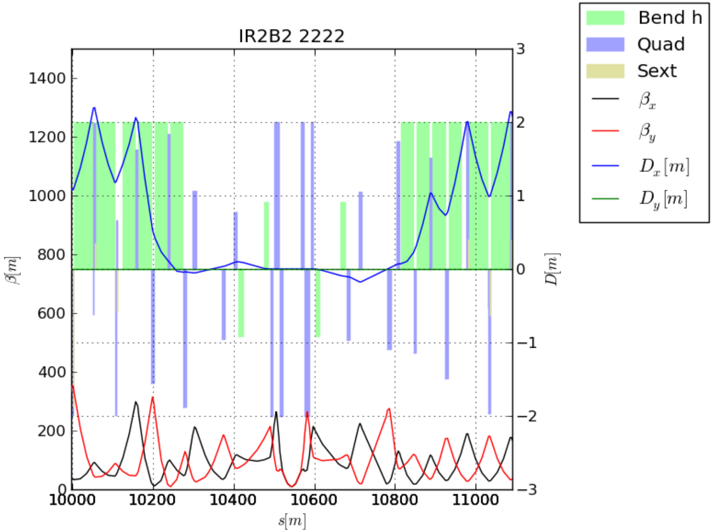


IR2B2 inj
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x[m]$
$D_y[m]$
$\beta[m]$
$D[m]$
$s[m]$
0
200
400
600
800
1000
1200
1400
3
2
1
0
−1
−2
−3
10000
10200
10400
10600
10800
11000

# IR2 Squeeze

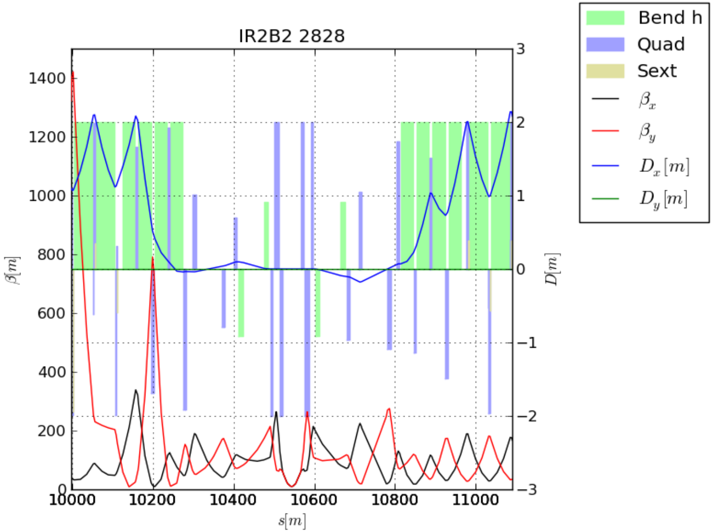

IR2B2 1111
$\beta[m]$
$D[m]$
$s[m]$
0
200
400
600
800
1000
1200
1400
10000
10200
10400
10600
10800
11000
3
2
1
0
−1
−2
−3
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x[m]$
$D_y[m]$

# IR2 Squeeze



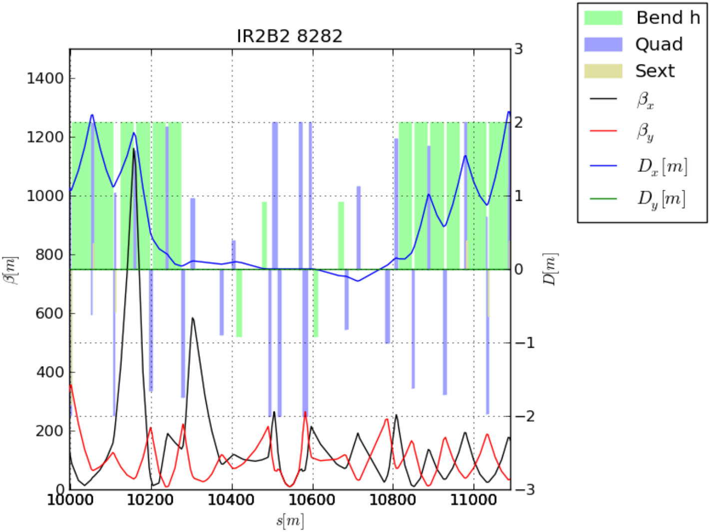
IR2B2 2222
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
1400
1200
1000
800
600
400
200
0
3
2
1
0
−1
−2
−3
10000
10200
10400
10600
10800
11000
$\beta[m]$
$D[m]$
$s[m]$

# IR2 Squeeze

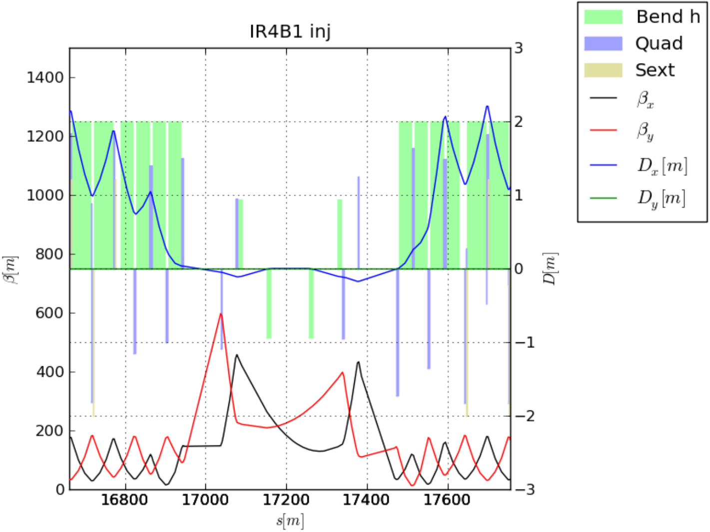


IR2B2 2828
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
1400
1200
1000
800
600
400
200
0
3
2
1
0
−1
−2
−3
10000
10200
10400
10600
10800
11000

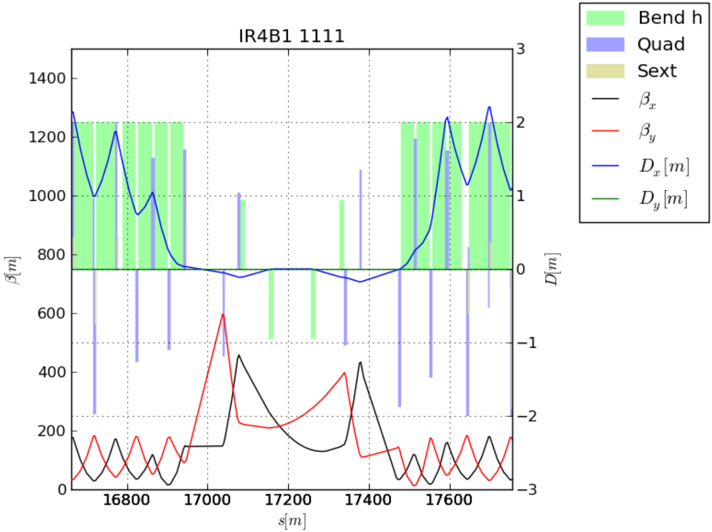
# IR2 Squeeze


IR2B2 8282
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x[m]$
$D_y[m]$
$\beta[m]$
$D[m]$
$s[m]$
1400
1200
1000
800
600
400
200
0
10000
10200
10400
10600
10800
11000
3
2
1
0
−1
−2
−3

# IR4 Squeeze


IR4B1 inj
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
0
200
400
600
800
1000
1200
1400
3
2
1
0
−1
−2
−3
16800
17000
17200
17400
17600

# IR4 Squeeze



IR4B1 1111
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
0
200
400
600
800
1000
1200
1400
16800
17000
17200
17400
17600
3
2
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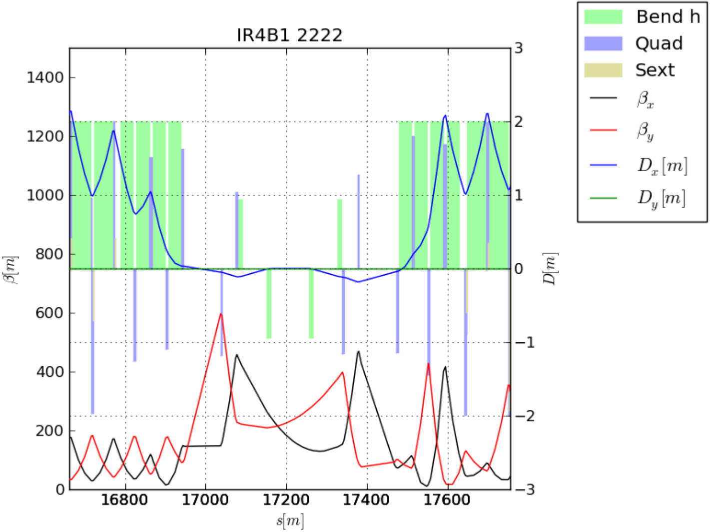
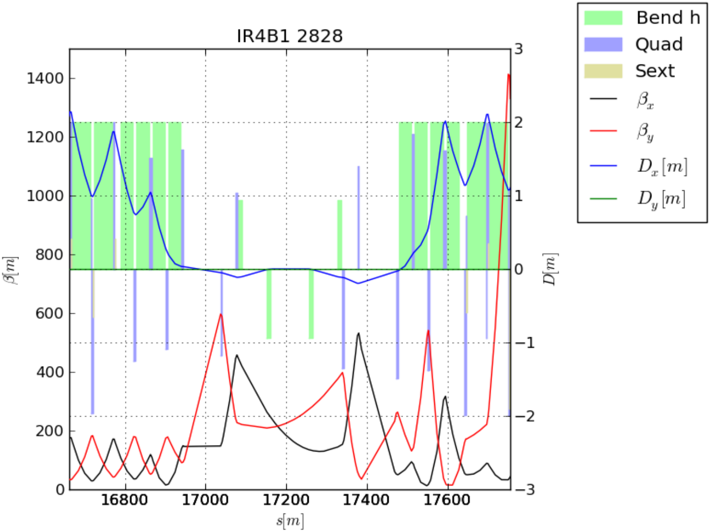
−1
−2
−3

# IR4 Squeeze


IR4B1 2222
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
1400
1200
1000
800
600
400
200
0
3
2
1
0
−1
−2
−3
16800
17000
17200
17400
17600

# IR4 Squeeze


IR4B1 2828
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
1400
1200
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16800
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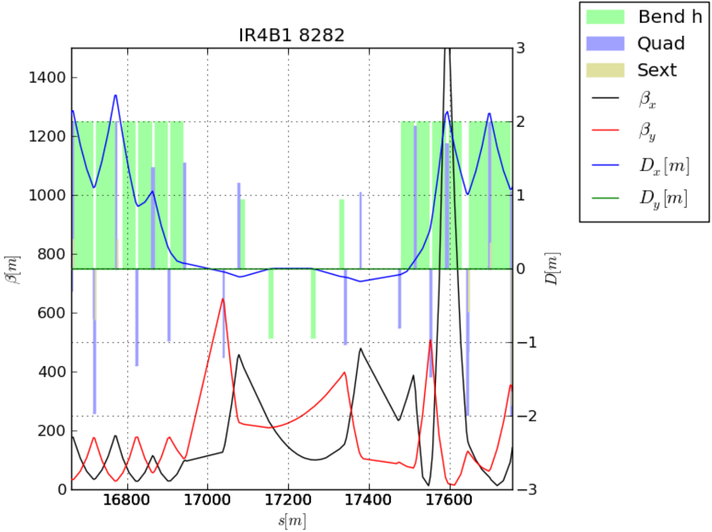
17400
17600

# IR4 Squeeze



IR4B1 8282
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
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200
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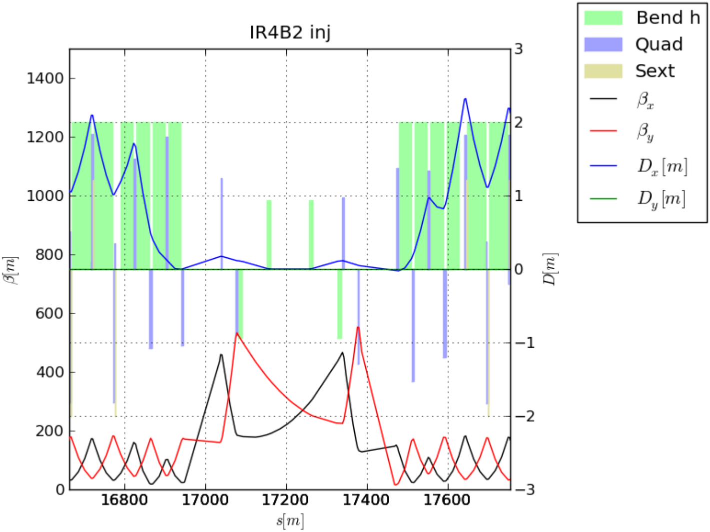
−3

# IR4 Squeeze



IR4B2 inj
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
0
200
400
600
800
1000
1200
1400
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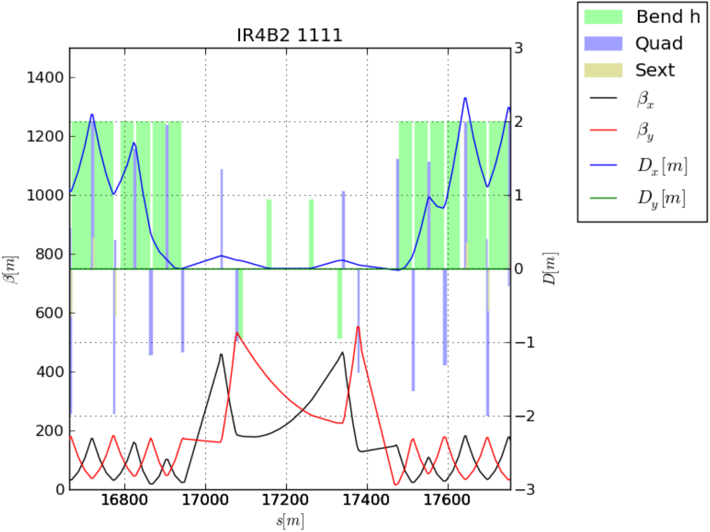
2
1
0
−1
−2
−3
16800
17000
17200
17400
17600

# IR4 Squeeze


IR4B2 1111
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
0
200
400
600
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1200
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17200
17400
17600
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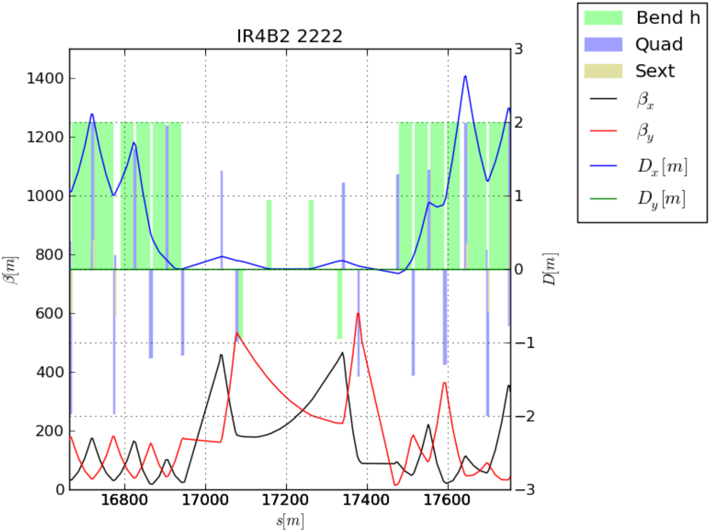
0
−1
−2
−3

# IR4 Squeeze



IR4B2 2222
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
0
200
400
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800
1000
1200
1400
16800
17000
17200
17400
17600
3
2
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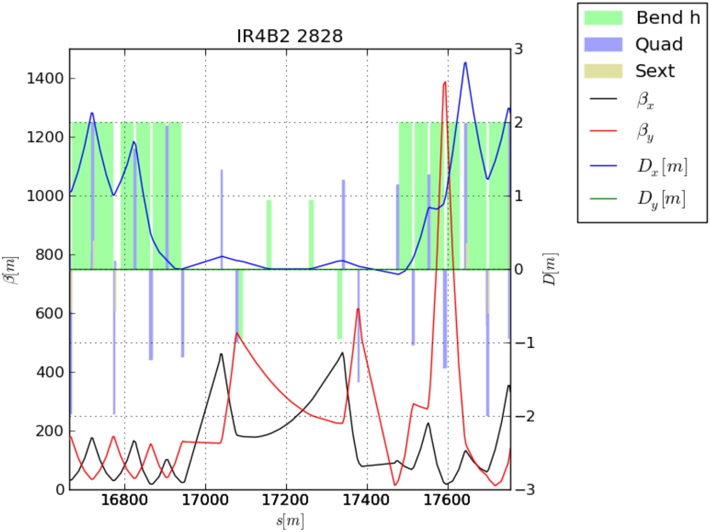
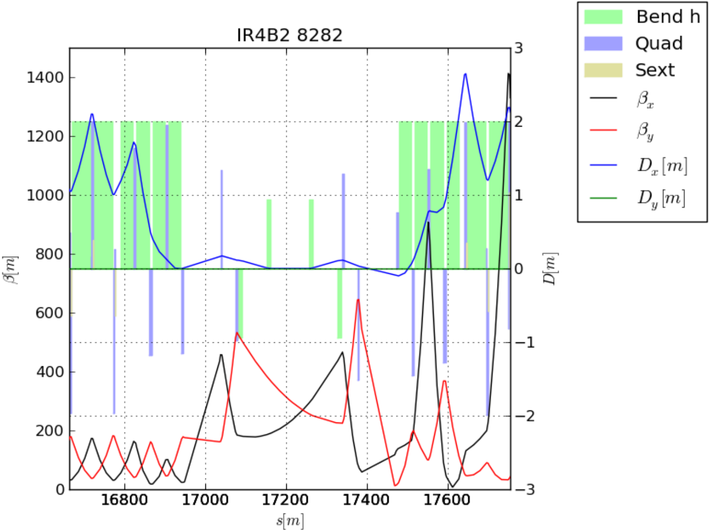
0
−1
−2
−3

# IR4 Squeeze



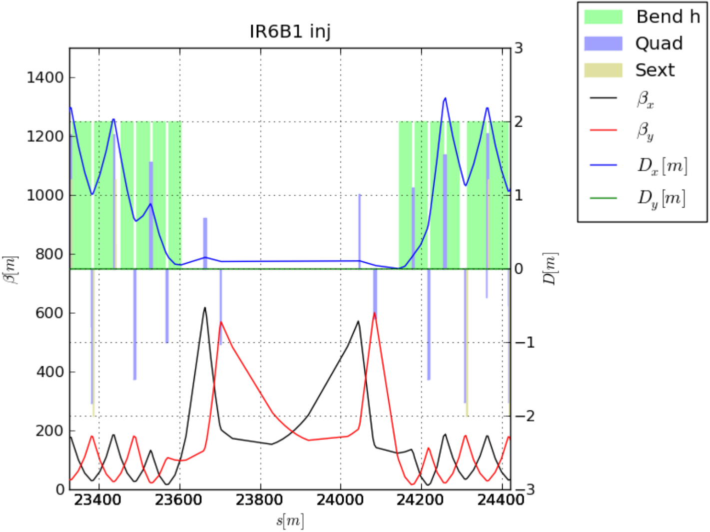
IR4B2 2828
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
0
200
400
600
800
1000
1200
1400
16800
17000
17200
17400
17600
3
2
1
0
−1
−2
−3

# IR4 Squeeze



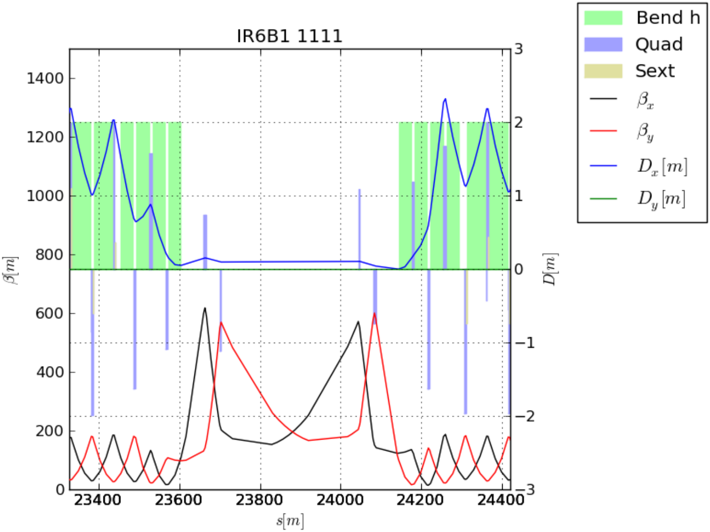
IR4B2 8282
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
0
200
400
600
800
1000
1200
1400
16800
17000
17200
17400
17600
3
2
1
0
−1
−2
−3

# IR6 Squeeze

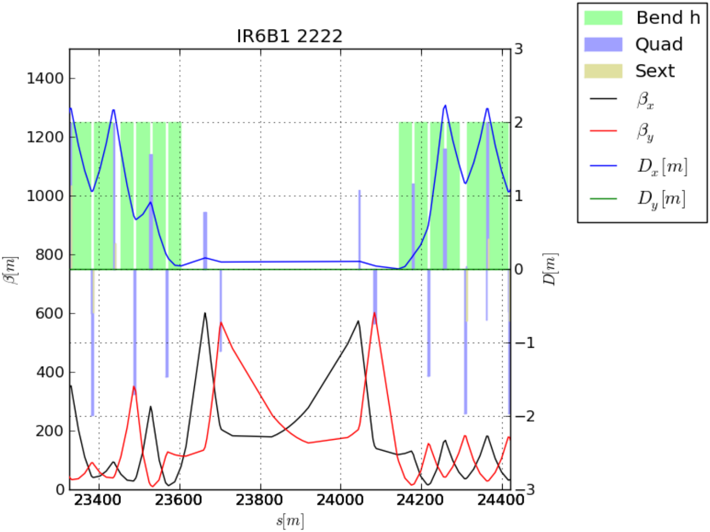


IR6B1 inj
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
1400
1200
1000
800
600
400
200
0
$\beta[m]$
3
2
1
0
−1
−2
−3
$D[m]$
23400
23600
23800
24000
24200
24400
$s[m]$

# IR6 Squeeze

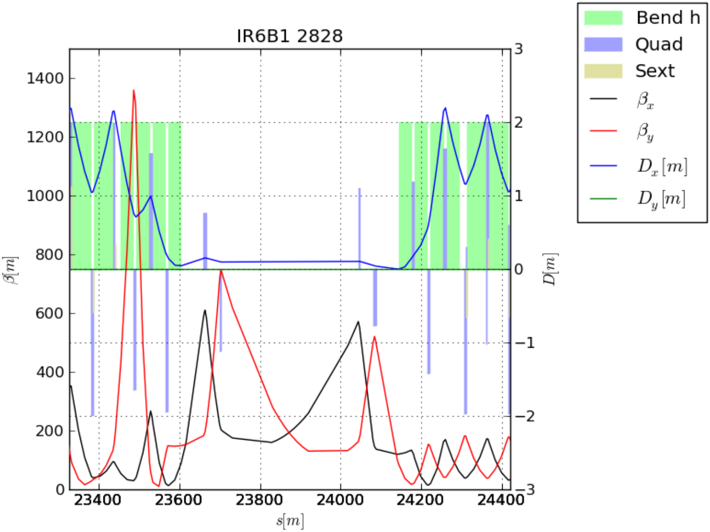

IR6B1 1111
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
1400
1200
1000
800
600
400
200
0
3
2
1
0
−1
−2
−3
23400
23600
23800
24000
24200
24400

# IR6 Squeeze

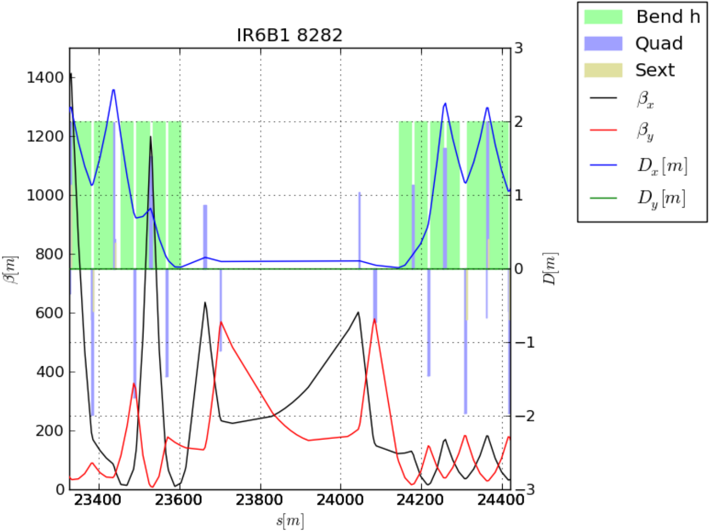


IR6B1 2222
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
1400
1200
1000
800
600
400
200
0
23400
23600
23800
24000
24200
24400
3
2
1
0
−1
−2
−3

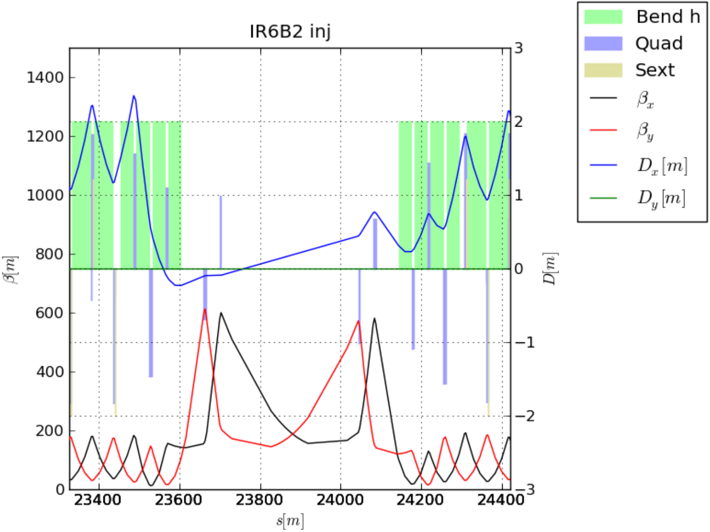
# IR6 Squeeze


IR6B1 2828
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
0
200
400
600
800
1000
1200
1400
23400
23600
23800
24000
24200
24400
−3
−2
−1
0
1
2
3

# IR6 Squeeze

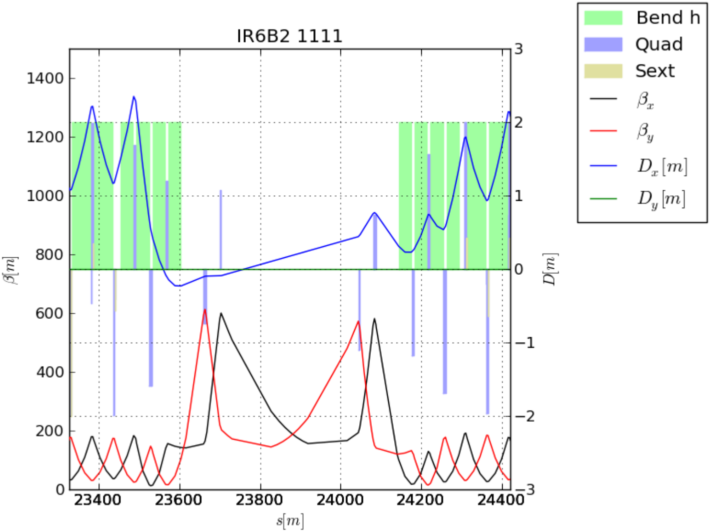

IR6B1 8282
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
1400
1200
1000
800
600
400
200
0
23400
23600
23800
24000
24200
24400
3
2
1
0
−1
−2
−3

# IR6 Squeeze



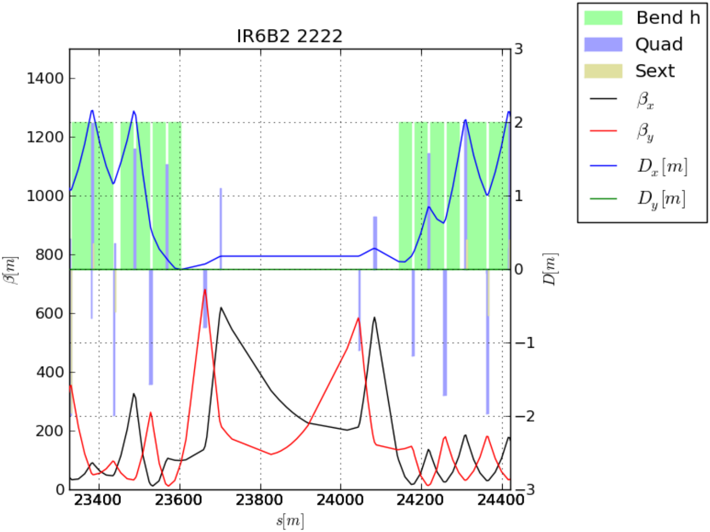
IR6B2 inj
1400
1200
1000
800
600
400
200
0
$\beta[m]$
23400
23600
23800
24000
24200
24400
$s[m]$
3
2
1
0
−1
−2
−3
$D[m]$
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x[m]$
$D_y[m]$

# IR6 Squeeze

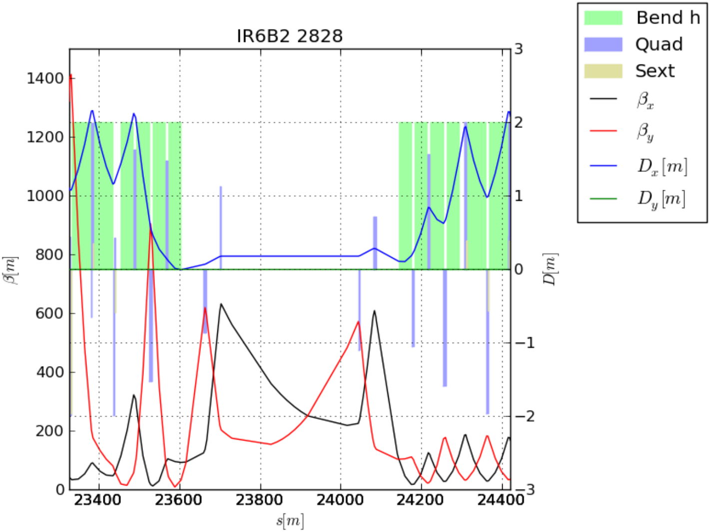


IR6B2 1111
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
0
200
400
600
800
1000
1200
1400
−3
−2
−1
0
1
2
3
23400
23600
23800
24000
24200
24400

# IR6 Squeeze

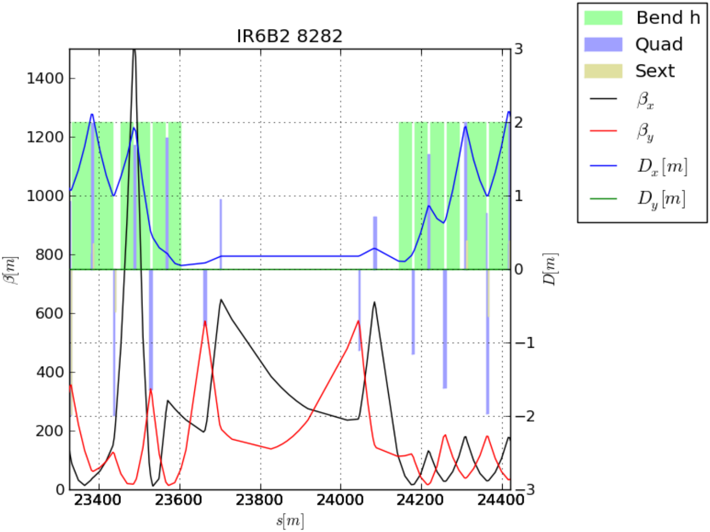

IR6B2 2222
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x[m]$
$D_y[m]$
$\beta[m]$
$D[m]$
$s[m]$
0
200
400
600
800
1000
1200
1400
23400
23600
23800
24000
24200
24400
3
2
1
0
−1
−2
−3

# IR6 Squeeze



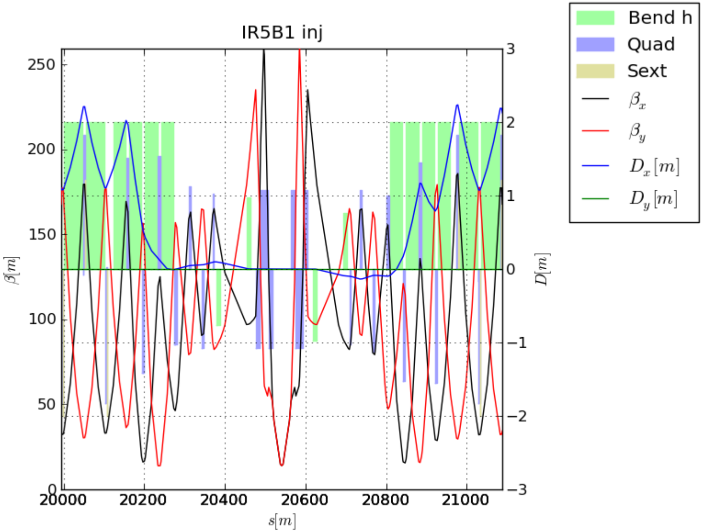
IR6B2 2828
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x[m]$
$D_y[m]$
$\beta[m]$
$D[m]$
$s[m]$
1400
1200
1000
800
600
400
200
0
3
2
1
0
−1
−2
−3
23400
23600
23800
24000
24200
24400

# IR6 Squeeze

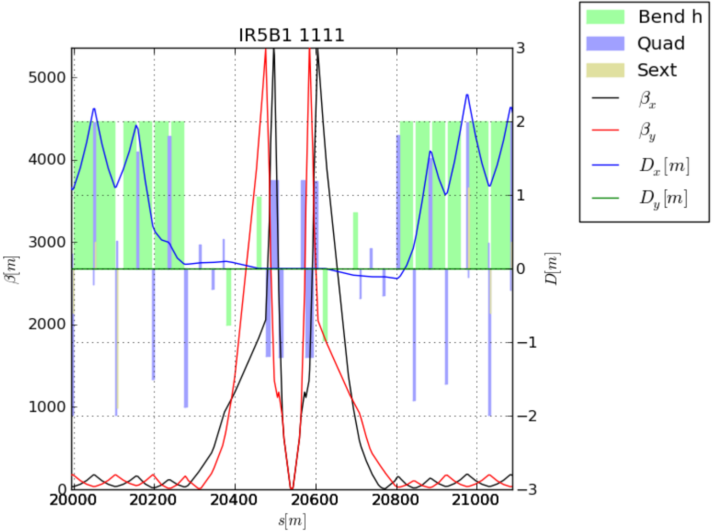


IR6B2 8282
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x[m]$
$D_y[m]$
$\beta[m]$
$D[m]$
$s[m]$
0
200
400
600
800
1000
1200
1400
23400
23600
23800
24000
24200
24400
−3
−2
−1
0
1
2
3

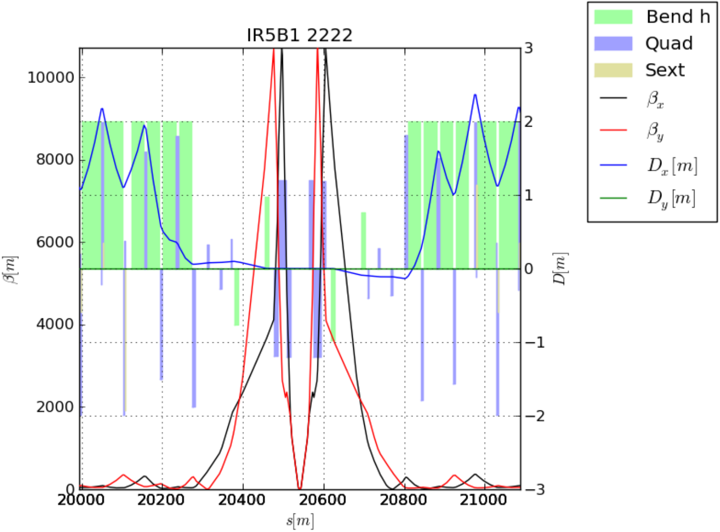
# LHC Squeeze


IR5B1 inj
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
0
50
100
150
200
250
3
2
1
0
−1
−2
−3
20000
20200
20400
20600
20800
21000

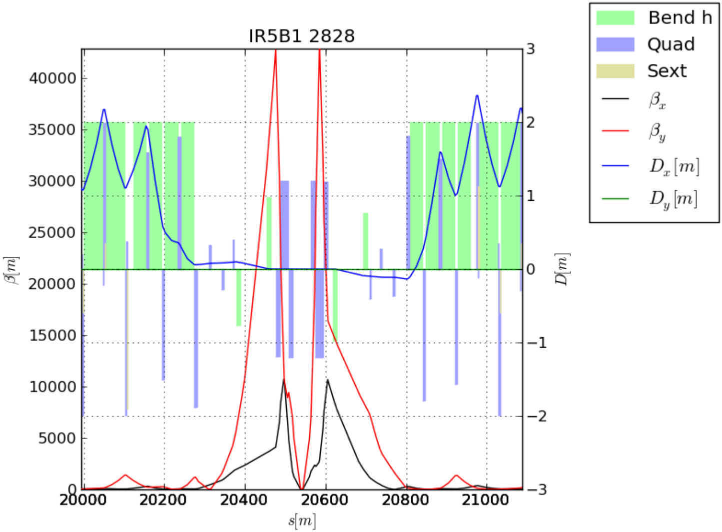
# LHC Squeeze


IR5B1 1111
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x[m]$
$D_y[m]$
$\beta[m]$
$D[m]$
$s[m]$
5000
4000
3000
2000
1000
0
3
2
1
0
−1
−2
−3
20000
20200
20400
20600
20800
21000

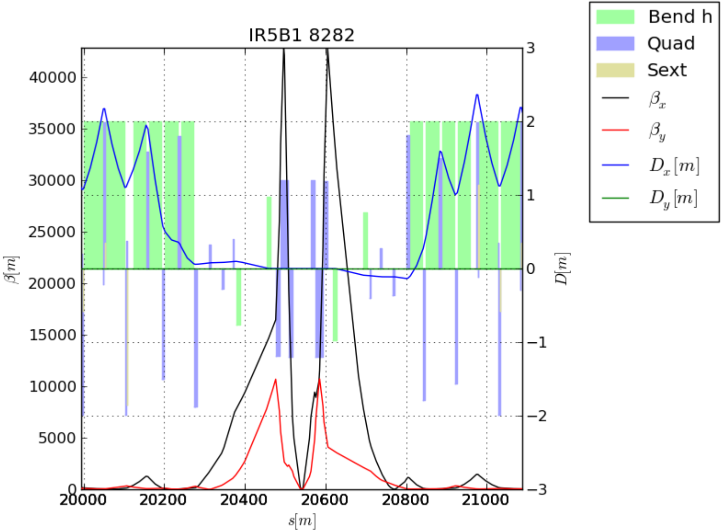
# LHC Squeeze


IR5B1 2222
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x[m]$
$D_y[m]$
$\beta[m]$
$D[m]$
$s[m]$
10000
8000
6000
4000
2000
0
20000
20200
20400
20600
20800
21000
3
2
1
0
−1
−2
−3

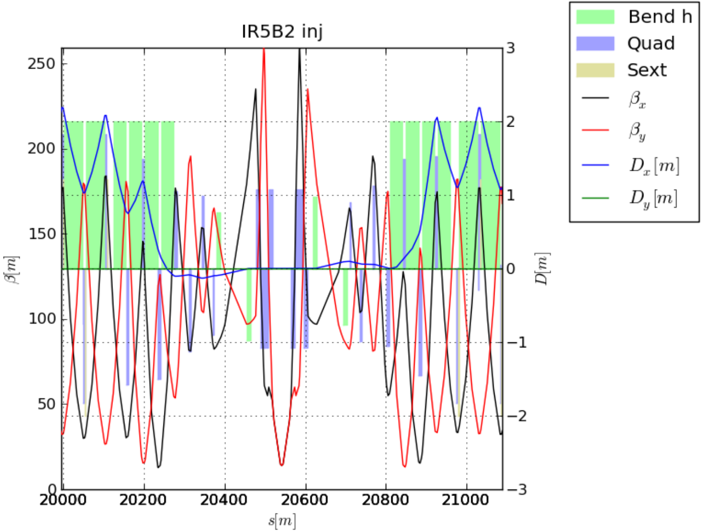
# LHC Squeeze


IR5B1 2828
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
40000
35000
30000
25000
20000
15000
10000
5000
0
20000
20200
20400
20600
20800
21000
3
2
1
0
−1
−2
−3

# LHC Squeeze

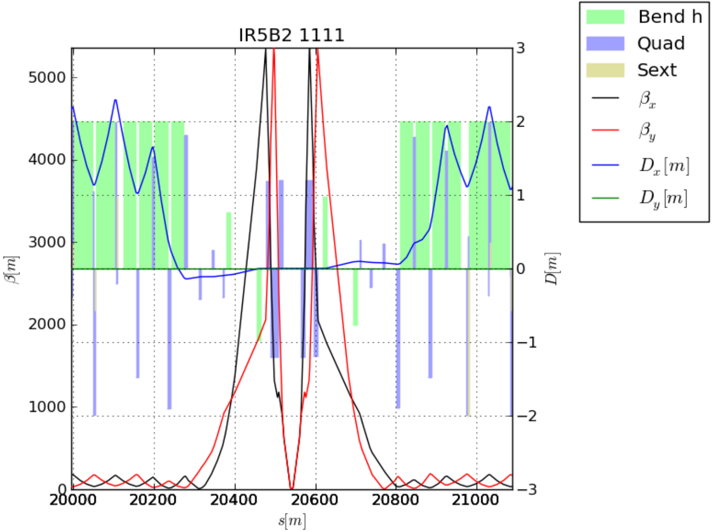

IR5B1 8282
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x[m]$
$D_y[m]$
$\beta[m]$
$D[m]$
$s[m]$
40000
35000
30000
25000
20000
15000
10000
5000
0
20000
20200
20400
20600
20800
21000
3
2
1
0
−1
−2
−3

# LHC Squeeze



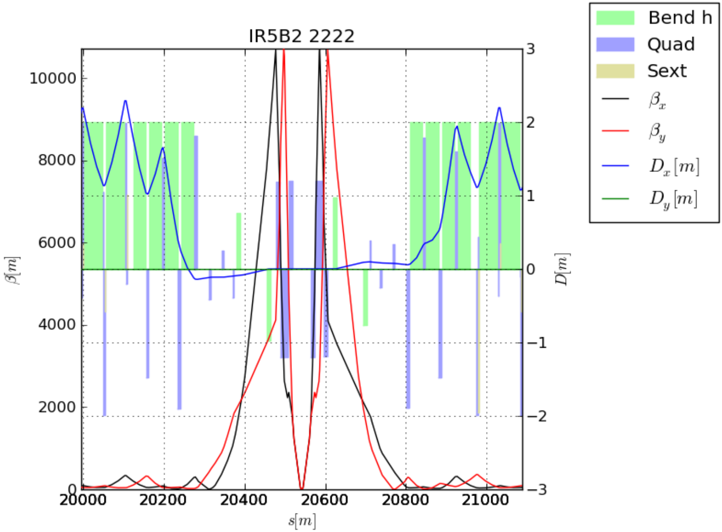
IR5B2 inj
250
200
150
100
50
0
20000
20200
20400
20600
20800
21000
$s[m]$
$\beta[m]$
3
2
1
0
−1
−2
−3
$D[m]$
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$

# LHC Squeeze



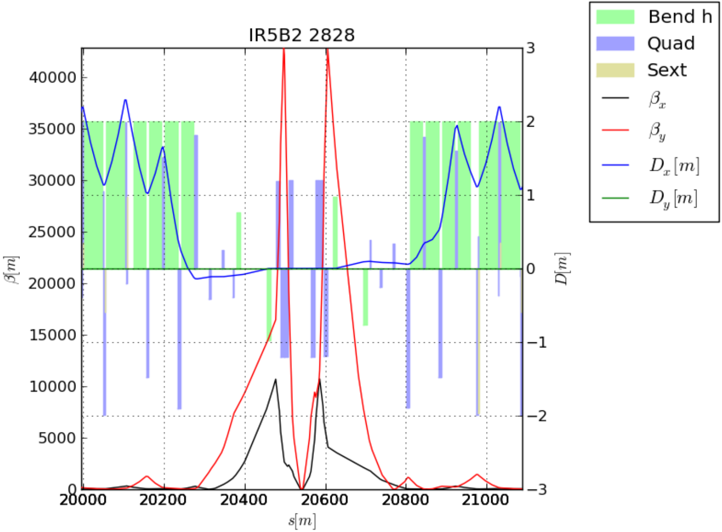
IR5B2 1111
5000
4000
3000
2000
1000
0
$\beta[m]$
20000
20200
20400
20600
20800
21000
$s[m]$
3
2
1
0
−1
−2
−3
$D[m]$
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$

# LHC Squeeze

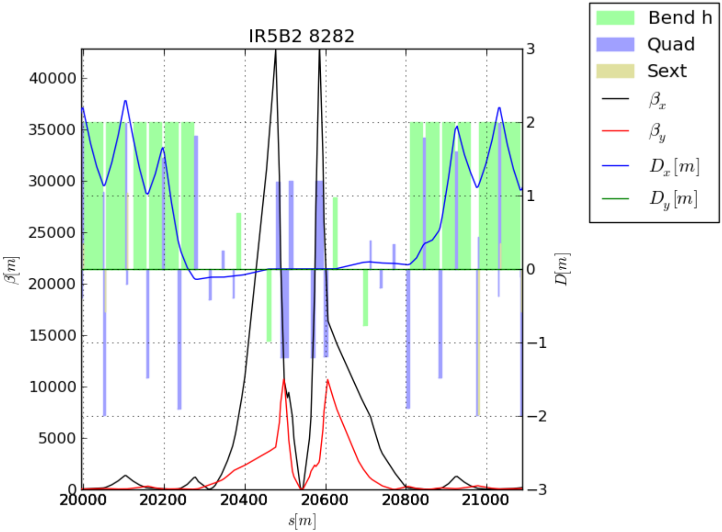


IR5B2 2222
10000
8000
6000
4000
2000
0
20000
20200
20400
20600
20800
21000
$s[m]$
$\beta[m]$
3
2
1
0
−1
−2
−3
$D[m]$
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$

# LHC Squeeze


IR5B2 2828
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
40000
35000
30000
25000
20000
15000
10000
5000
0
20000
20200
20400
20600
20800
21000
3
2
1
0
−1
−2
−3

# LHC Squeeze



IR5B2 8282
Bend h
Quad
Sext
$\beta_x$
$\beta_y$
$D_x\,[m]$
$D_y\,[m]$
$\beta[m]$
$D[m]$
$s[m]$
40000
35000
30000
25000
20000
15000
10000
5000
0
20000
20200
20400
20600
20800
21000
3
2
1
0
−1
−2
−3

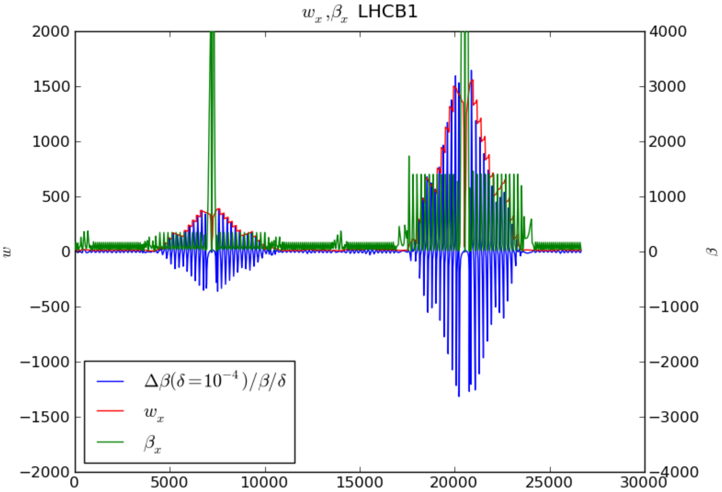
# IR1-5 triplet layout

As working hypothesis, we assumed the phase 1 project triplet layout with 120T/m gradient.
For the extreme cases we need the aperture be rescaled to 150mm, compatible then with Nb3Sn but with large margin.
The scheme allows a triplet layout with NbTi technology with a minor changes of the optics and chromatic correction.
With Nb3Sn magnets it is anyway possible to gain in:

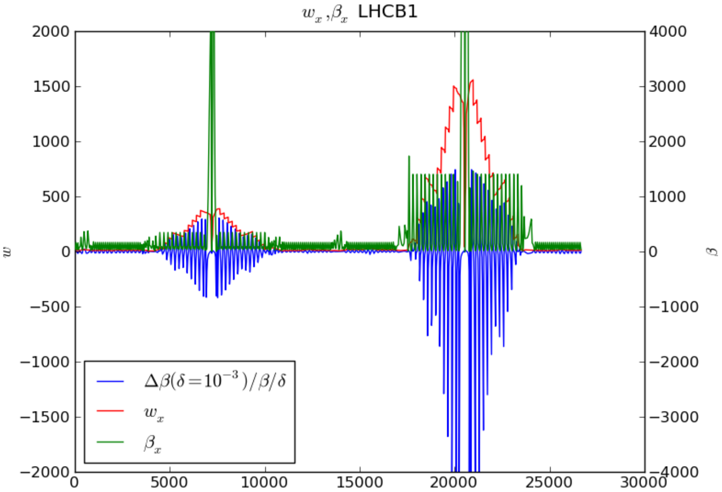
- parasitic encounters (shorter magnets)
- reduce beta max in the arcs at constant $\beta^*$ (thanks to the reduction of $\beta^*$ pre squeeze optics)

We will address the design of the triplet in layout in the next iteration when we optimize the $\beta^*$ ratios.

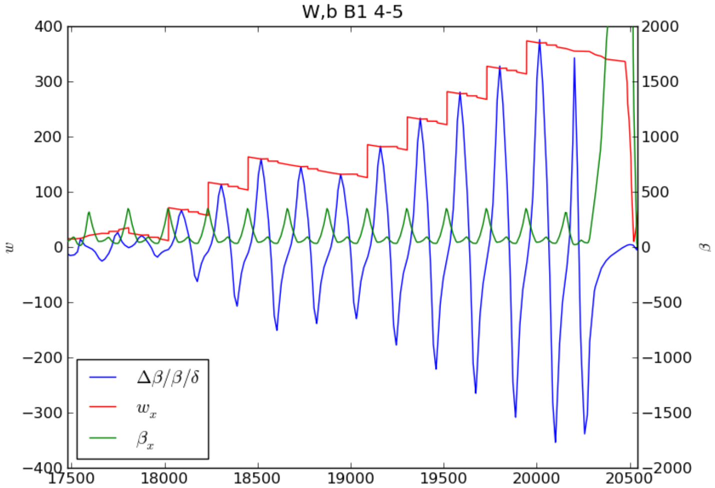
# Chromatic properties: beta beat 2882



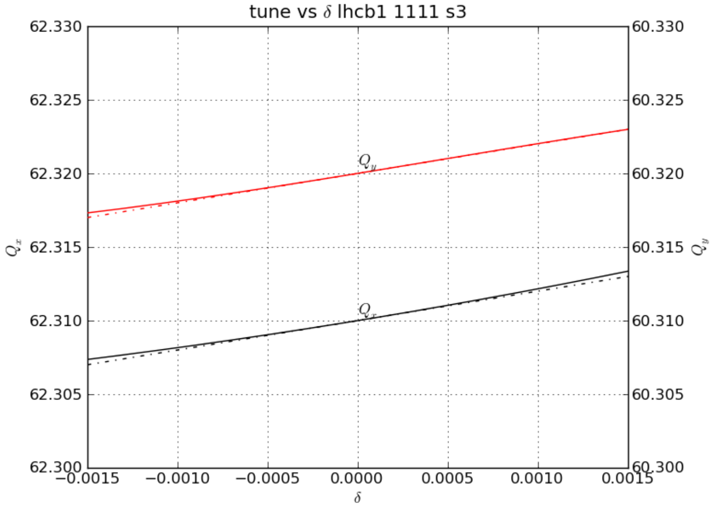
# Chromatic properties: beta beat 2882



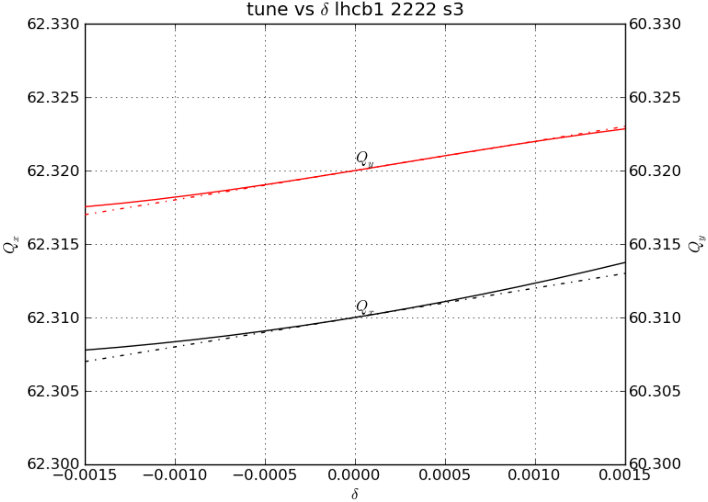
# Chromatic properties: beta beta



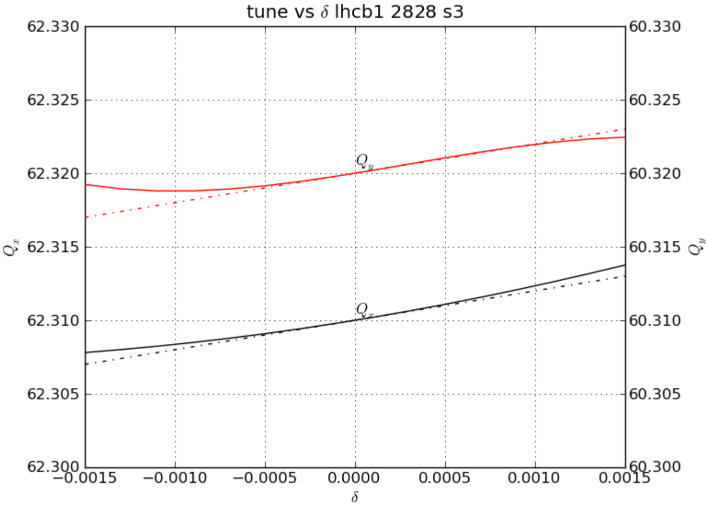
# Chromatic properties: tune



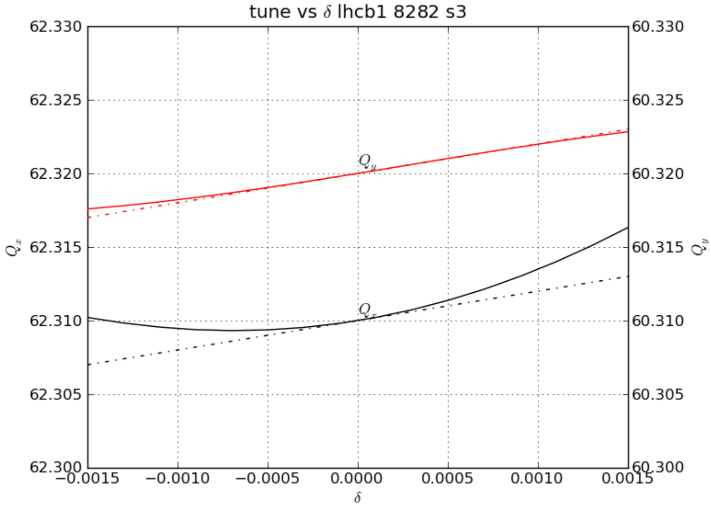
# Chromatic properties: tune



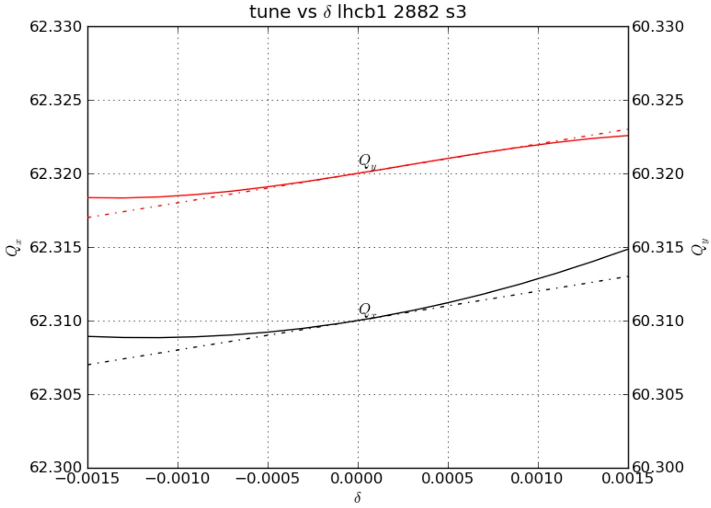
# Chromatic properties: tune



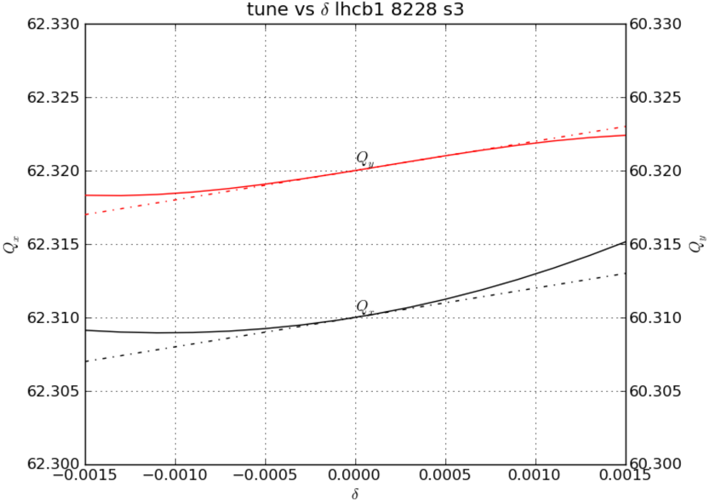
# Chromatic properties: tune



# Chromatic properties: tune



# Chromatic properties: tune



# Chromatic properties

- Beta beat is local around the experiments.
- Linear and non linear parts don't leak in the IRs and don't generate high order chromaticity.
- Chromatic properties stable during the squeeze.
- We effectively trade the chromatic perturbations with the geometric perturbations in the arcs by increasing the beta function in the arcs.

# Review of the first part

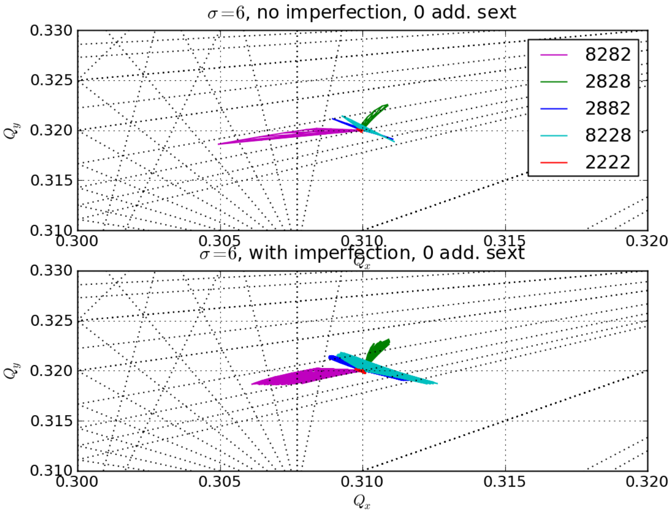
- SLHCV3 is a HL upgrade scenarion for the LHC
- The beta squeeze is reached in two stages:
  - up to an intermediate value (e.g. 60cm) as usual
  - up to extreme values (e.g. 7cm/30cm) using neighbor insertions: IR8 and IR2 for IP1, IR4 and IR6 for IP5
- The scheme eliminates the leakage of the offmomentum beta beat in the collimation insertion and in the triplet.
- Spurious dispersion can be corrected by orbit bumps in the arcs.
- The optics of IR1/5 is less constrained.
- 4 arcs are at $\pi/2$ per cell and there is $\pi$ between one family of sextupole and the triplet for each plane.
- When the neighbor insertions squeeze $\beta^*$, they generate a beta beat wave in arcs. Peaks in the arc are proportional to $\beta$ in the triplet and $1/\beta$ in the IP.

# Review of the first part: Optics scenarios

- Optics are labeled $f_x^{\mathrm{IP1}} f_y^{\mathrm{IP1}} f_x^{\mathrm{IP5}} f_y^{\mathrm{IP5}}$, where $f$ represents the squeeze factor from the intermediate optics.

| Name | IP1 | | | IP5 | | |
|---|---|---|---|---|---|---|
| | $\beta_x^*$ [m] | $\beta_y^*$ [m] | X plane | $\beta_x^*$ [m] | $\beta_y^*$ [m] | X plane |
| inj | 14 | 14 | H or V | 14 | 14 | V or H |
| 1111 | 0.60 | 0.60 | H or V | 0.60 | 0.60 | V or H |
| 2222 | 0.30 | 0.30 | H or V | 0.30 | 0.30 | V or H |
| 2828 | 0.30 | 0.075 | H | 0.30 | 0.075 | H |
| 2882 | 0.30 | 0.075 | H | 0.075 | 0.30 | V |
| 8228 | 0.075 | 0.30 | V | 0.30 | 0.075 | H |
| 8282 | 0.075 | 0.30 | V | 0.075 | 0.30 | V |

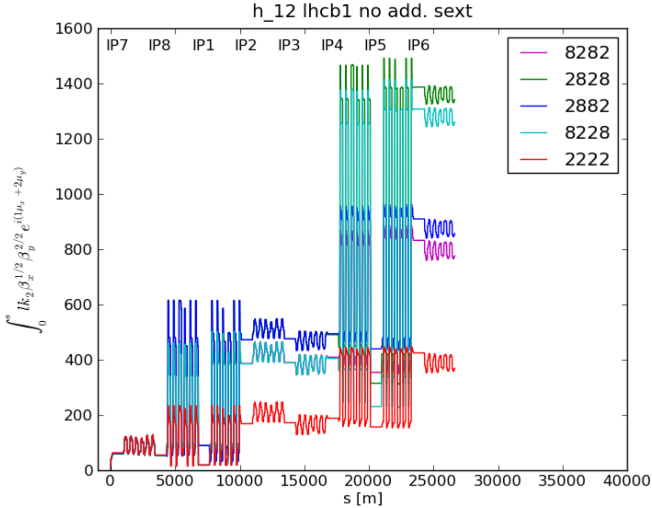
# Footprint with or without imperfection




Imperfections include all but new magnets (Q1-3/D1D2/Q4)

New regime for long term stability for the LHC!

# Driving Terms




Not exact compensation even if strong sextupoles are at $\pi$! The reason is that there are an odd number of strong sextupoles: only one is not compensated!

# Alternative sextupole options

There are several mitigation strategies at constant luminosity:

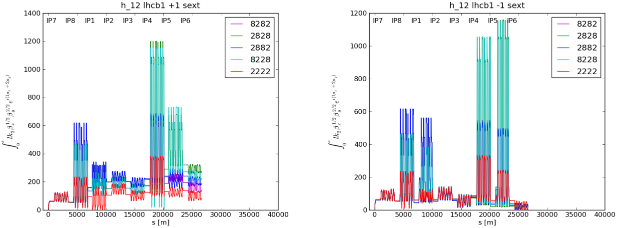
- add sextupoles in Q10 (there is room, it increases sextupole budget and therefore optimization margin)

- remove sextupole MS14 (easy, but we loose overall sextupole strength and optimization margins)

- readjust phase advances such $\mu_{\mathrm{IP}} \rightarrow \mu_{\mathrm{MS}} = \pi/2$ in Q12 and not Q14 (if it is possible, we then loose flexibility in the IR)

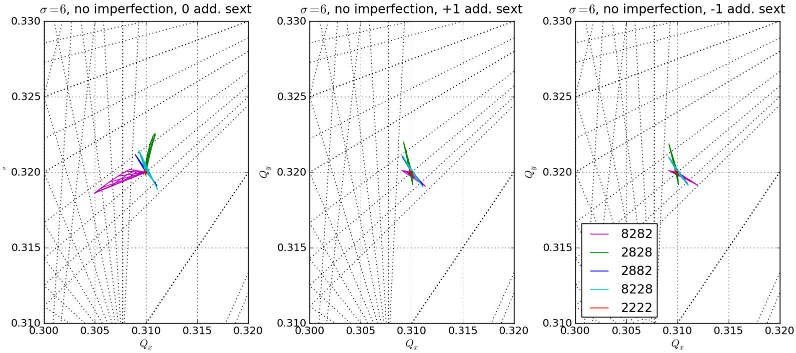
In addition to that we can try to gain by decreasing $\beta^*$ of the pre-squeeze optics to reduce the $\beta$-function in the arc at constant squeezed $\beta^*$ but we loose optics flexibility.

# Alternative sextupole options: driving terms

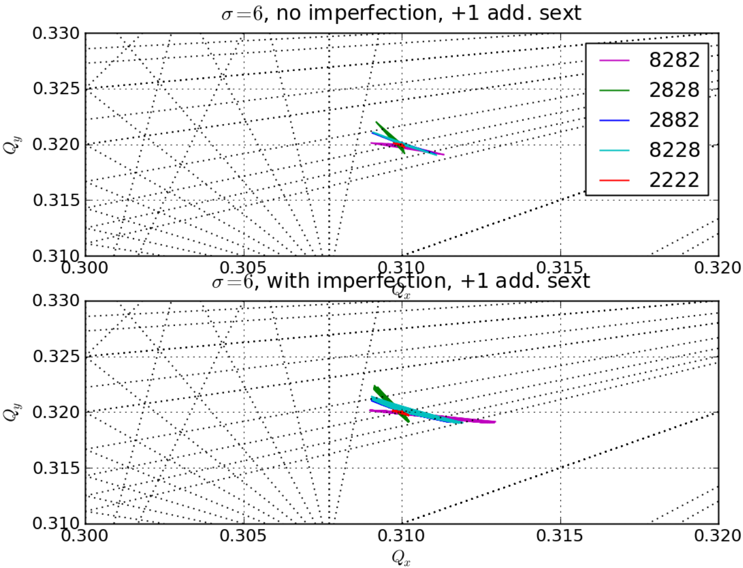



Adding a sextupole works not exactly because $\beta$ at Q10 is not the same as in the arc.
Removing a sextupole cancels exactly the driving terms, but the individual kick are higher.

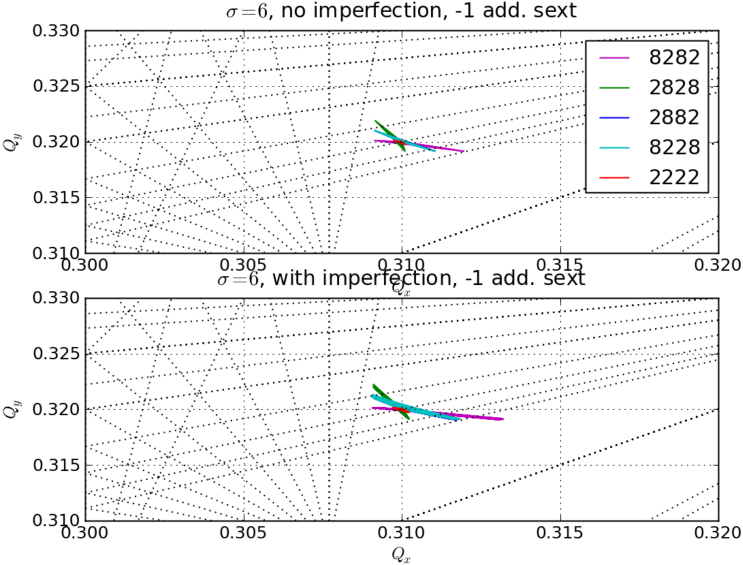
# Alternative sextupole options: footprint



# Footprint: adding sextupoles



# Footprint: removing sextupoles



# Tracking studies

- tune (62.28,60.31), (62.31,60.32)
- using $\delta = 0.00027 = (2.5\sigma_\delta)$
- include multipole error a,b from 2 to 15 order for: MB, MBRB, MBRS, MBX, MBW, MBXW
- include multipole error a,b from 3 to 15 order for: MQW, MQTL, MQMC, MQX, MQM, MQML, MQ
- exclude: MQY, new MQX, new D1/D2
- correct triplet error:
  - A2(1,-1), A3(2,1)(1,2) partial with MQSX
  - A3(0,3)(3,0), with MCSSX
  - A4(1,3), A4(3,1), with MCOSX
  - B4(4,0), B4(0,4), B4(2,2) partial with MCOX
  - B3(3,0)(0,3) partial,B3(1,2)(2,1) with MCSX
  - B6(6,0), B6(0,6), B6(4,2) partial, B6(2,4) partial, with MCTX
- correct arcs errors:
  - beta beating and tune with MQT weak sector
  - correct coupling with MQS
  - chromaticity with MS weak sector
  - chromatic coupling with MSS
  - b3 dipoles with MCS
  - b4 dipoles with MCO full strength
  - b5 dipoles with MCD

# Tracking studies: 2

Particle distribution:

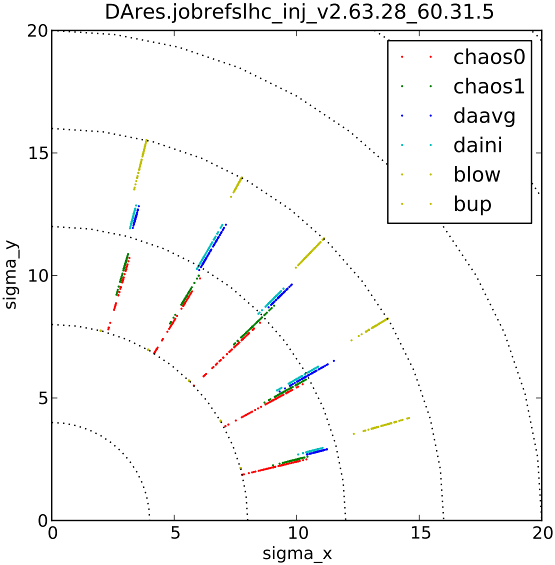
- Using 5 angles
- $2\sigma$ steps for 30 pairs

Post processing:

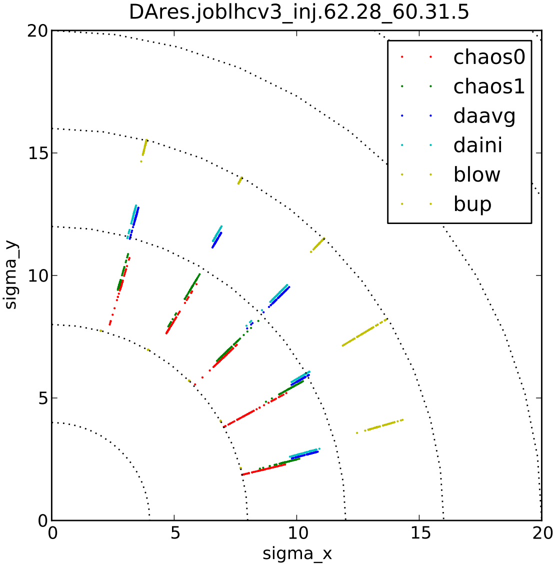
- b-low: initial value of the amplitude scan
- b-up: final value of the amplitude scan or value of sigma for which the pairs do not survive after less than 1000 turns
- chaos0: amplitude of the chaos onset using slope method
- chaos1: amplitude of the chaos onset using large distance method
- daini: maximum initial amplitude for particles that don't survive $10^5$ turns
- daavg: maximum average amplitude for particles that don't survive $10^5$ turns

refs: Run Environment for SixTrack, LHC Project Note 300; Estimates for long-term stability for the LHC, LHC-Project-Report-114.

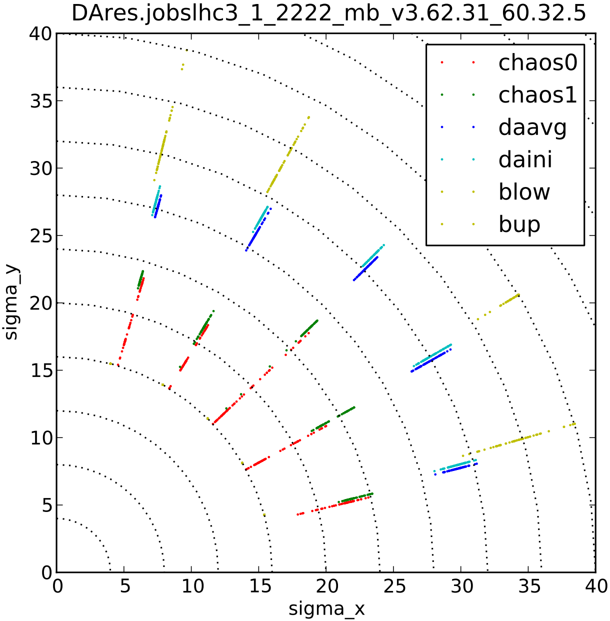
# Injection results



# Injection results



# Collision results



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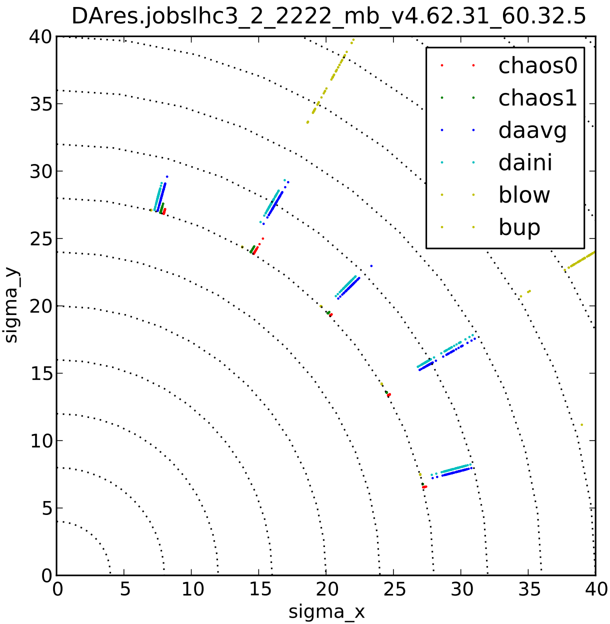

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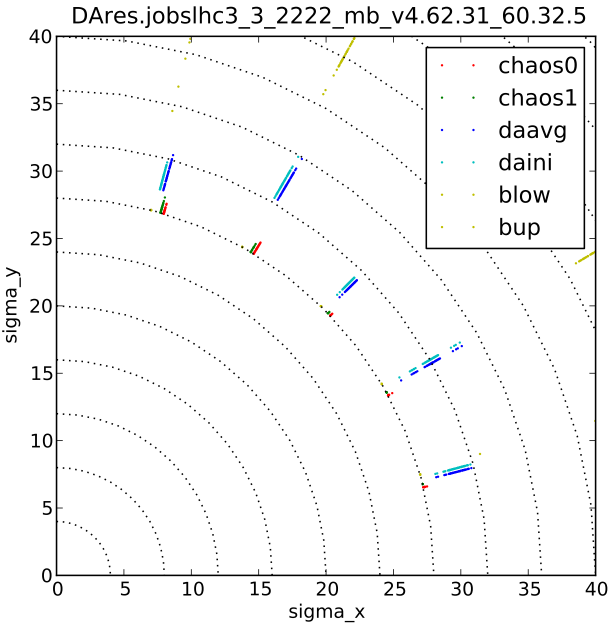

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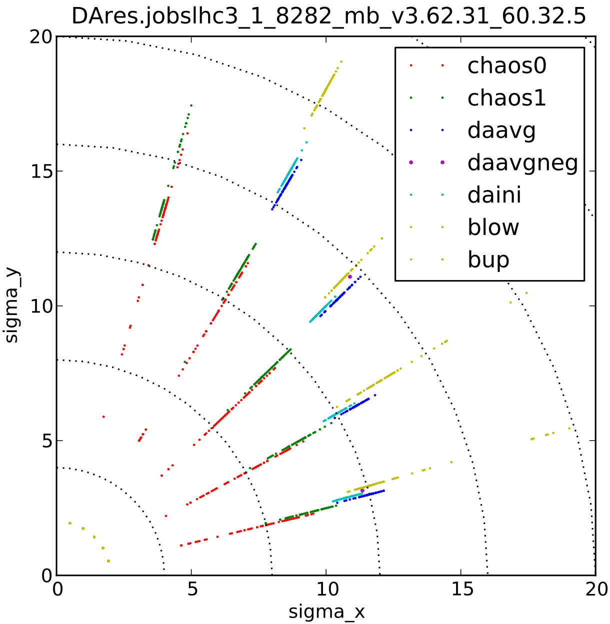

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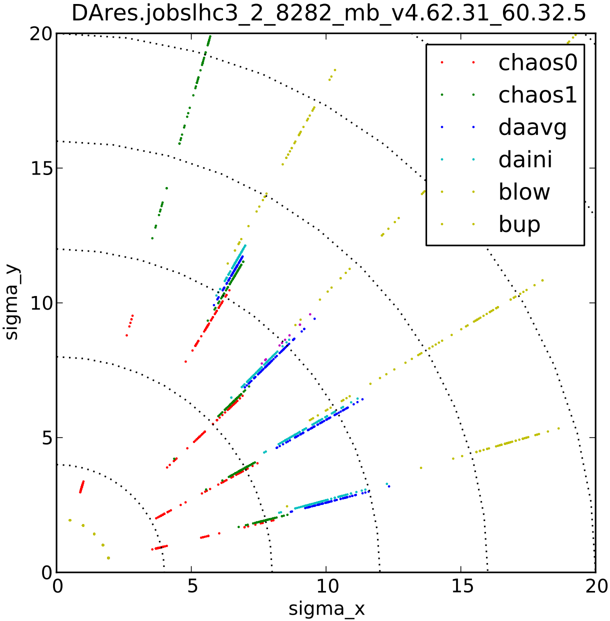

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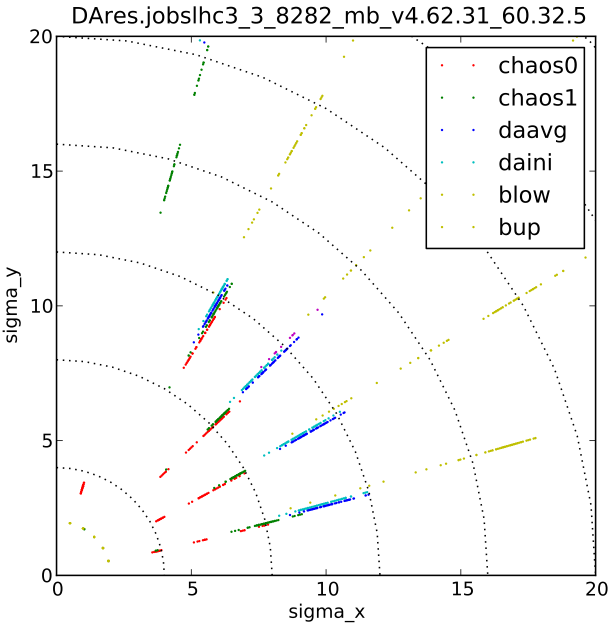

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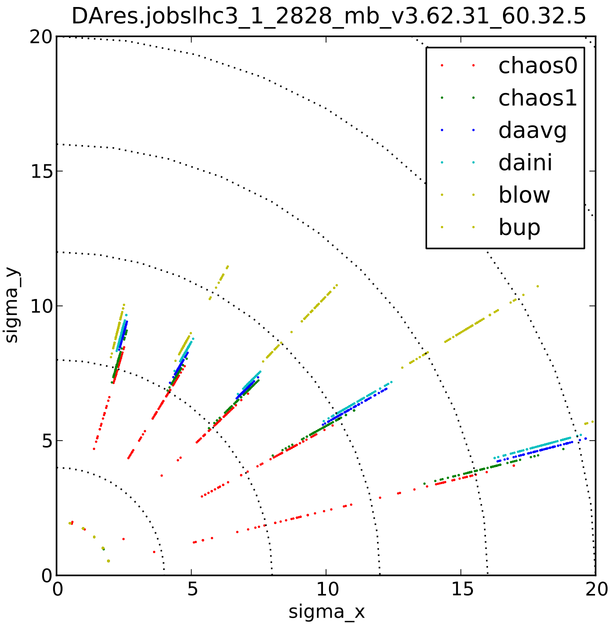

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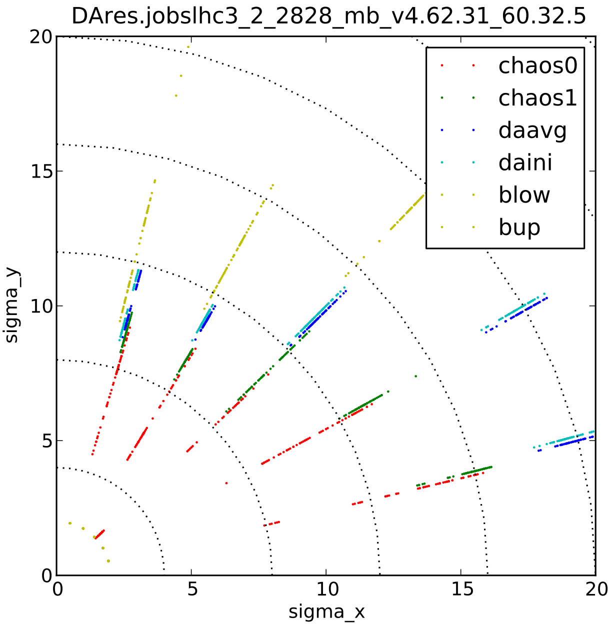

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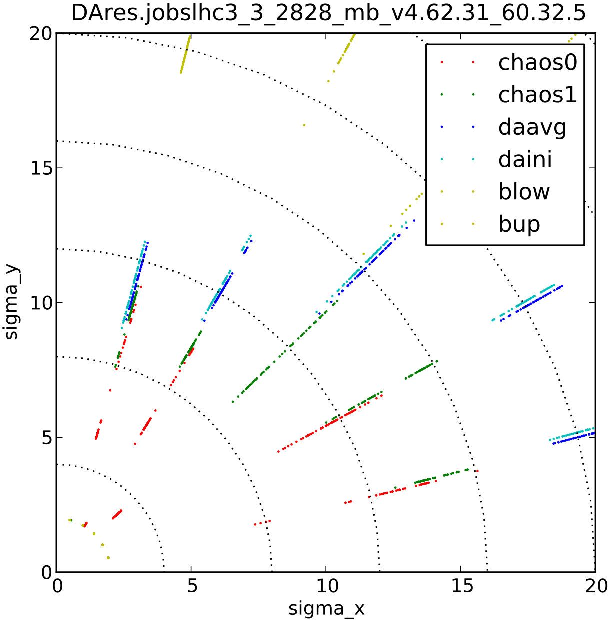

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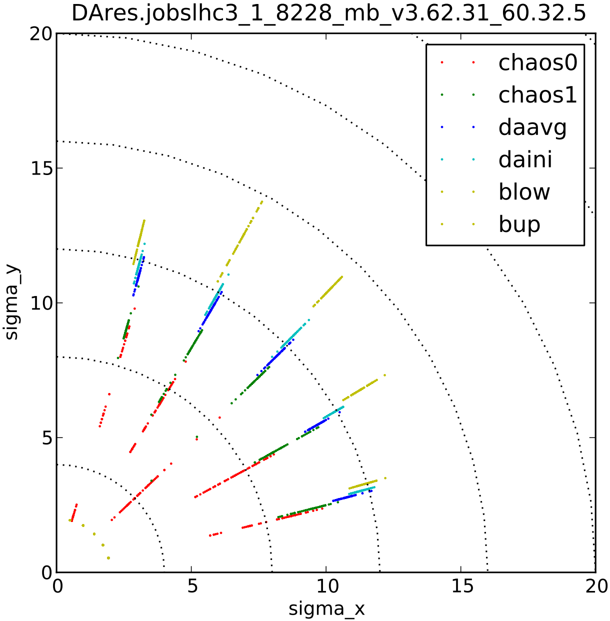

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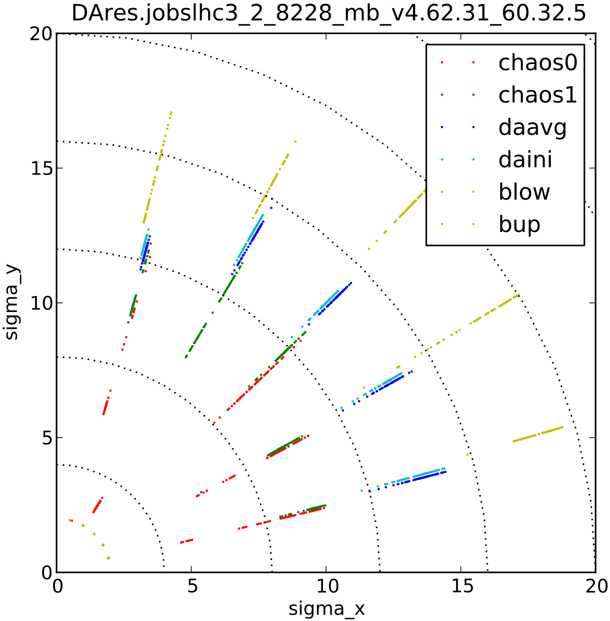

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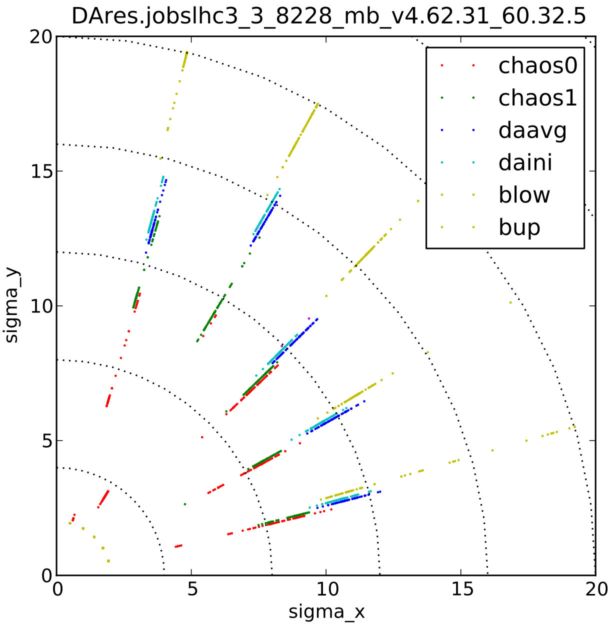

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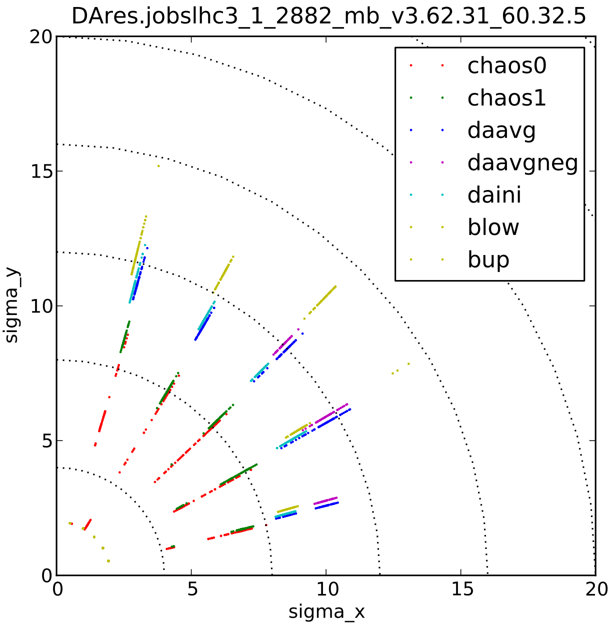

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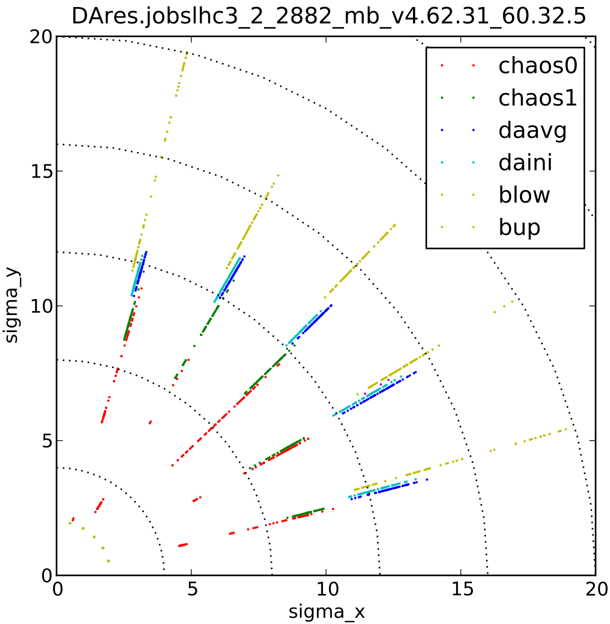

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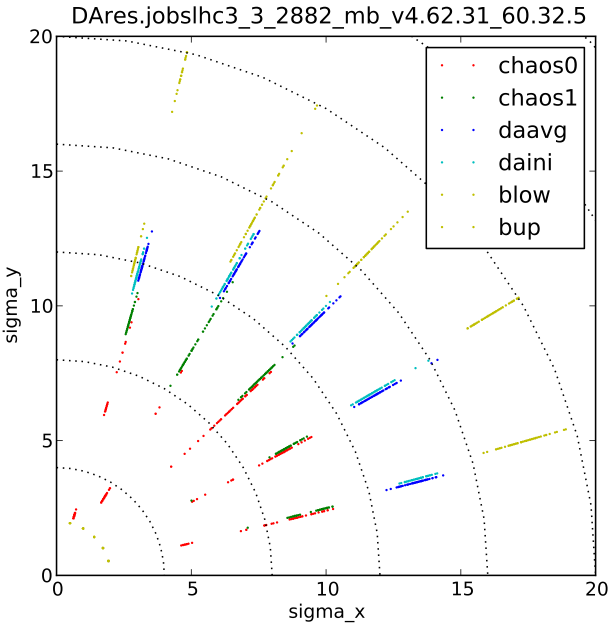
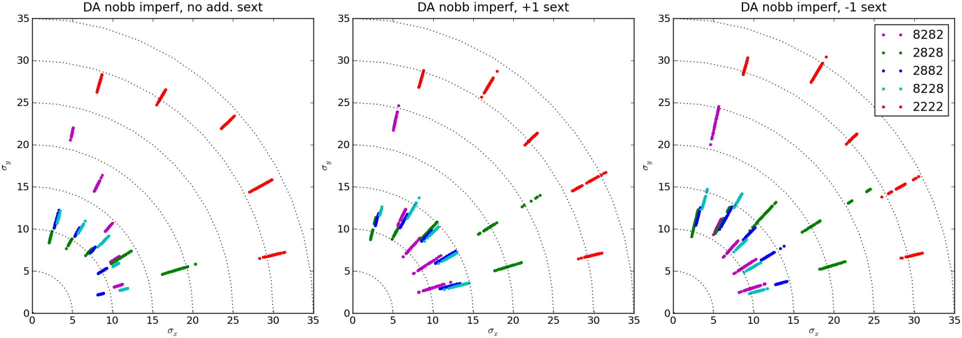


# DA results without beam beam

- inj : $> 10.13\sigma$, slightly smaller than nominal
- 1111 : very large no issue




- 2222 : well beyond the limit: no issue
- 2882, 8228: at the limit ($>$ mechanical aperture): to be checked with imperfection of new magnets (Q1-3,D1,D2,Q4) and beam beam, adding a sextupole raises DA a small angle
- 2828, 8282: already not acceptable

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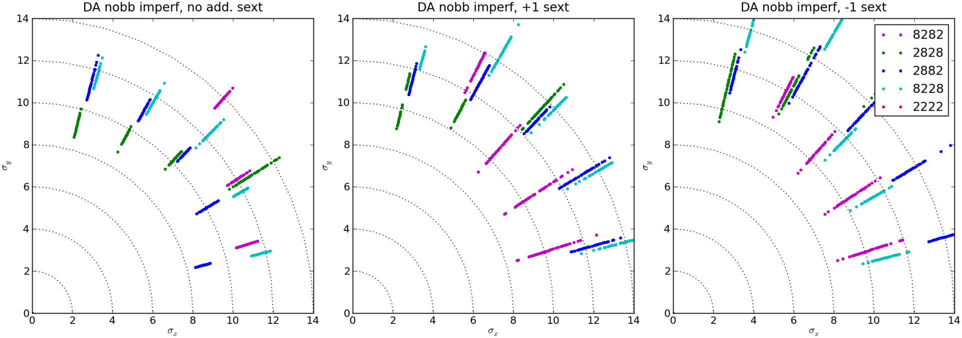


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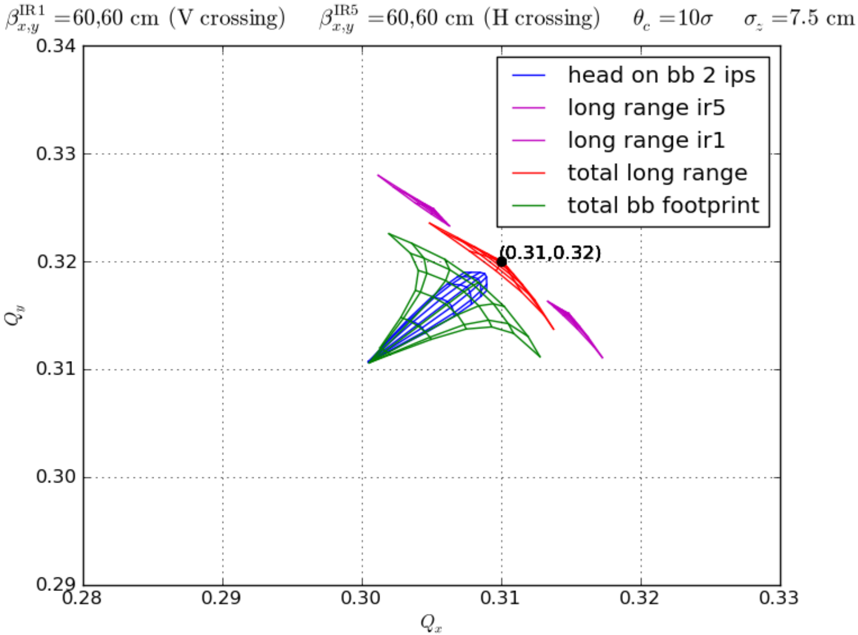
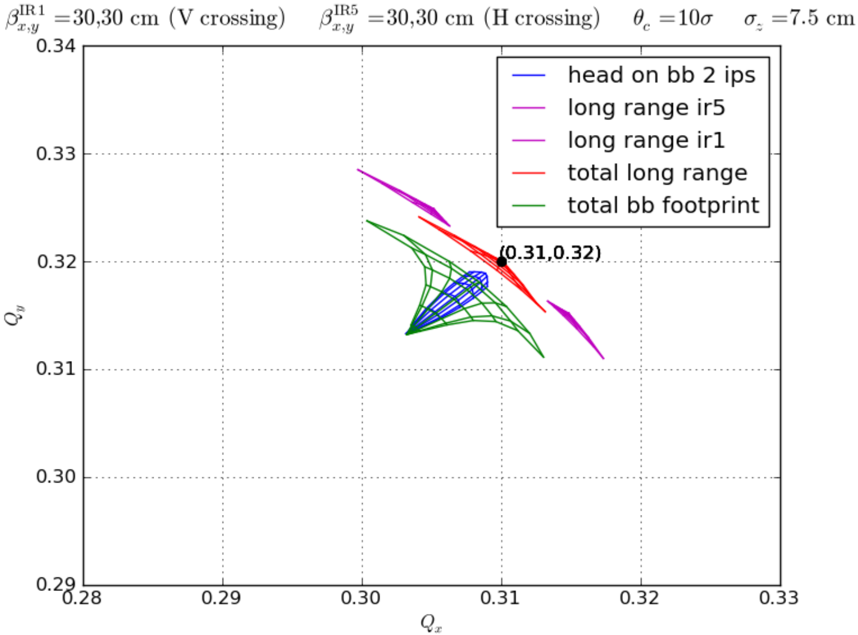
# Beam beam foot print



# Beam beam foot print



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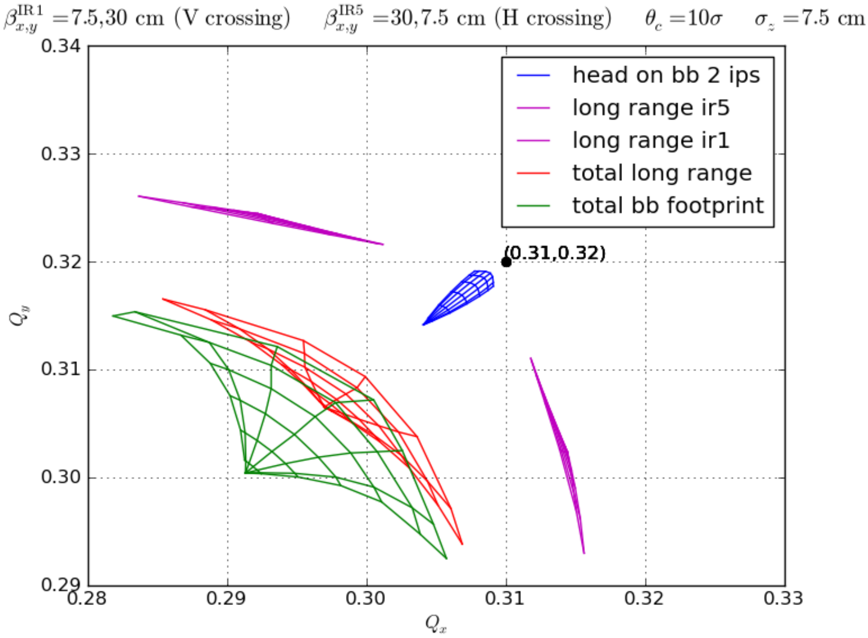
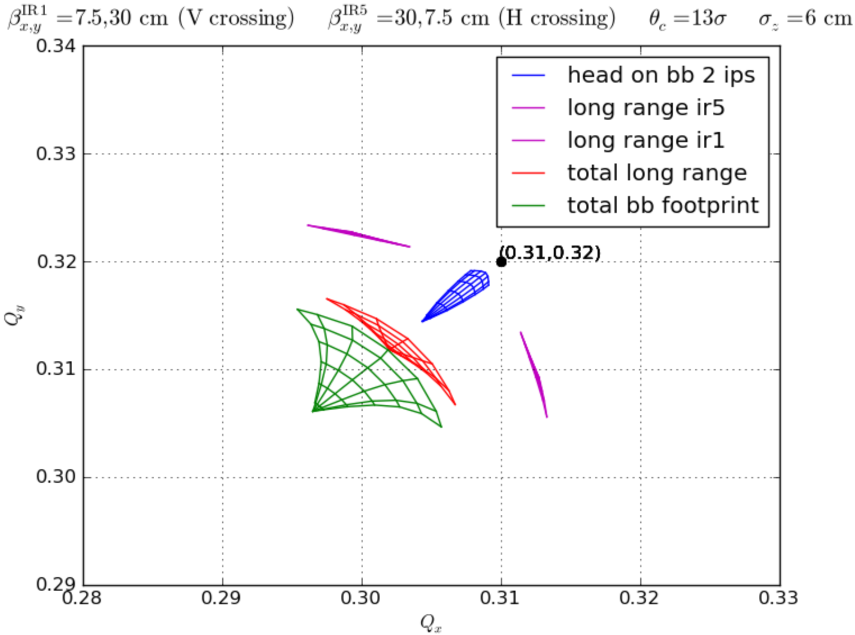


# Beam beam foot print



# What do we have to learn from additional studies

We explored the edges of our parameters space:

- optics and layout of the non experiment region looks ok
- first beam dynamics results are encouraging, but not conclusive

That defines the next steps:

- Fine tune beam and optics parameters (in particular $\beta^*$ pre-squeeze, $\beta^*$ aspect ratio) without and eventually with realistic magnet specs with the main goal of reducing the beta max in the arcs at constant luminosity.
- Understand beam beam long term stability with low $\beta^*$ and/or flat beams
- Specify triplet,D1,D2,Q4 field quality requirements (must not sensibly reduce DA w.r.t to ideal IR magnets, unless...)
- Understand sources of DA reduction (tune spread or resonances?) and find strategies to optimize it.
- Understand whether high betas in the arcs allow footprint control with multipole correctors.

# What can we learn from the machine and the experts

- By just commissioning:
  - Collimation system requirements (chromatic beating specs, aperture specs)
  - Long range beam beam and angle requirements (allow more accurate prediction on layout aperture constraints and luminosity gain)

- By dedicated studies:
  - Dynamic squeeze in IR4 (may benefit damper and crab cavities)
  - Operational issues with 90 degree in the arcs (ultimate test for almost all features)
  - Benchmark real dynamic aperture with simulations (this scheme allows to build case with DA $<$ mechanical aperture, a better understanding may relax requirements on field quality)