LHC IR Upgrade

Work outline and first results

Riccardo de Maria

CERN AB-ABP-LOC

24th May 2005

Motivations

Motivations for upgrading LHC:

- After 7 years of operation the IR magnets (Q1-3,D1-2) will reach the damage limit due to the radiation and they will need to be replaced.
- ...

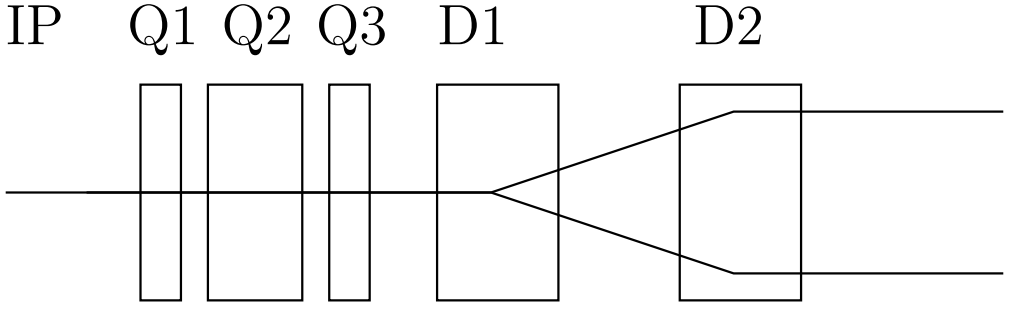
Because IR magnets provide the final focus to the IP (β^*), the luminosity can be upgraded.

Upgrade alternatives

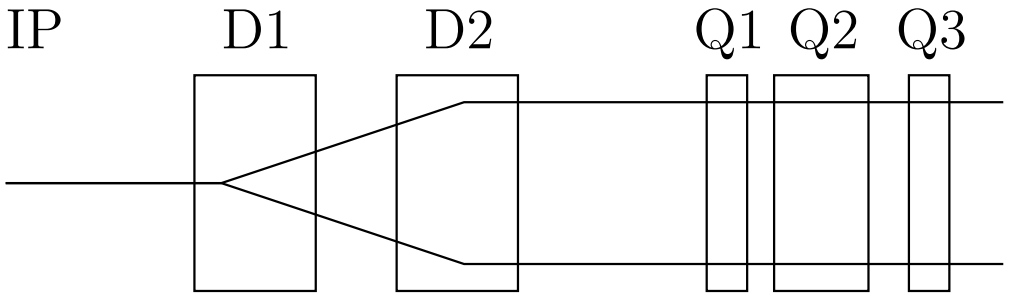
The upgrade aims to achieve $\beta^* = .25$cm.

There are two main strategies for upgrading:

- Maintain the present layout (quadrupole first option) and enhance the performance of the magnets



- Change the layout (dipole first option) and design new magnets



Review Nominal LHC Operational Margin

- Optic functions
- Minimum aperture margins
- Particle loss margins
- Influence of ground motion
- Crossing angle schemes

Insertion Layout

Development of new layouts according to the two designs:

- dipole first with separated 2-in-1 triplets
- quadrupole first with common aperture triplets

Insertion Layout Issues

- Specification for the required cold bore diameters
- Separation recombination dipole options compatible with radiation and heat load
- TAS and TAN absorber integration

Insertion Optics Issues

- Symmetric versus antisymmetric optics (i.e. Q1 focusing for beam 1 left and right)
- Dynamic squeeze implementation during operation
- Tunability of the experimental insertions
- Dynamic aperture and (local) chromaticity correction
- Beam sensitivity to ground motion and other vibrations
- Crossing angle schemes with tolerances during squeeze and operation

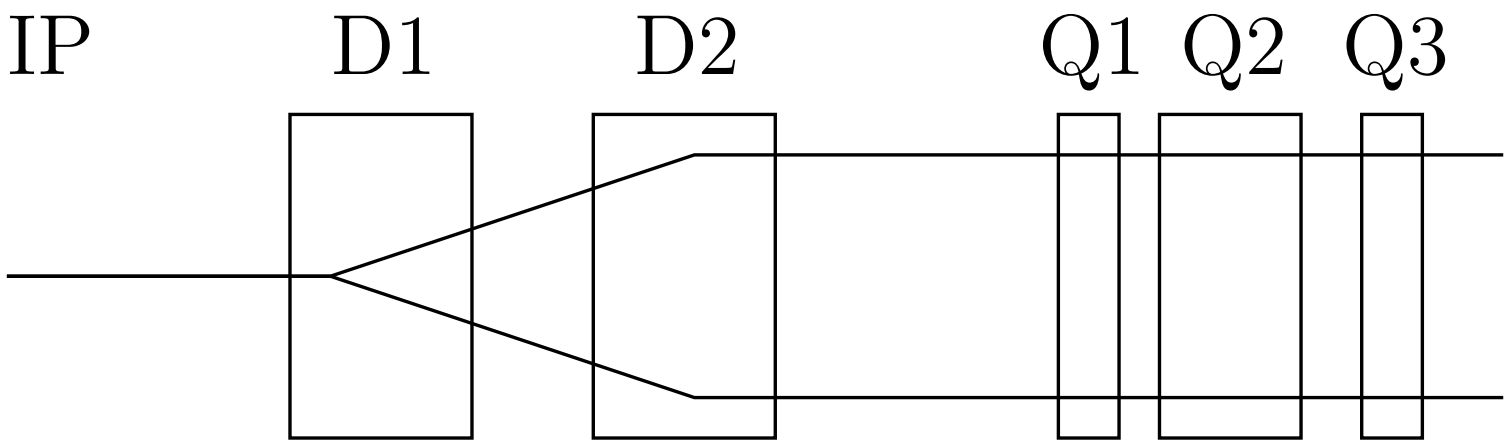
Other Issues

- Contribution of triplet field errors, long range beam-beam kicks crossing angle to the beam halo.
- Background generation in the experiments
- Field error correction options
- Minimum separation and crossing angle orbit control in existing hadron collider

First Results for the Dipole First Layout

- Introduction
- Optics Solutions
- Symmetric Optics Plots
- Problems
- Crossing Angle
- Ongoing Studies

Dipole First Layout



Specifications

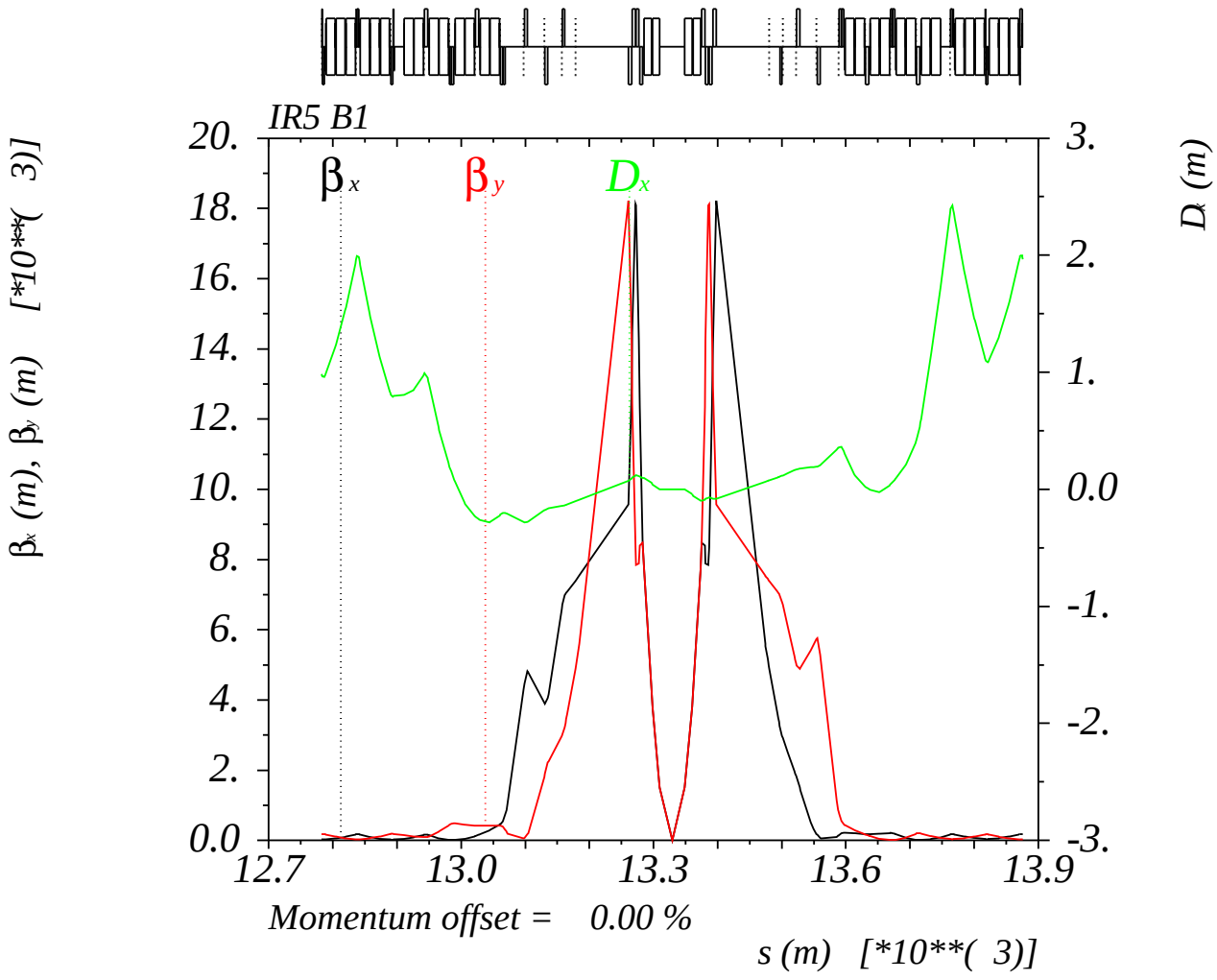
Requirements:

- $\beta^* = 0.25$m
- Distance from IP, $L^* = 19.05$m

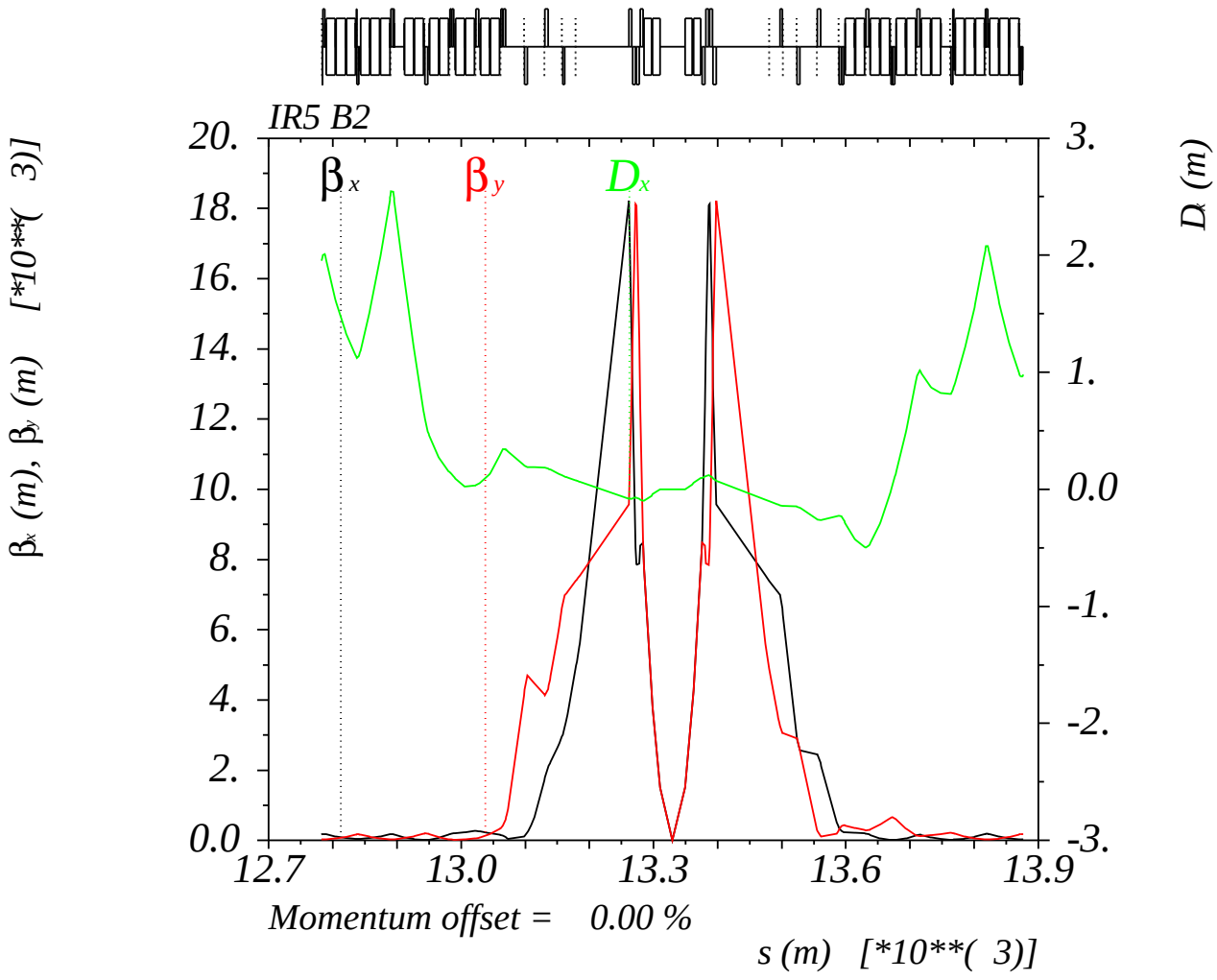
Limits:

- Peak field
- Aperture
- Radiation protection
- Tunability of IR region
- Chromaticity correction

Dipole First IR5 Beam 1 Plot



Dipole First IR5 Beam 2 Plot



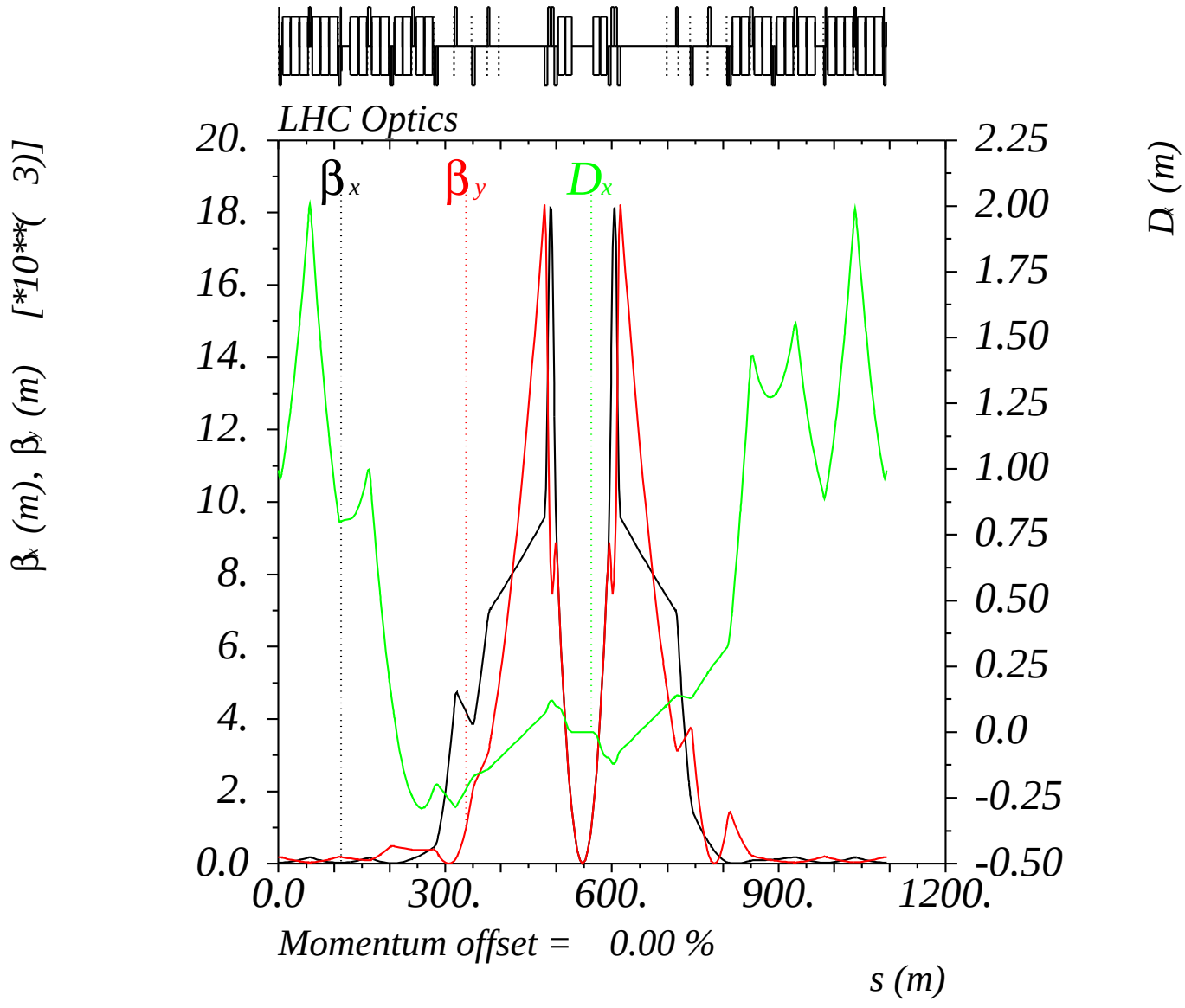
Dipole First Quadrupole Strength

IR5	Limit	Left Beam 1		Left Beam 2		Right Beam 1		Right Beam 1	
	g[T/m]	g[T/m]	% max	g[T/m]	% max	g[T/m]	% max	g[T/m]	% max
Q1	205	231.16	112.76%						
Q2	205	-256.84	125.29%						
Q3	205	280.19	136.68%						
Q4	160	54.67	34.17%	-47.62	29.76%	-31.08	19.42%	88.64	55.40%
Q5	160	-82.84	51.77%	65.72	41.08%	51.60	32.25%	-109.87	68.67%
Q6	160	112.95	70.59%	-110.62	69.14%	-114.50	71.56%	92.42	57.76%
Q7	200	-154.41	77.20%	178.46	89.23%	186.07	93.04%	-191.26	95.63%
Q8	200	11.14	5.57%	53.25	26.63%	-22.93	11.46%	102.18	51.09%
Q9	200	-69.19	34.59%	67.96	33.98%	95.69	47.84%	-100.43	50.22%
Q10	200	186.70	93.35%	-156.39	78.20%	-175.84	87.92%	197.49	98.75%
QTL11	205	118.71	57.91%	47.42	23.13%	55.04	26.85%	118.80	57.95%
QT12	205	112.28	54.77%	1.39	0.68%	62.77	30.62%	92.03	44.89%
QT13	205	5.57	2.72%	-115.50	56.34%	-89.23	43.53%	-116.68	56.92%

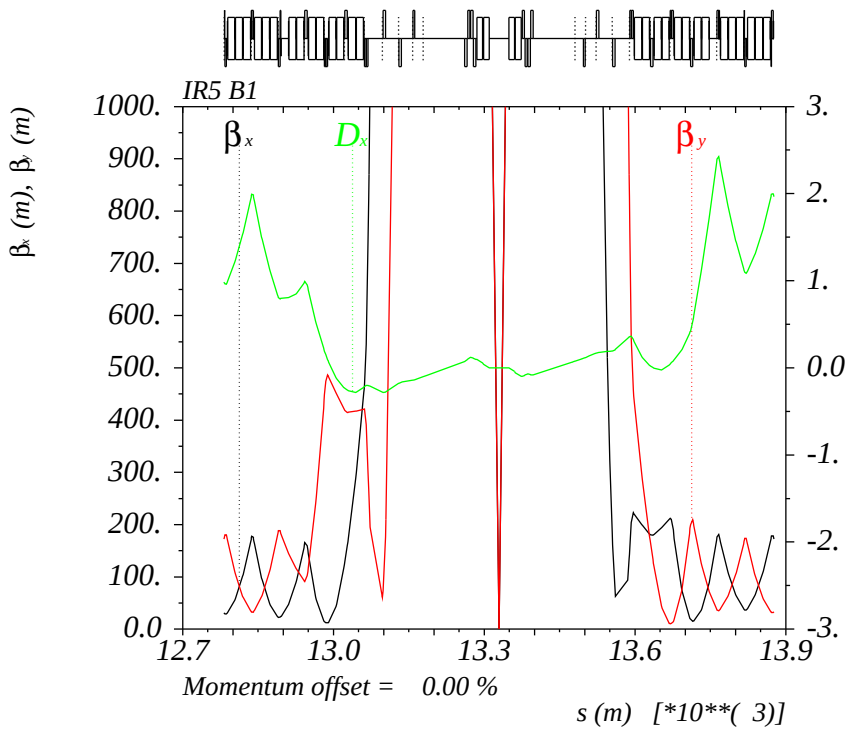
LHC V6.5 Quadrupole Strength

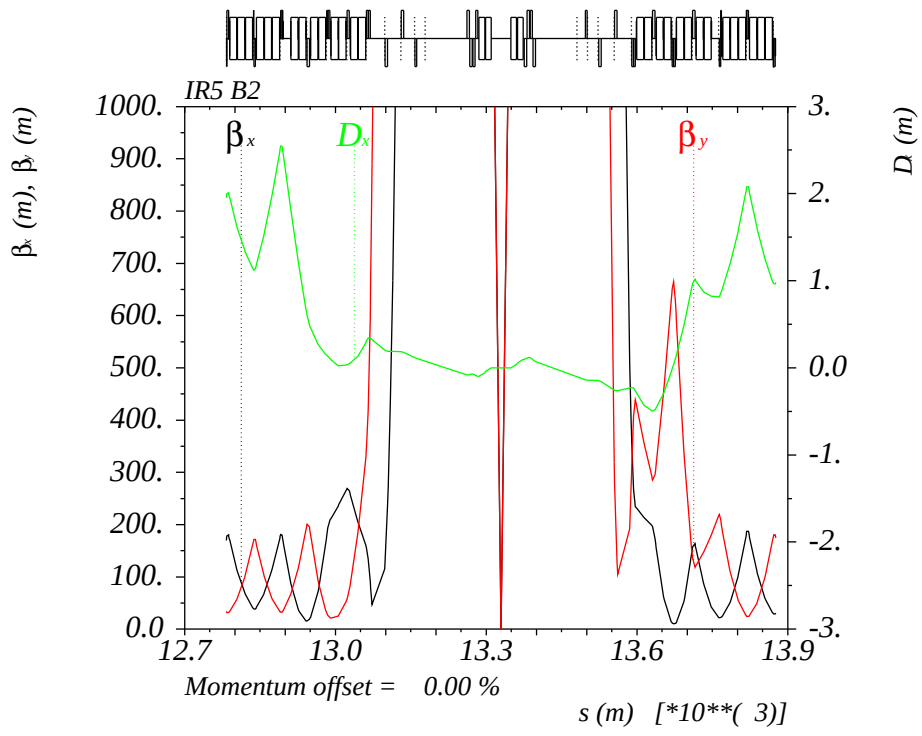
IR5	Limit	Left Beam 1		Left Beam 2		Right Beam 1		Right Beam 1	
	g[T/m]	g[T/m]	% max	g[T/m]	% max	g[T/m]	% max	g[T/m]	% max
QX	205	-203.72	99.37%						
Q4	160	57.52	35.95%	-95.84	59.90%	-57.52	35.95%	95.84	59.90%
Q5	160	-29.42	18.39%	70.91	44.32%	29.42	18.39%	-70.91	44.32%
Q6	160	45.87	28.67%	-20.43	12.77%	-45.87	28.67%	20.43	12.77%
Q7	200	-168.85	84.42%	171.10	85.55%	161.04	80.52%	-200.00	100.00%
Q8	200	155.04	77.52%	-175.88	87.94%	-111.97	55.99%	179.16	89.58%
Q9	200	-184.42	92.21%	156.25	78.12%	161.46	80.73%	-147.36	73.68%
Q10	200	173.71	86.85%	-166.93	83.47%	-150.48	75.24%	163.98	81.99%
QTL11	205	-101.58	49.55%	-10.24	4.99%	-11.50	5.61%	106.86	52.13%
QT12	205	-45.80	22.34%	-112.63	54.94%	-59.77	29.16%	-120.00	58.54%
QT13	205	-31.96	15.59%	-45.25	22.07%	56.86	27.73%	-55.85	27.24%

Symmetric optics: Beam 1 Plot



Problems in the Optics Functions





Matching problems

Problems encountered:

- Matching is in general very difficult
- Problems with phase matching (i.e. L5B1 and R5B2)
- Very difficult to keep alternative focusing (i.e. L5B2)

Possible explanations:

- Dispersion is not zero inside the triplets
- The task of dispersion suppression and twiss matching are no more separated between Q4-Q7 and Q8-Q13
- There is no symmetry between "beam 1 left", "Beam 1 right", "Beam 2 left", "Beam 2 right"

Tune Problems

IR3 beam 1 and 2 cannot be tuned as for V6.5 and
they have not the same phase advance.
IR7 has been used to compensate IR3 phases difference.

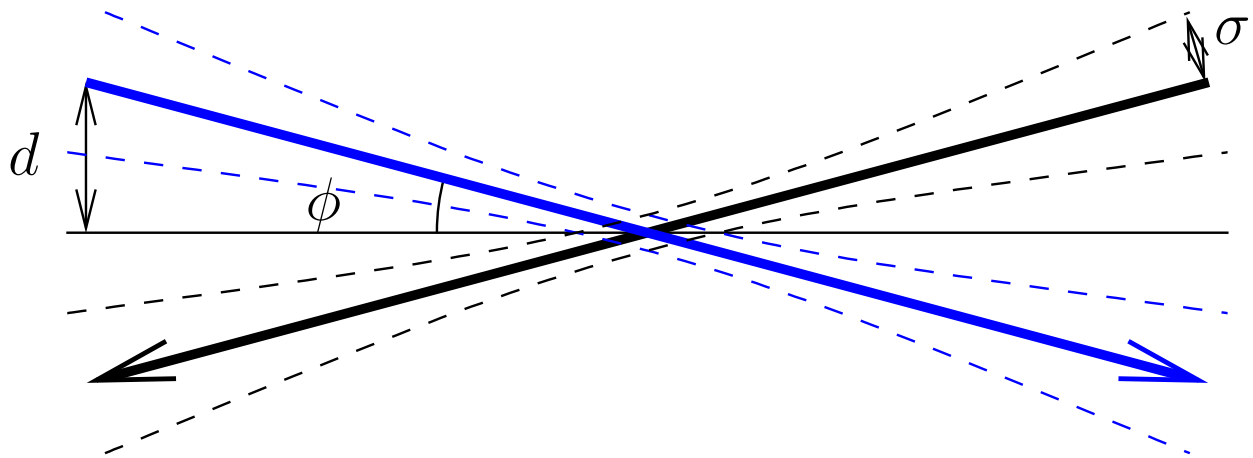
	Beam 1			Beam 2		
Name	Δs[m]	$\Delta\mu_x/2\pi$	$\Delta\mu_y/2\pi$	Δs[m]	$\Delta\mu_x/2\pi$	$\Delta\mu_y/2\pi$
IR1	1094.361	2.505	2.147	1094.361	2.505	2.147
IR2	1093.499	2.974	2.798	1093.361	2.991	2.844
IR3	1094.348	2.248	1.943	1094.361	2.250	2.018
IR4	1093.486	2.143	1.870	1093.652	2.143	1.870
IR5	1094.361	2.505	2.147	1094.652	2.505	2.147
IR6	1093.513	2.015	1.780	1093.652	2.015	1.780
IR7	1094.375	2.377	1.968	1094.361	2.482	2.039
IR8	1093.499	3.183	2.974	1093.361	3.059	2.782

LHC V6.5 Tune

	Beam 1			Beam 2		
Name	Δs[m]	$\Delta\mu_x/2\pi$	$\Delta\mu_y/2\pi$	Δs[m]	$\Delta\mu_x/2\pi$	$\Delta\mu_y/2\pi$
IR1	1094.361	2.633	2.649	1094.361	2.633	2.649
IR2	1093.499	2.974	2.798	1093.361	2.991	2.844
IR3	1094.348	2.248	1.943	1094.361	2.249	2.007
IR4	1093.486	2.143	1.870	1093.652	2.143	1.870
IR5	1094.361	2.633	2.649	1094.652	2.633	2.649
IR6	1093.513	2.015	1.780	1093.652	2.015	1.780
IR7	1094.375	2.377	1.968	1094.361	2.483	2.050
IR8	1093.499	3.183	2.974	1093.361	3.059	2.782

Crossing angle definitions

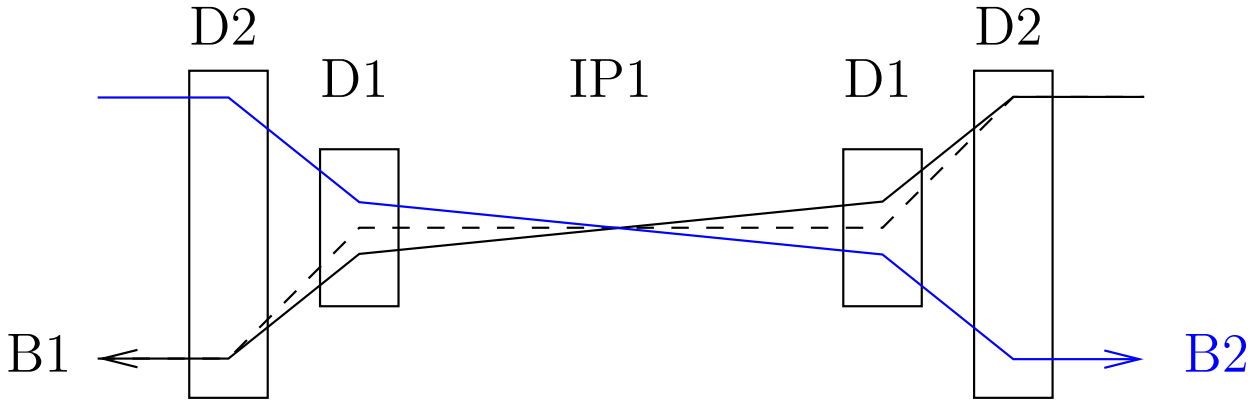
- d half separation
- ϕ half crossing angle
- σ RMS beam size



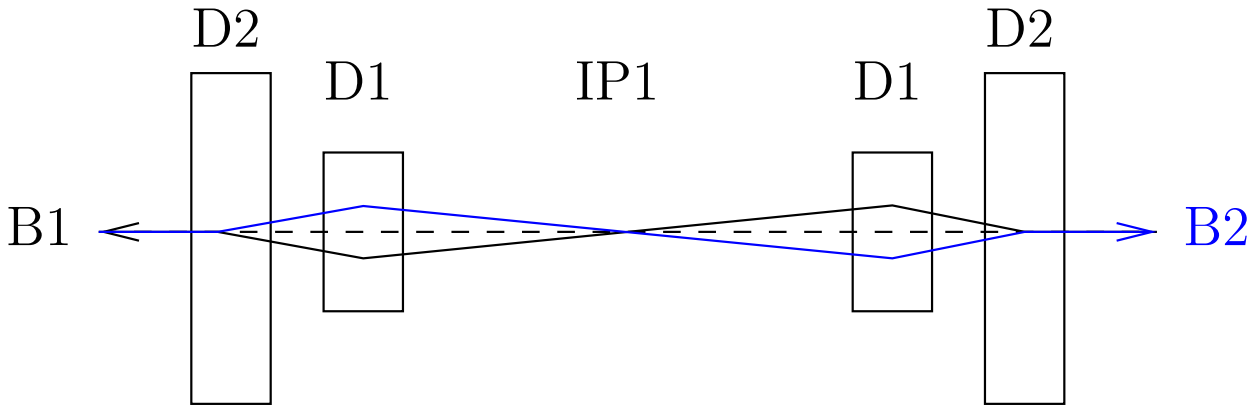
Crossing angle schemes

Crossing angle is achieved:

- for the horizontal plane by powering differently D1 and D2



- for the vertical plane by tilting D1 and D2



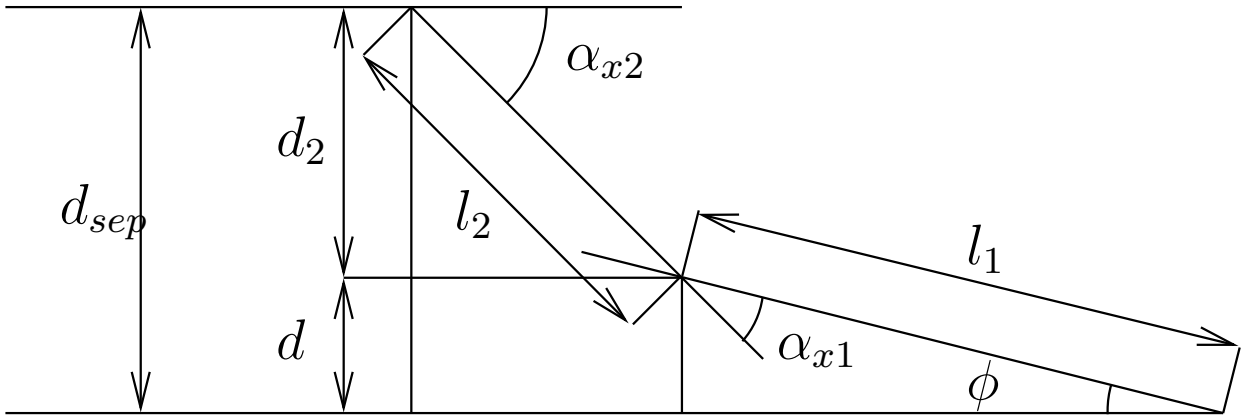
Crossing angle estimation

The crossing angle needed is based on the approximation

$$\frac{d}{\sigma} = \Phi\sqrt{\frac{\beta^*}{\varepsilon}}$$

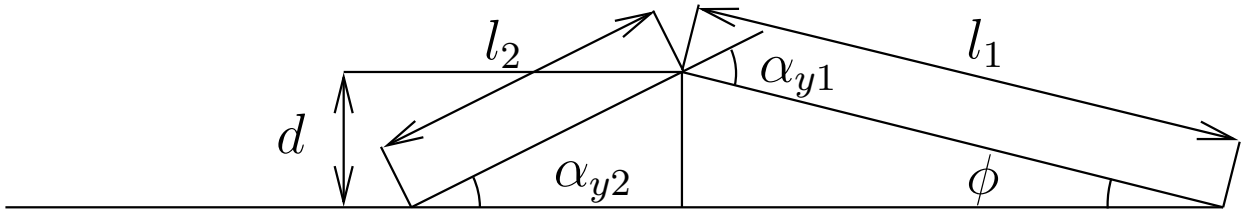
Data	Unit	LHC	Upg.
Energy	[GeV]	7000	7000
Relativistic gamma		7461	7461
Normalized emmittance	[μm rad]	3.750	3.750
Emmittance	[nm rad]	0.503	0.503
RMS beam size (sigma)	[μm]	16.63	11.21
Half crossing angle	[μrad]	142.5	211.4
Half separation	[σ]	4.714	4.714

Dipoles Strengths Calculation: Horizontal



$$\begin{aligned}
\mathrm{d}_{sep} &= \mathrm{d} + \mathrm{d}_2 \\
\mathrm{d} &= \mathrm{l}_1 \sin\phi \\
\mathrm{d}_2 &= \mathrm{l}_2 \sin(-\alpha_{x2}) \\
\alpha_{x2} &= -\arcsin\frac{\mathrm{d}_{sep} - \mathrm{l}_1 \sin\phi}{\mathrm{l}_2} < 0 \\
\alpha_{x1} &= -\alpha_{x2} - \phi > 0
\end{aligned}$$

Dipoles Strengths Calculation: Vertical



$$\mathrm{d} = \mathrm{l}_1 \sin\phi = \mathrm{l}_2 \sin\alpha_{\mathrm{y}2}$$

$$\alpha_{\mathrm{y}2} = \arcsin\frac{\mathrm{l}_1 \sin\phi}{\mathrm{l}_2}$$

$$\alpha_{\mathrm{y}1} = -(\alpha_{\mathrm{y}2} + \phi)$$

Dipoles Strengths Calculation: Tilting

Angle and tilting are adjusted to match the horizontal and vertical angle needed

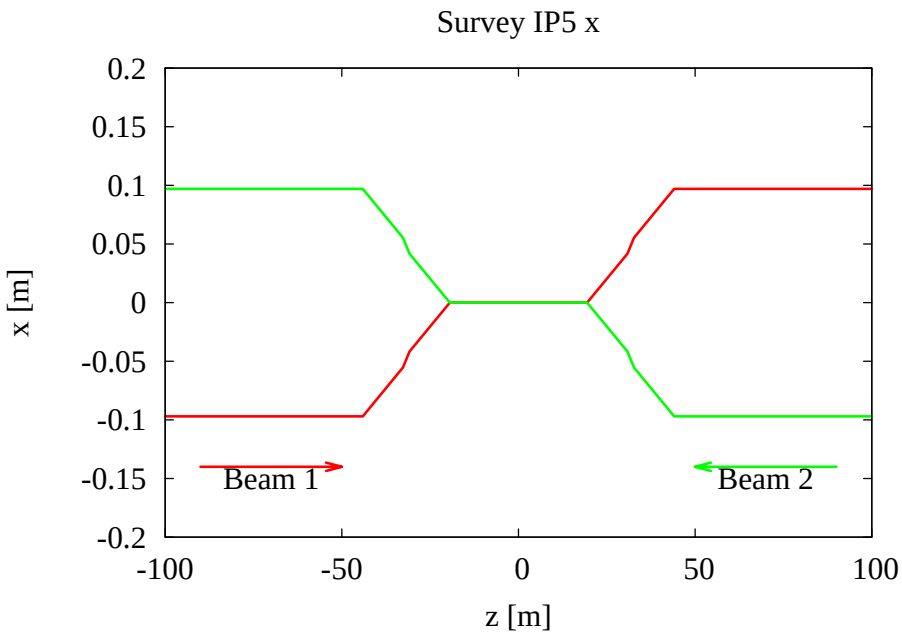
$$\alpha_x = \alpha \cos \vartheta$$
$$\alpha_y = \alpha \sin \vartheta$$
$$\alpha = \pm \sqrt{\alpha_x^2 + \alpha_y^2}$$
$$\vartheta = \arctan \frac{\alpha_y}{\alpha_x}$$

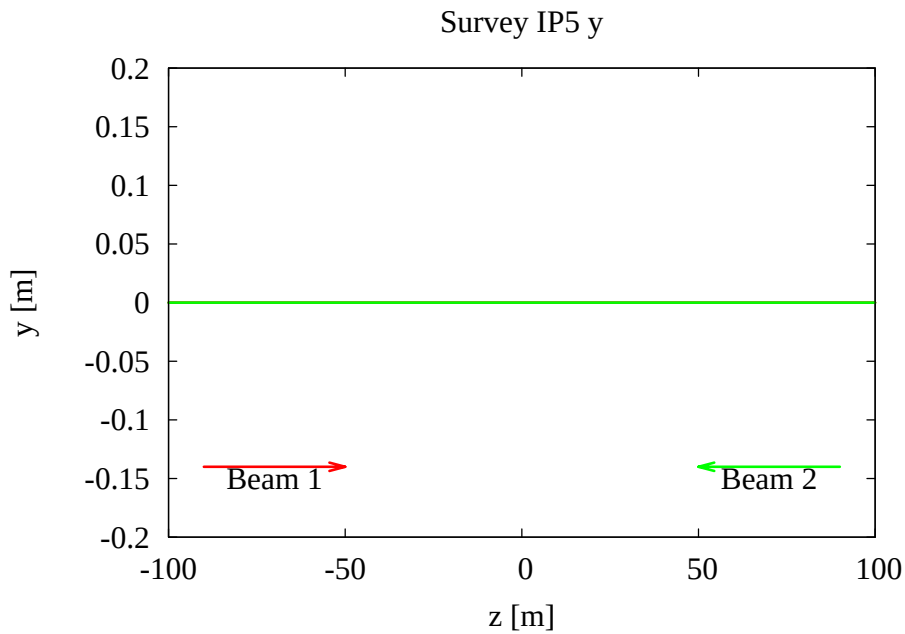
Dipoles strengths

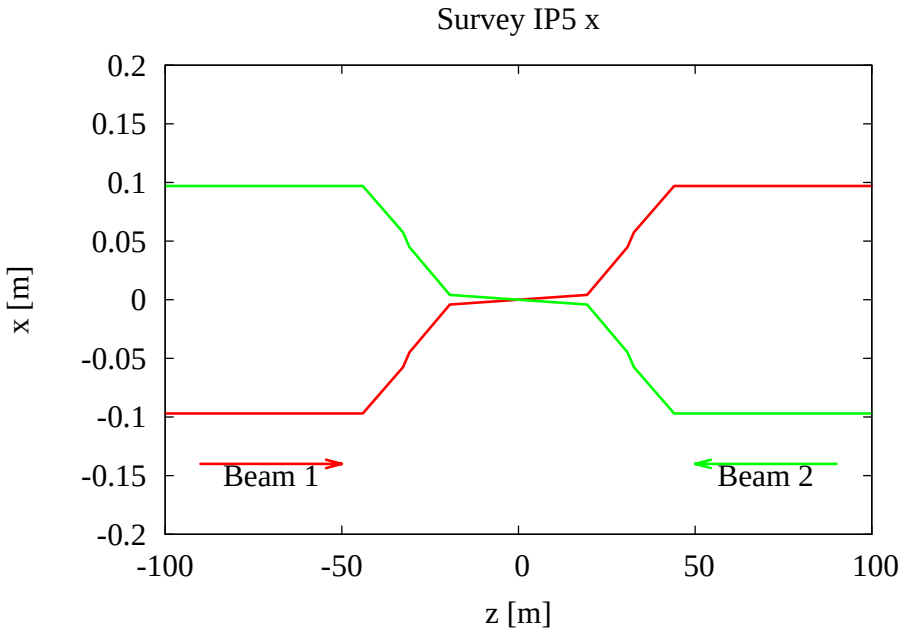
The dipoles angles are calculated using geometric calculations

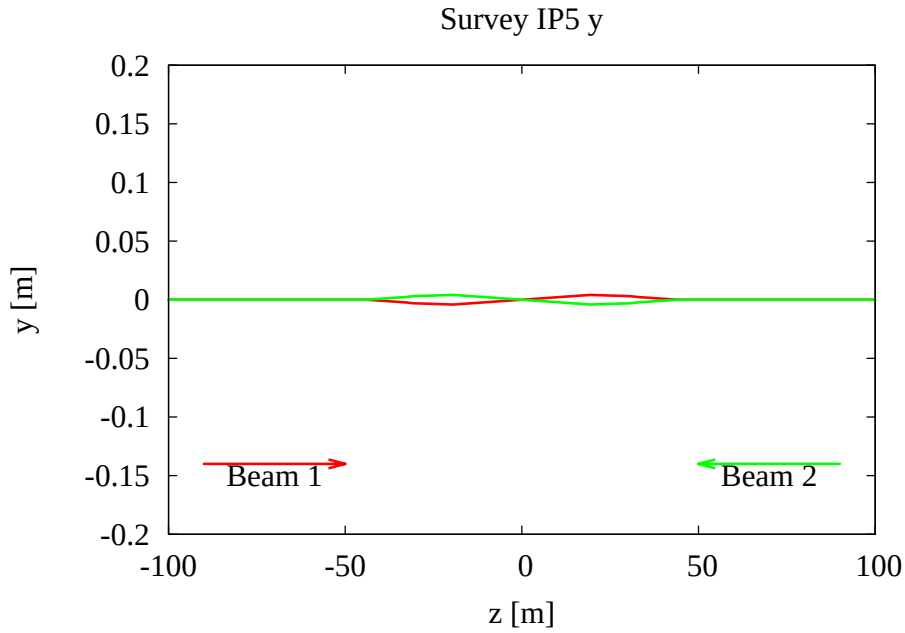
Data	Unit	No Cross	x Cross	y Cross
Parallel separation	[mm]	97.000		
D1/D2 lenght	[m]	11.400		
H Crossing angle	[mrad]	0.000	0.211	0.000
V Crossing angle	[mrad]	0.000	0.000	0.211
H Crossing sep (d)	[mm]	0.000	5.317	0.000
V Crossing sep (d)	[mm]	0.000	0.000	5.317
D1 left angle	[mrad]	7.337	6.724	7.363
D2 left angle	[mrad]	-7.337	-6.935	-7.348
D1 left k0	[1/km]	0.644	0.590	0.646
D2 left k0	[1/km]	-0.644	-0.608	-0.645
D1 left field	[T]	15.029	13.772	15.081
D2 left field	[T]	-15.029	-14.205	-15.051
D1 left tilt	[mrad]	0.000	0.000	-83.428
D2 left tilt	[mrad]	0.000	0.000	-54.756

Survey Plots

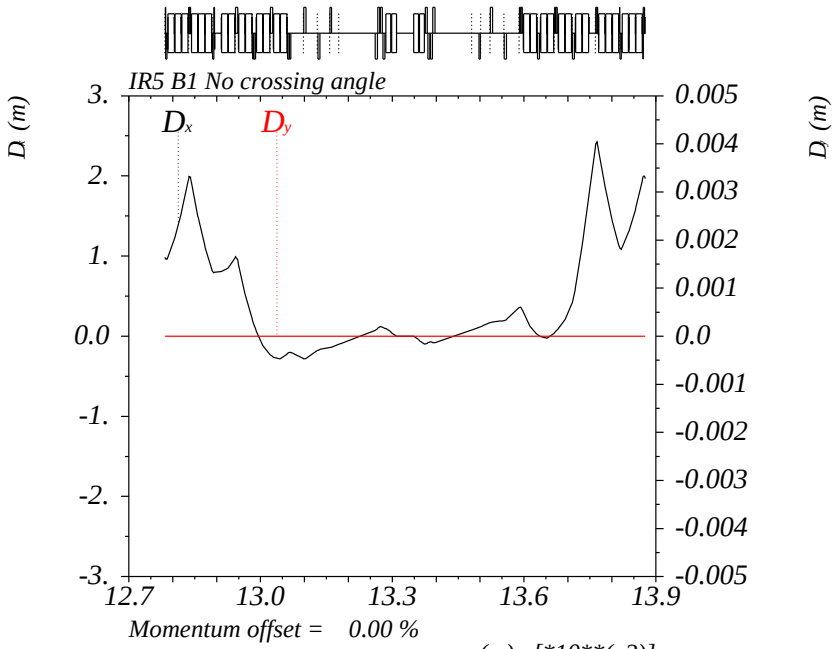


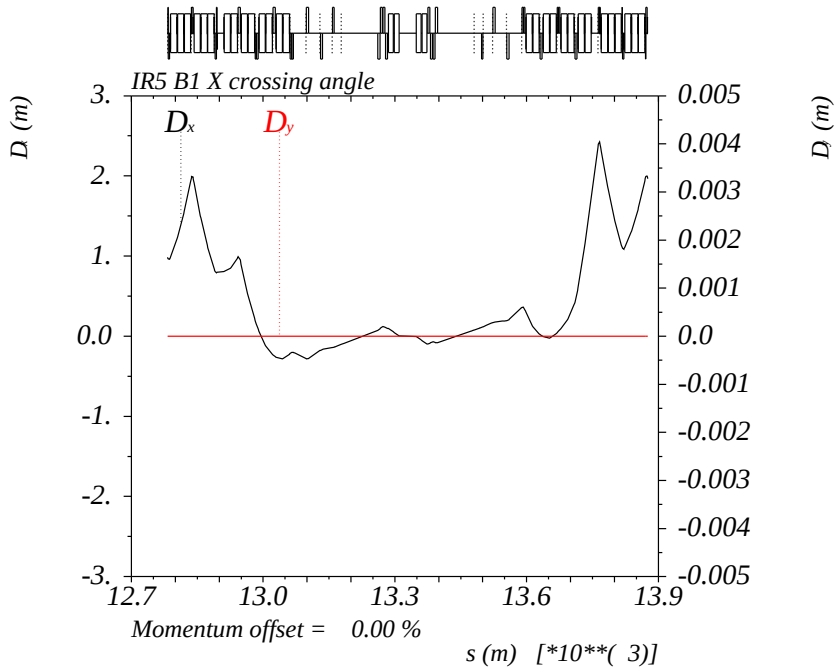


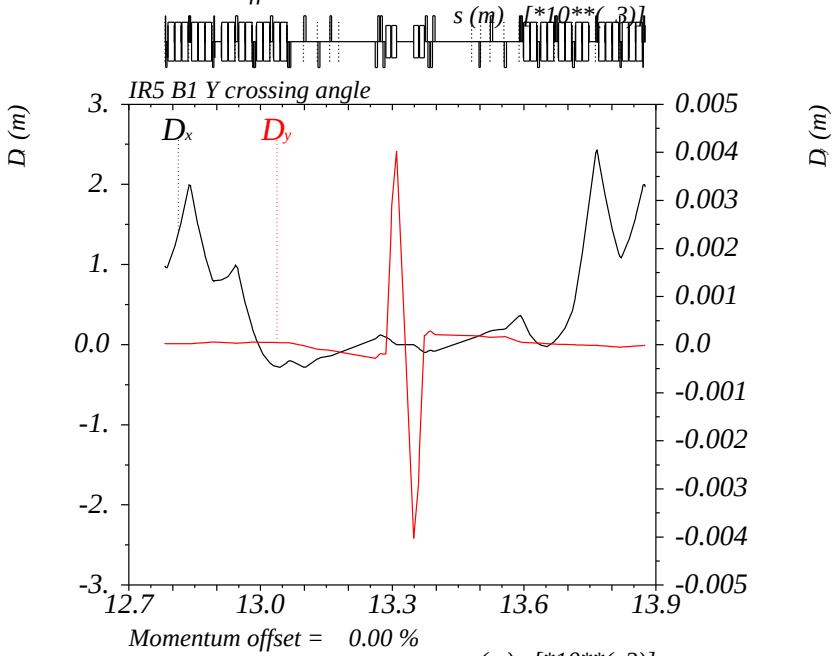




Dispersion Plots







Ongoing Studies

For the dipole first layout

- Chromaticity correction
- Dynamic aperture
- Injection optics and squeeze

. . . comments, suggestions are welcome.