HL-LHC Optics and layout update

R. De Maria

Thanks to G. Arduini, R. Bruce, F. Cerrutti, P. Diaz, S. Fartoukh, M. Fitterer, D. Gamba, M. Giovannozzi, P. Fessia, H. Prin, S. Redaelli, A. Tzinganis, B. Vasquez, I. Zurbano.

76th HiLumi WP2 Meeting 02/09/2016

Layout Changes 1.2 – 1.3

- Updated triplet layout for BPM position
- 2 crab cavities per side per IP, but compatibility for 4.
- TAXN-TCTs-TCLX-D2 revised layout
- Longer D2-MCBRD assembly (under study)
- 2xMCBYY+MQYY replaced by mask+4xMCBY+MQY
- MQY at 1.9K for Q5 in IR6
- HL-LHC layout based on LHC-LS2 layout
  - cold collimators, 11T MBH
  - Mask/MiniTAN in IR8 (under study)
  - residual non conformities (under study)

Optics Changes 1.2 – 1.3

- Round collision β*=20 cm as baseline limited by triplet
- Flat collision optics β*=40/15 cm limited by Q4
- Pre-squeeze β*=50 cm for quadrupole margins
- Ramp&Squeeze
- Optics variants
  - Pushed β*: 15 cm round, 30/7.5 cm flat in case of tighter collimator settings, better phase advance, alignment and deformations, optics correction not at the worst case.
  - Pushed LHCb: β* up to 1 m with ATS.
- Revised orbit knobs conventions
- Not studied yet:
  - IR6 with improved phase advance [1] for flat optics
  - IR6 vs dump constraints [2]
  - Q4 position optimization for aperture/integration
  - IR4 optimization for e-lens, feedback, RFQ etc…

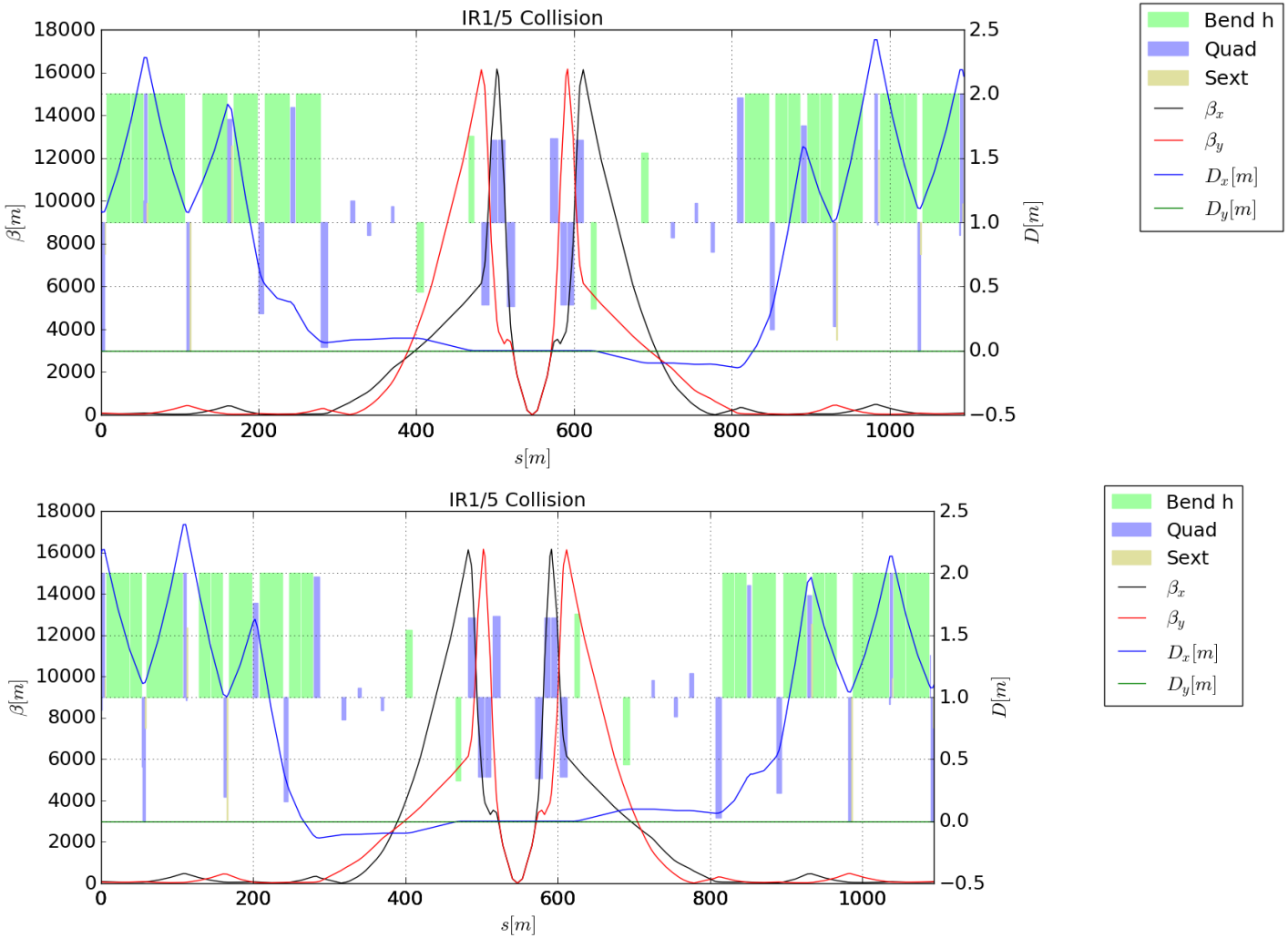
[1] S. Fartoukh, WP2 meeting, 27/11/2015

[2] C. Bracco, TCC meeting, 4/8/2016

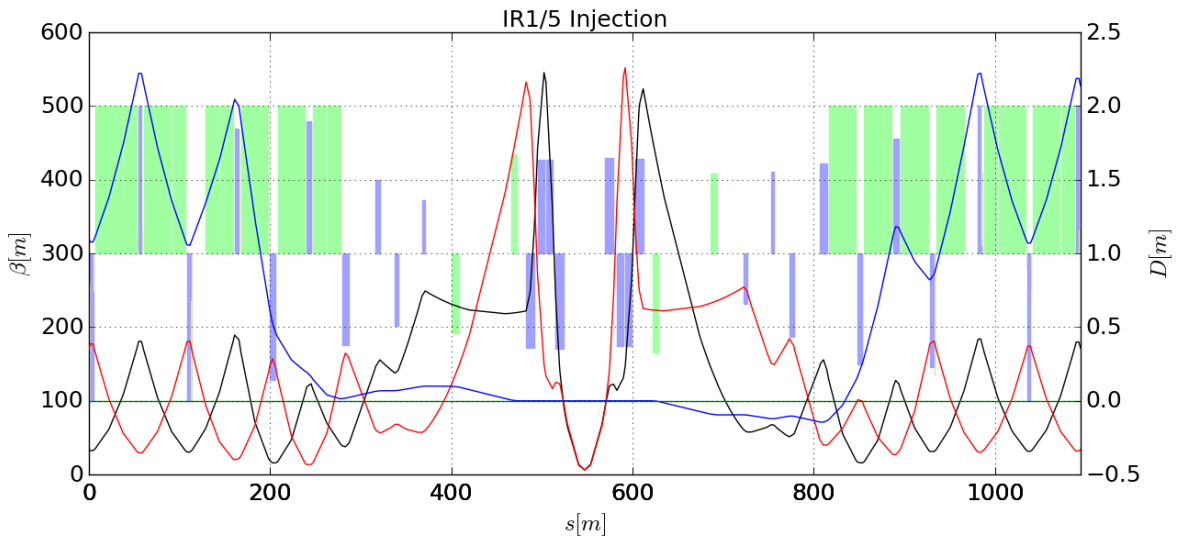
Workflow

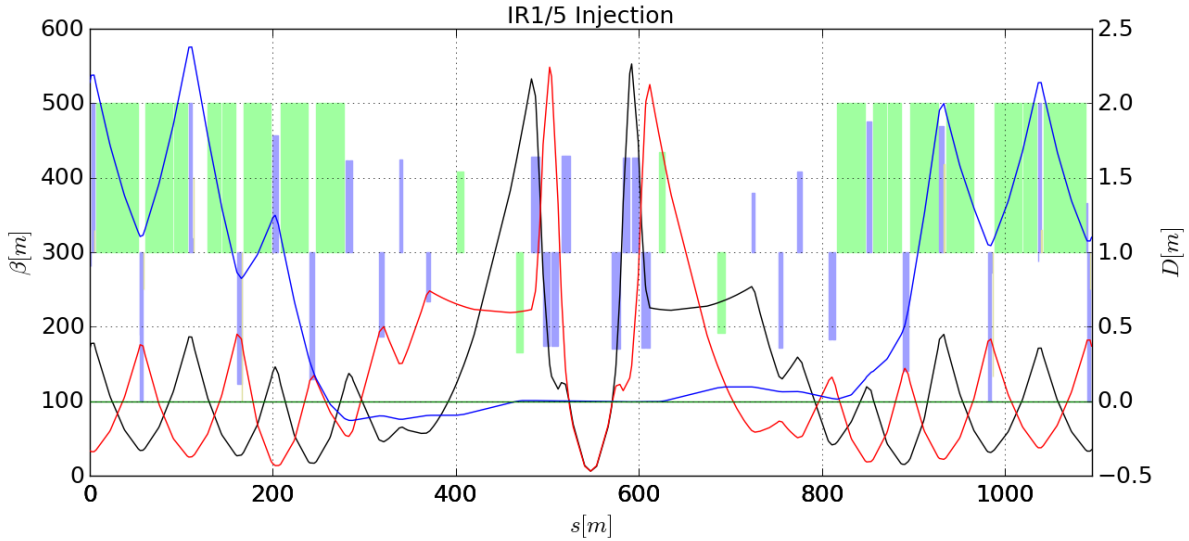
- Re-establish a complete set of layout/optics/aperture/errors files for studies in a new repository HLLHCV1.3.
- Study variants to improve performance.

Basic Optics IR1/5

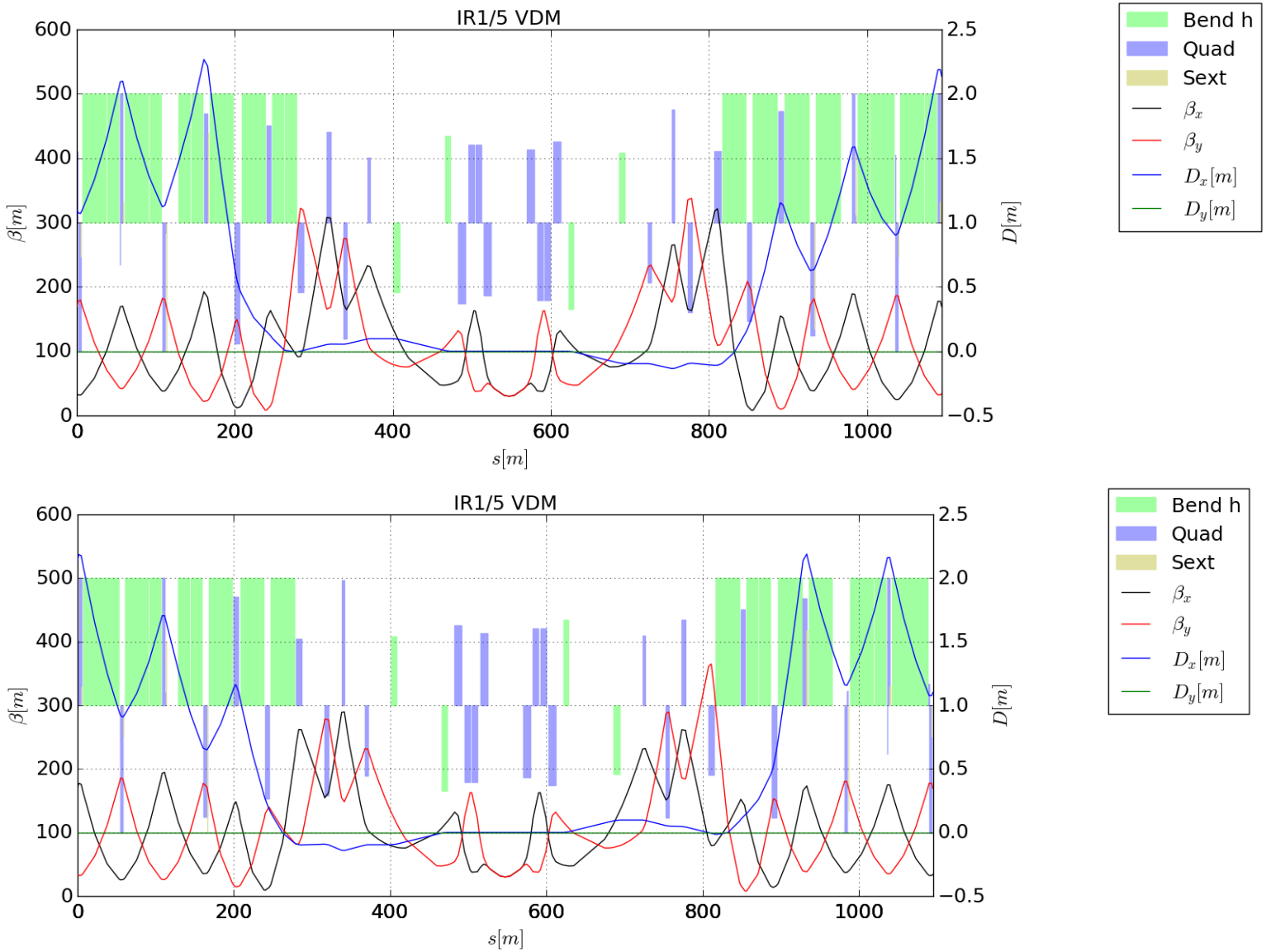


Basic Optics IR1/5



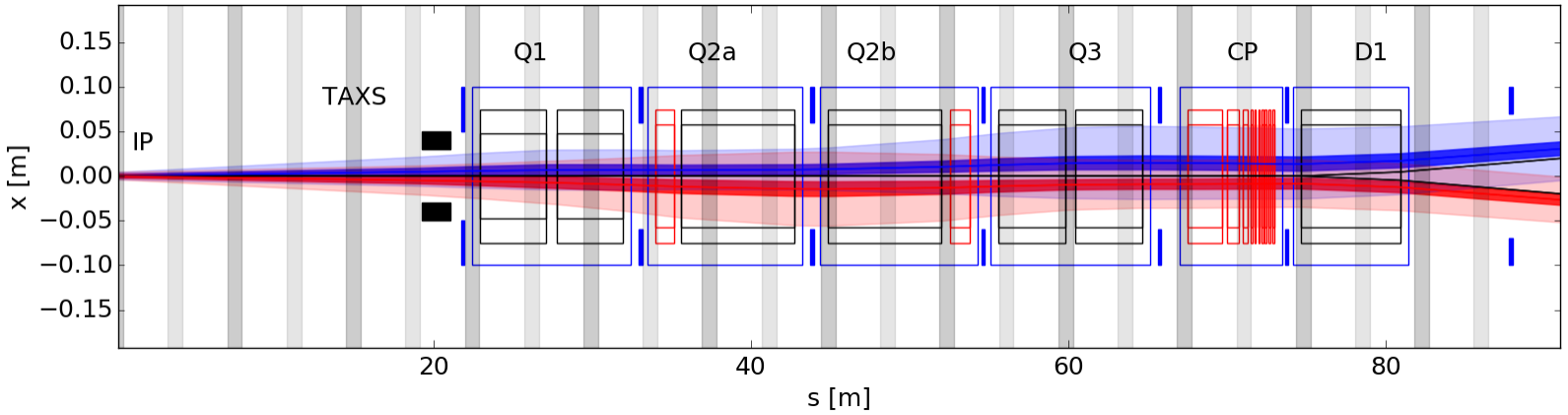


Basic Optics IR1/5



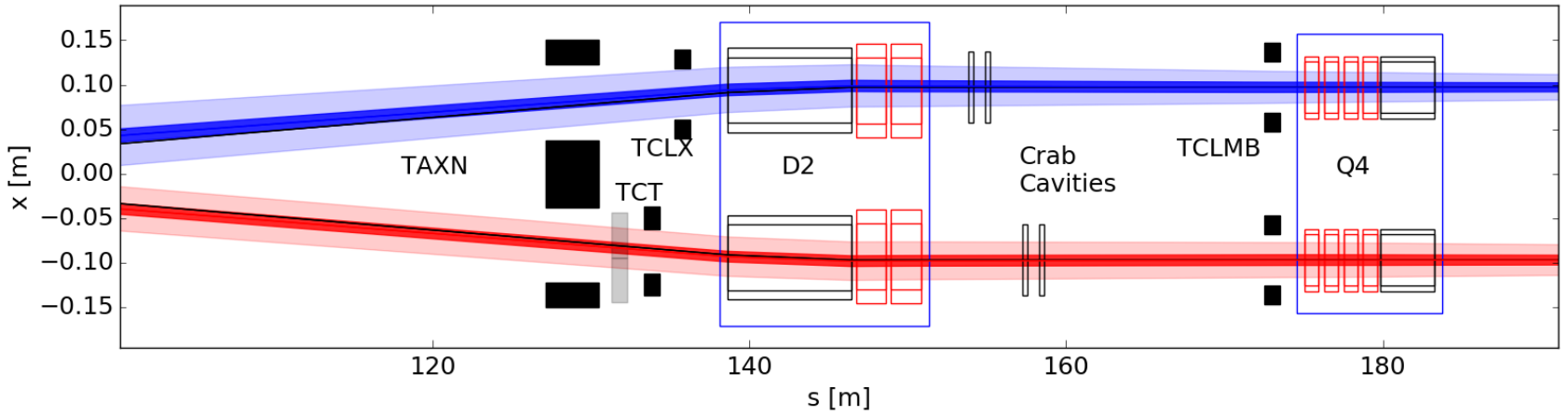
Updated triplet layout and BPM

- All layout moved by 8 cm towards the IP. L*=22.92
- Q1a-Q1b and Q3a-Q3b distance reduced by 4 cm.
- All BPM are further LR encounter by >57 cm
- Q1 strength reached nominal 132.6 T/m
- Q2-Q3 still below 132 T/m, room optics correction



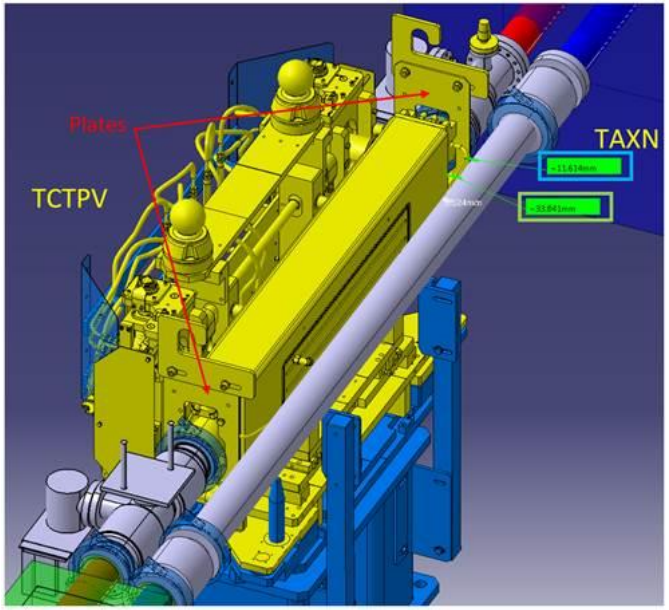
2 crab cavities

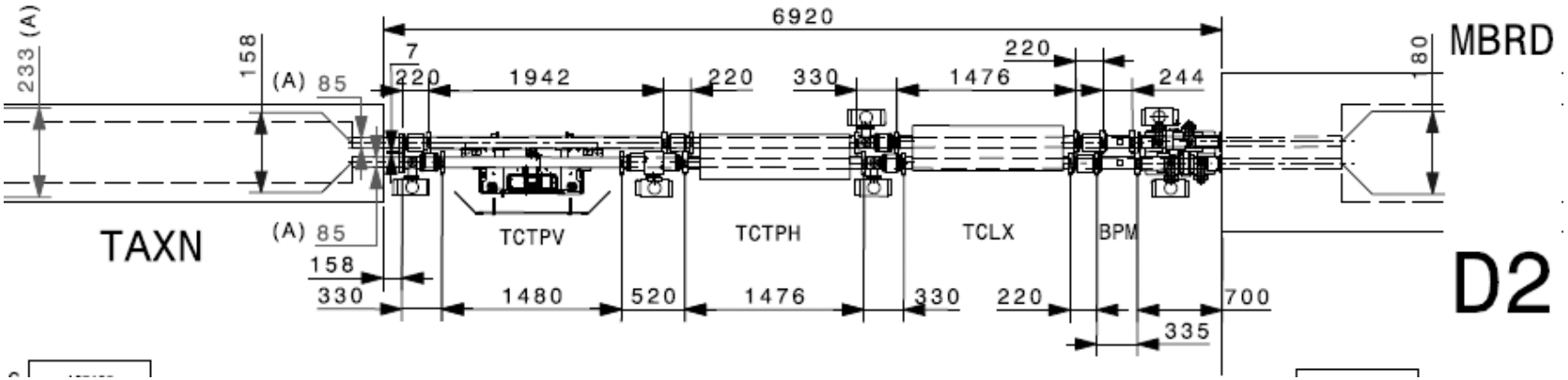
- Only 2 cavities per side per beam per IR.
- Civil engineering and tunnel space reserved for 4
- Used at max voltage 3.4 MV (it was at 2.9 MV in the last baseline)
- Easier to align (-> more margin in the corrector budget)



TAXN-TCTs-TCLX-D2

- Integration vacuum elements.
- No fifth axis. 2-in-1 TCLX, TCTPXH, tank design to be provided by collimation team.





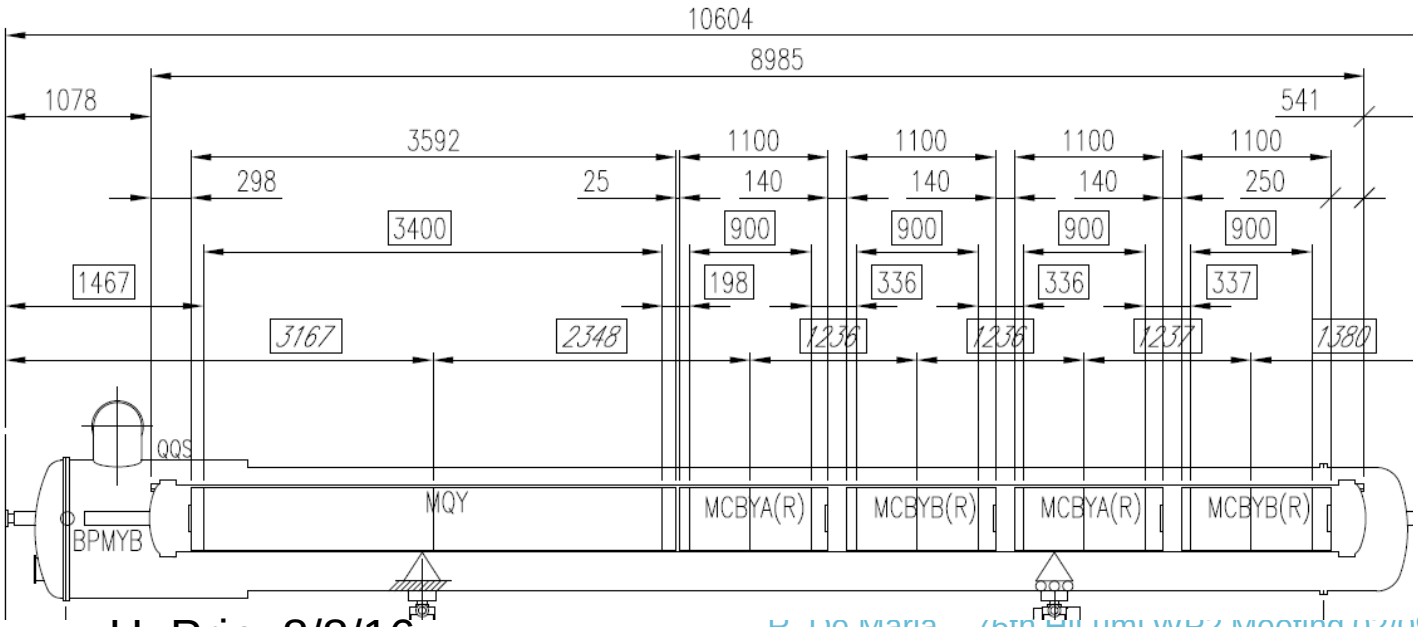
P. Diaz, V. Baglin, 23/8/16

D2-MCBRD assembly

- Request to separate MBRD from MBRCH/V as a long cold mass is beyond current manufacturing capabilities.
- SC Link connection not integrated yet.
- 1 m longer object -> no strength margin in D1 -> move crab assembly by 1 m -> loss 1.5% in crab cavity kick.
- Decision to be discussed by TCC.

Q4: MQYY -> MQY

- 2xMCBYY+MQYY replace by 4xMCBY+MQY
- Q4 becomes bottleneck for flat optics
- MCBY at 1.9K needed to fit with budget for 590 μrad crossing angle and 4 cavities
- MCBY at 4.5K just sufficient for 590 μrad crossing angle and 2 cavities.
- Additional margin in MCBRD needed in case of crossing angle levelling to avoid orbit variation during the fill.



H. Prin, 8/8/16

Orbit corrector budget

- IP crossing, separation, offset (**x:** ±295 μrad, **, s:** ±0.75 mm, **o:** ±2.0 mm)
- beam based alignment of crab cavities: **ccp**, **ccm** (shift): ±0.5 mm, **ccs** (slope): ±0.25 mm
- IT alignment and transfer function errors (**err**): ±0.5 mm transverse, ±10 mm longitudinal, $\pm 2 \times 10^{-3}$ relative gradient error, $\pm 2 \times 10^{-3}$ D2 relative field error (±2 σ from uniform errors).
- orbit correction from the arc (from LHC data to confirmed): **arc** 0.7 Tm;
- **lumi** scan knobs (single beam IP shift for 100μm)

	x-scheme [Tm]			cc alignment [Tm]			err [Tm]	arc [Tm]	lumi [Tm]	summary [Tm]		
name	x	s	o	ccp	ccm	ccs	err	arc	lumi	tot	max	margin [%]
MCBX1	0.14	0.11	1.16	0.19	0	0	0.92	0	0	2.42	2.5	3.3
MCBX2	0.07	0.05	0.79	0.19	0	0	1.40	0	0	2.17	2.5	1.5
MCBX3	2.11	0.2	0.94	0.45	0.15	0	0.78	0	0	4.43	4.5	1.4
MCBRD4	2.97	0.09	0	0.28	0.15	0.52	0.04	0.35	0.27	4.60	5	8.0
MCBY4	1.49	0.04	0.12	0.42	0.42	0.92	0	0.35	0.20	4.74	5.8	18
MCBY5	0	0	1.35	0.40	0.40	0.35	0	0	0	2.46	2.7	8.8
MCBY5	0	0	0	0	0	0	0	0.7	0	0.7	2.7	74
MCBC6	0	0	0.46	0	0	0	0	0.7	0	1.16	2.1	44
MCBC7	0	0	1.40	0	0	0	0	0.7	0	2.10	2.8	25

MQY at 1.9K for Q5 in IR6

- Larger strength in Q5 needed for flat optics from … and round optics from …
- No final optics requirements from dump studies
- Promising phase advance choice to increase phase advance from MKD to TCT, studied for round optics (S. Fartoukh).
- Request to optimize optics and avoid 1.9 K modifications.
- Optics files using HL1.2 phase.
- Studies for new phase on-going.

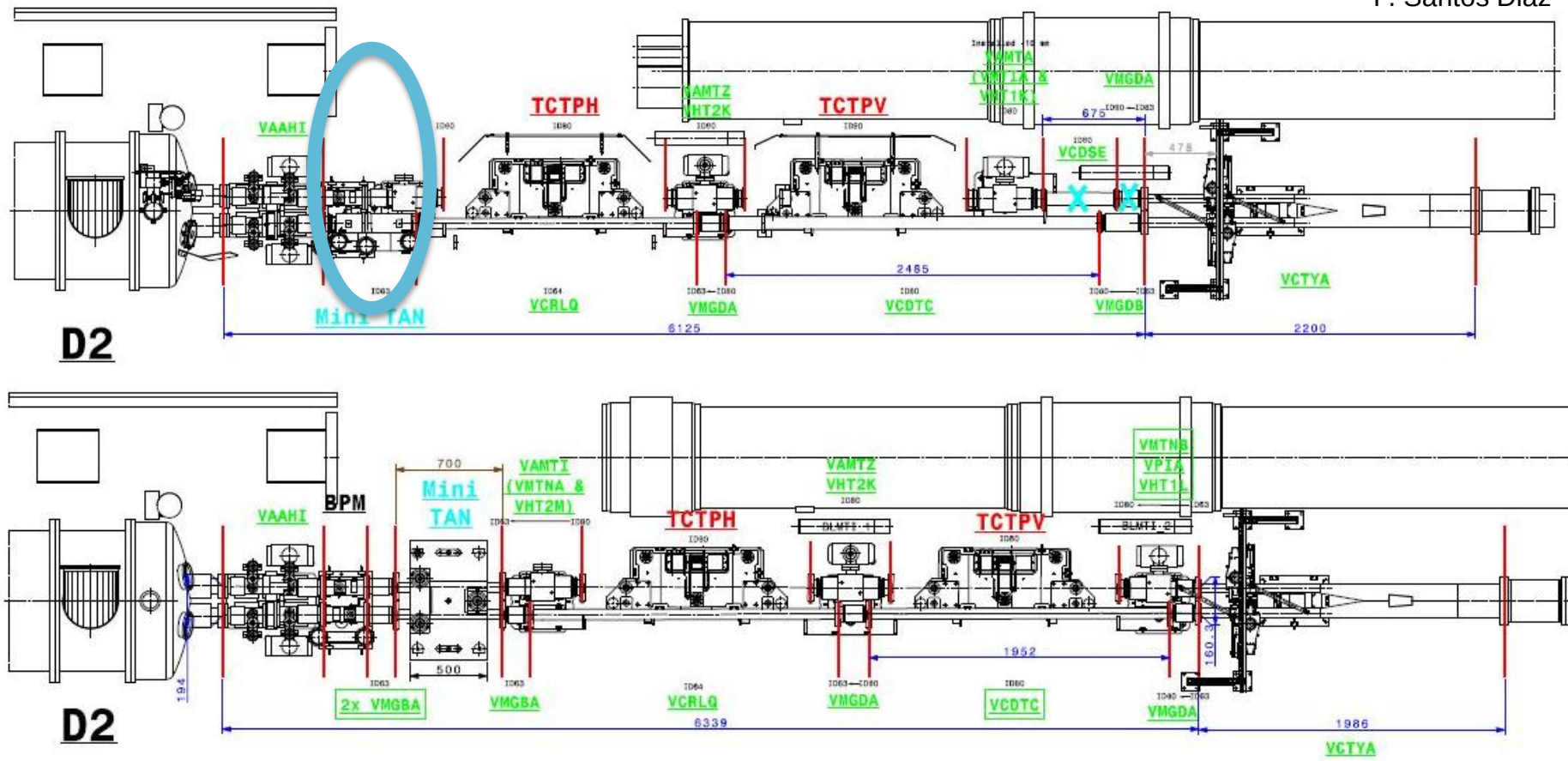
Cold collimators - MBH

- In LS2 we assume cold collimator with MBH replacing MB.B8R/L in IR7
- In Q11 IR2 in empty cryostats.

Mask/MiniTAN IR8

- For LS2 a mini tan and mask is being proposed.
- Integration / aperture studies on going.
- Not in the layout yet.

P. Santos Diaz



TODO

- Squeeze IR1-IR5-IR6 (old and new phase)
- Pre-squeeze optics robustness against imperfections
- Crab voltage range and optimization
- Release optics repository for studies
- IR4 for options

Back-up

	HLLHC					LHC			
	MCBXFA	MCBXFB	MCBRD	MBRD	MBXF	MCBX	MCBY	MBX	MBRC
Integrate field [T m]	4.5	2.5	5.0	35.0	35.0	1.5	2.3	39.7	39.7
Nom. Current [A]	1600	1600	430	12000	12000	550	72	5750	6050
Ramp rate [A/s]	15.0	15.0	2.0	20.0	20.0	2.5	0.7	18.0	13.0
Field Rate [mTm/sec]	42	23	23	58	58	7	21	124	85
Angle Rate [murad/sec@7TeV]	1.8	1.0	1.0	2.5	2.5	0.3	0.9	5.3	3.7
Ramp Acc. [A/s2]	5.0	5.0	1.0	2.0	2.0	0.2	0.3	2.0	2.0
Field Acc. [mTm/sec2]	14.1	7.8	11.6	5.8	5.8	0.5	7.8	13.8	13.1
Angle Acc. [murad/sec2@7TeV]	0.60	0.33	0.50	0.25	0.25	0.02	0.33	0.59	0.56
Time to full rate [sec]	3.0	3.0	2.0	10.0	10.0	12.5	2.7	9.0	6.5

Tentative ramp rates for dipoles.

Beam tolerances and collimation apertures

Beam tolerances have been re-defined by:

- taking into account LHC Run I positive experience
- adding safety margins based on possible unknowns.

For collimation:

- magnet protected by TCT: ≥12 σ
- magnet not protect by TCT: 17 σ or possibly less pending dedicated studies (R. Bruce) .

Beam Tolerance	LHC Design	LHC 2012-6 Coll.	HL-LHC Inj./Coll.
Emittance [μm] (normalization only)	3.75	3.5	3.5
β-beating [%]	20	5	10/20
Orbit error [mm]	4	0.5	4/2
Spurious Disp. [%]	27.3	10	14/10
Energy error [10^{-3}]	0.8	0.1	0.6/0.2
Target aperture with TCT (w/o TCT) [σ]	8.4	9.5(1)	9/12(17(2))

R. Bruce et al.

(1) With good MKD-TCT phase advance.
(2) or possibly less pending dedicated studies

Aperture and knobs effects V1.3

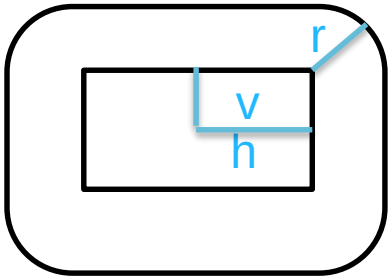
	Coil aperture	Beam[1] aperture[1]	Aperture spec[2]	Sep. Knob	Crossing Knob	Crab shift knob	Crab slope knob	Offset knob
	[mm]		[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
TAXS		Circle	60	0.8	6.1	0.0	0.0	2.0
MQXFA.[AB]1	150	Octagon	96, 96	0.8	11.2	0.0	0.0	2.4
MQXFB.[AB]2	150	Octagon	116, 106	1.2	16.7	0.2	0.0	3.6
MQXFA.[AB]3	150	Octagon	116, 106	0.8	16.6	0.4	0.0	2.8
MBXF	150	Octagon	116, 106	0.5	15.5	0.5	0.0	2.4
TAXN		Circle	85, 85	0.2	5.5	0.9	0.0	3.0
MBRD	105	Octagon	84, 84	0.1	3.3	1.0	0.0	3.3
MCBRD	105	Octagon	84, 84	0.1	1.7	1.0	0.1	3.4
TCLMB.4		RectEllipse	57.8, 48	0.0	0.0	0.4	0.2	3.7
MCBY	70	RectEllipse	57.8, 48	0.0	0.1	1.0	0.5	4.0
MQY	70	RectEllipse	57.8, 48	0.0	0.0	1.0	0.5	3.9
TCLMB.5		RectEllipse	57.8, 48	0.0	0.0	0.4	0.2	3.7
MCBY[HV].5	70	RectEllipse	57.8, 48	0.0	0.0	0.0	0.0	3.6
MQY.5	70	RectEllipse	57.8, 48	0.0	0.0	0.2	0.1	3.5
TCLMC.6		RectEllipse	45.1,35.3	0.0	0.0	0.0	0.0	2.3
MCBC[HV].6	56	RectEllipse	45.1,35.3	0.0	0.0	0.0	0.0	2.1
MQML.6	56	RectEllipse	45.1,35.3	0.0	0.0	0.0	0.0	2.1

[1]Either Beam screen or beam pipe;

[2] Mechanical tolerances already removed. Gaps: Circle -> radius, Octagon -> HV/45°, Rectellipse -> radius/gap. Rectellipse orientation optimized for collision optics.

Survey-fiducialization tolerances

	Ground motion			Fiducializaton		
	r [mm]	h [mm]	v [mm]	r [mm]	h [mm]	v [mm]
TAXS (*)	2.0	0	0	0	0.5	0.5
Triplets	0.6	0	0	0	1.0	1.0
BPMs	0	0	0	2.5	0	0
TAXN (*)	0.84	0.36	0	0	1.0	1.0
D1	0.6	0.36	0	0	1.0	1.0
D2/Q4/Q5	0.84	0.36	0	0	0.9	0.6



Value derived from J. Jeanneret, LHC rep 1007 but to be validated by survey, WP3, WP8(*) teams

Aperture margin definitions

Adding tolerances one by one in the next tables:

- Bare: no mechanical tolerances, perfect beam, perfect alignment
- Mech: mechanical tolerances in beam screen, perfect beam, perfect alignment
- Beam: mechanical tolerances in beam screen, imperfect beam (including triplet misalignments in orbit budget), perfect crab and perfect IP alignment
- Crab: mechanical tolerances in beam screen, imperfect beam (including triplet misalignments in orbit budget), crab misalignment, perfect IP alignment
- Offset: mechanical tolerances in beam screen, imperfect beam (including triplet misalignments in orbit budget), crab misalignment, IP misalignment

Aperture Margins: Round 15 cm

	Bare	Mech	Beam	Crab	Offset
TAXS	17.9	17.9	14.4	14.4	12.4
MQXFA.[AB]1	16.5	15.4	12.9	12.9	11.9
MQXFB.[AB][23]	12.3	11.6	9.7	9.7	8.7
MBXF	13	12.2	10.2	10.1	9.4
TAXN	17.8	17.8	15	14.6	13
MBRD	19.8	18.9	15.8	15	12.6
MCBRD	21.9	20.9	17.5	16.7	14.1
MCBY	20.1	20.1	16.4	15.5	12.3
MQY	22	22	17.9	17	13.5
TCLMB.5	22.7	22.7	18.5	18.5	14.5
MCBY[HV].5	23.4	23.4	19	18.8	14.6
MQY.5	24.2	24.2	19.6	19.4	15.1
TCLMC.6	30.3	30.3	24.7	24.7	22
MCBC[HV].6	31.3	31.3	25.6	25.6	25.6
MQML.6	31.3	31.3	25.5	25.5	22.6

$\theta_c = \pm 295$ μrad; $d_{sep} = \pm 0.75$ mm.
Aperture in σ at 7Tev 3.5 μm/γ

Aperture Margins: Round 20 cm

	Bare	Mech	Beam	Crab	Offset
TAXS	22.1	22.1	18	18	15.5
MQXFA.[AB]1	20.7	19.4	16.4	16.4	15.2
MQXFB.[AB][23]	15.7	14.9	12.7	12.6	11.5
MBXF	16.4	15.6	13.2	13	12.2
TAXN	21.4	21.4	18.1	17.7	15.8
MBRD	23.3	22.2	18.6	17.7	14.9
MCBRD	25.6	24.4	20.5	19.5	16.6
MCBY	23.3	23.3	19	18	14.2
MQY	25.4	25.4	20.8	19.7	15.6
TCLMB.5	26.2	26.2	21.4	21.4	16.8
MCBY[HV].5	27	27	21.9	21.7	16.9
MQY.5	27.9	27.9	22.7	22.5	17.5
TCLMC.6	34.9	34.9	28.5	28.5	25.3
MCBC[HV].6	36.1	36.1	29.5	29.5	29.5
MQML.6	36.1	36.1	29.4	29.4	26.1

$\theta_c = \pm 255$ μrad; $d_{sep} = \pm 0.75$ mm.
Aperture in σ at 7Tev 3.5 μm/γ

Aperture Margins: Flat 40/10 cm

	Bare	Mech	Beam	Crab	Offset
TAXS	18.4	18.4	15.1	15.1	13.5
MQXFA.[AB]1	17.5	16.6	14.2	14.2	13.3
MQXFB.[AB][23]	14.1	13.5	11.6	11.6	10.7
MBXF	14.7	14	12	11.9	11.3
TAXN	16.8	16.8	14.3	13.9	12.7
MBRD	18	17.3	14.6	14.2	12.7
MCBRD	19.8	19	16.1	15.6	14
MCBY	16.6	16.6	13.5	12.8	10.1
MQY	18	18	14.7	13.9	11
TCLMB.5	18.7	18.7	15.2	15.2	12.1
MCBY[HV].5	19.5	19.5	15.8	15.6	12.3
MQY.5	19.8	19.8	16.1	15.9	12.5
TCLMC.6	24.7	24.7	20.1	20.1	17.9
MCBC[HV].6	25.6	25.6	20.8	20.8	20.8
MQML.6	25.9	25.9	21.1	21.1	18.8

$\theta_c = \pm 210$ μrad; $d_{sep} = \pm 0.75$ mm.
Aperture in σ at 7Tev 3.5 μm/γ

Aperture Margins: Flat 40/15 cm

	Bare	Mech	Beam	Crab	Offset
TAXS	22.4	22.4	18.5	18.5	16.5
MQXFA.[AB]1	21.4	20.3	17.4	17.4	16.4
MQXFB.[AB][23]	17.2	16.5	14.3	14.2	13.2
MBXF	18	17.2	14.8	14.6	13.9
TAXN	20.5	20.5	17.5	17.1	15.5
MBRD	22	21.1	18	17.4	15.6
MCBRD	24.2	23.2	19.7	19.1	17.1
MCBY	20.3	20.3	16.5	15.7	12.4
MQY	22.1	22.1	18	17.1	13.5
TCLMB.5	22.8	22.8	18.6	18.6	14.8
MCBY[HV].5	23.9	23.9	19.3	19.1	15
MQY.5	24.2	24.2	19.7	19.5	15.4
TCLMC.6	30.2	30.2	24.7	24.7	21.9
MCBC[HV].6	31.3	31.3	25.5	25.5	25.5
MQML.6	31.7	31.7	25.9	25.9	23

$\theta_c = \pm 210$ μrad; $d_{sep} = \pm 0.75$ mm.
Aperture in σ at 7Tev 3.5 μm/γ