



BBCW potentials for Run 4

P. Bélanger, A. Poyet, K. Skoufaris, G. Sterbini on behalf of BBCW team

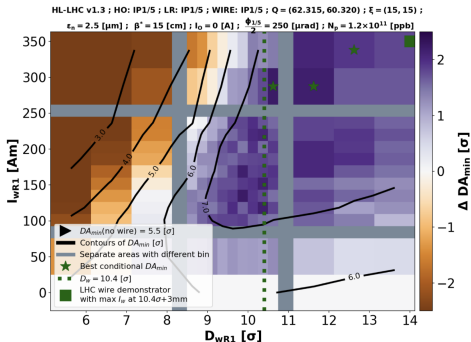
Our gratitude goes to HL-LHC, CERN and TRIUMF management for the support, WP2/5/13 for the inspiring discussions and encouragement, G. Iadarola and S. Kostoglou for helping with the xsuite code simulation framework.

Introduction

Assumption for the simulations

Results

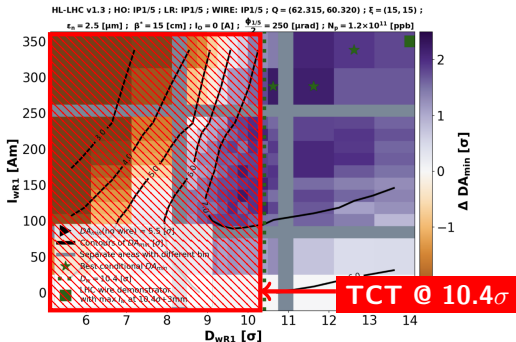
HL-LHC configurations¹



At the cost of $\int I_W dl$, the wire can be pushed away from the beam
 $\rightarrow \int I_W dl = 450 \text{ Am.}$

¹From PRAB 24 074001, 2021

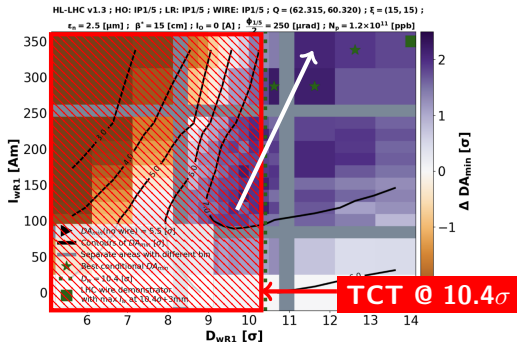
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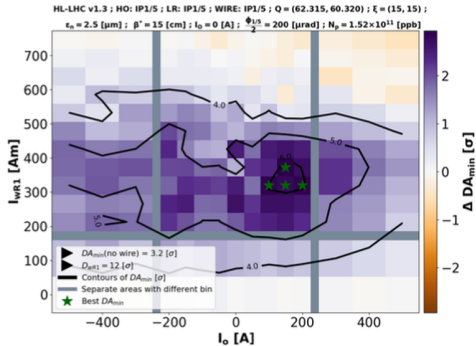
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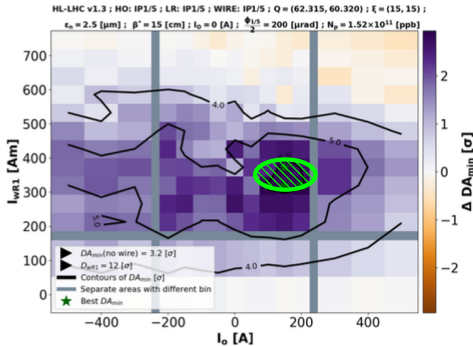
HL-LHC configurations²



Some synergies between the arc octupoles and the wires (at 12 σ).

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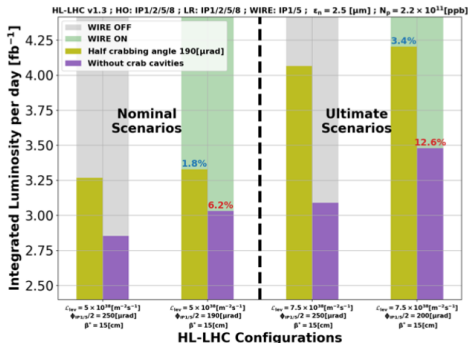
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HL-LHC configurations³



Performance gain by extending the levelling reach/time:

- w/ CC, BBCWs push $\int \mathcal{L} dt$ by 1.8-3.4%
- w/o CC, BBCWs push $\int \mathcal{L} dt$ by 6.2-12.6%

³From PRAB 24 074001, 2021

EYETS scenario to fix intensity limitation (HEL, dilution kickers, RF?)

*under review

Year	ppb [10^{11}]	Virtual lumi. [$10^{34}\text{cm}^{-2}\text{s}^{-1}$]	Days in physics	θ [μrad]	β_{start}^* [cm]	β_{end}^* [cm]	CC	Max. PU
2029	1.8	4.4	90	380*	70	30	exp	116
2030	1.8	9.0	120	500	100	20	on	132
EYETS (≈ 5 months) HEL, dilution kickers?								
2031	2.2	13.5	90	500	100	20	on	132
2032	2.2	13.5	160	500	100	20	on	132
2033-34			Long shutdown 4					
2035	2.2	13.5	140	500	100	20	on	132
2036	2.2	16.9	170	500	100	15	on	132
2036	2.2	16.9	200	500	100	15	on	200



HEL cryo connections for efficient installation in EYETS (and avoiding sector warm-up) is extra scope.

R. Tomas in LHC performance workshop, January 2022

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During the first years or Run 4, we expect a ramp-up of the HL-LHC performance (CC, β^* , ...)



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Run 4 OP scenario

- ◆ 3 major news since the 2021 annual HiLumi meeting, CSR meeting and Evian workshop
 - ★ Delay of the in-kind Russian contribution that could affect HEL, Y-chamber, low impedance collimators, dump
 - Will finally have to be descoped from HL project (as dilution kickers)
 - Decided to be insourced at CERN
 - ★ Risk of being limited at $\sim 1.8e11$ ppb in Run 4 due to RF power limitations and dump => Would reduce the luminosity by $\sim 20\%$ (mitigations to be explored)
 - Kept in, full insourced at CERN
 - ★ New dates for Run 3 and LS3
 - New baseline is to have it upgraded in LS3 and it is expected to be robust enough

=> An alternative plan was then proposed, with Run 3 studies fundamental for: intensity, e-cloud, emittance, beam-beam effects and optics control





23 E. Métral - 12th HL-LHC Collaboration Meeting, Uppsala, Sweden - 19/09/2022

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BBCW potential for Run 4

- Can we make use of the wire in an early stage of Run 4?

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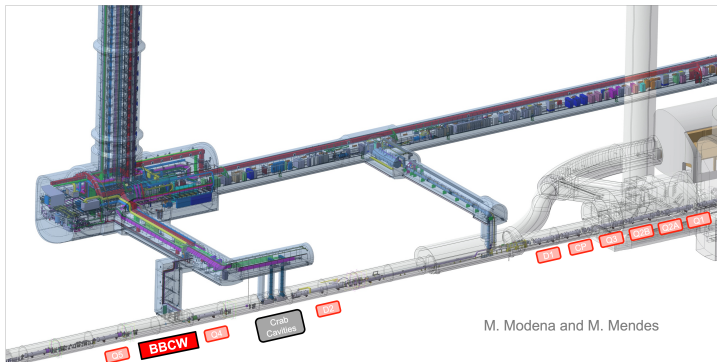
- Can we make use of the wire in an early stage of Run 4?
- What are the BBCW performance before reaching the $\beta^* = 15$ cm?
→ we will focus on $\beta^* = 30$ cm and $N_b = 1.8 \cdot 10^{11}$ ppb.

Introduction

Assumption for the simulations

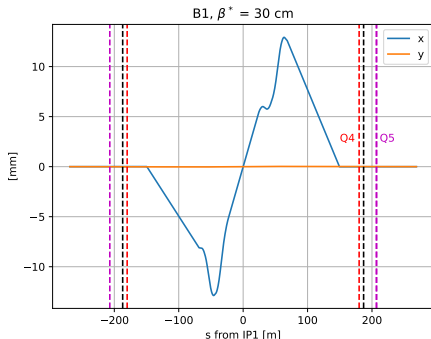
Results

“Reserved” space for the wire ⁴



⁴EDMS 2037987

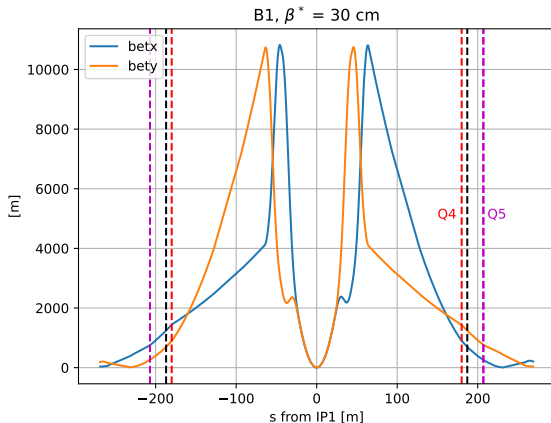
“Reserved” space for the wire ⁴



External to the crossing bump, close to the Q4.

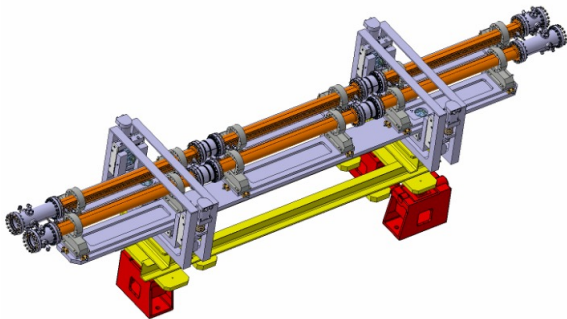
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“Reserved” space



β_y/β_x close to the ones proposed of PRAB 18 121001, 2015.

Proposed wires' layout⁵



1 assembly/side/IP \rightarrow 1 assembly = $3 \times$ 1-m wire modules/beam
1 module can carry 150 A \rightarrow 450 Am per beam/side/IP

⁵See Alessandro's presentation

Optics at $\beta^* = 30$ cm

	s from IP1 [m]	β_x [m]	β_y [m]	β_y/β_x
bbcw.i.3. 4I1 .b1	-189.50	1176.12	632.12	0.54
bbcw.i.2. 4I1 .b1	-188.25	1209.93	664.12	0.55
bbcw.i.1. 4I1 .b1	-187.00	1244.31	696.86	0.56
bbcw.i.1. 4r1 .b1	187.00	698.20	1243.97	1.78
bbcw.i.2. 4r1 .b1	188.25	664.72	1210.73	1.82
bbcw.i.3. 4r1 .b1	189.50	632.10	1177.87	1.86

In the simulations, we consider a 4.5 m assembly and 4×3 wires per beams.

At $\beta^* = 30$ cm, 7 TeV, $\epsilon_n = 2.5 \mu\text{m}$

	σ_x [mm]	σ_y [mm]
bbcw.i.3.4 1 1.b1:1	0.63	0.46
bbcw.i.2.4 1 1.b1:1	0.64	0.47
bbcw.i.1.4 1 1.b1:1	0.65	0.48
bbcw.i.1.4 r 1.b1:1	0.48	0.65
bbcw.i.2.4 r 1.b1:1	0.47	0.64
bbcw.i.3.4 r 1.b1:1	0.46	0.63

16 σ separation $\rightarrow \approx 10$ mm offset wrt the beam.

In the simulation, BBCWs are at the same **physical distance** from the beam. “BBCW at 16 σ ” means that all BBCWs are at

$$16 \max_{\text{BBCWs}} \sigma. \quad (1)$$

DISCLAIMER: the present BBCW demonstrators are strongly coupled with the TCT settings. We assume the HL BBCW will be

- **NOT embedded in the TCTs**
- **STILL in the TCTs shadow** (\rightarrow tight collimators setting are better for the BBCW, i.e. lower I_w).

Assuming the unfavourable collimators relaxed settings (TCT at 11.4σ for $\beta^* = 0.15$ m), two scenarios envisaged:

- **Scenario A:** BBCW at $> 16.1 \sigma$ at $\beta^* = 0.30$ m IF TCT position constant in mm
- **Scenario B⁶:** BBCW at $> 11.4 \sigma$ at $\beta^* = 0.30$ m IF TCT position constant σ .

⁶specific MKD-TCT phase constraints are needed.

At $\beta^* = 6$ m, 0.45 TeV, $\epsilon_n = 2.5 \mu\text{m}$

	σ_x [mm]	σ_y [mm]
bbcw.i.3.4 1 1.b1:1	1.13	0.50
bbcw.i.2.4 1 1.b1:1	1.14	0.49
bbcw.i.1.4 1 1.b1:1	1.16	0.49
bbcw.i.1.4 r 1.b1:1	0.49	1.17
bbcw.i.2.4 r 1.b1:1	0.49	1.15
bbcw.i.3.4 r 1.b1:1	0.50	1.13

Garage position of the BBCW driven by the injection σ

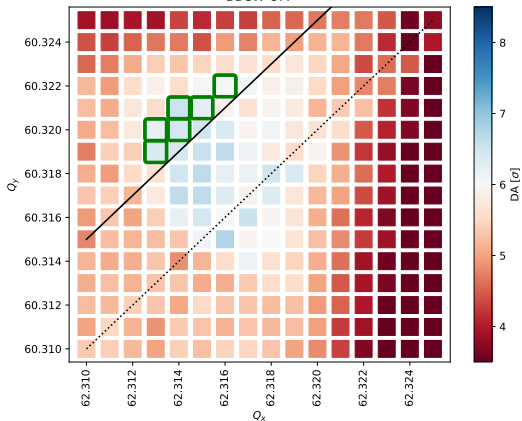
Assuming 25 σ of garage position yields ≈ 30 mm offset wrt the beam \rightarrow implication on the stroke of the BBCW movement.

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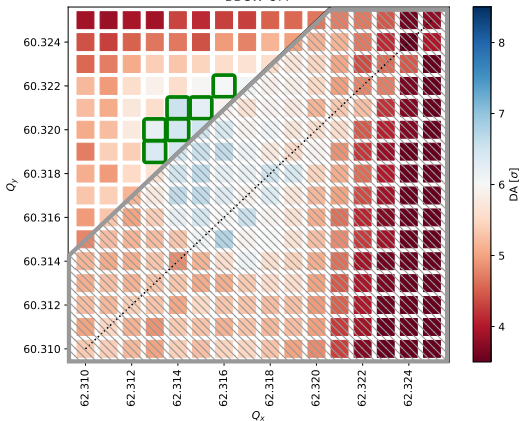
Results

HL-LHC v1.5, no MS.10, $N_b = 1.8 \times 10^{11}$ ppb, $\beta_{IP1/5}^* = 30$ cm, $\phi/2_{IP1/5} = 225$ μ rad
 $\sigma_z = 7.61$ cm, $\phi/2_{H,IP8} = 250$ μ rad, $\epsilon_n = 2.5$ μ m, $Q' = 15$, $I_{MO} = 100$ A, $C^- = 10^{-3}$
 BBCW OFF



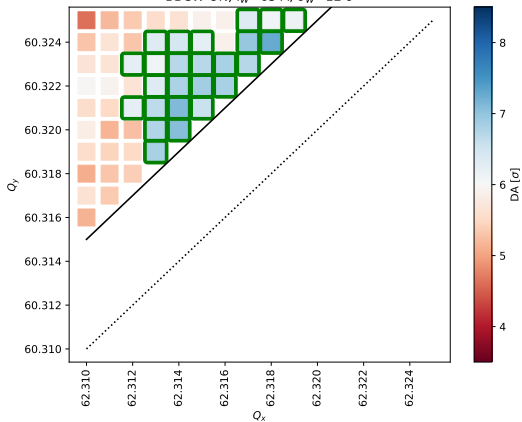
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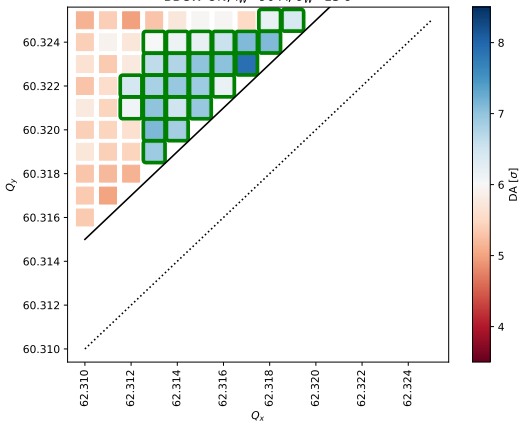
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 BBCW ON, $I_W=65$ A, $\sigma_W=12$ σ



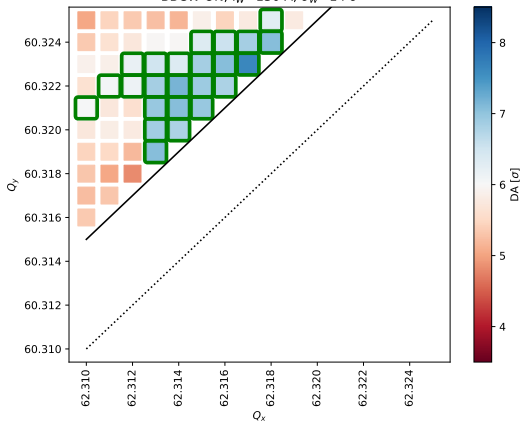
BBCW ON, $I_W = 65$ A at 12σ .

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 BBCW ON, $I_W=90$ A, $\sigma_W=13$ σ



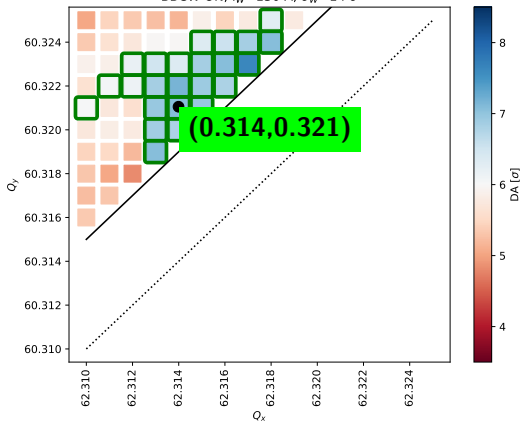
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 BBCW ON, $I_W=130$ A, $\sigma_W=14$ σ



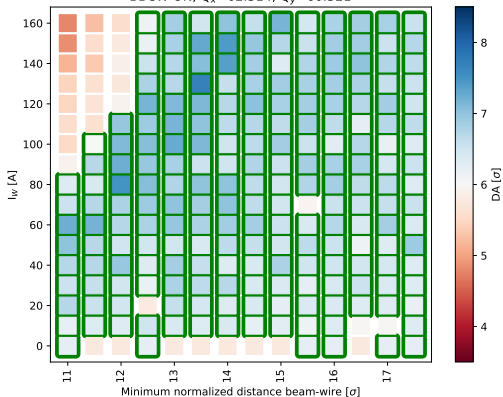
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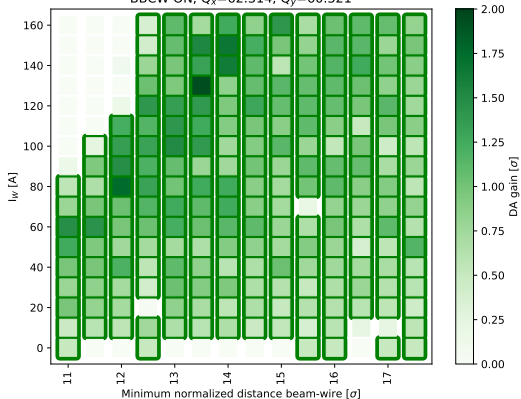
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 BBCW ON, $Q_x=62.314$, $Q_y=60.321$



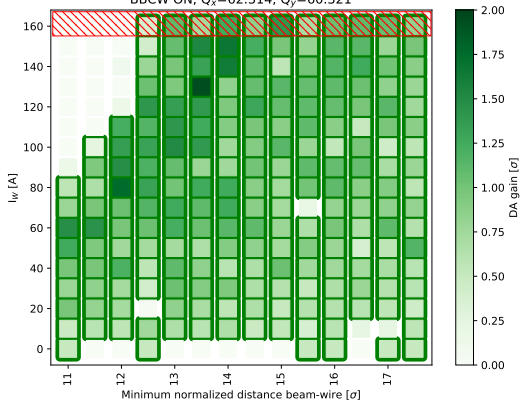
Distance vs I_w scan at $Q=(0.314, 0.321)$: **up to 2 σ of DA gain.**

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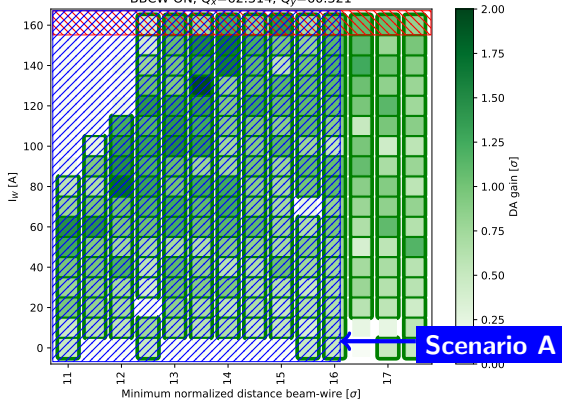
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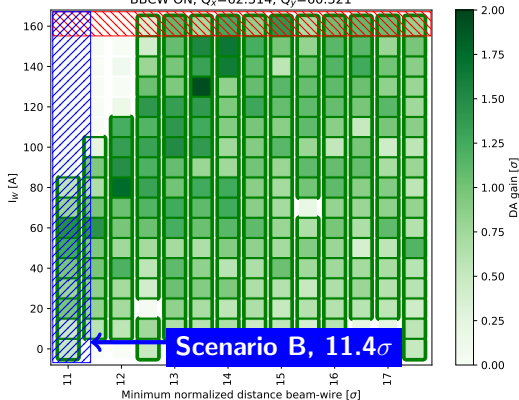
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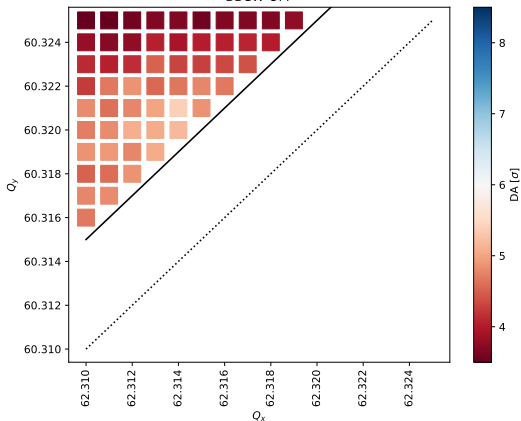
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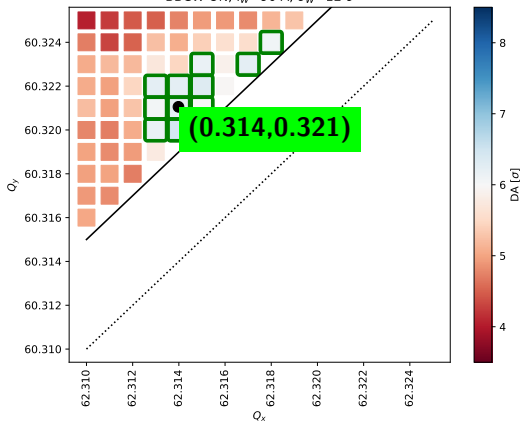
Distance vs I_w scan at $Q=(0.314, 0.321)$: **up to 2 σ of DA gain.**

HL-LHC v1.5, no MS.10, $N_b = 1.8 \times 10^{11}$ ppb, $\beta_{IP1/5}^* = 30$ cm, $\phi/2_{IP1/5} = 190$ μ rad
 $\sigma_z = 7.61$ cm, $\phi/2_{H,IP8} = 250$ μ rad, $\epsilon_n = 2.5$ μ m, $Q' = 15$, $I_{MO} = 100$ A, $C^- = 10^{-3}$
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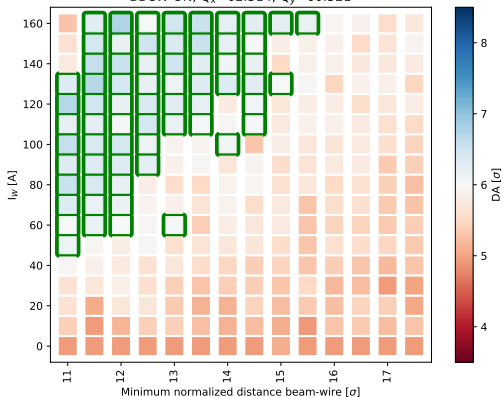
BBCW OFF with $\beta^* = 0.30$ m, $N_b = 1.8 \cdot 10^{11}$ ppb, $\theta_c/2 = 190$ μ rad.

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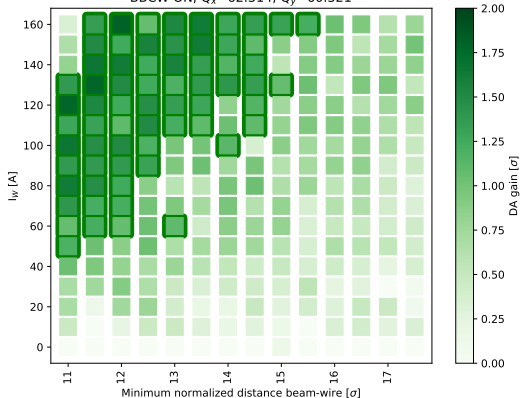
BBCW ON at 90 A and 12 σ .

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Distance vs I_w scan at $Q=(0.314, 0.321)$: **up to 2 σ of DA gain**

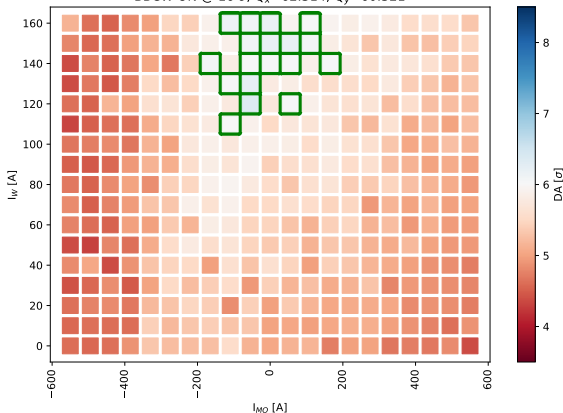
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Distance vs I_w scan at $Q=(0.314, 0.321)$: **up to 2 σ of DA gain**

Interplay with arc octupoles

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BBCW ON @ 16σ , $Q_x = 62.314$, $Q_y = 60.321$



If BBCW too far (16σ), can the arc octupole help? **Marginally.**

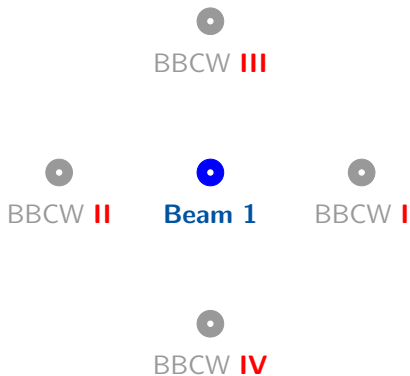
Special configurations



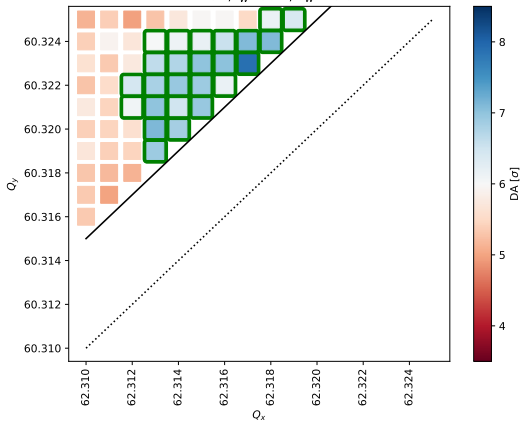
Special configurations



Special configurations

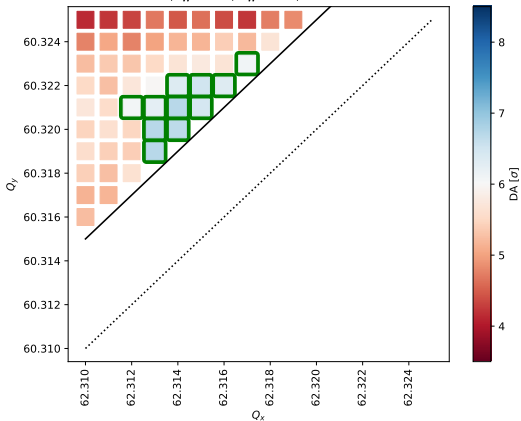


HL-LHC v1.5, no MS.10, $N_b=1.8 \times 10^{11}$ ppb, $\beta_{IP1/5}^* = 30$ cm, $\phi/2_{IP1/5} = 225$ μ rad
 $\sigma_z = 7.61$ cm, $\phi/2_{H,IP8} = 250$ μ rad, $\epsilon_n = 2.5$ μ m, $Q' = 15$, $I_{M0} = 100$ A, $C^- = 10^{-3}$
 BBCW ON, $I_W=90$ A, $\sigma_W=13 \sigma$



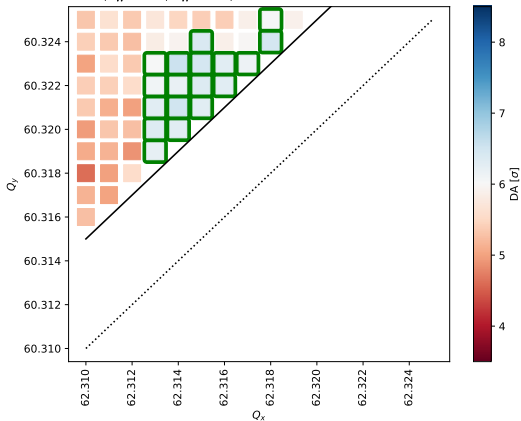
90 A @ 13 σ , BBCW █ in IP1, BBCW █ in IP5

HL-LHC v1.5, no MS.10, $N_b=1.8 \times 10^{11}$ ppb, $\beta_{IP1/5}^* = 30$ cm, $\phi/2_{IP1/5} = 225$ μ rad
 $\sigma_z = 7.61$ cm, $\phi/2_{H,IP8} = 250$ μ rad, $\epsilon_n = 2.5$ μ m, $Q' = 15$, $I_{M0} = 100$ A, $C^- = 10^{-3}$
 BBCW ON, $I_W=90$ A, $\sigma_W=13$ σ , external V in IP5



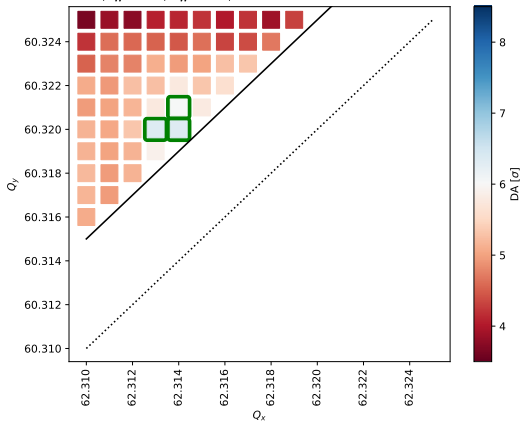
90 A @ 13 σ , BBCW I in IP1, BBCW II in IP5

HL-LHC v1.5, no MS.10, $N_b=1.8 \times 10^{11}$ ppb, $\beta_{IP1/5}^* = 30$ cm, $\phi/2_{IP1/5} = 225$ μ rad
 $\sigma_z = 7.61$ cm, $\phi/2_{H,IP8} = 250$ μ rad, $\epsilon_n = 2.5$ μ m, $Q' = 15$, $I_{M0} = 100$ A, $C^- = 10^{-3}$
 BBCW ON, $I_W=90$ A, $\sigma_W=13 \sigma$, external V in IP5 and internal V in IP1



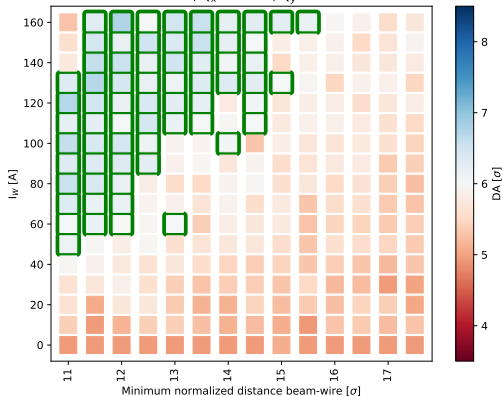
90 A @ 13σ , BBCW III in IP1, BBCW II in IP5

HL-LHC v1.5, no MS.10, $N_b=1.8 \times 10^{11}$ ppb, $\beta_{IP1/5}^+ = 30$ cm, $\phi/2_{IP1/5} = 225$ μ rad
 $\sigma_z = 7.61$ cm, $\phi/2_{H,IP8} = 250$ μ rad, $\epsilon_n = 2.5$ μ m, $Q' = 15$, $I_{MO} = 100$ A, $C^- = 10^{-3}$
 BBCW ON, $I_W=90$ A, $\sigma_W=13$ σ , external V in IP5 and external V in IP1



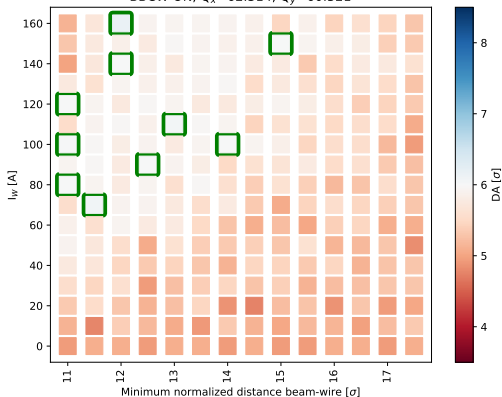
90 A @ 13σ , BBCW **IV** in IP1, BBCW **II** in IP5

HL-LHC v1.5, no MS.10, $N_b=1.8 \times 10^{11}$ ppb, $\beta_{IP1/5}^* = 30$ cm, $\phi/2_{IP1/5} = 190$ μ rad
 $\sigma_z = 7.61$ cm, $\phi/2_{H,IP8} = 250$ μ rad, $\epsilon_n = 2.5$ μ m, $Q' = 15$, $I_{MO} = 100$ A, $C^- = 10^{-3}$
 BBCW ON, $Q_x=62.314$, $Q_y=60.321$



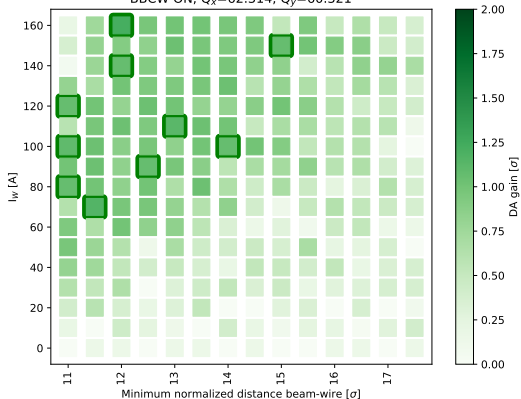
BBCW | in IP1, BBCW | in IP5

HL-LHC v1.5, no MS.10, $N_b=1.8 \times 10^{11}$ ppb, $\beta_{IP1/5}^* = 30$ cm, $\phi/2_{IP1/5} = 190$ μ rad
 $\sigma_z = 7.61$ cm, $\phi/2_{H,IP8} = 250$ μ rad, $\epsilon_n = 2.5$ μ m, $Q' = 15$, $I_{MO} = 100$ A, $C^- = 10^{-3}$
 BBCW ON, $Q_x=62.314$, $Q_y=60.321$



BBCW **(I+II)/2** in IP1, BBCW **(I+II)/2** in IP5

HL-LHC v1.5, no MS.10, $N_b=1.8 \times 10^{11}$ ppb, $\beta_{IP1/5}^* = 30$ cm, $\phi/2_{IP1/5} = 190$ μ rad
 $\sigma_z = 7.61$ cm, $\phi/2_{H,IP8} = 250$ μ rad, $\epsilon_n = 2.5$ μ m, $Q' = 15$, $I_{MO} = 100$ A, $C^- = 10^{-3}$
 BBCW ON, $Q_x=62.314$, $Q_y=60.321$



BBCW **(I+II)/2** in IP1, BBCW **(I+II)/2** in IP5

Conclusions

- The BBCW can be used to improve the machine performance in a BB dominated regime: **its beneficial impact in an early stage of Run 3 was confirmed by the simulations.**
- **TCT settings** at 11.4σ for $\beta^* = 30$ cm are crucial to relax the BBCW HW specifications.
- It could be used to prepare the high intensity beam at **190 μ rad before the CC operational deployment.**
- The BBCW commissioning time and overall availability is expected not have a minimum impact to the overall time dedicated to the HL-LHC Physics Program.
- Preliminary results show that the "special configurations" are less effective than the nominal one.

Thank you for your attention.



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