HL-LHC operations with LHCb at high luminosity operations

R. De Maria, N. Karastathis

Thanks to G. Arduini, F. Cerutti, I. Efthymiopoulos, S. Fartoukh, M. Giovannozzi

WP2 Meeting 20/3/2018

Peak luminosity

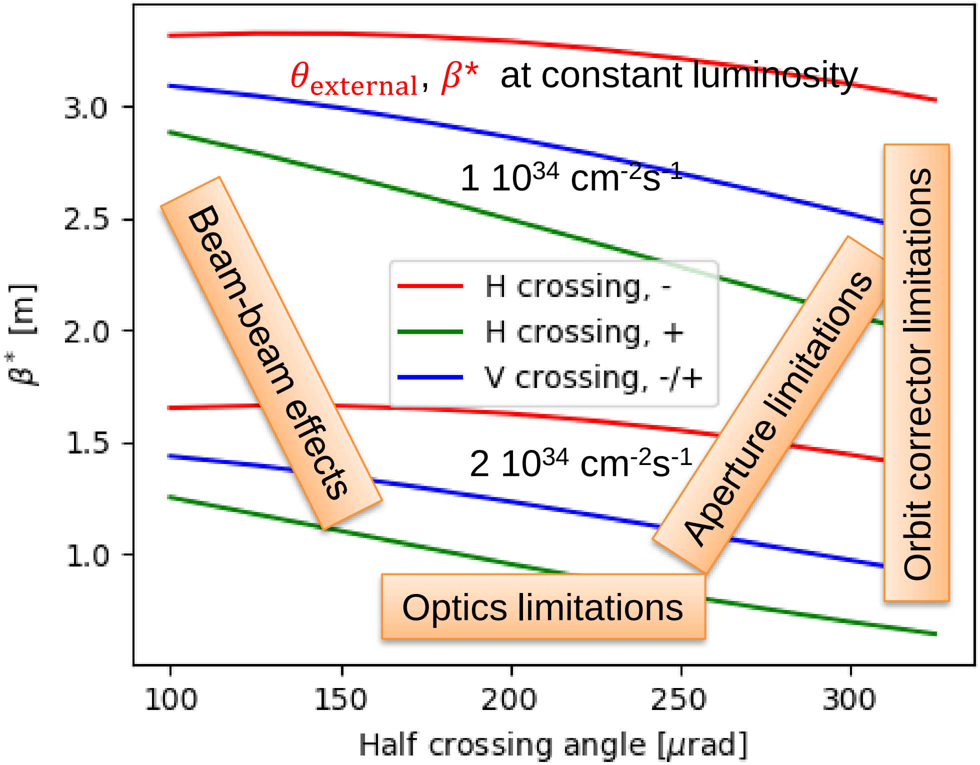
$$L = \frac{N_b^2 f_{rev} k_b}{4\pi\epsilon\sqrt{\beta_\times^* \beta_\parallel^*}} \cdot \frac{1}{\sqrt{1+\Phi_p^2}}$$

$$\Phi_p = \frac{\sigma_s}{\sigma_\times} \cdot \frac{\theta_\times}{2} = \frac{\sigma_s}{\beta_\times^*} \cdot \frac{\mathrm{bb_{sep}}}{2}$$

$$\theta_\times = \theta_{\mathrm{external}} \pm \theta_{\mathrm{spectrometer}} \cos \alpha_{\mathrm{plane}}$$

Protons per bunch	N_b	2.2 10^{11}
Number of Bunches	k_b	2572(2374)
R.M.S bunch length	σ_s	7.61(9.0) cm
+/- Polarity		B_y<0 / B_y>0

- Minimum β* is constrained by optics flexibility.
- Maximum crossing angle limited by orbit corrector strength
- For a given β*:
  - Aperture constrains maximum crossing angle.
  - Beam-beam effects (i.e. beam lifetime) constrains minimum crossing angle.



Aperture limitations in collision

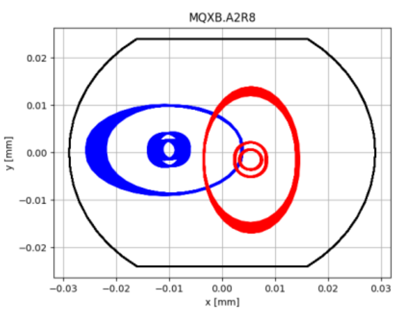
Maximum half external crossing angle as function of β*

β* [m]	H[1] [μrad]	H[2] [μrad]	V[3] [μrad]	V[1,4] [μrad]
1	-165	-220	±115	±220
1.5	-225	-275	±165	±235
2	-265	-310	±205	±270
3	-310	-310	±250	±310

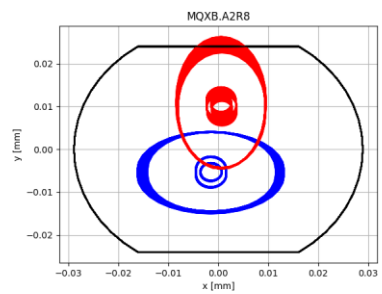
[1] with present TCDDM
[2] without present TCDDM
[3] crossing plane can be rotated during the ramp
[4] if beam screen is rotated, introducing strong limitations during the ramp

Aperture in the triplet is not symmetric (H=57.8 mm, V=48 mm) and cannot be rotated easily.

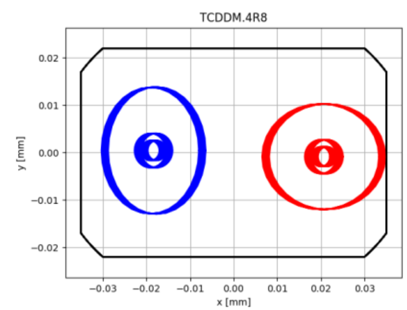
TCDDM needed for D1 protection
Present aperture bottleneck for Beam 2 H and Beam 1 V.



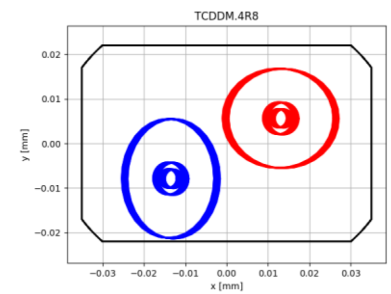
H crossing



V crossing



H crossing

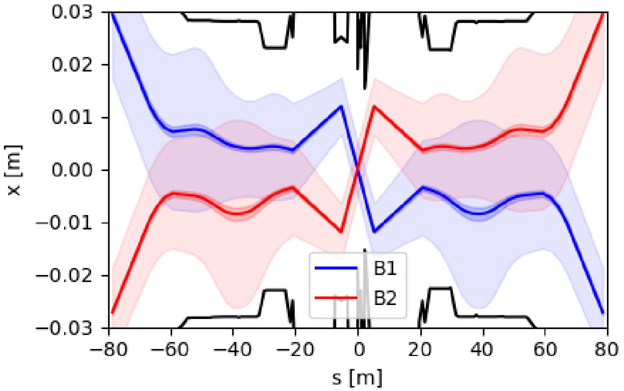


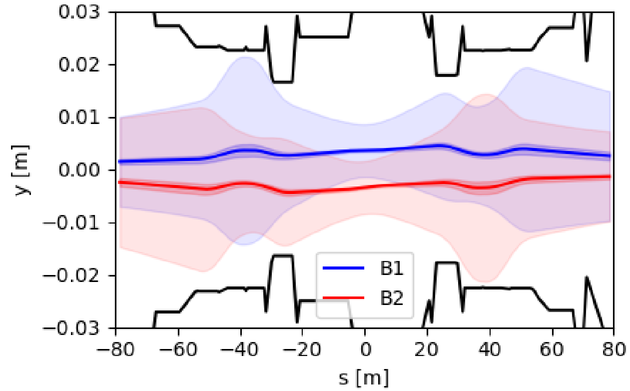
V crossing

Can we rotate the beam screen? Should we rotate the beam screen?

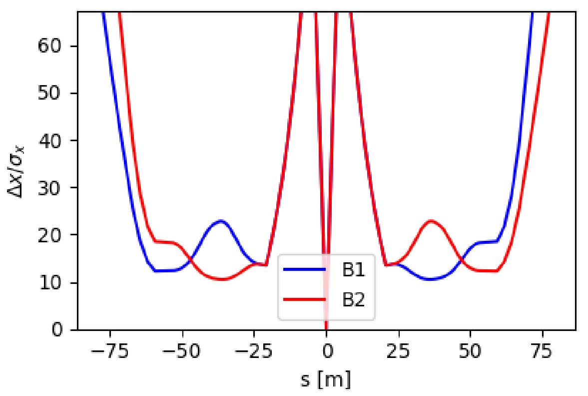
Constraints at injection

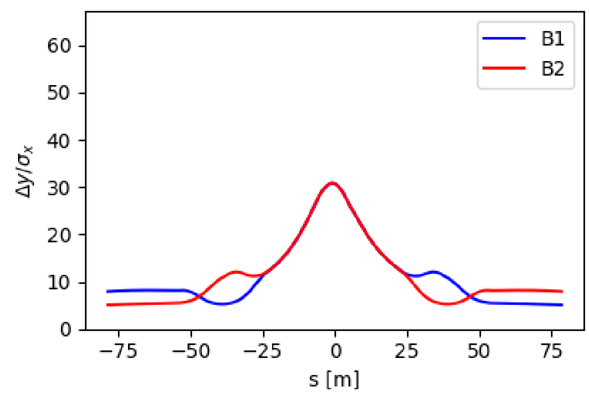
Baseline Horizontal crossing.

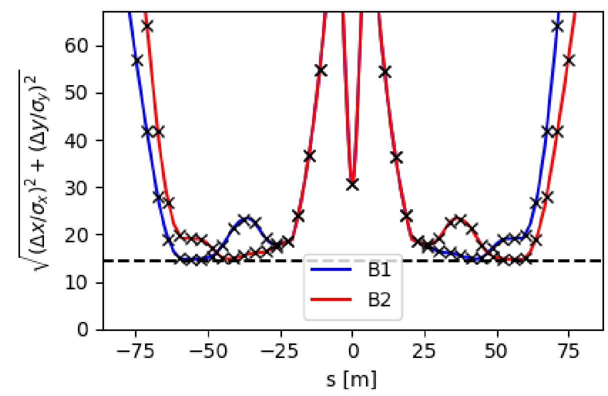




Pos. Spec., 450 GeV
-170 µrad, +3.5 mm







As the LHC, but with double the intensity in HL-LHC
This needs to be still validated.

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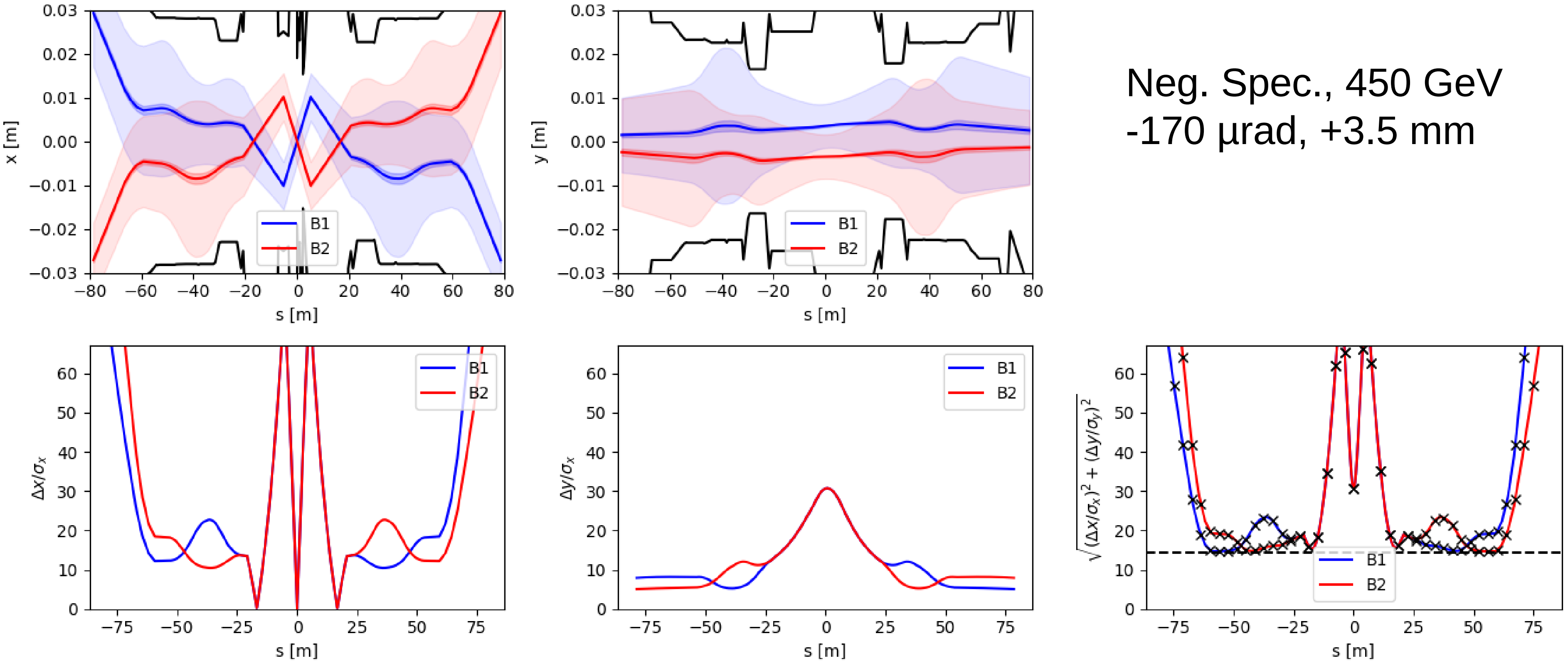

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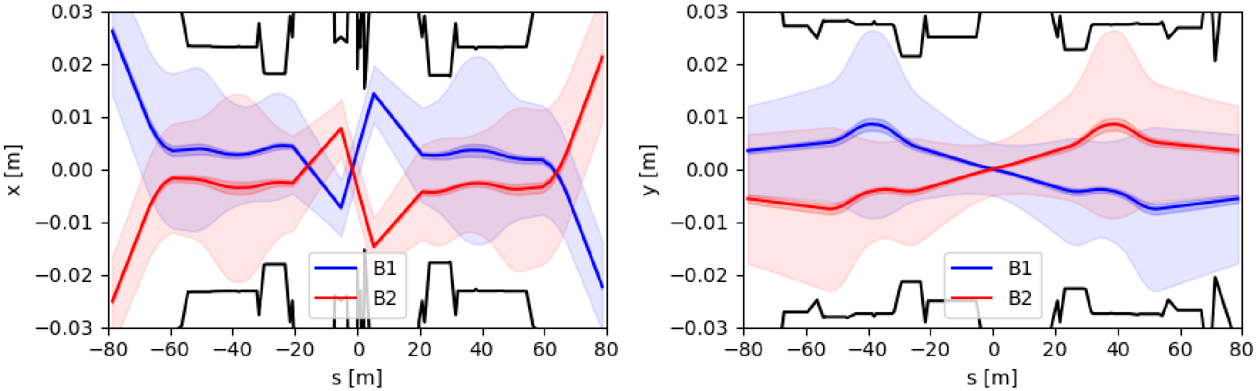
Constraints at injection

Vertical crossing with critical issues



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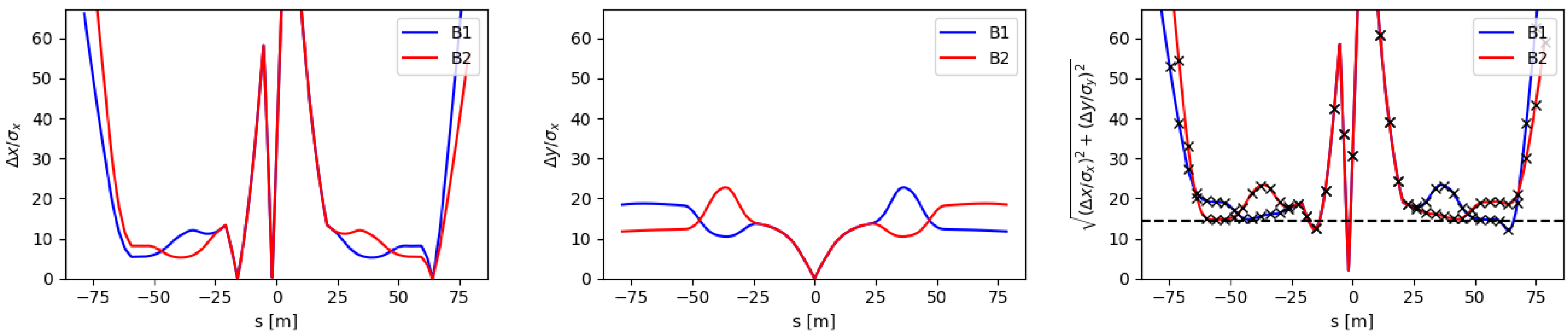

Additional close encounters, in particular close to the IP.
Not compatible with different ion species runs (e.g. Lead – Ion).
Not compatible with present orbit tolerance specifications for p-p.

Constraints at injection

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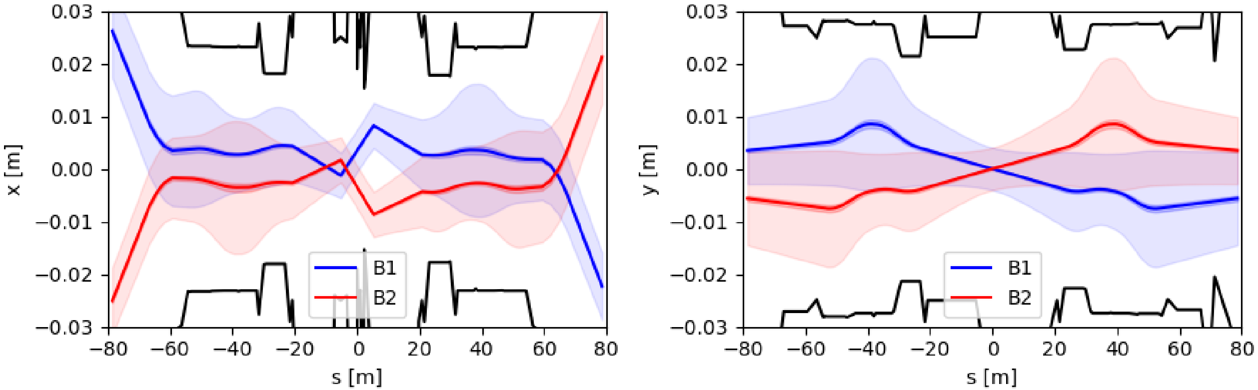

Neg. Spec., 1000 GeV
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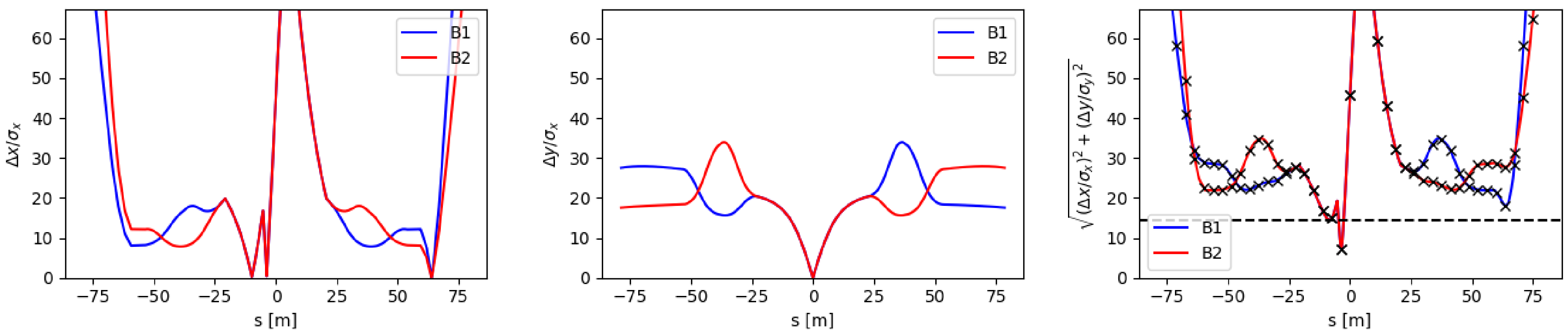

Close encounter moves with energy and needs strict control of the orbit during the ramp.

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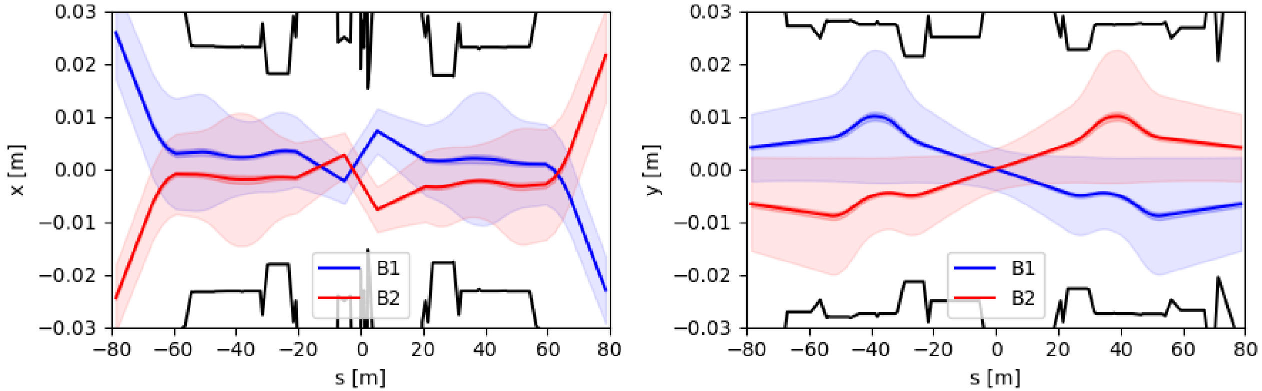
Constraints at injection

Vertical crossing with critical issues



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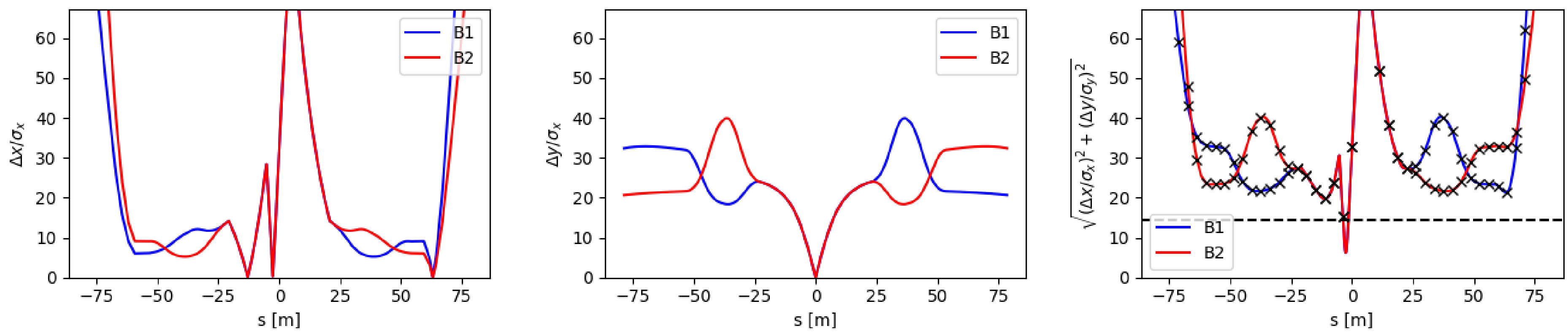

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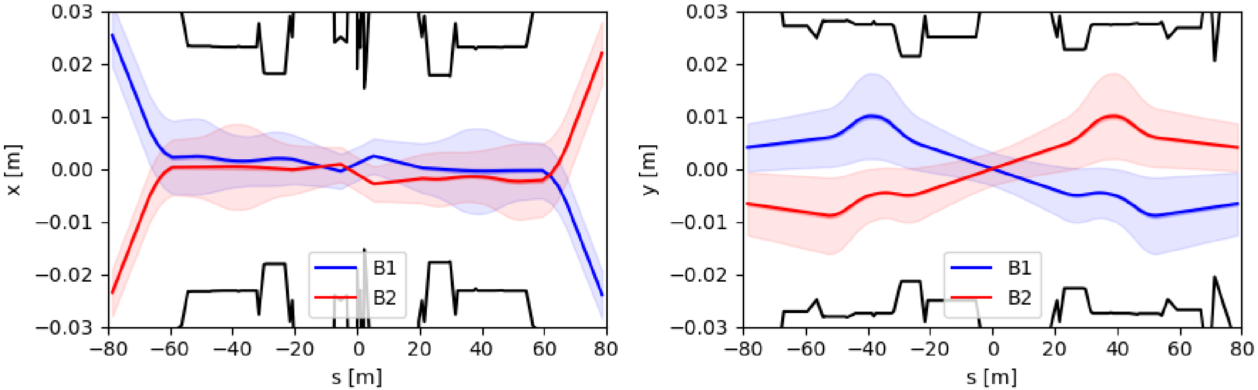
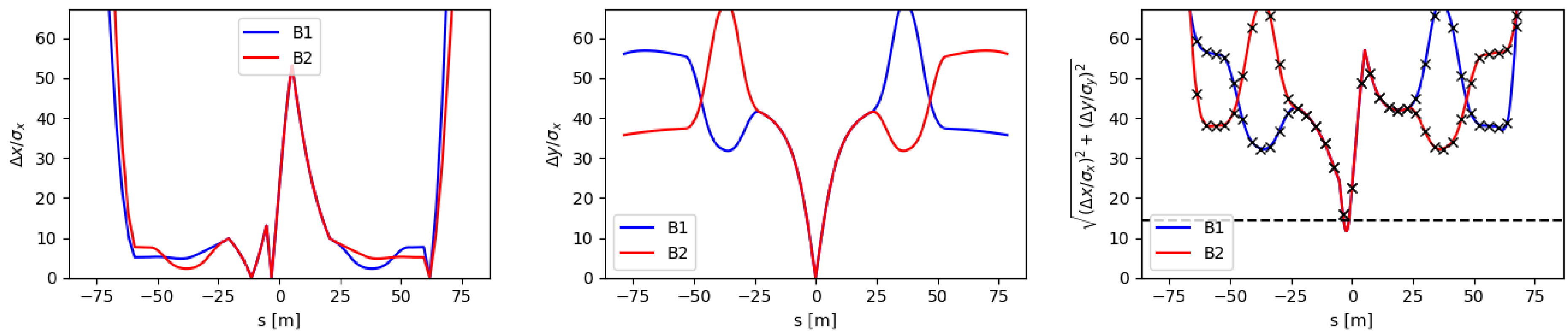


Neg. Spec., 3000 GeV
Rotated beam screen
-200 µrad, +1 mm



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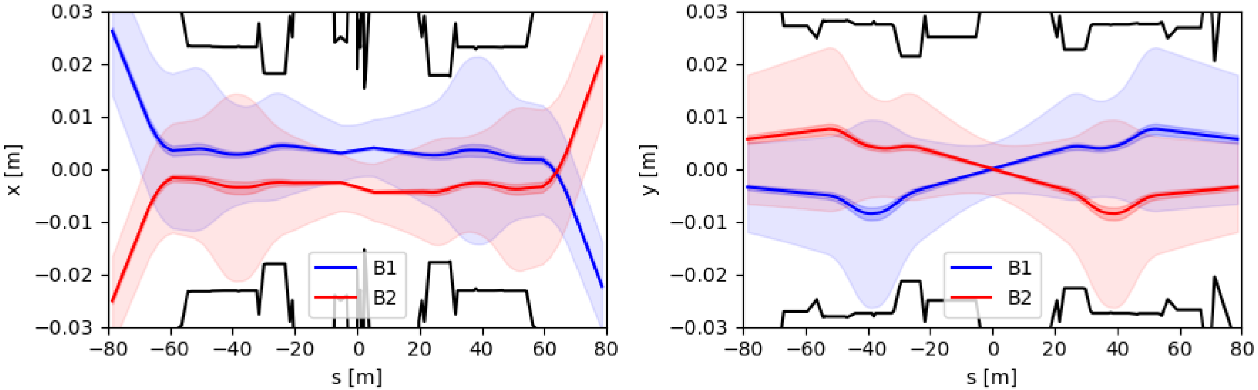
Constraints at injection

Vertical crossing with ramped spectrometer



Neg. Spec., 450 GeV
Rotated beam screen
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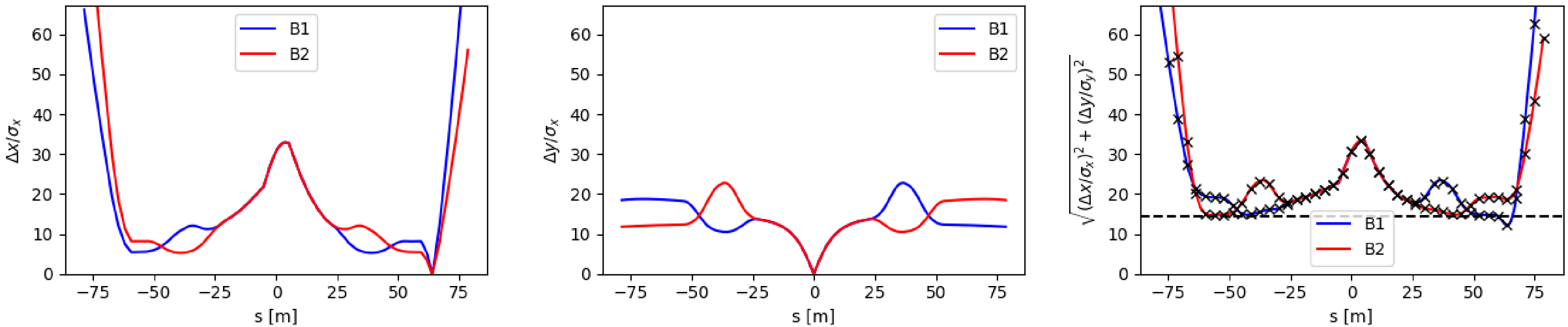
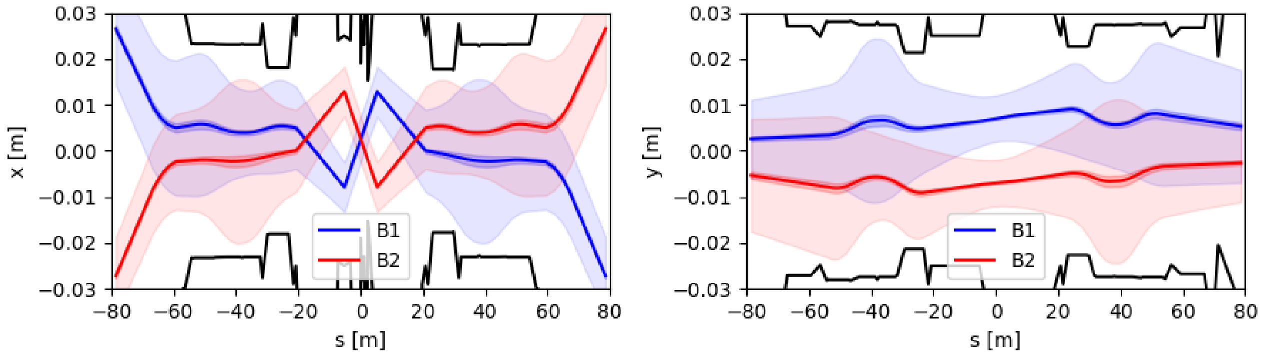


Vertical crossing is straightforward if spectrometer could be ramped with energy.

Constraints at injection

Horizontal crossing with extreme conditions



Pos. spec., 450 GeV
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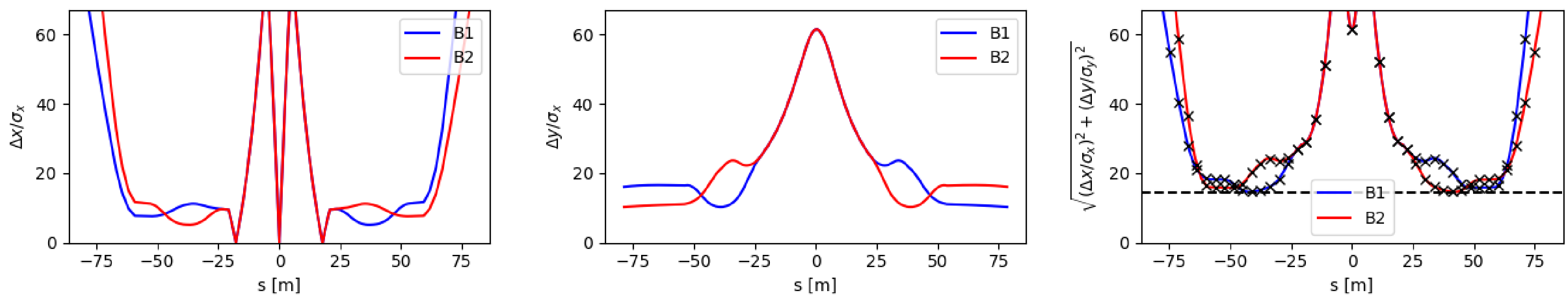
80 µrad (bias)
1.5 mm offset



This solution is more robust at injection, but uses about 3 times the typical orbit corrector at injection. As energy increase separation, offset and bias would need to be reduced quickly. Do we need this?

Constraints at injection

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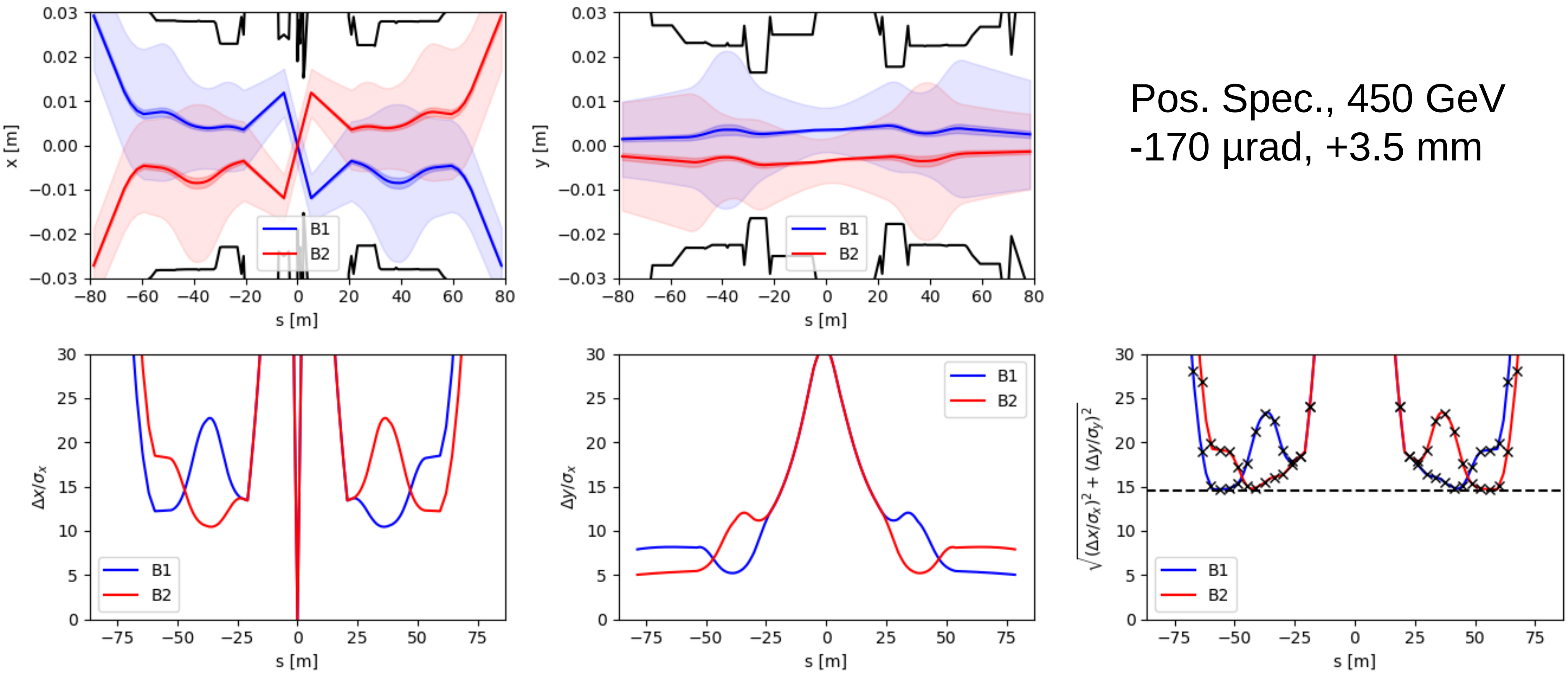

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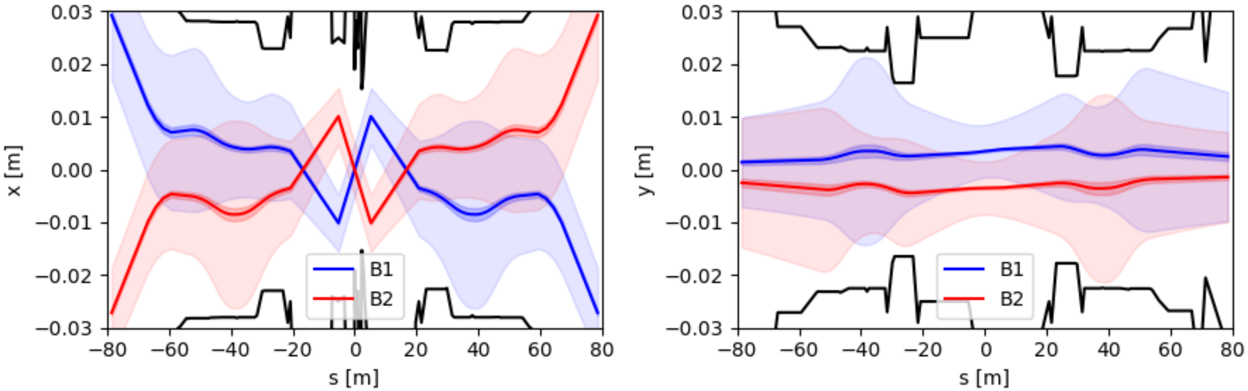

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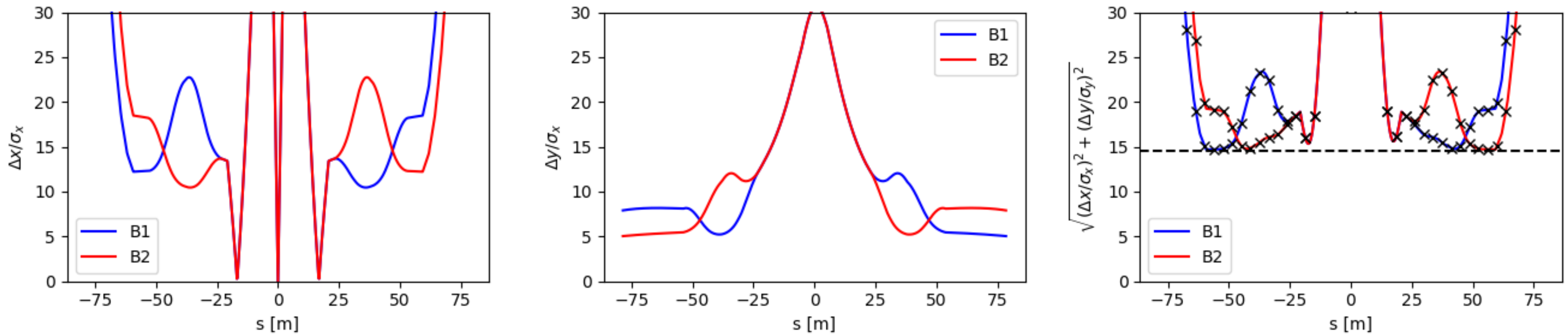

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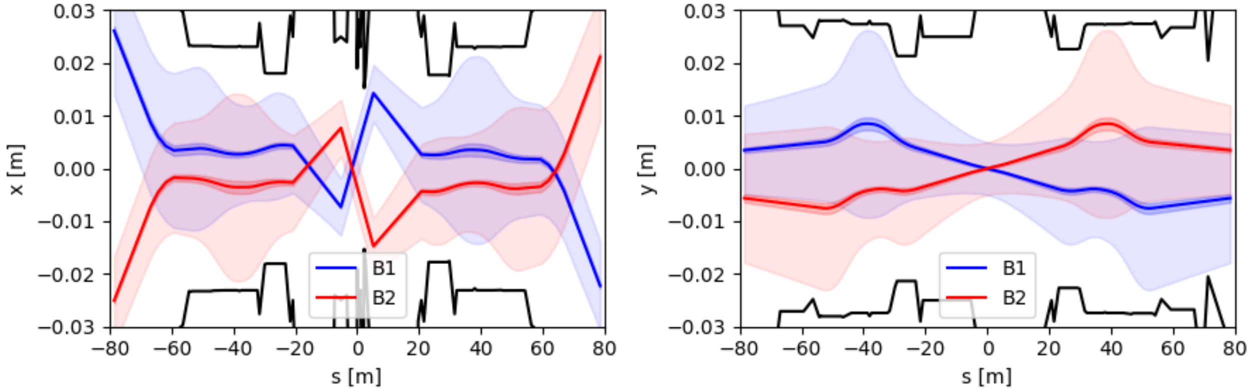

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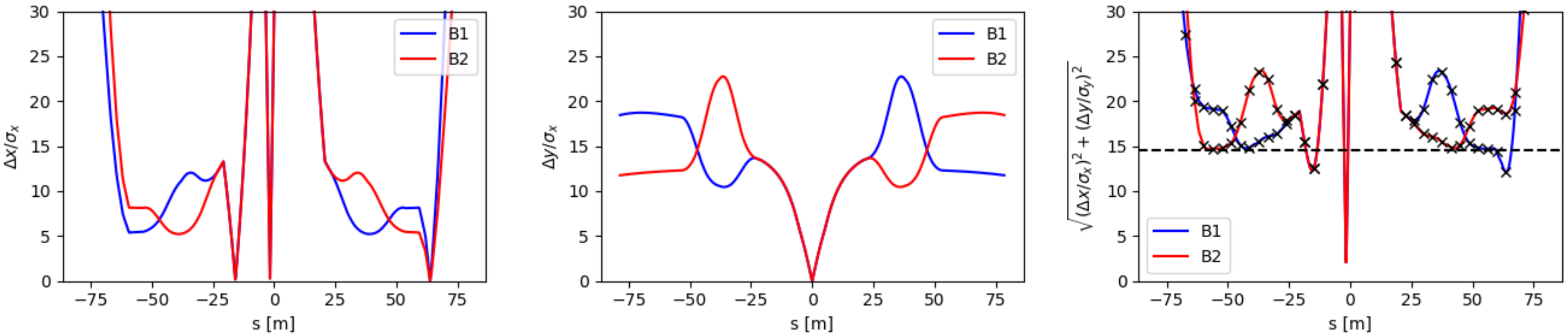

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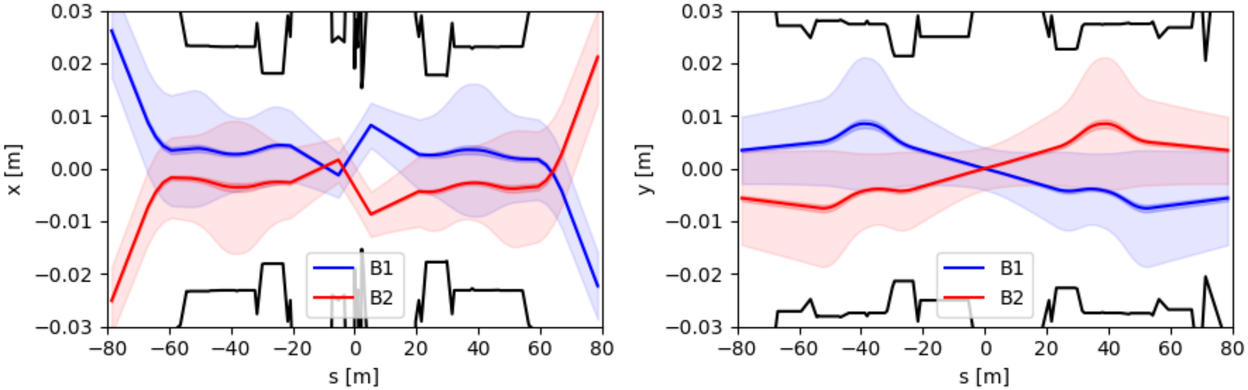

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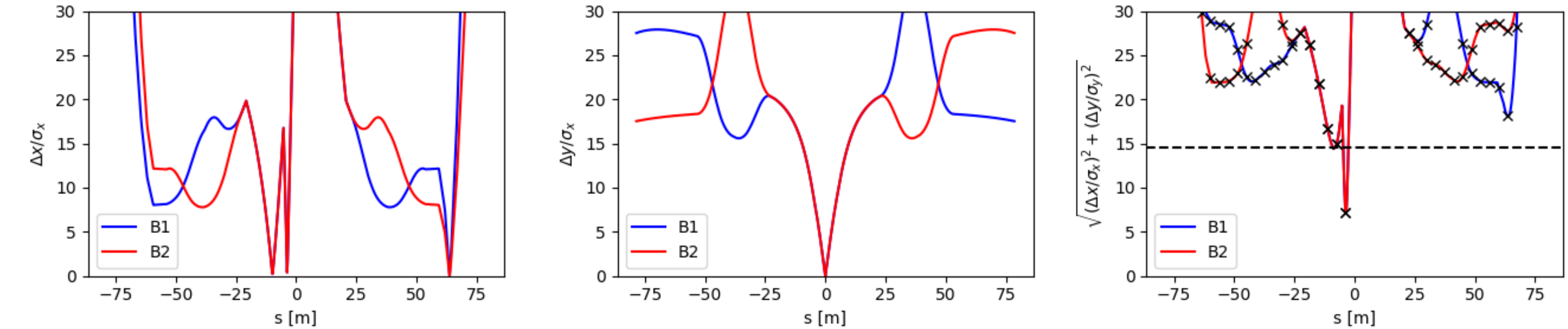

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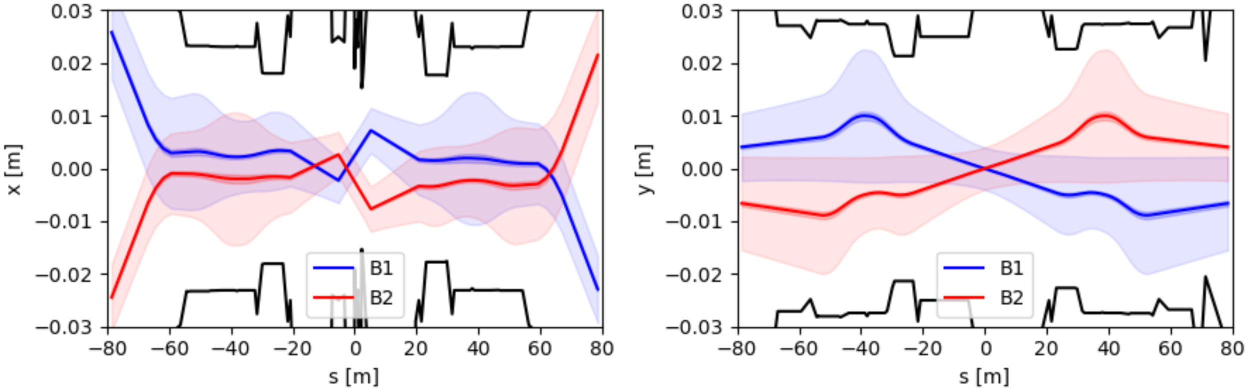

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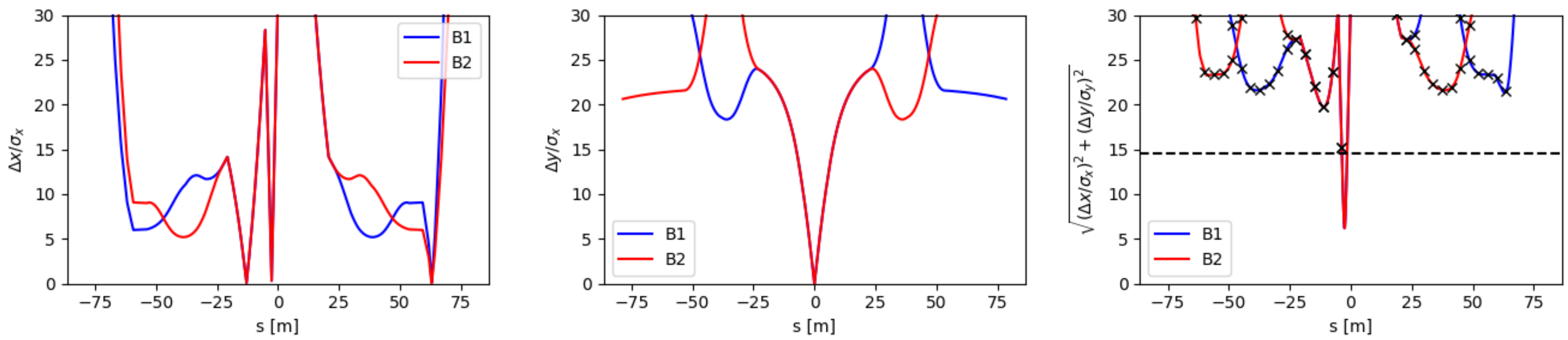

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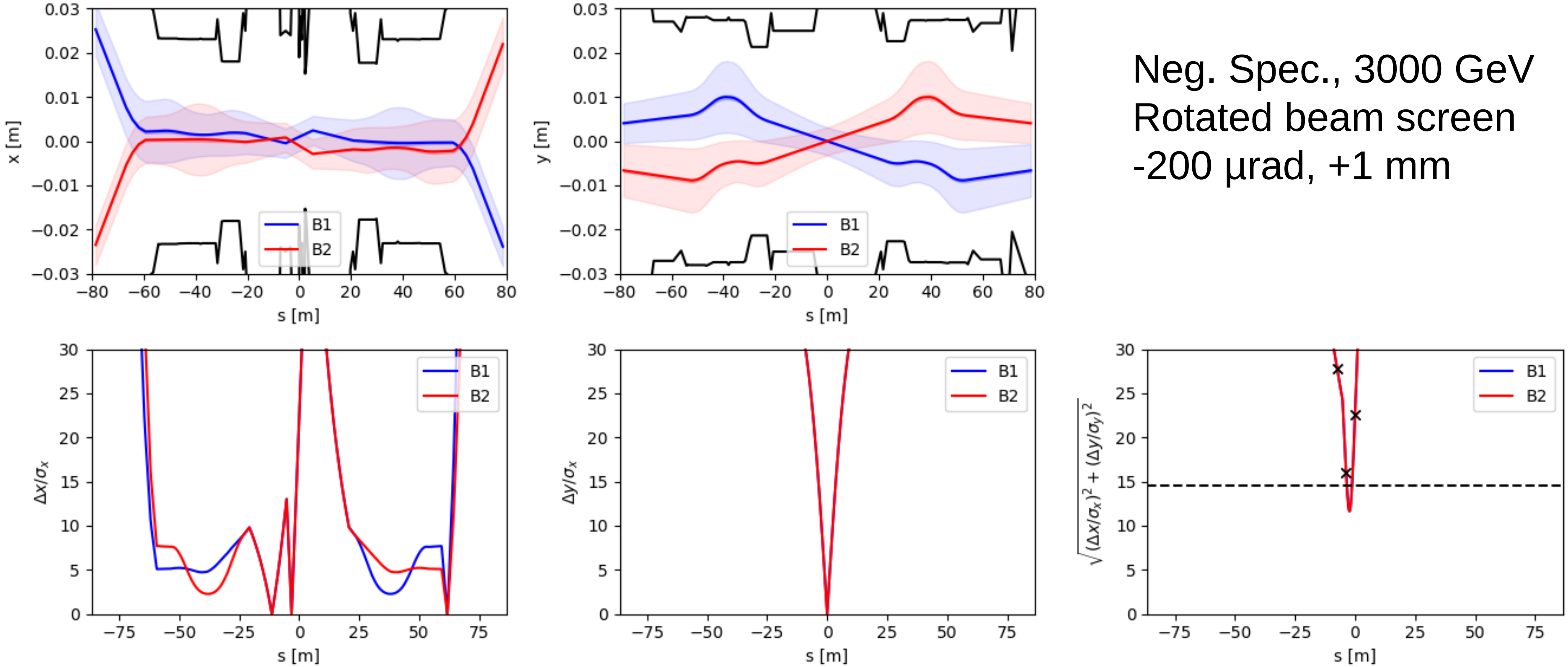

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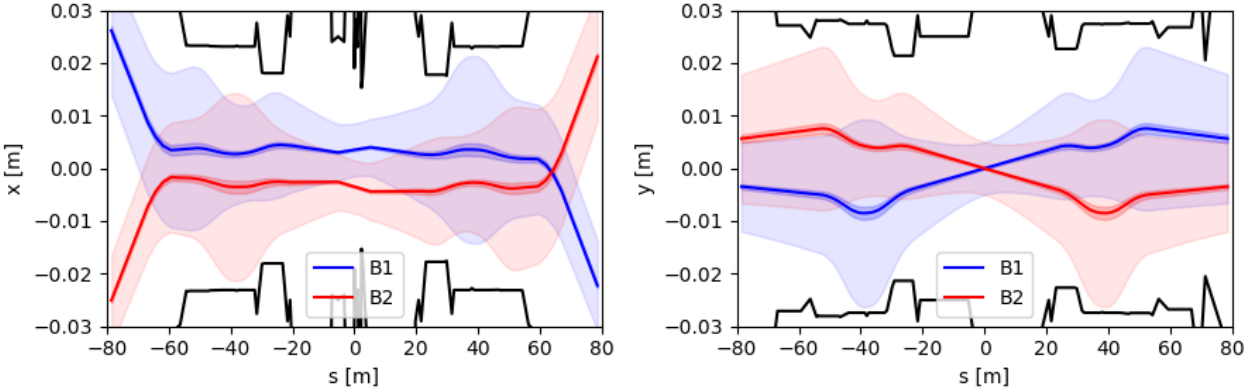
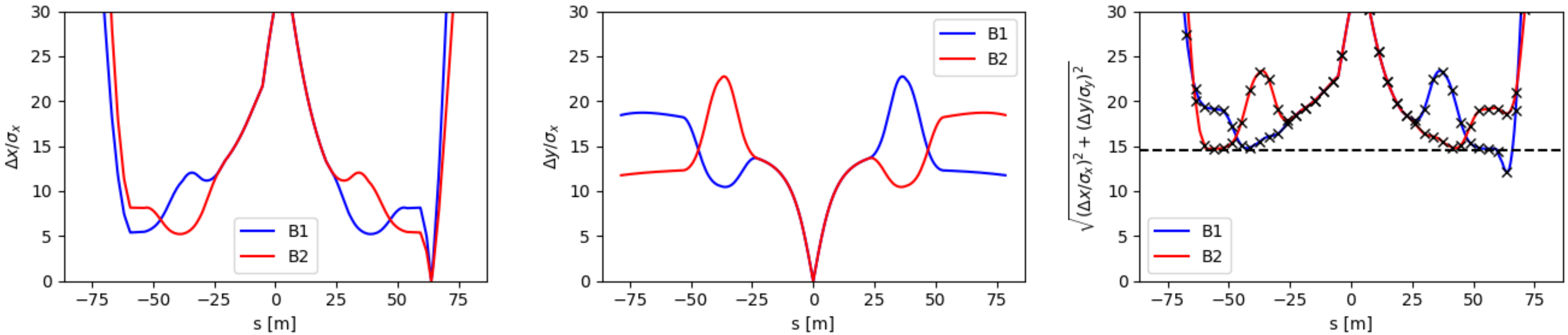
Vertical crossing with ramped spectrometer



Vertical crossing, -
450 GeV
Rotated beam screen
and ramped spectrometer



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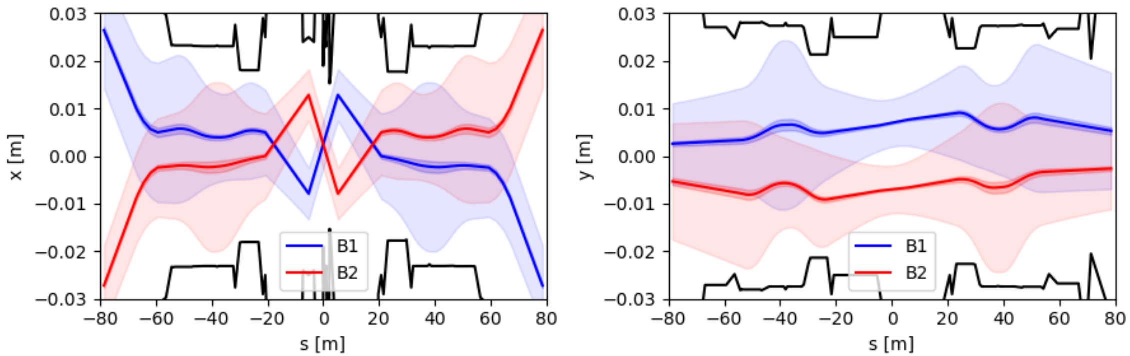

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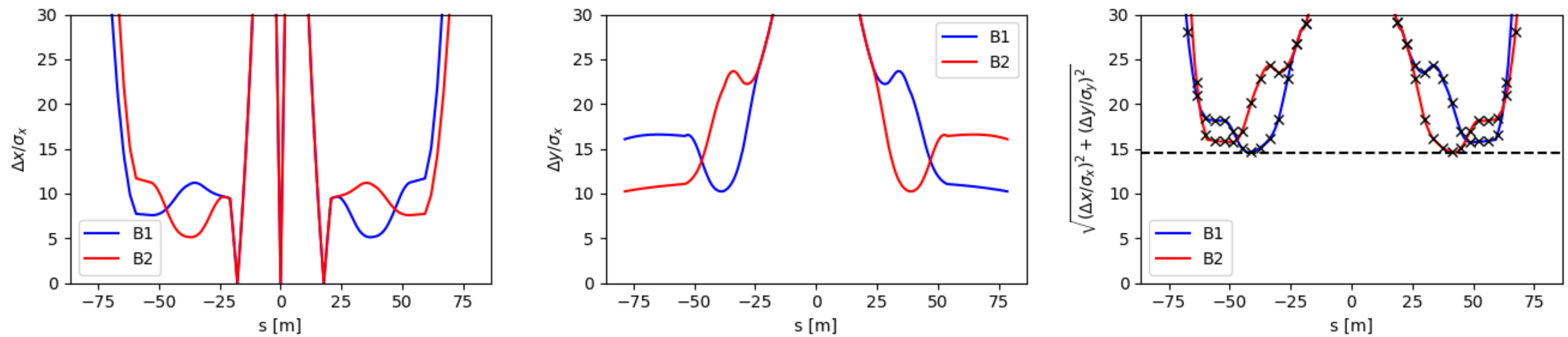
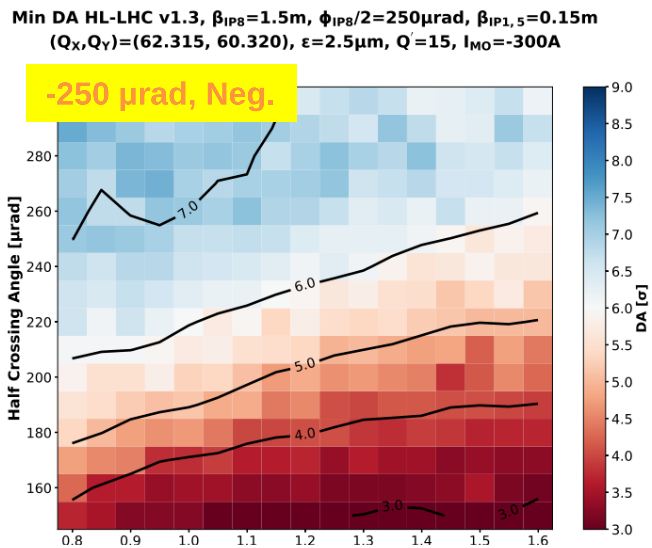
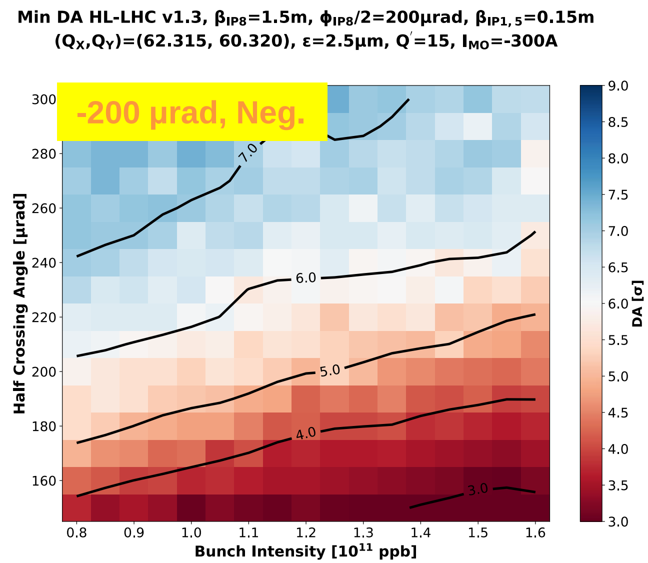


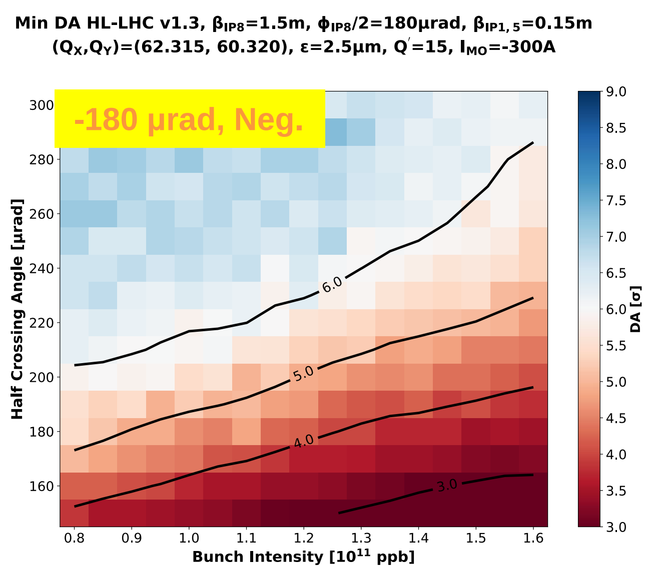
This solution is more robust at injection, but uses about 3 times the typical orbit corrector at injection. As energy increase separation, offset and bias would need to be reduced quickly. Do we need this?

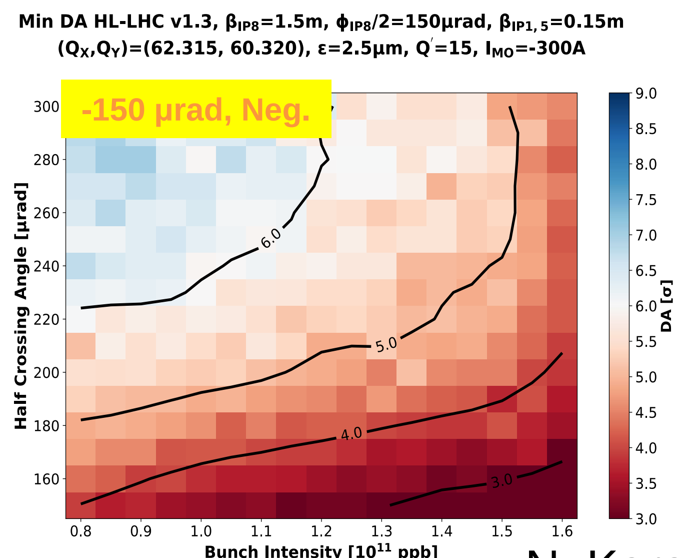
Beam-beam limitations at collision

DA margin at the end of Atlas/CMS levelling as a function of IR8 horizzontal half external angle









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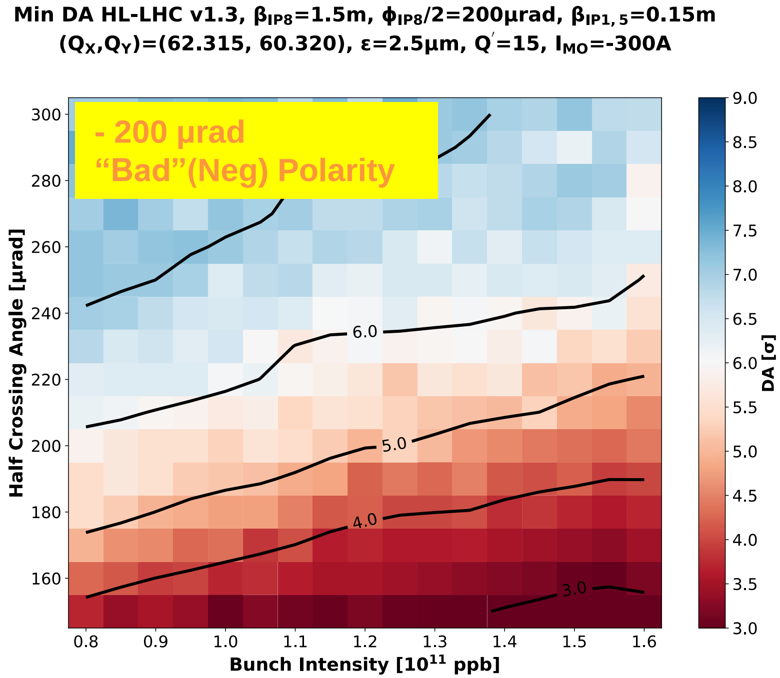
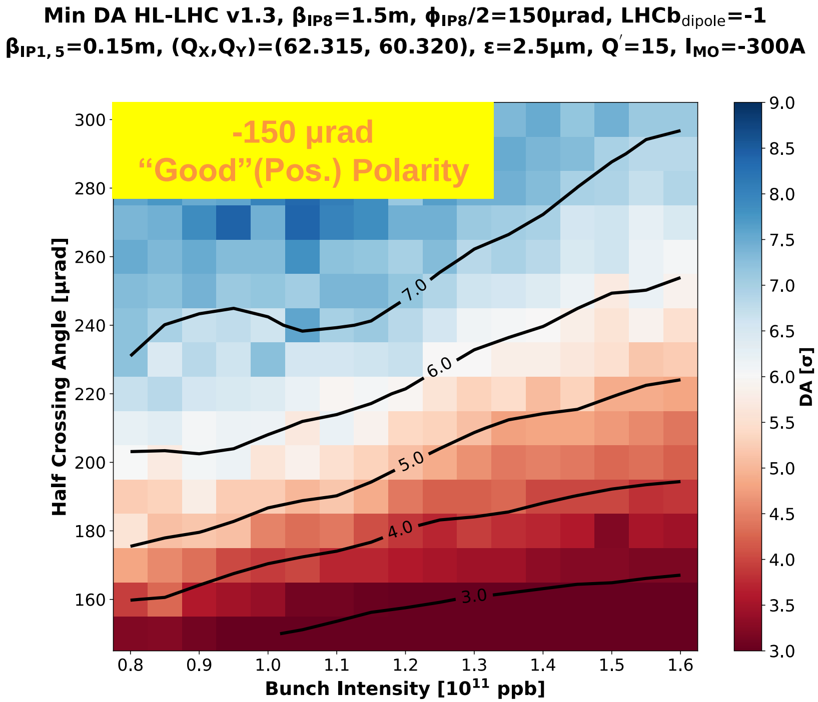
Beam-beam limitations at collision





Spectrometer polarity has an impact of minimum external crossing angle.

Possible IR8 external half crossing angle with horizontal crossing:

- -200 µrad with Neg. polarity (smaller total crossing angle)
- -150 µrad with Pos. polarity (larger total crossing angle)

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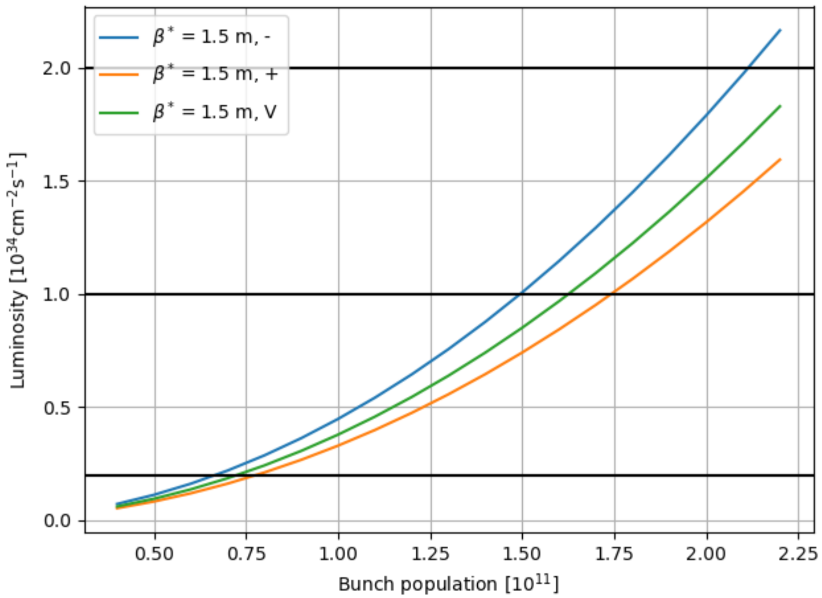
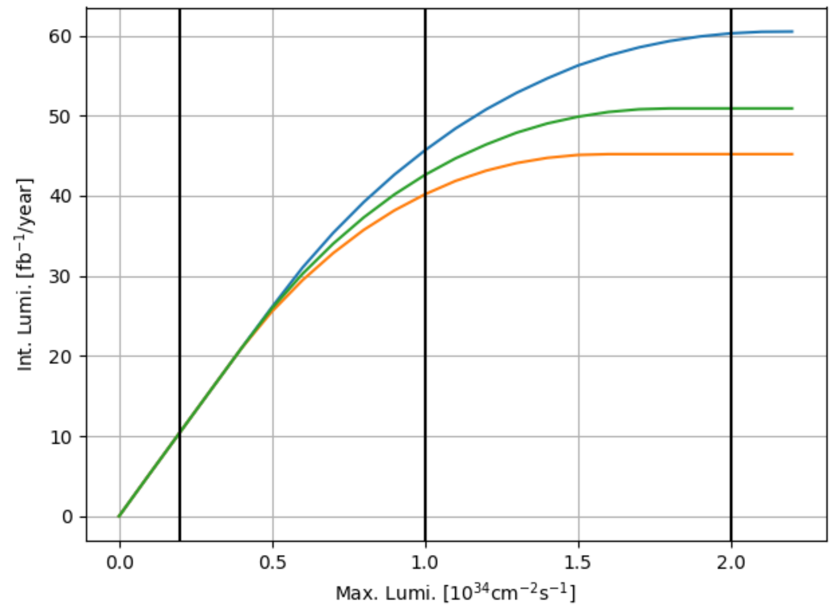
Tentative scenarios

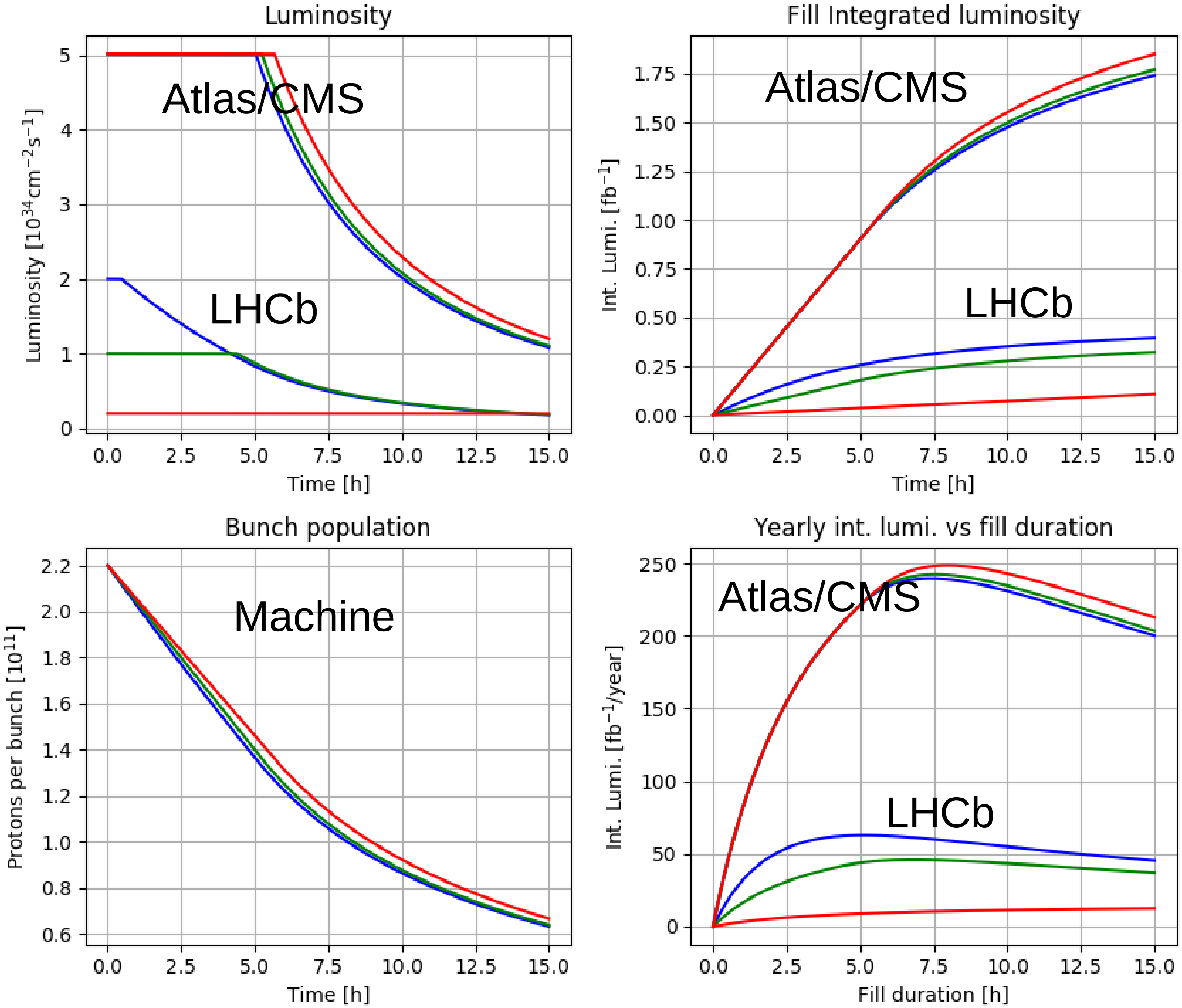
β* [m]	Ext. Crossing /Spec. Polarity	Peak Luminosity [10^{34}]
1.5	H/±200 /-	2.16
1.5	H/±150/+	1.59 (implies operation overhead)
1.5	V/±160/+ or -	1.8 (not simulated with DA)





Not strong advantage of designing the detector for 2 10^{34} $cm^{-2}s^{-1}$.
Beam screen rotation not needed for these configurations, small crossing angle also better for dose at constant luminosity.
Change of external crossing at each polarity swap, proposed this year in the LHC, will have some overhead but would give more int. luminosity then pure vertical crossing.

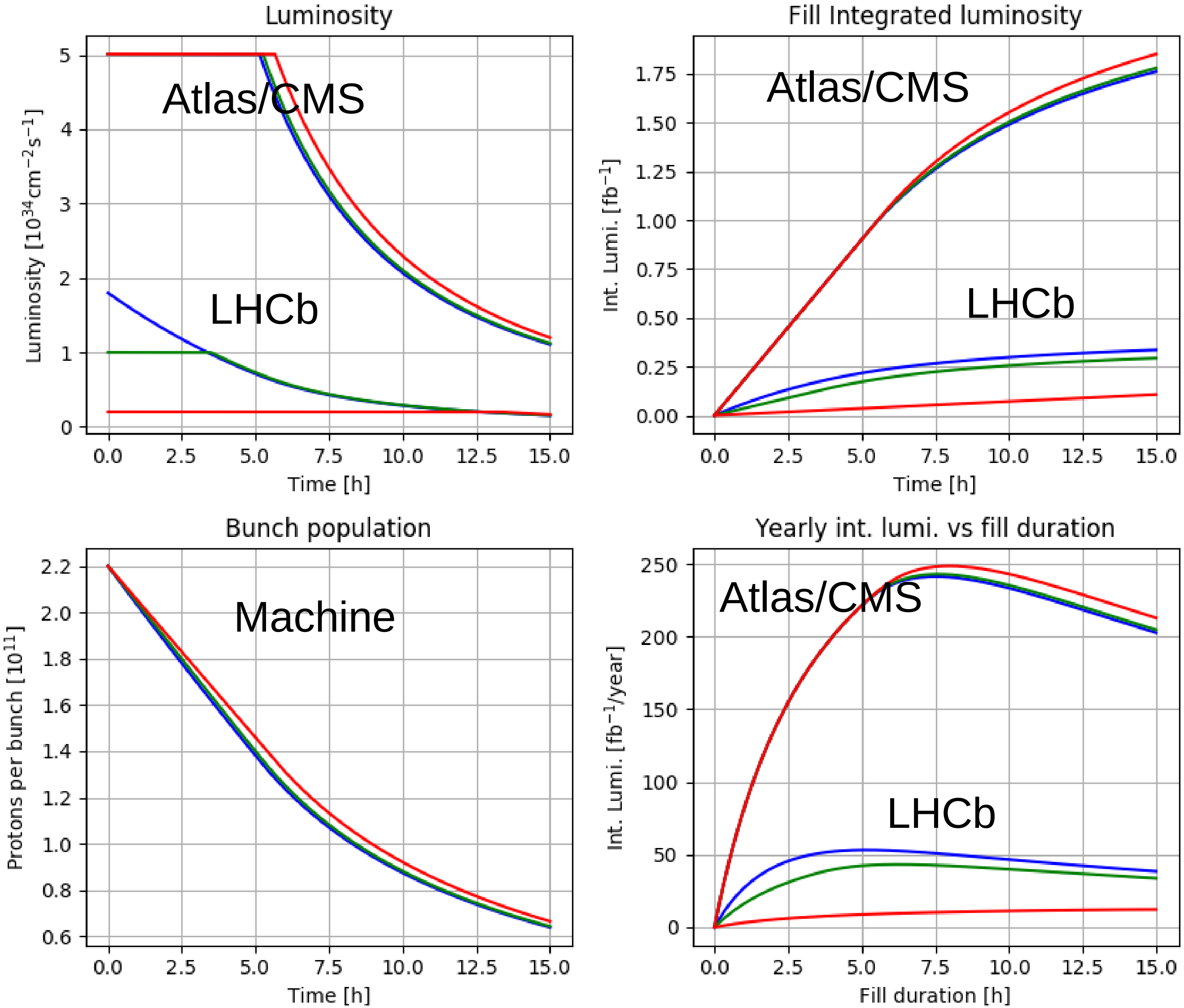
Examlpe of Luminosity evolution



Case with LHCb virtual luminosity of 2.16 10^{34} cm^{-2}s^{-1} with three levelling scenarios.

Simple model used for illustration only and not for quantitative estimates.

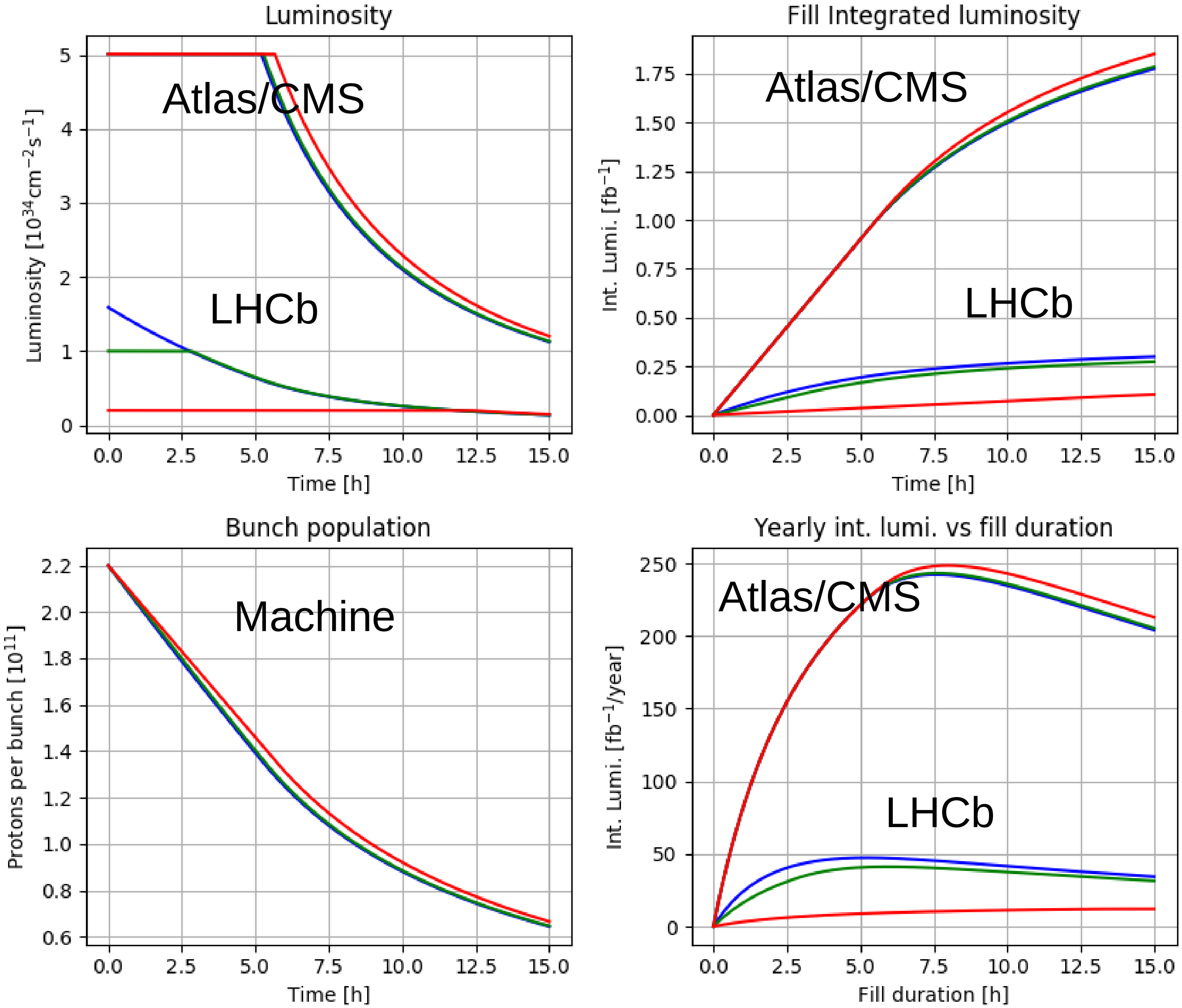
Examlpe of Luminosity evolution



Case with LHCb virtual luminosity of 1.8 10^{34} cm^{-2}s^{-1} with three levelling scenarios.

Simple model used for illustration only and not for quantitative estimates.

Examlpe of Luminosity evolution



Case with LHCb virtual luminosity of 1.59 10^{34} cm^{-2}s^{-1} with three levelling scenarios.

Simple model used for illustration only and not for quantitative estimates.

Open points

Validate the new proposed machine configuration for LHCb at high luminosity:

- Evaluate commissioning overhead of two external crossing angles depending on the polarity.
- Perform beam-beam simulation, in particular with vertical crossing.
- Perform energy deposition studies for the cycle for different crossing scenarios.
- Assess feasibility and cost of protecting devices such as: TAS, TAN, TCDDM, TCL. A study group is going to be put in place to provide information concerning the impact on HW and costs.

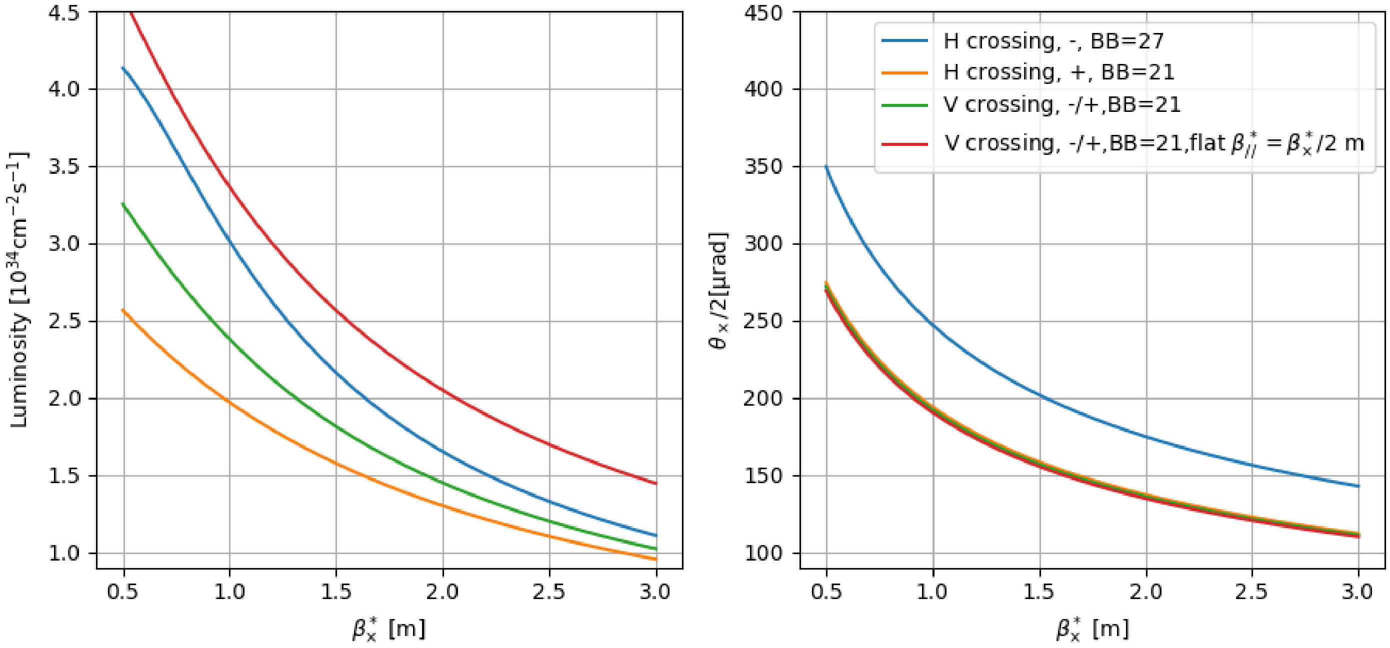
If operational margins exist one can consider the options:

- Flat beams (e.g. $\beta^*_{//} < \beta^*_X$) which gives more luminosity at constant aperture but additional beam-beam effects.
- Assess costs and risks of a beam-screen rotation which would give additional aperture margin with vertical crossing in case it would be possible to reduce β^* in the crossing plane with vertical crossing.

In parallel one would need to state what performance impact is acceptable for Atlas and CMS.

Backup

Flat optics



Luminosity [10^{34}cm^{-2}s^{-1}]
β_x^* [m]
$\theta_x/2$[μrad]
β_x^* [m]
H crossing, -, BB=27
H crossing, +, BB=21
V crossing, -/+,BB=21
V crossing, -/+,BB=21,flat $\beta_{//}^* = \beta_x^*/2$ m