Simulation studies for the beam-beam long range compensation using SixTrack

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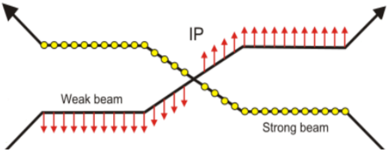
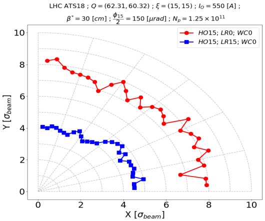
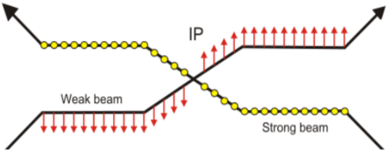
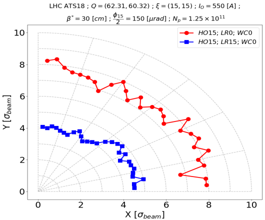




► **The DA is reduced by $\sim$3 σ in the presence of the Beam Beam Long Range (BBLR) interactions.**

BBLR overview & quantification of the problem





- **4D treatment of the beam-beam long range interaction (Bassetti-Erskine)**

$$B_\theta = -\frac{\beta_{st}}{c} E_r \;\rightarrow\; F_\perp = q\, E_r\, (1 + \beta_{we}\beta_{st}) = q\, E_{reff} \quad \text{and for } \sigma_x > \sigma_y:$$

$$\int_{-\infty}^{\infty} E_{xeff}\, ds = \frac{N_p\, q\, (1 + \beta_{we}\beta_{st})}{2\epsilon_0 \sqrt{2\pi(\sigma_x^2 - \sigma_y^2)}} \Im \left[\mathcal{F}\left(\frac{x + \imath y}{\sqrt{2(\sigma_x^2 - \sigma_y^2)}} \right) - Exp\left(-\frac{x^2}{2\sigma_x^2} - \frac{y^2}{2\sigma_y^2} \right) \mathcal{F}\left(\frac{x\sigma_y^2 + \imath y \sigma_x^2}{\sigma_x \sigma_y \sqrt{2(\sigma_x^2 - \sigma_y^2)}} \right) \right]$$

$$\int_{-\infty}^{\infty} E_{yeff}\, ds = \frac{N_p\, q\, (1 + \beta_{we}\beta_{st})}{2\epsilon_0 \sqrt{2\pi(\sigma_x^2 - \sigma_y^2)}} \Re \left[\mathcal{F}\left(\frac{x + \imath y}{\sqrt{2(\sigma_x^2 - \sigma_y^2)}} \right) - Exp\left(-\frac{x^2}{2\sigma_x^2} - \frac{y^2}{2\sigma_y^2} \right) \mathcal{F}\left(\frac{x\sigma_y^2 + \imath y \sigma_x^2}{\sigma_x \sigma_y \sqrt{2(\sigma_x^2 - \sigma_y^2)}} \right) \right]$$

All the quantities are measured from the center of the strong beam in the lab rest frame

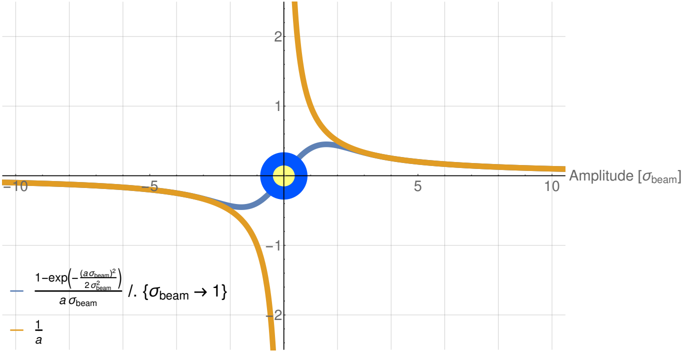
BBLR compensation with current carrying wire

- Assuming round beams ($\sigma_x = \sigma_y = \sigma$) for simplicity

$$\int_{-\infty}^{\infty} B_\theta \; ds = \frac{N_p \; q \; c \; \mu_0 \; \beta_{st}}{2\pi} \; \frac{1 - Exp\left(-\frac{r^2}{2\sigma^2}\right)}{r}$$

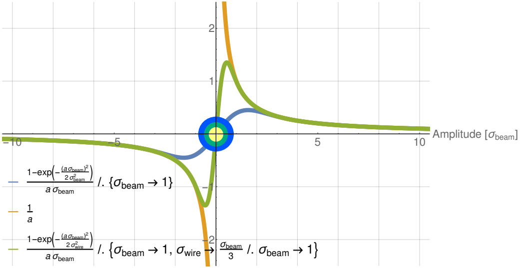
- Integrated field for 1D current carrying wire.

$$\int_{-\infty}^{\infty} B_\theta \; ds = \frac{N_p \; q \; c \; \mu_0}{2\pi} \; \frac{1}{r}$$



Wire-like module for MAD-X

- In order to reproduce a wire-like field in MAD-X, a “beambeam” element with smaller STD ($\sigma \rightsquigarrow$ emmitance) than the one in BBLR elements is used.



Wire-like module for MAD-X

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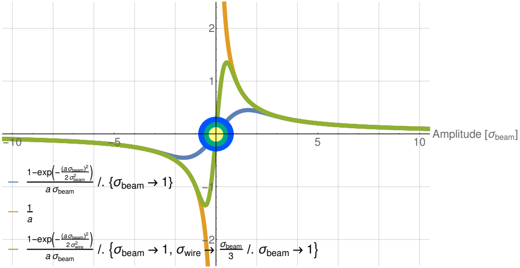


- The "beambeam" element in MAD-X gets a set of inputs (such as N_p, *energy*, ...) from the last Beam module of the sequence that it is a part of.

bbwire: beambeam, charge:=-integrated_current, sigx=sigy=$\frac{2\times10^{-3}}{6}$, bbdir=-1;

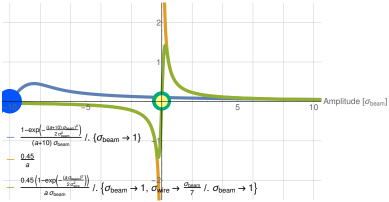
In order to reproduce the correct amplitude of the field ($1+\beta_{we}\beta_{st}$), a counter rotating beam in the bbwire is used.

For the STD the physical dimension of the wire (in [m]) is used.

Based on the above limitation, a negative change (in [$N_p qc$]) is needed for the compensation. Also, the charge attribute can be used for switching on and off the wire.

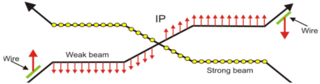
Complexity of the compensation

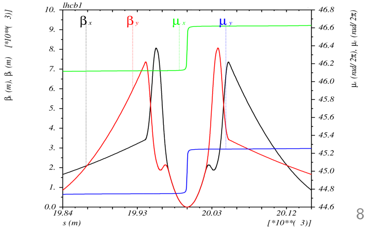
▶ In a realistic scenario:



• the beams are not round

• the wire can not be placed on top of the strong beam or at any of the proposed optimal positions [1]





• the wire must be far from the weak beam in order to protect the high amplitude particles ($\sim 6\sigma$)

• the phase advance between the BBLR kicks is small but not negligible

• there is some dispersion leak in the IR regions

[1] Phys.Rev. ST Accel. Beams 18, 121001-Published 1 Dec. 2015

LHC configuration

- In the following, the wires' current (I_{wire}) and position ($\mathcal{D}$ & s) that minimize all the resonance driving terms are used.

LHC configuration table

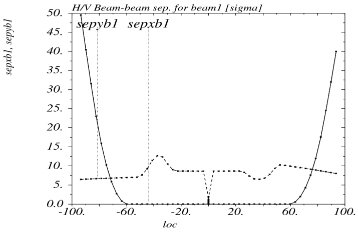
Name	Symbol	Value [units]
Energy	E	6500 $[GeV]$
Bunch population	N_b	1.25×10^{11} [1]
Horizontal tune	Q_x	62.31 [1]
Vertical tune	Q_y	60.32 [1]
Horizontal chromaticity	Q'_x or ξ_x	15 [1]
Vertical chromaticity	Q'_y or ξ_y	15 [1]
Octupole current	I_O	$\leq$ 550 $[A]$
Normalized emittance in both plains	ϵ_n	2.5 $[\mu m]$
Beta function at IP1 & IP5	β^*	30 $[cm]$
Half crossing angle at IP1 & IP5	$Xing15$ or $\frac{\phi_{15}}{2}$	150 or 170 $[\mu rad]$
Number of BBLR kicks per IP per site	N_{BBLR}	25 [1]

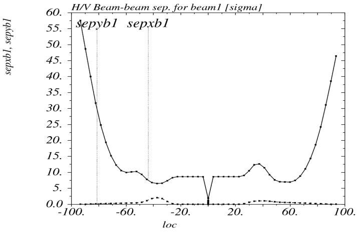
- The bump in IP5 is included in this studies

```
NAME                  S                X                  Y                 PX                 PY              BETX            BETY
%s                  %le              %le                %le                %le                %le               %le             %le
"IP5"       6664.568433  -3.723657792e-08  -0.001800006362  0.0001499729613  -9.092484961e-08       0.299913275     0.299924435
```

$Xing15 = 150\ [\mu rad]$ and $I_O = 550$ and $0\ [A]$

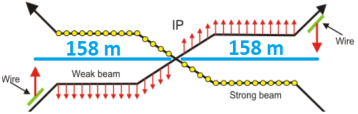
- Beam - beam separation in IP1 (left) and IP5 (right)





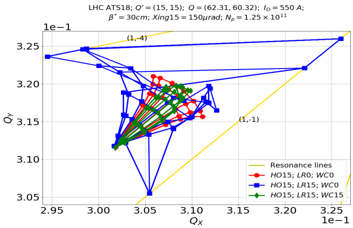
- Weak beam - wire separation (left) & longitudinal position of the wire (right) in IP1 and IP5

```
Distance in sigma of the wire compensator from the weak beam
x_dist_w_c_sig_l1.b1 =              0 ;
wire_c_x_l1.b1      =              0 ;
x_dist_w_c_sig_r1.b1 =              0 ;
wire_c_x_r1.b1      =              0 ;
y_dist_w_c_sig_l1.b1 =    10.16885529 ;
wire_c_y_l1.b1      =        0.00566 ;
y_dist_w_c_sig_r1.b1 =    7.317042966 ;
wire_c_y_r1.b1      =        0.00566 ;
x_dist_w_c_sig_l5.b1 =    7.318909121 ;
wire_c_x_l5.b1      =        0.00566 ;
x_dist_w_c_sig_r5.b1 =    10.17137826 ;
wire_c_x_r5.b1      =        0.00566 ;
y_dist_w_c_sig_l5.b1 =              0 ;
wire_c_y_l5.b1      =              0 ;
y_dist_w_c_sig_r5.b1 =              0 ;
wire_c_y_r5.b1      =              0 ;
```



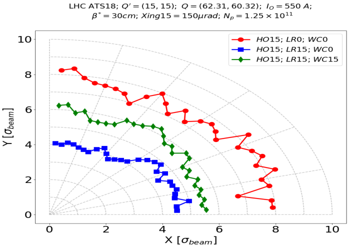
$Xing15 = 150\ [\mu rad]$ and $I_O = 550\ [A]$

▶ For $I_O = 550\ [A]$, a clear compensation can be seen in the footprint and in the Dynamic Aperture (DA) plots.



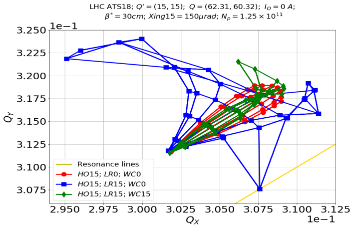
- The footprint wings (a behavior associated to the BBLR kicks) are very well compensated with the use of a wire.

- The minimum gain in DA is 1.5σ.



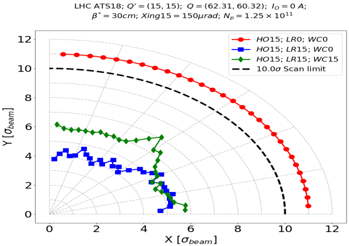
$Xing15 = 150\ [\mu rad]$ and $I_O = 0\ [A]$

▶ For $I_O = 0\ [A]$, a clear over-compensation can be seen in the footprint plot and it is also visible in the DA plot.



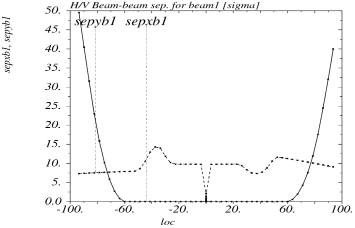
- The footprint wings are over-compensated (twist of the green footprint) with the use of a wire.

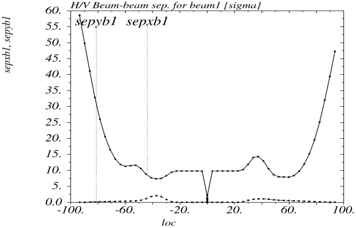
- Not as good as the previous results but still an important 1.0σ is gained with the use of a wire.



$Xing15 = 170\ [\mu rad]$ and $I_O = 550$ and $0\ [A]$

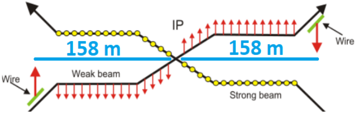
- Beam - beam separation in IP1 (left) and IP5 (right)





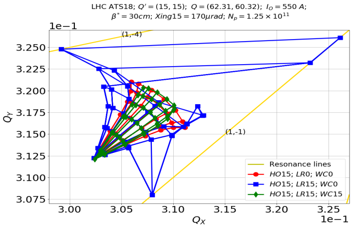
- Weak beam - wire separation (left) & longitudinal position of the wire (right) in IP1 and IP5

```
Distance in sigma of the wire compensator from the weak beam
x_dist_w_c_sig_l1.b1 =                0 ;
wire_c_x_l1.b1       =               0 ;
x_dist_w_c_sig_r1.b1 =                0 ;
wire_c_x_r1.b1       =               0 ;
y_dist_w_c_sig_l1.b1 =      11.52470251 ;
wire_c_y_l1.b1       =     0.006414666667 ;
y_dist_w_c_sig_r1.b1 =      8.292648487 ;
wire_c_y_r1.b1       =     0.006414666667 ;
x_dist_w_c_sig_l5.b1 =      8.294762879 ;
wire_c_x_l5.b1       =     0.006414666667 ;
x_dist_w_c_sig_r5.b1 =      11.52756122 ;
wire_c_x_r5.b1       =     0.006414666667 ;
y_dist_w_c_sig_l5.b1 =                0 ;
wire_c_y_l5.b1       =               0 ;
y_dist_w_c_sig_r5.b1 =                0 ;
wire_c_y_r5.b1       =               0 ;
```



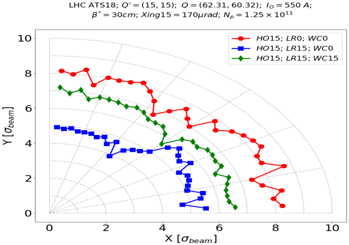
$Xing15 = 170\ [\mu rad]$ and $I_O = 550\ [A]$

▶ Again for $I_O = 550\ [A]$, a clear compensation can be seen in the footprint and the DA plots.



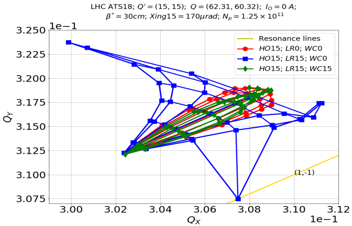
• The footprint opening is very well compensated with the use of a wire.

• The minimum gain in DA is $\sim 2.0\sigma$.



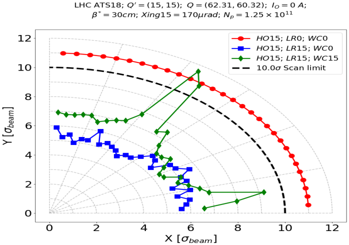
$Xing15 = 170\ [\mu rad]$ and $I_O = 0\ [A]$

▶ Again for $I_O = 0\ [A]$, some over-compensation can be seen in the footprint plot and it is also visible in the DA plot.

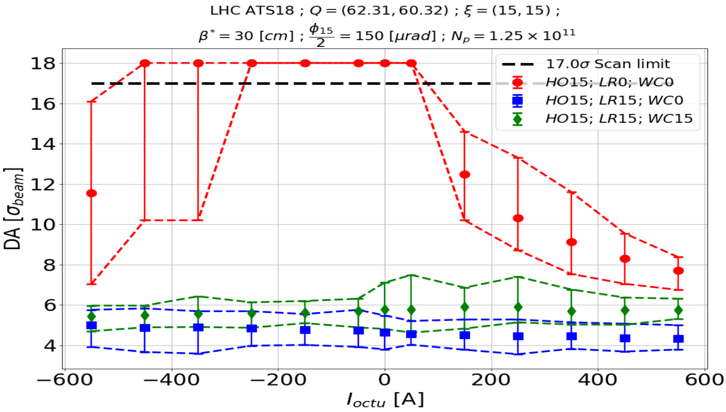


• With the use of a wire the footprint wings are compensated and some over-compensation can be seen at high amplitude particles.

• For the existing good DA, an extra $\sim 0.5\sigma$ is gained with the use of a wire.



$Xing15 = 150\ [\mu rad]$ and octupole current scan



- For any octupole current, at least 1.0σ is gained with the use of the wire compensators.

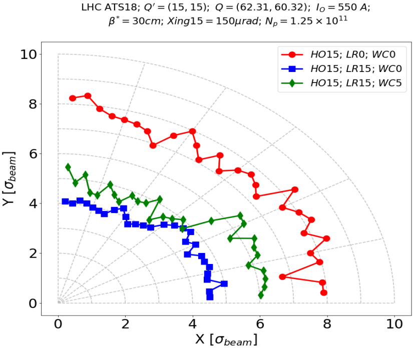
- For the machine configuration used, the greatest DA gain can be seen in the range of $I_O = 250 - 550\ [A]$.

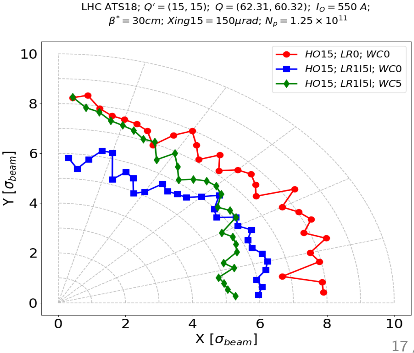
Wire only in IR5 and PACMAN bunches

▶ For the following, the matching is performed with the wire ON in order to preserve the same working point.

- Even for that sub-optimal configuration (LR in both IPs and compensation only in IP5), a 0.5σ is gained with the use of a wire compensator.

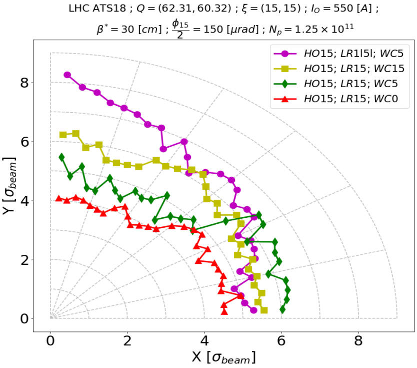
- The DA of the PACMAN bunches is not degraded in the presence of a wire.

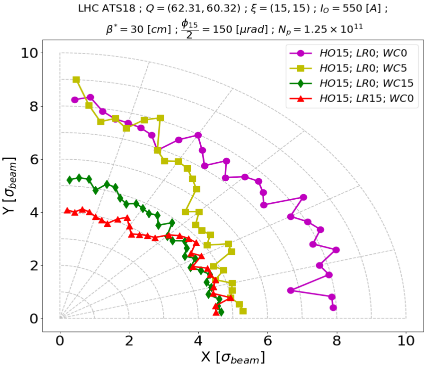




Wire behavior fast overview

- For any BBLR - wire configuration, the min DA is always better in the presence of the wire compensator.
- In the presence of the wire compensator, the LR free bunches do not suffer more than the ones that see only the BBLR kicks.

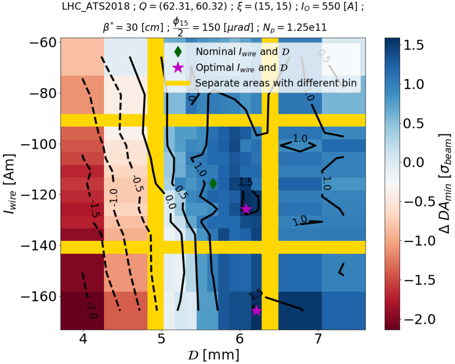


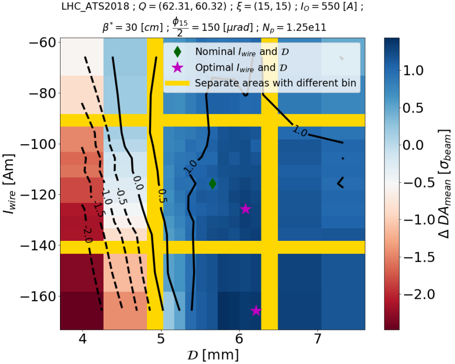


Search for better I_{wire} and $\mathcal{D}$

HO:IP1 ; LR:IP1 ; WIRE:IP1 (use of the nominal s position)
Target tune (Q_X, Q_Y)=(62.30506451 , 60.31668268)

- ▶ A greater DA can be achieved with a new optimal combination of the I_{wire} and $\mathcal{D}$.
- $\Delta_{min,mean}(\Delta DA_{Optimal} - \Delta DA_{Nominal}) = 0.5\sigma$

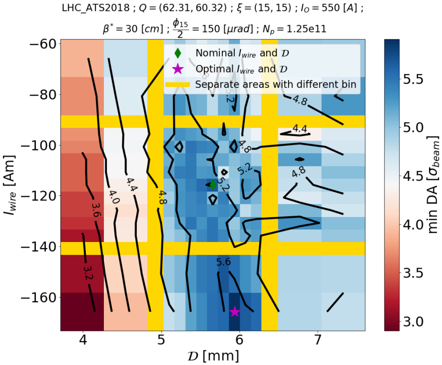


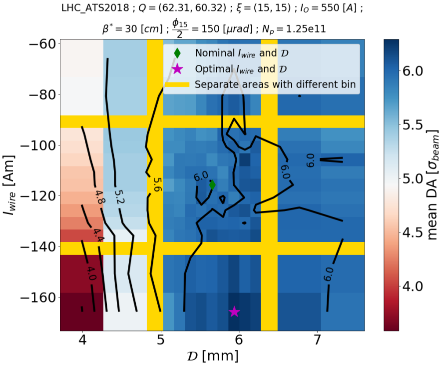


Search for better I_{wire} and $\mathcal{D}$

HO:IP1 ; LR:IP1 ; WIRE:IP1 (use of the nominal s position)
Target tune (Q_X, Q_Y)=(62.30182456 , 60.31164038)

- ▶ A greater DA can be achieved with a new optimal combination of the I_{wire} and $\mathcal{D}$.
- $\Delta_{min,mean}(DA_{Optimal} - DA_{Nominal}) = 0.3\sigma$

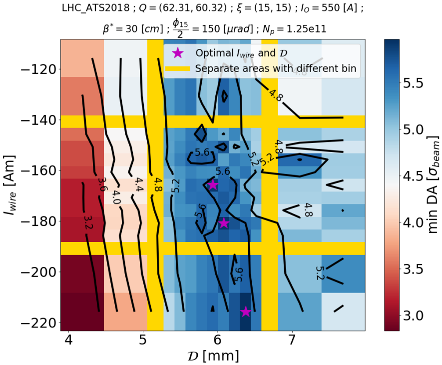


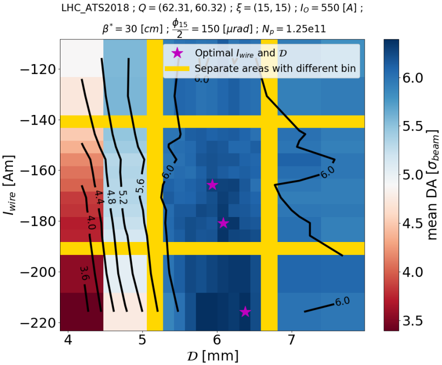


Search for better I_{wire} and $\mathcal{D}$

HO:IP1 ; LR:IP1 ; WIRE:IP1 (use of the nominal s position)
Target tune (Q_X, Q_Y)=(62.30182456 , 60.31164038)

- ▶ A few more optimal combinations for the I_{wire} and $\mathcal{D}$.
- $MAX[\Delta_{min}(DA_{Optimal} - DA_{Optimal})] \simeq 0.05\sigma$





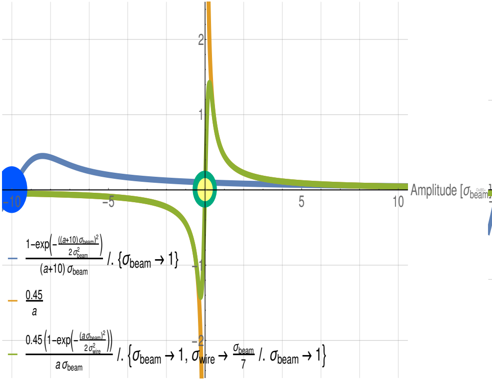
Closing

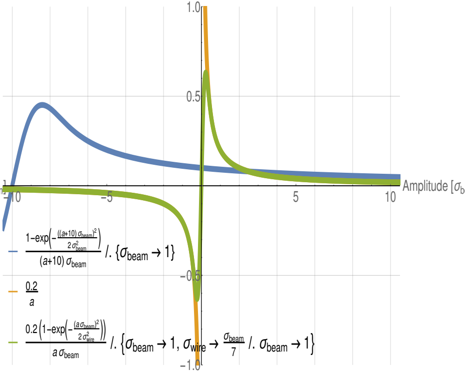
thank you

Special thanks to the wire team for the fruitful discussions!

Backup

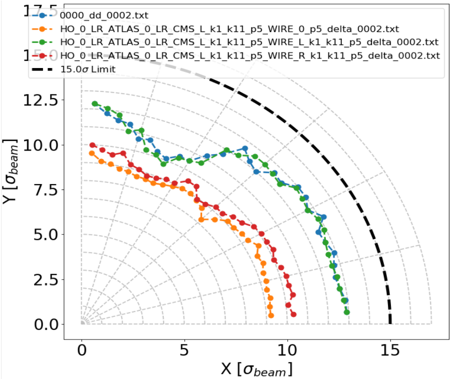
Normal compensation vs Focused compensation at the high amplitudes particles

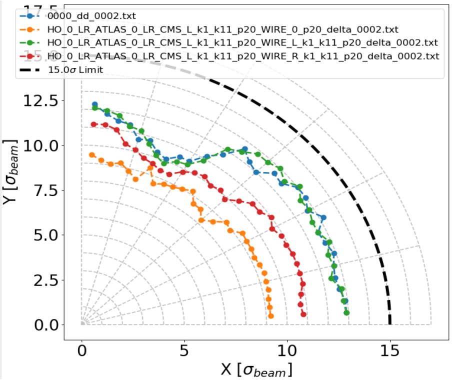




Backup

Contribution of the residual phase advance between the BBLR kicks in the DA





Backup

Sixtrack-wire vs bbwire