Simulations on beam beam compensation with wire

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November 23, 2011

Acknowledgements:

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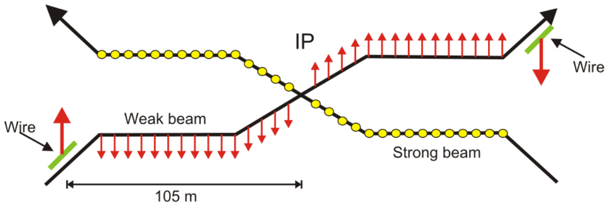
Outline

Previous studies

Studies based on to J.-P. Koutchouk's note: CERN-SL-2001-048-BI [4], wire position

- longitudinal position = 104.93 m after IP1 and IP5 [1] [2]
- transversal position = 9.5 σ [1]

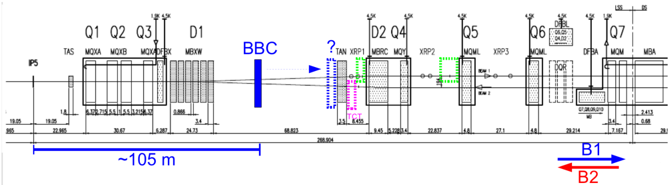


[1] with $\beta^* = 0.55m$, $\beta_{x,y} \approx 1740m$ and $\Delta\mu \approx 0.25^\circ$

Tested cases: Longitudinal positions

- Alternative longitudinal positions [2]

Test	IP1 dist m	β_x m	β_y m	IP5 dist m	β_x m	β_y m	
Nominal	104.93	1738.14	1734.77	104.93	1738.14	1734.78	BEST
TCT	-145.84	1581.02	635.83	-147.52	1574.90	602.24	
Q5	198.89	105.92	503.04	198.89	105.92	503.04	WORST
Additional test							
TCT Optβ 1	-145.84	1581.02	635.83	149.53	563.15	1567.60	
TCT Optβ 2	149.53	1574.90	602.26	-147.52	1574.90	602.24	MAYBE



[2] see R. Steinhagen "LHC BBC - a first proposal" [5]

Tested cases: Transverse position and Current

Transverse positions tested [3]

- wire at 9.5 σ
- wire at 11 σ

[3] see R. Steinhagen "LHC BBC - a first proposal" [5]

Current calculation for 9.5 σ

9.5 σ best current is given by :

$$I_{OPT} = \frac{n\ c\ q\ N}{L_w}$$

n = Long Range interactions # $\rightarrow 32$

c = Speed of light $\rightarrow 3 \cdot 10^8 m/s$

q = Proton charge $\rightarrow 1.602 \cdot 10^{-19} C$

N = # particles per opposite bunch $\rightarrow 1.15 \cdot 10^{11}$

L_w = wire length $\rightarrow 1m$

$$I_{OPT} = 176.8\ A$$

Current at 11 σ

Currents tested at 11 σ

- best results: wire current like at 9.5 σ $\Rightarrow$ $\boxed{I_{OPT} = 176.8\ A}$
- current value quadratically scaled [6] $\Rightarrow$ $\boxed{I = 237.0\ A}$

$$I = \frac{11^2}{9.5^2} \cdot I_{OPT}$$

$I = 237.0\ A$

Performed tests

To analyse the different cases we performed the following tests

Footprint analysis : 10000 particles tested , $[0\sigma, 6.5\sigma]$ initial distribution, 50.000 turns [4]

Instabilities analysis : 902 particles tested, $[0\sigma, 10\sigma]$ initial distribution, 300.000 turns.

Simulations made with bbtrack (Ulrich Dorda) [3]

[4] Modified gaussian (x,y) distribution $\rightarrow$ more particles in $[4\sigma, 6.5\sigma]$, for more details see [33]

Stability Criterion

bbtrack iterative process

- two particles tracked (shifted and not shifted)
- normalize their coordinates (3)
- for each turn i
  - Calculate the 4d cartesian distance $d_n(i)$
  - Particle marked as unstable if

$$\frac{d_n(i) - d_n(0)}{2d_n(\frac{i}{2})} > K \quad \text{In the test: } K = 3$$

Dynamical Radius, choise criterion

Last observed radius where stable particles count is higher than unstable one.

Tune moved

Central tune moved back to the original value.
In IP 1

$$\Delta Q_x = -\frac{r_p \; I_w \; L_w \; \beta_x}{2 \; \pi \; \gamma \; q \; c \; d^2}$$

$$\Delta Q_y = \frac{r_p \; I_w \; L_w \; \beta_y}{2 \; \pi \; \gamma \; q \; c \; d^2}$$

β_u = β at wire position (u = x, y)
d = wire y-distance

in IP 5 reversed signs and d = wire x-distance (34)

Square wire

Simulated square wire (1mm side) $\Rightarrow$ 4 point-like wires.

Example: Nominal Position Wire , 9.5 σ

IP1

x pos m	y pos m
0.00000	-0.00888

$\Rightarrow$

(-0.0005 , -0.00888)	(0.0005 , -0.00888)
(-0.0005 , -0.00988)	(0.0005 , -0.00988)

IP5

x pos m	y pos m
-0.00888	0.00000

$\Rightarrow$

(-0.00988, 0.0005)	(-0.00888, 0.0005)
(-0.00988, -0.0005)	(-0.00888, -0.0005)

Crossing angle 2 / 3

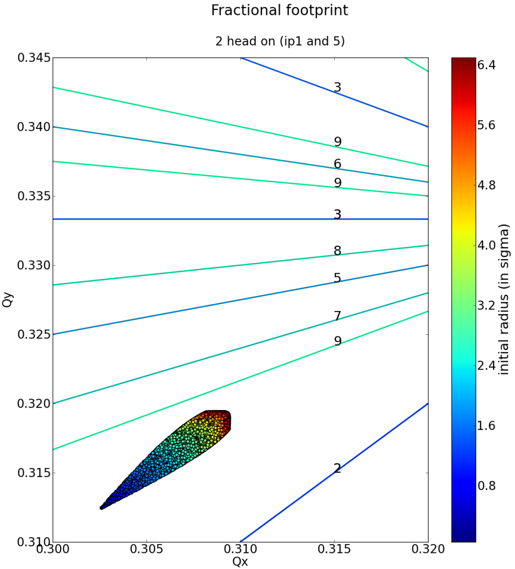
Additional test:

Crossing angle set to 2 / 3 of nominal values

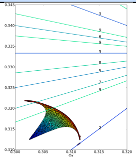
Affects

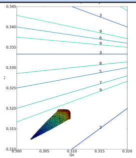
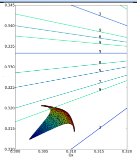
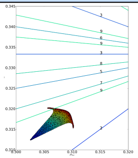
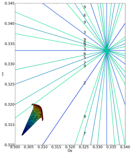
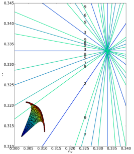
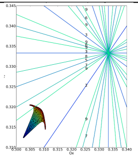
- Wire position
- Particles distribution (removed from test particles with radius $> 4\sigma$)

Test summary: Footprint

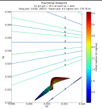
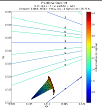
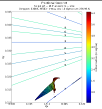
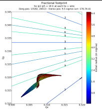
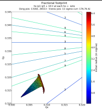
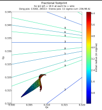
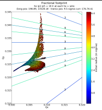
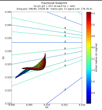
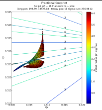
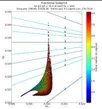
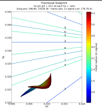
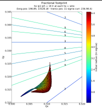


Test summary: Footprint

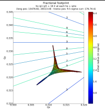
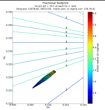
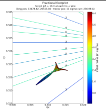
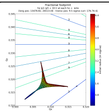
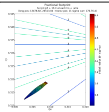
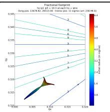
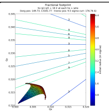
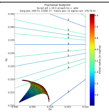
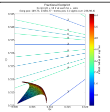
Test	
HO Long Range	

Test	9.5 σ 176 A	11 σ 176 A	11 σ 237 A
Wire at 105			
Square wire (BBC)			

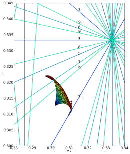
Test summary: Footprint part 2

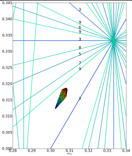
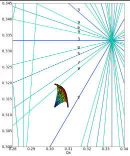
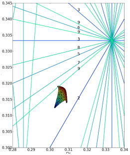
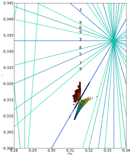
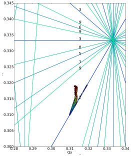
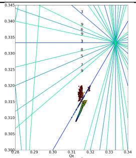
Test	9.5 σ 176 A	11 σ 176 A	11 σ 237 A
Wire at TCT			
Wire at TCT Tune Moved			
Wire at Q5			
Wire at Q5 Tune Moved			

Test summary: Footprint part 3

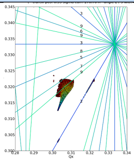
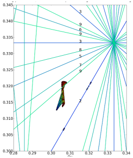
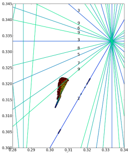
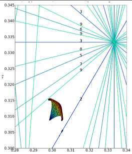
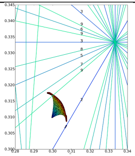
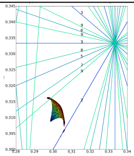
Test	9.5 σ 176 A	11 σ 176 A	11 σ 237 A
Wire at TCT mod			
Wire at TCT mod Tune Moved			
Wire at TCT mod 2			

Test summary: Footprint Crossing Angle 2/3 - 1

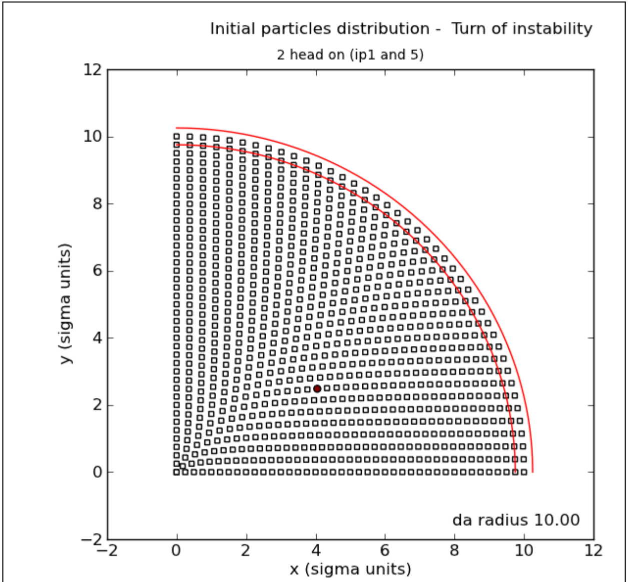
Test	
HO Long Range	

Test	6.3 σ 176 A	7.3 σ 176 A	7.3 σ 237 A
Wire at 105			
Wire at TCT			

Test summary: Footprint Crossing Angle 2/3 - 2

Test	6.3 σ 176 A	7.3 σ 176 A	7.3 σ 237 A
Wire at TCT Tune moved back			
Wire at TCT mod 2			

Test summary: Dynamical aperture



Test summary: Dynamical aperture

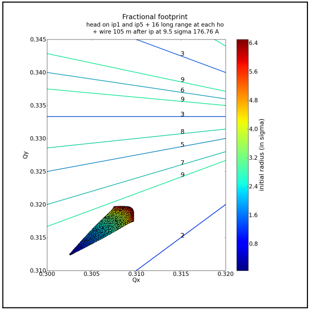
Test	Wire Pos σ	Curr A	R σ	Inst Part %	R optQ σ	Inst Part optQ %
HO Long Range			8.50	30.7		
Wire at 105	9.50	177	8.50	19.8		
Square Wire at 105	9.50	177	9.00	16.4		
Wire at 105	11	177	9.75	14.7		
Square Wire at 105	11	177	9.25	18.4		
Wire at 105	11	237	8.25	34.4		
Square Wire at 105	11	237	9.50	14.9		
Wire at TCT	9.5	177	8.25	30.8	7.75	33.8
Wire at TCT	11	177	8.75	24.6	8.50	28.4
Wire at TCT	11	237	8.50	26.5	8.50	28.2
Wire at Q5	9.5	177	5.75	52.5	7.00	43.5
Wire at Q5	11	177	7.50	35.9	8.25	30.0
Wire at Q5	11	237	7.00	45.6	7.75	37.9
Wire at TCT mod	9.5	177	7.00	43.1		
Wire at TCT mod	11	177	8.50	27.9		
Wire at TCT mod	11	237	8.50	30.5		
Wire at TCT mod 2	9.5	177	8.75	20.3		
Wire at TCT mod 2	11	177	9.00	23.4		
Wire at TCT mod 2	11	237	8.75	22.3		

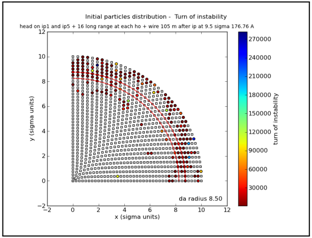
Dynamical aperture Crossing Angle 2 / 3

Test	Wire Pos	Curr	R	Inst Part	R optQ	Inst Part optQ
	σ	A	σ	%	σ	%
HO Long Range			5.25	62.08		
Wire at 105	6.33	177	5.25	35.03		
Wire at 105	7.33	177	6.00	35.70		
Wire at 105	7.33	237	6.00	30.16		
Wire at TCT	6.33	177	2.50	37.92	4.00	33.92
Wire at TCT	7.33	177	4.75	38.69	5.00	38.69
Wire at TCT	7.33	237	3.00	46.45	4.75	
Wire at TCT 2	6.33	177	5.50	31.37		
Wire at TCT 2	7.33	177	5.50	41.46		
Wire at TCT 2	7.33	237	5.75	36.14		

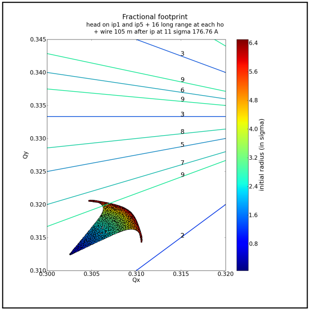
Wire at nominal position

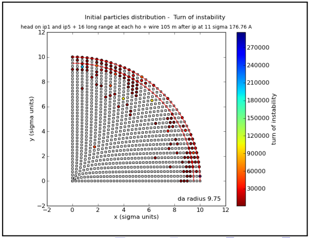
9.5 σ 176.76 A



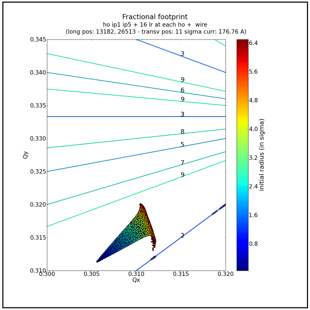


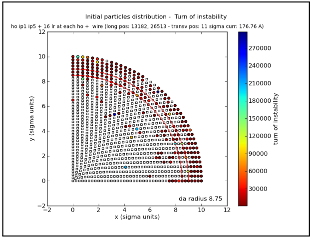
11 σ 176.76 A





Wire at TCT , 11 σ 176.76 A





	IP 1 m	IP 5 m
s	26513.04	13181.77
from IP	-145.84	-147.52
x pos	0.00000	-0.00979
y pos	-0.00622	0.00000
β_x	1581.02	1574.90
β_y	635.83	602.24

Dynamical Aperture

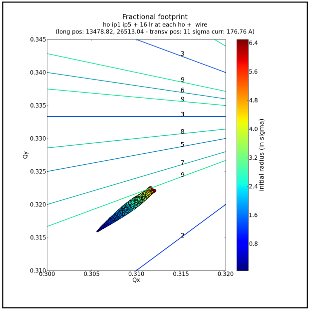
Radius 8.75 σ

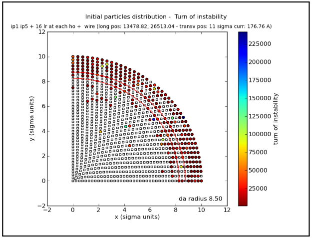
Wire at TCT modified , 11 σ 176.76 A

	IP 1 m	IP 5 m
s	26513.04	13478.82
from IP	-145.84	149.53
x pos	0.00000	-0.00585
y pos	-0.00622	0.00000
β_x	1581.02	563.15
β_y	635.83	1567.60

Dynamical Aperture

Radius 8.50 σ

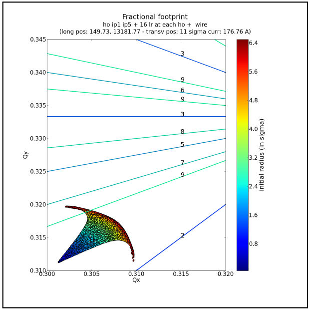


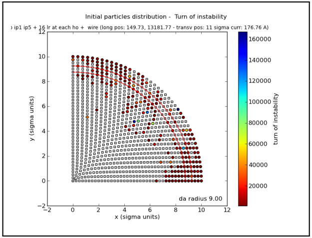


Wire at TCT modified 2 , 11 σ 176.76 A

Wire Compensation

T. Rijoff, F. Zimmermann



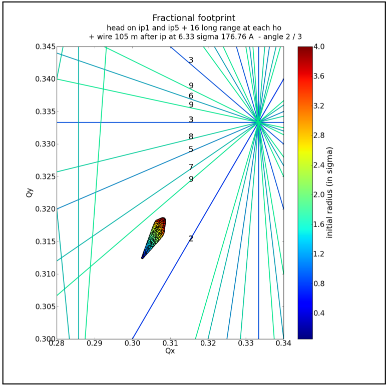


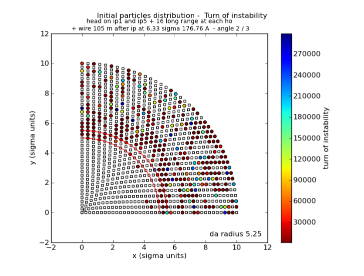
	IP 1 m	IP 5 m
s	149.73	13181.77
from IP	149.73	-147.52
x pos	0.00000	-0.00979
y pos	-0.00976	0.00000
β_x	559.44	1574.90
β_y	1566.89	602.24

Dynamical Aperture

Radius 9.00 σ

Wire at nominal position, 6.33 σ 176.76 A Crossing Angle 2 / 3

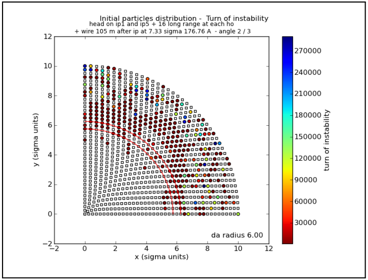




Dynamical Aperture

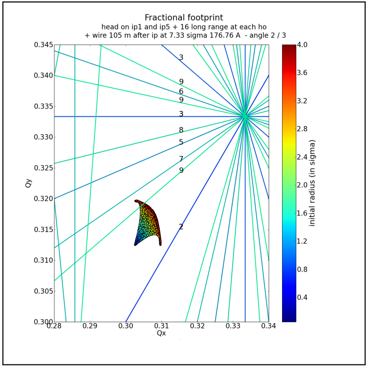
Radius 5.25 σ

Wire at nominal position, 7.33 σ 176.76 A Crossing Angle 2 / 3

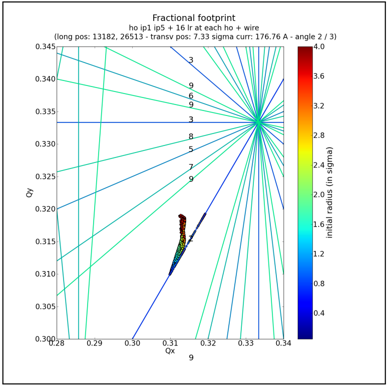


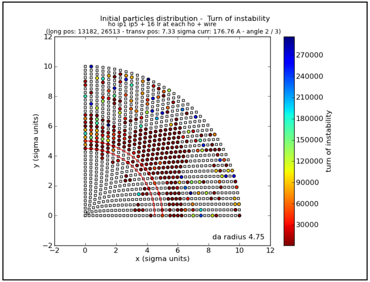
Dynamical Aperture

Radius $6.00\ \sigma$



Wire at TCT , 7.33 σ 176.76 A



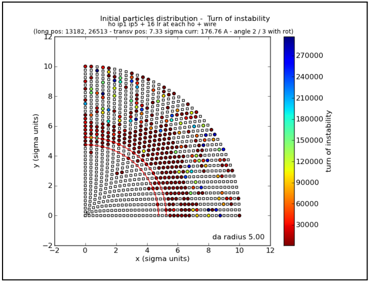


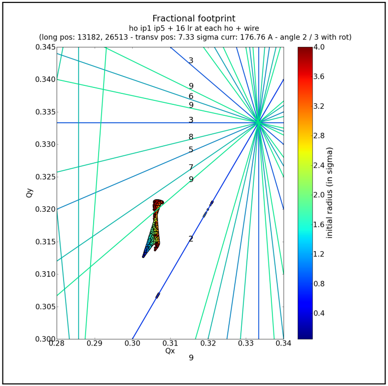
Dynamical Aperture

Radius 4.75 σ

Wire at TCT , 7.33 σ 176.76 A

Central tune moved back

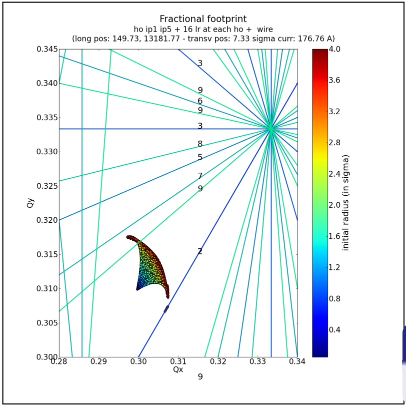


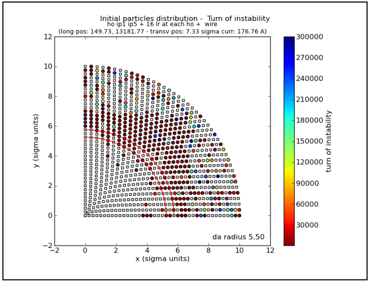


Dynamical Aperture

Radius 5.00 σ

Wire at TCT mod 2, 7.33 σ 176.76 A





Dynamical Aperture

Radius 5.50 σ

Conclusions and Outlook:

Wire compensation for the nominal LHC as been studied

- The best compensation is achieved with a wire at optimum location at 11 σ
- Wire at the 2nd modified TCT location also promises a good performance
- Changing the point like wire with a squared wire with (side 1 mm) seems to gives better results
- The results seem encouraging also changing the crossing angle to 2 / 3 of nominal value

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- U. Dorda.
  Bbtrack - a weak-strong long-range beam beam interaction simulation code.
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  Correction of the long-range beam-beam effect in lhc using electro-magnetic lenses. oai:cds.cern.ch:513685.
  (CERN-SL-2001-048-BI):4 p, Jul 2001.

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Scaling of diffusive aperture with wire current.
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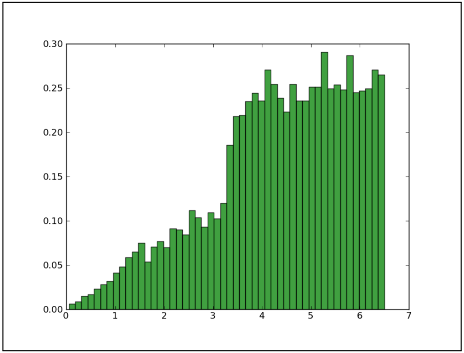
Particle distribution for footprint analysis

Footprint analysis tests are made modifying an initial gaussian distribution in x and y to obtain more particles with an initial radius between 4 and 6.5 σ



Tune moved

In IP 1

$$\Delta Q_x = -\frac{r_p\ I_w\ l_w\ \beta_x}{2\ \pi\ \gamma\ q\ c\ d^2} \tag{1}$$

$$\Delta Q_y = \frac{r_p\ I_w\ l_w\ \beta_y}{2\ \pi\ \gamma\ q\ c\ d^2} \tag{2}$$

r_p = classical proton radius $\rightarrow 1.5\ 10^{-18} m$

γ = relativistic $\gamma \rightarrow$ 7460.52

I_w = wire current

l_w = wire length $\rightarrow 1 m$

β_u = β at the wire position (u = x, y)

d = wire y-distance

Normalized coordinates

$$
\begin{aligned}
x_n &= \frac{x}{\sigma_x} \\
x'_n &= x'\sqrt{\frac{\beta_x}{\epsilon_x}} + x\frac{\alpha_x}{\sigma_x} \\
y_n &= \frac{y}{\sigma_y} \\
y'_n &= y'\sqrt{\frac{\beta_y}{\epsilon_y}} + y\frac{\alpha_y}{\sigma_y}
\end{aligned}
\tag{3}
$$