Proposal of Halo collimation system for ATF2

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  - First Analytical wakefield impact
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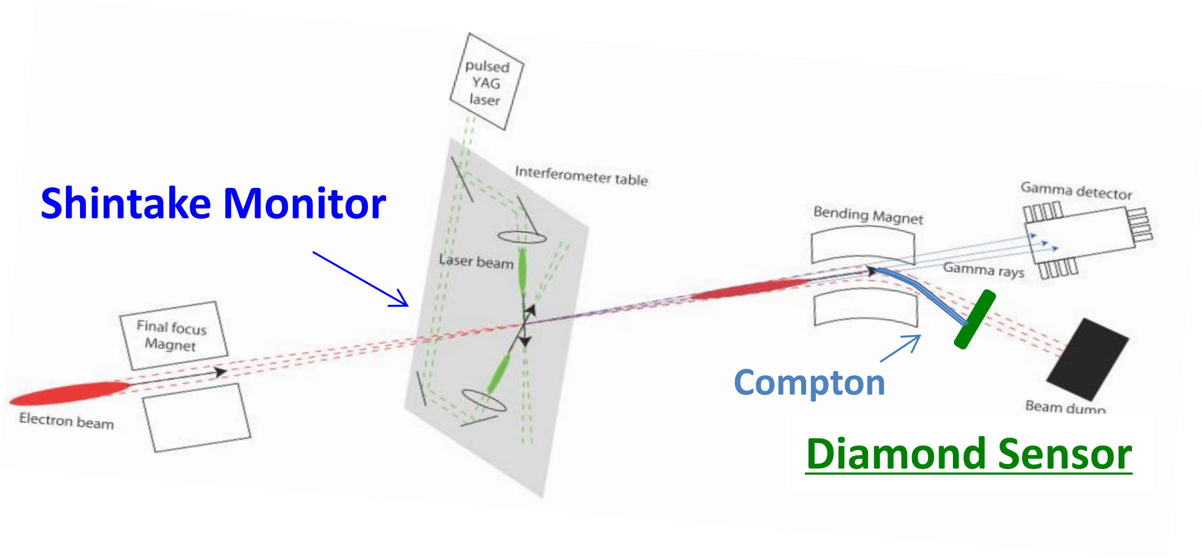
Motivation of the study

- **Reduction of the background noise at the Shintake Monitor** (IPBSM)

- Reduce halo extension, mainly in the **horizontal** plane, to **improve the detection efficiency of the Diamond Sensors (DS)** located between the BDUMP bending magnet and the DUMP to measure the beam halo distribution and the Compton electrons coming from the interaction between the laser and the electron beam



Methodology and working plan

1. Beam dynamics simulation and realistic tracking studies in ATF2 to evaluate the efficiency of a retractable halo collimation system (IFIC-LAL-KEK)

2. Design of a retractable halo collimation device: mechanical and material study (IFIC-LAL)

3. Construction and calibration of the halo collimation device (IFIC-LAL)

4. Software design of the halo collimation device control system (IFIC-LAL)

5. Installation and commissioning of the halo collimation device in ATF2 (IFIC-KEK-LAL)

6. Study of the halo control, background reduction and collimator wakefield studies using the ATF2 halo collimator (IFIC-KEK-LAL)

Beam dynamics simulation and realistic tracking studies: Tracking methodology

1. Beam core tracking EXT+FF+Post line of ATF2 using MAD-X

2. Tracking of the halo along EXT+FF+Post line of ATF2 using MAD-X
   – Scan to find the best location for a betatron halo collimator
   – Scan of different apertures in order to determine an efficient collimation system in terms of halo cleaning and wakefield minimization

Imput simulation parameters :

Beam core distribution: *Gaussian*

- Number of particles: *10000*
- *E=1.3 GeV*
- $\varepsilon_x = 2\ 10^{-9}$ *m.rad*
- $\varepsilon_y = 1.18\ 10^{-11}$ *m.rad*
- σ_E: *0.08%*
- Optics configuration: *10*x1 *(v5.0)*
  - *Multipoles*
  - *No misalignments*

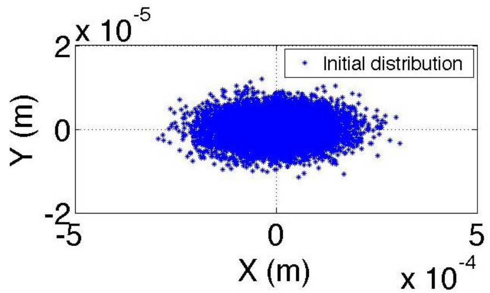
Halo models distribution: { Gaussian / *Uniform* / *Realistic* }

- Number of particles: *10000*
- *E=1.3 GeV*
- $\varepsilon_x = 2\ 10^{-9}$ *m.rad*
- $\varepsilon_y = 1.18\ 10^{-11}$ *m.rad*
- σ_E: *0.08%*
- Optics configuration: *10*x1 *(v5.0)*
  - *Multipoles*
  - *No misalignments*

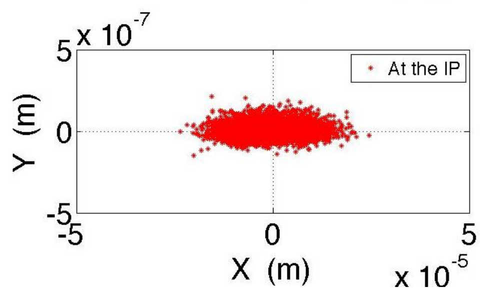
Beam dynamics simulation and realistic tracking studies: Beam core tracking

Tracking of a beam core Gaussian distribution:

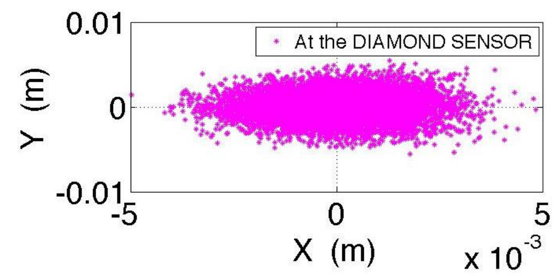
Entrance of the EXT line



IP



DS



	INITIAL		IP		DS	
	Optics	Tracking	Optics	Tracking	Optics	Tracking
σ_x (m)	$1.17\text{x}10^{-4}$	$1.18\text{x}10^{-4}$	$9.03\text{x}10^{-6}$	$10.10\text{x}10^{-6}$	$0.97\text{x}10^{-3}$	$1.26\text{x}10^{-3}$
σ_y (m)	$5.88\text{x}10^{-6}$	$5.87\text{x}10^{-6}$	$3.11\text{x}10^{-8}$	$3.68\text{x}\ 10^{-8}$	$1.50\text{x}10^{-3}$	$1.51\text{x}10^{-3}$

Beam dynamics simulation and realistic tracking studies: Tracking halo models

Halo tracking along the EXT and FF line of ATF2 using different halo models (values of **nx** and **ny** are chosen in order to compare the different halo model distributions and A_x and A_y are the transverse halo amplitude)

Gaussian distribution nx=28 ny=28 (A_x=3.3 mm, A_y=0.17mm)

$$\rho_z = n_z \frac{1}{\sigma_z \sqrt{2\pi}} e^{-\frac{z^2}{2\sigma_z^2}} \qquad z = x, y$$

Uniform distribution nx=76 ny=96 (A_x=3.3 mm, A_y=0.17mm)

$$\rho_z = n_z \frac{1}{(-\sigma_z) - \sigma_z} \ for \ -\sigma_z \leq z \leq \sigma_z$$

$$\rho_z = 0 \ for \ z < -\sigma_z \ and \ z > \sigma_z$$

Realistic distribution nx=60 ny=81.25 (A_x=3.3 mm, A_y=0.17mm)

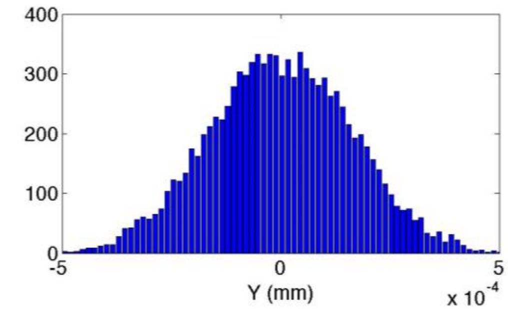
$$\rho_x = n_x x^{-3.5} (x \geq 3\sigma_x)$$

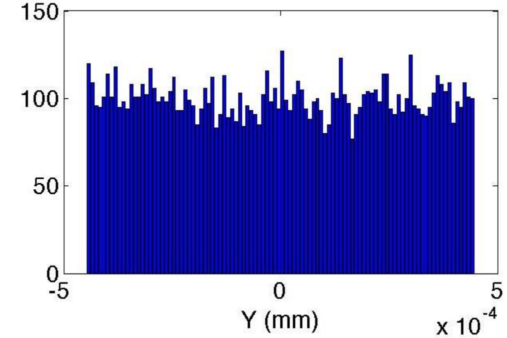
$$\rho_y = n_y y^{-3.5} (3\sigma_y \leq y \leq 6\sigma_y) \ and \ \rho_y = n_y y^{-2.5} (y \geq 6\sigma_y)$$

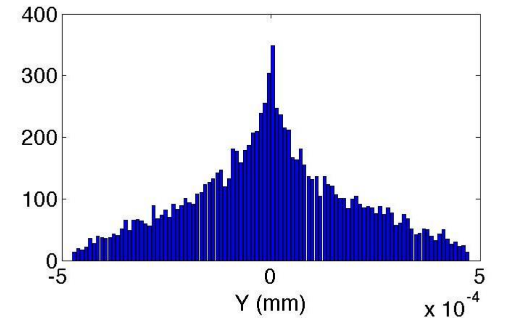
T. Suehara et al., "Design of a Nanometer Beam Size Monitor for ATF2, arXiv:0810.5467vl"

Initial halo distribution

Entrance of the EXT line







Beam dynamics simulation and realistic tracking studies: Betatron halo collimation

For a given collimator aperture, $a_{x,y}$, the betatron collimation depth, $N_{x,y}$, is defined:

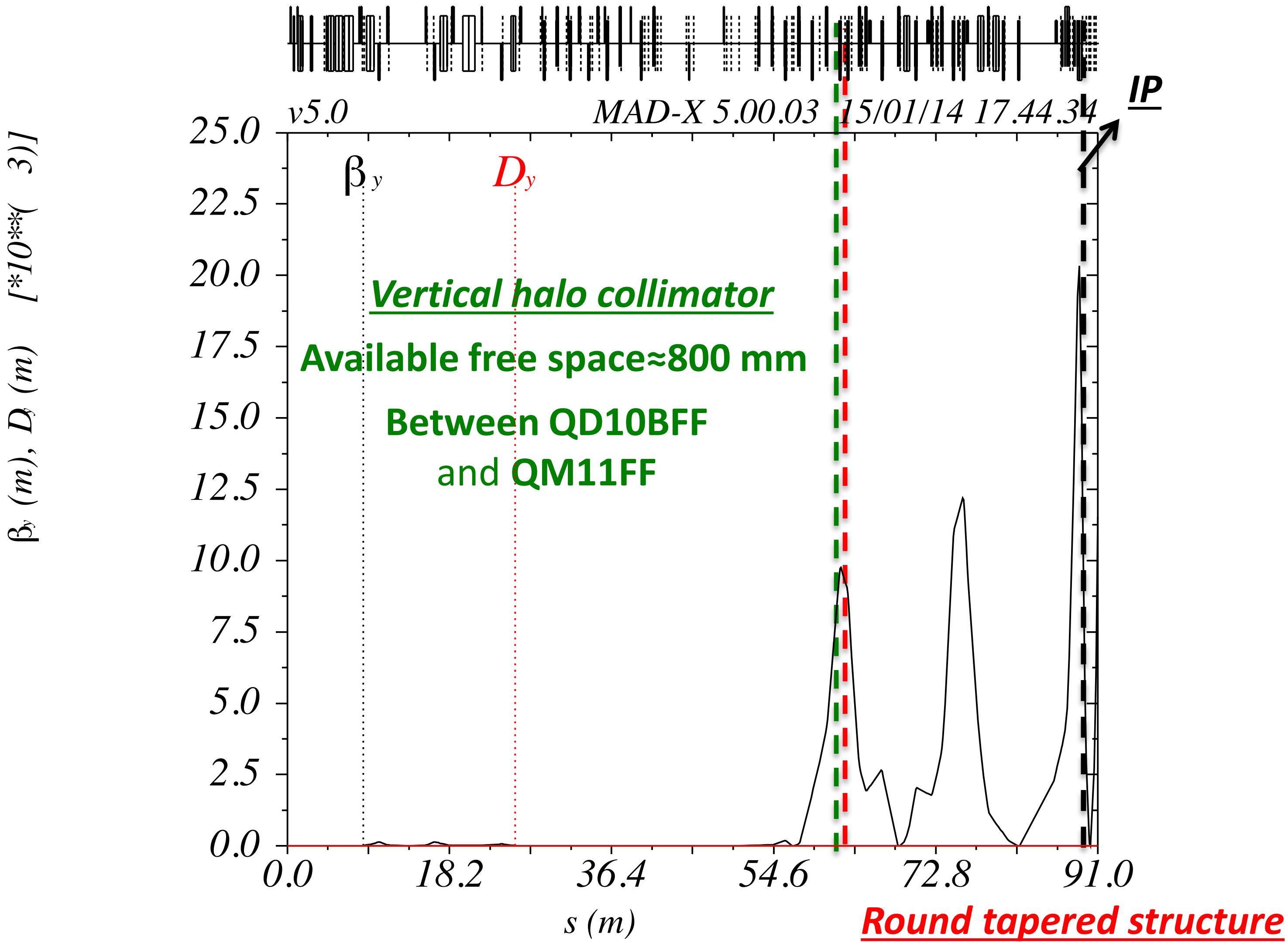
$$N_{x,y} = \frac{a_{x,y}}{\sigma_{x,y}}$$

To have a high efficient system:

- High $\beta_{x,y}$ for a given collimation depth with higher aperture
- $D_{x,y} \cong 0$ for a pure betatron collimation
- The collimator position in phase ($\Delta\mu_{x,y} = n\pi$ (n=1,2,3…)) with the place of interest
- Minimum available free space (600 mm)

Beam dynamics simulation and realistic tracking studies: Betatron halo collimation

Vertical collimator

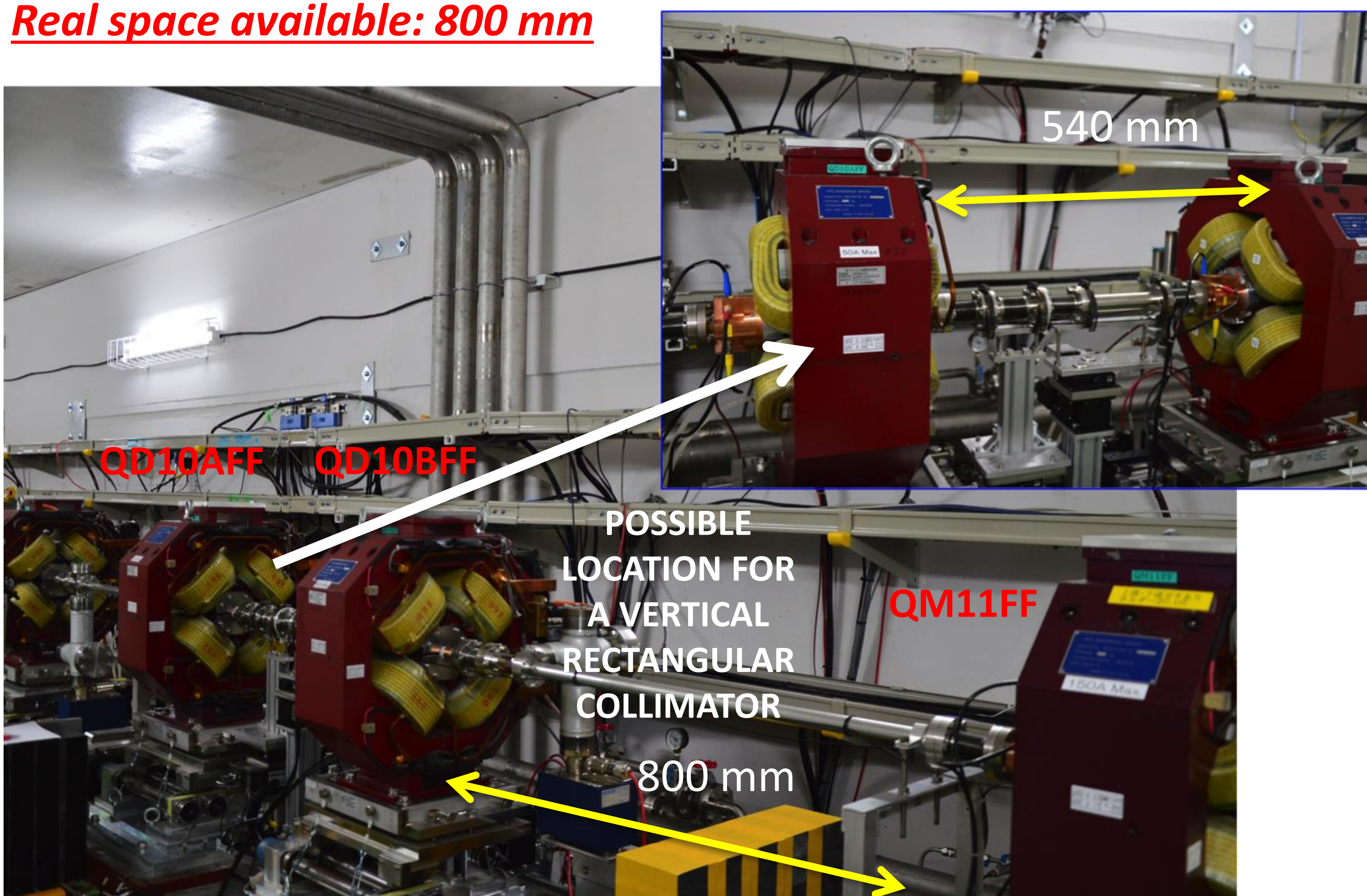


Beam dynamics simulation and realistic tracking studies: Betatron halo collimation

Vertical collimation

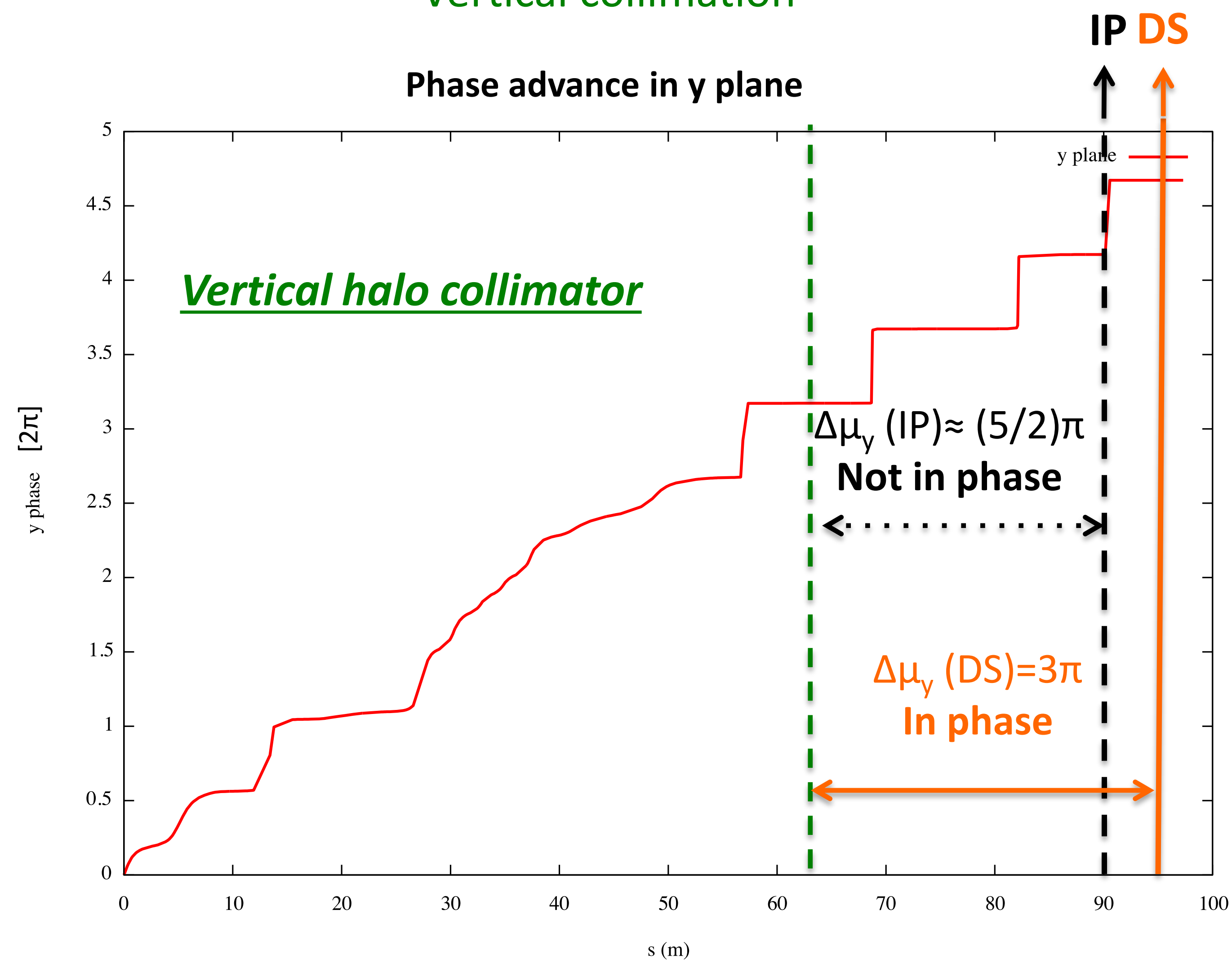
Real space available: 800 mm

DOWNSTREAM ROUND TAPERED COLLIMATOR



Beam dynamics simulation and realistic tracking studies: Betatron halo collimation

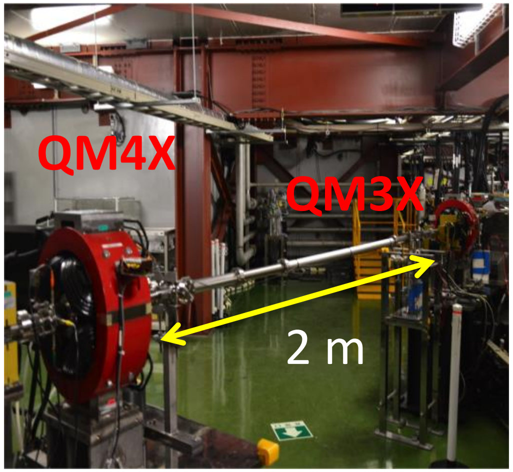
Vertical collimation



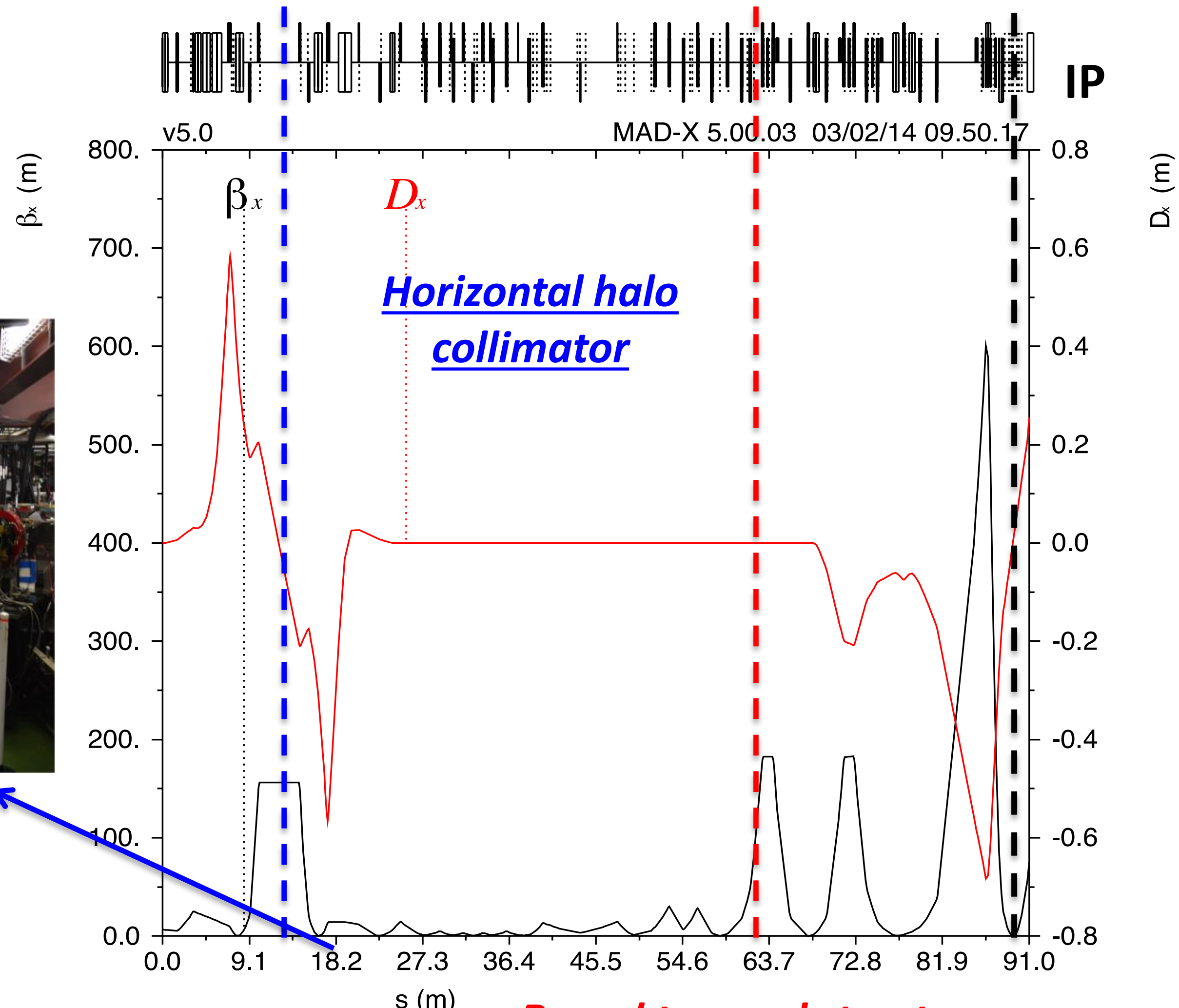
Beam dynamics simulation and realistic tracking studies: Betatron halo collimation

Horizontal collimation

Between QD3FX and QD4FX

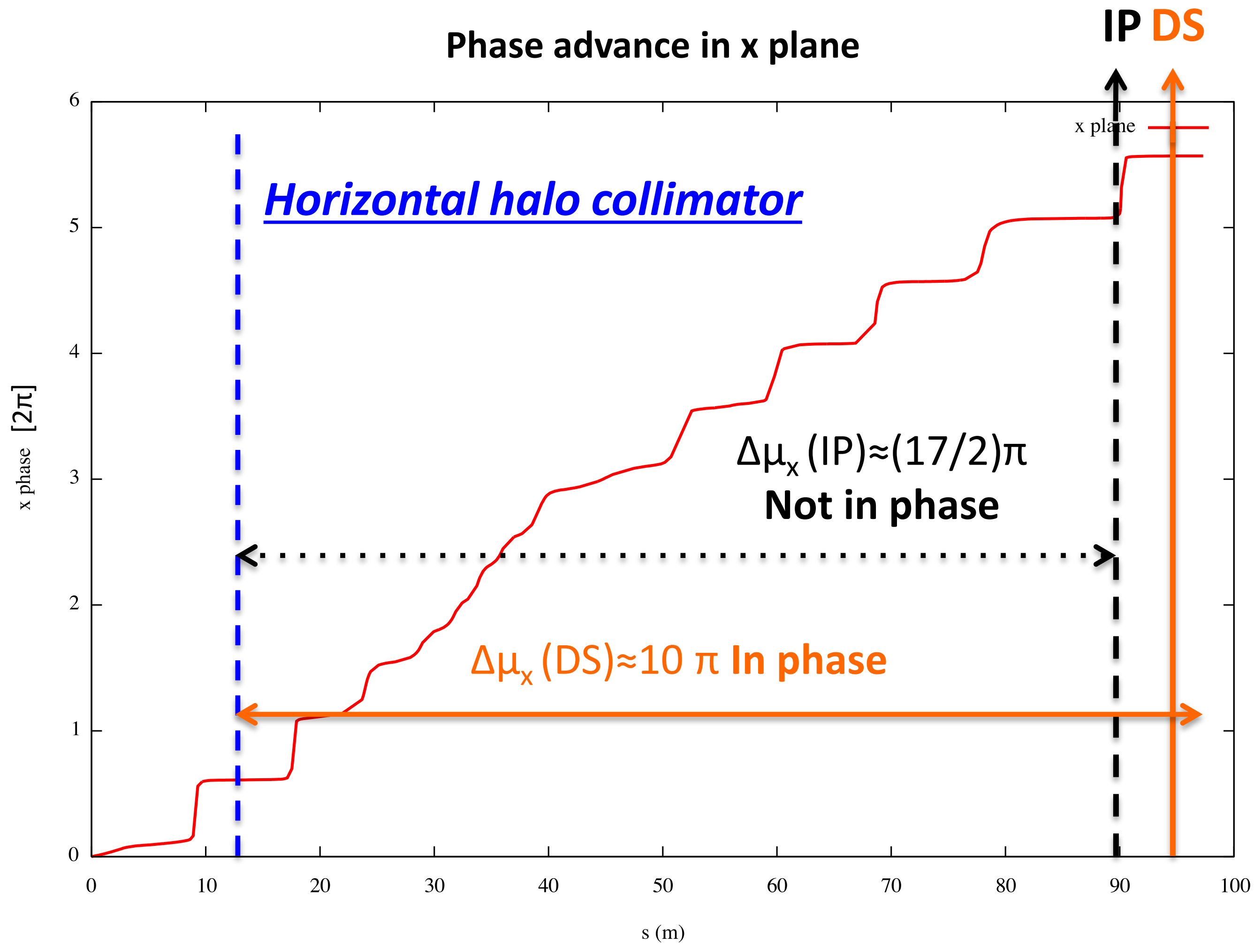


Available free space ≈2000 mm



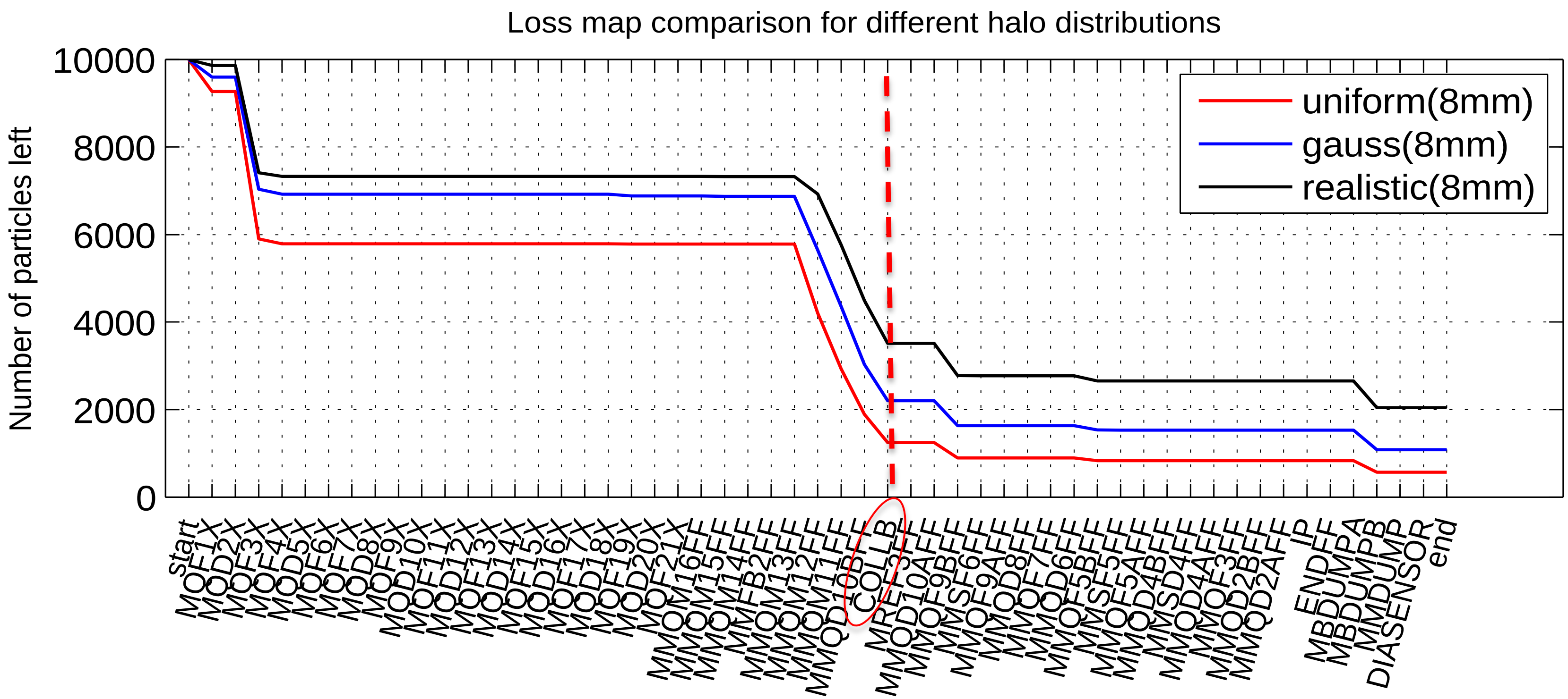
Beam dynamics simulation and realistic tracking studies: Betatron halo collimation

Horizontal collimation



Beam dynamics simulation and realistic tracking studies: Tracking results

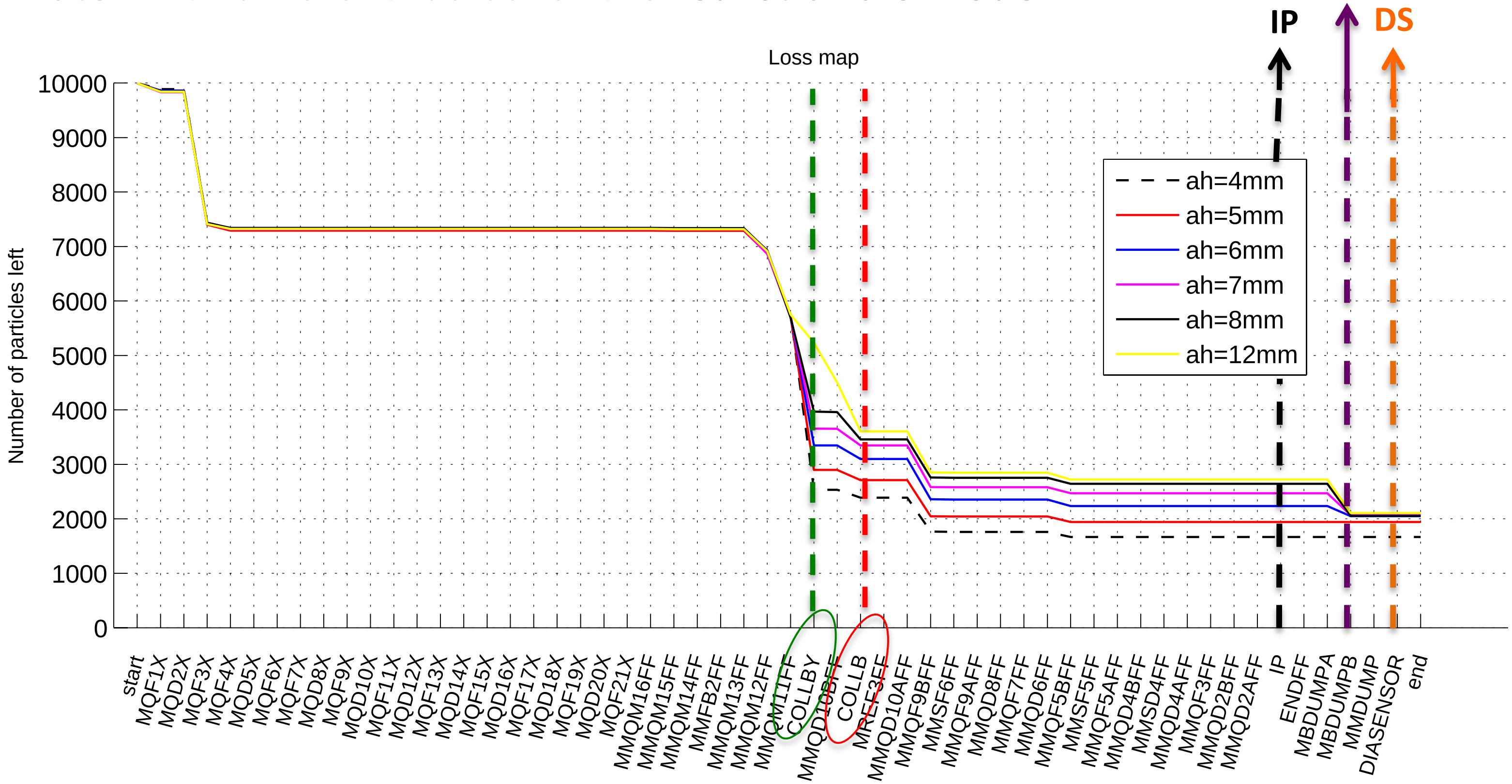
Tracking loss map considering **round tapered collimator** with 8 mm radius **for different halo models**



- We observe a similar behavior for the different halo models
- The most pessimistic case is the uniform one (as expected)

Beam dynamics simulation and realistic tracking studies: Tracking results

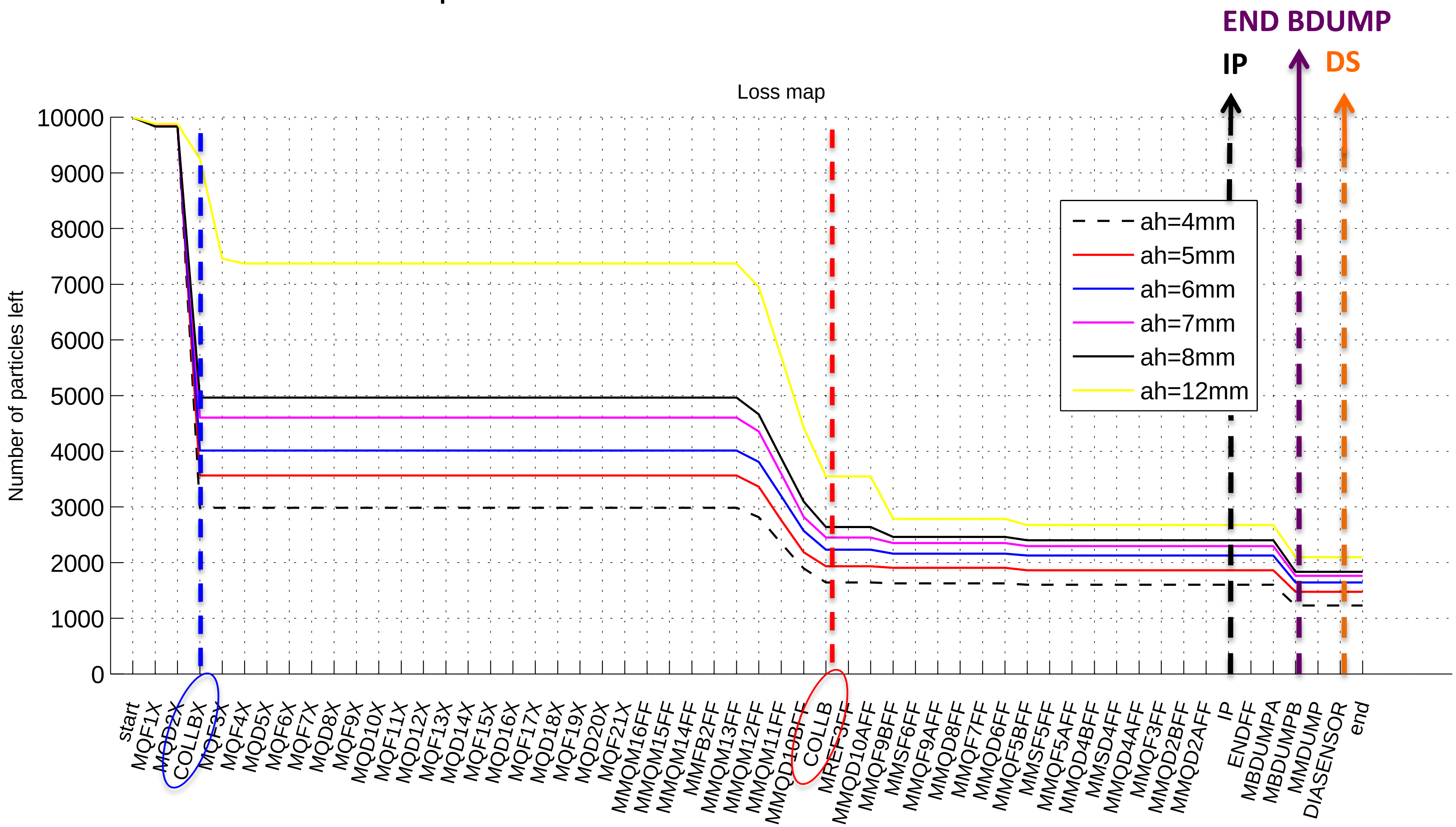
Tracking loss map considering **round tapered collimator** and a **vertical rectangular collimator** with different radius for the **realistic halo model**



For the collimator efficiency we look at the IP, at the end of the BDUMP (MBDUMPB) and at the DS

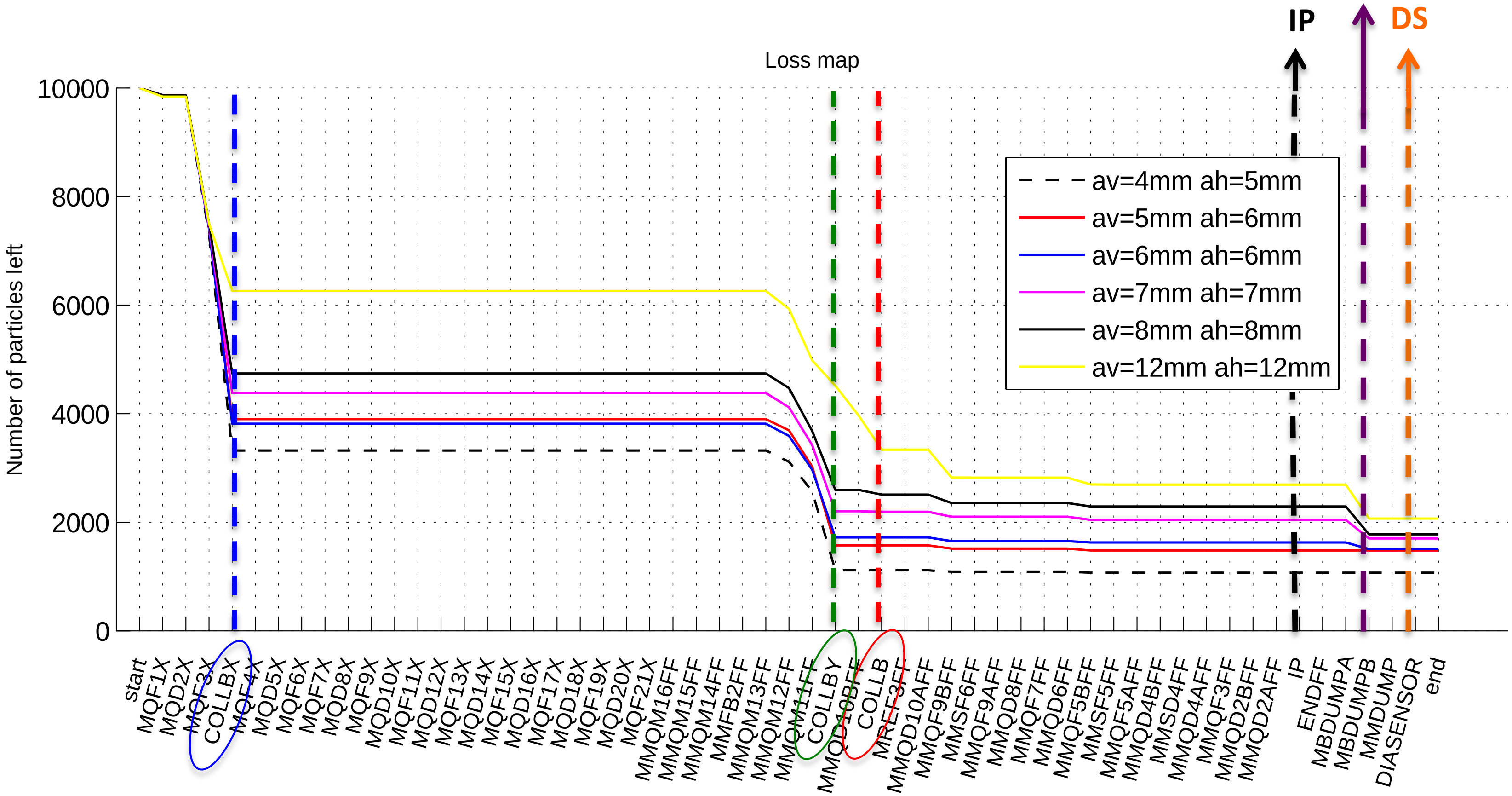
Beam dynamics simulation and realistic tracking studies: Tracking results

Tracking loss map considering **round tapered collimator** and **an horizontal rectangular collimator** and different apertures **for the realistic halo model**



Beam dynamics simulation and realistic tracking studies: Tracking results

Tracking loss map considering **round tapered collimator** and **two rectangular halo collimarors** (one **horizontal** and one **vertical**) and different apertures **for the realistic halo model**



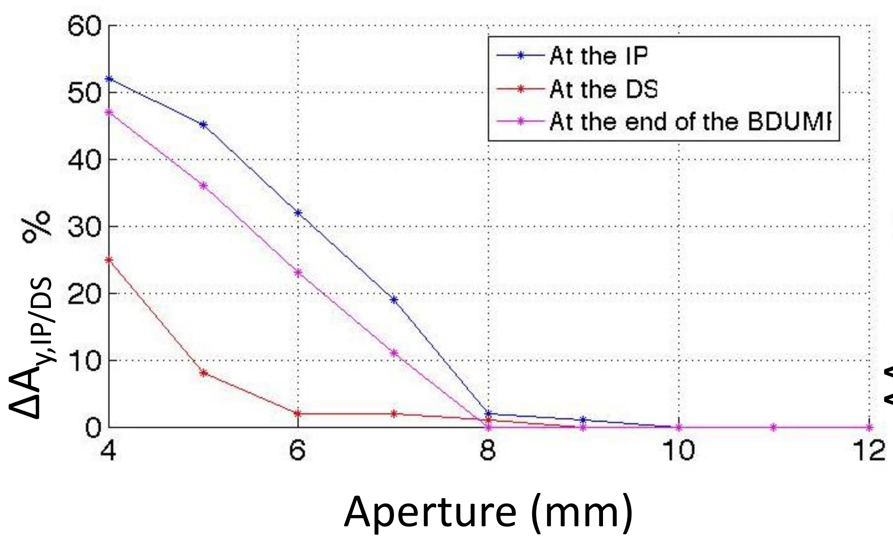
Beam dynamics simulation and realistic tracking studies: Tracking results

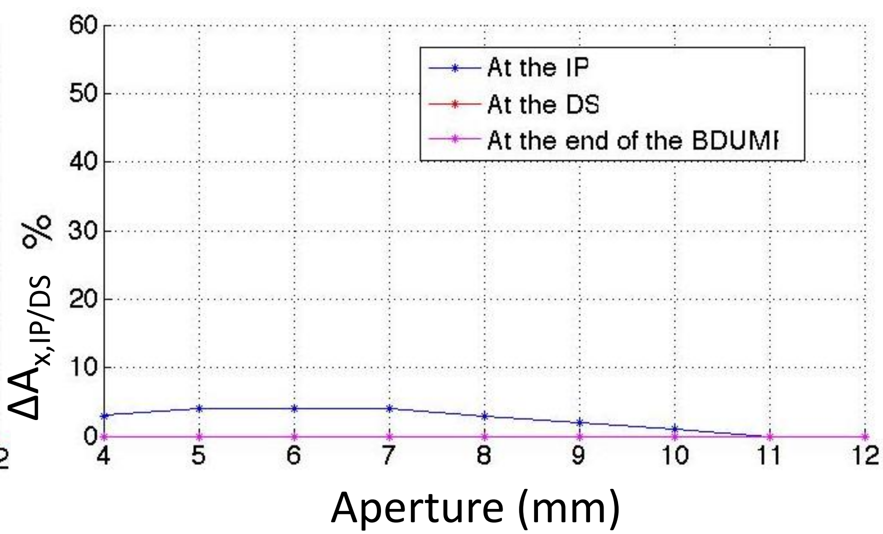
Variation of the **rms transverse halo amplitude, $\Delta A_{z,IP/DS}$,** for different apertures respect to the current situation in ATF2

$$\Delta A_{z,IP/DS} = \frac{A_{z,IP/DS} - A_{z,coll,IP/DS}}{A_{z,IP/DS}} \qquad z = x, y$$

$A_{z,IP/DS}$ rms vertical halo amplitude at the IP/DS ⟶ only the round tapered structure

$A_{z,coll.,IP/DS}$ rms vertical halo amplitude at the IP/DS ⟶ round tapered structure + rectangular vertical collimator





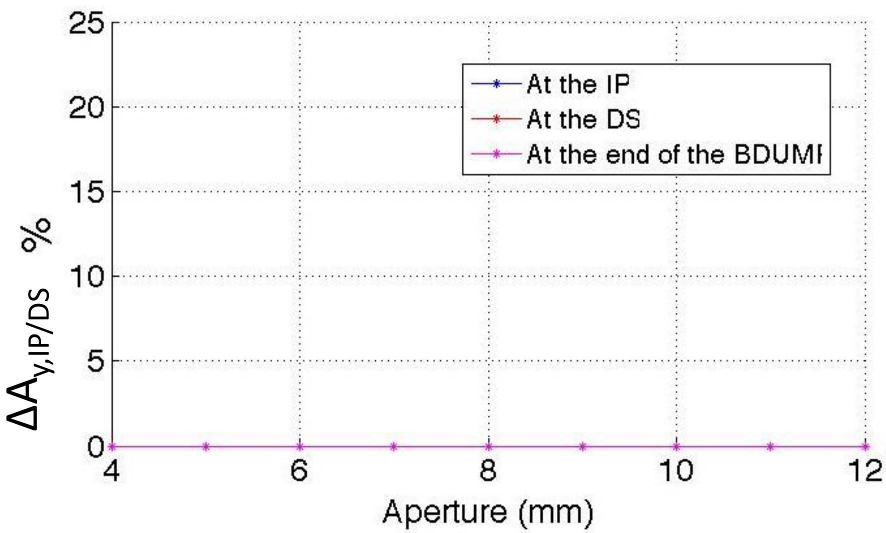
Beam dynamics simulation and realistic tracking studies: Tracking results

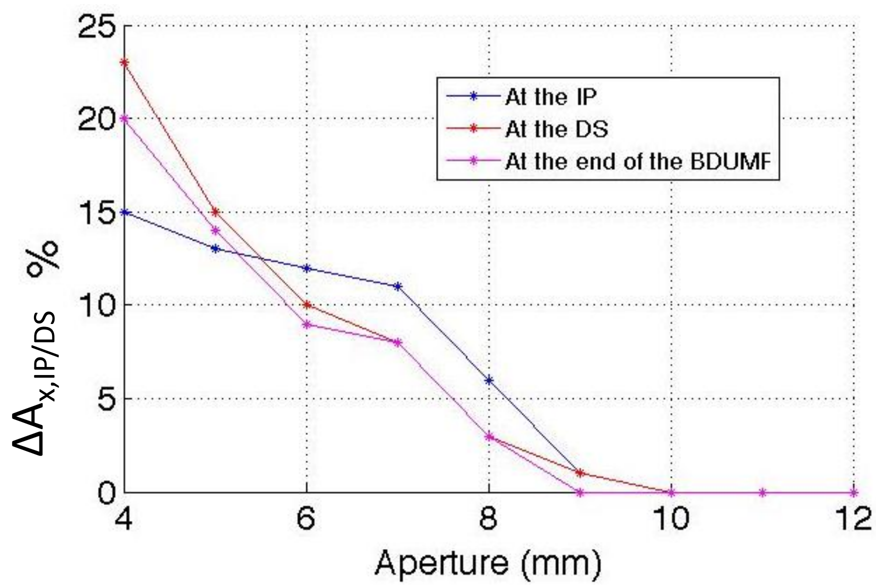
Variation of the **rms horizontal halo amplitude, $\Delta A_{z,IP/DS}$,** for different apertures respect to the current situation in ATF2

$$\Delta A_{z,IP/DS} = \frac{A_{z,IP/DS} - A_{z,coll,IP/DS}}{A_{z,IP/DS}} \qquad z = x, y$$

$A_{z,IP/DS}$ rms horizontal halo amplitude at the IP/DS ⟶ only the round tapered structure

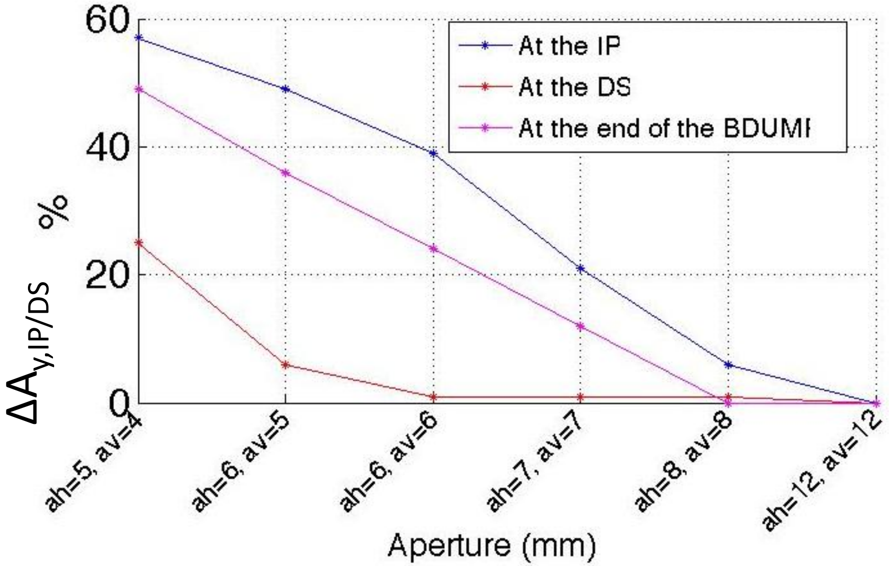
$A_{z,coll.,IP/DS}$ rms horizontal halo amplitude at the IP/DS ⟶ round tapered structure + rectangular horizontal collimator

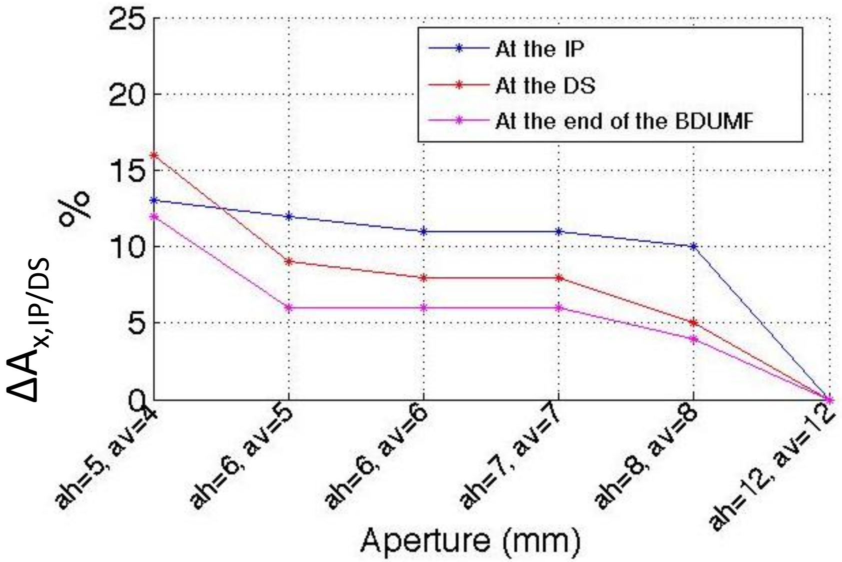




Beam dynamics simulation and realistic tracking studies: Tracking results

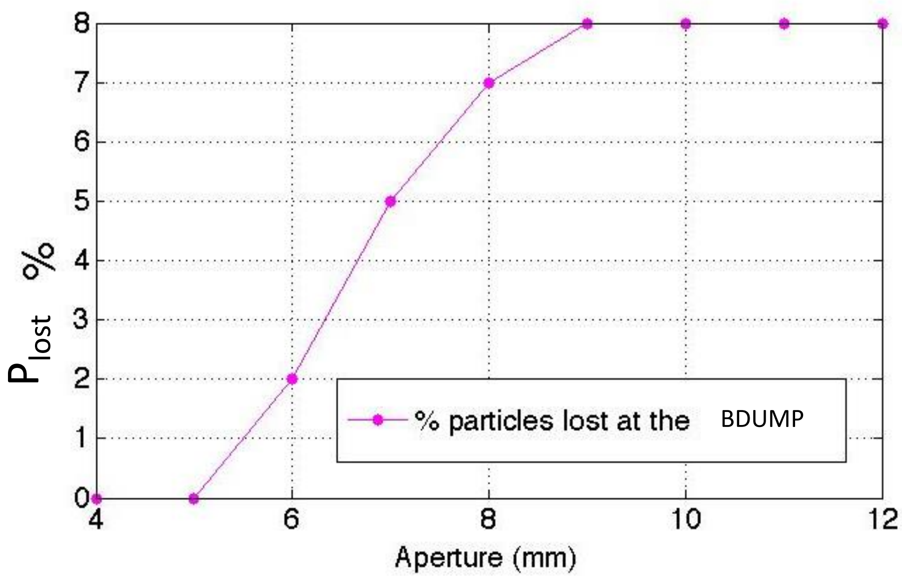
Variation of **rms vertical halo amplitude**, **$\Delta A_{y,IP/DS}$**, **and** the **rms horizontal halo amplitude**, **$\Delta A_{x,IP/DS}$**, for different radius respect to the current situation in ATF2 considering the round tapered structure, the vertical rectangular collimator and the horizontal rectangular collimator



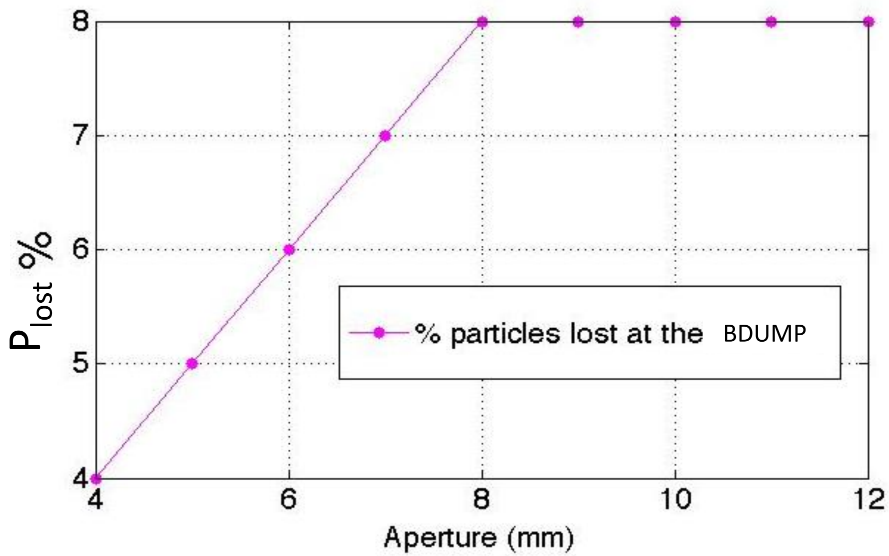


Beam dynamics simulation and realistic tracking studies: Tracking results

Percentage of particles lost at the BDUMP (at the center of the magnet) :



Round tapered structure +
vertical rectangular collimator



Round tapered structure +
horizontal rectangular collimator

$$P_{lost} = \frac{P_b - P_a}{P_b}$$

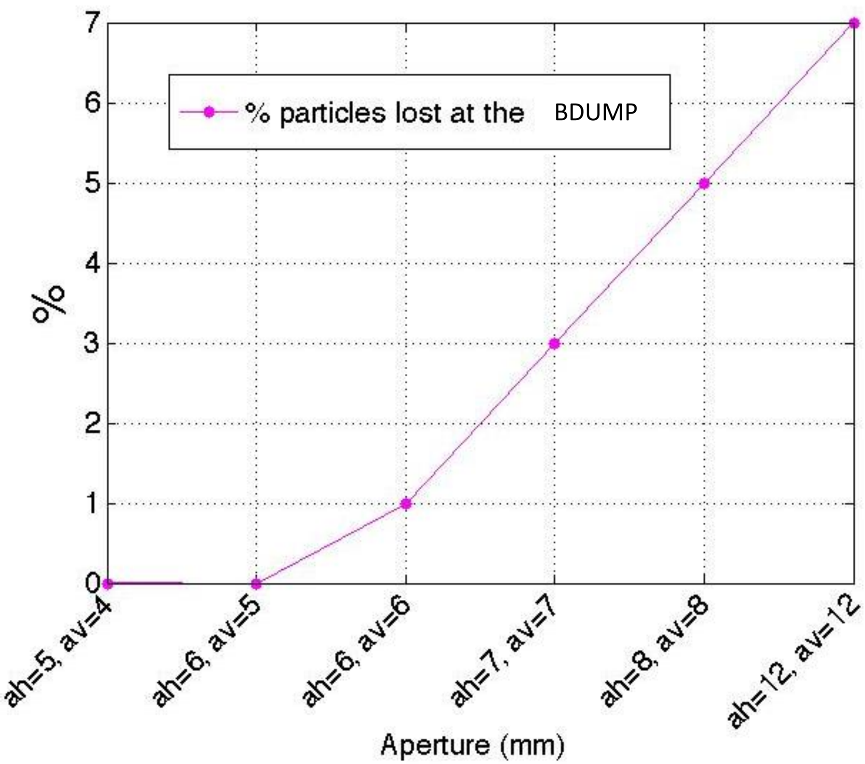
P_b : number of particles at the entrance of the the BDUMP
P_a : number of particles at the end of the BDUMP

Beam dynamics simulation and realistic tracking studies: Tracking results

Percentage of particles lost at the BDUMP (at the center of the magnet) :

Round tapered structure
+ vertical rectangular collimator + horizontal rectangular collimator

$$P_{lost} = \frac{P_b - P_a}{P_b}$$



P_b : number of particles at the entrance of the the BDUMP
P_a : number of particles after the end of the BDUMP

Beam dynamics simulation and realistic tracking studies: Tracking results

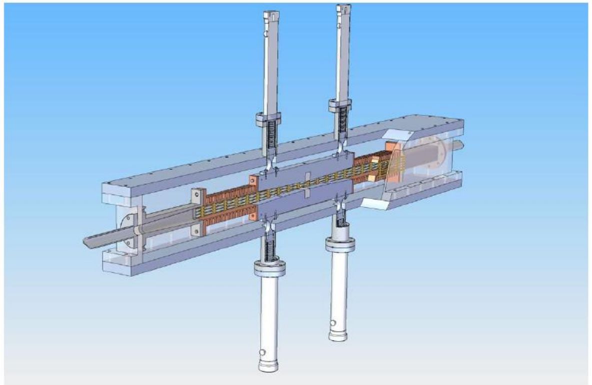
- A vertical halo collimation system based on **one vertical rectangular collimator** with an **aperture of 7 mm** has a reduction on the rms vertical halo amplitude at the **IP about 20%, at the BDUMP about 11% and at the DS about 2%. The reduction on the horizontal halo amplitude** at the **IP about 0%, at the DS about 0% and at the BDUMP about 0%**

- A horizontal halo collimation system based on one **horizontal rectangular collimator** with an **horizontal aperture of 7 mm** has a reduction on the rms horizontal halo amplitude at the **IP about 12%, about 7% at the BDUMP and** about **8% at the DS. The reduction on the vertical halo amplitude** at the **IP about 3%, at the DS about 0% and at the BDUMP about 0%**

- A system based on **two rectangular collimators** (one **vertical** and one **horizontal)** with an aperture of 7 mm both collimators gives a reduction on the rms **vertical halo amplitude** at the **IP about 21%, at the DS about 2% and at the BDUMP about 12%** and the reduction on the **rms horizontal halo amplitude** at the **IP about 12%, at the DS about 8% and at the BDUMP about 7%**

First mechanical design proposals

Rectangular collimator mechanical design examples with two retractable jaws



*"Full structure simulations of **ILC collimators**" J.D. A. Smith, Lancaster University/Cockcroft Institute, Warrington, UK, Proceedings of PAC09, Vancouver, BC, Canada*

*"**Small-Beta Collimation at SuperKEKB** to Stop Beam-Gas Scattered Particles and to avoid Transverse Mode Coupling Instability" Hiroyuki Nakayama (Belle-II/KEK)*

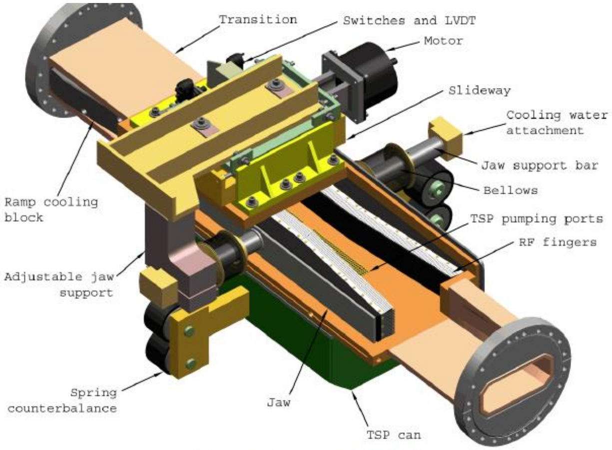
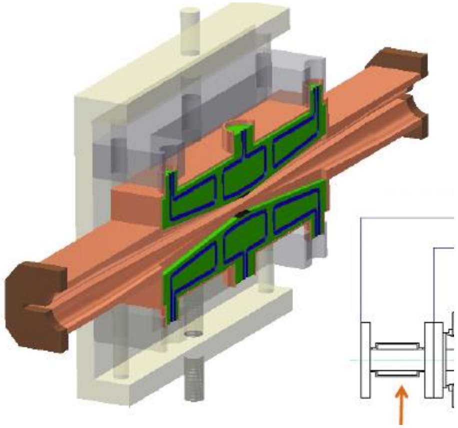


Figure 1: Cutaway view of the HER collimator

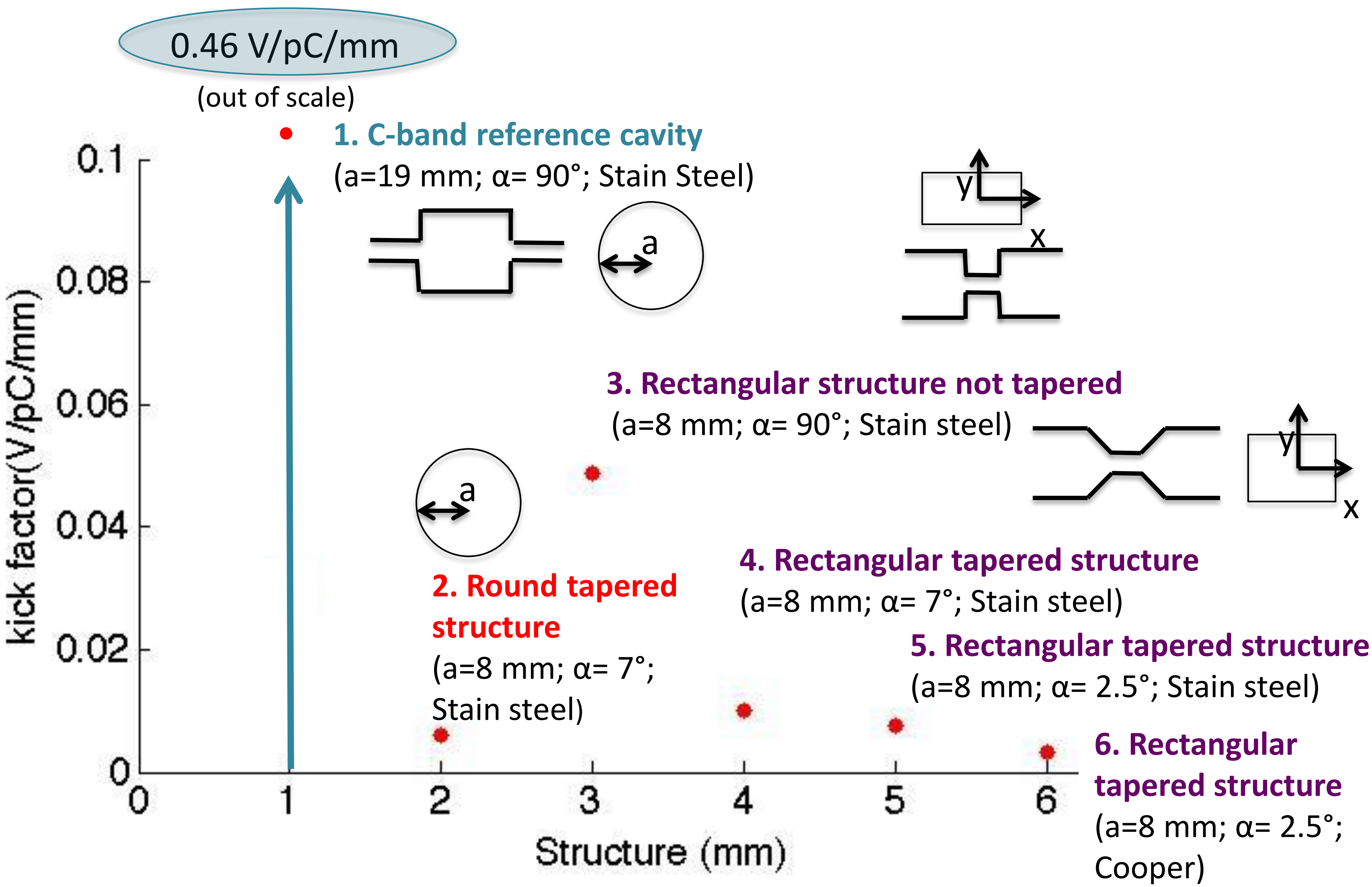


*"The **PEP-II Movable Collimators**", S. DeBarger, S. Metcalfe, et al., SLAC-PUB-11752*

Collimator basic components: two blocks of material which can move independently by using actuators, the cooling system and the side walls

First mechanical design proposals: First analytical wakefield impact

Analytical wakefield kick factor for the different collimator structures of interest:



Summary

- For a halo collimator system based on one **vertical rectangular halo collimator**; **one horizontal rectangular collimator**; **two rectangular collimators (one vertical and one horizontal)** we have evaluated possible locations and the cleaning efficiency at the IP, BDUMP and DS

- **A rectangular vertical collimatior with an aperture of 7 mm** has a reduction on the rms vertical halo amplitude at the **IP about 20%, at the BDUMP about 11% and at the DS about 2% while no effect on the horizontal amplitude.** A horizontal halo collimation system based on one **horizontal rectangular collimator** with an **aperture of 7 mm** has a reduction on the rms horizontal halo amplitude at the **IP about 12%, at the BDUMP about 7% and at the DS** about **8% and a vertical amplitude reduction about 3% at the IP and no effect at the BDUMP and at the DS**

Future work

- Design of a rectangular retractable halo collimation device: mechanical and material study
- Analytical wakefields have been evaluated and wakefield simulations are on going
- Energy collimation system study

Thank you for your attention!

Back up…

Tracking using MAD-X

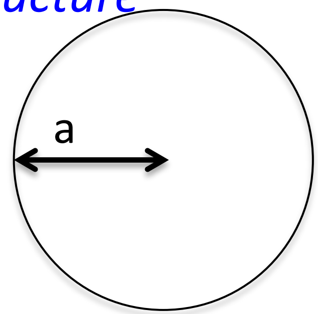
- ATF2 optics v5.0http://atf2flightsim.googlecode.com/svn/trunk/ATF2/FlightSim/latticeFiles/src/
- Files used:
  - common.xsifx -> corrections for difference between effective lengths and core lengths of the ATF2 dipoles, quadrupoles, sextupoles and dipole correctors
  - EXT_aper_v5.0.xsift
  - FF_aper_throu_v5.0.xsift
- No error misalignments have been considered
- Multipoles are considered:
  - Allmults_Ler_quad.madx

Halo collimation betatron depth

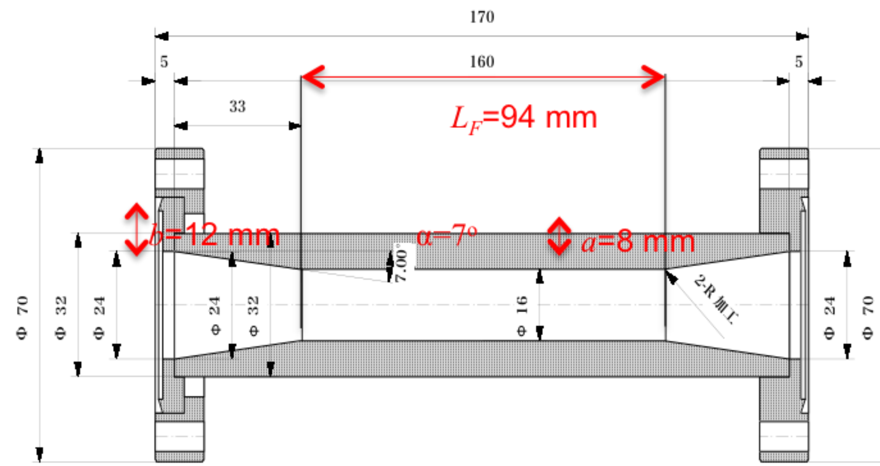
Aperture (mm)	Vertical (σ_y=0.3265)	Horizontal (σ_x=0.5592)
5	$15\sigma_y$	$9\sigma_x$
6	$18\sigma_y$	$11\sigma_x$
7	$21\sigma_y$	$13\sigma_x$
8	$24\sigma_y$	$15\sigma_x$
10	$30\sigma_y$	$18\sigma_x$

Betatron halo collimation: Collimation structures

1) Current Round tapered structure

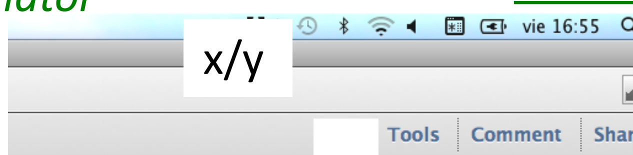


Homogeneous collimation



2)Rectangular collimator

Rectangular collimators in one plane



y/x

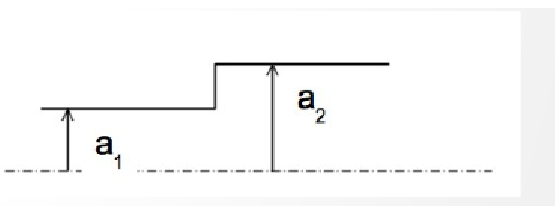
For the trackings studies using MAD-X we consider perfect collimators without length (only the aperture). The tapered structure is important when we estimate the wakefield effect of these structures

Analytical Wakefields formulas

- Analytical formulas from for the **C-band reference cavity**

Geometric kick, κ_g, component :

$$\kappa_g = \frac{Z_0 c}{\pi}\left(\frac{1}{a_{min}} - \frac{1}{a_{max}}\right)$$



Resistive kick, κ_g, component:

Long regime

$$0.63(2a^2/Z_0\sigma)^{\frac{1}{3}} << \sigma_z << 2a^2 Z_0 \sigma$$

$$\kappa_r = \frac{\Gamma(1/4)}{\pi a^2}\sqrt{\frac{2}{\sigma_z \sigma Z_0}}\left[\frac{L_F}{a} + \frac{1}{\alpha}\right]$$

(Ref: “Wakefield Effect at ATF2” S. Boogert, A.Lyapin (29/05/2013))

- rms kick of the centroid of the bunch:

Analytical Wakefields formulas

Round collimator

Geometric kick, κ_g, component :

Inductive regime $\alpha a/\sigma_z > 2\sqrt{\pi}$

(small tapered angles)

$$\kappa_g = \frac{\alpha}{\sqrt{\pi}\sigma_z}\left(\frac{1}{a} - \frac{1}{b}\right)$$

Diffractive regime $\alpha a/\sigma_z < 2\sqrt{\pi}$

(big tapered angles)

$$\kappa_g = \frac{2}{a^2}$$

Resistive kick, κ_g, component:

Long regime $0.63(2a^2/Z_0\sigma)^{\frac{1}{3}} << \sigma_z << 2a^2 Z_0 \sigma$

$$\kappa_r = \frac{\Gamma(1/4)}{\pi a^2}\sqrt{\frac{2}{\sigma_z \sigma Z_0}}\left[\frac{L_F}{a} + \frac{1}{\alpha}\right]$$

Rectangular collimator

Inductive regime $\sqrt{\alpha a/\sigma_z} < 6.2a/h$

(small tapered angles)

$$\kappa_g = \frac{\alpha\sqrt{\pi}h}{4\sigma_z}\left(\frac{1}{a^2} - \frac{1}{b^2}\right)$$

Intermediate regime $0.37 > \sqrt{\alpha a/\sigma_z} > 6.2a/h$

$$\kappa_g = \frac{8}{3}\sqrt{\frac{\alpha}{\sigma_z a^3}}$$

Diffractive regime $\sqrt{\alpha a/\sigma_z} > 0.37$

(big tapered angles)

$$\kappa_g = \frac{1}{a^2}$$

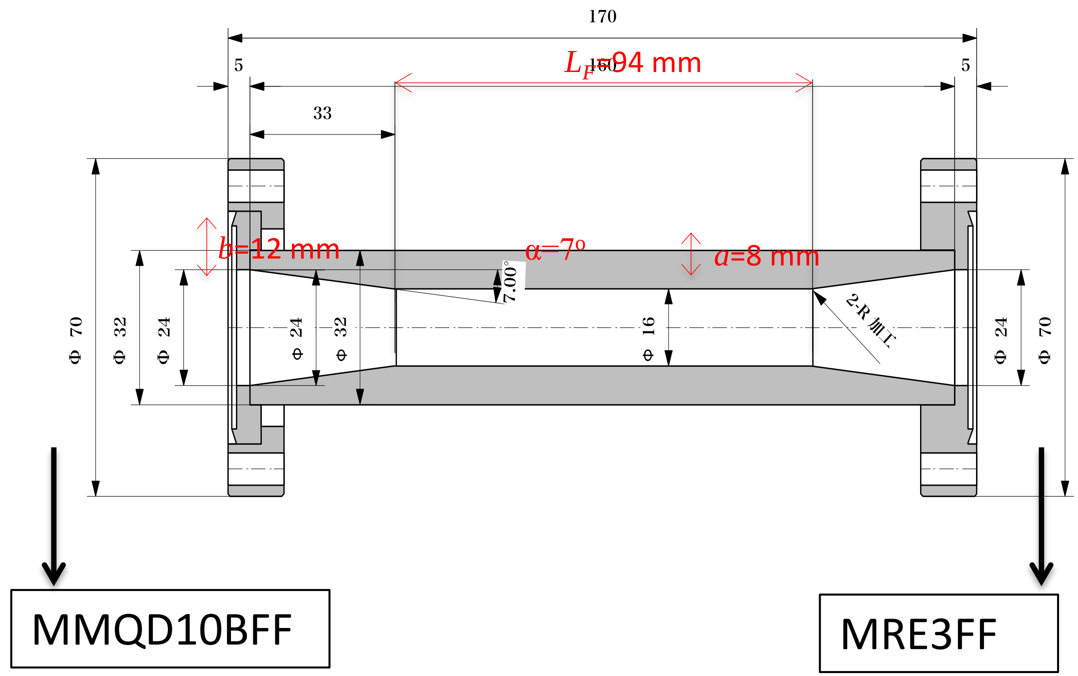
$$\kappa_r = \frac{\Gamma(1/4)\pi}{8a^2}\sqrt{\frac{2}{\sigma_z \sigma Z_0}}\left[\frac{L_F}{a} + \frac{1}{\alpha}\right]$$

Because of the ATF2 σ_z = 5 mm and the geometrical parameters of the collimators we are considering the regimes of interest are the inductive for the geometrical one and the long regime for the resistive component

[G.V. Stupakov, "High-frequency impedance of small angle collimators", PAC01] [A. Piwinski, DESY-HERA-92-04, 1992]

Calculation parameters for the round tapered structure at ATF2

- b=12 mm
- a=8 mm
- Z=376.7 Ohms
- c=3 10^8 m/s
- α=0.122 rad
- σ_z=7 mm (bunch length)
- Lf=94 mm
- N=10^{10}
- r_e=2.8179*10^{-12} mm
- γ=2544;
- β_y=7378 m
- ε_g=1.18 10^{11} m rad
- σ(Stain steel) = 1.45 10^3 S/mm



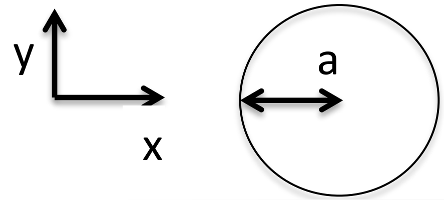
Calculation parameters for the rectangular tapered structure at ATF2

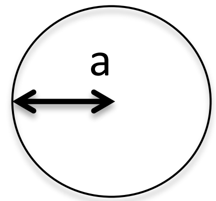
- b=12 mm
- a=8 mm (variable)
- Z=376.7 Ohms
- c=3 10^8 m/s
- α=0.122 rad (tapered angle variable)
- σ_z=7 mm (bunch length)
- Lf=94 mm
- N=10^{10}
- r_e=2.8179*10^{-12} mm
- γ=2544;
- β_y=7378 m
- ε_g=1.18 10^{11} m rad
- h=24 mm (when consider a rec. coll.)
- σ(Stain steel) = 1.45 10^3 S/mm
- σ(Cooper) = 5.81 10^3 S/mm

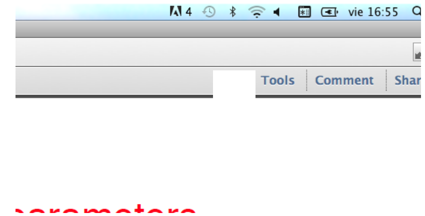
Wakefield study

A first approach has been done using analytical formulas:

C-band reference cavity

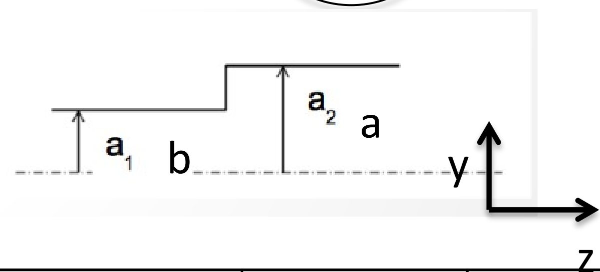


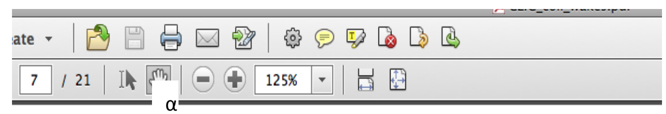




Round tapered structure

Rectangular tapered structure





	C-band reference cavity (a=19 mm; α= 90°; Stain Steel)	Round tapered structure (a=8 mm; α= 7°; Stain steel)	Rectangular structure (a=8 mm; α= 90°; Stain steel)	Rectangular tapered structure (a=8 mm; α= 7°; Stain steel)	Rectangular tapered structure (a=8 mm; α= 2.5°; Stain steel)	Rectangular tapered structure (a=8 mm; α= 2.5°; Cooper)
Analytical kick (V/pC/mm)	0.4600	0.0060	0.0489	0.0101	0.0076	0.0034