Transverse beam halo collimation and collimator wakefield studies at ATF2

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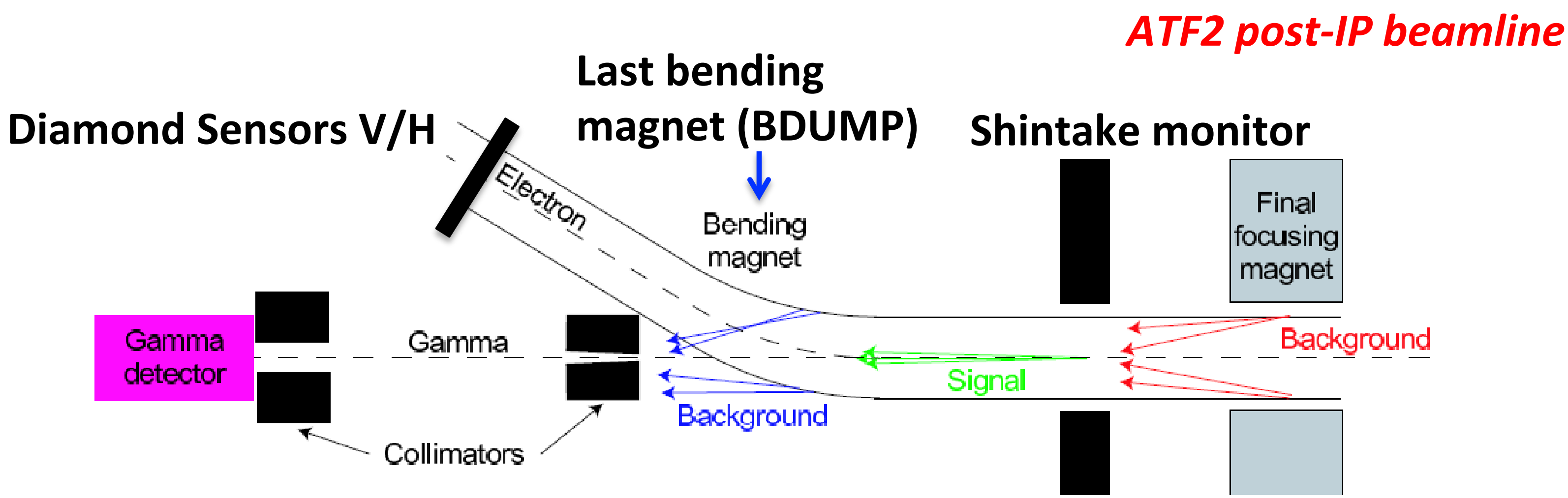
Outline

- Introduction and objectives
- Optic consideration studies and location optimization
- Beam dynamic simulations and realistic tracking studies
  - MADX
  - BDSIM
- Wakefield design considerations and impact study
- Installation and experimental program
- Implications of the collimator wakefield studies for ILC

Introduction and objectives



Beam halo and background investigation is an important issue for beam loss and background control in ATF2 and Future Linear Colliders (FLC)

Beam halo collimation has been studied in ATF2 with the main objectives of:

- ***Beam halo control and study*** in the vertical and horizontal plane
- ***Beam halo reduction*** to reduce the bremsstrahlung background that could be created at the **last bending magnet (BDUMP)**
- ***Beam halo reduction, especially in the horizontal plane*****,** to enable Compton electron measurements at the **horizontal DS**

Introduction and objectives

Objectives and status of the project

1. **Beam dynamics simulation and realistic tracking studies** to evaluate the efficiency of betatron and energy collimation in ATF2 (IFIC-LAL-KEK)
   - The **transverse collimation** is more efficient to achieve the ATF2 collimation objectives
     - A **single vertical collimation system** has been considered to be the **first priority** because it allows to reduce the losses in the BDUMP
     - In a second stage based a **single horizontal collimation system** could be also considered to enable the Compton electrons in the horizontal DS

2. **Design of a <u>vertical retractable halo collimation</u> device**: mechanical and material study (IFIC-LAL)

3. **Construction and calibration** of a vertical halo collimation device (IFIC-LAL)

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

5. **Installation and commissioning** in ATF2 planned for February 2016 (IFIC-KEK-LAL)

6. **Halo control (DS), efficiency studies and collimator wakefield measurements** (IFIC-KEK-LAL)

Optics considerations studies and location optimization

The choice of the best location for a collimation system is a tradeoff between the the optics, the collimation depth required and the wakefield impact induced

For a given collimator aperture***, a$_{x,y}$***, the **betatron collimation depth*, N$_{x,y}$***, is defined:

$$N_{x,y} = \frac{a_{x,y}}{\sigma_{x,y}} = \frac{a_{x,y}}{\sqrt{\epsilon_{x,y}\beta_{x,y} + (D_{x,y}\delta_E)^2}} \propto \frac{a_{x,y}}{\sqrt{\beta_{x,y}}}$$

The wakefield beam impact of a <u>rectangular collimation system</u>:

Amplification factor $$A_{\beta_{x,y}} \propto \frac{N_b}{\gamma}\beta_{x,y}\kappa_T \propto \frac{N_b}{\gamma}\frac{\beta_{x,y}}{a_{x,y}^2}$$

Where κ_T depends on the geometry and material of the collimator $\kappa_T \propto \frac{1}{a_{x,y}^2}$

(*Collimator Wakefield Calculations for ILC-TDR Report, P. Tenenbaum, LCC-0101, August 2002*)

Optics considerations for a single rectangular betatron collimation jaw:

- High $\beta_{x,y}$ for a given *N* with bigger *a*
- $\Delta\mu_{x,y}=n\pi$ in phase with the collimation point (BDUMP and DS)
- $D_{x,y} \cong 0$ for a pure betatron collimation

Optics considerations studies and location optimization

Vertical collimator:

Between **QD10BFF-QM11FF (FF)**

- β_y= 7126.51 m
- $\Delta\mu_y$=3π BDUMP and DS
- 0.8 m available free space length

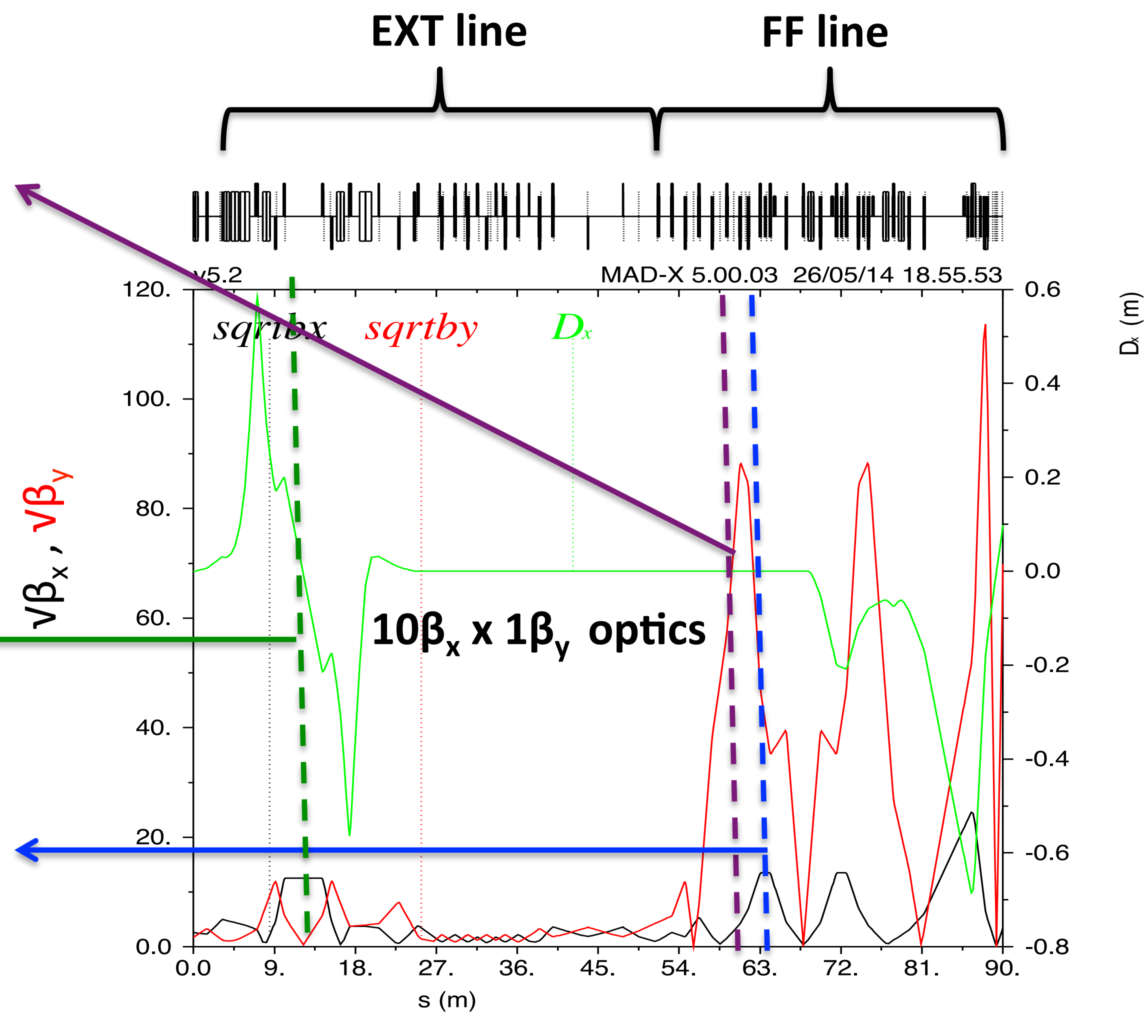
Horizontal collimator:

Pos1: **QD4FX-QD3FX (EXT line)**

- β_x=157.02 m
- $\Delta\mu_x$=10π BDUMP and DS
- 2 m free space length

Pos2: **QD10AFF-QF9BFF (FF)**

- β_x=135 m
- $\Delta\mu_x$=3π BDUMP and DS
- 0.7 m free space length



Pos2 is better candidate than **Pos1** because the location is after coupling correction section and $D_x \cong 0$

Beam dynamics simulation and realistic tracking studies: MADX

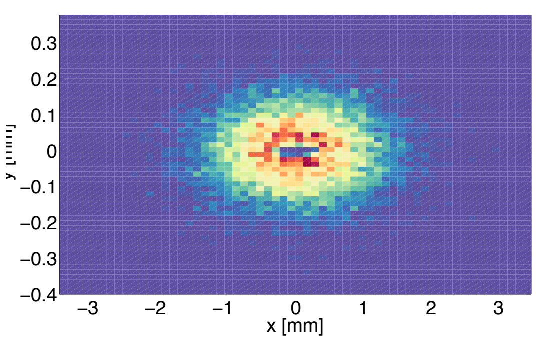
GOAL: To find the most **efficient collimation depth** in terms of **halo cleaning:**

- At the **last bending magnet (BDUMP)**: **reduce losses**
- **At the horizontal DS**: **cut the horizontal beam halo to the level of $10\sigma_x$**
  S.Liu, phd thesis "Development of Diamond Sensors for Beam Halo and Compton Spectrum Diagnostics after the Interaction Point of ATF2",LAL,08-2015

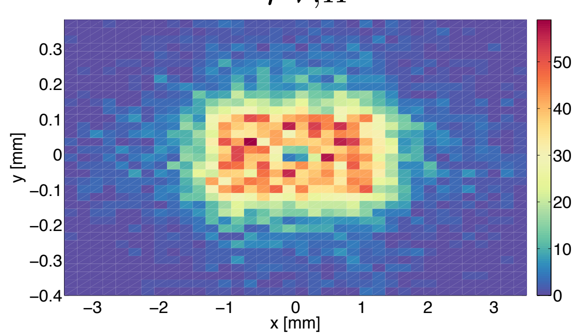
Tracking beam and halo input simulation parameters*:* loss map studies

- Horizontal and vertical beam halo models for x, y: Gaussian, Realistic and Uniform
- Number of particles: 10^4
- *E=1.3 GeV / σ_E: 0.08%*
- $\varepsilon_x = 2\ 10^{-9}$ *m.rad* / $\varepsilon_y = 1.18\ 10^{-11}$ *m.rad*
- Optics (10x1,1x1) ,Multipoles, No misalignments, No coupling between x-y planes

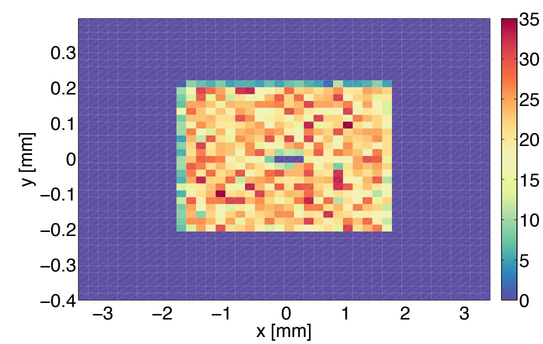
Gaussian



Realistic $\rho_{V,H} = AX^{-3.5}$



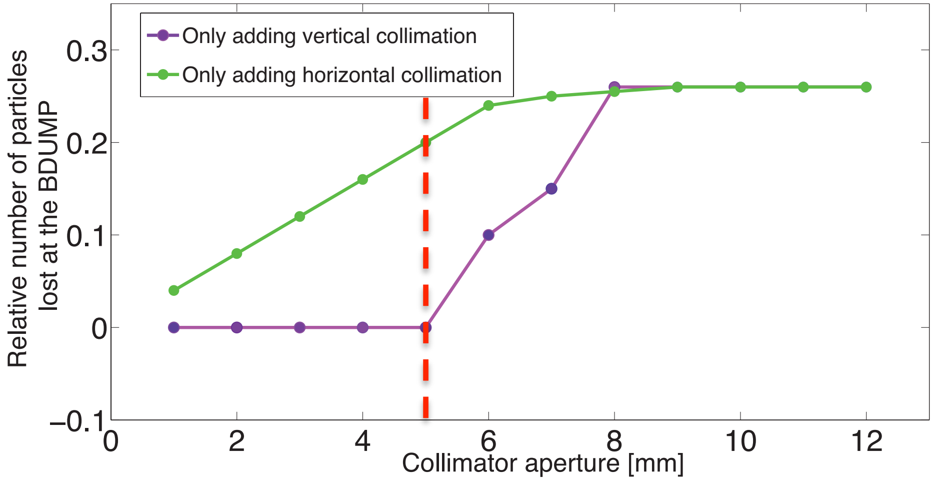
Uniform



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

Beam dynamics simulation and realistic tracking studies: MADX

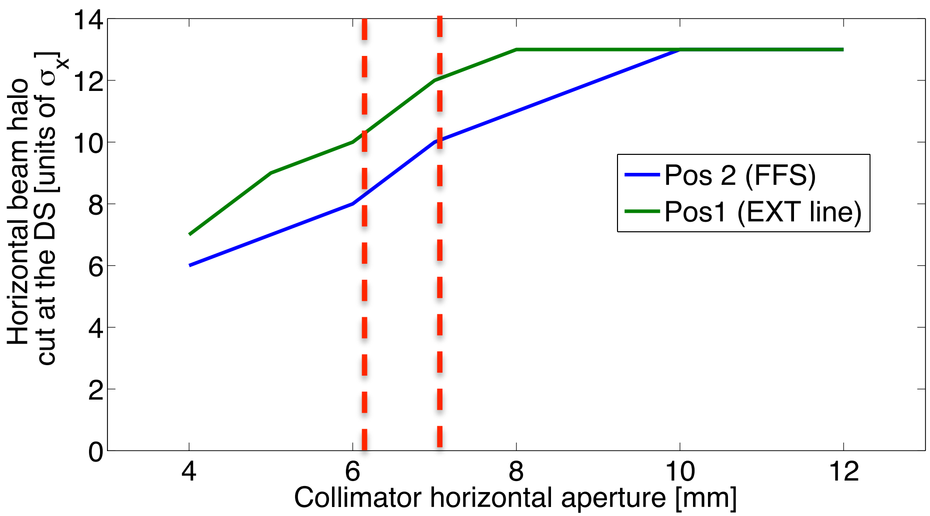
First collimation target: reduce the losses at the BDUMP



Only a **vertical collimation** system with **aV=5 mm** is required to avoid losses at the last bending magnet (BDUMP)

(Realistic halo model)

Second collimation target: cut the horizontal beam halo at the level of $10\sigma_x$ at H-DS



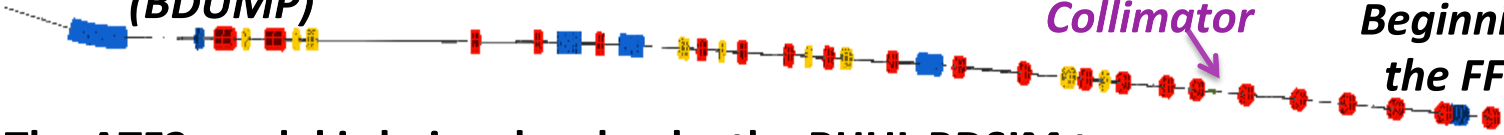
A **horizontal collimation** system with an aperture of **aH=6-7 mm** is required

(Realistic halo model)

Same conclusion for all the beam halo models

Beam dynamics simulation and realistic tracking studies: BDSIM

- **More accurate efficiency studies** including the generation of secondary particles



- **The ATF2 model is being develop by the RHUL BDSIM team**

	MADX		BDSIM	
	σ^*_x [μm]	σ^*_y [nm]	σ^*_x [μm]	σ^*_y [nm]
Sextupoles ON	9	37	9	227
Sextupoles OFF	10	647	10	650

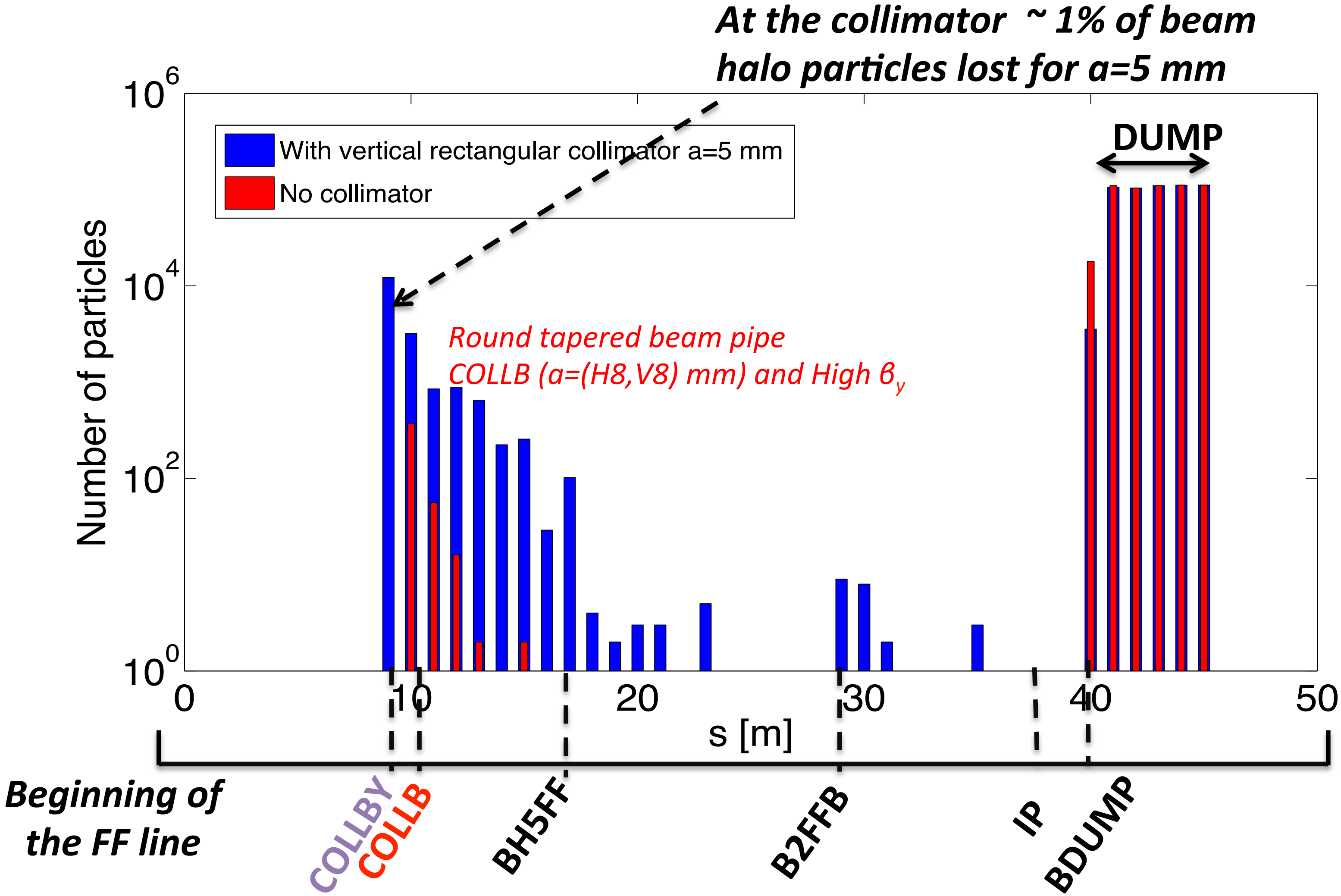
* The origin of this discrepancy is under investigation

Tracking beam and halo studies: work in progress

- Tracking from L200: **only the FFS** is being tracked
- **Only vertical collimator system** is being studied
- **Sextupoles OFF**
- **Number of particles**: 10^6
- Same optics used in MADX tracking simulations and a **Gaussian beam halo model**

Beam dynamics simulation and realistic tracking studies: BDSIM

Vertical collimation system efficiency study: **Primaries lost**
(10^6 particles and 10x1 optics)



Beam dynamics simulation and realistic tracking studies: BDSIM

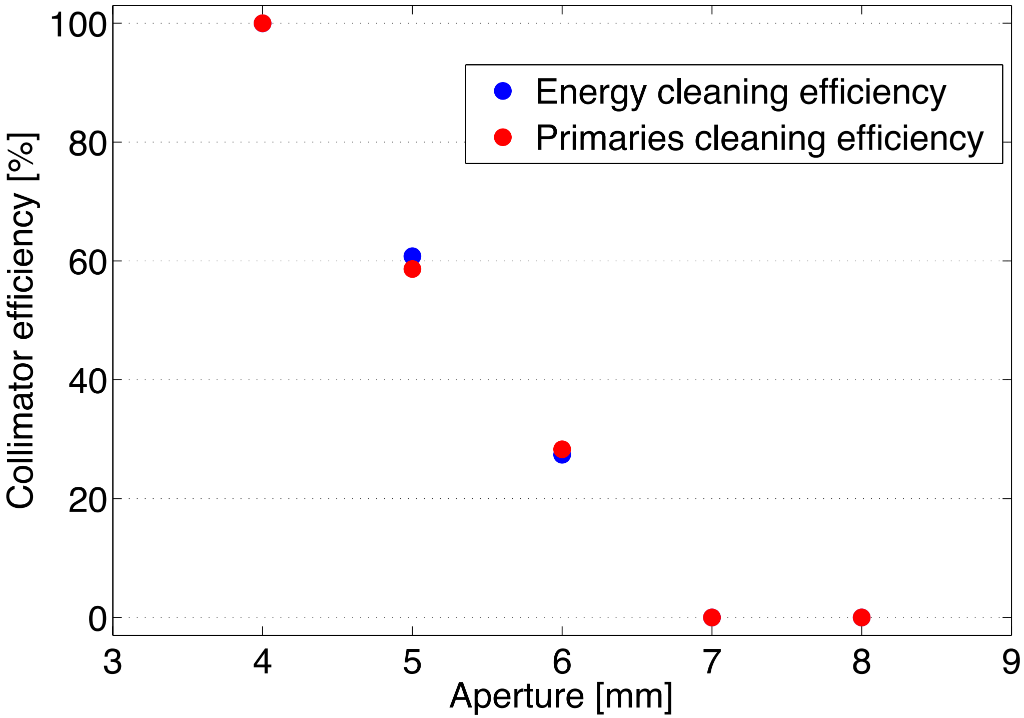
Vertical collimation system efficiency study summary (10^6 particles and 10x1 optics)

Energy cleaning efficiency at the BDUMP

$$ECE = 100 \times \left[1 - \frac{E^{BDUMP}_{with\ collimator}}{E^{BDUMP}_{no\ collimator}}\right]$$

Primaries cleaning efficiency at the BDUMP

$$PCE = 100 \times \left[1 - \frac{P^{BDUMP}_{with\ collimator}}{P^{BDUMP}_{no\ collimator}}\right]$$



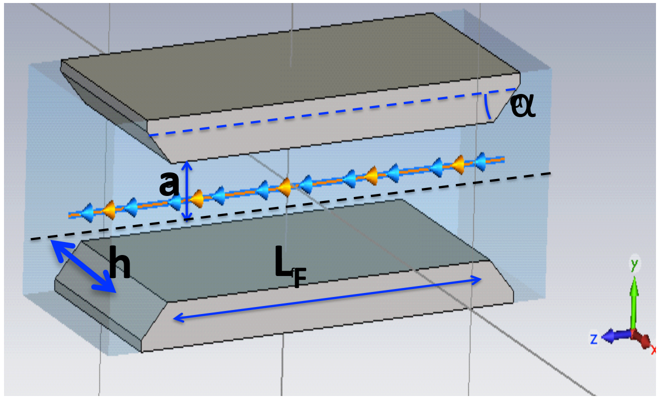
From these preliminary simulations with BDSIM the the efficiency of the vertical collimation system with a half aperture of 5 mm is about 60% (**without sextupoles**)

Future work:

- Sextupoles ON
- Simulations with realistic beam halo model
- Quantify the efficiency at the DS and IPBSM is terms of photons

Wakefield design considerations and impact study

The **vertical prototype** has been considered as the first priority



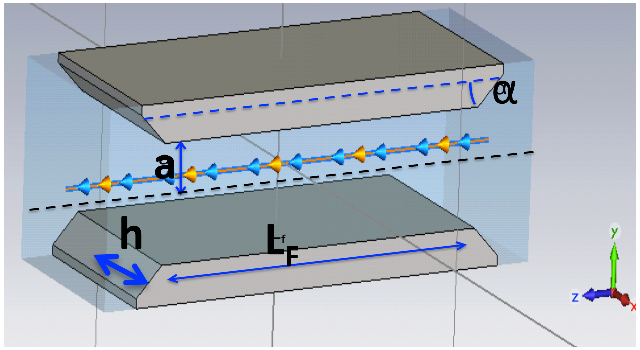
- Wakefield **collimator jaws** optimization
  - **Analytical** (Based on **Stupakov model 2002**)
  - **Numerical simulations** using **CST PS**

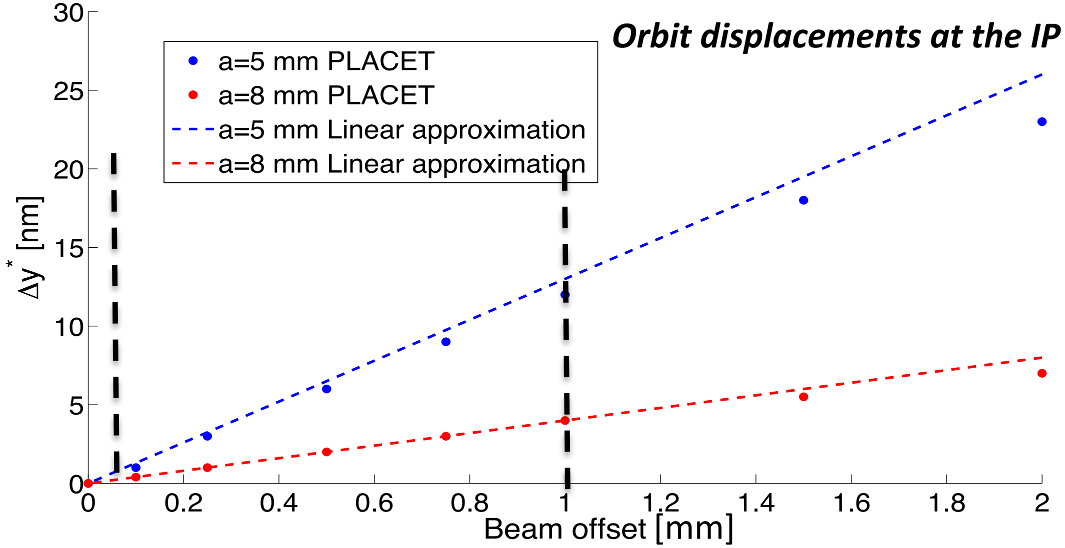
- Wakefields **beam impact induced (orbit distortion and beam size growth)**
  - **Linear approximation**
  - **PLACET tracking code**
    - *A discrepancy was found between the linear approximation and the tracking code PLACET*
    - *The problem was in how the limits of the models where implemented and the modification will be implements in the PLACET version 1.0.2*

- Wakefield impact study of the **realistic 3D collimator** mechanical design
  - **Numerical simulations** using **CST PS**

Wakefield design considerations and impact study

CST PS simulation-> Optimized jaws (mask): **L_f**=100 mm; **α**=3°; **a**=12-3 mm; **h**=12 mm; **L_T**=238 mm; Cu

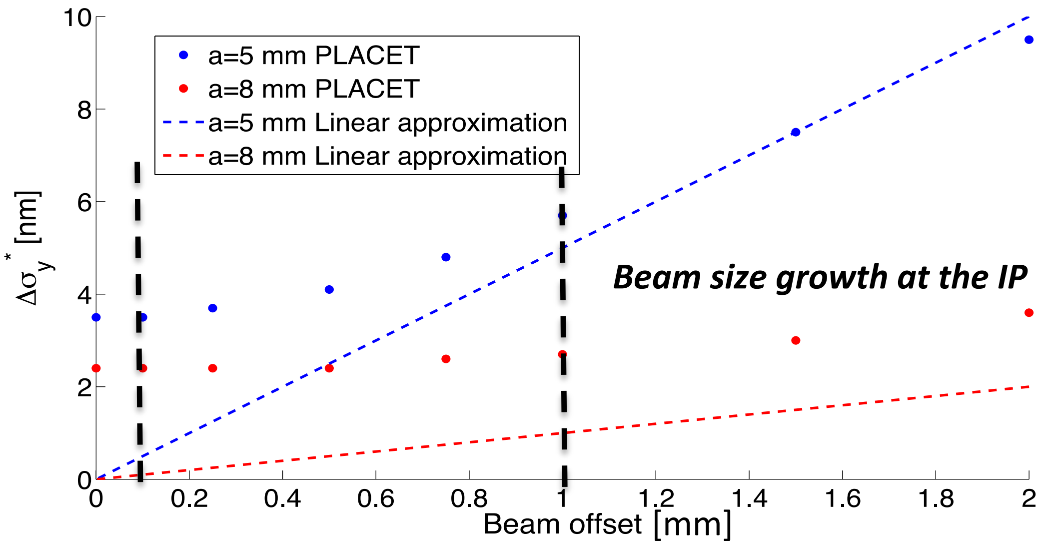




PLACET tracking code

- $N=6x10^9e$
- σ_z= 7 mm
- ***10x1 optics***

aV=5 mm		
y_{offset} [mm]	1	0.1
Δy * [nm]	12	2
$\Delta\sigma_y$ * [nm]	6	3.5

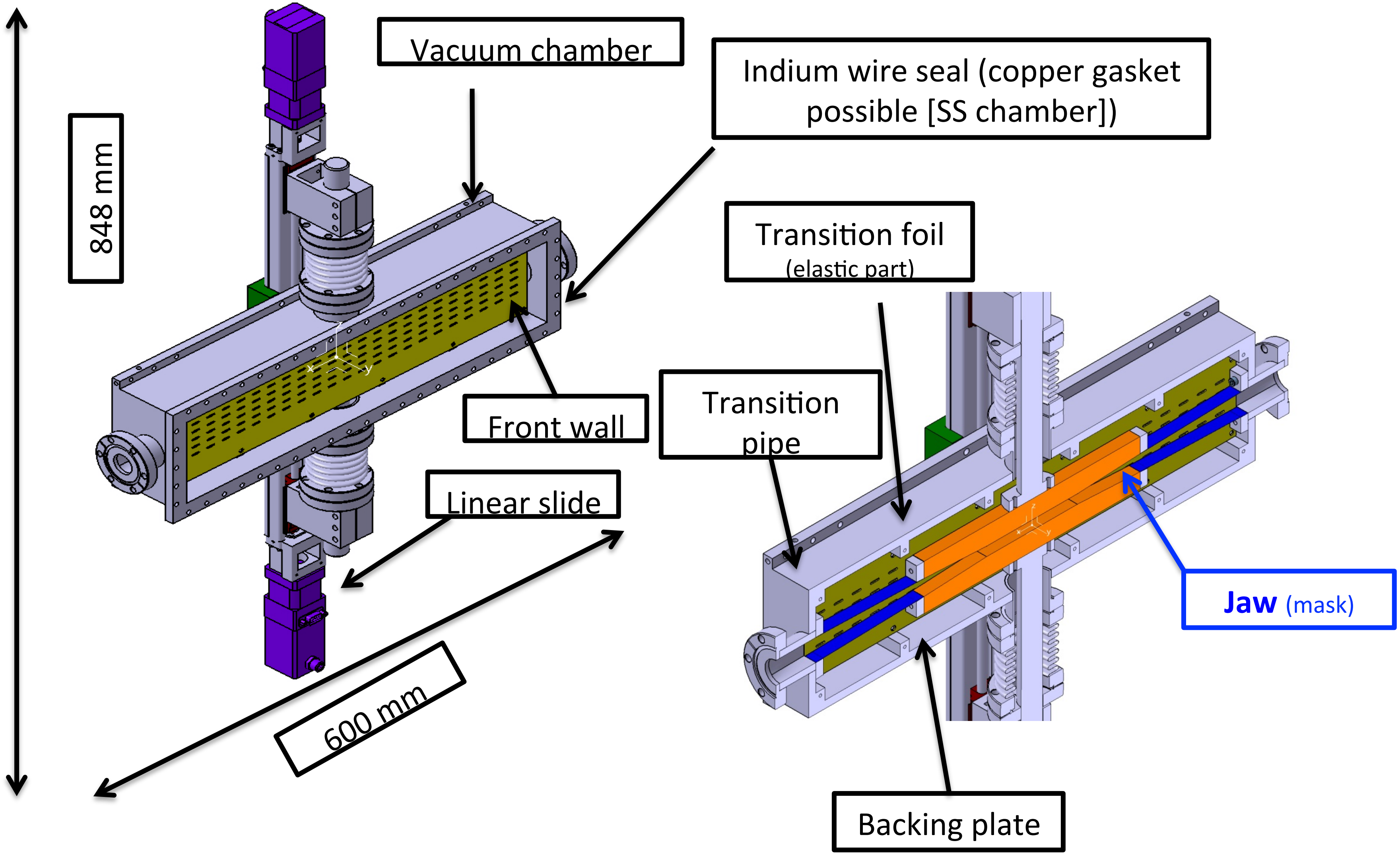


Good alignment is required

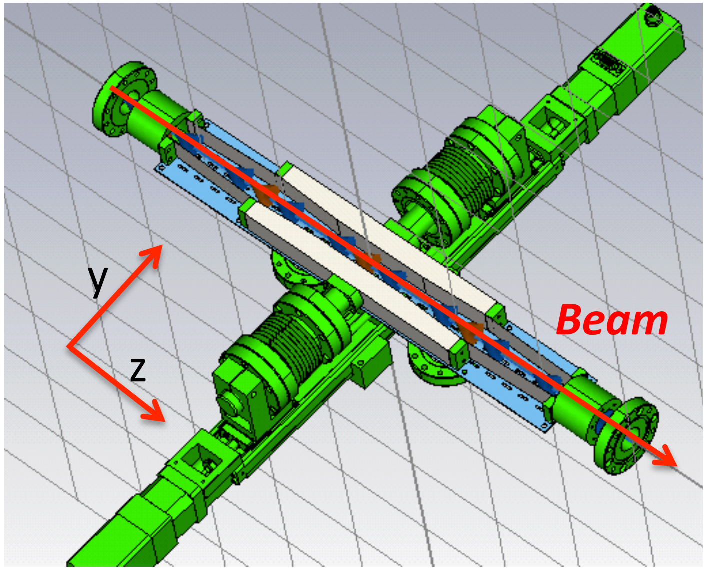
Wakefield design considerations and impact study

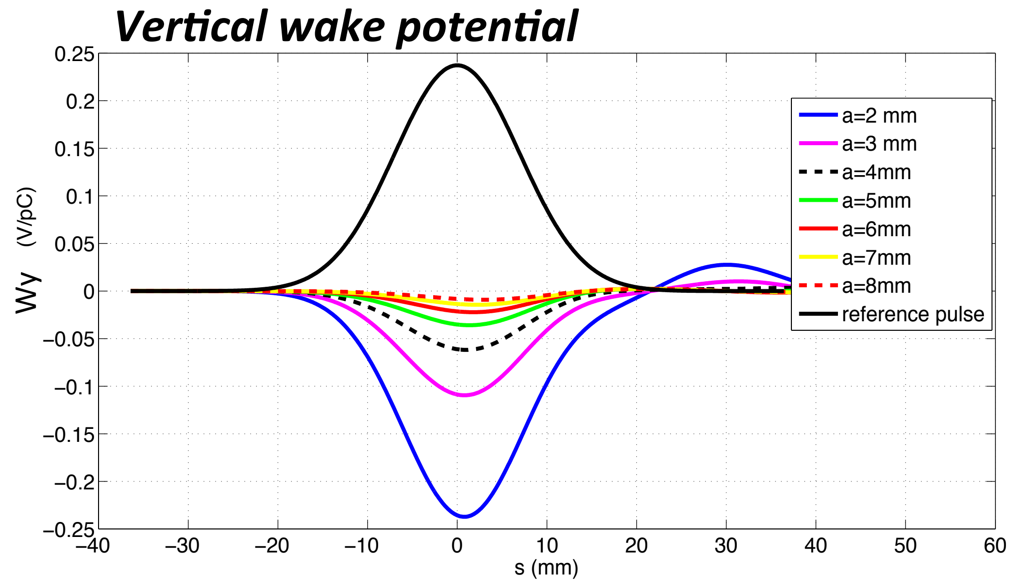
Based on preliminary design for the ILC collimators
*Full structure simulations of **ILC collimators**" J.D. A. Smith, Lancaster University/Cockcroft Institute, Warrington, UK, Proceedings of PAC09*

Material from S. Wallon (LAL)



Wakefield design considerations and impact study

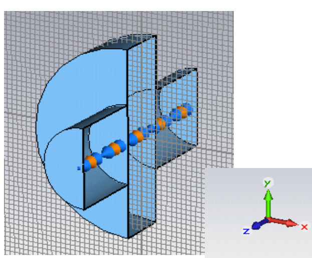


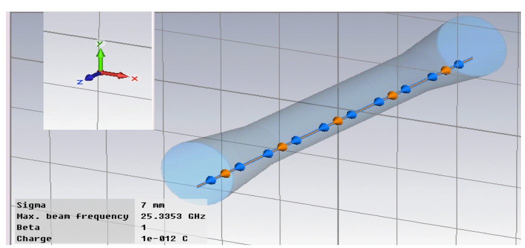


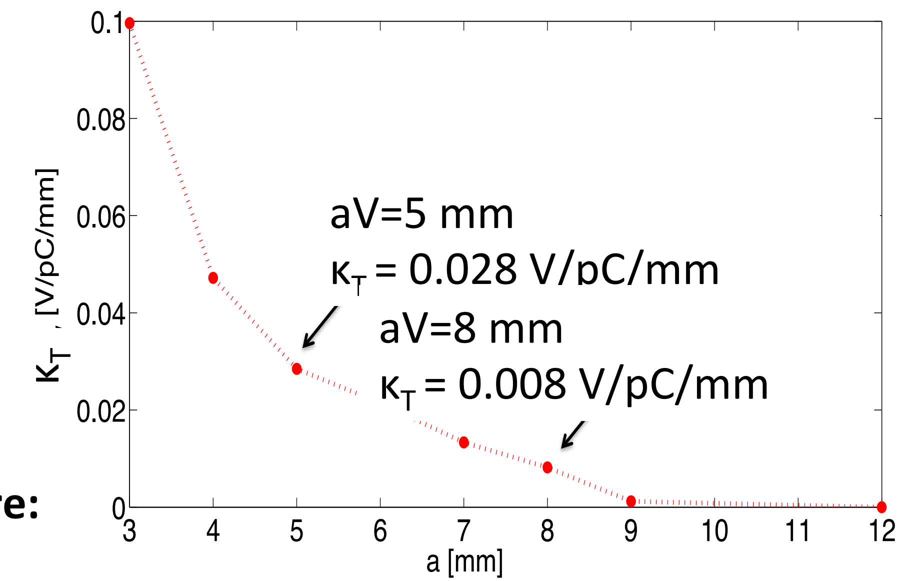
Beam: σ_z=7 mm , **N**=10^6 , 1mm vertical offset

Jaws made of Cu and rest made of SS

Jaws parameters : Lf: 100 mm, **α**: 3°





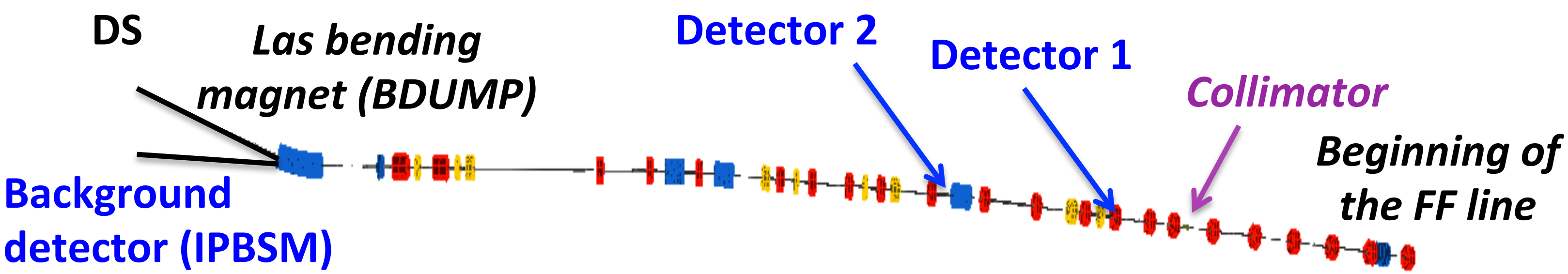


Reference cavity:
κ_T = 0.079 V/pC/mm

Round tapered structure:
κ_T = 0.006 V/pC/mm

Installation and experimental program

- ✓ **Installation** is planned for February 2016 (tentative schedule 8-12 of February)
- ✓ **Software control design** and integration on the ATF2 control room
- ✓ **Control tests and calibration** by using the BPMs and the Diamond Sensor (DS)
- ✓ **Experimental studies**
  - **Efficiency study** my means of **background measurements** using:
    - the **IPBSM background detector (IPBSM)**
    - **two other detectors** installed by RHUL team for background studies



- **Collimator wakefield measurements by** orbit variation measurements for different collimator positions with the **BPMs**

Implications of the collimator wakefield studies for ILC

- The **ILC betatron collimation system** requires small apertures in order to clean the halo efficiently and the wakefields induced have to be carefully studied
- **A first estimation of the impact of the complete ILC collimation system** based on analytical models was made P. Tenenbaum

Amplification factor $$A_\beta \propto \frac{N_e}{\gamma}\beta\kappa_T$$

Total Amplification factor $$A_{\beta,total} = \sum_i A_{\beta,i}|\sin 2\pi\nu_i|$$

- The **vertical collimation system prototype for ATF2** is based on a first mechanical **design for ILC and the geometry and materials are similar to some of the ILC betatron collimators**
- The wakefield impact measured at ATF2 can be normalized to the **energy**, **number of particles** and **bunch length** and scaled to the **ILC scenario**
- Based on these measurements we can estimate the accuracy of the **analytical collimator wakefield impact** calculations made for the ILC collimators which have a similar geometry and materials as the ATF2 prototype

Summary

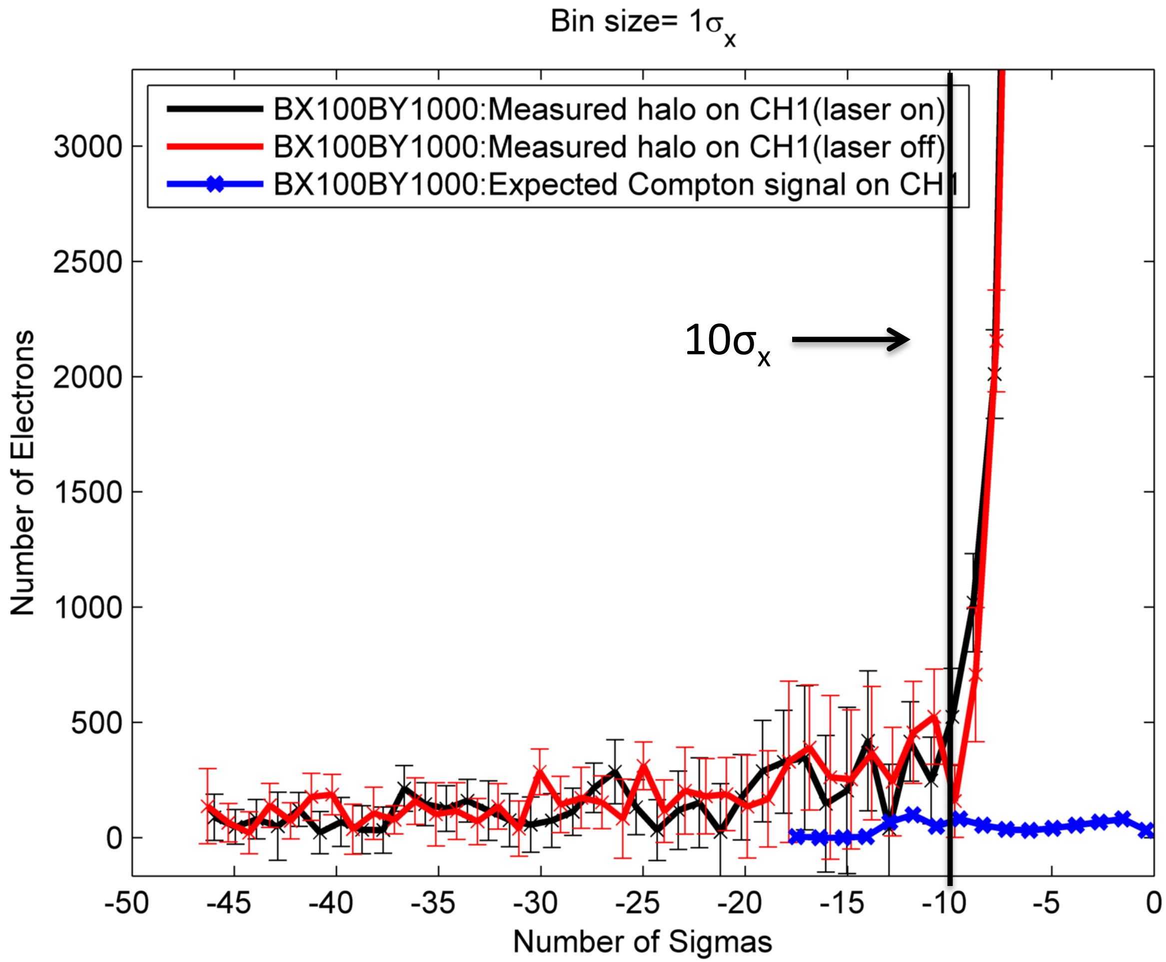
- **The feasibility and efficiency of a transverse tapered collimation** system has been completed using **MADX** and simulations using **BDSIM** are in progress
- **The vertical prototype has been considered the first priority** because can reduce the background in the BDUMP improving the performance the IPBSM and DS
- **A collimation wakefield study has been done** in order to optimize the jaws of the collimation system and estimate the beam dynamic impact of this system in ATF2. The wakefield impact is below 10% of vertical beam size for aV=5 mm and below 5% for aV=8 mm for alignment at the order of 1 μm
- The **mechanical design of a vertical prototype** has being completed, it is being **constructed at LAL and planned** to be **installed in ATF2** in **February 2016**
- The scaling of the measurements of the wakefield impact of the ATF2 collimation system to the ILC scenario is being investigated. These measurements will be crucial to estimate the **accuracy of the collimator wakefield impact calculations** made with analytical models for some of the the ILC collimators with similar geometries and materials

Thank you very much for your attention!

Back up…

Motivation

December 2014 run: horizontal beam halo measurements

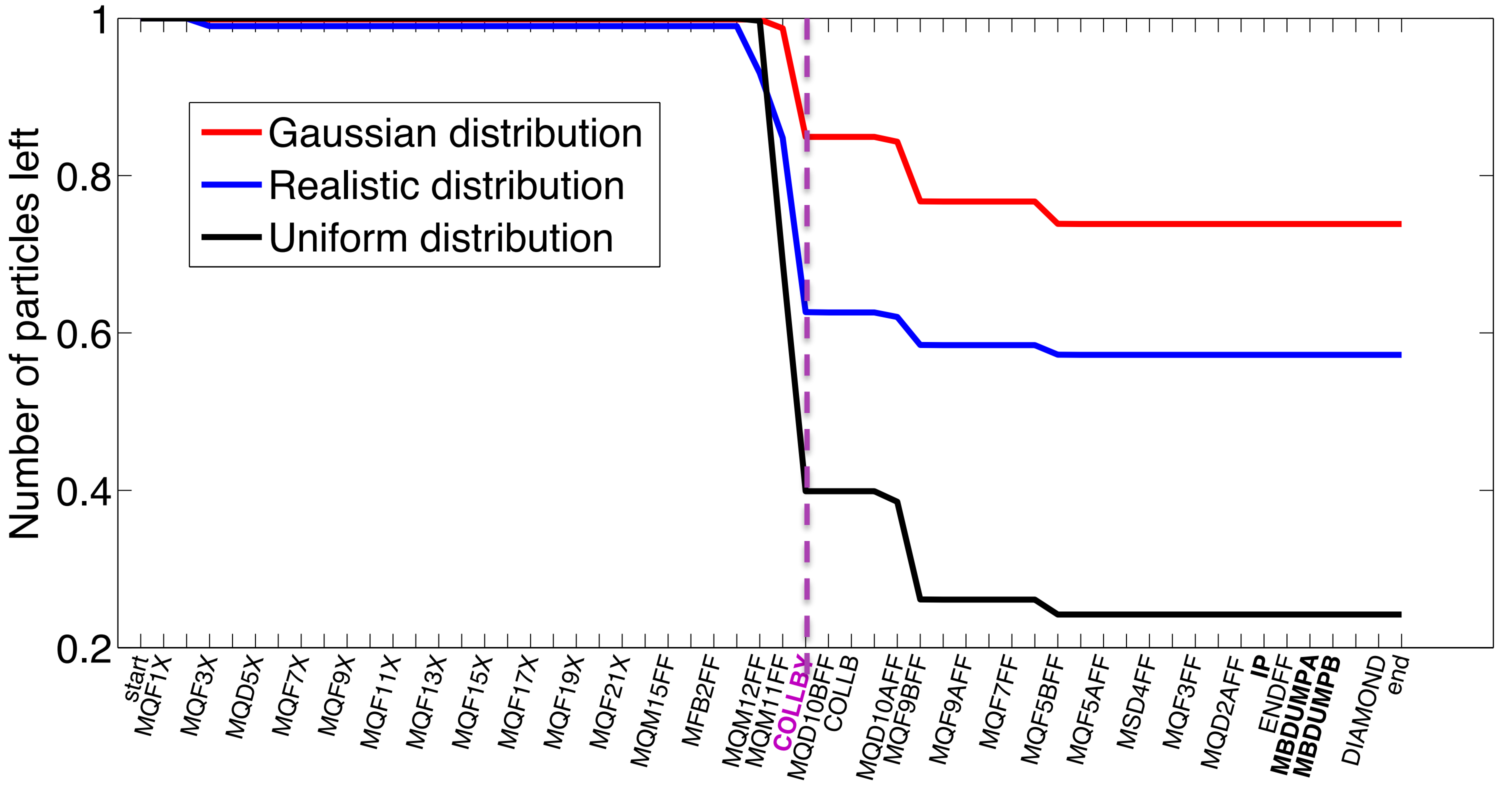


S.Liu, phd thesis "Development of Diamond Sensors for Beam Halo and Compton Spectrum Diagnostics after the Interaction Point of ATF2",LAL,08-2015

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	$30\sigma_y$	$18\sigma_x$
12	$37\sigma_y$	$21\sigma_x$
15	$46\sigma_y$	$27\sigma_x$

Loss map beam halo models comparison adding a vertical collimation system with a=(12H,5V) [mm]

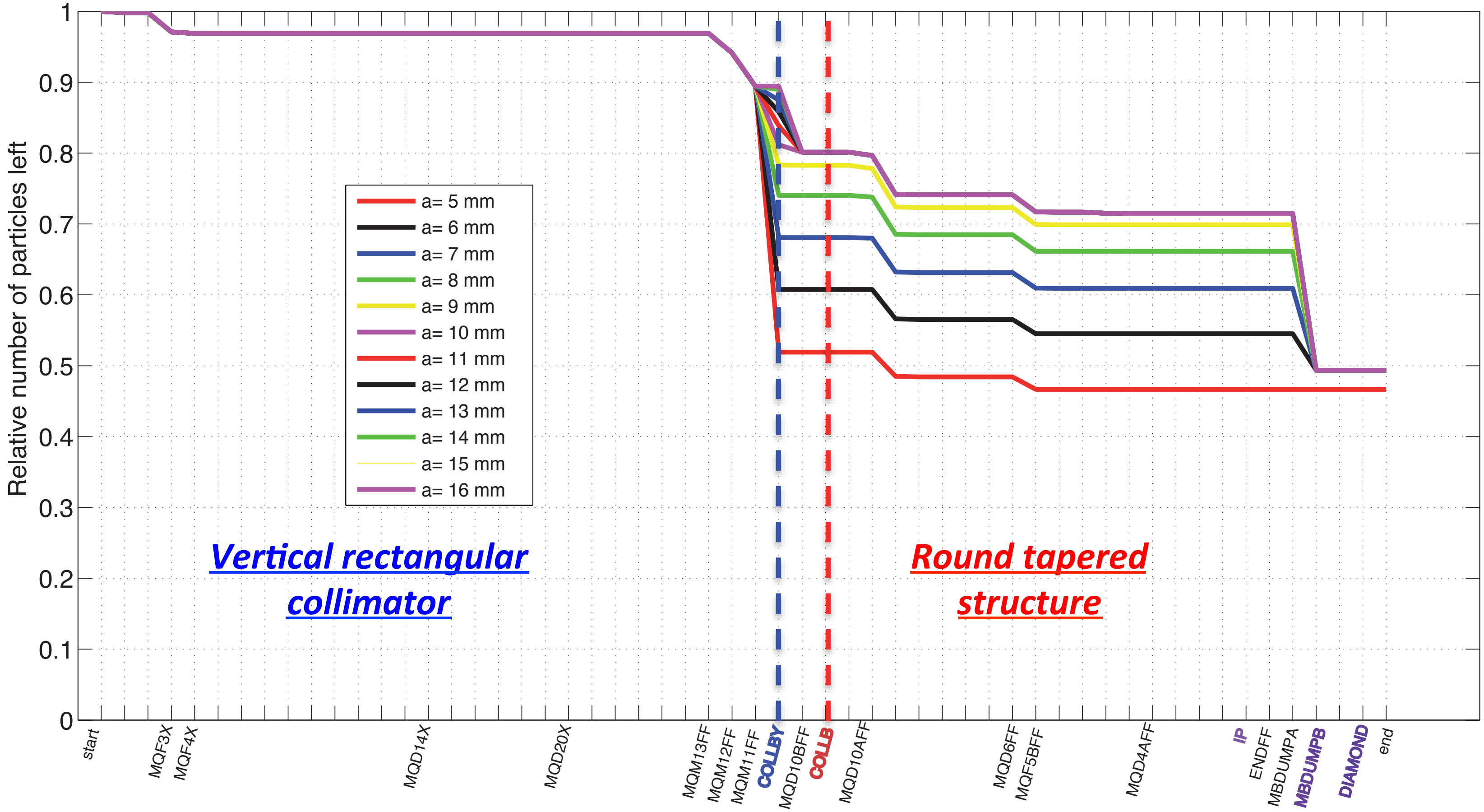


Similar behaviour is observed for all the beam halo models

Beam dynamics simulation and realistic tracking studies: MADX

Similar behavior is observed for the 3 **different beam halo models and for $1\beta_x x 1\beta_y$ optics**

Only vertical collimation, 10x1 optics, "realistic" halo model

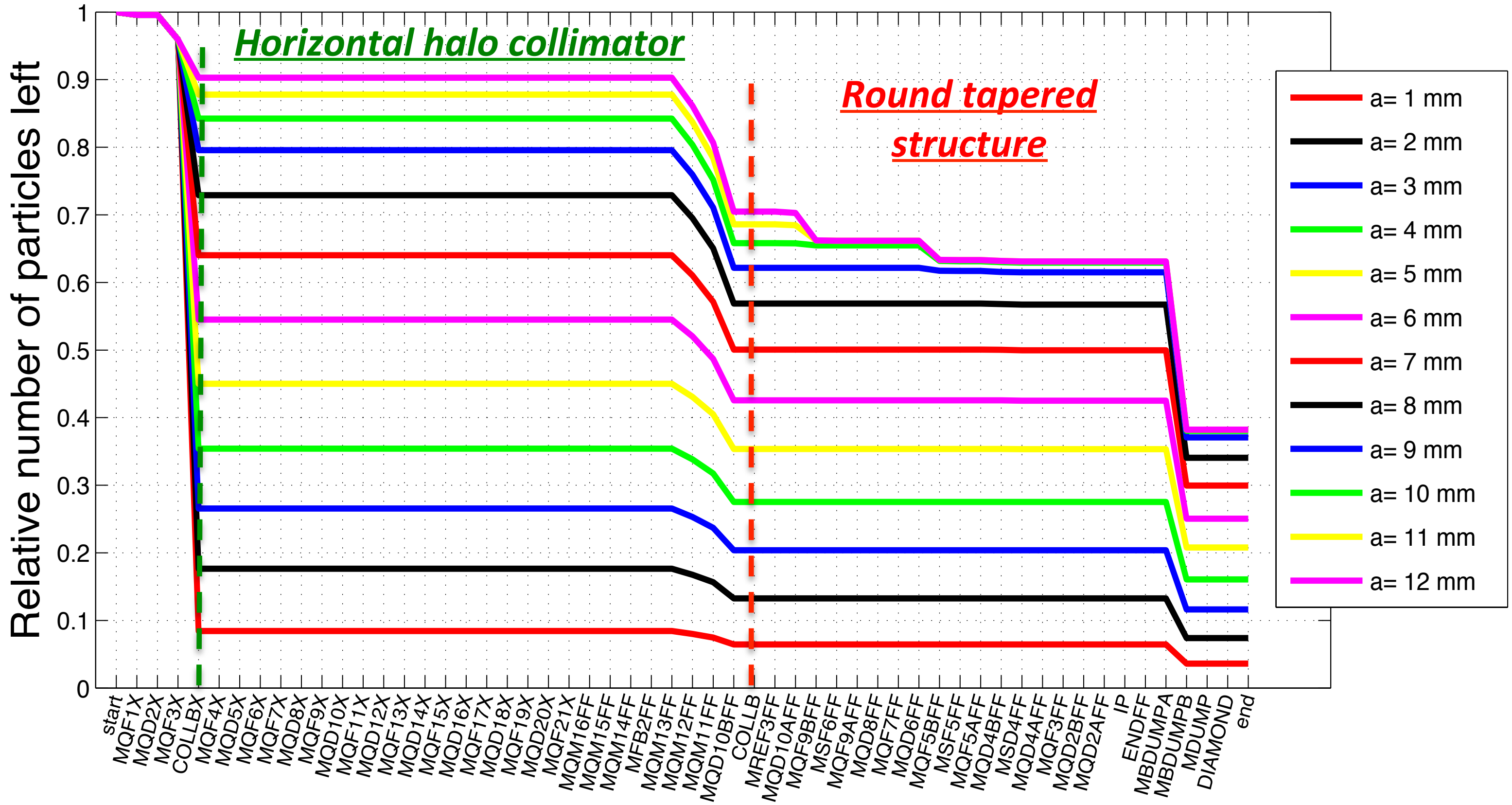


With a half aperture of 5 mm (17 σ_y) **we do not have losses at the BDUMP** enabling to control the **bremsstrahlung background at the Shintake monitor and DS**

Beam dynamics simulation and realistic tracking studies: MADX

Similar behavior is observed for the 3 **different beam halo models and for $1\beta_x x 1\beta_y$ optics**

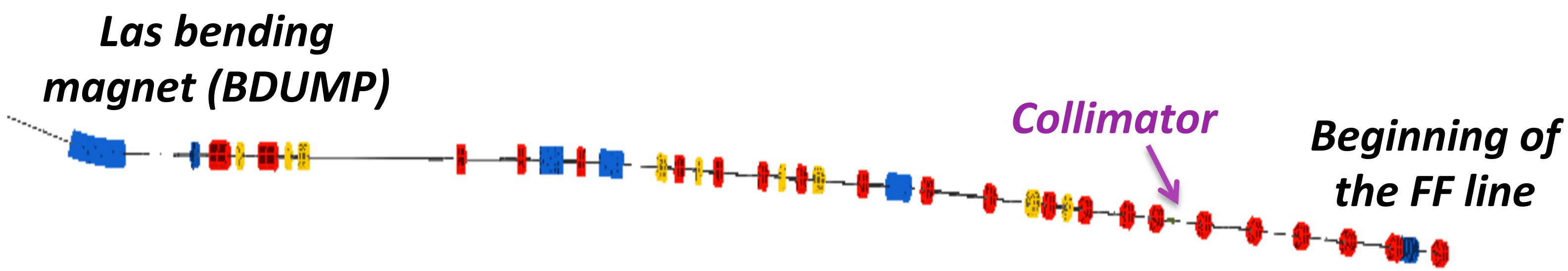
Only horizontal collimation, 10x1 optics, "realistic" halo model



Collimating only the horizontal plane we still have losses at the BDUMP

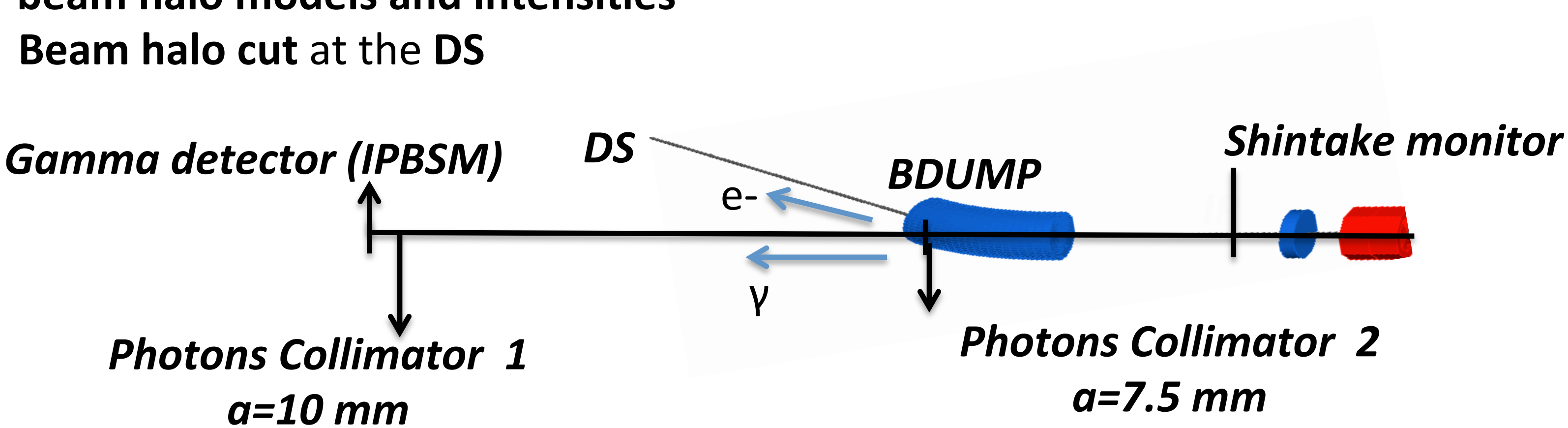
Beam dynamics simulation and realistic tracking studies: BDSIM

BDSIM is a **Geant4** extension toolkit for simulation of particle transport in accelerator beamlines. It provides fast in-vacuum **thick-lens tracking as well as the full physics processes of Geant4 when the particles propagate in material**



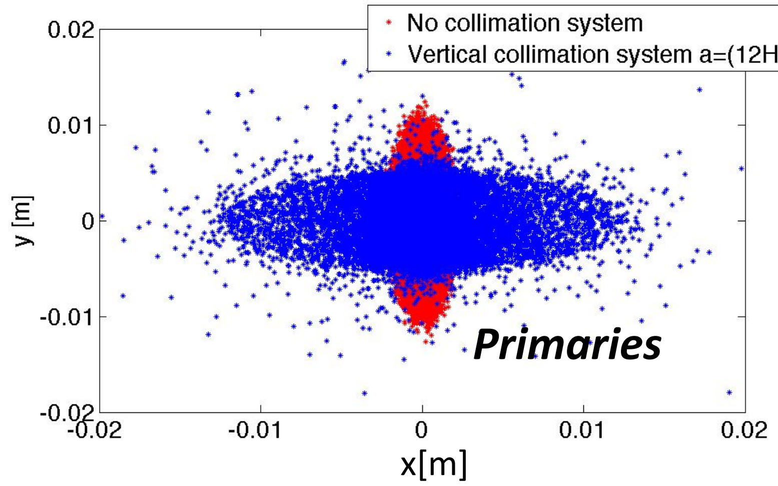
More accurate efficiency studies

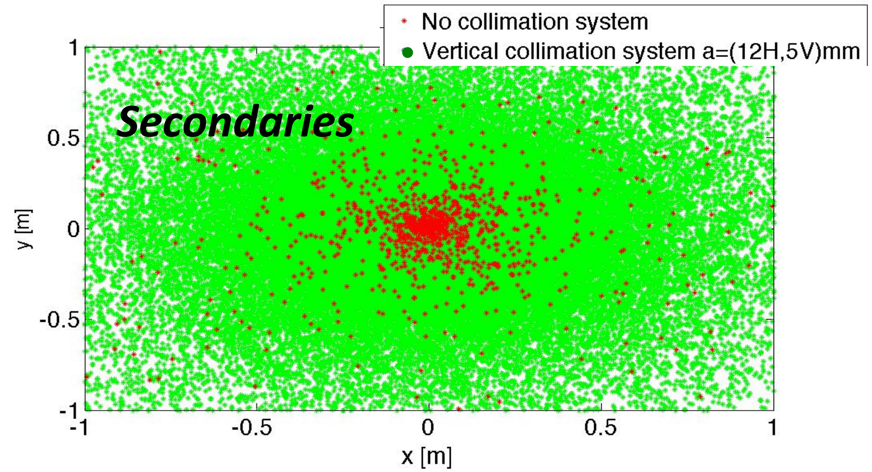
- **Realistic loss map** studies including the generation of secondary
- **Primary losses** in the last bending magnet (**BDUMP**)
- Quantify the **number of photons** that can reach the **IPBSM for different optics and beam halo models and intensities**
- **Beam halo cut** at the **DS**

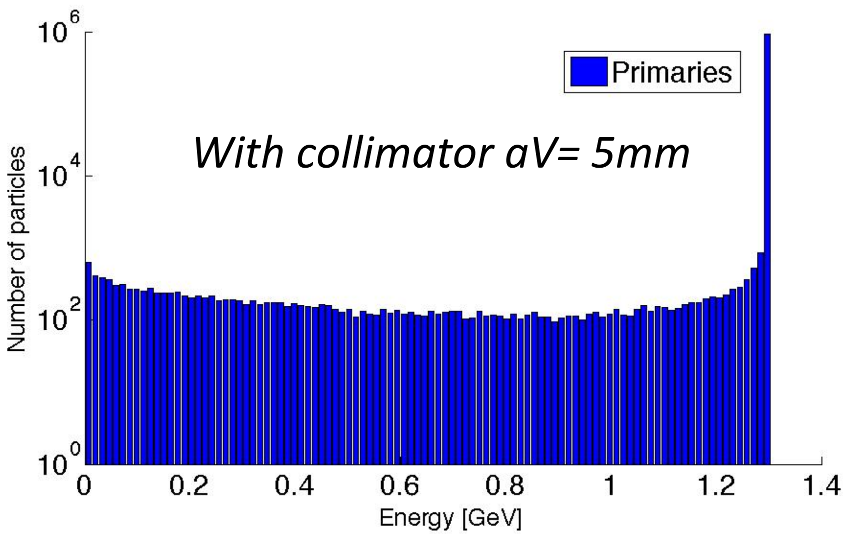


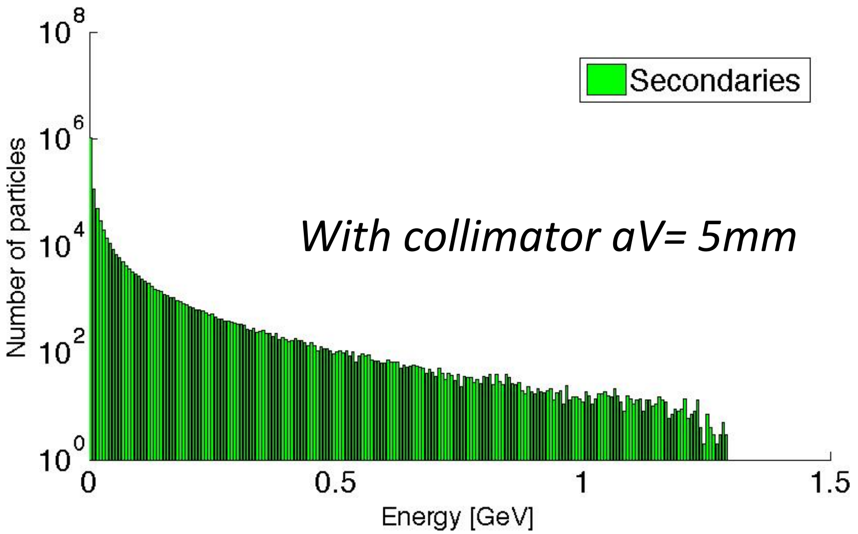
Beam dynamics simulation and realistic tracking studies: BDSIM

Beam halo distribution after the vertical collimator (10^6 particles and 10x1 optics)

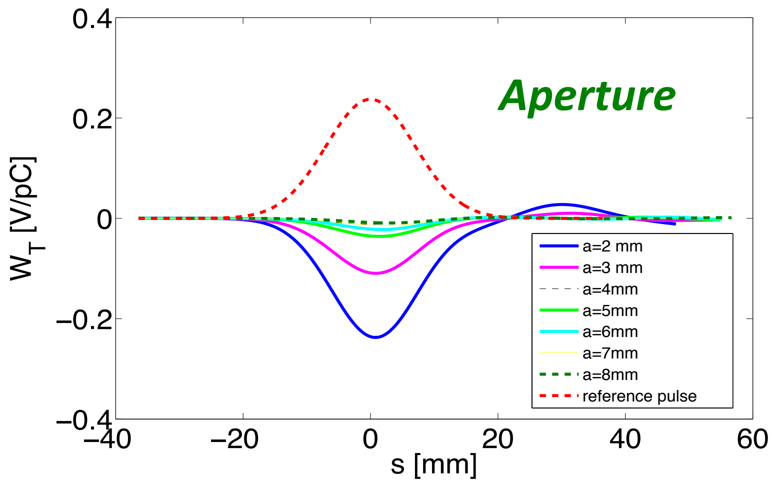


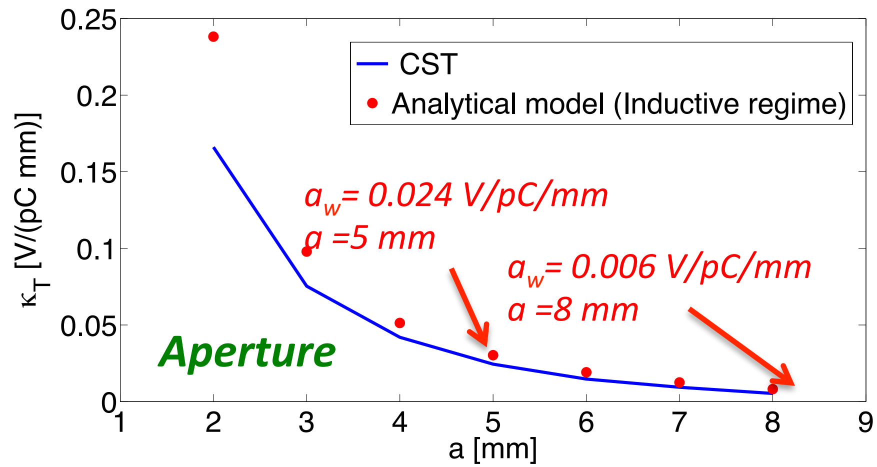


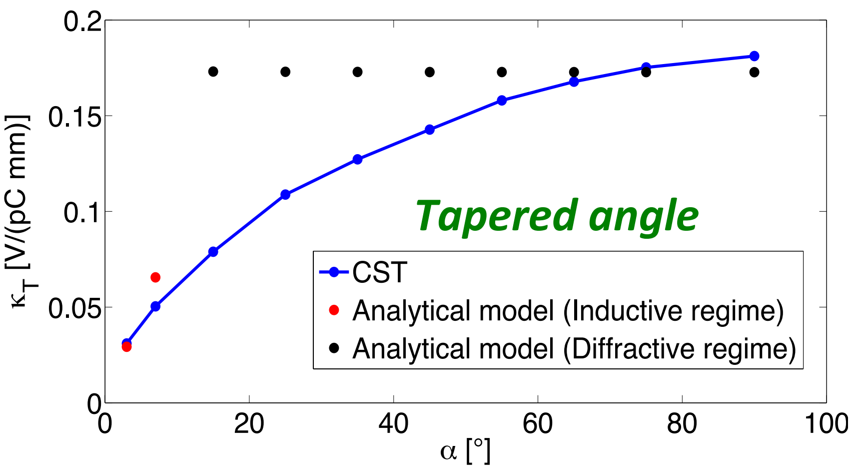


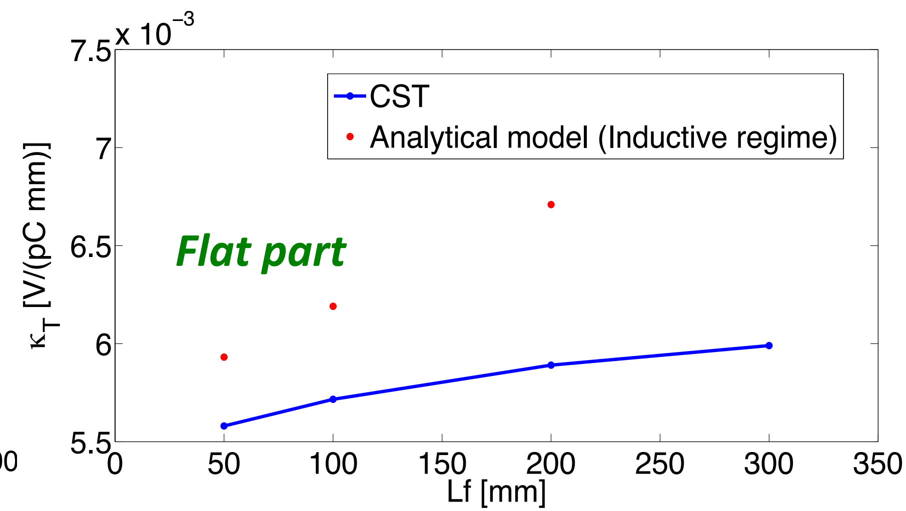


Design of a retractable halo collimation device: wakefield study







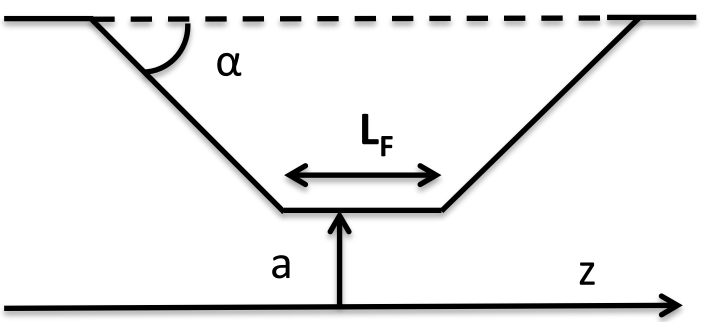


GOAL: To minimaze the kick to the order of 0.006 V/pC/mm at a=8 mm (negligible wakefield impact corresponding to a round tapered structure installed in ATF2)

Optimized jaws (mask): **L_f**=100 mm; **α**=3°; **a**=12-3 mm; **h**=12 mm; **L_T**=238 mm;Cu

Wakefield collimation studies and implications for ILC

	α	a	L_F
ILC SP1	0.02	0.3/0.75	8.6
ILC SP2	0.02	0.3/0.75	8.6
ILC AB1	0.02	4/4	429
ATF2 vertical	0.05	3-12	100



(ILC lattice repository: https://bitbucket.org/whitegr/ilc-lattices, M. Woodley 15-Apr-2015)

	ILC	ATF2
E [GeV]	500	1.3
N_b	20 x10^9	10 x10^9
σ_z [mm]	0.3	7
$\varepsilon^*_{x,y}$ (geometric)	11 mm/0.07 pm	4-40mm/12pm
$\beta^*_{x,y}$ [mm]	15/0.4	40/0.1

$$\Delta\sigma_y^* = \sqrt{\beta_y \beta_y^*} \sin \Delta\phi_y^* \frac{eq}{E} \kappa_T^{rms} \Delta y$$

“Collimator wakefield calculation for ILC-TDR Report” P. Tenenbaum, LCC-NOTE-0101 (20/08/2002)

$$\Delta y' = \kappa \Delta y \qquad \frac{n}{m} = \kappa \frac{\sigma_y}{\sigma'_y} \qquad A_\beta = \kappa \frac{\sigma_y}{\sigma'_y}$$

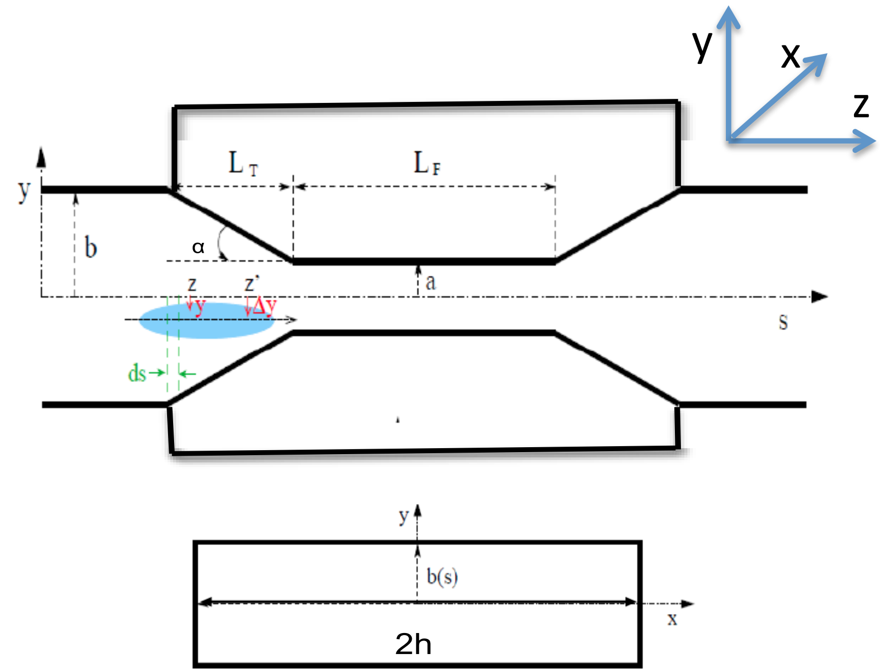
$$A_\beta = \kappa \beta \qquad A_{\beta,total} = \sum_i A_{\beta,i} \left| \sin 2\pi\nu_i \right|$$

- A combination of collimators with a A_β which exceeds 1 is unacceptable
- For the 2002 collimation system requirements the value exceeded 1 but the aperture requirements were more tight (some apertures smaller than 1 mm)
- In 2008 a new estimation has been made: EFFECT OF COLLIMATOR WAKEFIELDS IN THE BEAM DELIVERY SYSTEM OF THE INTERNATIONAL LINEAR COLLIDER* A. Toader, R. J. Barlow (University of Manchester, Manchester, U. K) F. Jackson, D. Angal-Kalinin (STFC Daresbury Laboratory, Warrington, U. K)

Rectangular collimator transverse dipole kick: analytical calculation

Geometric component

a: smallest aperture in the direction of collimation
b: biggest aperture in the direction of collimation
h: in a rectangular collimator is the half length of the aperture in the direction of non collimation
Lf: length of the flatter part
α: angle of the tapered part



[6] G.V. Stupakov, ``High-Frequency Impedance of Small-Angle Collimators, SLAC-PUB-9375, August 2002

"Near center approximation" (dipole kick applied to the centroid of the bunch)

Diffractive regime

α > 1 High frequency

$$\kappa_g = \frac{Z_0 c}{4\pi}\left(\frac{1}{a^2} - \frac{1}{b^2}\right) \quad for \quad \sqrt{\frac{\alpha a}{\sigma_z}} > 0.37$$

Intermediate regime

α < 1 High frecuency

$$\kappa_g = \frac{Z_0 c}{4\pi} 2.7 \sqrt{\frac{\alpha}{\sigma_z a^3}} \quad for \quad 0.37 > \sqrt{\frac{\alpha a}{\sigma_z}} > 3.1\frac{a}{h}$$

Inductive regime

α << ; w-> 0

$$\kappa_g = \frac{Z_0 c}{4\pi} \frac{\sqrt{\pi}\alpha h}{2\sigma_z}\left(\frac{1}{a^2} - \frac{1}{b^2}\right) \quad for \quad \sqrt{\frac{\alpha a}{\sigma_z}} < 3.1\frac{a}{h}$$

Rectangular collimator transverse dipole kick: analytical calculation

Resistive component

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

$$\kappa_r \simeq \frac{\pi}{8a^2}\Gamma(\frac{1}{4})\sqrt{\frac{2}{\sigma_z \sigma Z_0}}(\frac{L_F}{a} + \frac{1}{\alpha})$$

For the ATF2 beam and collimator parameters this regime is used

Where ***Z_0=376 Ω*** vacuum impedance, ***Γ(1/4) = 3.6256***, ***L_F*** collimator flat lenght

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

$$\kappa_r = \frac{1}{q}\int\int E_z(\vec{r}_0, z)dzds$$

$$E_z = -\frac{16q}{a^2}\left[\frac{1}{3}e^{-\frac{s}{s_0}}\cos\frac{\sqrt{3}s}{s_0} - \frac{\sqrt{2}}{\pi}\int_0^\infty \frac{x^2 e^{-\frac{x^2 z}{s_0}}}{x^6+8}dx\right]$$

[7] A.Piwinski, ``Wake fields and Ohmic losses in Flat vacuum chambers" DESY-HERA-92-04,1992

[8] K. Bane and M. Sands , Intermediate and short range wakefields, 1995