Analysis of the beam halo collimation system measurements

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14/03/2017

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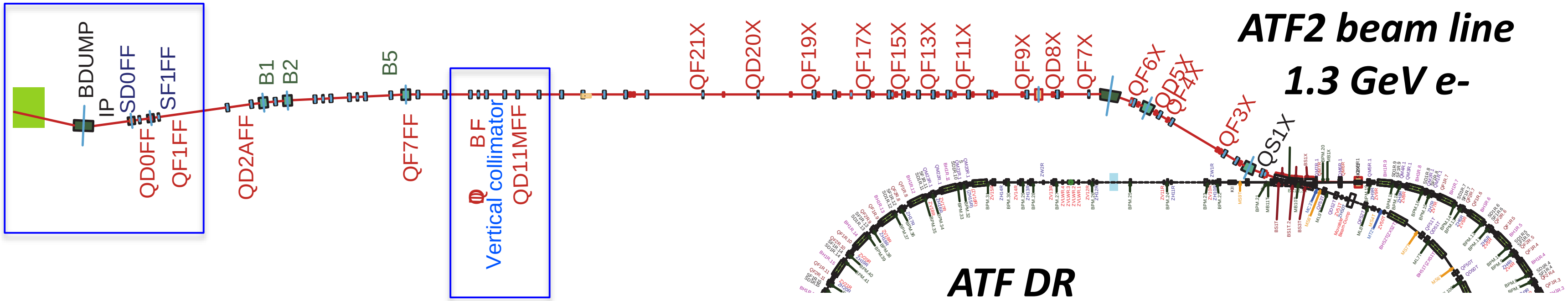
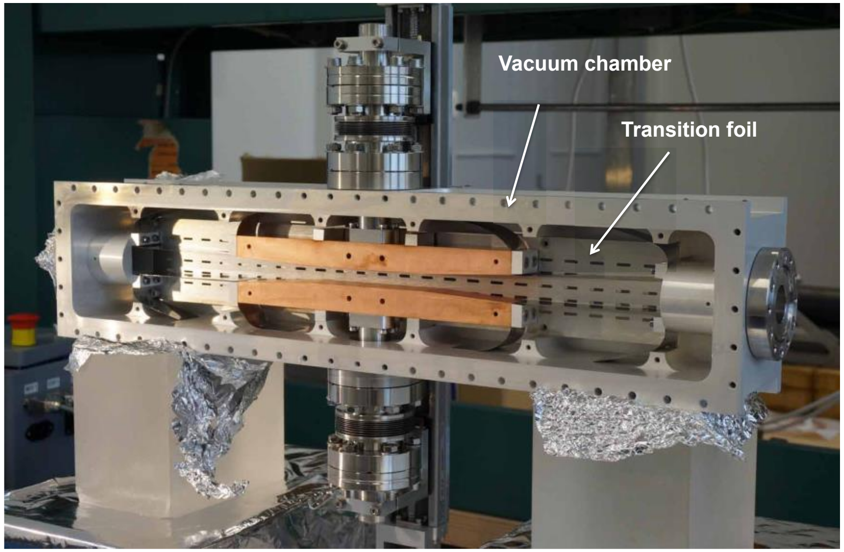
Introduction

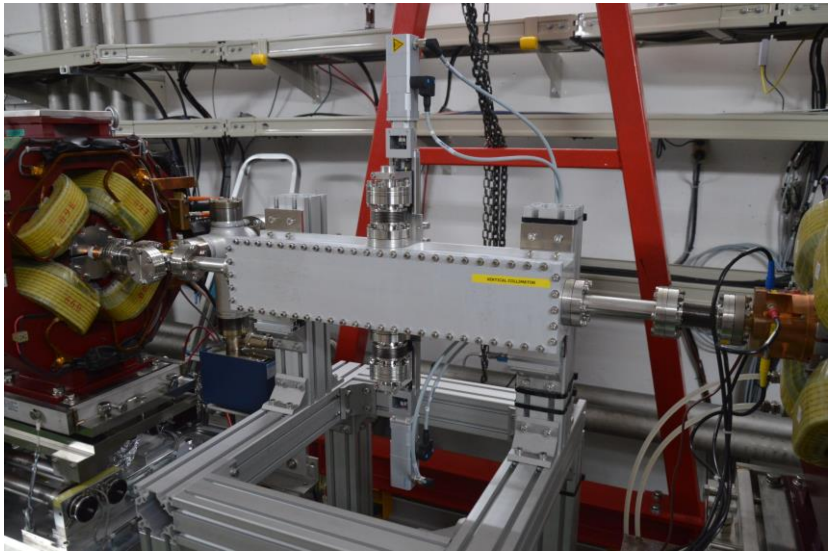
A vertical collimation system was installed in the ATF2 FFS in March 2016



✓ β^{c}_{y}=7126.51 m

✓ $\Delta\Phi_y^{\,BDUMP\text{-}C}$=3π and $\Delta\Phi_y^{\,DS\text{-}C}$=3π





Summary shifts 2016

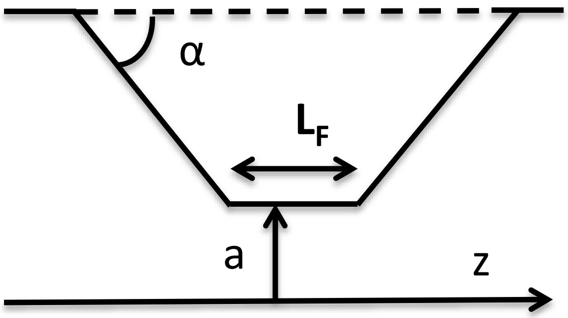
- **May: 6 shifts (over 2 weeks)**
  - ✓ **Background measurements** with **different beam and machine conditions**
    - Different beam intensities
    - Different vacuum pressure
    - Different optics ($10\beta_x x 1\beta_y$, $10\beta_x x 0.5\beta_y$)
  - ✓ **Collimator wakefield impact** measurements for **4 mm** half aperture

- **October: 2 shifts (over 2 weeks)**
  - ✓ Repeat the **background measurements for consistency**
  - ✓ **Collimator wakefield impact** measurements for **4 mm** half aperture
    - Increase scan range (maximum offset of 2 mm)
    - Evaluate the **bunch length intensity dependence** and Streak Camera

- **November/December: 1 shift (over 2 weeks)**
  - ✓ Study the **impact** of the collimator on the **beam size measurements**
  - ✓ **Collimator wakefield impact** measurements for **3 mm** half aperture
  - ✓ Participate on the intensity dependence studies

Collimator WK impact measurements 2016: Motivation

- Collimation is **tradeoff** between **efficiency** and the **WF impact** induced
- The collimator WF **increases** with **small apertures** and **high intensity** and could limit the achievable luminosity in FLC



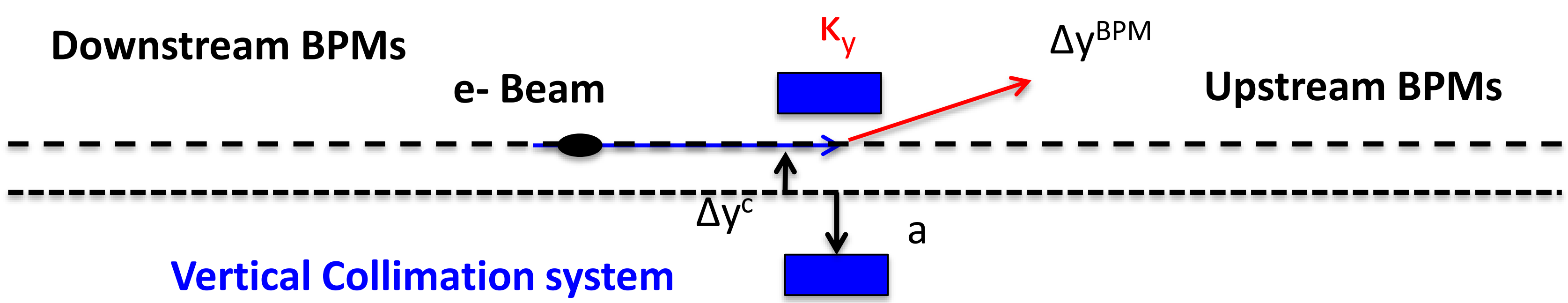
- **Benchmarking of analytic models, numeric simulations and measurements is essential for the design and optimization of the FLC collimation system**
  - Different **analytic models** regimes (inductive, intermediate, diffractive)
    - Only describe the **jaws** of the collimation system
    - Accuracy not good when the parameters sit close to the **limits**
    - Disagreements between published implemented in programs formulas...
  - **Discrepancies** about a factor 2 between analytical calculations, EM simulations and **measurements performed at ESA** (SLAC) (2001-2007) for some geometries

Collimator WK impact measurements 2016: Introduction

Experiment

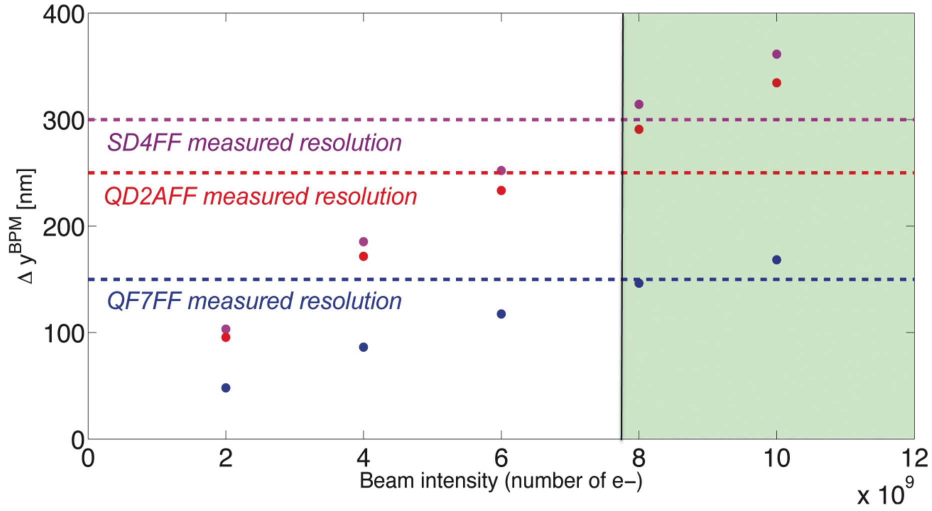
- **Retractable vertical collimation system half aperture from 3-12 (with mechanical stop) and 2-12 (without mechanical stop)**
- **45 Cavity BPMs** in the EXT and FFS with **resolution** about **~200 nm**
  - ✓ 32 downstream the collimator
  - ✓ 17 upstream the collimator
- Measure the **wakefield kick** by **changing the collimator-center-beam offset** and measuring the impact on the upstream BPMs orbit

$$\Delta y^{BPM} = R_{34}\frac{eq}{E}\kappa_y \Delta y^c$$



- a = 4 mm (maximum offset of 2 mm)
- a = 3 mm (maximum offset of 1 mm)

Experiment beam requirements and BPMs sensibility



Expected Δy^{BPM} it is of the order to 150-400 nm for 1 mm offset and **high beam intensity**

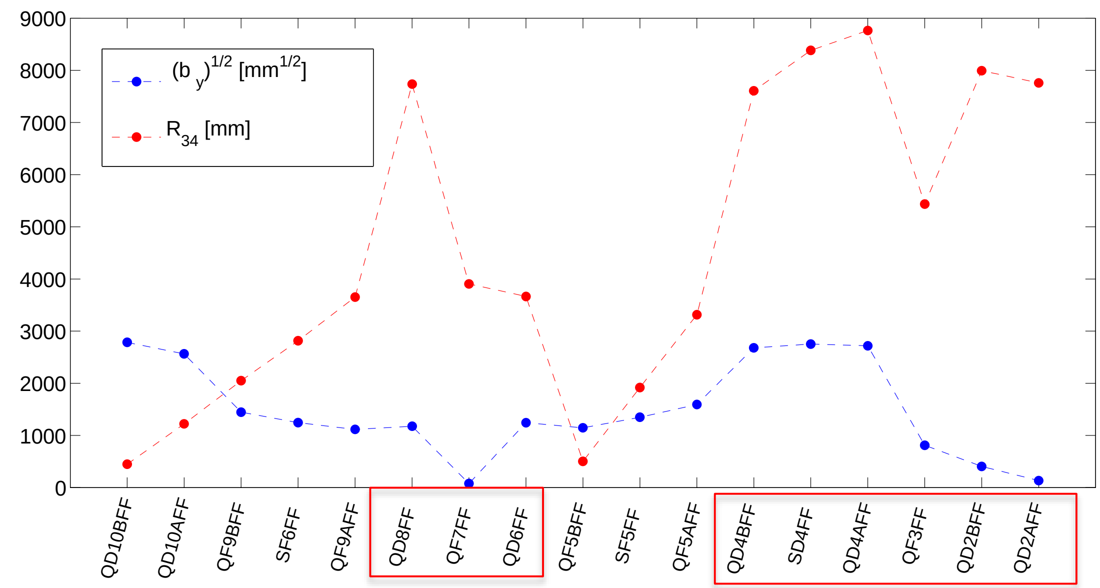
- $\sigma_z = 9$ mm
- $\Delta y^c = 1$ mm
- a= 4 mm
- **κ_y calculated with CST PS**
- R34: Design values lattice version v5.2
- 10βx × 1βy

❑ **High intensity** is required to induce an impact above the BPMs resolution (higher than 0.8×10^{10})

Sensitive BPMs

❑ **At highest R_{34}**

$$R_{34} = \sqrt{\beta^{BPM}\beta^{c}}\sin\phi^{BPMc}$$



Collimator WK impact measurements 2016: Introduction

Orbit data analysis and wakefield kick reconstruction

1. Remove noise pulses: zeros and pulses with position and charge > than "mean+5σ"

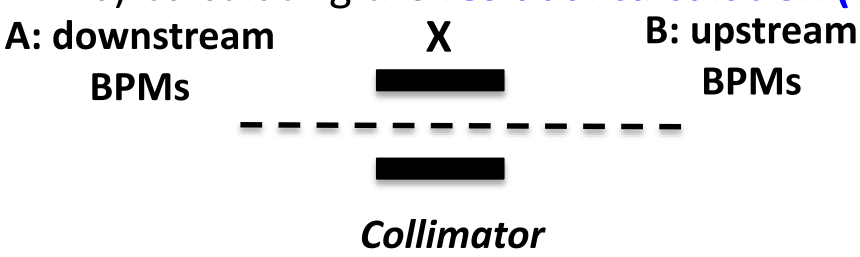
2. **Orbit jitter subtraction** is needed since wake kick is at the level of orbit jitter

a) Calculation of the **correlation matrix, X,** between upstream and downstream BPMs

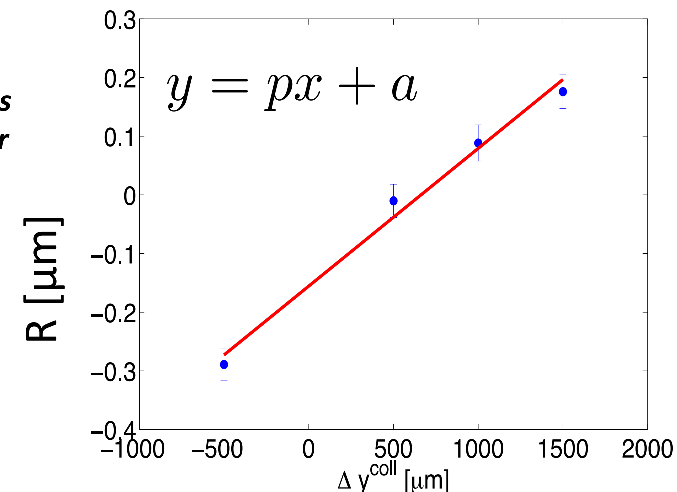
b) Calculating the **residual calculation (R)** for each collimator offset as

a) $AX = B \quad X = A^{-1}B$

b) $R = A'X - B'$



J. Snuverink et all,, `Measurements and simulations of wakefields at the Accelerator Test Facility 2, PRST-AB 19, 091002 (2016).



3. Plot R vs Δy^C and fit the data

4. Wakefield kick reconstruction

$$\kappa_y[V/pC/mm] = \frac{p}{R_{34}} \frac{E[eV]}{eq[pC]}$$

κ_y is the value to be compared with analytic and numeric simulations

Collimator WK impact measurements 2016: Introduction

The precision the wakefield kick reconstruction:

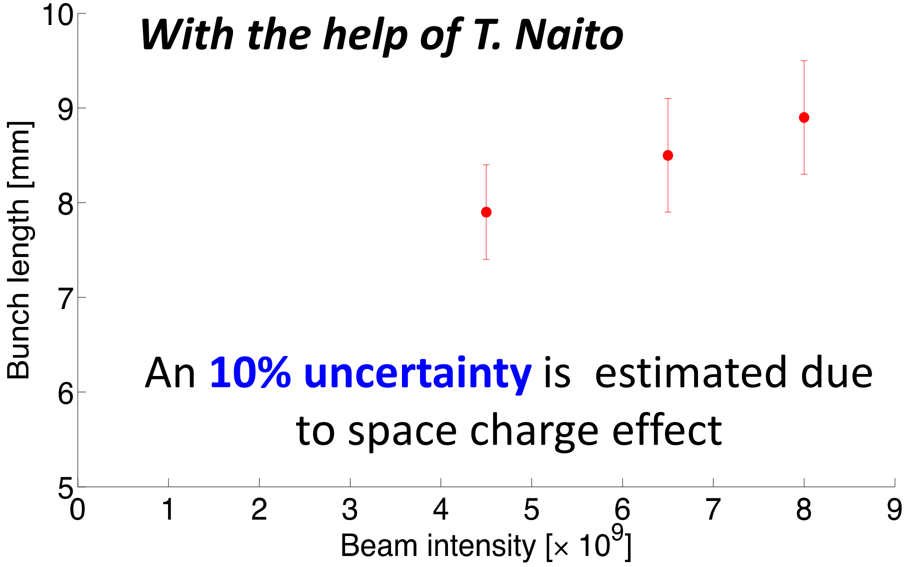
- **Beam intensity and stability**
- **BPMs resolution**
- **The optics**

The benchmarking accuracy will depends on:

- **Collimator aperture**
- **Bunch length measurements**

$$\kappa_y(a, \sigma_z \ldots) = \Delta y^{BPM} \frac{E}{R_{34} e q} \frac{1}{\Delta y^c}$$

$$\sigma_{\kappa_y} = \left[\sigma_p^2 \left(\frac{\partial \kappa_y}{\partial p} \right)^2 + \sigma_N^2 \left(\frac{\partial \kappa_y}{\partial N} \right)^2 \right]^{1/2}$$



An **10% uncertainty** is estimated due to space charge effect

Shift	a [mm]	BPMs calibration	σ_z [mm]	N
20/05/2016	4.0±0.2	No calibration	8.6±0.7	0.90±0.05
24/05/2016	4.0±0.2	Only FFS BPMs	9.1±0.7	0.90±0.6
27/05/2016	4.0±0.2	Complete	8.9±0.7	0.90±0.05
27/10/2016	4.0±0.2	Complete	8.9±0.7	0.80±0.06
1/12/2016	3.0±0.2	Complete	8.6±0.6	0.75±0.05

Collimator WK impact measurements 2016: Results

May 2016 run

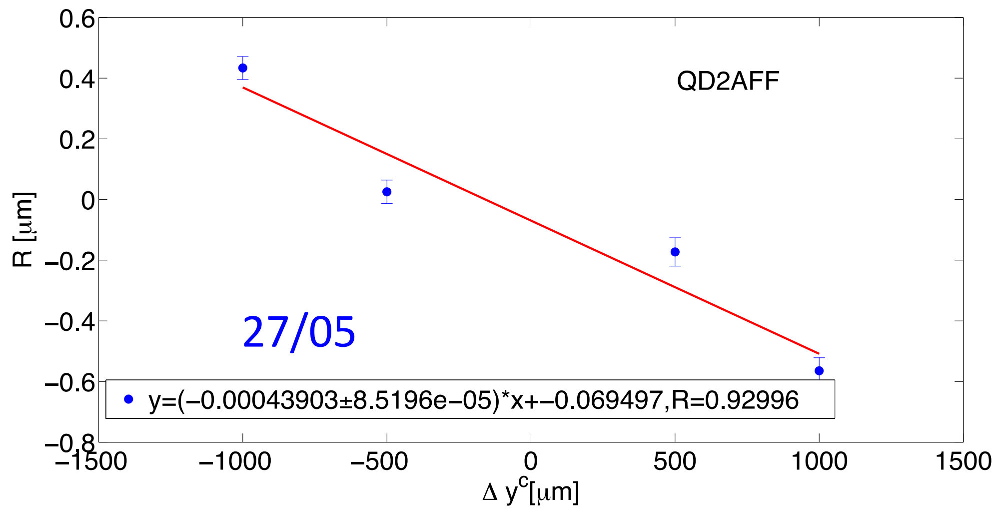
a= 4 mm

Orbit data

- ✓ 3 different shifts: 20-24-27/05
- ✓ I=0.9-0.95x10^{10}
- ✓ 10βx × 1βy

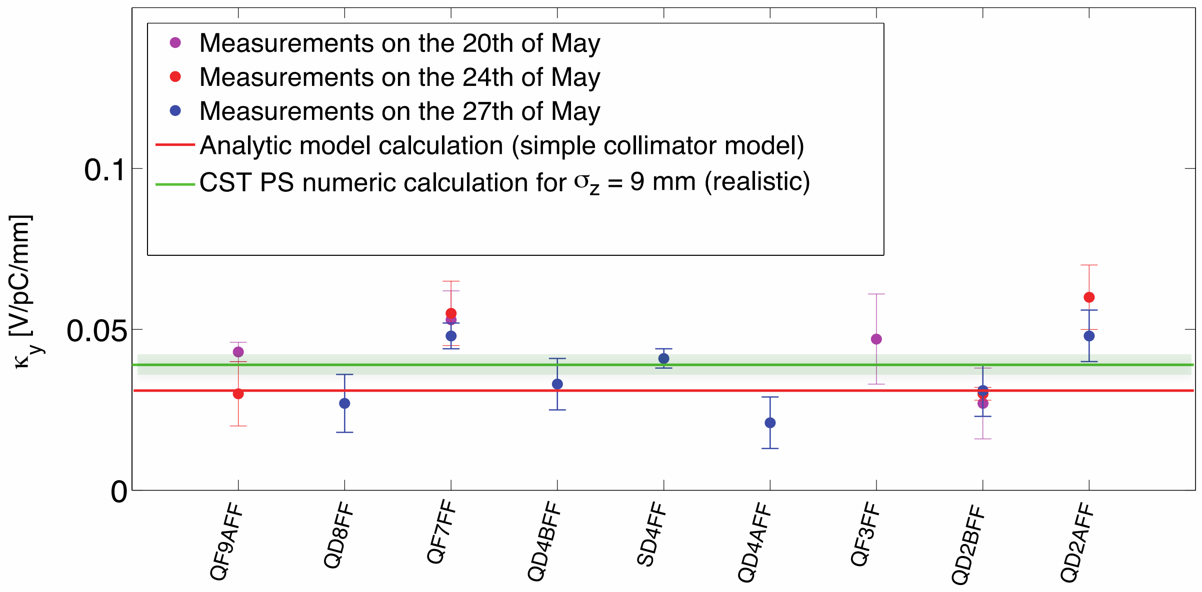
Results

- ❑ **$\kappa_y^{average}$ = 0. 040±0.003 V/pC/mm**
- ❑ $\Delta(\kappa_y^{an.\ (\sigma z=9\ mm)} - \kappa_y^{me.}) = 21\ \%$
- ❑ $\Delta(\kappa_y^{CST\ (\sigma z=9\ mm)} - \kappa_y^{me.}) = 8\ \%$



$$\kappa_y^{average} = \frac{\sum_i \kappa_y^i / \sigma_{\kappa^i}^2}{\sum_i 1/\sigma_{\kappa^i}^2}$$

CSTPS wakefield kick depicted in green for values of the bunch length between the measured error (**$8.9-0.7>\sigma_z>8.9+0.7$**)



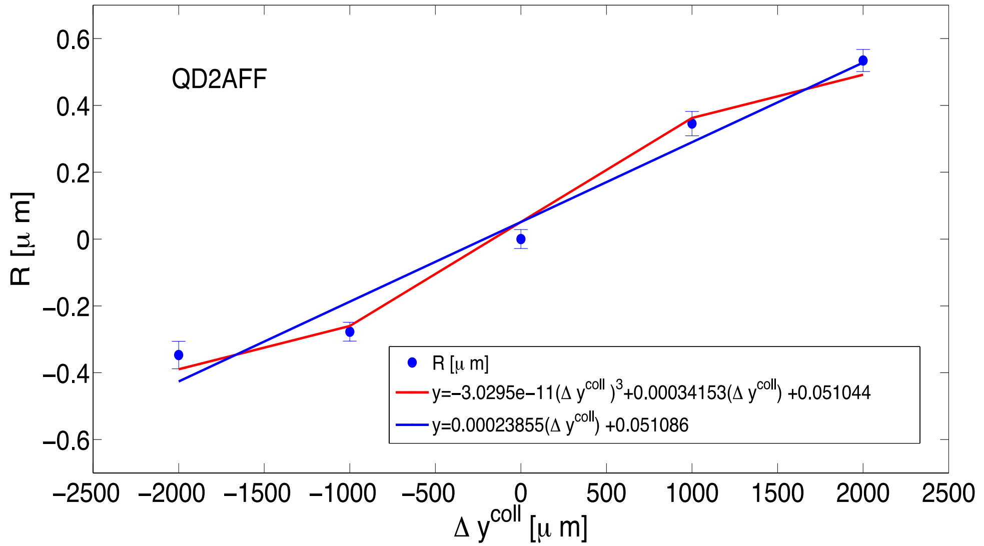
Collimator WK impact studies 2016: Results

October 2016 run

a=4 mm

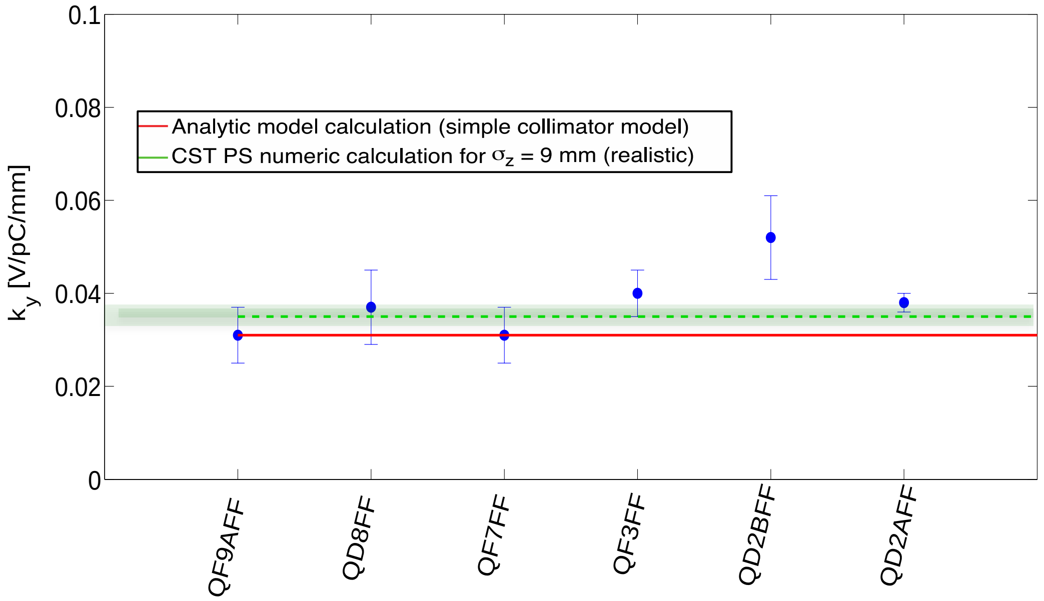
Orbit data

- ✓ 1 shift: 27/10
- ✓ Intensity 0.8×10^{10}
- ✓ $10\beta x \times 1\beta y$
- ✓ Remove the mechanical stop
- ✓ **Linear and third polynomial fit**



Results

- ❑ **$\kappa_y^{average}$ = 0. 038±0.003 V/pC/mm**
- ❑ $\Delta(\kappa_{T,y}^{an.\ (\sigma z=9\ mm)} - \kappa_{T,y}^{me.}) = 15\ \%$
- ❑ $\Delta(\kappa_{T,y}^{CST\ (\sigma z=9\ mm)} - \kappa_{T,y}^{me.}) = 3\ \%$



CSTPS wakefield kick depicted in green for values of the bunch length between the measured error (**$8.9-0.7>\sigma_z>8.9+0.7$**)

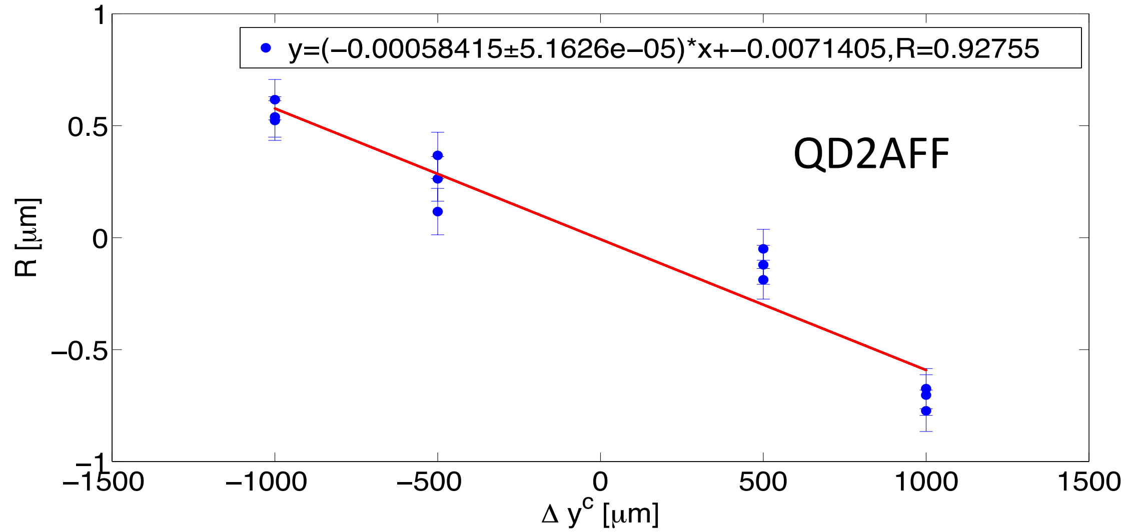
Collimator WK impact studies 2016: Results

November/December 2016 run

a= 3 mm

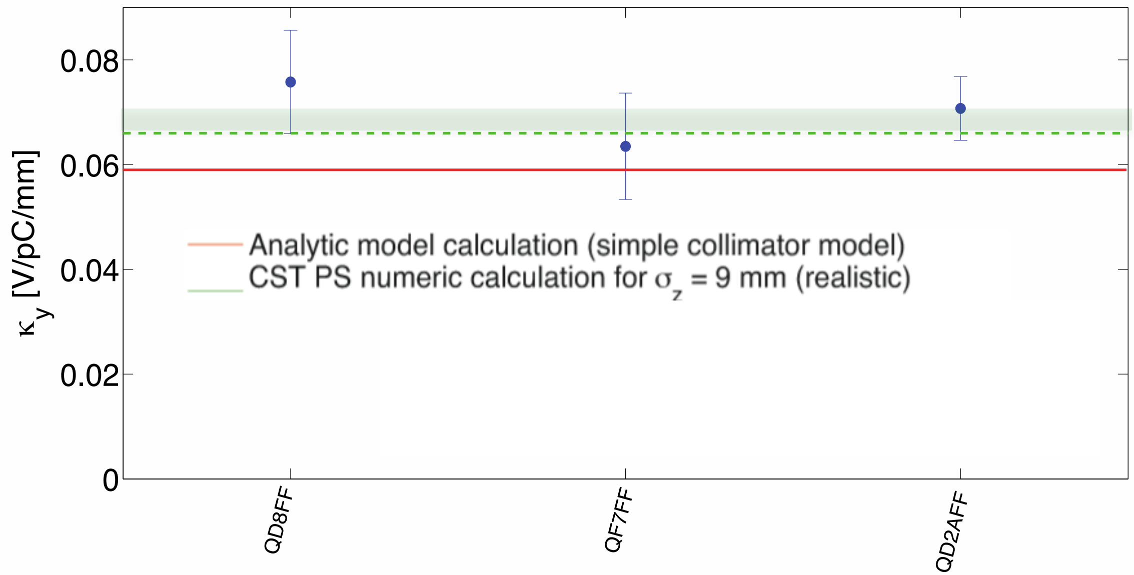
Orbit data

- ✓ 1 shift: 1/12
- ✓ Intensity 0.75×10^{10}
  - ✓ Only a=3 mm impact could be measured
  - ✓ Only at 3 BPMs (other removed)



Results

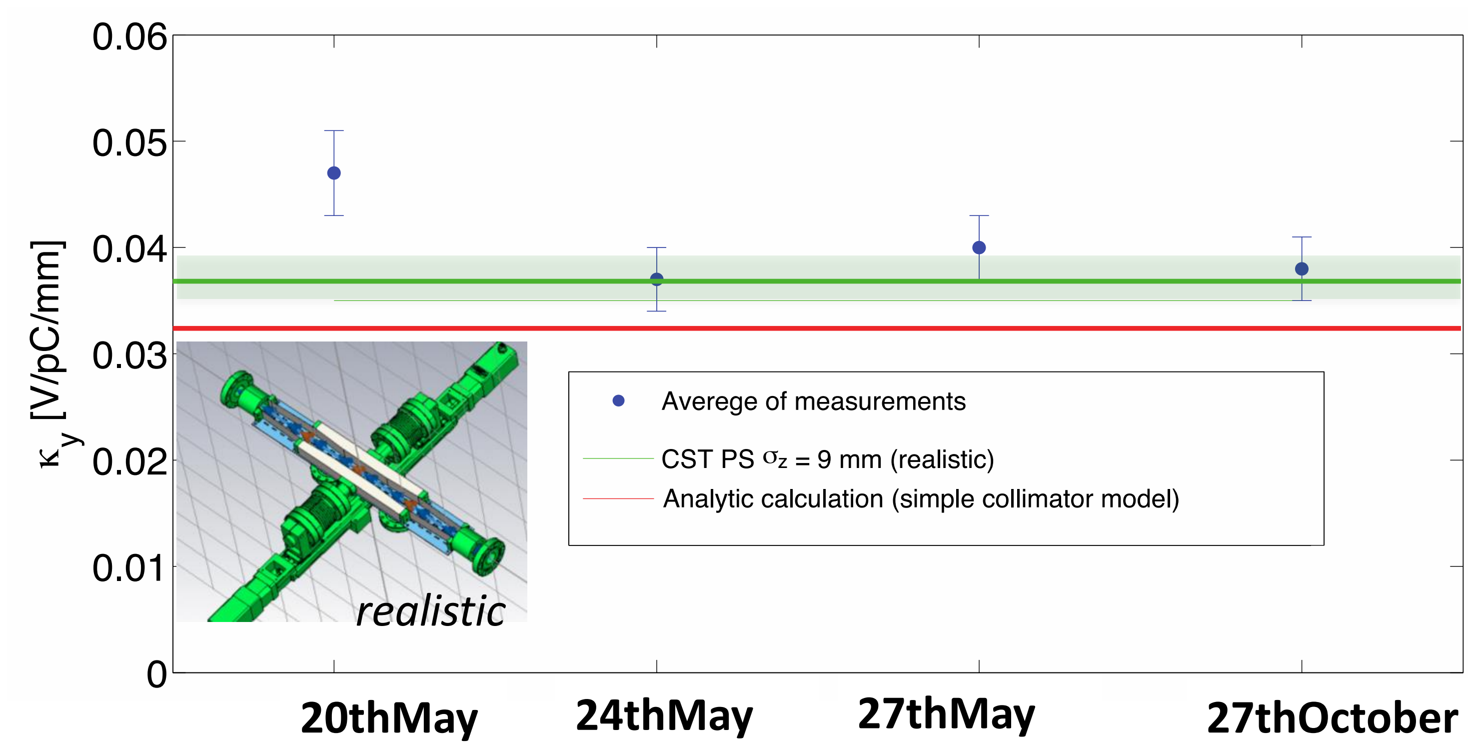
- ❑ **$\kappa_y^{average}$ = 0. 070±0.003 V/pC/mm**
- ❑ $\Delta(\kappa_{T,y}^{an.\ (\sigma z=9\ mm)} - \kappa_{T,y}^{me.}) = 15\%$
- ❑ $\Delta(\kappa_{T,y}^{CST\ (\sigma z=9\ mm)} - \kappa_{T,y}^{me.}) = 4\ \%$



CSTPS wakefield kick depicted in green for values of the bunch length between the measured error (**$8.6-0.6>\sigma_z>8.6+0.6$**)

Collimator WK impact studies 2016: Results

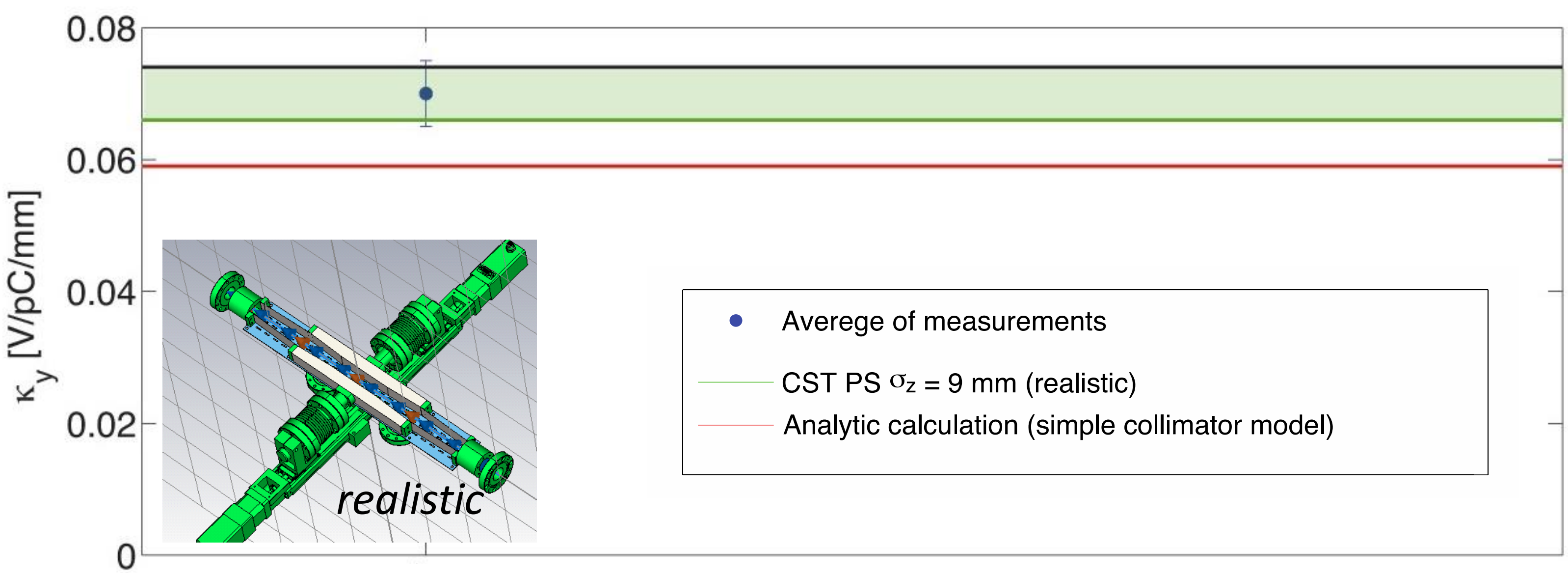
[mm]	[mm]	$\kappa_{T,y}$ [V/pC/mm]			
a	σ_z	Analytic	CST PS (jaws)	CST PS (realistic)	Measured
4	9.0±0.7	0.033	0.033	0.037	0.038±0.003



- Measurements are in agreement with the associated error with numeric simulations
- About 15% difference within measurements and analytic calculation of the jaws
- 11% difference in the CST PS calculation of the jaws and realistic model

Collimator WK impact studies 2016: Results

[mm]	[mm]	$\kappa_{T,y}$ [V/pC/mm]			
a	σ_z	Analytic	CST PS (jaws)	CST PS (realistic)	Measured
3	8.6±0.6	0.059	0.059	0.066	0.070±0.005

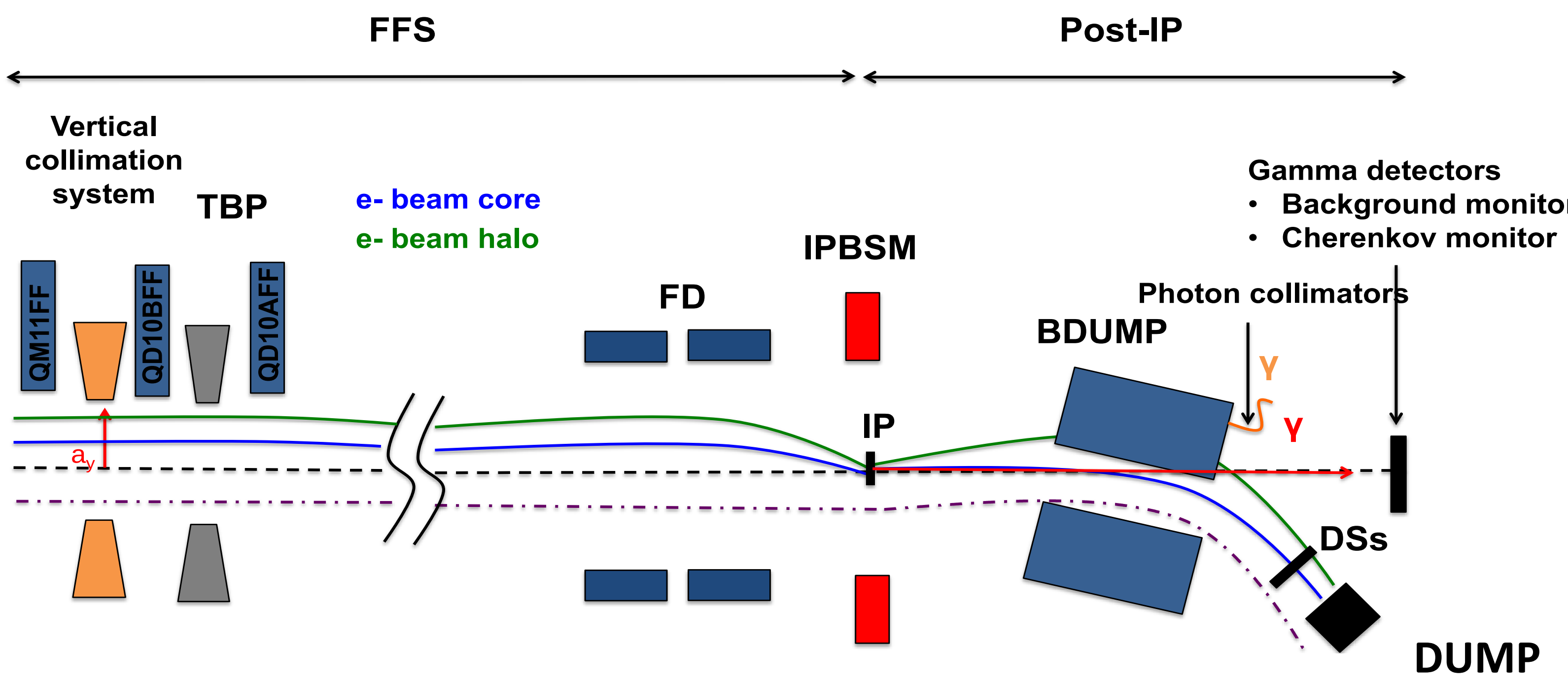


November/December

- ❑ Measurements are in agreement with the associated error with numeric simulation
- ❑ About 15% difference within measurements and analytic calculation of the jaws
- ❑ Measurement values for a=4 and 3 mm agree with the analytic expected scaling 1 /a^2

Motivation

- ❑ To measure the vertical collimation system **efficiency** in reducing the **background photons** in the **Post-IP**
  - ❑ To confirm our understanding of the background sources
- ❑ The vertical collimation system was installed in the context of beam halo investigation to provide a tool **to confirm the DS measurements**



Motivation

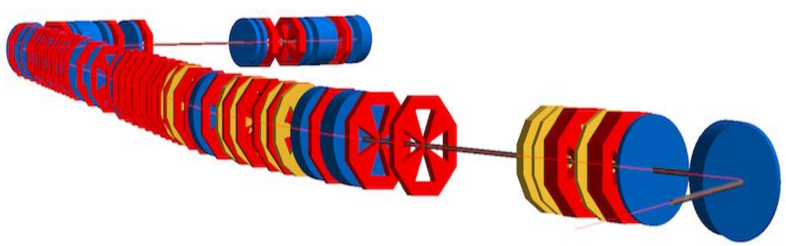
- **Benchmark** the **realistic** collimation system **efficiency** studies performed with the tracking code BDSIM

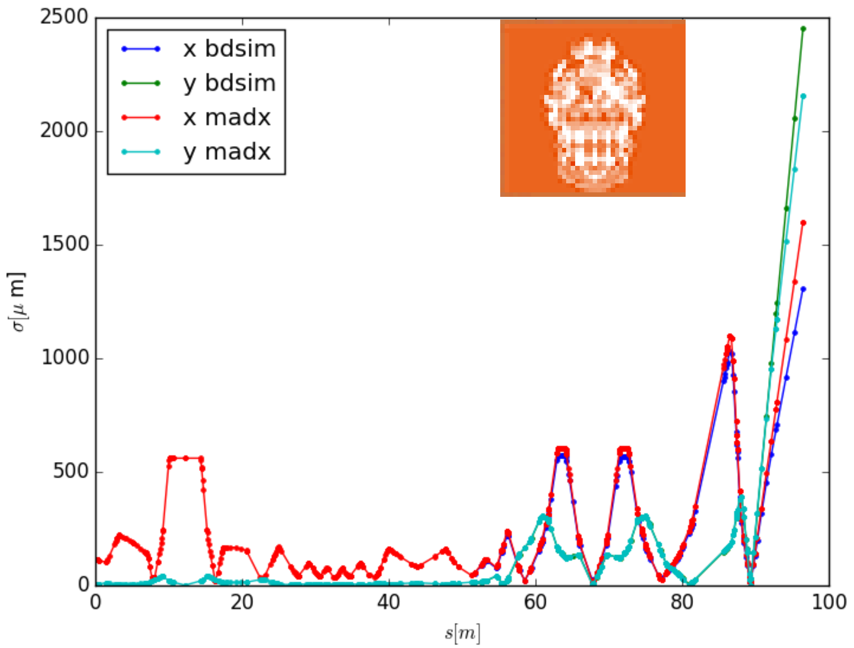
BDSIM is a **Geant4** extension toolkit for in-vacuum thick-lens tracking as well as the full physics processes of Geant4 when the particles propagate in material machines

Significant recent development of BDSIM has been performed and need to be **validate against a real machine**

ATF2 model has been update in **2016** by RHUL team and reproduces the nominal optics from particle tracking

Some geometry upgrades are been performed for better agreement with measurements (more by A. Schuetz)

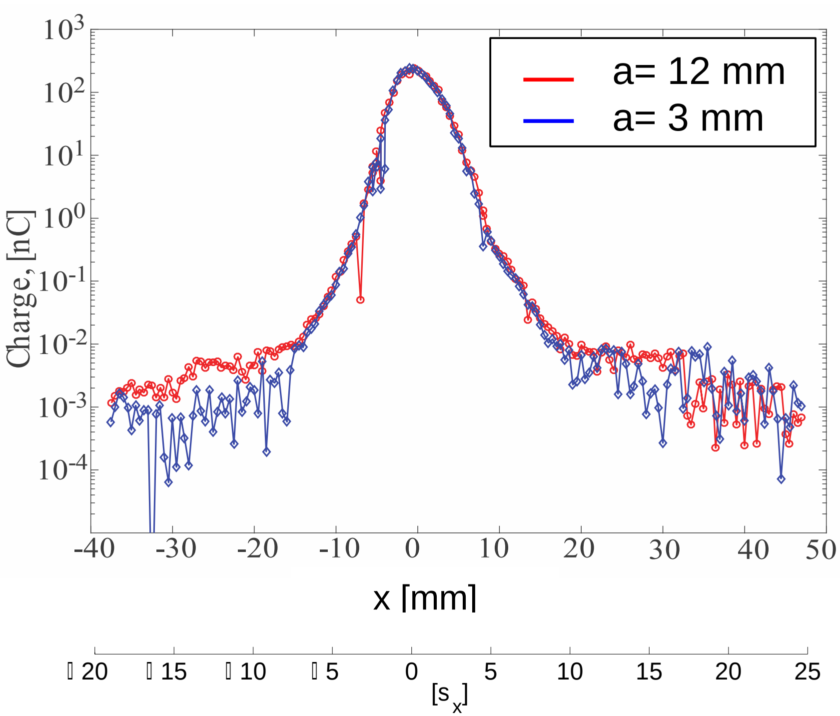


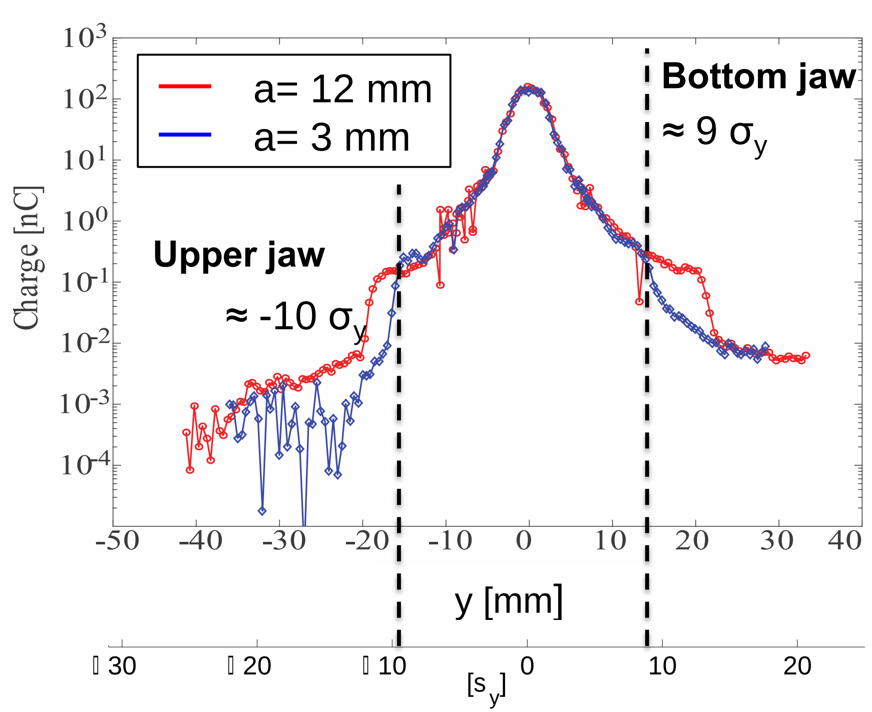


Realistic collimation efficiency and related measurements 2016: Results

Measurements were taken in March 11th 2016 with the DSs

To confirm the beam halo DS measurements by measuring the beam halo cut expected due to the collimation system





- ❑ These measurements were benchmarked with the WS and the observed cuts are **in agreement with MADX-PTC simulation** within 1 σ_y

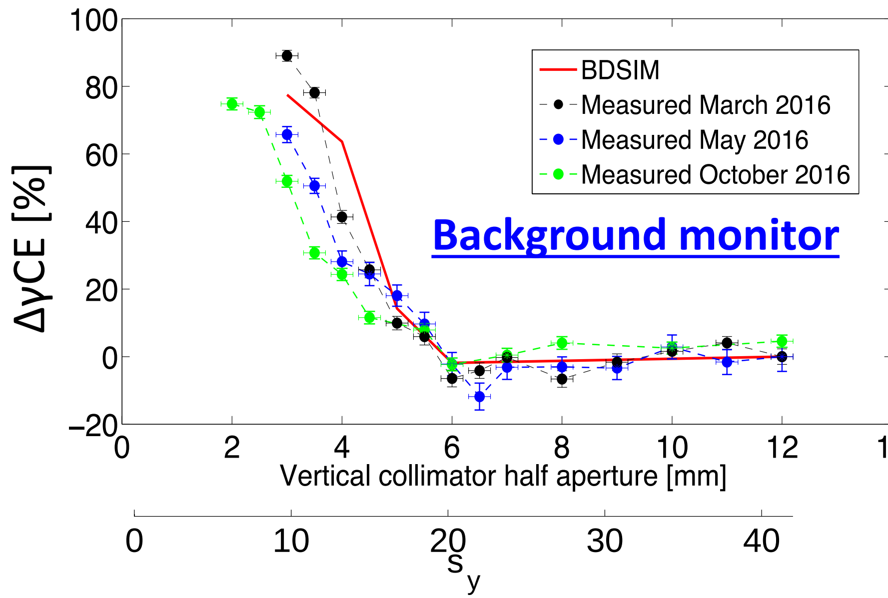
Realistic collimation efficiency and related measurements: Results

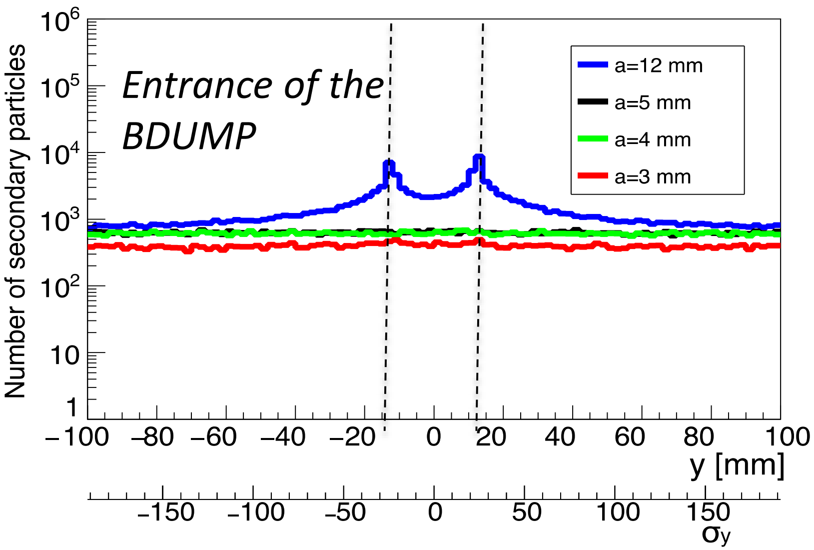
Realistic collimation system efficiency studies

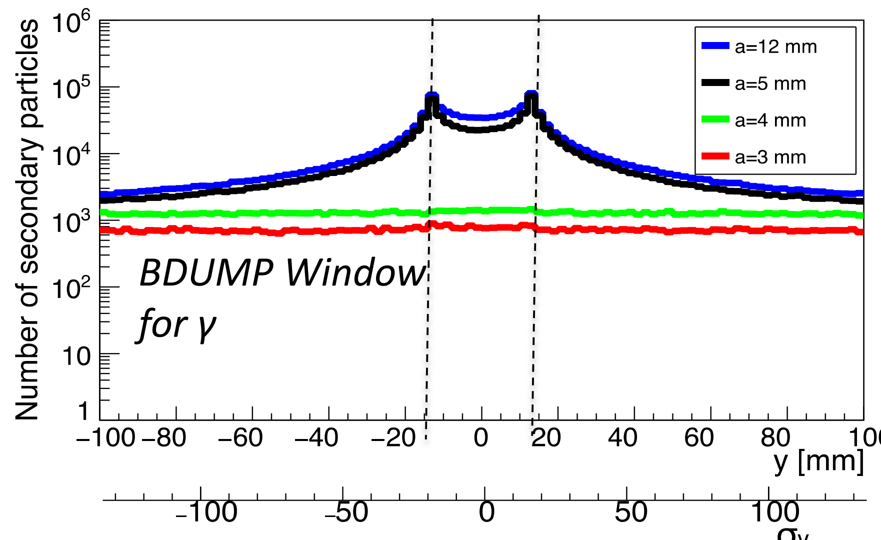
- The relative background is reduced when the collimator is closed more than **6 mm**

$$\Delta\gamma CE = 100\left(1 - \frac{\Delta\gamma_{wcoll}^{BDUMP-WINDOW}}{\Delta\gamma_{w/ocoll}^{BDUMP-WINDOW}}\right)$$

- The reduction of photons generated in the BDUMP was modeled using **BDSIM** (Geant4) as a function of the vertical collimation system half aperture showing **good consistency with measurements**

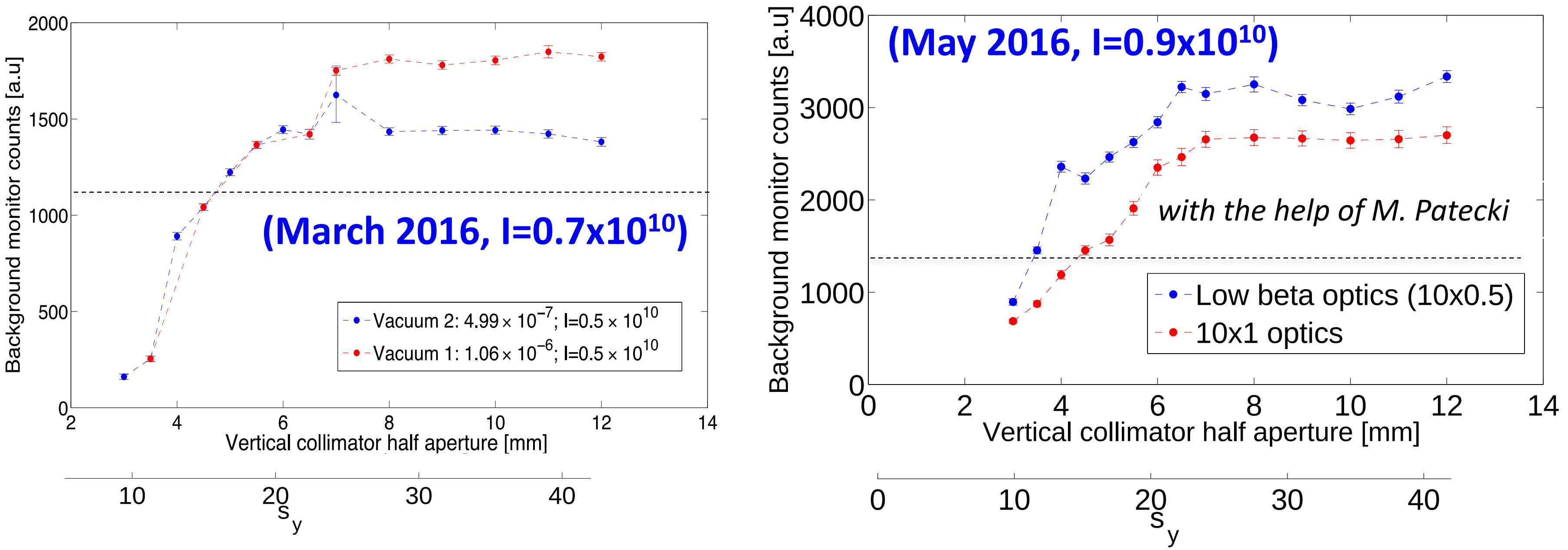






Realistic collimation efficiency and related measurements: Results

Background monitor measurements for different vacuum and optics



The **background level increases** for **high intensity**, **high vacuum** pressure and **low β**

To achieve the same level of background :

- No change in the collimation depth is observed with different vacuum pressure
- For **low β** optics the **collimation depth has to be reduced** about 3 σ_y

❑ Measurements were taken in **December 2016** with the **IPBSM** for the **(10βx × 1βy) optics and nominal machine conditions** and **no collimator aperture correlated effect** was observed

Summary

- A **retractable vertical collimation system** was installed in ATF2 in March 2016 and the functionality and efficiency in reducing the **background photons in the Post-IP has been** measured successfully.

- The **reduction of photons** generated in the **BDUMP** was modeled using **BDSIM** (Genat4) as a function of the vertical collimation system half aperture **showing good consistency with measurements.**

- **The collimator WF impact** has been completely studied by means of analytic models, numeric simulations and measurements. A **10% agreement on the benchmarking between CST PS** simulations and measurements has been measured which gives us the possibility to understand the impact of such a system improving the accuracy of past measurements. **This is crucial for FLCs since** the ATF2 vertical collimation system was inspired **on a first mechanical design of the ILC spoilers.**

- These WF measurements give **confidence on the CST PS simulations**, the wake potential calculated can be introduced in tracking codes. The **scaling to the ILC** bunch length of the **CST PS simulations for ATF2 has to be made.**

Thank you very much to the whole ATF2 collaboration for the help, beam time and knowledge shared! It has been a very nice experience!

Back up…

Beam dynamics simulation and realistic tracking studies

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	$46\sigma_y$	$27\sigma_x$

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 rectangular collimation system:

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

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

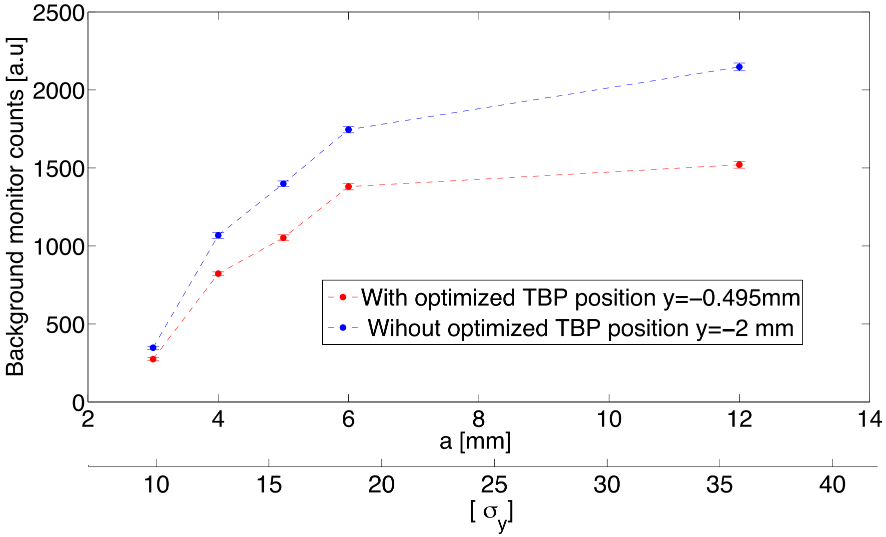
(*Collimator Wakefield Calculations for ILC-TDR Report, P. Tenenbaum, LCC-0101, August 2002*)

Optics considerations for a single rectangular betatron collimation jaw:

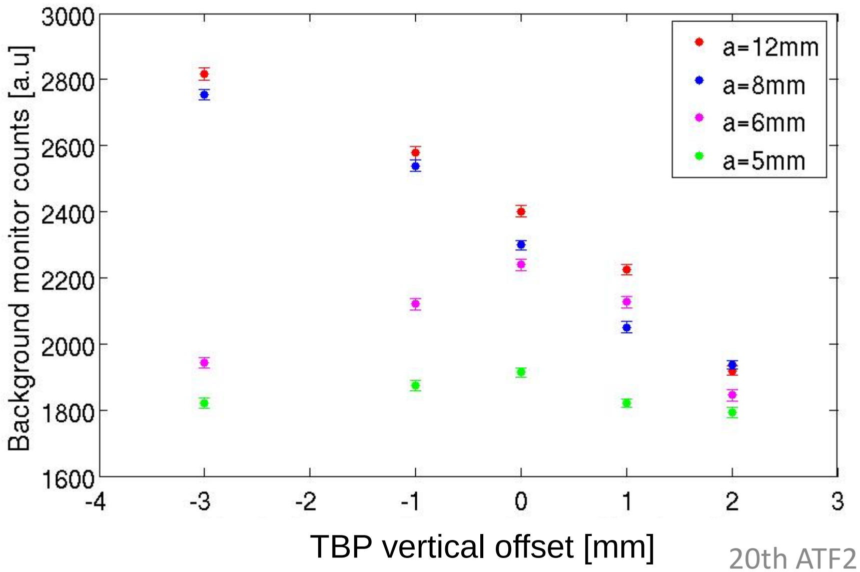
- High $\beta_{x,y}$ for a given *N* with bigger *a*
- $\Delta\mu_{x,y}=n\pi$ in phase with the collimation point (**BDUMP** and **DS**)
- $D_{x,y} \cong 0$ for a pure betatron collimation

Collimation efficiency and related measurements: Results

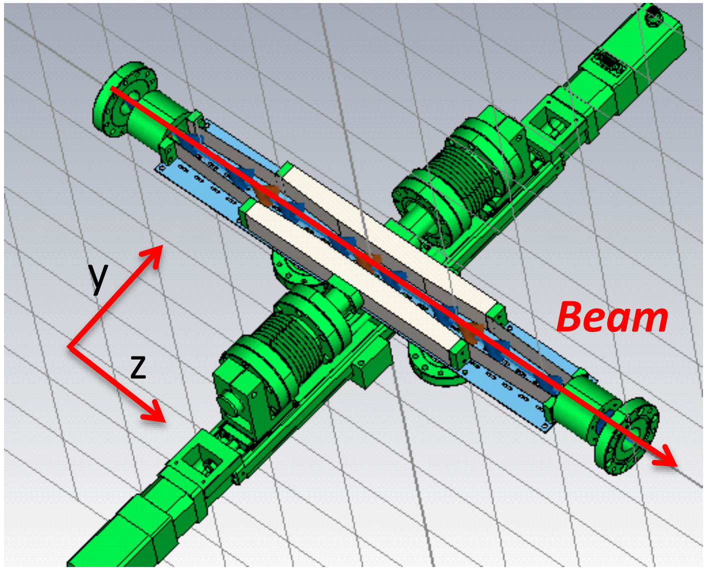
Measurements were taken in **May 2016** to investigate the collimation and TBP efficiency

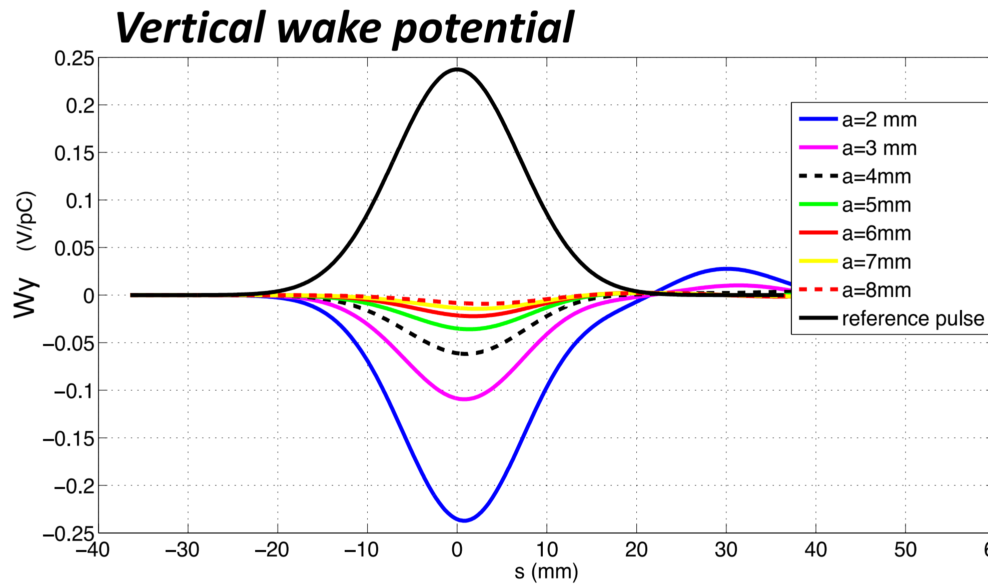


The TBP works as a collimation system but limited to a maximum symmetric cut of 18 σ_y for a centered beam in the BDUMP a 25-35% reduction of background is measured (orbit dependence)In order to achieve the same impact the vertical collimation system has to be closed between 5- 6 mm corresponding to 15-18 σ_y



Wakefield design considerations and impact study

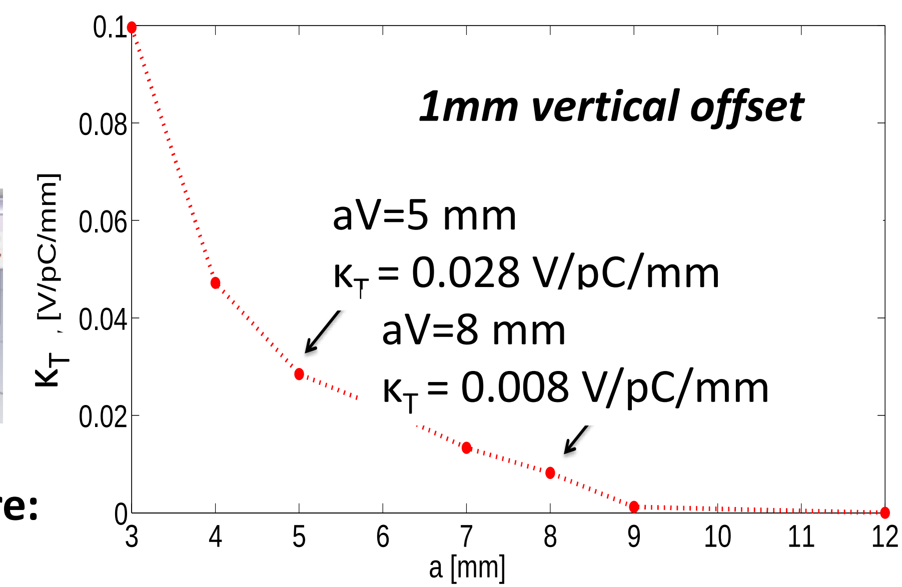


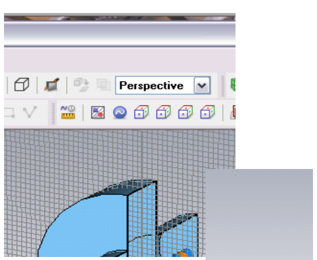


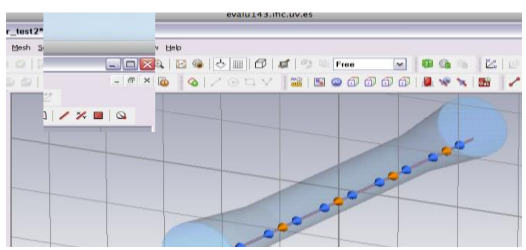
Beam: σ_z=7 mm , **N**=10^6 , 1mm vertical offset

Jaws made of Cu and rest made of SS

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





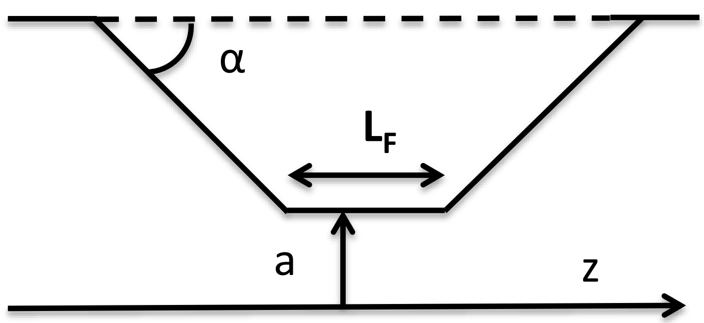


Reference cavity:
κ_T = 0.079 V/pC/mm

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

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

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