BEAM HALO COLLIMATION AND HALO STUDIES AT ATF2

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Some acts in collaboration with KEK team, G. White and E. Marin, A. Latina and J. Snuverink

i-link Project Meeting

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Motivation

Beam halo is an important issue for **beam loss and background control in accelerator machines as ATF2** and the **Future Linear Colliders (FLC)**

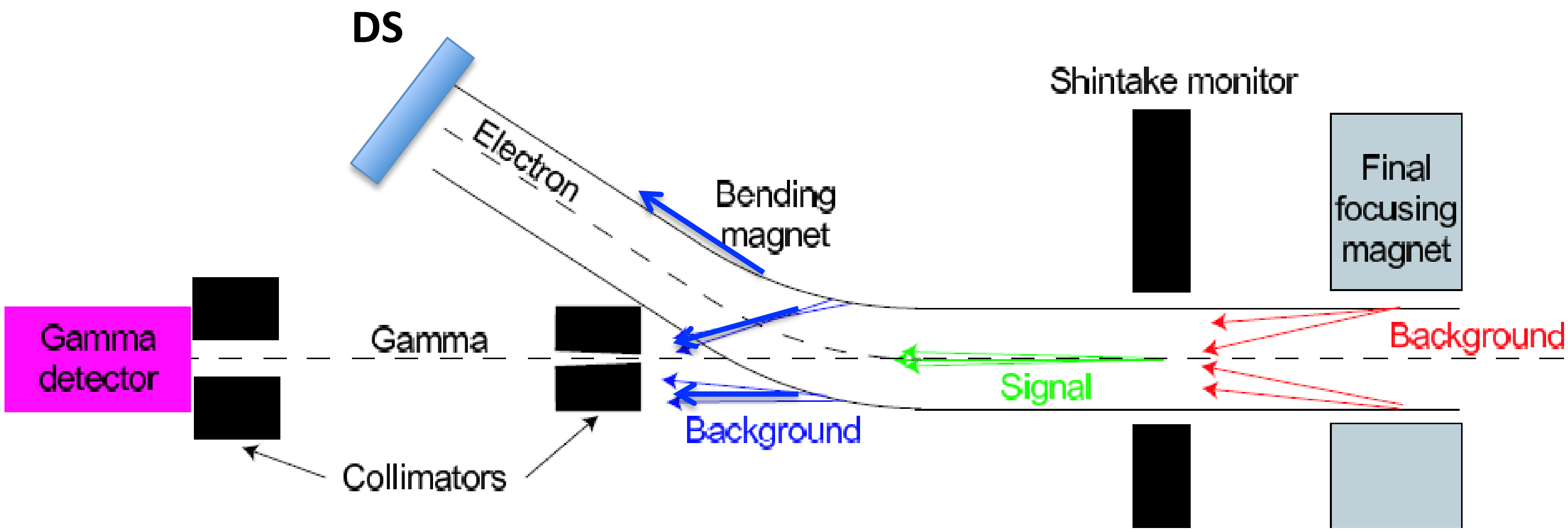
Two Diamond Sensors have been installed in December 2014 and beginning 2015 after the last bending magnet of ATF2 to perform dedicated horizontal and vertical **transverse beam halo distribution measurements**

Transverse beam halo collimation at ATF2 has been studied being the **main objective of the halo collimation system** to **control and reduce the beam halo** that could generate bremsstrahlung background limiting the performance of the key diagnostics devices around the final focus point as the **Shintake monitor (IPBSM) and the DS**

Outline

- Beam halo reduction: status report on the collimation project
- Beam halo measurements and parameterization in the EXT line

Transverse halo collimation system motivation



The main objectives of a transverse **halo collimation system** are:

- **Vertical and horizontal beam halo reduction** to enable controlling the **bremsstrahlung background in the Shintake monitor**
- **Beam halo control** to enable reliable measurements of **vertical and horizontal** beam halo at the **DS**
- **Horizontal beam halo reduction to enable Compton** electron measurements at the **DS**

Objectives of the project

1. **Beam dynamics simulation and realistic tracking studies** in ATF2 to evaluate the efficiency as a function of the half aperture of the collimator and find the best location (IFIC-LAL-KEK)

2. **Design of a retractable halo collimation 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** of the halo collimation device in ATF2 (IFIC-KEK-LAL)

6. **Halo control (DS), background reduction (SM and DS) and collimator wakefield studies** using the ATF2 vertical halo collimator system (IFIC-KEK-LAL)

Beam dynamics simulation and realistic tracking studies

Tracking studies along the EXT+FF+PostIP line of ATF2 using MAD-X -> Loss map

- **Beam core** (Gaussian distribution) -> No losses were observed
- **Beam halo**: (gaussian, uniform, “realistic”)

To find the **best location** and the most **efficient collimation depth** in terms of **halo cleaning and wakefield minimization** of a halo collimation system

Beam and halo input simulation parameters*:*

Number of particles: *10^4*

E*=1.3 GeV*

$\varepsilon_x = 2\ 10^{-9}$ *m.rad*

$\varepsilon_y = 1.18\ 10^{-11}$ *m.rad*

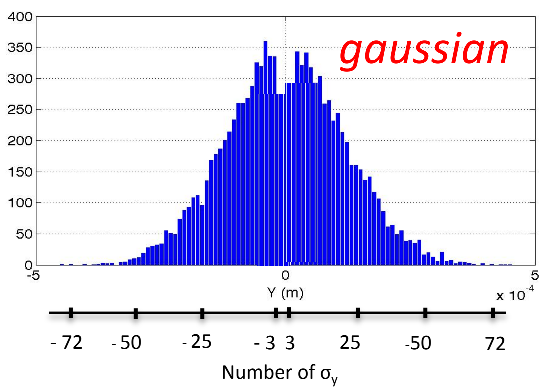
σ_E*: 0.08%*

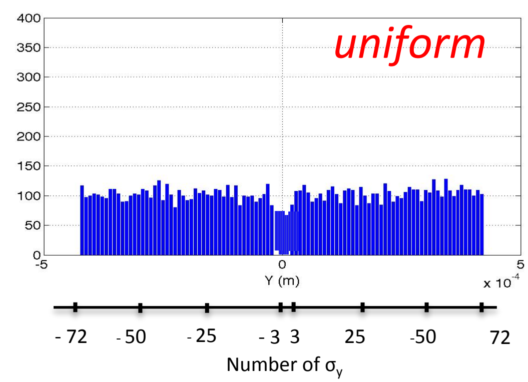
Optics configuration: *10x1 (v5.2)* / *1x1 (v5.2)*

Multipoles

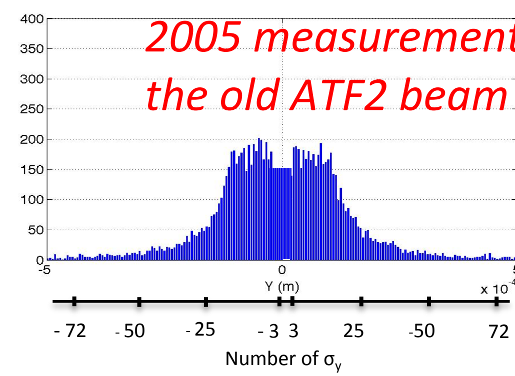
No misalignments

No coupling between x-y planes

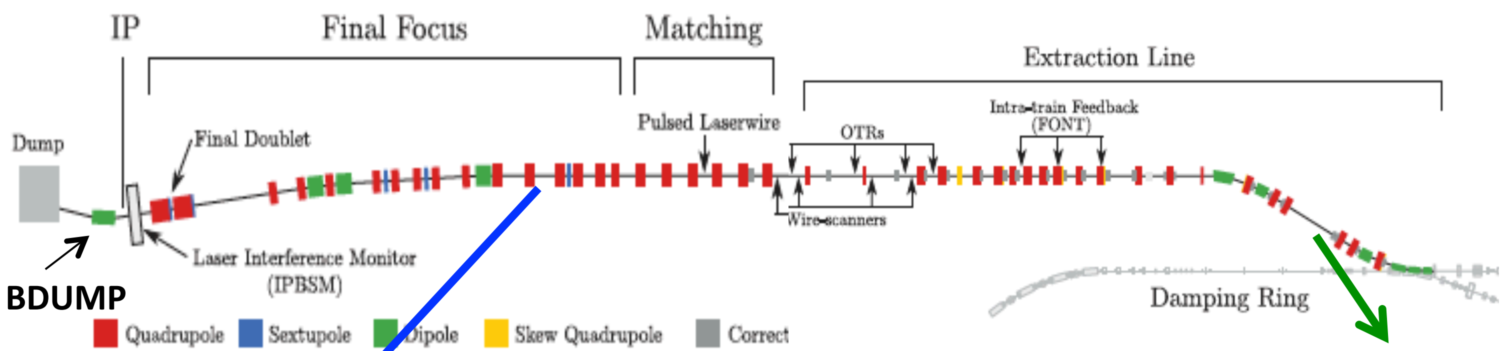


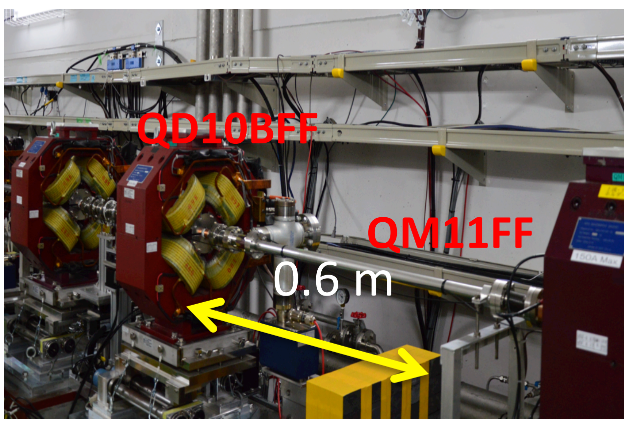


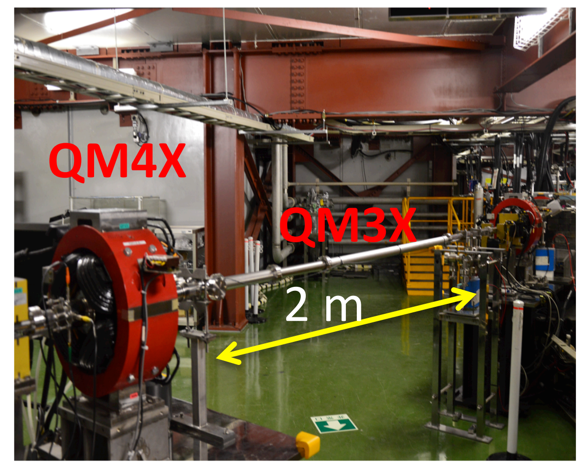
“realistic” based on 2005 measurements in the old ATF2 beam line



Beam dynamics simulation and realistic tracking studies







Horizontal halo collimation system in the EXT line

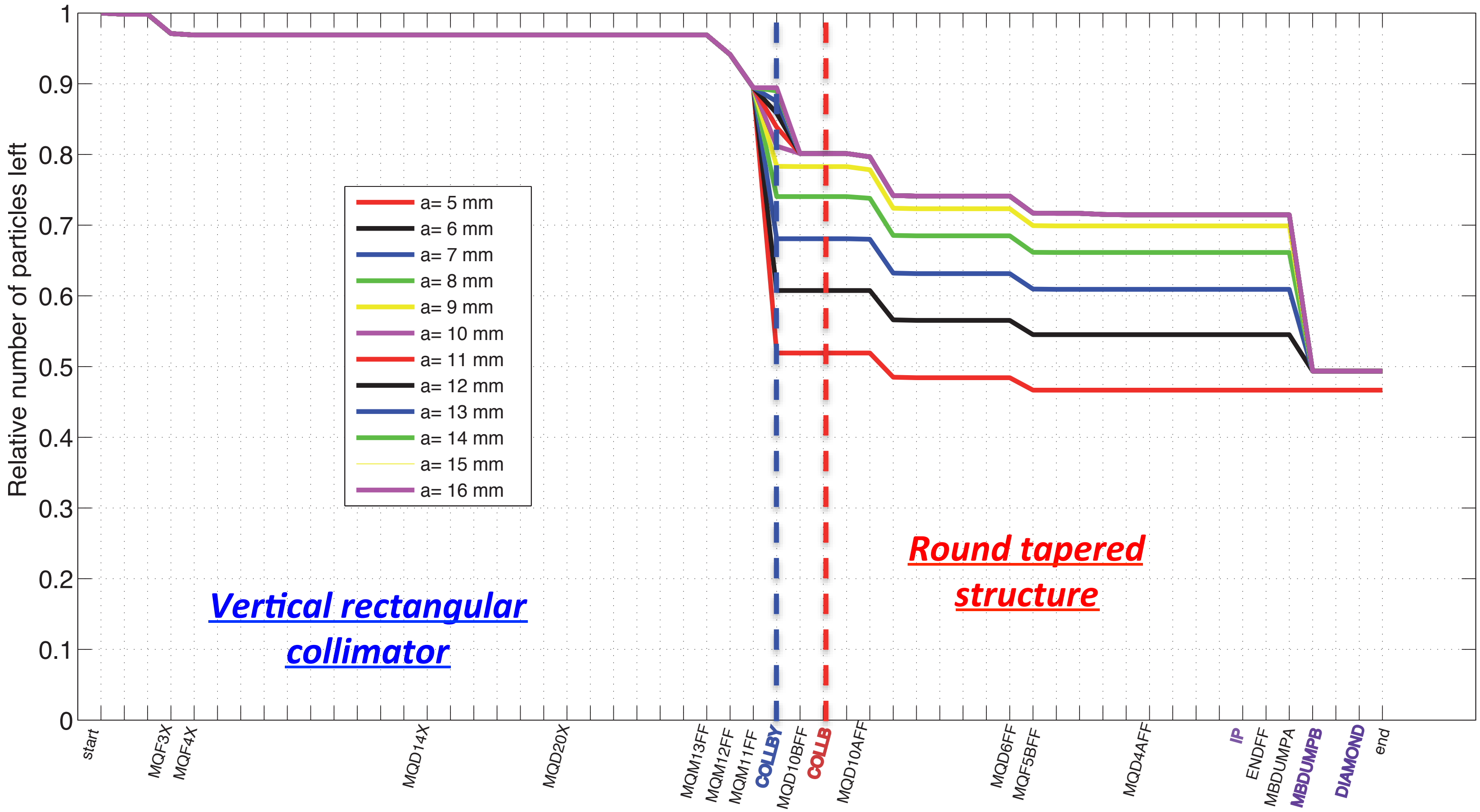
- Between **QD4FX-QD3FX**
- β_x=157.02 m
- 2 m available free space length

Vertical halo collimation system in the FFS

- Between **QD10BFF-QM11FF**
- β_y=7126.51 m
- 0.6 m available free space length

Beam dynamics simulation and realistic tracking studies

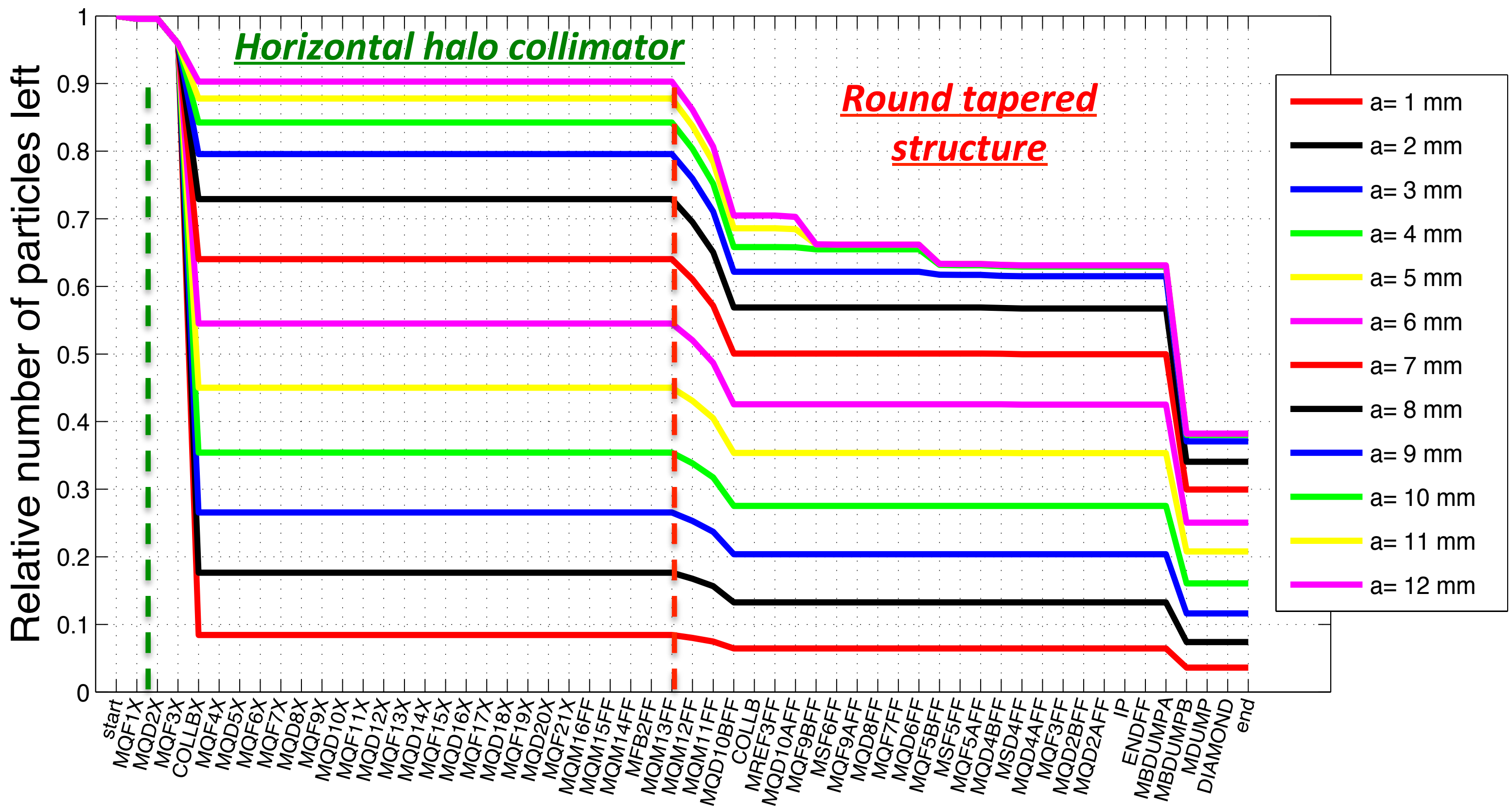
Only vertical collimation, 10x1 optics, "realistic" halo model



- **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

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

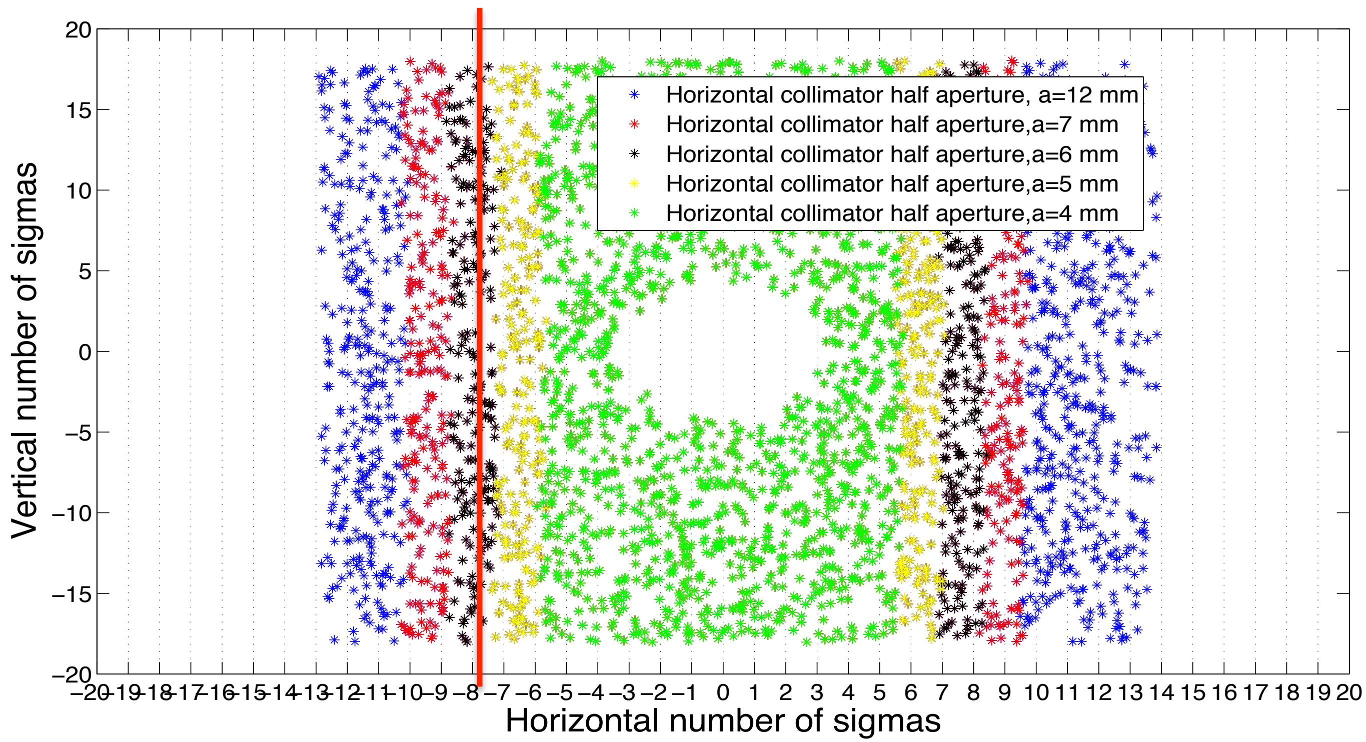


- **Collimating only the horizontal plane we still have losses at the BDUMP**

Beam dynamics simulation and realistic tracking studies

- **Horizontal beam halo collimation could enable Compton** electron measurements at the **DS**
- Based on recent measurements and **BDSIM** simulations the horizontal beam halo needs to be **collimated around 8 σ_x** in order to measure the Compton signal

Beam halo distribution at the Diamond Sensor



- **A horizontal aperture of 5 mm is need in order to cut the halo at the level of 8σ_x**

Collimation system beam halo losses

The losses at the collimator because of radiation safety at ATF **requires less than 0.4 % beam loss of the maximum intensity in normal operation**

a(mm)	No. cut $\sigma_{y,x}$	Particle lost I= 10^{10} (%)
Vertical beam halo collimator		
12	**37**	**0.01**
5	15	0.04
Horizontal bean halo collimator		
12	**27**	**0.01**
5	9	0.5

- **Tracking simulations to study beam losses and secondary particle emission and with BDSIM are in progress**

- **The ATF2 lattice is being update** -> S. Boogert, J. Snuverink, L. Nevay, H. Garcia-Morales, (RHUL)
  - New collimator geometry
  - Realistic geometrical apertures

Design of a retractable halo collimation device: wakefield study

- The vertical prototype has been considered as the first priority because can improve the performance of both SM and vertical DS
- A retractable prototype is being considered because of its flexibility in terms of operational aspects

Design of a retractable halo collimation device: Wakefield study

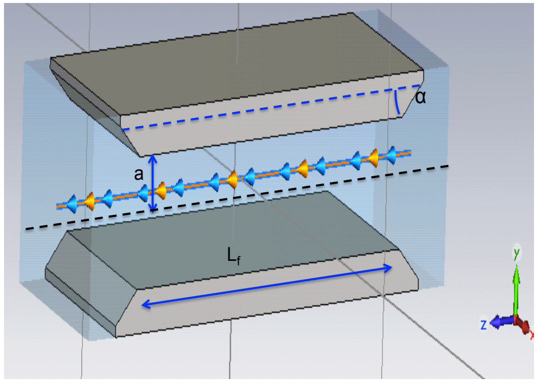
- Wakefield collimator jaws optimization
  - **Analytical** (Based on **Stupakov model 2002**)
  - **Numerical simulations** using **CST PS**
- Wakefield impact study of the realistic 3D collimator system with CST PS
- Wakefields beam impact induced studies (orbit distortion and beam size growth)
  - **Linear approximation**
  - **PLACET tracking code** (A. Latina and J. Snuverink)
    - *A discrepancy was found between the linear approximation and the tracking code PLACET.*
    - *The problem was in how the models where implemented in PLACET.*
    - *The modification will be implements in the PLACET version 1.0.2 and a published as a CLIC note.*

Collimator jaws optimization

➢ Numerical simulations using CST PS: simplified model

- **Rectangular chamber in x and y**
- **Two independent movable vertical jaws**
- **Beam**
  - y_{offset}**= 1 mm**
  - σ_z=7 mm
  - **N**=10^6

  (Charge 1pC)

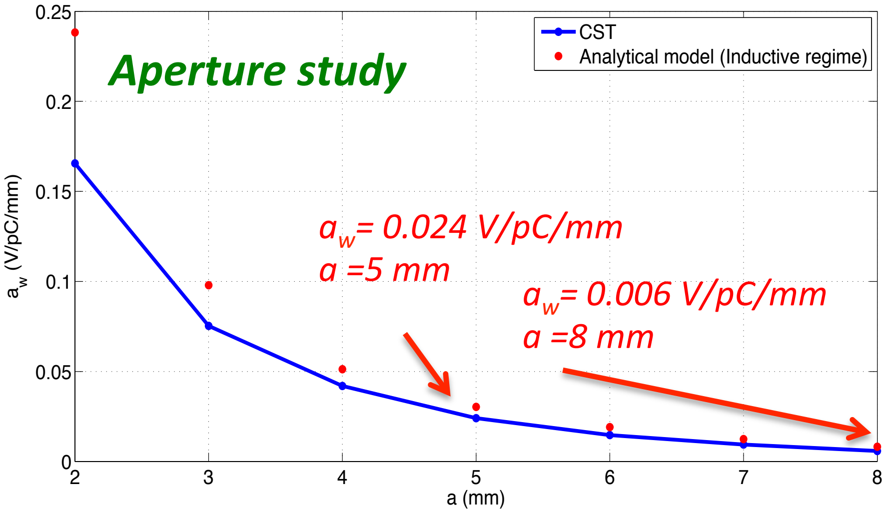


➢ Analytical calculations

[G. V. Stupakov, "High-frequency impedance of small-angle collimators", PAC01]

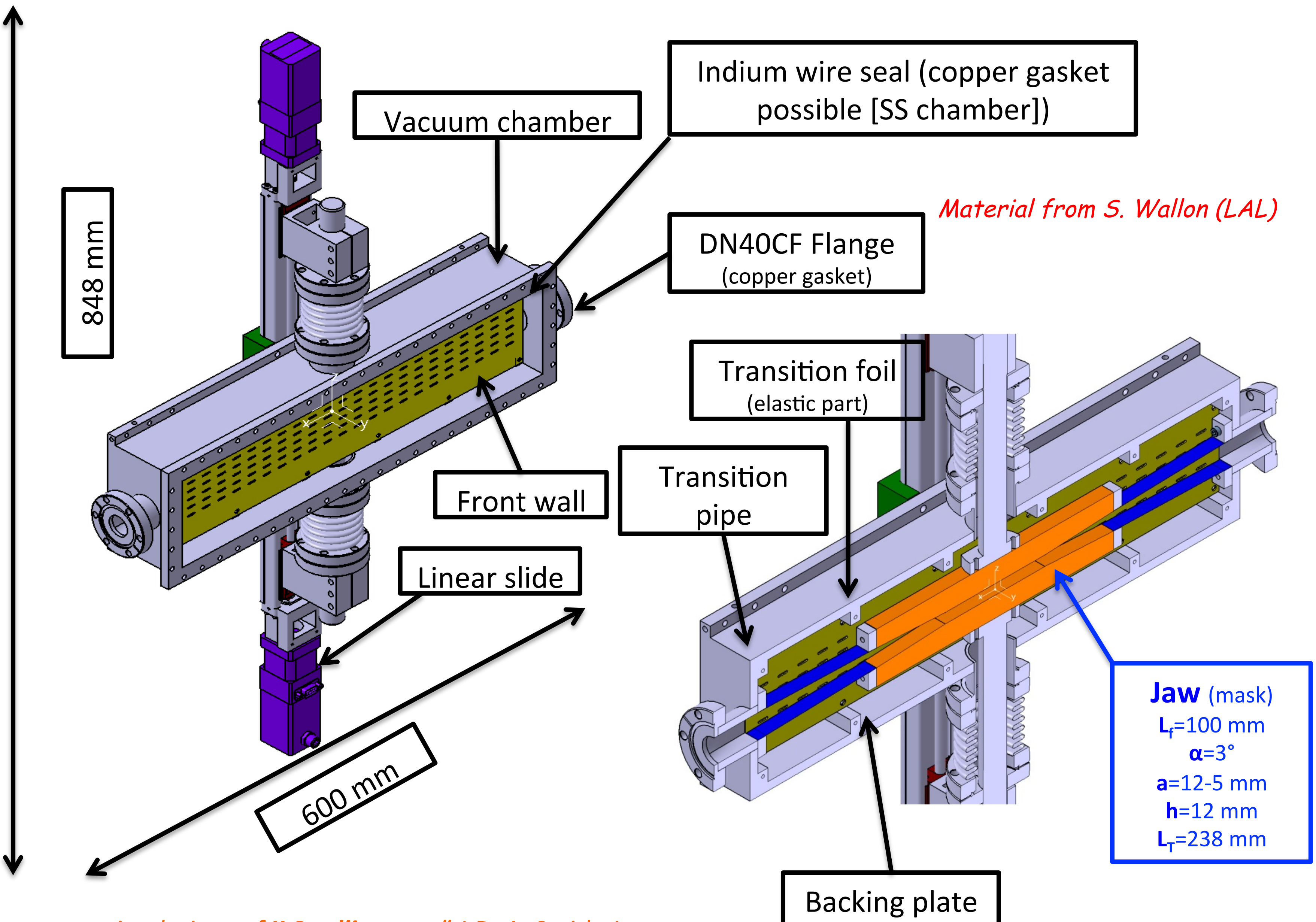
[G. Rumolo, A. Latina, D. Schulte,"Effects of wakefields in the CLIC BDS", EUROTeV 2006] [A. Piwinski, DESY-HERA-92-04, 1992]

- **Parameters studied**
  - **a**: between 2 mm and 8 mm
  - **Lf**: between 50 mm and 300 mm
  - **α**: between 3° and 90°
  - **Material**: Cu, Al, SS



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

First 3D design Design of a retractable halo collimation device

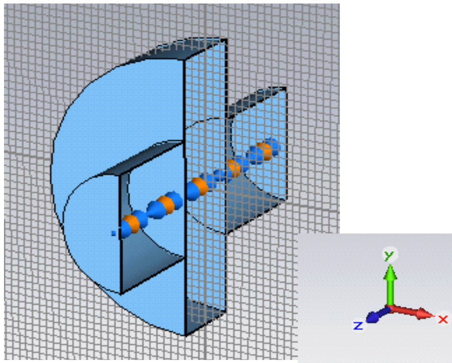


Material from S. Wallon (LAL)

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

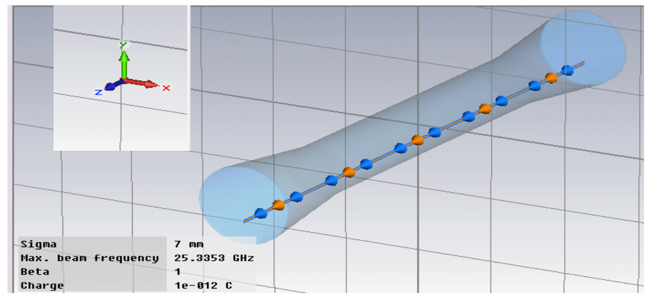
Wakefield impact study

Reference cavity

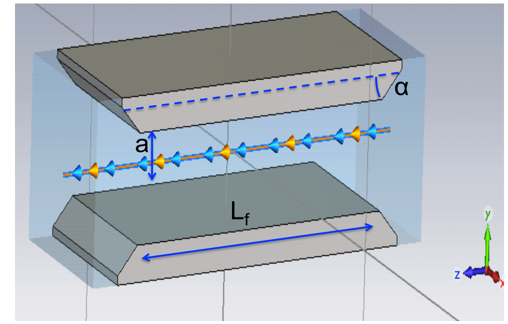


(high level of wakefields*)

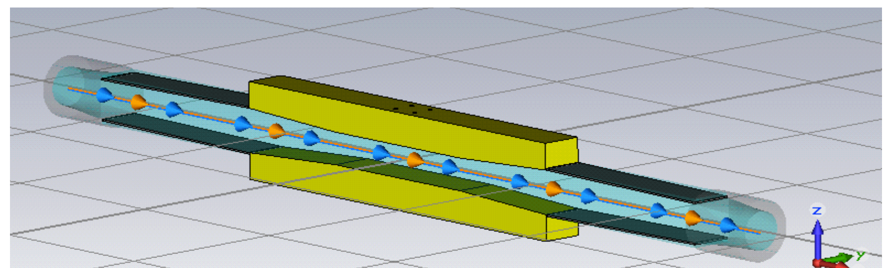
Round tapered "collimator"
(between **QD10BFF –QD10AFF)**



(low level of wakefields)



Rectangular tapered collimator

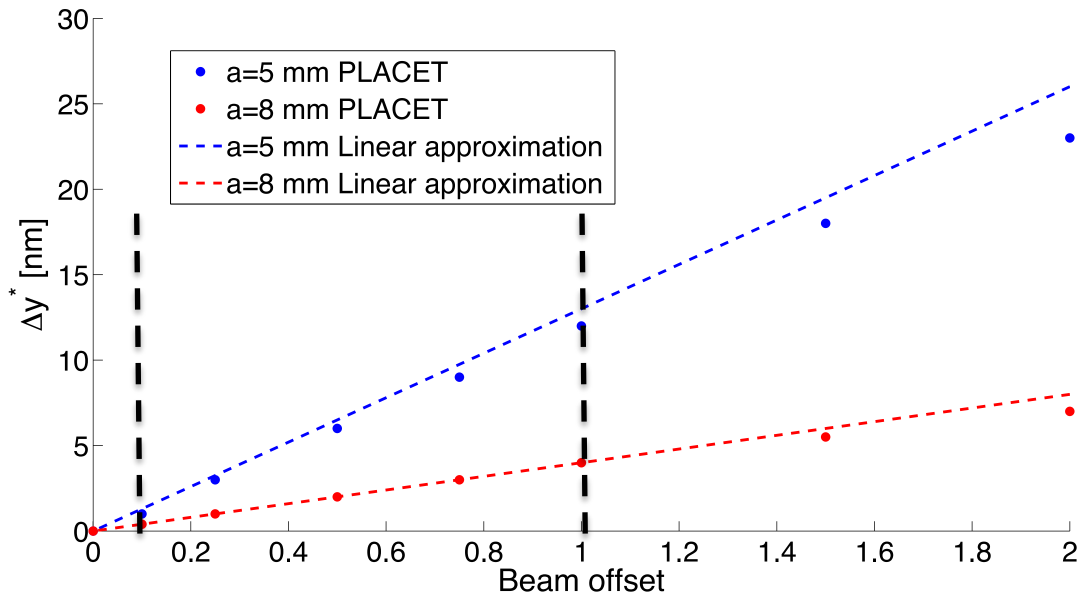


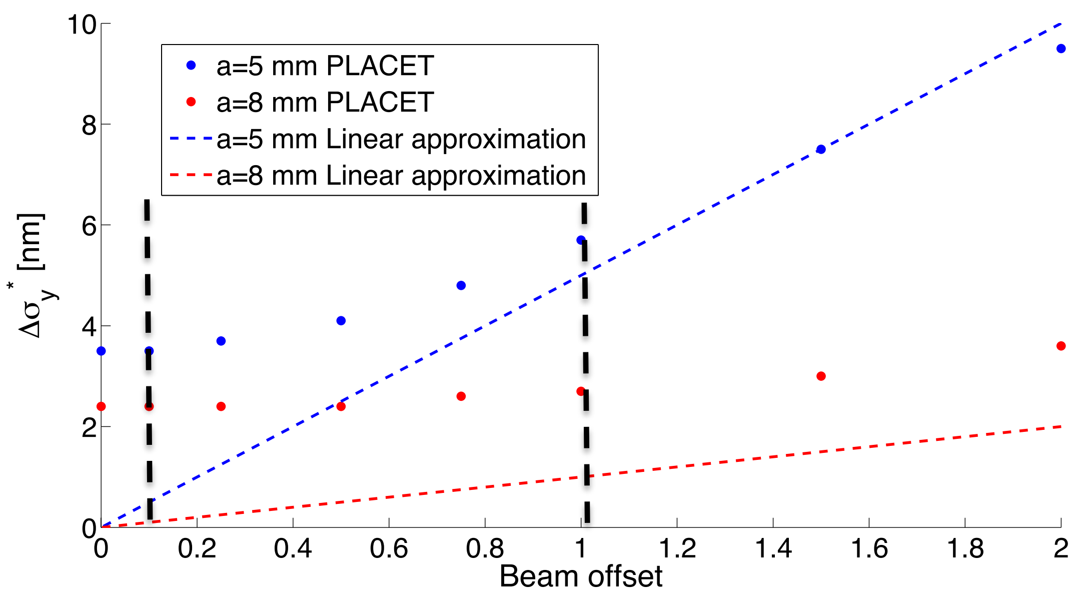
(jaws+transition part)

*https://agenda.linearcollider.org/event/5840/session/40/contribution/232/material/slides/0.pdf

	Refrence cavity	Round collimator	Rectangular collimator (a=8mm)	Rectangular realistic (a=8mm)	Rectangular realistic (a=5mm)
a_w (V/pC/mm)	0.089	0.0052	0.0061	0.008	0.028

Wakefields beam impact induced studies





Beam impact studies:

PLACET

- $N=6x10^9e$
- Rectangular collimator with L_F=100 mm, α=3°
- σ_z= 7 mm
- ***10x1 optics***

a=5 mm

y_{offset} = 1mm -> 0.1 mm

*Δy *= 12 nm -> 2 nm*

*$\Delta\sigma_y$ *= 6 nm -> 3.5 nm*

****In the case of the horizontal collimator with a=5mm the impact in the horizontal plane for 1 mm offset is smaller than 0.1%***

Summary

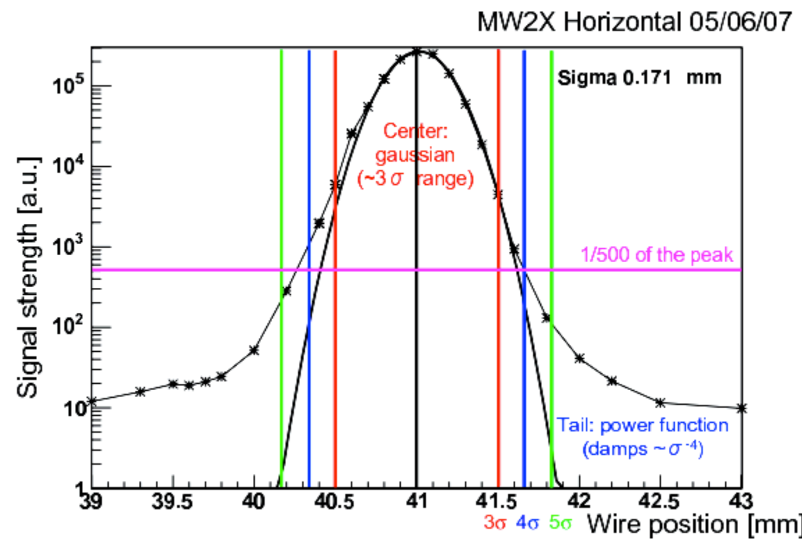
- A **vertical collimation system in the FFS** with **5 mm half aperture** to avoid any losses at the last bending magnet
- A **horizontal collimation system in the EXT line** with **5 mm** half aperture could be used to cut the horizontal halo at the DS around 10-8σ in order to enable the **Compton electron measurements**
- A **vertical collimator system has been designed with geometry and materials optimized to minimize the wakefield impact**. However in the case of the vertical collimator also **a good alignment** is required to ensure a low wakefield impact
- The **wakefield impact of a horizontal collimator** with the same design parameters as the vertical is lower than the 0.1% of the horizontal bema size
- The construction of a vertical collimator prototype is in progress- > Talk by S. Wallon

Work in progress

- **BDSIM simulations** are in progress to study losses at the collimator and secondary particles emission

Beam halo measurements and parameterization in the EXT line

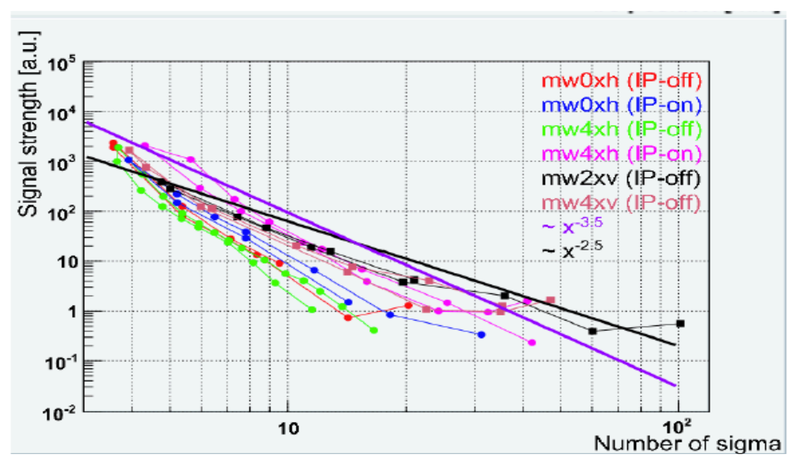
- The beam halo in the EXT line was measured in 2005 for the old EXT line
- **We want to update the parameterization in order to perform realistic tracking simulations of the beam halo**



Halo density parameterization

$$\rho_H/N = 1.0 \quad X^{-3.5} \quad with \quad 3 < X < 6$$

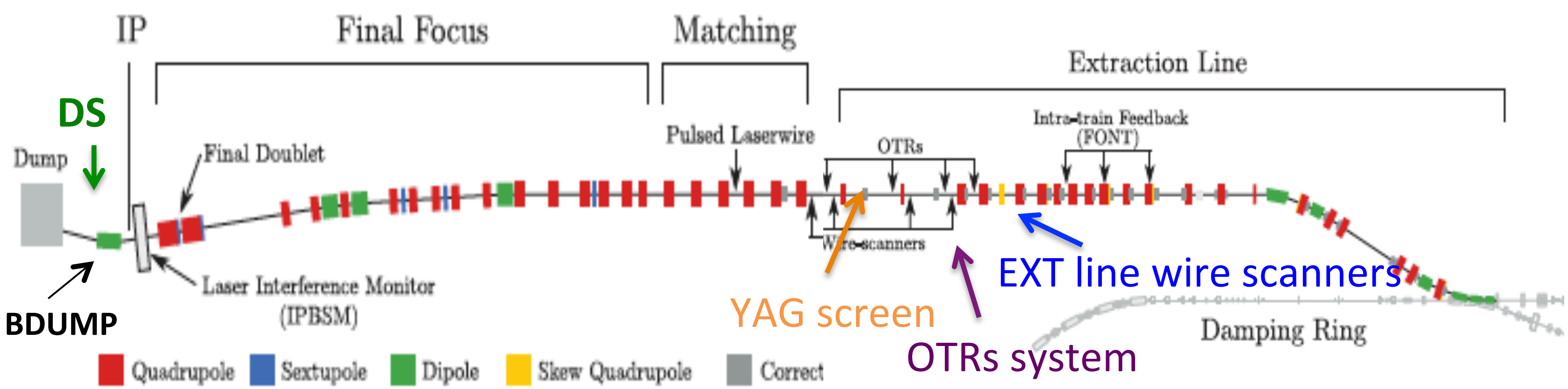
$$\rho_V/N = \begin{cases} 1.0 \quad X^{-3.5} & with \quad 3 < X < 6 \\ 0.17 \quad X^{-2.5} & with \quad X > 6 \end{cases}$$



***ρ_H** horizontal beam halo density,*
***ρ_V** vertical beam halo density*
***X** number of σ*
***N=10^{10}** electrons*

T. Suehara et al., "Design of a Nanometer Beam Size Monitor for ATF2", arXiv:0810.5467v1

Beam halo measurements in ATF2 EXT line



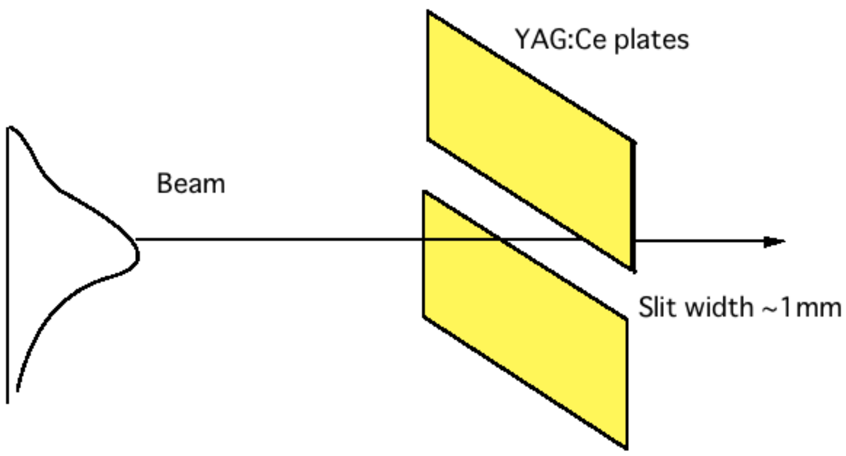
- YAG screen: measurements being done by T. Naito (2014/2015)
- EXT line wire scanners (WS) (2013)

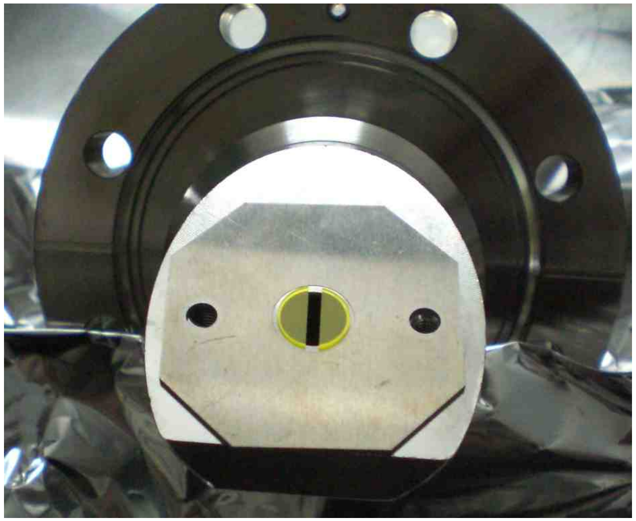
OTRs system halo/background studies: tails were compared with the WS tails but the **low dynamic range of OTRs images and optical aberrations** makes the measurements not comparable

2015 EXT Yag screen measurement campaign

2015/02/25 ATF2 project meeting
KEK T.Naito

0.5mm thickness (2014) -> 0.1mm thickness (2015)

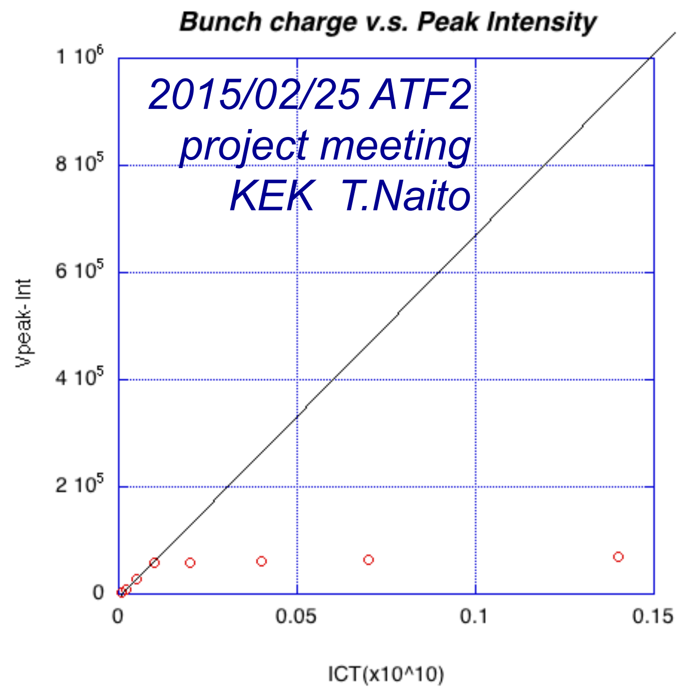




- The beam halo can be observed when hit the YAG:Ce (0.5mm thickness) screen with 1mm slot in vertical direction. The core part goes though without any interaction
- **The beam halo is scanned by moving the beam using the magnet ZV11X**

2015 EXT Yag screen measurement campaign

- **Data acquisition (2015 May)**
  - $I=0.15\times10^{10}$ and $I=0.4\times10^{10}$
  - 10x1 optics
- **Gaussian beam core**
  - σ_y~20 μm
  - Intensity of the core peak from linear extrapolation because of saturation
- **Data normalization**
  - Number of sigma normalization
  - Intensity normalization
- **Fit tails to the gaussian profile**

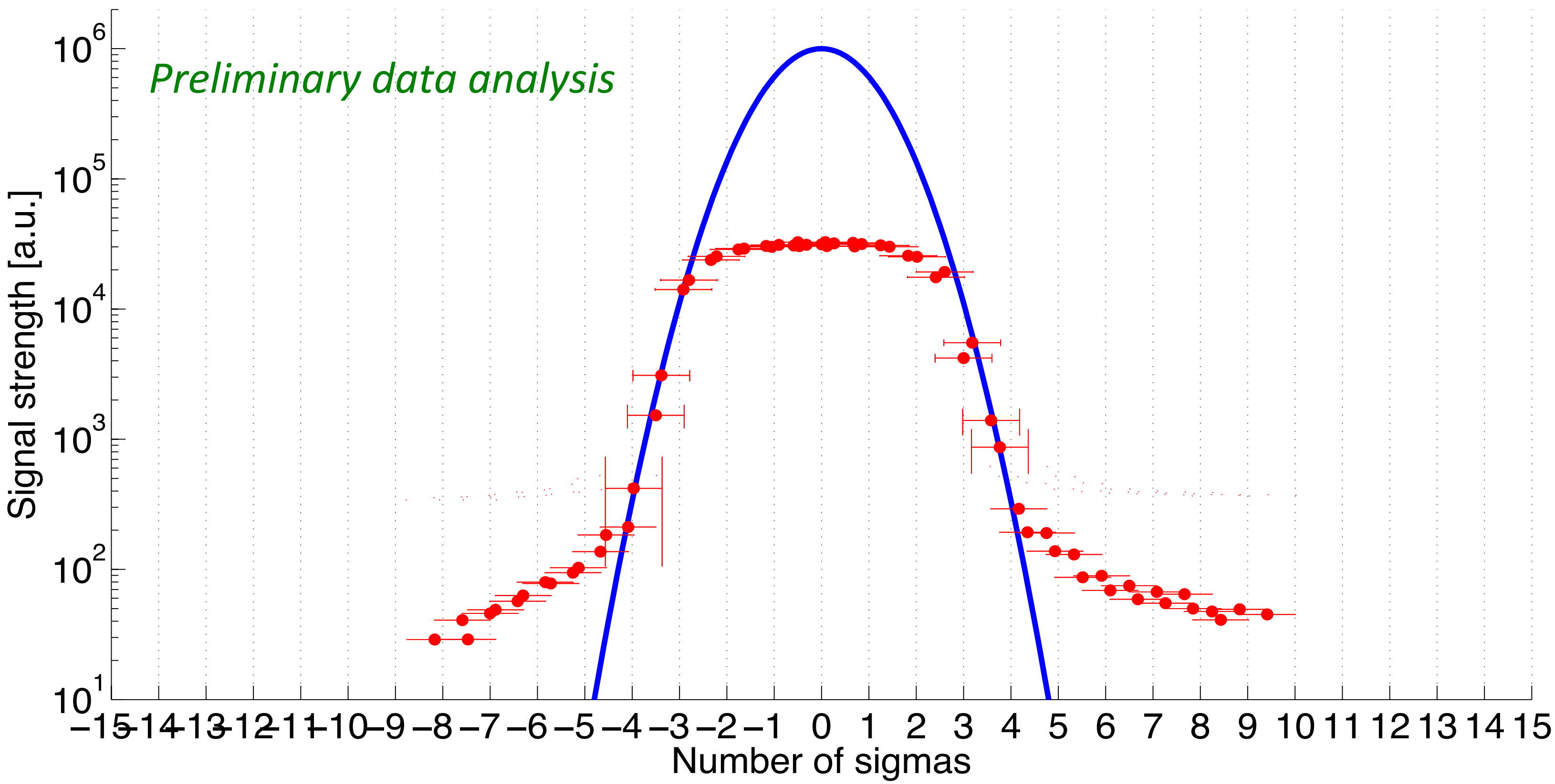


- **Fitting**
  - Power function **normalized to the total number of particles of the bunch, N**

$$\rho_{H,V}/N = (A/N)X^{-b}$$

2015 EXT Yag screen measurement campaign

- Combined data for the two intensities used for the measurements
- The tails differ from Gaussian around 4σ



Beam core-halo limit: new approach

- In the **first** wire scanner **analysis** we perform the fit **cutting at 3σ**

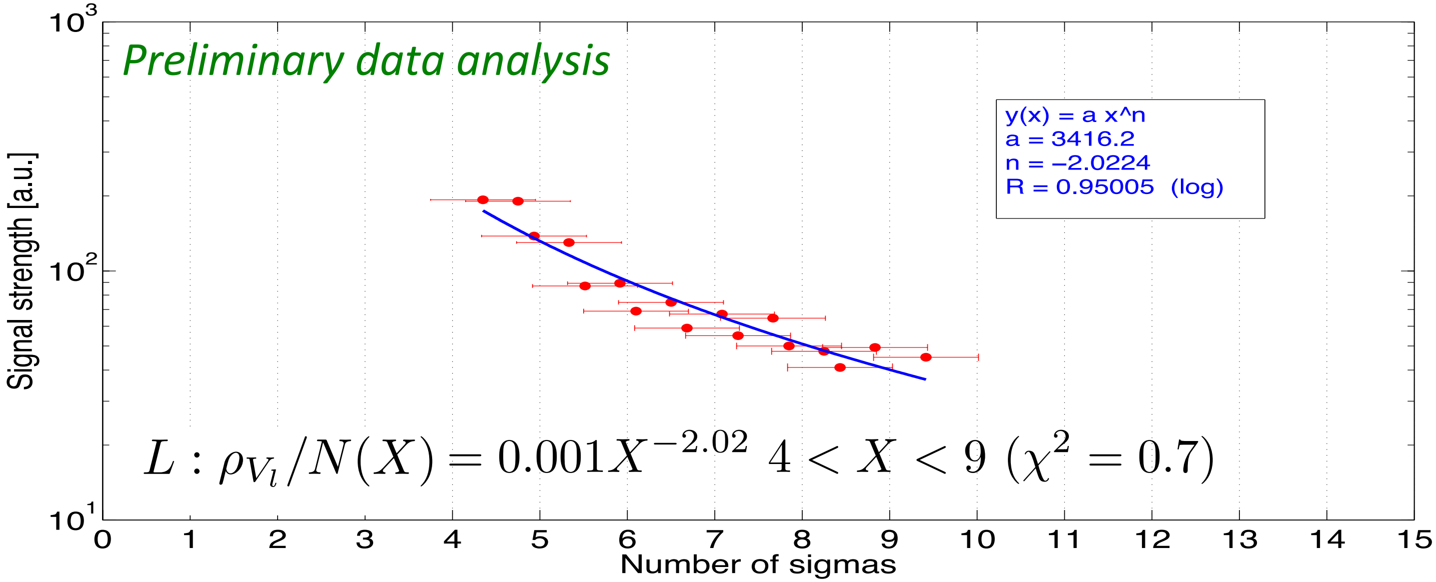
- **New criterion** to determine the limit between the core and halo is used based on:

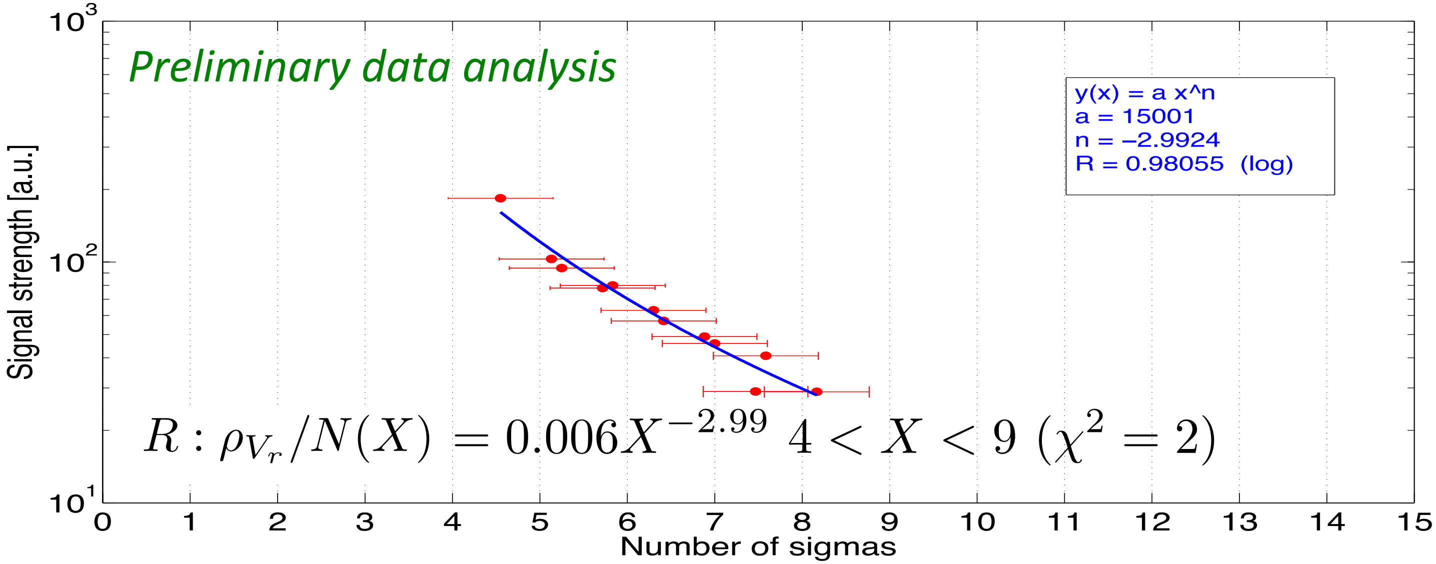
  P.A.P Nghiem, N. Chauvin, W. Simeoni, D. Uriot "Core-halo issues for a very high intensity beam" Applied physics letters 104, 074109 (2014)

- In this paper the core-halo limit is generalized as the location where there is the **steepest density gradient variation and it is related with the space charge field on the bunch**

- We plan to collaborate with Sacley team to analyze the beam halo data with the new approach and define a better parameterization of the beam halo distribution measured

2015 EXT Yag screen measurement campaign





Preliminary fitting summary and comparison

Wire scanner (MW2X)

$$R: \rho_{V_r}/N(X) = 0.006X^{-2.4}\ 4 < X < 7\ (\chi^2 = 2.8)$$

$$L: \rho_{V_l}/N = 0.004X^{-2.1} 4 < X < 7(\chi^2 = 3)$$

Yag-screen (trim coils ON)

$$R: \rho_{V_r}/N(X) = 0.006X^{-2.99}\ 4 < X < 9\ (\chi^2 = 2)$$

$$L: \rho_{V_l}/N(X) = 0.001X^{-2.02}\ 4 < X < 9\ (\chi^2 = 0.7)$$

- Vertical beam halo measurements with wire scanner (MW2X) taken in 2013 are consistent with the Yag screen measurements (2015). But both measurements are limited to a few sigmas (7-9σ)

Summary

- Beam halo tails measured with the Yag screen (2015) have been compared with the wire scanner (MW2X) data taken in 2013

- **A new beam core-halo limit has been used to analyze and fit the data**

- Beam halo measured with the **Yag screen and wire scanner are consistent**

- Beam halo in the EXT line is **still limited to a few sigmas (9σ)** therefore ways to improve the dynamic range of the Yag screen could be investigated

Thank you very much for your attention!!

Back up…

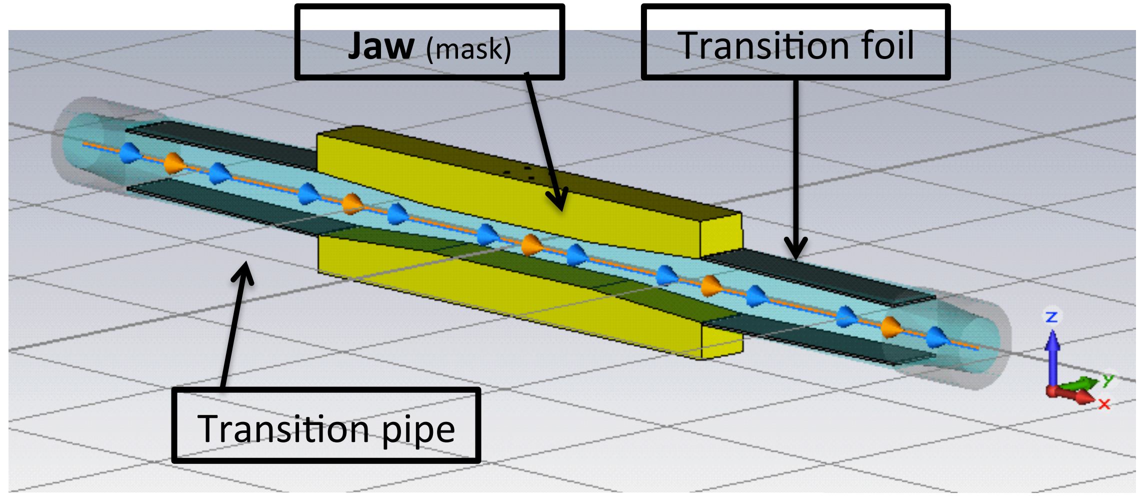
Beam dynamics simulation and realistic tracking studies

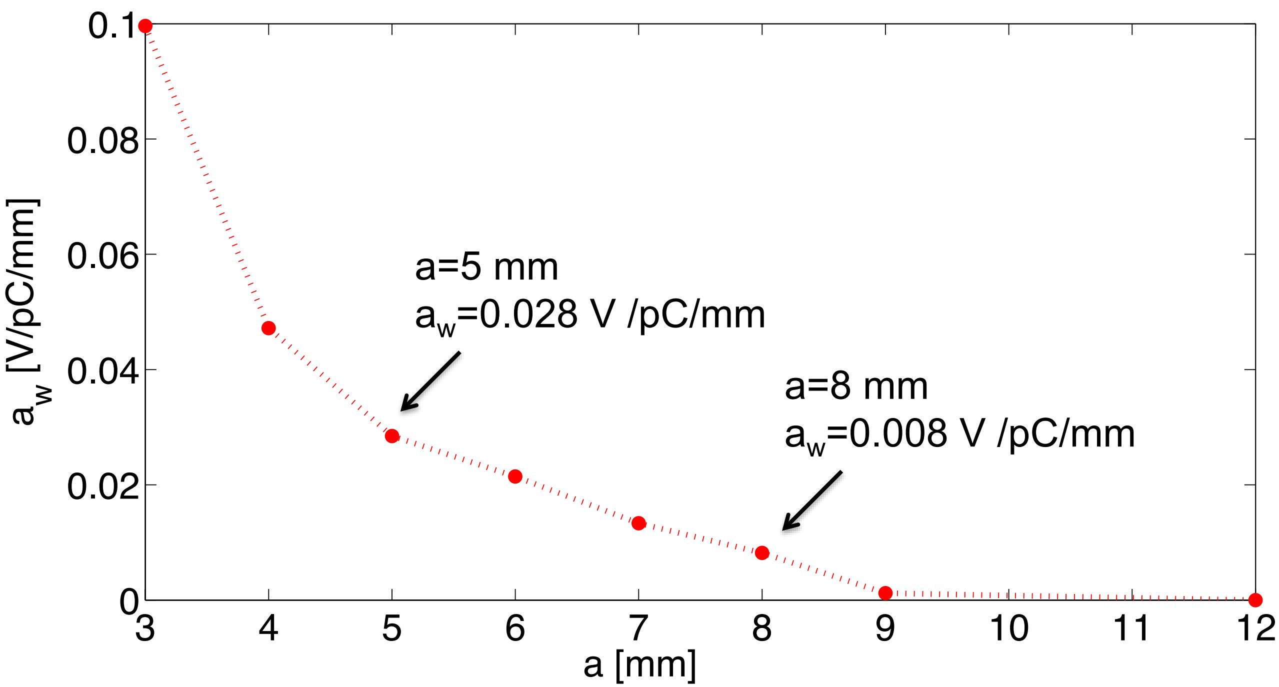
Halo collimation betatron depth

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	$46\sigma_y$	$27\sigma_x$

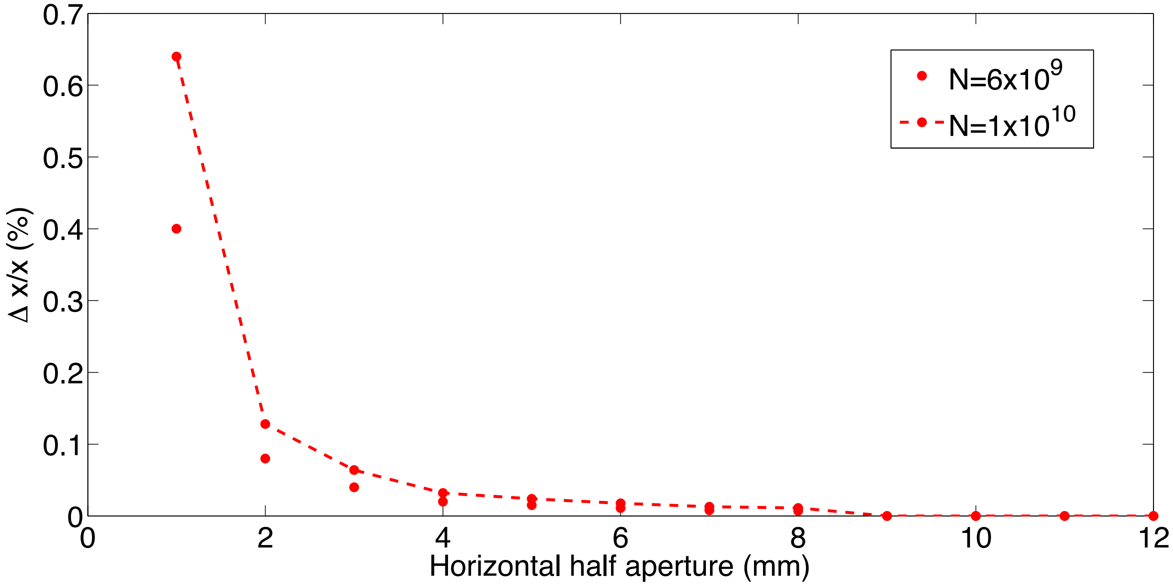
Design of a retractable halo collimation device: wakefield study

- **Beam:** σ_z=7 mm , **N**=10^6 (Charge 1pC)
- **Jaws made of Cu and other part made of SS**
- **Jaws: a**: 5 mm, **Lf**: 100 mm, **α**: 3°





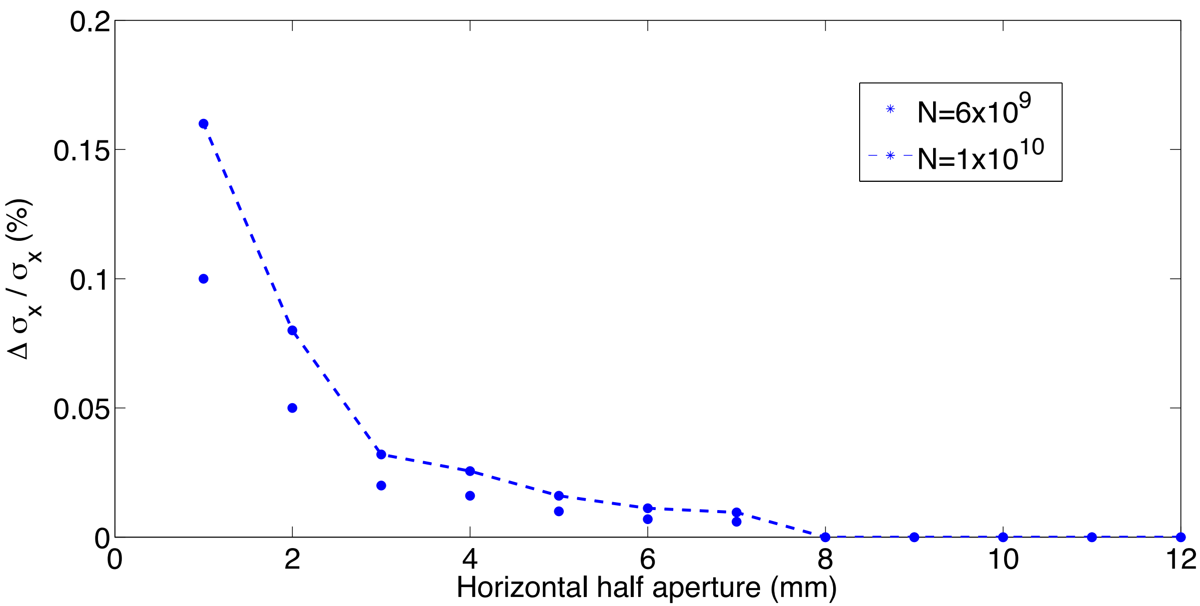
Wakefields beam impact induced studies



Beam impact studies:

PLACET

- $N=6x10^9e$, $N=1x10^{10}e$
- Rectangular collimator with L_F=100 mm, α=3°
- 1 mm offset
- σ_z= 7 mm
- ***10x1 optics***



Very small impact in the horizontal plane and negligible in the vertical plane even for 1 mm beam offset

2013 EXT wire scanners measurement campaign results

Vertical and horizontal beam halo measurements were done in the **EXT** line with **MW2X April 2013**

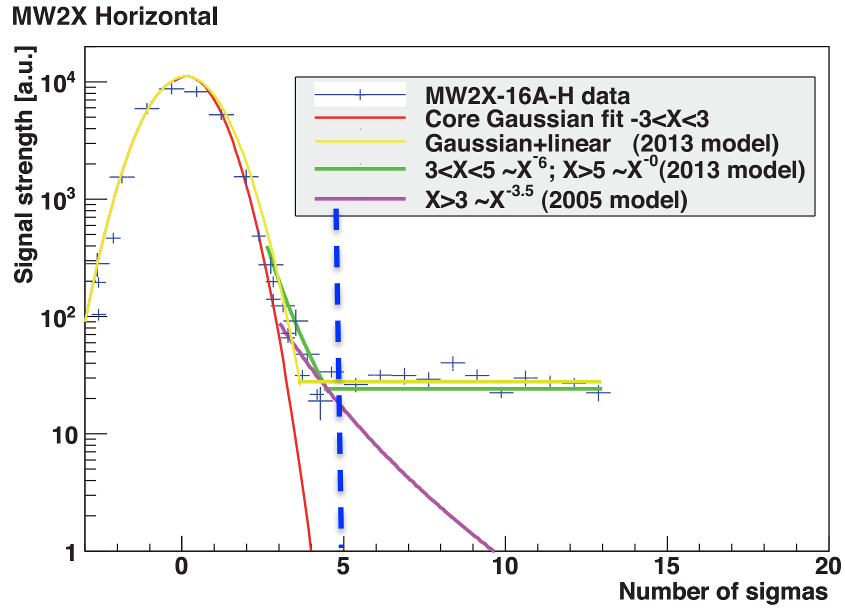
1. **Data acquisition with different PMT votages**
2. **Data normalization: voltage and number of sigmas**
3. **Data binning**
4. **Fitting range : X> 3σ**
5. **Fitting and normalization to N**

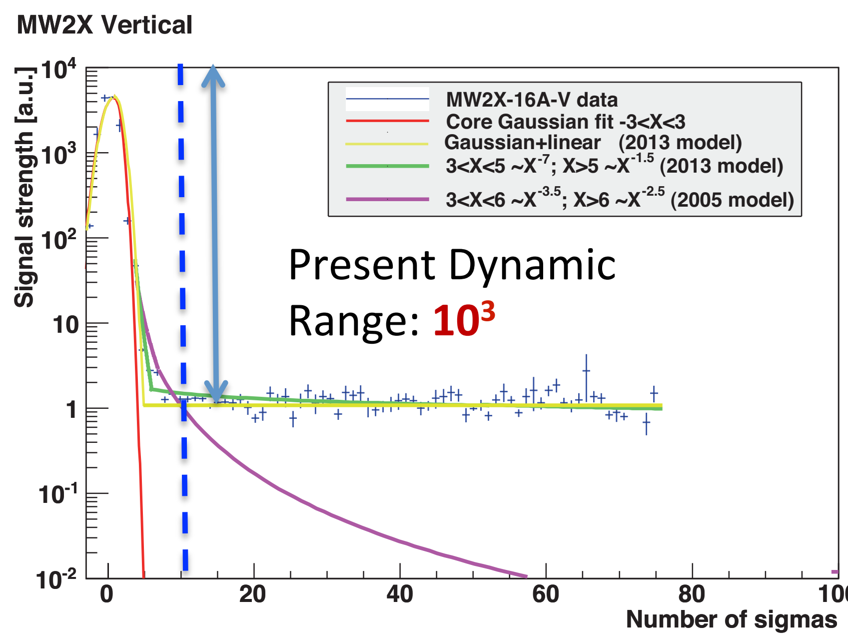
$$\rho_{H,V}/N = (A/N)X^{-b}$$

N: number of particles
X: number of sigmas
A, b: constants

Limited by:

- **dynamic range**
- **difficult data taken and combination**





Data comparison: Yag screen, WS and OTRs