BEAM HALO MEASUREMENTS AND HALO COLLIMATION IN ATF2

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Motivation

Investigation of **beam halo transverse distribution** is an **important issue** for **beam loss and background control** in **ATF2** and in **Future Linear Colliders (FLC)**.

In April 2013 **LAL** and **IFIC** have started to collaborate to study **transverse beam halo collimation in ATF2** and the project was approved by the ATF2 technical broad 2013.

The main objectives of the halo collimation system are:

- **The reduction of the background noise at the Shintake Monitor**
- **To control the halo extension**, in the vertical and horizontal plane, to enable reliable measurements of the **Diamond Sensor (DS)** that is installed after the BDUMP to investigate the transverse beam halo distribution

Prior to the (DS) installation carried out by the LAL group in December 2014 a first attempt of **transverse beam halo distribution measurement have been done** with the wire scanners installed in the ATF2 EXT line and Post-IP

Outline

- Beam halo measurement in the ATF2 EXT line
- Status report on the beam halo collimation project

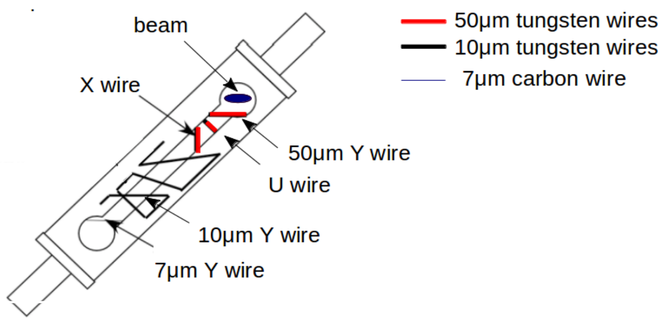
Beam halo measurements in ATF2 EXT line

Beam halo measurements were done in **2005** using the **wire scanners in the ATF beam line**

- These experiments have been updated for the **ATF2 beam line in 2013**

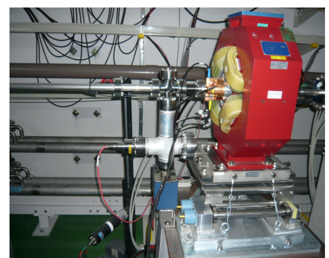
Transverse beam halo measurements have been done in the **EXT and post IP line**

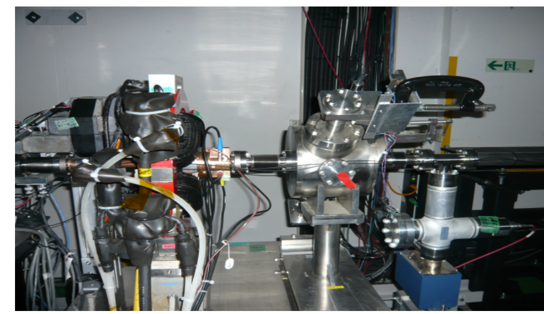
- **The data has been analyzed and** the new parameterization of the beam halo will be used for halo collimation tracking studies



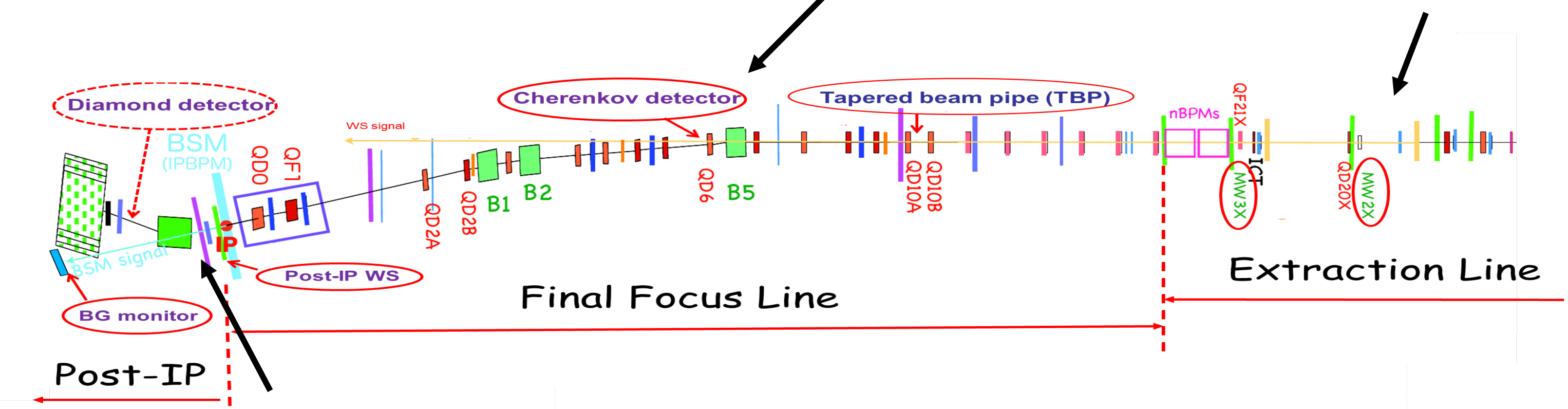
Wire scanner

Cherenkov Detector





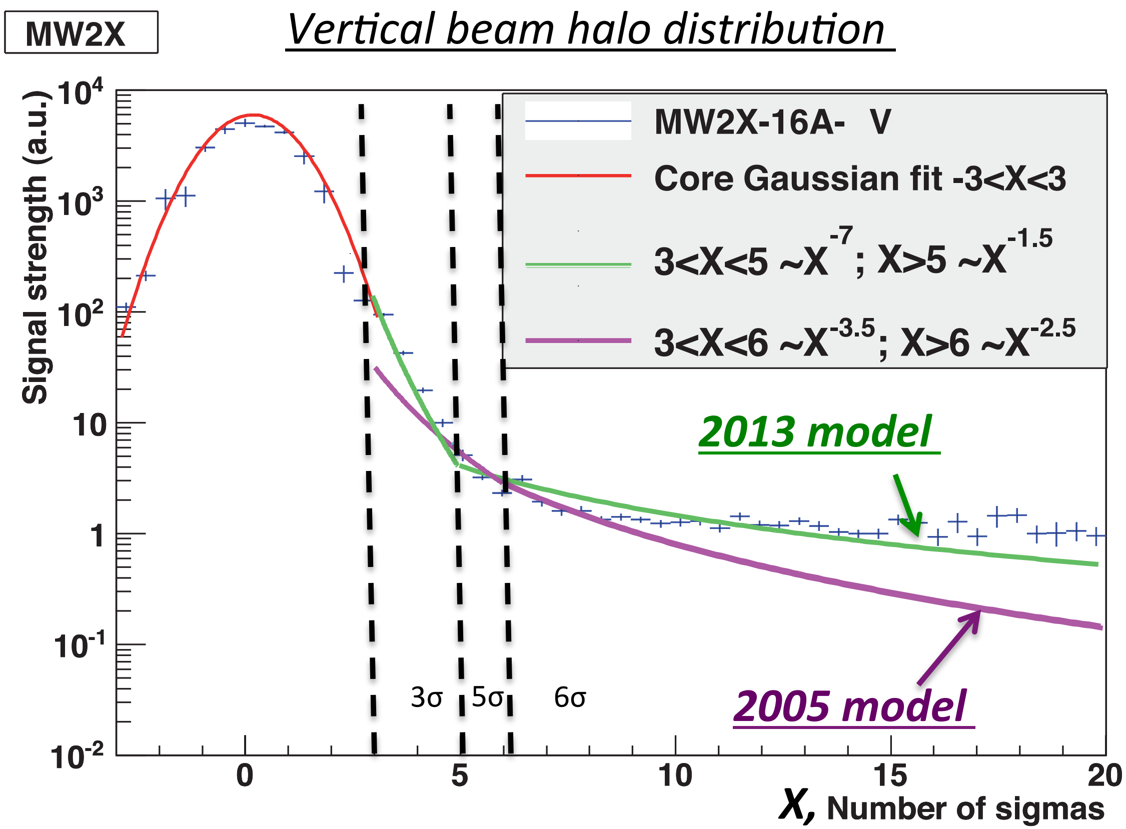
MW2X wire scanner



Post-IP wire scanner

ATF2 beam line

Beam halo measurements in ATF2 EXT line



2005 Halo Density Model

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

$$\rho_V/N = \begin{cases} 1.0 \quad X^{-3.5} & with \quad 3 < X < 6 \\ 1.7 \quad X^{-2.5} & with \quad X > 6 \end{cases}$$

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

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

On going work

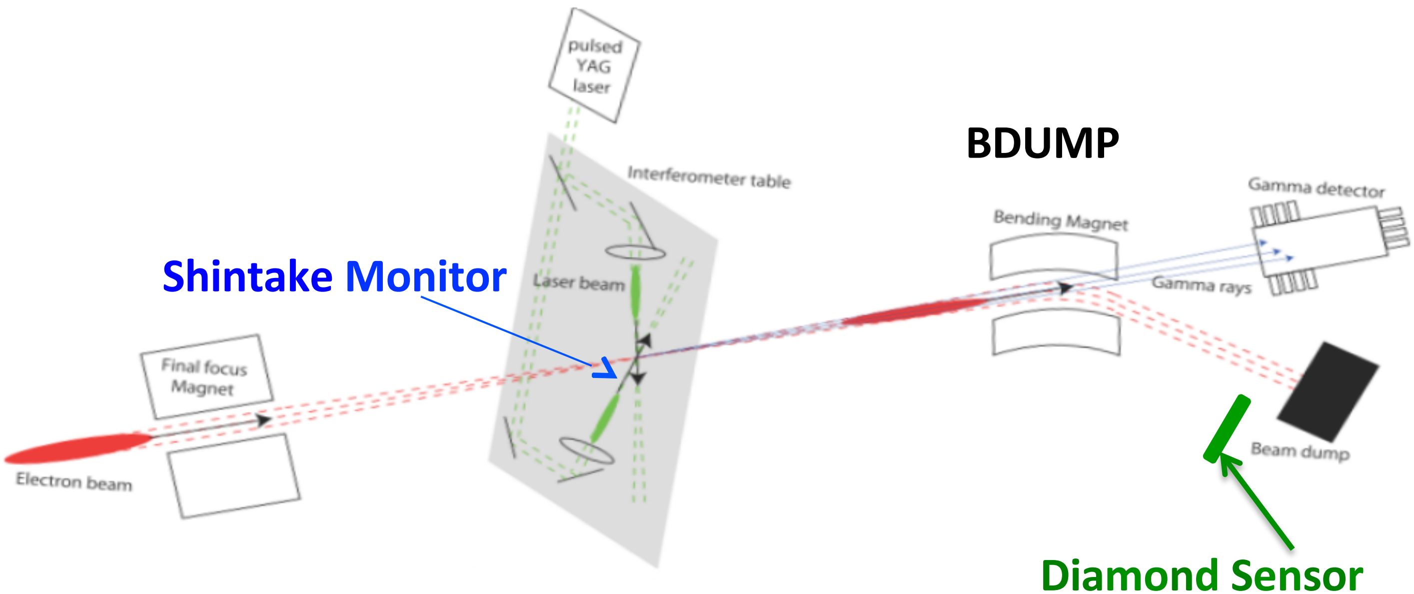
- In **December 2014** measurements with the **OTRs system** have been done in the EXT line of ATF2. The data is being analysed to investigate the beam halo distribution and **will be compared with the wire scanner beam halo measurements**

Beam halo collimation project

Motivation of the study

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

- Reduce halo extension, 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



IP and Post-IP ATF2 beam line

Objectives of the project

1. **Beam dynamics simulation and realistic tracking studies** in ATF2 to evaluate the efficiency of a rectangular 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. **Halo control, background reduction and collimator wakefield studies** using the ATF2 halo collimator (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 studies

- **Beam core** (Gaussian distribution) -> No losses were observed
- **Beam halo**: with **different optics and halo models** (gaussian, uniform, realistic) to find the **best location** and the most **efficient collimation depth** in terms of **halo cleaning and wakefield minimization** of a transverse betatron halo collimation system

Beam and halo input simulation parameters:

Number of particles: *10^4*

$\boldsymbol{E}$=1.3 GeV

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

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

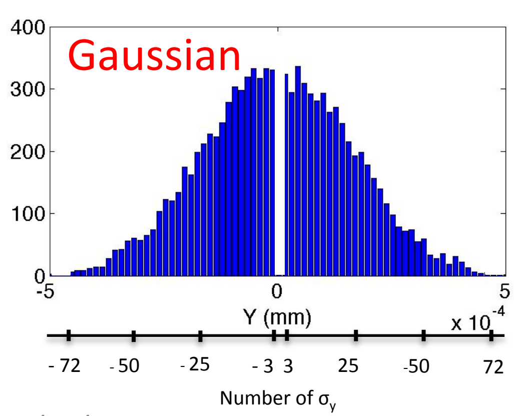
$\boldsymbol{\sigma_E}$: 0.08%

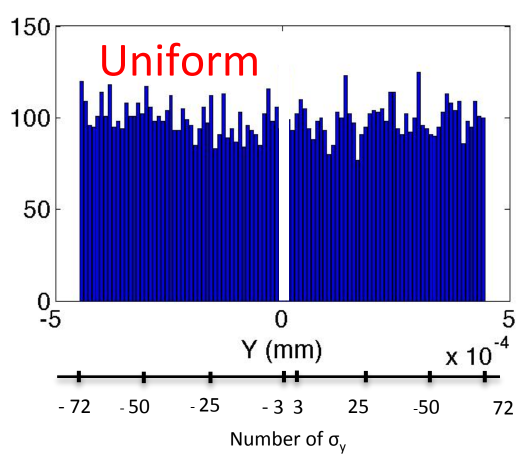
Optics configuration: { *10x1 (v5.2)*, *1x1 (v5.2)* }

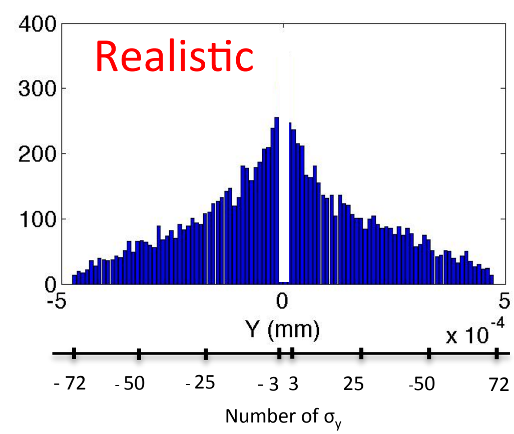
Multipoles

No misalignments

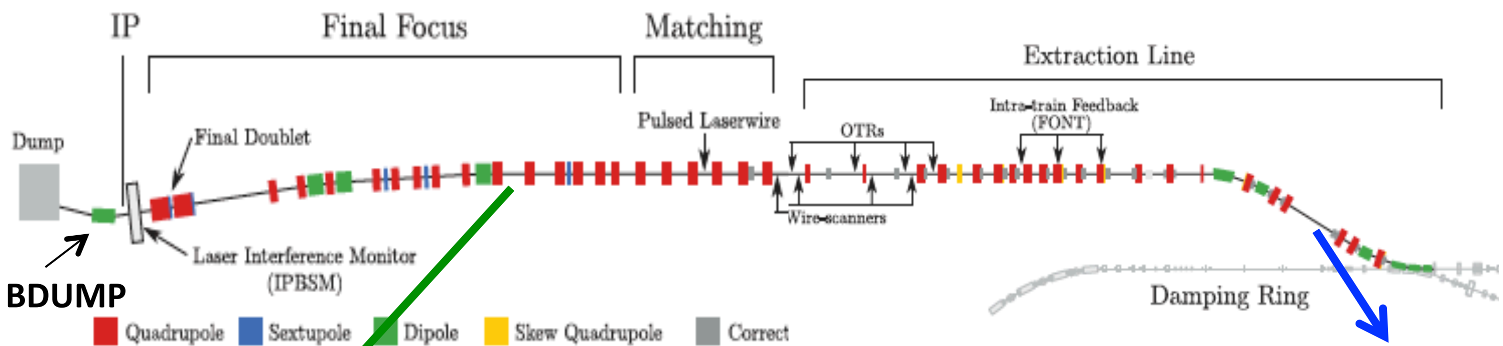
No coupling between x-y planes

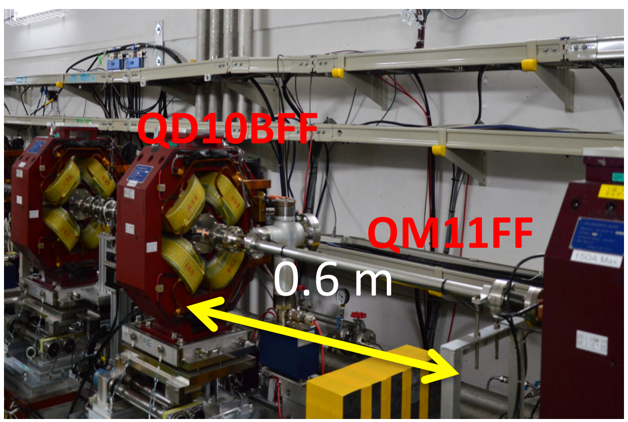


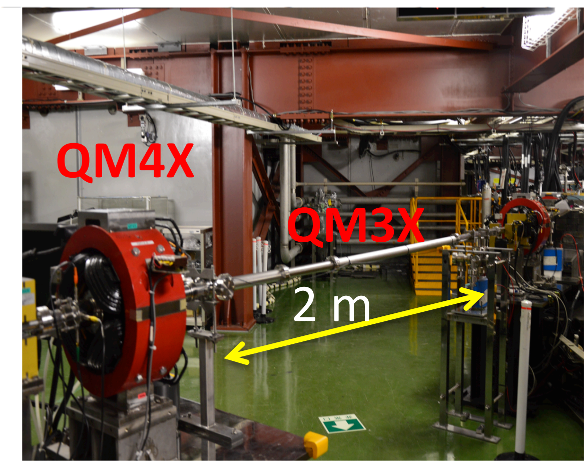




Beam dynamics simulation and realistic tracking studies







Horizontal halo collimator

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

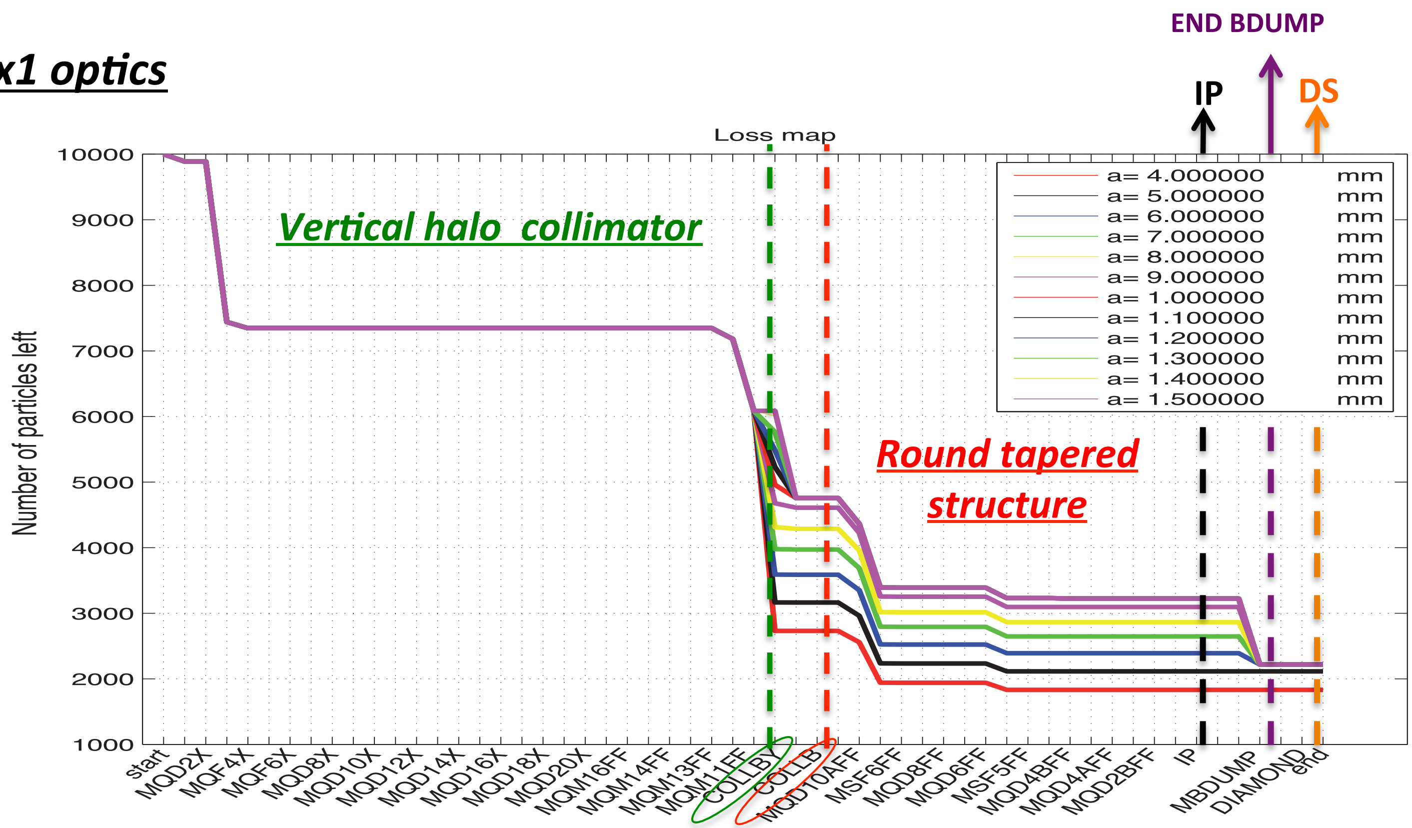
Vertical halo collimator

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

Beam dynamics simulation and realistic tracking studies

Tracking loss map considering **round tapered collimator** and a **vertical rectangular collimator with different half apertures** considering a **realistic halo model**

10x1 optics

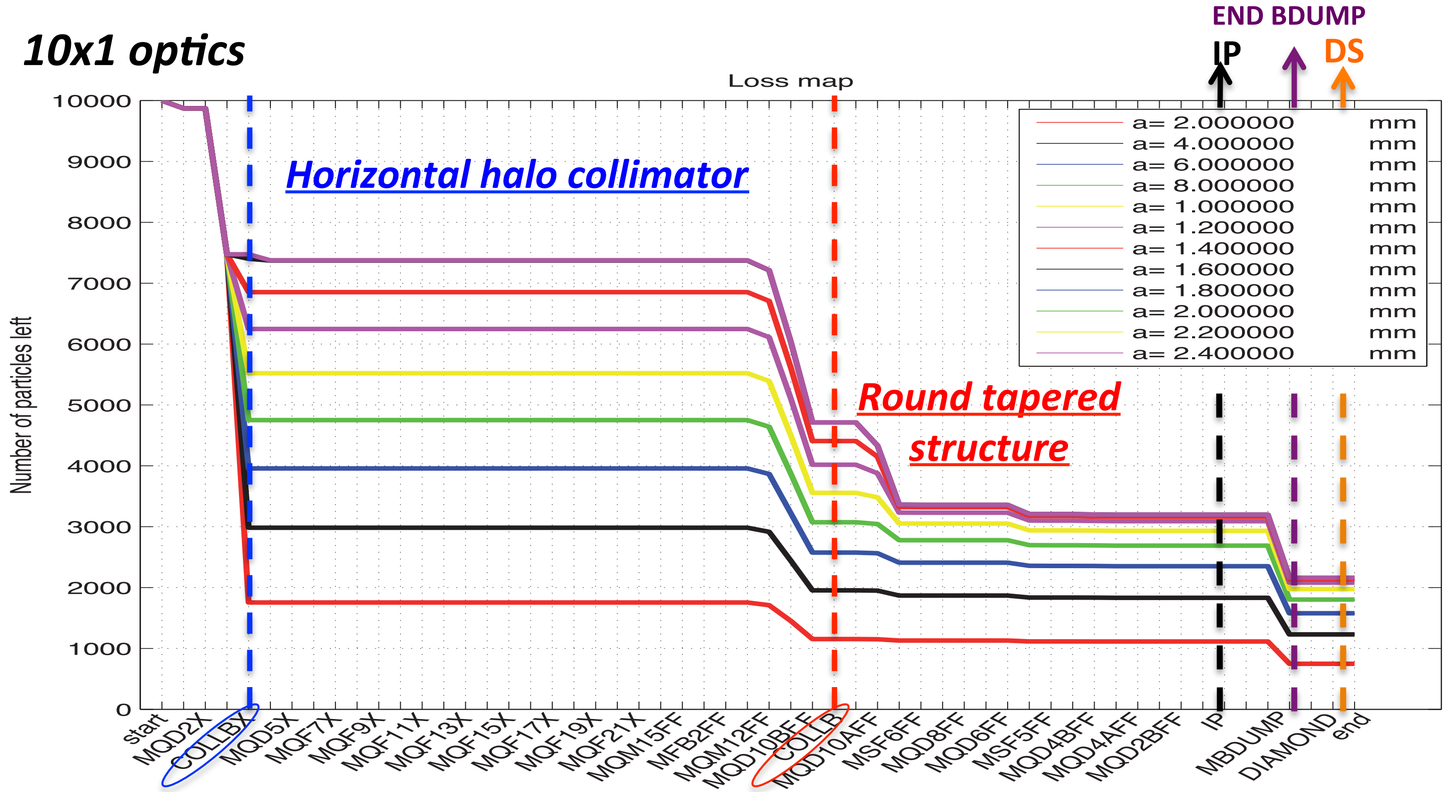


With a half aperture of 5 mm (17 σ_y) **we do not have losses at the BDUMP**

Beam dynamics simulation and realistic tracking studies

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

10x1 optics



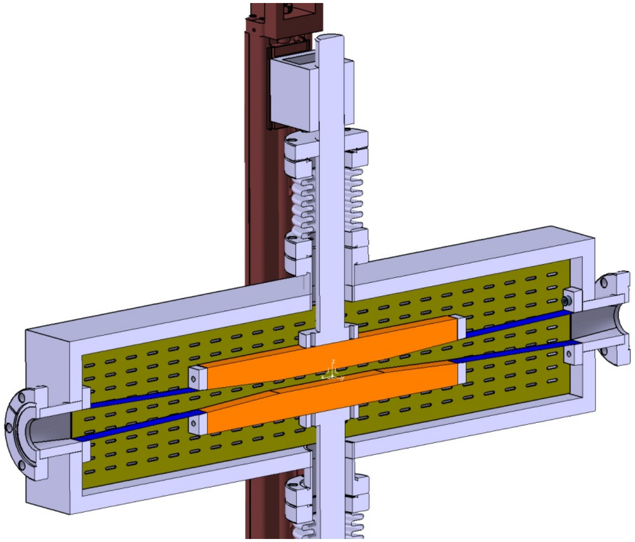
Even for a very small aperture of 2 mm (4 σ_x) we have losses at the **BDUMP**

Future work

➢ BDSIM tracking simulations to take into account secondary particles emission

Design of a retractable halo collimation device: mechanical and material study

A retractable halo collimation type is being considered because of its flexibility in terms of operational aspects



Geometrical and material study:

Wakefield study

- Dependence of the **wake potential** with the **geometrical parameters** and **material**
  - **Analytical (Stupakov model 2002)**

    -> Review calculation done in 2006
  - **Numerical simulations** using **CST PS**

➡ **This study has given the geometrical parameters for a first 3D design**

Thermal study-> is in progress

Beam impact studies (orbit distortion and beam size growth)

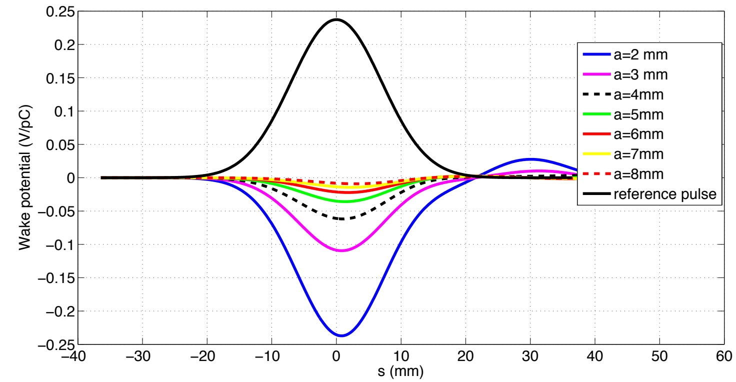
- **Analytical**
- **PLACET tracking code**
  - The wakefield impact of a rectangular collimator based on analytical calculation but with a longitudinal plane dependence added is implemented
  - This is being done in coordination with PLACET experts (A. Latina and J. Snuverink)

Design of a retractable halo collimation device: mechanical and material study

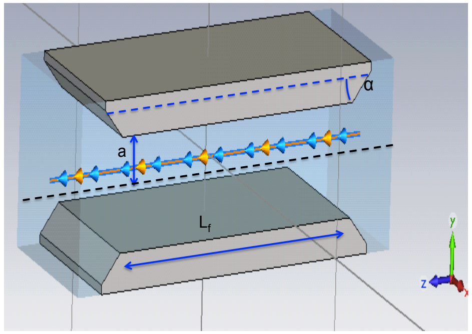
Geometrical and material study:

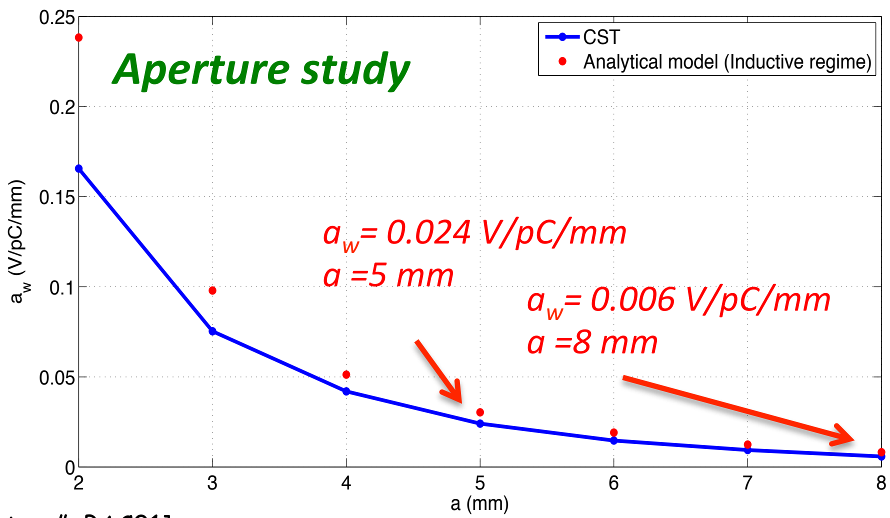
➢ Numerical simulations using CST PS: simplified model

- **Rectangular chamber in x and y**
- **Two independent movable vertical jaws**
- **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
- **Beam**
  - σ_z=7 mm
  - **N**=10^6 (Charge 1pC)



Wakepotential beam offset of 1 mm **L_F=100 mm, α=3°**



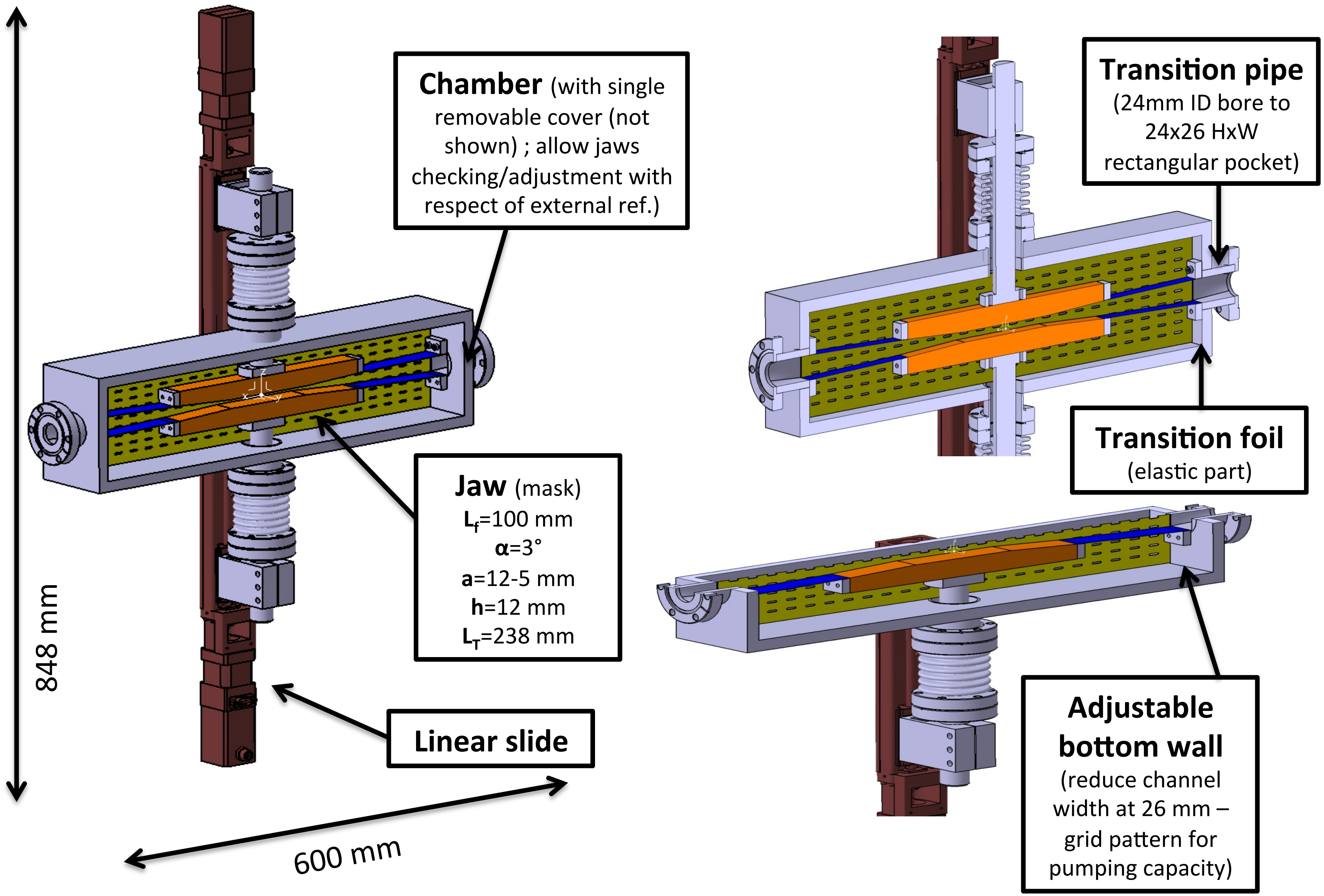


➢ Analytical calculations

[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]

First 3D design Design of a retractable halo collimation device



- **Real mechanical design and cost study of collimator is in progress**

Material from S. Wallon (LAL)

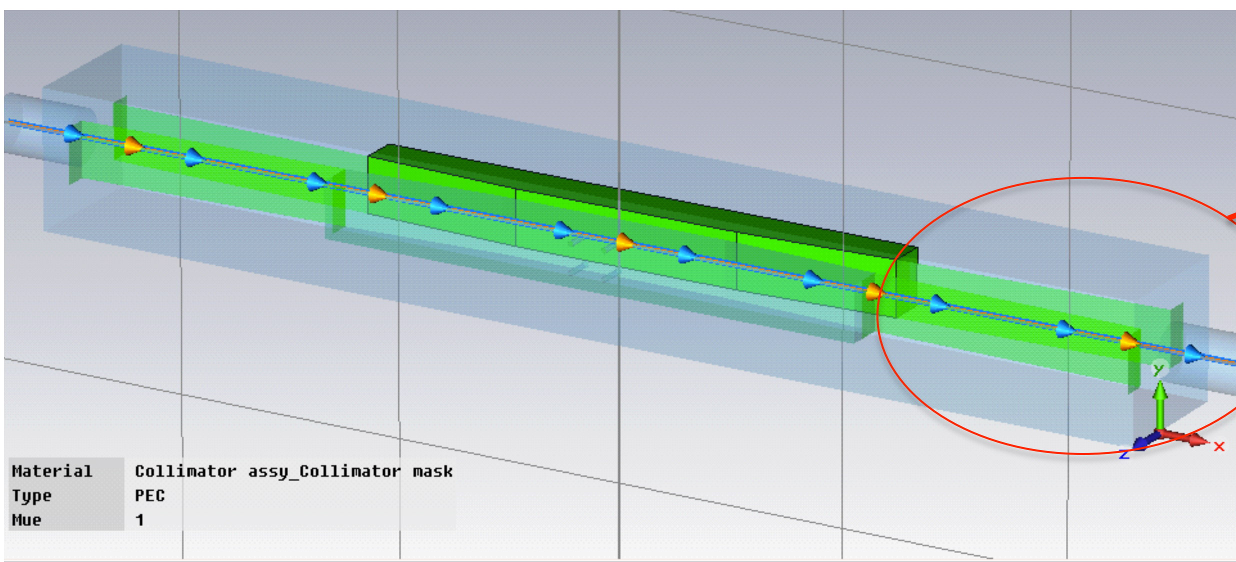
Design of a retractable halo collimation device: mechanical and material study

On going work

Numerical simulations using CST PS: new model

- **Two independent movable vertical jaws**
- **Parameters studied**
  - **a**: 5 mm
  - **Lf**: 100 mm
  - **α**: 3°
  - **Material**: PEC

- **Beam**
  - σ_z=7 mm
  - **N**=10^6 (Charge 1pC) (real beam 10^{10} but this parameter increases the time of the simulations and the wakepotential given is normalized to the charge)

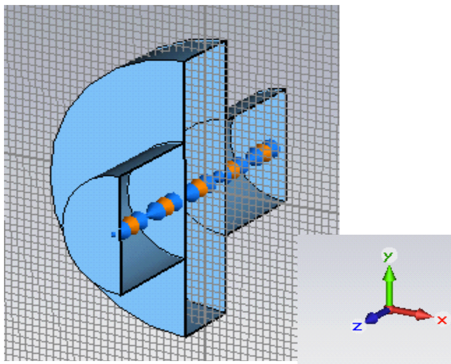


The transition part between the jaws and the beam pipe have been added

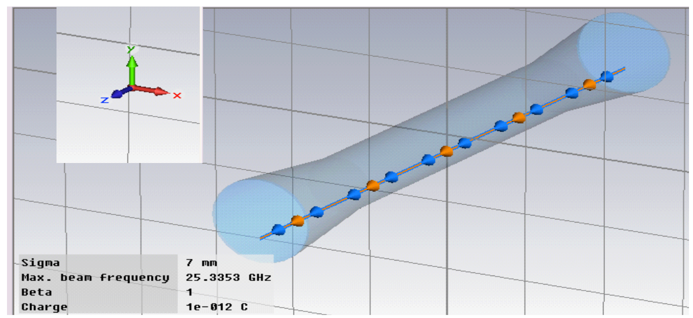
Design of a retractable halo collimation device: mechanical and material study

Beam impact studies: *first wakefield impact evaluation*

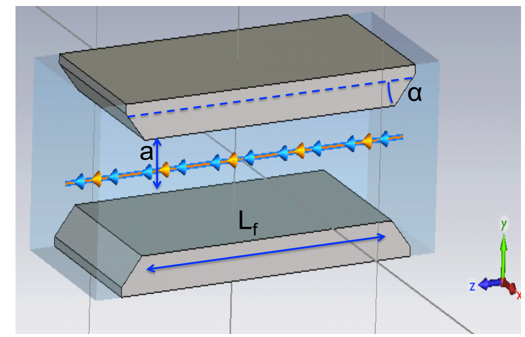
Reference cavity



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



Rectangular tapered collimator
a=8 mm, L_F=100 mm, α=3°



(high level of wakefields*)

(low level of wakefields)

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

	Refrence cavity	Round collimator	Rectangular collimator
a_w (V/pC/mm)	0.089	0.0052	0.0061

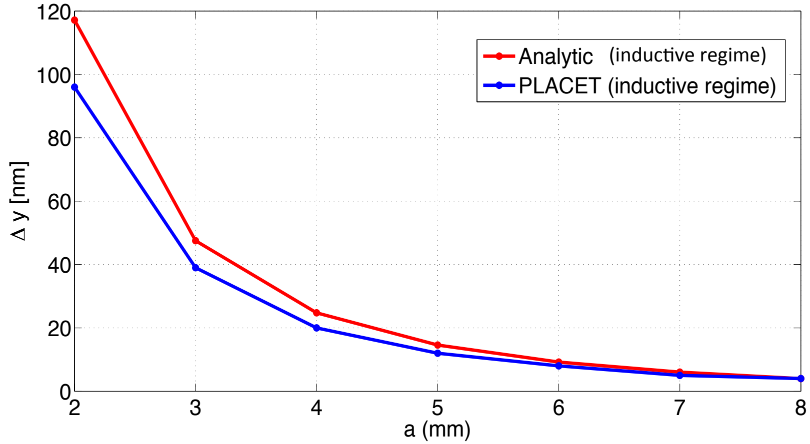
The transverse wakefield average kick of the rectangular tapered collimator:

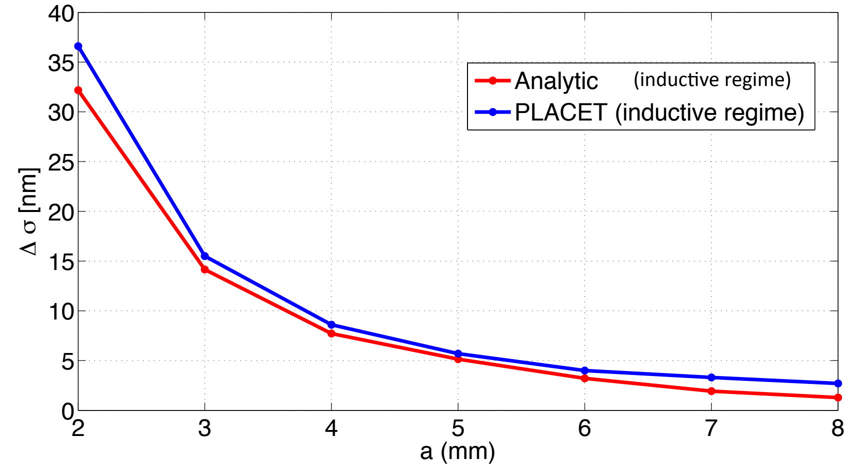
- with a=8 mm is comparable with the impact of the round tapered collimator
- with a=3 mm is comparable to the reference cavity

Design of a retractable halo collimation device: mechanical and material study

Beam impact studies: *analytical and PLACET tracking code studies*

- The same input parameters used in MADX tracking studies
- Rectangular collimator with a=5 mm, L_F=100 mm, α=3°





Orbit displacement (analytical):

a_W: analytic average kick

$$\Delta y = R_{34} a_\theta = \sqrt{\beta\beta^*} sin(\phi) \frac{eqy}{E} a_w$$

Beam size growth (semi-analytical):

σ_W: CST PS wake potential spread

a(mm)	Δy (nm) at IP		Δσ (nm) at the IP	
	Analytic	Placet	Analytic	Placet
5	13	12	5	6
8	4	4	1	3

Preliminary results

$$\Delta\sigma = \sqrt{\sigma^2 - \sigma_0^2} = R_{34}\sigma_\theta = \sqrt{\beta\beta^*} sin(\phi) \frac{eqy}{E} \sigma_w$$

**wakefieldeffect20130708.pptx*

Summary and future work

- **Beam halo measurements in the EXT line have been done** with:
  - **Wire scanners** in 2013-> The data has been analysed and an ATF2 note has been written.
  - **OTRs system** in December 2014 run -> the data is been analysed to investigate the transverse beam halo distribution and compare with the wire scanner measurements

- The best **location and the efficiency** as a function of the half aperture for a **vertical and a horizontal halo collimation system for ATF2** have been studied
- A **wakefield study has been done using analytical formulas and numerical simulations using CST PS** in order to optimize the geometrical parameters and materials of a rectangular collimator prototype and a **first preliminary 3D mechanical design** has been done with the optimized parameters
- The **wakefield impact** has been evaluated by comparison with other structures studied in ATF2 and the beam dynamics is also being studied by using the tracking code PLACET

- OTRs data analysis
- CST PS simulations with a more realistic collimator structure
- Real mechanical design and cost study of collimator is in progress
- Tracking studies by using BDSIM taking into account secondary particle emission

Thank you very much for your attention!

Back up…

Wire Scanner

Signal: Bremsstrahlung photons

Dynamic range limited by:

- Background level
- 14 bit ADC counts
- PMT high voltage

Background sources:

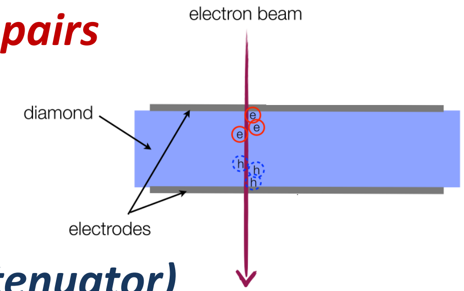
- Beam halo hitting the beam pipe
- Beam halo hitting another wire

Data Taking :

- Difficult to combine data
- Difficult to avoid beam position jitter

Diamond Detector

Signal: Ionized e- hole pairs



Dynamic range:

⇒ 1～ >10^8 e^-

(adding amplifier or attenuator)

Possible background:

- *Beam halo hitting B-Dump*

⇒ can be collimated by collimators upstream

- *Back-scattered particles from dump*

⇒ can be separated in time

- *Bremsstrahlung photons*

⇒ can be neglected?

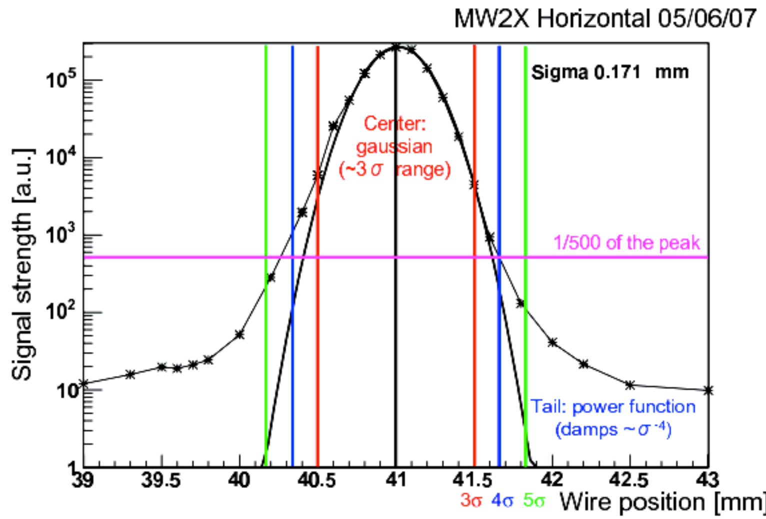
Data Taking :

- *Different channel for beam core and halo*

⇒ possible to do overall scan

Beam halo measurements in ATF in 2005

First beam halo measurements were done in ***2005*** using the wire scanners in ATF EXT line -> these experiments need to be updated for the present beam optics of ATF2



Halo Density Model

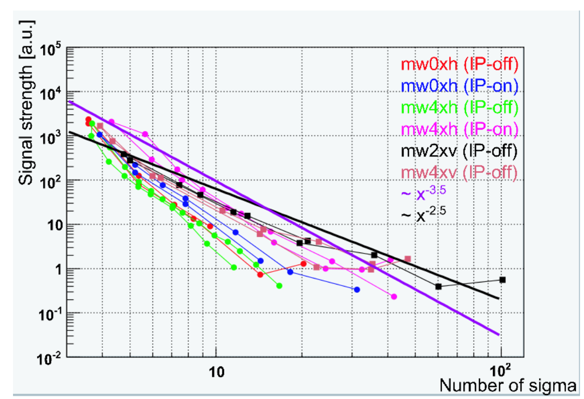
$$\rho_H/N = 1.0 \;\; X^{-3.5} \;\; with \;\; 3 < X < 6$$

$$\rho_V/N = \begin{cases} 1.0 \;\; X^{-3.5} & with \;\; 3 < X < 6 \\ 1.7 \;\; X^{-2.5} & with \;\; X > 6 \end{cases}$$

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

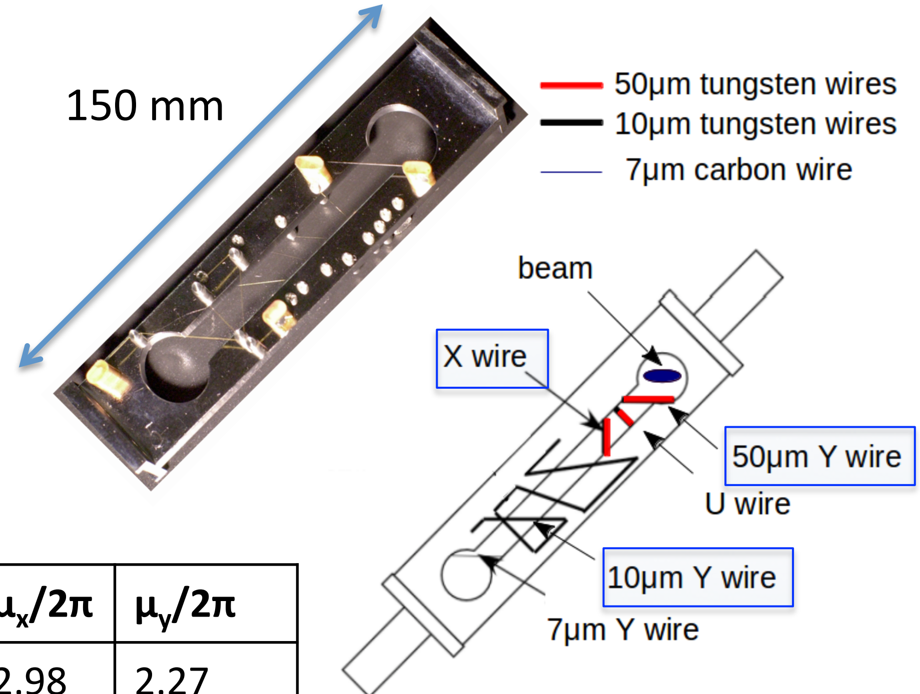
T. Suehara et al., "Design of a Nanometer Beam Size Monitor for ATF2", arXiv:0810.5467v1

ATF2_background_and_halo_study.pptx



Wire scanners set up

In each wire scanner eight wires are arranged and the set up is 45° to the beam direction.



	Position (m)	σ_x (μm)	σ_y (μm)	$\mu_x/2\pi$	$\mu_y/2\pi$
MW2X	43.54	88.54	11.77	2.98	2.27
IP	61.39	8.93	0.0367	4.04	2.96
Post-IPW	89.92	140.47	215.48	5.53	4.46

- At the **EXT line** with **MW2X**:
  - X wire (50 μm)→ horizontal
  - Y wires (10 μm) → vertical
- At the **Post-IP** with **Post-IPW**:
  - X wire (50 μm)→ horizontal
  - Y wires (50 μm) → vertical

Data acquisition and analysis

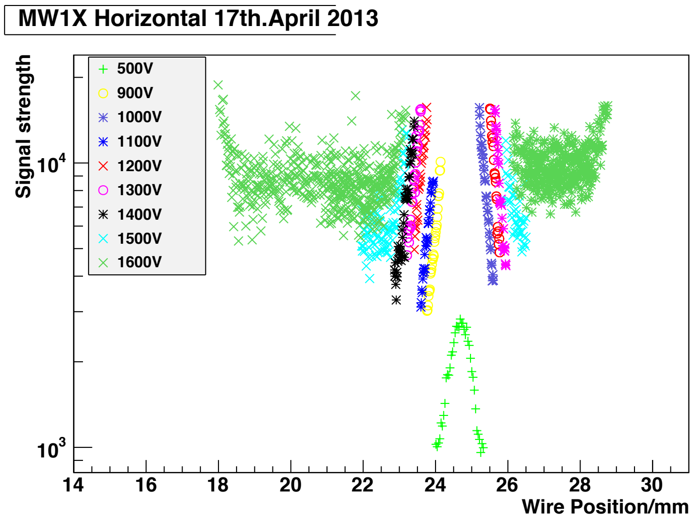
1.Data acquisition: the data was taken with **different PMT voltages** in order to be sensitive to beam halo particles. Lower PMT voltage is used for beam core and higher PMT voltage for beam halo

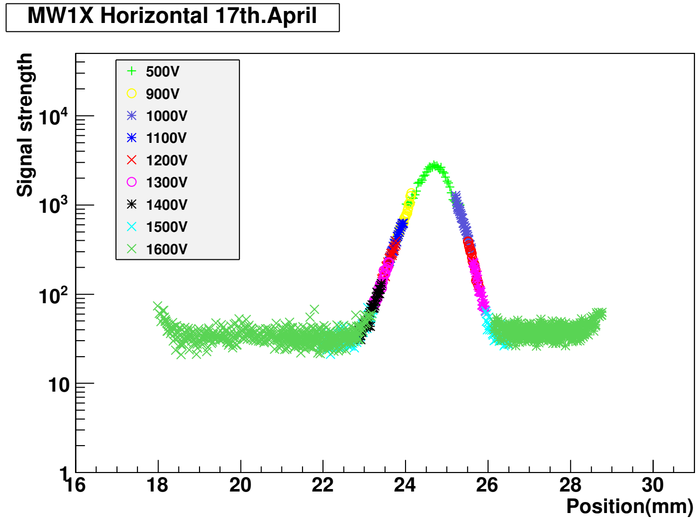
2.Data normalization: data is normalized to **intensity variation**, **wire orientation**, **number of sigmas** and **voltage** normalization

3.Data binning: in order to **reduce fluctuations** for the posterior analysis

4.Fitting range: we define the **fitting range** limited by the background (flat distribution)

5. Fitting model and normalization:





$$\rho_{H,V}/N = (A/N)X^{-b}$$ **N:** number of particles, **X:** number of sigmas

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	$46\sigma_y$	$27\sigma_x$

Beam dynamics simulation and realistic tracking studies in ATF2

An important issue when doing collimation is to control the losses at the collimator for radiation protection issues. It is reminded that radiation safety at ATF requires less than 0.4 % beam loss of the maximum intensity in normal operation

From the 2005 realistic , the total number e- in the beam halo can be estimated

$$\int_3^6 1.02\times10^9 X^{-3.5}\, dX + \int_6^{100} 0.17\times10^9 X^{-2.5}\, dX = 2.9\times10^7\, electrons$$

Halo loss rate at the collimator: $$\frac{\int_X^{100} 1.02\times10^9 X^{-3.5}\, dX}{\int_3^{100} 1.02\times10^9 X^{-3.5}\, dX}$$

Aperture (mm)	Number of sigmas cut (σ_y)	Halo loss rate from Tracking (%)	Halo loss rate from calculation (%)	Particle lost of real beam intensity of 10^{10} (%)
Vertical beam halo collimator				
12	37	0.5	1.3	0.004
Horizontal bean halo collimator				
12	27	0.2	0.9	0.001

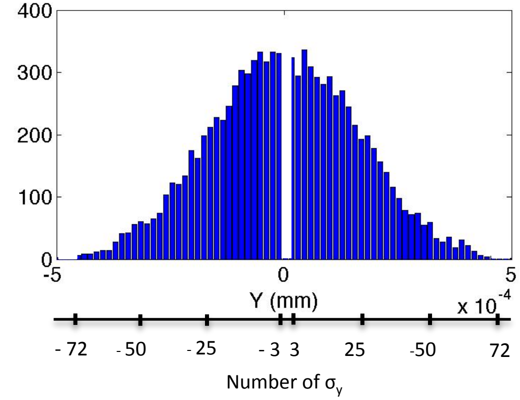
Future work

- Radiation level estimation in order to chose some components of the collimator

Beam dynamics simulation and realistic tracking studies in ATF2

Gaussian distribution: **nx=24 ny=28 (A_x=6 mm, A_y=0.43mm)**

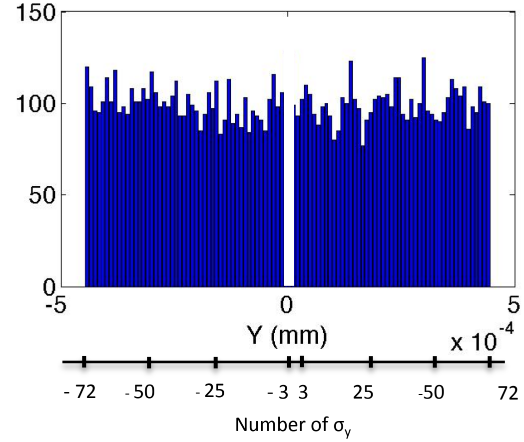
$$\rho_z = n_z \frac{1}{\sigma_z\sqrt{2\pi}} e^{-\frac{z^2}{2\sigma_z^2}} \qquad z = H, V$$



Uniform distribution: **nx=45 ny=72 (A_x=6 mm, A_y=0.3mm)**

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

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



Realistic distribution (2005 model): **nx=60 ny=81.25 (A_x=6 mm, A_y=0.3mm)**

$$\rho_H = 1.0 \; N \; X^{-3.5}$$

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

N: number of particles, **X:** number of sigmas

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