BEAM HALO MEASUREMENTS AND HALO COLLIMATION IN ATF2

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LCWS - 08/10/2014

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 the **transverse beam halo collimation in ATF2** and the project was approved by the **ATF2** technical board **at the beginning 2014**

The main objectives of the halo collimation system are:

- **The reduction of the background noise at the Shintake Monitor**
- **The control of the halo extension**, in the vertical and horizontal plane, to enable reliable measurements of the **Diamond Sensor (DS)** that will be installed after the BDUMP at the end of 2014 to **investigate the transverse beam halo distribution**

Prior to the (DS) installation carried out by the LAL group **transverse beam halo distribution measurements have been done** with the currently wire scanners installed in ATF2. The halo model given by these measurements could be used for the tracking halo collimation studies

Outline

- Beam halo measurement campaign 2013 analysis
- Status report on the collimation project

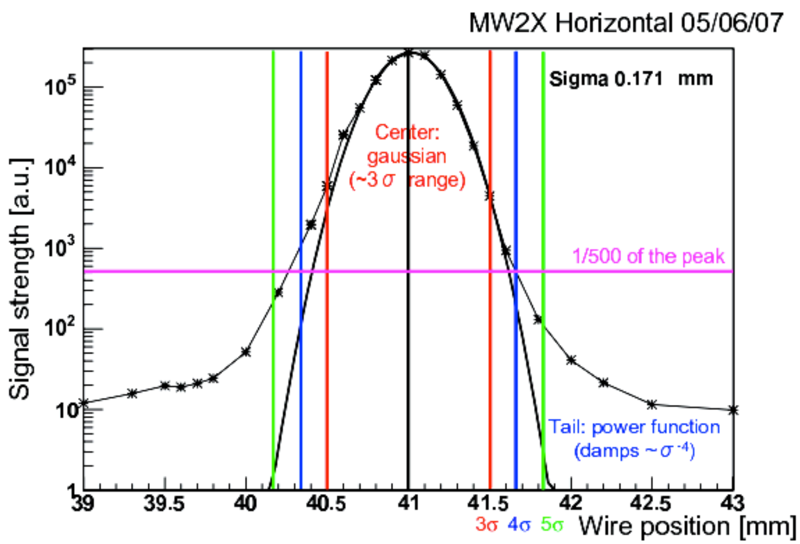
Beam halo measurements in ATF in 2005 (2005 model)

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

Halo Density Model

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

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



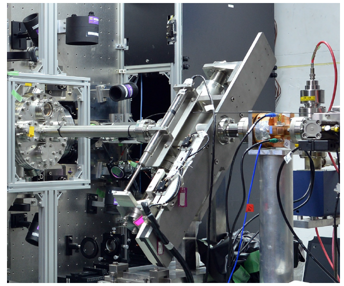
***ρ_H** horizontal beam halo density,*
***ρ_V** vertical beam halo density*
***X** number of σ*
***N=10^{10}** electrons*

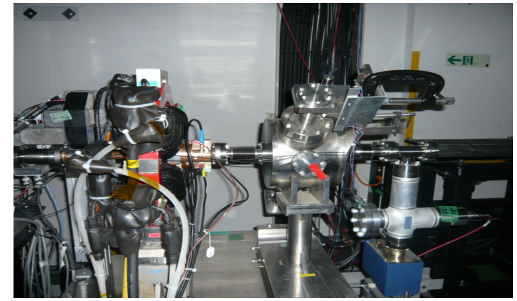
T. Suehara et al., "Design of a Nanometer Beam Size Monitor for ATF2", arXiv:0810.5467v1

ATF2_background_and_halo_study.pptx

Wire scanners and detectors location at ATF2

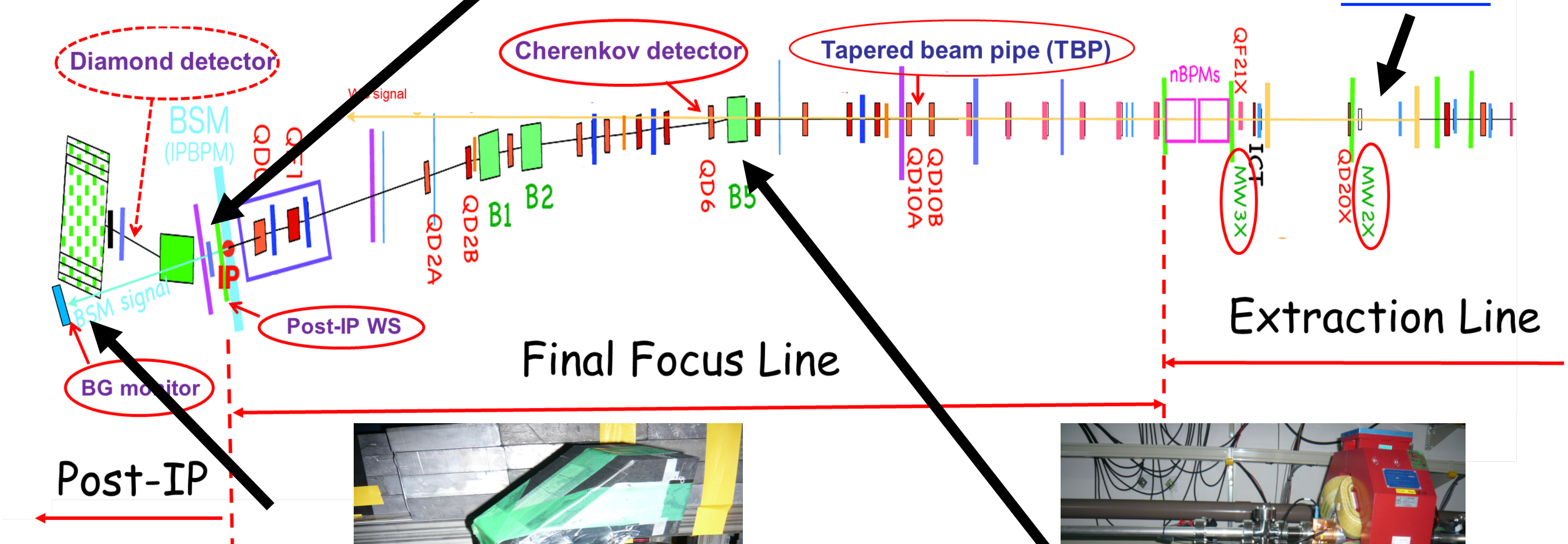
ATF2 beamline

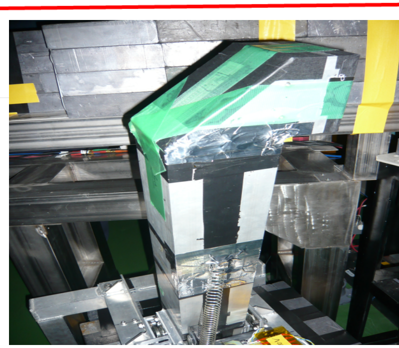




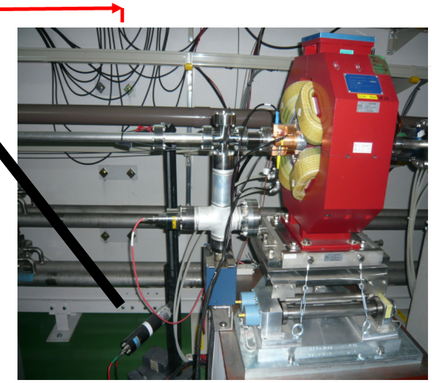
Post-IPW

MW2X





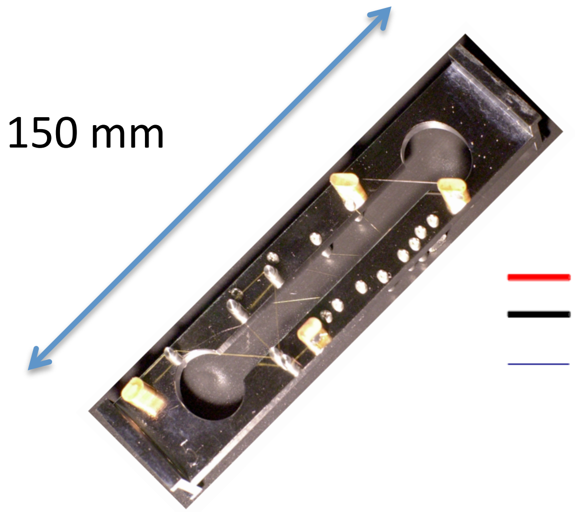
Scintillation Detector

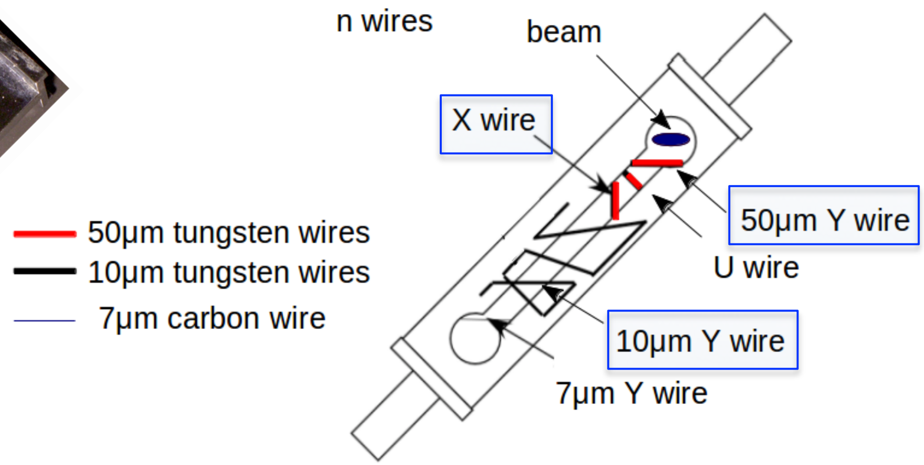


Cherenkov Detector

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	25.77	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

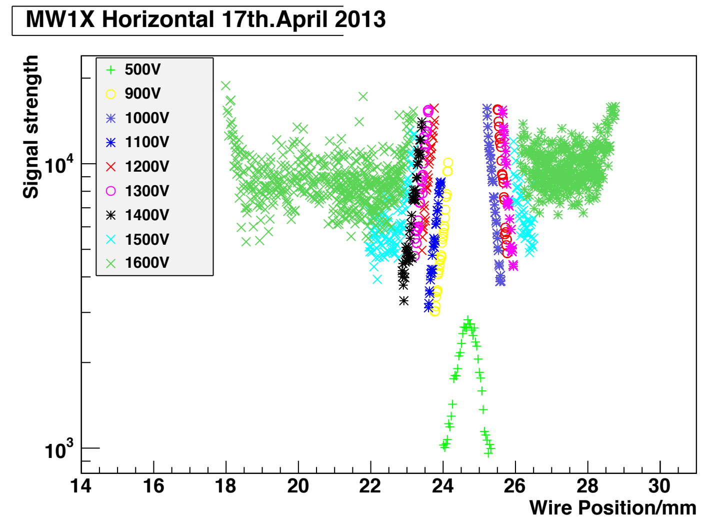
Data acquisition and analysis

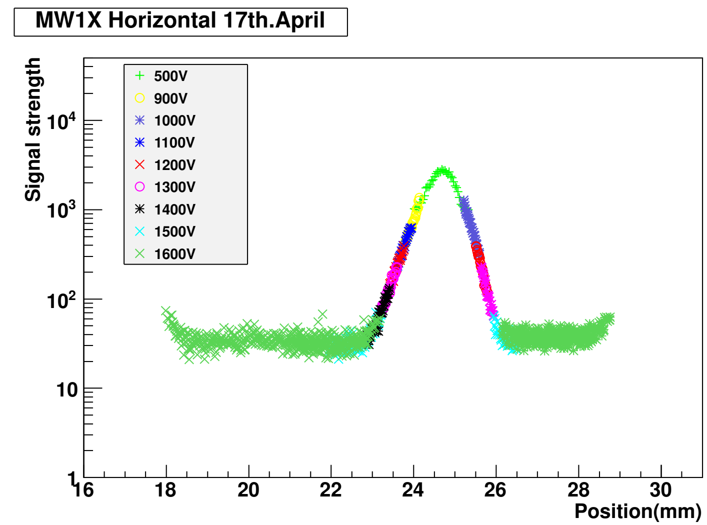
1. Data acquisition: the data was taken with **different PMT voltages** in order to be sensitive to beam halo particles. Lower PMT voltage is used for beam core and higher PMT voltage for beam halo

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)





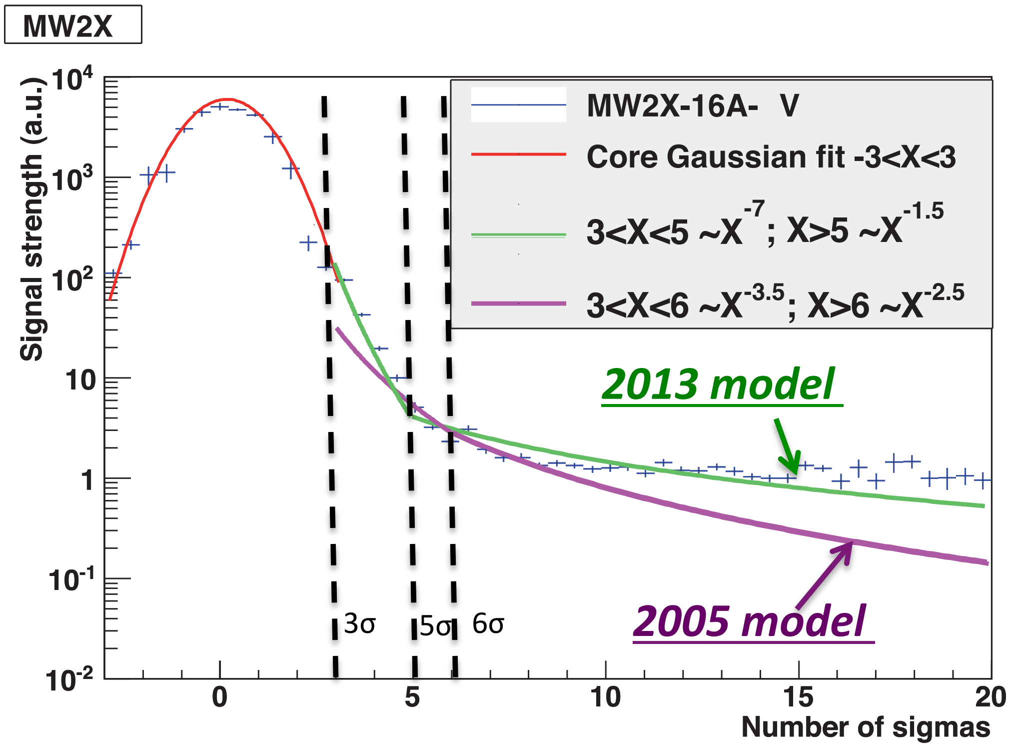
5. Fitting model and normalization:

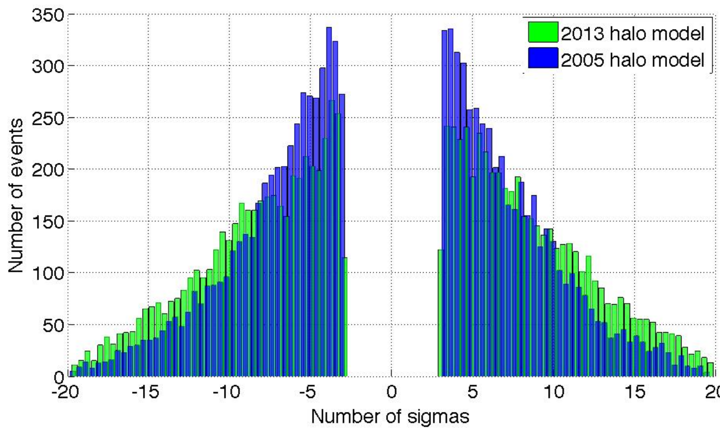
$$\rho_{H,V}/N = (A/N)X^{-b}$$

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

2013 wire scanners measurement campaign results

Vertical and horizontal beam halo measurements were done in the **EXT** line with **MW2X** on the 10th, 16th and 17th of **April 2013**





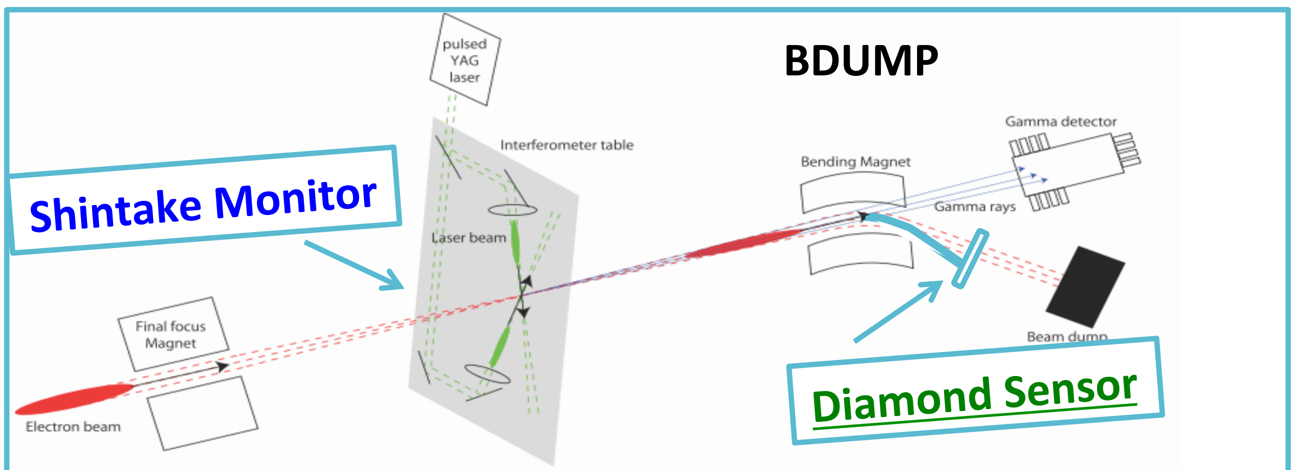
The 2013 halo model can be used for beam halo tracking studies in the collimation project

On going work

- The data with the **Post-IPW** is being analysed in order to compare it with future measurements with DS
- An ATF2 report is being written

Halo collimation system for ATF2

- **Reduction of the background noise at the Shintake Monitor** (IPBSM) by reducing the halo amplitude before the **BDUMP to reduce the probability of creating background photons that can be detected by the IPBSM monitor**
- The **control of the halo extension**, in the vertical and horizontal plane, to enable reliable measurements of the **DS** that will be located after the **BDUMP** at the end of 2014



Objectives of the project

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)

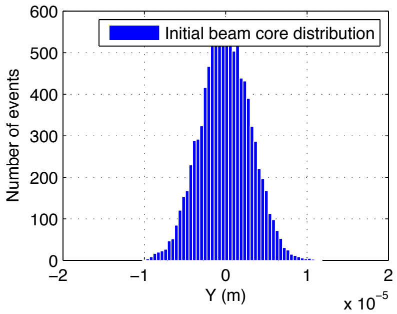
4. **Software design** of the halo collimation device control system (IFIC-LAL)

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

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

Beam dynamics simulation and tracking studies in ATF2

Tracking studies along the **EXT+FF+PostIP** line of **ATF2** using **MAD-X**



- **Beam core** (gaussian distribution)

  No losses were observed

- **Beam halo**
  - Scan to find the **best location** for a betatron halo collimator
  - Scan of **different half apertures** in order to determine an efficient collimation system in terms of **halo cleaning and wakefield minimization**
  - With **different optics**
  - With **different halo models** { *gaussian*, *uniform*, *realistic -> 2005 model* }

Beam and halo input parameters:

Number of particles: 10^4

$\boldsymbol{E}$=1.3 GeV

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

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

σ_E: 0.08%

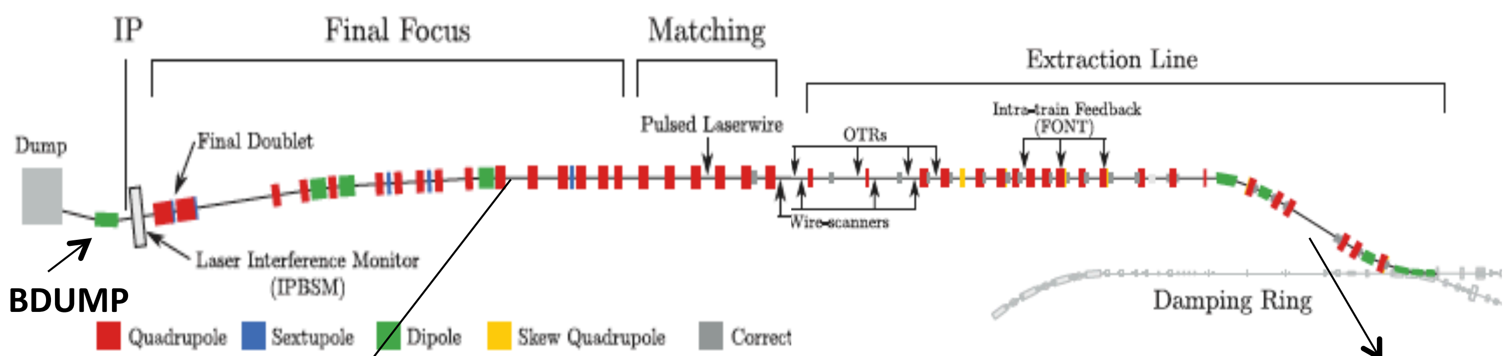
Optics configuration: { *10x1 (v5.2)*, *1x1 (v5.2)* }

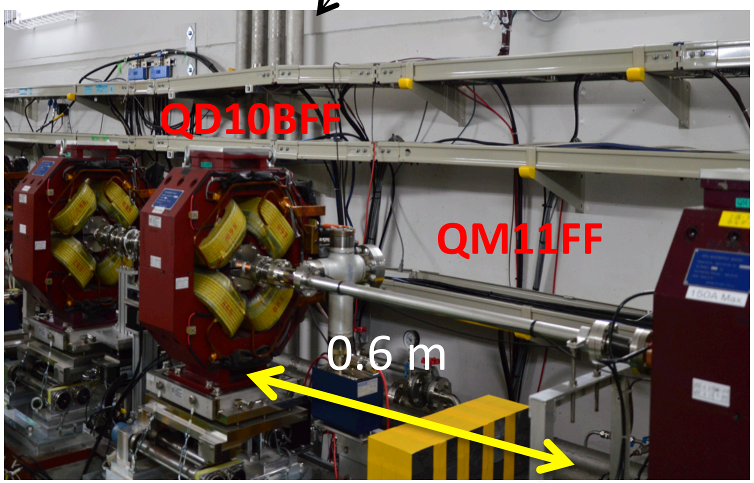
Multipoles

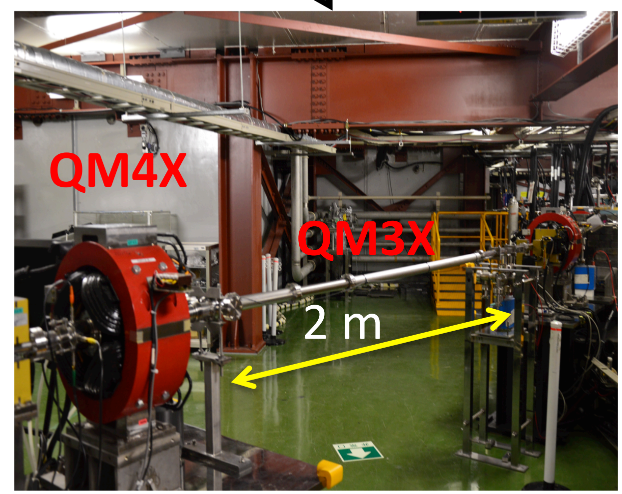
No misalignments

No coupling between x-y planes

Beam dynamics simulation and tracking studies in ATF2







Horizontal halo collimator

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

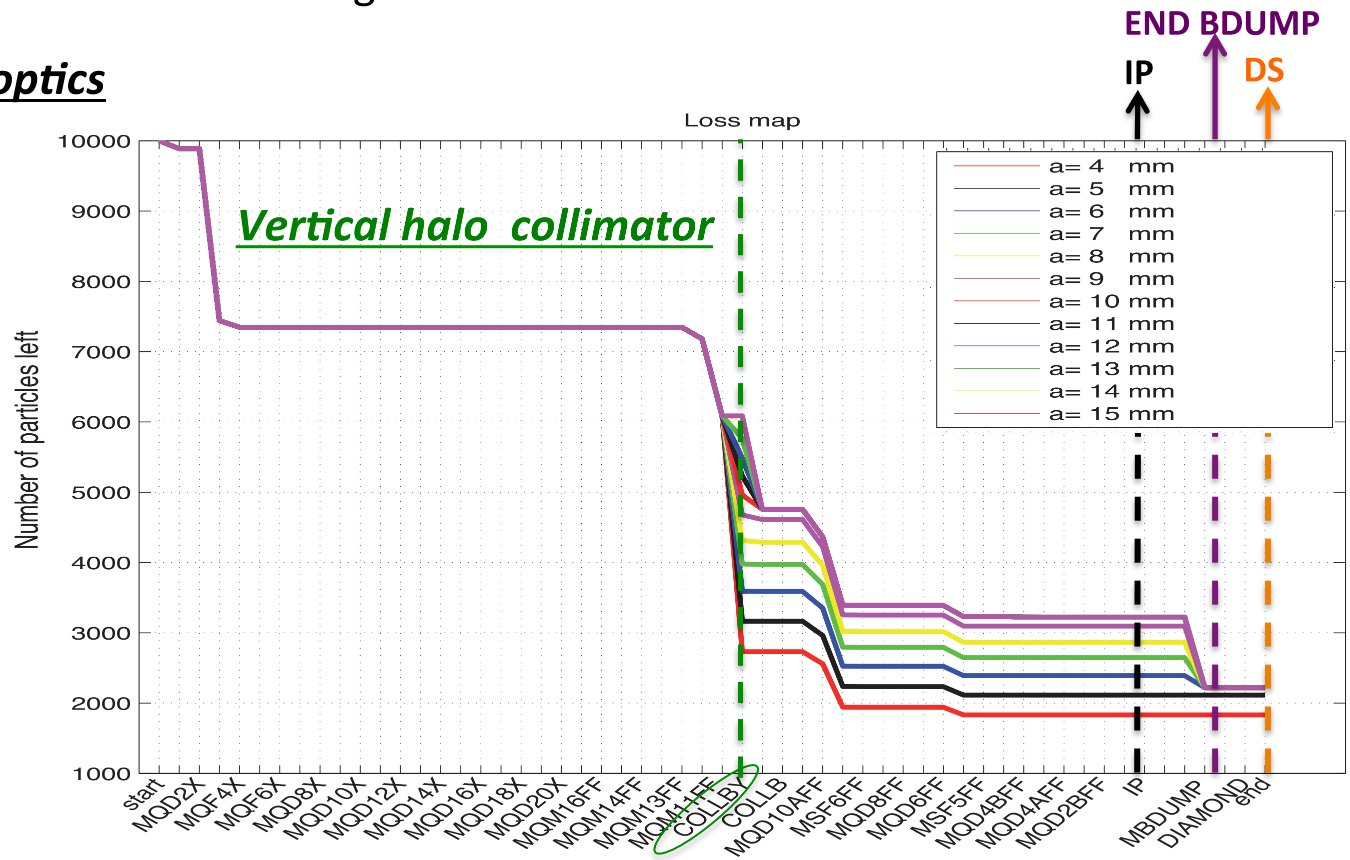
Vertical halo collimator

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

Beam dynamics simulation and tracking studies in ATF2

Tracking loss map considering a **vertical rectangular collimator with different half apertures** and considering a the **2005 realistic halo model**

10x1 optics

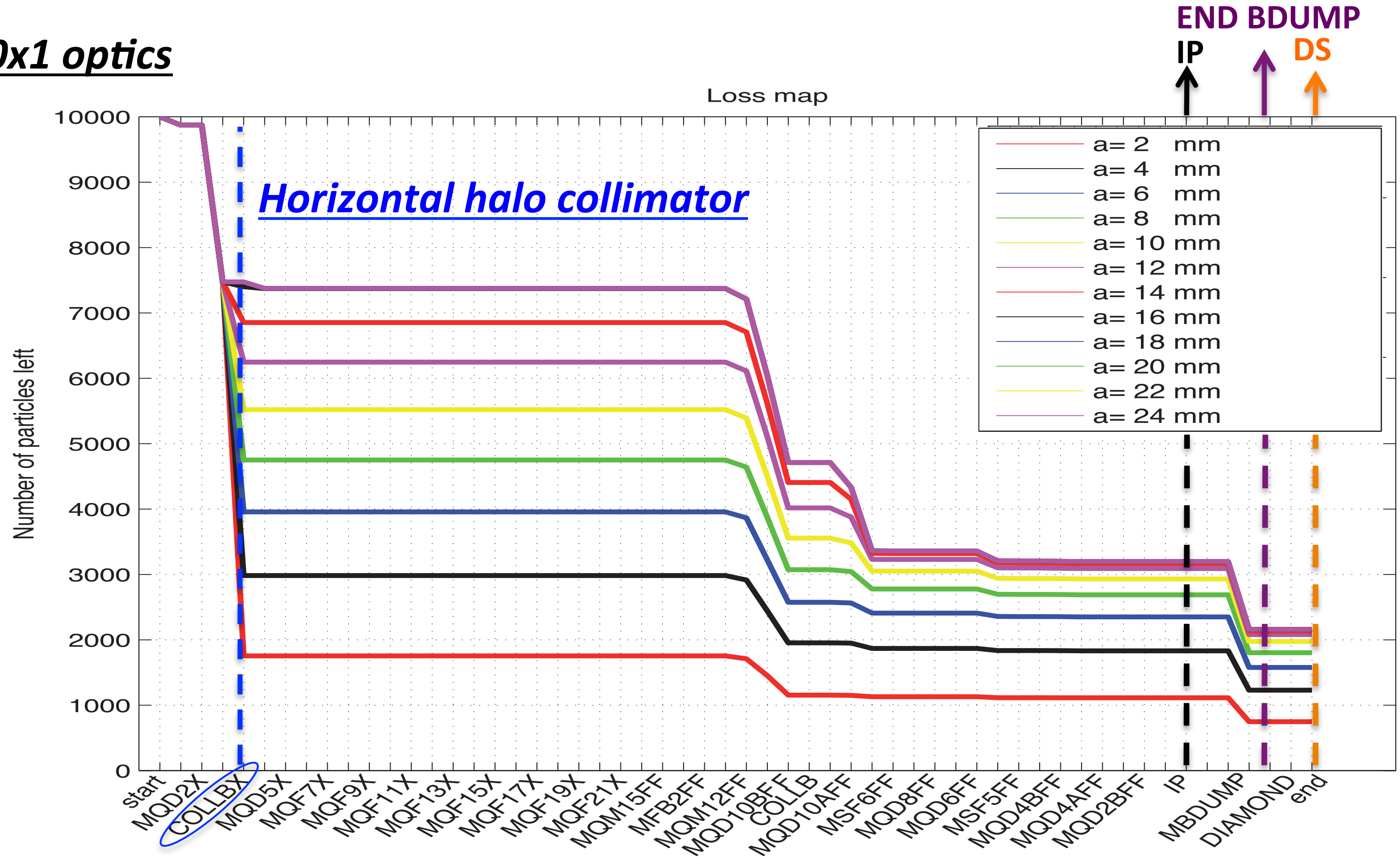


For a **vertical halo collimator with a half aperture of 5 mm** (15 σ_y) **we do not have losses at the BDUMP**

Beam dynamics simulation and tracking studies in ATF2

Tracking loss map considering **an horizontal rectangular collimator and different half apertures for the realistic 2005 halo model**

10x1 optics



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

Beam dynamics simulation and realistic tracking studies in ATF2

Tacking into account the **realistic distribution based on the 2005 beam halo model** and **N=10^{10}** we can estimate the **total number of beam halo electrons** :

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

Halo loss rate at the **vertical collimator** between **QD10BFF-QM11FF**

$$\frac{\int_X^{100} 1.02\times10^9 X^{-3.5}\,dX}{\int_3^{100} 1.02\times10^9 X^{-3.5}\,dX}$$

Half aperture (mm)	Number of sigmas cut (σ_y)	Halo loss rate from tracking (%)	Halo loss rate from calculation (%)	Particle lost of real beam intensity (N=10^{10}) (%)
5	15	5	6	0.02
8	24	2	3	0.008
12	37	0.5	1.3	0.004

- Simulation loss rate agree well with analytical estimation

On going work

- Same calculations for horizontal halo collimator
- Radiation level estimation in order to chose some components of the collimator

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

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

Collimator wakefield study

- Dependence of the **wakepotential** with the **geometrical parameters** and **material**
  - **Analytical (Stupakov model 2002)** **->** Review calculation done by G.Rumolo in 2006
  - **Numerical simulations** using **CST PS**

⇨ **This study has given the geometrical parameters to do a first 3D design**

On going work

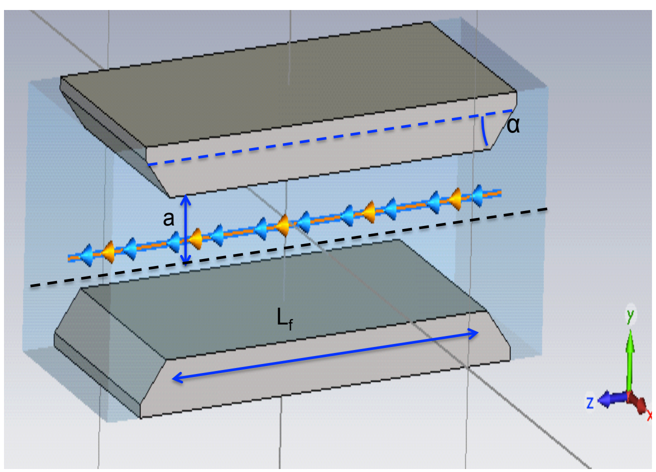
- **Beam impact studies** (orbit distortion and emittance dilution)
  - **Analytical**
  - **PLACET tracking code** with geometric and resistive collimator wakefield effect implemented (work in coordination with CERN group)

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

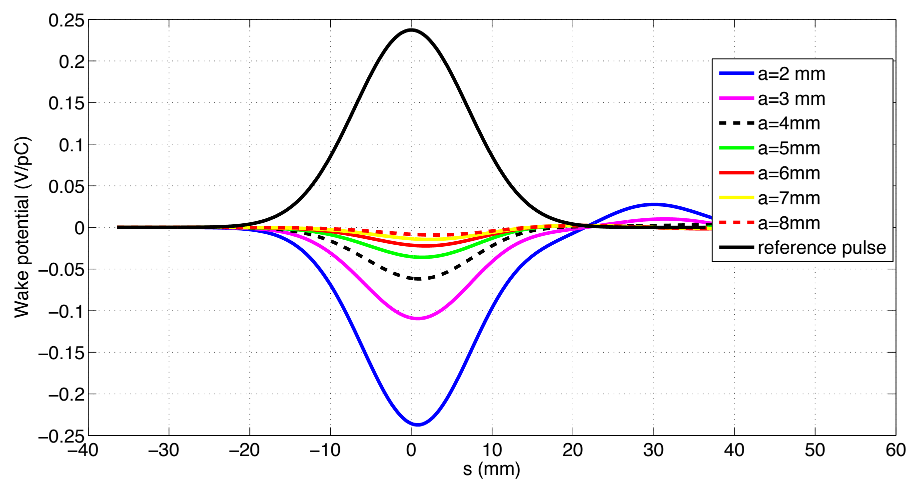
Numerical simulations using CST PS

- **Model**
  - Rectangular chamber in x and y
  - Two independent movable vertical jaws of perfect conductor
- **Parameters studied**
  - **a**: between 2 mm and 8 mm
  - $\mathbf{L_f}$: between 50 mm and 300 mm
  - **α**: between 3° and 90°

- **Beam**
  - $\boldsymbol{\sigma_z}$=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)



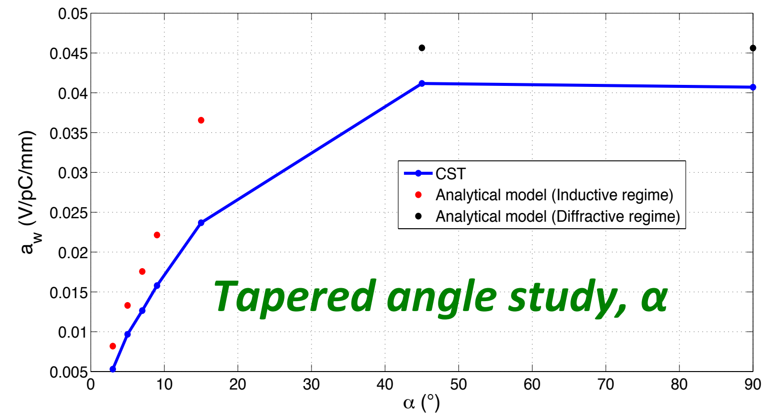
Wakepotential (beam offset of 1 mm, α=3° and L_f=100 mm)

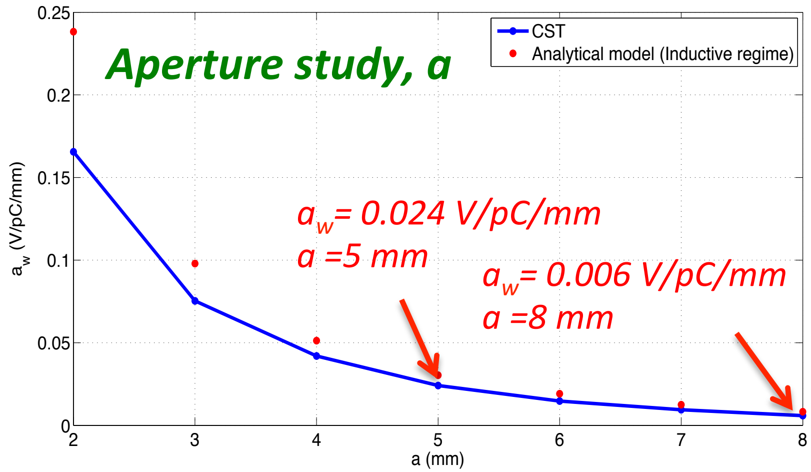


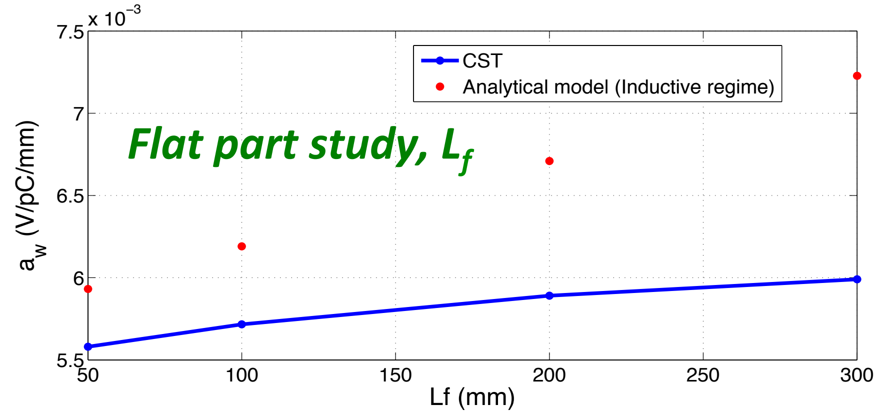
Design of a retractable halo collimation device: mechanical and material study (IFIC-LAL)

Comparison of **average wakepotential** given by **CST PS** simulations with the **analytical models**

$$a_w = \frac{1}{q\Delta y}\int_{-\infty}^{+\infty} \rho(z)W(z)dz$$



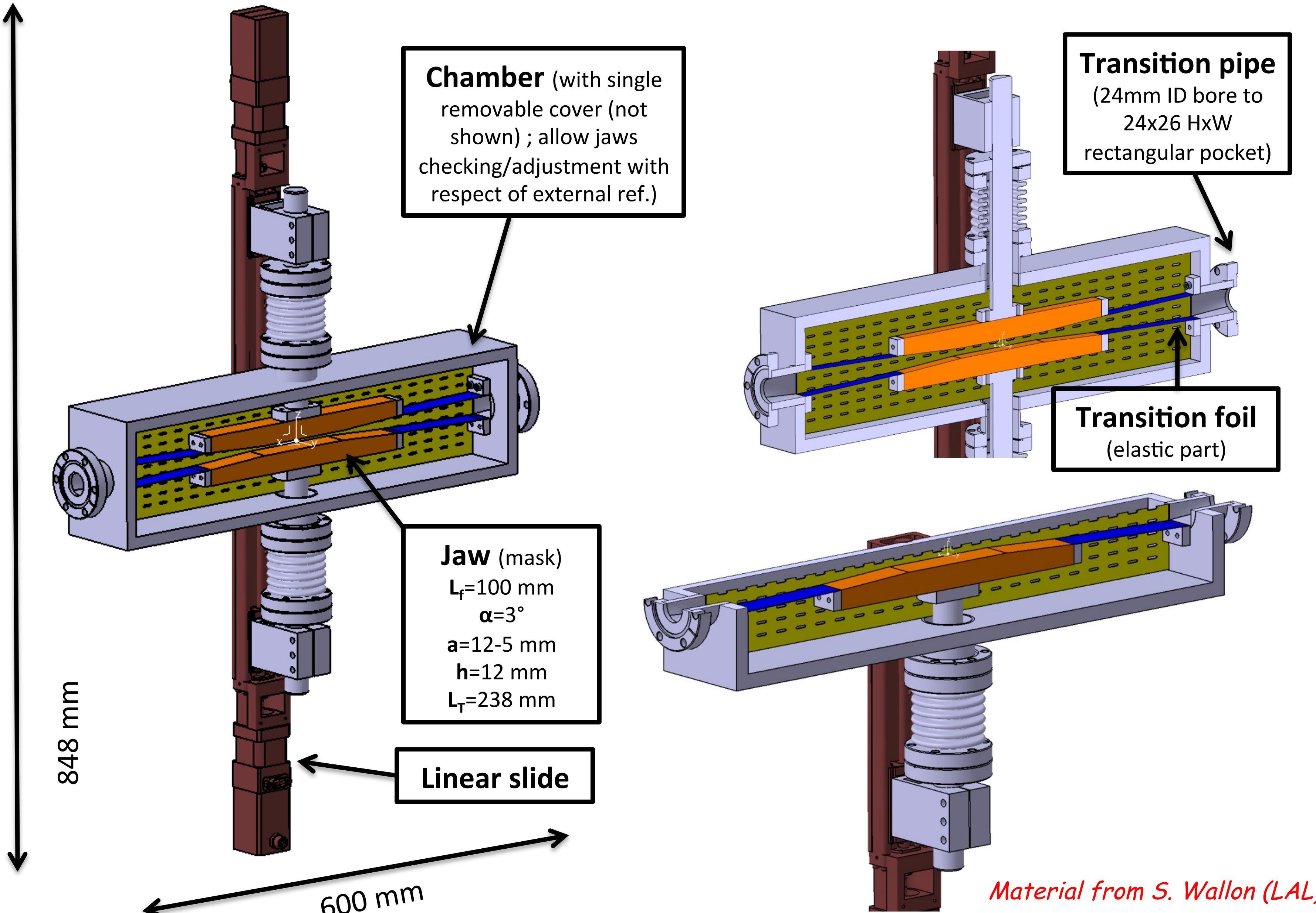




[G. V. Stupakov, "High-frequency impedance of small-angle collimators", PAC01] [A. Piwinski, DESY-HERA-92-04, 1992]
[G. Rumolo, A. Latina, D. Schulte,"Effects of wakefields in the CLIC BDS", EUROTeV 2006]

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

First 3D design of a retractable halo collimation device



Material from S. Wallon (LAL)

Summary and future work

- Beam halo measurements have been done using the wire scanners installed in **ATF2** prior to the **DS** installation. The data has been analysed and an ATF2 note is being written
- The location and half aperture of a **vertical and a horizontal halo collimation system for ATF2** have been optimized and we found that with a **vertical halo collimator of 5 mm half aperture** (15 σ_y) **we do not have losses at the BDUMP**
- Tracking studies with different optics and models show similar behaviour
- A **retractable** halo collimator type is being considered because of its flexibility in terms of operational aspects
- A **wakefield study has been started using analytical formulas and CST PS**
- A first preliminary 3D mechanical design has been done with the optimized parameters from CST PS simulations

- To complete the tracking studies with a the new parameterization calculated from the beam halo measurement campaign 2013 is being considered
- Beam impact studies (orbit distortion and emittance growth) with PLACET
- CST PS simulations with a more realistic collimator structure
- Real mechanical design and cost study of collimator

Thank you for your attention.

Back up…

Wire Scanner

Signal: Bremsstrahlung photons

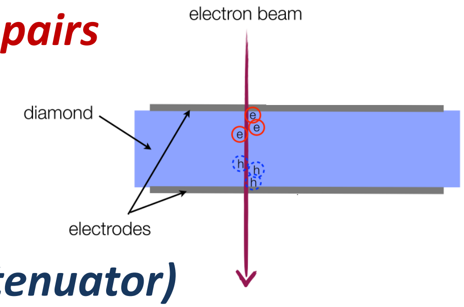
Dynamic range limited by:
- Background level
- 14 bit ADC counts
- PMT high voltage

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

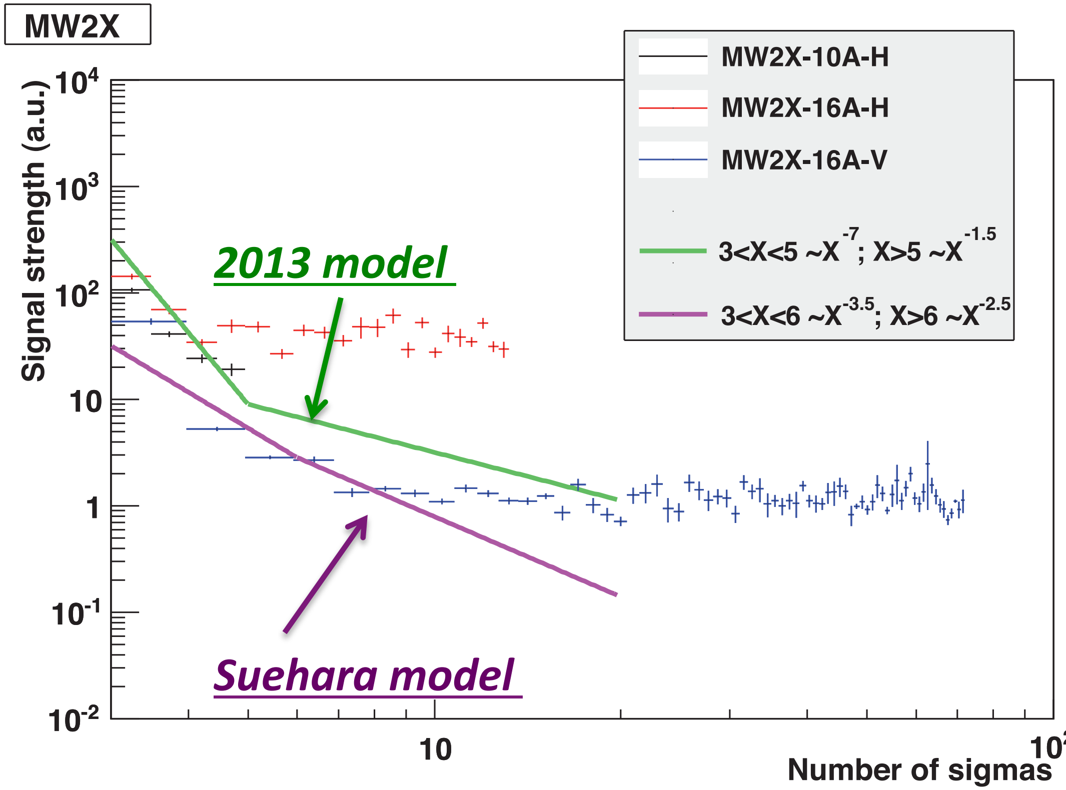
Halo collimation betatron depth

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	$46\sigma_y$	$27\sigma_x$

2013 wire scanners measurement campaign results

Vertical and horizontal beam halo measurements were done in the **EXT** line with **MW2X** on the 10th, 16th and 17th of **April 2013**

Red -> horizontal
Black-> horizontal
Blue -> vertical



- The beam halo observed is **symmetric** in the **EXT line**
- We observed a **background level for the horizontal** beam halo measurements **higher than for the vertical** measurements

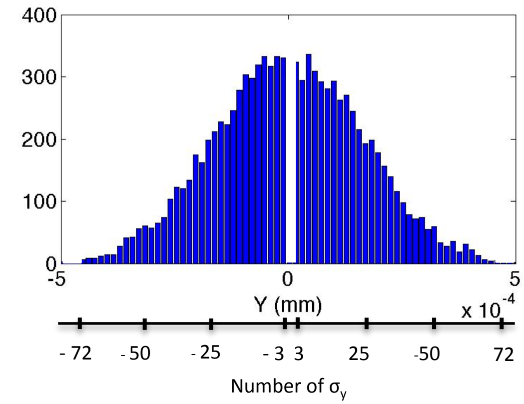
Beam dynamics simulation and tracking studies in ATF2

Gaussian distribution

nx=24 ny=28

(A_x=6 mm, A_y=0.43mm)

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



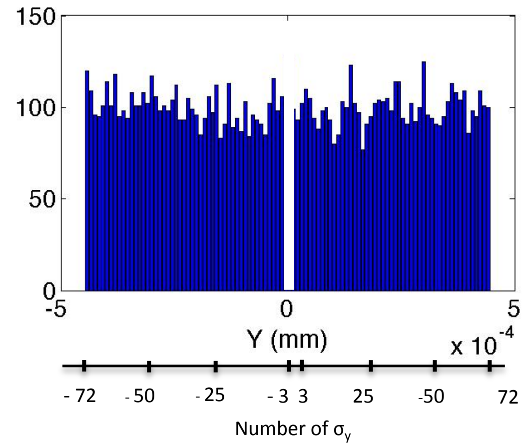
Uniform distribution

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)

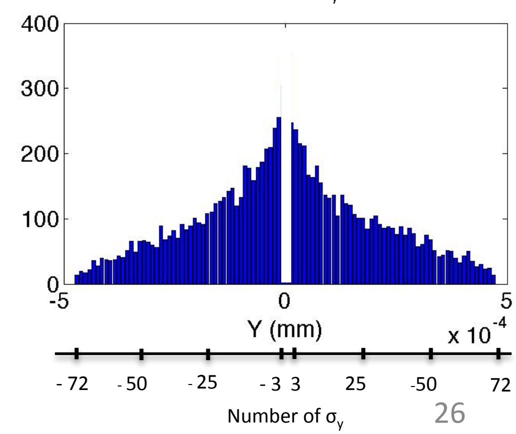
nx=60 ny=81.25

(A_x=6 mm, A_y=0.3mm)

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

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

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



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

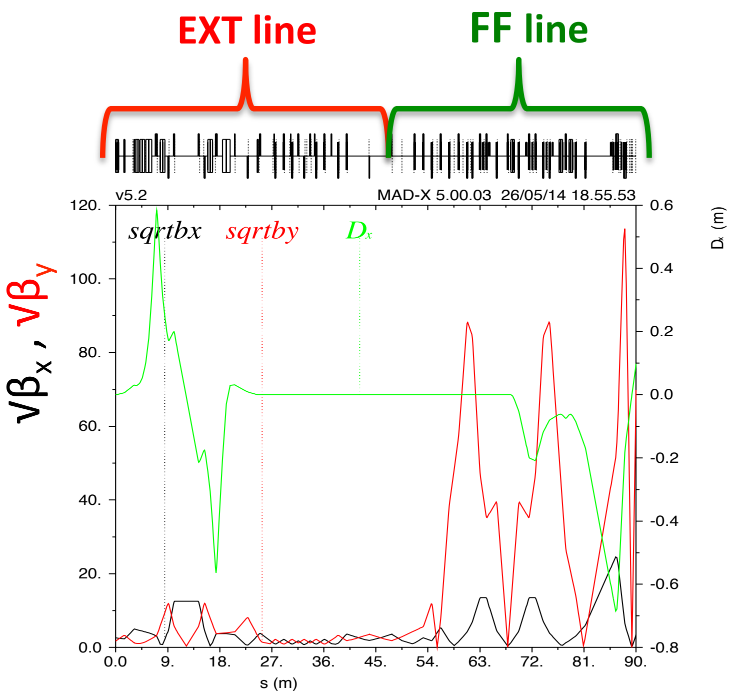
ATF2_background_and_halo_study.pptx

Beam dynamics simulation and tracking studies in ATF2

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

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

$$\sigma_{x,y} = \sqrt{\beta_{x,y}\epsilon_{x,y} + \delta_e D_{x,y}}$$



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

Minimum available free space (0.6 m)