CLIC Experiments at FACET / SLAC

A. Latina, J. Pfingstner, A. Grudiev, W. Wuensch, D. Schulte (CERN)

G. De Michele (EPFL / CERN / PSI)

E. Adli (Oslo Univ. / SLAC)

for the CLIC / CTF3 Collaboration

Overview

We propose three main experiments at FACET:

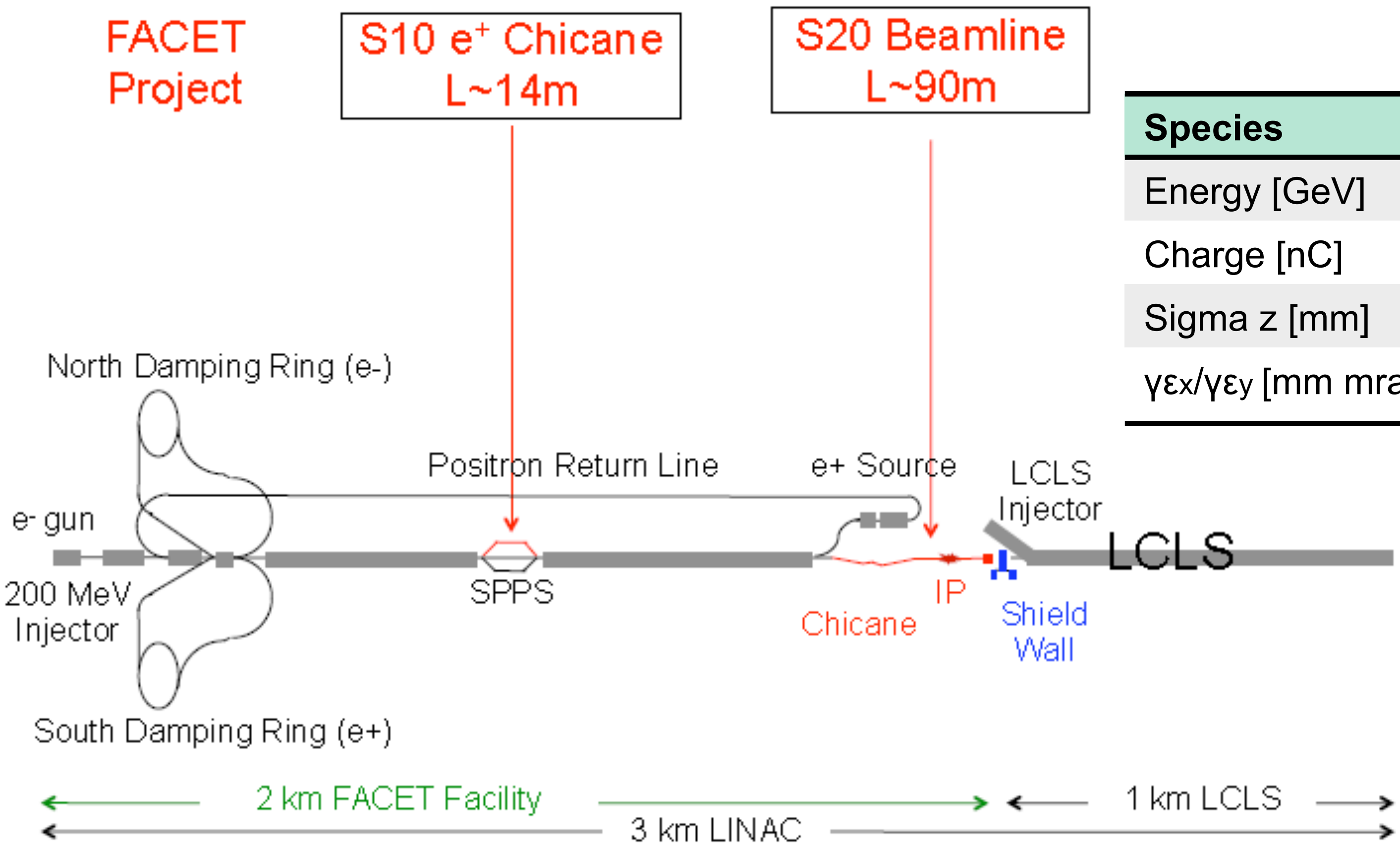
1) Dispersion-Free Steering and System Identification
   (aka: BBA-SI,, or T501)

2) Measurement of short- and long-range wakefields in the CLIC Accelerating Structures
   (aka: Experimental verification of wakefield suppression in the CLIC accelerating structures, CLASSE)

3) Measurement of collimators wakefield
   (see next talk by J. Resta-Lopez)

FACET Layout

The FACET facility uses the first two-thirds of the SLAC linac (sectors 0 through 20) to deliver electron (positron) beams to the experimental area



Species	e^+	e^-
Energy [GeV]	1.2-20	1.2-20
Charge [nC]	3.2…4.8	-2.6
Sigma z [mm]	1	1
$\gamma\varepsilon_x/\gamma\varepsilon_y$ [mm mrad]	30/3	30/3

Experimental verification of Beam-Based Alignment and System Identification Algorithms

- The very small emittances in future linear colliders require fast correction of static and dynamic imperfections, e.g. misalignment and ground motion. This is achieved using beam-based alignment algorithms and feedbacks

- The effectiveness of such algorithms is limited by the knowledge of the system, i.e. the matrix representing the response of the beam trajectory to the action of the correctors

- FACET, with its 2 km long linac accelerating electrons (and positrons) with micrometric emittances, offers an unique and ideal setup for testing beam-based alignment (BBA) and system identification (SI) algorithms

- We believe that this experiment is crucial to consolidate and perfect the procedures needed to commission and operate future linear colliders.

Emittance growth in the CLIC main linac

Emittance at ML injection	Static budget	Dynamic budget
H: ε_H<600 nm	$\Delta\varepsilon_H$<30 nm	$\Delta\varepsilon_H$<30 nm
V: ε_V<10 nm	$\Delta\varepsilon_V$<5 nm	$\Delta\varepsilon_V$<5 nm

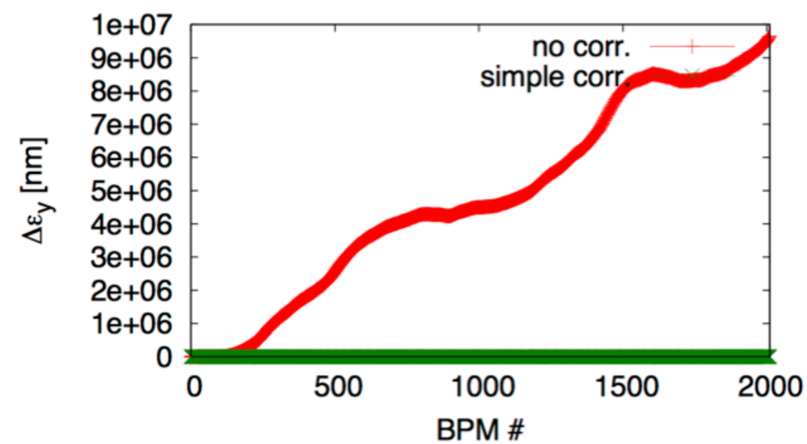
Pre-alignment specifications of the CLIC main linac components (for the beam to go through)

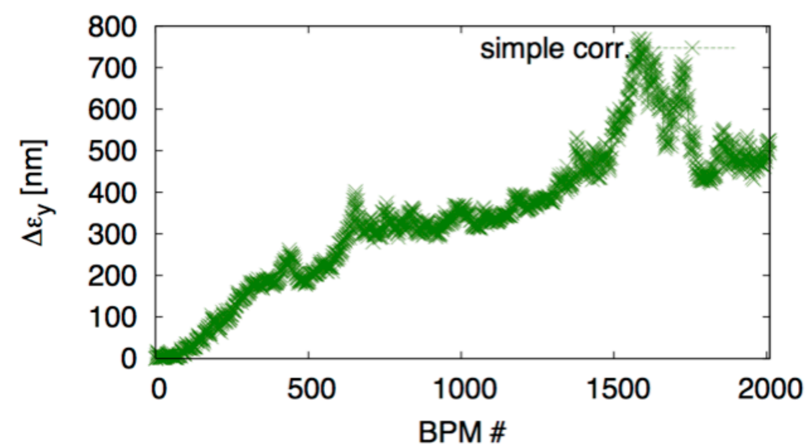
Imperfection	With respect to	Value
BPM offset	Wire reference	14 μm
BPM resolution	–	0.1 μm
Accelerating structure offset	Girder axis	10 μm
Accelerating structure tilt	Girder axis	140 μrad
Articulation point offset	Wire reference	10 μm
Girder end point	Articulation point	5 μm
Wake monitor	Structure centre	3.5 μm
Quadrupole roll	Longitudinal axis	100 μrad

Example of simple beam-based correction: 1:1 steering

$$\begin{pmatrix} y - y_0 \\ 0 \end{pmatrix} = \begin{pmatrix} \mathbf{R} \\ \beta \mathbf{I} \end{pmatrix} \begin{pmatrix} \theta_1 \\ \vdots \\ \theta_m \end{pmatrix}$$

Simulated emittance growth in the ML





A. Latina

DFS: remove dispersion to reduce the emittance growth

DFS correction:

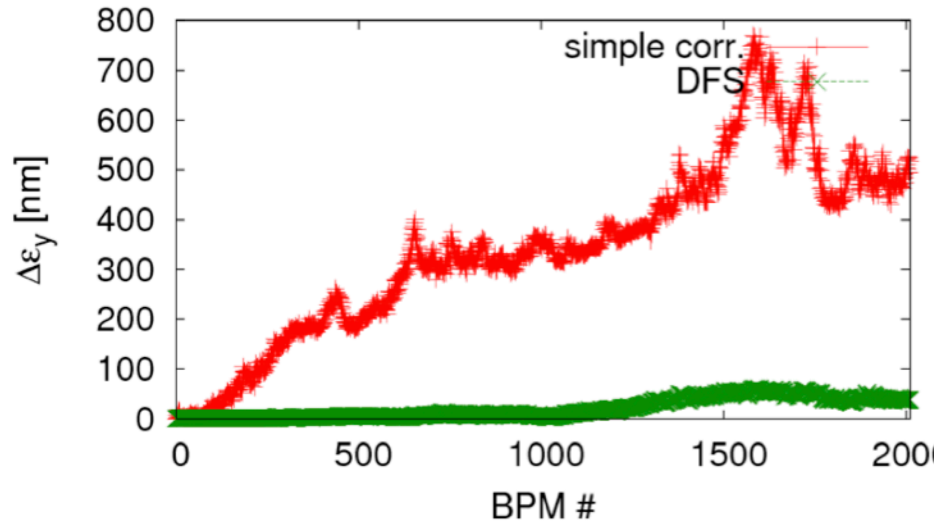
$$\begin{pmatrix} y - y_0 \\ \omega(\eta - \eta_0) \\ 0 \end{pmatrix} = \begin{pmatrix} \mathbf{R} \\ \omega\mathbf{D} \\ \beta\mathbf{I} \end{pmatrix} \begin{pmatrix} \theta_1 \\ \vdots \\ \theta_m \end{pmatrix}$$

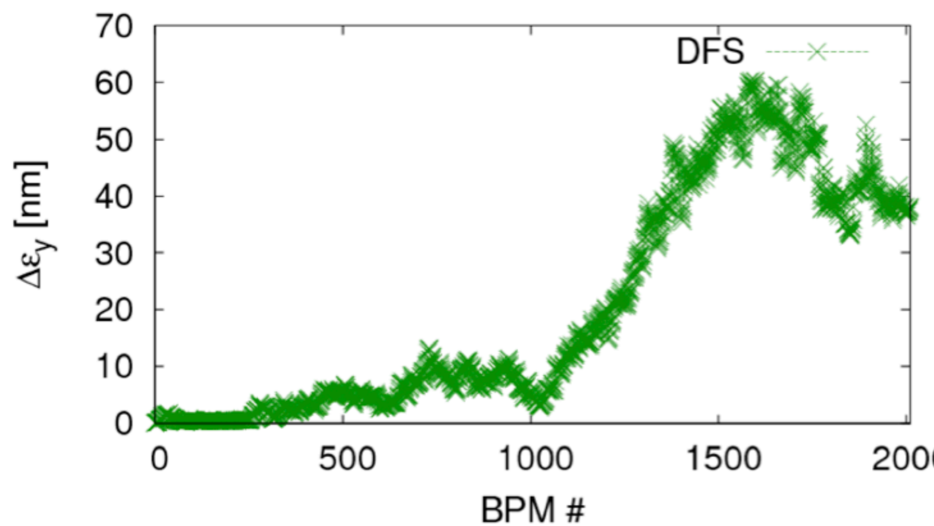
Emittance growth is largely reduced

- In CLIC: yet is far too large, due to wakefields in the accelerating structures

- In CLIC other BBA algorithms must be used (RF alignment)

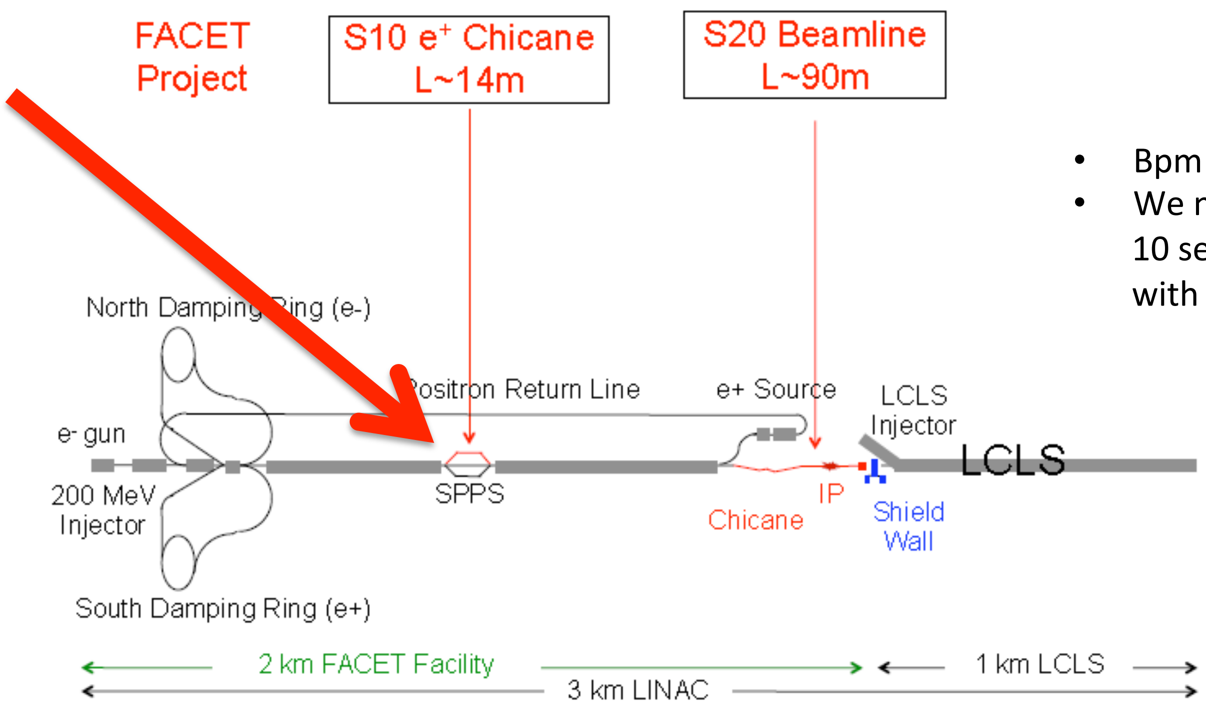
We need to test DFS.





BBA experiment at FACET

- We need to measure the orbit and the dispersion via BPM readings
- Energy difference to measure the dispersion has been obtained offsetting the RF-phase of 1 klystron in Sector 10, by 90 degrees
  - This induces a -1.3% energy difference at the end of the linac, about 300 MeV
  - (simulations showed that it is sufficient)



- Bpm resolution is ~40 um
- We need to sample the orbits for 10 seconds at 10 Hz to measure with resolution ~4 um

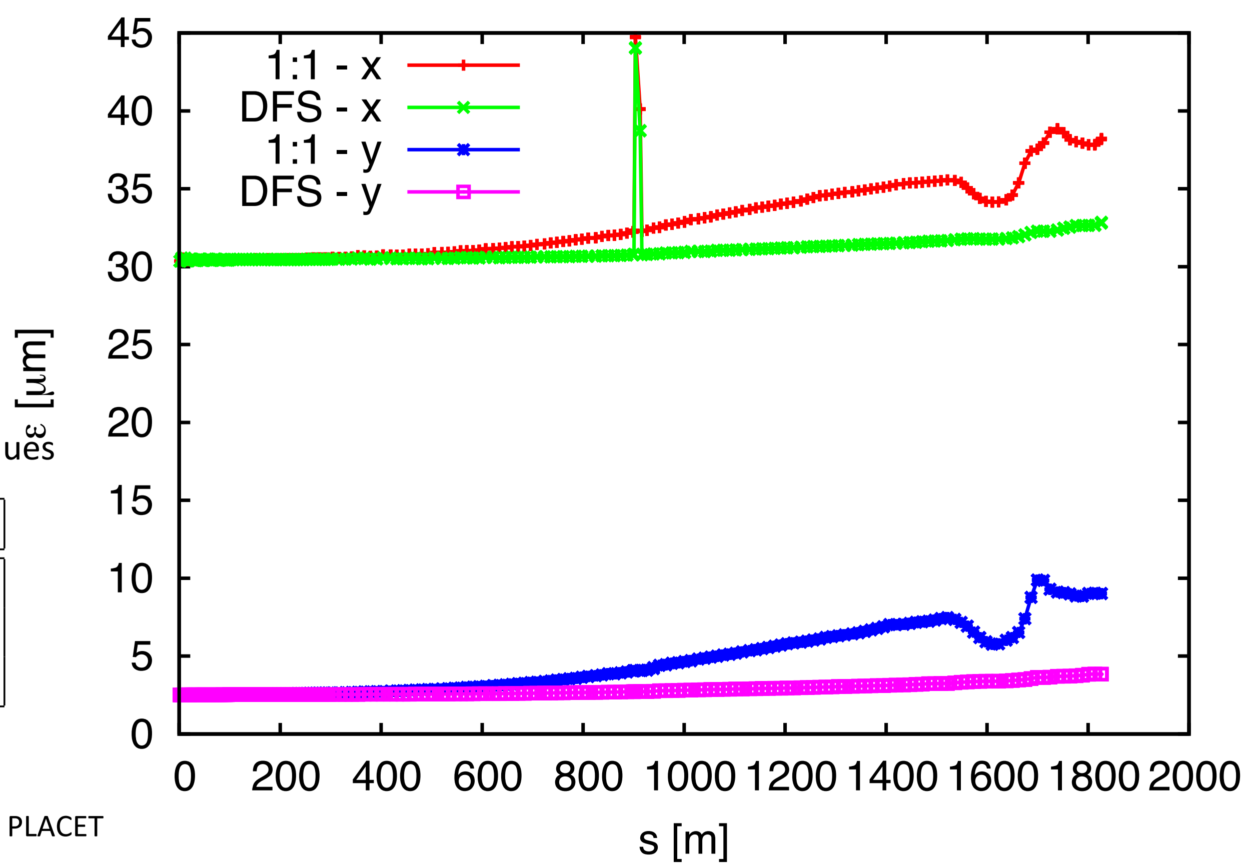
- Dispersion response is: D = R1 – R0

Simulation of BBA at FACET: Orbit and Dispersion Correction

Relevant beam parameters at injection

Symbol	Value
$\gamma\epsilon_x$	$3.0 \cdot 10^{-5}$ m · rad
$\gamma\epsilon_y$	$0.25 \cdot 10^{-5}$ m · rad
σ_z	1 mm
σ_E	1%
q	3.24 nC
E_0	1.19 GeV

Emittance growth with static imperfections, after beam-based alignment. The result is the average of 100 random seeds.



Misalignment and BPM precision values

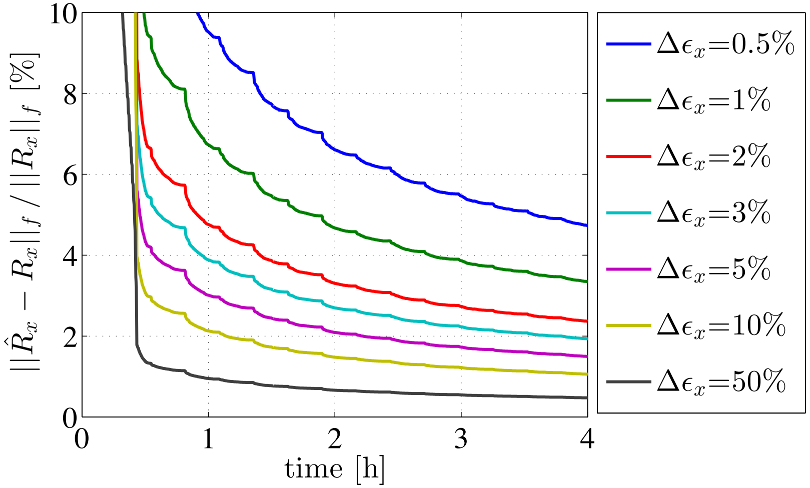
Symbol	Value, RMS
$\sigma_{\text{quadrupole offset}}$	100 μm
$\sigma_{\text{bpm offset}}$	100 μm
$\sigma_{\text{bpm precision}}$	5 μm

Simulations performed with the tracking code PLACET

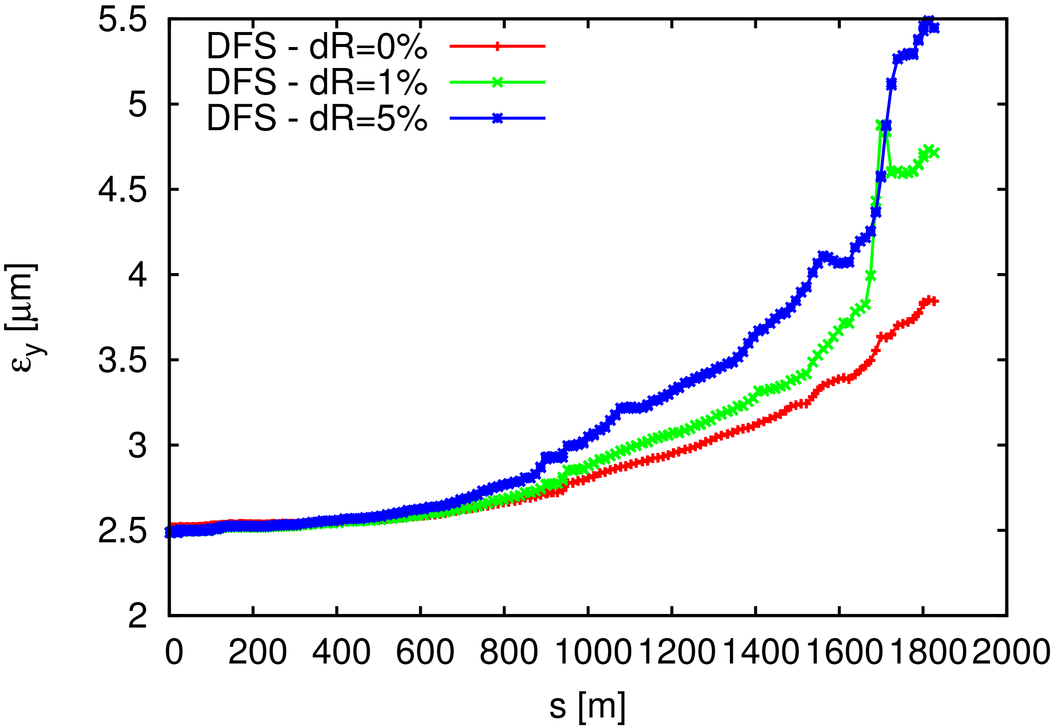
System Identification and BBA

Left: Speed of convergence assumed BPM resolution = 10 um (1 iteration = 15 seconds)

Right: Emittance growth after dispersion-free steering with imperfect model, compared to the case with perfect mode. The results are the average of 1000 random seeds.



The black line corresponds to exciting 1 mm oscillation with BPM resolution = 5 um



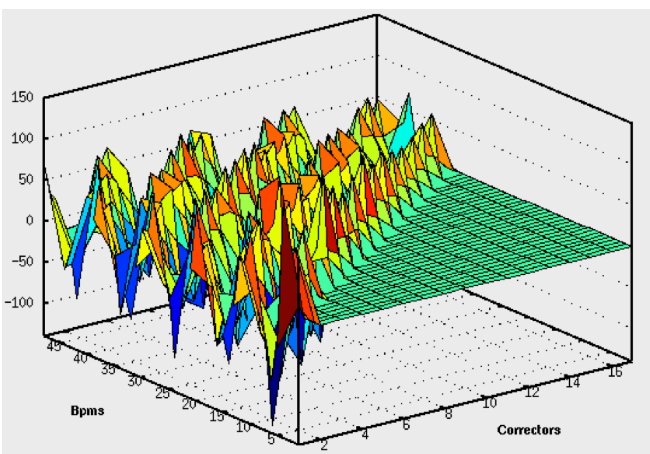
T501: CERN BBA at SLAC

T501: FACET test-beam proposal to study advanced global correction schemes for future linear colliders.

CERN-SLAC collaboration where algorithms developed at CERN are tested on the SLAC linac.

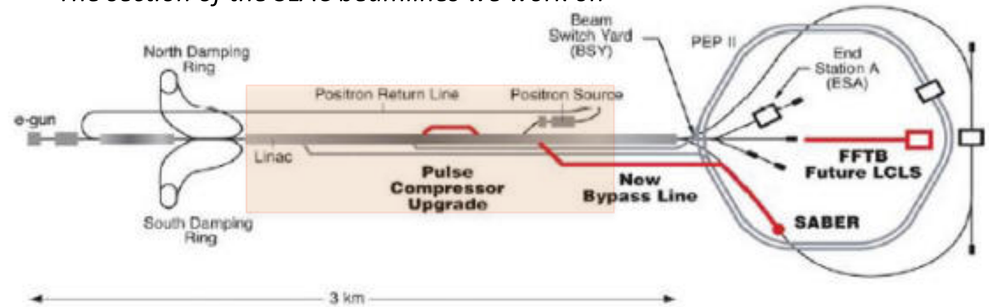
The study includes linac system identification, global orbit correction and global dispersion correction.

Successful system identification and global orbit correction has been demonstrated on a test-section of 500 m of the linac.

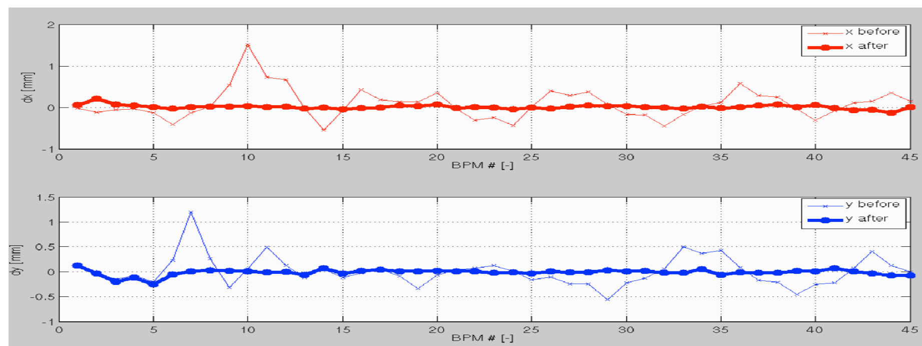


(Above) Measured Rx response matrix for the test-section of the linac (17 correctors, 48 BPMs)

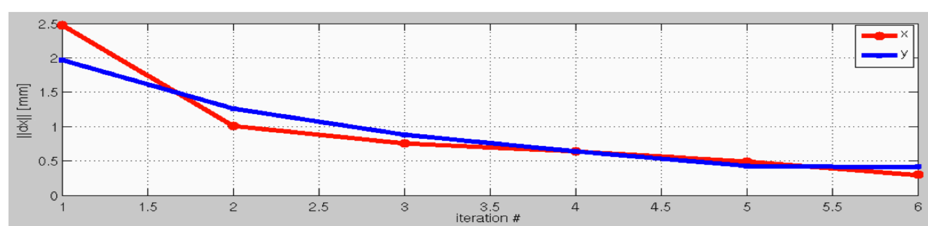
The section of the SLAC beamlines we work on



RESULT: Example of global orbit correction of a test-section of the SLC linac:



(above) Horizontal and Vertical trajectories before and after orbit correction



(above) Iterations of orbit correction: convergence of the algorithm

A. Latina, J.Pfingstner, D. Schulte (CERN), E. Adli (SLAC)

Experimental verification of wakefield suppression in the CLIC accelerating structures

The performance of main linac accelerating structures has a profound influence on the energy reach, luminosity and cost of CLIC.

The main crucial issues for the structures are:

• High gradient and power, 100 MV/m and 65 MW, operation at low, around 10^{-7}, breakdown rate.
• **Strong long-range wakefield suppression, about a factor 50 in six rf cycles (corresponding to bunch spacing).**
• Micron precision fabrication and alignment tolerances.

Motivation

High-gradient performance is being verified in high-power tests at SLAC, KEK and CERN. ✓

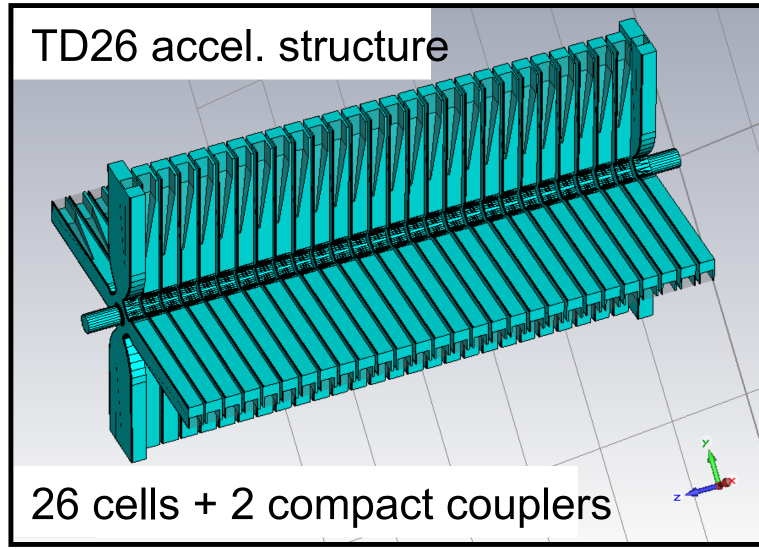
High-precision manufacture studies are underway, prototype are being made and tolerances are being verified. ✓

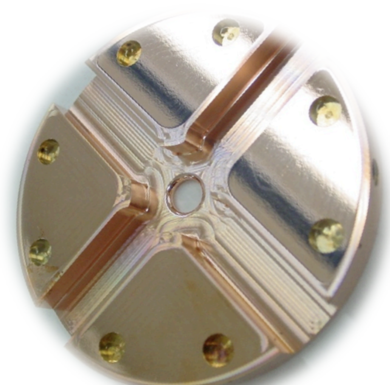
On the other hand, the long range wakefield behavior of the structures is determined primarily by: !

- **computer simulation,**
- **along with verification and benchmark experiments of related structures made at ASSET in the NLC/JLC and CLIC 30 GHz era.**

Why?

- One of the validations for the **CLIC baseline structure** is to demonstrate that the computed transverse long range wake-fields behavior is achieved in a **prototype test structure**.
- This will give us the confidence in the electromagnetic (EM) codes without spending excess time and money in further prototyping.



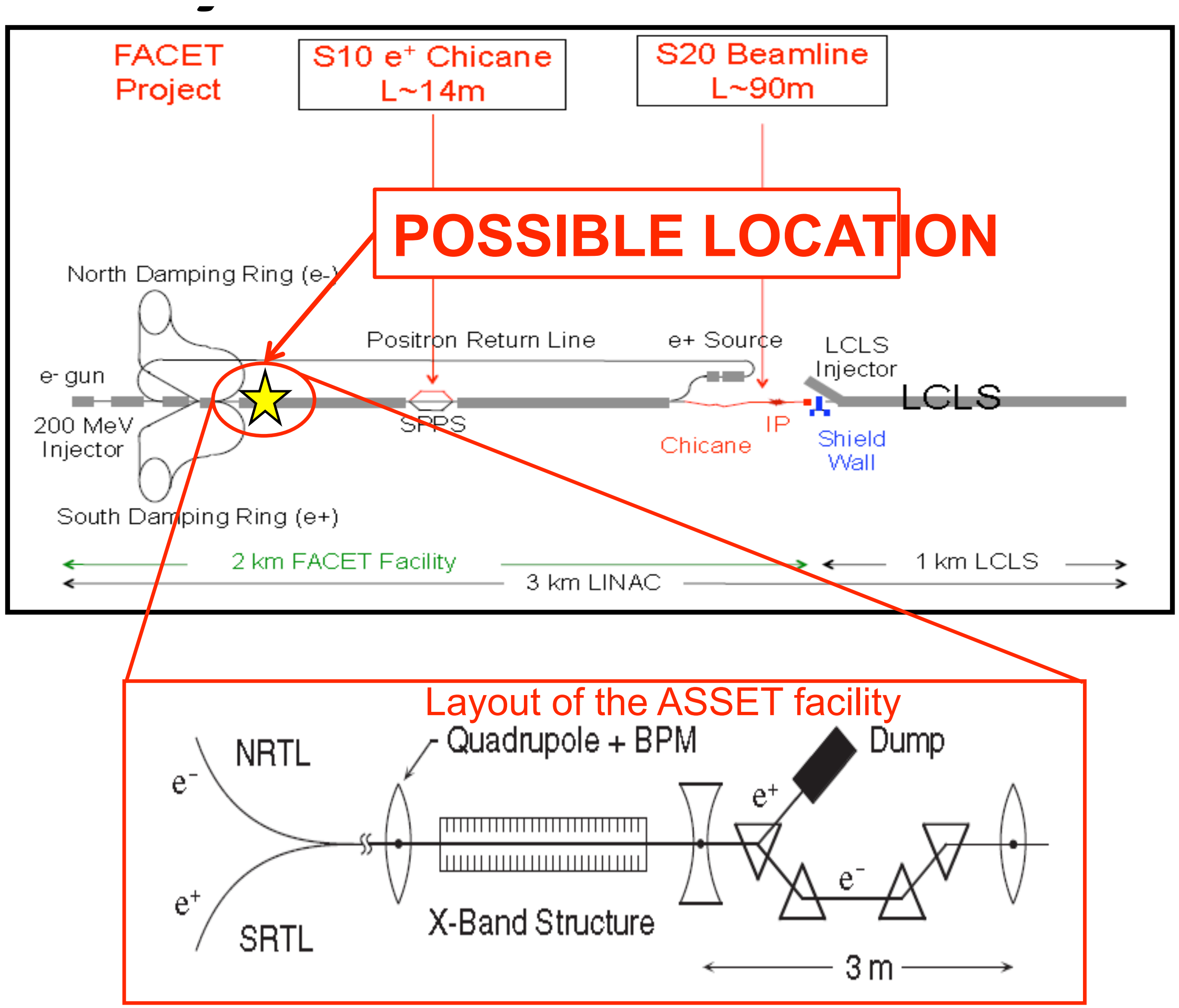


G. De Michele, A. Grudiev BE-RF

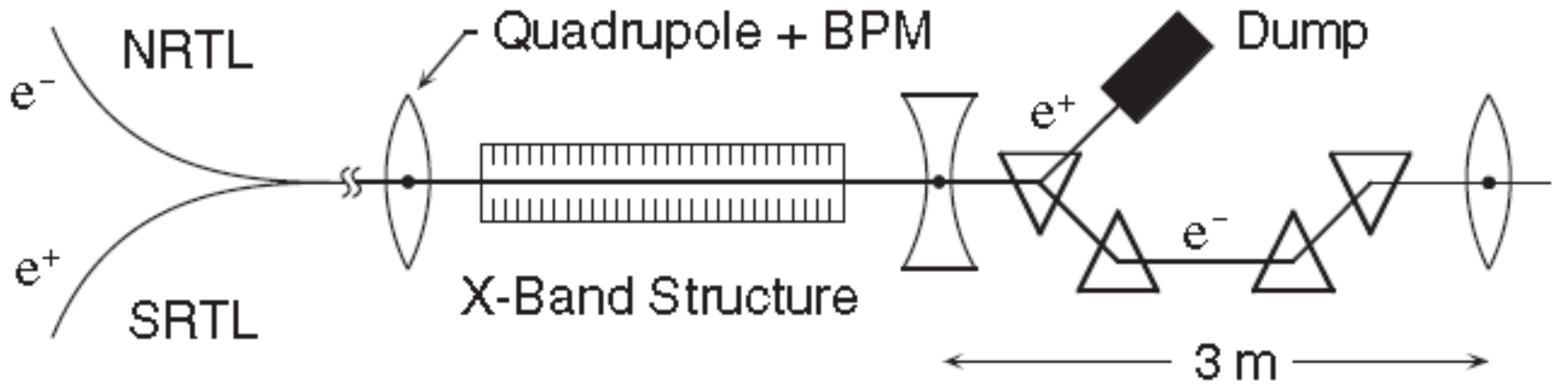
Regular cell geometry

Why FACET?

- Possibility of having driving and witness bunches with positrons and electrons.
- Adjustable bunch spacing for a timing span behind the driving bunch.
- Bunch length flexibility: ideally shorter than 1mm in order to resolve the 3rd dipole band which shows up a peak around 40GHz.



ASSET layout and beam parameters



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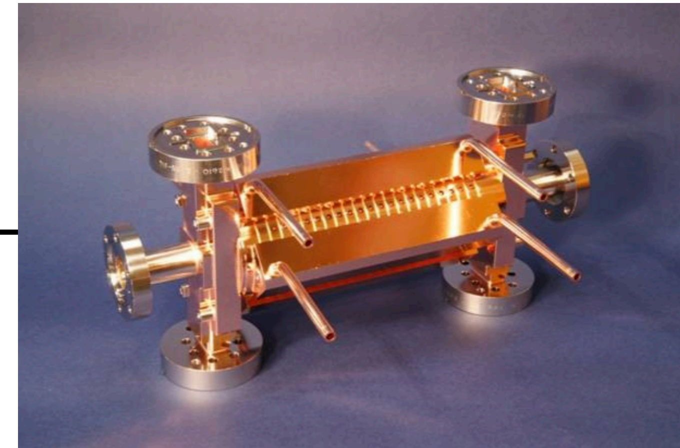
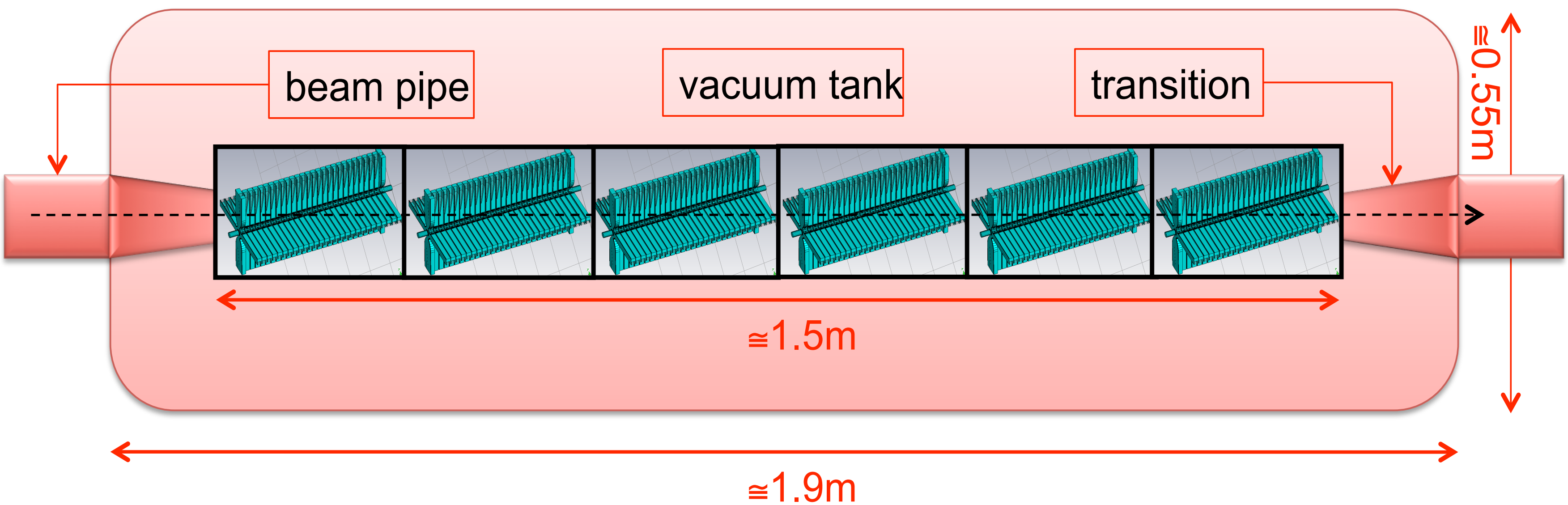
Prototype structure for wake-fields measurements



- 6 x TD26 accelerating structure
- Simple vacuum tank
- Clamped aluminum cells
- Total space needed: L x W x H ≅ 1.90 x 0.55 x **0.55 m**

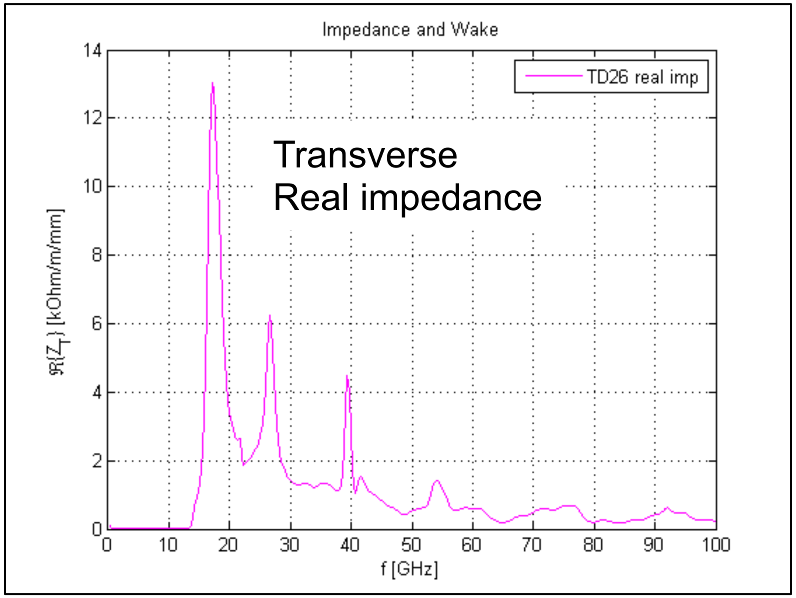


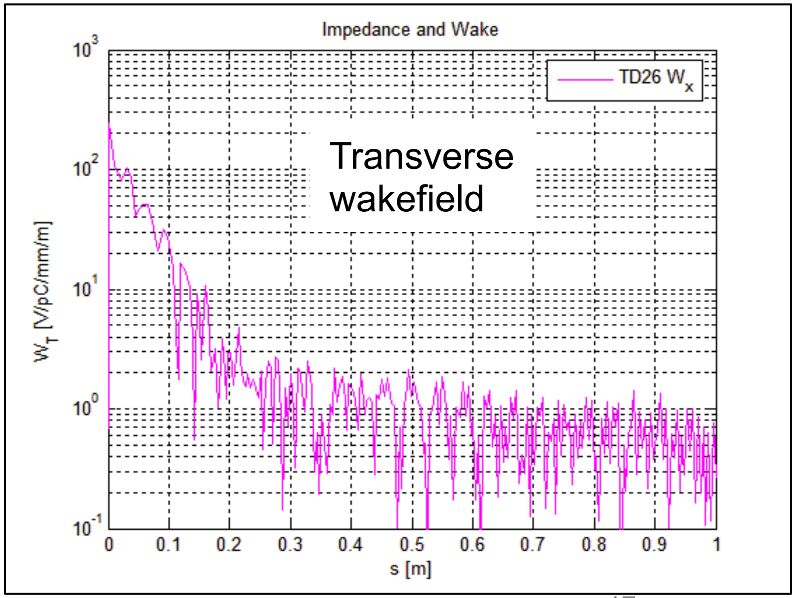
Deflection angle

The transverse wake-field can be extrapolated from the measurements of the deflecting angle $\Delta\phi_y$ of the witness bunch

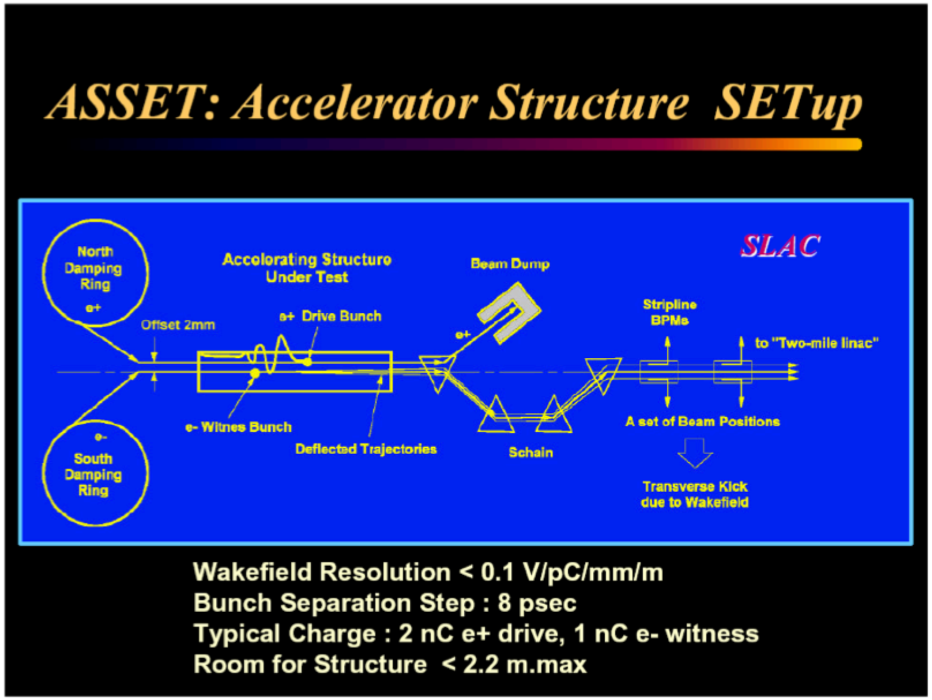
$$\Delta\varphi_y = \frac{q_w Q_d L e^{-\left(\frac{\omega\sigma_d}{2c}\right)^2} e^{-\left(\frac{\omega\sigma_w}{2c}\right)^2}}{E_w} \cdot W_\perp(t)\Delta y_d$$

- L active length of the structure
- E_w energy of the witness bunch
- $W_\perp(t)$ transverse wakefield
- Q_d drive bunch charge
- Δy_d drive bunch offset
- q_w witness charge
- σ_d drive bunch length
- σ_w witness bunch length





ASSET measurement method



- $W_\perp$ is the transverse wake function at time t behind the drive bunch, E_w (~ 1.2 GeV) is the witness bunch energy and Δy_d is the offset in the drive bunch from the electrical centre of the accelerating structure.
- Wake function units are transverse voltage per drive charge (en_d), drive offset and structure length (L_s), and $\zeta = e^2 L_s n_d \exp(-\omega^2\sigma^2/c^2)$

- Electron bunch serves as the witness bunch
- In traversing the DUT, the witness bunch is deflected by the wake function generated by the positron drive bunch.
- Witness bunch passes though chicane and down linac where trajectory is recorded by BPMs
- The transverse wake function is determined by measuring the change in the witness bunch deflection per unit change in the drive bunch offset in the structure.

- **Angular kick imparted to the witness bunch is found from ratio of the transverse to longitudinal energy:** $\Delta\theta_y = \zeta W_\perp(t)\Delta y_d / E_w$

Ref: Phys Rev Lett, 74, No 13,2475-2478
Phys. Rev. ST Accel. Beams 12, 104801, 2009

Main challenge

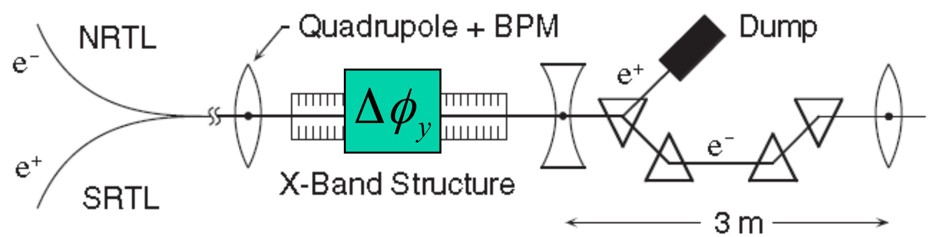
From the experiment proposal:

The exponential factors account for the Gaussian shape of the bunches. The transverse wake-field $W_\perp(t)$ is normalized in units of the drive bunch offset, drive bunch charge and structure length. In a case study where $Q_d = 3\,nC$, $E_w = 1.19\,GeV$, $L = 1.5\,m$, $W_\perp(t) = 1\,V/pC/mm/m$, $\Delta y_d = 0.5\,mm$ one obtains a deflecting angle $\Delta\Phi_y = 1.89\,\mu rad$ i.e. a BPM located downstream at 1 m distance should have less than $2\,\mu m$ resolution. This low value for the

An accurate data analysis is required

- Good knowledge of the optics is essential
- Orbit fit to determine the kick

$$\Delta\theta_y = A W_\perp(t) \Delta y_d$$



Summary and outlook

Three experiments have been proposed to SLAC from the CLIC collaboration:

1) Verification of Beam-Based Alignment and System Identification techniques for Future Linear Colliders (BBA)

2) An experiment to test the suppression of the long-range wakefields in the accelerating structures for the CLIC Main Linac, at FACET, has been proposed (CLASSE)

3) Collimator wakefields measurement (see next talk)

They all have been approved:

- BBA has already given promising results, more data taking will be performed soon
- CLASSE might see the prototypes installed in March; it awaits the positron beam to be performed