Potential of using CALIFES or CTF3 electron beam for LHC complex impedance studies

Elias Métral, Benoit Salvant, Carlo Zannini
for the impedance team

Acknowledgments :

Fritz Caspers, Roberto Corsini, Giovanni di Michele, Alexej Grudiev, Andrea Latina, Thibaut Lefevre, Helmut Schmickler, Rogelio Tomás Garcia, Christine Vollinger, Manfred Wendt.

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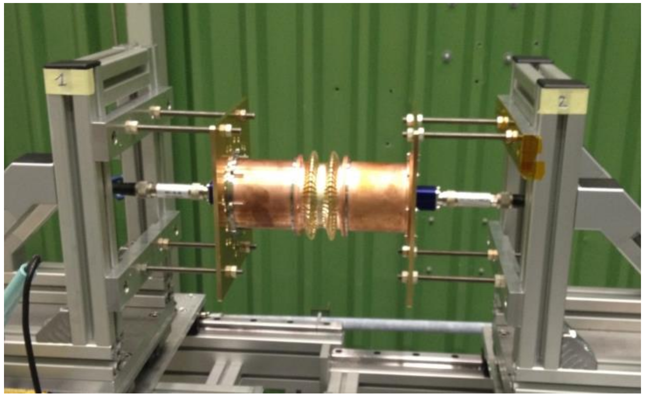
Context

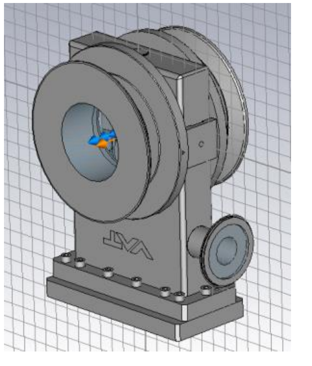
- Impedance team involved in design and approval of new and modified equipment in all CERN circular machines (in particular PSB, PS, SPS and LHC, but also AD, ELENA and CLIC damping rings).

- Tools at our disposal:
  - Bench measurements with wires and probes

    → problem: not direct measurement of impedance or wake, and possibly strong perturbation of the EM fields
  - Numerical simulations

    → problem: difficulty to reproduce reality with a model (e.g. design errors, small features, coatings, matching errors) , simulated exciting bunch is not a delta function.

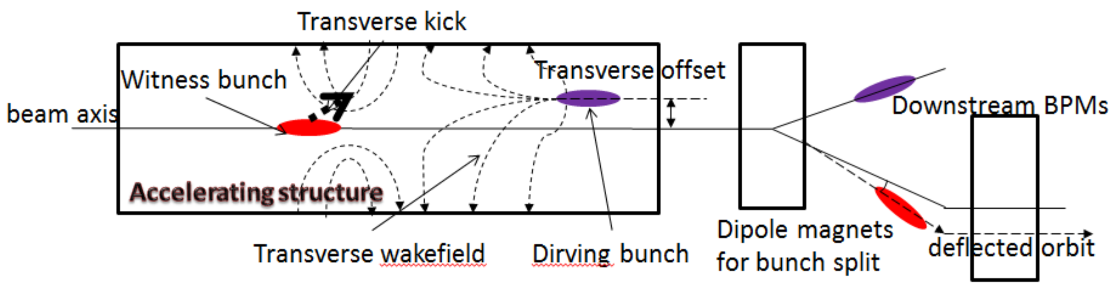




→ Measurement with electron bunches could be an interesting complement to these existing tools

Recent use electron beams to measure wakefields of accelerator structures

- Measurements of A. Latina and H. Zha at FACET (presentation at this workshop)



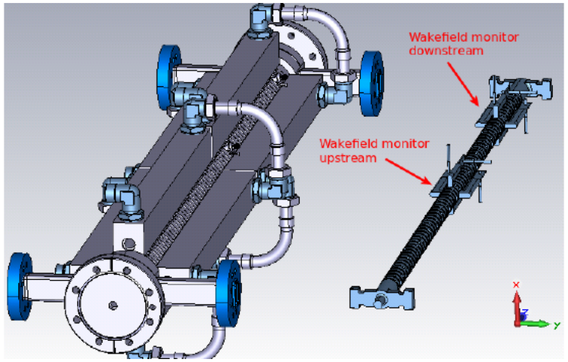
→
- Use of positrons and electrons
- Direct measurement
- Very short range wake

- See the following presentation by Steven Jamison

→
- Use of electrons
- Indirect measurement
- Very short range wake

- Measurements of G. di Michele at PSI and Trieste: using embedded wakefield monitors into a CLIC accelerating structure.

→
- Use of electrons
- Indirect measurement
- Very short range wake



Courtesy PhD thesis G. di Michele

→ What could we do with CALIFES?

Assumptions for LHC complex:

- Use of electrons only
- Direct or indirect measurement
- Long range wake

What would we be interested to measure?

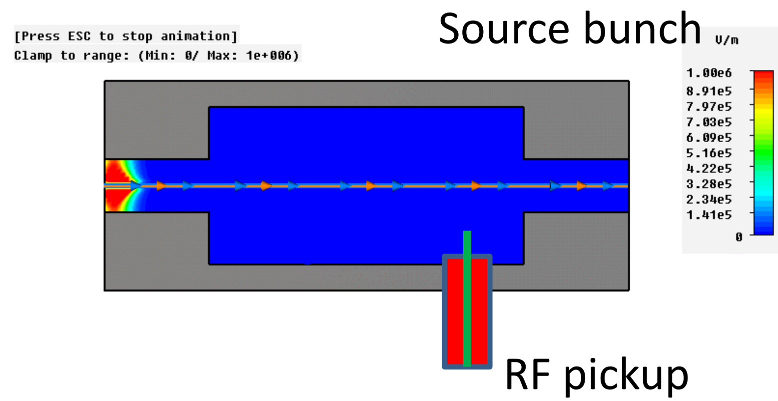
With a realistic exciting source:

- Direct measurement of generated electromagnetic fields
- Direct measurement of “wake function”
- Direct measurement of coherent effects between bunches
- Direct measurement of heating

Difficult to implement at CALIFES

→ This is what we would like, but the feasibility is yet to be proven

Direct measurement of generated electromagnetic fields



- Possibility to measure EM fields from available antennas, buttons, striplines, wires, all mode couplers already in the device (or installed just for that reason).
  → See also proposal of electro optical pickup in the following talk.

- Indirect measurement in principle, but possibility of direct benchmark of CST Particle Studio simulations with fields monitors and check their validity
  → probe measurements only validate the Qs from eigenmode simulations
  → wire measurements can perturb significantly the modes.
  → real interest in using an electron source

- For the case of the wirescanners for instance, possibility to directly measure the signals that we need
  → current induced by the beam → beam induced heating
  → would be very important, and the only direct way of measuring the heat load to the wire (besides installing it in the SPS or the LHC).

- For other devices, it would be an indirect measurement that could validate the model, meshing and simulation.

→ Simple measurement, would not need any additional hardware
→ Requires pre installation of a probe in the device (if there is not already one).
→ Switch from ferrite damping to coupler damping is proposed to avoid beam induced heating

What would we be interested to measure?

With a realistic exciting source:

- Direct measurement of generated electromagnetic fields
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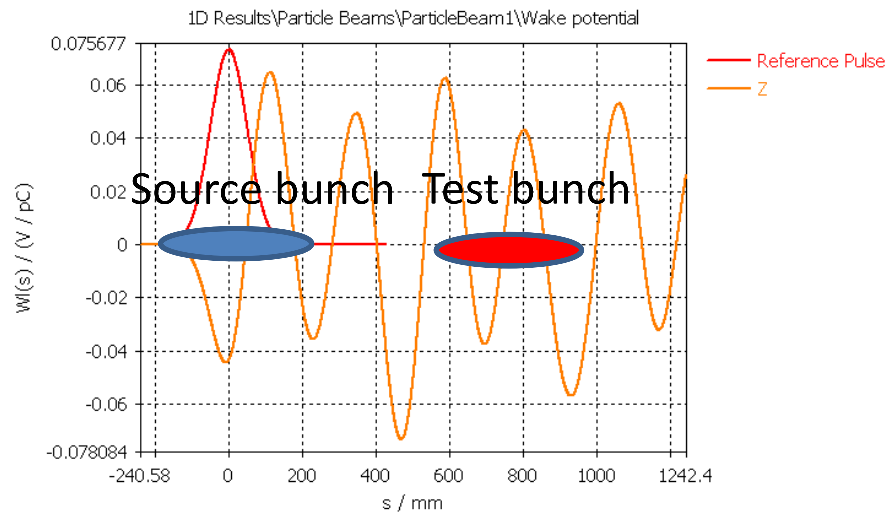
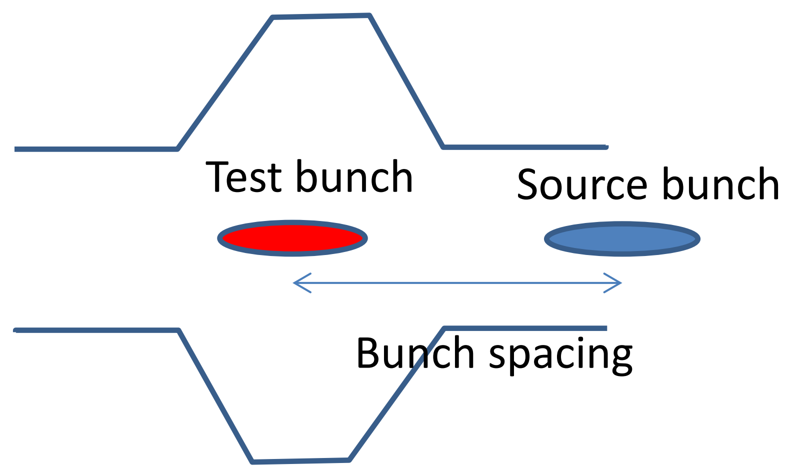
→ This is what we would like, but the feasibility is yet to be proven

Direct measurement of “wake function”

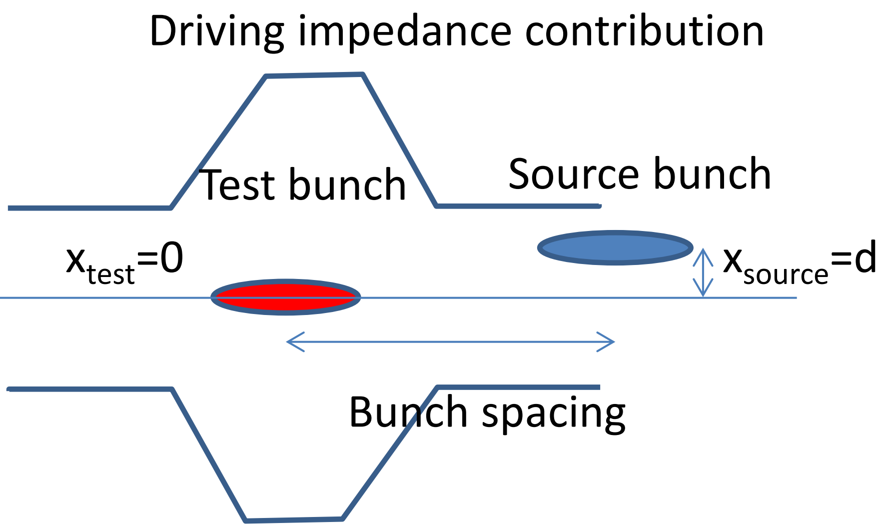
- Measurement of energy loss as a function of source/test bunch spacing → longitudinal wake
- Measurement of kick as a function of source/test bunch spacing → transverse wake
- In simulations, difficult to reach source bunch below 1 mm for standard devices due to mesh size.
- Very small bunch length achievable with electron beams (2 to 3 ps in CALIFES) → “wake function” could be measured provided the sampling is sufficient. Feasible?

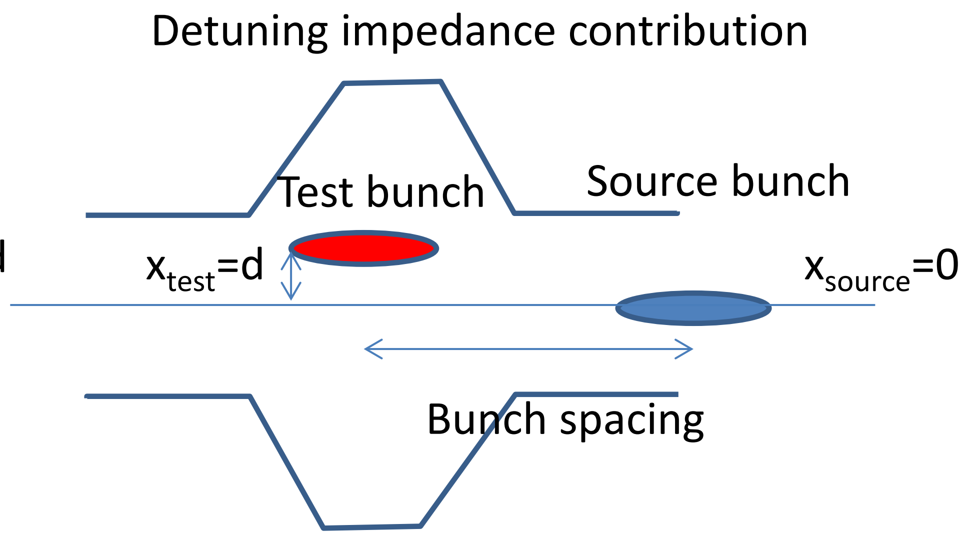




Direct measurement of “wake function”

- Important to disentangle the “dipolar” impedance contribution from the “quadrupolar” contribution to assess the impact on collective effects





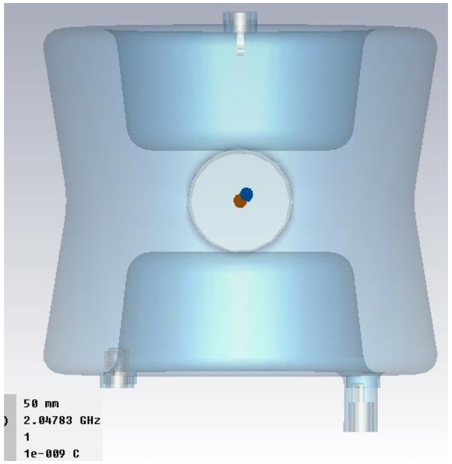
→ All particles in the test bunch receive the same kick
→ Coherent effect
→ Drives instabilities

→ All particles in the test bunch receive a kick proportional to their position
→ Incoherent effect
→ Impact on instability depends on the type of instability

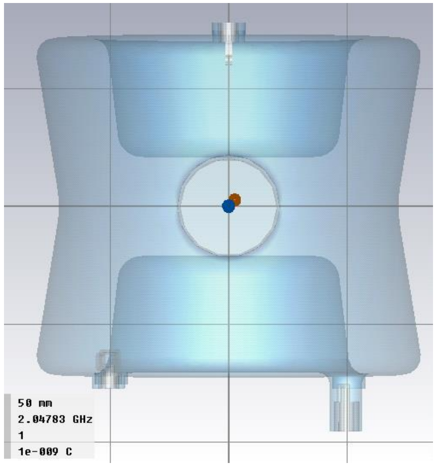
→ Can the orbits of the source and test bunches be controlled separately?

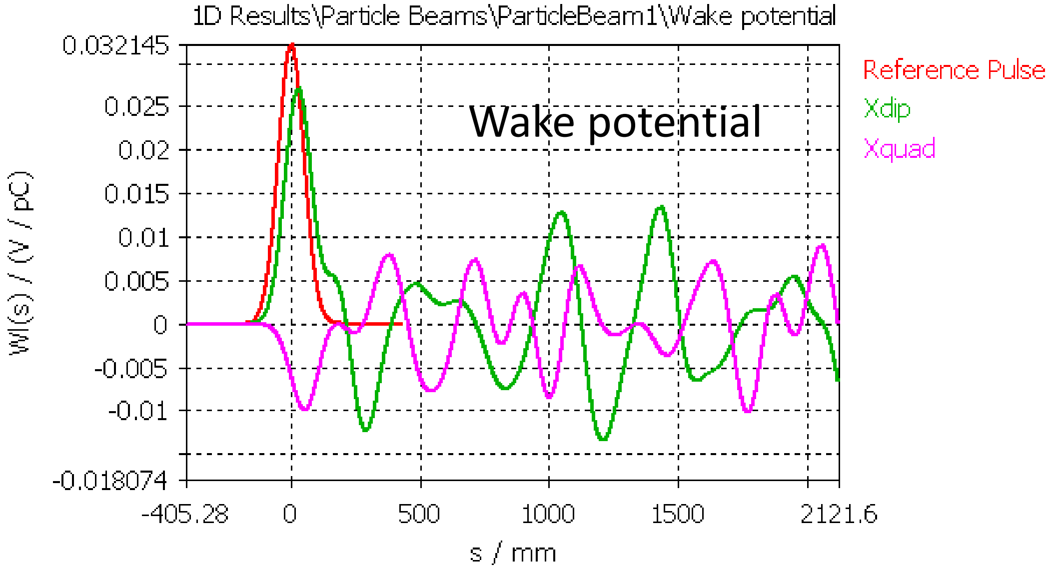
Example: LHC crab cavities

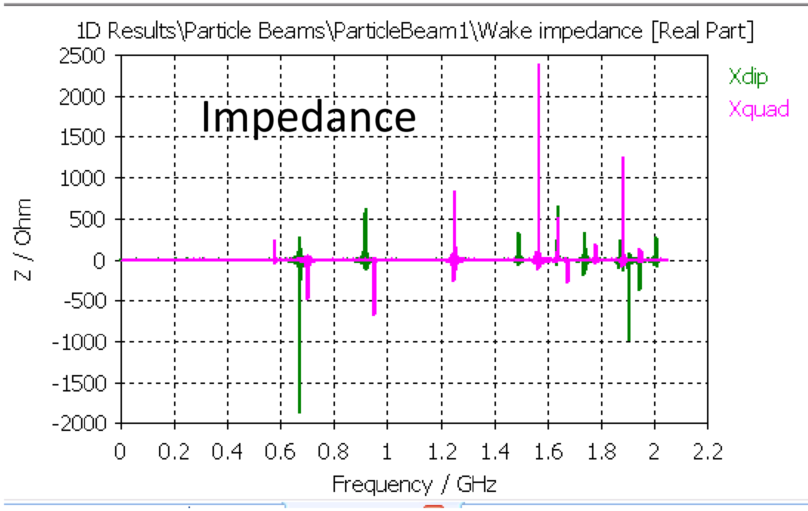
Driving impedance (also called dipolar impedance)



Detuning impedance (also called quadrupolar impedance)







- → Very different features between driving and detuning impedance and very different effects.
- → Detuning impedance generally small for cylindrically symmetric structures
- → Detuning impedance is very significant for SPS kickers (for instance) and tricky to obtain from wire measurements
- → Need to control separately source and test bunches

Potential limitations

- **Minimum kick strength observable with the BPM resolution**
  → Many components are in the 1 to 10 kOhm/m range for the transverse impedance, in the mOhm range for the longitudinal impedance
  → Previous studies show that the kick is of the order of 10 microns after 1 m for 10 kOhm/m
  → Roberto Corsini proposed possibilities to amplify this kick using lever arms
  → This could require 3 BPMs before the device and 3 BPMs after the device (H. Schmickler)
  → Reducing the energy of the test bunch would help!

- **Need to disentangle between the test and source bunch**
  → Can we resolve 0.1 ns between two bunches? Challenging together with resolution requirements
  → Would need special BPM development
  → Could a high bandwidth kicker be used (prototype installed in SPS to work in GHz range)?

- **Accurate control of the orbit and spacing of test vs source**
  → difficult to do with one electron source, contrary to FACET
  → ideas to delay the bunch, delay the laser pulse to control the spacing
  → ideas to move the laser pulse transverse position to control independently the transverse position
  → this could be the main limitation for the setup

- **Control of intensity of both bunches** (highest on source and low on test)

- **Available length** (for both device installation and for observation)
  → some critical elements are very long (SPS septa, LHC TDI and kickers).

- **Need for large flexibility in length and radius of input device**
  → the facility may become a tapering factory.

- **Contribution from the BPMs and tapers should not dominate** (from 40 mm/20 mm radius to the aperture of the element)

Potential limitations

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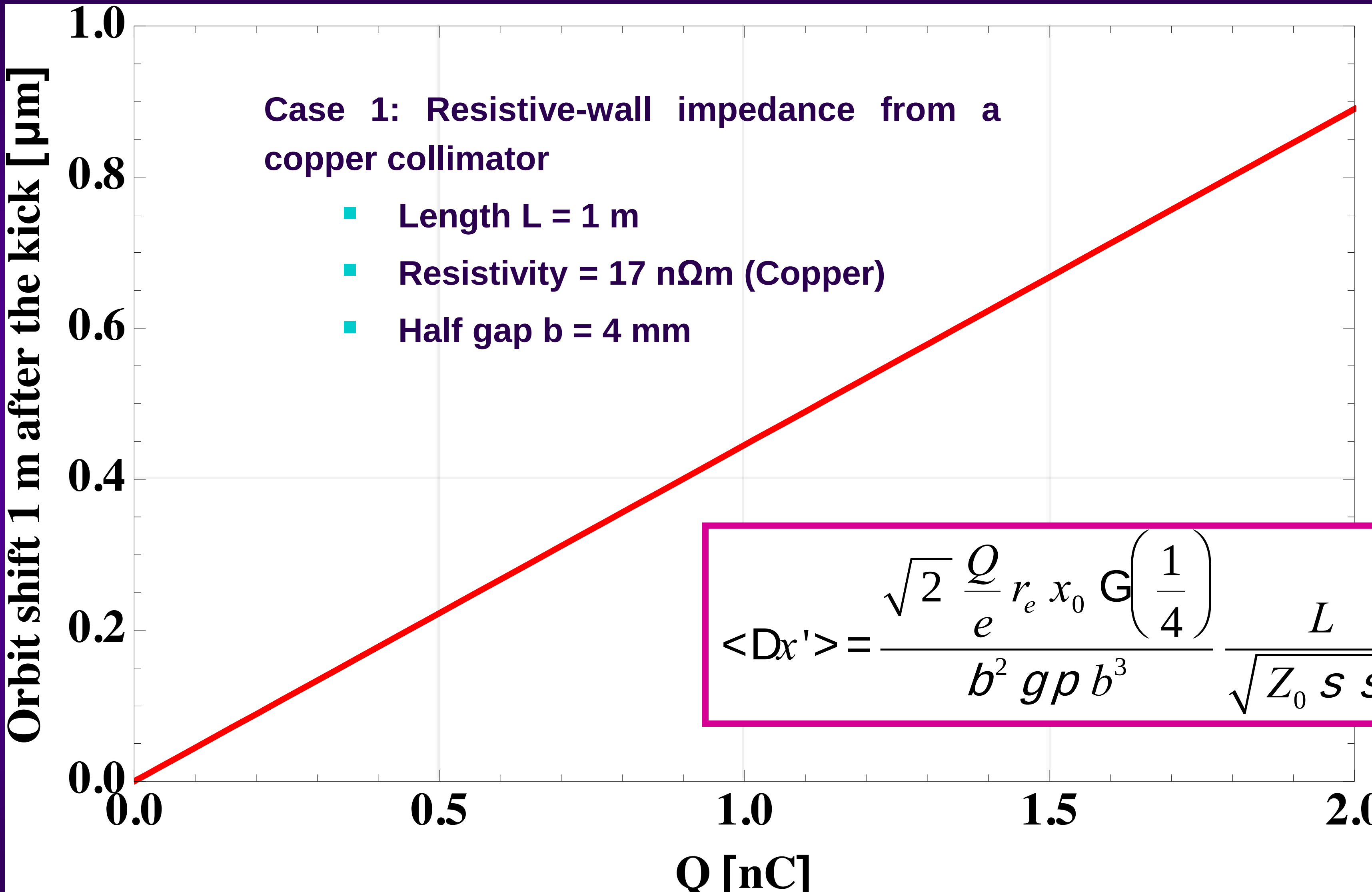
SOME IMPEDANCE COMPUTATIONS WITH CALIFES

Elias Métral

ASSUMPTIONS / CONDITIONS

- **Conditions**
  - **1 bunch of e-**
  - **E = 200 MeV**
  - **σ_t = 1 ps**
  - **ε = 20 μm (rms. norm.)**
  - **Initial beam transverse offset x_0 = 1 mm**
- **Case 1: Resistive-wall impedance from a copper collimator**
  - **Length L = 1 m**
  - **Resistivity = 17 nΩm (Copper)**
  - **Half gap b = 4 mm**
- **Case 2: Equipment with constant imaginary impedance**
  - **Z_t = K j**

CASE 1



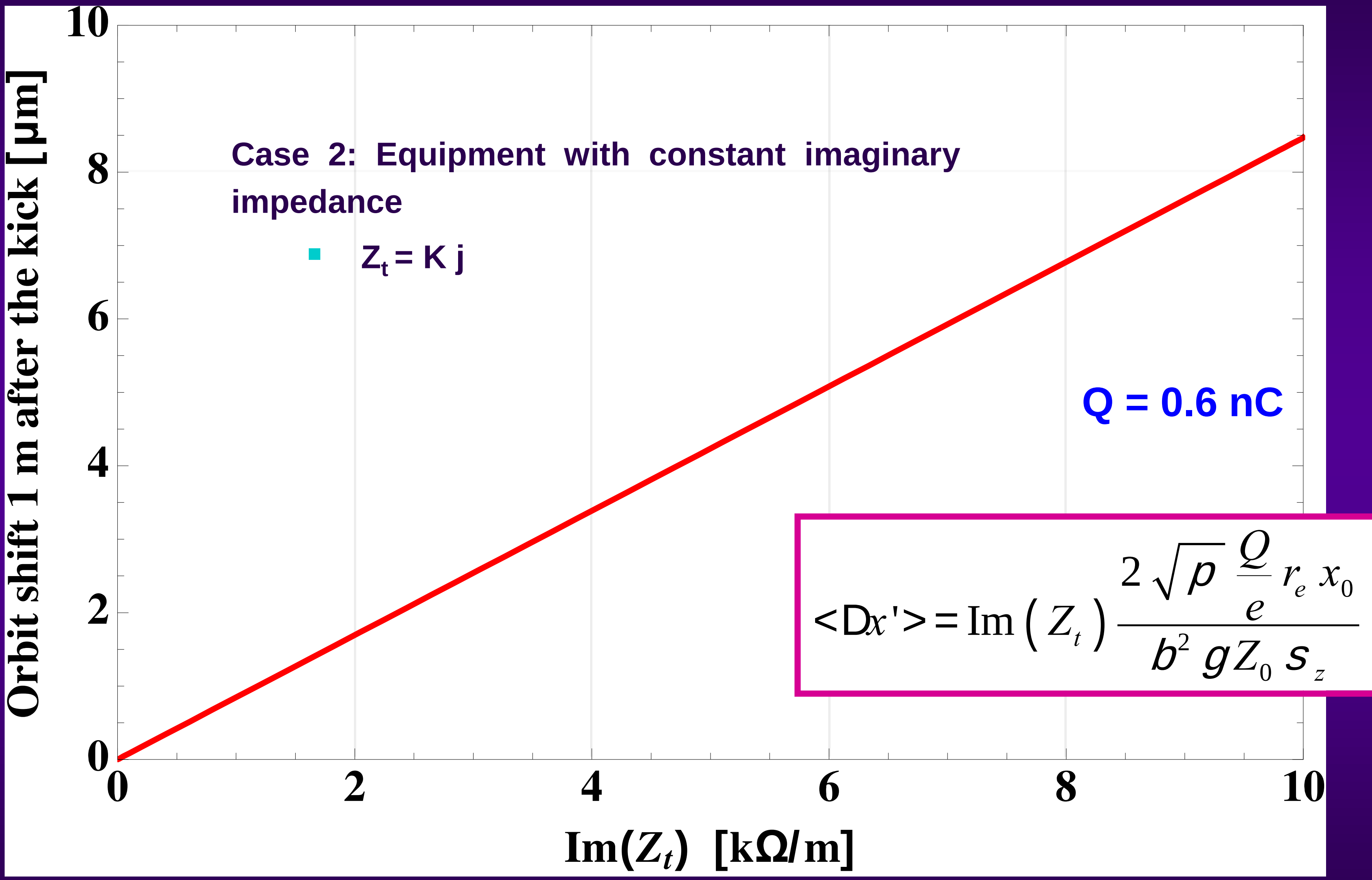
Case 1: Resistive-wall impedance from a copper collimator

- **Length L = 1 m**
- **Resistivity = 17 nΩm (Copper)**
- **Half gap b = 4 mm**

$$\langle \Delta x' \rangle = \frac{\sqrt{2}\,\frac{Q}{e}\, r_e\, x_0\, \Gamma\left(\frac{1}{4}\right)}{\beta^2 \gamma \pi b^3} \frac{L}{\sqrt{Z_0 \sigma \sigma_z}}$$

→ Challenging resolution

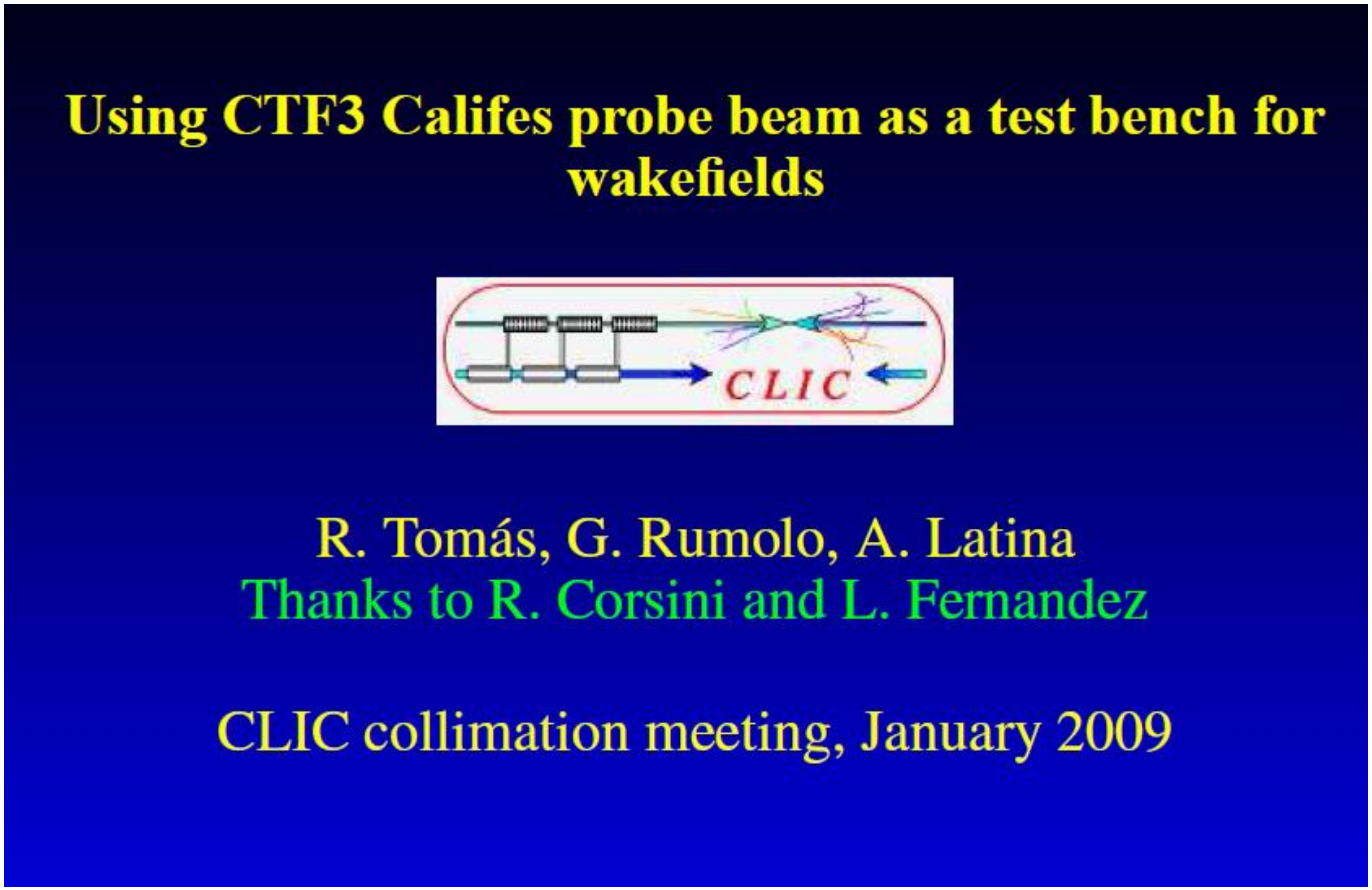
CASE 2



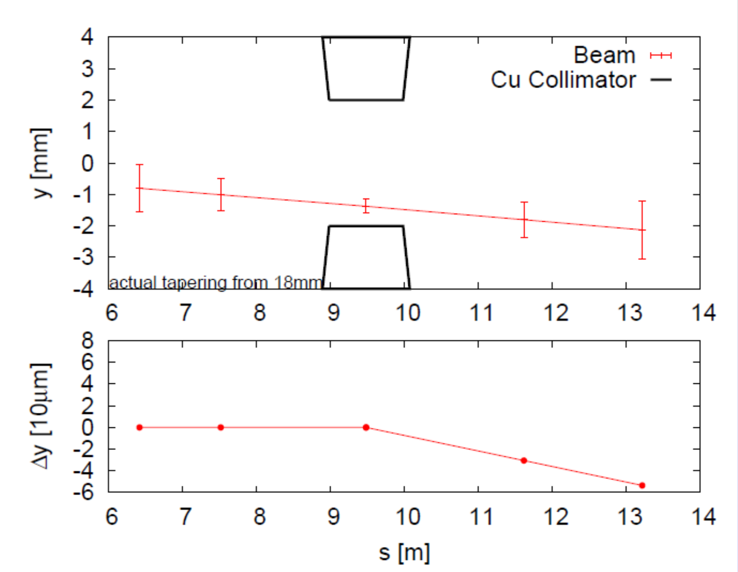
$$\langle \Delta x' \rangle = \mathrm{Im}\left(Z_t\right) \frac{2\sqrt{\pi}\,\frac{Q}{e}\,r_e\,x_0}{\beta^2\,\gamma\,Z_0\,\sigma_z}$$

→ Challenging resolution

Transverse displacement from previous work:



Cu collimator pushed example



Califes probe beam parameters

Energy	200 MeV
Energy spread	2%
Normalized emittances	20μm
Bunch charge	0.6nC
Bunch length	0.75ps

Same bunch charge as CLIC.

Bunch length is 5 times longer than CLIC.

Summary

- Existing set-up with almost 8m free distance
- Order of magnitude of position shift due to wakefield 10 μm.
- Therefore BPMs requirement in the 1μm level
- Non-linear wakefields?
- Reproducibility?

Potential limitations

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Example of LHC hardware to be measured

- Consolidation:
  - TDI beam screen consolidation
  - TCP replacement with spare
  - BSRT mirror design change
  - RF fingers consolidation, carroussel

- Upgrade:
  - Tertiary collimators with BPMs (TCTP and TCSP)
  - ATLAS-ALFA
  - “TOTEM consolidation” of existing Roman pots
  - MKI screen conductor upgrade
  - New experimental beam pipe in CMS and ATLAS
  - Schottky

- New equipment:
  - New TCL4 and TCL6
  - 3rd TCDQ module
  - BGV on B2
  - New “TOTEM upgrade” pots
  - New UA9 goniometer

- Non conformities:
  - Contacts in triplets

→ A whole zoo of devices with all kinds of aperture and lengths.

Potential limitations

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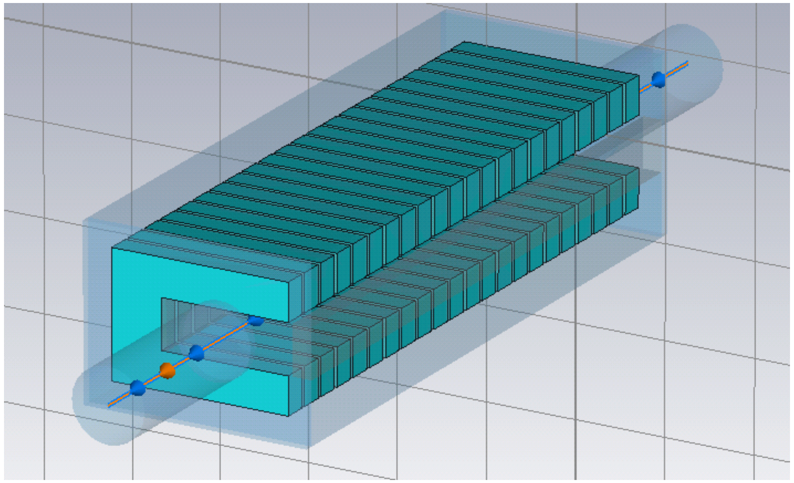
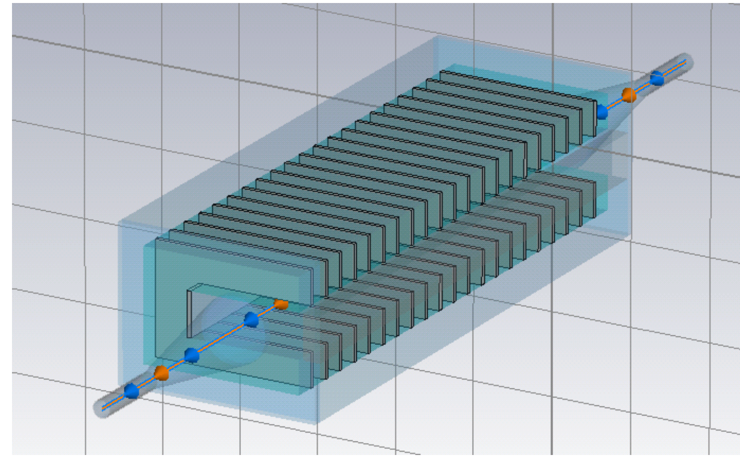
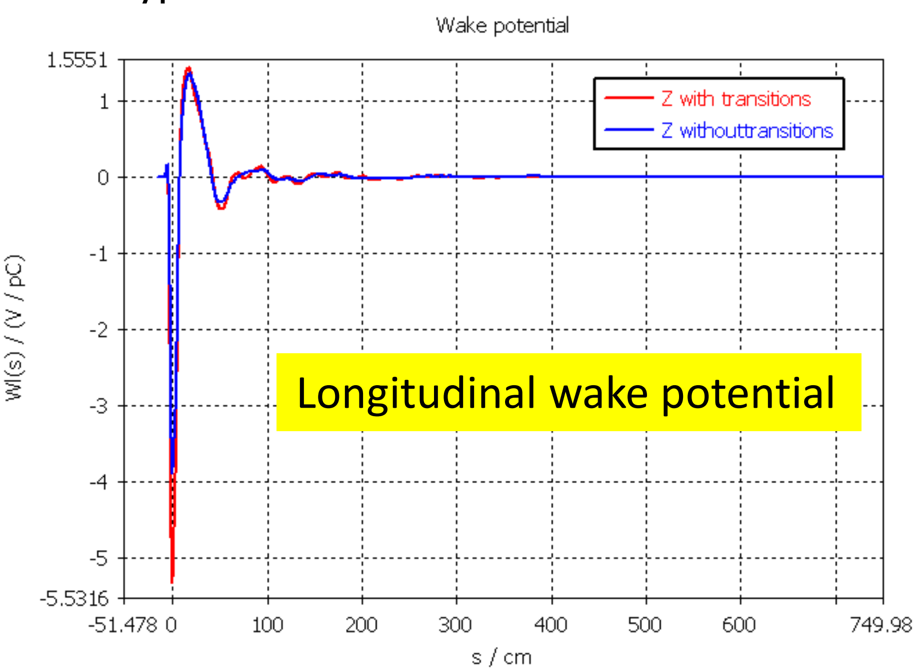
Example for the effect of transitions

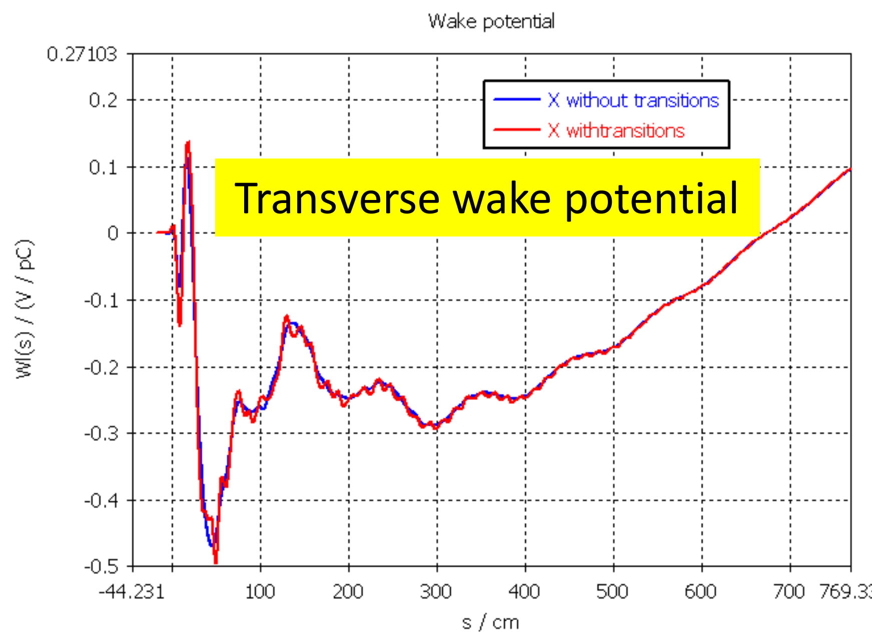


Typical SPS kicker in the SPS



Transitions needed for installation in CALIFES





→ For this case of SPS kickers the transitions would not be critical

Table of “ideal” requirements (draft, for discussion)

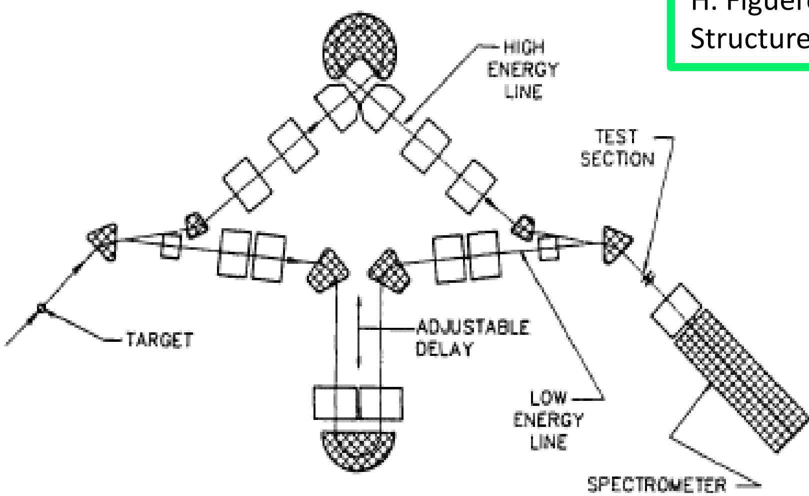
	Direct measurement	Wake function reconstruction
Intensity of the source bunch	~1 nC	~1 nC
Intensity of the test bunch	-	Not critical
Number of bunches	-	At least 2 bunches
Minimum bunch spacing	-	0.1 ns – 0.3 ns
Maximum bunch spacing	-	25 ns – 1 ms
Sampling in bunch spacing	-	0.1 ns within the first 5 ns, 0.3 ns after the first 5 ns
BPM resolution (time)	-	0.1 ns - 0.3 ns
BPM resolution (position)		1 micron
Source bunch energy	-	200 MeV
Test bunch energy	-	Would help if lower than 200 MeV
Available installation length	1.5 m for devices + 1 m for taper = at least 2.5 m	At least 2.5 m

Preliminary Conclusions from the discussions so far

- Using CALIFES or CTF3 beam to measure impedance may not work in many cases due to constraints:
  - need to tune the spacing/orbit between the source and the test bunches
  - Lower limit of detectable impedance kick/energy loss (due to available intensity, resolution of BPM and other impedance contributions that need to be added)
  - Available space and flexibility
  - BPM time resolution

- However, some reachable features can not be obtained with other means so far and we think it would be interesting to investigate further the feasibility of such measurements
  - “Wake function” with very short bunches (longitudinal/dipolar/quadrupolar)
  - In case it does not work, single bunch measurement could provide average kick (last resort if one cannot distinguish between two bunches, as in ESTB at SLAC)
  - Direct measurement of EM fields

Previous attempt: Argonne test facility

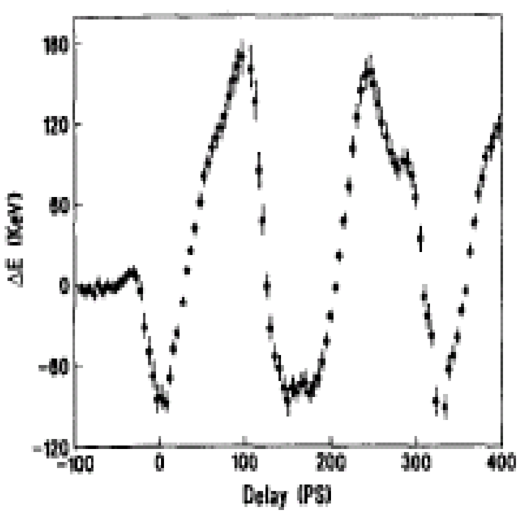


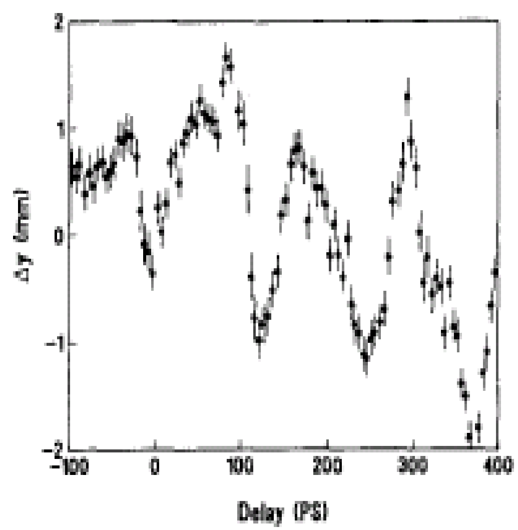
H. Figueroa et al., "Direct Measurement of Beam-Induced Fields in accelerating Structures", Physical Review Letters, Vol.60, N. 21, p.2144, (1988).

Beams

Two bunched beams of different energy and intensity with adjustable delay

Energy change and transverse offset induced on the trailing bunch





The change of energy of the trailing bunch (low intensity and energy) is mainly due to the effect of the wake fields because its own losses are negligible.

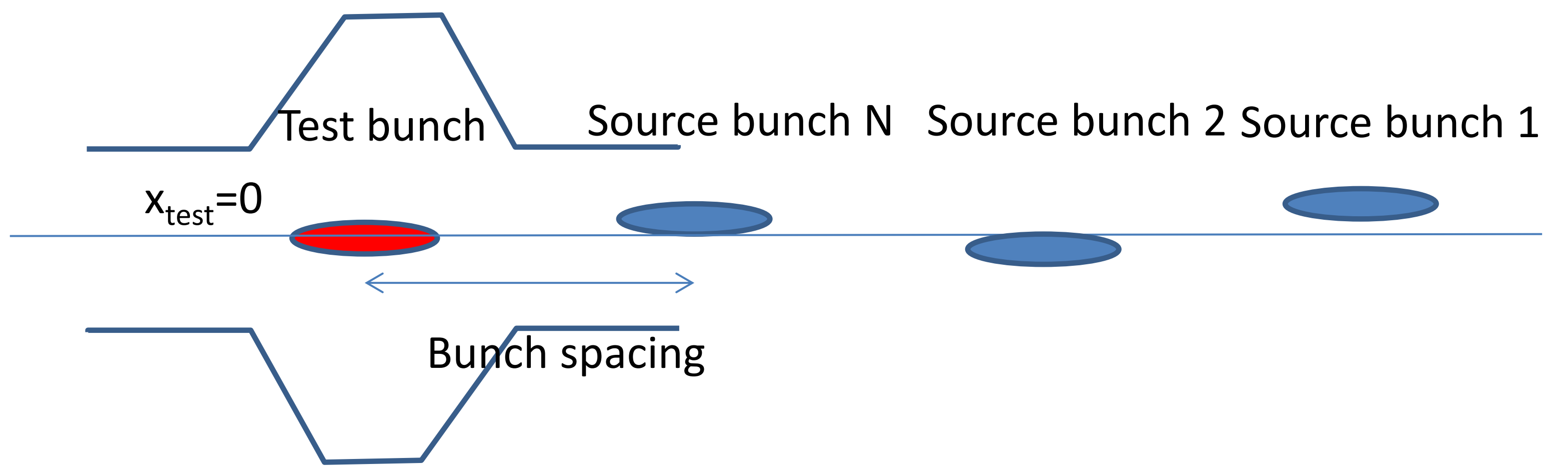
Direct measurement of coherent effects between bunches

- In case of high Q resonances, wake fields do not decay fast and another bunch comes when the fields have not yet decayed → coherent effects could therefore be checked.

- Need to generate several source bunches and one test bunch and to be able to adjust the spacing between the bunches.

→ Very interesting to study the coherent heat deposition: $P_{loss} \alpha\ M^2 Nb^2$

→ And the impact of coherence on transverse kicks



Direct measurement of beam induced temperature increase

- Monitor temperature of the device with many bunches

- Questions:
  - is the available intensity enough to generate enough power loss?
  - Need to be able to adjust the beam spectrum lines (therefore adjust the spacing to e.g. 25 ns)