Wakefield at ATF2
Identification of sources and mitigation

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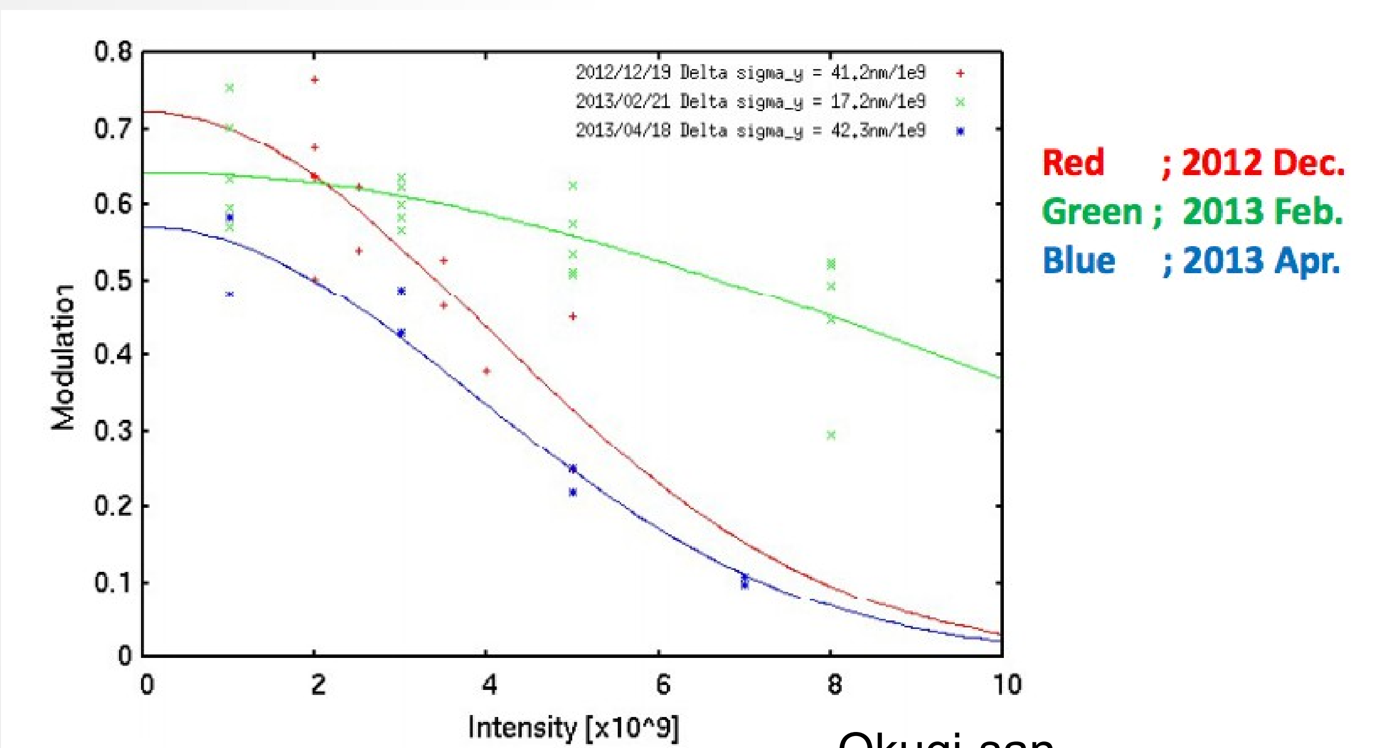
Outline

- Overview wakefield sources at ATF2
- Mitigation possibilities
- BPM reference cavity wakefield studies

Why discuss wakefield?

- December 2012 ~70 nm beam size was achieved, but only at very low intensity.
- Strong intensity dependence on beam size.



Okugi-san

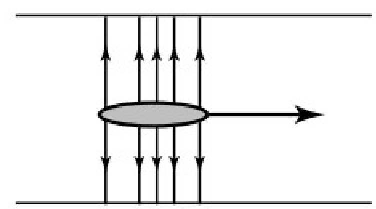
Wakefield

- Wakefield is mostly suspected to be the main cause of the remaining beam spot size growth in ATF2
- Main indications:
  - Beam size growth with increased intensity
    - Dependent on orbit
  - Beam size has large dependence on reference cavity mover
  - Other effects can not be excluded however
- Introduces a yz beam coupling (tilt)
  - Perceived as beam size growth
- Cannot be mitigated with e.g. sextupole knobs
- Reminder: also important imperfection for SLC and ILC/CLIC Main Linac

Wakefield

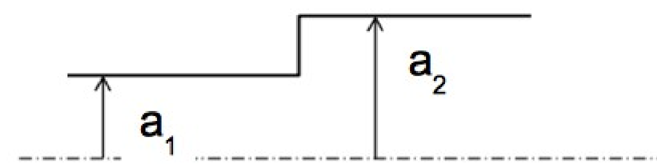
- Created due to interaction of the electromagnetic fields travelling with the beam with the walls of the beam chamber
- Resistive wake due to the finite conductance of the walls (more important when short bunches are considered in narrow chambers)

$$W(s) = \frac{Z_0 c}{2\pi^2 a^3}\sqrt{\frac{c}{\sigma s}}H(s)$$



- Geometric wake due to changes in the chamber size/geometry

$$W(s) = \frac{Z_0 c}{\pi}\left(\frac{1}{a_1^2} - \frac{1}{a_2^2}\right)H(s)$$

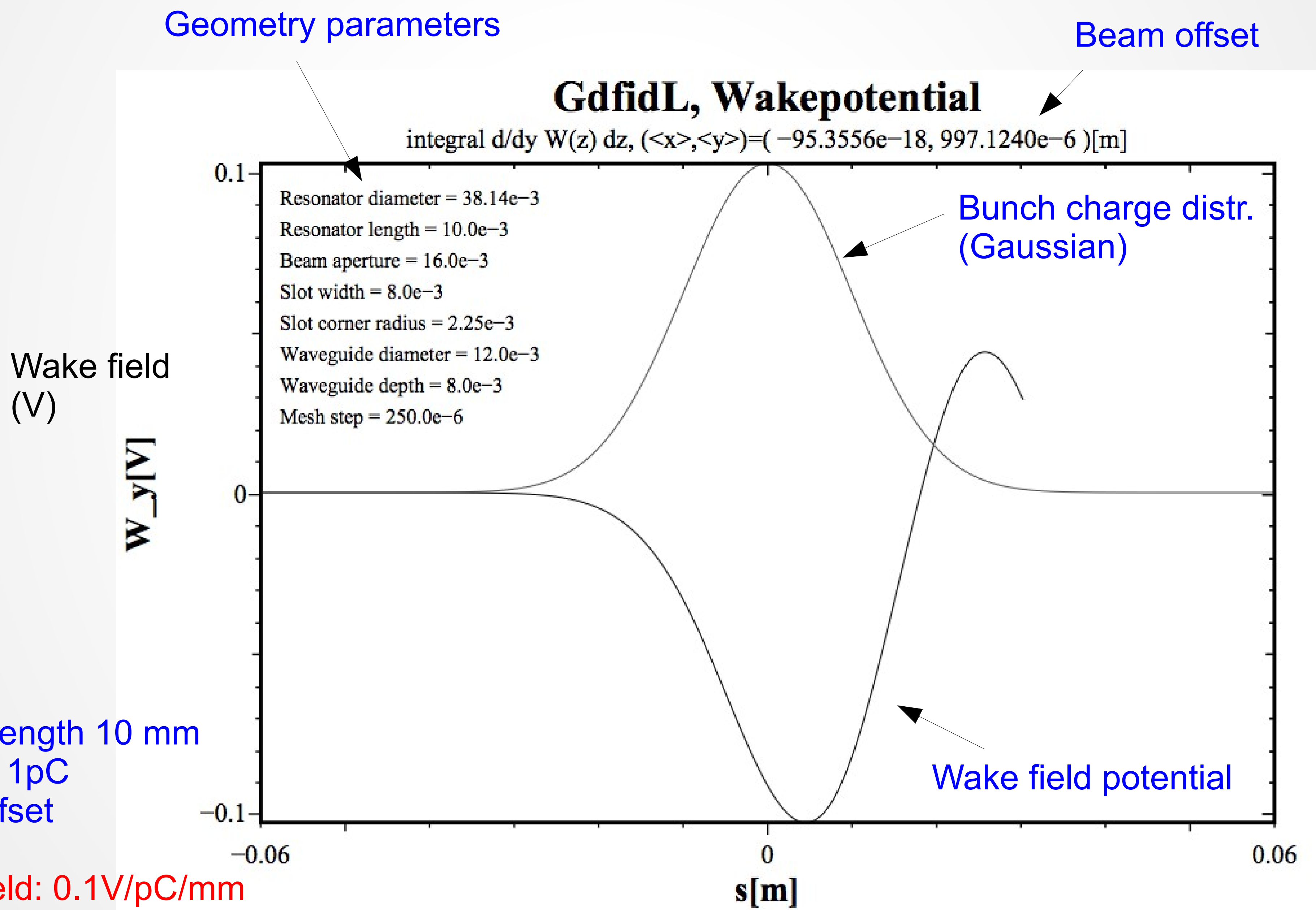


- (a aperture, H(s) beam distribution, σ beam conductivity)
- Here considering geometric wakes only
- Quick overview: K. Bane, A. Seryi http://accelconf.web.cern.ch/AccelConf/p07/PAPERS/THPMS039.PDF
- K. Bane: http://slac.stanford.edu/cgi-wrap/getdoc/slac-pub-4169.pdf

Wakefield

- Geometrical wake fields have been computed numerically with GdfidL (http://www.gdfidl.de)
  - Electromagnetic fields calculator in any 3D-structure
  - Finite element method
  - All higher modes included (up to cut-off frequency)
- The beam is represented as a line charge traveling along the z-axis with optional offsets in x and y, Gaussian distribution in z
- CPU and labor-intensive simulations (A. Lyapin, R. Ainsworth)
- Wake field shape dependent on beam shape itself
  - Bunch length
  - Beam offset

GdfidL: wakepotential



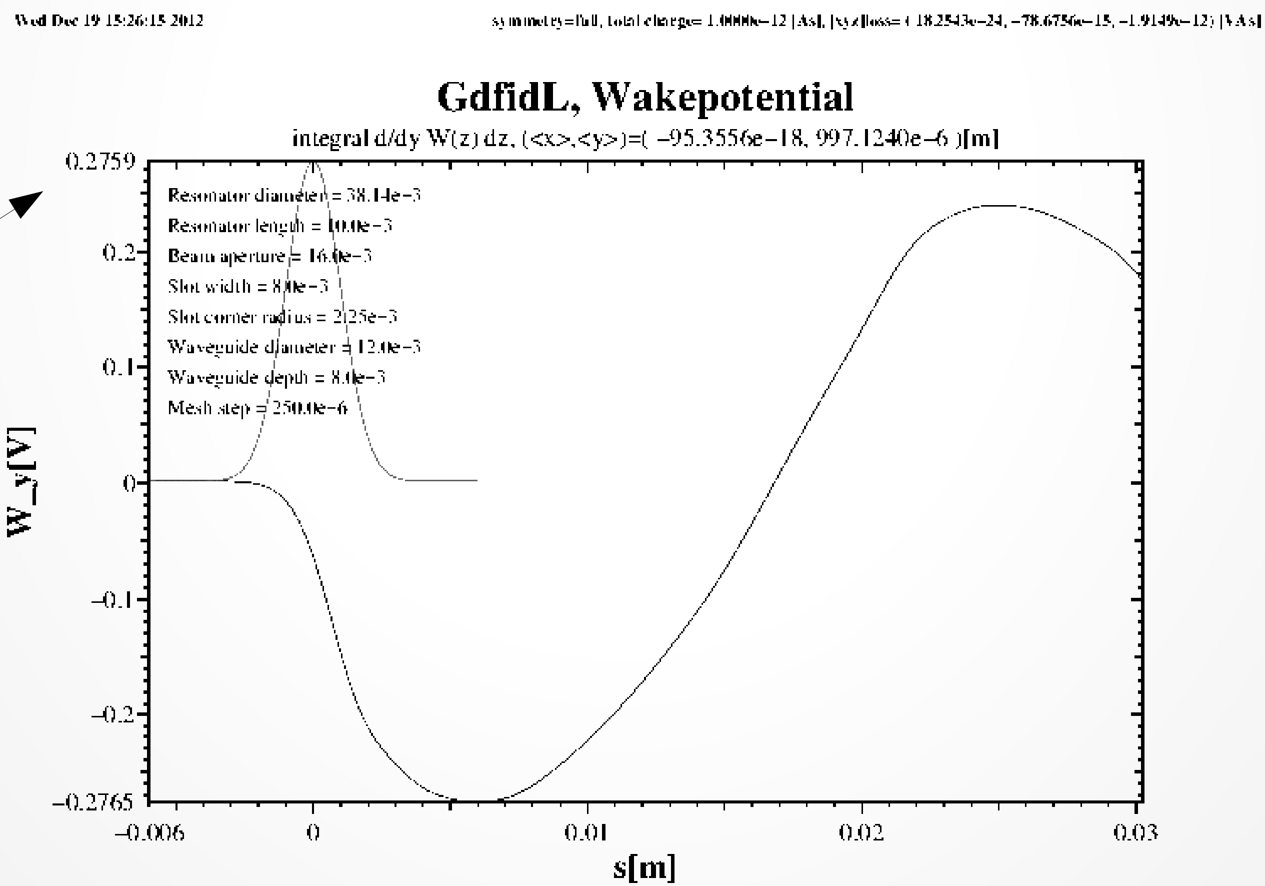
Bunch length 10 mm
Charge 1pC
1mm offset

Wakefield: 0.1V/pC/mm

Cavity BPM

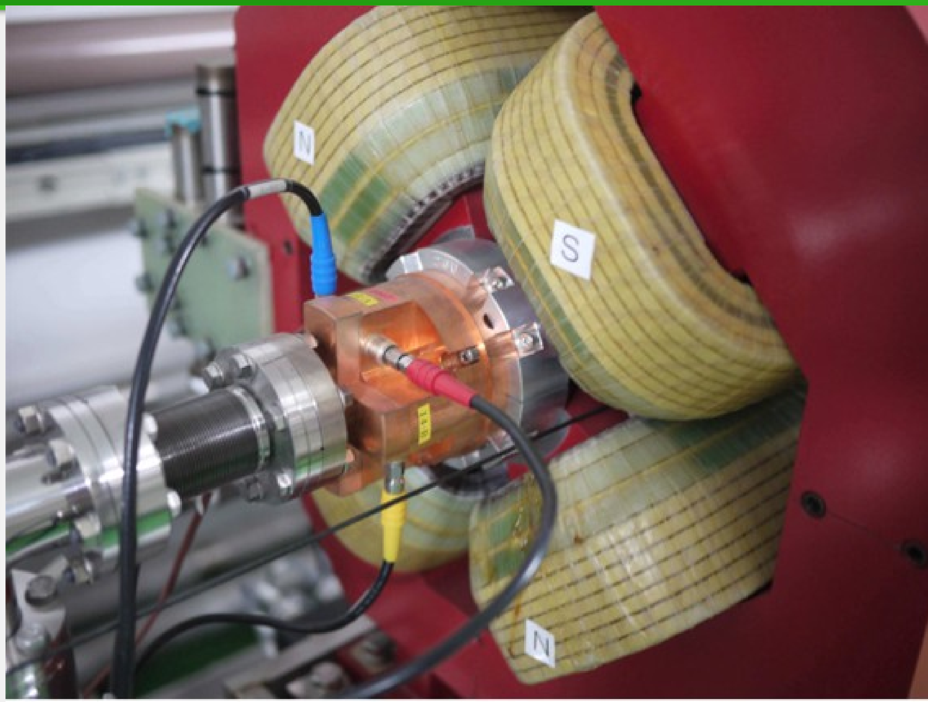
- Different bunch lengths:

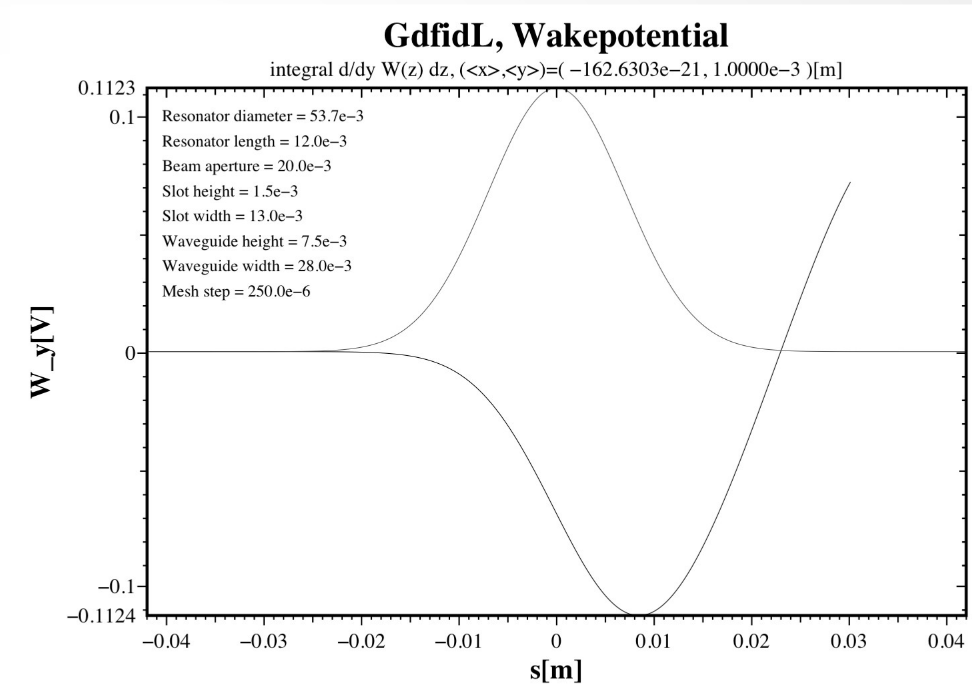
wakefield decreases with increasing bunch length



Short bunches don't 'see' peak field

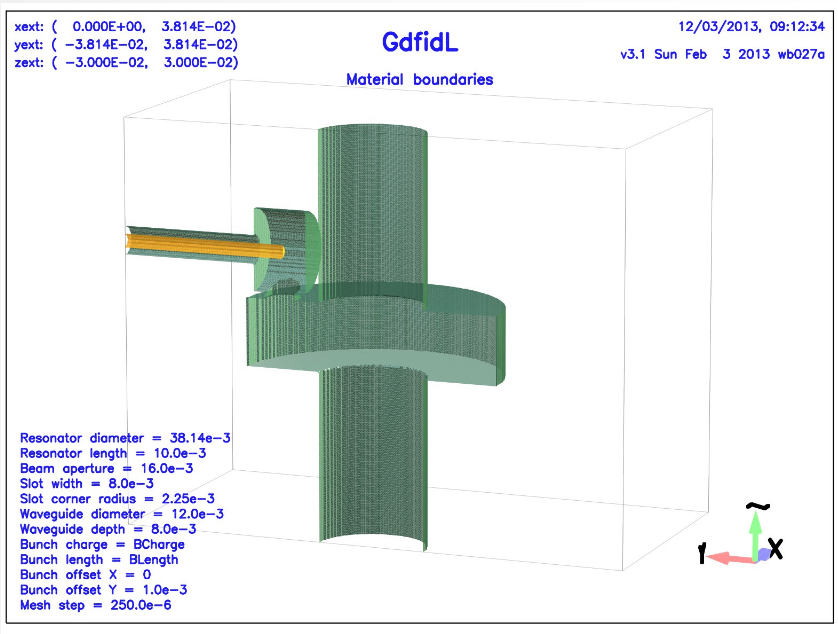
C-band CBPM

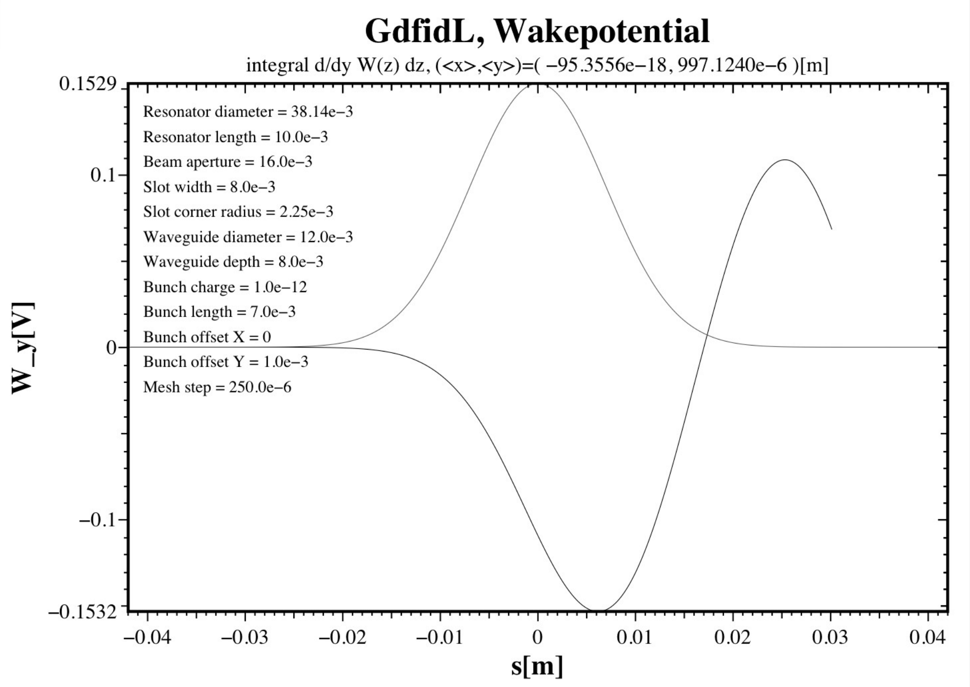




- High-impedance device (to provide a high position sensitivity)
- Typical resolution with attenuators ~200nm
- 30 nm without attenuation
- ~40 cavities in the beamline, the effect may be multiplied (although this depends on the orbit, beta function and alignment)
- Y.I. Kim et al. http://prst-ab.aps.org/pdf/PRSTAB/v15/i4/e042801
- Recent ATF review presentation: https://ilcagenda.linearcollider.org/getFile.py/access?subContId=0&contribId=7&resId=0&materialId=slides&confId=5973

C-band reference

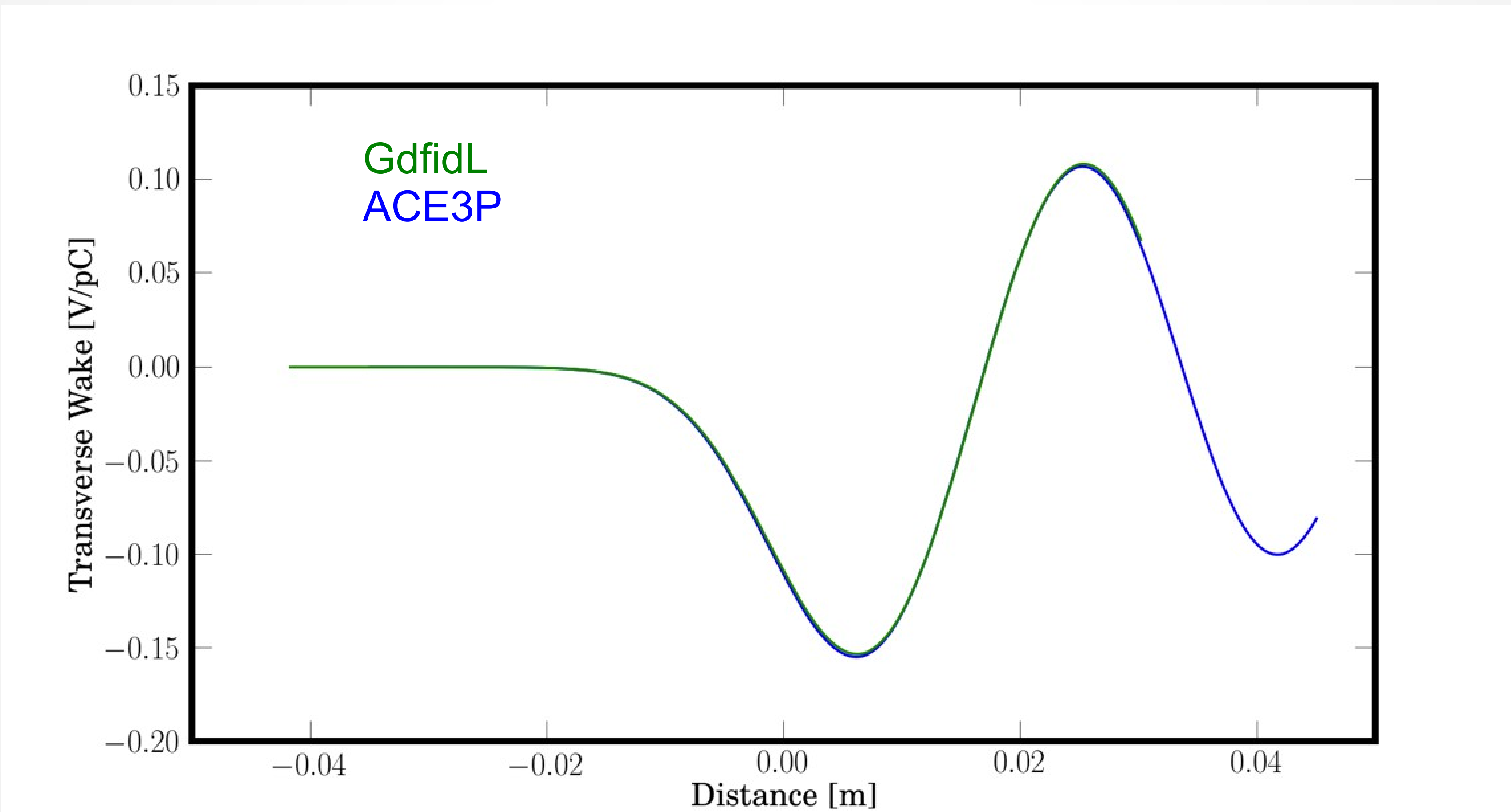




- Higher impedance than position cavity (smaller aperture and diameter)
- Used to be 4 in the beamline, now 1 providing the reference signal and 2 in the test location in April

Agreement GdfidL / ACE3P

ACE3P: https://portal.slac.stanford.edu/sites/ard_public/acd/Pages/Default.aspx

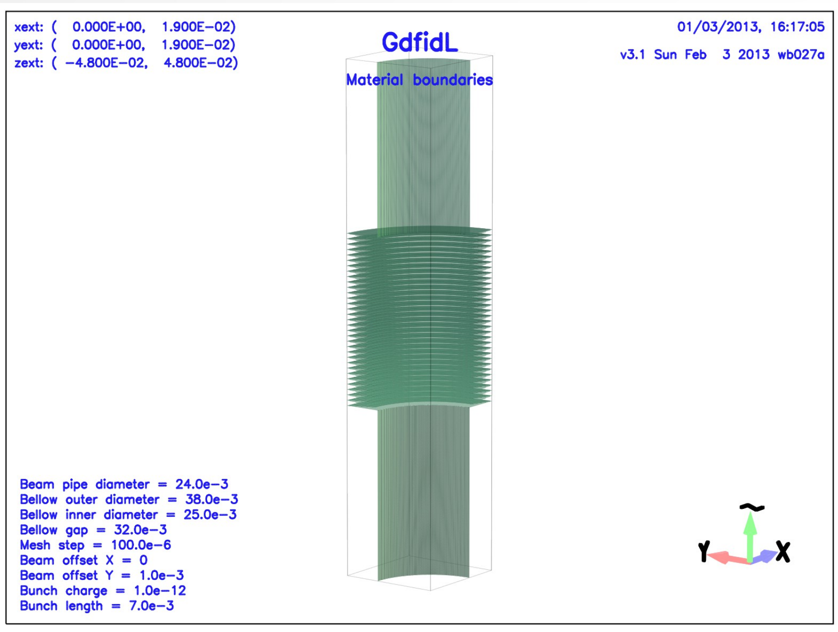


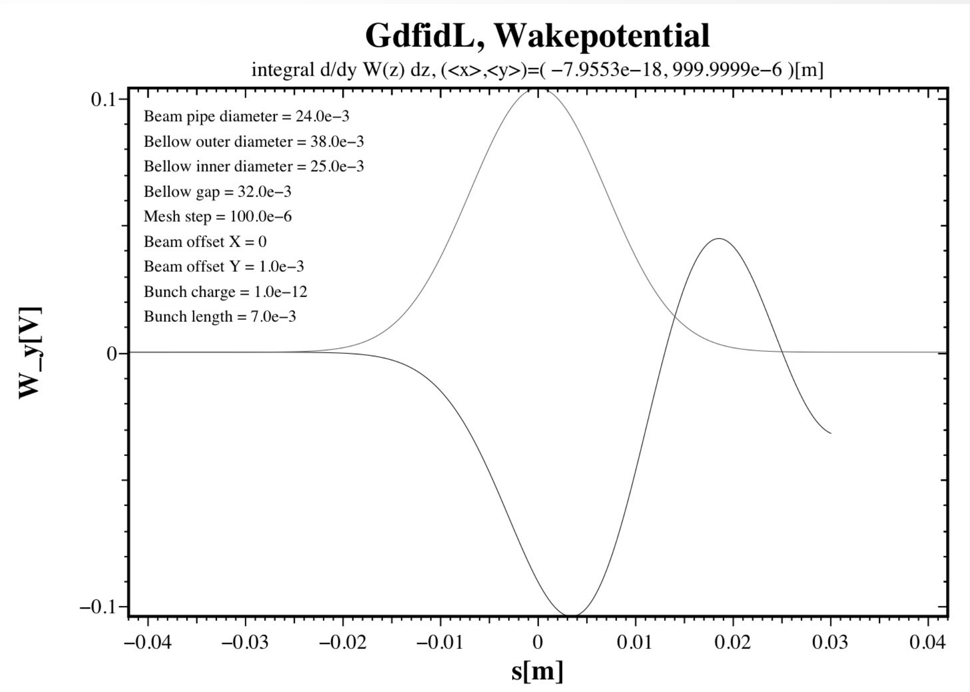
Rob Ainsworth (RHUL)

Wakefield

Rob Ainsworth (RHUL)

Bellows





- A very difficult geometry to simulate – flexible, can be in many states throughout the machine, can be extended/contracted most can also be offset in one end with respect to the other
- ATF2 beamline probably includes ~100 bellows
- A best guess simulation shows a wake similar to cavity BPMs both in shape and magnitude
- Many bellows shielded now
  - Wakefield contribution should be much reduced

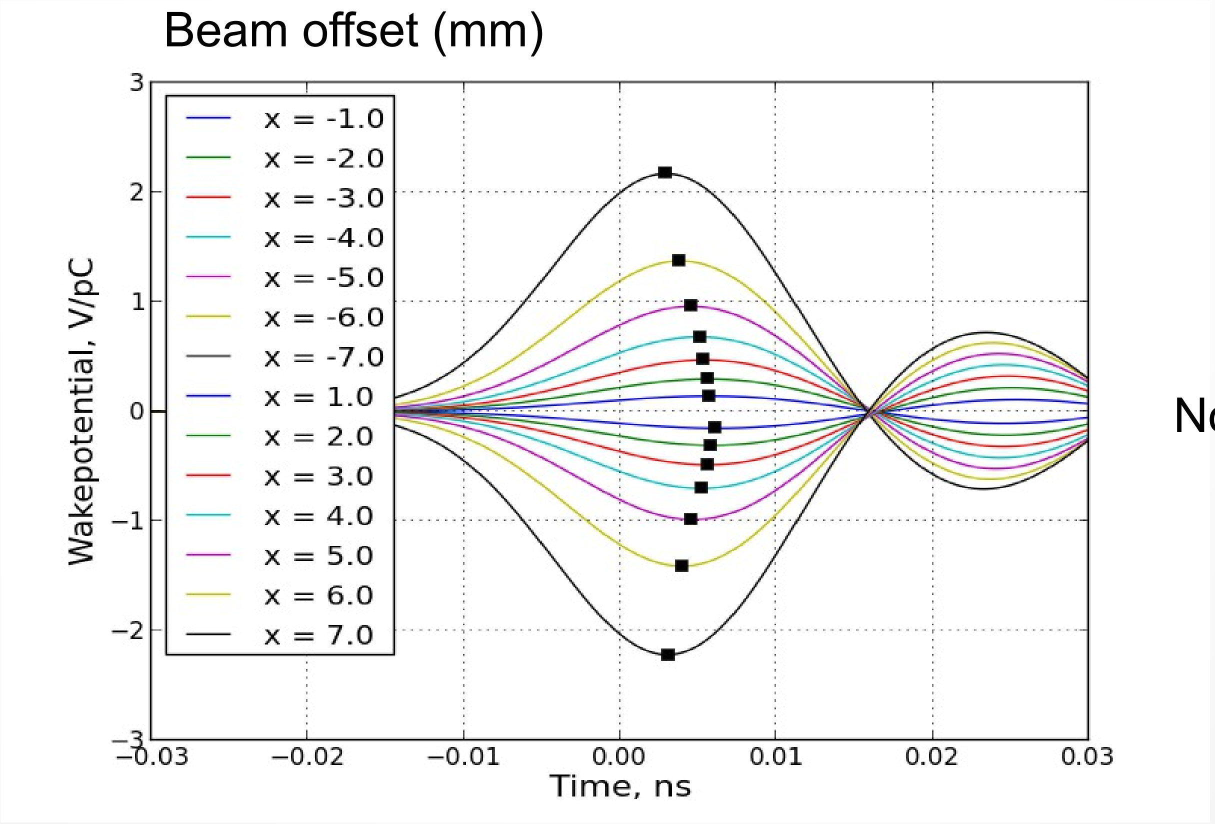
Naive total

Element	Peak wake, V/pC/mm	Quantity	Contribution, V/pC/mm
Bellows (un/shielded)	0.1/?	100	?
C-band position	0.11	35	4.0
IPBPM (vert.)	0.7	2	1.4
24-20 mm transitions	0.008	100	0.8
C-band reference	0.15	4	0.6
Vacuum port (X)	0.07	6	0.42

- Offsets and beta function are important (not taken into account here)
- Position cavities are likely to be much better aligned compared to other elements
- Some components are omitted, also there may be hidden contributions

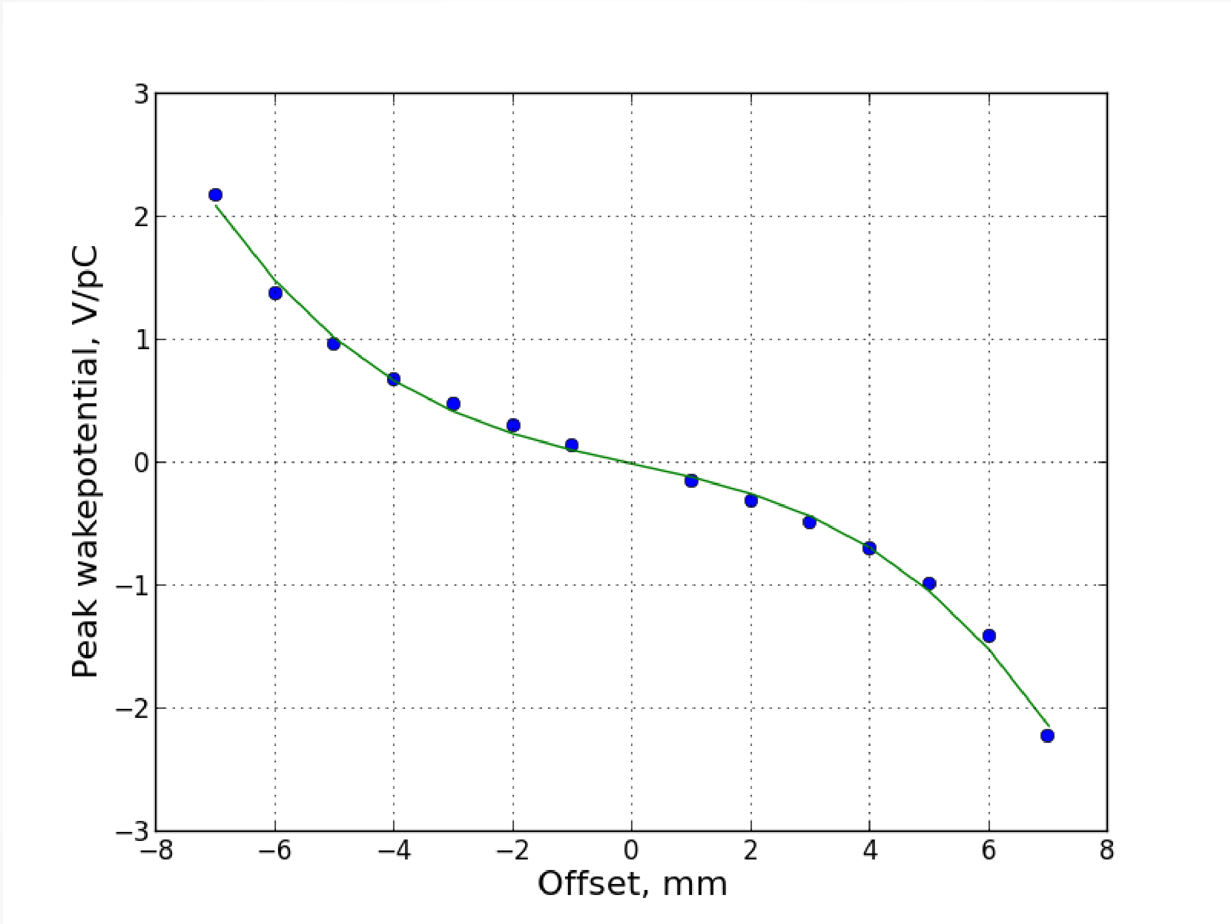
Non-linearity with offset

- Experimental data suggests non-linear component for large offsets
- Can happen very close to the wall
- Confirmed by both ACE3P and GdfidL



Non-linear after ~3mm

Non-linearity with offset



Piwinski: Impedances in Lossy Elliptical Vacuum Chambers, DESY 94-068

$$\langle \Delta y' \rangle \sim \left(\frac{y_0}{g} - \frac{2\pi^2}{3} \left(\frac{y_0}{g} \right)^3 \right) + O\left(\left(\frac{y_0}{g} \right)^5 \right)$$

g = aperture (gap width)

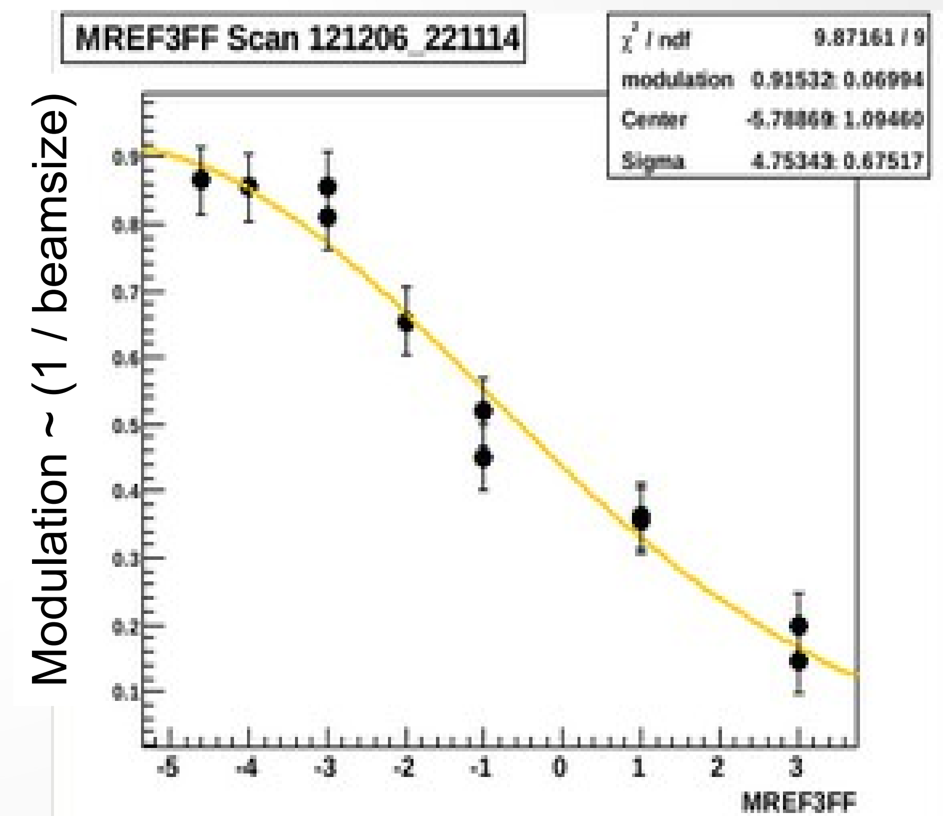
Mitigation possibilities

- Reduce wakefield contributions
  - Shielding
  - Reduce aperture steps
  - Etc.
- Compensate beam distortion
  - Add tunable wakefield
  - Good orbit

Wakefield compensation

- Reference cavity on mover at high beta location (“MREF3FF”)
- Goals:
  - Compensate wakefields from other locations
    - Simulations by Kubo-san show that most wakefields can be compensated
  - Study CBPM wakefield
- Originally one, but then a second reference cavity added to double effect, large effect observed
  - Served both
- Now (since May period) replaced by collimator and unshielded bellows on independent movers

Swing shift Thu 6-12 (7deg)



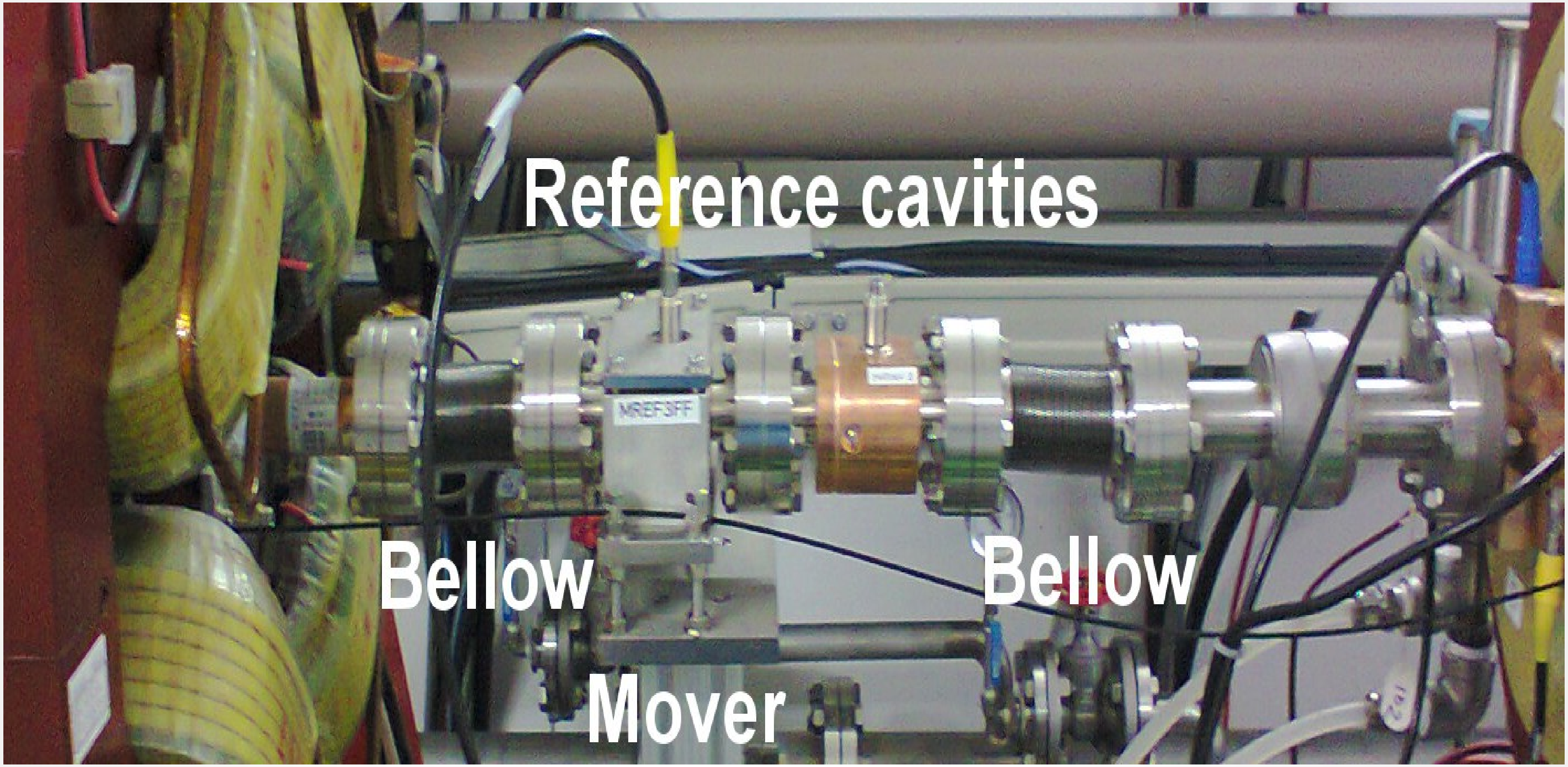
Reference cavity location

Wakefield free steering

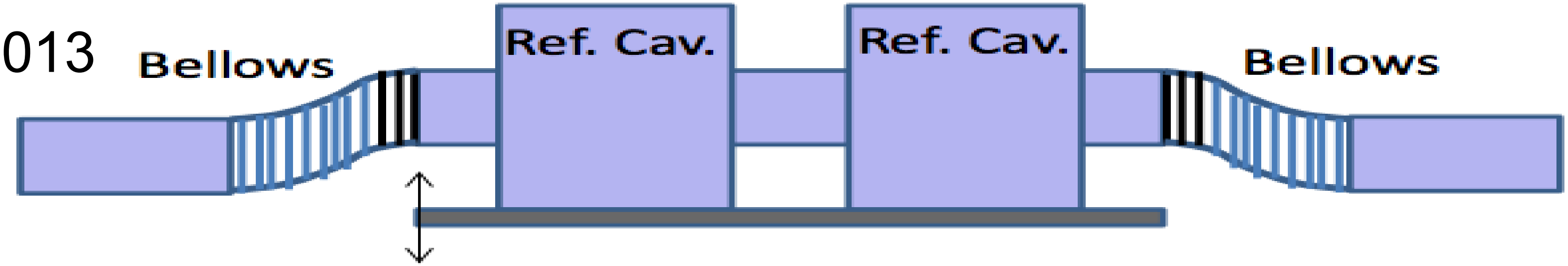
- At FACET (SLAC) a new steering algorithm has been tested with promising results
  - Algorithm finds orbit with no/low wakefield contribution
- See current talk by Andrea Latina for some details: https://ilcagenda.linearcollider.org/contributionDisplay.py?sessionId=26&contribId=152&confId=6000
- Might be interesting possibility also for ATF2. Simulations have been started.

Cavity BPM wakefield study

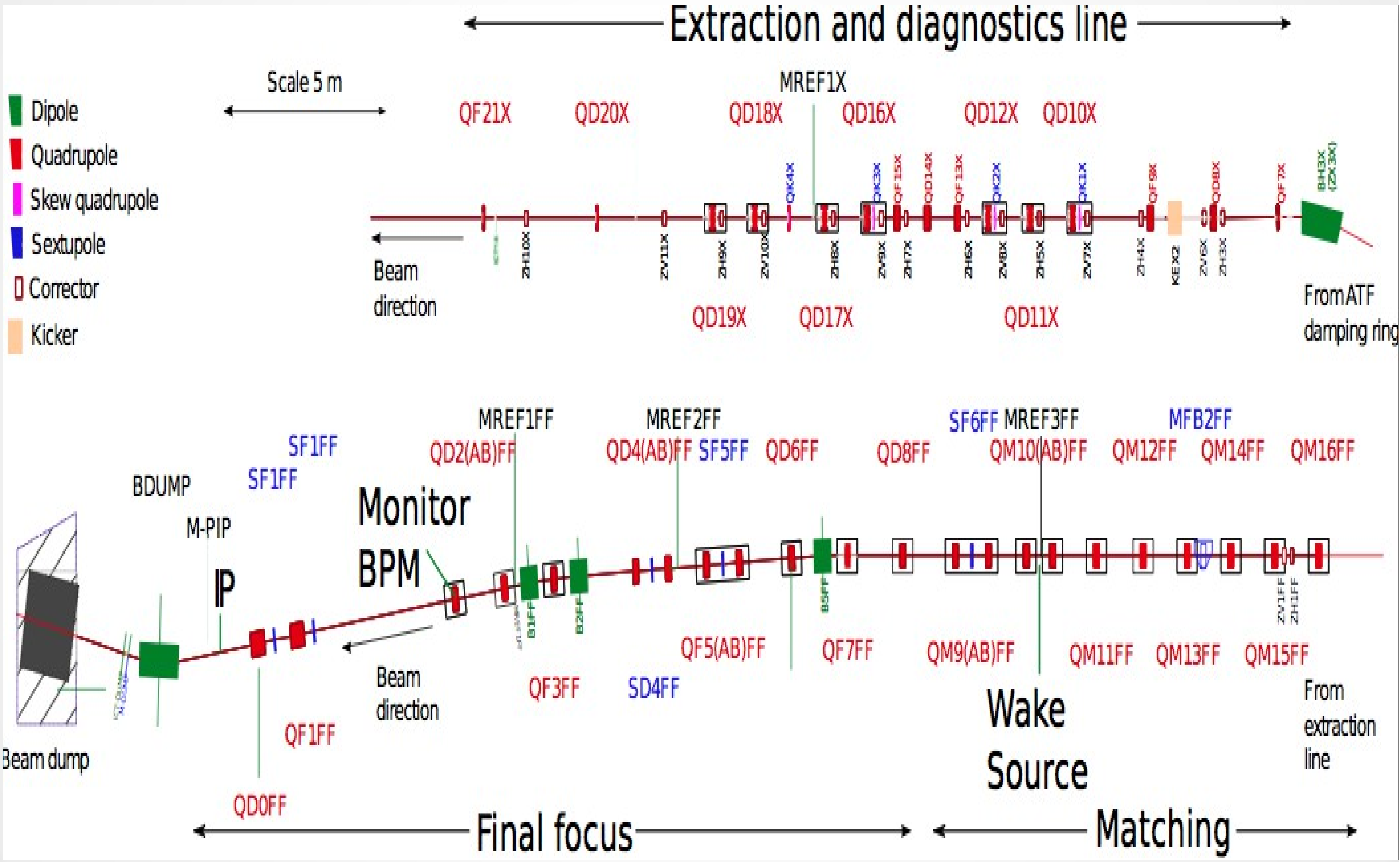
Wakefield compensation setup



April 2013



ATF2 layout

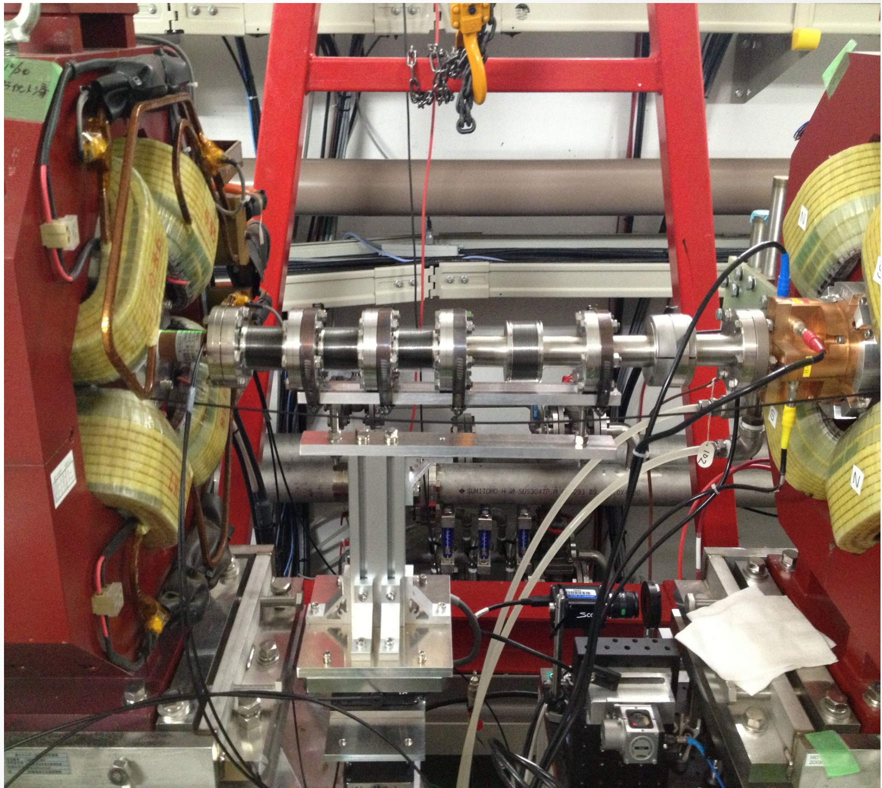


Extraction and diagnostics line
Scale 5 m
Dipole
Quadrupole
Skew quadrupole
Sextupole
Corrector
Kicker
MREF1X
QF21X
QD20X
QD18X
QD16X
QD12X
QD10X
Beam direction
QD19X
QD17X
QD11X
From ATF damping ring
MREF1FF
MREF2FF
SF6FF MREF3FF
MFB2FF
SF1FF
QD2(AB)FF
QD4(AB)FF SF5FF
QD6FF
QD8FF
QM10(AB)FF
QM12FF
QM14FF
QM16FF
BDUMP
SF1FF
M-PIP
Monitor BPM
IP
QF5(AB)FF
QF7FF
QM9(AB)FF
QM11FF
QM13FF
QM15FF
Beam direction
QF3FF
SD4FF
Wake Source
From extraction line
Beam dump
QF1FF
QD0FF
Final focus
Matching

Wakefield studies

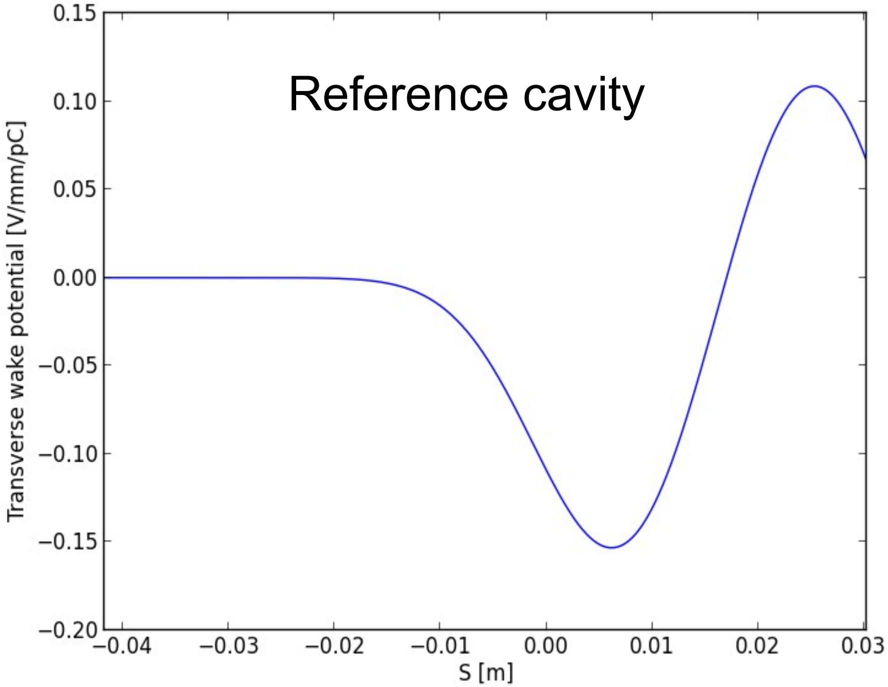
- Goal: measure wakefield from Cavity BPM
  - By looking at orbit change
- Some measurements done in December last year during continuous run (parasitically)
  - Effect is measurable, but some open questions
    - Bunch length
    - Charge was not monitored carefully
- Dedicated shifts last April
  - Using MREF mover setup
  - 3 setups were measured:

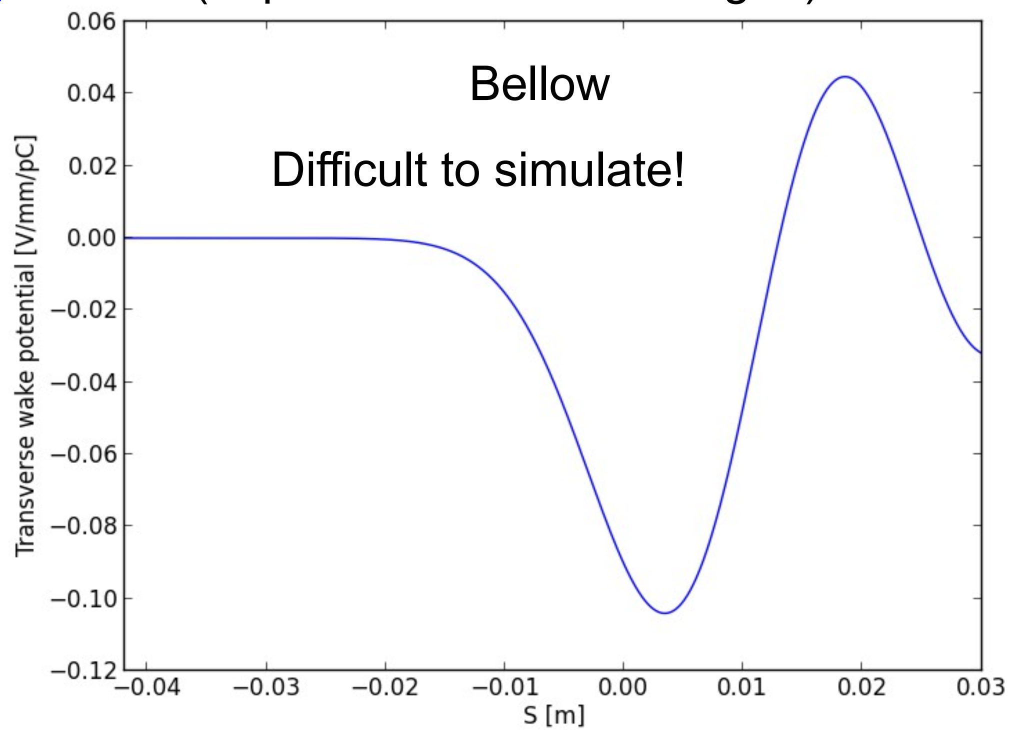
    1 ref. cavity, 2 ref. cavities, 3 bellows
  - Here only 2 ref. cavity setup shown
- QD10AFF magnet moves with setup, a few tenths of um per mm setup move



Wakefield

Bunch length 7 mm (dependent on bunch length!)





Max. 0.15 V/mm/pC
Good belief in simulation
Max. kick somewhat outside beam centre

Max. 0.10 V/mm/pC
Many uncertainties on shape
Wakefield calculation less reliable
Max. kick close to center

MREF cavity =
2 * Ref. Cavity + 2*step + 0.5 * 2 * bellow ~ 2 * 0.15 + 2 * 0.01 + 0.5 * 2 * 0.1? = 0.42 V/mm/pC

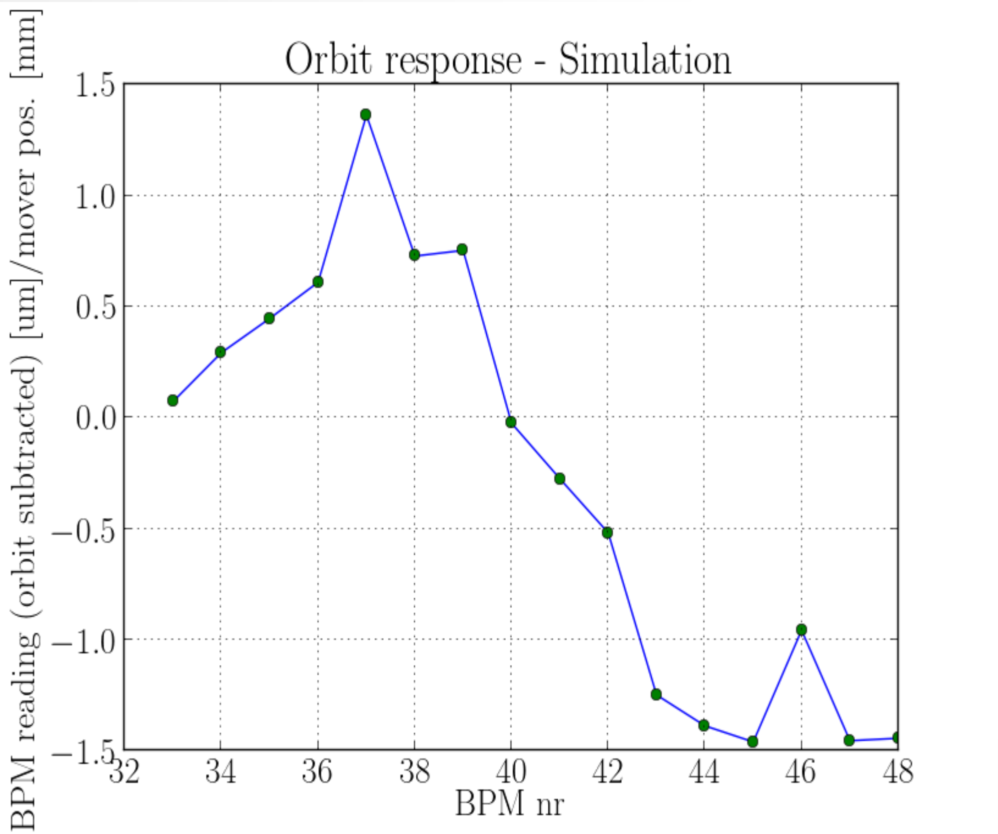
bellow moving only half way (approximately)

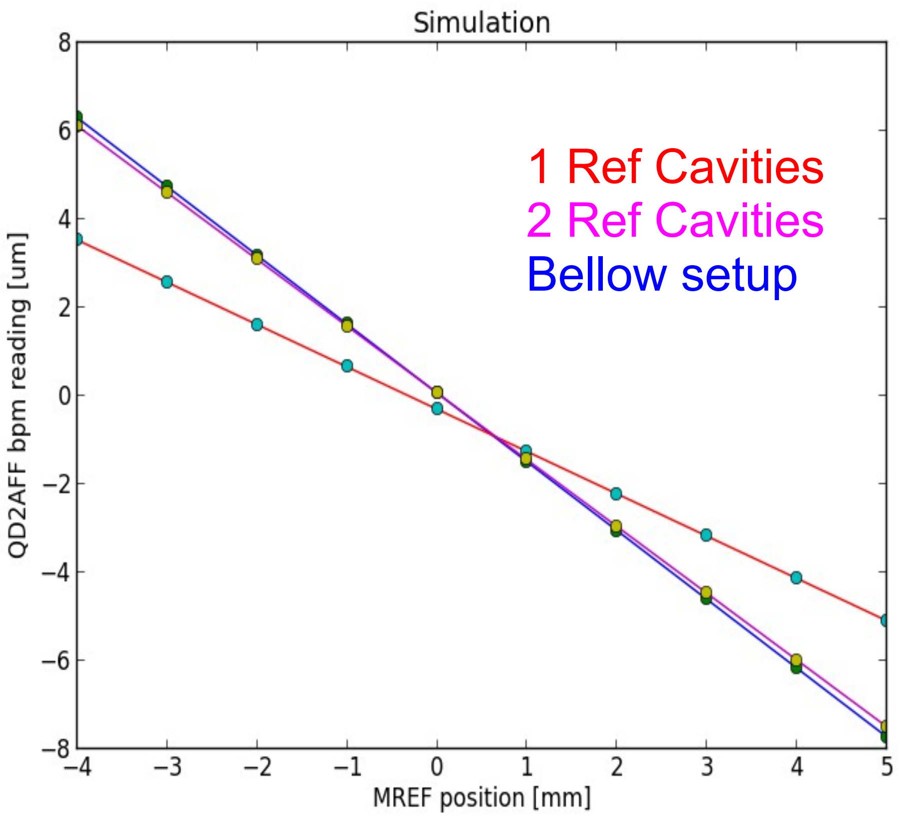
Simulation

Geometric wakefield realistically implemented in PLACET
Also longitudinal wakefield is added (only 1-2% effect on orbit)

Charge 6e9
Bunch length 7mm

QD2AFF BPM has largest effect





When removing one cavity, possible to subtract both setups and get wakefield of 1 cavity

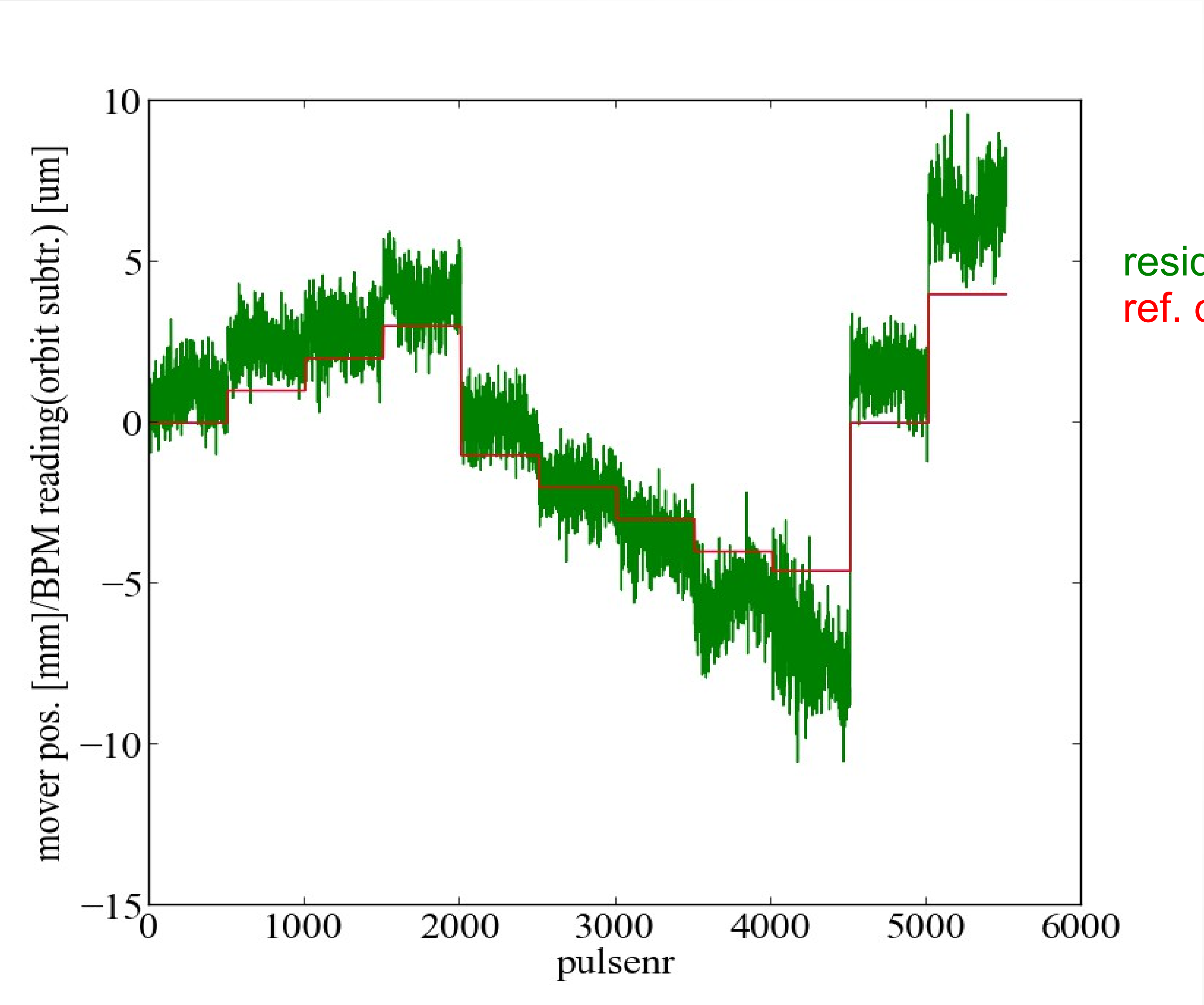
Orbit analysis

- Take all upstream BPM readings
- All BPM readings averaged subtracted
- Find contribution between those BPM readings and downstream BPM readings
- Subtract orbit jitter per pulse (by matrix inversion)
- Remaining correlation with MREF setup movement will give wakefield kick
- Reference setup ideally placed with high resolution cavity BPMs both upstream and downstream

Orbit analysis 2

- Divide BPM data wrt to reference cavity mover:
- Upstream orbit matrix A (n_1 BPMs x m pulses)
- Downstream orbit matrix B (n_2 BPMs x m pulses)
- Calculate correlation X (n_1 x n_2):
  - $AX=B \rightarrow X = A^{-1}B$ (inversion with SVD method)
- Residuals R (n_2 x m) (since over-constrained system):
  - $R = AX - B$

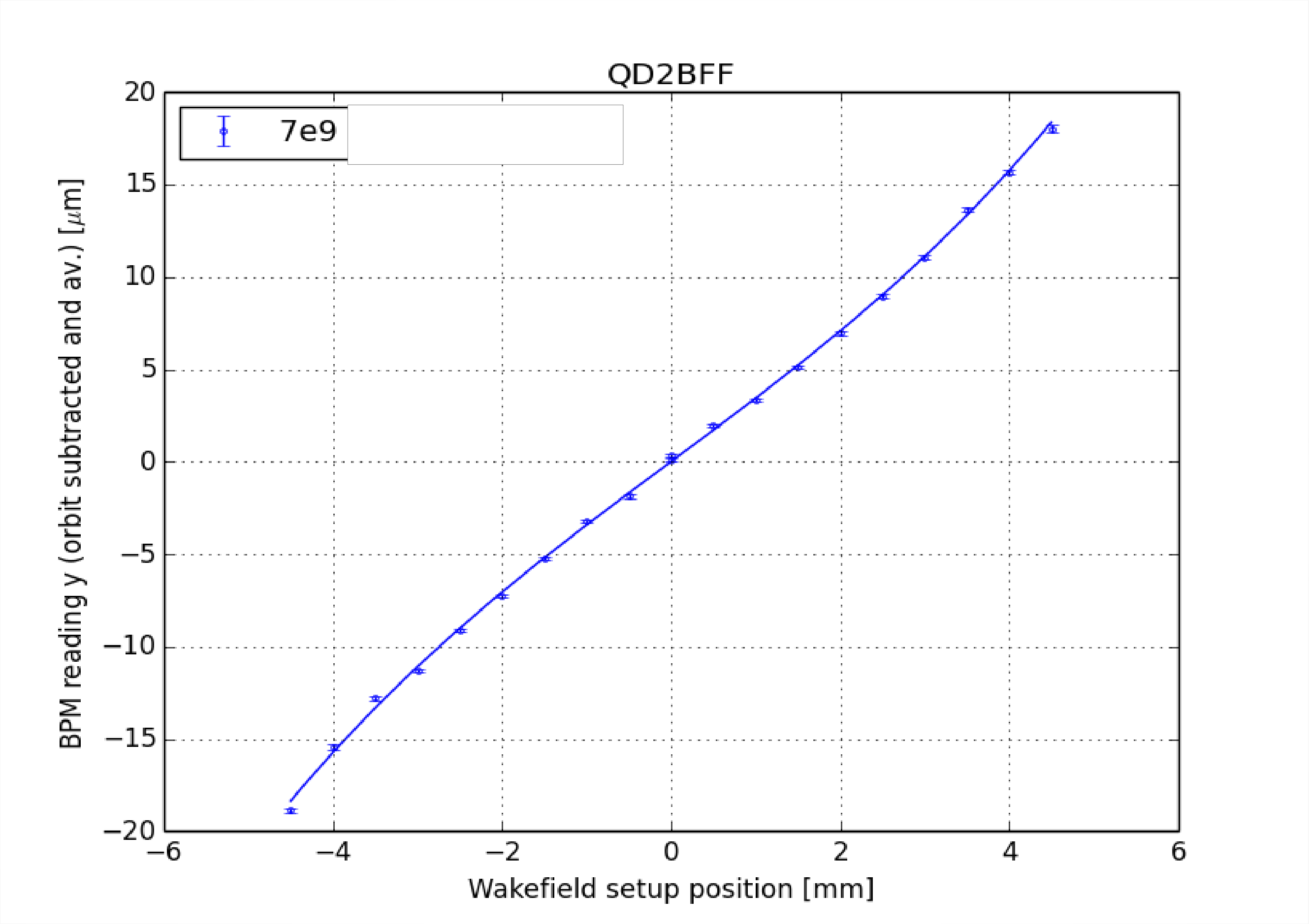
Example
QD2AFF vs ref. cavity position



residual BPM reading QD2AFF [um]
ref. cavity position [mm]

Clear correlation seen for all downstream BPMs with expected orbit pattern

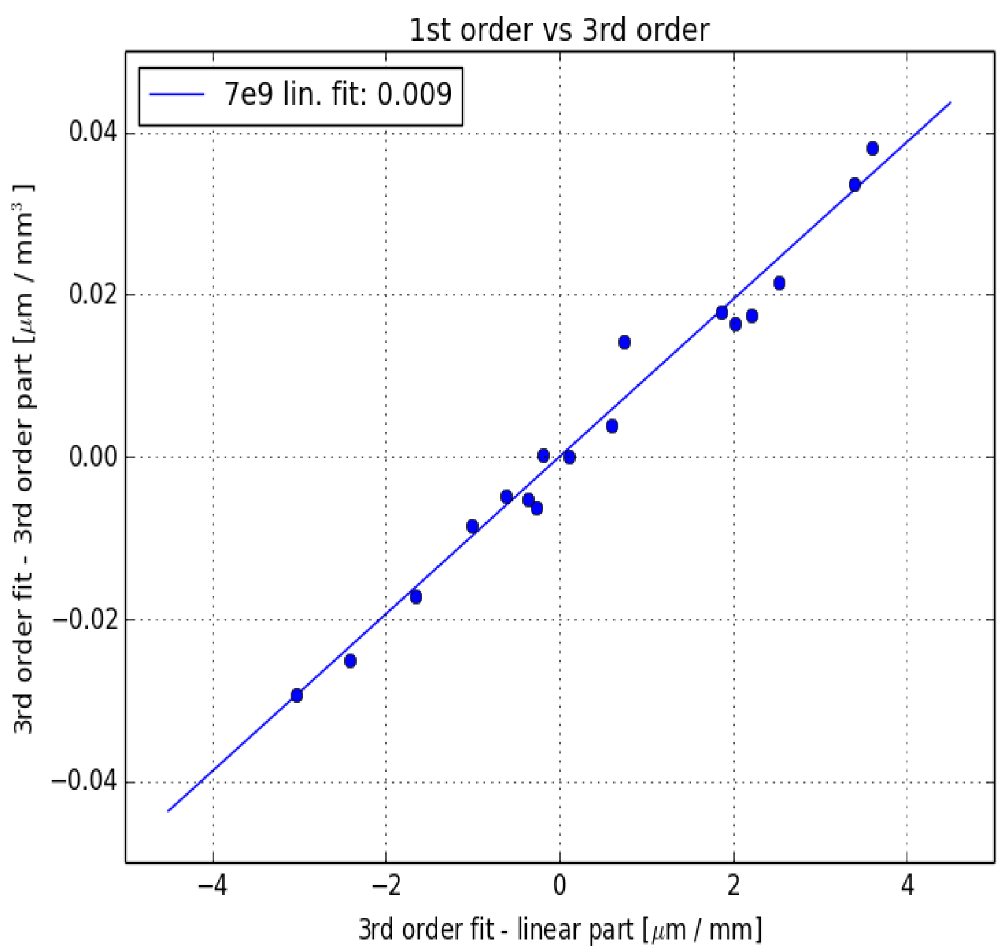
3^{rd} order fit



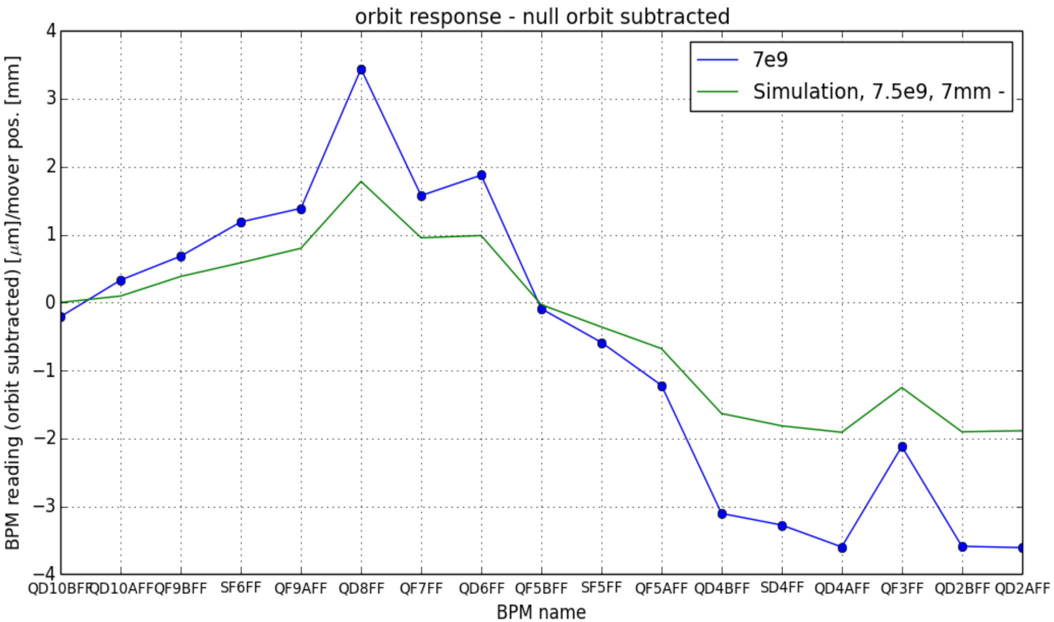
- Measurement fits well to 3^{rd} order polynomial
  - χ^2 much reduced compared to linear fit (only stat. error taken into account)

3^{rd} order fit - shape

- Same shape of 3^{rd} order polynomial for all BPM locations (as expected)

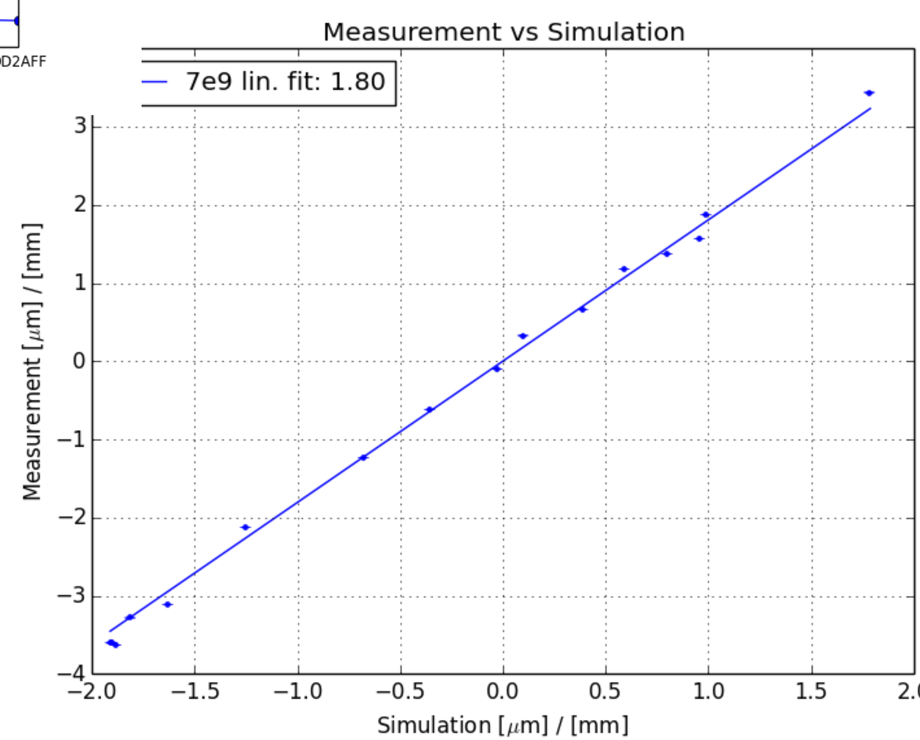


Comparison with simulation

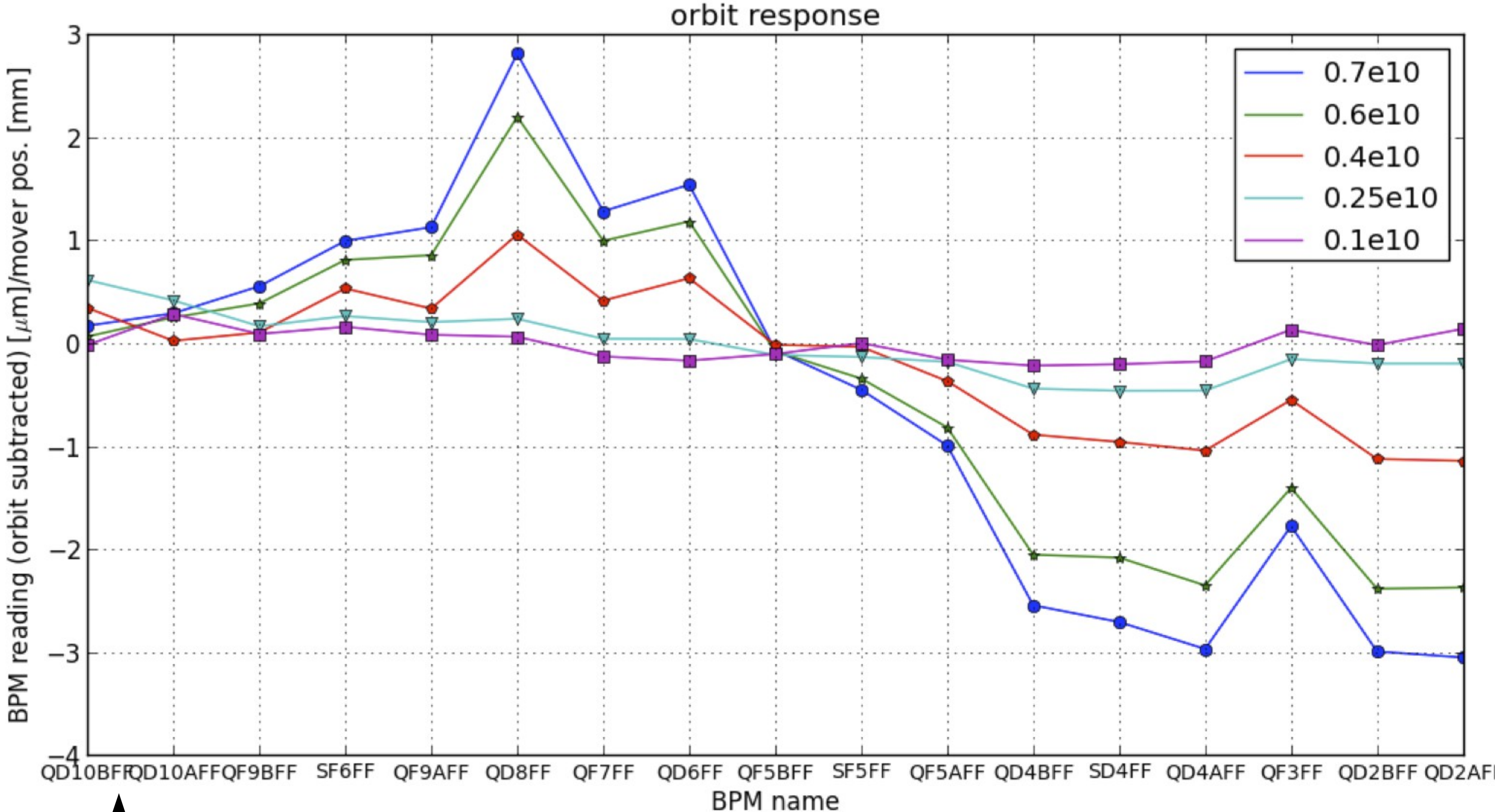


- Measured orbit shape agrees well
- Measured effect is 0.7 V/pC/mm
- About a factor 1.8 larger than simulation (numerical calculation + tracking)
- Reduced from earlier factor of 2.0

- Possible discrepancy might be due to bunch length or underestimation by simulation



Charge dependence



Mover setup

Beam direction

Charge dependence and orbit as expected

Conclusions

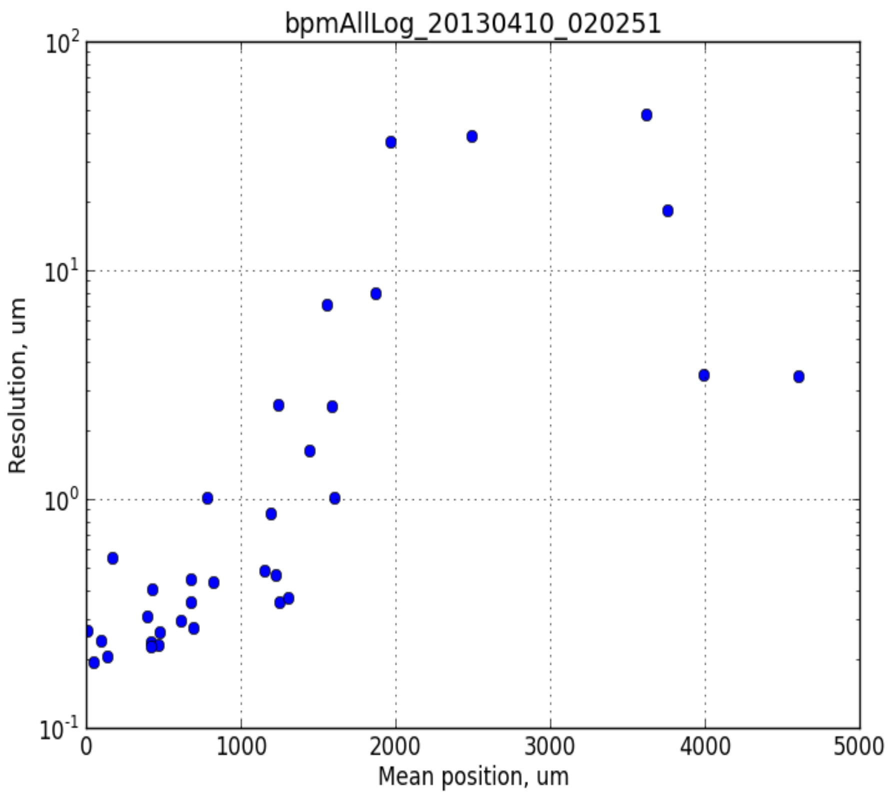
- Wakefield seems to be an important issue for ATF2
- Main wakefield sources in ATF2 are identified
  - BPMs at high beta are removed and bellows are shielded
- Wakefield compensation with movable reference cavities worked reasonably well for ATF2 December and 2013 runs
  - Current wakefield compensation setup has 2 movers, one with bellows and a collimator
- Wakefield from reference cavity observed in beam orbit
  - Correct intensity and bunch length (not shown) dependence observed
- No complete agreement between simulation and data
  - Correct wakefield calculation is difficult, lots of parameters
  - Several different methods (including observed beam size dependence) suggest wakefield is higher by factor 1.5-2 than expected from numerical calculation
- Some more details: IPAC13 paper: “Short Range Wakefield Measurements of High Resolution RF Cavity Beam Position Monitors at ATF2” (MOPWA052) and ICFA newsletter nr 61 (Final Focus issue)
- A more elaborate paper is close to finishing

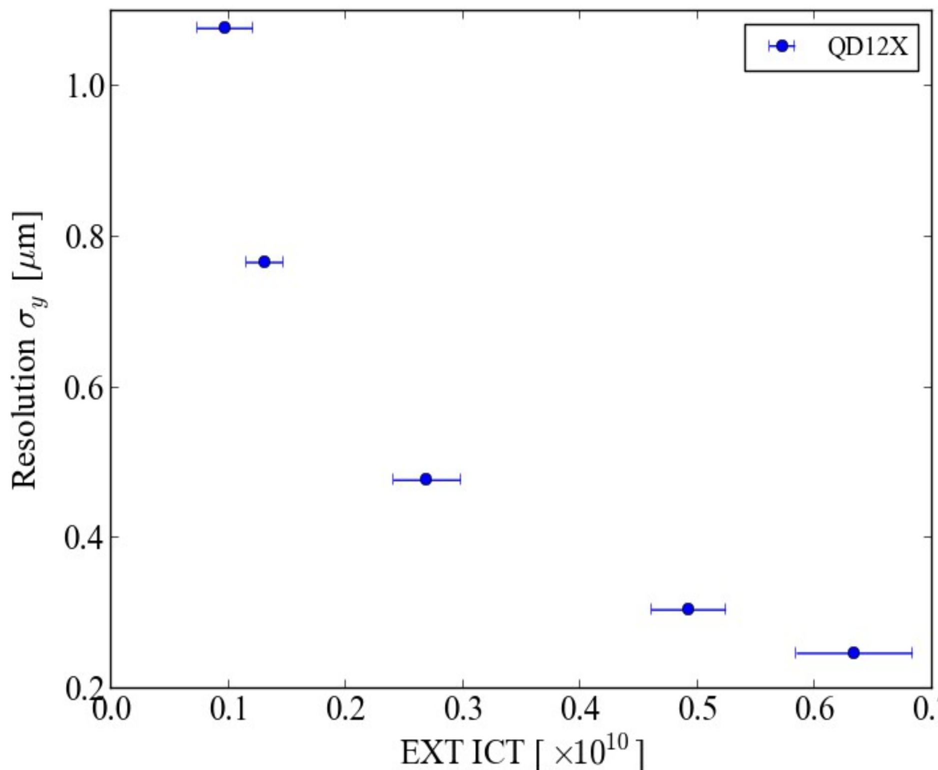
Backup

BPM resolution

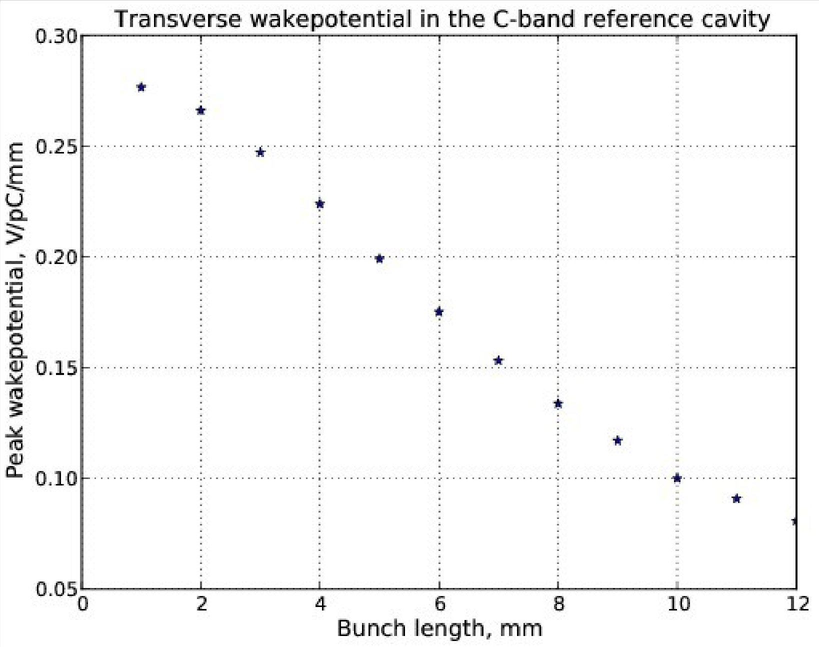
- Range of high resolution BPMs (with 20dB attenuation) is about 1um
- Resolution drops with low charge

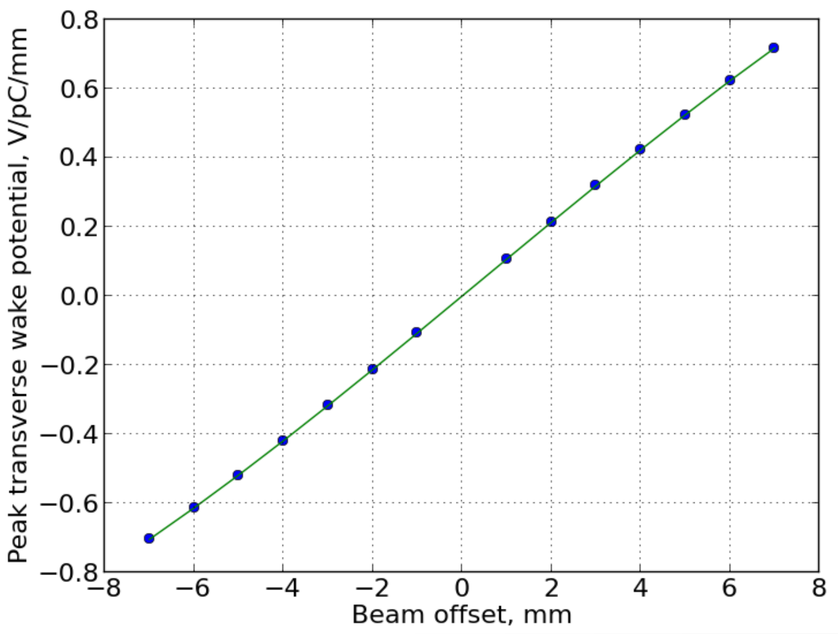
19 April 2013





Wakefield





- Interested in transverse wakes --> transverse kicks --> beam orbit / size effects
- Typically strong dependence on the bunch length for ATF2 parameters (7-10 mm) and geometries
- Transverse wake is quite linear vs. offset

QD0AFF

- Quadrupole QD10AFF moves by 0.5 um for each mm move of reference cavity

QD10AFF