Wakefield Effect at ATF2

S.Boogert, A.Lyapin, J.Snuverink (JAI-RHUL)
Y.I. Kim (JAI-Oxford)

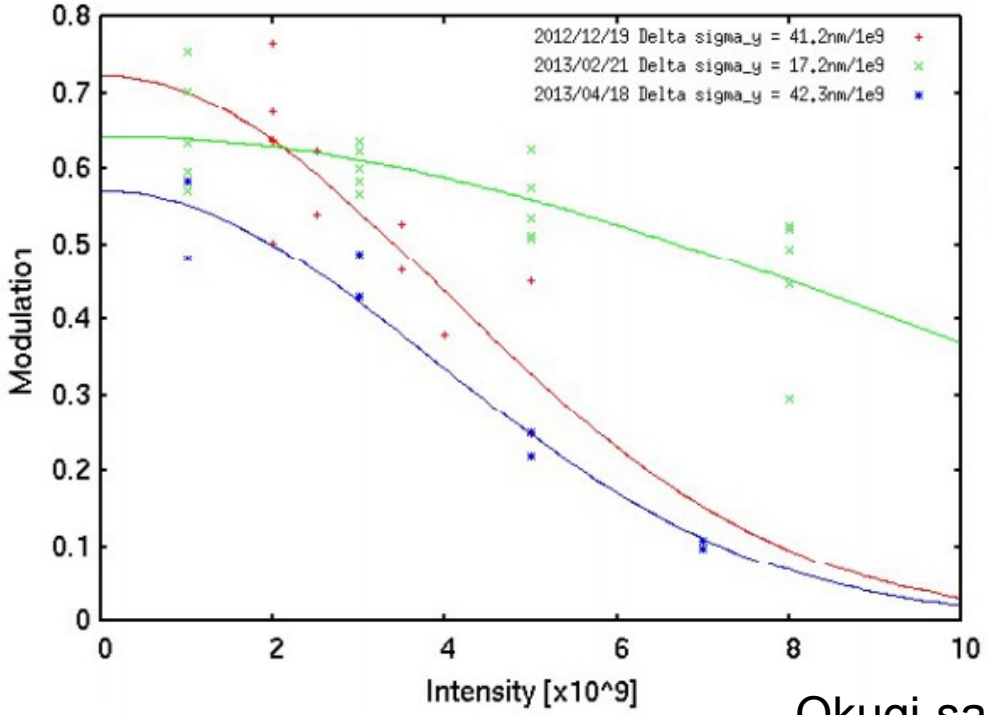
29/05/2013

Outline

- Overview wakefields at ATF2
- 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.



Red ; 2012 Dec.
Green ; 2013 Feb.
Blue ; 2013 Apr.

Okugi-san

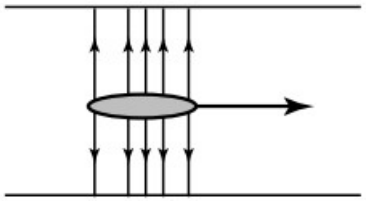
Wakefield

- 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

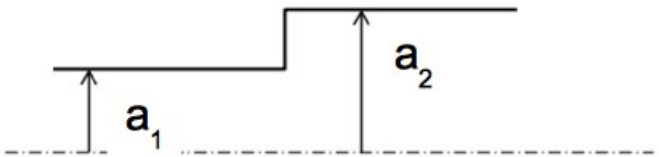
- Created due to interaction of the electromagnetic fields travelling with the beam with the walls of the beam chamber
- Resistive wake due to the finite conductance of the walls (more important when short bunches are considered in narrow chambers)

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



- 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

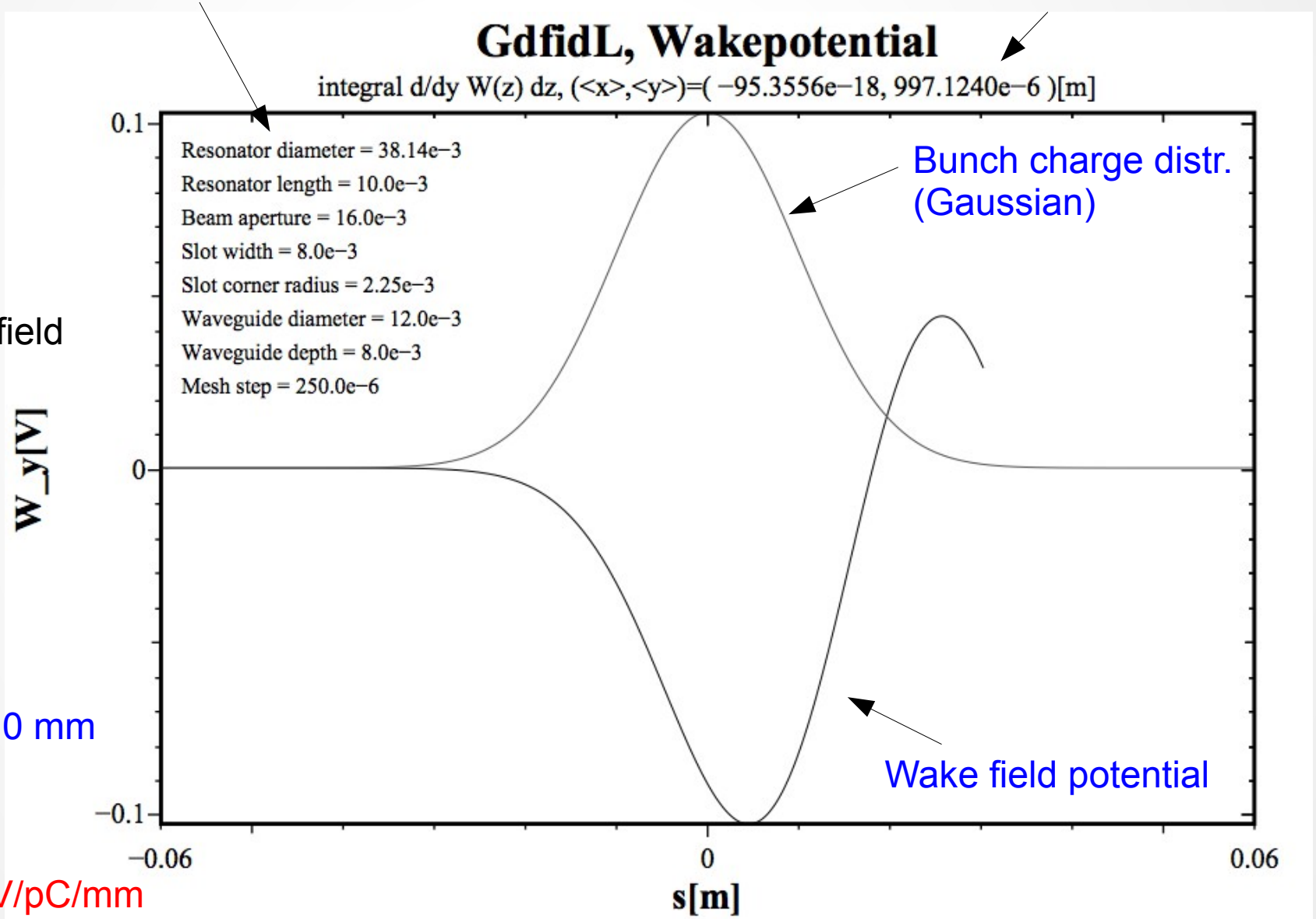
Wakefield

- 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)
- Wake field shape dependent on beam shape itself
  - Bunch length
  - Beam offset

GdfidL: wakepotential

Geometry parameters

Beam offset



Bunch charge distr. (Gaussian)

Wake field potential

Wake field (V)

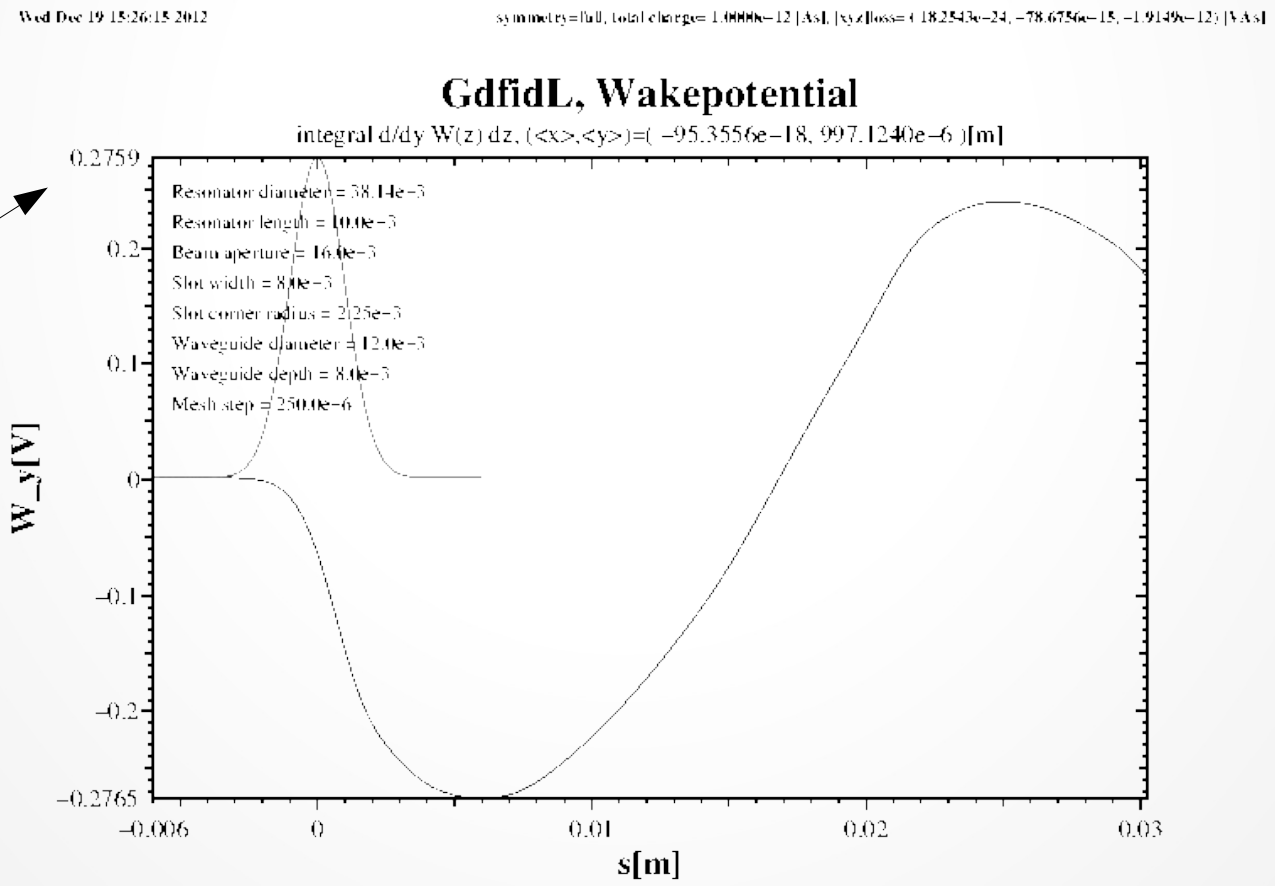
Bunch length 10 mm
Charge 1pC
1mm offset

Wakefield: 0.1V/pC/mm

Cavity BPM

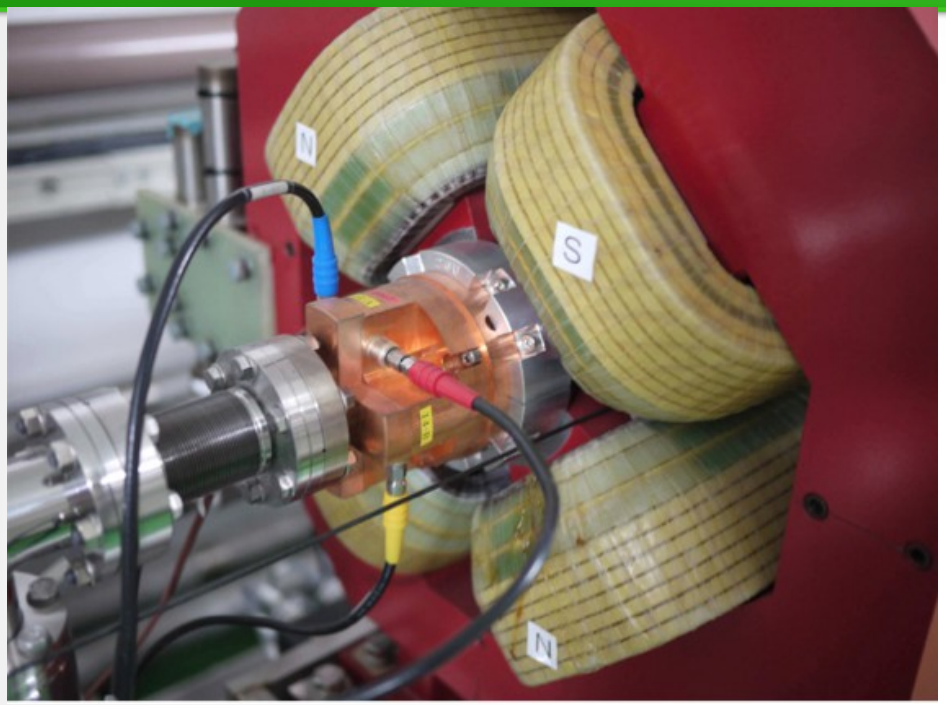
- Different bunch lengths:

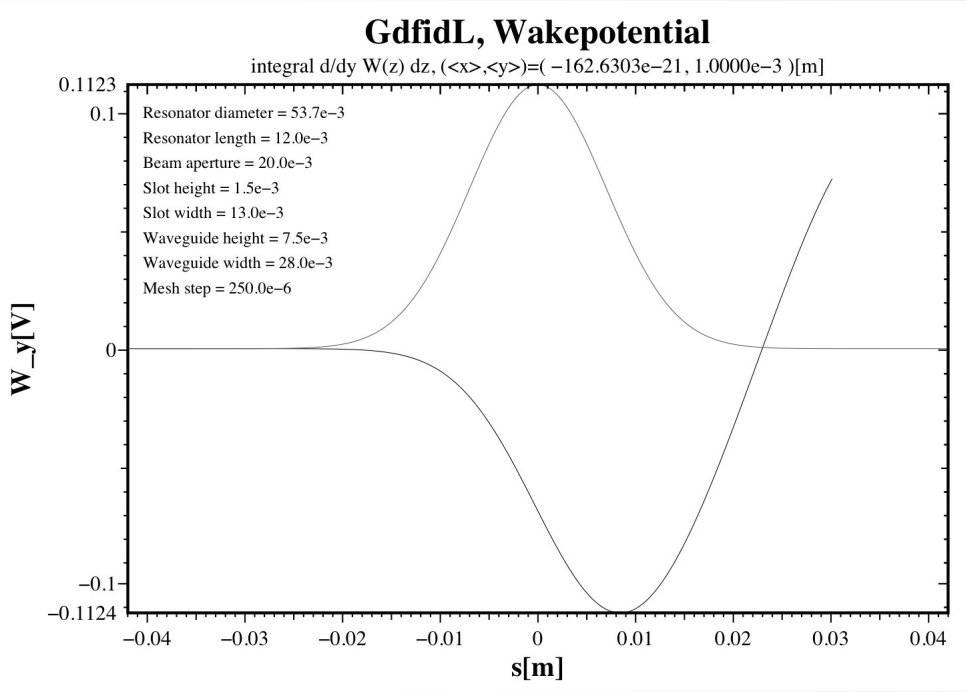
wakefield decreases with increasing bunch length



Short bunches don't 'see' peak field

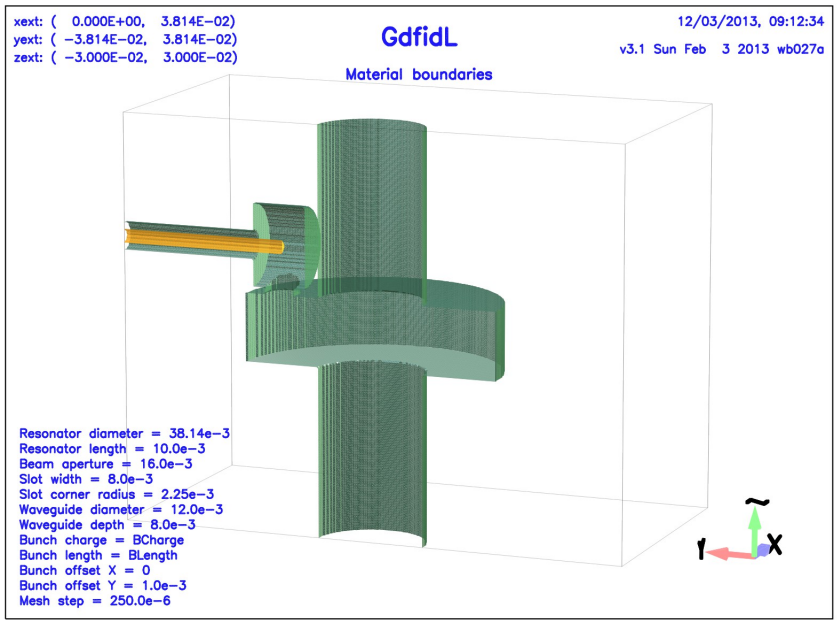
C-band CBPM

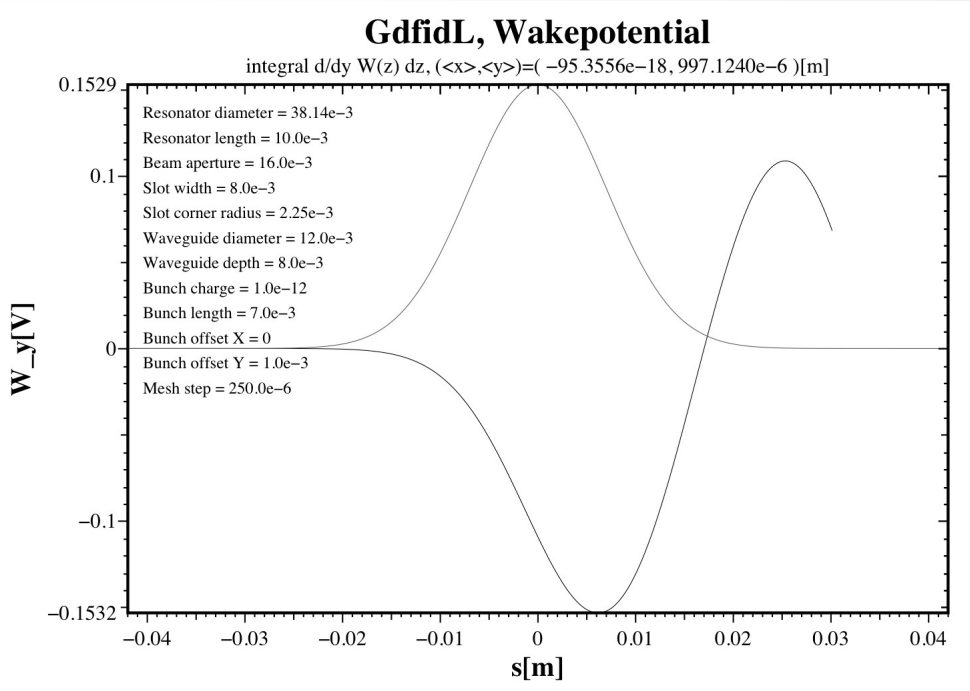




- High-impedance device (to provide a high position sensitivity)
- Typical resolution with attenuators ~200nm
- 30 nm without attenuation
- ~40 cavities in the beamline, the effect may be multiplied (although this depends on the orbit, beta function and alignment)
- Y.I. Kim et al. http://prst-ab.aps.org/pdf/PRSTAB/v15/i4/e042801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

C-band reference

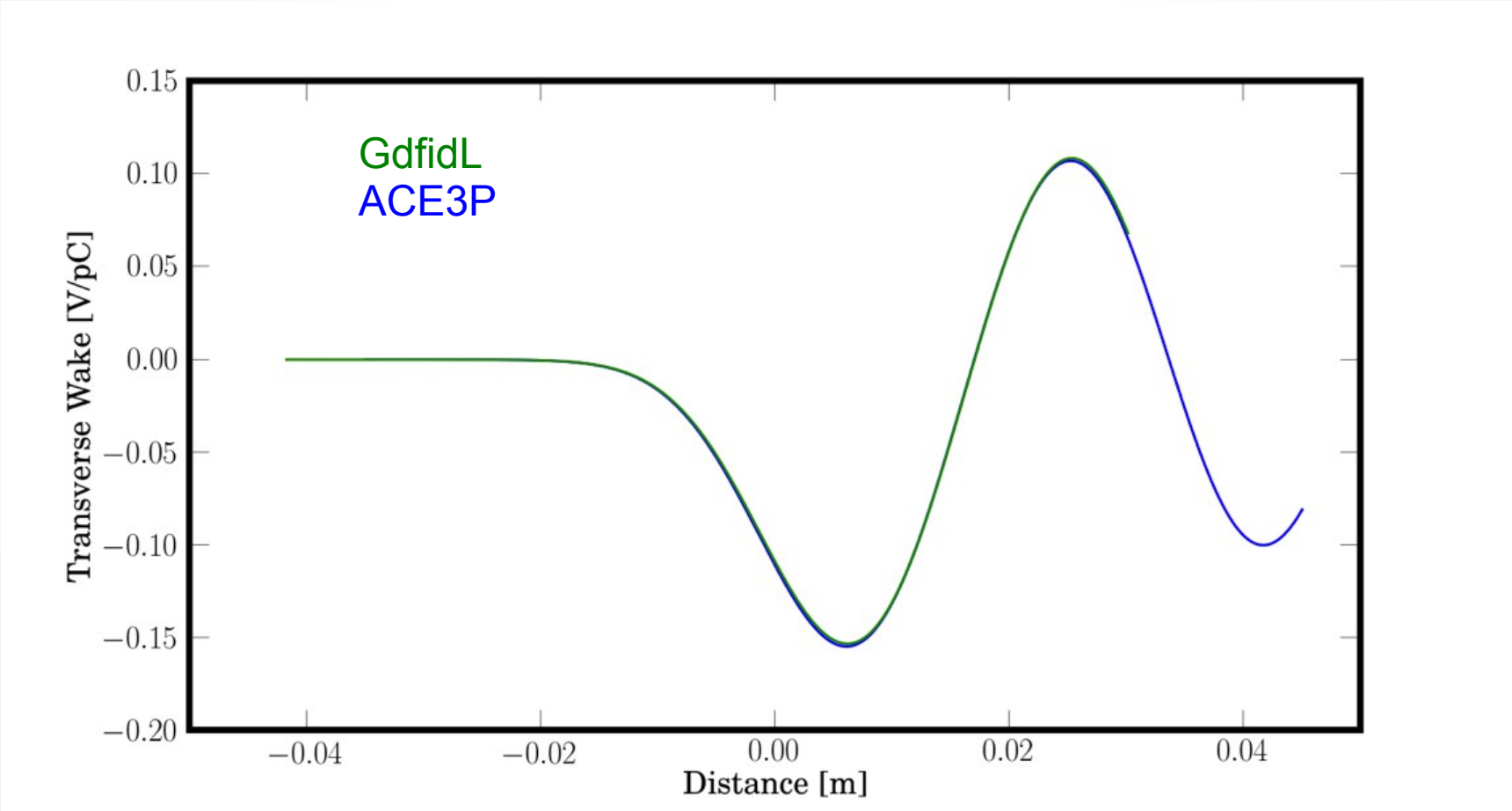




- Higher impedance than position cavity (smaller aperture and diameter)
- Used to be 4 in the beamline, now 1 providing the reference signal and 2 in the test location

Agreement GdfidL / ACE3P

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

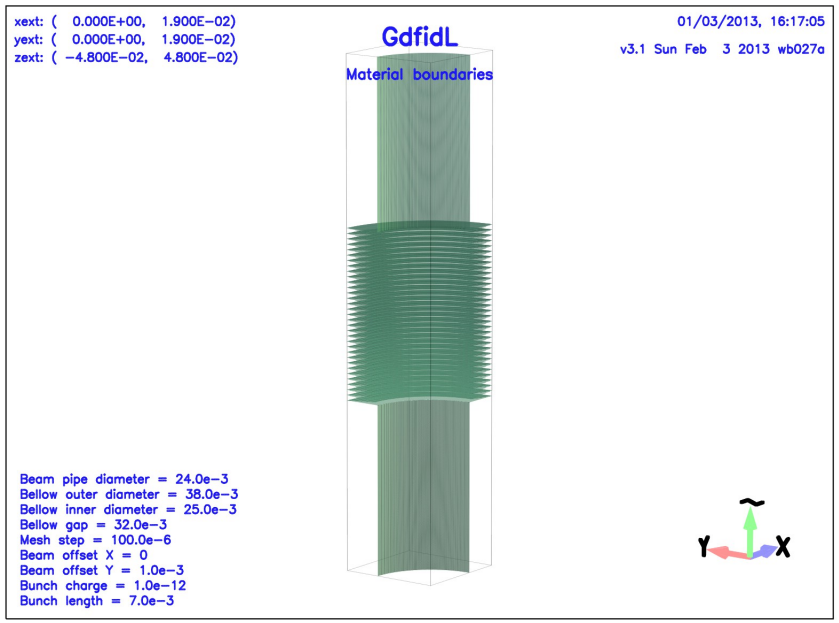


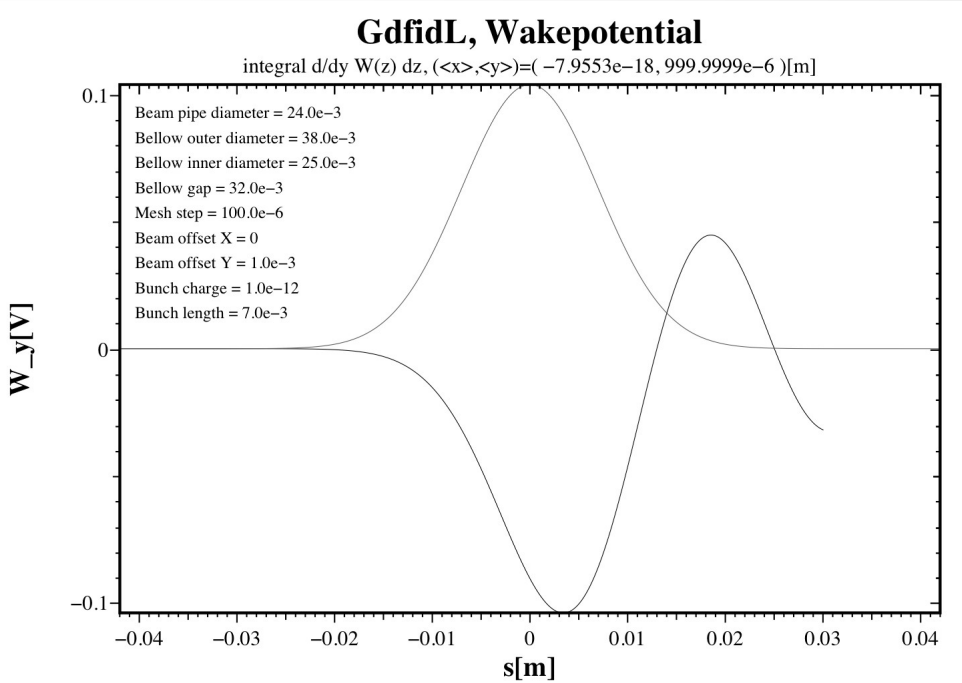
Rob Ainsworth (RHUL)

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 (May operation)
  - Wakefield contribution should be much reduced, needs to be resimulated

Naive total

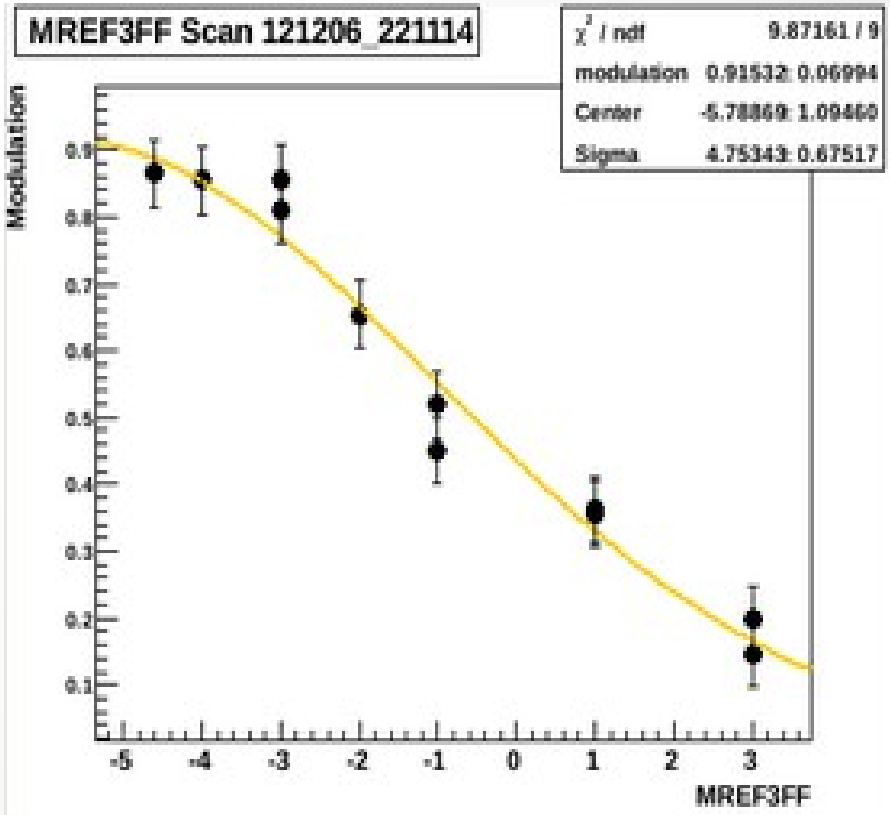
Element	Peak wake, V/pC/mm	Quantity	Contribution, V/pC/mm
Bellows (un/shielded)	0.1/?	100	?
C-band position	0.11	35	4.0
IPBPM (vert.)	0.7	2	1.4
24-20 mm transitions	0.008	100	0.8
C-band reference	0.15	4	0.6
Vacuum port (X)	0.07	6	0.42

- 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

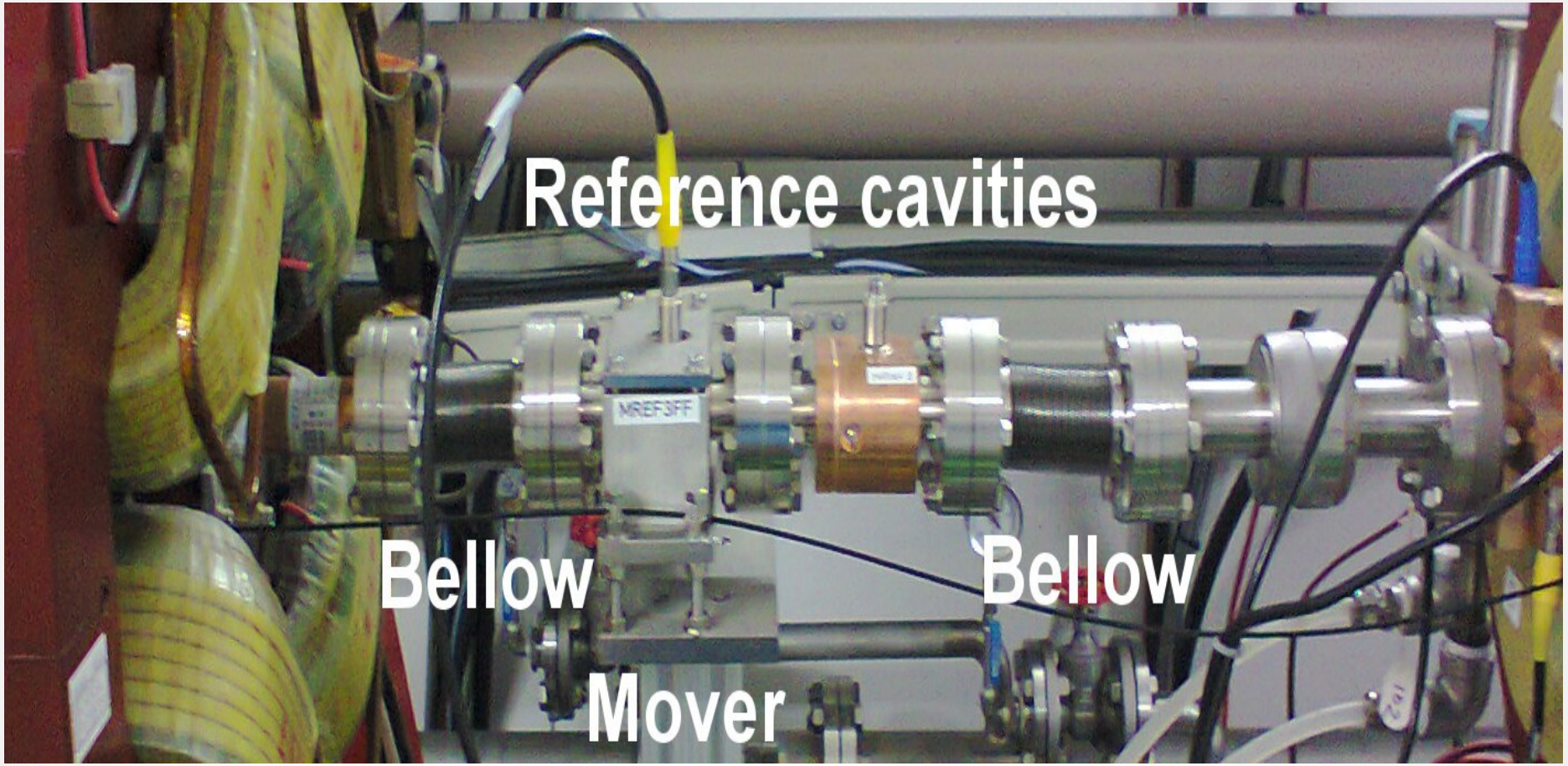
Wakefield compensation

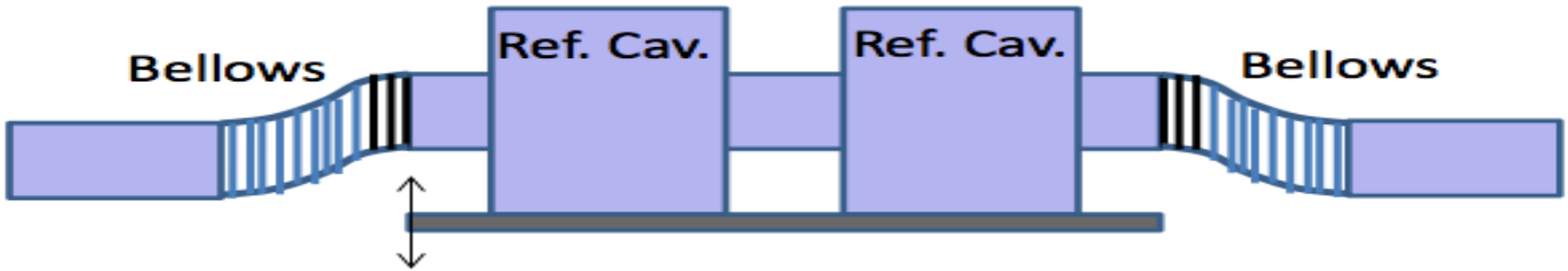
- Reference cavity on mover at high beta location (“MREF3FF”)
- Goals:
  - Compensate wakefields from other locations
    - Only those locations at about same phase advance
    - However simulation by Kubo-san showed that most wakefields can be compensated
  - Study CBPM wakefield
- Originally one, but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

Swing shift Thu 6-12 (7deg)

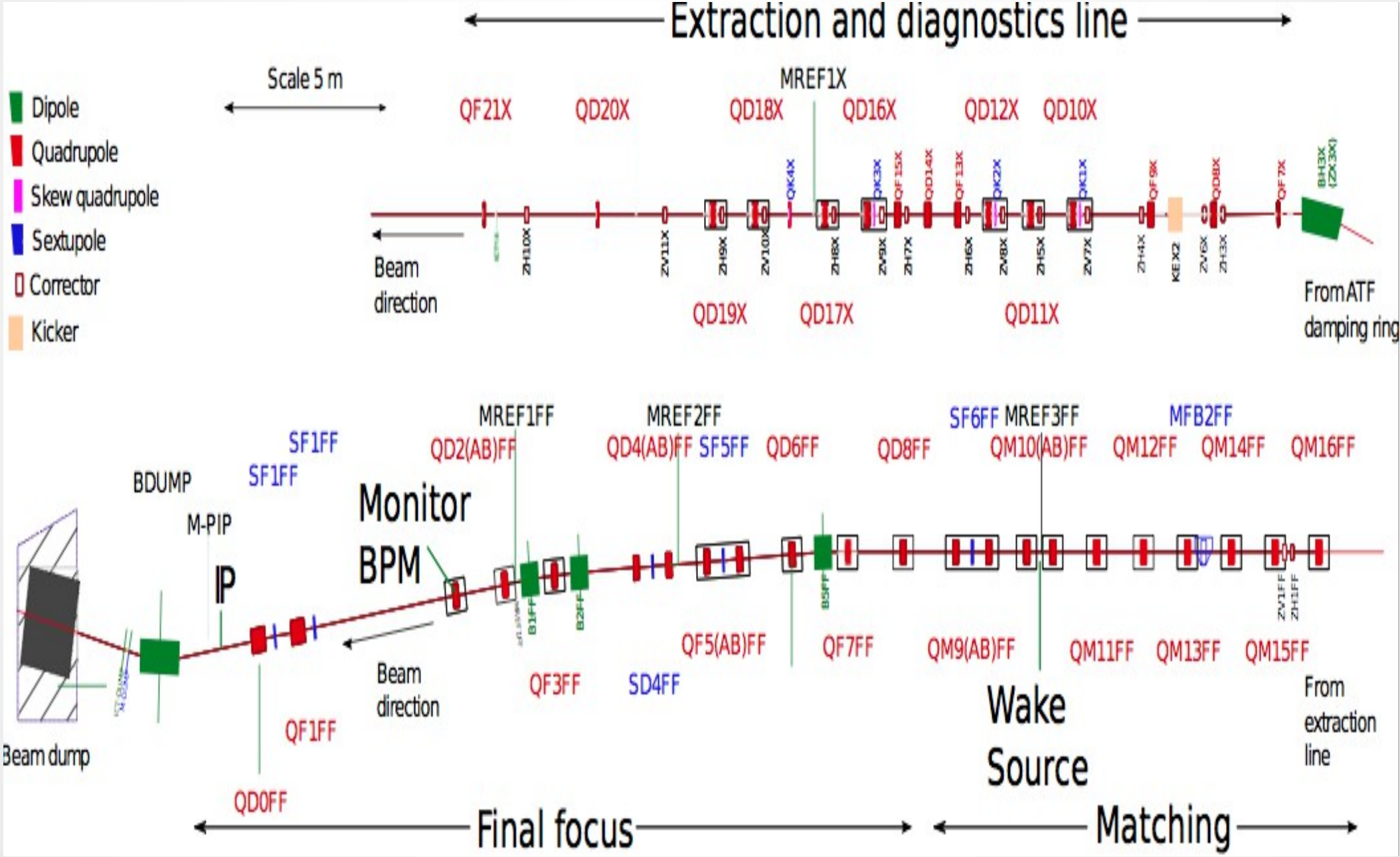


MREF3FF setup





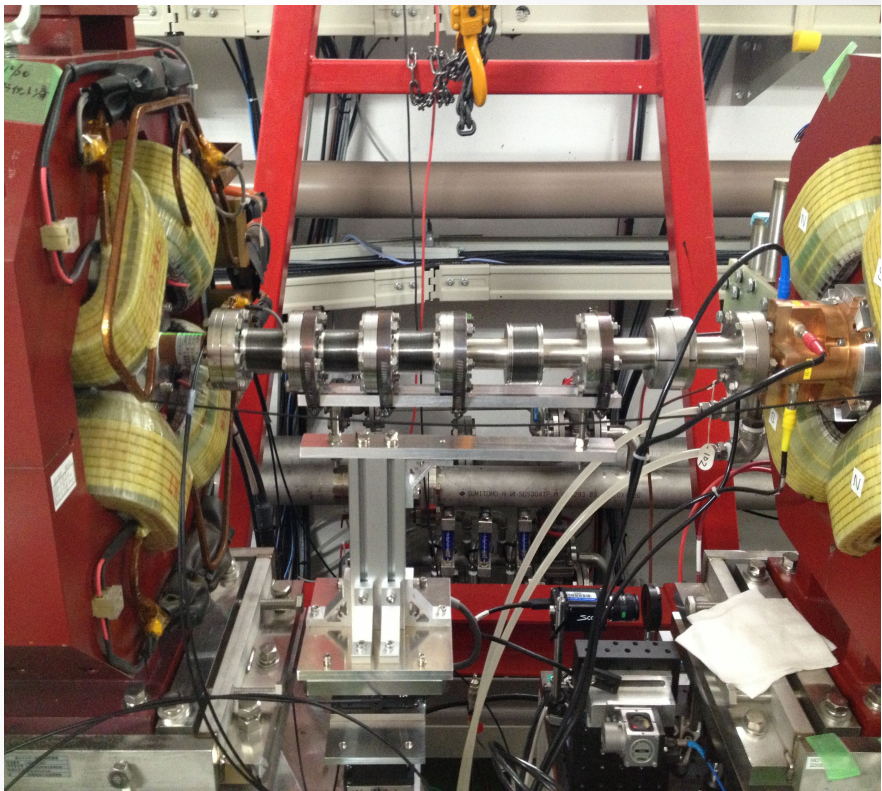
ATF2 layout


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
SF1FF
QD2(AB)FF
QD4(AB)FF
SF5FF
QD6FF
QD8FF
QM10(AB)FF
QM12FF
QM14FF
QM16FF
BDUMP
M-PIP
IP
Monitor
BPM
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

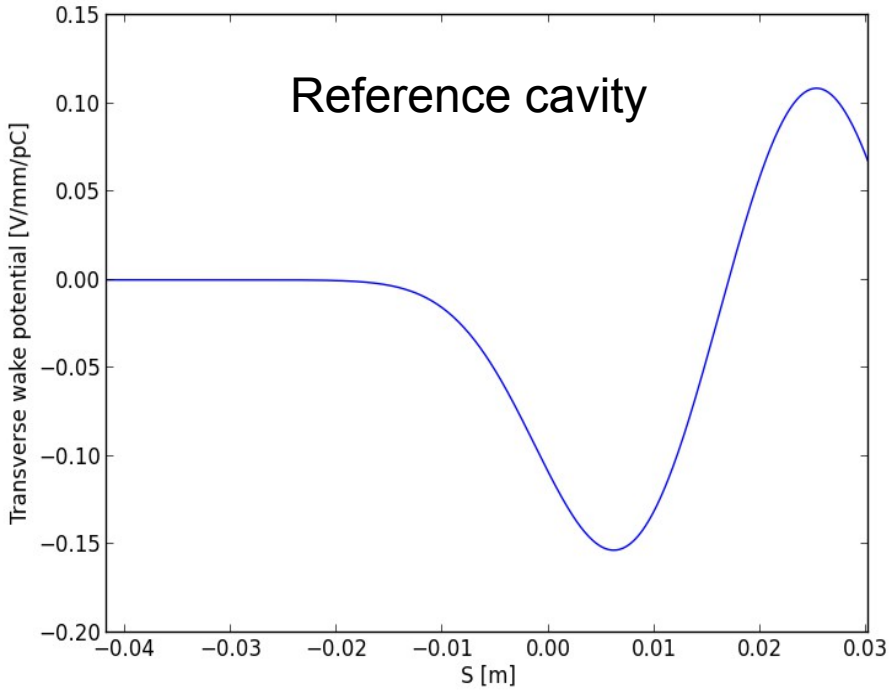
- Goal: measure wakefield from Cavity BPM
  - By looking at orbit change
- Some measurements done in December during continuous run (parasitically)
  - Effect is measurable, but some open questions
    - Bunch length
    - Charge was not monitored carefully
- Dedicated shifts last April
  - Using MREF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

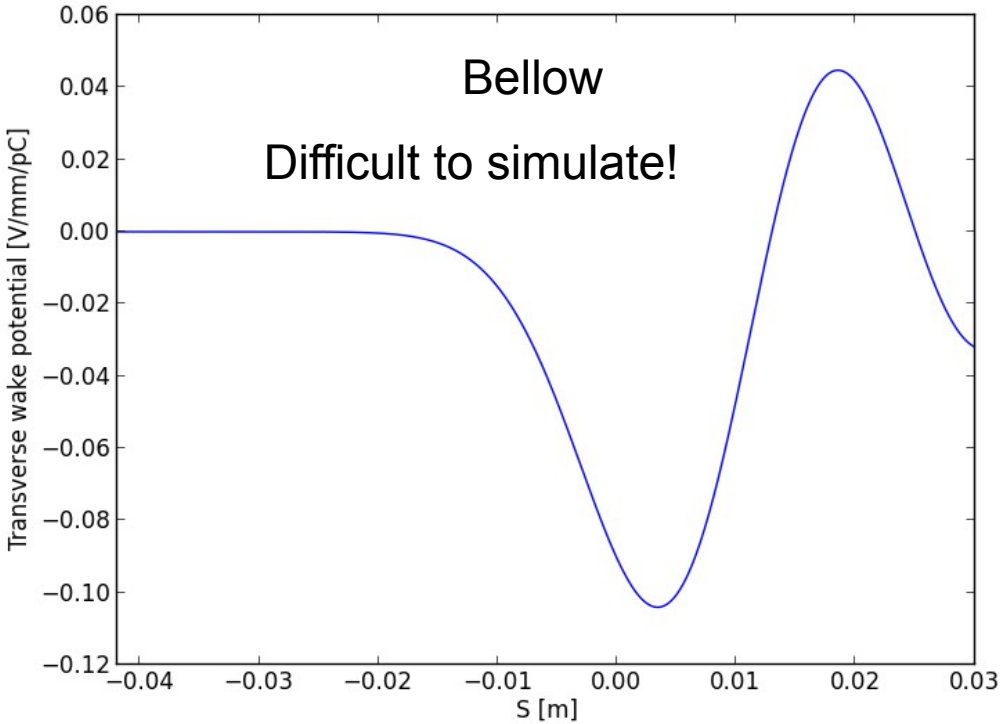
    1 ref. cavity, 2 ref. cavities, 3 bellows



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

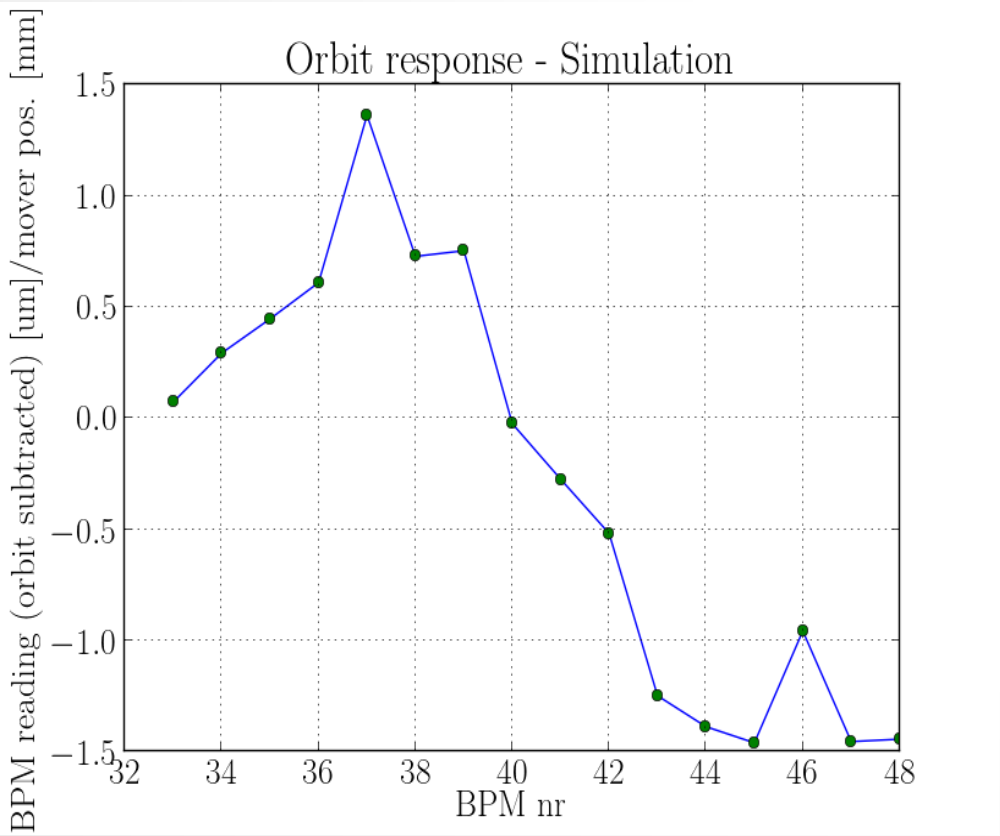
bellow moving only half way

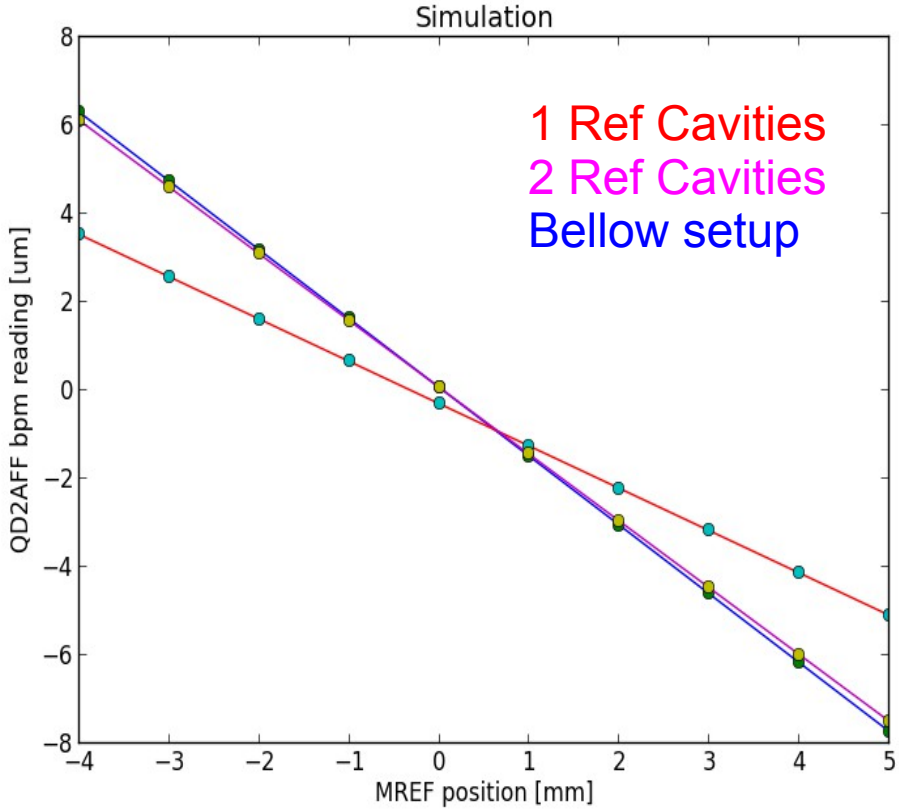
Simulation

Geometric wakefield realistically implemented in PLACET

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?

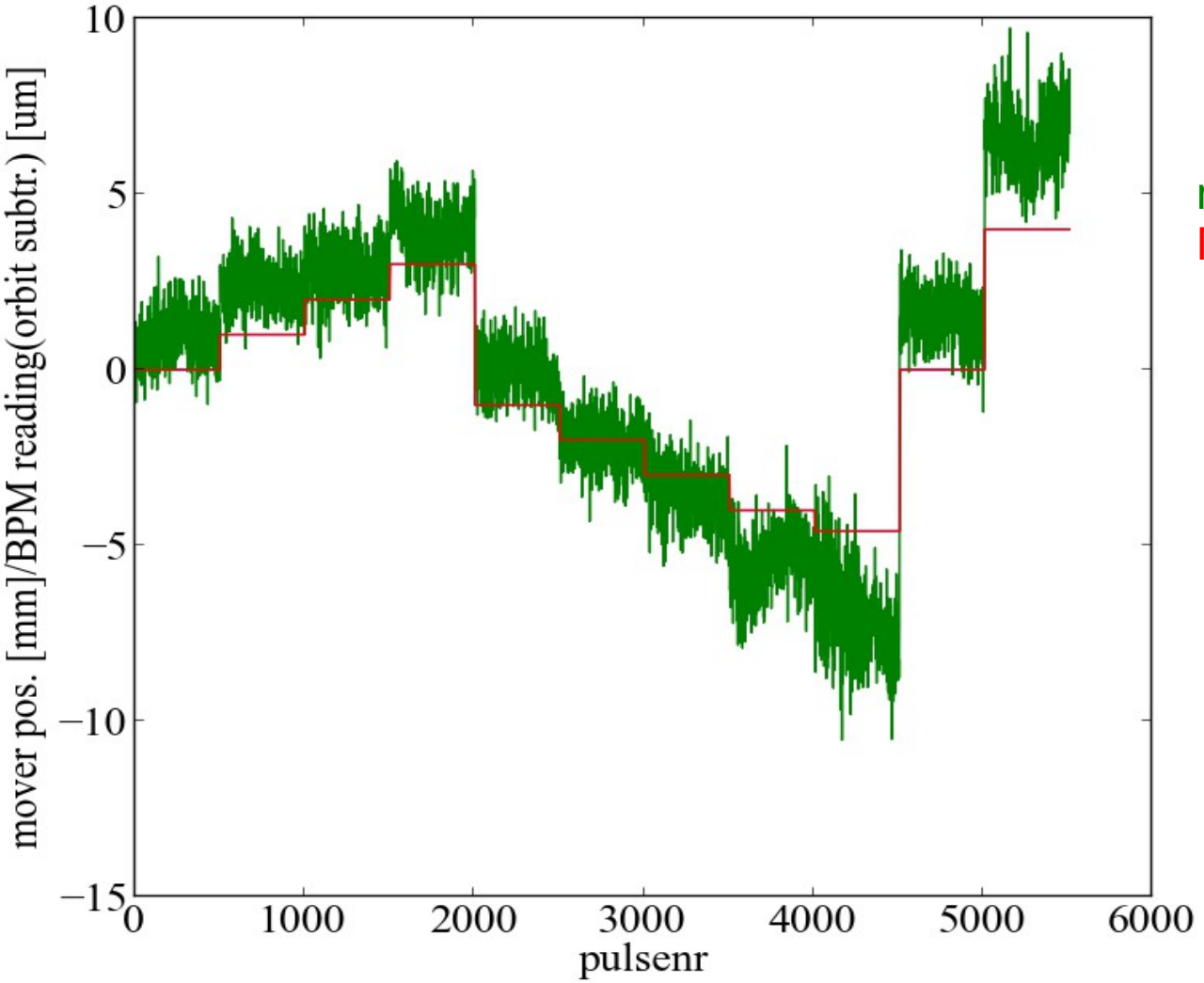
Orbit analysis

- 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):
  - $R = AX - B$

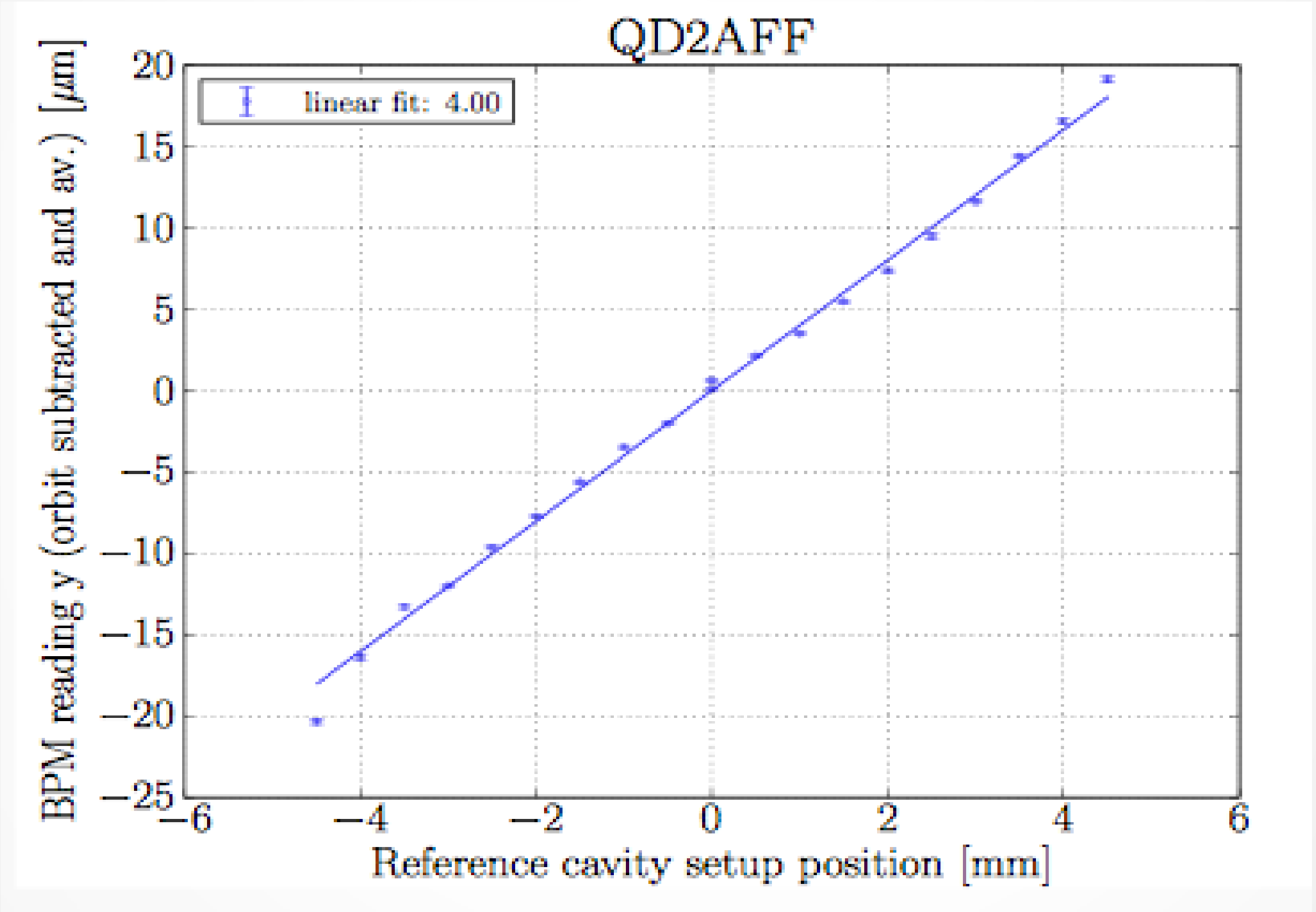
Example
QD2AFF vs MREF3FF position



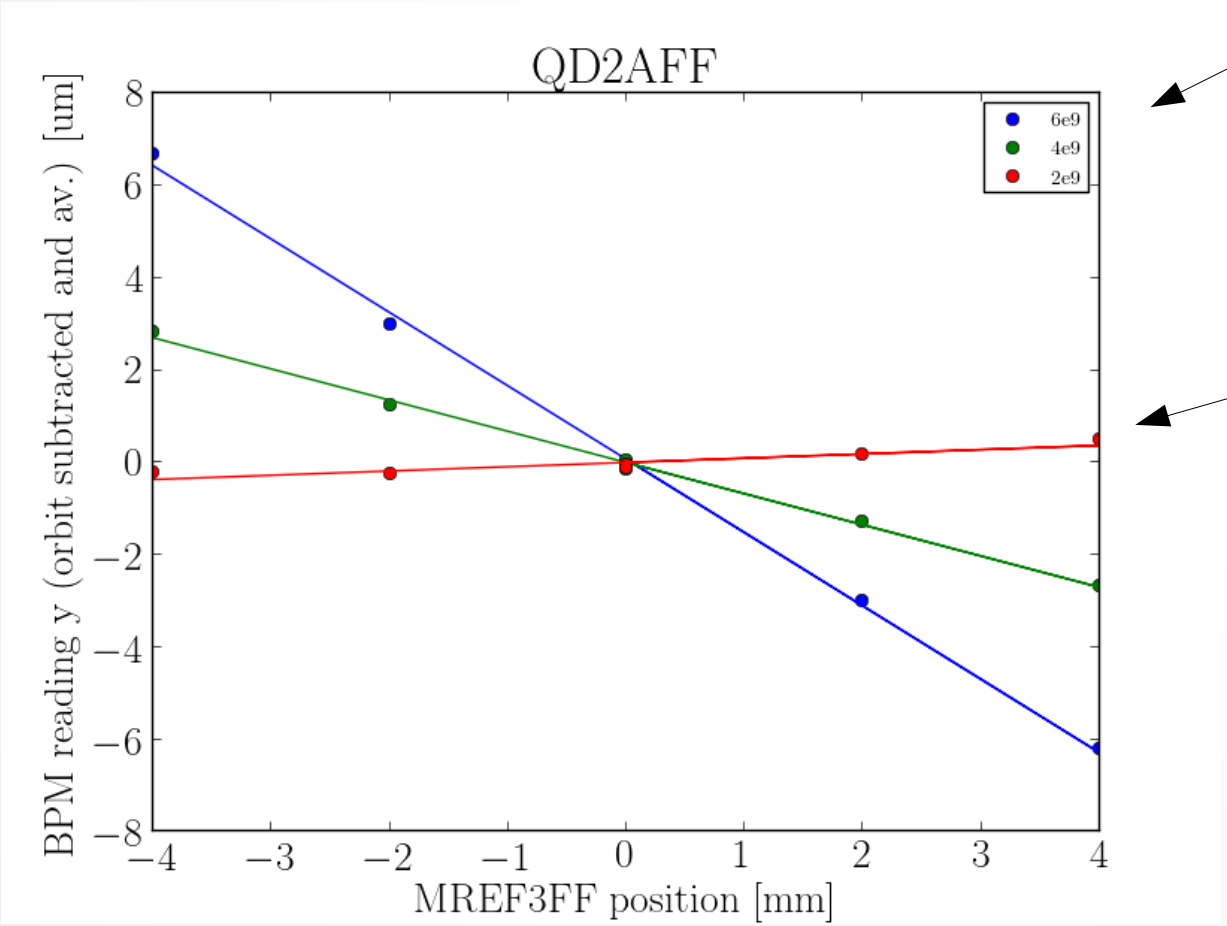
residual BPM reading QD2AFF [um]
MREF3FF position [mm]

Clear correlation seen for all downstream BPMs with expected orbit pattern

Orbit change



Charge scan



Indicative charge

No effect or negative slope because of low measurement sensitivity
See next slide

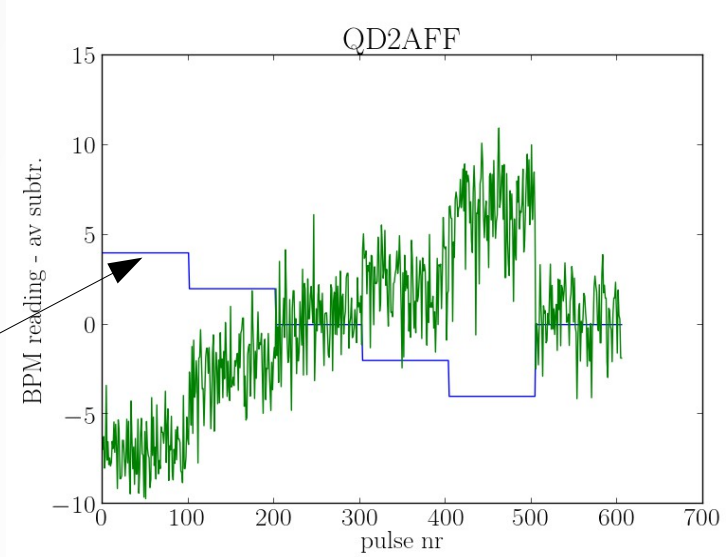
High-low charge

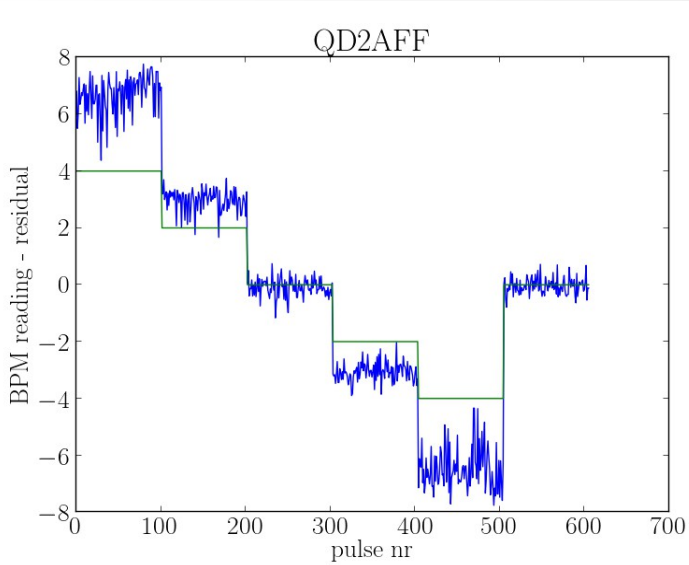
Orbit (average subtracted)

Orbit – jitter subtracted

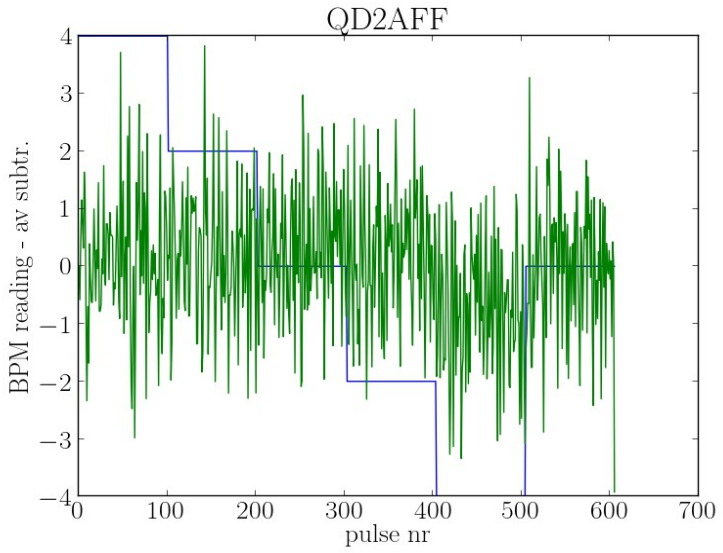
High Charge (0.6e10)

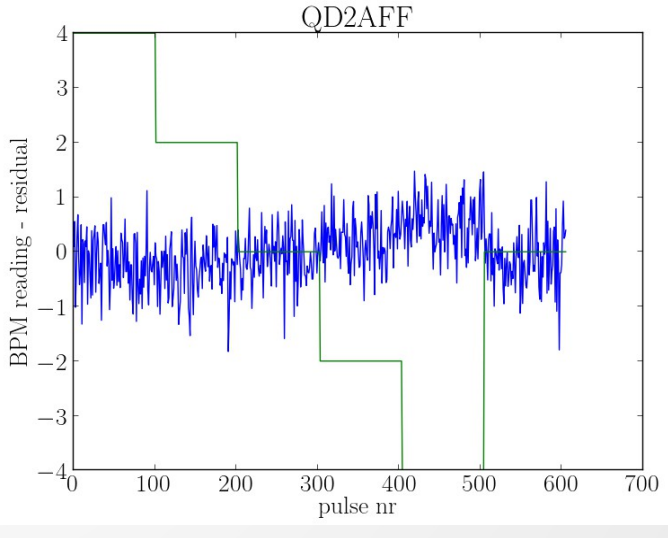
Ref cavity position





Low Charge (0.15e10)

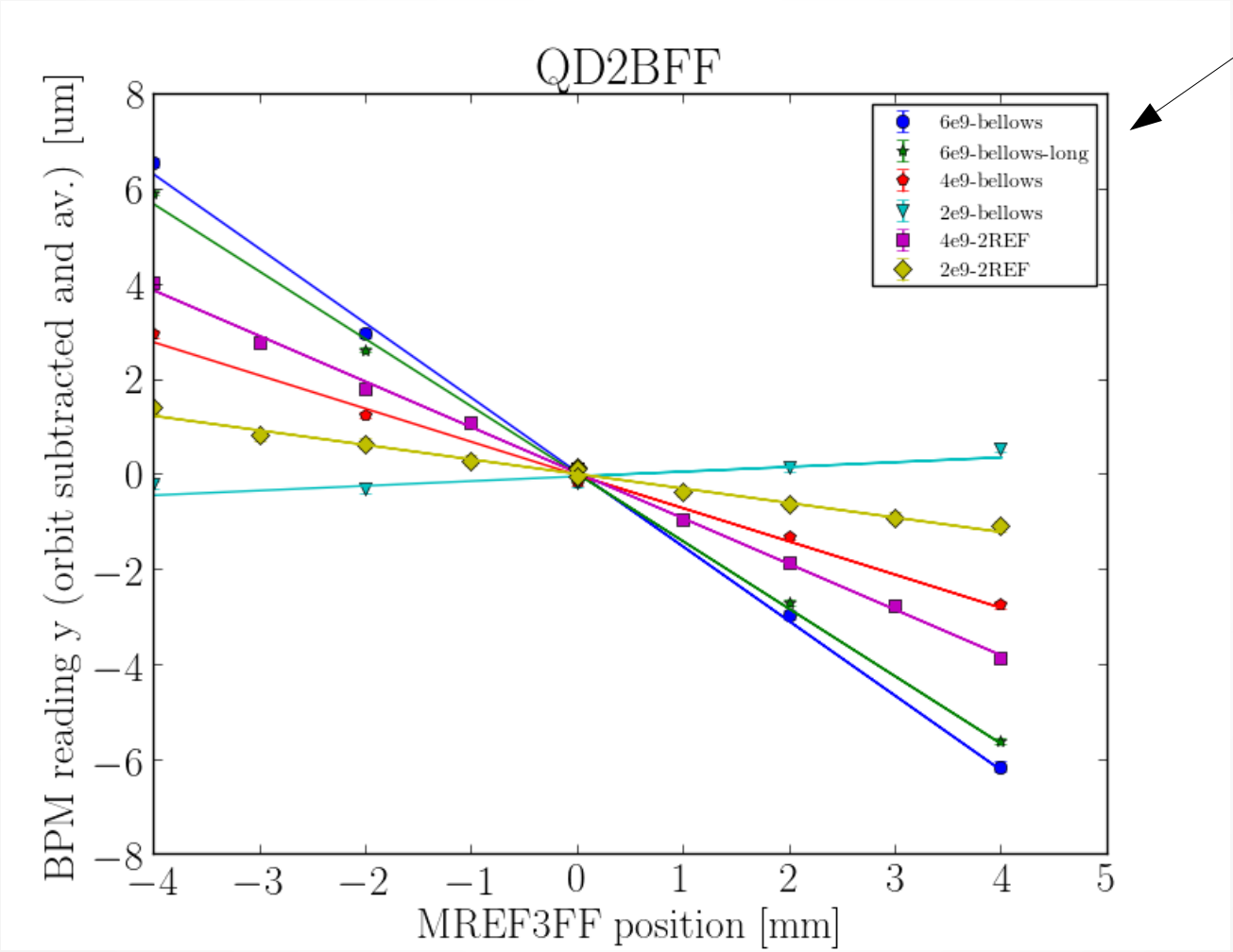




Effect smaller
Resolution lower
Orbit subtraction difficult

Bellows vs 2 reference cavities

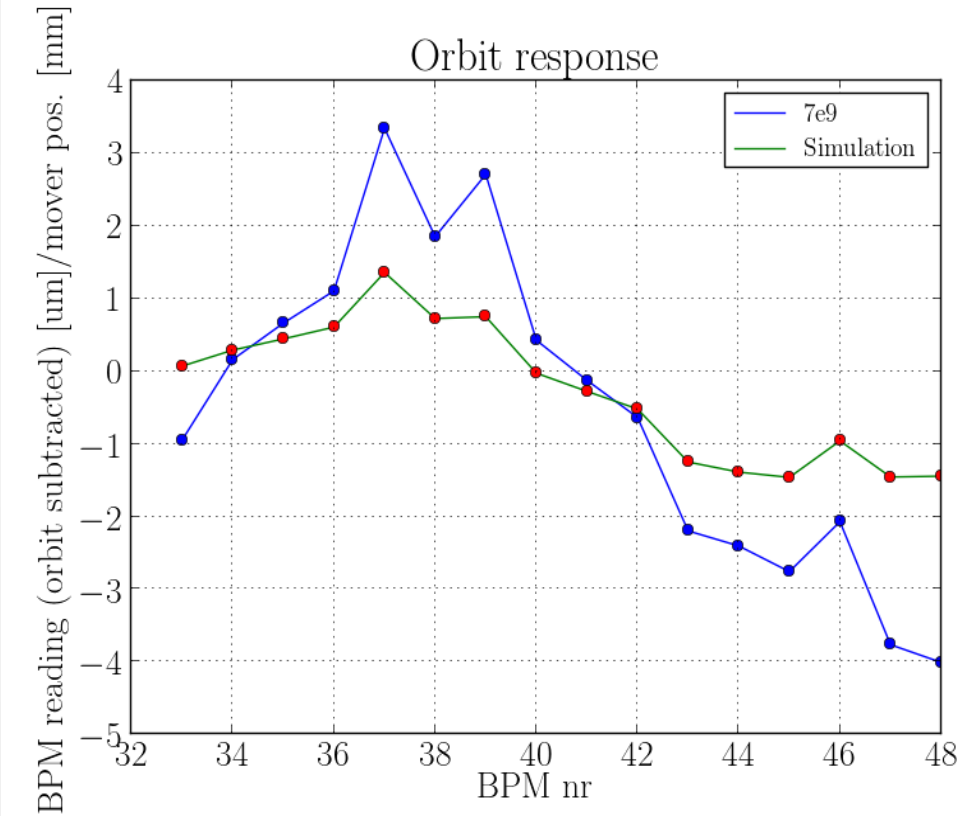
Indicative charge

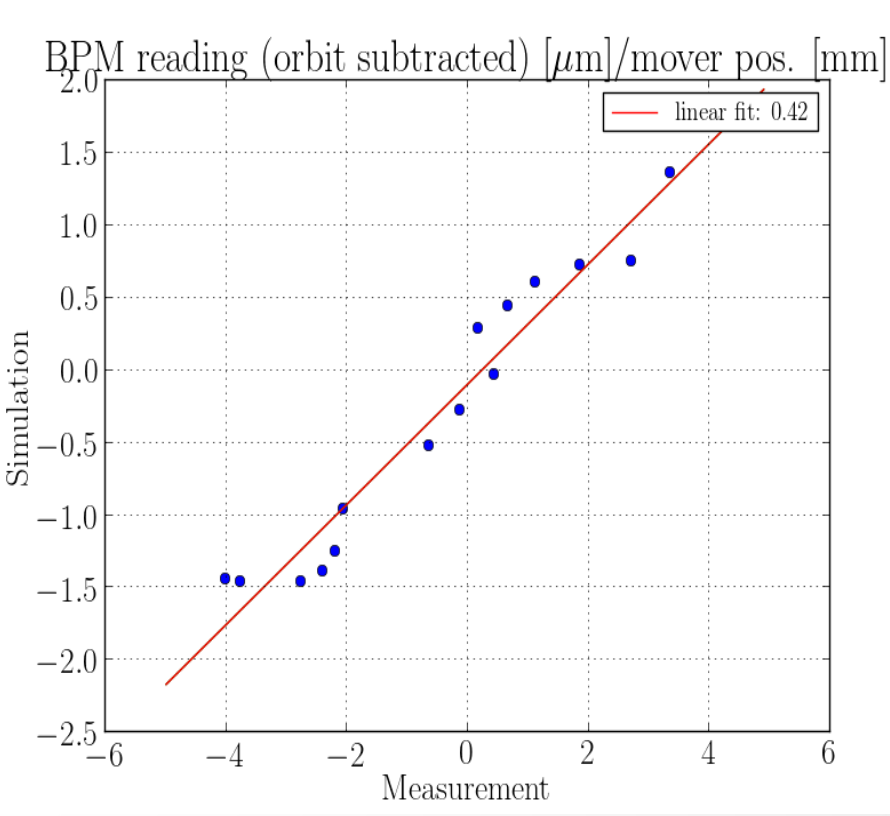


Bellow (3) setup and reference cavity (2) setup are similar (as predicted from simulation)

Comparison with simulation

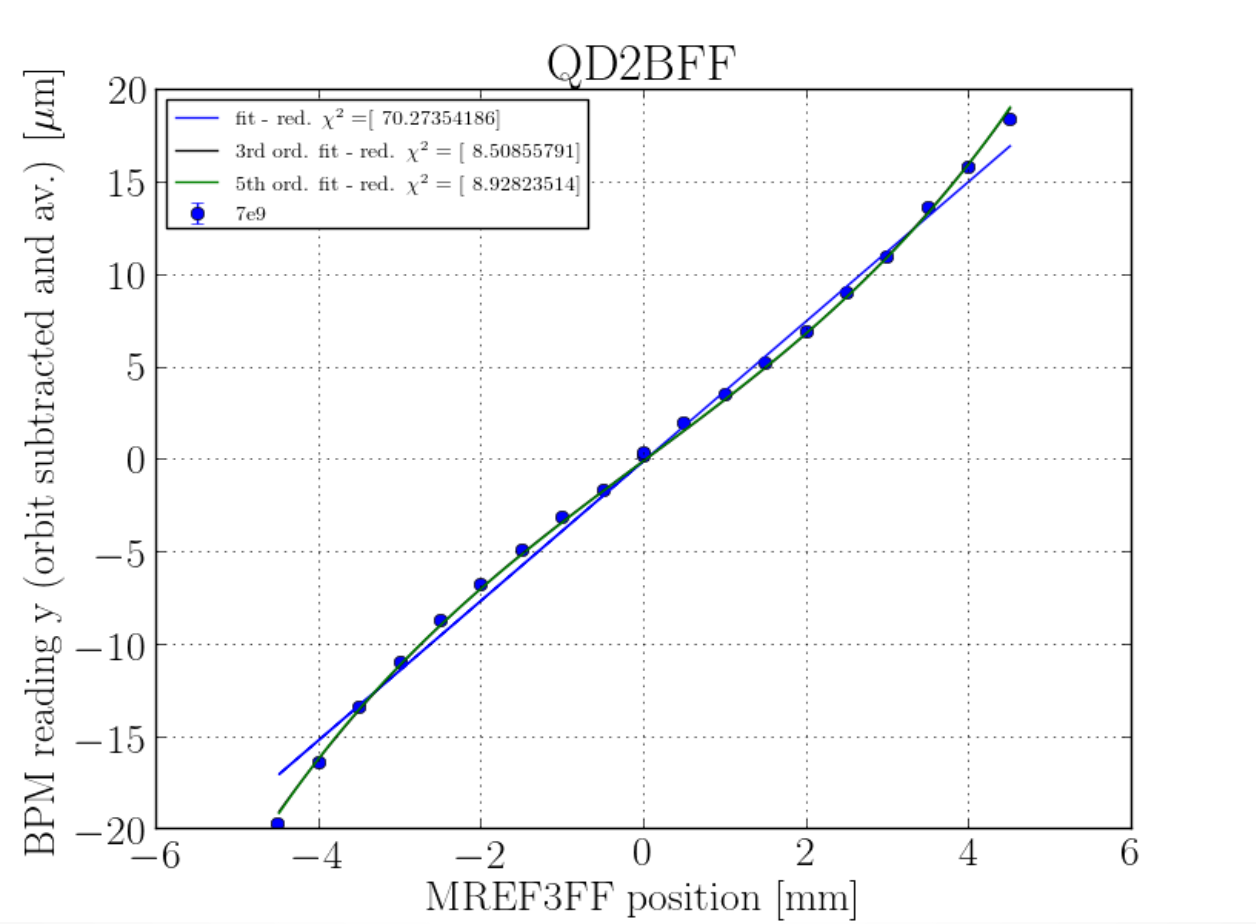
2 reference cavity setup





Measured effect (0.8 V/pC/mm) about a factor 2 larger than simulation (numerical calculation + tracking)
Measured orbit shape agrees well with simulation

3rd order fit



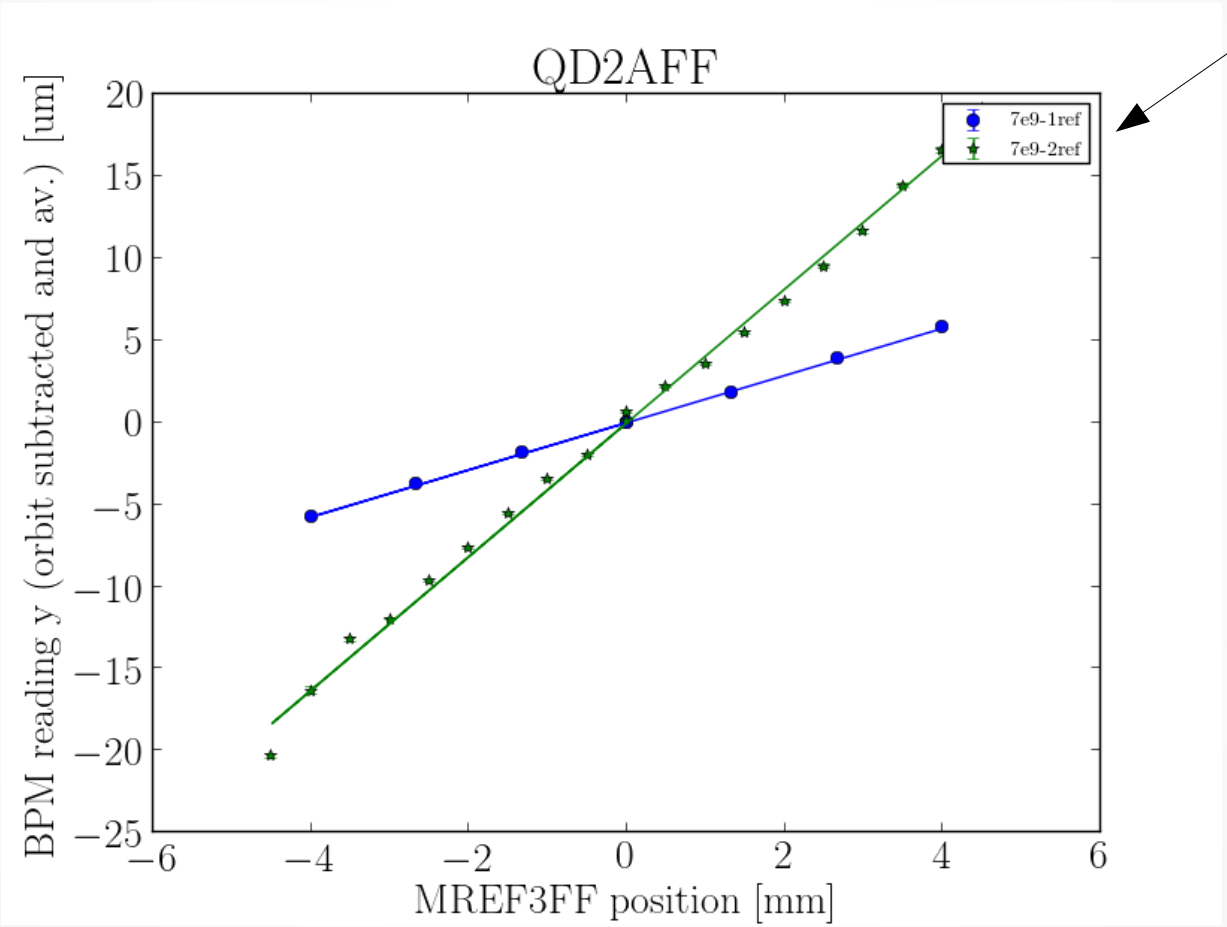
- Measurement fits much better to 3rd order polynomial
  - χ^2 much reduced (only stat. error taken into account)
- Not verified by numerical calculations but predicted and observed before in collimator studies, e.g. http://accelconf.web.cern.ch/AccelConf/e02/PAPERS/WEAGB002.pdf
- Checks are ongoing.
- This might reduce the discrepancy

Conclusions

- Wakefield seems to be an important issue for ATF2
- MREF3FF wakefield compensation worked reasonably well for ATF2 December and 2013 runs
- Improved understanding of wakefield problem
  - But many questions remaining
- Wakefield observed in beam orbit
  - Correct dependence of intensity and bunch length seen
- No complete agreement between simulation and data
  - Correct wakefield calculation is difficult, lots of effect
  - 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)
- Paper is planned
  - including bunch length measurements, improved analysis

Backup

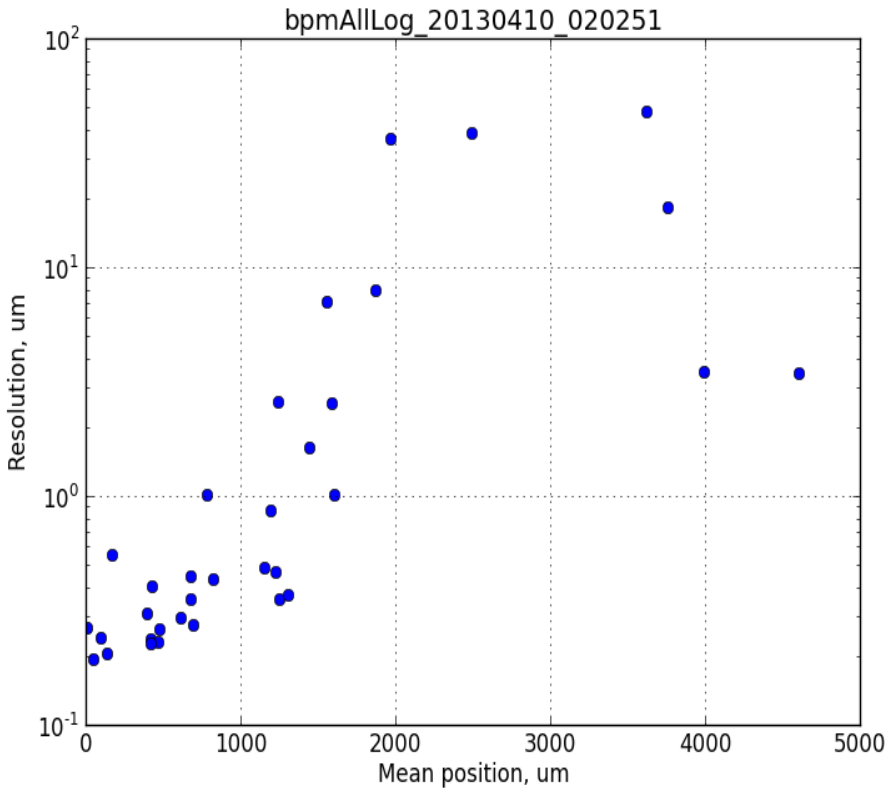
1ref vs 2ref



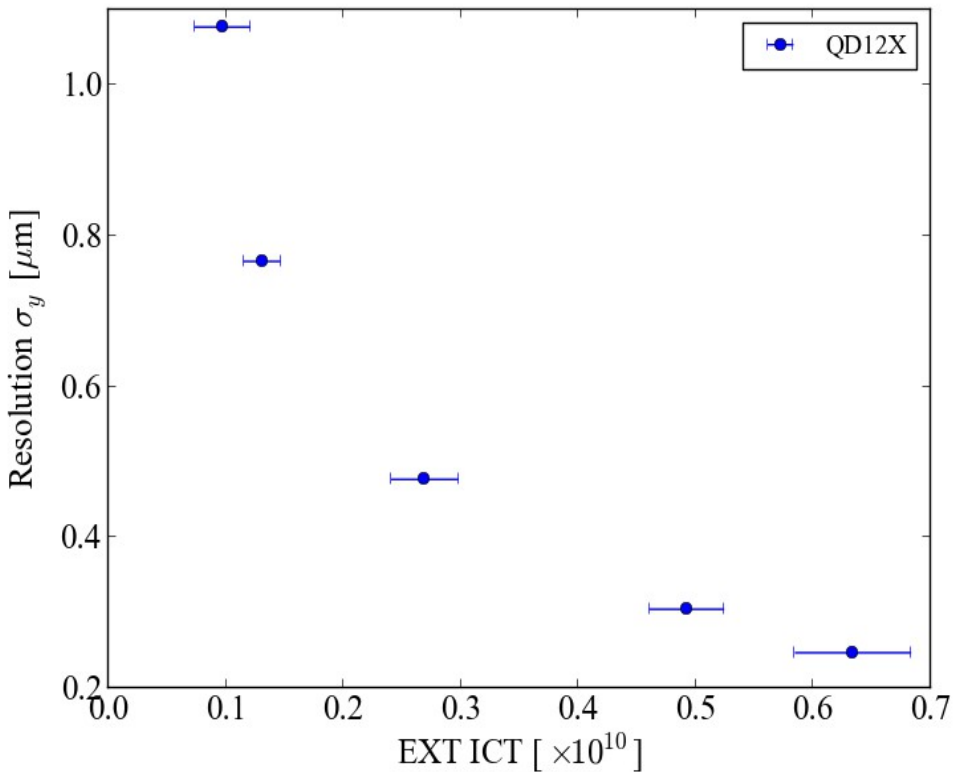
indicative

BPM resolution

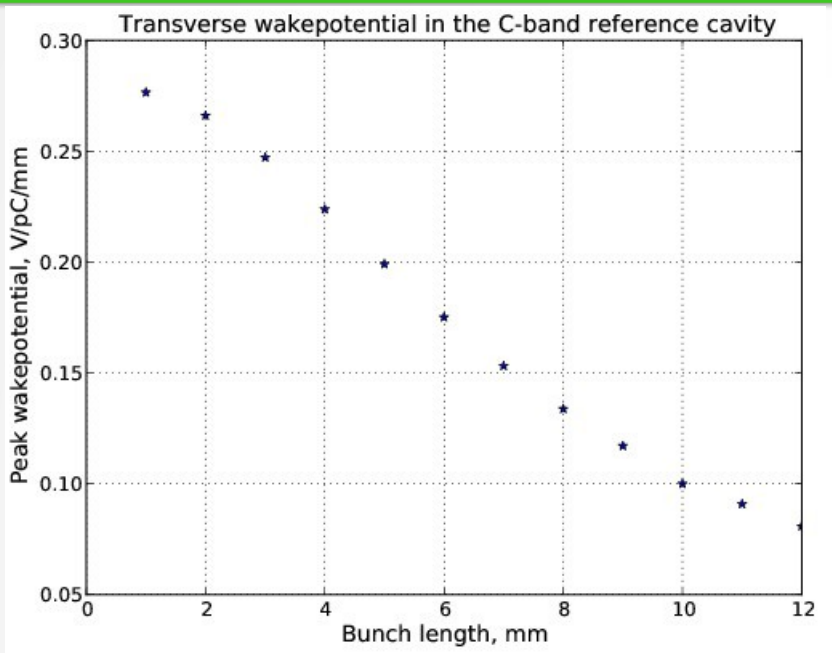
- Range of high resolution BPMs (with 20dB attenuation) is about 1um
- Resolution drops with low charge

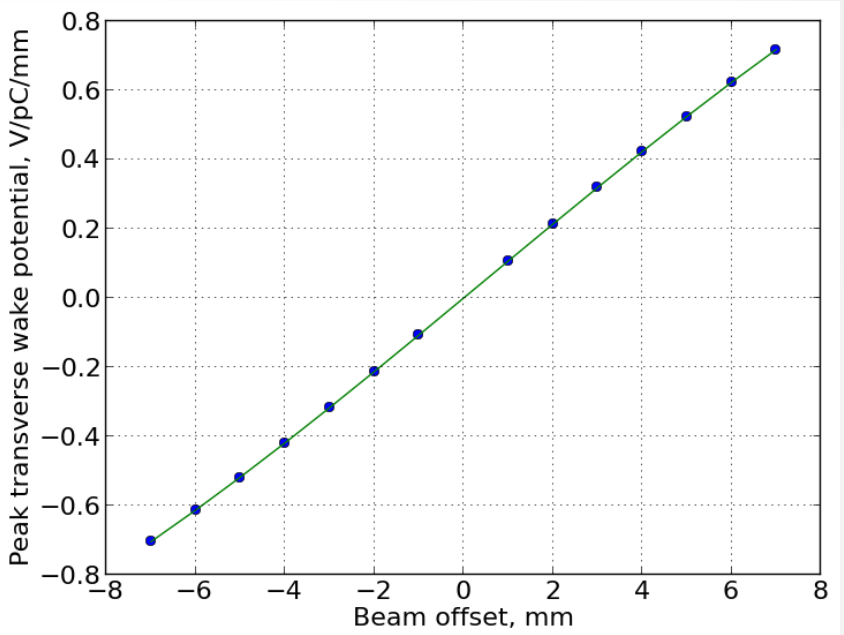


19 April 2013



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