M. Dehler

Wake field monitors
design, implementation and first experiences

PACMAN workshop, Debrecen, Hungary, June 13 2016

What is the basic idea of a WFM?
(or alignment monitor or ....)

Why do we want to have precise alignment between beam and devices?

- Minimize emittance dilution due to nonlinear magnetic field, wakes etc.

Traditional way of aligning components or finding golden orbits:

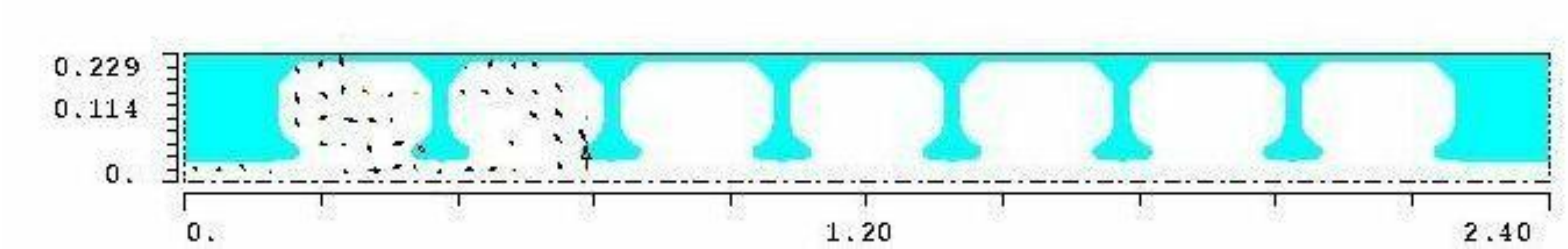
- Mechanical alignment
- BPM readings in conjunction with Beam Based Alignment (BBA), Dispersion Free Steering (DFS), emittance scans etc.etc.

Alternative idea:

- Measure directly the interaction destroying the beam quality (Hear the beam screaming …)
- For quadrupole magnets – synchrotron radiation (Any good ideas?)
- In RF structures – transverse wake fields

Wake fields in accelerating structures

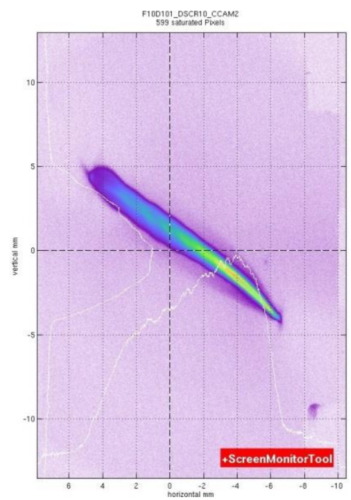
Charged particle radiate e.m. stray fields which excite resonances in the chamber



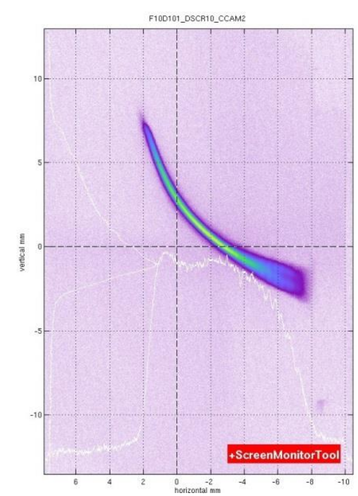
- These act back on the beam
- Directly – single bunch wakes
- Coherently adding up over a bunch train – long range wakes/HOMS

Ideal candidates for WFM: high frequency RF structures

- Here: X band structure (common development of PSI, CERN, ELETTRA)
- Part of injector (low beam energy = high sensitivity to wakes)
- linearize the longitudinal phase space for high efficiency bunch compression



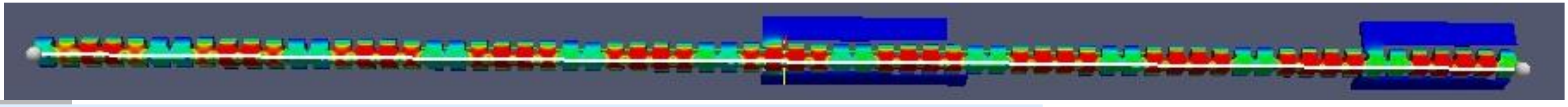
X Band on



X Band off

(measurements at FERMI@ELETTRA)

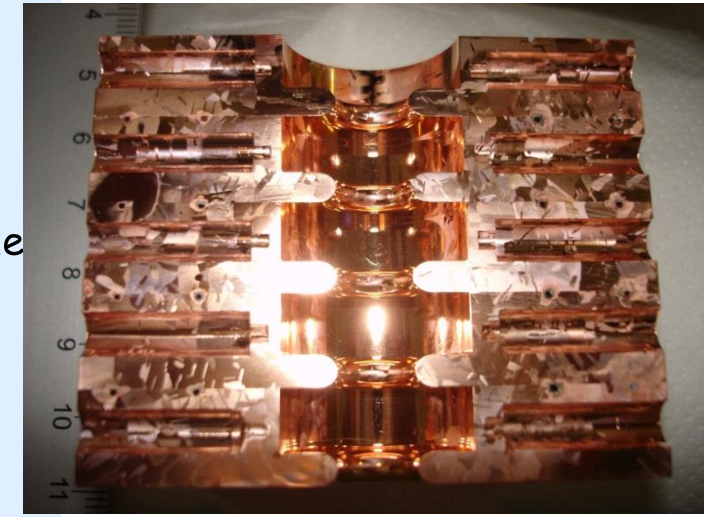
Main features



- Long constant gradient design: 72 cells, active length 750 mm
- No HOM damping
- Cooling design for 1 usec/100 Hz RF pulse
- Use 5π/6 phase advance:
  - Long cells with large mean aperture of 9.1 mm: small transverse wake
  - Intrinsically lower group velocity: Good gradient even for open design with large iris
- Wake field monitors to ensure optimum structure alignment
- Average gradient 40 MV/m (30 MeV voltage) with 29 MW input power
- Group velocity variation: 1.6-3.7%
- Fill time: 100 nsec
- Average Q: 7150
-
- In a constant impedance structure, all cells would have the same geometry, the beam would excite them at the same frequency and we would see lines in the wake spectrum.
- This is a constant gradient structure …

Above: field distribution as calculated with ACE3P

Prototype stack



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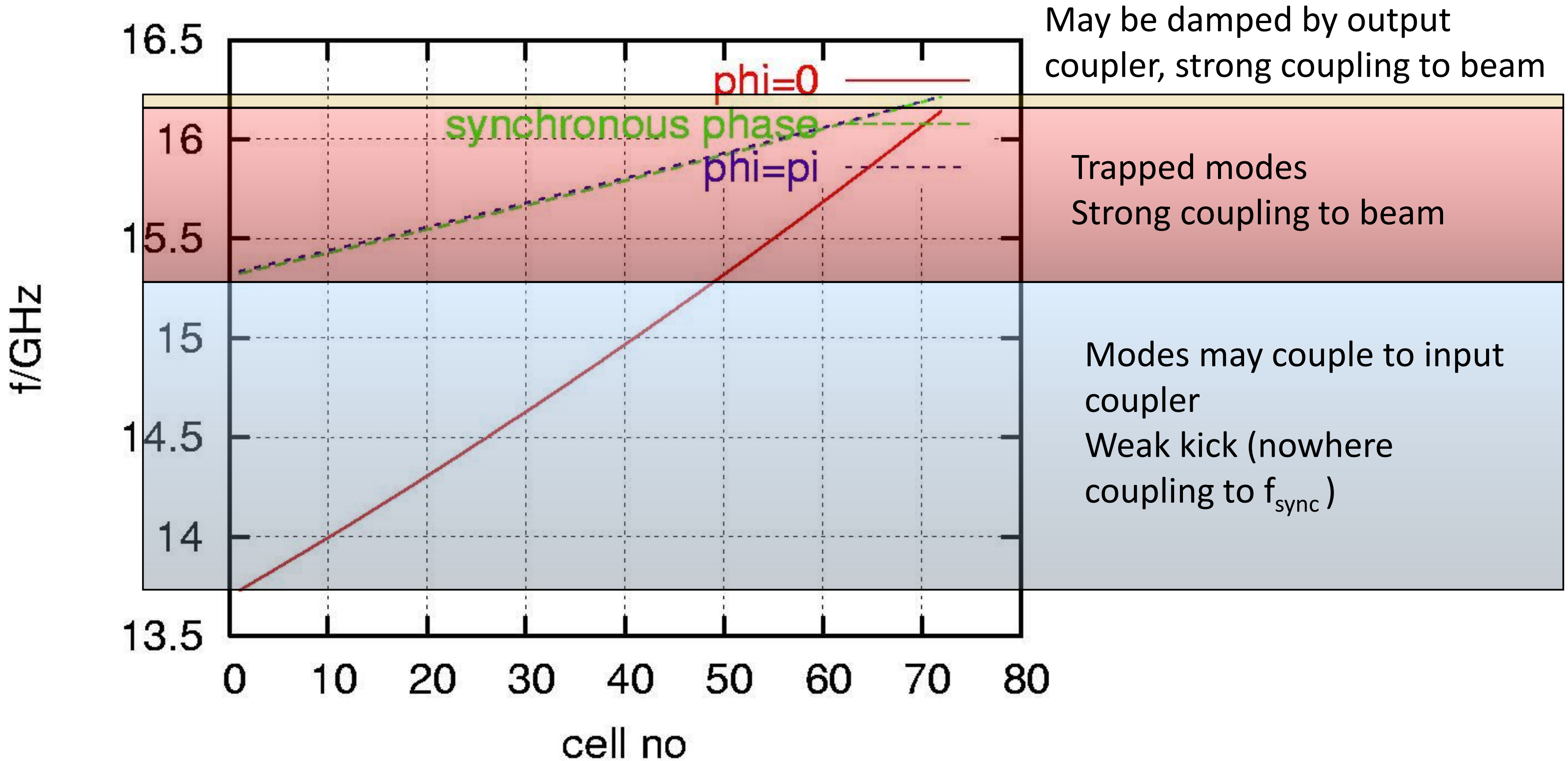
Lower dipole band limits versus cell number



- From distribution, we see distinct frequency bands

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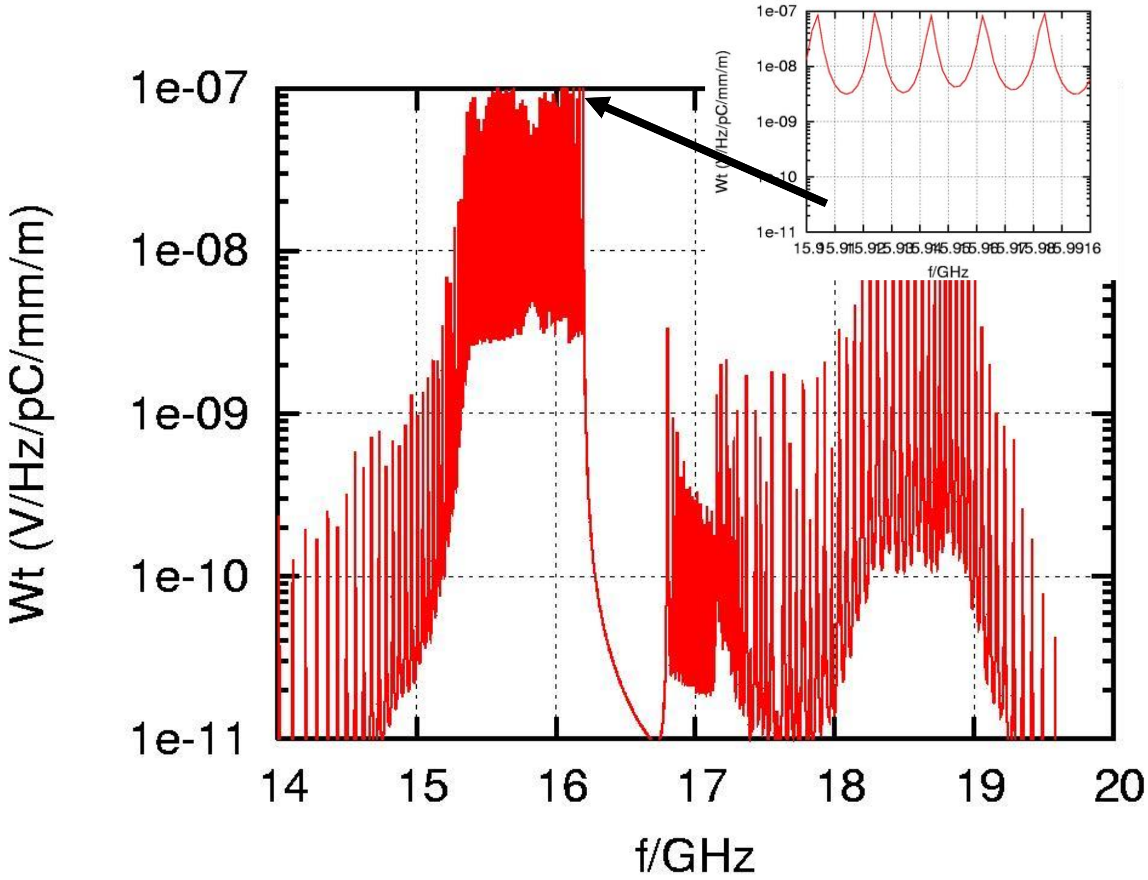
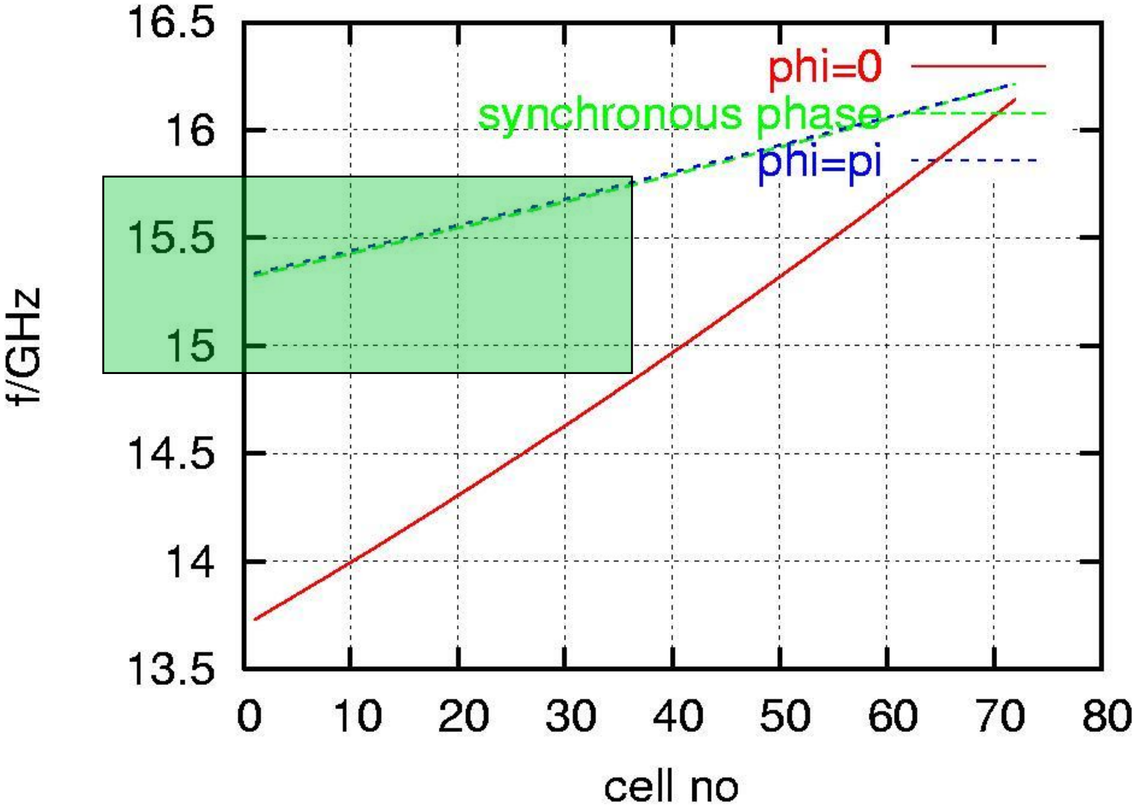
Transverse wake spectrum

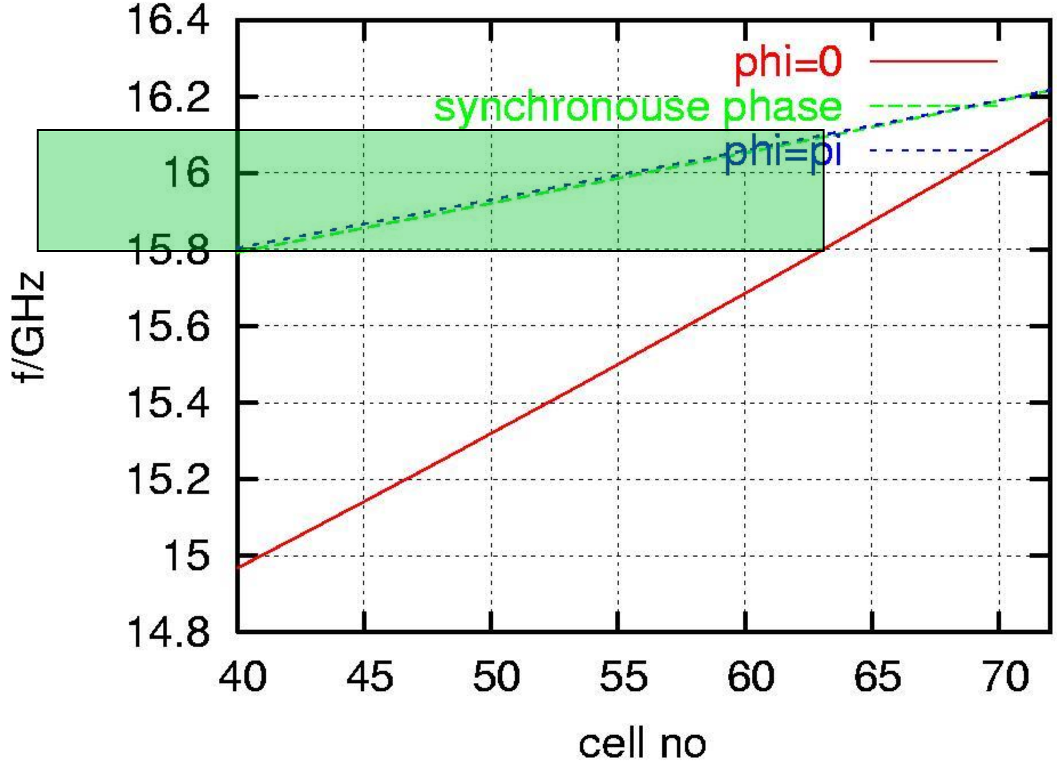


Cell 36 as upstream monitor



See contributions from the first half of the structure in the band
15.3-15.8 GHz

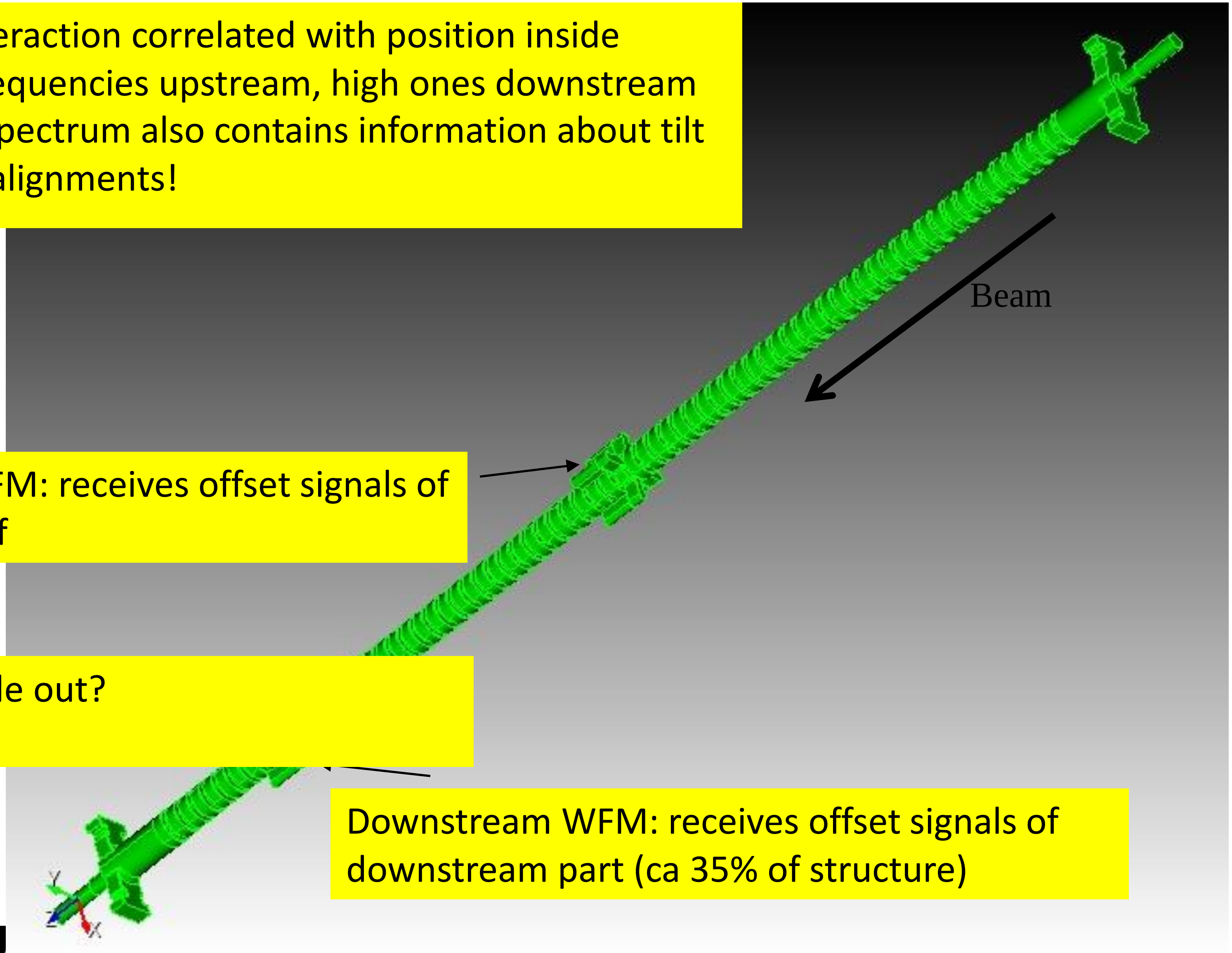
Cell 63 as downstream monitor



Restricted by bandwidth of dipole band:
Contributions from cells 40-63
Signal bandwidth 15.8-16.1 GHz

Two sets of monitors

Frequency of interaction correlated with position inside structure, low frequencies upstream, high ones downstream
Big Advantage: Spectrum also contains information about tilt and internal misalignments!



Upstream WFM: receives offset signals of upstream half

How to couple out?

Downstream WFM: receives offset signals of downstream part (ca 35% of structure)

Pickup geometry

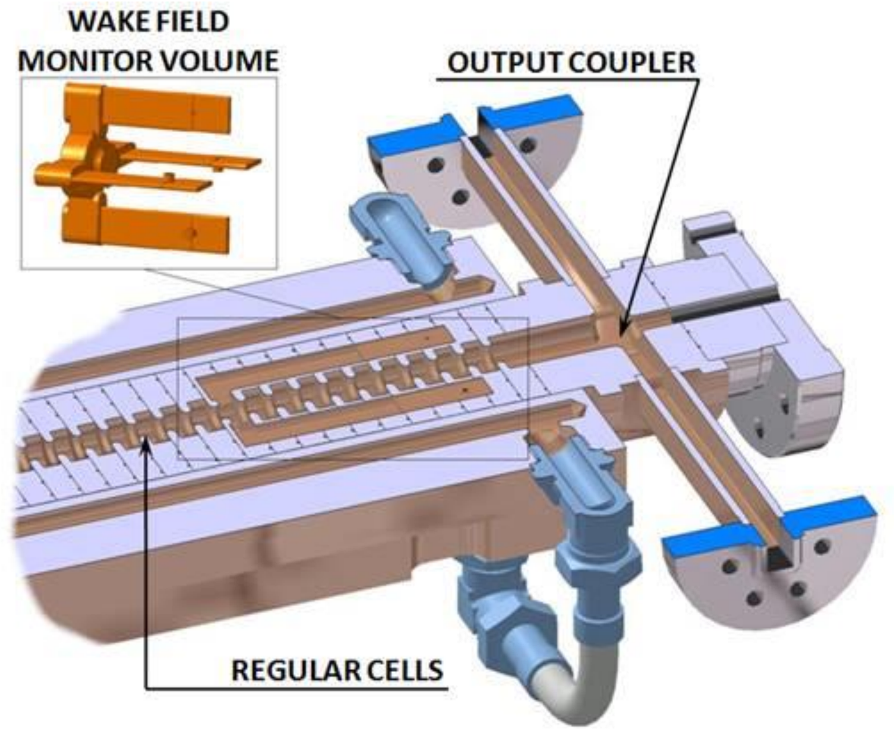
Goal: Extract transverse wake signals (uW-mW), while not getting drowned in fundamental power (tens of MW) and longitudinal HOMs

TE type coupling rejects by symmetry signals from TM type fundamental mode and longitudinal wakes

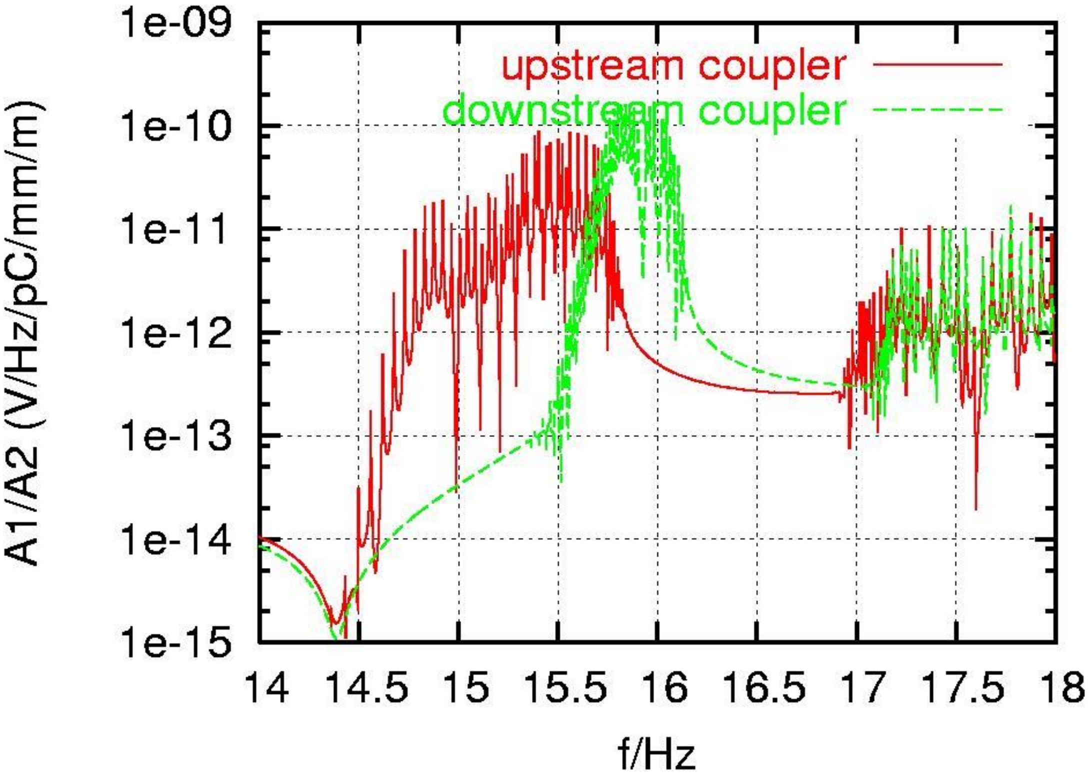
Need only small coupling (Qext<1000) to transverse dipoles for sufficient signal, minmum perturbance of cell geometry and minor loss in fundamental performance: 10% in Q, <2% in R/Q

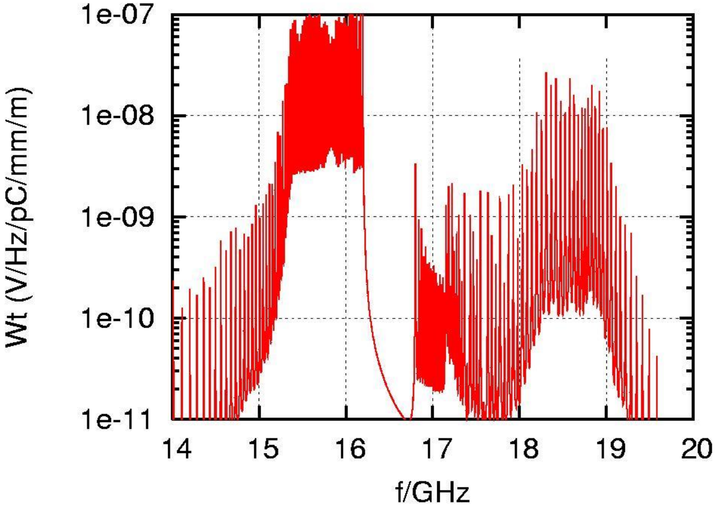
Output wave guides with coaxial transition connecting to measurement electronics

Big advantage: Even accounting for mechanical tolerances, extremely strong suppression of longitudinal signals – precondition for ultra high sensitivity measurements!!



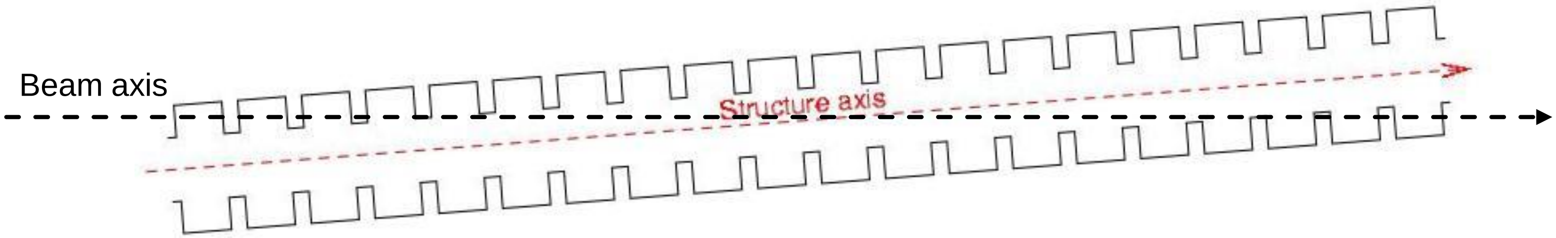
Simulated WFM signal spectra

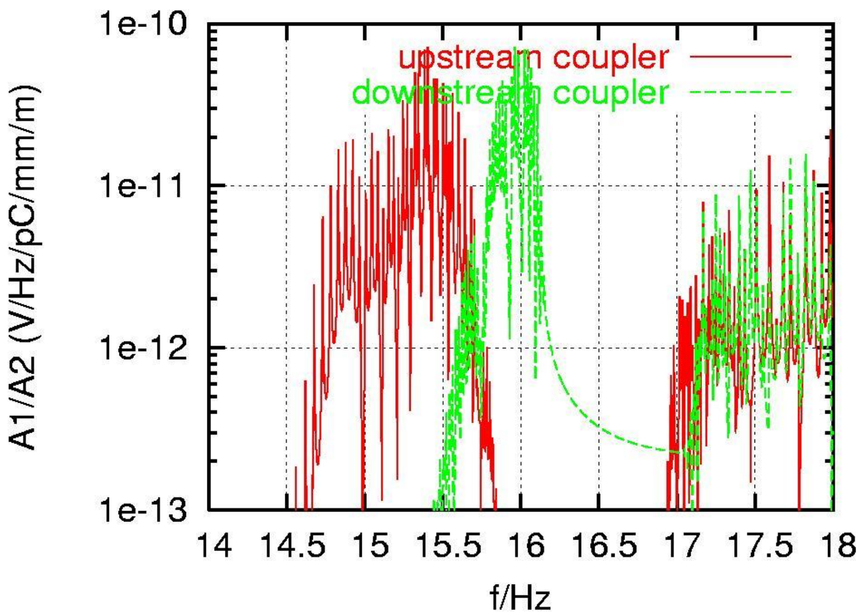




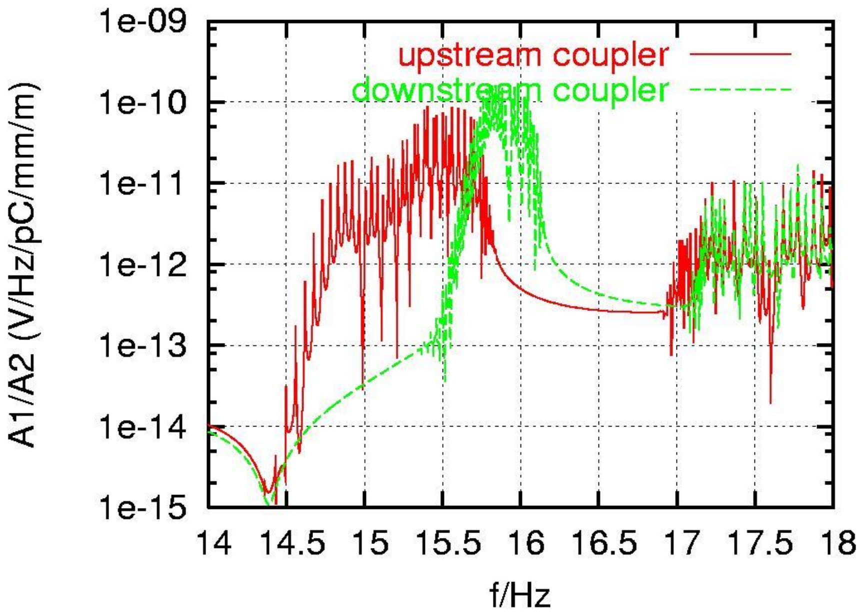
Dipole wake spectrum

Distinct pattern of structure tilt vs offset





Tilted

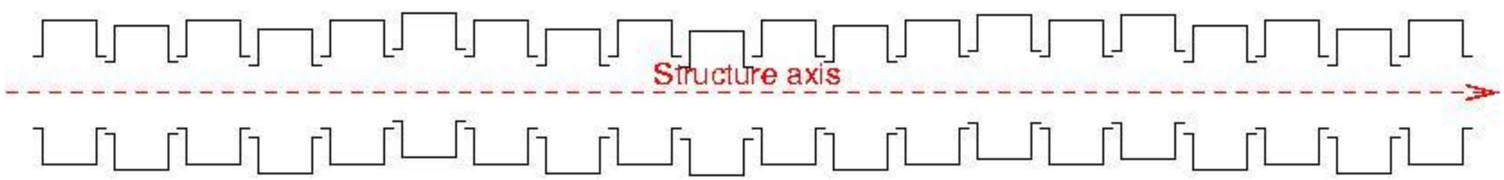


Offset

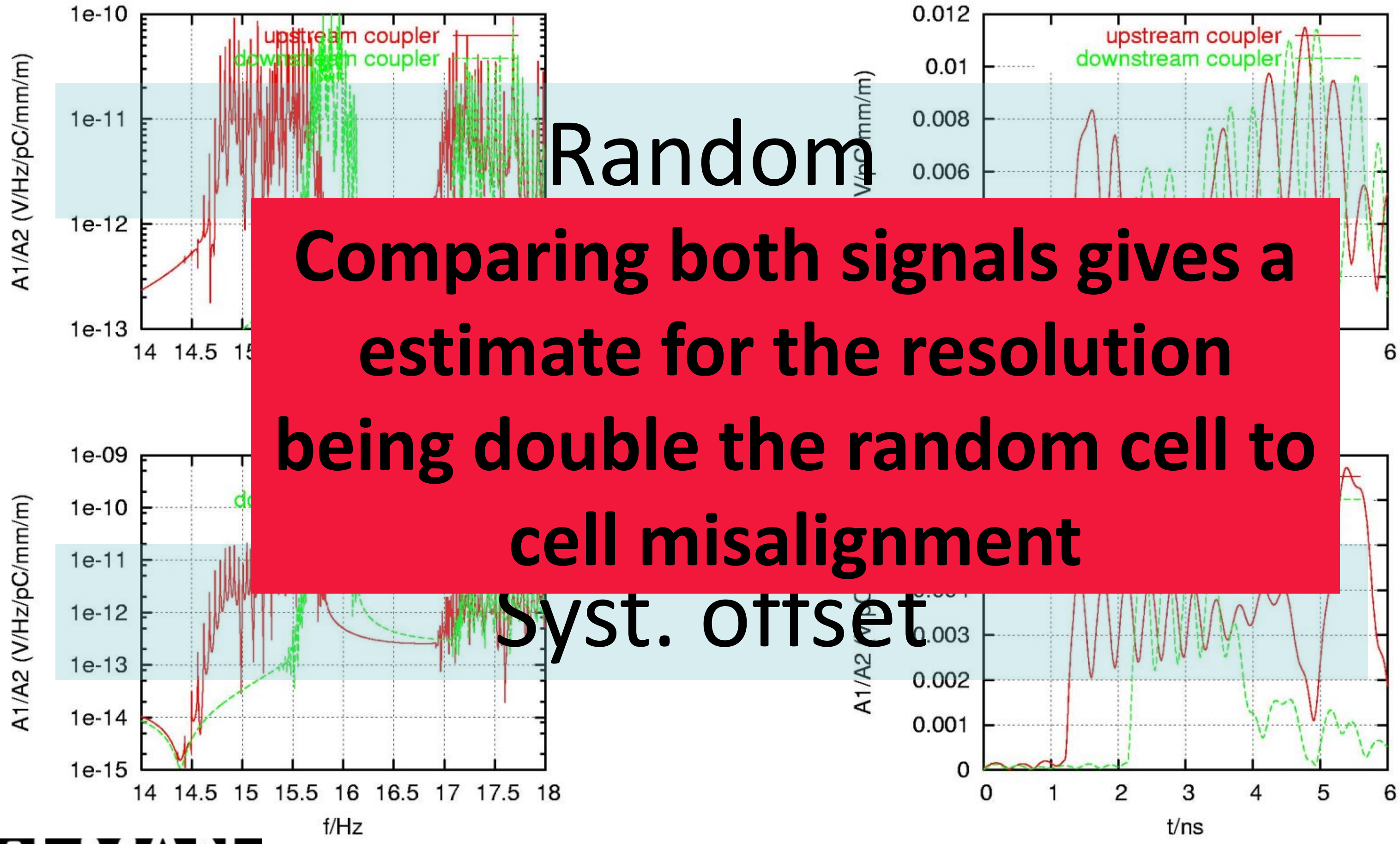
Expected Resolution

Dilution by

- Noise in RF front – only an issue for low bunch charges
- Spurious signal from fundamental, longitudinal wakes - negligible due to TE coupling, waveguide length
- Random misalignment of individual cells:



Comparing random misalignment systematic offset



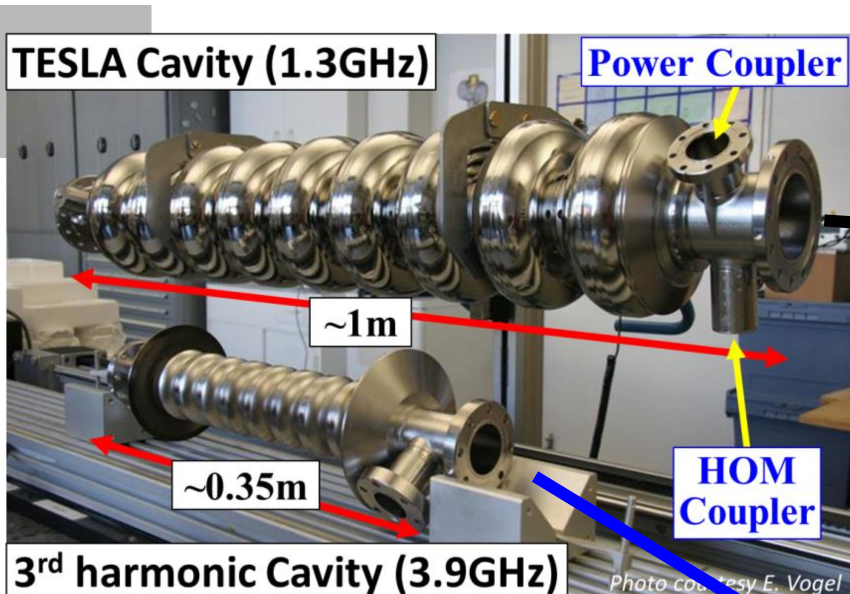
Random

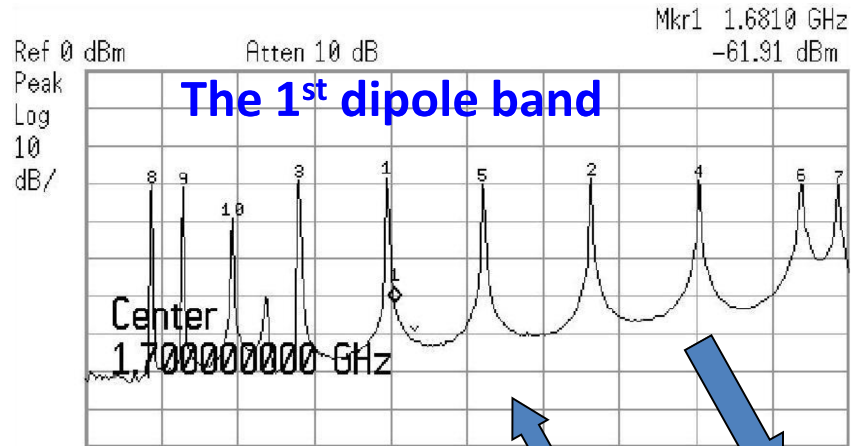
Comparing both signals gives a estimate for the resolution being double the random cell to cell misalignment

Syst. offset

... another WFM project at EXFEL using existing HOM couplers of SC RF structures

(Slide court. N. Baboi)



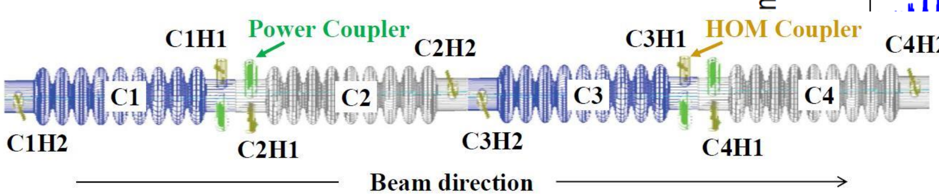


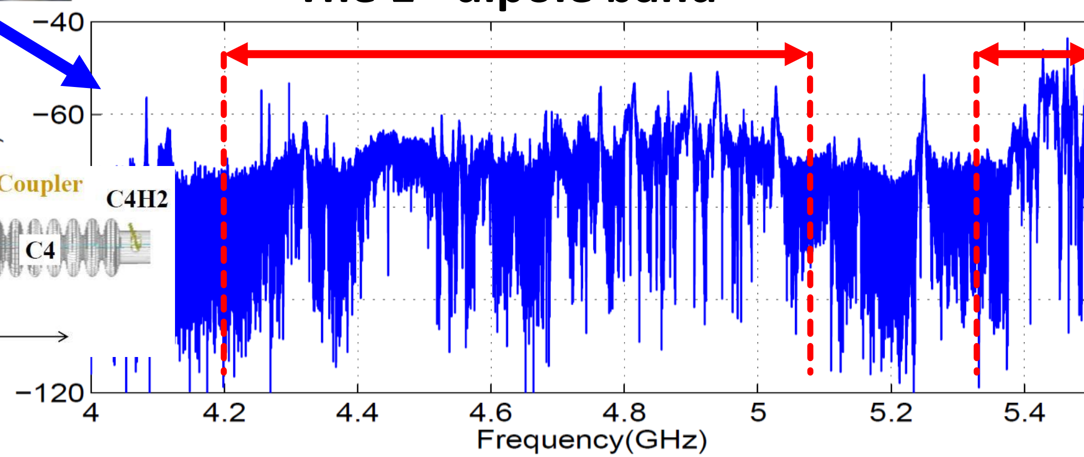
HOMBPM

The 2nd dipole band

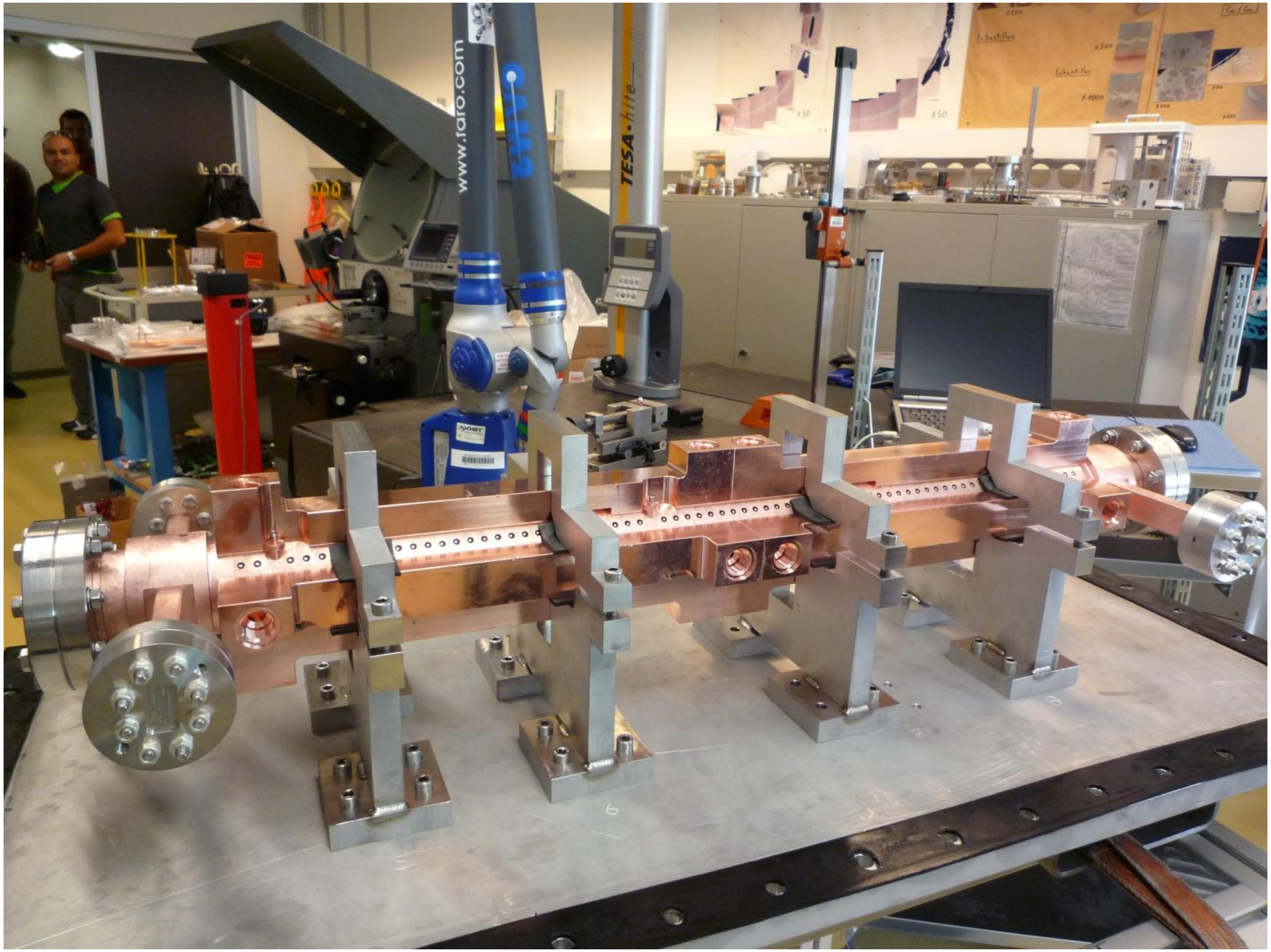
The 1st dipole band

Coupled cavities





Structure before vacuum bake out



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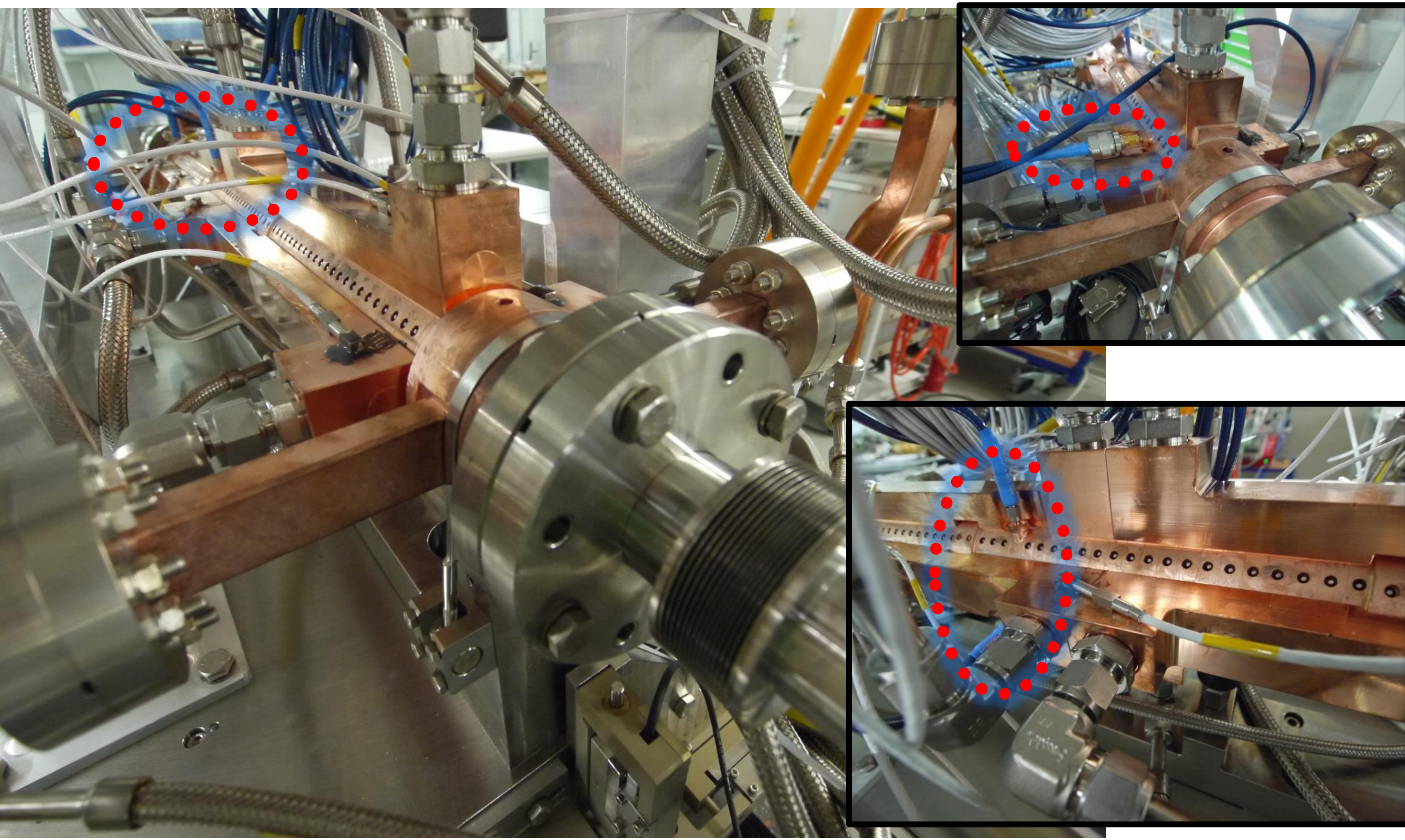
Close view of the structure



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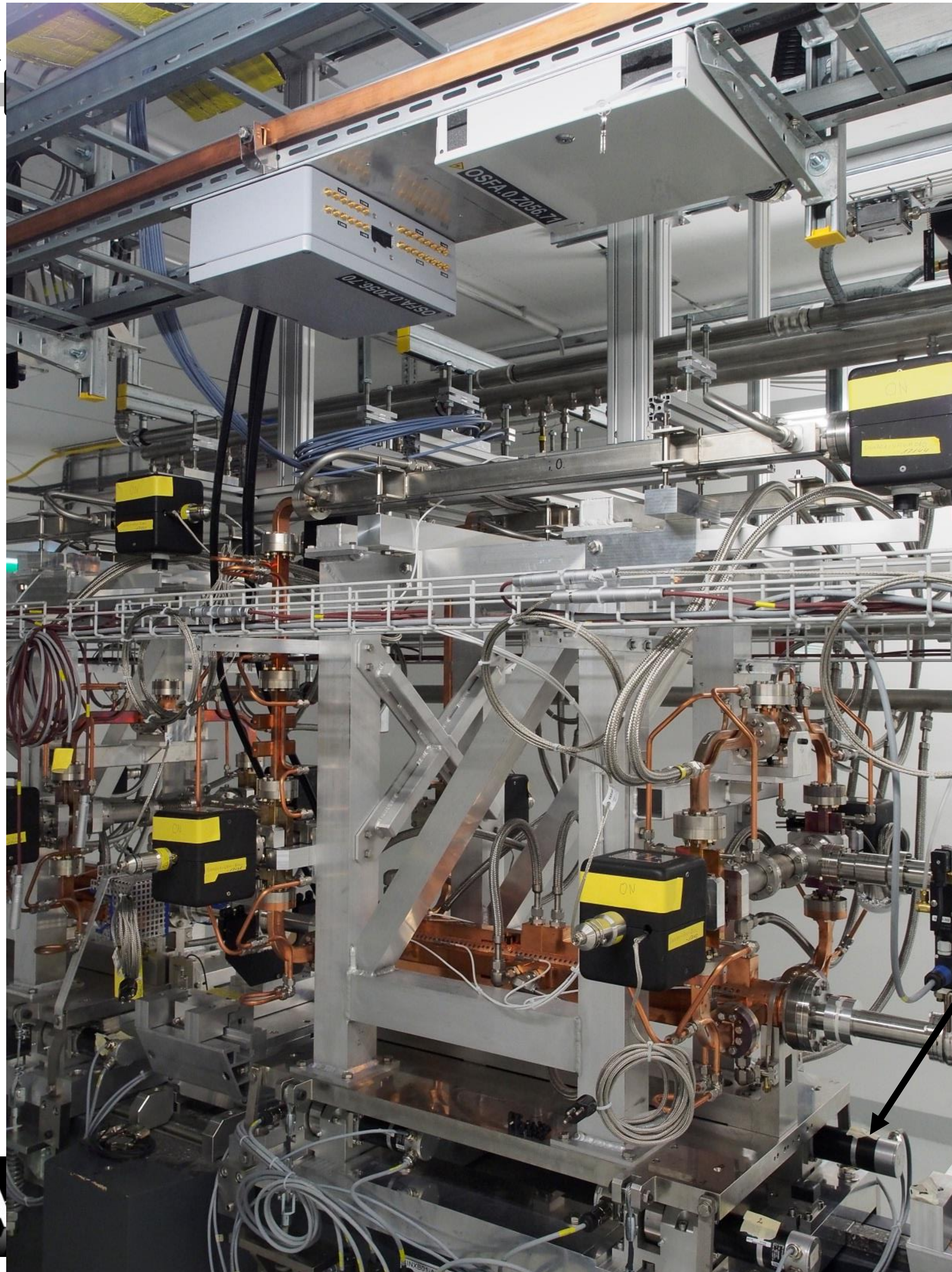
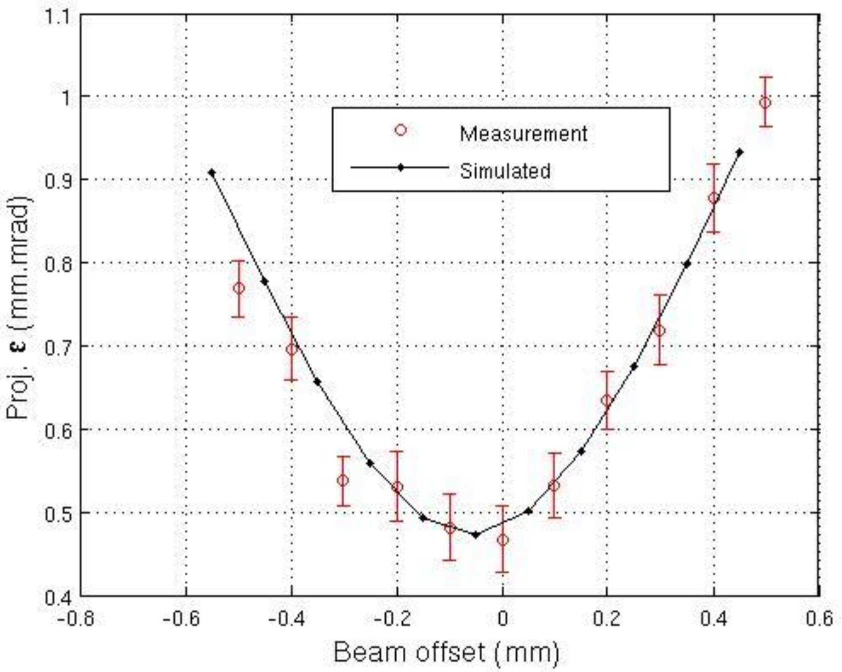


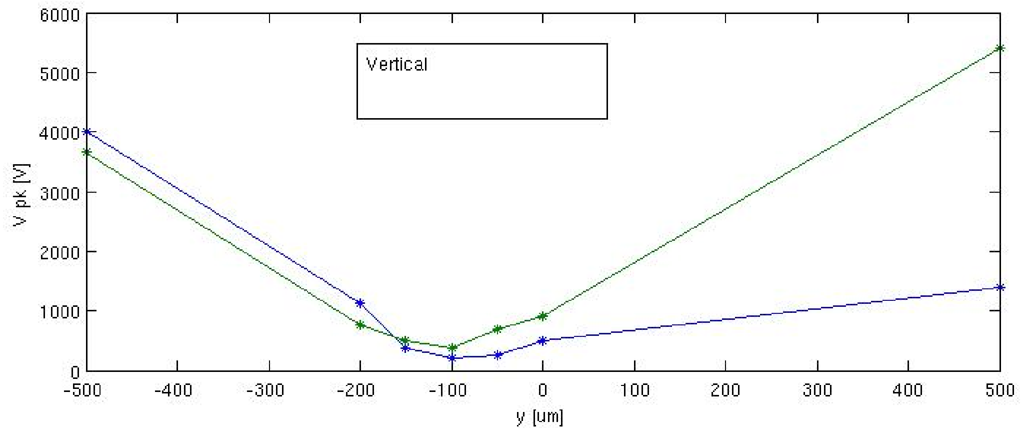
Structure installation inside SwissFEL tunnel

Mover stage for structure

Beam Measurements:
Are WFM readings a direct indicator of beam quality?



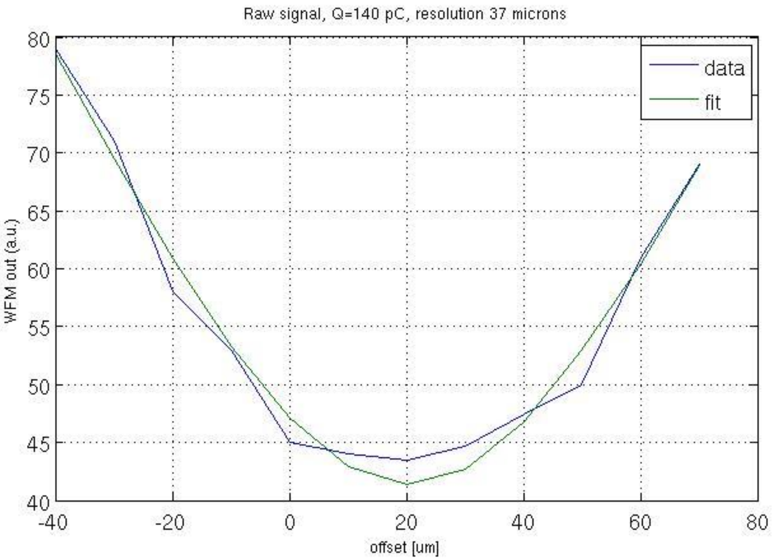
Scan of vertical emittance

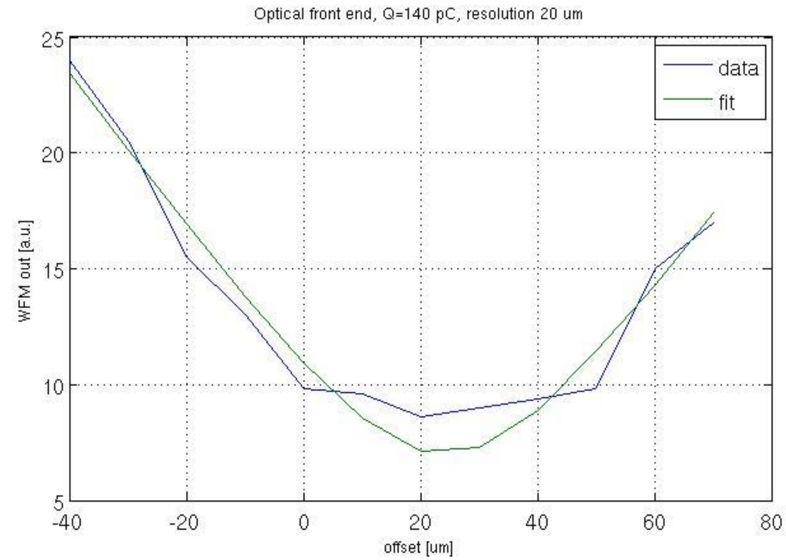


Amplitude of WFM raw signal
(Yes, it’s quite noisy!)

Quadratic fit gives minimal emittance for offset y = -75 um
(WFM predicts minimum at -100 um)

Resolution: state September 2014
(shutdown of SITF)



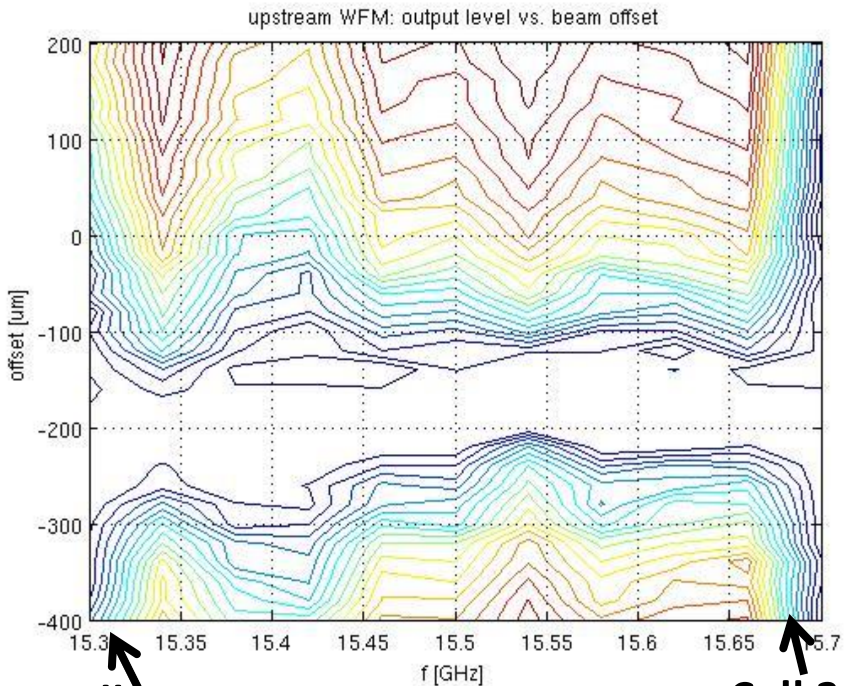


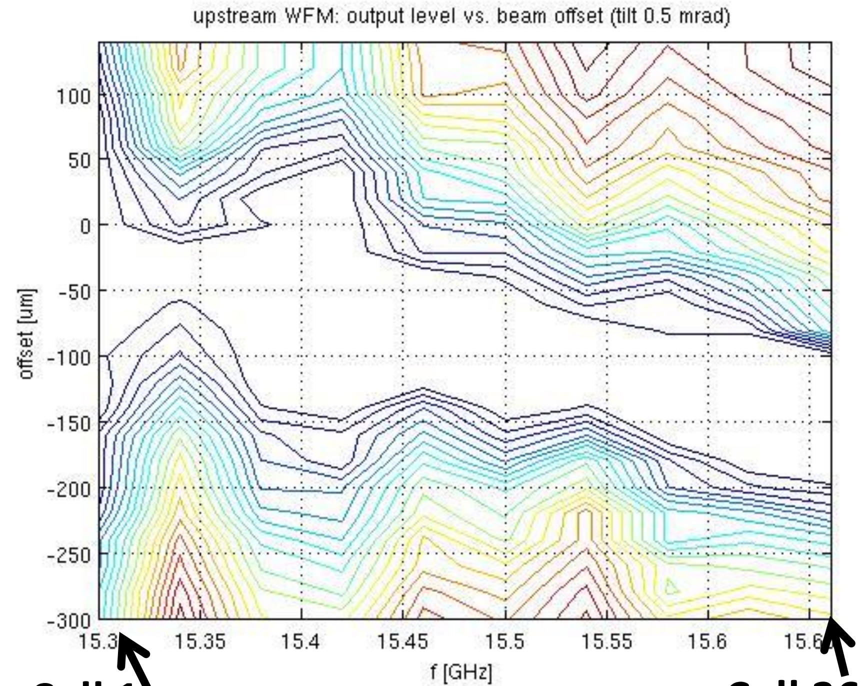
Comparison of system resolution, bunch charge 140 pC (nominal would be 200 pC)

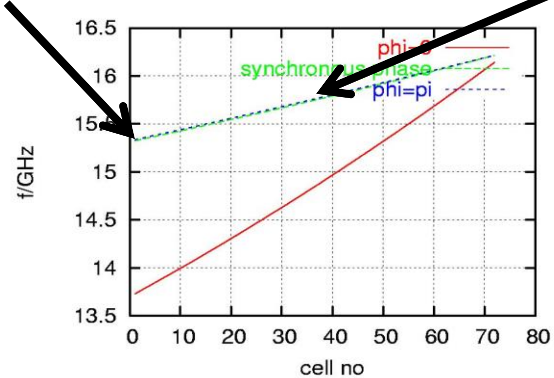
- Read out of raw signals via high speed scope, nominal 8 bit, ENOB ~ 6.5 bit, gives a resolution of 37 µm
- Optical front end (Laser/EOM/PD), read out via scope with electronic band width limitation resulting in resolution enhancement (ENOB ~ 9 bit), gives resolution of 20 µm
- Results deteriorated by bunch to bunch charge jitter and drift and mechanical hysteresis effects

BUT – important: scaled to 200 pC, EOM resolution of ~ 14 µm

Offset vs. tilted structure: Frequency scan with basic front end







(Rather noisy) frequency scan with narrow band filter (BW 10 MHz):

- Frequencies correspond to locations inside structure given by green sync. phase line shown left
- Location of minimum versus frequency shows tilts (and bends, kinks …) → advanced diagnostics may show structure defects

Summary

- **Wake field monitor as a versatile device:**
  - Beam position, beam trajectory alignment
  - Higher order misalignments (e.g. tilts)
  - Structure defects as kinks, bends
- **Special feature of presented solution:** Pickup explicitly designed as WFM, not parasitic use of HOM couplers as WFM devices like at CAS experiments or EXFEL device
- **Current state**
  - Within EuCARD-2 development of front end
    - Electro-optic signal transport and down conversion
    - Wide band system possibly suitable for other applications
  - Expecting tests of prototype system with beam in SwissFEL injector this summer
    - More precise measurements of offsets and tilts, hoping to approach principal resolution limit.
    - Spectral scan mode: Will we see details in internal alignment of structure?