PAUL SCHERRER INSTITUT

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Wake field monitors in a multi purpose X Band accelerating structure

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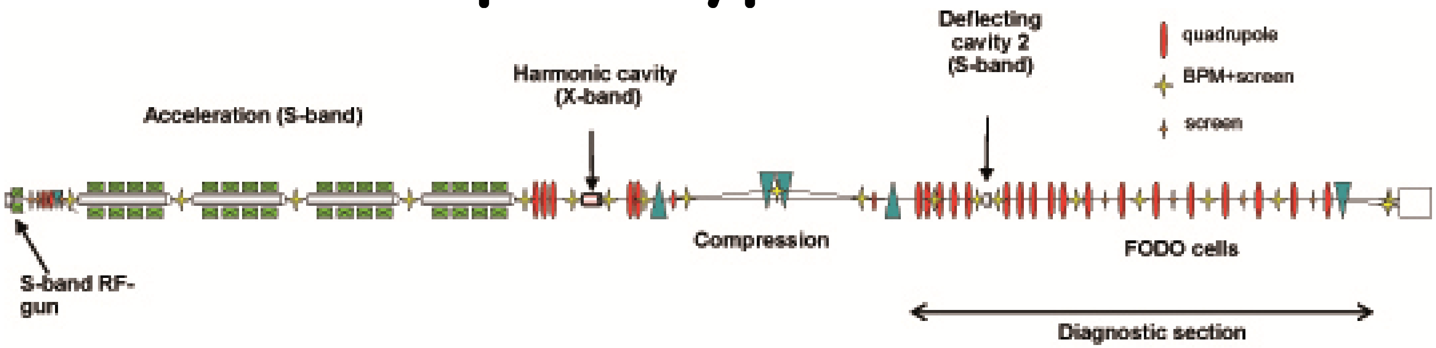
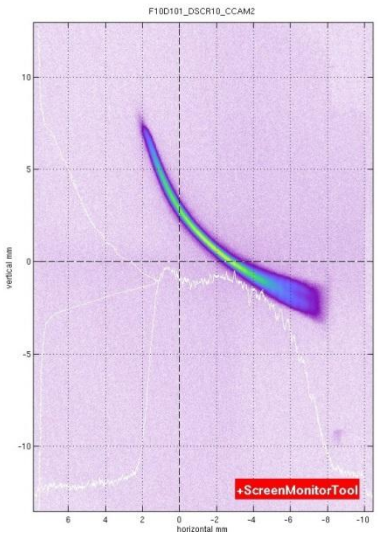
- Introduction
- WFM Basics
- Characterization with Beam
- Summary and Outlook

Introduction

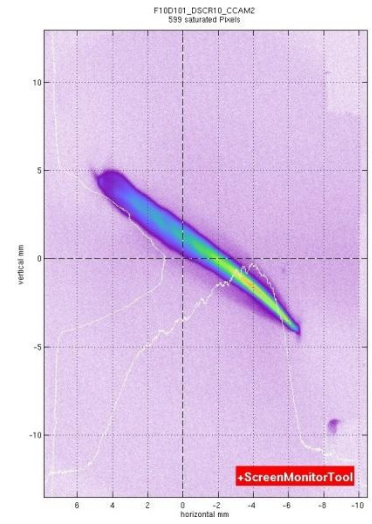
SwissFEL test injector SITF: A prototype testbed



X band structure (common development of PSI, CERN, ELETTRA) to linearize the longitudinal phase space for high efficiency bunch compression

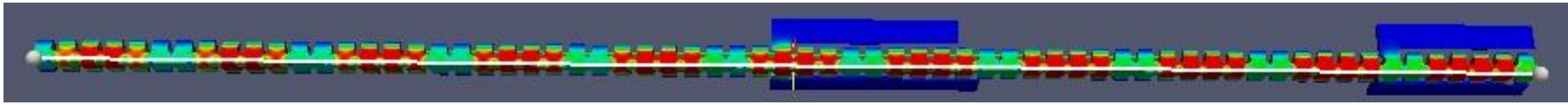


X Band off



X Band on

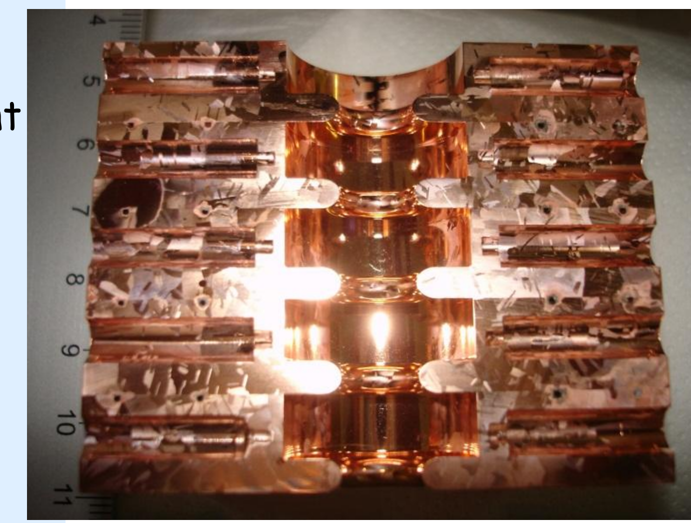
Main features



- Long constant gradient design: 72 cells, active length 750 mm
- No HOM damping
- Cooling design for 1 usec/100 Hz RF pulse
- Use $5\pi/6$ 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

Above: field distribution as calculated with ACE3P

Prototype stack



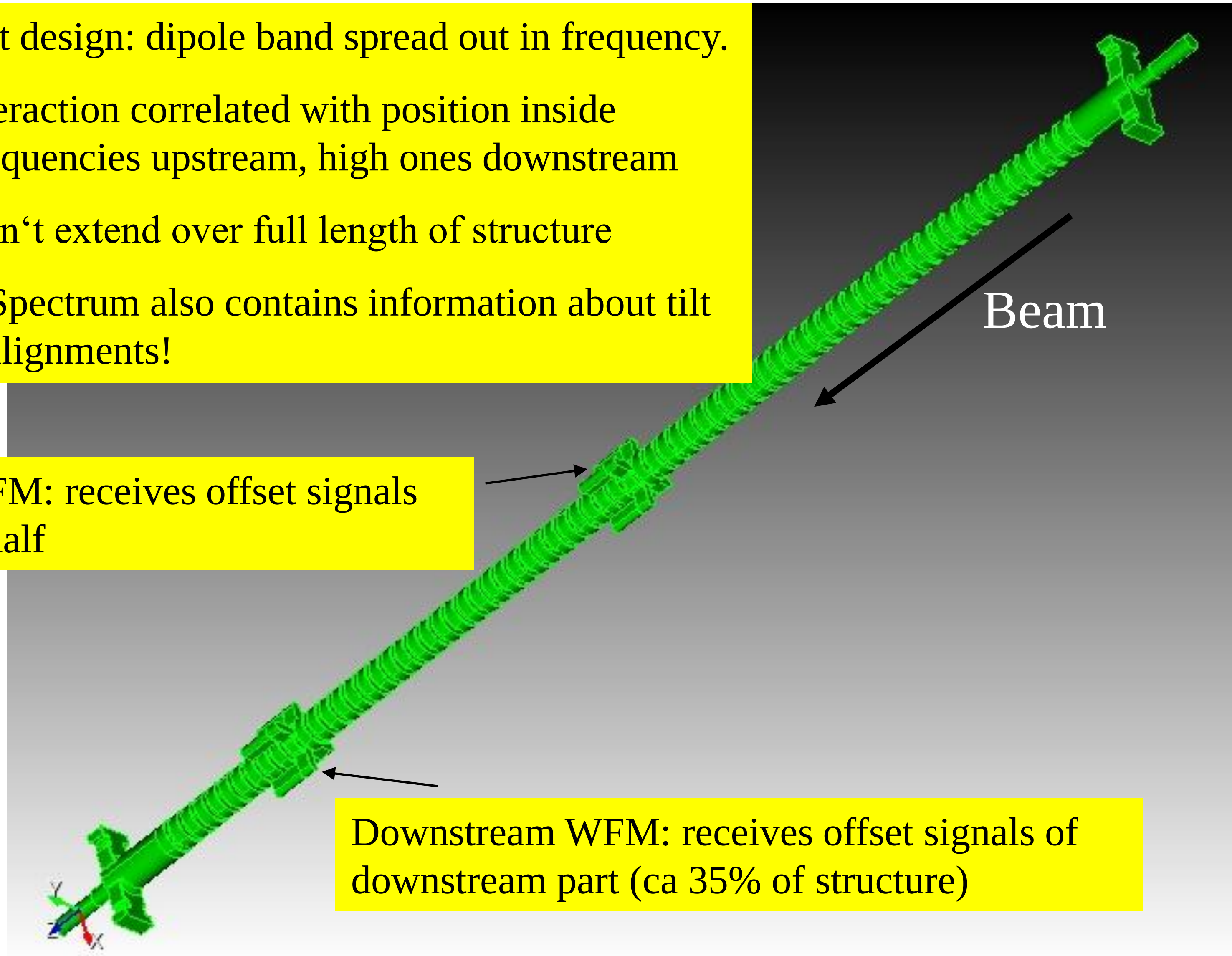
WFM Basics

Constant gradient design: dipole band spread out in frequency.

Frequency of interaction correlated with position inside structure, low frequencies upstream, high ones downstream

Dipole modes don‘t extend over full length of structure

Big Advantage: Spectrum also contains information about tilt and internal misalignments!



Upstream WFM: receives offset signals of upstream half

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

Pickup geometry

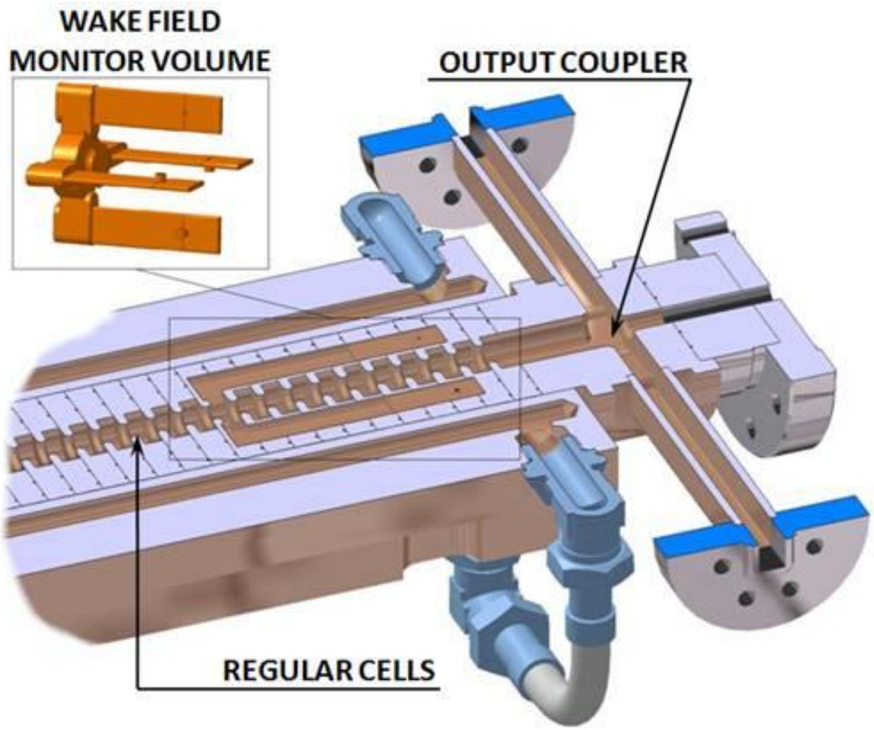
TE type coupling minimizes spurious signals from fundamental mode and longitudinal wakes

Need only small coupling (Qext<1000) for sufficient signal

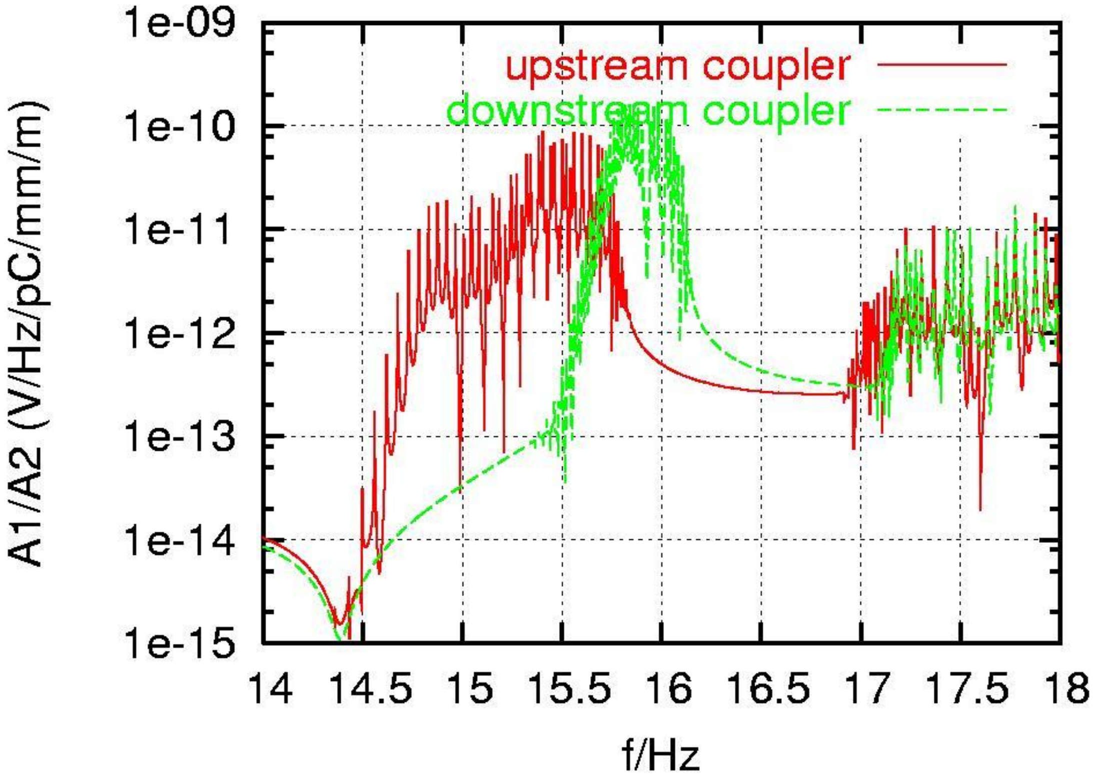
Minor loss in fundamental per- formance: 10% in Q, <2% in R/Q

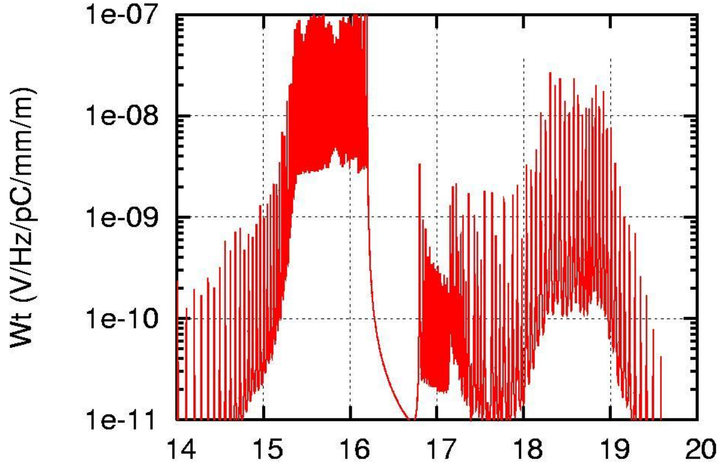
Output wave guides with coaxial transition connecting to measurement electronics

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



Output signal spectra





Dipole wake spectrum

Selective TE type coupling to internal dipole bands gives pure position dependent signal – like ideal BPM pickup, **but:**

- Signal is directly proportional to an effect degrading the beam: ensures optimum structure alignment as opposed to indirect methods as e.g. measuring the beam emittance
- Showing not only offsets but also errors in roll and pitch of the structure
- Giving information about internal alignment errors due to random offsets or bends

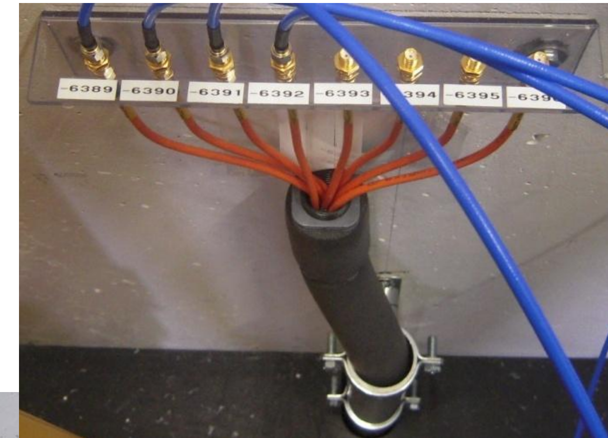
Characterization with Beam

Beam was set to golden orbit. Structure was moved (instead of beam) using the mechanical mover system to have clear picture of emittance dilution.

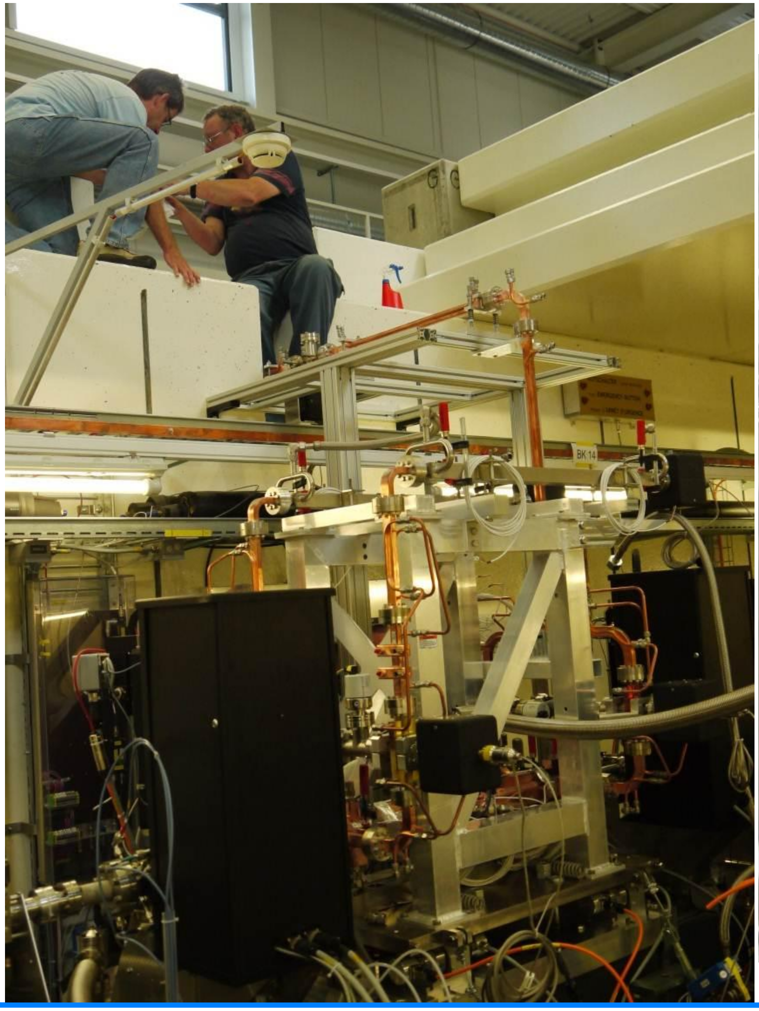
Two scopes were used, LeCroy SDA816zi digital scope (18 GHz BW, 40 GS/sec) and LeCroy 9 Zi-A (45 GHz, 120 GS/sec), on rent.

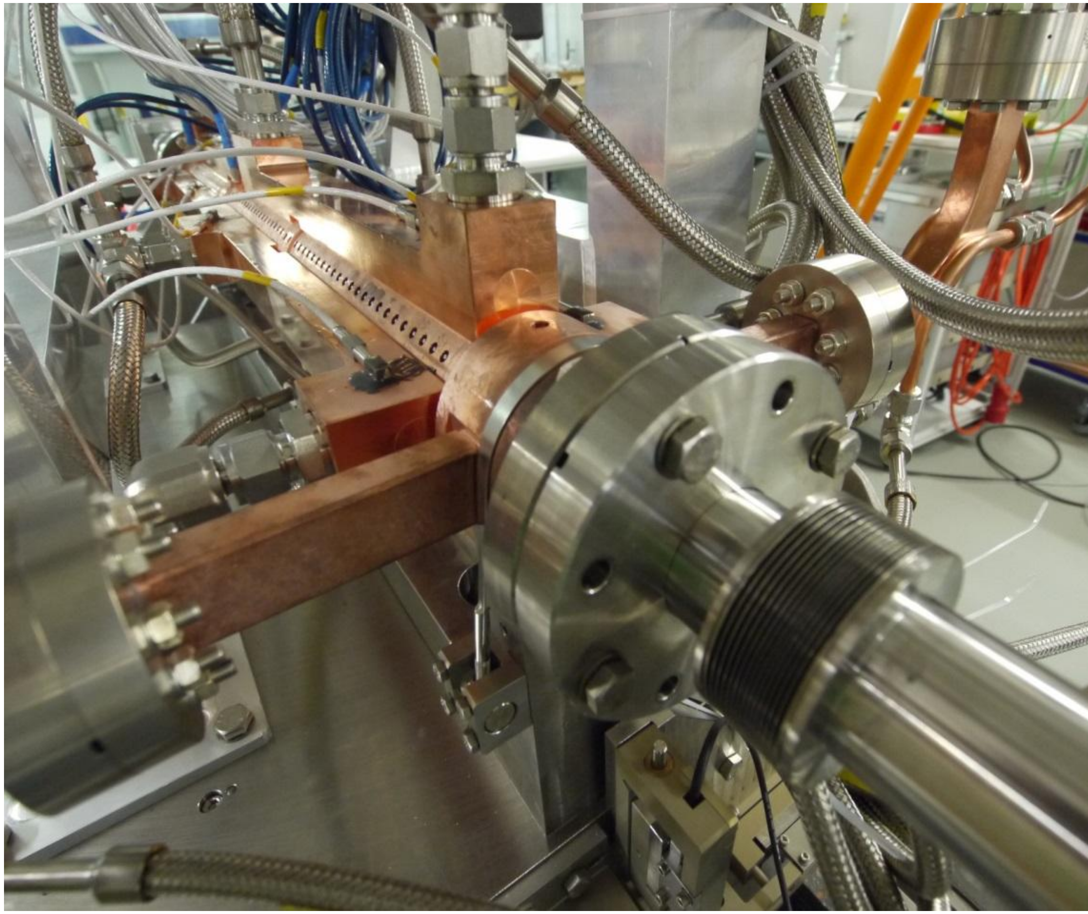
Questions:

- Signal spectra and amplitudes
- Wide bandwidth response
- Any longitudinal bands visible (as indication of internal tolerances)?
- Leakage of klystron power into monitors
- WFM predicts optimum position w.r.t. emittance dilution?

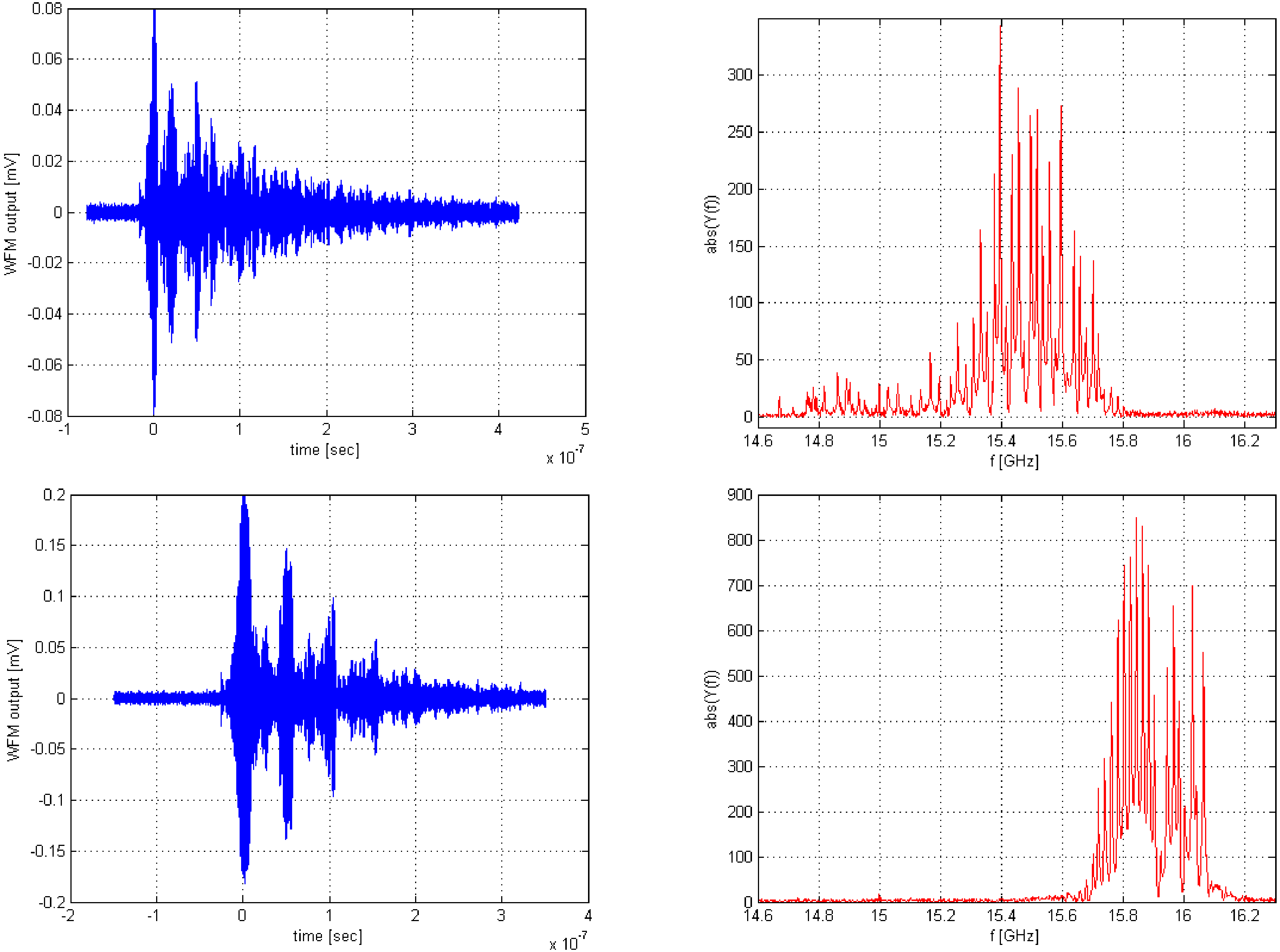


Impressions from the installation

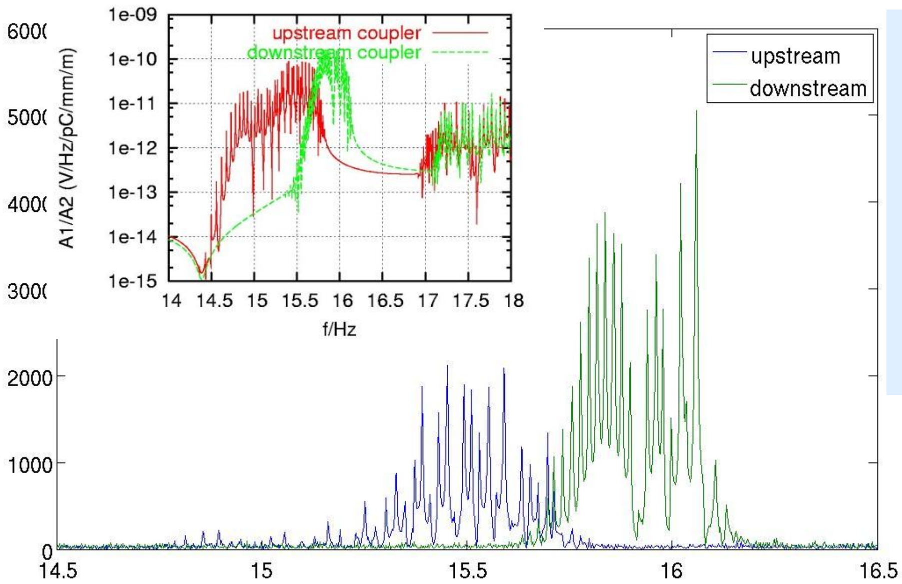




Typical signal output



Signal spectra



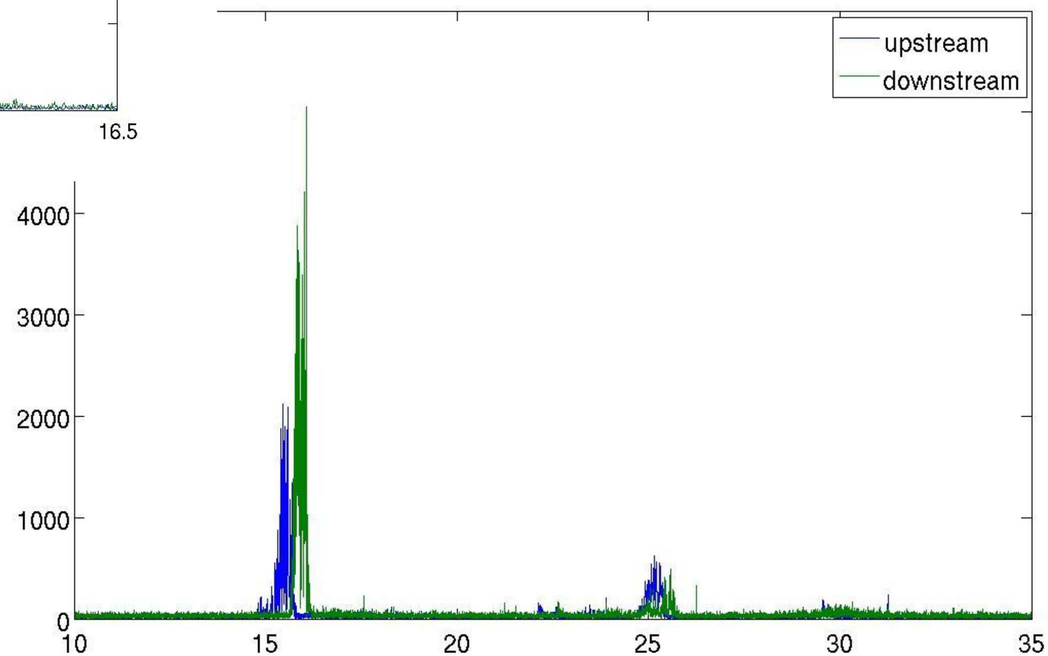
Spectral response in the measurement band as theoretically predicted

Wide Band spectrum (below) shows additional strong bands at 25 and 30 GHz (out of spec for cables, feedthroughs etc....)

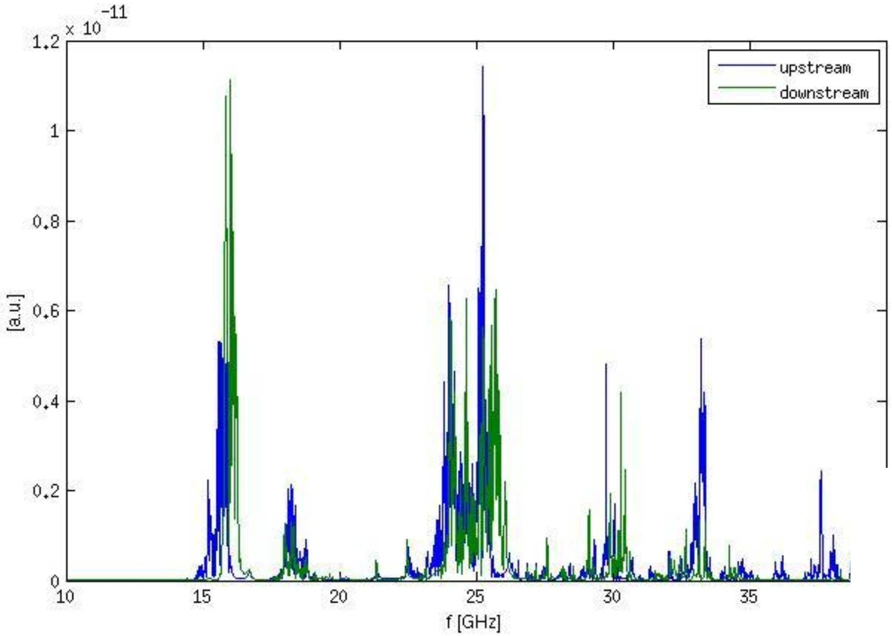
Single cell calculation show

- Monopole (longitudinal) modes near 12, 24 26.5, 30 GHz
- Dipole modes near 15.6, 18.5, 24.1, 26.8, 31 GHz

Which is which in the signal?

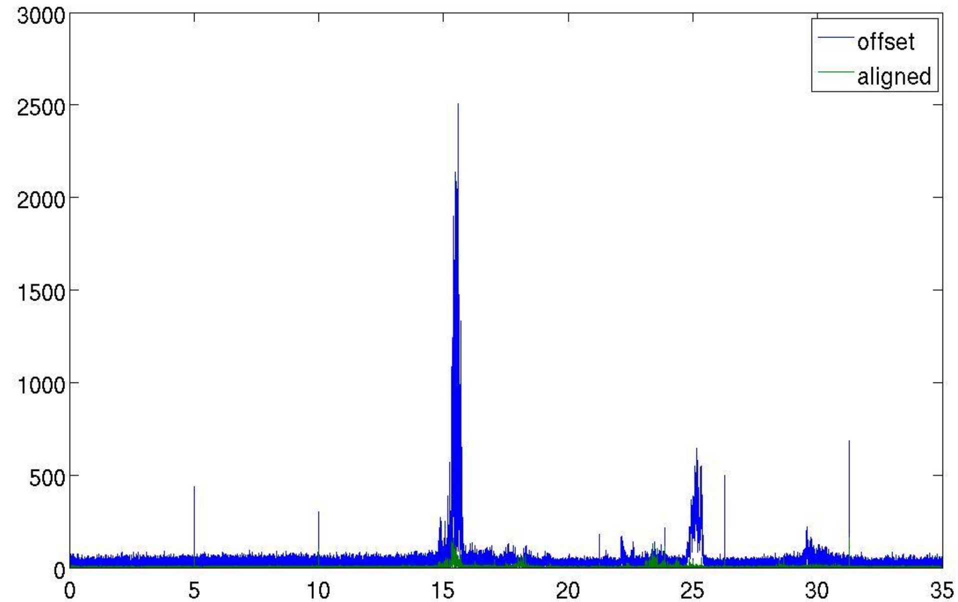


Signal spectra (contd.)



Simulation results with GdFidL:

- Discretization with 50um resolution, 9.3 billion meshpoints
- 2 weeks CPU time on cluster with 6 nodes (8 Xeon CPUs, 48 Gbyte RAM each)
- Confirm bands at 25/30 GHz



Comparing signal spectra of well aligned and offset structure gives the same answer:

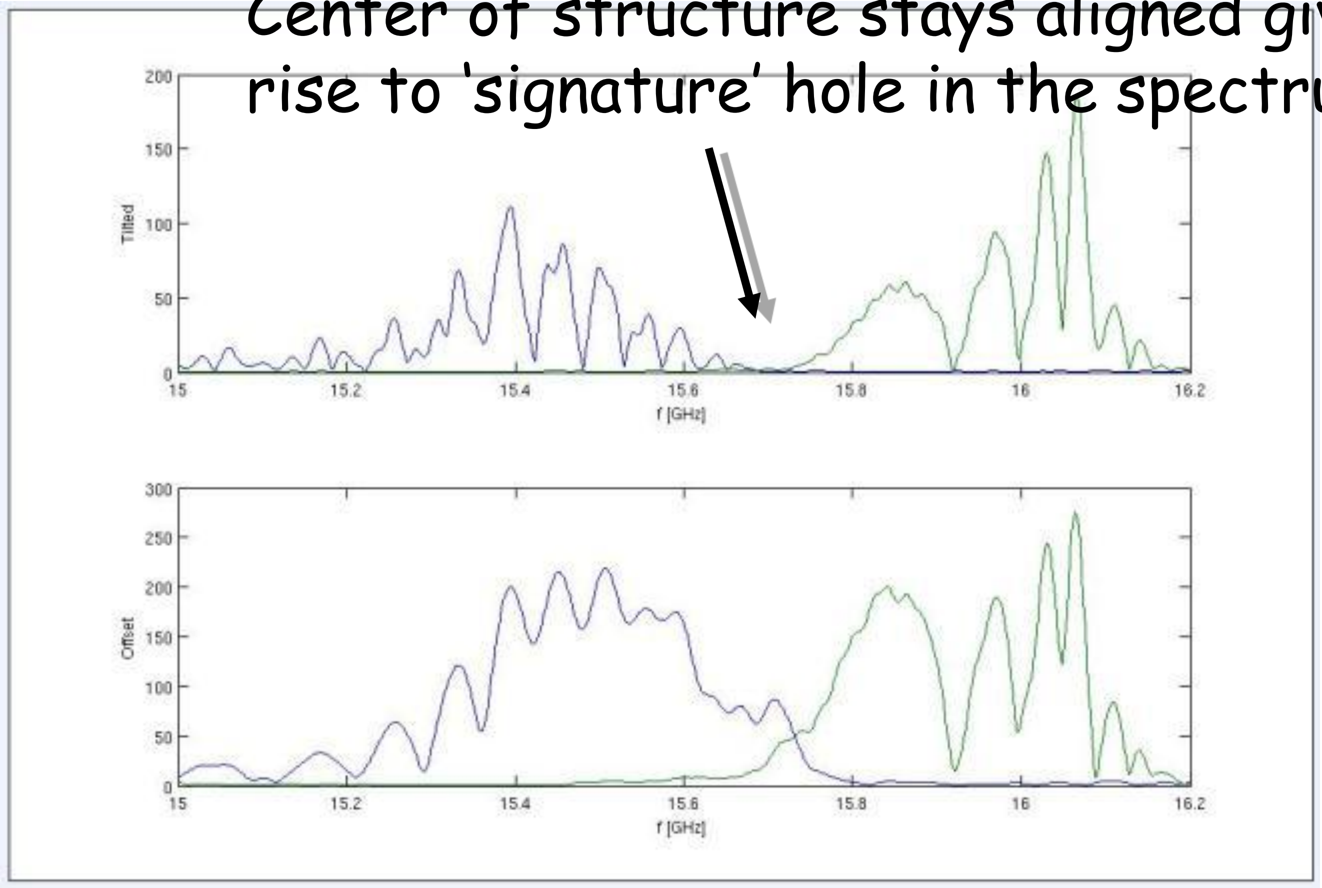
- Bands are position dependant, so are dipoles!
- Proves, that even very high frequency longitudinal wakes are getting rejected due to symmetry

WFM spectrum (smoothed) of horizontal tilt (flight angle) as compared to offset:

Center of structure stays aligned giving rise to 'signature' hole in the spectrum

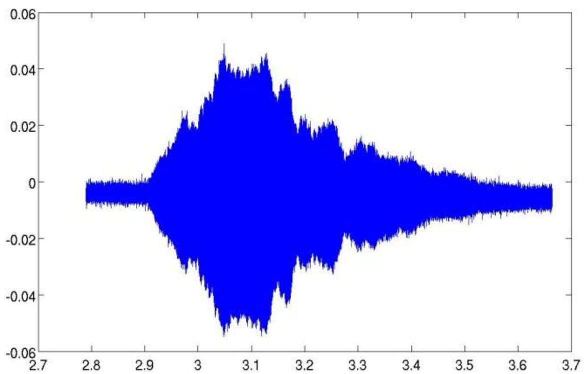
Tilted

Offset

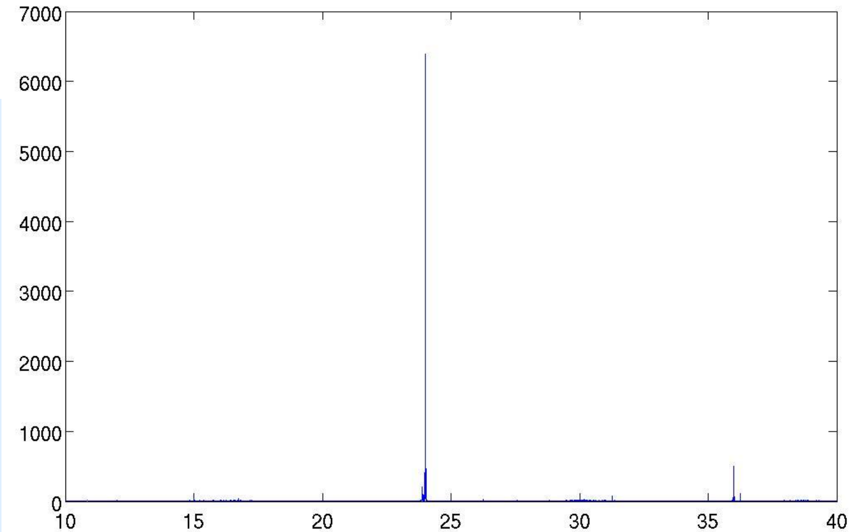


In principle, the spectrum also contains information about bends and random internal misalignments, but current setup is too noisy....

Residual signals



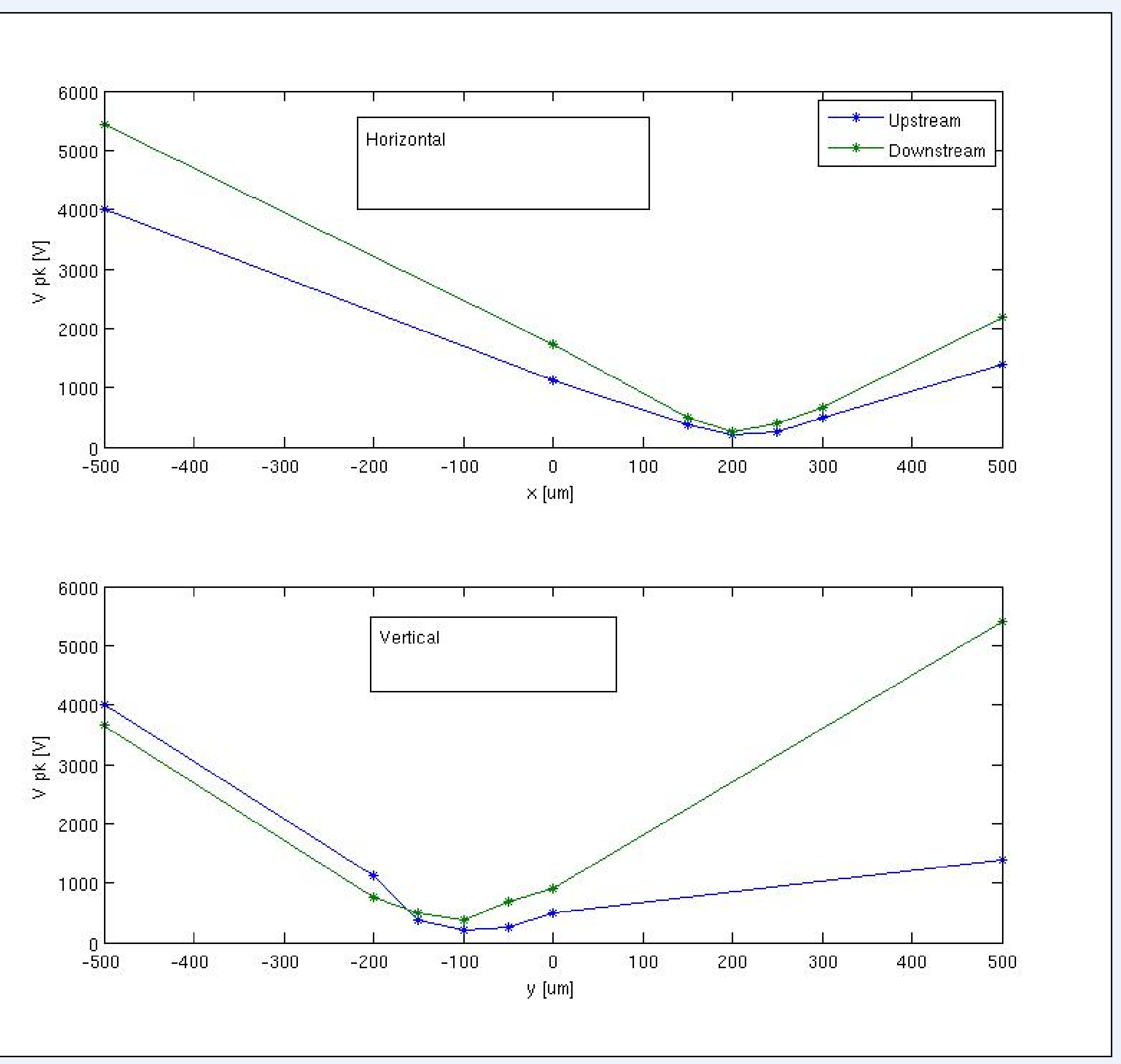
Signal without beam shows residual signal coming from X Band RF system (taking account of cable attenuation level ~ 1 V at WFM output)



FFT of signal shows:

- No trace at all of the 20 MW fundamental mode power, which means rejection by WFM in the excess of 130 dB (Making me really happy!)
- Despite considerable attenuation by the 8 m cable quite a bit of signal at 24 and 36 GHz harmonics, probably coming from klystron (or field emission in the structure?).
- 24/36 GHz far in the overmoded regions: cannot say anything about real power level inside and near structure
- Signals could spell trouble for BAM nearby (how about C Band klystrons?)

Sensitivity

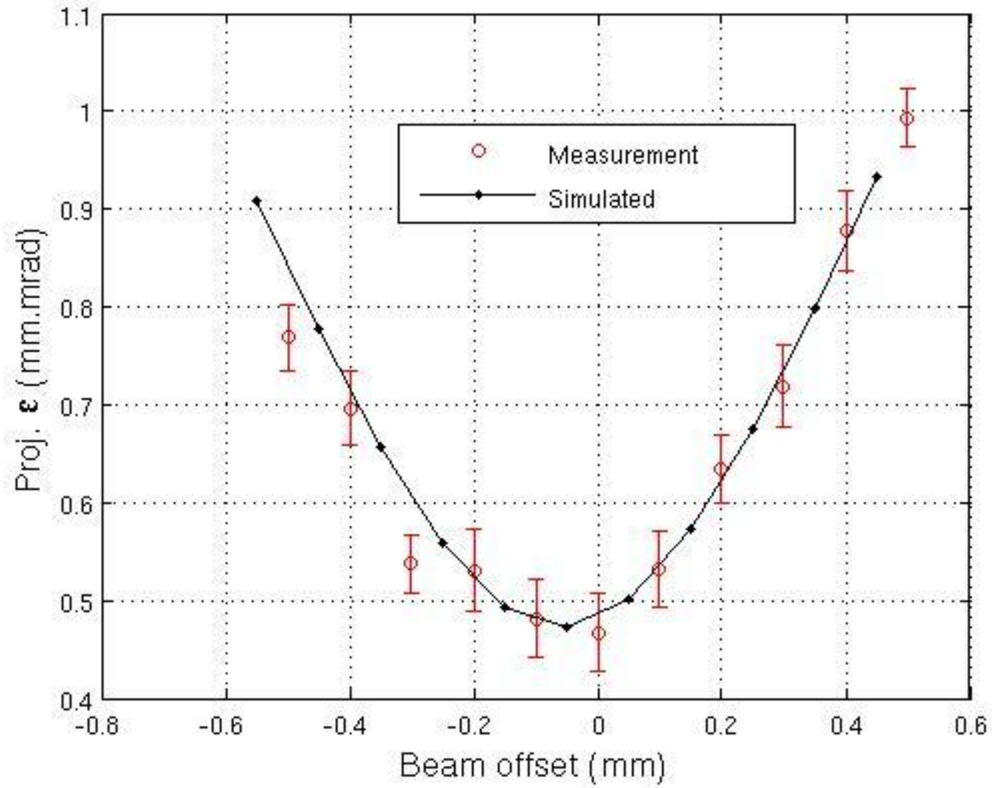


- Signal levels accounting for cable attenuation of 25 dB at 16 GHz
- Minimum signal x: +200 um
- Minimum signal y: -100 um
- Levels of 10 V/mm/nC OK:
  - CST wake solver gives 4V (full spectrum using relatively long bunch)
  - Eqv. Circuit model 6 V
  - Cannot yet do reasonable comparison to signal shape (pulse distortion by cable etc.)

Open question: seeing some cross talk between X and Y

Vertical emittance scan

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



Important proof of principle!

Summary and outlook

·Offsets: able to align structure to golden orbit (proven in the vertical plane and confident about horizontal), already with our provisional setup much faster than measuring emittance growth!

·Able to measure structure tilt via spectral pattern (different from structure offsets)

·Resolution as yet limited by digital noise of fast scope (ENOB ~ 6.5 bits)

·Measurements done as preparatory work for development of front ends (part of EuCARD2 projects), WFM performance close to theory – no road blocks identified.

·**More to come!**