PAUL SCHERRER INSTITUT PSI

Design and measurements for PSI-Trieste linearizer

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- General remarks
- Electrical and mechanical Design
- Measurements and Performance

A basic remark:

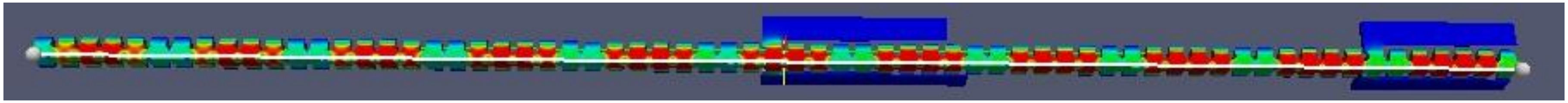
Every passive electromagnetic pickup (BPM, WCM etcetc) is a wake field monitor!

Form follows function (the Bauhaus era principle) – what are possible functions?

- Amplitude (which time or amplitude resolution, suitable for real time/feedback tasks?)
- Phase (which time or amplitude resolution, suitable for real time/feedback tasks?)
- Position (….)
- Effects on beam quality (e.g. emittance dilution)
- Properties of your structure instead of your beam

In Design, try to concentrate on select feature! I once tried to analyze HOM signals from FLASH – too much information!

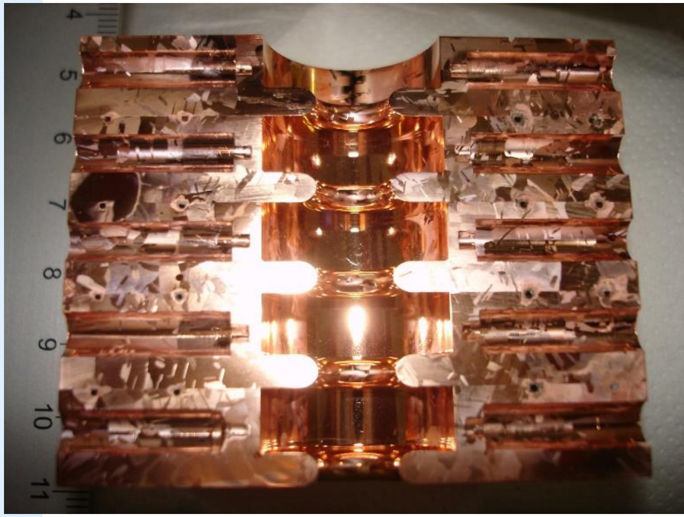
Combining CG and DDS prinples: the CG part



- 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

Above: field distribution as calculated with ACE3P

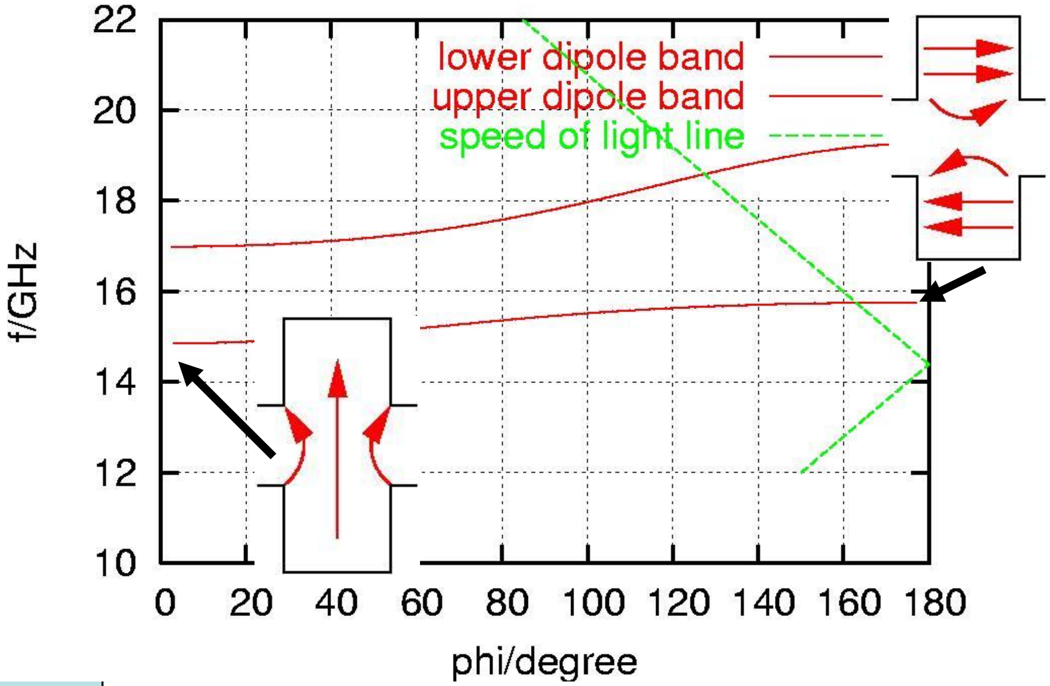
Prototype stack



Propagation characteristics of transverse HOM in multicell structures

Dispersion of a typical cell:

- Coupling to backward wave
- Synchronous phase of lower (strong kick) band near to π



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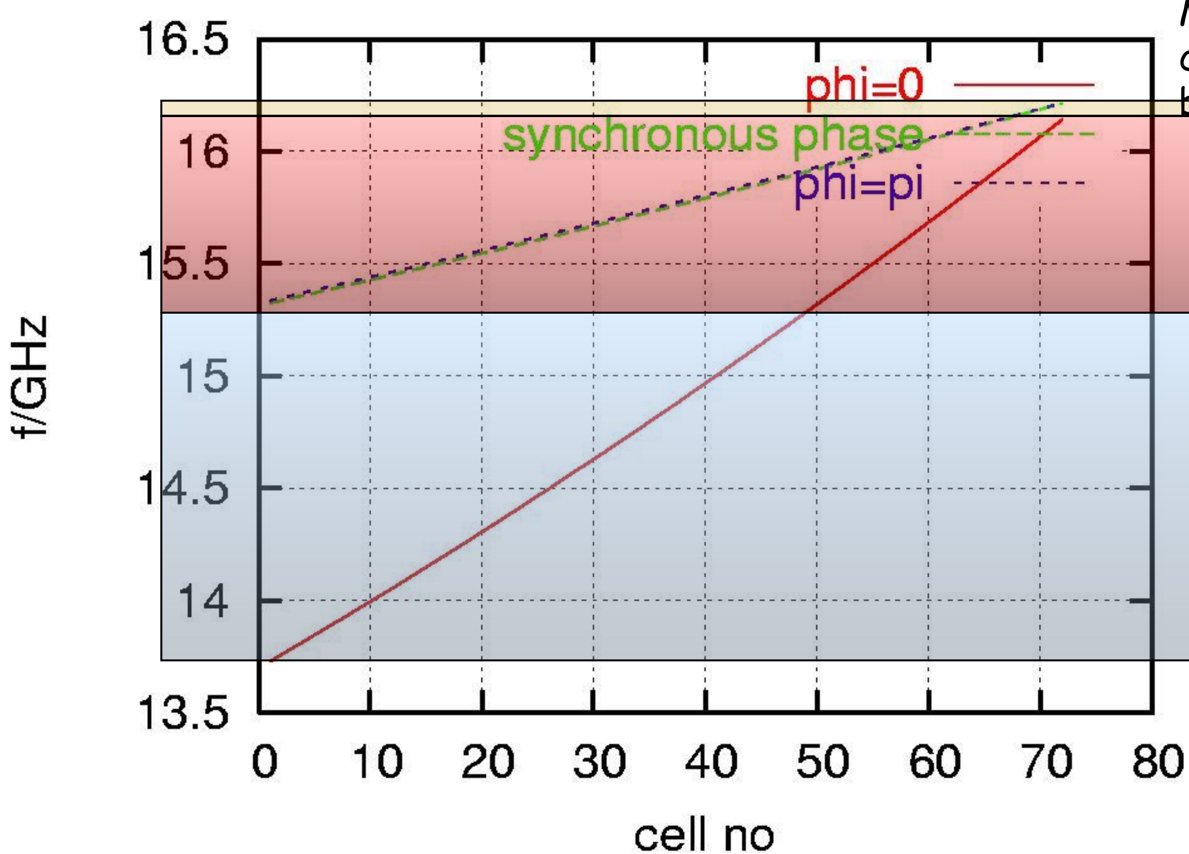
Lower dipole band versus cell No



May be damped by output coupler, strong coupling to beam

Trapped modes

Strong coupling to beam

Modes may couple to input coupler

Weak kick (nowhere coupling to f_{sync})

From distribution, we see distinct frequency bands

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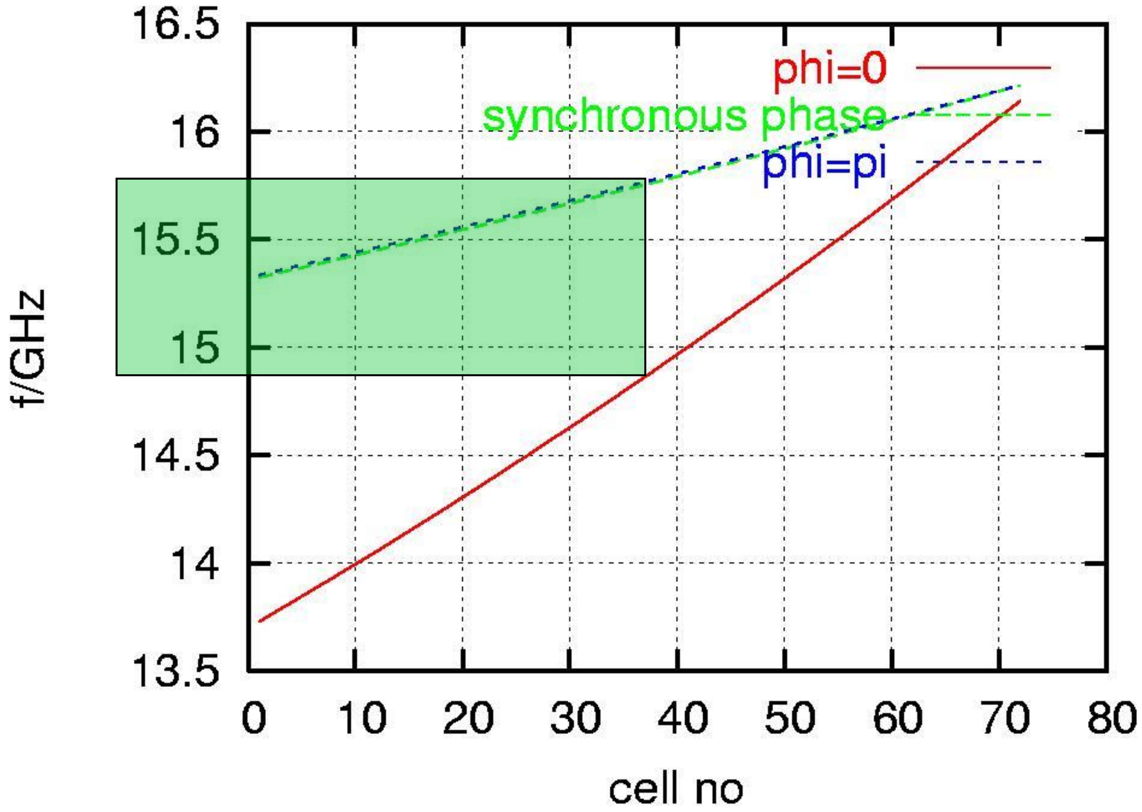
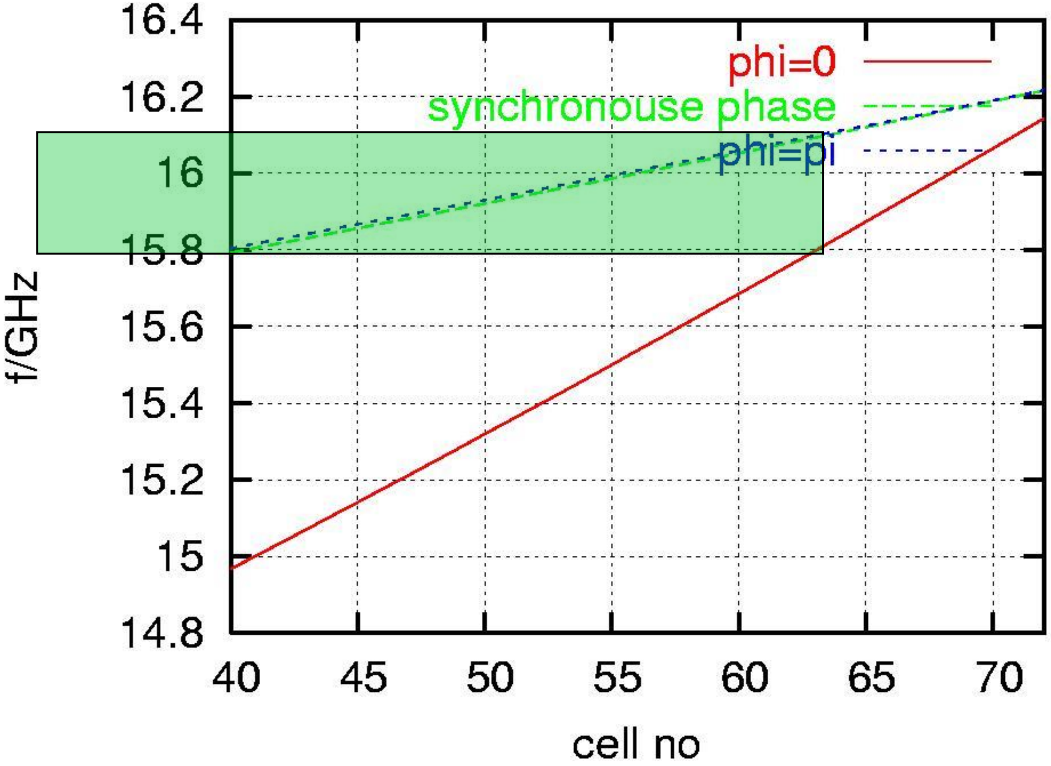
Cell 36 as upstream monitor



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

The DDS contribution: pickup geometry

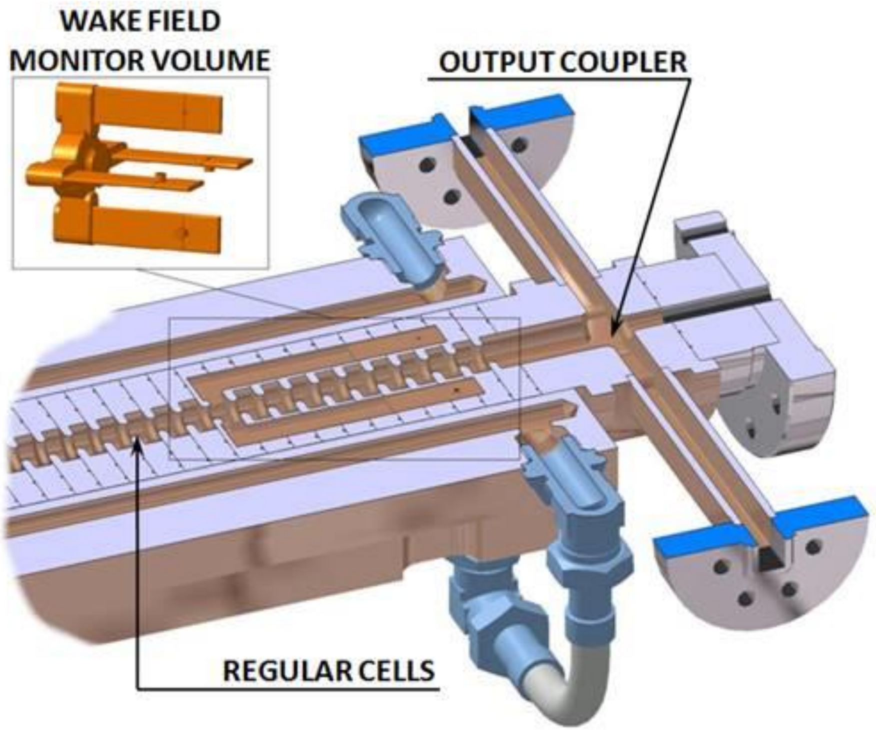
TE type coupling minimizes spurious signals from fundamental mode and longitudinal wakes

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

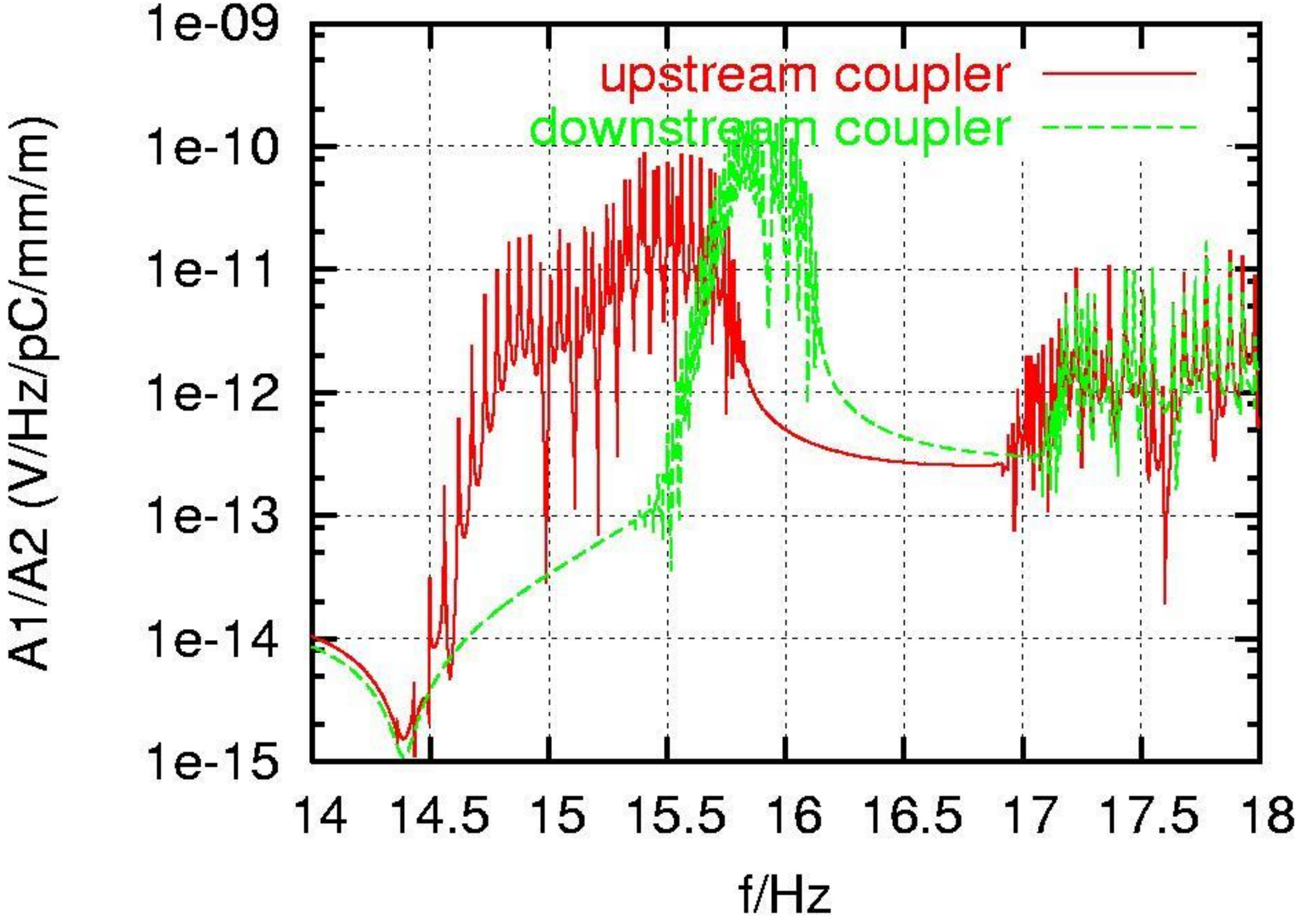
Minor loss in fundamental per- formance: 10% in Q, <2% in R/Q

Output wave guides with coaxial transition connecting to measurement electronics

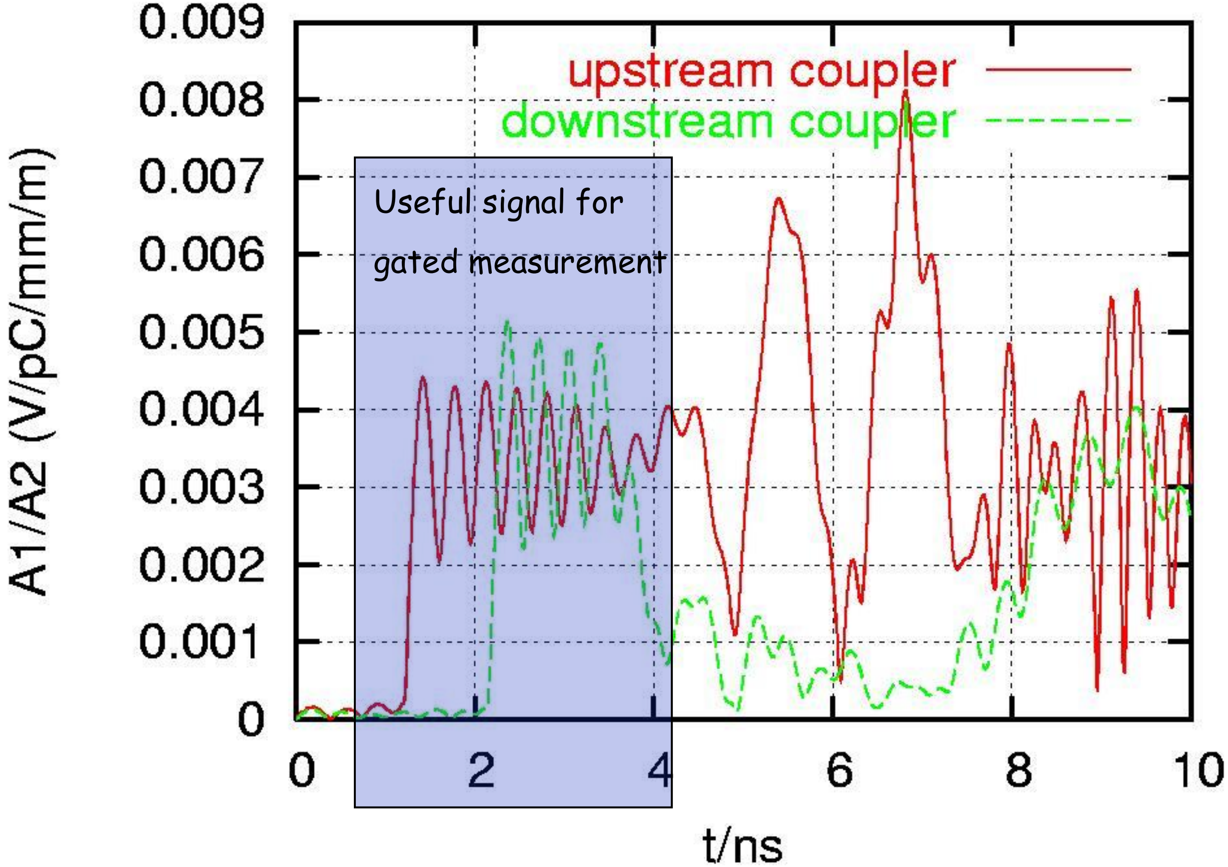
Big advantage: Even accounting for mechanical tolerances, extremely strong suppression of longitudinal signals – precondition for ultra high sensitivity measurements!!



Output signal spectra



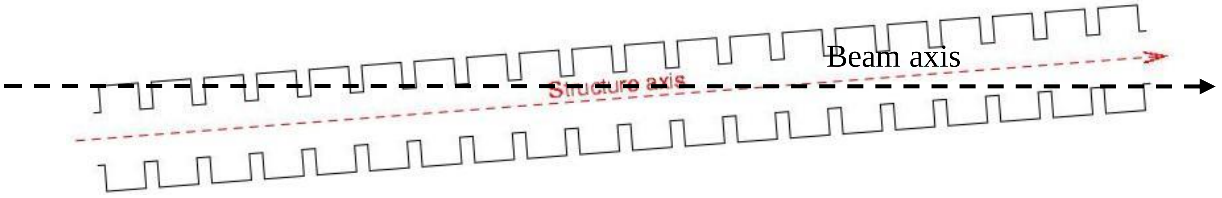
Signal envelopes of wake monitors

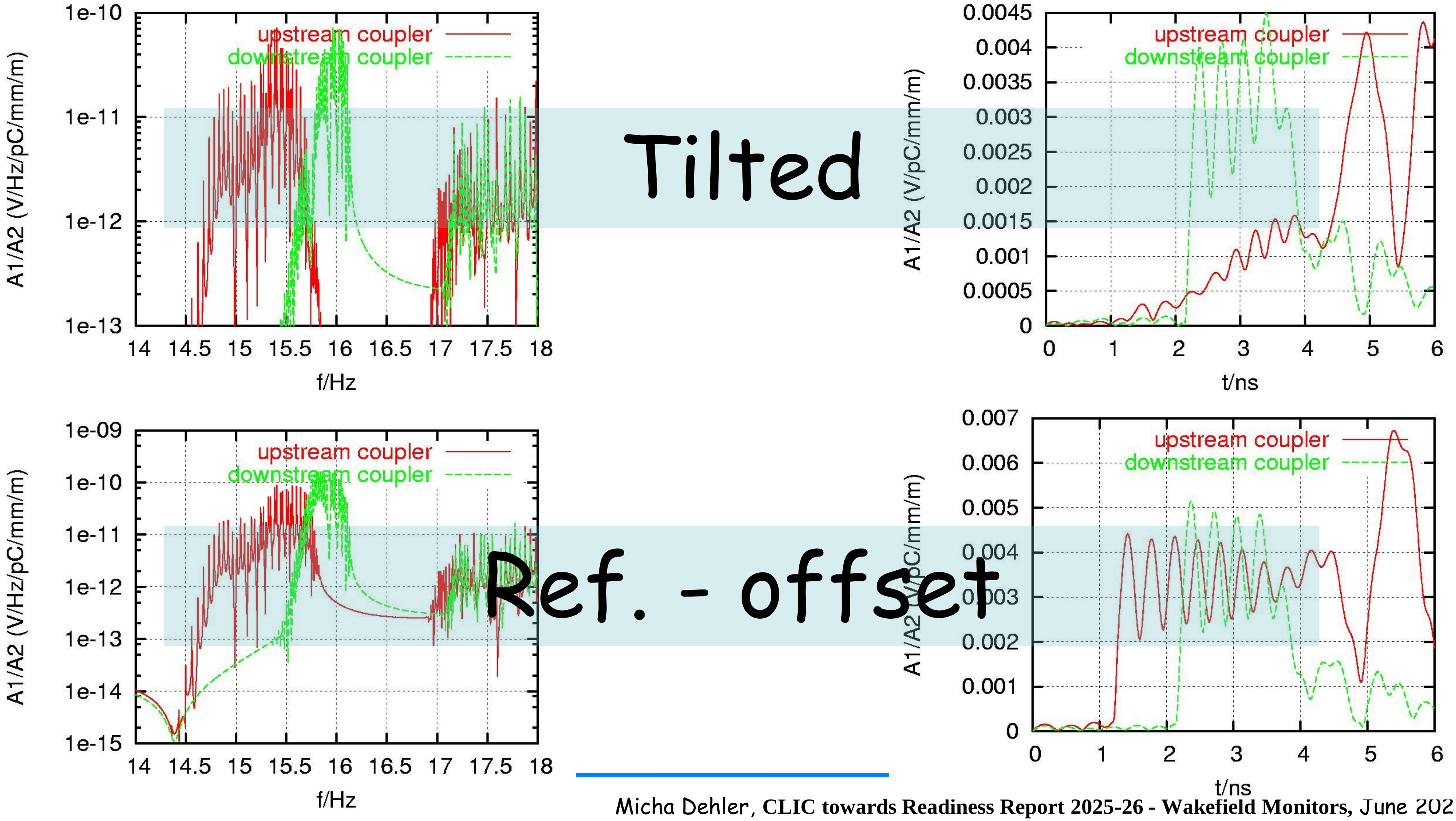


Signal at time t is correlated with frequency – is correlated with cell number…..

Can we learn something about internal misalignments?

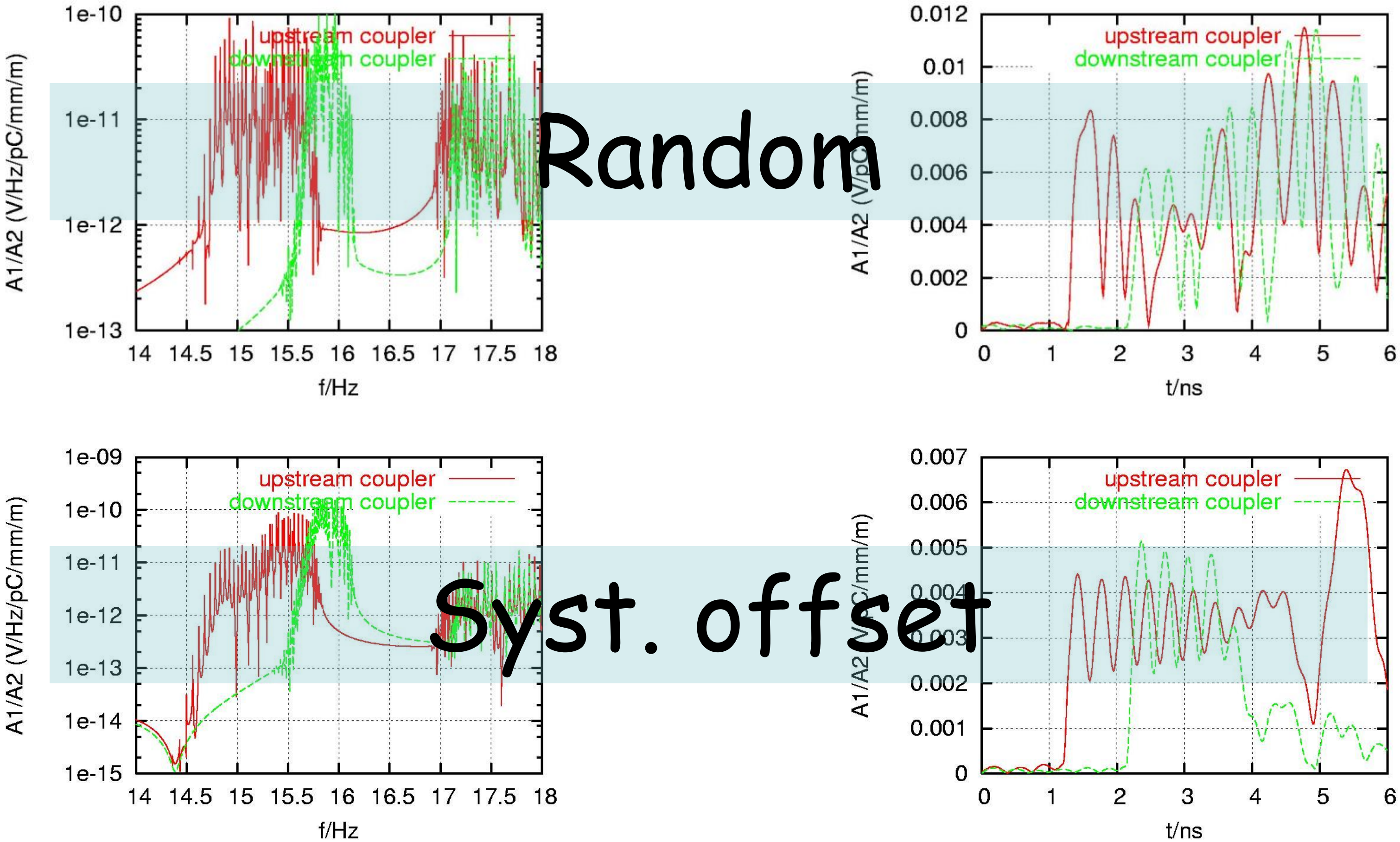
Structure tilt





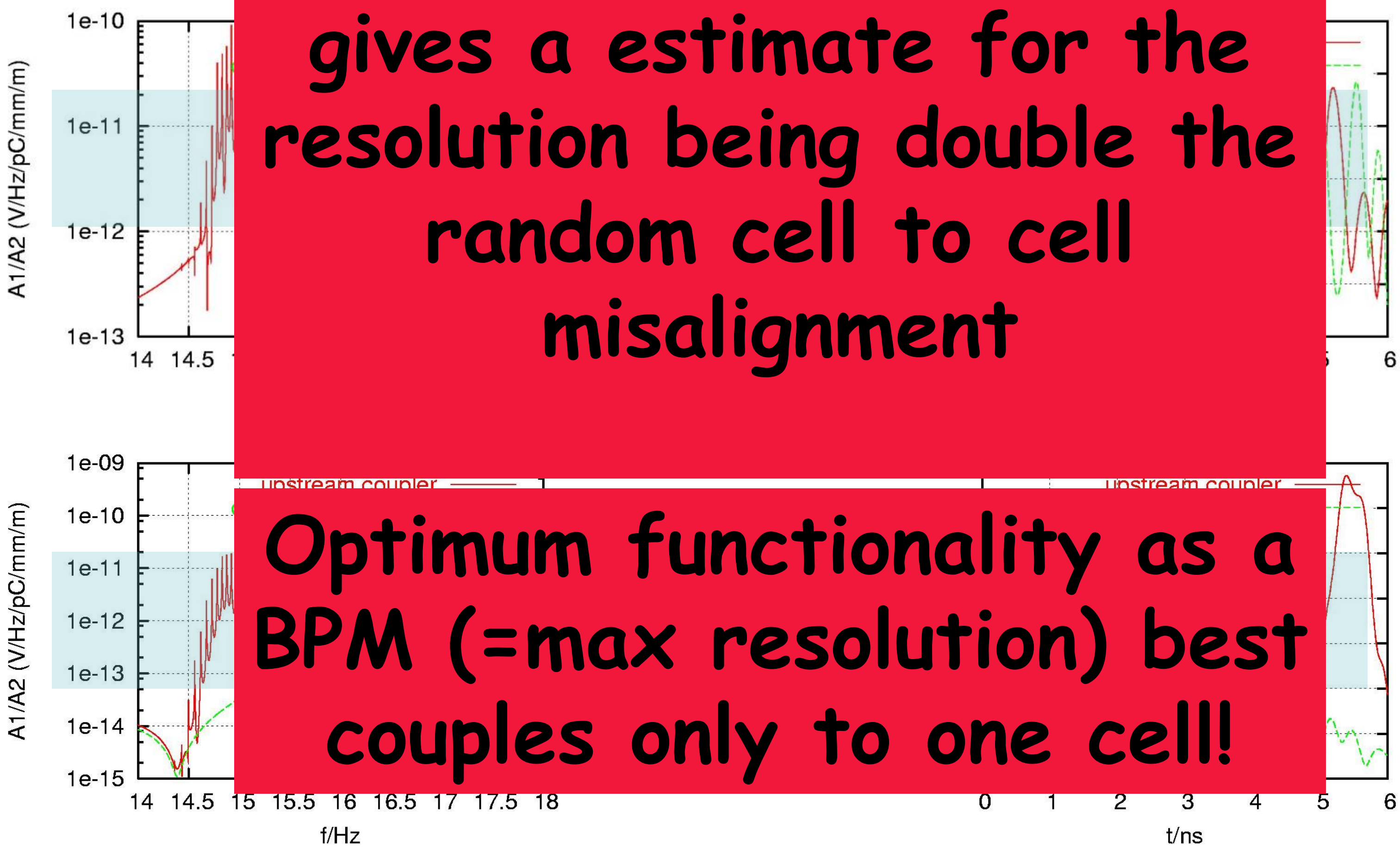
The resolution?

Comparing random misalignment with systematic offset



Resolution

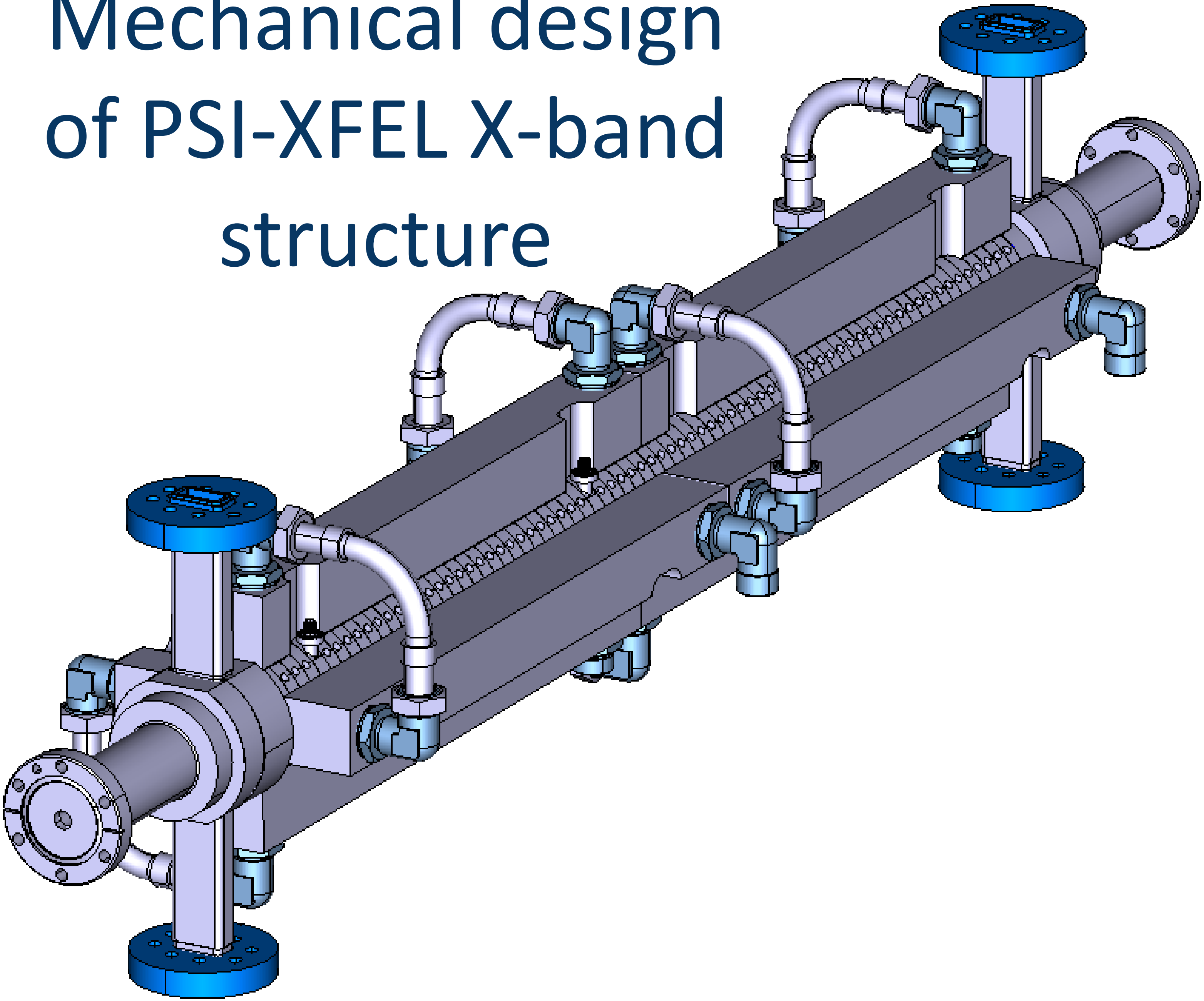
Comparing random misalignment with systematic offset



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

Optimum functionality as a BPM (=max resolution) best couples only to one cell!

Mechanical design of PSI-XFEL X-band structure



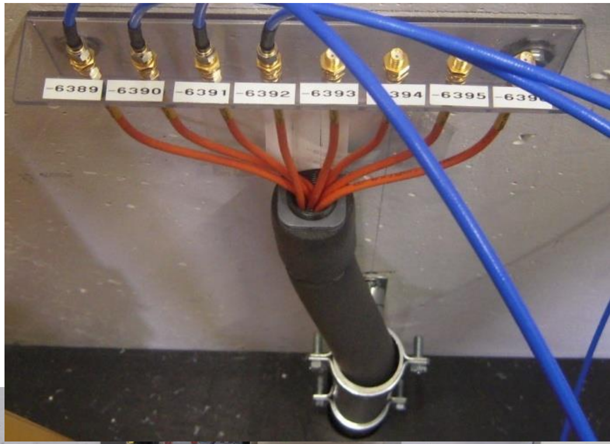
Beam Measurements

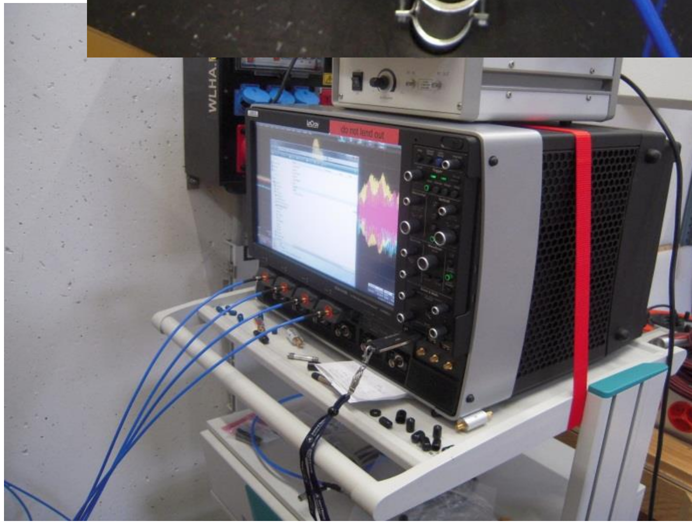
•Beam was set to golden orbit. Structure was moved (instead of beam) using the mechanical mover system to have clear picture of emittance dilution.

• Some measurements with high speed scopes (45 GHz bandwidth), some with EO front end

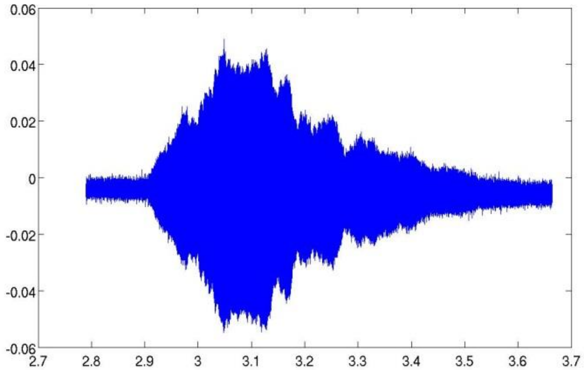
•Questions:

- Leakage of klystron power into monitor outputs
- Wide bandwidth response
- Longitudinal wakes visible (an indication of internal tolerances)?
- Emittance dilution versus optimum WFM alignment

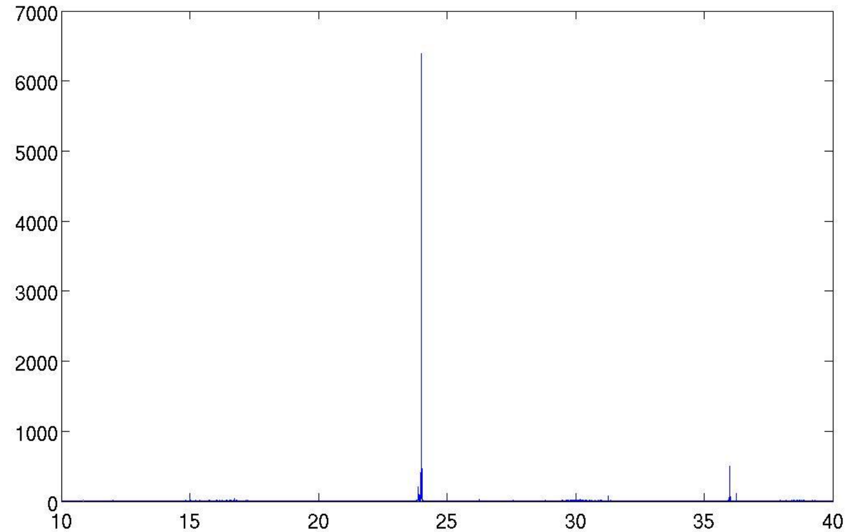




Residual signals



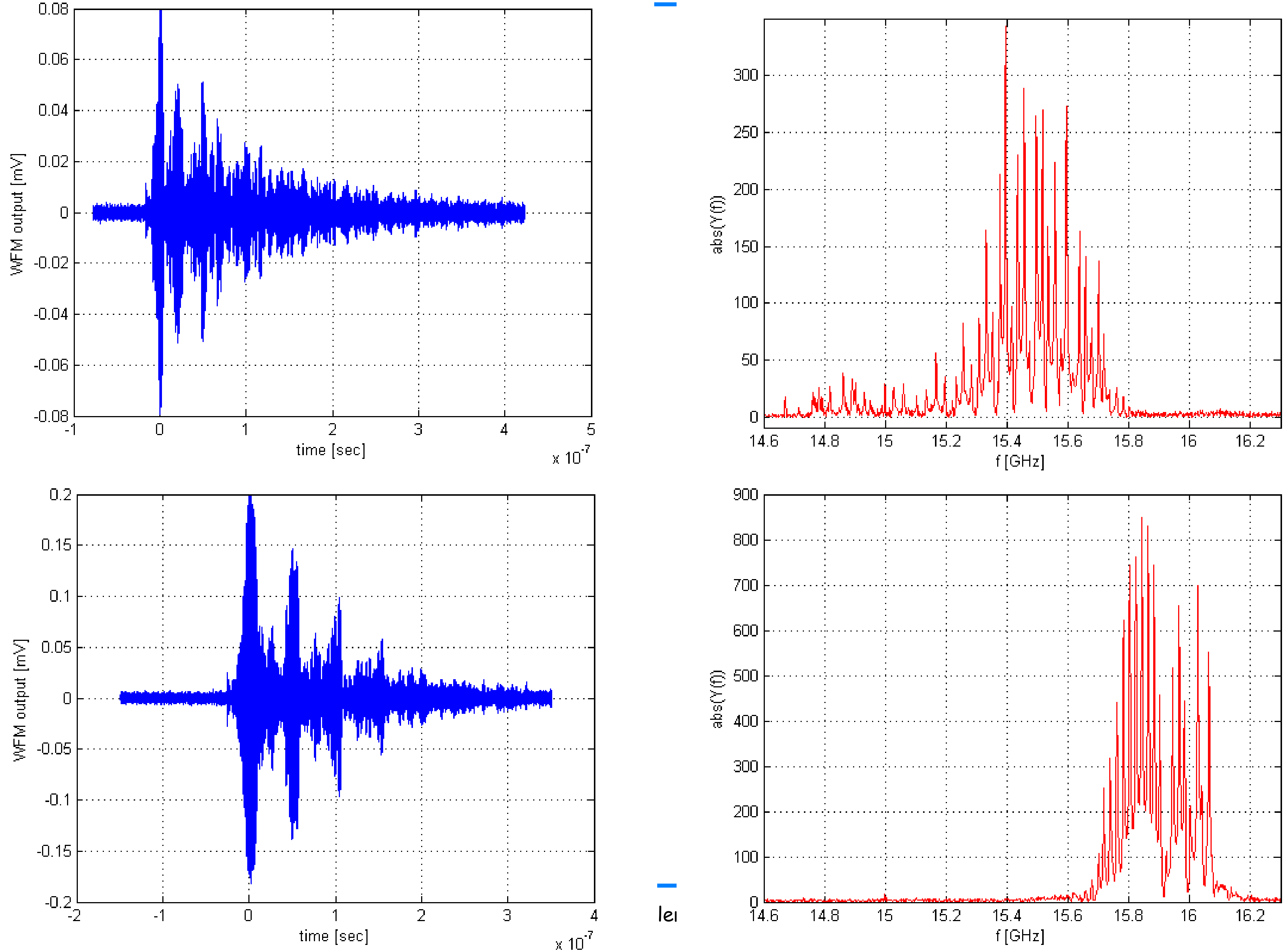
Signal without beam shows residual signal coming from X Band RF system (taking account of cable attenuation level ~ 1 V at WFM output)



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

Typical signal output



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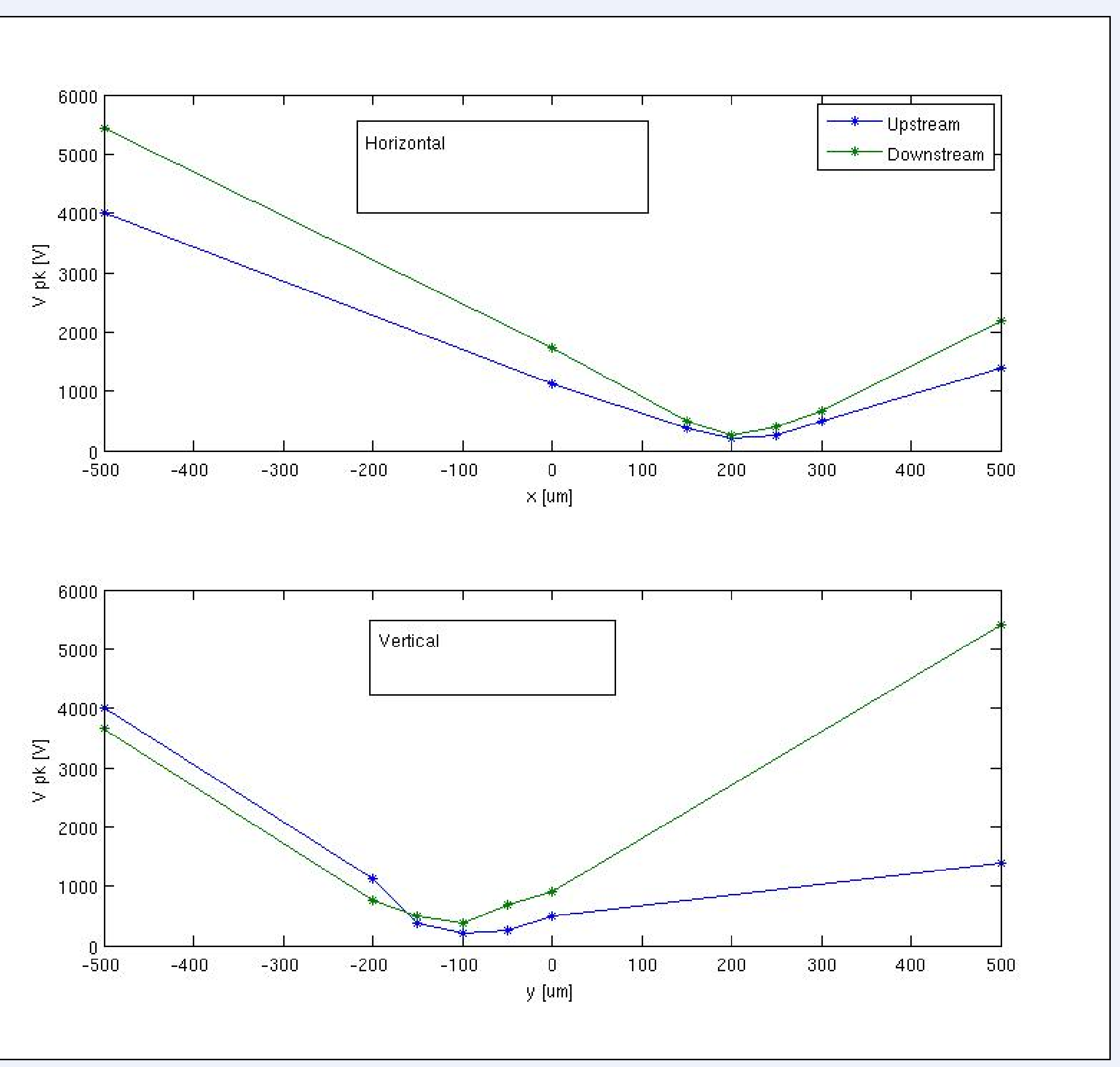
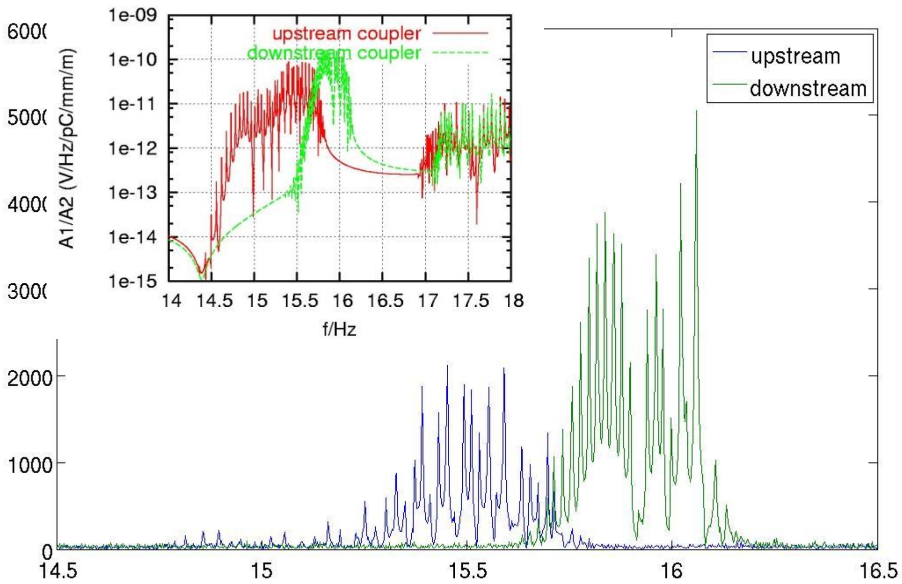
Sensitivity



- Signal levels accounting for cable attenuation of 25 dB at 16 GHz
- Minimum signal x: +200 um
- Minimum signal y: -120 um
- Levels of 10 V/mm roughly 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: cross talk between X and Y:
    - Structure is rotated, so should expect signal in both planes, **but**
    - Signal shapes should be very similar between upstream X and Y, downstream X and Y

Signal spectra



Spectral response in the measurement band as theoretically predicted

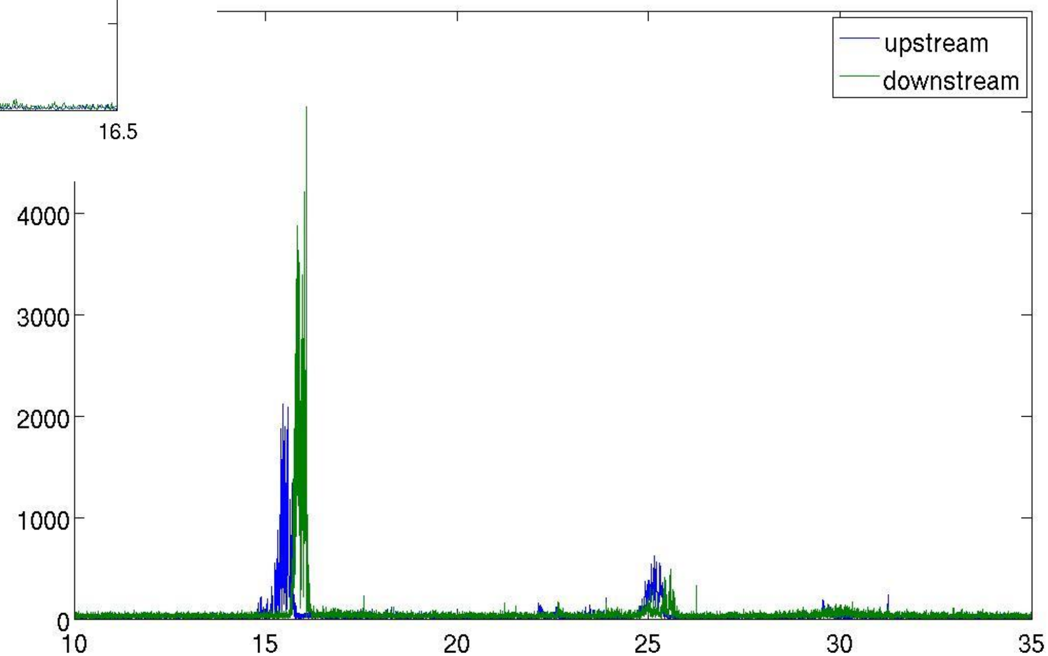
Wide Band spectrum (below) shows additional strong bands at 25 and 30 GHz

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?

- HOM spectra all position dependent, no longitudinal wake coupling! 😊

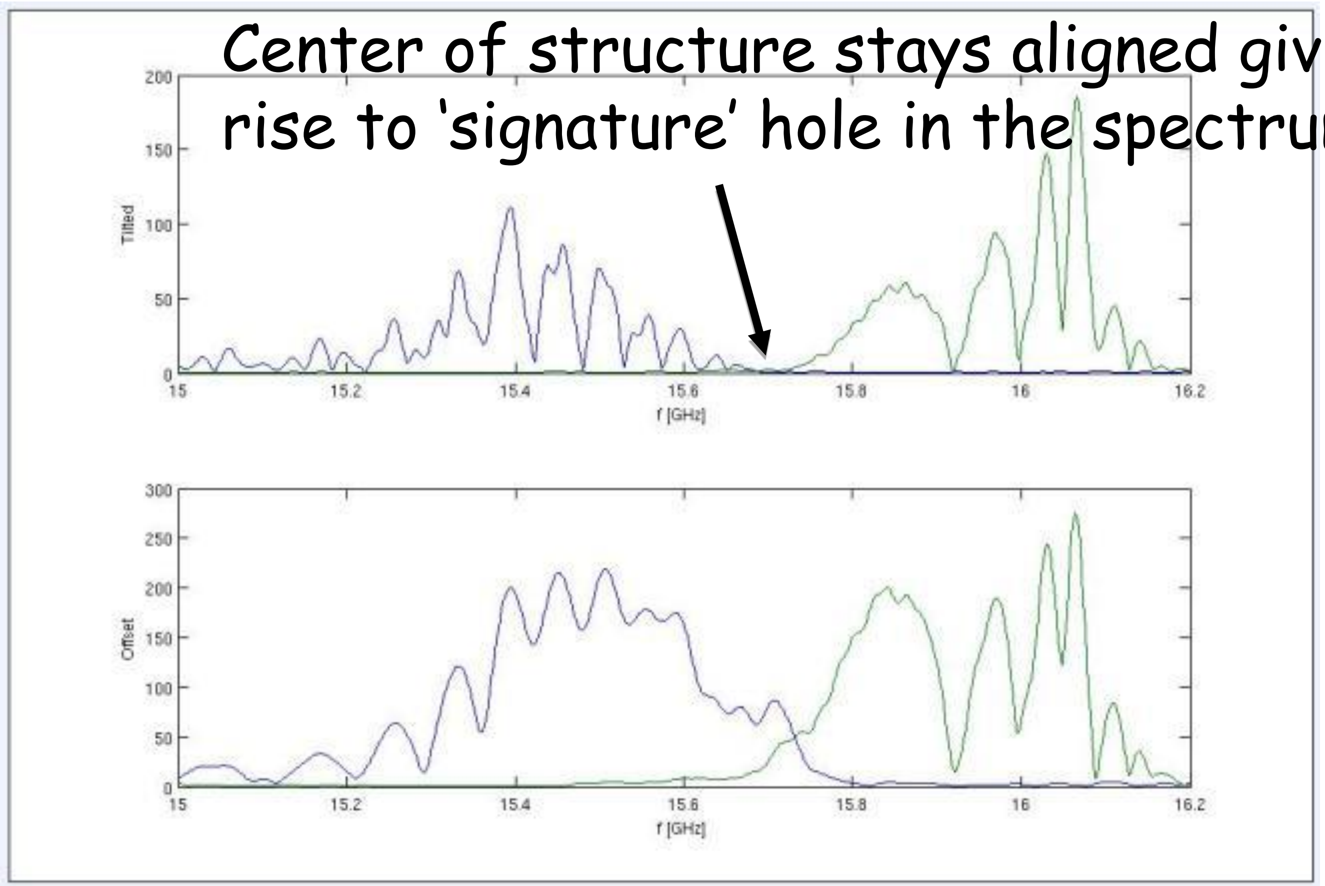


WFM spectrum of horizontal tilt compared to offset

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

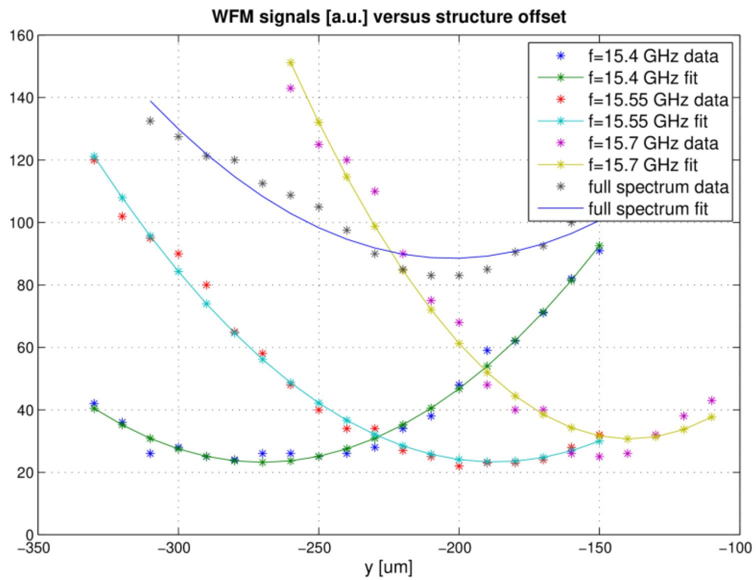
Tilted

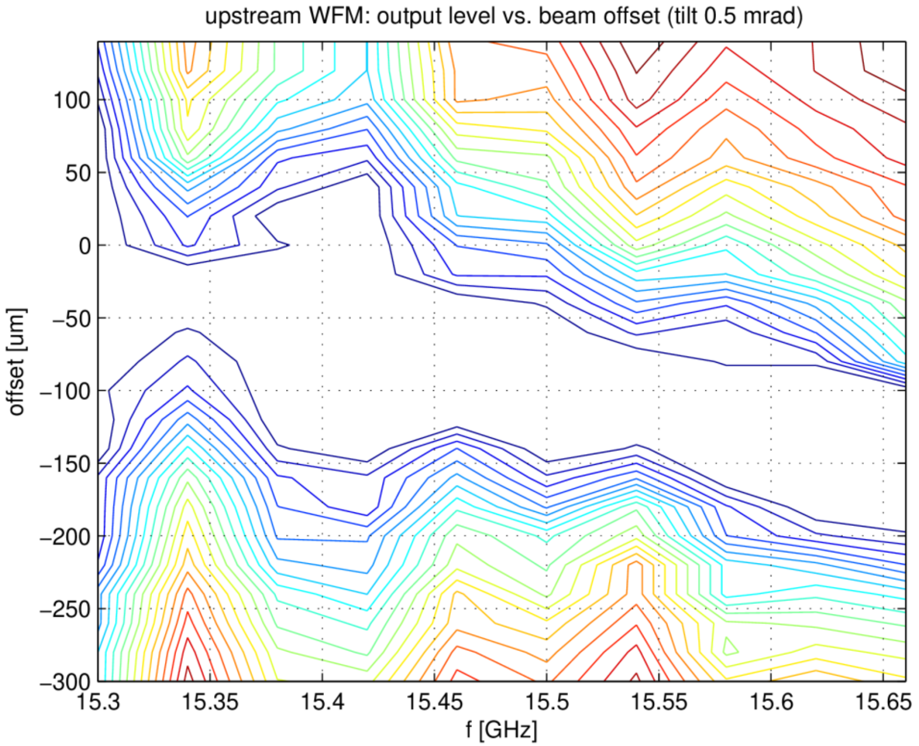
Offset



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

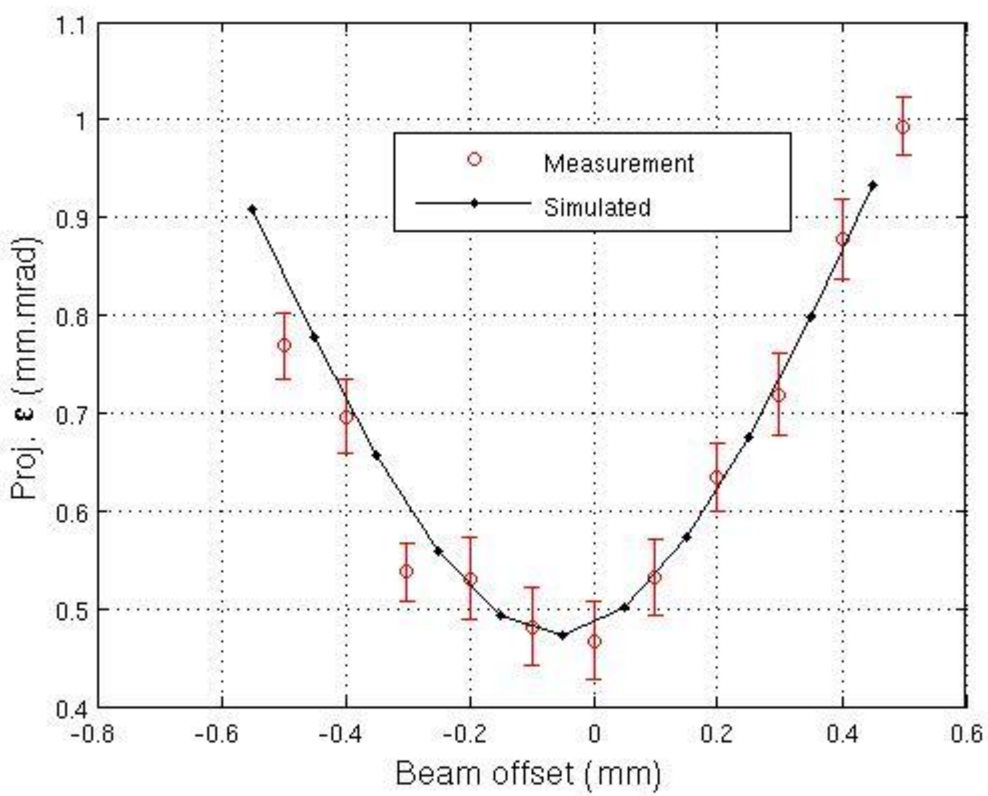
Same measurement using a front end





Vertical emittance scan (S. Bettoni)

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



The proof of principle!

Summary

Proven that:

- WFM signals predict emittance dilution due to structure
- Signals contains information about internal misalignment (tilt etc.)
- Not easily usable as a BPM (sign of offset would need a kind of I/Q processing, which is quite involved given the bandwidth).

Current state of things

- Structure in operation at SwissFEL, WFMs not part of control system
- WFM signals available in raw/EO form, possibility of parasitic tests

Any use for CLIC project?

Thank you very much for the attention