X-FEL X-band structure wake field monitor

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- The history
- Basic properties
- Wakefield monitors
- Performance
- Outlook

The history

A multi purpose accelerating structure

PSI/FERMI view:

An X band structure to compensate long. phase space nonlinearities

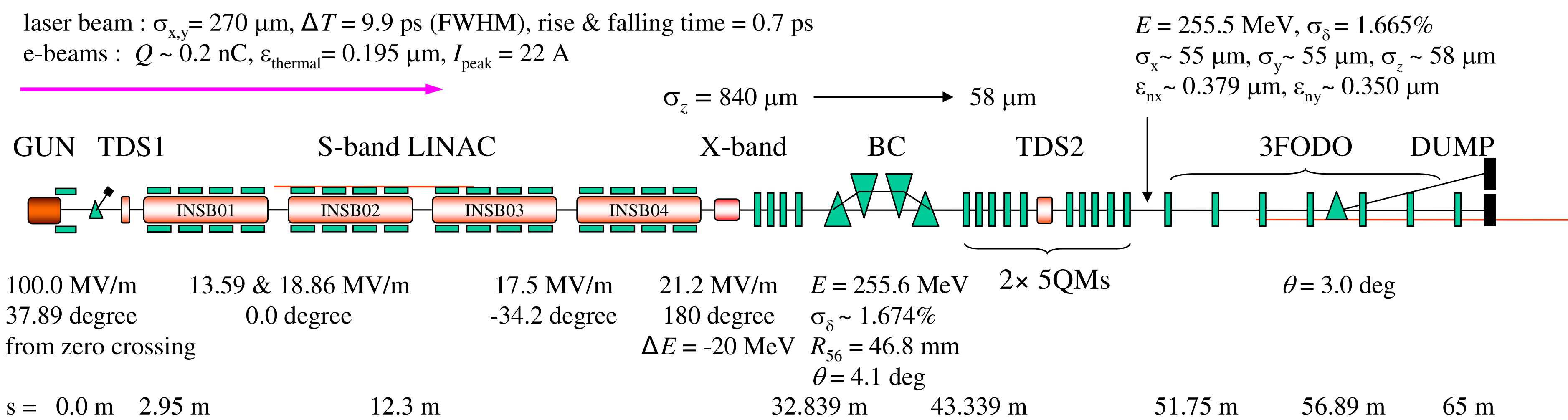
High gradient/power requirements of CLIC = a design for safe operation at the more relaxed parameters of the PSI X-FEL

CLIC view:

- Another data point in high gradient test program
- Validation of design and fabrication procedures
- A true long term test in another accelerator facility

RF design (mostly) by PSI, fabrication & LL RF test (mostly) at CERN, mechanical support & other parts by FERMI

PSI Injector



Special considerations for FEL facilities

- Operating structure at relatively low beam energies (PSI injector: 250 MeV)
- High sensitivity to transverse wakefields!
- Strategy:
  - Passive: Try to have open aperture while maintaining good RF efficiency and breakdown resilience
  - Active: Wake field monitors
    - See offsets before they show up as emittance dilution
    - Possibly measure higher order/internal misalignments (tilts, bends ….)

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Basic properties

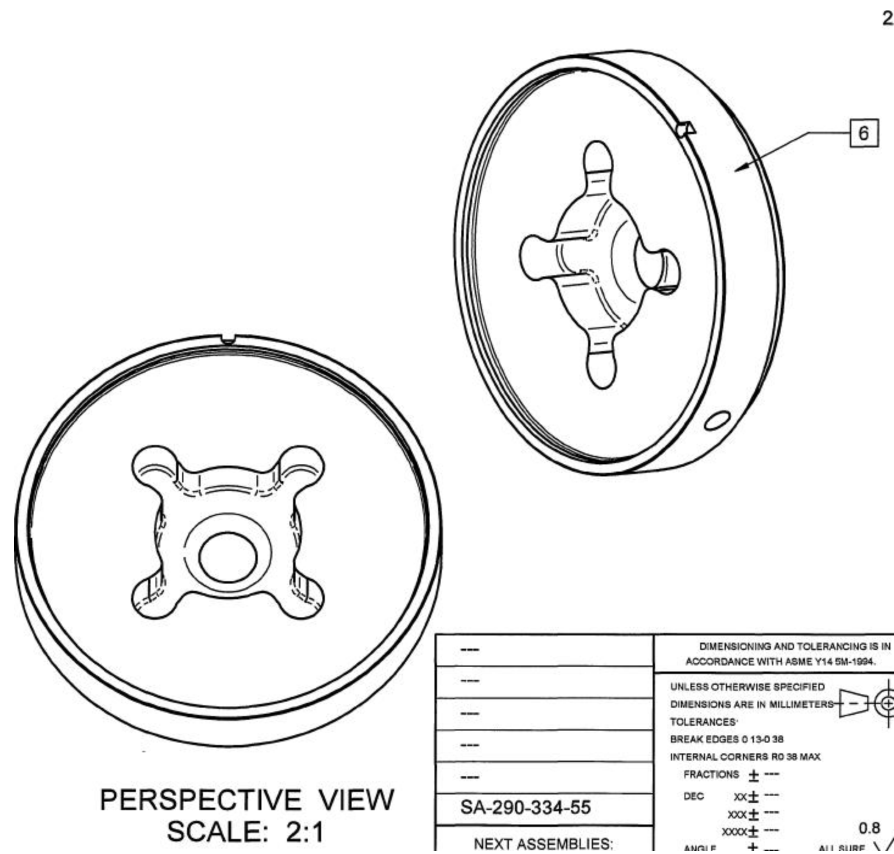
(a priori) Specifications

- Beam voltage 30 MeV at a max. power of 45 MW
- Mechanical length <1017 mm
- Iris diameter > 9 mm
- Wake field monitors
- Operating temperature 40 deg. C
- Constant gradient design, no HOM damping
- Fill time < 1 usec
- Cooling assuming 1 usec/100 Hz RF pulse

Reconciling efficiency & transverse wakes

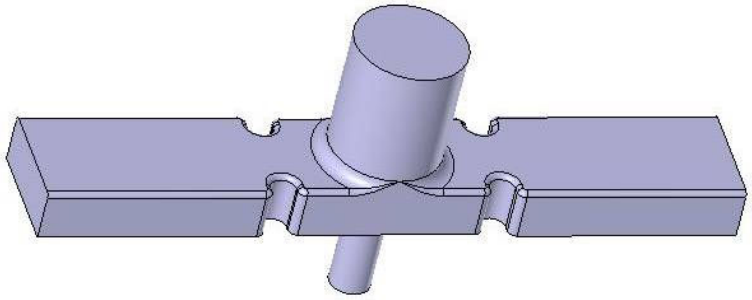
- Use 5π/6 phase advance:
  - Longer cells: smaller transverse wake
  - Intrinsically lower group velocity: Good gradient even for open design with large iris
  - Needs better mechanical precision
- Long constant gradient design (efficiency!)
- No HOM damping
- Wake field monitors to insure optimum structure alignment

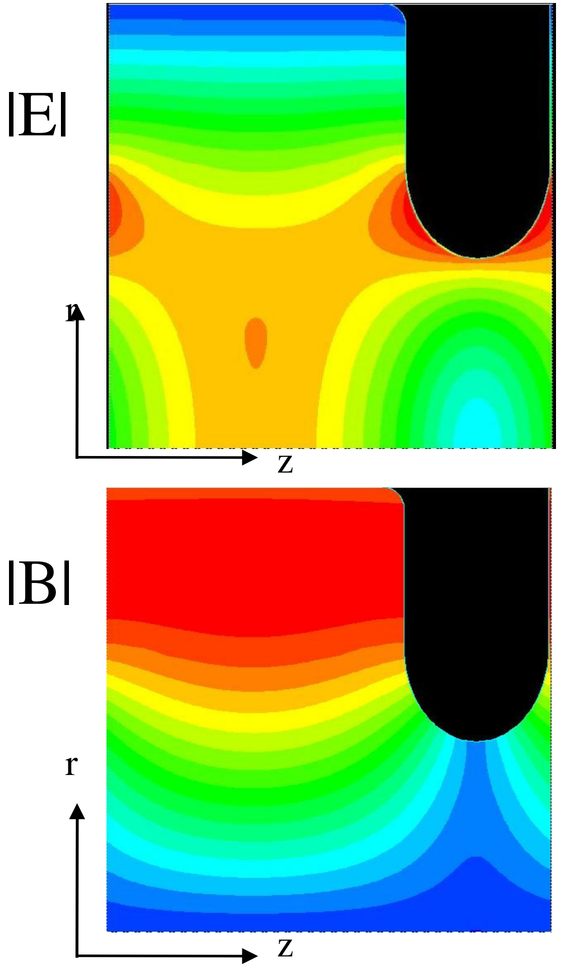
Do a castrated NLC type H75 without damping manifolds!



On the H75 design …

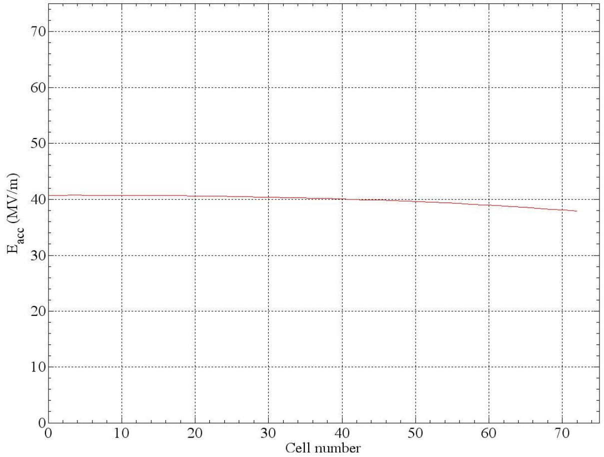
- Well optimized design (iris aperture, thickness and ellipticity varying of structure)
- Original design gives 65 MV/m for 80 MW input power
- Sucessfully tested up to 100 MV/m with SLAC mode launcher (below)

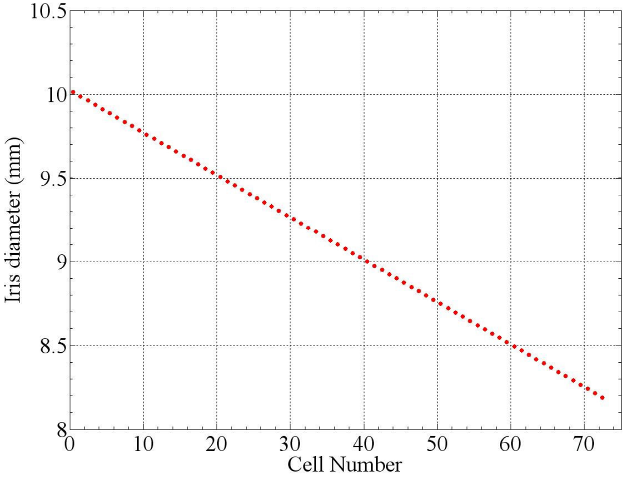




Constant gradient design

- 72 cells, active length 750 mm
- Relatively open structure – mean aperture 9.1 mm
- 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

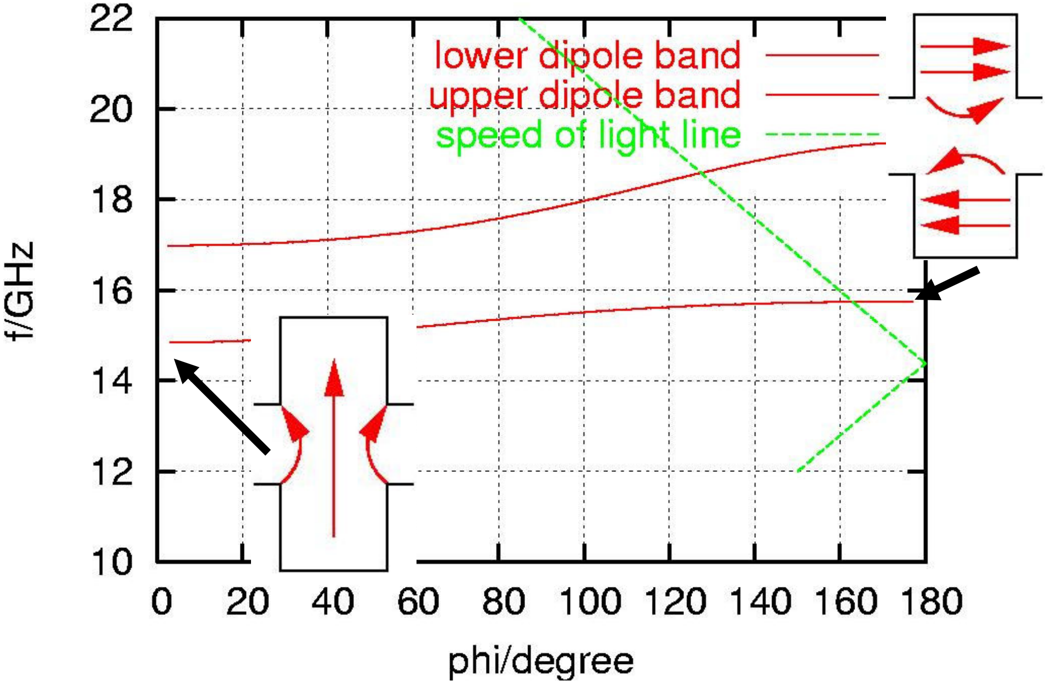




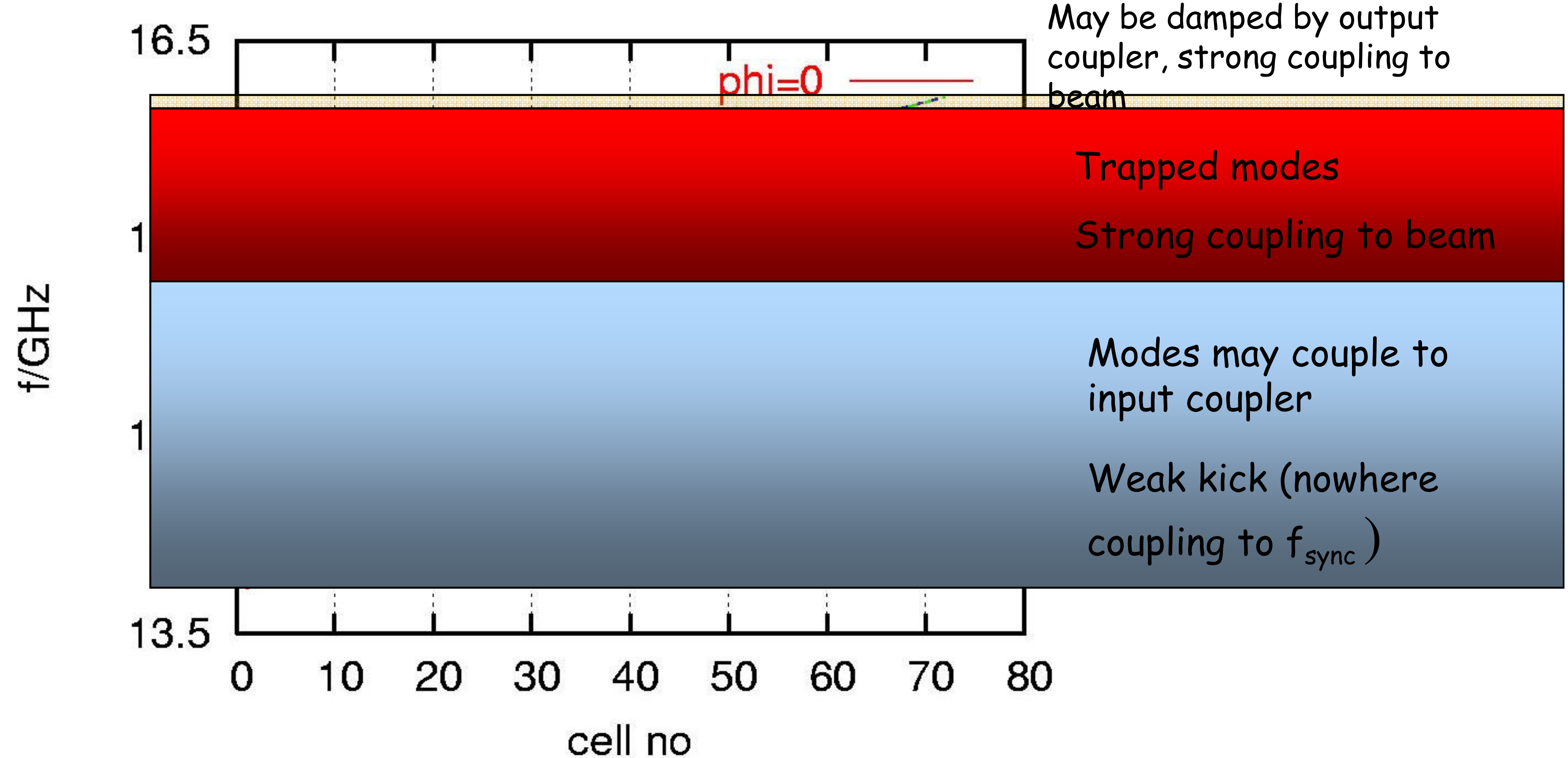
Dipole band properties

Dispersion curve of a typical cell:

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



Lower dipole band versus cell number



From distribution, we see distinct frequency bands

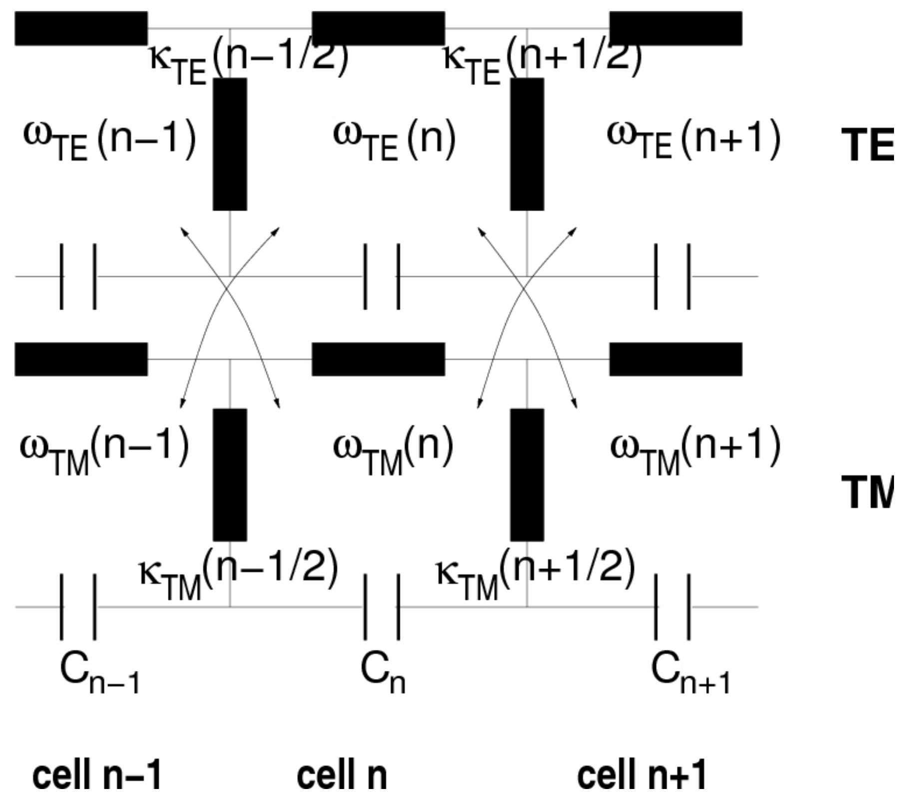
Bane-Gluckstern equivalent circuit model

- Quasi physical model of hybrid two mutually coupled chain of resonators describing TE and TM components.
- Parameters derived from numerically calculated dispersion curves and kick factors
- Advantages:
  - Modelling lowest two dipole bands
  - Very good fit of dispersion relations
  - Physically reasonable variation of kick factor with phase.

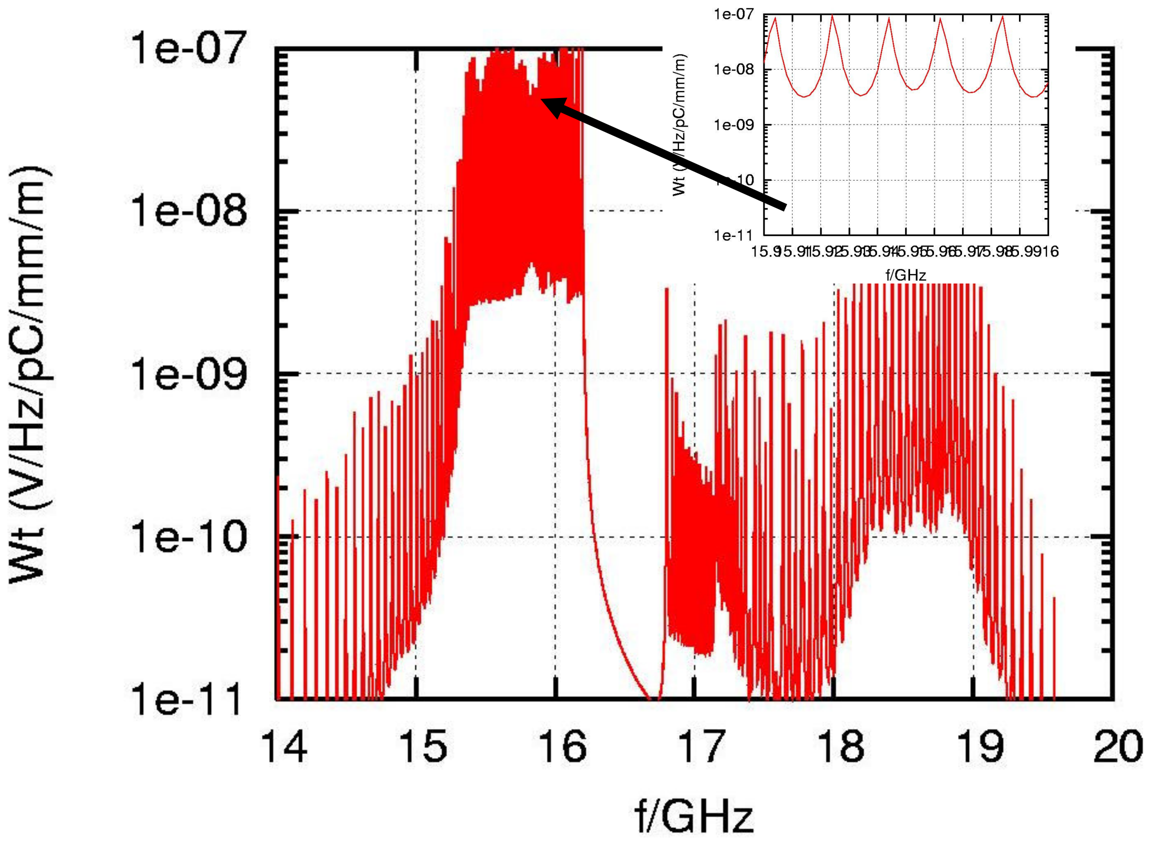
K.L.F. Bane, R.L. Gluckstern, The transverse wakefield of detuned X-band accelerator structure, SLAC-PUB-5783, 1992

Extension to with damping manifold:

R.M. Jones et al., PRST-AB 9:102001

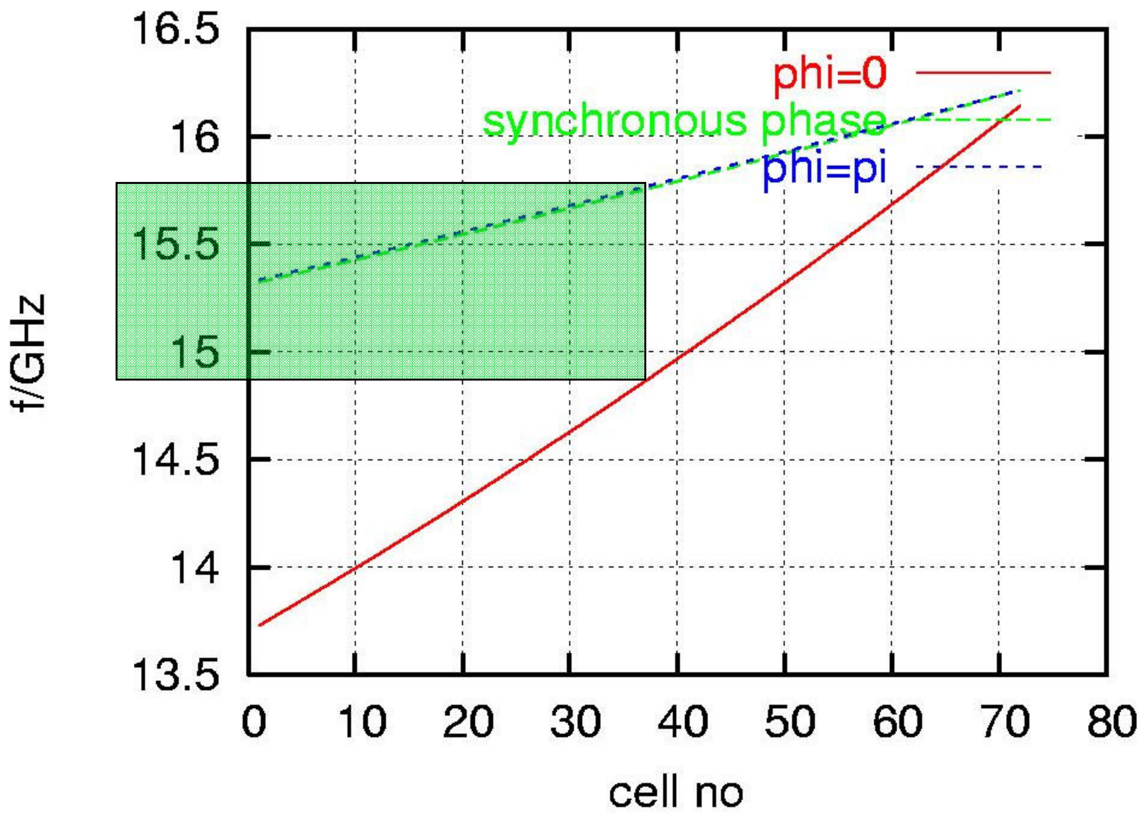


Transverse wake spectrum



Bane-Gluckstern equivalent circuit, solving inhomogeneous equations including conduction losses

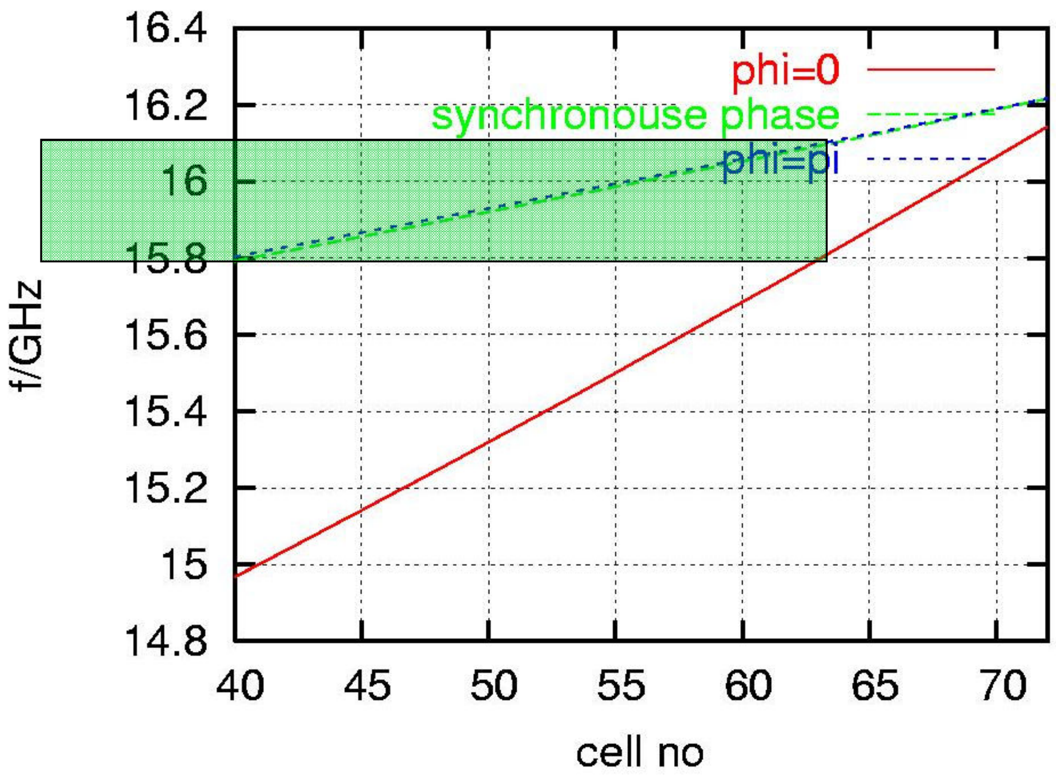
Cell 36 as upstream monitor



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:

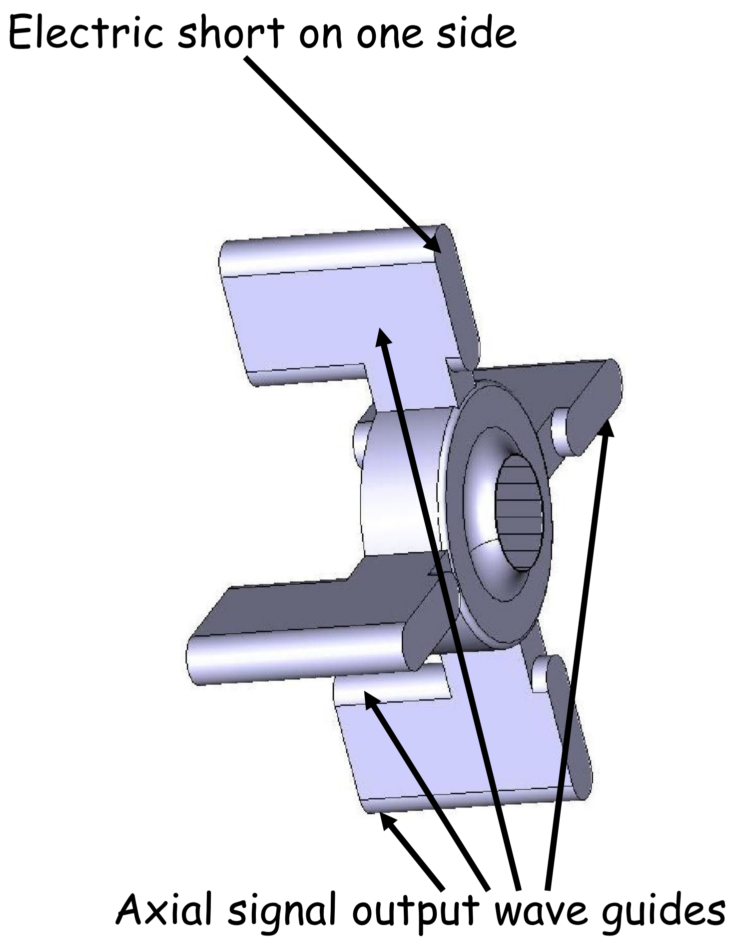
Contributions from cells 40-63

Signal bandwidth

15.8-16.1 GHz

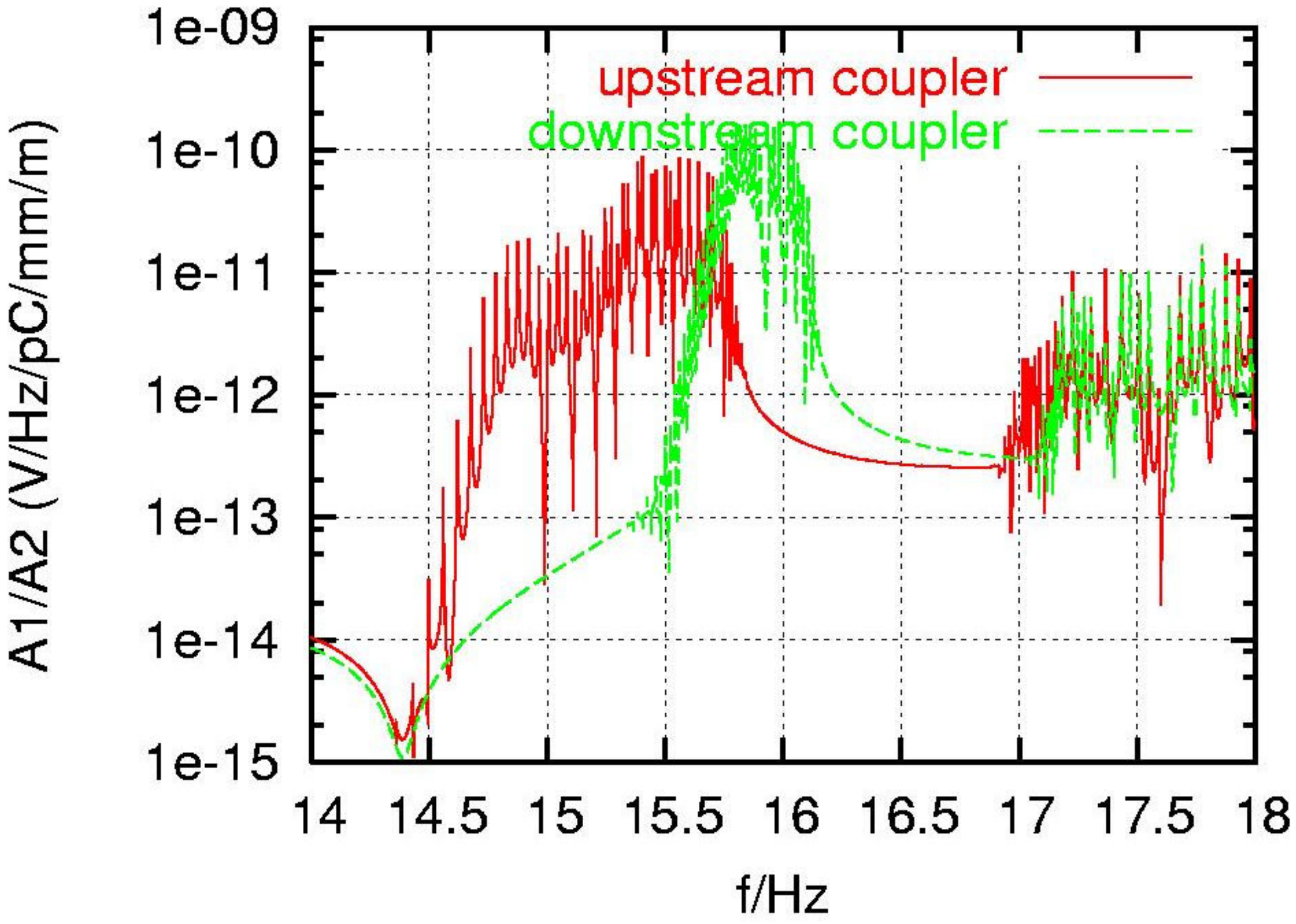
HOM coupler inspired from NLC DDS

- TE type coupling minimizes spurious signals from fundamental mode and longitudinal wakes
- Need only small coupling (Qext<1000) for sufficient signal
- Only minor loss in fundamental performance – 10% in Q, <2% in R/Q
- Output wave guides with coaxial transition connecting to measurement electronics

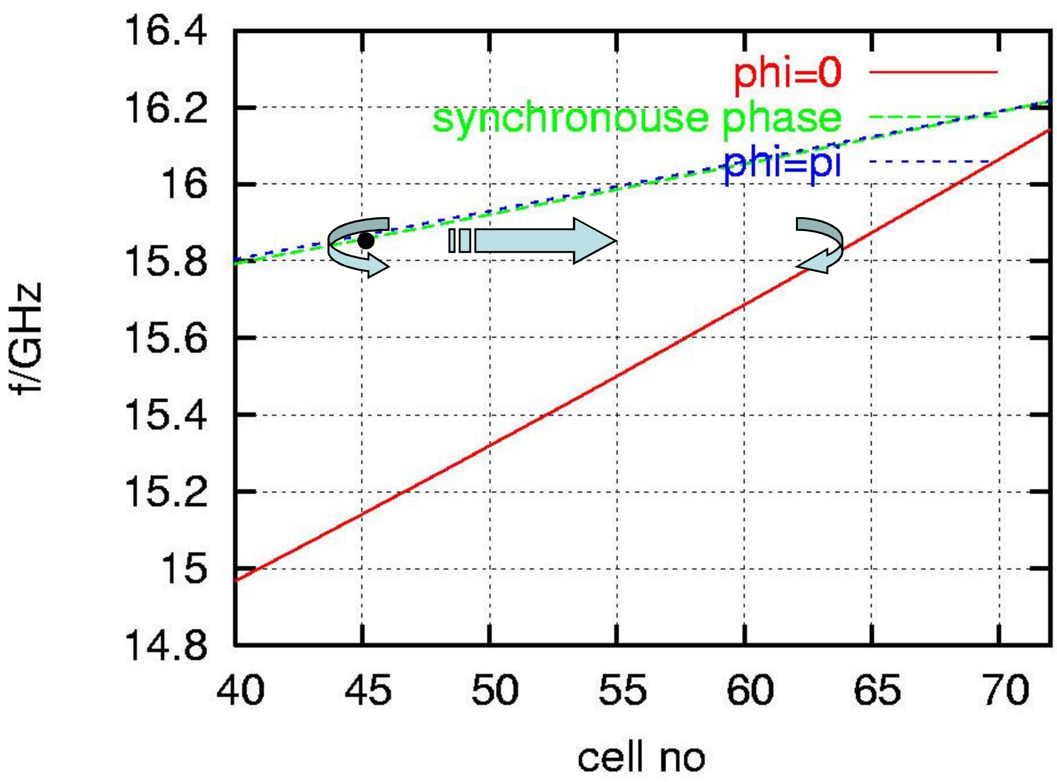


Performance

Output signal spectra



An approximate idea about time domain behavior
(looking only at cell 45)

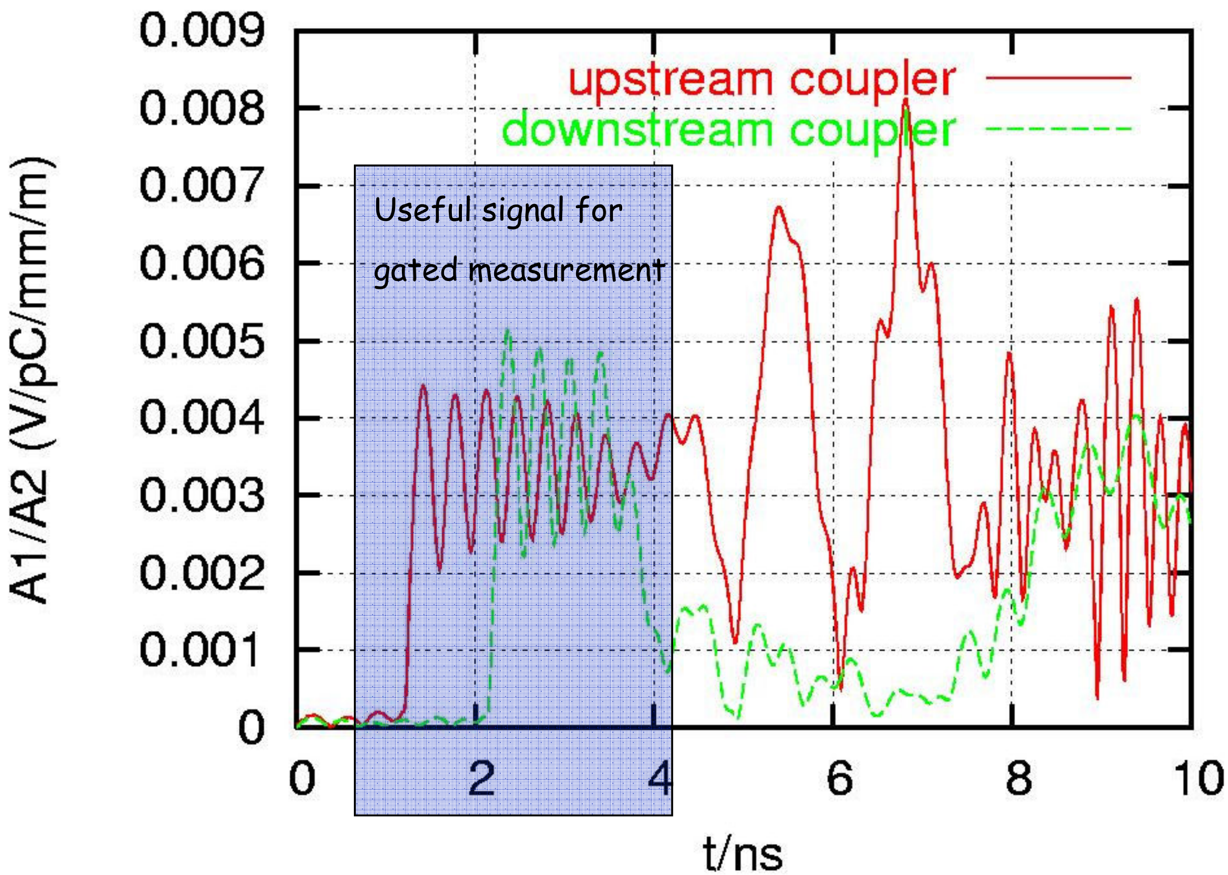


- As the beam passes cell 45, it will excite a backward wave at the synchronous frequency
- The wave will travel back to where this frequency has a phase advance of pi, where it is reflected
- From there it advances forward until it reaches the point with phase advance zero (cell 63..)

Wake signals from different cells (with their respective synchronous frequency) will arrive with a different delay at the coupler …

Alternative time domain measurement?

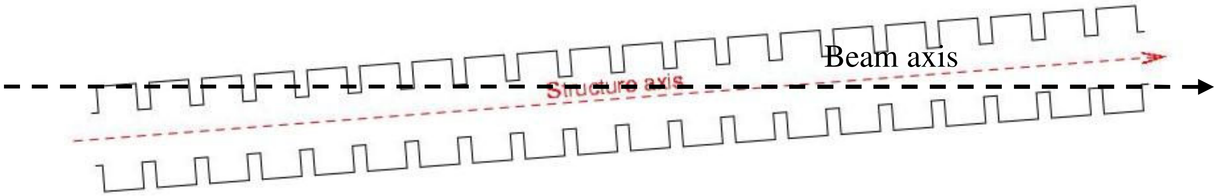
Signal envelopes of wake monitors

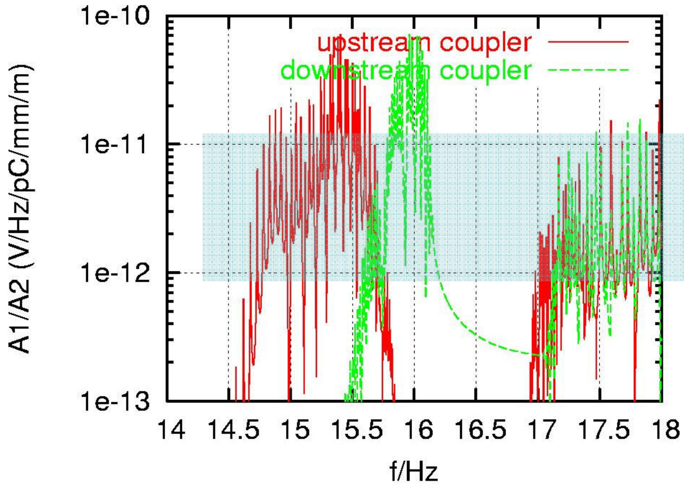


Signal at time t is correlated with frequency – is correlated with cell number…..

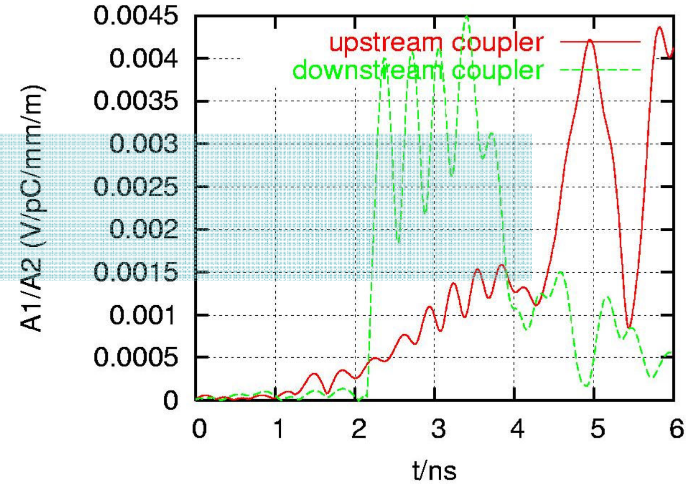
Can we learn something about internal misalignments?

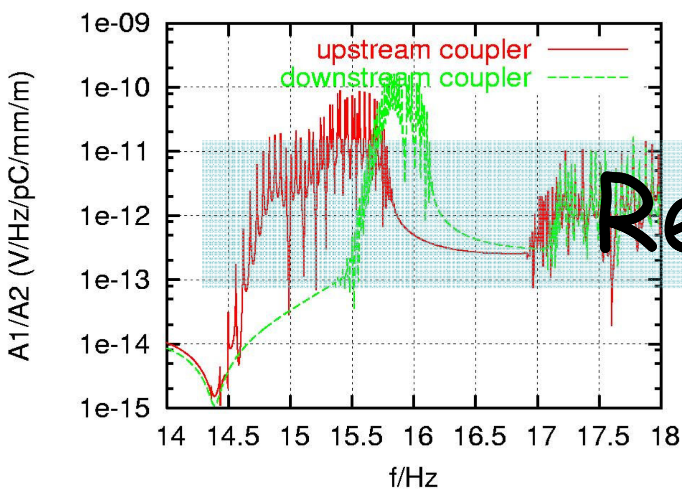
Structure tilt



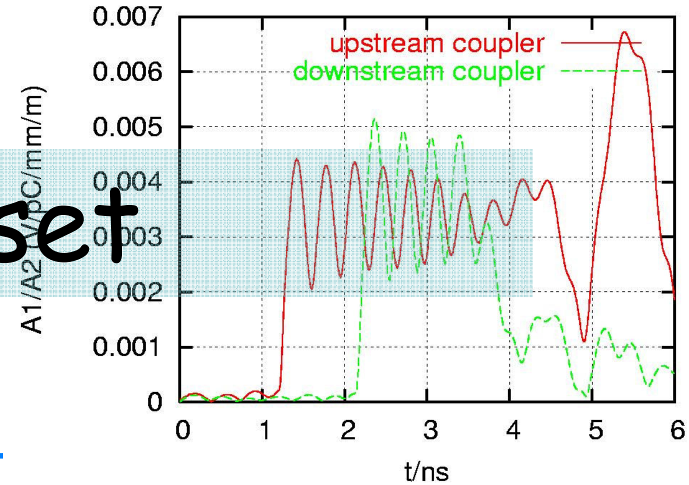


Tilted

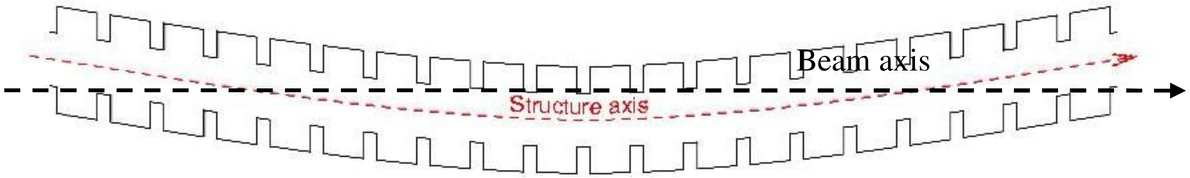




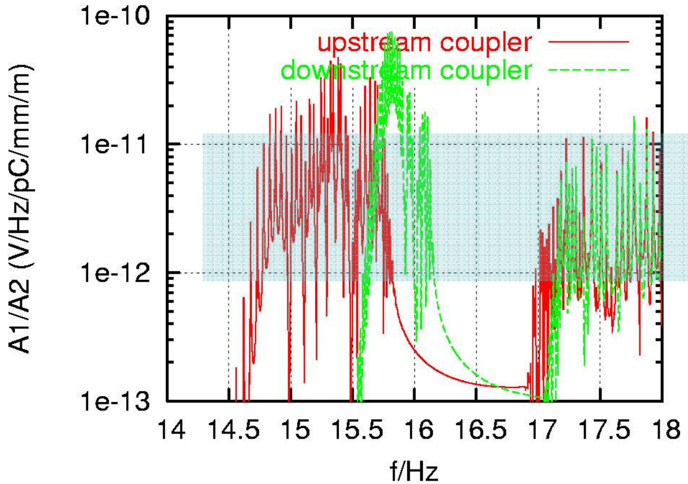
Ref. - offset

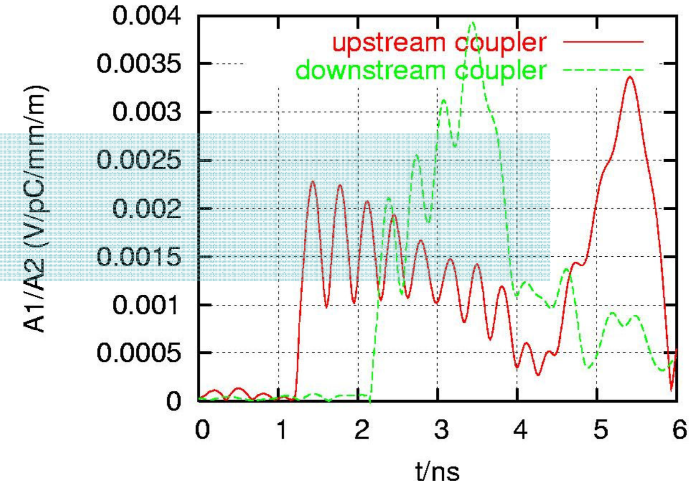


Structure bend

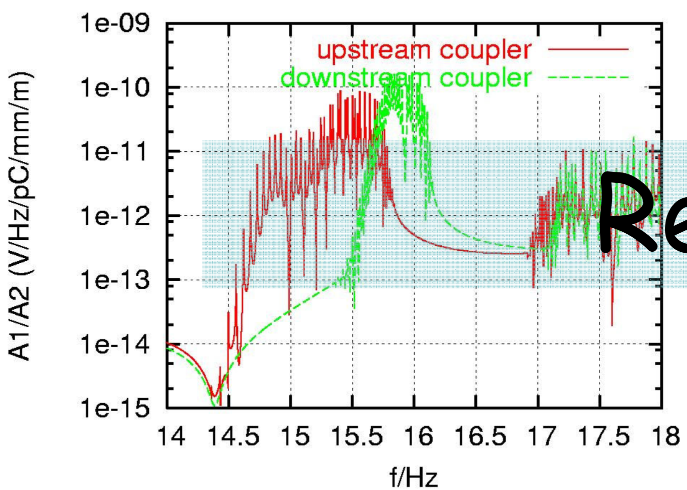


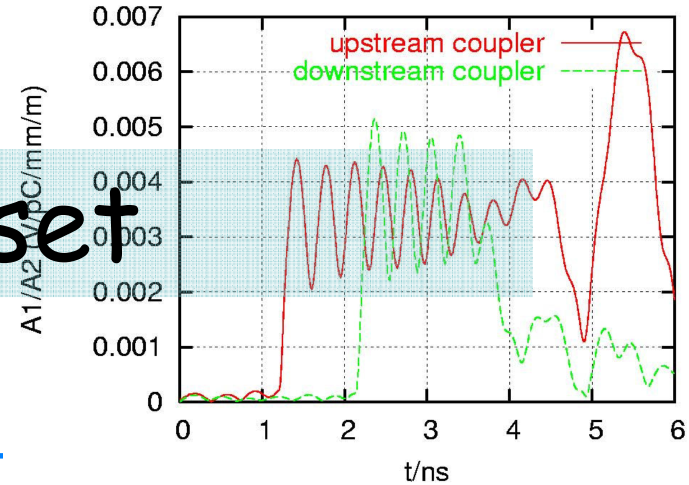
Bent





Ref. - offset

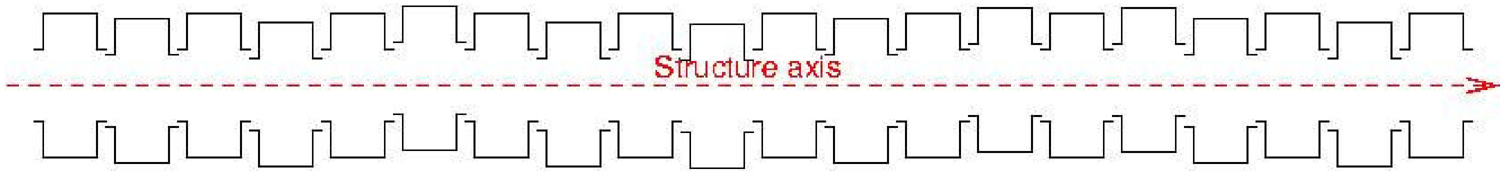




What could we expect as resolution?

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 plus (if still ncessary) additional filtering
- Random misalignment of individual cells:



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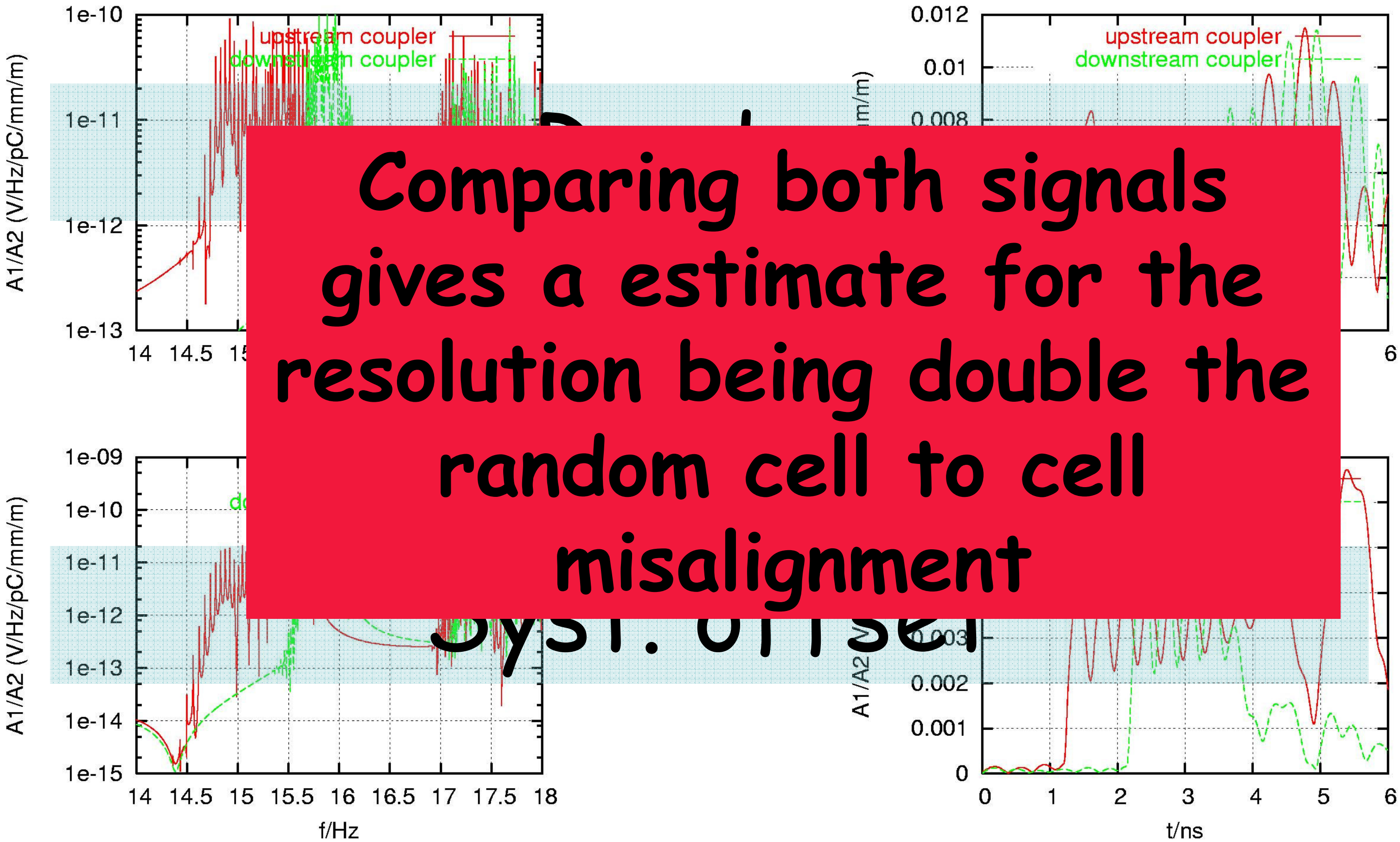
Comparing random misalignment to systematic offset



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

Summary

- Design for joint CERN/PSI/FERMI X band structure
- Special challenge transverse wake fields
  - 5π/6 design: open aperture, while efficient in terms of RF power
  - Wake field monitors
    - Separate decoupled signals for up and downstream part
    - Additional information from time domain envelopes of output signals
    - Forward feature: Resolution determined by internal structure alignment
    - Reverse feature: Noise floor in signal measures internal structure alignment
- In collaboration with SLAC to do validate circuit simulations using SLAC codes S3P/Tau3P
- In the process of fabricating structure (finished with RF/mechanical design, preparing for machining disks)
- Looking forward to tests with real beam ….