Studies of Dipole Mode Signals in Accelerating Structures

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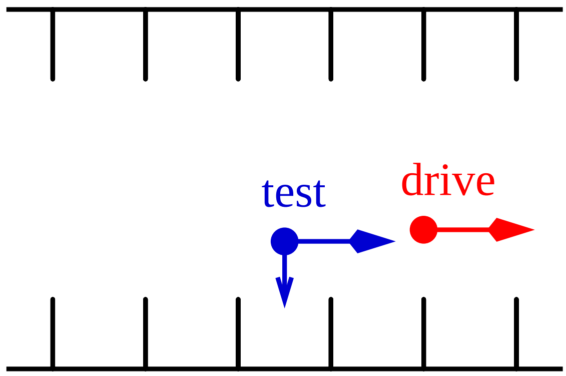
- Motivation, Principles . . .
- Application to S-Band Structures in the SLC
- Application to an X-Band Structure (ASSET experiment)
- Summary and Outlook

Motivation, Principles

- Transverse Wakefields in Accelerating Structures



drive particle off-center, deflection of test particle:

$$\theta_\perp(t) \propto W_\perp(t)\Delta x_d$$

Δx_d : drive particle offset

$W_\perp$: transverse wakefield

- wakefields dominate beam dynamics in linear accelerators

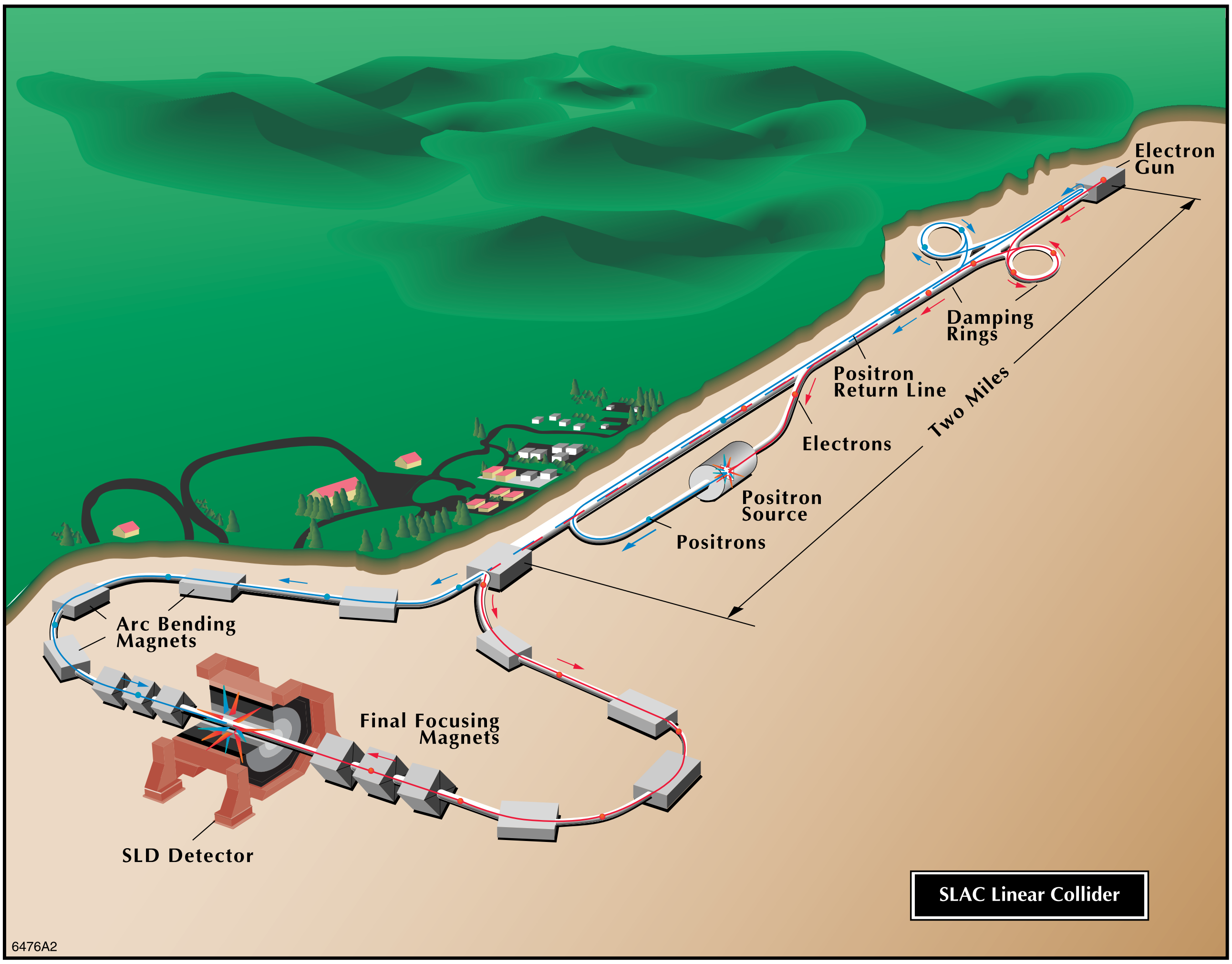
- structure scalings:
  high gradient $\rightarrow$ short wavelength $\rightarrow$ strong wakefields $\rightarrow$ tight tolerances

$$W_\perp(z \ll a) \propto z \left(\frac{a}{\lambda}\right)^{-4} \lambda^{-4} \propto f^3$$

$\Longrightarrow$ dipole-mode microwave-signals provide a direct measure for the beam offset in the frame of the structure

"ABSOLUTE" position measurement

Application to the SLC



- large scale linac, $\approx$ 900 ten-foot S-Band structures
- observe emittance growth of $\approx$ 30% in x, 100 – 200% in y while accelerating from 1.2 to 47 GeV
- Goal: ABSOLUTE beam position measurement in structures via dipole-modes without changing structures $\rightarrow$ simple access of signals

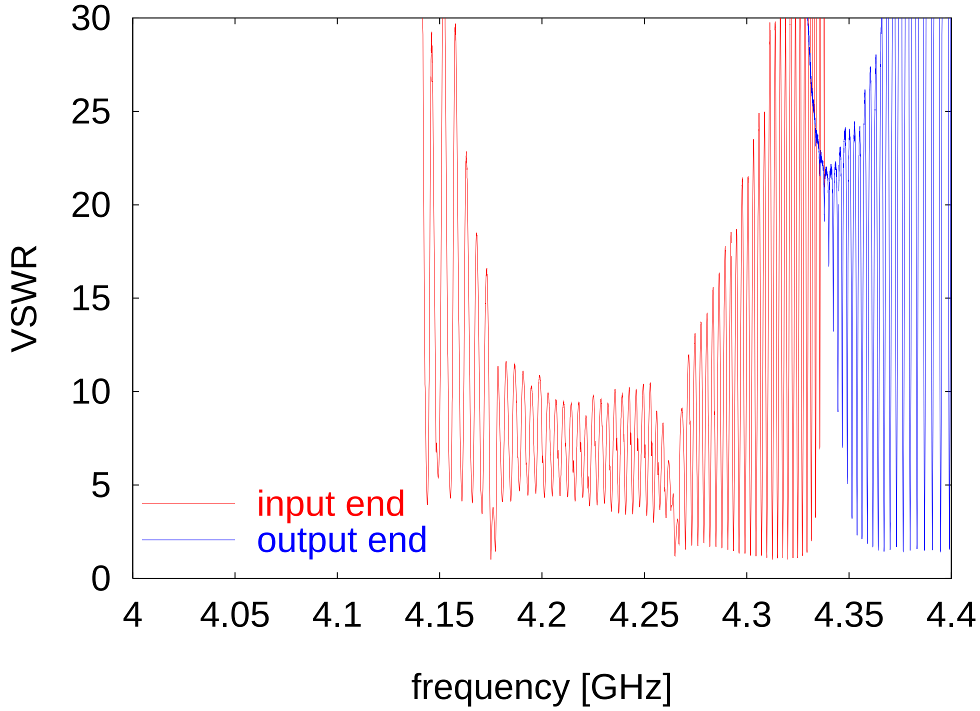
Signal Acquisition in the SLC

Layout of the SLAC Ten-Foot Structure

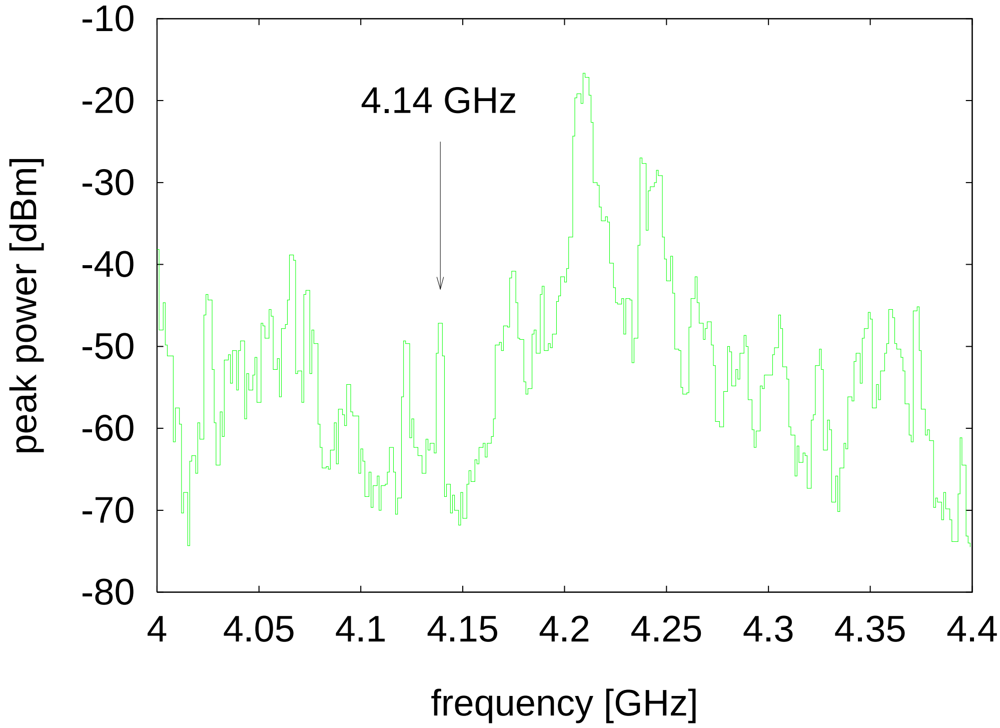
RF Power Distribution Scheme

Dipole Mode Spectrum

VSWR from Bench Measurements

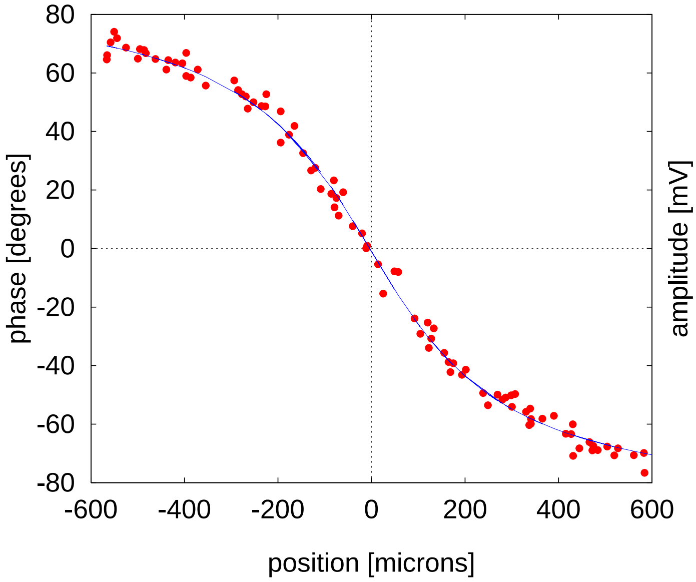


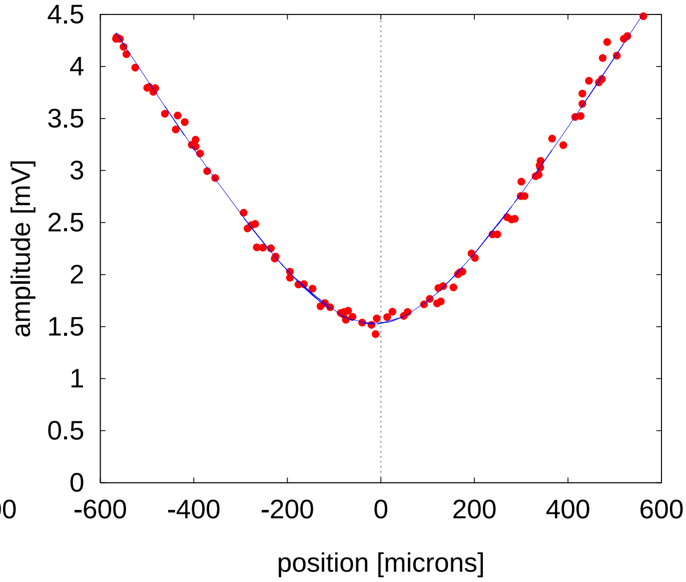
Observed Beam-Excited Spectrum



Phase and Amplitude Detection

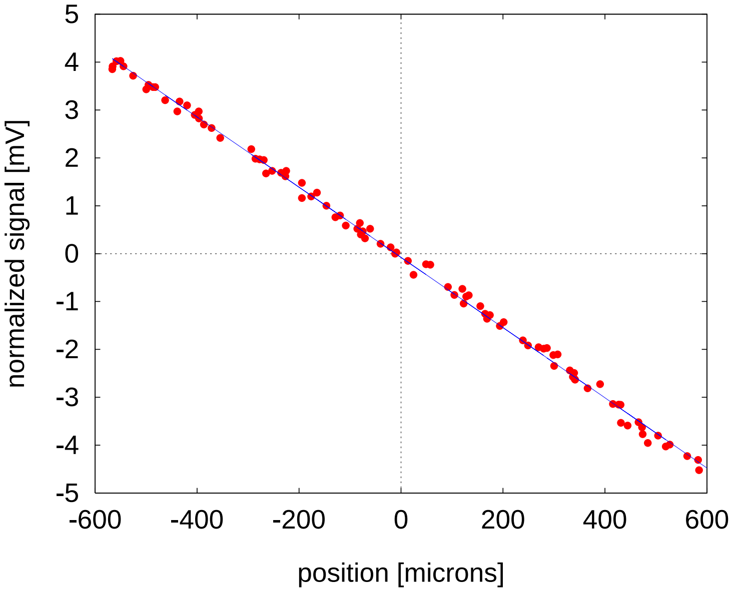
measure $\phi(x), \widehat{U}(x)$ $(f_0 = 4.139\text{GHz})$





$$\text{model}: \quad U(t) = A(x - x_0)\cos(\omega t) + B\cos(\omega t + \Delta\phi)$$
$$= \widehat{U}(x)\sin(\omega t + \phi(x))$$

linearize by computing: $\widehat{U} \cdot \sin(\phi(x)) = A(x - x_0) + B\cos(\Delta\phi)$



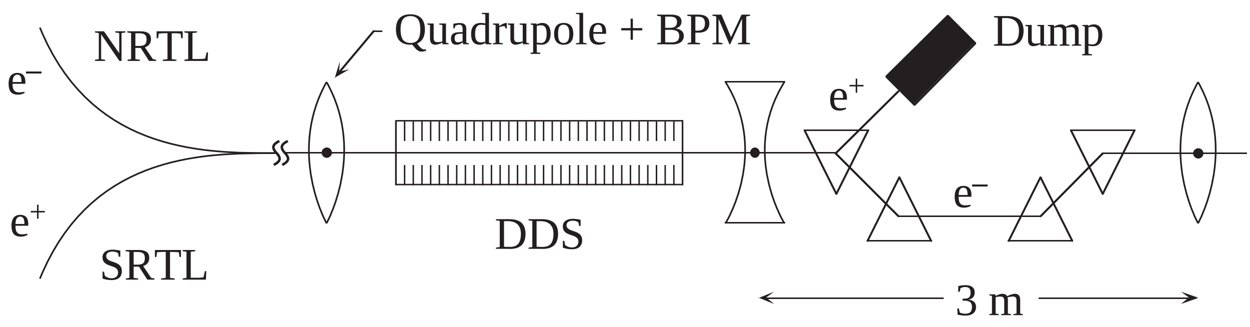
resolution from fit:
12 μm

$\Longrightarrow$ **resolution is good, however, out of phase component shifts measured center position (see also 9P.86)**

Test of an X-Band Structure in the SLC

Damped Detuned Structure (DDS)

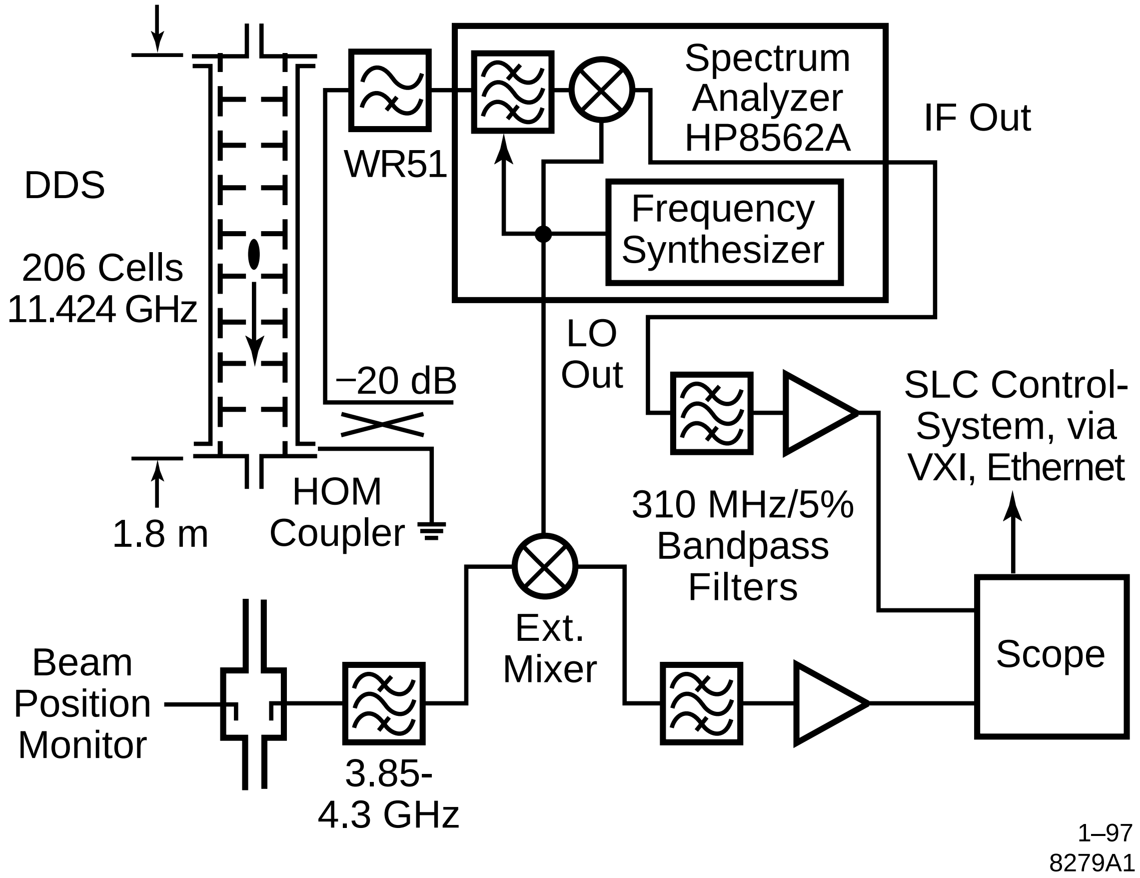
- X-Band (11.424 GHz), NLC prototype, 4 manifolds allow access of all dipole-modes (see also 5B.02, 3W.14, 5B.04)



Goals of the Experiment:

- study beam induced microwave signals
- infer wakefield directly by measuring the deflection of a trailing bunch
- combine both measurements to prove that wakefield is indeed minimal for minimal mode excitation

Processing Electronics for Microwave Signals



Possibilities:

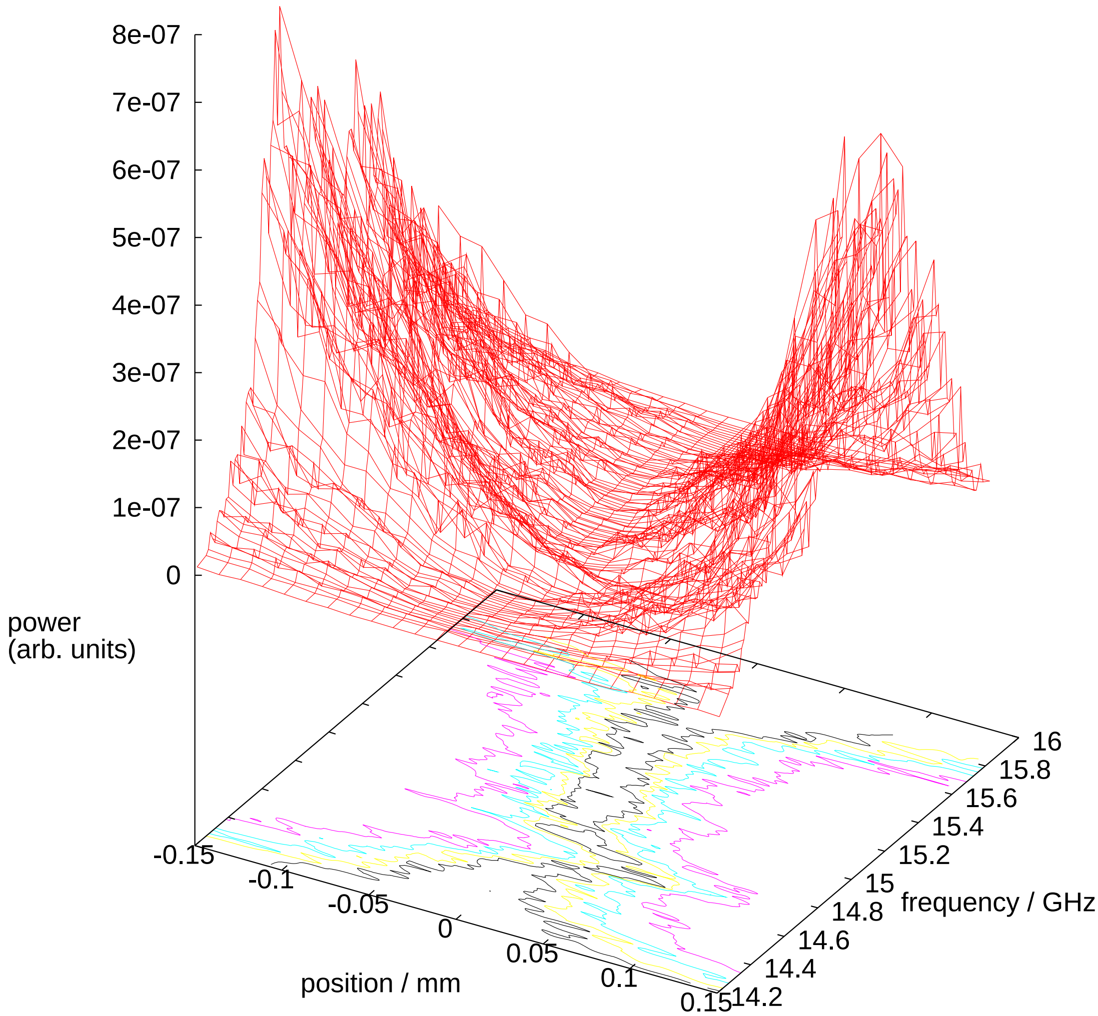
- study mode structure in range 10-50 GHz
- measure spectrum vs. parallel beam offset (power scans)
- amplitude and phase detection

Beam Based Structure Straightness Measurement

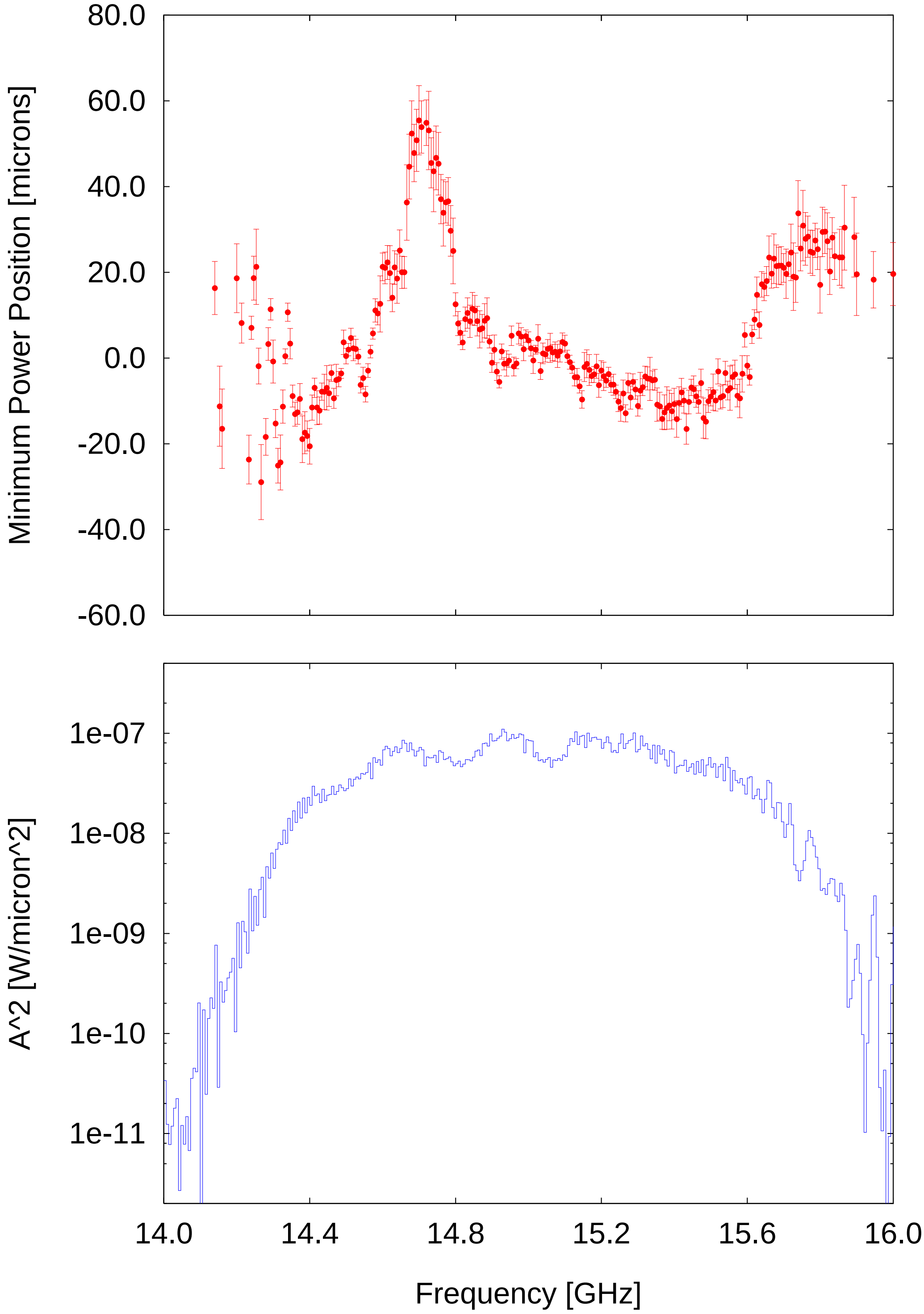
Method:

- move beam in parallel transversely across the structure and measure spectrum at each step
- fit parabolas to each frequency slice and obtain the *minimum power position* as a function of frequency
- convert frequency scale into cell positions

Power as Function of Frequency and Beam Position

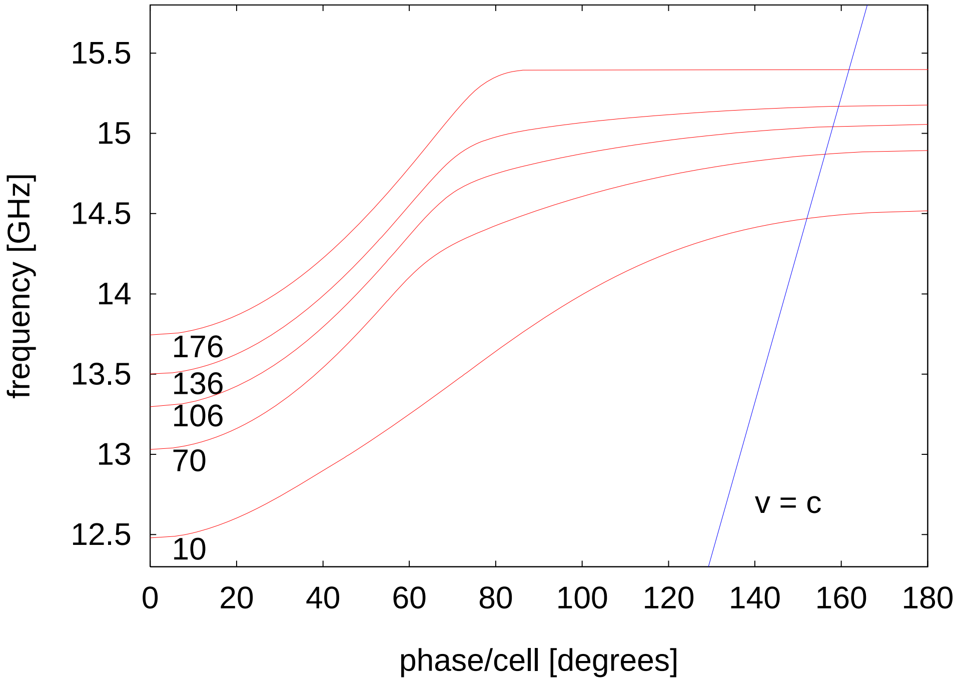


Power Parametrization: $P(\nu_n, y_k) = A_n^2 (y_k - y_n^{\rm min})^2 + B_n^2$

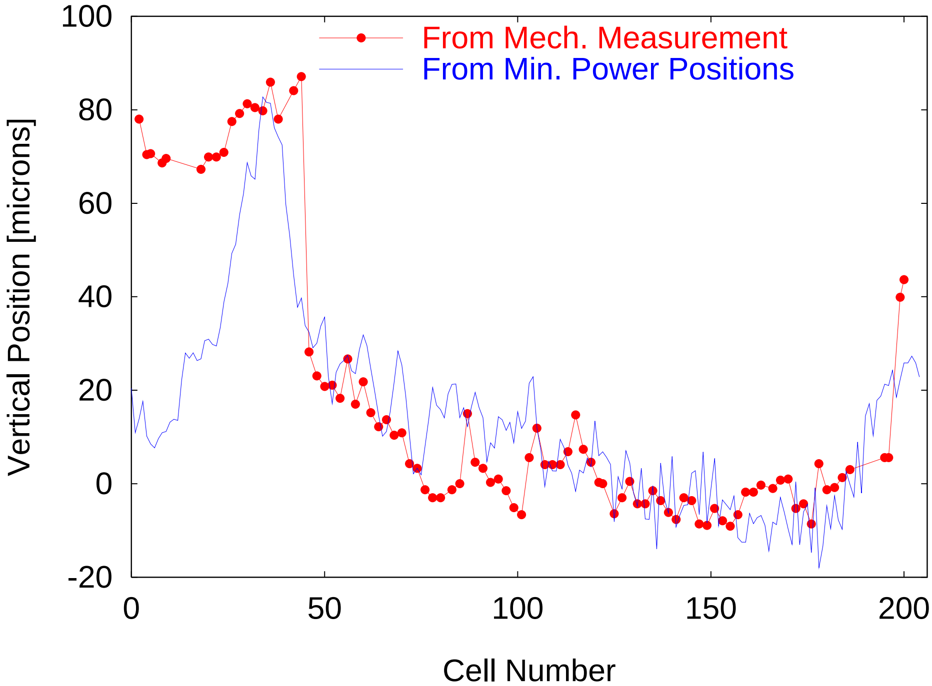


Conversion of Minimum Power Positions into Cell Positions (see also 3W.16)

qualitative picture - Brillouin curves for dipole modes



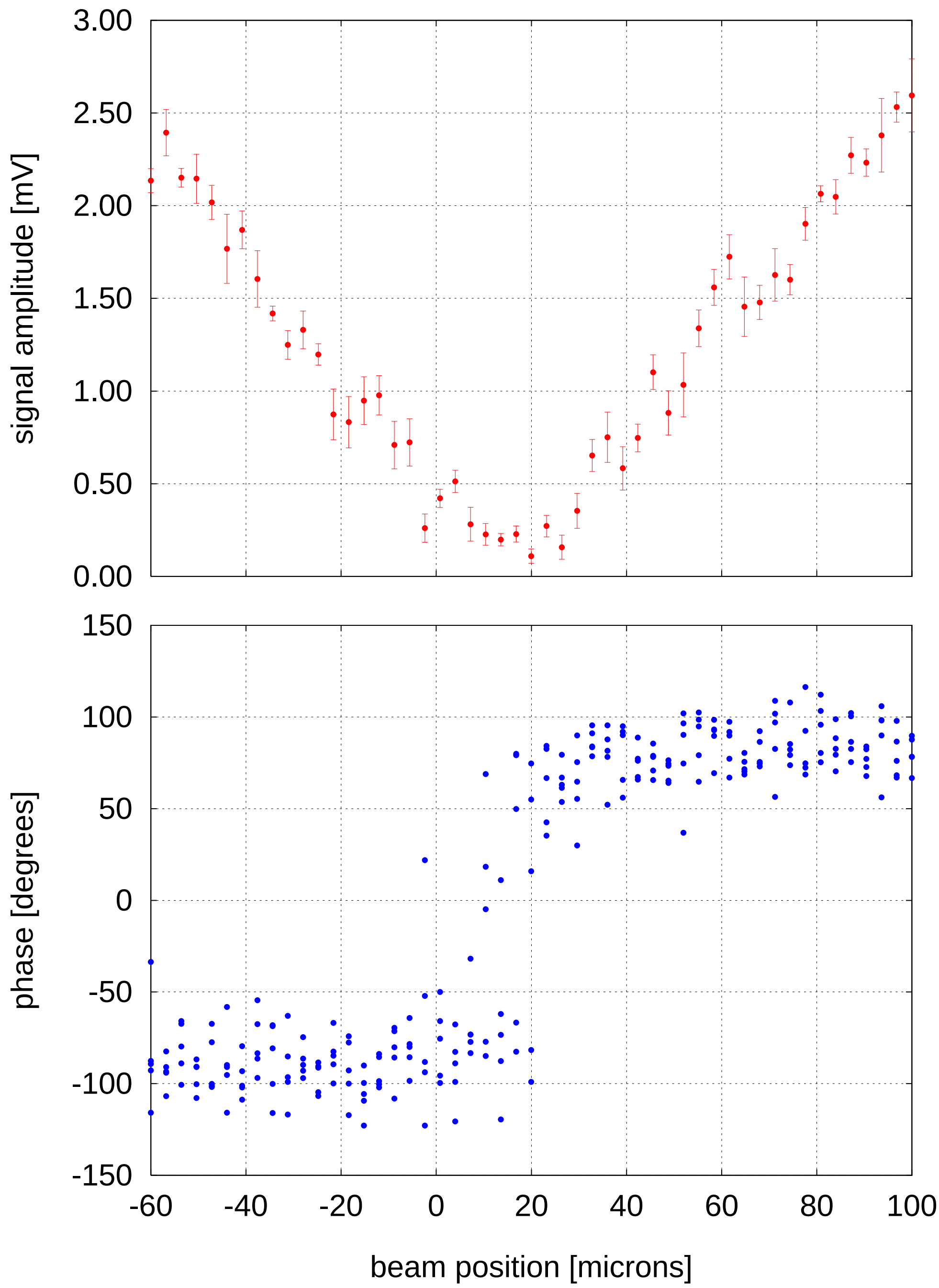
comparison with mechanical alignment measurement



Two Mode Beam Steering Using Phase and Amplitude Detection

⟹ use two modes, located at entrance and exit of structure, to align beam both in position and angle

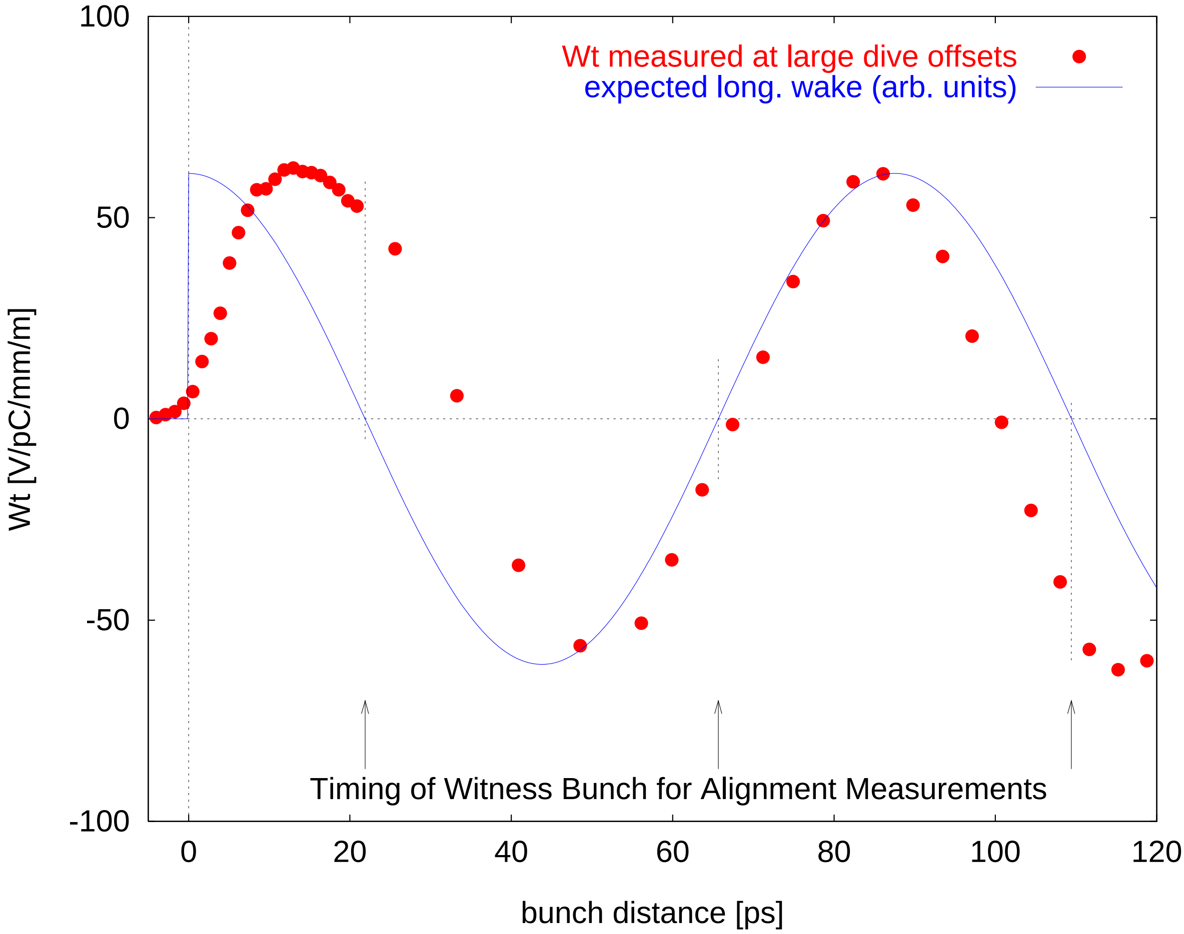
<u>example for amplitude and phase vs. beam position</u>



Verification of Alignment with Witness Beam Deflection Measurement

Method:

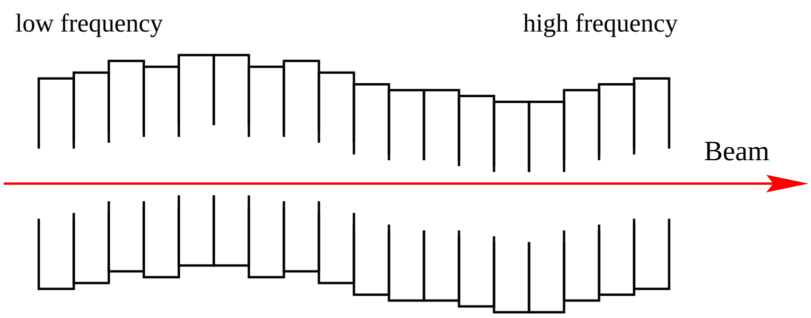
- center drive beam (e^+) using the described methods
- add witness beam (e^-) and measure its deflection
- sample wakefield curve such that beam-loading (long. wake) is suppressed
- fit sine-function to three points; convert amplitude into effective offset for drive beam



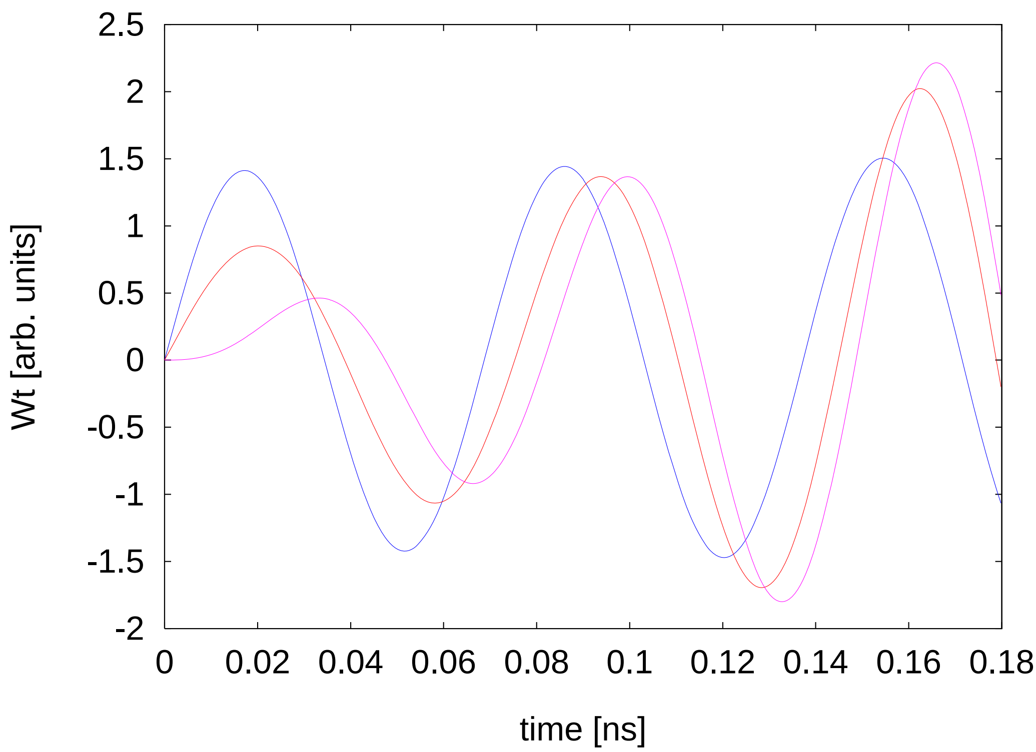
Effect of Internal Misalignments - Beating

Observation:
For small drive beam offsets we observe frequency/phase shifts in the wake function

different frequencies beat against each other

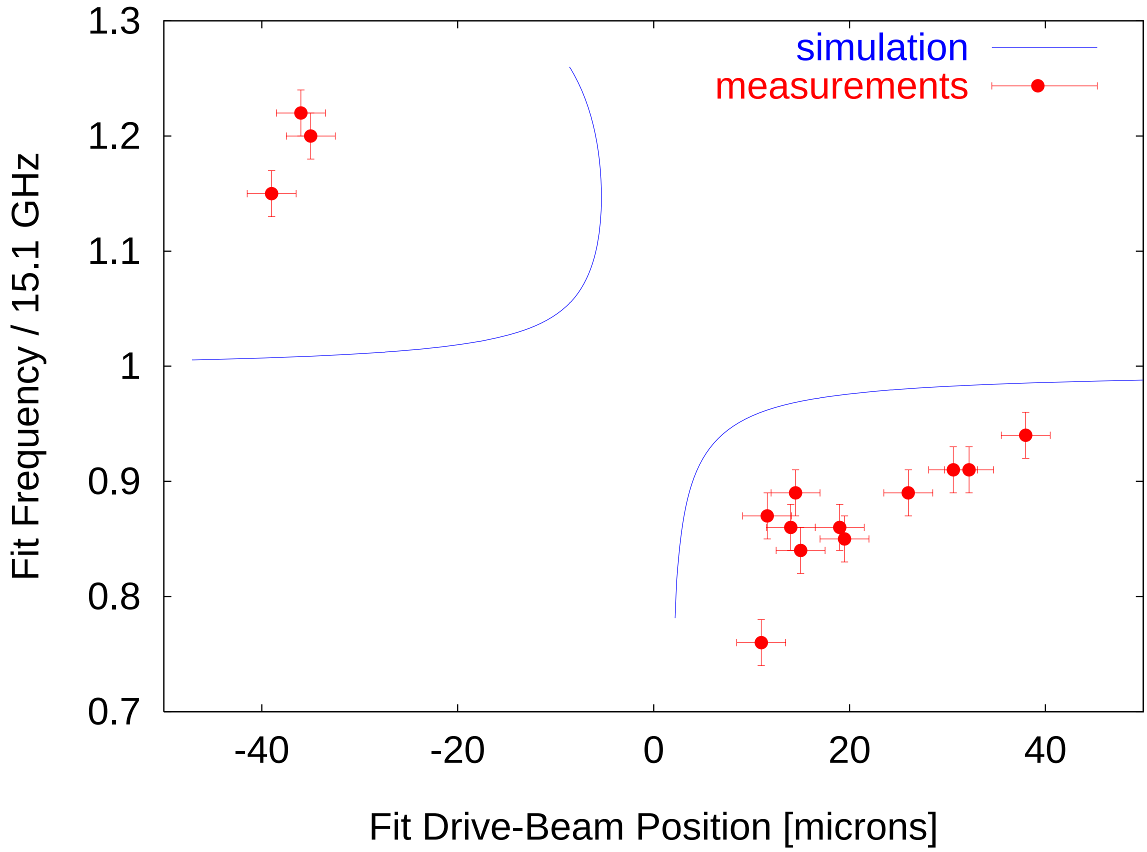


resulting wake-function for different beam positions



Results . . .

Inferred wakefield frequencies and drive beam offsets for several attempts at centering the drive beam.



$\Longrightarrow$ achieved alignment precision better than 40 μm

Summary

Dipole-mode based beam steering is a promising technique to control transverse wakefields, especially in high frequency accelerators.

SLC S-Band:

- 12 μm resolution demonstrated in two powered structures
- accuracy suffers from interference effects; dedicated studies in sector 2 using signals from individual structures are planned

NLC X-Band (DDS):

- accuracy of $<$ 40 μm achieved in an unpowered structure; limited by internal misalignments
- DDS design demonstrates: dedicated HOM couplers are important; access to all modes via manifolds is helpful; allows in situ straightness measurement of structure

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