Wake-fields and Beam Electrodynamics

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Wake-fields and HOM beam dynamics for the ILC:

- 1. Main linac e.m. field and beam electrodynamics simulations for ACD high gradient cavities
- 2. Globalised matrix technique of cascading
- 3. Review of x-y transverse coupling
- 4. Crab cavity wire simulations and measurements
- 5. HOM measurements at FLASH (FP7)




Personel

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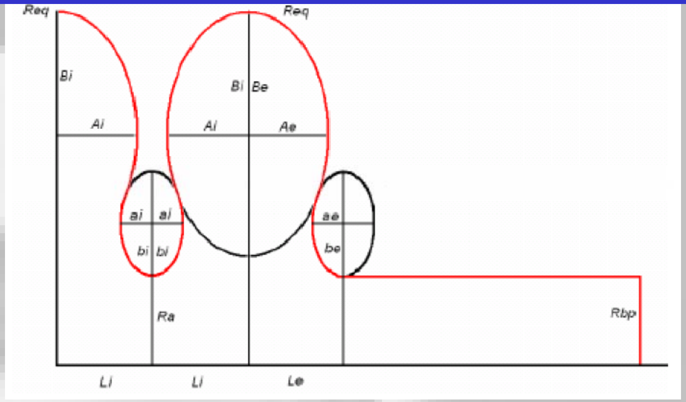
Collaborators: Nicoleta Baboi (DESY), Steve Molloy (SLAC), Toshiyasu Higo, Kenji Saito, (KEK), Hasan Padamsee (Cornell Univ.), Amos Dexter, Richard Carter (Univ. Lancaster), Roger Barlow (Univ. Manchester)

A Few Points Lifted From BCD Document

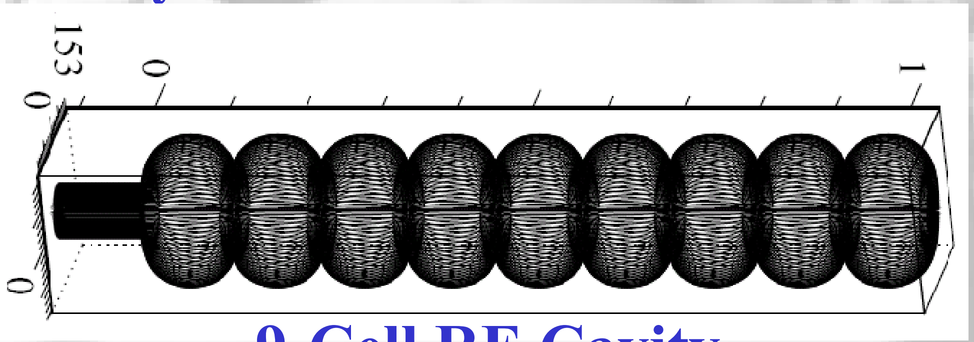
- **“Modifications/ variants of re-entrant:**
- smaller aperture re-entrant
- half-re-entrant.
- **Required R&D**
- Considerable R&D will be required and different check points:
- ***Wake fields:***
  - ***The allowed iris diameter must be specified from theoretical analysis. This is a trade off between allowable emittance growth (luminosity) and cost.***
  - ***Complete wake field analysis must be carried out computationally and checked with measurements.***
  - ***Cold tests of wake fields must be carried out on two or more adjacent cavities.***
  - ***Wake fields must be checked in modules with beam [trapped modes and influence of fabrication errors must be checked].***
- Gradient and Q:
  - Gradient and Q expectations up to at least 35MV/m must be achieved first in 9-cell cavity tests then in modules with beam.
  - ***…. Instrumenting the HOM readouts to provide a measure of the average beam position in the cryomodules. To better center the beam, the cryomodules would either be moved manually during down periods or equipped with remote-controllable movers to allow corrections during machine operation….”***

1. HOMs in Re-Entrant Cavity

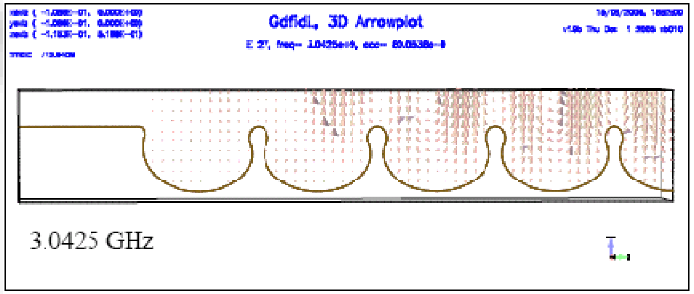
Cornell Single-Cell RE Cavity

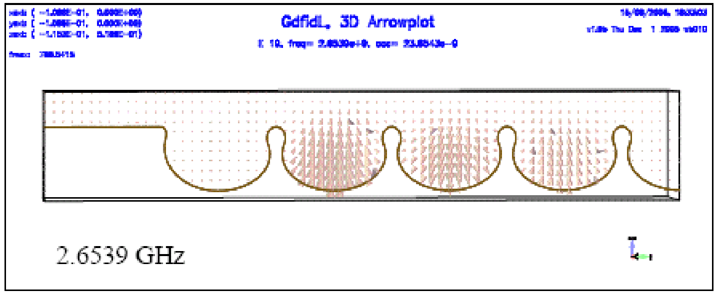


Parameters for GdfidL Simulations



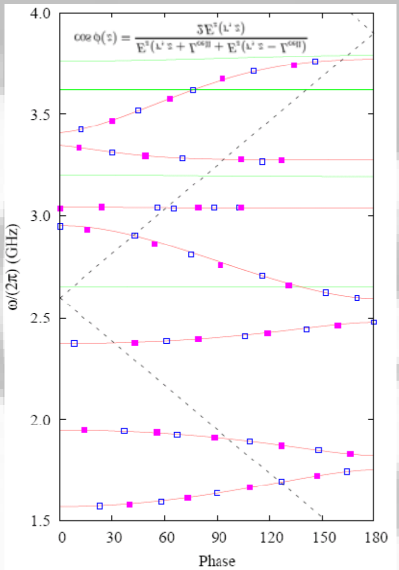
9-Cell RE Cavity





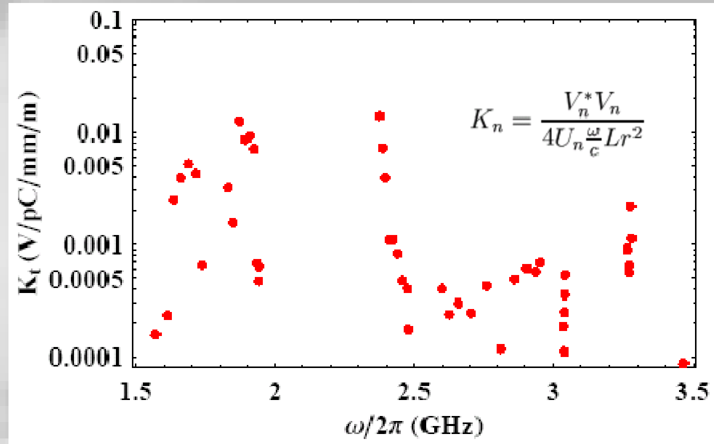
Simulations of Trapped Modes in RE Cavities

1. HOMs in Re-Entrant Cavity

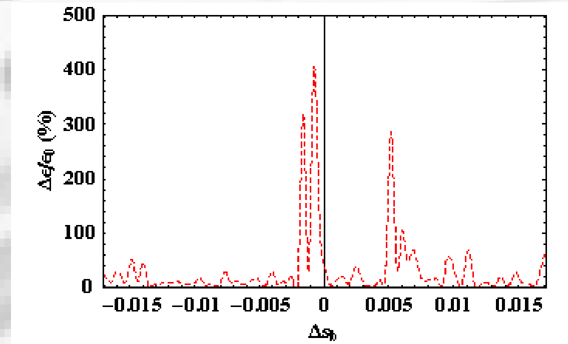


Brillouin Diagram
For RE Cavity

- ➢Solid line correspond to single-cell infinite periodic structure
- ➢Circles correspond to simulations made with 9 cell cavity (4.5 cells with E-wall and H-wall simulated separately)

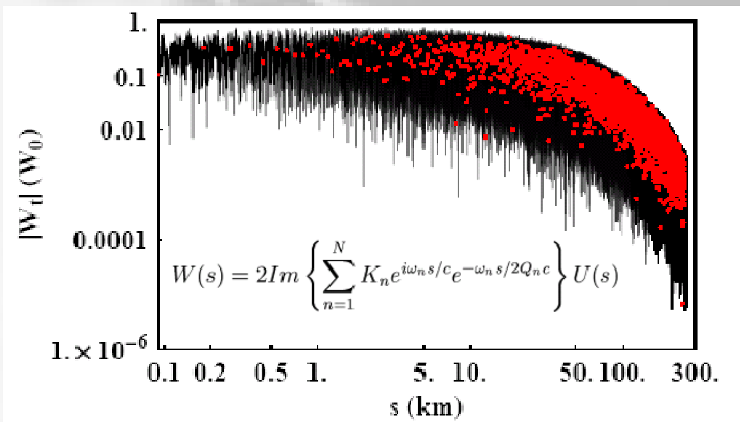


Multi-Cell Kick Factors



- ➢A small change in the bunch spacing (corresponding to a systematic error in the cels freqs) results in disturbingly large emittance dilution.

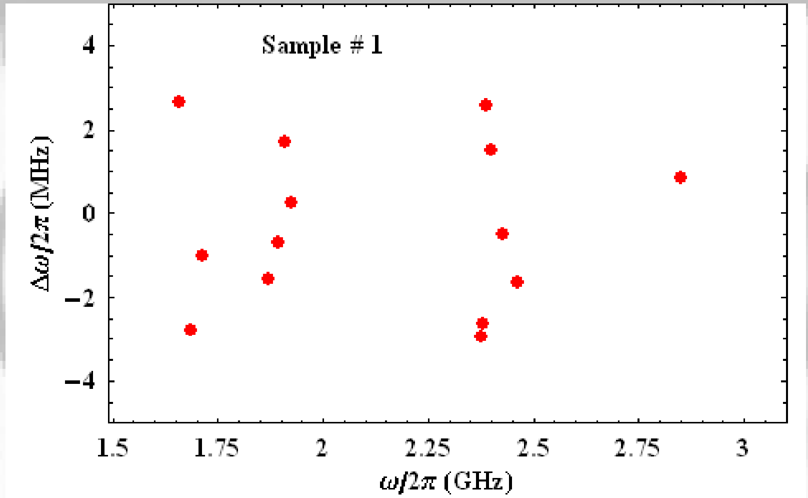
Emittance Dilution Vs Percentage Change In Bunch Spacing



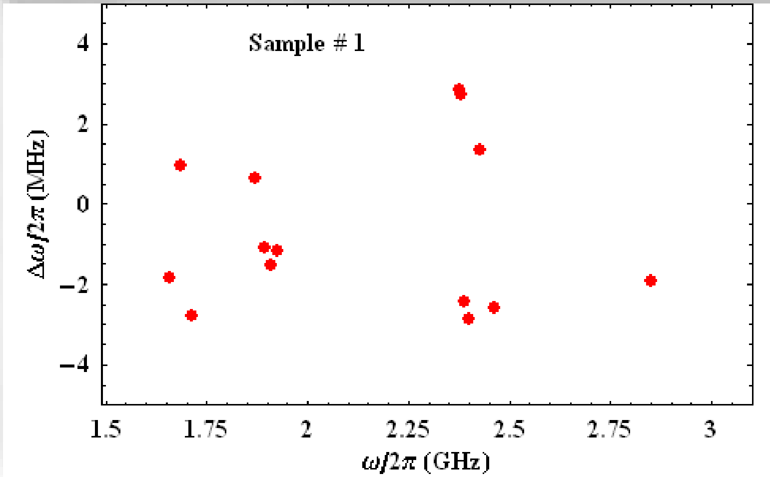
Wake-field Along Bunch Train

For details see Jones et al, Linac 2006

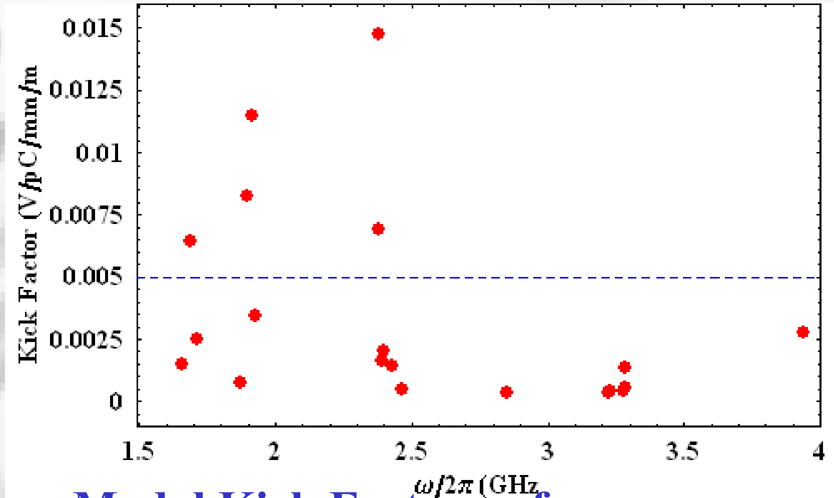
1. HOMs in Re-Entrant Cavity



Eigenfrequency error sample at Q~10^6

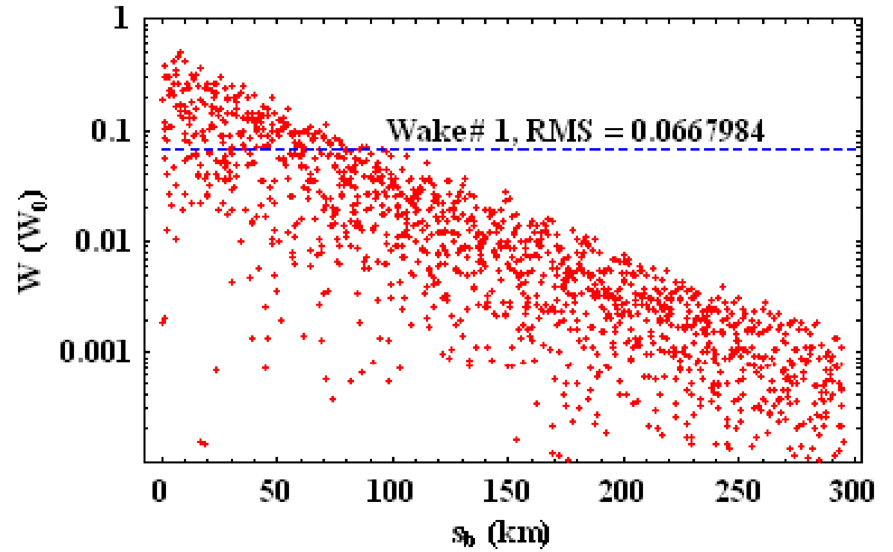


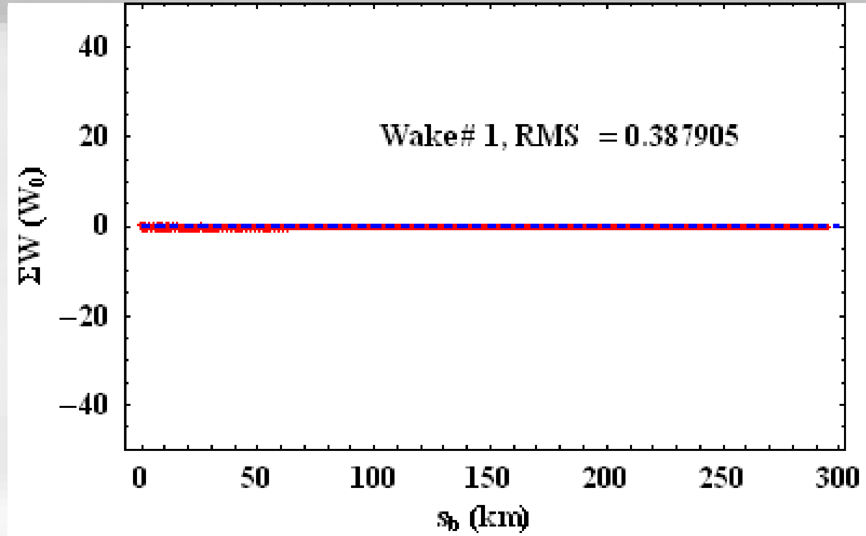
Eigenfrequency error sample at Q~10^5



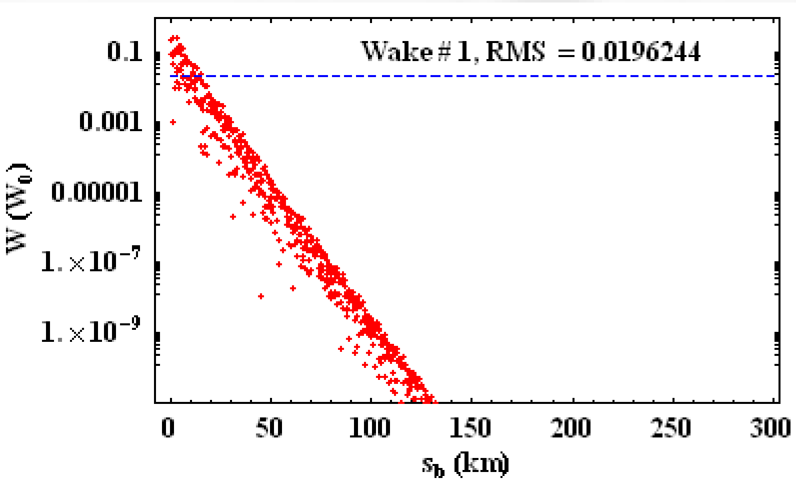
Modal Kick Factor vs frequency

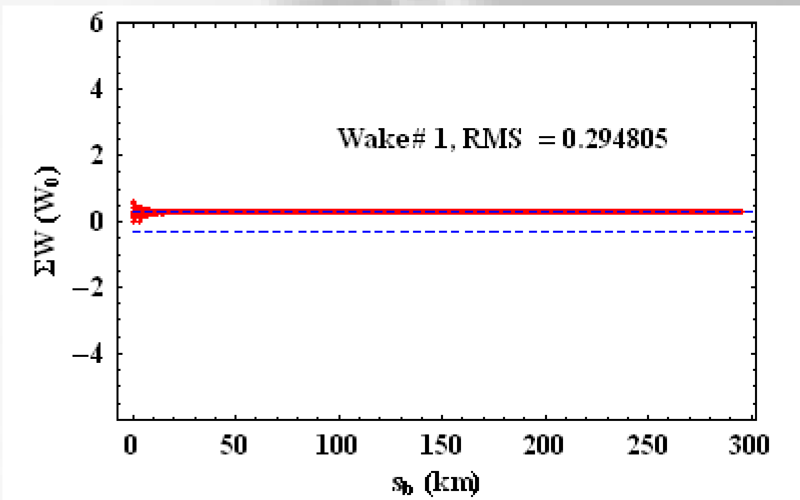
1. HOMs in Re-Entrant Cavity





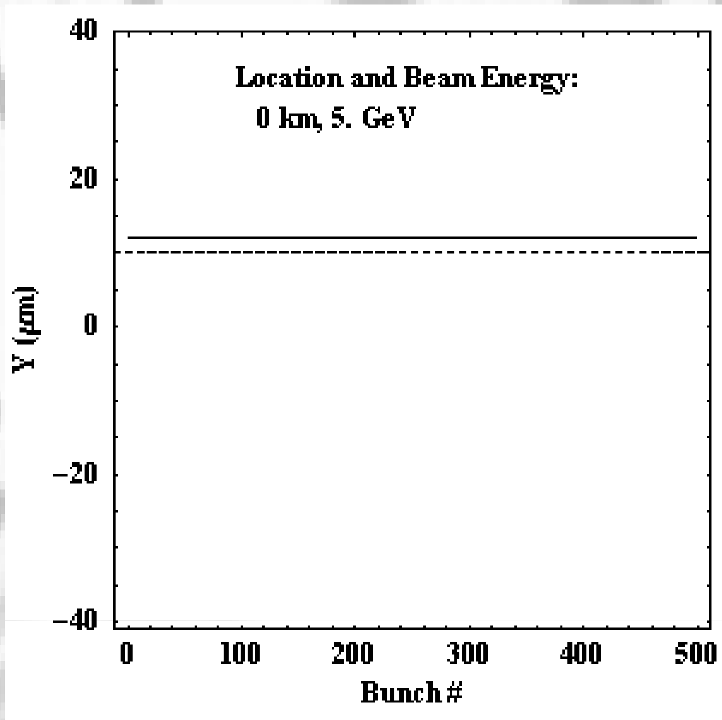
Amplitude of wake at bunch and corresponding sum wakefield for a Q of 10^6



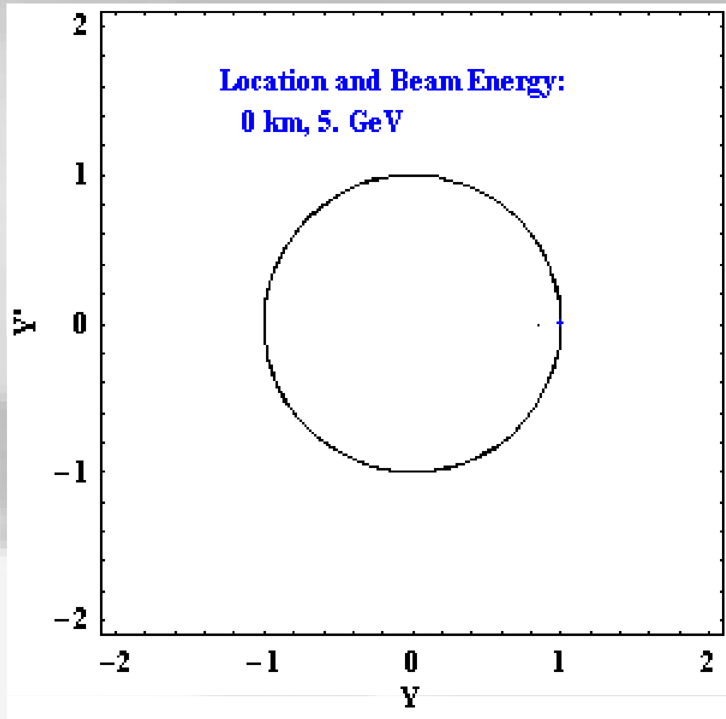


Amplitude of wake at bunch and corresponding sum wakefield for a Q of 10^6

1. Beam Dynamics in Re-Entrant Cavity

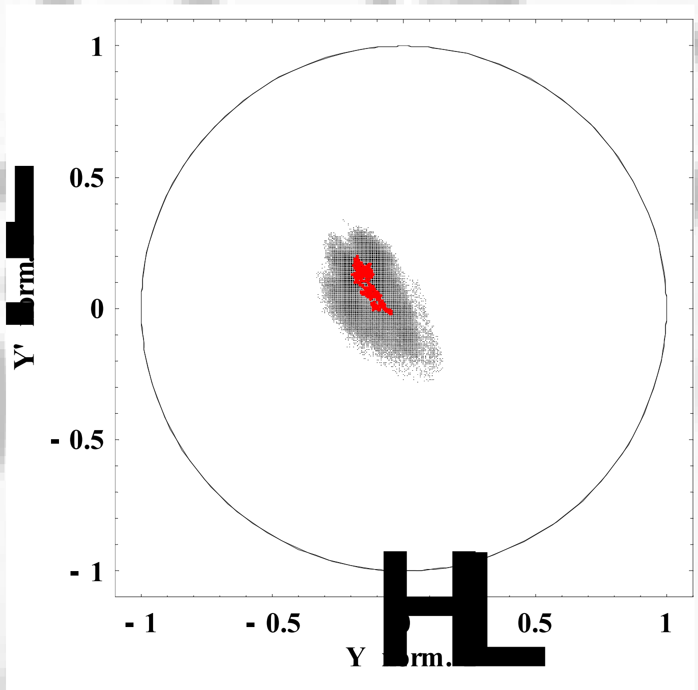


Transverse Displacement

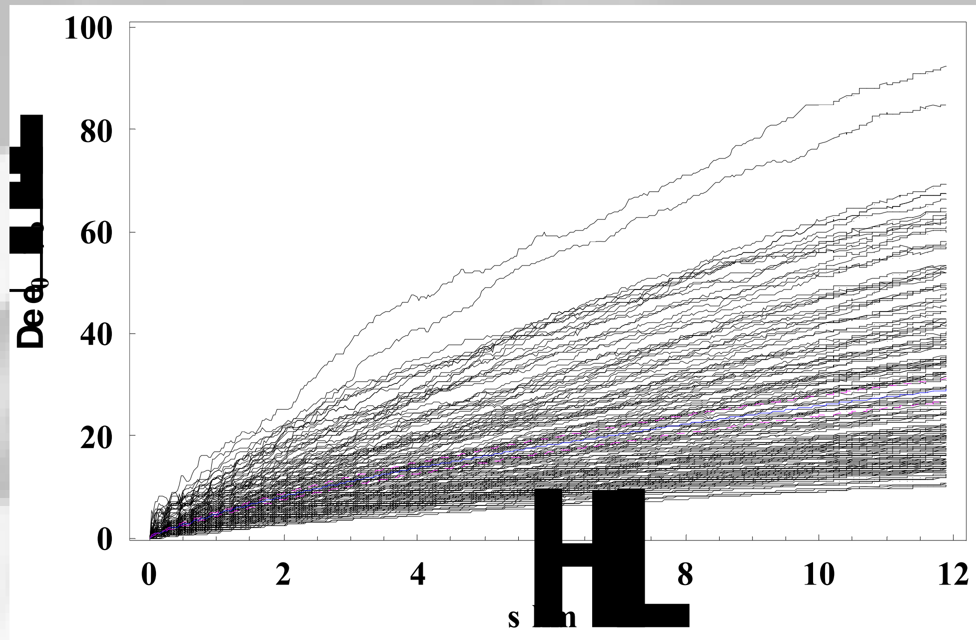


Phase Space: y-y'

- 500 particles in all simulations
- Initial vertical and horizontal offset 12 μm (~ σ_y) and 0 (~ σ_x), respectively.
- **Long range wakes included in simulations**

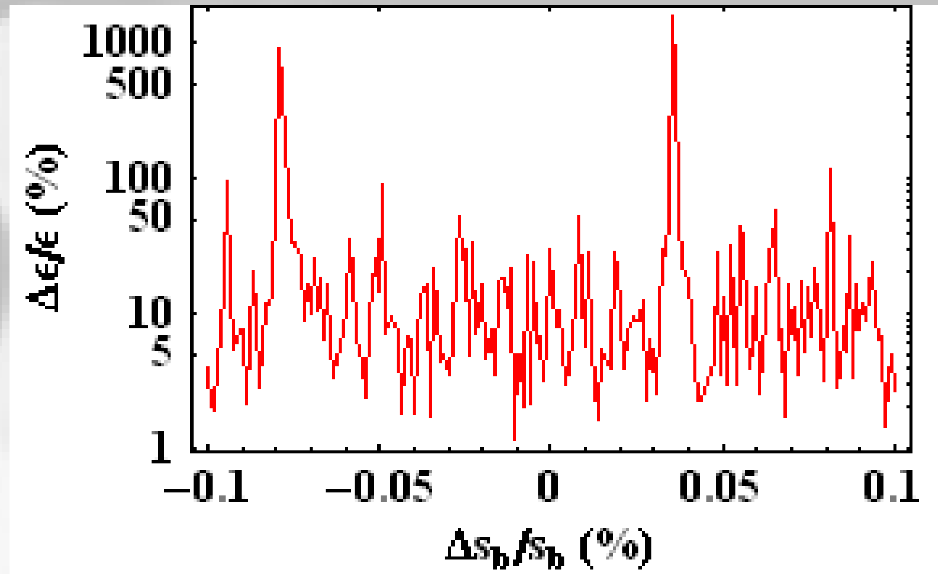


Y-Y' phase space at end of linac

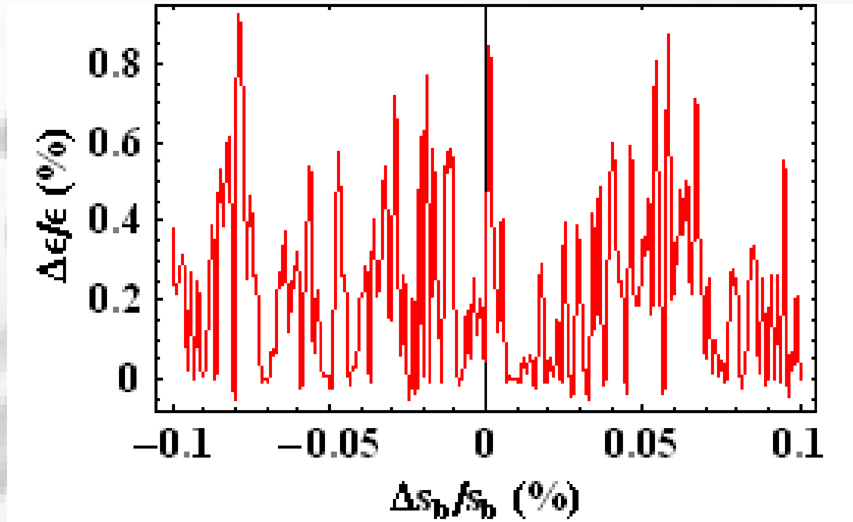


Emittance dilution due to long-range wake-fields damped with a Q of 10^6 in Re-entrant cavity. The beam is offset with $1\sigma_y$ (~12.4 μm).
The mean dilution is 17.25 % (with a standard error of .25 %). 200 machines are indicated together with the mean and the 95% confidence level.

1. Beam Dynamics in Re-Entrant Cavity



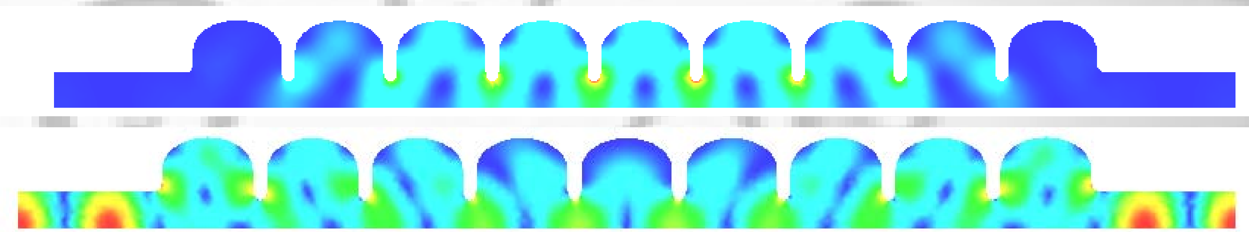
Emittance dilution due to long-range wake-fields damped with a Q of 10^6



Emittance dilution due to long-range wake-fields damped with a Q of 10^5

1. HOMs in Ichiro Cavity

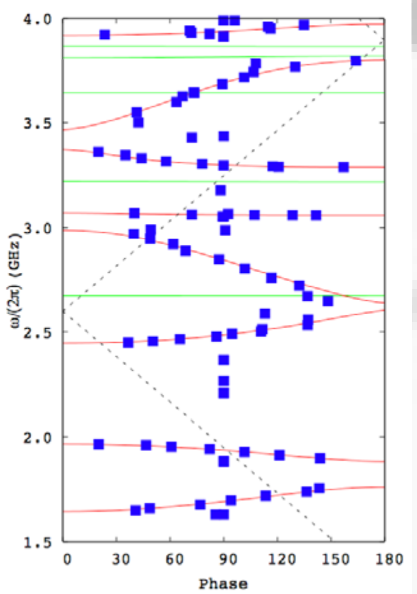
Ichiro Cavity fabricated at KEK



Trapped mode ~2.4498GHz

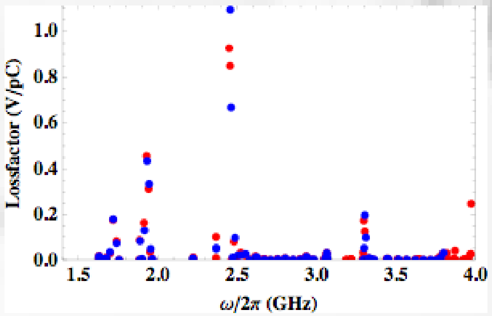
Multi-cavity mode ~2.6420GHz

Simulations of E-field of the 3rd band modes in Ichiro cavities



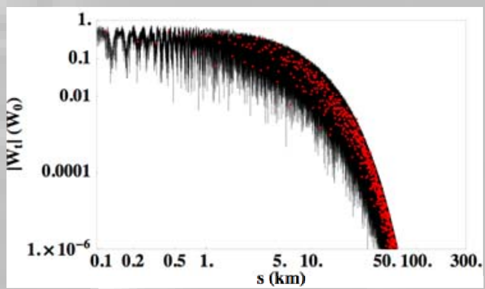
Dispersion curves of first 8 dipole and 5 sextupole bands

See Glasman, Jones et al. SRF2007 pubs.

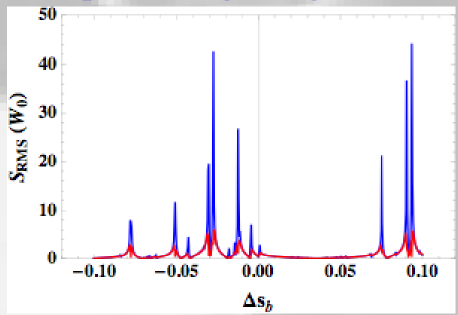


Comparison of Loss factors calculated with GdfidL (red) and MAFIA 2D (blue)

Detailed studies conducted on HOMS in Ichiro cavity. Sensitivity to systematic changes in frequency investigated. Detailed comparison of codes –MAFIA,HFSS, GdfidL, Analyst.

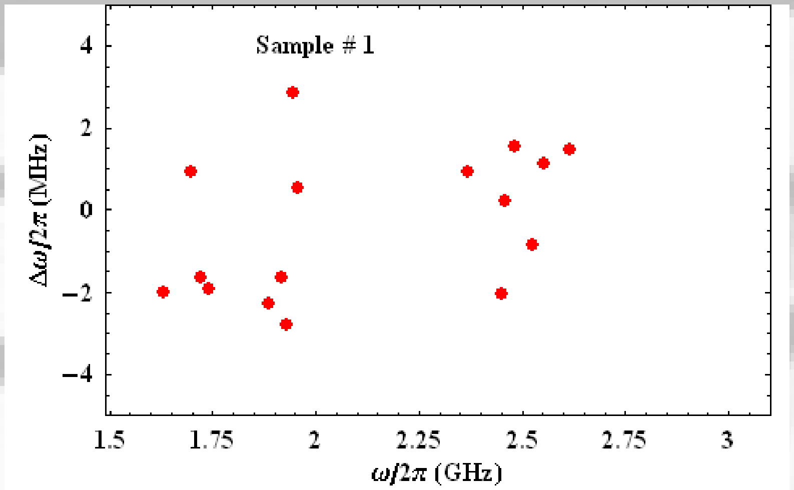


Envelope of long-range wake-field

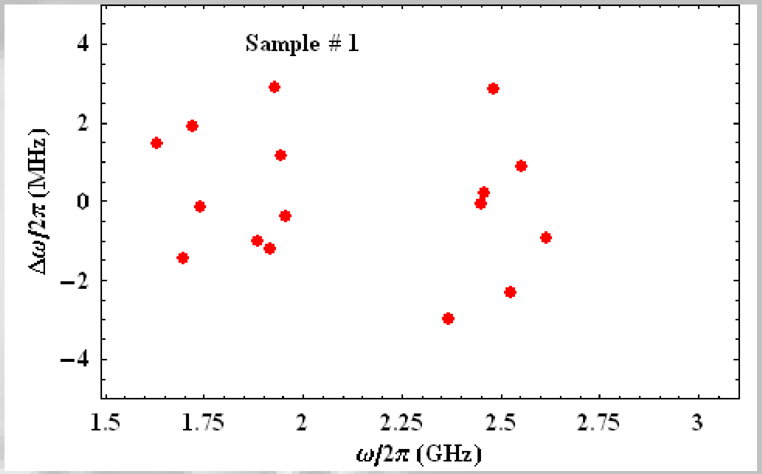


Sensitivity of RMS wake to small changes in bunch spacing

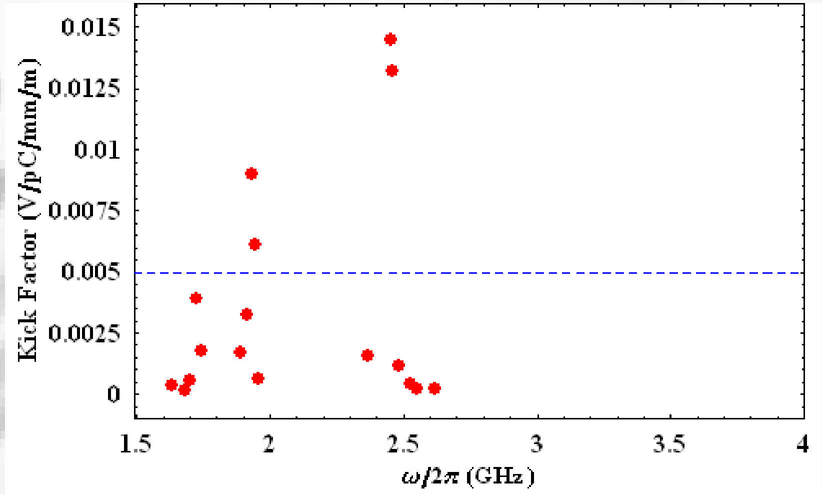
1. HOMs in Ichiro Cavity



Eigenfrequency error sample at Q~10^6

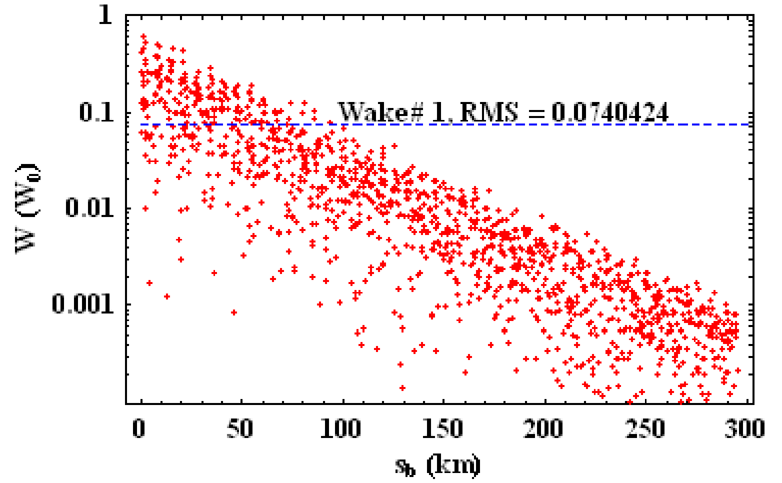


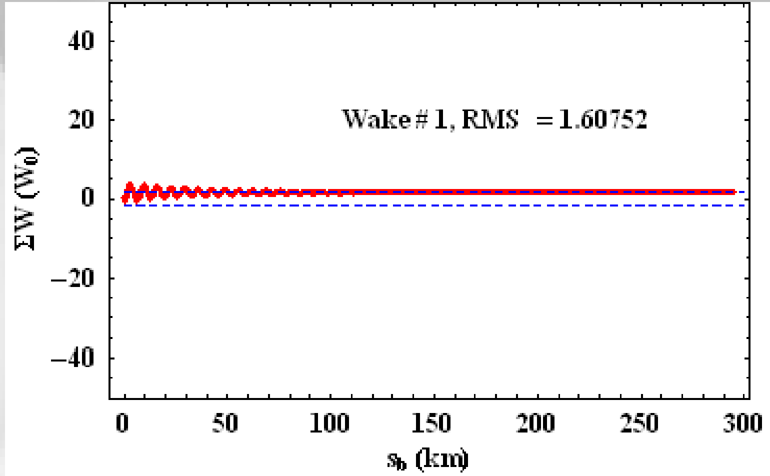
Eigenfrequency error sample at Q~10^5



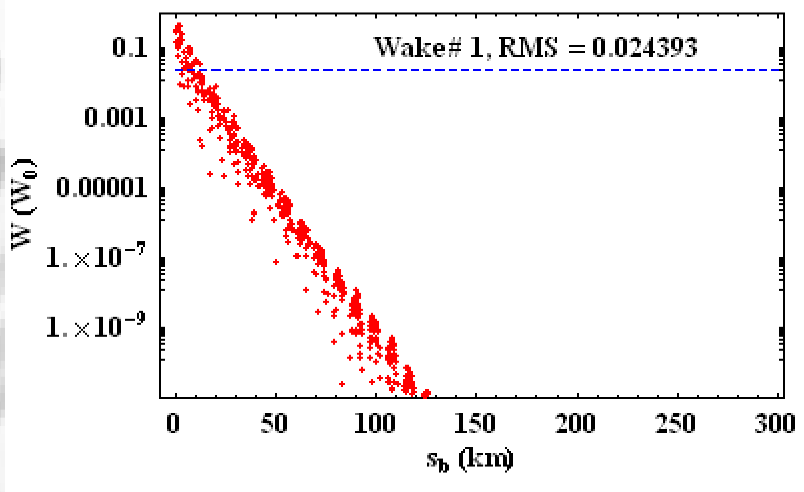
Modal Kick Factor vs frequency

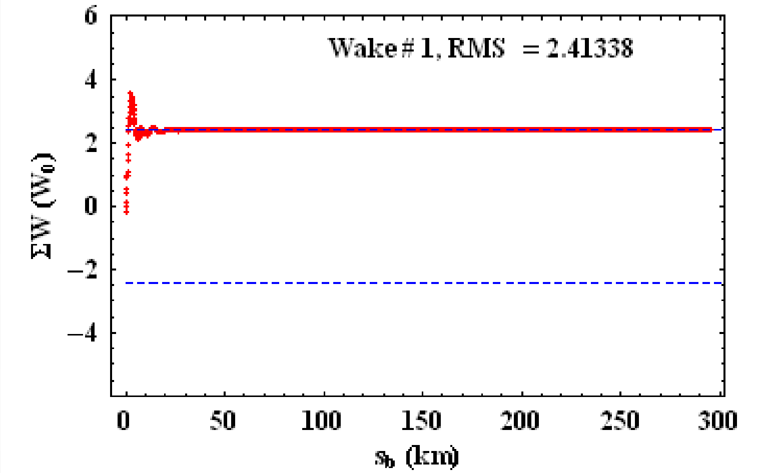
1. HOMs in Ichiro Cavity





Amplitude of wake at bunch and corresponding sum wakefield for a Q of 10^6





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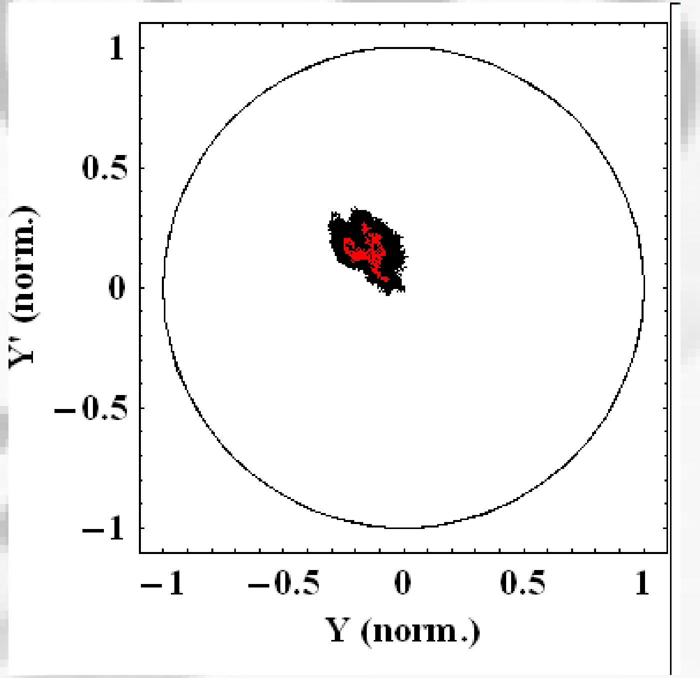
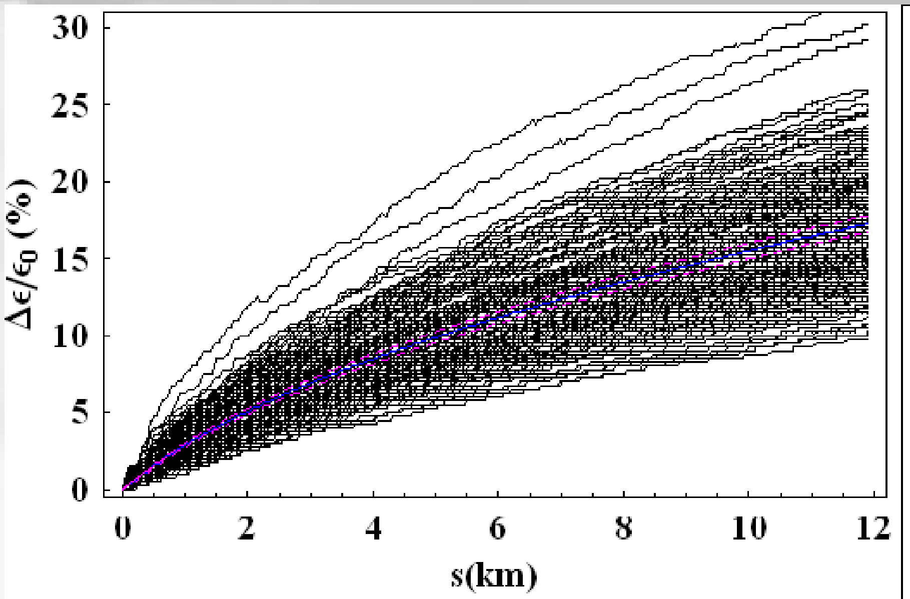
1. Beam Dynamics in Ichiro Cavity



Y-Y' phase space at end of linac



Emittance dilution due to long-range wake-fields damped with a Q of 10^6 in Ichiro cavity. The beam is offset with $1\sigma_y$ (~12.4 μm).
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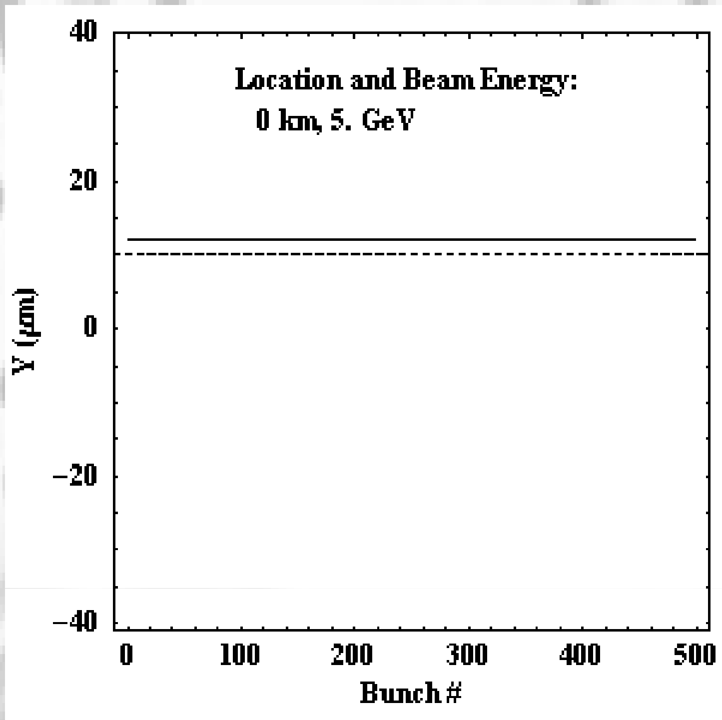
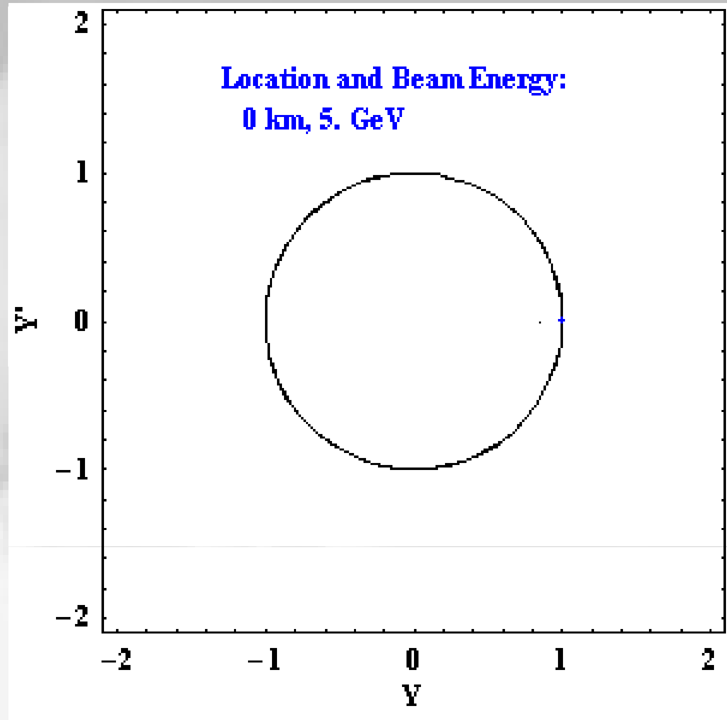


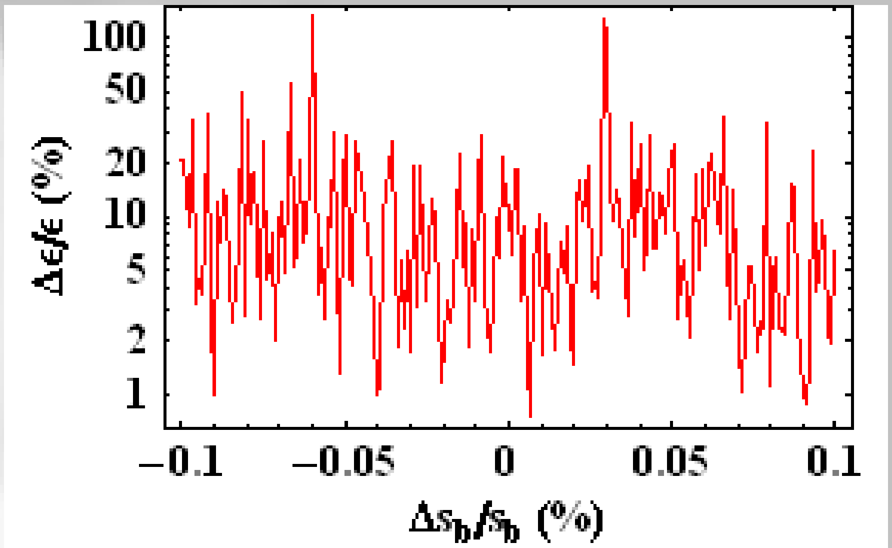
Transverse Displacement



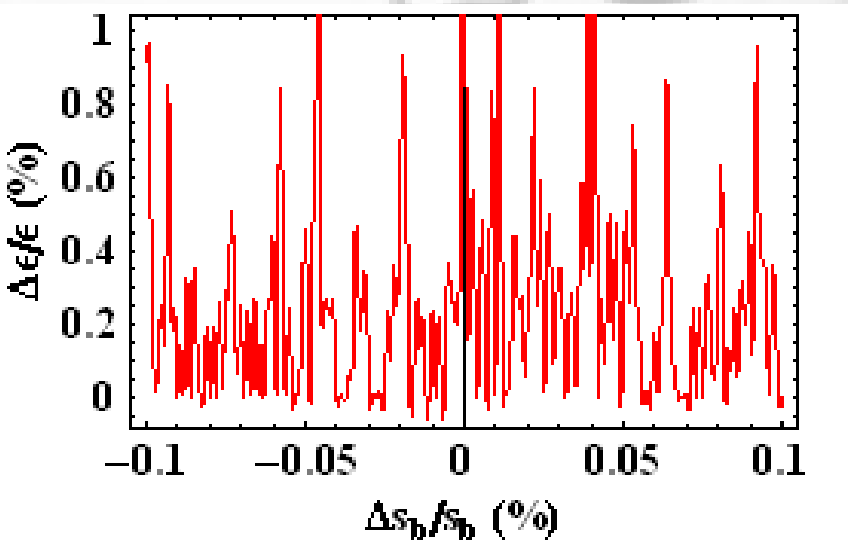
Phase Space: y-y'

- 500 particles in all simulations
- Initial vertical and horizontal offset 12 μm (~ σ_y) and 0 (~ σ_x), respectively.
- Long range wakes included in simulations

1. Beam Dynamics in Ichiro Cavity



Emittance dilution due to long-range wake-fields damped with a Q of 10^6 in Ichiro cavity



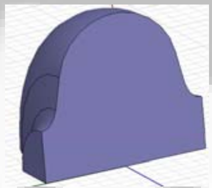
Emittance dilution due to long-range wake-fields damped with a Q of 10^5 in Ichiro cavity

2. EM Field in High Gradient Cavities

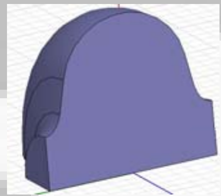
- **Simulation of Higher Order Modes (HOMs) in high gradient cavities**
- **Utilise 3D codes: GdfidL, HFSS, Analyst**
- **Use 2D codes, ABCI, Echo2D for bulk of cavity structures.**
- **Develop interface that *cascades* given sections to make more efficient calculations of overall fields.**
- **Focus on:**

1. **Re-entrant -Cornell Univ. design**
2. **Low-loss (Ichiro variant) –KEK design.**

2. Cascaded Computation of HOMs

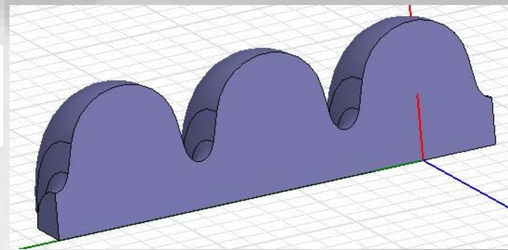


$$\underline{\underline{S}} = \begin{bmatrix} \underline{\underline{S}}_{11} & \underline{\underline{S}}_{12} \\ \underline{\underline{S}}_{21} & \underline{\underline{S}}_{22} \end{bmatrix}$$



$$\underline{\underline{S}} = \begin{bmatrix} \underline{\underline{S}}_{22} & \underline{\underline{S}}_{21} \\ \underline{\underline{S}}_{12} & \underline{\underline{S}}_{11} \end{bmatrix}$$

=>

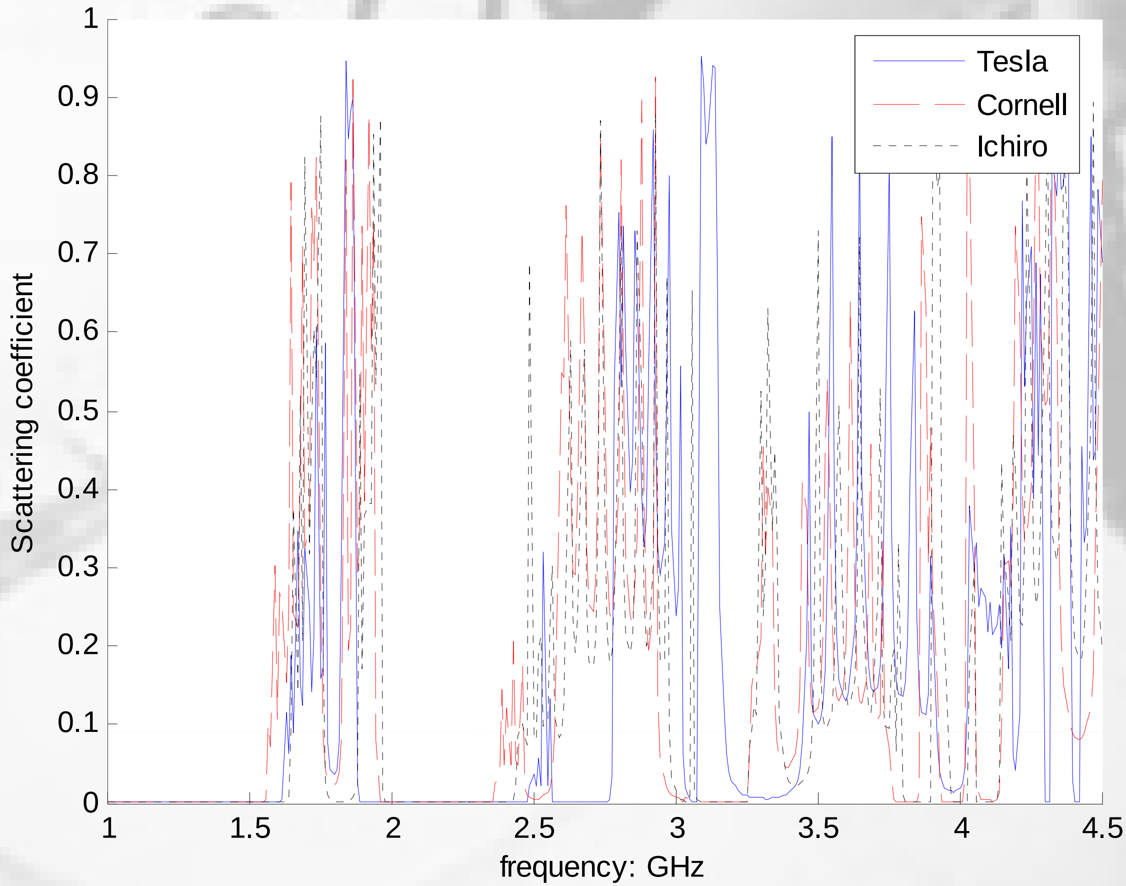


$$\underline{\underline{S}}_{11} = \underline{\underline{S}}^{a}_{12}\left[\underline{\underline{I}} - \underline{\underline{S}}^{b}_{11}\ \underline{\underline{S}}^{a}_{22}\right]^{-1}\underline{\underline{S}}^{b}_{11}\underline{\underline{S}}^{a}_{21} + \underline{\underline{S}}^{a}_{11}$$

$$\underline{\underline{S}}_{12} = \underline{\underline{S}}^{a}_{12}\left[\underline{\underline{I}} - \underline{\underline{S}}^{b}_{11}\ \underline{\underline{S}}^{a}_{22}\right]^{-1}\underline{\underline{S}}^{b}_{12}$$

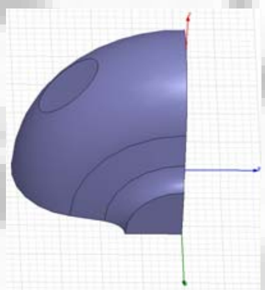
$$\underline{\underline{S}}_{21} = \underline{\underline{S}}^{b}_{21}\left[\underline{\underline{I}} - \underline{\underline{S}}^{a}_{22}\ \underline{\underline{S}}^{b}_{11}\right]^{-1}\underline{\underline{S}}^{a}_{21}$$

$$\underline{\underline{S}}_{22} = \underline{\underline{S}}^{b}_{21}\left[\underline{\underline{I}} - \underline{\underline{S}}^{a}_{22}\ \underline{\underline{S}}^{b}_{11}\right]^{-1}\underline{\underline{S}}^{a}_{22}\underline{\underline{S}}^{b}_{12} + \underline{\underline{S}}^{b}_{22}$$

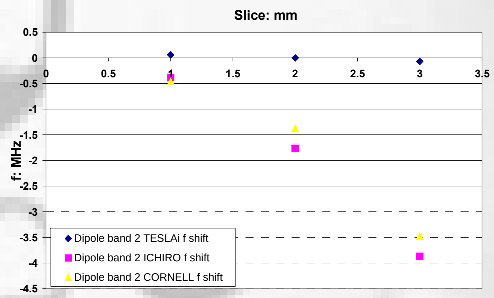


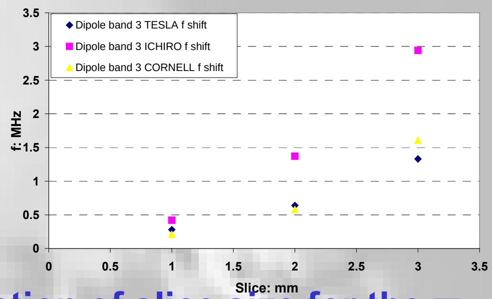
- ➢**Enables the distribution of HOMs to be computer for a whole series of cavities**
- ➢**Multi-module simulations are in progress and have been reported on a PAC07 and SRF07**

2. Cascaded Computation of HOMs -Fabrication Sensitivity Studies

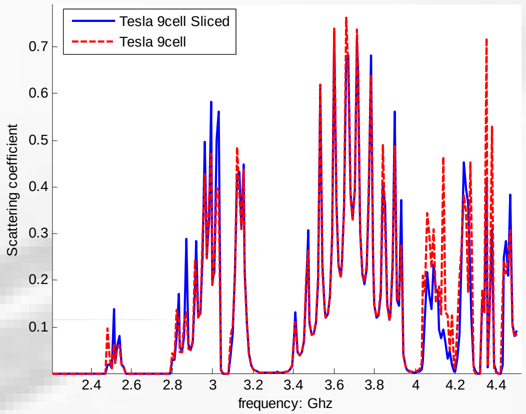


Quarter TESLA cell subjected to indentation

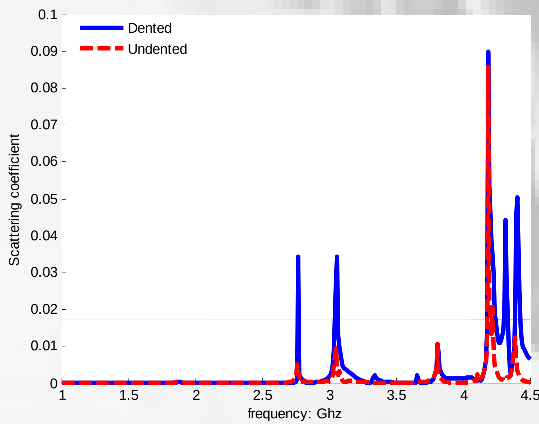




Frequency shifts as a function of slice size for the π (left) and 0 (right) mode of the second dipole band



S_{21} due to random distribution of dents in TESLA cavity compared with ideal structure. Dent ranges from 1 to 3 mm.



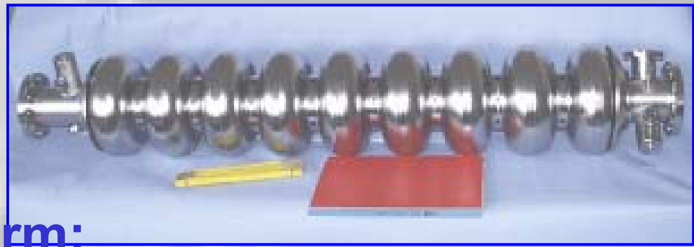
S_{21} for an unperturbed structure and a perturbed structure with a 1mm slice. TE_{11} mode scattered into the third mode (sextupole)

See Shinton and Jones, SRF2007 pubs.

3. Degenerate Dipole Mode Rotation and E.M. Field Coupling

$V_y = iV_x(0) \sin 2\theta \exp(i\langle\omega\rangle t) \sin(\Delta\omega t/2)$

Thus for $\theta = 0$ or $\pi/2$ $V_y(0) = 0$ as expected!



TESLA 9-Cell Cavity

The additional kick to the beam is of the form:

$V(t) = \Sigma K_n \sin(\omega_p t) \exp(-\omega_{pt}/2Q_p) U(t) y +$
$\Sigma K_n \cos(\langle\omega_p\rangle t) \sin(\Delta\omega_p t/2) \exp(-\langle\omega_{p>} t/2Q_p) U(t) x$

Where the sum is taken over all modes of interest and U(t) is the unit step function

=> Recent TTF experiments (Ross, Napoly & Baboi) suggest that this frequency splitting varies by ~ 400 kHz to 800 kHz. In all simulations presented here we use 600 kHz frequency splitting for all modes.

3. Degenerate Dipole Mode Rotation and E.M. Field Coupling

Make several injection offset simulations to investigate this issue.

1. **Force the angle of all couplers relative to the dipole field to be static.**
2. **Allow complete azimuthal randomization of couplers (0 to 2π).**
3. **Limit the azimuthal spread of the couplers.**

- **For *detailed* simulations consider a single machine for the above cases.**
- **For general emittance dilution consider 200 separate machines.**

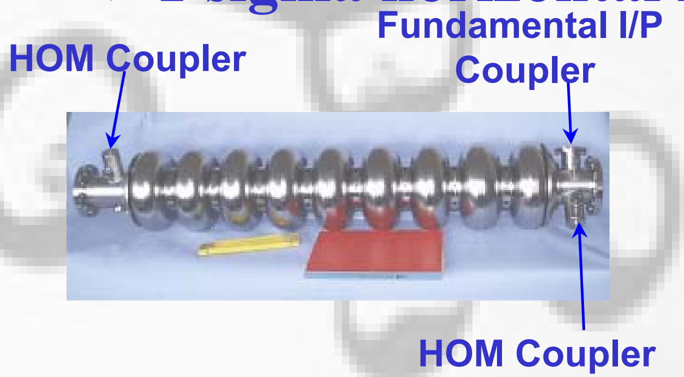
TYPICAL SIMULTATION PARAMETERS

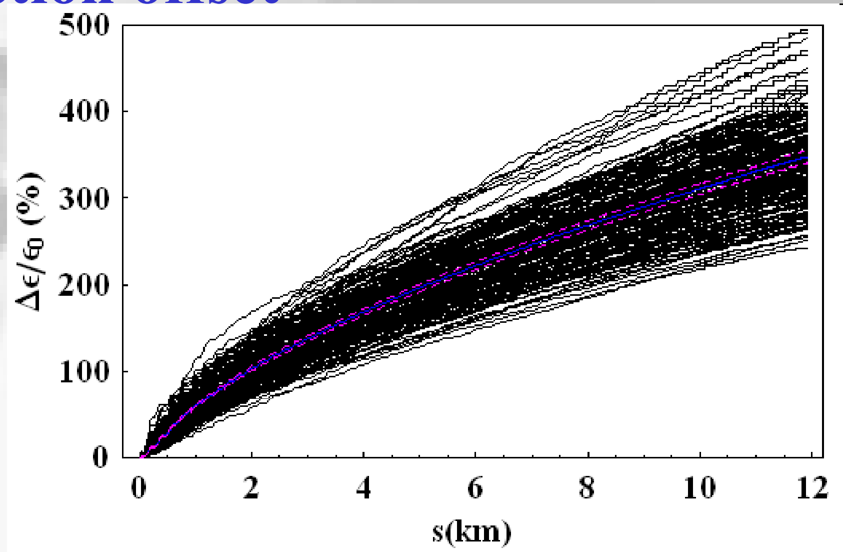
- **Injected emittance: $\varepsilon_{x,y}$ = 8e-6, 2e-8 m.rads**
- **Injection beam energy 5 GeV => O/P 500 GeV c.m. energy**
- **$\gamma_{i,f}$ ~ 9782, and 489,000**
- **All simulations made with LIAR.**
- **500 bunches in all simulations.**
- **Initial vertical and horizontal offset ~10 μm and 400μm.**
- **c.f. initial beam $\sigma_{y,x}$ (= $[\beta\varepsilon_n/\gamma]^{1/2}$) ~ 10.1 μm, 270 μm.**
- **$\sigma_{x',y'}$ (= $[(1+\alpha^2)/\beta\,\varepsilon_n/\gamma]^{1/2}$) ~ 5.1, 0.26 μrads**
- **Initial $\beta_{x,y}$ ~ 89.3, 50.7 m**

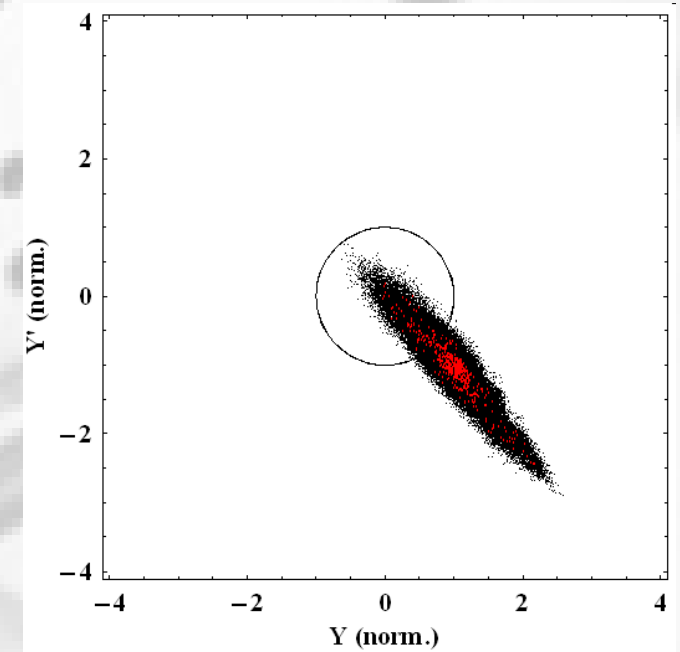
Does the Cross-Coupling of X-Y Motion Significantly Dilute the Beam Emittance?

3. Degenerate Dipole Mode Rotation and E.M. Field Coupling

- ➢Vertical emittance dilution from zero vertical injection offset
- ➢1 sigma horizontal injection offset







- •500 particles in all simulations and 200 machines shown
- •Initial vertical and horizontal offset 0 μm and 270μm (~ σ_x), respectively.
- •(c.f. initial beam $\sigma_{y,x}$ ~ 10.1 μm, 270 μm)
- •*Fixed azimuthal orientation of couplers.*
- •Long range wakes included in simulations

Fixed Azimuthal Phase Distribution (Yoff=0).

3. Degenerate Dipole Mode Rotation and E.M. Field Coupling

•Increase the damping of the HOM modes? At present the damping is ~10^4 - 10^5. It may be difficult to reduce the damping even further?

•The dipole frequency degeneracy's are already split –by ~ 400 kHz to 800 kHz. Increasing the splitting (which can be achieved by making markedly asymmetrical cavities) to say 10 MHz may allow the influence of mode coupling to be minimal over the length of the linac.

•Splitting the tune of the linac. Present design is 60/60 – horizontal/vertical. This may be the most straightforward to implement.

Re-entrant cavity shape is shown. Taken from Rong-Li Geng SRF 2005

Amelioration of Large Emittance Dilution?

3. Degenerate Dipole Mode Rotation and E.M. Field Coupling

- Present lattice has phase advance per cell of 60 degrees per cell.

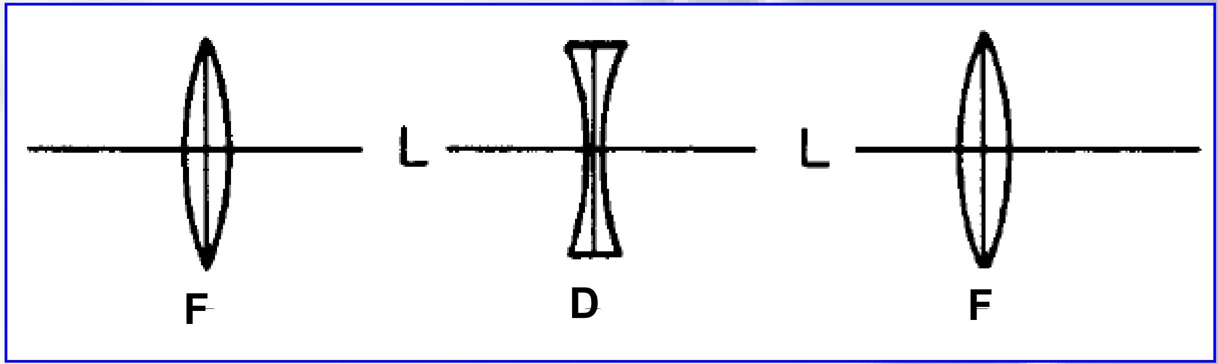
- Each lattice cell consists of two groups of:
quadupoles + 2 cryo-modules + quadrupole+ 2 cryo-modules.
- There are 12 cavities per cryo-module.
- If we split the tune then the coupling should be out of resonance.

- We look at 61/60 through 90/60.

- Single FODO array shown.

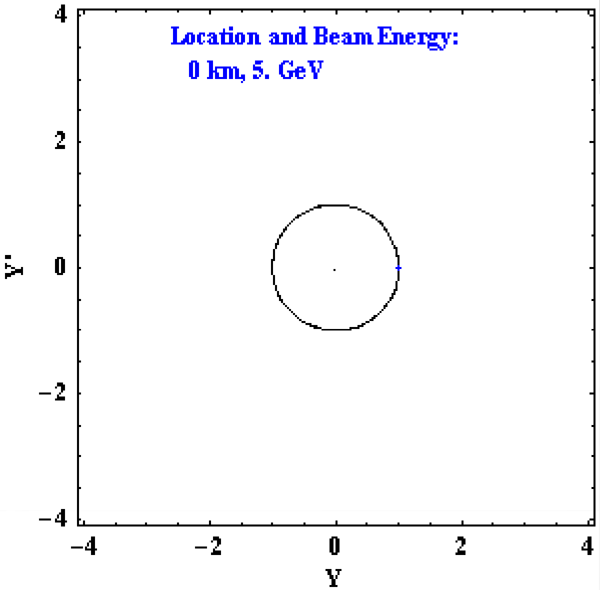
- We split the tune by raising the F functions for the focusing quadrupole with respect to the D quadrupole.

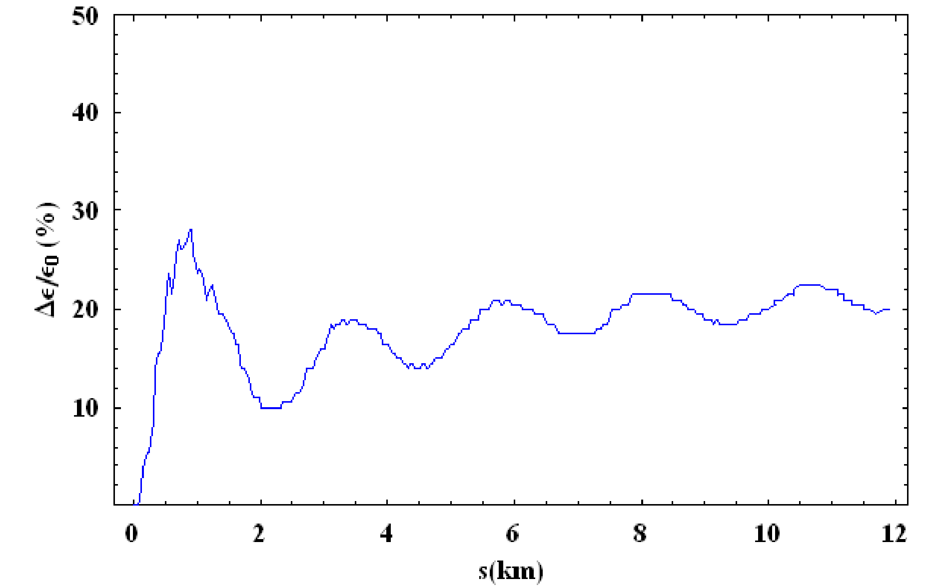
- The D quadrupole is then readjusted in order to achieve 60 in the vertical plane.

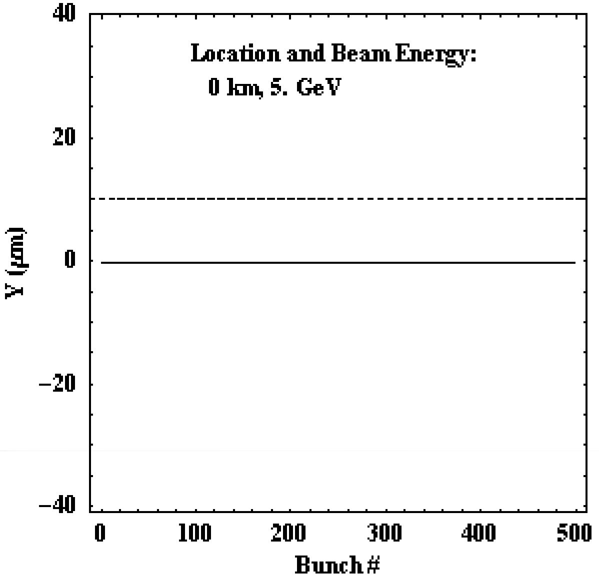


Split Tune of Lattice

3. Degenerate Dipole Mode Rotation and E.M. Field Coupling



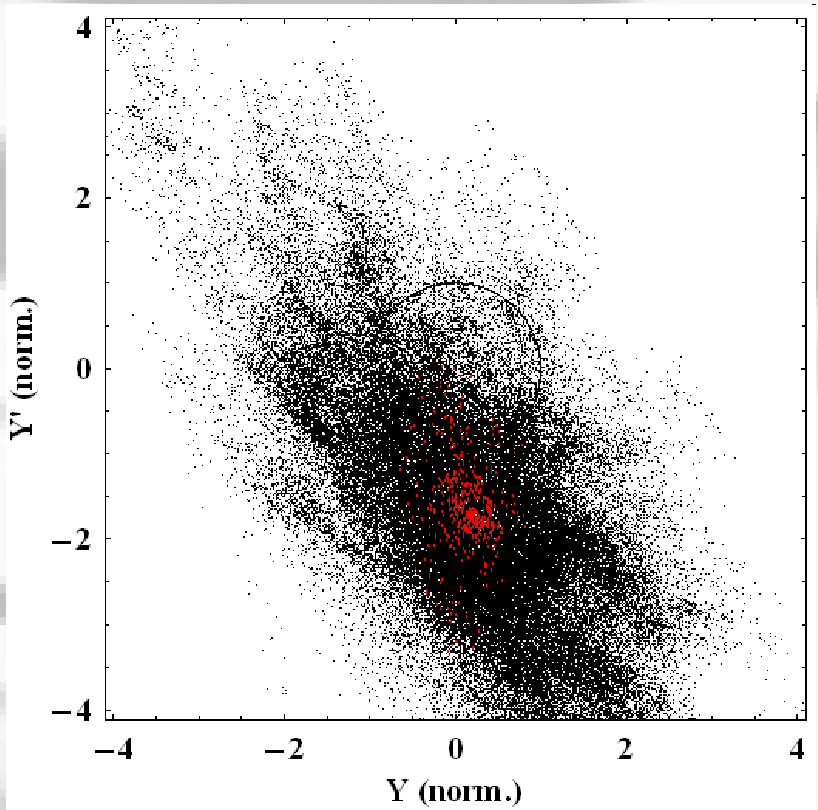




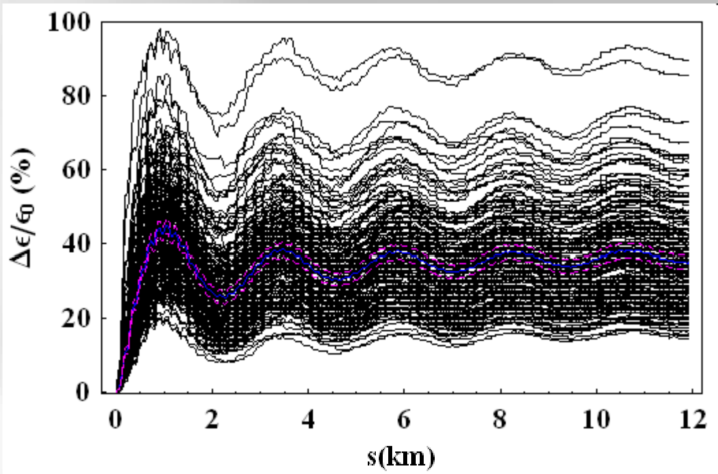
- 500 particles in all simulations
- Initial vertical and horizontal offset 0 μm and 270μm (~ σ_x), respectively.
- (c.f. initial beam $\sigma_{y,x}$ ~ 10.1 μm, 270 μm)
- *Fixed azimuthal orientation of couplers.*
- Long range wakes included in simulations

Cross-Coupled Motion *At* Fixed Azimuthal Phase Distribution (Yoff=0). ***Split Tune***

3. Degenerate Dipole Mode Rotation and E.M. Field Coupling



•Final mean dilution ~ 35% (95% CI 33, 37 %)



•500 particles in all simulations and 200 machines are illustrated

•The dashed line marks the injection offset of all bunches

•Initial vertical and horizontal offset 0 μm and 270μm (~ σ_x), respectively.

•(c.f. initial beam $\sigma_{y,x}$ ~ 10.1 μm, 270 μm)

•*Fixed azimuthal phase.*

•Long range wakes included in simulations

These have been rescaled relative to the previous ones

Cross-Coupled Motion *At* Fixed Azimuthal Phase Distribution (Yoff=0). *Split Tune 70/60*

Mode Coupling Summary

- Mode-coupling is a significant source of emittance dilution.

- Emittance dilution may be ameliorated by splitting the tune of the lattice.

- Further experimental data is needed on the actual splitting of the dipole degeneracies in frequencies that is likely to occur in the fabrication of several thousand ILC cavities (experiments at DESY, TTF already in progress will be helpful in this respect –Ross, Napoly, Baboi et al). In addition, simulations are in progress on the splitting of the tune encountered due to the HOM couplers.

- Analysis of the influence of higher order bands on emittance dilution in the presence of mode coupling is required.

Ref: Papers on beam dynamics of mode splitting by Jones *et al.* at PAC05, EPAC06

- **The effect of purposely distorting the shapes of the cavities in order to increase the frequency degeneracy splitting requires further study.**

- The feedback system, **FONT currently under study will need interfacing with the beam wake fields that result from realistic fabrication errors.**
- **GDE (Adolphsen/Ross/Hayano/Napoly**) have pointed out that mode characterisation studies and mode splitting under the influence of realistic fabrication errors are important issues.
- KEK (Hitoshi Hayano san) has started some preliminary mode measurements. UK collaboration has been initiated.
- **These are issues which will be encountered in the baseline and in the alternative, high-gradient designs**. In particular, the re-distribution of fields in the new cavity structure will require simulations of both the fields in the main body of the structure and within the vicinity of the

4. HOMs, Beam Dynamics in Crab Cavity

Personel

COCKCROFT INSTITUTE
Graeme Burt (Lancaster University)
Richard Carter (Lancaster University)
Amos Dexter (Lancaster University)
Imran Tahir (Lancaster University)
Philippe Goudket (ASTeC)
Peter McIntosh (ASTeC)
Alex Kalinin (ASTeC)
Carl Beard (ASTeC)
Lili Ma (ASTeC)
Roger Jones (Manchester University)

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MANCHESTER 1824
The University of Manchester

FNAL
Leo Bellantoni
Mike Church
Timergali Khabiboulline
Brian Chase

SLAC
Chris Adolphson
Kwok Ko
Zenghai Li
Liling Xiao

CERN
Andrea Latina
Daniel Shulte

4. ILC 3.9 GHz Crab Cavity

CKM Cavity design parameters

3.9 GHz

13 cells length = 0.5 m

B_{max} = 80 mT

E_{max} = 18.6 MV/m

L_{eff} = 0.5 m

$P_{\perp}$ = 5 M V/m

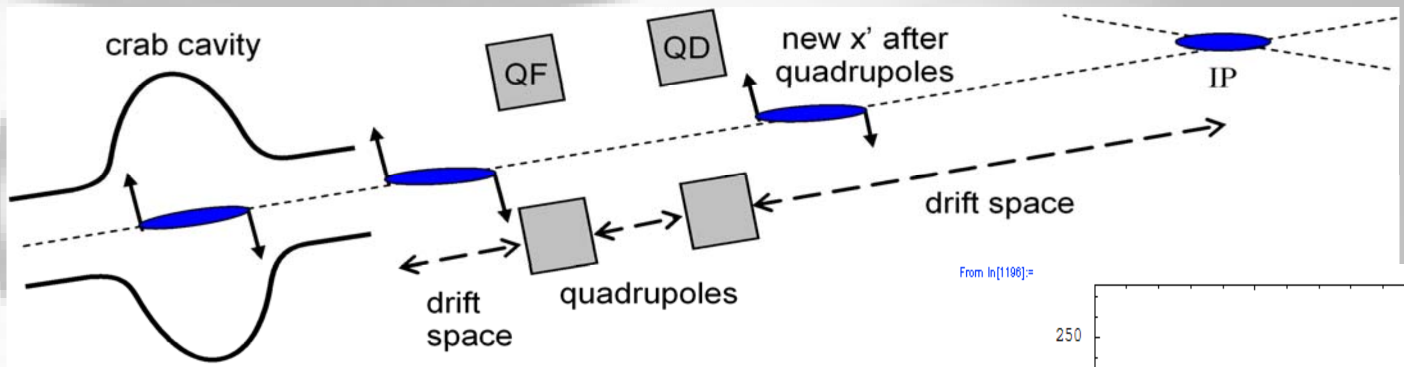
Courtesy: FNAL

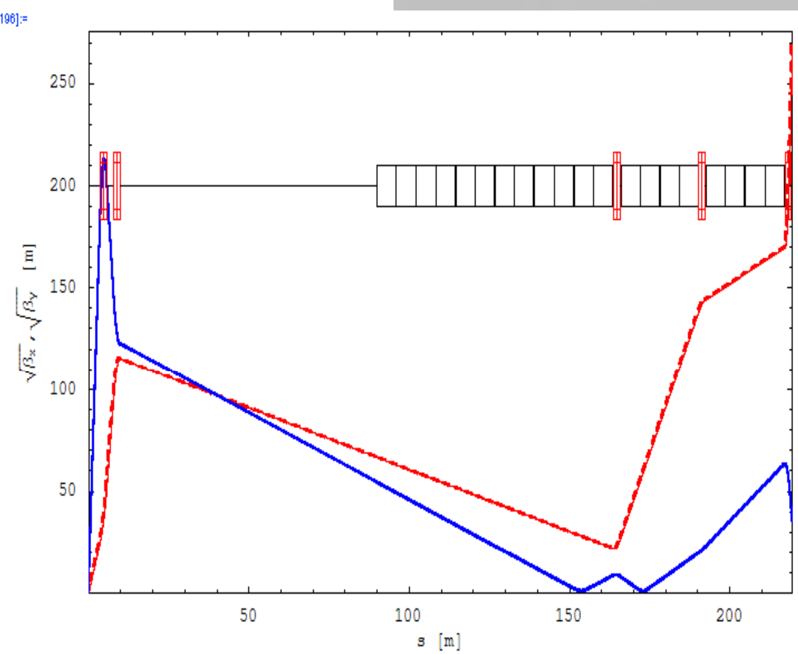
The ILC crab cavity is based on the FNAL deflecting mode cavity.

To minimise wakefields for the short time structure of the ILC bunches, the number of cells must be optimised against overall length and new couplers designed.

A 3.9 GHz cavity was favoured it is compact longitudinally and transversely.

4. ILC 3.9 GHz Crab Cavity





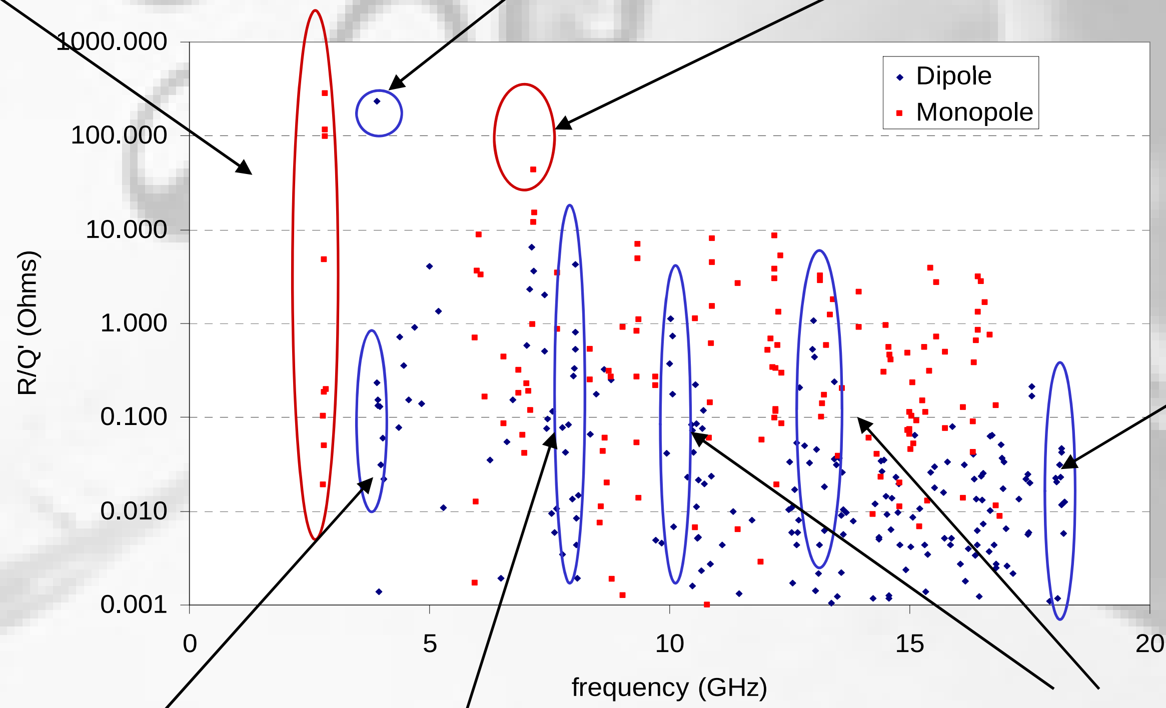
The crab cavity has to be close to the IP for phase synchronisation issues. This means that only the final focussing doublet is between the cavity and the IP. The positioning of the crab cavity at a region with a large beta function means that wakefield kicks are not focussed effectively.

4. ILC 3.9 GHz Crab Cavity

Lower Order Modes, 2.8 GHz

Operating and Same Order modes at 3.9 GHz

High impedance monopole modes are not a problem



Narrowband dipole modes seen up to 18 GHz

1st Dipole passband

Trapped 5th dipole passband at 8 GHz

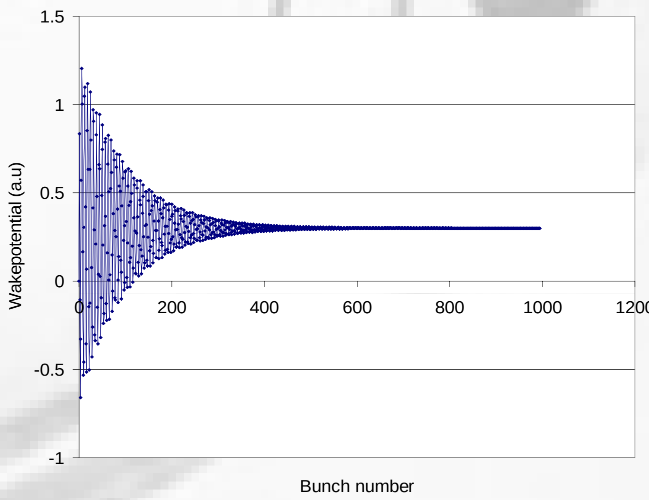
High dipole impedances seen at 10 GHz and 13 GHz

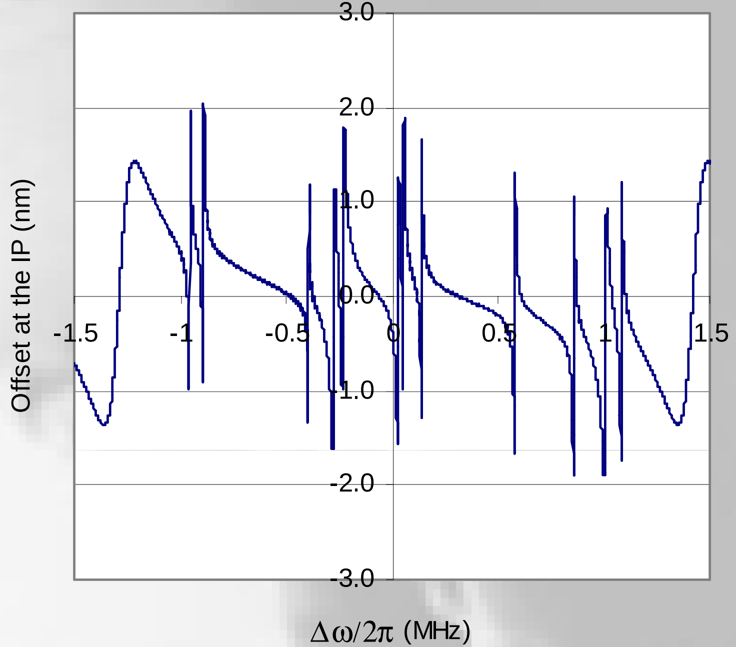
Mode Calculations in MAFIA

4. ILC 3.9 GHz Crab Cavity

A long range wakefield is a superposition of the fields created by each bunch.

$$W_{\perp,multi} = 2r\sum_{n=1}^{N}\sum_{m=1}^{M} K_m \sin\left(\omega_m n T_b / c\right)\exp\left(-\frac{\omega_m n T_b}{2Q_n c}\right)$$



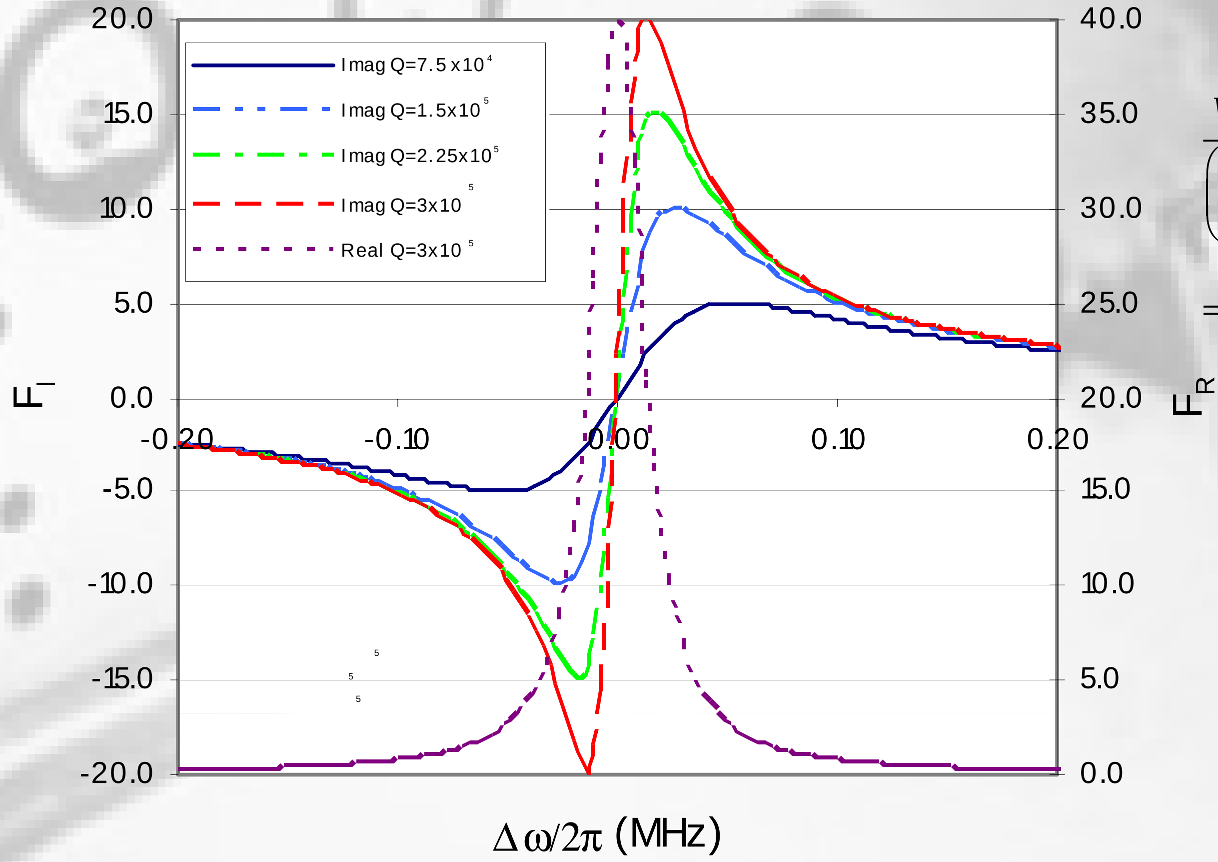


If the bunches all arrive at regular intervals and the same offset then the wakefield will tend to a finite constant value known as the sum wake.

It is useful to find the frequency dependence of the sum wake. As we sweep through the frequency errors we see that we see resonances with the bunch. Calculating the damping tolerances using this method is slow. However each resonance is due to a single mode hence a single-mode analysis of the damping requirements is valid.

Sum wake

4. ILC 3.9 GHz Crab Cavity



The single mode wakefield is given as

$$\frac{W_{\perp,single}}{\left(rc\frac{R}{2Q}\right)} = \sum_{n=1}^{N_b-1} \exp\left(-n\frac{T_b}{T_d}\right)\sin(\omega n T_b)$$

$$= \mathrm{Im}\left\{-\frac{e^{i\delta-d}}{e^{i\delta-d}-1} + \frac{e^{(i\delta-d)N_b}}{e^{i\delta-d}-1}\right\} = F_I = F_I^{\infty} + F_I^{N_b}$$

where

$$F_I^{\infty} = \frac{\sin\delta}{2(\cosh d - \cos\delta)}$$

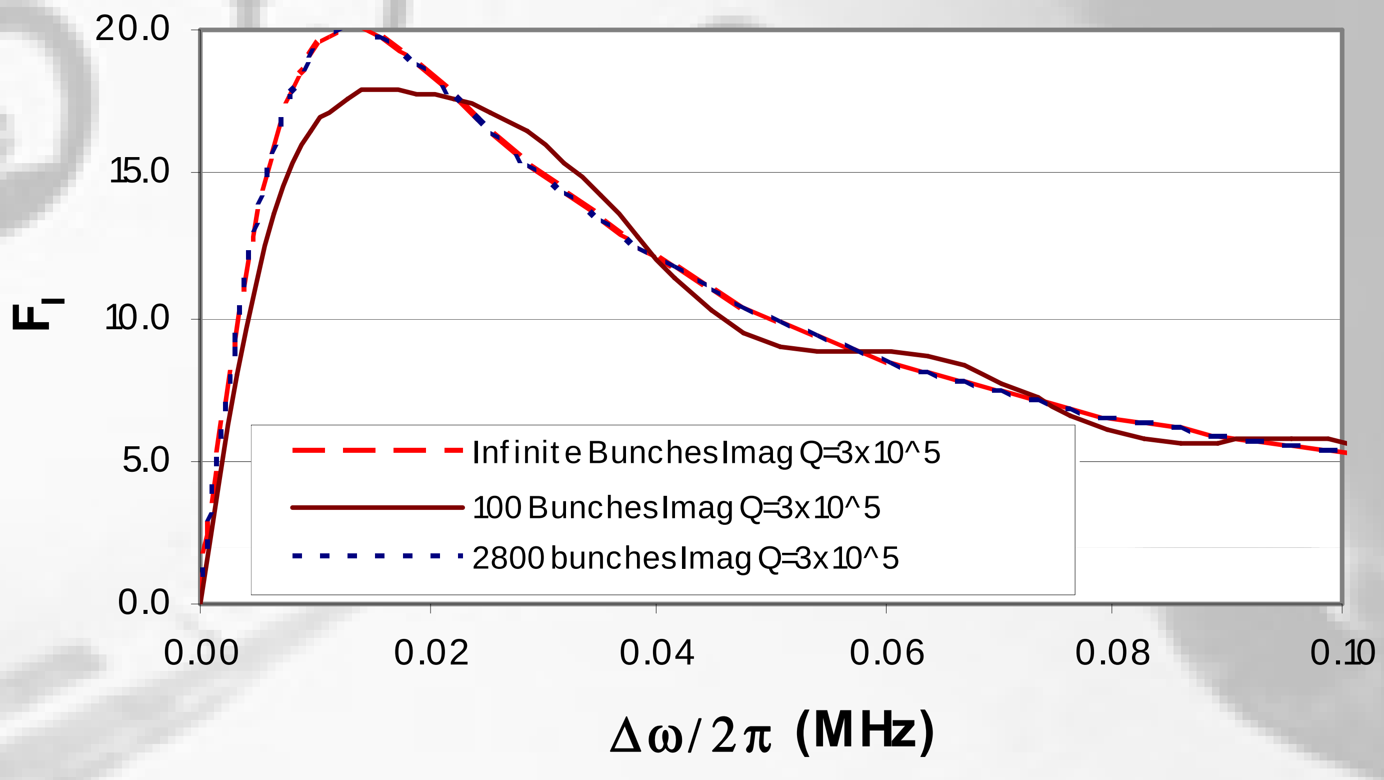
$$F_I^{N_b} = \frac{-e^{-N_b d}\left[e^d \sin N_b\delta + \sin(\delta - N_b\delta)\right]}{2(\cosh d - \cos\delta)}$$

$$\omega = \frac{2\pi h}{T_b} + \Delta\omega$$

$\delta = \Delta\omega Tb$, $d = Tb/Td$,

Single-Mode Sum Wake

4. ILC 3.9 GHz Crab Cavity



Depending on the Q factor, the sum wake can be reached very quickly, for the ILC we are likely to reach the sum wake within a few hundred bunches.

Finite Bunch trains

4. ILC 3.9 GHz Crab Cavity

We can rearrange the single-mode wakefield equation for the sum wake as a quadratic equation.

$$F^{\infty}_{I\,max} x^2 - \left[2F^{\infty}_{I\,max} Cos\delta + sin\,\delta\right] x + F^{\infty}_{I\,max} = 0$$

Where

$$x = \exp(-d) \equiv \exp(-T_b / T_d)$$

And F_{Imax} is the maximum allowable wakefield normalised by R/Q

The solution of this equation is

$$x = \frac{\left[2F^{\infty}_{I\,max} cos\delta + sin\,\delta\right] - \sqrt{\left[2F^{\infty}_{I\,max} cos\delta + sin\,\delta\right]^2 - 4(F^{\infty}_{I\,max})^2}}{2F_{I\,max}}$$

Giving a Q requirement of

$$Q = \frac{\omega T_b}{2\ln(1/x)}$$

Solving for Q

4. ILC 3.9 GHz Crab Cavity

- As we are summing the contribution to the wake from all previous bunches, resonances can appear. For longitudinal wakes we sum

$$\sum_n \cos(n\omega\tau)\exp(-n\frac{\omega\tau}{2Q}) \qquad \omega = \frac{2\pi}{n\tau}$$

hence resonances appear when

- It is more complex for transverse wakes as the sum is

$$\sum_n \sin(n\omega\tau)\exp(-n\frac{\omega\tau}{2Q})$$

- However we can find the resonances from the single-mode wake equation

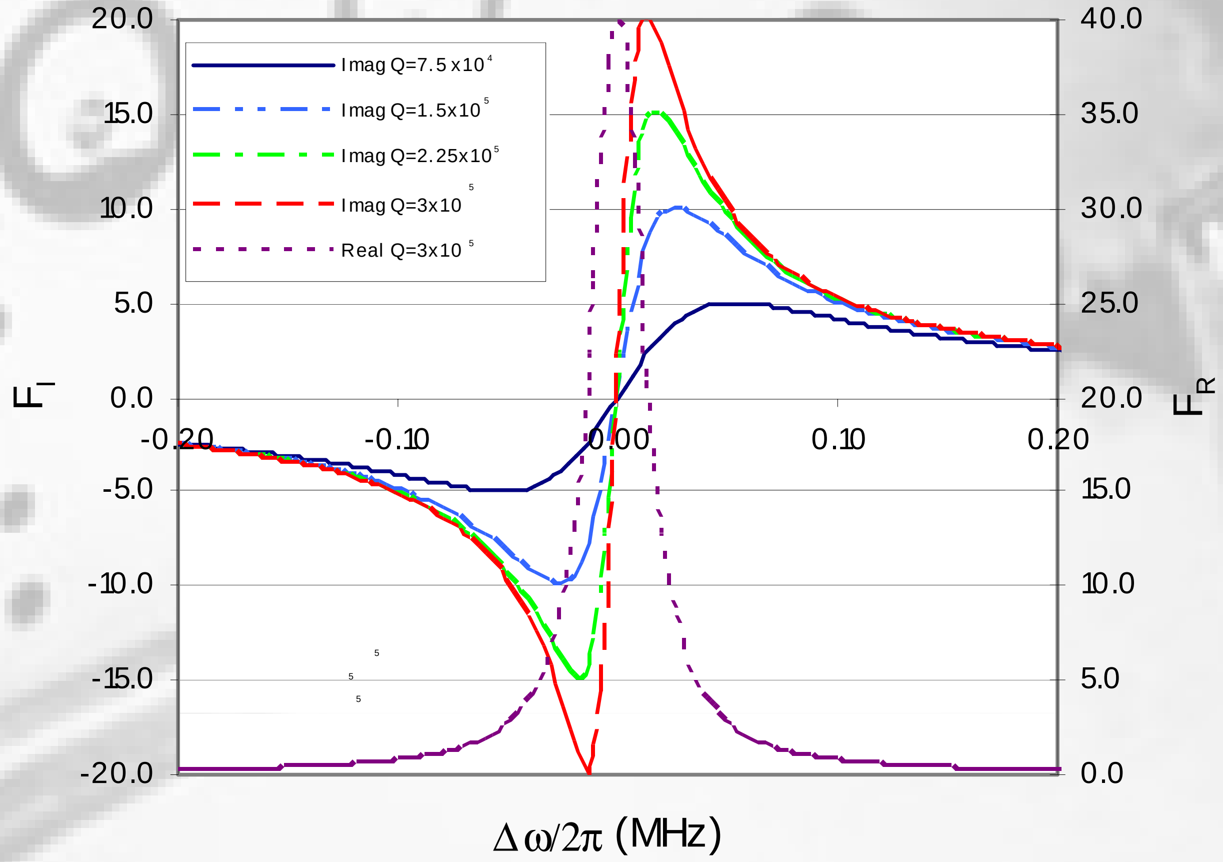
$$F_I^\infty = \frac{\sin\delta}{2\left(\cosh d - \cos\delta\right)}$$

Using $\frac{dF_I^\infty}{d\omega} = 0$

The solution of which is $\Delta\omega_{max} = \frac{1}{T_b}\cos^{-1}\left[sech\left(T_b / T_d\right)\right]$

Resonances

4. ILC 3.9 GHz Crab Cavity



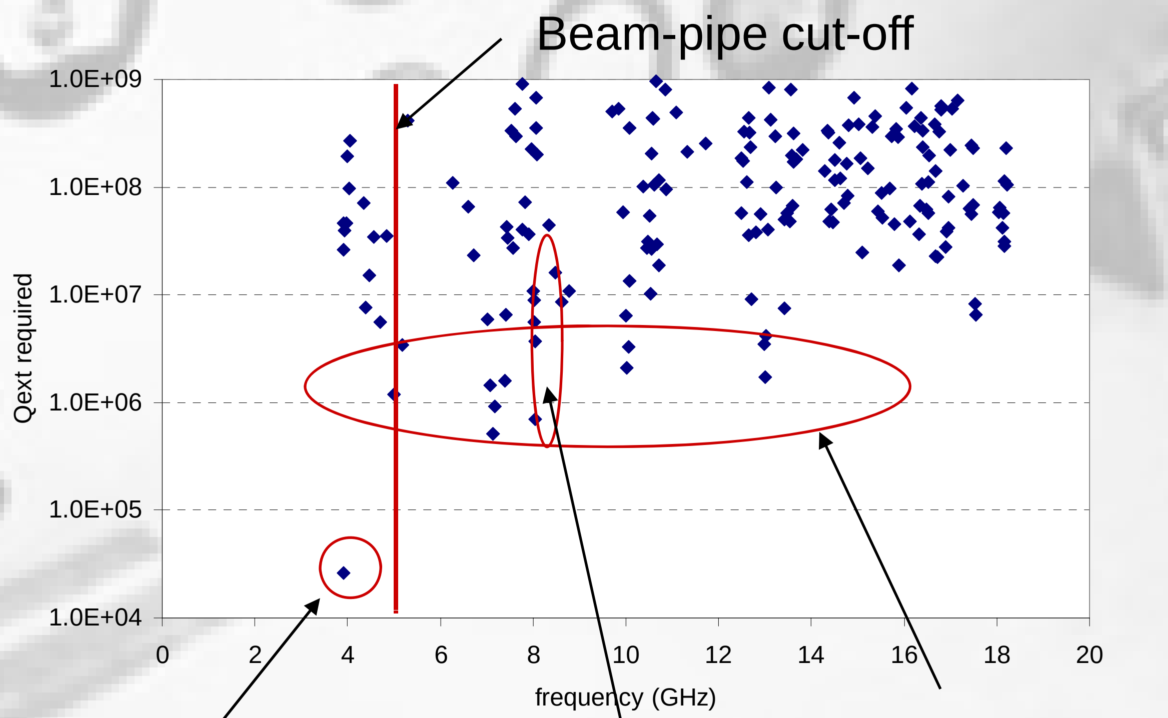
If we return to the single-mode sum wake we can see the two resonances at the frequencies either side of the longitudinal resonance

Single-Mode Sum Wake

4. ILC 3.9 GHz Crab Cavity

Damping Requirements

$$x = \frac{\left[2F^{\infty}_{I\,max}\cos\delta + \sin\delta\right] - \sqrt{\left[2F^{\infty}_{I\,max}\cos\delta + \sin\delta\right]^2 - 4(F^{\infty}_{I\,max})^2}}{2F_{I\,max}}$$



Same Order Mode, demanding spec, requires active damping

Trapped modes might need attention

These specs are not so demanding but might need checking

Inserting the frequencies of the resonances into the single damping solution already derived gives

$$x = \frac{-1 + \sqrt{1 + (2F^{\infty}_{I\max})^2}}{2\left|F^{\infty}_{I\max}\right|}$$

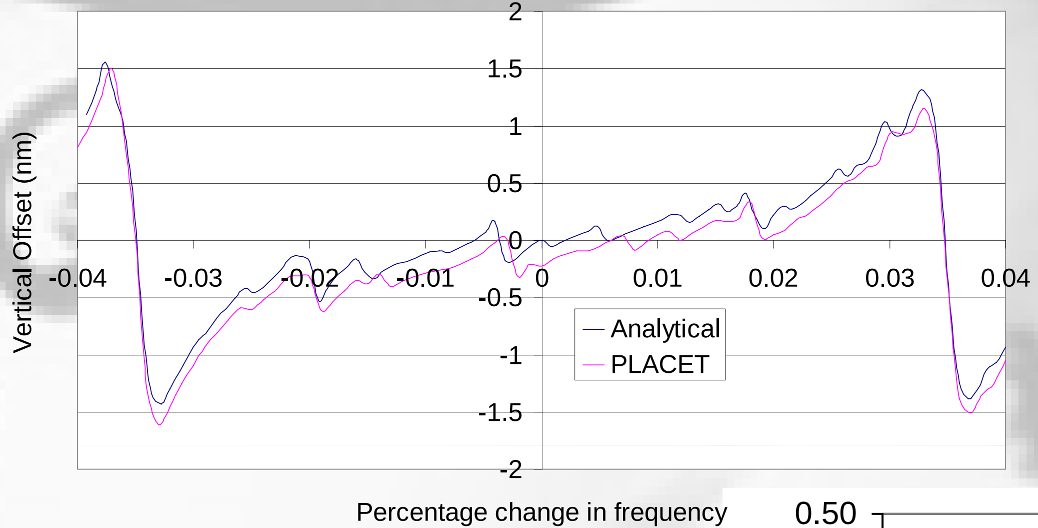
$$x = \exp(-d) \equiv \exp(-T_b / T_d)$$

And hence

$$Q = \frac{-\omega T_b}{2\ln\left[\dfrac{-1 + \sqrt{1 + (2F^{\infty}_{I\max})^2}}{2\left|F^{\infty}_{I\max}\right|}\right]}$$

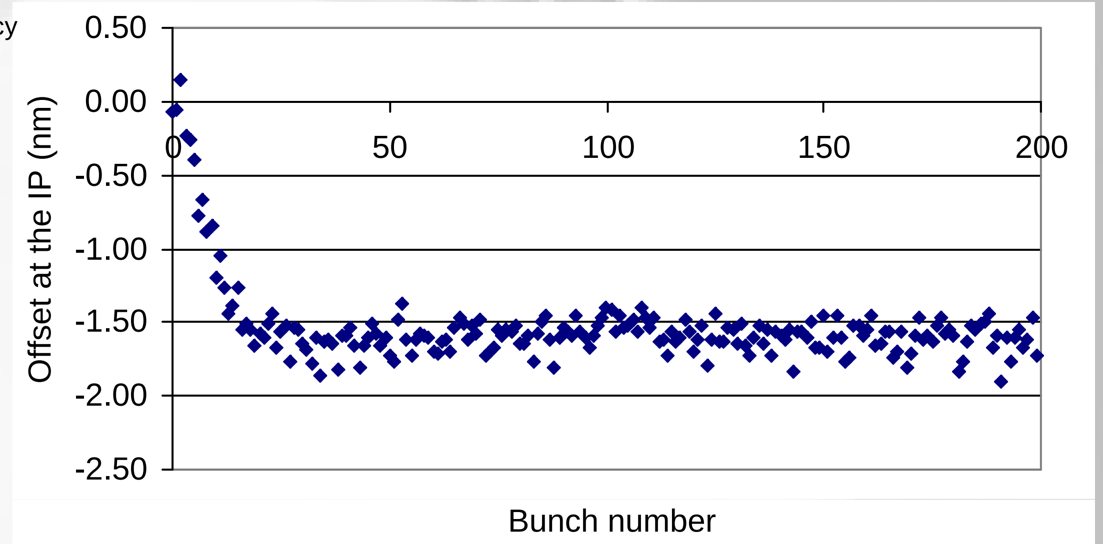
This is the damping required to keep the wakefields below the level F_{Imax}, for the worst case wakefields.

4. ILC 3.9 GHz Crab Cavity



The PLACET results show when the damping tolerances are met with a maximum Q of 1×10^5 the maximum vertical offset is 1.5 nm.

The results give good agreement with the previous analytical results.



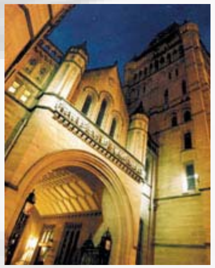
PLACET

5. High Precision SC Cavity Alignment/Diagnostics/BPM with HOM Measurements

Nicoleta Baboi, Olivier Napoly, Ursula van Rienen

Roger M. Jones

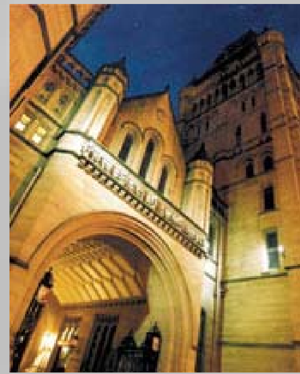
DESY, CEA Saclay, Univ. of Rostock, Univ. of Manchester/ Cockcroft Inst.



Invited talk at EGARD-OMIA,CERN. Spokesperson on behalf of Accelerator and Beam Studies and HOM FP7 collaboration

MANCHESTER
1824

The University
of Manchester



Deutsches Elektronen-Synchrotron
in der Helmholtz-Gemeinschaft
DESY

5. Aspects of HOMs in SC Accelerator Cavities

1. HOM based Beam Position Monitors (HOMBPM)

- **Initial electronics have been developed for single bunch and installed at FLASH allowing the beam to be centered to within 5 μm.**
- **Method needs to be verified with additional modes**
- **Multi-bunch issues need to be understood.**
- **The 3.9 GHz bunch shaping cavities being installed in FLASH and XFEL can readily dilute the beam emittance –important to instrument with electronics modules to diagnose the beam position and improve the emittance.**

2. HOM based phase monitors (HOMPM)

- **Measure phase of RF injected into the cavities with respect to the phase of beam.**
- **Proof of principle tests revealed the potential of a HOM-based method.**
- **Additional LLRF development at FLASH needed.**

3. HOM Cavity Diagnostics and ERLP (HOMCD)

▪HOM spectrum allows one to ascertain the cavity alignment and cell geometry.

▪Will investigate:

- mechanical deviations of individual cells from the ideal geometry,
- cell-to-cell misalignment,
- deformation of fields by couplers.

▪This part of the project requires beam-based measurements at FLASH, DESY and ERLP, Daresbury, and RF-based measurements using the wire test facility at the Cockcroft Institute.

4. HOM Distributions and Geometrical Dependences (HOMDG)

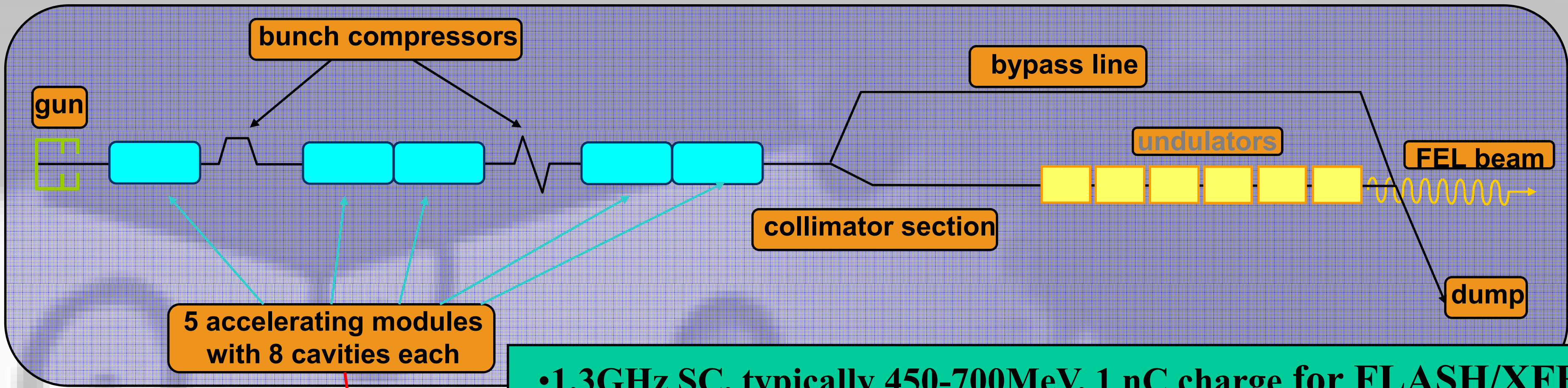
▪Combining finite element and S-matrix cascading techniques allows the eigenmodes in multiple accelerating cells and cavities to efficiently modeled. The University of Rostock and the University of Manchester have developed a suite of codes.

▪Will apply these powerful computing methods in order to specify allowable tolerances on fabrication and alignment of the TESLA cells and cavities for future colliders and light sources.

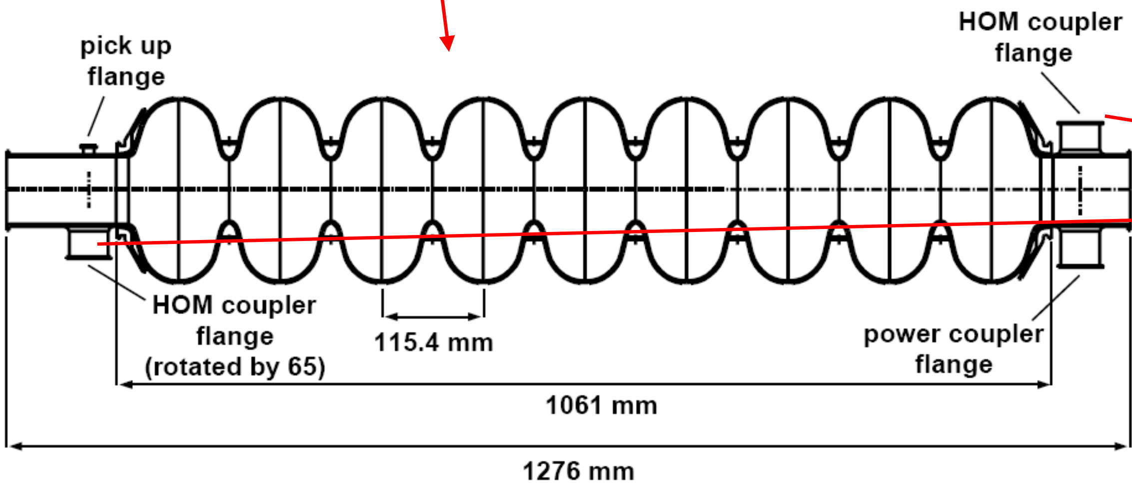
5. HOM studies for Proton Injectors (HOMPI)

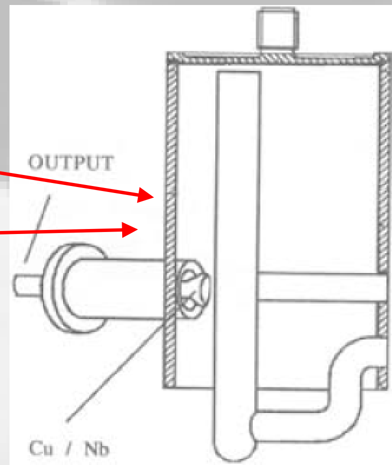
▪HOMS also impact the beam emittance and cause heating of the cavity in proton machines

▪Has the potential to benefit from similar HOM measurement diagnostics



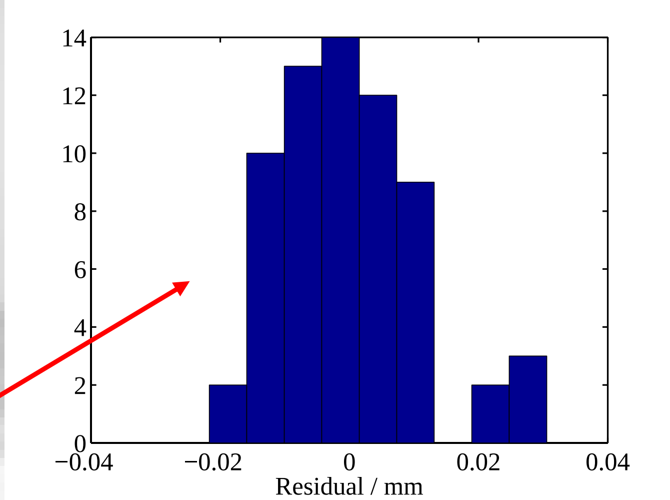
- 1.3GHz SC, typically 450-700MeV, 1 nC charge for FLASH/XFEL
- HOMs generated in accelerating cavities must be damped.
- These HOMs may also be monitored to obtain beam/cavity info
- Forty cavities exist at FLASH.
  - Couplers/cables already exist.
  - Electronics installed to monitor HOMs (wideband and narrowband response).

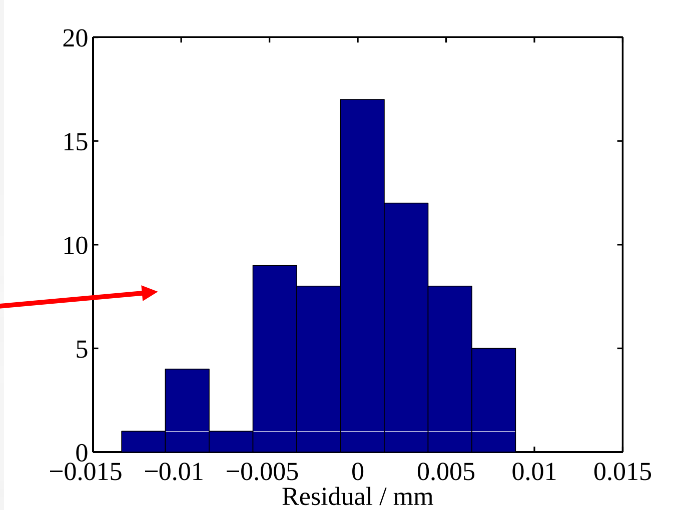




5. Analysis of Narrowband Signals – Beam Position

- Resolution of position measurement.
  - Predict the position at cavity 5 from the measurements at cavities 4 and 6.
  - Compare with the measured value.
- X resolution
  - 9 microns
- Y resolution
  - 4 microns





5. HOM-BPMs

- **Calibration based on SVD**
- **Resolution achieved:**
  - **~5/10µm rms (Y/X) single bunch, limited by LO**
- **Issues:**
  - **improve resolution**
  - **multi-bunch:**
    - **individual bunches measurable with lower resolution ($f_{rep} \leq$ 1MHz at FLASH)**
    - **speed issues**
  - **suitability of various HOMs**
  - **alternative electronics**
  - **<u>electronics for 3.9GHz cavities needed</u>**