NSRL 中国科学技术大学 国家同步辐射实验室 NATIONAL SYNCHROTRON RADIATION LABORATORY

A Study on the Improved Cavity Bunch Length Monitor for FEL

Q. Wang, Q. Luo, B. G. Sun, Y. L. Yang, Z. R. Zhou, P. Lu, F. F. Wu, L. L. Tang, T. Y. Zhou, X. Y. Liu, J. H. Wei

University of Science and Technology of China

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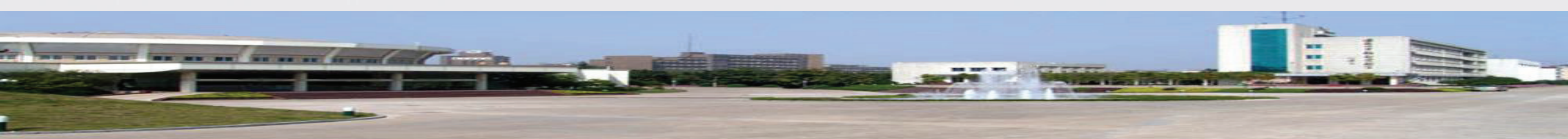

Outline

- Research Status
- Theoretical Basis
- Studies and Improvements
  - The design of a cavity bunch length monitor (CBLM) with high order mode for the NSRL IR-FEL (FELiChEM)
  - The design of the single cavity bunch length monitor
  - The influence of beam position offset
- Conclusion

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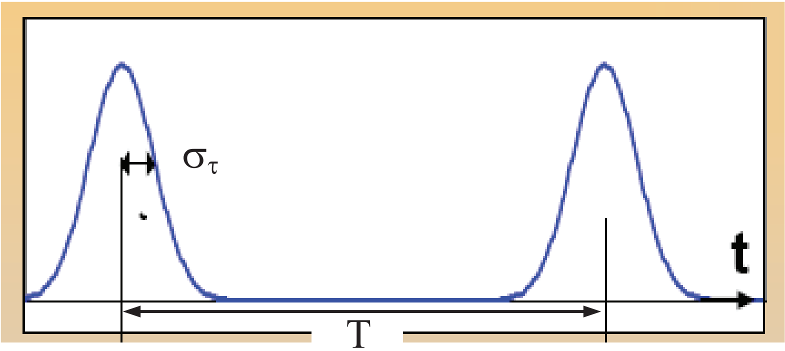
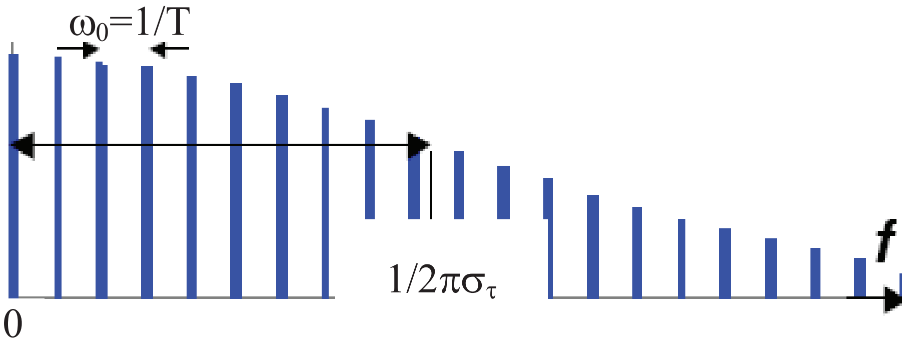
Research Status

- Bunch length measurement methods and devices for Linac and FEL.
  - Coherent Radiation
  - Electro-optic Sampling
  - Transverse RF Deflecting Cavity
  - Harmonic Method

Research Status

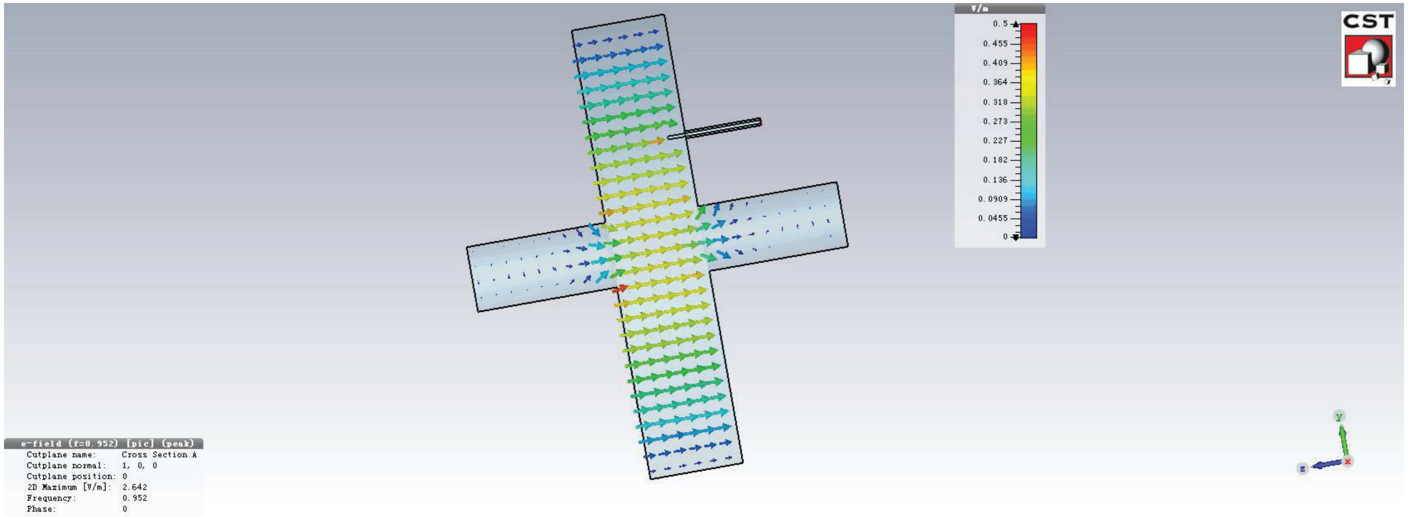
- Advantage of cavity monitors
  - Simple structure, wide application rage, and high signal to noise ratio





Research Status

- Advantage of cavity monitors
  - Compared with the Transverse RF Deflecting Cavity, the resonant cavity is nondestructive



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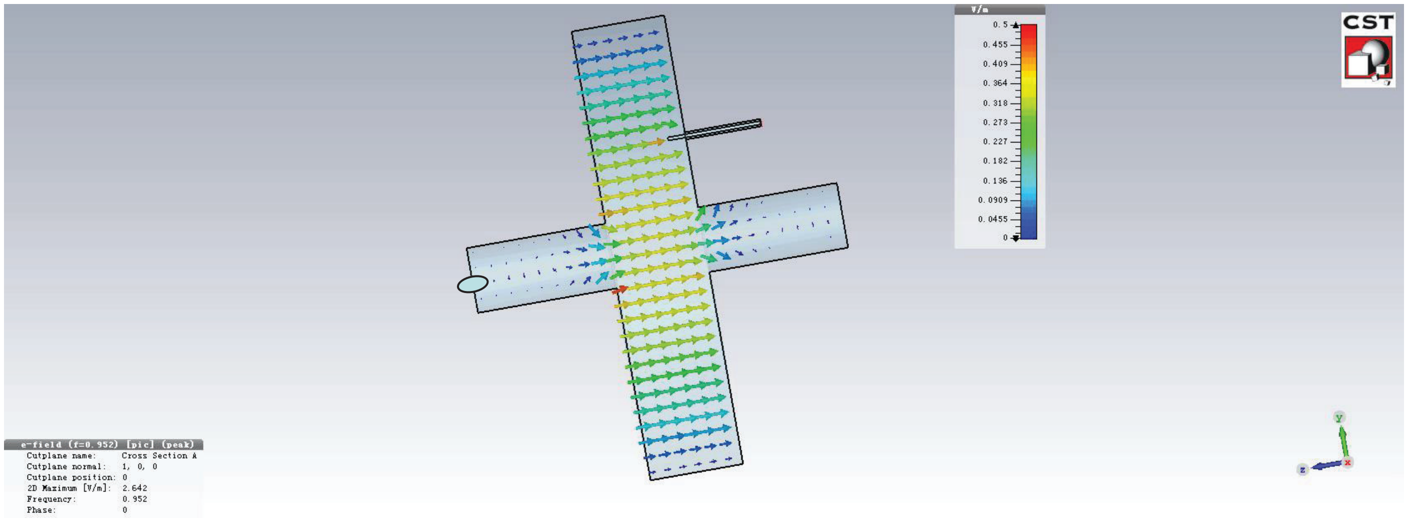
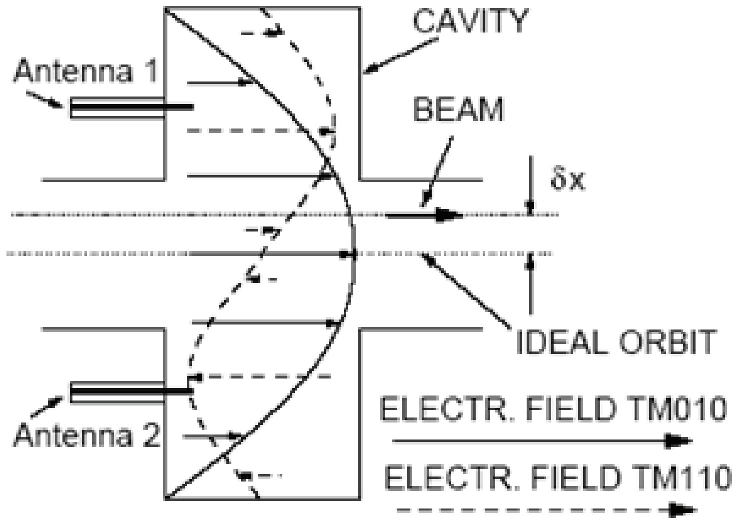
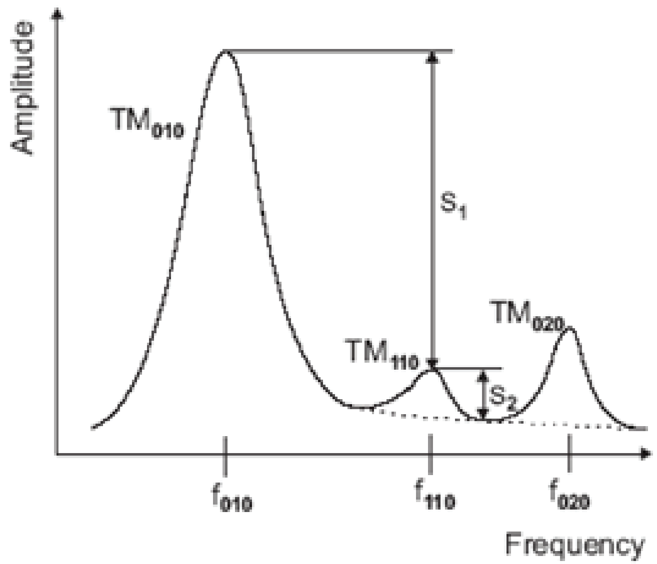


Research Status

- Advantage of cavity monitors
  - The eigenmodes of cavities are used in combined measurement of **bunch length**, **beam intensity**, **position** and **quadrupole moment** so that the whole diagnostic system is simplified and compact.





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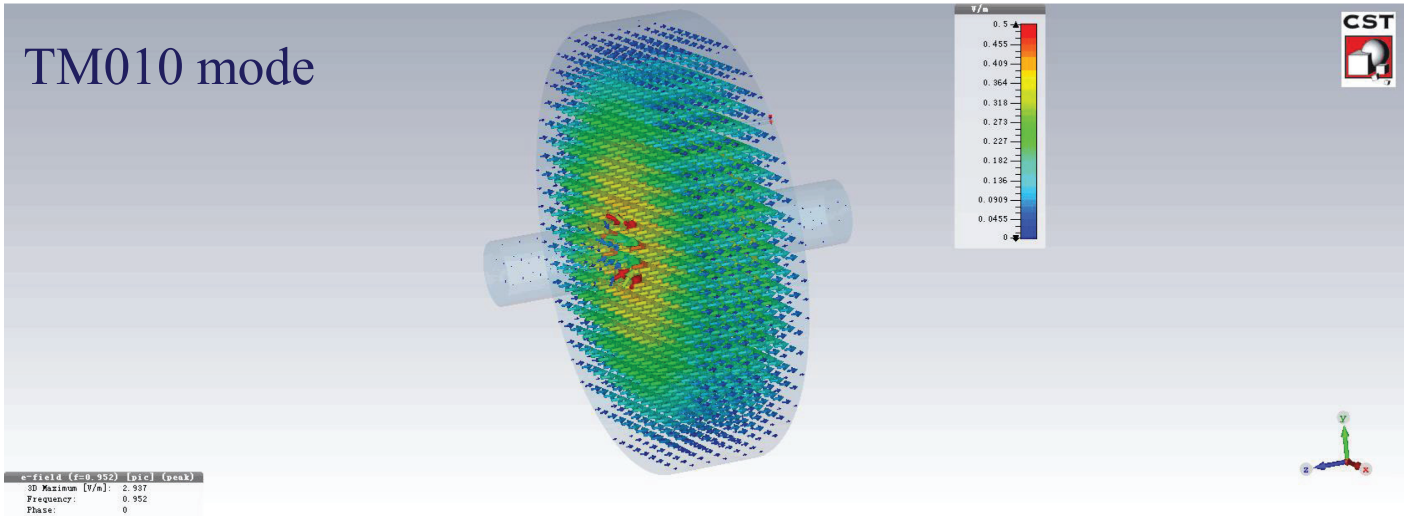
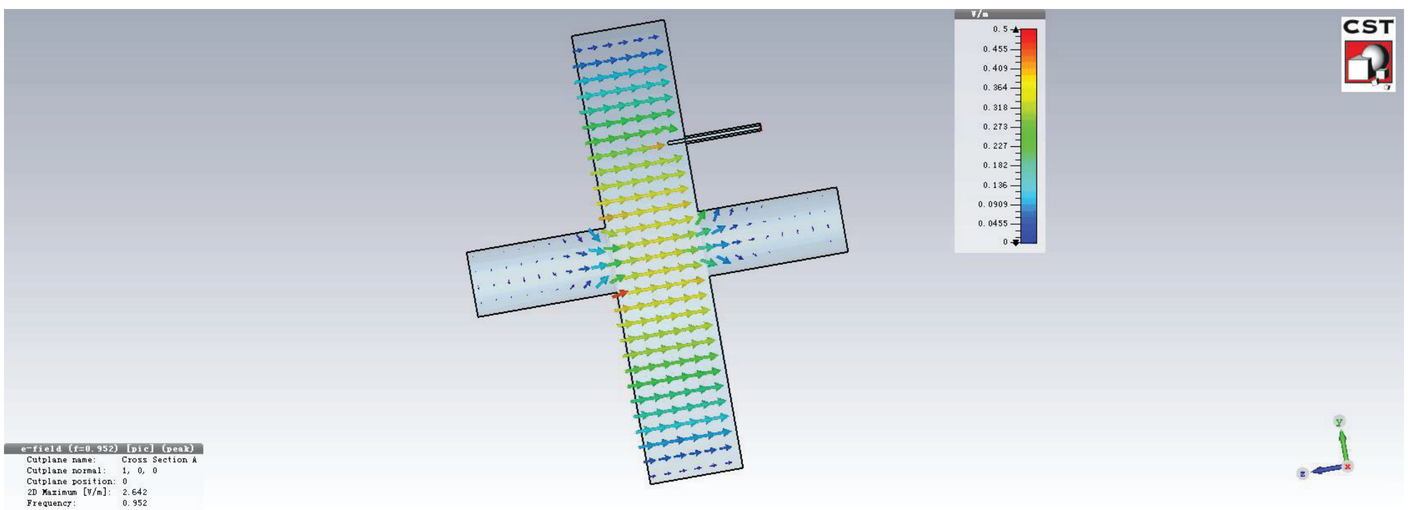
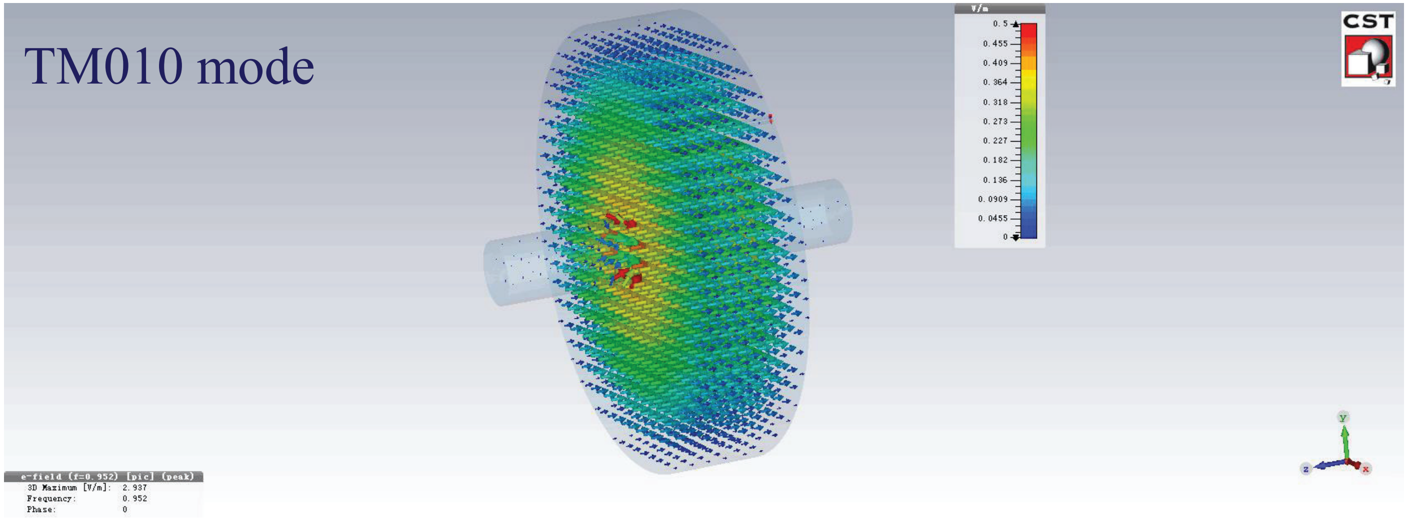
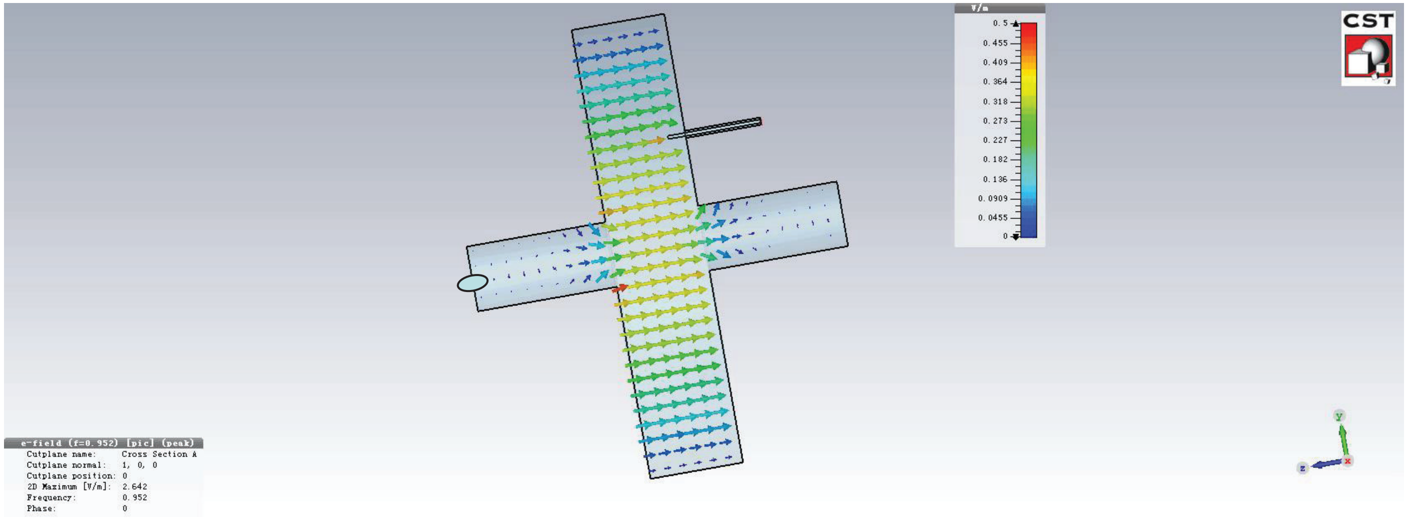
Theoretical Basis





Theoretical Basis





Theoretical Basis

- Assume a Gaussian distribution in beam direction with beam size σ_T, RF field is established when the bunch passes through a cavity. The power of the RF field can be expressed as

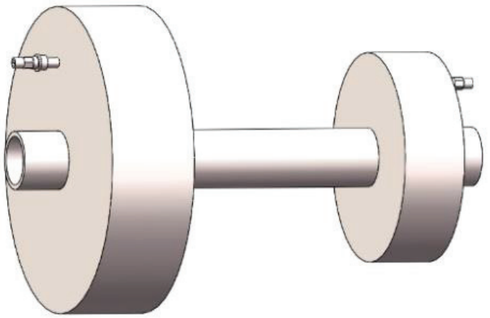
$$P = [I_0 \exp(-\frac{\omega^2 \sigma_\tau^2}{2})]^2 R$$

Where I_0 is pulse current, ω is resonance frequency of the mode, and R/Q is shunt impedance.

Theoretical Basis

- We need two cavities at least and the bunch length can be calculated by solving equation

$$\begin{cases} P_1 = [I_0 \exp(-\dfrac{\omega_1^2 \sigma_\tau^2}{2})]^2 R \\ P_2 = [I_0 \exp(-\dfrac{\omega_2^2 \sigma_\tau^2}{2})]^2 R \end{cases}$$



Both BEPCII and CERN utilize two cavities to determine the bunch length.

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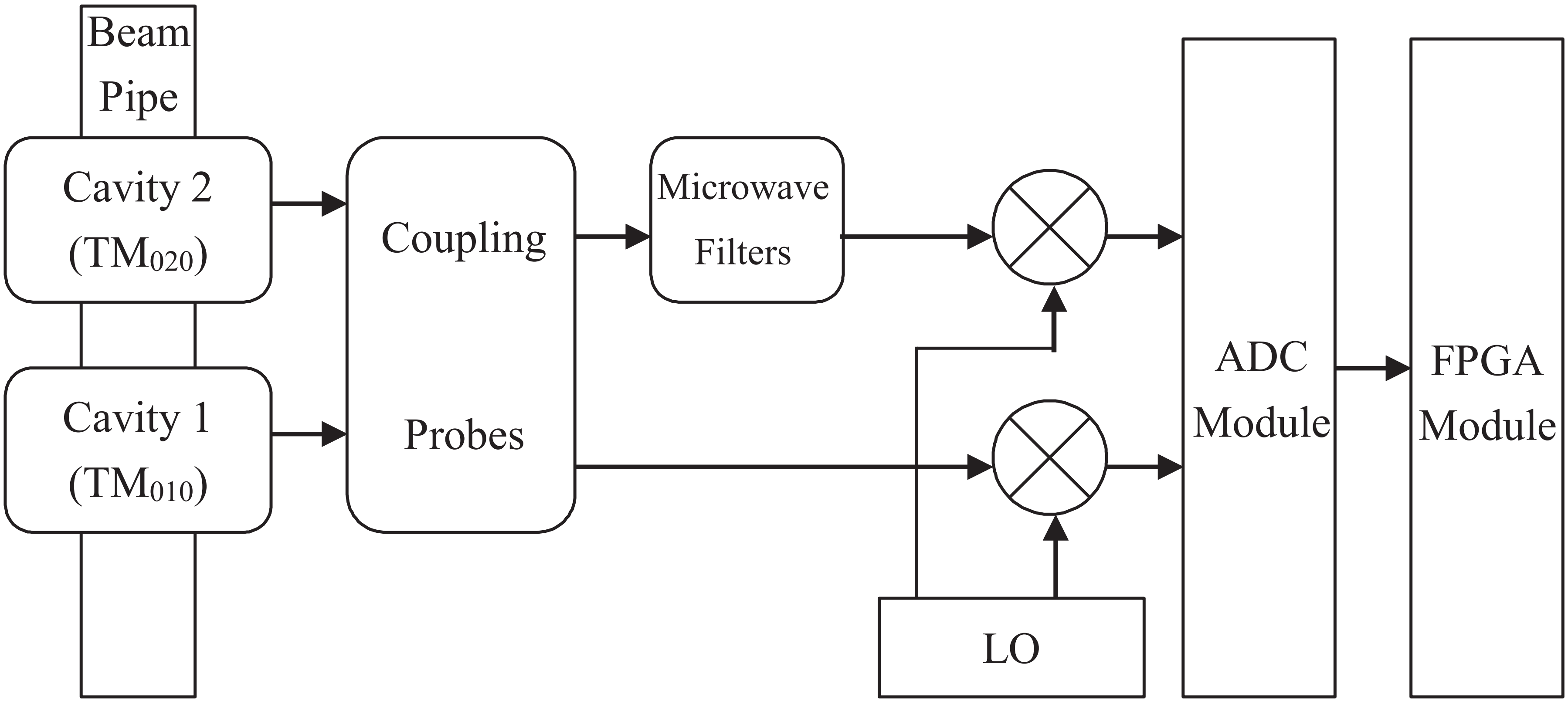
Studies and Improvements

- System Chart



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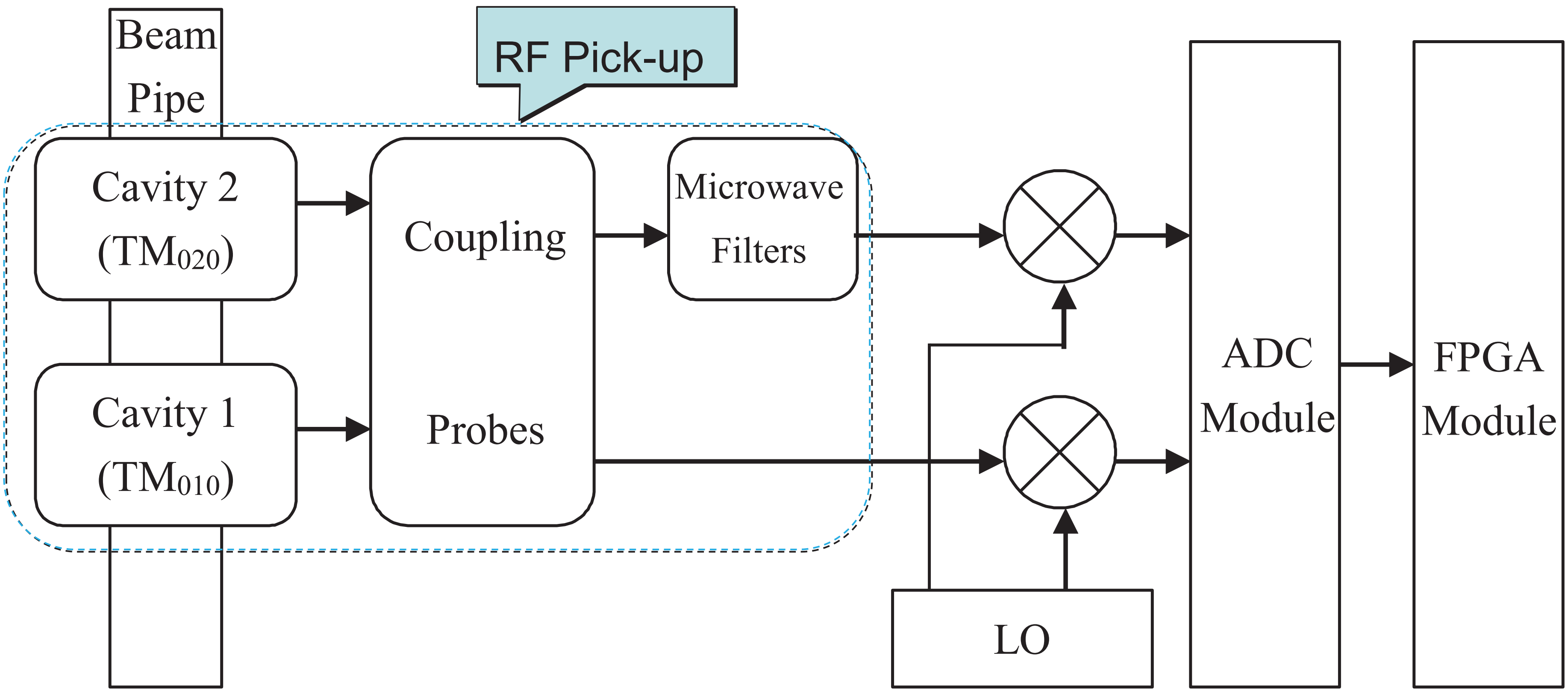

Studies and Improvements

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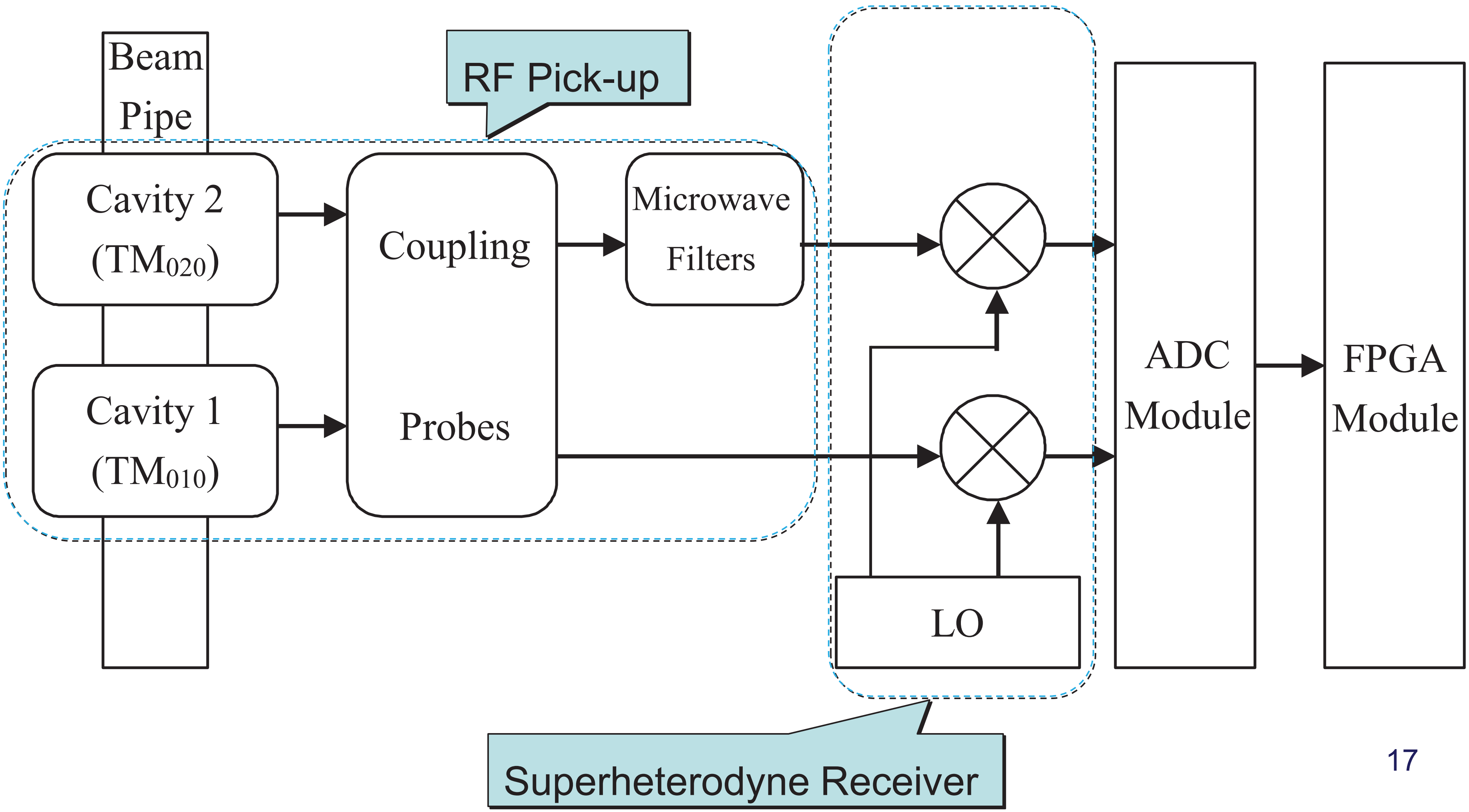

Studies and Improvements

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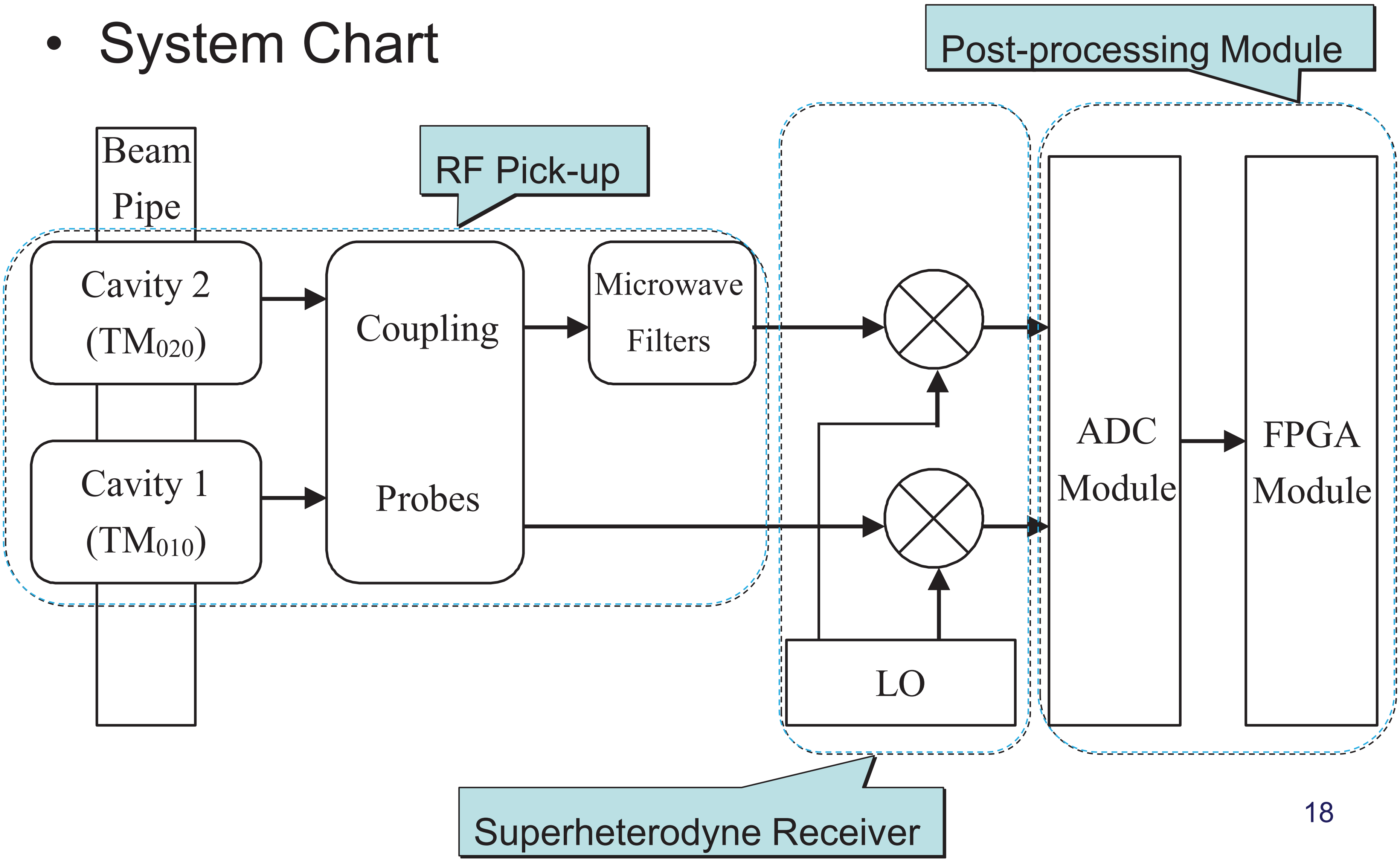


Studies and Improvements

- The expression of the cavity bunch length monitor theoretical resolution equation

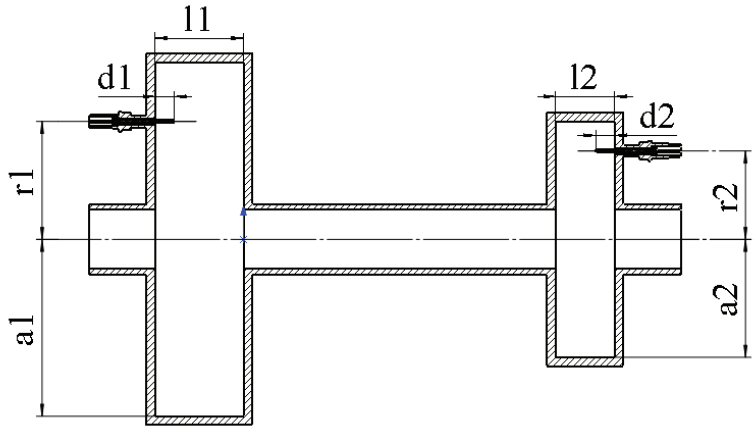
$$\Delta\sigma_{\tau r} = \frac{1}{(\omega_2^2 - \omega_1^2)\sigma_\tau}(10^{-SNR/20})$$

- In traditional cavity bunch length monitor, both the two cavities' work modes are TM010. The disadvantage of this type is that the beam pipe radius restricts working frequency of the cavity.

Studies and Improvements

- Improvement

TM010 mode → TM020 mode



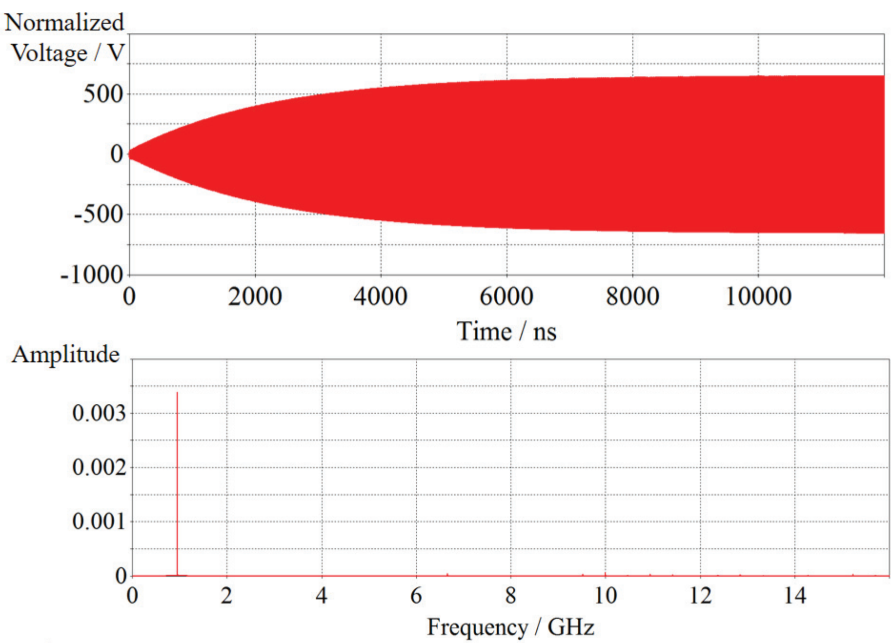
- This design overcome the difficulty of working frequency restriction caused by beam pipe radius and get higher resolution.

Studies and Improvements

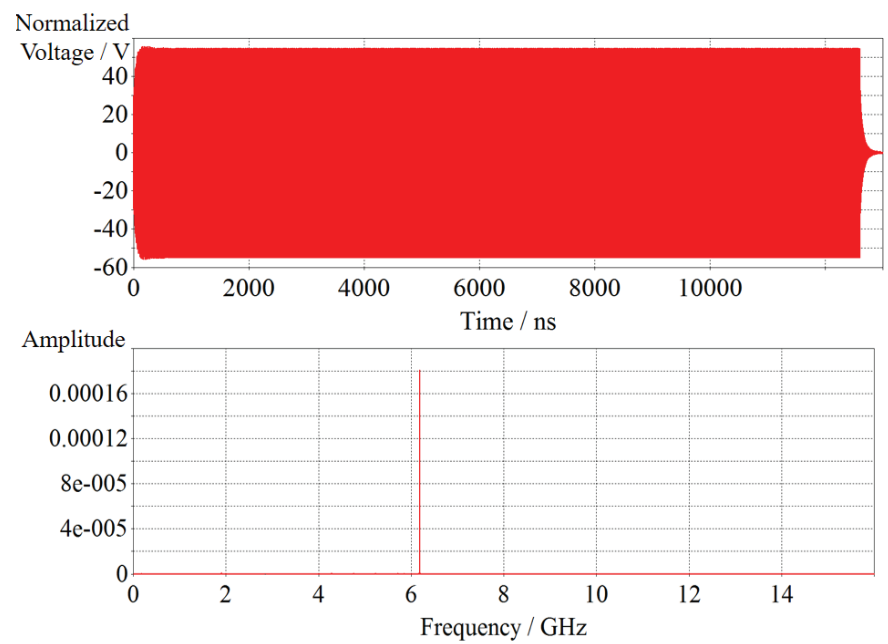
- Simulation Results

6000 bunches

$$Q_{ext} = \omega U / P_{out}$$



The output signals in time domain and in frequency domain of the second harmonic cavity (0.952GHz).



The output signals in time domain and in frequency domain of the thirtieth harmonic cavity (6.188GHz).

Studies and Improvements

- Simulation Results

bunch length /ps	simulation results /ps	relative error /%
5	5.068	1.360
4.5	4.570	1.556
4	4.074	1.841
3.5	3.582	2.354
3	3.088	2.931
2.5	2.596	3.821
2	2.102	5.112

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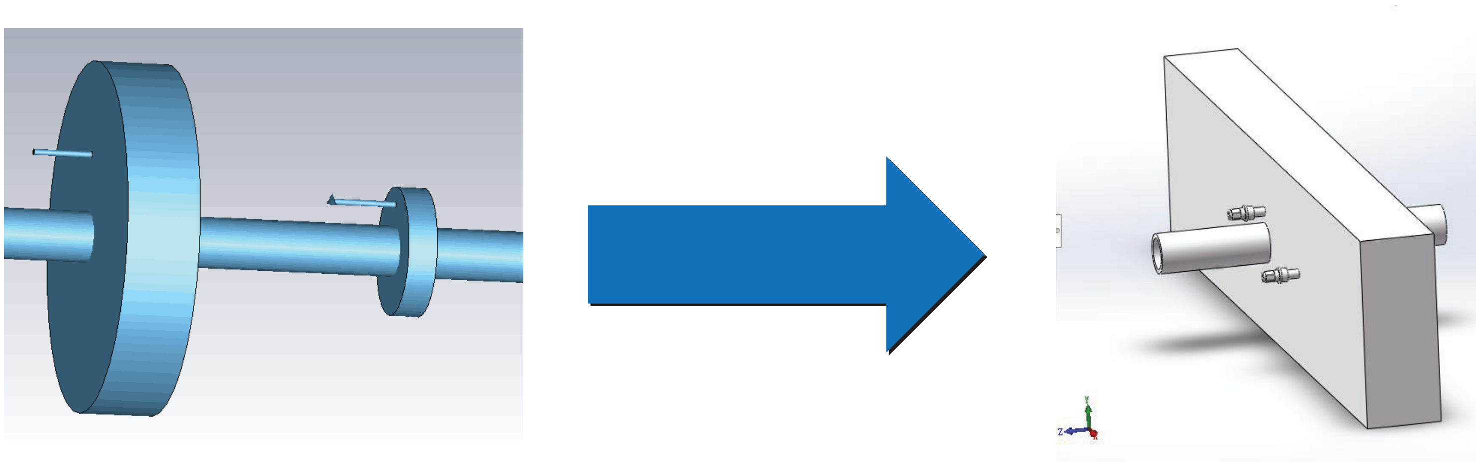
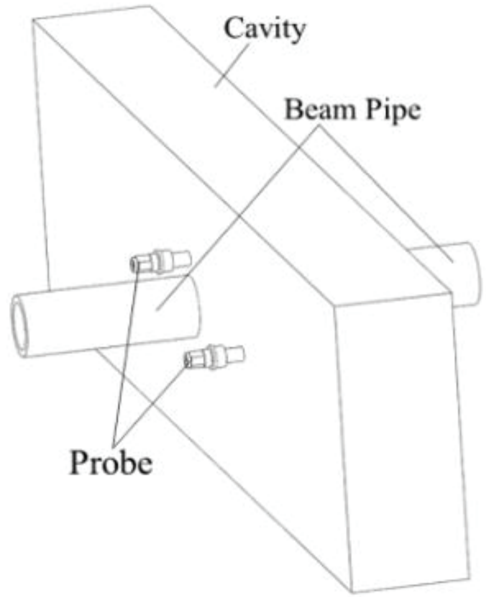
Studies and Improvements



- Compare with the traditional way, the new method do not need reference cavity. Two eigenmodes of a rectangular cavity are utilized to measure beam current and bunch length, so that the promoted monitor is simplified and compact.
- **TM310 mode (2.856GHz)** and **TM130 mode (7.616GHz)** are used to measure the bunch length.

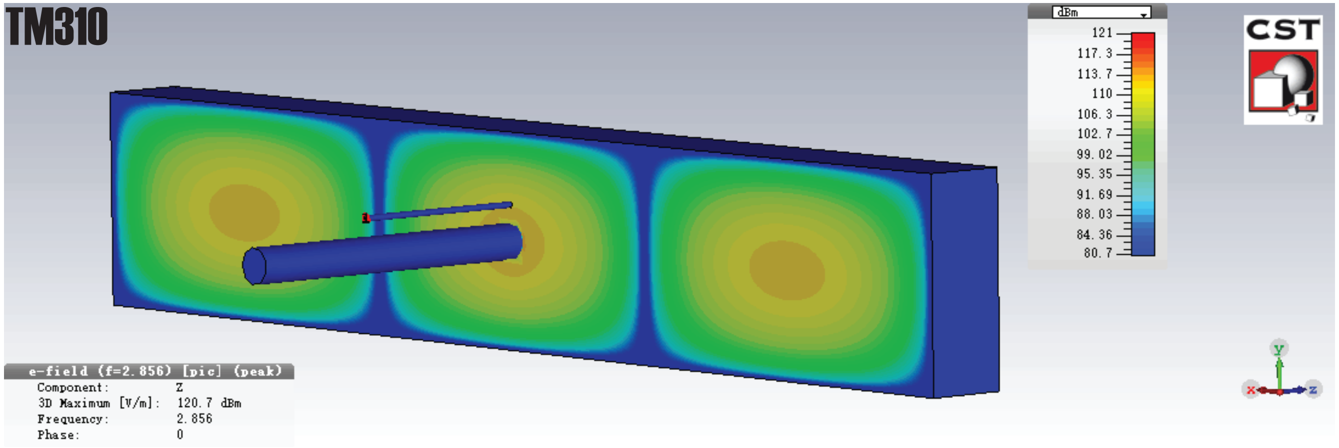
Studies and Improvements

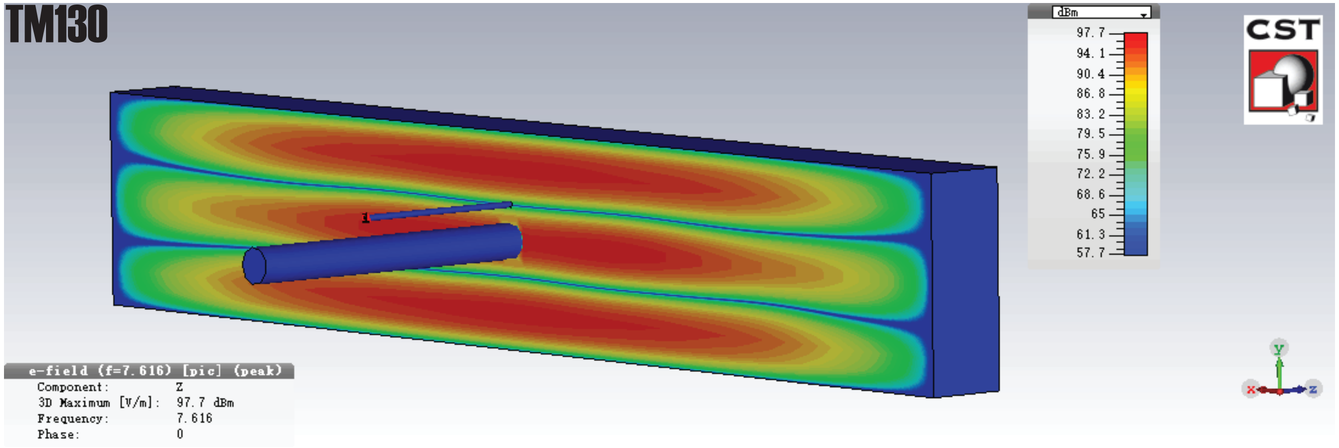


- Technical Challenge
  - Couple independently.
- Solutions
  - Two coaxial antennas are penetrated at special points to couple out the signals.

Improved CBLM

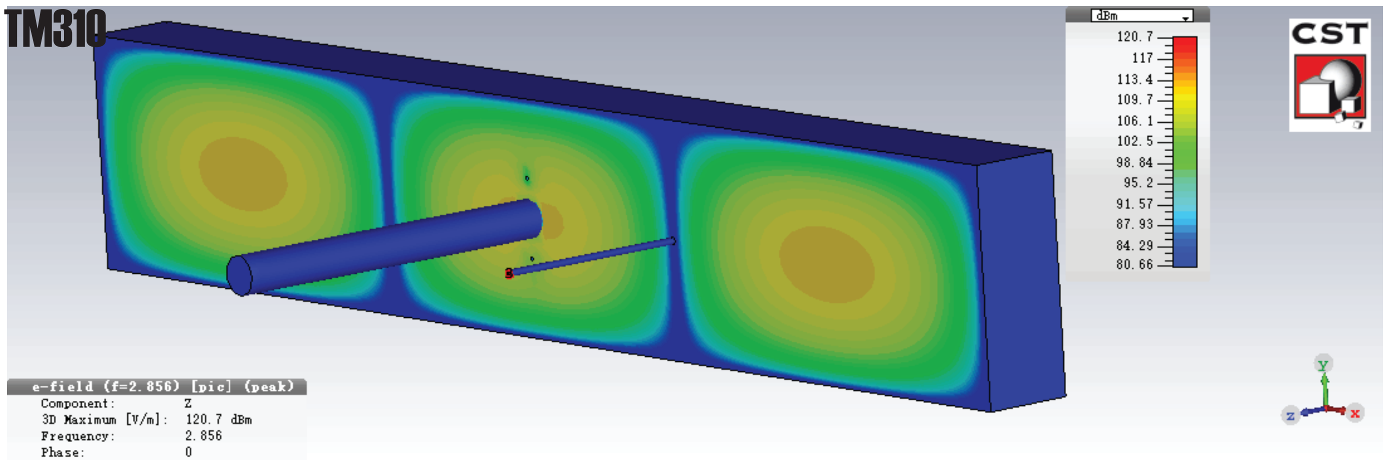
- Probe 1

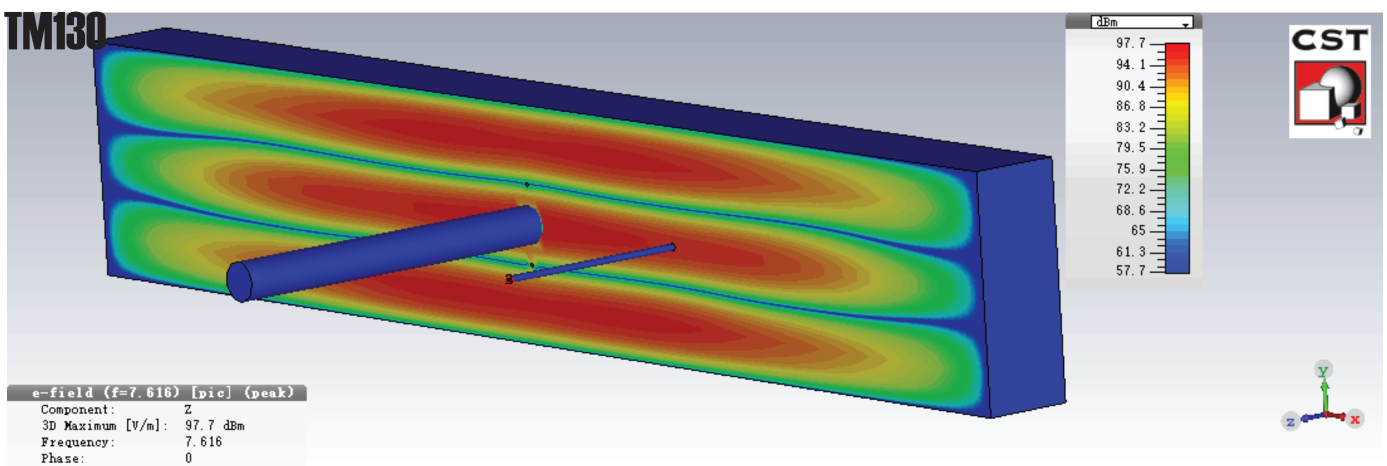




Improved CBLM

- Probe 2





Studies and Improvements

- Simulation Results

bunch length/ps	simulation results of single cavity/ps	relative error of single cavity/%	simulation results of double cavities/ps	relative error of double cavities/%
2	5.070	1.403	5.068	1.360
2.5	4.572	1.603	4.570	1.556
3	4.075	1.871	4.074	1.841
3.5	3.579	2.245	3.582	2.354
4	3.084	2.806	3.088	2.931
4.5	2.594	3.741	2.596	3.821
5	2.098	4.882	2.102	5.112

According to the results obtained from the CST, this monitor shows good performance in bunch length measurements.

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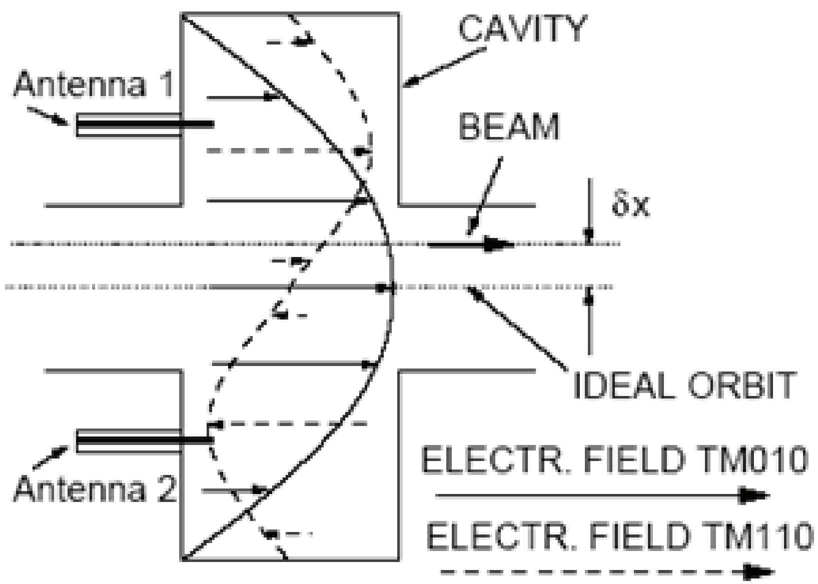
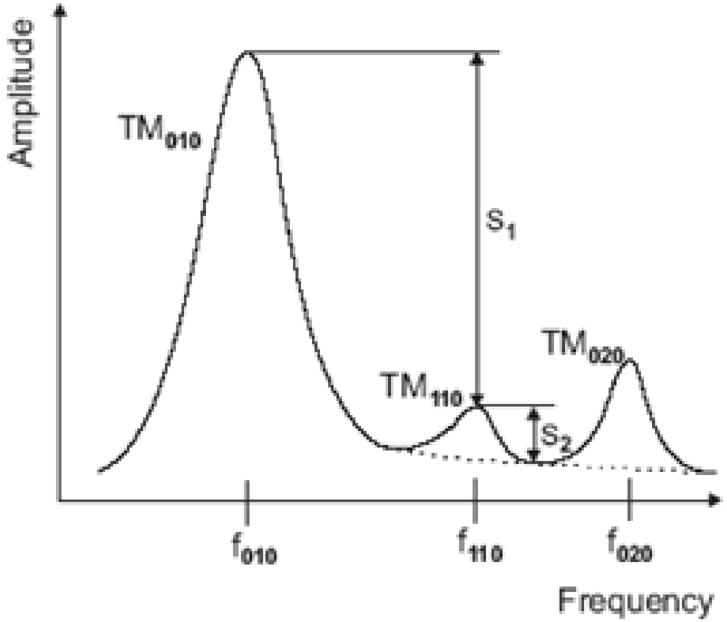
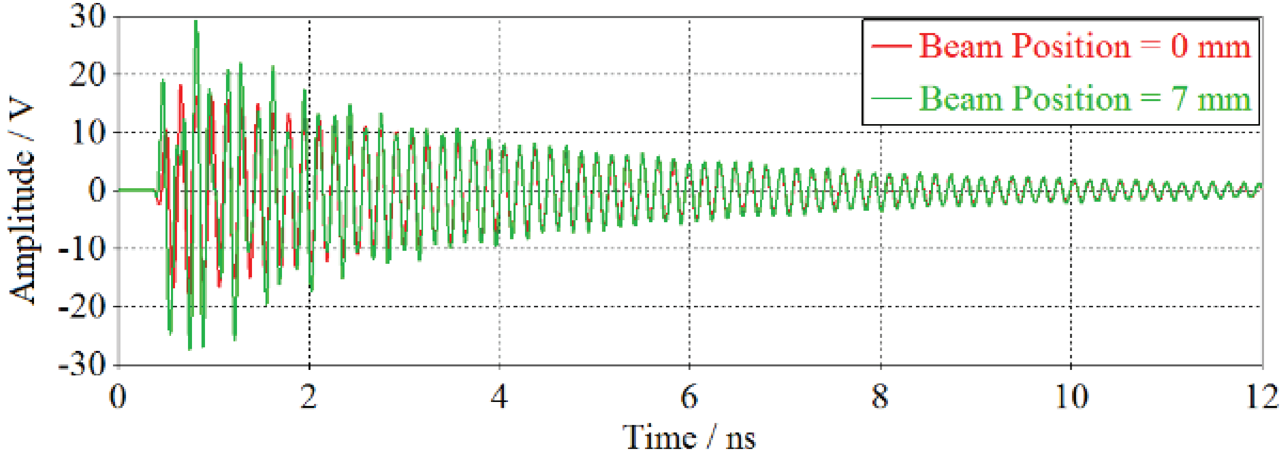
Studies and Improvements

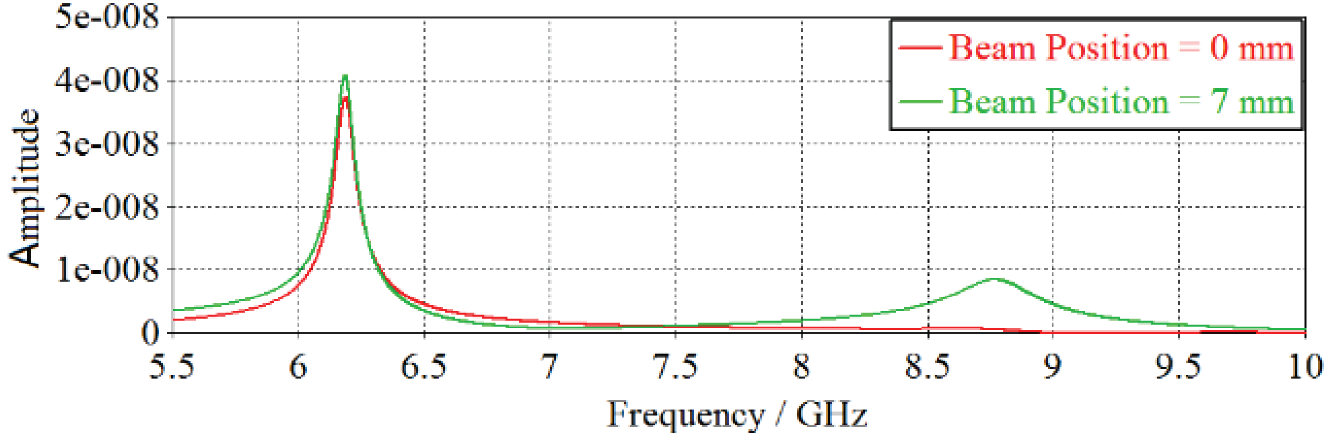
- When passing through the cavity with a position offset, the bunch will excite dipole modes such as TM110. These modes may make an impact on the output signals.





Studies and Improvements

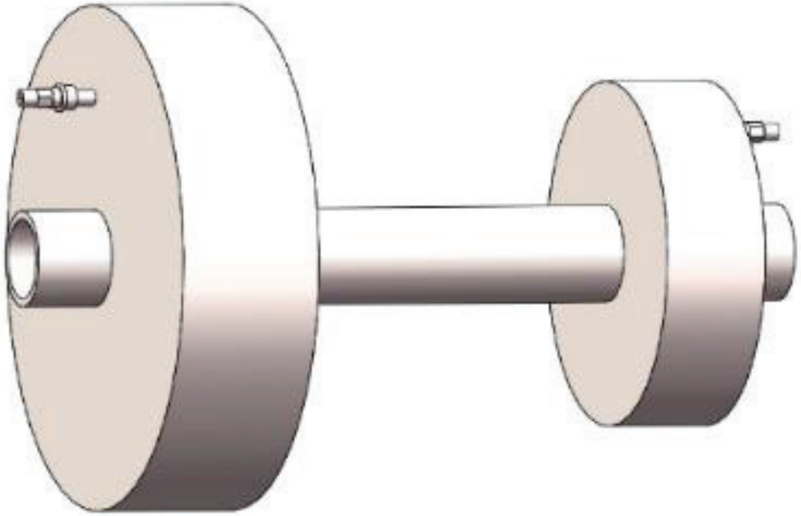




- The red line is the output signal when the bunch moves on axis of the cavity, and the green line is the output signal when the beam offset is seven millimeters.

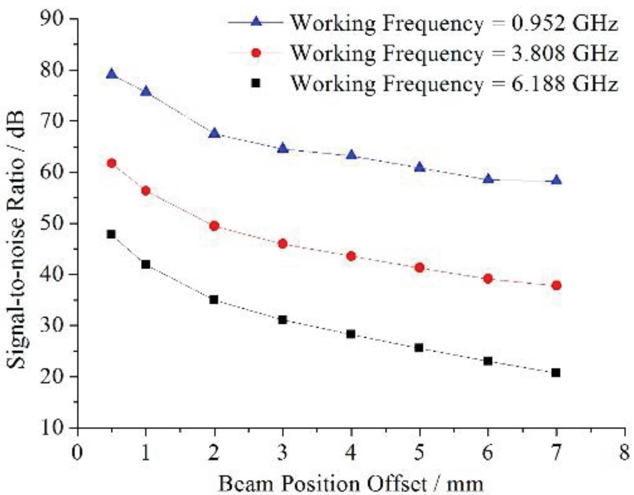
Studies and Improvements

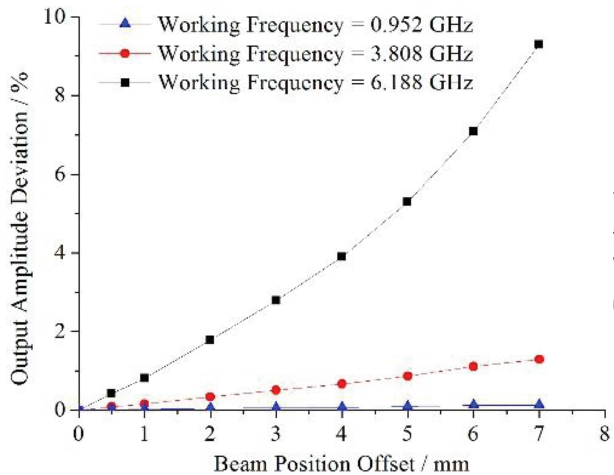
- The experimental device

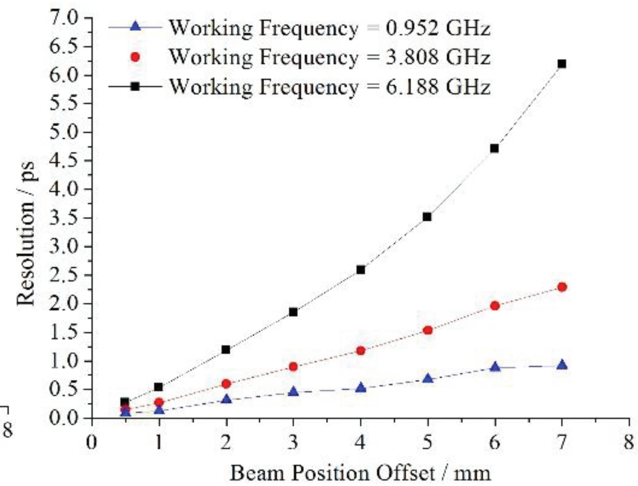


- The experimental device consists of two cavities. The first one is the reference cavity that works at TM010 mode with 0.476 GHz. The second one is the main cavity that works at TM010 mode as well.

Studies and Improvements

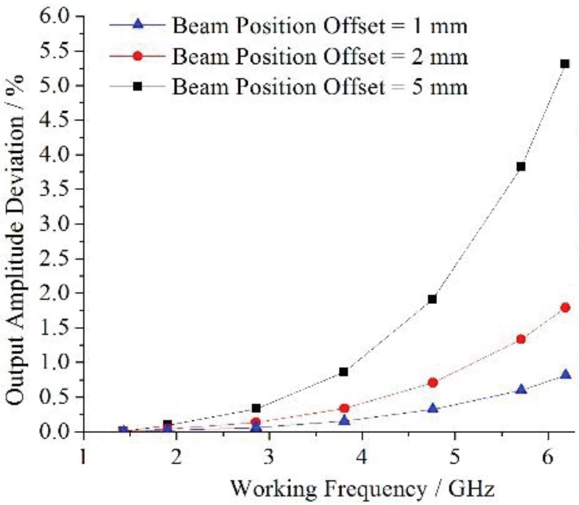


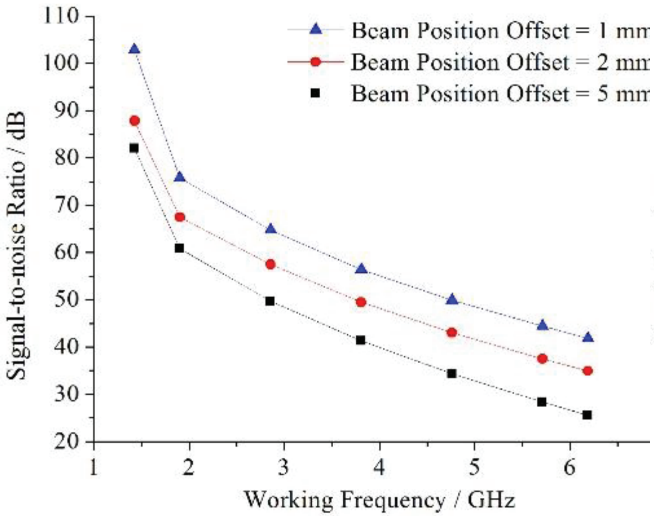


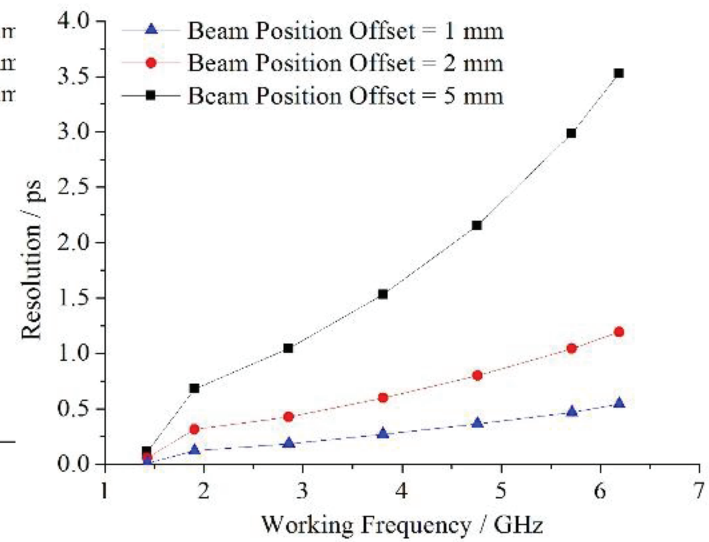


- The father away the beam sets from the axis of the cavity, the greater the deviation is. It follows that the SNR and the resolution decline.

Studies and Improvements



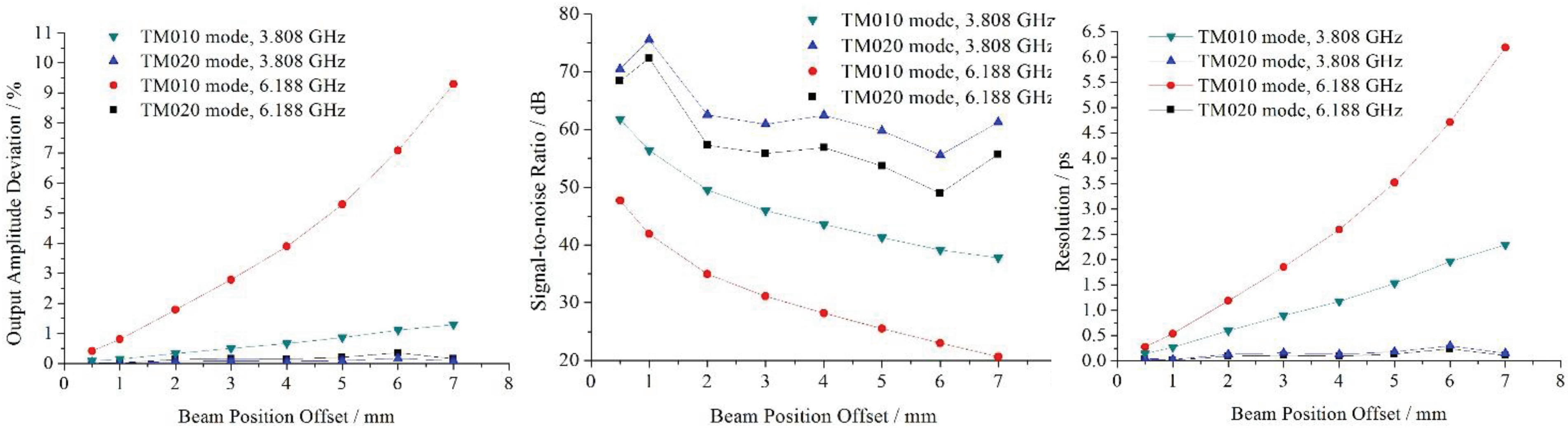




- The same beam position will introduce greater noise if working frequency is higher.

$$\Delta\sigma_{\tau r} = \frac{1}{(\omega_2^2 - \omega_1^2)\sigma_\tau}(10^{-SNR/20})$$

Studies and Improvements



- Comparing with TM010 mode, TM020 mode can be excited in larger cavity whose quality factor Q is higher. Using TM020 mode is able to obtain the high SNR and the high resolution compared with the traditional cavity with TM010 mode.

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Conclusion

- The framework of the whole diagnostic system is designed.
- To remove the limitation that working frequency and resolution are restricted by the radius of beam pipe, the bunch length monitor based on high order mode cavity is proposed.
- A kind of new method to measure bunch length of FEL with single cavity is presented.
- The laws of resolution change caused by some decisive factors such as working frequency and electromagnetic mode are analyzed.
- Offers the theoretical support for the design and application of bunch length monitor in the future light sources.

Thank you !