Status of the Cavity BPM Developments at KNU and Fermilab

Seunghwan Shin
KNU / Fermilab

17, March, 2009

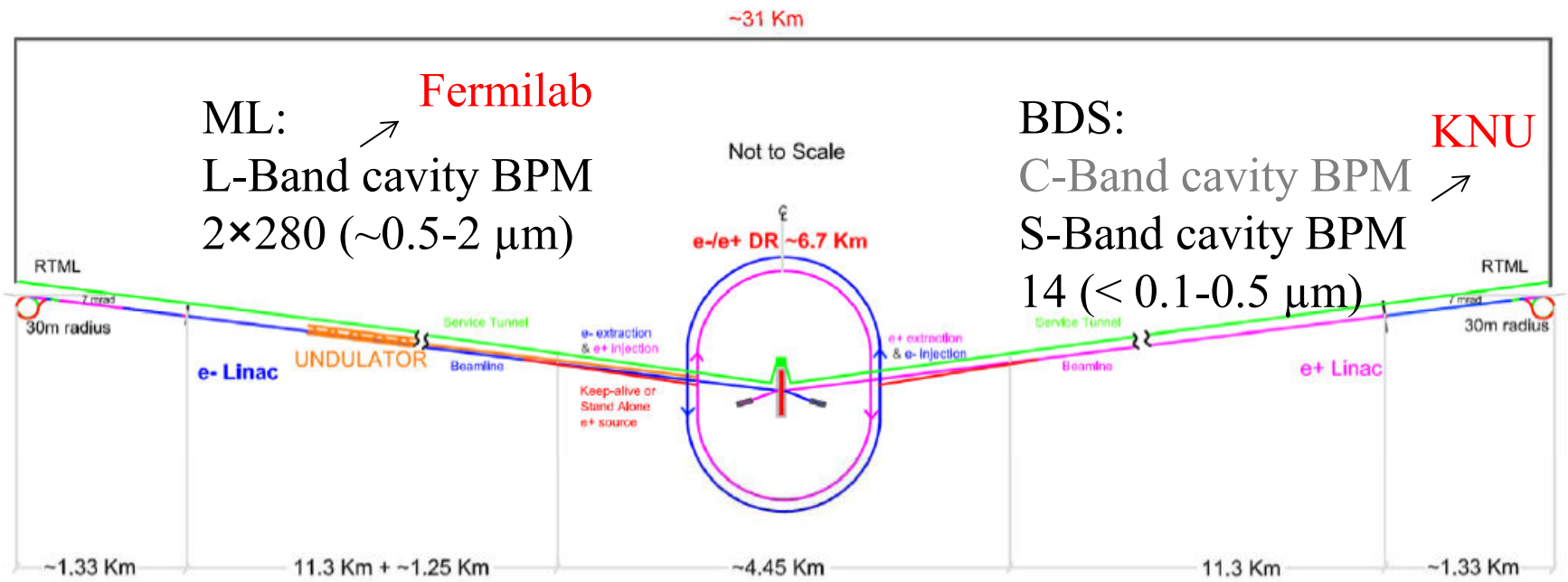
Agenda

- Introduction.
- Cavity BPM R&D for ILC BDS at KNU.
- Cavity BPM R&D for ILC ML at Fermilab.
- Remote machine study for future work.
- Summary.

Introduction / The requirement for high resolution BPM.

Realization of a precise beam handling is strongly required in future accelerators such as linear colliders (LC) and X-ray free electron lasers (XFEL). It goes without saying that a high resolution beam position measurement is the key.

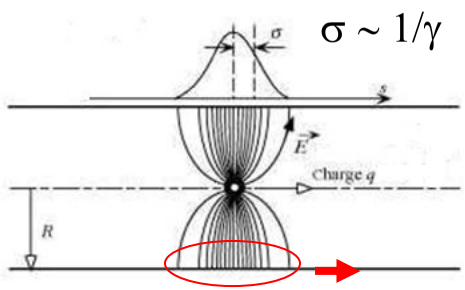
High luminosity ⇨ Small beam size (~ nm level) ⇨ Precise orbit control (~nm resolution)



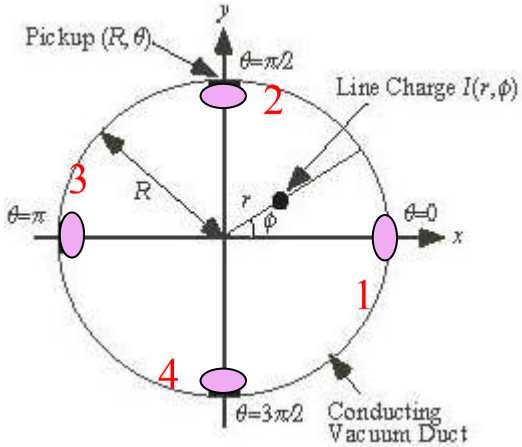
Schematic layout of the ILC complex

Introduction / Electrode BPM

Stripline BPM in ATF .



"Wall Current"



r << R

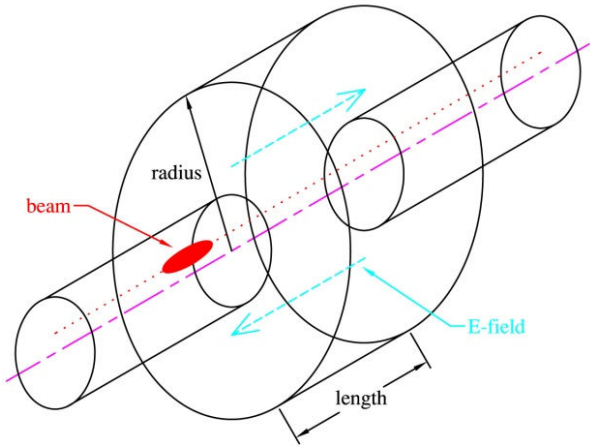
$$\left(\frac{\Delta}{\Sigma}\right)_x = \frac{j_1(r,\phi,R,\theta_1) - j_3(r,\phi,R,\theta_3)}{j_1(r,\phi,R,\theta_1) + j_3(r,\phi,R,\theta_3)} = \frac{r\cos\phi}{R/2} = \frac{x}{R/2}$$

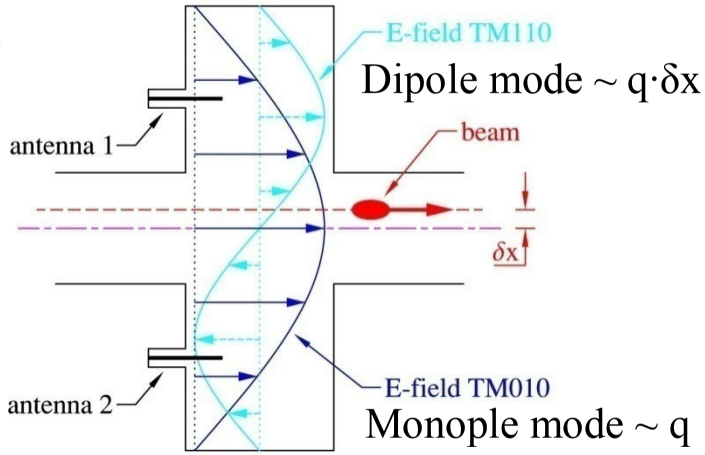
$$\left(\frac{\Delta}{\Sigma}\right)_y = \frac{j_2(r,\phi,R,\theta_2) - j_4(r,\phi,R,\theta_4)}{j_2(r,\phi,R,\theta_2) + j_4(r,\phi,R,\theta_4)} = \frac{r\sin\phi}{R/2} = \frac{y}{R/2}$$

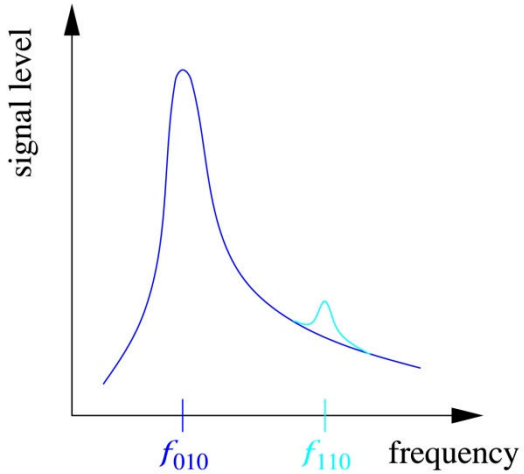
1. Large thermal noise due to wide band width.
2. Zero position also produce the large signal for each electrode.
3. Since the signals of electrode are read out independently, resolution is limited by ADC bit count.
   (To directly subtract analog signals)

Principle

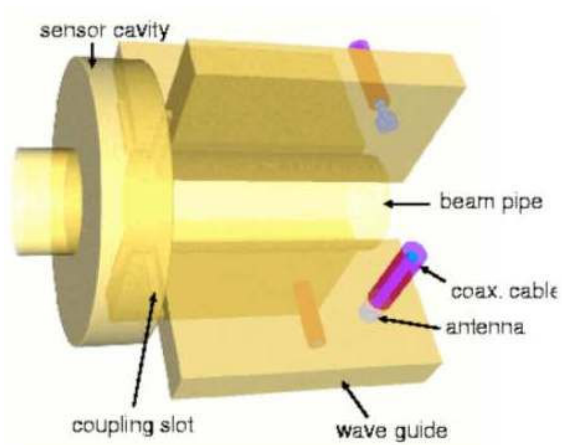
Generates dipole (TM110) and monopole (TM010) modes







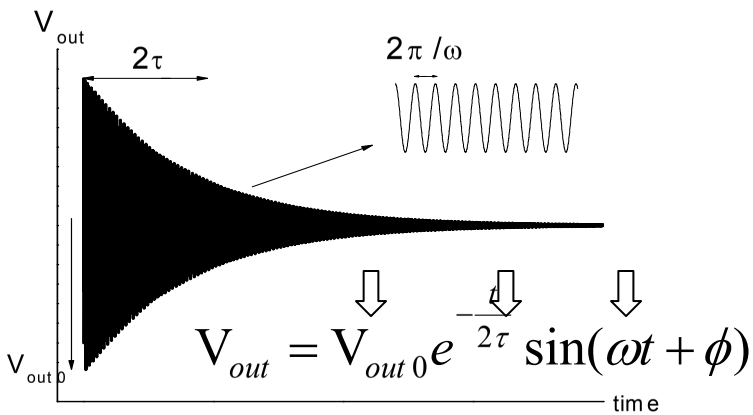
Needs monopole mode(TM110) suppression!



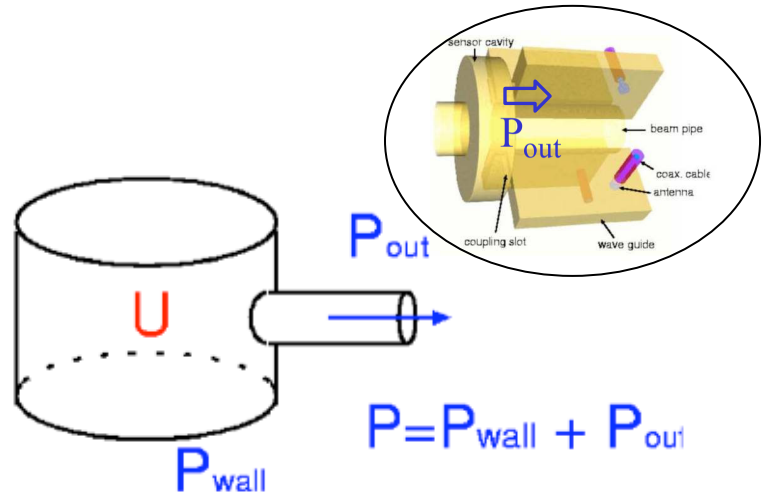
1. Small thermal noise due to narrow band width (~ MHz).
2. No signal at zero position.
3. Position is calculated with the dipole mode of cavity pickup
4. Normalization from different signal (monopole mode).

Dipole mode selectable coupler

Parameters for cavity BPM



$$V_{out} = V_{out\,0} e^{-\frac{t}{2\tau}} \sin(\omega t + \phi)$$



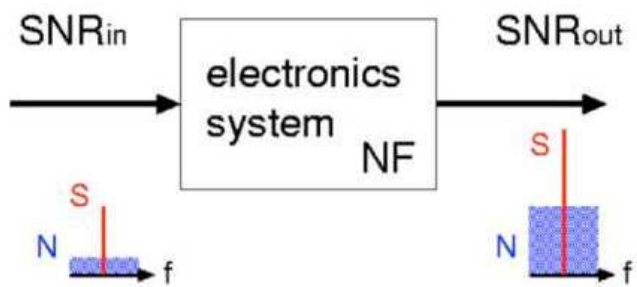
$$Q_0 \equiv \frac{\omega U}{P_{wall}} \qquad Q_{ext} \equiv \frac{\omega U}{P_{out}} \qquad Q_L \equiv \frac{\omega U}{P} \qquad \frac{1}{\omega\tau} \equiv \frac{1}{Q_L} = \frac{1}{Q_0} + \frac{1}{Q_{ext}}$$

S: $V_{out\,0} = \sqrt{ZP_{out}} = \frac{\omega q}{2}\sqrt{\frac{Z}{Q_{ext}}(R/Q)}$ ~δx

Where $R/Q = \frac{V^2}{\omega U}$ $\quad V = \int \vec{E} \cdot d\vec{z}$

N: $V_{Th} = \sqrt{4k_b T \cdot BW}$

$$NF = \frac{SNR_{in}}{SNR_{out}}$$

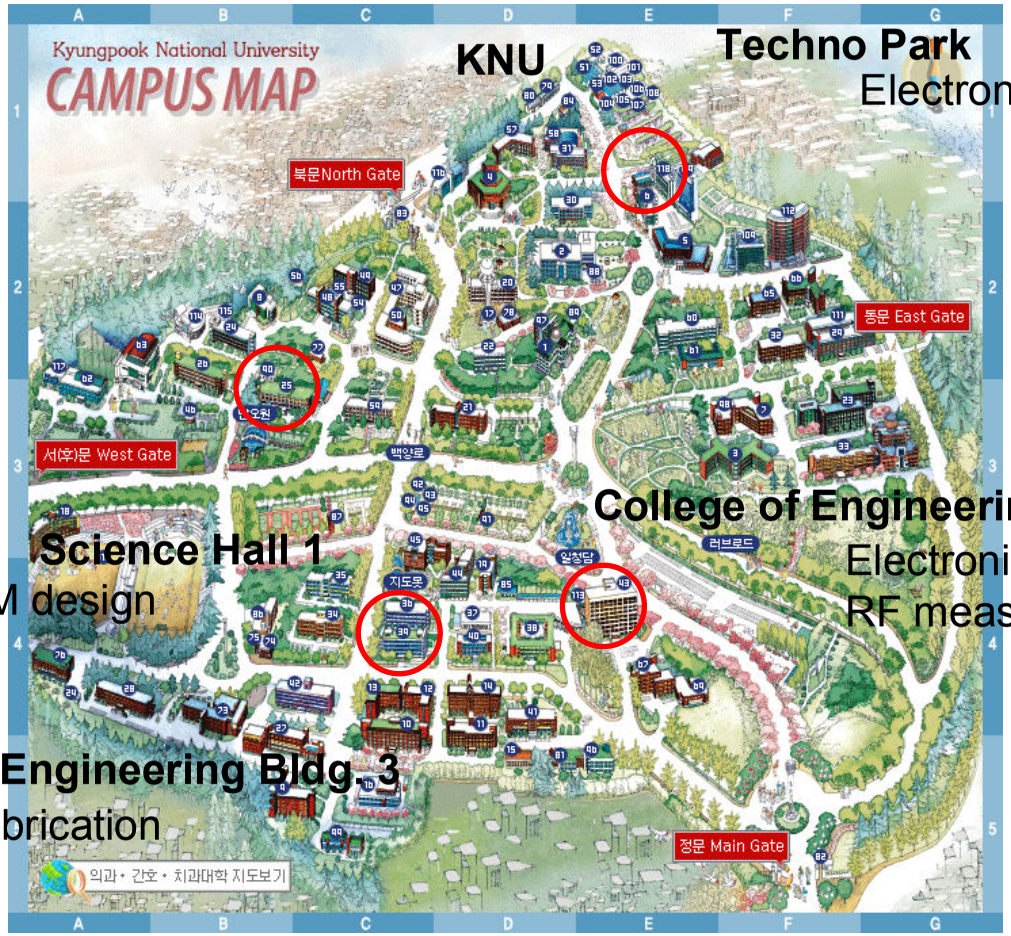


KNU activities / KNU introduction

September 2000:
The Centre for High-Energy Physics in Korea was formally inaugurated at KNU.

March 2006: Accelerator research was started.

September 2006: Cavity BPM R&Ds for ILC was started.

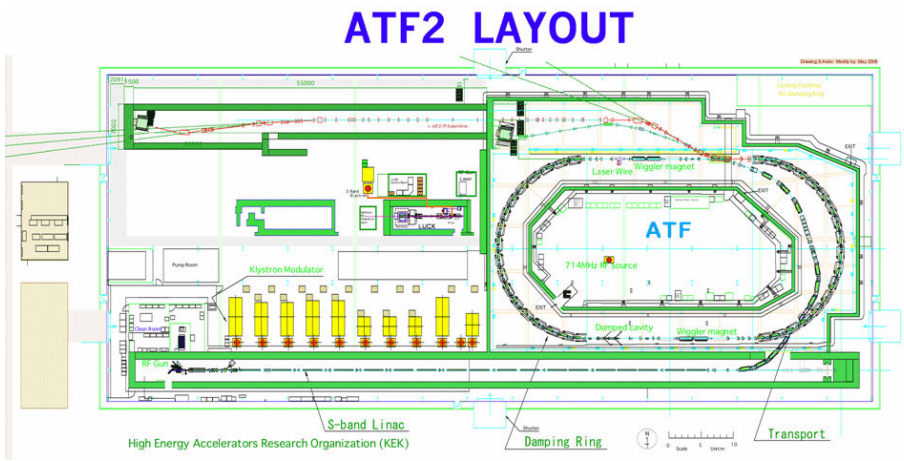


KNU activities / ATF introduction

ATF & ATF2 (KEK)

Why ATF ?
=> World's lowest emittance beam.

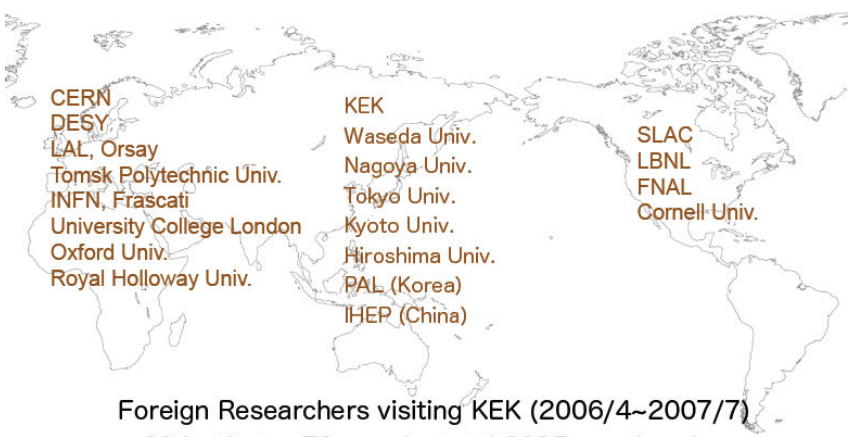
What's ATF2 for ?
=> Focusing the beams to nm size.
=> Providing sub nm stability.



T. Tauchi, ATF2 meeting, May 2008

N.Ternuma, LC project committee, 7 Aug.2007

ATF International Collaboration



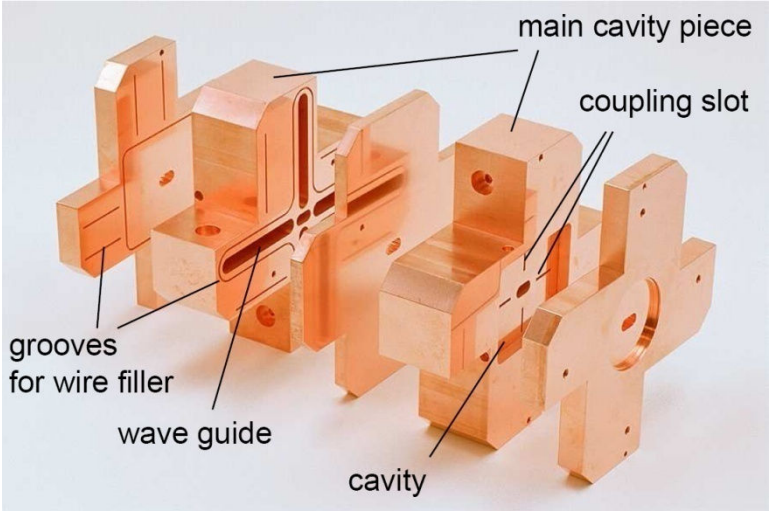
Foreign Researchers visiting KEK (2006/4~2007/7)
23 institutes,71 people, total 2085 people・day
(full-year researchers are excluded)

Asian Contributions

(1) Optics, beam tuning and commissioning
KEK, IHEP, KNU
(2) Shintake monitor (beam size monitor at IP)
KEK, University of Tokyo
(3) Quadrupole magnets: 28 in total
design (KEK, IHEP, SLAC), production (IHEP),
magnetic field measurement (KEK, IHEP)
(4) Cavity BPMs (QBPMs) with 100nm resolution ; 39 in total
design (KEK, PAL), production (PAL)
digital readout electronics (SLAC)
(5) IPBPM with 2nm resolution ; a IPBPM in BSM and a quartet at IP
design (KEK), production (KEK), electronics (KEK)
lower Q type R&D (KNU)
(6) S-band BPM (at the FD system , i.e. for QD0, SD0, QF1, SF1)
design and production (KNU) in collaboration with RHUL(UK)

KNU activities / KEK IP-BPM

Model introduction



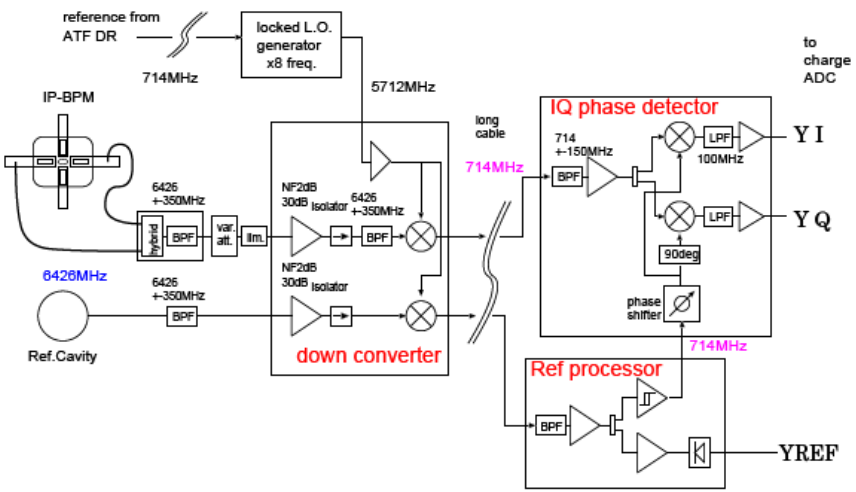
Characteristics

1. Narrow gap to be insensitive to the beam angle.
2. Small aperture (beam tube) to keep the sensitivity.
3. Separation of x and y signal. (Rectangular cavity)
4. Double stage homodyne down convertor.

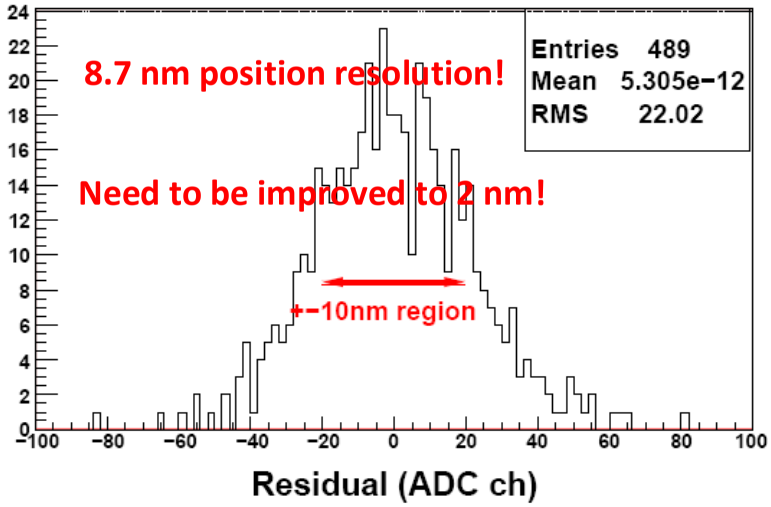
Design parameter

Port	f (GHz)	β	Q_0	Q_{ext}
X	5.712	1.4	5300	3901
Y	6.426	2	4900	2442

Electronics



Results



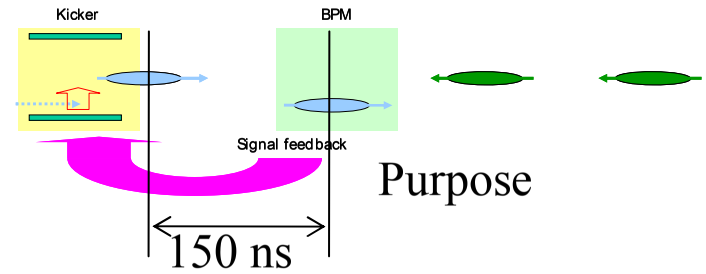
KNU activities / KNU low-Q IP-BPM

Characteristics

1. Same basic idea with KEK IP-BPM.
2. Short decay time 20 ns for x and y signals.
3. Short decay time 30 ns for reference signal.
4. Single stage homodyne down convertor.
5. L.O. signal from reference cavity.

Design parameter

Port	f (GHz)	β	Q_0	Q_{ext}
X	5.712	8	5900	730
Y	6.426	9	6020	670
Reference	6.426	0.0117	1170	100250



Purpose

Small value in reference cavity

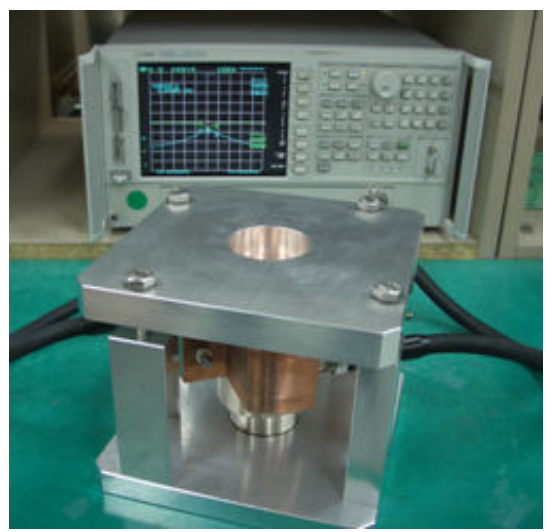
$$\frac{1}{Q_L}\left(=\frac{1}{\omega\tau}\right)=\frac{1}{Q_0}+\frac{1}{Q_{ext}}$$

Small value in sensor cavity

⇨ Larger coupling slot

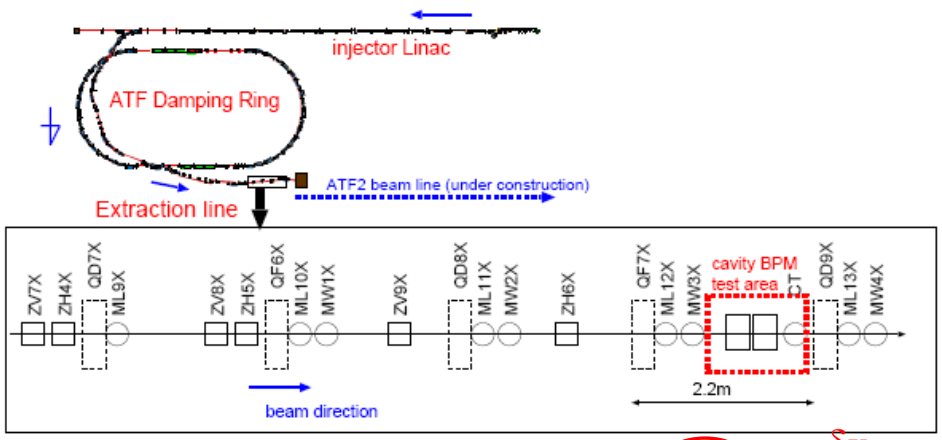
⇨ Other signal contamination

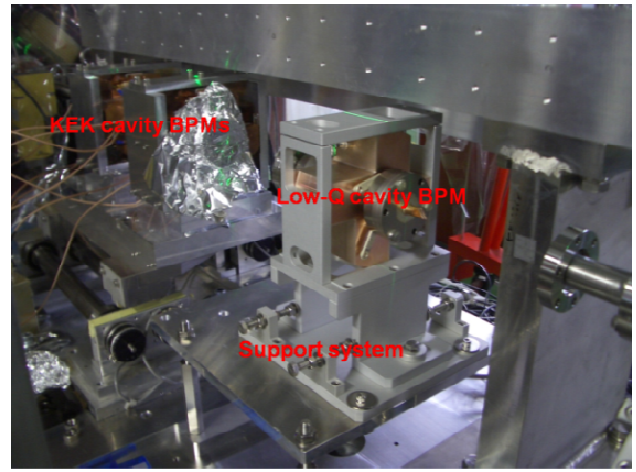
Development

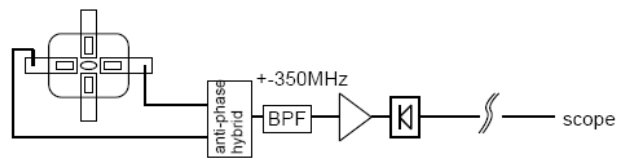


KNU activities / KNU low-Q IP-BPM

Basic beam test





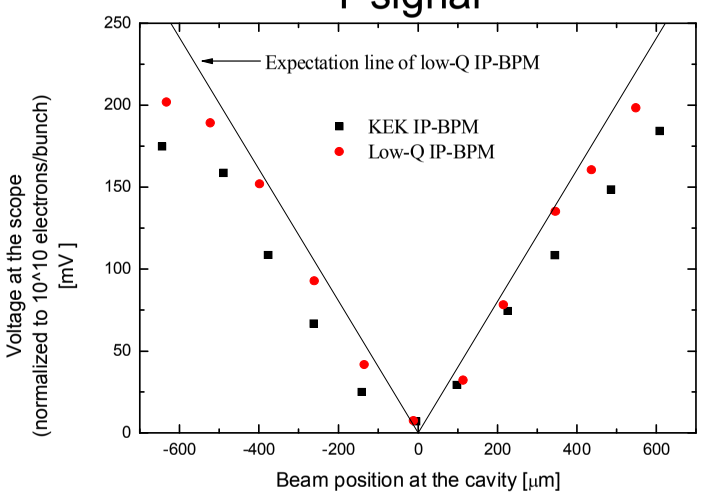


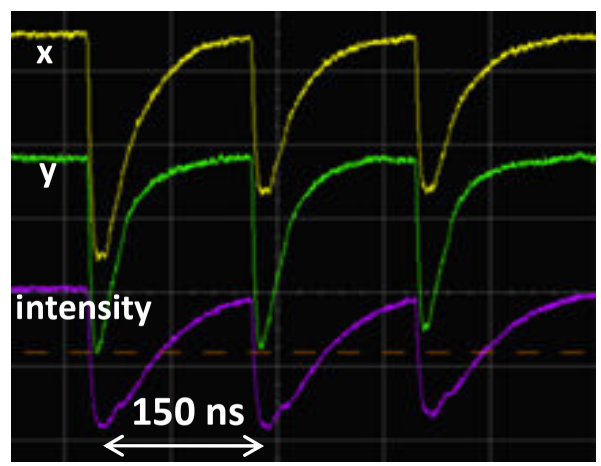
Results

$$V_{out\,0} = \frac{\omega q}{2}\sqrt{\frac{Z}{Q_{ext}}(R/Q)}$$

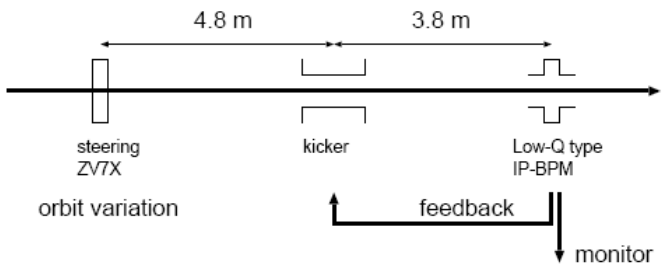
~δx

Y signal

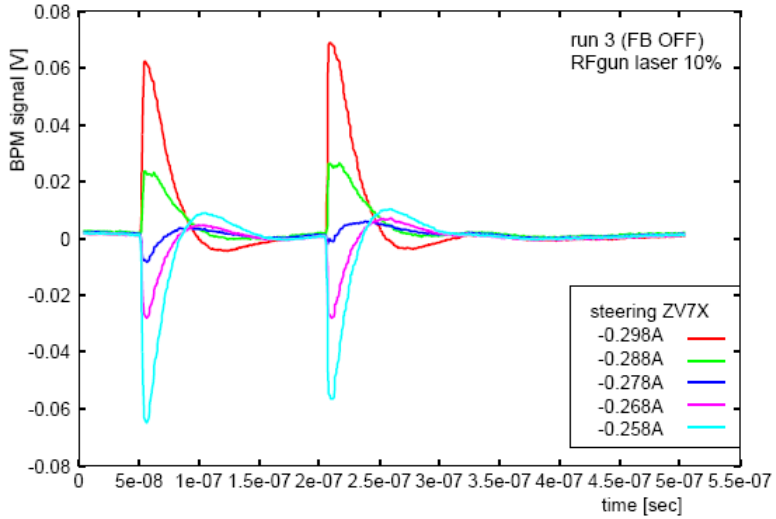


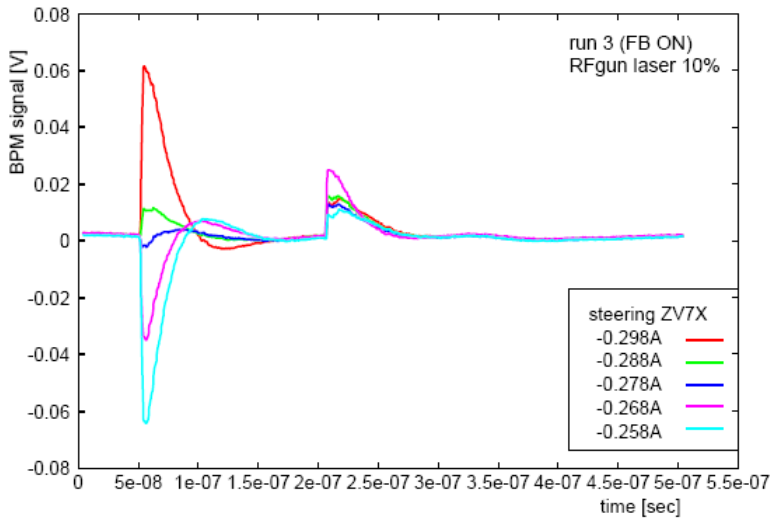


KNU activities / KNU low-Q IP-BPM

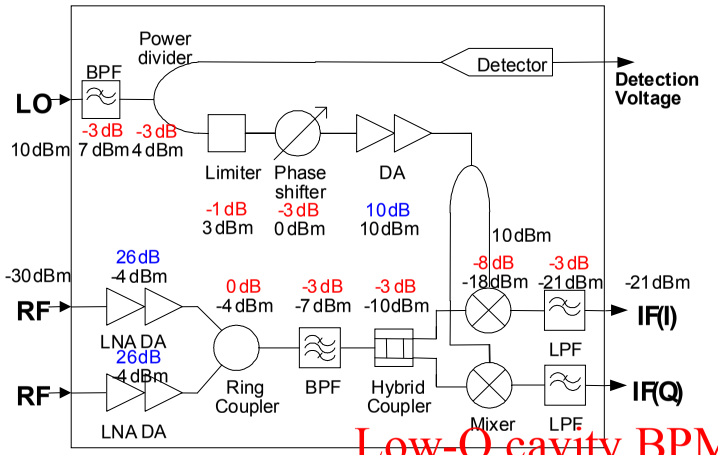


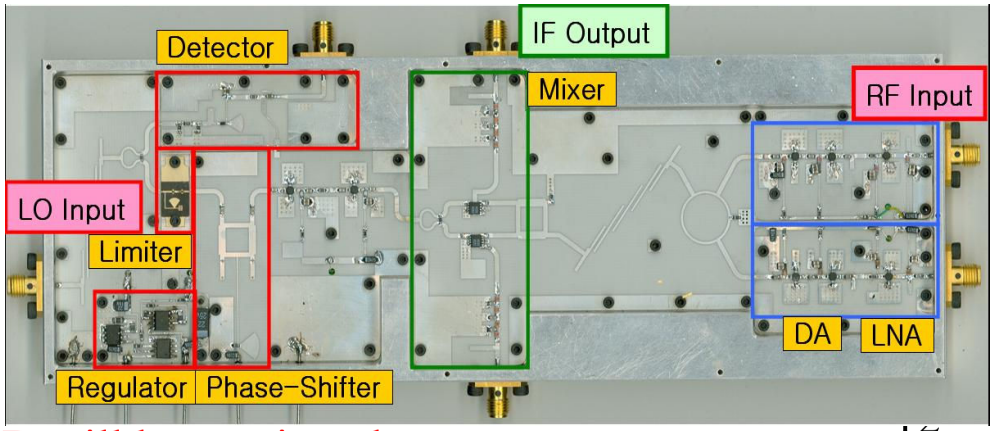
Preliminary feedback test by KEK





Electronics design

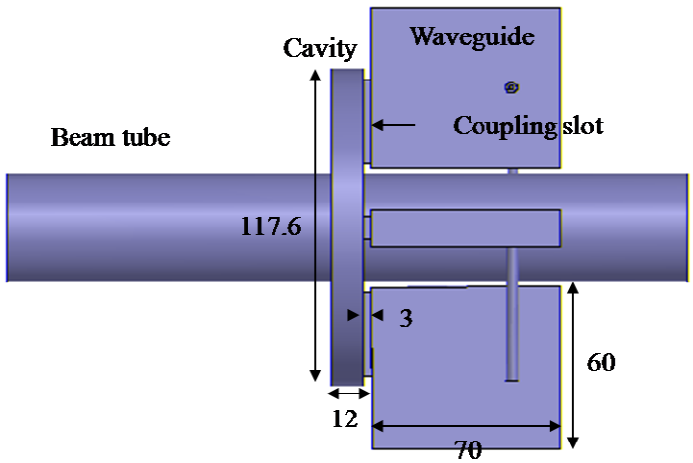




Low-Q cavity BPM R&D will be continued….

KNU activities / S-band BPM (KNU/LAPP/RHUL/KEK)

Model introduction



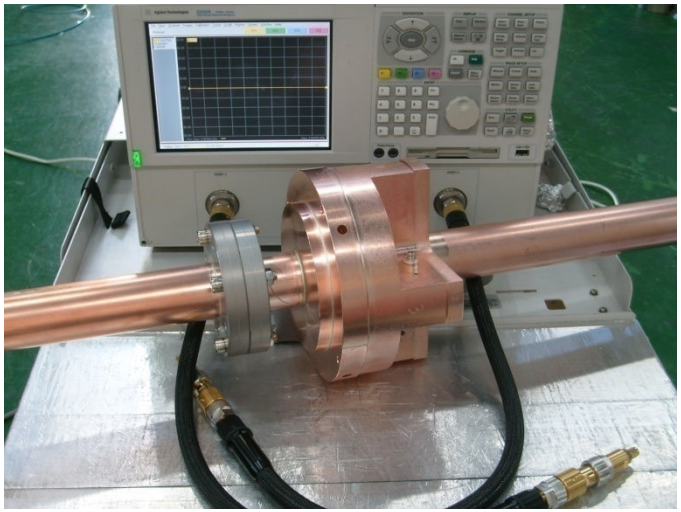
Characteristics

1. Submicron resolution for BBA with 1 μm.
2. A few mm dynamic range.
3. 40 mm diameter beam tube.
4. 22 MHz down-converted frequency.

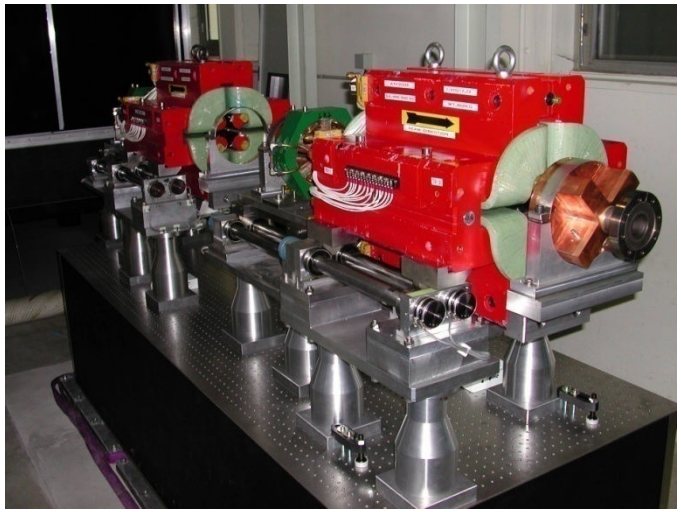
Design parameter

Port	f (GHz)	β	Q_0	Q_{ext}
X	2.878	2.5	6000	2400
Y	2.878	2.5	6000	2400

Fabrication & RF test



Installation at ATF2

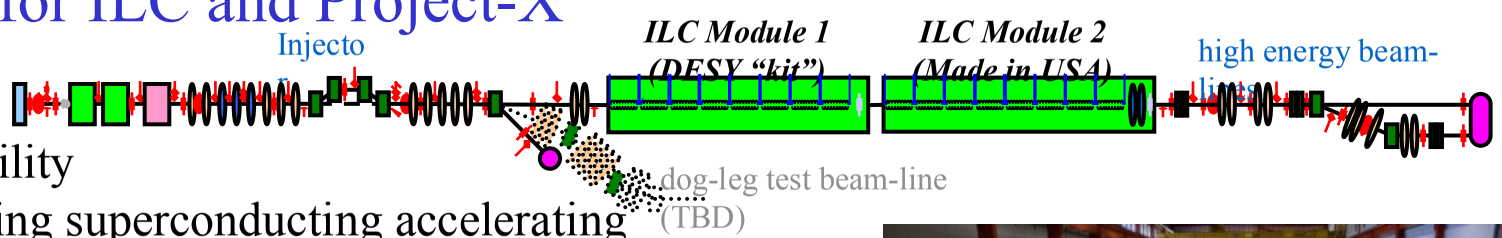


Fermilab activities / Overview

People: M. Wendt / A. Lunin / G. Remanov / N. Solyak / L. Valerio / I. Goini / S. Shin

FNAL cavity BPM for ILC ML (Fabrication)

NML for ILC and Project-X



Test facility
=> Testing superconducting accelerating modules with a beam structure similar to both Project-X and ILC.

FNAL cavity BPM for NML (Design)

Fermilab activities / Cold cavity BPM for ILC ML

Beam parameters, e.g.

–Bunch-to-bunch spacing $\Delta t_b \approx 370$ ns (ILC)

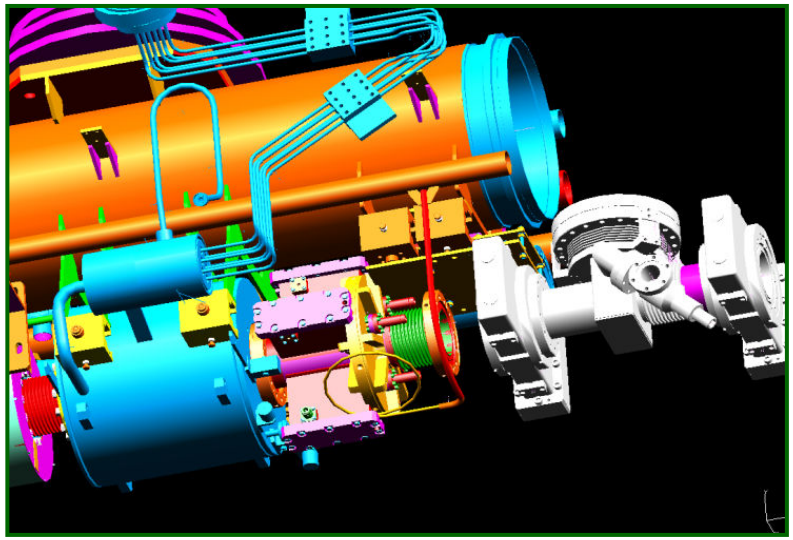
–Nominal bunch charge = 3.2 nC

Beam dynamic requirements

–< 1 μm resolution, single bunch for ILC

–Absolute accuracy < 300 μm

–Sufficient dynamic range

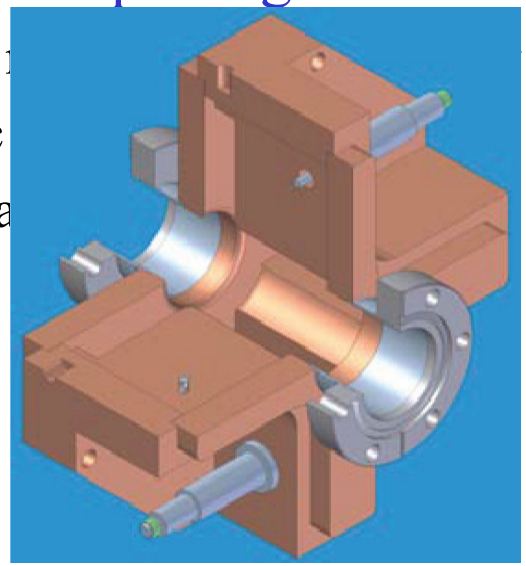


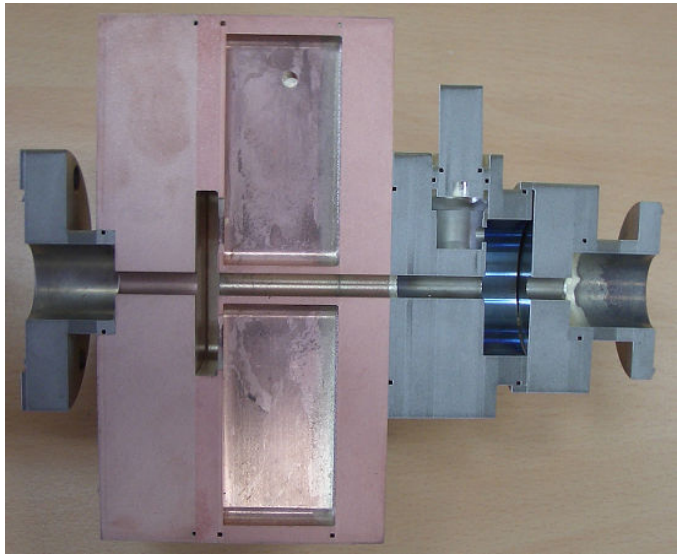
Cryomodule quad/BPM package

–Limited real estate, 78 !

–Operation at cryogenic

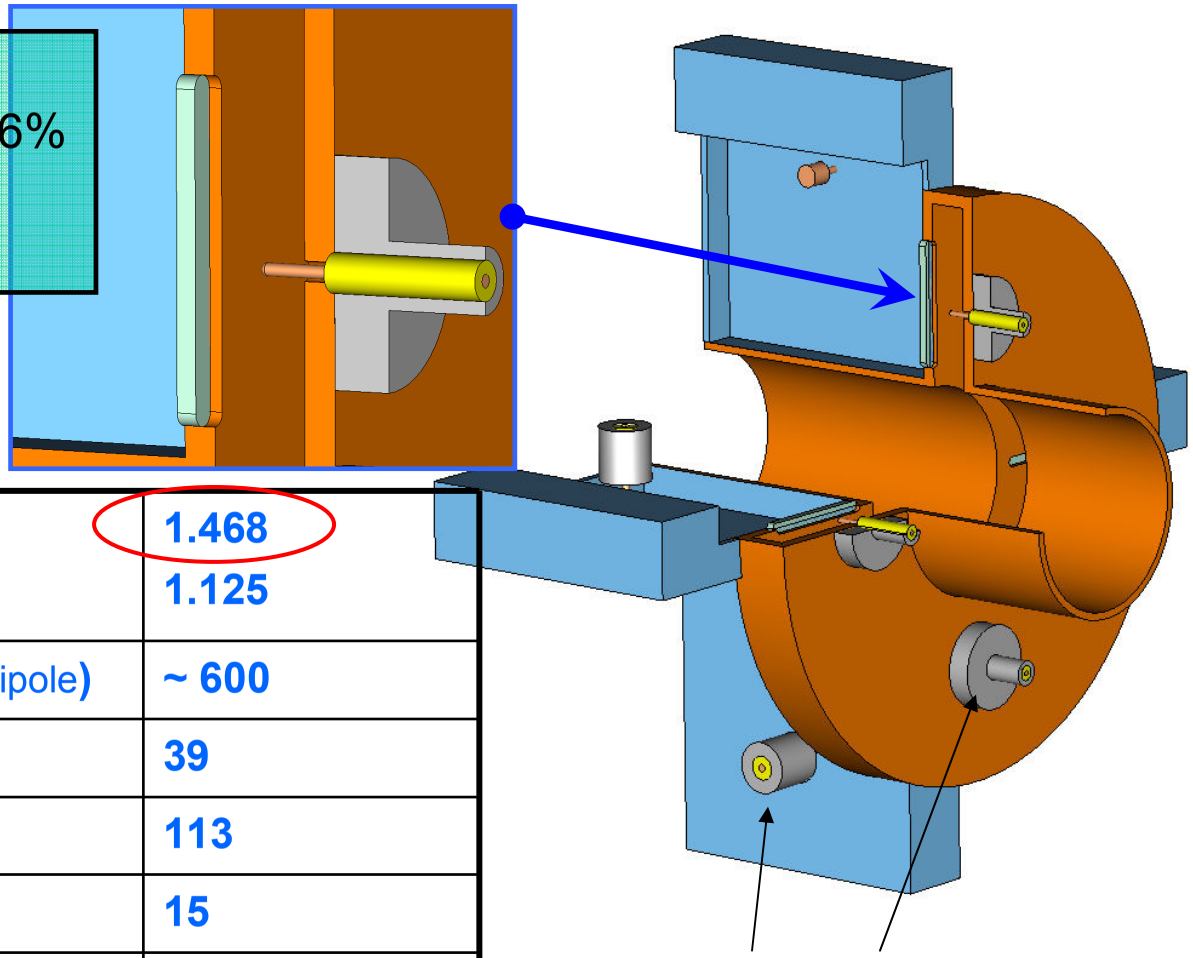
–Clean-room class 100 a





Fermilab activities / FNAL cold cavity BPM for ILC

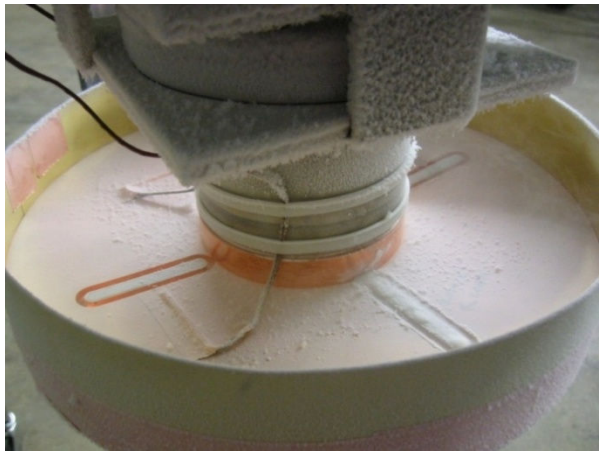
Window –
Ceramic brick of alumina 96%
$\varepsilon_r = 9.4$
Size: 51x4x3 mm

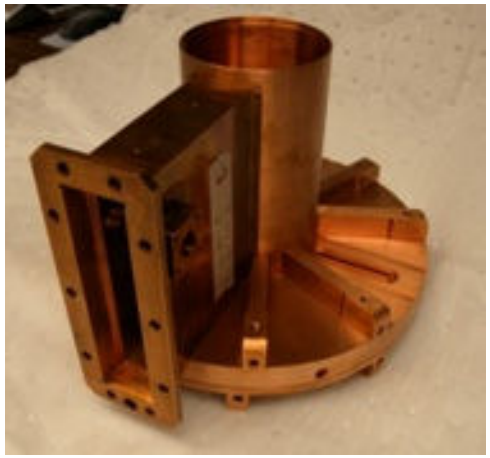


Frequency, GHz, dipole	**1.468**
monopole	**1.125**
Loaded Q (both monopole and dipole)	**~ 600**
Beam pipe radius, mm	**39**
Cell radius, mm	**113**
Cell gap, mm	**15**
Waveguide, mm	**122x110x25**
Coupling slot, mm	**51x4x3**

N type receptacles,
50 Ohm

Fermilab activities / FNAL cold cavity BPM for ILC





Status

Design ⇨ Fabrication

⇩

Low temperature UHV tests

⇩

Brazing
(Two halves & ceramic windows)

⇩

Waveguide fit

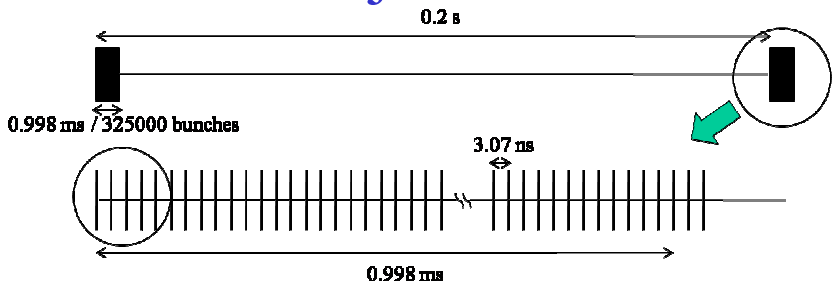
⇩

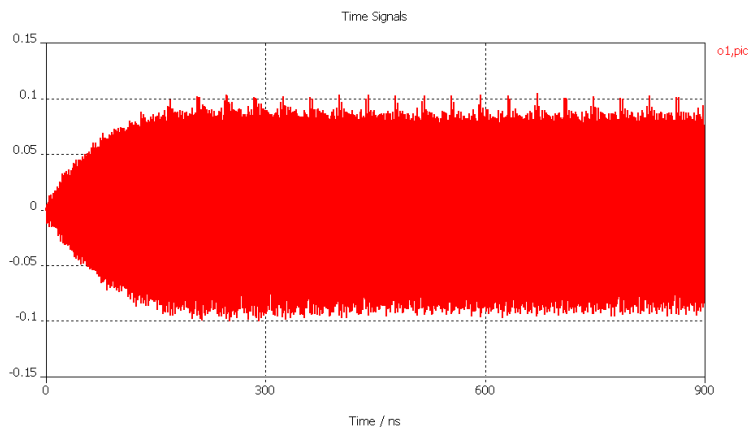
Brazing (Waveguide)

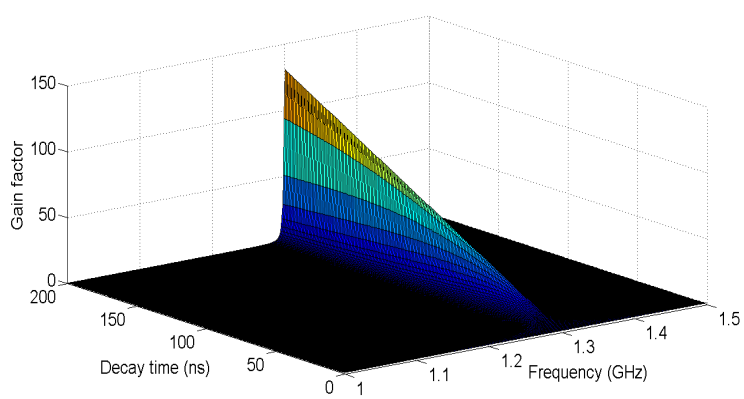
⇨ It should be modified for Project-X as well as ILC
1.3 GHz! Compact! Intensity signal from SC cavity!

Fermilab activities / Cold cavity BPM for NML

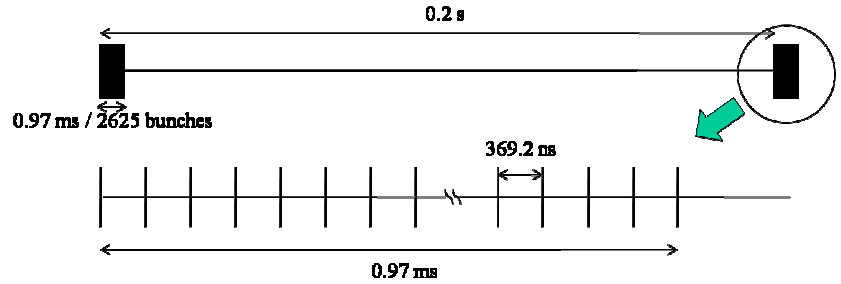
Project X-like

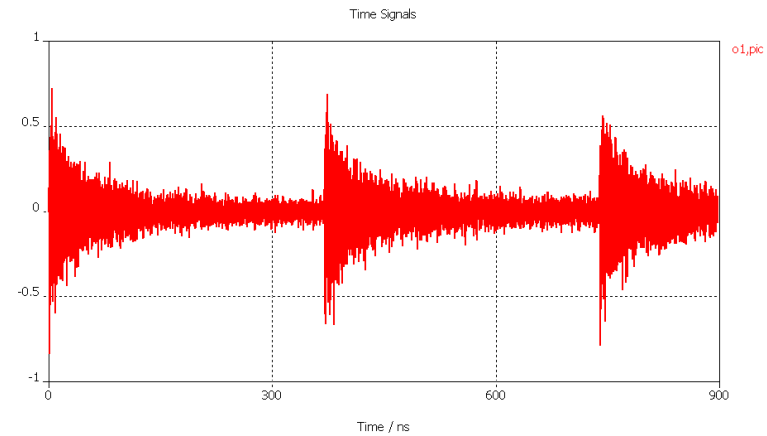


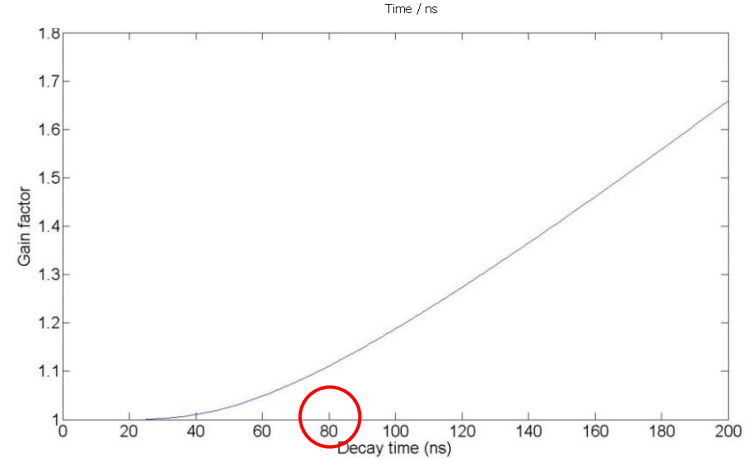




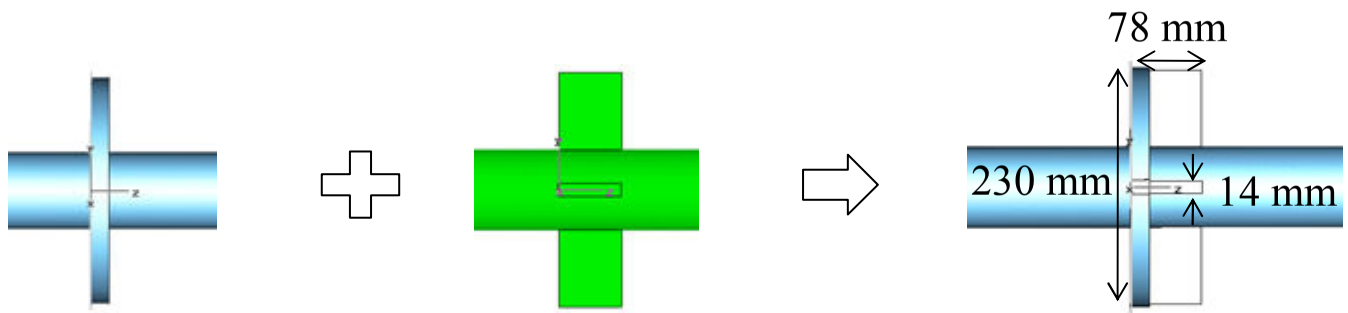
ILC-like







Designed model.



Pill box cavity with beam tube.

Rectangular cavity with beam tube.
But no mode (leakage to beam tube).

Combined model is cleanable.

Characteristics of designed model.

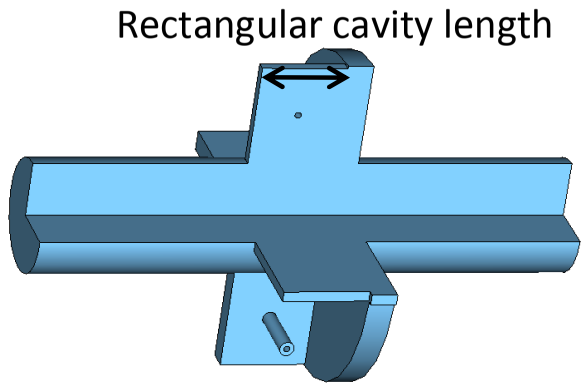
Design cavity BPM consists of cylindrical and rectangular cavities. Cylindrical cavity have eigen modes including dipole mode. But rectangular cavity have no eigen mode due to large beam tube.

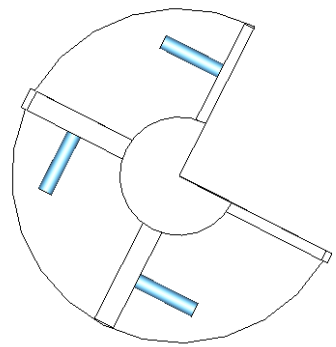
Boundaries between both cavities and between cavity and beam tube are open. It makes cavity BPM to be cleanable.

Dipole mode in cylindrical cavity easily leakage into rectangular cavity. But monopole mode doesn't.

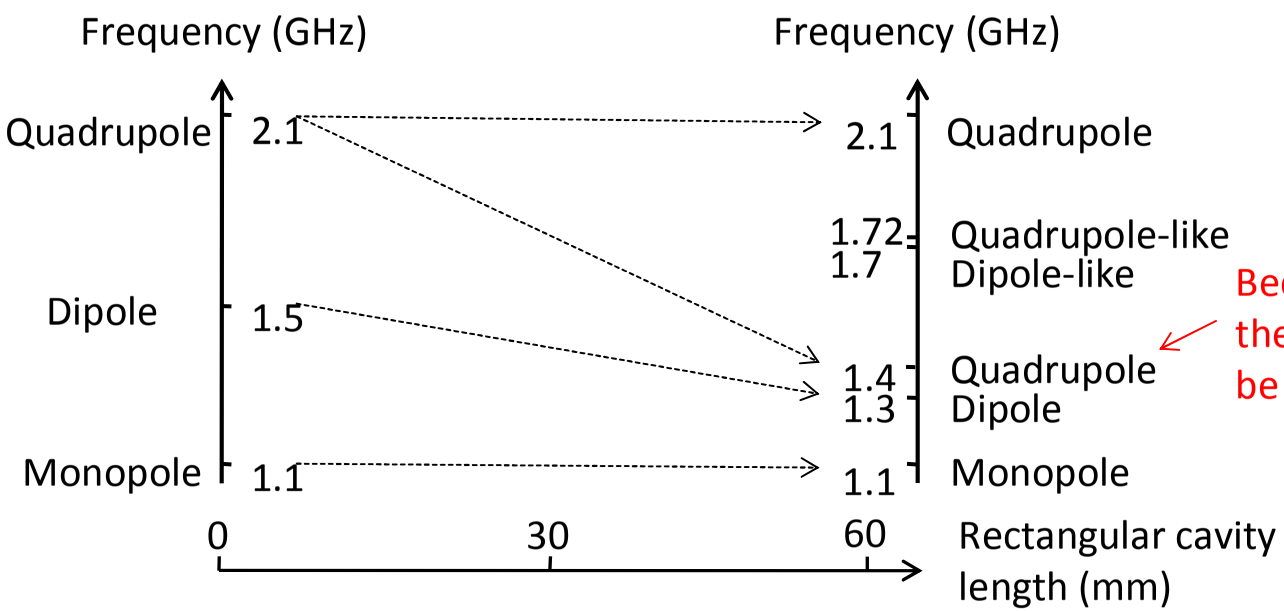
Fermilab activities / Cold cavity BPM for NML

Introduction to model.





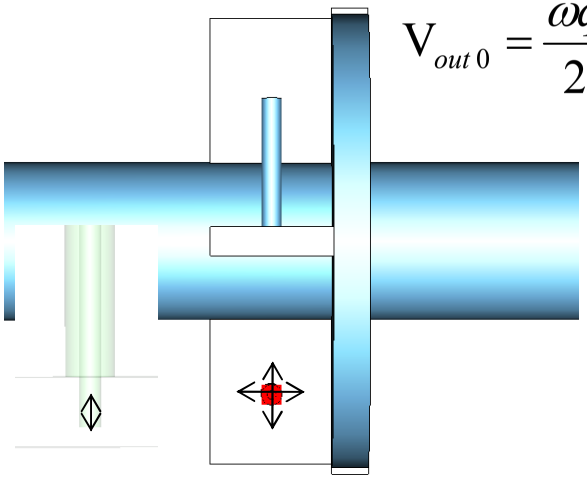
Eigen mode classification.



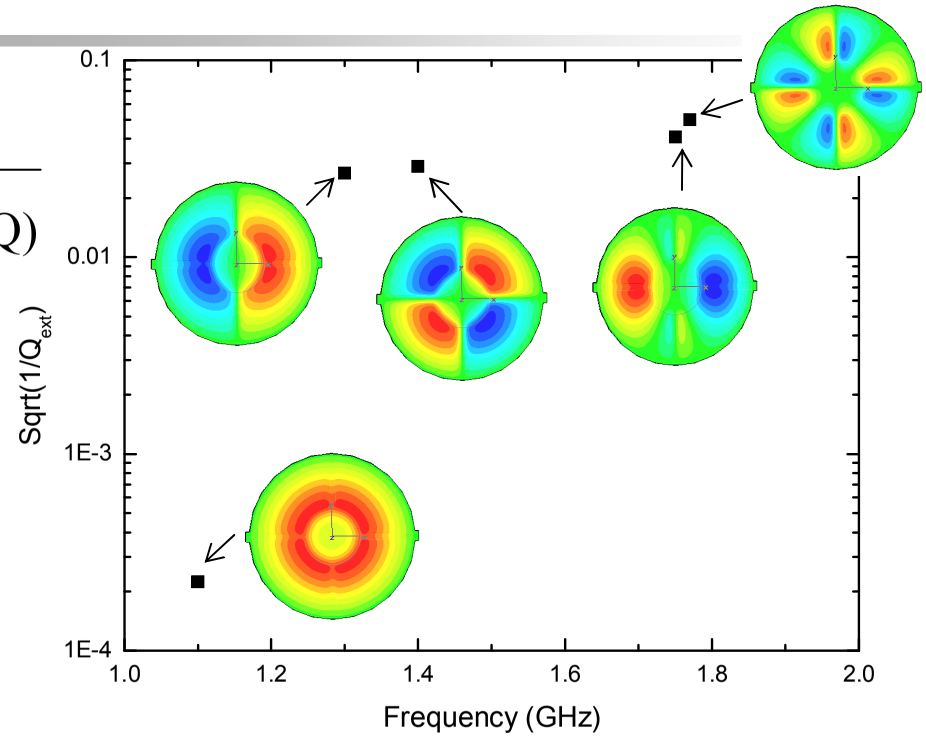
Because it is so close to dipole, the signal of this mode should be calculated in detail.

Fermilab activities / Cold cavity BPM for NML

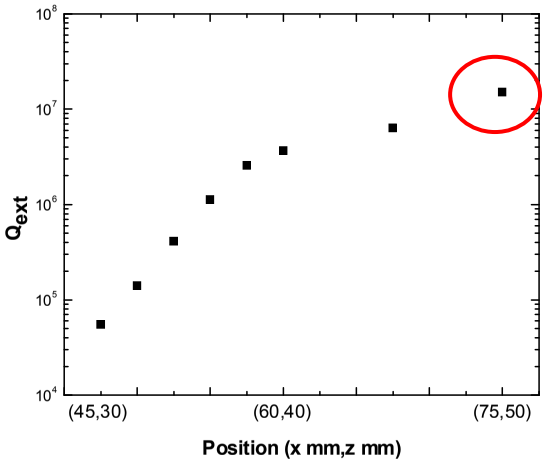
Coupling along position.



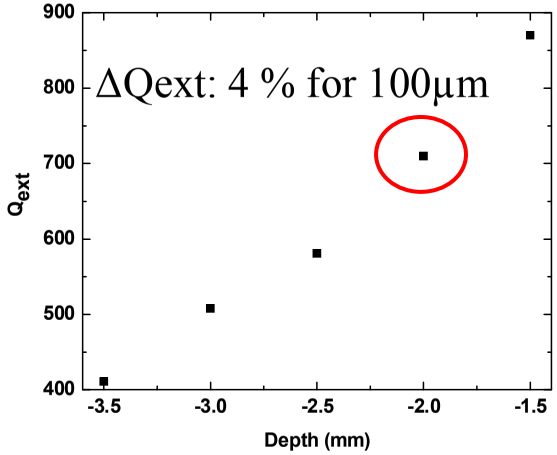
$$V_{out\,0} = \frac{\omega q}{2}\sqrt{\frac{Z}{Q_{ext}}(R/Q)}$$

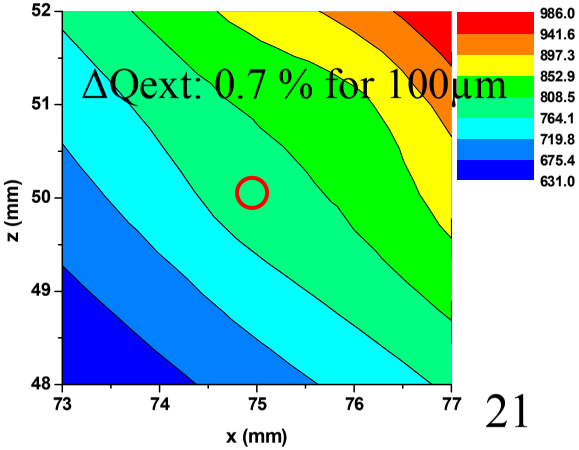


Monopole mode



Dipole mode



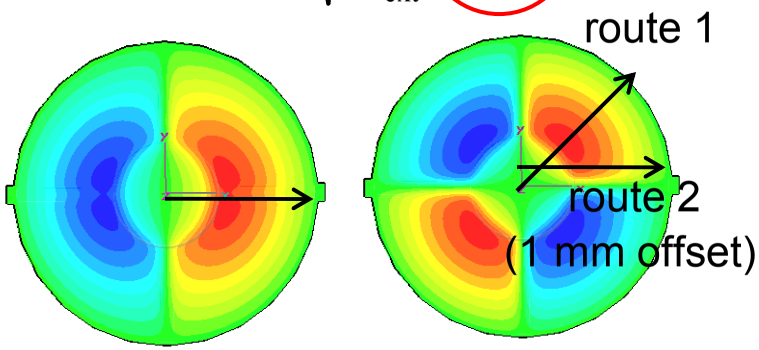


Fermilab activities / Cold cavity BPM for NML

Normalized shunt impedance.

$$V_{out\,0} = \frac{\omega q}{2}\sqrt{\frac{Z}{Q_{ext}}(R/Q)}$$

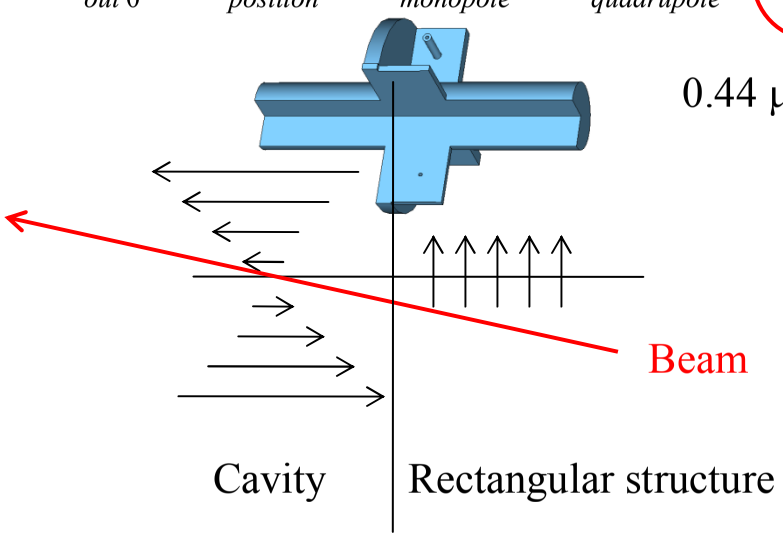
~δx

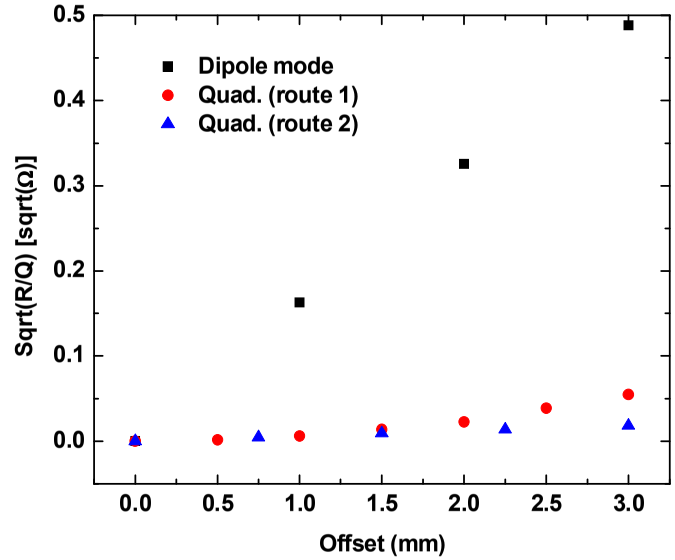


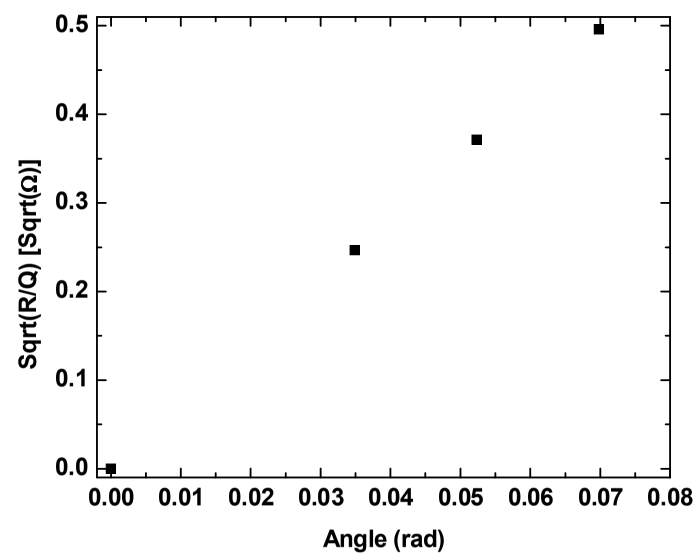
Dipole mode Quad. mode

$$V_{out\,0} = V_{position} + V_{monopole} + V_{quadrupole} + V_{angle}$$

0.44 μm / μrad

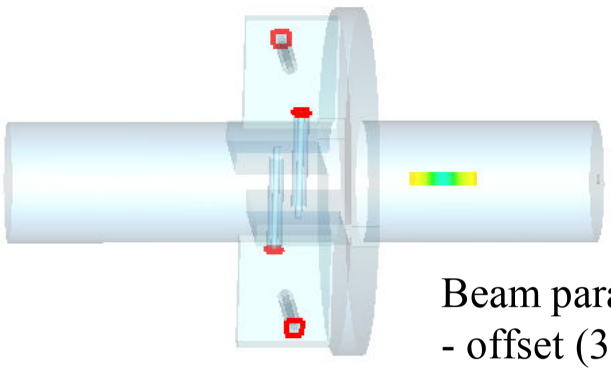




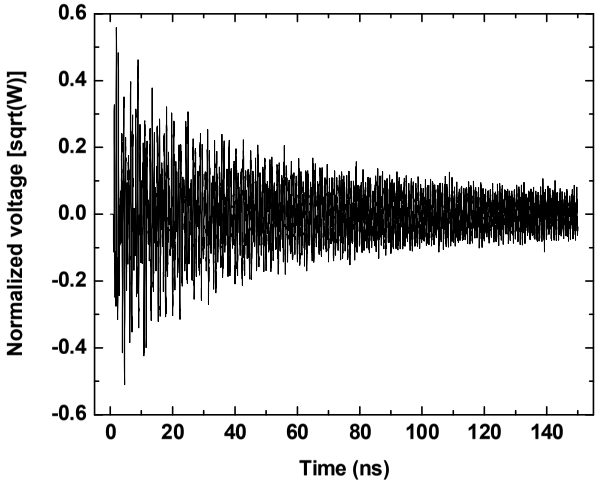


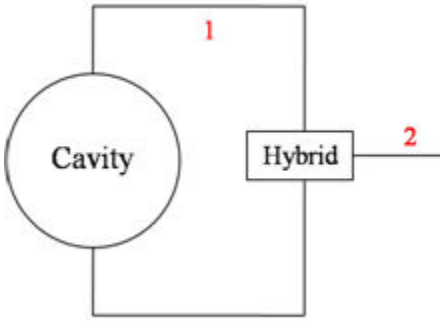
Fermilab activities / Cold cavity BPM for NML

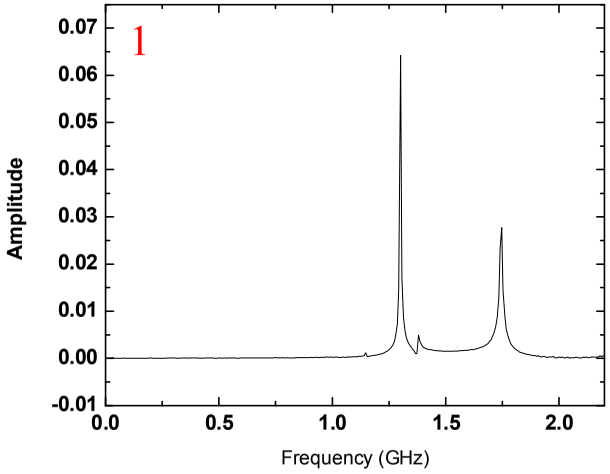
PIC simulation I.

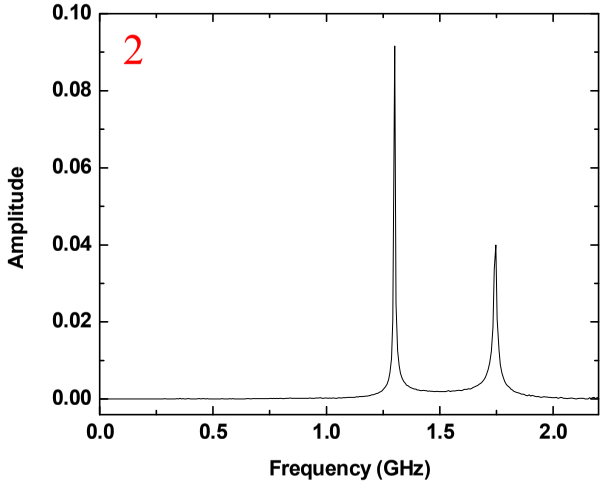


Beam parameters
- offset (3 mm,3mm)
- 3.2 nC
- 24 mm rms length

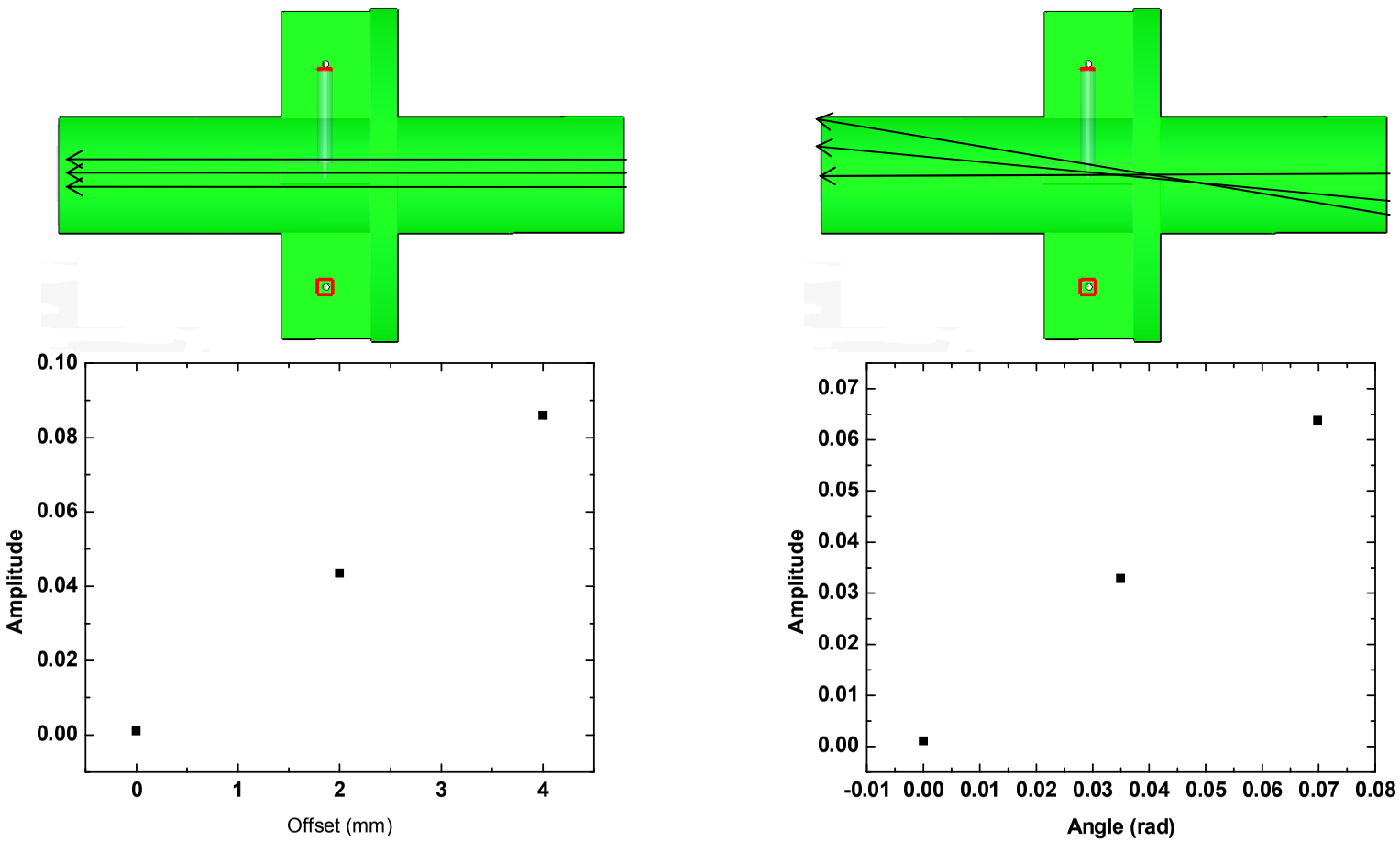








PIC simulation II.



Equivalent position signal of trajectory angle is ~ 0.43 μm / μrad (0.44 μm / μrad)

Design parameters and calculated signals.

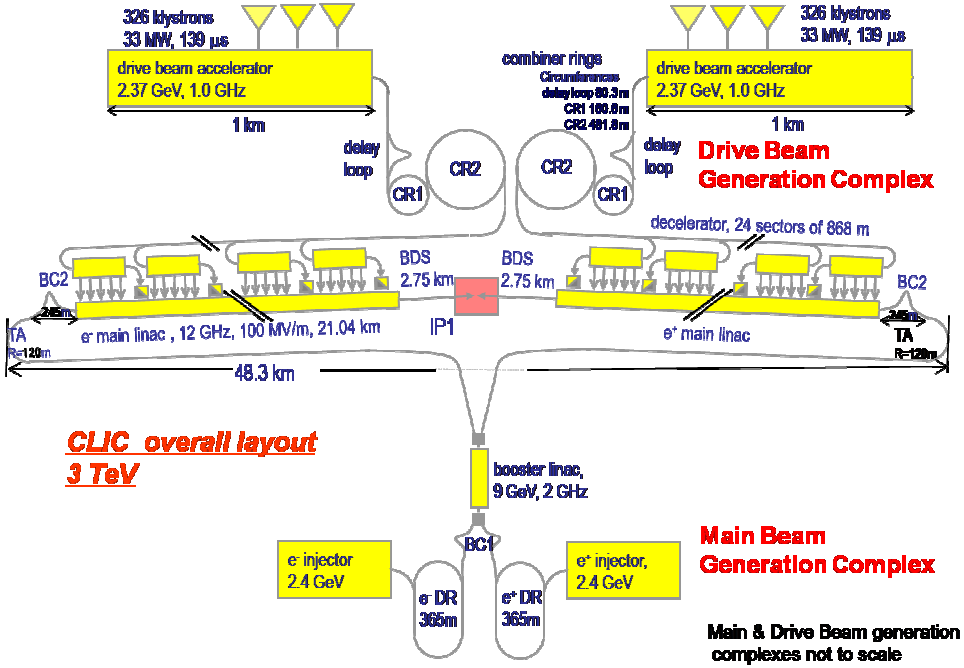
Parameter	Unit	Value
Dipole frequency	GHz	1.3
Q_L		640
Q_{ext}		710
Beam pipe radius	mm	39
Cavity Radius	mm	112
Cavity Length	mm	18

Signal	ILC-like	Project-X like (Single / Multi)
Thermal noise (μV)	4	4
Dipole at 1μm (μV)	400	(5.5 / 275)
Monopole at 1.3GHz (μV)	74	(1.0 / 0.5)
Beam trajectory angle (μm/μrad)	0.44	0.44

Fermilab activities / Other activity

Cavity BPM for CLIC

Informal yet!



Main beam

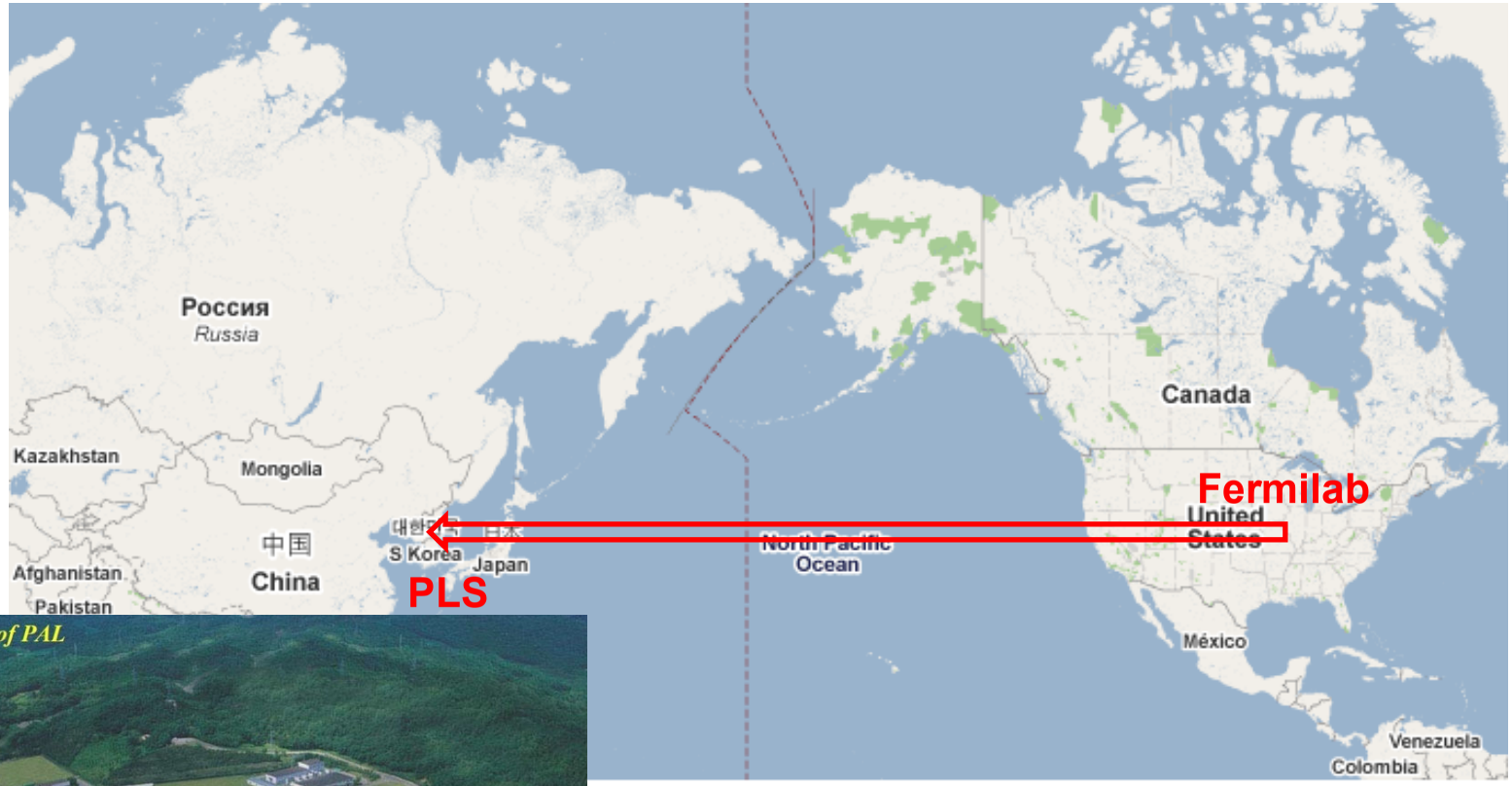
	Accuracy	Resolution	Stability	Range	Bandwidth	Beam tube aperture	Available length	Intercepting device?	How many?	Used in RT Feedback?	Machine protection Item?	Comments	Ref
BPM	5μm	50nm	100nm		35MHz	8.0mm	95/65mm	No	4176	Yes	Yes	Choke BPM? Inductive BPM	CLIC note 764

Drive beam

	Accuracy	Resolution	Stability	Range	Bandwidth	Beam tube aperture	Available length	Intercepting device?	How many?	Used in RT Feedback?	Machine protection Item?	Comments	Ref
BPM	20μm	2μm	?	<5mm	35MHz	23mm	104/74mm	No	41480	Yes	Yes	Inductive ? Strip line ?	CLIC note 764

Future work / Remote machine study for future work.

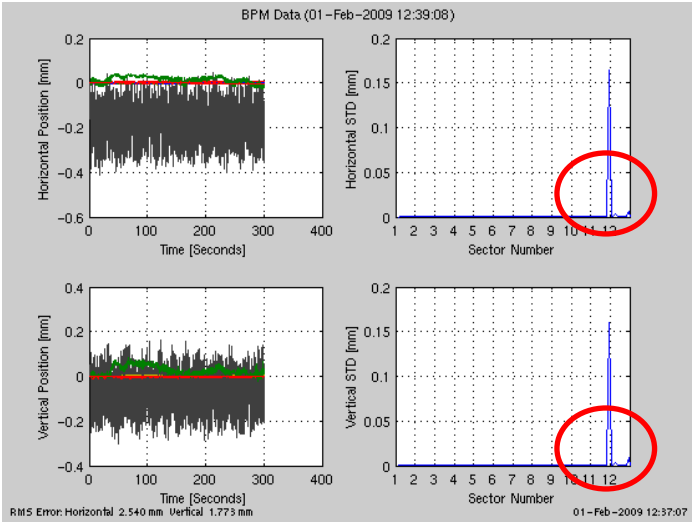
Remote access from Fermilab to PLS.

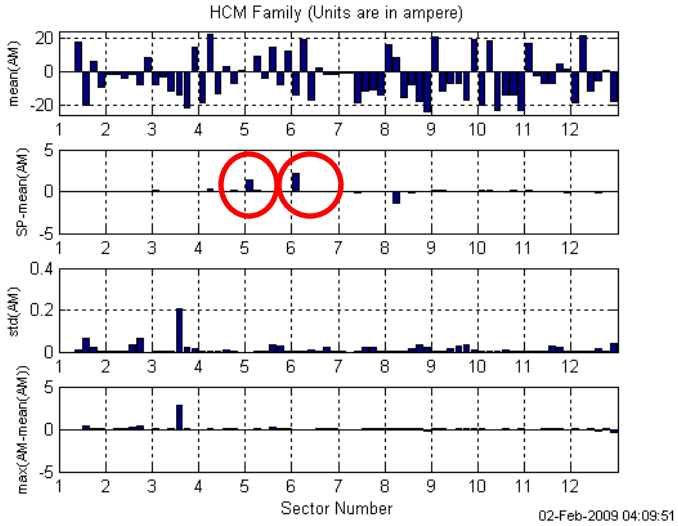


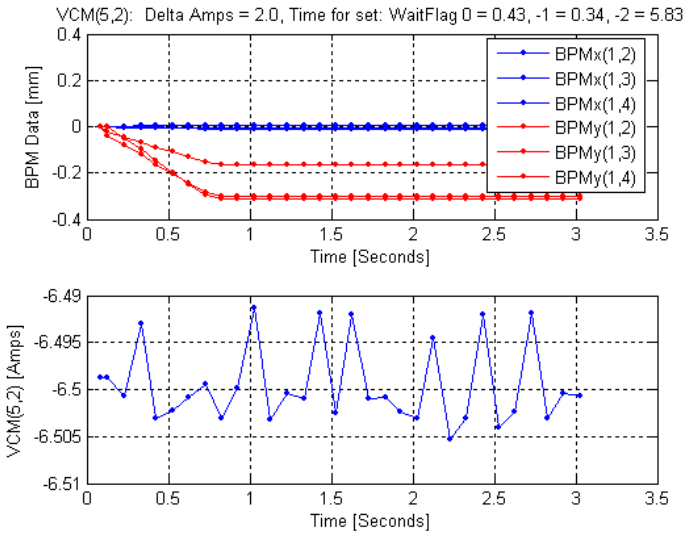
PLS is 3rd generation synchrotron radiation source.
Construction project: April 1988 ~ December 1994.
PLS II project: January 2009 ~ December 2011.
Energy 2.5 -> 3.0 GeV / Many IDs

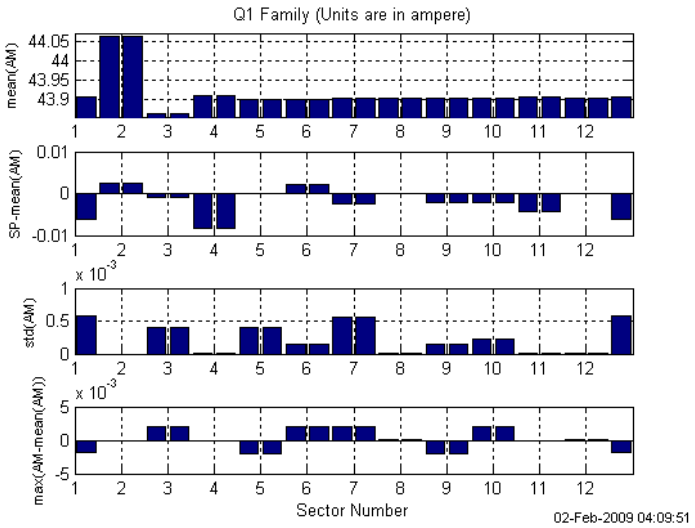
Future work / Remote machine study for future work.

Machine monitoring. (2009. 01. 31)



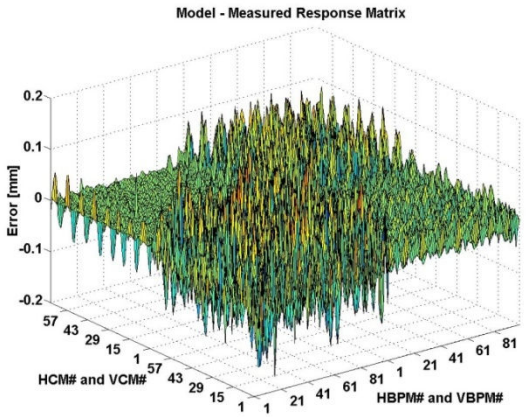


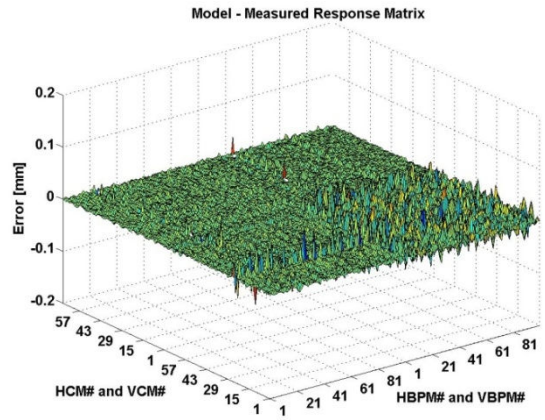


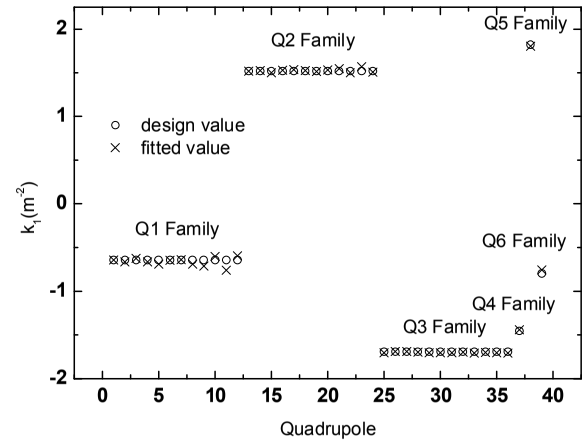


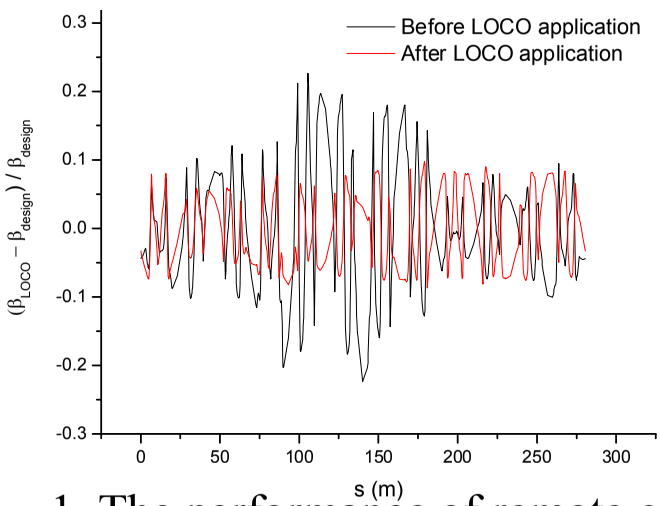
Future work / Remote machine study for future work.

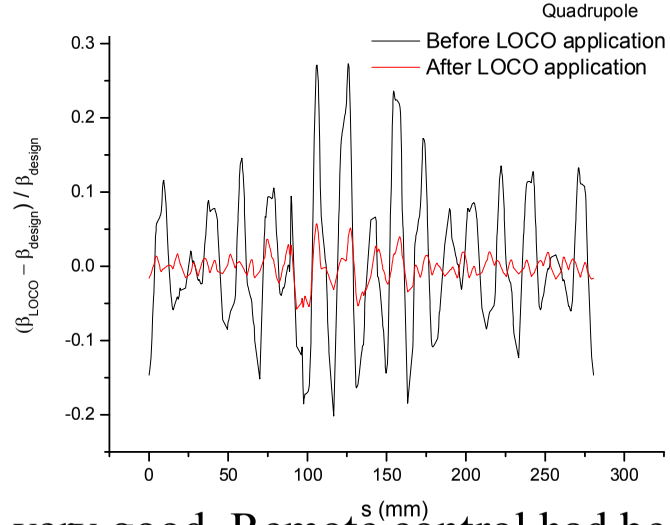
Lattice correction. (2009. 02. 28)











1. The performance of remote control was very good. Remote control had been done as if we were in PLS control room.
2. We hope this remote machine study to increase the interest for collaboration between Fermilab and some accelerator Lab. in Korea.

Summary

KNU activities

- KNU have performed cavity BPM R&Ds for ILC.
- System for cavity BPM development is established in KNU.
- Low-Q cavity BPM and S-band cavity BPM with international collaboration is being performed in KNU.

Fermilab activities

- The development of cold cavity BPM for ILC is almost done.
- Design studies for cold cavity BPM for NML are finished.
- Cavity BPM work for CLIC was informally started.

Future work

- The result of remote machine study was shown to increase the interest for collaboration.