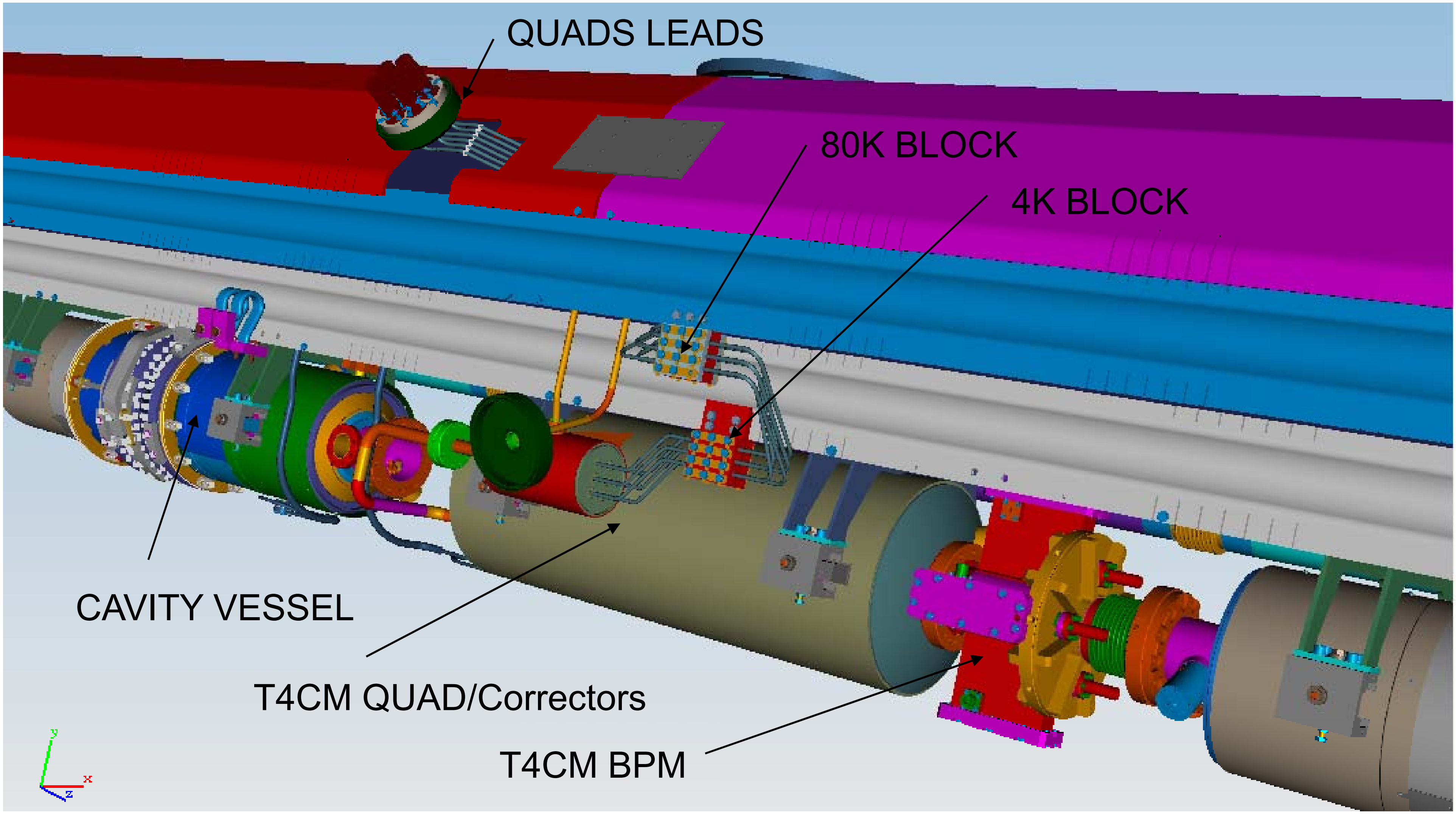
Main Linac Integration

Chris Adolphsen

Quadrupole Package

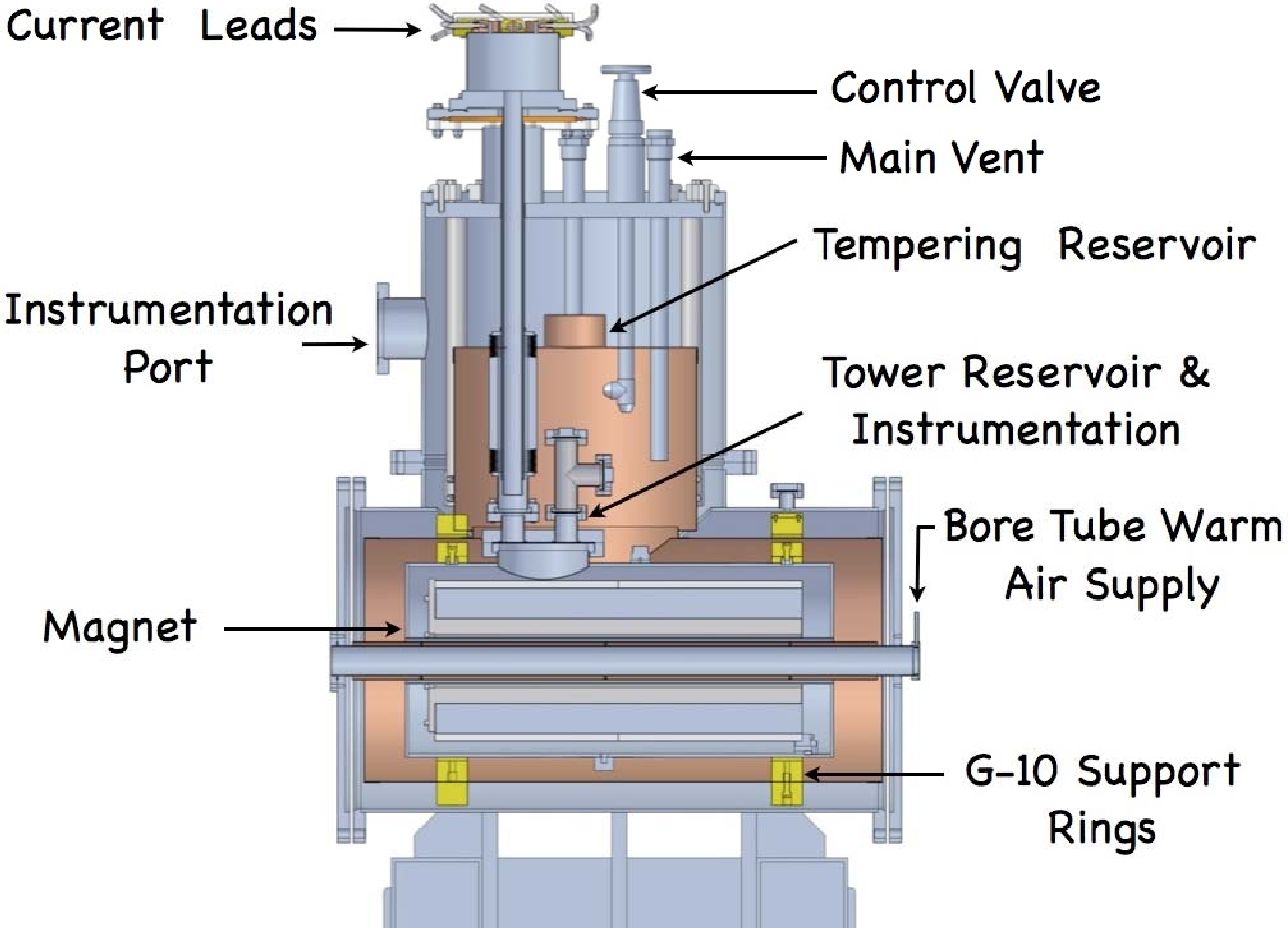


Quad Field and Position Requirements

- Installation Requirements
  - Local alignment to the cryomodule axis – covered in N. Ohuchi specs
  - Long range (10 m to 10 km) – Kubo et al working on specs
- Fast Motion (Vibration)
  - Require uncorrelated vertical motion > ~ 1 Hz to be < 100 nm
  - Many measurements being done – data show spec can be met
- Slow Motion (Drift)
  - For dispersion control, want quad to stay stable relative to it neighbors at few micron level, day to day
  - Although slow ground motion is large, it is correlated on over long distance range which makes its net effect small.
  - Also sensitive to cryo shielding temperature changes and tunnel temperature changes.
- Change of Field Center with Change in Field Strength
  - For quad shunting technique to be effective in finding the alignment between the quad and the attached bpm, quad center must not move by more than a few microns with a 20% change in field strength

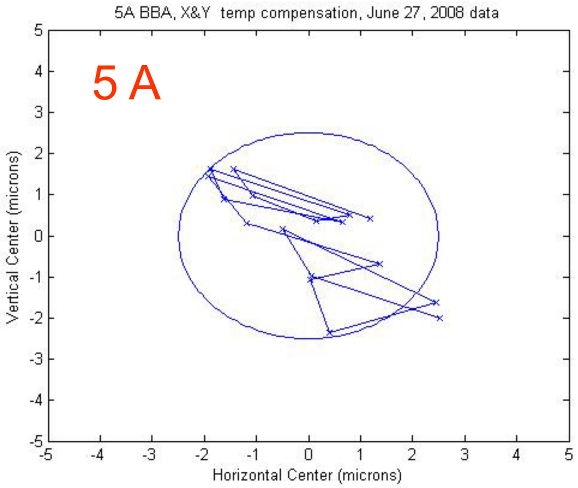
CIEMAT SC Quad Test at SLAC

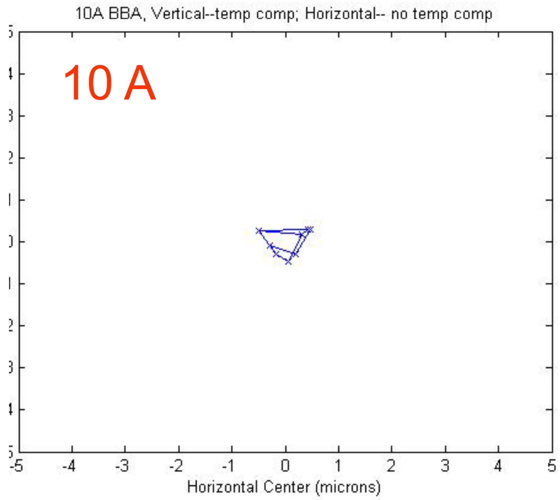
Cos(2ϕ), 0.6 m Long, 0.36 T/A Quad + X/Y Correctors

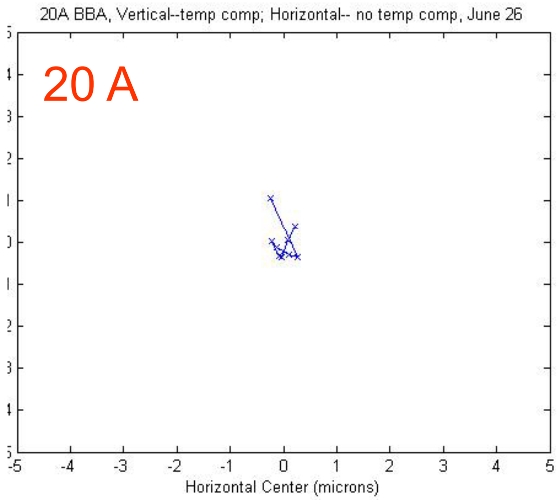


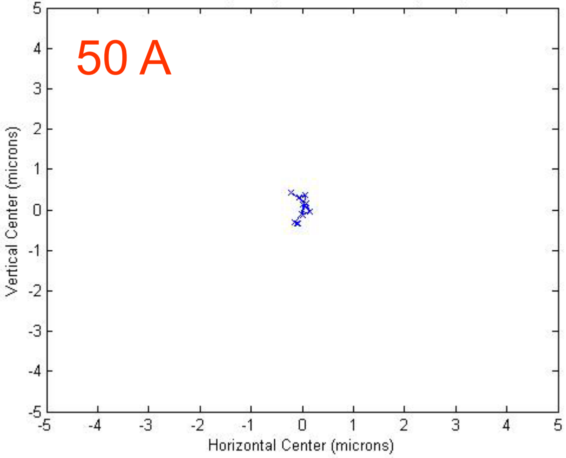
Center Motion with 20% Field Change

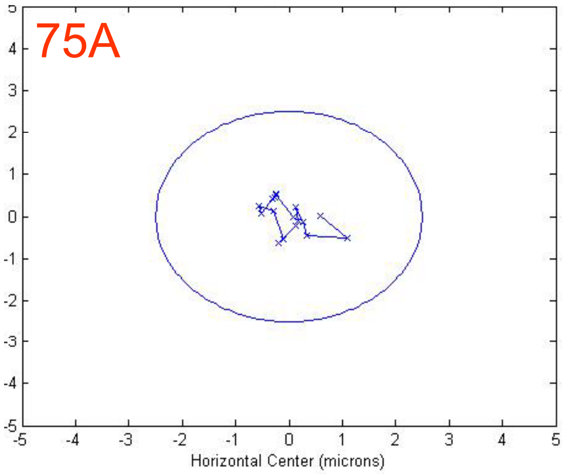
Motion Shown in Plots with +/- 5 μm Horizontal by +/- 5 μm Vertical Ranges

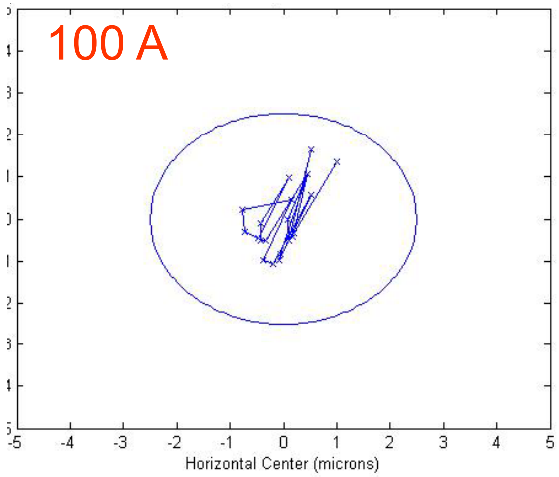




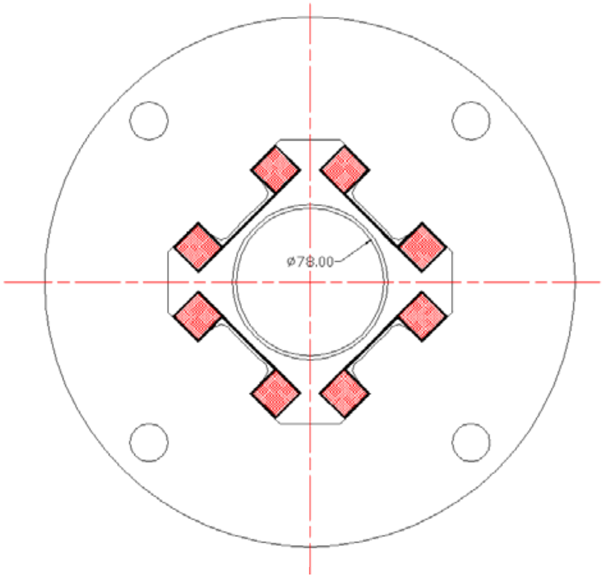




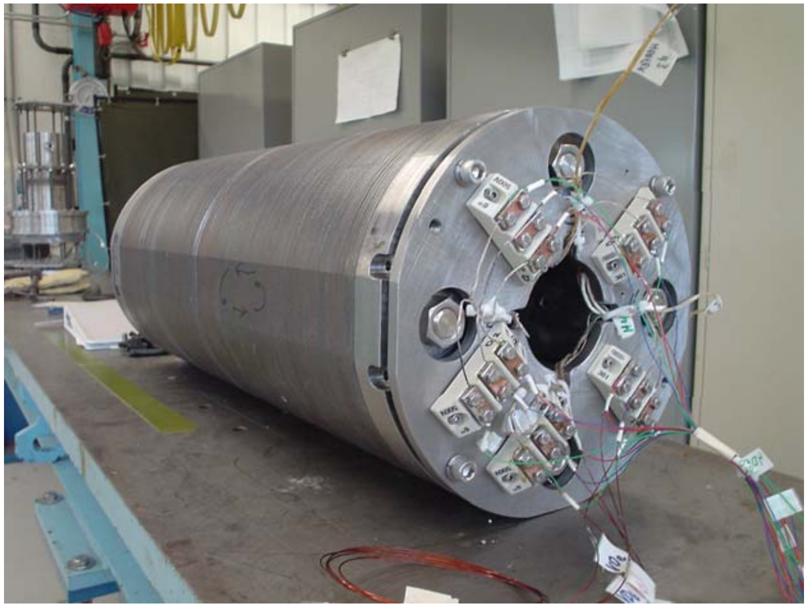




FNAL SC Quadrupole Design



A “superferric” design was chosen where saturated iron poles form a substancial part of the magnetic field in the quadrupole aperture.

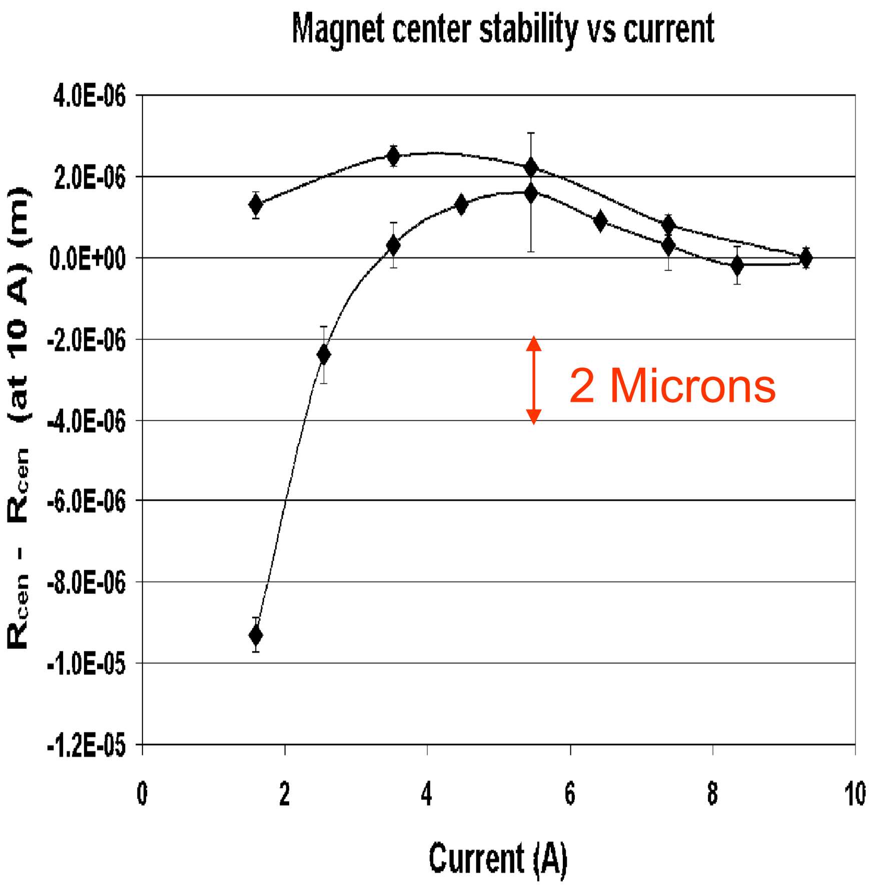


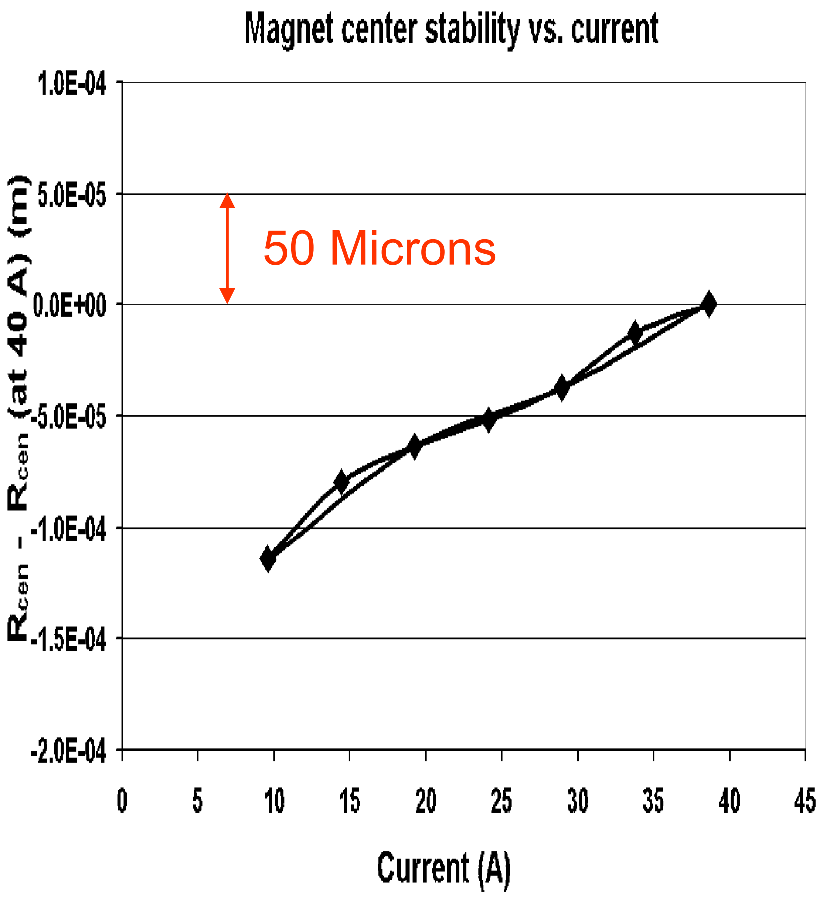
QUADRUPOLE MODEL PARAMETERS

Parameter	Unit	Value
Peak current at 36 T gradient	A	100
Magnet length	mm	680
NbTi superconductor diameter	mm	0.5
Superconductor filament size	µm	3.7
Superconductor critical current at 5 T and 4.2 K	A	200
Coil maximum field	T	3.3
Quadrupole coil number of turns/pole		700
Yoke outer diameter	mm	280

V. Kashikhin

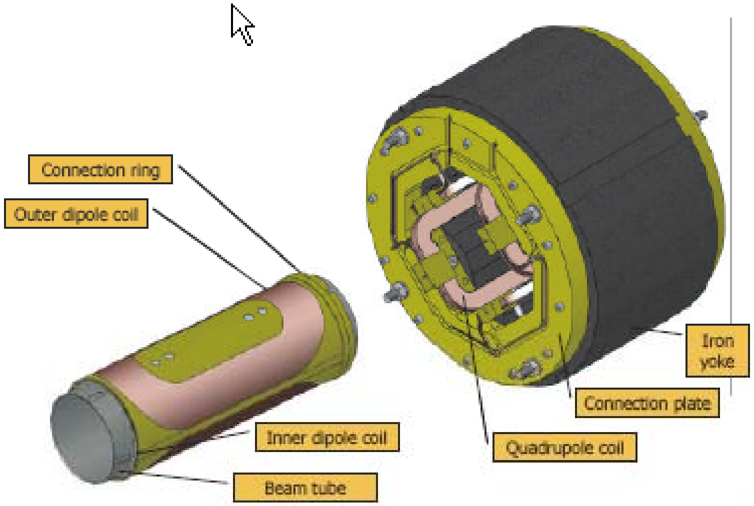
Center Motion with Field Change

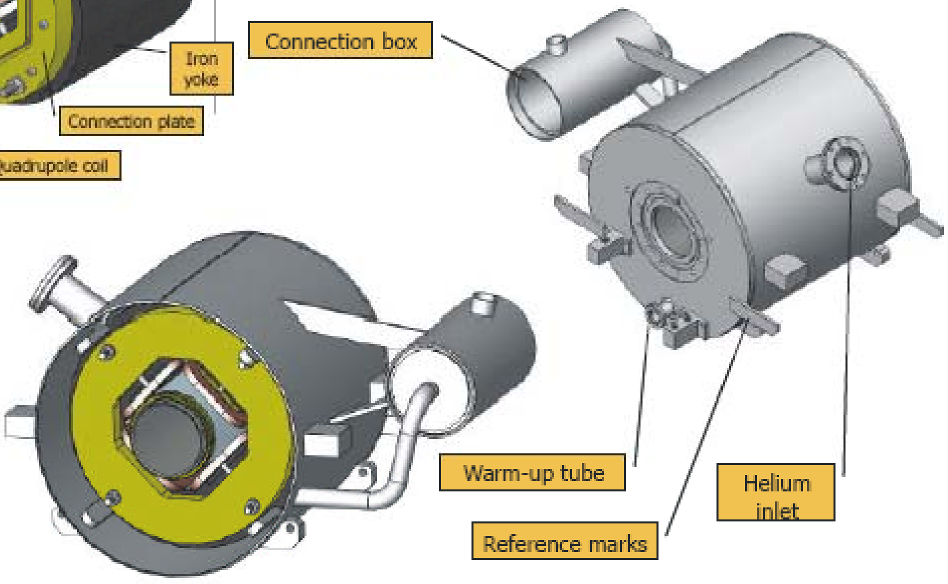


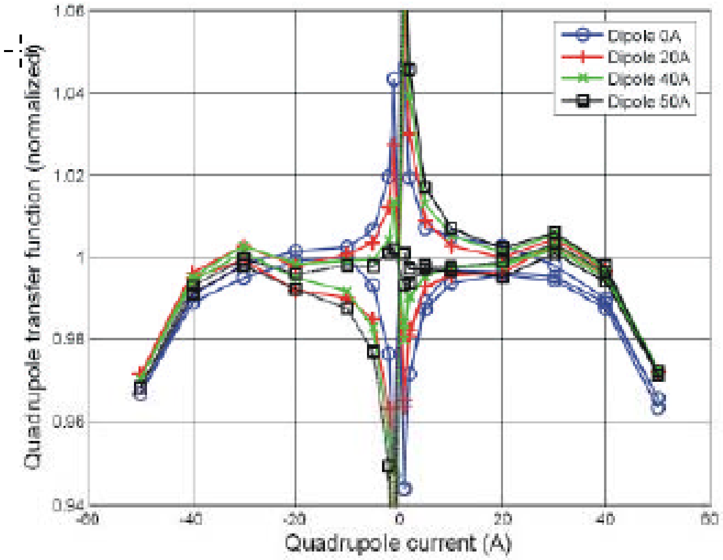


XFEL Prototype Superferric 6 T SC Quad

- Design according to TUEV pressure vessel rules
- Copperized beam tube
- Sliding supports on linear bearings
- BPM attached on endplate







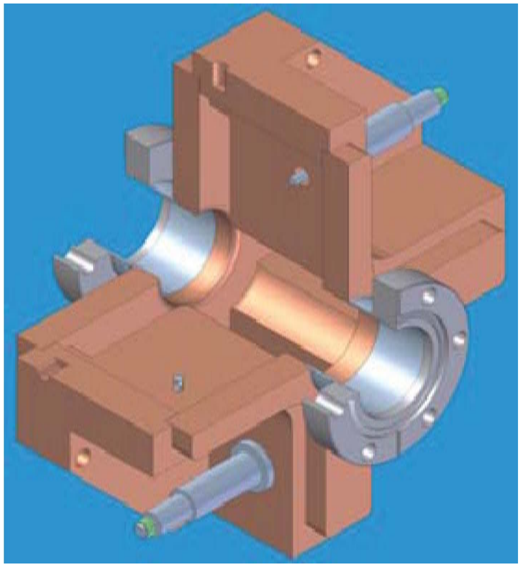
In first prototype, see significant, asymmetric magnetization plus dipole influence on quad

Fernando Toral

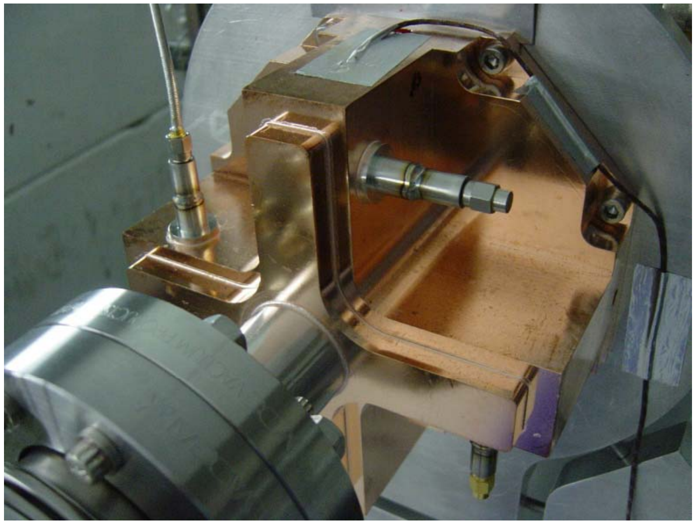
RF BPMs

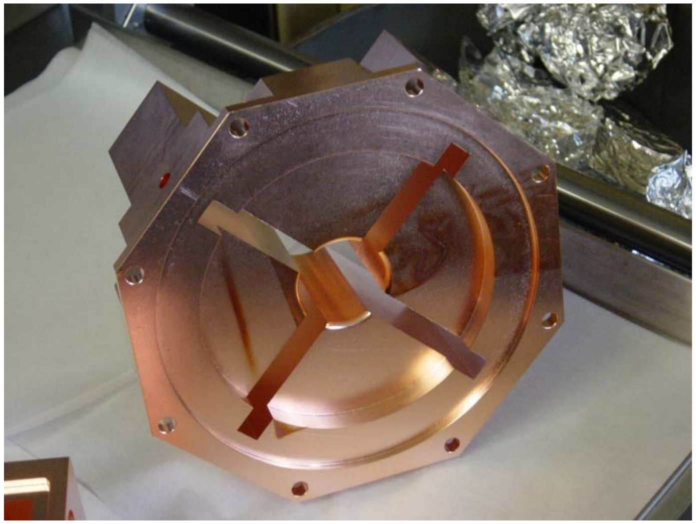
- Require
  - 1 micron level single bunch resolution
  - Ability to resolve bunch-by-bunch positions with 300 ns (150 ns) bunch spacing
  - Cleanable design so does not contaminate cavities
  - Readout system that is stable to 1 um on a time scale of a day for a fixed beam offset up to 1 mm.
- Linac Prototypes
  - SLAC half aperture S-Band version for ILC
  - FNAL L-Band version for NML/ILC
  - SACLAY L-Band version for XFEL/ILC
  - Pusan National University / KEK TM12 version

SLAC Half Aperture S-Band BPM



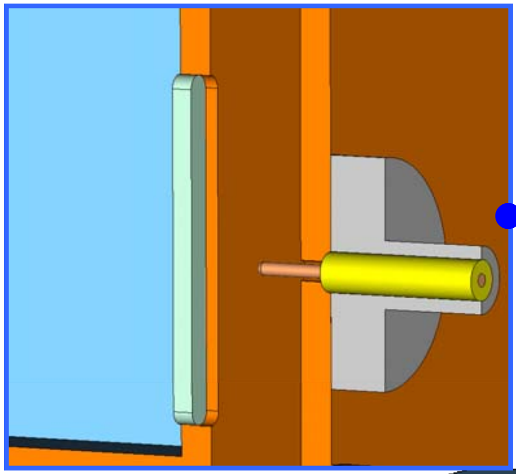
- SLAC approach:
  - S-Band design with reduced aperture (35 mm)
  - Waveguide is open towards the beam pipe for better cleaning
  - Successful beam measurements at SLAC-ESA, ~0.5 µm resolution
  - No cryogenic tests or installation
  - Reference signal from a dedicated cavity or source

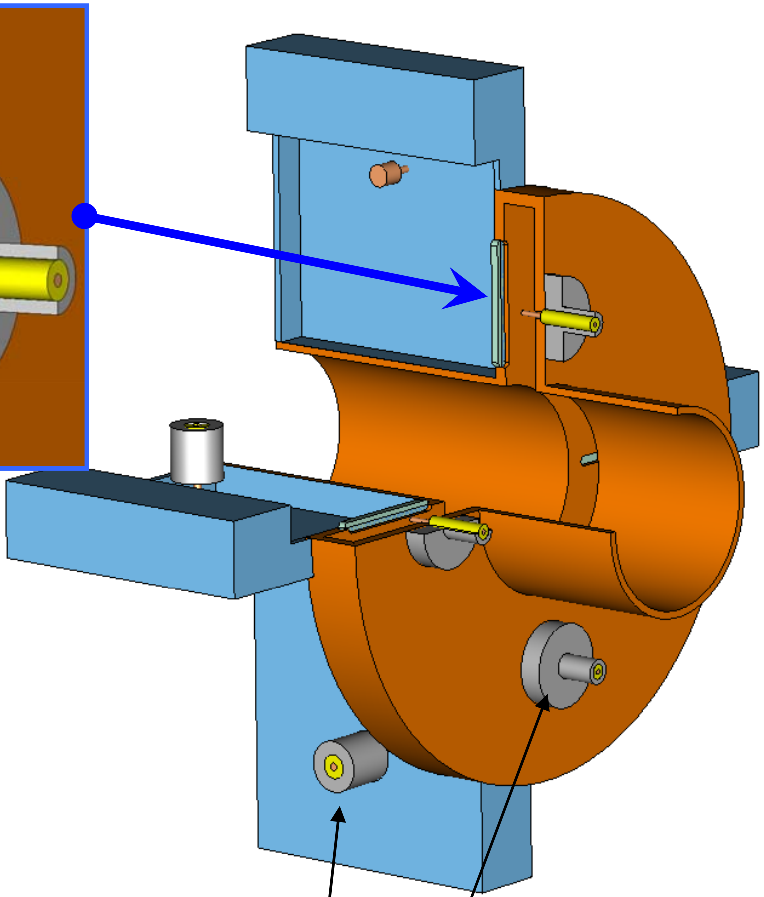




FNAL Full Aperture L-Band Design

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

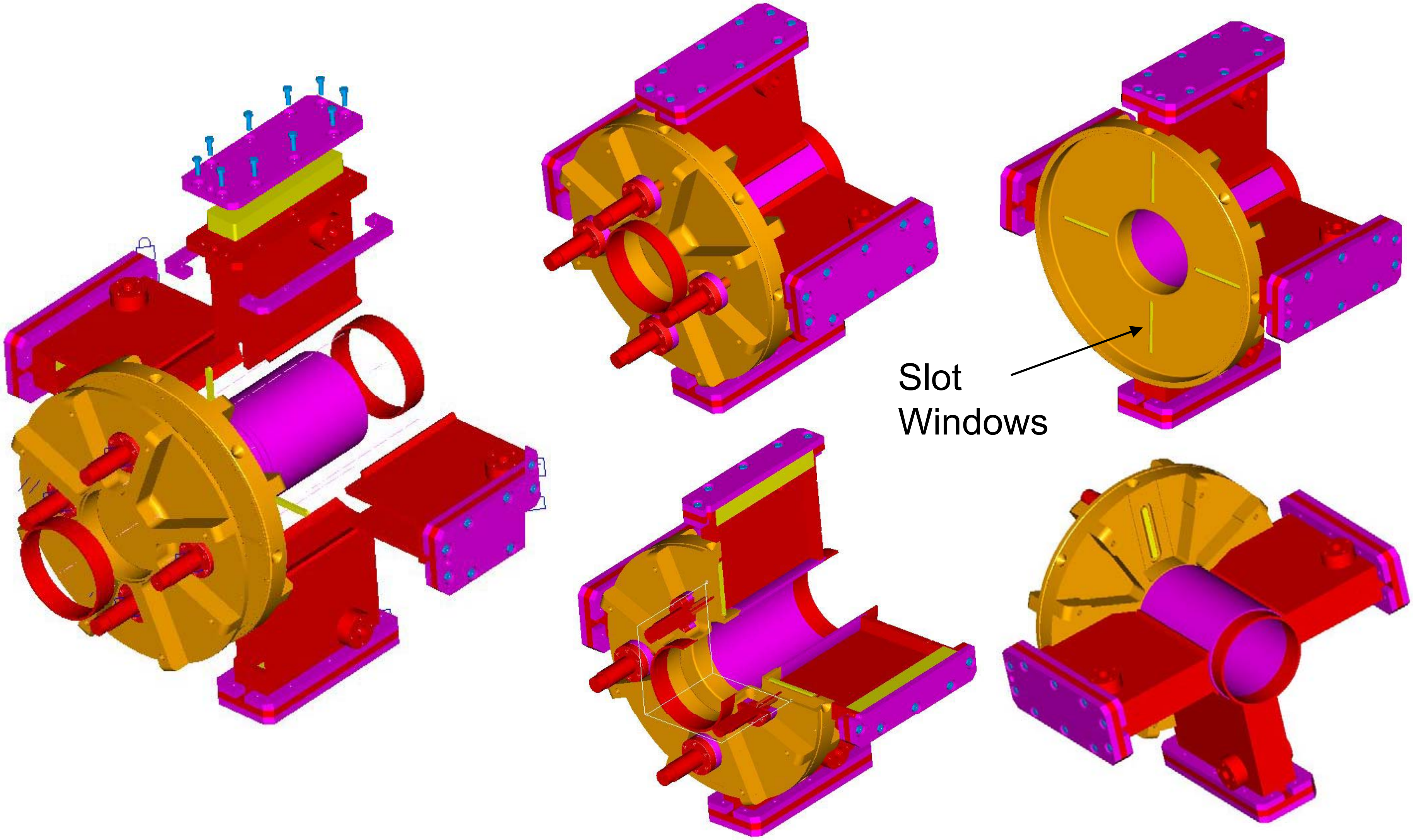




N type receptacles,
50 Ohm

Frequency, GHz, dipole monopole	1.468 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

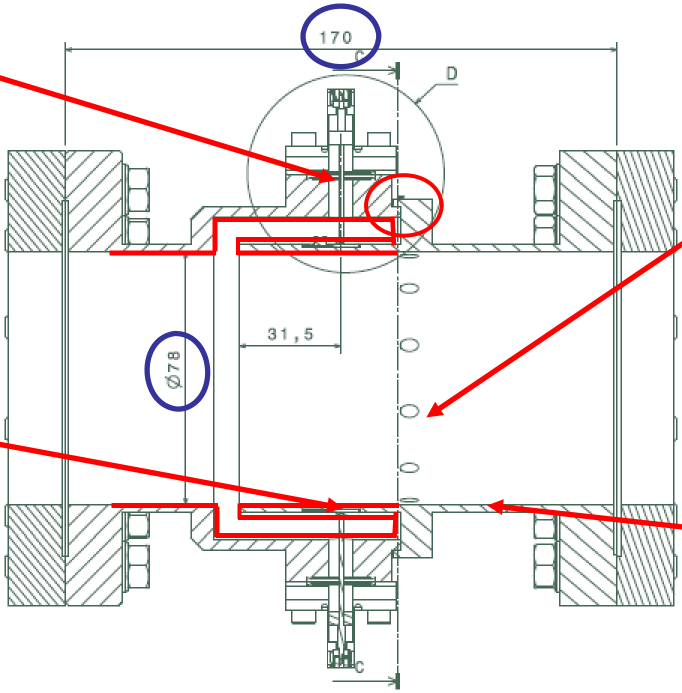
1.5 GHz Cavity BPM at FNAL



Reentrant Cavity BPM for XFEL

Achieved ~ 5 µm Resolution

Cryogenics tests at 4 K on feed-throughs is OK



Twelve holes of 5 mm diameter drilled at the end of the re-entrant part for a more effective cleaning (Tests performed at DESY).

Cu-Be RF contacts welded in the inner cylinder of the cavity to ensure electrical conduction.

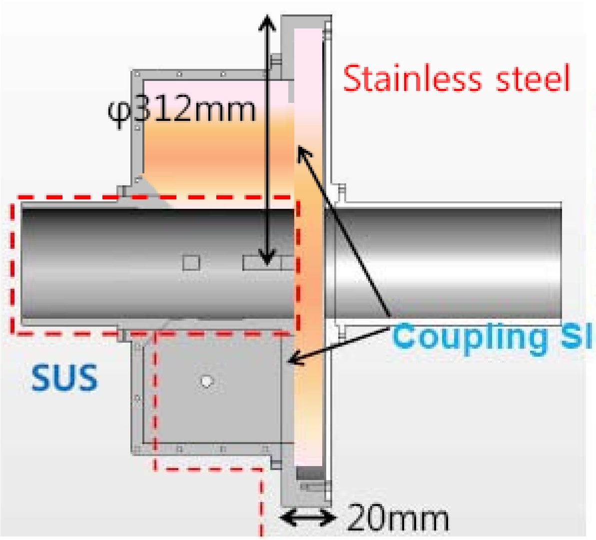
Copper coating (depth: 12 µm) to reduce losses. Heat treatment at 400°C to test: OK

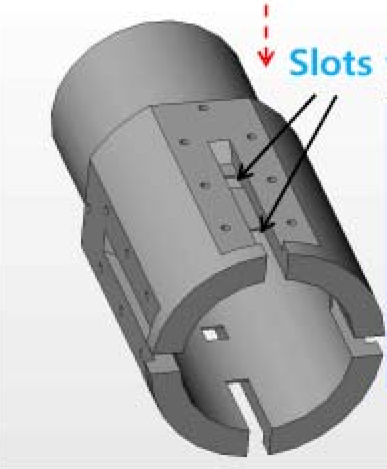
Eigen modes	F (MHz)	Q_l	$(R/Q)_l$ (Ω) at 5 mm	$(R/Q)_l$ (Ω) at 10 mm
	Measured	Measured	Calculated	Calculated
Monopole mode	1255	23.8	12.9	12.9
Dipole mode	1724	59	0.27	1.15

TM12, Full Aperture, 2.0 GHz BPM

Sun Young Ryu, Jung Keun Ahn (Pusan National University)
and Hitoshi Hayano (KEK-ATF)

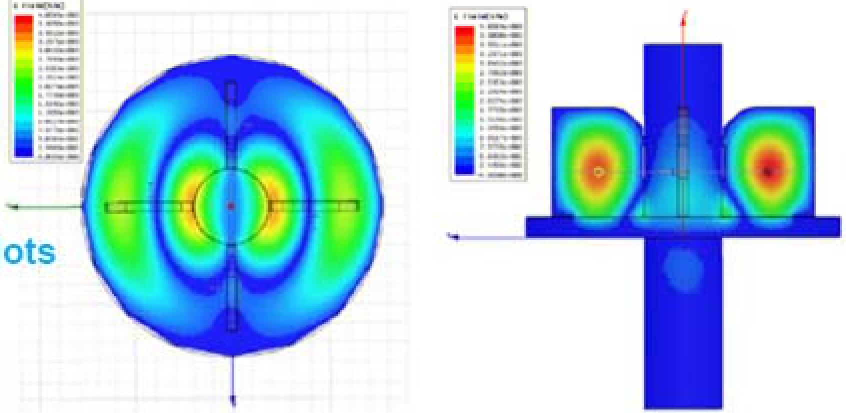
Achieved ~ 0.5 μm Resolution

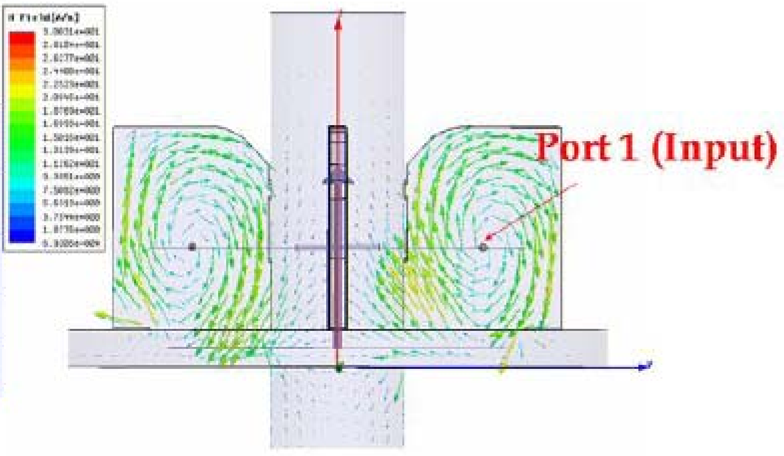




f_0	2.03GHz
BW	8MHz
Q_L	254.5
β	4.2
Q_0	1323.4

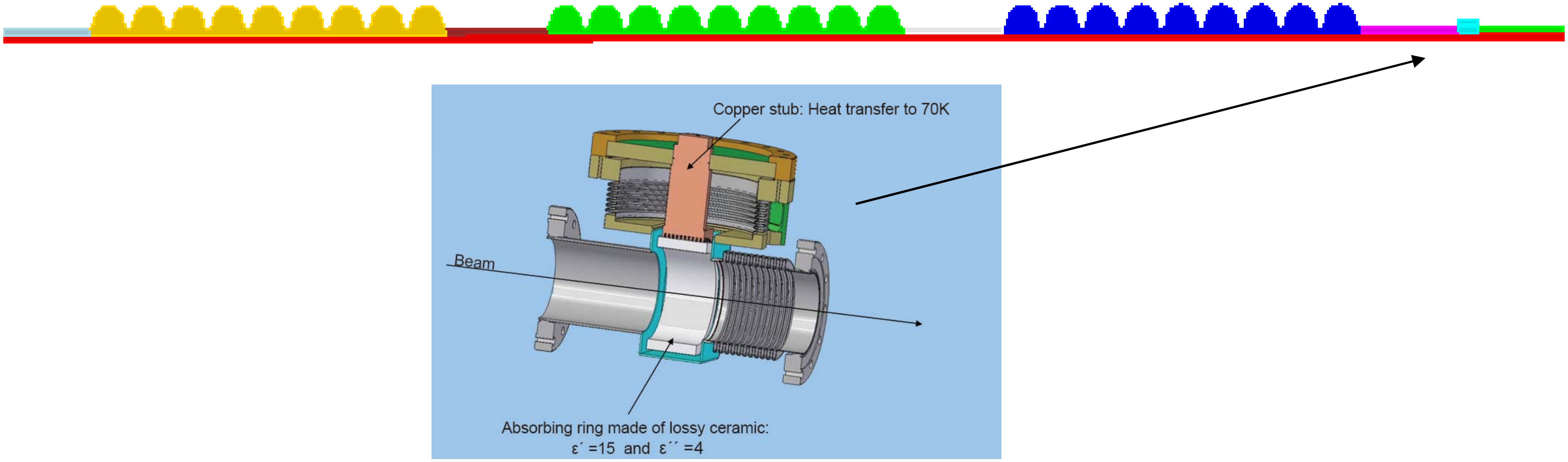
Calculation by HFSS





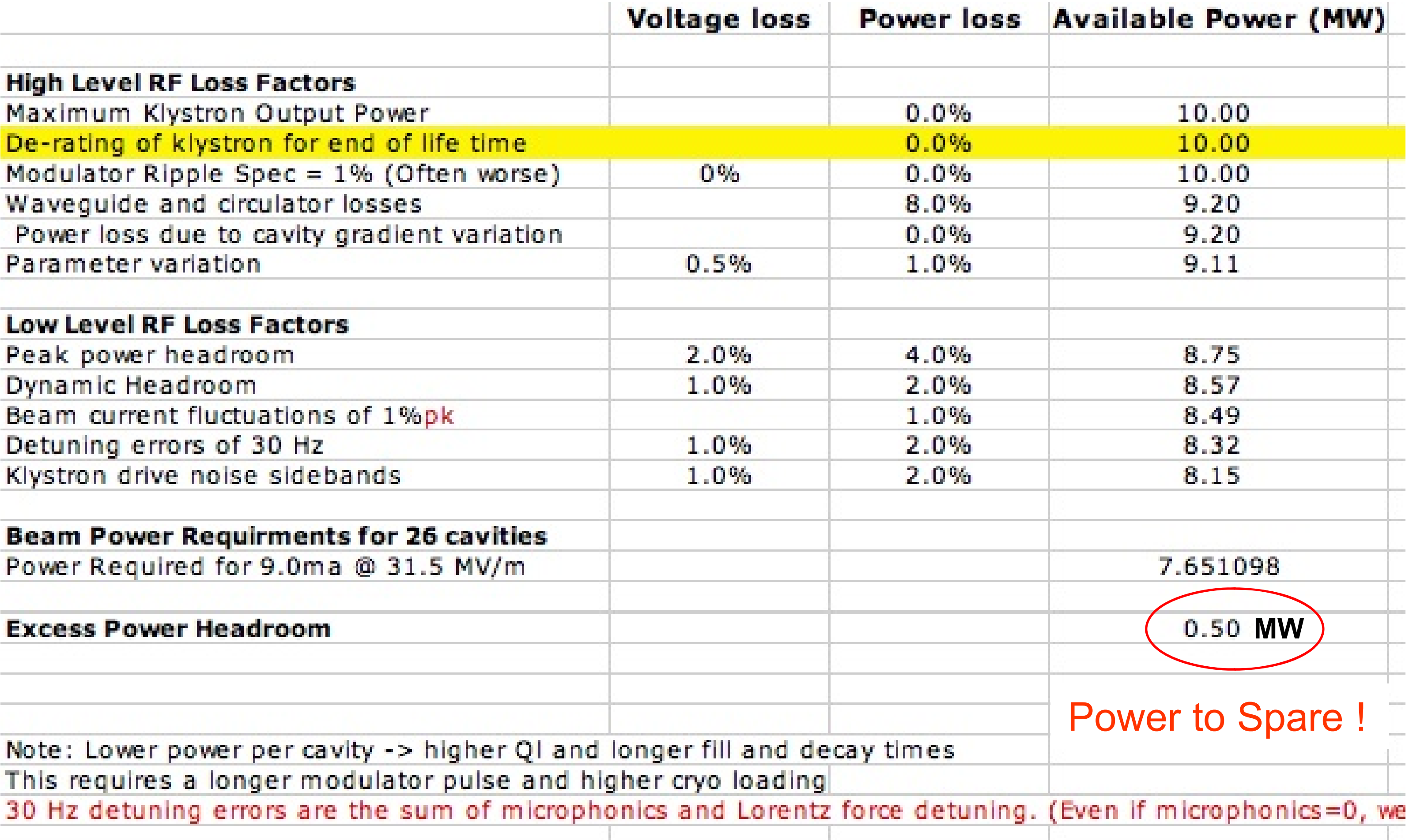
HOM Losses Along Beam Line at 70 K and 2 K

One bunch Q=3.2nc, bunch length=10mm Loss factor (V/pc)=9.96V/pc	**Lossy dielectric conductivity σ_{eff}=0.6(s/m)** **Dielectric constant ε_r=15, within 80ns**
Total Energy Generated by Beam (J)	10.208e-5
Energy propagated into beam pipe (J)	*4.44e-6*
Energy dissipated in the absorber (J)	*7.0e-7*
Energy loss on the Non SC beampipe wall (J) around absorber	9.3e-10
Energy loss in intersection between two cavities (J)	1.3e-9 (cold copper conductivity=3500e6Simm/m)



RF Station Power Budget

(Straw-man Proposal)

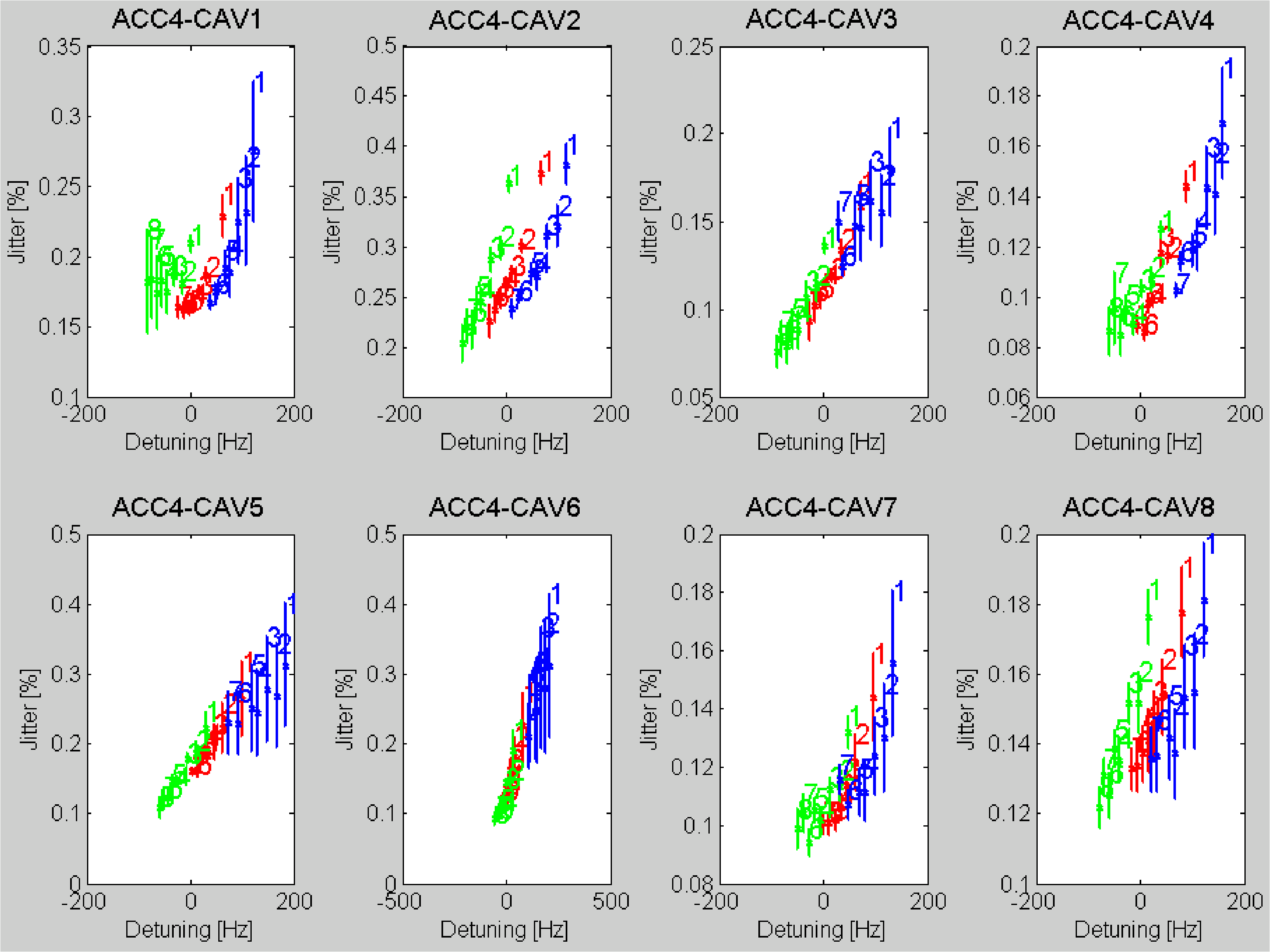


	Voltage loss	Power loss	Available Power (MW)
High Level RF Loss Factors			
Maximum Klystron Output Power		0.0%	10.00
De-rating of klystron for end of life time		0.0%	10.00
Modulator Ripple Spec = 1% (Often worse)	0%	0.0%	10.00
Waveguide and circulator losses		8.0%	9.20
Power loss due to cavity gradient variation		0.0%	9.20
Parameter variation	0.5%	1.0%	9.11
Low Level RF Loss Factors			
Peak power headroom	2.0%	4.0%	8.75
Dynamic Headroom	1.0%	2.0%	8.57
Beam current fluctuations of 1%pk		1.0%	8.49
Detuning errors of 30 Hz	1.0%	2.0%	8.32
Klystron drive noise sidebands	1.0%	2.0%	8.15
Beam Power Requirments for 26 cavities			
Power Required for 9.0ma @ 31.5 MV/m			7.651098
Excess Power Headroom			0.50 **MW**
Note: Lower power per cavity -> higher Ql and longer fill and decay times			
This requires a longer modulator pulse and higher cryo loading			
30 Hz detuning errors are the sum of microphonics and Lorentz force detuning. (Even if microphonics=0, we			

Power to Spare !

B. Chase

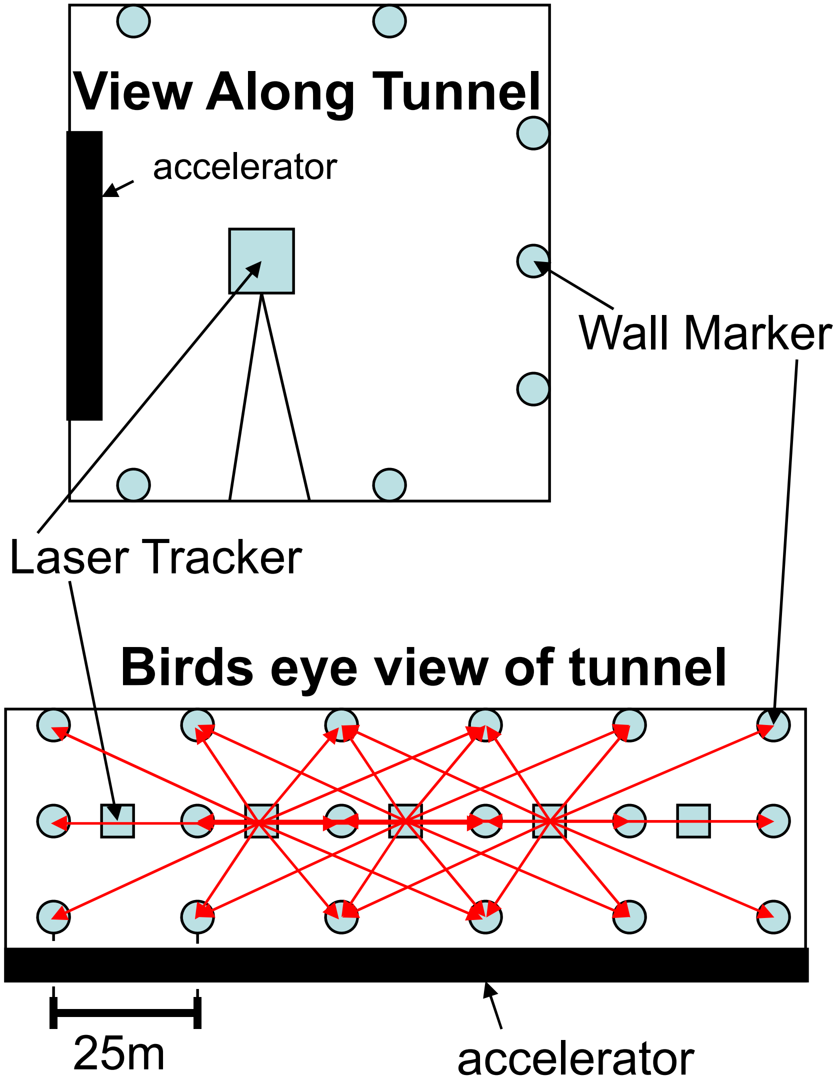
Studying FLASH Cavity Gradient Stability



Blue: Nominal + 100Hz Initial Detuning; Red: Nominal Initial Detuning; Green: Nominal – 100Hz Initial Detuning.

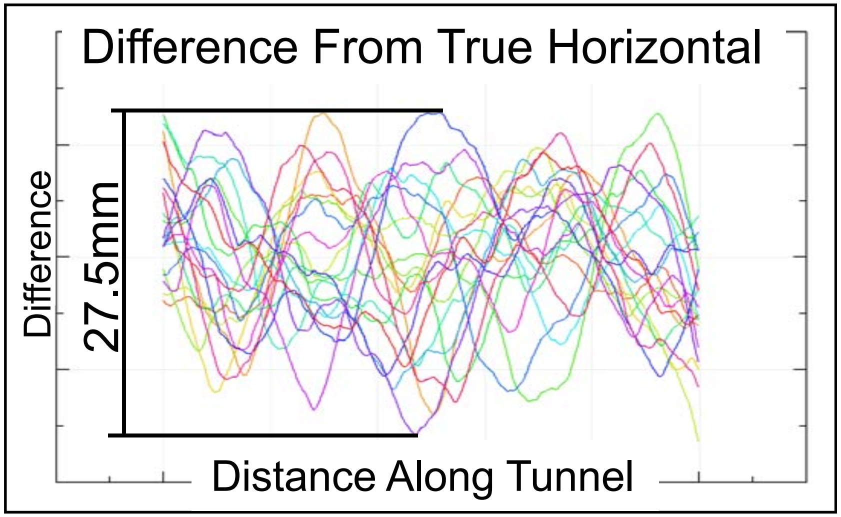
Linac Alignment Network

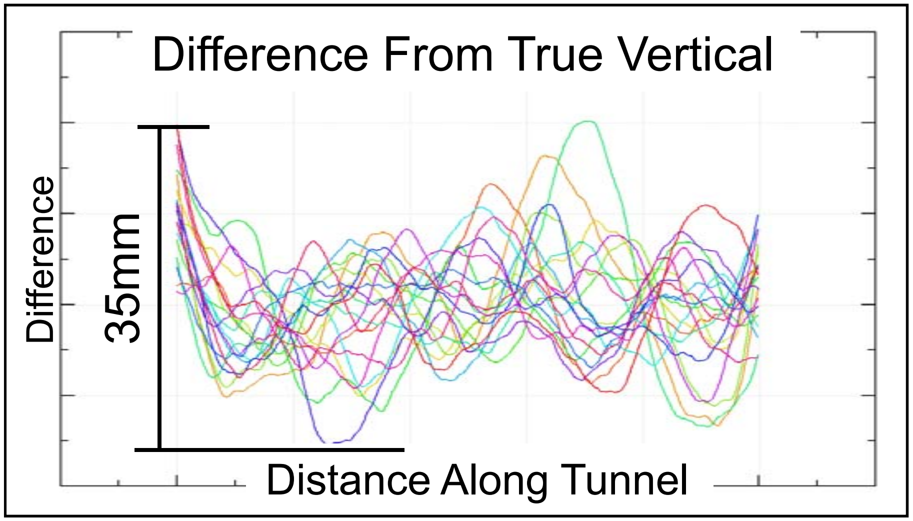
- Rings of 7 markers placed every 25m
  - Would like every 10m but current adjustment software not capable
- Network is Measured by a Laser Tracker
  - Laser tracker is placed between marker rings
  - Measures 2 rings up and down the tunnel
  - Statistical measurement Errors
    - Distance : 0.1mm+0.5ppm
    - Azimuth : 4.7 μrad
    - Zenith : 4.7 μrad
    - Errors estimated by experienced surveyors and laser tracker operators from DESY
  - Ignored all systematic errors from refraction in tunnel air (top hotter than bottom)



Alignment Simulations

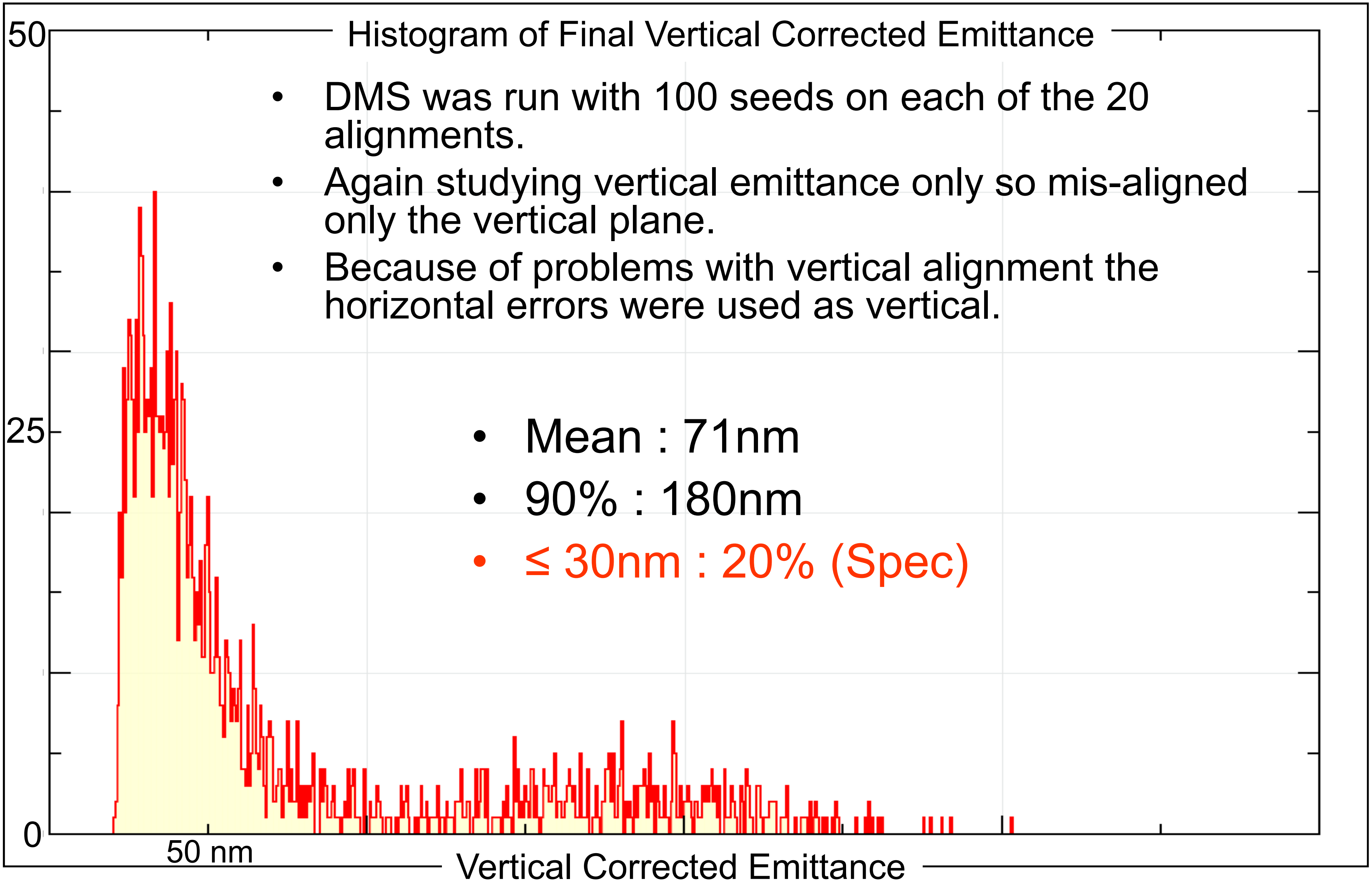
- Use PANDA to calculate error propagation through network
- 20 Reference Networks were simulated in JAVA
  - Length 12.5km
  - Including GPS every 2.5km assuming 10 mm rms errors
- Problem with vertical adjustment under investigation at DESY and by authors of PANDA





John Dale

Emittance Growth Simulations



- DMS was run with 100 seeds on each of the 20 alignments.
- Again studying vertical emittance only so mis-aligned only the vertical plane.
- Because of problems with vertical alignment the horizontal errors were used as vertical.

- Mean : 71nm
- 90% : 180nm
- ≤ 30nm : 20% (Spec)

MLI Summary

- Quad Package
  - Have SC quad that meets ILC spec and BPMs that look promising
  - Discussing issues of type of quad (cos(2phi) vs superferric) and whether to use a split quad
- Studies
  - Effectiveness of the HOM Absorber
  - RF Overhead and model for cavity gradient variations within and between pulses
    - Relevant for Klystron Cluster scheme
  - Linac Alignment
    - Conventional techniques may not be adequate – better models needed