Status of the Cold BPM Developments at CEA Saclay and Fermilab

Re-entrant Cavity BPM:

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Nelly Rouvière *IPN/Orsay*
Nicoleta Baboi, Dirk Noelle, Nils Mildner *DESY*

L-Band Cavity BPM:

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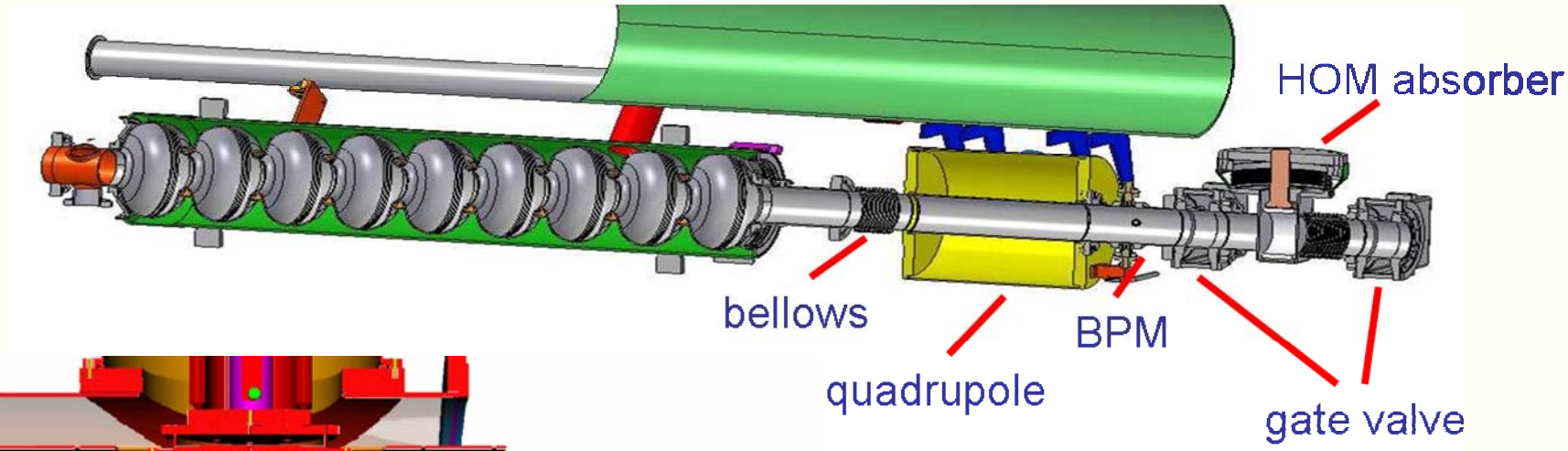
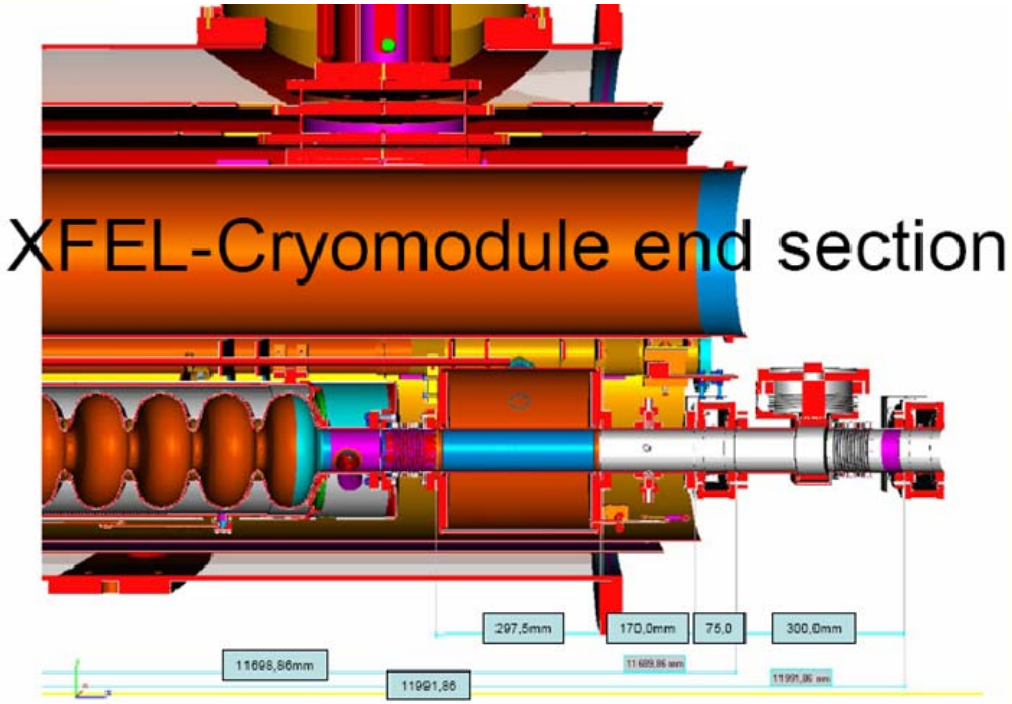
Parameters of SCRF Linac Projects

Parameter	ILC	XFEL	Project X
q_{bunch}	3.2 nC	1 nC	44 pC
I_{beam}	9 mA	5 mA	9 (14.3) mA
t_{beam}	0.97 ms	0.65 ms	1 ms
t_{bunch}	369.2 ns	200 ns	3.07 ns (3…5 bunches) (18.8 ns / 40 μs chopped)
bunches / train	2625	3250	325000
f_{rep}	5 Hz	10 Hz	5 Hz
Iris / beam pipe dia.	70 /78 mm	70 /78 mm	70 /78 mm
BPM resolution (single bunch, RMS)	0.5…1 μm	50 μm	?
BPM style	CM-free cavity	button / re-entrant cavity	?

The NML test facility linac will operate with "ILC-like", and / or "Project X like" (t_{bunch}= 0.77 ns) e^- beam parameters!

Button BPM (XFEL?, NML CM #1)





Common mode problem:

$$V_{elec}(x,y,\phi) \propto -\frac{2I_{beam}}{\pi}\arctan\frac{[(1+x)^2+y^2]\tan(\phi/4)-2y}{1-x^2-y^2}$$

with $x=X/R$ $y=Y/R$ $R=39mm$ $\phi=0.466$

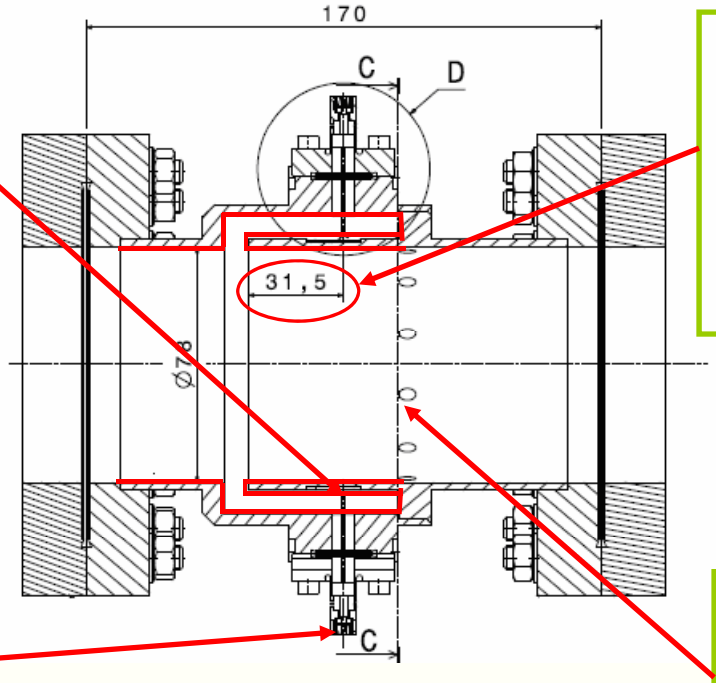
Position change: Δx = 1 μm

Signal change: $\Delta v_{elec} = 5\cdot10^{-5}$
(86 dB CM suppression required!)

Re-entrant Cavity BPM (Saclay)

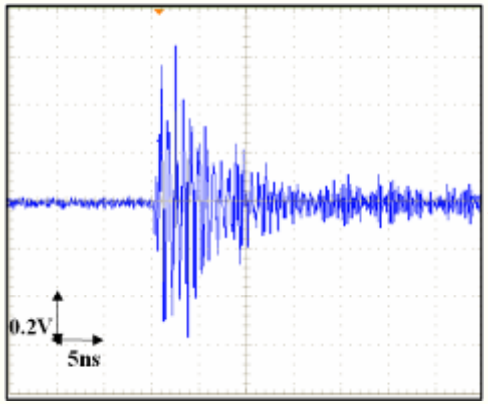
- **It is arranged around the beam tube and forms a coaxial line which is short circuited at one end.**
- **The cavity is fabricated with stainless steel as compact as possible :**
  - **170 mm length (minimized to satisfy the constraints imposed by the cryomodule)**
  - **78 mm aperture.**

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



Feedthroughs are positioned in the re-entrant part to reduce the magnetic loop coupling and separate the main RF modes (monopole and dipole)

Cryogenic tests in N2 : OK



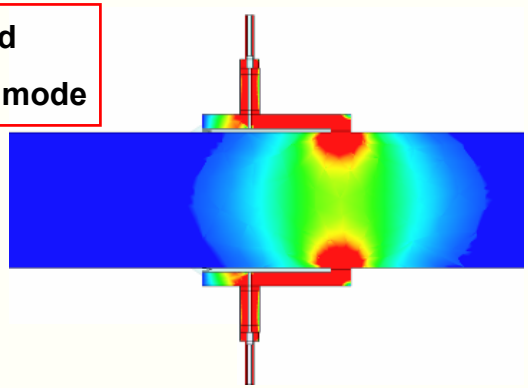
Signal from one pickup

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

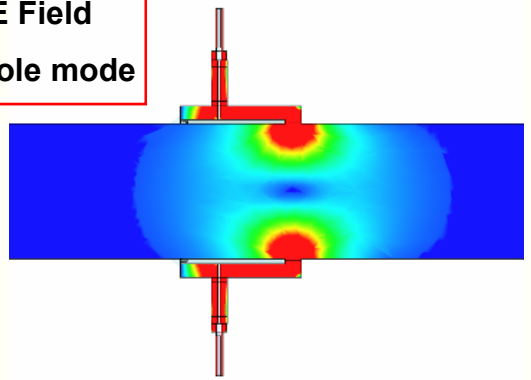
RF Characteristics of the BPM

Eigen modes	F (MHz)		Q_l		$(R/Q)_l$ (Ω) at 5 mm	$(R/Q)_l$ (Ω) at 10 mm
	Calculated with HFSS in eigen mode	Measured in the tunnel	Calculated with HFSS in eigen mode	Measured in the tunnel	Calculated	Calculated
Monopole mode	1250	1255	22.95	23.8	12.9	12.9
Dipole mode	1719	1724	50.96	59	0.27	1.15

E Field
Monopole mode

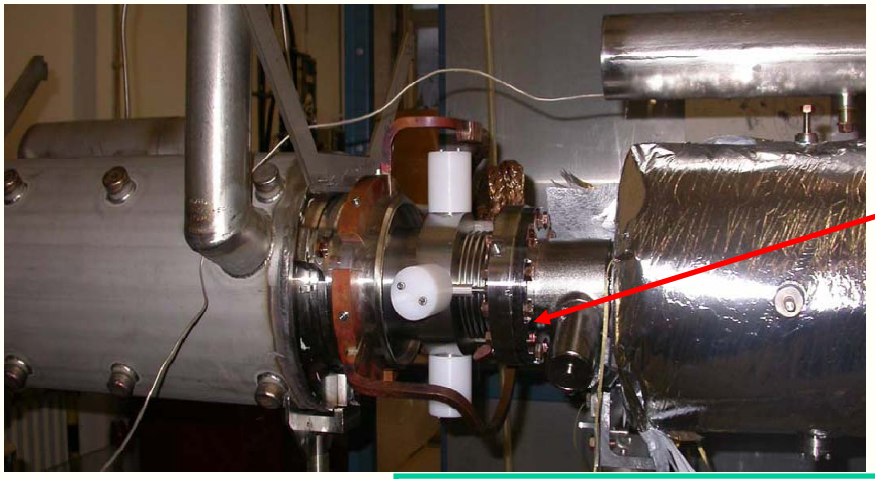


E Field
Dipole mode



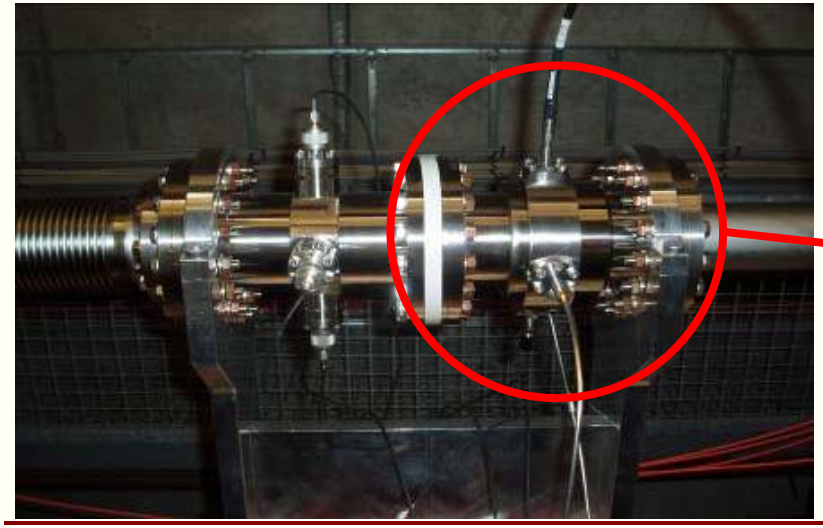
- Due to tolerances in machining, welding and mounting, some small distortions of the cavity symmetry are generated.
  - This asymmetry is called cross talk and the isolation is evaluated around 33 dB.

Re-entrant BPM at FLASH



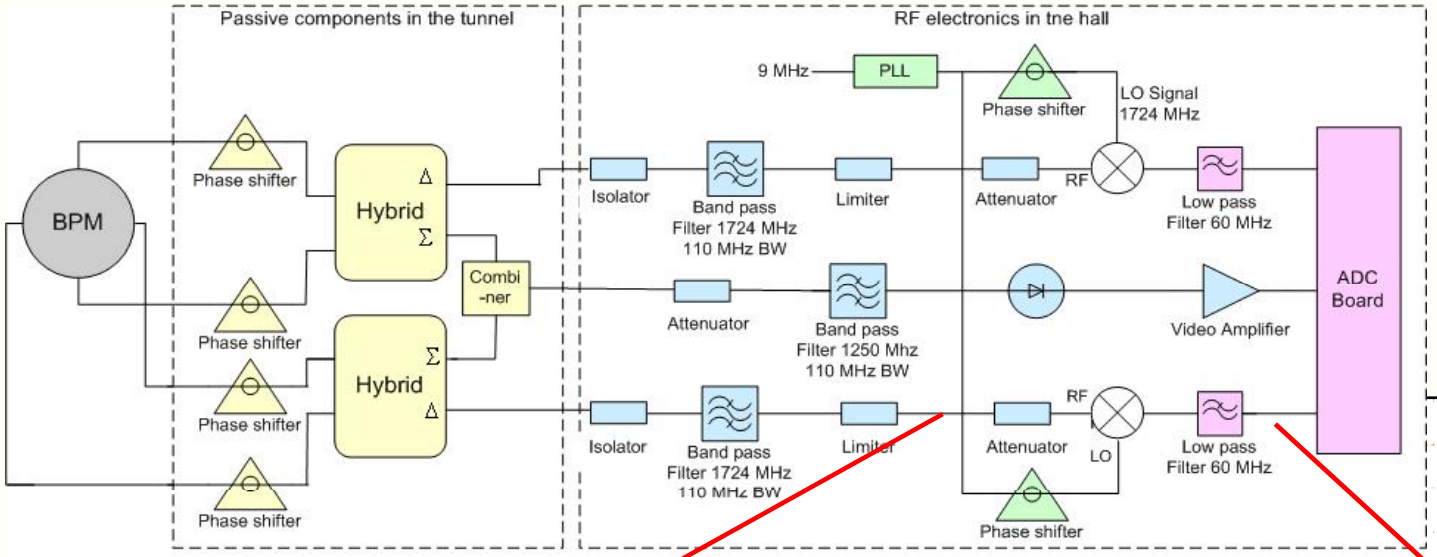
Re-entrant cavity BPM located at cryogenic temperature inside the cryomodule (ACC1).

Re-entrant cavity BPM installed in a warm section on the FLASH linac

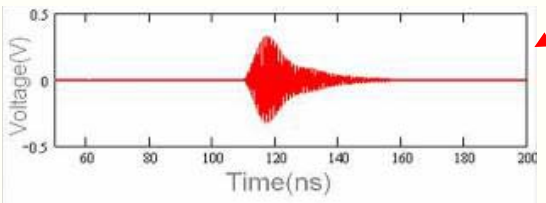


CM Rejection Scheme

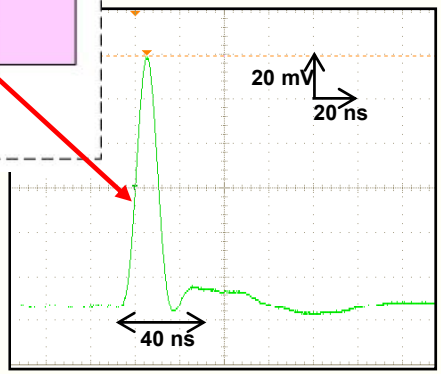
- The rejection of the monopole mode, on the Δ channel, proceeds in three steps :
  - a rejection based on a hybrid coupler, having isolation > 20 dB in the range of 1…2 GHz.
  - a frequency domain rejection with a band pass filter centered at the dipole mode frequency. Its bandwidth of 110 MHz also provides a noise reduction.
  - a synchronous detection.



RF signal

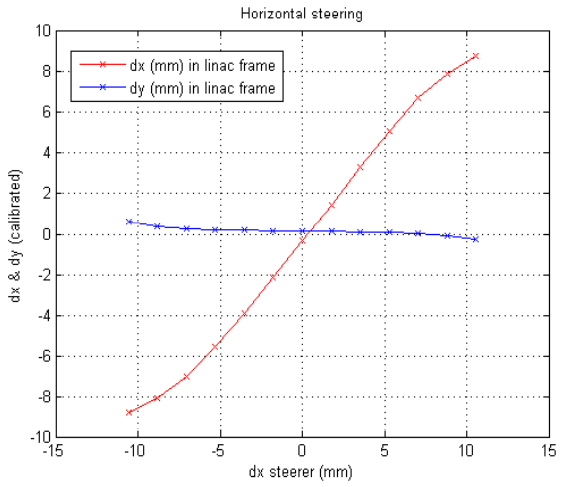


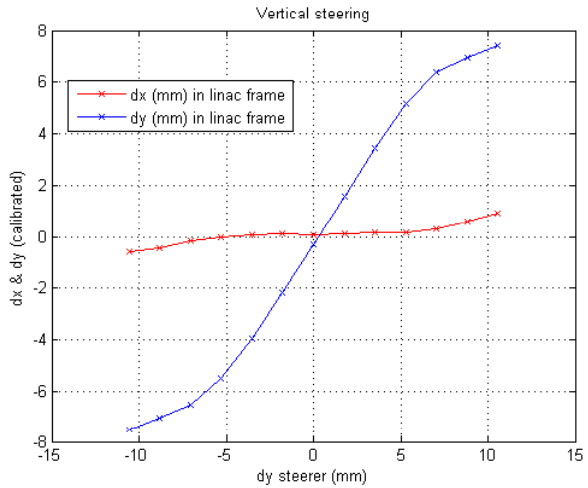
IF signal behind Lowpass Filter on channel Δ



Beam Test at FLASH (1)

- **To calibrate the BPM:**
  - **Beam is moved with one steerer.**
  - **Calculate for each steerer setting, the relative beam position in using a transfer matrix between steerer and BPM (magnets switched off to reduce errors and simplify calculation).**
  - **Average of 500 points for each steerer setting.**





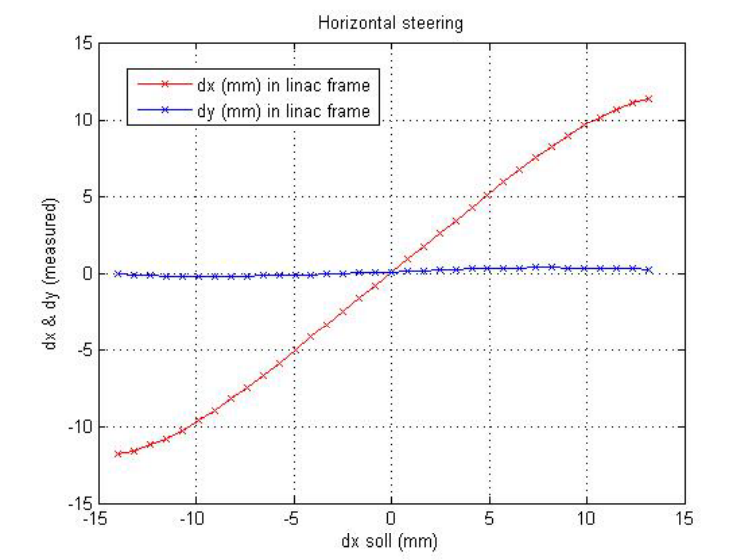
Calibration results from horizontal (left) and vertical (right) steering

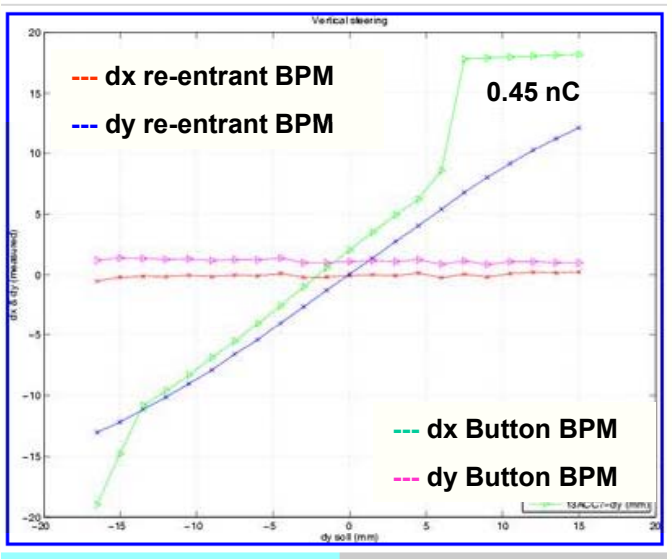
→ **Good linearity in a range ± 5 mm**

→ **RMS resolution: ~4 µm on the Y channel**
~8 µm on the X channel
} **with 1 nC**

Beam Test at FLASH (2)

With an attenuator 6 dB on each channel





Good linearity : ± 12 mm @ 1 nC

± 15 mm @ 0.45 nC

Resolution measurement:

correlation of the reading of one BPM in one plane against the readings of all other BPMs in the same plane (using linear regression).

Charge	Resolution Re-entrant	Resolution Re-entrant+ 6 dB attenuator
1.0 nC	~ 4 µm	~ 7 µm
0.8 nC		~ 12 µm
0.5 nC	~ 11.8 µm	~ 21 µm
0.2 nC	~ 30.1 µm	~ 55 µm

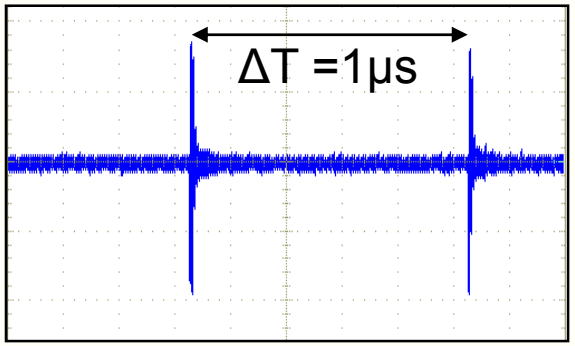
Time Resolution

- **Damping time is given by using the following formula:** $\tau = \frac{1}{\pi * BW}$

with $BW = \frac{f_d}{Q_{ld}}$

fd: dipole mode frequency
Q_ld: loaded quality factor for the dipole mode

- **Considering the system (cavity + signal processing), the time resolution is determined, since the rising time to 95% of a cavity response corresponds to 3τ.**

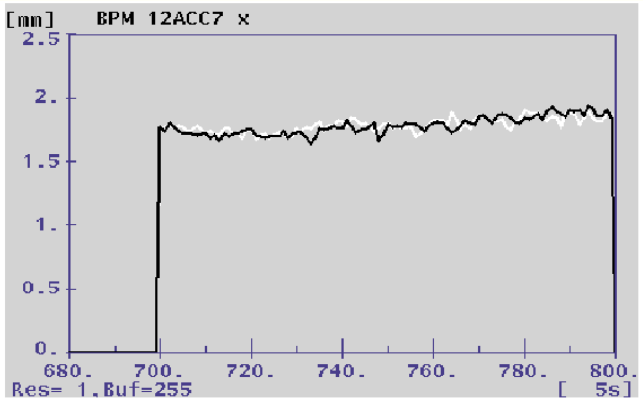


RF signal measured at one pickup

	Damping Time cavity only	Time resolution cavity + electronics
BPM	9.4 ns	40 ns

Time resolution for re-entrant BPM

100 bunches read by the re-entrant BPM



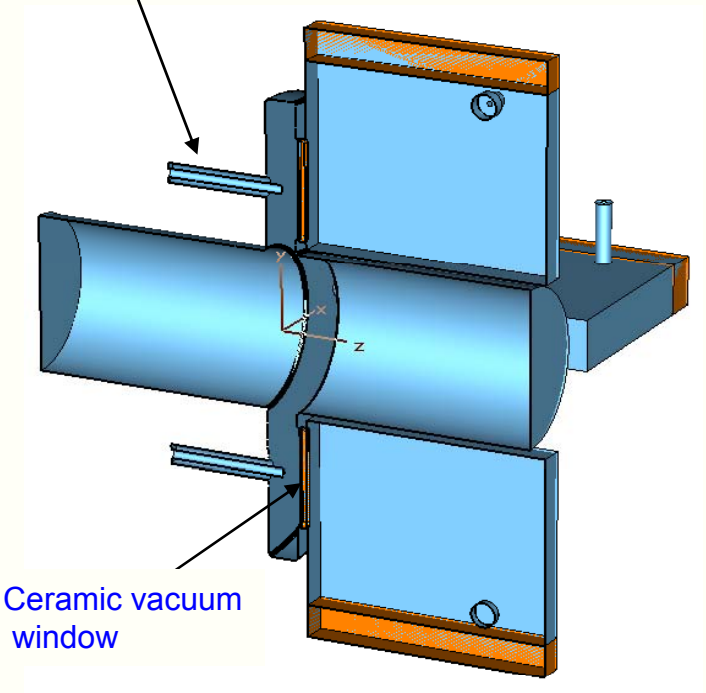
Possibility bunch to bunch measurements

CM-free L-Band Cavity BPM

- **Features:**
  - Cold L-Band cavity BPM with < 1 μm resolution, having an aperture of 78 mm diameter, and fits in the ILC (3+, 4) cryostat.
  - Waveguide-loaded pillbox with slot coupling.
  - Dimensioning for f_{010} and f_{110} symmetric to f_{RF}, f_{RF} = 1.3 GHz, f_{010} = 1.12 GHz, f_{110} = 1.47 GHz.
  - Dipole- and monopole ports, no reference cavity for intensity signal normalization and signal phase (sign).
  - Q_{load} ≈ 600 (tunable range ~360…800).
  - Minimization of the X-Y cross-talk (dimple tuning).
  - Simple (cleanable) mechanics.
- **Status**
  - All EM simulations (incl. tolerances, etc.) completed. All dimensions frozen.
  - Successful temperature cycling tests of ceramic windows.
  - Measurements on the monopole mode feedthrough antenna.
  - Study of the final BPM assembly inside a type 3+ cryostat.

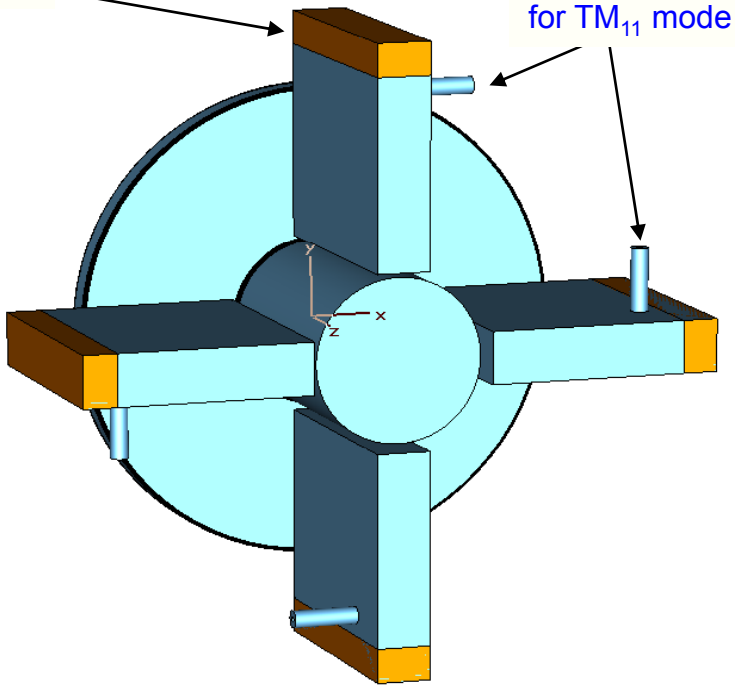
EM Modeling

Vacum coaxial feedthrow for TM_{01} mode output



Ceramic slab

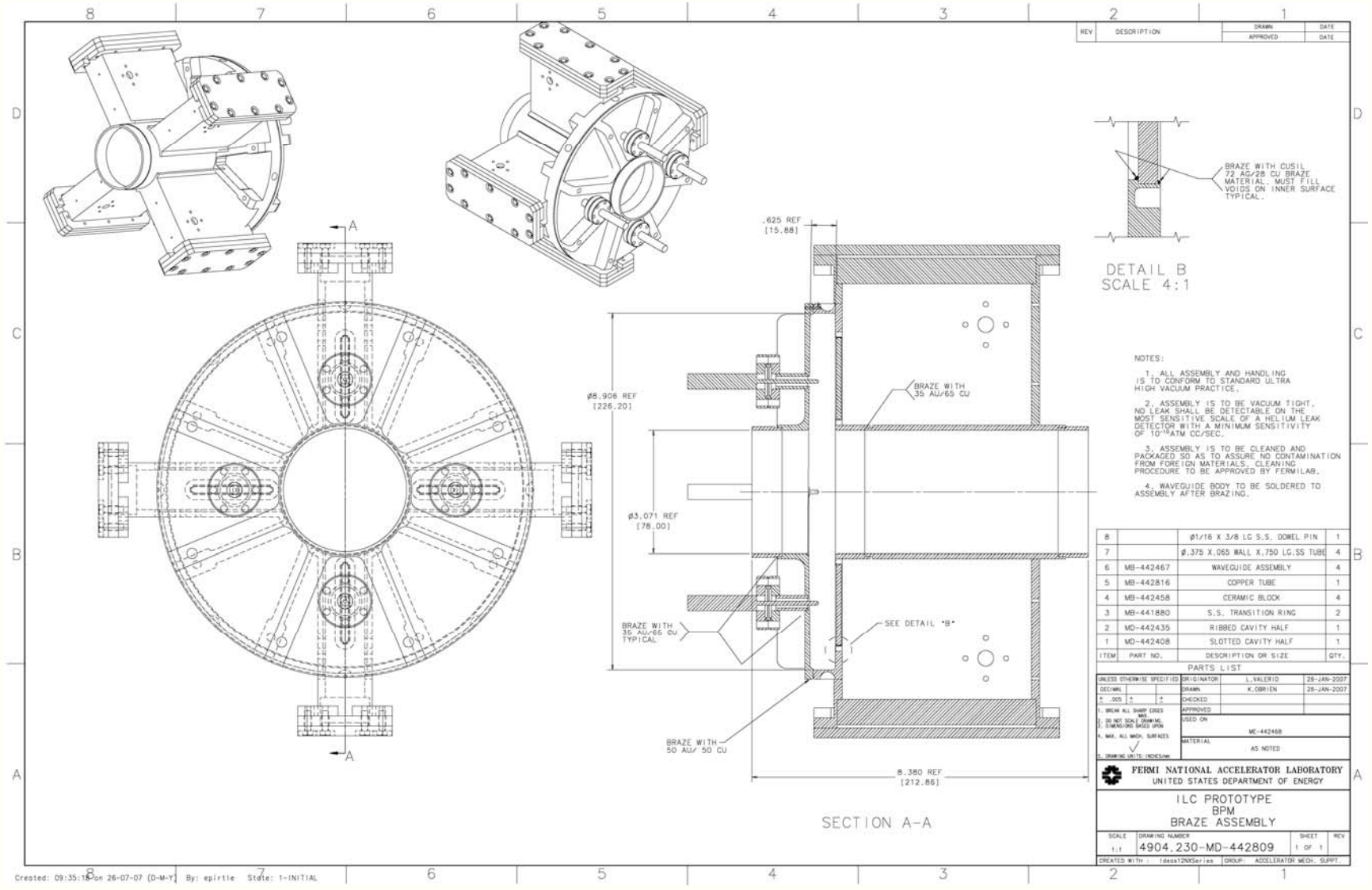
Coaxial feedthrow for TM_{11} mode output



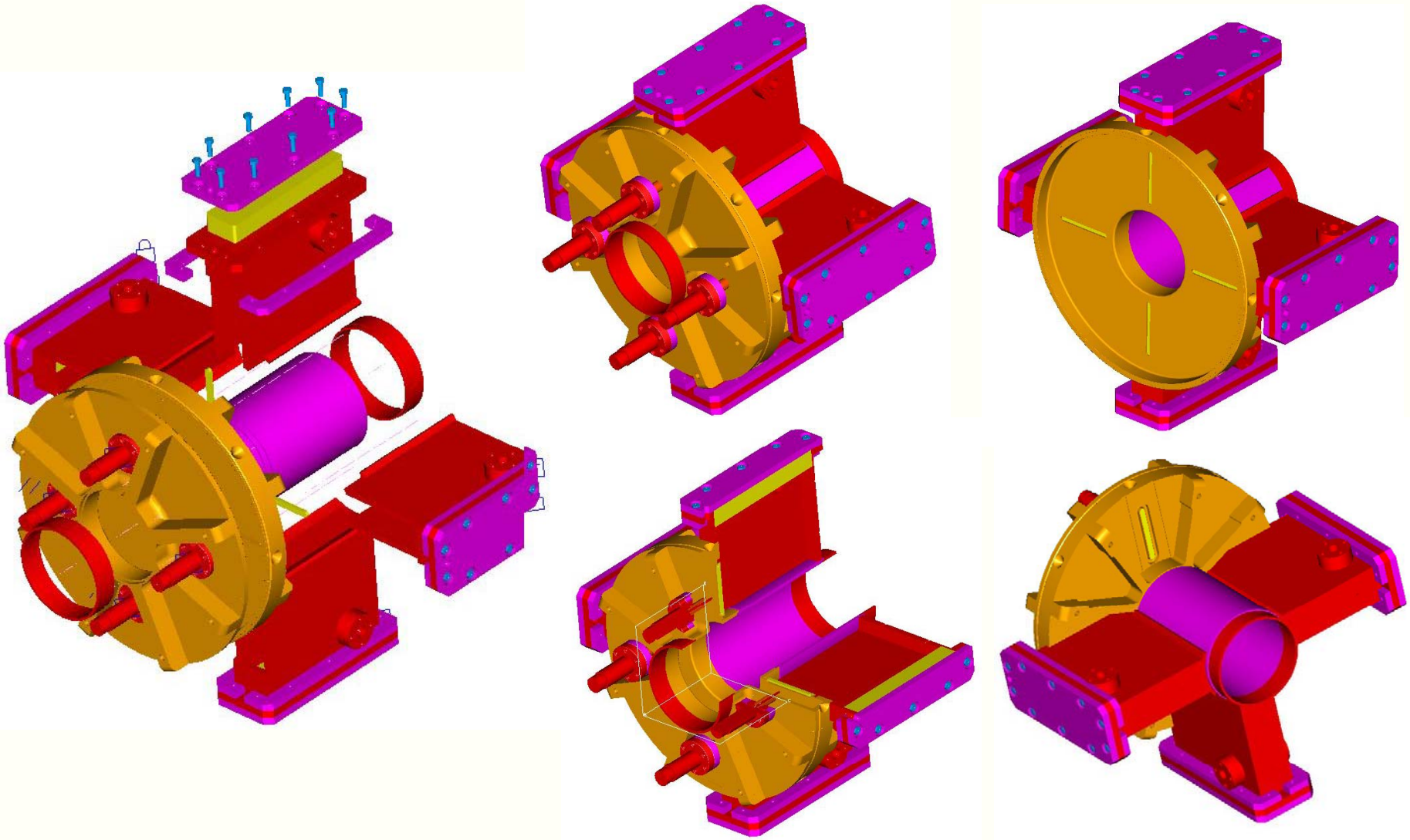
Cavity diameter: 226 mm
Gap length: 15 mm
Pipe diameter: 78 mm
Waveguide: 120 x 25 mm

Features:
1. Ceramic (Al_2O_3) brazed vacuum windows
2. Common TM_{110} and TM_{010} cavity
3. Symmetrical signal processing
4. Time resolution: ~300 ns (bunch by bunch)
5 . Position resolution: < 1 μm (± 1 mm)

Construction Drawing

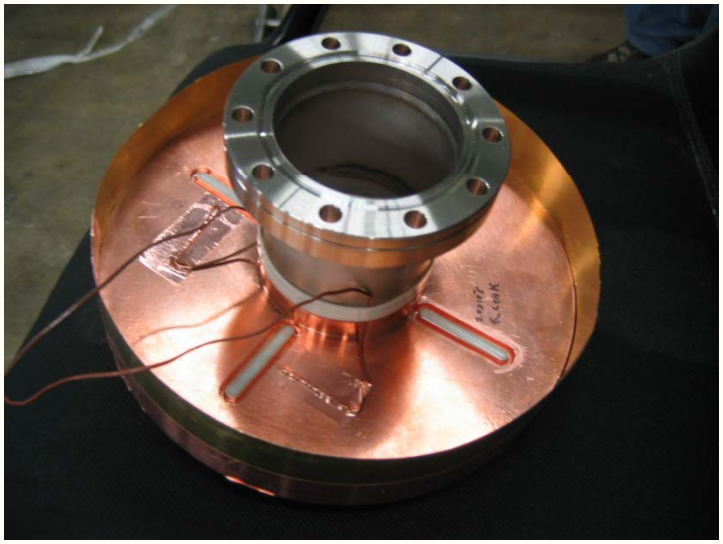


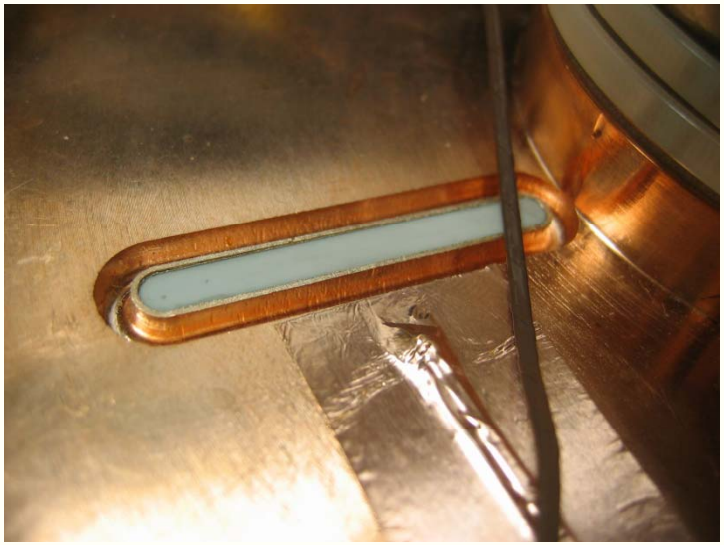
Construction Details (3D-Views)

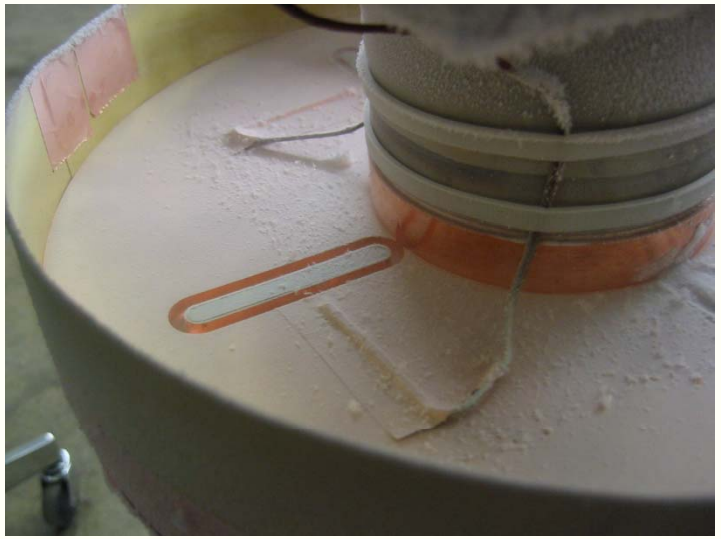


Cryogenic Tests

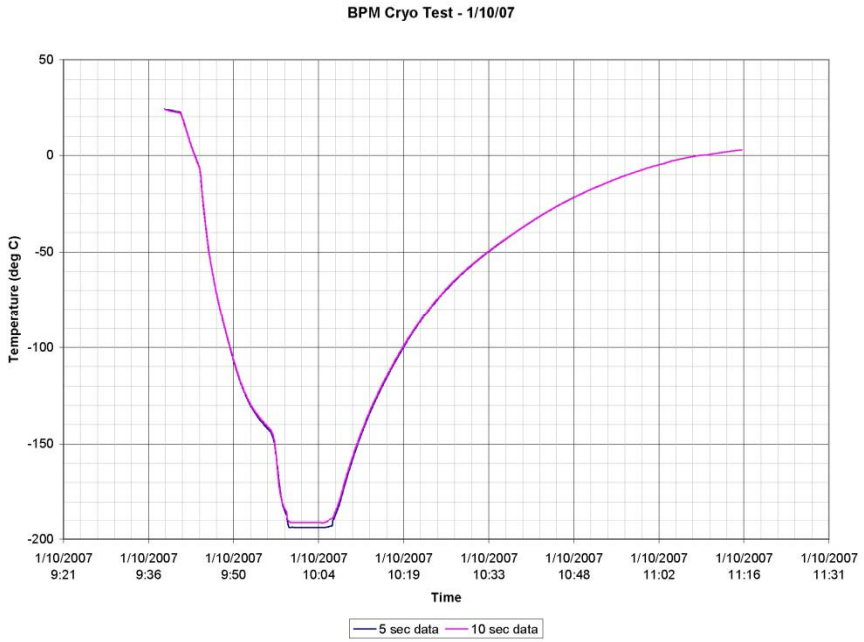
Cryogenic Tests

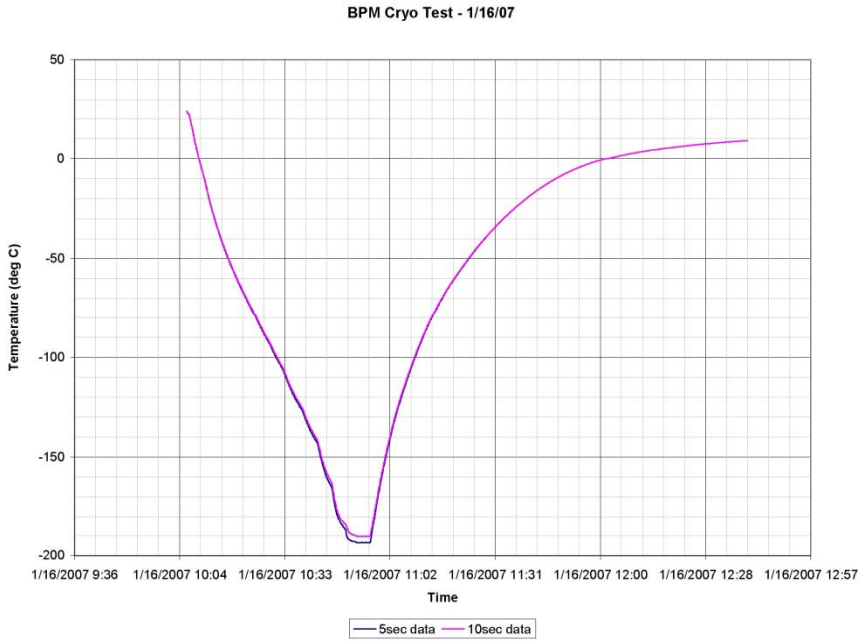






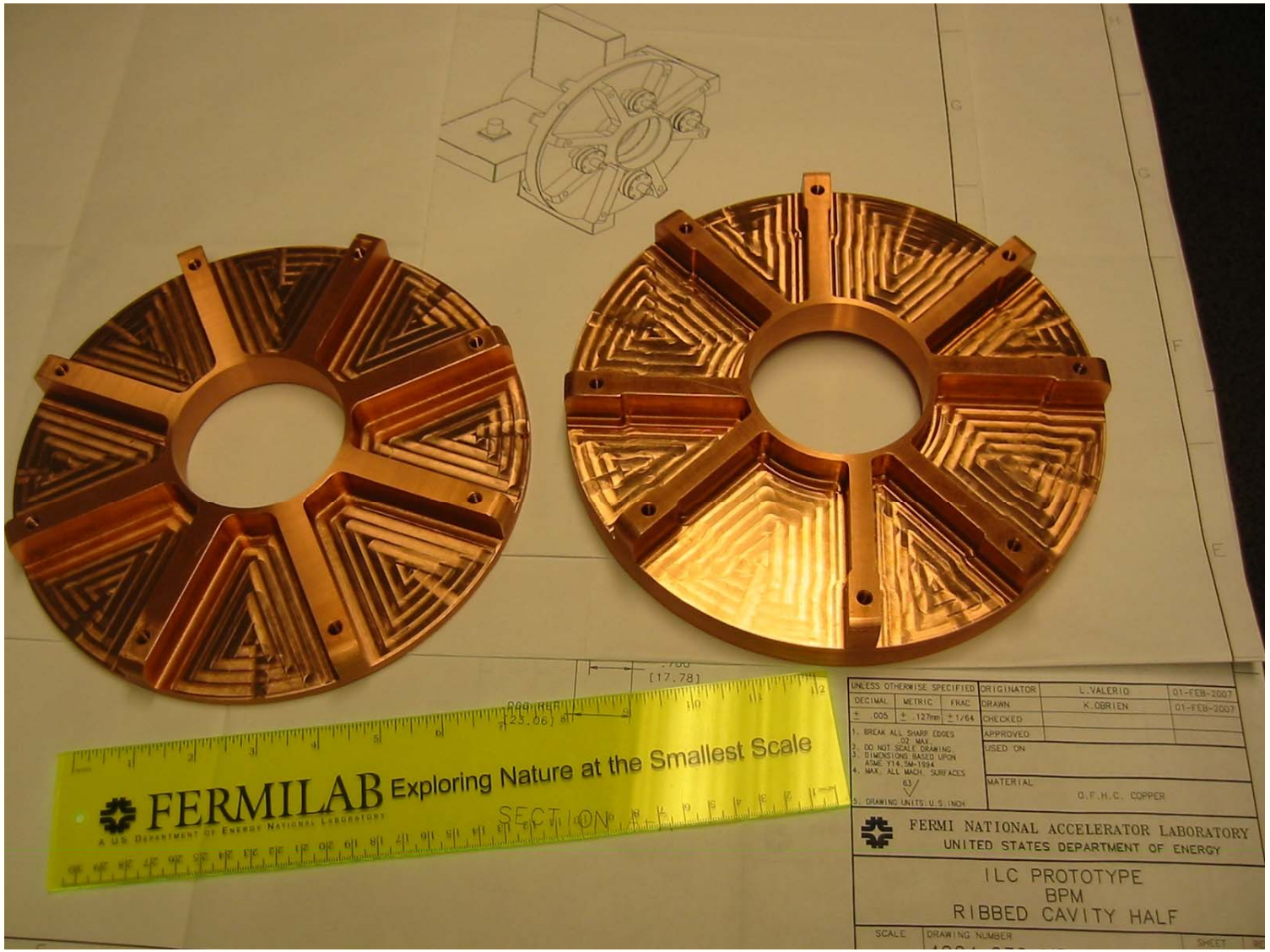
Temperature Cycling



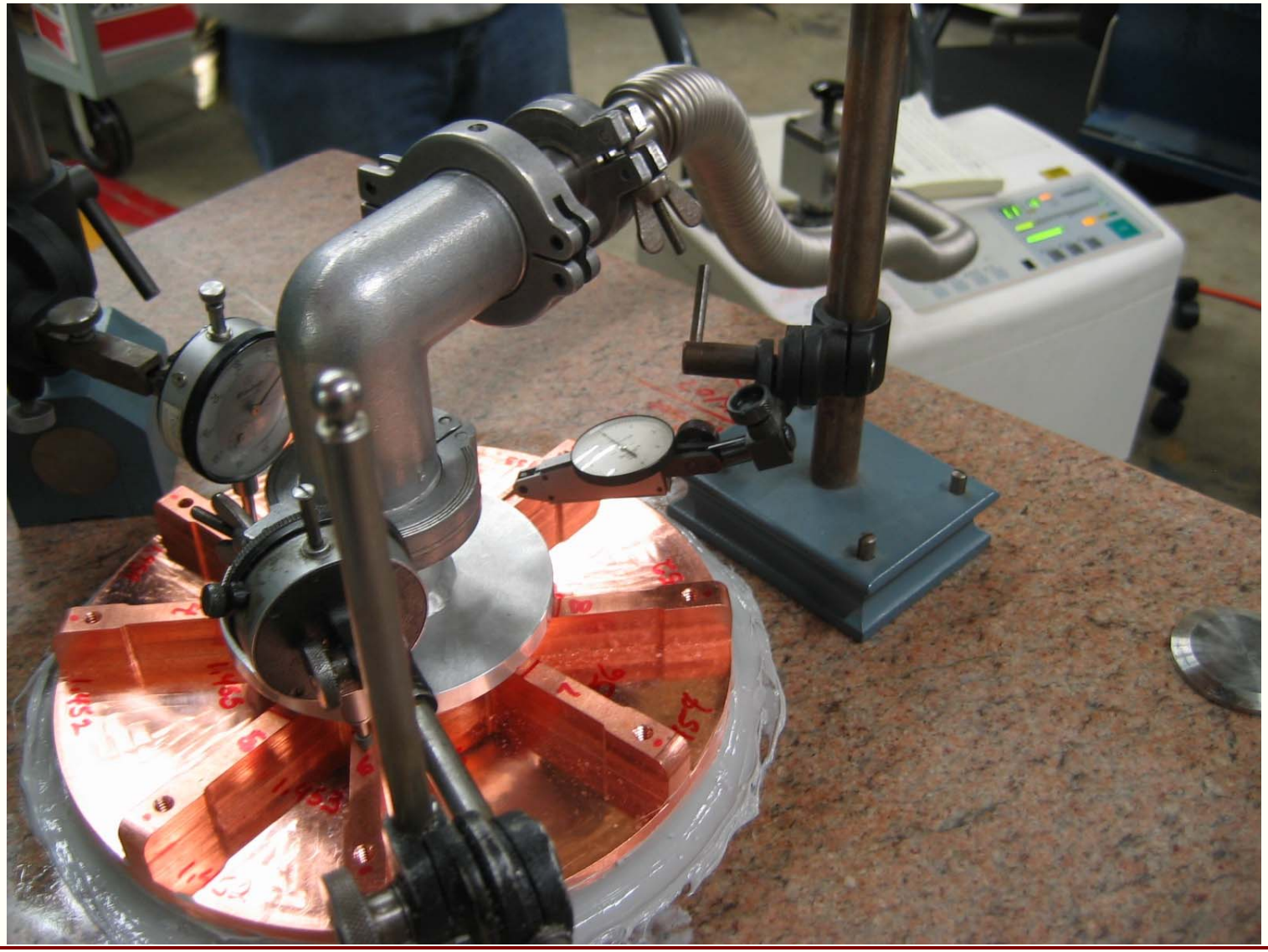


- **3 cryo temperature cycles:**
  - **30-45 min. cool-down from room temperature to ~80 K**
  - **~ 60 min. warm-up form 80 K to room temperature**
  - **How many cycles do we need?!**

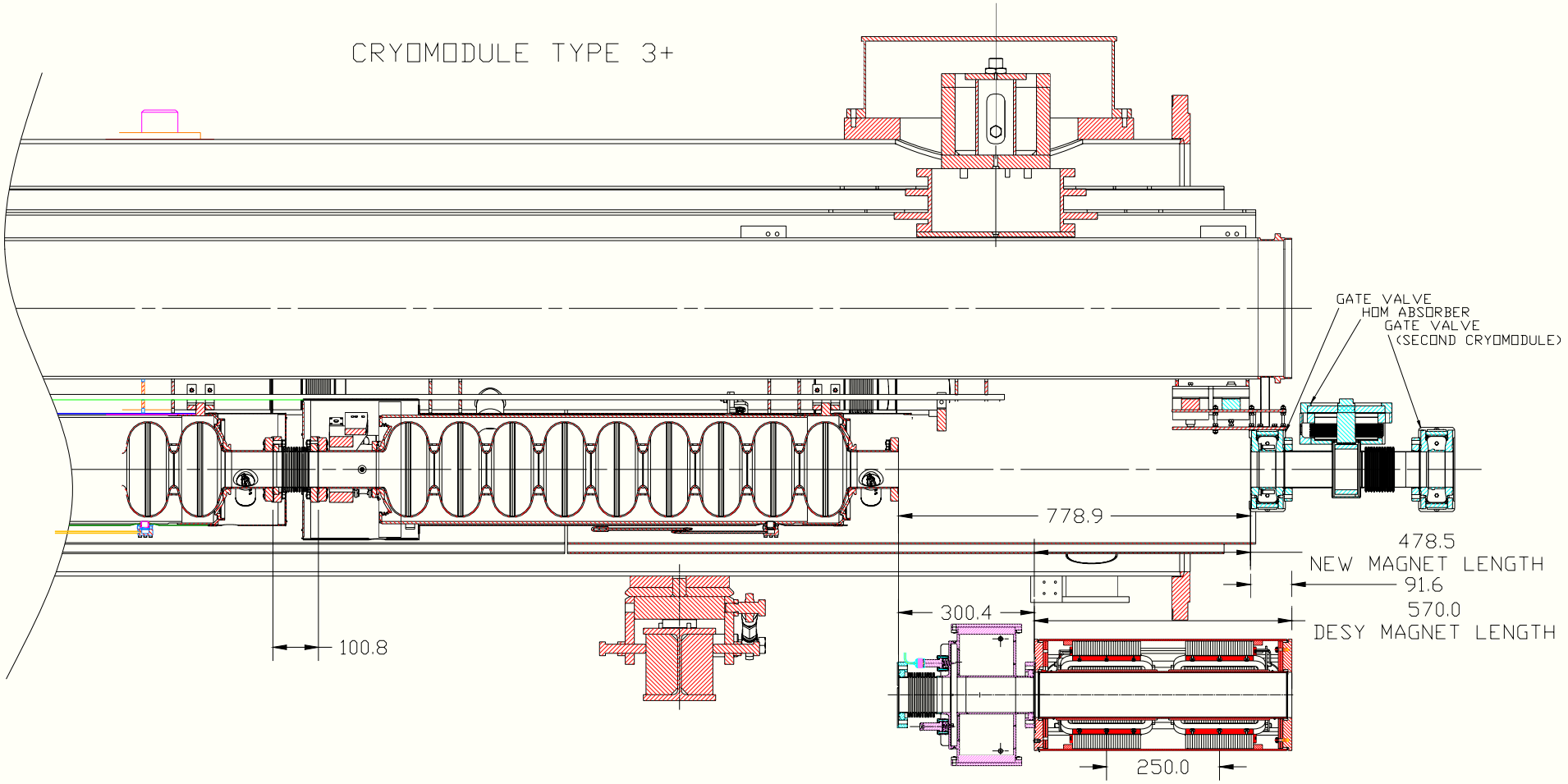
Cold Cavity BPM Prototyping



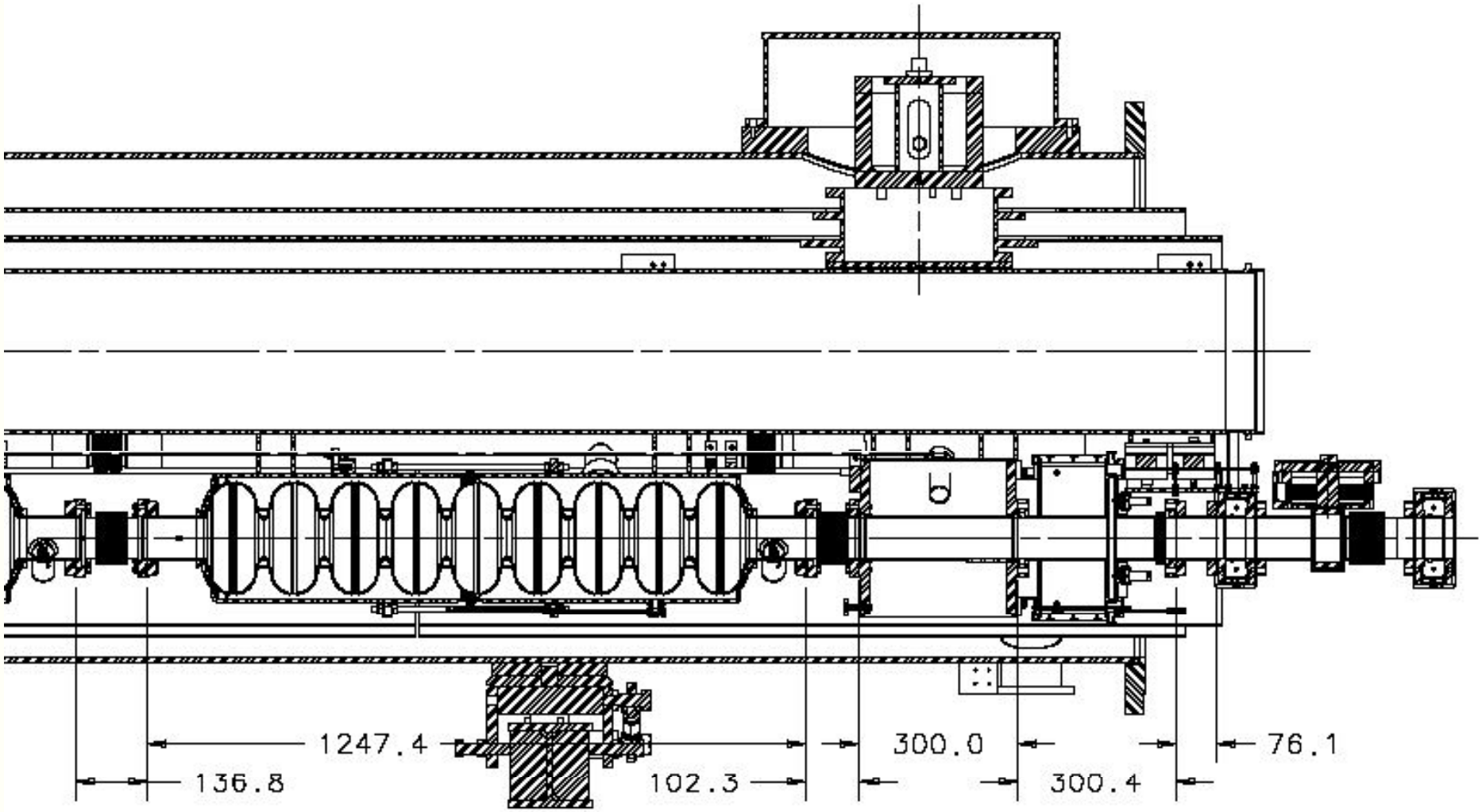
Defection Tests



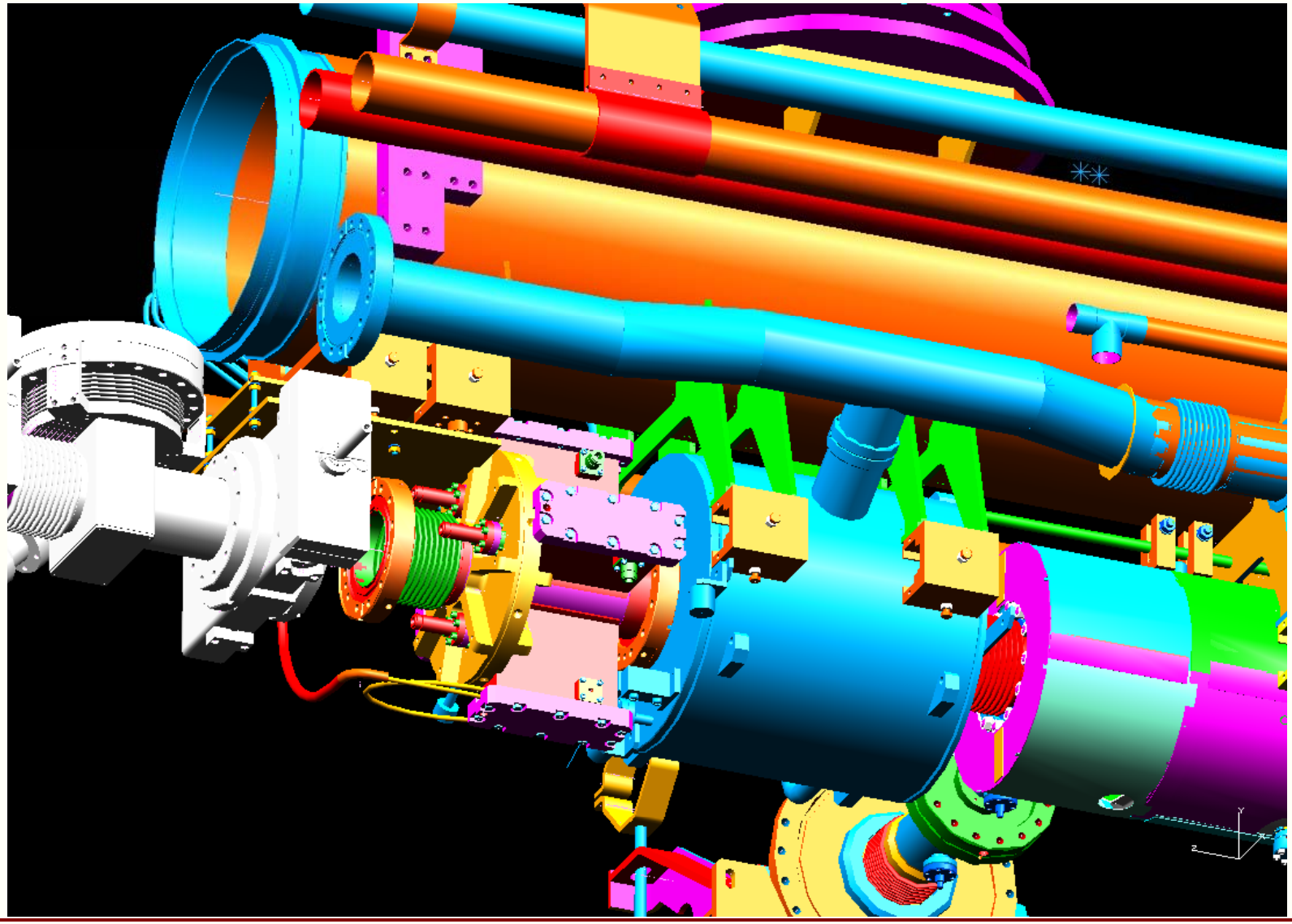
CM 3+ Layout with Quad & BPM



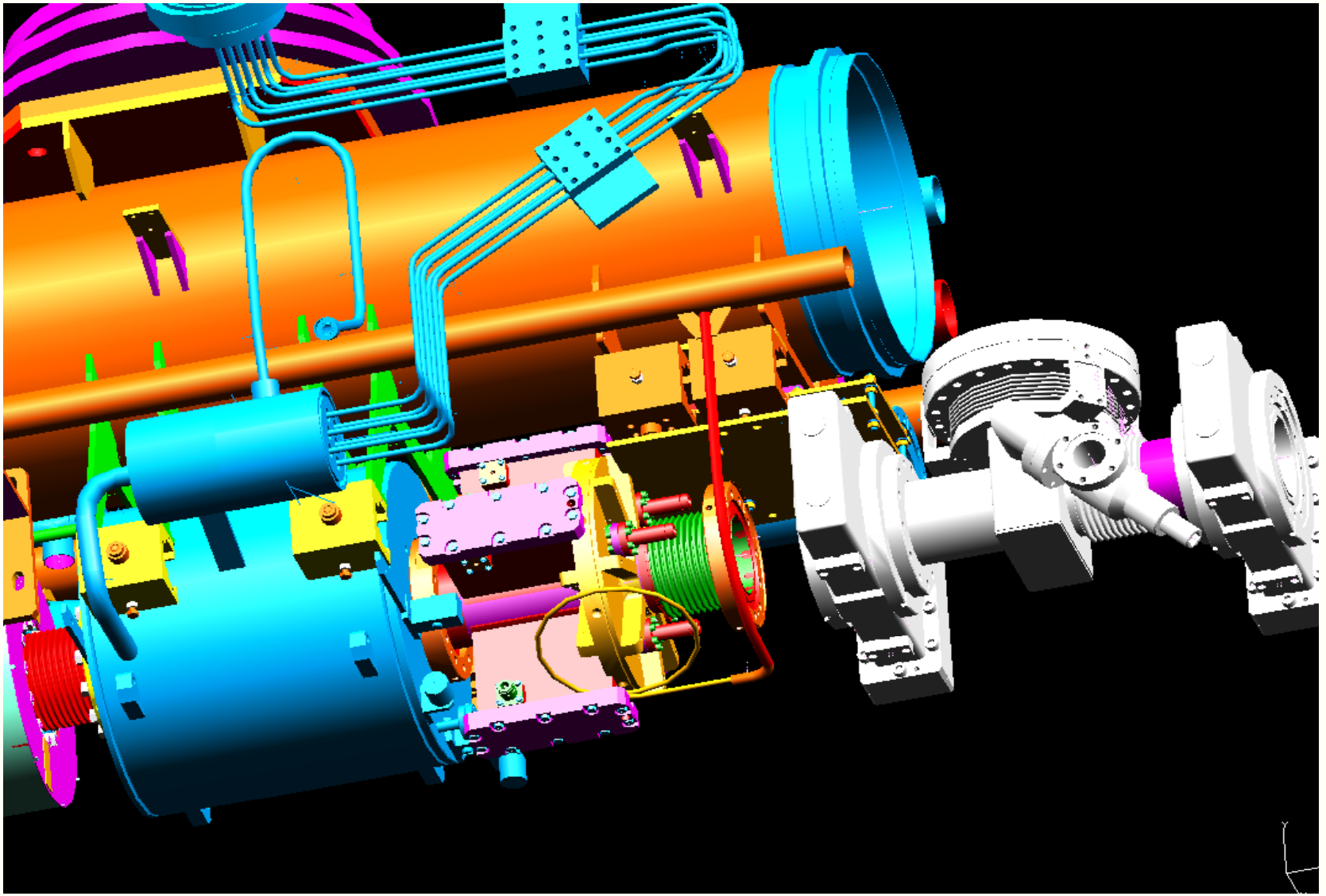
CM 3+ with new Quad & BPM



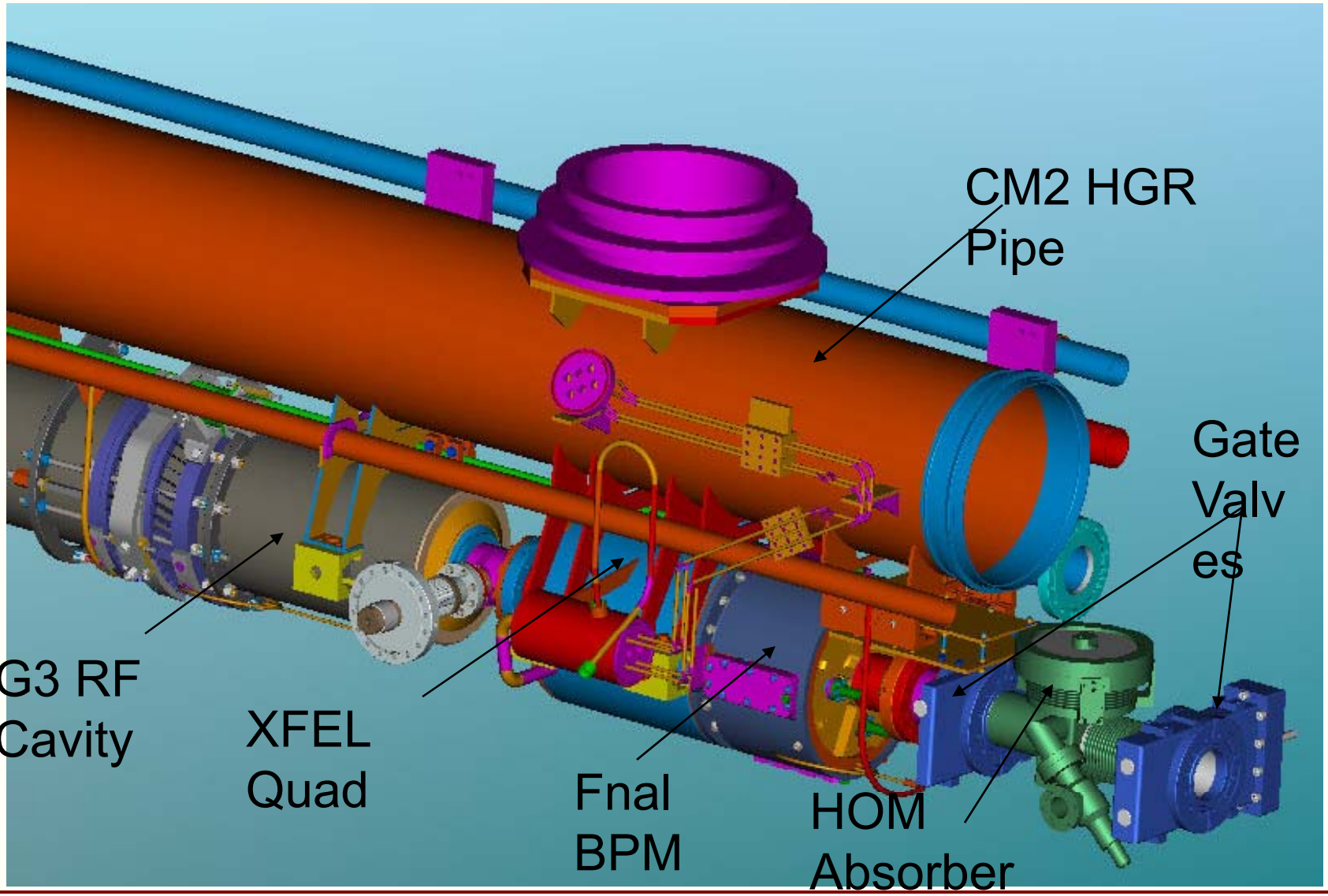
CM 3+ with new Quad & BPM



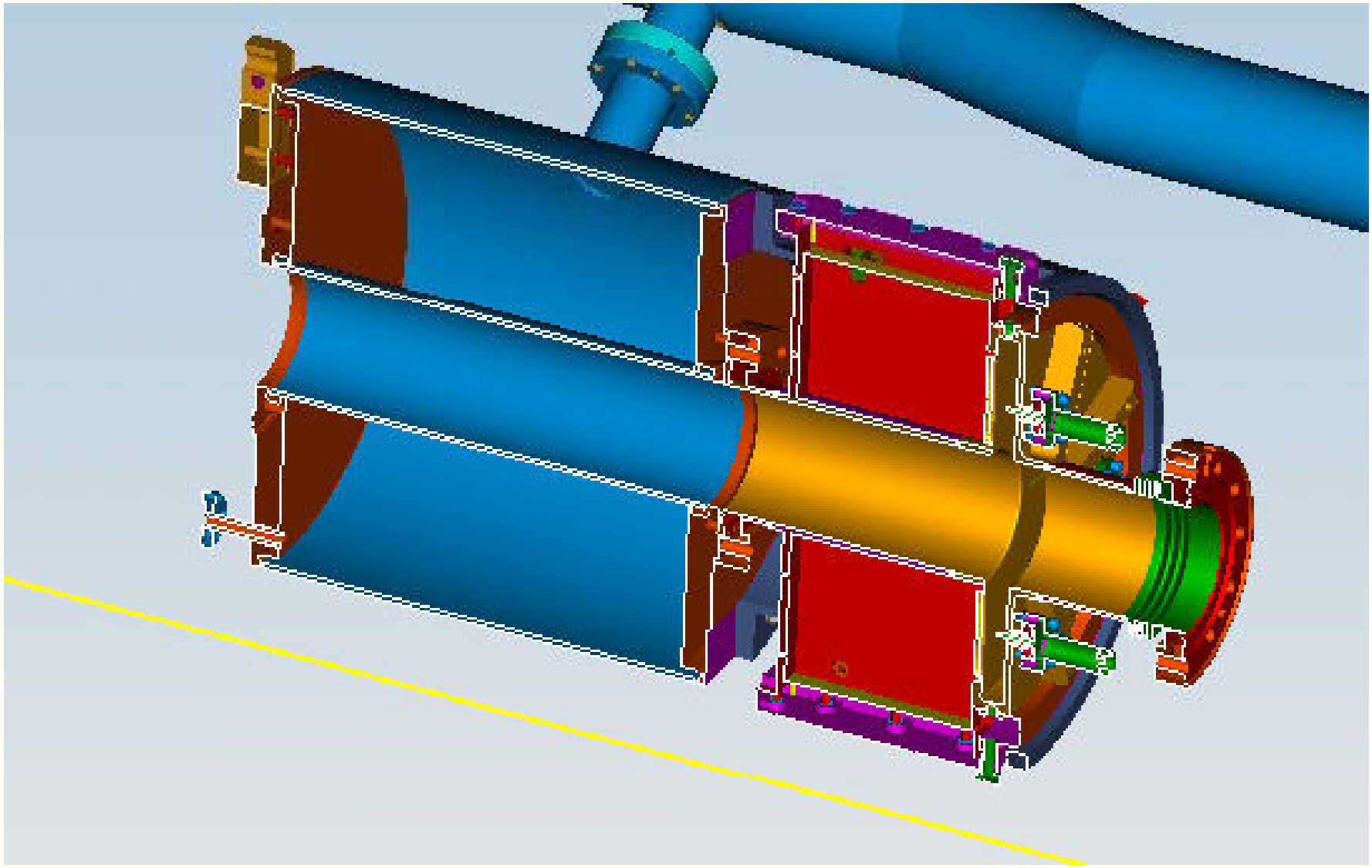
CM 3+ with new Quad & BPM



CM 3+ with new Quad & BPM



Cross-section View Quad & BPM



L-Band Cavity BPM: Next Steps…

- NO activities since December 2007, restarted just 2 weeks ago (April 2008)
- New hire: Seughwan Shin (fellowship) dedicated to cold cavity BPM development.
- L-Band BPM design goes NOW into prototyping, “warm” dimensions!
- Vacuum and RF bench tests.
- Beam tests (warm) at A0, KEK?
- Investigation of a modified design with f_{110} = 1.3 GHz, to satisfy both: ILC and Project X like beam at NML.

Summary

- Three different cold BPM detector styles with full 78 mm aperture are currently under investigation:
- Button BPM (DESY):
  - Installed at NML cryomodule #1. CM suppression of 86 dB required for 1 µm resolution. 10…50 µm single bunch resolution seems to be achievable.
- Re-entrant Cavity BPM (CEA-Saclay):
  - Long term development (7+ years). Compact design, but not CM-free.
  - Successful cold and warm beam tests. 5…10 µm single bunch resolution achieved!
  - Complicated, expensive, and sensitive read-out system (calibration!).
- CM-free L-Band Cavity BPM (Fermilab):
  - Design frozen. Single bunch resolution potential < 1 µm. Successful temperature cycling. Manufacturing of a warm prototype underway.
  - Cold cavity BPM for NML cryomodule #2 (type 3+) needs to be modified in case of a Project X like beam operation.