Fermilab BPM R&D Activities

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Fermilab BPM R&D

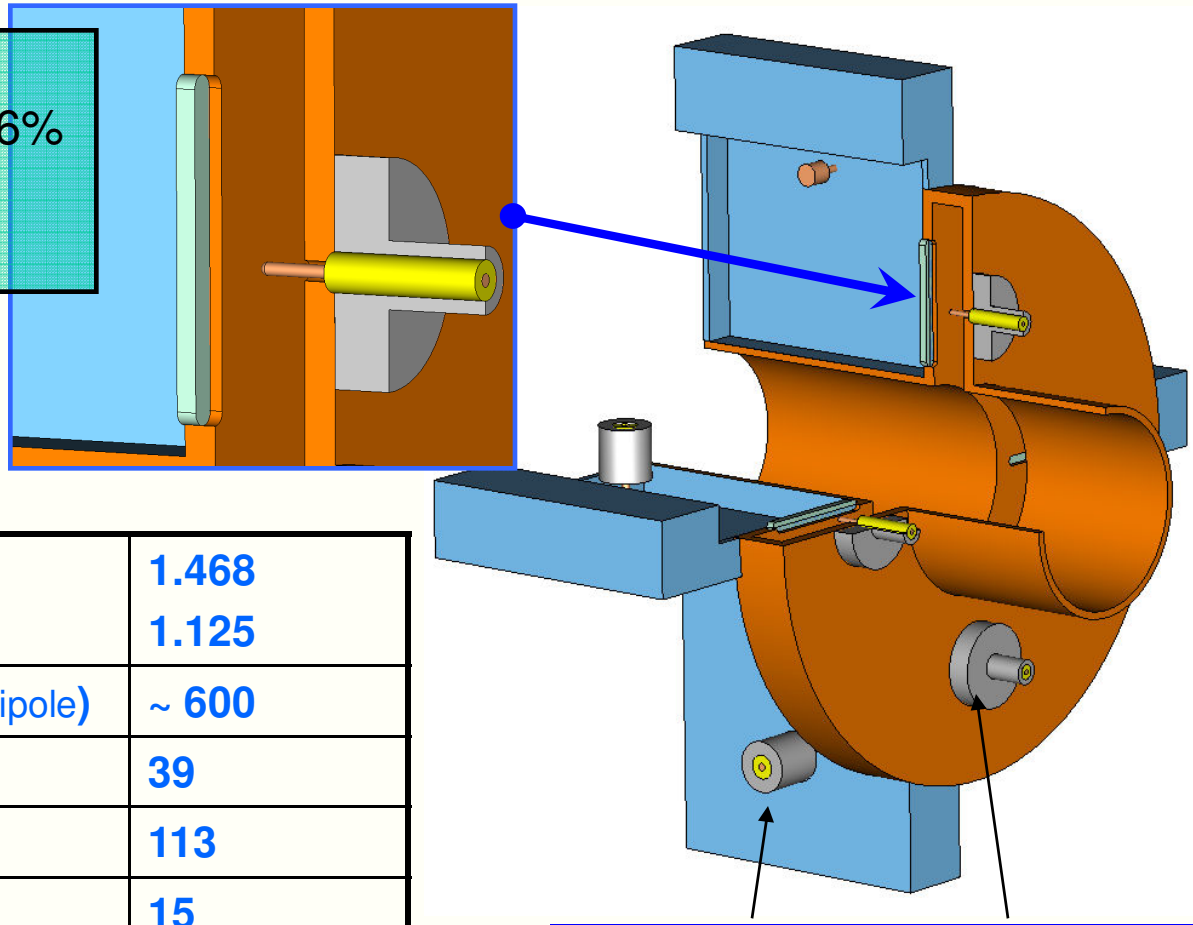
- Cold CM-free high resolution L-Band cavity BPM for an ILC cryomodule (type III+ or IV)
  - Only slow advances (not required for Fermilab's Project X)
  - 1st prototype ready for RF characterization this summer
    - "Warm" dimensions
    - Waveguide lids, feedthrough adapters, etc. in machine shop
- Cold "button"-style BPM for Project X and NML
  - ~25 µm bunch-by-bunch (~300 nsec spacing) resolution is sufficient.
- CLIC Main Linac X-Band cavity BPM proposal (with CERN)
  - EM design of CM-free dipole mode resonator and monopole mode reference cavity.
  - Design target: 100 nm spatial, 50 nsec time resolution.
- Analog / digital BPM read-out electronics (with KEK)
  - Flexible BPM system with single pass TBT (broadband) and high resolution narrowband filters
  - Upgrade installation this springtime at the ATF damping ring

Cold BPM for an ILC Cryomodule

- **ILC beam parameters, e.g.**
  - Macro pulse length t_{pulse} = 800 µs
  - Bunch-to-bunch spacing $\Delta t_b \approx 370$ ns
  - Nominal bunch charge = 3.2 nC
- **Beam dynamic requirements**
  - < 1 µm resolution, single bunch (emittance preservation, beam jitter sources)
  - Absolute accuracy < 300 µm
  - Sufficient dynamic range (intensity & position) and linearity
- **Cryomodule quad/BPM package**
  - Limited real estate, 78 mm beam pipe diameter!
  - Operation at cryogenic temperatures (2-10 K)
  - Clean-room class 100 and UHV certification

Fermilab L-Band Design

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

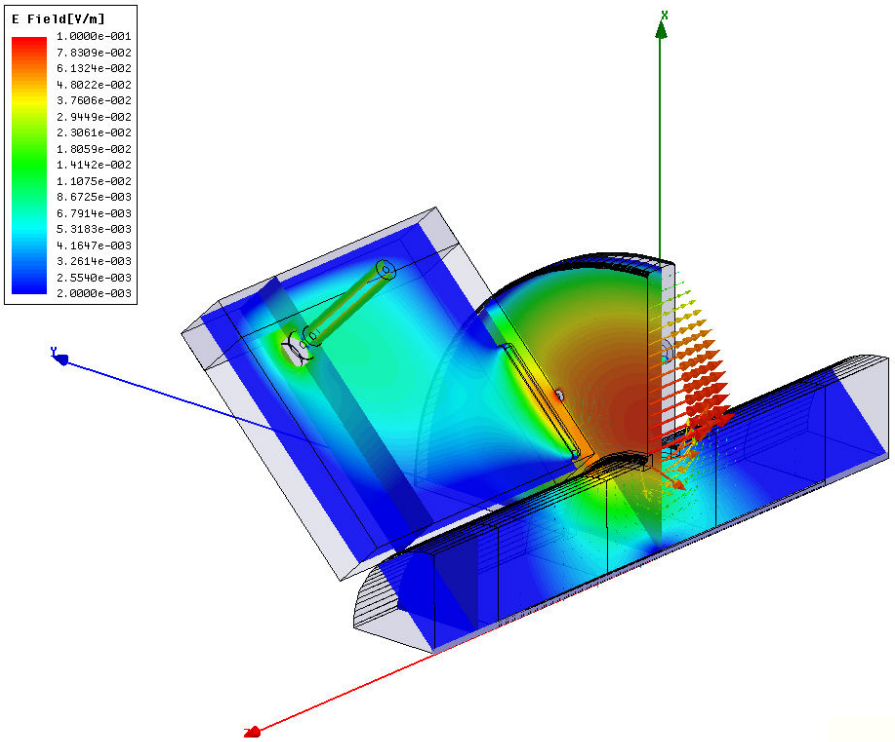


N type receptacles,50 Ohm

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**

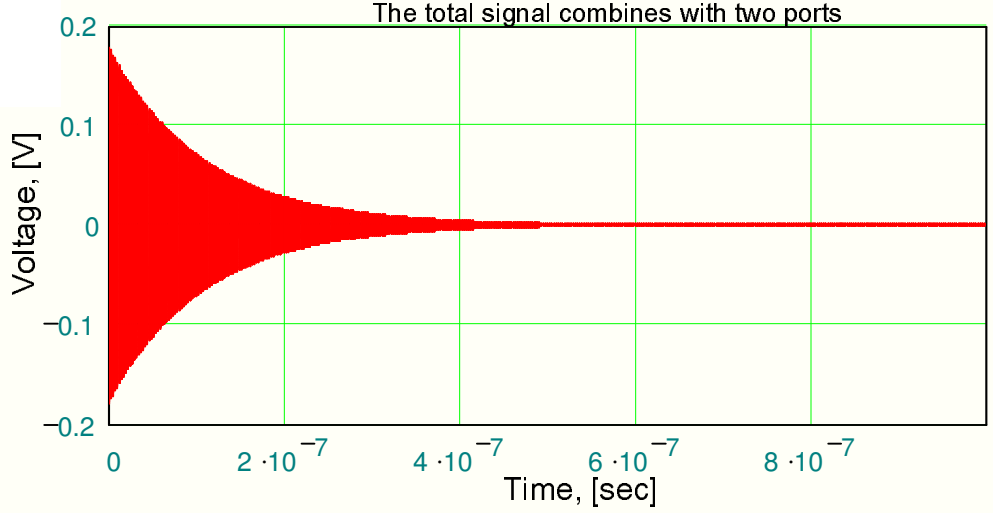
G.Romanov-FNAL

HFSS Simulations: Dipole Mode



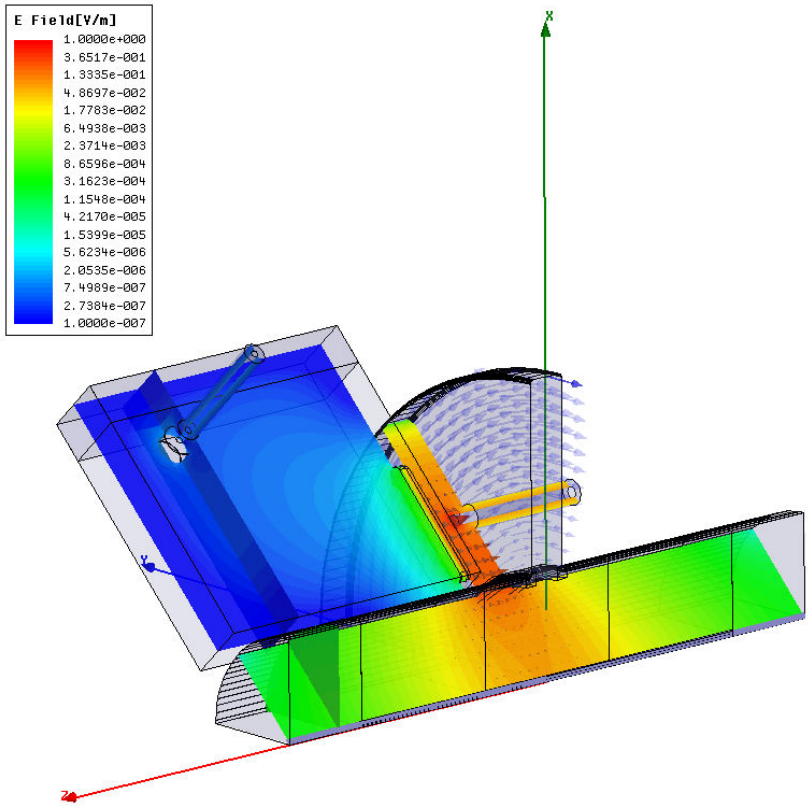
Frequency, [GHz]	1.480
Q, External Q, Surface (Cu) Q, Ceramic(AL_2O_3)	500 22000 5600
Test charge, [coulomb] (X=0, Y=1mm)	1E-9
Stored energy, [joule]	5.9e-11
Output Voltage at T=0*, [V]	0.24

* Normalized to 50 Ohm,
The total signal combines with two ports

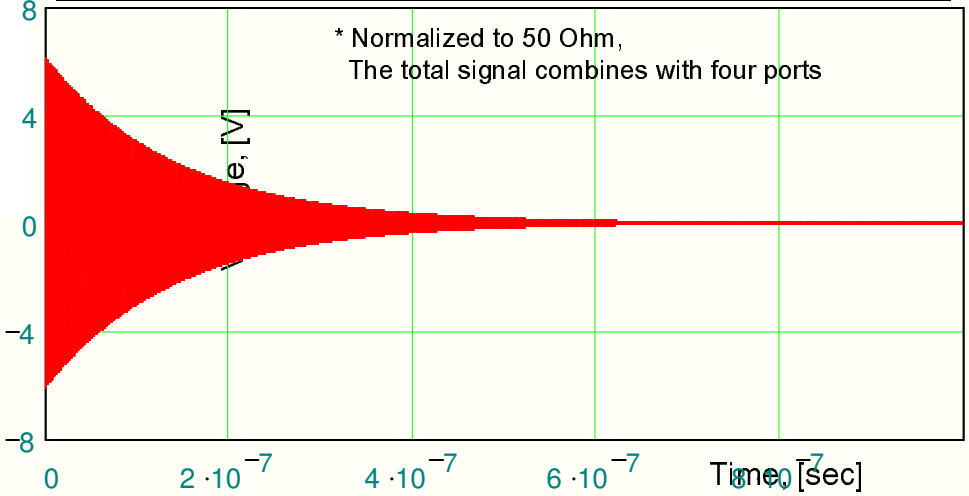


A.Lunin - FNAL

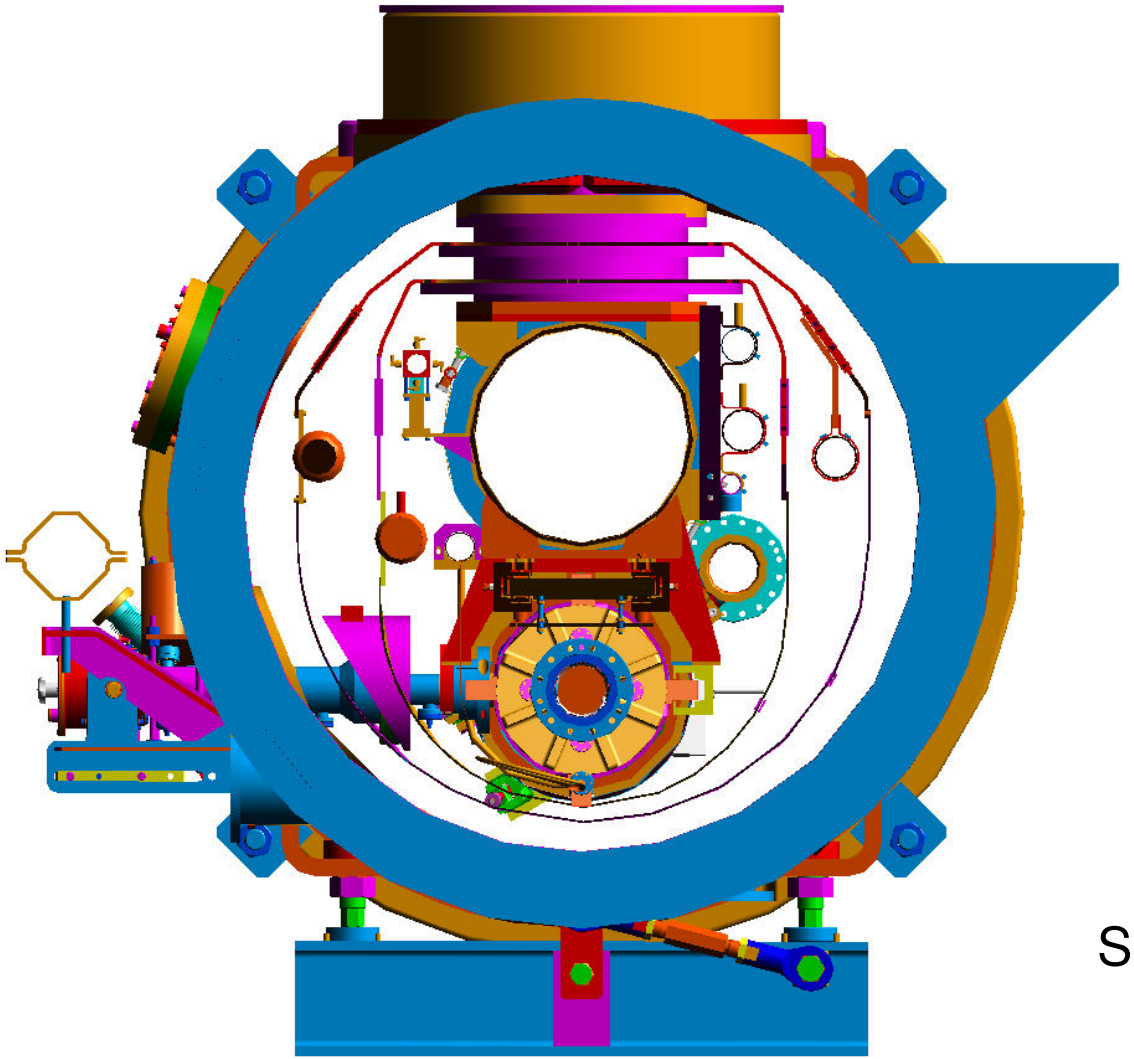
Simulations: Monopole Mode

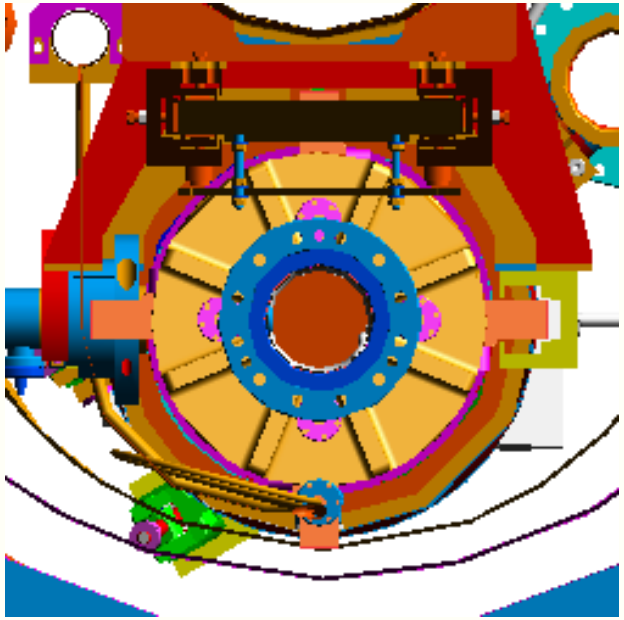


Frequency, [GHz]	1.120
Q, External Q, Surface (Cu) Q, Ceramic(AL_2O_3)	550 19500 7.9E6
Test charge, [coulomb] (X=0, Y=1mm)	1E-9
Stored energy, [joule]	6.1E-8
Output Voltage at T=0*, [V]	6.1
Coupling with TM_{11} port, Output Voltage at T=0*, [V]	5.6E-5



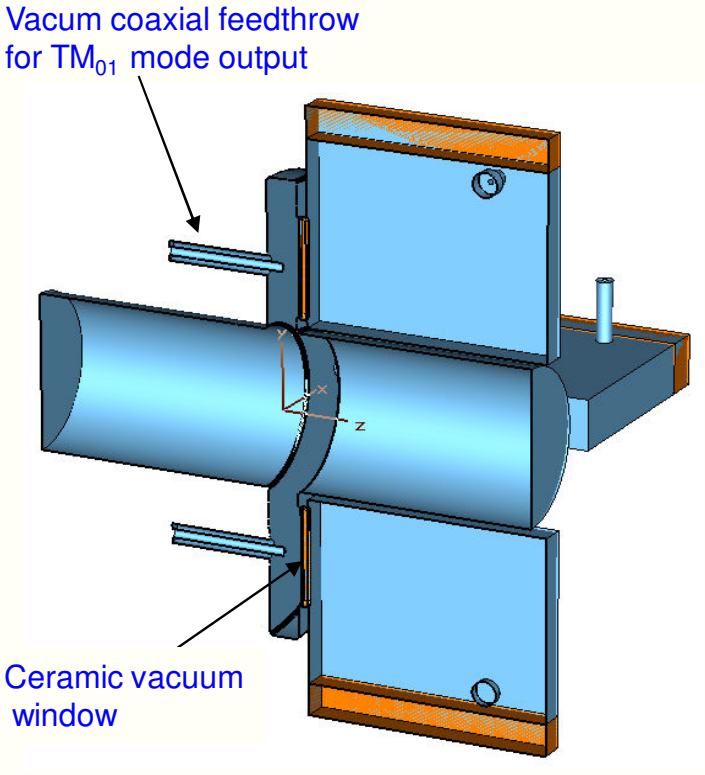
CM Type III+ BPM Real-Estate

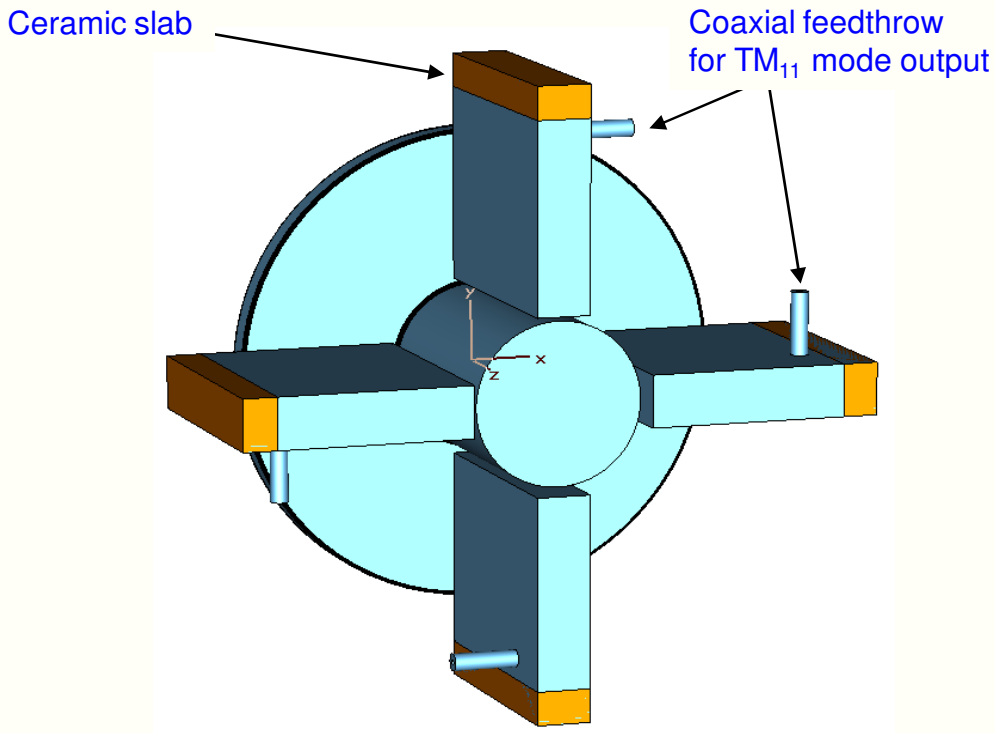




Section View showing BPM

Shortened Waveguides

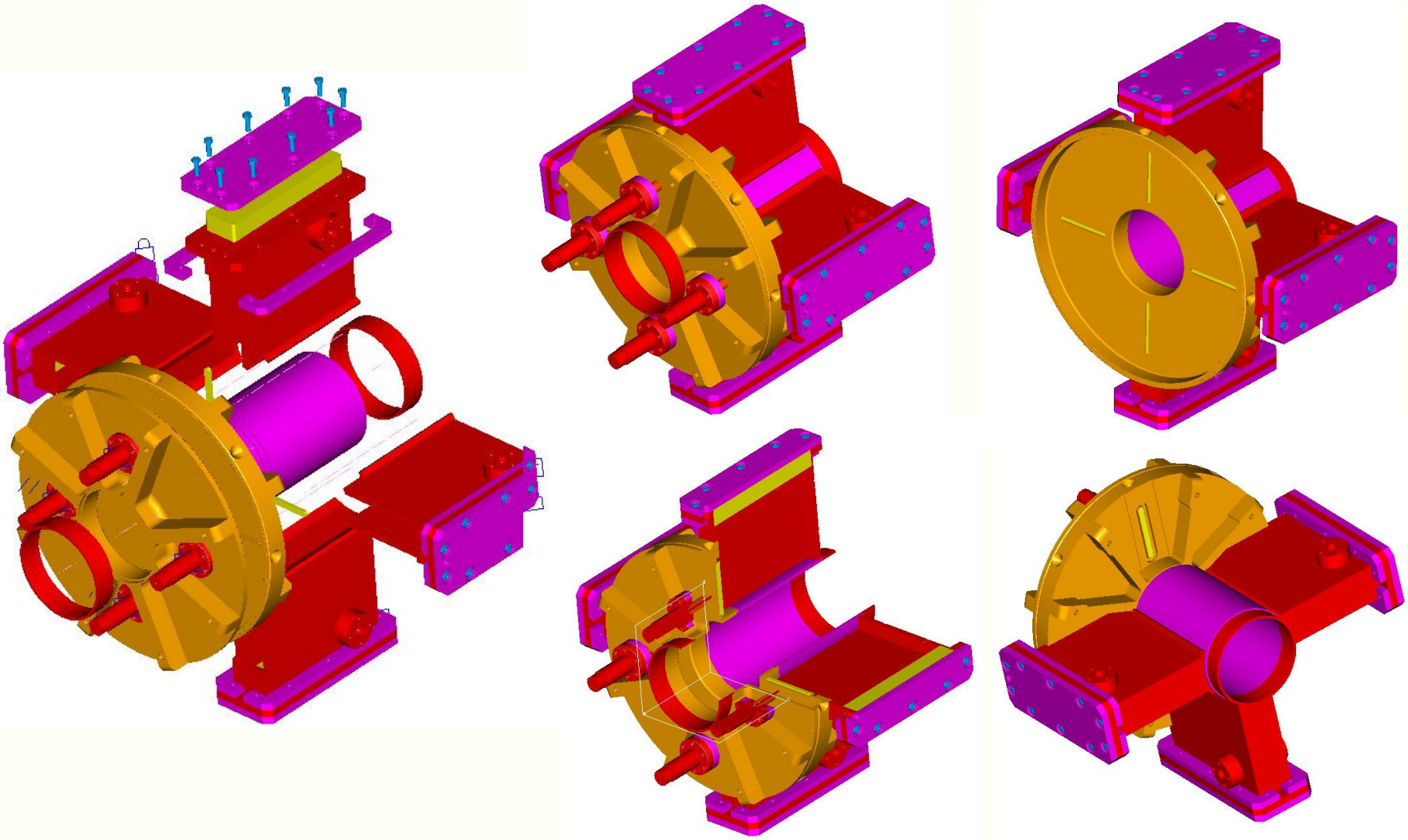


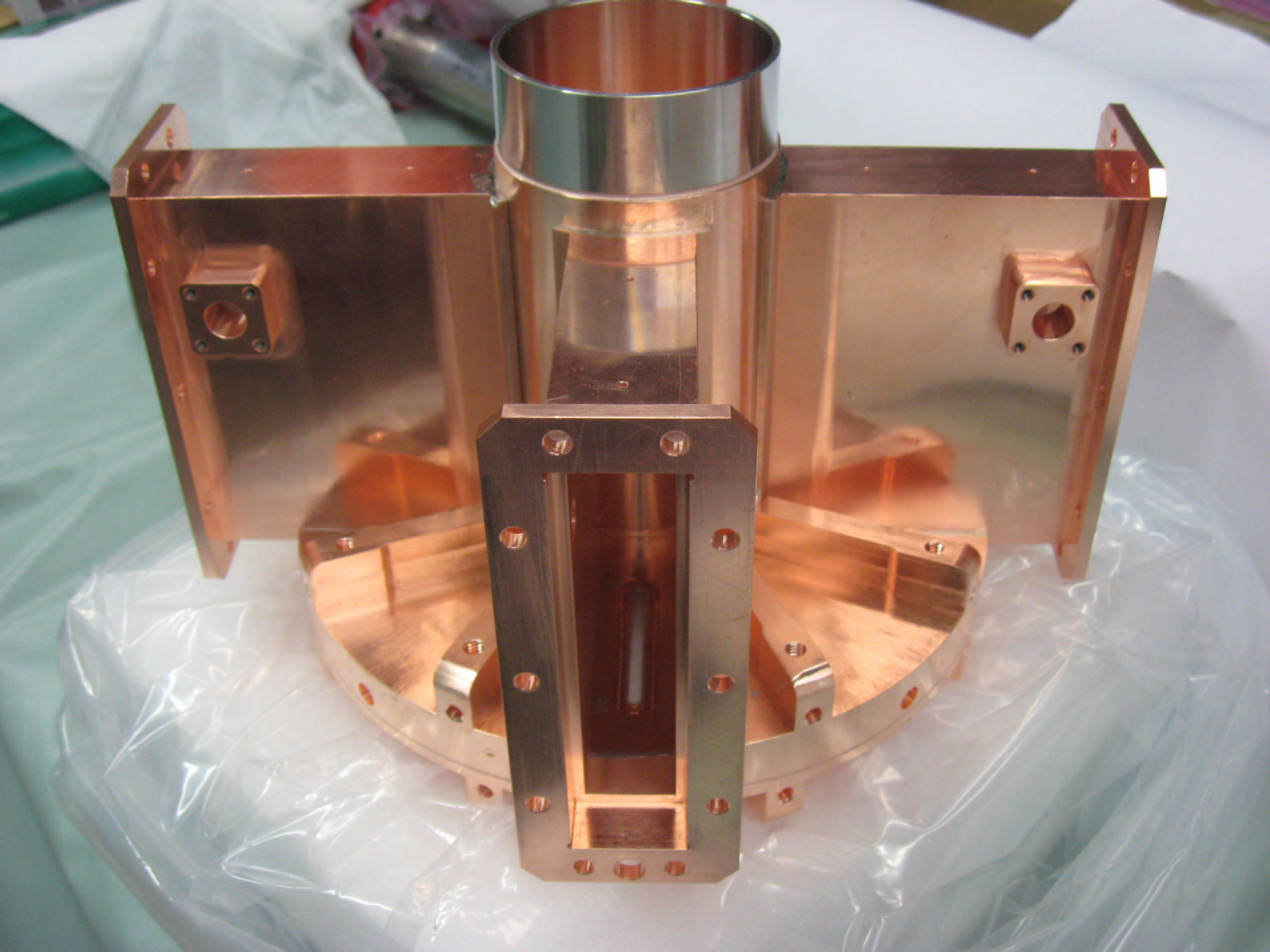


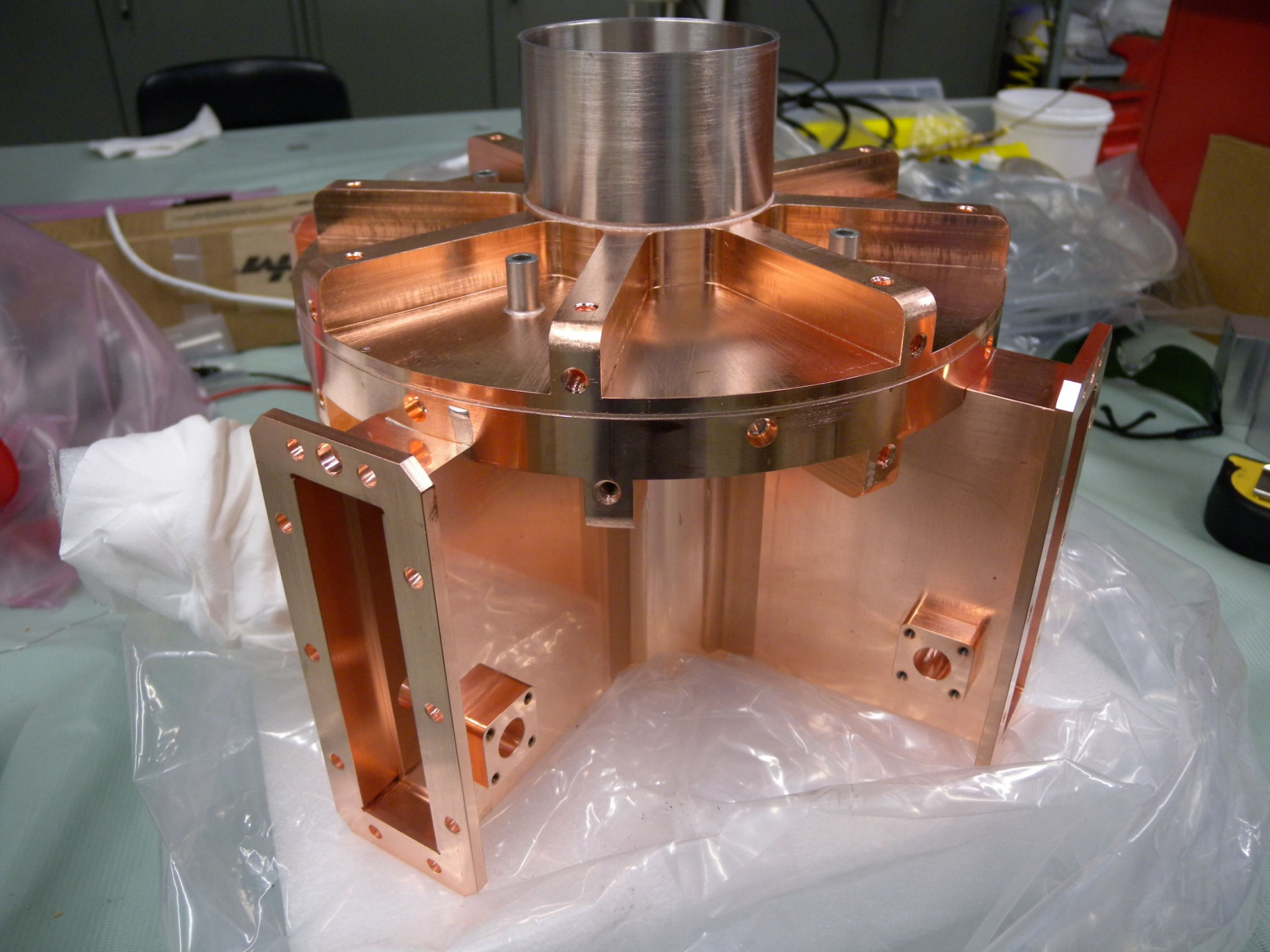
Cavity diameter: 113 mm
Gap length: 15 mm
Pipe diameter: 78 mm
Waveguide: 120 x 25 mm

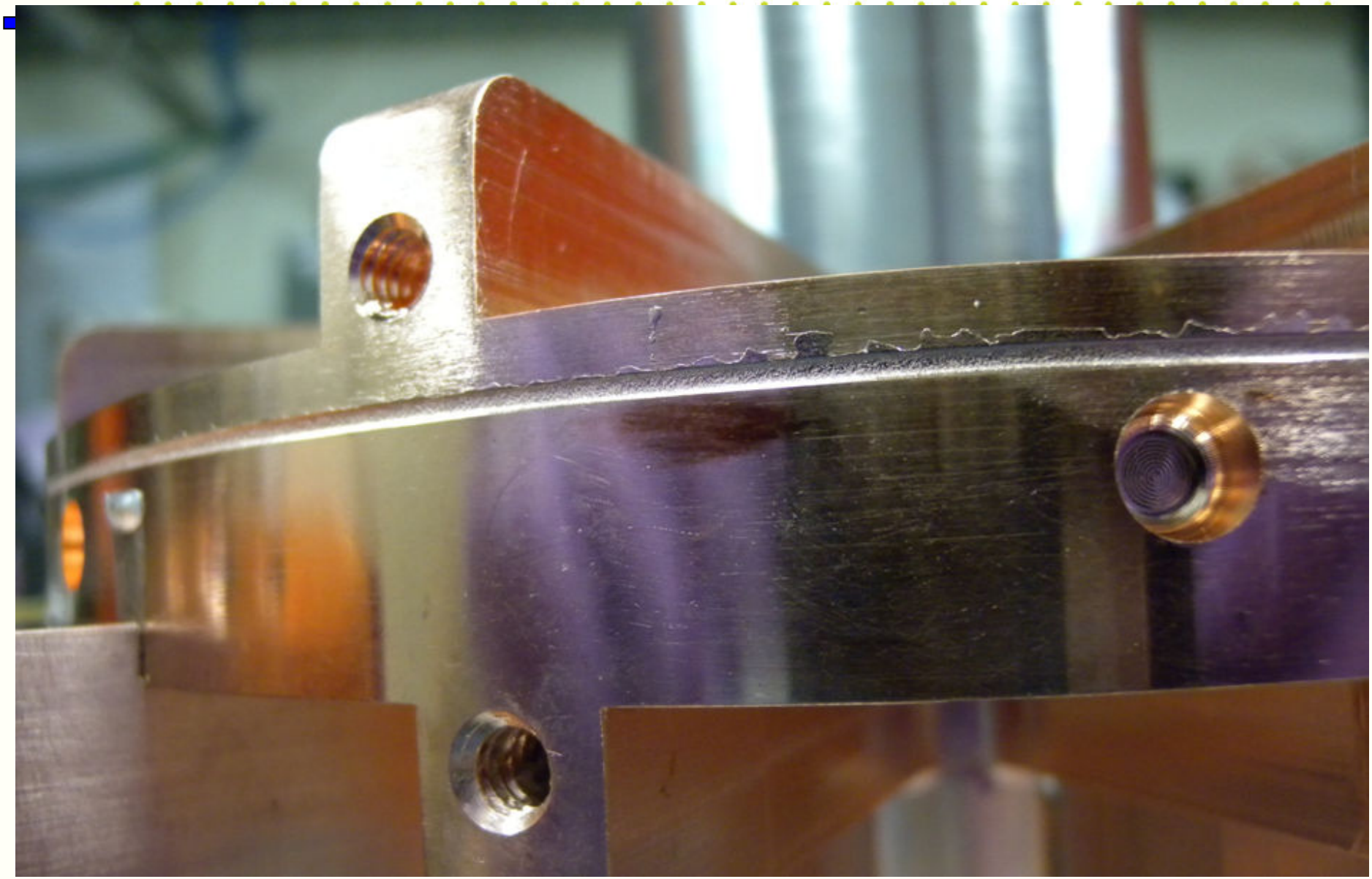
Features:
1. Ceramic (Al_2O_3) brazed vacuum windows
2. Common TM_{11} and TM_{01} cavity
3. Symmetrical signal processing
4. Time resolution: 1 μs (bunch by buch)
5 . Position resolution: < 1 μm (± 1 mm)

Construction Details





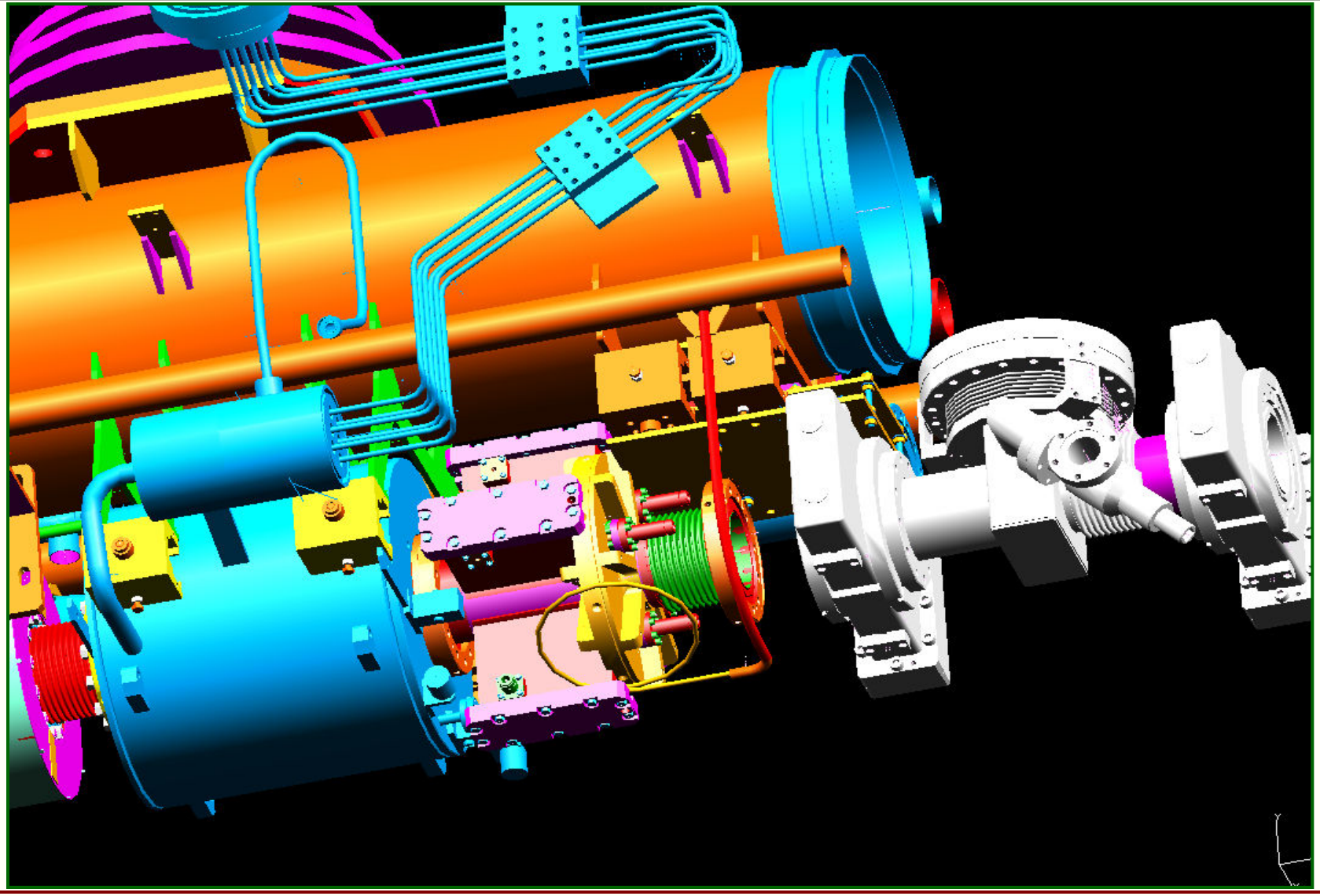




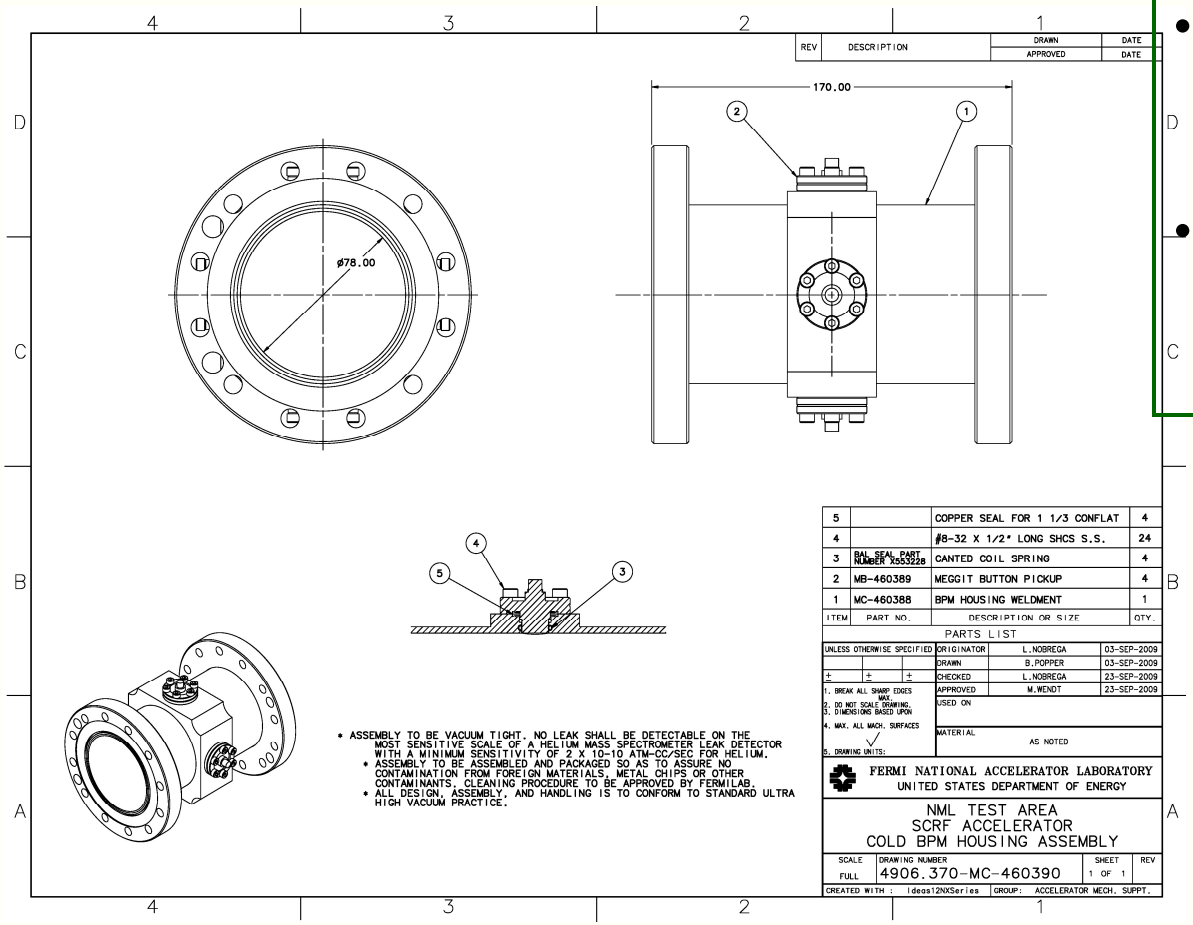
Status & Next Steps…

- All brazing procedures successfully completed!
  - The cavity BPM is vacuum tight!
- Finalize cavity BPM (this spring)
  - Waveguide lids, flanged adapters, etc. are in manufacturing process.
  - All other parts (feedthroughs, WG ceramics, etc.) are in hand.
  - Final assembly steps will follow immediately (April/May?!).
- Setup for RF measurements (this summer)
  - Check / tune resonant frequencies and Q-value
  - Tune to minimize xy cross talk (dimples)
- Complete BPM for beam tests
  - Weld beam pipe and flanges
  - Vacuum certification
- This prototype ILC cavity BPM has “warm” dimensions
  - To be tested in a warm accelerator environment, e.g. A0PI, ATF

Cold ILC BPM in a Type III+ CM



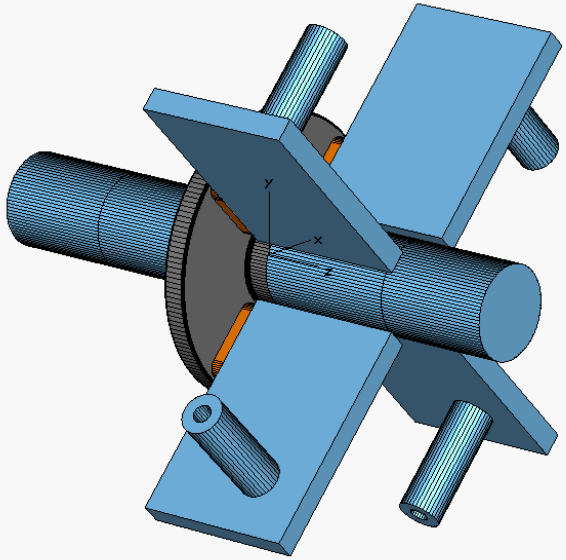
Cold Button BPM for NML CM2



- Version with 11 mm dia. buttons is in production (CM2)
- Version with larger button feedthroughs is under development.

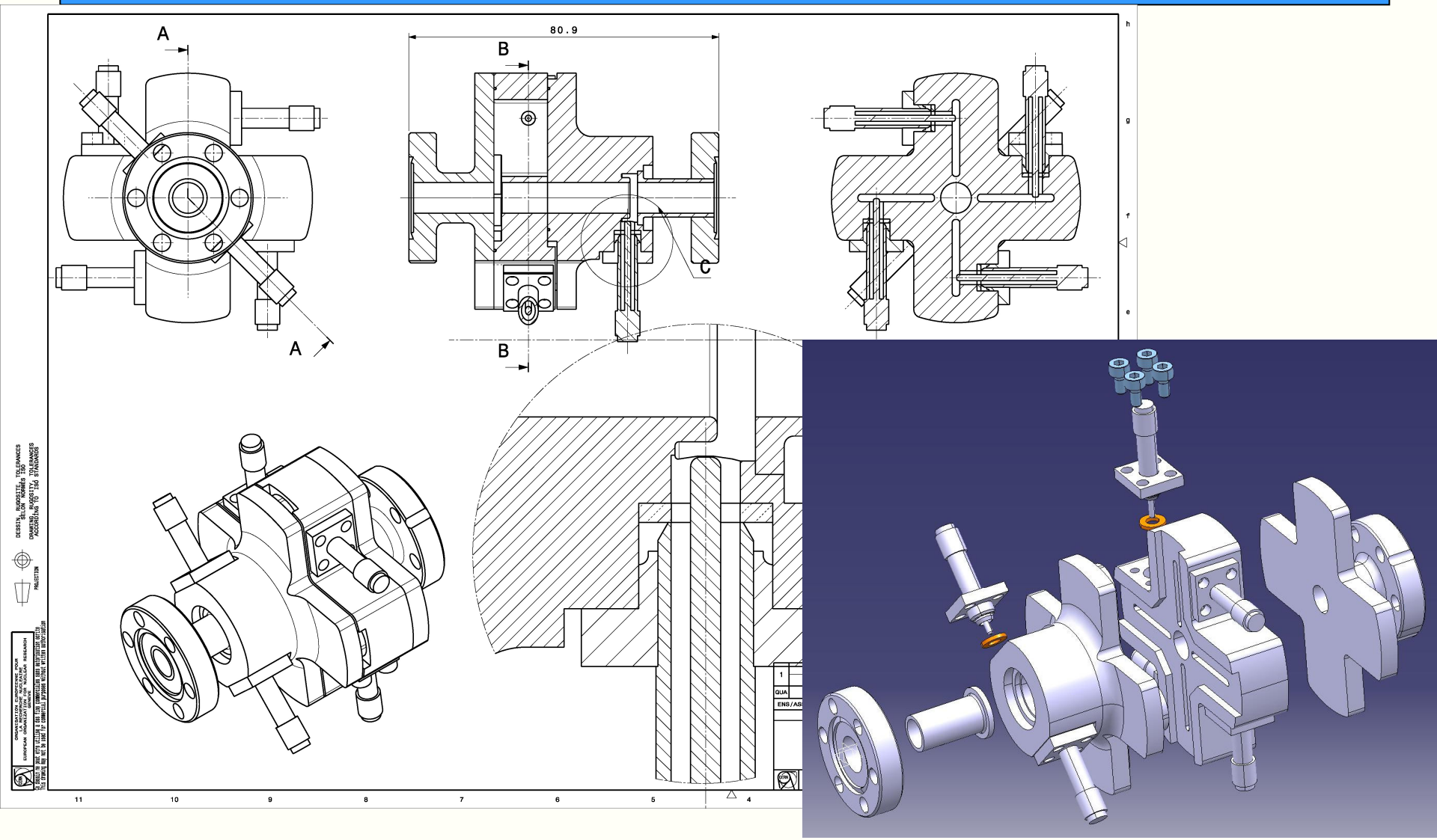
CLIC / CTF Main Linac BPM

	CLIC	CTF
Nominal bunch charge [nC]	0.6	?
Bunch length (RMS) [μm]	44	?
Batch length, bunch spacing [nsec]	156, 0.5	?, 0.333564
Beam pipe radius [mm]	4	4
BPM time resolution [nsec]	<50	<50
BPM spatial resolution	<0.1	<0.1
BPM dynamic range [μm]	±100	±100
BPM dipole mode frequency f_{110} [GHz]	14.0000	14.98962
REF monopole mode frequency f_{010} [GHz]	14.0000	14.98962
Number of BPMs	~4000 (!)	>3
Longitudinal real estate	<90 mm	na



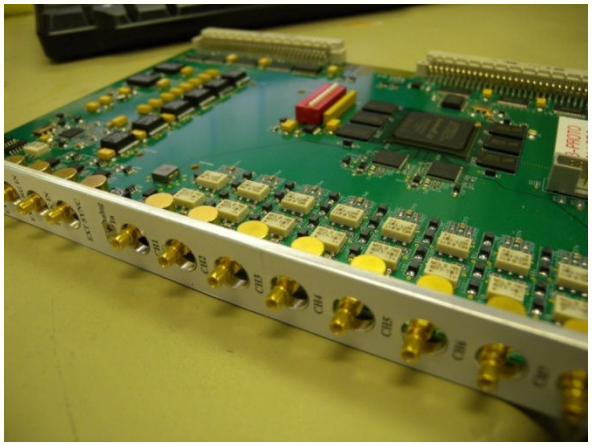
- **WG-loaded, low-Q X-Band design (Fermilab-CERN)**
  - **Q_l ~ 300, resonator material: 304 stainless steel**
  - **CTF prototype includes a monopole mode reference cavity (same frequency)**
  - **~50 nsec time resolution, <100 nm spatial resolution**
- **EM design, tolerances, signal characteristics, etc. finalized.**
- **CTF prototype mechanical design underway (see next slides).**

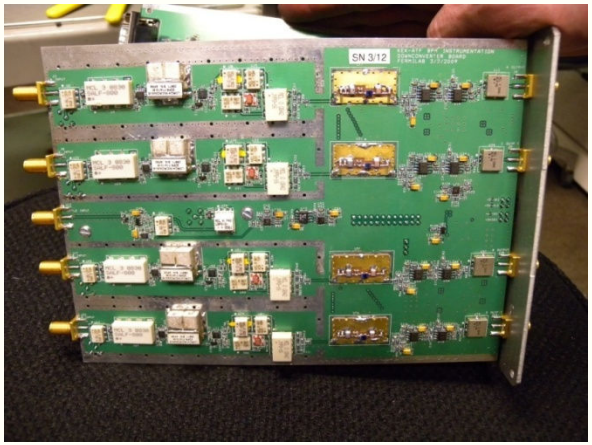
CTF Cavity BPM (preliminary!)

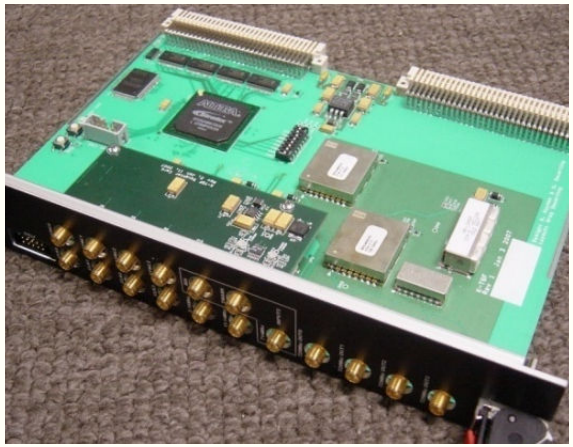


BPM Read-out System

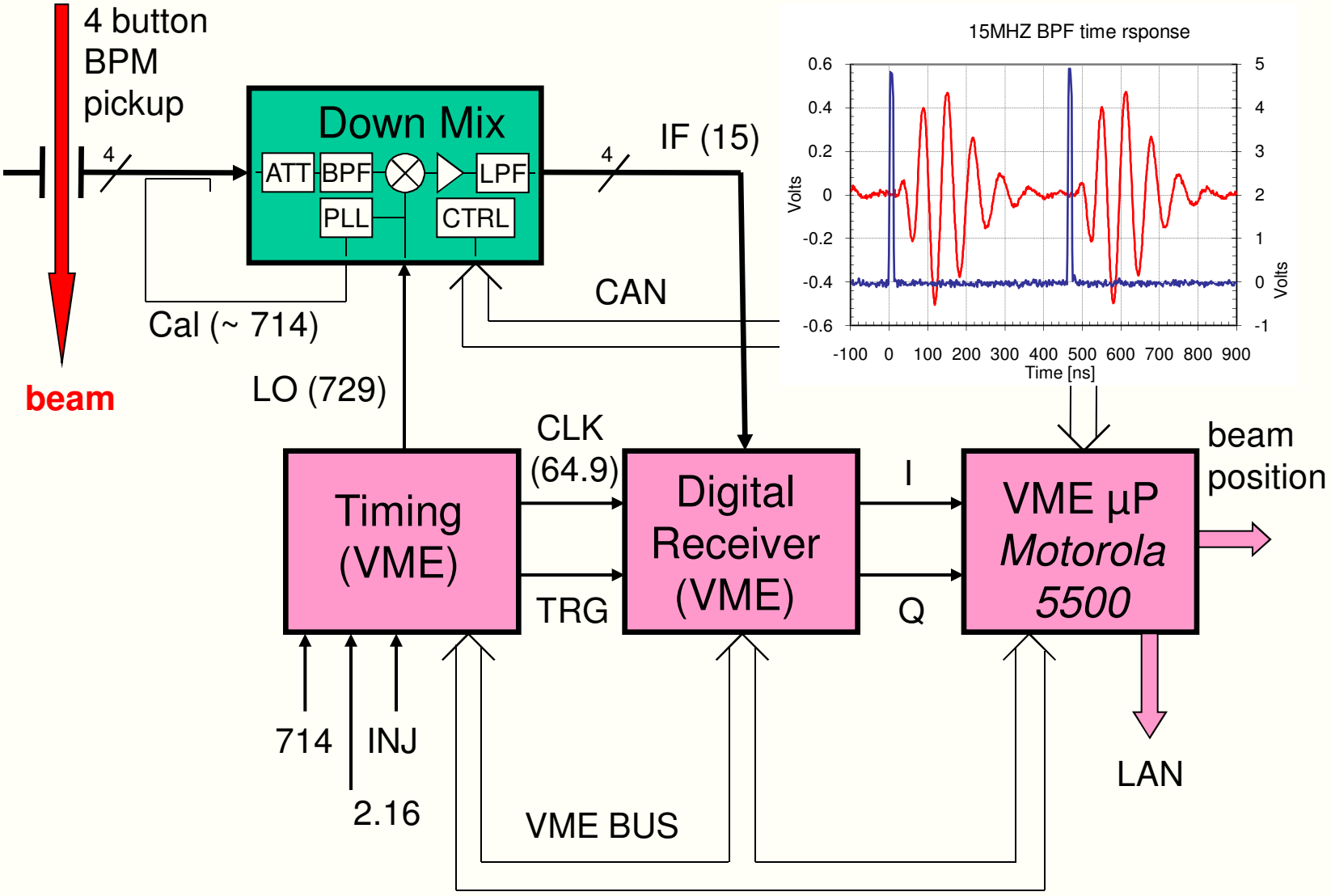
- Based on in-house developed analog & digital signal processing hard- and firmware
  - Implemented this June at the ATF damping ring (to a total of 96 BPMs)
  - Demonstrated <200 nm resolution (narrowband), <10 µm TBT resolution (broadband, ~400 nsec)
  - Integrated calibration system
- Modified versions to be applied for
  - Linac / transport-line button-style BPMs (electrons / hadrons)
  - Cavity BPMs, HOM signal processing, etc.







BPM Read-out Hardware (ATF)



Summary

- Fermilab continues instrumentation and diagnostics R&D for the ILC and other HEP accelerator projects.
- BPM activities include detector and read-out systems.
- The cold L-Band cavity BPM progress is very slow, but still moving!
  - We still plan for a beam test of the prototype.
- A X-Band cavity BPM R&D for the CLIC Main Linac has been initiated in collaboration with CERN
  - The prototype design operates at CTF bunch frequencies.
- ILC/LC collaboration activities are focused on the KEK ATF damping ring BPM upgrade project.
  - With minor modifications this read-out system can be applied to other BPM detectors and systems, also for HOM signals.