LCLS-II FPC Aluminum Waveguide Box

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with work done by Chris Nantista and Ken Premo
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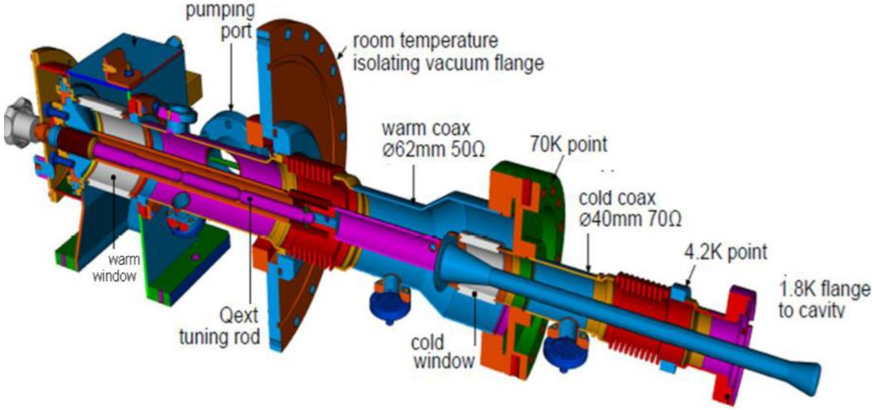
The FPC

The LCLS-II L-Band SRF cavity fundamental power coupler (FPC) is a complex device which must satisfy requirements in the following areas:

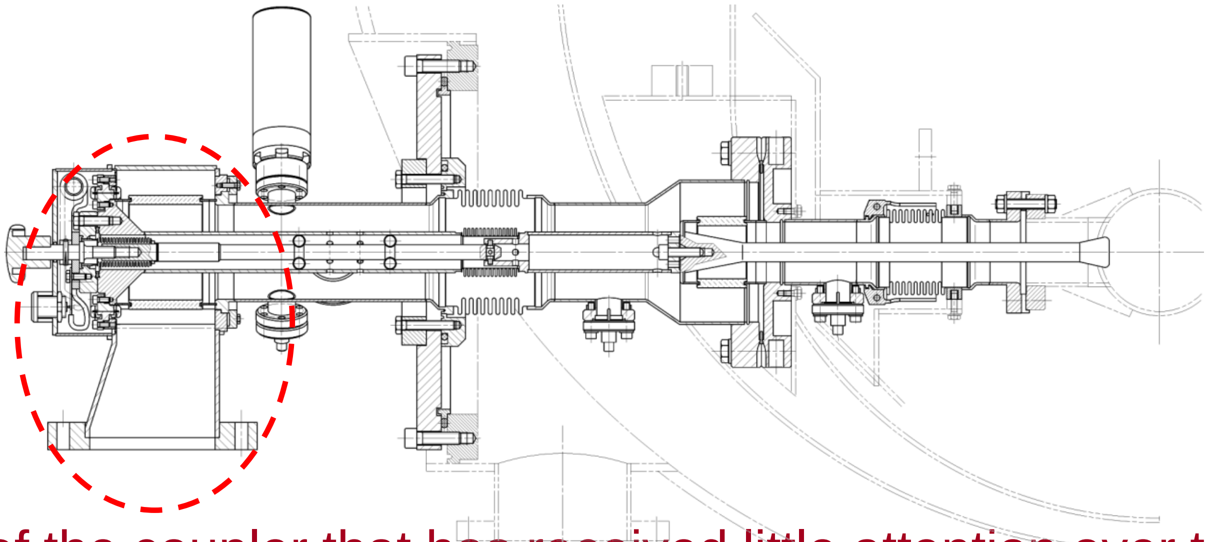


- RF
- mechanical
- cryogenic/thermal
- vacuum
- tunability

The adopted design, with minor modifications to adapt it for CW use and low beam current, is basically the mature one inherited from the TESLA / TTF3 / ILC / E-XFEL programs.

It brings RF power from its external waveguide feed interface, through a coaxial structure incorporating 2 RF vacuum windows and 3 bellows, to an antenna coupling to the evanescent field in the cavity beam pipe, deep inside the cryomodule.

Waveguide Box



One part of the coupler that has received little attention over the years due to its robustness is the *waveguide box*, a compact robust design

This is a compact piece of shorted waveguide, *tapered* down in height from its WR650 flange and matched with side *posts* through a cylindrical window and into the perpendicular warm coaxial section. Large holes in the top and bottom broad walls allow attachment of this section and the tuning mechanism of its center conductor.

Inspiration/Motivation

SLAC

Simple in appearance, the TTF3 waveguide box is a combination of 13 copper, stainless steel and brass pieces, brazed and soldered together, with walls of sheet metal.

Serge Prat of Orsay noted this was “the most expensive part” of the coupler.

As part of an industrial study, a different fabrication approach was explored – machining from a single block.

Despite a successful prototype, this change was not implemented.

Serge Prat, TTC08

LCLS II FPC Design Review Feedback

Design Review for LCLS II FPC held August 29, 2014

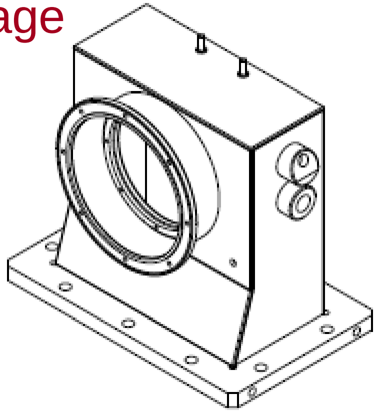
- At this review we stated "The change of the wave guide box (WGB) from soldered copper to aluminum machined part will be reviewed separately"

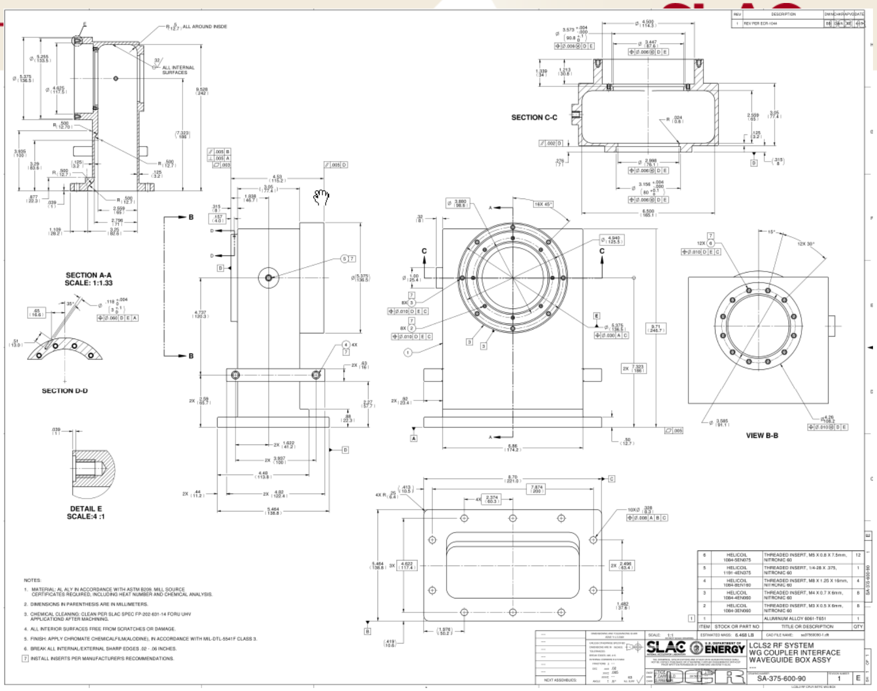
Review Recommendations Related to WGB:

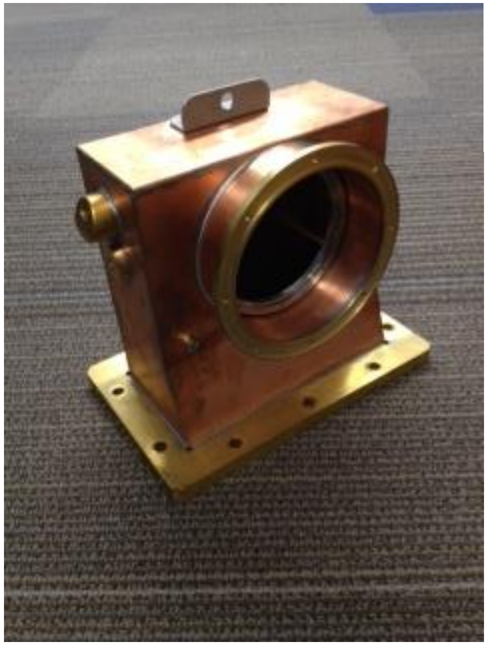
- The flex rings (capacity replacement) should be as flexible as possible. Especially when the aluminum WGB without the membrane is used. As the aluminum WGB is without any flexibility, removing the flex ring for a capacitor at a later stage will not be possible.
  - Response: Flex ring will utilize the existing Bowden design as implemented by XFEL. This is a fully annealed copper ring and is therefore a more flexible design.
- From the past experience the RF contacts between the WGBs and the warm coupler parts are critical. The improvement by the flex rings is sufficient for two contacts. The contact at the backside of the WGB should be also improved by changing the screw size from M4 to at least M5. The thickness of the flange at the WGB can be increased for higher connecting forces. In addition a soft copper seal of 0.3-0.5mm thickness would guarantee a perfect RF contact.
  - Response: Flange thickness was increased and screw size was increased to M5. RF contact tested with no leakage, additional copper seal was not required.
- The air cooling connections on the WGB are probably kept as an option. They should be at the right position. The highest losses at the warm ceramic are opposite to the WGB short, here the air connections are needed if any.
  - Response: Although we don't intend to use it, we kept this feature as part of the WGB assembly.

DESY Design vs LCLS II Design

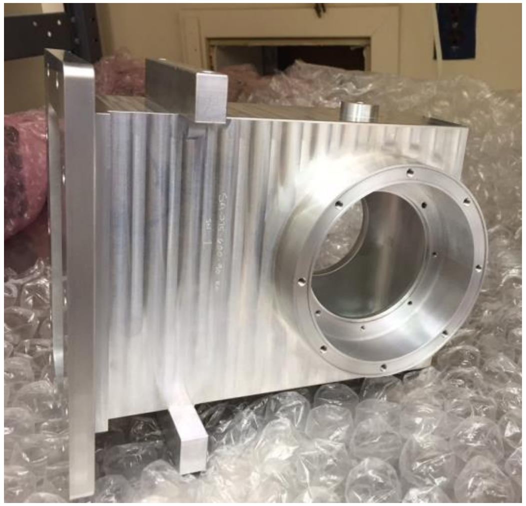
DESY design: Soldered copper sheet with brass flanges: expensive: possible misalignment, solder cracking and RF leakage



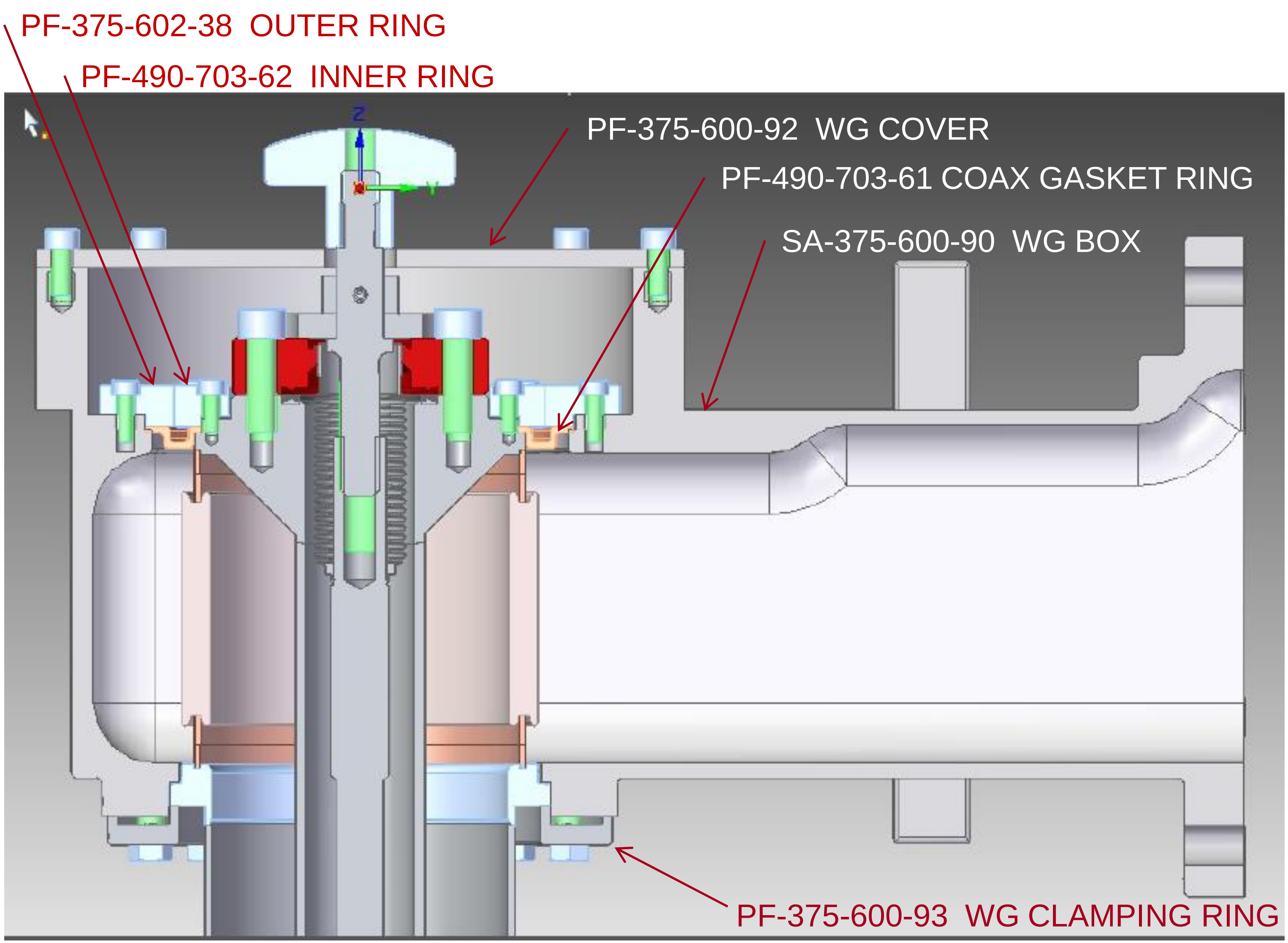


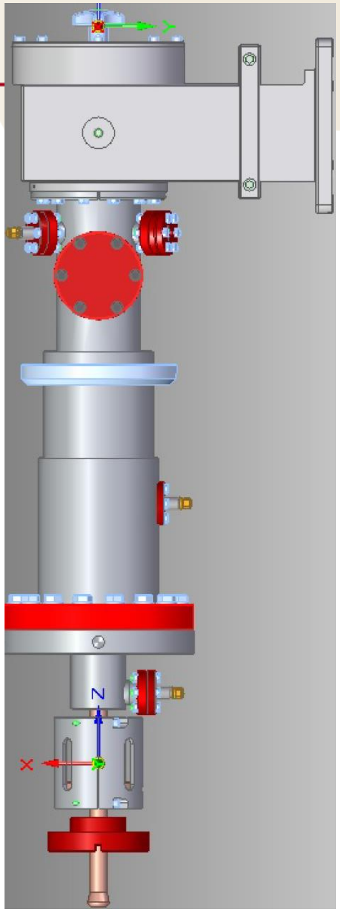


LCLS II design: Fabricated from single piece of Al, cost effective, allows for precision alignment, no RF leakage



WGB Assembly on Coupler: SA-375-602-37 WG COUPLER INTERFACE





Procurement Plan, Risks & Costs

- ✓ Confirmed manufacturability:
  - Fabricated, assembled and tested “pre-prototype” components
- ✓ Confirmed Vendor Capability:
  - Received responses to request for information from two vendors
- Prototype order for 16 with delivery required by late September
- Production order for 264 with delivery to match or exceed coupler deliveries
- Minimal risk-these are all “standard” manufactured components
  - Since these are all manufactured components we will place with single or multiple vendors as required to meet cost and schedule
  - Will provide vendor oversight, first article inspection and periodic inspections as required
- Costs for the WG Box and associated components
  - First two “pre-prototype” were about $7000 each
  - Sixteen prototype units will be about $4000 each
  - Production order of 264 will be about $3000 each

Waveguide Box Redesign

DESY waveguide box was designed with the fabrication method of sheet metal and posts in mind

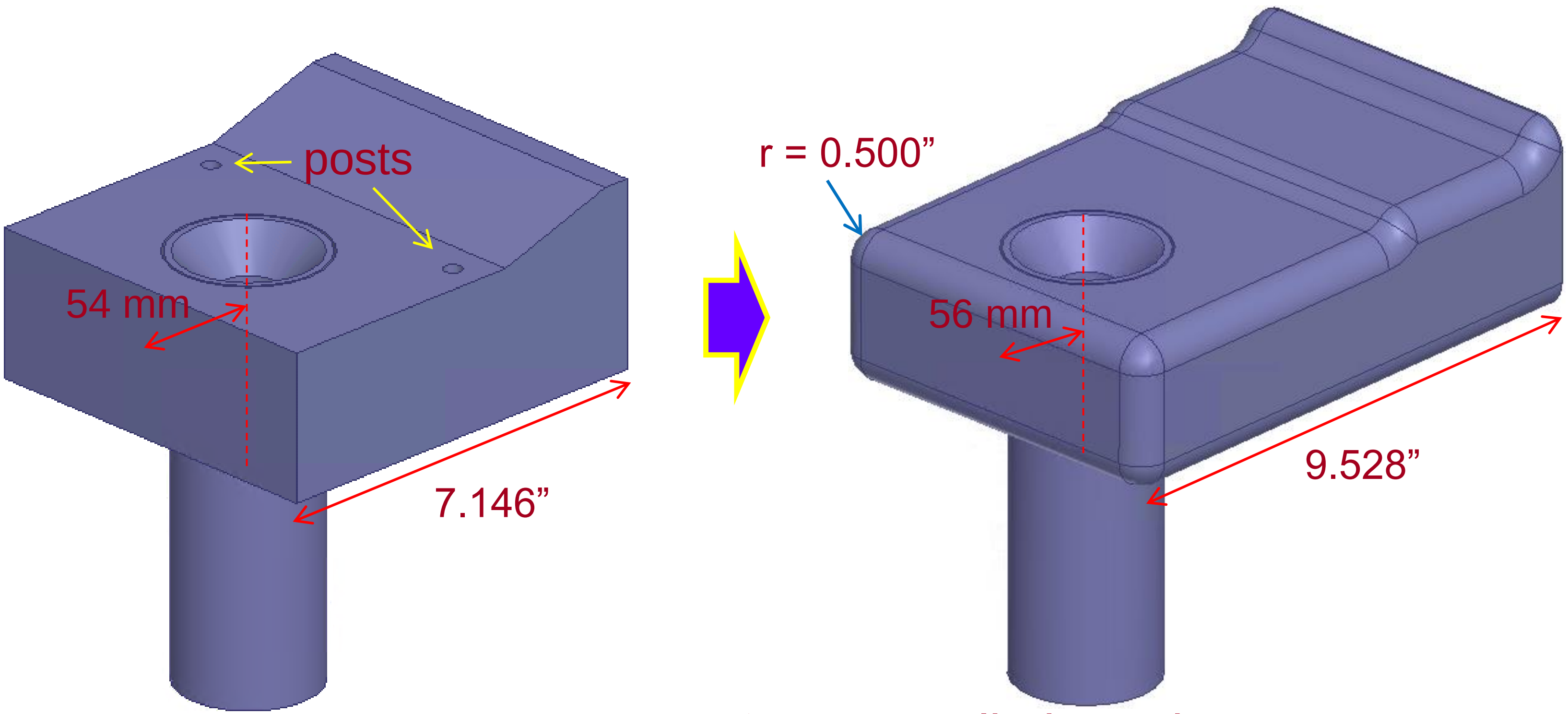
The mechanical details were impressively replicated in the machined model, but it could be made easier (cheaper) to produce in quantity if redesigned to accommodate this new fabrication method, *i.e.* if we applied the engineering concept of “design for manufacturability” (DFM).

Taking it back a step to RF design, there are different ways to match the waveguide-to-coax transition.

Specifically, we could eliminate the posts, sharp corners and the linear taper.

Geometry Comparison

OLD BOX NEW BOX

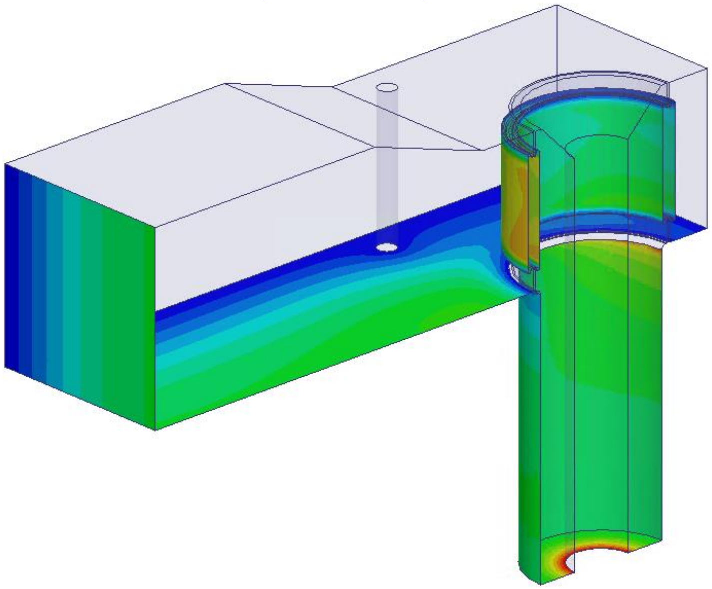


- posts eliminated
- height transition and matching achieved via a radiused double-step taper
- corners rounded to ½ inch

Simulated RF Performance Comparison

SLAC

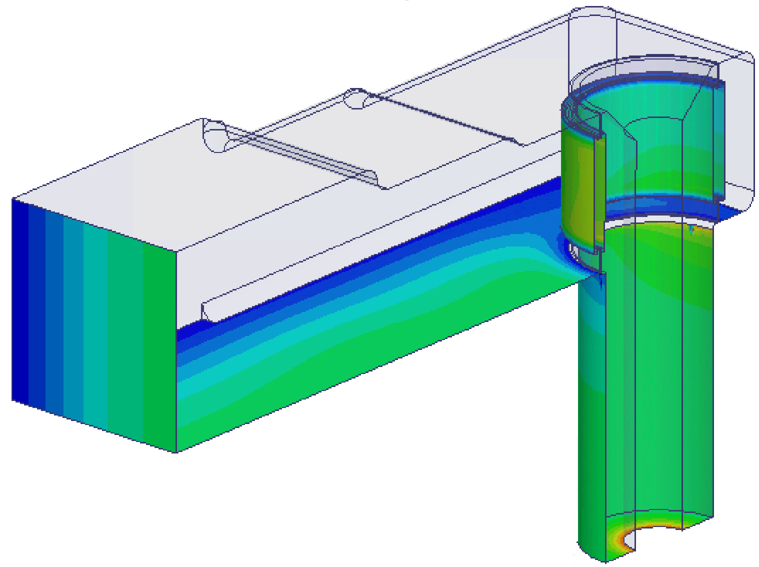
OLD BOX



Freq		S:1:1	S:2:1
1.3 (GHz)	1:1	(0.0033468, 50.1)	(0.99929, -178)
	2:1	(0.99929, -178)	(0.003435, 138)

return loss: 0.0011% (-49.5 dB)
transmission: 99.88%

NEW BOX

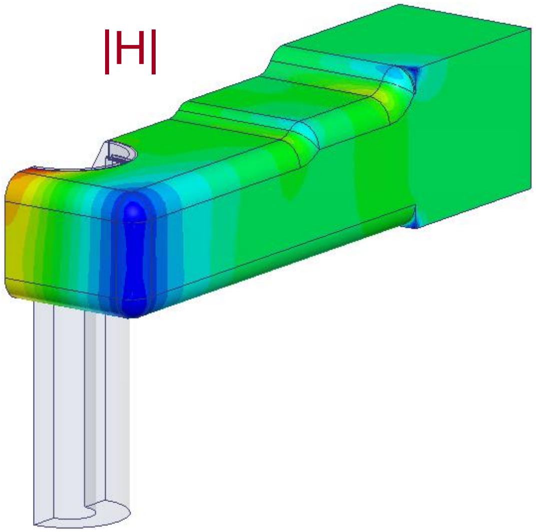


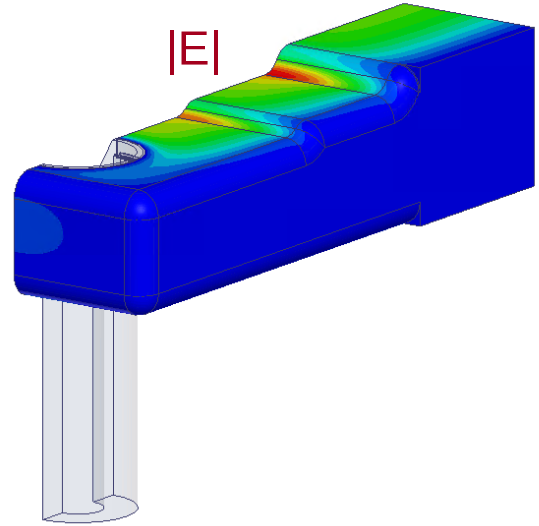
Freq		S:1:1	S:2:1
1.3 (GHz)	1:1	(0.0026504, -154)	(0.99926, -69.2)
	2:1	(0.99926, -69.2)	(0.0028221, -163)

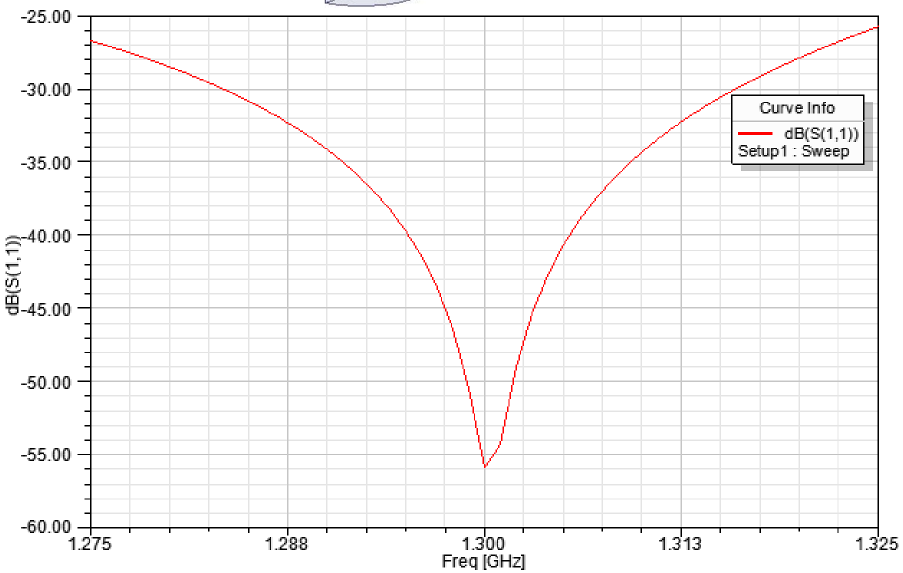
return loss: 0.0007% (-51.5 dB)
transmission: 99.85%

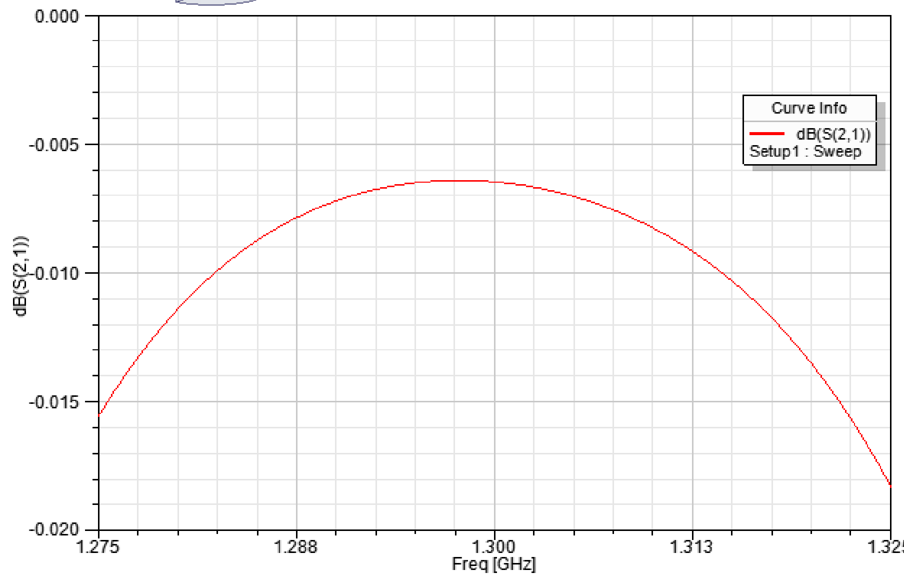
Quality of RF match into coaxial section reproduced.

Fields and Frequency Sweeps







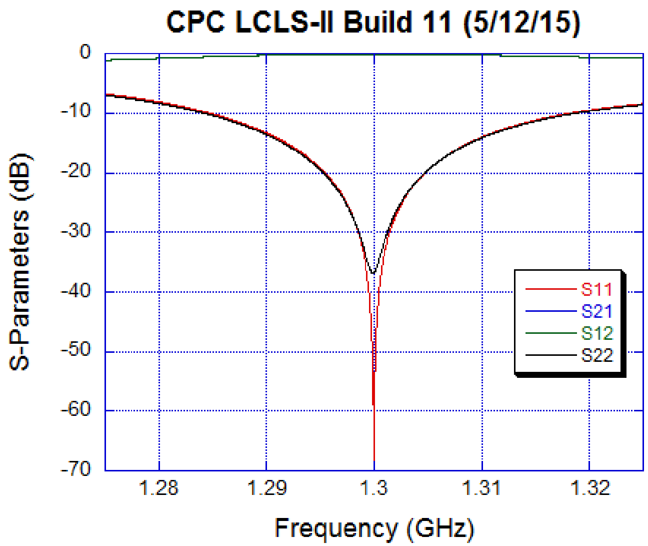


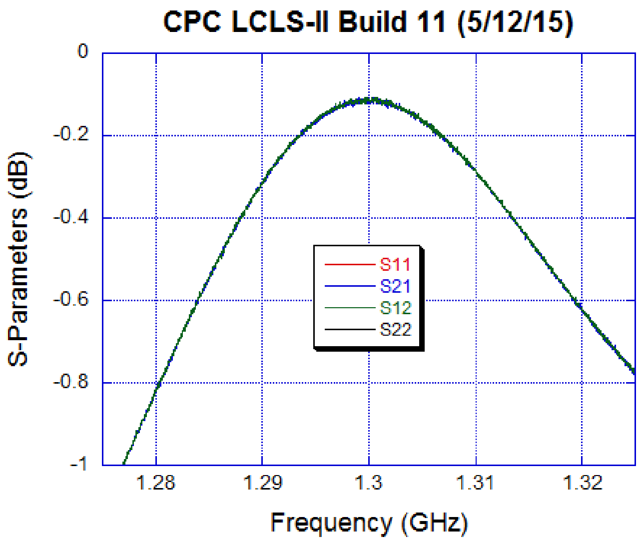
CPC Tuning Cold Test Comparison

Old WG Box

@ 1.3 GHz

$|S_{11}|$: -62.8 dB
$|S_{21}|$: -0.109 dB
$|S_{12}|$: -0.115 dB
$|S_{22}|$: -36.7 dB

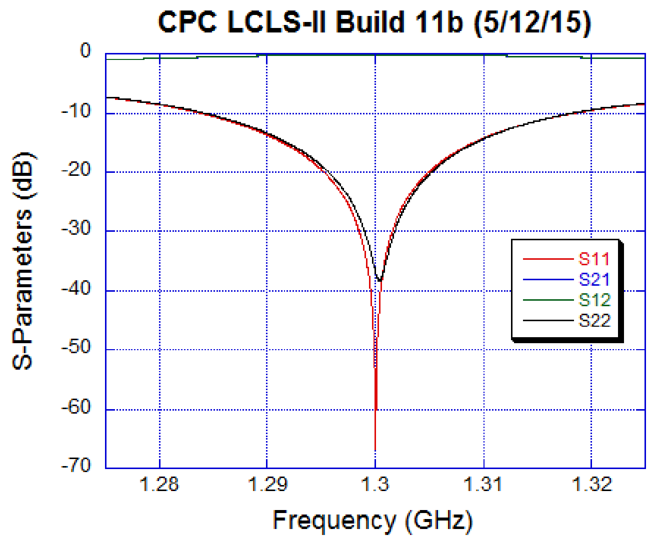


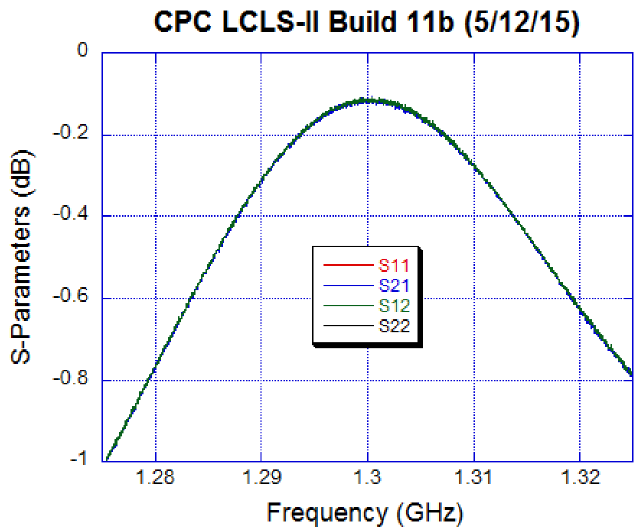


New WG Box

@ 1.3 GHz

$|S_{11}|$: -66.7 dB
$|S_{21}|$: -0.118 dB
$|S_{12}|$: -0.117 dB
$|S_{22}|$: -36.9 dB



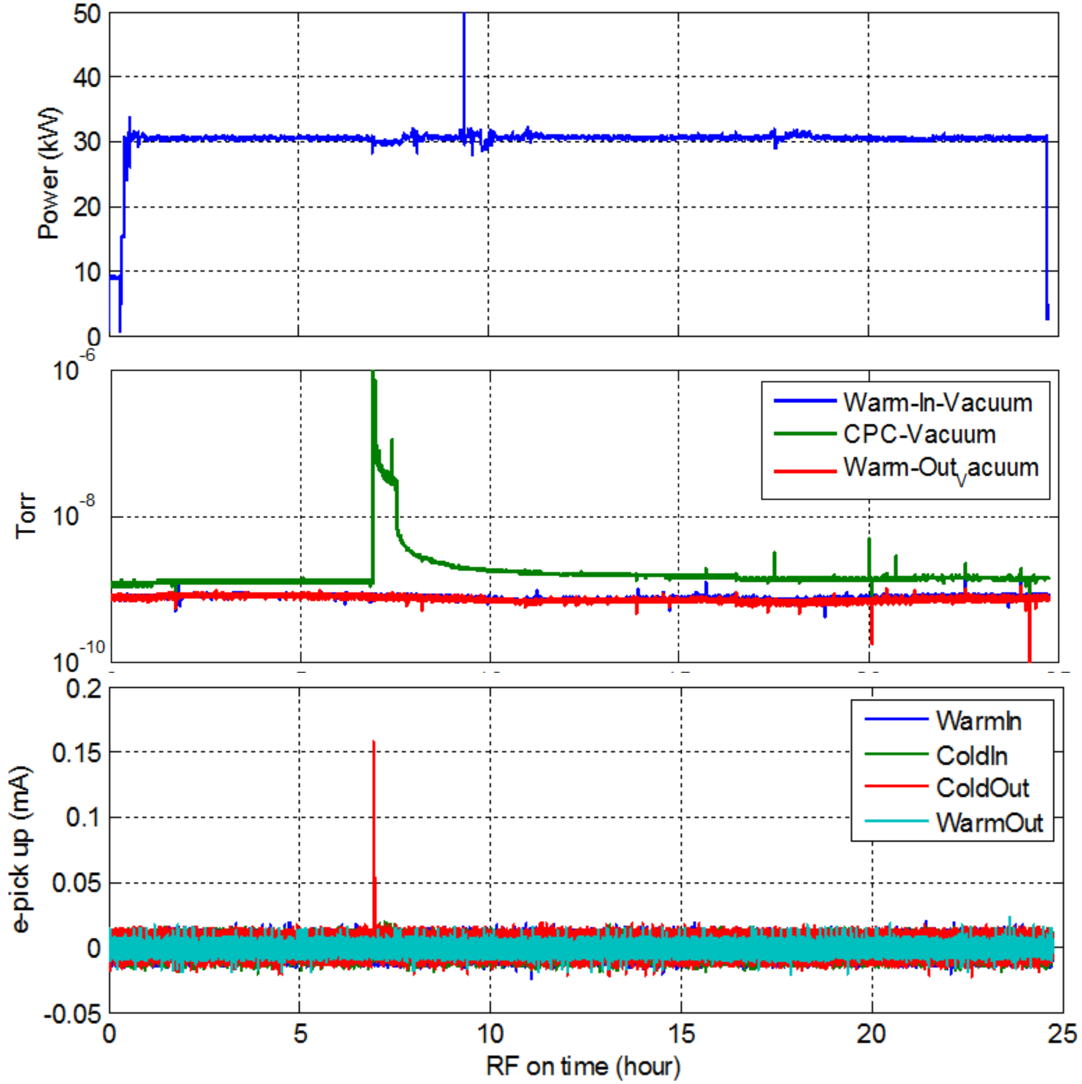


CPC High Power Test

SLAC

High power RF testing of coupler pair w/ new boxes successfully completed without trouble.

No RF leak detected during run.



Faya Wang

Waveguide box integration into cryomodule

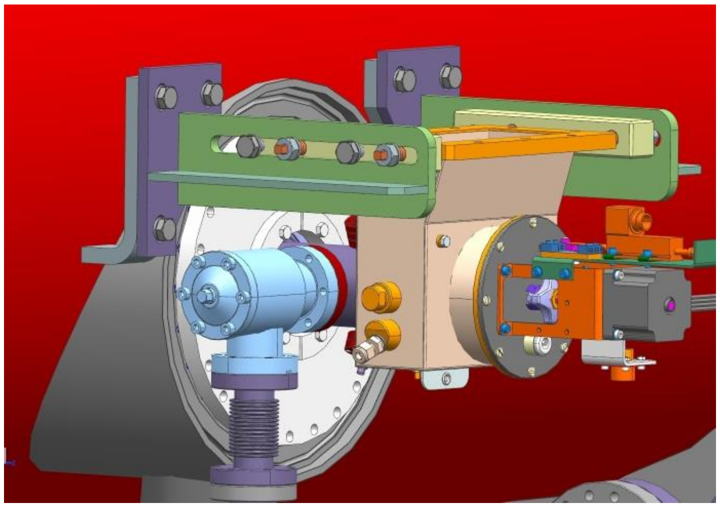
SLAC

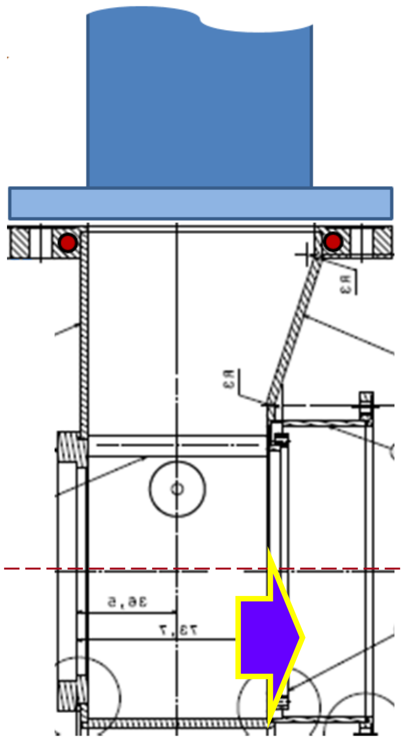
Solid model of WG provided by SLAC was assembled to FNAL cryomodule model in order to identify problems with new design

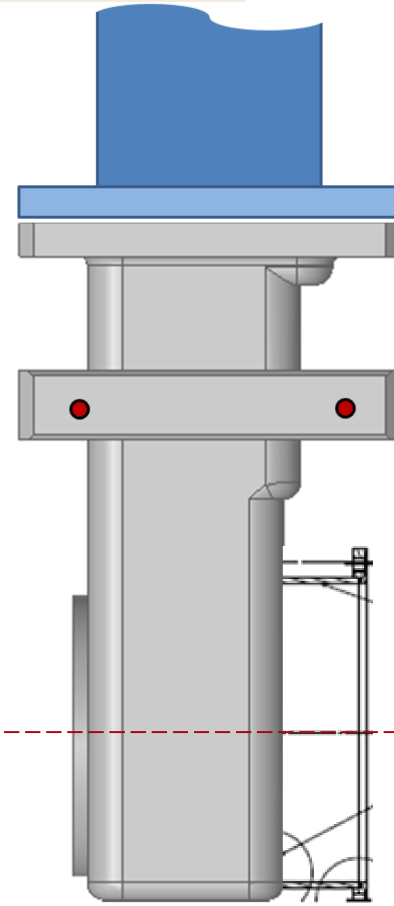
Interfaces to Cryomodule

- Attachment to support brackets
  - Holes in waveguide align with support axles
- Attachment to Coupler warm end
  - Back of waveguide appears to fit without interference (gasket needed?)
  - Front of waveguide (coax gasket ring) appears to fit without interference
- Installation
  - No changes needed for installation procedure, same as previous WGs
  - Motorized tuner will be used for test stand, no issues with WG
- Clearance
  - No clearance issues identified by visual inspection of modeled assembly
- No issues identified with installation

Mechanical Bracing to Cryomodule



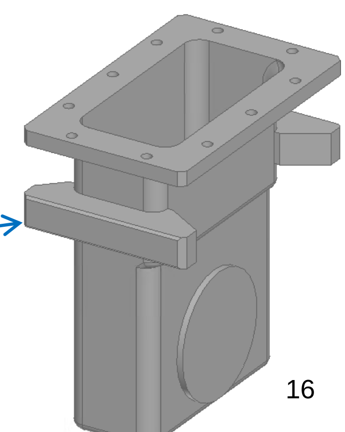




Easier to make up flange connection.

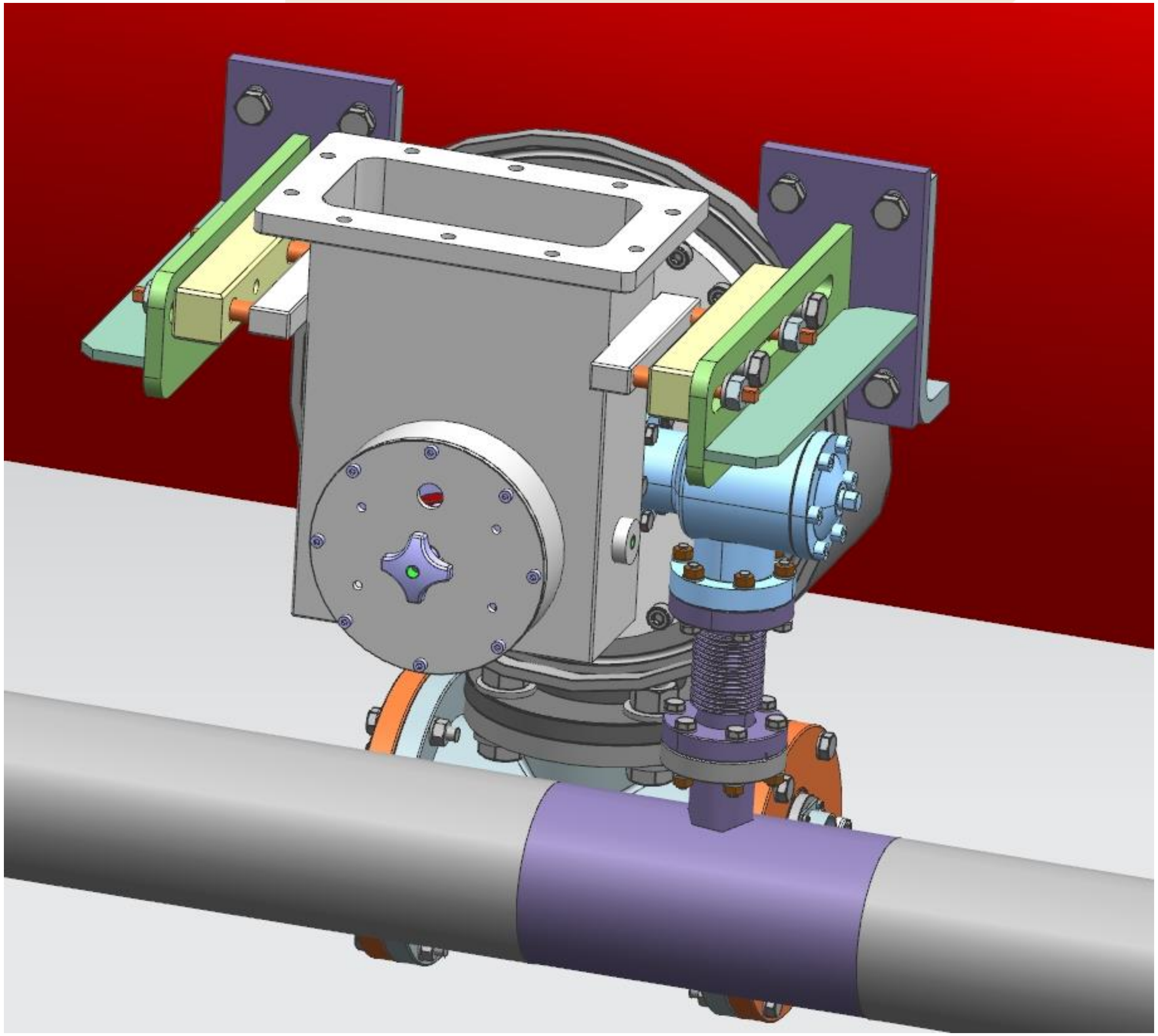
cryomodule support brace interface

Old box attached to CM braces via tapped holes in flange edge.

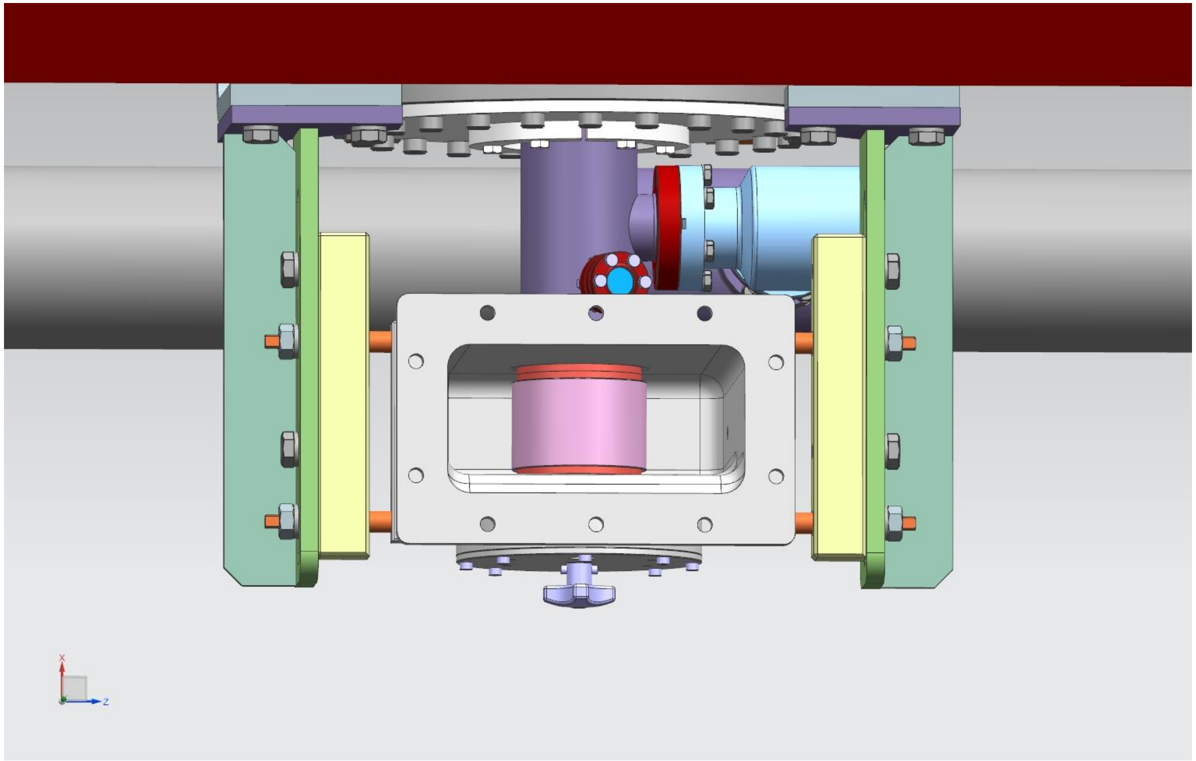


Added length allows incorporation of special brackets in new box for more stable bracing and clearer flange access.

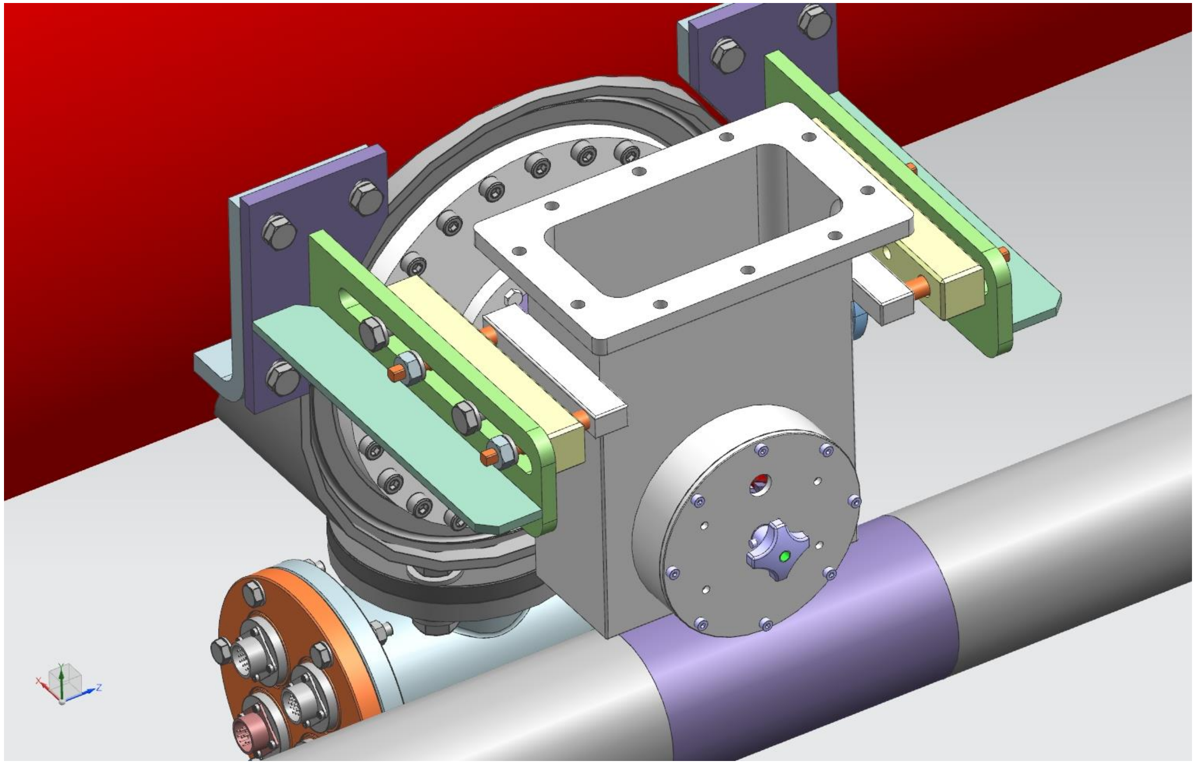
Overall view of assembly



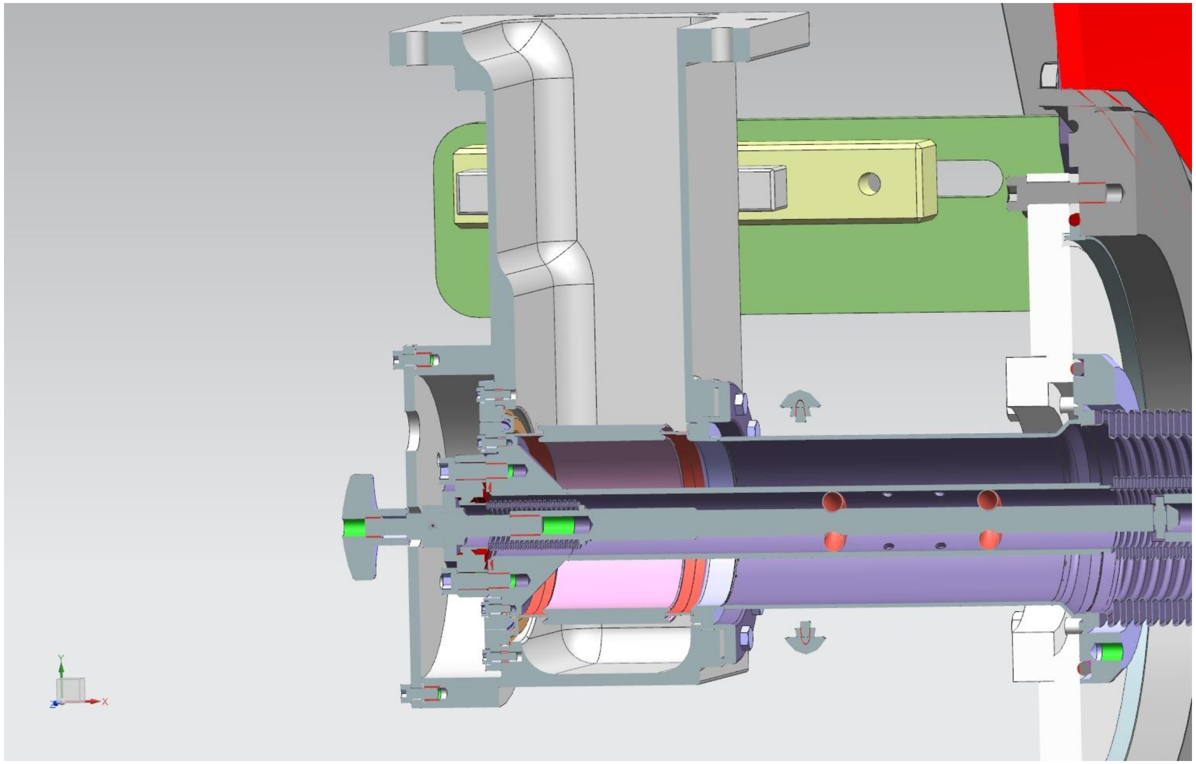
Assembly top view



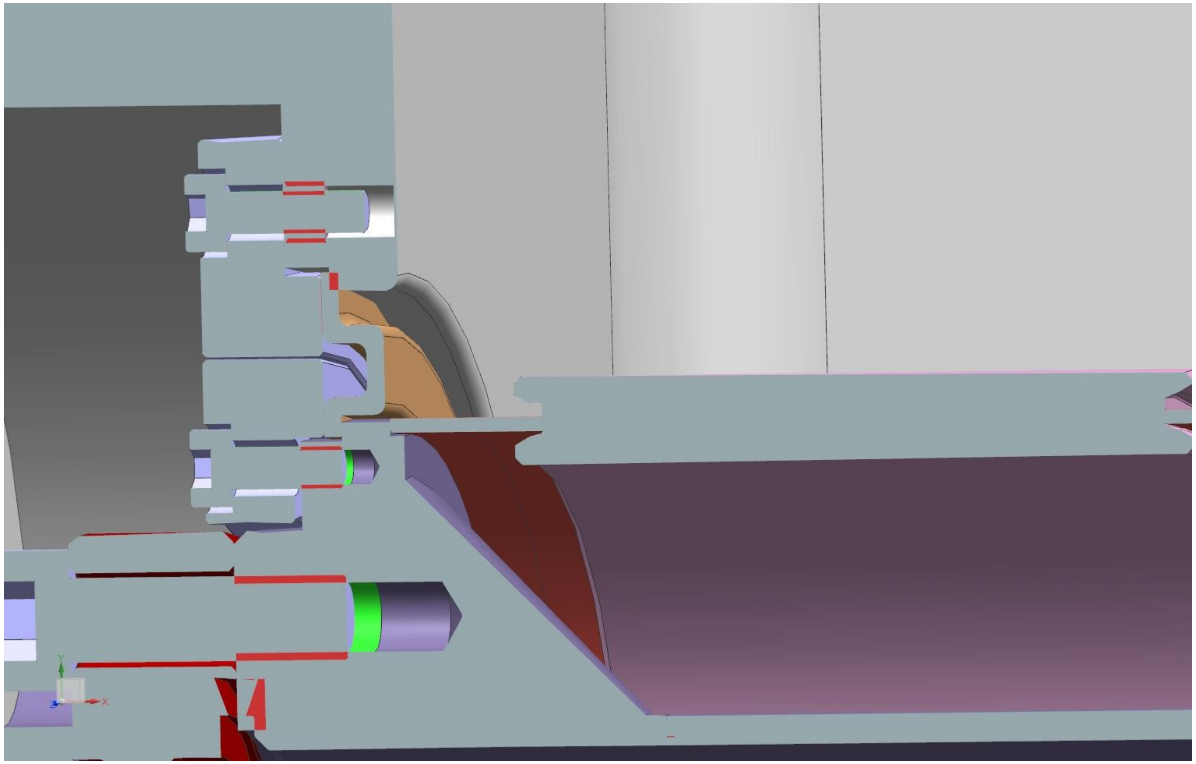
Attachment axle connection



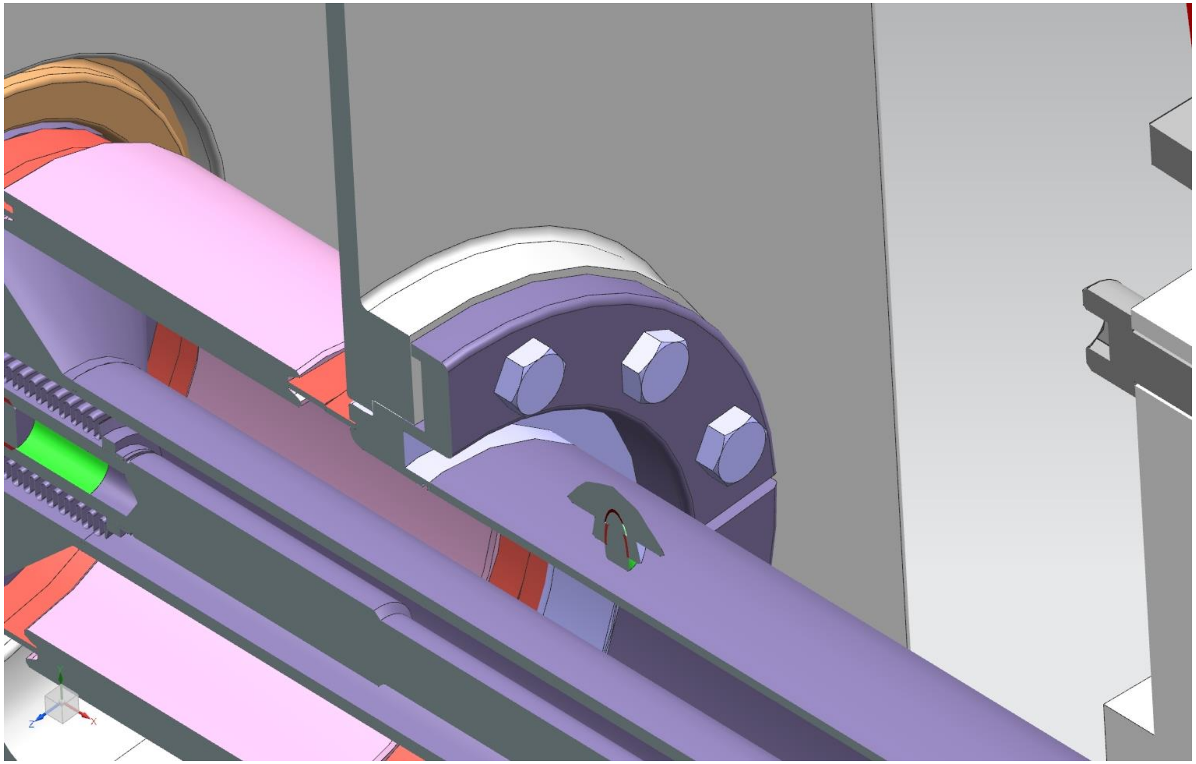
Section view of assembly



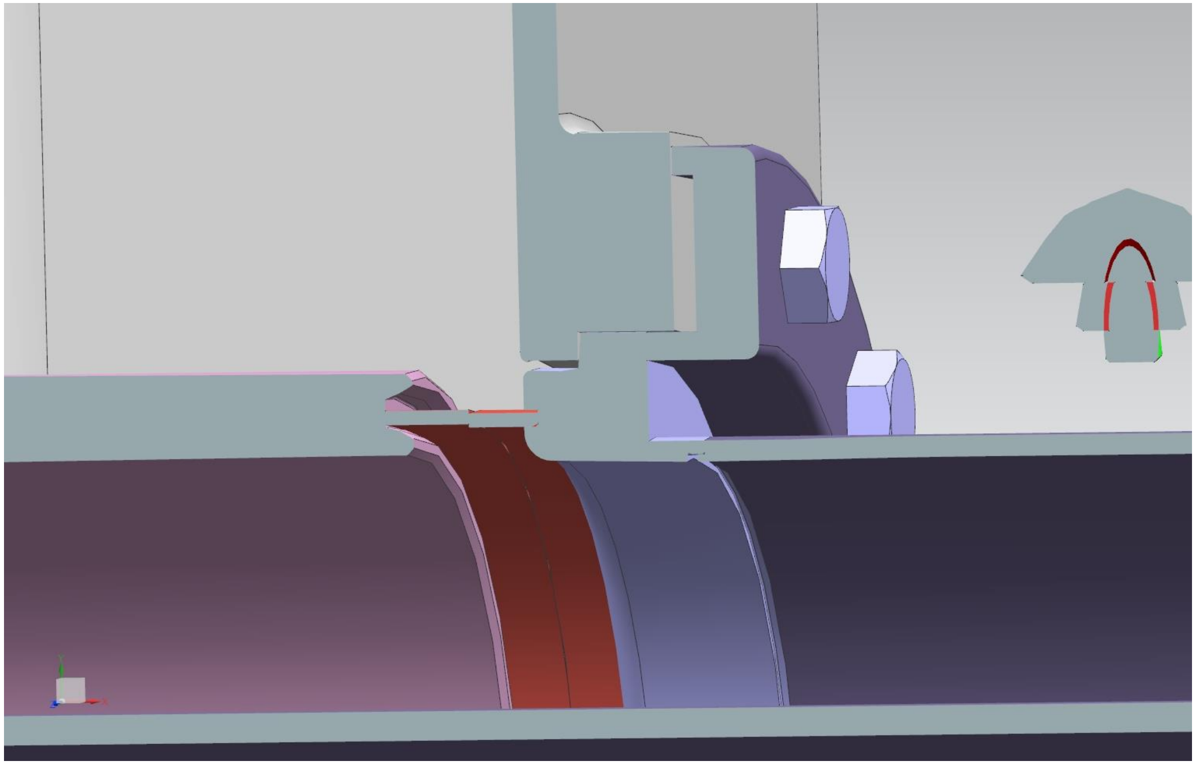
Front of waveguide, Coax



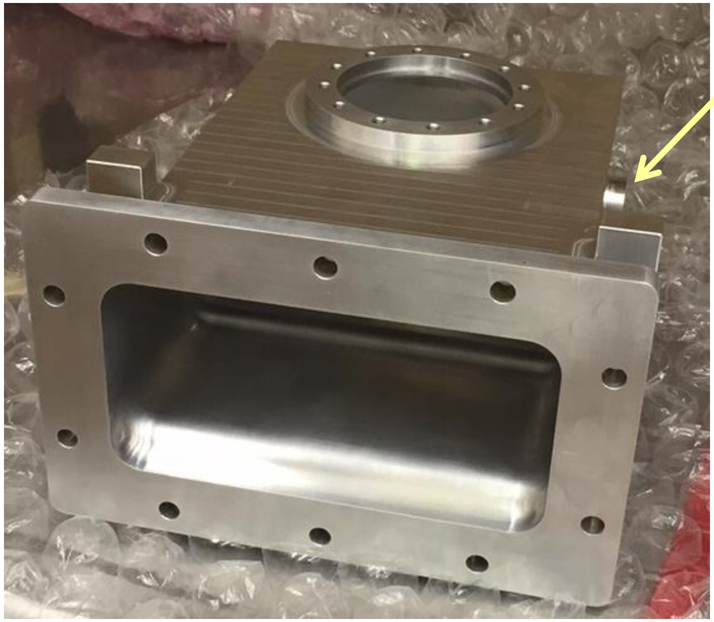
Back of waveguide connection



Back of waveguide connection

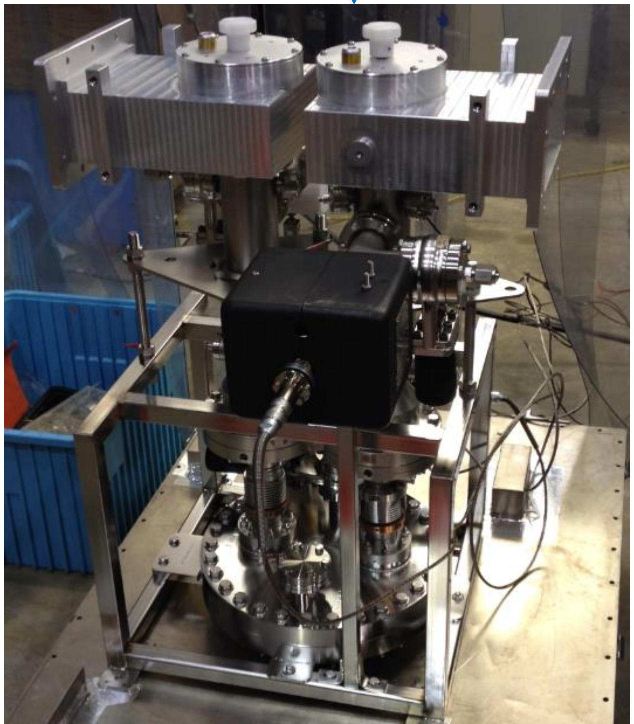


Pictures of Aluminum Prototypes



Only one of 3 side hole retained for gas purging/NIRP pressurization. (and possibly multipactor detection)

Pair assembled on couplers installed on a CPC for RF testing



Summary

- New waveguide box motivated by cost savings
- RF redesign to maximize benefit of new fabrication approach
- New design equals old in simulation
- Monolithic machining from aluminum
- Bracing and side holes updated
- Prototypes successfully RF tested
- Installation of WG box onto cryomodule has been reviewed
- Interfaces have been identified and incorporated into design

End