HORN PROJECTS AT COLORADO

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University of Colorado

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Horn Projects at Colorado

- The history
- Horn 1, version 3
  - Scope of project
  - Highlights of the assembly work
  - Our biggest challenge: seals
- Future projects

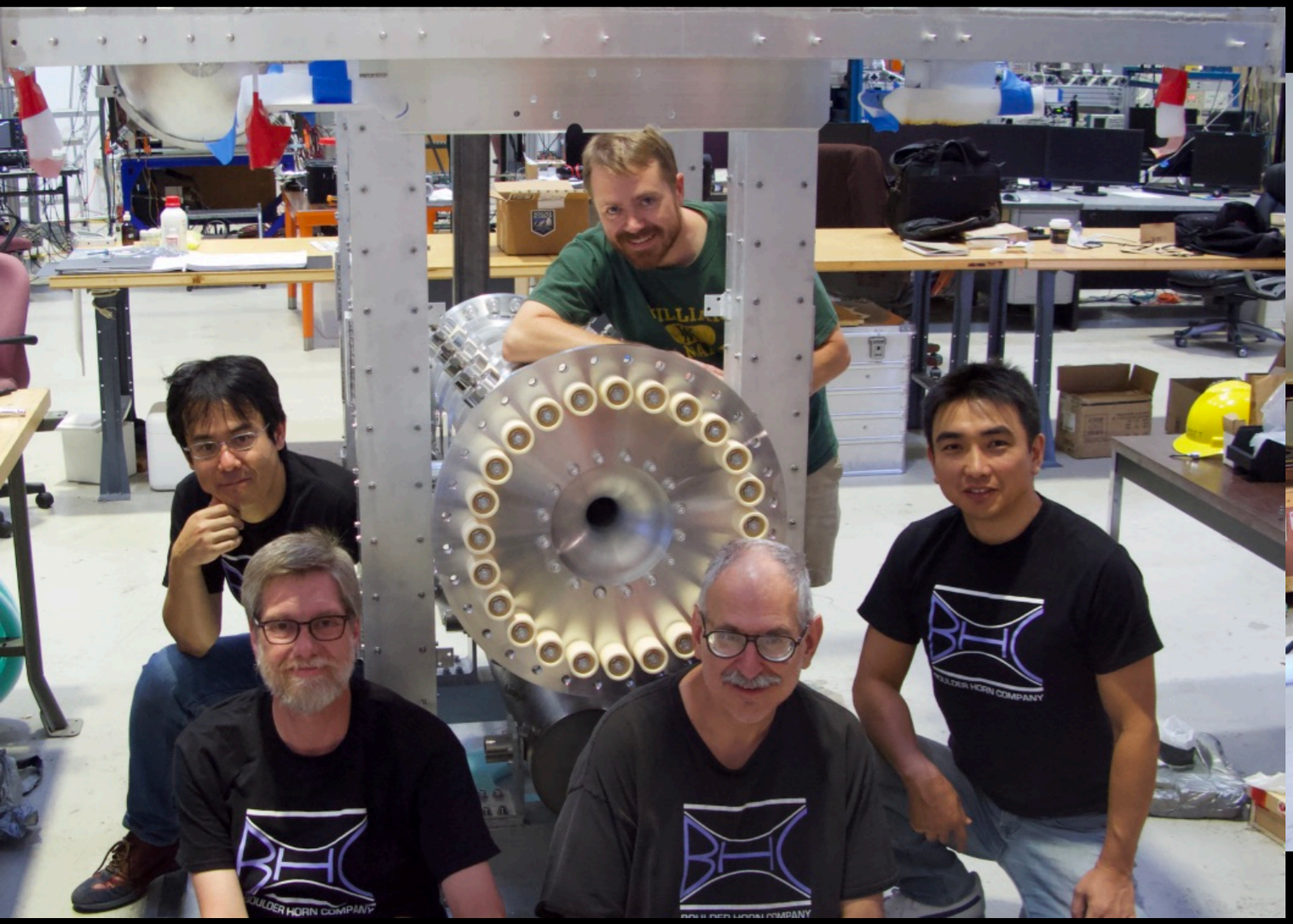
Horn project history

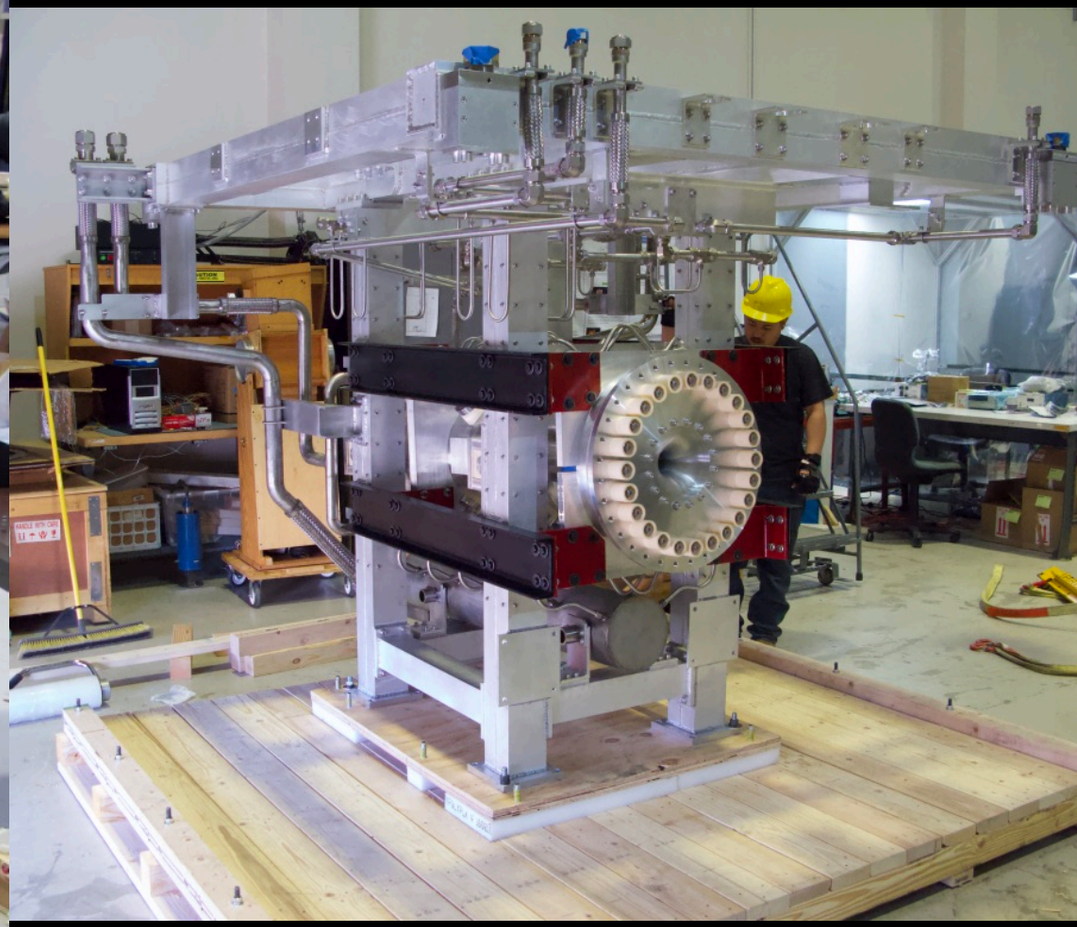
- The University of Colorado group has made horns in our laboratory (a former cyclotron high-bay) since the beginning of T2K
- Design and production have been fully collaborative between us and KEK, with Bartoszek Engineering as our main engineering resource
- We've delivered three horns to T2K since 2008
  - The original Horn 2
  - The spare Horn 2 (now operating)
  - The second spare Horn 1 (delivered in January)
- Other horns (2x Horn1, 2x Horn 3) have been made in Japan

The first Horn 2: 2007-2008

The spare Horn 2: 2012-2013

The second spare Horn 1: 2014-2019





Second spare Horn 1 project

- Began work in 2014, shipped in December 2018
- Very long project duration: funding profile limited annual progress at times
- Some changes to interface locations, but few changes to actual horn other than improved upstream water seals (see Sekiguchi-san's talk from yesterday)

Second spare Horn 1 project

THE ASSEMBLY TEAM

- Bartoszek Engineering:
  - Larry Bartoszek
  - Chris Daurer
- Colorado:
  - Stephen Coleman
  - Zachary Liptak (2014-17)
  - EDZ
  - Kerrie Dochen
  - Susan Born
  - Yoshikazu Nagai
- KEK:
  - Taku Ishida
  - Tetsuro Sekiguchi

Similarities to previous horns

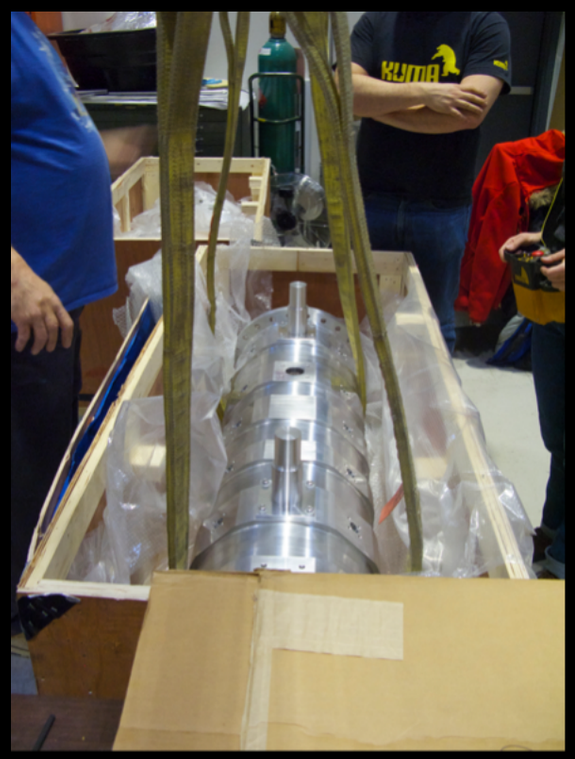
- Fundamental design concepts are similar to Horn 2.
- Water and helium nozzle/ceramic/flange assemblies are basically identical (but see later slides!). Small ceramic parts interchangeable.
- Extensively using three major parts vendors from previous two horns:
  - O'Keefe Ceramics, Colorado
  - GETT Industries, Illinois
  - CU Physics machine shop

Major differences from previous horns

- Assembly fixtures were designed for the larger Horn 2. Had to adapt rotating fixture and assembly plate to assemble a smaller horn.
- Significant modification of design model, new drawings needed for US production
- More parts were provided by Japan, due to original Horn 1 being designed to JIS stock:
  - Metric square channel and C-channel tubing is very difficult to find in US. KEK purchased sufficient amounts and had shipped to US.
  - We had the C-channel welded into square channel in the US, and then supplied the box beams to vendors for columns, top frame. Requires tighter coordination with vendors and prompt domestic shipping, and more time.
- Smaller size means more parts can be done domestically (big ceramic ring) and even in-house (upstream flange).

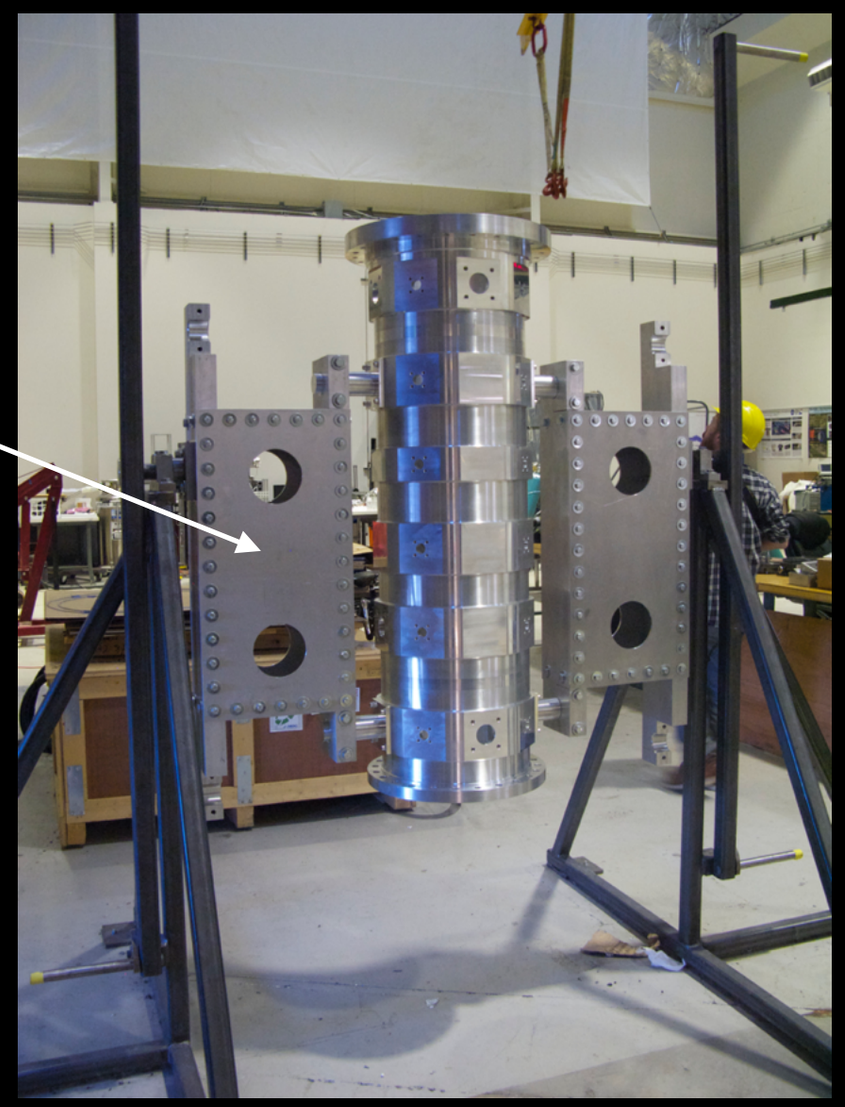
Parts from Japan

- Inner and Outer conductors delivered in 2015
- 100mm aluminum C-channel and 10mm stainless square channel delivered as well: this JIS stock is not easily available in the US.



Production early 2016

- Acquired all small ceramic parts for horn
- Completed many production drawings for parts
- Adapted horn rotating fixture, assembly plate from Horn 2 project for smaller Horn 1
- Mounted outer conductor on rotating fixture

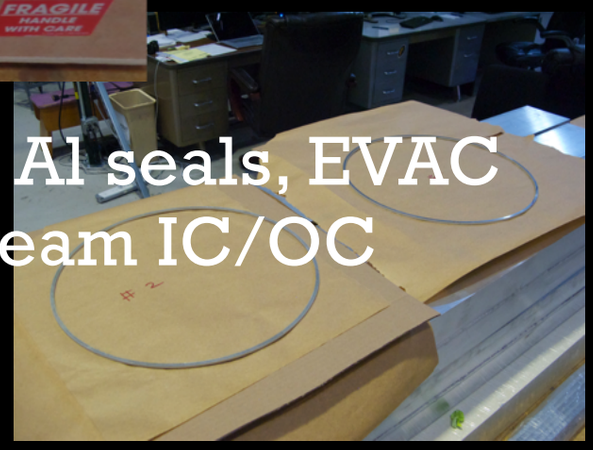


Production steps 2016

- US parts production/delivery:
  - Drain tank

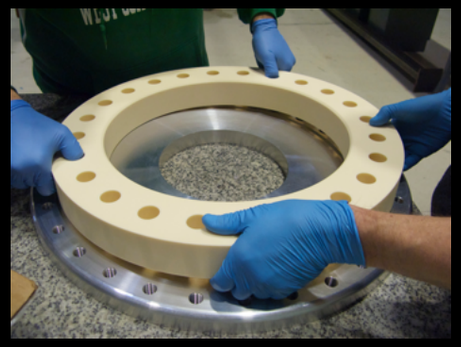
  - Water nozzles/flanges

- Basically all seals: IC/OC downstream conducting Al seals, EVAC and Helicoflex for ports, large Helicoflex for upstream IC/OC connection

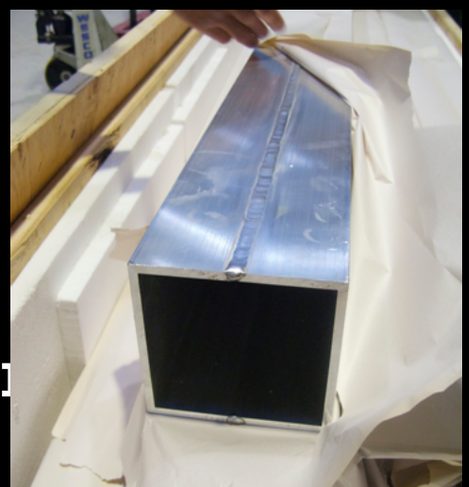


- Upstream flange

- Big ceramic rings

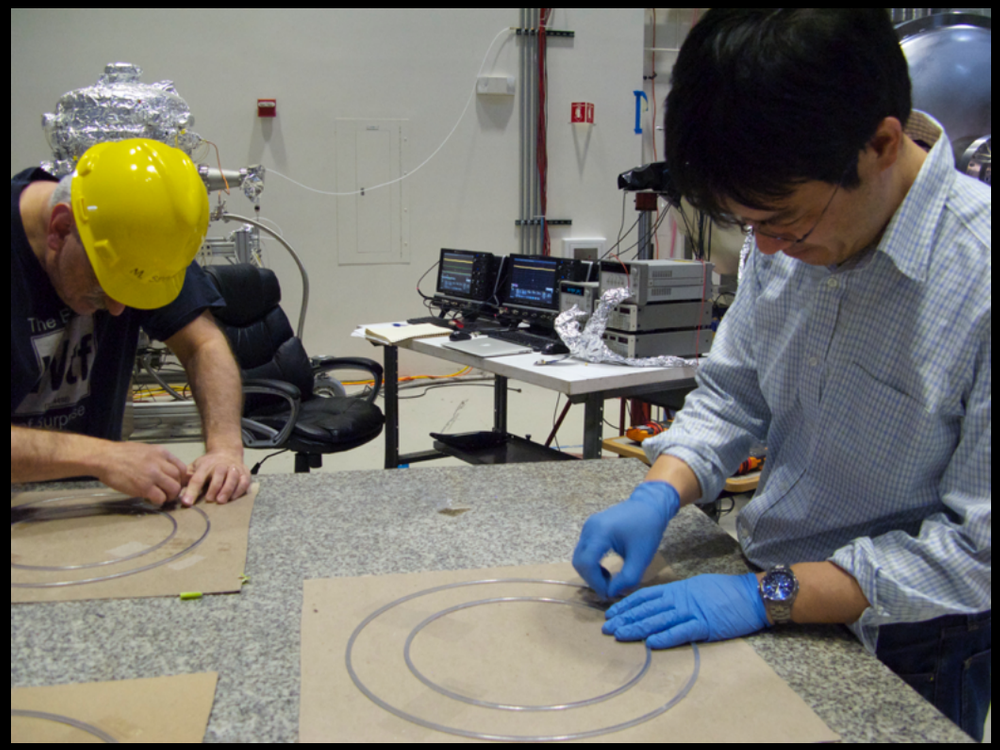


- C-channels welded into box beams for top frame a

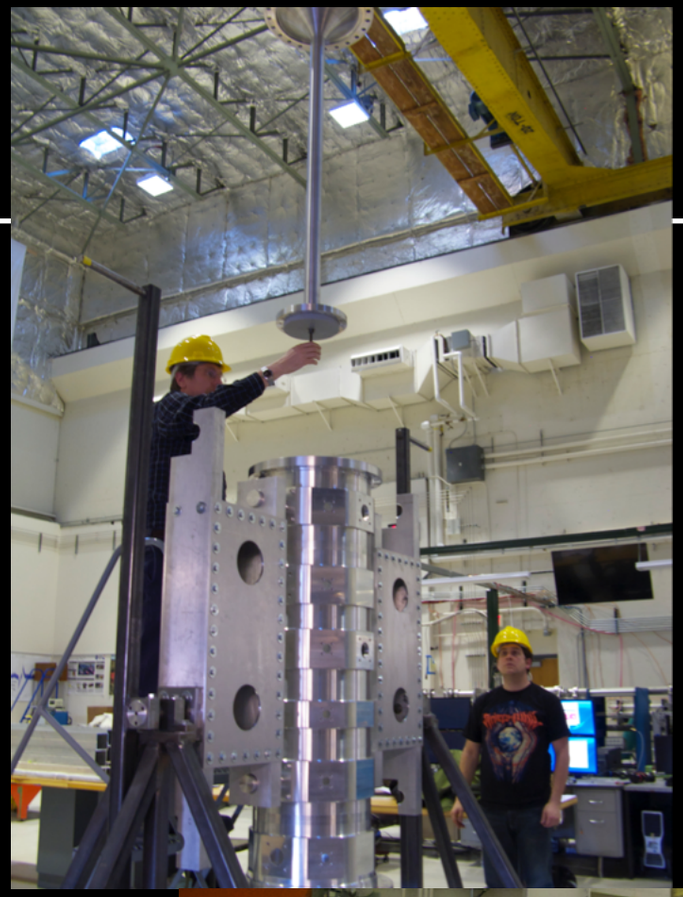


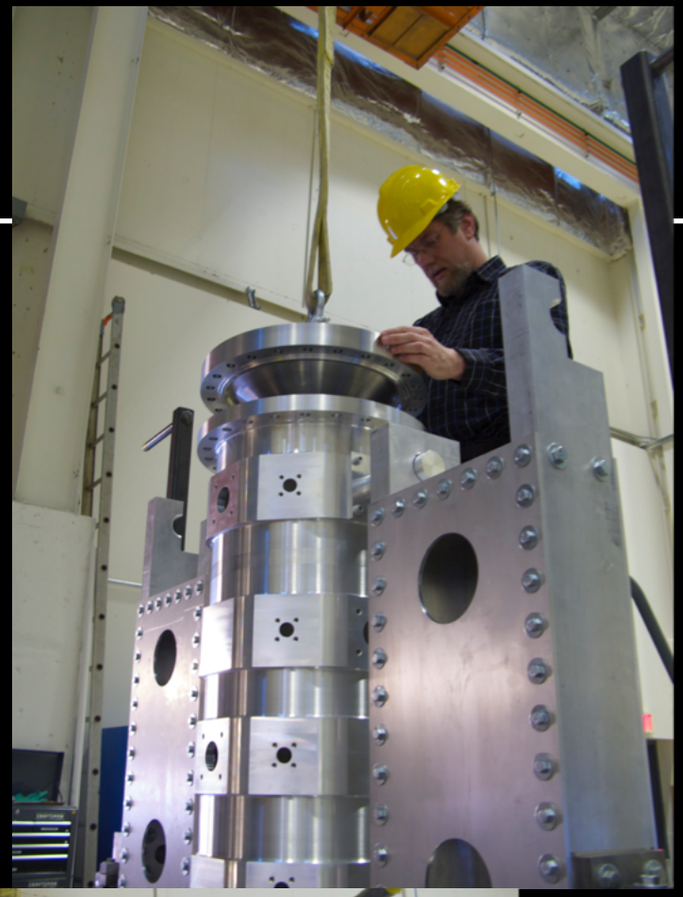
Work on parts 2016

- Cleaned all parts that face the water
- Built lifting fixture for inner conductor
- Stoned custom seals to remove water-jet burr

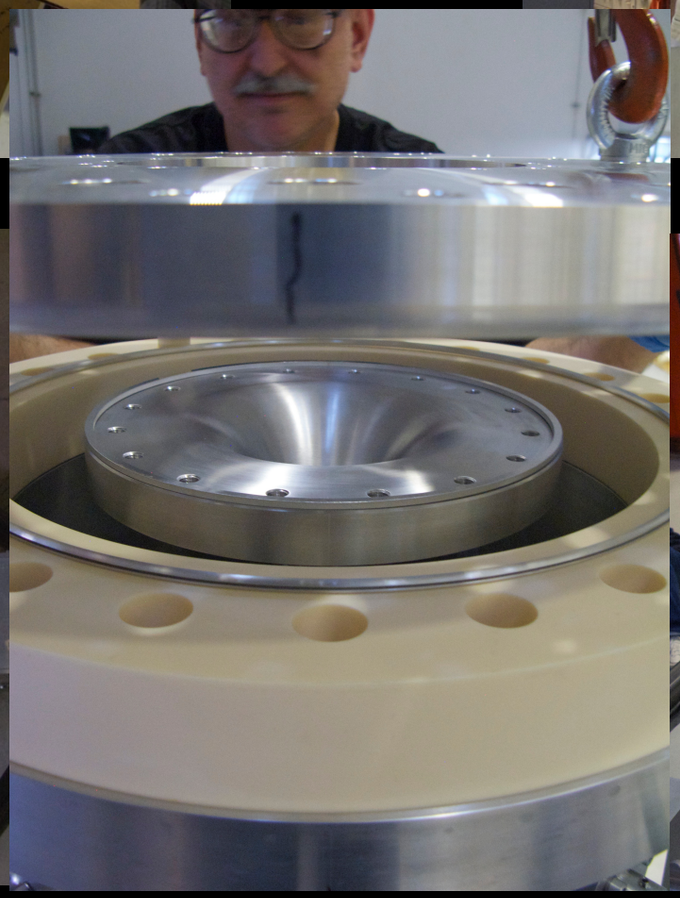


Install IC into OC, tighten downstream seal

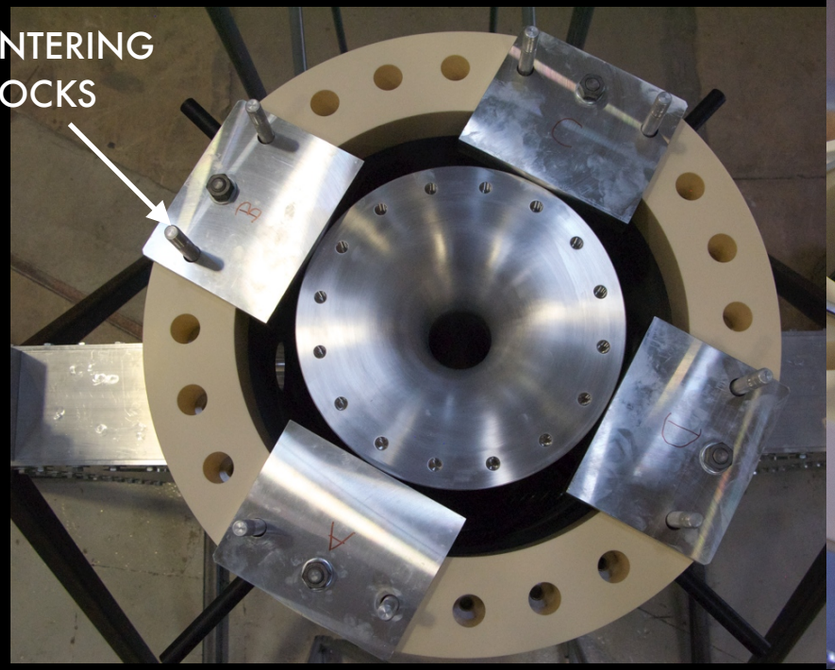




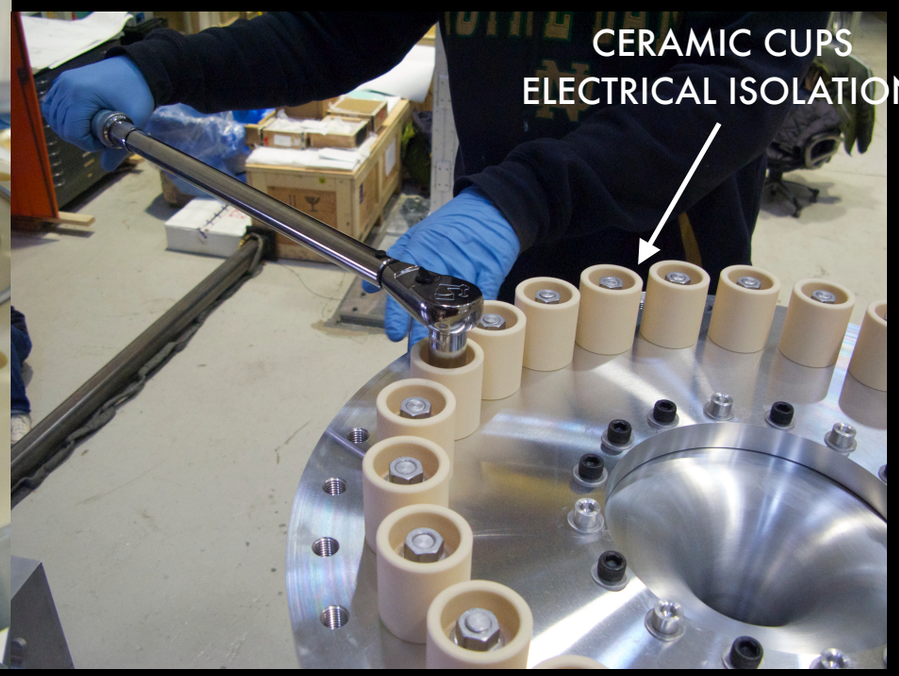
Ceramic ring and upstream seal late 2016



IC CENTERING BLOCKS

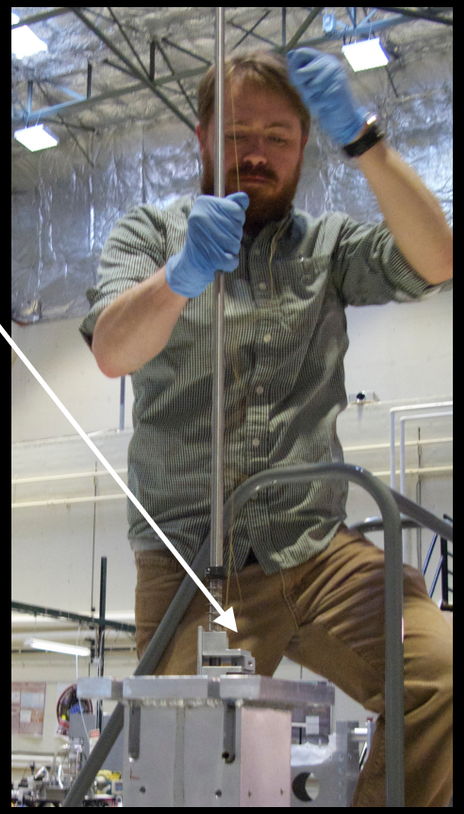


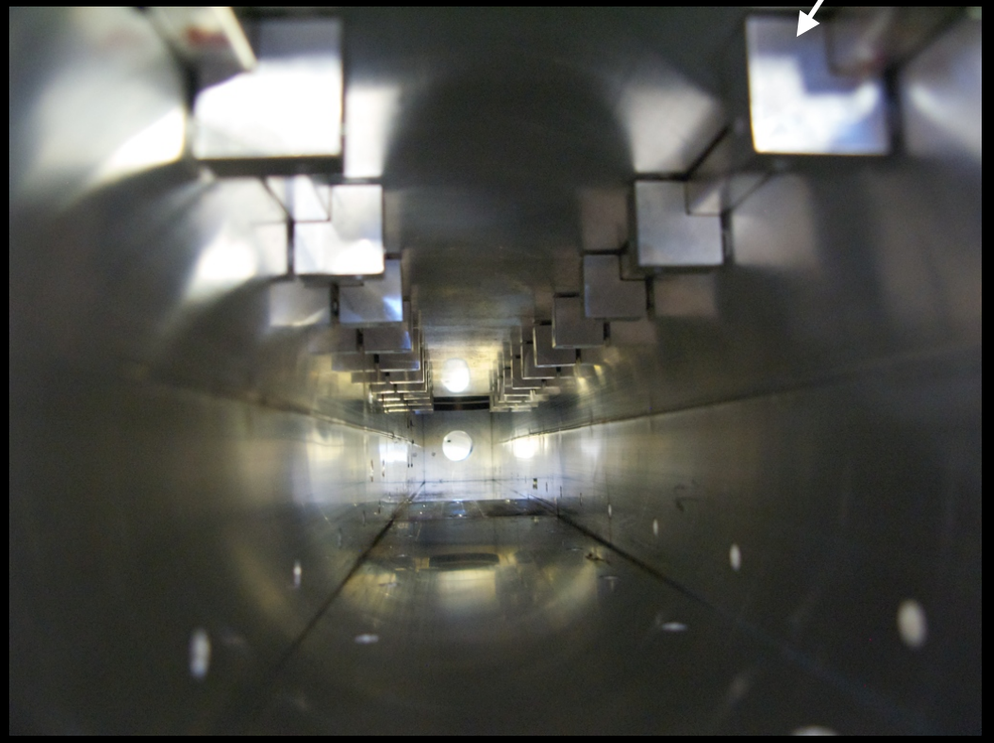
CERAMIC CUPS ELECTRICAL ISOLATION



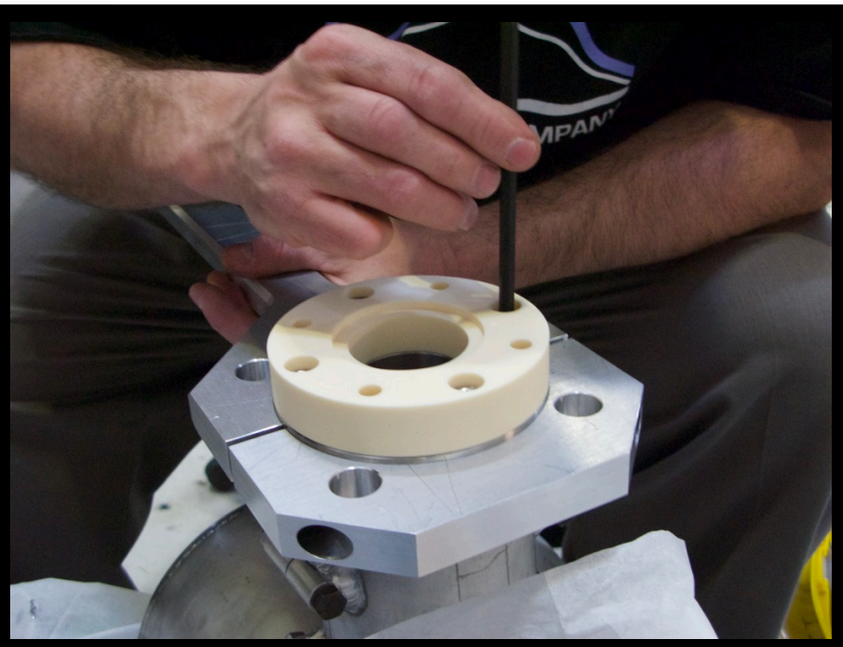
Columns and frame cooling early 2017

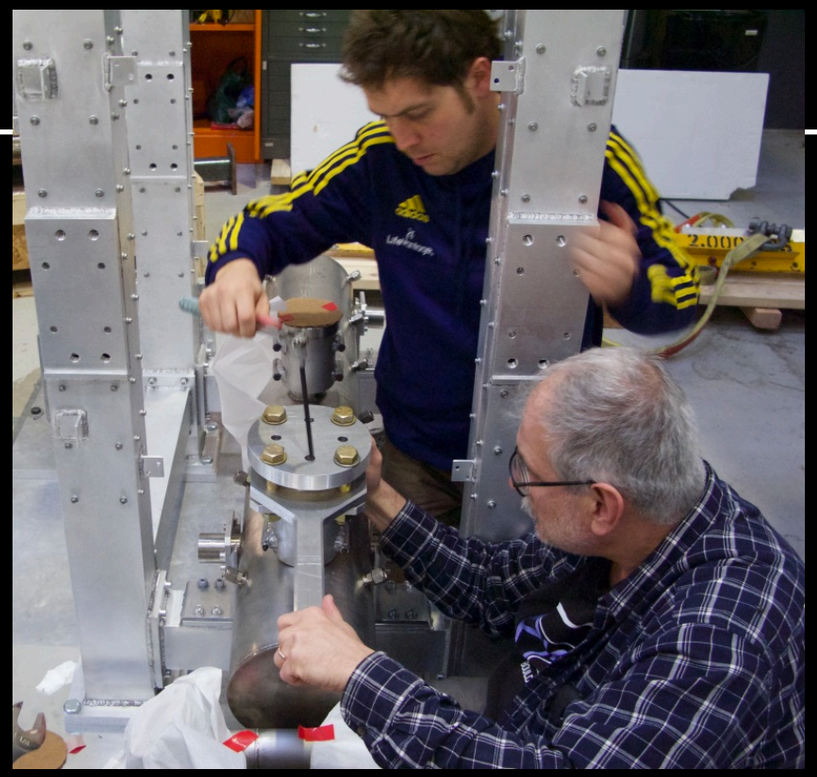
CLAMPING BLOCKS





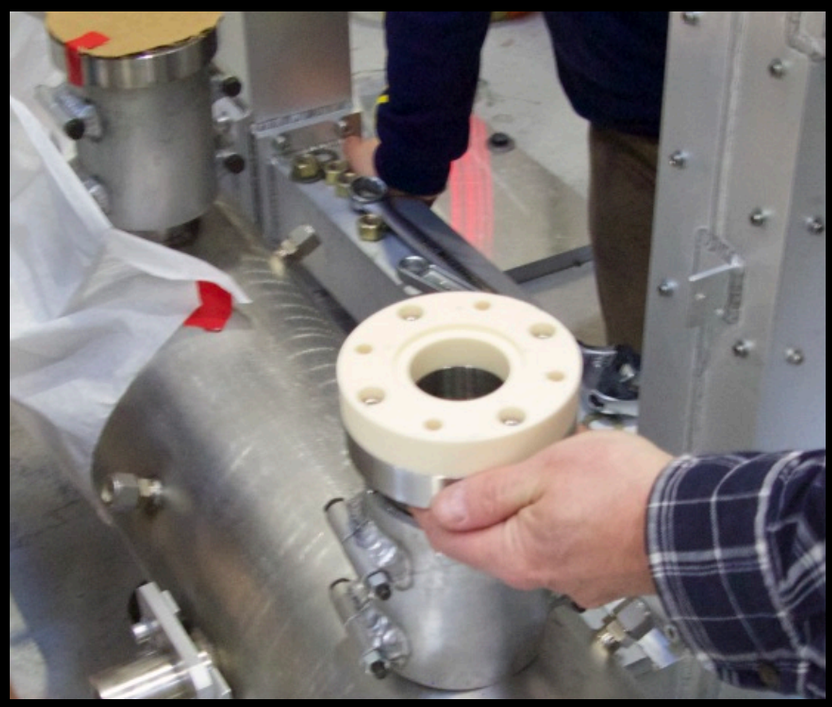
Drain tank installation, ports spring 2017



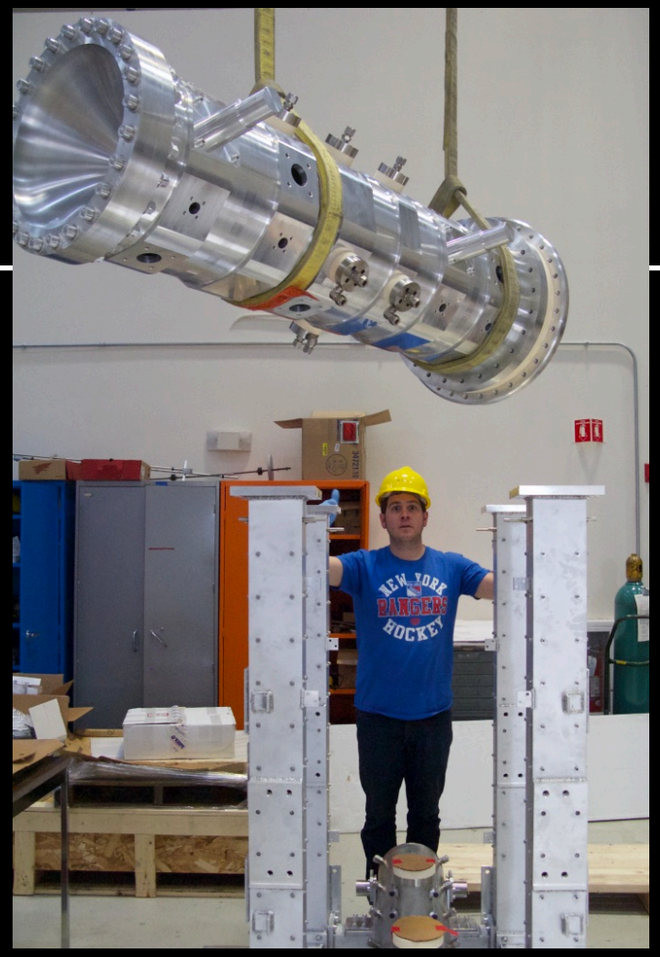


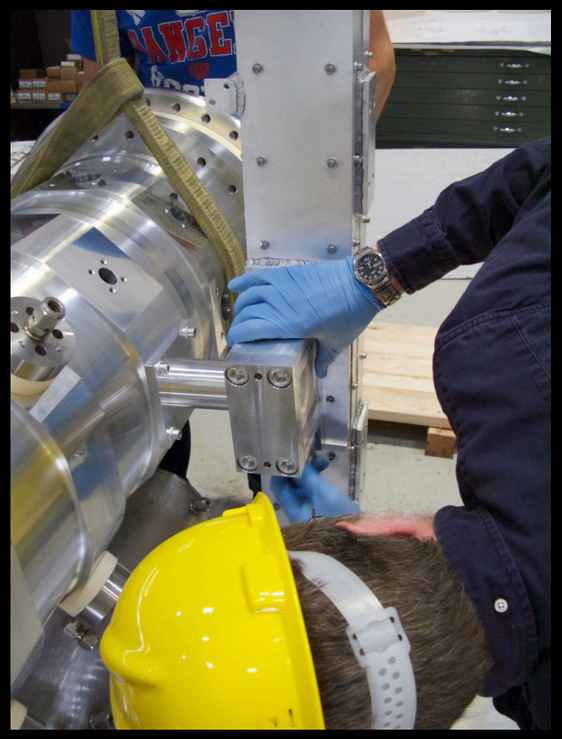
But note: issues discussed later!

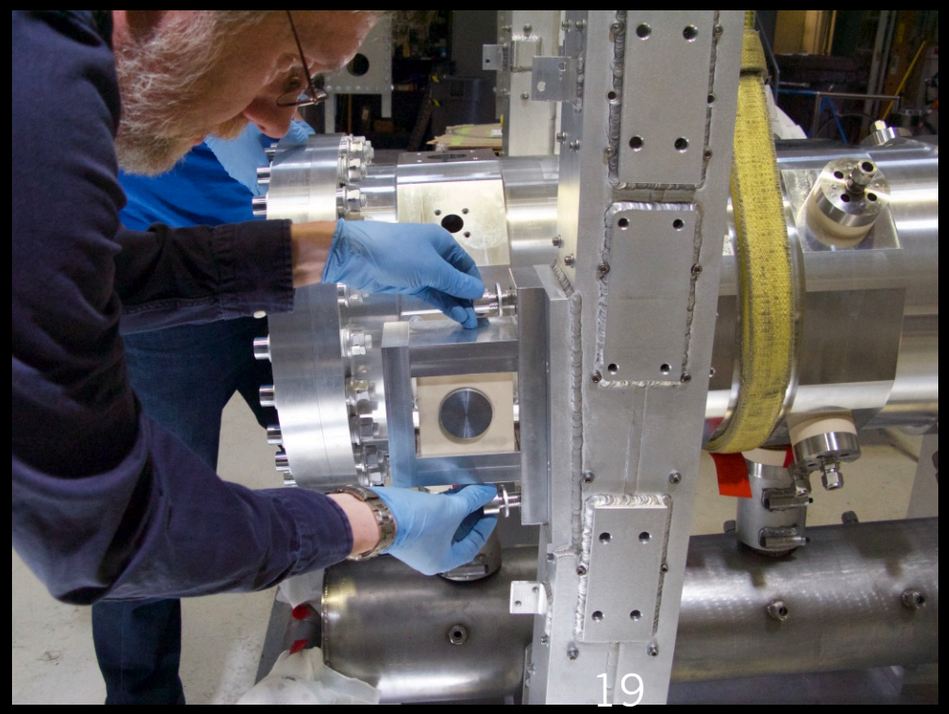
SEAL CRUSHING PLATE



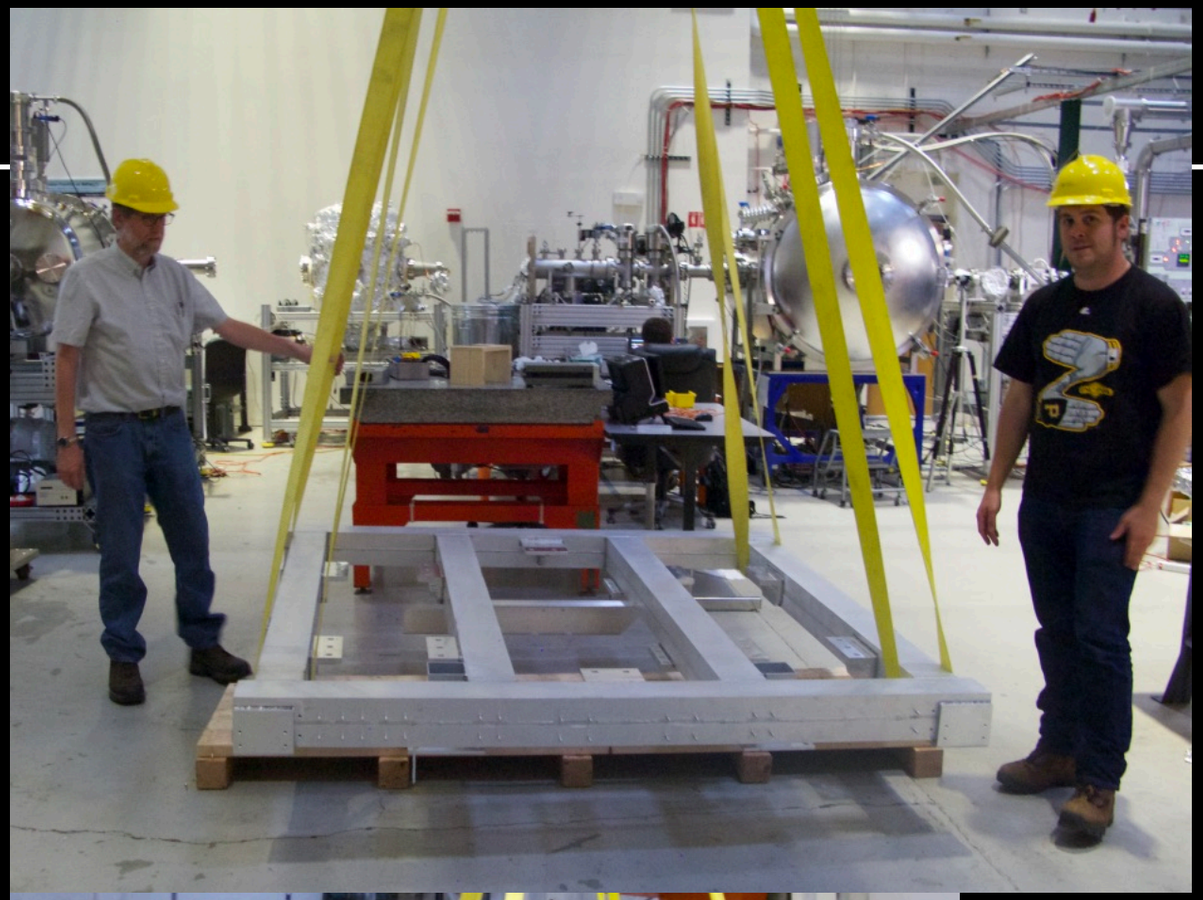
Horn into frame
Spring 2017





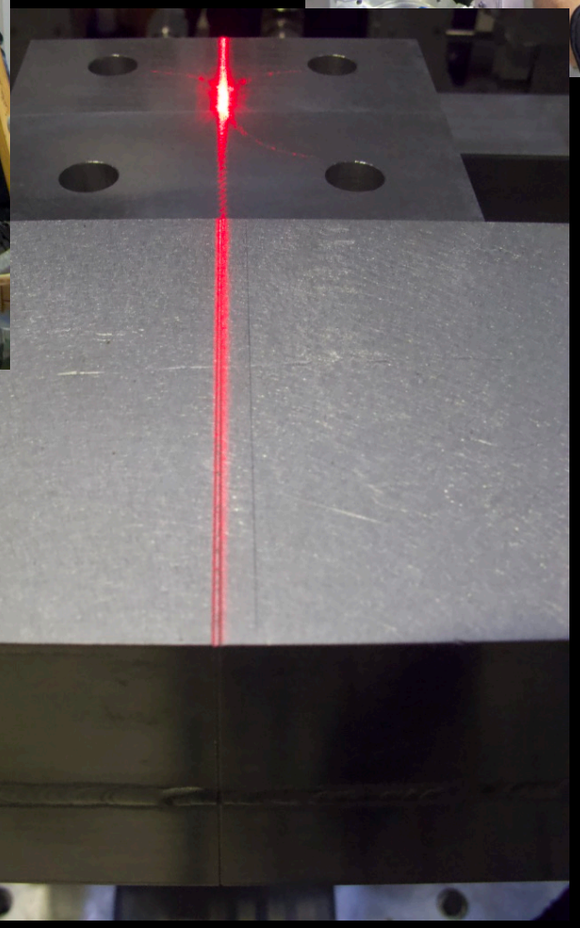


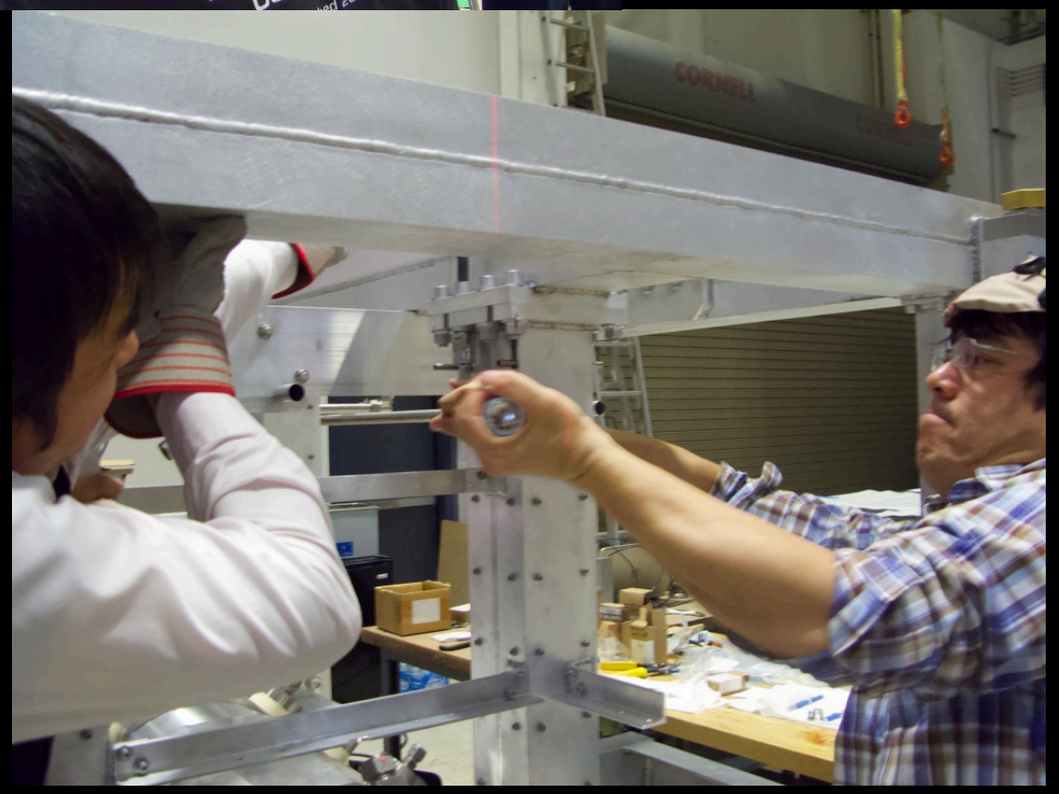
Top frame
Summer 2017



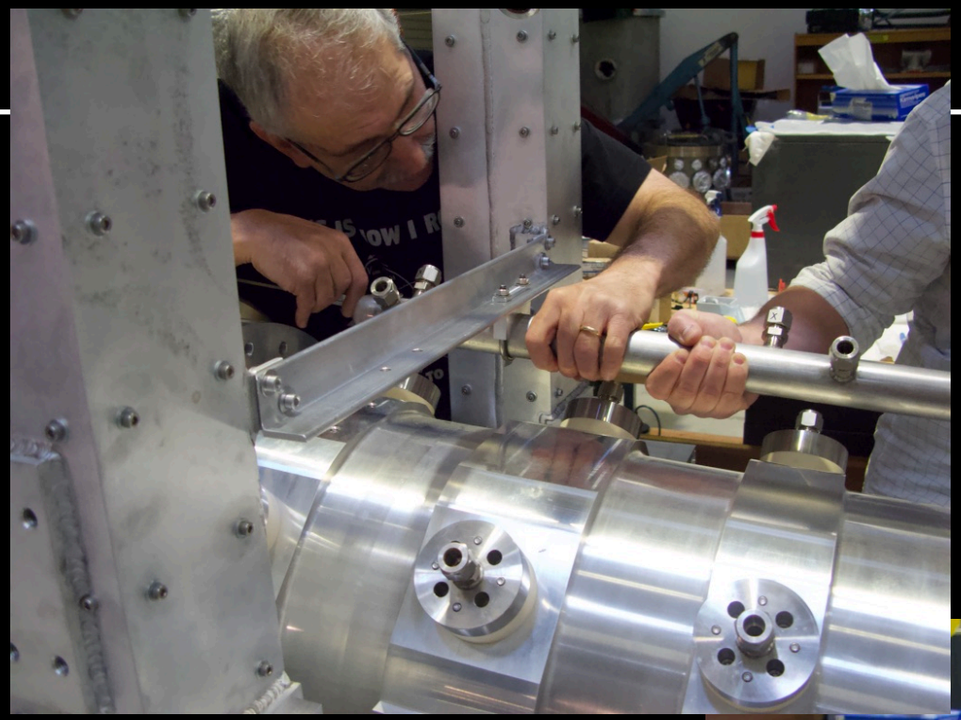
Water pipes: 2018

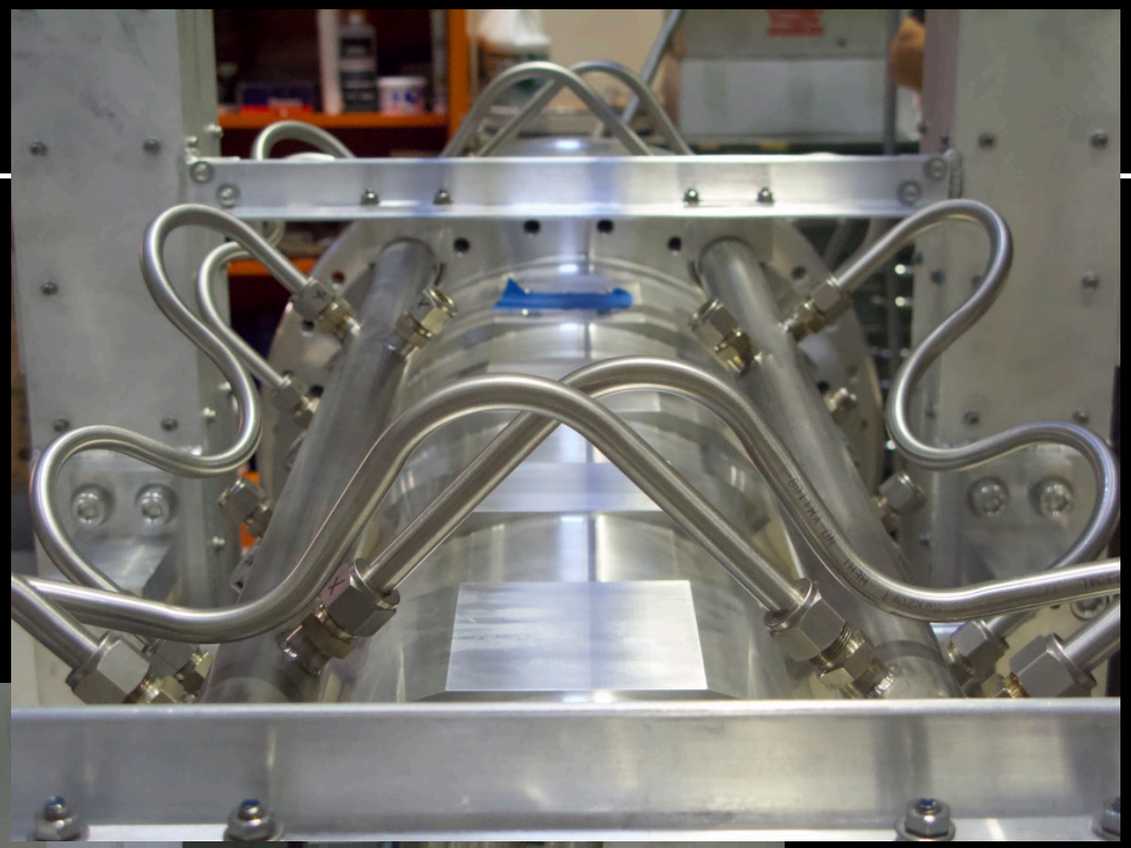
Final alignment of top frame

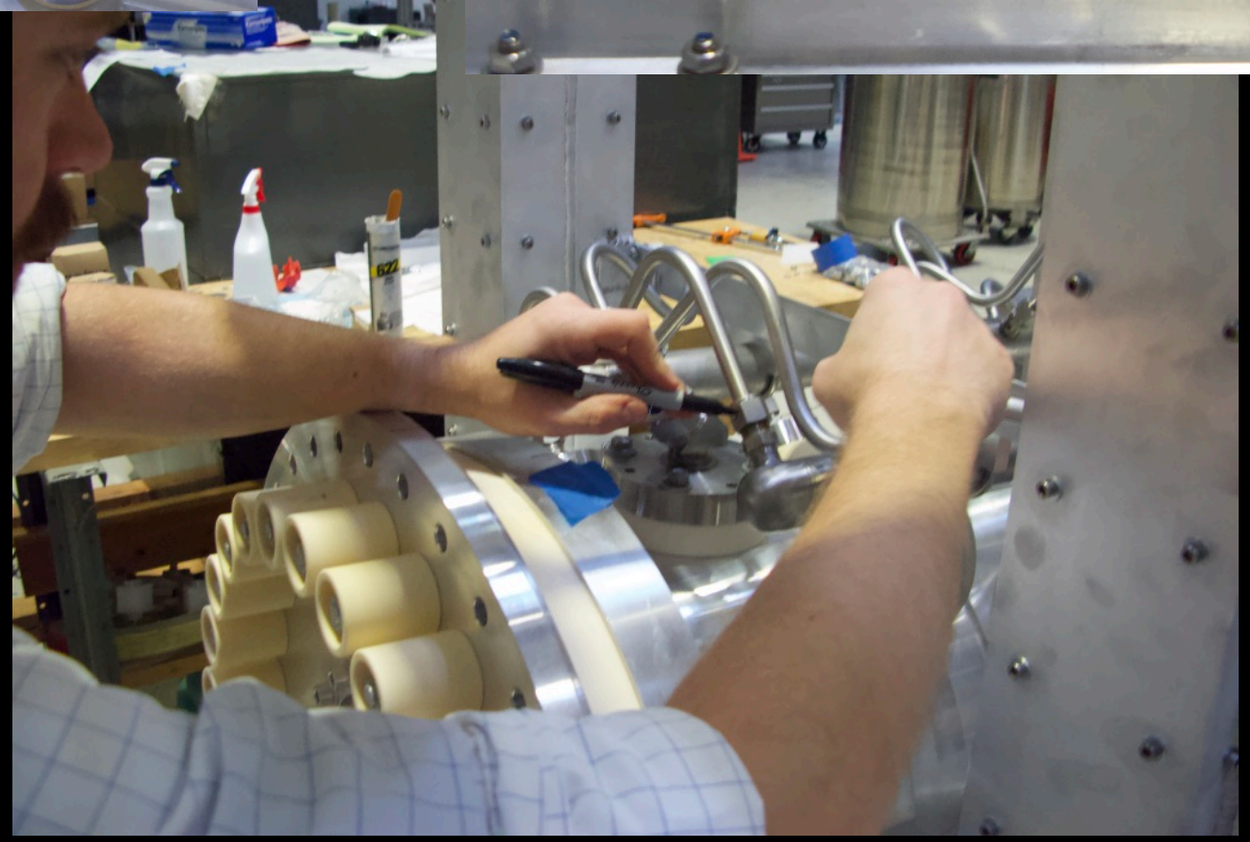




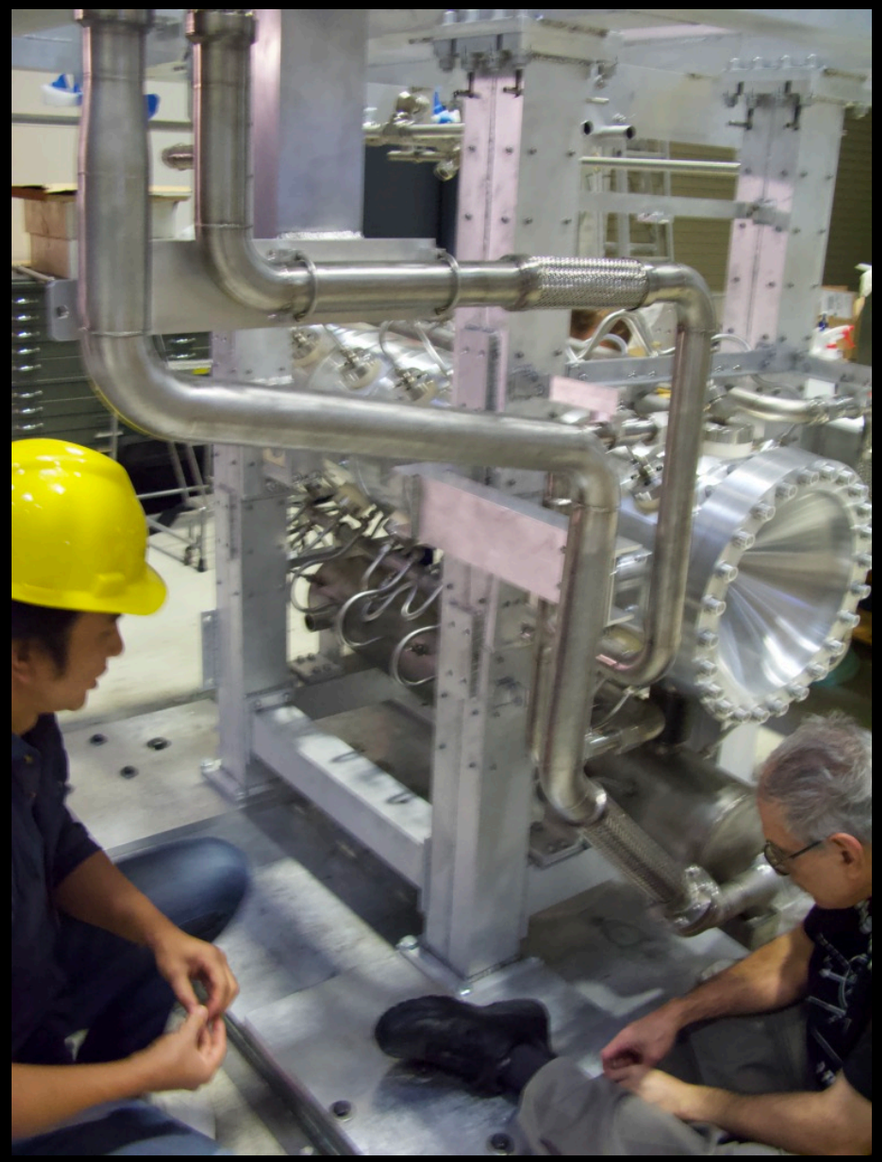
Water tubing installation



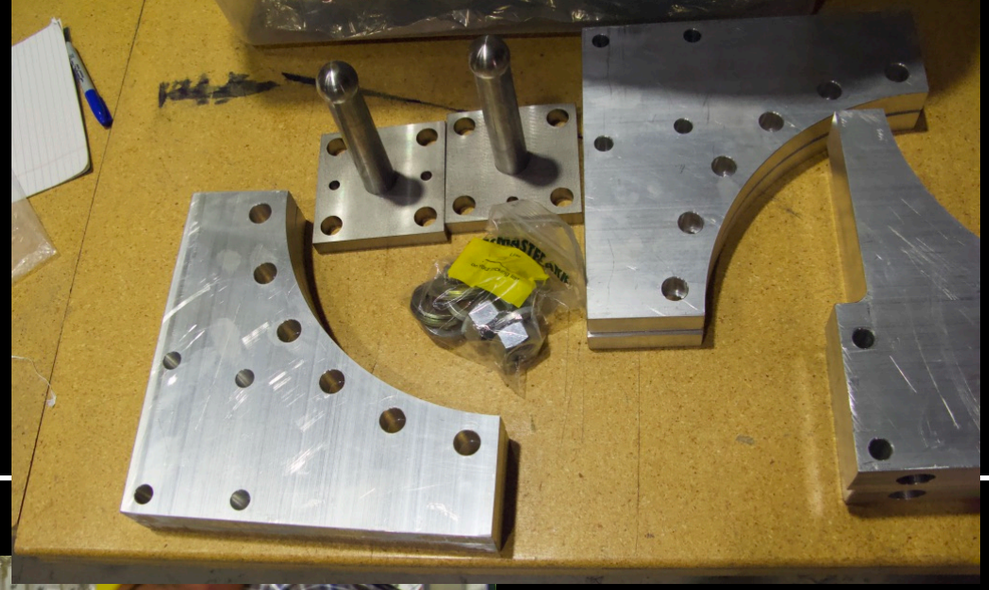


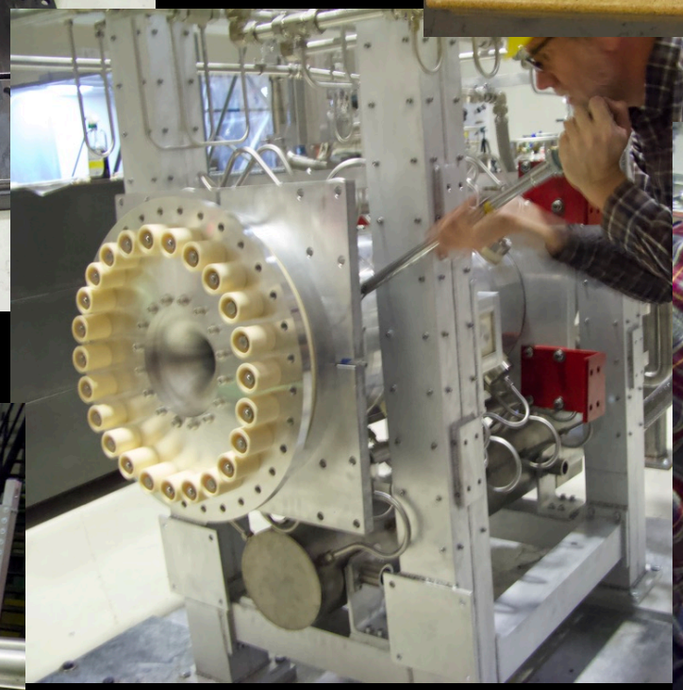


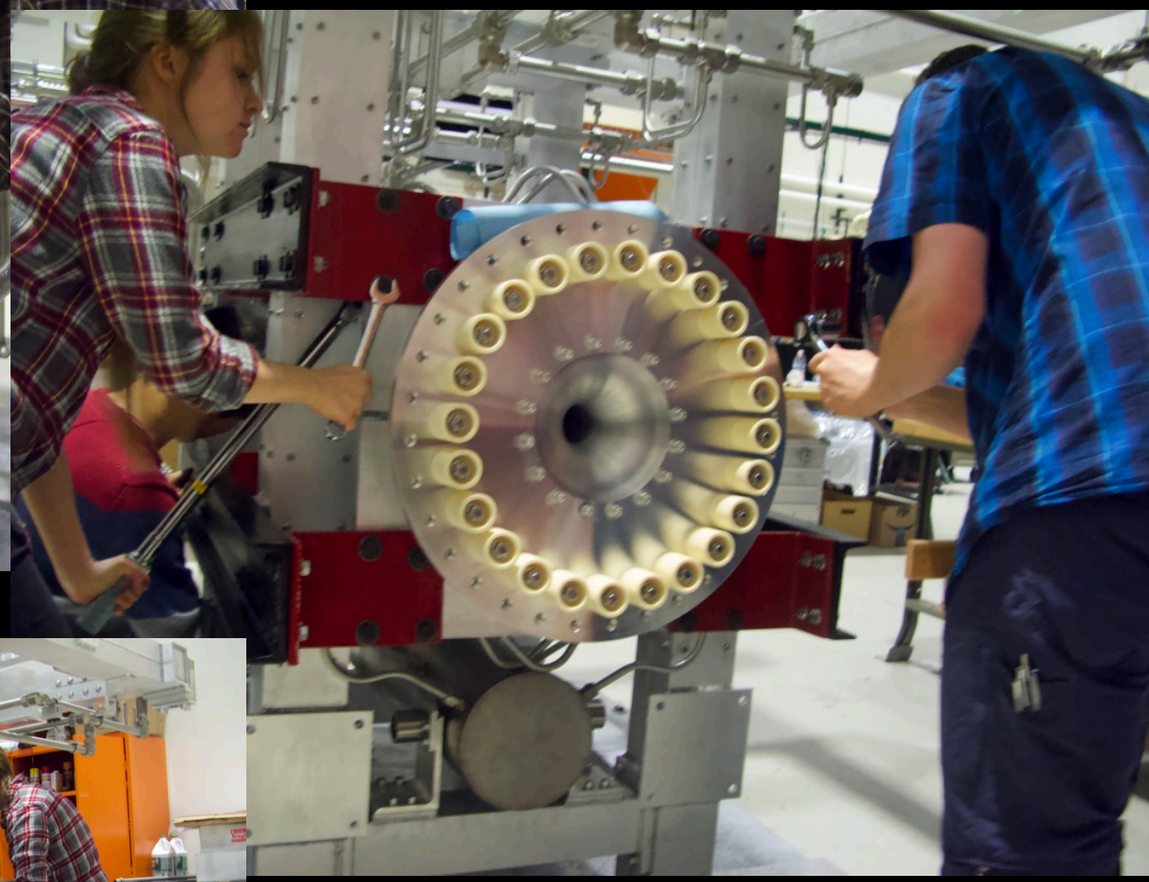
Supply and drain pipes

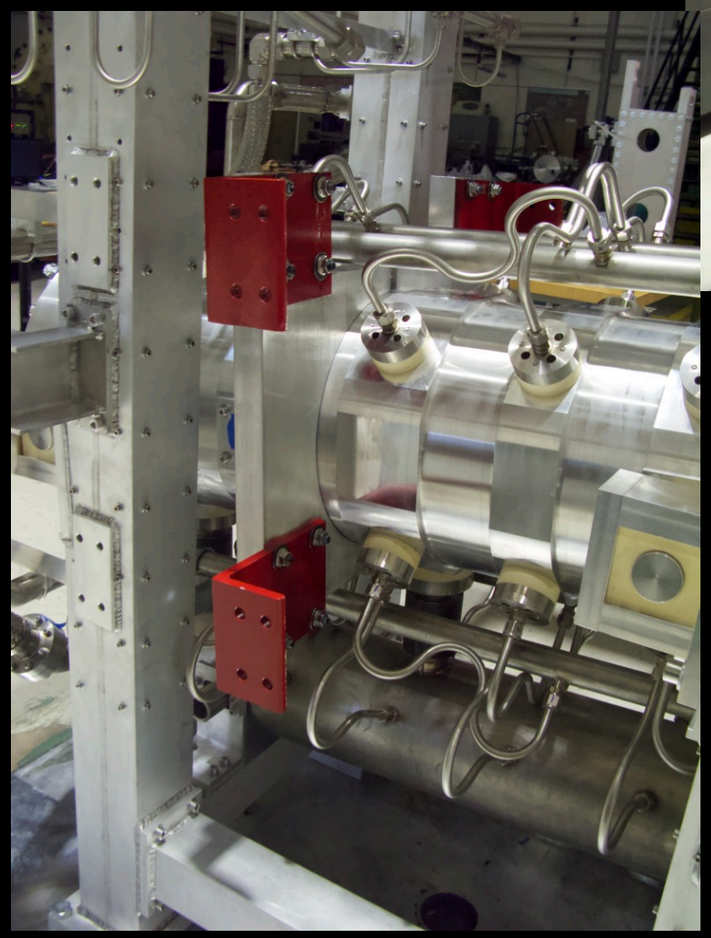


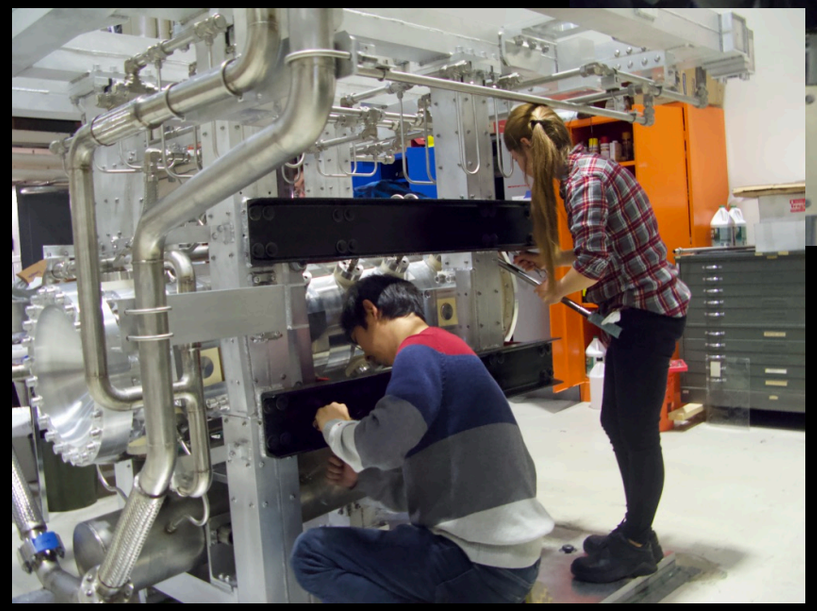
Shipping fixture





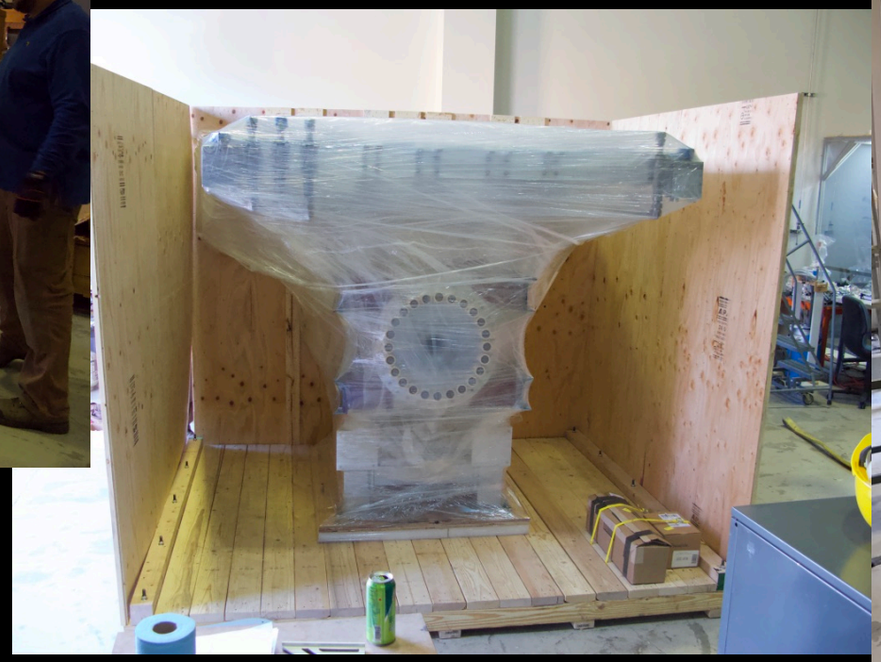






Goal of the shipping fixture is general stiffening of the horn and constraint against internal movement

Crating



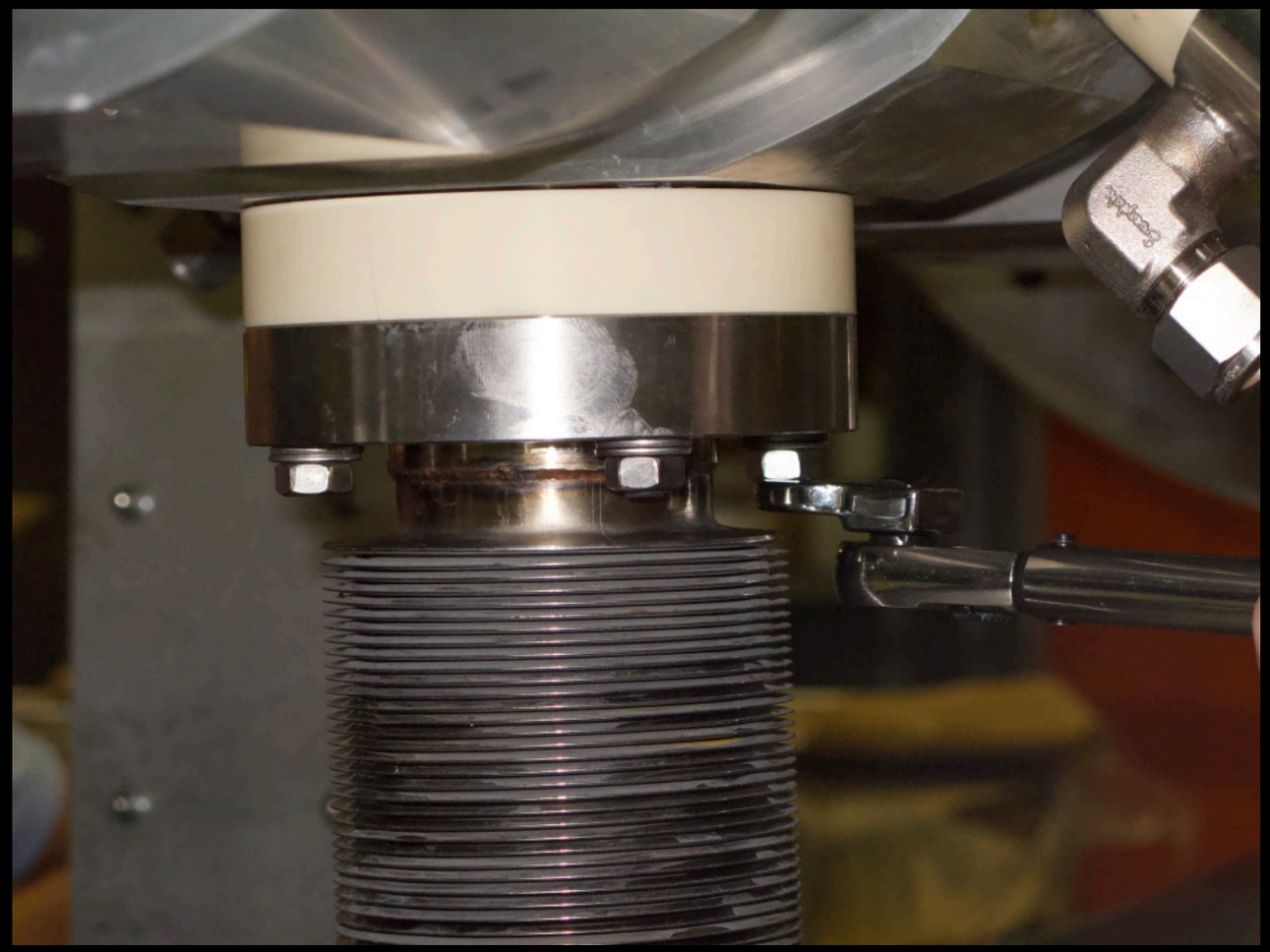
Shipment and delivery

- Horn was loaded on December 29, carried by truck to Los Angeles airport
- Korean Air Cargo to Narita via Seoul
- About a week in customs
- Delivered to KEK on January 15
- Tested on current; water leaks fixed
- Almost ready to install if current Horn 1 fails…

Biggest challenge on this horn: drain tank seals

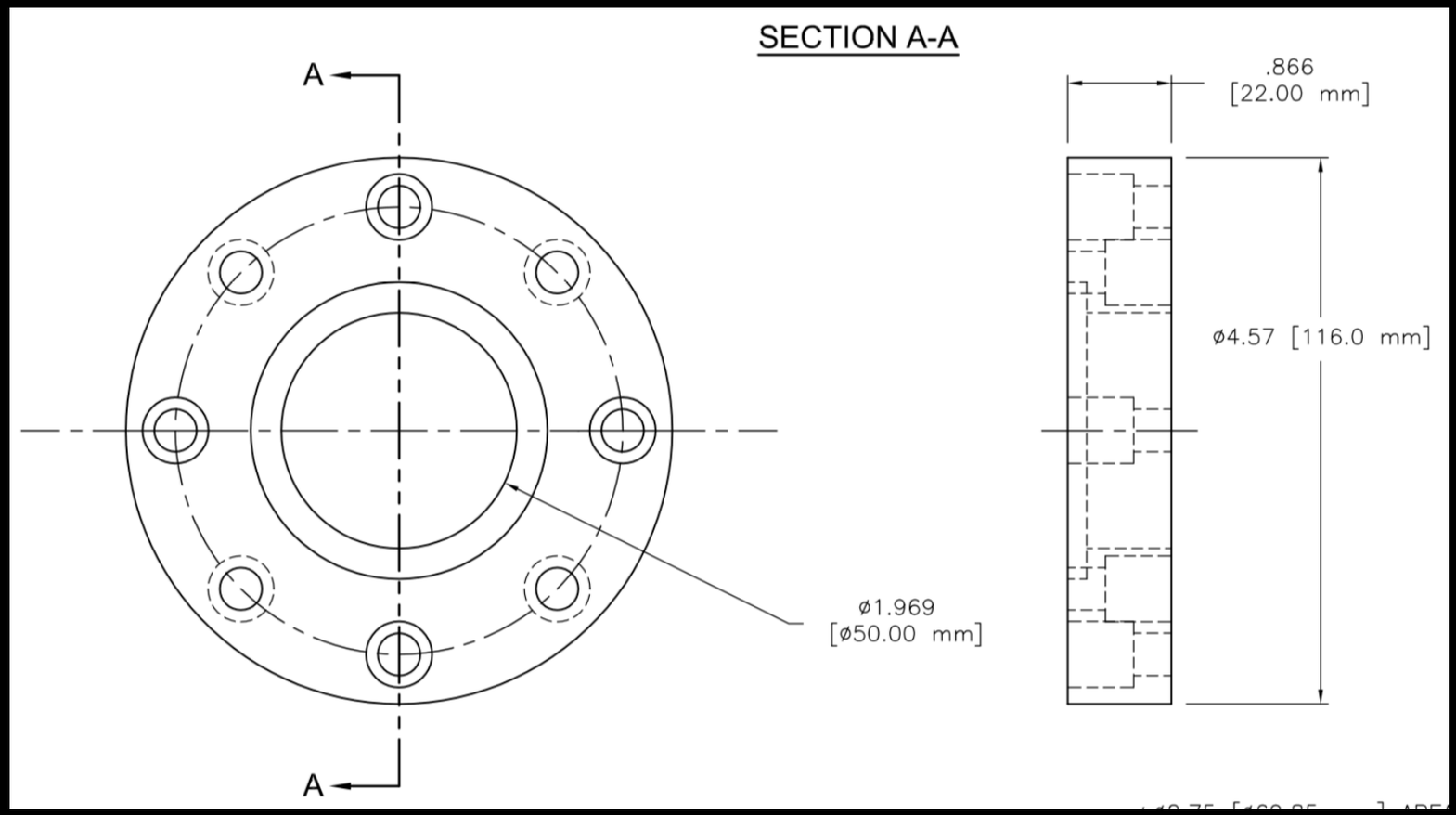
- Aluminum horn and stainless steel water system are isolated from each other by a ceramic break

- The same seal geometry has been used on all T2K horns



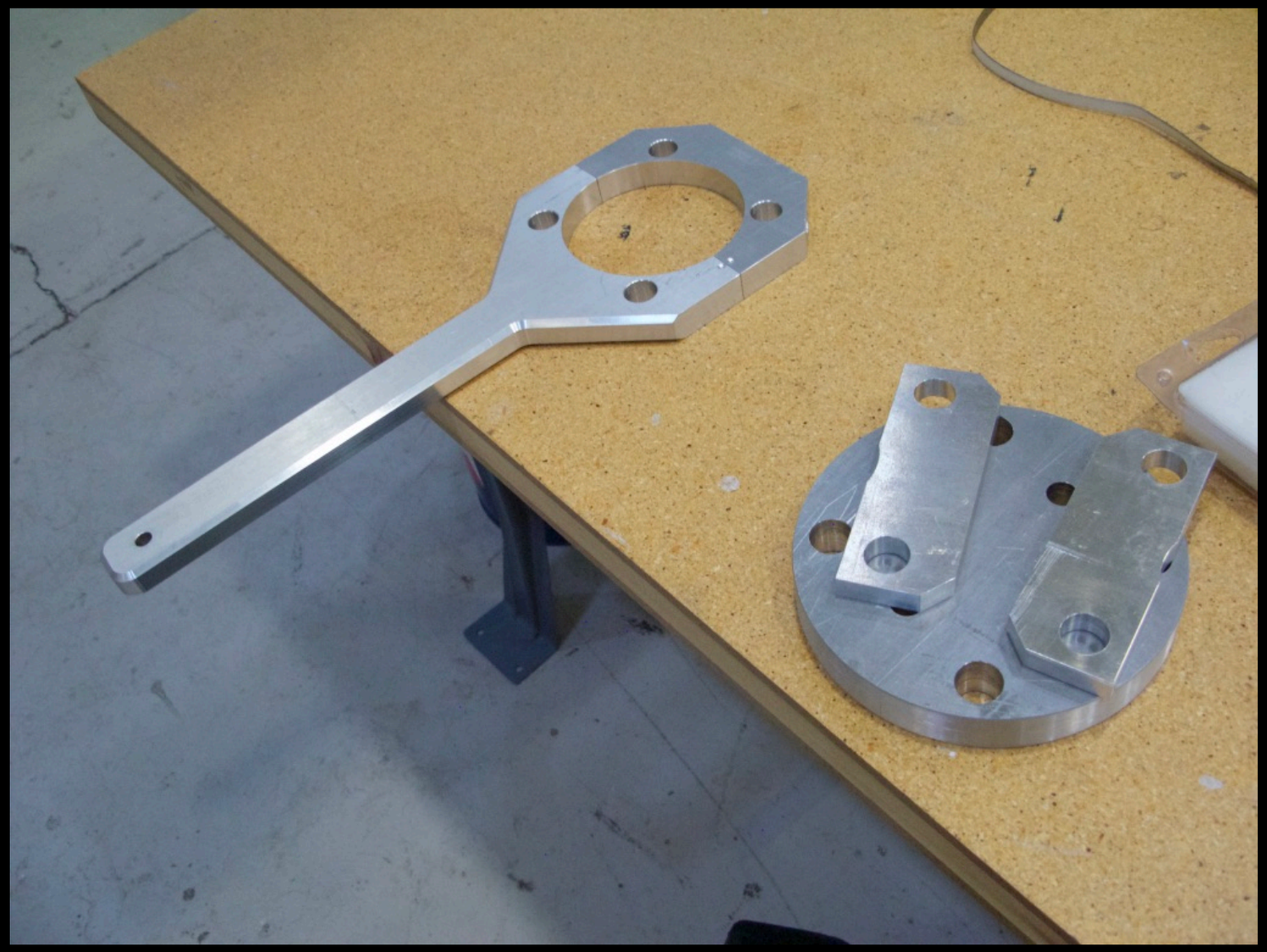
Seal and isolation design

- Ceramic plate that forms the electrical break has two offset 8mm bolt circles
- Four screws hold the ceramic-stainless seal
- The other four hold the ceramic-aluminum seal
- Note that the counterbore for socket-head screws points opposite directions for the two sets of holes



First: make the stainless-ceramic seal

- The Helicoflex seals here are too stiff to be crushed by stainless bolts alone
- External crushing force needed
- Enter… the Crusher

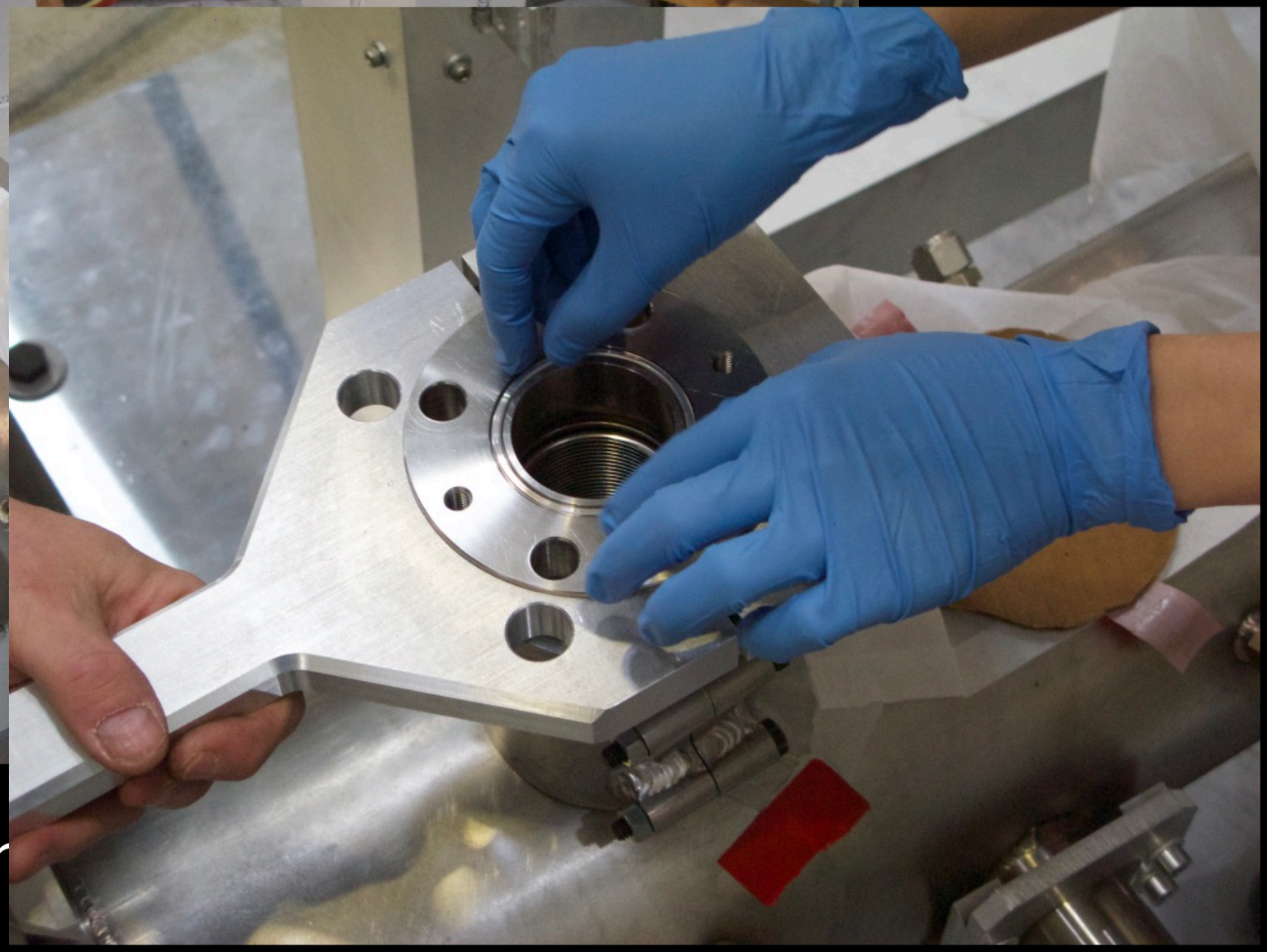


Steps to crush the Helicoflex

1. Clamp the custom wrench

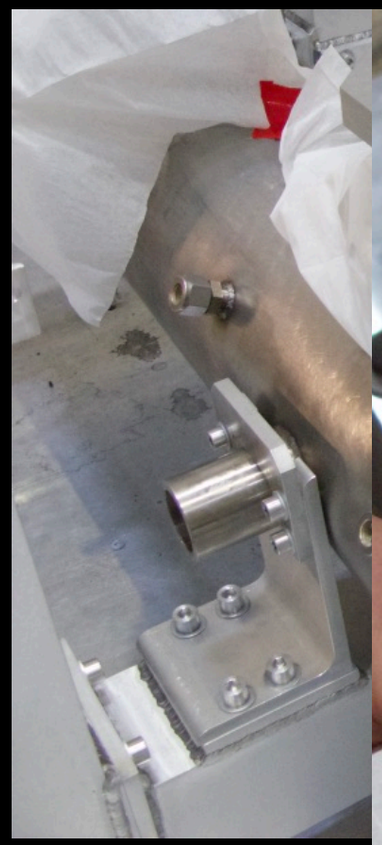
Steps to crush the Helicoflex

1. Clam

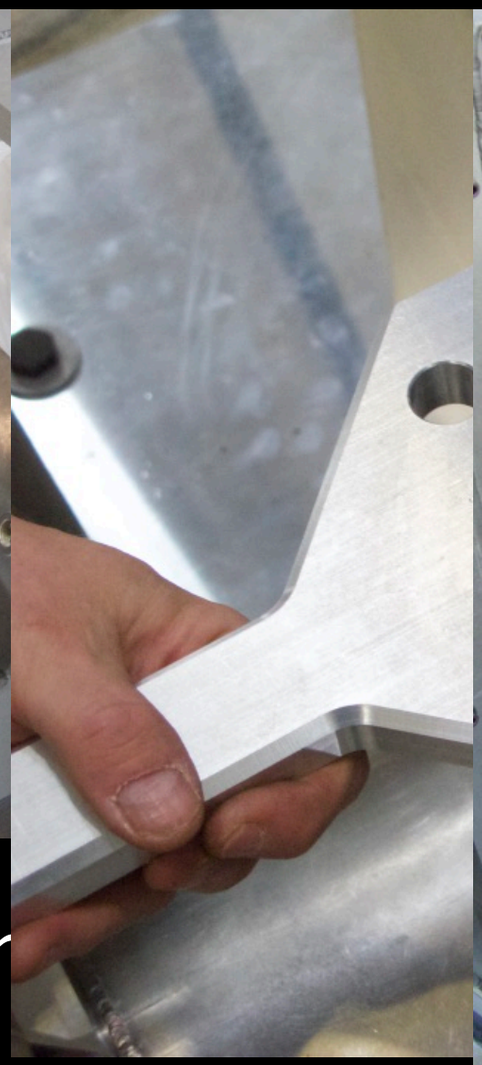


2. Place the seal

Steps to crush the Helicoflex



1. Clam

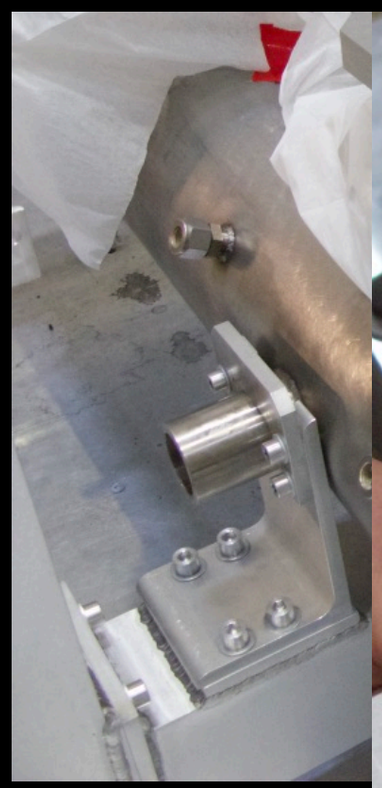


2. Place t

3. Crush the seal with 1-inch bolts

Complete when no light visible between faces

Steps to crush the Helicoflex



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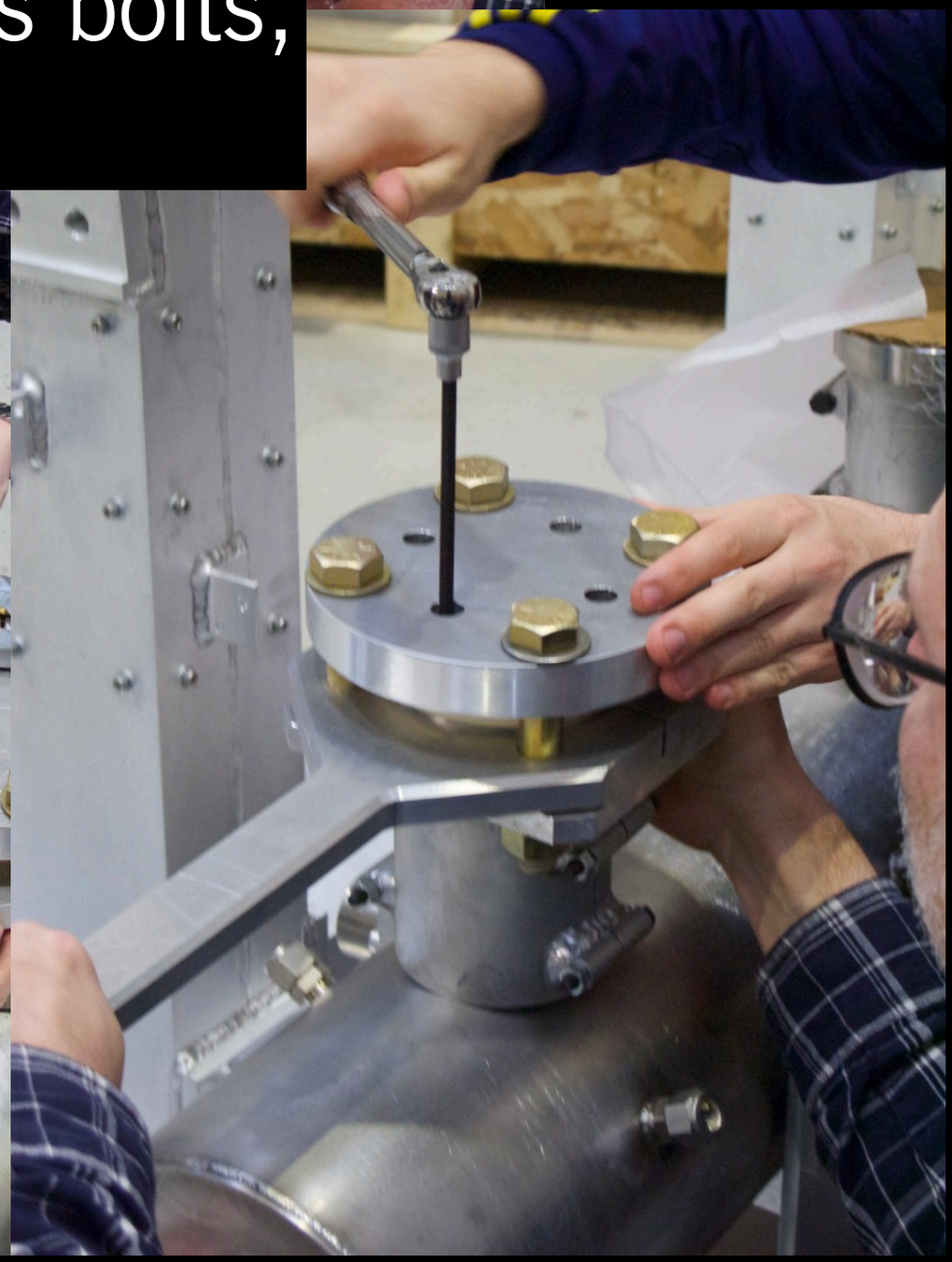


4. Insert the permanent stainless bolts, torque to spec

Steps to crush the Helicoflex

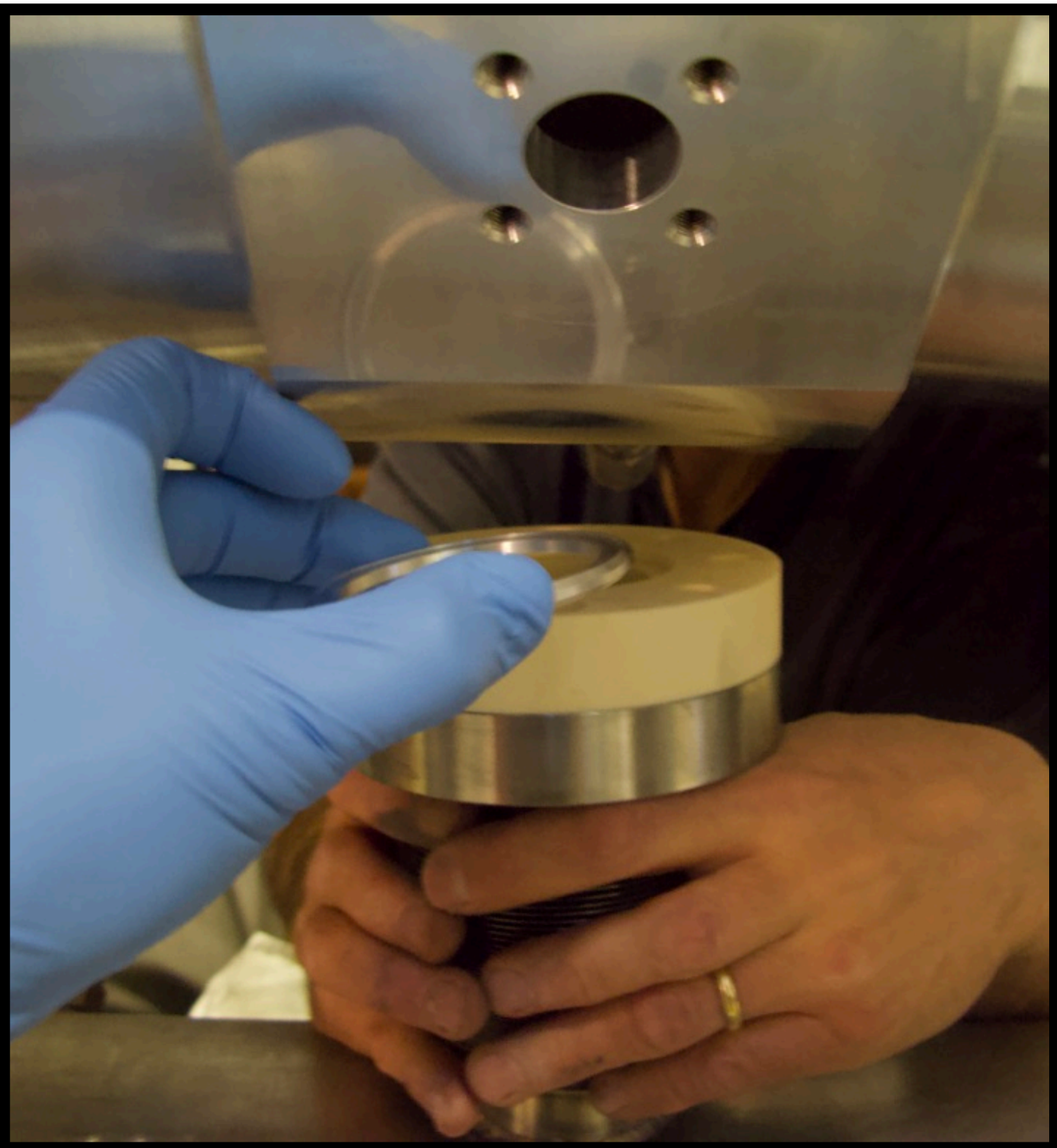
4. Ins

1. C

5. Remove the crusher

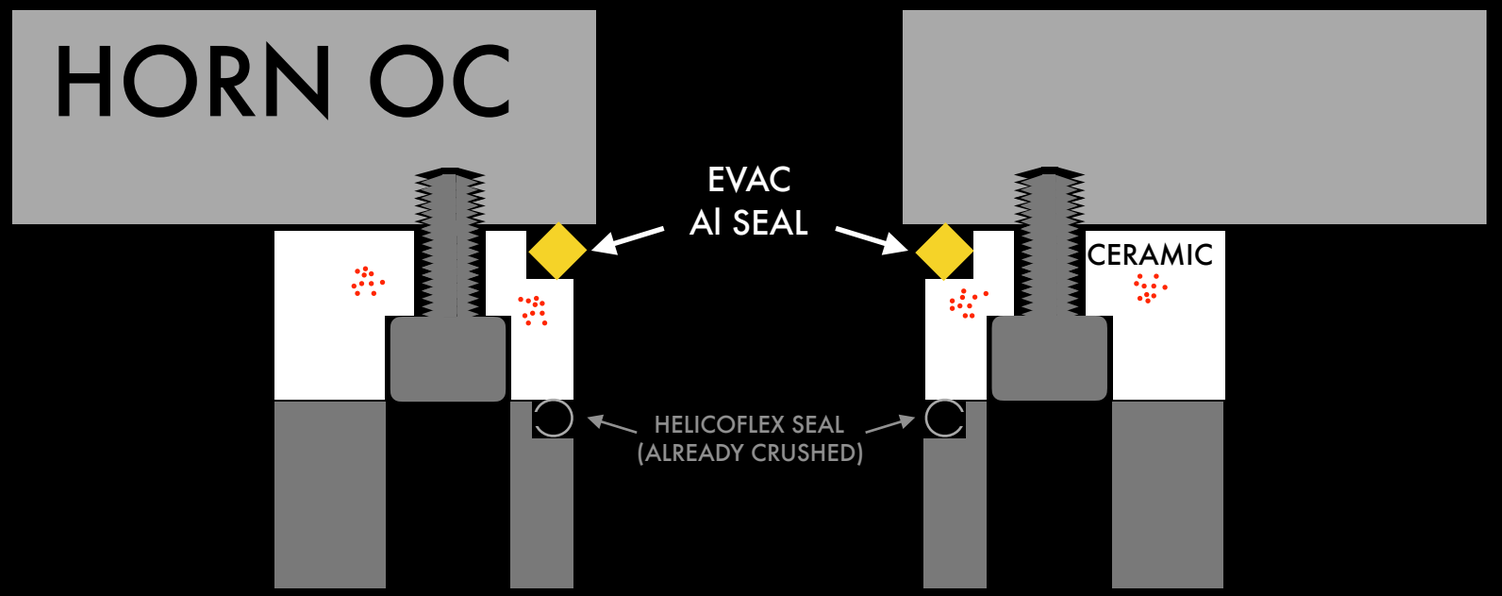
Ceramic-aluminum seal issues

- The seal is a custom EVAC diamond cross-section seal
  - Should be softer than Helicoflex
- Horn is in the way, so we can't use the crusher
- Original plan, which worked in Horn 2:
  - Crush the seals by over-torquing 8mm stainless screws in the nominal location
  - Replace the screws one-by-one with aluminum at standard torque (130 in-lb = 14.6 N-m)

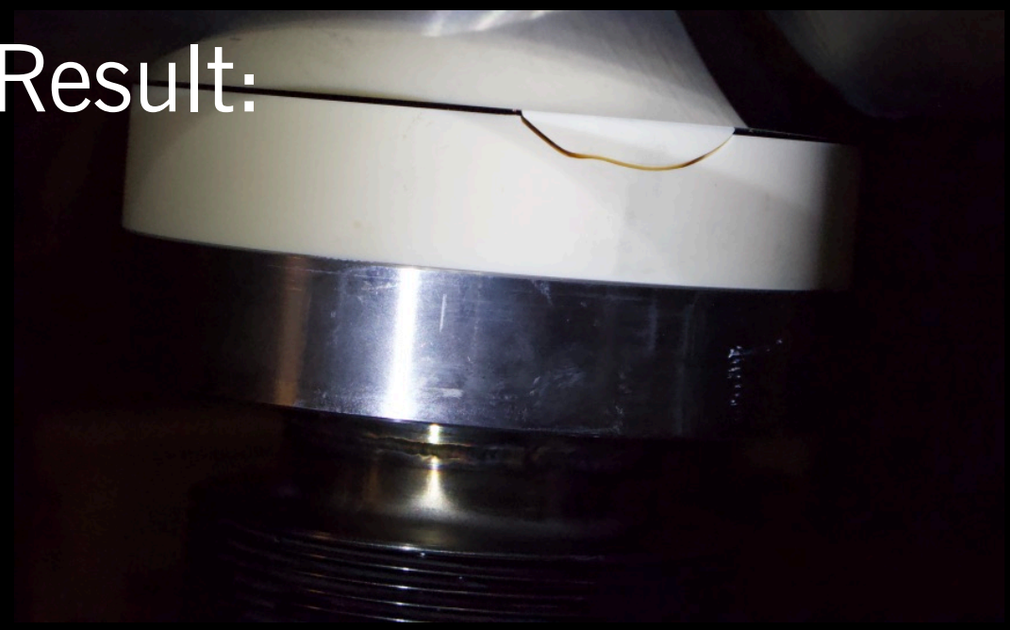


Ceramic-aluminum seal issues

- A fundamental problem with this crushing procedure is that before the ceramic is in full contact with the horn, the seal acts as a fulcrum
- A region of the ceramic (roughly the red dots in cartoon) is in substantial shear and/or tension
- Ceramics have poor strength in tension!

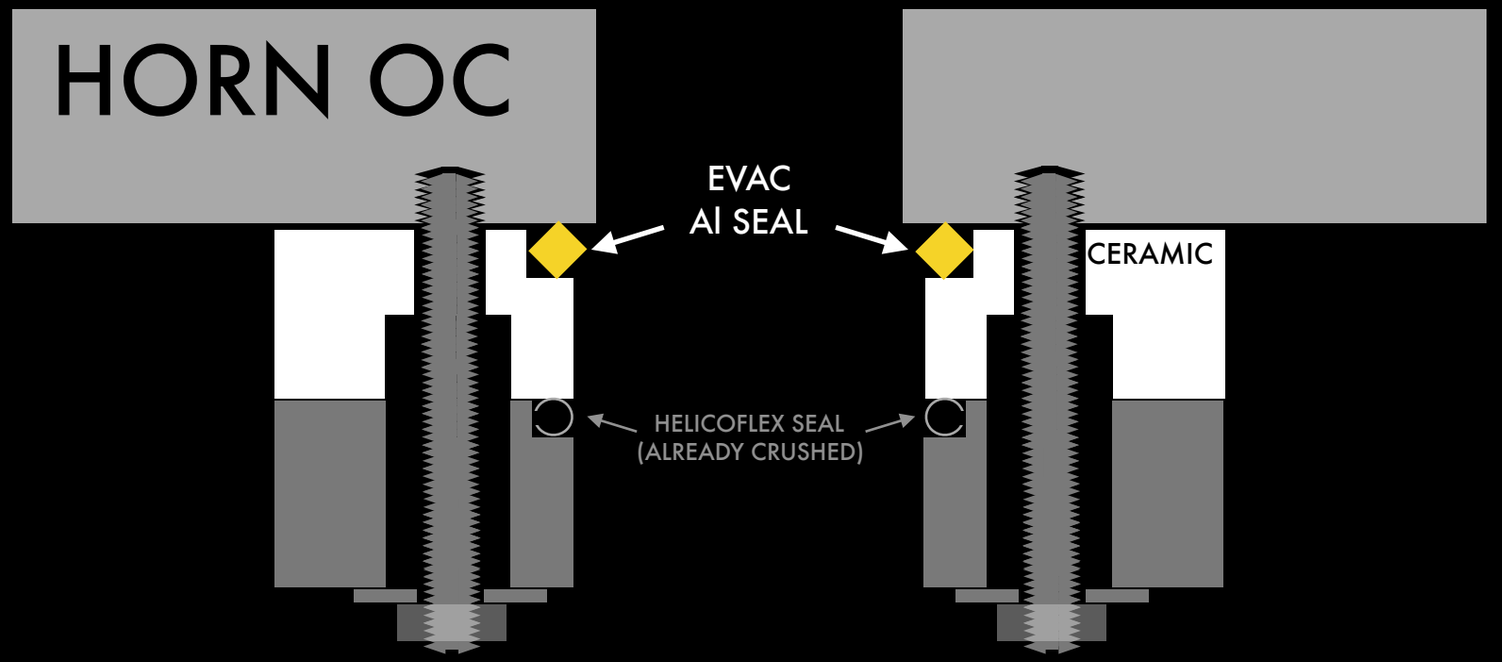


Result:



Ceramic-aluminum seal issues

- Replaced socket-head screws with grade 8 steel threaded rods
- Placed nut and washer on the far side of the stainless flange
- Seal is crushed with ceramic all in compression!
- Replace rods one-by-one with Al screws
- A side benefit: safer to apply high torque to a nut than to use Allen key on the socket head



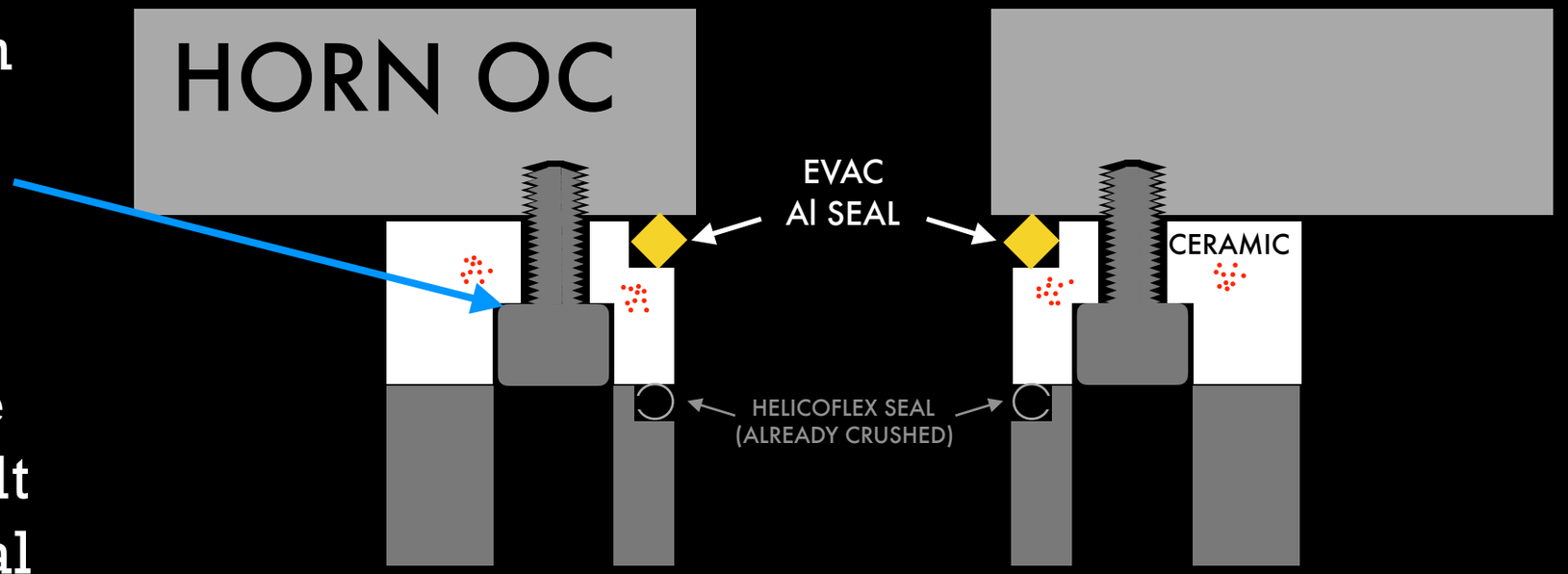
- Suggestion came from our plasma physics colleagues who use another part of the lab space

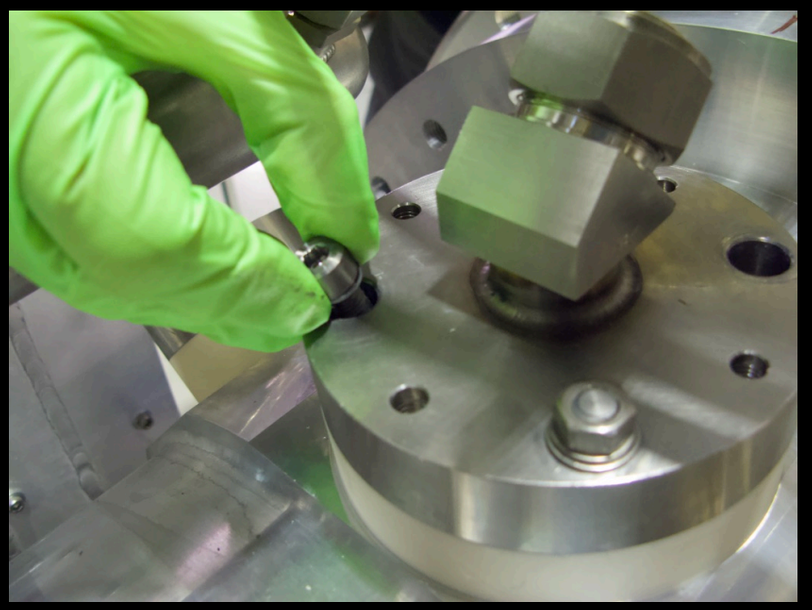
Ceramic-aluminum seal issues

- We built a test fixture for this concept
- Seal crushed to ceramic-metal contact with much less torque: 150-200 in-lb vs. not fully crushed at 400+ when the ceramic broke on the horn!
- Why would this be different?

Ceramic-aluminum seal issues

- There is friction between the screw head and the ceramic counterbore
- If friction is high, a significant fraction of the torque applied to the bolt is not translated into axial force on the ceramic
- Reduced this effect by making thin custom Al glide washers to sit inside the ceramic counterbore



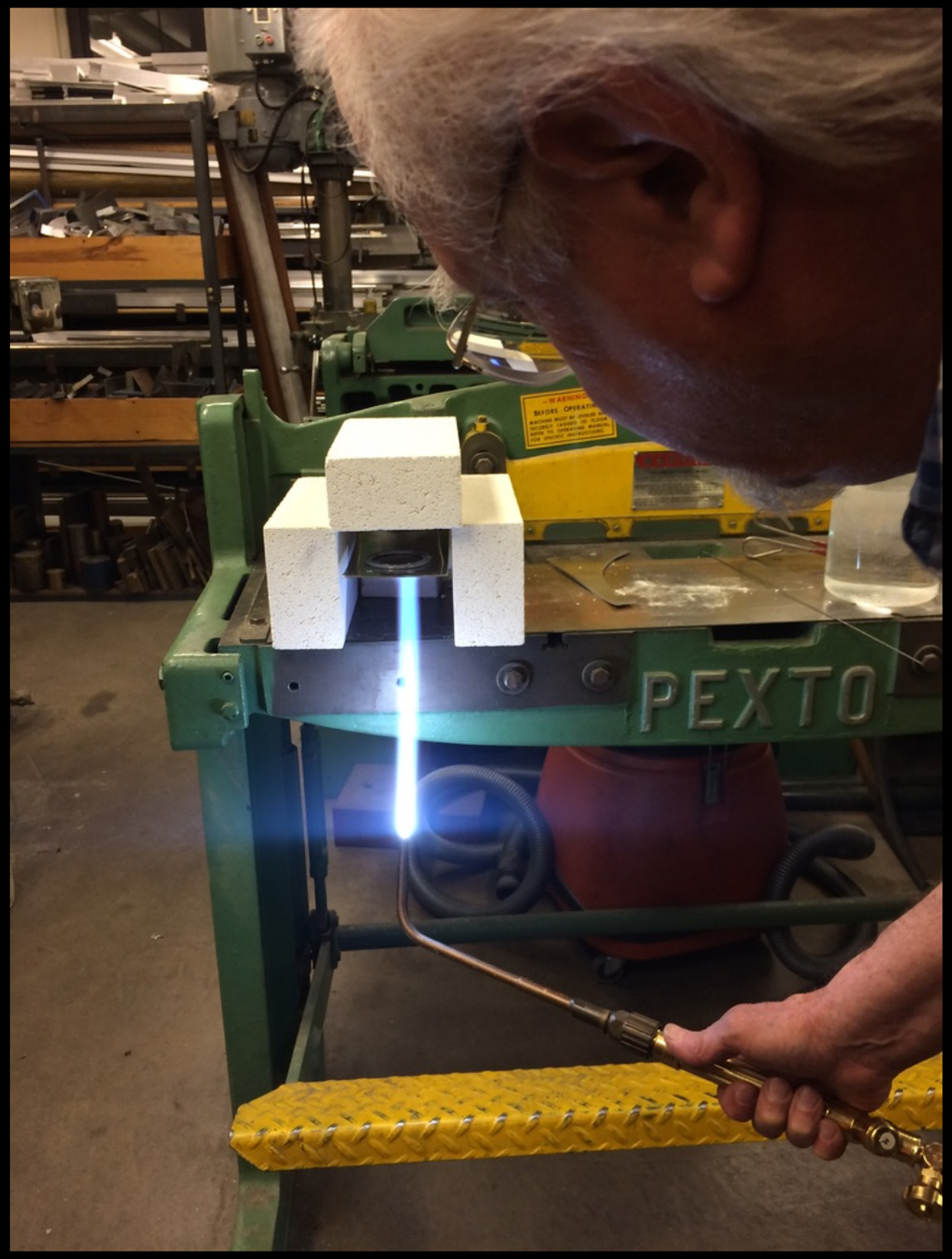


Ceramic-aluminum seal issues

- In the end, leak-tightness was achieved by:
  - Using the threaded rods and external crushing nuts to crush the seal initially
  - Replacing the threaded rods one-by-one with grade 5 titanium socket-head cap screws
  - Inserting the aluminum glide washers into the ceramic counterbores
  - Keeping the final screws at a torque of 310 in-lb (35 N-m), about 40% above nominal torque for an 8mm titanium screw
- ALL of these changes were necessary to get a seal that did not leak air under 0.5 atmospheres overpressure!

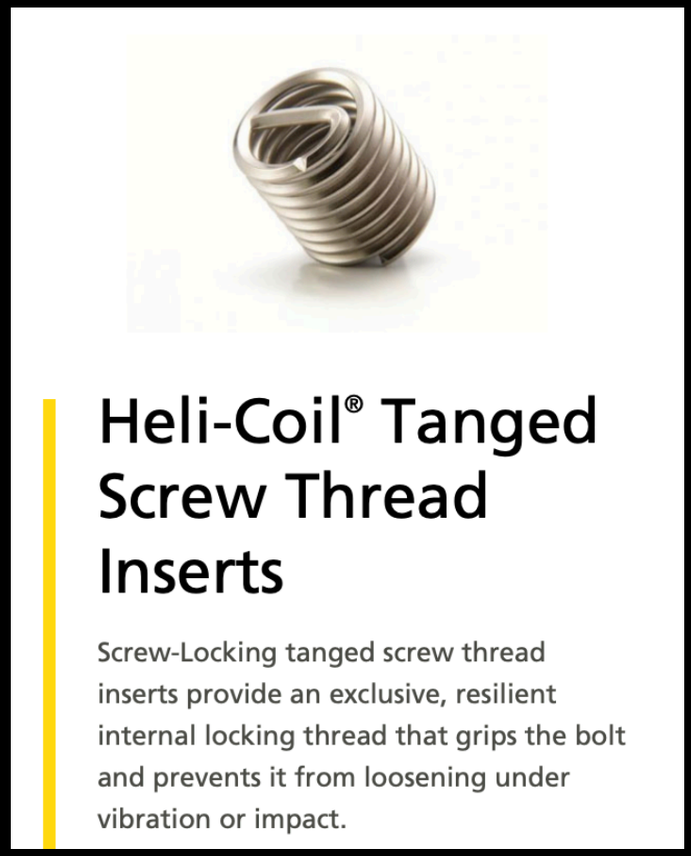
Ceramic-aluminum seal issues

- Why was this so difficult??
- The two previous horns we built had this same seal design and (though it was difficult) we crushed the seals with stainless bolts and the seals did not leak.
- Change in seal alloy hardness?
  - We tried new and old stock seals and no significant difference seen.
  - We used a Rockwell hardness tester on the seal materials. Results were difficult to interpret, but showed no significant new-old difference.
  - We even tried annealing the seals but were unsuccessful.



Ceramic-aluminum seal issues

- Only candidate we have now: Helicoils in the tapped holes in the OC
- These are thread inserts designed to improve strength and resist vibration
- Outer conductor vendor put these in all tapped holes; previous horns we built did not have these
- We did ensure the coils were properly seated before inserting screws, but this did not affect the tightening
- Previous horns made in Japan likely used helicoils, but we do not know how they crushed the seals
- Helicoil hypothesis does *not* explain the ceramic failure problem though.



For next horn: plan to specify no helicoils; replace 8mm with 10mm screws

Next project: Horn 2, SN3

- We are working with KEK now on a new Horn 2 project.
- Major changes in the design (see Sekiguchi-san's talk):
  - New strengthened inner conductor
  - New cooling loops for striplines, outer conductor flange
  - New financial structure

Horn 2, SN3

Look for updates at the next NBI!

BARTOSZEK ENGINEERING

University of Colorado Boulder

BOULDER HORN COMPANY

KEK 大学共同利用機関法人 高エネルギー加速器研究機構

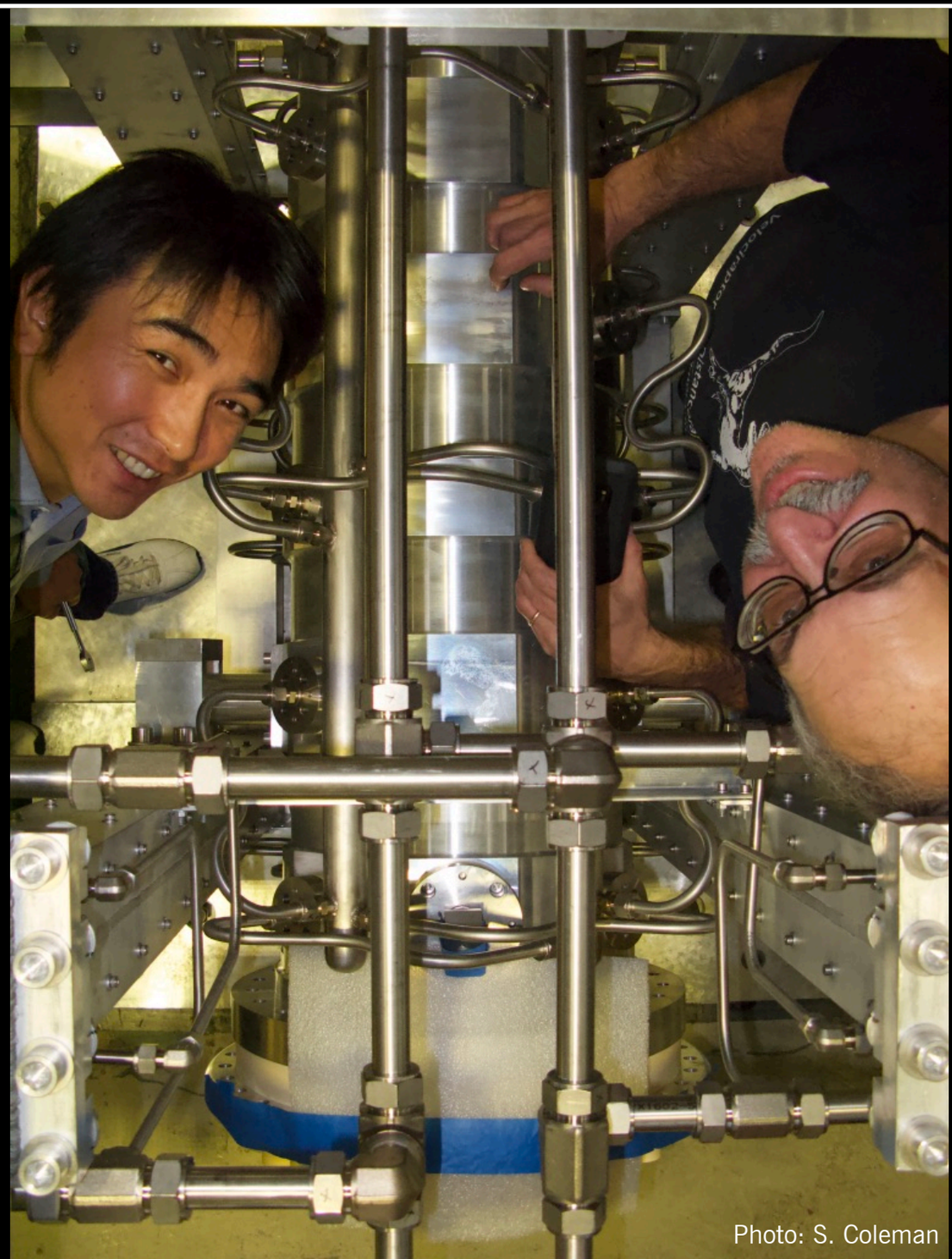


Photo: S. Coleman