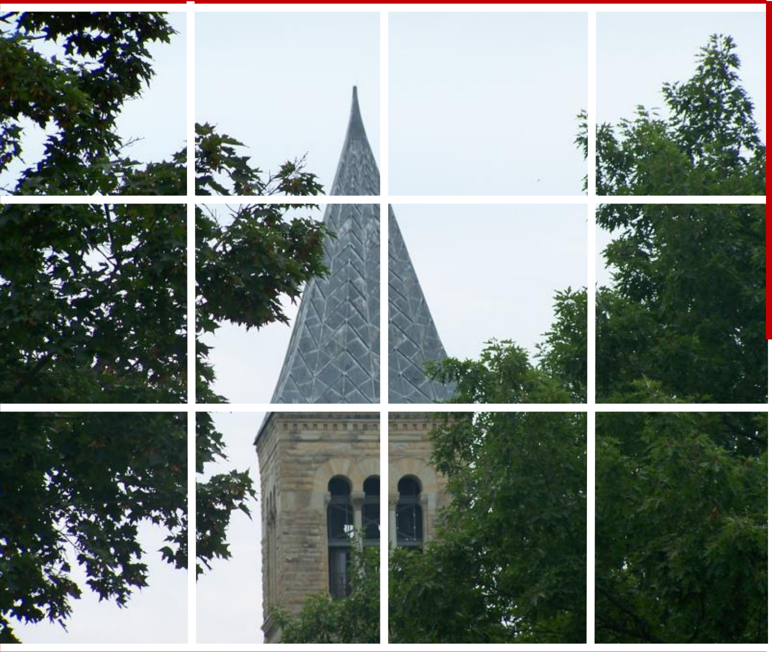
Vacuum Science and Technology for Particle Accelerators



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Albuquerque, New Mexico
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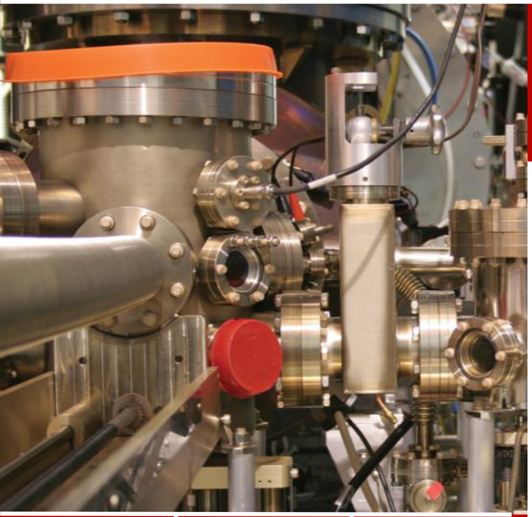
Cornell Laboratory
for Accelerator-based Sciences
and Education (CLASSE)

NATIONAL ACCELERATOR LABORATORY



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Bellows – Functions

- *Make up for transverse offsets in beamline hardware, and minor misalignments*
- *Provide installation personnel with sufficient flexibility to install hardware.*
- *Reduce stresses on adjacent vacuum joints.*
- *Provide adequate expansion and/or contraction ability during thermal cycles.*
- *Provide required movements for functioning instruments, such as beam profile viewers.*

Bellows – Key Parameters

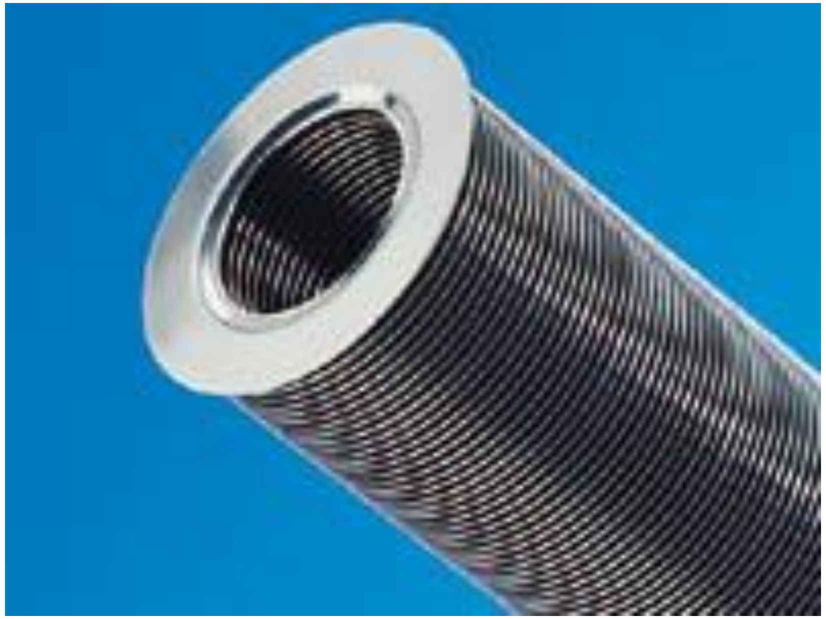
- Bellows free length
- Bellows maximum extended length
- Bellows minimum compressed length
- Bellows maximum transverse offset
- Maximum number of cycles
- Bellows end configurations

Types of Flexible Bellows

Edge-Welded

- Very flexible, both axial and transverse
- Very long stroke available
- Non-circular cross section available
- User-configurable, from most vendors

- Higher cost
- Need mechanical and corrosion protections

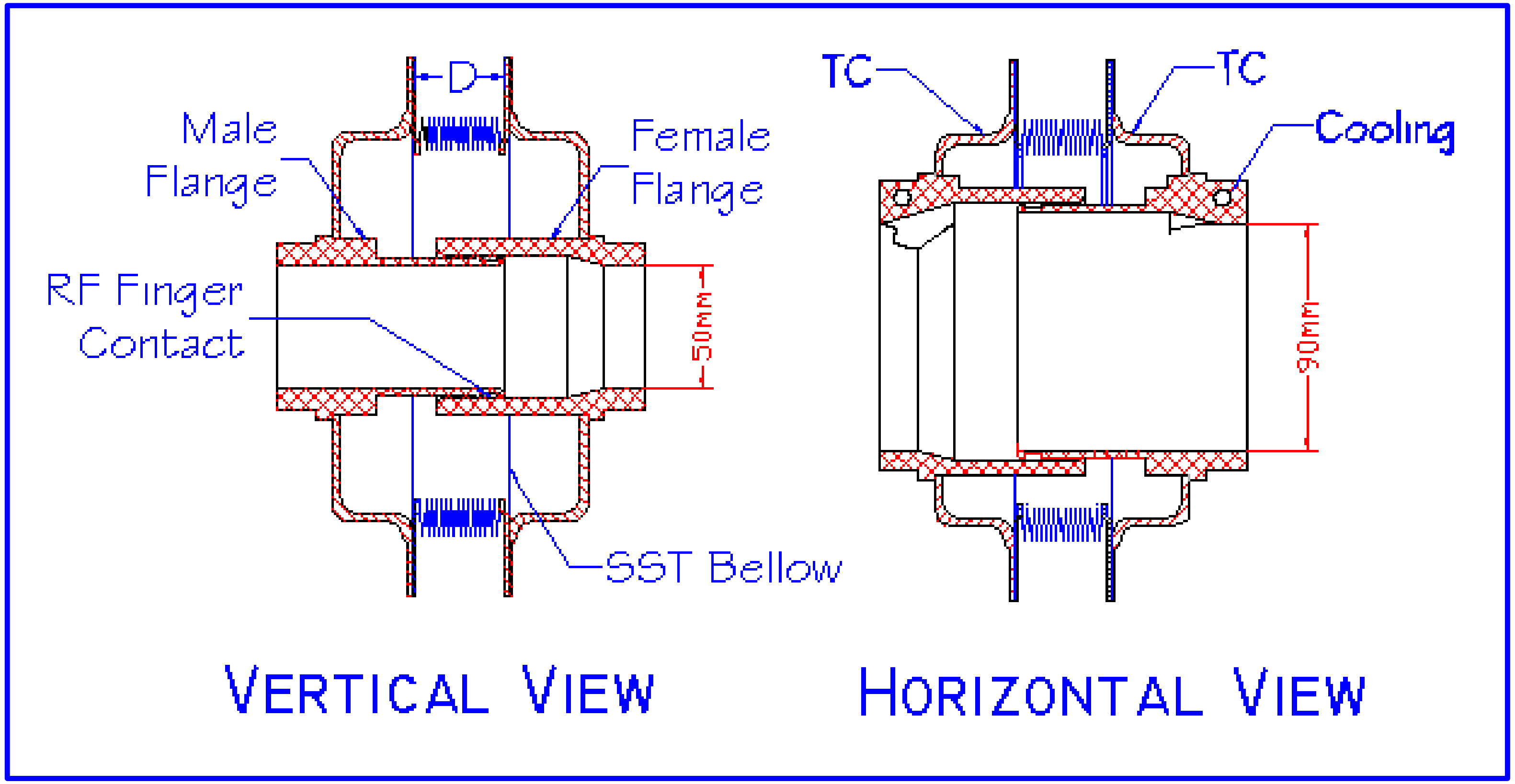


Hydro-formed

- More robust, comparing to welded
- Lower cost
- Usually good transverse flexibility

- Not good for long stroke application

RF-Shielded Sliding Joint in CESR



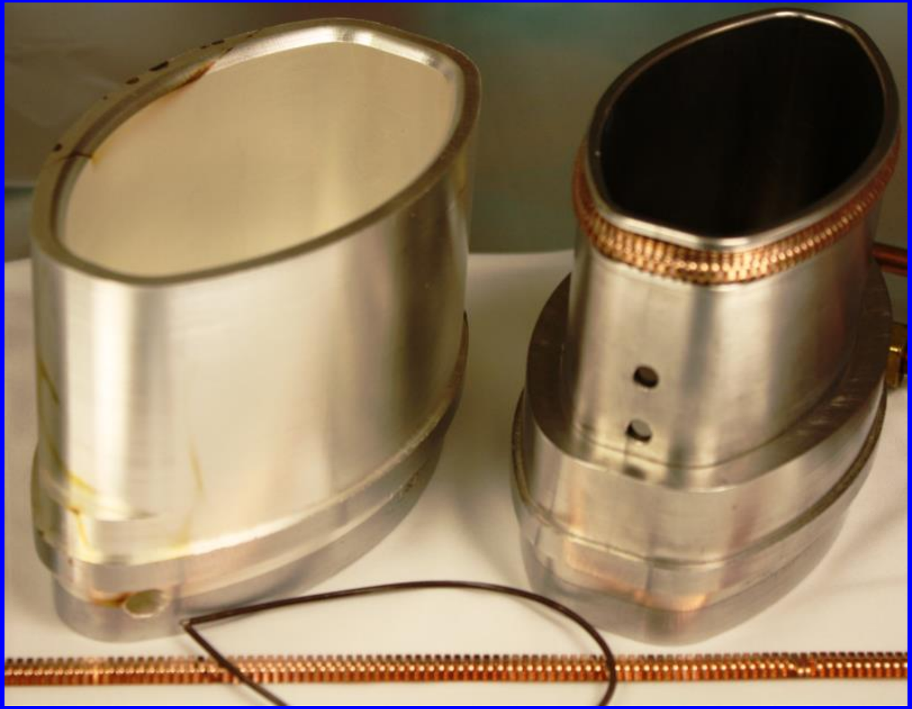
In storage rings (or accelerators with intense short bunched beams), bellows MUST be shielded from the beam. Otherwise, wake-field will be excited in the cavities to:

- → *Cause damage to the bellows*
- → *Induce negative effects to the beam.*

Sliding Joint in CESR – Parts

~120 used in CESR, each provide 1.75" Stroke

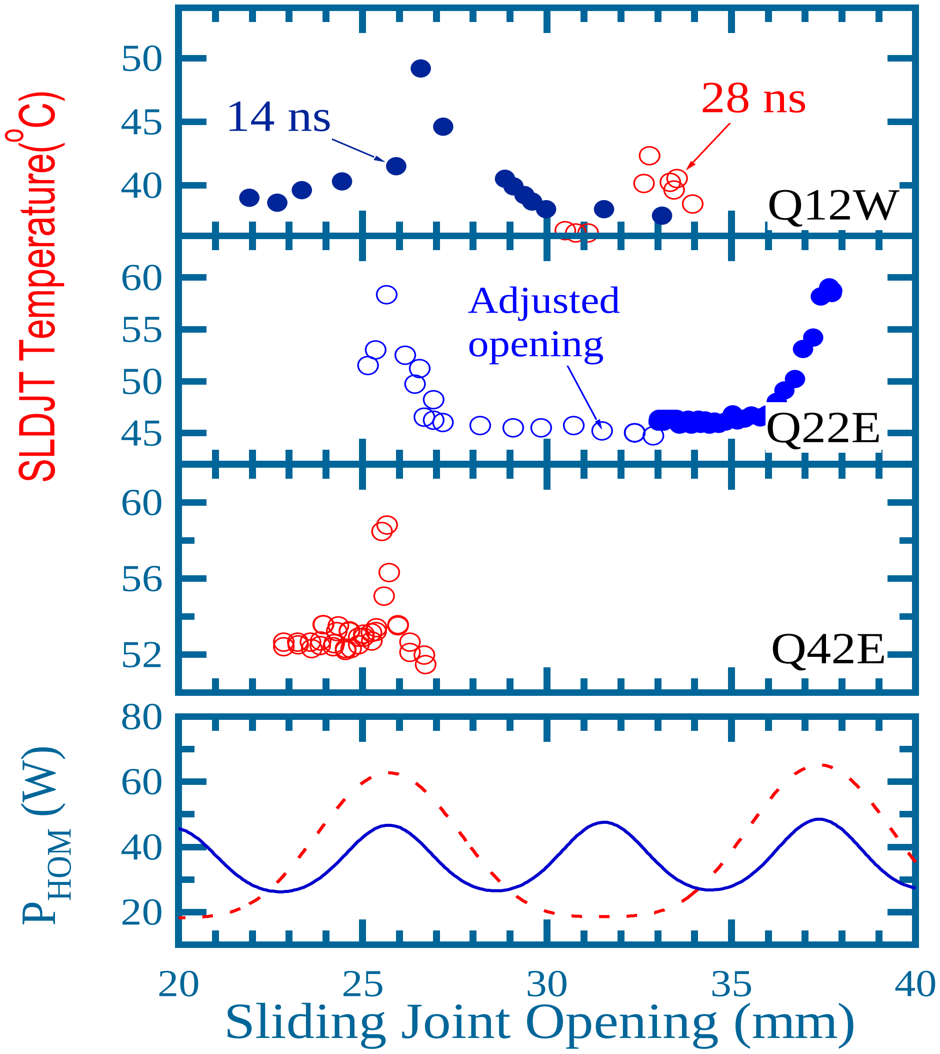
Two sliding oval-shaped tubes, made of 6061-T6 aluminum, and Be-Cu RF fingers. One with hard coating, one with silver coating.



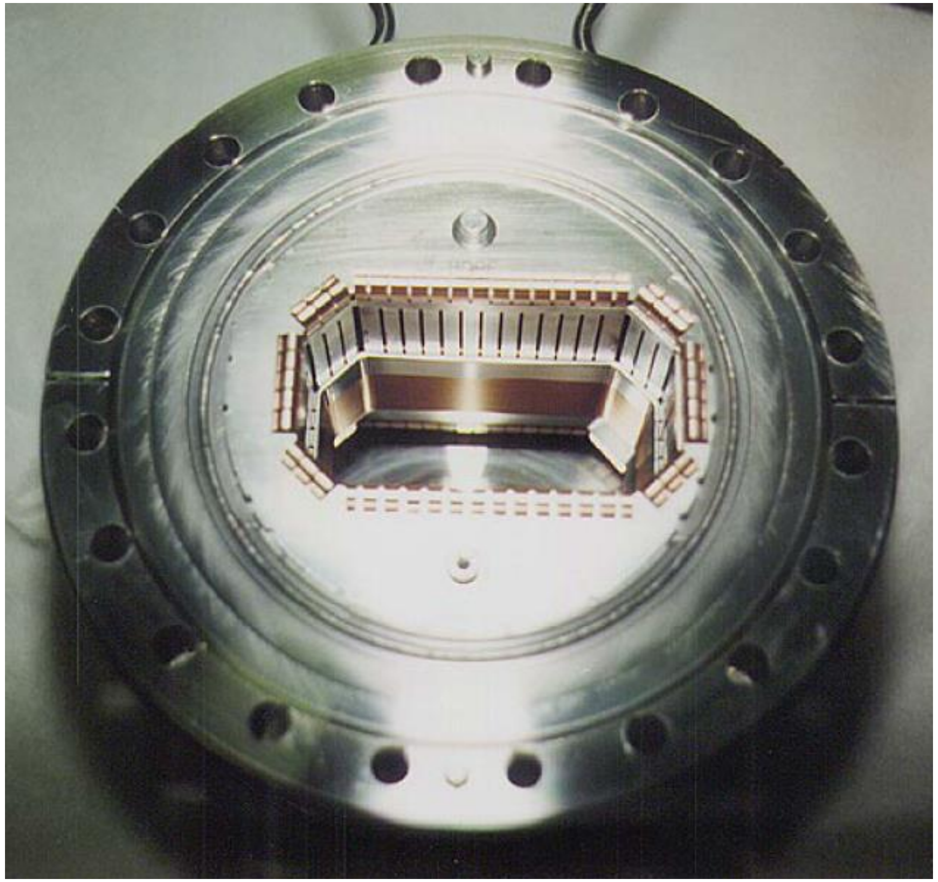
Friction bonded pans enable transitions between aluminum to stainless steel bellows

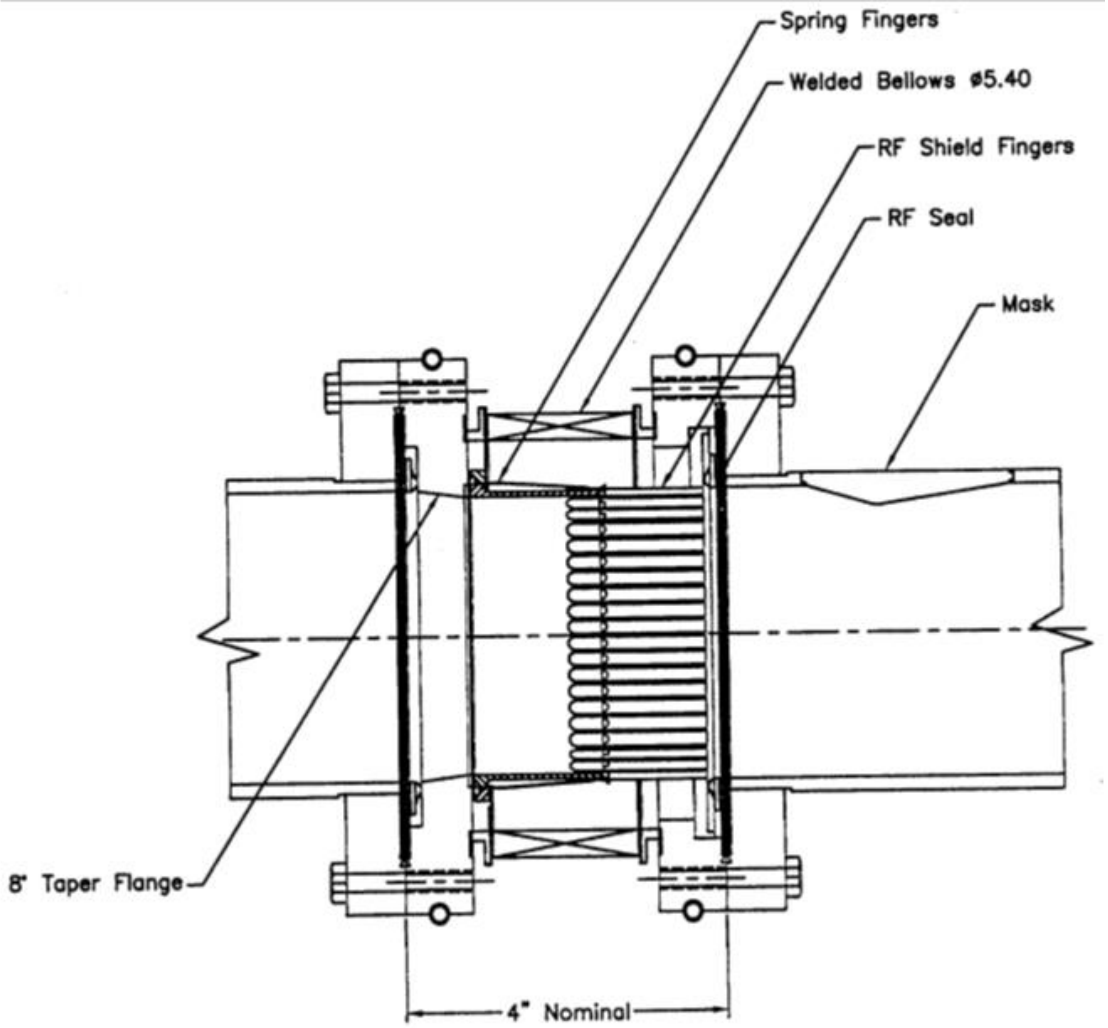
Sliding Joint in CESR – RF Heating

- *CESR sliding joint was designed more than 30 years ago.*
- *Though with the RF-contact shielding the bellows, the steps in the CESR sliding joints forms a RF cavities.*
- *We have observed resonant RF excitation in the cavities, and cause significant heating some particular opening.*
- *Most modern designs of RF-shielded bellows have much smoother transitions, to reduce RF-impedance.*

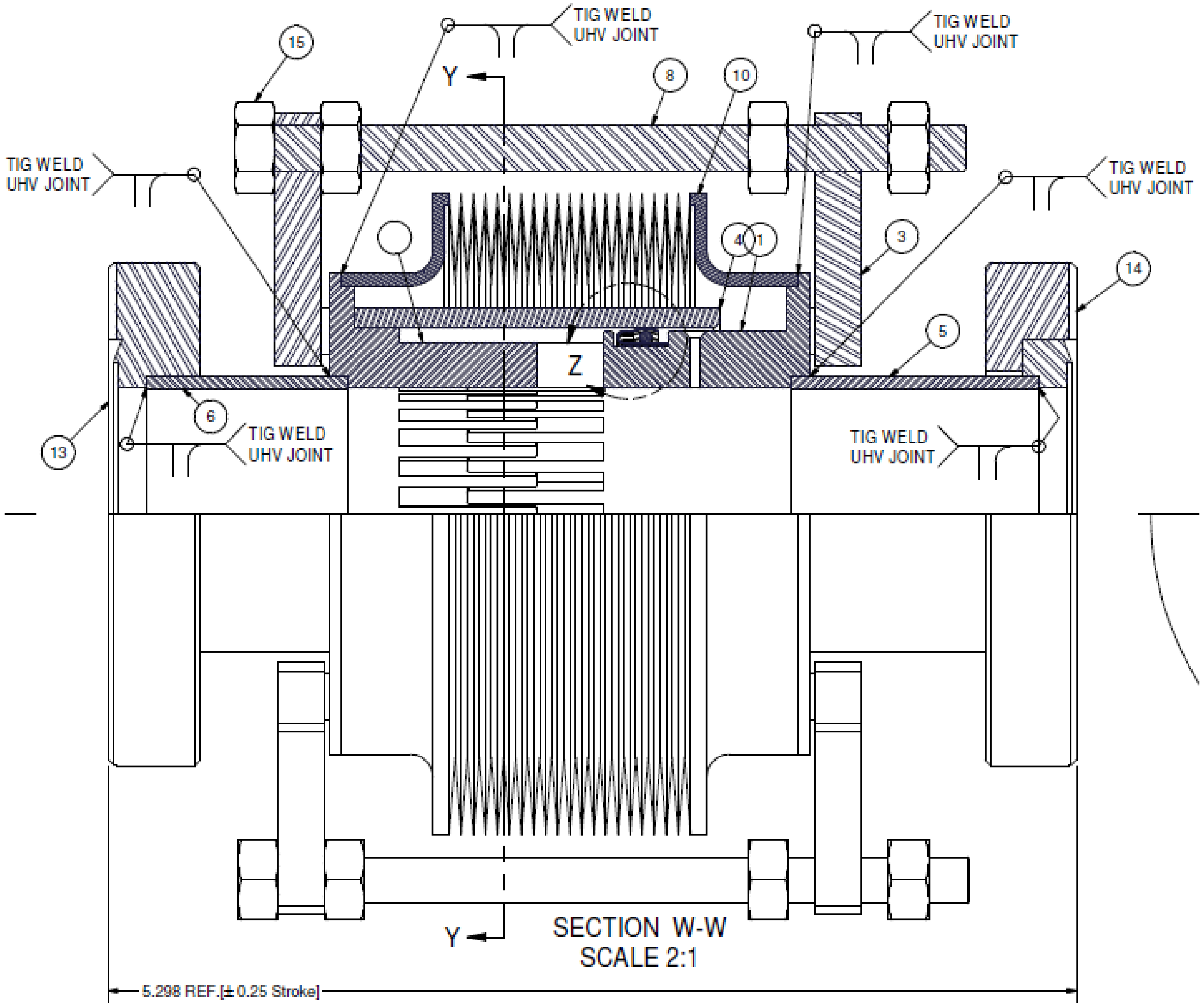


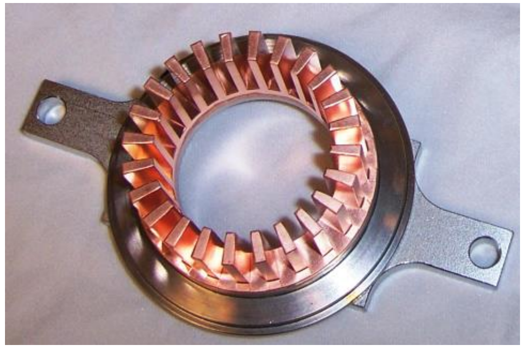
RF-Shielded Sliding Joint of PEP II

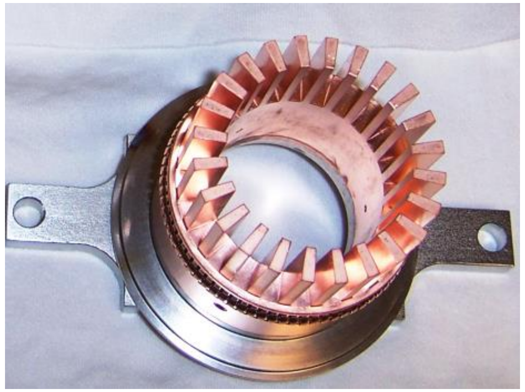




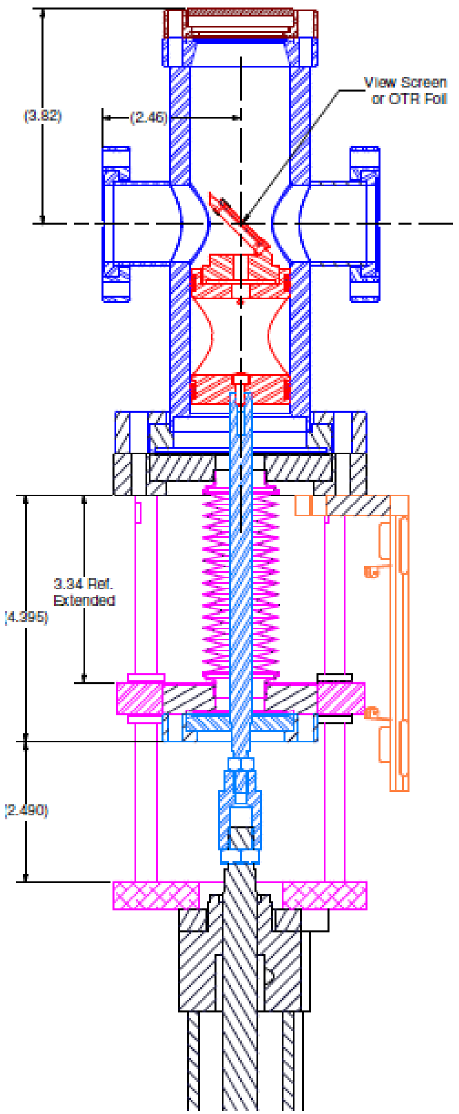
RF-Shielded Sliding Joint of KEK Style

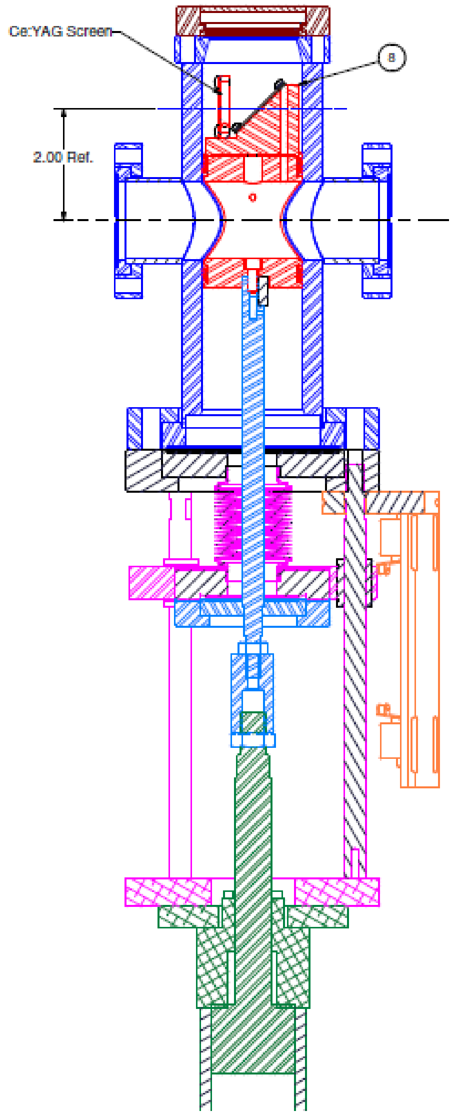


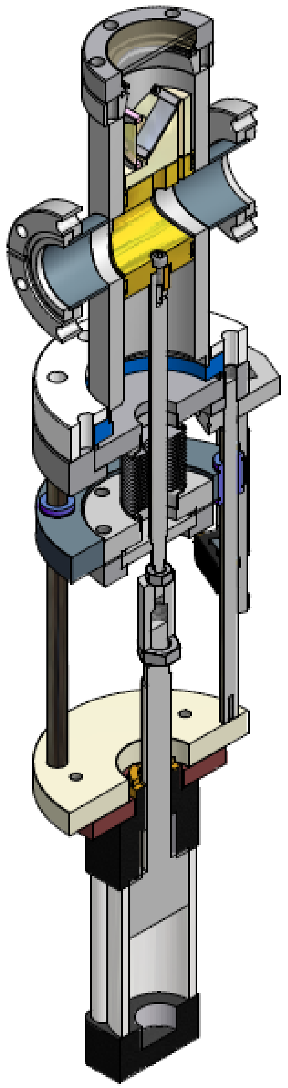


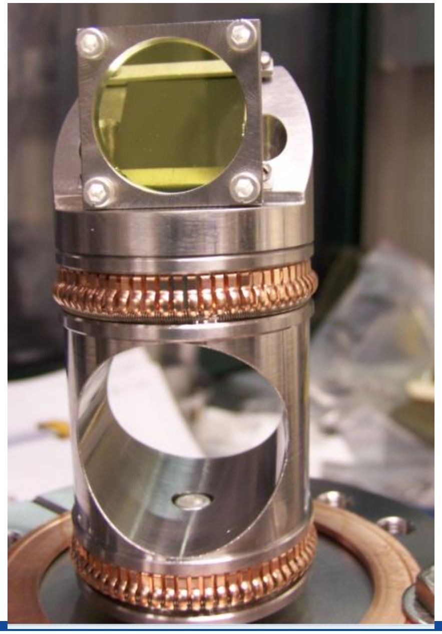


RF-Shielded Beam Viewer for Cornell ERL/CBETA





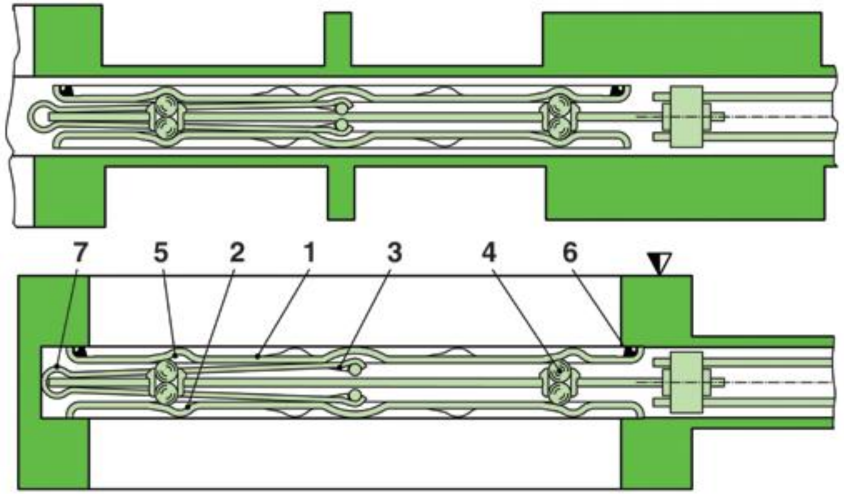




Vacuum Valves for Accelerators

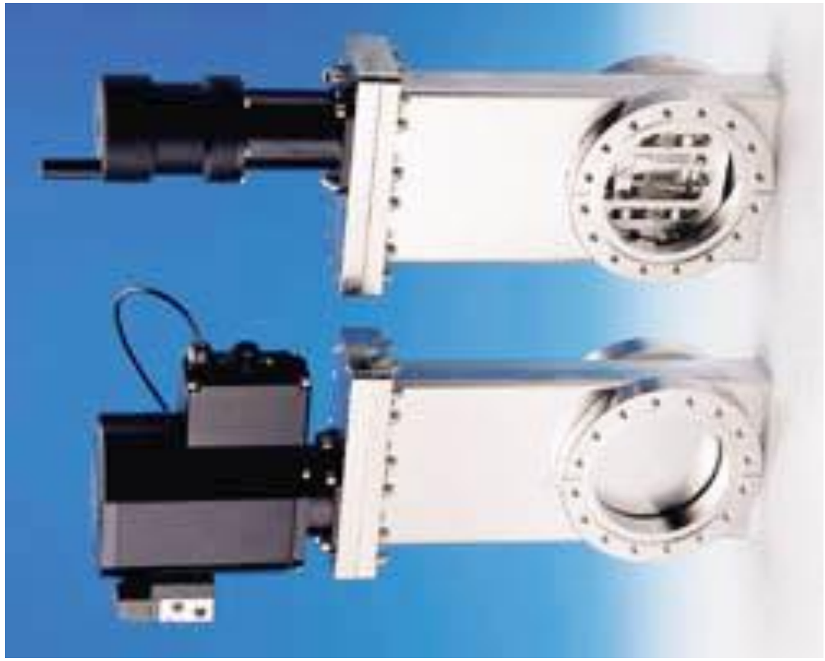
- All-metal Gate Valves
- All-metal Angle Valves
- RF All-metal Gate Valves
- Fast Closing Valves

UHV Gate Valves



- ▼ - valve seat side
- 1 - valve gate
- 2 - counter plate
- 3 - leaf springs
- 4 - ball pairs
- 5 - detents
- 6 - gate seal
- 7 - spring stop

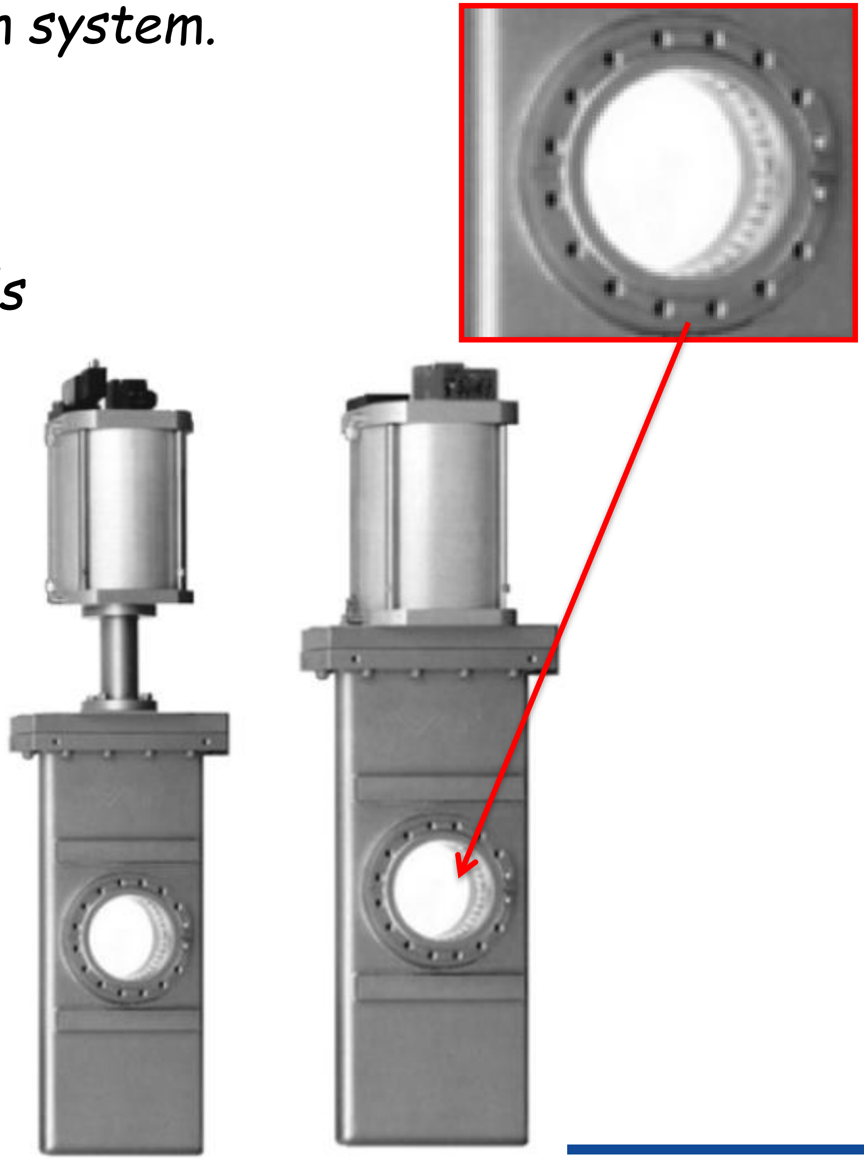
- *All-metal UHV valves only available from VAT Valves*
- *ID from 35-mm to 320-mm*



- *Gate valves with metal bonnet seals and elastomer flap seals are more available.*
- *For general UHV system, this is an low-cost alternative.*
- *ID from 35-mm to 320-mm*

RF Shielded All-metal Gate Valves

- *Used as sectoring vacuum sections in large accelerator vacuum system.*
- *Pneumatic actuated, allowing vacuum system interlocking.*
- *316L stainless steel body with elastically deformed metal seals*
- *RF trailer deploys at open position.*
- *Max. operating temperature 200°C*
- *Bellows sealed, allowing 100,000 cycles*



RF Seal on CESR Gate Valve

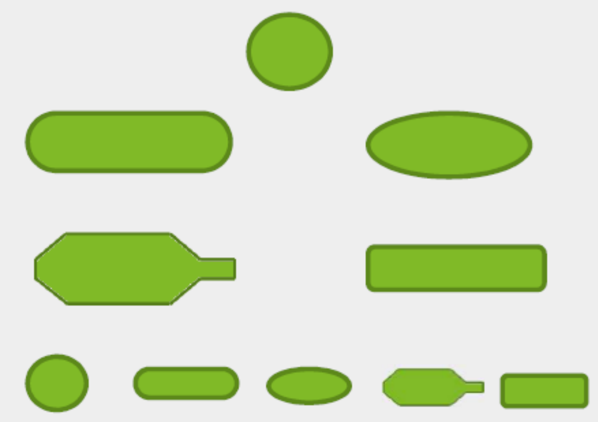
Comb-Style RF Seal on KEK/TPS GVs

IUVSTA 80 WORKSHOP

ALL METAL RF SECTOR VALVES – DEVELOPMENT AND POSSIBILITIES

KURT SONDEREGGER – GENERAL MANAGER ALL-METAL VALVES

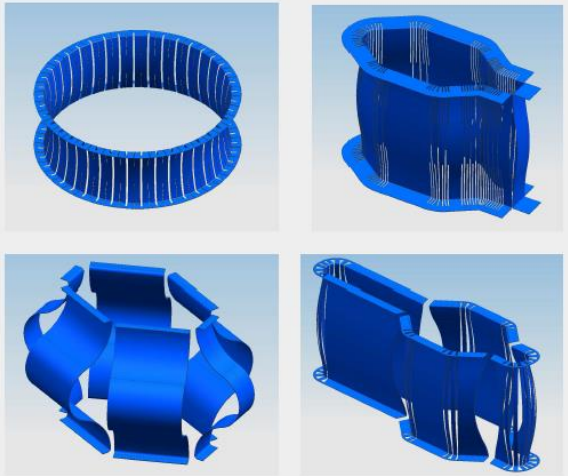
27.OCTOBER 2016



VAT gate valve shapes

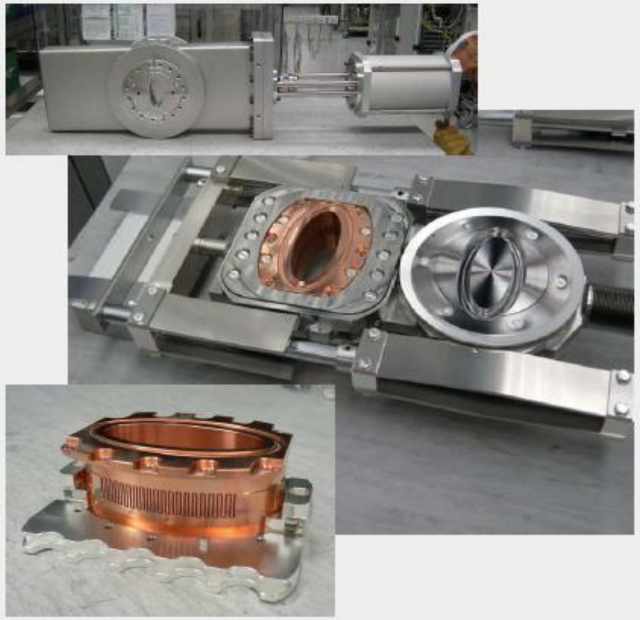
RF valves

- At the beginning the RF contacts were made with single RF fingers
  - Difficult in assembly
  - No uniform bending around the circumference
- Then all the valves were changed to RF bands
  - No slots in straight sections
  - Uniform bending
  - Easy assembly and clamping for best repeatability

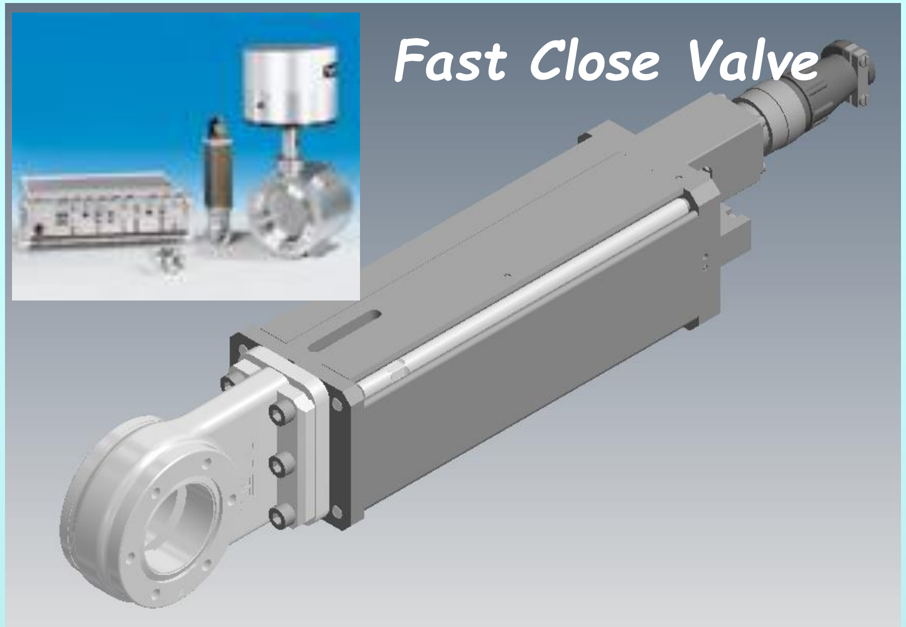


Comb type RF valves

- Based on the comments of Spring 8 we expected, that this is not a solution for synchrotrons
- However it will be a solution for powerful basic research accelerators
- Then NSRRC (TW) tested two prototypes and decided to go with the comb type RF valves for their new 3-GeV light source – the Taiwan Photon Source (TPS)



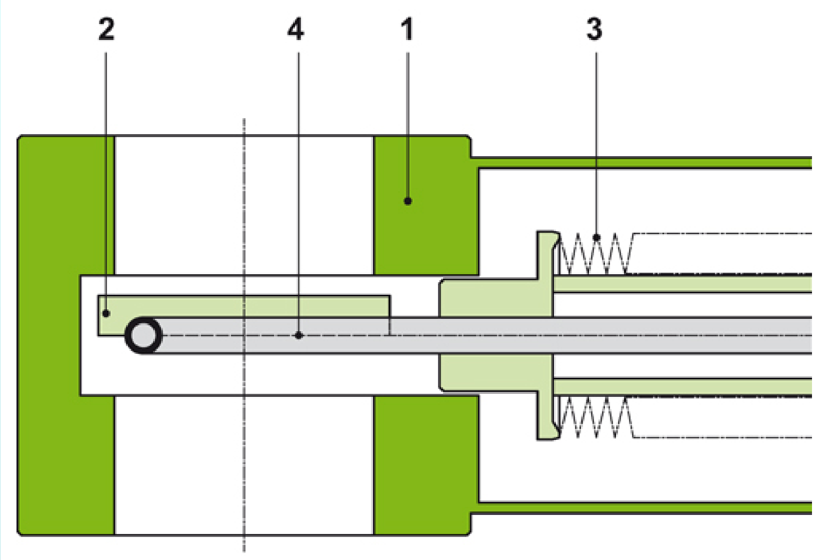
Fast Close and Beam Stop Valves



- Closing time: < 10-ms after trigger
- Usually used on X-ray beamlines
- Need reliable and fast vacuum gauges at engineered distance from the valve, to provide sensible valve closing trigger.
- Most firings are false trigging !!

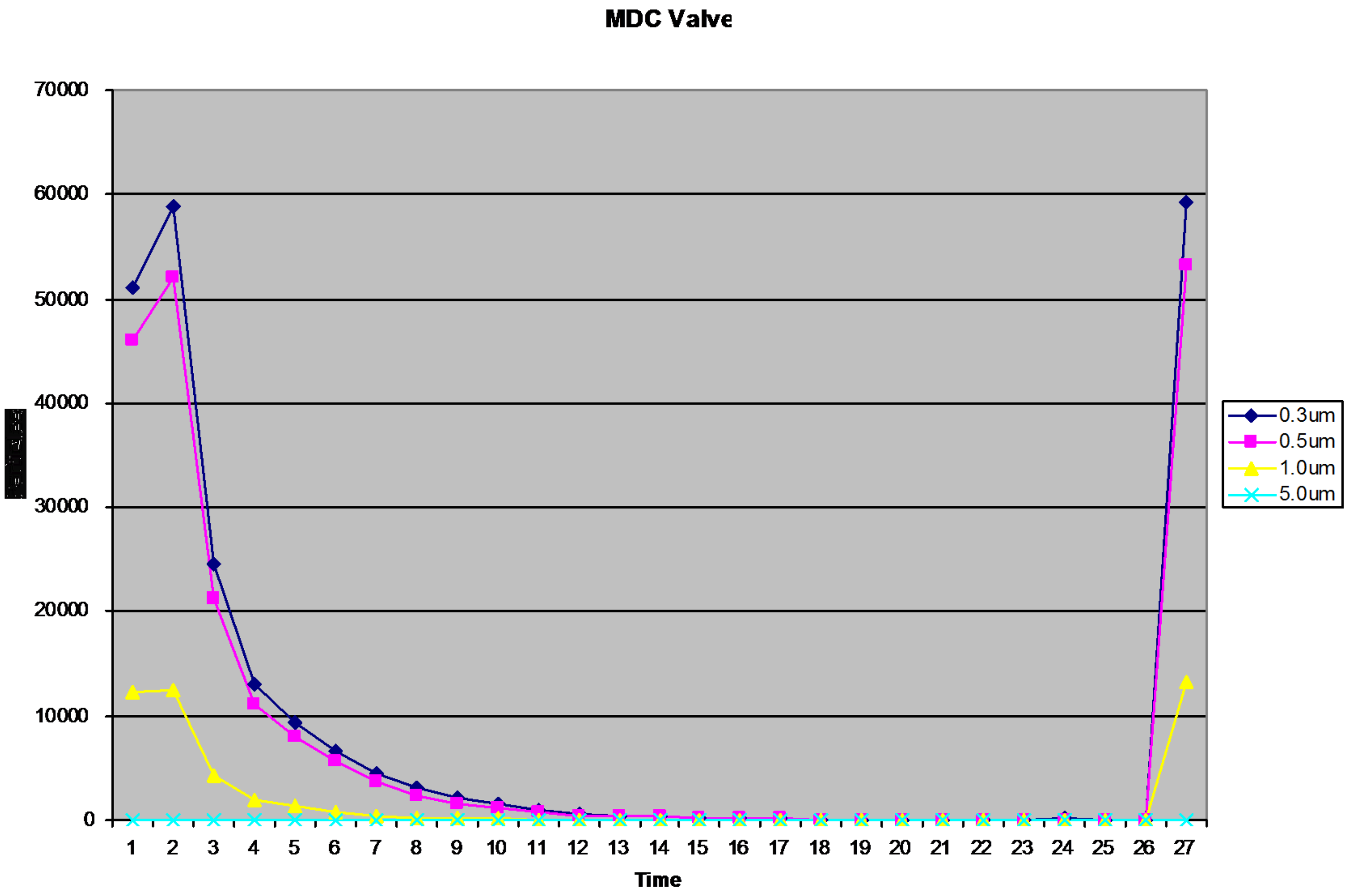
Beam Stop for X-ray beamlines

- P_{max}: 5 kW
- Max. Power density: 25 W/mm^2

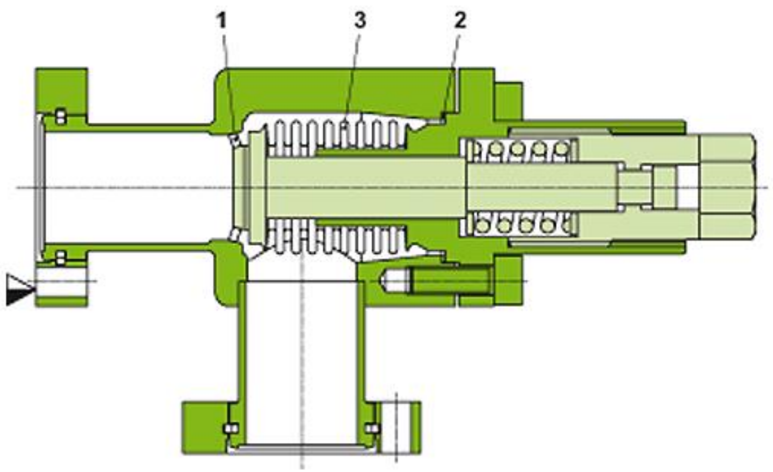


1. Body; 2. Copper Plate
3. bellows; 4. Water cooling

Particle Generation While Actuating Gate Valves



All-metal Angle Valves



- ▼ - valve seat side
- 1 - VATRING
- 2 - bonnet seal
- 3 - bellows

- *All-metal Easy-Close angle valves, no torque wrench needed.*
- *Best in dust-free environment*

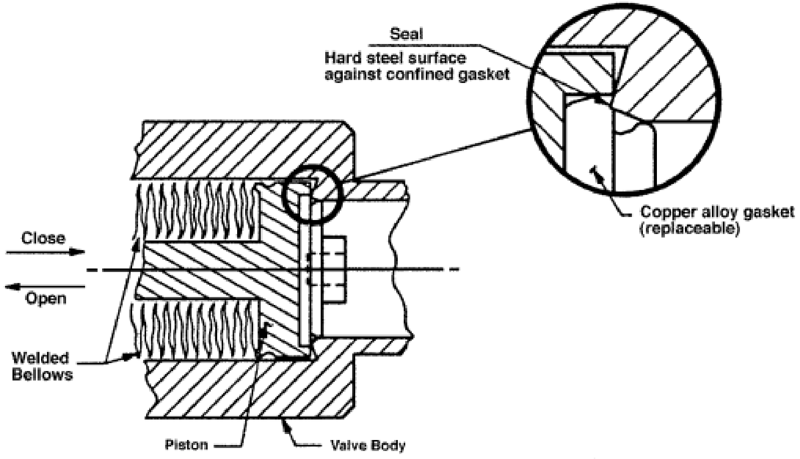
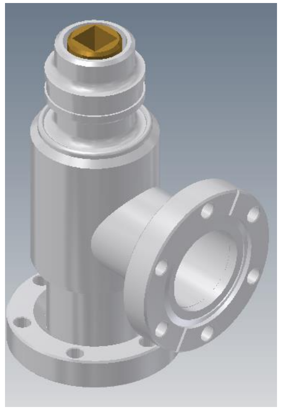


Figure 1-1 Sealing Principle

- *All-metal angle valves with copper gasket seals. More robust.*
- *More sealing cycles with increasing torque*



Used for roughing, purging and venting vacuum systems

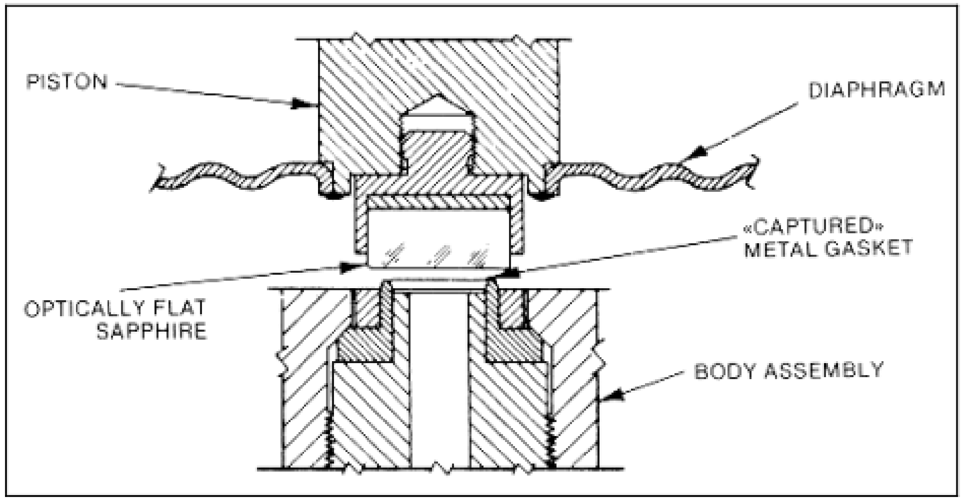
Variable Leak Valves

- A variable leak valve is used for vacuum equipment that need to control the amount of gas introduction.

- It enables the gas introduction of remarkably small amount; minimum controllable leakage is less than 1×10^{-9} torr·L/sec.

- Additionally, it is all-metal and can be baked up to 450℃, making it ideal for ultra-high vacuum equipment.

- The seal surface is fragile, so one must NOT close the valve too fast.



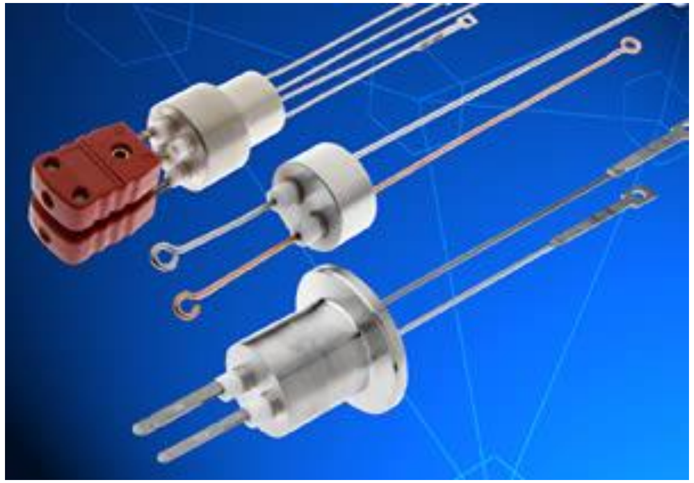
Electrical Feedthroughs

- Coaxial
- Power
- High Current
- High Voltage
- Breaks
- RF Power

Instrumentation Feedthroughs

Multi-pin feedthroughs

Sub-D feedthroughs



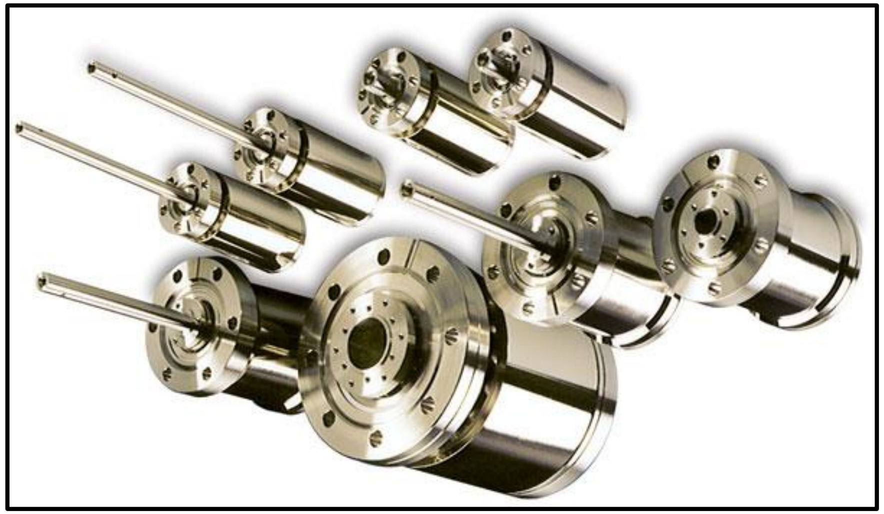
Thermocouple feedthroughs

Linear Motion & Multi-motion Feedthroughs

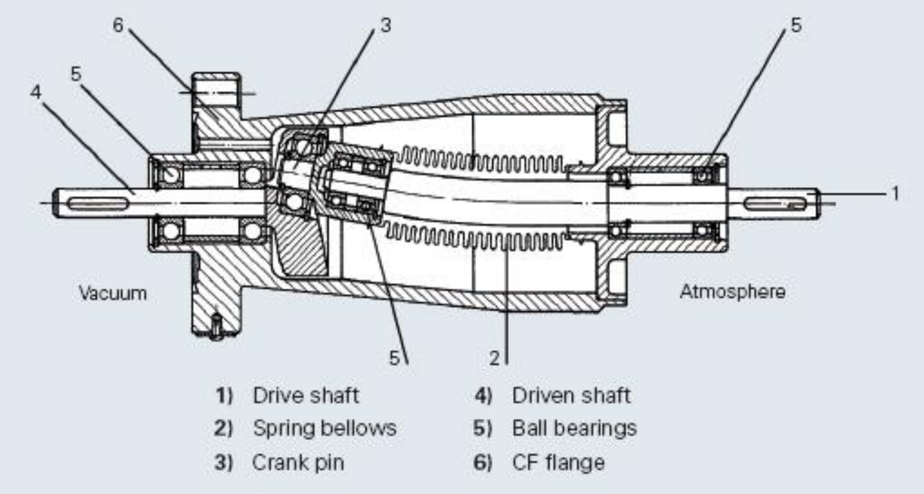
- The class of feedthroughs span from simple "push-pull" to precision units.
- Manual, motorized, and pneumatic action.
- UHV compatible
- Linear travel ranges from ½" to 6".
- Magnetic coupled translator for over 48" travel. For very long translators, 'dead-end' pumping may be required for some UHV applications.
- Multi-axis stages

Rotary Motion Feedthroughs

- *Manual or motorized actuation.*
- *UHV compatible*
- *Torque to 50 oz-in*
- *Speeds to 50 rpm*



Magnetic Coupled

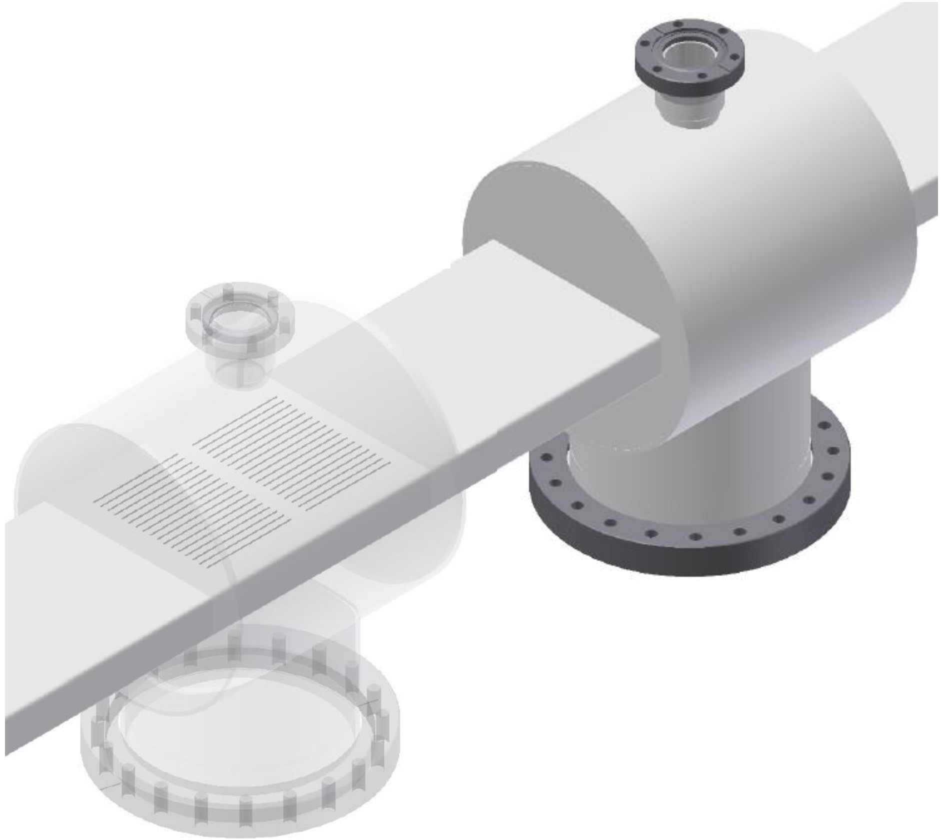


Bellows Coupled ("Cat's Tail")

Pumping Ports for Beampipes

These components must maximize conductance to the pump, while minimizing detrimental effects on the beam.

- To connect the beam space to the vacuum pumps, opening have to be made between the beampipe wall and the pump port.
- The most common openings are in the form of slots along the beam direction, as illustrated here.
- Beam bunches passing by the slots radiates RF power, contributing RF impedances.
- The losses from the pumping slots should be checked to within the allowed impedance 'budget'.



RF Loss Factor of Pumping Slot

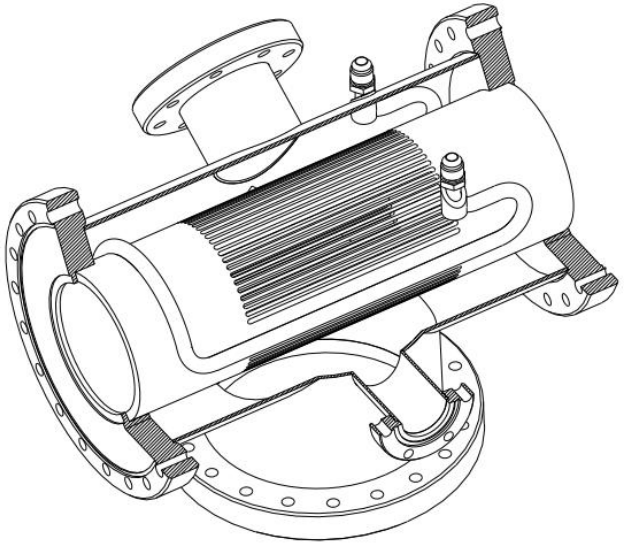
For a single slot on a round beam pipe, the loss factor (in unit of V/ pC) is:

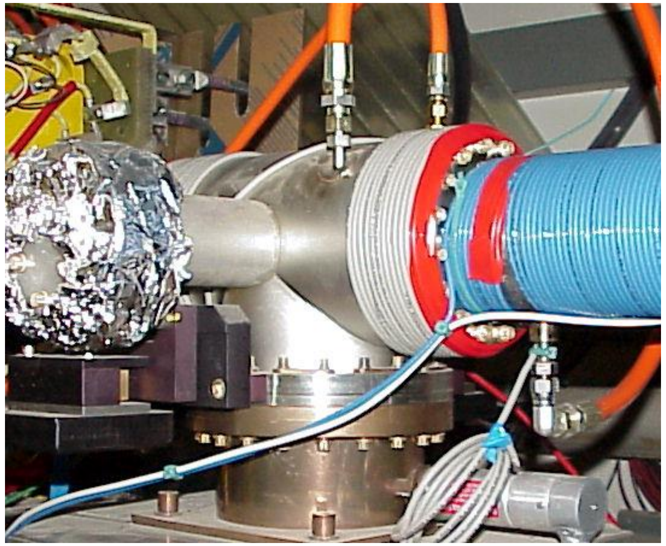
$$k = 1.24\times 10^{-3}\,\frac{n_b}{\sigma_b^5}\cdot\frac{l_{slot}^2\cdot w_{slot}^4}{r_{pipe}^2}$$

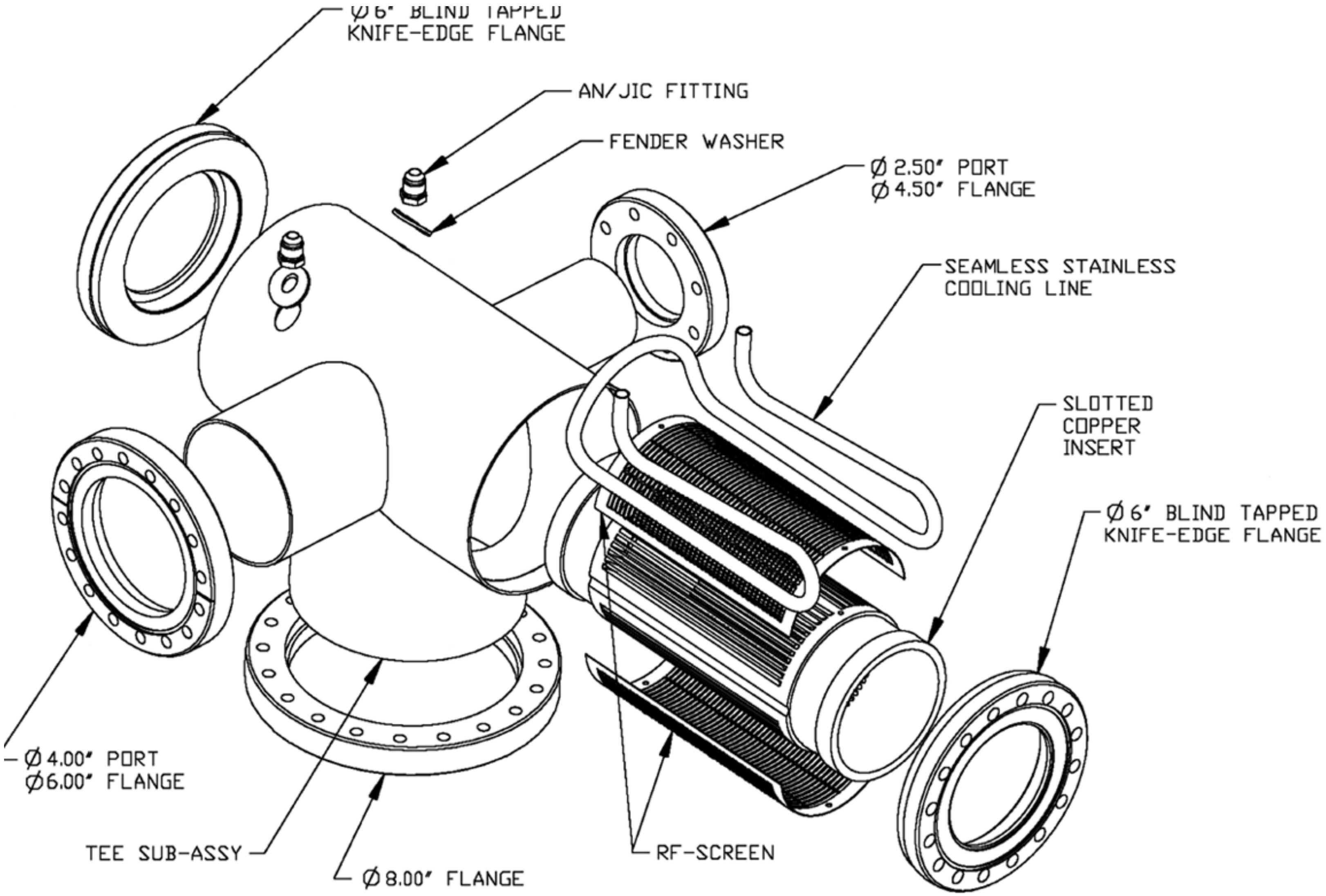
- n_b is the number of bunches
- σ_b is the beam bunch length in mm
- l_{slot} and w_{slot} are the length and width in mm of the slot, respectively,
- r_{pipe} is the inner radius of the beam pipe

- RF loss at a slot is severer for very short bunches
- Long, narrow slots are the better 'compromise' between RF loss and gas conductance

PEP-II Pump Tee

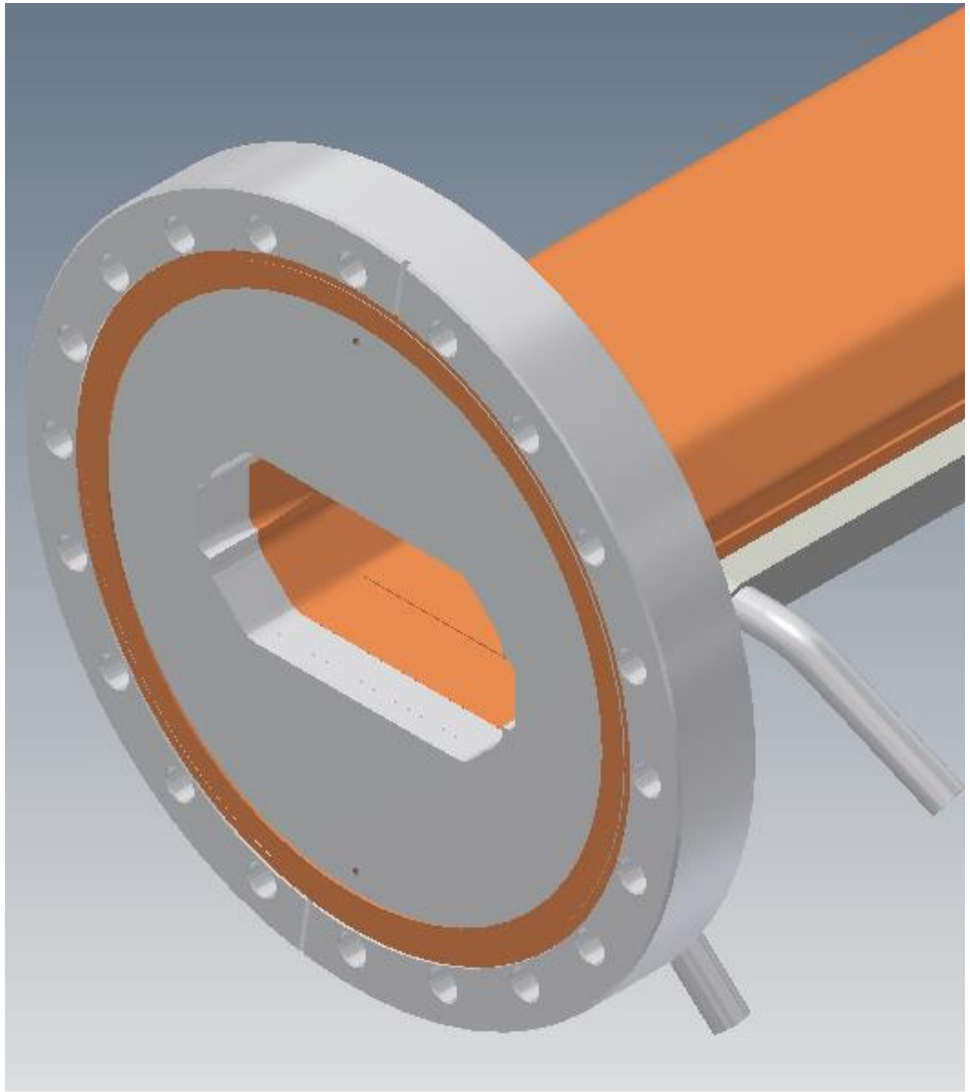




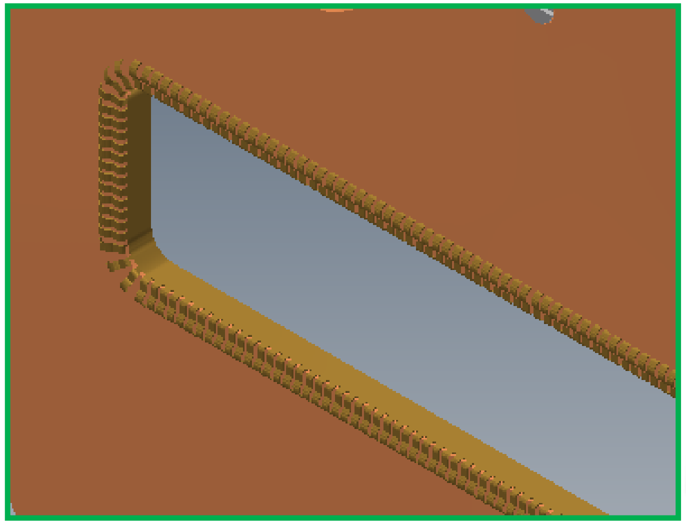


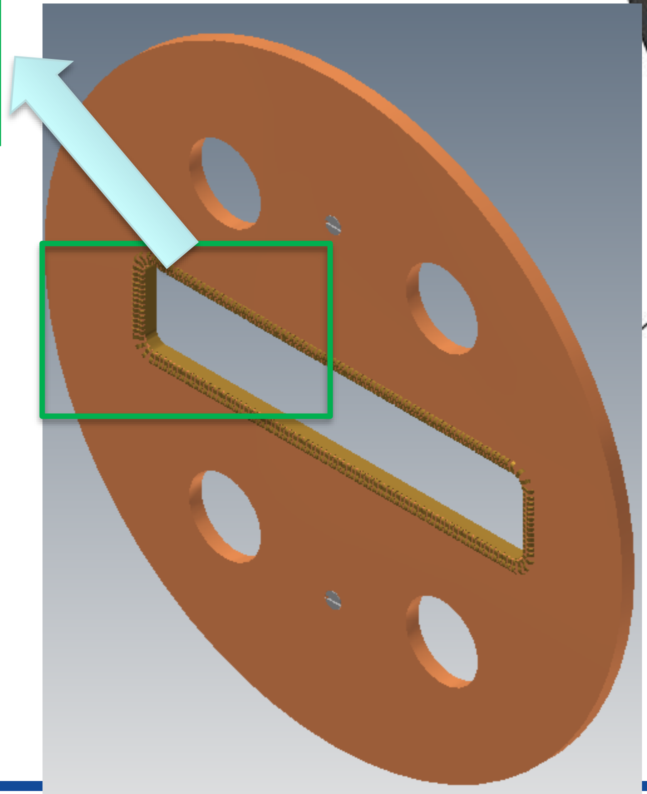
RF 'Cavities' in Flange Joints

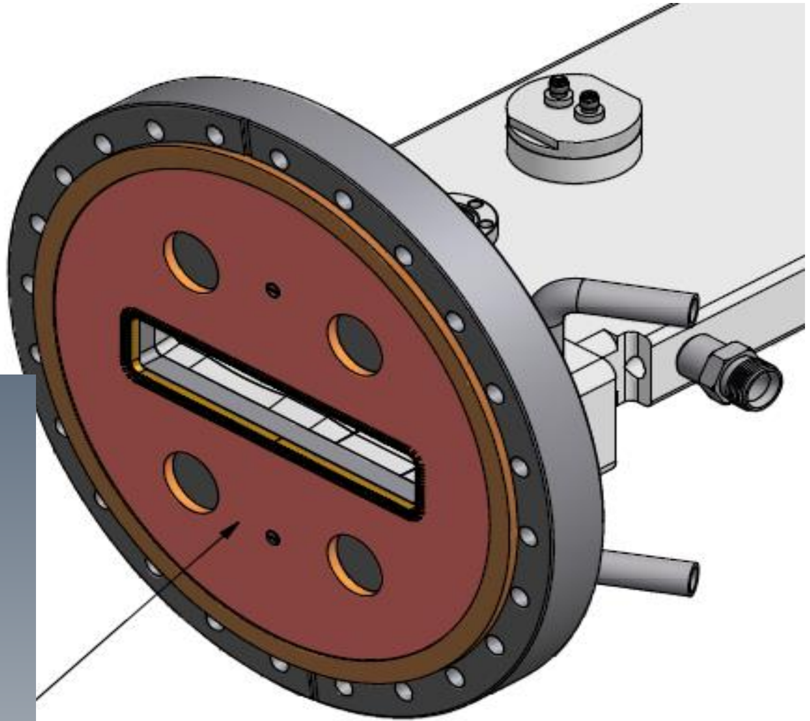
- Making beamline flange joints using regular Cu gaskets may form RF cavities, particularly when the beam aperture differs significantly from the flange cross shape.
- Measures must be taken to bridge the gap to form a smooth bore beamline.
- Some of the methods are:
  - ✓ *RF insert with spring fingers*
  - ✓ *Gap rings*
  - ✓ *Zero-gap gaskets, similar to VATSEALs*



RF Insert at Flange Joints

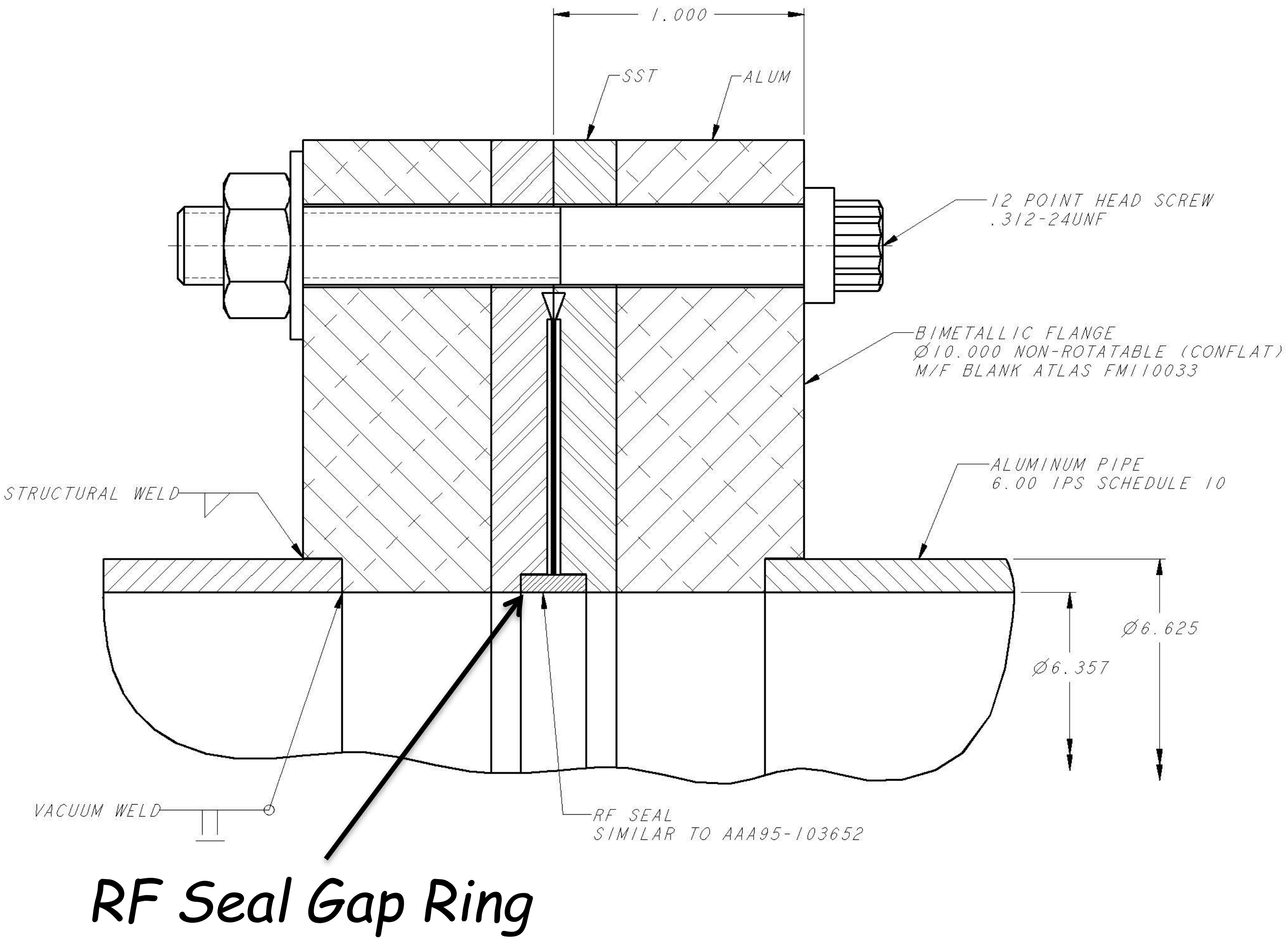




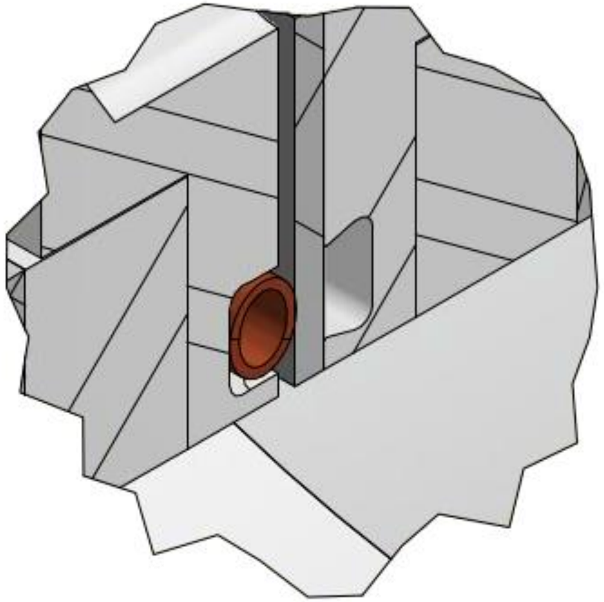


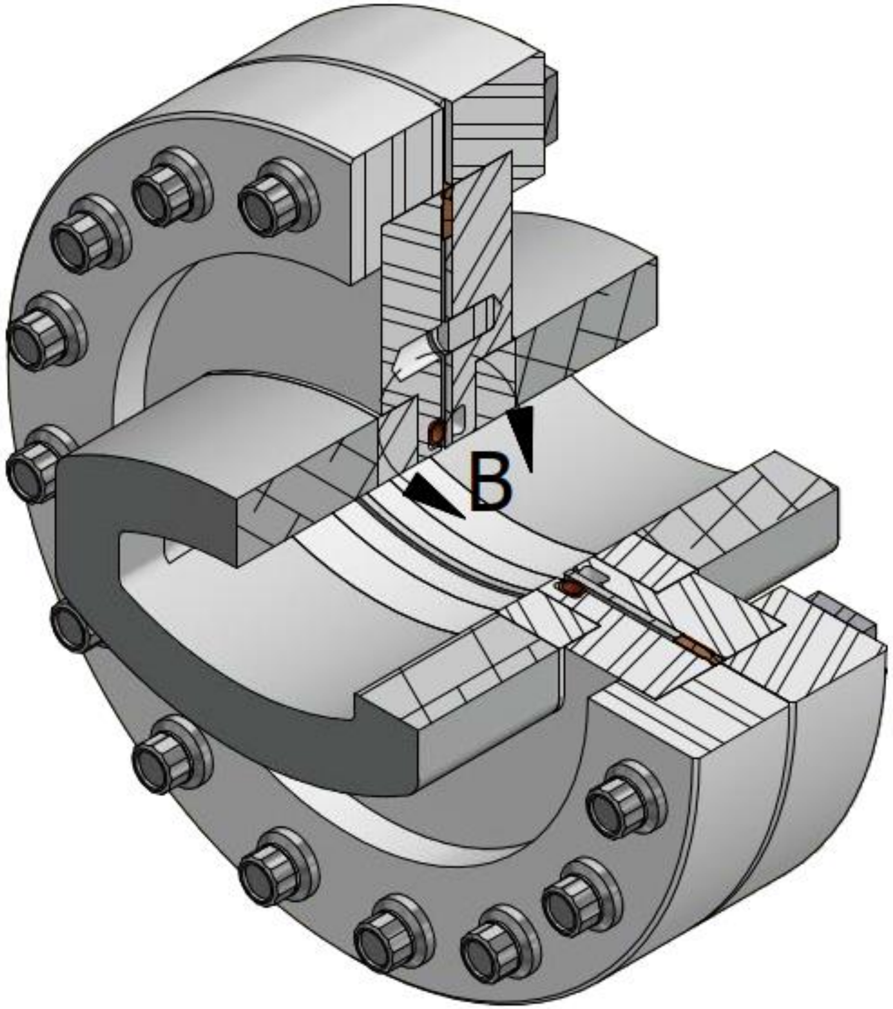
Be-Cu RF Finger strip brazed onto Cu RF insert, to bridge the flange gap, on the vacuum side of the vacuum gasket.

'Gap Ring' at Flange Joints

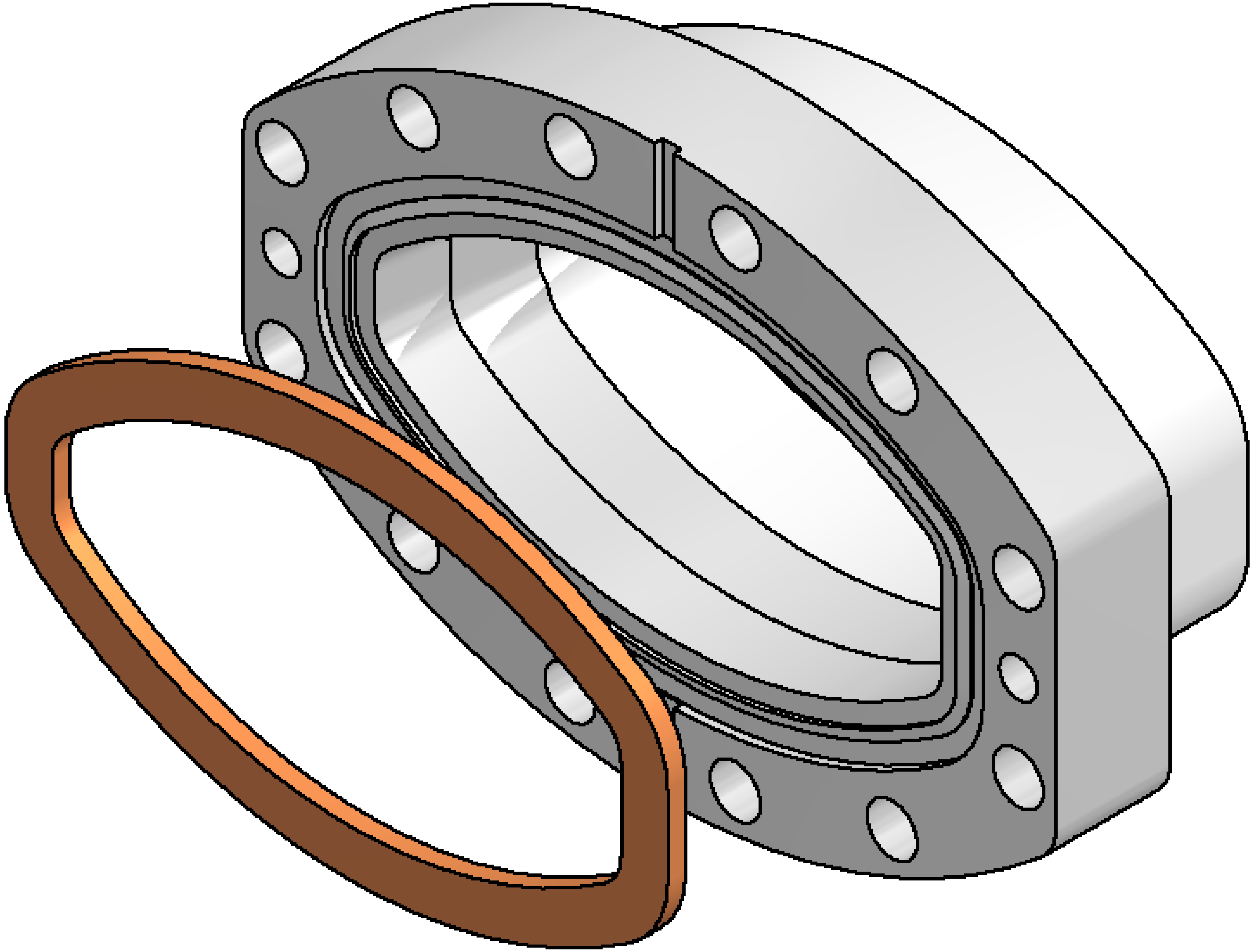


Canted Coil Spring at Flange Joints (NSLS-II/CHESS-U)

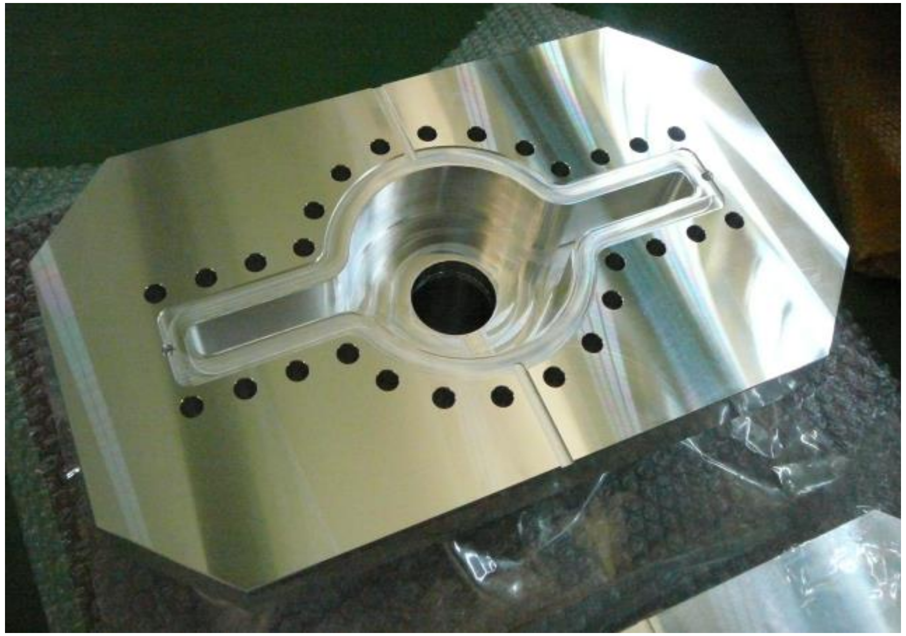


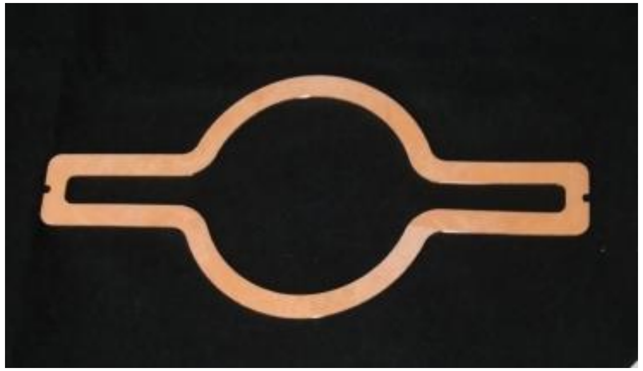


Flange design with minimized 'cavity'



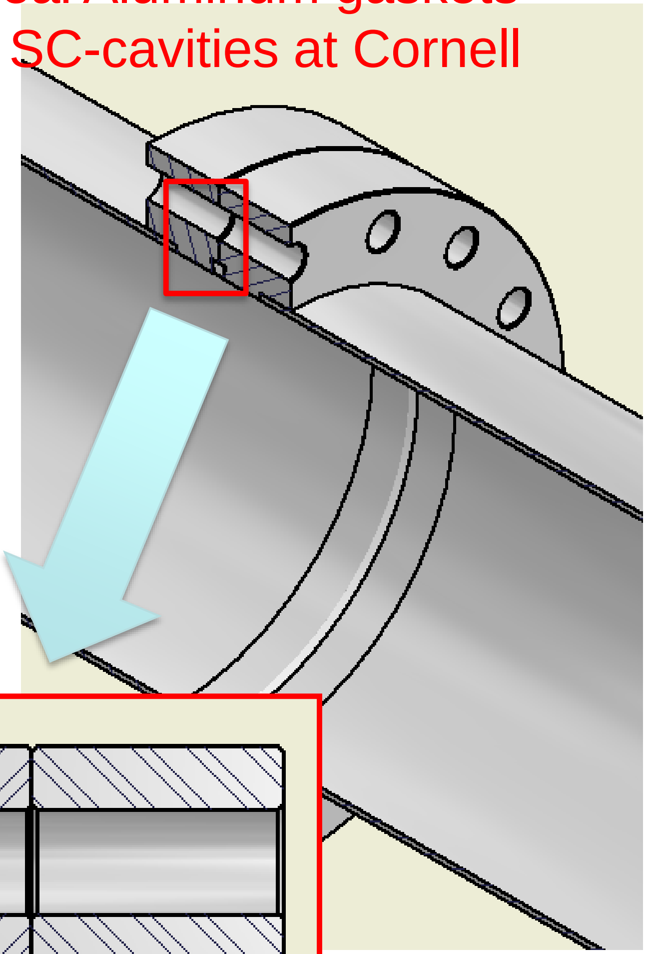
Zero-Impedance Flange Joints

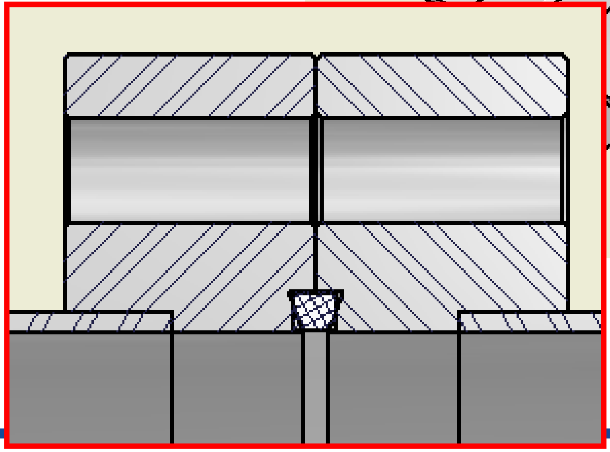




Face-Seal Copper Gaskets
used in KEK SuperB

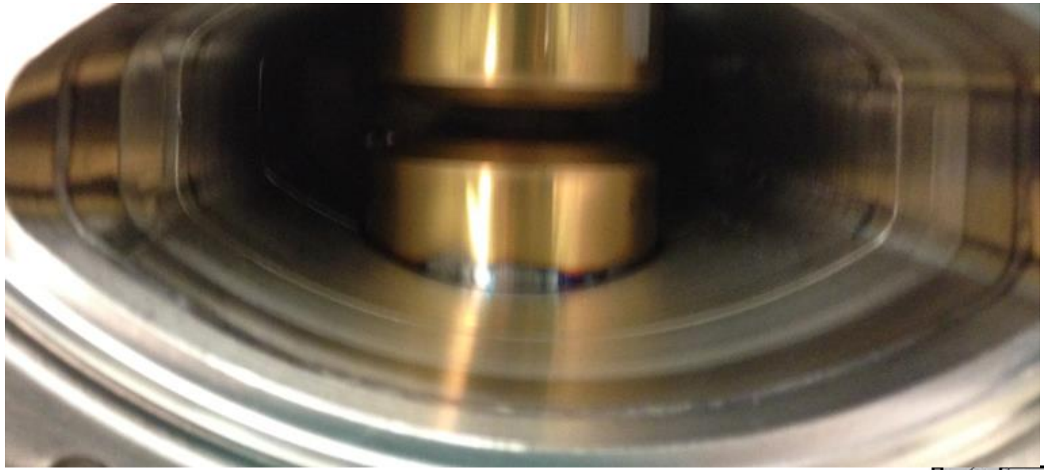
Taper-Seal Aluminum gaskets
Used at SC-cavities at Cornell

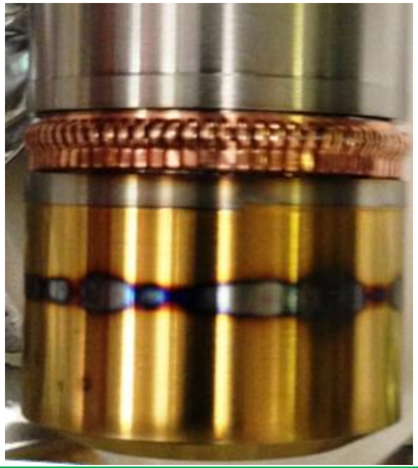


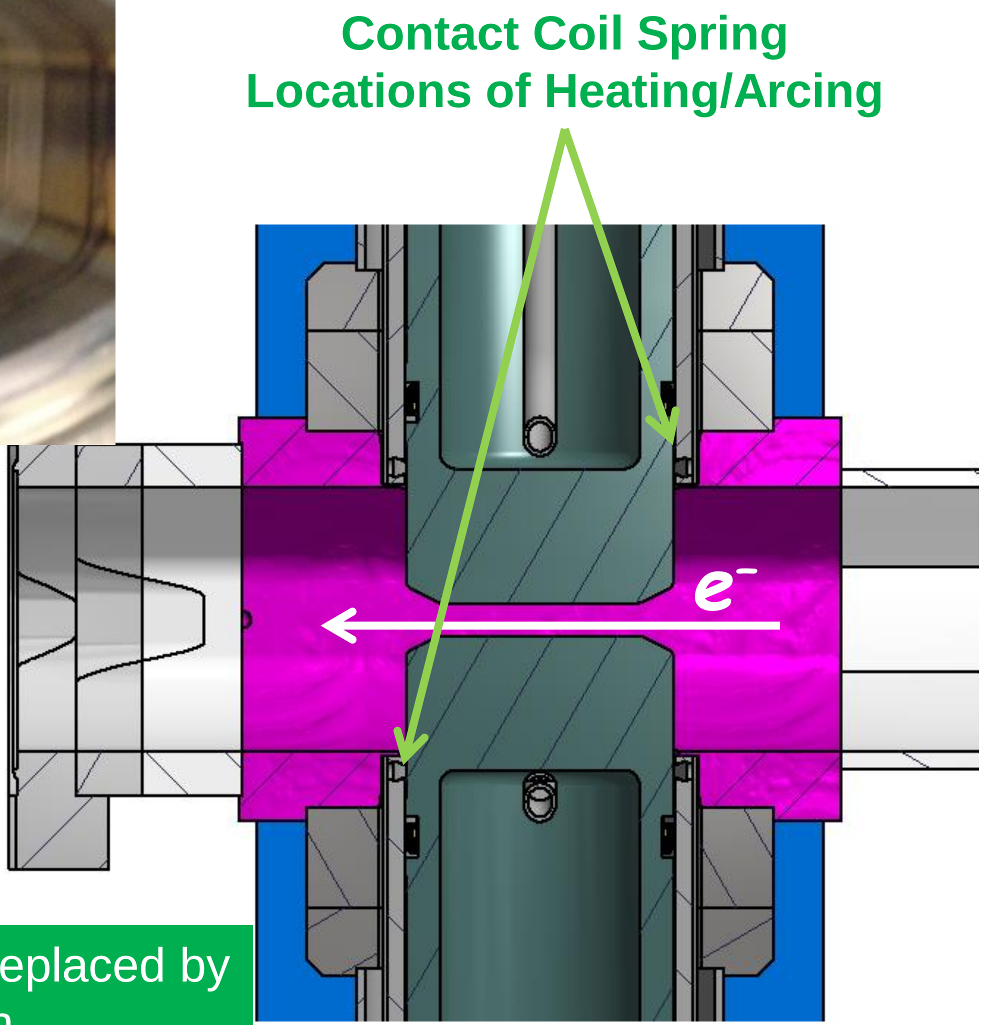


Bad Thing Happens with Bad RF Contacts

A Vertical Scraper at CESR

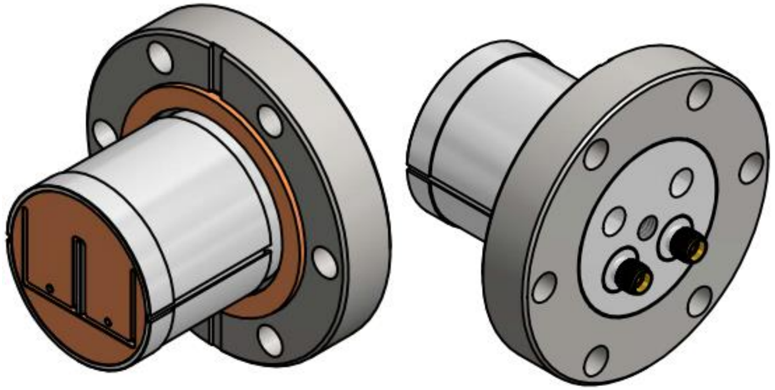


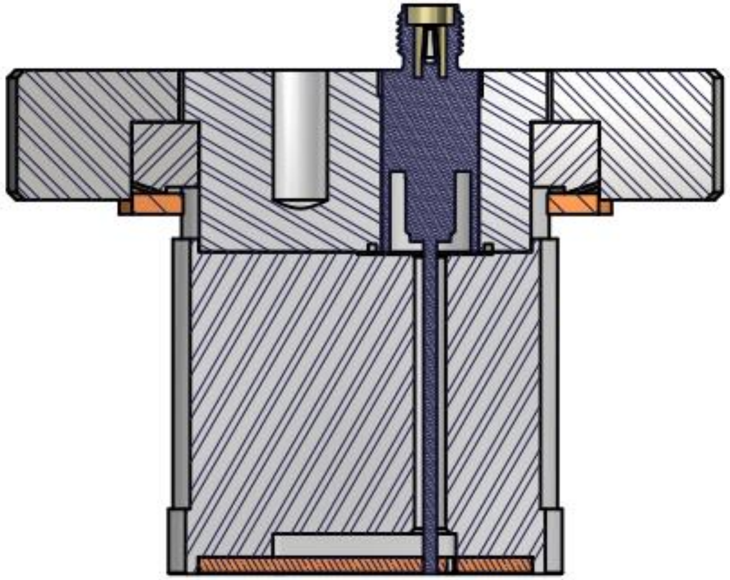




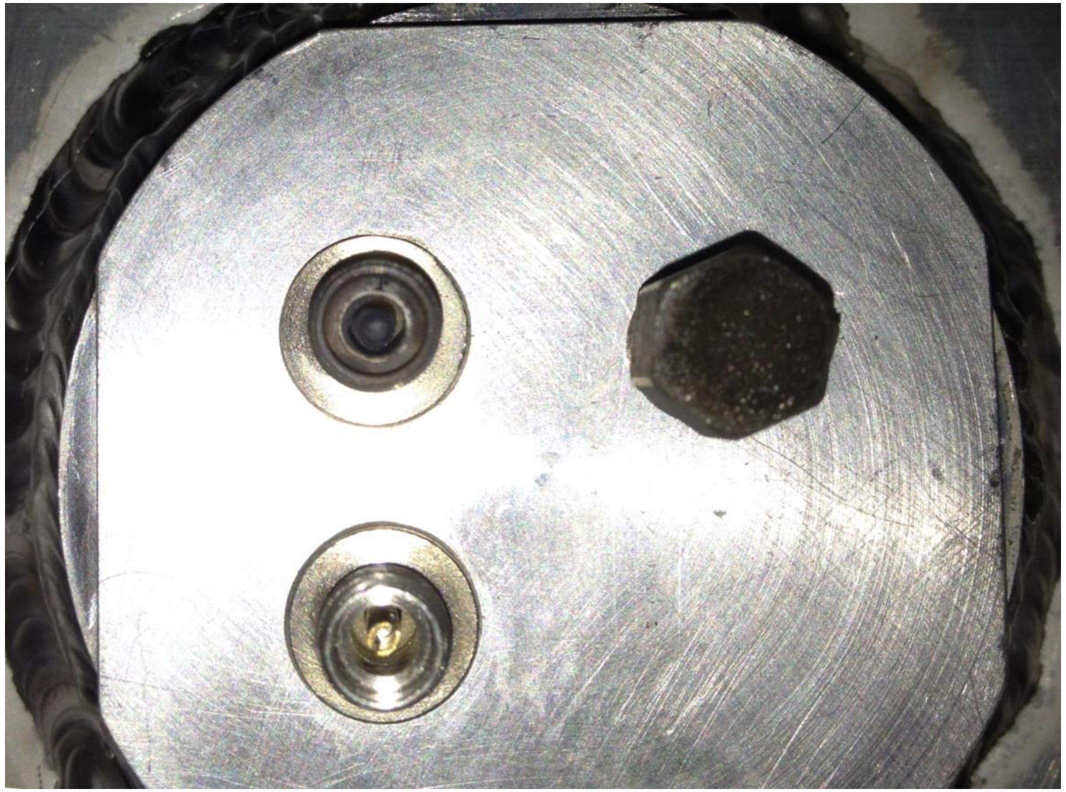
High resistive stainless coil springs were replaced by BeCu finger contact in an improved design

Bad Thing Happens w/ Bad RF Termination





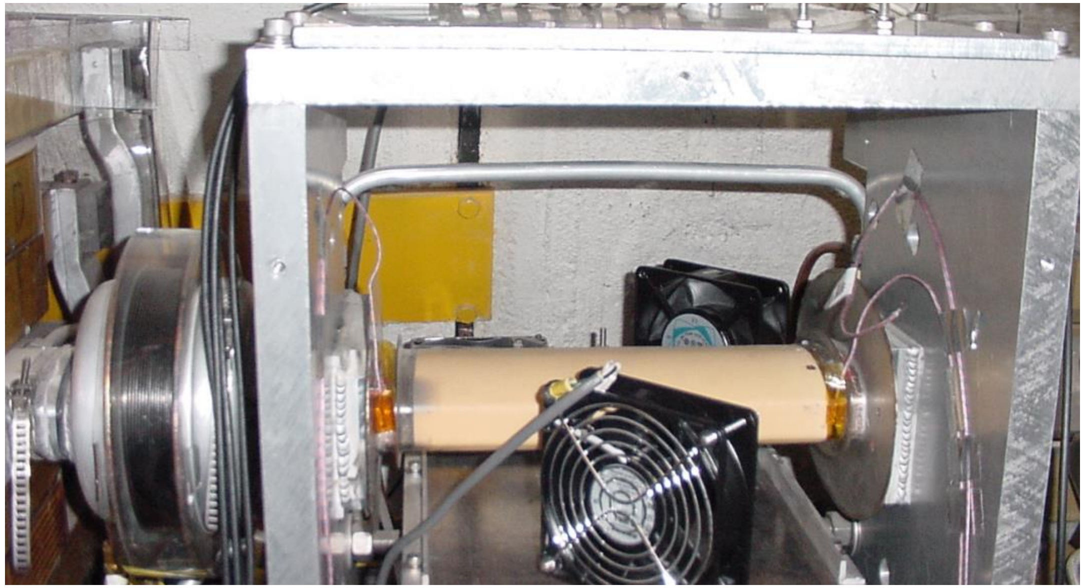
Damaged SMA, resulting from a shorting SMA cap



A Stripline BPM on 5-mm Undulator at CESR

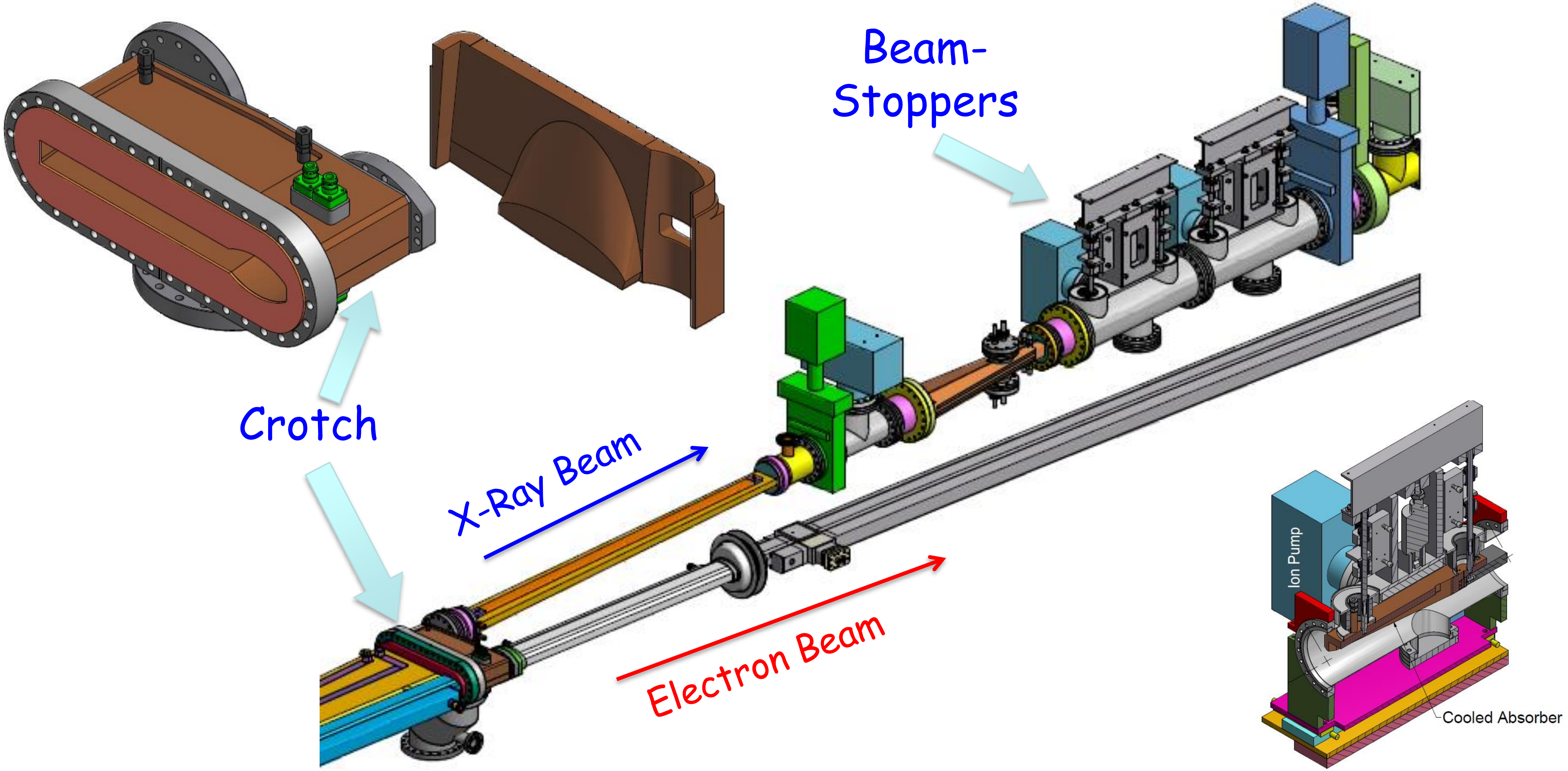
Ceramic Beampipes

- Almost all storage rings have ceramic beampipes, as parts of fast magnets for beam injection and feedback control systems.
- The ceramic body usually made of alumina, and jointed to metal flanges via vacuum braze. A strong-back structure is normally used to support the ceramics.
- Thin metallic coating is deposited on the inner surface of the ceramics, to provide conductive pass for image current. The coating is usually slightly thicker than the corresponding skin-depth, but thin enough to allow external field penetrate through.



A CESR ceramic pipe mounted on strong-back frame, with flexible ends

A Typical X-Ray Beamline Front-End



X-Ray Beamline Front-End – Typical Components

1. Crotch – Provide safe separation of X-ray beam from the accelerator vacuum system. For high beam current storage rings, part of the crotch experience high density of SR power.

2. Beam stoppers (or shutters) – Provide safe isolation between the X-ray beamline from the accelerator vacuum system. Multiple stoppers for redundancy.

3. X-ray windows (Be windows) and low-E filters

4. Fast-closing gate valves with vacuum triggering system

5. For windowless X-ray beamlines, adequate vacuum delay lines with differential pumping.