PIP-II SSR1 Cryomodule Technical Issues

Leonardo Ristori

TTC Meeting

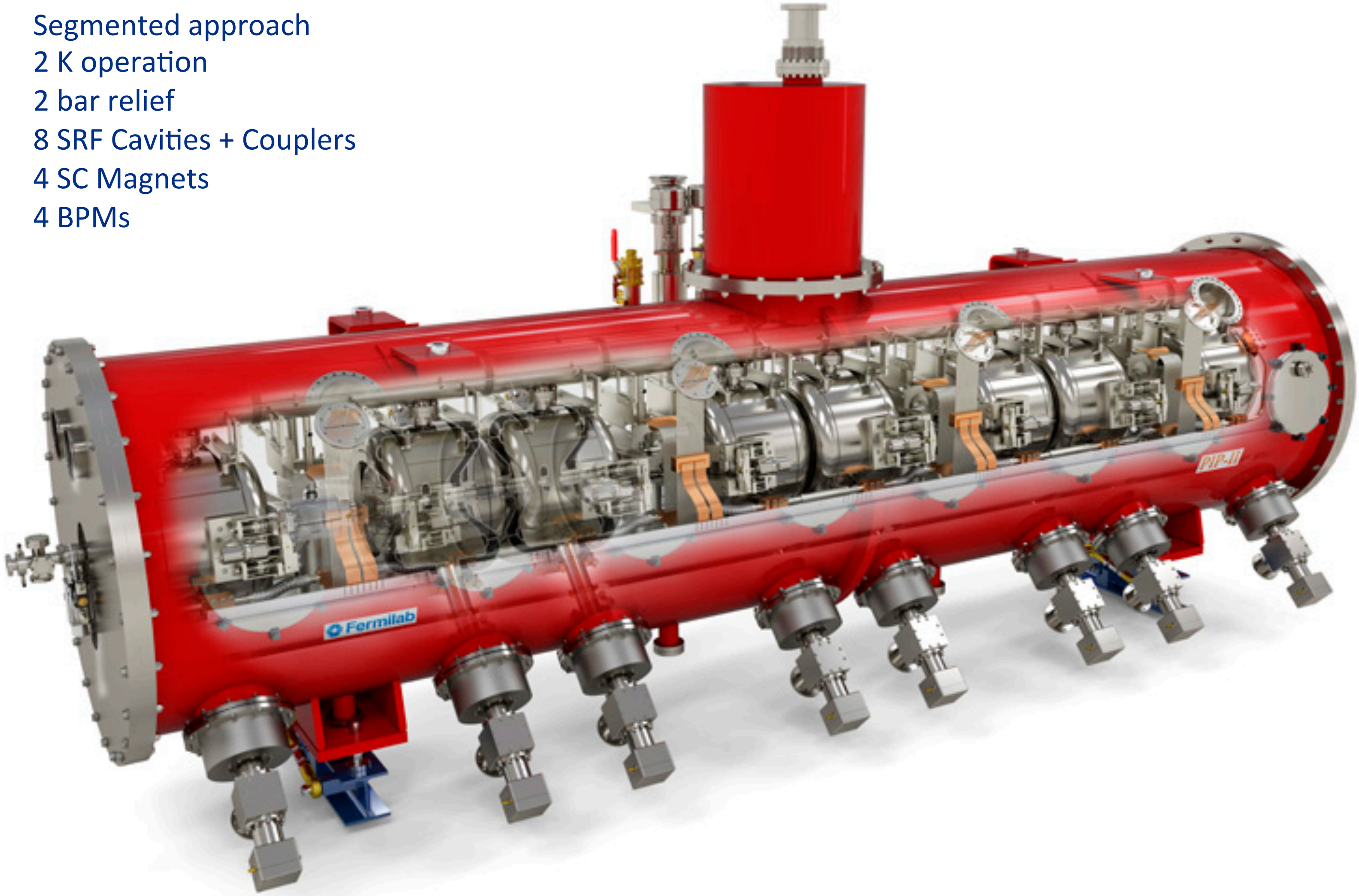
CEA Saclay, 5-8 July 2016

Topics

- The Fermilab SSR1 Cryomodule
- Study on vacuum manifold
- Study on cool-down for alignment
- String Assembly Challenges
- Cryomodule Assembly Strategy
- Spoke Tuner
  - Requirements
  - Prototype
  - Production
- Coupler
  - Requirements
  - Prototype Test to Failure
  - Production
  - Electro-deposited bellows
  - Low pressure gap window

SSR1 Cryomodule

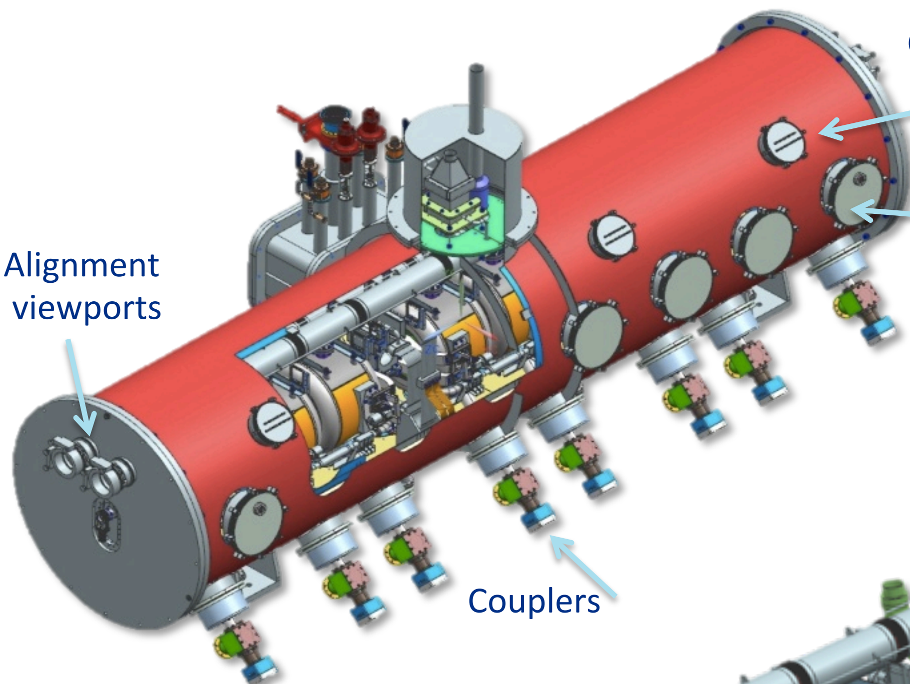
- Segmented approach
- 2 K operation
- 2 bar relief
- 8 SRF Cavities + Couplers
- 4 SC Magnets
- 4 BPMs

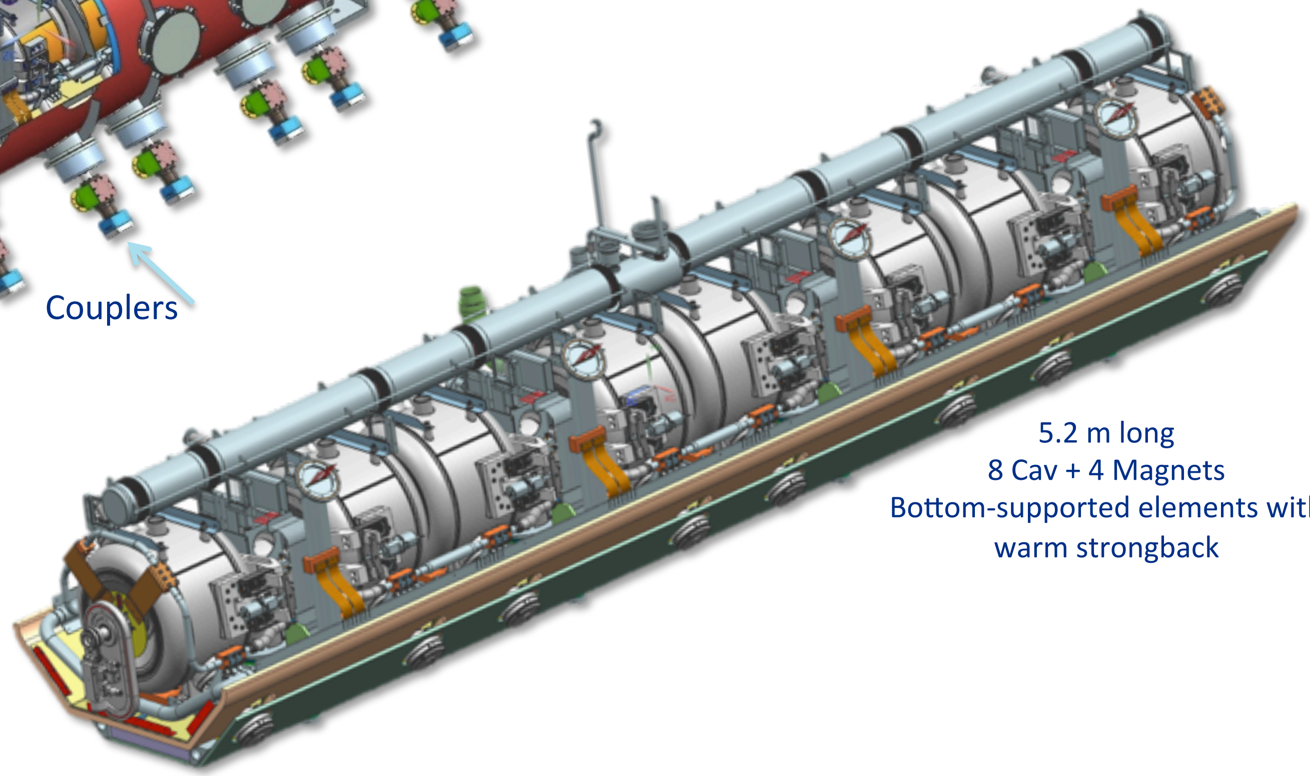


SSR1 Cryomodule

L. Ristori, T. Nicol, Y. Orlov, D. Passarelli, M. Parise

http://accelconf.web.cern.ch/AccelConf/PAC2013/papers/thpma09.pdf





5.2 m long
8 Cav + 4 Magnets
Bottom-supported elements with warm strongback

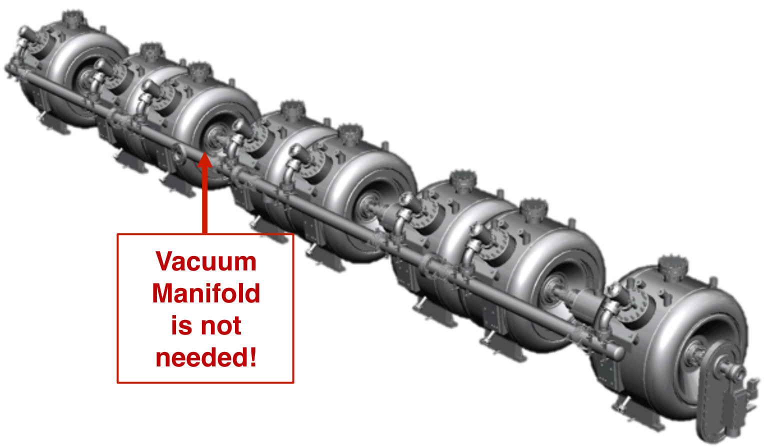
SSR1 Cryomodule R&D Goals

- Validate new spoke cavity cryomodule design concepts
  - Room temperature strongback
  - Individual support posts to control axial motion
  - Conduction cooled magnet current leads (not new, but new to us)
  - Single-window coaxial input coupler
  - Integral beam instrumentation
  - Determine the practicality of tuner access ports
- Validate alignment concepts
  - Gain experience with the required alignment tolerances
  - Verify alignment stability during cooldown
- Verify static and dynamic heat load estimates
- Clean-Room assembly in New Facility (Lab 2)
  - Gain experience with strings of spoke cavities, solenoids, and beam instrumentation, e.g. cleanroom operations, shipping and handling, etc.

Work by M. Parise

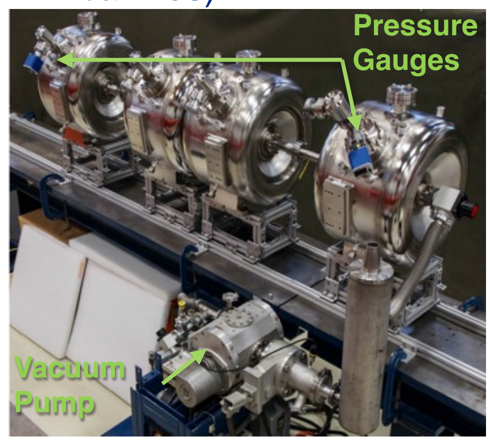
SSR1 String Assembly: Beam-line vacuum

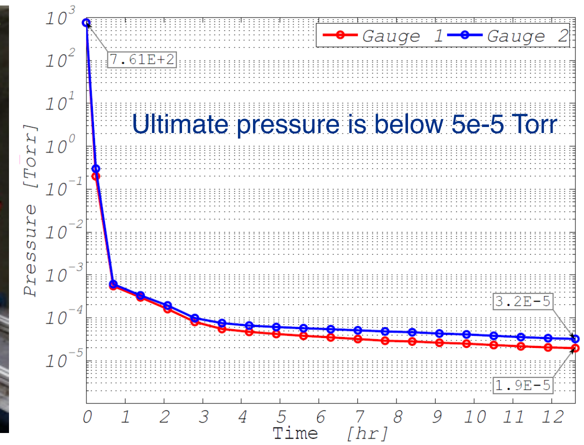
High vacuum level (< 5E-5 Torr) is needed inside the beam line volume before the introduction of liquid helium.
Maximum acceptable time set to 12 hours



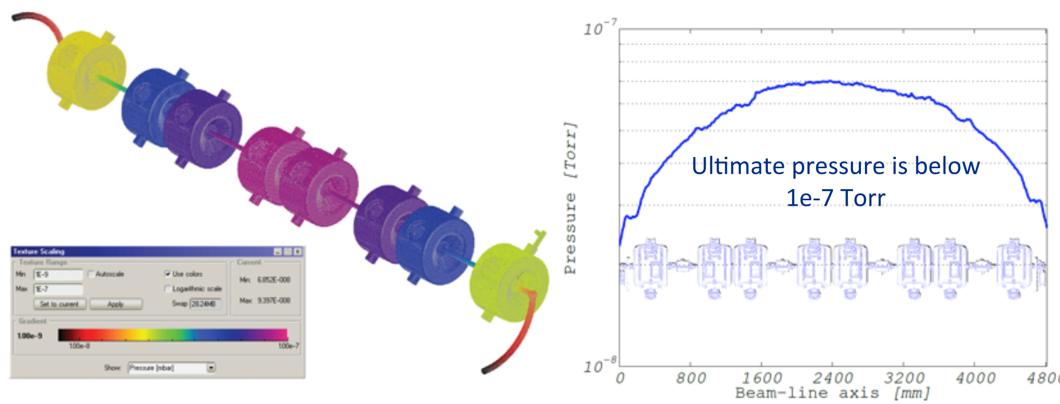
The high-vacuum level at room temperature can be achieved pumping down by the beam ports only. Furthermore, simulations performed on the entire string with clean components show that the achievable pressure would be of **7E–8 Torr** pumping from both ends.

- Measurements (very conservative conditions, moisture in cavities)





- Vacuum simulation (ideal scenario)



High-vacuum Simulations and Measurements on the SSR1 Cryomodule Beam-line, D. Passarelli et al., Proceedings of SRF2015, Whistler, BC, Canada

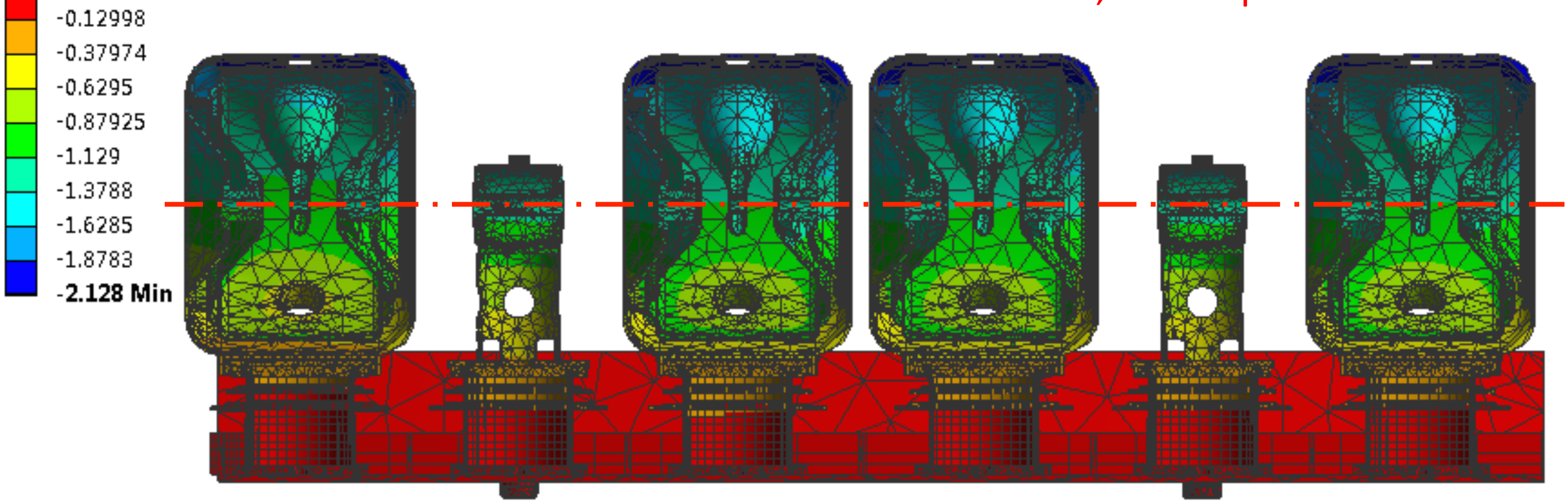
Cool-down displacements

- Thanks to strong-back at room temperature, no longitudinal displacements.
- Vertical displacements of magnets and cavities are the same, since the supporting structures are made of same material (→ same thermal contraction)

C: Static Structural
Directional Deformation
Type: Directional Deformation(Y Axis)
Unit: mm
Global Coordinate System
Time: 1
9/23/2015 2:17 PM

Transverse cavity alignment error, mm RMS	<1
Angular cavity alignment error, mrad RMS	≤10
Transverse solenoid alignment error, mm RMS	<0.5
Angular solenoid alignment error, mrad RMS	<1

Predicted beamline shift: ↓down ~1mm, will be pre-set

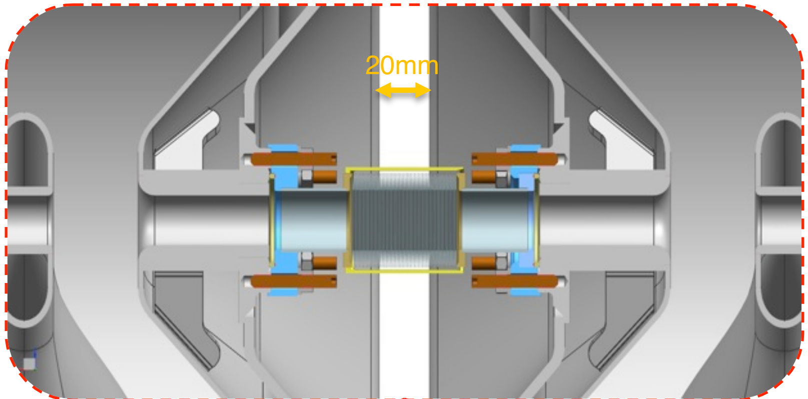


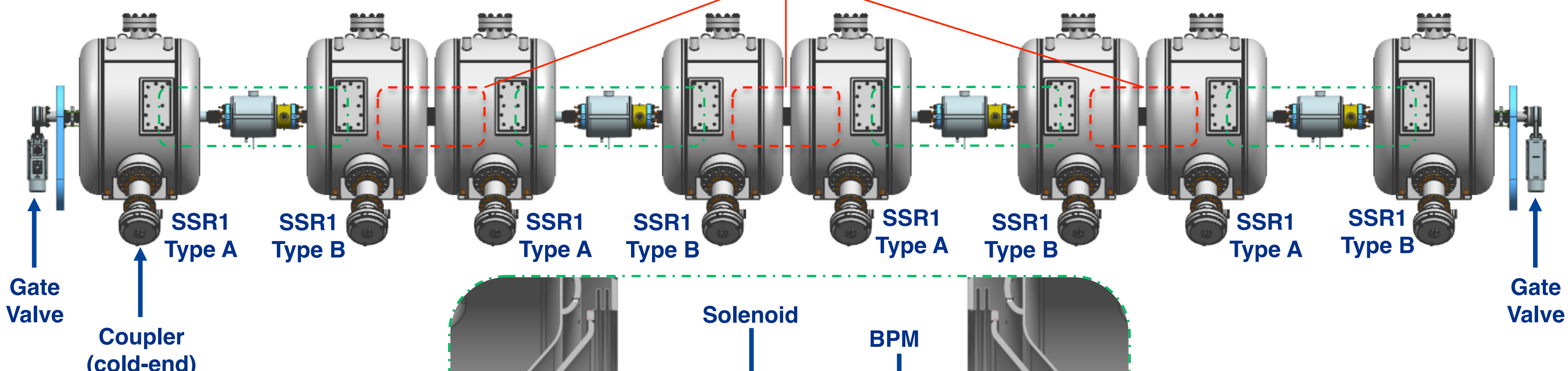
Fermilab

SSR1 String Assembly: design features

Interconnection cavity-cavity

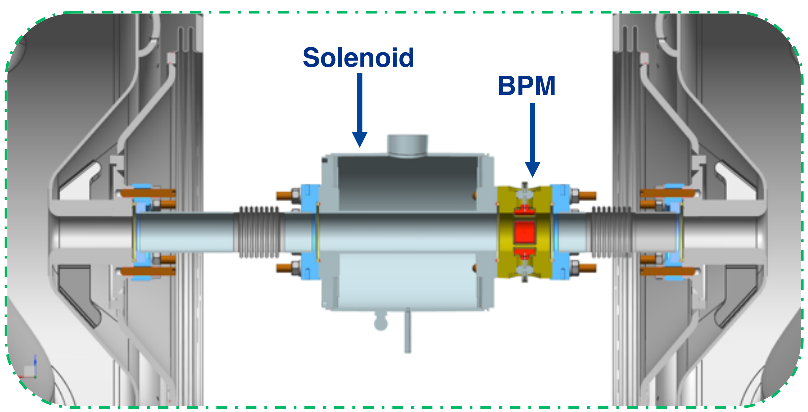
Edge-welded bellows assembly
Al-diamond seals
SiBr set screws
316L stainless nuts and washers





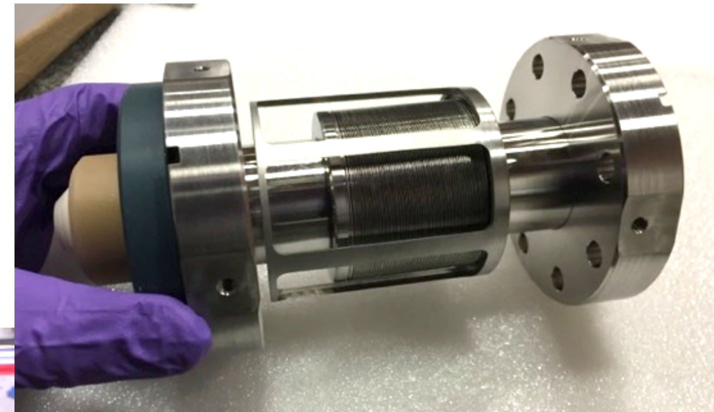
Interconnection cavity-magnet-BPM-cavity

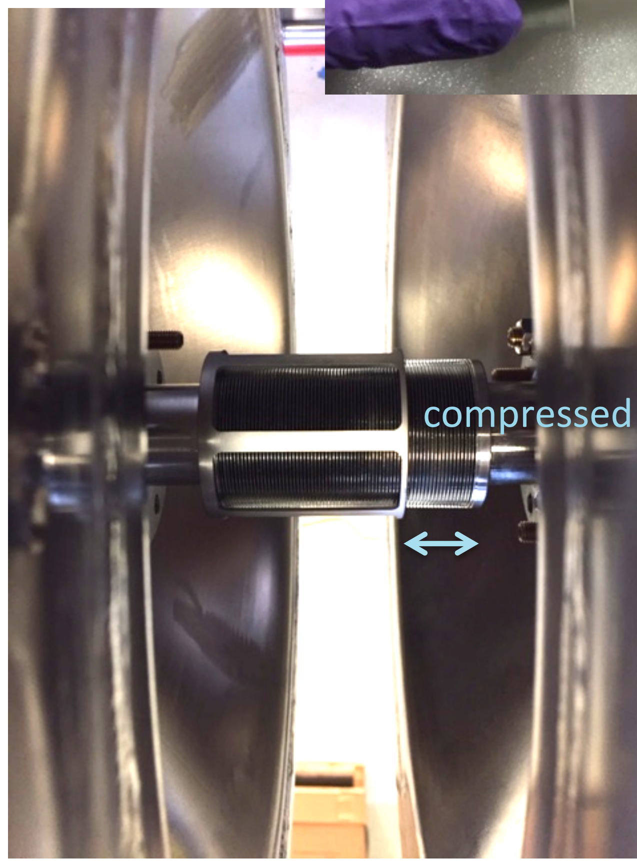
Hydro-formed bellows assemblies
Al-diamond seals
SiBr set screws
316L stainless nuts and washers



Cavity-Cavity Connection

Bellows allow enough room to perform the assembly (tested outside the cleanroom)

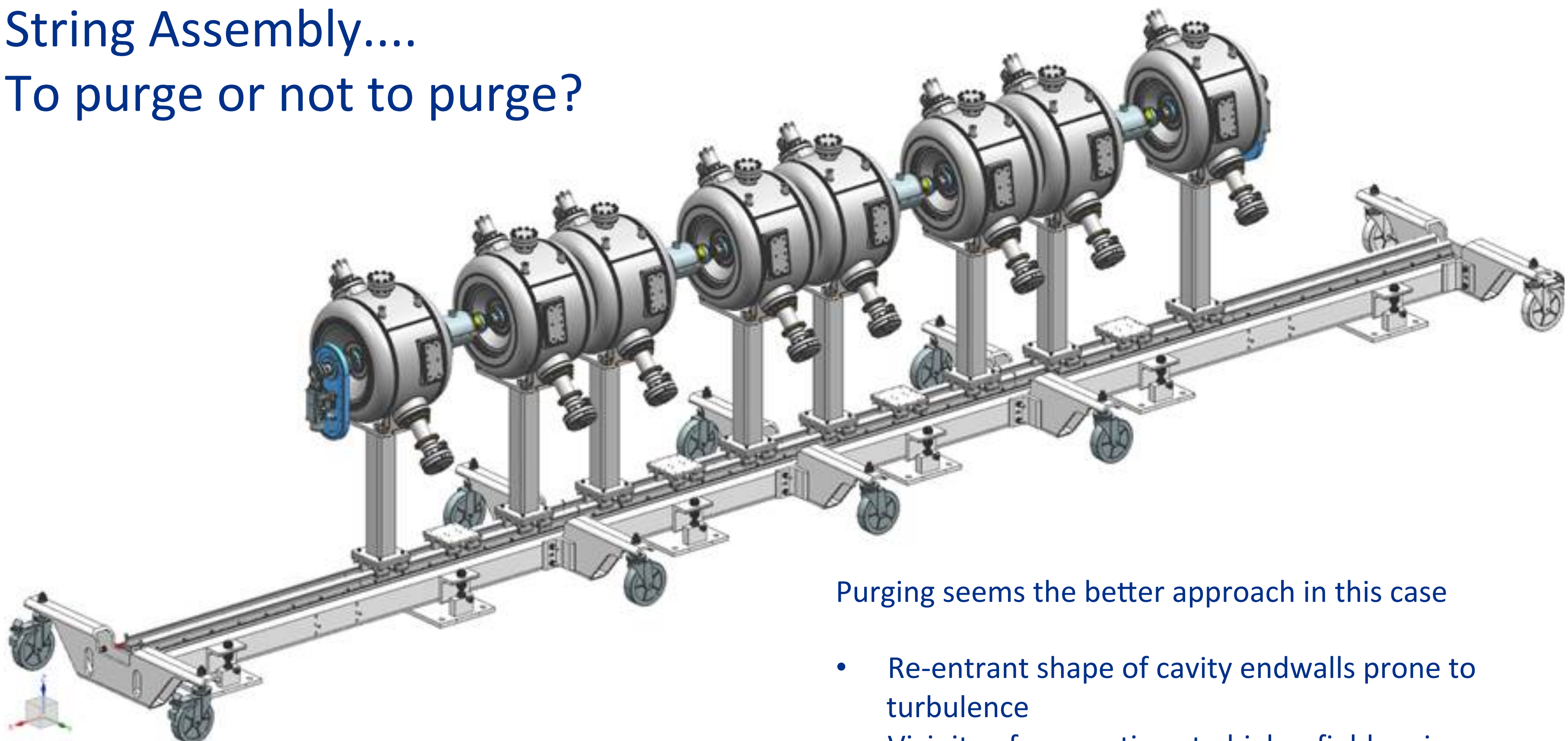




<u>Cleanliness?</u>
Edge-welded bellows were subjected to cleaning and extensive testing in cleanroom. Results were excellent and repeatable.
US cleaning sufficient, HPR better.

Cavity-Magnet String on Rail System

String Assembly....
To purge or not to purge?



Purging seems the better approach in this case

- Re-entrant shape of cavity endwalls prone to turbulence
- Vicinity of connections to high e-field regions, high risk
- First cleanroom assembly for new facility
- First non 9-cell cryomodule at Fermilab

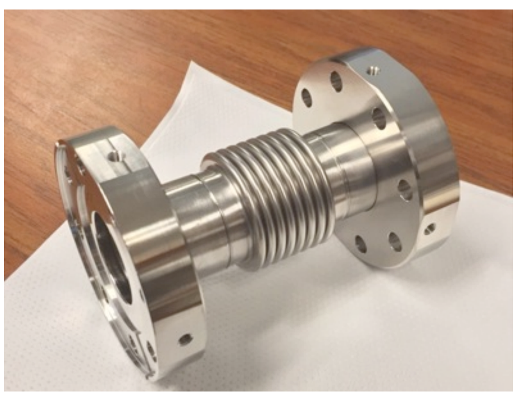
Work by D. Passarelli – M. Parise

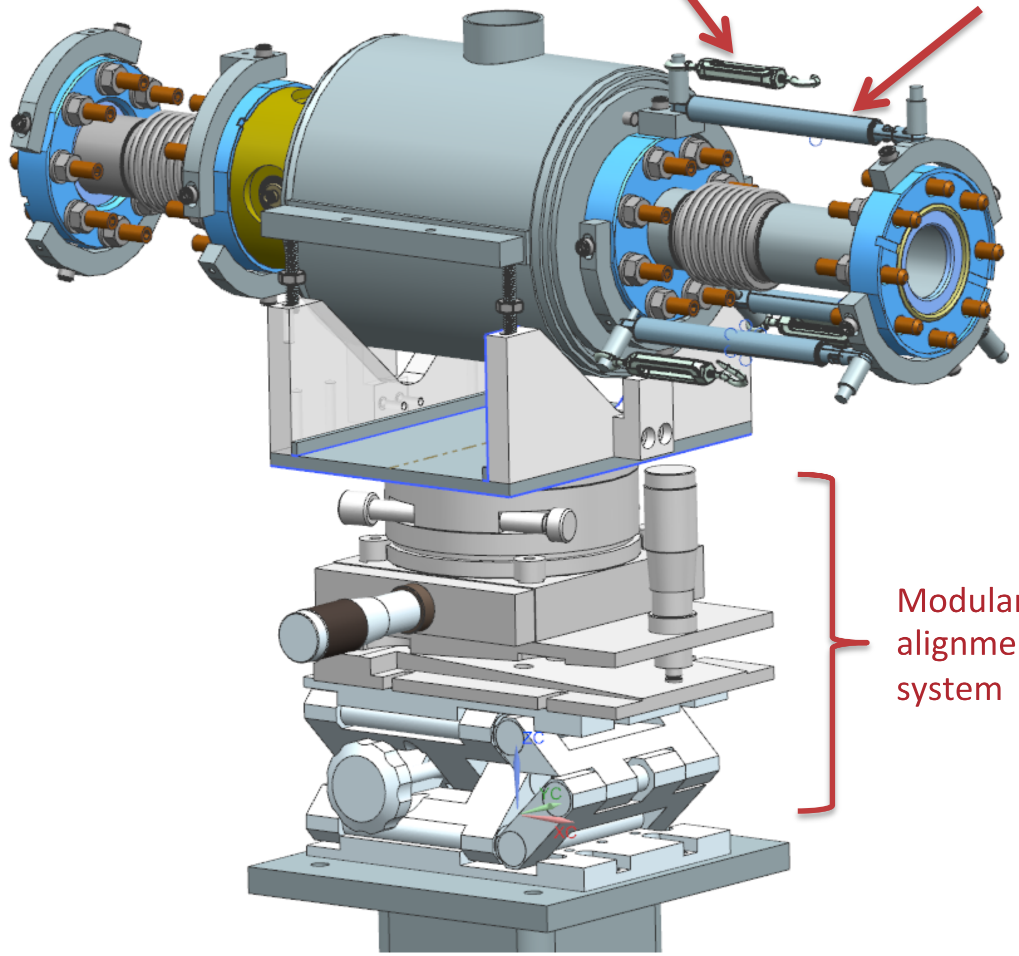
Rail System – staged outside cleanroom

Magnet-BPM Installation Tool

Work by M. Parise

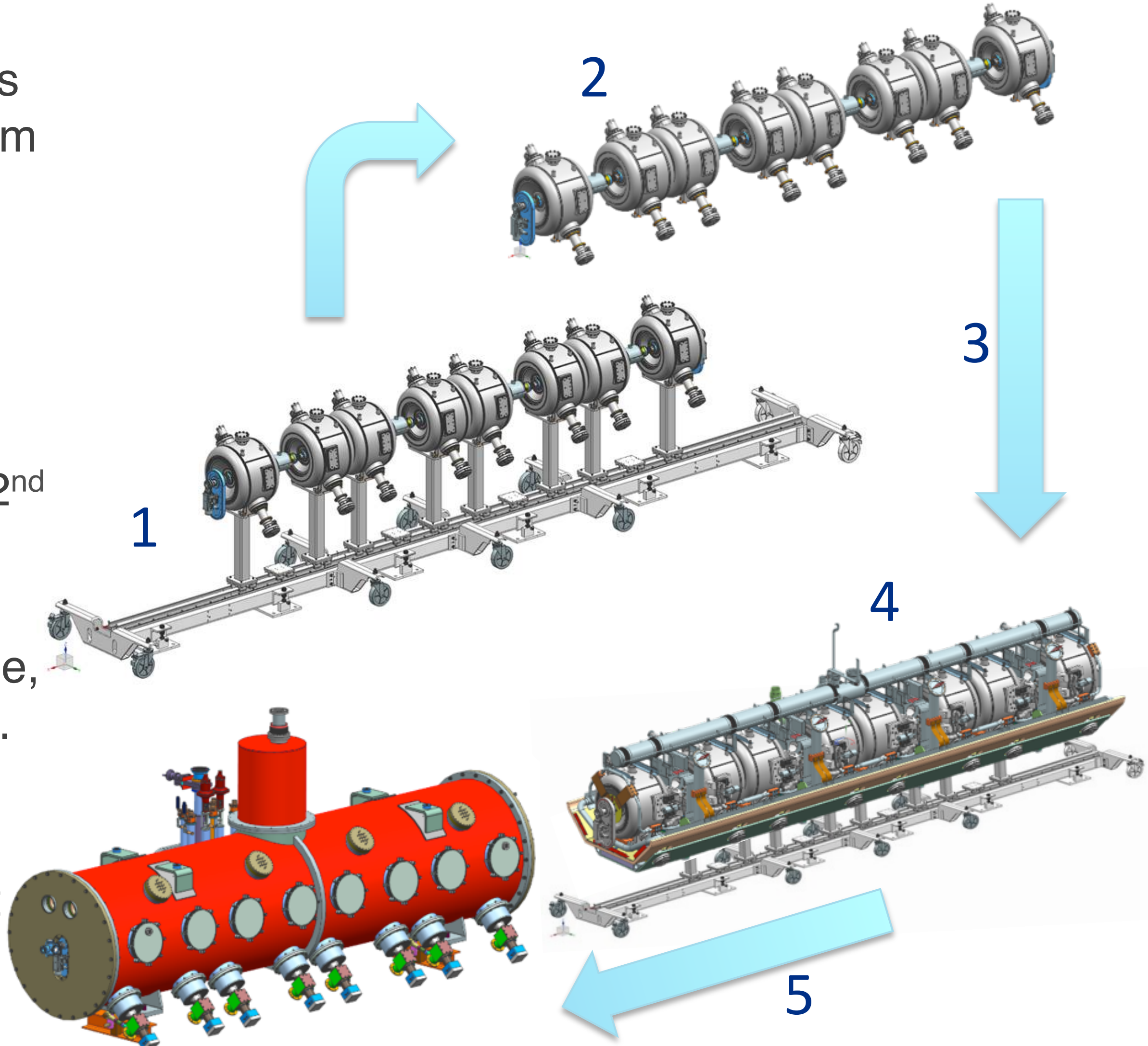
- Magnet, BPM, 2 bellows, assembled and HPR washed prior to installation
- Aligned using modular system employing independent devices for each DOF
- Bellow alignment braces still not finalized





Cryomodule Assembly Strategy (not finalized)

1. In cleanroom, Rough alignment done, clocking is fixed. String with rail system comes out of cleanroom.
2. String is made rigid by tooling (not pictured) and lifted by crane
3. String is lowered on strongback assembly, on 2nd rail system
4. Cold mass assembly is completed (tuners, 2-phase, current leads, piping, MLI). Final alignment is done.
5. Cold mass inserted in vacuum vessel (rollers not pictured). Alignment is checked.



SSR1 Tuner: Requirements

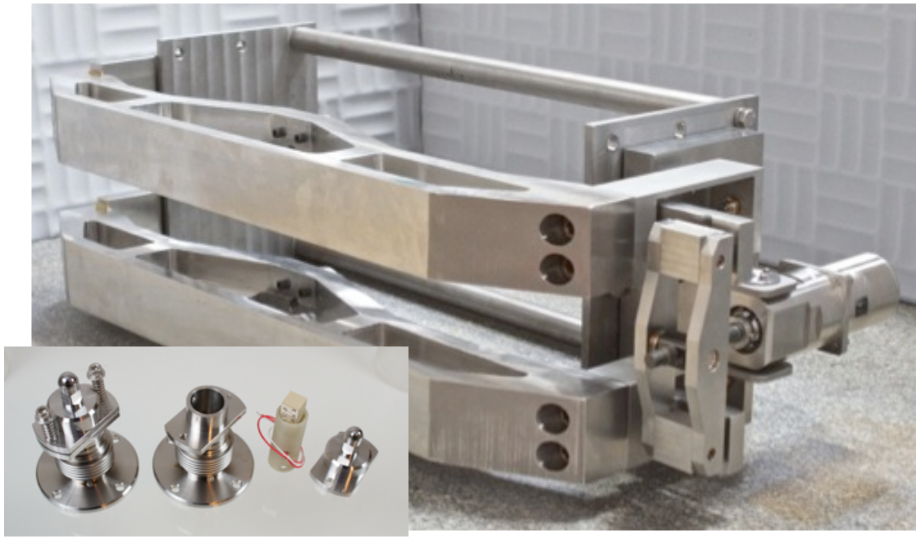
Parameter	*Value*	*Notes*
Total Frequency Range	> 135 kHz	From FRS
Frequency Resolution of stepper motor	< 20 Hz	From FRS
Piezo Frequency Range	> 1 kHz	From FRS
Tuner Passive spring constant	30 kN/mm	Derives from df/dP requirement
Sensitivity of end-wall	540 kHz/mm	Simulation/Experimental
Cavity wall spring constant (K_{cav})	30 kN/mm	Simulation/Experimental

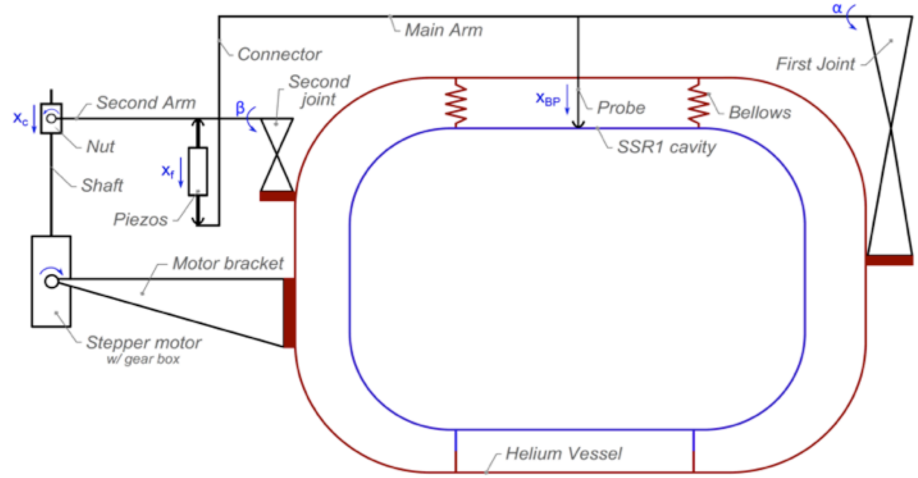
Parameter	*Value*	*Notes*
Stepper motor max force	± 1300 N	Symmetrical
Stepper motor resolution*	0.1 µm (100 nm)	At interface with 2^{nd} lever
Piezo stroke @ RT	64 µm ± 2%	Measured
Piezo stroke @ operating T	15µm (25% of RT)	
Piezo max rated force	3360-5040 N	4200 N ± 20% (blocking force)
Piezo max operating force	2688 N	3360 · 80%

Parameter	*Value*	*Notes*
Motor Travel at beam pipe	> 0.25 mm	135/540 kHz
Piezo Travel at beam pipe	> 1.85 µm	1/540 kHz
Maximum Force at beam pipe	7500 N	0.25 mm · 30000 N/mm
Motor Resolution at beam pipe	< 37 nm	20/540000 mm
Motor Tuning Efficiency (Te)	< 37 %	37/100 nm
Motor Mechanical Advantage (M)	> 5.8	7500/1300 N, **picked 6**
Piezo Tuning Efficiency (Te)	> 12 %	1.85/15 µm
Piezo Mechanical Advantage (M)	> 1.4	0.5^* · 7500/2688 N, **picked 2**
Piezo Elastic Efficiency (E)	> 24 %	2 · 12 % (Te · M)

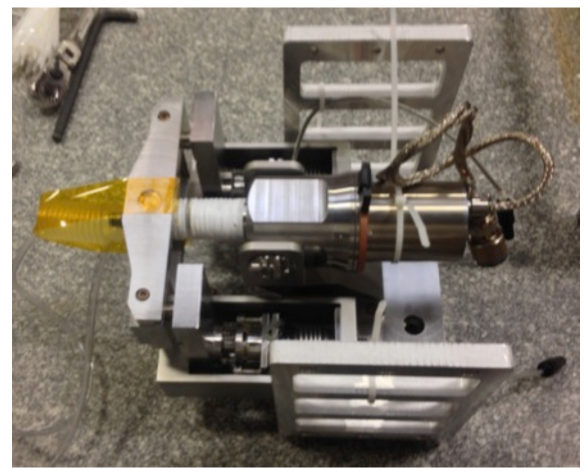
Prototype Tuner

D. Passarelli

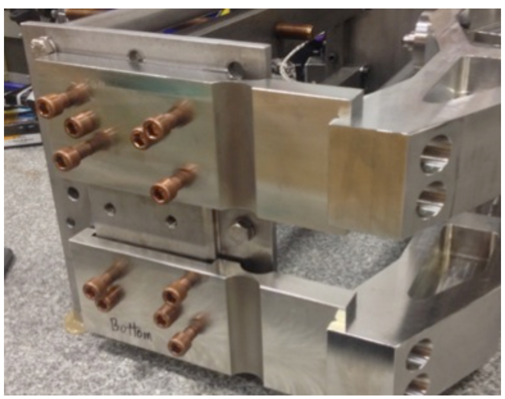




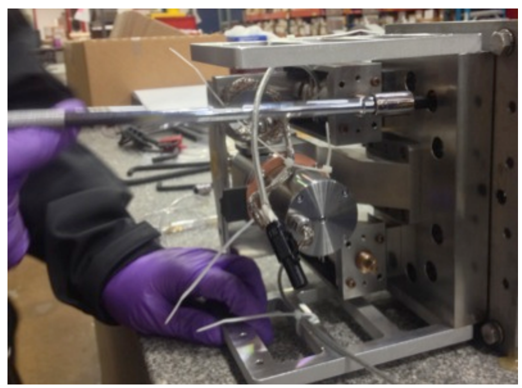
Cartridge with motor and piezos



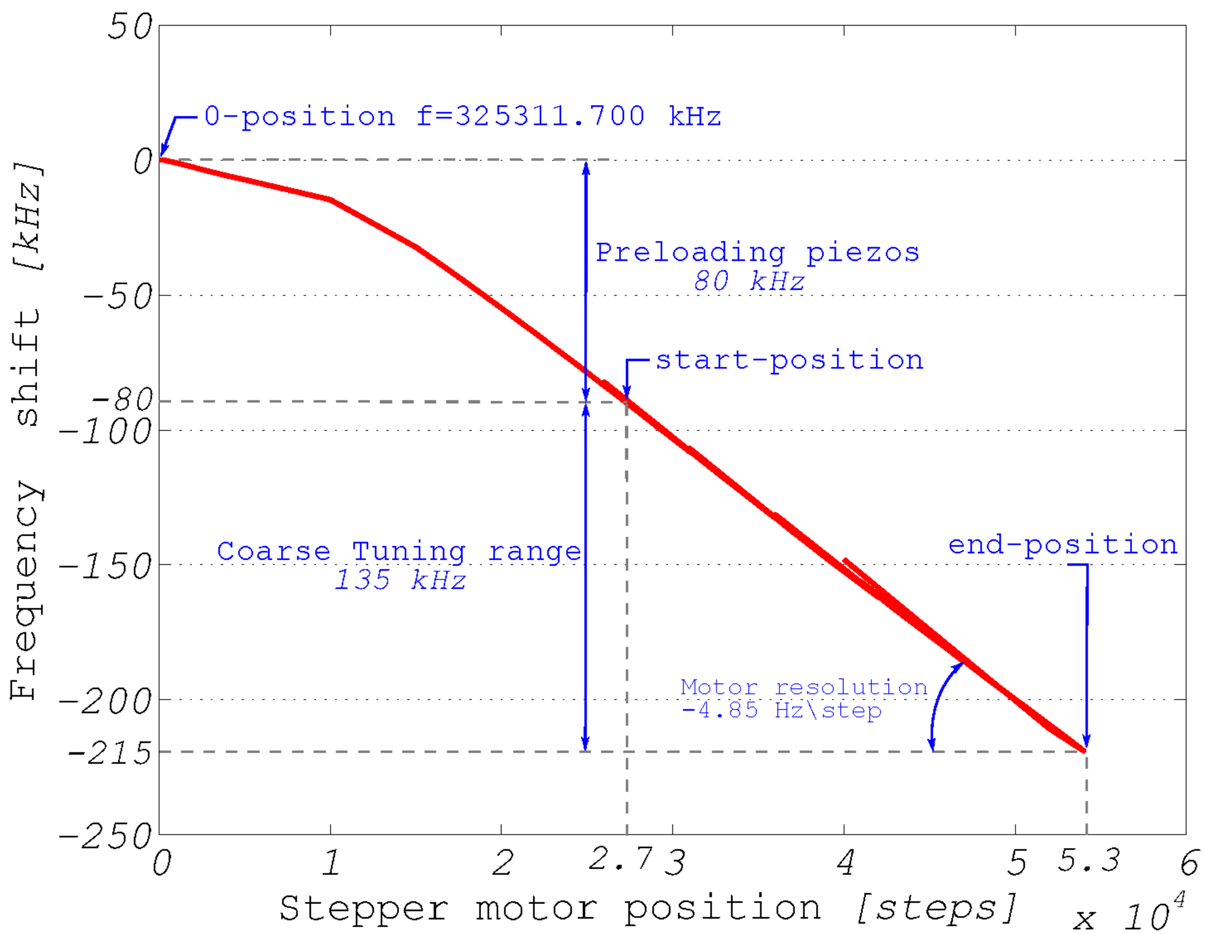
Alignment system for main arms



Installation of cartridge



SSR1 Tuner: Testing



- Tuning is achieved with cavity always under compression
- Spec is > 135kHz range
- Motor and Piezos are in series
- Preload of Piezos is achieved by engaging the motor up to 80 kHz shift

Studies of microphonics control of the SSR1 cavity have being carried out using this tuner mechanism.

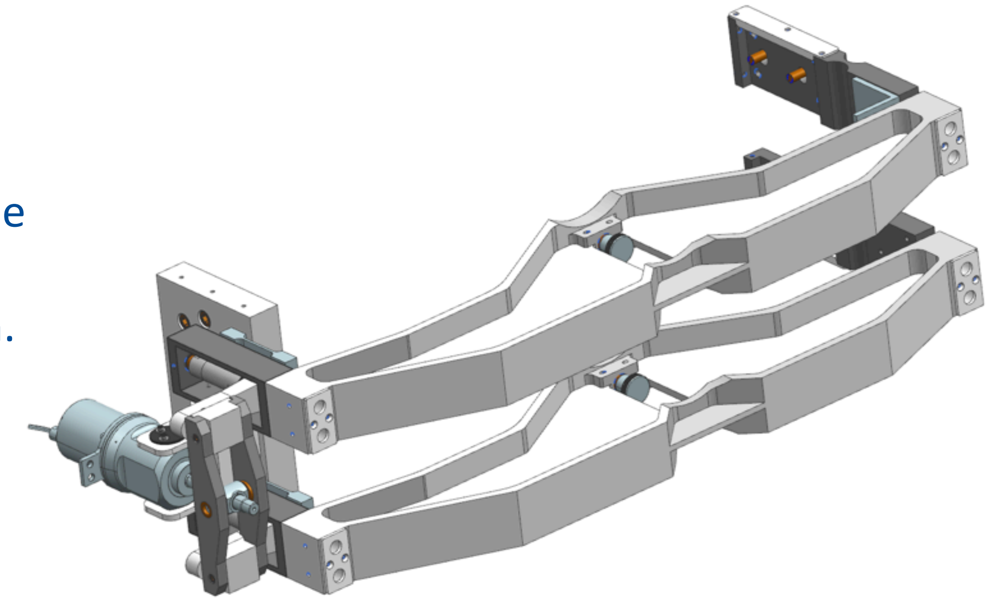
Performance of the Tuner mechanism for SSR1 Resonators During Fully Integrated Tests at Fermilab, D. Passarelli et. al., Proceedings of SRF2015, Whistler, Canada, THPB061

Production SSR1 Tuner

Work by D. Passarelli

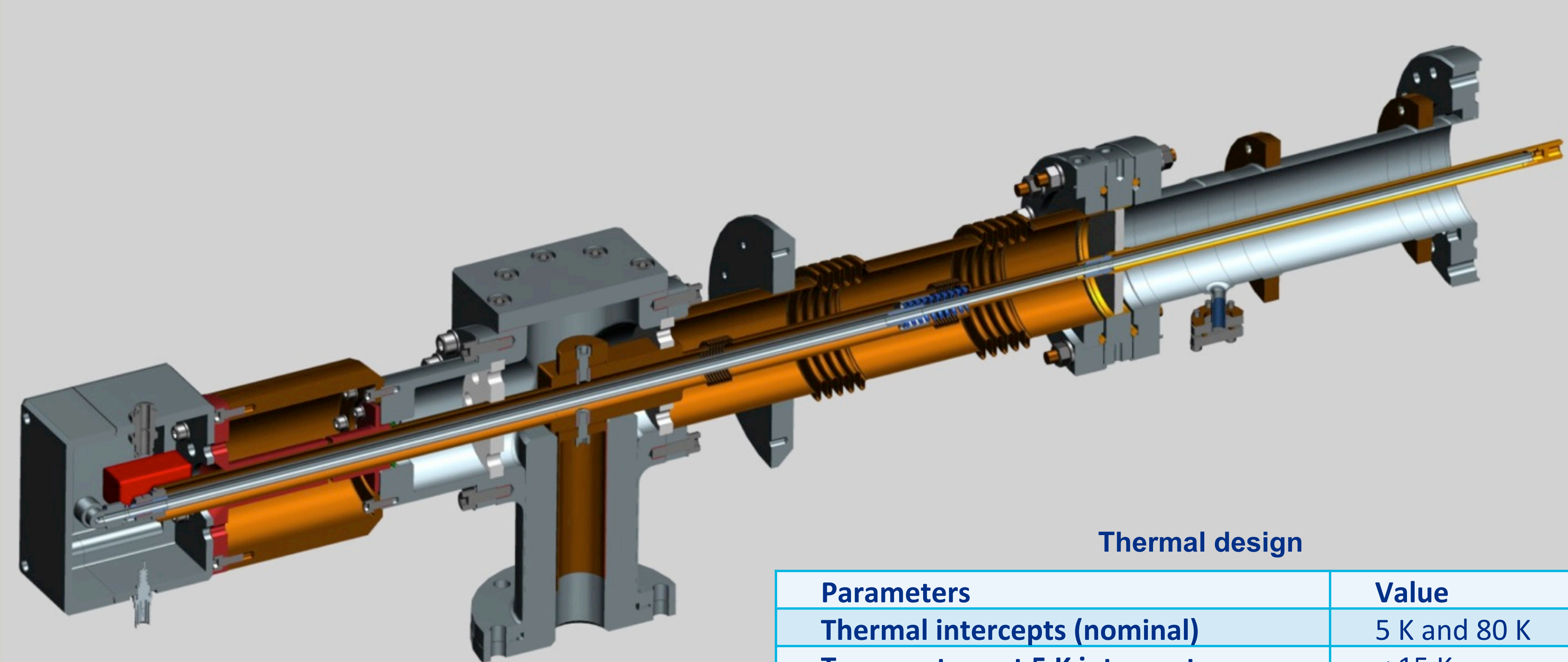
- Based on the experiences gained assembling and testing the prototype tuner we're updating the design of the tuner for the production version.

- Main changes:
  - Clearance with beam connections
  - Integration of commercial encapsulated piezos stack (same used for LCLS-II). Replacing the "homemade" ones which are considered less reliable.
  - Easier installation: improve connections among parts
  - Easier handling: reduce the overall weight of components without loosing stiffness (efficiency)



325 MHz Power Coupler

Work by S. Kazakov



Thermal design

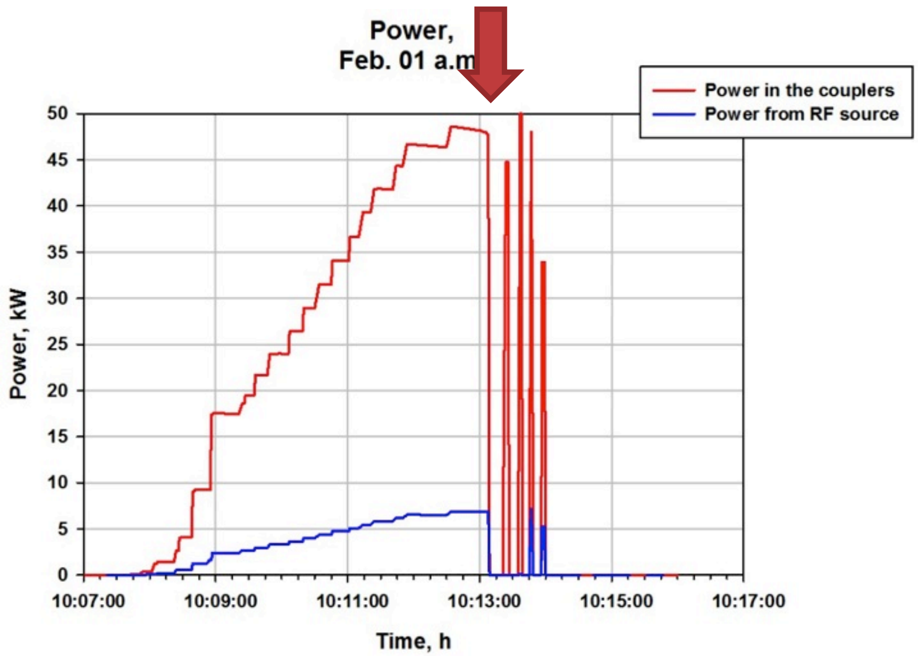
Parameters	Value
Thermal intercepts (nominal)	5 K and 80 K
Temperature at 5 K intercept	< 15 K
Temperature at 80 K intercept	< 125 K
2K heat load (30 kW)	**< 1 W**
5K heat load (30 kW)	**< 6 W**
80K heat load (30 kW)	**< 11 W**
Antenna tip temperature (30 kW)	< 330 K
Antenna cooling media	Air
Air flow rate (30 kW)	< 2 g/s
Max cooling air pressure drop	< 1.0 bar

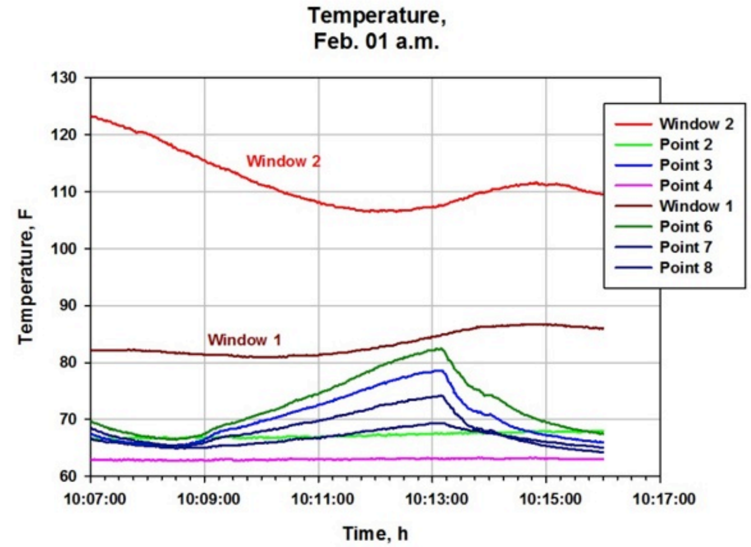
Electro-magnetic design

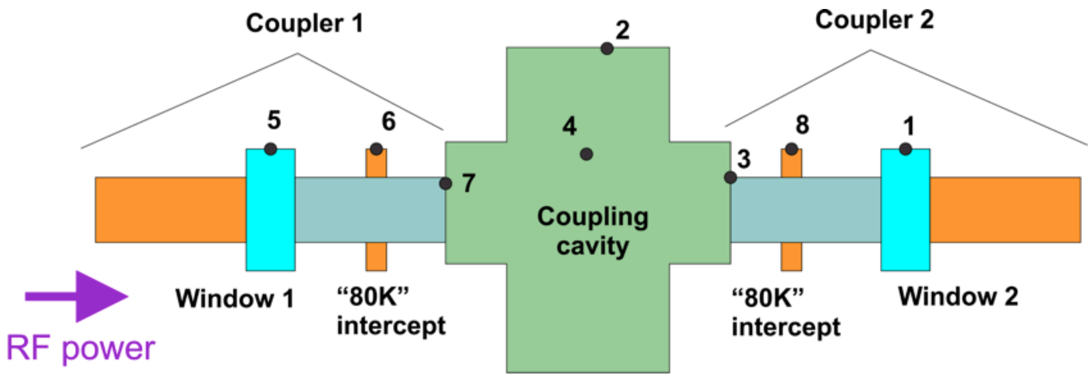
Parameter	Value
Frequency	325 MHz
Pass band (S_{11}<0.1)	> 1 MHz
PIP-II Operating power (CW reflection)	15 kW
Acceptance Testing power	**30 kW**
HV bias	**~ 4kV**

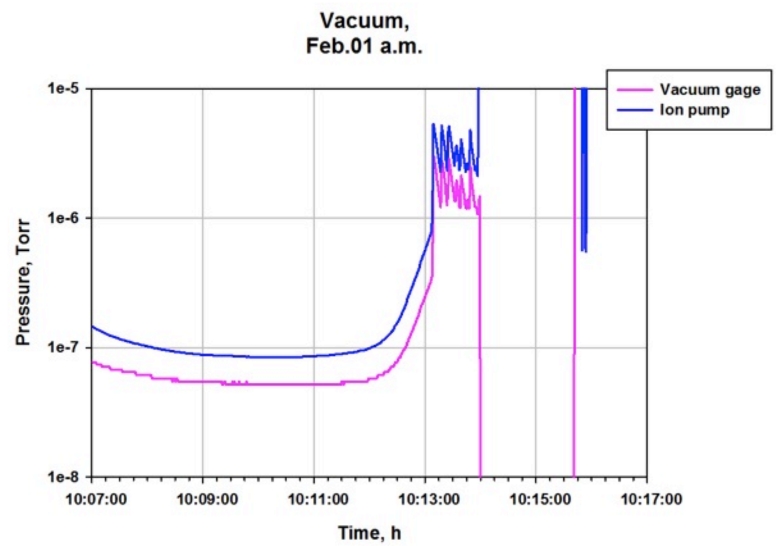
Work by S. Kazakov

1 Prototype Tested to Failure (reached 47 kW, successful)



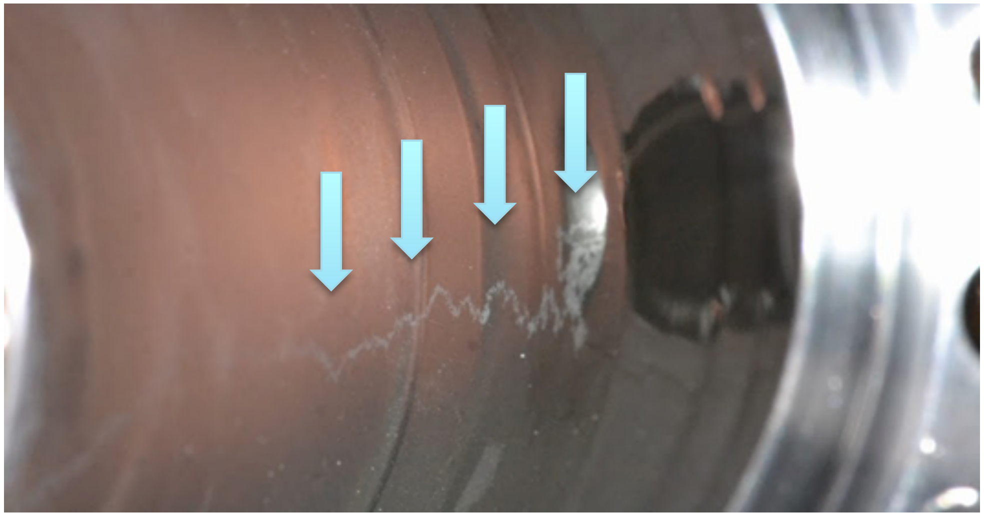


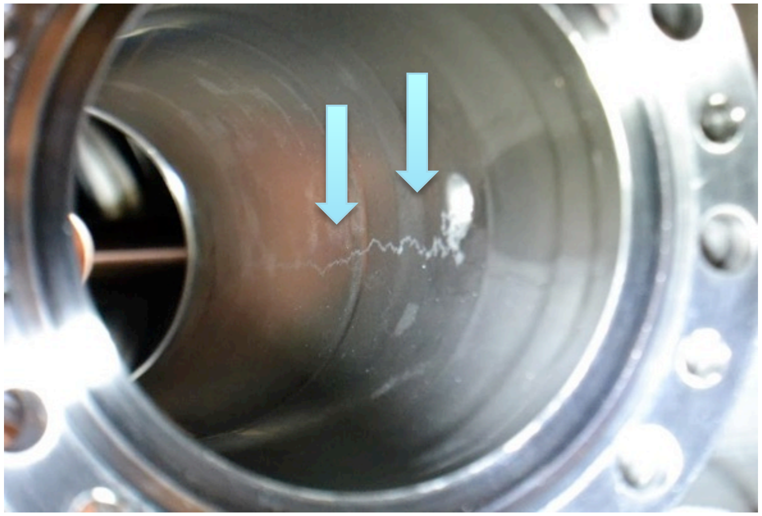


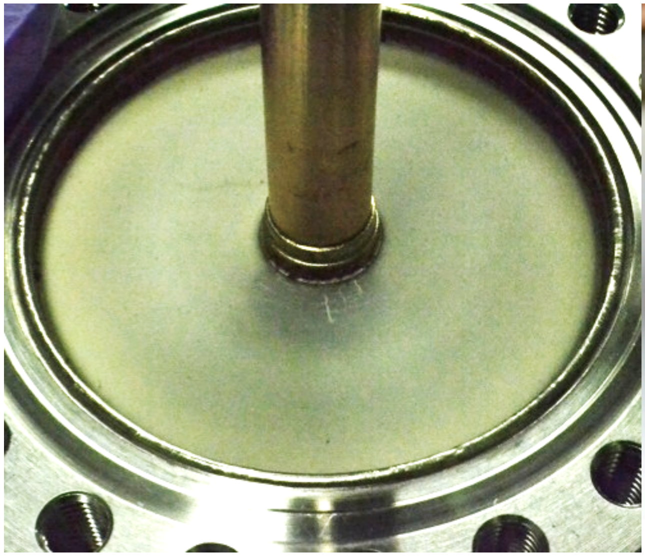


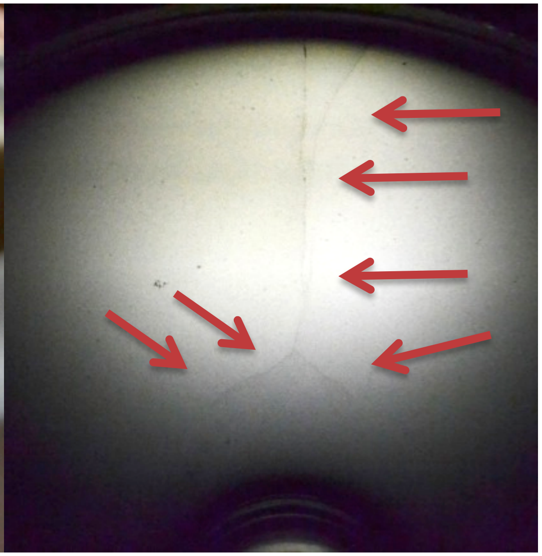
Failed Coupler

Work by S. Kazakov





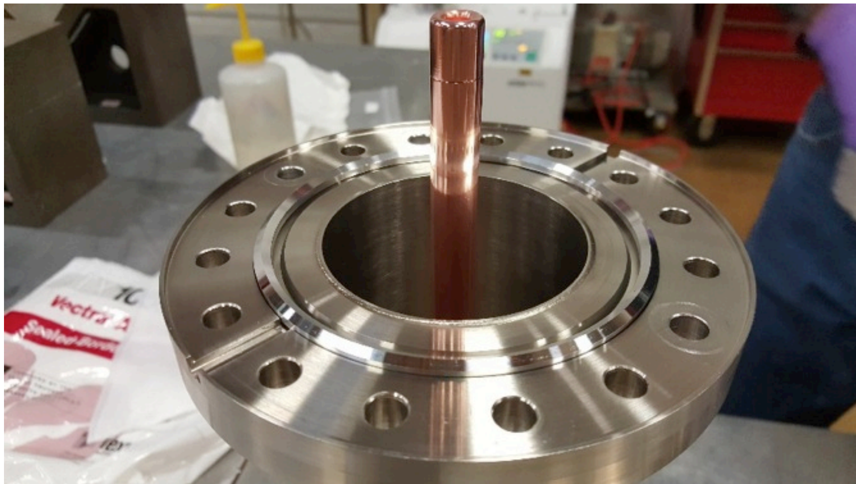


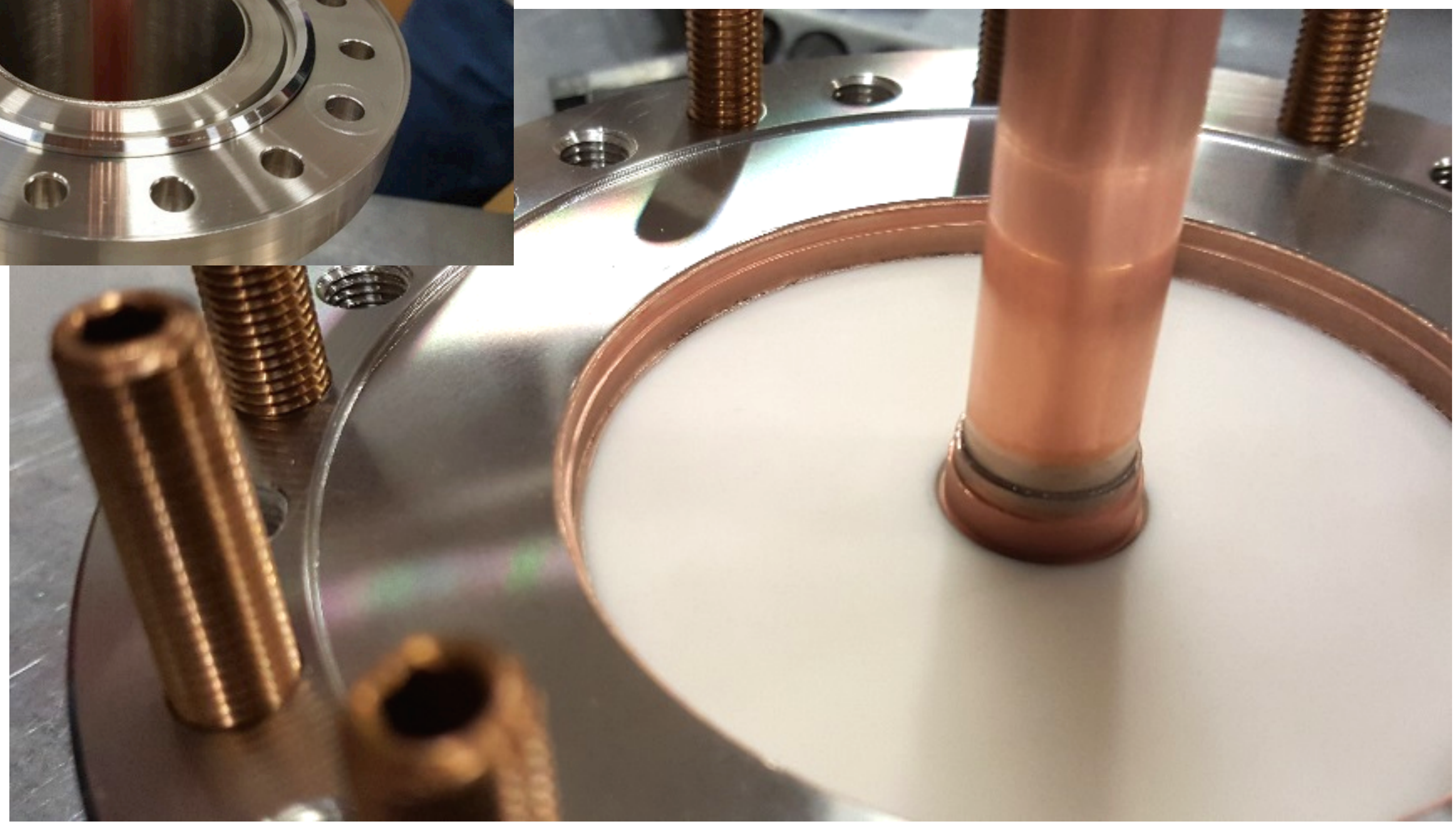


Work by S. Kazakov

Production Couplers

- Much better quality visually than prototypes
- High Power Tests this month





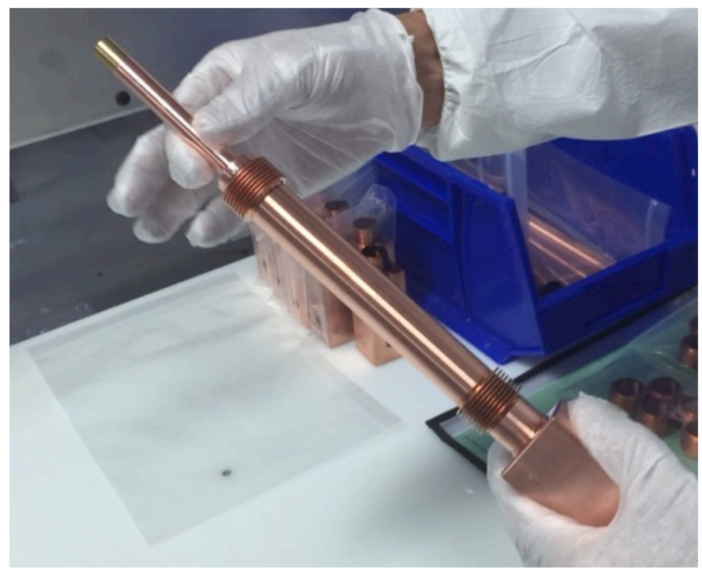
Electro-Deposited Bellows

Work by O. Pronitchev

Alternative to copper-plating (which has lots of potential issues)

PROS
- Flexible and elastic
- Vacuum integrity
- Flawless internal finish
- Very tight tolerance on shape

CONS
- 25um internal layer of Nickel is slightly magneti, not a problem for PIP-II
- limited suppliers



Ceramic Window with Low Pressure Gap

- Low pressure gas is kept between windows
- Advantages:
  - reliability as two windows
  - compact as single window (antenna can be easily cooled)
  - lower bending forces on window, compared to single window of same total thickness
- Occurrence leaks can be detected: decrease of pressure in gap indicates of crack in inner window, increasing pressure in gap indicates of crack in outer window.
- Any single crack is not fatal for accelerator.