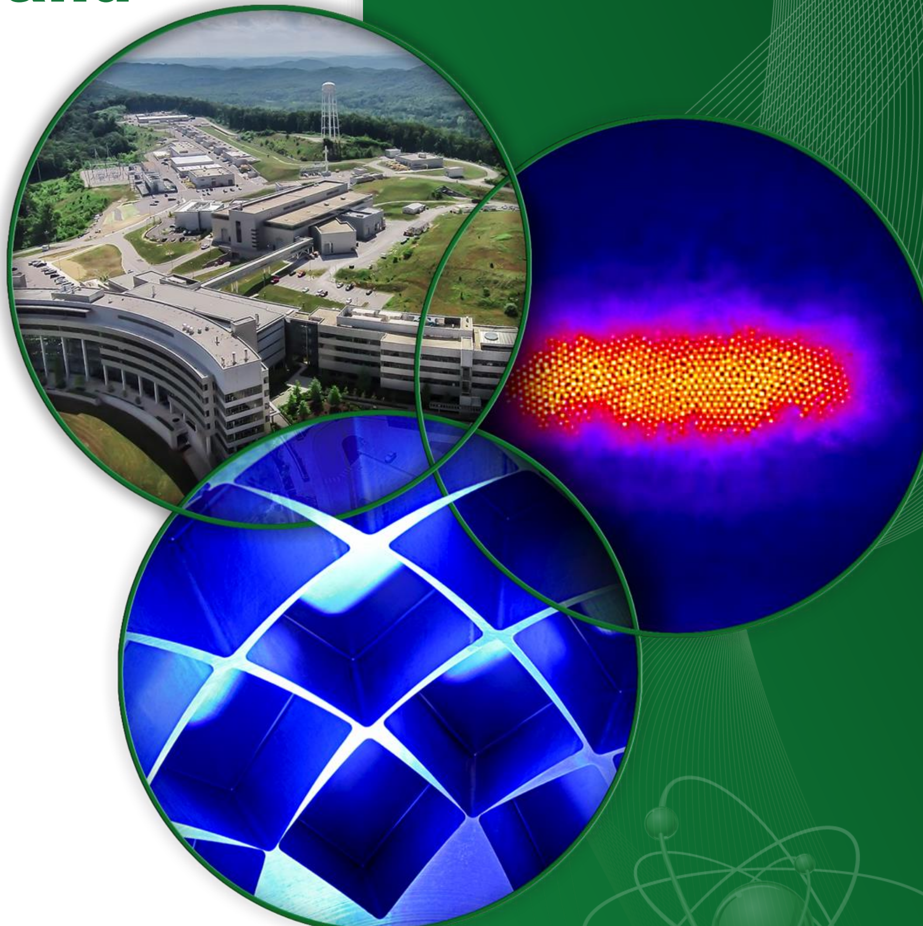
Fundamental Power Couplers Overview, Performance, and Plans at the Spallation Neutron Source



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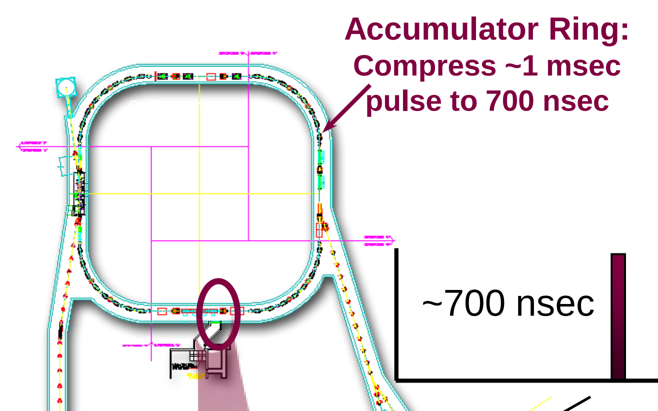
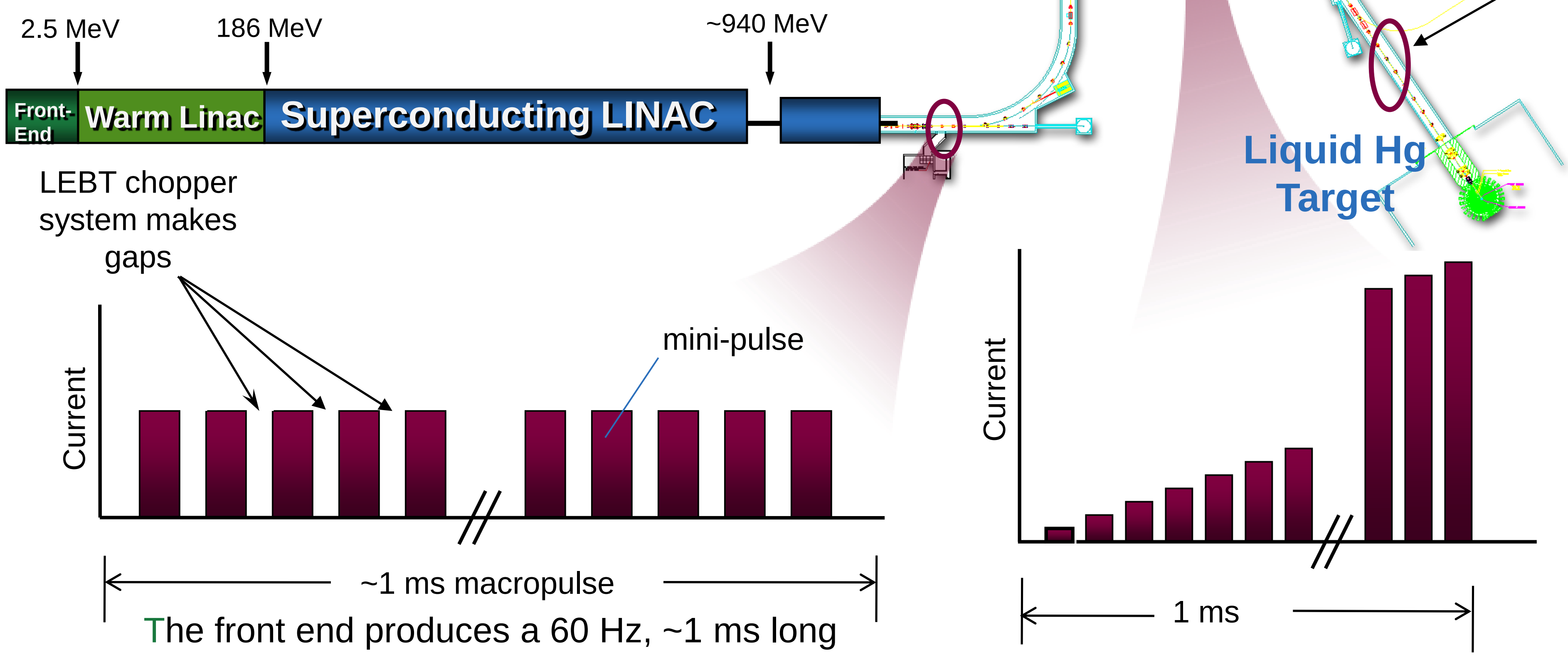
The SNS is now capable of operating routinely at power levels above 1 MW

- **SNS is the highest power pulsed neutron source in the world**
- **The machine has over 100,000 control points and cycles ~5.2 million times a day**
- **Power (and base neutron flux) is the product of:**
  - **Beam Energy**
  - **Peak Current**
  - **Chopping Fraction**
  - **Pulse Length**
  - **Repetition Rate**





The front end produces a 60 Hz, ~1 ms long chopped H- beam

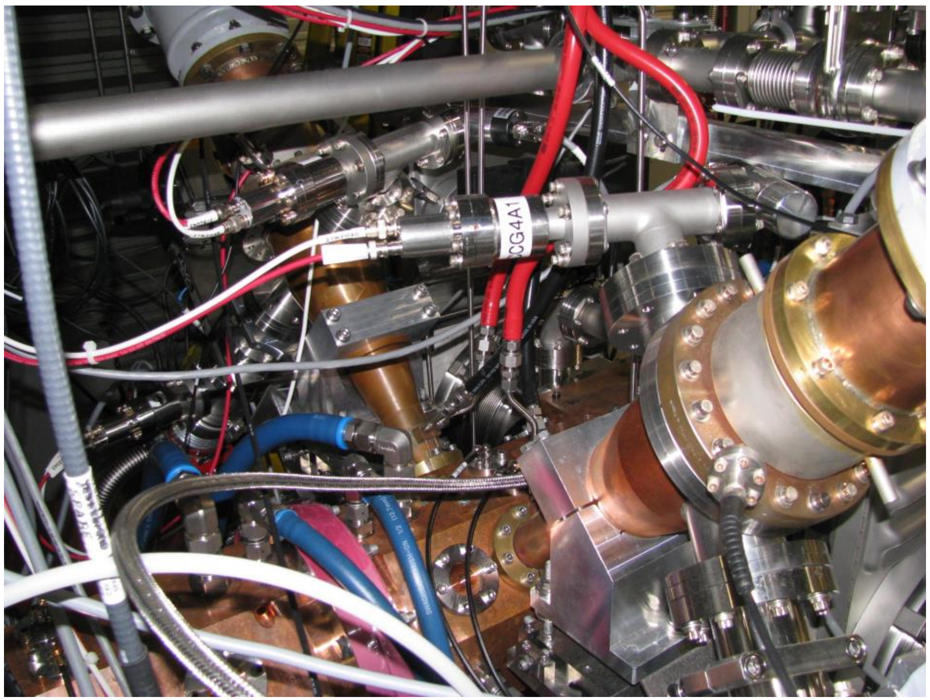
The SNS Linac cavities are powered by four unique types of fundamental power couplers

Type	Configuration	Couplers per cavity	Frequency (MHz)	Peak Power (kW)	Pulse Width (ms)	Duty Factor (%)	Average Power (kW)
RFQ	Coaxial	2	402.5	650/2	1	6	19.5
DTL	Waveguide	1	402.5	2000	1.1	6.6	133
CCL	Waveguide	2	805	3700/2	1.1	6.6	122
SCL	Coaxial with transition to waveguide	1	805	500	1.3	7.8	39

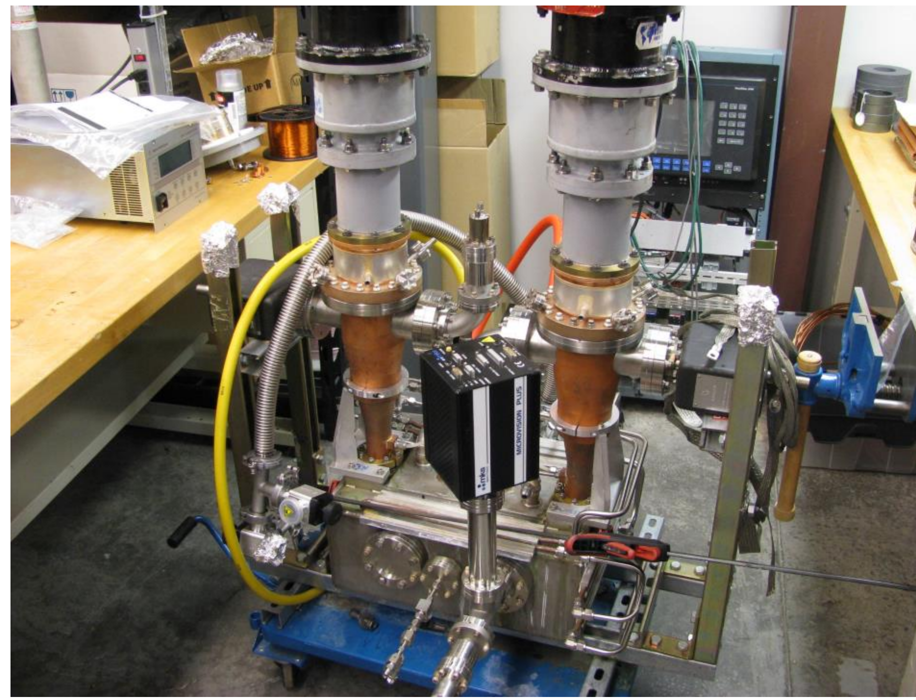
Notes:
1. All couplers feature a single Alumina ceramic window.
2. SCL couplers also feature a gas barrier at the waveguide flange.
3. Power numbers are typical maximum operating parameters at this time and do not indicate maximum capabilities of the couplers.

The RFQ is powered by two coaxial couplers

- 402.5 MHz, 325 kW peak, 19.5 kW average per coupler
- Based on the SCL coupler design; window assembly by Toshiba.
- Loop coupling with water-cooled loop
- Water cooling at outer diameter surface of ceramic
- Power split at waveguide magic tee above RFQ structure
- Operating RFQ featured eight couplers originally (of a different design)



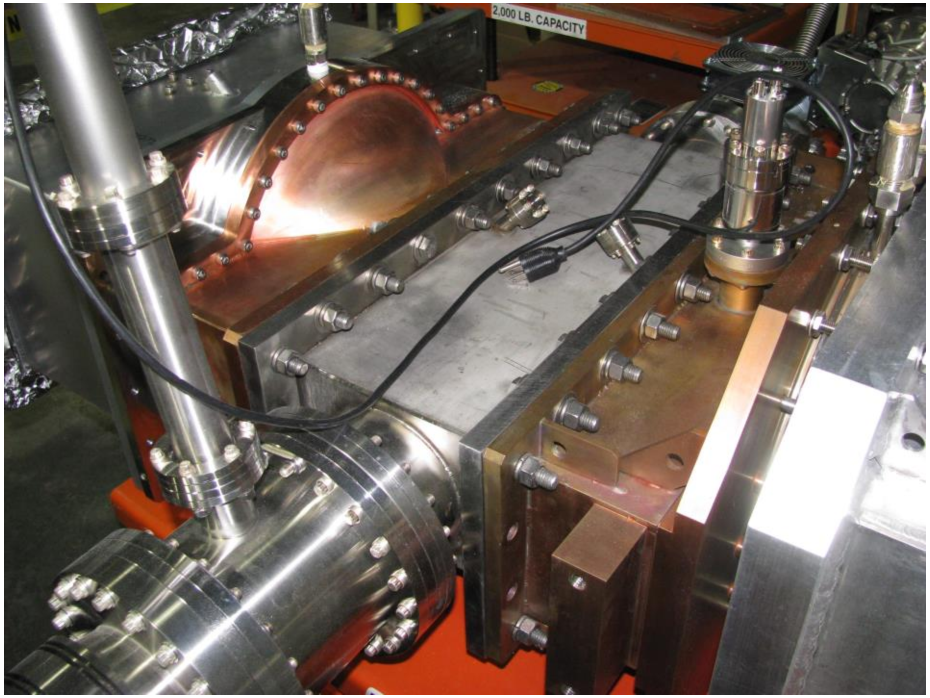
Coupler pair mounted on the new spare RFQ presently under test.



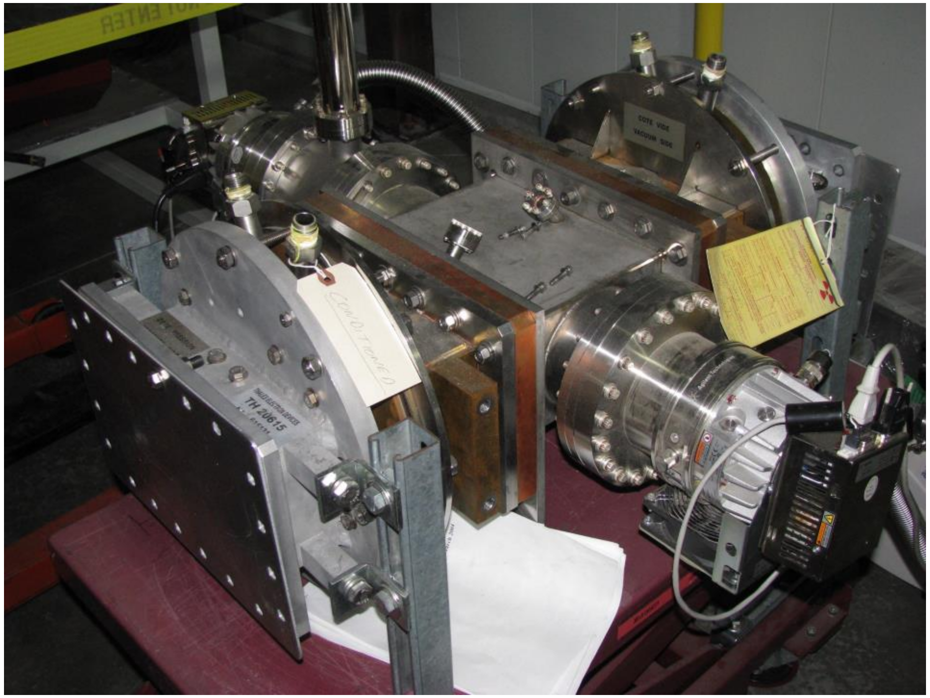
Coupler pair mounted on a bridge waveguide for testing, conditioning, and storage.

The DTL and CCL are powered by coupling irises, evacuated waveguides, and waveguide windows

- DTL: 402.5 MHz, 2000 kW peak, 133 kW average per coupler
- CCL: 805 MHz, 1850 kW peak, 122 kW average per coupler
- Water cooling at outer diameter surface of ceramic



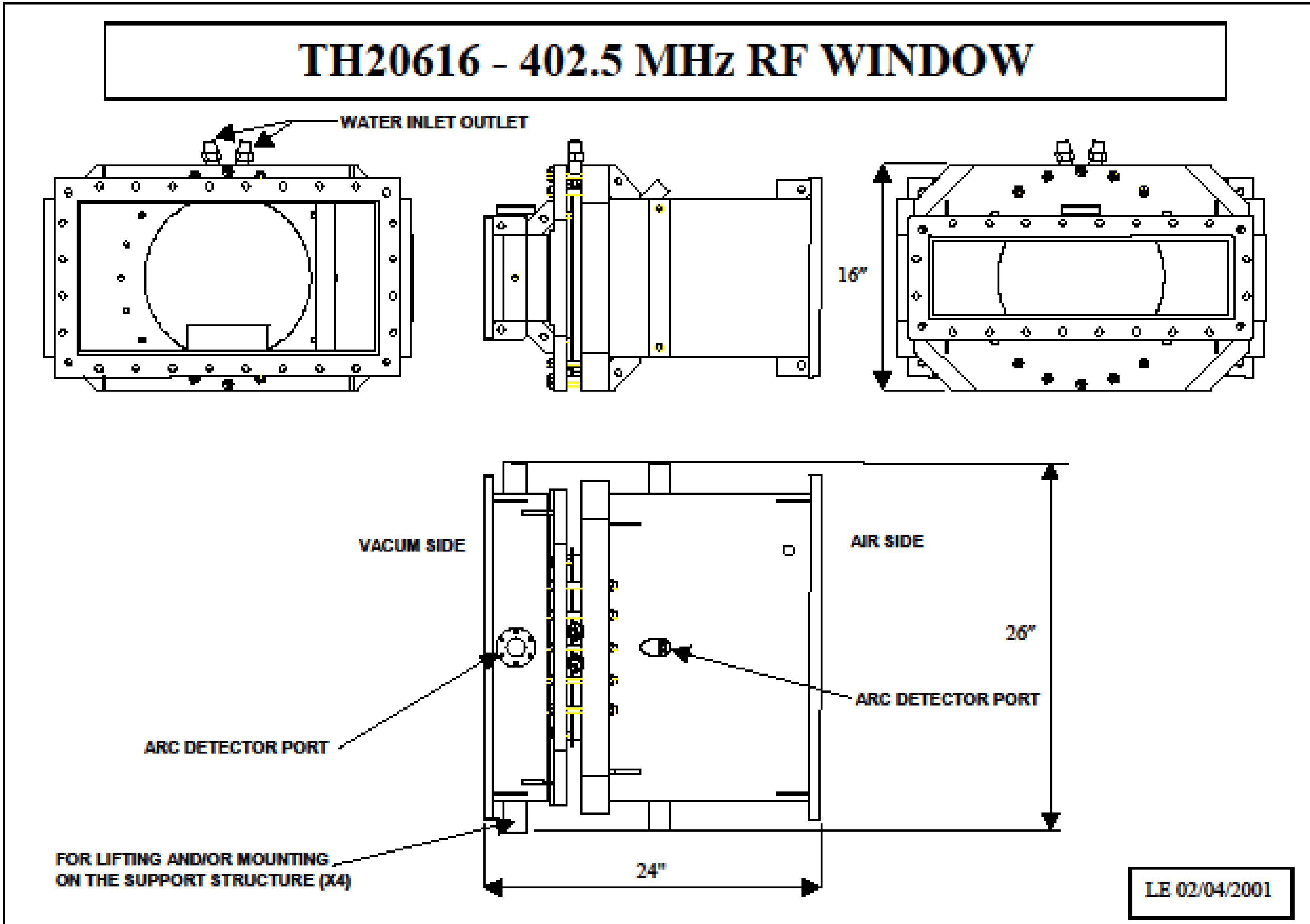
DTL windows mounted on bridge waveguide for testing, conditioning, and storage. Window to left is prototype of new design (Mega). Window on right is standard Thales window used in the Linac.



CCL windows mounted on bridge waveguide for testing, conditioning, and storage. Both are standard Thales windows used in the Linac.

Installation photo illustrating attachment of DTL coupling iris and waveguide to DTL tank

Illustration of DTL window



SNS SRF cavity

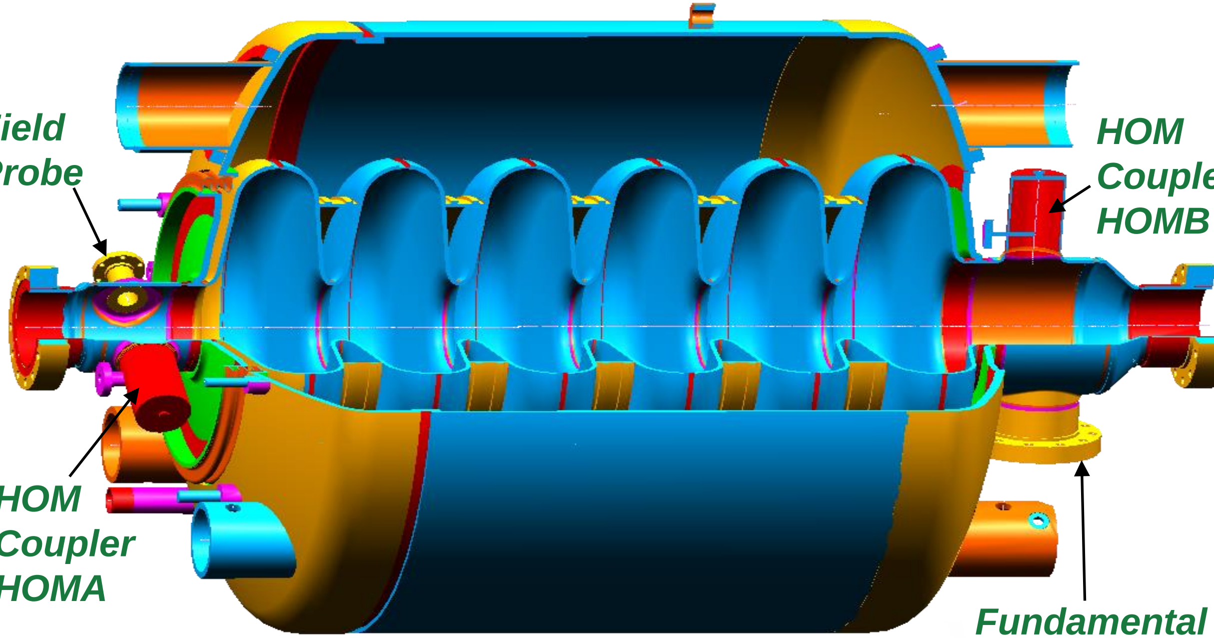
Major Specifications:

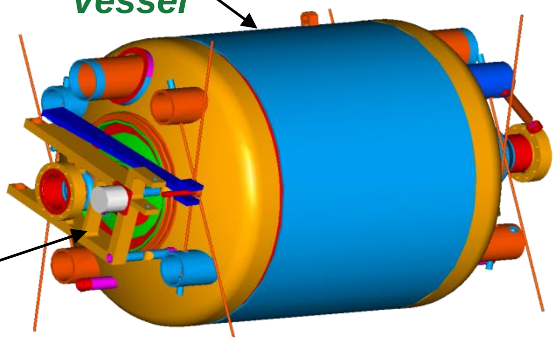
E_a=15.9 MV/m at β=0.81

E_a=10.2 MV/m at β=0.61

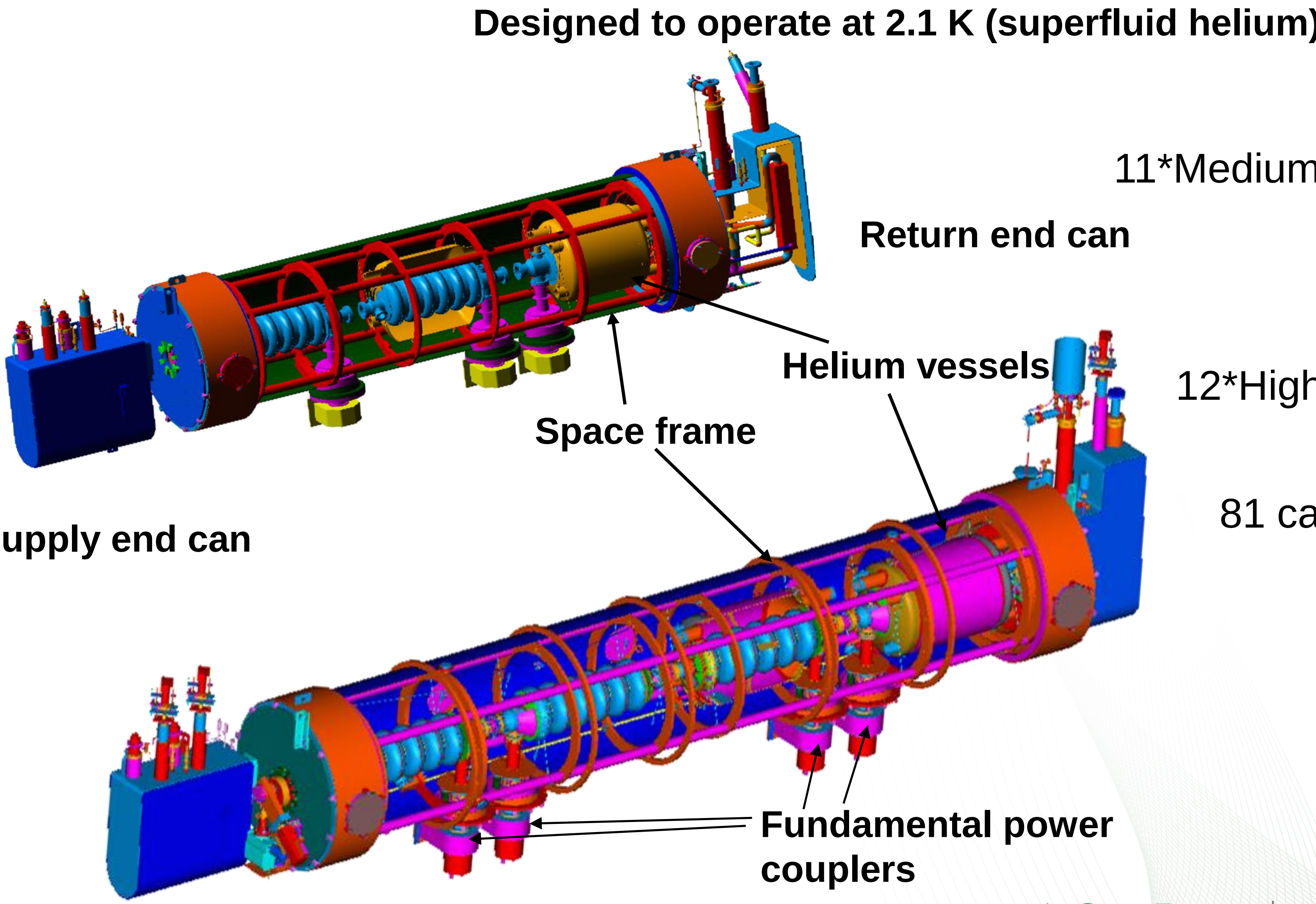
&

Q_o> 5E9 at 2.1 K





SNS Cryomodule



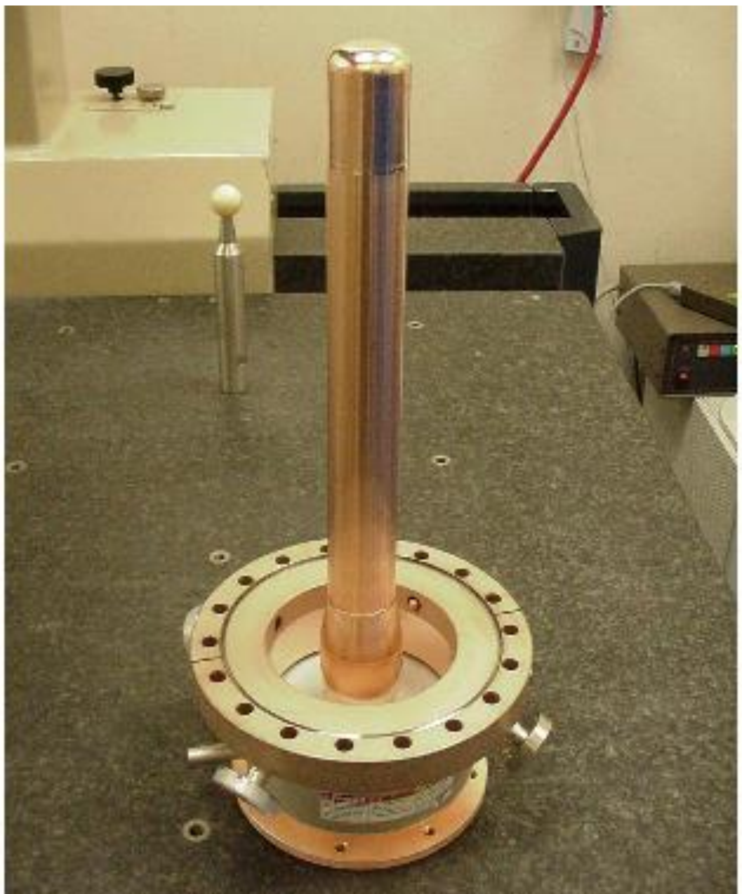
11*Medium beta

12*High beta

81 cavities

The SCL cavities are powered by coaxial couplers that include a coaxial to waveguide transition

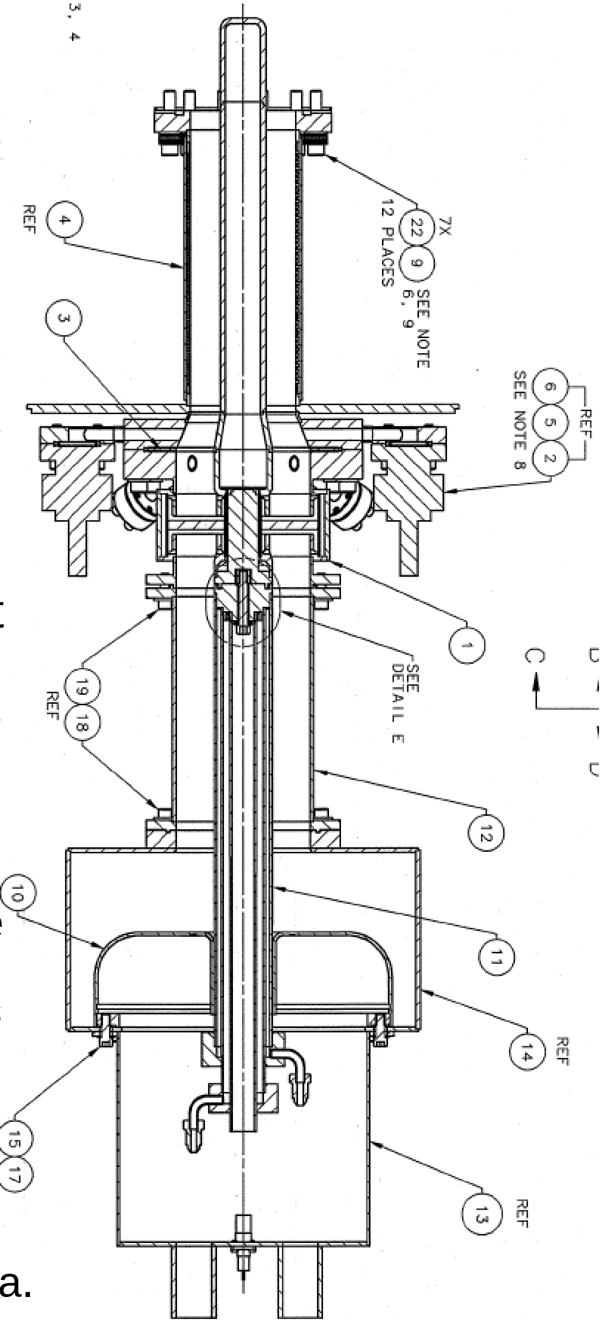
- 805 MHz, 500 kW peak, 39 kW average per coupler
- Water cooling of inner conductor on air side of window
- Gaseous helium cooling of outer conductor on vacuum side of window
- Conduction cooling of window
- Window design basis was the KEK-B coupler



- Equipped for DC bias
- Electron pickup at window
- Optical arc detection at window
- Cold-cathode vacuum gauging at window

- Only 2-3 failures since commissioning. Failure mode is small vacuum leak at outer conductor braze joint.

Window and inner conductor assembly produced by Toshiba.



Fundamental Power Coupler Test Results - Tests performed at LANL

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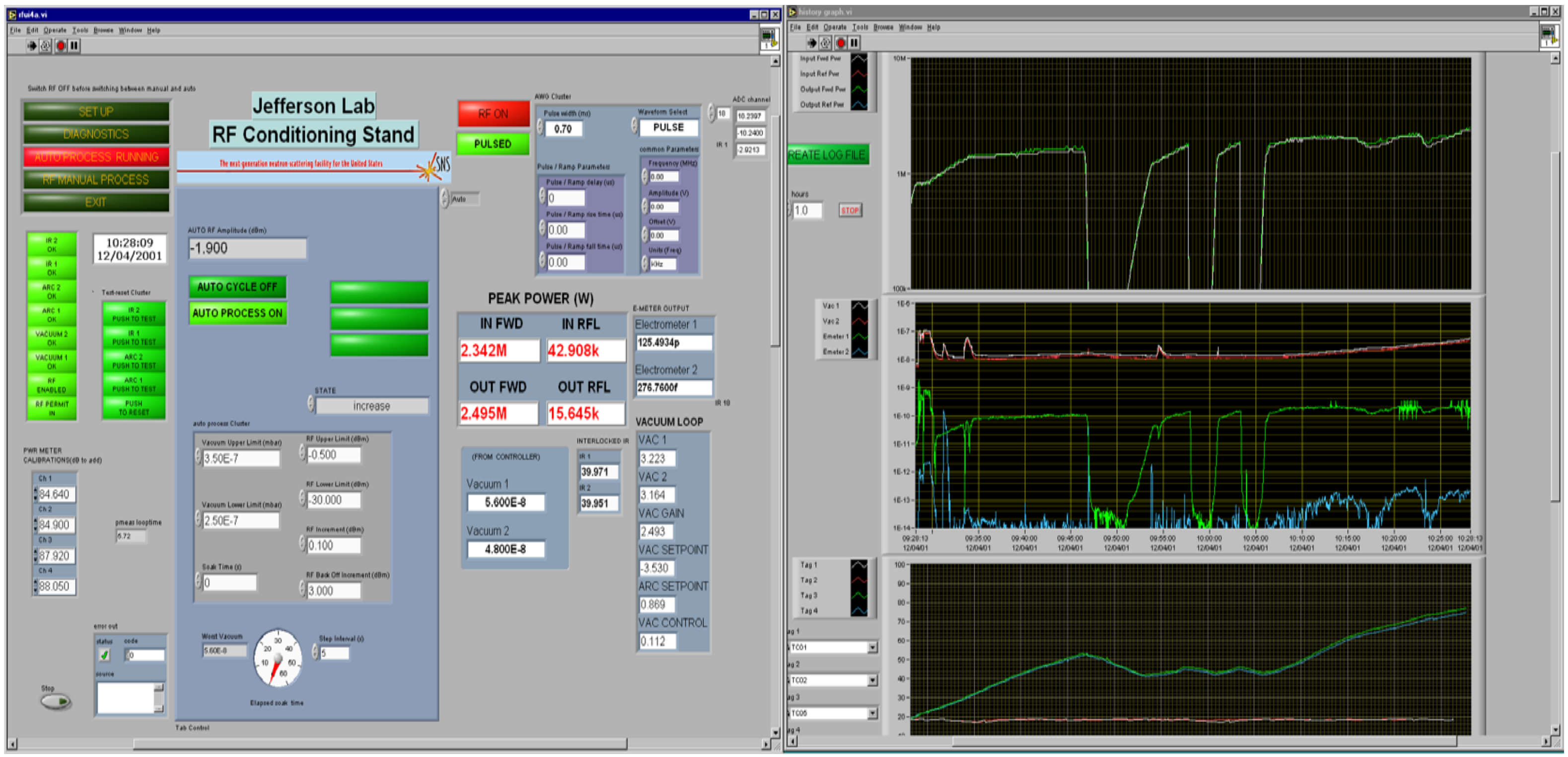
Reached 2 MW Peak Power!!!! 50 kW Average.



Recent RFQ History at SNS

- Oct 2012: Vacuum degradation during power outage. Impact uncertain.
- Jun 2013: RFQ retuned; transmission increased ~15%.

  Replaced B coupler due to flow restriction in the loop cooling circuit.
- Oct 2013: Replaced B coupler due to heating.
- Jan 2014: Replaced A coupler due to heating.

  The RFQ performance was adequate for sustained 1.3-1.4 MW beam power on target through Jun 2014.
- Jul 2014: RFQ accidently vented and exposed to water vapor.
- Aug 2014: RFQ accidently vented and exposed to water vapor *again*.

  ➔ RFQ performance degraded as result of these events.
- Oct 2014: Removed and inspected B coupler.

  No damage observed ➔ reinstalled coupler.

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Future Plans for the Production RFQ

- Apr 2015: Plan to replace B coupler with a freshly conditioned spare.

  Plan to install X-Ray view ports.

  Plan to replace at least one field probe.

- Later: Plan to install a vacuum gate valve in the beamline between the LEBT and the RFQ.

  - The original valve was removed long ago due to reliability problems.

  - Experience has shown that a functioning gate valve is essential.

- Ongoing: Ensure adequate spares to meet neutron production goals.

  - RF couplers and field probes

- Eventual: Remove the production RFQ from the Front-End and reinstall in the Integrated Test Stand Facility.

RFQ Couplers Status

March 2015

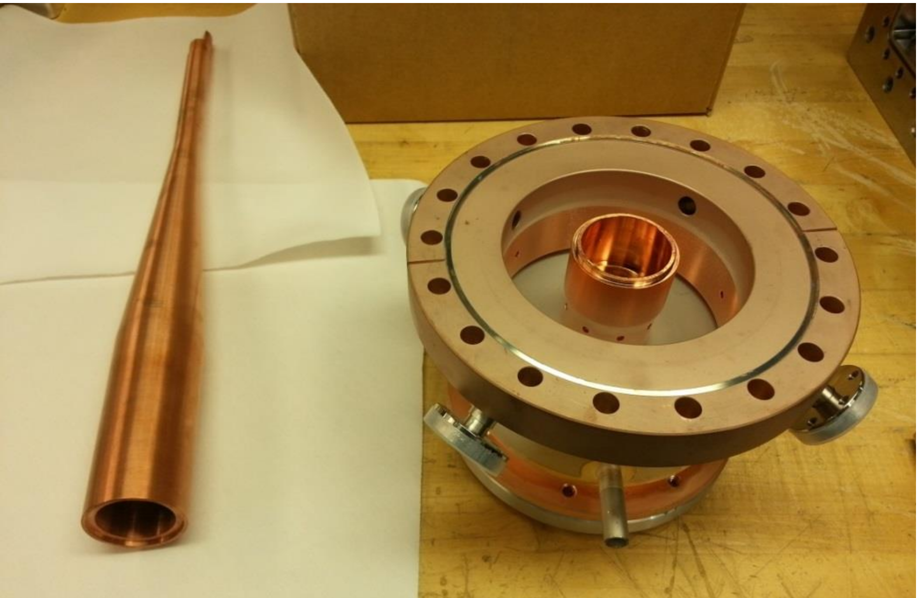
- One new spare has been RF conditioned and is ready for installation
  - Installation on production RFQ planned for April 13, 2015
- Two reconditioned spares have been used on the spare RFQ
  - They performed reliably during the spare RFQ acceptance testing in August, 2014
- Three spares have been ordered from a US vendor (CPI)
  - Delivery has been delayed due to technical challenges
- Four spares have been ordered to a Japanese manufacturer (Toshiba)
  - Delivery planned for end of May, 2015
  - Toshiba produced all of the RF couplers presently used in the superconducting linac and RFQ
- Two couplers are being constructed in house using spare ceramic windows
- Four outer conductors are available

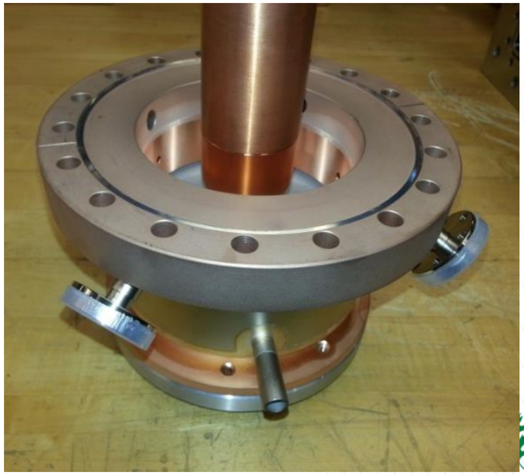
Courtesy of Y. Kang

Fabrication of two additional RFQ Couplers

Courtesy of Y. Kang

- The coupler inner conductor assembly has been built as a single structure at the manufacturer.
- Two coupler inner conductors have been built by joining the antennas onto the ceramic windows
  - Two ceramic windows manufactured as prototypes have been available (on the shelf at SNS)
  - The antennas for the coupling loop have been separately manufactured
  - Joining Copper parts has been performed successfully for the two assemblies
  - Vacuum leak check has been performed successfully
  - High power RF conditioning is to be performed





RFQ Coupler Outer Conductors (on the shelf)

Courtesy of Y. Kang

Four DTL RF Vacuum Windows Replaced to Date

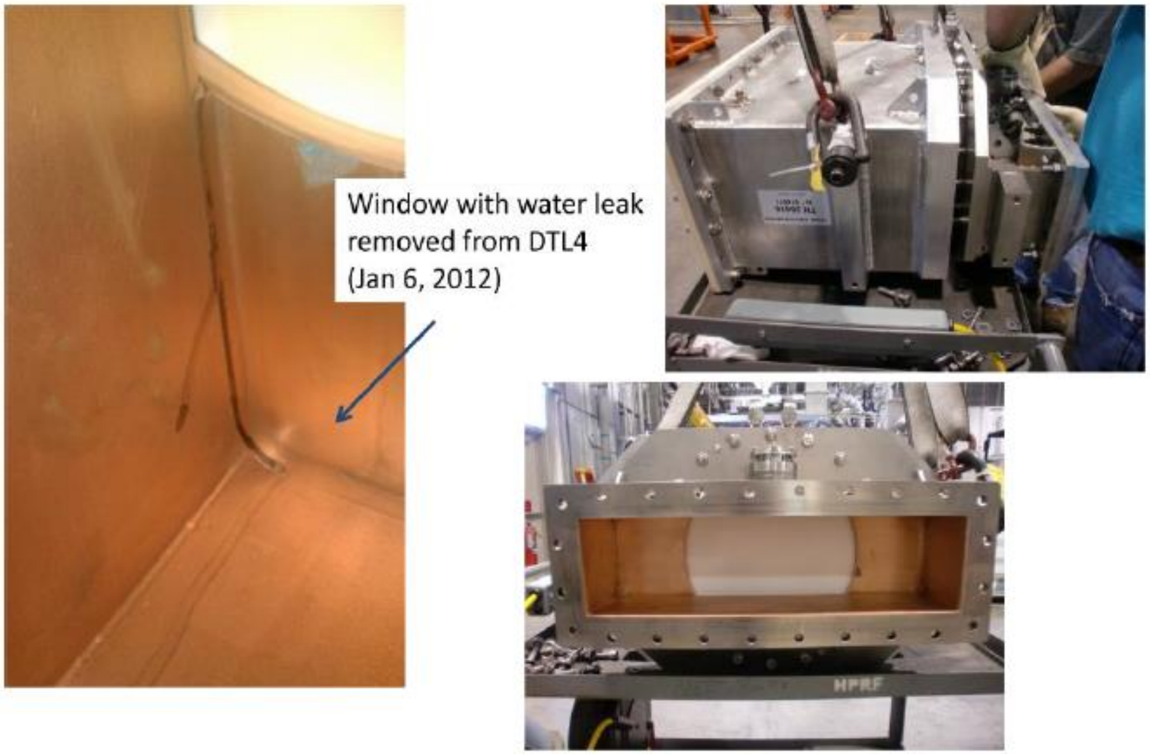


Figure 1 - DTL Window with water leak into vacuum

- **DTL6 window replaced 1/21/10 because of suspected flange or O-ring vacuum leak**
- **DTL4 window replaced 4/26/11 because of arcing**
- **DTL4 window replaced 12/26/11 because of water leak to vacuum**
- **DTL5 window replaced 4/15 because of ceramic break**
- **DTL5 window to be replaced 7/15 because of vacuum leak**

Five CCL RF Vacuum Windows Replaced to Date

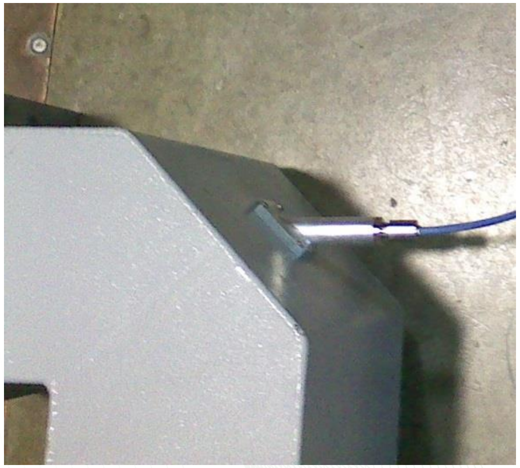
Figure 3 - CCL Window with fracture of ceramic window.

- **CCL2b window broken 11/2/07**
- **CCL3b window broken 2/3/11**
- **CCL4b window broken 1/28/12**
- **CCL1b & CCL4b windows replaced due to excessive arcing and vacuum activity July 2012**

IR Window Temperature Measurement

- Utilizes commercially available system
- Indirect measurement of surface window temperature
  - allows for tracking temperature changes in window
  - plan to implement interlock
- Integrated into EPICS via transmitter PLC
- Prototype system – installed on CCL3 & 4

Raytek Controller
(in transmitter rack)



Sensor in waveguide
(in Linac tunnel)

Actions Taken to Prevent Further RF Window Failures

- RF Structures team commissioned to investigate problems and create a Risk Mitigation Plan → Completed June 2012
- Key elements:
  - Order additional spares from Thales (3 each for DTL and CCL) ☑
  - Develop alternative window designs with experienced RF vendor ☑
  - Implemented more conservative procedure for *in situ* RF conditioning ☑
  - Develop interlock based on infrared measurement of window temperature ☐
- Significantly, nearly all of the CCL ion pumps were replaced during the summer 2012 shutdown due to poor performance
- Numerous vacuum system improvements are planned for the DTL

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Issues of Concern

- Vendor reliability in areas of quality and schedule
- Renewal of ceramic surfaces
  - Feasibility of removing vapor deposition from fully assembled window
  - Methods of removal: blasting with Alumina grit
  - Renewal of anti-multipactor coating, e.g., TiN
- Replacement of failed ceramics
  - Is it better to build an entirely new window assembly? (presently in discussion with Thales on this topic)
- Failure of RFQ couplers not well understood
- Development of robust reliable infrared (IR) temperature measurement and interlock
- Prediction of window lifetime (IR temperature measurement?)
- Validation of new window designs

Summary

- The SNS fundamental power couplers have generally met performance requirements, but…
- Several failures have occurred with non-trivial operational impacts
  - RFQ couplers require periodic replacement.
  - DTL & CCL windows occasionally break resulting in uncontrolled venting of the beamline.
  - A few SCL couplers developed small leaks; repairs mandated removal of cryomodules from the Linac.
- Working to improve supply chain and develop repair methods for failed couplers.
- Good interlocks and conditioning procedures are basic requirements, but they don't guarantee against failures.
- IR temperature measurement and interlock may be key to preventing window breakage and predicting end of life.