Progress in Cavity and Cryomodule Design for the Project X Linac

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Fermilab
PAC'11
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U.S. DEPARTMENT OF ENERGY

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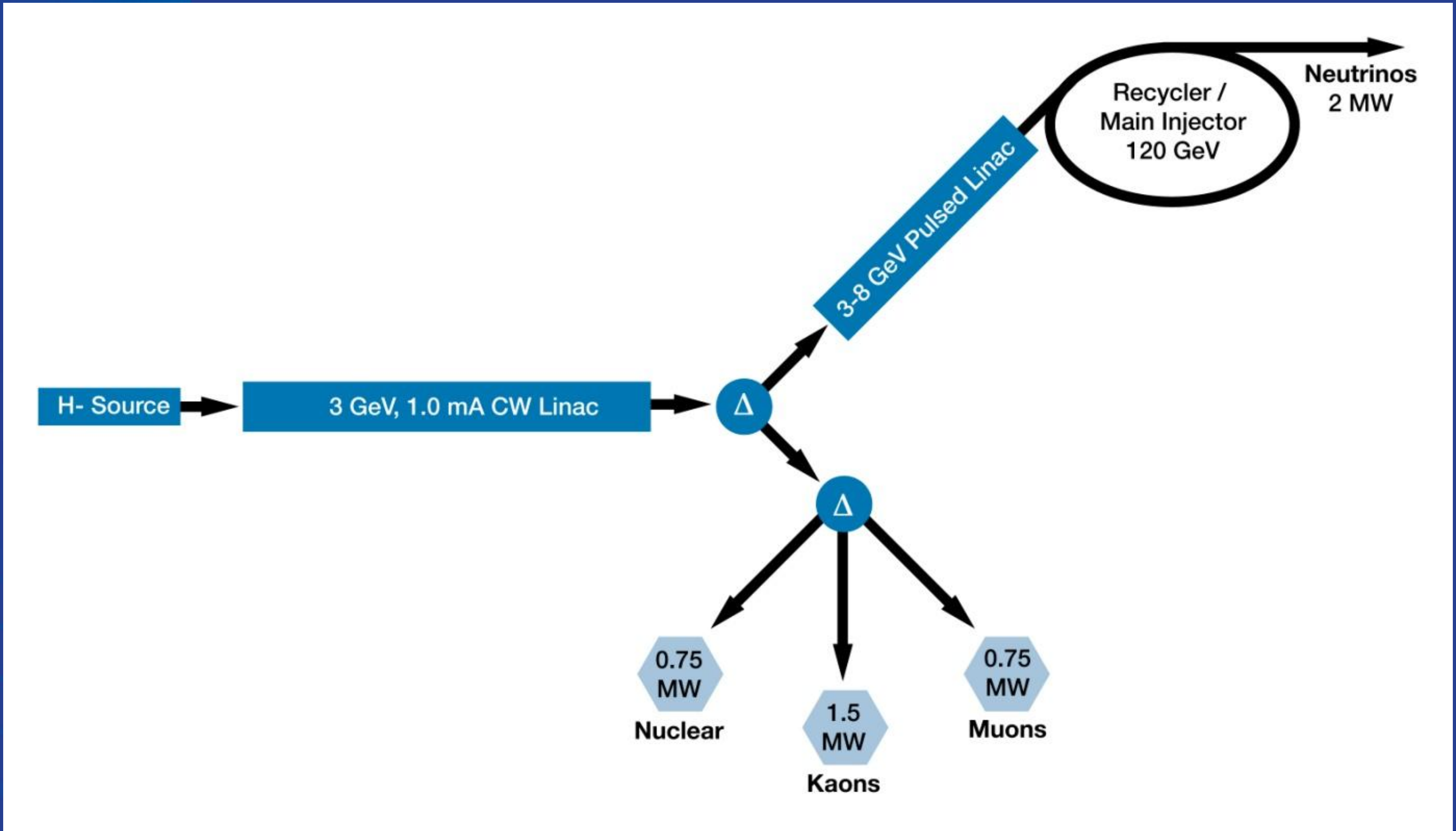
Project X Reference Design



Project X – New Multi Megawatt Proton Source
S. Nagaitsev, Friday morning invited oral

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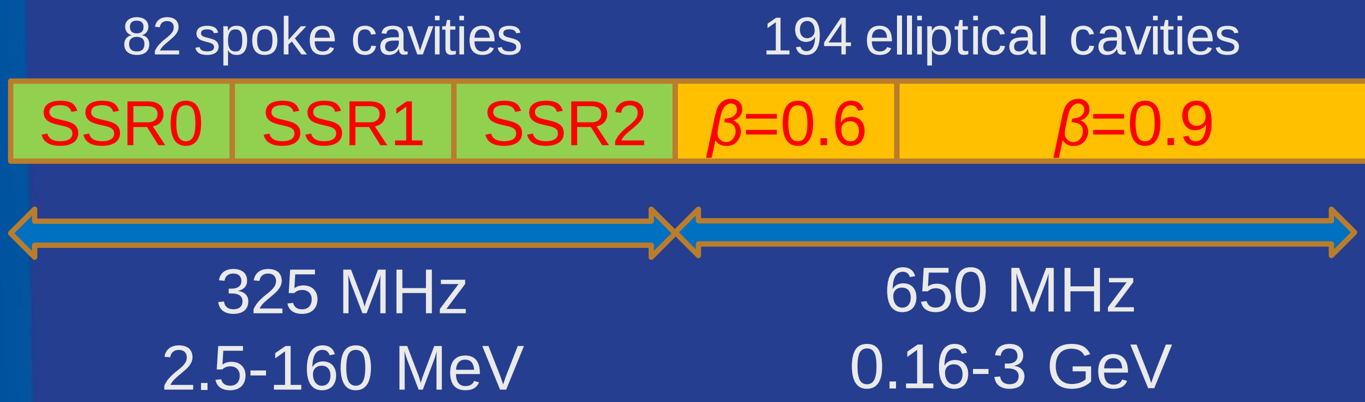
Project X Reference Design
3 GeV, 1 mA, continuous wave H- Linac



Section	Freq	Energy (MeV)	Cav/mag/CM	Type
SSR0 (β_G=0.11)	325	2.5-10	18/18/1	SSR, solenoid
SSR1 (β_G=0.22)	325	10-32	20/20/ 2	SSR, solenoid
SSR2 (β_G=0.4)	325	32-160	44 /24/ 4	SSR, solenoid
LB 650 (β_G=0.61)	650	160-520	42/28/ 7	5-cell elliptical, doublet
HB 650 (β_G=0.9)	650	520-3000	152/38/19	5-cell elliptical, doublet

Project X is a collaborative program

- Collaboration MOU for R&D phase:

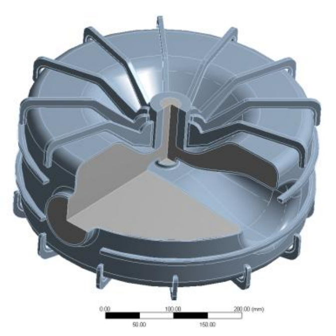
ANL	ORNL/SNS
BNL	MSU
Cornell	TJNAF
Fermilab	SLAC
LBNL	ILC/ART
BARC/Mumbai	IUAC/Delhi
RRCAT/Indore	VECC/Kolkata

- Next collaboration meeting:
  - April 12-14, 2011, at ORNL / SNS
  - https://indico.fnal.gov/conferenceDisplay.py?confId=4043

Electromagnetic Designs of 325 MHz Single-Spoke Resonators have been Completed

- Three designs cover the beta range 0.11 – 0.42

cavity type	β_G	Freq MHz	$U_{acc,\,max}$ MeV	E_{max} MV/m	B_{max} mT	R/Q, Ω	G, Ω	$Q_{0,2K}$ $\times 10^9$	$P_{max,2K}$ W
SSR0	β=0.114	325	0.6	32	39	108	50	6.5	0.5
SSR1	β=0.215	325	1.47	28	43	242	84	11.0	0.8
SSR2	β=0.42	325	3.34	32	60	292	109	13.0	2.9



- SSR0 (β = 0.11)
  - Design optimization in progress
  - Iterating between EM and mechanical designs to achieve:
    - required EM parameters,
    - minimum frequency sensitivity (dF/dP),
    - tunability,
    - minimum length,
    - and manufacturability
  - Plan to initiate procurement of 1-2 prototypes in mid FY11

EM Design of the Low-Beta SC Cavities for the Project X Front End

I. Gonin et al., TUP070

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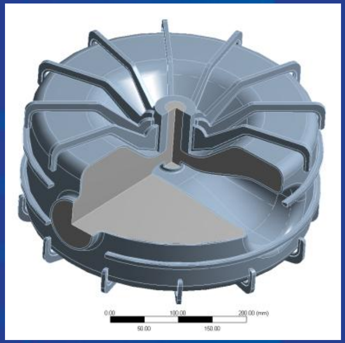
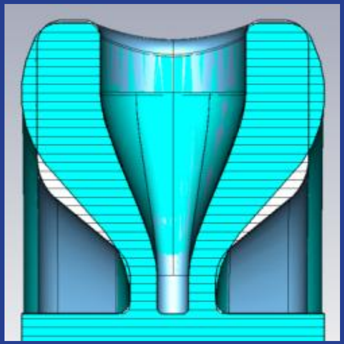
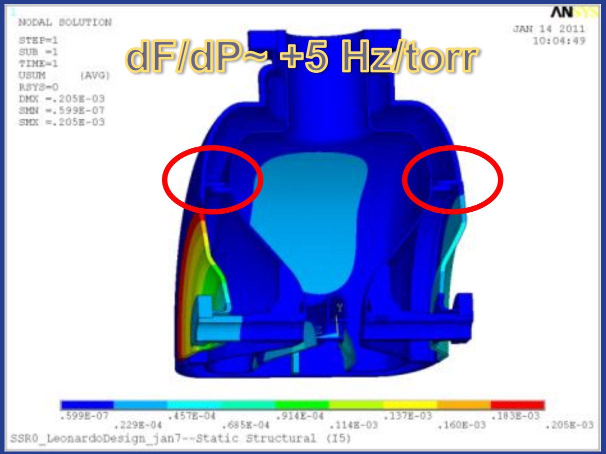
Recent Developments on the SSR0 Design



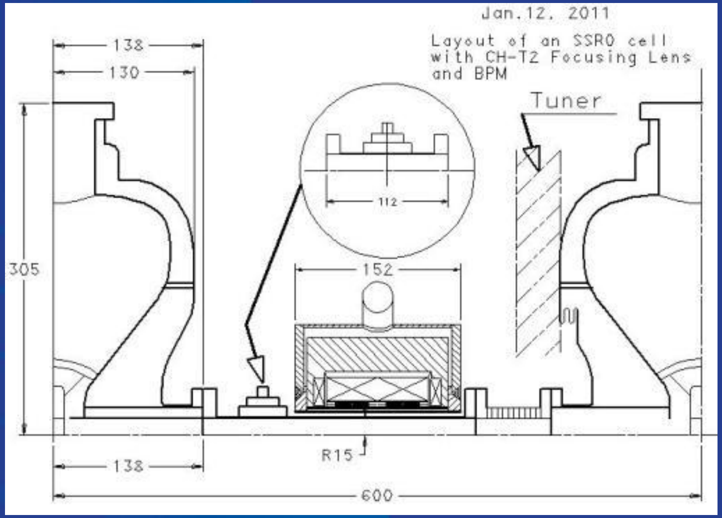
Initial Concept



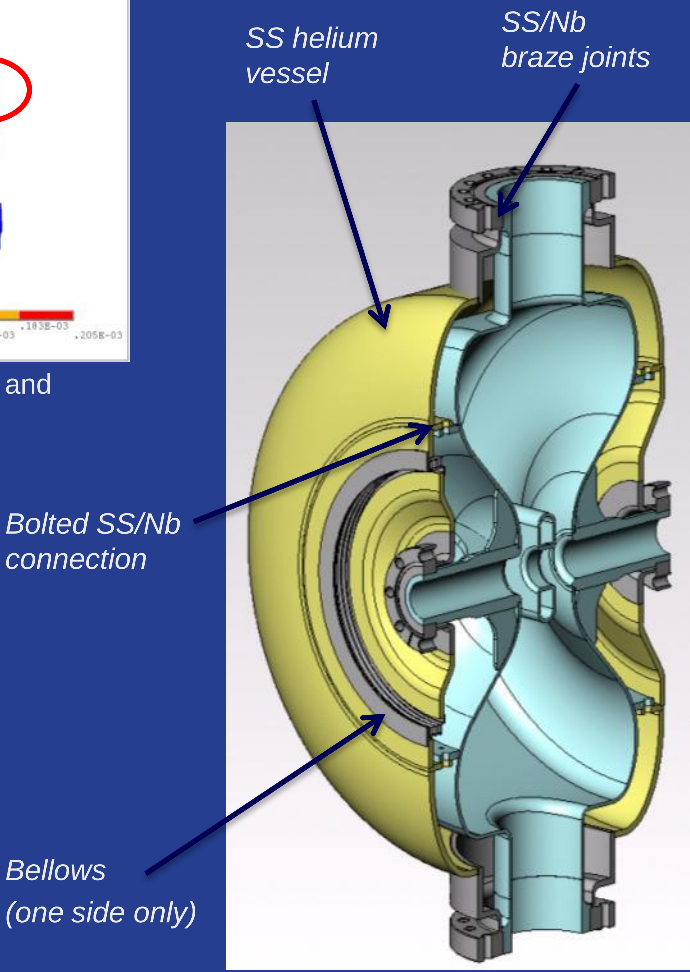
Rounded end walls to reduce frequency sensitivity to pressure variations



Connection between helium vessel and cavity wall key to minimizing dF/dP



Lattice spacing requirement: <610 mm
Need BPM, solenoid, bellows and tuner between cavities
Appears feasible (but tight)



Mechanical Design

Design of Single Spoke Resonators for Project X
L. Ristori et al., TUP084

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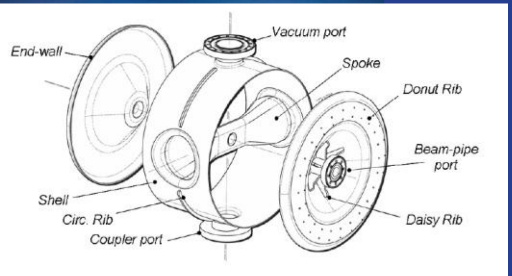
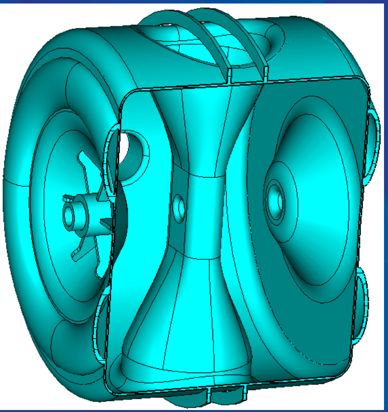
Status of Design Work on 325 MHz Single-Spoke Resonators SSR1 and SSR2



- SSR1 (β = 0.22)
  - EM and mechanical design complete
  - Two prototypes have been fabricated by Zanon and Roark, processed in collaboration with ANL, and tested at Fermilab
  - Two cavities in fabrication at IUAC/Delhi
    - Expected to arrive at Fermilab in FY11
  - Ten cavities in fabrication by Niowave/Roark
    - Expected deliveries beginning in spring 2011; complete by end of CY11
  - SSR1 development started under HINS program and is therefore more advanced



- SSR2 (β = 0.42)
  - EM design complete
  - mechanical design on hold while we complete higher priority work on SSR0 and SSR1 cavities

New 325 MHz Test Capabilities Developed

SSR1 prototype ready for vertical dewar testing.

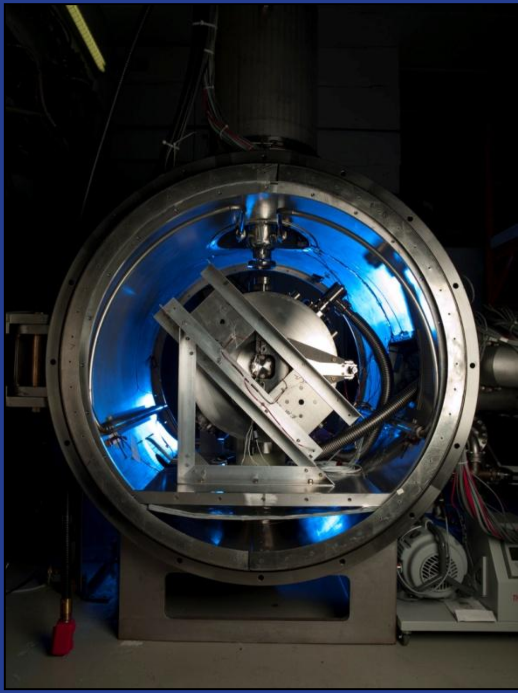
The testing was carried out in the vertical dewar used for 1.3 GHz cavity testing with the addition of new electronics and tooling.

Spoke Cavity Test Cryostat completed and commissioned.

Includes cryostat, shielded enclosure, helium distribution, vacuum system, instrumentation, RF power, and safety interlocks.

Enables 4.2 K testing of “dressed” 325 MHz single-spoke resonators.

Will be upgraded for 2 K operation in FY12.

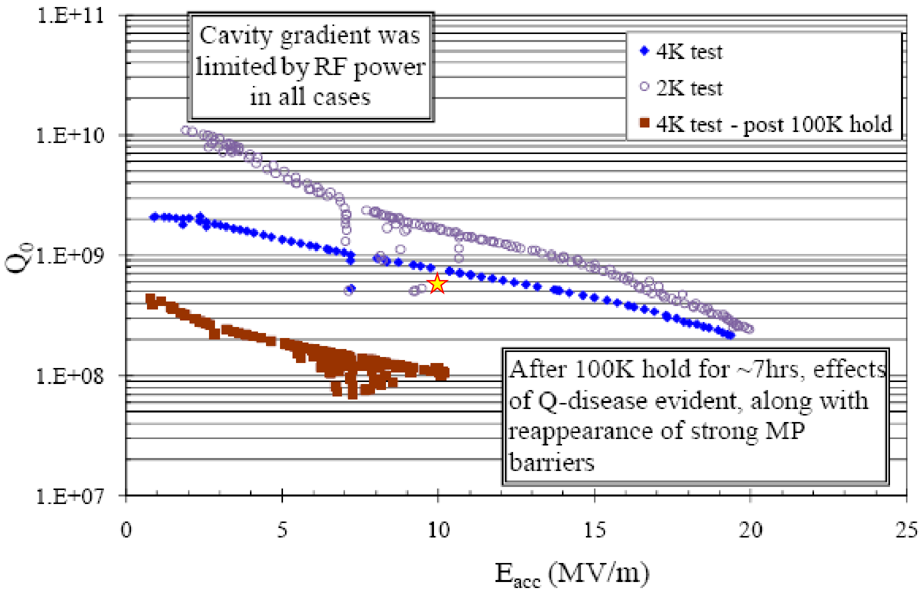


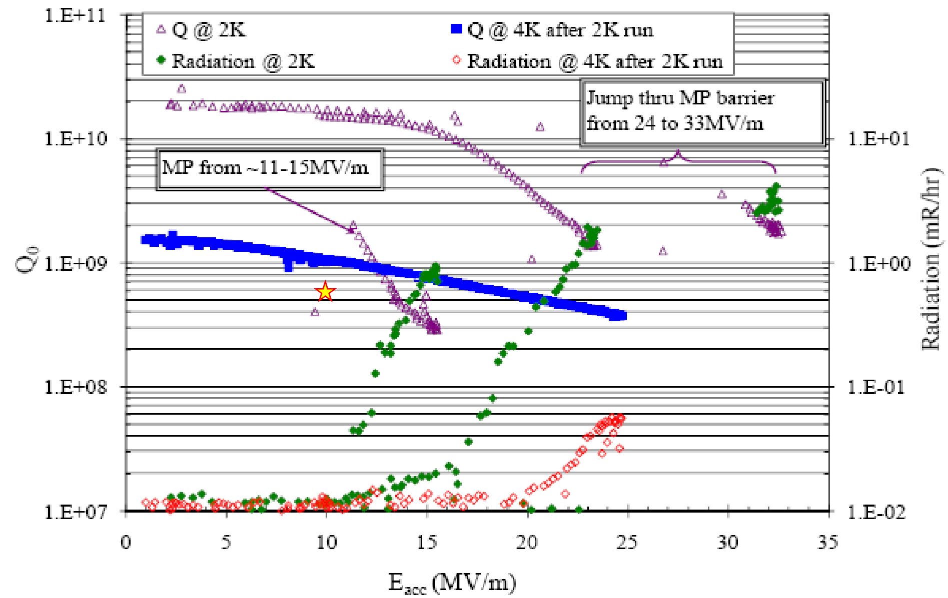
Dressed SSR1 prototype under preparation for testing.

All auxiliaries, including RF couplers, tuners, and magnetic shielding included.

Prototype SSR1 Cavities Exceeded Performance Expectations in Vertical Dewar Testing

★ Design Specifications: Gradient = 10 MV/m, Qo = 5e8, 4.2K





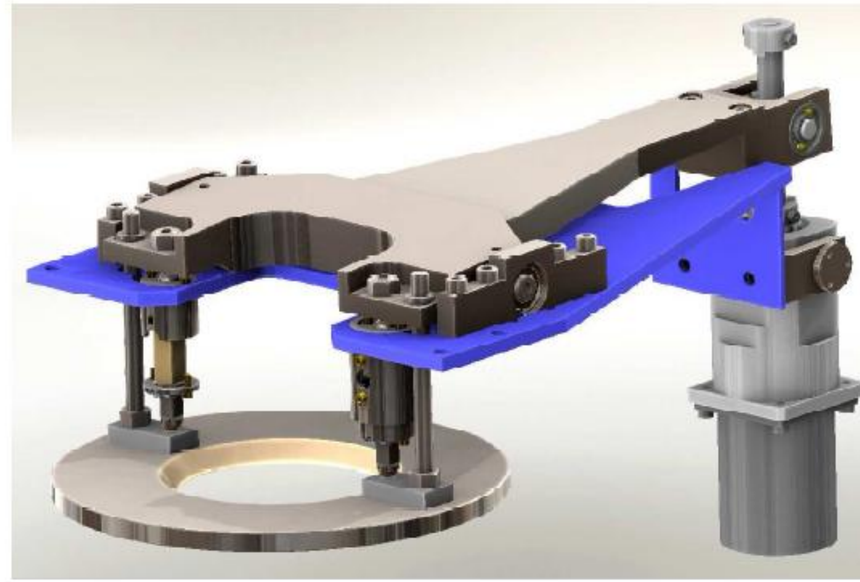
- SSR1-01: Q_0 vs. E_{acc} at 2.0 K and 4.4 K from the fourth cold test.
- During cool down, a 7 hr hold at 100 K produced a large Q_0 drop, confirming Q disease.
- Subsequently baked SSR1-01 at 600 C for 10 hours at Jlab.

- SSR1-02: Q_0 vs. E_{acc} from the first cold test of SSR1-02.
- X-rays increase at MP barriers, then disappear after punch through.

Collaborated with Jefferson Lab and Argonne in Preparation for the First Test of a Spoke Cavity with its Helium Vessel

- 10 hr, 600 °C vacuum bake for hydrogen degassing at Jlab
- Adjust cavity tune at room temperature: fixture to inelastically stretch or compress at beam pipes (capable of ± 250 kHz) at FNAL.
- Weld on the helium vessel: argon purge and temperature and frequency monitoring at FNAL.
- Degreasing, flash BCP (20 min at 13 C) and HPR at ANL.

Helium Vessel and Tuner Installed in Preparation for Testing in the Spoke Cavity Test Cryostat



- SSR1-01 inside 316L stainless steel (SS) helium vessel with tuner.
- Vessel TIG welded to SS flanges (brazed to niobium ports).
- Fabricated according to ASME pressure vessel code.
- Bellows between endwall and collar welded to beampipe flange.

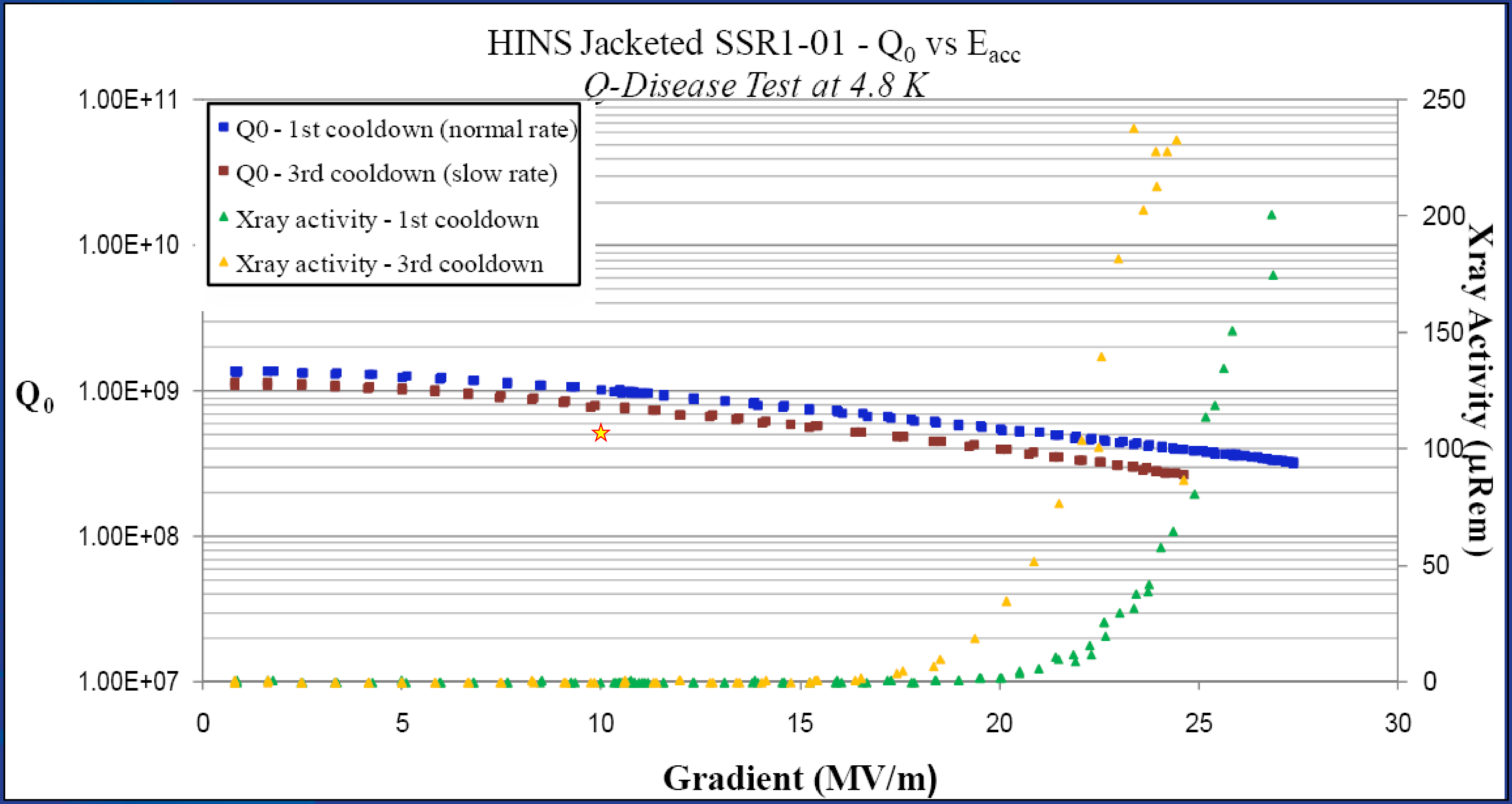
- Two piezo actuators “in series” with slow tuner arms (pivot with 5:1 mech. advantage).
- Stepping motor with harmonic drive,1:100 ratio (0.9 Hz/step).
- Present tests with a tuner on each end.
- Low profile along beam required due to close proximity to solenoid.

- 325 MHz SRF Spoke Cavity Tuner Tests
- Microphonics in the CW Project X Linac

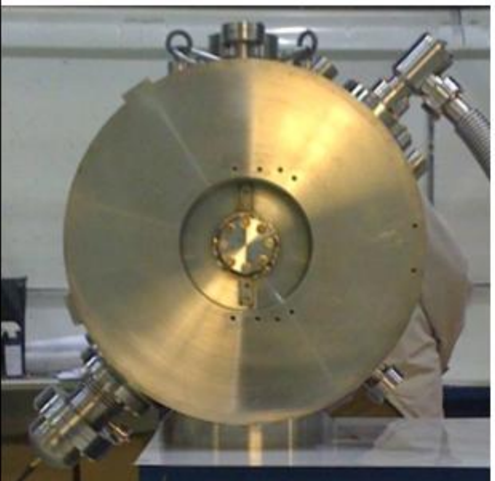
Y. Pischalnikov, W. Schappert, et al., TUP080, TUP086

First Test Result in Spoke Cavity Test Cryostat

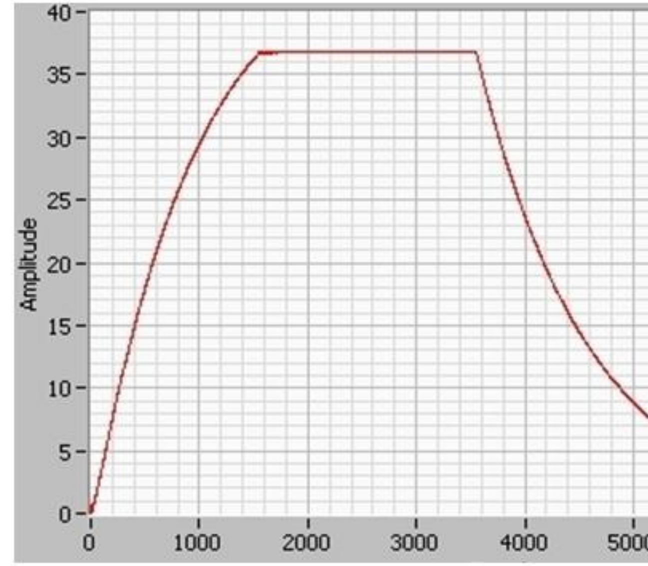
- CW test with high-Q input coupler

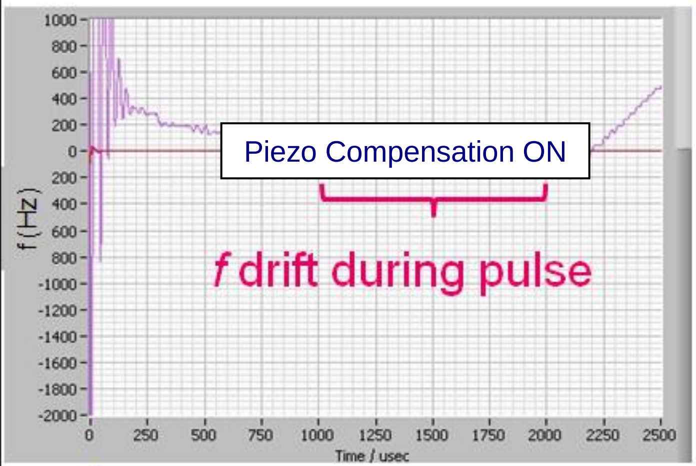


High-Power Pulsed Testing Results

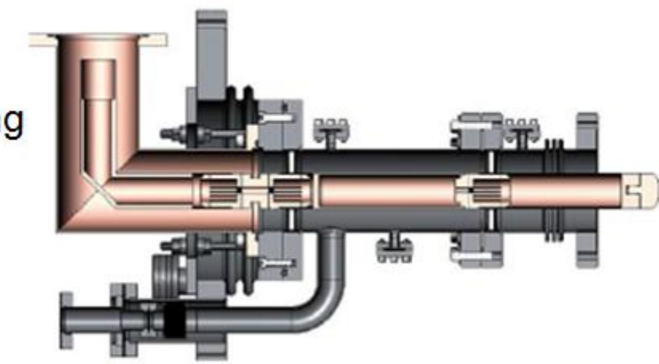


- 1st pulsed test, 1st test with power coupler: Q_L ~1e6
  - Reached 36.5 MV/m with ~2ms flattop
  - ~40 MV/m quench limit for short pulse



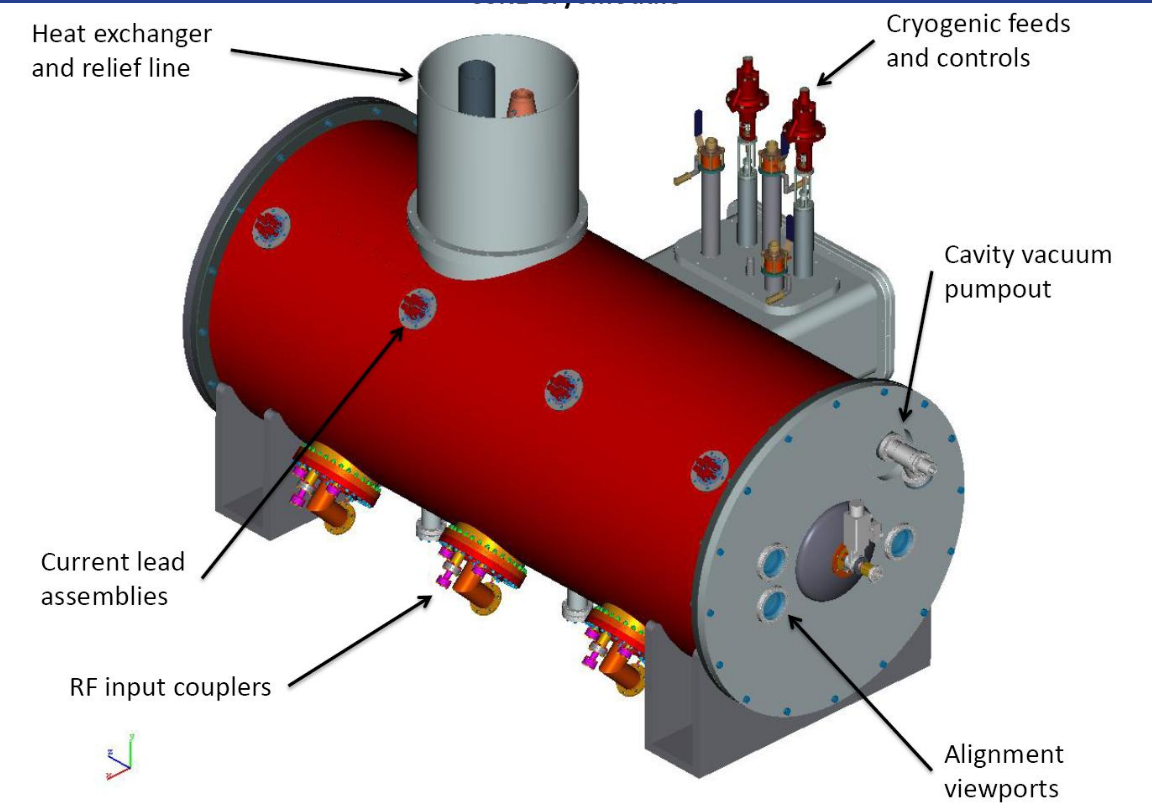


- Fast tuner tests - piezos: (Pischalnikov, Schappert)
  - Lorentz Force detuning ~3kHz peak to peak w/no compensation
  - Piezo compensation reduces f drift to ~50 Hz during pulse



Prototype Four-Cavity SSR Cryomodule

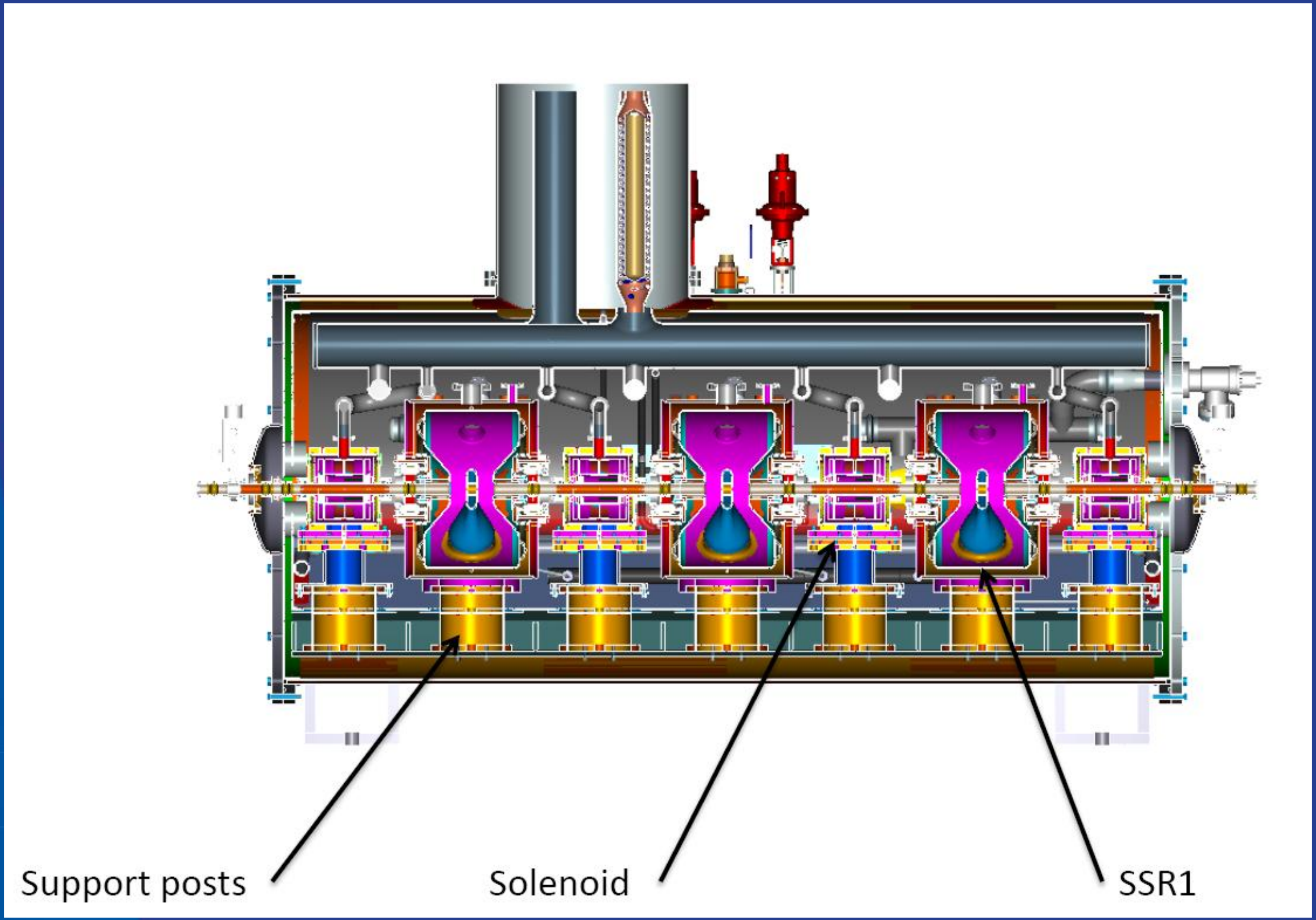
- Features 4 cavities, 4 solenoids, and beam instrumentation
- Intended to validate design concepts and alignment requirements, and demonstrate that tight lattice spacing is achievable



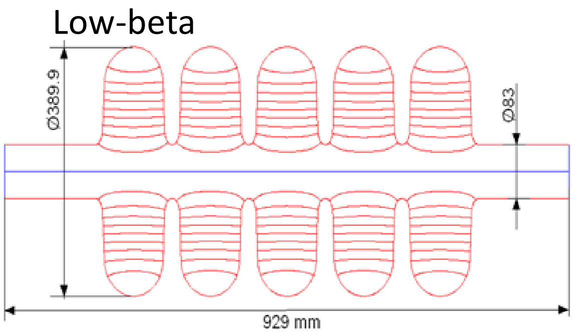
Cryomodule Design for 325 MHz Superconducting Single Spoke Cavities and Solenoids

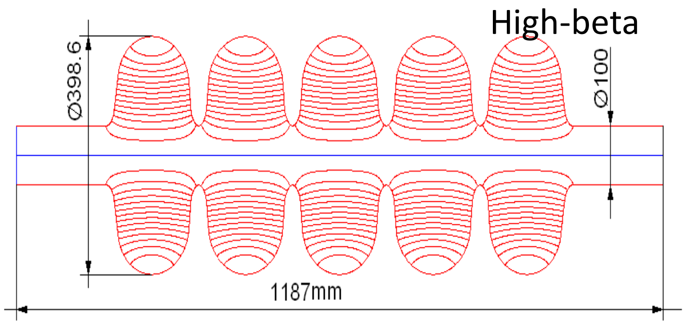
T. Nicol et al., TUP079

Cross Section of Prototype SSR Cryomodule



Basic Electromagnetic Design of 650 MHz β = 0.6 and β = 0.9 Five-Cell Cavities is Complete





β_G	0.61	0.9	
Length (from iris to iris)	705	1038	mm
Aperture	83	100	mm
Cavity diameter	389.9	400.6	mm
R/Q, Ohm	378	638	Ω
G - factor	191	255	Ω
Max. gain per cavity (ϕ-0)	11.7	19.3	MeV
Gradient	16.6	18.6	MV/m
Max surface electric field	37.5	37.3	MV/m
E_{pk}/E_{acc}	2.26	2.0	
Max surf magnetic field	70	70	mT
B_{pk}/E_{acc}	4.21	3.75	mT/(MeV/m)

- Concept EM Design of the 650 MHz Cavities for the Project X
- HOMs in the Project X Linac

V. Yakovlev et al., TUP089, TUP088

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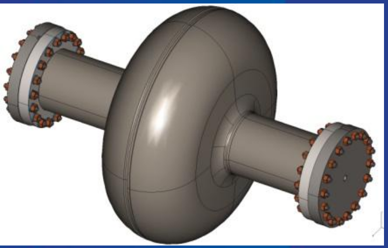
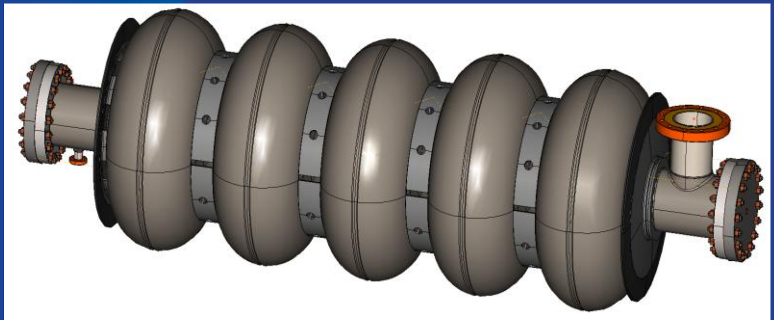
650 MHz Cavity Prototypes and Readiness for Processing & Testing



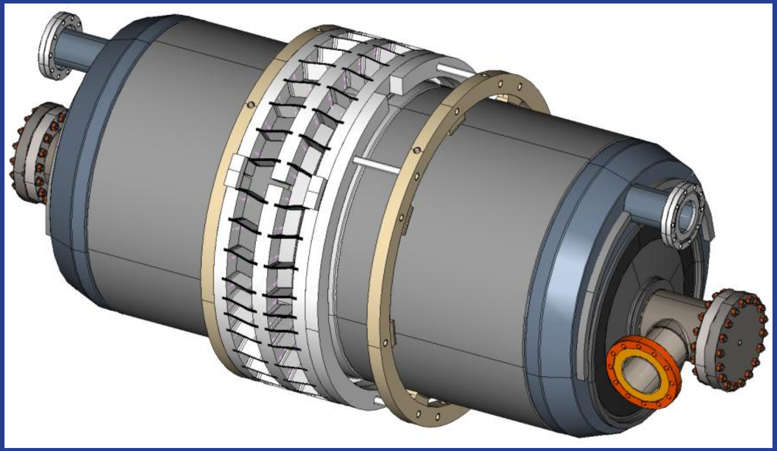
- Single-cell designs complete for β = 0.6 and β = 0.9 cavities
  - Two single-cell β = 0.6 cavities are being prototyped at Jefferson Lab in context of Project X collaboration
  - Six single-cell β = 0.9 cavities on order from AES; expected in Q3 FY11
- Modifications in progress at Fermilab vertical test stand
- Cavity cage design complete and a few prototypes are on hand
  - Compatible with existing tooling for cavity handling, high pressure rinsing, and optical inspection
- Electro-polishing tools under development at ANL and AES
- BCP capability exists at ANL and in US industry
- Optical inspection system undergoing modifications for use with 650 MHz cavities (was designed for 1.3 GHz cavities)

650 MHz Five-Cell beta=0.9 Cavity Design Status

- Drawing package nearly complete
- Fabrication specification in progress
- Niobium material on-hand
- Weld samples in progress to verify end cell to beam tube adaptor design
- Plan to be ready to initiate prototype procurements in FY11



Cavity Model:
- Niobium wall thickness is 4 mm
- Nb/Ti flanges with Al hex seals
- Stiffening rings located to minimize dF/dP while maintaining tunability



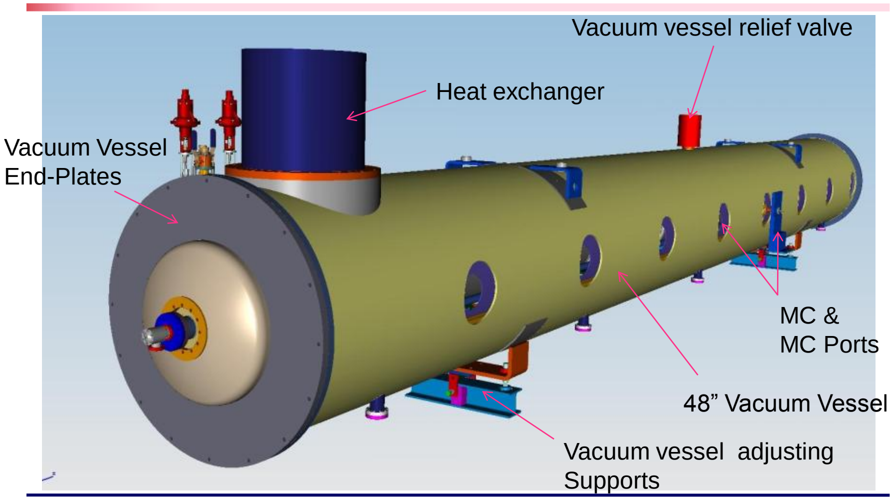
Concept for pass-through helium vessel utilizing blade tuner

Status of the Mechanical Design of the 650 MHz Cavities for Project X
S. Barbanotti et al., TUP069

650 MHz Cryomodule Design Concepts

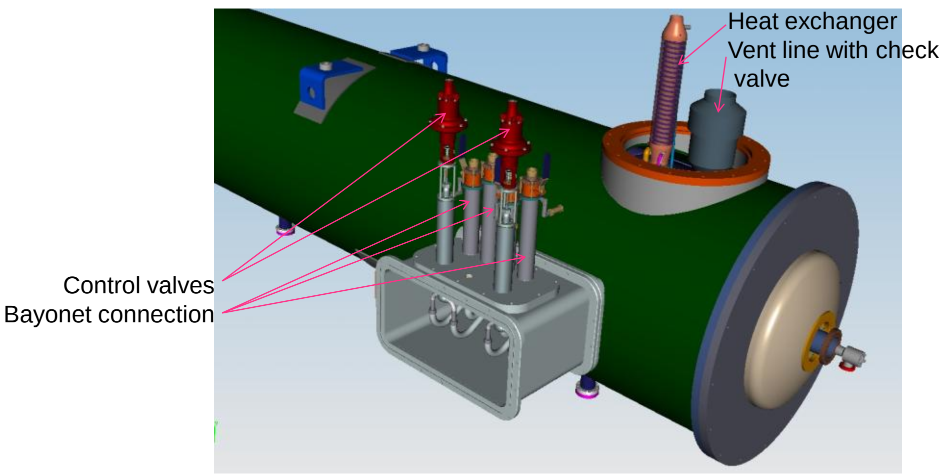
- Basic Concept: stand-alone 8-cavity cryomodule with integral heat exchanger and bayonet connections to cryogenic distribution system
  - Maximum heat load to 2 K system: 250 W
  - Overall length: ~12 m
  - Vacuum vessel diameter : ~1.2 m (48”)

650 MHz Cryomodule (concept)



Tom Peterson -- Cryomodules | 650MHz Cryomodule Concept, Y. Orlov | Page 25

650 MHz Cryomodule (concept)



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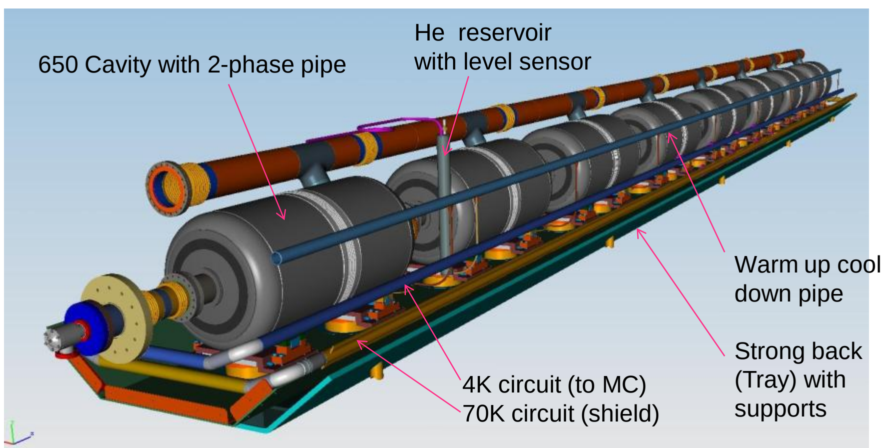
650 MHz Cryomodule Design Concepts

- Support Concept: each cavity supported by two posts; cavity string supported by single strong-back
- ILC/XFEL style (left) uses two-phase pipe separate from cavity helium vessel
- SNS style (right) integrates two-phase pipe into helium vessel
  - Larger surface area of helium bath may offer advantages – under evaluation

650 MHz Cavity string on the strong back (XFEL cavity style)



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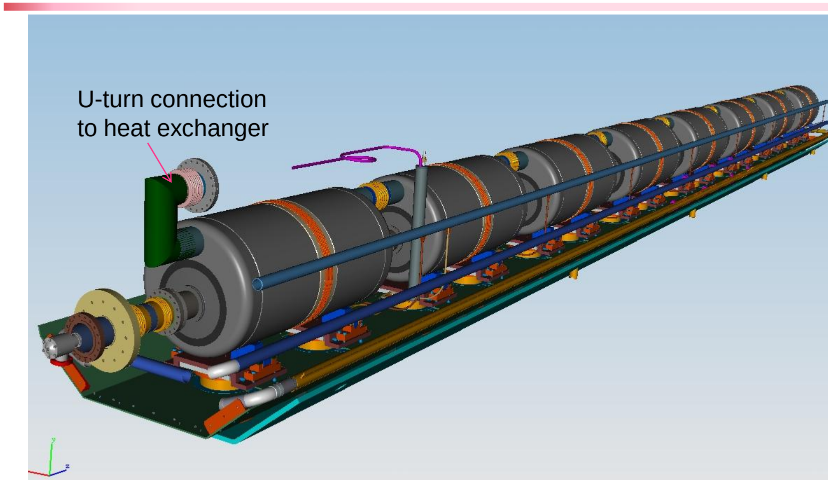
650 MHz Cavity string on the strong back (SNS cavity style)



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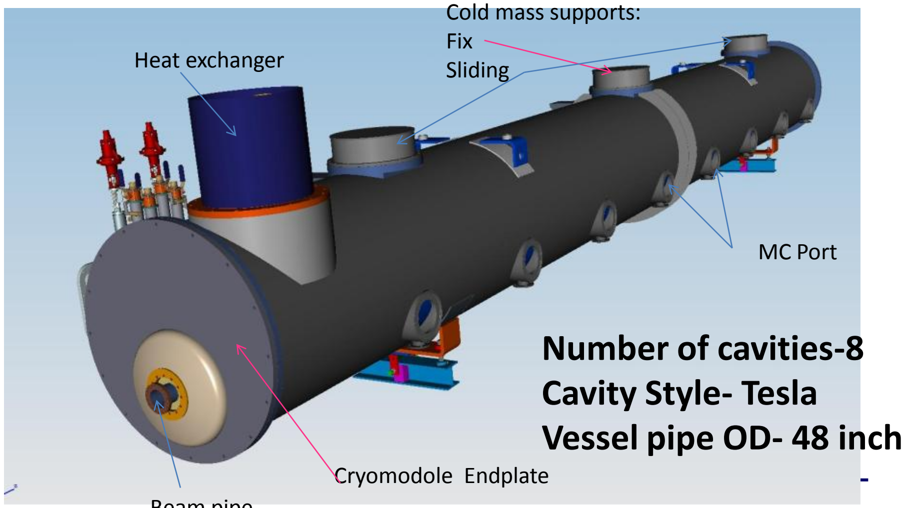
650 MHz Cryomodule Design Concepts

- Support Concept: support cavity string from helium return pipe
- Unlike ILC or XFEL cryomodules, the helium return pipe is closed at the ends so that we have a stand-alone cryomodule
- This is our preferred configuration
- Cryomodule design effort being carried out in collaboration with RRCAT and TJNAF

CM650 TESLA STYLE-STANDALONE



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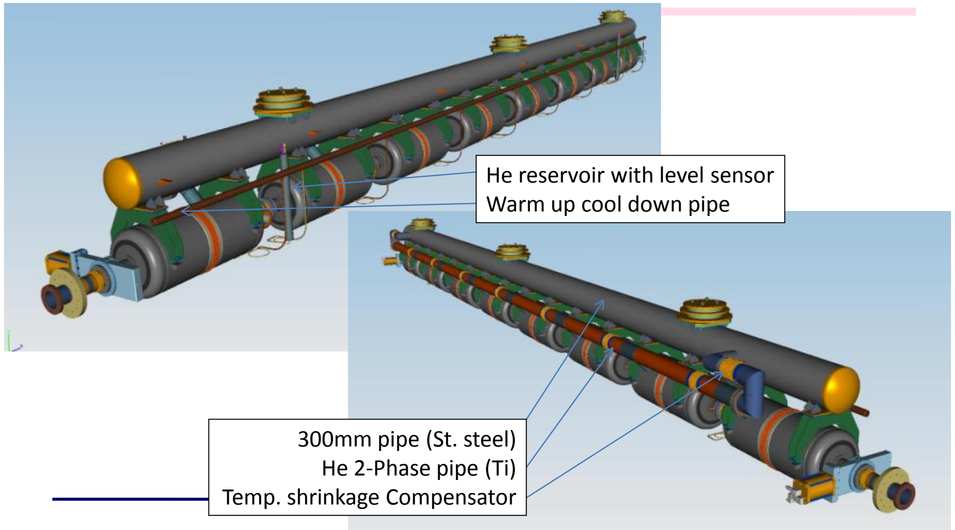
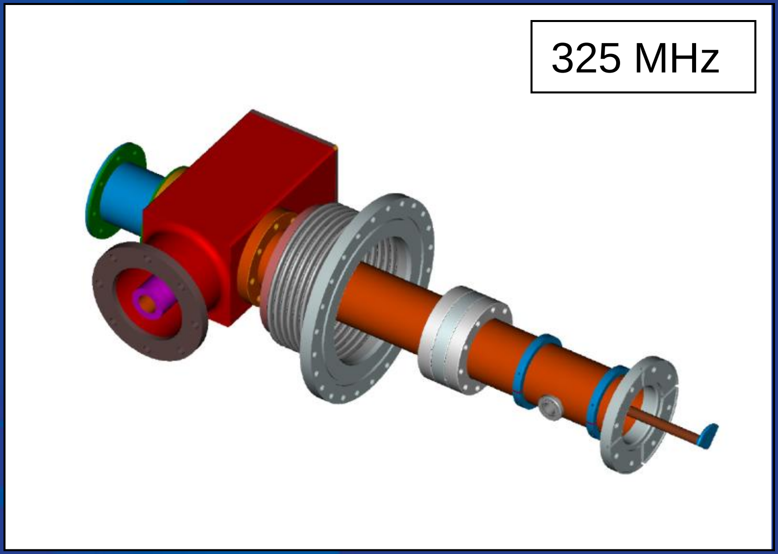
CM650 TESLA STYLE-STANDALONE. CAVITY STRING & 300mm PIPE

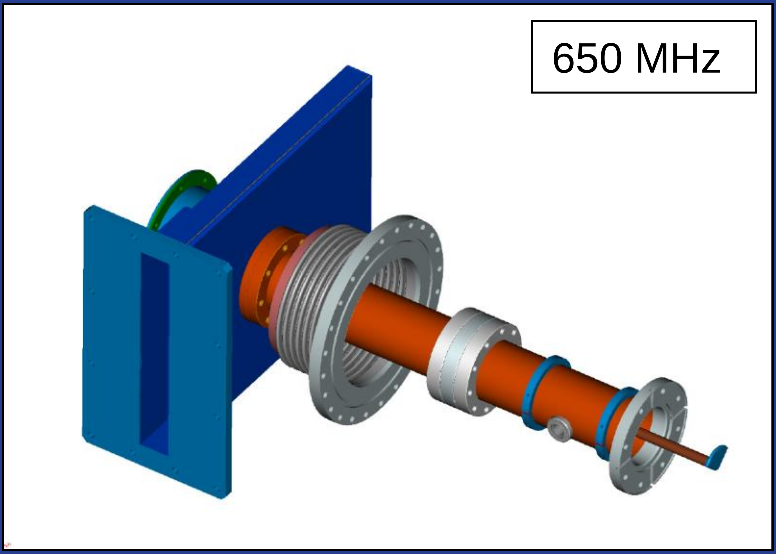


Tom Peterson -- Cryomodules

RF Power Coupler Development

- Designs have been developed for 325 and 650 MHz RF couplers
  - 6 kW at 325 MHz; 30 kW at 650 MHz; continuous wave
  - Coaxial section is same for both frequencies
  - Multipactor, thermal, and RF calculations complete; mechanical calculations in progress
  - Forced-air cooling is planned
  - Ready to proceed to prototype construction and testing





HP Couplers for the Project X
S. Kazakov et al., TUP072

Summary

- We have conceptual and detailed designs that are consistent with the Project X reference design
- Cavity and cryomodule development is in progress in collaboration with:
  - ANL, TJNAF, ORNL/SNS, IUAC/Delhi, RRCAT/Indore, and VECC/Kolkata
  - ESS and CERN SPL on an informal basis
  - and industrial partners
- We will fabricate and test prototype cavities over the next 1-2 years
- We will move from conceptual design to detailed design of cryomodules and build prototypes as needed
- Acknowledgements
  - Thanks to the colleagues from all of the collaborating institutions!