Project X Cavity and Cryomodule Development

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U.S. DEPARTMENT OF ENERGY

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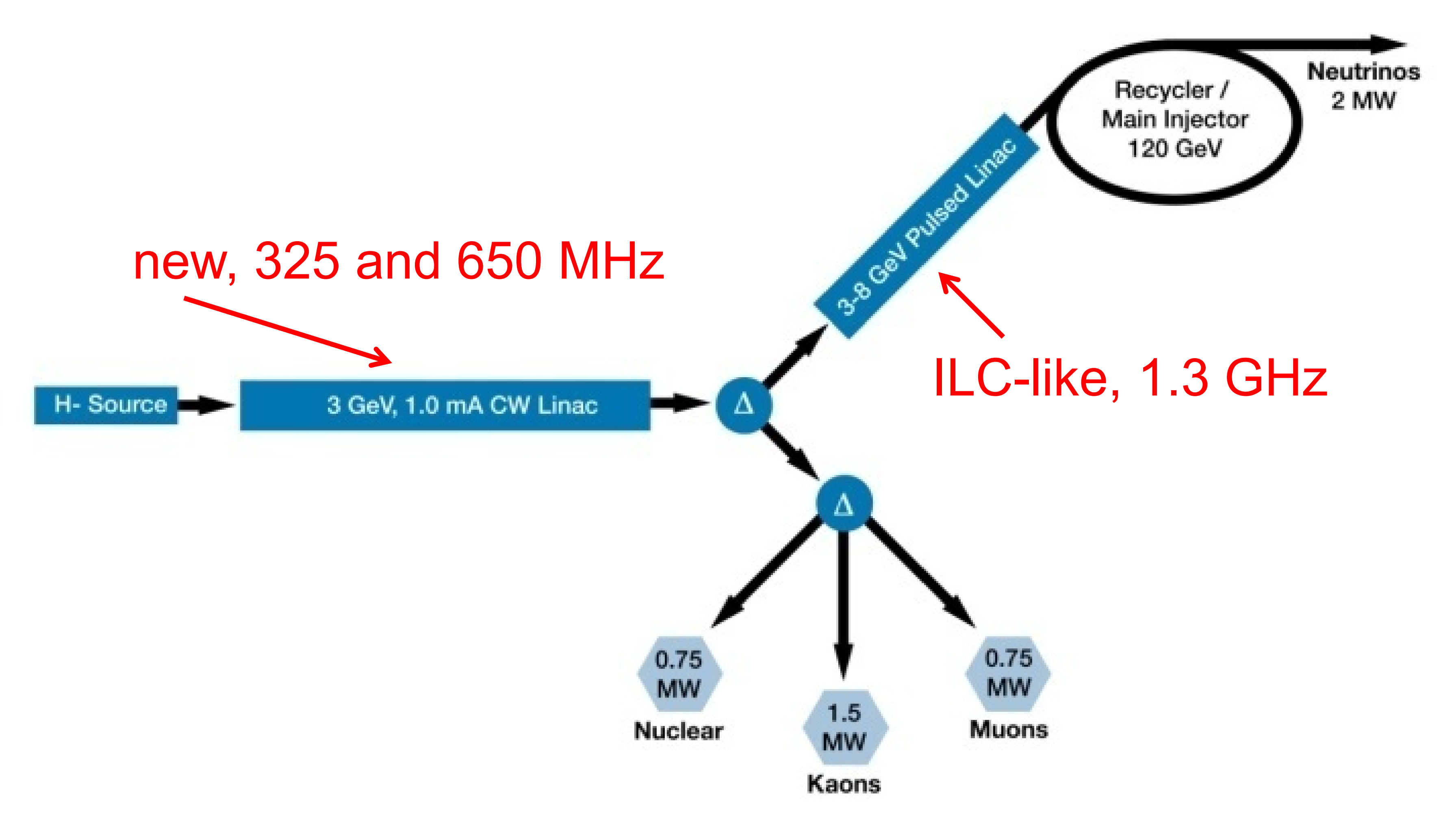
Project X Accelerator Complex



Two accelerator sections comprised of SRF cavities

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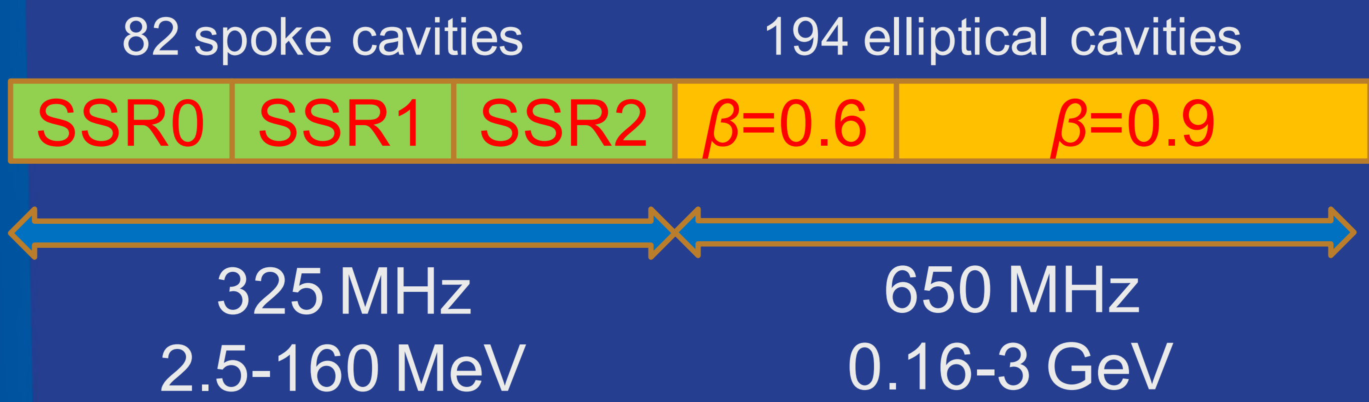
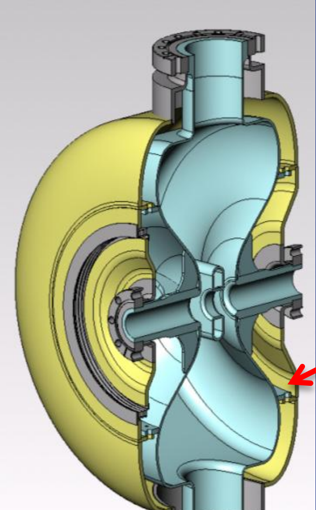
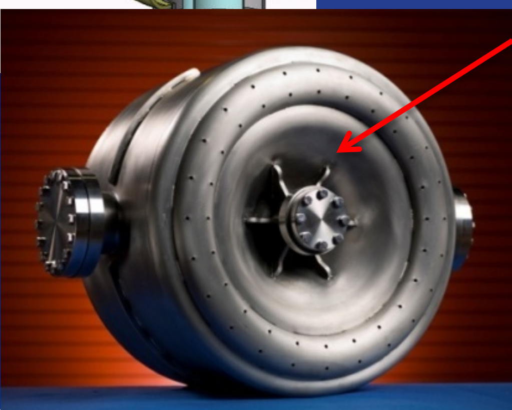
Project X Reference Design
3 GeV, 1 mA, continuous wave H- Linac



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=0.42)	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

325 MHz Cavities: Single-Spoke Resonators

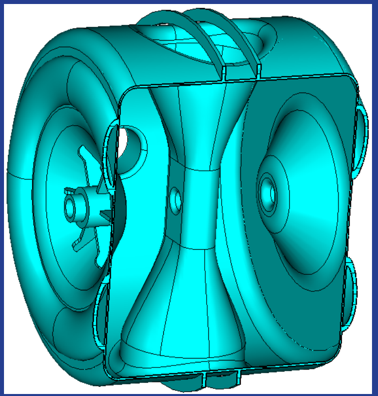




- **SSR0 (β = 0.11)**
  - EM and mechanical design complete, ready for prototyping
- **SSR1 (β = 0.22)**
  - Started under HINS program and is therefore more advanced
  - Two prototypes have been fabricated by Zanon and Roark, processed in collaboration with ANL & JLab, tested at Fermilab
  - Two cavities in fabrication at IUAC-Delhi (Fall 2011)
  - Ten cavities in fabrication by Niowave-Roark (1st delivered, remainder in FY11)
  - One cavity was tested dressed at Fermilab with He vessel, coupler, tuner

SSR2(β = 0.42)

- EM design complete
- Mechanical design in progress



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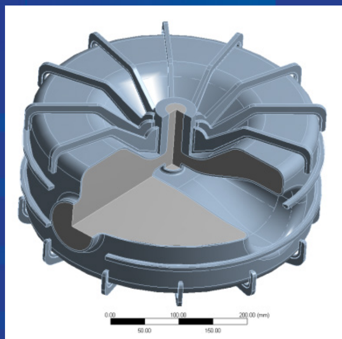
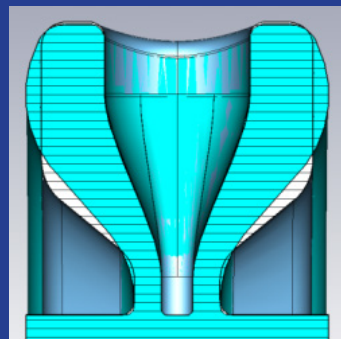
325 MHz Single-Spoke Resonators

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	0.114	325	0.6	32	39	108	50	6.5	0.5
SSR1	0.215	325	1.47	28	43	242	84	11.0	0.8
SSR2	0.42	325	3.34	32	60	292	109	13.0	2.9

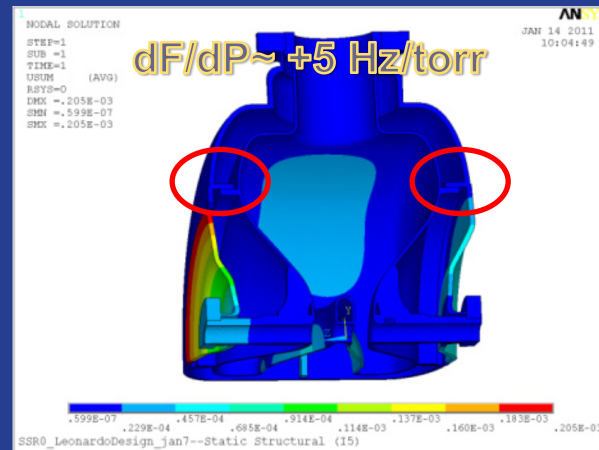
Recent Developments on the SSR0 Design



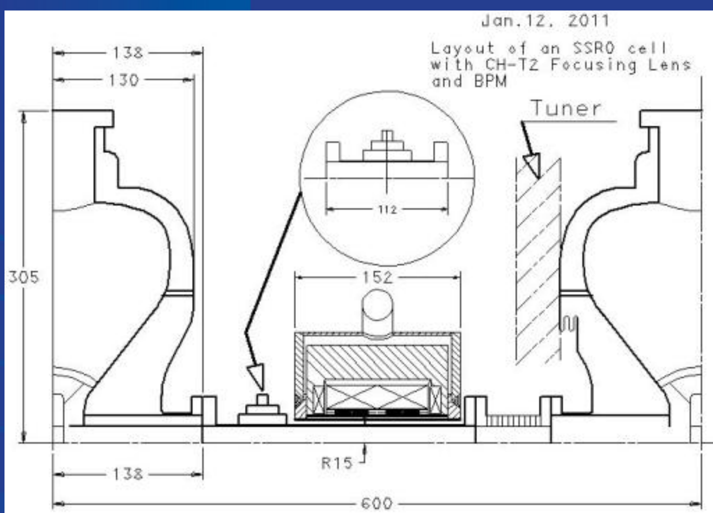
Initial Concept



Rounded end walls to reduce frequency sensitivity to pressure variations



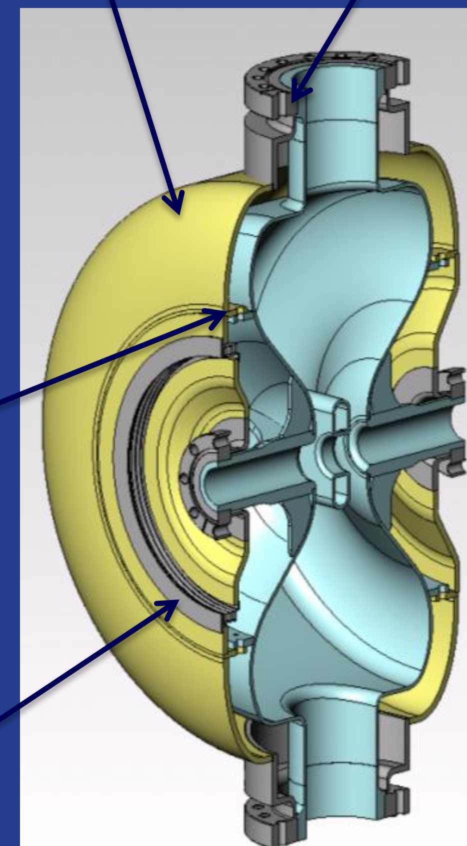
Connection between helium vessel and cavity wall key to minimizing dF/dP



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

SS helium vessel

SS/Nb braze joints



Bolted SS/Nb connection

Bellows (one side only)

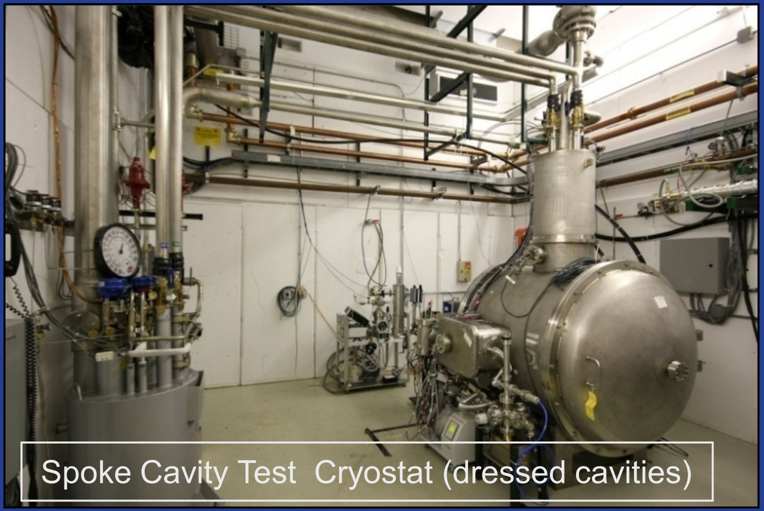
Mechanical Design

New 325 MHz Test Capabilities Developed

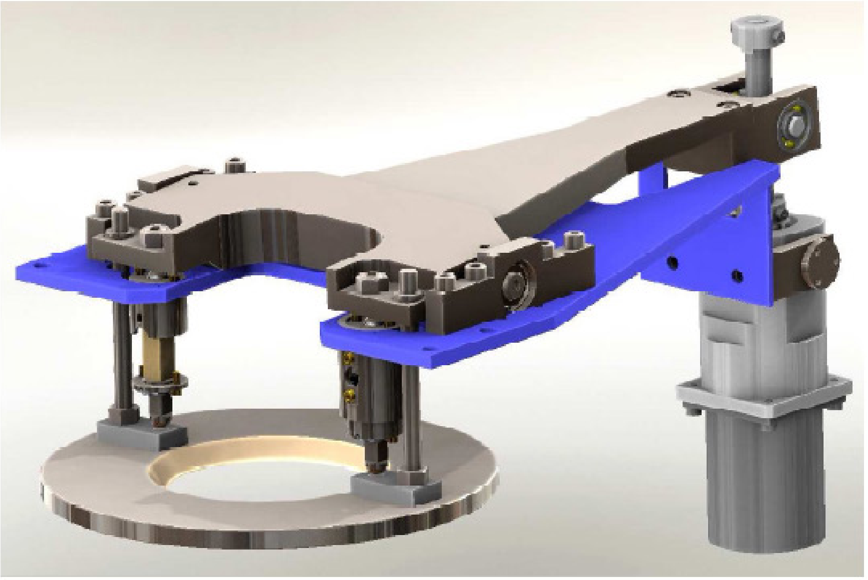
- **Bare cavity test capability**
  - FNAL/Vertical Cavity Test Facility, designed for 1.3 GHz cavities, was modified w/ new electronics & tooling
- **Dressed cavity test capability**
  - Spoke Cavity Test Cryostat completed & commissioned
  - Includes cryostat, shielded enclosure, helium distribution, 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


SSR1 vertical test


SSR1 dressed test


Spoke Cavity Test Cryostat (dressed cavities)

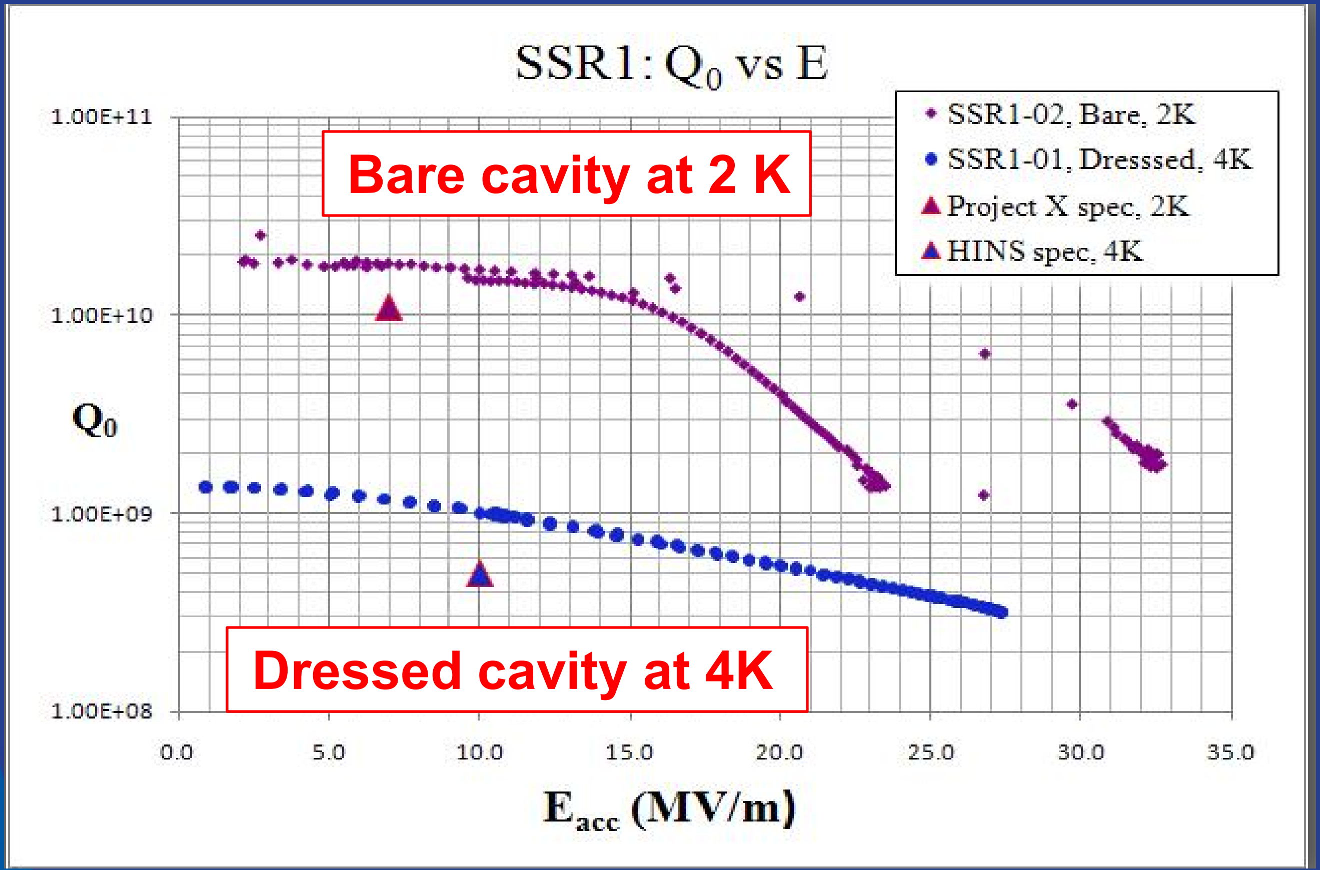
Helium Vessel and Tuner Installed in Preparation for Testing in the Spoke Cavity Test Cryostat



- 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.

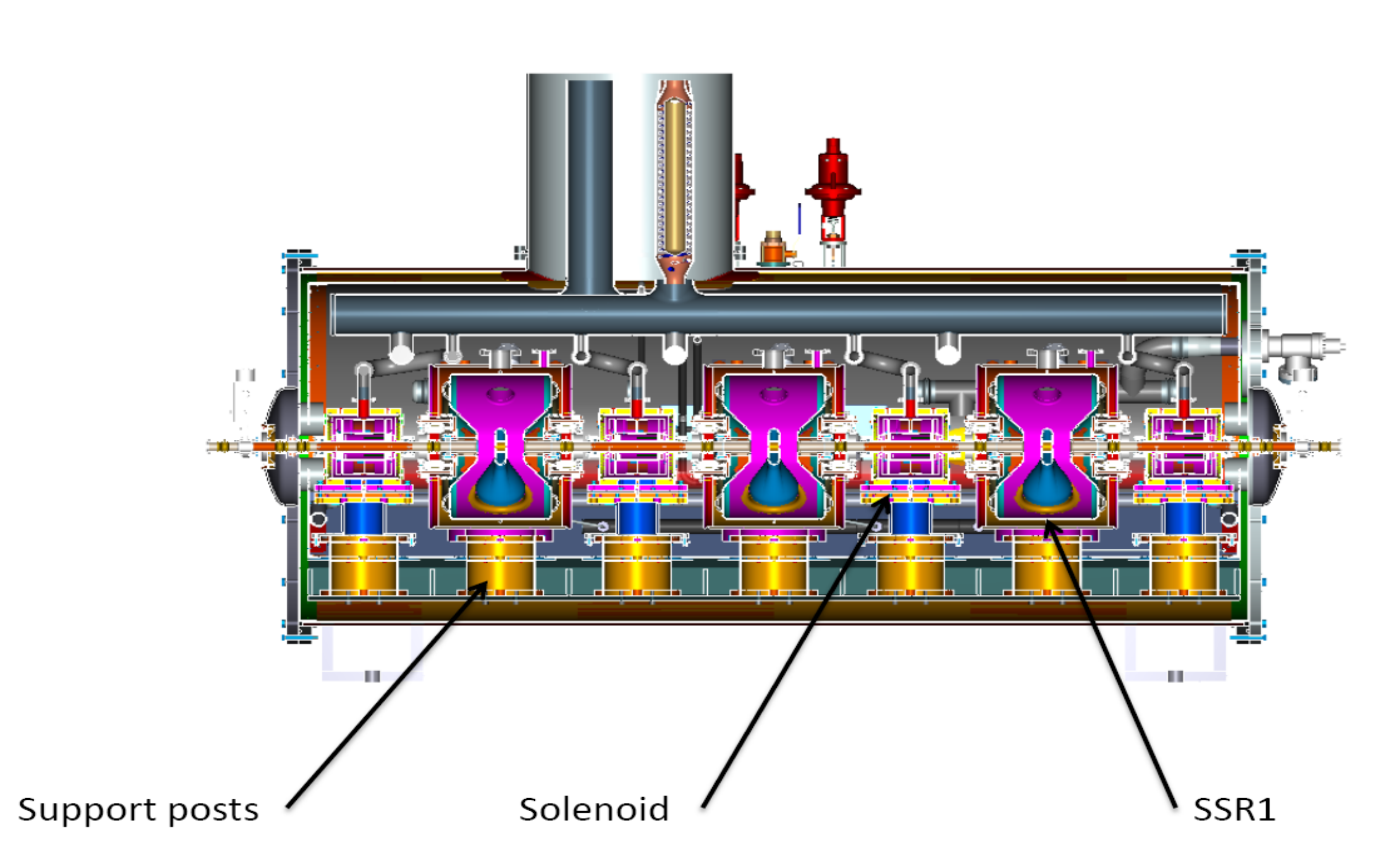
SSR1 Prototypes Exceeded Performance Specs



- Two SSR1 spoke resonators performed well in vertical dewar tests at 2K; one of these was tested dressed at 4K.
- Proof of principle shown in plot: bare cavity exceeded Project X specification; dressed cavity at 4K exceeded the HINS specification

Prototype Three-Cavity SSR Cryomodule

- Conceptual design features three 325 MHz cavities, four solenoids, and beam instrumentation
- Intended to validate design concepts and alignment requirements for PX and demonstrate that tight lattice spacing is achievable



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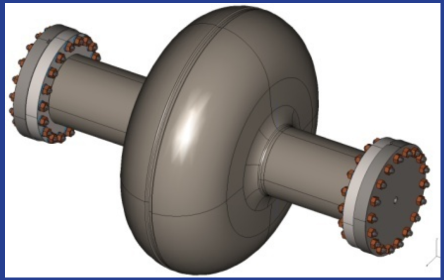
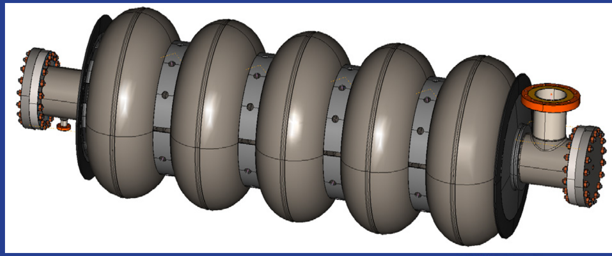
650 MHz Cavities: Elliptical Five-Cells at $\beta_G = 0.61$ and $\beta_G = 0.9$

- Because of CW operation, heat load on the cryogenic system is substantial
  - For purposes of cryogenic system design, the dynamic heat load is limited to 250 W at 2K per cryomodule
    - <35W per cavity ($\beta_G = 0.61$) and <25W per cavity ($\beta_G = 0.9$)
- Flatness of cavity walls may complicate surface processing
- Single-cell designs complete for $\beta = 0.61$ and $\beta = 0.9$ cavities
  - Two single-cell $\beta = 0.61$ cavities were designed, fabricated, processed, and tested at Jefferson Lab
  - Six single-cell $\beta = 0.9$ cavities on order from AES; expected in FY11

  Prototyping of single-cell $\beta = 0.9$ cavities in progress at RRCAT
- Five-cell design complete for $\beta = 0.9$ cavities
  - Two 5-cell $\beta = 0.9$ cavities to be ordered from industry in FY11





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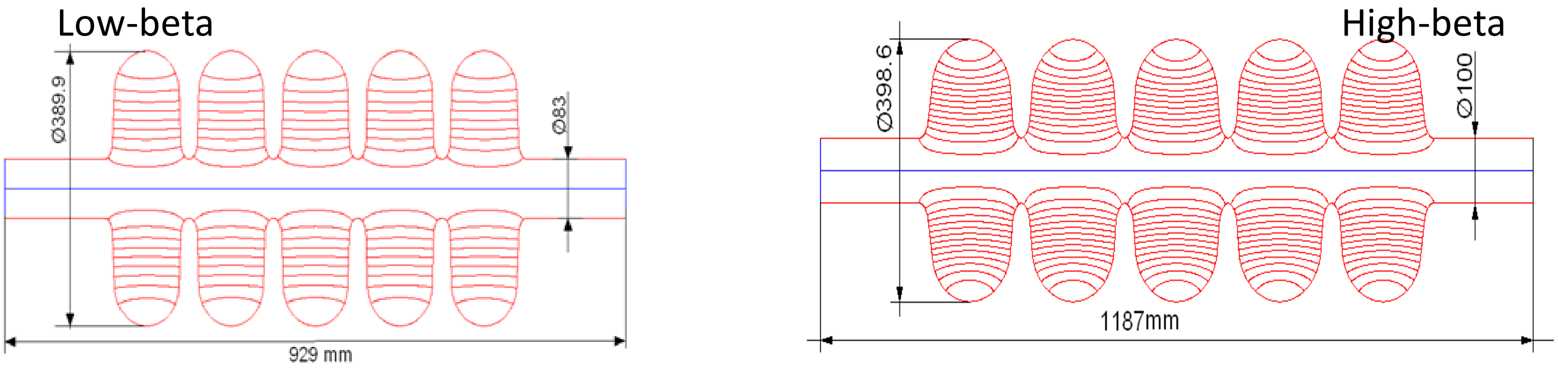
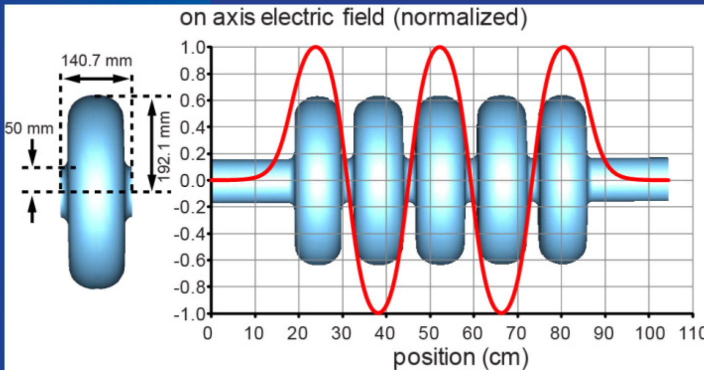
FNAL EM Design 650 MHz β_G = 0.61 and 0.9 5-Cell Cavities



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)

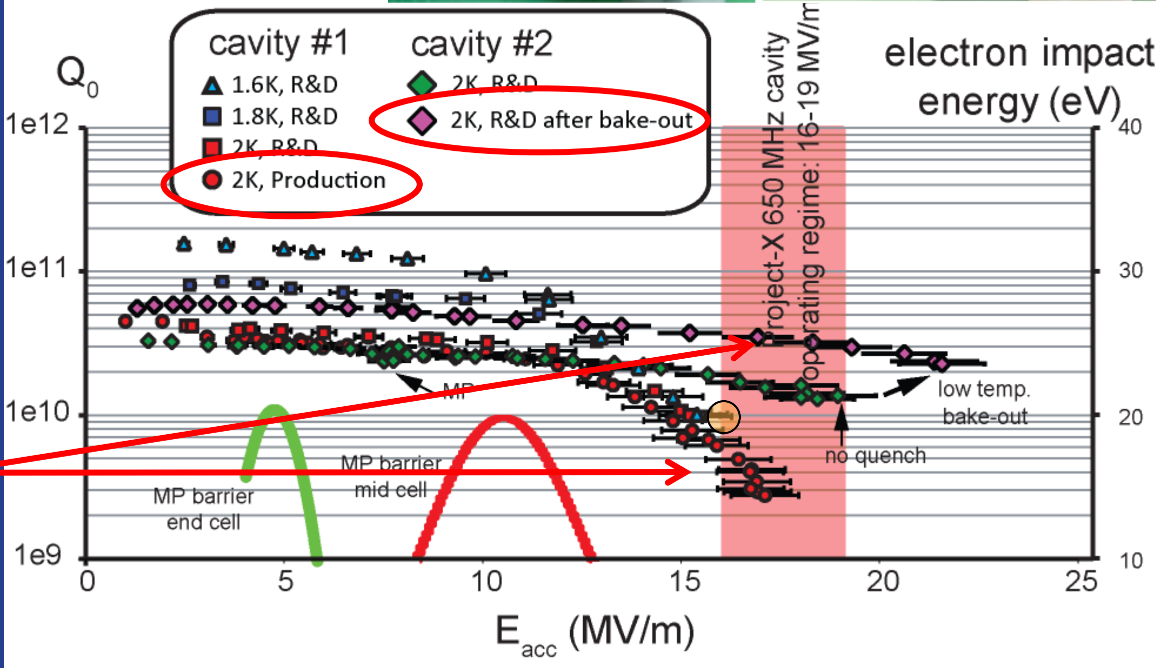
JLab EM Design 650 MHz β_G = 0.61 5-Cell Cavities



parameter	unit	Project-X JLAB	Project-X Fermilab
$\beta = v/c$		0.61	0.61
frequency	MHz	650	650
active length (iris-to-iris)	mm	694	705
equator diameter E	mm	380.4	389.9
iris aperture A	mm	100	83
tube diameter	mm	ditto	ditto
E/A		3.84	4.70
A/λ		0.217	0.180
cell-to-cell coupling	%	1.40	0.75
R/Q	Ω	296.6	378
G	Ω	190	191
R/Q·G	Ω^2	56466	72198
U_{eff}	MV	12	12
E_{acc}	MV/m	17.3	17.0
E_{peak}/E_{acc}		2.71	2.26
B_{peak}/E_{acc}		4.78	4.21
B_{peak}	mT	82.6	71.6
E_{peak}	MV/m	46.9	38.4
Q_0 assumed at 2K		1.72e10	1.72e10
P_{cav}	W	28.2	22.0

650 MHz design confirmation: JLab β_G = 0.61 cavity

- Two JLab cavities processed with standard techniques, including bulk BCP, 600C for 10 hours hydrogen degassing, and light BCP (no EP)
- Power requirement corresponds to Q_0>8.8E9 at 2K for E_{acc}=16 MV/m and Q_0>1.3E10 at 2K for E_{acc}=19 MV/m
  - Q_0 requirement achieved at 16 MV/m for cavity #2
- Further surface processing likely to bring both cavities up to performance requirement; EP may not be required
- Mechanical studies required to extend design to 5-cell



Final 2K results

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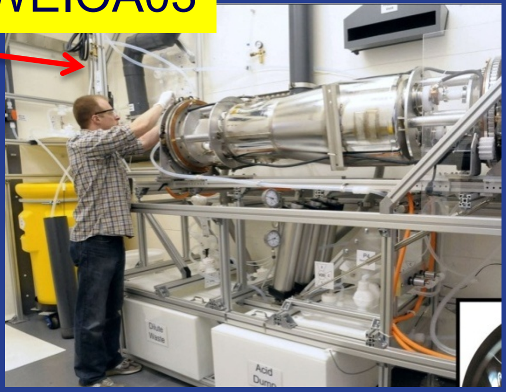
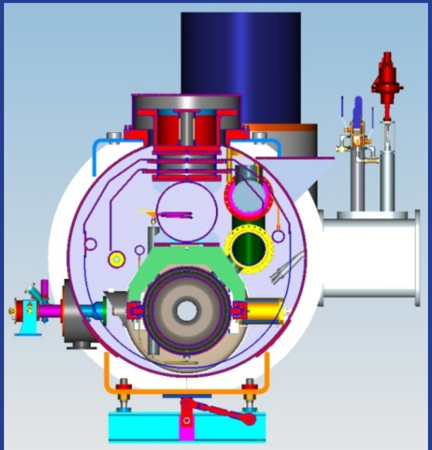
650 MHz Cavities: FNAL/ANL Infrastructure Readiness

- Cavity handling and inspection upgrades
  - Cavity cage design complete and several prototypes are on hand, which are compatible with existing tooling for cavity handling, high pressure rinsing, and optical inspection
  - Optical inspection at Fermilab (mods to 1.3 GHz KEK/Kyoto system)
- Cavity processing
  - High-pressure rinsing and test preparation at FNAL/ANL facility
  - BCP processing capability at JLab or US industry
  - Plan centrifugal barrel polishing as an option **TUPO025**
  - EP at FNAL/ANL or US industry
  - EP tools under development at ANL and AES **WEIOA03**
- Cavity testing
  - Bare cavity testing at Fermilab
    - mods to RF system and mechanical tooling
  - New dressed cavity test cryostat being designed



650 MHz Cryomodule

- Two types of cryomodules, containing different numbers and types of cavities and focusing elements, to be made as similar as possible
- Most design work so far is for the $\beta_G = 0.9$ cryomodule, which contains eight cavities per cryomodule for an overall length of 12 m
- The number of cavities per cryomodule based on practical heat load limit of 250 W per cryomodule to the 2 K circuit, primarily due to sizing considerations for helium piping and heat exchanger
- The baseline design concept includes cryomodules closed at each end, individual insulating vacuums, with warm beam pipe and magnets in between cryomodules, so that individual cryomodules can be warmed up and removed while adjacent cryomodules remain cold.



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Conclusions

- Cavity & cryomodule designs for Project X 3 GeV linac underway
- Cavity prototypes built so far performing to requirements:
  - 325 MHz SSR1 cavities have shown excellent performance in bare and dressed cavity tests
  - 650 MHz $\beta_G = 0.61$ single-cell cavities have demonstrated the feasibility of the design for 5-cell cavities
- Cavity design, fabrication, and test are underway to confirm designs for the complement of cavities required for Project X within the next 1-2 years.
- Cryomodule conceptual design work has identified baseline configurations that will also be further developed over the next couple of years
  - Prototype cryomodules will be built to confirm the design

Acknowledgements and References

- Many thanks to our Fermilab, national, and international collaborators for their hard work and excellent contributions to cavity and cryomodule development for Project X.

- Please see these related SRF2011 contributions and references therein for more information:

  - T. Peterson et al., “650 MHz Cryomodules for Project X at Fermilab – Requirements and Concepts,” MOPO003
  - L. Ristori et al., “Design of Single Spoke Resonators at Fermilab”, MOPO024
  - F. Marhauser et al., “Preliminary Test Results from 650 MHz Single Cell Medium Beta Cavities for Project X,” MOPO070
  - C. Cooper et al., “Integrated Cavity Processing Apparatus at Fermilab,” TUPO025
  - S. Gerbick et al., “A New Electropolishing System For Low-Beta SC Cavities,” WEIOA03

- Please see the complete list of references in the proceedings