Proton Linac for Nuclear Waste Transmutation

New low-velocity superconducting section

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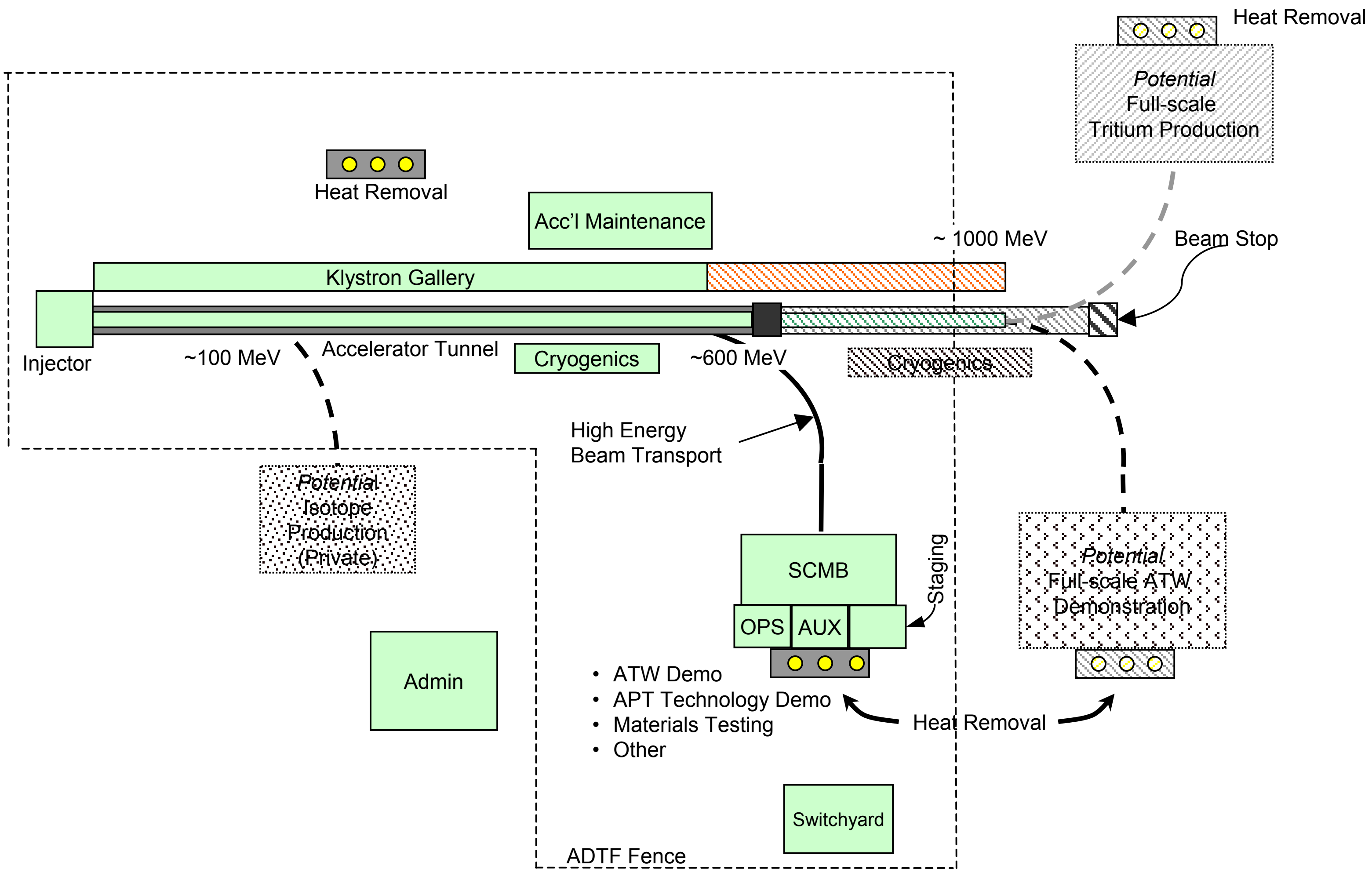
Outline

- Importance of Accelerator Transmutation of Nuclear Waste (ATW)
- New Advanced Accelerator Applications (AAA) Project and Accelerator Demonstration Test Facility (ADTF).
- ADTF linac design based on APT.
- The arguments for replacing the normal-conducting linac section with superconducting cavities.
- The new superconducting ADTF design.

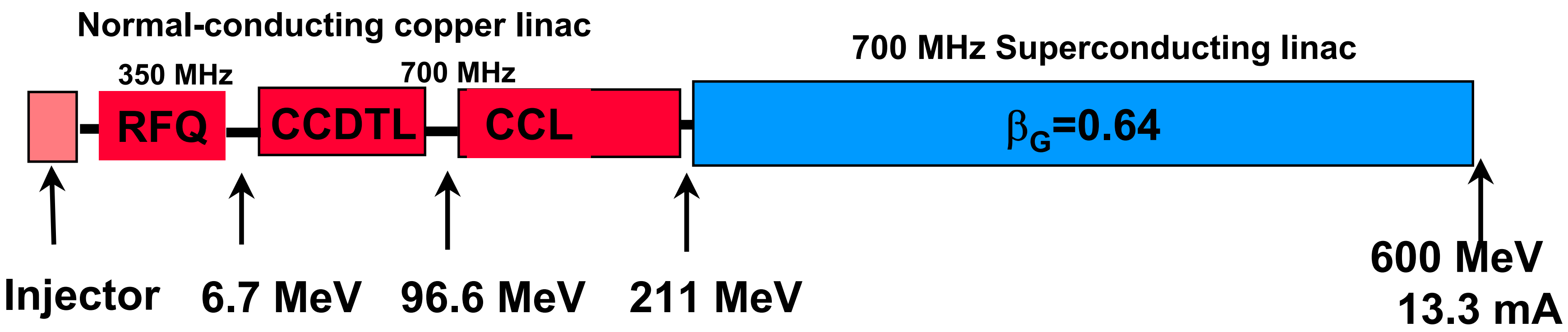
Advanced Accelerator Applications (AAA) Project

- There is a critical need to maintain and renew the Nation's nuclear science, technology and engineering infrastructure.
- There is a need for an R&D program to develop and demonstrate Accelerator Transmutation of Waste (ATW).
- There is a need to maintain a viable tritium production backup capability (APT) for national security, in accordance with Congressional concerns.
- AAA (Advanced Accelerator Applications) integrates ATW and APT.
- Program objective is to construct a proton-linac driven facility as a test bed to demonstrate nuclear technologies.
- This is called ADTF (Accelerator Demonstration Test Facility).

Accelerator Driven Test Facility (ADTF) Concept



APT linac design was our starting point for ADTF linac



-CW linac, 13.3 mA, 600 MeV, 8 MW average beam power.
Normal conducting linac below 211 MeV.
-Superconducting cavities were used only above 211 MeV because there was less confidence in superconducting cavity structures for <200 MeV.

We looked at a superconducting option to replace the normal-conducting linac from 6.7 MeV to 211 MeV with superconducting cavities.

- Replacing the normal conducting linac from 6.7 MeV to 211 MeV would save 57 MW of ac power.

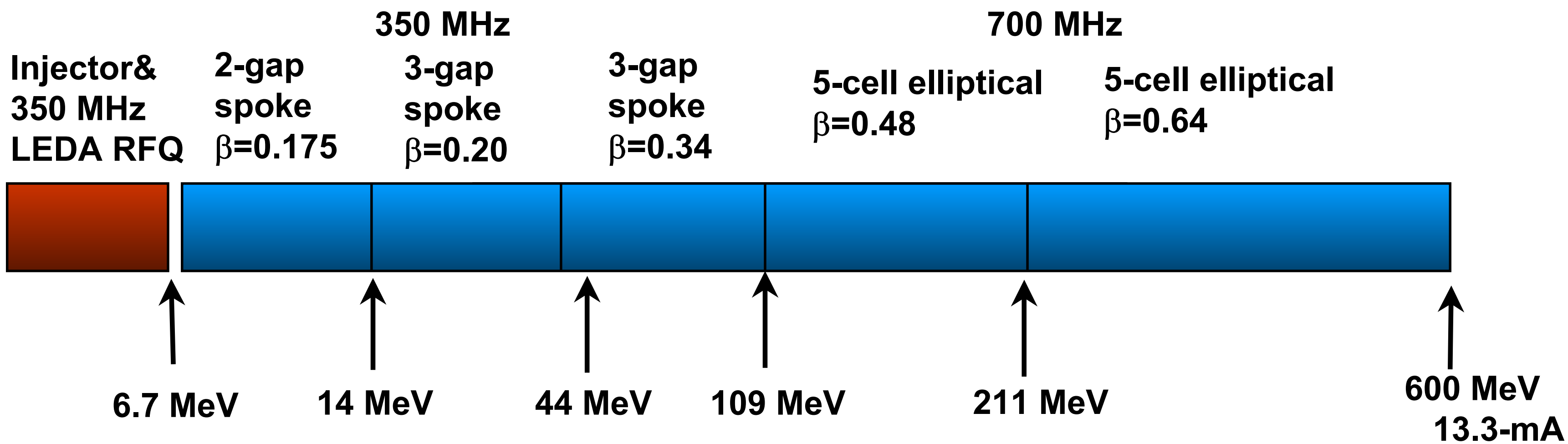
- LANL and Saclay/Milano have built and tested single-cell elliptical cavities near β=0.48. High gradients (>10MV/m) at 2K were achieved.

- The spoke cavity has been developed at Argonne as part of the RIA concept suitable for the lower velocity range from about β=0.2 to 0.5.

- High gradients (>10MV/m) were achieved at LANL in test of β=0.3 ANL spoke cavity at 4K.

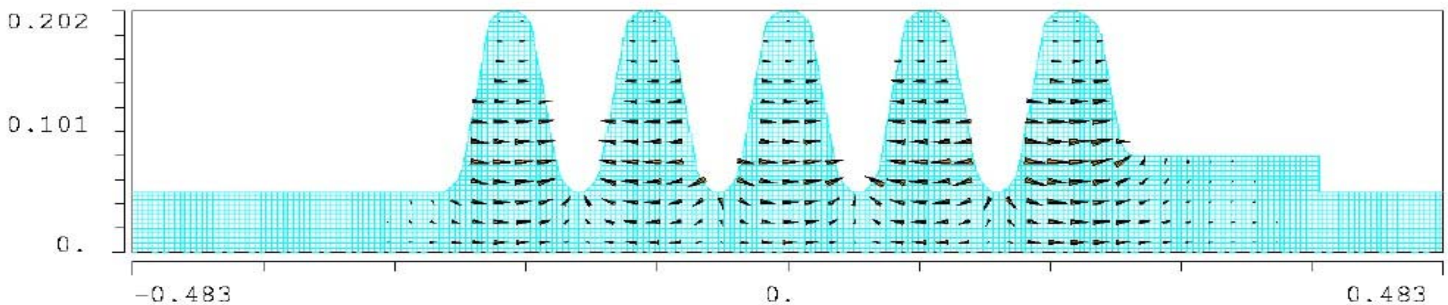
- Using these accelerating structures we conclude it is now feasible to extend the superconducting linac all the way from 211 MeV to the end of the RFQ (6.7 MeV).

ADTF Superconducting Linac Design



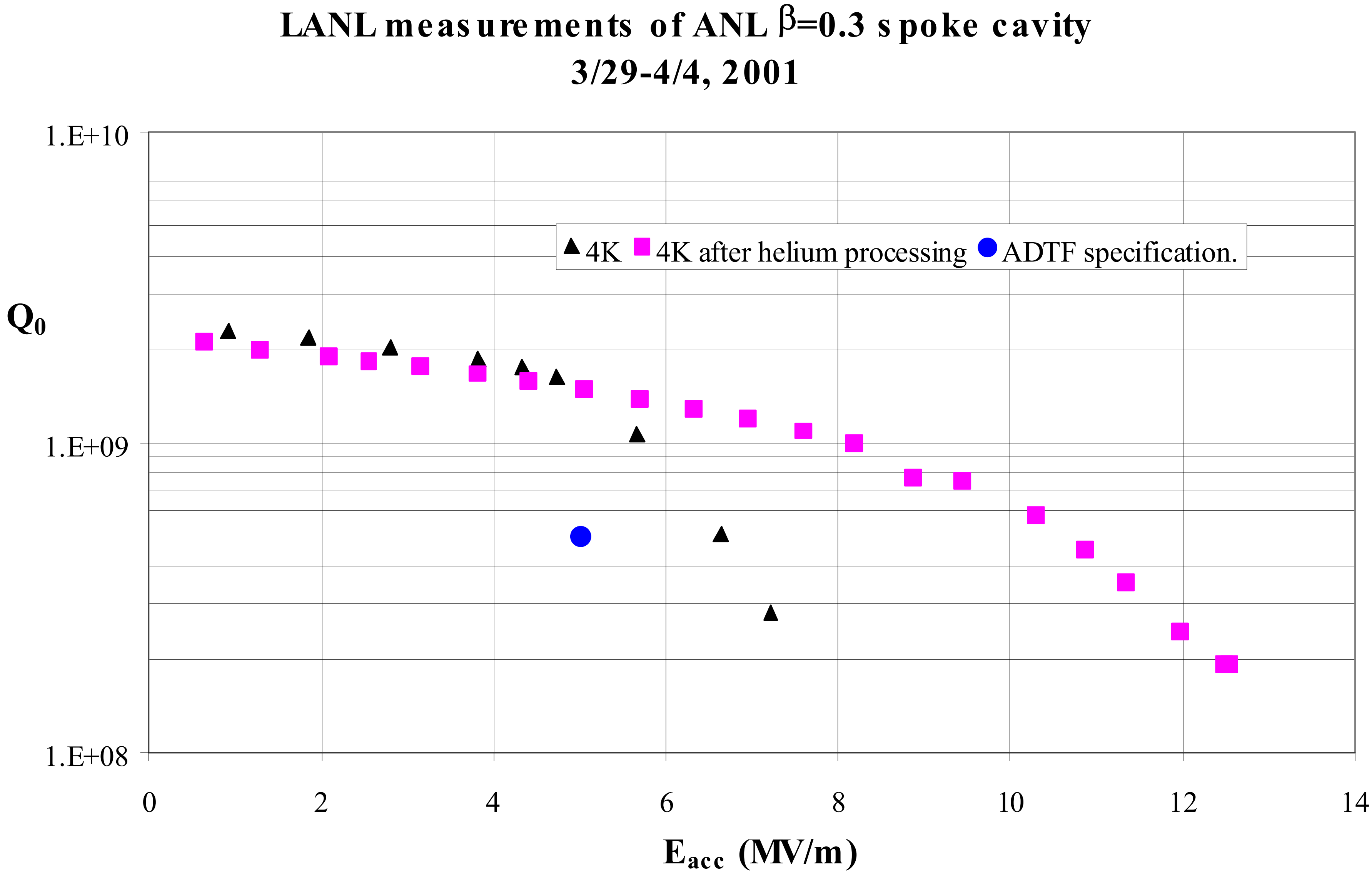
- NC linac to 211 MeV replaced with four new SC sections each with identical cavity shapes and cryomodules.
- Conservative input power-coupler capacity < 60 kW and accelerating gradients (<10 MV/m).
- Superconducting solenoid magnets used for focusing below 211 MeV.
- New SC low energy linac saves 57 MW ac power.

β=0.48 elliptical cavity electric field

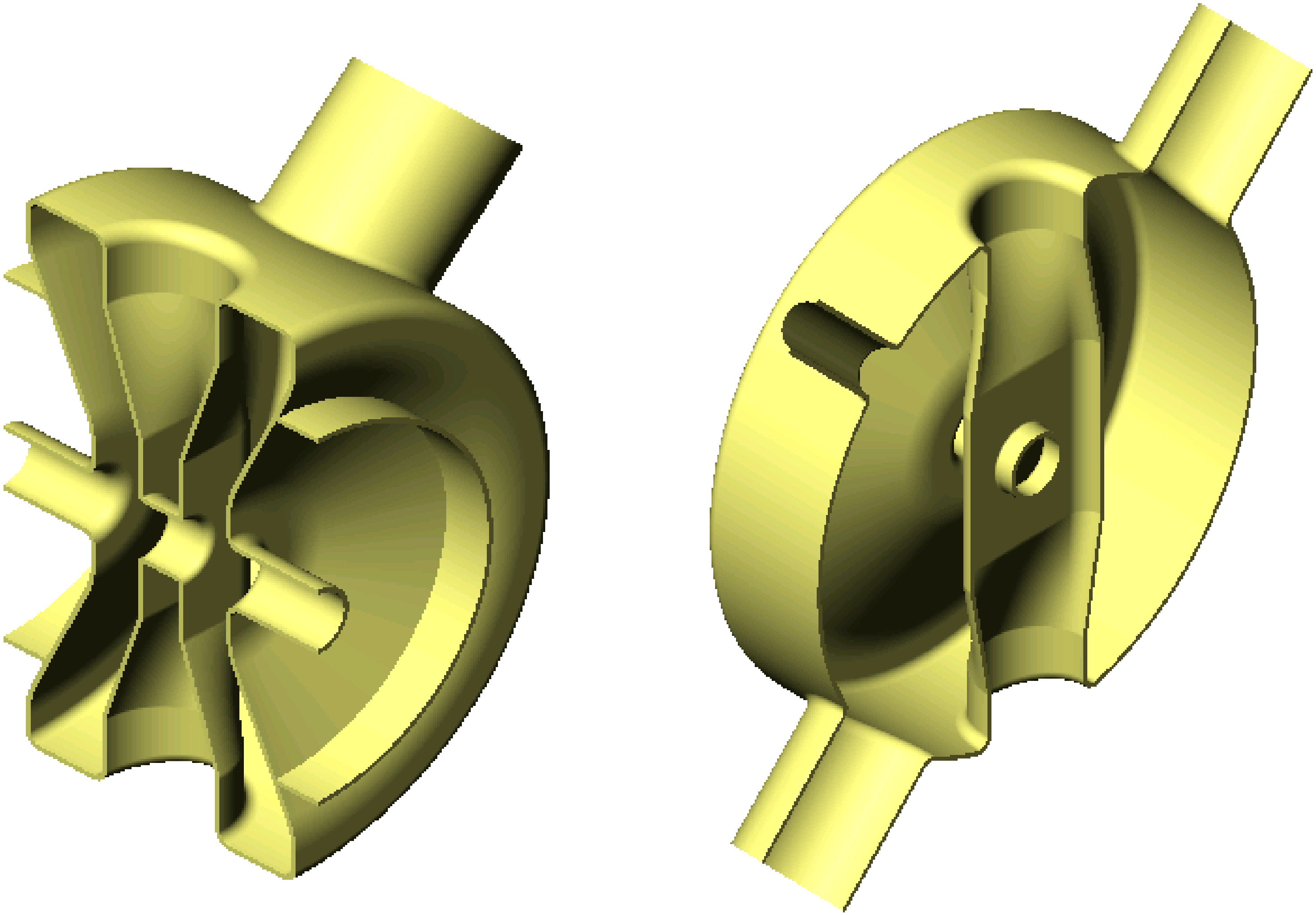


Spoke cavities for low-velocity applications have achieved high-gradient performance.

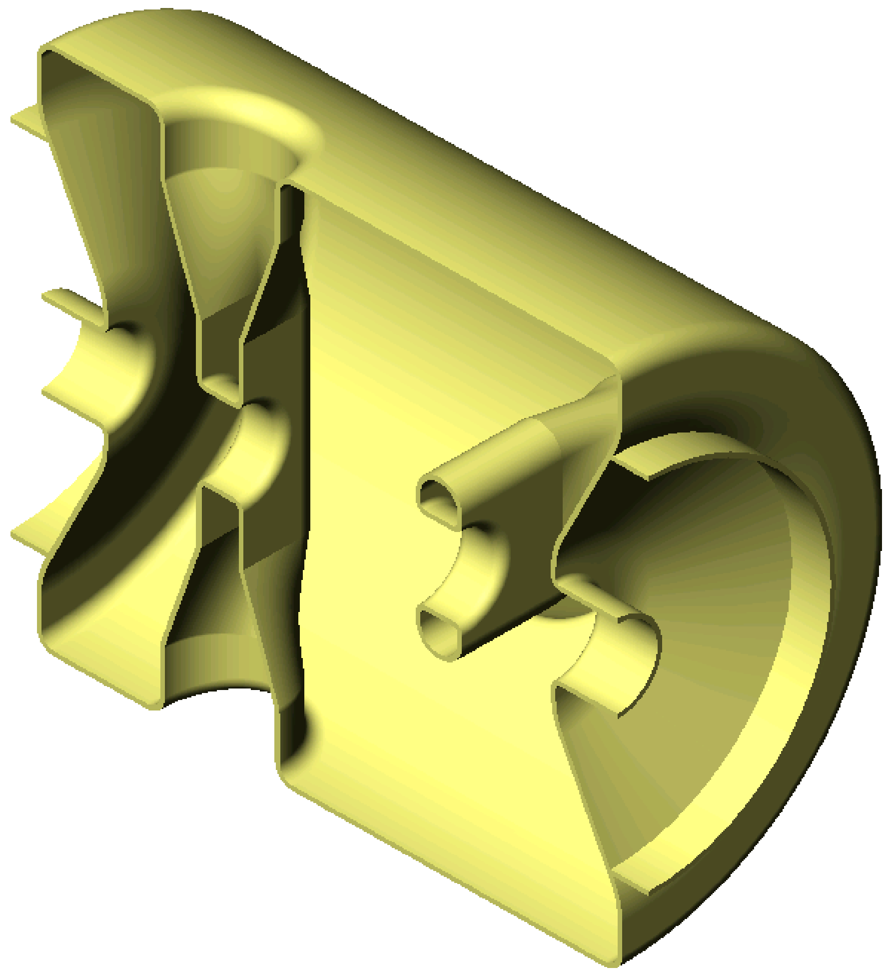
- 350-MHz 2-gap spoke structures for beta=0.3 and 0.4 have been developed by ANL for the proposed RIA project.
- Tests of this cavity at LANL in April showed excellent high-gradient performance.


LANL measurements of ANL β=0.3 spoke cavity
3/29-4/4, 2001
1.E+10
1.E+09
1.E+08
Q0
4K
4K after helium processing
ADTF specification.
0
2
4
6
8
10
12
14
Eacc (MV/m)

β = 0.175 2-Gap Spoke Resonator Geometry

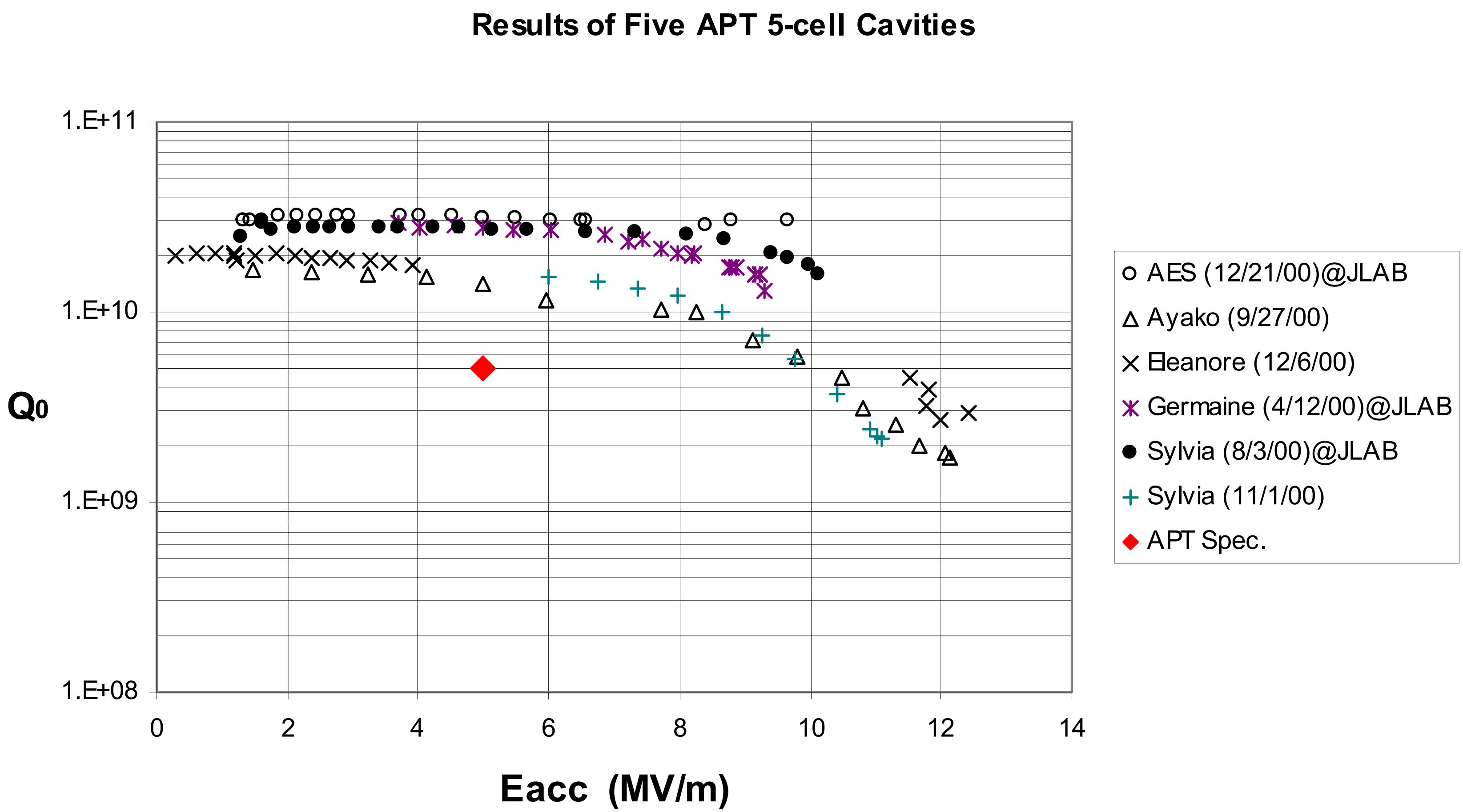


β = 0.34 3-Gap Spoke Resonator Geometry



β=0.48 elliptical cavity

APT beta=0.64 cavity



Results of Five APT 5-cell Cavities
1.E+11
1.E+10
1.E+09
1.E+08
Q0
0
2
4
6
8
10
12
14
Eacc (MV/m)
AES (12/21/00)@JLAB
Ayako (9/27/00)
Eleanore (12/6/00)
Germaine (4/12/00)@JLAB
Sylvia (8/3/00)@JLAB
Sylvia (11/1/00)
APT Spec.

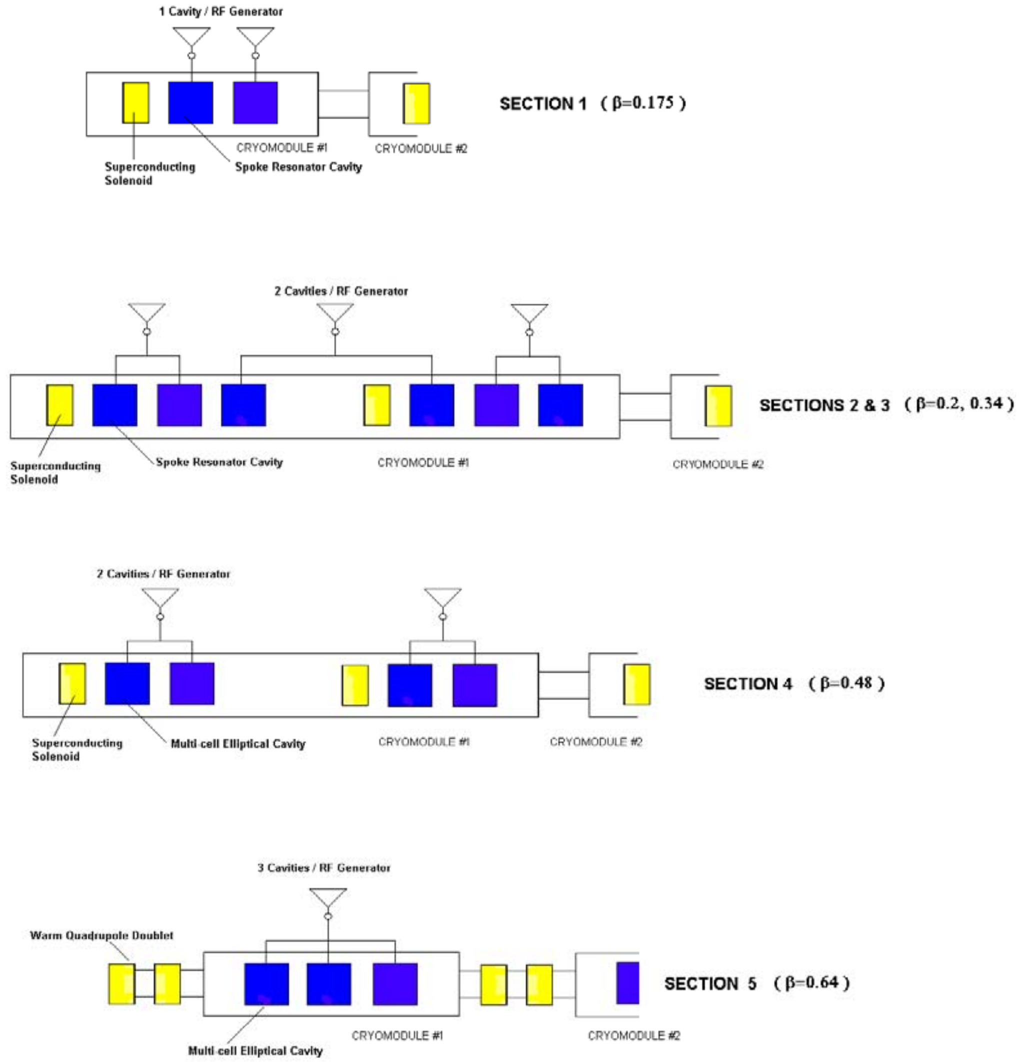
ADTF Superconducting Linac Parameters

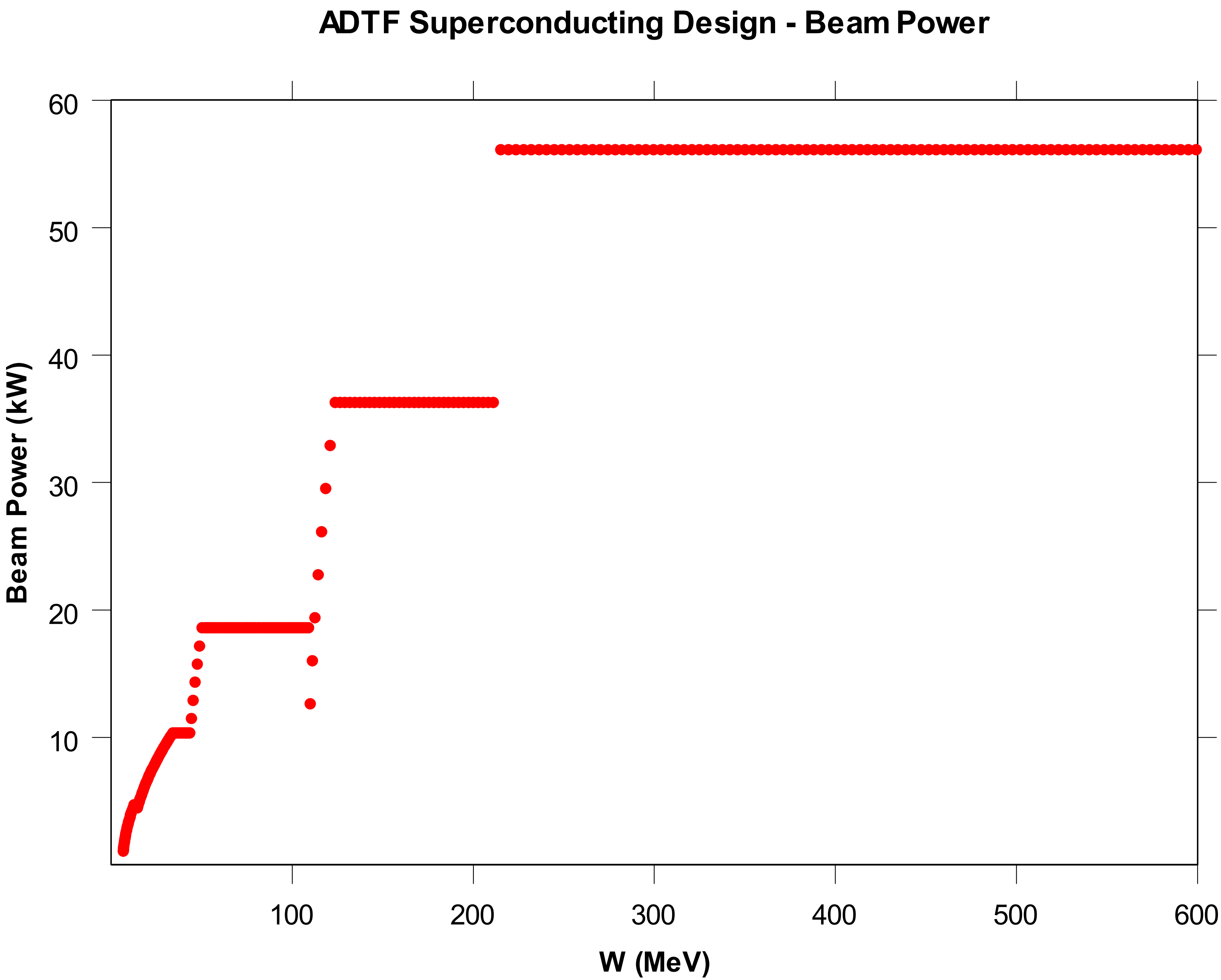
	Section 1	Section 2	Section 3	Section 4	Section 5	Total
Structure Type	2-gap spoke	3-gap spoke	3-gap spoke	5-cell ellipt	5-cell ellipt	
Frequency (MHz)	350	350	350	700	700	
Cavity Geometric Beta	0.175	0.2	0.34	0.48	0.64	
Cavity Bore Radius (cm)	2.0	3.5	4.0	5.0	6.5	
Cav/cryomodule	4	6	6	4	3	
Cav/section	32	48	48	40	93	261
No. of cryomodules	8	8	8	10	31	65
DW/cav (MeV)	0.08 - 0.35	0.33 - 0.78	0.86 - 1.40	0.95 - 2.73	4.22	
Win,section (MeV)	6.7	14.2	43.5	109.0	211.0	
Wout,section (MeV)	14.2	43.5	109.0	211.0	600.0	
Section Length (m)	36.2	48.8	55.4	64.8	191.6	396.8
Coupler Power @ 13.3 mA (kW)	4.7	10.4	18.6	36.3	56.1	
No. of Cavities per RF Generator	1	2	2	2	3	
No. of RF Generators	32	24	24	20	31	131
Magnet Type	SC Solenoid	SC Solenoid	SC Solenoid	SC Solenoid	RT Quad Doublet	

Superconducting low-energy linac design choices

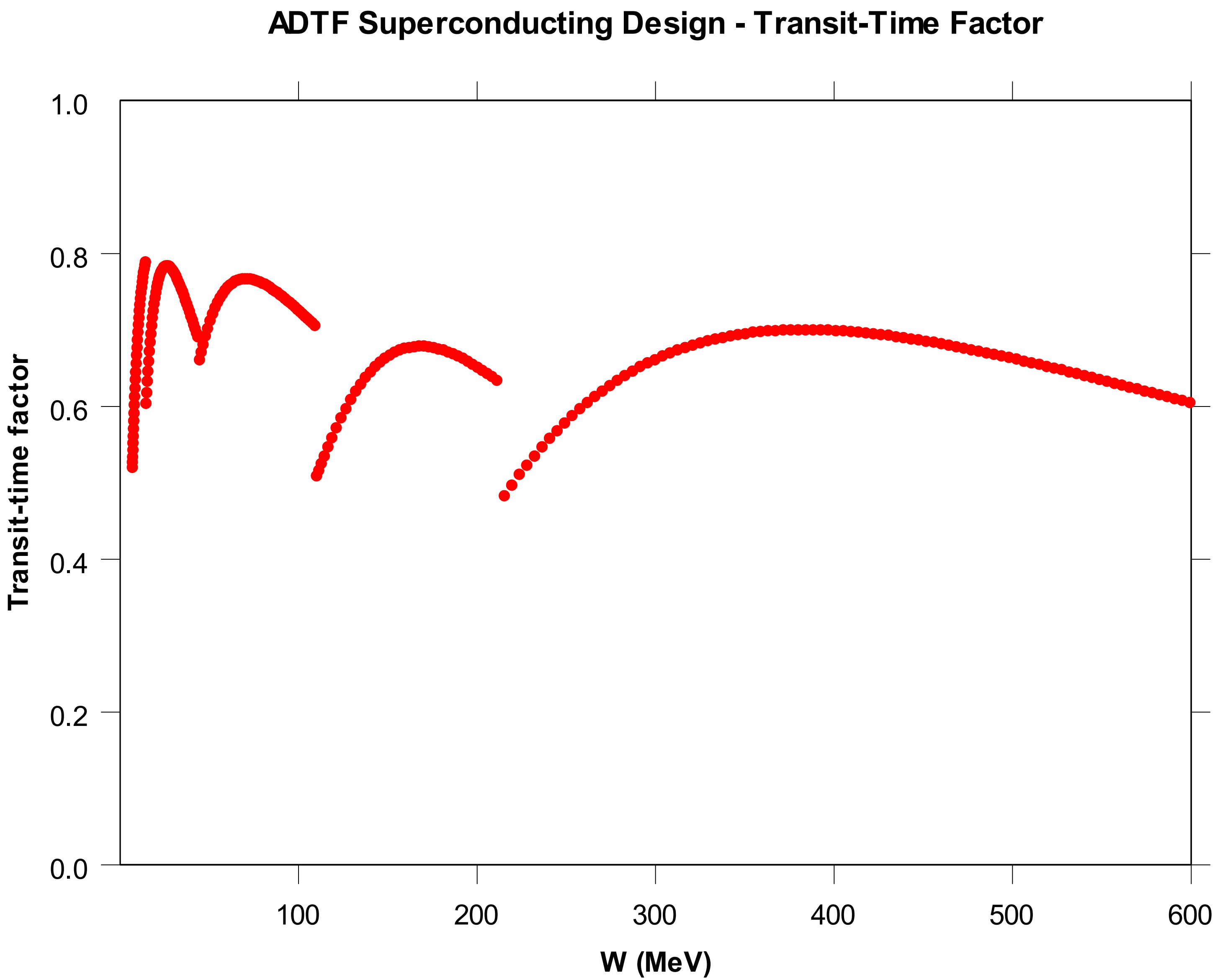
- Number of cells per cavity is chosen small enough to cover the velocity range with just a few cavity shapes.
- Conservatively chosen accelerating gradients allows margin for fault compensation.
  -E_{acc}< 10 MV/m for β=0.64 700-MHz elliptical cavities.
  -E_{acc}< 7 MV/m for β=0.48 700-MHz elliptical cavities.
  -E_{acc}< 5 MV/m for 350-MHz spoke cavities.
- RF generator sizes chosen sufficiently small to allow continued beam operation if an RF module fails.
- Design for large aperture to rms ratio especially for beam energies above 50 MeV where activation concerns are greatest.
- Use superconducting solenoids to provide compact focusing lattice to control emittance and halo growth from space-charge forces. (β=0.48 section could use quad doublets instead.)

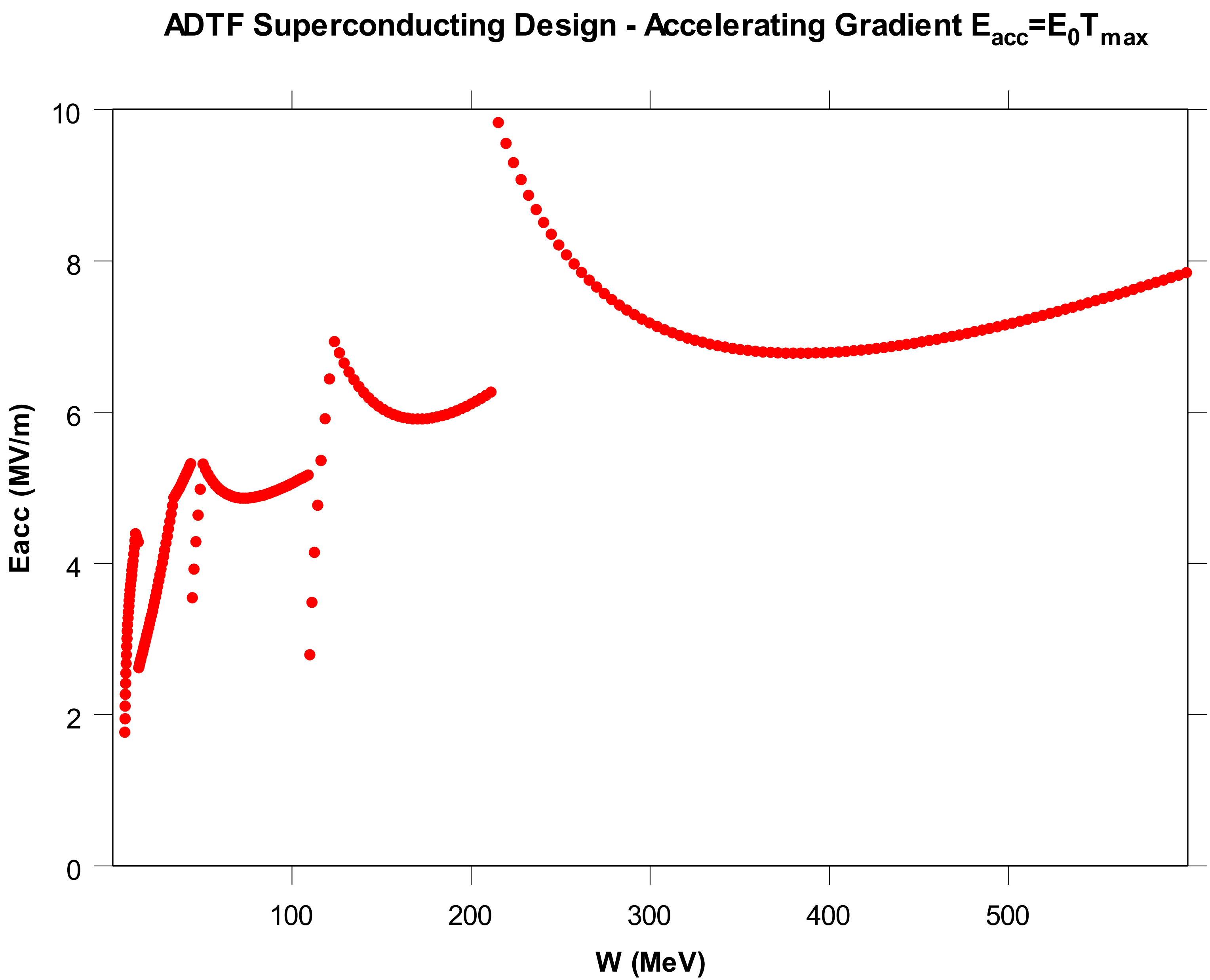
RF architectures for the 5 superconducting sections

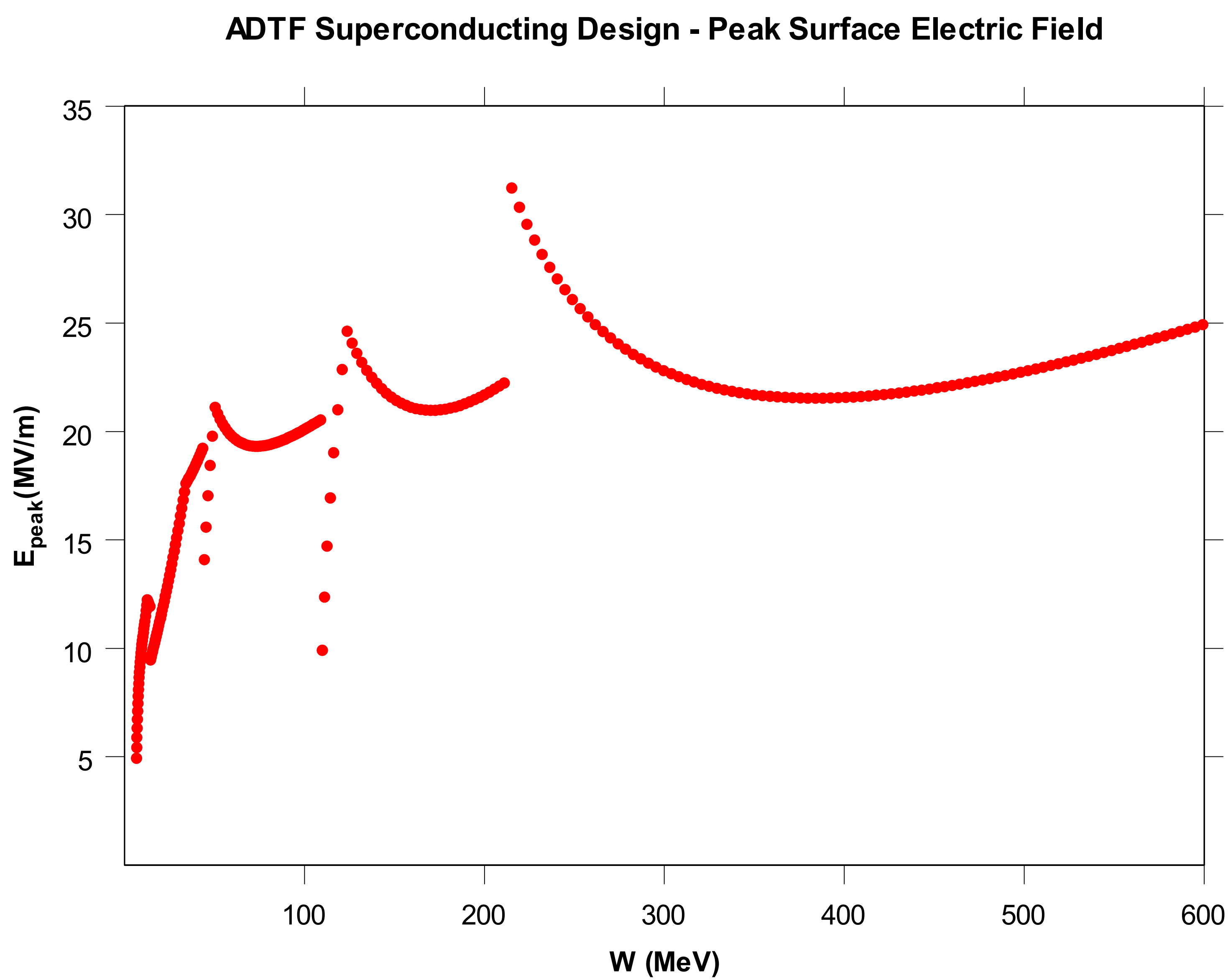


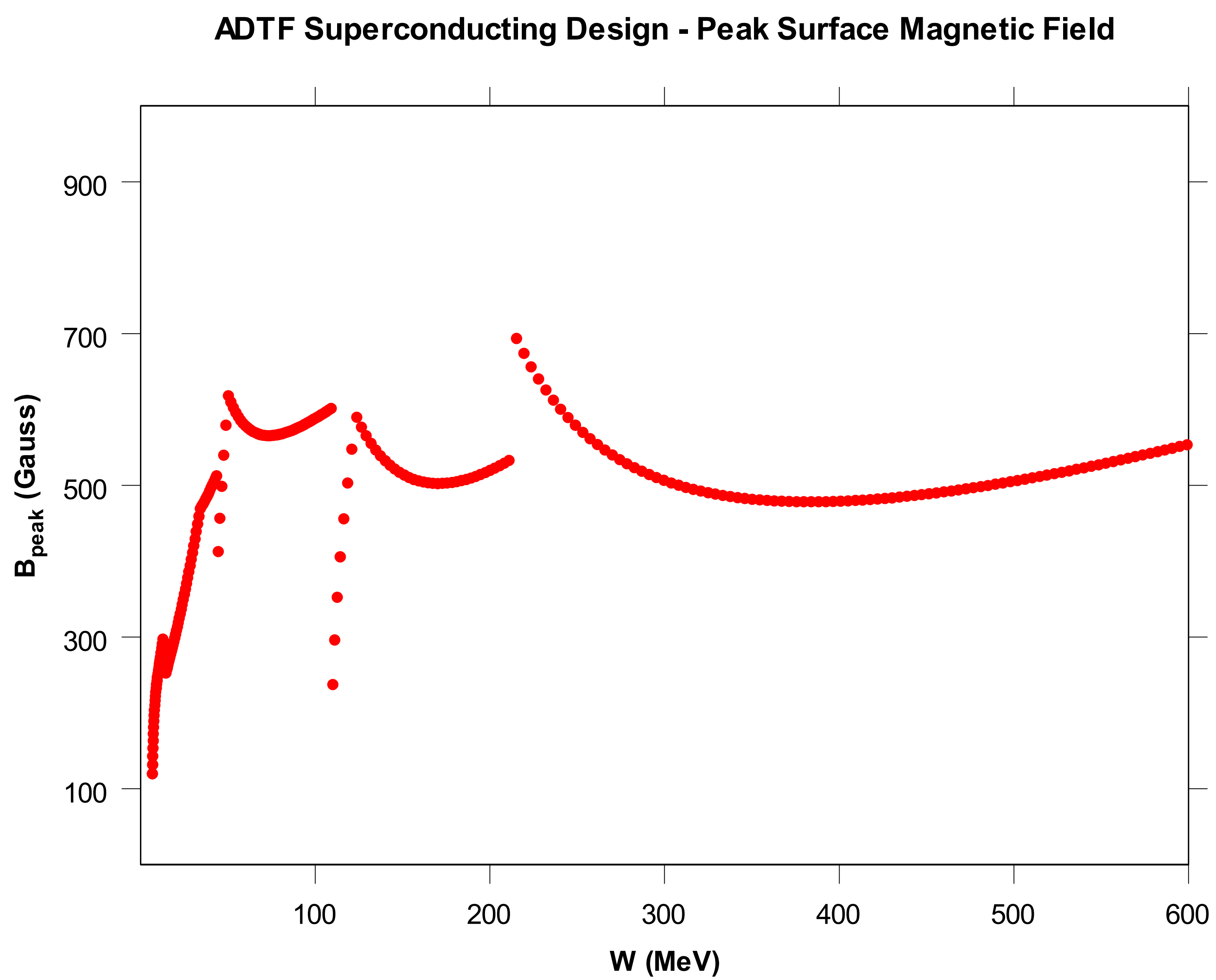


ADTF Superconducting Design - Beam Power
Beam Power (kW)
W (MeV)
60
50
40
30
20
10
100
200
300
400
500
600


ADTF Superconducting Design - Transit-Time Factor
1.0
0.8
0.6
0.4
0.2
0.0
Transit-time factor
100
200
300
400
500
600
W (MeV)


ADTF Superconducting Design - Accelerating Gradient $E_{acc}=E_0T_{max}$
Eacc (MV/m)
0
2
4
6
8
10
100
200
300
400
500
W (MeV)


ADTF Superconducting Design - Peak Surface Electric Field
35
30
25
20
15
10
5
100
200
300
400
500
600
W (MeV)
E_{peak}(MV/m)


ADTF Superconducting Design - Peak Surface Magnetic Field
900
700
500
300
100
Bpeak (Gauss)
100
200
300
400
500
600
W (MeV)

Beam interrupts are a serious concern for accelerator-driven reactors

- An important design goal for AAA is to reduce beam interrupts substantially to limit thermal stresses in the target.
- A superconducting linac provides advantages for reducing beam interrupts:

  -Combining a small number of cells per cavity (large velocity acceptance) with independent phasing of the cavities and larger bore radius provides ability to continue beam delivery even with rf module or focusing magnet failures.

  -Superconducting linac allows beam continuity in presence of common faults. Can continue running with single point failures of RF modules, cavities, rf windows, magnets, magnet power supplies.

Advantages of a low-velocity ADTF superconducting linac

- Cavity RF power dissipation is reduced by almost 10^5 factor; AC operating power is substantially reduced.
  -Saves 57-MW AC power out of 80-MW total for 600-MeV linac.
- Larger bore radius becomes affordable, relaxing alignment, steering, and matching tolerances, and reducing beam loss and activation threat.
  -Aperture increases typically by factor of 2 in low-velocity linac.
  -Aperture to rms size ratio from 50 to 211 MeV increases by an average of about 40%.
- Reliability of rf system greatly improved because superconducting linac allows use of more reliable lower power tubes.
- Superconducting linac can continue delivering beam even with component failures.
- Simulation results show superconducting linac provides ways for reducing most common beam interrupts in the linac.

Summary

- A superconducting low-velocity linac provides significantly reduced operating power. Saves 57 MW out of 80 MW.
- A superconducting low-velocity linac provides more ways for reducing beam-interrupts in the linac.
- A superconducting low-velocity linac provides larger apertures, relaxing alignment, steering, and matching requirements, and reduces activation threat.
- The superconducting elliptical β=0.48 cavity and the superconducting spoke cavities provide the AAA program with an opportunity for an ADTF with a superconducting linac from 6.7 to 600 MeV.
- **An external review committee in April unanimously recommended replacement of normal-conducting linac with superconducting spoke cavities, and noted extraordinary progress in spoke cavity development.**