Argonne NATIONAL LABORATORY

Workshop on ADS - 2010

Concept for 1 GeV/10 MW Superconducting Proton Linac for ADS

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On behalf of the ANL Accelerator Development Group

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U.S. DEPARTMENT OF ENERGY

Content

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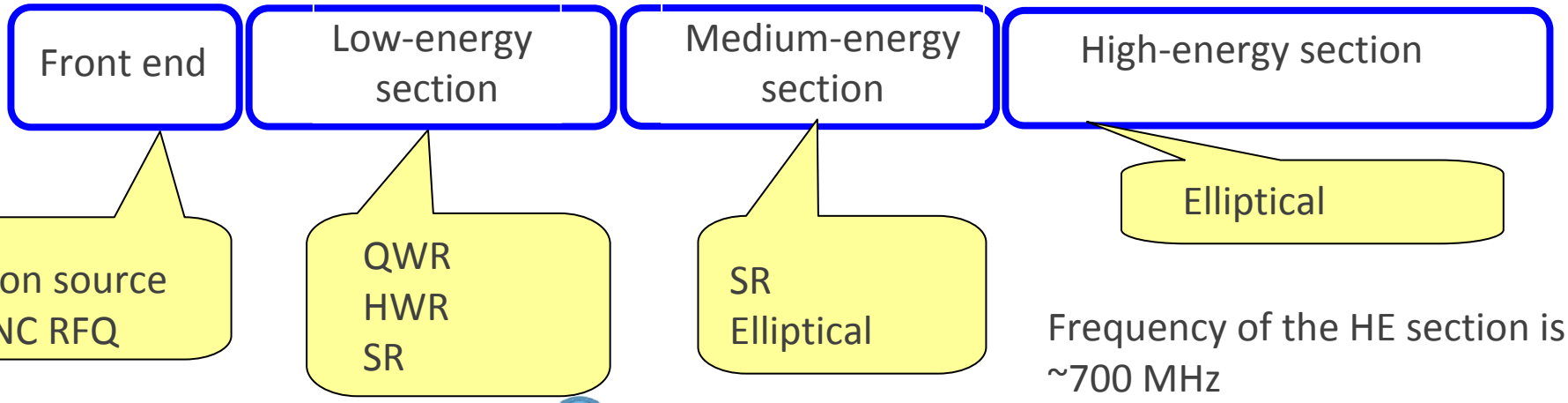
- Highly reliable, high-power proton Linac
  - Design philosophy
  - layout
  - parameters
- Normal conducting CW RFQ
- SRF at ANL
- Recently built TEM-class cavity parameters
- RF couplers
- List of Prototyping work toward 10 MW driver
- Conclusion

Motivation of Work

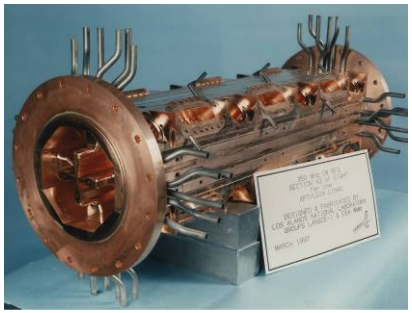
- Work is being done under an Argonne LDRD project entitled, “Near-Term Spent Nuclear Fuel Disposal Using Accelerator Driven System”
- The LDRD project is to develop a proposal for a design concept using a site-neutral demonstration facility for transmuting minor actinides… leading to an ultimate production facility
- A goal is to define the demonstration facility based on existing technology, as much as possible
- Work includes concept development for sub critical assembly, target, fuel processing , and accelerator
- Initial work is to
  - define the optimal parameters of the demonstration facility
  - Develop a pre-conceptual layout
  - Identify any needed R&D or Prototyping
  - Begin to address R&D issues as funding allows
- The remainder of this talk focuses on the accelerator design concept addressing these objectives.

1 GeV Superconducting Proton Linac for ADS Demonstration

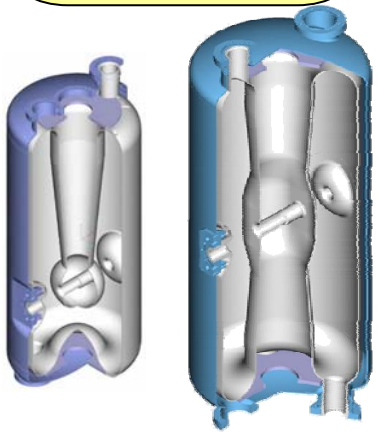
- Power level of the overall demonstration system is a topic for ongoing research
- As an example, for the initial design we assume 10 mA beam which results in 10 MW system at 1 GeV

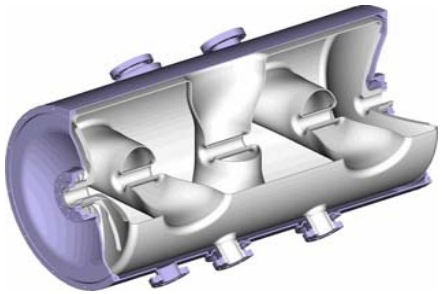


Frequency of the HE section is ~700 MHz



LANL LEDA RFQ
Courtesy D. Schrage

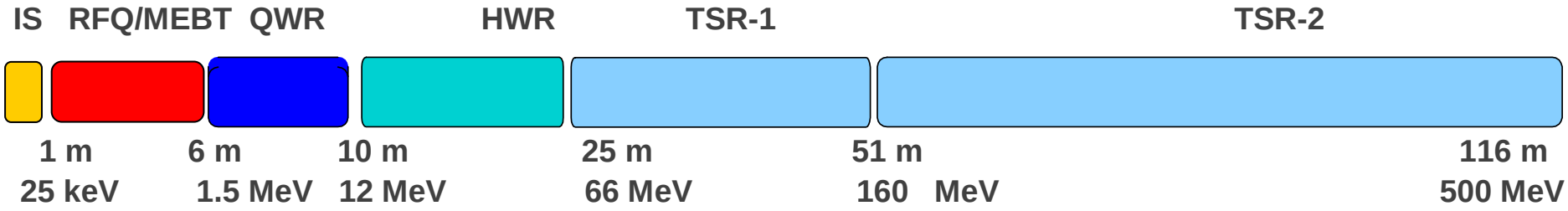




SNS SC cavities
Courtesy J. Galambos

500 MeV Front End Based on TEM-class SC Cavities

- Beam energy – 500 MeV
- Beam current - 10 mA
- Operation temperature – 2K
- Dynamic cryogenic load – 1.1 kW



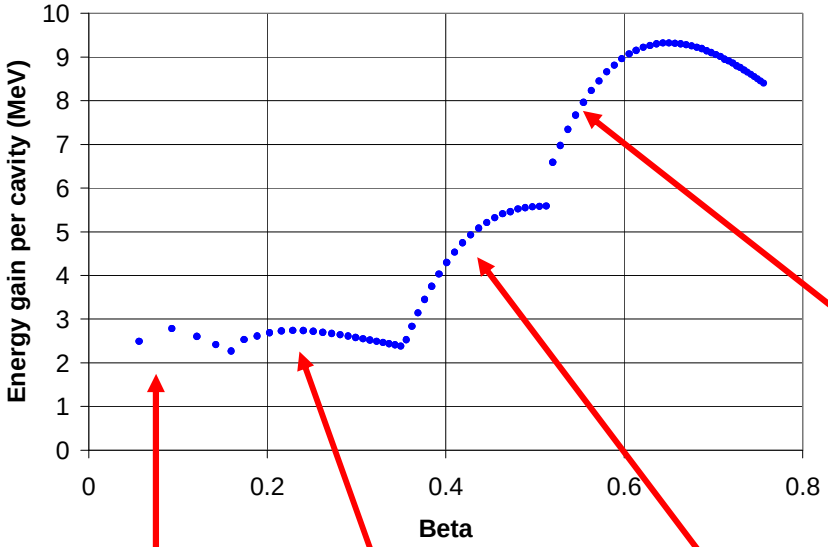
Cavity type	β_G	# of cavities	# of cryomod.	Energy MeV	Length m	Max. RF power kW per cavity
QWR	0.1	5	1	12	4	30
HWR	0.22	19	2	66	15	30
TSR-1	0.52	20	4	160	26	60
TSR-2	0.65	39	13	600	65	100
TOTAL		**83**	**21**		**110**	

Design Philosophy

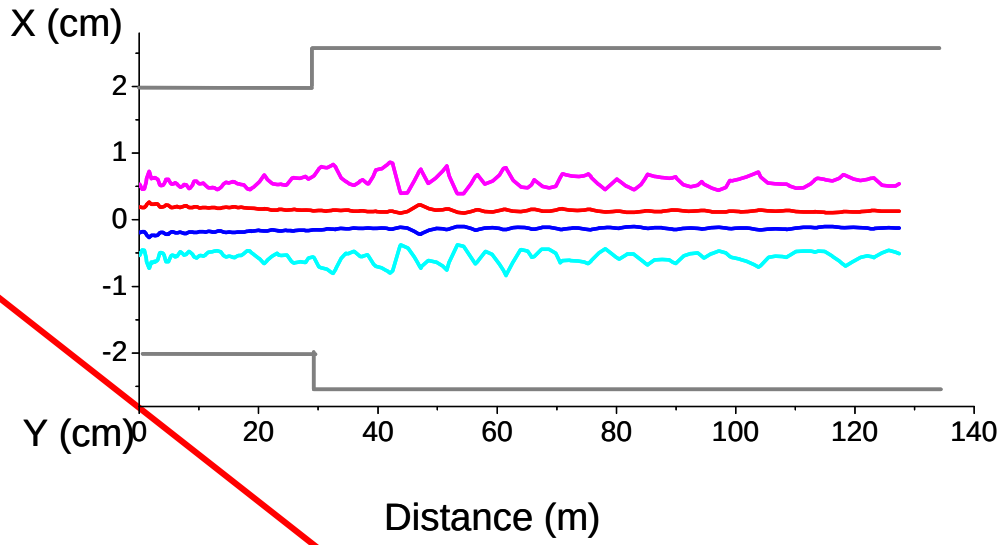
- Reduced number of components results in higher availability
  - Low frequency TEM-class cavities in the front end and medium section
  - Large aperture 40 mm for QWR, HWR and 50 mm for TSR
- Apply world-class advanced SRF technology
  - Available in several US Labs including ANL
- SC cavities are based on demonstrated average performance
  - B_{peak} ~70 mT
  - E_{peak} ~35 MV/m
- Moderate specifications to RF power couplers
  - Transmitted RF power is below 100 kW
  - No fast tuner is required, microphonics is controlled by the available RF power
- Focusing by SC magnets (solenoids)

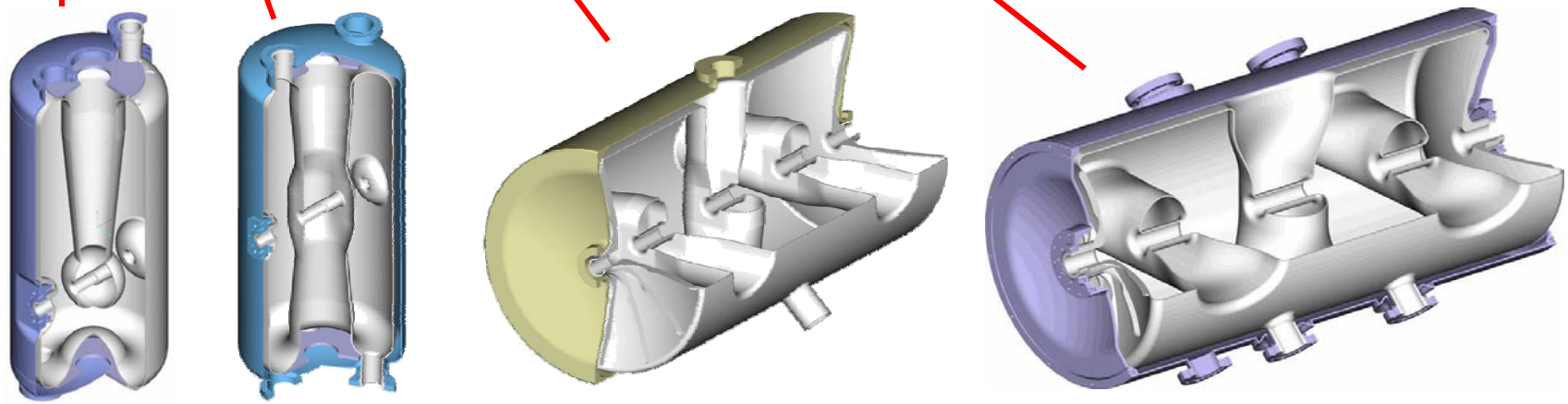
500 MeV Linac Parameters

Beam energy gain per cavity



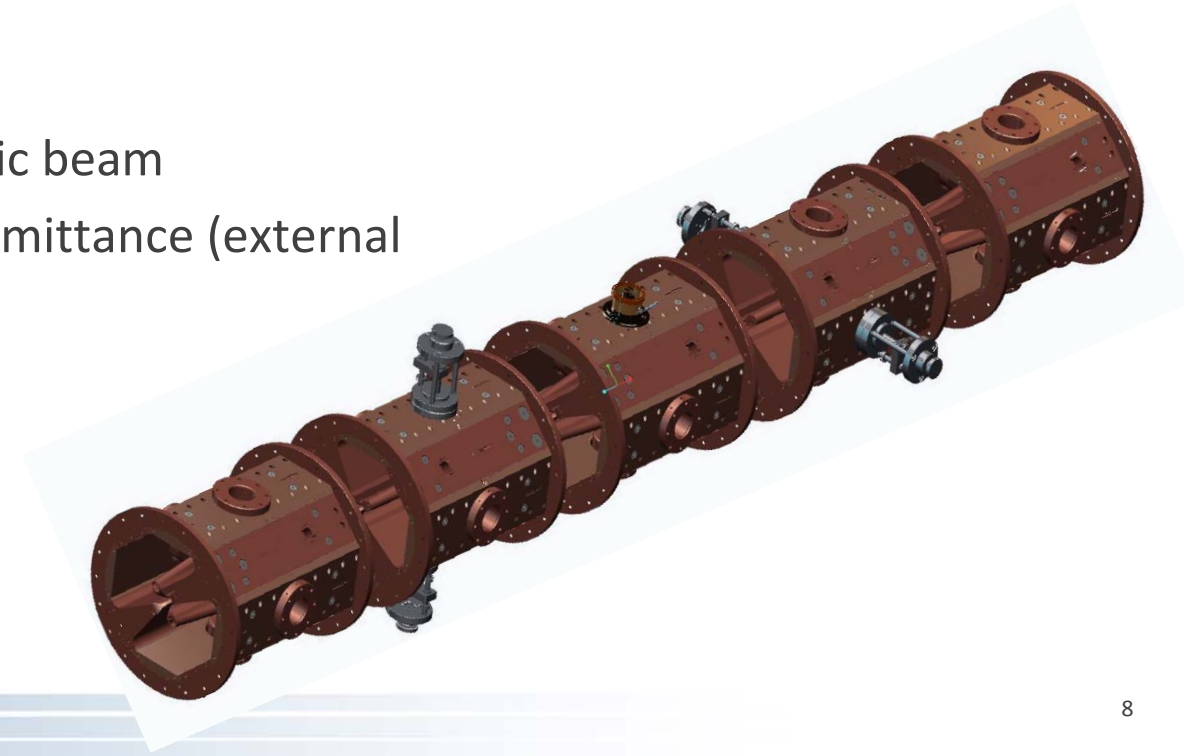
Beam envelopes (rms and total) along the Linac





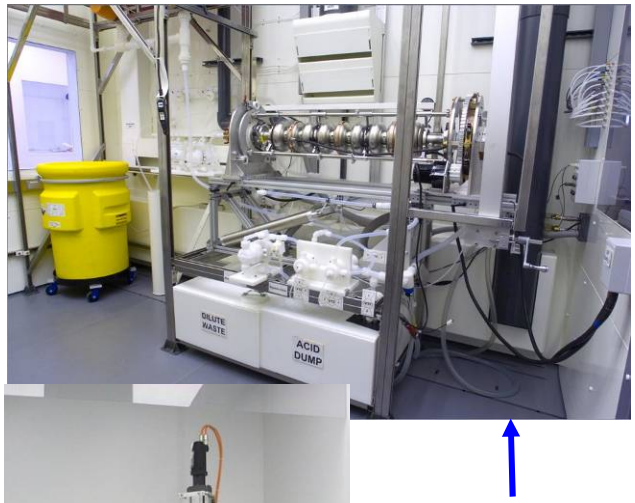
Current RFQ Project at ANL Physics Division

- 60.625 MHz, CW regime of operation
- Total accelerating voltage - 2.1 MV
- Length - 3.9 m
- OFE copper, high-temperature furnace brazing
- 50 kW RF power
- New features
  - Forms axially-symmetric beam
  - Very low longitudinal emittance (external bunching)
  - Increased efficiency of acceleration



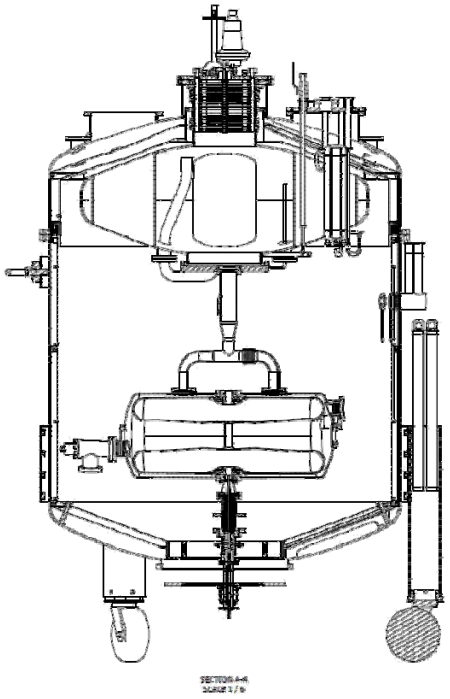
Advanced SRF Technology at ANL

- Developed several TEM class SC cavities to cover velocity range from 0.008c to 0.8c
  - Surface processing, 2K large test cryostat



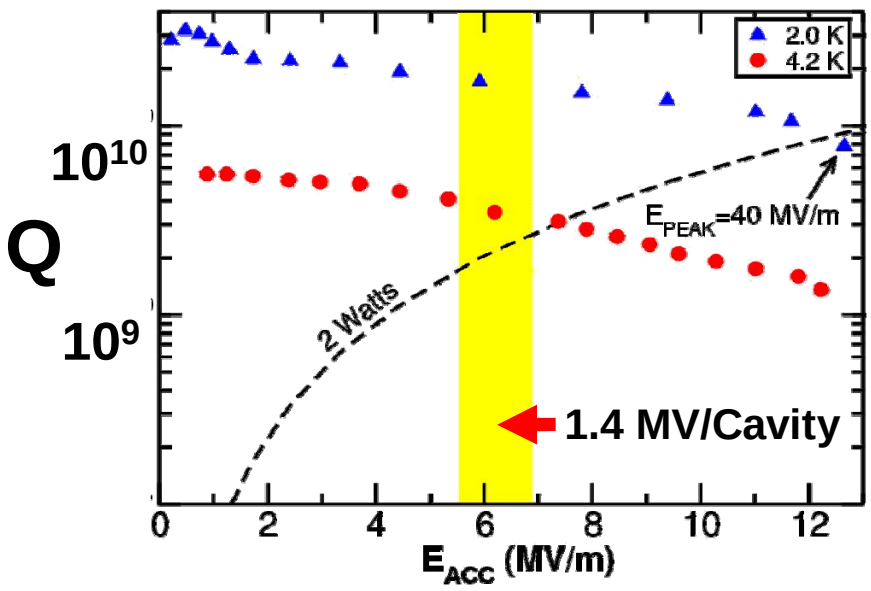
EP

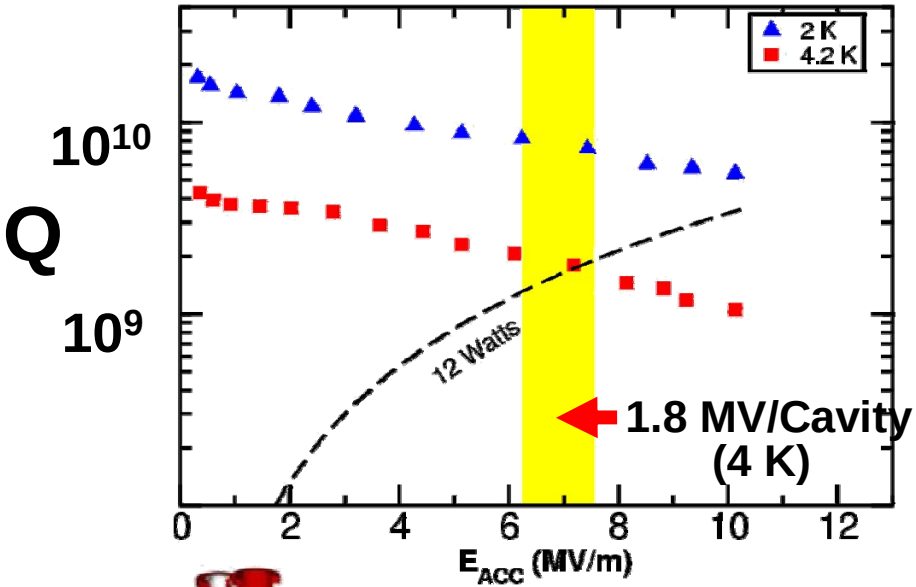
HPR

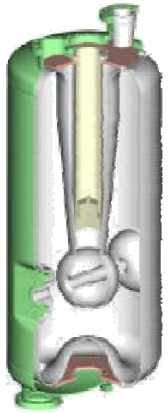


Test Cryostat

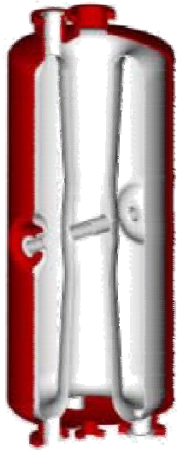
Typical Performance of ANL Built Cavities







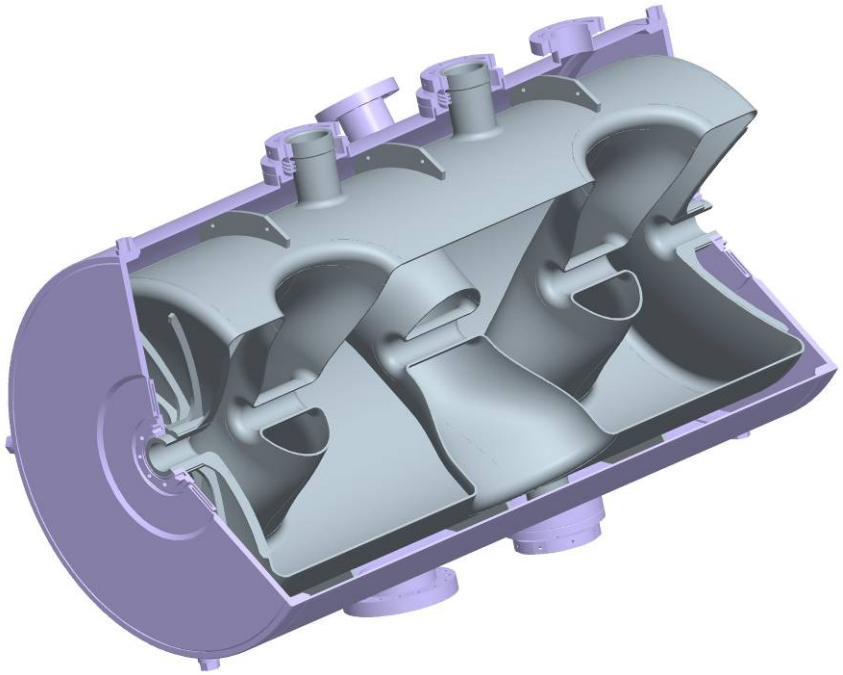
β=0.15 QWR, f_0=115 MHz



β=0.25 HWR, f_0=172.5 MHz

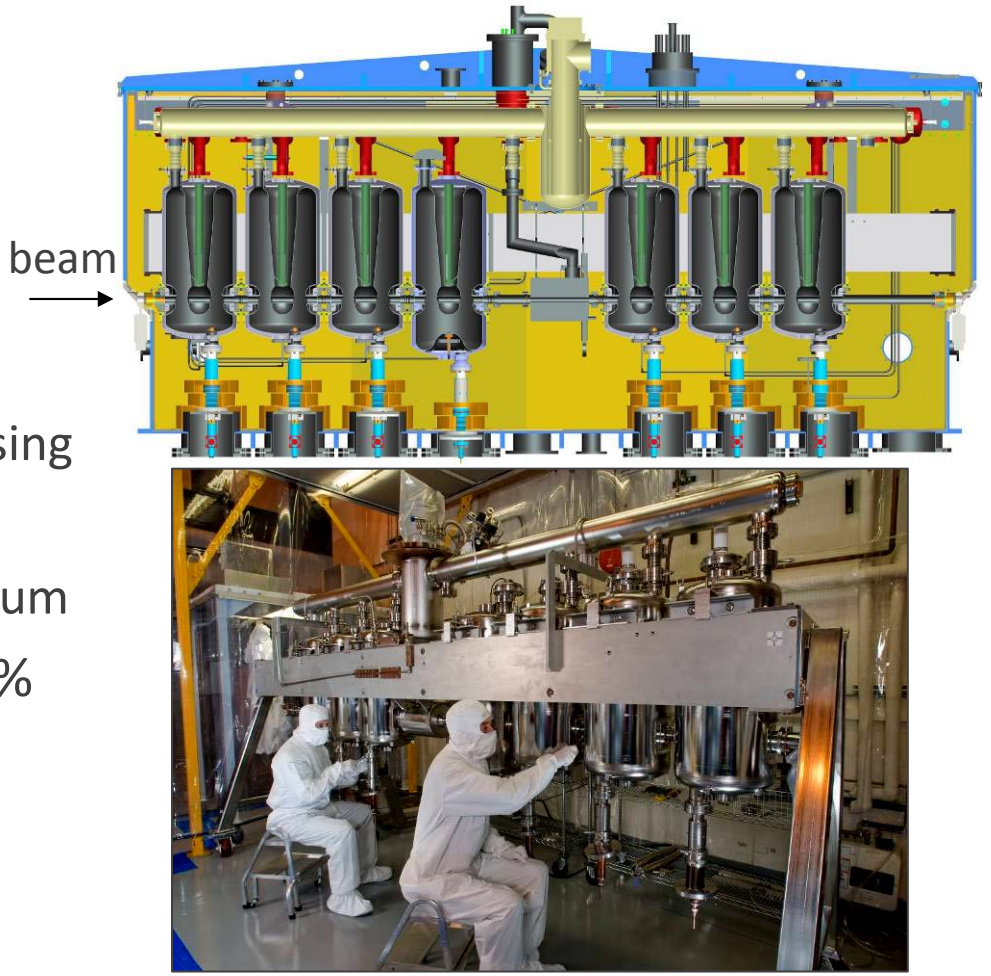
Medium Beta Triple-Spoke Cavities (β=0.5 and β=0.62)

- More efficient at 2K – the residual resistance is 5 nΩ



ATLAS Energy Upgrade (Completed in 2009)

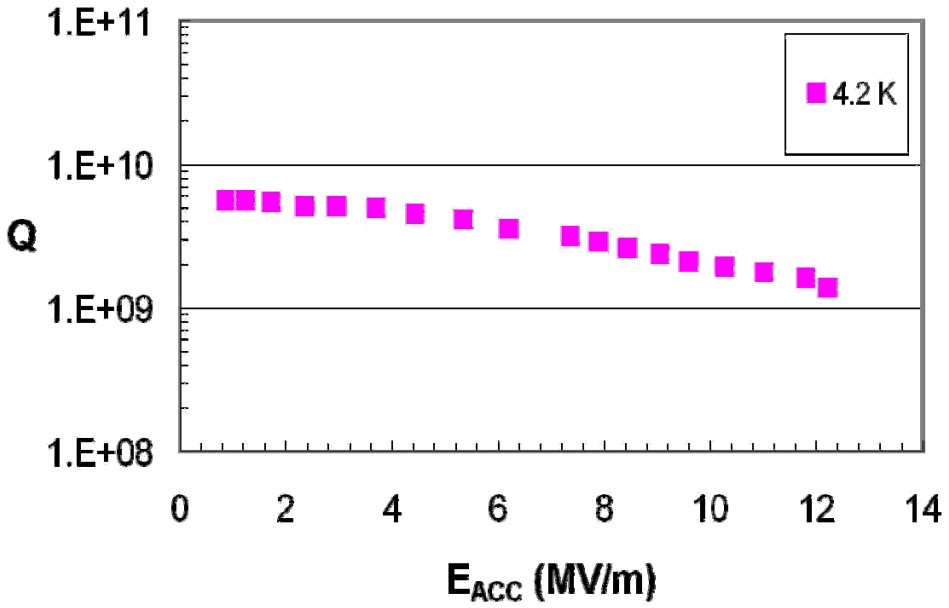
- 7 quarter wave SC resonators
- Innovative features
  - Advanced EM and Mech. design
  - Steering corrected drift-tubes
  - State-of-the-art surface processing and clean assembly
  - Separate cavity & cryostat vacuum
- ATLAS energy increase by 30-40%
  - Highest real-estate gradient
- Commissioned –July 2009



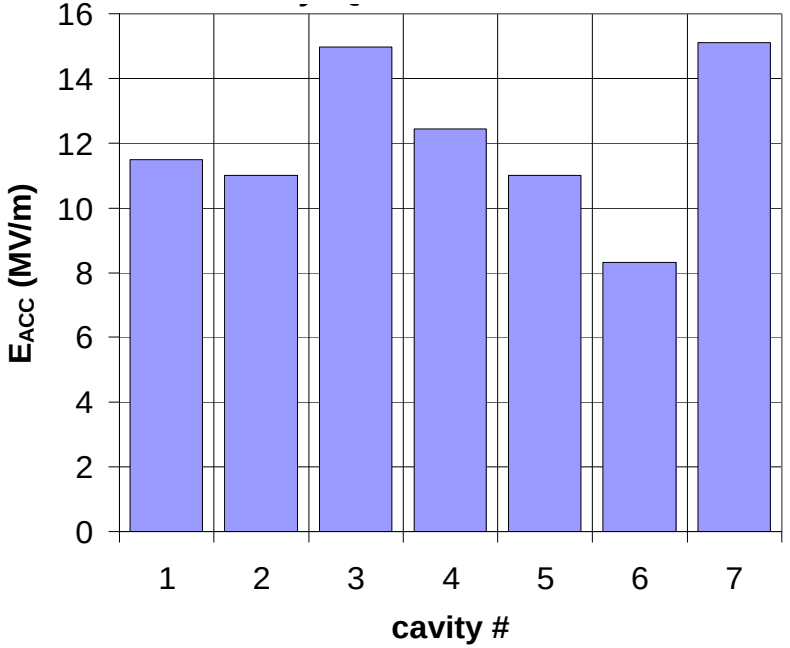
Cavity Accelerating Fields

- Accelerating gradients as high as **15 MV/m**
- Max. Accelerating Voltage = 3.75 MV/cavity, E_{PEAK} = 48 MV/m, B_{PEAK} = 88 mT
- **Average B_{PEAK} =71 mT, E_{PEAK} =36 MV/m**

Field Performance Cavity #4
(a typical performer)



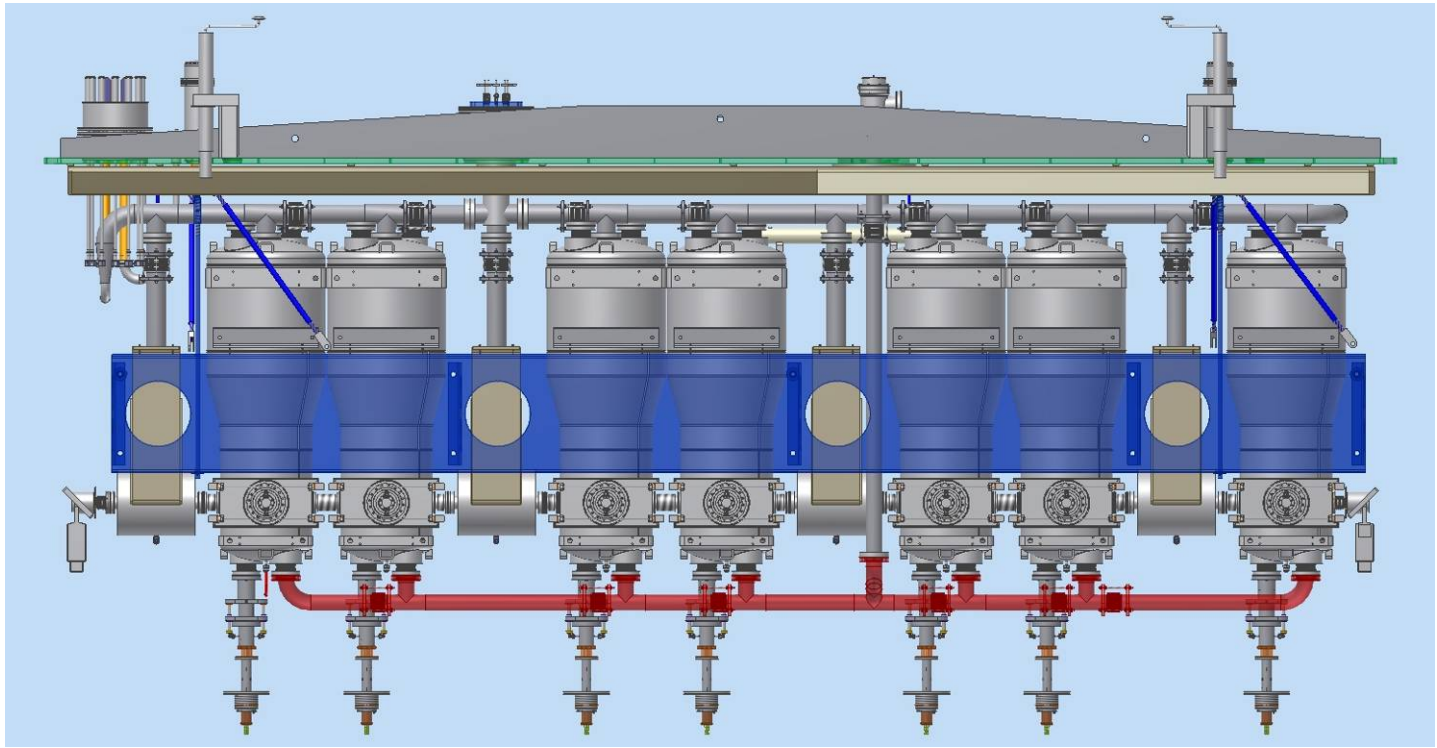
Maximum field for all cavities



New Cryomodule for the ATLAS Upgrade (Commissioning in 2013)

7 QWRs, four 9-Tesla SC solenoids, total design voltage is 17.5 MV, best performance ~25 MV

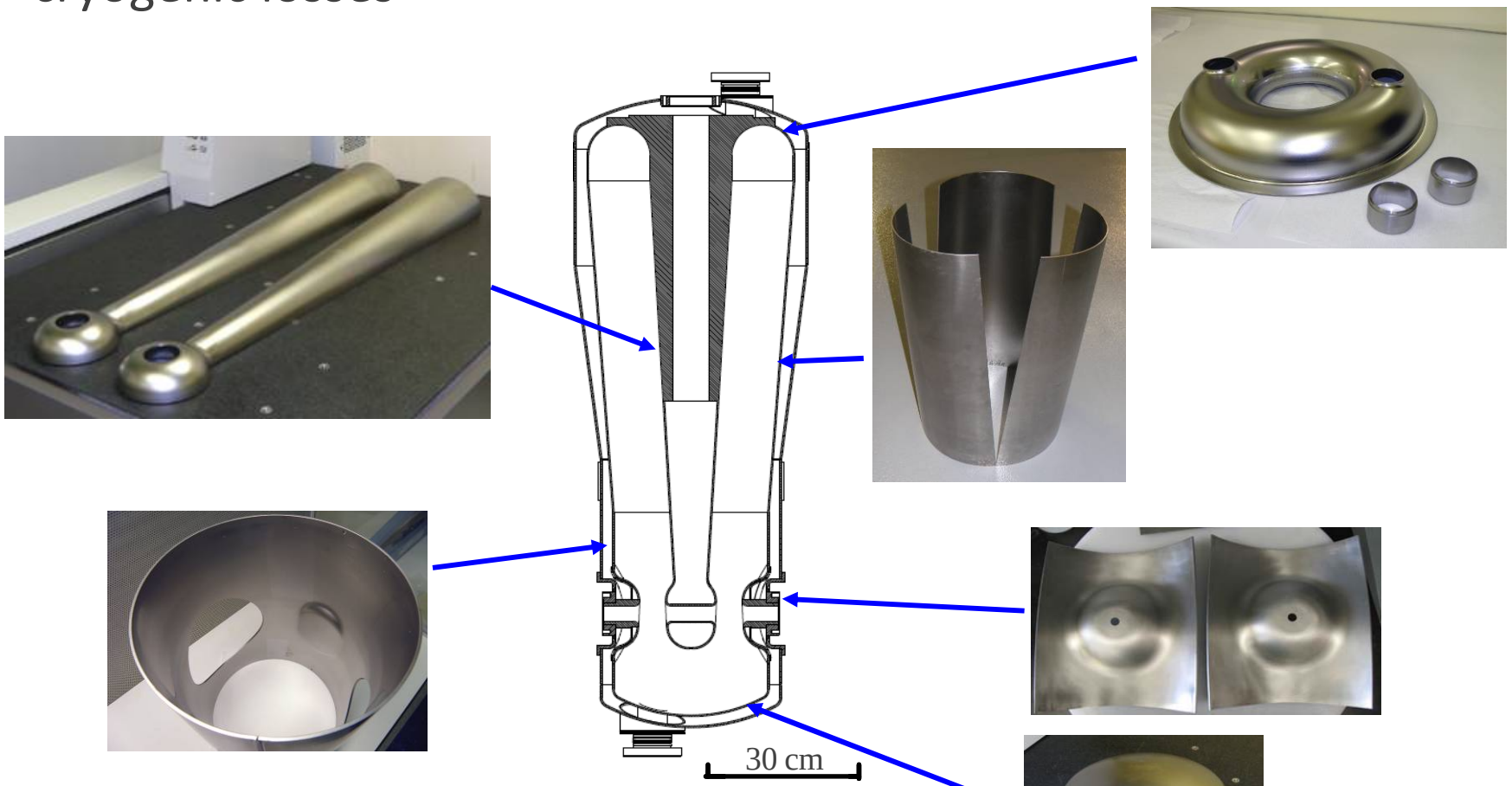
5.12-meter long, Separate vacuum, Improved design



Engineering 3D model of the cavity-solenoid string

New SC Cavities for the ATLAS Upgrade

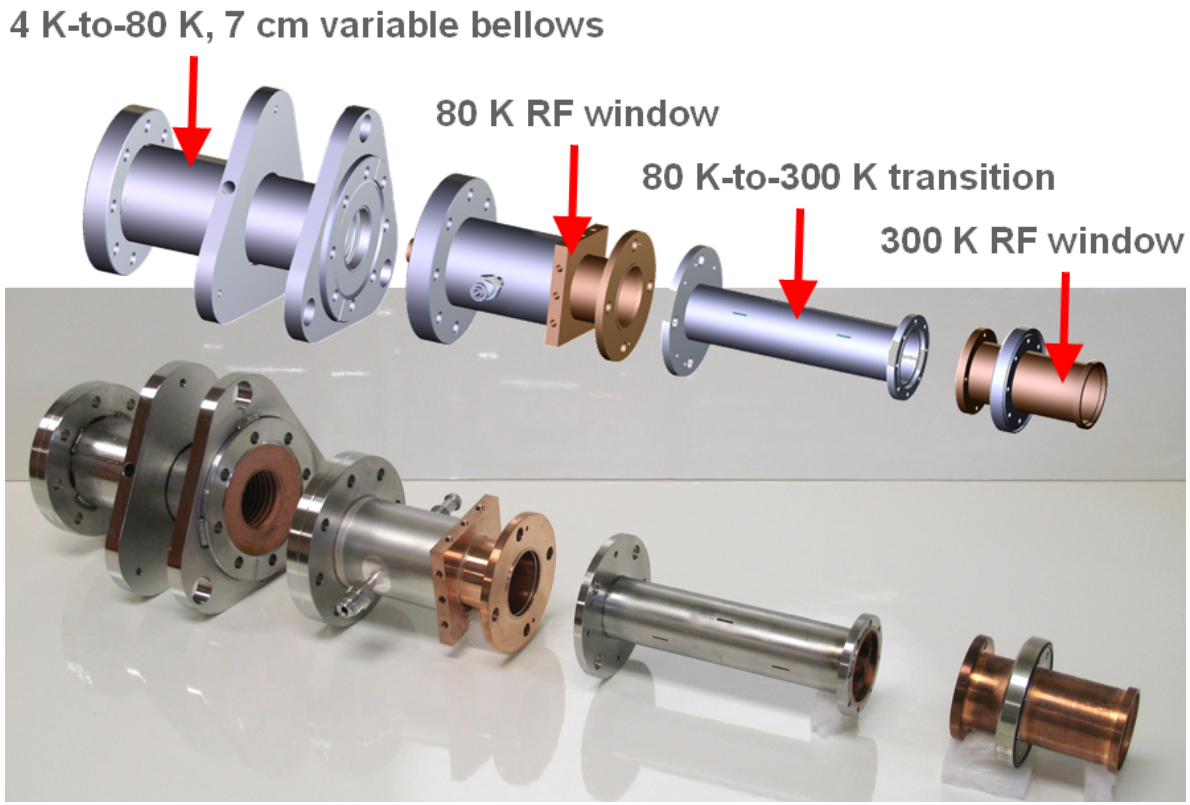
Highly optimized to obtain high accelerating gradients and low cryogenic losses



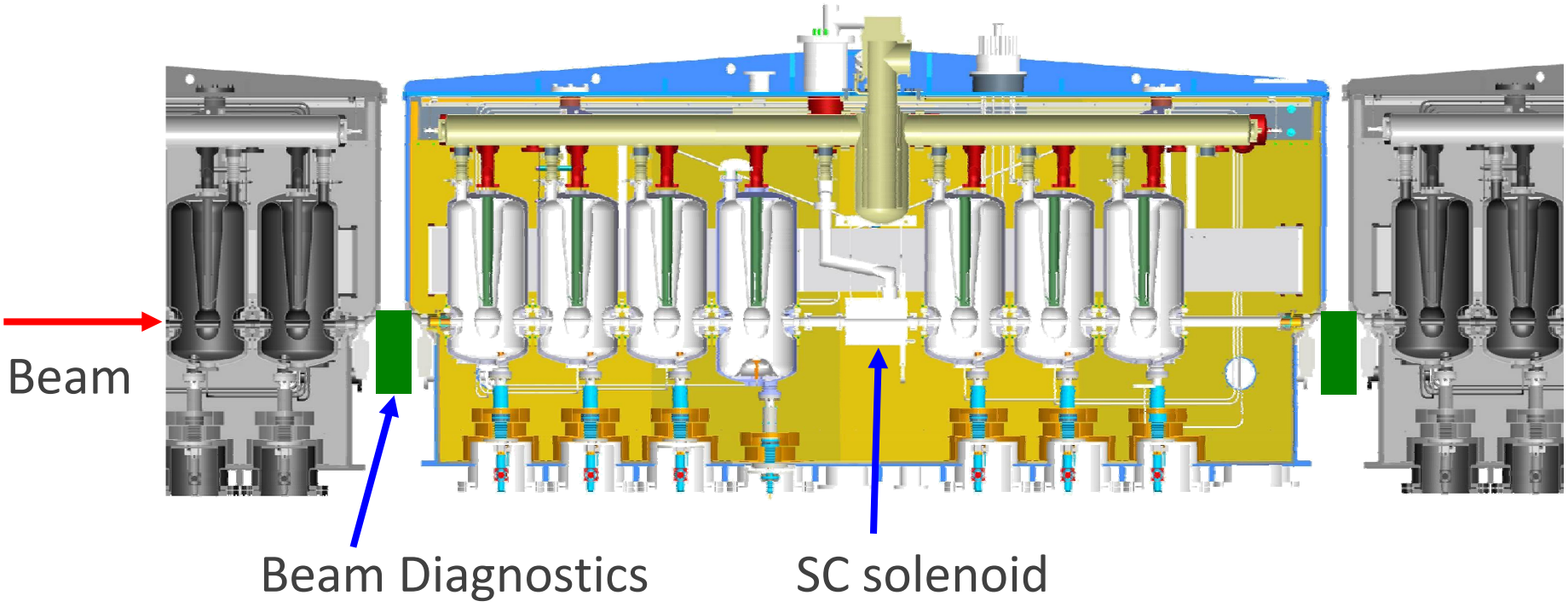
Niobium parts are being die formed in Industry (AES)

RF Couplers

- 4-kW coupler developed for the ATLAS upgrade, 1-5/8” coax
  - LN cooled cold window, adjustable -70 mm stroke
- Can be a base for higher power with increased coax diameter



Accelerator Lattice



- High packing factor
- Beam diagnostics box between the cryomodules

List of Initial Prototyping Work

- Define and fix operating frequencies
  - 704 MHz and its sub-harmonics are recommended
    - Original LANL proposal was 700 MHz and 350 MHz
    - All European Proton/Ion accelerators including ADS linac are being designed at 704 MHz and its sub-harmonics
- Optimize beam dynamics
- Develop prototypes of all SC cavities (4 types) with high power couplers
- Develop and build front end including CW RFQ, MEBT and the first 2 SC cryomodules
  - Demonstrate stable operation at 10 mA and deliver 250 kW beam

Conclusion

- Both SC and NC technologies are mature for immediate development and construction of 1 GeV/10 MW linac
- There are no technical issues on the accelerator side, thorough cost optimization should be performed
- Based on our recent completed and active project, the cost of the linac can be determined with high accuracy