High Intensity Proton Beams: Indian Perspective

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On behalf of IIFC (BARC, IUAC, RRCAT, VECC)

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Why High Intensity proton beams?

- Utilisation of Th in energy generation,
- Transmutation of Actinides,
- Medical isotope production,
- Medical proton/ion therapy,
- Spallation neutron source.

How?

Capacity and expertise building through IIFC and technology demonstration of warm accelerators.

Leverage the superconducting RF technology for higher energies.

Stage wise development of proton accelerators and their applications.

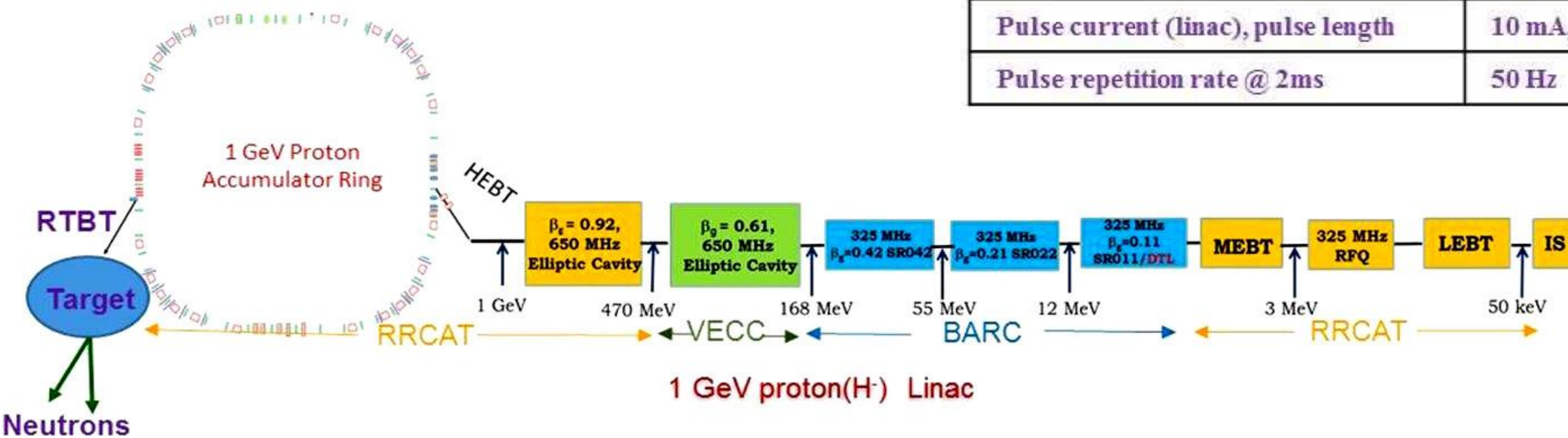
20 MeV – at BARC. Low Energy High Intensity Proton Accelerator (LEHIPA).

3 MeV/10 MeV - at RRCAT.

Final Goal – 1 GeV protons.

Proton Accelerator Programme in India

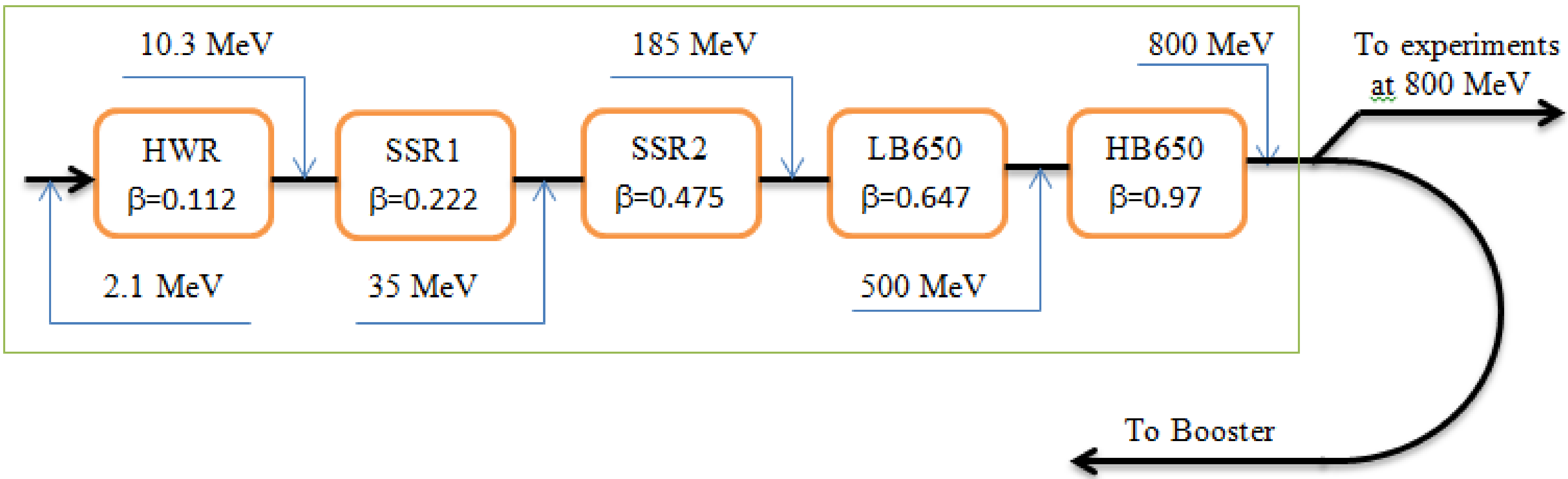
Parameter	Value
Proton beam power on target	1 MW
Proton beam kinetic energy on target	1 GeV
Pulse current (linac), pulse length	10 mA,
Pulse repetition rate @ 2ms	50 Hz



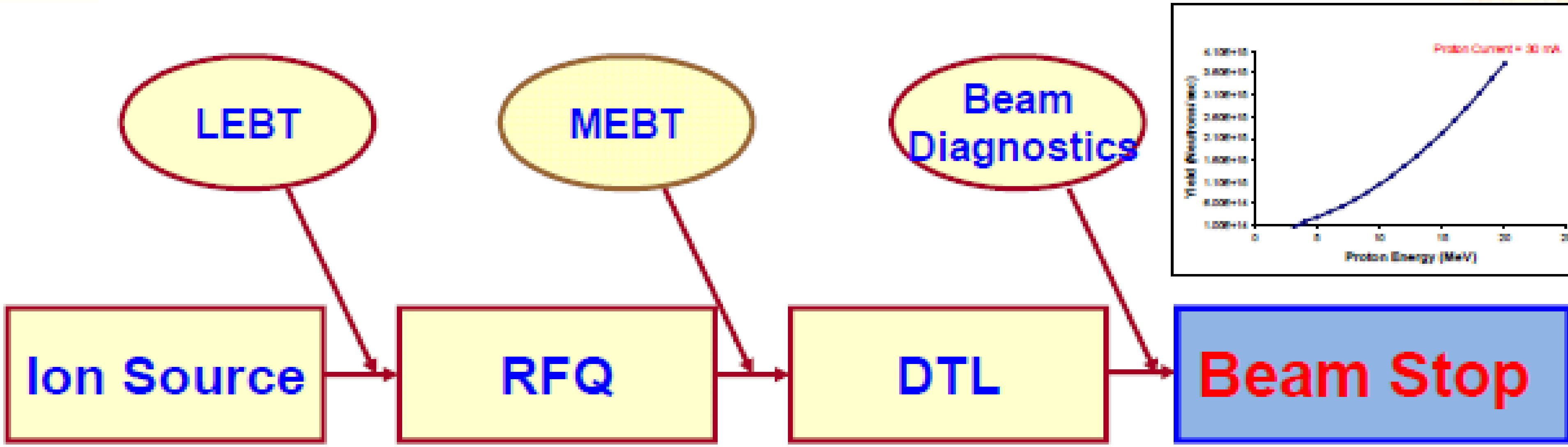
Possible applications of proton beam:

- 3 MeV proton beam for radiobiology experiments
- Depth dose curve measurements for proton beam at desired energy
- Proton therapy related experiments at 70-230 MeV
- Nuclear Physics experiments at 1GeV

Indian Institutions and Fermilab Collaboration
Proton Improvement Project (PIP-II)
(BARC, RRCAT, VECC, IUAC)



20 MeV High Intensity LINAC

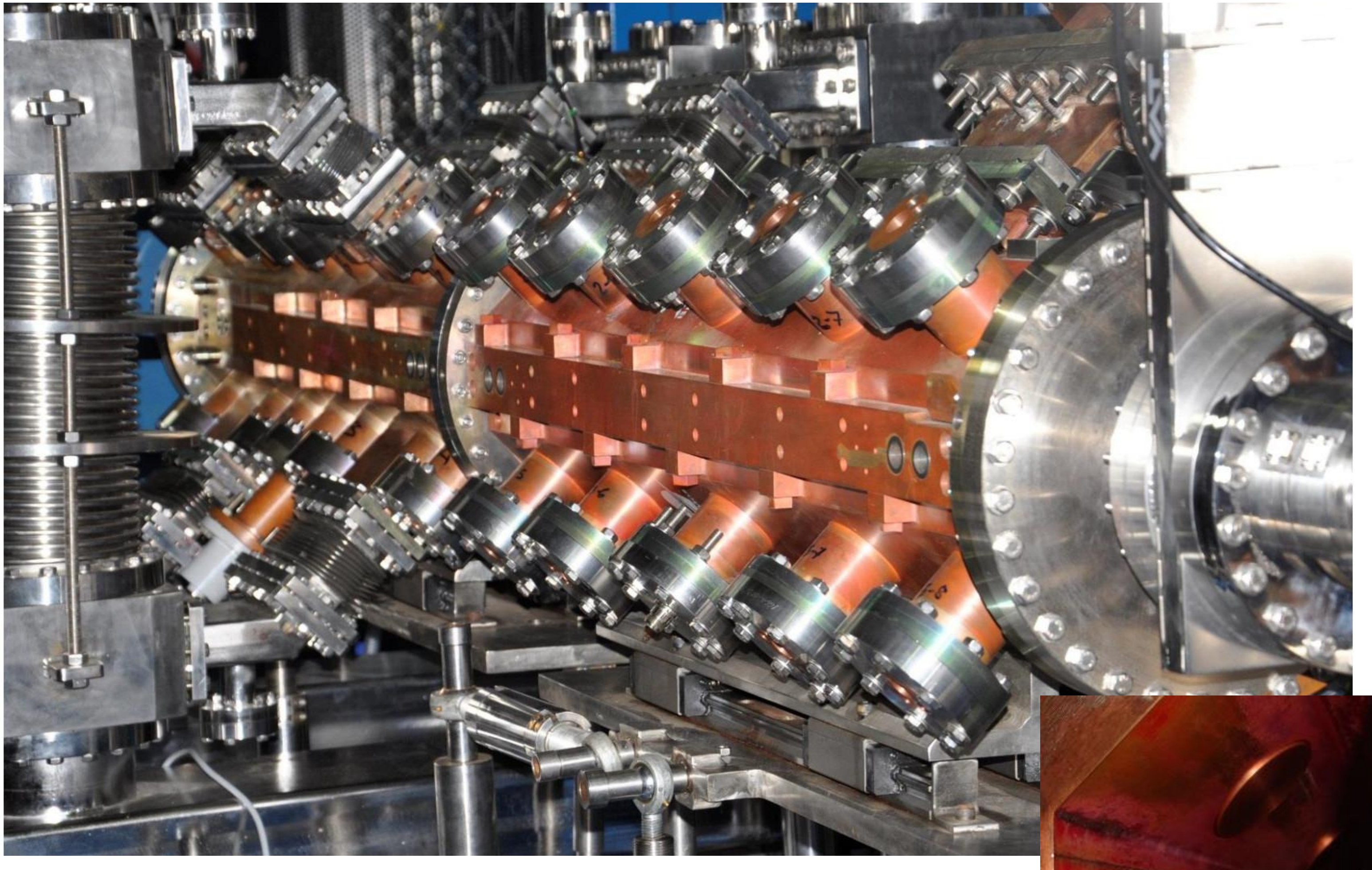


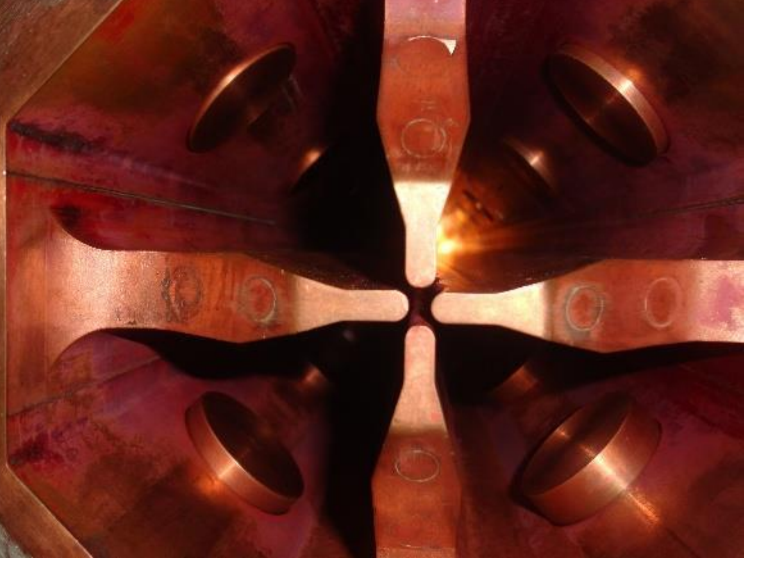
2.45 GHz ECR, 50 keV, 60 mA

352 MHz 4-vane RFQ, 3 MeV

352 MHz DTL, 4 Tanks, 20 MeV

Extracted 42 mA





RFQ-LEHIPA, BARC

2mA proton beam accelerated to
3 MeV with 65% transmission.

352.2 MHz Prototype Drift Tube Linac

Protons accelerated to 6.8 MeV through the first DTL tank.
Peak beam current of 2.5 mA,
Average beam current of 1 μA with 93% transmission.

325 MHz RF amplifier dev at BARC

1 kW Amplifier

- Power: 1 kW
- Overall Gain:> 65dB
- Efficiency : 61 %
- 2nd Harmonics:-41.5 dB

3 kW Amplifier

- Power: 3 kW
- Overall Gain: > 65 dB
- Efficiency : 65 %
- 2nd Harmonics: - 41.9dB

7 kW Amplifier

- Power: 7 kW
- Overall Gain: > 90 dB
- Efficiency : 68 %
- 2nd Harmonics: - 41.9 dB

20 kW Amplifier

1. Power: 19.8 kW (CW)
   : 20 kW (Pulse)
2. Efficiency: 62 %
3. Overall Gain: 89 dB
4. Harmonics , 40 dB

BARC Contributions to IIFC:

Accelerator Physics Design

RFQ

SSR2 Design

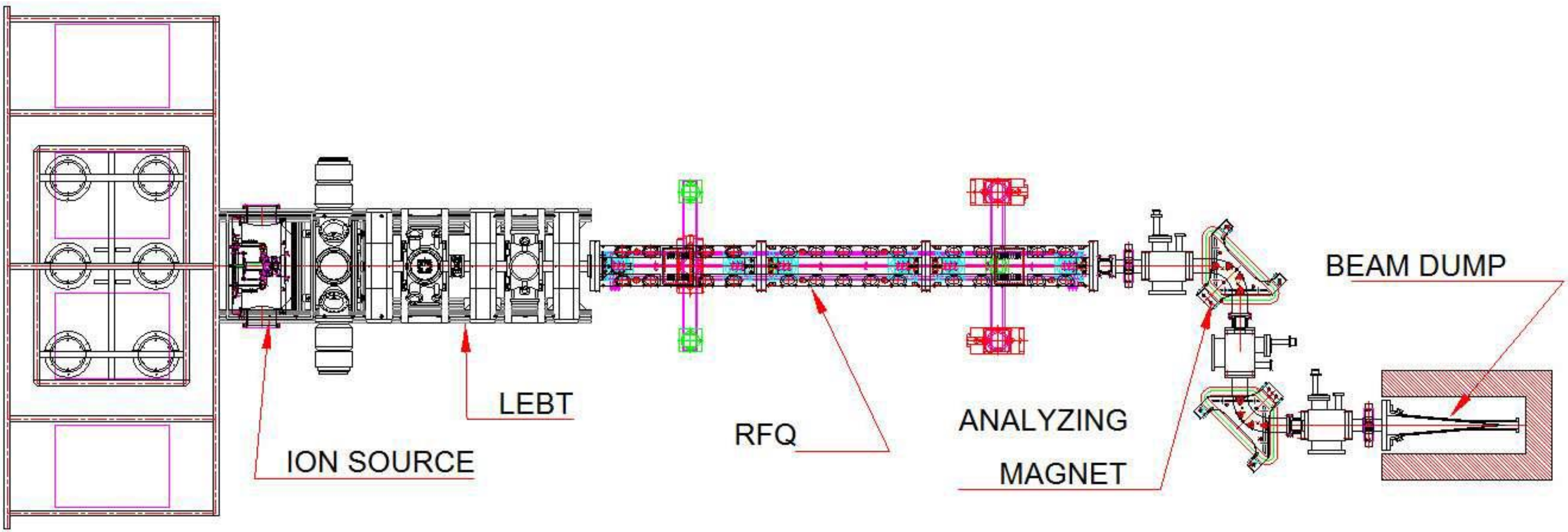
325 MHz RF Coupler

650 MHz RF Coupler

Beam dump

RF amplifier development.

Front End Test Stand (FETS), RRCAT

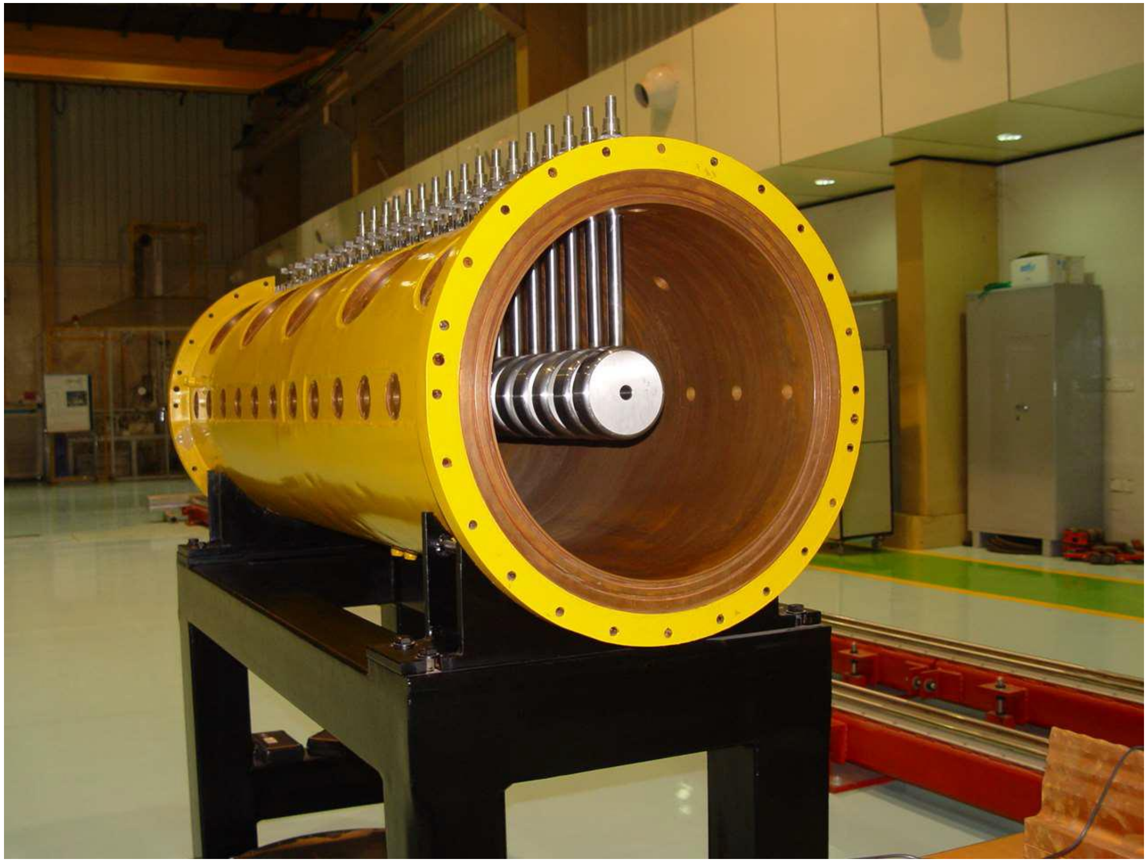


ECR Proton Source

10 mA CW proton beam current up to 35 keV beam energy.

Multi-cusp Arc based H- ion source

H- ion beam current 12 mA at 50 kV DC



352.2 MHz Prototype Drift Tube Linac

$0.03 < \beta$ (v/c) < 0.4 (~2 MeV up to ~ 100 MeV)

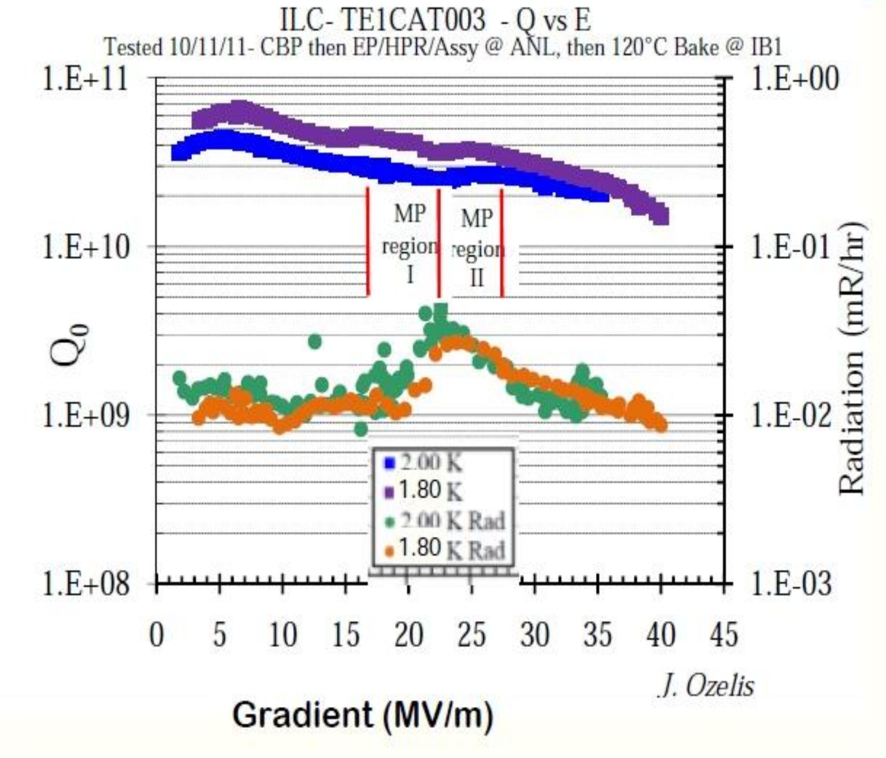
Development of 3Mev Radio Frequency Quadrupole, RRCAT

Superconducting RF Development

In early phase RRCAT started developing 1.3 GHz SCRF cavities in collaboration with Fermilab (2007-12), ILC design.

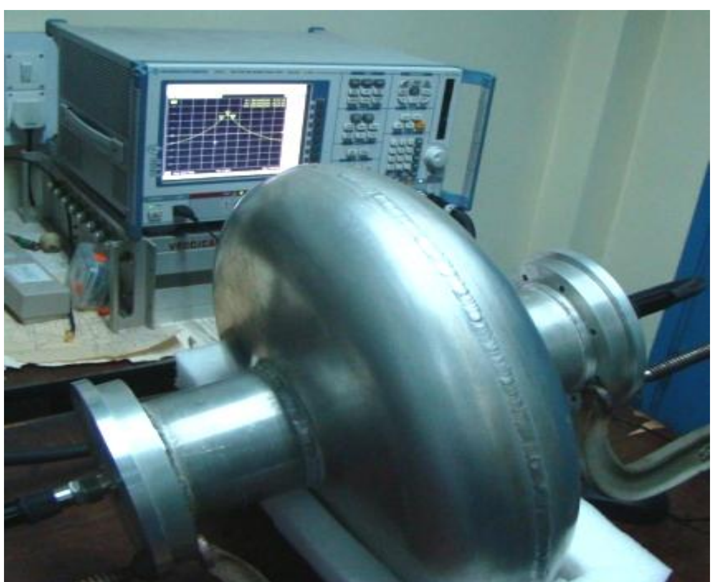
The cavity parts were machined at RRCAT and e-beam welded at IUAC.

Single Cell, 1.3 GHz

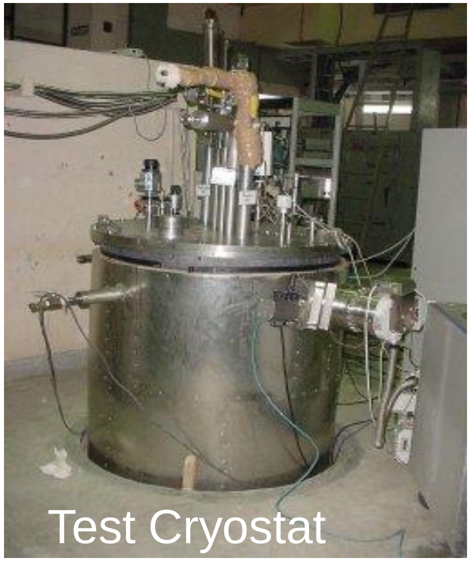


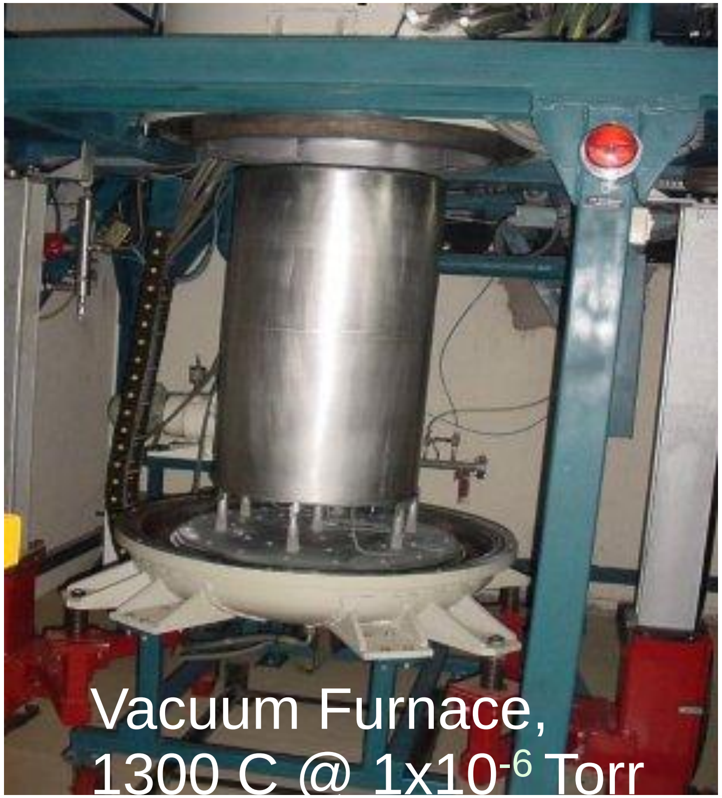
Spoke Cavity, 352 MHz, β = .22
IUAC-BARC

5-Cell 1.3 GHz cavity
RRCAT-IUAC



352 MHz, β = 0.61
single cell, VECC-IUAC





Resonator Fabrication Facility at IUAC

Under the Indian Institutions and Fermilab Collaboration (IIFC) in PIP-II, major infrastructure developed at RRCAT.

SCRF infrastructure:

- Clean rooms,
- VTS,
- HTS,
- RF test stands,
- cavity processing facilities (clean room, annealing, HPR),
- Cryogenics,
- vacuum test stands

Development of β = 0.90, 0.92 HB650 cavities and jacketing,

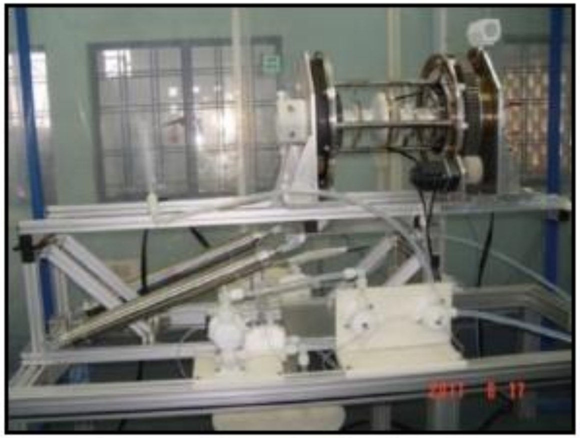
Development of Tuners for LB and HB cavities,

40kW Solid state amplifiers for HB 650 MHz cavities,

Infrastructure for SCRF Cavity Fabrication and Processing at RRCAT, Indore

Cavity forming facility

Centrifugal barrel polishing machine

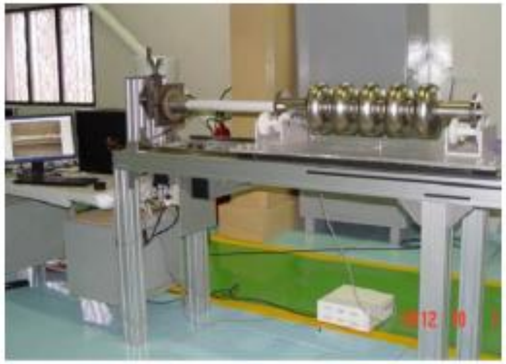


Electro-polishing setup

High pressure rinsing Set up

15 kW e-beam welding machine

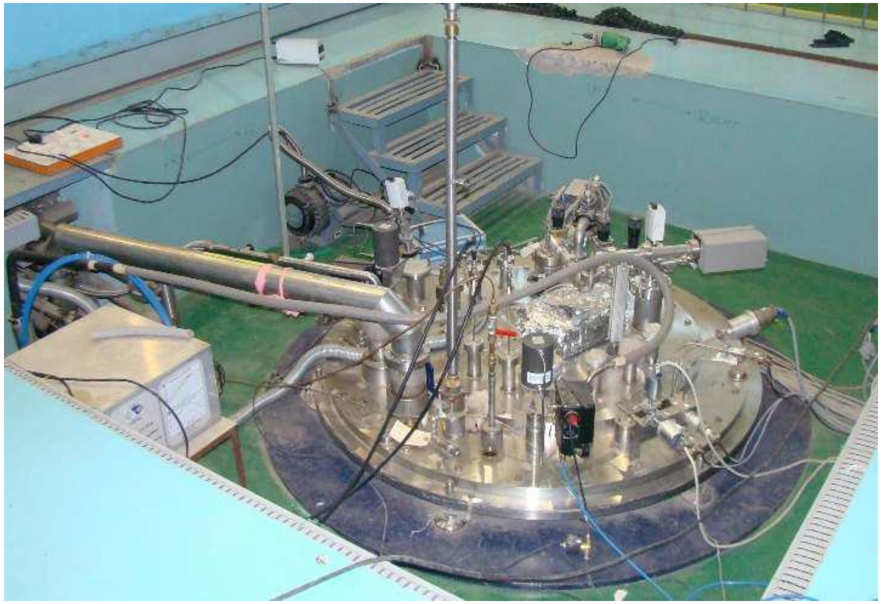
SIMS setup



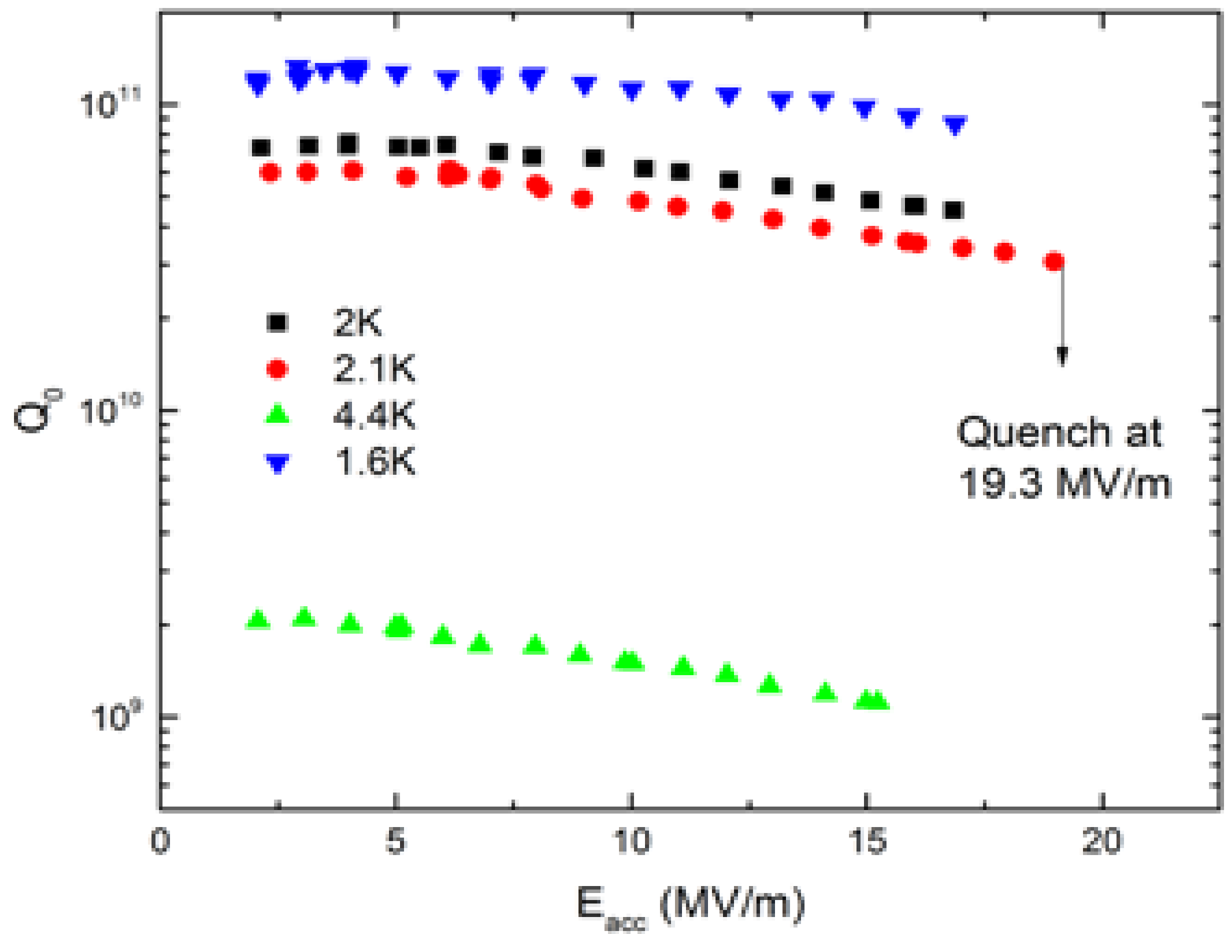
Optical bench setup

3D CMM

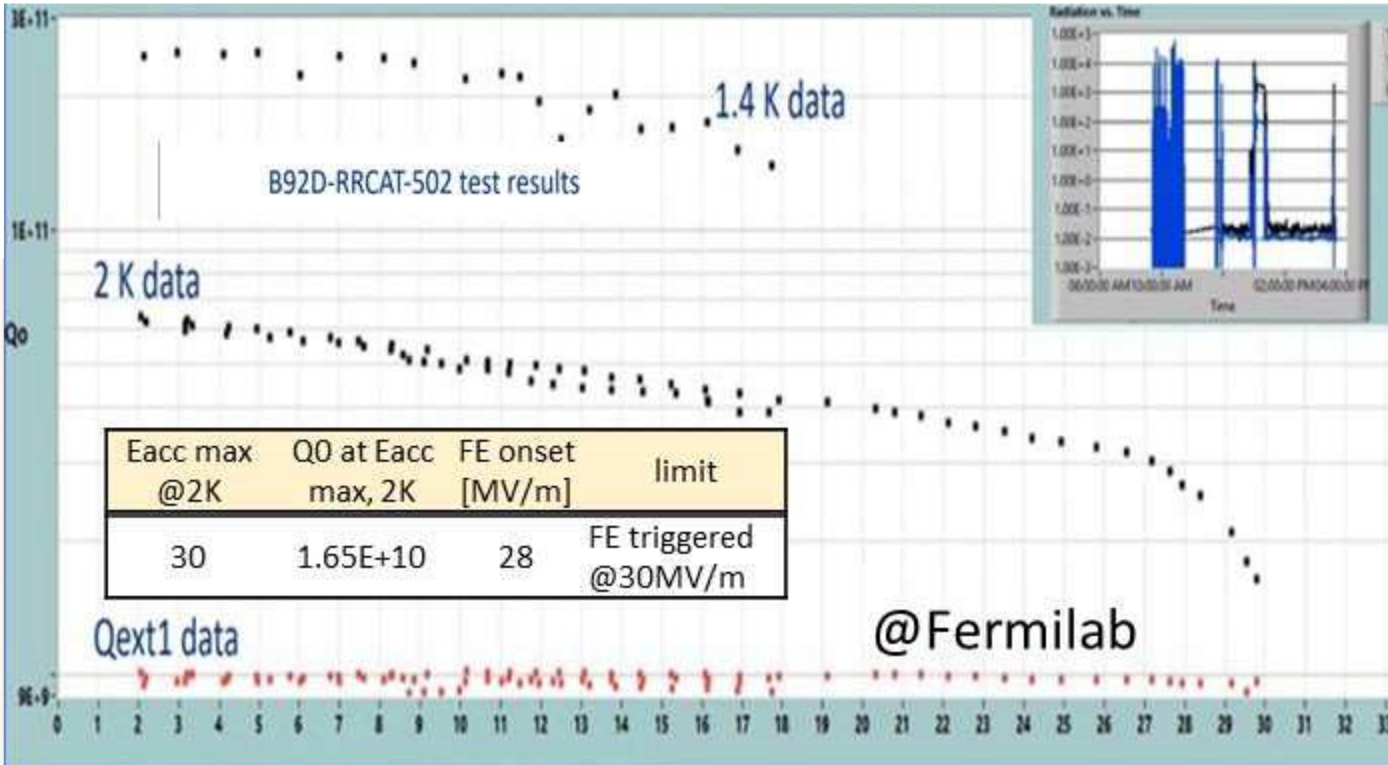
Vertical Test Stand



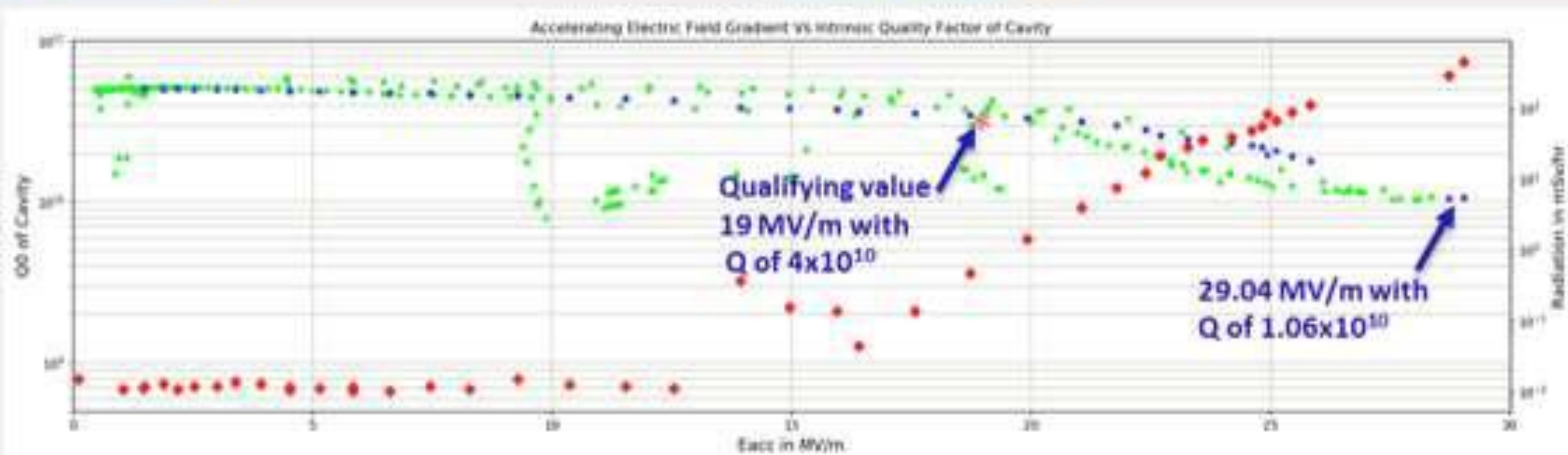
HTS with cavity



10^{11}
10^{10}
10^{9}
Q_0
0
5
10
15
20
E_{acc} (MV/m)
2K
2.1K
4.4K
1.6K
Quench at
19.3 MV/m



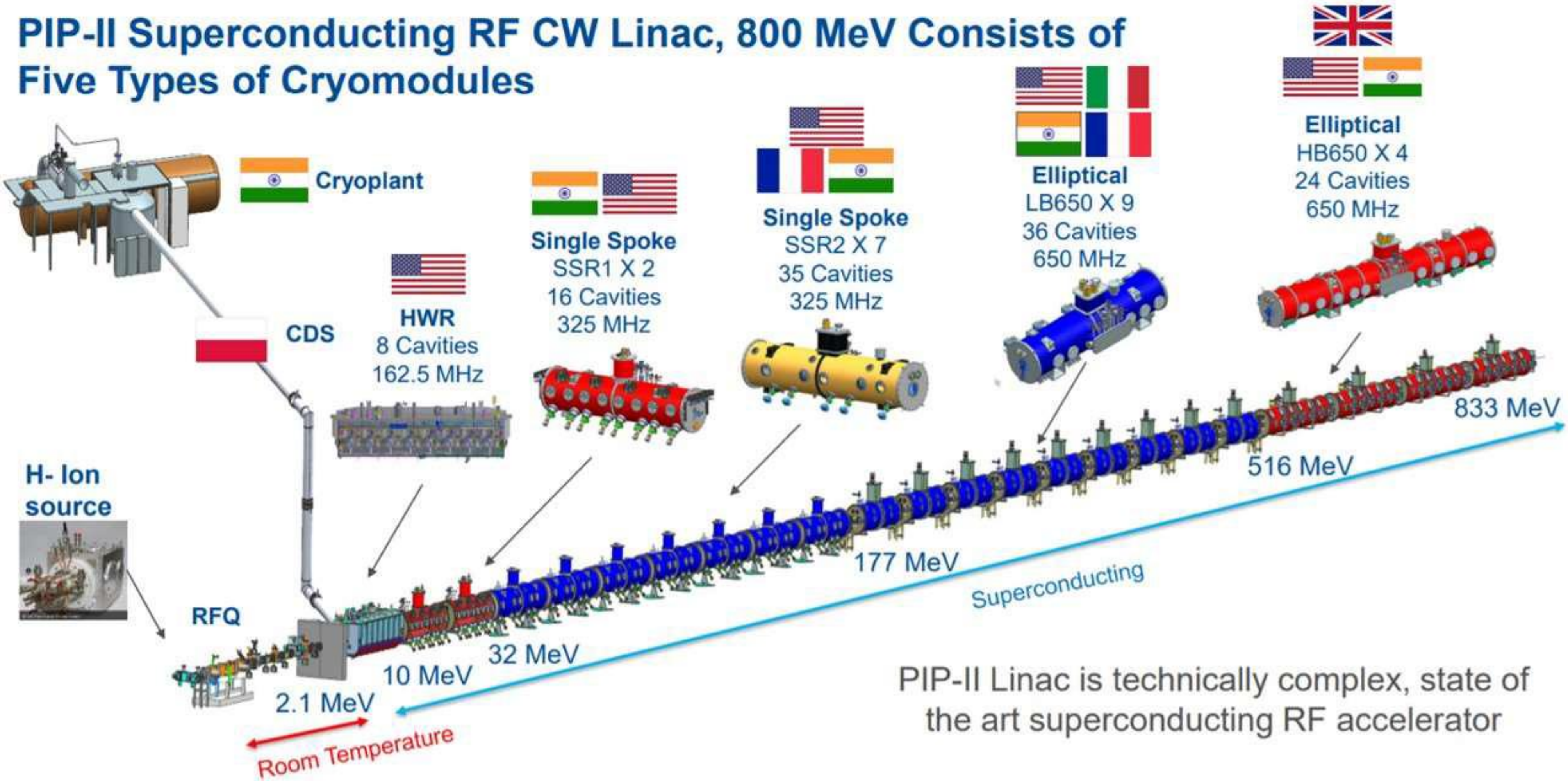
Eacc max @2K	Q0 at Eacc max, 2K	FE onset [MV/m]	limit
30	1.65E+10	28	FE triggered @30MV/m



32 kW/ 650 MHz RF amplifier testing at FNAL and results up to 32 kW

40 kW/ 650 MHz RF amplifier testing at FNAL and results up to 40 kW

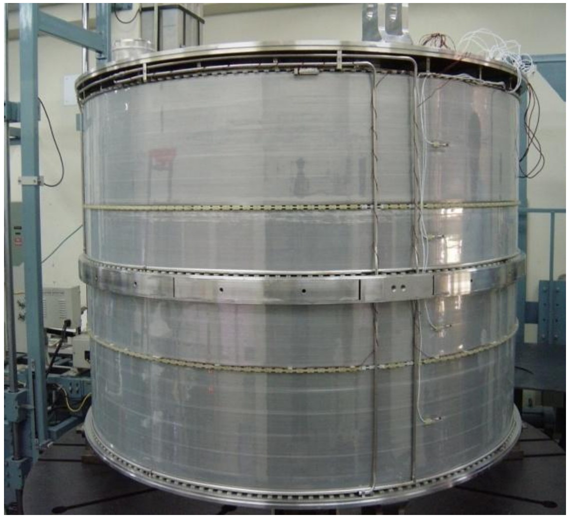
PIP-II Superconducting RF CW Linac, 800 MeV Consists of Five Types of Cryomodules



PIP-II Linac is technically complex, state of the art superconducting RF accelerator

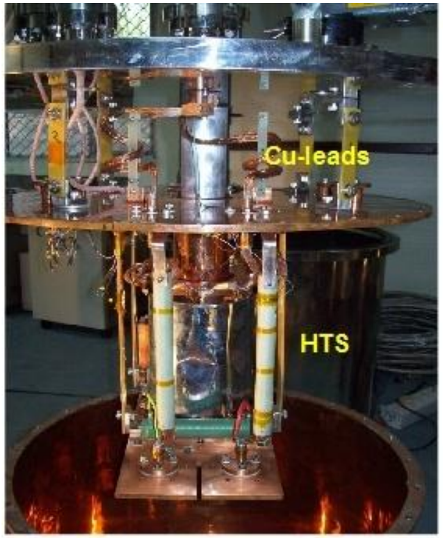
PIP-II is the world's highest energy and power CW proton linac, and the U.S. first accelerator project to be built with major international contributions

Magnet and He liquefier



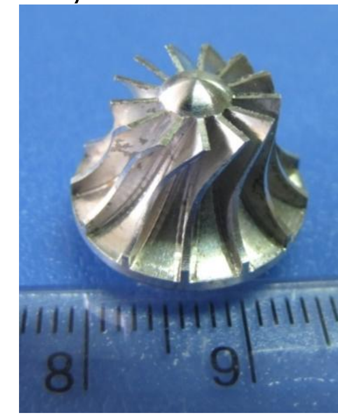
Superconducting Magnet coil winding facility, VECC

Magnet Assembly



Cryofree High T_c Superconducting Magnet, 6.2 T, IUAC

16 mm turbine
264,000 RPM



First indigenous helium liquefier,
RRCAT 20-50 l/hr

20K Helium Refrigerator Developed at BARC

Assembled turboexpanders

He Impurity Monitor,
IUAC

Compact Brazed Plate & Fin Heat Exchangers

SUMMARY

Recent progress in warm front end and SRF is presented

Significant progress in development and testing of ion sources, LEBT, RFQ and DTL, HB 650 MHz cavities.

1.3 GHz Cavities developed and qualified.

All the necessary SRF infrastructure along with Vertical Test Stands and Horizontal Test Stands created.

40kW, 650 MHz Solid State Amplifiers built and one delivered to Fermilab.

Thank You