# A Glimpse into Development of the Heavy-Ion Superconducting LINAC Booster at TIFR

4th Professor Manoj Kumar Pal Memorial Lecture, SINP-AA

*R. G. Pillay,*

*retired Senior Professor, TIFR & ex-Visiting Professor, IIT Ropar.*

# Introduction

# Brief history of accelerators

**1919** **Rutherford** gets the first nuclear reactions using natural alpha rays (from radio activity) of few MeV.
*« He notes already that he will need many MeV to study the atomic nucleus »*

**1932** **Cockcroft & Walton** build a 700 KV electrostatic generator and break Lithium nucleus with 400 KeV protons.
*(Nobel Price in 1951)*

**1924** **Ising** proposes the acceleration using a variable electric field between drift tubes (the father of the LINAC).

**1928** **Wideroe** uses **Ising** principle with an RF generator, 1MHz, 25 kV and accelerate potassium ions up to 50 keV.

**1929** **Lawrence** driven by **Wideroe** & **Ising** ideas invents the cyclotron.
**Van de-Graff** demonstrates 80kV high voltage generator, using charging belts.

**1931** **Livingston** demonstrates the cyclotron principle by accelerating hydrogen ions up to 80 KeV.

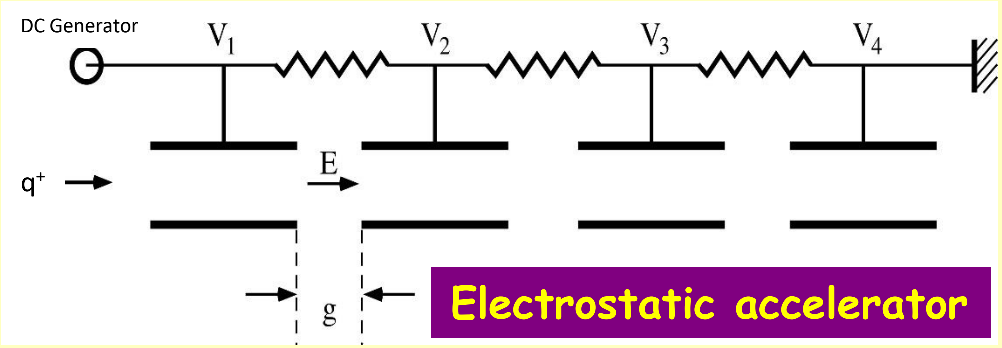
# Methods of Acceleration of a Charged Particle

## Force = charge x Electric Field

### 1_ Electrostatic Field

Energy gain : $W = n.e(V_1 - V_4)$

limitation : $V_{generator} = \Sigma V_i$



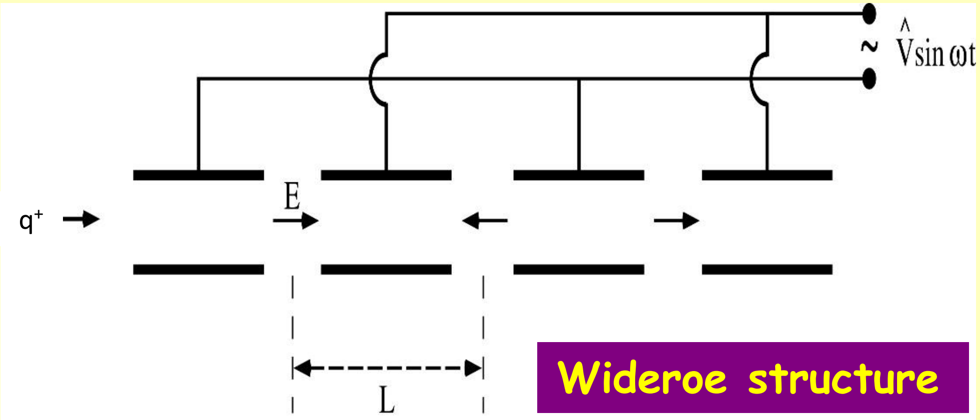

### 2_ Radio-frequency Field

Synchronism : ➡ **L=vT/2**

v=particle velocity

T= RF period

alternatively $L = v\frac{T}{2} = \beta\frac{\lambda_0}{2}$

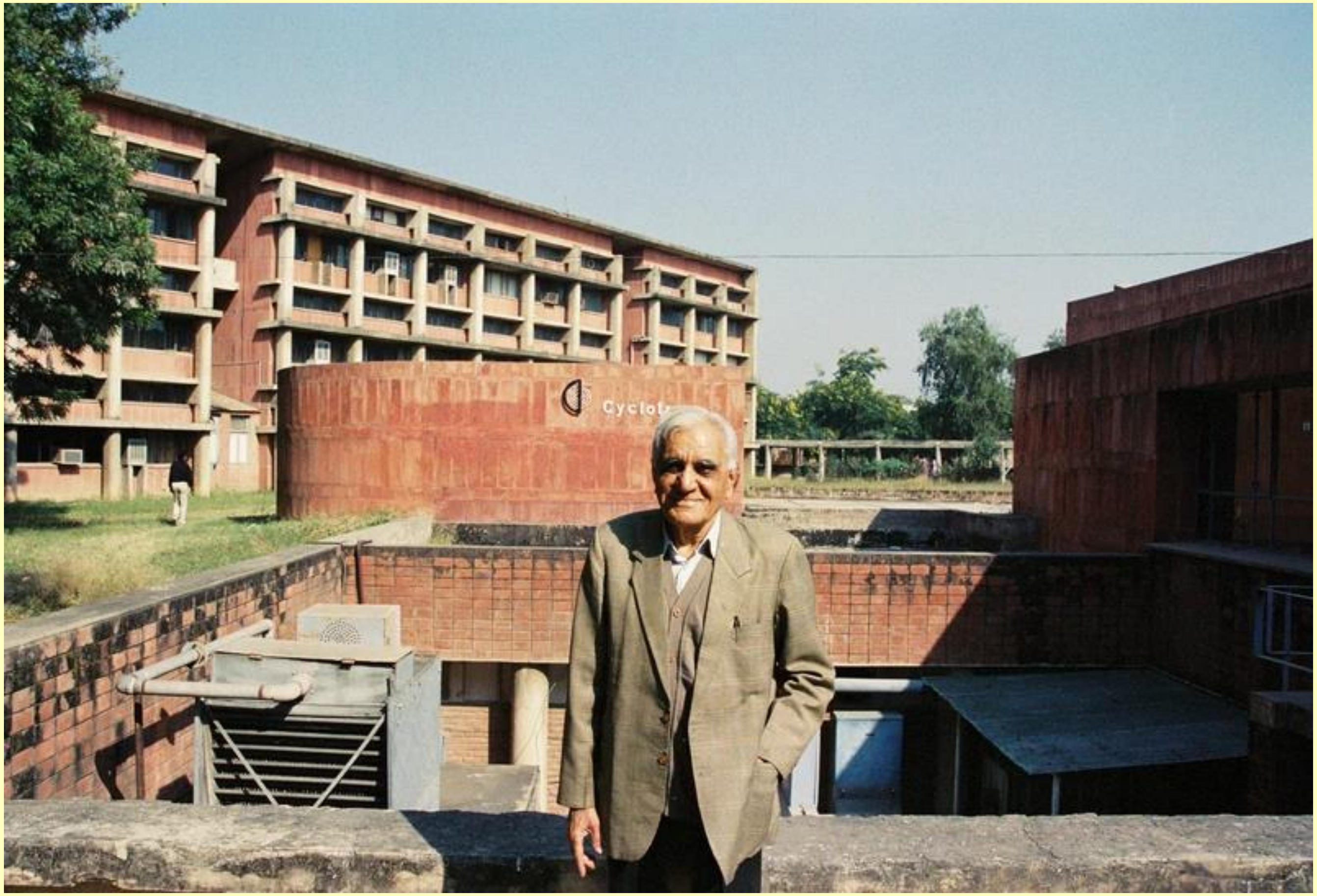


# Early Accelerators in India

# Cyclotron at SINP

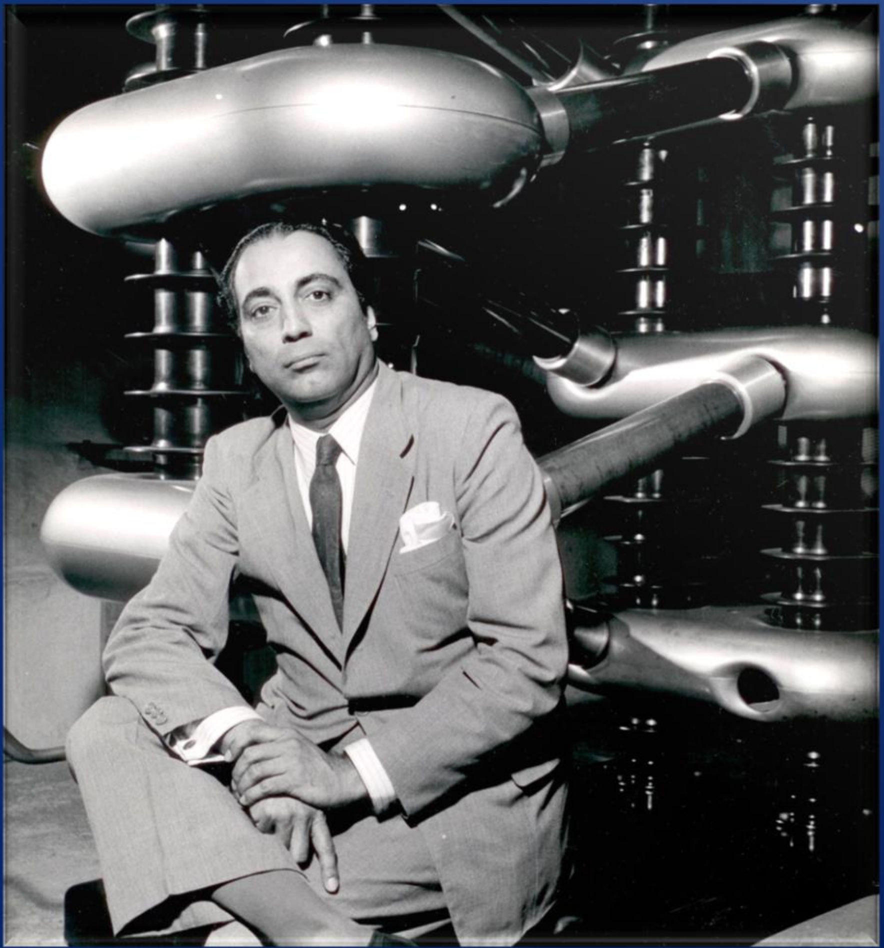
**Professor Meghnad Saha**
**Cyclotron from Lawrence Berkeley Lab**
**Support systems rebuilt at SINP**

# Cyclotron at PU

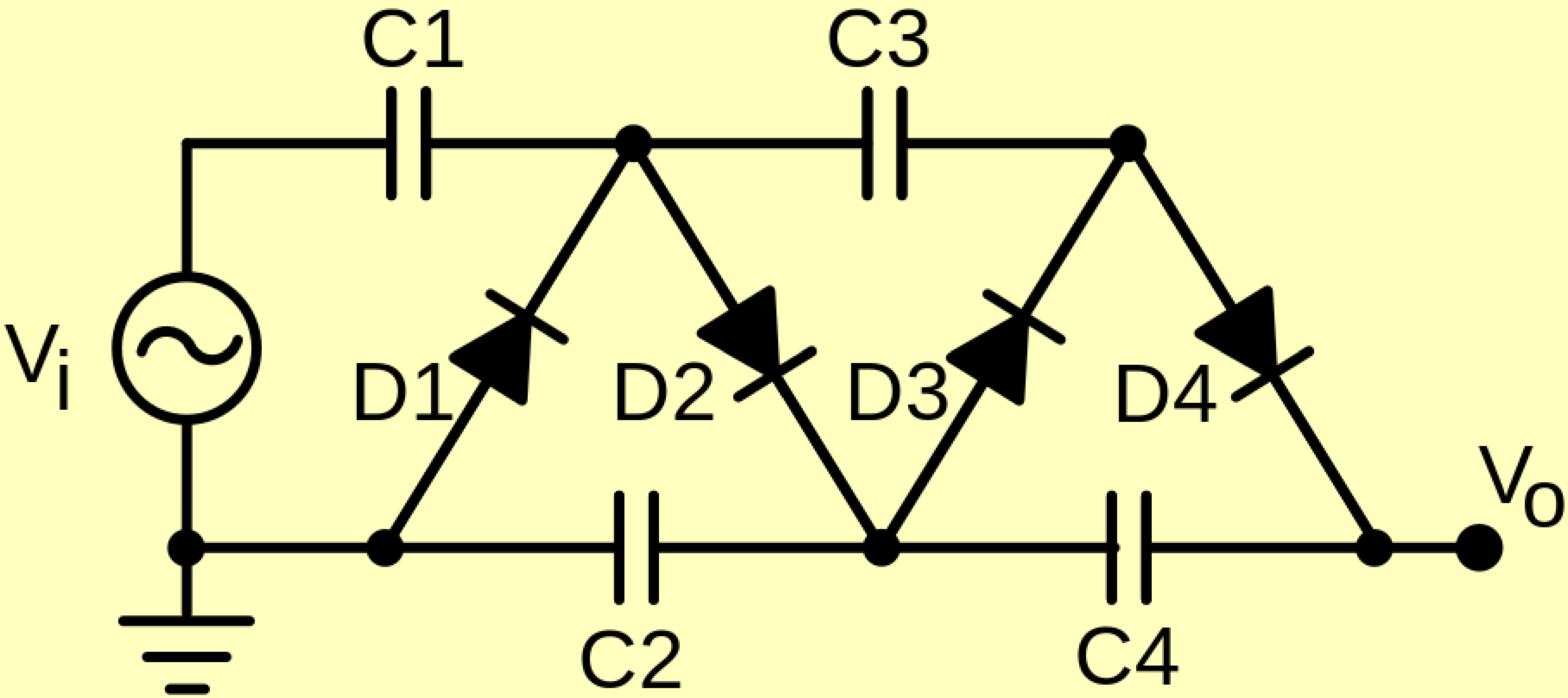


**Professor Harnam Singh Hans**
**Cyclotron from University of Rochester, New York**
**Support systems rebuilt at PU**

# 1MV Cascade Generator at TIFR 1953-54



# Cockcroft-Walton Voltage Multiplier Stack
## first truly-high Voltage technology




**1932** **Cockcroft & Walton** build a 700 KV electrostatic generator and break Lithium nucleus with 400 KeV protons.
***(Nobel Price in 1951)***

# 1MV Cascade Generator at TIFR 1953-54

**Homi Bhabha (Director TIFR & Chairman AEC):**

- Accelerate 1 MeV protons to be used as a neutron generator (p + Li or p + Be reactions).
- Tall & thick cascade Hall (~1 m radiation shielding).
- Accelerator installed and operational, well before rest of campus was ready and inaugurated.

**Part of a Grand Vision:**

- Setup the Variable Energy Cyclotron (project started in late 60’s & early 70’s).
- Setup the Heavy-ion Accelerator (project started in late 70’s & early 80’s).

# e-LINAC development at TIFR

## Special Microwave Products Unit (setup in 70's)


**mid 80's: moved as SAMEER to Department of Electronics, main campus inside IIT Mumbai.**

**Built generations of 3 to 6 MeV and dual energy 6/9 MeV e-LINACS for radiotherapy & radiography.**

**Industrial e-LINAC at VSSC Trivandrum (in 90s) & Medical e-LINAC at PGI Chandigarh.**

# Pelletron

# Medium Energy Heavy Ion Accelerator
# MEHIA Project

## 14 MV Pelletron + SC-Booster (Indigenous Development)

*Prof. R. P. Sharma*

*Prof. H.G. Devare*

*Dr. M.K. Mehta*

*Prof. S.K. Mitra*

*Prof. C.V.K. Baba*

*Dr. S.S. Kapoor*

**Technological breakthrough in High Voltage generation by Prof. Raymond G. Herb, U. Wisconsin, Madison, USA.**

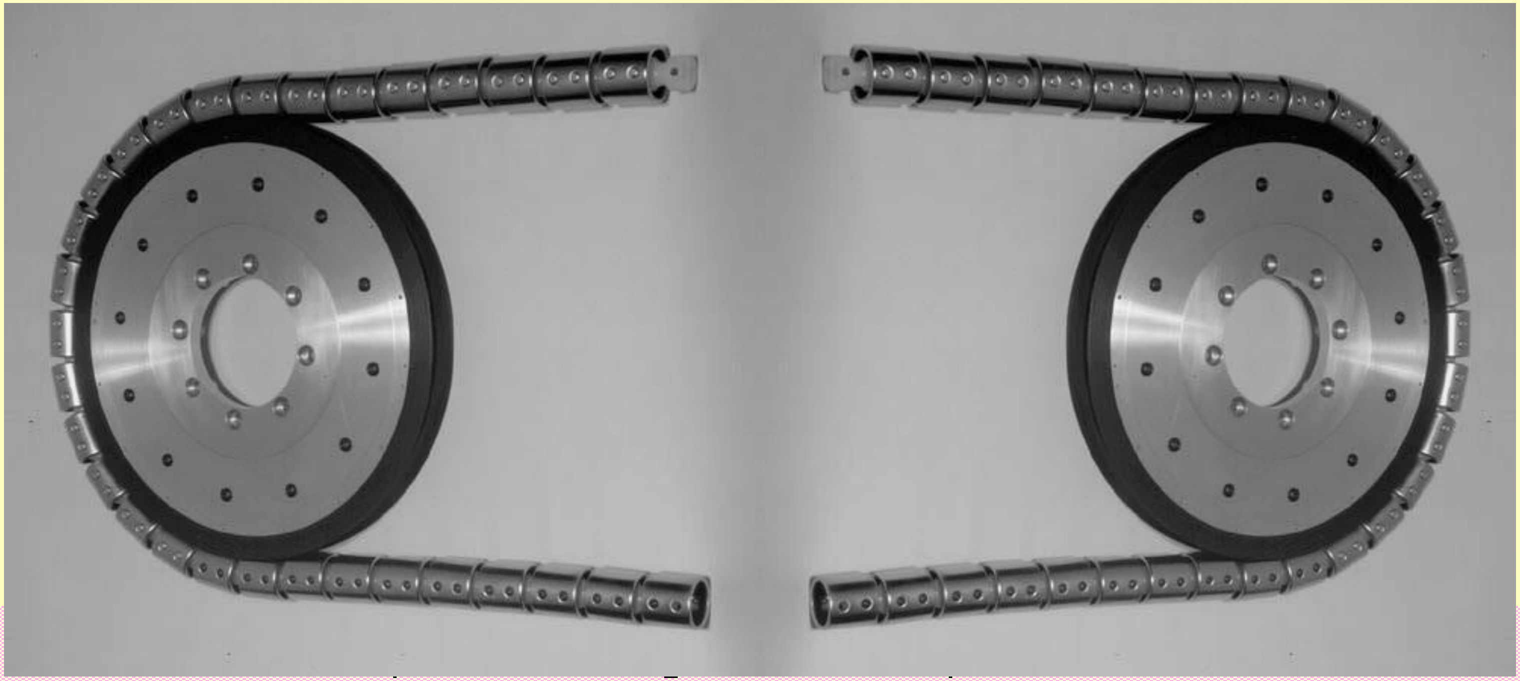
**Replaced rubber charging belt in the Van DeGraff design, by a chain of metal beads on a nylon string.**

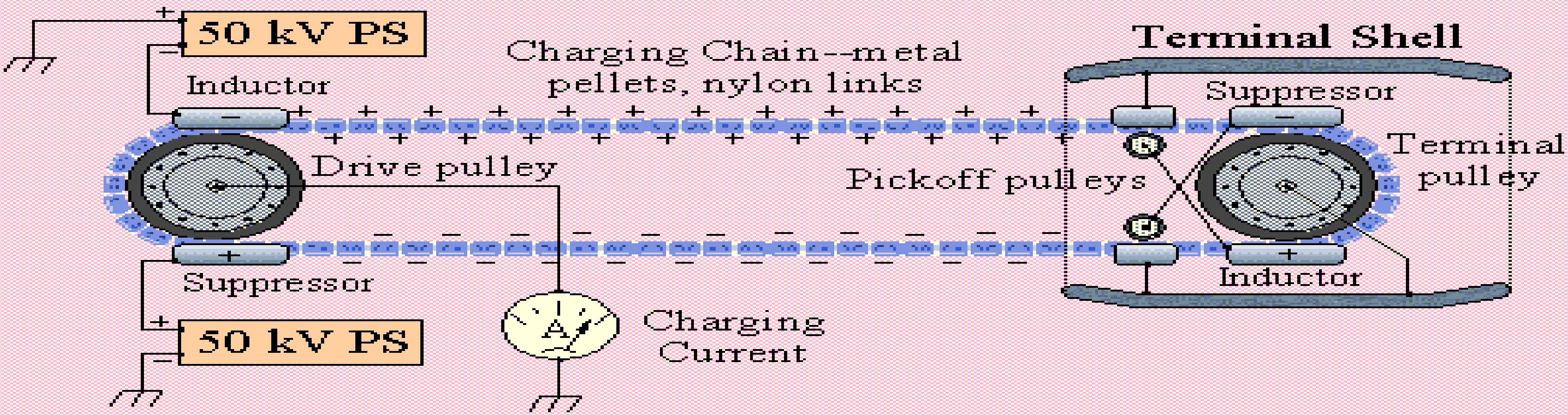
**>10 MV became feasible with very high currents.**

**Pelletron optimum design was ~14 MV.**

**Pelletron project approved and commenced in late 70’s early 80’s.**

# Pelletron Charging Principle






# Next Generation Van DeGraff Generator


Negative Ion Source

Beams
H, He, Li, …, C, O, F, …,
Ti, Fe, Ni, …, Ag, Sn, I

Accelerating Tank

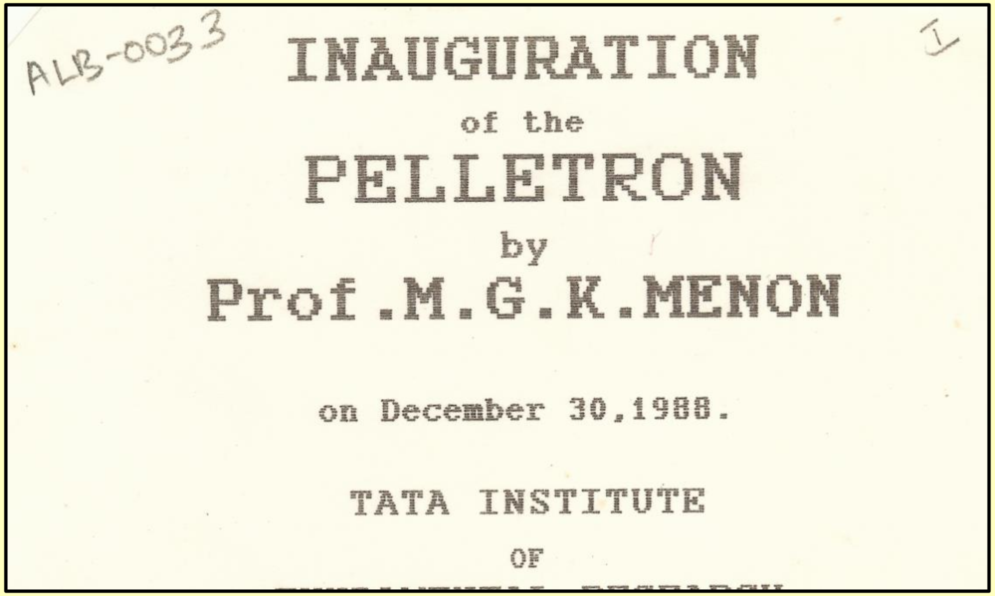
-

Stripper foil

+

Bending Magnets

Superconducting LINAC



ALB-0033

I

# INAUGURATION

of the

# PELLETRON

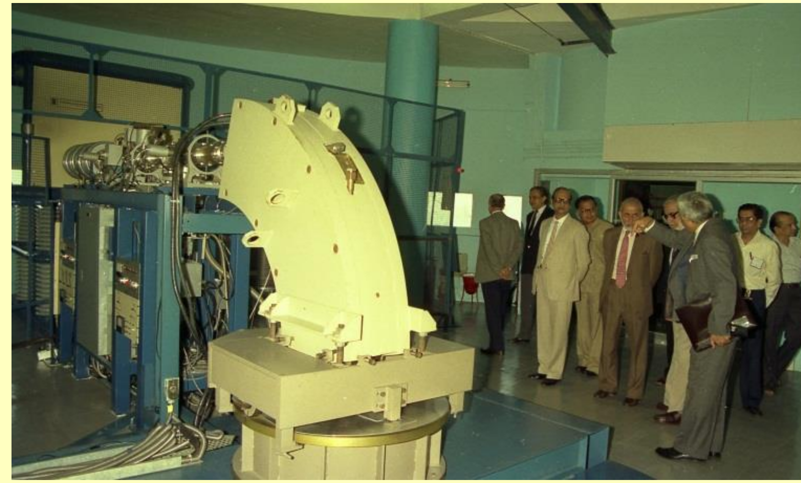
by

## Prof.M.G.K.MENON

on December 30,1988.

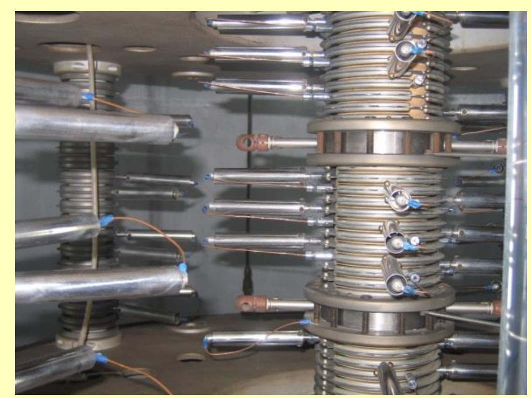
TATA INSTITUTE

OF



# *Pelletron (operational since Dec'88)*

**1 MV Sections**
**New Accelerator Tubes**
**Divider Resistor Chain**



**14 MV Tandem Accelerator**
**6-7 Atm. of $SF_6$ in Tank**

# Super Conducting LINAC Booster

# Super Conducting Heavy Ion Booster

**Prof. H.G. Devare, Prof. R.P. Sharma**

(TIFR)

**Dr. V.S. Ramamurthy, Dr. S.S. Kapoor**

(BARC)

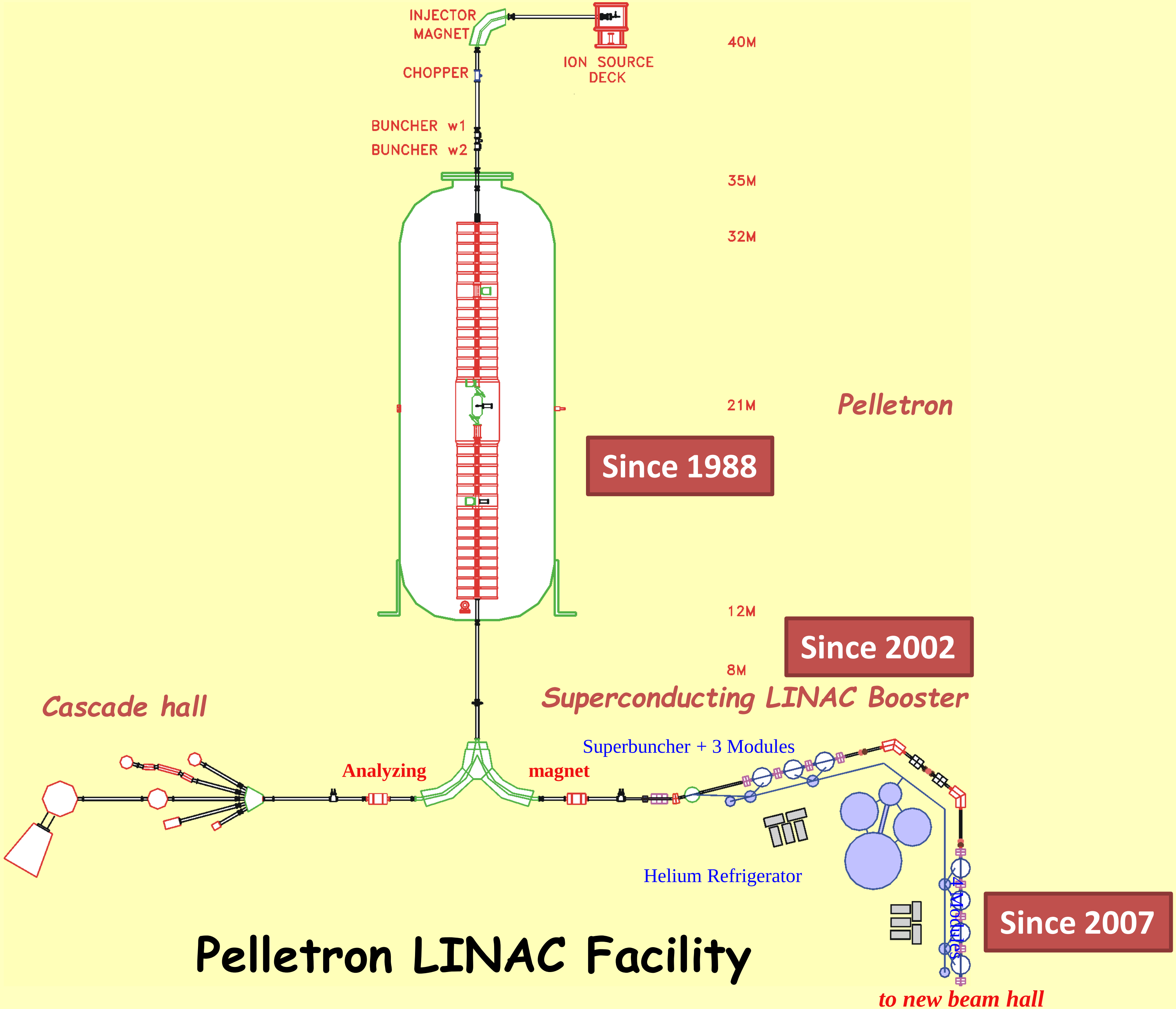
**TIFR**

**(late) M.B. Kurup, R.G. Pillay**
**Maneesh Pandey (M.Tech-Cryogenics) / …**
**Lalit V. Kamble (Lab Assistant) & …**
**Electronics & Mechanical Eng. (Scientific Assistants) & …**
**DNAP, CWK, TSR**

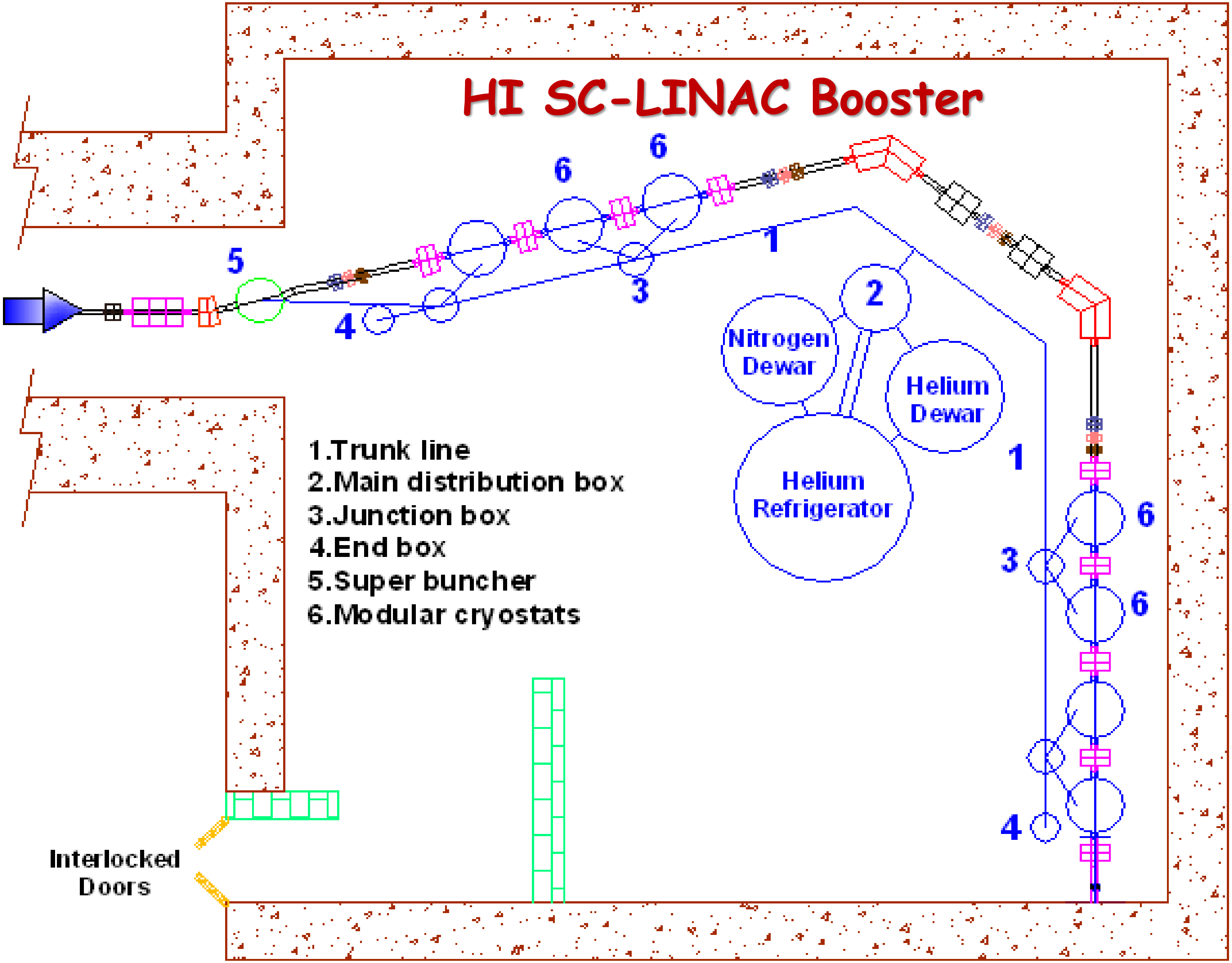
**BARC**

**B. Srinivasan (NPD), Sudheer Singh (NPD), Gopal Joshi (ED)**
**Pramod V. Bhagwat (Pelletron-NPD), NPD, ED, TPD, CWK**

# Pelletron LINAC Facility



# HI SC-LINAC Booster




1.Trunk line
2.Main distribution box
3.Junction box
4.End box
5.Super buncher
6.Modular cryostats

# Phase Angle Synchronization

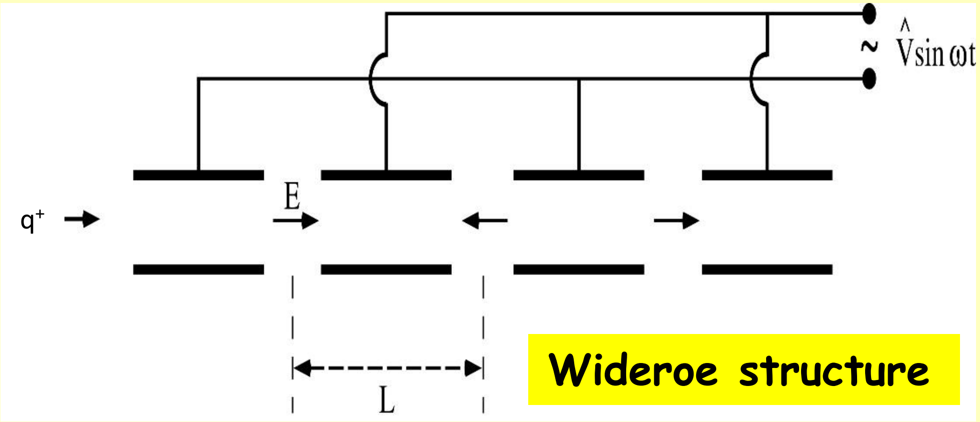
Radio-frequency Field

Synchronisation → L=vT/2

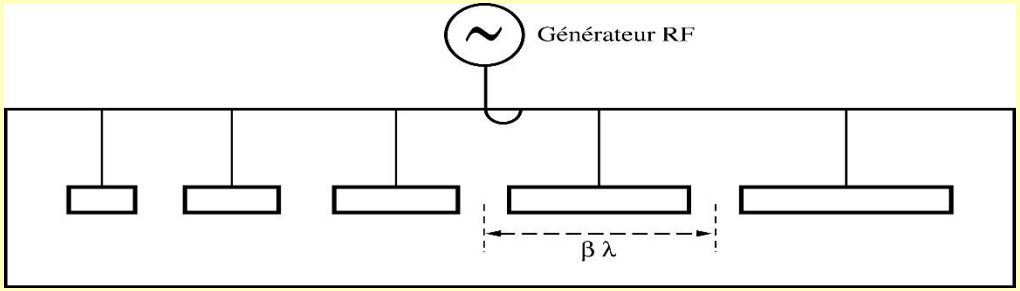
v=particle velocity

T= RF period

$$L = v\frac{T}{2} = \beta\frac{\lambda_0}{2}$$




**Beam Bunches Surf Riding**

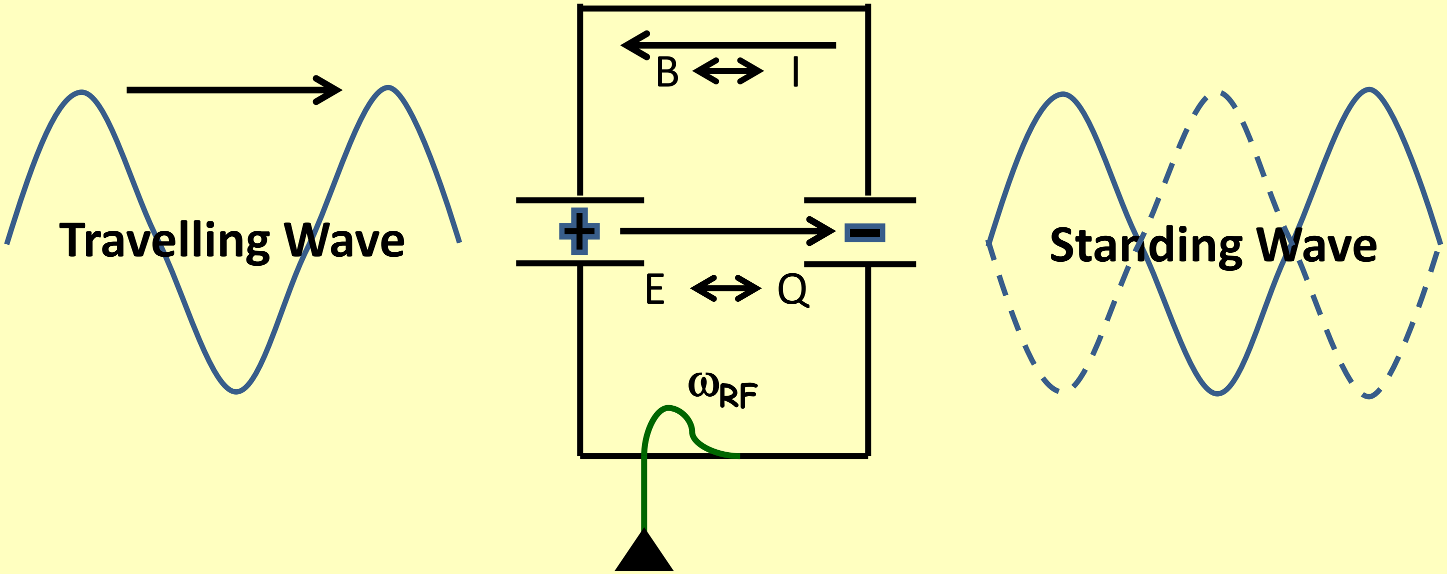



**π Mode L = β λ / 2**

**ALVAREZ structure, ions with specific m/q**

# Resonant Cavities

## Trap Electromagnetic Wave inside an enclosed Volume




The electromagnetic wave is constrained in the cavity

Sequence of such independent cavities make an accelerator

Losses due to resistive heating can be minimised by making the walls superconducting

# Advantage of Superconductivity in Accelerators

**Quality factor ; Q** $= \omega\,\tau\,(= \frac{f}{\Delta f})$

Swing (Q~10), Guitar String (Q~100)

**QWR ; f = 150 MHz ; V(acceleration) ~ 0.5 MV/q**

Q(Cu, 300K) ~$10^4$; P ~ 50 kW

Q(Pb, 4.2K) ~$10^8$; P ~ 5.0 W

Q(Nb, 7.2K) ~$10^9$; P ~ 0.5 W

**Cost of cooling** 4.2K:300K ~ 1 : 500-1000

**Superconducting LINAC smaller & efficient**

# RF Superconductivity

| | |
|---|---|
| Room Temperature | 300°K |
| Liquid Nitrogen | 77°K |
| Liquid Hydrogen | 20°K |
| Liquid Helium | 4°K |

Superconductors (Pb 7.2K, Nb 9.2K)

Surface Resistance $R_S$ = 0 (DC)

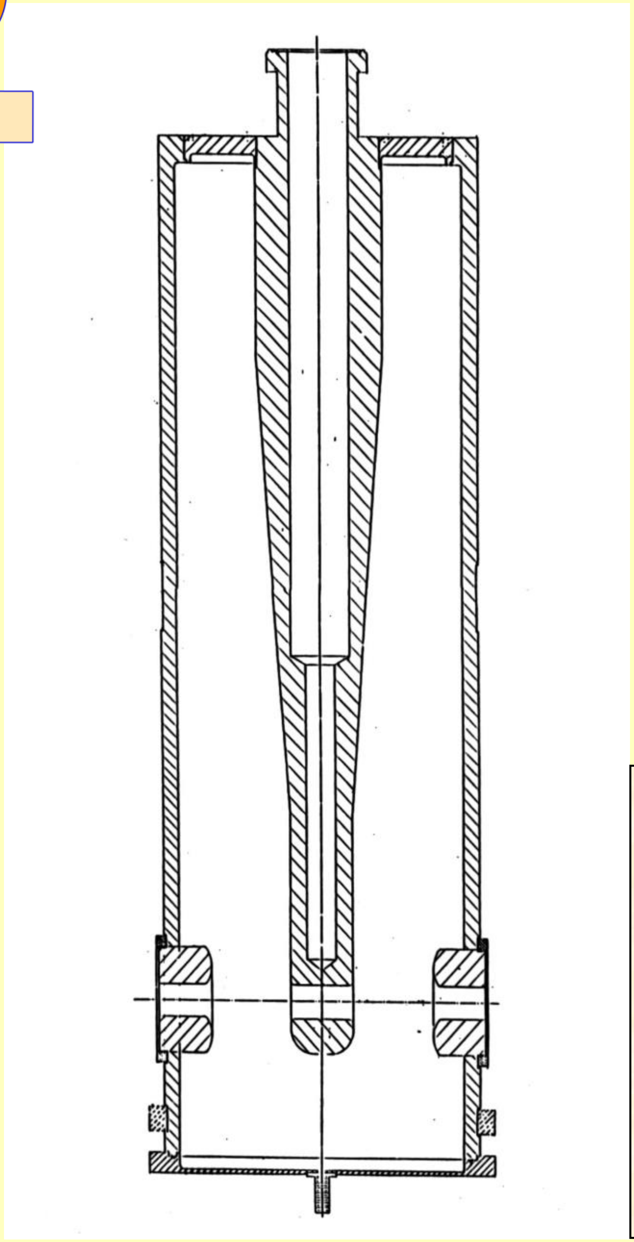
$R_S$ (Nb @4.2K) ~ 10 nΩ (RF)

$R_S$ (Cu @300K) ~ 10 mΩ (RF)

# Development Activities
# Engineering & Technology

# Cavities

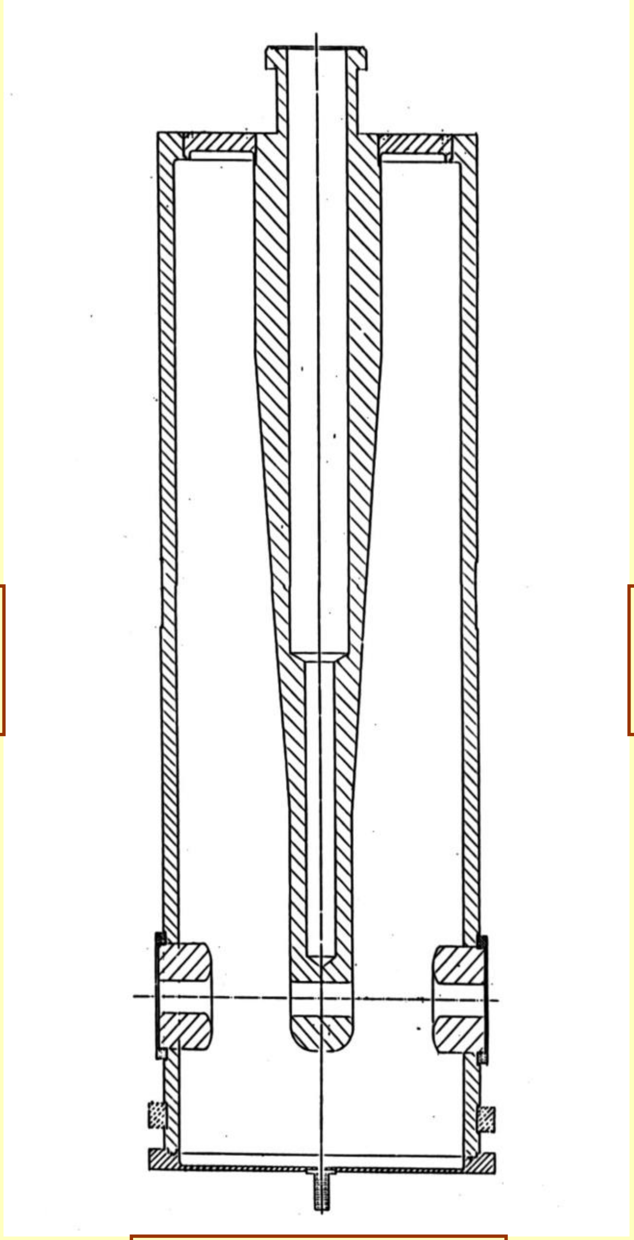
- Accelerating Cavities (TIFR, NPD, CDM, Aarti Eng., SAMEER),
- Pb Plating (TIFR, NPD),
- Repair manufacturing faults in Cavity (TIFR),
- Cavity accessories: RF couplers, fine tuners (TIFR, CWK).



*Quarter Wave Resonators*

| | |
|---|---|
| Material | Oxygen-free high conductivity Cu |
| Superconducting surface | 2 μm thick Pb |
| Frequency | 150 MHz |
| Optimum velocity | 0.1c |
| Acceleration voltage | 0.5 Million Volts @ 6 Watts |

QWR designed at Univ. of NY, Stony Brook



Side Beam Ports
Brazing

Frequency matching
Pb Plating

Weld Repairs

# Module


***7 Modules***

***28 Resonators***

***Design Energy gain 14MV/q***

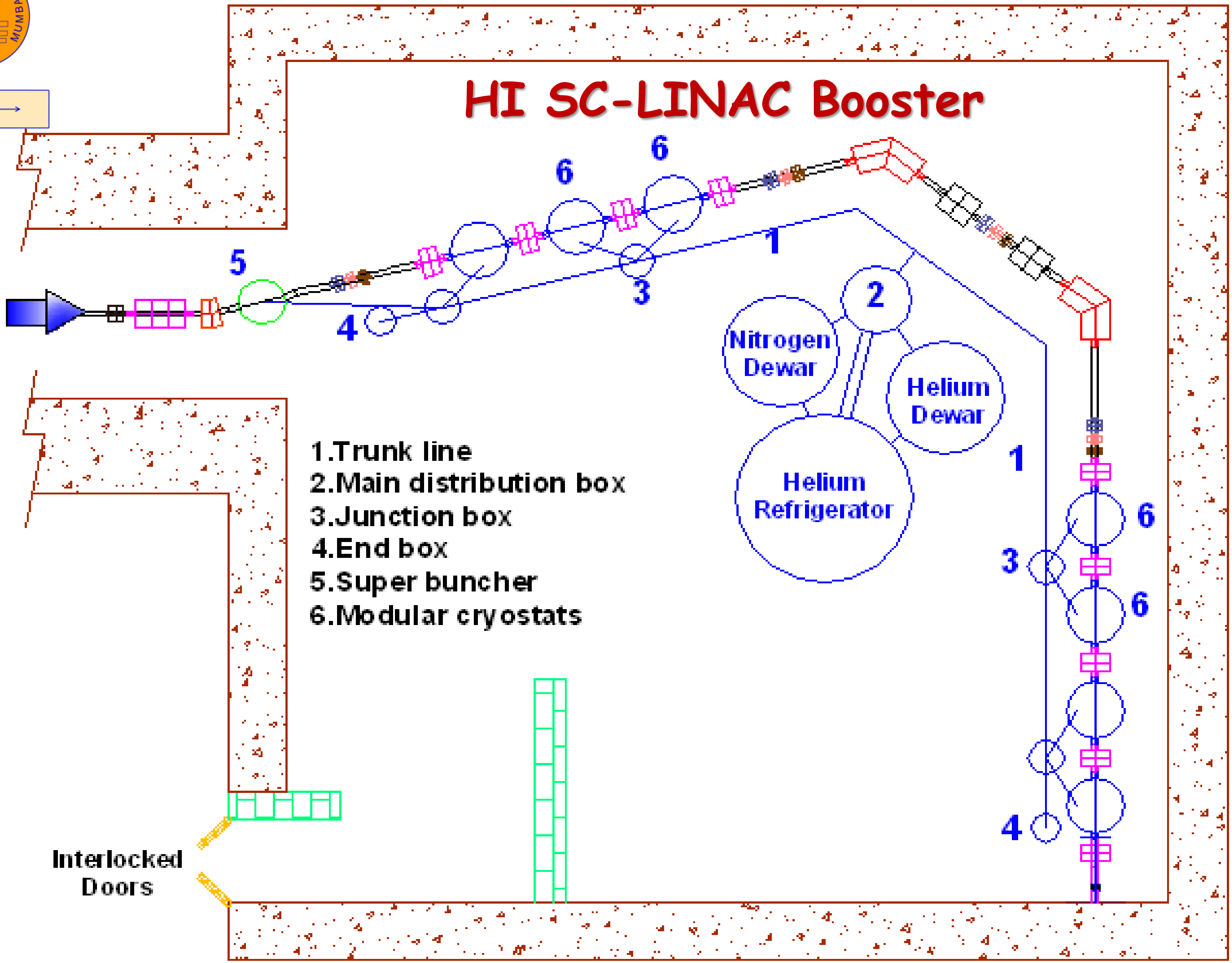
# Bunched Beam & Transport

- Beam Bunching (TIFR, NPD),

  Longitudinal Phase Space matching (TIFR),
- Accelerator Layout & Beam Transport (TIFR, Danfysik),

  Mid-Bend Beam Optics (TIFR, NPD).

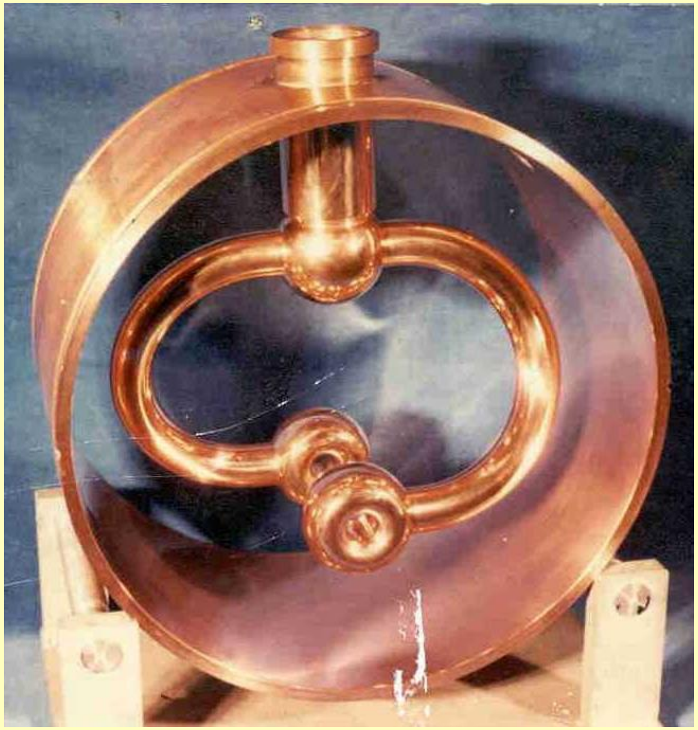
# HI SC-LINAC Booster

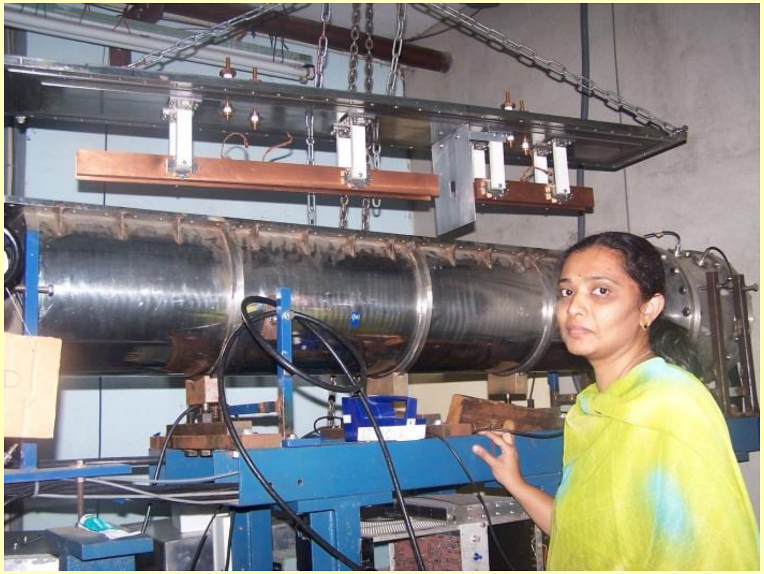


# Superbuncher cavity

Before Plating

After Lead Plating





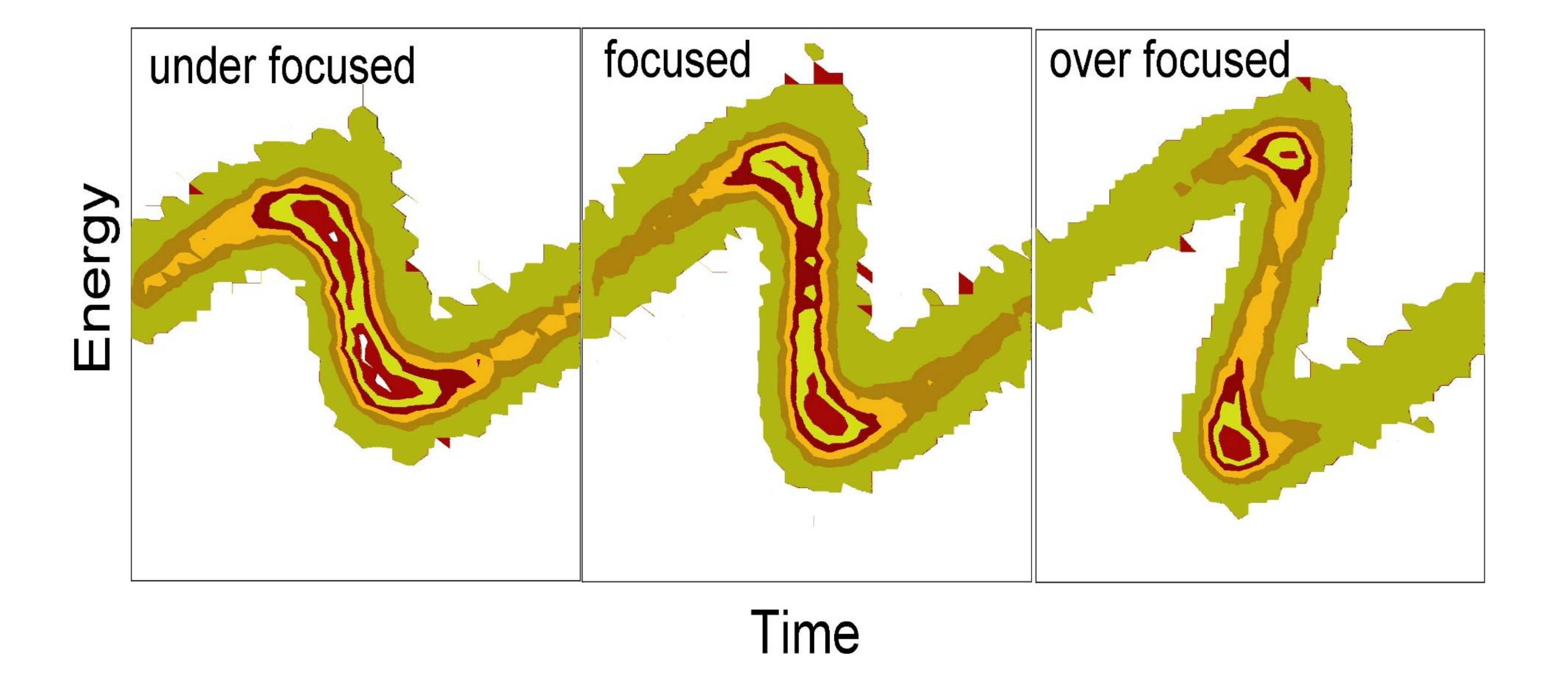
Sweeper installation

Mid bend installation

# LINAC Mid-Bend

# Longitudinal Phase Space after LINAC Mid-Bend

**Late ↔ Early**




Bend has to be achromatic and isochronous

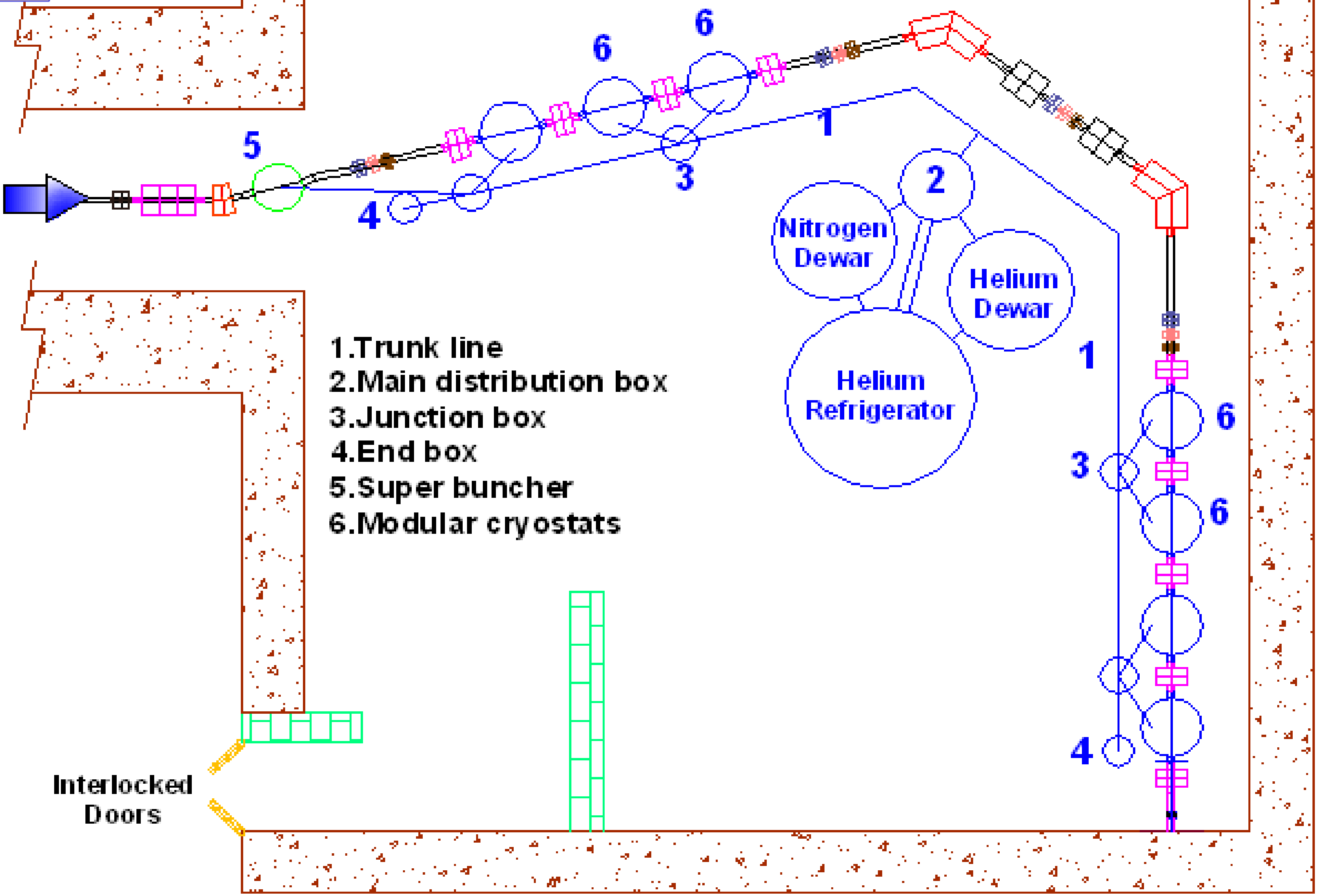
Unit spatial & angular magnification

Mirror symmetric set of bending & focussing magnets

# Liquid He Refrigerator & Cryogenic Distribution

- Customised Liquid Helium Refrigerator (TIFR, Linde),
- Modular Cryostats (TIFR, NPD, CDM, Vac. Tech.),
- Cryogen Distribution (TIFR, Weka),
- Helium gas recovery & Storage (TIFR, NPD, PLF, Bauer).

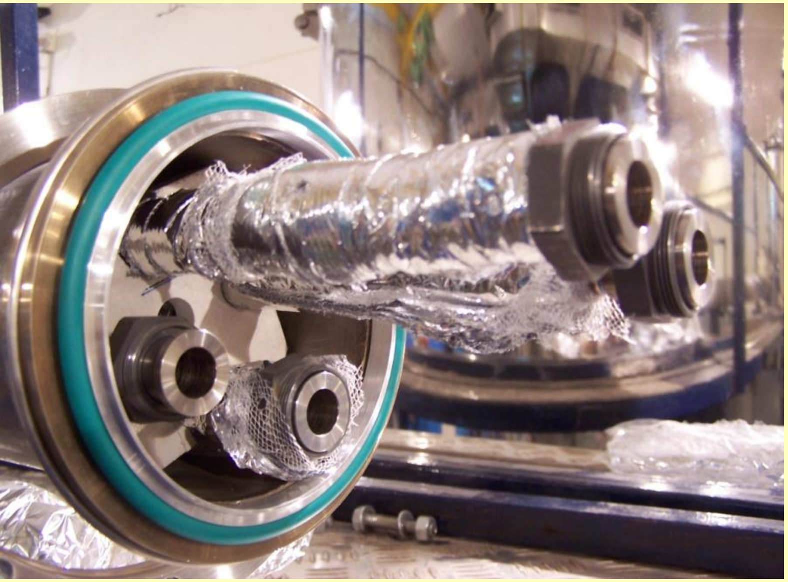
# HI SC-LINAC Booster

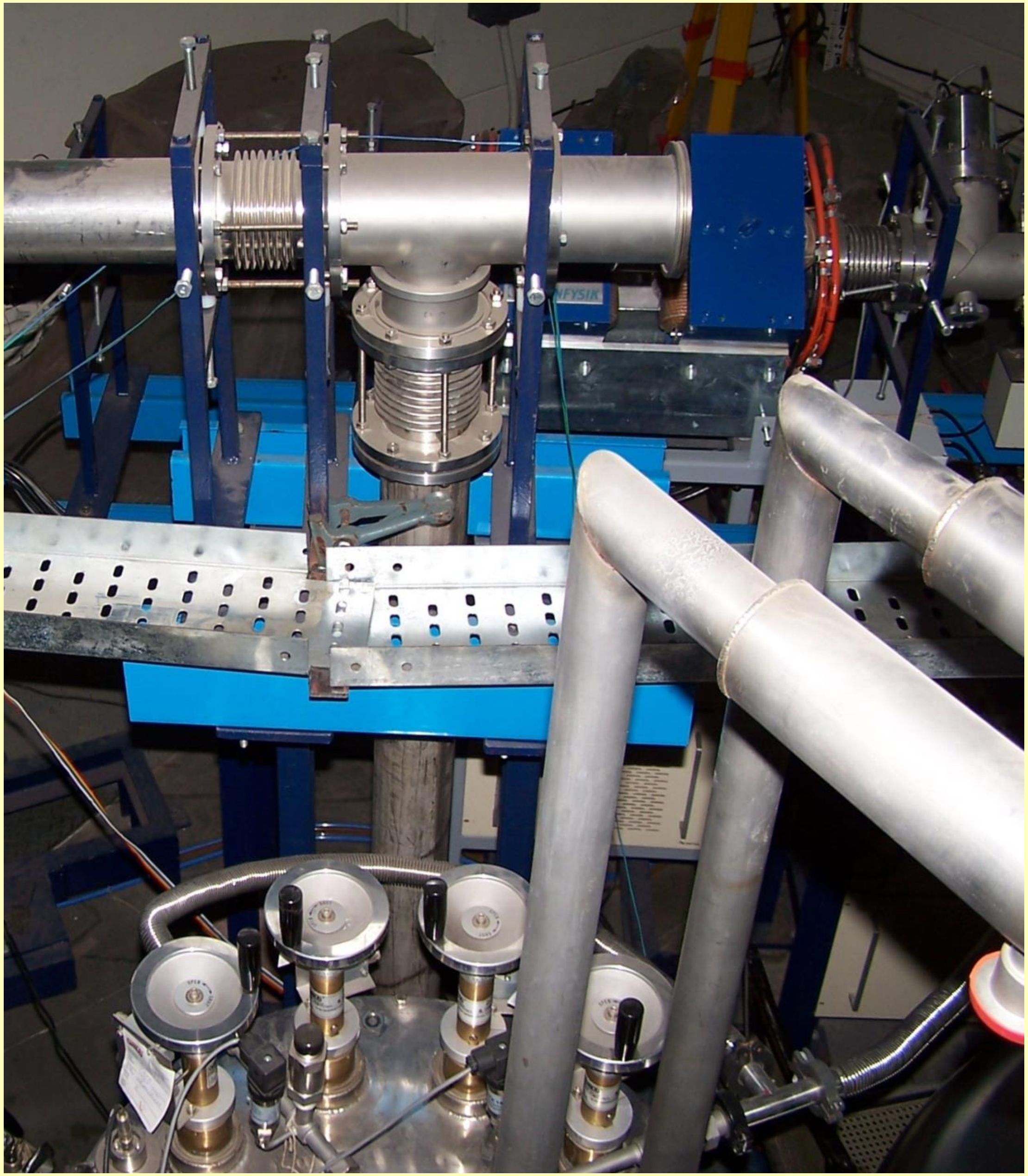


# View of TCF50S, $LN_2$ Storage and Main Box

# Trunk Line

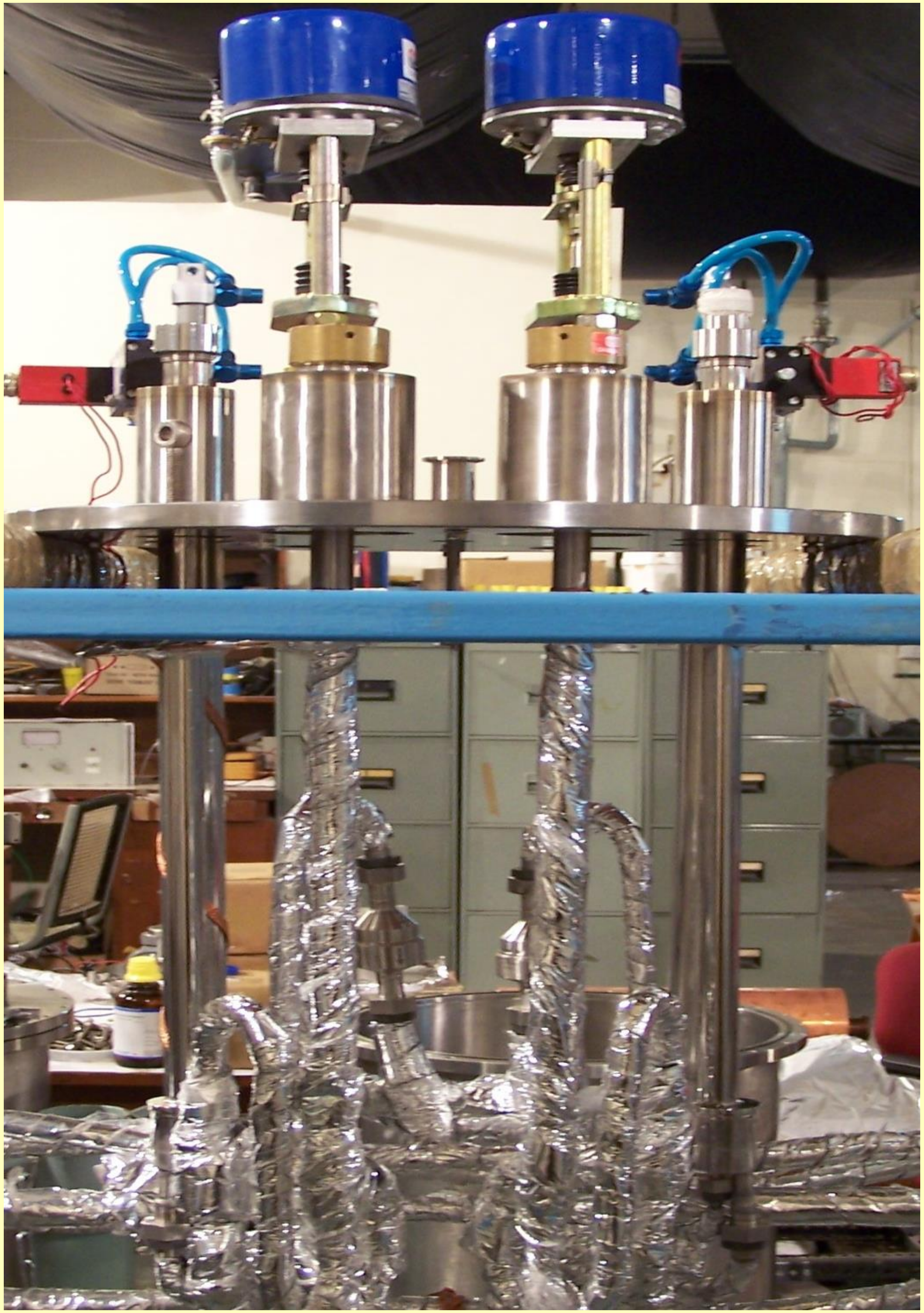
- Vacuum insulated trunk line 100mm dia with four tubes
- Made in separate sections with kennol fittings supported by Glass fibre loaded teflon spacers
- ~100mW/m





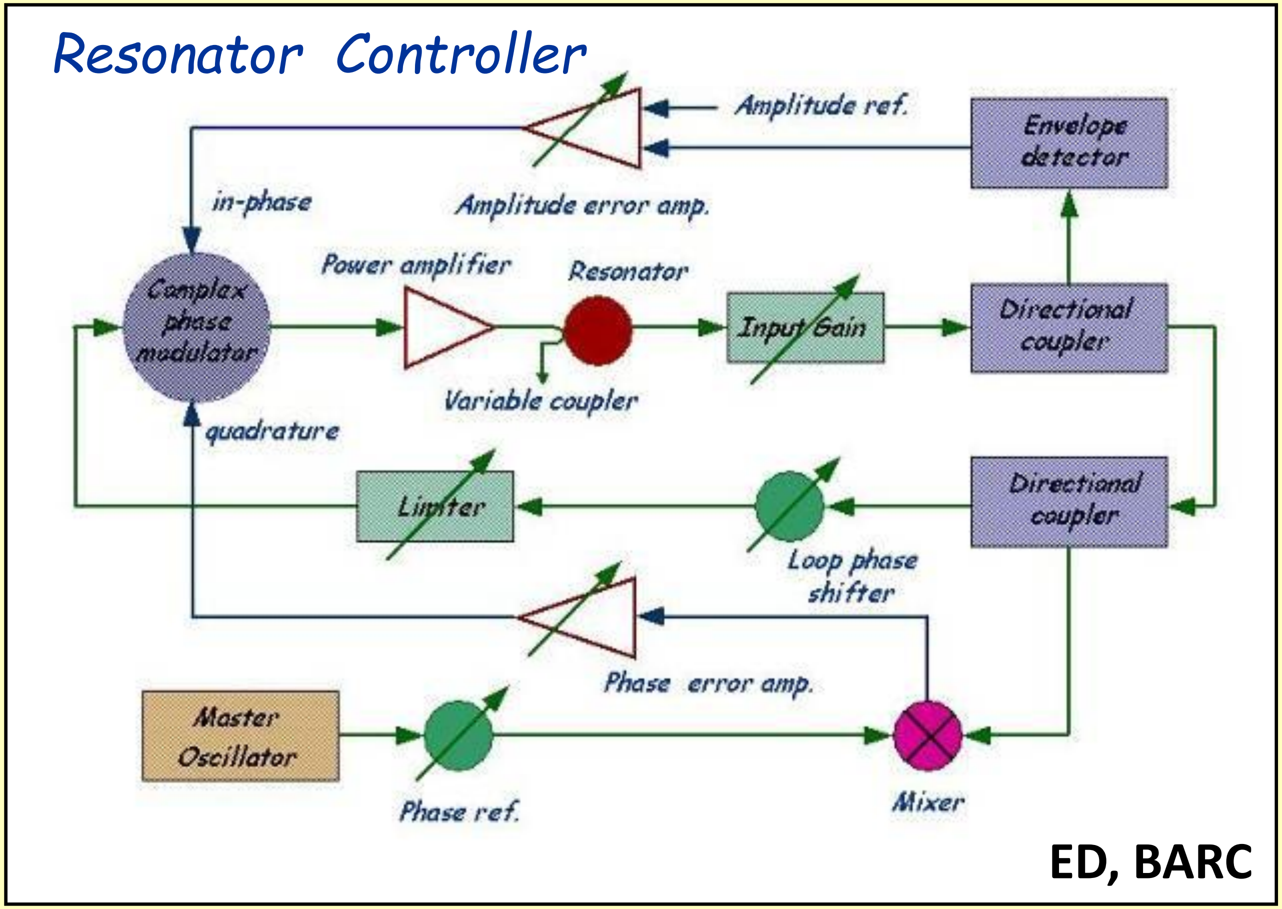
# Junction Box

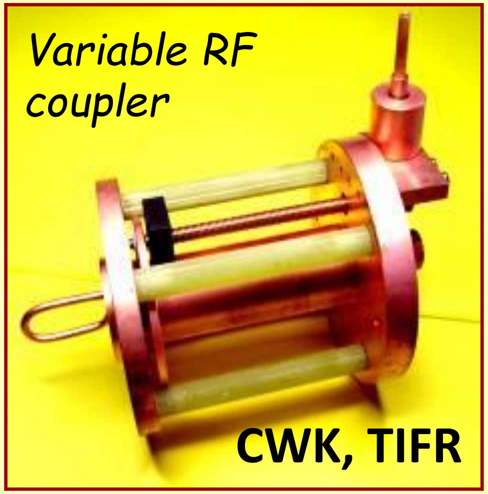
- WEKA make cryogenic valves for LHe
- WEKA make Transfer tube Bayonet for LHe
- WEKA make Cryogenic check valves
- Indigenously developed valves and bayonet for $LN_2$



# RF & Accelerator Control

- Resonator RF & Accelerator control (TIFR, NPD, ED),
- RF Power amplifiers (TIFR, NPD, ED, BEL),




Based on a Self-excited Loop with Amplitude and Phase corrections

Intrinsic resonator bandwidth ~1Hz @ 150MHz

Cavity resonant frequency variations ~±25Hz

Field level set by limiter and variable coupler

Stability <0.1% in Amplitude & <0.1° in Phase (IUAC Delhi, ANU Canberra)

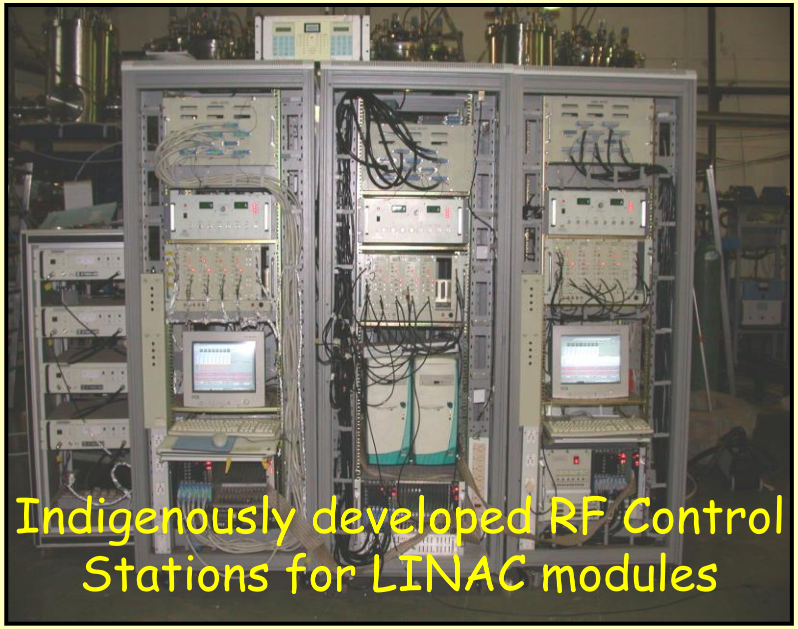
# *RF Electronics and LINAC Control System*

*In house development using Indigenous/easily available RF modules*

*150 Watts, 150 MHz RF Power Amplifiers (BEL)*

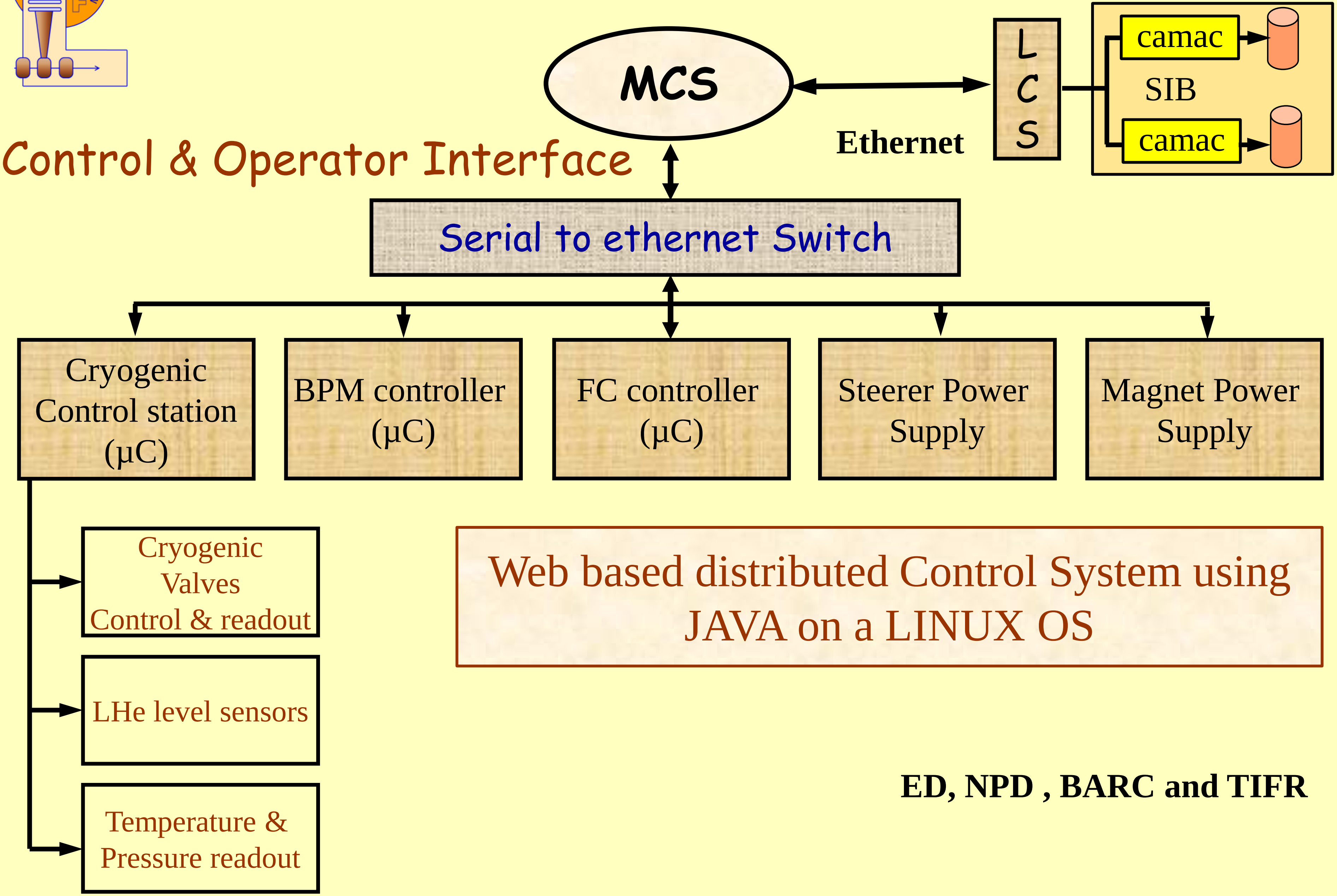
LINUX based Operating system with JAVA (NPD, BARC)

Web based distributed control system (master + local stations)




**BEL**

# Instrumentation for Control & Monitor




Web based distributed Control System using JAVA on a LINUX OS

**ED, NPD , BARC and TIFR**

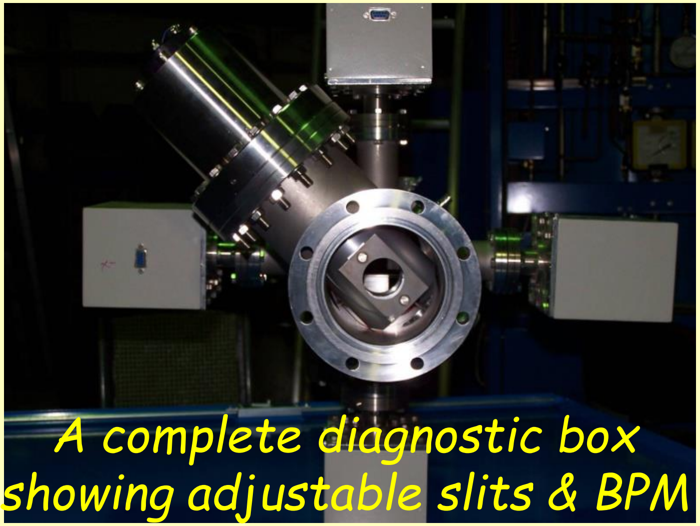
# Vacuum & Beam Diagnostics

- Beam Diagnostics (BPM, FC) (TIFR, CWK, Excel Inst.),
- Diagnostic box (TIFR, Vac. Tech., Excel Inst.)
- Vacuum Beamlines (TIFR, CWK),
- Pumping stations (TIFR, CWK, TPD, Pfeiffer).

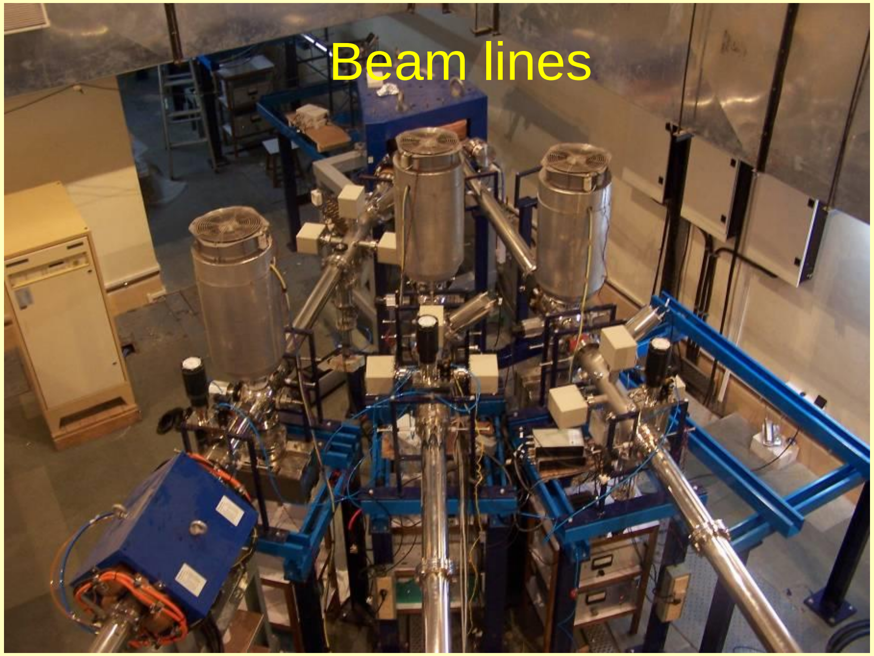
# Development of Beamline components & Diagnostic elements

Ion pump and Sublimator pump

BPM & Faraday Cup



A complete diagnostic box showing adjustable slits & BPM

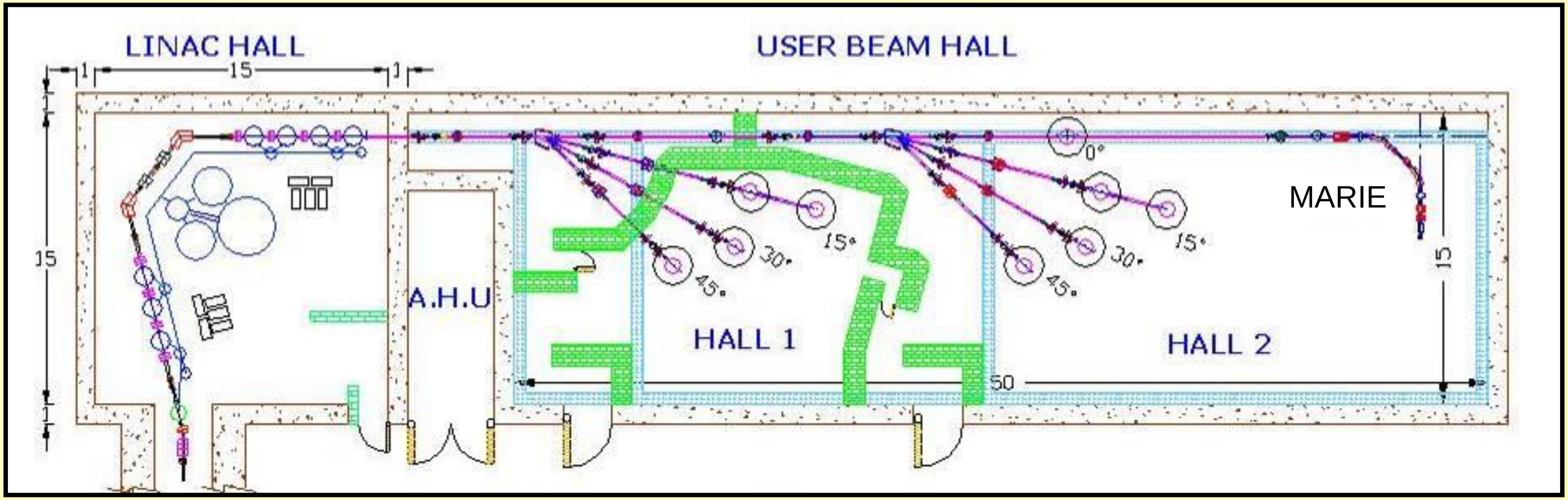


Beam lines

# User Beam Halls

- Cranes, Lighting, A/C, Service Trenches (TIFR, TSR).
- Beam Transport (TIFR, Danfysik),
- Beam Diagnostics (BPM, FC) (TIFR, CWK, Excel Inst.),
- Diagnostic box (TIFR, Vac. Tech., Excel Inst.)
- Vacuum Beamlines (TIFR, CWK),
- Pumping stations (TIFR, CWK, TPD, Pfeiffer),

# LINAC & Experimental Facilities




Radiation Shielded Halls

# Hall II

# Hall I

# Development – continued

- Accelerate heavier ions (> A ~ 30-40)

  needs higher injection voltage and low-beta cavities
- Pelletron Tube Upgrade – ongoing

  2 x 1 MV modules changed, rest to be done
- Cavity Upgrade from Pb/Cu to Nb – ongoing

  joint PLF TIFR & NPD BARC initiative
- RF control Analog to FPGA-Digital – ongoing

  to improve accuracy, stability and reliability

# Acknowledgement


- PLF, TIFR
- DNAP, TIFR
- NPD, IADD, BARC
- Electronics Division, ACnD, BARC
- Health Physics, RSSD, BARC
- TIFR Central Workshop
- BARC CDM
- LTF, TIFR
- TIFR Central Services
- All our Vendors (Indian & Foreign)

Design, develop and fabricate indigenously.
all critical components of S-LINAC booster



The superconducting LINAC was a major milestone
in the development of accelerator technology in our country.

Phase I commissioned on September 22nd, 2002
Phase II commissioned on July 9th, 2007
LINAC dedicated to users on Nov. 28th, 2007

## Phase I inauguration September 22, 2002

## LINAC Dedicated to users on November 28, 2007

# Thank you