Operational experience with superconducting LINAC booster at Mumbai

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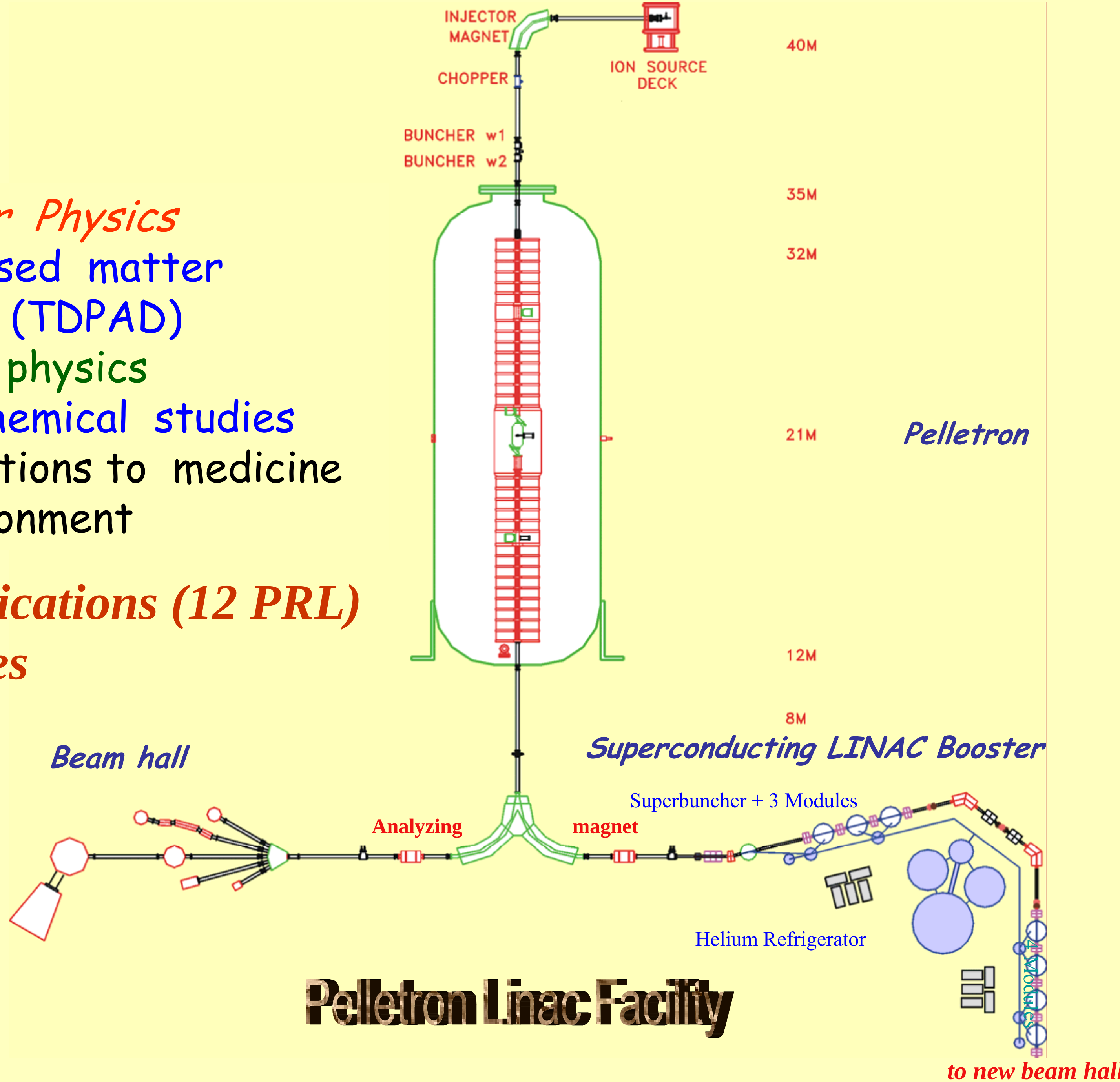
Tata Institute of Fundamental Research, Mumbai

- *Nuclear Physics*
- Condensed matter physics (TDPAD)
- Atomic physics
- Radiochemical studies
- Applications to medicine & environment

458 Publications (12 PRL)
77 Theses



Pelletron Linac Facility

Superconducting LINAC Booster

Joint TIFR – BARC Project

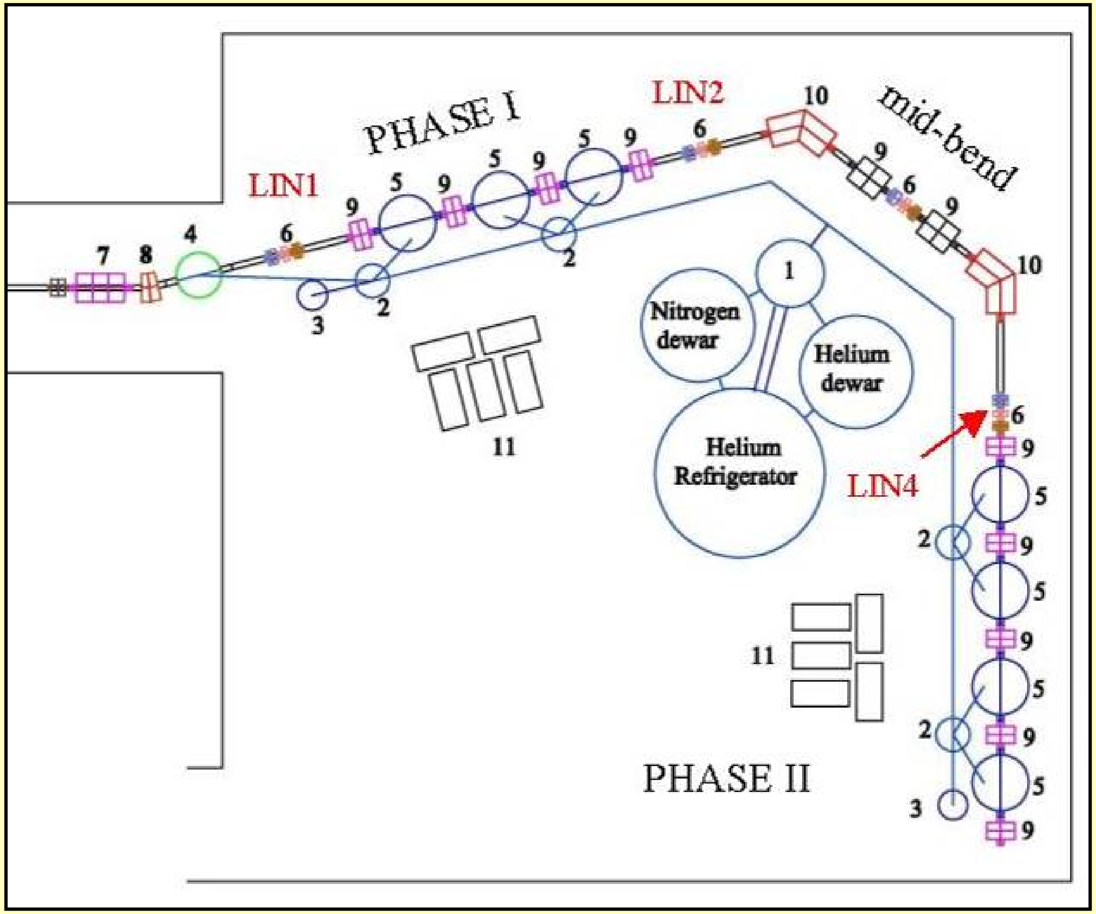
Dept of Atomic Energy, India

Specifications

Heavy ions upto A~80
E/A~5-12 MeV

Energy gain 14MV/q
Module 7 nos
Resonators 28 nos

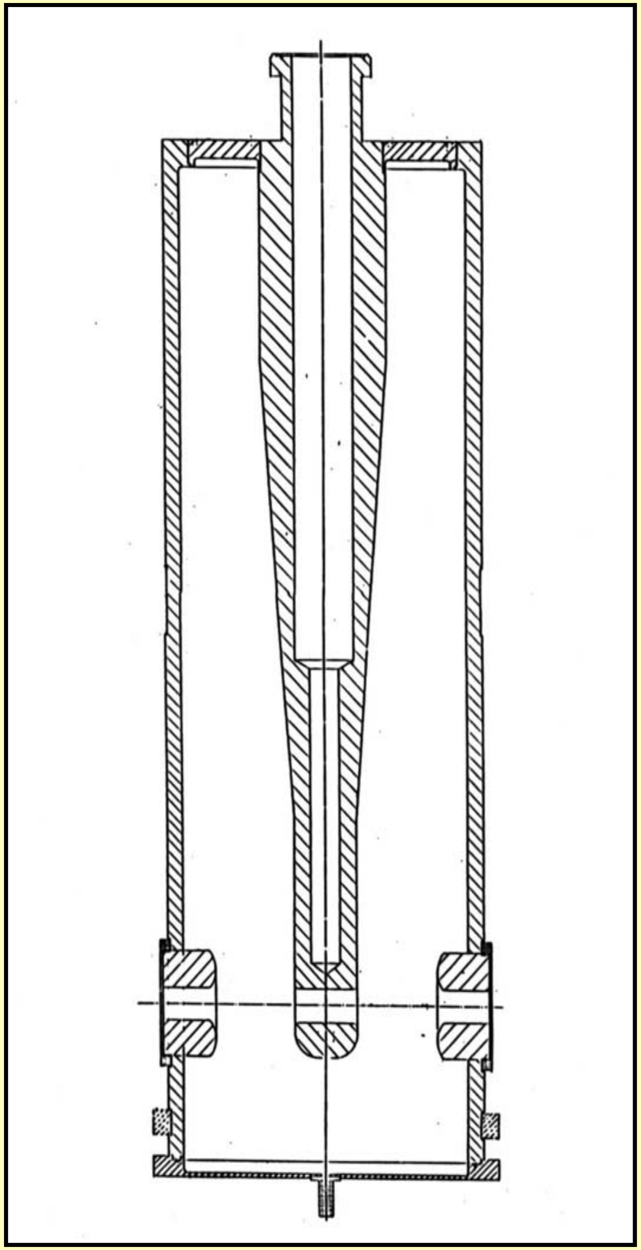
Bunch width ~200 ps
Beam Intensity 0.1-10 pnA



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

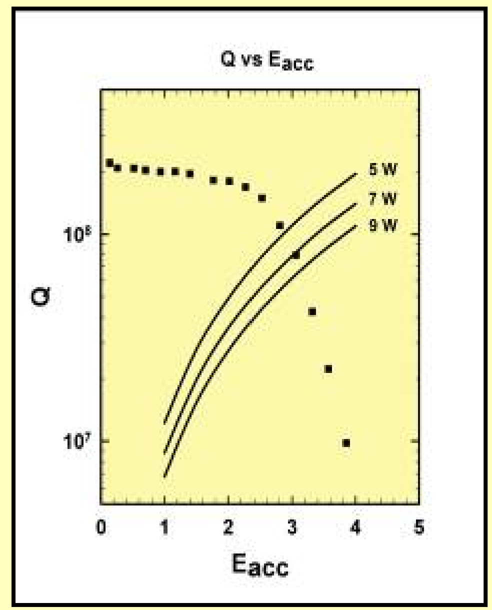
Critical components of LINAC booster have been designed, developed and fabricated indigenously.

The superconducting LINAC has been a major milestone in the development of accelerator technology in India.



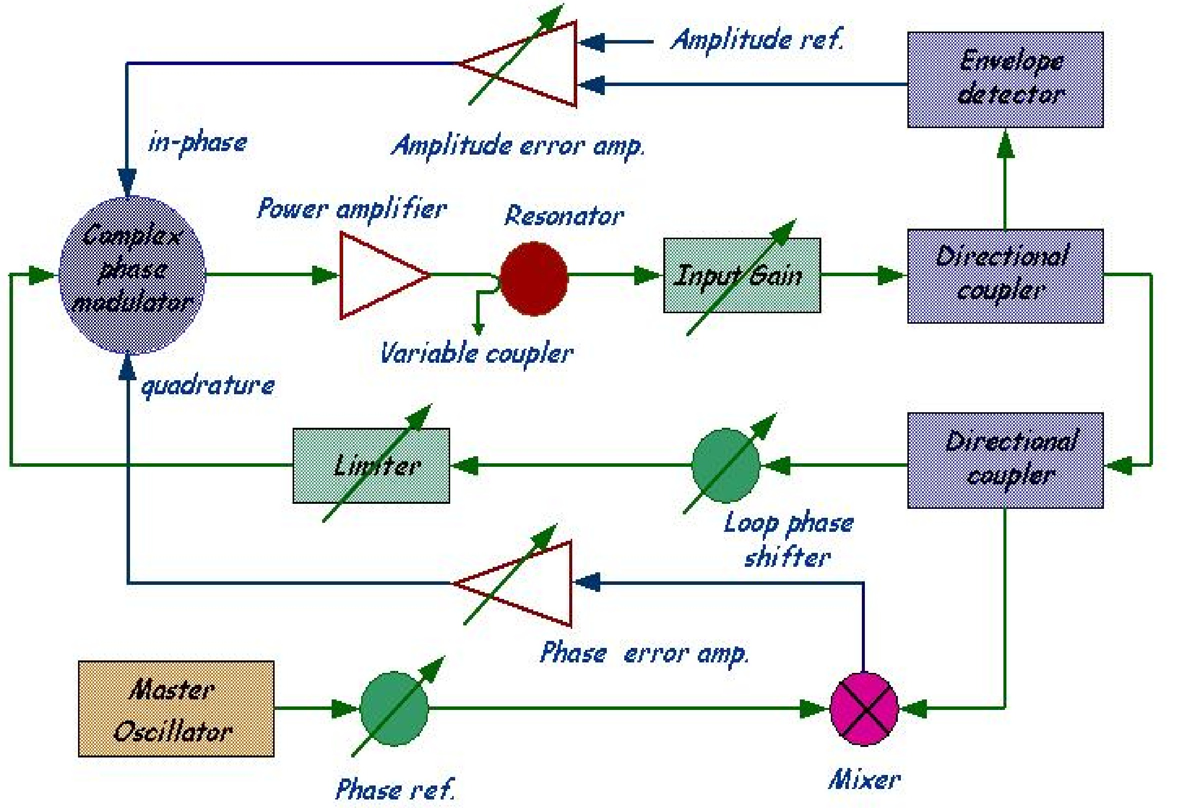
Quarter Wave Resonators

Material	**OFHC Cu**
Superconducting surface	**2 μm thick. Pb**
Frequency	**150 MHz**
Cavity Length	**64 cm**
Cavity Diameter	**20 cm**
Optimum velocity	**β=0.1**
Design goal	**2.5 to 3 MV/m @ 6 to 9 Watts**



RF Electronics for Superconducting Resonators

In house development, uses either indigenous or easily available RF modules



RF Controller (schematic)

Variable RF coupler

Also delivered to ANU, Canberra & IUAC, New Delhi

Resonator Controller

Indigenously developed RF Control Stations for LINAC modules

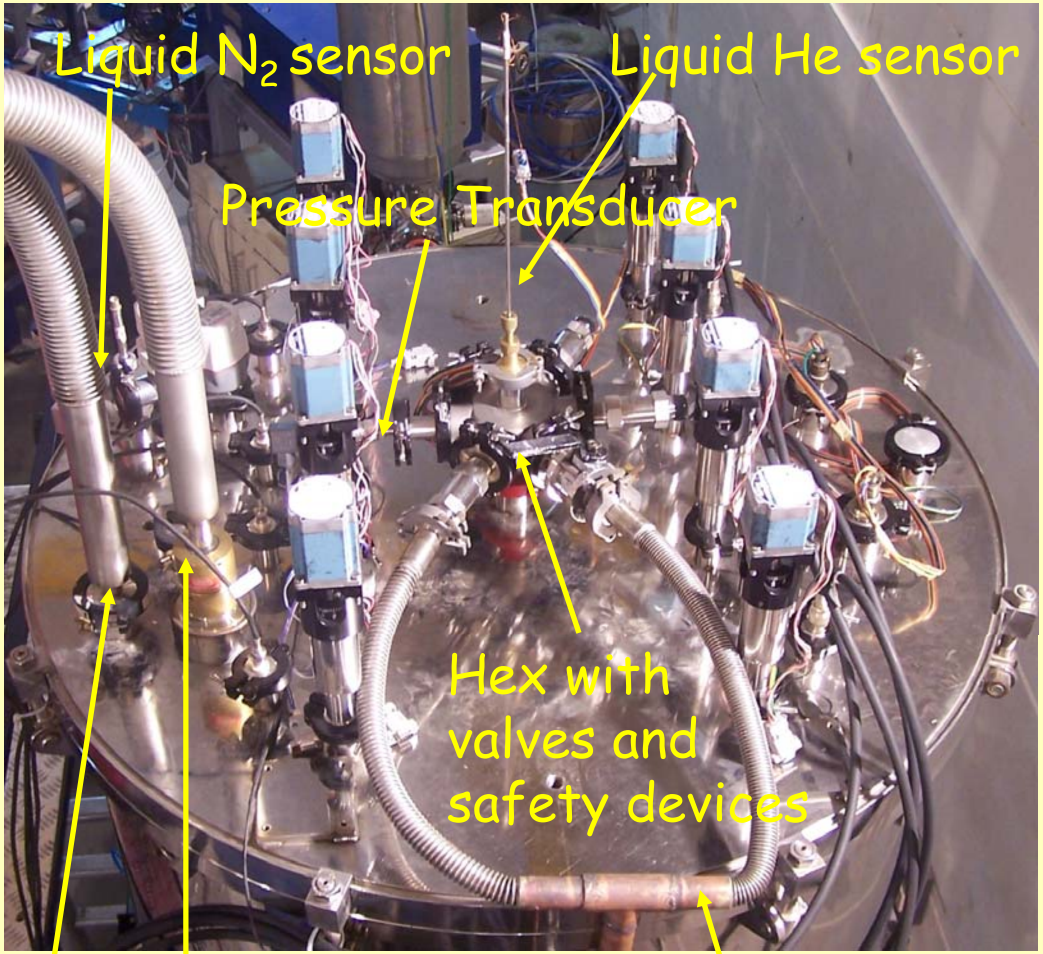
Cryogenics for the Linac

Linde TCF50S

Al Plate Fin Heat Exchangers
Two stage Turbine Expansion Engines
Two stage JT Expansion
250 KW Screw Compressor, 62 g/s

	Refrigeration at 4.5 K,	Liquification
Without LN2	300W	50 l/hr
With LN2pre-cooling	450W	120 l/hr

Module Cryostat

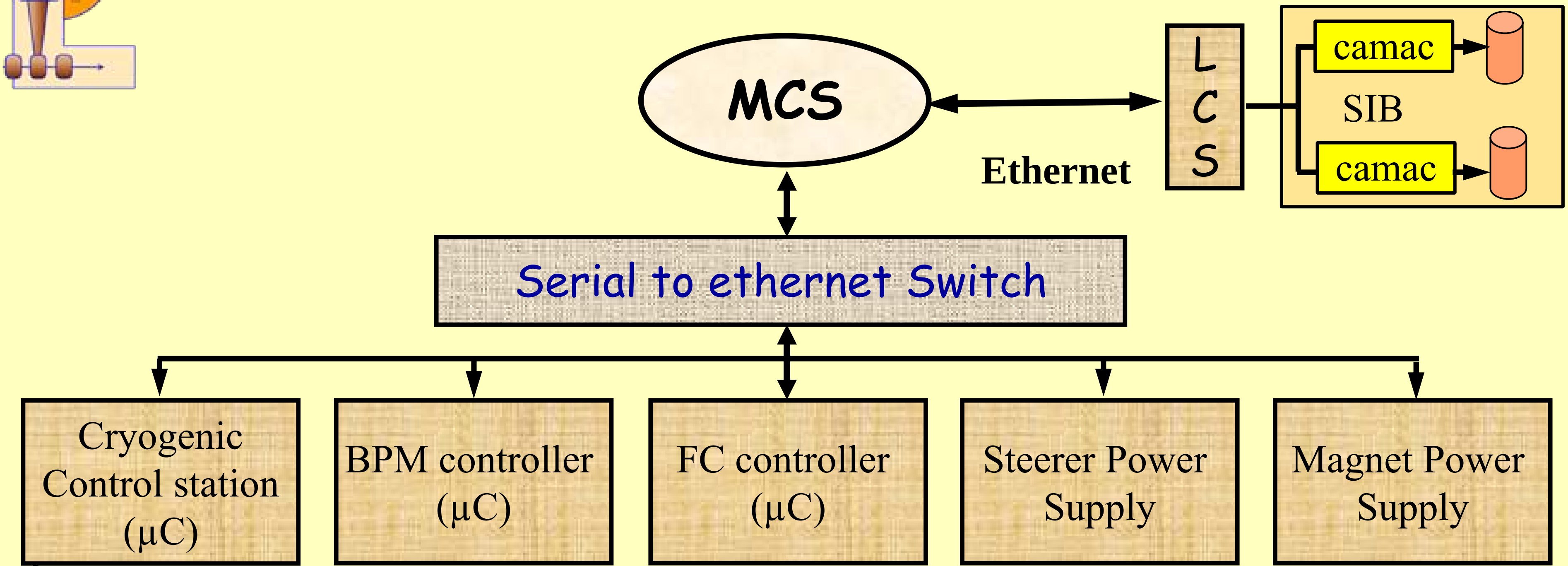


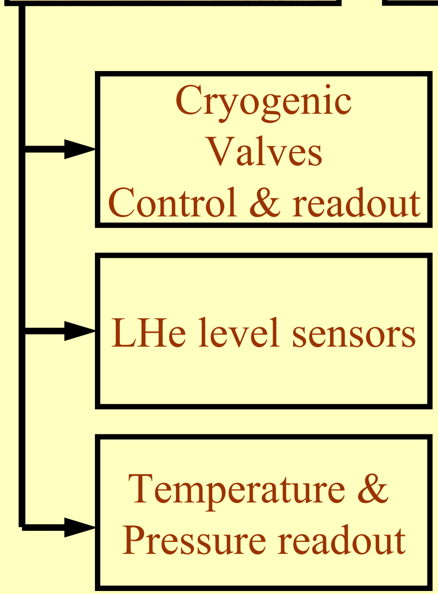
Cryogenics …

	Estimated Heat Load		Actual Heat Load
	Phase I	Phase II	
Distribution box, main box and trunk line	16W	16W	50W
Transfer tube and cryostat, 12W each	4x12W=48W	4x12W=48W	130W
QWR @6W each and Superbuncher @4W	12x6W=72W 1 x 4W =4W	16x6W=96W	172W
Total (Phase I + II)	**300W**		**352W**

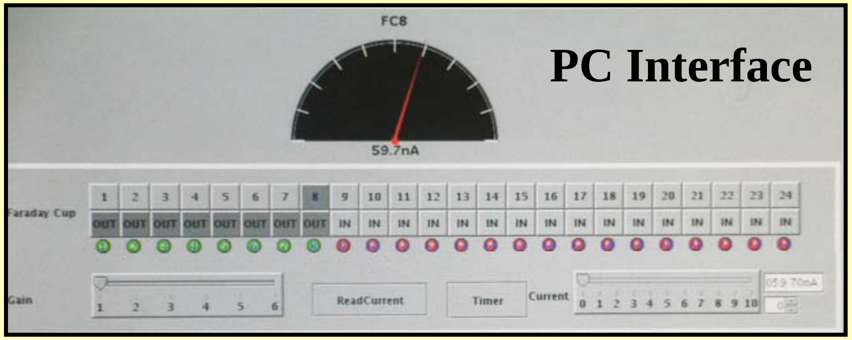
The entire cryogenic distribution was fabricated and assembled on-site and has performed very well.

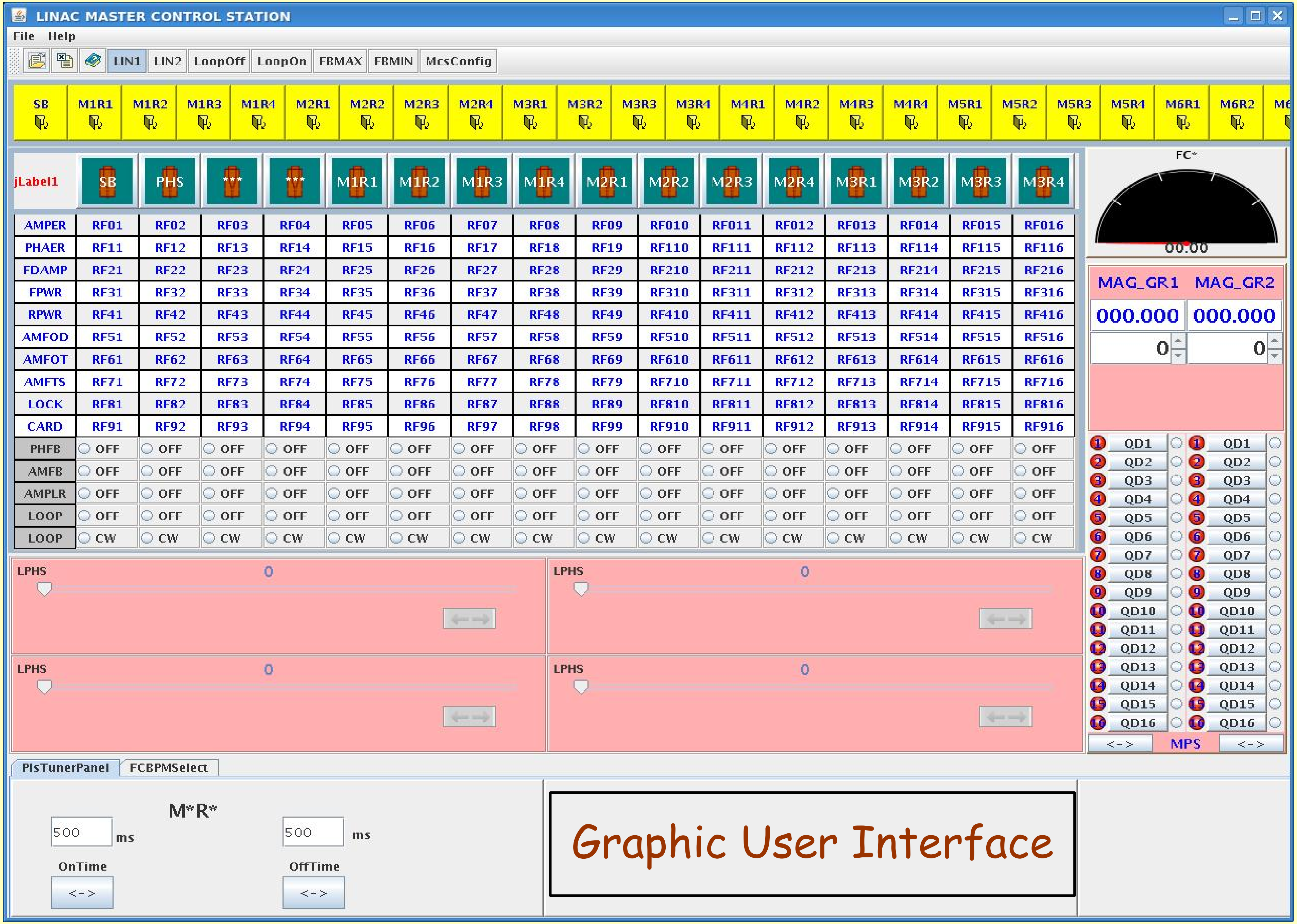
Control & Operator Interface





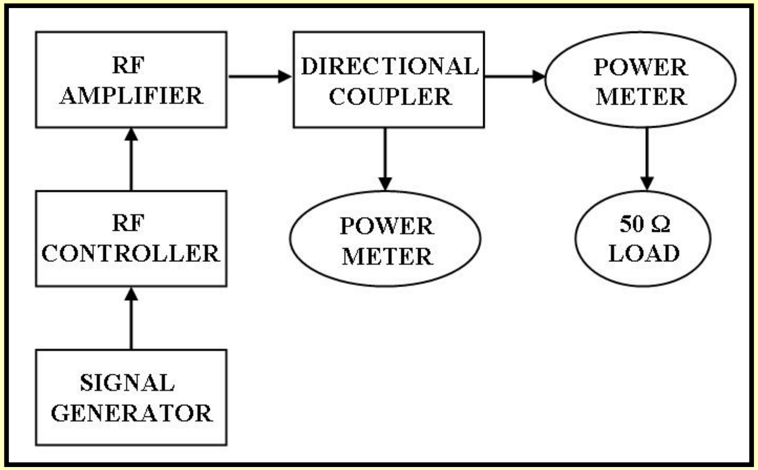
Web based distributed Control System using JAVA on a LINUX OS



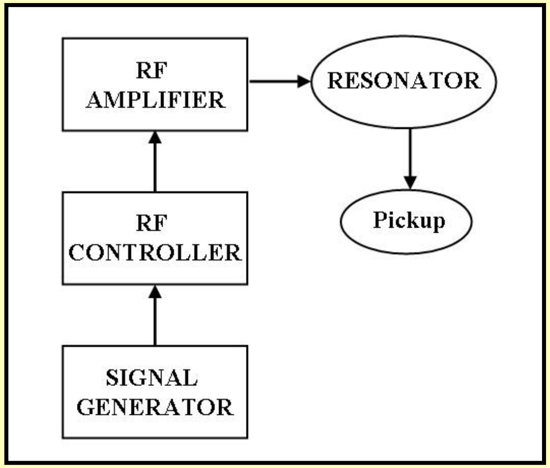


Graphic User Interface

Resonator Power settings & Field measurement

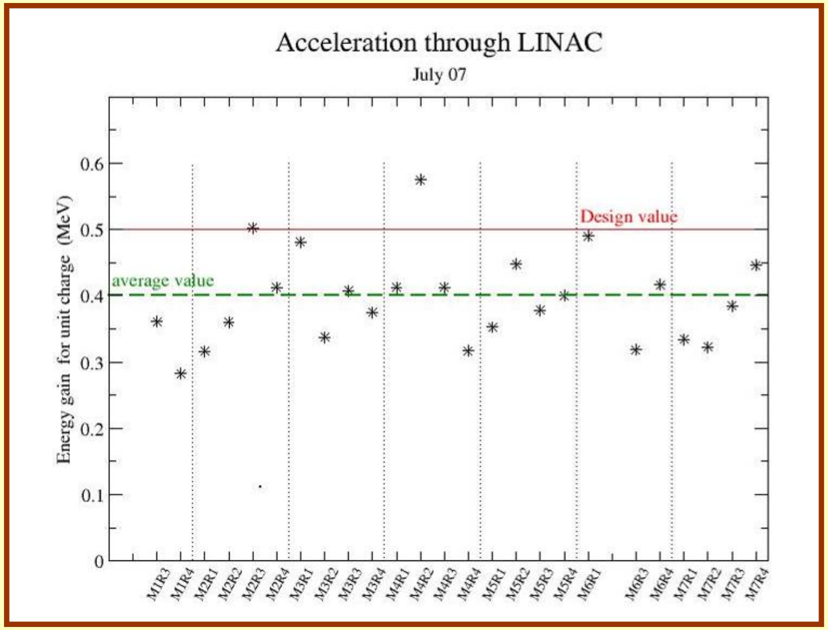


Calibration of controller card



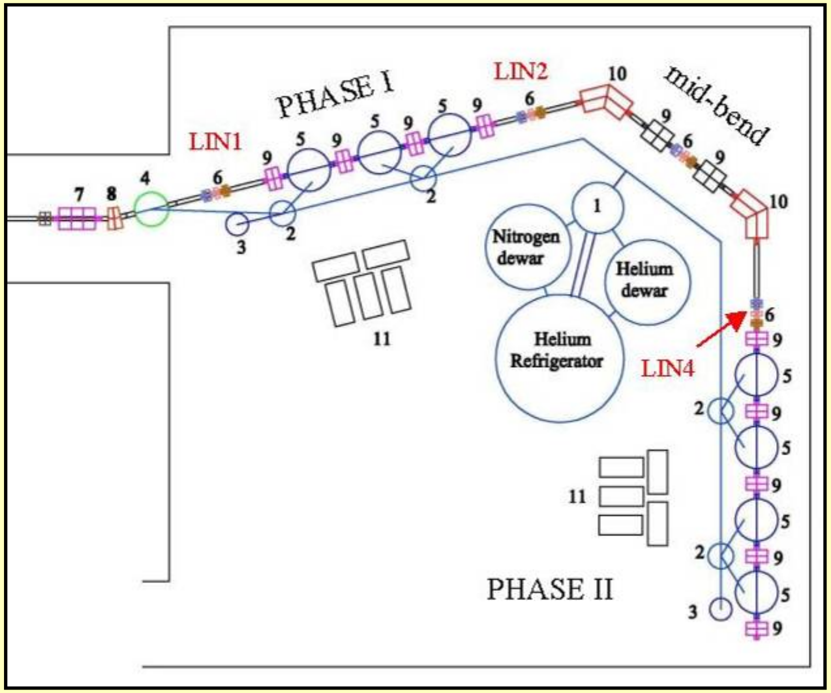
Set @ equal power levels (6W)

- Calibrate controller by measuring output power
- Set resonators at 6W and measure energy gain with DC beam to get resonator fields
- Set QP at 50W and restore field amplitude (6W pickup) by over-coupling



Beam Acceleration

Possible to accelerate a wide variety of beams, all resonator phases can be set independently



- Matching across Linac Phase I to Phase II

  Achromatic, Isochronous, QD-MD-QD-QD-MD-QD mid-bend section

- Optimization of Beam quality at target

  synchronous phase $\Phi_{res} = \pm 20$ (time de-focusing/focusing) to maintain time focusing

→transmission, energy spread and time structure

Reference phase offsets

- The reference phase in the controller (Φ_{REF}) for each individual resonator needs to be determined as a function of Q, M and β of incident ions.
- To set Φ_{REF}, it is necessary to measure the phase offsets (Φ_0) for each resonator channel
- Phase of the RF field (Φ_{res}) as seen by the beam bunch:

$$\Phi_{res} = \omega t + \Phi_{REF} - \Phi_0$$

$t = l/\beta c$ is the arrival time of the beam particle after the drift length l

- Φ_0 is independent of the beam and depends only on the hardware
- Φ_{REF} for all cavities were measured
  - $\Phi_{res} = 0$ (bunching) & $\Phi_{res} = \pi$ (de-bunching), corresponding to zero energy gain
  - for different beams (C, O, Si) over a wide range of velocities ($\beta \sim 0.05$ to 0.12)
- Φ_0 extracted from Φ_{REF} values for $\Phi_{res} = 0$: $\Phi_{REF} = \Phi_0 - \omega t$

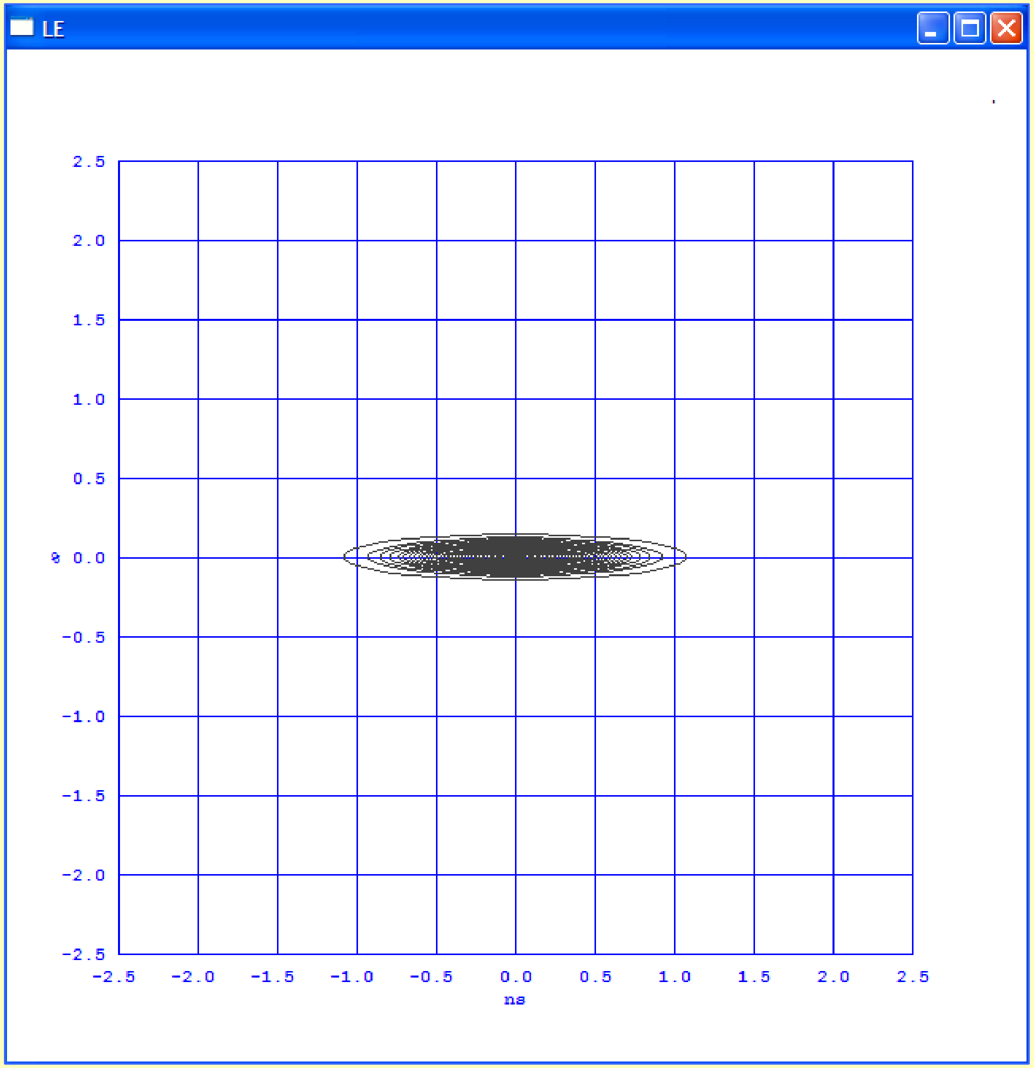
Synchronous Phase (Φ_{res}) settings

- Developed a program to optimize the longitudinal phase space ΔE- ΔT at target based on complete non-linear algebra using the measured resonator field values.
- Program tracks the evolution of the longitudinal phase space for 2^N configurations corresponding to both time focusing (-20°) & time de-focusing (+20°) of N resonators.
- Phase I (SB, M1 to M3) & Phase II (M4 to M7) are computed sequentially.
- Choose the solutions which satisfy compact phase space (min. ΔE, ΔT) criteria.
- For any given set of Φ_{res},

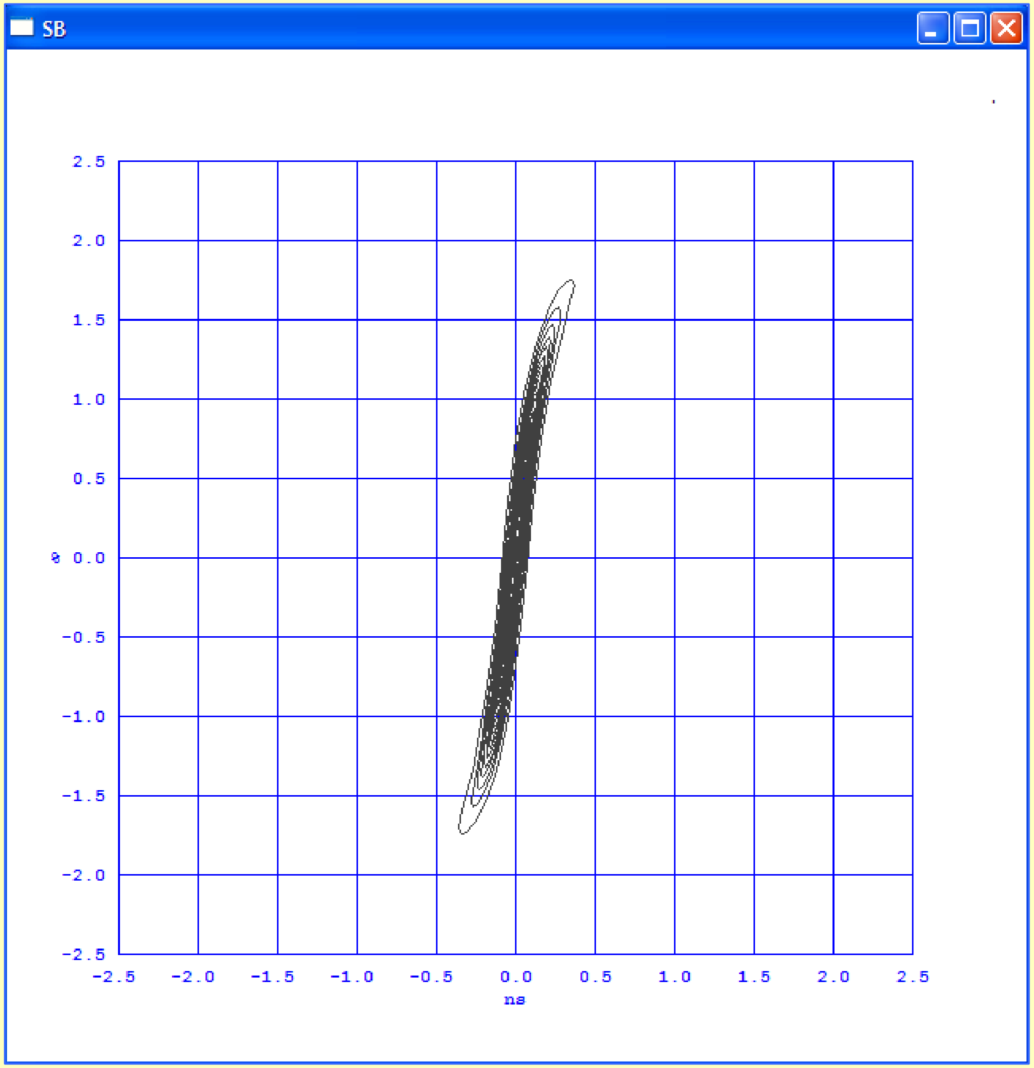
$$\Phi_{REF}(k+1) = \Phi_{REF}(k) + \Delta\Phi_0(k+1, k) - \Delta\Phi_{res}(k+1,k) - \omega(t_{k+1} - t_k)$$

- For the Phase I, the starting 2D Gaussian distribution with $\sigma_t \sim 0.375$ ns, $\sigma_e \sim 0.05$ MeV, is taken from longitudinal phase space measurements of the bunched beam at the injection of the LINAC.
- For the Phase II, the starting phase space is taken as a bounding 2D Gaussian distribution describing the output of the Phase I.

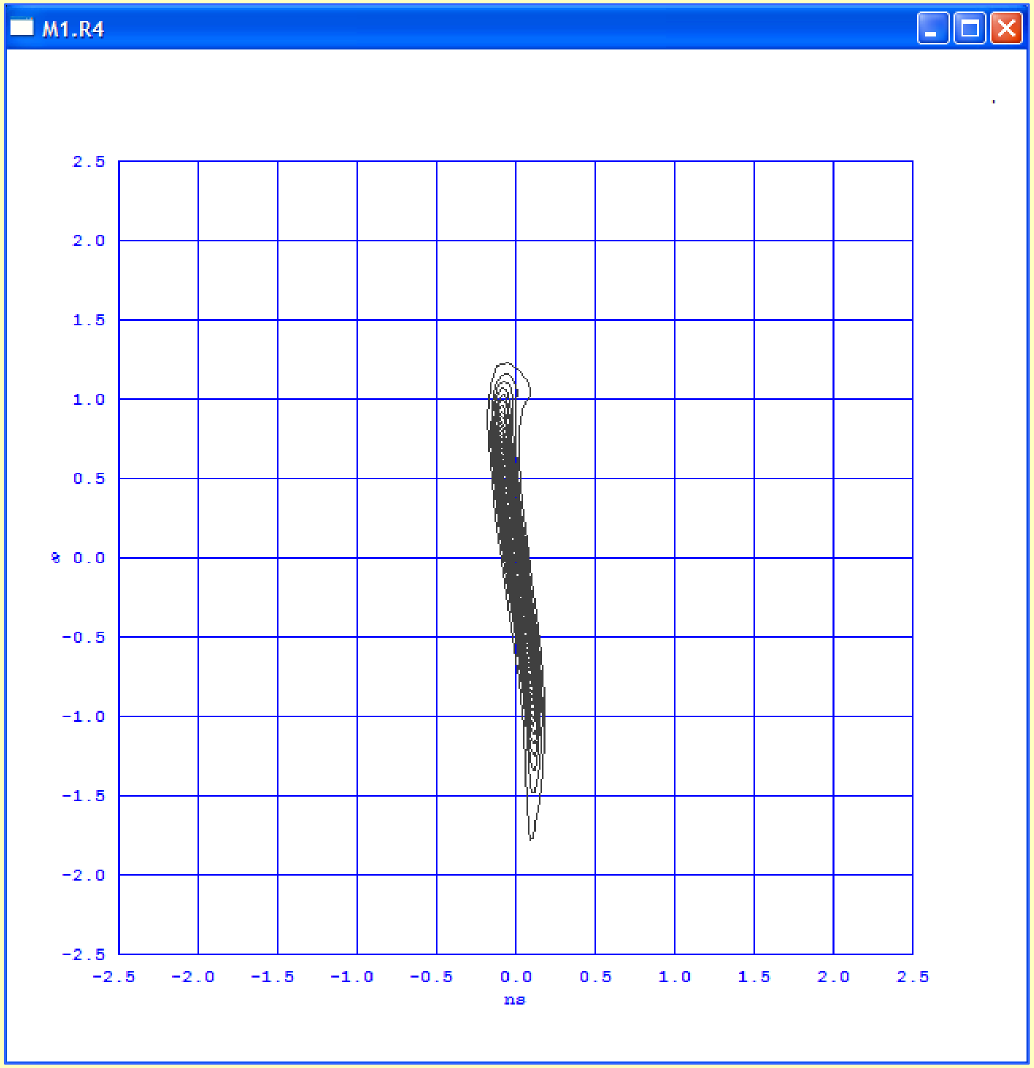
Longitudinal phase space



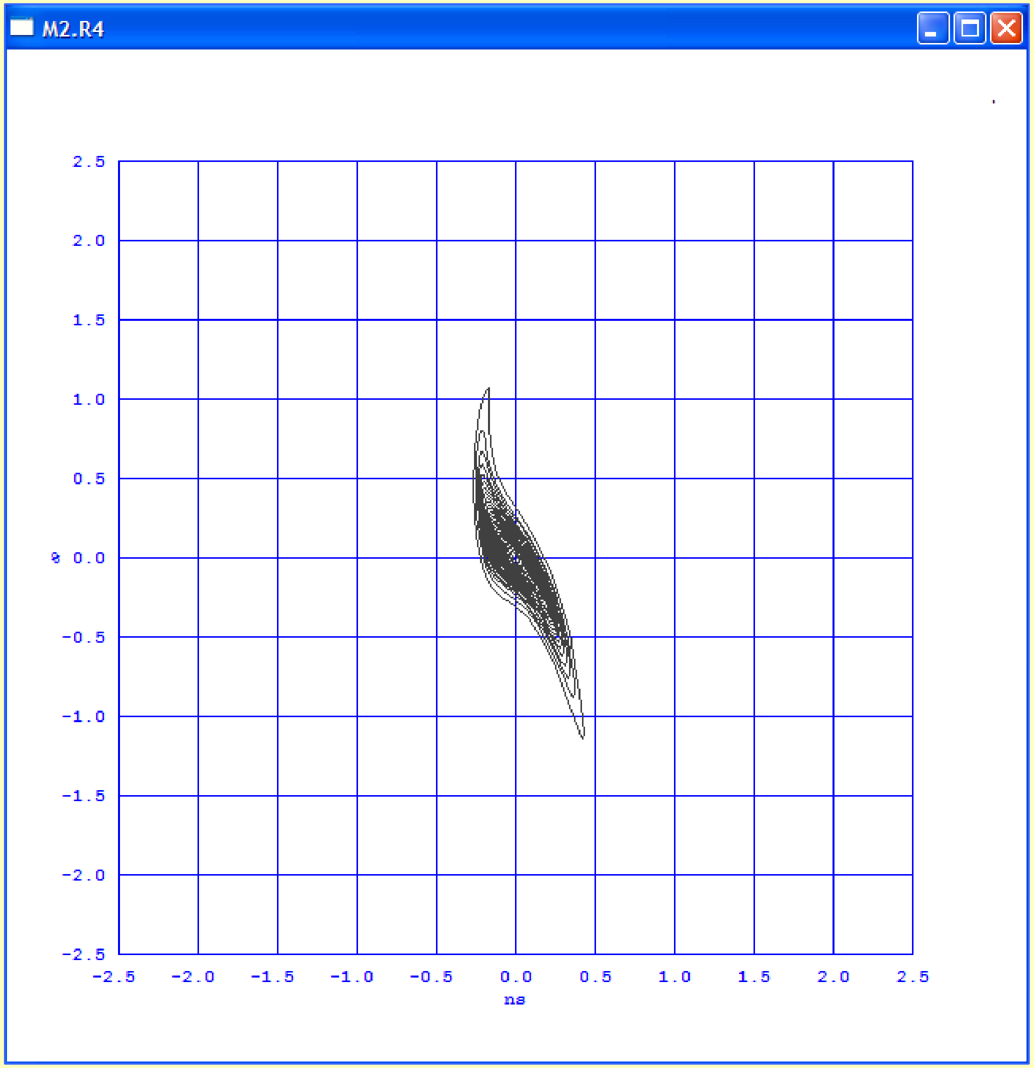
At LINAC Injection



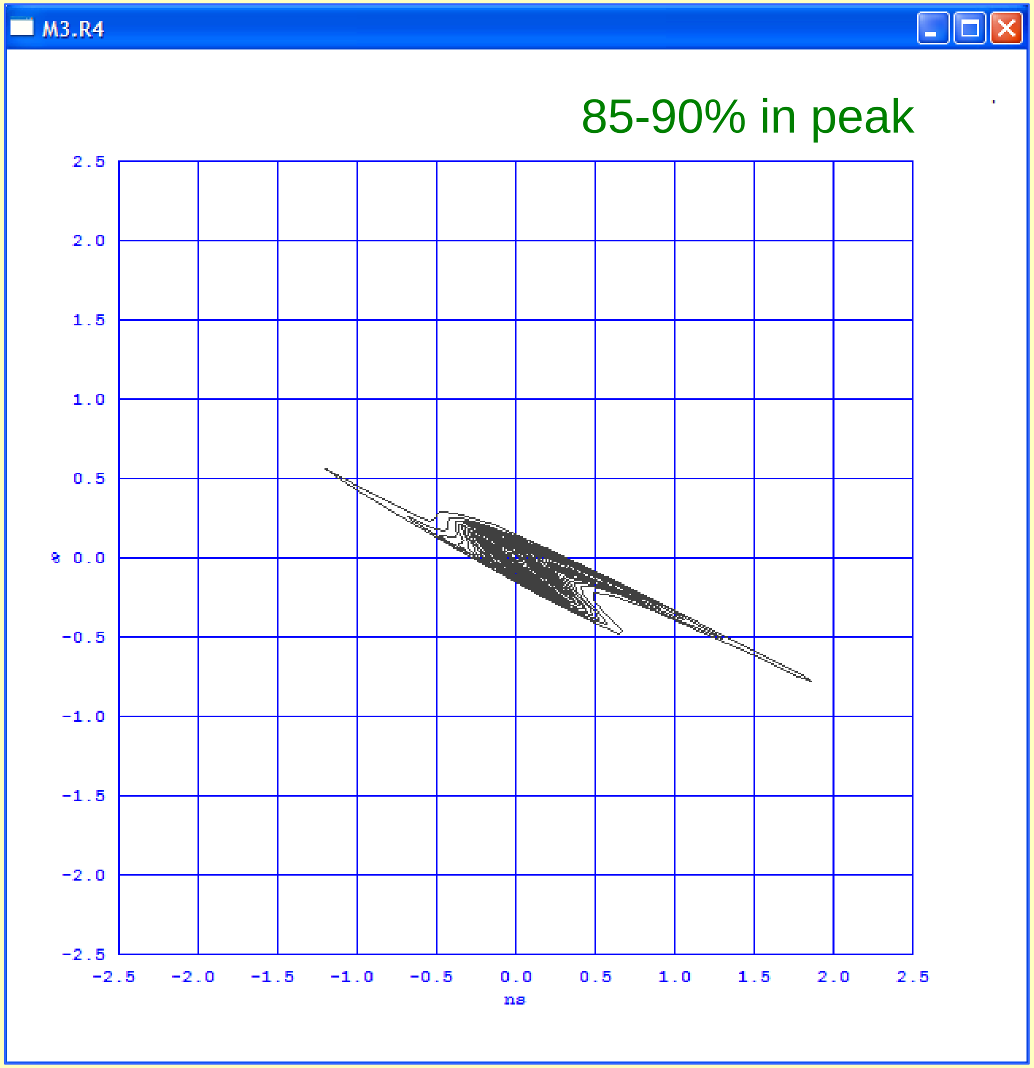
After Superbuncher at the entry of M1



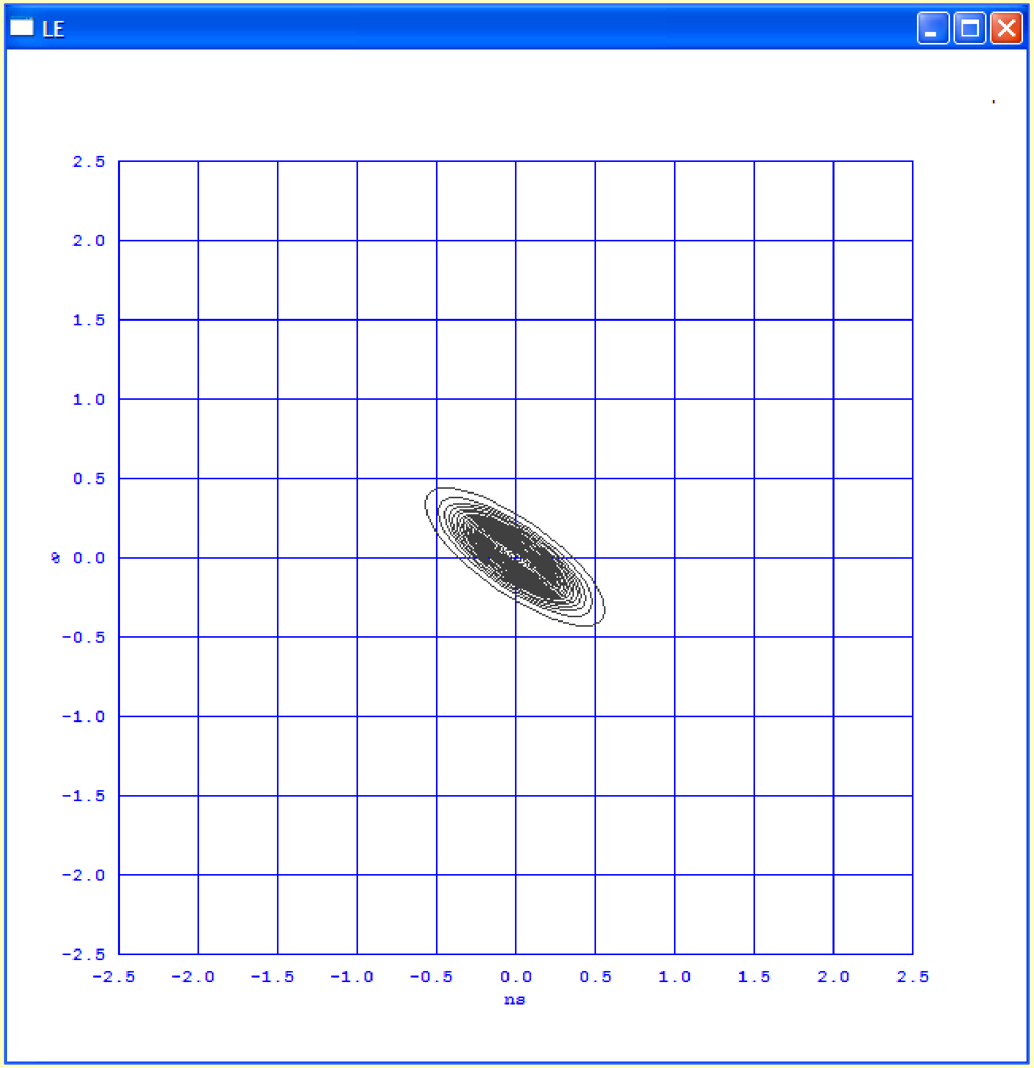
After M1, at the entry of M2



After M2, at the entry of M3



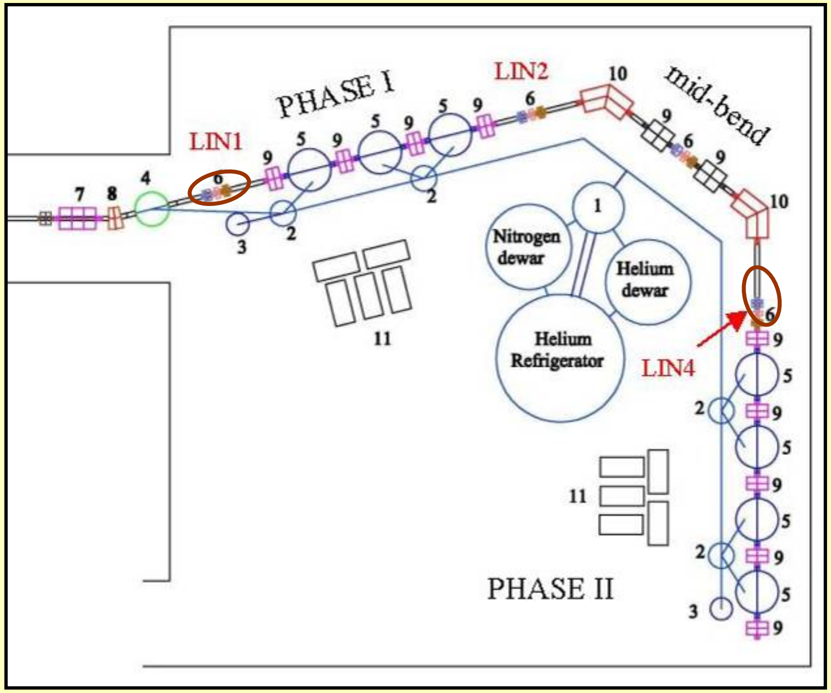
After mid-bend, at the Phase II entry



Equivalent distribution for the Phase II

Evolution of longitudinal phase space

Final configuration corresponding to an optimal phase space at target determined by measurement of the transmission and the time structure.



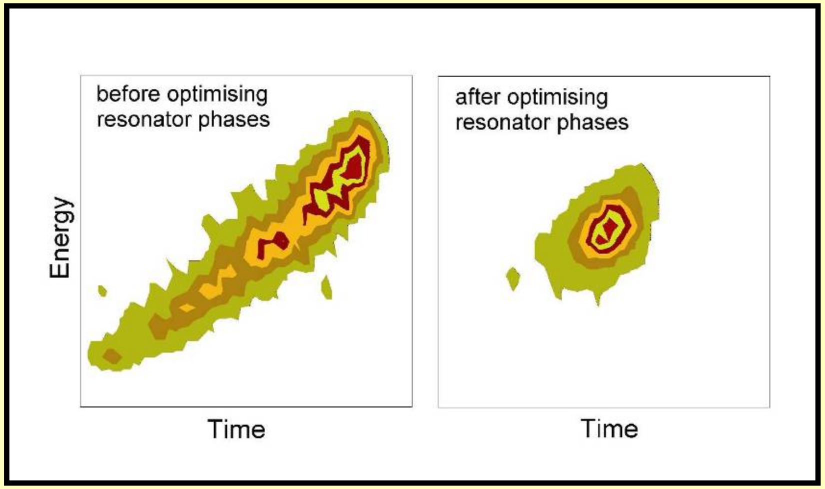
Timing Detector (1” BaF_2)

@LIN1 : entrance of Phase I

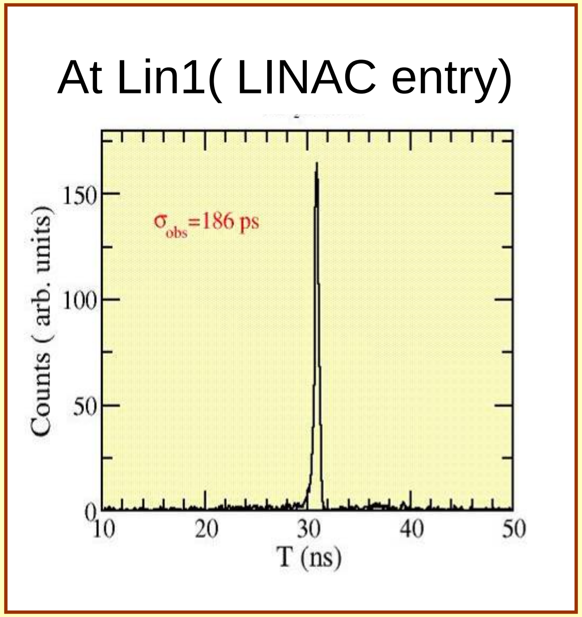
@LIN4 : entrance of Phase II

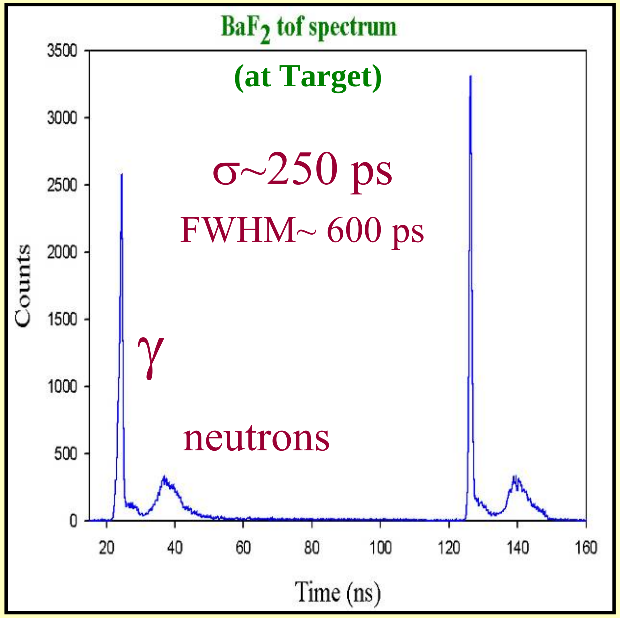
@LIN7 : after switching magnet

@target position



Longitudinal phase space after mid-bend (E-T measurement)





Experiments with LINAC

Nov.07, July08, Jan.09

Beam	E_{pell} (MeV)	E_{LINAC} (MeV)	E_{total} (MeV)
^{12}C	82.5	37.5	120.0
^{16}O	93.6	22.1	115.7
^{19}F	94.0	50.2	144.2
^{28}Si	90-100	48-109	138-209

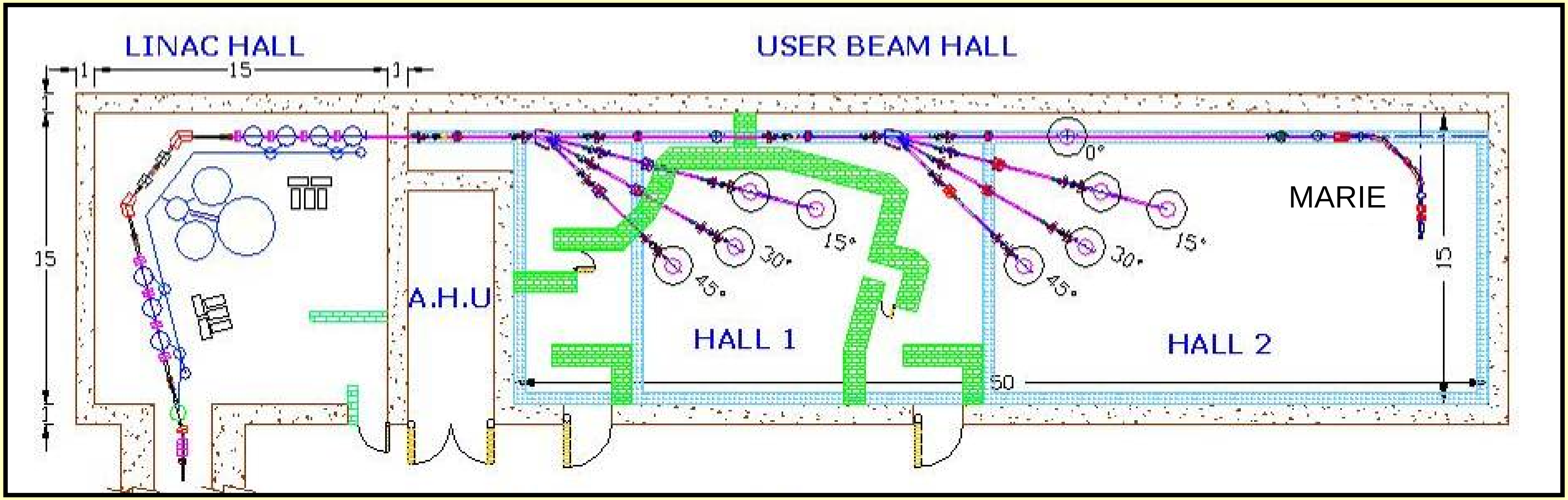
Typical tuning time 6-8 hours

Beam transmission

from LINAC entrance to LINAC exit ~80-85%

from LINAC entrance to target (after collimator) ~50%

Experimental Facilities



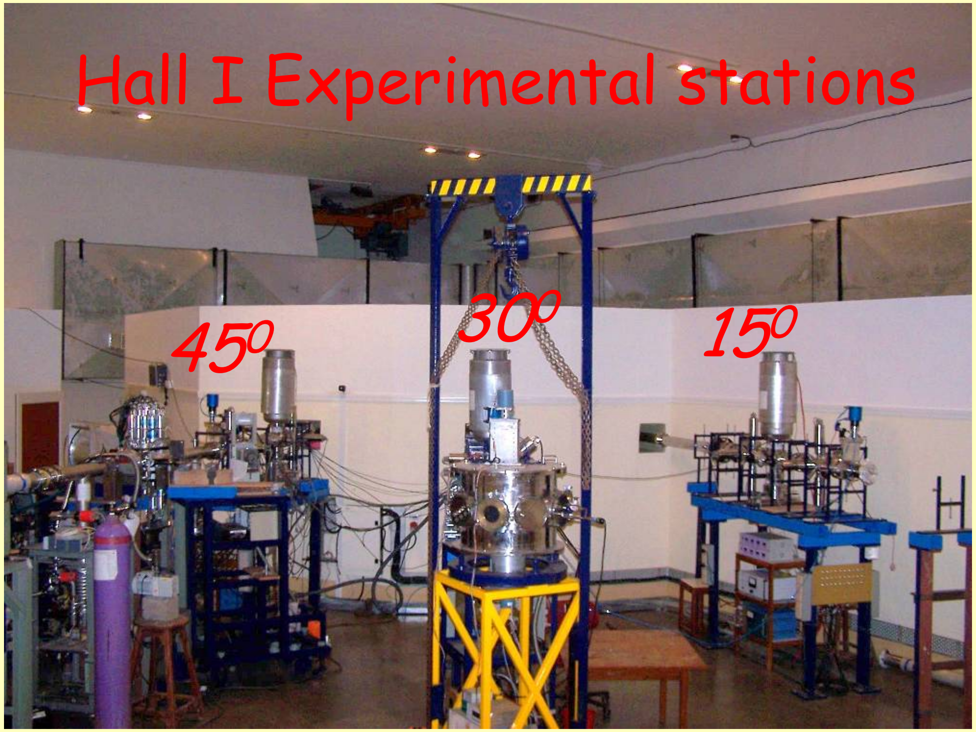
Hall 1

- Condensed Matter Physics (7 T Magnet) & Atomic, Molecular & Cluster Physics
- General Purpose Scattering Chamber
- High energy gamma ray & neutron wall

Hall 2

- General Purpose/ Irradiation line
- HPGe Spectrometer (INGA)
- Charged particle ball
- **M**omentum **A**chromat for **R**adioactive **I**on **E**xperiments

User beam Hall



MARIE

INGA

OUTLOOK

- Extend operations to heavier beams (upto Ni)
- Cryogenic upgrade (operation without precool, rebuncher)
- Improvements to OIF
- Development of digital RF controller cards

R.G. Pillay, J. N. Karande, S. S. Jangam, P. Dhumal,
M.S. Pose, C. Rozario, S.K. Sarkar, R.D. Deshpande, and S.R.Sinha

B. Srinivasan, S.K. Singh

&

LINAC team

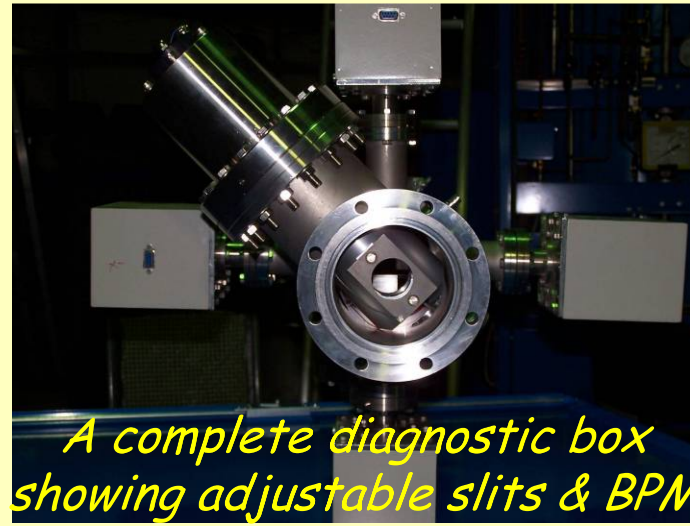
TIFR

- **Dept of Nuclear & Atomic Physics**
- **Central Workshop**
- **Central Services**
- **Low Temperature Facility**

BARC

- **Nuclear Physics Division**
- **Electronics Division**
- **Central Workshop**

Beam Diagnostic devices



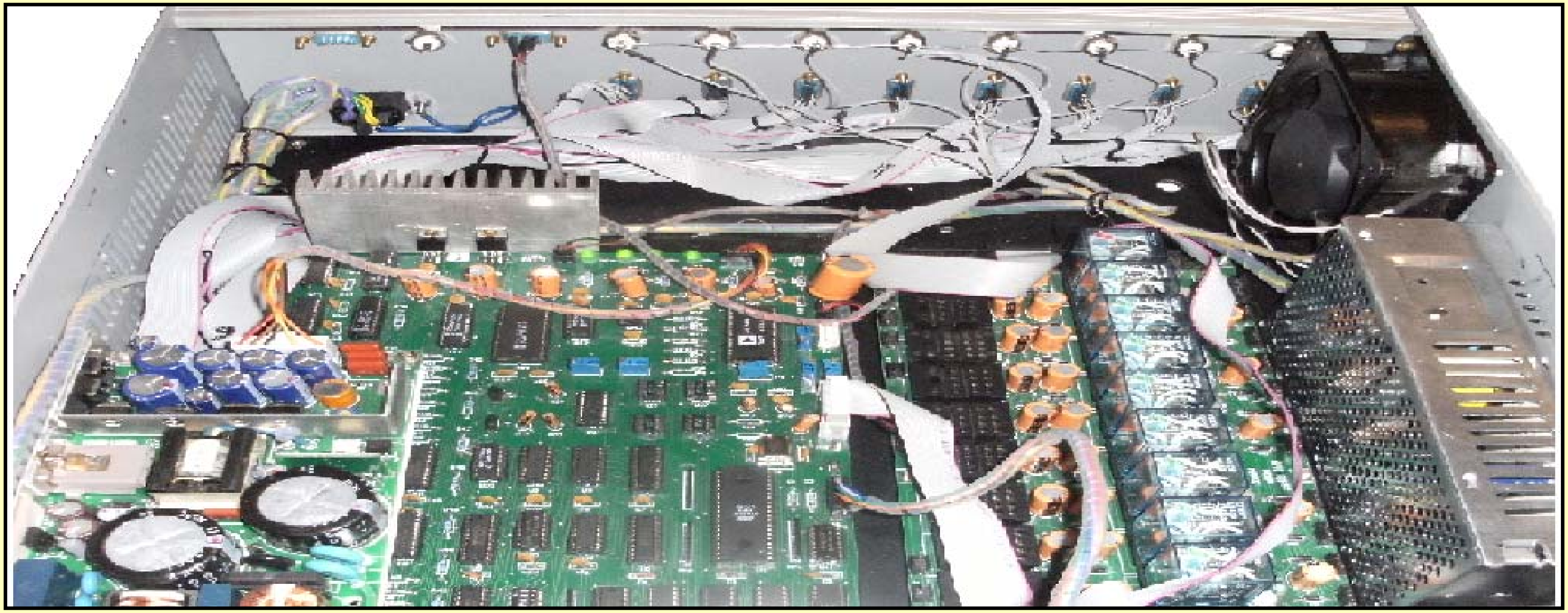
A complete diagnostic box showing adjustable slits & BPM

BPM developed at TIFR

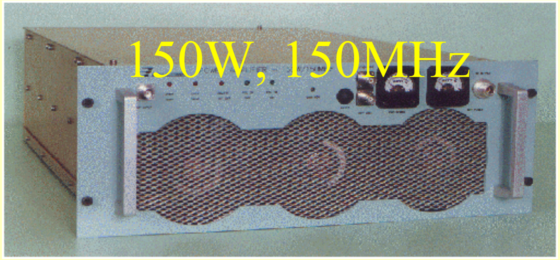
Faraday cup

Magnetic Steerer

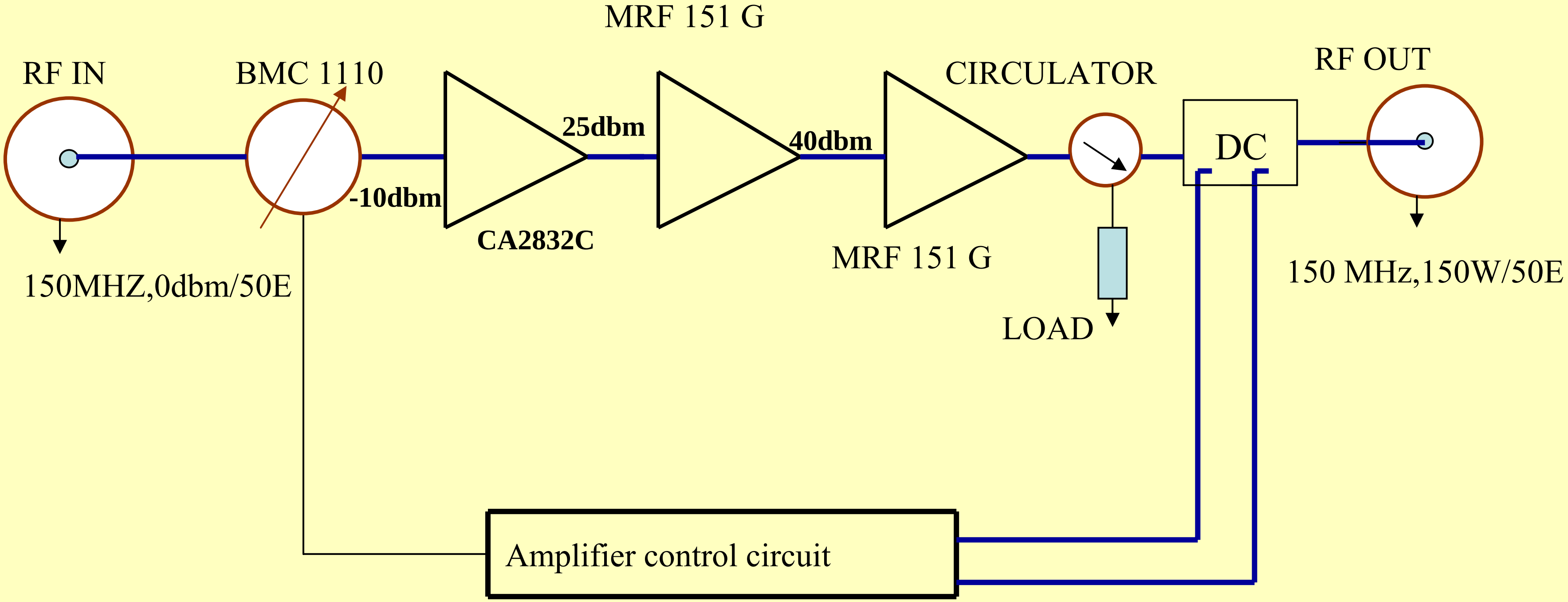
FC Controller internal view



RF POWER AMPLIFIER



For Conditioning Resonators



Collaborative effort of BEL, BARC-TIFR and IUAC