FEL Activities In India

Srinivas Krishnagopal

Beam Physics & FEL Laboratory, RRCAT, Indore

28th International FEL Conference,

28 August – 1 September 2006, Berlin, Germany

Collaborators

Vinit Kumar	Kamal Kumar Pant	*Former BP&FEL Members*
Arvind Kumar	Umesh Kale	Rajesh Gupta
Bhaskar Biswas	Shankar Lal	Renuka Rajput
Pravin Nerpagar	V. Kodiarasan	Bhas Bapat
Pratima Jain	Saket Gupta	

Sanjay Chouksey (CAT), Vijendra Prasad (CAT), S. Mahadevan (IGCAR), Rohin Parkar

Major Accelerator Laboratories in India

- **Raja Ramanna Centre for Advanced Technology (RRCAT)**
  (INDUS light sources, CUTE-FEL, photoinjectors, SNS)
- **Bhabha Atomic Research Centre (BARC)**
  (ADS injector linac, industrial linacs)
- **Variable Energy Cyclotron Centre (VECC)**
  (variable energy & superconducting cyclotrons)
- **Tata Institute of Fundamental Research (TIFR)**
  (Pelletron + s/c post-accelerator)
- **Inter-University Accelerator Centre (IUAC)**
  (Pelletron + s/c post-accelerator)

FEL-related Activities

(1) Terahertz Free-Electron Laser

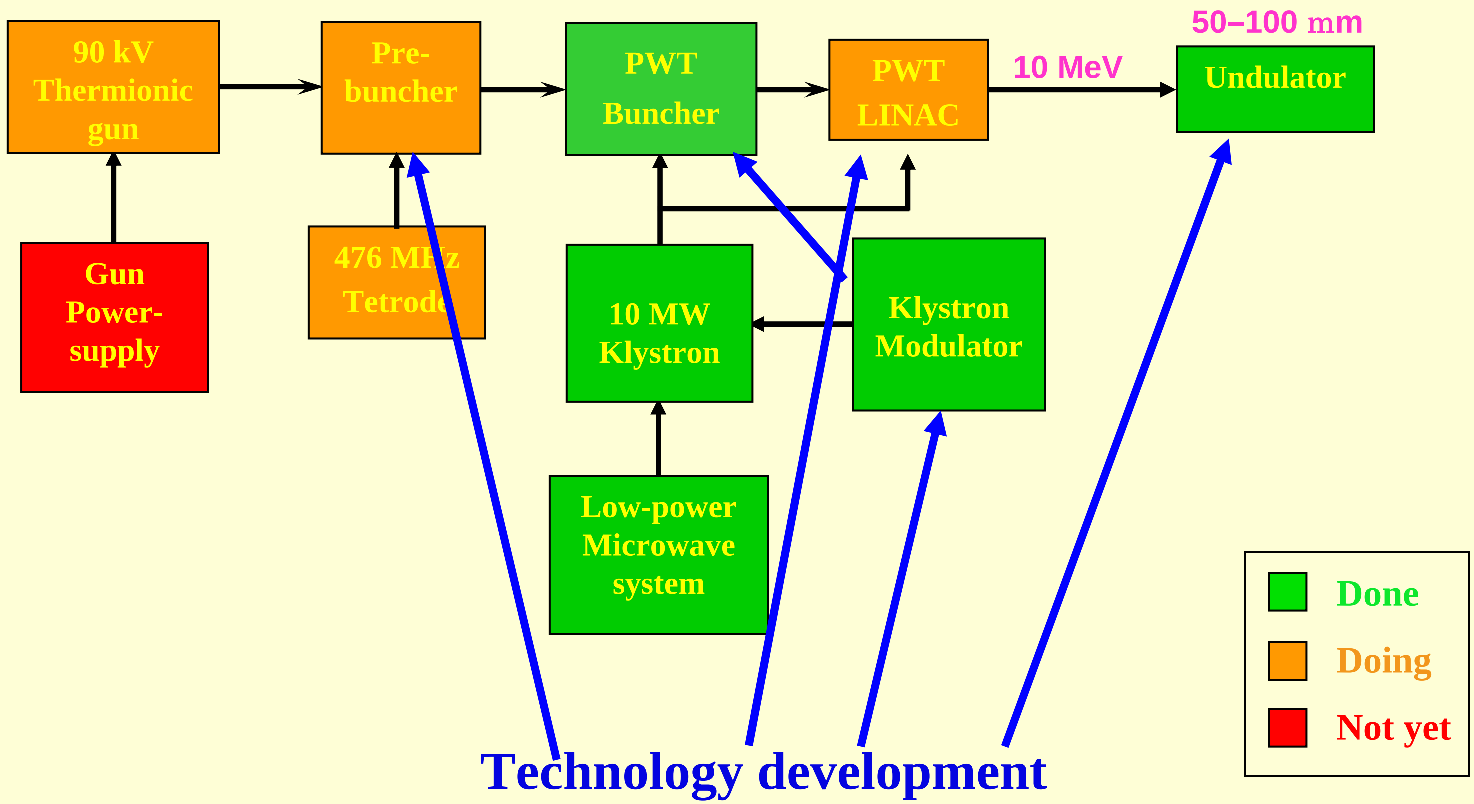
Tunable terahertz radiation from 50-100 μm. Driven by a 10-15 MeV linac with a thermionic gun and PWT structure. Planar, Halbach, pure-permanent magnet undulator, 5 cm period, 2.5 m length, developed in-house.

(2) Photoinjectors

High-brightness electron beams from an S-band photocathode gun, based on the BNL/SLAC/UCLA Gun 3 design; Plane Wave Transformer (PWT) linac structures; 25 MW klystron modulator.

The CUTE-FEL Project

We are building a **C**ompact, **U**ltrafast, **TE**rahertz **F**ree-**E**lectron **L**aser (**CUTE-FEL**), lasing between 50 – 100 mm (with a 10-15 MeV electron beam).



The CUTE-FEL Parameters

Electron beam parameters

Energy	10 – 15 MeV
RMS energy spread	0.5%
Peak current	20 A
RMS norm. emittance	30p mm-mrad

(200-100 cm^{-1} ; 6-3 THz)

Radiation parameters

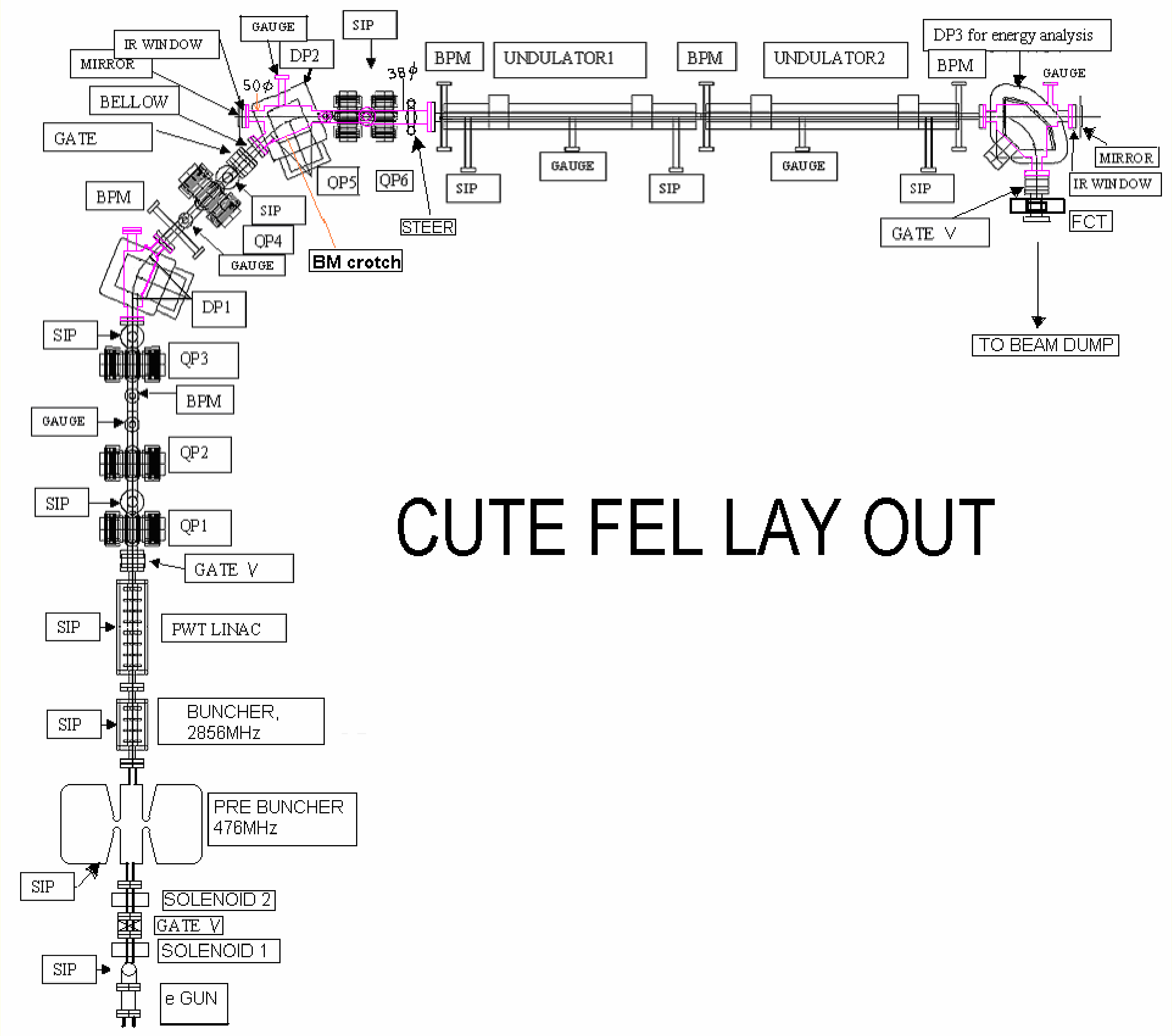
Wavelength	50-100 μm
Cavity length	4.1 m
Mirror reflectivity	0.99%
Out-coupling hole diameter	4 mm

Undulator parameters

Type	PPM, Halbach, planar
Period length	50 mm
Undulator length	2.5 m
Gap	35 – 100 mm
Max. undulator param.	0.80
Magnet material	NdFeB
Magnet size	12.5 x 12.5 x 50 mm^3

Gen. 1

CUTE FEL LAY OUT

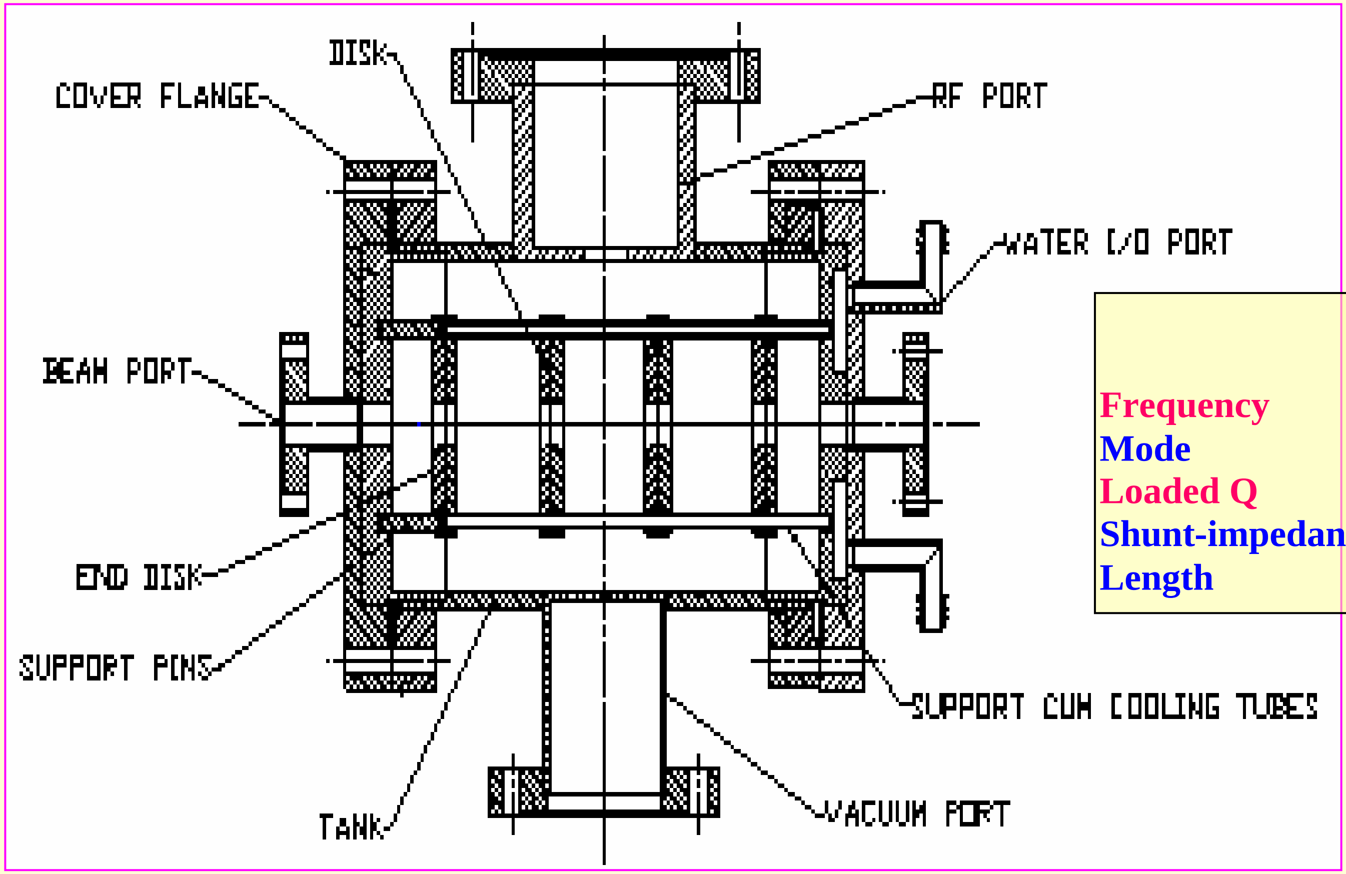


Pre-buncher

Prototype designed, developed and tested. Final pre-buncher designed and indented

The Plane Wave Transformer (PWT) Linac

The Plane Wave Transformer (PWT) linac is a new kind of linac structure, with strong coupling and hence looser fabrication tolerances and higher shunt impedance. The only operating PWT linac is at UCLA.



Parameters

Frequency	2856 MHz
Mode	π mode
Loaded Q	8,000
Shunt-impedance	486 Ohms
Length	21 cm

PWT linac design simulations

[A. Kumar, et al., Phys. Rev. ST Accel. Beams, 5, 033501 (2002)]

TABLE III. Input beam parameters for PARMELA simulations.

Parameters	Values at input end of PWT structure
Bunch charge	1 nC
Bunch length	10 ps
Bunch distribution	Gaussian
Peak current	100 Amps
Initial energy	5 MeV
Average field gradient	32 MV/m

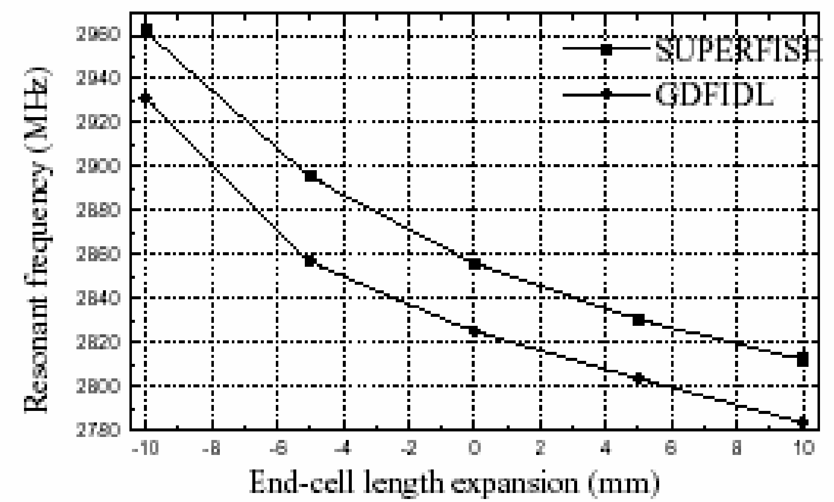
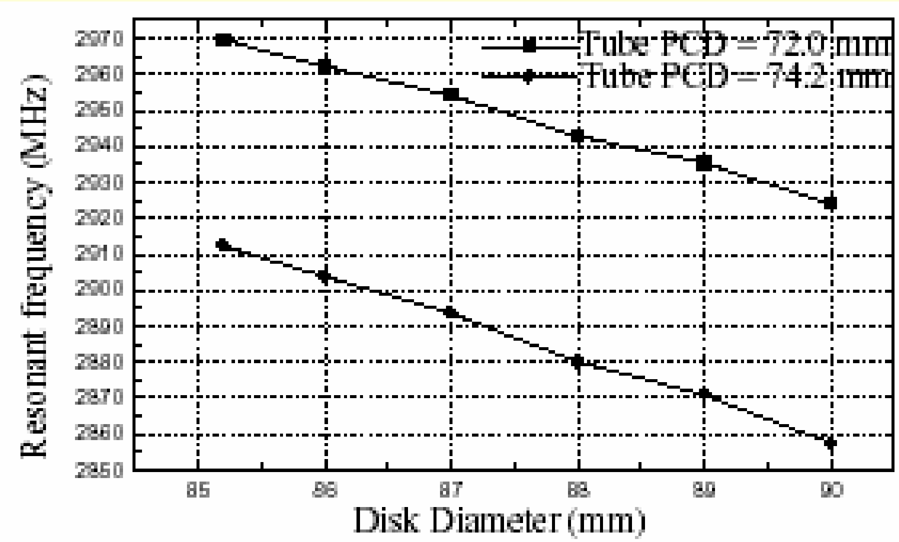


FIG. 5. Structure length effect on resonant frequency of the PWT linac structure.



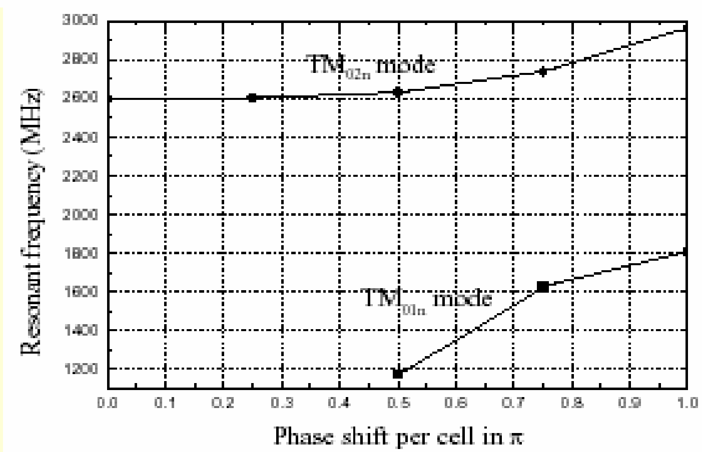
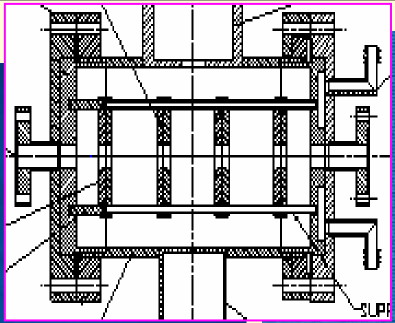
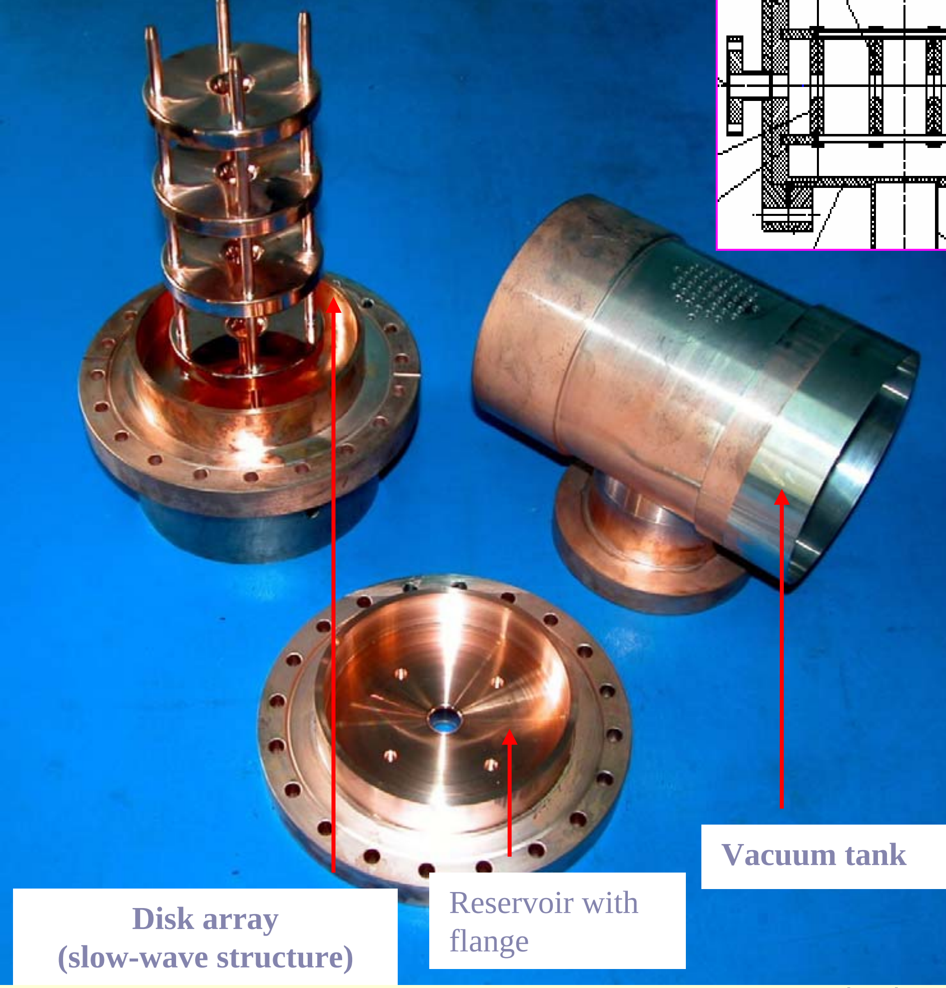


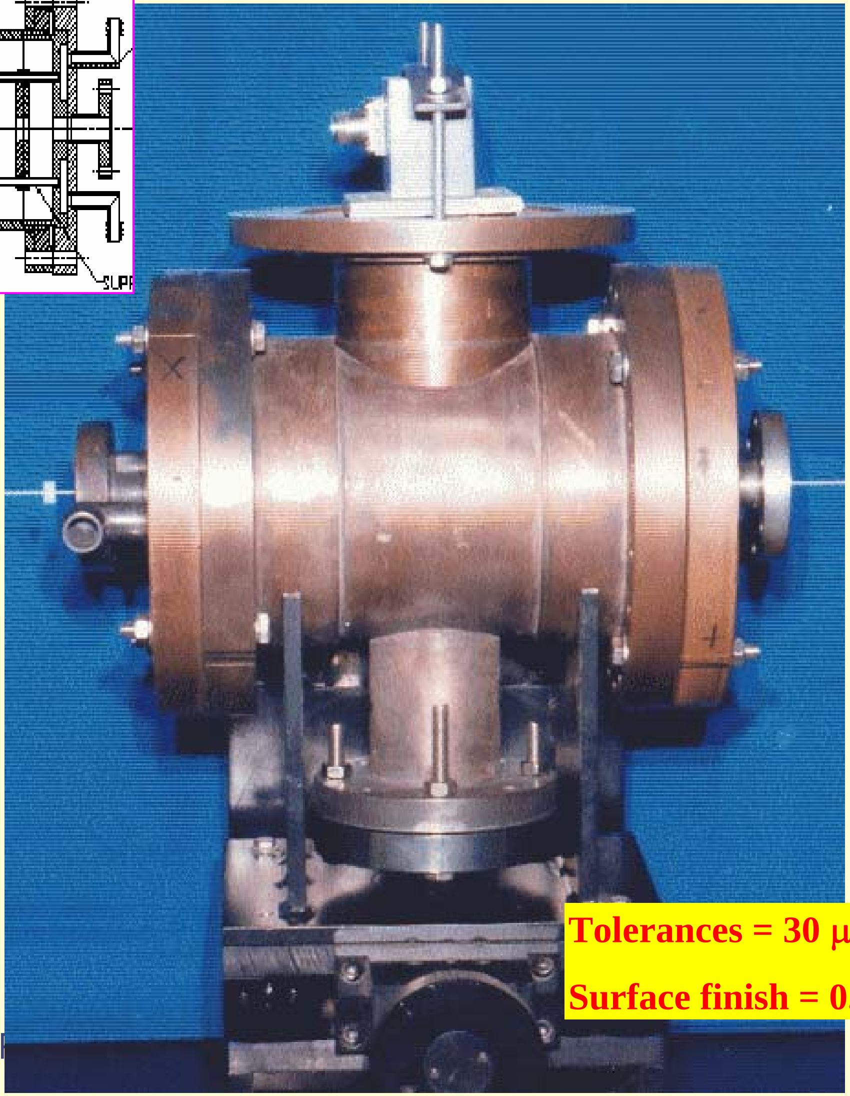
FIG. 6. Dispersion curves for the 4-cell PWT structure.

PWT linac fabrication

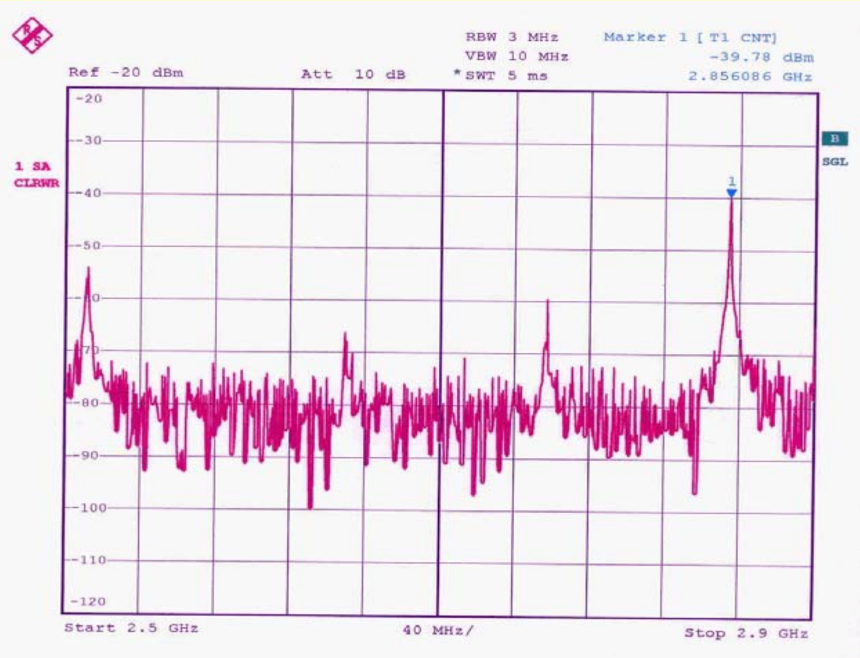
We have successfully developed the technology for fabricating linac structures

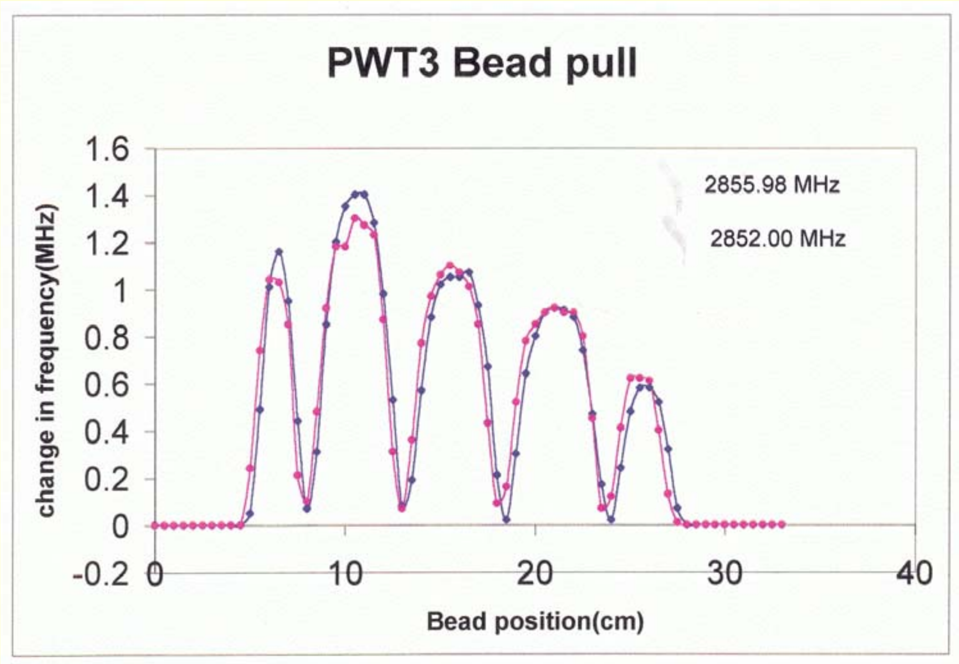


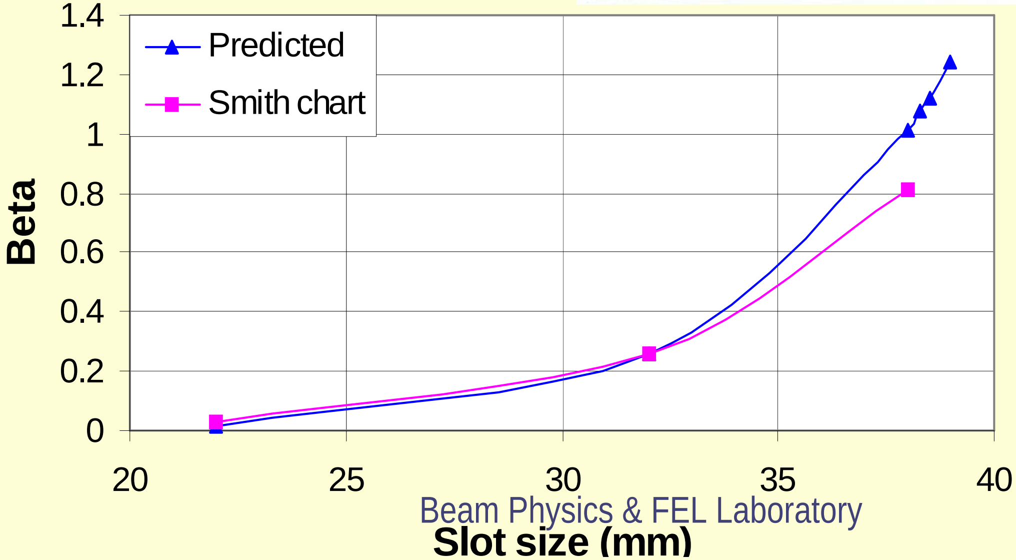




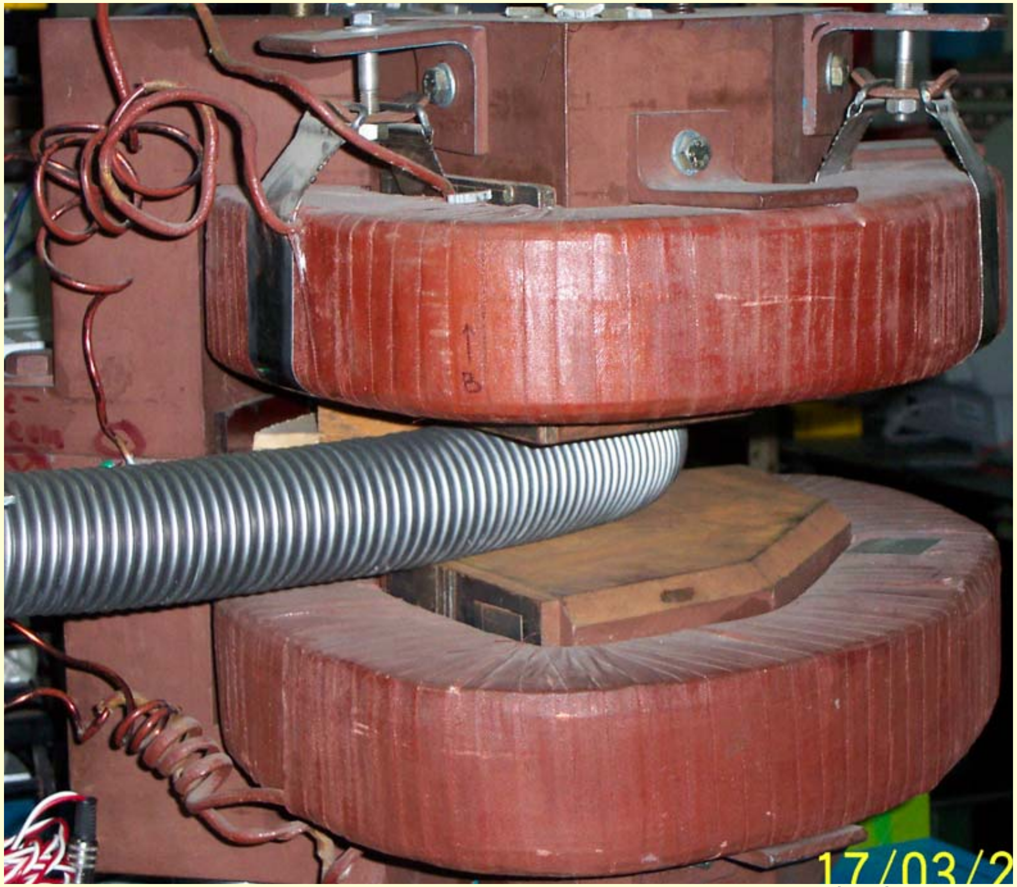
PWT linac test results



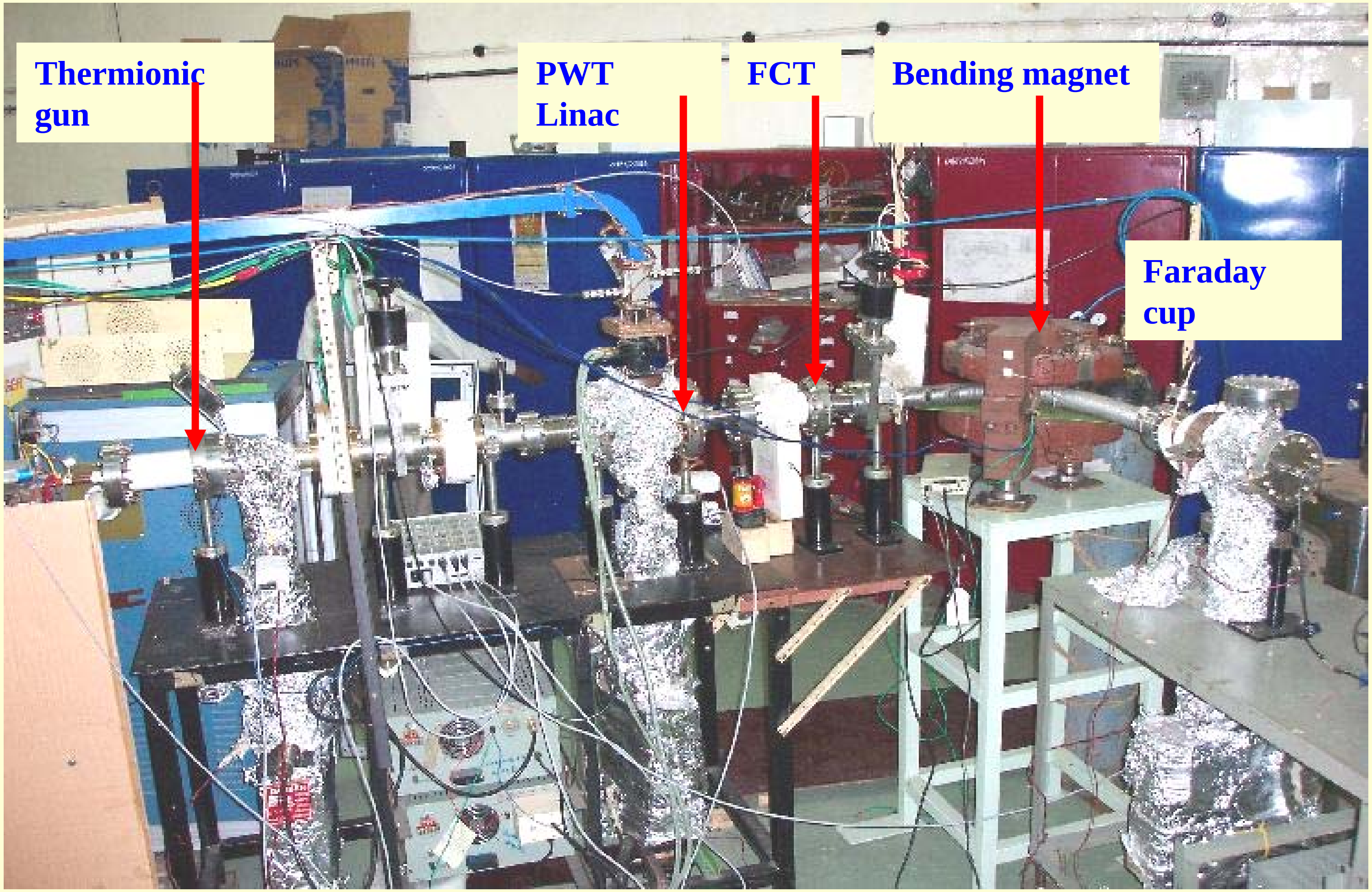




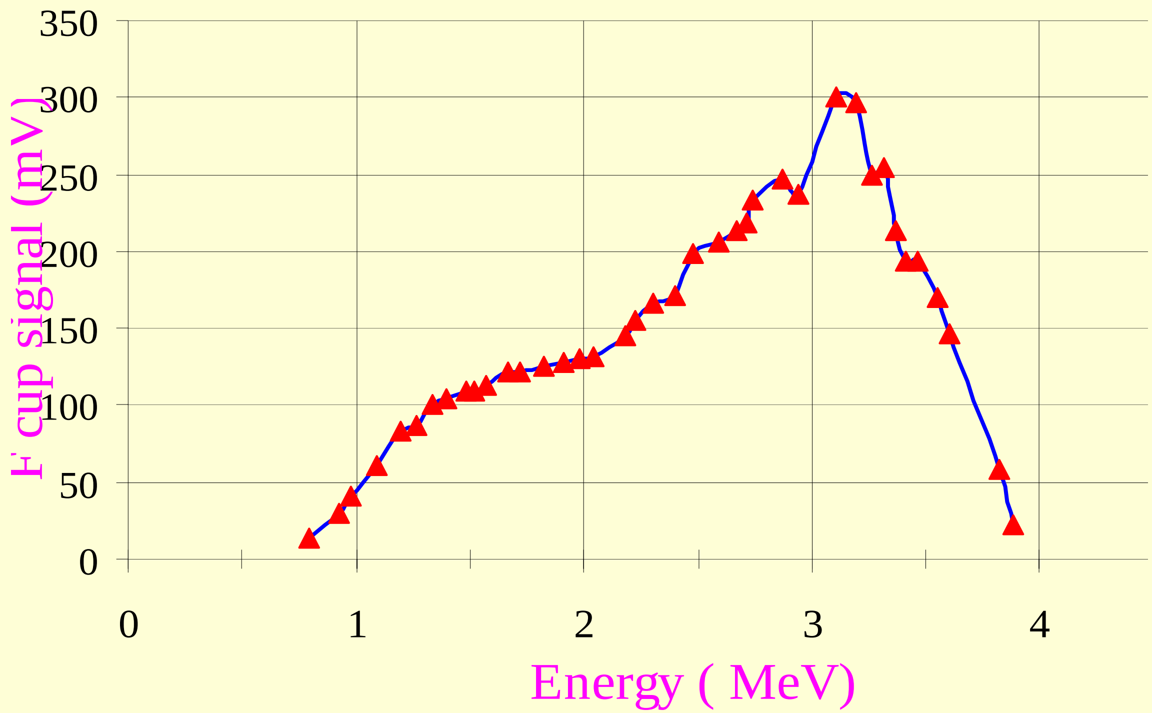
Dipole & quadrupole magnets



Setup for acceleration trials with PWT3 structure



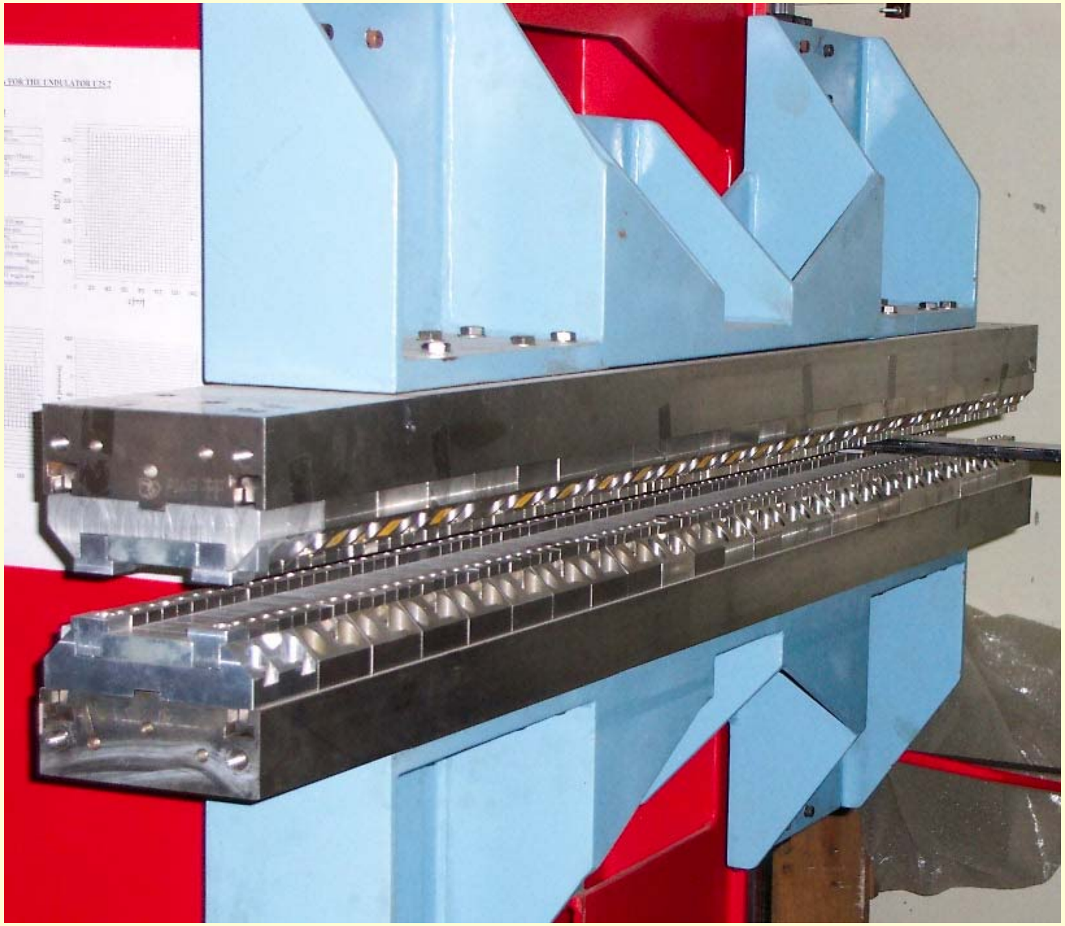
Acceleration results



<u>Figure</u>: Beam was injected into the linac from a DC gun, so electrons will be accelerated to different energies, depending on the RF phase that they see. The figure shows the energy spectrum of the accelerated electrons.

- **Maximum acceleration energy = 3.7 MeV (in 21 cm)**
- **Accelerating gradient achieved ~ 25 MV/m (with 5 MW RF power)**

Undulator



Parameters

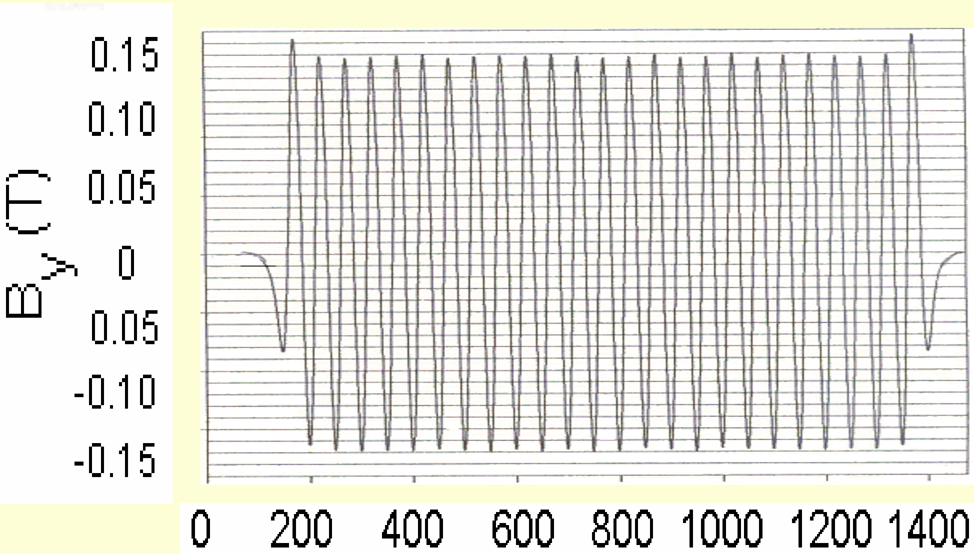
Type	**Pure permanent magnet**
Magnet material	**NdFeB**
Magnet size	**12.5x12.5x50 mm^3**
Undulator period	**5 cm**
Undulator length	**2.5 m**
Gap variation	**33 – 100 mm**
Max. und. Parameter	**0.80**

R
Y
B
OFF
DANGER
Keep Distance.
recision aligned structure.
e do not touch/disturb.
TRAJECTORY OF U25.2 WITH CORRECTOR COIL
FIELD, 9FEB2005
S.B.3
I.C.FROM
18/10/2005

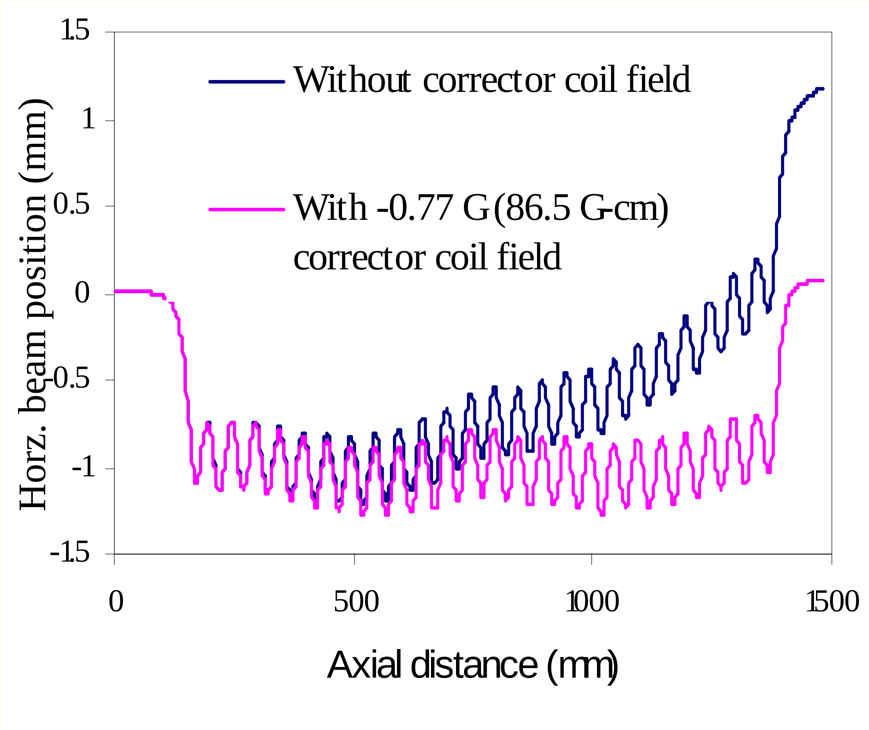
Characteristics of U25.1 and U25.2

Παραμετερ	Design	U25.1	U25.2
Ερρορ ιν Πεακ φιελδ (ρμσ)	<1%	0.9%	0.7%
Ερρορ ιν περιοδ (ρμσ)	<100 microns	82 micr.	80 micr.
Πηασε σηακε (ρμσ, δεγρεε)	< 5	2	2
Beam wander (r.m.s.)	< 0.5	1.14	0.33

VERTICAL FIELD AND TRAJECTORIES



Vertical Field in U25.1



Horizontal Trajectory in U25.1, with and without corrector coil

Undulators are now ready to accept beam from the linac

Photocathode gun

Nominal Parameters

- 4-5 MeV energy
- 1 nC charge (in 10 ps)
- Cu photocathode
- 5 mJ (IR) Nd:VAN laser

[A. Kumar, et al., Phys. Rev. ST Accel. Beams, 5, 103501 (2002)]

TABLE II. Comparison of the measured and simulated results.

	SUPERFISH Design values (MHz)	SUPERFISH (Fabricated) (MHz)	GDFIDL Fabricated) (MHz)	Cold tests (MHz)
Full-cell	2789	2788	2789	2795
Half-cell	2854	2883	2881	2898
Coupled cells	2856	2883	2881	2875

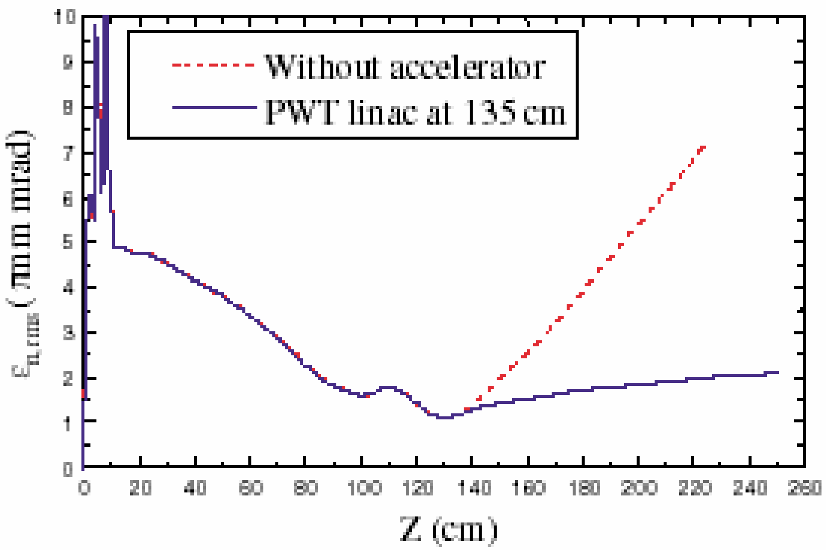


FIG. 9. (Color) PARMELA simulations for transverse emittance variation with distance, with a solenoid magnet field of 4.5 kG at 16 cm from cathode and a 4-cell PWT linac at 135 cm.

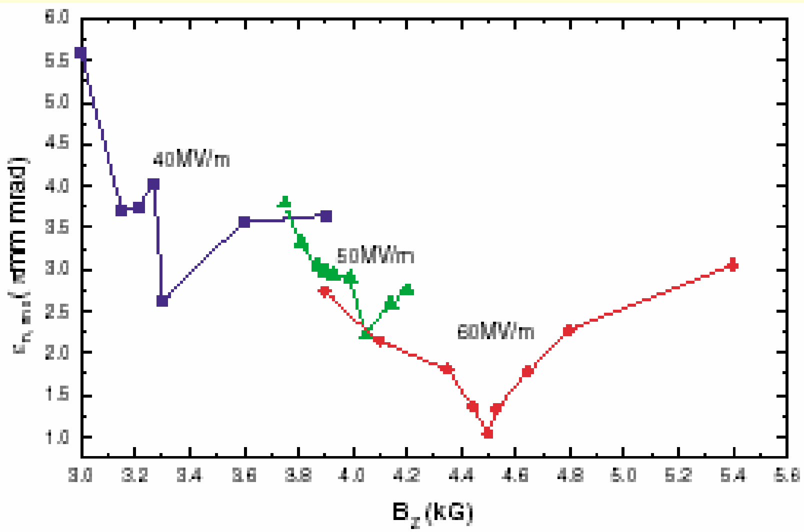
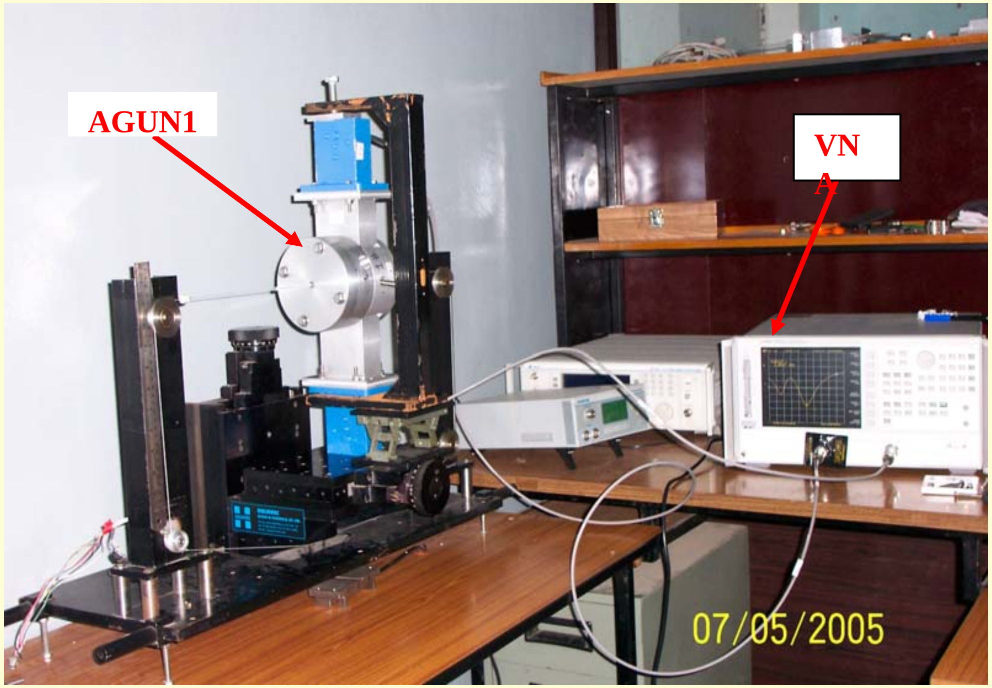
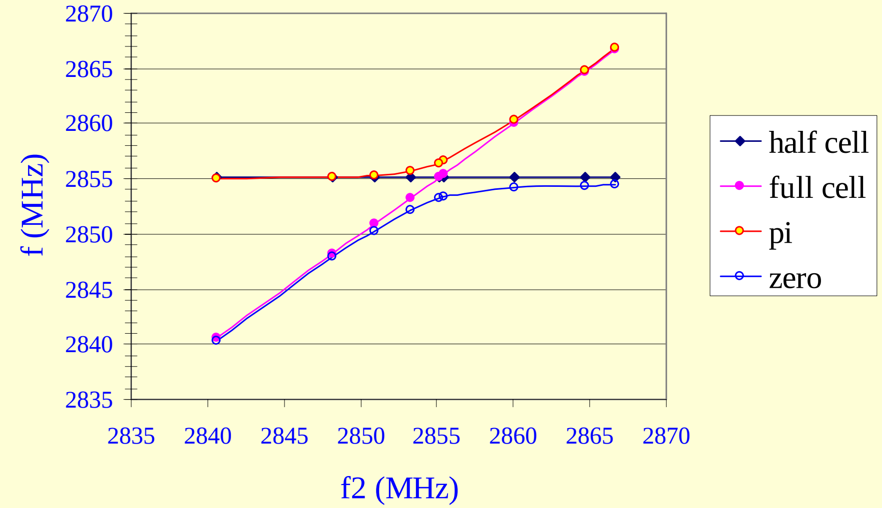


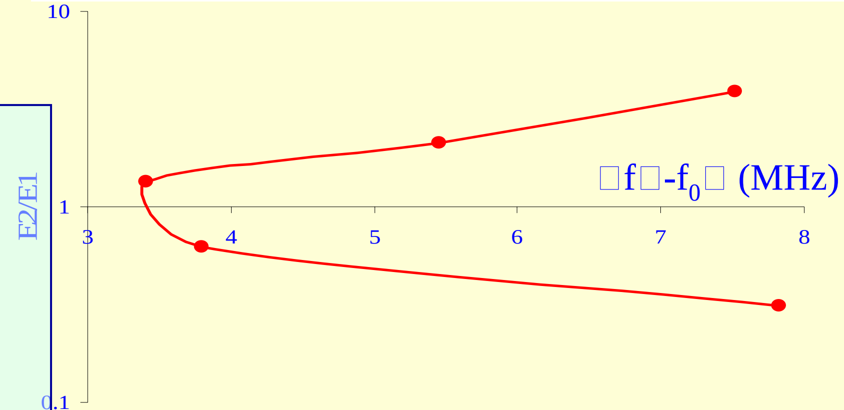
FIG. 4. (Color) Normalized transverse rms emittance variation with magnetic field for different electric field gradients.

Cold model investigations





Modal vs independent full cell frequency



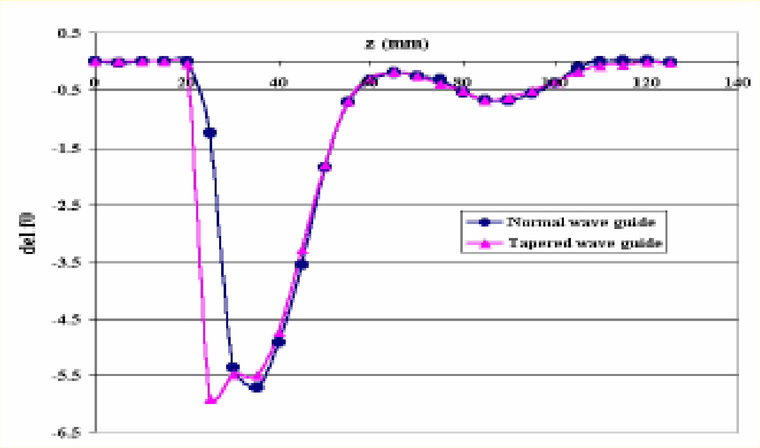
Field balance vs mode separation

Prototyping

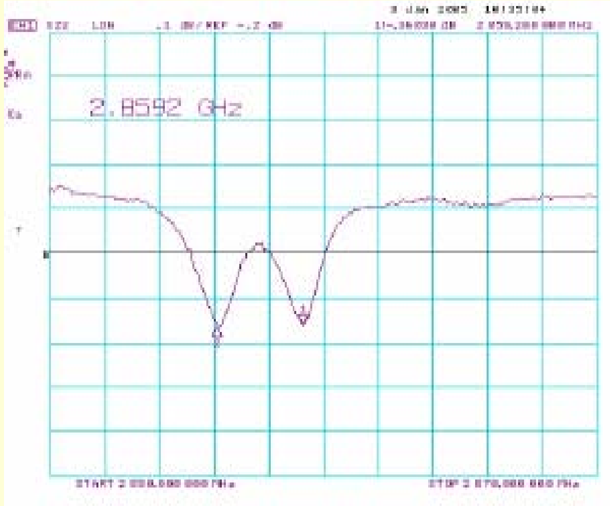
- Two OFE Cu prototypes for qualifying machining by difft. Vendors
- Two ETP Cu prototypes for qualifying brazing
- Two Al prototypes for physics tests and tuning
- Two ETP Cu prototypes for tuning the gun

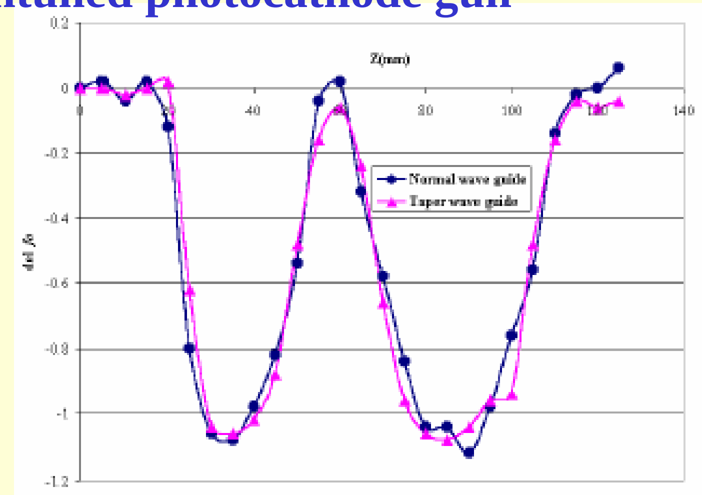
Tuning the photocathode gun

Need to tune to get: (i) p mode at 2856 MHz; (ii) b ~ 1; (iii) field balance ~ 1



Spectrum and bead-pull for the untuned photocathode gun

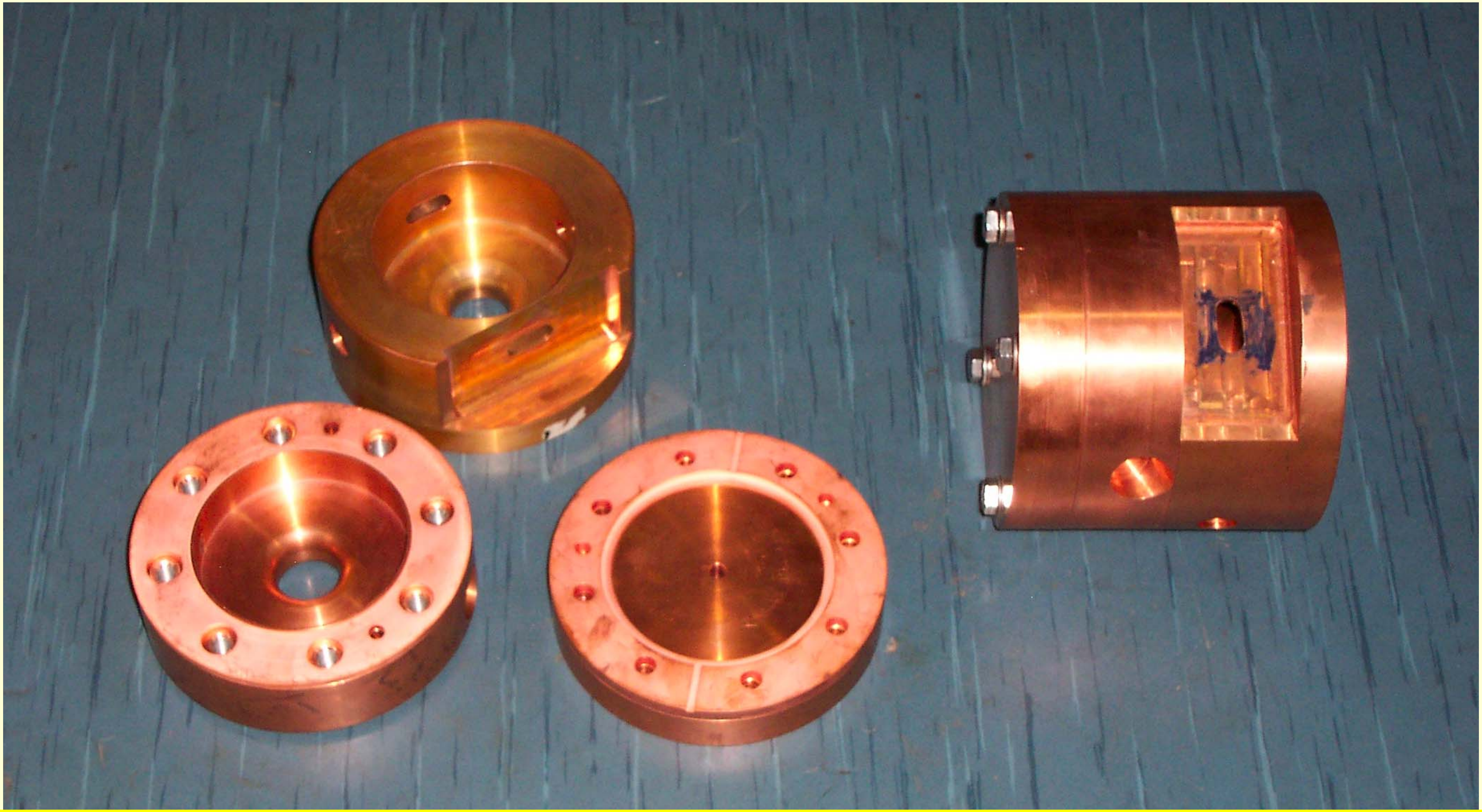




Spectrum and bead-pull for the tuned photocathode gun (100 mm cut on full cell)

Al prototypes

ETP Cu prototypes



We have placed an order for fabricating four photocathode guns

Future Plans

- **An Indo-French Workshop on FELs was held in Goa, India, in March this year.**
- **Feedback from the Indian users was that a 4GLS would be highly desirable, but recommended a staged approach.**
- **Substantial interest even in an IR-FEL facility**

Roadmap for a 4GLS

	Stage I	Stage II	Stage III
Wavelength (nm)	1,000	10	0.1
Energy (GeV)	0.1	1	10
Norm. emit. (mm.mrad)	5	3	1
Undulator Period (mm)	50	30	30
Undulator Length (m)	5	30	100
Undulator Parameter ‘K’	1	1.5	3
Peak Current (kA)	0.1	2	4
Pulse Structure (fs @ Hz)	1,500 @ 50	150 @ 50	75 @ ???
Accelerator Technology	Normal; S-band	Normal; S-band	???

SUMMARY

- **Right now we are getting ready to inject beam from the linac into the undulator for the CUTE-FEL**

- **There is substantial user interest for an IR-FEL facility (Stage I of the proposed roadmap)**

- **We are also looking for approval for detailed design studies for a DUV-FEL (Stage II of the roadmap) – where we look forward to collaboration with the international community**

Acknowledgements

- **Power Supplies Division, RRCAT**

  S. Kotaiah, A.C. Thakurta, T.A. Puntambekar, S.R. Tiwari, M. Gandhi, M. Koli

- **Instrumentation & Controls Division, RRCAT**

  A. G. Bhujle, V. Bhanage, L. Jain, V.P. Singh

- **Magnet Division, RRCAT**

  S.S. Prabhu, R.S. Shinde, K. Ruwali

- **RFM Section, RRCAT**

  P.R. Hannurkar, P. Shrivastava

- **Coolant Systems Section, RRCAT**

  Pravin Kumar, R.M. Pandey

- **Vacuum Section, RRCAT**

  S. K. Shukla, V. Sathe

- **DMRL, DRDO & LPSC, ISRO (brazing)**

  K. Mallikharjuna Rao, Rajeshwar Rao

  P. Raghuthama Rao, D. Gangadhar, C. Karthikeyan, M. Gani, K. Ravi Kumar