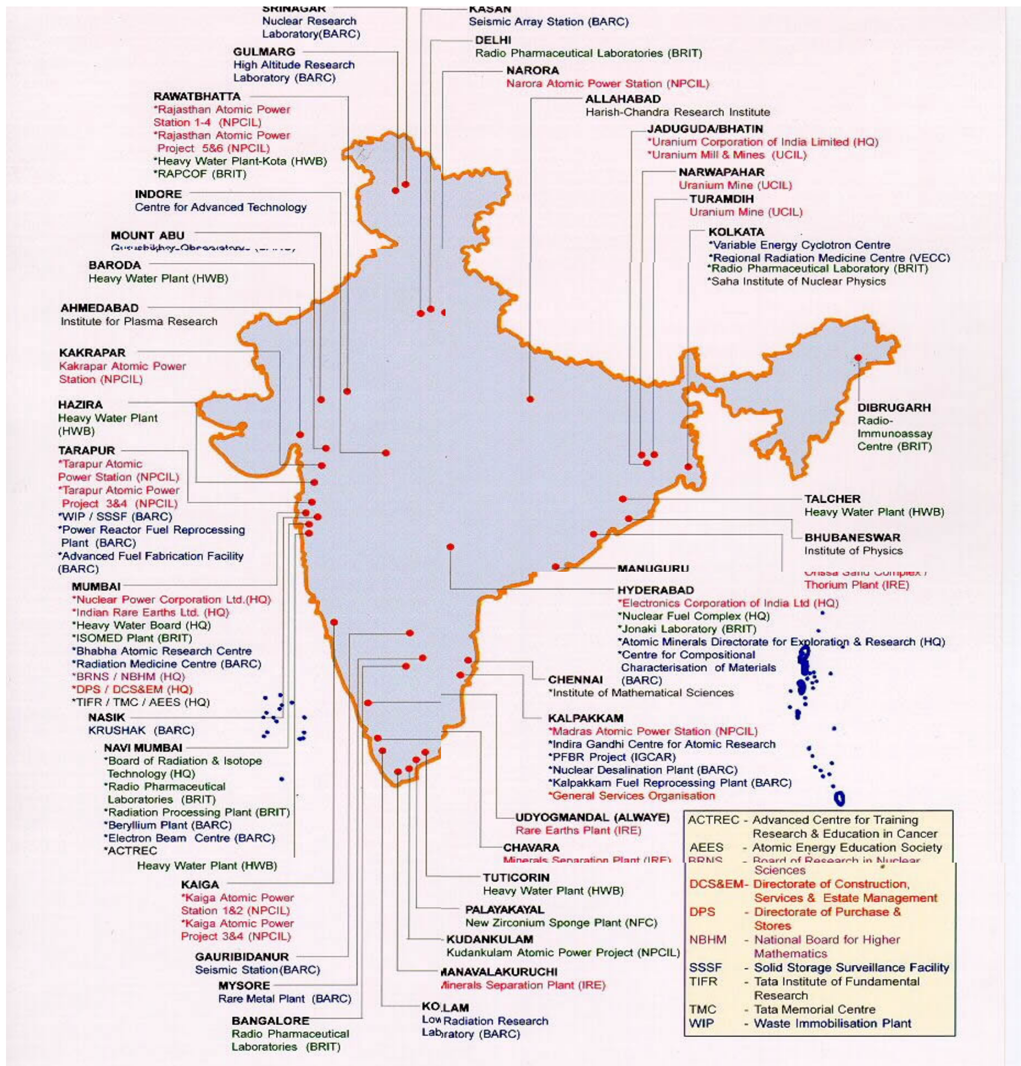
Indian Synchrotron Light Sources
Indus-1 & Indus-2

Gajendra Kumar Sahoo
MPY, DESY

Atomic Energy Establishments in India




INDIA
States and Union Territories
N
JAMMU & KASHMIR
Srinagar
HIMACHAL PRADESH
Shimla
Chandigarh
PUNJAB
UTTARANCHAL
Dehradun
DELHI
HARYANA
PAKISTAN
CHINA (TIBET)
ARUNACHAL PRADESH
NEPAL
SIKKIM
Gangtok
BHUTAN
Itanagar
ASSAM
Dispur
NAGALAND
Kohima
Shillong
Imphal
MANIPUR
MEGHALAYA
Agartala
TRIPURA
Aizawl
MIZORAM
MYANMAR
RAJASTHAN
Jaipur
UTTAR PRADESH
Lucknow
Patna
BIHAR
GUJARAT
Gandhinagar
Bhopal
MADHYA PRADESH
Ranchi
JHARKHAND
WEST BENGAL
Calcutta
CHHATTISGARH
Raipur
ORISSA
Bhubaneshwar
BANGLADESH
DIU
DAMAN
DADAR & NAGAR HAVELI
MAHARASHTRA
Mumbai (Bombay)
ARABIAN SEA
Hyderabad
ANDHRA PRADESH
YANAM (Pondicherry)
BAY OF BENGAL
Panaji
GOA
KARNATAKA
Bangalore
LAKSHADWEEP
Chennai (Madras)
PONDICHERRY (Puduchchery)
MAHE (Pondicherry)
TAMILNADU
KARAIKAL (Pondicherry)
Port Blair
ANDAMAN & NICOBAR ISLANDS
KERALA
Thiruvananthapuram
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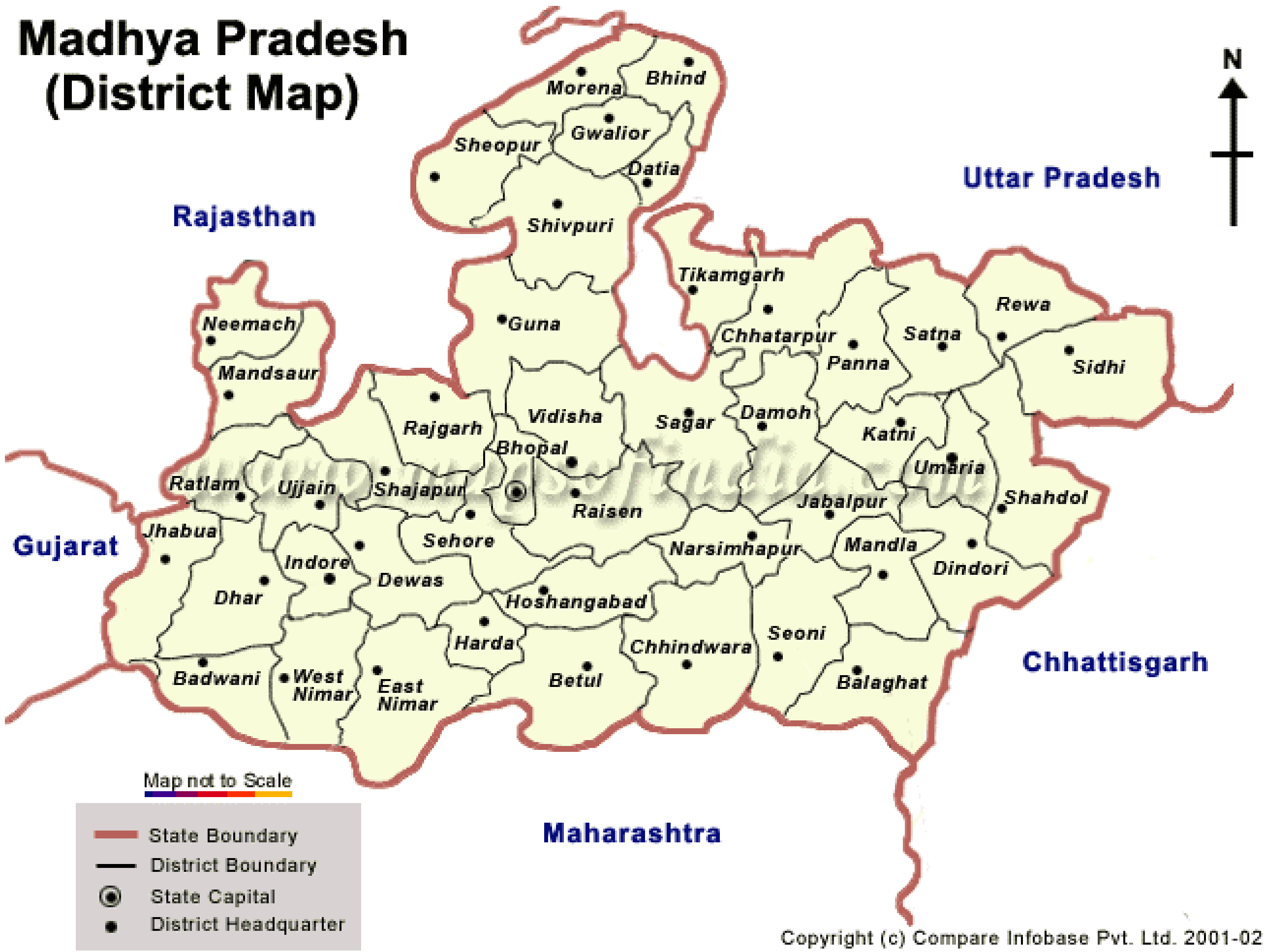
Map not to Scale


Madhya Pradesh
(District Map)
Rajasthan
Uttar Pradesh
Gujarat
Chhattisgarh
Maharashtra
N
Morena
Bhind
Sheopur
Gwalior
Datia
Shivpuri
Tikamgarh
Guna
Neemach
Mandsaur
Chhatarpur
Panna
Satna
Rewa
Sidhi
Rajgarh
Vidisha
Bhopal
Sagar
Damoh
Katni
Umaria
Shahdol
Ratlam
Ujjain
Shajapur
Raisen
Jabalpur
Jhabua
Sehore
Narsimhapur
Mandla
Dindori
Indore
Dhar
Dewas
Hoshangabad
Harda
Chhindwara
Seoni
Badwani
West Nimar
East Nimar
Betul
Balaghat
Map not to Scale
State Boundary
District Boundary
State Capital
District Headquarter
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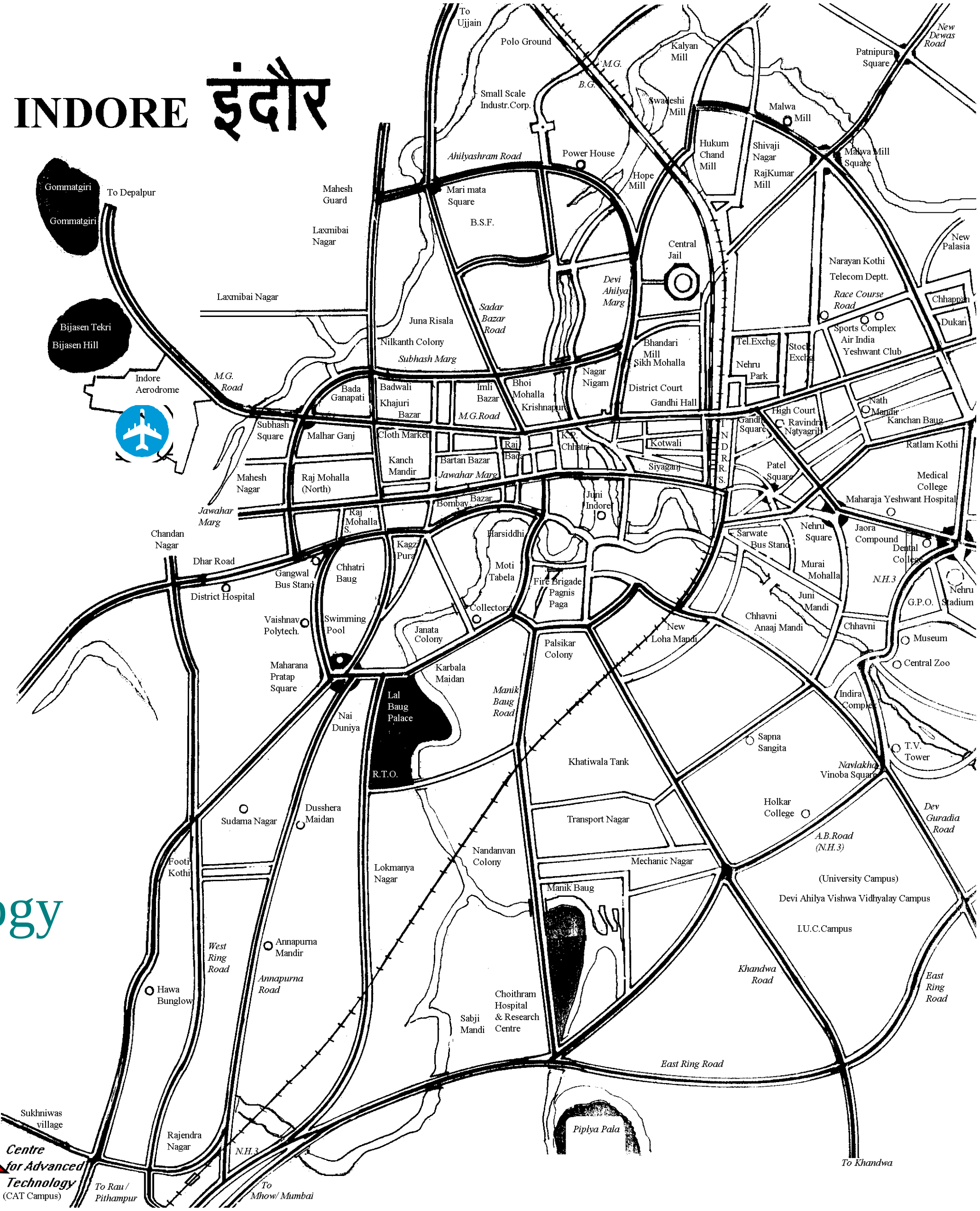


Centre for Advanced Technology

Department of Atomic Energy

Govt. of India

History of accelerators in India

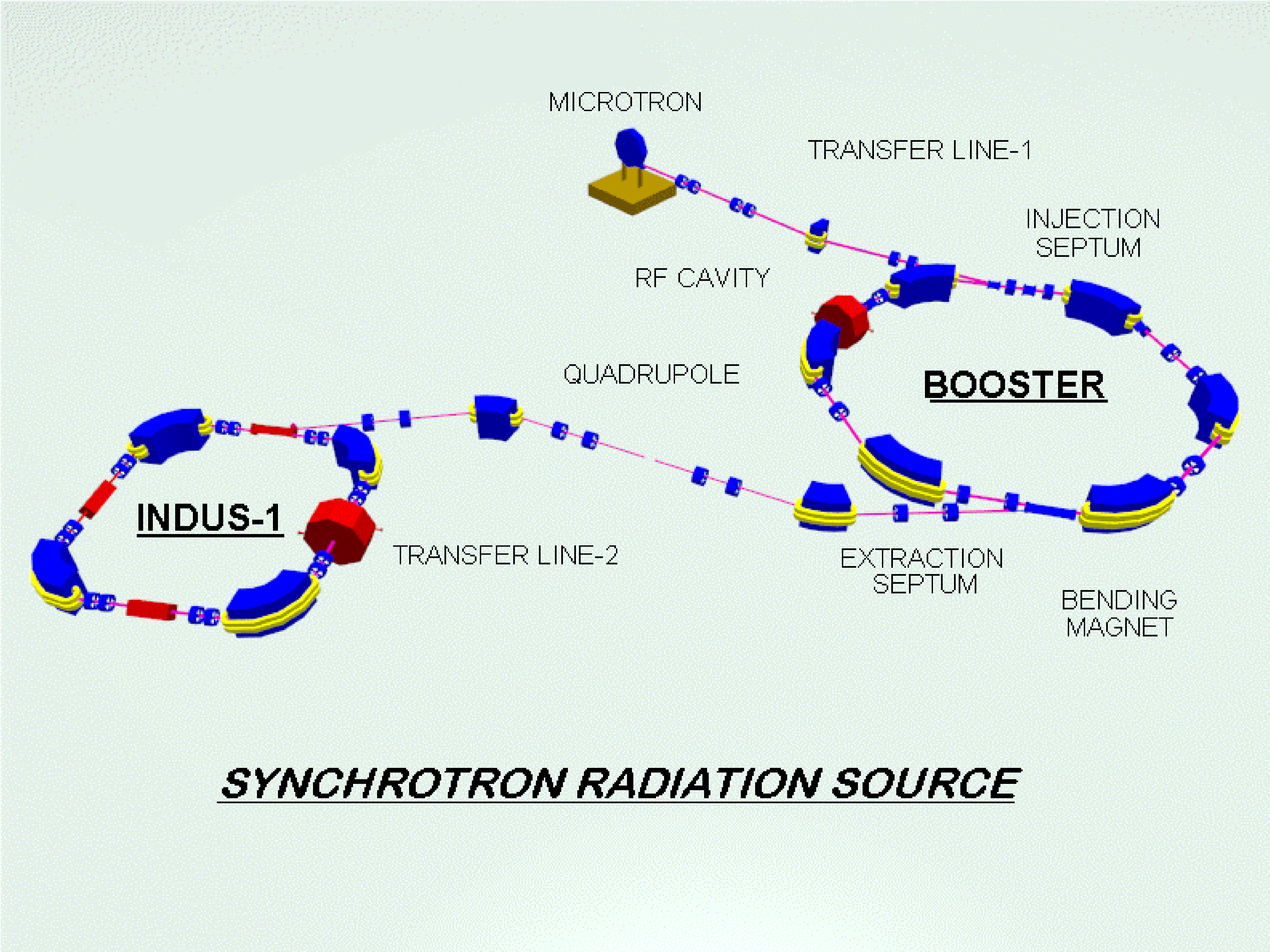
- The development of accelerators in India started in 1940 when Prof. Meghnad Saha developed a 37" cyclotron at Saha Institute of Nuclear Physics, Kolkotta.
- A 1 MeV Cascade Generator was commissioned at Tata Instutute of Fundamental Research, Mumbai (1950).
- A 5.5 MeV Van-de-Graff accelerator was installed at Bhabha Atomic Research Centre, Mumbai (1960).
- The accelerator technology in India took a great leap on indigenously designed and built of a 224 cm diameter Variable Energy Cyclotron at VEC Centre, Kolkotta (1978).
- Successful operation of 14 MeV Pelletron at TIFR, Mumbai and NSC, New Delhi (1989).

Contents

- INDUS SRS facility (US$3.8 Million)
  - Pre-injector Microtron
  - Injector Synchrotron
  - 450MeV Storage Ring(Indus-1)
- Commissioning
- Indus-2 design & status (US$18.4 Million)

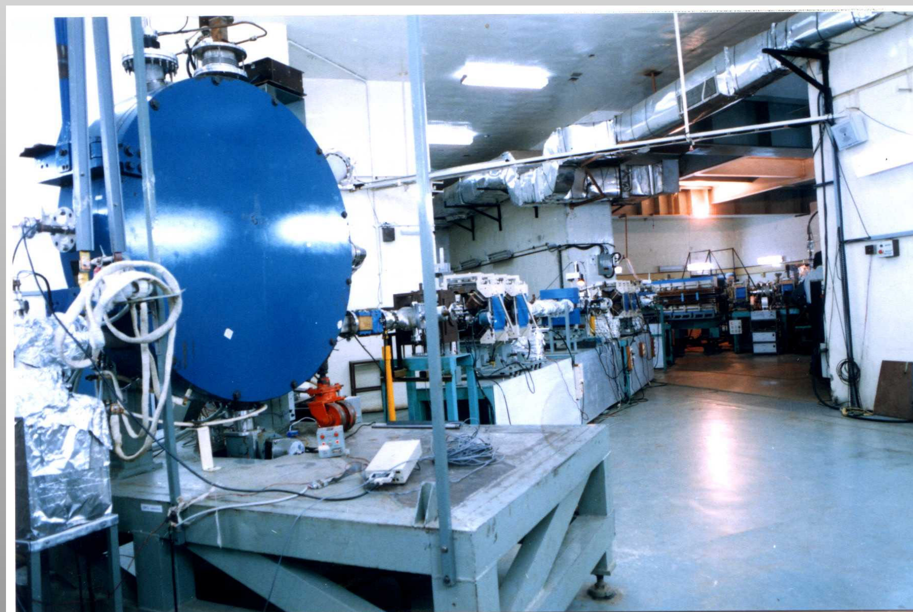
Indus-1
Synchrotron Radiation Facility

- 20 MeV Classical Microtron - as Preinjector
- Transfer Line -1
- 20 - 700 MeV (Max.) Booster Synchrotron
- Transfer Line -2
- 450 MeV Electron Storage Ring - Indus-1


MICROTRON
TRANSFER LINE-1
INJECTION SEPTUM
RF CAVITY
QUADRUPOLE
BOOSTER
INDUS-1
TRANSFER LINE-2
EXTRACTION SEPTUM
BENDING MAGNET
SYNCHROTRON RADIATION SOURCE

20 MeV Microtron

- The 20MeV microtron is of classical … Its major components are an …rating cavity and a dipole …t. The directly heated electron …r LaB_6 has been incorporated … the accelerating cavity …ing at 2.856GHz. The electrons …d from the cathode are …rated to 20MeV in 22 orbits … Type-II injection scheme.



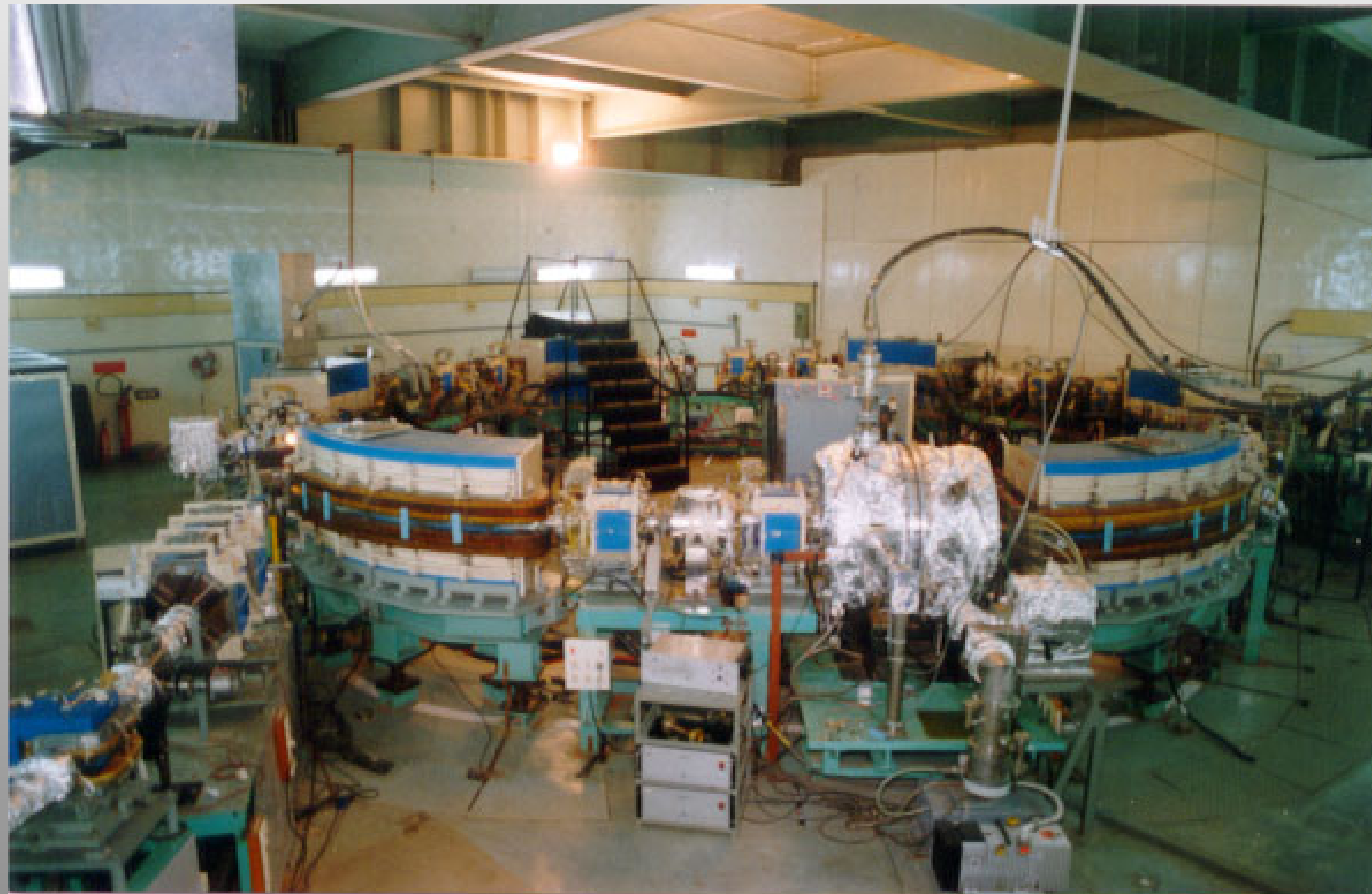
20 MeV Microtron

- The microtron was commissioned towards the end of 1994. Since then it is regularly delivering a 20MeV beam of pulse current 20mA, pulse length 1μs at a repetition rate of 1Hz.

Transfer Line - 1

- Transfer Line -1 transports 20 MeV electrons from the microtron to the synchrotron.

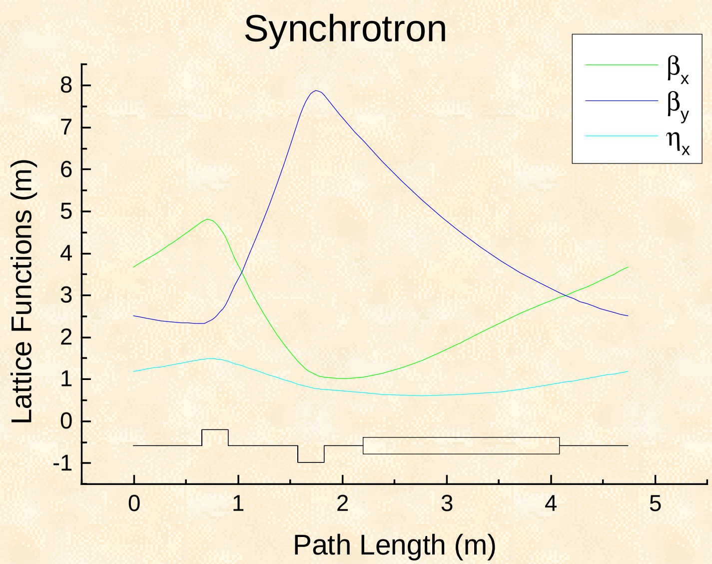
20 - 700 MeV Synchrotron



20 - 700 MeV Synchrotron

The synchrotron consists of six superperiods, each having a bending magnet and a quadrupole doublet. A multiturn injection scheme has been chosen for injecting 20MeV electrons extracted from the microtron to the synchrotron. The scheme requires three kickers to produce a compensated bump. These kickers are located in the straight section S1, S2 and S6. The synchrotron has a harmonic number of 3 and repetition rate of 1Hz. The accelerated electrons are extracted using fast kicker in S2 and having a rise time of 40-50ns. During the extraction process one out of the three bunches is lost and only two bunches are extracted out.

Synchrotron

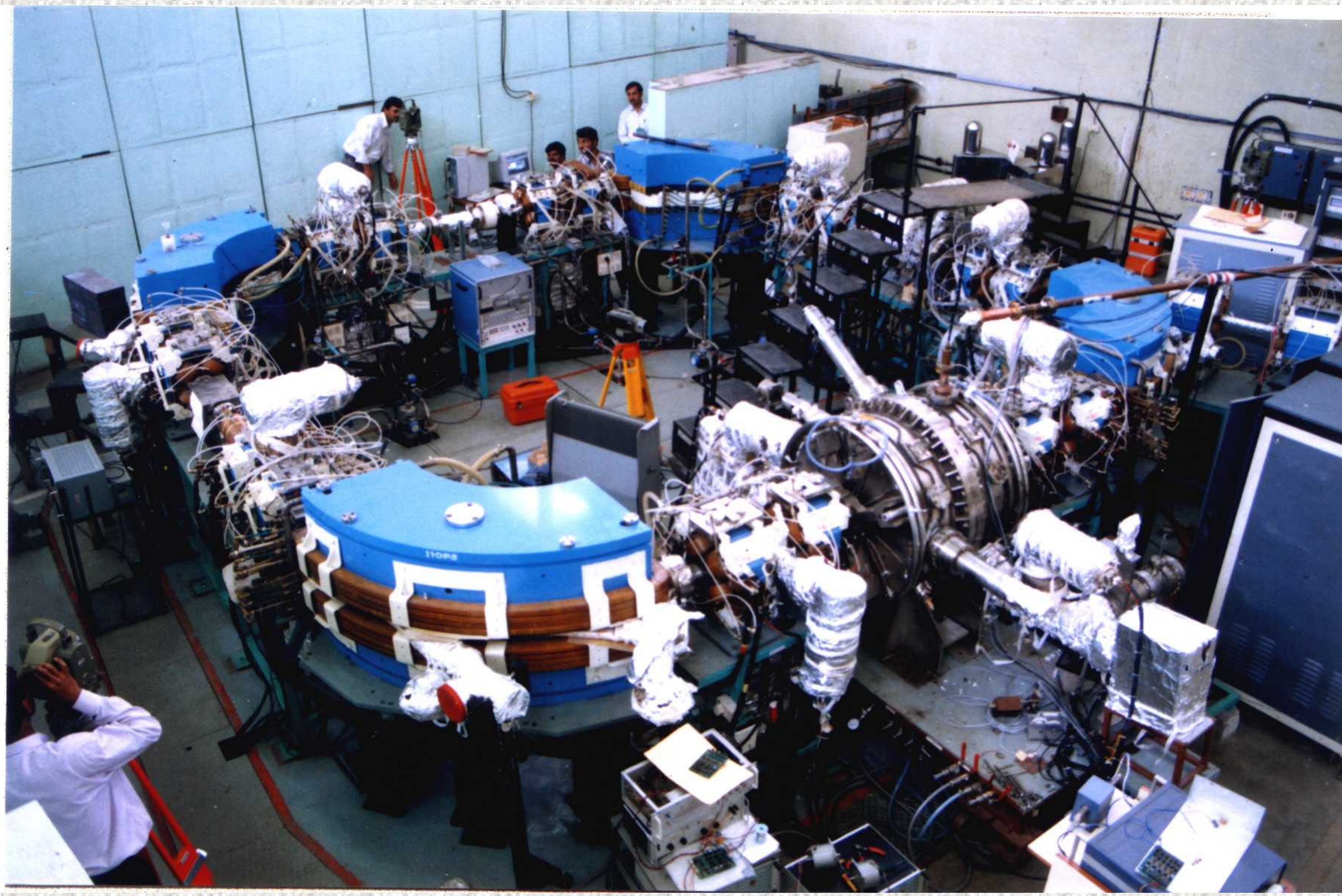


Energy	: 450-700MeV
Beam Current	: 11mA
Circumference	: 28.44m
Bending Field(Max.)	: 1.32T
Tune point	: 2.25, 1.22
(operating at)	: 2.20, 1.44
Beam emittance 450MeV	: 8.8×10^{-8} m.rad
700MeV	: 2.0×10^{-7} m.rad
Revolution Frequency	: 10.54MHz
Harmonic number	: 3
Momentum Compaction factor	: 0.151
Bunch length measured 450MeV	: 1.4ns

Transfer Line - 2

Two bunches out of three are extracted out of the synchrotron and are transported at 450 MeV to the Storage Ring Indus-1 in Transfer Line - 2.

Storage Ring Indus-1



The magnetic lattice of the ring has four superperiods each consisting of a dipole magnet with a field index of 0.5 and two quadrupole doublets. Each superperiod has a 1.3m long straight section. The injection septum and RF cavity are installed in section S1 and S3 respectively. The injection kicker is installed in section S3. To correct the natural chromaticity a pair of sextupoles are used in each superperiod.

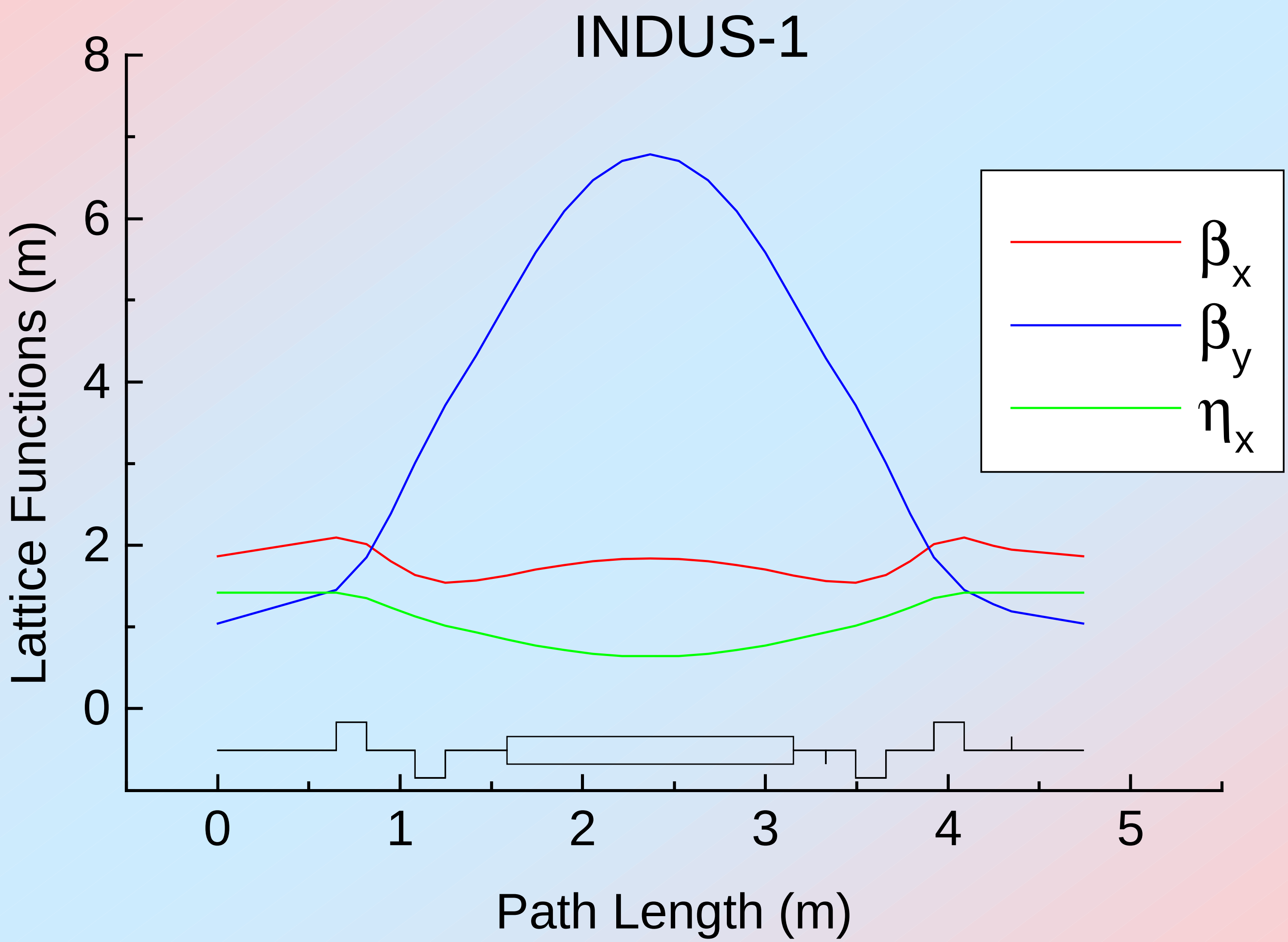
MAIN PARAMETERS OF INDUS -1

Energy	**450 MeV**
Current	**100 mA** *
Critical wavelength(λ_c)	**61.38 Å (BM)**
	30.69 Å (W)
Circumference	**18.966 m**
Bending radius	**1.0 m**
Superperiods	**4**
Beam emittance (ε_x)	**7.3 x 10^{-8} m.rad**
(ε_y)	**7.3 x 10^{-10} m.rad**
	(1% coupling assumed)
Beam size (σ_x)	**0.28 mm**
(σ_y)	**0.07 mm**
	(Centre of BM)
Photon flux (λ_c)	**7.2 x 10^{11} (BM)**
	7.2 x 10^{11} (W)
	Ph/(s.mrad.0.1 % BW)
Brightness (λ_c)	**3.2 x 10^{12} (BM)**
	3.0 x 10^{12} (W)
	Ph/(s.mm^2.mrad^2.0.1%BW)
RF frequency	**31.613 MHz**
Harmonic number	**2**
Beam lifetime	**2.0 hours** **

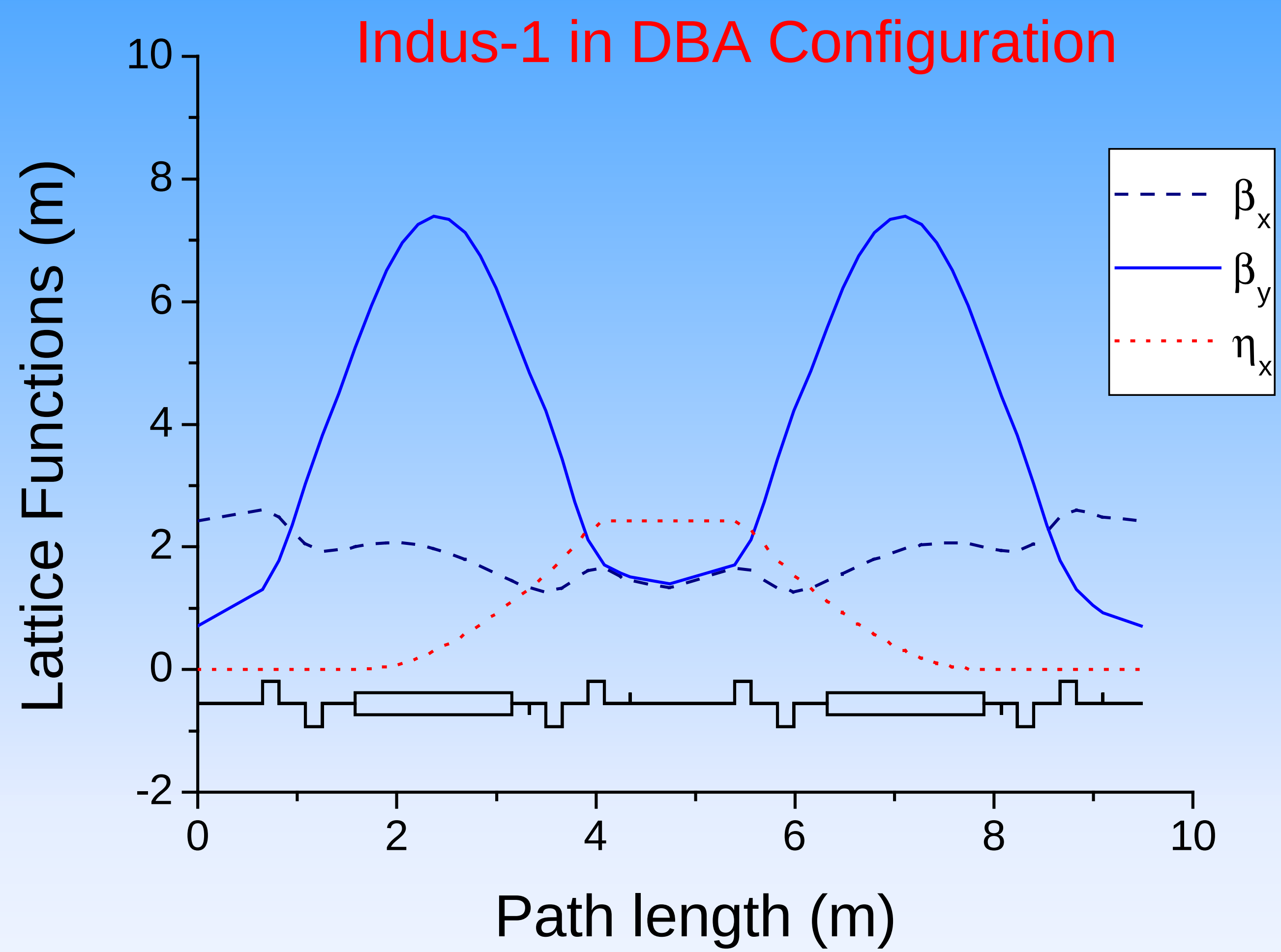
* 200 mA stored current achieved.

** 75 minutes at 100 mA achieved

BM : Bending Magnet (1.5 T) ; W : 3T Wiggler



INDUS-1
Lattice Functions (m)
8
6
4
2
0
0
1
2
3
4
5
Path Length (m)
β_x
β_y
η_x


Indus-1 in DBA Configuration
Lattice Functions (m)
Path length (m)
10
8
6
4
2
0
-2
0
2
4
6
8
10
βx
βy
ηx

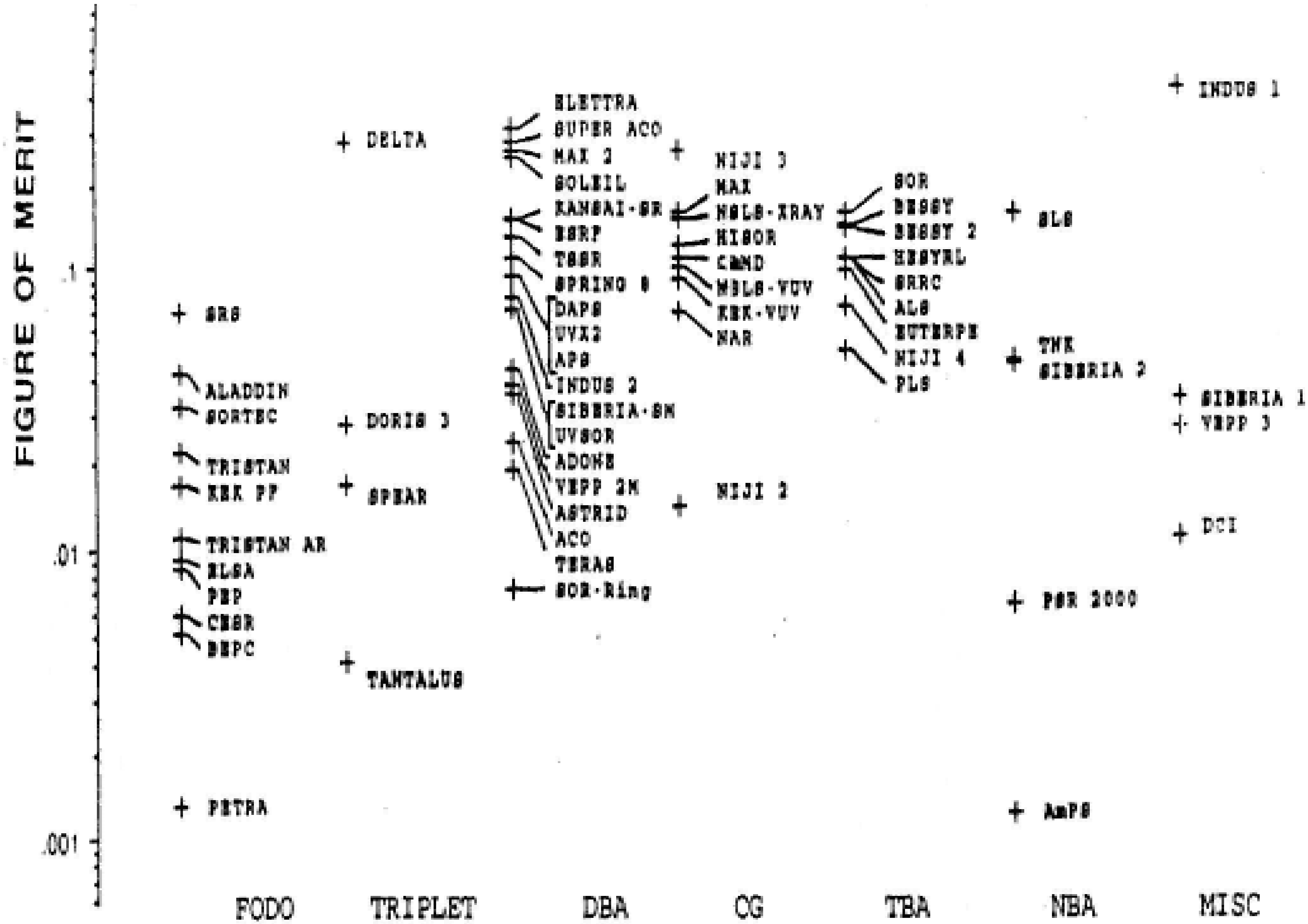
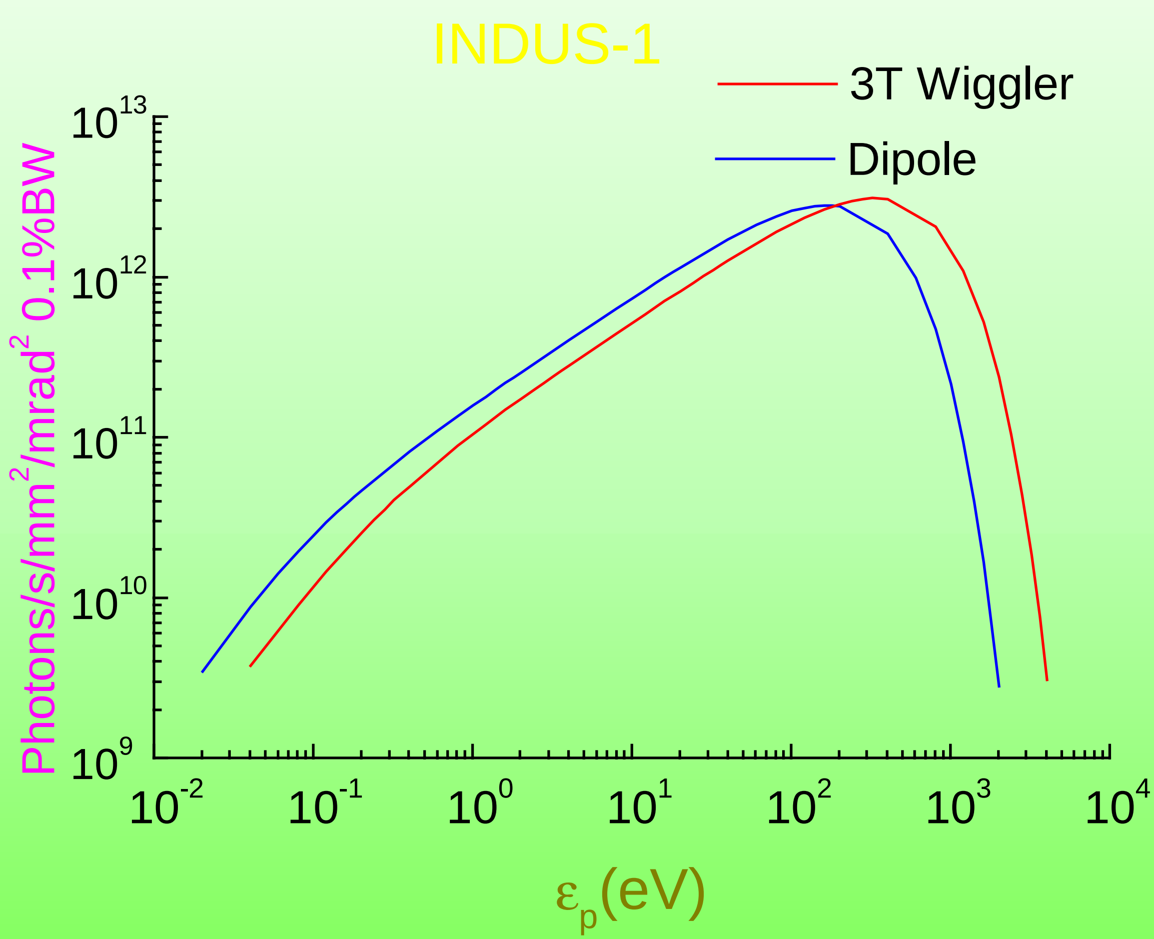
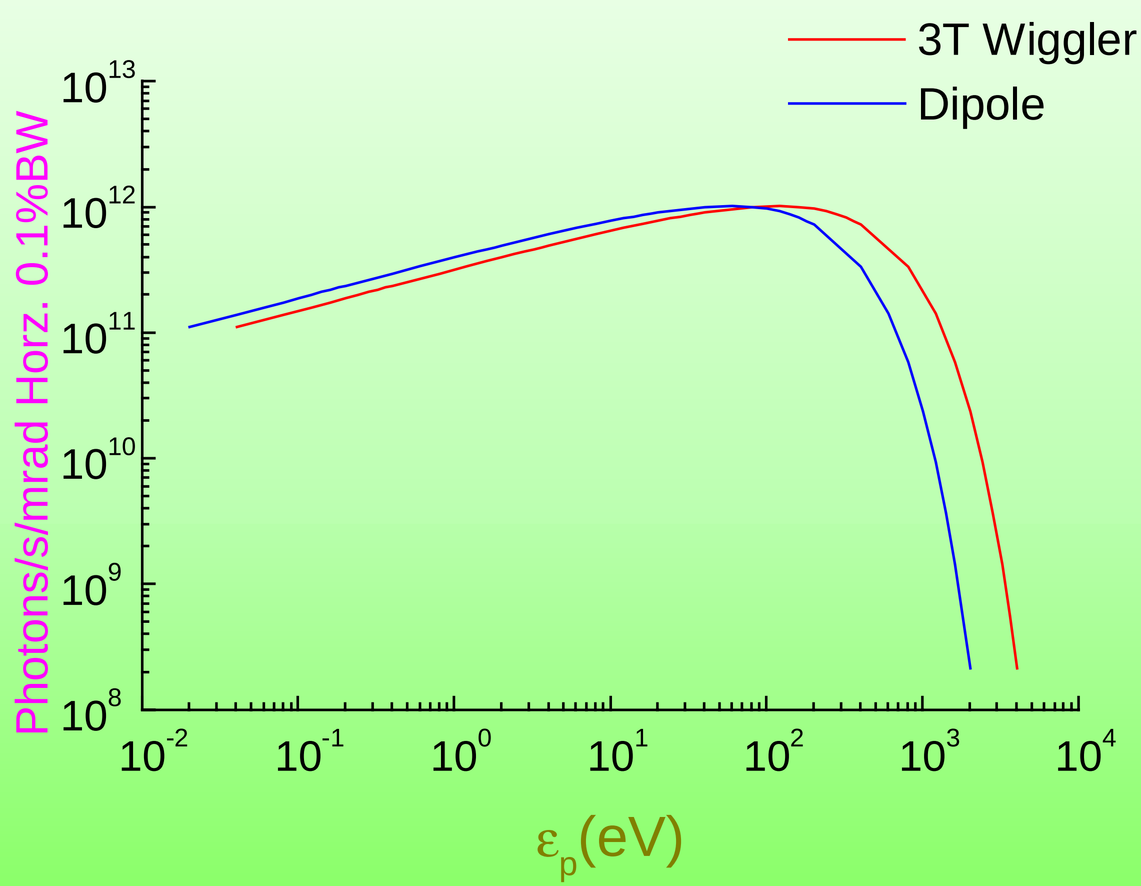


Figure 2. Emittance figure of merit versus lattice structure

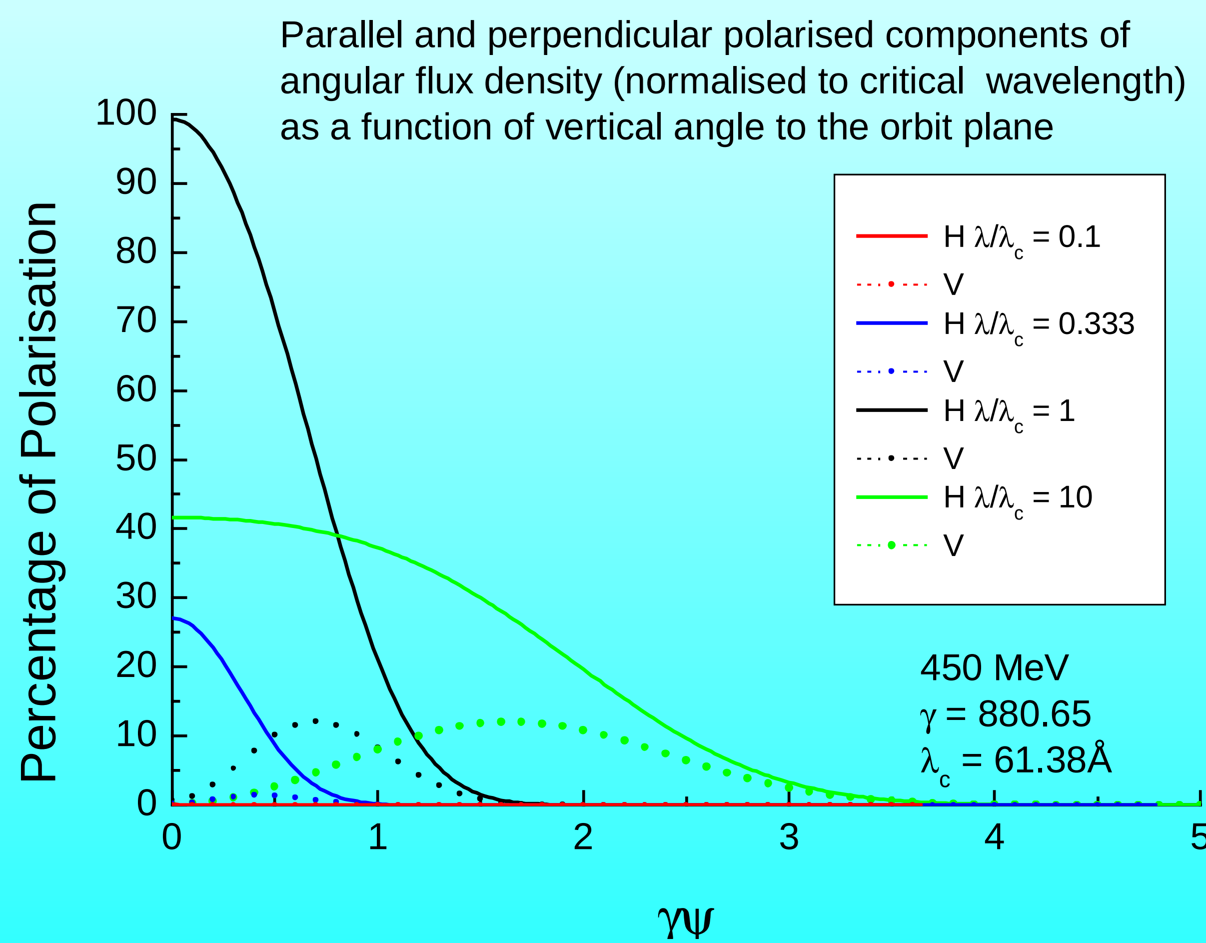
Indus-1: Source Brightness



Indus-1: Spectral Flux



Indus-1: Spectral Flux



Commissioning of Indus-1


Visible light from INDUS-1

Beamlines of INDUS-1

No.Beamlines	Preoptics	Monochromator	Postoptics	Type of Experiment
Centre for Advanced Technology, Indore/Bhabha Atomic Research Centre, Mumbai:				
1. Metrology	Toroidal Mirror	Toroidal Grating	Toroidal Mirror	Soft X-ray reflectivity, Calibration of detectors, General Purpose (40-1000Å)
2. Photoelectron Spectroscopy	Toroidal Mirror	Toroidal Grating	Toroidal Mirror	Angle resolved and angle integrated surface physics (40-1000Å)
3. VUV Spectroscopy	3 Cylindrical Mirrors	6.65m off axis Eagle mount Spectrograph		Atomic and molecular spectral studies (4-40eV with a resolution of 2×10^5)
4. Photophysics	Toroidal Mirror	Seya Nomioka	Toroidal Mirror	Time resolved spectroscopy (150-3000Å)
5. Photo Absorption Spectroscopy	Elliptical Mirror	Plane grating		L-edge absorption spectroscopy (20-1225Å)
Inter University Consortium, Indore:				
6. Photoelectron Spectroscopy	Toroidal Mirror	Toroidal Grating	Toroidal Mirror	Angle resolved and angle integrated surface physics (40-1000Å)
7. Photo Absorption Spectroscopy	Elliptical Mirror	Plane grating		L-edge absorption spectroscopy (20-1225Å)

Beamlines on Indus-1

Reflectivity Beamline

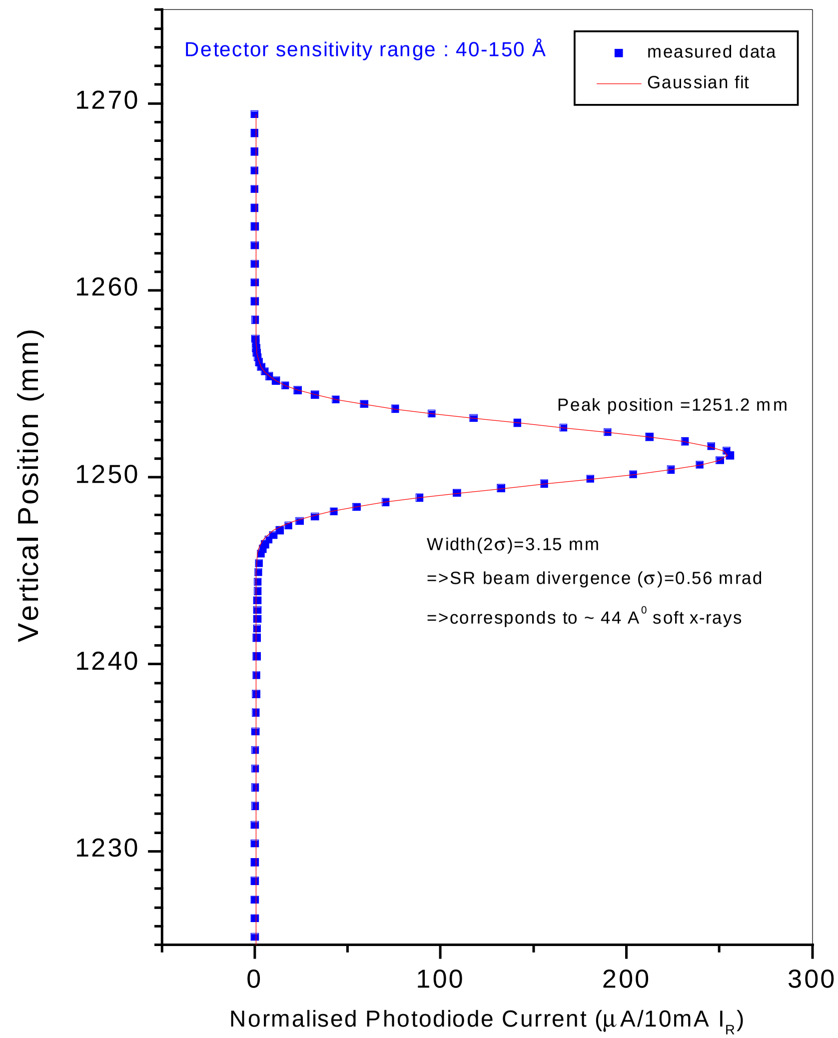
(Operational in November 2000)

It is a multipurpose beamline that can be used for a variety of applications including study of materials (metals, semiconductors, thin films etc.) in the VUV and soft x-rays regime.

Reflectivity Beamline on Indus-1

First detection of soft X-ray radiation from Indus-1

CAT-TGM beamline : 10 July 2000



Beamlines on Indus-1

Angle Integrated Photoelectron Spectroscopy beamline

(Operational in November 2000)

This beamline is built by the Inter University Consortium for DAE facilities and is again a TGM based beamline with toroidal mirrors as pre- and post-focusing optics. The acceptance of the beamline is 10 mrad horizontal by 4 mrad vertical. This beamline can be used to obtain information on electron density of states, band structure of bulk materials, and surface physics.

Beamlines on Indus-1

Angle Resolved Photoelectron Spectroscopy beamline

(Operational in March 2001)

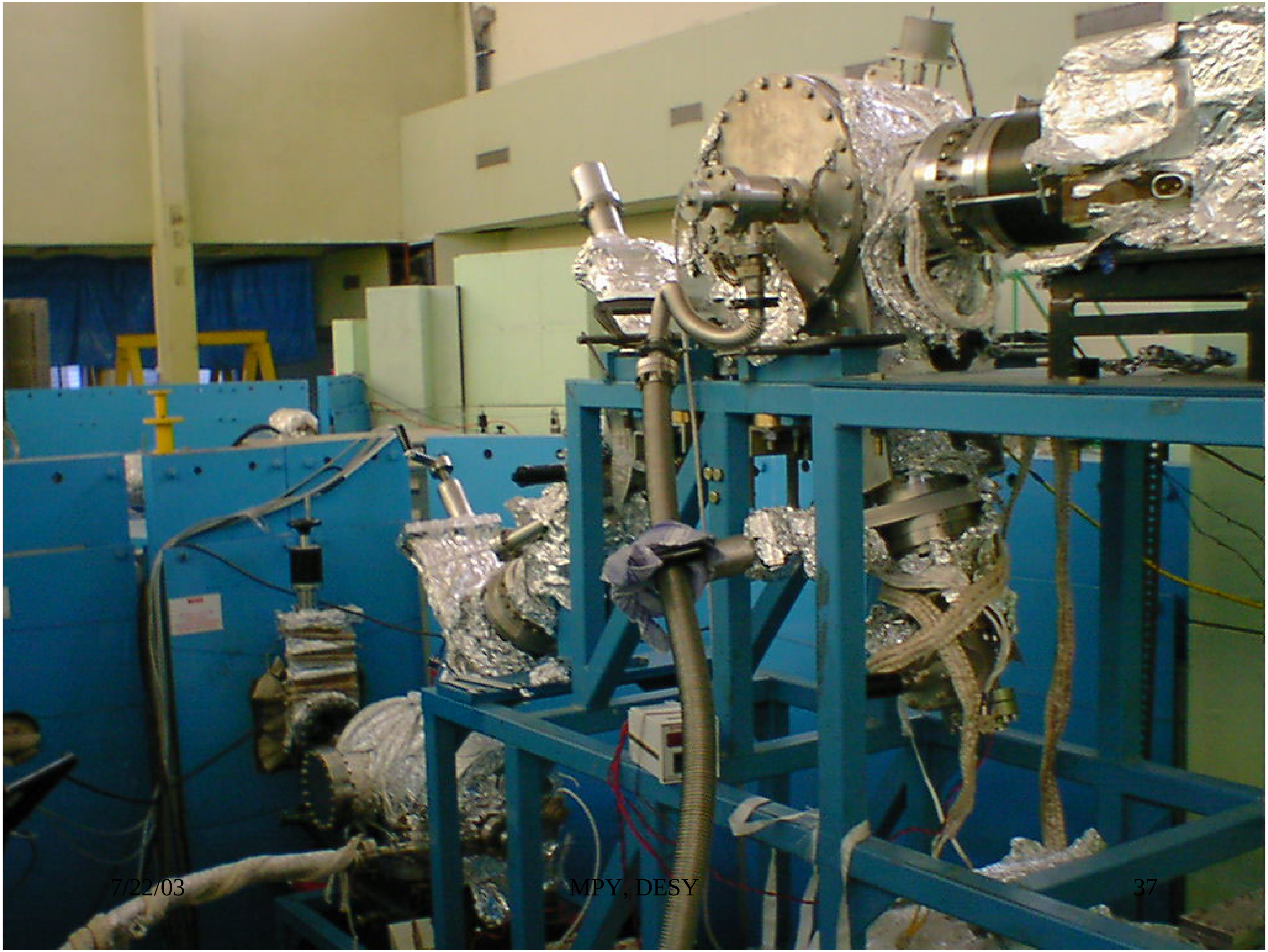
This beamline built by Bhabha Atomic Research Centre (BARC), Mumbai, is based on a toroidal grating monochromator. The experimental station, however, is a UHV chamber housing an angle integrated as well as angle resolved electron analyser. The chamber also has a low-energy electron diffraction (LEED) - Auger probe for orientation of single crystal, a sample manipulator, an argon-ion sputter etch gun for in-situ sample cleaning and detection. The resolution of the electron energy analyser is 50-100 meV.

Beamlines on Indus-1

Photo Physics beamline

(Operational in March 2001)

The photophysics beamline is being built by BARC and will be mainly used for carrying out experiments in areas such as photo dissociation, time resolved spectroscopy and auto ionisation etc. It is designed around an indigenously built one metre Seya-Namioka monochromator and covers the spectral region of 500 – 2500 Å with an average resolution of 1 Å. The beamline acceptance is 41 mrad horizontal by 5.6 mrad vertical. The experimental station consists of a ¼ meter UHV cell for absorption and emission spectroscopy experiments in gas phase and an UHV chamber and sample holder for solid samples.



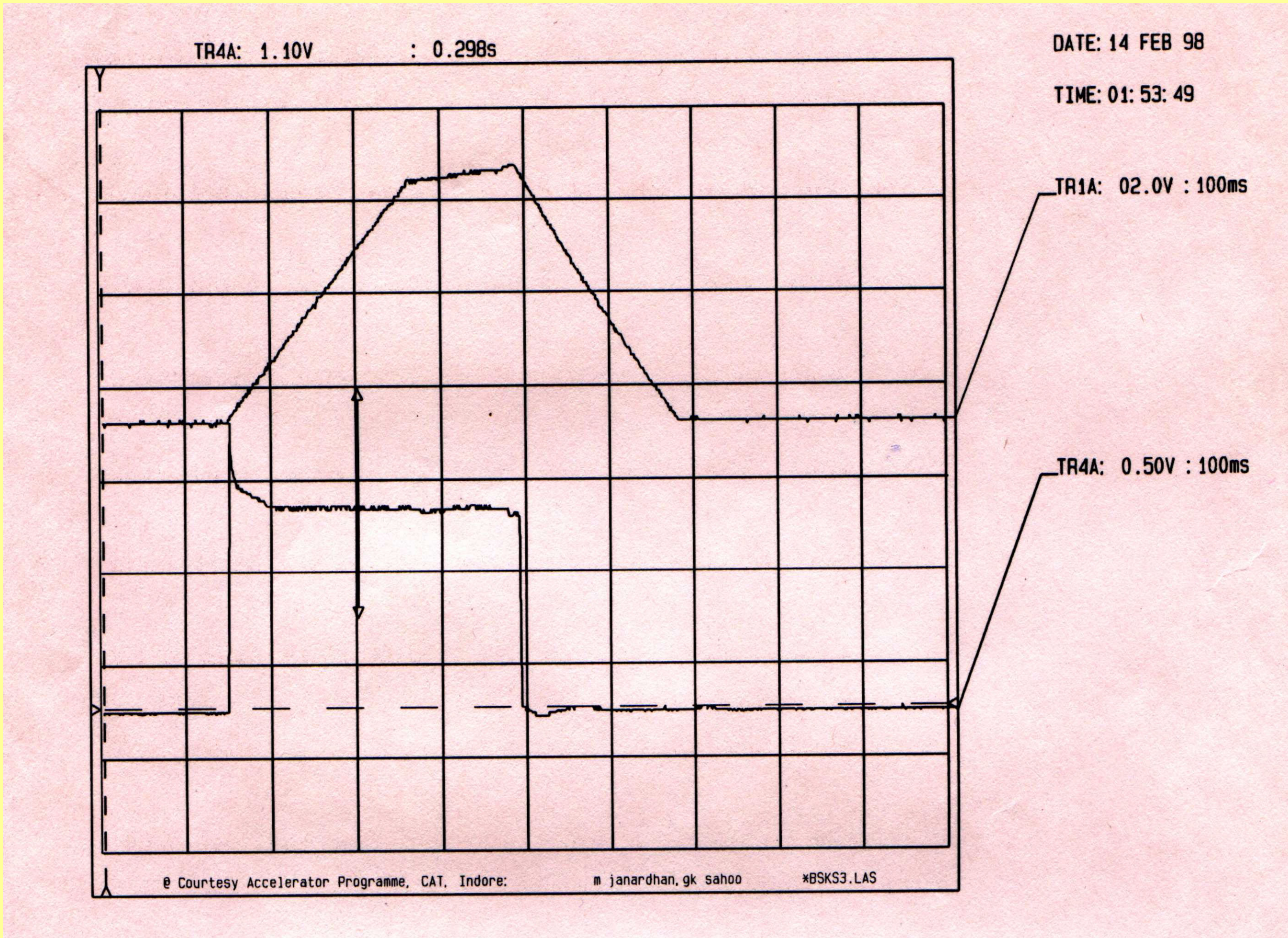
Beamlines on Indus-1

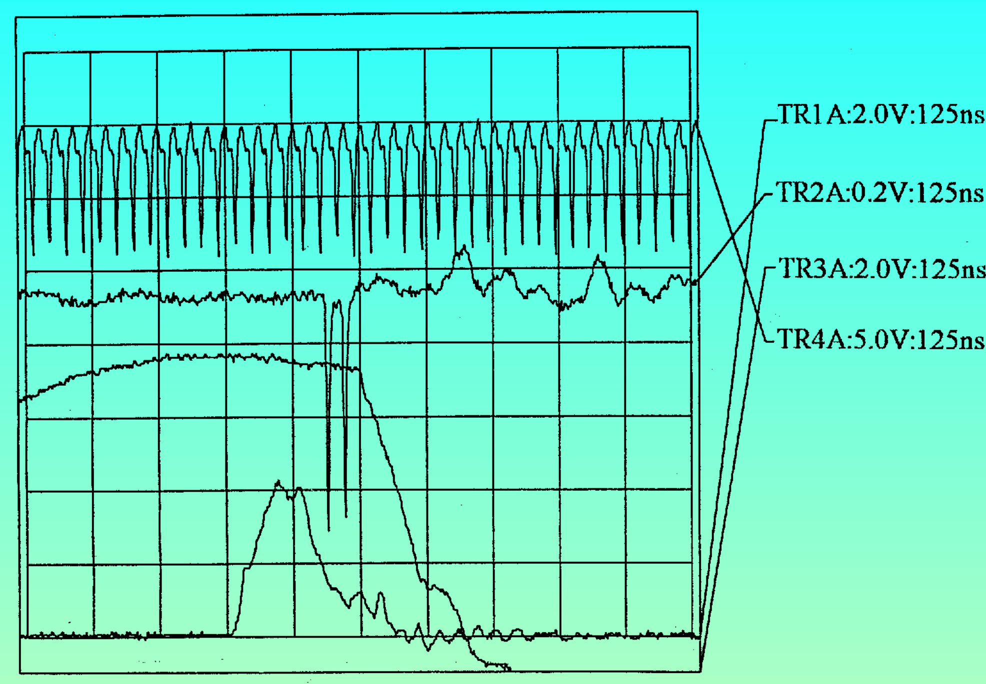
Beamlines under consideration

1) A high resolution beamline to cover the spectral region of 400 – 2000 Å for recording high resolution spectra of atomic and molecular vapours, and

2) A photo absorption spectroscopy beamline directed towards studying absorption edge in the energy range 100-700 eV have been designed.

DCCT signal during ramping in synchrotron





TRA1A : Booster Extraction Kicker pulse

TRA2A : Wall Current Monitor at end of TL-2

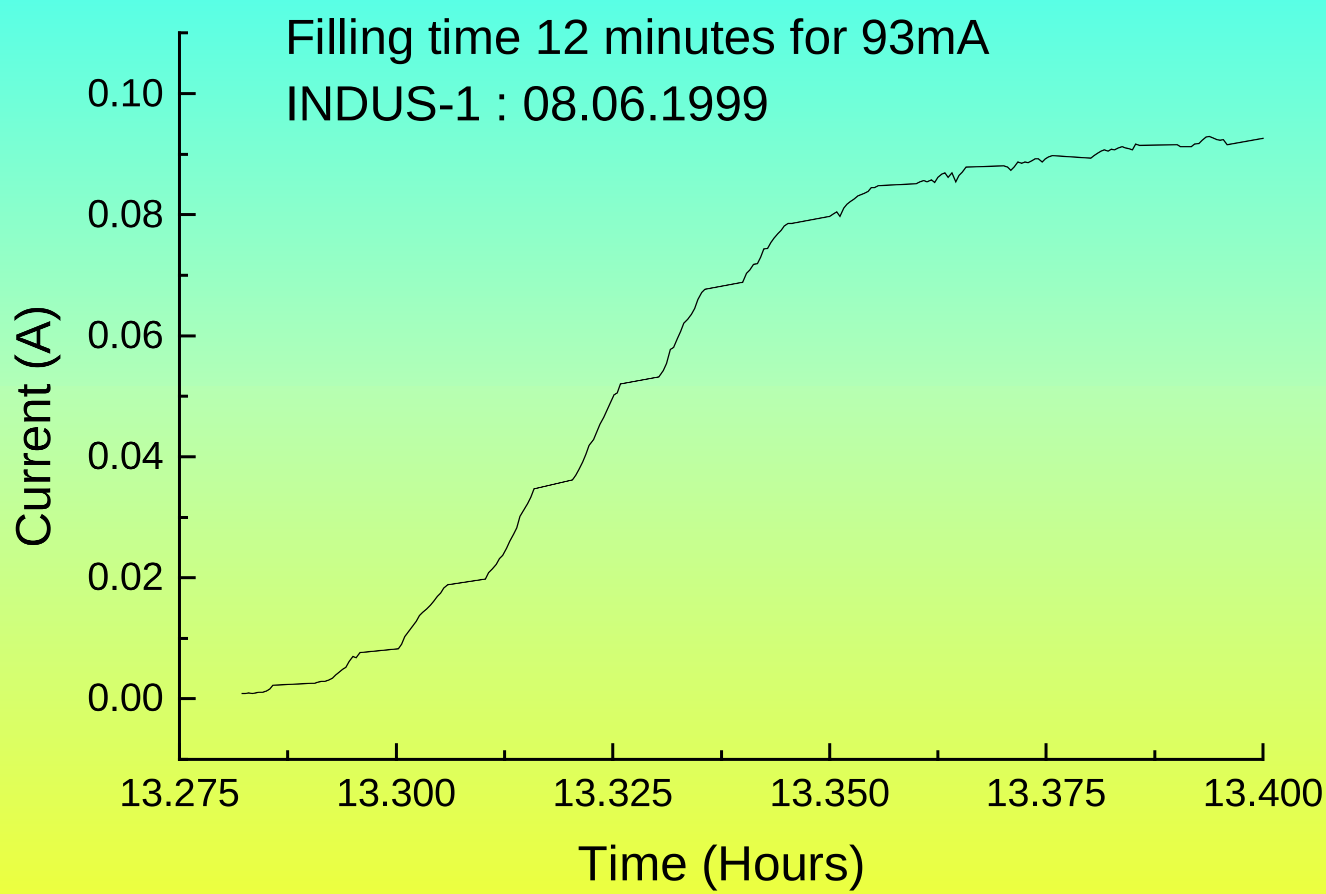
TRA3A : Injection kicker in Storage ring

TRA4A : WCM showing train of pulses in storage ring section 3

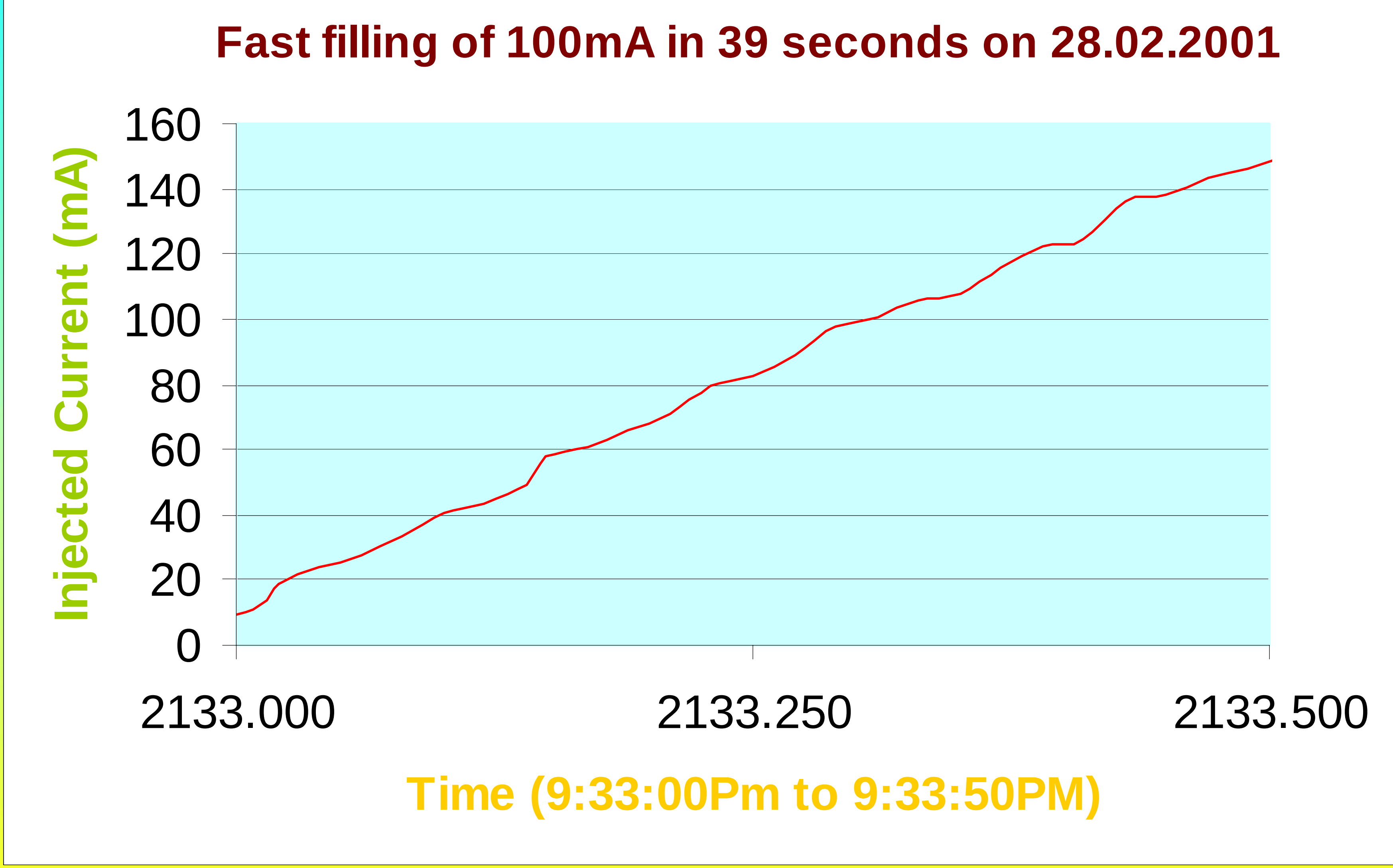
Important Dates in Commissioning

January, 1994	- Commissioning of 20MeV microtron started
September, 1994	- Microtron Commissioned, 20MeV, 15mA beam extracted
	- Transfer Line -1 commissioned. Emittance and lattice functions measured
October, 1994	- Commissioning of Synchrotron Started
January, 1995	- 40mA peak current in DCCT observed at 20MeV in synchrotron
	- Tunes and β functions measured, Chromaticities & aperture estimated
	- Ramping power supplies ready
September, 1995	- Beam acceleration to 480MeV with 1.8mA achieved
November, 1996	- Extraction of two bunches out three from synchrotron
	- Commissioning of Transfer line-2
August, 1997	- Injected beam observed in INDUS-1
April, 1999	- First accumulation of beam in INDUS-1
June, 1999	- INDUS-1 commissioned with more 100mA stored current

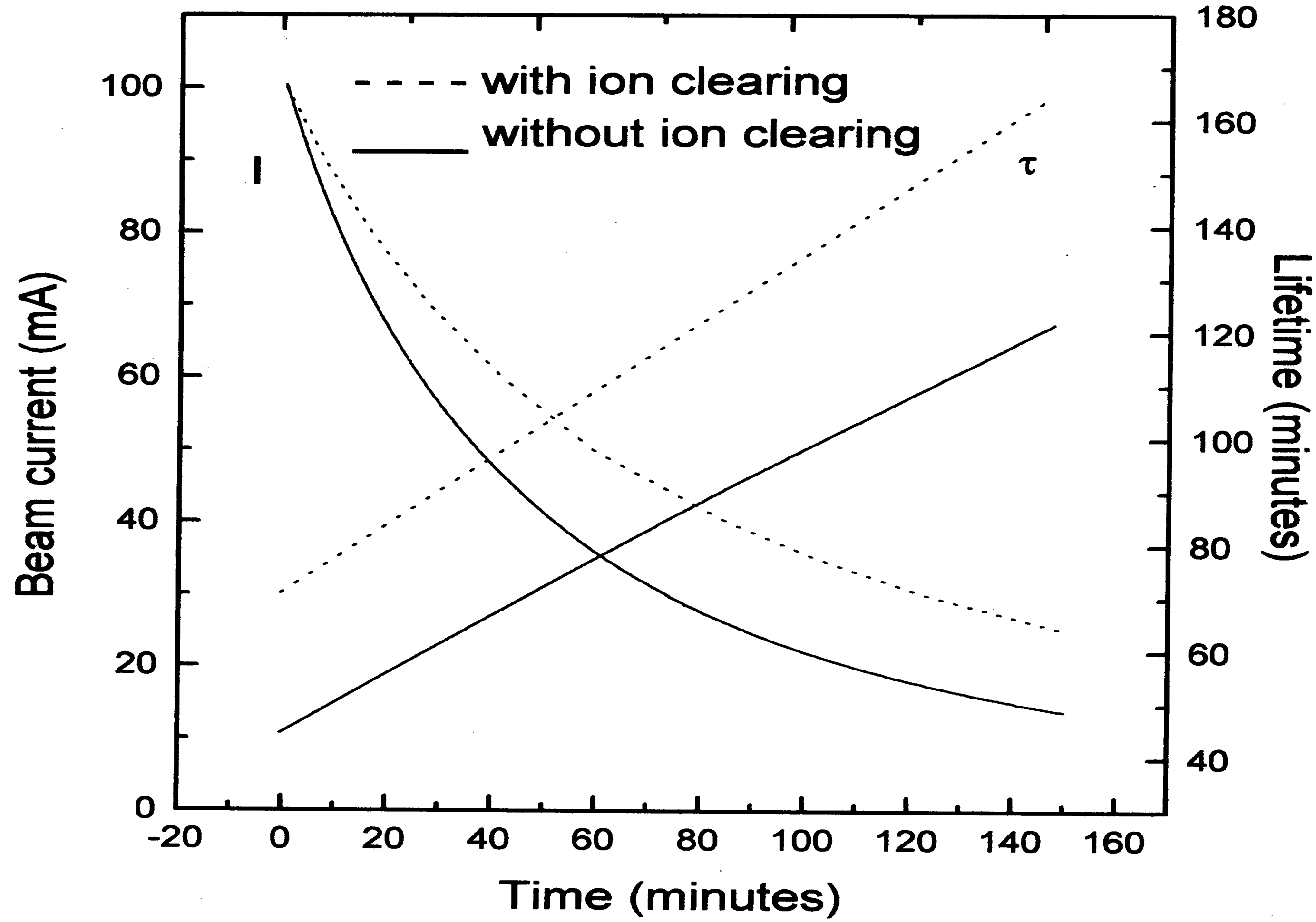
Filling of Indus-1



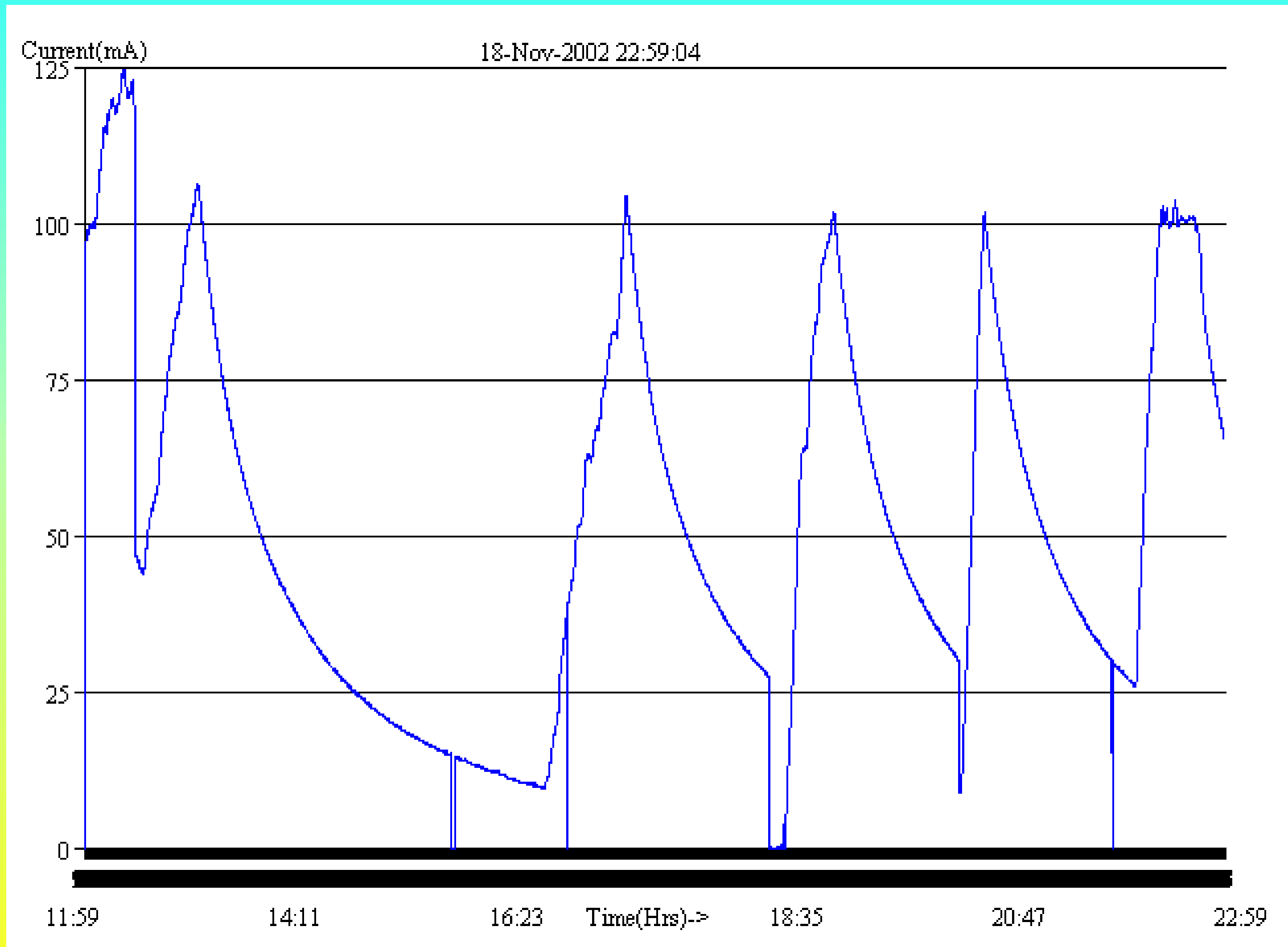
Filling of Indus-1



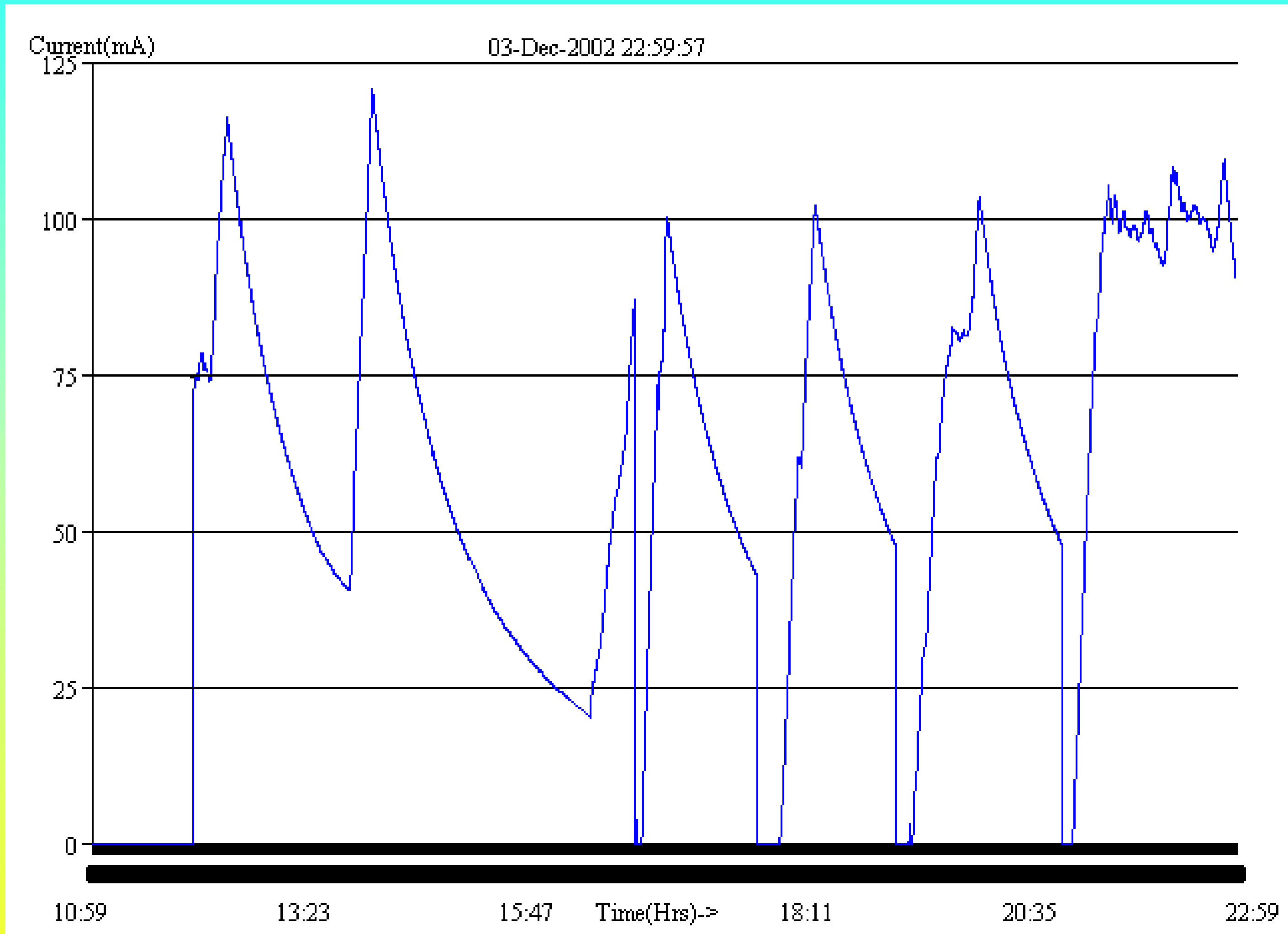
Effect of ion clearing electrode in beam lifetime



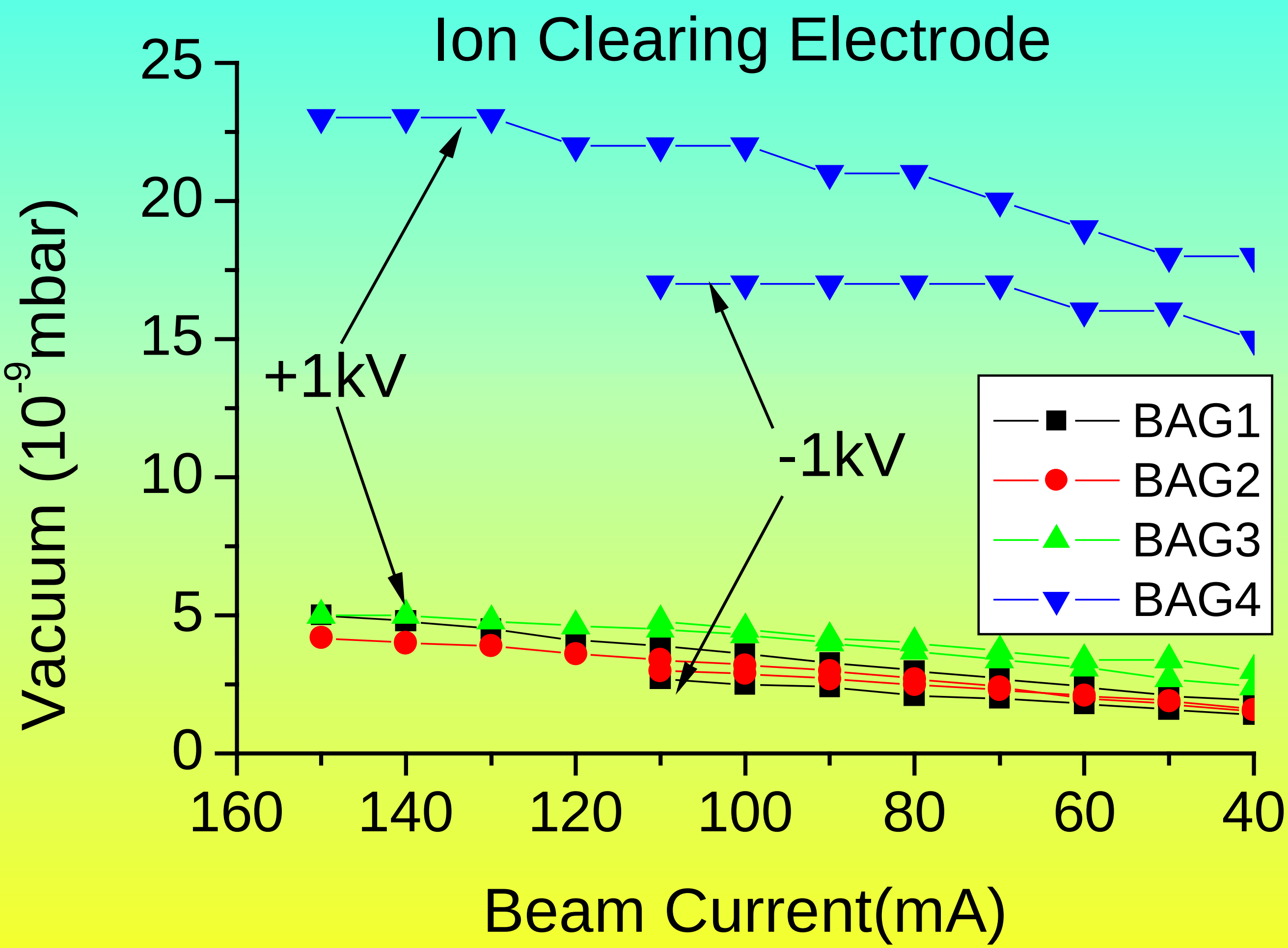
Indus-1 in operation: 18 Nov 2002



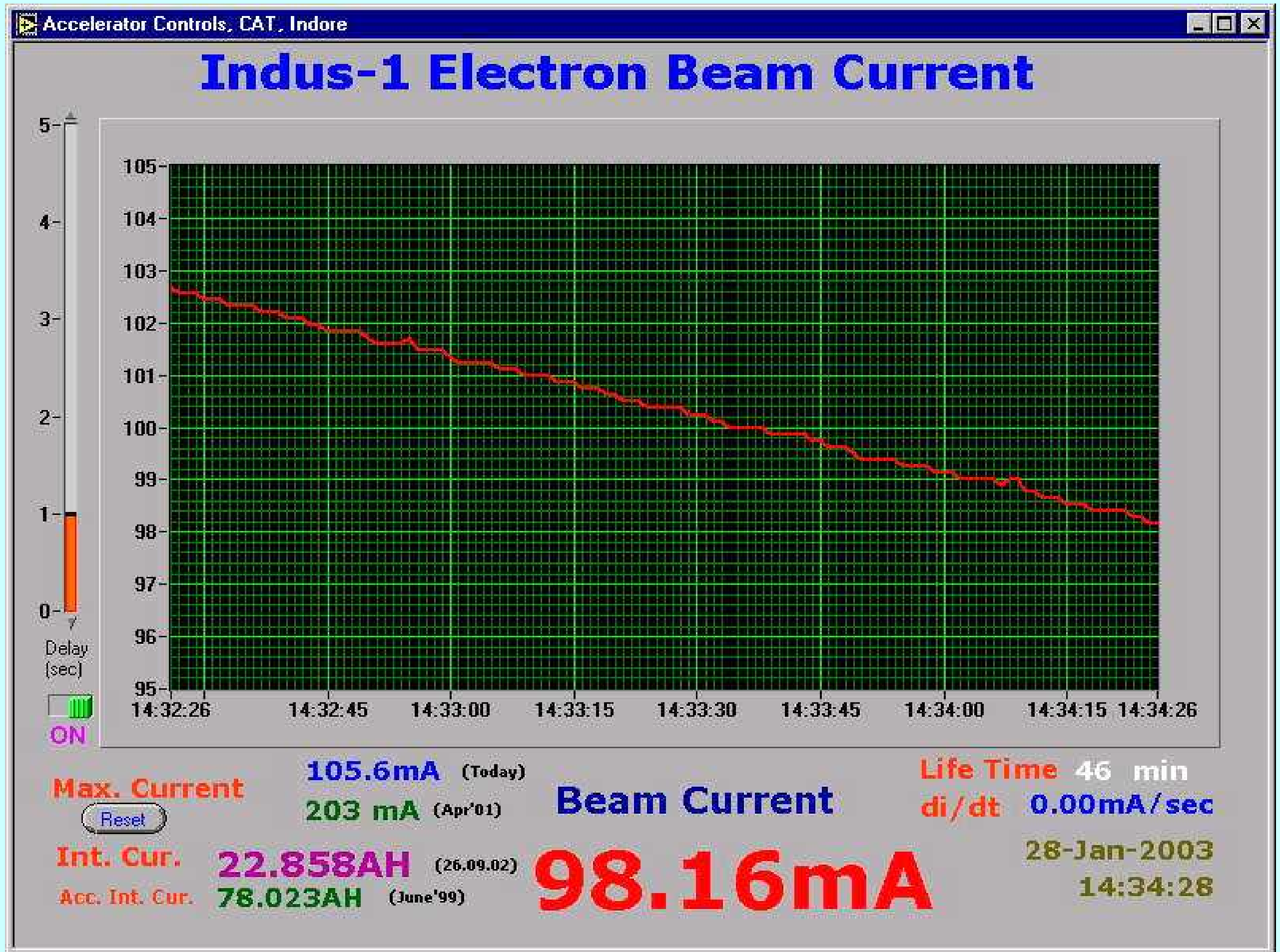
Indus-1 in operation: 03 Dec 2002



Indus-1 operation: Vacuum in Dec 2002



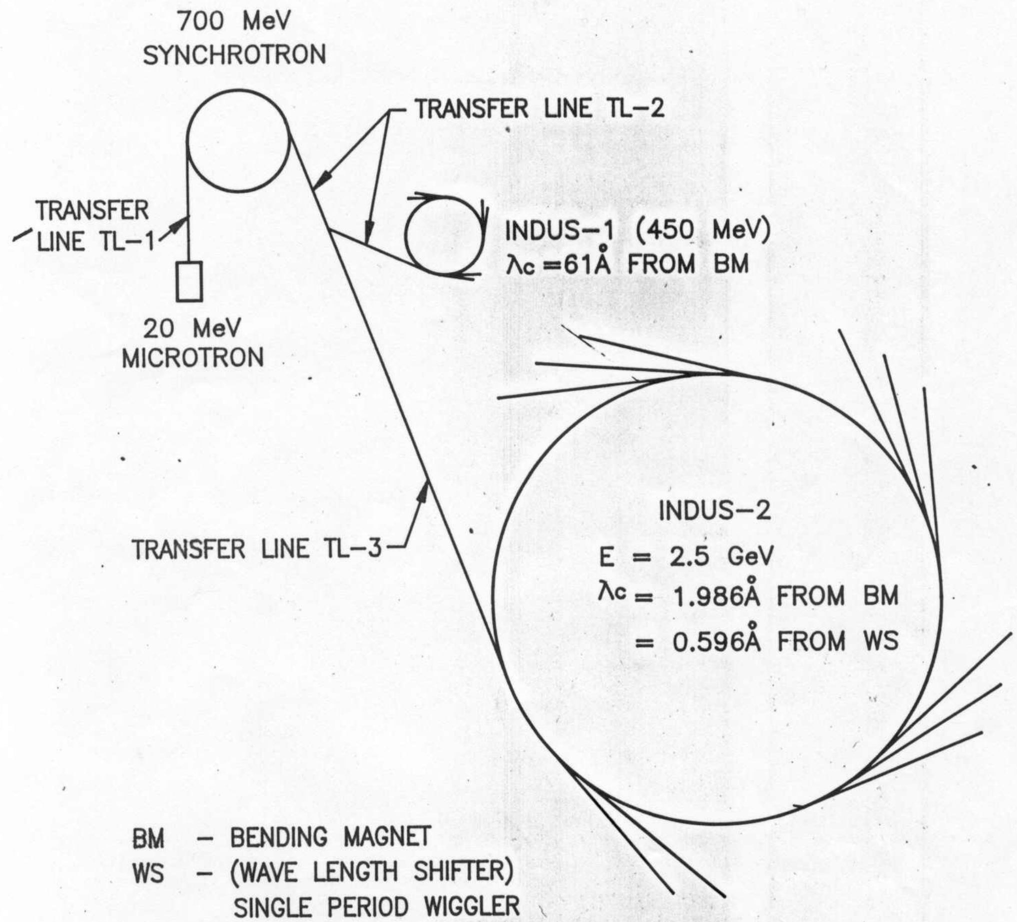
Logging of Beam Current



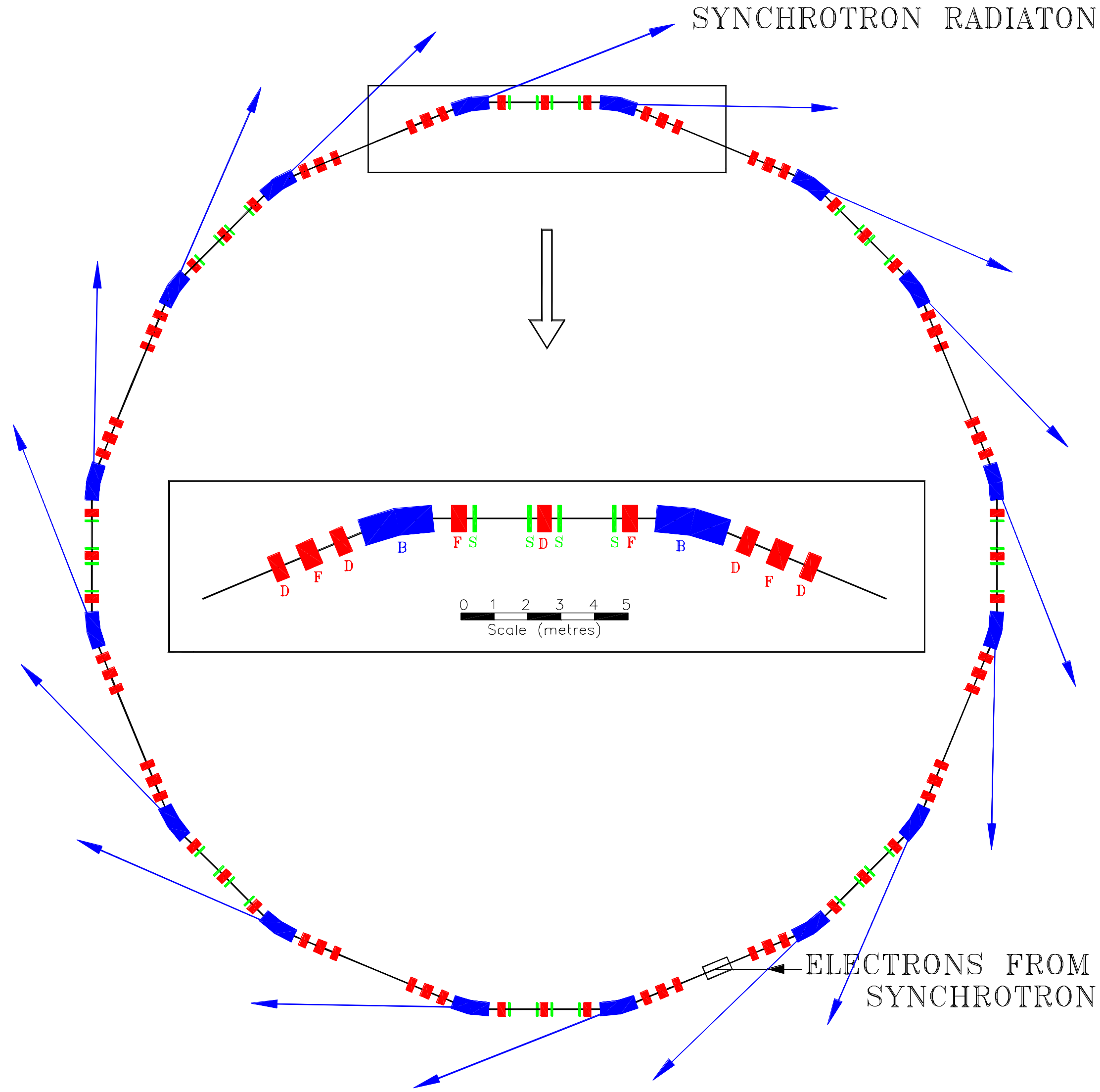
Synchrotron Light Source Indus-2

THEN (OCT. 1984)

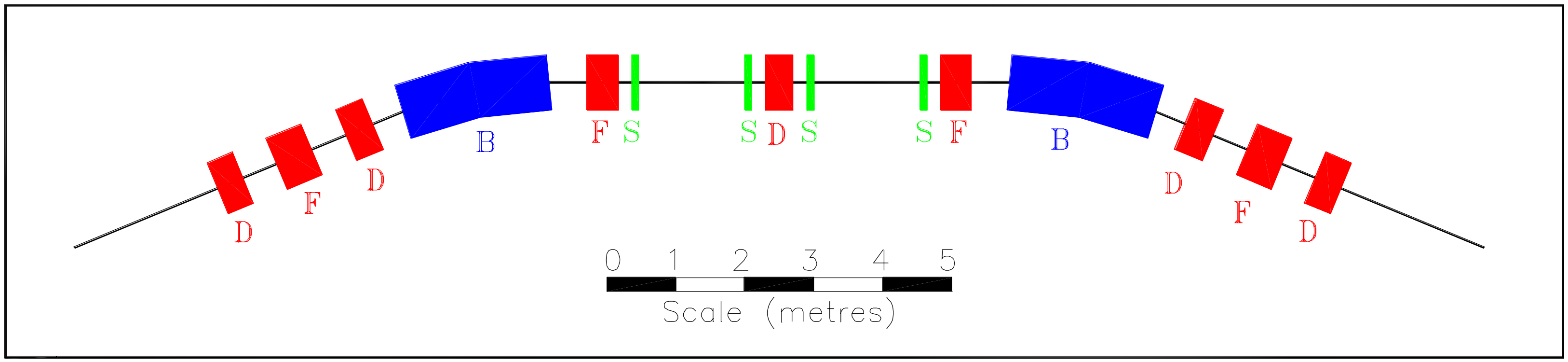
NOW (JULY 2002)



SCHEMATIC LAYOUT OF SYNCHROTRON RADIATION SOURCES
INDUS-1 & INDUS-2



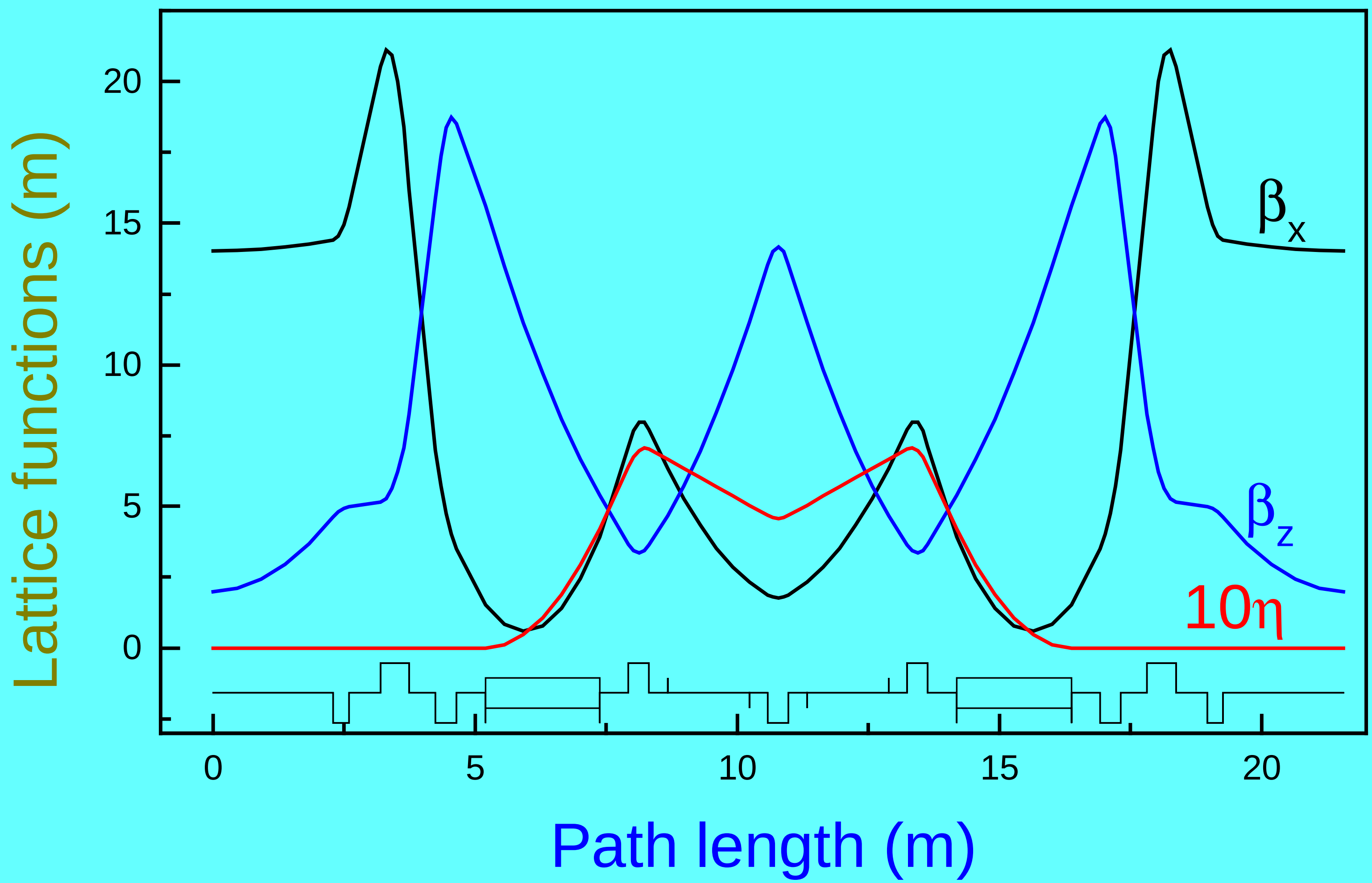
INDUS−2 LATTICE



Unit Cell of Indus-2

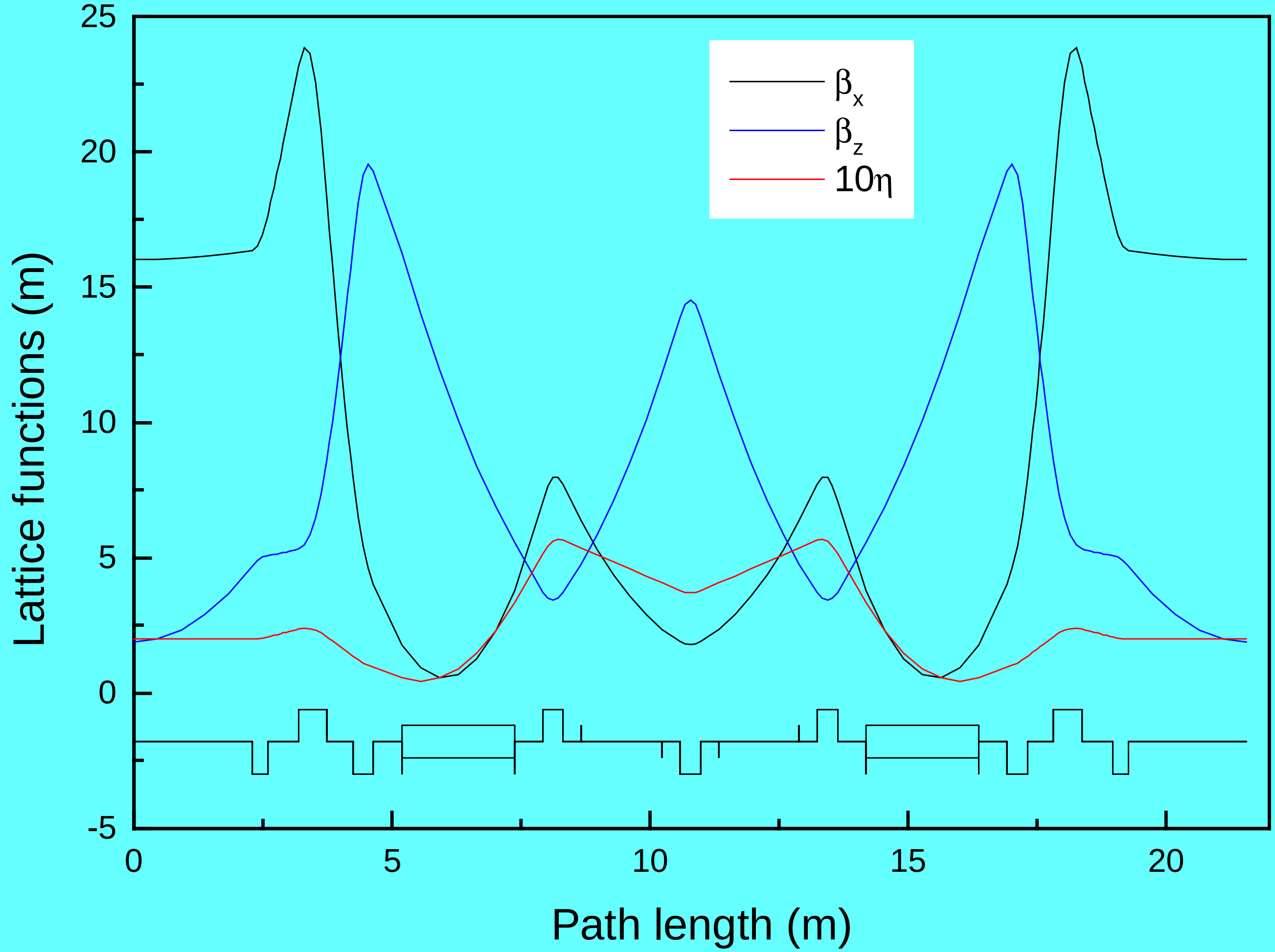
The storage ring Indus-2 consists of 8 unit cells each providing a 4.58m long straight section for insertion devices. Its unit cell has two 22.5º bending magnets, a triplet of quadrupoles for the control of dispersion in the achromat section, two quadrupole triplets for the adjustment of beam sizes in the long straight section, and four sextupoles in the achromat section for the correction of chromaticities.

Lattice function of INDUS-2

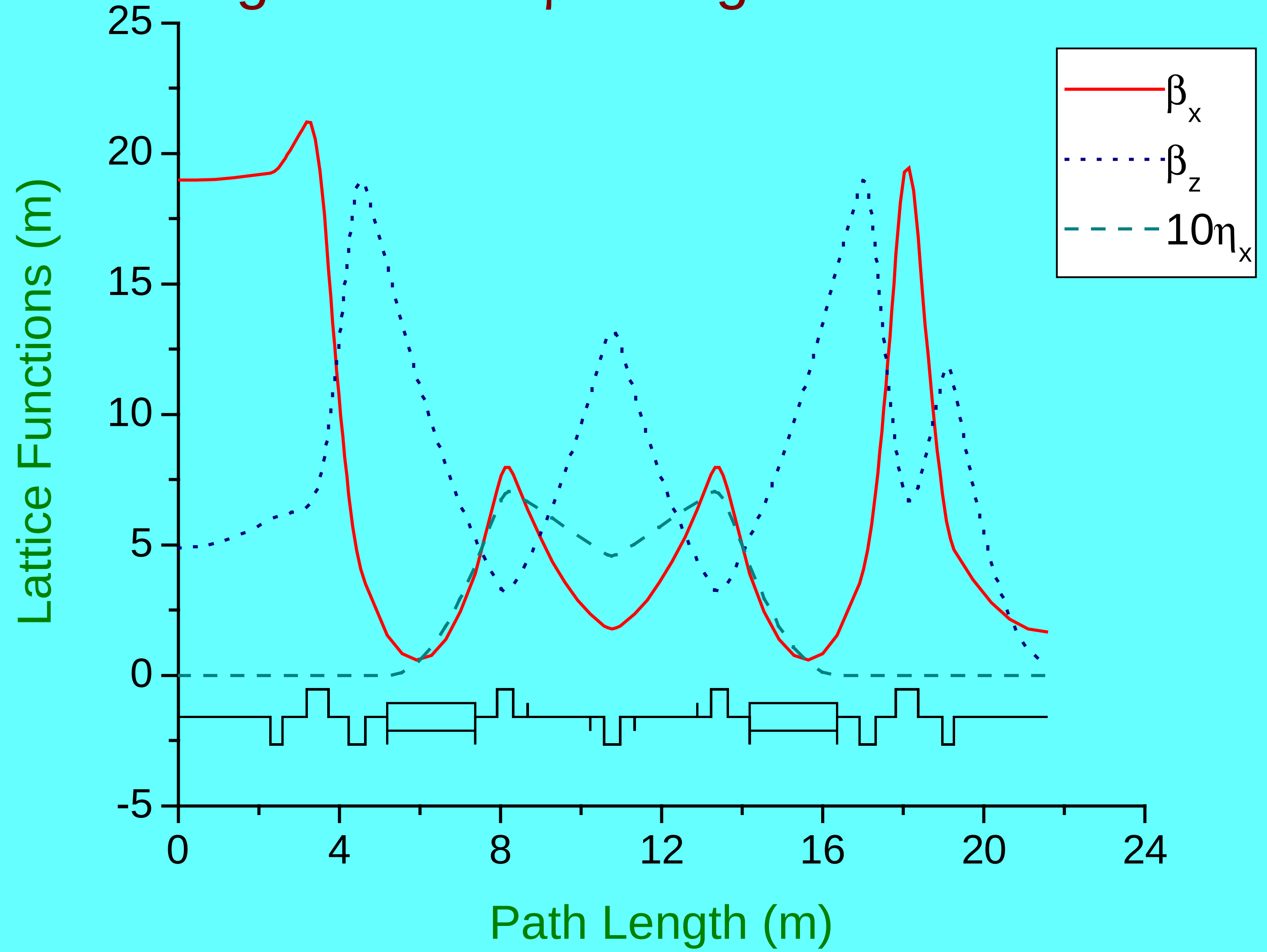


Lattice functions with nonzero dispersion

$\varepsilon_x = 2.2 \times 10^{-8}$ m.rad at 2GeV



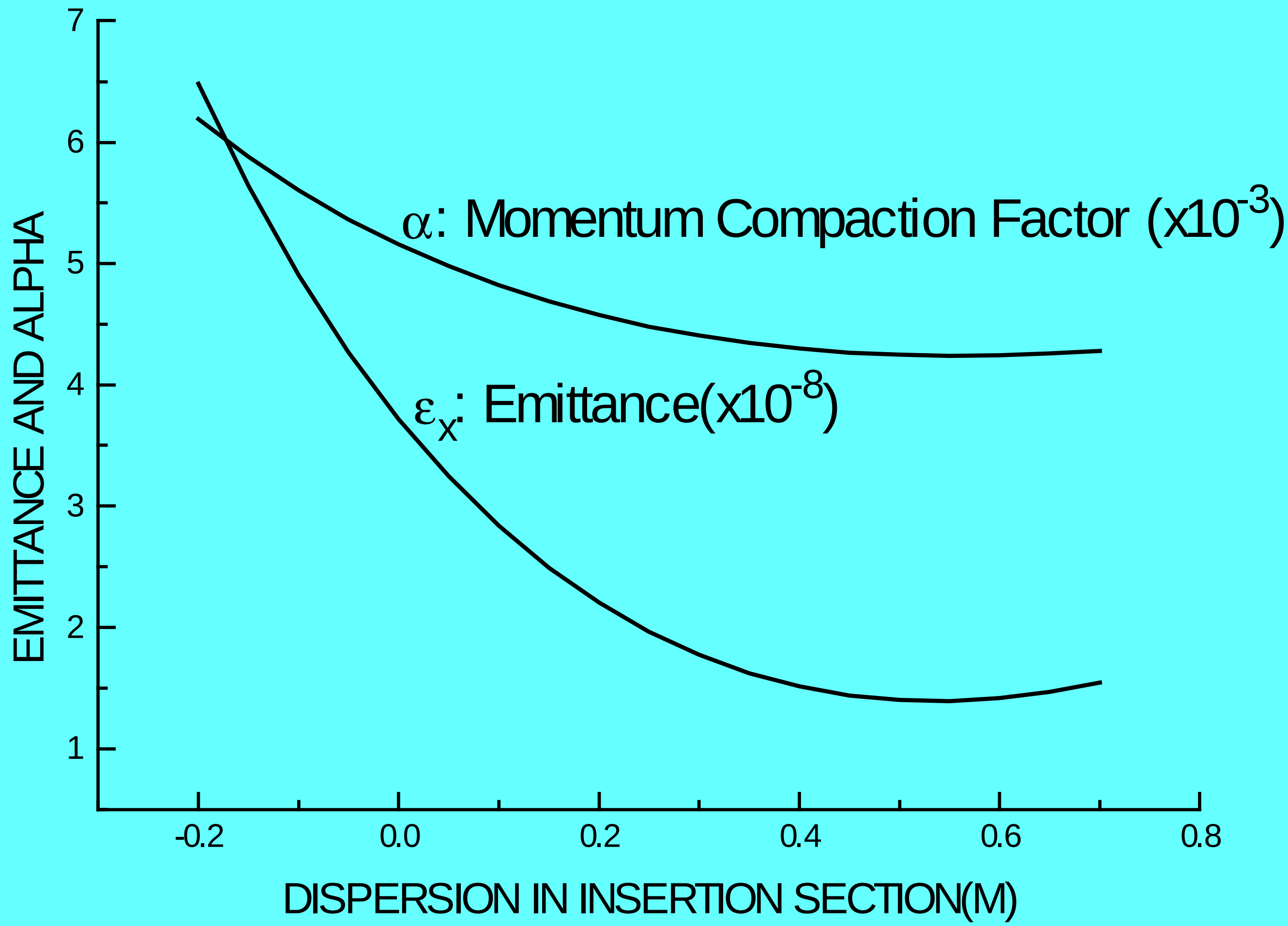
High and low β configuration for Indus-2



Parameters of INDUS-2

Energy		: 2	2.5 GeV
Current		: 300 mA	
Bending Field		: 1.2	1.502T
Critical Wavelength (λ_c)		: 3.88Å	1.986Å (BM)
		: 0.93Å	0.596Å (WS)
		: 2.59Å	1.659Å (MW)
Circumference		: 172.4743 M	
Typical tune point		: 9.2, 5.2	
Beam emittance	ε_x	: 3.72 x 10^{-8}	5.81x10^{-8}m.rad
	ε_y	: 3.72 x 10^{-9}	5.81x10^{-9}m.rad
Momentum compaction factor α		: 0.0052	
Natural chromaticities ξ_x, ξ_y		: -19.05, -12.01	
Electron beam size and divergence			
Centre of bending magnet σ_x, σ_y		: 0.187, 0.190	0.234, 0.237 mm
	$\sigma_{x'}$, $\sigma_{y'}$	: 0.290, 0.050	0.359, 0.062 mrad
Centre of insertion section σ_x, σ_y		: 0.722, 0.086	0.903, 0.108 mm
	$\sigma_{x'}$, $\sigma_{y'}$	: 0.052, 0.043	0.064, 0.054 mrad
Bunch length	$2\sigma_l$	: 1.77	2.23 cm
Beam lifetime (1% coupling)		: 15	24 hours
Energy spread		: 7.2 x 10^{-4}	9.0 x 10^{-4}
Damping times (τ_x, τ_y, τ_ε)		: 9.26, 9.02, 4.45	4.74, 4.62, 2.28 ms
Revolution frequency		: 1.738 MHz	
RF frequency		: 505.808 MHz	
Harmonic number		: 291	
Power loss		: 76.3 kW	186.6 kW (BM)
		: 4.3 kW	6.7 kW (WS)
		: 5.2 kW	8.1 kW (MW)

BM: Bending Magnet
MW: Multipole Wiggler (1.8T)
WS: Wavelength shifter (5 T)


α: Momentum Compaction Factor (x10^-3)
ε_x: Emittance(x10^-8)
EMITTANCE AND ALPHA
DISPERSION IN INSERTION SECTION(M)
7
6
5
4
3
2
1
-0.2
0.0
0.2
0.4
0.6
0.8

Injection into Indus-2

The beam will be injected in the horizontal plane via two septum magnets (one thick and another thin one) by a multiturn injection process in one of the 4.5 m long straight section by employing a compensated bump which will be produced by means of four kickers. The maximum kick angle produced by the kicker is 25 mrad, which will produce an orbit bump of ≈ 20 mm. The kicker pulse is a half sine wave of 1.8-3.0 μsec duration. The thin septum will bend the beam through 2° and the thickness of this septum is 1 mm. The pulse shape of the thin septum is half sine wave of 20 μsec duration. The thick septum will bend the beam through 19° and its pulse shape is a half sine wave of 100 μsec width or it can be of DC type.

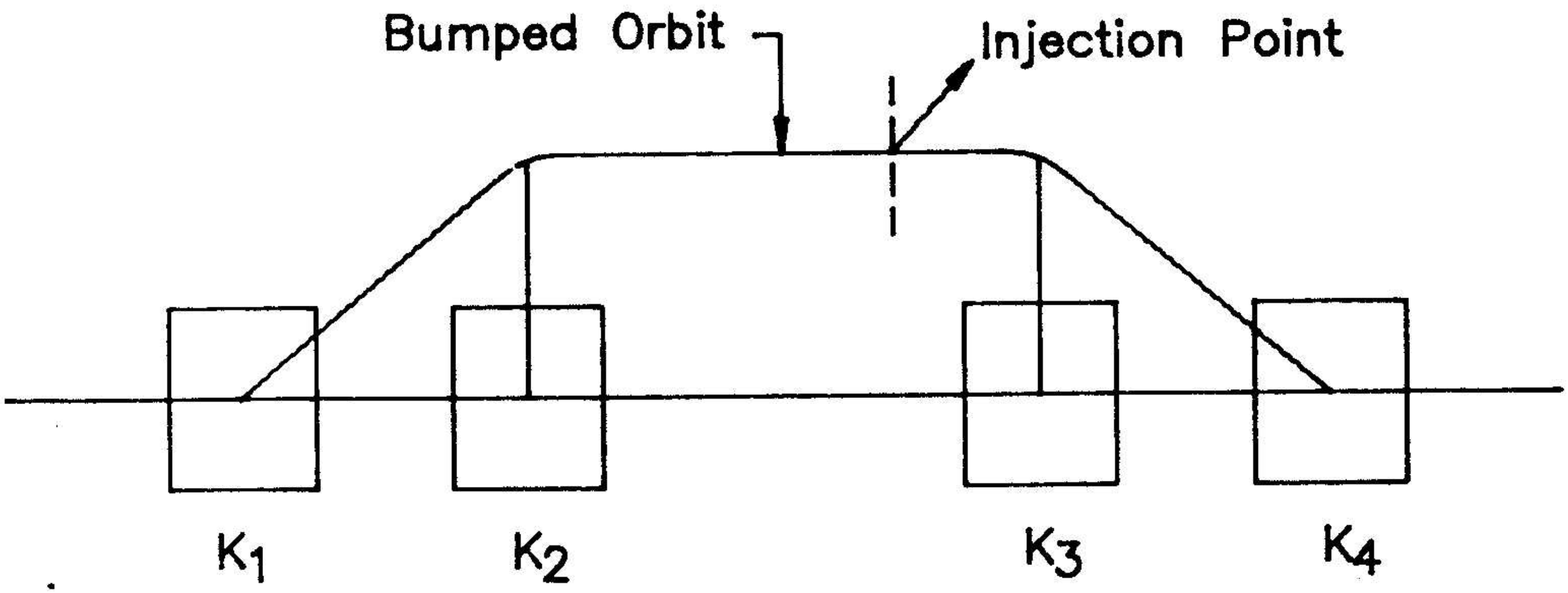
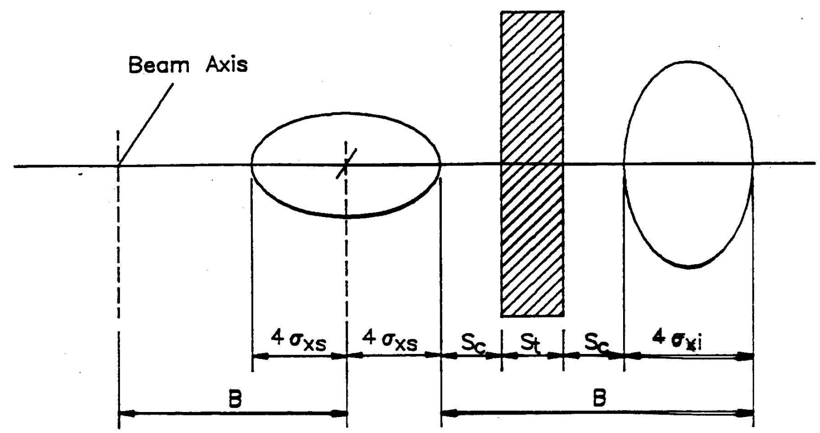
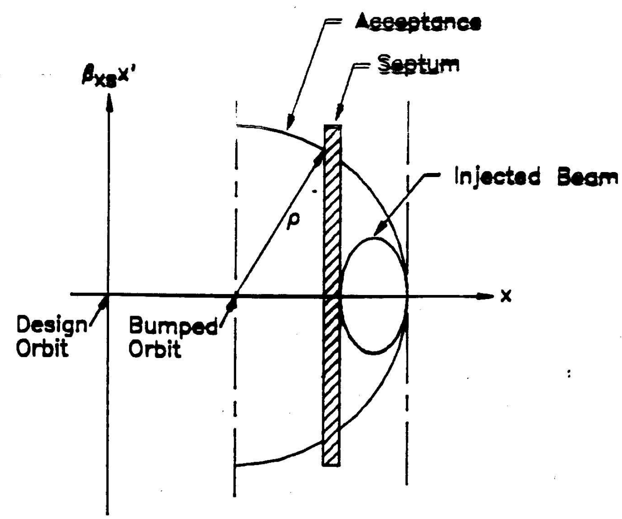


FIG. 1 — LAYOUT OF INJECTION SECTION



Stored Beam
Septum
Injected Beam
Beam Axis
4 σ_{xs}
4 σ_{xs}
S_c
S_t
S_c
4 σ_{xi}
B
B

FIG.2



Acceptance
Septum
$\beta_{xs}x'$
Injected Beam
ρ
x
Design Orbit
Bumped Orbit

FIG.3

Filling Scheme in Indus-2

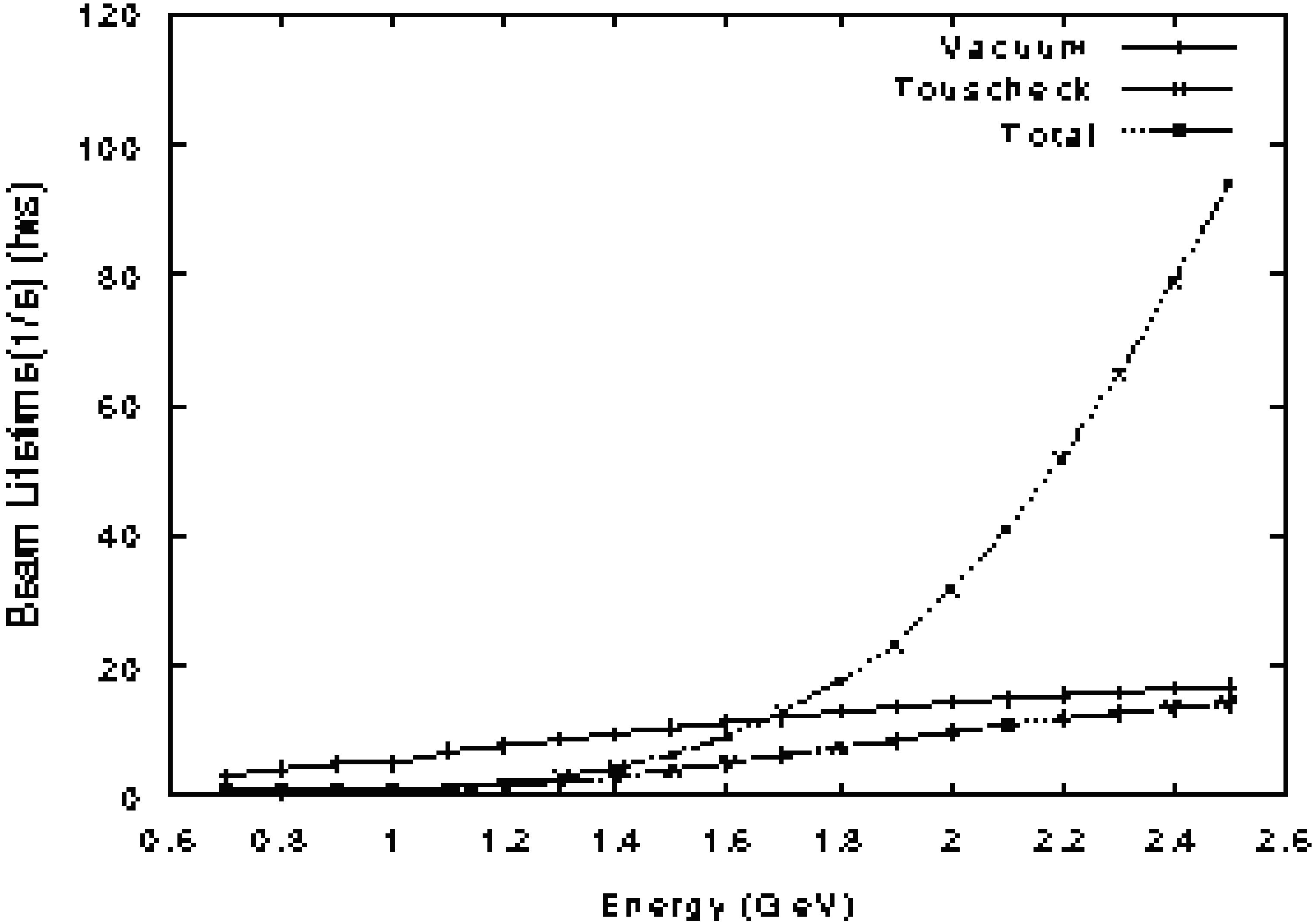
Indus-2 has a harmonic number of 291, the separation between two buckets is 1.977ns. Thus two bunches extracted from the synchrotron separated by 31.613ns will fill the 1st and 17th bucket of Indus-2. The extraction time of the synchrotron bunches will be adjusted in such a way that during consecutive fillings, 2nd and 18th, 3rd and 19th etc. buckets will be filled. This process will continue till all the buckets are filled to the desired current level.

Ion trapping is the major problem in electron storage rings. The easiest way to overcome this problem is to fill the buckets in an asymmetric manner. Calculations carried out for Indus-2 parameters reveal that filling typically 194 consecutive buckets out of 291, thus leaving a gap of 97 buckets will minimize the ion trapping problem. The logic of such asymmetric filling is again based on the control of extraction timing from the synchrotron. The timing system will make it possible to do selective filling of buckets.

It is also desirable for some experiments to operate the machine in the single bunch mode operation. In this case, only single bunch will be extracted from the synchrotron. The extraction timing will be adjusted in such way that the extracted bunch will be transferred to the same bucket of Indus-2.

Beam lifetime calculations

- **Bunch lengthening and increase in energy spread due to single bunch instabilities considered.**
- **Emittance increase due to intra beam scattering accounted for.**
- **Aperture : ± 15 mm (x) and ± 8 mm (z).**
- **Cavity voltage : 300 kV – 1.5 MV for 600 – 2.5 GeV & synchrotron tune kept constant**



Vacuum
Touscheck
Total
Beam Lifetime(1/e) (hrs)
Energy (GeV)
0
20
40
60
80
100
120
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6

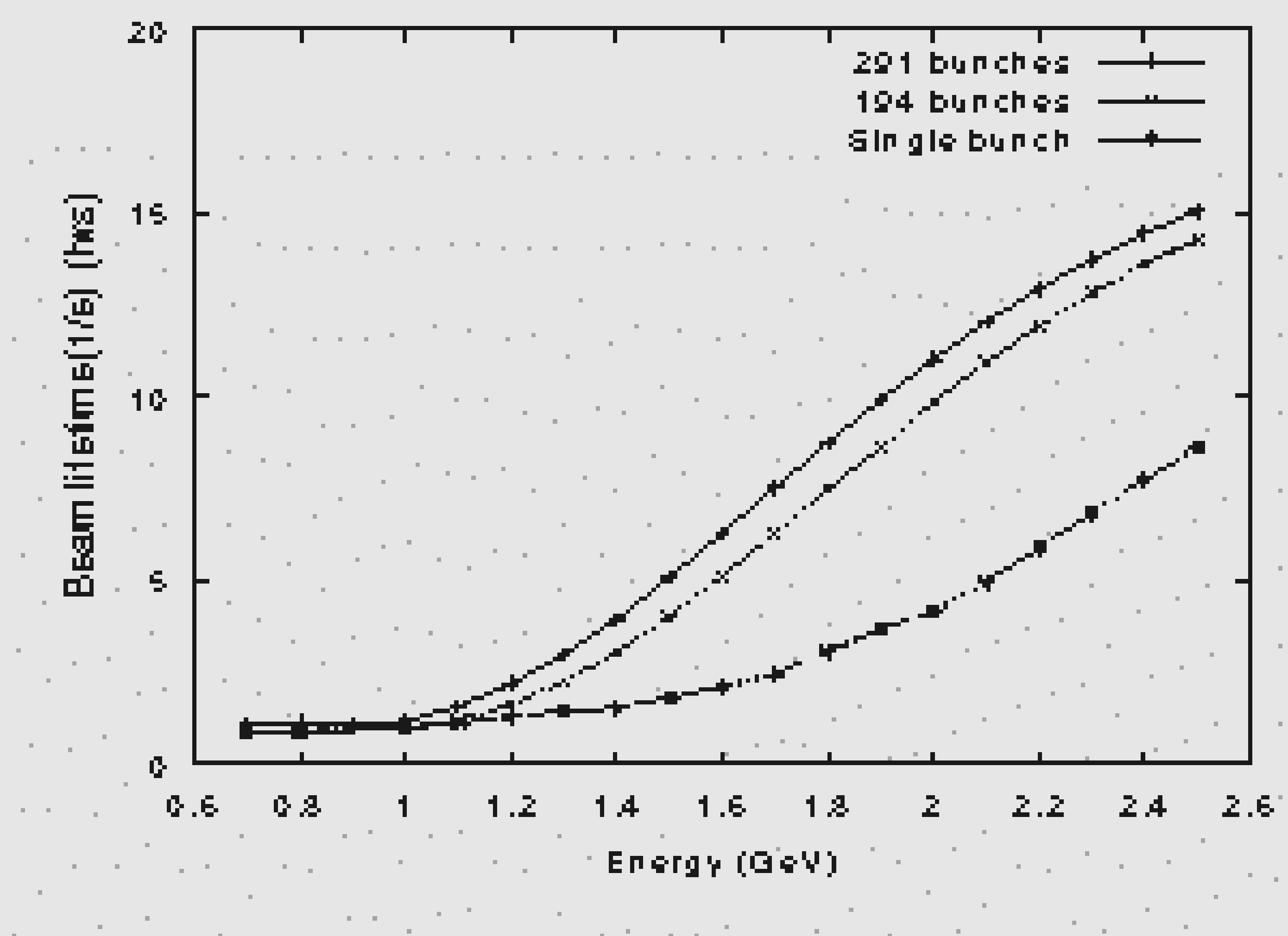


Figure 5: Beam lifetimes in different filling patterns

1. Multibunch mode

(194 buckets fill, 97 buckets empty)
Current : 300 mA (1.55 mA per bunch
12.1 A peak current)
Lifetime : 12 h @ 2 GeV, 21 h @ 2.5 GeV

2. Single bunch mode

Current : 8 mA (8 mA per bunch
65.2 A peak current)
Lifetime : 3 h @ 2 GeV, 7.5 h @ 2.5 GeV

3. Three bunch mode

(Three symmetric bunches)
Current : 24 mA (8 mA per bunch
65.2 A peak current)
Lifetime : 3 h @ 2 GeV, 7.5 h @ 2.5 GeV

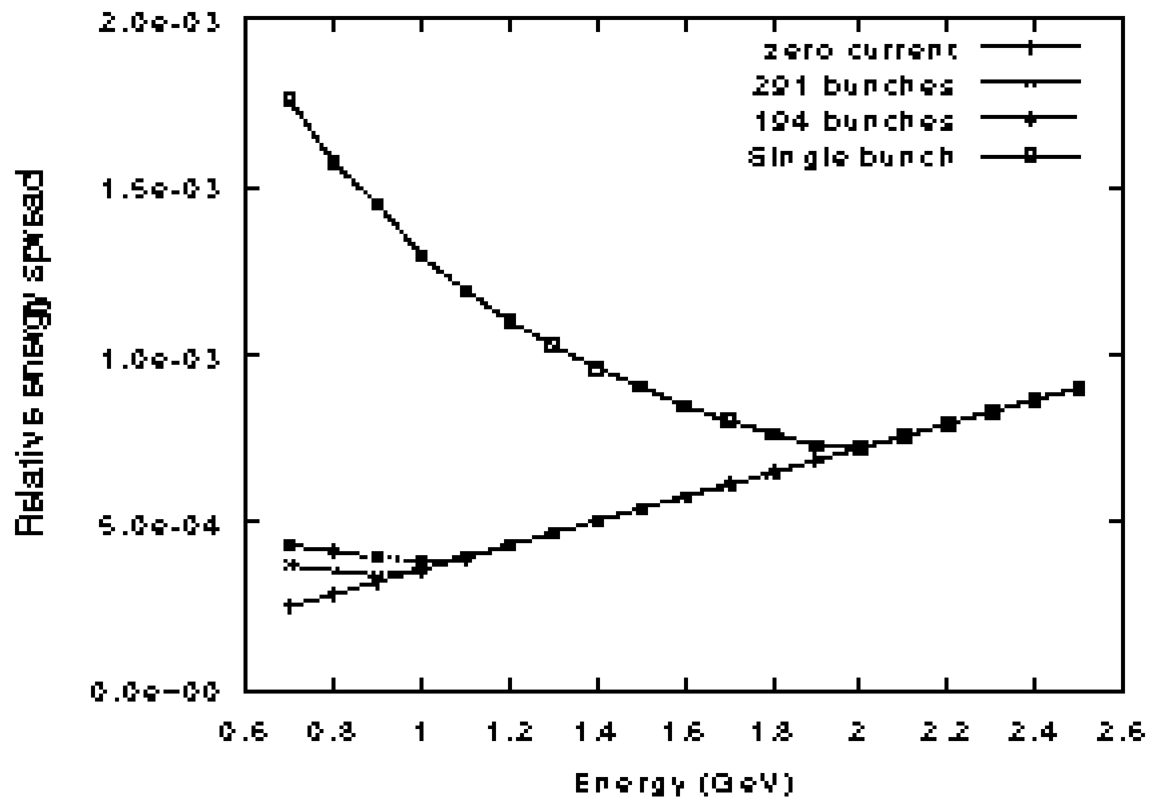


Figure 2: Bunch widening

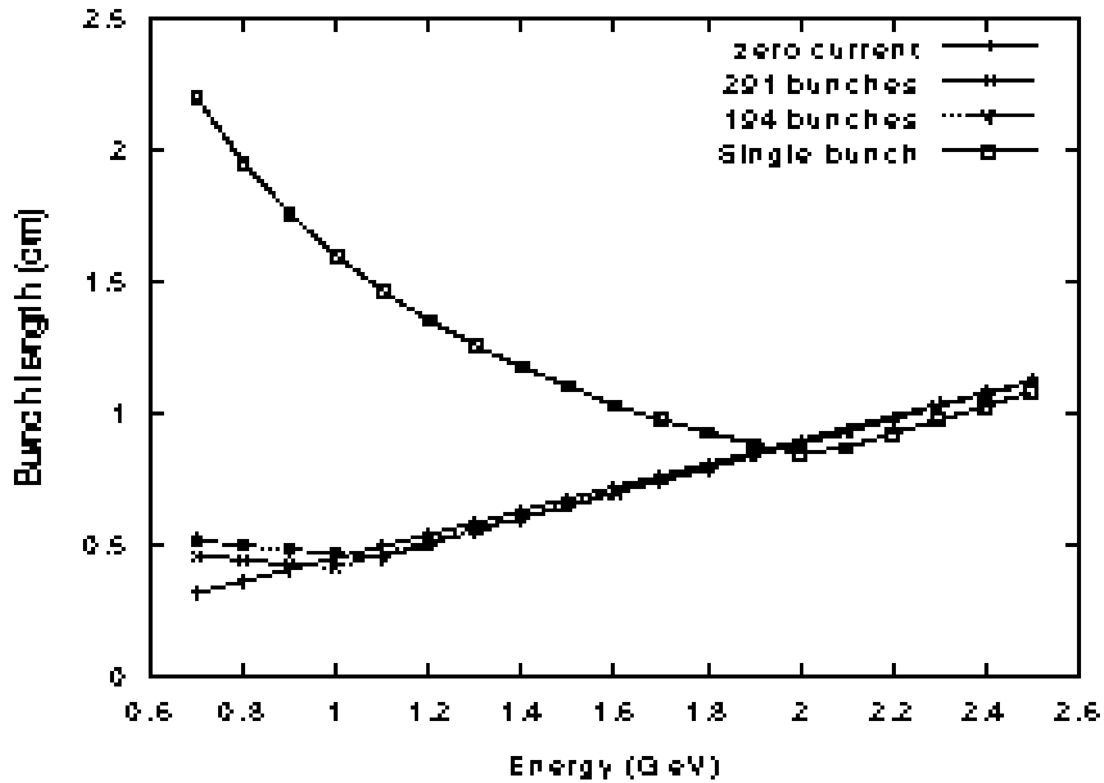


Figure 1: Bunch lengthening

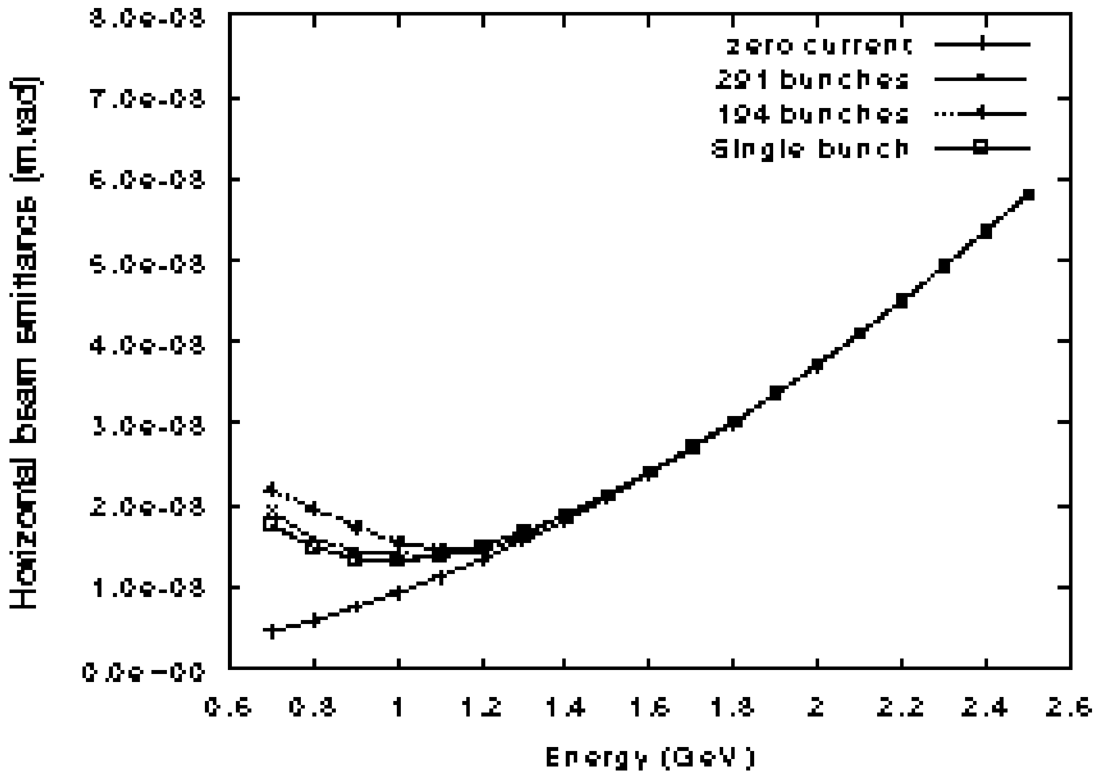


Figure 3 : Emittance blow up

Closed Orbit Distortion in Indus-2

The Closed Orbit Distortion (COD) depends on the magnet misalignment errors and magnetic field errors. The COD has different values at different locations around the ring which depends on the beam optics. In the design stage, the position and the magnitude of error is not known. In order to estimate the COD, a statistical method is followed, in which the probable errors are randomly distributed with some specified rms values and the resulting COD due to these errors is obtained. For Indus-2, the following rms values of errors are assumed for dipoles, quadrupoles and sextupoles,

$\delta s = 0.1$ mm, $\delta x = 0.1$ mm (0.2 mm for dipoles), $\delta y = 0.1$ mm,

$\delta\theta s = 0.2$ mrad, $\delta\theta x = 0.5$ mrad, $\delta\theta y = 0.5$ mrad

Magnets for Indus-2

Name	Type	Length (mm)	Good field x(mm) z(mm)	Gradient Maximum	Strength(2.5GeV) min	max	Numbers per ring
Q1 :	D-Quadrupole	300	±32 x ±17	16T/M	0.0	2.0 M^{-2}	16
Q2 :	F-Quadrupole	550	±32 x ±17	16T/M	0.7	2.0 M^{-2}	16
Q3 :	D-Quadrupole	400	±32 x ±17	16T/M	0.7	2.0 M^{-2}	16
Q4 :	F-Quadrupole	400	±32 x ±17	16T/M	1.0	2.0 M^{-2}	16
Q5 :	D-Quadrupole	400	±32 x ±17	16T/M	0.7	2.0 M^{-2}	8
BM :	Dipole	2179.48	±32 x ±17	1.502T	0.36	1.502T	16
S1 :	Sextupole	200	±32 x ±17	400T/M^2	0.0	5.0M^{-2}	16
S2 :	Sextupole	200	±32 x ±17	400T/M^2	0.0	5.0M^{-2}	16
Shf :	Sextupole	150	±32 x ±17	200T/M^2	0.0	2.5M^{-2}	16

Strength : $k = (dB_Z/dx)/(B\rho)$ for quadrupoles and $S = (d^2B_Z/dx^2)/(2B\rho)$ for sextupoles

Dipole field tolerances

7.1 Systematic (Integrated over dipole length)

The higher order multipole components should be minimized.

$\Delta Bl/Bl = 5.0\text{x}10^{-4}$ at transverse position of ±35mm for the central trajectory with y=0.

The Taylor's expansion of magnetic field is given by

$$B(x,y) = B_y + i\,B_x = B\rho \sum_{n=1}^{\infty} (b_n + i\,a_n)\,(x + i\,y)^{n-1}$$

Where a_n and b_n are skew and normal components for 2n-pole fields.

defined as b_n =. $(d^{n-1}B_y/dx^{n-1})/(B\rho.(n-1)!)$ and a_n =. $(d^{n-1}B_x/dy^{n-1})/(B\rho.(n-1)!)$

$b_1 l$	$b_2 l$	$b_3 l$	$b_4 l$	$b_5 l$	$b_6 l$	$b_{10} l$
0.0	0.0	0.05	0.14	0.0	0.0	0.0

7.2 Random/Normal (Integrated over dipole length) $\Delta Bl/Bl = \pm 4.0\text{x}10^{-4}$ (magnet to magnet)

$b_1 l$	$b_2 l$	$b_3 l$	$b_4 l$	$b_5 l$	$b_6 l$	$b_{10} l$
0.0	7.0×10^{-4}	0.03	1.5	0.0	0.0	0.0

7.3 Error at constant energy or during ramping $\Delta B/B = \pm 1.0\text{x}10^{-4}$

8. Effective magnetic length 2.17948m

9. Length error $\Delta l/l = \pm 5.0\text{x}10^{-4}$ (magnet to magnet)

Quadrupole field tolerances

3. Gradient errors

3.1 Systematic (Integrated over quadrupole length) $\Delta K/K = \pm 0.0001$ at ± 35mm

$b_1 l$	$b_2 l$	$b_3 l$	$b_4 l$	$b_5 l$	$b_6 l$	$b_{10} l$
0.0	0.0	0.0	0.0	0.0	1250.0	4133598.0

3.2 Random/Normal $\Delta Kl/Kl = \pm 0.0005$ (magnet to magnet)

$b_1 l$	$b_2 l$	$b_3 l$	$b_4 l$	$b_5 l$	$b_6 l$	$b_{10} l$
0.0	0.0002	0.05	2.5	12.5	250.0	1377866.0

3.3 Random/Skew (Integrated over quadrupole length)

$a_1 l$	$a_2 l$	$a_3 l$	$a_4 l$	$a_5 l$	$a_6 l$	$a_{10} l$
0.0	0.0026	0.0	0.0	0.0	0.0	0.0

3.4 Error with time $\Delta Kl/Kl = \pm 5.0\text{x}10^{-4}$ (magnet to magnet)

4. Magnetic length as indicated in 2.3

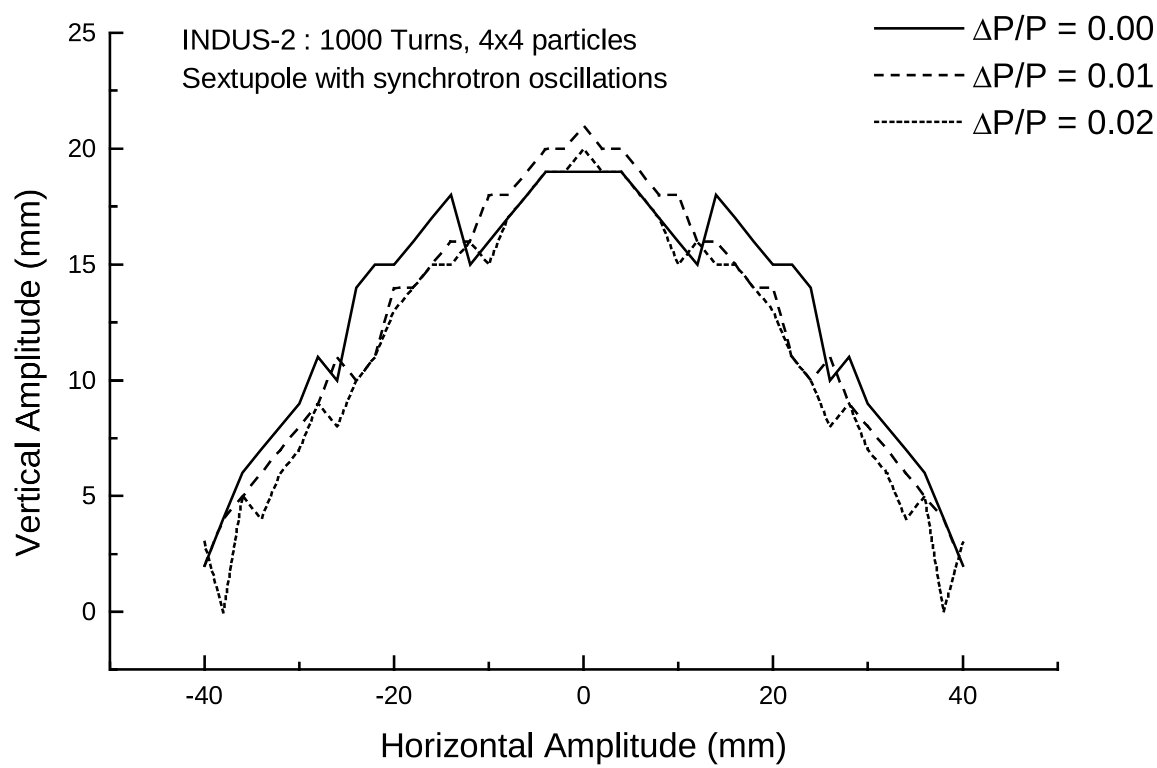
5. Magnetic length error $\Delta l/l = \pm 5.0\text{x}10^{-4}$ (magnet to magnet)

Power Supply tolerances

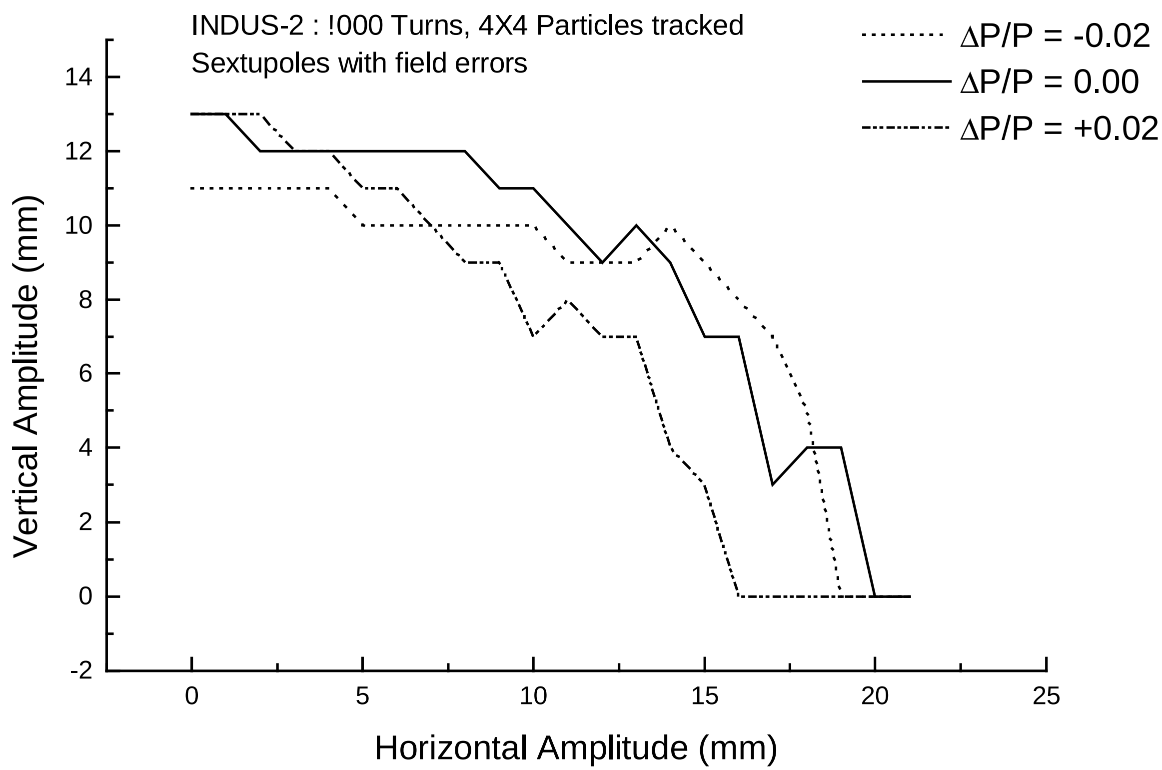
Stability/Reproducibility	: $\pm 5.0\text{x}10^{-5}$
Ripple and noise	: $\pm 1.0\text{x}10^{-4}$
Setting Resolution	: $\pm 5.0\text{x}10^{-5}$

At injection energy of 600 MeV $\Delta I/I \sim \pm 1.0\text{x}10^{-4}$.

Dynamic Aperture



Dynamic Aperture



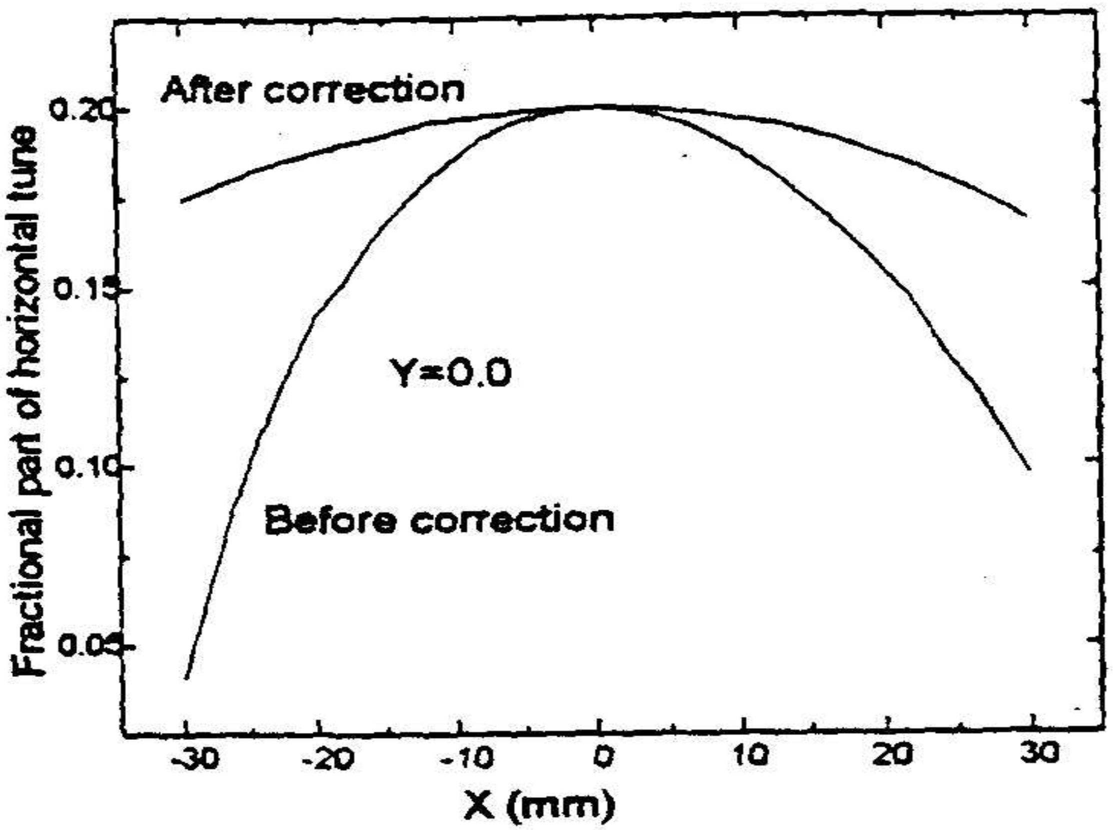


Fig.5(a) Amplitude-dependent horizontal tune with and without harmonic correction

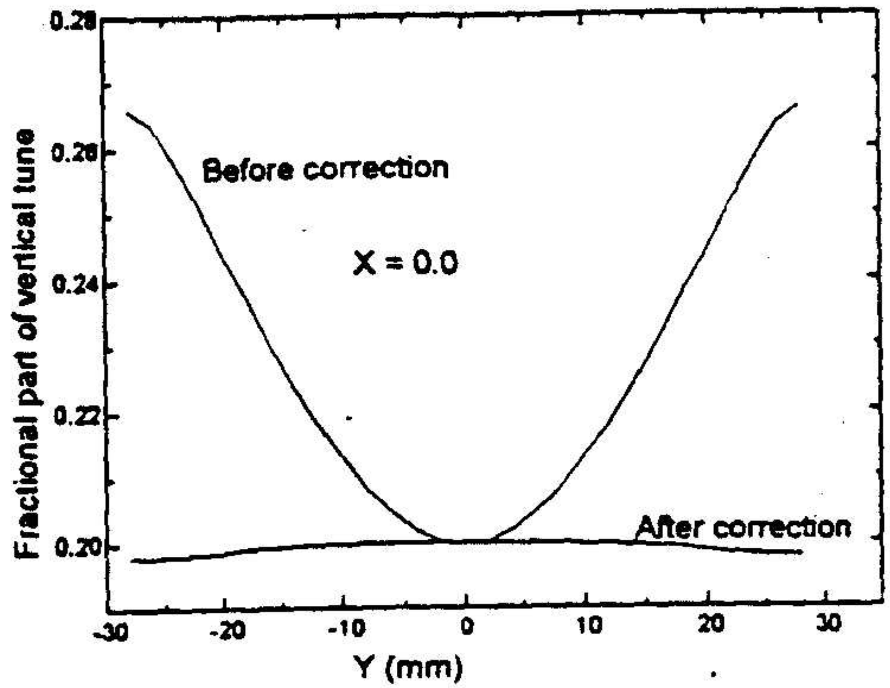


Fig.5(b) Amplitude dependent vertical tune with and without harmonic correction

The proposed Insertion Devices

- Wavelength Shifter 5.0T, 36cm
- Multipole Wiggler 1.8T, 35cm, 6 periods
- Undulator 0.39T, 4cm, 100 periods

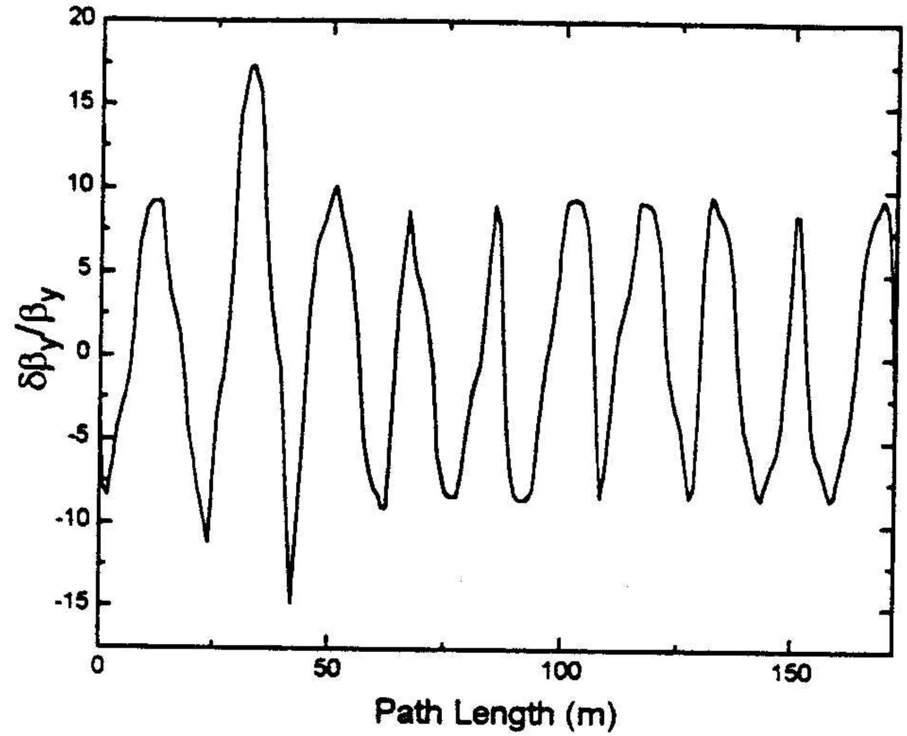


Fig.8 Vertical beta beat in presence of three insertion devices for 2.0 GeV

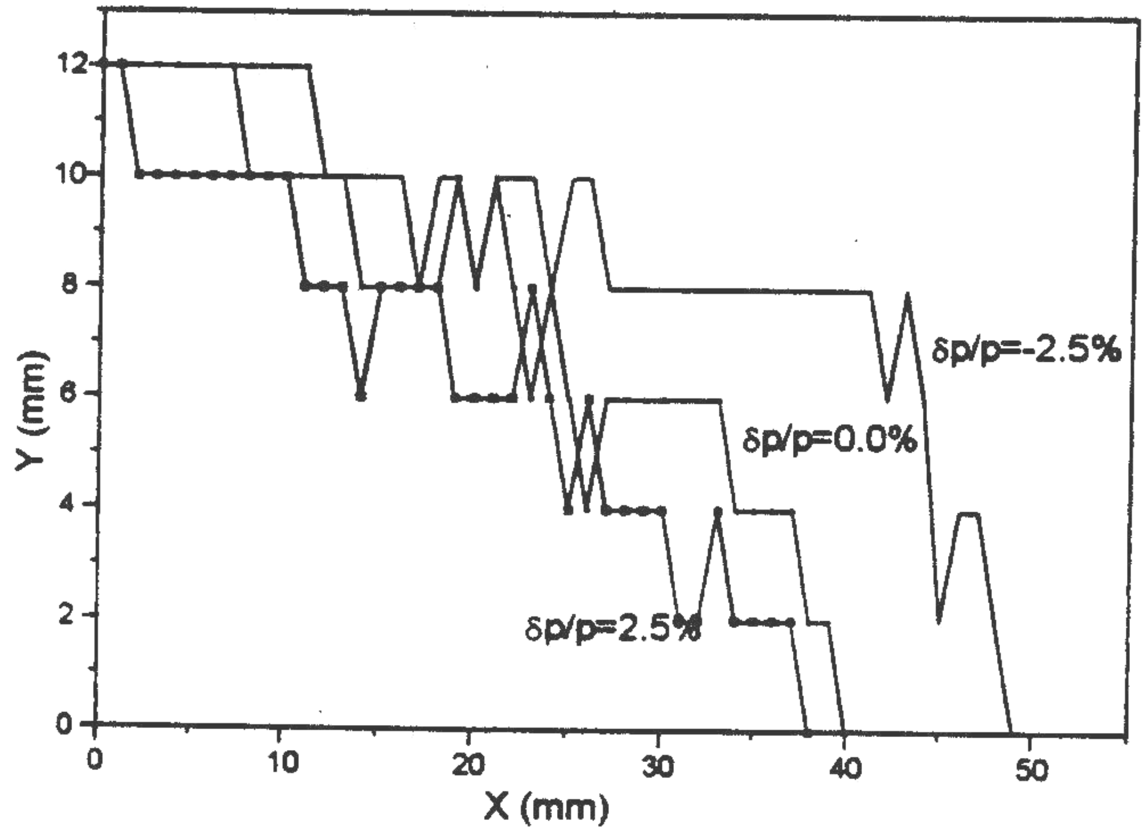
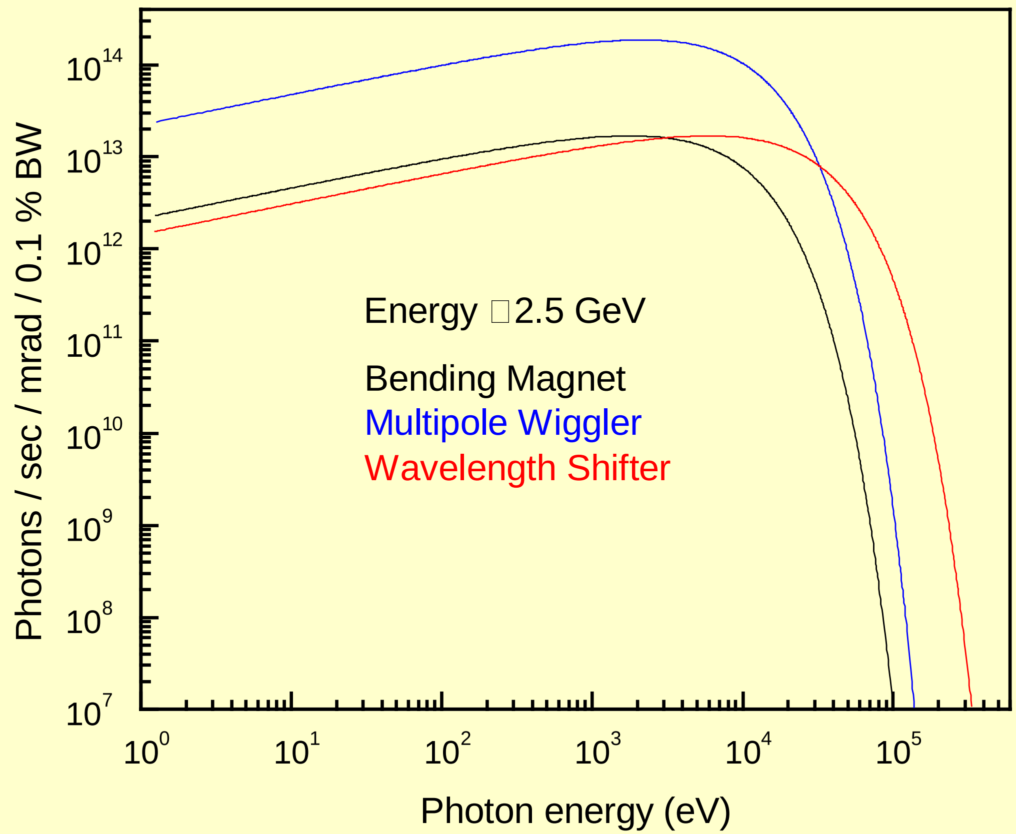


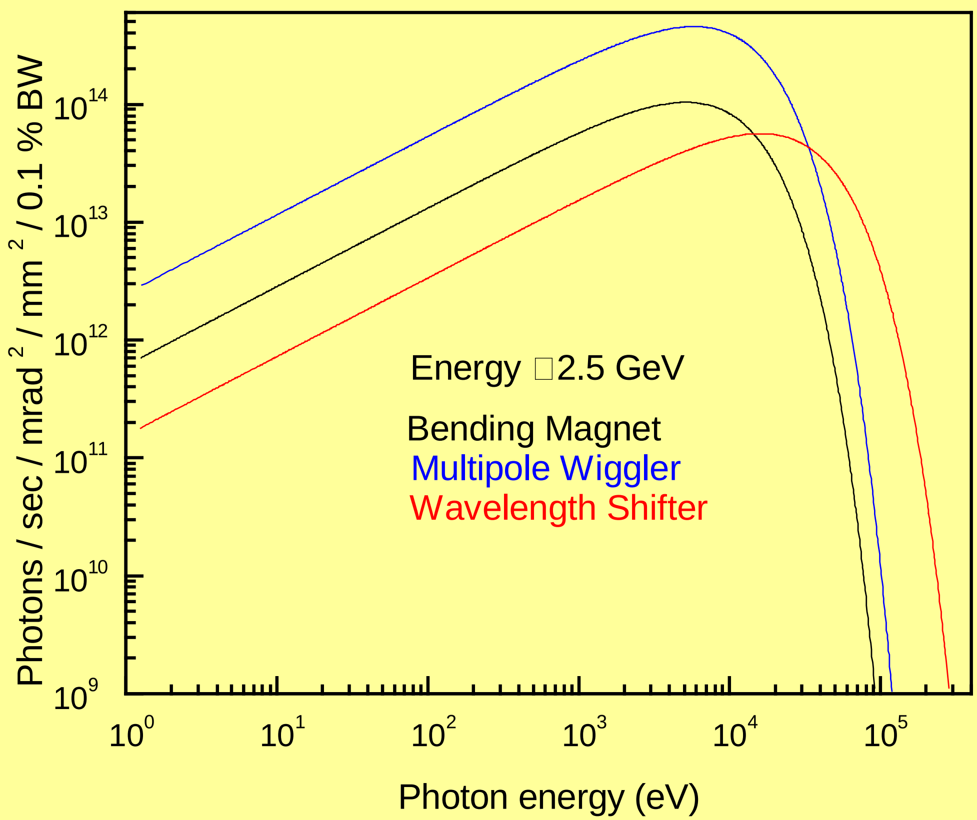
Fig.9 Dynamic Aperture with three insertion devices for 2.0GeV

Indus-2: Spectral Flux



Spectral flux vs photon energy

Indus-2: Source Brightness



Spectral brightness vs photon energy

Table - 2 : Flux and brightness at some typical wavelengths

Radiation Source	Photon Wavelength (Å)	Flux F1 (2.0 GeV)	Brightness B1 (2.0 GeV)	Flux F2 (2.5 GeV)	Brightness B2 (2.5 GeV)	F2/F1	B2/B1
Bending Magnet	2.00	4.69×10^{12}	7.13×10^{13}	1.21×10^{13}	1.02×10^{14}	2.58	1.43
	1.00	8.76×10^{11}	1.91×10^{13}	5.62×10^{12}	6.80×10^{13}	6.42	3.56
	0.50	2.43×10^{10}	7.44×10^{11}	9.98×10^{11}	1.69×10^{13}	41.1	22.7
	0.25	1.44×10^{7}	5.98×10^{8}	2.50×10^{10}	5.75×10^{11}	1736	961
	λ_c ($3.88^*, 2.00^\#$)	9.59×10^{12}	1.03×10^{14}	1.20×10^{13}	1.02×10^{14}	1.25	0.99
SC Wiggler	2.00	1.30×10^{13}	5.30×10^{13}	1.69×10^{13}	4.37×10^{13}	1.30	0.82
	1.00	1.01×10^{13}	5.77×10^{13}	1.54×10^{13}	5.49×10^{13}	1.52	0.95
	0.50	4.98×10^{12}	4.02×10^{13}	1.05×10^{13}	5.18×10^{13}	2.11	1.29
	0.25	9.96×10^{11}	1.10×10^{13}	4.06×10^{12}	2.67×10^{13}	4.08	2.43
	λ_c ($0.93^*, 0.60^\#$)	9.62×10^{12}	5.71×10^{13}	1.20×10^{13}	5.47×10^{13}	1.25	0.96
Multipole Wiggler	2.00	8.58×10^{13}	2.86×10^{14}	1.48×10^{14}	4.54×10^{14}	1.72	1.59
	1.00	3.00×10^{13}	1.40×10^{14}	8.13×10^{13}	3.41×10^{14}	2.71	2.44
	0.50	2.97×10^{12}	1.86×10^{13}	2.01×10^{13}	1.10×10^{14}	6.77	5.91
	0.25	2.29×10^{10}	1.83×10^{11}	9.45×10^{11}	6.38×10^{12}	41.3	34.9
	λ_c ($2.59^*, 1.66^\#$)	1.05×10^{14}	3.10×10^{14}	1.32×10^{14}	4.42×10^{14}	1.25	1.43

- **Critical wavelength at 2.0 GeV ; # Critical wavelength at 2.5 GeV**

Beam lines

- X-ray Fluorescence-Microprobe beamline
- EXFAS beamline
- Grazing incidence magnetic scattering beamline
- Photo Electron Spectroscopy beamline
- Small Angle Scattering beamline

Beam lines
5T Wavelength Shifter

- Material Science beamline for Powder Diffraction
- Energy Dispersive X-ray Diffraction beamline
- Protein Crystallography beamline

Present Status of Indus-2

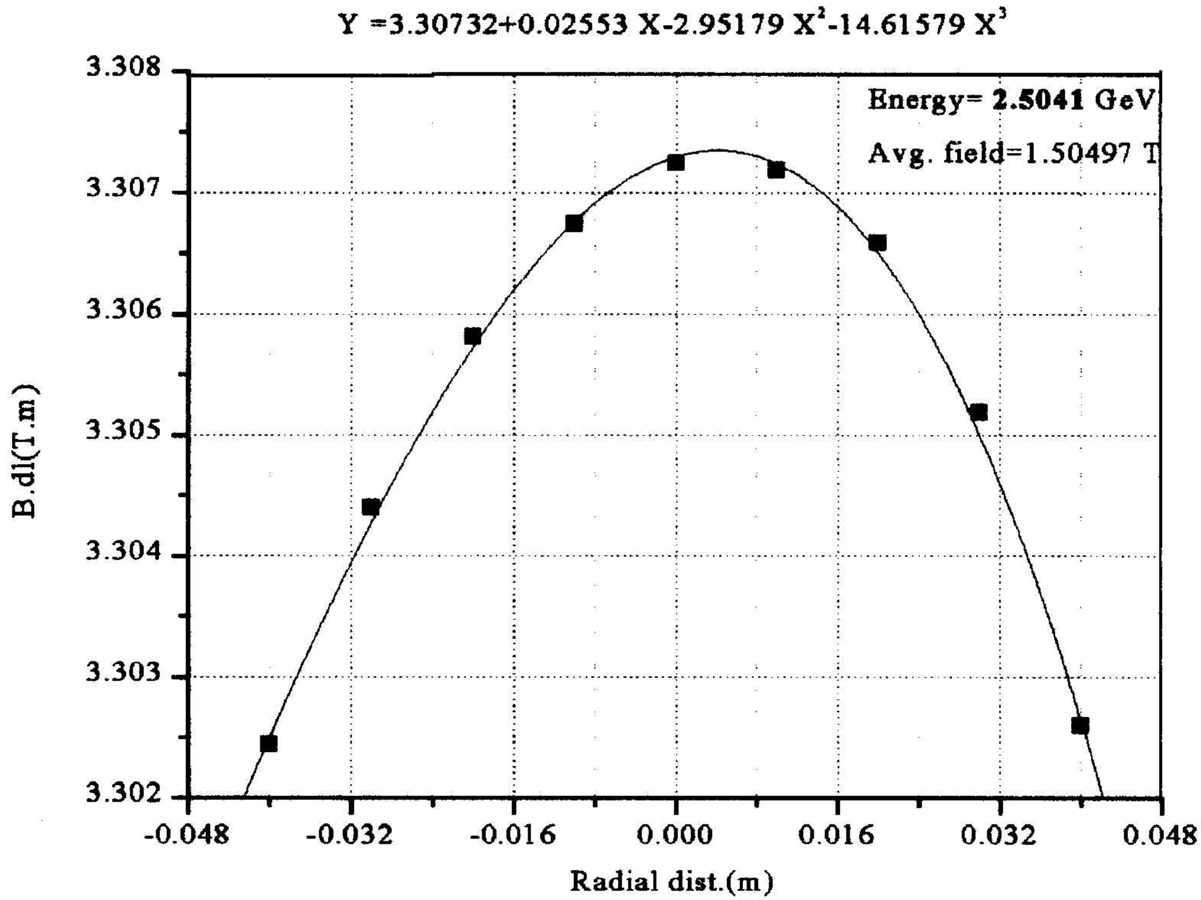
Indus-2 Tunnel

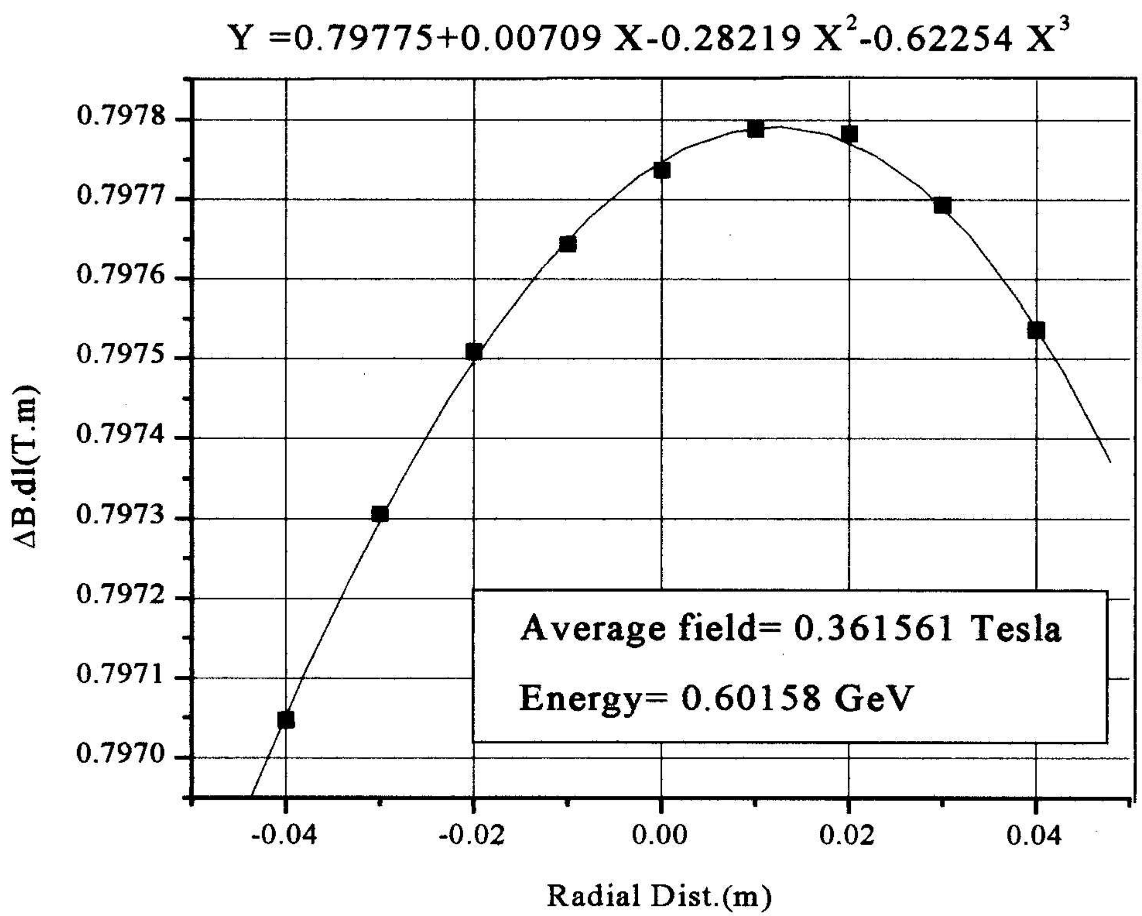
circumference ≈180 m


CAT INDORE

Magnets for Indus-2
Dipole Magnets

The main dipole magnet field is designed to be 1.5 Tesla. The 17 dipole magnets (including one reference magnet) are constructed from 5.8mm thick plates of low carbon steel highly homogenous iron supplied by M/s Cockreill Sambre, Belgium. This soft magnetic material was selected for the construction as it is a high purity iron with carbon 0.01%, Mn 0.3%, Si 0.1%, P 0.02% and S 0.02%. High saturation induction of this material will help in the linear response of these magnets. These magnets will be ramped from 3 KG to 15 KG in a period of 300 seconds and will be constructed vertically arranging 5.8 mm thick plates and welding together. The plates will be insulated from each other which will minimise the field distortions due to eddy currents. The pole gap is 50 mm. The energising coils are oxygen free high conductivity copper (OFHC) square hollow conductors.


Y =3.30732+0.02553 X-2.95179 X²-14.61579 X³
Energy= 2.5041 GeV
Avg. field=1.50497 T
B.dl(T.m)
3.308
3.307
3.306
3.305
3.304
3.303
3.302
-0.048
-0.032
-0.016
0.000
0.016
0.032
0.048
Radial dist.(m)


Y =0.79775+0.00709 X-0.28219 X^2-0.62254 X^3
0.7978
0.7977
0.7976
0.7975
0.7974
0.7973
0.7972
0.7971
0.7970
ΔB.dl(T.m)
Average field= 0.361561 Tesla
Energy= 0.60158 GeV
-0.04
-0.02
0.00
0.02
0.04
Radial Dist.(m)

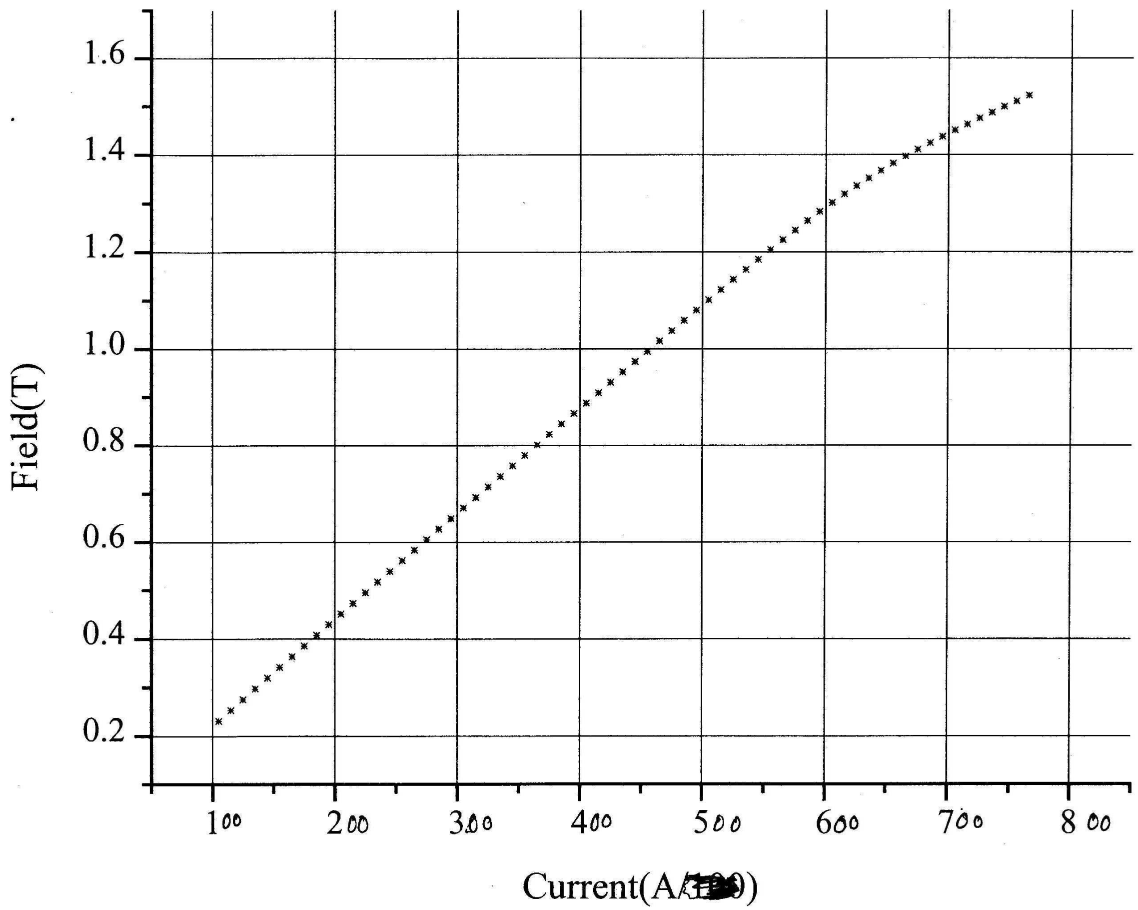

1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
Field(T)
100
200
300
400
500
600
700
800
Current(A/

Fig. 1

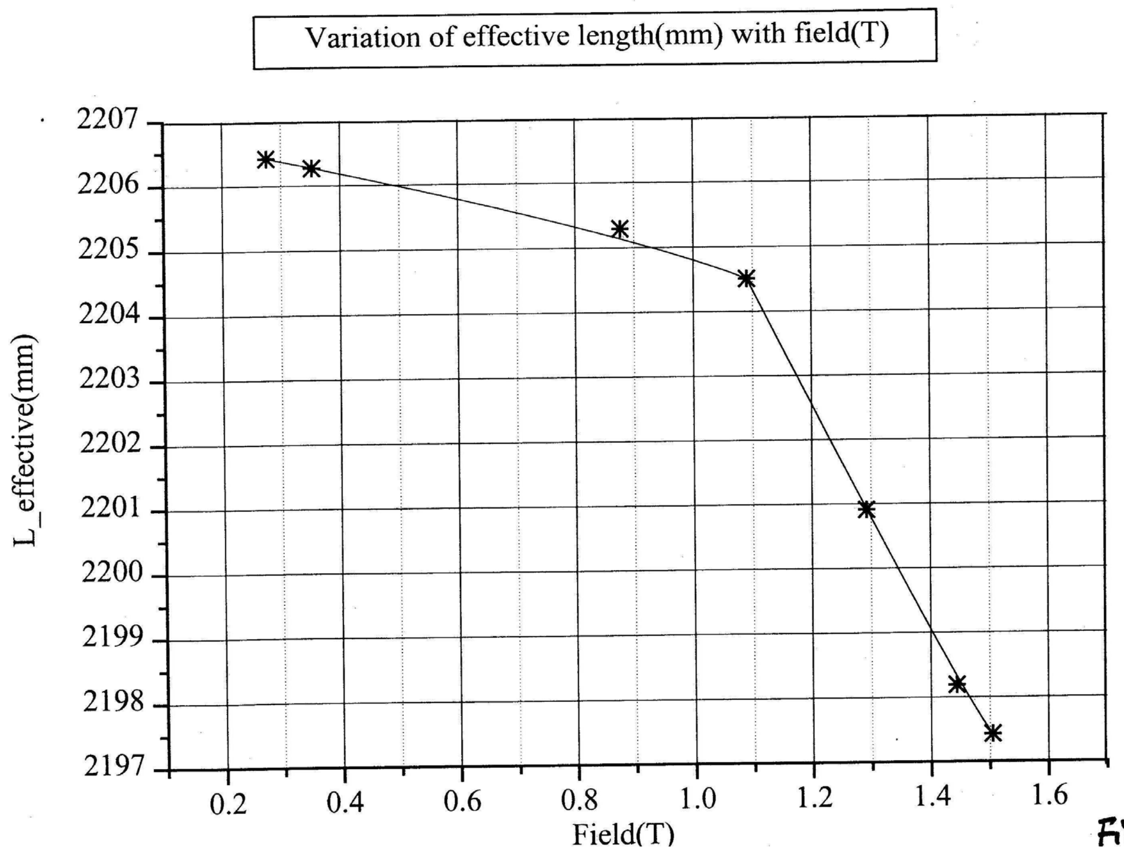
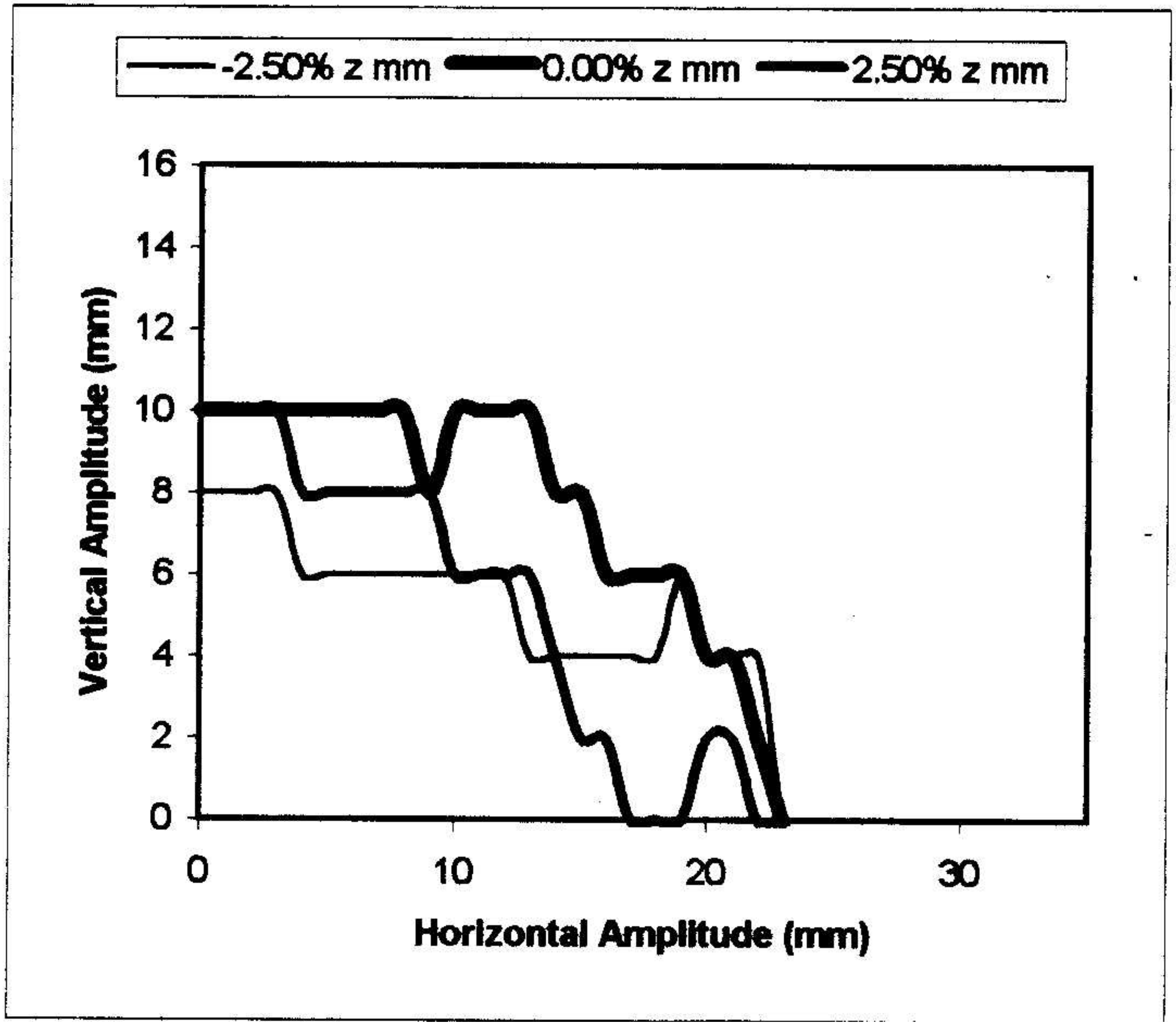

Variation of effective length(mm) with field(T)
L_effective(mm)
2207
2206
2205
2204
2203
2202
2201
2200
2199
2198
2197
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Field(T)

Fig. 2

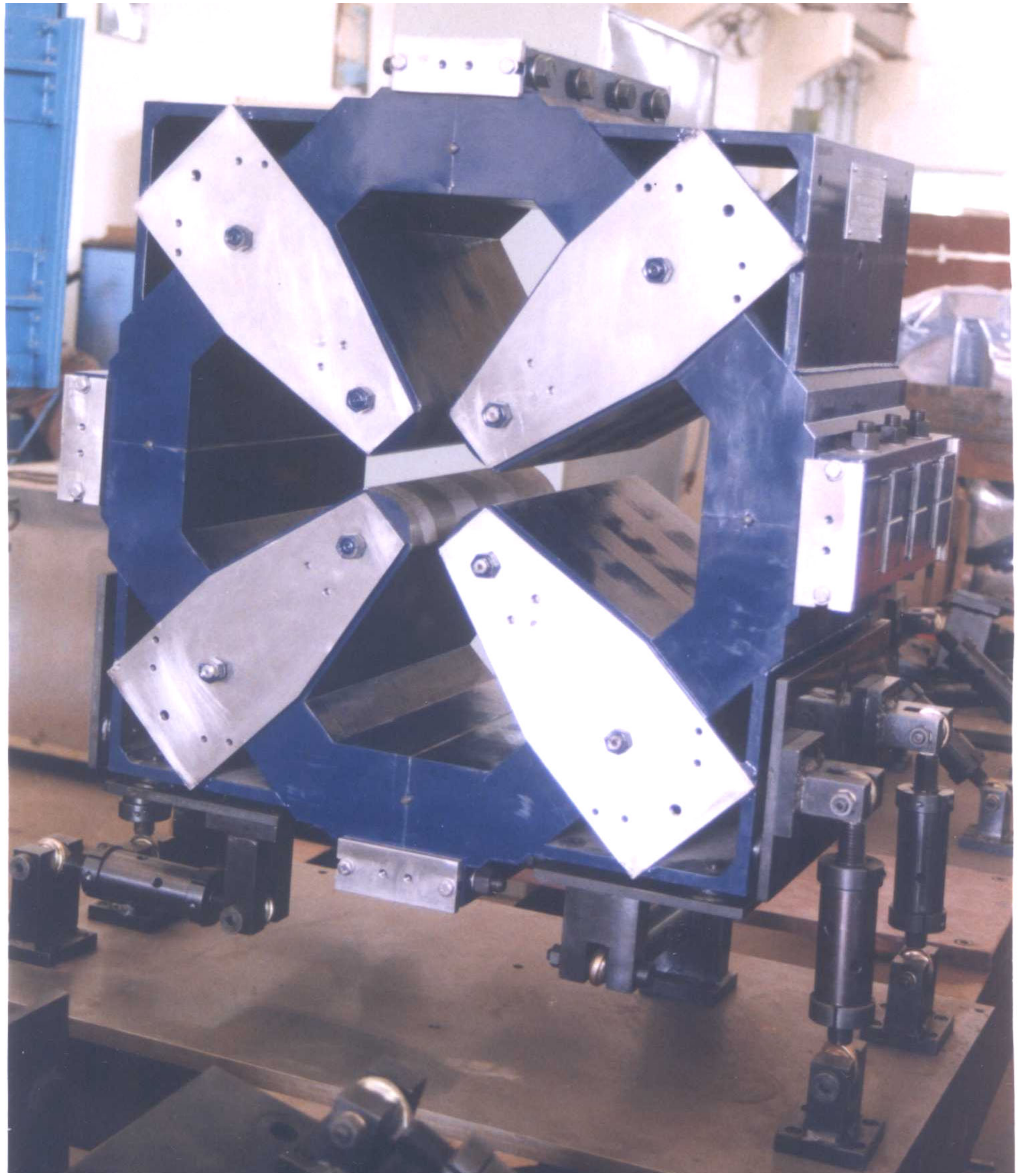


Dynamic aperture in the presence of measured field errors in dipole and quadrupole magnets

Dipole Magnet

Magnets for Indus-2
Quadrupole Magnets

A total of 72 quadrupoles with a field strength of 16 T/m will be used. The quadrupole magnets have aperture of 85 mm and their length varies from 300 mm to 500 mm comprising of five different lengths of magnets. The magnets are of laminated construction with the laminations stamped from CRNGO silicon steel of 0.50/0.65 mm thick, M-36/M-27 grade. 32 quadrupoles which are located just before and after each dipole magnet are open type. These are constructed of 1.5mm thick soft iron similar in material composition to that of dipole magnets. The energising coils which are isolated and epoxy potted are of OFHC square hollow conductors.



Magnets for Indus-2

Sextupole Magnets

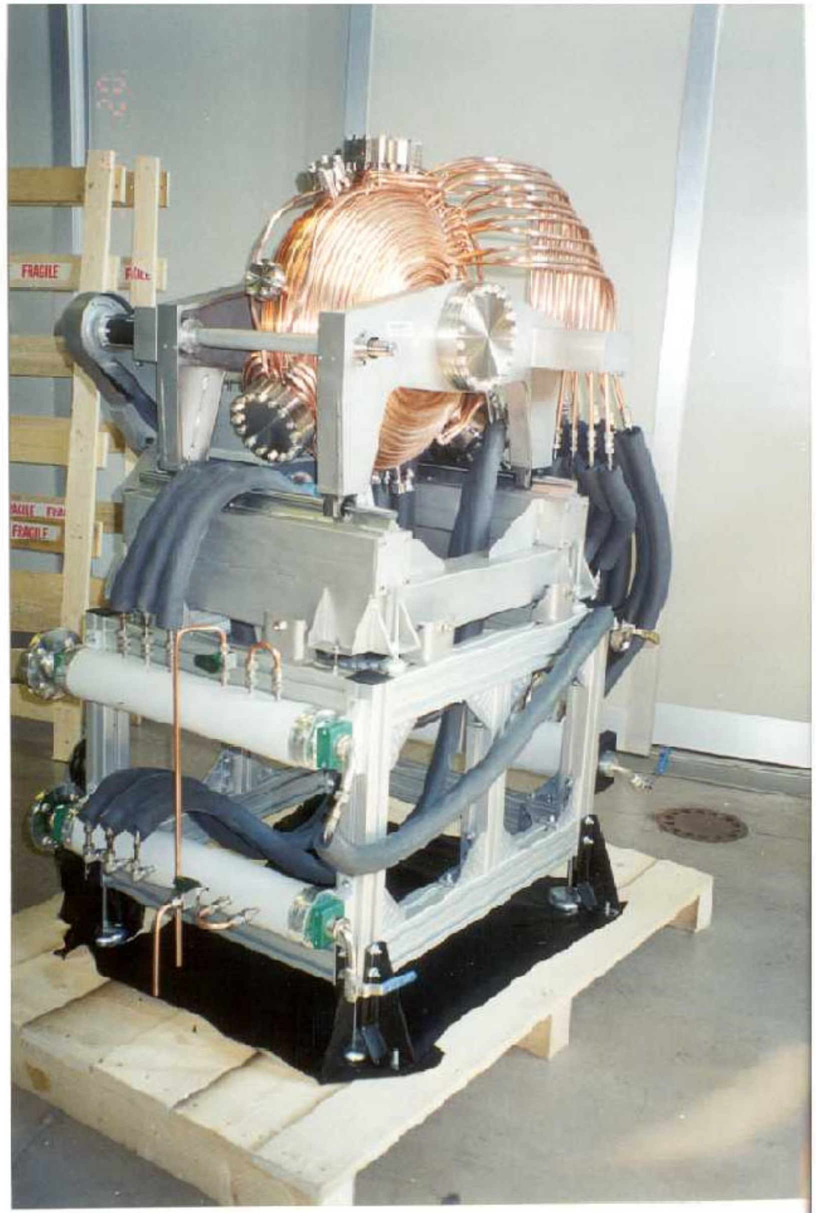
The sextupole magnet construction as well as its energising coils are similar to that of quadrupoles. 32 Nos. of sextupoles with field strength of 400 T/m^2 and 16 Harmonic sextupoles with a field strength of 200 T/m^2 will be used.

In addition 42 Nos. of combined function steering magnets, 8 vertical steering magnets, 16 horizontal steering magnets will be employed apart from steering coils on dipole magnets to correct the beam orbit.


DANFYSIK

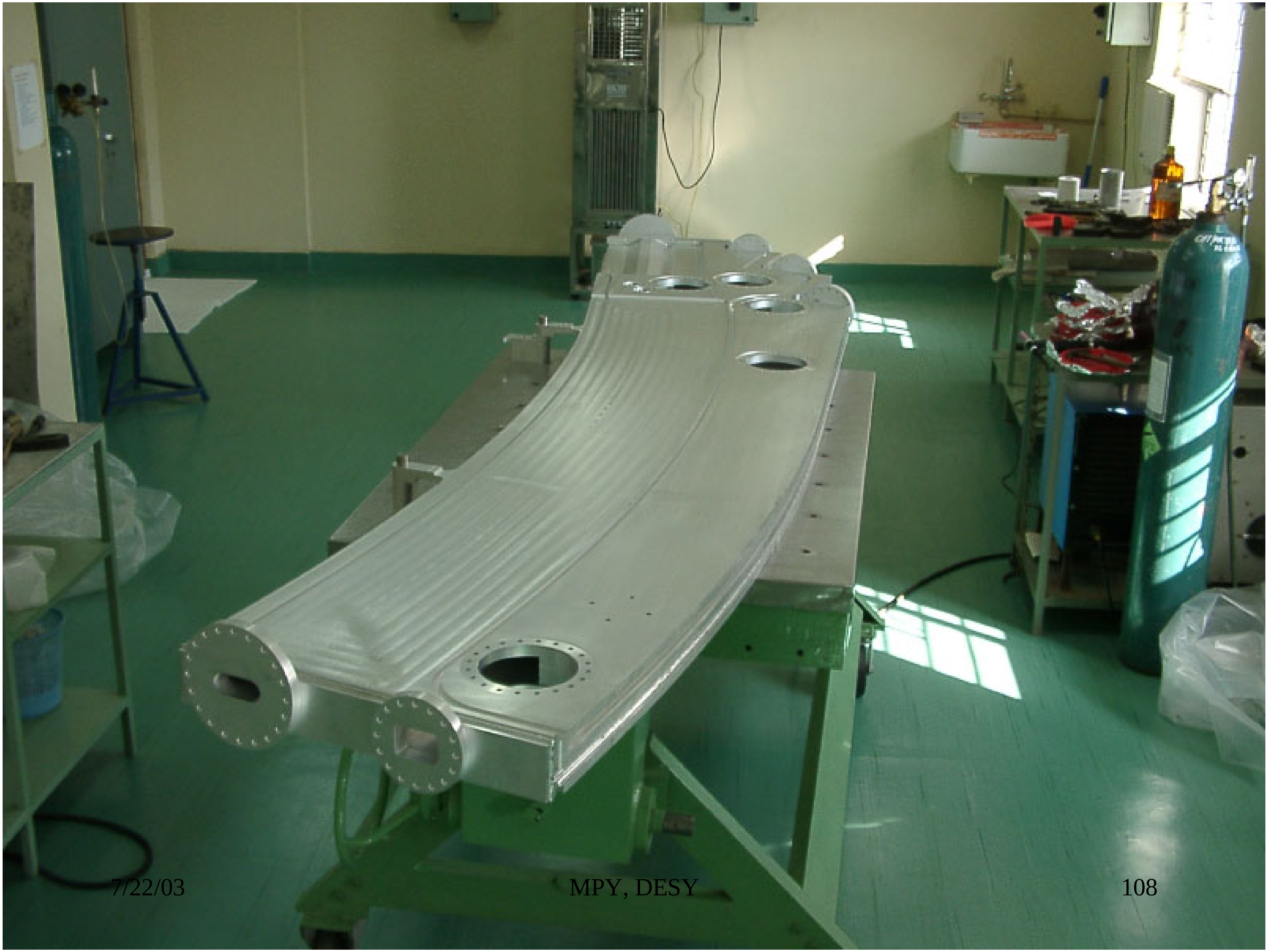
RF Cavities of Indus-2

The total beam power requirement from RF system will be about 322 kW. Four RF stations will be used to deliver this power to four RF cavities. Sincrotrone Trieste, Italy has already supplied 4 RF Cavities. The cavities will be exited by 60 kW RF power source. The RF source is built around 60 kW multi cavity multi beam klystron tube. The klystrons and circulators are being procured from Russia and are ready. All related power supplies and RF components have been developed. Low level RF control system will be used to regulate amplitude, phase and frequency of cavity gap voltage.


FRAGILE

Indus-2 Vacuum Chamber

The 16 Nos. of dipole vacuum chambers of ante chamber design, being fabricated from Aluminium alloy 5083 H321, consisting of upper and lower halves machined separately and welded together after chemical cleaning. Two beam ports at 5° and 10° are provided in each dipole chamber. In addition, another port at 0° is also provided in five dipole chambers downstream of the five straight sections meant for insertion devices. All the dipole chambers have been machined using bridge type milling machine at Hindustan Aeronautics Limited, Nashik.



Concluding Remark

The assembly of magnets and vacuum chambers will start in the month of October, 2003. The commissioning likely to start beginning of the next year.

for more details visit:

Http://www.cat.ernet.in

Acknowledgements

- The design and commissioning of Indus facility is a team work of many scientists, engineers and technical personnel of the Accelerator Programme of CAT. The team has contributed in this project at every stage and all the members of the Accelerator Programme are responsible in building up this national facility.


Danke Schön