Status of Indus-2

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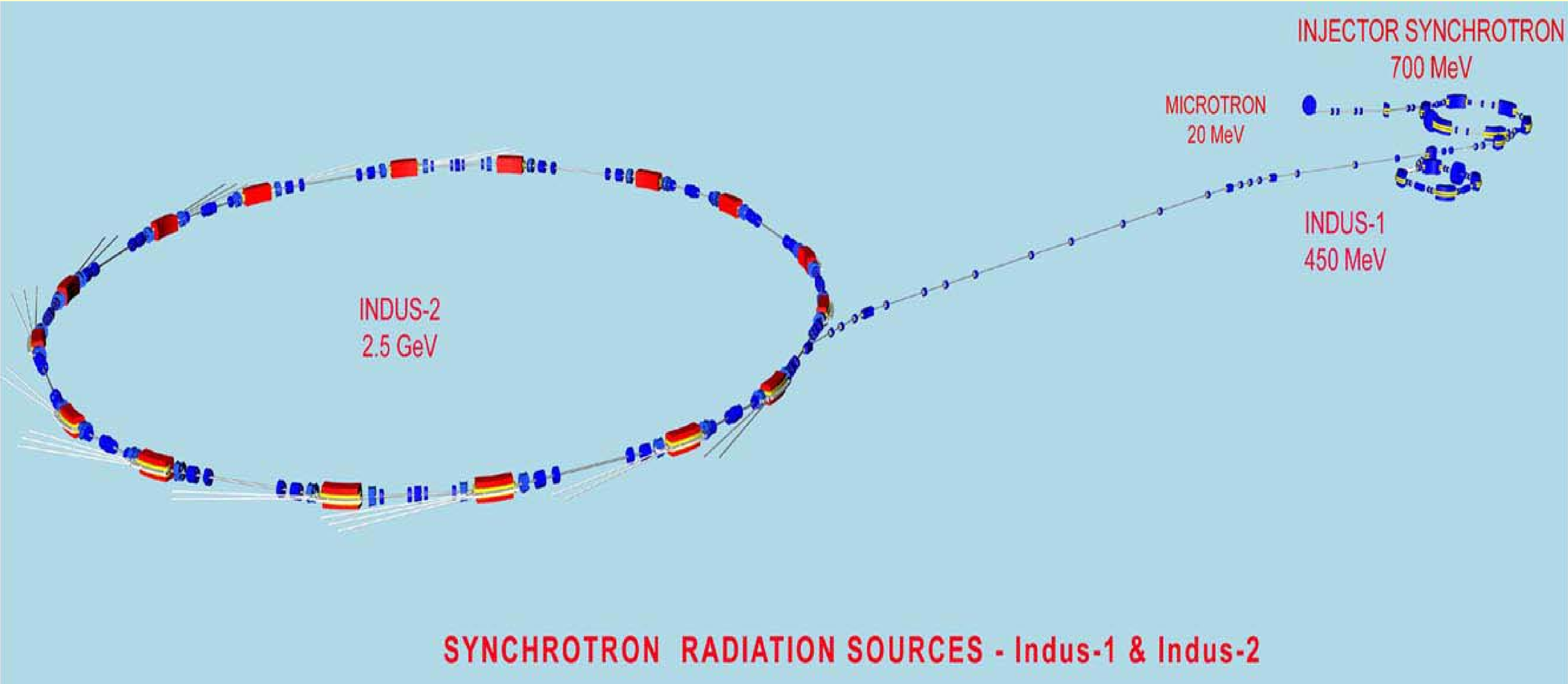
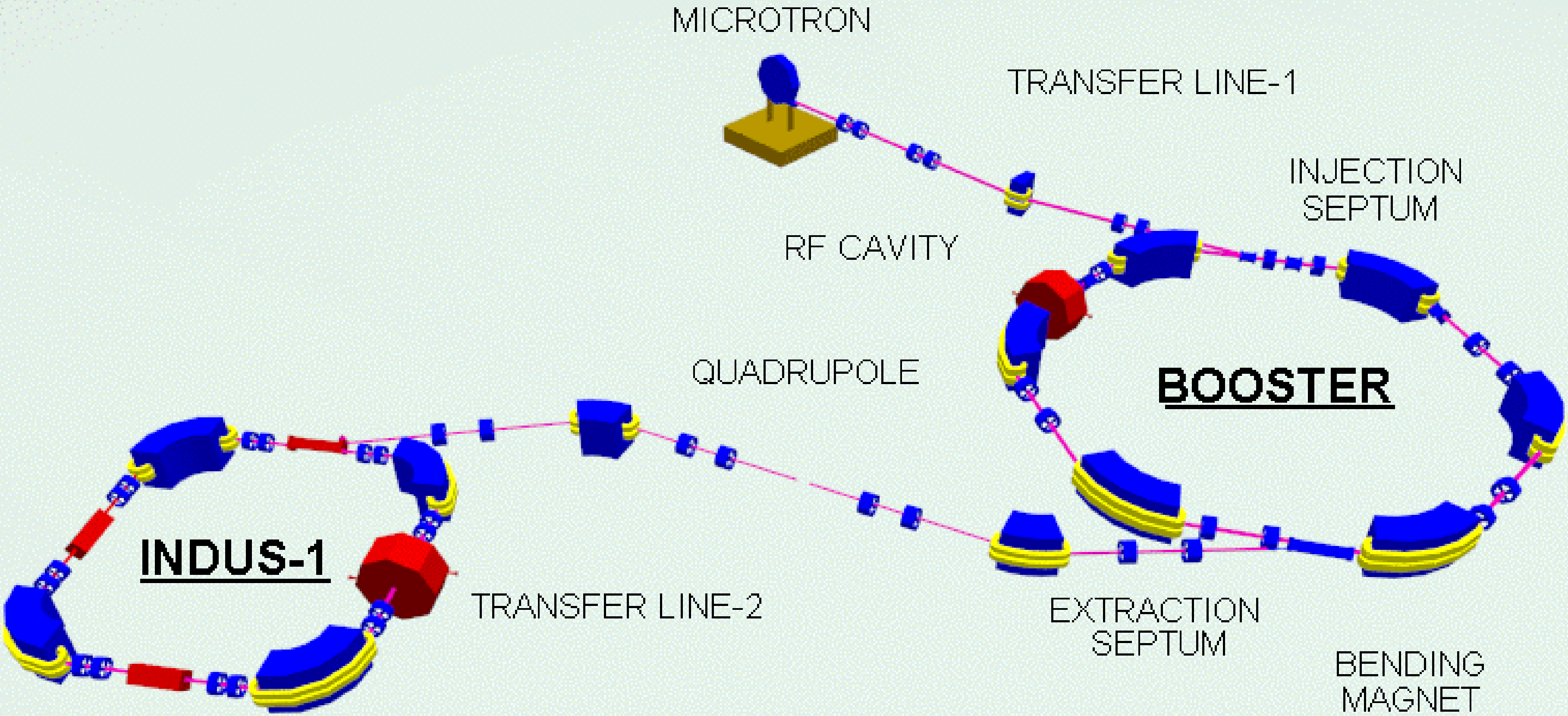
Schematic of Indus-2





SYNCHROTRON RADIATION SOURCE

Design criteria for synchrotron radiation source

1. **Users' requirement**

High Photon Flux *(Ph/(s.mrad.0.1 % BW))*
High Brightness *(Ph/(s.mm^2.mrad^2.0.1%BW))*

High Brightness is achieved with a small beam emittance

- **Long straight sections for insertion devices** ***(zero or small dispersion)***

Minimum emittance for a Chasman Green lattice

$\varepsilon_x = 10^{-7} E^2(\mathrm{GeV})\theta^3(\mathrm{rad})$

θ: bending angle per magnet

E : Beam energy

For a ring with 16 bending magnets

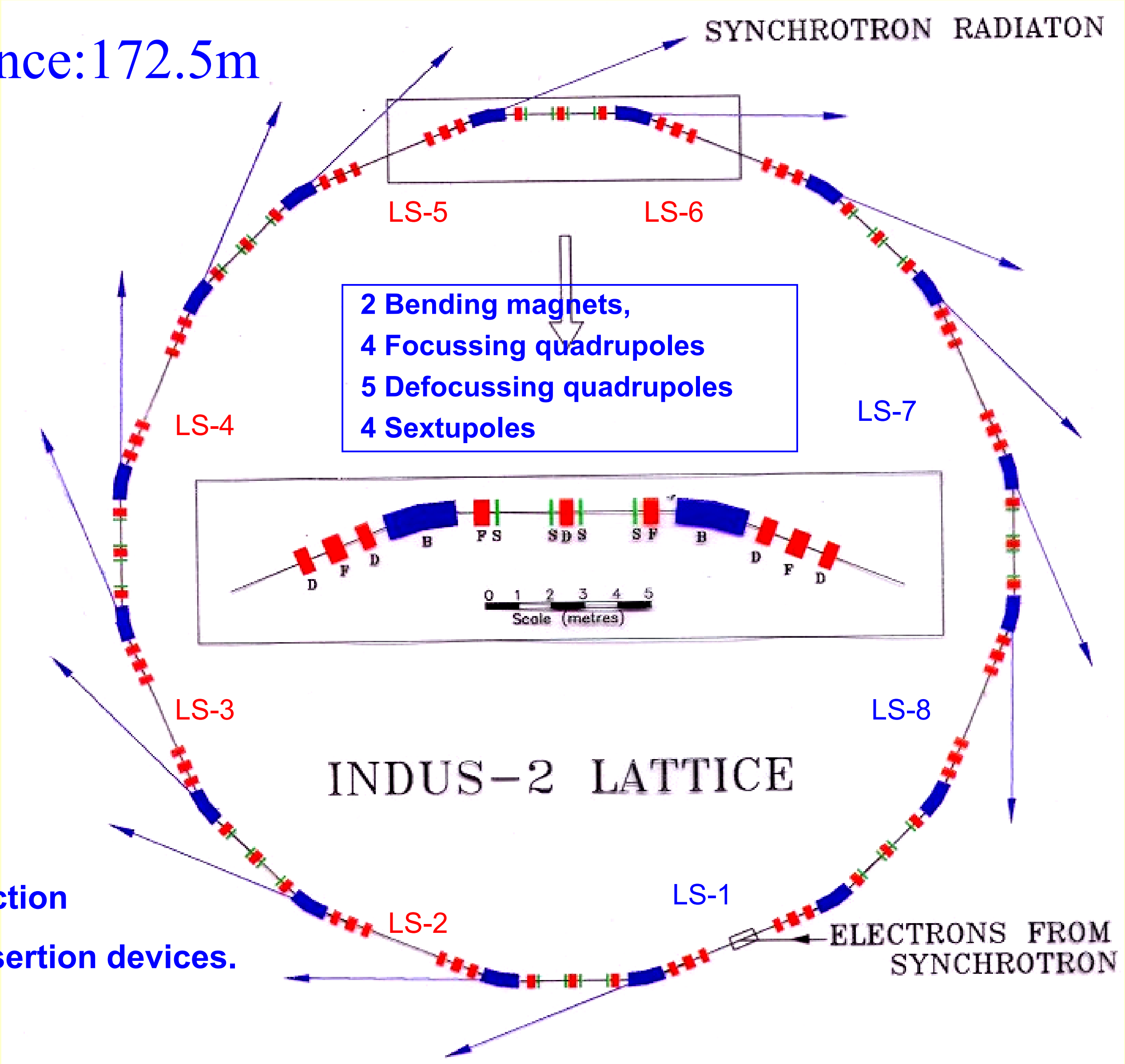
$\varepsilon_x(\mathrm{minimum}) = 3.78\mathrm{x}10^{-8}$ m.rad @ 2.5GeV

For Indus-2

$\varepsilon_x = 5.82\mathrm{x}10^{-8}$ m.rad @ 2.5GeV

Indus – 2 lattice

Circumference:172.5m

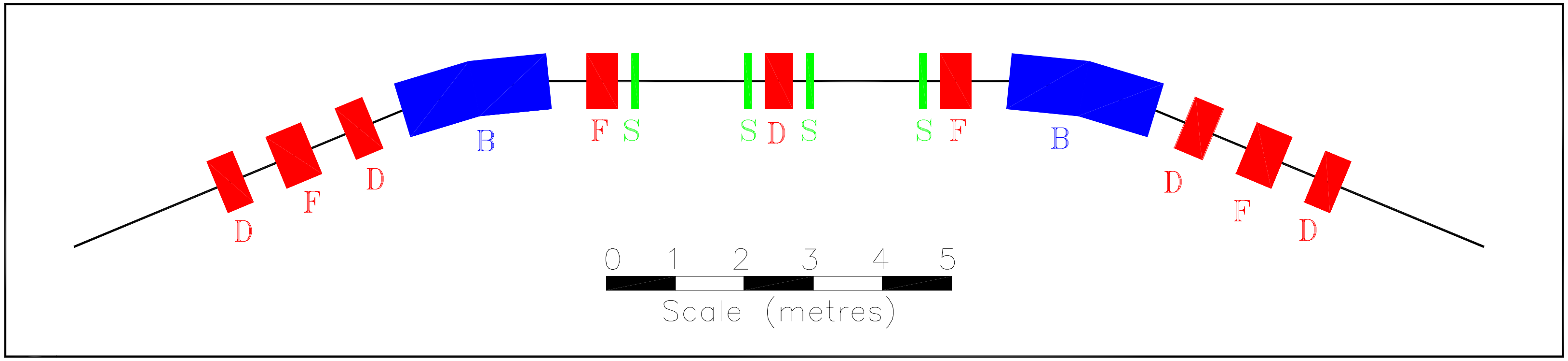


LS-1: used for injection

LS-2 to LS-6: for insertion devices.

LS-7: Unusable

LS-8: for RF cavities



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.

Parameters of Indus-2

Maximum energy		:	2.5 GeV
Maximum current		:	300 mA
Lattice type		:	Expanded Chasman Green
Superperiods		:	8
Circumference		:	172.4743 m
Bending field		:	1.502 T
Typical tune points		:	9.2, 5.2
Beam Emittance	ε_x	:	5.81×10^{-8} mrad
	ε_y	:	5.81×10^{-9} mrad
Available straight section for insertion devices		:	5
Maximum straight length available for insertion devices		:	4.5 m
Beam size	σ_x	:	0.234 mm
(Centre of bending magnet)	σ_y	:	0.237 mm
Beam envelope vacuum		:	< 1 $\times 10^{-9}$ mbar
Beam life time		:	15 Hrs
RF frequency		:	505.812 MHz
Critical wavelength		:	1.98 Å (Bending Magnet) 0.596 Å (High Field Wiggler)
Power loss		:	186.6 kW (Bending magnet)

Magnets:

Dipoles : 16; Q'poles: 32 focusing & 40 defocusing type; S'poles: 32

Indus-2 consists of

Number of dipole magnets: 16

Number of quadrupole magnets: 72

Number of sextupole magnets: 32

Number of horizontal steering magnets: 48

Number of vertical steering magnets: 40

Number of magnet power supplies

No. of P/S for 16 dipole magnets: 1
No. of P/S for quadrupole Q1 family (16): 8
No. of P/S for quadrupole Q2 family (16): 8
No. of P/S for quadrupole Q3 family (16): 8
No. of P/S for quadrupole Q4 family (16): 1
No. of P/S for quadrupole Q5 family (08): 1
No. of P/S for sextupoles (32): 2
There are independent power supplies for horizontal (48+16) and vertical steering magnets (40).

Beam Diagnostic Devices

11 Beam Position Monitors (BPM)
1 Wall Current Monitor (WCM)
1 DCCT
56 Beam Position Indicators (BPI)
1 Sighting Beamline
6 Striplines (2 used for tune measurements)
3 Scrappers

Objective of commissioning

To inject, store and accumulate electrons at the injection energy,
to accelerate these electrons to 2-2.5GeV and
to retain them for a long duration

Activities before Indus-2 commissioning:

1. Sorting of dipole, quadrupole magnets for placement in the ring.

2. Studies of relaxed optics.

3. Checking the polarities of all dipole, quadrupole, sextupole, horizontal and vertical steering magnets.

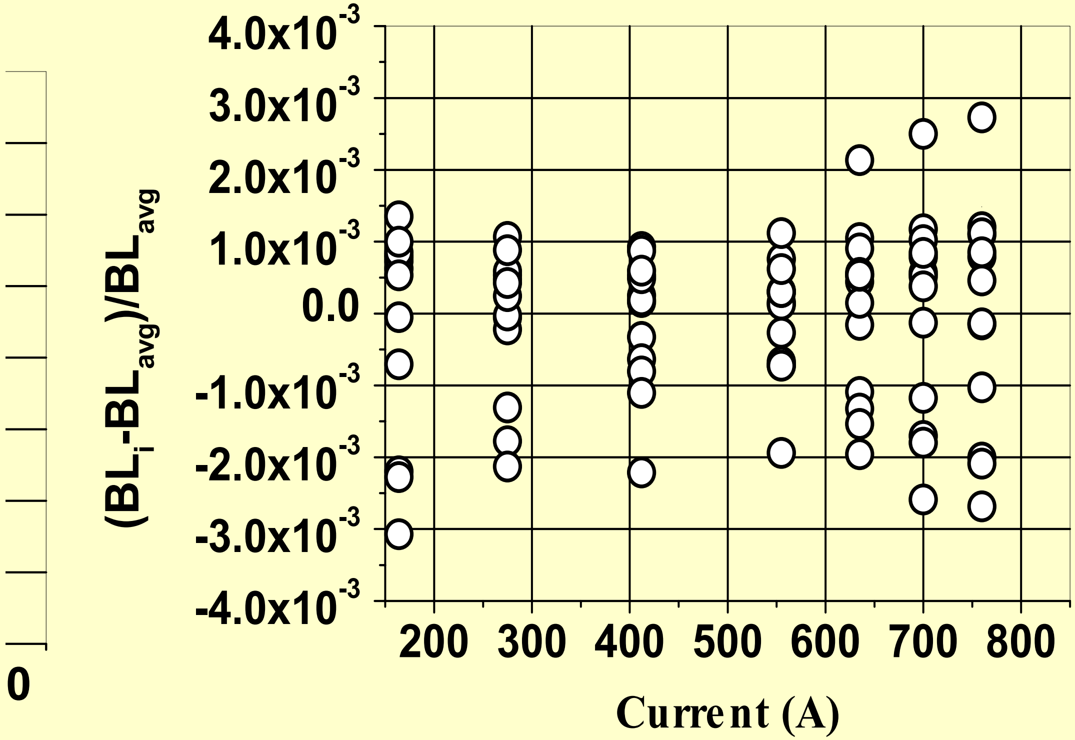


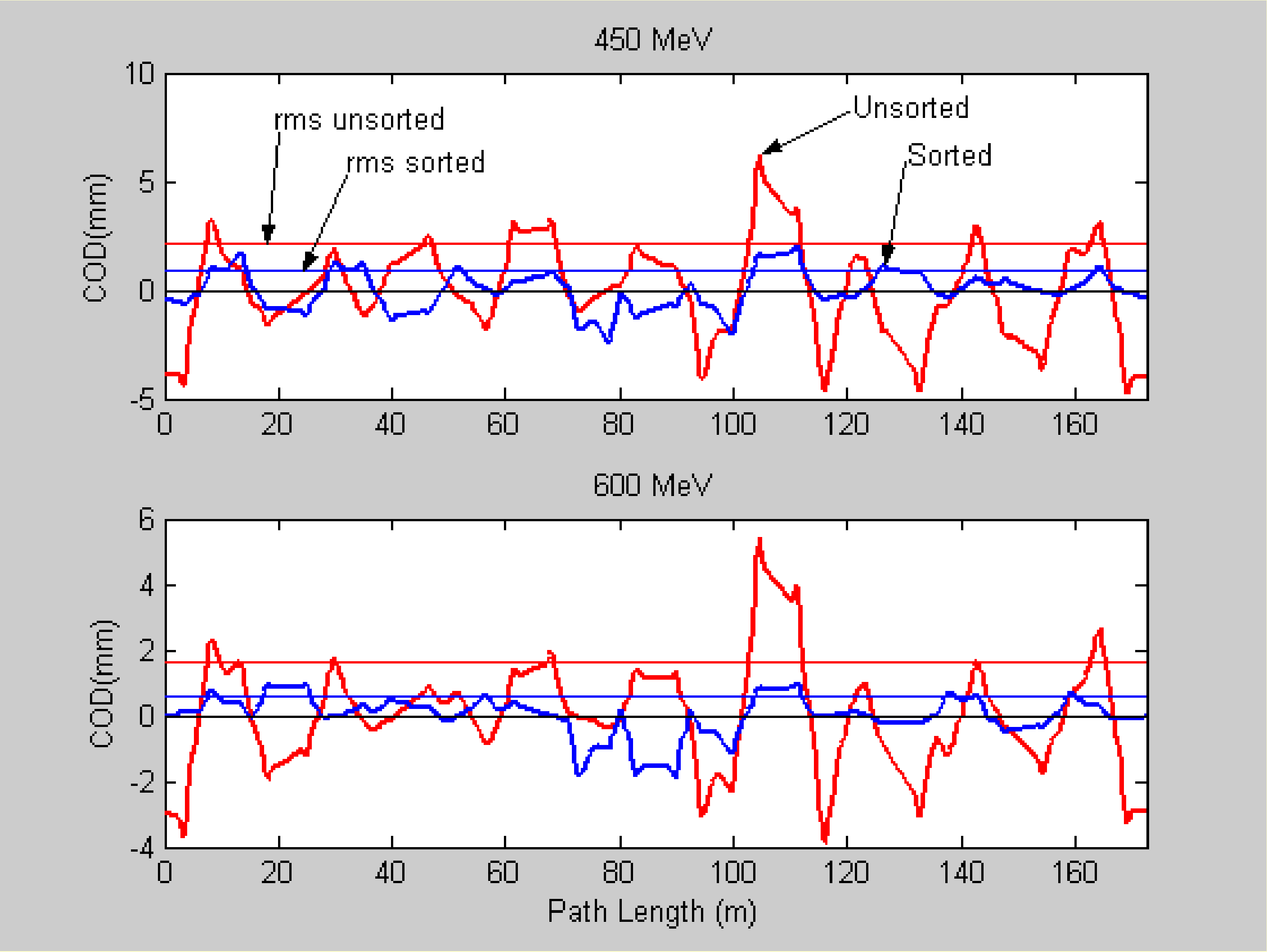
Fig.8 : Relative integrated strength variations for all the Indus-2 bending magnets with excitations

- **Magnet to magnet strength variation : $\pm 3 \times 10^{-3}$**

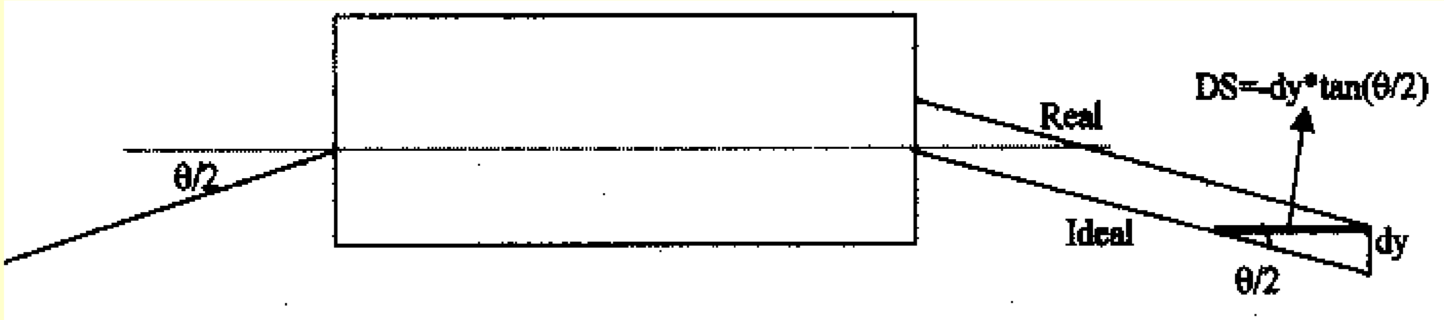
-

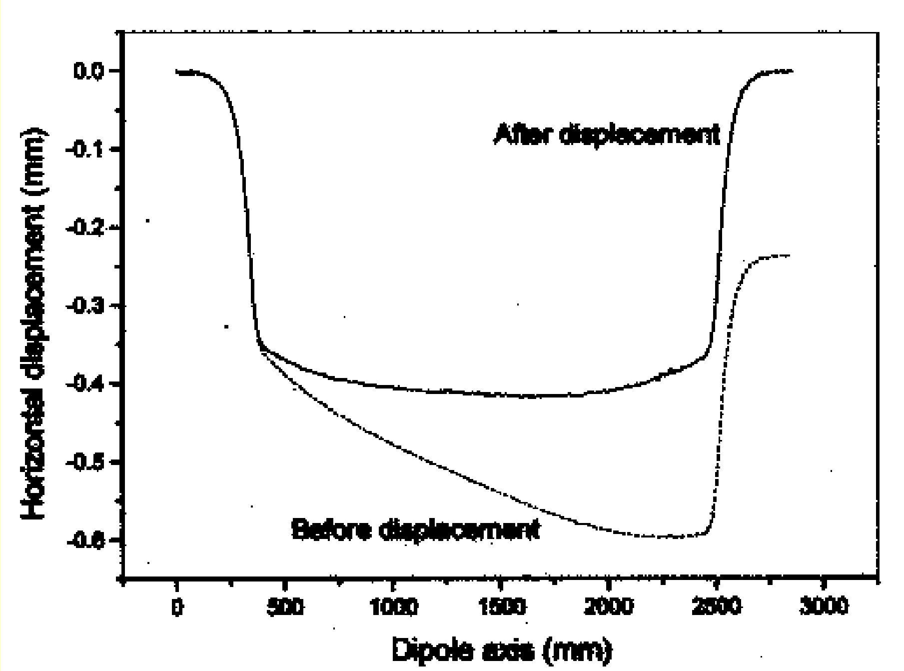
Dipole Magnet Sorting

The unsorted (red) and sorted(blue) closed orbit at 450 and 600 MeV.



Trajectory in a Real Dipole





Trajectory Corrections in Dipoles

Due to fringe field & asymmetric field pattern of the magnets the real trajectory do not coincide with the ideal trajectory at the exit of the magnet.

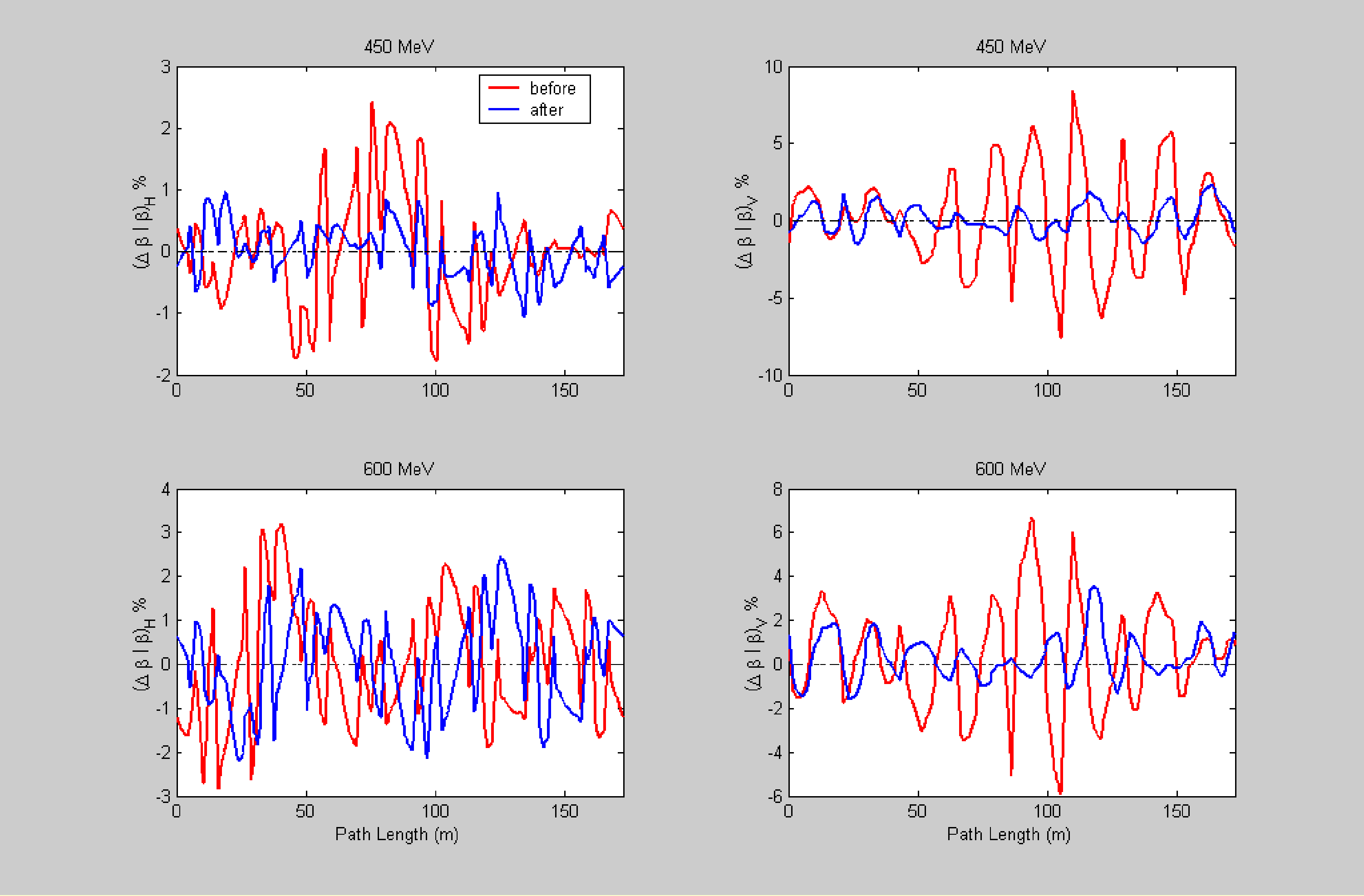
Dipole magnets were required to be shifted in the beam direction to avoid such a situation. This displacement is in the range of –1 to +2 mm.

The circumference was 2.56mm shorter than the ideal circumference at 450/600MeV.

The whole ring was stretched in outward direction by 0.4 mm to compensate the circumference error.

Quadrupole Magnet Sorting

The unsorted (red) and sorted (blue)beta beat over the ring at 450 and 600 MeV (magnet to magnet field error: $\pm 3 \times 10^{-3}$)



Major steps in commissioning

Four turn beam circulation

Beam injection & storage at 450MeV

Beam injection & storage at 550MeV

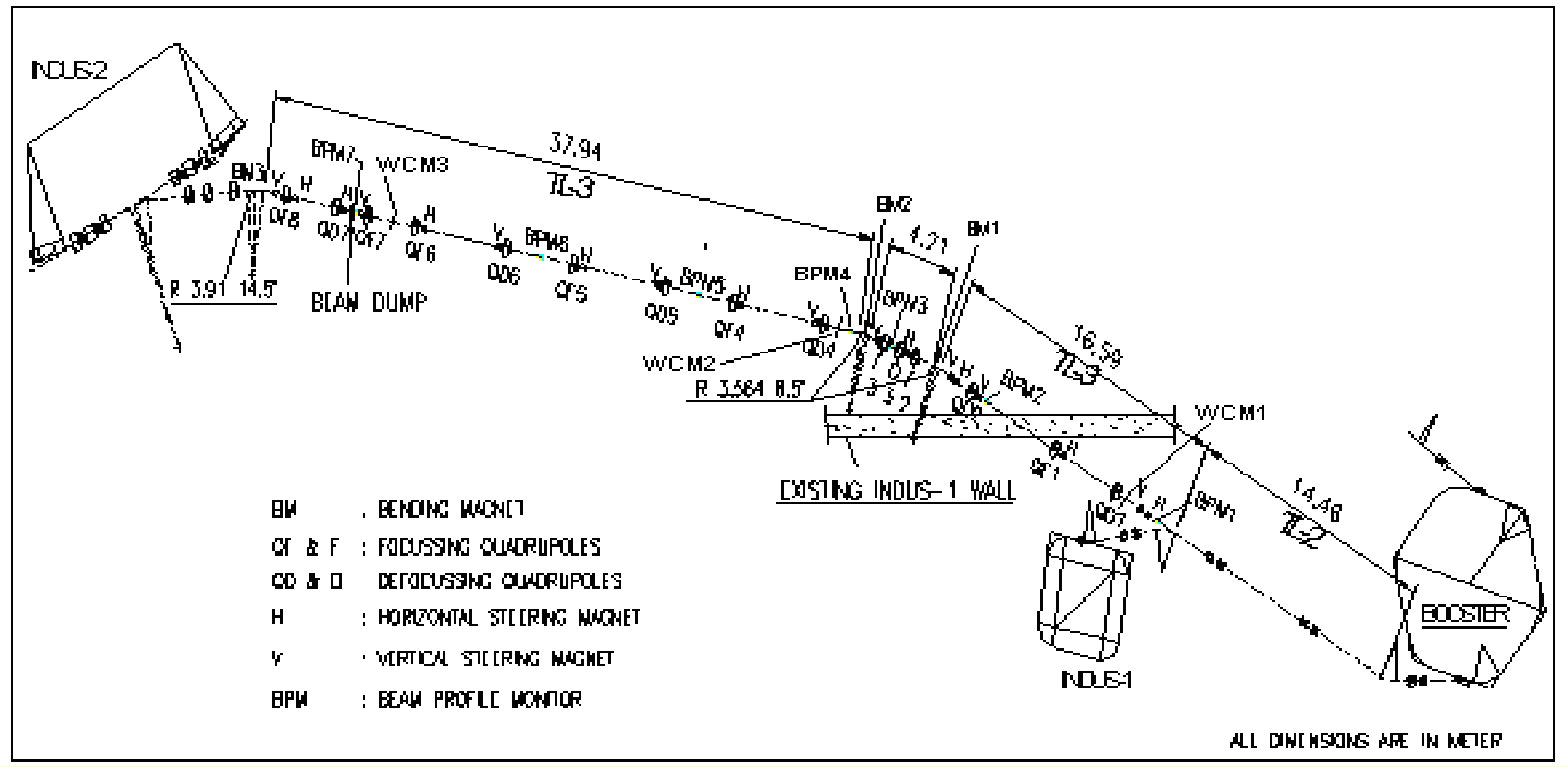
(Damping time: 445ms at 550MeV and 810ms at 450MeV)

Beam acceleration to 2GeV and higher

Closed orbit correction

Delivery of SR to users

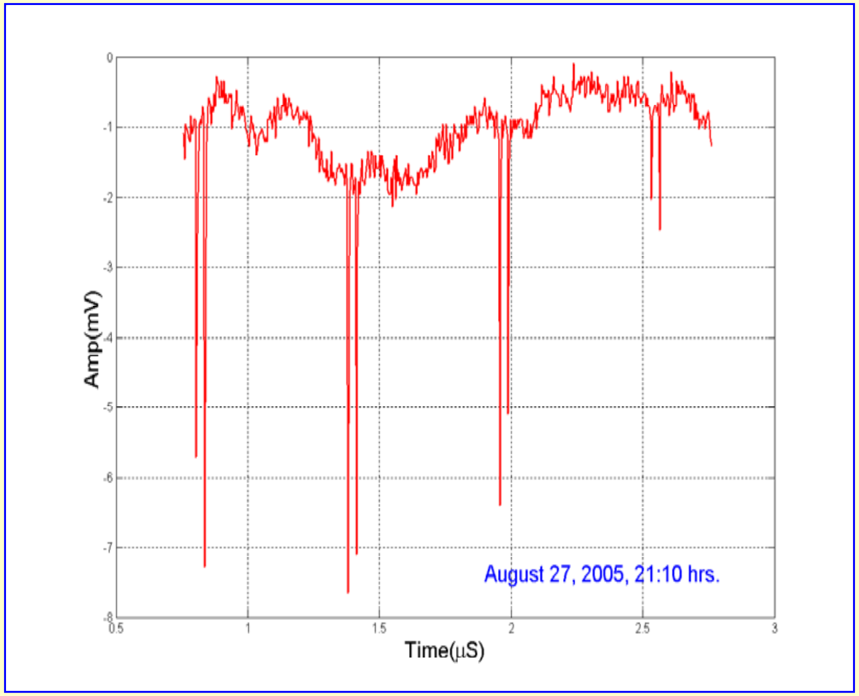
Transfer line from Booster to Indus-2



Total length of the line = 88. 2 m

Four Turn Beam Circulation in Indus-2

- **Four turn beam circulation seen on wall current monitor (WCM) signal on 27th August,2005**



Comparison of two optics

Parameters	Design optics	Present optics B (II)
ν_x, ν_y	9.2 5.2	9.3 6.2
$X_{co}/\Delta x$, $Y_{co}/\Delta y$	49.2 41.6	36.0 31.4
	25.7 20.8	26.5, 14.2
υ υ	5.5, 4.4	5.7, 3.1
ε@ 2.5 GeV (nm rad)	56.6	126.0
d ν_x	$-83x^2-410y^2$	$-72x^2-86y^2$
d ν_y	$-59x^2+283y^2$	$-29x^2+37y^2$

Indus-2 optics

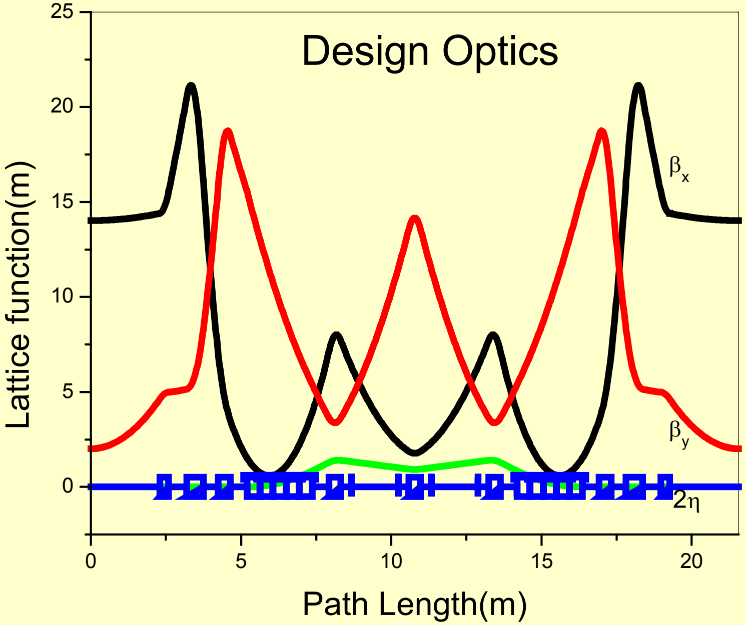


Fig. Lattice functions of Indus-2 (9.2,5.2)

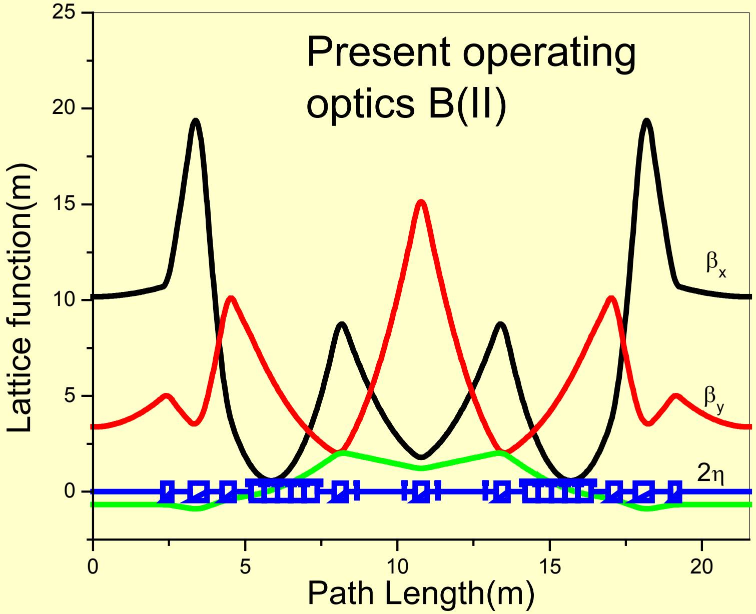
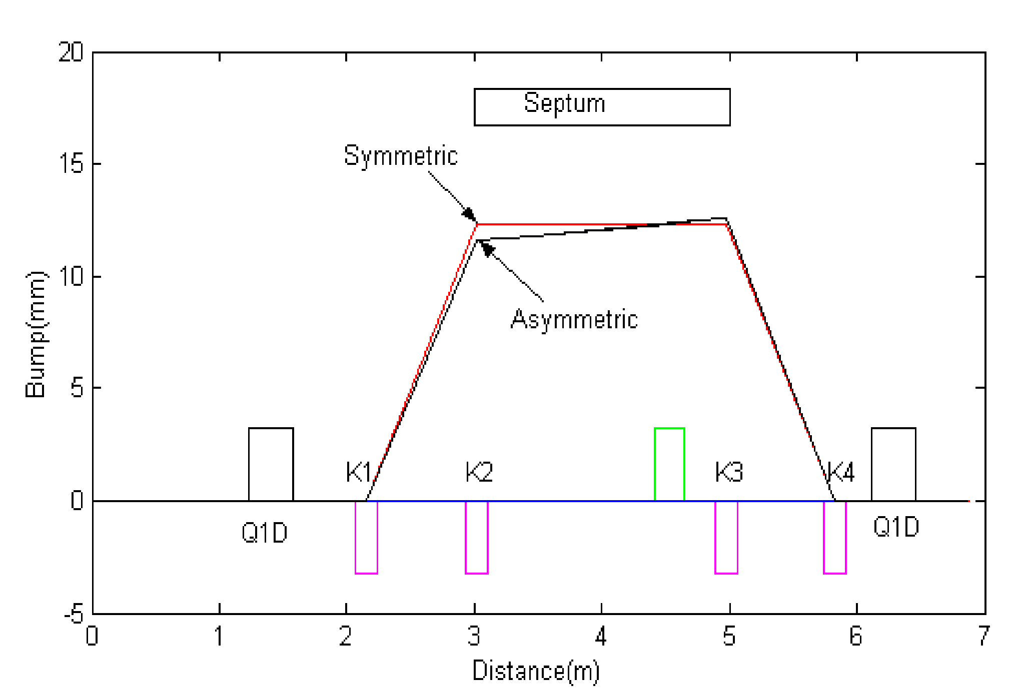


Fig. Lattice functions of Indus-2 (9.3,6.2)

Injection scheme

Device	Angle	Pulse width
Thick Septum	19°	100μs
Thin Septum	2°	50μs
Kickers (Four)	0.72°/10 mm	3 μs



Four kicker scheme for the injection is used

Possibility to generate symmetric as well as asymmetric bump

Measured pulse length of the kickers magnet

Kicker magnet	$T_r(\mu s)$	$T_f(\mu s)$
K1	1.30	1.53
K2	1.27	1.53
K3	1.29	1.60
K4	1.29	1.60

T_r: Rise time & T_f: Fall time

Trials for beam accumulation

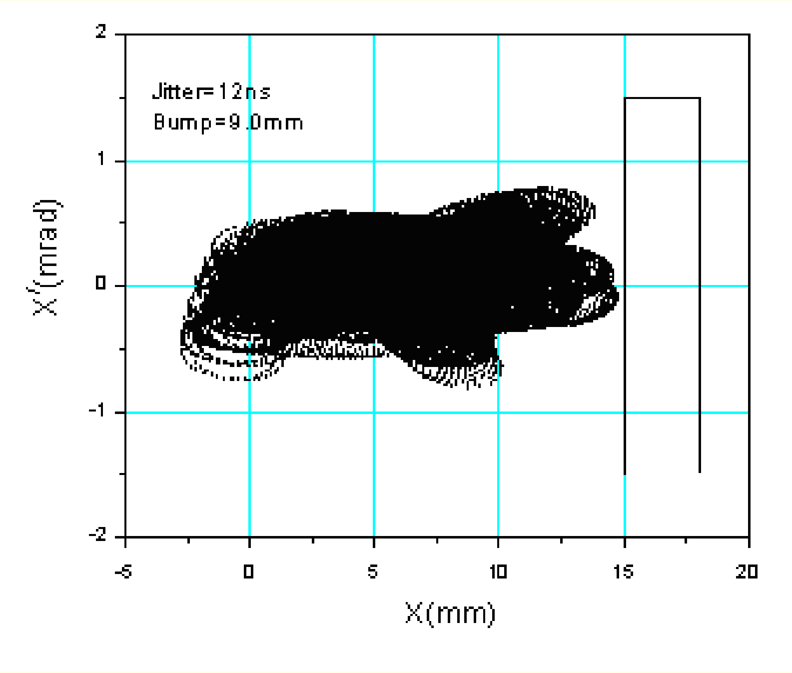
Partial stored beam loss during injection

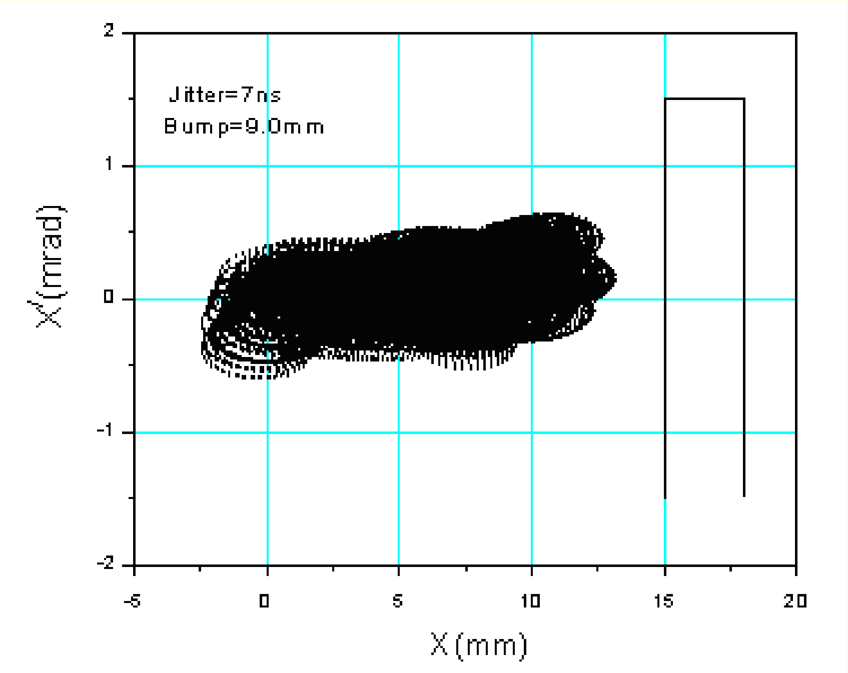
Mismatch between pulse widths of kickers and its jitter

Initially this was minimized by reducing bump strength, which leads to additional oscillation to stored beam and injected beam

Better solution by reducing kicker jitter from ±12ns to ±7ns

Beam dynamical tracking results

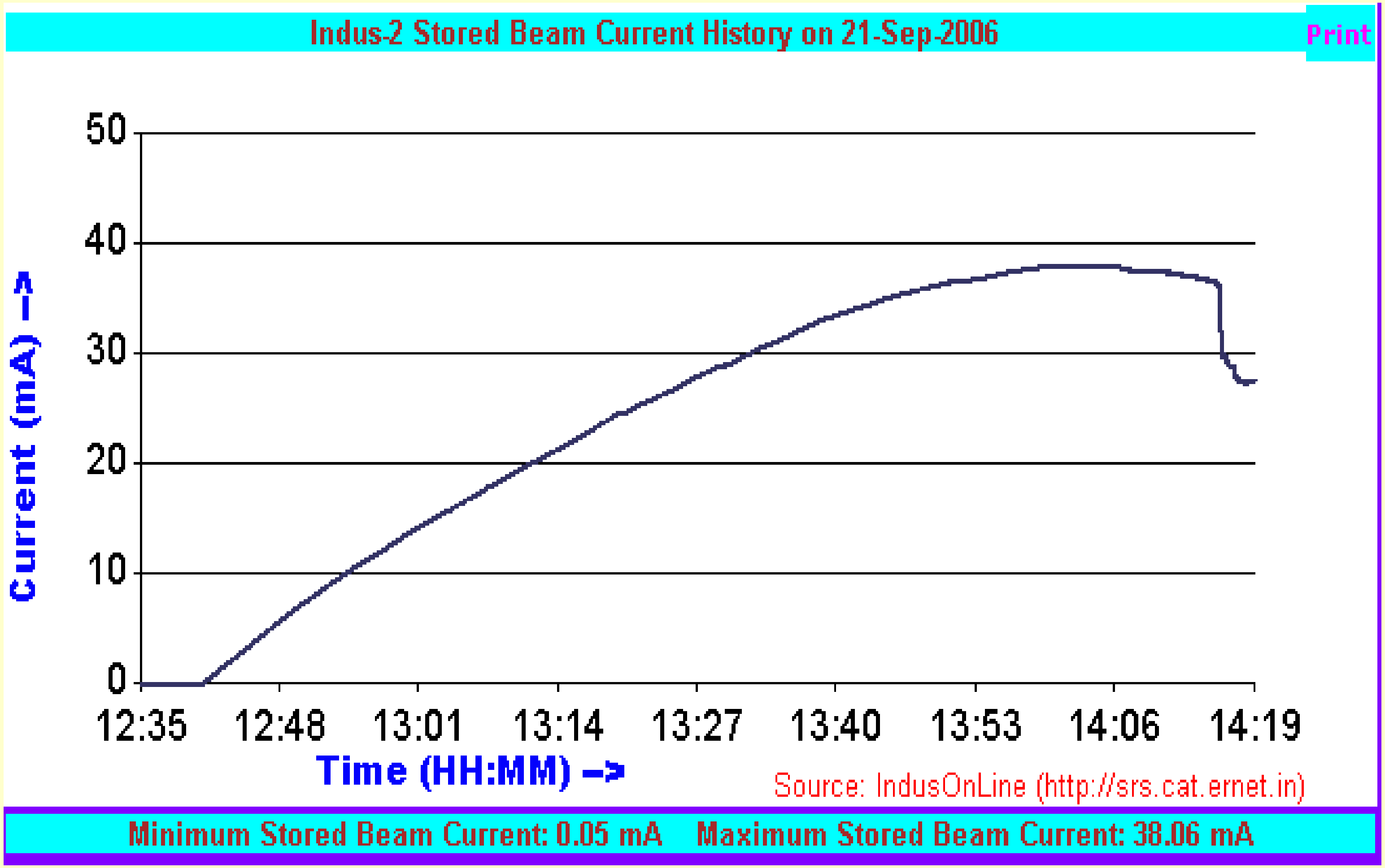


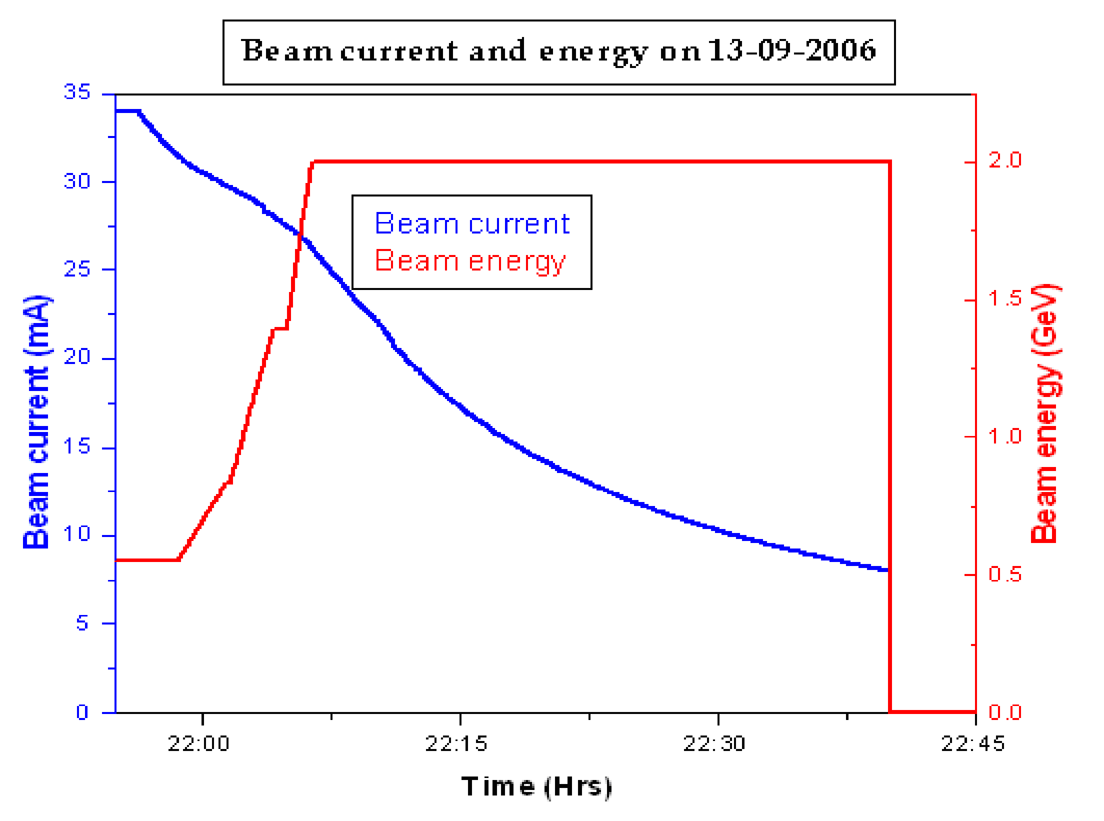


Kicker jitter of ±12ns

Kicker jitter of ±7ns

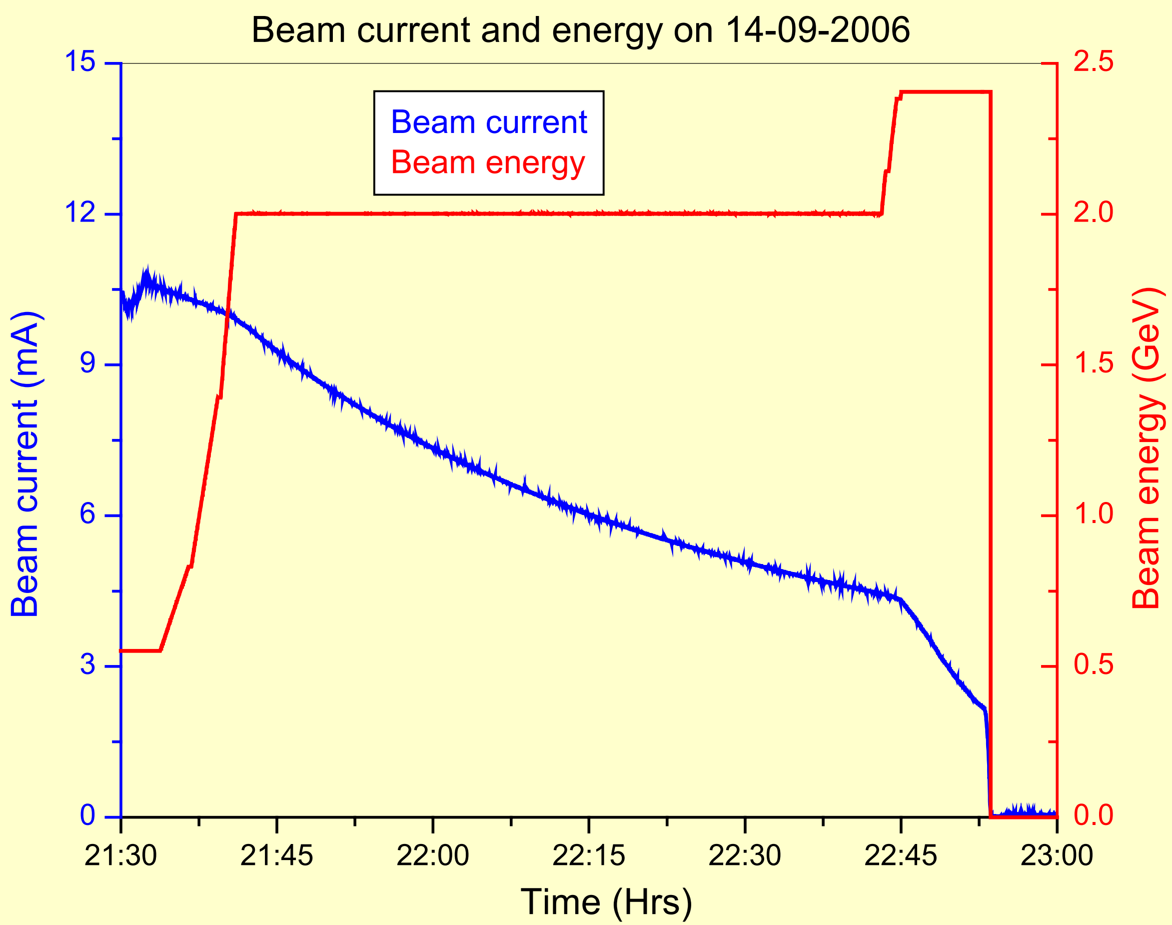
Maximum stored current: 38 mA





34mA beam current was accumulated at beam injection energy, beam energy ramp started, 26mA beam current sustained at 2 GeV. Two RF stations were in operation. RF Station 1: 400 KV, Station 4: 370 KV

Energy (GeV)	Rate (MeV/Minute)	Time (Minutes)
0.55-0.83	100	2.8
0.83-1.39	203	2.8
1.39-2.00	406	1.5
0.55-2.00		7.1



Beam energy was increased from 2 to 2.4 GeV. The beam current at 2.4 GeV was 4.3mA.

RF Station 1: 530 KV, Station 4: 410KV

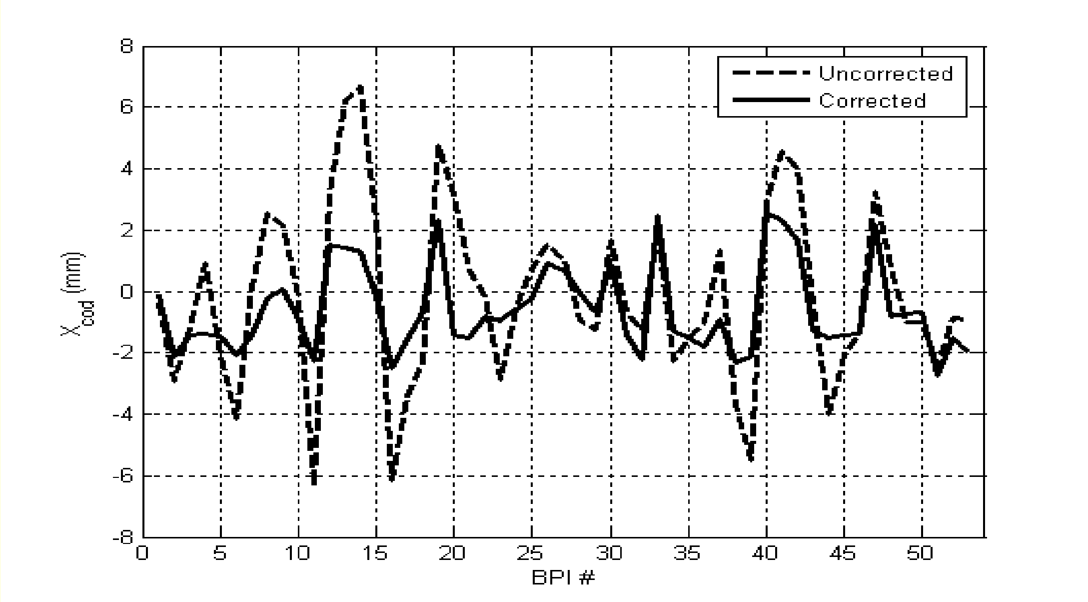
Closed orbit correction

To provide more space for beam oscillations (Improvement in injection efficiency)

No need to adjust orbit at beamlines

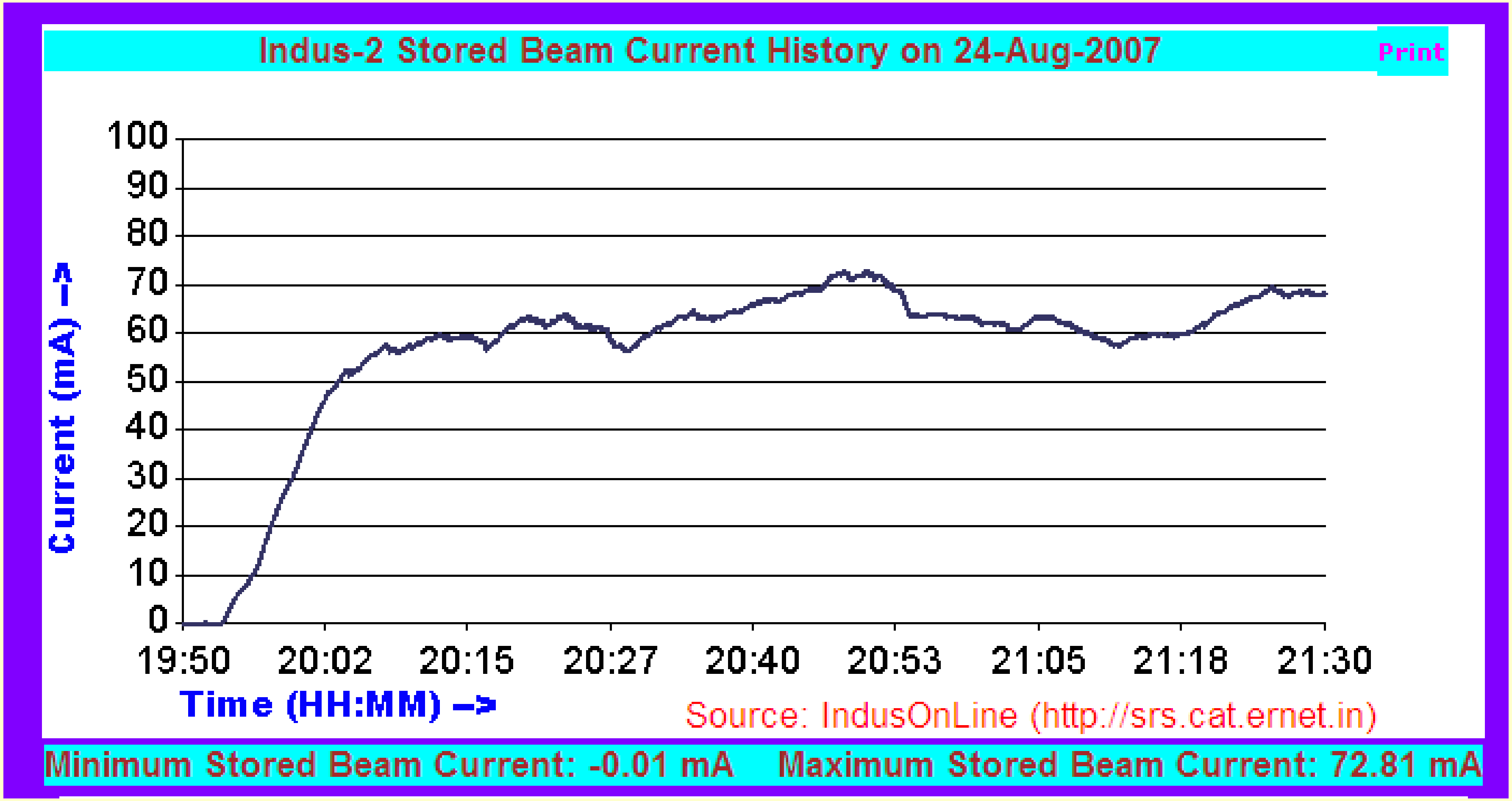
Improvement in beam lifetime

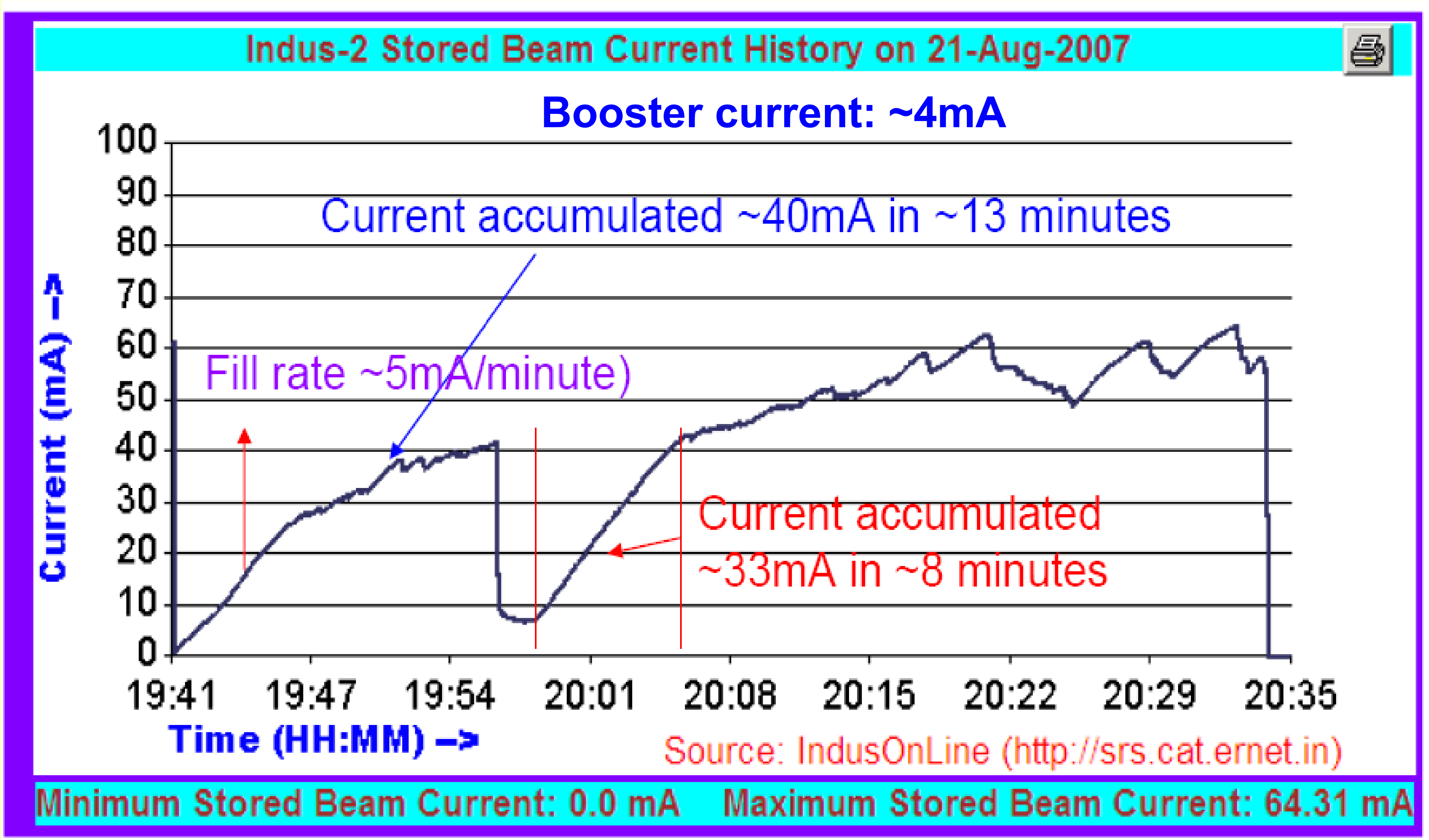
Orbit correction in horizontal plane



Measured horizontal closed orbit distortion at 53 beam position indicators and its correction using 16 horizontal correctors out of 48. The corrector strength corresponding to 10 singular values out of 16 considered.

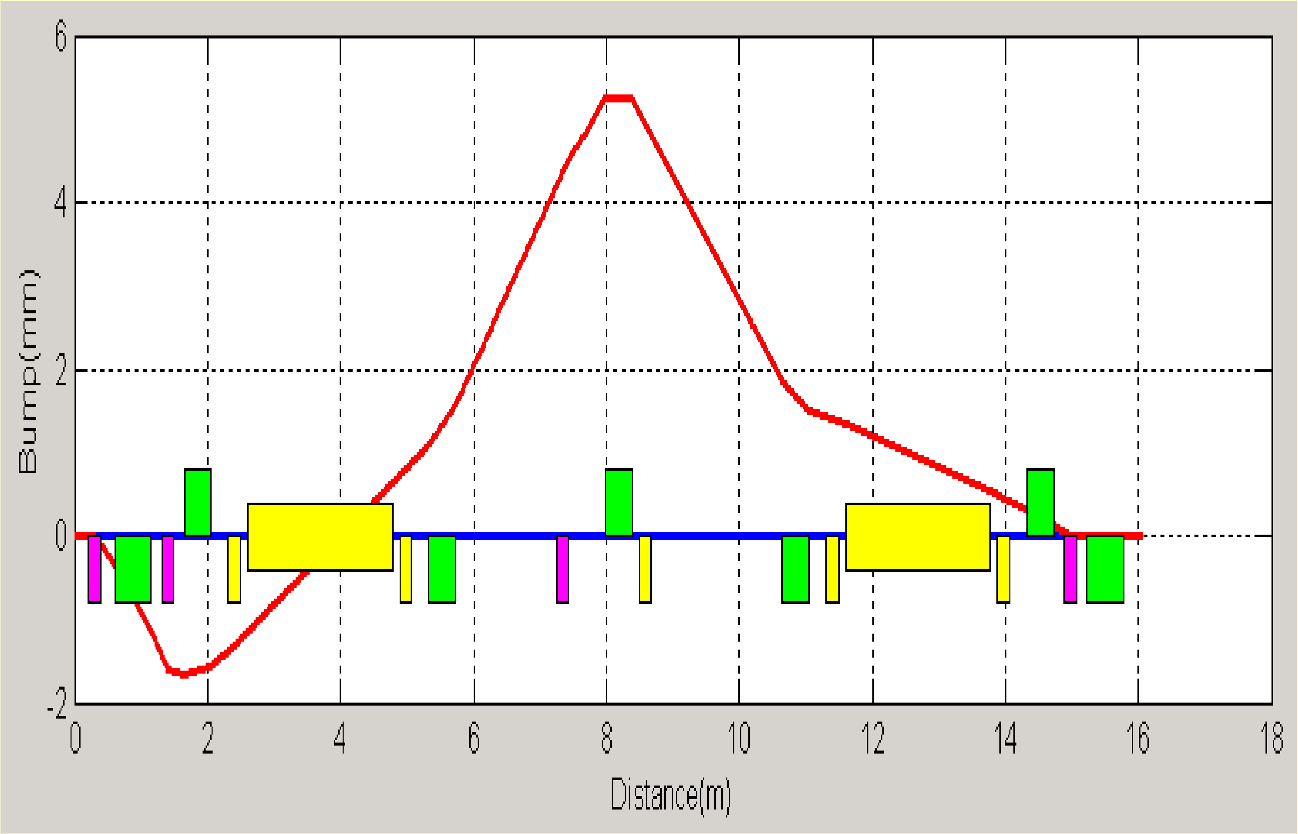
COD_x	Uncorrected	Corrected
Absolute Max (mm)	6.7	2.75
RMS(mm)	2.9	1.54


Indus-2 Stored Beam Current History on 24-Aug-2007
Print
Current (mA) -->
100
90
80
70
60
50
40
30
20
10
0
19:50
20:02
20:15
20:27
20:40
20:53
21:05
21:18
21:30
Time (HH:MM) -->
Source: IndusOnLine (http://srs.cat.ernet.in)
Minimum Stored Beam Current: -0.01 mA
Maximum Stored Beam Current: 72.81 mA

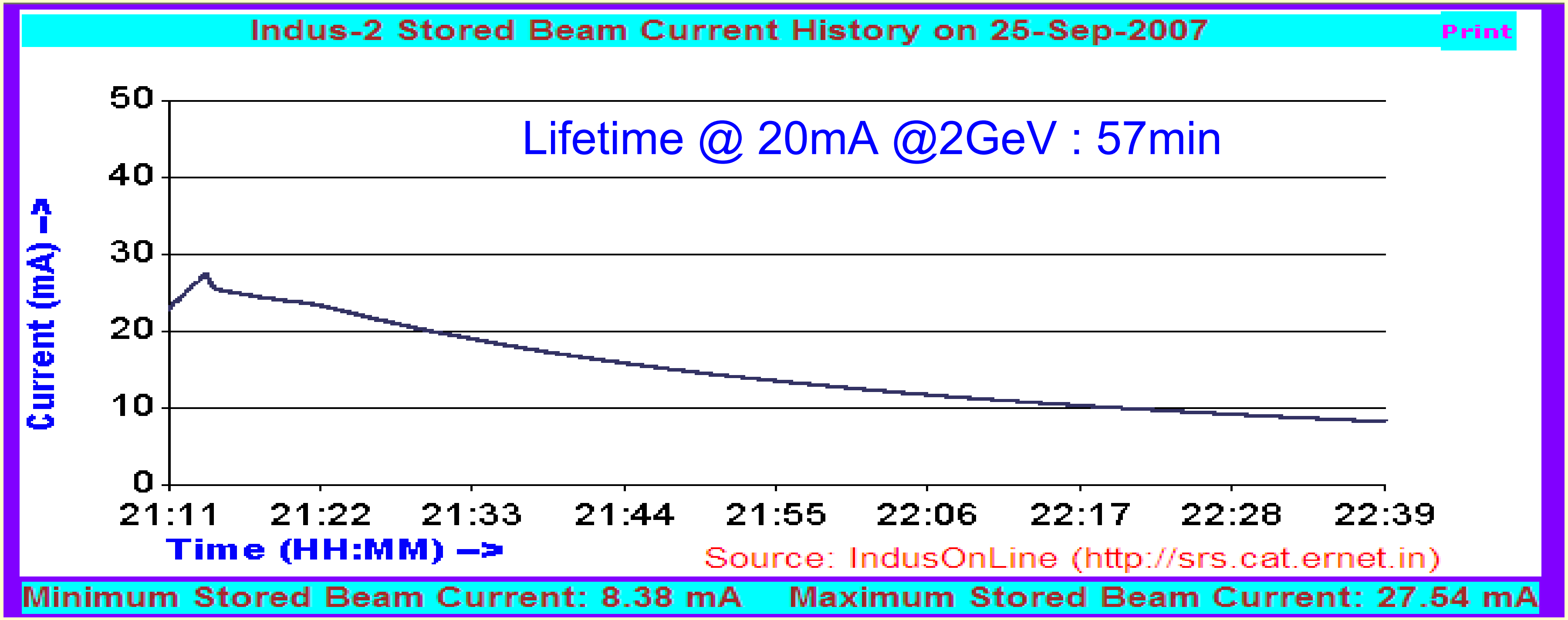


Fill rate: 5mA/minute or **85**μA/**s**

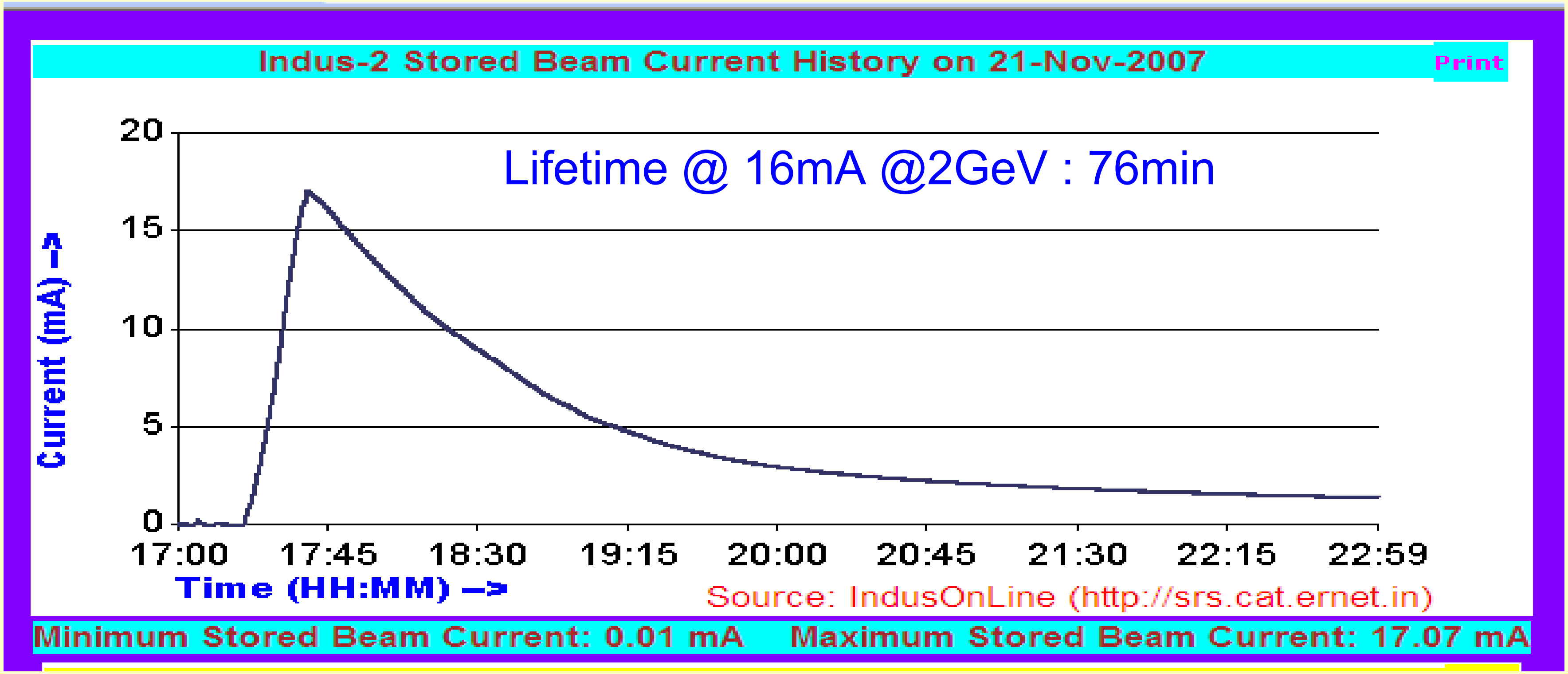
Closed orbit correction at DP-05

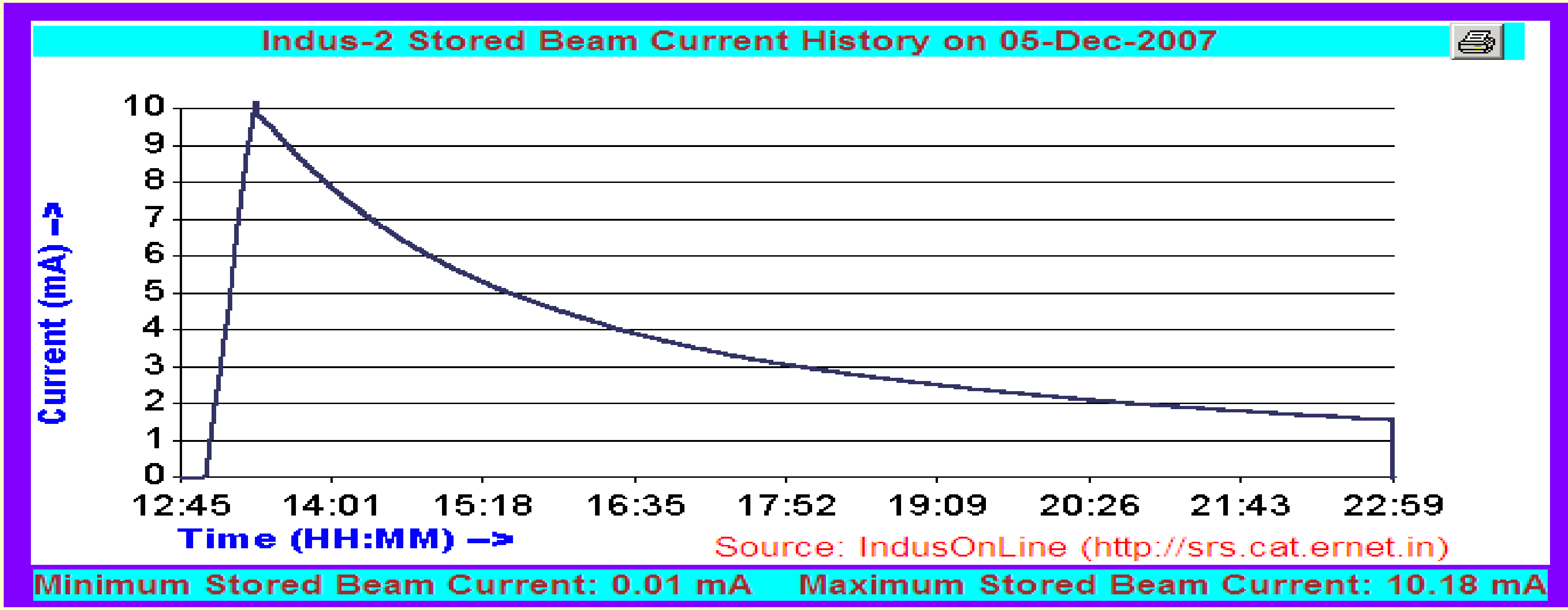


A vertical rotation of 0.8mrad of beam orbit was generated at DP-05 to correct the vertical angle of the orbit at the beam line (BL-12) and consequently using the SR from the BL-12 a diffraction pattern of graphite was obtained.



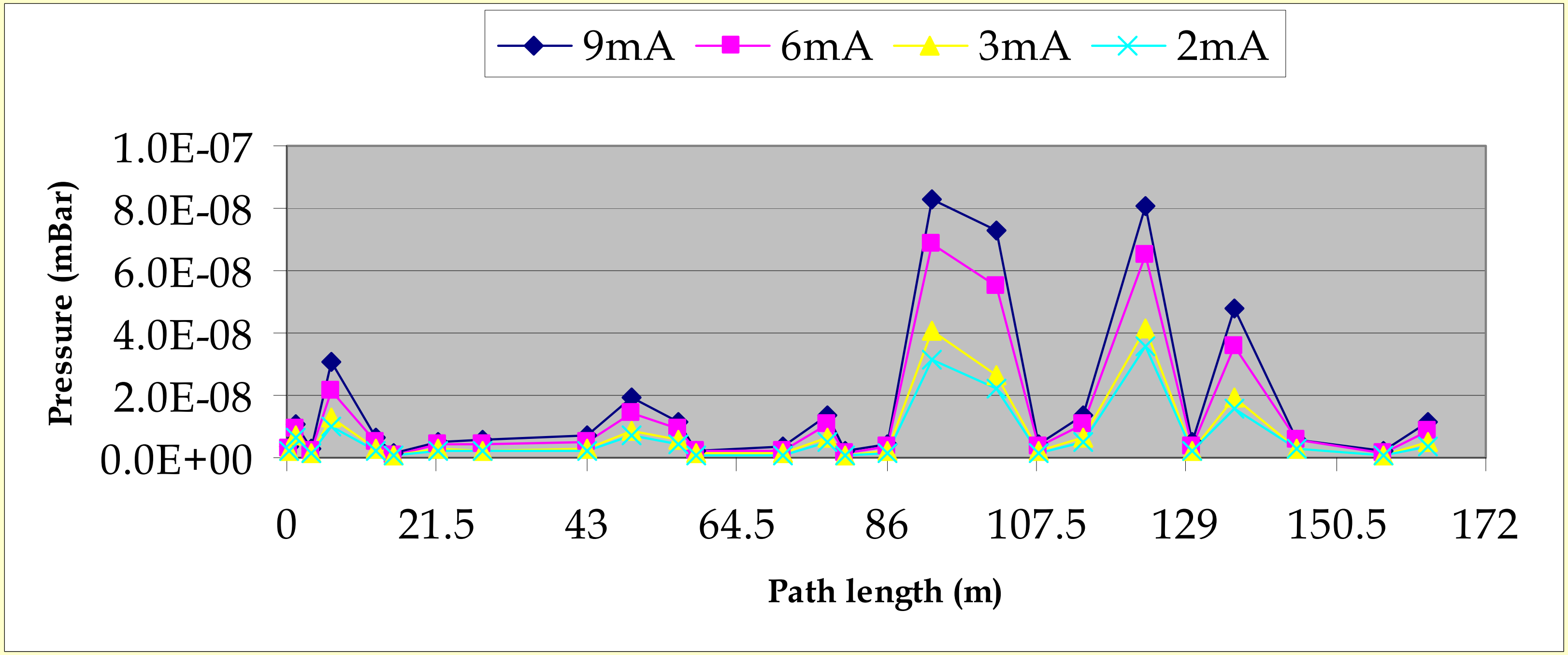
Indus-2 Stored Beam Current History on 25-Sep-2007
Print
Lifetime @ 20mA @2GeV : 57min
50
40
30
20
10
0
Current (mA) -->
21:11
21:22
21:33
21:44
21:55
22:06
22:17
22:28
22:39
Time (HH:MM) -->
Source: IndusOnLine (http://srs.cat.ernet.in)
Minimum Stored Beam Current: 8.38 mA
Maximum Stored Beam Current: 27.54 mA


Indus-2 Stored Beam Current History on 21-Nov-2007
Print
Lifetime @ 16mA @2GeV : 76min
Current (mA) -->
20
15
10
5
0
17:00
17:45
18:30
19:15
20:00
20:45
21:30
22:15
22:59
Time (HH:MM) -->
Source: IndusOnLine (http://srs.cat.ernet.in)
Minimum Stored Beam Current: 0.01 mA
Maximum Stored Beam Current: 17.07 mA



Beam lifetime @ 2GeV	
Beam Current (mA)	**Lifetime (min)**
9	161
6	209
3	375
2	489

Condition of pressures in ring on Dec 5, 2007



Beam lifetime @ 2GeV	
Beam Current (mA)	**Lifetime (Min)**
9	161
6	209
3	375
2	489

Further improvement studies

To increase beam current

- Increase accumulation rate => Increase booster current
- Improve vacuum
- Correct closed orbit
- Optimization of beam optics
- Optimization of RF parameters

To increase beam lifetime *(for SR experiments)*

- Improve vacuum
- Correct closed orbit

To correct closed orbit *(To provide radiation to the users at the correct position and angle)*

To increase beam energy to 2.5GeV

To implement low emittance optics

Accumulation rate = Filling rate – Decay rate

Filling rate: $di/dt = I_B.x.y.z$

I_B= Booster current
$x = (T_B/ T_{I2}).\eta.\alpha$
T_B = Revolution period in Booster
T_{I2} = Revolution period in Indus-2
η= Extraction efficiency
α = Transfer efficiency from Booster to Indus-2
y = Fractional acceptance due to transverse dynamics
z = Fractional acceptance due to longitudinal dynamics
x, y and z<1

To increase beam current

Rate of filling > Rate of decay $\Rightarrow$ Good Vacuum

Filling rate: di/dt = I_B.x.y.z

I_B= 1mA

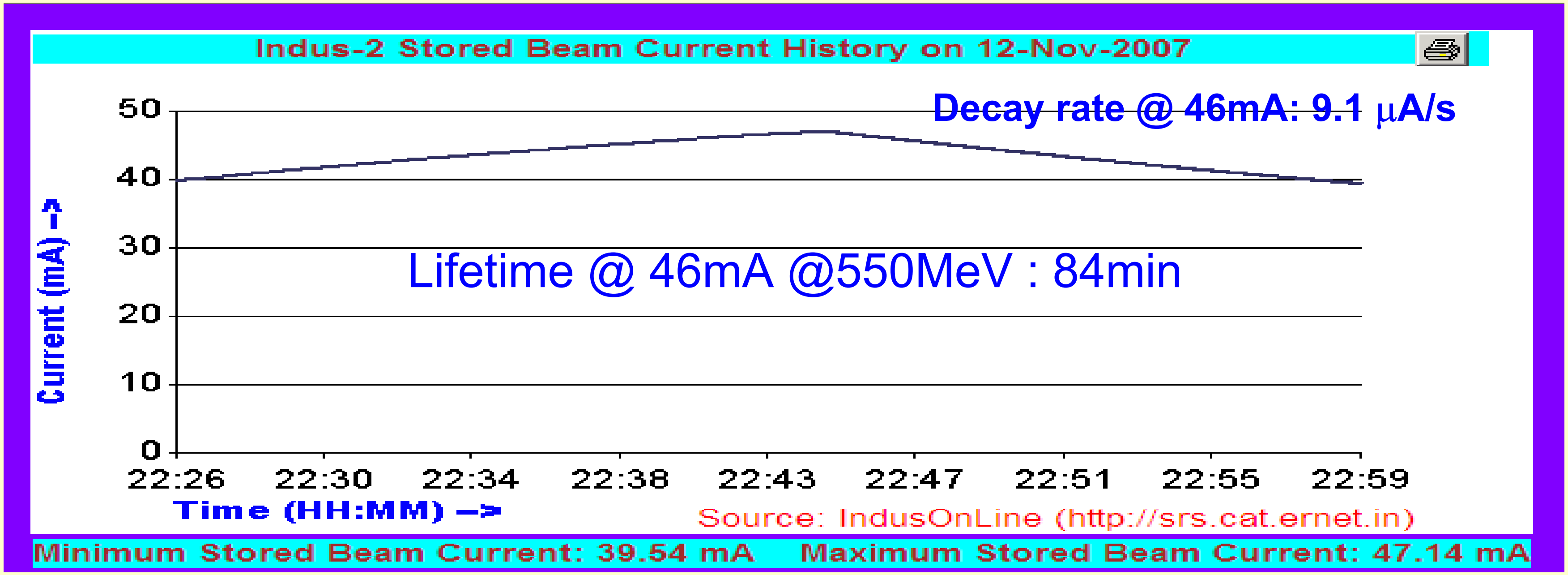
T_B/T_{I2} = 94.9ns/575.3ns = 0.165, η = 2/3, α = 0.9

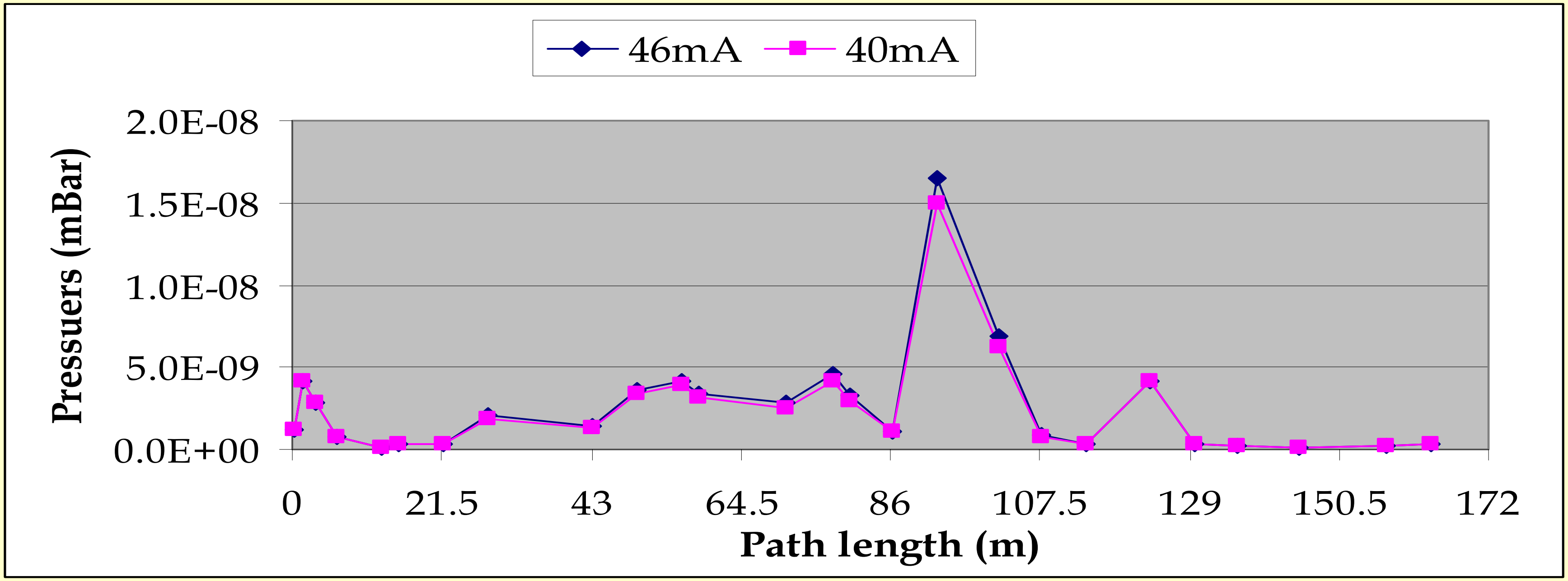
x = 0.1

y = 0.67 (1σ in x plane)

z = 0.67 (1σ_l *(~ 0.5ns)* acceptance)

di/dt = 45μA/s


Indus-2 Stored Beam Current History on 12-Nov-2007
Decay rate @ 46mA: 9.1 μA/s
Lifetime @ 46mA @550MeV : 84min
Current (mA) -->
50
40
30
20
10
0
22:26
22:30
22:34
22:38
22:43
22:47
22:51
22:55
22:59
Time (HH:MM) -->
Source: IndusOnLine (http://srs.cat.ernet.in)
Minimum Stored Beam Current: 39.54 mA
Maximum Stored Beam Current: 47.14 mA


46mA
40mA
Pressuers (mBar)
2.0E-08
1.5E-08
1.0E-08
5.0E-09
0.0E+00
0
21.5
43
64.5
86
107.5
129
150.5
172
Path length (m)

Fill rates in Indus-2

Date	Fill rate	Booster current
24-05-2006	21μA/s	1-1.5mA
28-09-2006	29μA/s	1-1.5mA
21-08-2007	85μA/s	4-5mA

Experimental decay rate @ 46mA: 9.1μA/s

At 46mA Average Vacuum : 5×10^{-9} mBar

At 70mA Average Vacuum : 8×10^{-9} mBar

At 100mA Expected Vacuum : 1×10^{-8} mBar

Expected decay rate : 20-30μA/s

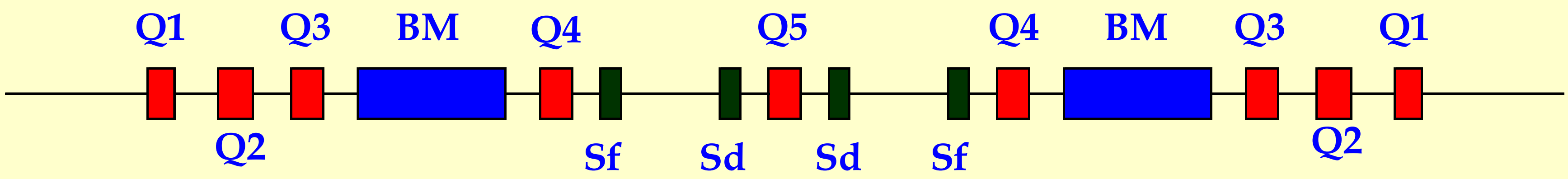
Storage of 100mA not difficult

Proposed optics

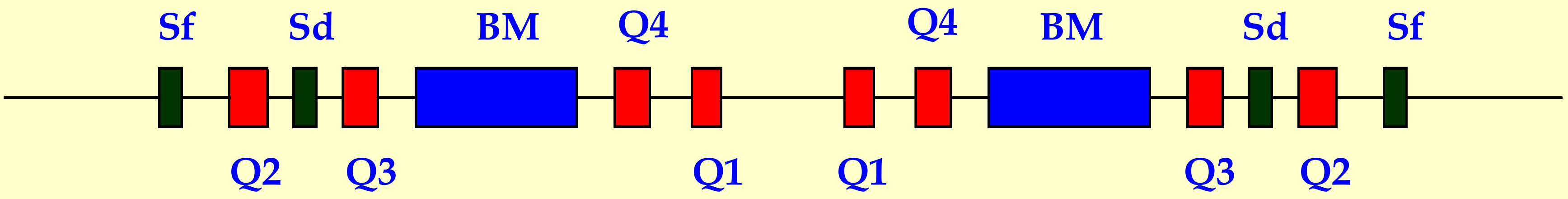
Parameters	Proposed optics	Present optics
ν_x, ν_y	9.3 6.2	9.3 6.2
$X_{co}/\Delta x$, $Y_{co}/\Delta y$	22.1 30.5	36.0 31.4
	13.6 16.0	26.5, 14.2
υ υ	2.9 3.4	5.7, 3.1
ε@ 2.5 GeV (nm rad)	68	126
d ν_x	$-44x^2 - 163y^2$	$-72x^2 - 86y^2$
d ν_y	$-29x^2 + 28y^2$	$-29x^2 + 37y^2$
DA (2×10^5 turns)	44, 22(1.%), 12(-1.%)	47, 24(1%), 14(-1%)

Unit cell of Indus-2

Present Cell



Proposed Cell



The beam emittance is expected to reduce to nearly half the present value with the proposed cell.

Long straight section: 4.5m, Short straight section: 3.3m

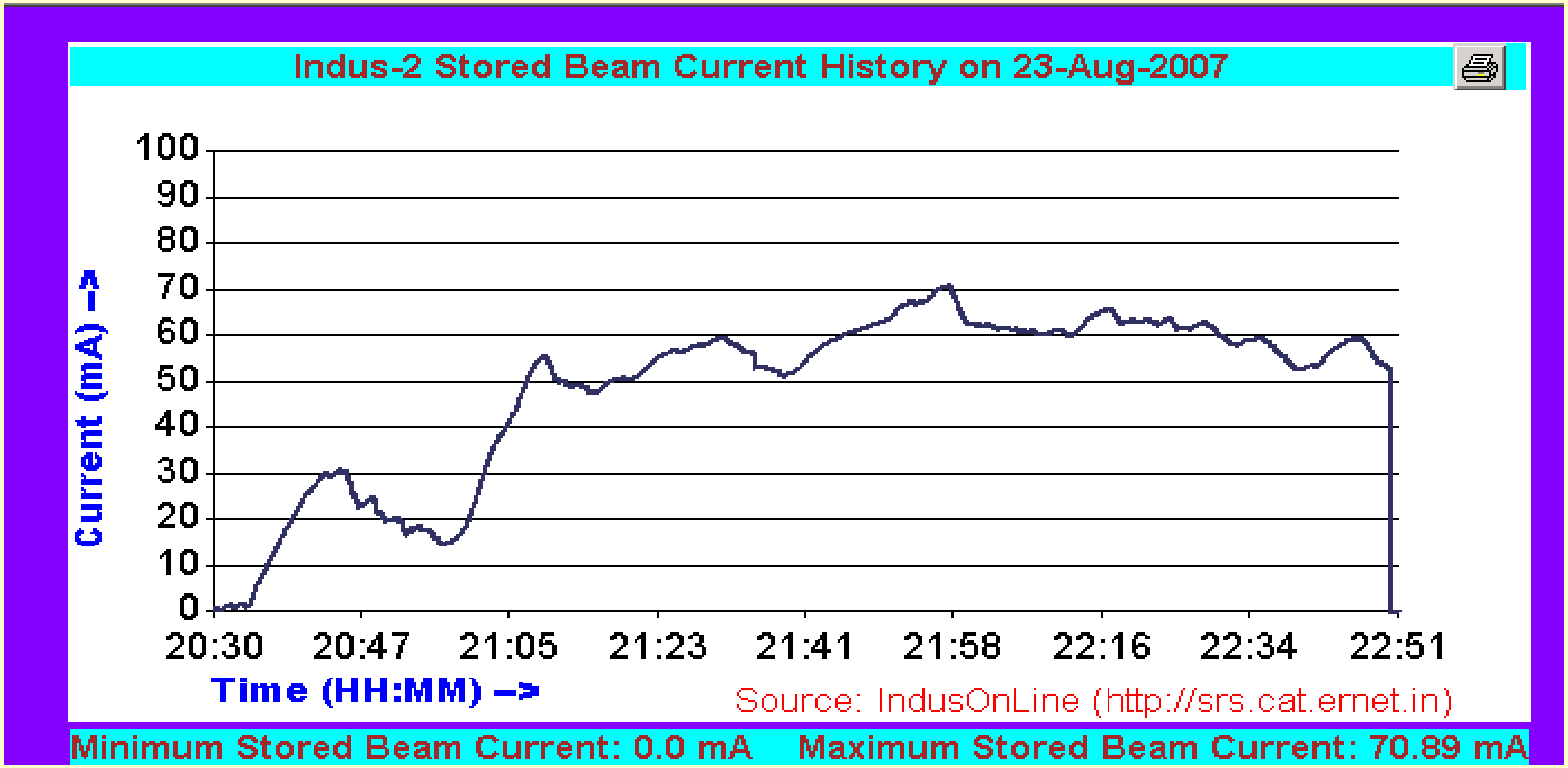
Conclusions

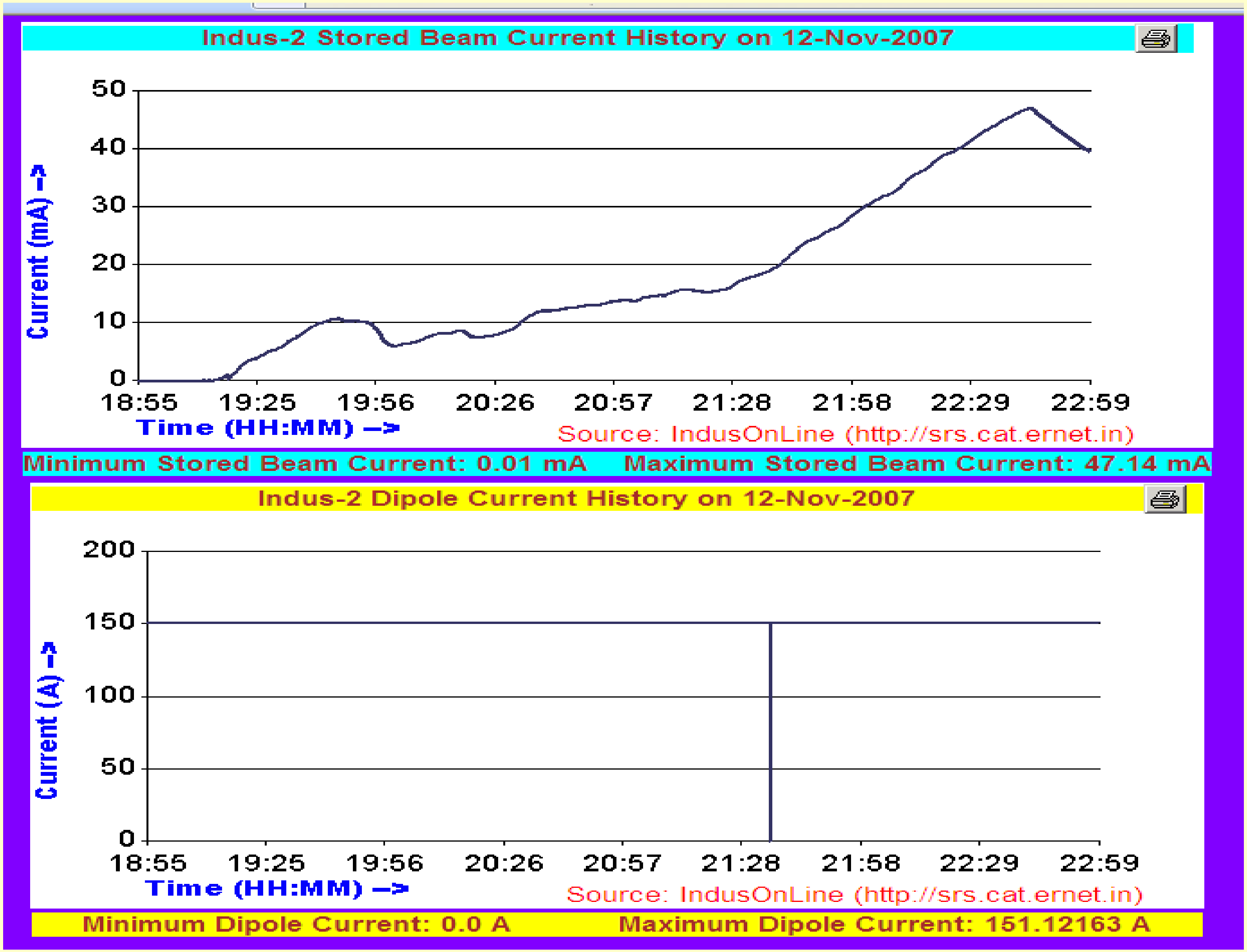
To increase current improve booster current

To increase reproducibility in performance – Cycling of TL-1 and TL-2 magnets to be implemented

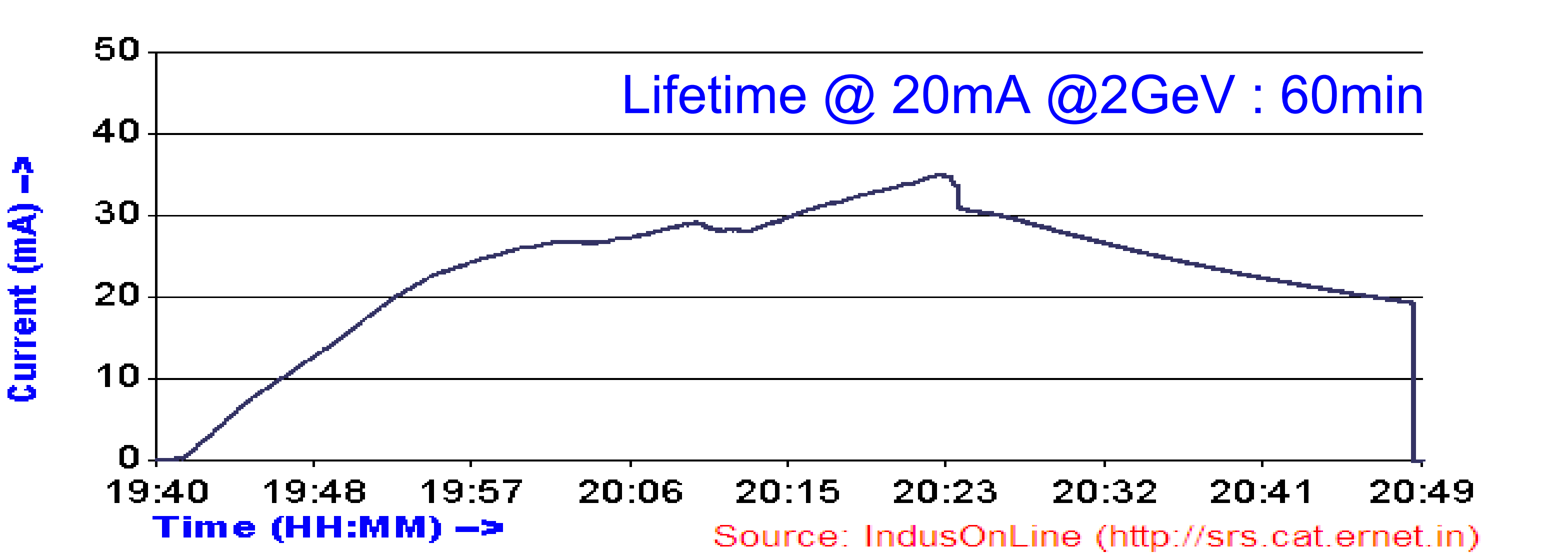
Thank you

Indus-2 filling pattern



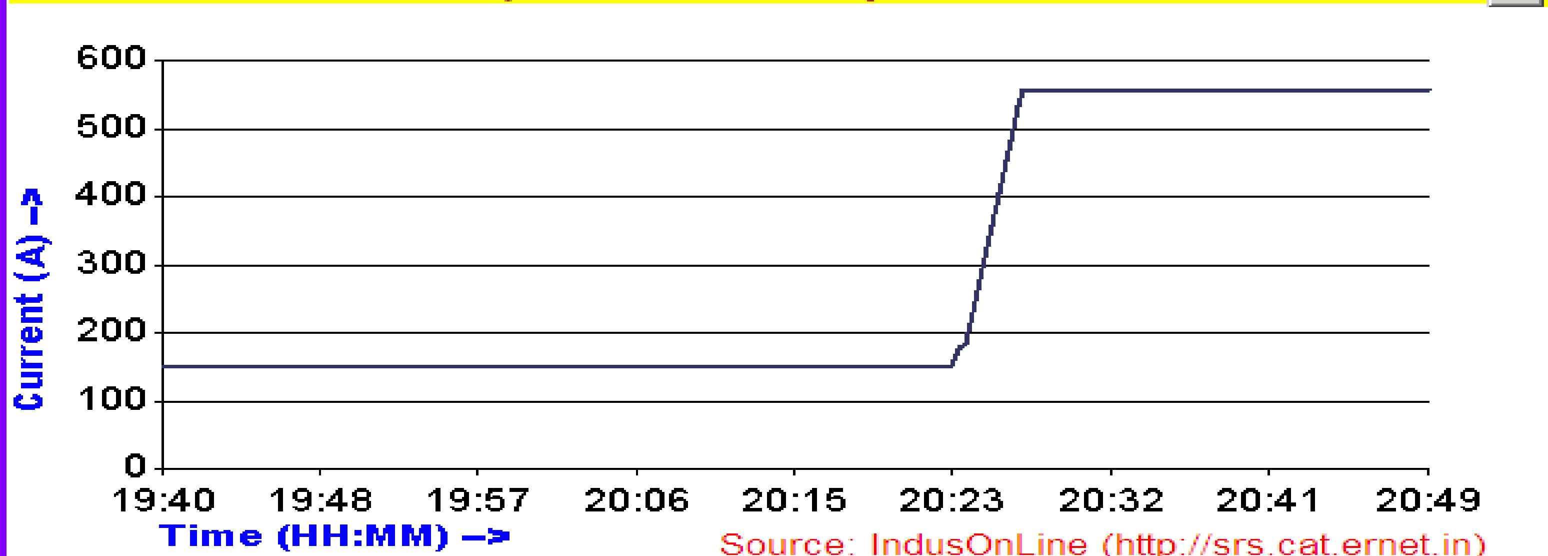

Indus-2 Stored Beam Current History on 12-Nov-2007
Current (mA) -->
50
40
30
20
10
0
18:55
19:25
19:56
20:26
20:57
21:28
21:58
22:29
22:59
Time (HH:MM) -->
Source: IndusOnLine (http://srs.cat.ernet.in)
Minimum Stored Beam Current: 0.01 mA
Maximum Stored Beam Current: 47.14 mA
Indus-2 Dipole Current History on 12-Nov-2007
Current (A) -->
200
150
100
50
0
18:55
19:25
19:56
20:26
20:57
21:28
21:58
22:29
22:59
Time (HH:MM) -->
Source: IndusOnLine (http://srs.cat.ernet.in)
Minimum Dipole Current: 0.0 A
Maximum Dipole Current: 151.12163 A

Indus-2 Stored Beam Current History on 29-Oct-2007

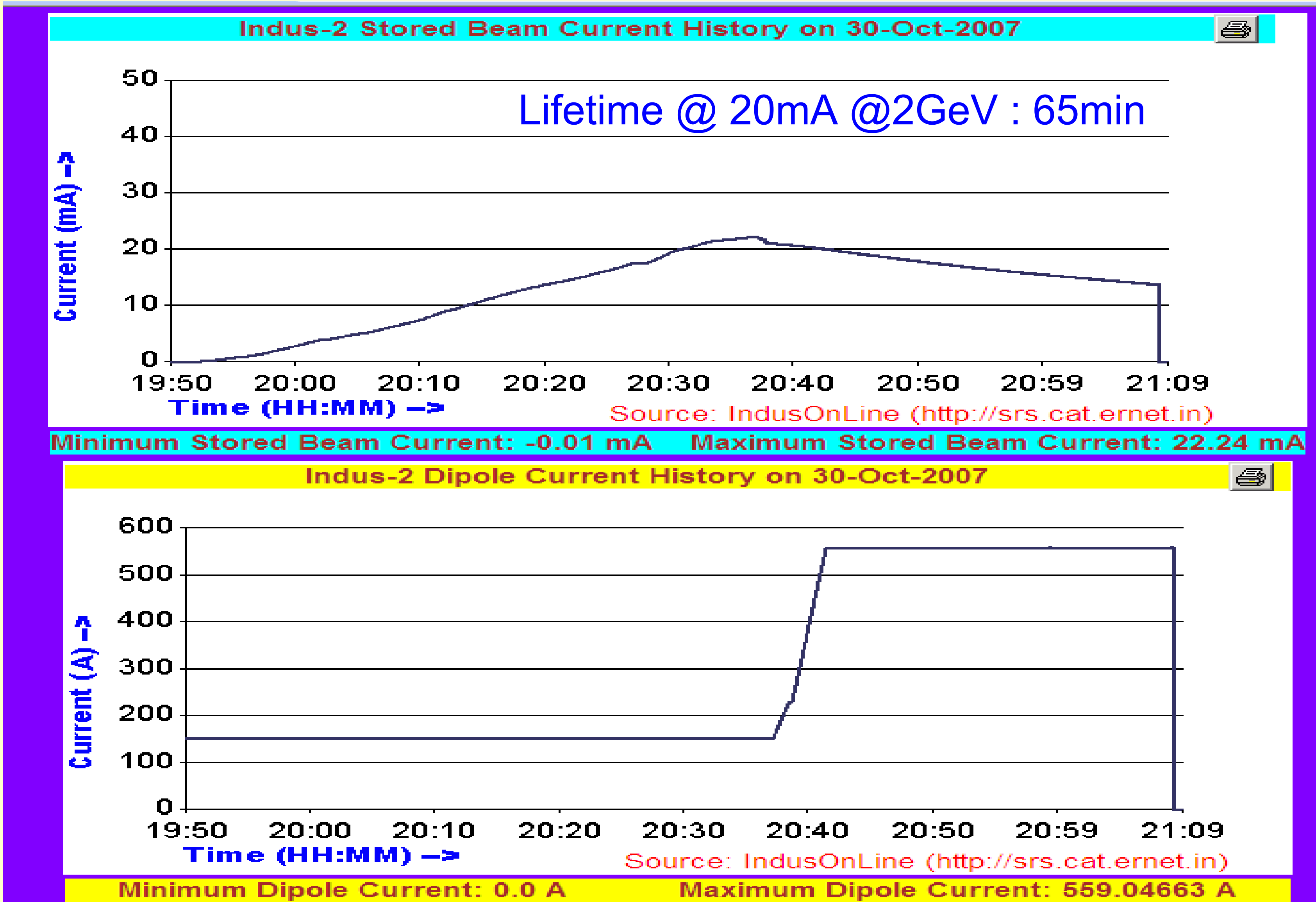


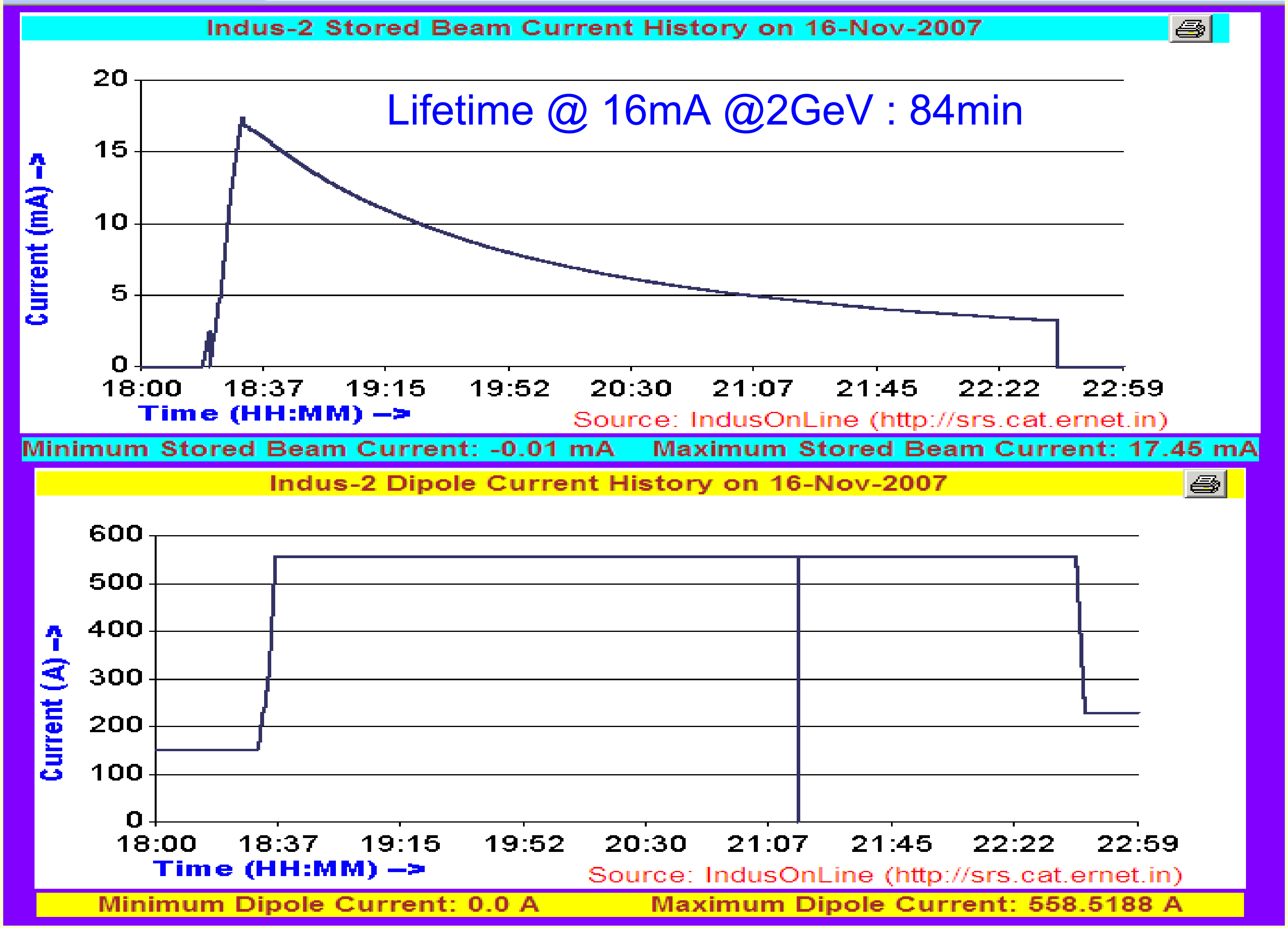
Minimum Stored Beam Current: 0.0 mA   Maximum Stored Beam Current: 35.09 mA

Indus-2 Dipole Current History on 29-Oct-2007

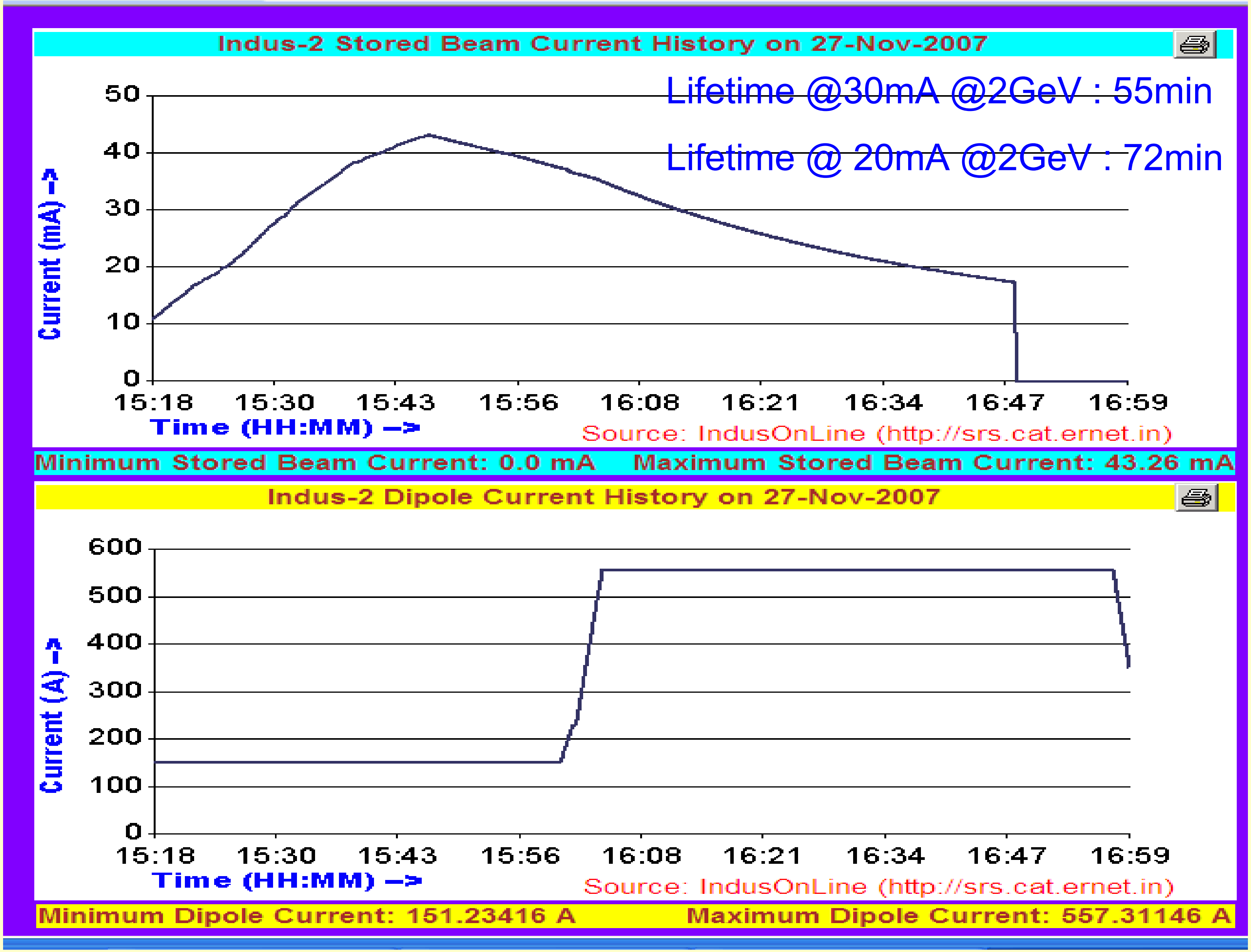


Minimum Dipole Current: 151.01613 A   Maximum Dipole Current: 557.19464 A

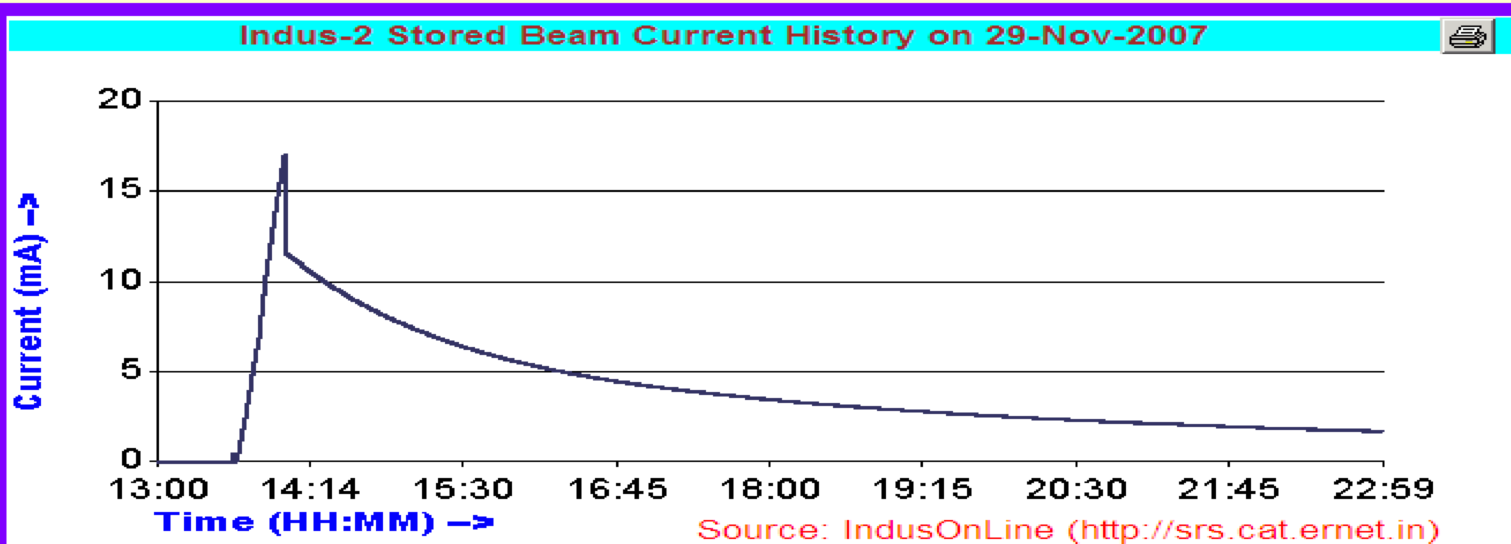

Indus-2 Stored Beam Current History on 30-Oct-2007
Lifetime @ 20mA @2GeV : 65min
Current (mA) –>
50
40
30
20
10
0
19:50 20:00 20:10 20:20 20:30 20:40 20:50 20:59 21:09
Time (HH:MM) –>
Source: IndusOnLine (http://srs.cat.ernet.in)
Minimum Stored Beam Current: -0.01 mA
Maximum Stored Beam Current: 22.24 mA
Indus-2 Dipole Current History on 30-Oct-2007
Current (A) –>
600
500
400
300
200
100
0
19:50 20:00 20:10 20:20 20:30 20:40 20:50 20:59 21:09
Time (HH:MM) –>
Source: IndusOnLine (http://srs.cat.ernet.in)
Minimum Dipole Current: 0.0 A
Maximum Dipole Current: 559.04663 A



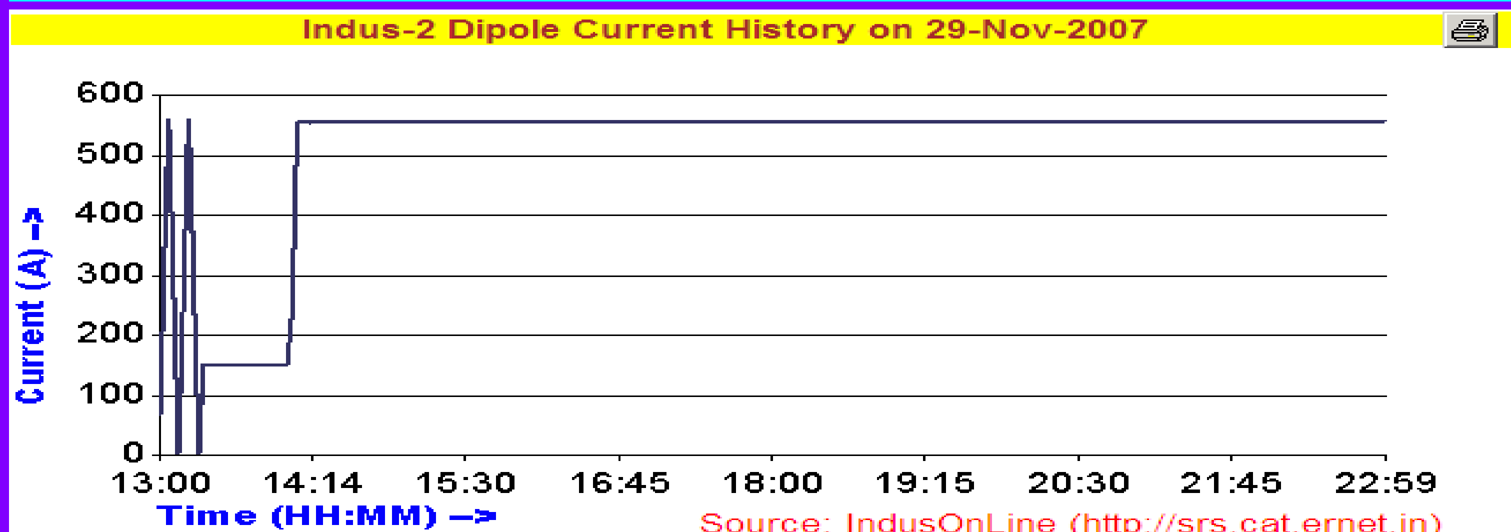
Indus-2 Stored Beam Current History on 16-Nov-2007
Lifetime @ 16mA @2GeV : 84min
Current (mA) ->
20
15
10
5
0
18:00
18:37
19:15
19:52
20:30
21:07
21:45
22:22
22:59
Time (HH:MM) ->
Source: IndusOnLine (http://srs.cat.ernet.in)
Minimum Stored Beam Current: -0.01 mA
Maximum Stored Beam Current: 17.45 mA
Indus-2 Dipole Current History on 16-Nov-2007
Current (A) ->
600
500
400
300
200
100
0
18:00
18:37
19:15
19:52
20:30
21:07
21:45
22:22
22:59
Time (HH:MM) ->
Source: IndusOnLine (http://srs.cat.ernet.in)
Minimum Dipole Current: 0.0 A
Maximum Dipole Current: 558.5188 A



Indus-2 Stored Beam Current History on 27-Nov-2007
Lifetime @30mA @2GeV : 55min
Lifetime @ 20mA @2GeV : 72min
Current (mA) -->
50
40
30
20
10
0
15:18
15:30
15:43
15:56
16:08
16:21
16:34
16:47
16:59
Time (HH:MM) -->
Source: IndusOnLine (http://srs.cat.ernet.in)
Minimum Stored Beam Current: 0.0 mA
Maximum Stored Beam Current: 43.26 mA
Indus-2 Dipole Current History on 27-Nov-2007
Current (A) -->
600
500
400
300
200
100
0
15:18
15:30
15:43
15:56
16:08
16:21
16:34
16:47
16:59
Time (HH:MM) -->
Source: IndusOnLine (http://srs.cat.ernet.in)
Minimum Dipole Current: 151.23416 A
Maximum Dipole Current: 557.31146 A



Minimum Stored Beam Current: 0.0 mA Maximum Stored Beam Current: 17.09 mA

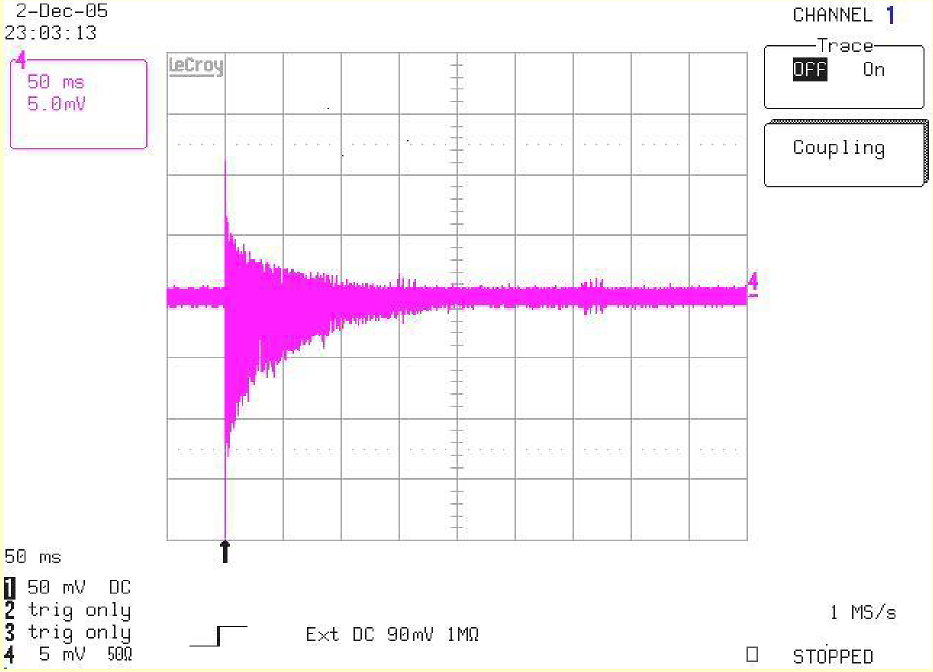


Minimum Dipole Current: 5.120278 A Maximum Dipole Current: 560.4196 A

FIRST SYNCHROTRON LIGHT OUT OF INDUS-2

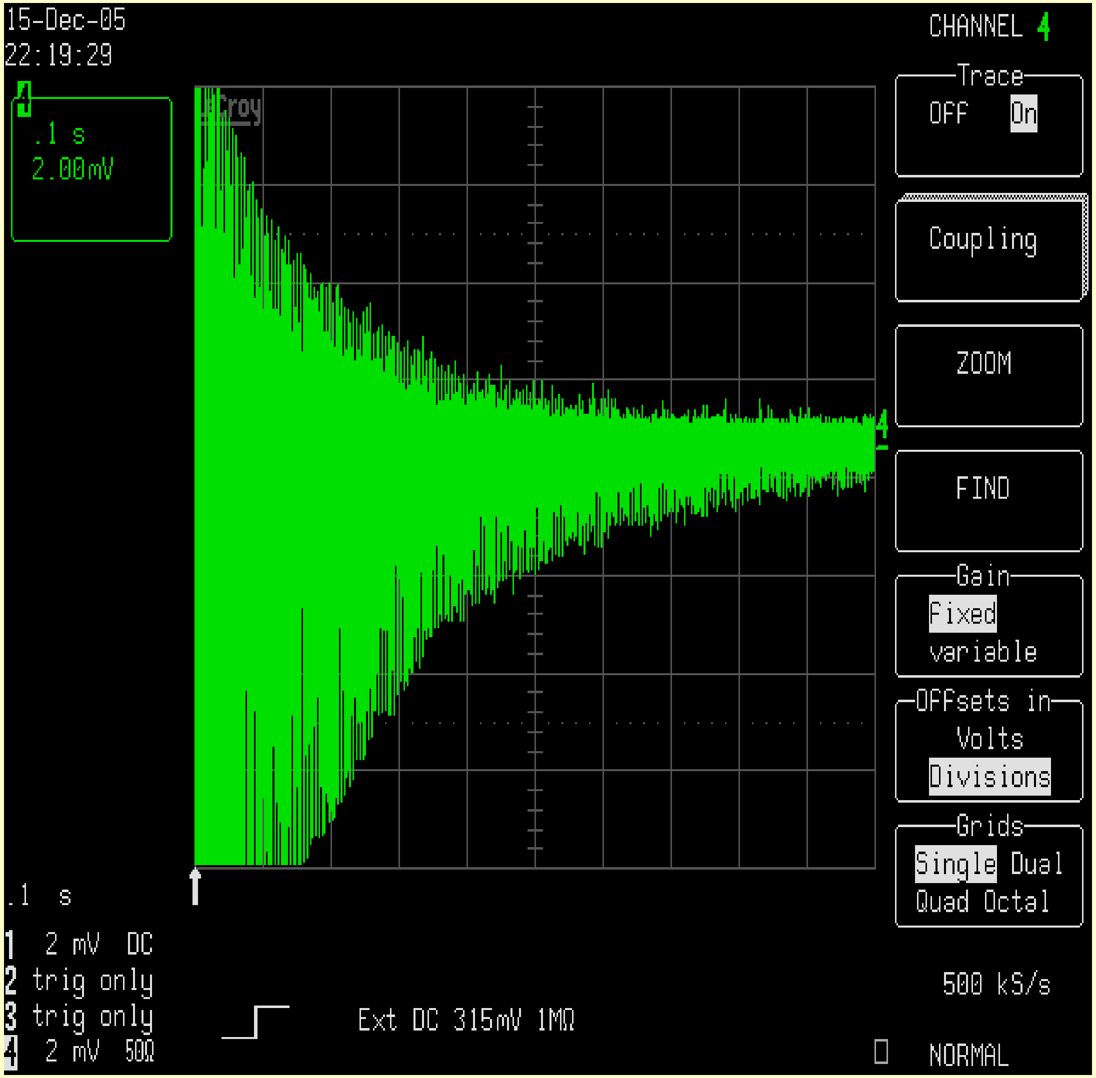
RECORDED ON DEC. 2, 2005

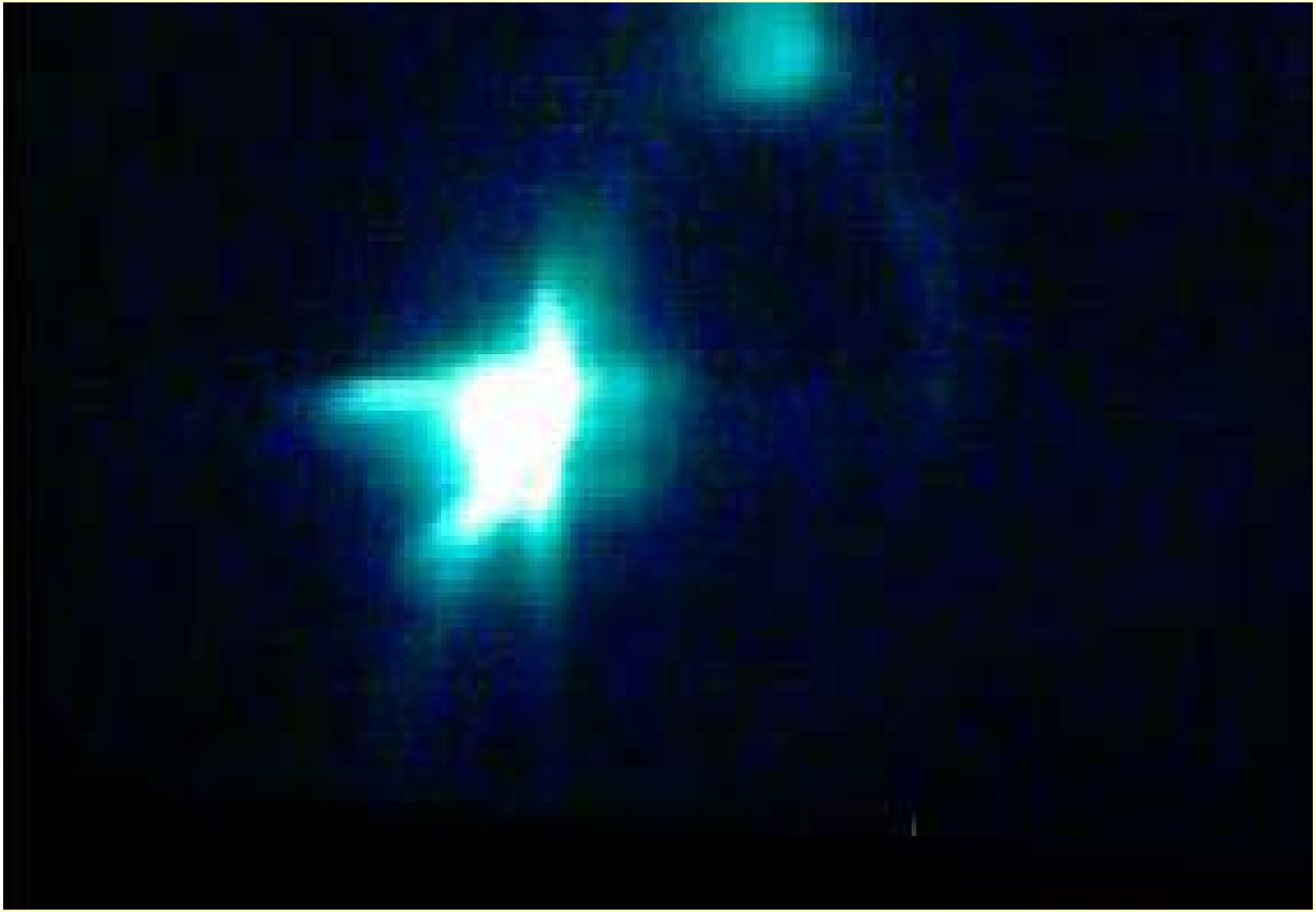
USING CCD CAMERA ON THE "SIGHTING BEAM-LINE"



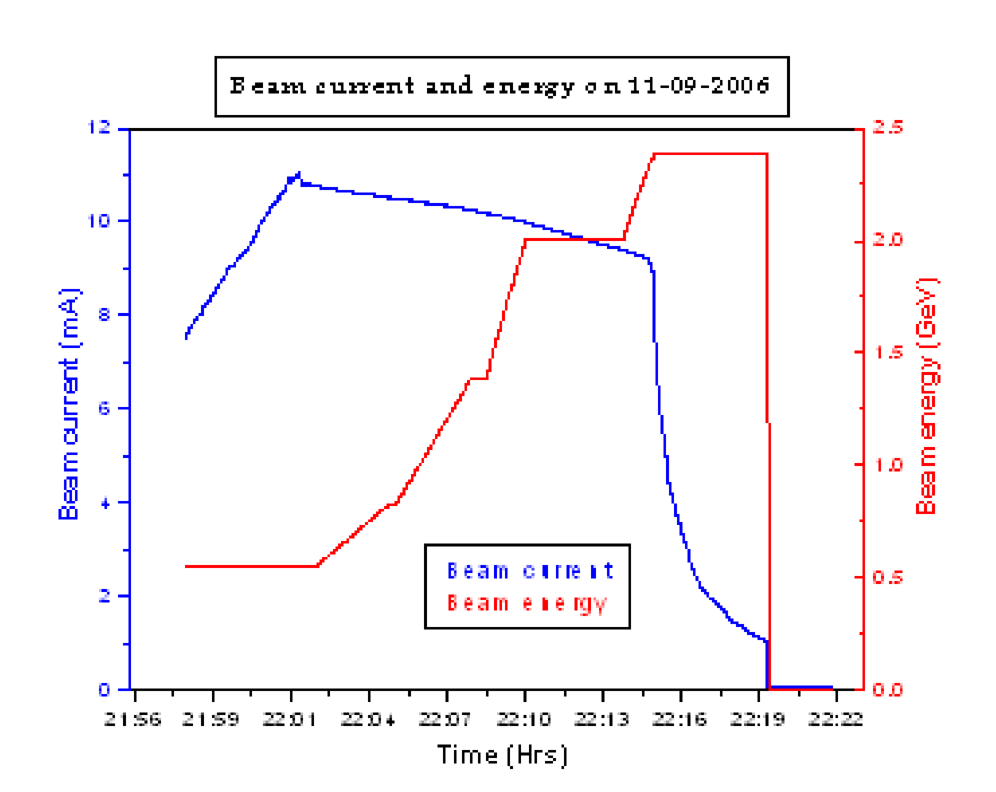
CURRENT MONITOR SIGNAL INDICATING SURVIVAL OF BEAM UPTO 200ms

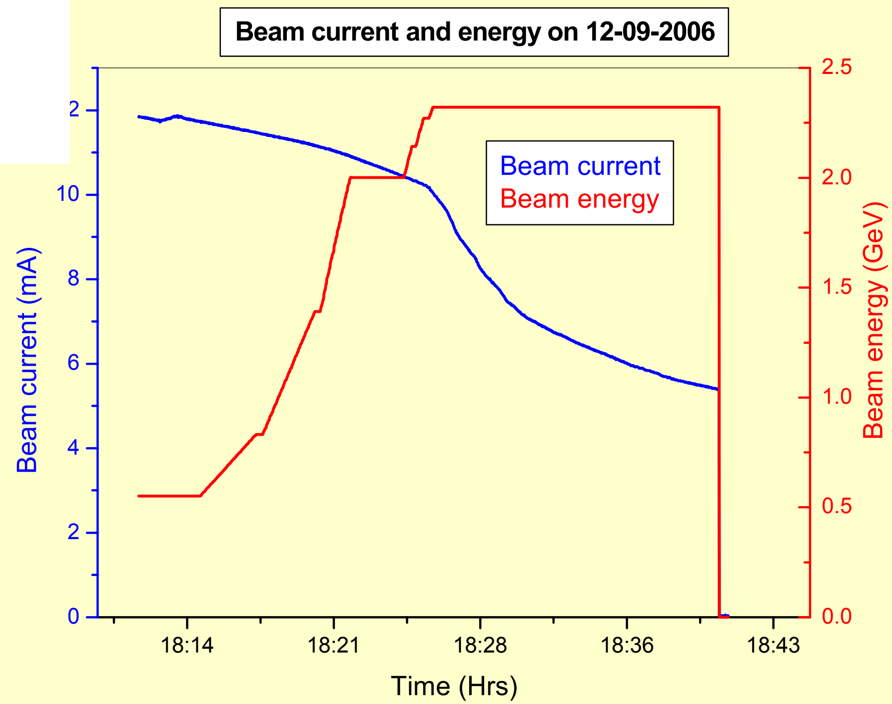
Beam circulation up to **1 second** was seen on wall current monitor on **15th December, 2005**

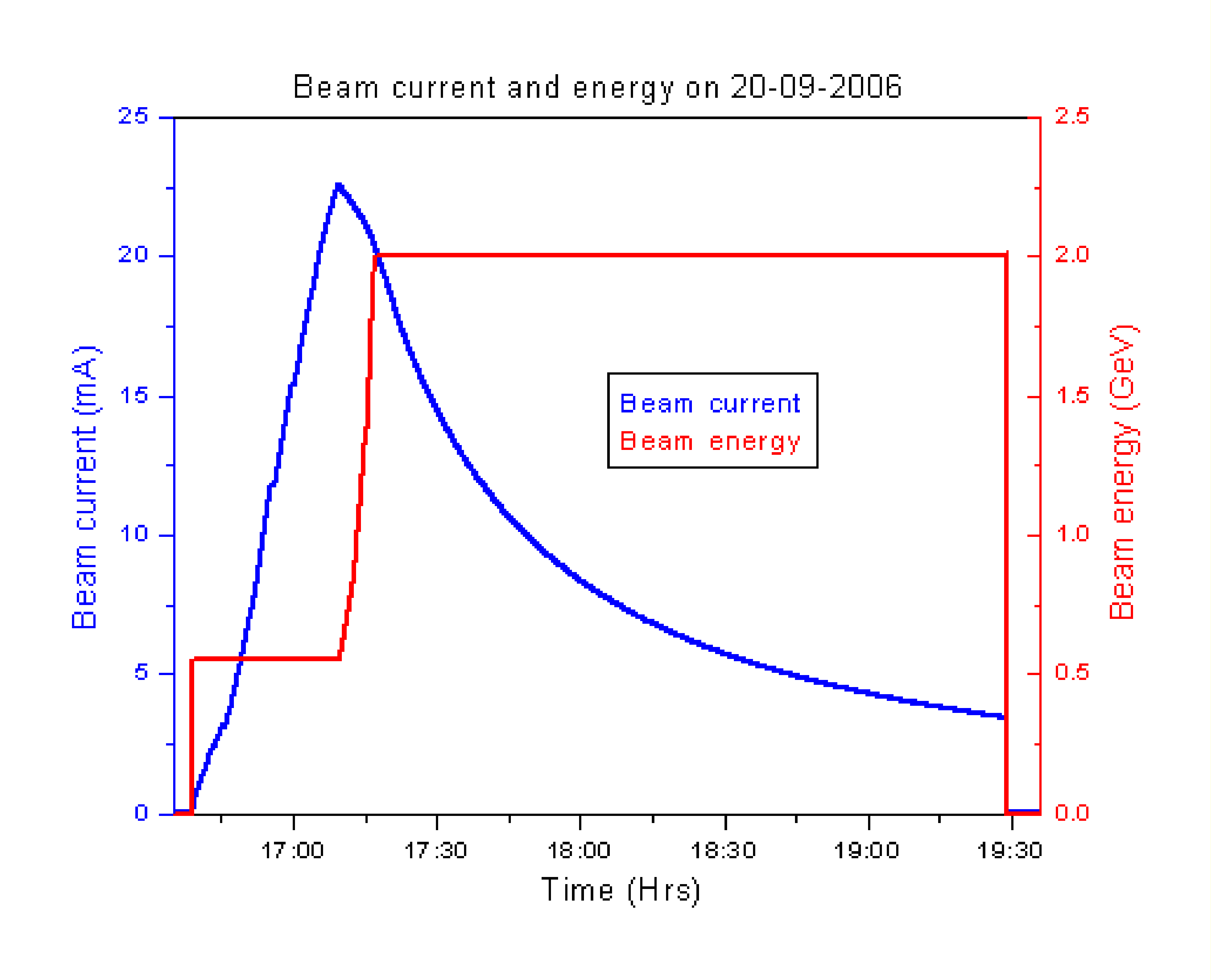




Synchrotron Light at 2mA Beam Current as seen by CCD onsighting beamline on Feb 17, 2006


Beam current and energy on 11-09-2006
Beam current (mA)
Beam energy (GeV)
Time (Hrs)
Beam current
Beam energy
0
2
4
6
8
10
12
0.0
0.5
1.0
1.5
2.0
2.5
21:56 21:59 22:01 22:04 22:07 22:10 22:13 22:16 22:19 22:22


Beam current and energy on 12-09-2006
Beam current (mA)
Beam energy (GeV)
Time (Hrs)
Beam current
Beam energy
0
2
4
6
8
10
2
0.0
0.5
1.0
1.5
2.0
2.5
18:14 18:21 18:28 18:36 18:43


Beam current and energy on 20-09-2006
Beam current (mA)
Beam energy (GeV)
Time (Hrs)
Beam current
Beam energy
0
5
10
15
20
25
0.0
0.5
1.0
1.5
2.0
2.5
17:00
17:30
18:00
18:30
19:00
19:30