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THE NSLS-II BOOSTER DEVELOPMENT AND COMMISSIONING

9 October 2014

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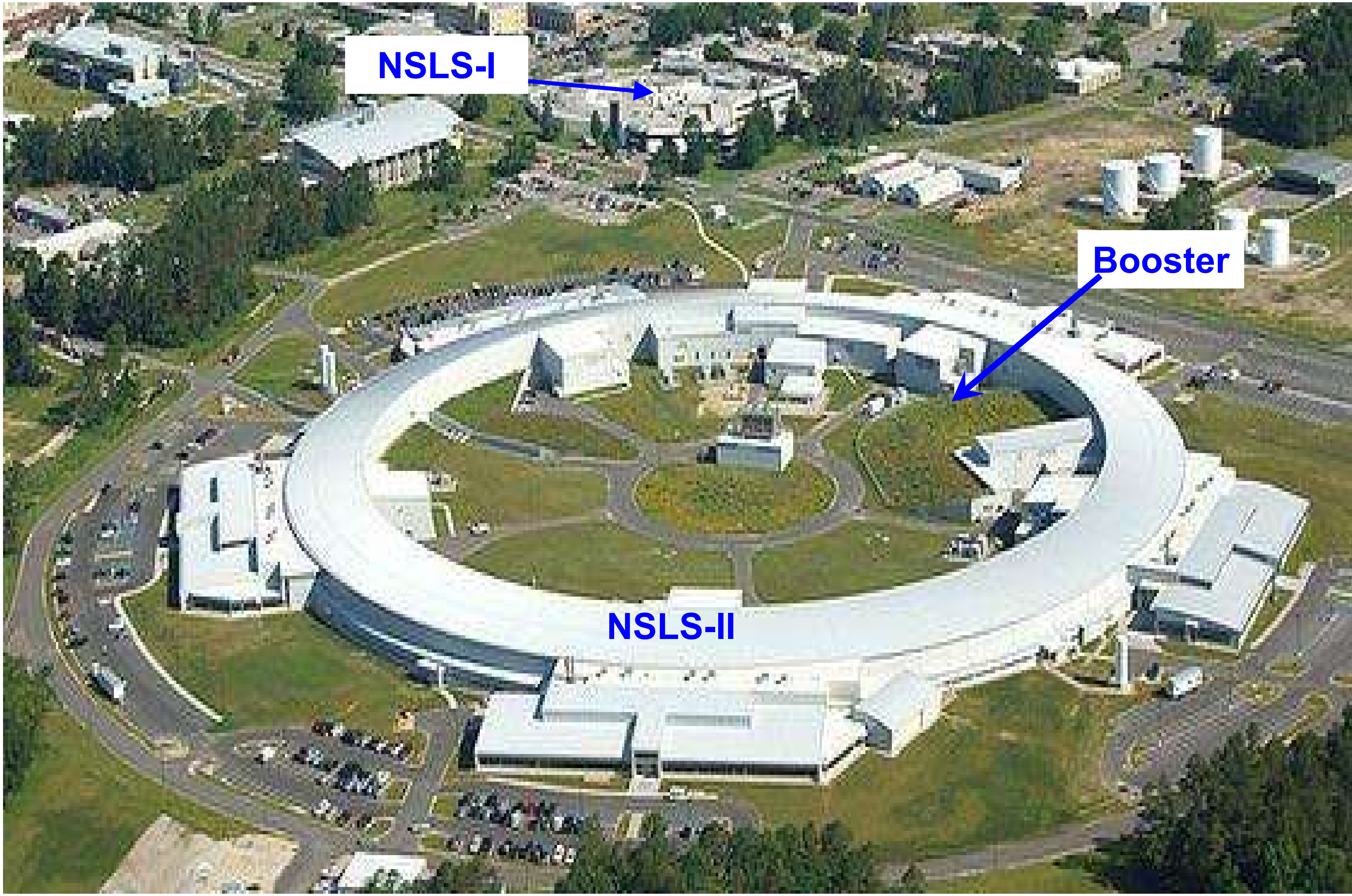
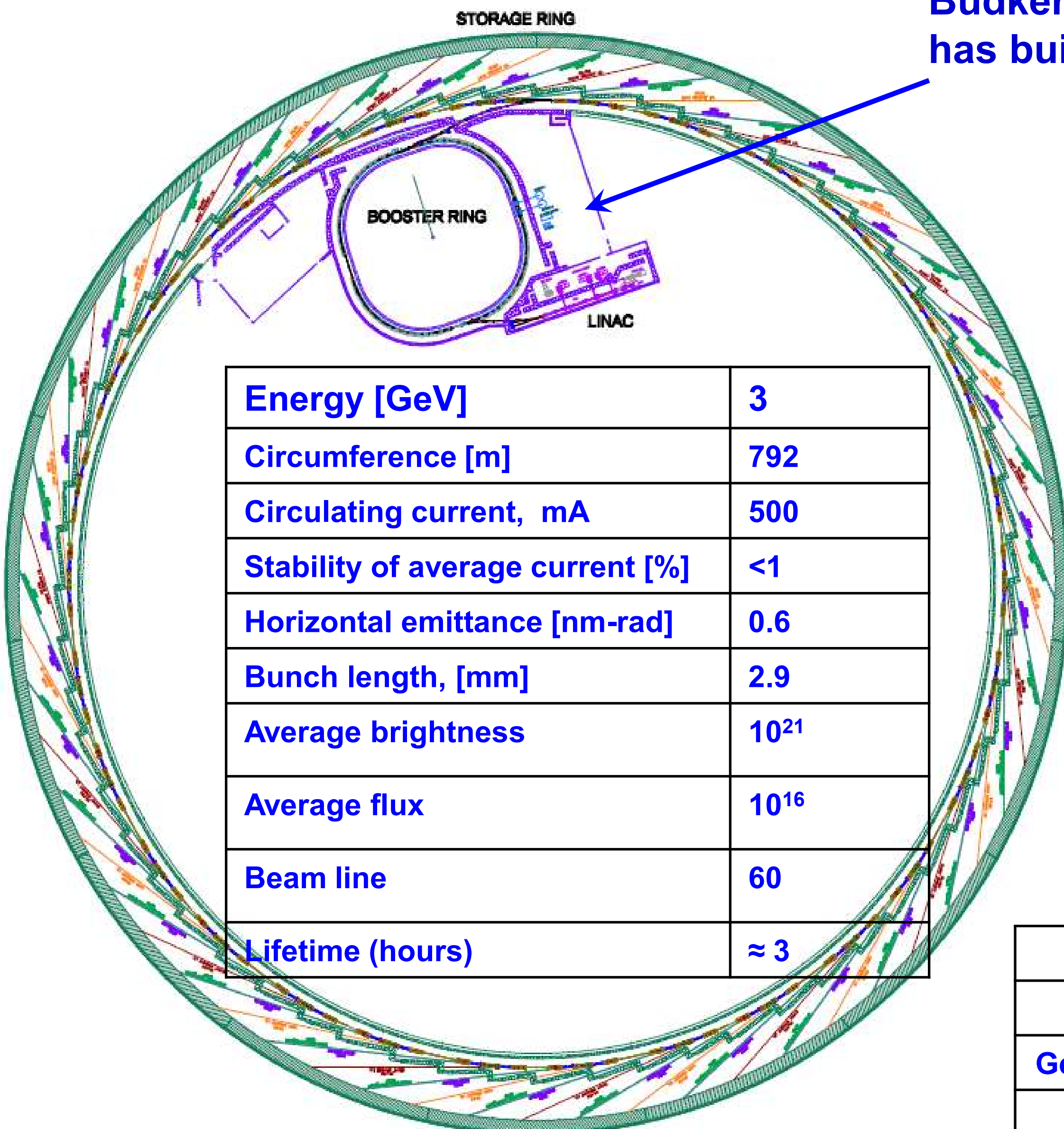
National Synchrotron Light Source II



NSLS-II Storage Ring

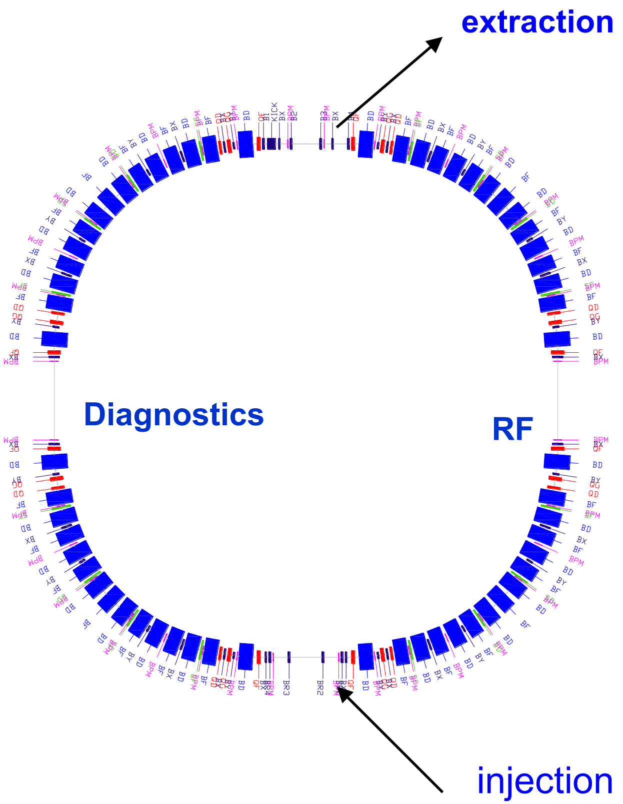
Budker Institute of Nuclear Physics has built a turnkey booster for NSLS-II



Energy [GeV]	3
Circumference [m]	792
Circulating current, mA	500
Stability of average current [%]	<1
Horizontal emittance [nm-rad]	0.6
Bunch length, [mm]	2.9
Average brightness	10^{21}
Average flux	10^{16}
Beam line	60
Lifetime (hours)	≈ 3

Linac(Accsel)	
Energy MeV	200
Geometric emittance nm-rad	150
Energy spread σ_E/E	$<1*10^{-2}$

Main parameter of the booster



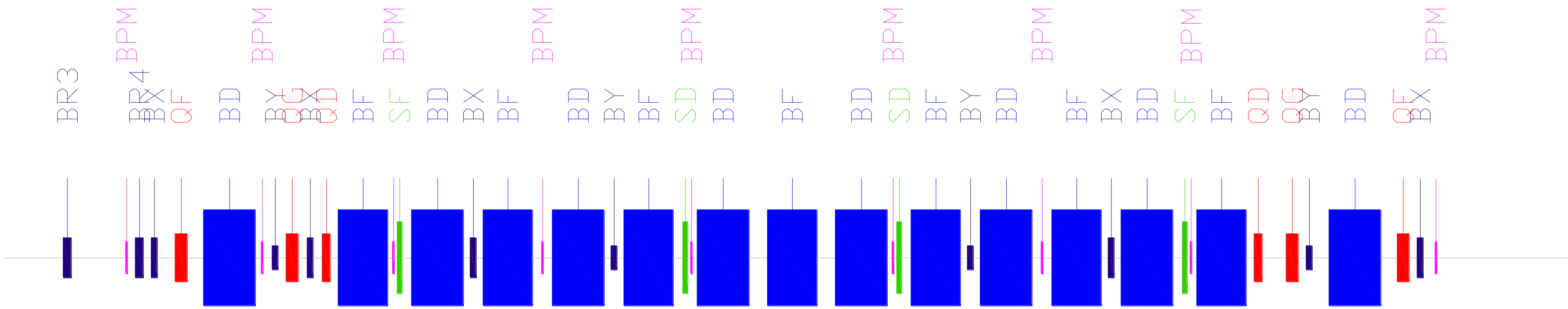
Energy	200 MeV	3 GeV
Number of periods	4	
Circumference, m	158.4	
Repetition rate, Hz	1(2)	
Bunch number	1, 80÷-150	
Current, mA	0,5, 25	
Revolution time, nsec	528	
RF frequency, MHz	499.68	
RF harmonic number	264	
Betatron tunes: $\surd_X$ / $\surd_Y$	9.645 / 3.41	
Natural chromaticity: $\xi x/ \xi y$	–9.5/–13.5	
Corrected chromaticity: $\xi x/ \xi y$	1.25 / 2.05	
Momentum compaction factor, α	0.00838	
RF voltage, MV	0.2	1.2
RF acceptance, $\varepsilon_{RF,}$ %	1.65	0.54
Horizontal emittance, ε_X, nm-rad	0.166	37.4
Energy spread, s_E/E	$0.55 \cdot 10^{-4}$	$8.23 \cdot 10^{-4}$
Energy loss per turn, Usr, kV	0.0135	686
Dumping times: $(\tau_{X,Y}, \tau_S)$	(15.6, 7.8)s	(4.62, 2.31)ms

The magnetic lattice includes four quadrants. Every quadrant contains five regular cells with two modified cells at the ends of the quadrant for dispersion suppression.

BUDKER INSTITUTE OF NUCLEAR PHYSICS

BROOKHAVEN NATIONAL LABORATORY

Booster layout (quadrant)



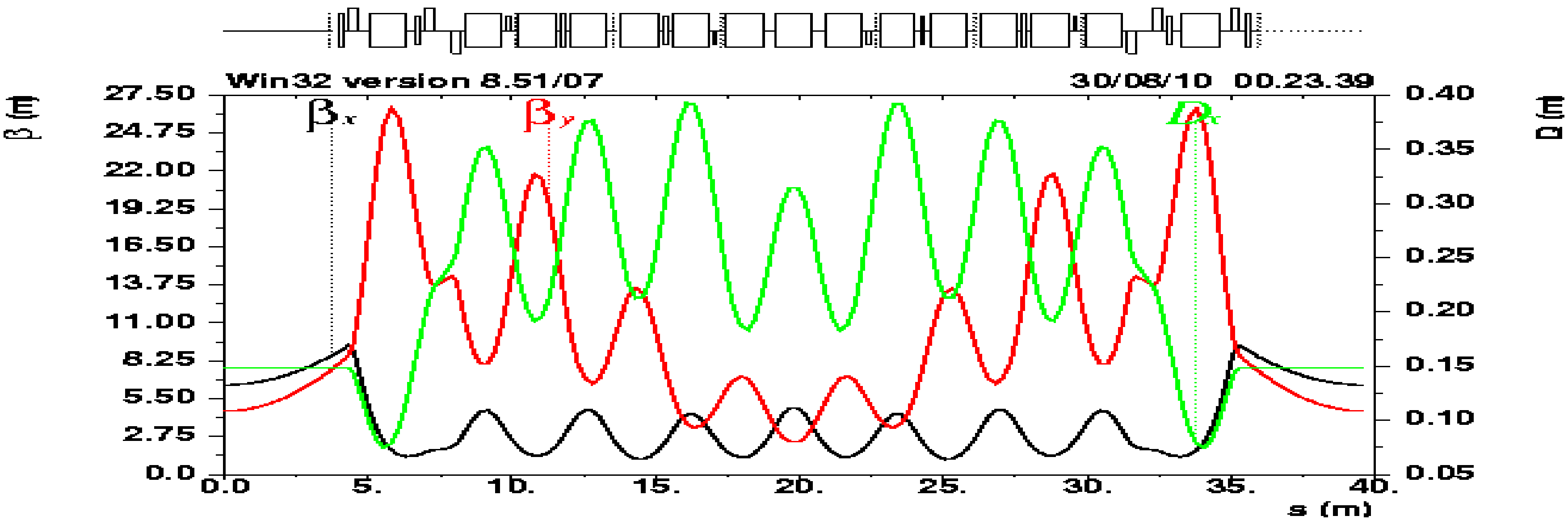
Each quadrant contains the following magnetic elements:

8 combined-function defocusing dipole magnets (BD) with 8.39° bending angle,
7 combined-function focusing dipole magnets (BF) with 3.27° bending angle,
6 quadrupole magnets to adjust the tune point,
2 SD sextupole magnets and 2 SF sextupole magnets to increase flexibility for the chromaticity compensation. Each sextupole has a separate power supply.

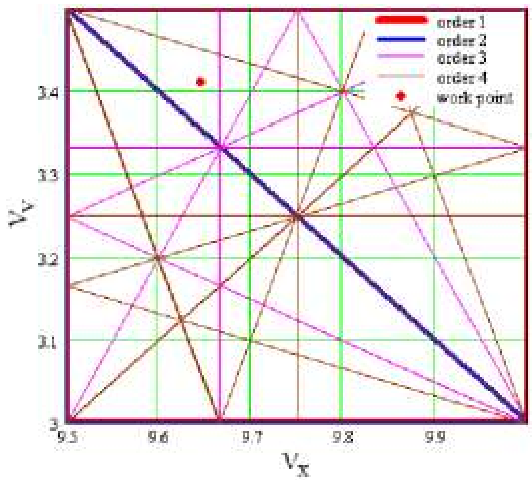
Both dipoles are H-shape curved magnets with parallel ends.

To compensate major part of chromaticity a sextupole component is incorporated in both dipole magnets.

Lattice functions in ¼ of the BS (MAD simulation)



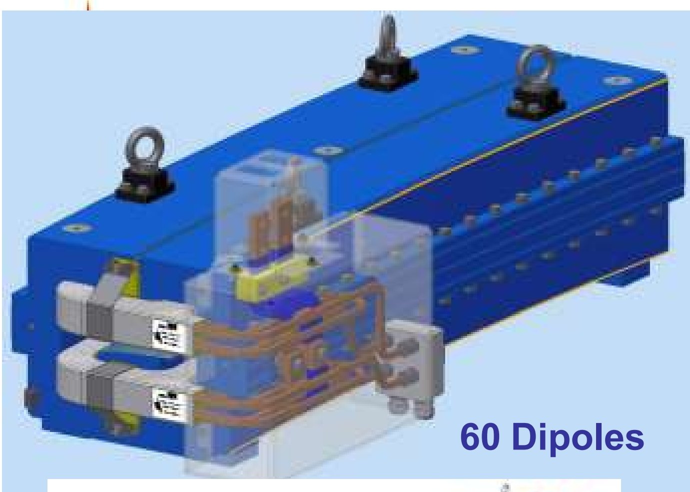
The scale for dispersion function is on the right



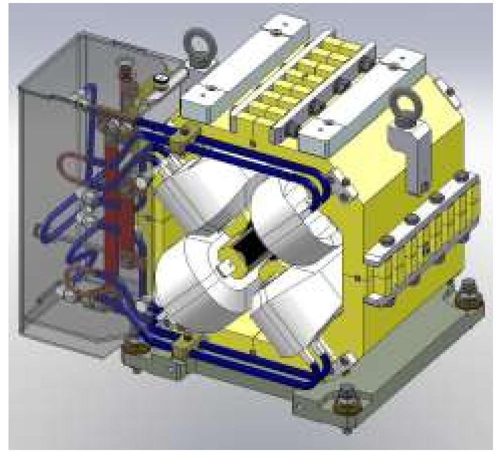
Working point at the betatron tune diagram together with resonances (up to the 4th order**).**

The working point (9.645 / 3.41) is chosen to be at sufficient distance from dangerous sum and half-integer resonances.

Magnets and Girders

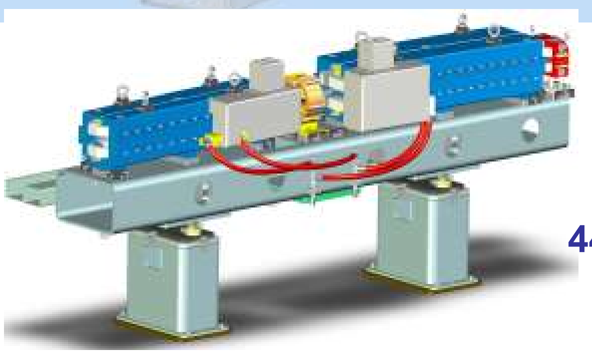


60 Dipoles



24 Quadrupoles

16 Sextupoles



44 girders

20 CX Correctors

16 CY Correctors

NSLS-II booster; arc #3 before an RF straight.

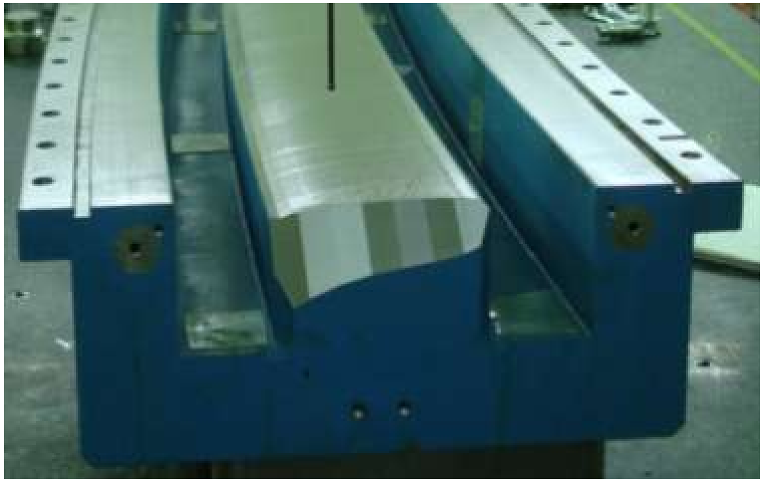
Design parameters of the booster magnets

Magnets	Total Number	Magnetic length, m	Magnetic force for 3 GeV		
			T	T/m	T/m2
BF Dipoles	28	1.24	0.46	8.2	36
BD Dipoles	32	1.30	1.13	-5.6	-43
Quadrupoles	8+8+8	0.30		20.4	
Sextupoles	16	0.12			400
Correctors	20+16	0.13	0.1		

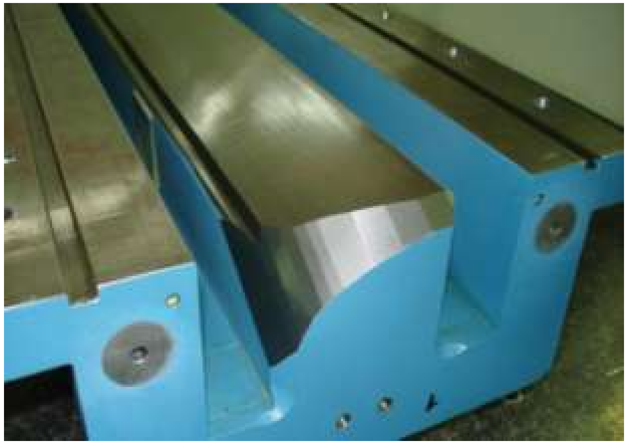
Production of magnets

•The BINP workshop has designed and produced all dies for magnet laminations with the accuracy up to 5 μm on the critical surfaces
•The BF and BD dipoles have complicated end chamfers After magnetic calculation, the 3D model of the dipole yokes was transferred to a designer. The designer processed the 3D model and sent it to the workshop for a milling machine and a coordinate measurement machine to check the produced end chamfers. As a result, the prototypes meet the specifications after two iterations

The BF and BD dipoles end chamfers

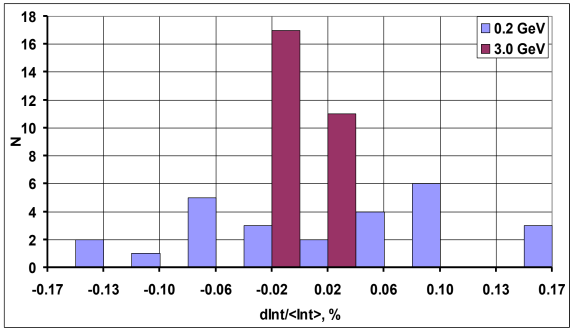


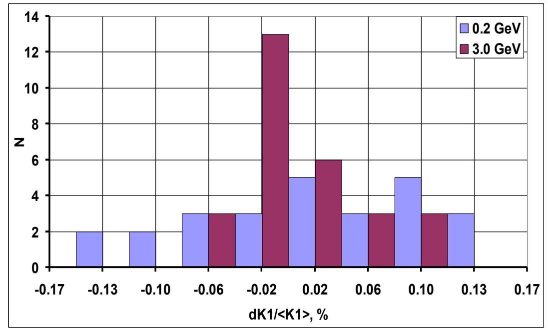
BD dipole

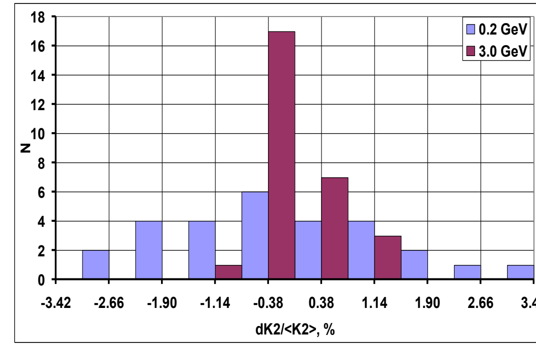


BF dipole

The results of measuring the BD magnets

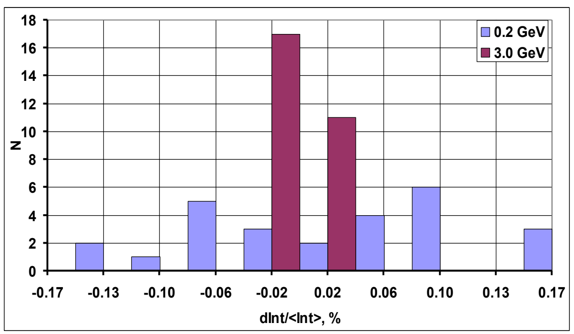


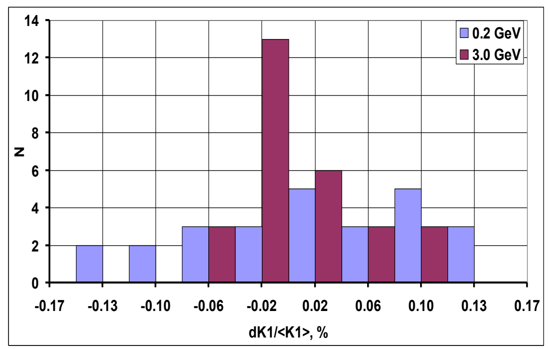


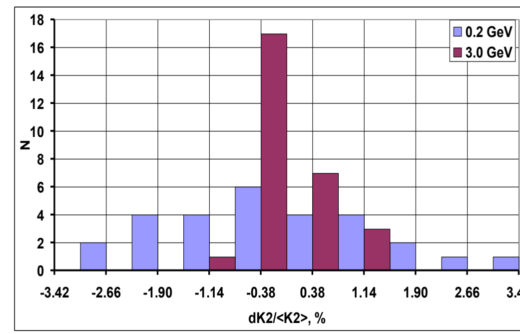


BF

The results of measuring the BF magnets







Errors in the integral field

Gradient

Sextupole component

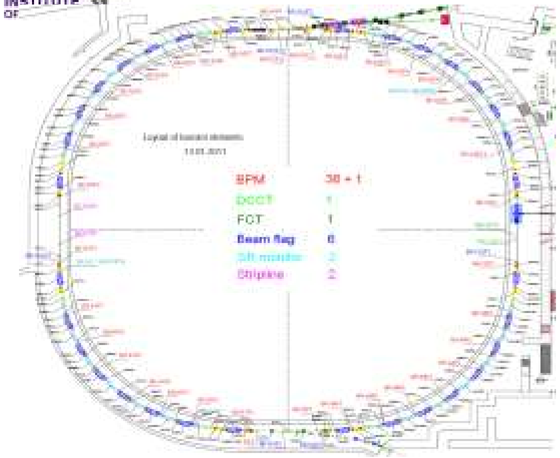
Histograms deviation field integrals (left), K1 (center) and K2 (right) components from the design values for BD and BF magnets. Blue column on the energy 0.2 GeV, purple on the energy of 3 GeV

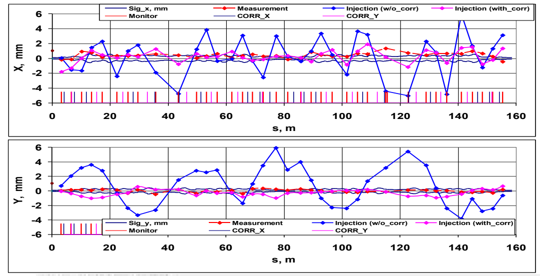
As can be seen from Figure 4 the quality of the magnetic field better than the original requirements: difference of integrated parameters between dipoles should not exceed: for integral of a field <0.1%, for integral of a gradient <0.5% and for integral of a sextupole field component <5%

Tolerances of the magnetic elements

Error type	σ		
Energy, GeV	Orig.	0.2	3
Dipole magnet BF			
Relative error in the dipole field integral	1×10^{-3}	0.97×10^{-3}	0
Relative error in the gradient integral	5.0×10^{-3}	0.9×10^{-3}	0.4×10^{-3}
Relative error in the K_2 integral	5.0×10^{-2}	1.6×10^{-2}	0.5×10^{-2}
Dipole magnet BD			
Relative error in the dipole field integral	1×10^{-3}	0.75×10^{-3}	0
Relative error in the gradient integral	5.0×10^{-3}	1.9×10^{-3}	1.6×10^{-3}
Relative error in the K_2 integral	5.0×10^{-2}	1.3×10^{-2}	0.5×10^{-2}
Quadrupole magnet			
Relative error in the K_1 gradient integral	5.0×10^{-3}	2.3×10^{-3}	0.87×10^{-3}
Sextupole magnet			
Relative error in the K_2 gradient integral	5.0×10^{-2}	2.1×10^{-2}	0.25×10^{-2}

Diagnostics and Instrumentation



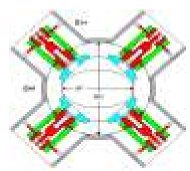


Electrostatic BPMs

(36 pieces)

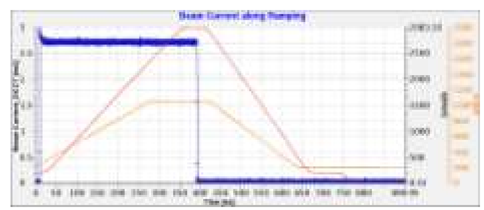
Signal from Booster FCT showing bunch pattern in long pulse mode.

Fast current transformer Bergoz FCT-WB-CF6"-60.4-40-20:1-UHV-H

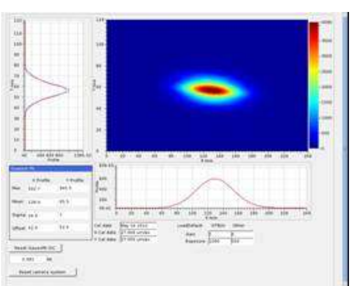


Tune measurement system

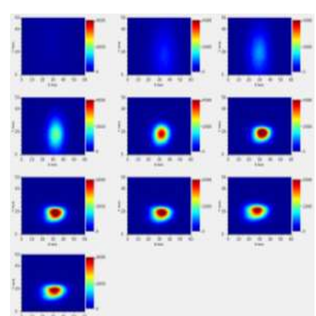
Two identical sets of four 50-Ω striplines are used, one set is a kicker for beam excitation; another one is a pickup for measurement of a beam response signal.



DC current transformer Bergoz NPCT-CF4.5"-60.4-120-UHV-H



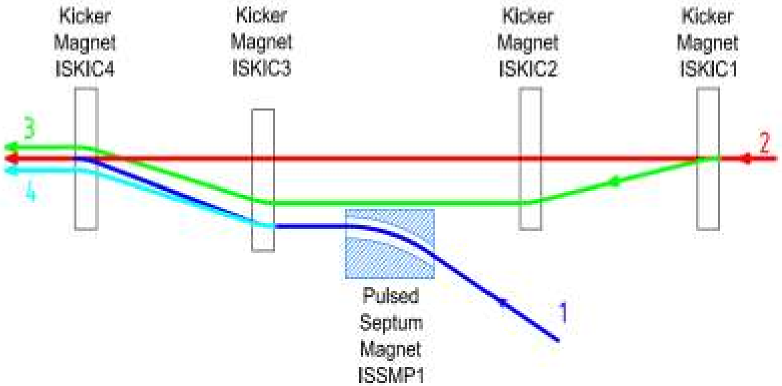
Beam flag (8 pieces)



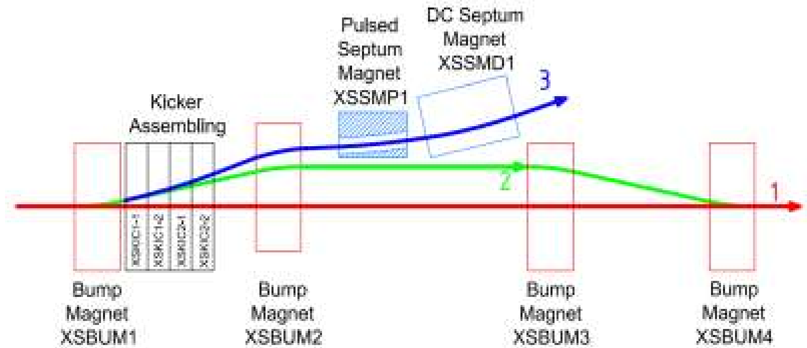
Synchrotron radiation monitor

(2 pieces)

INJECTION AND EXTRACTION SYSTEM



Injection straight section

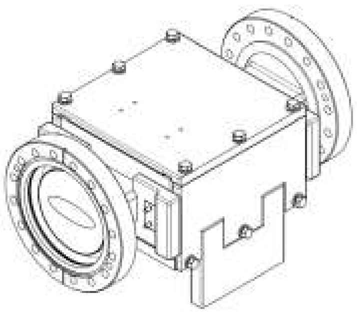


Extraction straight section

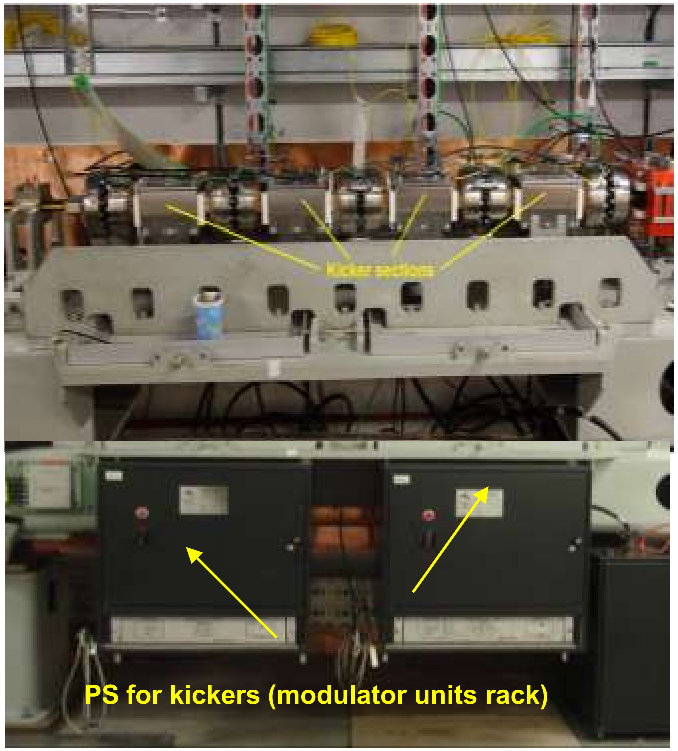
Main Parameters of IES Magnets

Magnets	Q-ty	Magnetic length, m	Field T	Angle mrad	Pulse µs	Field stability
Injection System for 200 MeV						
Kicker	4	0.207	0.055	17	0.3	$\pm 5 \times 10^{-3}$
Septum(AC)	1	0.75	0.112	125	100	$\pm 1 \times 10^{-3}$
Extraction System for 3 GeV						
Bump	4	0.17	0.46	7.8	1500	$\pm 1 \times 10^{-3}$
Kicker	1	0.83	0.073	6.1	0.3	$\pm 2 \times 10^{-3}$
Septum(AC)	1	0.6	0.8	48	150	$\pm 2 \times 10^{-4}$
Septum(DC)	1	1.2	0.89	106	-	$\pm 2 \times 10^{-4}$

Injection and Extraction Kicker

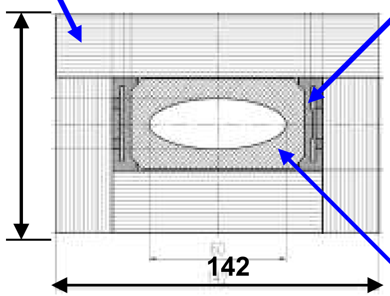


Kicker module.
General view



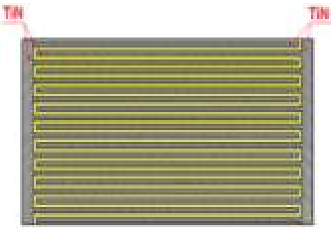
CMD5005 ferrite

Copper bus covered
by organosilicon compound "Viksint "

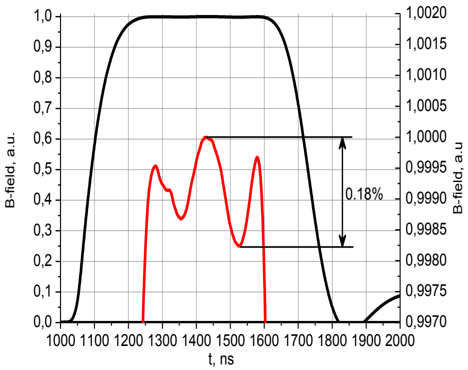


Extraction kicker assembly layouts.

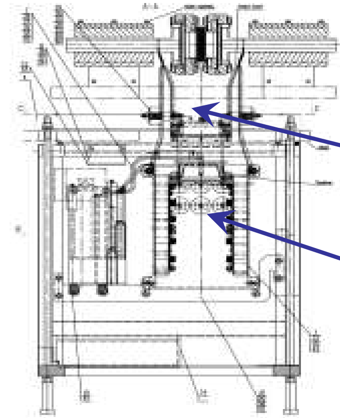
Al2O3 (aluminium oxide) ceramic



The coating is made as strips of 3.4 mm width with 3.4 mm



Extraction kicker B-field waveform normalized to maximum (720 G)



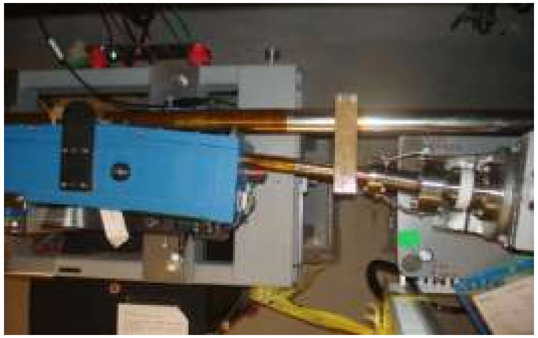
Thyratron

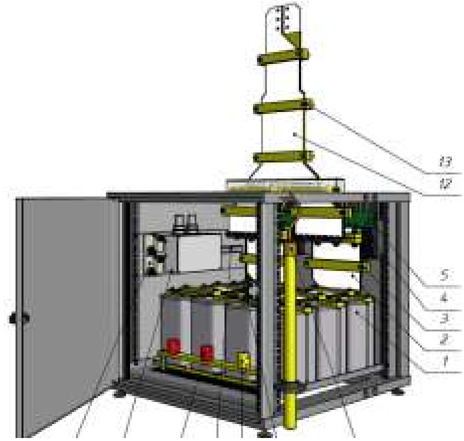
PFN

Extraction kicker-pulser assembly

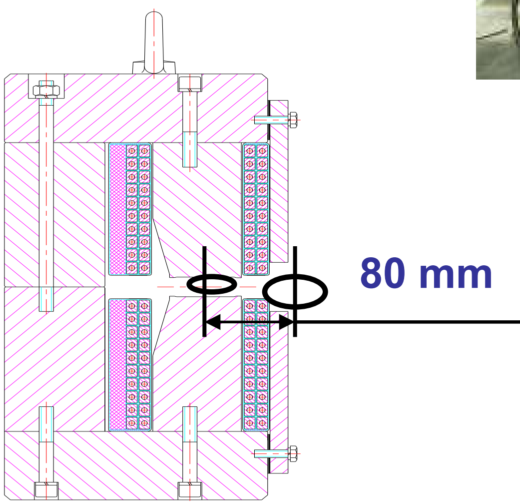
Extraction AC and DC septums

Out of vacuum eddy-current type septum magnets used for booster NSLS-II. Pulsed septum magnet consists of the C-shape laminated steel yoke with single-turn excitation coil.

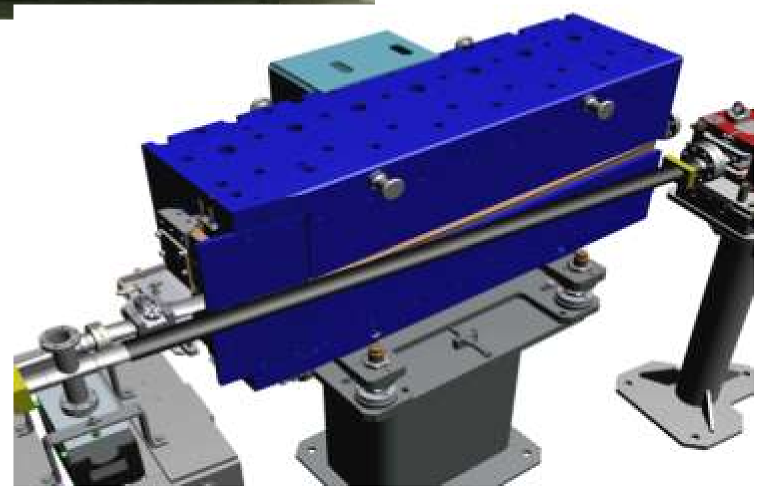




Extraction septum pulser unit



DC septum cross section



Requirement -Integral of a stray field ∫Hdl ≤1 Gs*m

Timeline

•Budker Institute of Nuclear Physics won this tender in May 2010.

•The booster was designed, produced and delivered in full to BNL by September 2012.

•During 2013 the booster was assembled and all equipment was tested.

•The authorization to start the commissioning was received in November 2013.

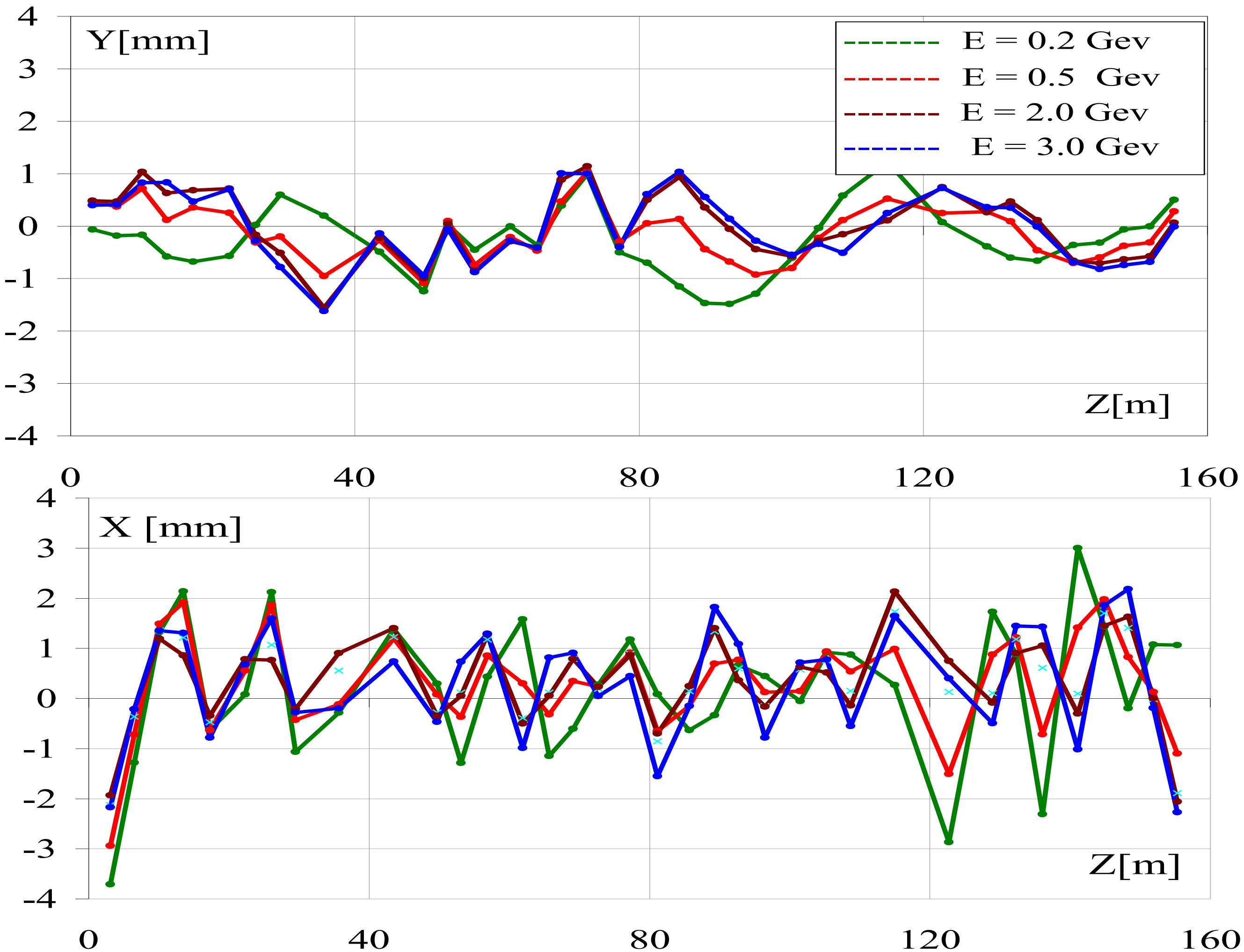
•The BNL and BINP teams started beam injection into the Booster on December 8. The first turn was closed soon by tuning the LTB and BR orbit correctors.

•The beam was accelerated to 3 GeV by the end of 2013.

•The commissioning of the booster was successfully completed in February 2014

Beam orbit

Thanks to the good quality of the booster magnets and precise booster alignment, commissioning of the booster passed without any problems. After achievement of the captured beam, the orbit at injection was corrected and the beam was accelerated.

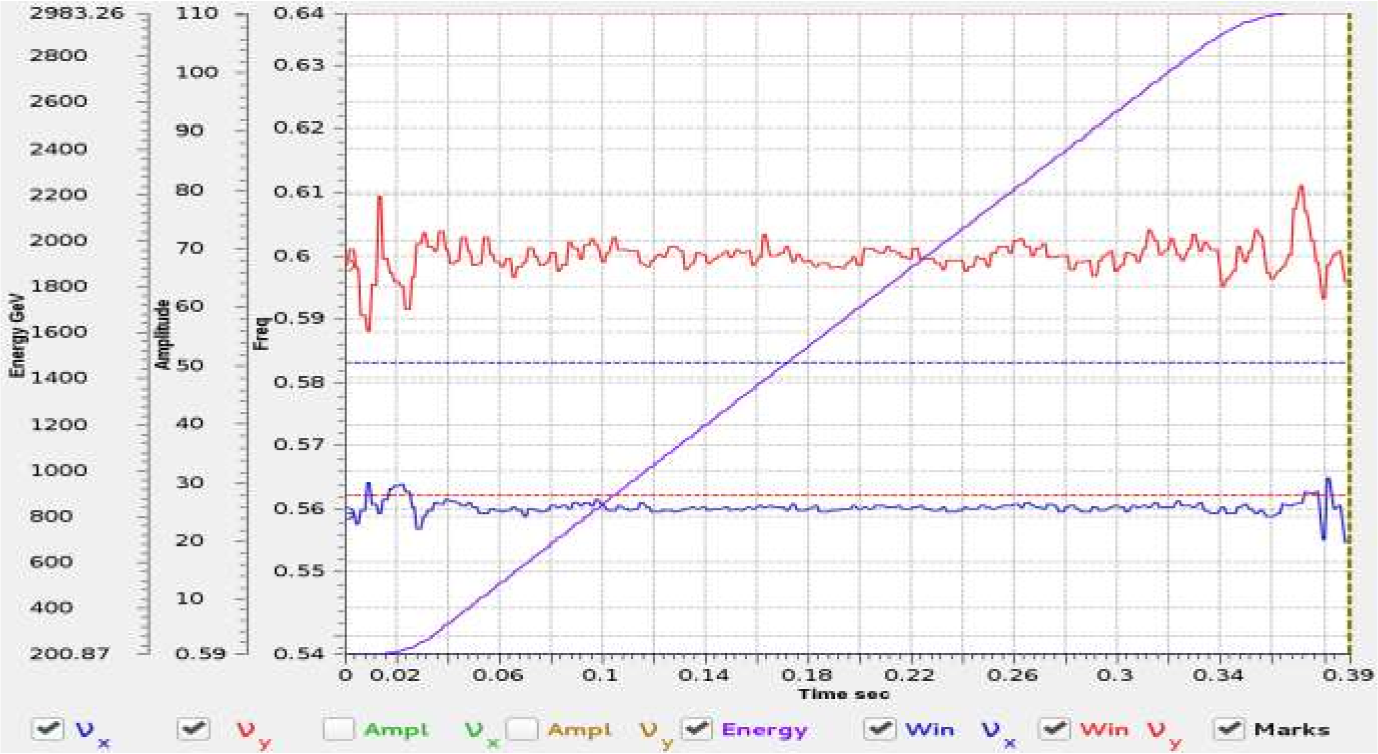


Vertical and horizontal orbit of beam along the whole ramp

As can be seen from Figure, the beam orbit remains constant during the ramp with accuracy of ± 1 mm in the vertical plane and ± 2 mm in the horizontal without additional correction.

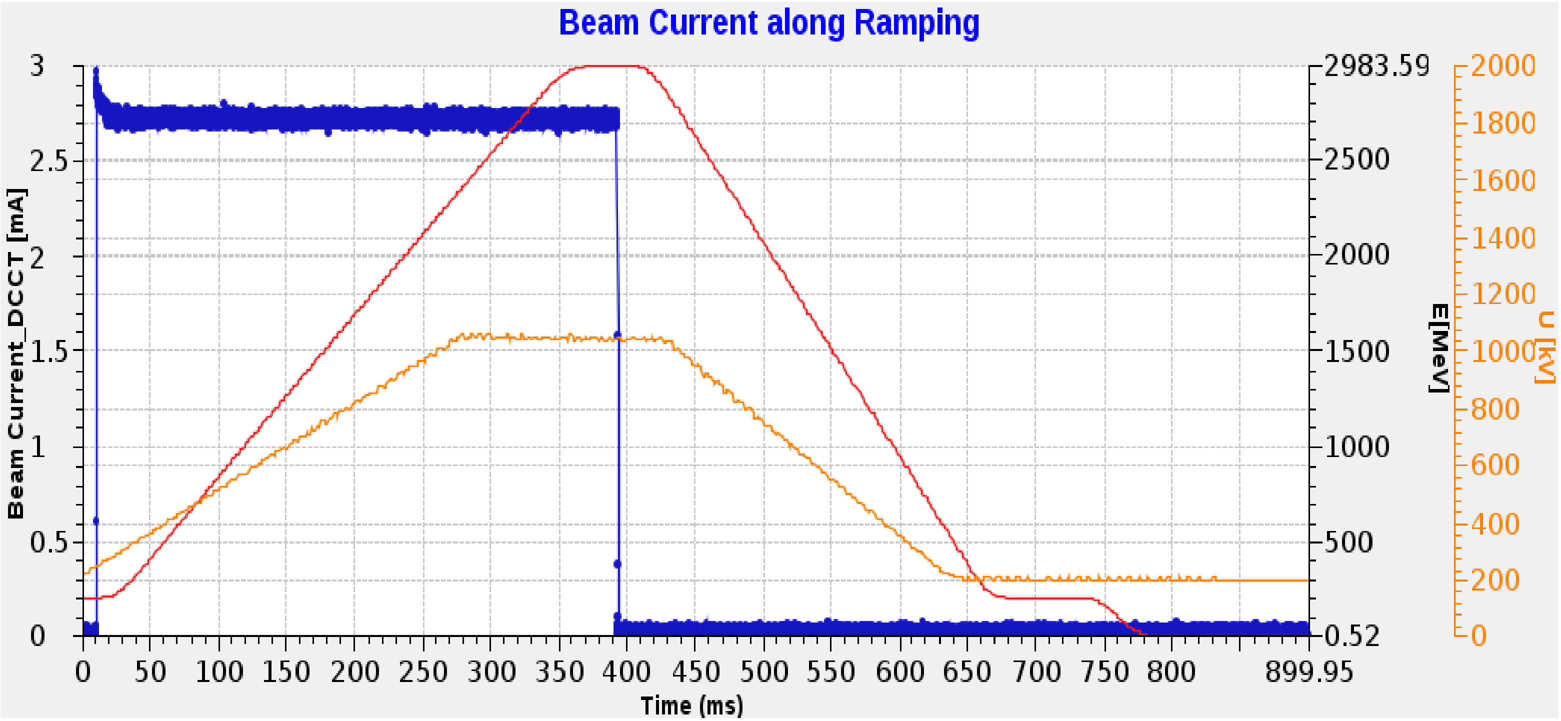
Tunning

Thereafter the optical model of the magnetic structure was improved towards better booster ring parameters using the data of the final booster survey and the results from beam position monitors. The optical functions and betatron tunes were corrected throughout the ramp. As a result, the betatron frequences over the entire ramp remained constant



The horizontal (blue) and vertical (red) tunes along the whole ramp (purple)

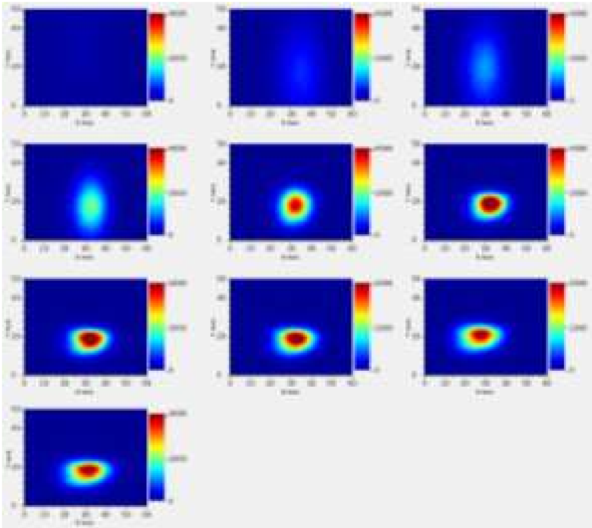
Transmission

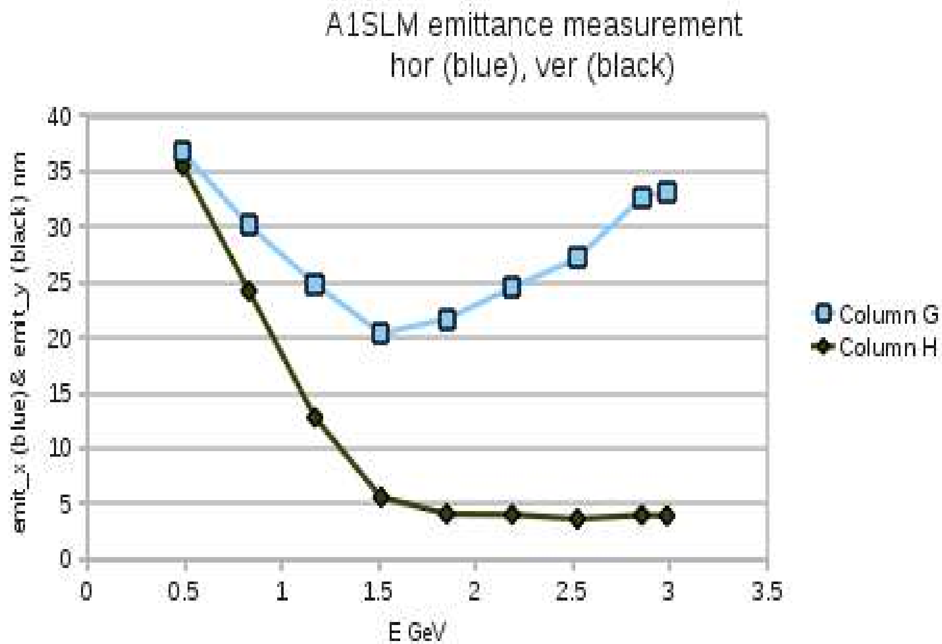


The beam current from DCCT (blue), the beam energy according dipole magnet currents (red) and the RF cavity voltage (orange) during 1Hz-cycle.

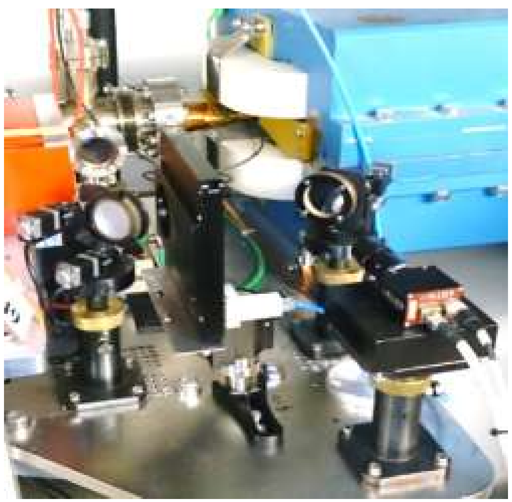
After adjustment optical functions of the booster and linac-to-booster transport line, efficiency of particle capture and acceleration was increased up to ~ 95 %

Emittance measurement





Horizontal and vertical emittance during the acceleration cycle as determined by the profile of the synchrotron light seen by the BR-A1SLM monitor



Synchrotron radiation monitor

Using operating machine currents, Twiss parameters at the source are estimated to be $\beta x = 5.8$ m, $\beta y = 23.8$ m, and ηx=0.1 m.
At extraction energy the measured emittances were

$$\varepsilon_X = 33 \text{ nm and } \varepsilon_Y = 4 \text{nm.}$$

CONCLUSION

The NSLS-II 3-GeV booster synchrotron has passed the acceptance testing and the machine performance closely corresponds to the project requirements.

	Design	Measured
Beam energy	**3+/-0.15 GeV**	**~3 GeV**
Bunch charge	**0.5…15 nC**	**0.5…10 nC**
Bunch train	**1 / 80…160 bunches**	**1 / 75 bunches**
Beam energy spread @3GeV	**0.08%**	**0.10%**
Beam emittance X	**38 nm rad**	**33 nm rad**
Beam emittance Y	**4 nm rad**	**4…8 nm rad**
Charge transport efficiency between ICTs in LB and BSR TL	**>75%**	**~80% as seen between LtB and BsT FCTs**

The booster commissioning was successfully completed in February 2014.
The commissioning of NSLS-II Storage Ring was started in March 2014 and stored beam was achieved on April 5, 2014.

Thank you for your attention !