BUDKER INSTITUTE OF NUCLEAR PHYSICS

BROOKHAVEN NATIONAL LABORATORY

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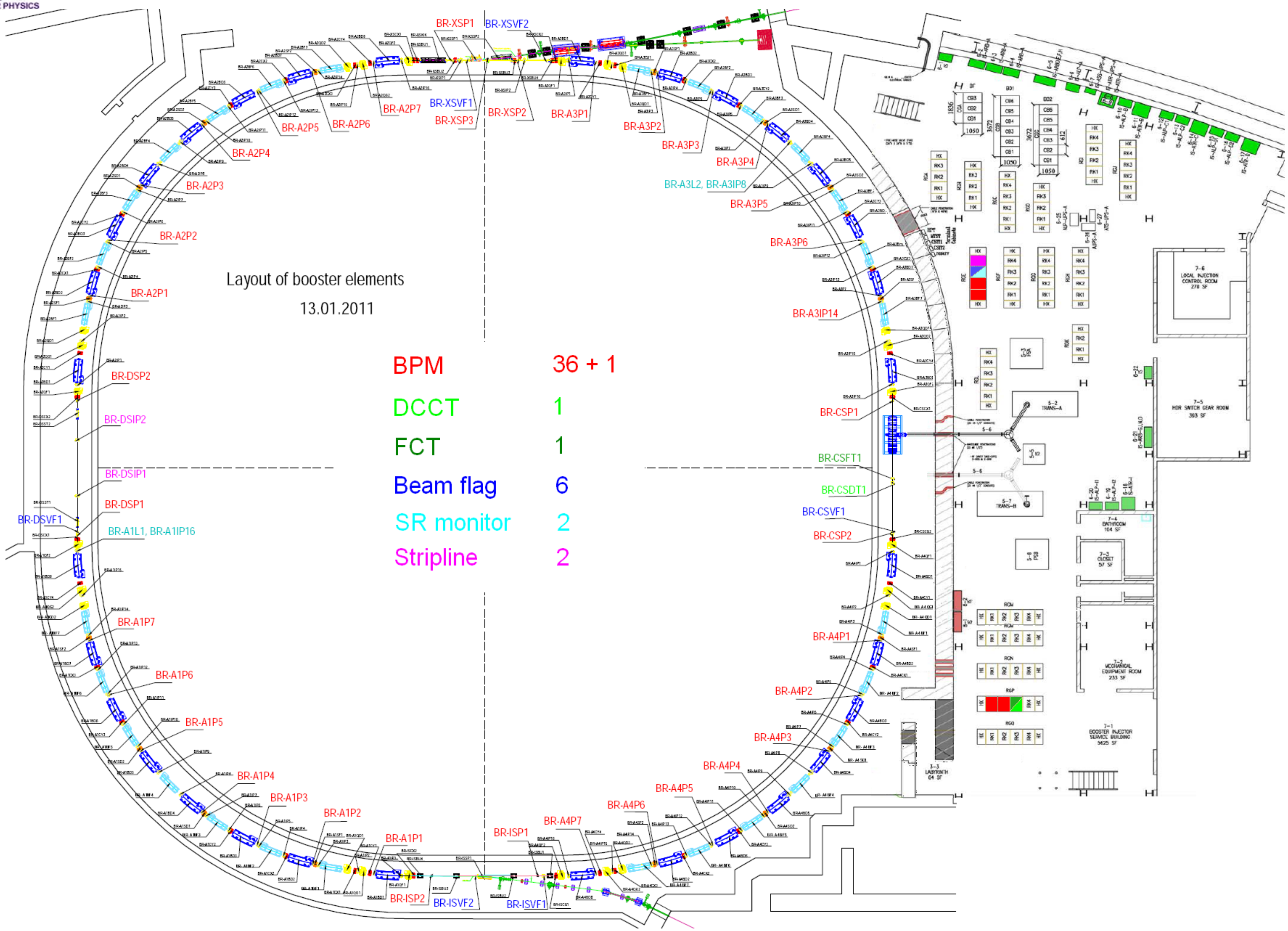
Booster NSLSS-II beam diagnostics

RUPAC 2012, St. Petersburg, 28 September

Booster NSLSS-II projected parameters

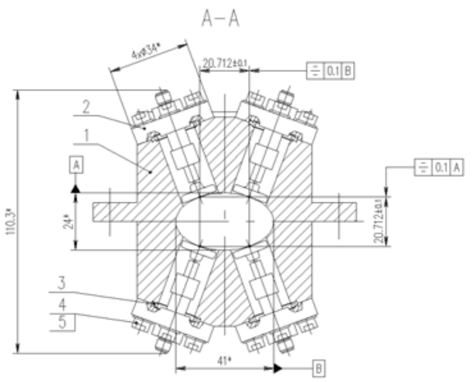
Perimeter	158,4 m
Injection energy	200 MeV
Extraction energy	3 000 MeV
Repetition rate	1 Hz
HF	499,68 MHz
Horizontal emittance (3 GeV)	< 40 nm·rad
Extraction pulses jitter	< 0,1 %
Beam charge	10 nC
Linac - main ring charge efficiency	> 70 %
Annual operation time	6 000 h
Unplanned shutdown time	<0,1 %

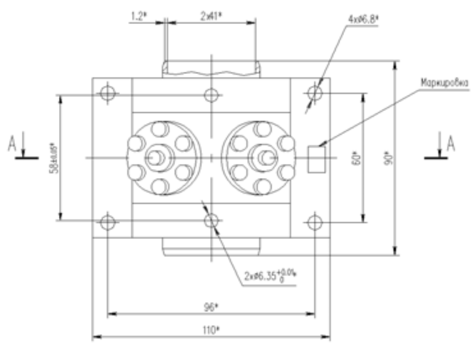
Beam diagnostic systems

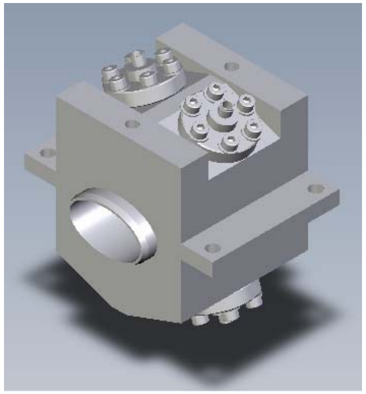


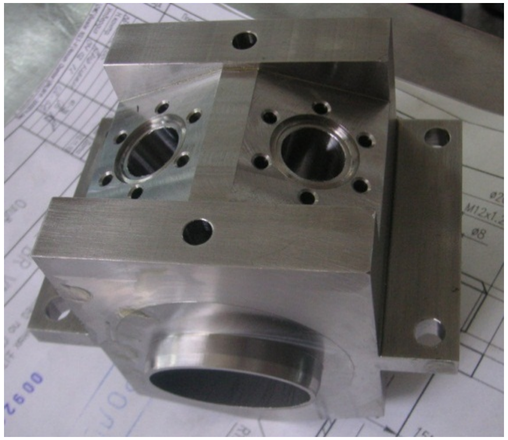
Beam position monitors
BPM housings and supports (BINP)

Type 1 (arcs): 28+1 pcs

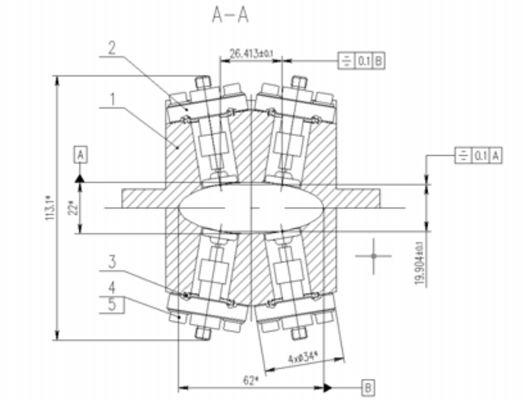


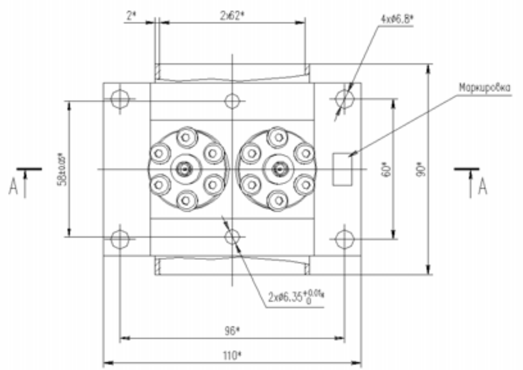


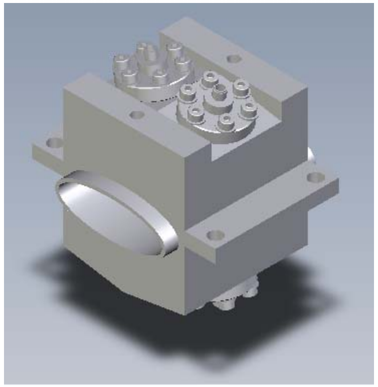




Type 2 (sections): 8 pcs

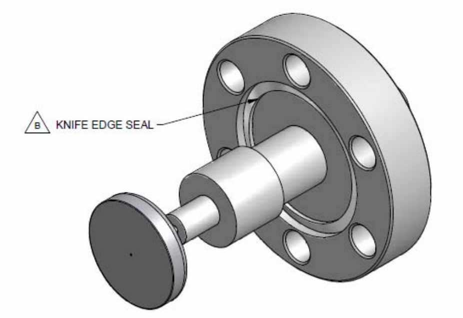






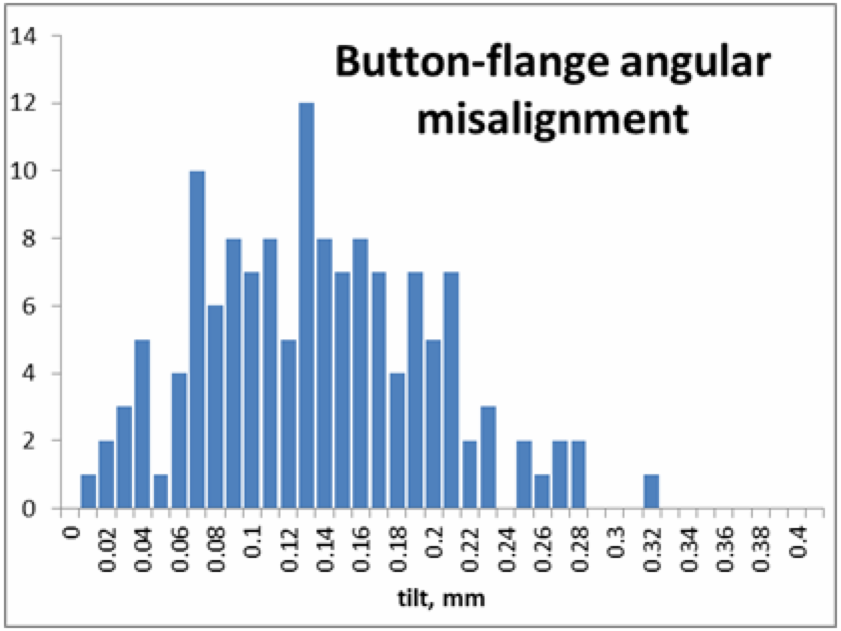
All 37 BPM housings have been manufactured and most of them are installed

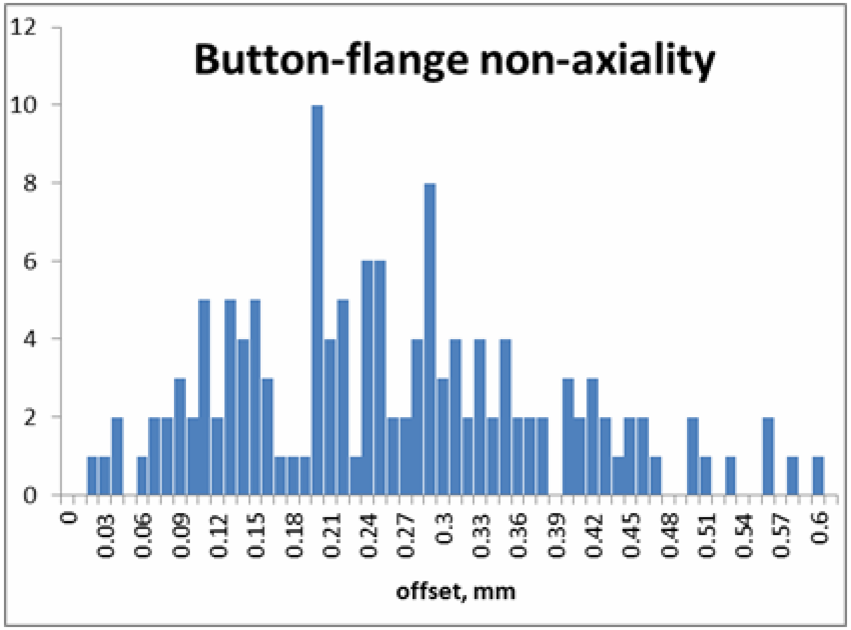
Beam position monitors
Button electrodes (MPF products Inc.)



159 buttons have been manufactured.
A quality problem was faced when assembling the 1st BPM: the design dimensional tolerances of 0.005” (0.127 mm) were not fulfilled.

For all buttons, the button-flange angular misalignment and button-flange non-axiality have been measured using Zeiss machine.





5 defective buttons have been replaced by MPF according to manufacturer's warranty.

Beam position monitors
Bench measurements (BINP)

All BPM assemblies have been measured using a test bench.

A 3rd–order polynomial linearization is implemented. Using the data measured, a table of coefficients has been calculated for each BPM.

The measurement results are summarized in the inspection reports.

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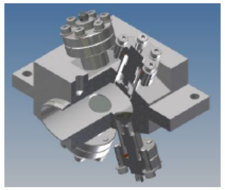
INSPECTION REPORT

NSLS-II Booster

BPM Assembly BR-A1PKU2



2011

4. ELECTRIC MEASUREMENTS

The button capacitances have been measured by a LCR Meter MT4090 (Motech Industries, Inc.) at 10 kHz, certified accuracy is 2%. The measured data are given below:

Pickup-electrode	Part number	Capacitance, pF
A	0017	8.55
B	0023	8.60
C	0022	8.55
D	0018	8.30

The coordinate grid of BPM has been measured using a movable RF antenna with a 3 MHz sine signal. The signals induced to the buttons are measured. The horizontal X and vertical Y coordinates are calculated using the formulae:

$$X = K_{X0}\frac{V_A - V_B - V_C + V_D}{V_A + V_B + V_C + V_D}, \qquad Y = K_{Y0}\frac{V_A + V_B - V_C - V_D}{V_A + V_B + V_C + V_D}. \qquad (1)$$

where V_A, V_B, V_C, V_D are the amplitudes of voltage induced to the buttons A, B, C, D, respectively; K_{X0}, K_{Y0} are the initial scale factors, calculated on the base of first derivative at the BPM center. The measurement results are given in Fig. 1, the antenna positions are shown by crosses connected by the motion path, the measured values – by circles.

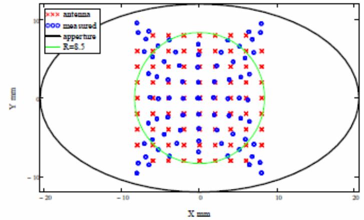


Fig. 1. Measured data without linearization.

Producer:	BINP	BPM:	BR-A1PKU2
Customer:	BNL	Date:	

An error of beam position calculated using the linear formulae (1) can exceed 1 mm inside the circle of 8.5 mm radius. To decrease this error, a 3rd–order polynomial linearization is implemented; X and Y are calculated as:

$$X = \sum_{i,j} C_{Xij} x^i y^j, \qquad Y = \sum_{i,j} C_{Yij} x^i y^j. \qquad (2)$$

where x and y are the coarse values of coordinates calculated using the formulae:

$$x = K_X\frac{V_A - V_B - V_C + V_D}{V_A + V_B + V_C + V_D}, \qquad y = K_Y\frac{V_A + V_B - V_C - V_D}{V_A + V_B + V_C + V_D}. \qquad (3)$$

The polynomial terms with x^0y^0 give the shift of BPM electrical zero. Corrected scale factors K_X, K_Y and polynomial coefficients C_{Xij}, C_{Yij} are calculated from the data shown in Fig. 1, for a circle of 8.5 mm radius (optimization region), inside which the accurate measurements of beam position are required.

The result of linearization is presented in Fig. 2, the antenna positions are shown by crosses, the measured values – by circles.

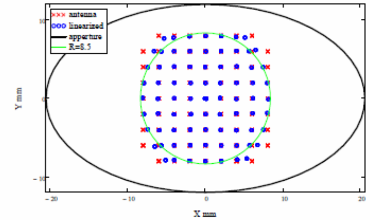
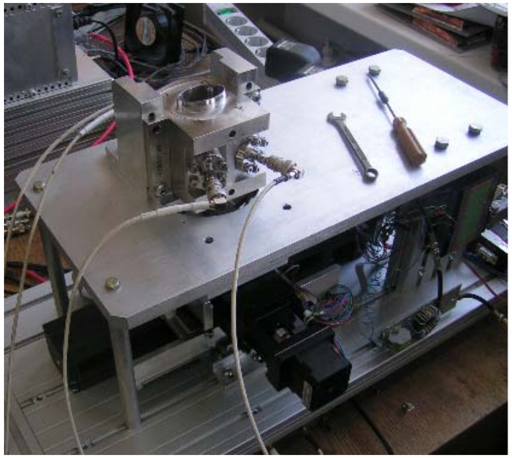


Fig. 2. Measured data with linearization.

Producer:	BINP	BPM:	BR-A1PKU2
Customer:	BNL	Date:	



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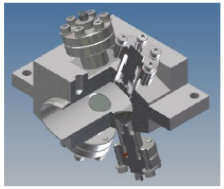
INSPECTION REPORT

NSLS-II Booster

BPM Assembly BR-XSPKU1



2011

4. ELECTRIC MEASUREMENTS

The button capacitances have been measured by a LCR Meter MT4090 (Motech Industries, Inc.) at 10 kHz, certified accuracy is 2%. The measured data are given below:

Pickup-electrode	Part number	Capacitance, pF
A	245	8.23
B	237	8.37
C	247	8.16
D	206	7.98

The coordinate grid of BPM has been measured using a movable RF antenna with a 3 MHz sine signal. The signals induced to the buttons are measured. The horizontal X and vertical Y coordinates are calculated using the formulae:

$$X = K_{X0}\frac{V_A - V_B - V_C + V_D}{V_A + V_B + V_C + V_D}, \qquad Y = K_{Y0}\frac{V_A + V_B - V_C - V_D}{V_A + V_B + V_C + V_D}. \qquad (1)$$

where V_A, V_B, V_C, V_D are the amplitudes of voltage induced to the buttons A, B, C, D, respectively; K_{X0}, K_{Y0} are the initial scale factors, calculated on the base of first derivative at the BPM center. The measurement results are given in Fig. 1, the antenna positions are shown by crosses connected by the motion path, the measured values – by circles.

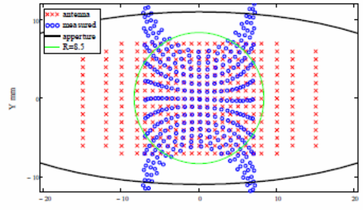


Fig. 1. Measured data without linearization.

Producer:	BINP	BPM:	BR-XSPKU1
Customer:	BNL	Date:	

An error of beam position calculated using the linear formulae (1) can exceed 1 mm inside the circle of 8.5 mm radius. To decrease this error, a 3rd–order polynomial linearization is implemented; X and Y are calculated as:

$$X = \sum_{i,j} C_{Xij} x^i y^j, \qquad Y = \sum_{i,j} C_{Yij} x^i y^j. \qquad (2)$$

where x and y are the coarse values of coordinates calculated using the formulae:

$$x = K_X\frac{V_A - V_B - V_C + V_D}{V_A + V_B + V_C + V_D}, \qquad y = K_Y\frac{V_A + V_B - V_C - V_D}{V_A + V_B + V_C + V_D}. \qquad (3)$$

The polynomial terms with x^0y^0 give the shift of BPM electrical zero. Corrected scale factors K_X, K_Y and polynomial coefficients C_{Xij}, C_{Yij} are calculated from the data shown in Fig. 1, for a circle of 8.5 mm radius (optimization region), inside which the accurate measurements of beam position are required.

The result of linearization is presented in Fig. 2, the antenna positions are shown by crosses, the measured values – by circles.

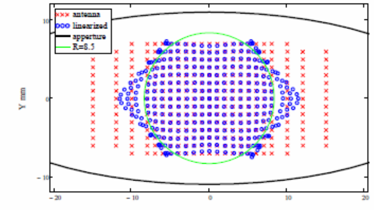
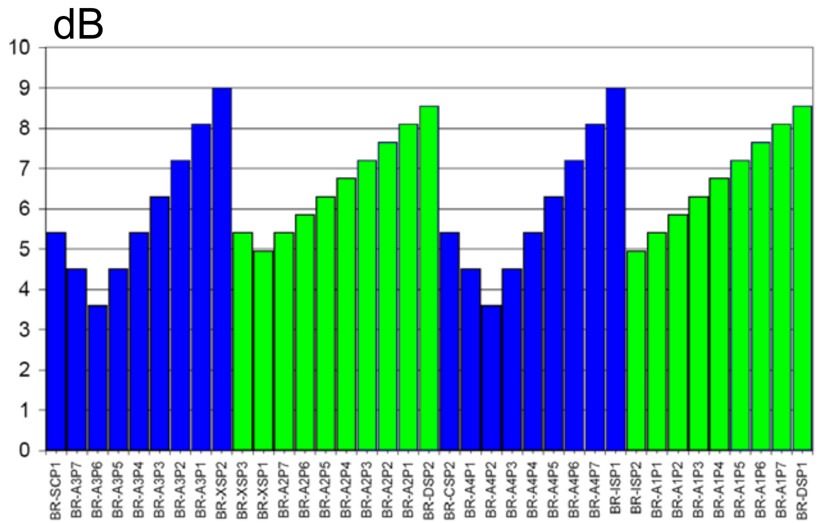


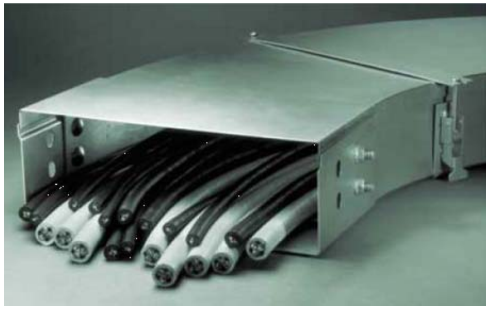
Fig. 2. Measured data with linearization.

Producer:	BINP	BPM:	BR-XSPKU1
Customer:	BNL	Date:	

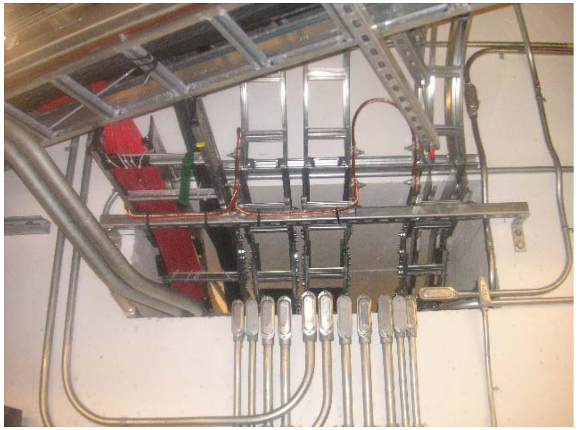
Beam position monitors
Cabling (BNL)



LMR400 (9 dB/100 m @ 500 MHz)
LMR240 (18 dB/100 m @ 500 MHz)

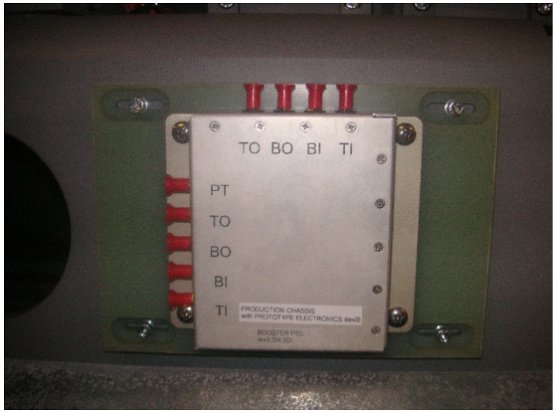


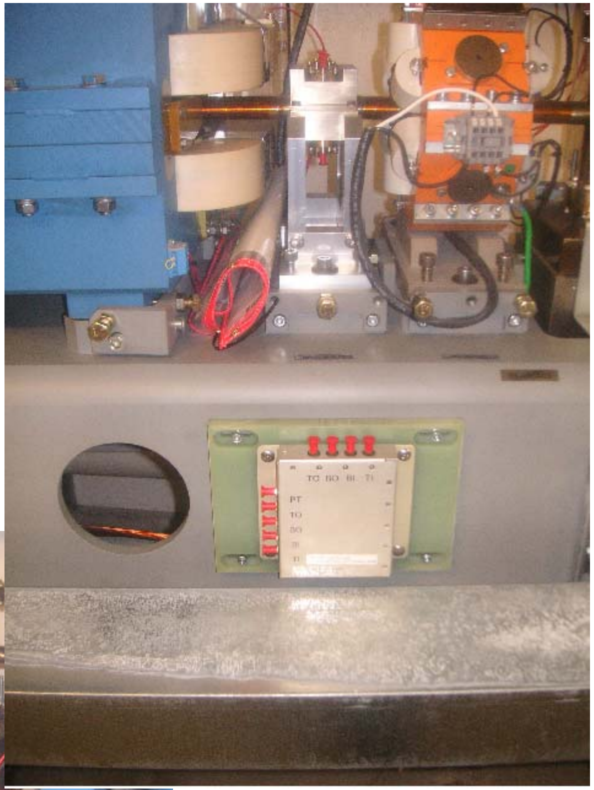
Additional noise protection is provided by shielded cable trays

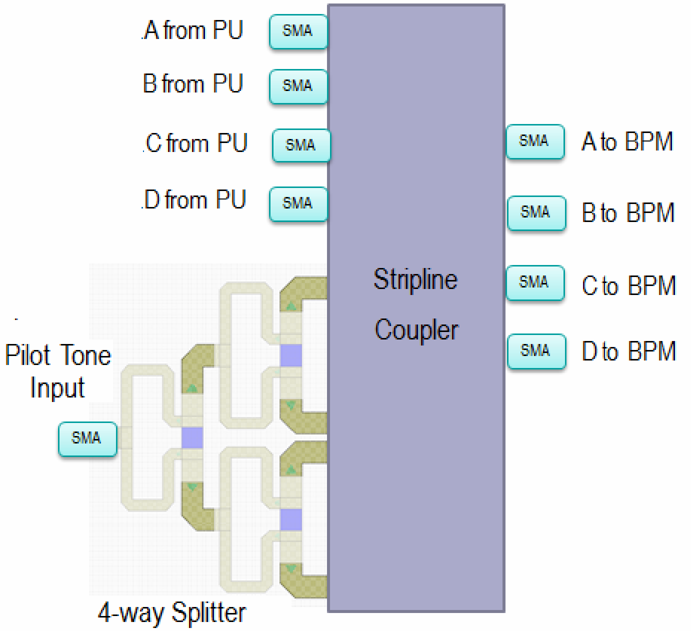


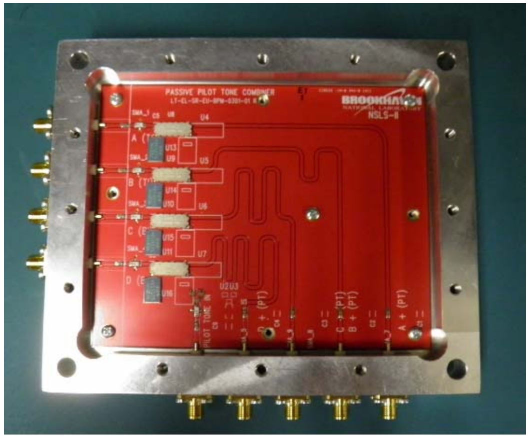
Beam position monitors
PTC module (BNL)

All PTC modules with support plates for booster have been manufactured.





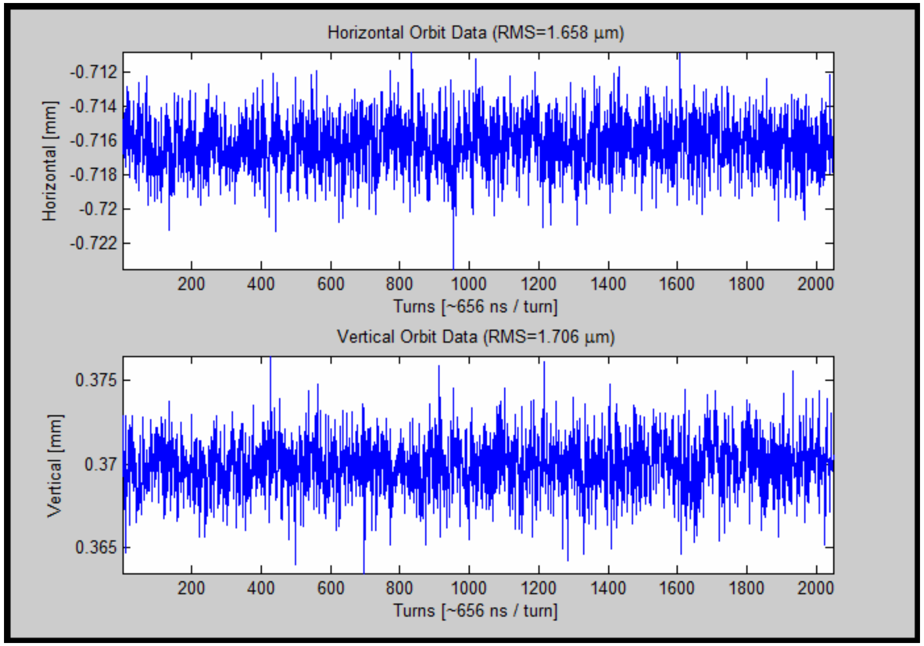


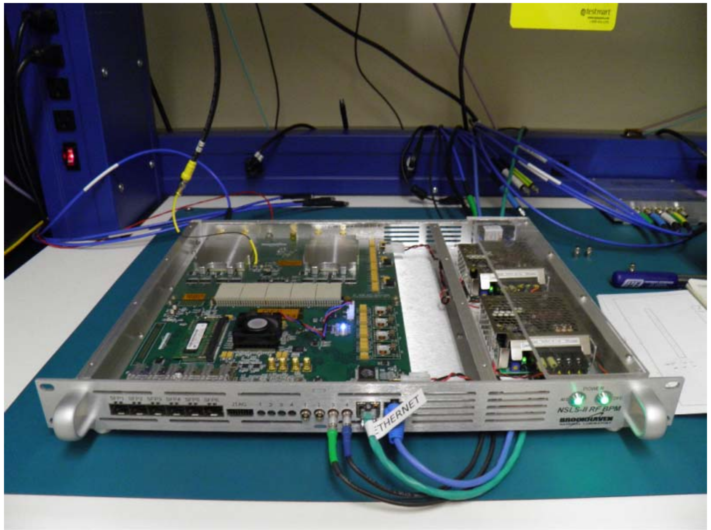


Beam position monitors
BPM receivers (BNL)

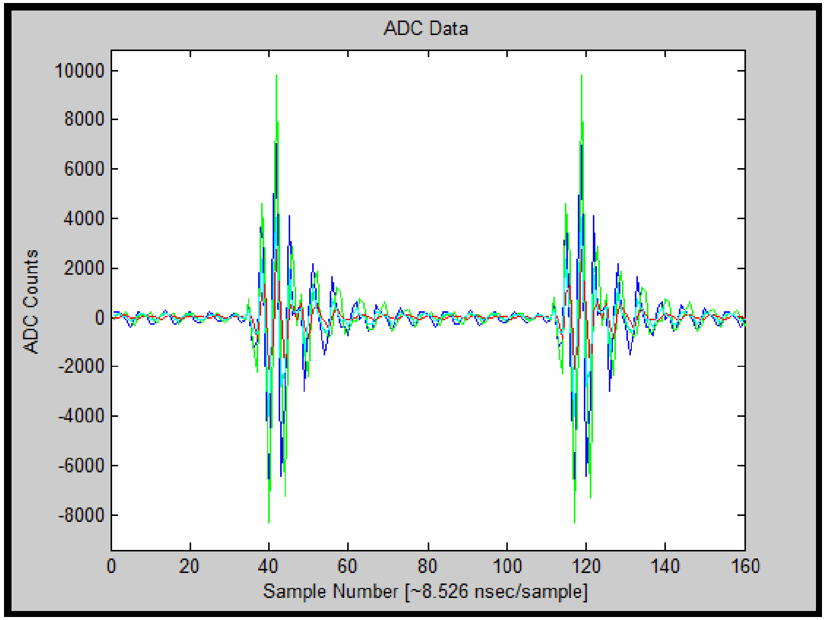
Successful Beam Test has been performed at ALS (Berkeley lab).

Turn-by-turn resolution: σ_x=1.66μm, σ_y=1.71μm

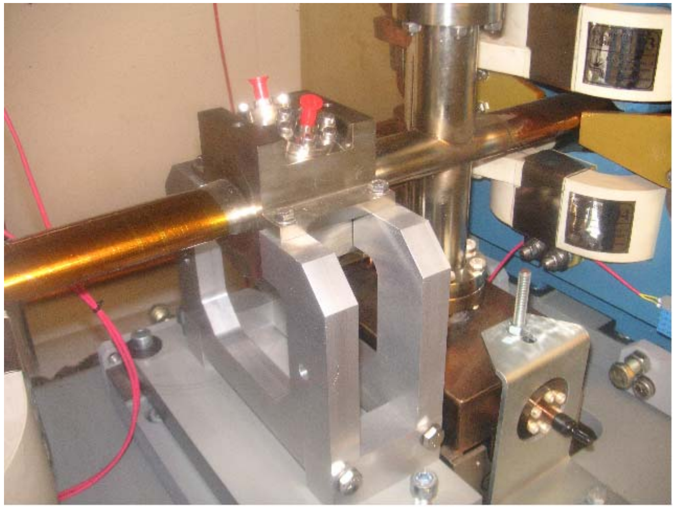


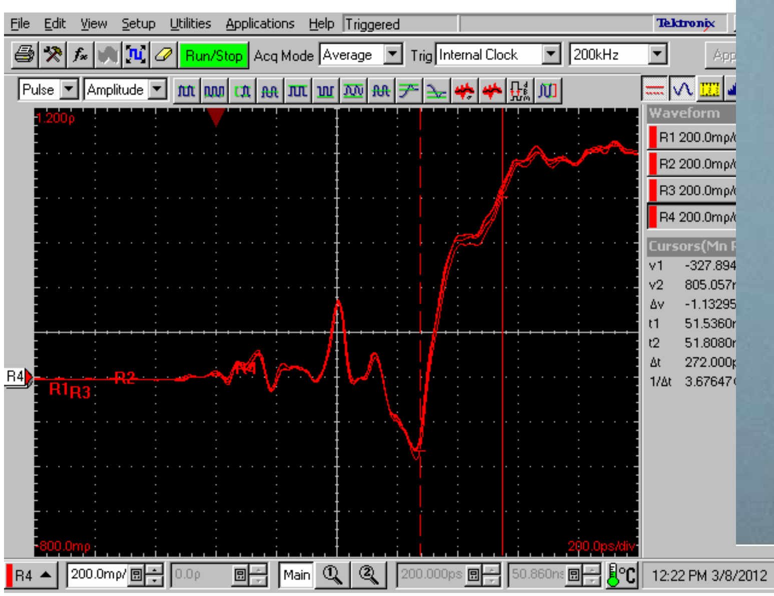


Single-bunch signal



Beam position monitors
Testing and installation (BNL)





Beam position monitors
Software (BNL)

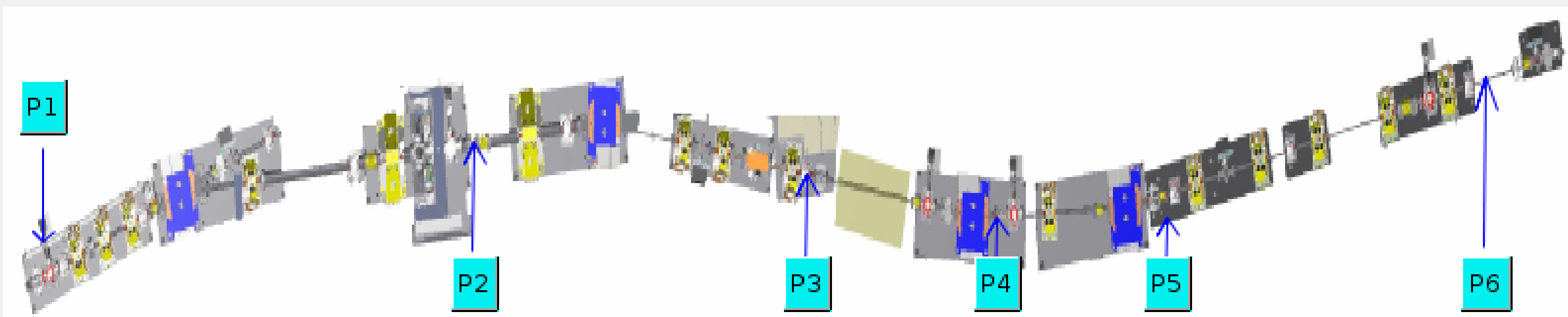
LTB_BPM

Horizontal

Name	Current	Position-X	GoldenTraj	Difference
{LTB_P1}	0.002052 m/	0.000 um	0.000 um	0
{LTB_P2}	0.010098 m/	2,223.415 ur	0.000 um	2,223
{LTB_P3}	-0.000535 m	8,060.281 ur	0.000 um	8,060
{LTB_P4}	Disconnecte	Disconnecte	Disconnecte	Disconnecte
{LTB_P5}	Disconnecte	Disconnecte	Disconnecte	Disconnecte
{LTB_P6}	Disconnecte	Disconnecte	Disconnecte	Disconnecte

Vertical

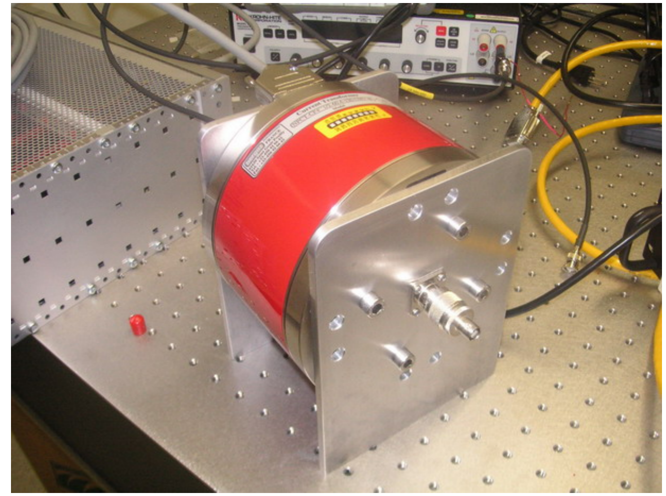
Name	Position-Y	GoldenTraj	Difference
{LTB_P1}	0.000 um	0.000	0
{LTB_P2}	612.244 um	0.000	612
{LTB_P3}	8,061.257 ur	0.000	8,061
{LTB_P4}	Disconnecte	Disconnecte	Disconnecte
{LTB_P5}	Disconnecte	Disconnecte	Disconnecte
{LTB_P6}	Disconnecte	Disconnecte	Disconnecte



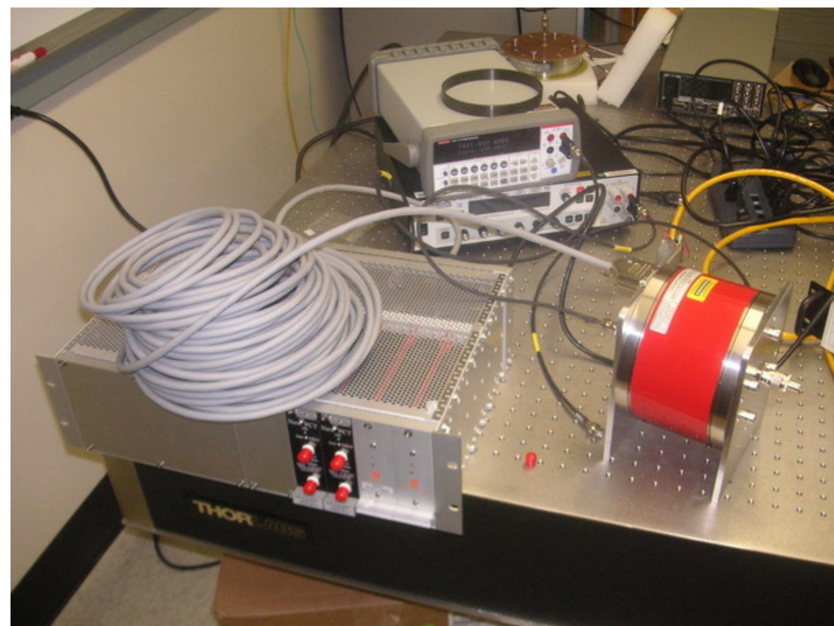
LTD1

Trajectory Correction

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

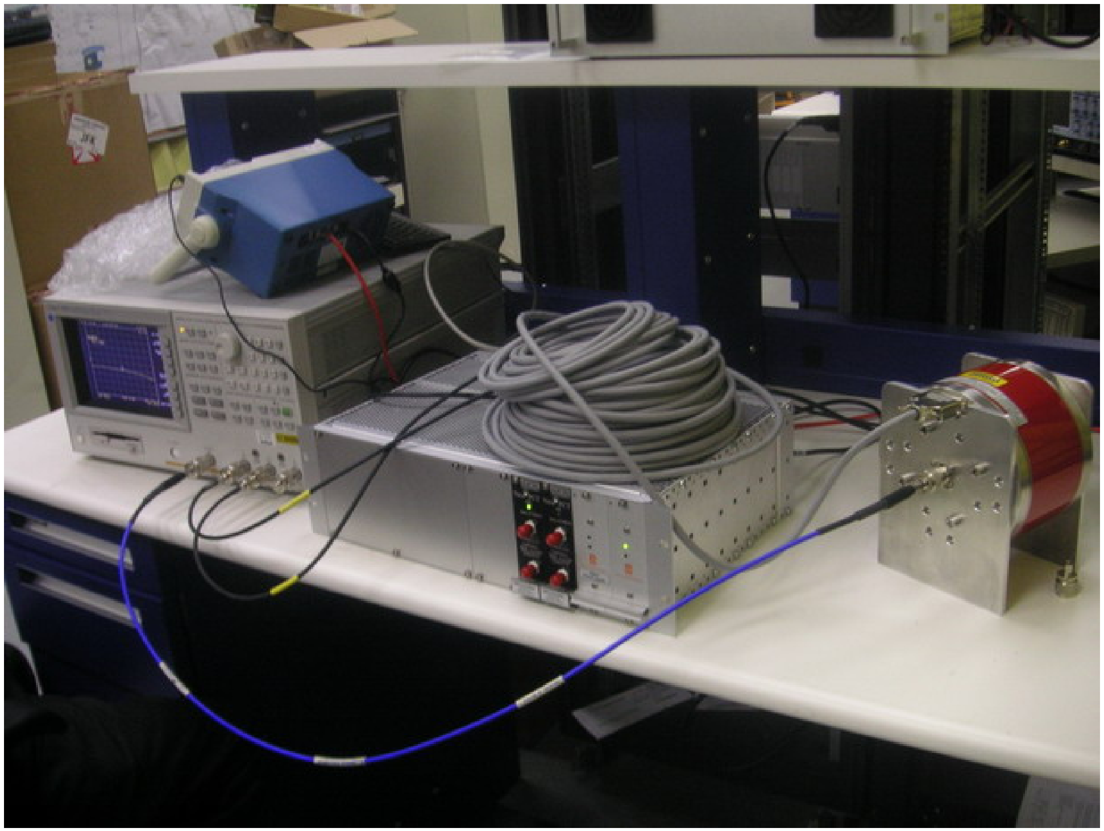


Measured sensitivity:
10.05 V / 20 mA DC, no zero offset correction

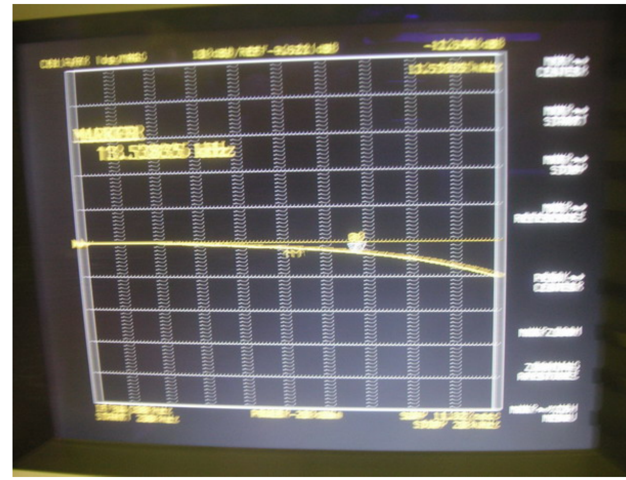


DC current transformer
Bergoz NPCT-CF4.5"-60.4-120-UHV-H

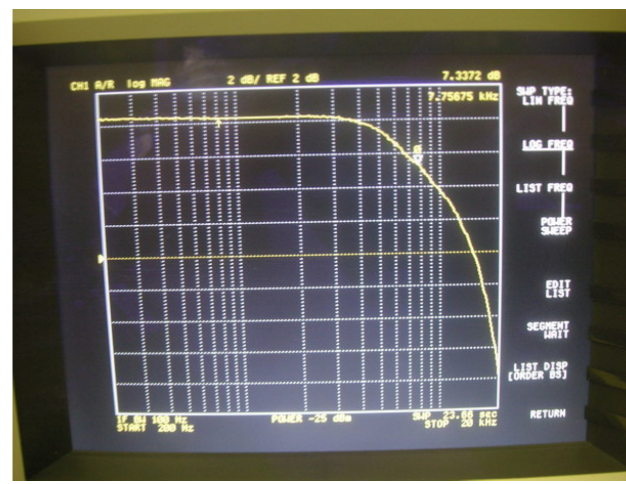
Bandwidth has been measured using Agilent 4395



Measured bandwidth (-3 dB):
range 200 mA - 13.5 kHz



range 20 mA - 7.75 kHz

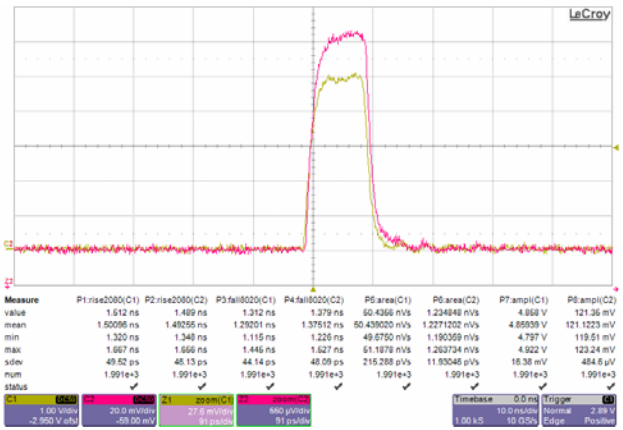


Fast current transformer

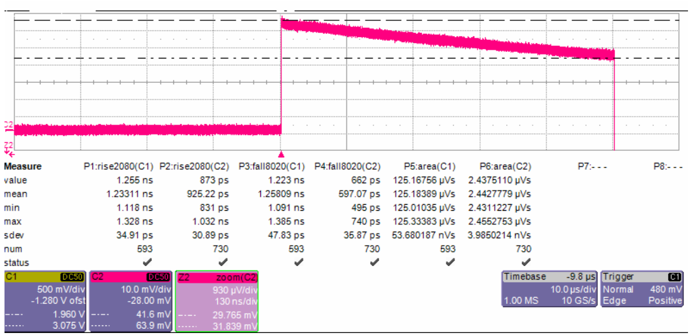
Bergoz FCT-WB-CF6"-60.4-40-20:1-UHV-H

Fast current transformer (FCT) model FCT-CF6”-60.4-UHV-20:1-H serial number 2426 was tested. Measurements were performed using DG645 pulse generator by Stanford Research Systems, LeCroy digital oscilloscope model 7300A and Agilent network analyzer E5071C.

The upper cut off frequency @ -3 dB is 1.1108 GHz.



The FCT time constant measured is 0.13 ns



Pulse amplitude:

63.9 mV → 41.6 mV

Signal loss: 34.89%

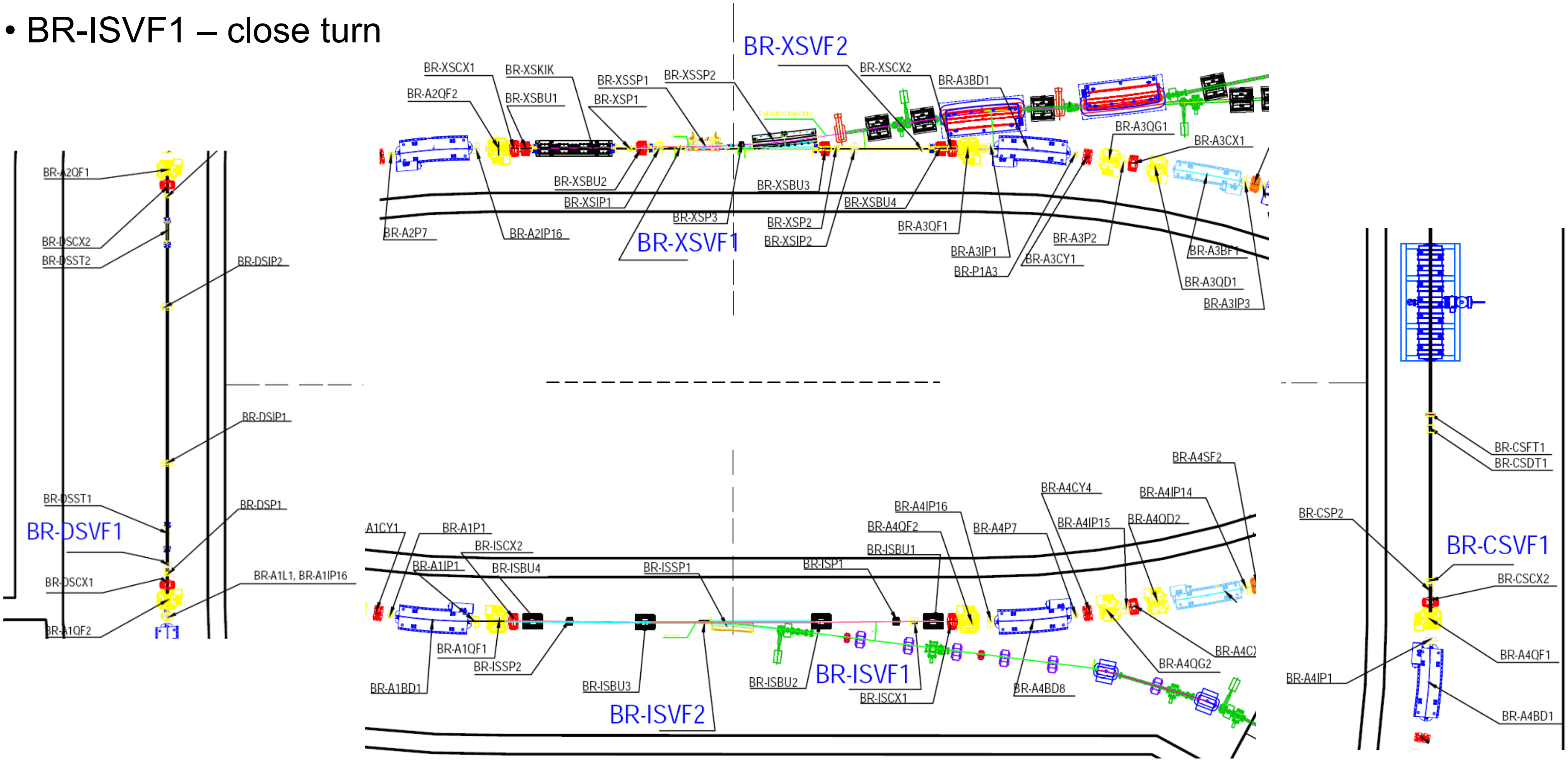
Pulse duration: 50μs

Droop: 0.85%/μs

Beam flags
Layout

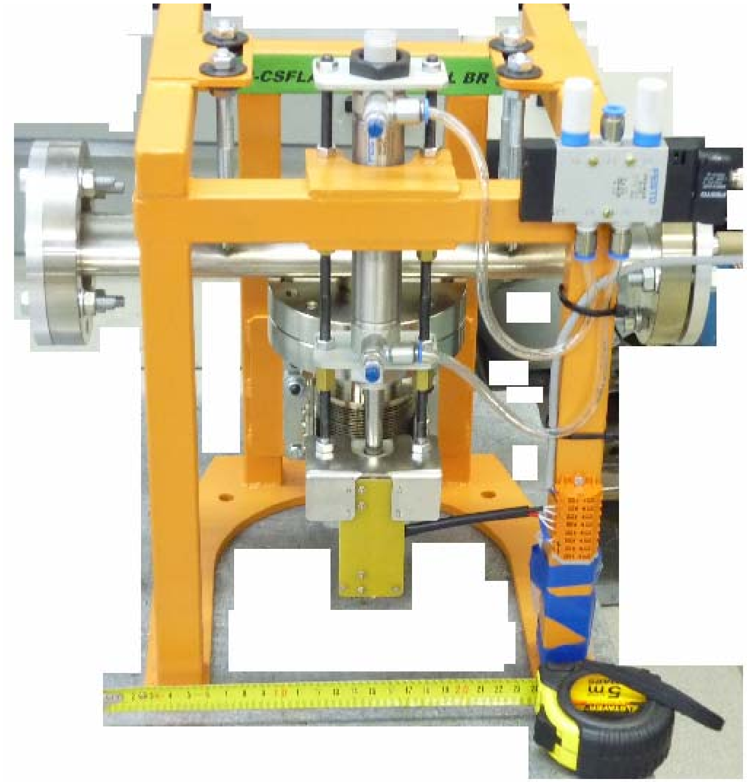
6 beam flags are used to measure transverse beam profile and position in the single-pass mode.

- BR-ISVF2 beam flag is used to adjust the septum and injection kickers;
- BR-DSVF1 – to pass the A1 arc;
- BR-XSVF1 and BR-XSVF2 – A2 arc and Extraction Section;
- BR-CSVF1 – A3 arc and RF Section;
- BR-ISVF1 – close turn



Beam flags
Design & Manufacturing (BINP)

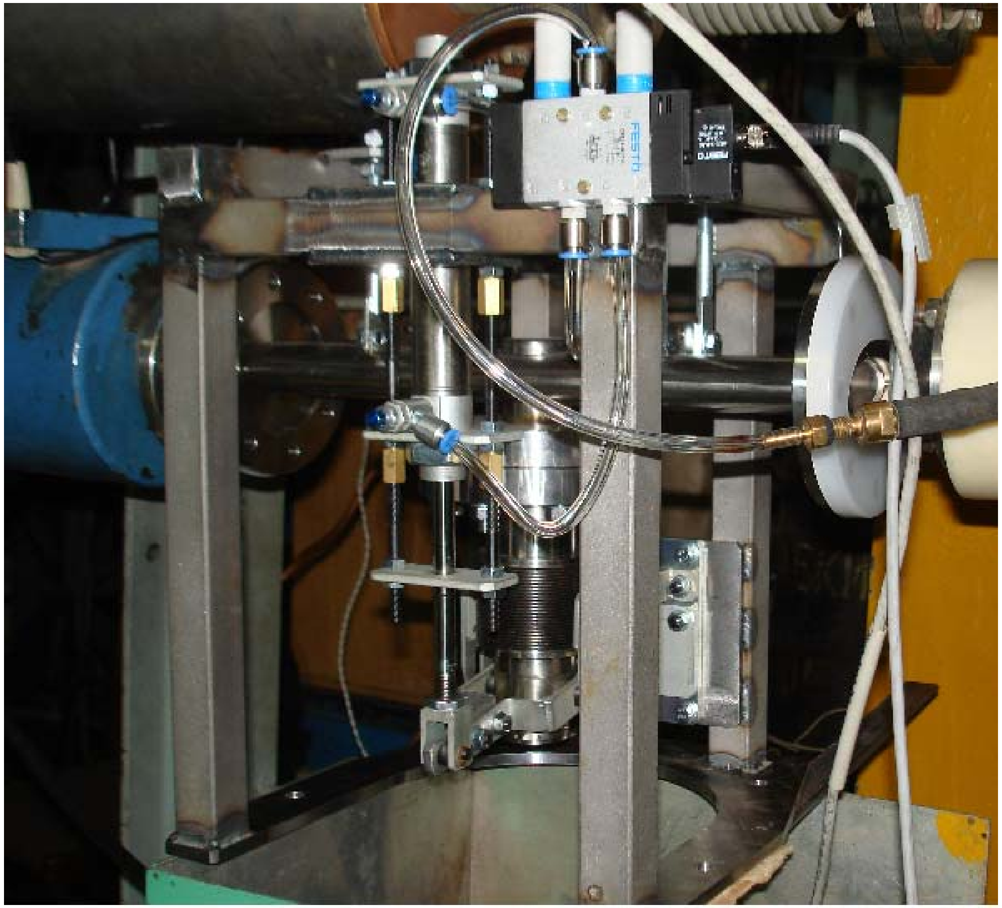
- The screen is contained in a UHV-compatible body, which moves in and out as a whole.
- Crystal phosphor YAG:Ce is used.
- The CCD camera is radiation-protected with a lead shield.
- When the beam flag is moved out, the vacuum chamber is smooth.

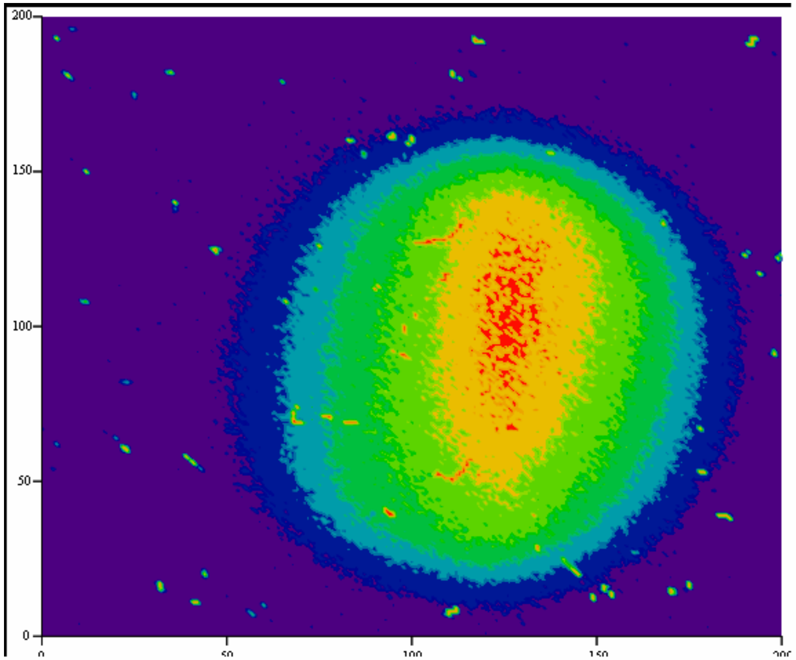


- **6 beam flags have been manufactured, tested and sent to BNL.**

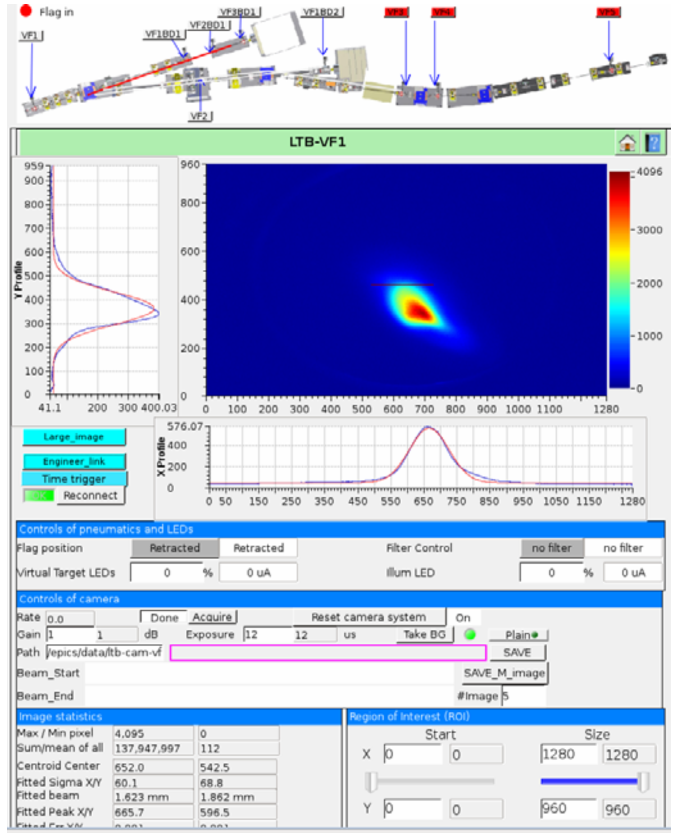
Beam flags
Beam test (BINP)

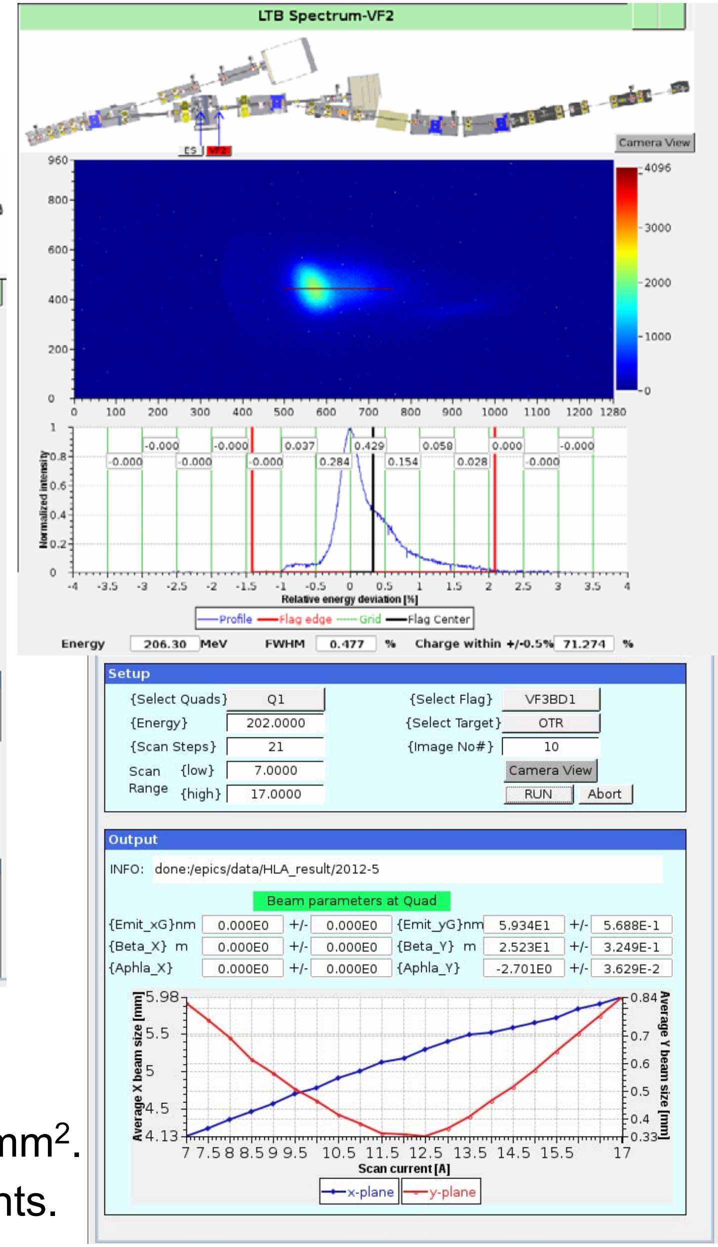
The screen sensitivity was experimentally estimated at a BINP operating accelerator facility.
A visible image was observed for the 350-MeV electron beam of about $7 \cdot 10^5$ particles (0.1 pC).





Beam flags
Linac-LBT experience (BNL)



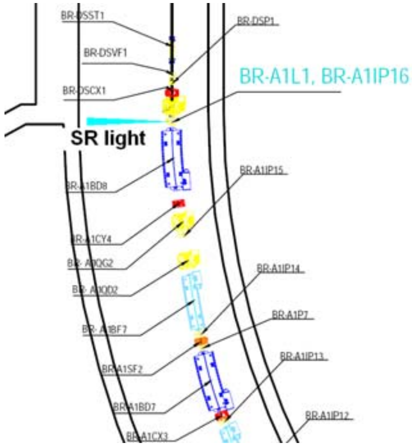


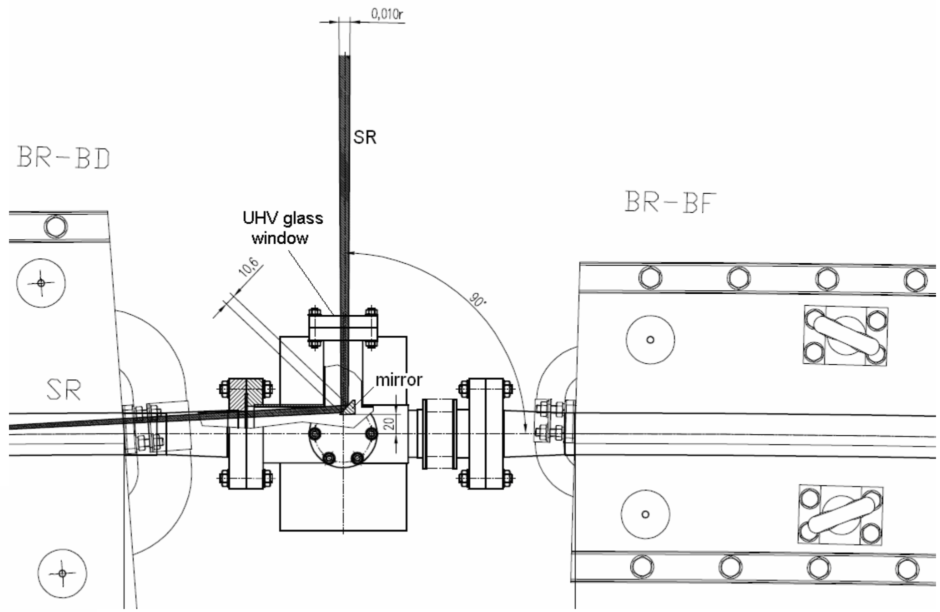
YAG:Ce screen is saturated at beam intensity about 35 pC/mm^2.

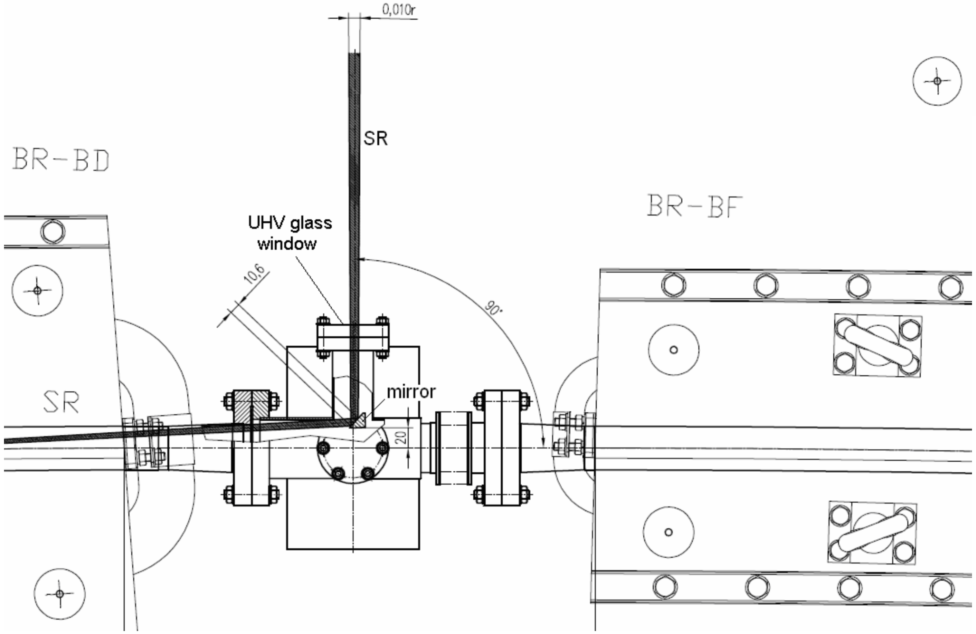
OTR from aluminum foil is used for quantitative measurements.

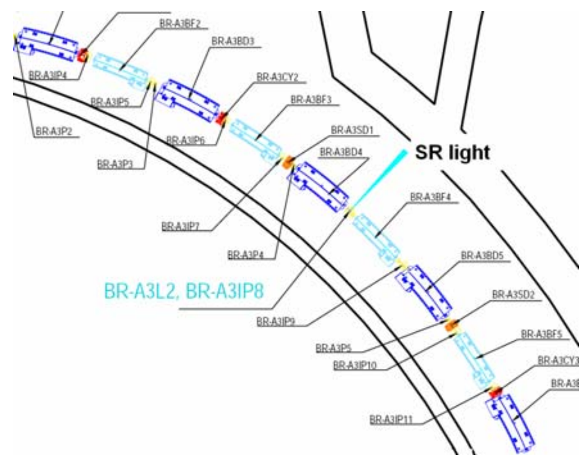
SR output ports
Layout

One SR output port is located in the 3rd arc and another is close to the DS straight section, in a place with minimal dispersion.



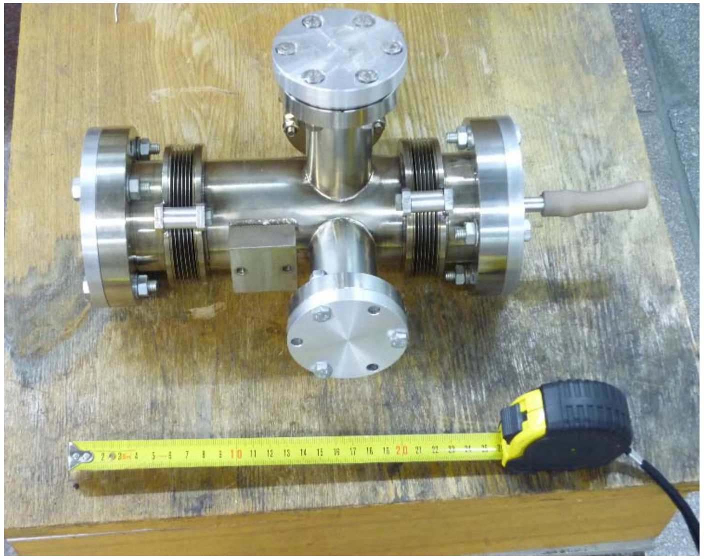


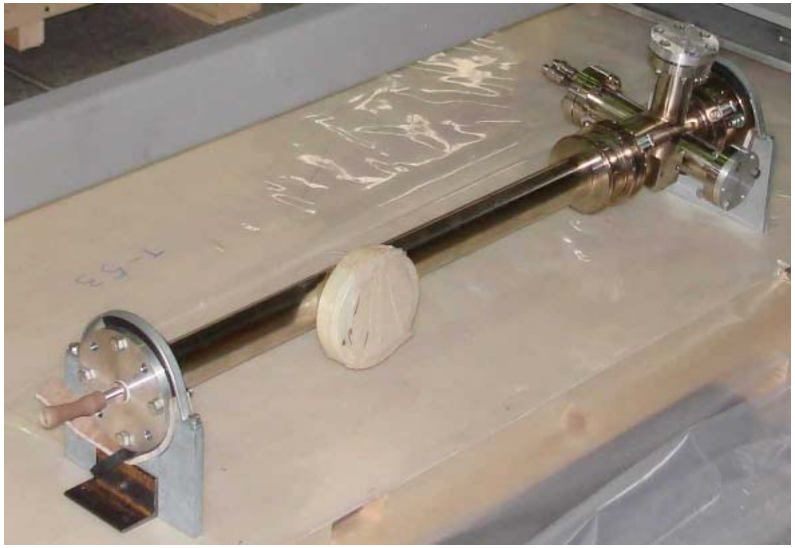




SR output ports
Manufacturing (BINP)

- **2 SR output ports have been manufactured and sent to BNL.**





Optical equipment

Objective lens M118FM25 (Tamron, Japan)

Focal Length	25 mm
Aperture Range	1.6 – 16
Angle of View (hor×ver)	16.6° ×12.5°
Focusing Range	0.1 m – ∞
Operation	Manual with lock
Back Focus (in air)	12.92 mm

CCD camera Prosilica CG1290 (Allied Vision Technology, USA)

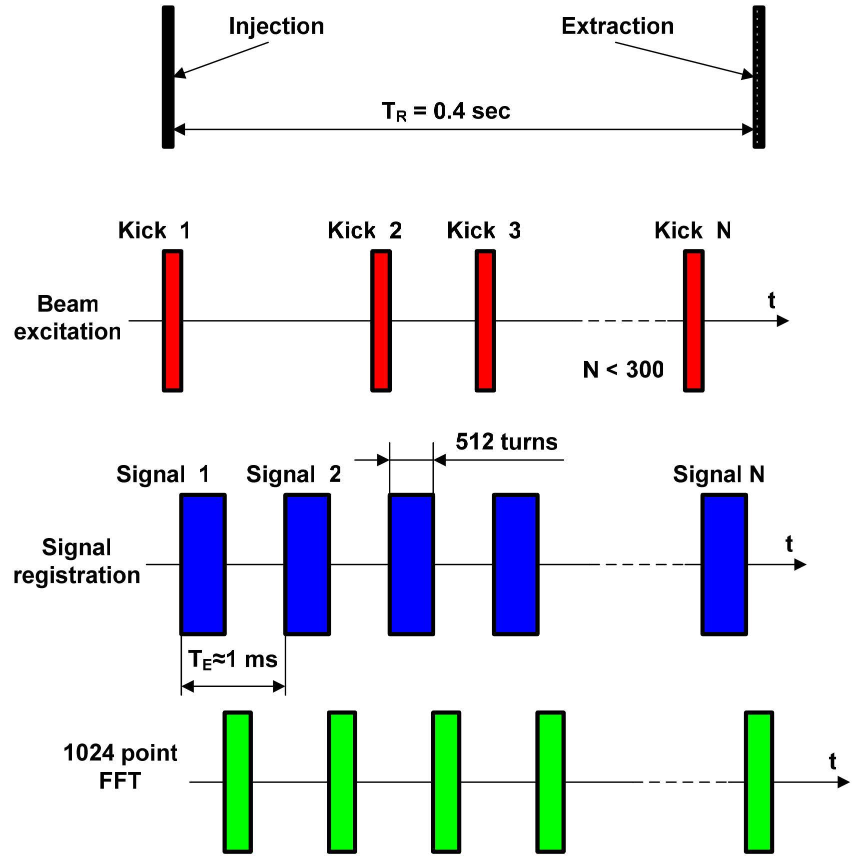
Resolution	1280 × 960
Max frame rate at full resolution	32 fps
A/D	12 bit
Output	8/12 bit
Sensor	Sony ICX445
Cell size	3.75 μm
On-board FIFO	16 MB

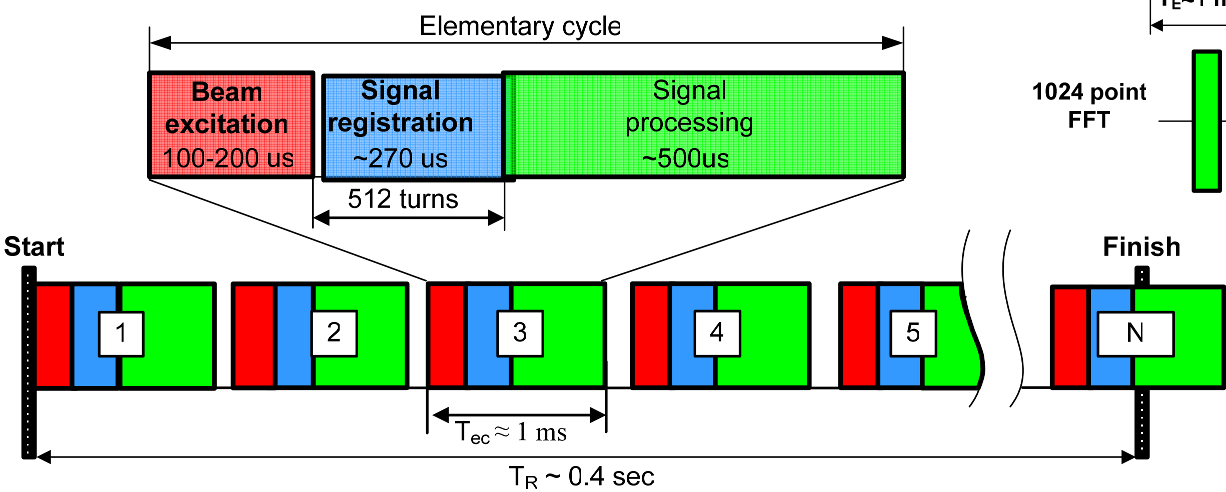
- **8 CCD cameras and 8 objective lenses have been ordered by BNL.**
- **To provide noise protection, the non-shielded Ethernet cable is replaced by the shielded cable Belden 7860 ENH.**

Tune measurement system
Operation

- The kicking method is used.
- The beam is excited by RF pulses with the frequency close to $f_B = (1 - \nu_{x,y})f_0$.
- Duration of the RF pulse is 100-500 µs.
- The signal is sampled by an ADC and is processed by a FPGA circuit.
- During the Booster energy ramp T_R, measurements of ν_x and ν_y are performed with a time interval of about 1 ms.
- For the total ramp duration of 0.3-0.4 s, the system can provide 300-400 tune measurements.

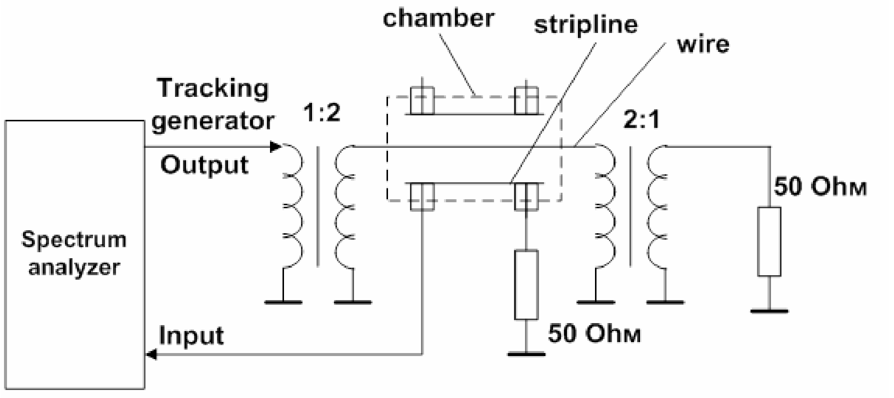
Time scheme





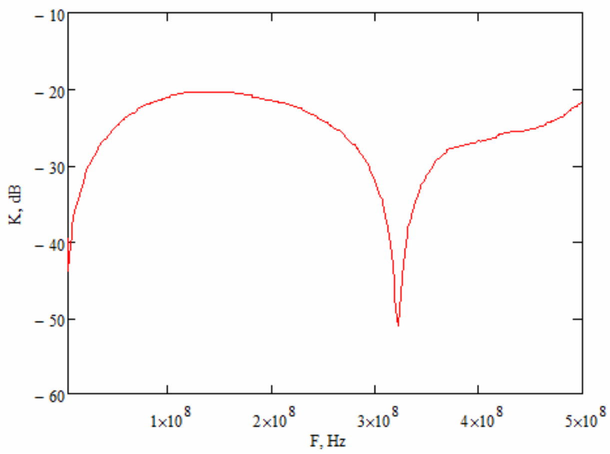
Tune measurement system
Striplines

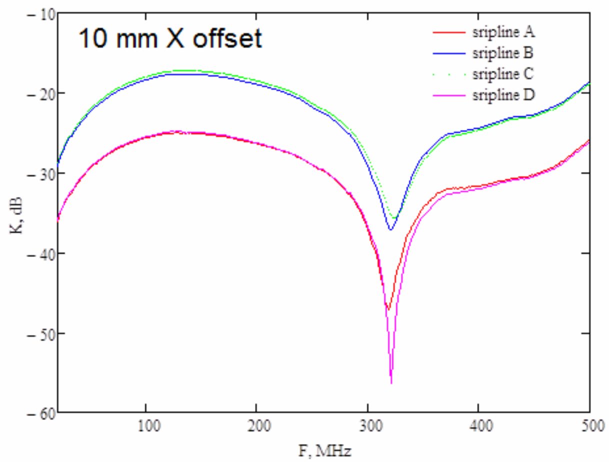
Test bench scheme

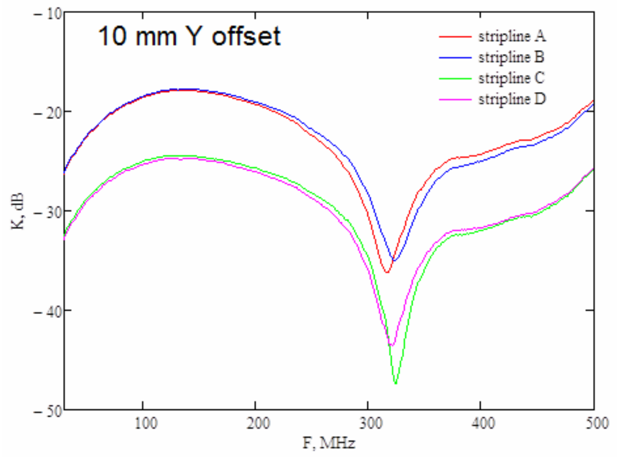


Measured sensitivity @ 500 MHz is about 9 V/A;
9 mV (-30 dBm) signal for 1 mA of beam current.

Measured scale factors: K_X = 24.4 mm
K_Y = 26.9 mm.





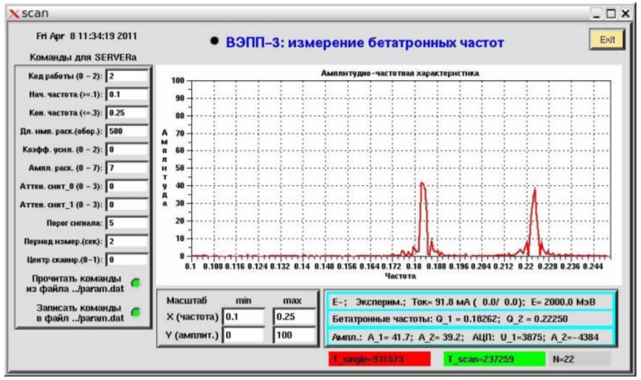


- **3 stripline assemblies have been manufactured, tested and delivered to BNL.**
- **3 E&I 1020L power amplifiers have been purchased by BNL.**

Tune measurement system
Signal processing electronics

- **The Signal processing electronics has been manufactured, tested in BINP and delivered to BNL.**

- A prototype of the Signal processing electronics has been tested at VEPP-3.



Beam diagnostic racks

Commissioning steps

	Required beam diagnostics	Esti-mated time	Responsible persons
Pre-commissioning (Hardware & software testing)	All		
LINAC beam optimization	LBT Beam Flags and BPMs		
Passing beam through the septum	LBT BPMs in single-pass mode, Booster flag	2	V.Smaluk, G.Wang
Passing beam through 1st, 2nd, 3rd and 4th arcs	BPMs in single-pass mode, beam flags	8	V.Smaluk
Circulating beam at 200 MeV	BPMs, SR monitors, TMS, DCCT	3	S.Karnaev
Beam-based alignment	BPMs in turn-by-turn and orbit modes	7	S.Sinyatkin, V.Smaluk
Orbit correction	BPMs in orbit mode, DCCT, TMS	3	T.Shaftan, D.Shatilov
Magnet lattice optimization	BPMs, SR monitors, TMS, DCCT	3	S.Sinyatkin, I.Okunev
Injection and hysteresis loop optimization	1 BPM in turn-by-turn mode	2	V.Kiselev, A.Zhuravlev

Commissioning steps

	Required beam diagnostics	Esti-mated time	Responsible persons
Turning RF ON; capturing beam	BPMs, TMS, DCCT	3	S.Karnaev, J.Rose
Accelerating beam up the ramp	BPMs, SR monitors, TMS, DCCT	14	S.Sinyatkin, T.Shaftan
Orbit correction at 3 GeV for extraction	BPMs in orbit mode, DCCT, TMS	3	R.Fliller, D.Shatilov
Outgassing	DCCT	20	A.Semenov
Emittance measurement	Beam flags and BPMs in XS	3	O.Meshkov, R.Fliller
Turning ON bumps	BPMs in orbit mode	2	R.Fliller
Turning ON kicker and septum, beam extraction optimization	DTL BPMs and Flags	4	E.Blum, V.Kiselev, S.Karnaev
Beam stacking	FCT, BPMs, DCCT	7	V.Kiselev, T.Shaftan

Beam diagnostics software

- Beam passage observation
- Beam current monitoring
- Beam stacking observation
- Closed orbit measurement and correction
- Emittance measurement
- Chromaticity measurement
- Beam parameters monitoring
- Betatron tune measurement
- Analysis of Turn-By-Turn BPM data

LINAC beam optimization

BUDKER INSTITUTE OF NUCLEAR PHYSICS

BROOKHAVEN NATIONAL LABORATORY

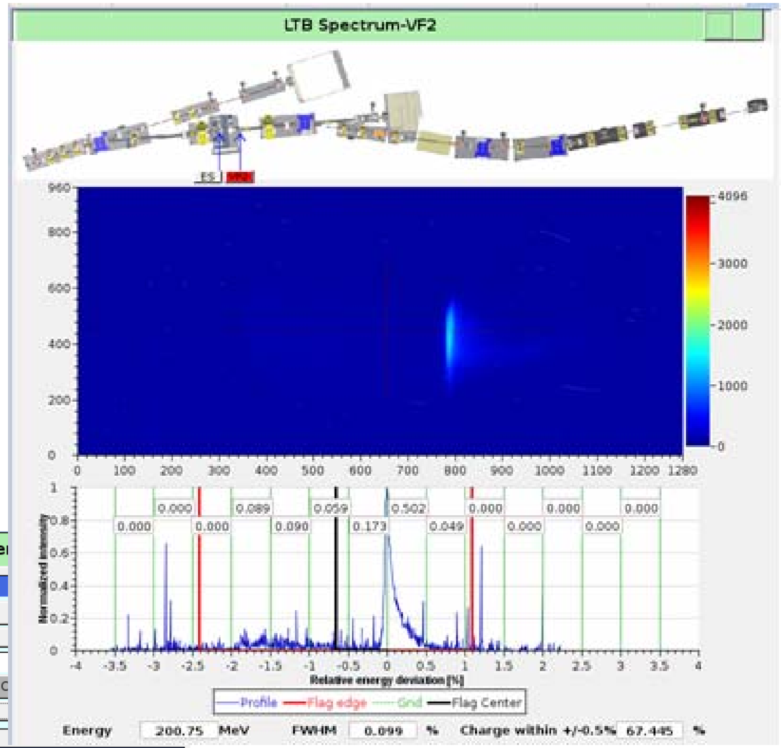
Procedure

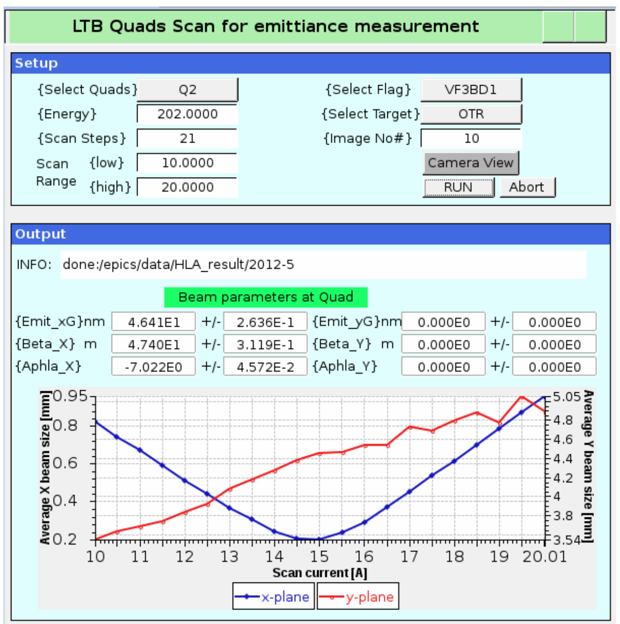
Get LINAC beam with required parameters, deliver beam to the injection septum.

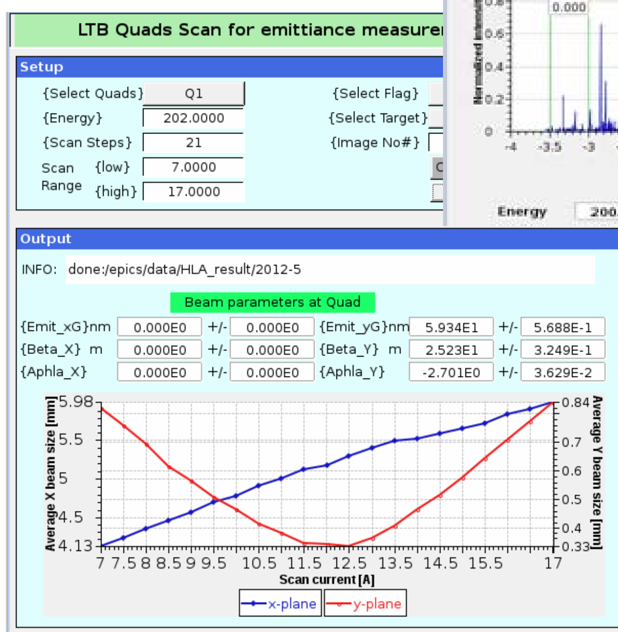
Requirements

LBT Beam Flags and BPMs;

LINAC beam energy and emittance measurement tools.







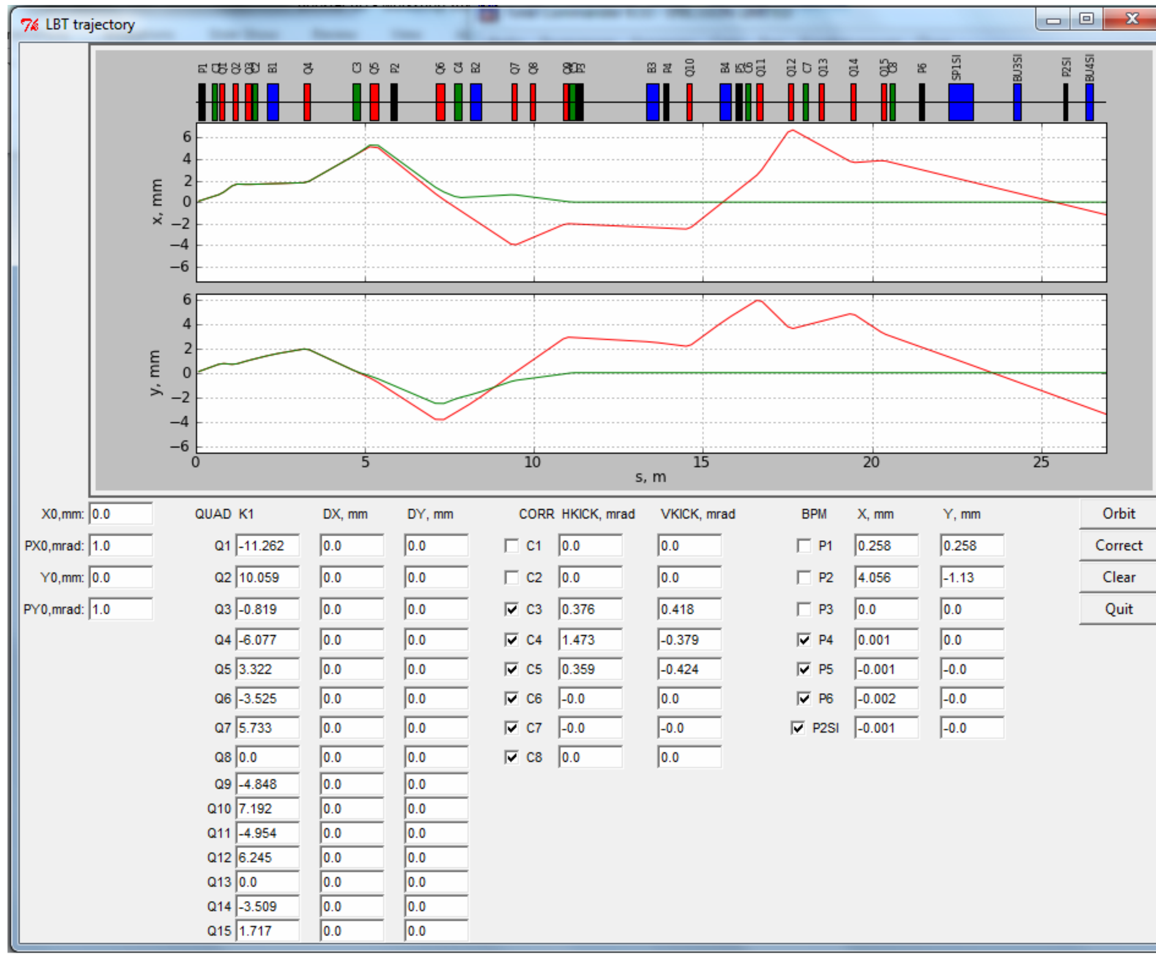
Passing beam through the septum

Procedure

Measure transport matrix.
Optimize beam position at BPMs.
Use upstream Beam Flag to align the system.

Requirements

LBT correctors and BPMs;
1 LBT flag and
1 Booster flag;
Operation with PSCs.
Beam diagnostic software.



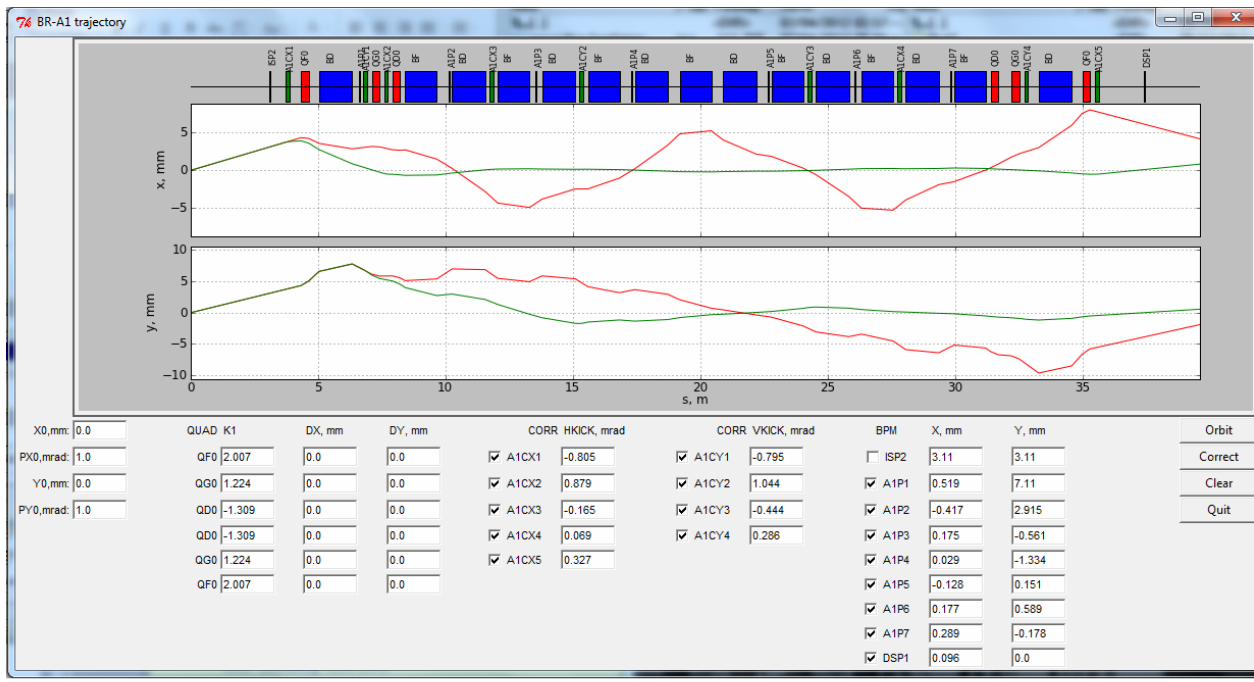
Passing beam through 1st Booster arc

Procedure

Adjust currents of LBT correctors to change initial coordinates.
Use 7 arc correctors. Send flat ramp tables into them, adjust currents.
Measure transport efficiency & beam coordinates at BPMs.
Repeat *N* times, optimize until transport efficiency > 95%.

Requirements

9 Booster BPMs in single-pass mode,
2 Booster flags;
Operation with PSCs.
Beam diagnostic software.



The same procedure is for passing through 2nd, 3rd and 4th arcs

Thank you for your attention!