BNL-94072-2011-CP

Status of the RHIC head-on beam-beam compensation project

W. Fischer, M. Anerella, E. Beebe, D. Bruno, D. Gassner, X. Gu, R.C. Gupta, J. Hock, A.K. Jain, R. Lambiase C. Liu, Y. Luo, M. Mapes, T. Miller, C. Montag, B. Oerter, M. Okamura, A.I. Pikin, D. Raparia, Y. Tan, R. Than, P. Thieberger, J. Tuozzolo, and W. Zhang

Presented at the 2011 Particle Accelerator Conference (PAC'11)
New York, N.Y.
March 28 – April 1, 2011

Collider-Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy
Office of Science

Notice: This manuscript has been authored by employees of Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy. The publisher by accepting the manuscript for publication acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes.

DISCLAIMER

STATUS OF THE RHIC HEAD-ON BEAM-BEAM COMPENSATION PROJECT*

W. Fischer†, M. Anerella, E. Beebe, D. Bruno, D. Gassner, X. Gu, R.C. Gupta, J. Hock, A.K. Jain, R. Lambiase, C. Liu, Y. Luo, M. Mapes, T. Miller, C. Montag, B. Oerter, M. Okamura, A.I. Pikin, D. Raparia, Y. Tan, R. Than, P. Thieberger, J. Tuozzolo, and W. Zhang
Brookhaven National Laboratory, Upton, New York, USA

Abstract

Two electron lenses are under construction for RHIC to partially compensate the head-on beam-beam effect in order to increase both the peak and average luminosities. The final design of the overall system is reported as well as the status of the component design, acquisition, and manufacturing.

INTRODUCTION

An overview of the RHIC head-on beam-beam compensation project is given in [1], and more details in [2]. With 2 head-on beam-beam interactions in IP6 and IP8, a third interaction with a low-energy electron beam is added near IP10 to partially compensate the the head-on beam-beam effect. Two electron lenses are under construction, one for each ring. Both will be located in a region common to both beams, but each lens will act only on one beam. With head-on beam-beam compensation up to a factor of two improvement in luminosity is expected together with a polarized source upgrade [3]. The current RHIC polarized proton performance is documented in Ref. [4].

An electron lens (Fig. 1) consists of an DC electron gun, warm solenoids to focus the electron beam during transport, a superconducting main solenoid in which the interaction with the proton beam occurs, steering magnets, a collector, and instrumentation.

The main developments in the last year are given below. The experimental program for polarized program at 100 GeV was expected to be finished by the time the electron lenses are commissioned. However, decadal plans by the RHIC experiments STAR and PHENIX show a continuing interest at both 100 GeV and 250 GeV, and a larger proton beam size has been accommodated in the design (Tab. 1).

Over the last year beam and lattice parameters were optimized [5, 6], and RHIC proton lattices are under development for optimized electron lens performance [7, 8]. The effect of the electron lens magnetic structure on the proton beam was evaluated [9], and found to be correctable. Experiments were done in RHIC [10] and the Tevatron [11].

GUN AND COLLECTOR

The basic designs of gun and collector are unchanged [1, 2]. To accommodate a larger electron beam the cathode radius of the gun was increased from 3.5 to 4.1 mm. The

* Work supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy, and in part by the U.S. LHC Accelerator Research Program.

† Wolfram.Fischer@bnl.gov

Table 1: Reference cases for RHIC beam-beam and beam-lens interactions.

quantity	unit	value	
proton beam parameters			
total energy E_p	GeV	100	250
relativistic factor β_p	...	0.99996	0.99999
relativistic factor γ_p	...	106.6	266.4
bunch intensity N_p	10^{11}	— 2.0 —	
$\beta^*_{x,y}$ at IP6, IP8 (p-p)	m	0.85	0.5
$\beta^*_{x,y}$ at IP10 (p-e)	m	— 10.0 —	
lattice tunes (Q_x, Q_y)	...	— (0.695,0.685) —	
rms emittance ϵ_n, initial	mm mrad	— 2.5 —	
rms beam size at IP6, IP8 σ^*_p	μm	140	70
rms beam size at IP10 σ^*_p	μm	485	310
rms bunch length σ_s	m	0.30	0.25
rms momentum spread $\delta p/p$	10^{-3}	0.55	0.30
hourglass factor F, initial	...	0.95	0.88
beam-beam parameter ξ/IP	...	— 0.010 —	
number of beam-beam IPs	...	— 2+1* —	
electron lens parameters			
distance of center from IP	m	— 2.0 —	
effective length L_e	m	— 2.1 —	
kinetic energy E_e	keV	— 6.4 —	
relativistic factor β_e	...	— 0.16 —	
relativistic factor γ_e	...	— 1.013 —	
electron line density n_e	10^{11}m^{-1}	— 0.82 —	
electrons in lens N_{e1}	10^{11}	— 1.7 —	
electrons encountered N_{e2}	10^{11}	— 2.0 —	
current I_e	A	— 0.62 —	

*One head-on collision in IP6 and IP8 each, and a compensating head-on collision in IP10.

cathodes (LB_6 and IrCe) were produced at BINP in Novosibirsk. With a nominal current density of 6 A/cm^2 IrCe was chosen as cathode material for a long lifetime (>10,000 h).

A completed gun is shown in Fig. 2. In addition to the nominal DC mode, a pulsed mode is now under design to allow for electron lens operation parasitic to physics stores. In this mode only the last bunch of a train will be affected by the lens. This requires the electron lens to turn on in less than 100 ns, with a repetition frequency of 78 kHz.

A partially assembled collector is shown in Fig. 3. Its ability to dissipate the electron beam energy has been designed with a safety factor of 4 [2].

The gun and collector power supplies are referenced to the cathode. The gun supplies include the cathode bias supply, the cathode heater, the beam forming supply, and two anode supplies (DC and pulsed). The collector power supply is rated with 10 kV at 2 A, and will limit the energy deposited in the device should an arc occur. An ion extractor is powered with respect to the cathode potential. A suppressor element is powered with respect to the collector.

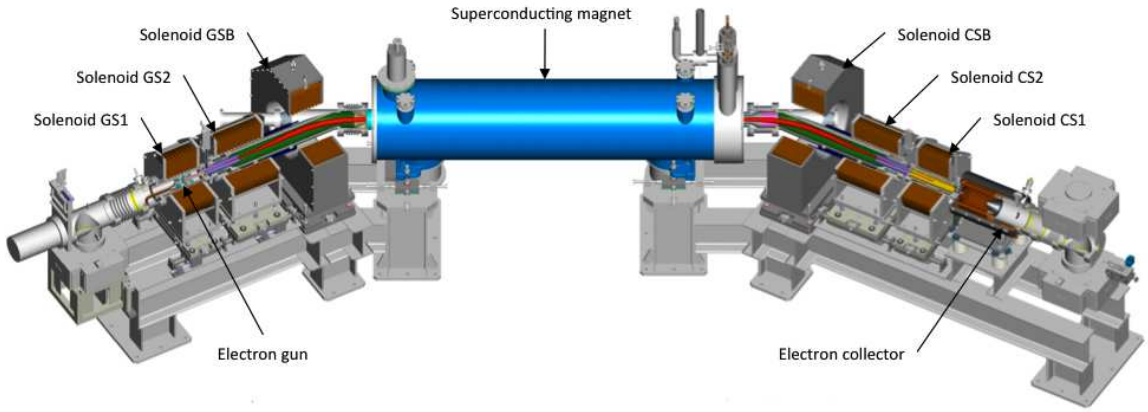

Figure 1: RHIC electron lens. The electrons in the DC beam move from left to right and interact with the protons, that are moving in the opposite direction, inside the superconducting solenoid.

SUPERCONDUCTING MAIN SOLENOID

The design for the superconducting main solenoid is complete. The magnet has a warm bore and a maximum field of 6 T. The cryostat includes a number of additional magnets [12]. The main parameters are given in Tab. 2.

Fringe field (FF) solenoid coils at both end are included to allow for a guiding and focusing solenoid field for the electrons of no less than 0.3 T between the superconducting magnet and the warm transport solenoids GSB and CSB (Fig. 1). To achieve the desired field uniformity over a range of field strengths B_s, anti-fringe field (AFF) coils are placed next to the FF coils. Both the FF and AFF coils on both ends can be powered independently to avoid forming a magnetic bottle with a low main field B_s.

Included in the cryostat are 5 short (0.5 m) dipole correctors in both the horizontal and vertical plane, to correct for the solenoid field straightness to ± 50 μm. A long (2.5 m) dipole corrector in each transverse plane allows changing the angle of the electron beam inside the main magnet by ± 1 mrad (at 6 T) to align the electron and proton beams.

To reduce the number of layers in the main, FF, and AFF coils, and thereby the manufacturing time, a large conductor was chosen, and the current in these coils is 470, 470, and 330 A [12]. The magnet is cooled by liquid helium, which can be supplied from the RHIC refrigeration system or a local Dewar. A total of 17 individual coils (main, 2x FF, 2x AFF, 10x straightness, 2x angle) can be powered. Coil winding is now in process.

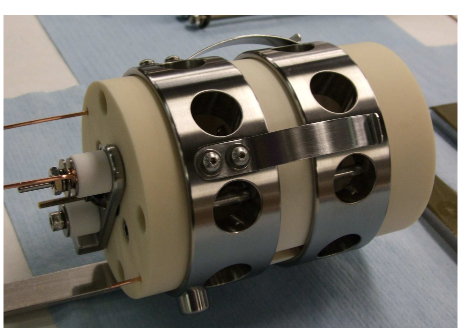

Figure 2: Completed DC electron gun. Nominal parameters are given in Tab. 1.

Table 2: Main parameters of the superconducting solenoids and correction magnets in the same cryostat.

quantity	unit	value
cryostat length	mm	2838
warm bore inner diameter	mm	154
uniform field region	mm	± 1050
maximum main field B_s	T	6.0
field uniformity $\Delta B_s/B_s$	...	± 0.006 (3-6 T)
field straightness	μm	± 50 (3-6 T)
fringe field solenoid field	T	0.3
straightness correctors (5H+5V)	Tm/mrad	$\pm 0.010/\pm 3$ (at 6 T)
angle correctors (1H+1V)	Tm/mrad	$\pm 0.015/\pm 1$ (at 6 T)

WARM MAGNETS

The electron beam is transported from the gun to the main solenoid, and from the main solenoid to the collector through three solenoids each (Fig. 1) [13]. These provide focusing with a solenoid field of at least 0.3 T. Within the GS2 and CS2 solenoids are also horizontal and vertical steering magnets that can move the beam by ± 5 mm in the main solenoid in either plane. The power consumption of both electron lenses with nominal parameters is limited to a total of 500 kW in order to avoid upgrades to the electrical and water cooling infrastructure in IR10. The main parameters are given in Tab. 3. All warm magnets and associated power supplies are on order.

INSTRUMENTS, VACUUM, TEST BENCH

The instrumentation monitors the current and shape of the electron beam, electron beam losses, and the overlap of the electron with the proton beam. The following items are included (quantity is per lens):

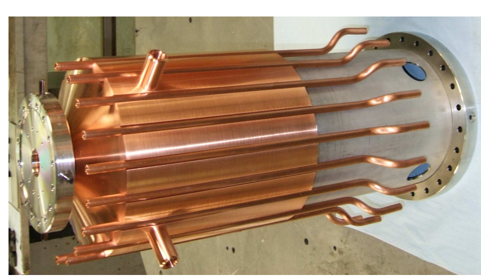

Figure 3: Partially assembled electron collector with beam entrance on the left side and visible cooling pipes.

Table 3: Main parameters of the warm magnets.

quantity	unit	GS1 CS1	GS2 CS2	GSB CSB	GSX CSX	GSY CSY
ID	mm	174	234	480	194	210
OD	mm	553	526	860	208	224
length	mm	262	379	262	500	500
No layers	...	13	10	13	12	12
No pancakes	...	9	13	9		
inductance	mH	20	20	40	0.2	0.2
resistance	mΩ	40	50	80	20	20
current	A	1188	731	769	258	271
power	kW	58	26	45	1.4	1.7
ΔT	K	13.4	3.6	14.2	5.9	6.9
Δp	bar	1.5	1.5	1.5	1.5	1.5
solenoid field B_s	T	0.8	0.45	0.32		

- beam position monitors (2)
- bremsstrahlungs monitor (2) [14]
- halo monitor (2) [15]
- differential current monitor (1)
- beam loss monitor drift tubes (10)
- collector temperature sensor (1)
- profile monitor (YAG screen) (1)
- pin-hole monitor (1)
- ion collector (1)

The electron beam BPMs only sees a signal with a pulsed electron beam, and are used to bring the electron and proton beams in close proximity. The final alignment is done with the the bremsstrahlungs monitor [14], halo monitor [15], or based on proton BTF and proton loss signals. Alignment was found to be a critical parameter in the Tevatron electron lenses, and the beams have to be aligned within a fraction of the rms beam size, which is as small as 310 μm (Tab. 1).

The differential current monitor, the drift tubes, ion collector, and collector temperature sensor all monitor the electron beam loss in the lens. The YAG screen and pin-hole profile monitors can only be used in low a low power mode [2]. The drift tubes are also used to extract ions from the lens vacuum that are formed after residual gas ionization. The extracted ion current is monitored in an ion collector [2].

The gun and collector vacuum will be UHV compatible, with a design pressure of 10^{-10} Torr, and interface to the RHIC warm bore with a nominal pressure of 10^{-11} Torr. For this reason all of the components shall be bakable to 250°C. All-metal gate valves separate the gun and collector vacuum. The gun and collector chambers will have a confined gas load by using a conductance limiting aperture, and enough installed pumping speed. All vacuum chambers interfacing with the RHIC warm bore will be made from stainless steel.

All instruments are largely designed with the exception of the halo and bremsstrahlungs monitors. These monitors are new and still require work.

An electron lens test bench is under construction (Fig. 5) to test instrumentation and to characterized the electron beam as a function of the voltages and fields in the gun and solenoids. The design is complete. Most of the test bench components will be used in the RHIC electron lens.

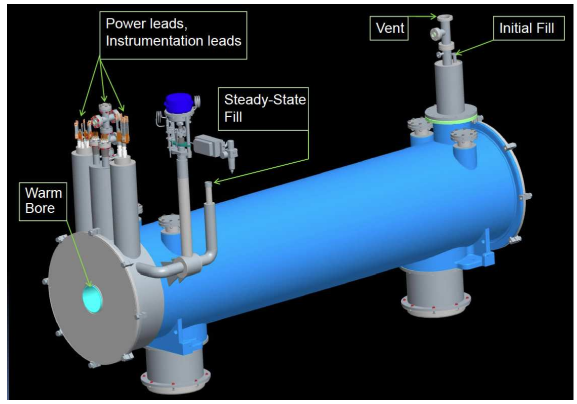

Figure 4: Superconducting main solenoid with warm bore, power and instrumentation lead, helium vent, and fill pipes.

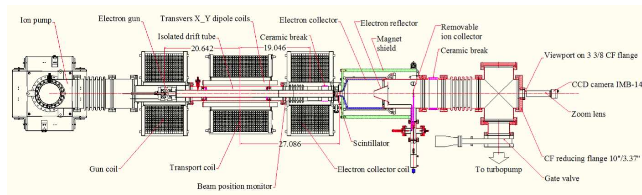

Figure 5: Electron lens test bench consisting of gun, three warm solenoids, steering collector, and instrumentation.

SUMMARY

Partial head-on beam-beam compensation is planned in RHIC with electron lenses. The main solenoid, electron gun and collector, the electron beam transport, and instrumentation are designed and under construction. Installation in the RHIC rings is planned for 2012, contingent on available funding. A luminosity gain of up to a factor of two is expected together with a polarized proton source upgrade [3] that can deliver higher bunch intensities.

ACKNOWLEDGMENTS

We are thankful for discussion and support to many, in particular the staff of the BNL Superconducting Magnet Division, and J. Alessi, A. Fedotov, G. Ganetis, G. Kuznezov, K. Ohmi, T. Roser, F. Schmidt, L. Snydstrup, V. Shiltsev, A. Valishev, and F. Zimmermann.

REFERENCES

[1] W. Fischer et al., “Status of ...”, IPAC’10, pp. 513 (2010).
[2] A. Pikin et al., “Structure and ... “, these proceedings.
[3] A. Zelenski et al., “High-intensity, ...”, these proceedings.
[4] H. Huang et al., “RHIC polarized ...”, these proceedings.
[5] Y. Luo et al., “The effects ...”, these proceedings.
[6] Y. Luo, et al., “Optimizing ...”, these proceedings.
[7] C. Montag, “Lattice design ...”, these proceedings.
[8] M. Blaskiewicz et al., “Impact of ...”, these proceedings.
[9] X. Gu et al., “The effects ...”, these proceedings.
[10] C. Montag et al., “Beam exp. ...”, these proceedings.
[11] G. Stancari, A. Valishev, “Results ...”, these proceedings.
[12] R.C. Gupta et al., “Magnetic design ...”, these proceedings.
[13] X. Gu et al., “Beam transport ...”, these proceedings.
[14] C. Montag et al., IPAC’10, pp. 1632 (2010)
[15] P. Thieberger et al., “Proposed electr. ...” these proceedings.